EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

Submitted to: Eur. Phys. J. C

CERN-EP-2026-156
7th July 2026

Measurement of the b-jet identification efficiency in dileptonic $t\bar{t}$ events using proton–proton collision data at $\sqrt{s}$ = 13.6 TeV collected with the ATLAS detector

The ATLAS Collaboration

This paper presents the performance of the identification of jets containing b-hadrons (b-jets) for the GN2 algorithm, a transformer-based model for jet flavour tagging, using data collected by the ATLAS detector at the LHC. The analysis uses proton–proton collision data recorded in 2022 and 2023 at a centre-of-mass energy of $\sqrt{s}$ = 13.6 TeV, corresponding to an integrated luminosity of 56 fb^{-1}. The b-jet identification efficiency and jet flavour composition are extracted simultaneously from a sample enriched in top-quark pair events ($t\bar{t}$). This efficiency is measured as a function of the jet transverse momentum in the range of 20–400 GeV and across six intervals of cumulative efficiency as derived in simulated $t\bar{t}$ events: [100%, 90%], [90%, 85%], [85%, 77%], [77%, 70%], [70%, 65%], and [65%, 0%]. The GN2 algorithm demonstrates significant performance improvements over its predecessor DL1d, achieving up to a factor of two (three) higher rejection of light-flavour (charm-flavour) jets at the same b-jet efficiency. The measured efficiencies in data are compared with simulation to derive correction factors ranging from 0.9 to 1.3. The total uncertainty is around 1% for jets with transverse momentum larger than 60 GeV in the [65%, 0%] interval of cumulative efficiency.

Contents

1 Introduction

The ability to separate jets of different flavours, known as jet flavour tagging, is of crucial importance to the physics programme of the ATLAS experiment [1] at the Large Hadron Collider (LHC) [2]. In particular, the ability to identify jets containing b-hadrons (b-jets) or c-hadrons (c-jets) and reject the large background of light-flavour jets plays a central role in the observation of the Higgs boson decay into bottom quarks and in the search for the Higgs boson decay into charm quarks [3–5], many Standard Model (SM) precision measurements [6, 7], top-quark physics [8, 9], searches for Higgs boson pair production [10–13] and physics beyond the SM [14–16].

Dedicated algorithms, referred to as jet flavour tagging algorithms, are exploited by the ATLAS Collaboration when analysing data to identify b-jets or c-jets. For the identification of b-jets, which is the focus of this paper, these algorithms typically rely on the long lifetime, high mass, large decay multiplicity of b-hadrons, and the properties of the b-quark fragmentation. These physical characteristics are reflected by properties of charged-particle tracks, most notably large transverse and longitudinal impact parameters (d_0, z_0), which serve as the primary input for the tagging algorithms. The previous generation of algorithms utilised Deep Neural Networks [17] and Recurrent Neural Networks [18] to process these inputs. The current state-of-the-art algorithm used for Run 3 data analysis is GN2 [19], a General Network (GN) series machine-learning algorithm for flavour tagging based on the transformer architecture [20].

GN2 predicts the probabilities of a jet being a b-jet (p_b), a c-jet (containing a c-hadron but no b-hadron, p_c), a τ-jet (containing a hadronically decaying τ-lepton but no b- or c-hadrons, p_τ), or a light-flavour jet (p_u) otherwise. A b-jet tagging discriminant $D_{\mathtt{GN2}}$ is defined as:

$$D_{\mathtt{GN2}} = \ln\left(\frac{p_b}{f_c \cdot p_c + f_\tau \cdot p_\tau + (1 - f_c - f_\tau) \cdot p_u}\right),$$

where the coefficients $f_c = 0.2$ and $f_\tau = 0.01$ were optimised to maximise the rejection of background jets in simulated $t\bar{t}$ events. In addition to flavour prediction, GN2 is trained on auxiliary tasks, such as vertex prediction and track origin prediction [19]. These tasks improve the convergence of the training, enhance the overall flavour tagging performance, and increase the interpretability of the model. Evaluated in Monte Carlo (MC) simulation, GN2 provides a significant improvement on the previous algorithm (DL1d), with an increase in light-flavour jet rejection by a factor of two and c-jet rejection by a factor of three at the same b-jet tagging efficiency.

This paper reports on the measurement of the GN2 b-jet tagging efficiency in data using proton–proton (pp) collisions recorded at $\sqrt{s} = 13.6$ TeV during 2022 and 2023. The measurement, also referred to as calibration, is used to derive correction factors, known as Scale Factors (SF), to account for differences in efficiency between data and MC simulation. The calibration is performed in Pseudo-Continuous b-jet Tagging (PCBT) bins, defined as exclusive ranges of the $D_{\texttt{GN2}}$ discriminant corresponding to intervals of cumulative b-jet tagging efficiency. A high-purity sample of $t\bar{t}$ events is selected, where each top-quark decays as $t \to Wb$, with a branching ratio close to 100%, and the W-boson decays leptonically, either in the electron channel or the muon channel ($W \to \ell\nu$). The selection requires exactly two isolated leptons with different flavours and opposite charges, along with two hadronic jets. This decay mode provides an abundant source of b-jets. Following the method in Ref. [21], the b-jet tagging efficiency is extracted simultaneously with the jet flavour composition of the sample using a maximum likelihood approach. Systematic uncertainties are studied and incorporated into the final results.

This paper is structured as follows. Section 2 describes the ATLAS detector. Data and MC samples are discussed in Section 3. The reconstruction of physics objects and event selection are covered in Section 4. Section 5 describes the calibration method, while Section 6 discusses the uncertainties. Finally, results are shown in Section 7, followed by the conclusion in Section 8.

2 ATLAS detector

The ATLAS detector [1, 22] at the LHC covers nearly the entire solid angle around the collision point.[1] It consists of an inner tracking detector surrounded by a thin superconducting solenoid, electromagnetic and hadronic calorimeters, and a muon spectrometer incorporating three large superconducting air-core toroidal magnets.

The inner-detector system (ID) is immersed in a 2 T axial magnetic field and provides charged-particle tracking in the range $|\eta| < 2.5$. The high-granularity silicon pixel detector covers the interaction region and typically provides four measurements per track, the first hit generally being in the insertable B-layer (IBL). It is followed by the SemiConductor Tracker (SCT), which usually provides eight measurements per track. These silicon detectors are complemented by the transition radiation tracker (TRT), which enables radially extended track reconstruction up to $|\eta| = 2.0$. The TRT also provides electron identification information based on the fraction of hits (typically 30 in total) above a higher energy-deposit threshold corresponding to transition radiation.

The calorimeter system covers the pseudorapidity range $|\eta| < 4.9$. Within the region $|\eta| < 3.2$, electromagnetic calorimetry is provided by barrel and endcap high-granularity lead/liquid-argon (LAr) calorimeters, with an additional thin LAr presampler covering $|\eta| < 1.8$ to correct for energy loss in material

[1] ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the centre of the detector and the z-axis along the beam pipe. The x-axis points from the IP to the centre of the LHC ring, and the y-axis points upwards. Polar coordinates (r, ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the z-axis. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln\tan(\theta/2)$ and is equal to the rapidity $y = \frac{1}{2}\ln\left(\frac{E+p_z}{E-p_z}\right)$ in the relativistic limit. Angular distance is measured in units of $\Delta R \equiv \sqrt{(\Delta y)^2 + (\Delta\phi)^2}$.

upstream of the calorimeters. Hadronic calorimetry is provided by the steel/scintillator-tile calorimeter, segmented into three barrel structures within $|\eta| < 1.7$, and two copper/LAr hadronic endcap calorimeters. The solid angle coverage is completed with forward copper/LAr and tungsten/LAr calorimeter modules optimised for electromagnetic and hadronic energy measurements, respectively.

The muon spectrometer (MS) comprises separate trigger and high-precision tracking chambers measuring the deflection of muons in a magnetic field generated by the superconducting air-core toroidal magnets. The field integral of the toroids ranges between 2.0 and 6.0 T m across most of the detector. Three layers of precision chambers, each consisting of layers of monitored drift tubes, cover the region $|\eta| < 2.7$, except in the innermost layer of the endcap region, where layers of small-strip thin-gap chambers and Micromegas chambers both provide precision tracking in the region $1.3 < |\eta| < 2.7$. The muon trigger system covers the range $|\eta| < 2.4$ with resistive-plate chambers in the barrel, thin-gap chambers in the endcap regions, and the aforementioned small-strip thin-gap chambers and Micromegas chambers in the innermost layer of the endcap.

The luminosity is measured mainly by the LUCID–2 detector that records Cherenkov light produced in the quartz windows of photomultipliers located close to the beampipe.

Events were selected by the first-level trigger system implemented in custom hardware, followed by selections made by algorithms implemented in software in the high-level trigger [23]. The first-level trigger accepted events from the 40 MHz bunch crossings at a rate close to 100 kHz, which the high-level trigger further reduced in order to record complete events to disk at an average rate of about 3 kHz.

The Run-3 detector configuration benefits from several upgrades compared with that of Run 2 to maintain high detector performance at the higher pileup levels of Run 3. The improvements include a new innermost layer of the muon spectrometer in the endcap region, which provides higher redundancy and a large reduction in fake muon triggers. The trigger system also benefits from new digital electronics readout of the LAr calorimeters with significantly increased granularity. Other updates and further details are provided in Ref. [22].

A software suite [24] is used in data simulation, in the reconstruction and analysis of real and simulated data, in detector operations, and in the trigger and data acquisition systems of the experiment.

3 Data and simulated samples

This measurement is performed using data collected during the 2022 and 2023 periods at $\sqrt{s} = 13.6$ TeV, corresponding to an integrated luminosity of 56.0 ± 1.1 fb^{-1}, after applying data quality requirements [25–27]. The luminosity is primarily measured by the LUCID-2 detector [28] located close to the beam pipe. Data are recorded using triggers that require the presence of a single electron (muon) with the minimum transverse momentum (p_{T}) exceeding a threshold of 26(24) GeV [23].

MC simulated samples are used to estimate the yield of $t\bar{t}$ production and other processes satisfying the selection criteria. Simulated $t\bar{t}$ events are used to define the PCBT bins, while all MC samples are utilised in the extraction of the calibration SFs that correct for differences in b-jet tagging efficiency between simulation and data. The nominal $t\bar{t}$ samples were generated with Powheg Box v2 [29–31] for the matrix element calculation at next-to-leading-order (NLO) in quantum chromodynamics (QCD) and interfaced to Pythia 8.308 [32] with the A14 set of tuned parameters [33, 34] for the parton showers, hadronisation and the underlying event. The h_{damp} parameter, which regulates the high-p_{T} radiation in the matrix element to parton shower matching, is set to $1.5 \times m_{\text{top}}$. The NNPDF3.0NLO [35] and NNPDF2.3LO [36] parton distribution functions (PDFs) are used in the matrix element calculation and the parton shower modelling, respectively. Three alternative $t\bar{t}$ samples were produced for the evaluation of modelling uncertainties. The first one accounts for the modelling uncertainty in the parton shower radiation, in which the h_{damp} parameter is set to $3.0 \times m_{\text{top}}$ and the Var3 parameter variation group [37] is increased. The second set of alternative samples were generated with different choices for the $p_{\text{T,hard}}$ parameter [38], to evaluate the uncertainty in the matching between the NLO hard-scatter matrix element calculations and the parton shower [39]. The final alternative sample, which is used to evaluate the parton shower modelling uncertainties, was produced with Powheg Box v2 interfaced to Herwig 7.2.3 [40] with the default tune.

The non-$t\bar{t}$ processes considered in the measurement either produce two prompt leptons or one prompt lepton and at least one non-prompt lepton candidate. These background processes include single top-quark production, single boson V+jets and diboson VV production (where V is either a Z- or a W-boson). The nominal sample for the production of a single top-quark in association with a W boson (Wt) is simulated with Powheg Box v2 interfaced to Pythia 8.308 using the "diagram removal" scheme [41, 42]. The samples for s- and t-channel production of a single top-quark were also produced with Powheg Box v2 interfaced to Pythia 8.308. Fully leptonically decaying diboson processes were simulated with Sherpa v2.2.14 and Sherpa v2.2.16 [43–45]. Samples of Z+jets, W+jets, and semileptonically decaying diboson processes, were produced with Sherpa v2.2.14. Alternative Wt samples were produced with Powheg Box v2 interfaced to Pythia 8 using the "diagram subtraction" scheme [41, 42] to assess the uncertainty related to the overlap between the $t\bar{t}$ and Wt production processes.

The effect of pile-up in the same and neighbouring bunch crossings was modelled in the simulation by overlaying the hard-scattering event with simulated inelastic pp events [46] generated with Epos 2.0.1.4 [47, 48] and Pythia 8.3. The events generated with Epos used the Epos LHC tune, while the Pythia events used the NNPDF2.3LO set of PDFs and the A3 set of tuned parameters [49]. Pythia is used to simulate events that contain at least one high p_{T} jet, isolated photon or lepton from a b-hadron decay, while Epos is used to simulate all remaining events in the sample. The events are generated independently and a filter is applied to the Epos generated events to veto the event topologies simulated by Pythia. Events in the simulation were then reweighted to match the observed distribution of the average number of interactions per bunch crossing in data. The EvtGen [50] package was used to model the decay of heavy flavour hadrons, except samples generated with Sherpa that has its own model for hadron decays. All MC samples were processed through the full ATLAS detector simulation [51] based on Geant4 [52], and are reconstructed using the same algorithms as in data.

4 Object definition and event selection

Events are required to have at least one reconstructed collision vertex with two or more associated tracks with $p_{\text{T}} > 500$ MeV. The primary vertex is defined as the vertex with the highest $\sum p_{\text{T}}^2$ of its associated tracks [53, 54]. To obtain a b-jet-enriched sample, events compatible with originating from the dileptonic decay of a $t\bar{t}$ pair are selected. This preselection requires exactly one electron candidate and one muon candidate with opposite charges and exactly two jets. At least one lepton must be identified in the trigger system and match one of the two offline lepton candidates. Corrections are applied to the simulation to account for known differences in trigger efficiency between the data and MC simulation.

Electron candidates are reconstructed from energy deposits in the Electromagnetic calorimeter matched to tracks in the ID [55]. They are required to satisfy $|\eta| < 2.47$, excluding the calorimeter transition region $1.37 < |\eta| < 1.52$, and have a transverse momentum $p_{\mathrm{T}} > 28$ GeV. Electrons must satisfy a tight identification criterion [55]. To select prompt electrons, candidates must fulfil tight isolation requirements [55], which include the requirement to be isolated from nearby tracks in the ID and from additional calorimeter activity. Electron energies are calibrated using the Z mass peak [56]. SFs are derived in $Z \to ee$ events and applied to the simulation to account for differences in reconstruction, identification, and isolation efficiencies between data and MC simulation.

Muon candidates are reconstructed from high-quality tracks in the MS matched to tracks in the ID [57]. They are required to have $|\eta| < 2.5$ and $p_{\mathrm{T}} > 28$ GeV, and to satisfy a medium identification criterion [57]. Similar to electron candidates, muon candidates must also fulfil tight isolation requirements. SFs are derived in $Z \to \mu\mu$ events and applied to the simulated events to account for differences in muon reconstruction, identification, and isolation efficiencies between data and MC simulation. Muon momenta are calibrated using the Z mass peak [58].

Electron and muon candidates must originate from the primary vertex by requiring $|z_0| \sin\theta < 0.5$ mm (where θ is the polar angle of the track), as well as $|d_0|/\sigma_{d_0} < 5$ for electrons (where σ_{d_0} represents the uncertainty in the transverse impact parameter) or $|d_0|/\sigma_{d_0} < 3$ for muons.

Jets are reconstructed from particle-flow objects combining ID and calorimeter information [59], using the anti-k_t algorithm [60, 61] with a radius parameter of $R = 0.4$. The jet four-momentum is calibrated to the particle level using a combination of simulation-based corrections and in situ calibrations [62]. Jets are required to be central ($|\eta| < 2.5$) and to have $p_{\mathrm{T}} > 20$ GeV. To suppress the contamination from pile-up jets, the jet vertex tagger (JVT) algorithm is applied to jets with $|\eta| < 2.4$ and $p_{\mathrm{T}} < 60$ GeV [63], requiring a tight JVT selection criterion. In the MC simulation, reconstructed jets are labelled according to their flavour using truth information, following a procedure referred to as *truth labelling*. A reconstructed jet is labelled as a b-jets if it contains at least one weakly decaying b-hadron with $p_{\mathrm{T}} > 5$ GeV within a cone of size $\Delta R < 0.3$ around the jet axis [21]. If no b-hadrons are found within the cone, matching to c-hadrons is considered using the same selection criteria, followed by matching to τ-leptons. All remaining jets are labelled as light-flavour jets. In the following, a reconstructed jet that has been truth labelled as a b-jet, c-jet or light-flavour jet is referred to as a *truth* b-jet, c-jet or light-flavour jet, respectively.

Overlap removal is applied to avoid double-counting physics objects. To prevent double-counting electron energy deposits as jets, all reconstructed jets within $\Delta R < 0.2$ of a reconstructed electron are removed. If the nearest jet surviving the selection is within $\Delta R < 0.4$ of the electron, the electron is discarded. To minimise the fraction of muons from heavy-flavour decays inside jets mistakenly identified as prompt muons, muons are required to be separated by $\Delta R > 0.4$ from the nearest jet. In cases where a muon and a jet are reconstructed within $\Delta R < 0.4$ of one another, the muon is removed if the jet has at least three associated tracks; otherwise, the jet is removed. This ensures that high-energy muons undergoing significant energy loss in the calorimeter are not mistakenly considered as jets.

The following preselection criteria are applied, on top of the trigger requirements, to select a sample enriched in $t\bar{t}$ events:

- **Lepton selection**. Exactly two well-identified leptons of different flavour and opposite charges ($e\mu$) are required to suppress the background from Z+jets and non-prompt leptons events. To minimise the contamination from events where the two leptons originate from τ-lepton decays, the electron–muon invariant mass $m_{e\mu}$ is required to be above 50 GeV.

- **Jet selection**. Events with exactly two jets with $p_{\mathrm{T}} > 20$ GeV are selected. This requirement suppresses the contribution of events with high-p_{T} light-flavour jets from final- or initial-state radiation or hadronic W-boson decays.
- **Jet–lepton pair invariant mass selection**. There are two unique ways to pair the two leptons and the two jets. To best associate the objects originating from the same top-quark decay, the pairing that minimises $\sqrt{m^2_{j_1,\ell_i} + m^2_{j_2,\ell_j}}$ is chosen, where j_1 (j_2) is the leading(subleading) in p_{T} of the jet, and $\ell_{i,j}$ are the two leptons. This pairing procedure selects the jet–lepton pairing most compatible with the top-quark decay topology, for which the invariant mass has a kinematic endpoint at around $m_{j,\ell} \lesssim 150$ GeV. Both $m_{j_1,\ell}$ and $m_{j_2,\ell}$ are further required to be above 20 GeV to avoid mis-modelling associated with very soft objects.

The mis-tagging rate of non-b-jet components in the MC simulation has been corrected with the procedure described in Section 6. After the correction, the data and MC comparison of the η and p_{T} distributions of the leading and subleading jets for events satisfying the preselection are shown in Figure 1. In the upper panel, the pre-fit MC distribution is shown as a breakdown of the $t\bar{t}$ contribution and the non-$t\bar{t}$ processes. In the ratio panel, the pre-fit MC distribution is compared with the post-fit MC distribution corrected by the measured b-jet tagging efficiency and jet flavour composition (measurement method described in Section 5).

Based on the truth flavour of the leading and subleading selected jets in simulation, events are labelled as bb, bl, lb, or ll. Here, l refers to all non-b jets, including c-jets, of which the contribution is one order of magnitude smaller than that of light-jets after the preselection. Specifically, bb (ll) events are those where both (neither) of the selected jets are truth b-jets.

Events satisfying the preselection are further categorised depending on the jet–lepton invariant masses $m_{j_1,\ell}$ and $m_{j_2,\ell}$ shown in Figure 2 to define a Signal Region (SR) enriched in bb events and three Control Regions (CR) enriched in lb, bl, and ll events. These control regions help to estimate the background contamination from mistagged events. The SR is defined by requiring both $m_{j_1,\ell}$ and $m_{j_2,\ell}$ to be below 175 GeV. In the SR, the bb purity is approximately 58%; the remaining 42% consists of events where one or both jets are truth light or charm jets. The categorisation is summarised in Table 1 and the jet flavour compositions are shown in Figure 3.

Table 1: Definition of signal and control regions for the simultaneous estimate of the b-jet tagging efficiencies and the jet truth flavour compositions bb, ll, bl, lb. The jet–lepton invariant mass is defined as $m_{j,\ell}$.

Analysis region	Description	Selection
SR	bb-enriched	$m_{j1,\ell} < 175$ GeV and $m_{j2,\ell} < 175$ GeV
$\mathrm{CR_{LL}}$	ll-enriched	$m_{j1,\ell} \geq 175$ GeV and $m_{j2,\ell} \geq 175$ GeV
$\mathrm{CR_{BL}}$	bl-enriched	$m_{j1,\ell} < 175$ GeV and $m_{j2,\ell} \geq 175$ GeV
$\mathrm{CR_{LB}}$	lb-enriched	$m_{j1,\ell} \geq 175$ GeV and $m_{j2,\ell} < 175$ GeV

The leading jet p_{T} distribution in the SR is shown in Figure 4(a), showing good data–MC agreement within the total uncertainty. The GN2 score distribution of the leading jet is shown in Figure 4(b) with the six PCBT bins: [100%, 90%], [90%, 85%], [85%, 77%], [77%, 70%], [70%, 65%], and [65%, 0%]. Each PCBT bin represents an exclusive interval of the corresponding GN2 score, or equivalently, an interval of the cumulative b-jet tagging efficiency.

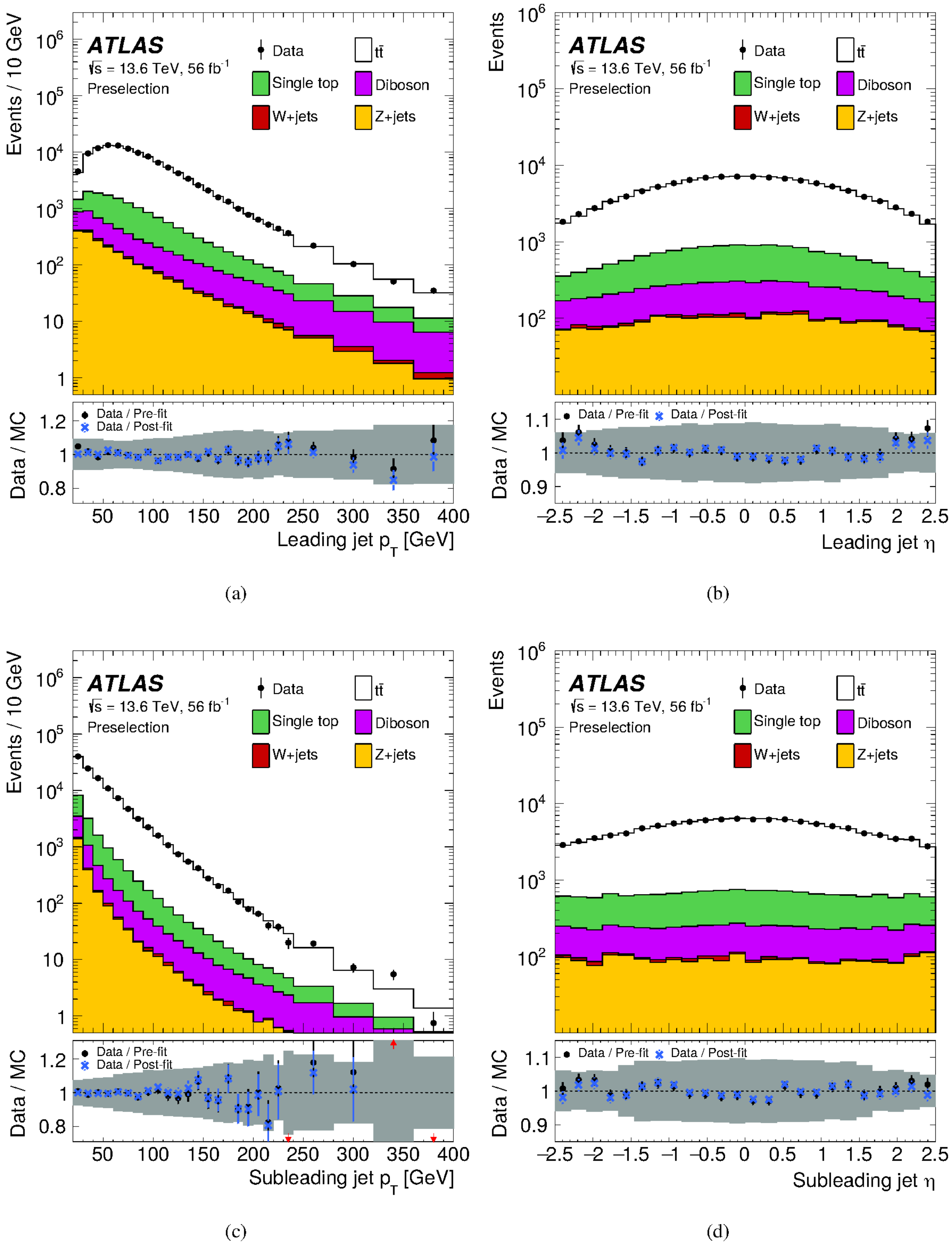
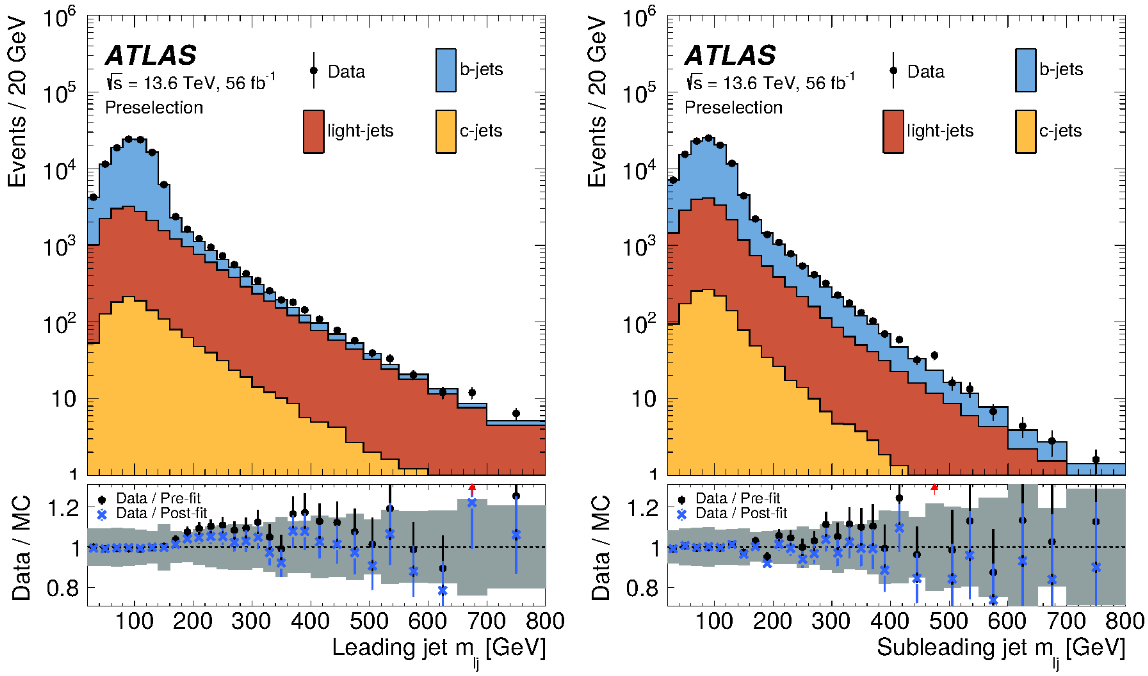


Figure 1: Distributions of the (a) leading jet p_{T}, (b) leading jet η, (c) subleading jet p_{T} and (d) subleading jet η, for events satisfying the selection criteria in data and MC samples. MC events are split into the $t\bar{t}$ signal and the background processes. The total contribution of simulated MC events is normalised to the total data yield. The bottom panels show the data-to-MC ratio, where the black markers correspond to the pre-fit MC simulation and the blue markers correspond to the post-fit MC simulation. The error bars represent the statistical uncertainty of the data. The shaded band, displayed only in the bottom panel, is the sum in quadrature of MC statistical and systematic uncertainties (described in Section 6) in the pre-fit MC simulation.



(a) (b)

Figure 2: Distribution of the jet–lepton invariant masses for the (a) leading and (b) sub-leading selected jets, shown both in data and simulation after preselection. Simulated events are classified in terms of the flavour composition of the two jets. The non-b-jet contribution in the MC simulation has been corrected by the measured light-jet mis-tagging scale factors, as described in Section 6. The total contribution of simulated MC events is normalised to the total data yield. The bottom panels show the data-to-MC ratio, where the black markers correspond to the pre-fit MC simulation and the blue markers correspond to the post-fit MC simulation. The error bars represent the statistical uncertainty of the data. The shaded band is the sum in quadrature of MC statistical and systematic uncertainties in the pre-fit MC simulation (consisting of detector uncertainties and physics modelling uncertainties described in Section 6).

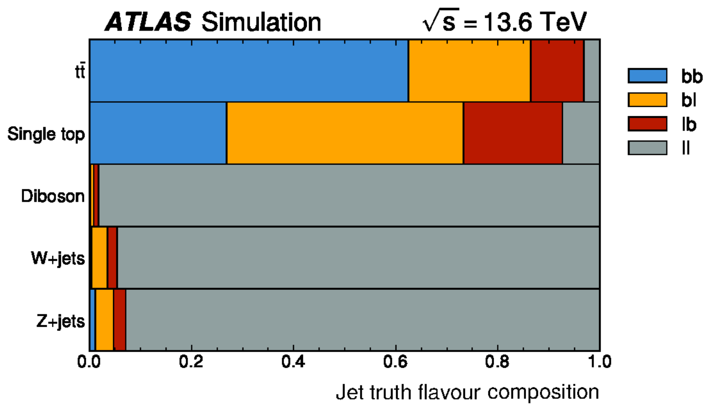
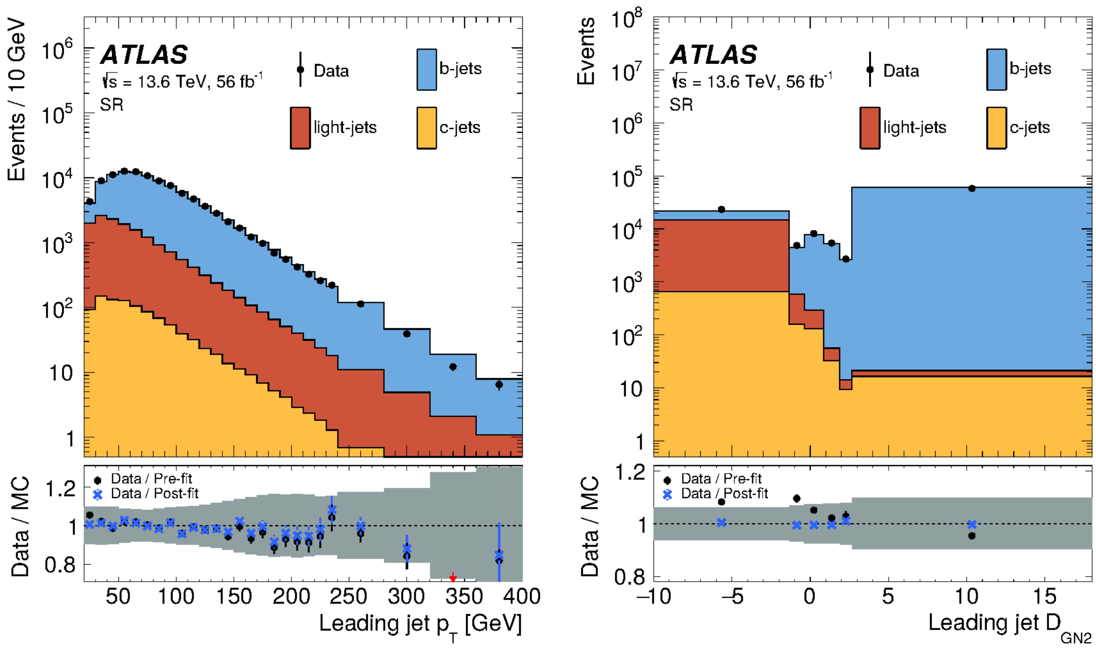


Figure 3: Jet truth flavour compositions of $t\bar{t}$ events and non-$t\bar{t}$ processes in the SR according to the MC simulation.



(a) (b)

Figure 4: Leading jet (a) p_{T} distribution and (b) GN2 score distribution within the SR, where the six PCBT bins follow the increase of the GN2 score: [100%, 90%], [90%, 85%], [85%, 77%], [77%, 70%], [70%, 65%] and [65%, 0%]. The non-b-jet contribution in the MC simulation has been corrected by the measured light-jet mis-tagging scale factors, as described in Section 6. The total contribution of simulated MC events is normalised to the total data yield. The bottom panel shows the data-to-MC ratio, where the black markers correspond to the pre-fit MC simulation and the blue markers correspond to the post-fit MC simulation. The error bars represent the data's statistical uncertainty. The shaded band is the sum in quadrature of MC statistical and systematic uncertainties in the pre-fit MC simulation (consisting of detector uncertainties and physics modelling uncertainties described in Section 6).

5 Extraction of the b-jet tagging efficiency

The method of b-jet tagging efficiency extraction based on the maximum likelihood approach has been documented in detail in Ref. [21] and is briefly summarised below.

In both the SR and three CRs, the selected events are binned into a two-dimensional grid of the leading jet p_{T} (T^m) and subleading jet p_{T} (T^n). The bin boundaries of [20, 40, 60, 140, 400] GeV are selected to have enough number of events to perform the b-jet tagging efficiency measurement in each bin and to ensure the convergence of the likelihood fit. This corresponds to 10 (T^m, T^n) bins in the SR and in each of the three CRs. The composition of jet flavour is dependent on the jet p_{T}. For example, the fraction of bb events in the SR as a function of the leading and subleading jet p_{T} is shown in Figure 5. The lower fraction of bb events in the low jet p_{T} region is due to a lower purity of $t\bar{t}$ events in this phase space, as compared with the region of $60 <$ jet $p_{\mathrm{T}} < 400$ GeV. In contrast, the high jet p_{T} area is dominated by the $t\bar{t}$ process; therefore ensuring fractions of bb events to be higher than 80%. In the SR, events in each (T^m, T^n) bin are further divided into 6×6 PCBT bins of the leading jet (O^k) and subleading jet (O^p). This categorisation strategy results in 390 bins in the input to the likelihood fit, including 10 (T^m, T^n) in each of the CRs and 360 (T^m, T^n, O^k, O^p) bins in the SR.

The total prediction of each (T^m, T^n) bin in one of the CRs ($\mathrm{CR_{LL}}$, $\mathrm{CR_{BL}}$, or $\mathrm{CR_{LB}}$) is expressed as:

$$\nu_{CR}(T^m, T^n) = c^{m,n}_{bb}\nu^{m,n}_{CR,bb} + c^{m,n}_{bl}\nu^{m,n}_{CR,bl} + c^{m,n}_{lb}\nu^{m,n}_{CR,lb} + c^{m,n}_{ll}\nu^{m,n}_{CR,ll},$$

that is the sum of the predicted numbers of events ν in all jet flavour compositions, each multiplied by the corresponding jet flavour composition correction factor (c_{bb}, c_{bl}, c_{lb} or c_{ll}). The jet flavour composition correction factors are shared between the CRs and SR predictions and allow to adjust the jet flavour composition to data. They are determined for each systematic uncertainty variation, which reduces the sensitivity to the mis-modelling of jet flavour composition in the simulation and improve the precision of the measurement. The total prediction of each (T^m, T^n, O^k, O^p) bin in the SR is written as:

$$\begin{aligned}
\nu_{SR}(T^m, T^n, O^k, O^p) = {} & c^{m,n}_{bb}\nu^{m,n}_{SR,bb} \cdot \mathcal{P}_b(O^k|T^m) \cdot \mathcal{P}_b(O^p|T^n) \\
& + c^{m,n}_{bl}\nu^{m,n}_{SR,bl} \cdot \mathcal{P}_b(O^k|T^m) \cdot \mathcal{P}_l(O^p|T^n) \\
& + c^{m,n}_{lb}\nu^{m,n}_{SR,lb} \cdot \mathcal{P}_l(O^k|T^m) \cdot \mathcal{P}_b(O^p|T^n) \\
& + c^{m,n}_{ll}\nu^{m,n}_{SR,ll} \cdot \mathcal{P}_l(O^k|T^m) \cdot \mathcal{P}_l(O^p|T^n),
\end{aligned}$$

where the $\mathcal{P}_b$ are the b-jet tagging efficiencies to be measured in PCBT bins for each interval of jet p_{T} and $\mathcal{P}_l$ are the light-jet mis-tagging rates computed from the MC, where the correction on the light-jet mis-tagging rate derived from a dedicated calibration analysis has been accounted for and applied to the total non-b-jet contribution.

The likelihood is defined as:

$$\ln \mathcal{L}(\hat{\Theta}) = \sum_{m,n}\left[\sum_{\text{LL, BL, LB}}\left(-\nu_{CR}(\hat{\Theta}) + n_{CR}\ln\nu_{CR}(\hat{\Theta})\right) + \sum_{k,p}\left(-\nu_{SR}(\hat{\Theta}) + n_{SR}\ln\nu_{SR}(\hat{\Theta})\right)\right], \quad (1)$$

where n_{CR} is the observed number of events in each $(T^m,\ T^n)$ bin for the three CRs, n_{SR} is that in each (O^k, O^p, T^m, T^n) bin for the SR, and

$$\hat{\Theta} = \left(\mathcal{P}_b(O^k|T^m), c^{m,n}_{bb}, c^{m,n}_{bl}, c^{m,n}_{lb}, c^{m,n}_{ll}\right)$$

is the list of free parameters to be determined. The unitarity constraint is applied to the b-jet tagging efficiency from all PCBT bins, resulting in five free parameters of $\mathcal{P}_b$ in each of the four jet p_{T} bins. In total, there are fourty jet flavour composition correction factors and twenty $\mathcal{P}_b$'s to be determined by the fit. The minimisation of the likelihood with respect to the data, which is evaluated numerically by RooFit [64], returns the most probable value of $\hat{\Theta}$ and their statistical uncertainty due to the finite number of events in the data.

The likelihood fit has been tested for bias using pseudo-data from the nominal MC simulation and from MC samples with varied jet flavour compositions. These tests showed the fit introduces negligible bias, so no additional systematic uncertainty related to the fitting procedure is required.

6 Uncertainties

Uncertainties related to the measurement of the b-jet tagging efficiency arise from both statistical and systematic origin due to detector effects and physics modelling.

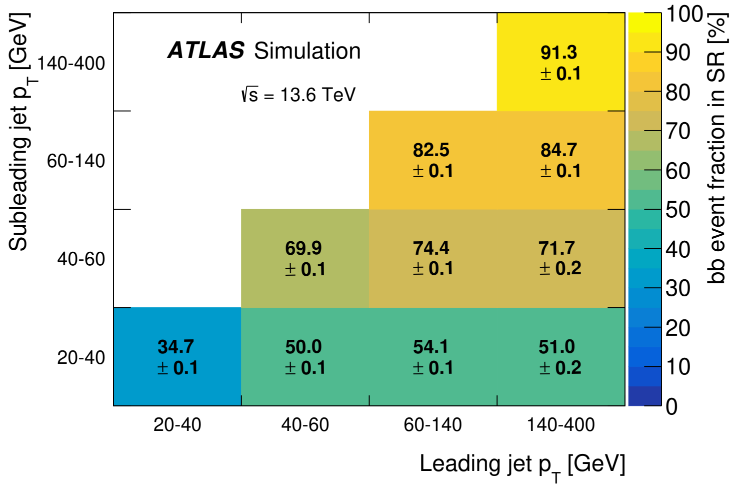


Figure 5: Fraction of bb flavour events in the signal region from all simulated MC contributions as a function of the leading and subleading jet p_{T}. Uncertainties are statistical only.

The data statistical uncertainty in the b-jet tagging efficiency is directly taken from the error matrix returned by the minimisation of the likelihood. The size of the data statistical uncertainty varies from 0.5% in the [65%, 0%] PCBT bin and medium jet p_{T} range of $60 < p_{\mathrm{T}} < 140$ GeV to around 10% in the [100%, 90%] PCBT bin and low jet p_{T} range of $20 < p_{\mathrm{T}} < 40$ GeV. The uncertainty in the b-jet tagging efficiency due to the finite number of simulated MC events of all processes is estimated by the bootstrap method [65]. The standard deviation of b-jet tagging efficiency obtained from repeated fits using resampled MC events is taken to be the MC statistical uncertainty. This uncertainty source is the largest in the [100%, 90%] PCBT bin and low jet p_{T} range of $20 < p_{\mathrm{T}} < 40$ GeV, where it reaches 3%. In the other PCBT bins, the MC statistical uncertainty amounts to no more than 0.5%.

Systematic uncertainties in the b-jet tagging efficiency are estimated by replacing the nominal MC prediction with a systematic variation and repeating the likelihood fit. The offset between the efficiency from the nominal fit to the data and the efficiency obtained with the systematic variation is taken to be the systematic uncertainty of the source under study. The uncertainties of up and down variations of the same systematic source on the b-jet tagging efficiency are symmetrised with respect to the result of the nominal fit. The first group of systematic uncertainties from the detector response is related to the uncertainty in the lepton selection efficiency, the lepton energy correction, energy scale and resolution of jets, the uncertainty in pile-up modelling and the uncertainty related to the performance of the JVT algorithm [66]. Jet energy scale and resolution uncertainties are the leading uncertainty sources related to detector response. The detector uncertainties are below 4% in all bins except the [100%, 90%] PCBT bin in the low jet p_{T} range of $20 < p_{\mathrm{T}} < 40$ GeV, where it can go up to 18% due to large jet energy scale and resolution uncertainties. The second group of systematic uncertainties concerns the physics modelling of $t\bar{t}$ and single top-quark production. This group of systematic uncertainties consists of the following:

- Uncertainties originating from PDFs are accounted for by following the PDF4LHC recommendations [67, 68]. The five-flavour scheme with variation on α_{s} is used for the $t\bar{t}$ production process and the single top production process in the s- and Wt channels, while the four-flavour scheme is used for the single top production in the t-channel. The PDF uncertainty is considered uncorrelated between different processes.

- Uncertainties in the QCD radiation are evaluated by increasing or decreasing the amount of initial-state radiation (ISR) and final-state radiation (FSR) within Pythia 8 [37]. These uncertainties are considered uncorrelated between different processes.
- Uncertainties in the matching between the matrix element calculation and the parton shower are taken into account by changing the choice of the Powheg-hardness definition and using a different damping factor. The MC sample of this variation is described earlier in Section 3.
- Uncertainties in the modelling of the parton shower and hadronisation processes are assessed by comparing the difference between Pythia 8 and Herwig 7.
- The impact of the interference between the single top tW and $t\bar{t}$ production is investigated by comparing the difference between the nominal “diagram removal” scheme and the alternative “diagram subtraction” scheme, as discussed in Section 3.

The size of the $t\bar{t}$ modelling uncertainties ranges from 0.5% in the [70%, 65%] PCBT bin and medium p_{T} region of $60 < p_{\mathrm{T}} < 140$ GeV to 14% in the [100%, 90%] PCBT bin and low jet p_{T} region of $20 < p_{\mathrm{T}} < 40$ GeV, where the uncertainties in the modelling of parton shower and hadronisation processes and in the modelling of QCD FSR dominate. The single top modelling uncertainties, dominated by the difference between the 'diagram removal' scheme and the 'diagram subtraction' scheme, are below 1% except the [100%, 90%] PCBT bin. In the [100%, 90%] PCBT bin, the single top modelling uncertainties are the largest, where they amount to the maximum of 6% in the region of $140 <$ jet $p_{\mathrm{T}} < 400$ GeV. The other sources of physics modelling uncertainties not listed above, including the uncertainties in the production cross-sections of V+jets and diboson processes, were found to be negligible in previous measurement of the b-jet tagging efficiencies [21] and are therefore not included in this work.

The last group of systematic uncertainties consists of two sources estimated from dedicated procedures. The first source is the uncertainty in the rate of electrons not originating from the Z- or W-boson decay (non-prompt electrons) in the MC simulation. The other uncertainty originates from the correction on the probability for non-b-jets, mainly light-flavour jets, to mistakenly be identified as b-jets. Non-prompt leptons are included in the simulation of the nominal MC. Even though non-prompt electrons predicted by the simulation only reach per-mille level fraction in the total event yield, the mis-modelling of the non-prompt electron rate is expected to introduce a non-negligible source of uncertainty to the measurement of the b-jet tagging efficiency. The uncertainty variation on the non-prompt electron rate is derived from a data-driven approach. First, event selections are carried out as described in Section 4, but two same-charged leptons are required instead of the nominal opposite-charge selection. Then, the ratio of data subtracted by the MC contribution with a prompt electron over the MC events with a non-prompt electron is computed in three coarse bins of electron p_{T}: [0, 150, 300, 400] GeV. The ratio is the highest for $0 <$ electron $p_{\mathrm{T}} < 150$ GeV, reaching 5.5 (3.4) in the data taken during 2022 (2023). For $300 <$ electron $p_{\mathrm{T}} < 400$ GeV, the ratio drops to 1.3 (1.6) for the data taken during 2022 (2023). Finally, this ratio is applied as correction factors to reweight the events with a non-prompt electron in the nominal MC as a function of electron p_{T}, thereby producing the uncertainty variation of the non-prompt electron rate. Typically, the non-prompt electron rate uncertainty is important only in the lowest jet p_{T} bin of $20 < p_{\mathrm{T}} < 40$ GeV, spanning the range from 1% to 7%.

The central value of the total non-b-jet mis-tagging rate is corrected using scale factors derived from a dedicated calibration analysis for light-jet mis-tagging rate. The method of the calibration is similar to the one described in [69]. The light-jet mis-tagging scale factors are compatible with unity for the [100%, 90%] PCBT bin, and vary between 1.3 and 1.5 most of the other PCBT bins. The impact of the uncertainties associated with the light-jet mis-tagging rate calibration is evaluated in this measurement. In all PCBT bins except the [65%, 0%] PCBT bin, the mis-tagging systematic uncertainties in the b-jet tagging efficiency is the largest in the first jet p_T bin between 20 and 40 GeV. The relative uncertainty amounts to 2% on the b-jet tagging efficiency in the [100%, 90%] and [90%, 85%] PCBT bins for 20 < jet p_T < 40 GeV, where the fraction of non-truth b-jet is the largest. The mis-tagging systematic uncertainties decreases with a higher fraction of b-jet contribution in the PCBT bins.

The total uncertainty is the sum in quadrature of the data statistical uncertainty, the MC statistical uncertainty and all the systematic uncertainties, computed for each PCBT and jet p_T bin and ranges from 1% in the [65%, 0%] PCBT bin for 60 < jet p_T < 140 GeV to 25% in the [100%, 90%] PCBT bin for 20 < jet p_T < 40 GeV.

7 Results

With the likelihood fit described in Section 5, measurements of the GN2 b-jet tagging efficiency are carried out in each PCBT bin as a function of jet p_T, as shown in Figure 6. For illustrative purposes, the measurements are also compared with the efficiency evaluated from simulated $t\bar{t}$ samples after the SR selection. For each PCBT bin O^k and jet p_T interval T^m, the simulation-to-data scale factor of the b-jet tagging efficiency is the ratio of the measured b-jet tagging efficiency ($\mathcal{P}_b^{\text{Data}}(O^k|T^m)$) over the b-jet tagging efficiency in the sum of all nominal MC samples ($\mathcal{P}_b^{\text{MC}}(O^k|T^m)$)

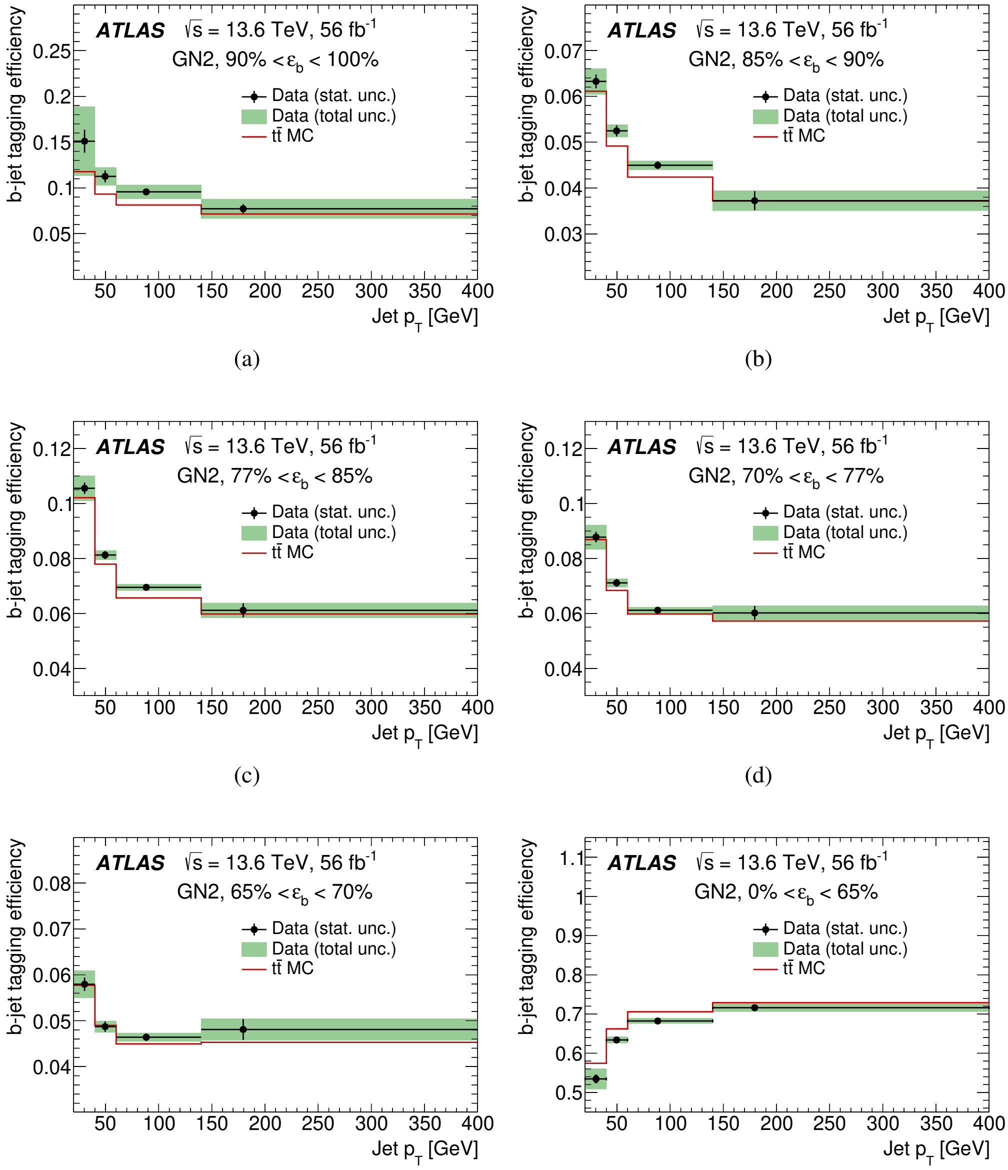
$$SF(O^k, T^m) = \frac{\mathcal{P}_b^{\text{Data}}(O^k|T^m)}{\mathcal{P}_b^{\text{MC}}(O^k|T^m)}.$$

Scale factors are derived for all PCBT bins as a function of jet p_T, as shown in Figure 7. The scale factors, ranging from 0.9 to 1.3, are applied as weights in ATLAS physics analyses. The post-fit values of the flavour composition correction factors c_{bb}, c_{bl}, c_{lb} and c_{ll} range from 0.7 to 1.3, depending on the flavour composition and jet p_T intervals, and are listed in Table 2.

Table 2: Post-fit values of jet flavour composition correction factors c_{bb}, c_{bl}, c_{lb} and c_{ll} in intervals of leading and subleading jet p_T. Only data statistical uncertainties are quoted.

Leading jet p_T [GeV]	Subleading jet p_T [GeV]	Correction factors			
		c_{bb}	c_{bl}	c_{lb}	c_{ll}
$20 < p_{T,1} < 40$	$20 < p_{T,2} < 40$	0.89 ± 0.03	0.88 ± 0.02	0.83 ± 0.03	1.02 ± 0.04
$40 < p_{T,1} < 60$	$20 < p_{T,2} < 40$	0.90 ± 0.02	0.85 ± 0.03	0.78 ± 0.05	0.97 ± 0.04
	$40 < p_{T,2} < 60$	0.93 ± 0.02	0.89 ± 0.05	0.75 ± 0.06	1.18 ± 0.10
$60 < p_{T,1} < 140$	$20 < p_{T,2} < 40$	0.89 ± 0.02	0.85 ± 0.02	0.88 ± 0.05	0.98 ± 0.04
	$40 < p_{T,2} < 60$	0.90 ± 0.01	0.81 ± 0.04	0.87 ± 0.04	1.08 ± 0.07
	$60 < p_{T,2} < 140$	0.90 ± 0.01	0.83 ± 0.04	0.87 ± 0.04	1.04 ± 0.11
$140 < p_{T,1} < 400$	$20 < p_{T,2} < 40$	0.82 ± 0.03	0.82 ± 0.03	0.99 ± 0.10	1.18 ± 0.08
	$40 < p_{T,2} < 60$	0.85 ± 0.03	0.66 ± 0.06	0.89 ± 0.09	1.23 ± 0.16
	$60 < p_{T,2} < 140$	0.82 ± 0.02	0.80 ± 0.06	1.07 ± 0.07	1.30 ± 0.16
	$140 < p_{T,2} < 400$	0.78 ± 0.03	1.21 ± 0.02	1.21 ± 0.13	1.06 ± 0.03

The uncertainty in the measurement of b-jet tagging efficiency for the [65%, 0%] PCBT bin is summarised in Figure 8. The leading uncertainties in the low jet p_T region are the detector systematic uncertainties, which are dominated by the uncertainties in the energy scale and resolution of jets. For 60 < jet p_T < 140 GeV where the number of events is the largest, the uncertainty breakdown is summarised for all PCBT bins in



(a) (b) (c) (d) (e) (f)

Figure 6: GN2 b-jet tagging efficiency as a function of jet p_{T} for all PCBT bins: (a) [100%, 90%], (b) [90%, 85%], (c) [85%, 77%], (d) [77%, 70%], (e) [70%, 65%] and (f) [65%, 0%]. The measurement is shown together with the efficiency derived from simulated $t\bar{t}$ events satisfying the SR selection. Vertical error bars include data statistical uncertainties only while the green bands correspond to the sum in quadrature of data statistical, MC statistical and systematic uncertainties. The markers are located at the mean of the b-jet p_{T} distribution in each p_{T} bin.

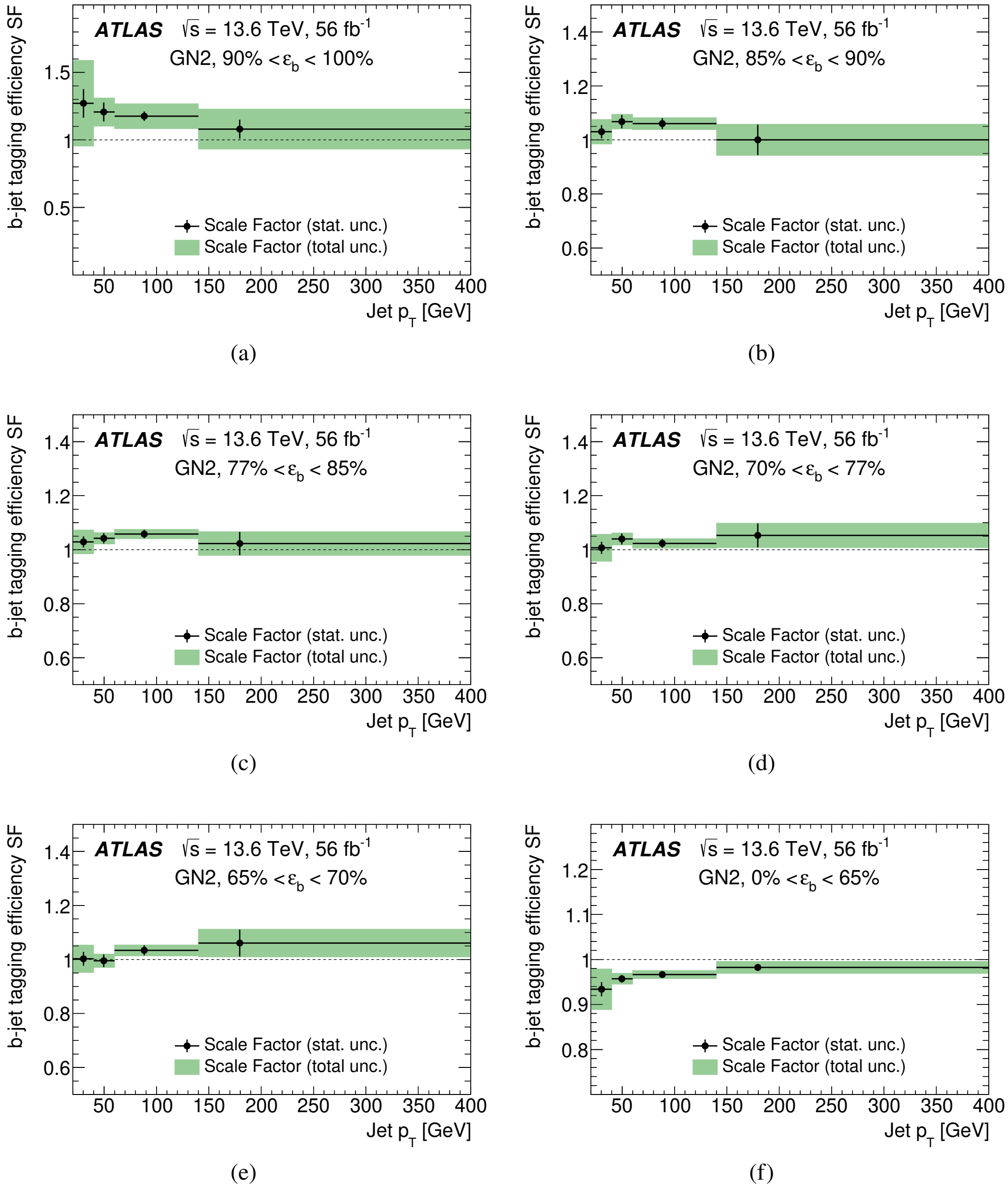


Figure 7: b-jet tagging efficiency simulation-to-data scale factors of GN2 as a function of jet p_{T} for all PCBT bins: (a) [100%, 90%], (b) [90%, 85%], (c) [85%, 77%], (d) [77%, 70%], (e) [70%, 65%] and (f) [65%, 0%]. Vertical error bars include data statistical uncertainties only while the green bands correspond to the sum in quadrature of data statistical, MC statistical and systematic uncertainties. The markers are located at the mean of the b-jet p_{T} distribution in each p_{T} bin.

Table 3. The total uncertainty in this interval of jet p_T ranges between 0.9% and 7.8%, depending on the PCBT bin. For jet p_T larger than 140 GeV, the data statistical uncertainty increases.

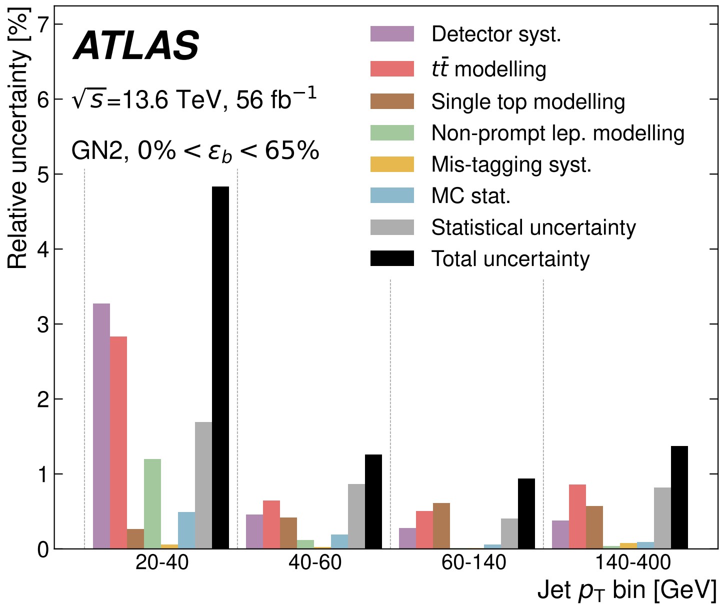


Figure 8: Breakdown of the relative uncertainties impacting the b-jet tagging efficiency in the [65%, 0%] PCBT bin as a function of the jet p_T. Detector systematic uncertainties, $t\bar{t}$ modelling uncertainties, single top modelling uncertainties, non-prompt lepton correction uncertainties, light-flavour jet mis-tagging uncertainties, MC statistical uncertainties, data statistical uncertainties, and total uncertainties are shown from left to right in each bin of jet p_T.

Table 3: Relative uncertainty breakdown for the b-jet tagging efficiency in the $60 < p_T < 140$ GeV jet p_T bin. The PCBT bins are intervals of cumulative b-jet tagging efficiency.

Source of uncertainty	Relative uncertainty [%] on b-jet tagging efficiency per PCBT bin					
	[100%, 90%]	[90%, 85%]	[85%, 77%]	[77%, 70%]	[70%, 65%]	[65%, 0%]
Detector syst.	2.2	0.3	0.2	0.3	0.2	0.3
$t\bar{t}$ modelling	4.5	0.7	0.5	0.5	0.5	0.5
Single top modelling	5.2	0.1	0.5	0.6	0.5	0.6
Non-prompt lep. modelling	0.1	0.1	0.2	<0.1	0.1	<0.1
Mis-tagging syst.	0.6	0.5	0.2	0.2	0.1	<0.1
MC stat.	0.5	0.1	0.1	0.1	0.1	0.1
Total systematic uncertainties	7.3	0.9	0.8	0.8	0.8	0.8
Statistical uncertainty	3.0	1.9	1.5	1.6	1.8	0.4
Total uncertainty	7.8	2.1	1.7	1.7	1.9	0.9

8 Conclusion

The b-jet performance of the GN2 algorithm is studied with data recorded by the ATLAS experiment during the years 2022 and 2023 of Run 3 at a centre-of-mass energy of 13.6 TeV, corresponding to an integrated luminosity of 56 fb^{-1}.

The measurement of the b-jet tagging efficiency of the GN2 algorithm in pp collisions relies on a sample enriched in dileptonic $t\bar{t}$ events, which is obtained by selecting events with exactly two jets, a single electron and a single muon of opposite electric charge. These selected events are further categorised according to the p_{T} of the two jets, the invariant mass of the two jet–lepton pairs, and the PCBT bins of the two jets. The categorised events are used as input to a likelihood fit that simultaneously infers the b-jet tagging efficiencies and the jet flavour composition of the data. The b-jet tagging efficiencies are measured for jets with a transverse momentum between 20 and 400 GeV, providing b-jet tagging efficiencies in each PCBT bin. Simulation-to-data scale factors are then computed in PCBT bins as a function of jet p_{T} by dividing the measured efficiency in collision data by the expected value in the simulation. The simulation-to-data scale factors obtained from the measurements are between 0.9 and 1.3. The measured b-jet tagging efficiencies have a total uncertainty of around 1% for jets with transverse momentum larger than 60 GeV in the [65%, 0%] interval of cumulative efficiency. The precision of the measurement at low jet p_{T} is mostly limited by the uncertainties in jet energy calibration and physics modelling, while at high jet p_{T} the total uncertainty receives a larger contribution from the statistical uncertainty of the data. The jet flavour composition correction factors inferred from the data events are also reported for all intervals of jet p_{T}.

These results validate the outstanding b-jet tagging performance of the GN2 algorithm used by the ATLAS experiment during the Run 3 data-taking. The central values of the b-jet tagging efficiency scale factors of the GN2 algorithm are provided to ATLAS physics analyses, along with the uncertainties and correlation scheme of uncertainties sources across jet p_{T} and PCBT bins.

Acknowledgements

We thank CERN for the very successful operation of the LHC and its injectors, as well as the support staff at CERN and at our institutions worldwide without whom ATLAS could not be operated efficiently.

The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN, the ATLAS Tier-1 facilities at TRIUMF/SFU (Canada), NDGF (Denmark, Norway, Sweden), CC-IN2P3 (France), KIT/GridKA (Germany), INFN-CNAF (Italy), NL-T1 (Netherlands), PIC (Spain), RAL (UK) and BNL (USA), the Tier-2 facilities worldwide and large non-WLCG resource providers. Major contributors of computing resources are listed in Ref. [70].

We gratefully acknowledge the support of ANPCyT, Argentina; YerPhI, Armenia; ARC, Australia; BMWFW and FWF, Austria; ANAS, Azerbaijan; CNPq and FAPESP, Brazil; NSERC, NRC and CFI, Canada; CERN; ANID, Chile; CAS, MOST, NSFC and FRFCU, China; Minciencias, Colombia; MEYS CR, Czech Republic; DNRF and DNSRC, Denmark; IN2P3-CNRS and CEA-DRF/IRFU, France; SRNSFG, Georgia; BMFTR, HGF and MPG, Germany; GSRI, Greece; RGC and Hong Kong SAR, China; ICHEP and Academy of Sciences and Humanities, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; NWO, Netherlands; RCN, Norway; MNiSW, Poland; FCT, Portugal; MNE/IFA, Romania; MSTDI, Serbia; MSSR, Slovakia; ARIS and MVZI, Slovenia; DSI/NRF, South Africa; MICIU/AEI, Spain; SRC and Wallenberg Foundation, Sweden; SERI, SNSF and Cantons of Bern and Geneva, Switzerland; NSTC, Taipei; TENMAK, Türkiye; STFC/UKRI, United Kingdom; DOE and NSF, United States of America.

Individual groups and members have received support from BCKDF, CANARIE, CRC and DRAC, Canada; CERN-CZ, FORTE and PRIMUS, Czech Republic; COST, ERC, ERDF, Horizon 2020 and Marie Skłodowska-Curie Actions, European Union; Investissements d'Avenir Labex, Investissements d'Avenir Idex and ANR, France; DFG and AvH Foundation, Germany; Herakleitos, Thales and Aristeia programmes co-financed by EU-ESF and the Greek NSRF, Greece; BSF-NSF and MINERVA, Israel; NCN and NAWA, Poland; La Caixa Banking Foundation, CERCA and AGAUR programs from Generalitat de Catalunya and PROMETEO and GenT Programmes Generalitat Valenciana, Spain; Göran Gustafssons Stiftelse, Sweden; The Royal Society and Leverhulme Trust, United Kingdom; Eric and Wendy Schmidt Fund for Strategic Innovation, United States of America.

In addition, individual members wish to acknowledge support from Chile: Agencia Nacional de Investigación y Desarrollo (ANID FONDECYT reg. 1230987, FONDECYT 1230812, FONDECYT 1240864, Fondecyt 3240661, Fondecyt Regular 1240721); China: Fundamental Research Funds for the Central Universities (010-63263105), Chinese Ministry of Science and Technology (MOST-2023YFA1605700, MOST-2023YFA1609300), National Natural Science Foundation of China (NSFC 12275265, NSFC-W2543005); Czech Republic: Czech Science Foundation (GACR - 24-11373S), Ministry of Education Youth and Sports (ERC-CZ-LL2327, FORTE CZ.02.01.01/00/22_008/0004632), PRIMUS Research Programme (PRIMUS/21/SCI/017); EU: H2020 European Research Council (ERC - 101002463); European Union: European Research Council (BARD No. 101116429, ERC - 101219398, ERC - 948254, ERC 101089007), European Regional Development Fund (HE COFUND GA No.101081355, ERDF), Marie Sklodowska-Curie Actions (GAP-101168829); France: Agence Nationale de la Recherche (ANR-21-CE31-0013, ANR-22-EDIR-0002, ANR-24-CE31-0504-01); Germany: Deutsche Forschungsgemeinschaft (DFG - 469666862); China: Research Grants Council (GRF); Italy: Istituto Nazionale di Fisica Nucleare (LHC-MIUR - 28003/2025), Ministero dell'Università e della Ricerca (NextGenEU 153D23001490006 M4C2.1.1, NextGenEU I53D23000820006 M4C2.1.1, SOE2024_0000023); Japan: Japan Society for the Promotion of Science (JSPS KAKENHI JP25H0063, JSPS KAKENHI JP22H01227, JSPS KAKENHI JP22H04944, JSPS KAKENHI JP22KK0227, JSPS KAKENHI JP24K23939, JSPS KAKENHI JP24KK0251, JSPS KAKENHI JP25H00650, JSPS KAKENHI JP25H01291, JSPS KAKENHI JP25K01011, JSPS KAKENHI JP25K01023); Poland: Polish National Science Centre (NCN 2021/42/E/ST2/00350, NCN OPUS 2023/51/B/ST2/02507, NCN OPUS nr 2022/47/B/ST2/03059, NCN UMO-2019/34/E/ST2/00393, UMO-2022/47/O/ST2/00148, UMO-2023/49/B/ST2/04085, UMO-2023/51/B/ST2/00920, UMO-2024/53/N/ST2/00869); Spain: Agència de Gestió d'Ajuts Universitaris i de Recerca. (AGAUR - 2023 BP 00141), Ministry of Science and Innovation (RYC2019-028510-I, RYC2020-030254-I, RYC2021-031273-I, RYC2022-038164-I), Ministerio de Ciencia, Innovación y Universidades/Agencia Estatal de Investigación (EU NextGenerationEU (PRTR-C17.I1), PID2022-142604OB-C22); Sweden: Carl Trygger Foundation (Carl Trygger Foundation CTS 22:2312), Swedish Research Council (Swedish Research Council 2023-04654, VR 2021-03651, VR 2022-03845, VR 2022-04683, VR 2023-03403, VR 2024-05451, VR 2025-05940), Knut and Alice Wallenberg Foundation (KAW 2023.0366); Switzerland: Swiss National Science Foundation (SNSF - PCEFP2_194658); United Kingdom: The Binks Trust, Royal Society (NIF-R1-231091); United States of America: U.S. Department of Energy (ECA DE-AC02-76SF00515), John Templeton Foundation (John Templeton Foundation 63206), Neubauer Family Foundation.

References

[1] ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, JINST **3** (2008) S08003.

[2] L. Evans and P. Bryant, *LHC Machine*, JINST **3** (2008) S08001.

[3] ATLAS Collaboration, *Measurements of Higgs bosons decaying to bottom quarks from vector boson fusion production with the ATLAS experiment at $\sqrt{s} = 13$ TeV*, Eur. Phys. J. C **81** (2021) 537, arXiv: 2011.08280 [hep-ex].

[4] ATLAS Collaboration, *Measurements of WH and ZH production with Higgs boson decays into bottom quarks and direct constraints on the charm Yukawa coupling in 13 TeV pp collisions with the ATLAS detector*, JHEP **04** (2025) 075, arXiv: 2410.19611 [hep-ex].

[5] ATLAS Collaboration, *Measurement of Higgs boson decay into b-quarks in associated production with a top-quark pair in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector*, JHEP **06** (2022) 097, arXiv: 2111.06712 [hep-ex].

[6] ATLAS Collaboration, *Measurement of the jet mass in high transverse momentum $Z(\rightarrow b\bar{b})\gamma$ production at $\sqrt{s} = 13$ TeV using the ATLAS detector*, Phys. Lett. B **812** (2021) 135991, arXiv: 1907.07093 [hep-ex].

[7] ATLAS Collaboration, *Measurements of the production cross-section for a Z boson in association with b- or c-jets in proton–proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector*, Eur. Phys. J. C **84** (2024) 984, arXiv: 2403.15093 [hep-ex].

[8] ATLAS Collaboration, *Measurements of the top quark branching ratios into channels with leptons and quarks with the ATLAS detector*, Phys. Rev. D **92** (2015) 072005, arXiv: 1506.05074 [hep-ex].

[9] ATLAS Collaboration, *Precise measurement of the $t\bar{t}$ production cross-section and lepton differential distributions in $e\mu$ dilepton events from $\sqrt{s} = 13$ TeV pp collisions with the ATLAS detector*, Eur. Phys. J. C **86** (2026) 470, arXiv: 2509.15066 [hep-ex].

[10] ATLAS Collaboration, *Combination of Searches for Higgs Boson Pair Production in pp Collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector*, Phys. Rev. Lett. **133** (2024) 101801, arXiv: 2406.09971 [hep-ex].

[11] ATLAS Collaboration, *Search for pair production of boosted Higgs bosons via vector-boson fusion in the $b\bar{b}b\bar{b}$ final state using pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector*, Phys. Lett. B **858** (2024) 139007, arXiv: 2404.17193 [hep-ex].

[12] ATLAS Collaboration, *Search for the non-resonant production of Higgs boson pairs via gluon fusion and vector-boson fusion in the $b\bar{b}\tau^+\tau^-$ final state in proton–proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector*, Phys. Rev. D **110** (2024) 032012, arXiv: 2404.12660 [hep-ex].

[13] ATLAS Collaboration, *Study of Higgs boson pair production in the $HH \rightarrow b\bar{b}\gamma\gamma$ final state with $308\,fb^{-1}$ of data collected at $\sqrt{s} = 13$ TeV and 13.6 TeV by the ATLAS experiment*, Phys. Lett. B **876** (2026) 140280, arXiv: 2507.03495 [hep-ex].

[14] ATLAS Collaboration, *Search for pair production of third-generation leptoquarks decaying into a bottom quark and a τ-lepton with the ATLAS detector*, Eur. Phys. J. C **83** (2023) 1075, arXiv: 2303.01294 [hep-ex].

[15] ATLAS Collaboration, *Search for Higgs boson decays into a pair of pseudoscalar particles in the $bb\mu\mu$ final state with the ATLAS detector in pp collisions at $\sqrt{s} = 13$ TeV*, Phys. Rev. D **105** (2022) 012006, arXiv: 2110.00313 [hep-ex].

[16] ATLAS Collaboration, *Search for $W' \to tb$ decays in the hadronic final state using pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector*, Phys. Lett. B **781** (2018) 327, arXiv: 1801.07893 [hep-ex].

[17] ATLAS Collaboration, *Deep Sets based Neural Networks for Impact Parameter Flavour Tagging in ATLAS*, ATL-PHYS-PUB-2020-014, 2020, URL: https://cds.cern.ch/record/2718948.

[18] ATLAS Collaboration, *ATLAS flavour-tagging algorithms for the LHC Run 2 pp collision dataset*, Eur. Phys. J. C **83** (2023) 681, arXiv: 2211.16345 [physics.data-an].

[19] ATLAS Collaboration, *Transforming jet flavour tagging at ATLAS*, Nature Commun. **17** (2026) 541, arXiv: 2505.19689 [hep-ex].

[20] A. Vaswani et al., *Attention Is All You Need*, (2017), arXiv: 1706.03762 [cs.CL].

[21] ATLAS Collaboration, *ATLAS b-jet identification performance and efficiency measurement with $t\bar{t}$ events in pp collisions at $\sqrt{s} = 13$ TeV*, Eur. Phys. J. C **79** (2019) 970, arXiv: 1907.05120 [hep-ex].

[22] ATLAS Collaboration, *The ATLAS experiment at the CERN Large Hadron Collider: a description of the detector configuration for Run 3*, JINST **19** (2024) P05063, arXiv: 2305.16623 [physics.ins-det].

[23] ATLAS Collaboration, *The ATLAS trigger system for LHC Run 3 and trigger performance in 2022*, JINST **19** (2024) P06029, arXiv: 2401.06630 [hep-ex].

[24] ATLAS Collaboration, *Software and computing for Run 3 of the ATLAS experiment at the LHC*, Eur. Phys. J. C **85** (2025) 234, arXiv: 2404.06335 [hep-ex], Erratum: Eur. Phys. J. C **85** (2025) 907.

[25] ATLAS Collaboration, *Preliminary analysis of the luminosity calibration of the ATLAS 13.6 TeV data recorded in 2022*, ATL-DAPR-PUB-2023-001, 2023, URL: https://cds.cern.ch/record/2853525.

[26] ATLAS Collaboration, *Preliminary analysis of the luminosity calibration for the ATLAS 13.6 TeV data recorded in 2023*, ATL-DAPR-PUB-2024-001, 2024, URL: https://cds.cern.ch/record/2900949.

[27] ATLAS Collaboration, *ATLAS data quality operations and performance for 2015–2018 data-taking*, JINST **15** (2020) P04003, arXiv: 1911.04632 [physics.ins-det].

[28] G. Avoni et al., *The new LUCID-2 detector for luminosity measurement and monitoring in ATLAS*, JINST **13** (2018) P07017.

[29] P. Nason, *A new method for combining NLO QCD with shower Monte Carlo algorithms*, JHEP **11** (2004) 040, arXiv: hep-ph/0409146.

[30] S. Frixione, P. Nason and C. Oleari,
Matching NLO QCD computations with parton shower simulations: the POWHEG method,
JHEP **11** (2007) 070, arXiv: 0709.2092 [hep-ph].

[31] S. Alioli, P. Nason, C. Oleari and E. Re, *A general framework for implementing NLO calculations in shower Monte Carlo programs: the POWHEG BOX*, JHEP **06** (2010) 043,
arXiv: 1002.2581 [hep-ph].

[32] C. Bierlich et al., *A comprehensive guide to the physics and usage of PYTHIA 8.3*,
SciPost Phys. Codebases (2022) 8, arXiv: 2203.11601 [hep-ph].

[33] ATLAS Collaboration, *ATLAS Pythia 8 tunes to 7 TeV data*, ATL-PHYS-PUB-2014-021, 2014,
URL: https://cds.cern.ch/record/1966419.

[34] ATLAS Collaboration, *Summary of ATLAS Pythia 8 tunes*, ATL-PHYS-PUB-2012-003, 2012,
URL: https://cds.cern.ch/record/1474107.

[35] NNPDF Collaboration, R. D. Ball et al., *Parton distributions for the LHC run II*,
JHEP **04** (2015) 040, arXiv: 1410.8849 [hep-ph].

[36] NNPDF Collaboration, R. D. Ball et al., *Parton distributions with LHC data*,
Nucl. Phys. B **867** (2013) 244, arXiv: 1207.1303 [hep-ph].

[37] ATLAS Collaboration, *Studies on top-quark Monte Carlo modelling for Top2016*,
ATL-PHYS-PUB-2016-020, 2016, URL: https://cds.cern.ch/record/2216168.

[38] S. Höche, S. Mrenna, S. Payne, C. T. Preuss and P. Skands,
A Study of QCD Radiation in VBF Higgs Production with Vincia and Pythia,
SciPost Phys. **12** (2022) 010, arXiv: 2106.10987 [hep-ph].

[39] ATLAS Collaboration, *Studies on the improvement of the matching uncertainty definition in top-quark processes simulated with Powheg+Pythia8*, ATL-PHYS-PUB-2023-029, 2023,
URL: https://cds.cern.ch/record/2872787.

[40] J. Bellm et al., *Herwig 7.2 release note*, Eur. Phys. J. C **80** (2020) 452,
arXiv: 1912.06509 [hep-ph].

[41] S. Frixione, E. Laenen, P. Motylinski, C. White and B. R. Webber,
Single-top hadroproduction in association with a W boson, JHEP **07** (2008) 029,
arXiv: 0805.3067 [hep-ph].

[42] E. Re, *Single-top Wt-channel production matched with parton showers using the POWHEG method*, Eur. Phys. J. C **71** (2011) 1547, arXiv: 1009.2450 [hep-ph].

[43] T. Gleisberg et al., *Event generation with SHERPA 1.1*, JHEP **02** (2009) 007,
arXiv: 0811.4622 [hep-ph].

[44] S. Höche, F. Krauss, S. Schumann and F. Siegert, *QCD matrix elements and truncated showers*,
JHEP **05** (2009) 053, arXiv: 0903.1219 [hep-ph].

[45] E. Bothmann et al., *Event generation with Sherpa 2.2*, SciPost Phys. **7** (2019) 034,
arXiv: 1905.09127 [hep-ph].

[46] ATLAS Collaboration, *Emulating the impact of additional proton–proton interactions in the ATLAS simulation by presampling sets of inelastic Monte Carlo events*, Comput. Softw. Big Sci. **6** (2022) 3,
arXiv: 2102.09495 [hep-ex].

[47] S. Porteboeuf, T. Pierog and K. Werner, *Producing Hard Processes Regarding the Complete Event: The EPOS Event Generator*, arXiv: 1006.2967 [hep-ph].

[48] T. Pierog, I. Karpenko, J. M. Katzy, E. Yatsenko and K. Werner, *EPOS LHC: Test of collective hadronization with data measured at the CERN Large Hadron Collider*, Phys. Rev. C **92** (2015) 034906, arXiv: 1306.0121 [hep-ph].

[49] ATLAS Collaboration, *The Pythia 8 A3 tune description of ATLAS minimum bias and inelastic measurements incorporating the Donnachie–Landshoff diffractive model*, ATL-PHYS-PUB-2016-017, 2016, URL: https://cds.cern.ch/record/2206965.

[50] D. J. Lange, *The EvtGen particle decay simulation package*, Nucl. Instrum. Meth. A **462** (2001) 152.

[51] ATLAS Collaboration, *The ATLAS Simulation Infrastructure*, Eur. Phys. J. C **70** (2010) 823, arXiv: 1005.4568 [physics.ins-det].

[52] S. Agostinelli et al., *Geant4 – a simulation toolkit*, Nucl. Instrum. Meth. A **506** (2003) 250.

[53] ATLAS Collaboration, *Development of ATLAS Primary Vertex Reconstruction for LHC Run 3*, ATL-PHYS-PUB-2019-015, 2019, URL: https://cds.cern.ch/record/2670380.

[54] ATLAS Collaboration, *Track and Vertex Reconstruction with the ATLAS Inner Detector*, (2026), arXiv: 2605.07585 [physics.ins-det].

[55] ATLAS Collaboration, *Electron and photon efficiencies in LHC Run 2 with the ATLAS experiment*, JHEP **05** (2024) 162, arXiv: 2308.13362 [hep-ex].

[56] ATLAS Collaboration, *Electron and photon energy calibration with the ATLAS detector using LHC Run 2 data*, JINST **19** (2024) P02009, arXiv: 2309.05471 [hep-ex].

[57] ATLAS Collaboration, *Muon reconstruction and identification efficiency in ATLAS using the full Run 2 pp collision data set at $\sqrt{s} = 13$ TeV*, Eur. Phys. J. C **81** (2021) 578, arXiv: 2012.00578 [hep-ex].

[58] ATLAS Collaboration, *Studies of the muon momentum calibration and performance of the ATLAS detector with pp collisions at $\sqrt{s} = 13$ TeV*, Eur. Phys. J. C **83** (2023) 686, arXiv: 2212.07338 [hep-ex].

[59] ATLAS Collaboration, *Jet reconstruction and performance using particle flow with the ATLAS Detector*, Eur. Phys. J. C **77** (2017) 466, arXiv: 1703.10485 [hep-ex].

[60] M. Cacciari, G. P. Salam and G. Soyez, *The anti-k_t jet clustering algorithm*, JHEP **04** (2008) 063, arXiv: 0802.1189 [hep-ph].

[61] M. Cacciari, G. P. Salam and G. Soyez, *FastJet user manual*, Eur. Phys. J. C **72** (2012) 1896, arXiv: 1111.6097 [hep-ph].

[62] ATLAS Collaboration, *Jet energy scale and resolution measured in proton–proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector*, Eur. Phys. J. C **81** (2021) 689, arXiv: 2007.02645 [hep-ex].

[63] ATLAS Collaboration, *Performance of pile-up mitigation techniques for jets in pp collisions at $\sqrt{s} = 8$ TeV using the ATLAS detector*, Eur. Phys. J. C **76** (2016) 581, arXiv: 1510.03823 [hep-ex].

[64] W. Verkerke and D. Kirkby, *The RooFit toolkit for data modeling*, 2003, arXiv: physics/0306116 [physics.data-an].

[65] ATLAS Collaboration, *Evaluating statistical uncertainties and correlations using the bootstrap method*, ATL-PHYS-PUB-2021-011, 2021, URL: https://cds.cern.ch/record/2759945.

[66] ATLAS Collaboration, *Tagging and suppression of pileup jets with the ATLAS detector*, ATLAS-CONF-2014-018, 2014, URL: https://cds.cern.ch/record/1700870.

[67] J. Butterworth et al., *PDF4LHC recommendations for LHC Run II*, J. Phys. G **43** (2016) 023001, arXiv: 1510.03865 [hep-ph].

[68] R. D. Ball et al., *The PDF4LHC21 combination of global PDF fits for the LHC Run III*, J. Phys. G **49** (2022) 080501, arXiv: 2203.05506 [hep-ph].

[69] ATLAS Collaboration, *Calibration of the light-flavour jet mistagging efficiency of the b-tagging algorithms with Z+jets events using 139 fb^{-1} of ATLAS proton–proton collision data at $\sqrt{s} = 13$ TeV*, Eur. Phys. J. C **83** (2023) 728, arXiv: 2301.06319 [hep-ex].

[70] ATLAS Collaboration, *ATLAS Computing Acknowledgements*, ATL-SOFT-PUB-2026-001, 2026, URL: https://cds.cern.ch/record/2952666.

The ATLAS Collaboration

G. Aad[102], E. Aakvaag[17], B. Abbott[121], S. Abdelhameed[83b], K. Abeling[54], N.J. Abicht[48], S.H. Abidi[30], M. Aboelela[44], A. Aboulhorma[36e], H. Abramowicz[154], B.S. Acharya[68a,68b,m], A. Ackermann[62a], J. Ackerschott[55], C. Adam Bourdarios[4], L. Adamczyk[85a], S.V. Addepalli[146], M.J. Addison[101], J. Adelman[117], A. Adiguzel[22c], T. Adye[135], A.A. Affolder[137], Y. Afik[39], M.N. Agaras[13], A. Aggarwal[100], C. Agheorghiesei[28c], A. Ahmad[83a], F. Ahmadov[38,ad], S. Ahuja[95], S. Ahuja[165], X. Ai[113c], G. Aielli[75a,75b], A. Aikot[165], M. Ait Tamlihat[36e], T.P.A. Åkesson[98], D. Akiyama[170], N.N. Akolkar[25], S. Aktas[168], G.L. Alberghi[24b], J. Albert[167], U. Alberti[20], P. Albicocco[52], S. Alderweireldt[51], Z.L. Alegria[122], M. Aleksa[37], I.N. Aleksandrov[38], C. Alexa[28b], T. Alexopoulos[10], F. Alfonsi[24b], M. Algren[55], M. Alhroob[169], B. Ali[133], H.M.J. Ali[91,v], S. Ali[32], S.W. Alibocus[92], M. Aliev[34c], G. Alimonti[70a], C. Allaire[65], B.M.M. Allbrooke[149], D.R. Allen[122], J.S. Allen[101], J.F. Allen[51], C.S. Alley[1], E.R. Almazan[137], A. Aloisio[71a,71b], F. Alonso[90], C. Alpigiani[140], A. Alvarez Fernandez[100], M. Alves Cardoso[55], M.G. Alviggi[71a,71b], M. Aly[101], Y. Amaral Coutinho[81b], C. Amelung[37], M. Amerl[101], T. Amezza[128], B. Amini[53], K. Amirie[158], A. Amirkhanov[38], D. Amperiadou[155], S. An[82], C. Anastopoulos[142], T. Andeen[11], J.K. Anders[92], A.C. Anderson[58], A. Andreazza[70a,70b], S. Angelidakis[9], A. Angerami[41], A.V. Anisenkov[38], A. Annovi[73a], C. Antel[37], E. Antipov[148], M. Antonelli[52], F. Anulli[74a], M. Aoki[82], T. Aoki[156], M.A. Aparo[13], L. Aperio Bella[47], M. Apicella[31], C. Appelt[154], A. Apyan[27], M. Arampatzi[10], S.J. Arbiol Val[86], C. Arcangeletti[52], A.T.H. Arce[50], M. Arcuri[43b,43a], J-F. Arguin[108], S. Argyropoulos[155], J.-H. Arling[47], O. Arnaez[4], H. Arnold[148], G. Artoni[74a,74b], H. Asada[111], S. Asatryan[175], N.A. Asbah[37], R.A. Ashby Pickering[169], A.M. Aslam[95], J. Assahsah[36d], K. Assamagan[30], R. Astalos[29a], K.S.V. Astrand[98], S. Atashi[162], R.J. Atkin[34a], H. Atmani[36f], P.A. Atmasiddha[129], K. Augsten[133], A.D. Auriol[40], V.A. Austrup[101], A.S. Avad[94], G. Avolio[37], A. Azzam[13], D. Babal[29b], H. Bachacou[136], K. Bachas[155,p], A. Bachiu[35], E. Bachmann[49], M.J. Backes[62a], A. Badea[39], T.M. Baer[106], M. Bahmani[19], D. Bahner[53], K. Bai[124], L. Baines[94], O.K. Baker[174], D. Bakshi Gupta[8], L.E. Balabram Filho[81b], V. Balakrishnan[121], R. Balasubramanian[4], P. Balek[85a], E. Ballabene[24b,24a], F. Balli[136], L.M. Baltes[62a], W.K. Balunas[127], I. Bamwidhi[83c], E. Banas[86], M. Bandieramonte[130], S. Bansal[25], L. Barak[154], M. Barakat[47], E.L. Barberio[105], D. Barberis[18b], M. Barbero[102], M.Z. Barel[116], T. Barillari[110], M-S. Barisits[37], T. Barklow[146], P. Baron[134], D.A. Baron Moreno[101], A. Baroncelli[61], A.J. Barr[127], J.D. Barr[96], F. Barreiro[99], J. Barreiro Guimarães da Costa[14], M.G. Barros Teixeira[131a], F. Bartels[37], R. Bartoldus[146], A.E. Barton[91], P. Bartos[29a], M. Baselga[48], S. Bashiri[86], A. Bassalat[65,b], M.J. Basso[159a], S. Bataju[44], R. Bate[166], R.L. Bates[58], M. Battaglia[137], D. Battulga[19], M. Bauce[74a,74b], L. Bauckhage[47], P. Bauer[25], L.T. Bayer[47], L.T. Bazzano Hurrell[31], T. Beau[128], J.Y. Beaucamp[90], S. Beauceron[128], P.H. Beauchemin[161], P. Bechtle[25], H.P. Beck[20,o], K. Becker[169], A.J. Beddall[80], V.A. Bednyakov[38], C.P. Bee[148], L.J. Beemster[16], M. Begalli[81d], M. Begel[30], J.K. Behr[47], J.F. Beirer[37], F. Beisiegel[25], M. Belfkir[83c], G. Bella[154], L. Bellagamba[24b], A. Bellerive[35], C.D. Bellgraph[67], P. Bellos[21], I. Benaoumeur[21], D. Benchekroun[36a], F. Bendebba[36a], Y. Benhammou[154], K.C. Benkendorfer[167], L. Beresford[47], M. Beretta[52], E. Bergeaas Kuutmann[163], N. Berger[4], B. Bergmann[133], J. Beringer[18a], M. Berkat[136], G. Bernardi[5], C. Bernius[146], F.U. Bernlochner[25], A. Berrocal Guardia[13], T. Berry[95], P. Berta[134], A. Berti[131a], R. Bertrand[102], S. Bethke[110], A. Betti[74a,74b], T.F. Beumker[173], A.J. Bevan [94], L. Bezio [55], N.K. Bhalla [53], S. Bharthuar [110], S. Bhatta [148], P. Bhattarai [146], Z.M. Bhatti [118], K.D. Bhide [164], V.S. Bhopatkar [122], R.M. Bianchi [130], G. Bianco [24b,24a], O. Biebel [109], M. Biglietti [76a], P. Bijl[53], C.S. Billingsley[44], Y. Bimgdi [36f], M. Bindi [54], A. Bingham [173], A. Bingul [22b], C. Bini [74a,74b], G.A. Bird [33], M. Biros [134], S. Biryukov [149], T. Bisanz [48], E. Bisceglie [24b,24a], J.P. Biswal [135], D. Biswas [144], M. Biyabi [14], I. Bloch [47], A. Blue [58], U. Blumenschein [94], V.S. Bobrovnikov [38], L. Boccardo [56b,56a], M. Boehler [53], B. Boehm [168], D. Bogavac [13], L.S. Boggia [128], V. Boisvert [95], P. Bokan [163], T. Bold [85a], M. Bomben [5], M. Bona [94], M. Boonekamp [136], A.G. Borbély [58], G. Borissov [91], A. Borkar [168], D. Bortoletto [127], M. Borysova [171], D. Boscherini [24b], M. Bosman [13], K. Bouaouda [36a], L. Boudet [136], J. Boudreau [130], E.V. Bouhova-Thacker [91], D. Boumediene [40], R. Bouquet [56b,56a], A. Boveia [120], D. Boye [30], I.R. Boyko [38], L. Bozianu [55], J. Bracinik [21], N. Brahimi [4], G. Brandt [173], O. Brandt [33], B. Brau [103], R. Brener [171], L. Brenner [116], R. Brenner [163], S. Bressler [171], M. Brettell [96], G. Brianti [116], D. Britton [58], D. Britzger [110], I. Brock [25], R. Brock [107], H. Bronson[129], G. Brooijmans [41], A.J. Brooks[67], E.M. Brooks [159b], E. Brost [30], L.M. Brown [167,159a], L.E. Bruce [60], T.L. Bruckler [127], P.A. Bruckman de Renstrom [86], B. Brüers [47], A. Bruni [24b], G. Bruni [24b], D. Brunner [46a,46b], M. Bruschi [24b], N. Bruscino [74a,74b], T. Buanes [17], Q. Buat [140], D. Buchin [110], A.G. Buckley [58], J. Bucko [134], M. Buhring [49], O. Bulekov [80], B.A. Bullard [146], T.O. Buratovich [90], S. Burdin [92], C.D. Burgard [48], A.M. Burger [89], B. Burghgrave [8], O. Burlayenko [53], J. Burleson [164], J.C. Burzynski [121], V. Büscher [100], P.J. Bussey [58], O. But [25], J.M. Butler [26], C.M. Buttar [58], J.M. Butterworth [96], P. Butti[37], W. Buttinger [135], C.J. Buxo Vazquez [107], A.R. Buzykaev [38], S. Cabrera Urbán [165], L. Cadamuro [65], H. Cai [37], Y. Cai [24b,112c,24a], Y. Cai [112a], M.A. Cairo[129], V.M.M. Cairo [37], O. Cakir [3a], N. Calace [37], P. Calafiura [18a], G. Calderini [128], P. Calfayan [35], L. Calic [98], G. Callea [58], L.P. Caloba[81b], D. Calvet [40], S. Calvet [40], R. Camacho Toro [128], S. Camarda [37], D. Camarero Munoz [27], P. Camarri [75a,75b], C. Camincher [37], M. Campanelli [96], A. Camplani [42], V. Canale [71a,71b], A.C. Canbay [3a], E. Canonero [95], J. Cantero [165], F. Capocasa [27], P. Cappelli [27], M. Capua [43b,43a], A. Carbone [70a,70b], R. Cardarelli [75a], J.C.J. Cardenas [8], M.P. Cardiff [27], G. Carducci [43b,43a], T. Carli [37], G. Carlino [71a], J.I. Carlotto [13], B.T. Carlson [130,q], E.M. Carlson [167], L. Carminati [70a,70b], A. Carnelli [4], M. Carnesale [37], S. Caron [115], E. Carquin [138g], I.B. Carr [105], S. Carrà [72a,72b], G. Carratta [24b,24a], C. Carrion Martinez [165], A.M. Carroll [124], N. Cartalade [40], M.P. Casado [13,h], P. Casolaro [71a,71b], M. Caspar [47], F. Cassinese [90], W.R. Castiglioni [39], F.L. Castillo [4], V. Castillo Gimenez [165], N.F. Castro [131a,131e], A. Catinaccio [37], J.R. Catmore [126], T. Cavaliere [4], V. Cavaliere [30], E. Celebi [80], S. Cella [30], V. Cepaitis [55], K. Cerny [123], A.S. Cerqueira [81a], A. Cerri [73a,ap], L. Cerrito [75a,75b], F. Cerutti [18a], B. Cervato [70a,70b], A. Cervelli [24b], G. Cesarini [52], S.A. Cetin [80], V.C. Chabalala [34j], P.M. Chabrillat [128], R. Chakkappai [65], S. Chakraborty [169], A. Chambers [60], J. Chan [18a], J.D. Chapman [33], E. Chapon [136], D.G. Charlton [21], C. Chauhan [132], Y. Che [112a], S. Chekanov [6], G.A. Chelkov [38,a], H. Chen [30], J. Chen [141a], J. Chen [145], M. Chen [59], S. Chen [87], S.J. Chen [112a], X. Chen [141a], X. Chen [15,ai], Z. Chen [61], C.L. Cheng [146], H.C. Cheng [63a], S. Cheong [146], A. Cheplakov [38], E. Cherepanova [116], E. Cheu [7], K. Cheung [64], L. Chevalier [136], G. Chiarelli [73a], G. Chiodini [69a], A.S. Chisholm [21], J.L. Chisholm [166], A. Chitan [28b], M. Chitishvili [165], M.V. Chizhov [38,r], K. Chmiel [76a,76b], K. Choi [11], Y. Chou [140], E.Y.S. Chow [115], G. Christou [51], K.L. Chu [171], M.C. Chu [63a], Z. Chubinidze [52], J. Chudoba [132], J.J. Chwastowski [86], D. Cieri [110], K.M. Ciesla [85a], V. Cindro [93], A. Ciocio [18a], F. Cirotto [71a,71b], Z.H. Citron [171], M. Citterio [70a], D.A. Ciubotaru[28b], A. Clark [55], P.J. Clark [51], N. Clarke Hall [96], C. Clarry [158], S.E. Clawson [47], C. Clement [46a,46b], L. Clissa [24b,24a], Y. Coadou [102], M. Cobal [68a,68c], A. Coccaro [56b], M.G. Cochran Branson [140], R.F. Coelho Barrue [131a],

R. Coelho Lopes De Sa[103], S. Coelli[70a], M.M. Cohen[129], L.S. Colangeli[158], B. Cole[41], P. Collado Soto[99], J. Collot[59], M.R. Coluccia[69a], I. Combes[65], P. Conde Muiño[131a,131g], L.H.J. Condren[162], M.P. Connell[34c], S.H. Connell[34c], E.I. Conroy[127], M. Contreras Cossio[11], F. Conventi[71a,ak], A.M. Cooper-Sarkar[127], L. Corazzina[74a,74b], F.A. Corchia[24b,24a], A. Cordeiro Oudot Choi[140], L.D. Corpe[40], M. Corradi[74a,74b], F. Corriveau[104,ab], A. Cortes-Gonzalez[156], M.J. Costa[165], F. Costanza[4], D. Costanzo[142], J. Couthures[4], G. Cowan[95], K. Cranmer[172], L. Cremer[48], D. Cremonini[24b,24a], S. Crépé-Renaudin[59], F. Crescioli[128], T. Cresta[72a,72b], M. Cristinziani[144], M. Cristoforetti[77a,77b], T.M. Critchley[55], E. Critelli[96], A. Cueto[99], H. Cui[96], Z. Cui[7], B.M. Cunnett[149], W.R. Cunningham[58], E. Cuppini[110], F. Curcio[165], J.R. Curran[51], M.J. Da Cunha Sargedas De Sousa[56b,56a], J.V. Da Fonseca Pinto[81b], C. Da Via[101], W. Dabrowski[85a], T. Dado[37], S. Dahbi[151], T. Dai[106], D. Dal Santo[20], C. Dallapiccola[103], M. Dam[42], G. D'amen[30], V. D'Amico[109], J.R. Dandoy[35], M. D'Andrea[56b,56a], D. Dannheim[37], G. D'anniballe[73a,73b], M. Danninger[145], V. Dao[148], G. Darbo[56b], F. Dattola[47], S. D'Auria[70a,70b], A. D'Avanzo[71a,71b], T. Davidek[134], J. Davidson[169], I. Dawson[94], K. De[8], C. De Almeida Rossi[158], N. De Biase[47], S. De Castro[24b,24a], N. De Groot[115], P. de Jong[116], H. De la Torre[117], A. De Maria[112a], S. De Miranda Rimes[81d], A. De Salvo[74a], U. De Sanctis[75a,75b], F. De Santis[69a,69b], A. De Santo[149], J.B. De Vivie De Regie[59], K.G. De Vries[116], J. Debevc[93], D.V. Dedovich[38], J. Degens[92], A.M. Deiana[44], J. Del Peso[99], L. Delagrange[27], F. Deliot[136], C.M. Delitzsch[48], M. Della Pietra[71a,71b], D. Della Volpe[55], A. Dell'Acqua[37], L. Dell'Asta[70a,70b], M. Delmastro[4], C.C. Delogu[56b,56a], P.A. Delsart[59], S. Demers[174], M. Demichev[38], H. Denizli[22a,l], M.G. Depala[92], L. D'Eramo[40], D. Derendarz[86], L. Derin[56b,56a], F. Derue[128], P. Dervan[92,*], A.M. Desai[1], K. Desch[25], F.A. Di Bello[73a,73b], A. Di Ciaccio[75a,75b], L. Di Ciaccio[4], D. Di Croce[37], C. Di Donato[71a,71b], A. Di Girolamo[37], G. Di Gregorio[65], A. Di Luca[77a,77b], B. Di Micco[76a,76b], R. Di Nardo[76a,76b], K.F. Di Petrillo[39], M. Diamantopoulou[35], F.A. Dias[116], M.A. Diaz[138a,138b], A.R. Didenko[38], M. Didenko[165], S.D. Diefenbacher[18a], E.B. Diehl[106], S. Díez Cornell[47], C. Diez Pardos[144], C. Dimitriadi[147], A. Dimitrievska[21], A. Dimri[148], Y. Ding[61], J. Dingfelder[25], T. Dingley[127], I-M. Dinu[28b], S.J. Dittmeier[62b], F. Dittus[37], M. Divisek[134], B. Dixit[92], F. Djama[102], T. Djobava[152b], C. Doglioni[101,98], A. Dohnalova[29a], Z. Dolezal[134], K. Domijan[85a], K.M. Dona[39], M. Donadelli[81d], B. Dong[107], J. Donini[40], A. D'Onofrio[71a,71b], M. D'Onofrio[92], J. Dopke[135], A. Doria[71a], N. Dos Santos Fernandes[131a], I.A. Dos Santos Luz[81e], P. Dougan[44], M.T. Dova[90], A.T. Doyle[58], M.P. Drescher[54], E. Dreyer[171], I. Drivas-koulouris[10], M. Drnevich[118], D. Du[61], T. Du[39], T.A. du Pree[116], Z. Duan[112a], M. Dubau[4], F. Dubinin[38], M. Dubovsky[29a], E. Duchovni[171], G. Duckeck[109], P.K. Duckett[96], O.A. Ducu[28b], D. Duda[51], A. Dudarev[37], M.M. Dudek[86], E.R. Duden[27], M. D'uffizi[101], L. Duflot[65], M. Dührssen[37], I. Duminica[28g], A.E. Dumitriu[28b], M. Dunford[62a], T. Duong[4], A. Duperrin[102], A.F. Duque Bran[40], H. Duran Yildiz[3a], A. Durglishvili[152b], G.I. Dyckes[18a], M. Dyndal[85a], B.S. Dziedzic[37], G.H. Eberwein[127], B. Eckerova[29a], J.C. Egan[96], S. Eggebrecht[54], E. Egidio Purcino De Souza[81e], G. Eigen[17], K. Einsweiler[18a], T. Ekelof[163], P.A. Ekman[98], S. El Farkh[36b], Y. El Ghazali[61], H. El Jarrari[104], A. El Moussaouy[36a], I. Elbaz[154], D. Elitez[37], M. Ellert[163], F. Ellinghaus[173], T.A. Elliot[95], J. Elmsheuser[30], M. Elsawy[83b], M. Elsing[37], D. Emeliyanov[135], Y. Enari[82], S. Epari[108], D. Ernani Martins Neto[86], F. Ernst[37], M. Escalier[65], C. Escobar[165], R. Estevam De Paula[81c], E. Etzion[154], G. Evans[131a,131b], H. Evans[67], L.S. Evans[47], S. Ezzarqtouni[36a], F. Fabbri[24b,24a], L. Fabbri[24b,24a], G. Facini[96], V. Fadeyev[137], D. Fakoudis[100], S. Falciano[74a], L.F. Falda Ulhoa Coelho[27], F. Fallavollita[110], G. Falsetti[43b,43a], J. Faltova[134], C. Fan[164], K.Y. Fan[63b], Y. Fan[14], Y. Fang[14,112c],

M. Fanti [70a,70b], M. Faraj [68a,68c], Z. Farazpay [97], A. Farbin [8], A. Farilla [76a], K. Farman [151], J.N. Farr [174], M.S. Farrington [60], S.M. Farrington [135,51], F. Fassi [36e], D. Fassouliotis [9], L. Fayard [65], G. Fazzino [62b], P. Federic [134], P. Federicova [132], M. Feickert [172], L. Feligioni [102], D.E. Fellers [18a], C. Feng [113b], Y. Feng[14], Z. Feng [65], B. Fernandez Barbadillo [91], P. Fernandez Martinez [66], C. Fernandez Ruiz [33], J. Ferrando [91], A. Ferrari [163], P. Ferrari [116,115], R. Ferrari [72a], D. Ferrere [55], C. Ferretti [106], M.P. Fewell [1], D. Fiacco [74a,74b], F. Fiedler [100], P. Fiedler [133], S. Filimonov [38], M.S. Filip [28b,s], A. Filipčič [93], E.K. Filmer [159a], F. Filthaut [115], M.C.N. Fiolhais [131a,131c,c], L. Fiorini [165], W.C. Fisher [107], T. Fitschen [101], I. Fleck [144], P. Fleischmann [106], T. Flick [173], M. Flores [34d,ag], L.R. Flores Castillo [63a], M. Foll [126], F.M. Follega [77a,77b], N. Fomin [33], J.H. Foo [158], A. Formica [136], M. Fornasiero [149], A.C. Forti [101], N. Forti [24b,24a], E. Fortin [102], A.W. Fortman [18a], L. Foster [18a], L. Fountas [9], H. Fox [91], P. Francavilla [73a,73b], S. Francescato [60], S. Franchellucci [20], M. Franchini [24b,24a], S. Franchino [62a], D. Francis[37], L. Franco [47], L. Franconi [47], M. Franklin [60], G. Frattari [37], Y.Y. Frid [154], N. Fritzsche [37], A. Froch [55], D. Froidevaux [37], J.A. Frost [135], Y. Fu [107], S. Fuenzalida Garrido [138g], Y.C. Fujikake [137], M. Fujimoto [148], K.Y. Fung [63a], E. Furtado De Simas Filho [81e], M. Furukawa [156], M. Fuste Costa [47], P. Fuste Martin [13], J. Fuster [165], A. Gaa [54], A. Gabrielli [24b,24a], A. Gabrielli [158], G. Gagliardi [56b,56a], L.G. Gagnon [18a], S. Galantzan [154], J. Gallagher [1], E.J. Gallas [127], A.L. Gallen [163], B.J. Gallop [135], K.K. Gan [120], Y. Gao [51], Z. Gao [112a], A. Garabaglu [140], F.M. Garay Walls [138a,138b], C. García [165], A. Garcia Alonso [116], A.G. Garcia Caffaro [174], J.E. García Navarro [165], M.A. Garcia Ruiz [23b], M. Garcia-Sciveres [18a], G.L. Gardner [129], R.W. Gardner [39], N. Garelli [161], R.B. Garg [146], J.M. Gargan [33], C.A. Garner[158], C.M. Garvey [34a], V.K. Gassmann[161], G. Gaudio [72a], A.J. Gavin [94], J. Gavranovic [93], I.L. Gavrilenko [131a], C. Gay [166], G. Gaycken [124], A. Gekow[120], C. Gemme [56b], M.H. Genest [59], A.D. Gentry [114], S. George [95], T. Geralis [45], A.A. Gerwin [121], P. Gessinger-Befurt [37], M. Ghani [169], K. Ghorbanian [94], A. Ghosal [144], A. Ghosh [162], A. Ghosh [7], B. Giacobbe [24b], S. Giagu [74a,74b], A. Giannini [61], S.M. Gibson [95], D.T. Gil [85b], B.J. Gilbert [41], D. Gillberg [35], G. Gilles [116], D.M. Gingrich [2,aj], M.P. Giordani [68a,68c], P.F. Giraud [136], G. Giugliarelli [68a,68c], D. Giugni [70a], F. Giuli [75a,75b,al], I. Gkialas [9,i], B.C. Gladwyn [127], C. Glasman [99], M. Glazewska [20], R.M. Gleason [162], G. Glemža [47], I. Gnesi [24b,24a,am], Y. Go [30], M. Goblirsch-Kolb [37], B. Gocke [48], D. Godin[108], B. Gokturk [22a], S. Goldfarb [105], T. Golling [55], M.G.D. Gololo [34c], A. Golub [140], J.P. Gombas [107], A. Gomes [131a,131b], G. Gomes Da Silva [144], A.J. Gomez Delegido [37], R. Gonçalo [131a], A. Gongadze [152c], F. Gonnella [21], J.L. Gonski [146], R.Y. González Andana [51], S. González de la Hoz [165], M.V. Gonzalez Rodrigues [47], R. Gonzalez Suarez [163], S. Gonzalez-Sevilla [55], L. Goossens [37], B. Gorini [37], E. Gorini [69a,69b], A. Gorišek [93], T.C. Gosart [129], A.T. Goshaw [50], M.I. Gostkin [38], S. Goswami [122], C.A. Gottardo [37], S.A. Gotz [109], M. Gouighri [36b], A.G. Goussiou [140], N. Govender [34c], R.P. Grabarczyk [127], I. Grabowska-Bold [85a], K. Graham [35], E. Gramstad [126], S. Grancagnolo [69a,69b], C.M. Grant[1], P.M. Gravila [28f], F.G. Gravili [69a,69b], H.M. Gray [18a], M. Greco [110], M.J. Green [1], C. Grefe [25], A.S. Grefsrud [17], I.M. Gregor [47], K.T. Greif [162], P. Grenier [146], S.G. Grewe[110], K. Grimm [32], S. Grinstein [13,x], E. Gross [171], J. Grosse-Knetter [54], L.H. Grossman [18b], L. Guan [106], G. Guerrieri [37], R. Guevara [126], R. Gugel [100], J.A.M. Guhit [106], A. Guida [19], E. Guilloton [169], S. Guindon [37], F. Guo [14,112c], J. Guo [141a], L. Guo [47], L. Guo [112b,u], Y. Guo [106], Y. Guo [41], A. Gupta [48], R. Gupta [130], S. Gupta [27], S. Gurbuz [25], S.S. Gurdasani [47], G. Gustavino [74a,74b], P. Gutierrez [121], L.F. Gutierrez Zagazeta [129], M. Gutsche [49], C. Gutschow [96], W. Guérin [89], C. Gwenlan [127], C.B. Gwilliam [92], E.S. Haaland [126], A. Haas [118], M. Habedank [58], C. Haber [18a], R.J. Haberle [171], H.K. Hadavand [8], A. Haddad [40], A. Hadef [49], A.I. Hagan [91], J.J. Hahn [144], M. Haleem [168], J. Haley [122], G.D. Hallewell [102], J.A. Hallford [47], K. Hamano [167], H. Hamdaoui [163], M. Hamer [25], S.E.D. Hammoud [65], E.J. Hampshire [95], L. Han [112a], L. Han [61], S. Han [14], K. Hanagaki [82], M. Hance [137], D.A. Hangal [41], H. Hanif [145], M.D. Hank [129], J.B. Hansen [42], P.H. Hansen [42], T. Harenberg [173], S. Harkusha [175], M.L. Harris [103], Y.T. Harris [25], J. Harrison [13], P.F. Harrison[169], M.L.E. Hart [96], N.M. Hartman [110], N.M. Hartmann [109], R.Z. Hasan [95,135], Y. Hasegawa [143], D. Hashimoto [111], F. Haslbeck [37], S. Hassan [126], R. Hauser [107], M. Haviernik [134], C.M. Hawkes [21], R.J. Hawkings [37], Y. Hayashi [156], D. Hayden [107], R.L. Hayes [116], C.P. Hays [127], J.M. Hays [94], H.S. Hayward [92], M. He [14,112c], Y. He [47], Y. He [96], N.B. Heatley [94], V. Hedberg [98], J. Heilman [35], S. Heim [47], T. Heim [18a], J.J. Heinrich [124], L. Heinrich [110], J. Hejbal [132], M. Helbig [49], A. Held [172], S. Hellesund [17], C.M. Helling [166], F.N.E. Henry [58], H. Herde [98], Y. Hernández Jiménez [148], G. Herten [53], R. Hertenberger [109], L. Hervas [37], M.E. Hesping [100], N.P. Hessey [159a], J. Hessler [110], R. Hicks [129], M. Hidaoui [36b], N. Hidic [134], E. Hill [158], T.S. Hillersoy [17], S.J. Hillier [21], J.R. Hinds [107], F. Hinterkeuser [25], M. Hirose [125], S. Hirose [160], D. Hirschbuehl [173], B. Hiti [93], J. Hobbs [148], R. Hobincu [28e], N. Hod [171], A.M. Hodges [164], M.C. Hodgkinson [142], B.H. Hodkinson [127], A. Hoecker [37], D.D. Hofer [106], J. Hofer [165], J. Hofner [100], M. Holzbock [37], L.B.A.H. Hommels [33], V. Homsak [127], J.J. Hong [67], T.M. Hong [130], B.H. Hooberman [164], W.H. Hopkins [6], M.C. Hoppesch [164], Y. Horii [111], M.E. Horstmann [110], M.M. Horzela [54], S. Hou [151], M.R. Housenga [164], J. Howarth [58], J. Hoya [6], M. Hrabovsky [123], T. Hryn'ova [4], P.J. Hsu [64], S.-C. Hsu [140], T. Hsu [65], M. Hu [18a], P. Hu [63b], Q. Hu [61], S. Huang [33], X. Huang [14,112c], Y. Huang [134], Y. Huang [112b], Y. Huang [14], Z. Huang [65], Z. Hubacek [133], F. Huegging [25], T.B. Huffman [127], M. Hufnagel Maranha De Faria [81a], C.A. Hugli [47], M. Huhtinen [37], S.K. Huiberts [17], R. Hulsken [104], C.E. Hultquist [18a], D.L. Humphreys [103], N. Huseynov [12], J. Huston [107], B. Huth [37], J. Huth [60], L. Huth [47], R. Hyneman [7], G. Iacobucci [55], G. Iakovidis [30], L. Iconomidou-Fayard [65], J.P. Iddon [37], P. Iengo [71a,71b], Y. Iiyama [156], T. Iizawa [156], Y. Ikegami [82], D. Iliadis [155], N. Ilic [158], H. Imam [36a], G. Inacio Goncalves [81d], S.A. Infante Cabanas [138c], T. Ingebretsen Carlson [46a,46b], J.M. Inglis [94], G. Introzzi [72a,72b], M. Iodice [76a], V. Ippolito [74a,74b], R.K. Irwin [92], M. Ishino [156], W. Islam [172], C. Issever [19], S. Istin [22a,ar], K. Itabashi [125], H. Ito [170], R. Iuppa [77a,77b], A. Ivina [171], F. Ivone [37], S. Izumiyama [111], V. Izzo [71a], P. Jacka [133], P. Jackson [1], P.R. Jacobson [50], P. Jain [47], K. Jakobs [53], J. Jamieson [58], W. Jang [156], S. Jankovych [116], B.K. Jashal [135], M. Javurkova [103], P. Jawahar [101], L. Jeanty [124], J. Jejelava [152a,ae], P. Jenni [53,f], L. Jerala [93], C.E. Jessiman [35], H. Jia [166], J. Jia [148], K. Jia [146], X. Jia [110,112c], C. Jiang [51], Q. Jiang [63b], S. Jiggins [47], M. Jimenez Ortega [165], J. Jimenez Pena [13], S. Jin [112a], A. Jinaru [28b], O. Jinnouchi [139], P. Johansson [142], K.A. Johns [7], J.W. Johnson [137], F.A. Jolly [47], D.M. Jones [149], E. Jones [47], P. Jones [33], R.W.L. Jones [91], T.J. Jones [92], H.L. Joos [37], R. Joshi [120], J. Jovicevic [16], X. Ju [18a], J.J. Junggeburth [37], T. Junkermann [62a], A. Juste Rozas [13,x], M.K. Juzek [86], S. Kabana [138f], A. Kaczmarska [86], S.A. Kadir[146], M. Kado [110], H. Kagan [120], M. Kagan [146], A. Kahn [129], C. Kahra [100], T. Kaji [156], E. Kajomovitz [153], N. Kakati [171], N. Kakoty [13], S. Kandel [8], E. Kanellaki [45], N. Kanellos [10], D. Kar [34j,*], E. Karentzos [25], K. Karki [8], O. Karkout [116], S.N. Karpov [38], Z.M. Karpova [38], V. Kartvelishvili [91,152b], E. Kasimi [155], J. Katzy [47], S. Kaur [35], R. Kavak [164], K. Kawade [143], M.P. Kawale [121], C. Kawamoto [87], E.F. Kay [37], S. Kazakos [107], K. Kazakova [102], J.M. Keaveney [34a], R. Keeler [167], G.V. Kehris [60], J.S. Keller [35], J.M. Kelly [167], J.J. Kempster [149], O. Kepka [132], J. Kerr [159b], B.P. Kerridge [135], B.P. Kerševan [93], L. Keszeghova [29a], R.A. Khan [130], A. Khanov [122], M. Kholodenko [131a], T.J. Khoo [19], G. Khoriauli [168], Y. Khoulaki [36a], Y.A.R. Khwaira [128], D. Kim [6], D.W. Kim [18b], Y.K. Kim [39], N. Kimura [96], M.K. Kingston [54], F. Kirfel [25], J. Kirk [135], A.E. Kiryunin [110], S. Kita [160], O. Kivernyk [25], M. Klassen [37], C. Klein [35], L. Klein [168], M.H. Klein [44], S.B. Klein [55], U. Klein [92], A. Klimentov [30], P. Kluit [116], S. Kluth [110], E. Kneringer [78], T.M. Knight [158], A. Knue [48], M. Kobel [49], D. Kobylianskii [171], S.F. Koch [37], M. Kocian [146], P. Kodyš [134], D.M. Koeck [124], T. Koffas [35], K. Kojima [82], O. Kolay [49], I. Koletsou [4], T. Komarek [86], S. Kondo [156], K. Köneke [54], A.X.Y. Kong [1], T. Kono [119], N. Konstantinidis [96], P. Kontaxakis [55], B. Konya [98], R. Kopeliansky [41], S. Koperny [85a], R. Koppenhofer [53], I. Kopsalis [10], K. Korcyl [86], K. Kordas [155,d], A. Korn [96], S. Korn [54], I. Korolkov [13], O. Kortner [110], S. Kortner [110], W.H. Kostecka [117], M. Kostov [29a], V.V. Kostyukhin [144], A. Kotsokechagia [37], A. Kotwal [50], A. Koulouris [37], A. Kourkoumeli-Charalampidi [72a,72b], O. Kovanda [124], R. Kowalewski [167], W. Kozanecki [124], G. Kramberger [93], P. Kramer [25], A. Krasznahorkay [103], A.C. Kraus [117], J.W. Kraus [173], J.A. Kremer [47], N.B. Krengel [144], T. Kresse [158], L. Kretschmann [173], J. Kretzschmar [92], P. Krieger [158], K. Krizka [21], K. Kroeninger [48], H. Kroha [110], J. Kroll [132], J. Kroll [129], K.S. Krowpman [107], U. Kruchonak [38], H. Krüger [25], N. Krumnack [79], J. Krupa [146], M.C. Kruse [50], O. Kuchinskaia [38], S. Kuday [3a], S. Kuehn [37], R. Kuesters [53], T. Kuhl [47], V. Kukhtin [38], Y. Kulchitsky [38], S. Kuleshov [138d,138b], J. Kull [1], E.V. Kumar [109], M. Kumar [34j], N. Kumari [47], P. Kumari [159b], A. Kupco [132], O. Kuprash [53], H. Kurashige [84], L.L. Kurchaninov [159a], O. Kurdysh [4], M. Kuze [139], A.K. Kvam [103], J. Kvita [123], N.G. Kyriacou [140], M. Laassiri [30], C. Lacasta [165], H. Lacker [19], D. Lacour [128], E. Ladygin [38], A. Lafarge [40], B. Laforge [128], T. Lagouri [174], F.Z. Lahbabi [36a], S. Lai [54], W.S. Lai [96], I.K. Lakomiec [54], J.E. Lambert [167], S. Lammers [67], W. Lampl [7], C. Lampoudis [155], G. Lamprinoudis [168], A.N. Lancaster [117], U. Landgraf [53], M.P.J. Landon [94], V.S. Lang [53], A.J. Lankford [162], F. Lanni [37], C.S. Lantz [164], K. Lantzsch [25], A. Lanza [72a], M. Lanzac Berrocal [165], T. Lari [70a], D. Larsen [17], L. Larson [11], F. Lasagni Manghi [24b], M. Lassnig [37], H.C. Lau [167], S.D. Lawlor [142], R. Lazaridou [162], M. Lazzaroni [70a,70b], E.T.T. Le [162], H.D.M. Le [107], E.M. Le Boulicaut [174], D.O. Le Guennec [136], L.T. Le Pottier [18a], B. Leban [24b,24a], F. Ledroit-Guillon [59], T.F. Lee [159b], L.L. Leeuw [34h], M. Lefebvre [167], C. Leggett [18a], L.M. Lehmann [116], W.A. Leight [103], W. Leinonen [115], A. Leisos [155,t], M.A.L. Leite [81c], C.E. Leitgeb [19], R. Leitner [134], K.J.C. Leney [44], T. Lenz [25], S. Leone [73a], C. Leonidopoulos [51], A. Leopold [147], J. LePage-Bourbonnais [35], R. Les [107], C.G. Lester [33], J. Levêque [4], L.J. Levinson [171], G. Levrini [24b,24a], M.P. Lewicki [86], C. Lewis [140], D.J. Lewis [4], L. Lewitt [142], A. Li [30], B. Li [113b], C. Li [106], C-Q. Li [110], H. Li [113b], H. Li [101], H. Li [15], H. Li [61], H. Li [113b], J. Li [141a], L. Li [141a], R. Li [174], S. Li [141b,141a], T. Li [5], Y. Li [14], Z. Li [14,112c], Z. Li [61], S. Liang [14,112c], Z. Liang [14], M. Liberatore [136], B. Liberti [75a], G.B. Libotte [81d], K. Lie [63c], J. Lieber Marin [81e], H. Lien [67], H. Lin [106], S.F. Lin [148], L. Linden [109], R.E. Lindley [7], J.H. Lindon [37], J. Ling [60], E. Lipeles [129], A. Lipniacka [17], A. Lister [166], J.D. Little [67], B. Liu [113a], B.X. Liu [112b], D. Liu [153], D. Liu [137], E.H.L. Liu [21], H. Liu [112b], J.K.K. Liu [118], K. Liu [141b], K. Liu [141b], M. Liu [61], M.Y. Liu [61], P. Liu [113b], Q. Liu [146], S. Liu [148], X. Liu [113b], Y. Liu [112b,112c], Y. Liu [164], Y.L. Liu [113b], Y.W. Liu [61], Z. Liu [65,j], S.L. Lloyd [94], E.M. Lobodzinska [47], P. Loch [7], E. Lodhi [158], K. Lohwasser [142], E. Loiacono [122], J.D. Lomas [21], I. Longarini [162], R. Longo [24b,24a,am], A. Lopez Solis [13], N.A. Lopez-canelas [7], N. Lorenzo Martinez [4], A.M. Lory [109], M. Losada [83b], G. Löschcke Centeno [4], X. Lou [14,112c], P.A. Love [91], M. Lu [65], S. Lu [129], Y.J. Lu [151], H.J. Lubatti [140], C. Luci [74a,74b], F.L. Lucio Alves [112a], J.A. Lue [124], F. Luehring [67], B.S. Lunday [129], O. Lundberg [147], J. Lunde [37], N.A. Luongo [6], M.S. Lutz [158], A.B. Lux [26], D. Lynn [30], R. Lysak [132], V. Lysenko [133], E. Lytken [98], V. Lyubushkin [38], T. Lyubushkina [38], M.M. Lyukova [148],

H. Ma[30], K. Ma[61], L.L. Ma[113b], W. Ma[61], Y. Ma[113b], P.C. Machado De Abreu Farias[81e], D. Macina[37], R. Madar[40], T. Madula[96], J. Maeda[84], T. Maeno[30], P.T. Mafa[34f], H. Maguire[142], M. Maheshwari[33], V. Maiboroda[65], G. Maineri[70a,70b], A. Maio[131a,131b,131d], K. Maj[85a], O. Majersky[47], S. Majewski[124], A. Makita[156], N. Makovec[65], V. Maksimovic[16], B. Malaescu[128], J. Malamant[126], Pa. Malecki[86], F. Malek[59,n], M. Mali[93], D. Malito[95], A. Maloizel[5], A. Malvezzi Lopes[81d], S. Malyukov[38], J. Mamuzic[93], G. Mancini[52], M.N. Mancini[27], G. Manco[72a,72b], S.S. Mandarry[149], I. Mandić[93], L. Manhaes de Andrade Filho[81a], I.M. Maniatis[171], J. Manjarres Ramos[89], D.C. Mankad[171], A. Mann[109], T. Manoussos[37], M.N. Mantinan[39], S. Manzoni[37], L. Mao[141a], X. Mapekula[34c], A. Marantis[155], R.R. Marcelo Gregorio[1], G. Marchiori[5], C. Marcon[70a], E. Maricic[16], M. Marinescu[47], S. Marium[47], M. Marjanovic[121], A. Markhoos[53], M. Markovitch[65], M.K. Maroun[103], M.C. Marr[145], T.L. Marsault[136], G.T. Marsden[101], Z. Marshall[18a], S. Marti-Garcia[165], J. Martin[96], T.A. Martin[135], V.J. Martin[51], B. Martin dit Latour[17], L. Martinelli[74a,74b], V.I. Martinez Outschoorn[103], P. Martinez Suarez[37], S. Martin-Haugh[135], G. Martinovicova[134], V.S. Martoiu[28b], A. Martone[89], A.C. Martyniuk[96], A. Marzin[37], D. Mascione[77a,77b], L. Masetti[100], J. Masik[101], A.L. Maslennikov[38], S.L. Mason[41], P. Massarotti[71a,71b], P. Mastrandrea[73a,73b], A. Mastroberardino[43b,43a], R. Mastrofrancesco[72a,72b], T. Masubuchi[125], T.T. Mathew[124], J. Matousek[134], D.M. Mattern[48], K. Mauer[47], J. Maurer[28b], T. Maurin[58], B. Maček[93], C. Mavungu Tsava[102], A.E. May[101], E. Mayer[40], R. Mazini[34j], S.M. Mazza[137], E. Mazzeo[37], J.P. Mc Gowan[167], S.P. Mc Kee[106], C.C. McCracken[166], E.F. McDonald[105], L.F. Mcelhinney[91], J.A. Mcfayden[149], R.P. McGovern[167], R.P. Mckenzie[34j], D.J. Mclaughlin[96], S.J. McMahon[135], C.M. Mcpartland[92], R.A. McPherson[167,ab], S. Mehlhase[109], A. Mehta[92], D. Melini[165], B.R. Mellado Garcia[14,ah], A.H. Melo[54], F. Meloni[47], A.M. Mendes Jacques Da Costa[101], L. Meng[91], S. Menke[110], M. Mentink[37], E. Meoni[43b,43a], G. Mercado[117], S. Merianos[155], C. Merlassino[68a,68c], C. Meroni[70a,70b], J. Metcalfe[6], A.S. Mete[6], E. Meuser[100], C. Meyer[67], J-P. Meyer[136], Y. Miao[112a], R.P. Middleton[135], M. Mihovilovic[65], L. Mijović[51], G. Mikenberg[171], M. Mikestikova[132], M. Mikuž[93], H. Mildner[100], A. Milic[37], D.W. Miller[39], E.H. Miller[146], A. Milov[171], D.A. Milstead[46a,46b], T. Min[112a], I.A. Minashvili[152b], A.I. Mincer[118], B. Mindur[85a], M. Mineev[38], Y. Mino[87], L.M. Mir[13], M. Miralles Lopez[58], M. Mironova[18a], M. Missio[40], A. Mitra[169], V.A. Mitsou[165], Y. Mitsumori[111], P.S. Miyagawa[94], R. Mizuhiki[84], T. Mkrtchyan[37], M. Mlinarevic[96], T. Mlinarevic[96], M. Mlynarikova[134], L. Mlynarska[85a], C. Mo[141a], H. Mobius[47], S. Mobius[20], M.H. Mohamed Farook[114], S. Mohapatra[41], M.F. Mohd Soberi[51], S. Mohiuddin[122], G. Mokgatitswane[34j], R. Mole[21], L. Moleri[171], U. Molinatti[127], L.G. Mollier[20], L. Monaco[37,58], B. Mondal[132], S. Mondal[134], K. Mönig[47], E. Monnier[102], L. Monsonis Romero[165], A. Montella[46a,46b], M. Montella[120], F. Montereali[76a,76b], F. Monticelli[90], S. Monzani[68a,68c], M.E.E. Moors[25], A. Morancho Tarda[42], N. Morange[65], M. Moreno Llácer[165], C. Moreno Martinez[55], J.M. Moreno Perez[23b], P. Morettini[56b], S. Morgenstern[62a], M. Morii[60], M. Morinaga[156], F. Morodei[74a,74b], P. Moschovakos[37], B. Moser[53], M. Mosidze[152b], T. Moskalets[44], P. Moskvitina[115], C.J. Mosomane[34b], J. Moss[32], T. Motta Quirino[81d], A. Moussa[36d], Y. Moyal[171,k], H. Moyano Gomez[13], E.J.W. Moyse[103], T.G. Mroz[86], S. Muanza[102], M. Mucha[25], J. Mueller[130], D. Muller[144], G.A. Mullier[163], A.J. Mullin[33], J.J. Mullin[50], A.C. Mullins[44], A.E. Mulski[60], D.P. Mungo[158], D. Munoz Perez[122], F.J. Munoz Sanchez[101], W.J. Murray[169,135], E. Musajan[61], M. Muškinja[93], C. Mwewa[47], A.J. Myers[8], G. Myers[106], M. Myska[133], B.P. Nachman[146], I.A. Nadas[28d], K. Nagai[127], K. Nagano[82], R. Nagasaka[156], J.L. Nagle[30,ao], E. Nagy[102], A.M. Nairz[37], T. Nakagawa[87],

Y. Nakahama [82], K. Nakamura [82], K. Nakkalil [5], A. Nandi [62b], H. Nanjo [125], E.A. Narayanan [44], Y. Narukawa [156], L. Nasella [70a,70b], S. Nasri [83c], C. Nass [25], G. Navarro [23a], A. Nayaz [19], S. Nechaeva [24b,24a], F. Nechansky [132], L. Nedic [127], A. Negri [72a,72b], M. Negrini [24b], C. Nellist [116], C. Nelson [104], K. Nelson [106], S. Nemecek [132], M. Nessi [37,g], M.S. Neubauer [164], J. Newell [92], P.R. Newman [21], Y.W.Y. Ng [164], B. Ngair [83b], H.D.N. Nguyen [108], J.D. Nichols [121], R. Nicolaidou [136], J. Nielsen [137], M. Niemeyer [54], J. Niermann [37], N. Nikiforou [37], I. Nikolic-Audit [128], P. Nilsson [30], G. Ninio [154], A. Nisati [74a], D. Nishimura [156], R. Nisius [110], N. Nitika [171], E.K. Nkadimeng [34b], T. Nobe [156], D. Noll [146], T. Nommensen [150], M.B. Norfolk [142], B.J. Norman [35], L.C. Nosler[18a], M. Noury [36a], J. Novak [93], T. Novak [93], P. Novotny [171], R. Novotny [133], L. Nozka [123], K. Ntekas [37], D. Ntounis [146], N.M.J. Nunes De Moura Junior [81b], J. Ocariz [128], I. Ochoa [131a], A. Odella Rodriguez [13], S. Oerdek [47], J.T. Offermann [39], A. Ogrodnik [86], A. Oh [101], C.C. Ohm [147], H. Oide [82], M.L. Ojeda [37], Y. Okumura [156], L.F. Oleiro Seabra [131a], I. Oleksiyuk [55], G. Oliveira Correa [13], D. Oliveira Damazio [30], J.L. Oliver [1], R. Omar [67], A.P. O'Neill [20], Y. Onoda[139], A. Onofre [131a,131e,e], P.U.E. Onyisi [11], M.J. Oreglia [39], D. Orestano [76a,76b], R. Orlandini [76a,76b], R.S. Orr [158], L.M. Osojnak [41], Y. Osumi [111], G. Otero y Garzón [31], H. Otono [88], M. Ouchrif [36d], F. Ould-Saada [126], T. Ovsiannikova [140], M. Owen [58], R.E. Owen [135], S.A. Oyeniran [114], V.E. Ozcan [22a], F. Ozturk [86], N. Ozturk [8], S. Ozturk [80], H.A. Pacey [127], K. Pachal [159a], A. Pacheco Pages [13], C. Padilla Aranda [13], G. Padovano [74a,74b], S. Pagan Griso [18a], L. Pagani [75a,75b], J. Pampel [25], D.K. Panchal [11], C.E. Pandini [59], J.G. Panduro Vazquez [135], H.D. Pandya [1], H. Pang [136], P. Pani [47], G. Panizzo [68a,68c], L. Panwar [128,w], L. Paolozzi [21], S. Parajuli [164], A. Paramonov [6], C. Paraskevopoulos [52], D. Paredes Hernandez [63b], S.R. Paredes Saenz [51], A. Pareti [72a,72b], K.R. Park [41], T.H. Park [110], F. Parodi [56b,56a], J.A. Parsons [41], J.A. Partridge[137], U. Parzefall [53], B.A. Paschen [18a], B. Pascual Dias [40], L. Pascual Dominguez [99], E. Pasqualucci [74a], S. Passaggio [56b], F. Pastore [95], P. Patel [86], U.M. Patel [50], J.R. Pater [101], T. Pauly [37], A. Paunovic [16], F. Pauwels [134], C.I. Pazos [161], M. Pedersen [126], R. Pedro [131a], O. Penc [132], C.C. Penelaud [128], S. Peng [15], G.D. Penn [174], B.S. Peralva [81d], A.P. Pereira Peixoto [140], L. Pereira Sanchez [146], D.V. Perepelitsa [30,ao], G. Perera [103], E. Perez Codina [37], M. Perganti [10], H. Pernegger [37], S. Perrella [74a,74b], K. Peters [47], R.F.Y. Peters [101], B.A. Petersen [37], T.C. Petersen [42], E. Petit [102], V. Petousis [133], A.R. Petri [70a,70b], T. Petru [134], M. Pettee [18a], A. Petukhov [80], K. Petukhova [37], R. Pezoa [138g], L. Pezzotti [24b,24a], G. Pezzullo [174], L. Pfaffenbichler [37], A.J. Pfleger [78], T.M. Pham [172], T. Pham [105], P.W. Phillips [135], G. Piacquadio [148], E. Pianori [18a], F. Piazza [124], R. Piegaia [31], D. Pietreanu [28b], A.D. Pilkington [101], T. Pilusa [34j], M. Pinamonti [68a,68c], J.L. Pinfold [2], G. Pinheiro Matos [41], B.C. Pinheiro Pereira [131a], J. Pinol Bel [13], A.E. Pinto Pinoargote [128], L. Pintucci [68a,68c], K.M. Piper [149], A. Pirttikoski [55], D.A. Pizzi [35], L. Pizzimento [63b], A. Plebani [33], M.-A. Pleier [30], V. Pleskot [134], E. Plotnikova[38], G. Poddar [94], R. Poettgen [98], L. Poggioli [128], S. Polacek [134], G. Polesello [72a], A. Poley [145], A. Polini [24b], C.S. Pollard [169], Z.B. Pollock [120], E. Pompa Pacchi [121], N.I. Pond [96], D. Ponomarenko [67], L. Pontecorvo [37], S. Popa [28a], G.A. Popeneciu [28d], A. Poreba [37], D.M. Portillo Quintero [159a], S. Pospisil [133], M.A. Postill [142], P. Postolache [28c], K. Potamianos [169], P.A. Potepa [85a], I.N. Potrap [38], C.J. Potter [33], H. Potti [150], J. Poveda [165], M.E. Pozo Astigarraga [37], R. Pozzi [37], A. Prades Ibanez [75a,75b], S.R. Pradhan [142], J. Pretel [167], D. Price [101], M. Primavera [69a], L. Primomo [68a,68c], M.A. Principe Martin [99], R. Privara [123], T. Procter [85b], M.L. Proffitt [140], N. Proklova [129], K. Prokofiev [63c], G. Proto [110], J. Proudfoot [6], M. Przybycien [85a], W.W. Przygoda [85b], A. Psallidas [45], D. Pudzha [52], P. Puhl [57], H.I. Purnell [1], D. Pyatiizbyantseva [115], J. Qian [106], R. Qian [107], D. Qichen [127], Y. Qin [13], T. Qiu [51],

A. Quadt [54], M. Queitsch-Maitland [101], G. Quetant [55], R.P. Quinn [166], D. Rafanoharana [110], J.L. Rainbolt [39], S. Rajagopalan [30], E. Ramakoti [38], L. Rambelli [56b,56a], I.A. Ramirez-Berend [35], K. Ran [106,112c], S.D. Randles [92], D.S. Rankin [129], N.P. Rapheeha [34j], H. Rasheed [28b], A. Rastogi [18a], S. Rave [100], S. Ravera [56b,56a], B. Ravina [37], I. Ravinovich [171], M. Raymond [37], A.L. Read [126], N.P. Readioff [142], D.M. Rebuzzi [72a,72b], A.S. Reed [58], K. Reeves [27], D. Reikher [37], A. Rej [48], H. Ren [61], M. Renda [28b], F. Renner [47], A.G. Rennie [58], M. Repik [55], A.L. Rescia [43b,43a], S. Resconi [70a], M. Ressegotti [56b], S. Rettie [116], W.F. Rettie [35], M.M. Revering [33], O.L. Rezanova [38], P. Reznicek [134], H. Riani [36d], N. Ribaric [37], B. Ricci [68a,68c], E. Ricci [77a,77b], R. Richter [110], E. Richter-Was [85b], M. Ridel [128], S. Ridouani [36d], P. Riedler [37], E.M. Riefel [46a,46b], J.O. Rieger [116], M. Rimoldi [34c], L. Rinaldi [24b,24a], P. Rincke [163,54], G. Ripellino [163], I. Riu [13], J.C. Rivera Vergara [167], F. Rizatdinova [122], E. Rizvi [94], B.R. Roberts [39], S.S. Roberts [137], D. Robinson [33], A. Robson [58], A. Rocchi [75a,75b], C. Roda [73a,73b], F.A. Rodriguez [117], S. Rodriguez Bosca [37], Y. Rodriguez Garcia [23a], A.M. Rodríguez Vera [117], S. Roe[37], J.T. Roemer [37], O. Røhne [126], R.A. Rojas [37], Z. Rokavec[93], C.P.A. Roland [128], A. Romaniouk [78], E. Romano [72a,72b], M. Romano [24b], N. Rompotis [92], L. Roos [128], S. Rosati [74a], L. Roscher [47], B.J. Rosser [39], E. Rossi [127], E. Rossi [71a,71b], L.P. Rossi [60], L. Rossini [53], R. Rosten [120], M. Rotaru [28b], R. Roth [37], D. Rousseau [65], D. Rousso [47], S. Roy-Garand [55], A. Rozanov [102], Z.M.A. Rozario [58], Y. Rozen [153], A. Rubio Jimenez [165], V.H. Ruelas Rivera [19], T.A. Ruggeri [1], A. Ruggiero [127], A. Ruiz-Martinez [165], A. Rummler [37], G.B. Rupnik Boero [37], N.A. Rusakovich [38], S. Ruscelli [48], H.L. Russell [167], G. Russo [137], J.P. Rutherfoord [7], S. Rutherford Colmenares [118], M. Rybar [134], P. Rybczynski [85a], A. Ryzhov [44], F. Safai Tehrani [74a], S. Saha [1], B. Sahoo [171], B.T. Saifuddin [121], M. Saimpert [136], I. Sainz Saenz Diez [62a], G.T. Saito [81c], M. Saito [156], T. Saito [156], A. Sala [70a,70b], O.T. Salin [65], A. Salnikov [146], J. Salt [165], A. Salvador Salas [154], F. Salvatore [149], A. Salzburger [37], D. Sammel [53], E. Sampson [91], D. Sampsonidis [155,d], D. Sampsonidou [124], M.A.A. Samy [58], J. Sánchez [165], V. Sanchez Sebastian [165], H. Sandaker [126], C.O. Sander [47], J.A. Sandesara [172], M. Sandhoff [173], C. Sandoval [23b], L. Sanfilippo [62a], D.P.C. Sankey [135], T. Sano [87], A. Sansar [22c], A. Sansoni [52], M. Santana Queiroz [18b], L. Santi [37], C. Santoni [40], H. Santos [131a,131b], L. Santos Pereira Trigo [47], E. Sanzani [24b,24a], K.A. Saoucha [83d], J.G. Saraiva [131a,131d], J. Sardain [7], S. Sarkar [50], O. Sasaki [82], K. Sato [160], C. Sauer[37], E. Sauvan [4], P. Savard [158,aj], M. Savic [164], R. Sawada [156], C. Sawyer [135], L. Sawyer [97], A.M. Sayed [27], C. Sbarra [24b], A. Sbrizzi [24b,24a], R. Scaglioni [72a,72b], T. Scanlon [96], J. Schaarschmidt [140], U. Schäfer [100], A.C. Schaffer [65,44], D. Schaile [109], R.D. Schamberger [148], C. Scharf [19], M.M. Schefer [20], D. Scheirich [134], M. Schernau [138f], C. Scheulen [55], C. Schiavi [56b,56a], M. Schioppa [43b,43a], S. Schlenker [37], T. Schlomer [54], J. Schmeing [173], C.R. Schmidt [49], E. Schmidt [110], M.A. Schmidt [173], K. Schmieden [25], C. Schmitt [100], N. Schmitt [100], S. Schmitt [47], N.A. Schneider [109], L. Schoeffel [136], A. Schoening [62b], P.G. Scholer [35], E. Schopf [144], M. Schott [25], S. Schramm [55], T. Schroer [55], H-C. Schultz-Coulon [62a], M. Schumacher [53], B.A. Schumm [137], Ph. Schune [136], H.R. Schwartz [7], A. Schwartzman [146], T.A. Schwarz [106], Ph. Schwemling [136], R. Schwienhorst [107], F.G. Sciacca [20], A. Sciandra [30], G. Sciolla [27], S.A. Scoville [130], F. Scuri [73a], C.D. Sebastiani [37], K. Sedlaczek [117], A. Sehrawat [138b], S.C. Seidel [114], B.D. Seidlitz [41], C. Seitz [47], J.M. Seixas [81b], G. Sekhniaidze [71a], L. Selem [128], N. Semprini-Cesari [24b,24a], A. Semushin [175], V. Senthilkumar [116], L. Serin [65], M. Sessa [71a,71b], H. Severini [121], F. Sforza [56b,56a], A. Sfyrla [55], Q. Sha [14], H. Shaddix [117], A.H. Shah [33], R. Shaheen [147], J.D. Shahinian [129], M. Shamim [37], L.Y. Shan [14], M. Shapiro [18a], A. Sharma [37], A.S. Sharma [166], P. Sharma [30], K. Shaw [149], S.M. Shaw [101], D. Shemyakin [171], Q. Shen [14], D.J. Sheppard[145], P. Sherwood[96], L. Shi[112b], X. Shi[14], S. Shimizu[82], S. Shirabe[88], M. Shiyakova[38,z], M.J. Shochet[39], D.R. Shope[126], B. Shrestha[121], S. Shrestha[120,aq], I. Shreyber[38], M.J. Shroff[104], P. Sicho[132], A.M. Sickles[164], E. Sideras Haddad[34j], A.C. Sidley[116], A. Sidoti[24b], F. Siegert[49], Dj. Sijacki[16], F. Sili[61], J.M. Silva[51], I. Silva Ferreira[81b], M.V. Silva Oliveira[30], S.B. Silverstein[46a], S. Simion[65], R. Simoniello[37], E.L. Simpson[101], H. Simpson[149], L.R. Simpson[6], S. Simsek[80], S. Sindhu[54], S.N. Singh[27], S. Singh[30], S. Sinha[47], S. Sinha[101], M. Sioli[24b,24a], K. Sioulas[9], I. Siral[37], E. Sitnikova[47], J. Sjölin[46a,46b], A. Skaf[54], E. Skorda[21], P. Skubic[121], M. Slawinska[86], I. Slazyk[17], I. Sliusar[126], V. Smakhtin[171], B.H. Smart[135], S.Yu. Smirnov[138b], Y. Smirnov[34c], O. Smirnova[98], J.L. Smith[101], M.B. Smith[35], R. Smith[146], H. Smitmanns[100], M. Smizanska[91], K. Smolek[133], P. Smolyanskiy[133], A.A. Snesarev[38], H.L. Snoek[116], R.M. Snyder[50], S. Snyder[30], R. Sobie[167,ab], A. Soffer[154], C.A. Solans Sanchez[37], E.Yu. Soldatov[38], U. Soldevila[165], A.A. Solodkov[34j], S. Solomon[27], A. Soloshenko[38], O.V. Solovyanov[40], P. Sommer[49], A. Sopczak[133], A.L. Sopio[51], F. Sopkova[29b], J.D. Sorenson[114], I.R. Sotarriva Alvarez[139], V. Sothilingam[62a], O.J. Soto Sandoval[138c,138b], S. Sottocornola[67], R. Soualah[83a], D. South[47], N. Soybelman[171], S. Spagnolo[69a,69b], A.S. Spellman[124], D. Sperlich[53], B. Spisso[71a,71b], L. Splendori[102], M. Spousta[134], E.J. Staats[35], R. Stamen[62a], E. Stanecka[86], W. Stanek-Maslouska[47], M.V. Stange[49], B. Stanislaus[18a], M.M. Stanitzki[47], G.H. Stark[137], J. Stark[89], P. Staroba[132], P. Starovoitov[83d], R. Staszewski[86], C. Stauch[109], G. Stavropoulos[45], A. Stefl[37], A. Stein[100], P. Steinberg[30], B. Stelzer[145,159a], H.J. Stelzer[130], O. Stelzer[159a], H. Stenzel[57], T.J. Stevenson[149], G.A. Stewart[47], G. Stoicea[28b], M. Stolarski[131a], S. Stonjek[110], A. Straessner[49], J. Strandberg[147], S. Strandberg[46a,46b], M. Stratmann[173], M. Strauss[121], T. Strebler[102], P. Strizenec[29b], R. Ströhmer[168], D.M. Strom[124], R. Stroynowski[44], A. Strubig[46a,46b], S.A. Stucci[30], B. Stugu[17], J. Stupak[121], N.A. Styles[47], D. Su[146], S. Su[61], X. Su[61], D. Suchy[29a], A.D. Sudhakar Ponnu[54], L. Sudit[171], Y. Sue[82], K. Sugizaki[129], D.M.S. Sultan[127], L. Sultanaliyeva[25], S. Sultansoy[3b], S. Sun[172], W. Sun[14], S. Sundar Raman[166], N. Sur[98], J.P. Surdutovich[120], N. Suri Jr[174], M.R. Sutton[149], M. Svatos[132], P.N. Swallow[33], S.N. Swatman[37], M. Swiatlowski[159a], A. Swoboda[37], I. Sykora[29a], M. Sykora[134], T. Sykora[134], D. Ta[100], K. Tackmann[47,y], A. Taffard[162], R. Tafirout[159a], Y. Takubo[82], M. Talby[102], N.M. Tamir[154], A. Tanaka[156], J. Tanaka[156], R. Tanaka[65], M. Tanasini[148], Z. Tao[166], S. Tapia Araya[138g], S. Tapprogge[100], A. Tarek Abouelfadl Mohamed[37], S. Tarem[153], K. Tariq[14], G. Tarna[37], G.F. Tartarelli[70a], M.J. Tartarin[141b], P. Tas[134], M. Tasevsky[132], E. Tassi[43b,43a], A.C. Tate[164], Y. Tayalati[36e,aa], G.N. Taylor[105], W. Taylor[159b], R.J. Taylor Vara[165], A.S. Tegetmeier[89], P. Teixeira-Dias[95], J.J. Teoh[158], K. Terashi[156], J. Terron[99], S. Terzo[13], M. Testa[52], R.J. Teuscher[158,ab], A. Thaler[78], T. Theveneaux-Pelzer[102], J.P. Thomas[21], E.A. Thompson[18a], P.D. Thompson[21], E. Thomson[129], R.E. Thornberry[30], T.M. Thory-Rao[21], C.N. Thotamuna Wijewardhana[148], C. Tian[61], Y. Tian[55], V. Tikhomirov[80], Yu.A. Tikhonov[38], D. Timoshyn[134], E.X.L. Ting[1], P. Tipton[174], A. Tishelman-Charny[30], K. Todome[139], S. Todorova-Nova[134], L. Toffolin[68a,68c], M. Togawa[82], J. Tojo[88], S. Tokár[29a], O. Toldaiev[67], G. Tolkachev[102], M. Tomoto[82], L. Tompkins[146], E. Torrence[124], H. Torres[89], D.I. Torres Arza[138g], E. Torres Reoyo[165], E. Torró Pastor[165], M. Toscani[31], C. Tosciri[39], M. Tost[11], D.R. Tovey[142], T. Trefzger[168], P.M. Tricarico[13], A. Tricoli[30], I.M. Trigger[159a], S. Trincaz-Duvoid[128], D.A. Trischuk[167], A. Tropina[38], D. Truncali[75a,75b], L. Truong[34c], M. Trzebinski[86], A. Trzupek[86], F. Tsai[148], A. Tsiamis[155], P.V. Tsiareshka[38], S. Tsigaridas[159a], A. Tsirigotis[155,t], V. Tsiskaridze[152a], E.G. Tskhadadze[152a], H.F. Tsoi[129], Y. Tsujikawa[87], V. Tsulaia[18a], K. Tsuri[119], D. Tsybychev[148], Y. Tu[63b], A. Tudorache[28b], V. Tudorache[28b], S.B. Tuncay[127],

S. Turchikhin [56b,56a], I. Turk Cakir [3a], R. Turra [70a], T. Turtuvshin [38,ac], P.M. Tuts [41], Y. Uematsu [82], F. Ukegawa [160], P.A. Ulloa Poblete [138c,138b], G. Unal [37], A. Undrus [30], J. Urban [29b], P. Urrejola [138e], G. Usai [8], R. Ushioda [157], M. Usman [108], F. Ustuner [51], Z. Uysal [80], V. Vacek [133], B. Vachon [104], T. Vafeiadis [37], A. Vaitkus [96], C. Valderanis [109], E. Valdes Santurio [46a,46b], M. Valente [37], S. Valentinetti [24b,24a], A. Valero [165], E. Valiente Moreno [165], A. Vallier [89], J.A. Valls Ferrer [165], D.R. Van Arneman [116], R. Van Den Broucke [128], A. Van Der Graaf [48], H.Z. Van Der Schyf [34j], P. Van Gemmeren [6], M. Van Rijnbach [37], S. Van Stroud [96], I. Van Vulpen [116], P. Vana [134], M. Vanadia [75a,75b], U.M. Vande Voorde [147], W. Vandelli [37], E.R. Vandewall [146], D. Vannicola [154], R. Vari [74a], M. Varma [174], E.W. Varnes [7], C. Varni [85a], D. Varouchas [65], L. Varriale [165], K.E. Varvell [150], M.E. Vasile [28b], A. Vasileiadou [9], L. Vaslin [82], M.D. Vassilev [146], A. Vasyukov [38], L.M. Vaughan [122], R. Vavricka [134], T. Vazquez Schroeder [13], J. Veatch [32], V. Vecchio [101], M.J. Veen [103], I. Veliscek [30], I. Velkovska [93], L.M. Veloce [158], F. Veloso [131a,131c], A.G. Veltman [51], S.H. Venetianer [161], S. Veneziano [74a], A. Ventura [69a,69b], A. Verbytskyi [110], M. Verducci [73a,73b], C. Vergis [94], M. Verissimo De Araujo [81b], W. Verkerke [116], J.C. Vermeulen [116], C. Vernieri [146], M. Vessella [162], M.C. Vetterli [145,aj], A. Vgenopoulos [100], N. Viaux Maira [138g,af], L. Vicenik [133], T. Vickey [142], O.E. Vickey Boeriu [142], G.H.A. Viehhauser [127], L. Vigani [62b], M. Vigl [110], M. Villa [24b,24a], M. Villaplana Perez [165], E.M. Villhauer [39], E. Vilucchi [52], M. Vincent [165], M.G. Vincter [35], A. Visibile [116], A. Visive [116], C. Vittori [161], I. Vivarelli [24b,24a], M.I. Vivas Albornoz [47], E. Voevodina [110], F. Vogel [109], J.C. Voigt [49], P. Vokac [133], Yu. Volkotrub [85b], L. Vomberg [25], E. Von Toerne [25], B. Vormwald [37], K. Vorobev [50], M. Vos [165], K. Voss [144], M. Vozak [37], L. Vozdecky [121], N. Vranjes [16], M. Vranjes Milosavljevic [16], M. Vreeswijk [116], N.K. Vu [112a], R. Vuillermet [37], I. Vukotic [39], I.K. Vyas [35], J.F. Wack [33], A. Wada [111], S. Wada [160], C. Wagner [146], J.M. Wagner [18a], W. Wagner [173], S. Wahdan [173], H. Wahlberg [90], C.H. Waits [121], J. Walder [135], R. Walker [109], K. Walkingshaw Pass [58], W. Walkowiak [144], A. Wall [129], E.J. Wallin [98], T. Wamorkar [146], K. Wandall-Christensen [165], A. Wang [61], A.Z. Wang [137], C. Wang [47], C. Wang [11], H. Wang [18a], J. Wang [63c], P. Wang [101], P. Wang [96], R. Wang [60], R. Wang [106], R. Wang [6], S.M. Wang [151], S. Wang [14,an], T. Wang [115], T. Wang [61], W.T. Wang [127], W. Wang [113c], X. Wang [164], X. Wang [141a], X. Wang [47], Y. Wang [148], Y. Wang [114], Z. Wang [14], Z. Wang [63b], C. Wanotayaroj [82], A. Warburton [104], A.L. Warnerbring [144], S. Waterhouse [96], A.T. Watson [21], H. Watson [51], M.F. Watson [21], E. Watton [37], G. Watts [140], B.M. Waugh [96], J.M. Webb [53], C. Weber [30], M.S. Weber [20], C. Wei [61], Y. Wei [53], A.R. Weidberg [127], E.J. Weik [118], J. Weingarten [48], C. Weiser [53], C.J. Wells [47], P.S. Wells [37], T. Wenaus [30], T. Wengler [37], N.S. Wenke [110], N. Wermes [25], D. Werner [47], M. Wessels [62a], A.M. Wharton [91], A.S. White [37], A. White [8], M.J. White [1], D. Whiteson [162], L. Wickremasinghe [125], W. Wiedenmann [172], M. Wielers [135], R. Wierda [147], C. Wiglesworth [42], H.G. Wilkens [37], J.J.H. Wilkinson [33], S. Williams [33], S. Willocq [103], D.J. Wilson [101], P.J. Windischhofer [39], F.I. Winkel [31], F. Winklmeier [124], B.T. Winter [53], M. Wittgen [146], M. Wobisch [97], T. Wojtkowski [59], Z. Wolffs [116], J. Wollrath [37], M.W. Wolter [86], H. Wolters [131a,131c], M.C. Wong [137], E.L. Woodward [41], S.D. Worm [47], B.K. Wosiek [86], K.A. Wozniak [55], K.W. Woźniak [86], S. Wozniewski [54], K. Wraight [58], C. Wu [158], J. Wu [156], M. Wu [112b], M. Wu [115], S.L. Wu [172], S. Wu [14,an], X. Wu [61], Y.Q. Wu [158], Y. Wu [61], Z. Wu [102], Z. Wu [112a], J. Wuerzinger [110], T.R. Wyatt [101], B.M. Wynne [51], S. Xella [42], L. Xia [112a], M. Xie [61], A. Xiong [124], I. Xiotidis [37], D. Xu [14], H. Xu [61], L. Xu [61], R. Xu [129], T. Xu [106], W. Xu [112a], Y. Xu [140], Z. Xu [51], R. Xue [130], B. Yabsley [150], S. Yacoob [11], Y. Yamaguchi [82], E. Yamashita [156], H. Yamauchi [160], T. Yamazaki [18a], Y. Yamazaki [84], S. Yan [58], Z. Yan [103], C. Yang [18a], H.J. Yang [141a], H.T. Yang [61], S. Yang [61], X. Yang [37], X. Yang [14], Y. Yang [156], Y. Yang[61], W-M. Yao [18a], C.L. Yardley [149], J. Ye [14], S. Ye [30], X. Ye [61], I. Yeletskikh [38], B. Yeo [18b], M.R. Yexley [96], T.P. Yildirim [127], K. Yorita [170], C.J.S. Young [37], C. Young [146], I.N.L. Young [58], N.D. Young[124], Y. Yu [61], J. Yuan [14,112c,an], M. Yuan [106], R. Yuan [141b], L. Yue [96], M. Zaazoua [61], B. Zabinski [86], I. Zahir [36a], Q.U.A. Zahoor [51], A. Zaio[56b,56a], Z.K. Zak [86], T. Zakareishvili [165], S. Zambito [55], J. Zang [156], R. Zanzottera [70a,70b], O. Zaplatilek [133], E. Zaya [147], C. Zeitnitz [173], H. Zeng [14], D.T. Zenger Jr [27], T. Ženiš [29a], S. Zenz [94], D. Zerwas [65], W. Zhan [61], B. Zhang [169], D.F. Zhang [142], G. Zhang [14,an], J. Zhang [113b], J. Zhang [6], L. Zhang [61], L. Zhang [112a], P. Zhang [14,112c], R. Zhang [112a], S. Zhang [36e], Y. Zhang [140], Y. Zhang [96], Y. Zhang [61], Y. Zhang [112a], Z. Zhang [101], Z. Zhang [18a], Z. Zhang [113b], Z. Zhang [65], H. Zhao [140], T. Zhao [113b], Y. Zhao [35], Z. Zhao [61], Z. Zhao [61], A. Zhemchugov [38], J. Zheng [112a], K. Zheng [164], L. Zheng [113b], X. Zheng [61], Z. Zheng [146], D. Zhong [164], B. Zhou [106], B. Zhou [141b,141a], N. Zhou [141a], Y. Zhou [15], Y. Zhou [112a], Y. Zhou[7], Z. Zhou [61], J. Zhu [106], X. Zhu[141b], Y. Zhu [141a], X. Zhuang [14], K. Zhukov [67], P. Ziakas [4], N.I. Zimine [38], J. Zinsser [62b], M. Ziolkowski [144], L. Živković [16], A. Zoccoli [24b,24a], K. Zoch [37], A. Zografos [37], T.G. Zorbas [142], L. Zwalinski [37].

[1]Department of Physics, University of Adelaide, Adelaide; Australia.
[2]Department of Physics, University of Alberta, Edmonton AB; Canada.
[3(a)]Department of Physics, Ankara University, Ankara;[(b)]Division of Physics, TOBB University of Economics and Technology, Ankara; Türkiye.
[4]LAPP, Université Savoie Mont Blanc, CNRS/IN2P3, Annecy; France.
[5]APC, Université Paris Cité, CNRS/IN2P3, Paris; France.
[6]High Energy Physics Division, Argonne National Laboratory, Argonne IL; United States of America.
[7]Department of Physics, University of Arizona, Tucson AZ; United States of America.
[8]Department of Physics, University of Texas at Arlington, Arlington TX; United States of America.
[9]Physics Department, National and Kapodistrian University of Athens, Athens; Greece.
[10]Physics Department, National Technical University of Athens, Zografou; Greece.
[11]Department of Physics, University of Texas at Austin, Austin TX; United States of America.
[12]Institute of Physics, Azerbaijan Academy of Sciences, Baku; Azerbaijan.
[13]Institut de Física d'Altes Energies (IFAE), Barcelona Institute of Science and Technology, Barcelona; Spain.
[14]Institute of High Energy Physics, Chinese Academy of Sciences, Beijing; China.
[15]Physics Department, Tsinghua University, Beijing; China.
[16]Institute of Physics, University of Belgrade, Belgrade; Serbia.
[17]Department for Physics and Technology, University of Bergen, Bergen; Norway.
[18(a)]Physics Division, Lawrence Berkeley National Laboratory, Berkeley CA;[(b)]University of California, Berkeley CA; United States of America.
[19]Institut für Physik, Humboldt Universität zu Berlin, Berlin; Germany.
[20]Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern; Switzerland.
[21]School of Physics and Astronomy, University of Birmingham, Birmingham; United Kingdom.
[22(a)]Department of Physics, Bogazici University, Istanbul;[(b)]Department of Physics Engineering, Gaziantep University, Gaziantep;[(c)]Department of Physics, Istanbul University, Istanbul; Türkiye.
[23(a)]Facultad de Ciencias y Centro de Investigaciónes, Universidad Antonio Nariño, Bogotá;[(b)]Departamento de Física, Universidad Nacional de Colombia, Bogotá; Colombia.
[24(a)]Dipartimento di Fisica e Astronomia A. Righi, Università di Bologna, Bologna;[(b)]INFN Sezione di

Bologna; Italy.
[25]Physikalisches Institut, Universität Bonn, Bonn; Germany.
[26]Department of Physics, Boston University, Boston MA; United States of America.
[27]Department of Physics, Brandeis University, Waltham MA; United States of America.
[28(a)]Transilvania University of Brasov, Brasov;[(b)]Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest;[(c)]Department of Physics, Alexandru Ioan Cuza University of Iasi, Iasi;[(d)]National Institute for Research and Development of Isotopic and Molecular Technologies, Physics Department, Cluj-Napoca;[(e)]National University of Science and Technology Politechnica, Bucharest;[(f)]West University in Timisoara, Timisoara;[(g)]Faculty of Physics, University of Bucharest, Bucharest; Romania.
[29(a)]Faculty of Mathematics, Physics and Informatics, Comenius University, Bratislava;[(b)]Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice; Slovak Republic.
[30]Physics Department, Brookhaven National Laboratory, Upton NY; United States of America.
[31]Universidad de Buenos Aires, Facultad de Ciencias Exactas y Naturales, Departamento de Física, y CONICET, Instituto de Física de Buenos Aires (IFIBA), Buenos Aires; Argentina.
[32]California State University, CA; United States of America.
[33]Cavendish Laboratory, University of Cambridge, Cambridge; United Kingdom.
[34(a)]Department of Physics, University of Cape Town, Cape Town;[(b)]iThemba Labs, Western Cape;[(c)]Department of Mechanical Engineering Science, University of Johannesburg, Johannesburg;[(d)]National Institute of Physics, University of the Philippines Diliman (Philippines);[(e)]Department of Physics, Stellenbosch University, Matieland;[(f)]University of KwaZulu-Natal, School of Agriculture and Science, Mathematics, Westville;[(g)]University of South Africa, Department of Physics, Pretoria;[(h)]University of Pretoria, Department of Mechanical and Aeronautical Engineering, Pretoria;[(i)]University of Zululand, KwaDlangezwa;[(j)]School of Physics, University of the Witwatersrand, Johannesburg; South Africa.
[35]Department of Physics, Carleton University, Ottawa ON; Canada.
[36(a)]Faculté des Sciences Ain Chock, Université Hassan II de Casablanca;[(b)]Faculté des Sciences, Université Ibn-Tofail, Kénitra;[(c)]Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA-Marrakech;[(d)]LPMR, Faculté des Sciences, Université Mohamed Premier, Oujda;[(e)]Faculté des sciences, Université Mohammed V, Rabat;[(f)]Institute of Applied Physics, Mohammed VI Polytechnic University, Ben Guerir; Morocco.
[37]CERN, Geneva; Switzerland.
[38]Affiliated with an international laboratory covered by a cooperation agreement with CERN.
[39]Enrico Fermi Institute, University of Chicago, Chicago IL; United States of America.
[40]LPC, Université Clermont Auvergne, CNRS/IN2P3, Clermont-Ferrand; France.
[41]Nevis Laboratory, Columbia University, Irvington NY; United States of America.
[42]Niels Bohr Institute, University of Copenhagen, Copenhagen; Denmark.
[43(a)]Dipartimento di Fisica, Università della Calabria, Rende;[(b)]INFN Gruppo Collegato di Cosenza, Laboratori Nazionali di Frascati; Italy.
[44]Physics Department, Southern Methodist University, Dallas TX; United States of America.
[45]National Centre for Scientific Research "Demokritos", Agia Paraskevi; Greece.
[46(a)]Department of Physics, Stockholm University;[(b)]Oskar Klein Centre, Stockholm; Sweden.
[47]Deutsches Elektronen-Synchrotron DESY, Hamburg and Zeuthen; Germany.
[48]Fakultät Physik, Technische Universität Dortmund, Dortmund; Germany.
[49]Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden; Germany.
[50]Department of Physics, Duke University, Durham NC; United States of America.
[51]SUPA - School of Physics and Astronomy, University of Edinburgh, Edinburgh; United Kingdom.

[52]INFN e Laboratori Nazionali di Frascati, Frascati; Italy.
[53]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg; Germany.
[54]II. Physikalisches Institut, Georg-August-Universität Göttingen, Göttingen; Germany.
[55]Départment de Physique Nucléaire et Corpusculaire, Université de Genève, Genève; Switzerland.
[56][(a)]Dipartimento di Fisica, Università di Genova, Genova;[(b)]INFN Sezione di Genova; Italy.
[57]II. Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen; Germany.
[58]SUPA - School of Physics and Astronomy, University of Glasgow, Glasgow; United Kingdom.
[59]LPSC, Université Grenoble Alpes, CNRS/IN2P3, Grenoble INP, Grenoble; France.
[60]Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge MA; United States of America.
[61]Department of Modern Physics and State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei; China.
[62][(a)]Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg;[(b)]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg; Germany.
[63][(a)]Department of Physics, Chinese University of Hong Kong, Shatin, N.T., Hong Kong;[(b)]Department of Physics, University of Hong Kong, Hong Kong;[(c)]Department of Physics and Institute for Advanced Study, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong; China.
[64]Department of Physics, National Tsing Hua University, Hsinchu; Taiwan.
[65]IJCLab, Université Paris-Saclay, CNRS/IN2P3, 91405, Orsay; France.
[66]Centro Nacional de Microelectrónica (IMB-CNM-CSIC), Barcelona; Spain.
[67]Department of Physics, Indiana University, Bloomington IN; United States of America.
[68][(a)]INFN Gruppo Collegato di Udine, Sezione di Trieste, Udine;[(b)]ICTP, Trieste;[(c)]Dipartimento Politecnico di Ingegneria e Architettura, Università di Udine, Udine; Italy.
[69][(a)]INFN Sezione di Lecce;[(b)]Dipartimento di Matematica e Fisica, Università del Salento, Lecce; Italy.
[70][(a)]INFN Sezione di Milano;[(b)]Dipartimento di Fisica, Università di Milano, Milano; Italy.
[71][(a)]INFN Sezione di Napoli;[(b)]Dipartimento di Fisica, Università di Napoli, Napoli; Italy.
[72][(a)]INFN Sezione di Pavia;[(b)]Dipartimento di Fisica, Università di Pavia, Pavia; Italy.
[73][(a)]INFN Sezione di Pisa;[(b)]Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa; Italy.
[74][(a)]INFN Sezione di Roma;[(b)]Dipartimento di Fisica, Sapienza Università di Roma, Roma; Italy.
[75][(a)]INFN Sezione di Roma Tor Vergata;[(b)]Dipartimento di Fisica, Università di Roma Tor Vergata, Roma; Italy.
[76][(a)]INFN Sezione di Roma Tre;[(b)]Dipartimento di Matematica e Fisica, Università Roma Tre, Roma; Italy.
[77][(a)]INFN-TIFPA;[(b)]Università degli Studi di Trento, Trento; Italy.
[78]Universität Innsbruck, Department of Astro and Particle Physics, Innsbruck; Austria.
[79]Department of Physics and Astronomy, Iowa State University, Ames IA; United States of America.
[80]Istinye University, Sariyer, Istanbul; Türkiye.
[81][(a)]Departamento de Engenharia Elétrica, Universidade Federal de Juiz de Fora (UFJF), Juiz de Fora;[(b)]Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro;[(c)]Instituto de Física, Universidade de São Paulo, São Paulo;[(d)]Rio de Janeiro State University, Rio de Janeiro;[(e)]Federal University of Bahia, Bahia; Brazil.
[82]KEK, High Energy Accelerator Research Organization, Tsukuba; Japan.
[83][(a)]Khalifa University of Science and Technology, Abu Dhabi;[(b)]New York University Abu Dhabi, Abu Dhabi;[(c)]United Arab Emirates University, Al Ain;[(d)]University of Sharjah, Sharjah; United Arab Emirates.
[84]Graduate School of Science, Kobe University, Kobe; Japan.
[85][(a)]AGH University of Krakow, Faculty of Physics and Applied Computer Science, Krakow;[(b)]Marian

Smoluchowski Institute of Physics, Jagiellonian University, Krakow; Poland.
[86]Institute of Nuclear Physics Polish Academy of Sciences, Krakow; Poland.
[87]Faculty of Science, Kyoto University, Kyoto; Japan.
[88]Research Center for Advanced Particle Physics and Department of Physics, Kyushu University, Fukuoka ; Japan.
[89]L2IT, Université de Toulouse, CNRS/IN2P3, UPS, Toulouse; France.
[90]Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata; Argentina.
[91]Physics Department, Lancaster University, Lancaster; United Kingdom.
[92]Oliver Lodge Laboratory, University of Liverpool, Liverpool; United Kingdom.
[93]Department of Experimental Particle Physics, Jožef Stefan Institute and Department of Physics, University of Ljubljana, Ljubljana; Slovenia.
[94]Department of Physics and Astronomy, Queen Mary University of London, London; United Kingdom.
[95]Department of Physics, Royal Holloway University of London, Egham; United Kingdom.
[96]Department of Physics and Astronomy, University College London, London; United Kingdom.
[97]Louisiana Tech University, Ruston LA; United States of America.
[98]Fysiska institutionen, Lunds universitet, Lund; Sweden.
[99]Departamento de Física Teorica C-15 and CIAFF, Universidad Autónoma de Madrid, Madrid; Spain.
[100]Institut für Physik, Universität Mainz, Mainz; Germany.
[101]School of Physics and Astronomy, University of Manchester, Manchester; United Kingdom.
[102]CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille; France.
[103]Department of Physics, University of Massachusetts, Amherst MA; United States of America.
[104]Department of Physics, McGill University, Montreal QC; Canada.
[105]School of Physics, University of Melbourne, Victoria; Australia.
[106]Department of Physics, University of Michigan, Ann Arbor MI; United States of America.
[107]Department of Physics and Astronomy, Michigan State University, East Lansing MI; United States of America.
[108]Group of Particle Physics, University of Montreal, Montreal QC; Canada.
[109]Fakultät für Physik, Ludwig-Maximilians-Universität München, München; Germany.
[110]Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München; Germany.
[111]Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya; Japan.
[112(a)]Department of Physics, Nanjing University, Nanjing;[(b)]School of Science, Shenzhen Campus of Sun Yat-sen University;[(c)]University of Chinese Academy of Science (UCAS), Beijing; China.
[113(a)]School of Physics, Nankai University, Tianjin;[(b)]Institute of Frontier and Interdisciplinary Science and Key Laboratory of Particle Physics and Particle Irradiation (MOE), Shandong University, Qingdao;[(c)]School of Physics, Zhengzhou University; China.
[114]Department of Physics and Astronomy, University of New Mexico, Albuquerque NM; United States of America.
[115]Institute for Mathematics, Astrophysics and Particle Physics, Radboud University/Nikhef, Nijmegen; Netherlands.
[116]Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam; Netherlands.
[117]Department of Physics, Northern Illinois University, DeKalb IL; United States of America.
[118]Department of Physics, New York University, New York NY; United States of America.
[119]Ochanomizu University, Otsuka, Bunkyo-ku, Tokyo; Japan.
[120]Ohio State University, Columbus OH; United States of America.
[121]Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman OK; United States of America.

[122]Department of Physics, Oklahoma State University, Stillwater OK; United States of America.
[123]Palacký University, Joint Laboratory of Optics, Olomouc; Czech Republic.
[124]Institute for Fundamental Science, University of Oregon, Eugene, OR; United States of America.
[125]Graduate School of Science, University of Osaka, Osaka; Japan.
[126]Department of Physics, University of Oslo, Oslo; Norway.
[127]Department of Physics, Oxford University, Oxford; United Kingdom.
[128]LPNHE, Sorbonne Université, Université Paris Cité, CNRS/IN2P3, Paris; France.
[129]Department of Physics, University of Pennsylvania, Philadelphia PA; United States of America.
[130]Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh PA; United States of America.
[131][(a)]Laboratório de Instrumentação e Física Experimental de Partículas - LIP, Lisboa;[(b)]Departamento de Física, Faculdade de Ciências, Universidade de Lisboa, Lisboa;[(c)]Departamento de Física, Universidade de Coimbra, Coimbra;[(d)]Centro de Física Nuclear da Universidade de Lisboa, Lisboa;[(e)]Departamento de Física, Escola de Ciências, Universidade do Minho, Braga;[(f)]Departamento de Física Teórica y del Cosmos, Universidad de Granada, Granada (Spain);[(g)]Departamento de Física, Instituto Superior Técnico, Universidade de Lisboa, Lisboa; Portugal.
[132]Institute of Physics of the Czech Academy of Sciences, Prague; Czech Republic.
[133]Czech Technical University in Prague, Prague; Czech Republic.
[134]Charles University, Faculty of Mathematics and Physics, Prague; Czech Republic.
[135]Particle Physics Department, Rutherford Appleton Laboratory, Didcot; United Kingdom.
[136]IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette; France.
[137]Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz CA; United States of America.
[138][(a)]Departamento de Física, Pontificia Universidad Católica de Chile, Santiago;[(b)]Millennium Institute for Subatomic physics at high energy frontier (SAPHIR), Santiago;[(c)]Instituto de Investigación Multidisciplinario en Ciencia y Tecnología, y Departamento de Física, Universidad de La Serena;[(d)]Universidad Andres Bello, Department of Physics, Santiago;[(e)]Universidad San Sebastian, Recoleta;[(f)]Instituto de Alta Investigación, Universidad de Tarapacá, Arica;[(g)]Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso; Chile.
[139]Department of Physics, Institute of Science, Tokyo; Japan.
[140]Department of Physics, University of Washington, Seattle WA; United States of America.
[141][(a)]State Key Laboratory of Dark Matter Physics, School of Physics and Astronomy, Shanghai Jiao Tong University, Key Laboratory for Particle Astrophysics and Cosmology (MOE), SKLPPC, Shanghai;[(b)]State Key Laboratory of Dark Matter Physics, Tsung-Dao Lee Institute, Shanghai Jiao Tong University, Shanghai; China.
[142]Department of Physics and Astronomy, University of Sheffield, Sheffield; United Kingdom.
[143]Department of Physics, Shinshu University, Nagano; Japan.
[144]Department Physik, Universität Siegen, Siegen; Germany.
[145]Department of Physics, Simon Fraser University, Burnaby BC; Canada.
[146]SLAC National Accelerator Laboratory, Stanford CA; United States of America.
[147]Department of Physics, Royal Institute of Technology, Stockholm; Sweden.
[148]Departments of Physics and Astronomy, Stony Brook University, Stony Brook NY; United States of America.
[149]Department of Physics and Astronomy, University of Sussex, Brighton; United Kingdom.
[150]School of Physics, University of Sydney, Sydney; Australia.
[151]Institute of Physics, Academia Sinica, Taipei; Taiwan.
[152][(a)]E. Andronikashvili Institute of Physics, Iv. Javakhishvili Tbilisi State University, Tbilisi;[(b)]High

Energy Physics Institute, Tbilisi State University, Tbilisi;[(c)]University of Georgia, Tbilisi; Georgia.
[153]Department of Physics, Technion, Israel Institute of Technology, Haifa; Israel.
[154]Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv; Israel.
[155]Department of Physics, Aristotle University of Thessaloniki, Thessaloniki; Greece.
[156]International Center for Elementary Particle Physics and Department of Physics, University of Tokyo, Tokyo; Japan.
[157]Graduate School of Science and Technology, Tokyo Metropolitan University, Tokyo; Japan.
[158]Department of Physics, University of Toronto, Toronto ON; Canada.
[159(a)]TRIUMF, Vancouver BC;[(b)]Department of Physics and Astronomy, York University, Toronto ON; Canada.
[160]Division of Physics and Tomonaga Center for the History of the Universe, Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba; Japan.
[161]Department of Physics and Astronomy, Tufts University, Medford MA; United States of America.
[162]Department of Physics and Astronomy, University of California Irvine, Irvine CA; United States of America.
[163]Department of Physics and Astronomy, University of Uppsala, Uppsala; Sweden.
[164]Department of Physics, University of Illinois, Urbana IL; United States of America.
[165]Instituto de Física Corpuscular (IFIC), Centro Mixto Universidad de Valencia - CSIC, Valencia; Spain.
[166]Department of Physics, University of British Columbia, Vancouver BC; Canada.
[167]Department of Physics and Astronomy, University of Victoria, Victoria BC; Canada.
[168]Fakultät für Physik und Astronomie, Julius-Maximilians-Universität Würzburg, Würzburg; Germany.
[169]Department of Physics, University of Warwick, Coventry; United Kingdom.
[170]Waseda University, Tokyo; Japan.
[171]Department of Particle Physics and Astrophysics, Weizmann Institute of Science, Rehovot; Israel.
[172]Department of Physics, University of Wisconsin, Madison WI; United States of America.
[173]Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal; Germany.
[174]Department of Physics, Yale University, New Haven CT; United States of America.
[175]Yerevan Physics Institute, Yerevan; Armenia.
[a] Also at Affiliated with an institute formerly covered by a cooperation agreement with CERN.
[b] Also at An-Najah National University, Nablus; Palestine.
[c] Also at Borough of Manhattan Community College, City University of New York, New York NY; United States of America.
[d] Also at Center for Interdisciplinary Research and Innovation (CIRI-AUTH), Thessaloniki; Greece.
[e] Also at Centre of Physics of the Universities of Minho and Porto (CF-UM-UP); Portugal.
[f] Also at CERN, Geneva; Switzerland.
[g] Also at Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève; Switzerland.
[h] Also at Departament de Fisica de la Universitat Autonoma de Barcelona, Barcelona; Spain.
[i] Also at Department of Financial and Management Engineering, University of the Aegean, Chios; Greece.
[j] Also at Department of Modern Physics and State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei; China.
[k] Also at Department of Physics, Ben Gurion University of the Negev, Beer Sheva; Israel.
[l] Also at Department of Physics, Bolu Abant Izzet Baysal University, Bolu; Türkiye.
[m] Also at Department of Physics, King's College London, London; United Kingdom.
[n] Also at Department of Physics, Stellenbosch University; South Africa.
[o] Also at Department of Physics, University of Fribourg, Fribourg; Switzerland.

[p] Also at Department of Physics, University of Thessaly; Greece.
[q] Also at Department of Physics, Westmont College, Santa Barbara; United States of America.
[r] Also at Faculty of Physics, Sofia University, 'St. Kliment Ohridski', Sofia; Bulgaria.
[s] Also at Faculty of Physics, University of Bucharest; Romania.
[t] Also at Hellenic Open University, Patras; Greece.
[u] Also at Henan University; China.
[v] Also at Imam Mohammad Ibn Saud Islamic University; Saudi Arabia.
[w] Also at Indian Institute of Technology (IIT), Jodhpur; India.
[x] Also at Institucio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona; Spain.
[y] Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg; Germany.
[z] Also at Institute for Nuclear Research and Nuclear Energy (INRNE) of the Bulgarian Academy of Sciences, Sofia; Bulgaria.
[aa] Also at Institute of Applied Physics, Mohammed VI Polytechnic University, Ben Guerir; Morocco.
[ab] Also at Institute of Particle Physics (IPP); Canada.
[ac] Also at Institute of Physics and Technology, Mongolian Academy of Sciences, Ulaanbaatar; Mongolia.
[ad] Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku; Azerbaijan.
[ae] Also at Institute of Theoretical Physics, Ilia State University, Tbilisi; Georgia.
[af] Also at Millennium Institute for Subatomic physics at high energy frontier (SAPHIR), Santiago; Chile.
[ag] Also at National Institute of Physics, University of the Philippines Diliman (Philippines); Philippines.
[ah] Also at School of Physics, University of the Witwatersrand, Johannesburg; South Africa.
[ai] Also at The Collaborative Innovation Center of Quantum Matter (CICQM), Beijing; China.
[aj] Also at TRIUMF, Vancouver BC; Canada.
[ak] Also at Università di Napoli Parthenope, Napoli; Italy.
[al] Also at Universita degli Studi Link; Italy.
[am] Also at University and INFN Torino, Torino; Italy.
[an] Also at University of Chinese Academy of Sciences (UCAS), Beijing; China.
[ao] Also at University of Colorado Boulder, Department of Physics, Colorado; United States of America.
[ap] Also at University of Siena; Italy.
[aq] Also at Washington College, Chestertown, MD; United States of America.
[ar] Also at Yeditepe University, Physics Department, Istanbul; Türkiye.
[*] Deceased