EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

Submitted to: Phys. Lett. B.

CERN-EP-2026-059
20th March 2026

A search for lepton-flavour violating $\tau \to 3\mu$ decays with the ATLAS detector

The ATLAS Collaboration

A search for charged lepton flavour violation in $\tau \to 3\mu$ decays is performed in pp collisions at a centre-of-mass energy of 13 TeV using ATLAS data collected between 2016 and 2018, corresponding to an integrated luminosity of 137 fb^{-1}. The search focuses on the electroweak $W \to \tau\nu$ production channel. Data are collected using two-muon and three-muon triggers and a multivariate analysis is used to separate the signal from the background. An unbinned likelihood fit is then performed to the resulting three-muon invariant mass spectrum and the data are found to be compatible with the background-only hypothesis. The observed (expected) limit on the branching ratio $B(\tau \to 3\mu)$ is found to be 8.7×10^{-8} (7.5×10^{-8}) at 90% CL.

Contents

1 Introduction

In the Standard Model (SM), flavour is not a fundamental symmetry and its violation is observed in both the neutrino [1] and quark sectors [2, 3]. It is therefore natural to question whether flavour conservation is violated for charged leptons. Although neutrino oscillations provide a route for charged Lepton Flavour Violation (cLFV) in the SM, the corresponding branching ratios ($\mathcal{B}$) are vanishingly small, of the order 10^{-55} [4]. Any observation of cLFV would therefore be unambiguous evidence of physics beyond the SM (BSM). Searches for cLFV have been carried out in the decays of both muons and τ-leptons, however, the most stringent limits on cLFV for the τ-lepton are currently about four orders of magnitude weaker than those for the muon decay channel [5, 6]. Theoretical arguments suggest that new physics effects would be stronger for the heavier τ-lepton [7]. Several BSM theoretical frameworks provide an enhancement to the rate of cLFV, with predicted τ-lepton flavour violating $\mathcal{B}$ of the order 10^{-9} [8–12], potentially detectable by current experiments.

This paper presents a new search for the cLFV process $\tau^{\pm} \rightarrow \mu^{\pm}\mu^{\mp}\mu^{\pm}$, henceforth referred to as $\tau \rightarrow 3\mu$. The most stringent limits on this process are obtained by the Belle II and LHCb experiments. The Belle-II experiment set an observed (expected) limit of 1.9×10^{-8} (1.8×10^{-8}) at 90% confidence level (CL) [6],[1] using 424 fb^{-1} of e^+e^- collision data with a centre-of-mass energy near the $\Upsilon(4S)$ resonance. Other stringent limits were set using e^+e^- collision data by the Belle experiment with an observed limit of 2.1×10^{-8} [13] using 782 fb^{-1} of data, and by the BaBar experiment with an observed (expected) limit of 3.3×10^{-8} (4.0×10^{-8}) [14] using 468 fb^{-1} of data. Using proton–proton (pp) collision data at the Large Hadron Collider (LHC) at $\sqrt{s}$ = 13 TeV, the LHCb experiment set an observed (expected) limit of 1.9×10^{-8} (2.0×10^{-8}) [15] using 5.4 fb^{-1} of data collected during Run 2, matching the previous most stringent observed limit. The CMS experiment set an observed (expected) limit of 2.9×10^{-8} (2.4×10^{-8}) [16] using 131 fb^{-1} of data collected during Run 2. The most recent analysis by the ATLAS experiment used 20.3 fb^{-1} of data collected during Run 1 at $\sqrt{s}$ = 8 TeV to set an observed (expected) limit of 37.6×10^{-8} (39.4×10^{-8}) [17].

[1] All limits are reported at 90% CL in line with previous results.

The search for $\tau \to 3\mu$ presented here uses 137 fb^{-1} of pp collision data at $\sqrt{s} = 13$ TeV collected from 2016–2018 by the ATLAS experiment. This is the first ATLAS search for this process using Run 2 data, and supersedes the previous result. At the LHC, τ-leptons are produced in large quantities either through the decays of heavy flavour hadrons, referred to as the heavy-flavour (HF) signal, or through the decays of W and Z bosons, including W bosons from top-quark decays, referred to as the electroweak (EW) signal. Although the HF signal, primarily composed of $D_s \to \tau\nu_\tau$ decays, dominates at the LHC, the τ-leptons produced by the EW signal have on average a larger transverse momentum and are better isolated from hadronic activity. A large fraction of the HF signal is not recorded by ATLAS due to trigger limitations, and the analysis is instead optimised for the dominant $W \to \tau\nu_\tau$ contribution. The statistical interpretation considers both the full EW and HF τ-lepton production mechanisms, which are henceforth referred to as the signal.

The signature of interest consists of three muons from a secondary vertex, with a three-muon invariant mass $m_{3\mu}$ consistent with the τ-lepton mass. The data were collected using multi-muon triggers. Candidate three-muon vertices are then reconstructed. Simulated signals and sideband data are used in a multivariate analysis (MVA) to classify events optimally in view of the small expected signal-to-background ratio. Both the signal and background are parameterised using functional forms in the $m_{3\mu}$ spectrum. A signal-plus-background fit is performed simultaneously in all fit categories, allowing the smooth background to be estimated from the data sidebands while searching for a resonant signal close to the τ-lepton mass.

2 ATLAS detector

The ATLAS experiment [18] at the LHC is a multipurpose particle detector with a forward–backward symmetric cylindrical geometry and a near 4π coverage in solid angle.[2] It consists of an inner tracking detector surrounded by a thin superconducting solenoid providing a 2 T axial magnetic field, electromagnetic and hadronic calorimeters, and a muon spectrometer.

The inner detector (ID) covers the pseudorapidity range $|\eta| < 2.5$. It consists of silicon pixel, silicon microstrip, and transition radiation tracking detectors, with the addition for Run 2 of an inner pixel layer known as the insertable B-layer (IBL). Lead/liquid-argon (LAr) sampling calorimeters provide electromagnetic (EM) energy measurements with high granularity within the region $|\eta| < 3.2$. A steel/scintillator-tile hadronic calorimeter covers the central pseudorapidity range ($|\eta| < 1.7$). The endcap and forward regions are instrumented with LAr calorimeters for EM and hadronic energy measurements up to $|\eta| = 4.9$.

The muon spectrometer (MS) surrounds the calorimeters and is based on three large superconducting air-core toroidal magnets with eight coils each. The field integral of the toroids ranges between 2.0 and 6.0 T m across most of the detector. The muon spectrometer includes a system of precision tracking chambers up to $|\eta| = 2.7$ and fast detectors for triggering up to $|\eta| = 2.4$.

The luminosity is measured mainly by the LUCID–2 [19] detector that is located close to the beampipe. A two-level trigger system was used to select events [20]. The first-level trigger is implemented in hardware

[2] 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 $\Delta R \equiv \sqrt{(\Delta y)^2 + (\Delta\phi)^2}$.

and used a subset of the detector information to accept events at a rate close to 100 kHz. This is followed by a software-based trigger that reduced the accepted rate of complete events to 1.25 kHz on average depending on the data-taking conditions.

A software suite [21] 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

The data were taken during pp collisions by ATLAS, during the years 2016–2018 of the Run 2 LHC data-taking period. This dataset corresponds to an integrated luminosity of 137 fb^{-1} [22] at $\sqrt{s}$ = 13 TeV. Only events recorded when LHC beams were stable and all ATLAS detector systems were operational are considered [23]. Data collected in 2015 with an additional luminosity of 3 fb^{-1} are omitted, as the dedicated triggers described in Section 5 were not yet fully operational.

For the EW signal, three sources of τ-lepton production are modelled: $W \to \tau\nu_\tau$, $Z \to \tau\tau$ and $t\bar{t} \to \tau X$. The Powheg Box MC event generator [24–28] was used to model these signal samples at next-to-leading order (NLO) in QCD. Events are interfaced with the Pythia 8.245 [29] generator to model the parton shower, hadronisation, underlying event, and particle decays. The $W \to \tau\nu_\tau$ and $Z \to \tau\tau$ samples used the AZNLO [30] set of tuned parameters (tune) and the CT10nlo PDF set [31] for the hard-scattering processes, whereas the CTEQ6L1 PDF set [32] was used for the parton shower. Top-quark pair-production with at least one τ-lepton in the decay ($t\bar{t} \to \tau X$) used the A14 [33] tune with the NNPDF3.0nlo [34] PDF set for the hard scattering process and the NNPDF2.3lo [35] PDF set for the parton shower. These simulated samples are normalised to W, Z and $t\bar{t}$ production cross-sections as measured in ATLAS data for $\sqrt{s}$ = 13 TeV [36, 37]. Given the current stringent experimental limits on $B(\tau \to 3\mu) < 10^{-7}$, only one of the τ-leptons is allowed to decay into three muons for the Z and $t\bar{t}$ samples. At production level, the W production mode provides 83% of all τ-leptons in the EW signal, followed by the Z production mode (16%) with only minor contributions from the $t\bar{t}$ production mode (1%).

Three HF signal modes of τ-lepton production are modelled: D_s mesons decaying to τ-leptons, with the D_s either being produced directly (prompt) or through B-meson decays (non-prompt); and direct B-meson to τ-lepton decays. The Pythia 8 generator was used to create these signal samples at leading-order QCD with the A14 tune and NNPDF2.3lo PDFs. Decays of heavy-flavour hadrons and τ-leptons are performed by EvtGen [38]. The D_s samples are normalised to the production cross-section (σ = 5000 ± 360 (stat) ± 590 (syst) nb) measured by ATLAS [39] at $\sqrt{s}$ = 13 TeV with a branching ratio of $B(D_s \to \tau\nu_\tau)$ = 5.4 ± 0.1% [40]. The prompt and non-prompt contributions to D_s production are predicted in simulation to be 80% and 20%, respectively, although the exact value for this fraction was not found to make a significant difference to the analysis. The direct B-meson sample was scaled relative to the total D_s sample using a value of 48% based on Monte Carlo simulation. Furthermore, the branching ratio $B(B \to \tau X)$ = 3.4 ± 0.4% [41] is taken into account in the normalization of this sample.

The $\tau \to 3\mu$ decays are modelled isotropically with the kinematics of the decay products determined via phase space without polarisation or spin effects taken into account, as there are multiple possible new physics scenarios with different spin correlations. This is a standard benchmark setting also used in previous analyses [6, 15, 16].

All the generated events are passed through the simulation of the ATLAS detector based on Geant4 [42, 43] and reconstructed with the same algorithms as used for data. The effect of multiple interactions in the same and neighbouring bunch crossings (pile-up) was modelled by overlaying the simulated hard-scattering event with inelastic pp events generated with PYTHIA 8.186 [44] using the NNPDF2.3LO PDF set [35] and the A3 tune [45]. The simulated events are weighted to reproduce the distribution of pile-up observed in the data.

4 Object reconstruction

Muons are reconstructed from hits in both the ID and MS sub-detectors, with the track parameters determined using the combined information [46]. Muons must have a transverse momentum (p_{T}) greater than 4 GeV, and $|\eta| \leq 2.4$. They must also satisfy the "Loose" identification criteria [46].

To form a three-muon decay candidate, referred to as a triplet, all events containing at least three muons with a total charge of $Q = \pm 1$ are selected. These muons must share the same interaction origin point. Due to the relatively long lifetime of the τ-lepton, this interaction vertex may be displaced on average from the primary vertex (PV), resulting in a secondary vertex (SV). The SV is determined using the muon track parameters and uncertainties to find the optimal intersection point of the three tracks by minimising the χ^2 of the fit [47]. If multiple SV candidates are found for the same event, the candidate is used that has the smallest impact parameter of the muon-triplet momentum with respect to the PV (a_0). The muon-triplet momentum is calculated as the vector sum of the individual muon momenta. Tracks determined to originate from a SV are refitted with respect to this vertex and the PV is refitted excluding the tracks associated with the SV. The triplet direction is defined as the vector between the PV and SV.

Hadronic jets are reconstructed using the anti-k_t algorithm [48] as implemented in FastJet [49] with a jet radius parameter $R = 0.4$. The inputs to this algorithm are particle flow objects [50], which combine measurements from the ATLAS inner detector and calorimeters. Only tracks matched to the PV are used to mitigate pile-up effects. The jets are calibrated to the electromagnetic scale [50], with their axis corrected to point back to the PV. Jets are corrected for pile-up contributions, energy loss in uninstrumented parts of the detector and data-to-MC differences. Any jet within $\Delta R = 0.2$ of a muon, or matched with the inner-detector track of a muon using ghost association [51], is removed if it has fewer than three associated tracks.

The missing transverse momentum ($\vec{p}_{\mathrm{T}}^{\mathrm{miss}}$) (with magnitude $E_{\mathrm{T}}^{\mathrm{miss}}$) [52] is calculated as the negative vector sum of the transverse momenta for muons, jets, and additional contributions. These additional contributions may be calculated either using ID tracks associated with a vertex but not matched to a jet or muon or using unmatched clusters of energy in the calorimeter. The missing transverse momentum calculated using these contributions is referred to as $\vec{p}_{\mathrm{T}}^{\mathrm{track-miss}}$ and $\vec{p}_{\mathrm{T}}^{\mathrm{calo-miss}}$, respectively.

All reconstructed simulated objects have their reconstruction and selection efficiencies and their energy/momentum scale and resolution corrected to data.

5 Trigger and event selection

The data were collected with several two- and three-muon triggers, with small variations between the three years of data taking. In each year, a trigger requiring one muon in the first-level trigger system with $p_{\mathrm{T}} \geq 20$ GeV and a second muon in the software-based higher-level trigger system with $p_{\mathrm{T}} \geq 6$ GeV provides the highest efficiency for signal candidates with at least one high-momentum muon. The intermediate momentum range is covered by triggers that require two muons in the first-level trigger system with $p_{\mathrm{T}} \geq 10\,\mathrm{GeV}$ for 2016 data, while in 2017 and 2018 a trigger with $p_{\mathrm{T}} \geq 11\,\mathrm{GeV}$ and $p_{\mathrm{T}} \geq 6\,\mathrm{GeV}$ for the leading and subleading muon provides better efficiency. Finally, a trigger requiring three muons in the first-level trigger system with $p_{\mathrm{T}} \geq 4\,\mathrm{GeV}$ provides a lower threshold on muon momenta to maximize the signal acceptance for all years.

A particular challenge for the trigger system are close-by muons from the decays of high-momentum τ-leptons that result in overlapping muon trigger regions of interest, reducing the total trigger efficiency [53]. The simulated signal trigger efficiency is corrected via a data-driven method where the multi-muon trigger efficiency is calculated as product of individual muon trigger efficiencies as a function of p_{T} and $q \times \eta$ (where q is the muon charge), and correction factors as a function of ΔR. These individual trigger efficiencies and correction factors are measured in data from $J/\psi \to \mu\mu$ events using a tag-and-probe method [53]. The nominal results are obtained with the corrected trigger efficiencies and the full difference to the uncorrected trigger efficiencies is applied as a systematic uncertainty.

The analysis considers events in an extended three-muon mass range around the τ-lepton mass, $1500\,\mathrm{MeV} < m_{3\mu} < 2000\,\mathrm{MeV}$, which is the region used for fits. All analysis steps are initially completed by excluding the range $1700\,\mathrm{MeV} < m_{3\mu} < 1850\,\mathrm{MeV}$ that would contain 95% of the signal, which is referred to as the signal region. The sidebands are used to model the background, composed primarily of random combinations of one or two muons with additional tracks that are misidentified as belonging to muons. This approach to background modelling was used, as simulations are unreliable for modelling combinatorial background and would require an extremely large sample size.

The analysis is optimised to be sensitive to very small signal-to-background ratios. By comparing expected signal and sideband background distributions, loose preselections are applied to remove background-dominated regions while leaving plenty of events to train an MVA classifier later. To reject poor quality SVs, the SV χ^2 must be less than 40 and the transverse SV impact parameter (a_0^{xy}) of the triplet divided by its uncertainty ($\sigma_{a_0^{\mathrm{xy}}}$) is required to be $a_0^{\mathrm{xy}}/\sigma_{a_0^{\mathrm{xy}}} < 6$. Triplet candidates with significant close-by activity in the calorimeters are removed with a selection on the sum of transverse energy (E_{T}) of energy clusters within a cone of $\Delta R = 0.2$ around the triplet four-momentum [46], $E_{\mathrm{T}}^{\mathrm{iso}}(\Delta R = 0.2) < 20\,\mathrm{GeV}$. Similarly, triplet candidates are required to be isolated from tracks in the ID, excluding those associated with the muon triplet, by limiting the scalar sum of the p_{T} of ID tracks to $p_{\mathrm{T}}^{\mathrm{iso}}/p_{\mathrm{T}}^{\mathrm{triplet}} < 1.0$, where $p_{\mathrm{T}}^{\mathrm{iso}}$ is calculated as a sum over tracks within $\Delta R = \min(0.3, 10\mathrm{GeV}/p_{\mathrm{T}}^{\mathrm{triplet}})$ of the triplet four-momentum for muons with $p_{\mathrm{T}} < 50\,\mathrm{GeV}$, and $\Delta R = 0.2$ otherwise. Selections are also applied to the refitted di-muon invariant mass for each two-muon combination within the triplet (both same-sign and opposite-sign charge), $m_{\mu\mu} > 325\,\mathrm{MeV}$, to reject muons produced from final state radiation photon conversions and low-mass background. After the preselection $960,000$ events remain in the background sidebands.

Another minor source of background is from muon pairs produced in the decay of $\omega(782)$ and $\phi(1020)$ mesons combined with a third muon, or a track misidentified as belonging to a muon, to create an SV mistaken for signal. Events containing an oppositely charged muon combination with a di-muon invariant mass within 34 MeV of these meson masses [40] are removed.

The signal-to-background ratio is improved further using a gradient boosted decision tree (BDT), implemented using XGBoost [54]. After the application of the preselection, both the simulated EW signal events and aforementioned background events from the sidebands in real data are split into two equal halves (based on odd and even event numbers) and used to train two BDTs, which are then subsequently used to classify the events in the other sample. This splitting method is a version of the k-fold method with $k = 2$ [55], and aims to reduce the bias of the BDT. The values of the BDT hyperparameters are determined to

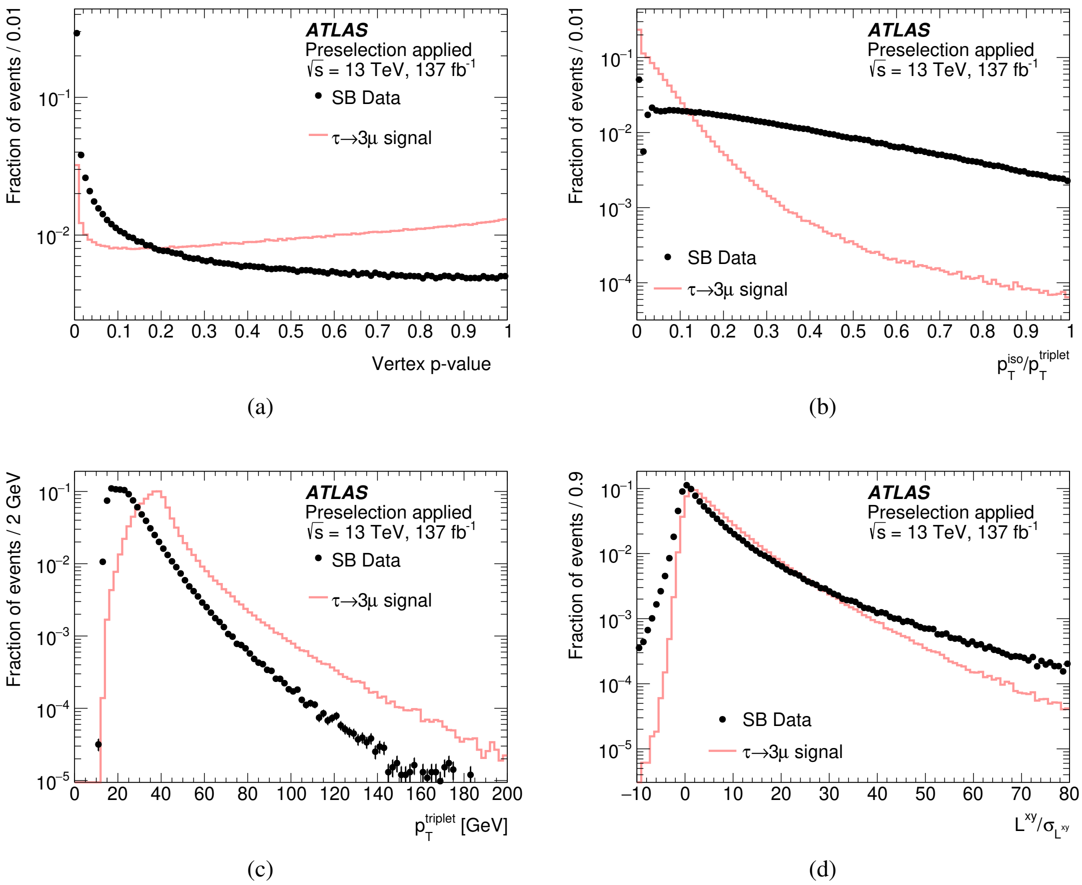

Figure 1: Distributions of representative example variables used in the BDT event classification: (a) vertex quality p-value, (b) muon isolation $p_{\mathrm{T}}^{\mathrm{iso}}/p_{\mathrm{T}}^{\mathrm{triplet}}$, (c) triplet p_{T}, $p_{\mathrm{T}}^{\mathrm{triplet}}$ and (d) significance of the transverse distance between the PV and SV $L^{\mathrm{xy}}/\sigma_{L^{\mathrm{xy}}}$. The plots show both the EW $\tau \to 3\mu$ signal sample (histogram) and data from the sidebands (SB Data) (markers) after the preselection cuts. All distributions are normalised to unit area.

optimise the model accuracy: a maximum BDT depth of 8 is used; the minimum child weight, a measure of sample size at each node, is set to 3; and the hyperparameter η, related to the amount the tree weights are adjusted at each iteration, is set to 1. At each stage of node evaluation, 80% of the data, randomly chosen, are used, to prevent over-training. The other hyperparameters are set to their default values, and the logistic loss function [54] is used.

The BDT uses 18 input variables related to the vertex quality, muon isolation, muon triplet kinematics, and correlations between the muon triplet and $E_{\mathrm{T}}^{\mathrm{miss}}$. All variables are defined in Table 1, with representative examples shown in Figure 1. The variables are selected to ensure the BDT cannot reconstruct the triplet mass and sculpt the mass distribution. Certain variables, such as $m_{3\mu}^{\mathrm{miss}}$ and $\Delta m_{3\mu}$, were initially optimised for τ-leptons from HF decays. However, as they are found to not compromise the BDT performance, they are kept. While many of the input features contribute to the discrimination power of the BDT, the most important variables are $\Delta\phi(\mathrm{triplet}, E_{\mathrm{T}}^{\mathrm{calo\text{-}miss}})$, $a_0^{xy}/\sigma_{a_0^{xy}}$ and $p_{\mathrm{T}}^{\mathrm{triplet}}$.

The resulting BDT score distributions for simulated signal events and background events from the data sidebands are shown in Figure 2. Good discrimination between signal and background events is observed;

Table 1: List of input variables used in the BDT and their definitions.

Variable	Description
Vertex quality	
Track p-value product	Product of the three muons refitted ID track p-values from the track fit.
$\chi^2_{\text{4-track}}$	χ^2-value of the SV with 4 ID tracks instead of the usual 3. This variable helps identify events where the triplet contains muons from independent vertices with further charged particles.
Vertex p-value	The p-value associated with the triplet vertex from the SV fit.
Muon isolation	
$E_{\text{T}}^{\text{iso}}(\Delta R = 0.2)$	Muon calorimeter isolation with $\Delta R = 0.2$.
$E_{\text{T}}^{\text{iso}}(\Delta R = 0.4)$	Muon calorimeter isolation with $\Delta R = 0.4$.
$p_{\text{T}}^{\text{iso}}/p_{\text{T}}^{\text{triplet}}$	Muon track isolation with $\Delta R = 0.2$ divided by the triplet p_{T}.
Triplet related quantities	
$a_0^{xy}/\sigma_{a_0^{xy}}$	Triplet transverse SV IP significance.
$L^{xy}/\sigma_{L^{xy}}$	Significance of the distance in the transverse plane from the PV to the SV projected onto the direction of the vertex candidate's transverse momentum.
$\Delta\phi(\text{triplet}, \vec{p}_{\text{T}}^{\text{track-miss}})$	Azimuthal angle between the triplet and the track-based $E_{\text{T}}^{\text{miss}}$ calculation.
$\Delta\phi(\text{triplet}, \vec{p}_{\text{T}}^{\text{calo-miss}})$	Azimuthal angle between the triplet and the calorimeter-based $E_{\text{T}}^{\text{miss}}$ calculation.
$p_{\text{T}}^{\text{triplet}}$	Transverse momentum of the vector sum of the refitted muon momenta
η_{triplet}	η of the refitted SV of the triplet.
$m_{\text{coll-jet}}$	Invariant mass of the closest jet reconstructed within $\Delta R \leq 0.4$ to the muon triplet.
$\left\vert\vec{p}_{\text{T}}^{\text{triplet}} - \vec{p}_{\text{T}}^{\text{jet}}\right\vert$	Momentum balance between the triplet candidate and the leading p_{T} hadronic jet, if a jet is reconstructed.
$\left\vert\sum_{\text{PV}} \vec{p}_{\text{T}}^{\text{track}}\right\vert$	Modulus of the vector sum of the p_{T} of all tracks with $p_{\text{T}} > 1$ GeV associated with the PV of the triplet.
$m_{\text{T}}^{\text{track}}$	The transverse mass of the triplet, calculated using the triplet p_{T} and the track-based $E_{\text{T}}^{\text{miss}}$: $m_{\text{T}}^{\text{track}} = \sqrt{2E_{\text{T}}^{\text{track-miss}} p_{\text{T}}^{\text{triplet}}(1 - \cos(\Delta\phi(\text{triplet}, E_{T}^{\text{track-miss}})))}$.
$m_{3\mu}^{\text{miss}}$	A measure of the missing energy at the point of the initially decaying particle $m_{3\mu}^{\text{miss}} = \sqrt{m_{\text{I}}^2 + m_{3\mu}^2 - 2E_{\text{I}}E_{\text{triplet}} + 2p_{\text{I}}p_{\text{triplet}}\cos(\Delta\alpha_{S-P})}$. This variable was optimised for the HF signal from a D_s decay, so it uses $m_{\text{I}} = m_{3\mu} + m_{D_s} - m_{\tau}$, where E_{I} is the total energy at the PV, $\vec{p}_I = \frac{m_{\text{I}}}{m_{3\mu}} p_{\text{triplet}}\hat{S}$ is the scaled momentum of the initially decaying particle with magnitude p_{I}, p_{triplet} is the total momentum of the muons triplet, $\hat{S}$ is the unit vector pointing from the PV to SV, and $\Delta\alpha_{S-P}$ is the angle between $p_{\vec{\text{triplet}}}$ and $\hat{S}$.
$\Delta m_{3\mu}$	A measure of the maximum possible missing energy at the point of the initially decaying particle, effectively the invariant mass of the initially decaying particle, minus the mass of the triplet: $\Delta m_{3\mu} = \sqrt{2(p_{\text{T}}^{\text{triplet}}\sin(\Delta\alpha_{S-P}))^2 + m_{3\mu}^2} - m_{3\mu}$.

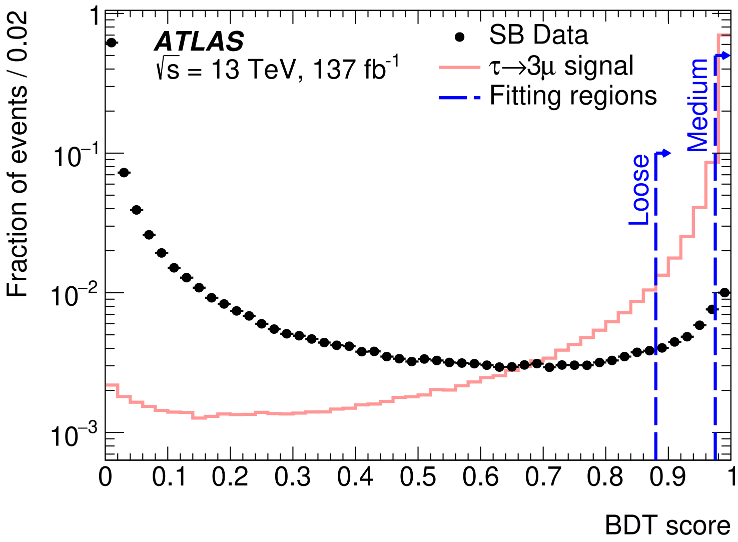

Figure 2: BDT score distribution for the EW $\tau \to 3\mu$ signal sample (histogram), and background from sideband data (SB Data) (markers). All distributions are normalised to unit area, and the error bars are too small to be visible. The vertical lines mark the boundaries of the loose (0.88 <BDT≤ 0.975) and medium (0.975 <BDT≤ 0.998) BDT bins used for the event categorisation. The tight boundary (0.998 <BDT) is not shown as it is indistinguishable from the vertical axis.

Table 2: Number of events in each fit category. The top two lines (EW and HF signal) correspond to the expected signal for $B(\tau \to 3\mu) = 1 \times 10^{-7}$, while in the lower two lines the fitted background contributions and the observed data events in the signal region (1700 MeV < $m_{3\mu}$ < 1850 MeV) are listed.

	Events in fit category					
BDT category	Loose		Medium		Tight	
Source	Barrel	Endcap	Barrel	Endcap	Barrel	Endcap
EW signal	1.0	2.0	3.2	5.8	2.5	5.3
HF signal	1.0	2.4	0.6	1.4	0.1	0.2
Background in signal region	191.9	275.8	88.0	135.6	3.4	6.4
Signal region data	209	291	86	141	5	5

additionally no significant over-training was found.

Events are split into different categories to optimise the sensitivity based on the BDT output score and different $m_{3\mu}$ detector resolutions. Events in the barrel, defined as $|\eta_{\text{triplet}}| < 1.2$, are found to have a signal mass resolution of approximately 25 MeV, significantly better than the resolution, about 34 MeV, for the remainder of the events that are assigned to the endcap category. Therefore, barrel and endcap events are separated. To find the optimal BDT categories, the expected limit on $B(\tau \to 3\mu)$ is determined for a range of different BDT categories by performing a simultaneous unbinned maximum-likelihood fit on the $m_{3\mu}$ distribution in all fit categories. The optimal limit is achieved using three BDT categories, referred to as loose, medium and tight, as indicated on Figure 2. Table 2 shows the expected and observed signal and background yields in all six categories.

The simulated signals are parameterised separately in each category with a double sided Crystal Ball (DSCB) function [56, 57], which models the signal $m_{3\mu}$ distribution well. The background $m_{3\mu}$ shape is

Table 3: Signal normalisation uncertainties from different systematic variations for the six fit categories. Only effects with a magnitude of at least 1% in at least one category are reported. The effect of each systematic variation is treated as correlated between categories. Systematic effects shown with different signs refer to migration effects that lead to anti-correlations between the yields of different categories. Further global signal normalisation effects are discussed in the text.

	Systematic signal uncertainty [%]					
BDT category	Loose		Medium		Tight	
Systematic uncertainty	Barrel	Endcap	Barrel	Endcap	Barrel	Endcap
Trigger efficiency	±26.7	±10.1	±20.9	±9.1	±16.2	±11.4
Muon reconstruction efficiency	±3.7	±3.5	±3.4	±3.2	±2.9	±3.0
$E_{\mathrm{T}}^{\mathrm{miss}}$ track resolution	±1.9	±1.1	±0.8	±1.2	∓2.4	∓2.3
Jet energy scale	±5.0	±3.3	±0.9	±0.4	∓5.1	∓3.2
Pile-up	±1.5	±1.5	< 0.1	< 0.1	∓1.8	∓1.4

parameterised by a smooth function, chosen as an exponential, with the exponent allowed to be positive or negative. This is determined to be a suitable model in two ways. First, it is tested if the background model is able to describe the data sidebands. Second, signal-plus-background fits are performed to signal-depleted regions of low BDT score, defined as the point below which less than 10% of the signal would be retained. The measured signal yield in this region, known as the spurious signal [58], is found to be suitable following the criteria in Ref.[59] for the chosen functional form.

6 Systematic uncertainties

The analysis is found to be limited by the statistical uncertainty of the dataset. Experimental systematic uncertainties apply to the simulated signal, as the background is determined directly from the data. Further cross-checks on the impact of the choice of background parameterisation are reported at the end of this Section, including a dedicated systematic uncertainty.

The main source of systematic uncertainty is from the trigger efficiency, determined as described in Section 5. Additional uncertainties are also considered for: the muon reconstruction efficiency as determined in $J/\psi \to \mu\mu$ and $Z \to \mu\mu$ events using a tag-and-probe method [46]; the jet energy scale [60]; the resolution of the $E_{\mathrm{T}}^{\mathrm{miss}}$ [52]; and the level of pile-up [61]. These effects vary in size between the fit categories and correlations are considered. The effect on the signal normalisation for each category is shown in Table 3. Other systematic variations are found to have an effect of less than 1% and are neglected.

Further sources of systematic uncertainties have a global effect on the normalisation. The uncertainty in the integrated luminosity is 0.84% [22], obtained using the LUCID-2 detector [19] for the primary luminosity measurements, complemented by measurements using the inner detector and calorimeters. The uncertainty on the EW signal cross-section is conservatively taken as the maximum fractional uncertainty in the $W \to \ell\nu$, $Z \to \ell\ell$ and $t\bar{t}$ cross-section measurements [36, 37], which is 3.0%. For the HF signal, the uncertainty in the D_s inclusive production cross-section [39] of 14% is used along with a 1.9% uncertainty in the $B(D_s \to \tau\nu_\tau)$ [40] and a 12% uncertainty in the $B(B \to \tau X)$ [41]. The impact of further simulation modelling uncertainties are expected to be negligible and are not considered.

The effect of the systematic uncertainties in the signal shape is also considered, with the muon momentum calibration [62] being the only variation having an effect. The muon momentum scale uncertainty has a maximum effect on the mean of the signal DSCB of 0.1% in the barrel and 0.3% in the endcap. The momentum resolution has a maximum effect on the width of the signal DSCB of 3.2% (0.8%) in the barrel and 1.6% (3.3%) in the endcap for the ID (MS) contribution.

The impact of a different choice of background parameterisation on the number of background events has been investigated by replacing the nominal exponential function by a second-order polynomial or a power law. The different functions resulted in a maximum 5% change in the number of extracted background events, well within the statistical uncertainty on the background extraction. Constraining the background to be constant or falling with increasing $m_{3\mu}$ results in no systematic change in the number of background events. Although the magnitude of the spurious signal uncertainty is found to be suitable following the criteria in Ref. [59] for the chosen functional form, a systematic uncertainty to account for possible residual mismodelling effects is applied. The spurious signal yield, in the signal-depleted region mentioned previously, is scaled for each of the fit categories and treated as an uncorrelated systematic uncertainty. This background parameterisation uncertainty only has a small impact on the final results.

7 Results

To find evidence for the decay of $\tau \to 3\mu$ or to set a limit on the branching ratio, a simultaneous unbinned maximum-likelihood fit is performed on the $m_{3\mu}$ distribution in all six fit categories. The sum of EW and HF signals are parameterised in each category separately with a DSCB, while the background is parameterised with an exponential function. The systematic uncertainties as discussed in Section 6 are implemented as nuisance parameters in the fit. For these fits, $B(\tau \to 3\mu)$ is varied as the parameter of interest, and the profile likelihood test statistic in the asymptotic approximation [63] is used. Injection tests with signals in the range of $B(\tau \to 3\mu) = 10^{-8}$–$10^{-6}$ are performed to verify that the fit is unbiased.

Figure 3 shows the background-only fit and the expected signal, for $B(\tau \to 3\mu) = 1 \times 10^{-6}$, in the unblinded $m_{3\mu}$ spectra. No significant signal is observed and the best-fit signal strength value is $B(\tau \to 3\mu) = (1.5 \pm 4.0) \times 10^{-8}$. An upper limit is set using the CL_s method [64]. The observed (expected) upper limit is found to be $B(\tau \to 3\mu) < 8.7\times10^{-8}$ (7.5×10^{-8}) at 90% CL. The upper limit is also calculated at 95% CL, resulting in an observed (expected) upper limit of 10.6×10^{-8} (9.3×10^{-8}). The CL_s limit scan is shown in Figure 4. The small difference between the observed and expected limits is due to upward data fluctuations in four out of six categories, as shown in Table 2.

Using pseudo experiments to calculate the limit instead of the asymptotic approximation is found to have a negligible impact on the limits obtained: the observed limit improves by 1%, while the expected limit worsens by 3%. Excluding all systematic uncertainties results in an improvement to the expected limit by 4.4%, with the trigger efficiency systematic uncertainty having the largest contribution of 2.1%, followed by the spurious signal systematic uncertainty contribution of 1.8%.

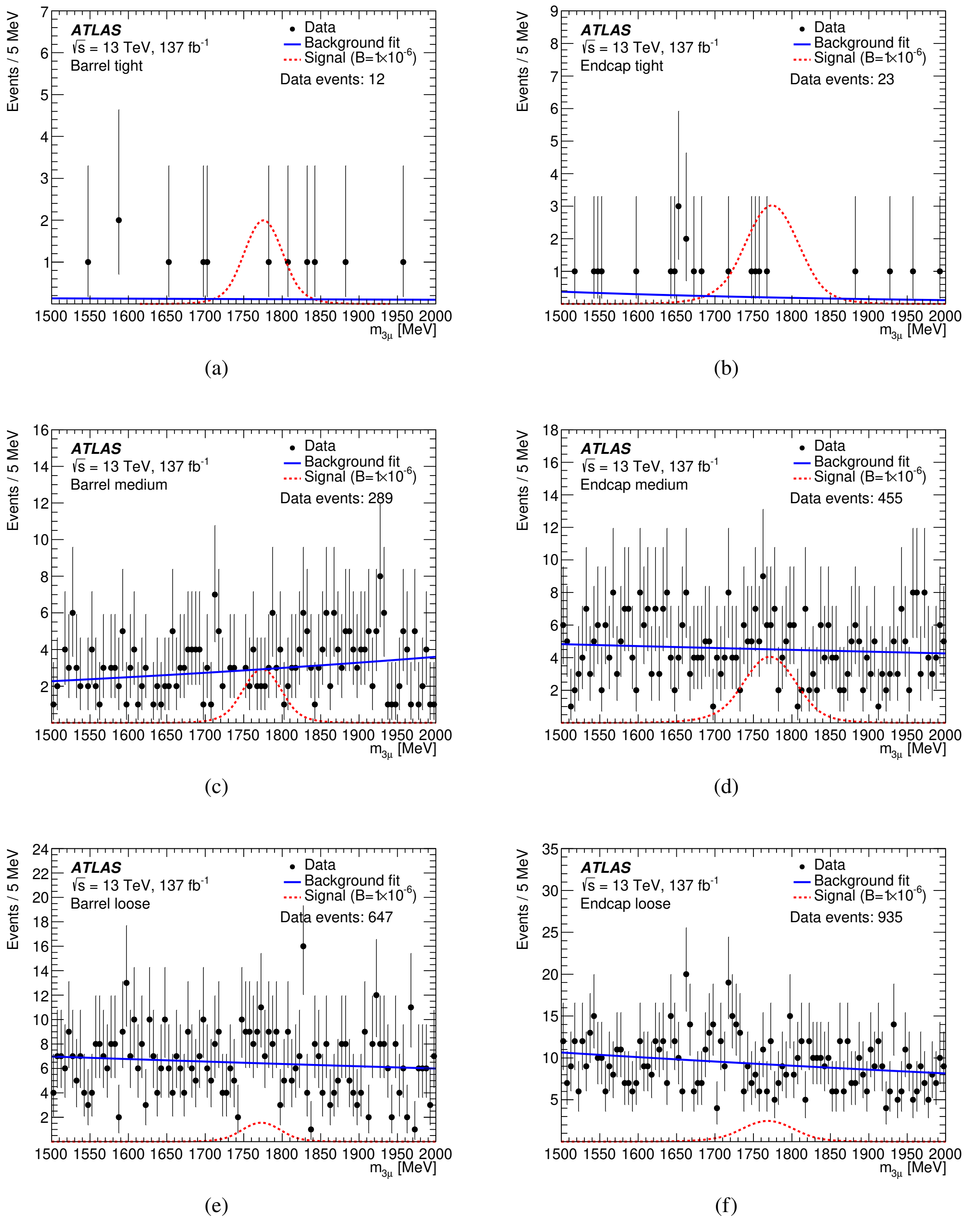

Figure 3: The $m_{3\mu}$ in data (markers), background-only fit (solid line) and expected EW plus HF signal, for $B(\tau \to 3\mu) = 1 \times 10^{-6}$ as an illustration (dotted line) in the (a,c,e) barrel and (b,d,f) endcap categories for the (a,b) tight, (c,d) medium and (e,f) loose BDT categories.

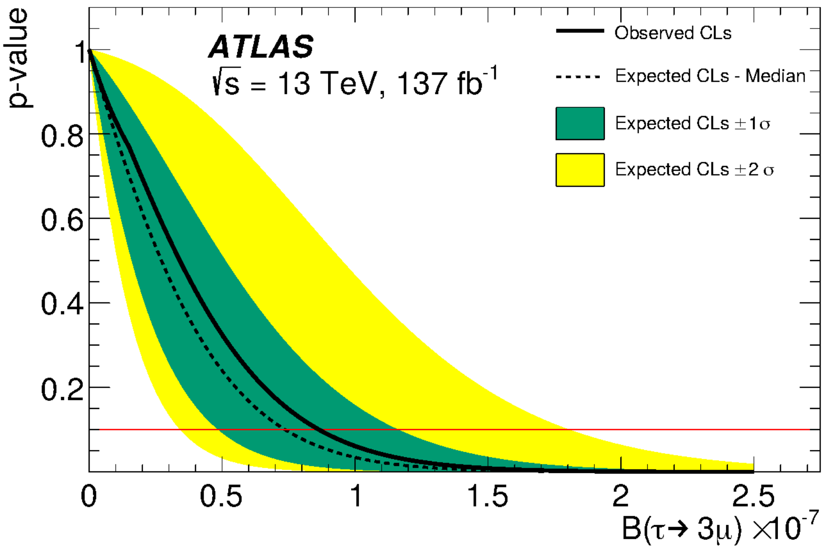

Figure 4: $B(\tau \to 3\mu)$ limit scan showing the expected limit (dotted line), $\pm 1(2)\sigma$ error bands (green and yellow), and the observed limit using the CL_s method (solid line). A p-value of 0.1 (90% CL) is shown by the horizontal line.

8 Conclusion

This paper presents a search for the cLFV process $\tau \to 3\mu$, using 137 fb^{-1} of pp collision data collected by the ATLAS experiment during Run 2 of the Large Hadron Collider at $\sqrt{s} = 13$ TeV. The analysis is optimised using MVA analysis techniques for electroweak sources, but also considers τ-lepton production from heavy-flavour sources. No evidence for $\tau \to 3\mu$ decays is found and observed (expected) limits are set on $B(\tau \to 3\mu) < 8.7\times10^{-8} (7.5\times10^{-8})$ at 90% CL. This result improves upon the previous ATLAS Run 1 limit by a factor of 5, where a factor of 3 is expected solely from the larger production cross-sections at the increased centre-of-mass energy and larger integrated luminosity. The additional improvement is attributed to detector improvements such as the new IBL detector, improved machine learning methods, and more efficient triggers. The analysis is limited by statistical uncertainties and thus improvements in sensitivity are expected with the analysis of additional data.

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. [65].

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 and NSFC, 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: 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 - 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: Ministero dell'Università e della Ricerca (NextGenEU 153D23001490006 M4C2.1.1, NextGenEU I53D23000820006 M4C2.1.1, NextGenEU I53D23001490006 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 JP25K01023); Norway: Research Council of Norway (RCN-314472); 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 (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] Super-Kamiokande Collaboration, *Atmospheric neutrino oscillation analysis with external constraints in Super-Kamiokande I-IV*, Phys. Rev. D **97** (2018) 072001, arXiv: 1710.09126.

[2] N. Cabibbo, *Unitary Symmetry and Leptonic Decays*, Phys. Rev. Lett. **10** (12 1963) 531, URL: https://cds.cern.ch/record/344106.

[3] M. Kobayashi and T. Maskawa, *CP-Violation in the Renormalizable Theory of Weak Interaction*, Progress of Theoretical Physics **49** (1973) 652.

[4] G. Hernández-Tomé, G. López Castro and P. Roig, *Flavor violating leptonic decays of τ and μ leptons in the Standard Model with massive neutrinos*, Eur. Phys. J. C **79** (2019) 84, arXiv: 1807.06050 [hep-ph], Erratum: Eur. Phys. J. C **80** (2020) 438.

[5] MEG II Collaboration, *A search for $\mu^+ \to e^+\gamma$ with the first dataset of the MEG II experiment*, Eur. Phys. J. C **84** (2024) 216, arXiv: 2310.12614 [hep-ex], Erratum: Eur. Phys. J. C **84** (2024) 1042.

[6] Belle II Collaboration, *Search for lepton-flavor-violating $\tau^- \to \mu^-\mu^+\mu^-$ decays at Belle II*, JHEP **09** (2024) 062, arXiv: 2405.07386 [hep-ex].

[7] A. de Gouvêa and P. Vogel, *Lepton Flavor and Number Conservation, and Physics Beyond the Standard Model*, Prog. Part. Nucl. Phys. **71** (2013) 75, arXiv: 1303.4097 [hep-ph].

[8] D. N. Dinh, A. Ibarra, E. Molinaro and S. T. Petcov, *The $\mu - e$ conversion in nuclei, $\mu \to e\gamma, \mu \to 3e$ decays and TeV scale see-saw scenarios of neutrino mass generation*, JHEP **08** (2012) 125, arXiv: 1205.4671 [hep-ph], Erratum: JHEP **09** (2013) 23.

[9] R. Alonso, M. Dhen, M. B. Gavela and T. Hambye, *Muon conversion to electron in nuclei in type-I seesaw models*, JHEP **01** (2013) 118, arXiv: 1209.2679 [hep-ph].

[10] F. Feruglio, P. Paradisi and A. Pattori, *On the Importance of Electroweak Corrections for B Anomalies*, JHEP **09** (2017) 061, arXiv: 1705.00929 [hep-ph].

[11] Y. Kajiyama, *Lepton flavor violating tau decay by R-parity violation in a family symmetry*, Soryushiron Kenkyu Electron. **116** (2008) A164, arXiv: 0711.0286 [hep-ph].

[12] P. Athron et al., *Likelihood analysis of the flavour anomalies and $g - 2$ in the general two Higgs doublet model*, JHEP **01** (2022) 037, arXiv: 2111.10464 [hep-ph].

[13] Belle Collaboration, *Search for lepton-flavor-violating τ decays into three leptons with 719 million produced $\tau^+\tau^-$ pairs*, Phys. Lett. B **687** (2010) 139, arXiv: 1001.3221 [hep-ex].

[14] BaBar Collaboration, *Limits on τ lepton-flavor violating decays into three charged leptons*, Phys. Rev. D **81** (2010) 111101, arXiv: 1002.4550 [hep-ex].

[15] LHCb Collaboration, *Search for $\tau^- \to \mu^-\mu^+\mu^-$ decays at the LHCb experiment with Run 2 data*, (2026), arXiv: 2601.20785 [hep-ex].

[16] CMS Collaboration,
Search for the lepton flavor violating $\tau \to 3\mu$ decay in proton–proton collisions at $\sqrt{s} = 13$ TeV,
Phys. Lett. B **853** (2024) 138633, arXiv: 2312.02371 [hep-ex].

[17] ATLAS Collaboration,
Probing lepton flavour violation via neutrinoless $\tau \to 3\mu$ decays with the ATLAS detector,
Eur. Phys. J. C **76** (2016) 232, arXiv: 1601.03567 [hep-ex].

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

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

[20] ATLAS Collaboration, *Performance of the ATLAS trigger system in 2015*,
Eur. Phys. J. C **77** (2017) 317, arXiv: 1611.09661 [hep-ex].

[21] 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.

[22] ATLAS Collaboration,
Luminosity determination in pp collisions at $\sqrt{s} = 13$ TeV using the ATLAS detector at the LHC,
Eur. Phys. J. C **83** (2023) 982, arXiv: 2212.09379 [hep-ex].

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

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

[25] 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].

[26] 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].

[27] S. Alioli, P. Nason, C. Oleari and E. Re,
NLO vector-boson production matched with shower in POWHEG, JHEP **07** (2008) 060,
arXiv: 0805.4802 [hep-ph].

[28] S. Frixione, G. Ridolfi and P. Nason,
A positive-weight next-to-leading-order Monte Carlo for heavy flavour hadroproduction,
JHEP **09** (2007) 126, arXiv: 0707.3088 [hep-ph].

[29] T. Sjöstrand et al., *An introduction to PYTHIA 8.2*, Comput. Phys. Commun. **191** (2015) 159,
arXiv: 1410.3012 [hep-ph].

[30] ATLAS Collaboration, *Measurement of the Z/γ^* boson transverse momentum distribution in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector*, JHEP **09** (2014) 145,
arXiv: 1406.3660 [hep-ex].

[31] H.-L. Lai et al., *New parton distributions for collider physics*, Phys. Rev. D **82** (2010) 074024,
arXiv: 1007.2241 [hep-ph].

[32] J. Pumplin et al.,
New Generation of Parton Distributions with Uncertainties from Global QCD Analysis,
JHEP **07** (2002) 012, arXiv: hep-ph/0201195.

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

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

[36] ATLAS Collaboration, *Precise measurements of W- and Z-boson transverse momentum spectra with the ATLAS detector using pp collisions at $\sqrt{s}$ = 5.02 TeV and 13 TeV*,
Eur. Phys. J. C **84** (2024) 1126, arXiv: 2404.06204 [hep-ex].

[37] ATLAS Collaboration, *Inclusive and differential cross-sections for dilepton $t\bar{t}$ production measured in $\sqrt{s}$ = 13 TeV pp collisions with the ATLAS detector*, JHEP **07** (2023) 141,
arXiv: 2303.15340 [hep-ex].

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

[39] ATLAS Collaboration, *Differential cross-section measurements of $D^{\pm}$ and $D_s^{\pm}$ meson production in proton–proton collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector*, JHEP **07** (2025) 086,
arXiv: 2412.15742 [hep-ex].

[40] Particle Data Group, P. Zyla et al., *Review of Particle Physics*,
Prog. Theor. Exp. Phys. **2020** (2020) 083C01.

[41] CMS Collaboration,
Search for the lepton flavor violating decay $\tau \to 3\mu$ in proton–proton collisions at $\sqrt{s}$ = 13 TeV,
JHEP **01** (2021) 163, arXiv: 2007.05658 [hep-ex].

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

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

[44] T. Sjöstrand, S. Mrenna and P. Skands, *A brief introduction to PYTHIA 8.1*,
Comput. Phys. Commun. **178** (2008) 852, arXiv: 0710.3820 [hep-ph].

[45] 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.

[46] 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].

[47] V. Kostyukhin, *VKalVrt - package for vertex reconstruction in ATLAS*, ATL-PHYS-2003-031, 2003,
URL: http://cds.cern.ch/record/685551.

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

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

[50] 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].

[51] M. Cacciari and G. P. Salam, *Pileup subtraction using jet areas*, Phys. Lett. B **659** (2008) 119, arXiv: 0707.1378 [hep-ph].

[52] ATLAS Collaboration, *The performance of missing transverse momentum reconstruction and its significance with the ATLAS detector using 140 fb^{-1} of $\sqrt{s} = 13$ TeV pp collisions*,
Eur. Phys. J. C **85** (2025) 606, arXiv: 2402.05858 [hep-ex].

[53] ATLAS Collaboration, *Performance of the ATLAS muon triggers in Run 2*,
JINST **15** (2020) P09015, arXiv: 2004.13447 [physics.ins-det].

[54] T. Chen and C. Guestrin, *XGBoost: A Scalable Tree Boosting System*, Proceedings of the 22nd ACM SIGKDD International Conference on Knowledge Discovery and Data Mining (2016).

[55] Y. Coadou, *Boosted decision trees*, (2022), arXiv: 2206.09645 [physics.data-an].

[56] M. Oreglia, *A Study of the Reactions $\psi' \to \gamma\gamma\psi$*, SLAC-R-0236 (1980),
URL: www.slac.stanford.edu/cgi-wrap/getdoc/slac-r-236.pdf.

[57] ATLAS Collaboration, *Search for Scalar Diphoton Resonances in the Mass Range 65–600 GeV with the ATLAS Detector in pp Collision Data at $\sqrt{s} = 8$ TeV*, Phys. Rev. Lett. **113** (2014) 171801, arXiv: 1407.6583 [hep-ex].

[58] ATLAS Collaboration, *Measurement of Higgs boson production in the diphoton decay channel in pp collisions at center-of-mass energies of 7 and 8 TeV with the ATLAS detector*,
Phys. Rev. D **90** (2014) 112015, arXiv: 1408.7084 [hep-ex].

[59] ATLAS Collaboration, *Recommendations for the Modeling of Smooth Backgrounds*,
ATL-PHYS-PUB-2020-028, 2020, URL: https://cds.cern.ch/record/2743717.

[60] 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].

[61] ATLAS Collaboration, *Measurement of the Inelastic Proton–Proton Cross Section at $\sqrt{s} = 13$ TeV with the ATLAS Detector at the LHC*, Phys. Rev. Lett. **117** (2016) 182002,
arXiv: 1606.02625 [hep-ex].

[62] 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].

[63] G. Cowan, K. Cranmer, E. Gross and O. Vitells,
Asymptotic formulae for likelihood-based tests of new physics, Eur. Phys. J. C **71** (2011) 1554, arXiv: 1007.1727 [physics.data-an], Erratum: Eur. Phys. J. C **73** (2013) 2501.

[64] A. L. Read, *Presentation of search results: the CL_s technique*, J. Phys. G **28** (2002) 2693.

[65] 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[122], S. Abdelhameed[118a], K. Abeling[54], N.J. Abicht[48], S.H. Abidi[30], M. Aboelela[44], A. Aboulhorma[36e], H. Abramowicz[155], B.S. Acharya[68a,68b,m], A. Ackermann[62a], C. Adam Bourdarios[4], L. Adamczyk[85a], S.V. Addepalli[147], M.J. Addison[101], J. Adelman[117], A. Adiguzel[22c], T. Adye[136], A.A. Affolder[138], 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[166], X. Ai[113c], G. Aielli[75a,75b], A. Aikot[166], M. Ait Tamlihat[36e], T.P.A. Åkesson[98], D. Akiyama[171], N.N. Akolkar[25], S. Aktas[169], G.L. Alberghi[24b], J. Albert[168], U. Alberti[20], P. Albicocco[52], S. Alderweireldt[51], Z.L. Alegria[123], M. Aleksa[37], I.N. Aleksandrov[38], C. Alexa[28b], T. Alexopoulos[10], F. Alfonsi[24b], M. Algren[55], M. Alhroob[170], B. Ali[134], 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[150], D.R. Allen[123], J.S. Allen[101], J.F. Allen[51], C.S. Alley[1], E.R. Almazan[138], A. Aloisio[71a,71b], F. Alonso[90], C. Alpigiani[141], 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[129], B. Amini[53], K. Amirie[159], A. Amirkhanov[38], D. Amperiadou[156], S. An[82], C. Anastopoulos[143], 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[149], M. Antonelli[52], F. Anulli[74a], M. Aoki[82], T. Aoki[157], M.A. Aparo[13], L. Aperio Bella[47], M. Apicella[31], C. Appelt[155], A. Apyan[27], M. Arampatzi[10], S.J. Arbiol Val[86], C. Arcangeletti[52], A.T.H. Arce[50], J-F. Arguin[108], S. Argyropoulos[156], J.-H. Arling[47], O. Arnaez[4], H. Arnold[149], G. Artoni[74a,74b], H. Asada[111], S. Asatryan[176], N.A. Asbah[37], R.A. Ashby Pickering[170], A.M. Aslam[95], J. Assahsah[36d], K. Assamagan[30], R. Astalos[29a], K.S.V. Astrand[98], S. Atashi[163], R.J. Atkin[34a], H. Atmani[36f], P.A. Atmasiddha[130], K. Augsten[134], A.D. Auriol[40], V.A. Austrup[101], A.S. Avad[94], G. Avolio[37], A. Azzam[13], D. Babal[29b], H. Bachacou[137], K. Bachas[156,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[125], L. Baines[94], O.K. Baker[175], D. Bakshi Gupta[8], L.E. Balabram Filho[81b], V. Balakrishnan[122], R. Balasubramanian[4], P. Balek[85a], E. Ballabene[24b,24a], F. Balli[137], L.M. Baltes[62a], W.K. Balunas[128], I. Bamwidhi[118b], E. Banas[86], M. Bandieramonte[131], A. Bandyopadhyay[25], S. Bansal[25], L. Barak[155], 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[147], P. Baron[135], D.A. Baron Moreno[101], A. Baroncelli[61], A.J. Barr[128], J.D. Barr[96], F. Barreiro[99], J. Barreiro Guimarães da Costa[14], M.G. Barros Teixeira[132a], F. Bartels[62a], R. Bartoldus[147], A.E. Barton[91], P. Bartos[29a], M. Baselga[48], S. Bashiri[86], A. Bassalat[65,b], M.J. Basso[160a], S. Bataju[44], R. Bate[167], R.L. Bates[58], S. Batlamous[99], M. Battaglia[138], D. Battulga[19], M. Bauce[74a,74b], L. Bauckhage[47], P. Bauer[25], L.T. Bayer[47], L.T. Bazzano Hurrell[31], T. Beau[129], J.Y. Beaucamp[90], S. Beauceron[129], P.H. Beauchemin[162], P. Bechtle[25], H.P. Beck[20,o], K. Becker[170], A.J. Beddall[80], V.A. Bednyakov[38], C.P. Bee[149], L.J. Beemster[16], M. Begalli[81d], M. Begel[30], J.K. Behr[47], J.F. Beirer[37], F. Beisiegel[25], M. Belfkir[118b], G. Bella[155], L. Bellagamba[24b], A. Bellerive[35], C.D. Bellgraph[67], P. Bellos[21], I. Benaoumeur[21], D. Benchekroun[36a], F. Bendebba[36a], Y. Benhammou[155], K.C. Benkendorfer[168], L. Beresford[47], M. Beretta[52], E. Bergeaas Kuutmann[164], N. Berger[4], B. Bergmann[134], J. Beringer[18a], M. Berkat[137], G. Bernardi[5], C. Bernius[147], F.U. Bernlochner[25], A. Berrocal Guardia[13], T. Berry[95], P. Berta[135], A. Berti[132a],

R. Bertrand [102], S. Bethke [110], A. Betti [74a,74b], T.F. Beumker [174], A.J. Bevan [94], L. Bezio [55], N.K. Bhalla [53], S. Bharthuar [110], S. Bhatta [149], P. Bhattarai [147], Z.M. Bhatti [119], K.D. Bhide [53], V.S. Bhopatkar [123], R.M. Bianchi [131], 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 [174], A. Bingul [22b], C. Bini [74a,74b], G.A. Bird [33], M. Biros [135], S. Biryukov [150], T. Bisanz [48], E. Bisceglie [24b,24a], J.P. Biswal [136], D. Biswas [145], 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 [169], D. Bogavac [13], L.S. Boggia [129], V. Boisvert [95], P. Bokan [164], T. Bold [85a], M. Bomben [5], M. Bona [94], M. Boonekamp [137], A.G. Borbély [58], G. Borissov [91], A. Borkar [169], D. Bortoletto [128], D. Boscherini [24b], M. Bosman [13], K. Bouaouda [36a], L. Boudet [137], J. Boudreau [131], E.V. Bouhova-Thacker [91], D. Boumediene [40], R. Bouquet [56b,56a], A. Boveia [121], D. Boye [30], I.R. Boyko [38], L. Bozianu [55], J. Bracinik [21], N. Brahimi [4], G. Brandt [174], O. Brandt [33], B. Brau [103], R. Brener [172], L. Brenner [116], R. Brenner [164], S. Bressler [172], M. Brettell [96], G. Brianti [116], D. Britton [58], D. Britzger [110], I. Brock [25], R. Brock [107], H. Bronson[130], G. Brooijmans [41], A.J. Brooks[67], E.M. Brooks [160b], E. Brost [30], L.M. Brown [168,160a], L.E. Bruce [60], T.L. Bruckler [128], 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 [141], D. Buchin [110], A.G. Buckley [58], J. Bucko [135], M. Buhring [49], O. Bulekov [80], B.A. Bullard [147], T.O. Buratovich [90], S. Burdin [92], C.D. Burgard [48], A.M. Burger [89], B. Burghgrave [8], O. Burlayenko [53], J. Burleson [165], J.C. Burzynski [122], 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 [136], C.J. Buxo Vazquez [107], A.R. Buzykaev [38], S. Cabrera Urbán [166], L. Cadamuro [65], H. Cai [37], Y. Cai [24b,112c,24a], Y. Cai [112a], M.A. Cairo[130], V.M.M. Cairo [37], O. Cakir [3a], N. Calace [37], P. Calafiura [18a], G. Calderini [129], P. Calfayan [35], L. Calic [98], G. Callea [58], L.P. Caloba[81b], D. Calvet [40], S. Calvet [40], R. Camacho Toro [129], 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 [166], 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 [131,q], E.M. Carlson [168], L. Carminati [70a,70b], A. Carnelli [4], M. Carnesale [37], S. Caron [115], E. Carquin [139g], I.B. Carr [105], S. Carrá [72a,72b], G. Carratta [24b,24a], C. Carrion Martinez [166], A.M. Carroll [125], 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], L. Castillo Garcia [13], V. Castillo Gimenez [166], N.F. Castro [132a,132e], A. Catinaccio [37], J.R. Catmore [127], T. Cavaliere [4], V. Cavaliere [30], E. Celebi [80], S. Cella [30], V. Cepaitis [55], K. Cerny [124], 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], P.M. Chabrillat [129], R. Chakkappai [65], S. Chakraborty [170], A. Chambers [60], J. Chan [18a], J.D. Chapman [33], E. Chapon [137], B. Chargeishvili [153b], D.G. Charlton [21], C. Chauhan [133], Y. Che [112a], S. Chekanov [6], G.A. Chelkov [38,a], H. Chen [30], J. Chen [142a], J. Chen [146], M. Chen [59], S. Chen [87], S.J. Chen [112a], X. Chen [142a], X. Chen [15,ai], Z. Chen [61], C.L. Cheng [173], H.C. Cheng [63a], S. Cheong [147], A. Cheplakov [38], E. Cherepanova [116], E. Cheu [7], K. Cheung [64], L. Chevalier [137], G. Chiarelli [73a], G. Chiodini [69a], A.S. Chisholm [21], J.L. Chisholm [167], A. Chitan [28b], M. Chitishvili [166], M.V. Chizhov [38,r], K. Choi [11], Y. Chou [141], E.Y.S. Chow [115], G. Christou [51], K.L. Chu [172], M.C. Chu [63a], Z. Chubinidze [52], J. Chudoba [133], J.J. Chwastowski [86], D. Cieri [110], K.M. Ciesla [85a], V. Cindro [93], A. Ciocio [18a], F. Cirotto [71a,71b], Z.H. Citron [172], M. Citterio [70a], D.A. Ciubotaru[28b], A. Clark [55], P.J. Clark [51], N. Clarke Hall [96], C. Clarry [159], 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 [141], R.F. Coelho Barrue [132a], R. Coelho Lopes De Sa [103], S. Coelli [70a], M.M. Cohen [130], L.S. Colangeli [159], B. Cole [41], P. Collado Soto [99], J. Collot [59], M.R. Coluccia [69a], I. Combes[65], P. Conde Muiño [132a,132g], L.H.J. Condren [163], M.P. Connell [34c], S.H. Connell [34c], E.I. Conroy [128], M. Contreras Cossio [11], F. Conventi [71a,ak], A.M. Cooper-Sarkar [128], L. Corazzina [74a,74b], F.A. Corchia [24b,24a], A. Cordeiro Oudot Choi [141], L.D. Corpe [40], M. Corradi [74a,74b], F. Corriveau [104,ab], A. Cortes-Gonzalez [157], M.J. Costa [166], F. Costanza [4], D. Costanzo [143], J. Couthures [4], G. Cowan [95], K. Cranmer [173], L. Cremer [48], D. Cremonini [24b,24a], S. Crépé-Renaudin [59], F. Crescioli [129], T. Cresta [72a,72b], M. Cristinziani [145], M. Cristoforetti [77a,77b], T.M. Critchley [55], E. Critelli [96], A. Cueto [99], H. Cui [96], Z. Cui [7], B.M. Cunnett [150], W.R. Cunningham [58], E. Cuppini[110], F. Curcio [166], 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 [152], 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 [146], V. Dao [149], G. Darbo [56b], F. Dattola [47], S. D'Auria [70a,70b], A. D'Avanzo [71a,71b], T. Davidek [135], J. Davidson [170], I. Dawson [94], K. De [8], C. De Almeida Rossi [159], 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 [150], 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 [137], 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 [175], M. Demichev [38], H. Denizli [22a,l], M.G. Depala [92], L. D'Eramo [40], D. Derendarz [86], L. Derin [56b,56a], F. Derue [129], 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 [139a,139b], A.R. Didenko [38], M. Didenko [166], S.D. Diefenbacher [18a], E.B. Diehl [106], S. Díez Cornell [47], C. Diez Pardos [145], C. Dimitriadi [148], A. Dimitrievska [21], A. Dimri [149], Y. Ding[61], J. Dingfelder [25], T. Dingley [128], I-M. Dinu [28b], S.J. Dittmeier [62b], F. Dittus [37], M. Divisek [135], B. Dixit [92], F. Djama [102], T. Djobava [153b], C. Doglioni [101,98], A. Dohnalova [29a], Z. Dolezal [135], 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 [136], A. Doria [71a], N. Dos Santos Fernandes [132a], I.A. Dos Santos Luz [81e], P. Dougan [44], M.T. Dova [90], A.T. Doyle [58], M.P. Drescher [54], E. Dreyer [172], I. Drivas-koulouris [10], M. Drnevich [119], 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 [172], 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 [153b], G.I. Dyckes [18a], M. Dyndal [85a], B.S. Dziedzic [37], G.H. Eberwein [128], B. Eckerova [29a], J.C. Egan [96], S. Eggebrecht [54], E. Egidio Purcino De Souza [81e], G. Eigen [17], K. Einsweiler [18a], T. Ekelof [164], P.A. Ekman [98], S. El Farkh [36b], Y. El Ghazali [61], H. El Jarrari [104], A. El Moussaouy [36a], I. Elbaz [155], D. Elitez [37], M. Ellert [164], F. Ellinghaus [174], T.A. Elliot [95], J. Elmsheuser [30], M. Elsawy [118a], M. Elsing [37], D. Emeliyanov [136], Y. Enari [82], S. Epari [108], D. Ernani Martins Neto [86], F. Ernst[37], M. Escalier [65], C. Escobar [166], R. Estevam De Paula [81c], E. Etzion [155], G. Evans [132a,132b], H. Evans [67], L.S. Evans [47], S. Ezzarqtouni [36a], F. Fabbri [24b,24a], L. Fabbri [24b,24a], G. Facini [96], V. Fadeyev [138], D. Fakoudis [100], S. Falciano [74a], L.F. Falda Ulhoa Coelho [27], F. Fallavollita [110],

G. Falsetti [43b,43a], J. Faltova [135], C. Fan [165], 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 [152], J.N. Farr [175], M.S. Farrington [60], S.M. Farrington [136,51], F. Fassi [36e], D. Fassouliotis [9], L. Fayard [65], G. Fazzino [62b], P. Federic [135], P. Federicova [133], M. Feickert [173], 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 [164], 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 [134], S. Filimonov [38], M.S. Filip [28b,s], A. Filipčič [93], E.K. Filmer [160a], F. Filthaut [115], M.C.N. Fiolhais [132a,132c,c], L. Fiorini [166], W.C. Fisher [107], T. Fitschen [101], I. Fleck [145], P. Fleischmann [106], T. Flick [174], M. Flores [34d,ag], L.R. Flores Castillo [63a], M. Foll [127], F.M. Follega [77a,77b], N. Fomin [33], J.H. Foo [159], A. Formica [137], M. Fornasiero [150], 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 [155], N. Fritzsche [37], A. Froch [55], D. Froidevaux [37], J.A. Frost [136], Y. Fu [107], S. Fuenzalida Garrido [139g], Y.C. Fujikake [138], M. Fujimoto [149], K.Y. Fung [63a], E. Furtado De Simas Filho [81e], M. Furukawa [157], M. Fuste Costa [47], J. Fuster [166], A. Gaa [54], A. Gabrielli [24b,24a], A. Gabrielli [159], G. Gagliardi [56b,56a], L.G. Gagnon [18a], S. Galantzan [155], J. Gallagher [1], E.J. Gallas [128], A.L. Gallen [164], B.J. Gallop [136], K.K. Gan [121], Y. Gao [51], Z. Gao [112a], A. Garabaglu [141], F.M. Garay Walls [139a,139b], C. García [166], A. Garcia Alonso [116], A.G. Garcia Caffaro [175], J.E. García Navarro [166], M.A. Garcia Ruiz [23b], M. Garcia-Sciveres [18a], G.L. Gardner [130], R.W. Gardner [39], N. Garelli [162], R.B. Garg [147], J.M. Gargan [33], C.A. Garner[159], C.M. Garvey [34a], V.K. Gassmann[162], G. Gaudio [72a], A.J. Gavin [94], J. Gavranovic [93], I.L. Gavrilenko [132a], C. Gay [167], G. Gaycken [125], A. Gekow[121], C. Gemme [56b], M.H. Genest [59], A.D. Gentry [114], S. George [95], T. Geralis [45], A.A. Gerwin [122], P. Gessinger-Befurt [37], M. Ghani [170], K. Ghorbanian [94], A. Ghosal [145], A. Ghosh [163], 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 [137], G. Giugliarelli [68a,68c], D. Giugni [70a], F. Giuli [75a,75b,al], I. Gkialas [9,i], C. Glasman [99], M. Glazewska [20], R.M. Gleason [163], 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 [141], J.P. Gombas [107], A. Gomes [132a,132b], G. Gomes Da Silva [145], A.J. Gomez Delegido [37], R. Gonçalo [132a], A. Gongadze [153c], F. Gonnella [21], J.L. Gonski [147], R.Y. González Andana [51], S. González de la Hoz [166], M.V. Gonzalez Rodrigues [47], R. Gonzalez Suarez [164], S. Gonzalez-Sevilla [55], L. Goossens [37], B. Gorini [37], E. Gorini [69a,69b], A. Gorišek [93], T.C. Gosart [130], A.T. Goshaw [50], M.I. Gostkin [38], S. Goswami [123], C.A. Gottardo [37], S.A. Gotz [109], M. Gouighri [36b], A.G. Goussiou [141], N. Govender [34c], R.P. Grabarczyk [128], I. Grabowska-Bold [85a], K. Graham [35], E. Gramstad [127], 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 [163], P. Grenier [147], S.G. Grewe[110], K. Grimm [32], S. Grinstein [13,x], E. Gross [172], J. Grosse-Knetter [54], L.H. Grossman [18b], L. Guan [106], G. Guerrieri [37], R. Guevara [127], R. Gugel [100], J.A.M. Guhit [106], A. Guida [19], E. Guilloton [170], S. Guindon [37], F. Guo [14,112c], J. Guo [142a], L. Guo [47], L. Guo [112b,u], Y. Guo [106], Y. Guo [41], A. Gupta [48], R. Gupta [131], S. Gupta [27], S. Gurbuz [25], S.S. Gurdasani [47], G. Gustavino [74a,74b], P. Gutierrez [122], L.F. Gutierrez Zagazeta [130], M. Gutsche [49], C. Gutschow [96], W. Guérin [89], C. Gwenlan [128], C.B. Gwilliam [92], E.S. Haaland [127], A. Haas [119], M. Habedank [58], C. Haber [18a], R.J. Haberle[172], H.K. Hadavand[8], A. Haddad[40], A. Hadef[49], A.I. Hagan[91], J.J. Hahn[145], M. Haleem[169], J. Haley[123], G.D. Hallewell[102], J.A. Hallford[47], K. Hamano[168], H. Hamdaoui[164], 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[138], D.A. Hangal[41], H. Hanif[146], M.D. Hank[130], J.B. Hansen[42], P.H. Hansen[42], T. Harenberg[174], S. Harkusha[176], M.L. Harris[103], Y.T. Harris[25], J. Harrison[13], P.F. Harrison[170], M.L.E. Hart[96], N.M. Hartman[110], N.M. Hartmann[109], R.Z. Hasan[95,136], Y. Hasegawa[144], D. Hashimoto[111], F. Haslbeck[37], S. Hassan[127], R. Hauser[107], M. Haviernik[135], C.M. Hawkes[21], R.J. Hawkings[37], Y. Hayashi[157], D. Hayden[107], R.L. Hayes[116], C.P. Hays[128], 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[125], L. Heinrich[110], J. Hejbal[133], M. Helbig[49], A. Held[173], S. Hellesund[17], C.M. Helling[167], F.N.E. Henry[58], H. Herde[98], Y. Hernández Jiménez[149], G. Herten[53], R. Hertenberger[109], L. Hervas[37], M.E. Hesping[100], N.P. Hessey[160a], J. Hessler[110], R. Hicks[130], M. Hidaoui[36b], N. Hidic[135], E. Hill[159], T.S. Hillersoy[17], S.J. Hillier[21], J.R. Hinds[107], F. Hinterkeuser[25], M. Hirose[126], S. Hirose[161], D. Hirschbuehl[174], B. Hiti[93], J. Hobbs[149], R. Hobincu[28e], N. Hod[172], A.M. Hodges[165], M.C. Hodgkinson[143], B.H. Hodkinson[128], A. Hoecker[37], D.D. Hofer[106], J. Hofer[166], J. Hofner[100], M. Holzbock[37], L.B.A.H. Hommels[33], V. Homsak[128], J.J. Hong[67], T.M. Hong[131], B.H. Hooberman[165], W.H. Hopkins[6], M.C. Hoppesch[165], Y. Horii[111], M.E. Horstmann[110], M.M. Horzela[54], S. Hou[152], M.R. Housenga[165], J. Howarth[58], J. Hoya[6], M. Hrabovsky[124], T. Hryn'ova[4], P.J. Hsu[64], S.-C. Hsu[141], T. Hsu[65], M. Hu[18a], P. Hu[63b], Q. Hu[61], S. Huang[33], X. Huang[14,112c], Y. Huang[135], Y. Huang[112b], Y. Huang[14], Z. Huang[65], Z. Hubacek[134], F. Huegging[25], T.B. Huffman[128], 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[157], T. Iizawa[157], Y. Ikegami[82], D. Iliadis[156], N. Ilic[159], H. Imam[36a], G. Inacio Goncalves[81d], S.A. Infante Cabanas[139c], 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[157], W. Islam[173], C. Issever[19], S. Istin[22a,ar], K. Itabashi[126], H. Ito[171], R. Iuppa[77a,77b], A. Ivina[172], F. Ivone[37], S. Izumiyama[111], V. Izzo[71a], P. Jacka[134], P. Jackson[1], P.R. Jacobson[50], P. Jain[47], K. Jakobs[53], J. Jamieson[58], W. Jang[157], S. Jankovych[116], B.K. Jashal[136], M. Javurkova[103], P. Jawahar[101], L. Jeanty[125], J. Jejelava[153a,ae], P. Jenni[53,f], L. Jerala[93], C.E. Jessiman[35], H. Jia[167], J. Jia[149], X. Jia[110,112c], C. Jiang[51], Q. Jiang[63b], S. Jiggins[47], M. Jimenez Ortega[166], J. Jimenez Pena[13], S. Jin[112a], A. Jinaru[28b], O. Jinnouchi[140], P. Johansson[143], K.A. Johns[7], J.W. Johnson[138], F.A. Jolly[47], D.M. Jones[150], E. Jones[47], K.S. Jones[8], P. Jones[33], R.W.L. Jones[91], T.J. Jones[92], H.L. Joos[37], R. Joshi[121], J. Jovicevic[16], X. Ju[18a], J.J. Junggeburth[37], T. Junkermann[62a], A. Juste Rozas[13,x], M.K. Juzek[86], S. Kabana[139f], A. Kaczmarska[86], S.A. Kadir[147], M. Kado[110], H. Kagan[121], M. Kagan[147], A. Kahn[130], C. Kahra[100], T. Kaji[157], E. Kajomovitz[154], N. Kakati[172], 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[91,153b], E. Kasimi[156], J. Katzy[47], S. Kaur[35], R. Kavak[165], K. Kawade[144], M.P. Kawale[122], C. Kawamoto[87], E.F. Kay[37], S. Kazakos[107], K. Kazakova[102], J.M. Keaveney[34a], R. Keeler[168], G.V. Kehris[60], J.S. Keller[35], J.M. Kelly[168], J.J. Kempster[150], O. Kepka[133], J. Kerr[160b], B.P. Kerridge[136], B.P. Kerševan[93], L. Keszeghova[29a], R.A. Khan[131],

A. Khanov[123], M. Kholodenko[132a], T.J. Khoo[19], G. Khoriauli[169], Y. Khoulaki[36a], Y.A.R. Khwaira[129], D. Kim[6], D.W. Kim[18b], Y.K. Kim[39], N. Kimura[96], M.K. Kingston[54], F. Kirfel[25], J. Kirk[136], A.E. Kiryunin[110], S. Kita[161], O. Kivernyk[25], M. Klassen[162], C. Klein[35], L. Klein[169], 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[159], A. Knue[48], M. Kobel[49], D. Kobylianskii[172], S.F. Koch[37], M. Kocian[147], P. Kodyš[135], D.M. Koeck[125], T. Koffas[35], K. Kojima[82], O. Kolay[49], I. Koletsou[4], T. Komarek[86], S. Kondo[157], K. Köneke[54], A.X.Y. Kong[1], T. Kono[120], N. Konstantinidis[96], P. Kontaxakis[55], B. Konya[98], R. Kopeliansky[41], S. Koperny[85a], R. Koppenhofer[53], K. Korcyl[86], K. Kordas[156,d], A. Korn[96], S. Korn[54], I. Korolkov[13], B. Kortman[116], O. Kortner[110], S. Kortner[110], W.H. Kostecka[117], M. Kostov[29a], V.V. Kostyukhin[145], A. Kotsokechagia[37], A. Kotwal[50], A. Koulouris[37], A. Kourkoumeli-Charalampidi[72a,72b], O. Kovanda[125], R. Kowalewski[168], W. Kozanecki[125], G. Kramberger[93], P. Kramer[25], A. Krasznahorkay[103], A.C. Kraus[117], J.W. Kraus[174], J.A. Kremer[47], N.B. Krengel[145], T. Kresse[159], L. Kretschmann[174], J. Kretzschmar[92], P. Krieger[159], K. Krizka[21], K. Kroeninger[48], H. Kroha[110], J. Kroll[133], J. Kroll[130], K.S. Krowpman[107], U. Kruchonak[38], H. Krüger[25], N. Krumnack[79], J. Krupa[147], 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[139d,139b], J. Kull[1], E.V. Kumar[109], M. Kumar[34j], N. Kumari[47], P. Kumari[160b], A. Kupco[133], O. Kuprash[53], H. Kurashige[84], L.L. Kurchaninov[160a], O. Kurdysh[4], M. Kuze[140], A.K. Kvam[103], J. Kvita[124], N.G. Kyriacou[141], M. Laassiri[30], C. Lacasta[166], H. Lacker[19], D. Lacour[129], E. Ladygin[38], A. Lafarge[40], B. Laforge[129], T. Lagouri[175], F.Z. Lahbabi[36a], S. Lai[54], W.S. Lai[96], I.K. Lakomiec[54], J.E. Lambert[168], S. Lammers[67], W. Lampl[7], C. Lampoudis[156], G. Lamprinoudis[169], A.N. Lancaster[117], U. Landgraf[53], M.P.J. Landon[94], V.S. Lang[53], A.J. Lankford[163], F. Lanni[37], C.S. Lantz[165], K. Lantzsch[25], A. Lanza[72a], M. Lanzac Berrocal[166], T. Lari[70a], D. Larsen[17], L. Larson[11], F. Lasagni Manghi[24b], M. Lassnig[37], H.C. Lau[168], S.D. Lawlor[143], R. Lazaridou[163], M. Lazzaroni[70a,70b], E.T.T. Le[163], H.D.M. Le[107], E.M. Le Boulicaut[175], L.T. Le Pottier[18a], B. Leban[24b,24a], F. Ledroit-Guillon[59], T.F. Lee[160b], L.L. Leeuw[34h], M. Lefebvre[168], C. Leggett[18a], L.M. Lehmann[116], G. Lehmann Miotto[37], M. Leigh[55], W.A. Leight[103], W. Leinonen[115], A. Leisos[156,t], M.A.L. Leite[81c], C.E. Leitgeb[19], R. Leitner[135], K.J.C. Leney[44], T. Lenz[25], S. Leone[73a], C. Leonidopoulos[51], A. Leopold[148], J. LePage-Bourbonnais[35], R. Les[107], C.G. Lester[33], J. Levêque[4], L.J. Levinson[172], G. Levrini[24b,24a], M.P. Lewicki[86], C. Lewis[141], D.J. Lewis[4], L. Lewitt[143], 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[142a], L. Li[142a], R. Li[175], S. Li[142b,142a], T. Li[5], Y. Li[14], Z. Li[14,112c], Z. Li[61], S. Liang[14,112c], Z. Liang[14], M. Liberatore[137], B. Liberti[75a], G.B. Libotte[81d], K. Lie[63c], J. Lieber Marin[81e], H. Lien[67], H. Lin[106], S.F. Lin[149], L. Linden[109], R.E. Lindley[7], J.H. Lindon[37], J. Ling[60], E. Lipeles[130], A. Lipniacka[17], A. Lister[167], J.D. Little[67], B. Liu[113a], B.X. Liu[112b], D. Liu[154], D. Liu[138], E.H.L. Liu[21], H. Liu[112b], J.K.K. Liu[119], K. Liu[142b], K. Liu[142b], M. Liu[61], M.Y. Liu[61], P. Liu[113b], Q. Liu[147], S. Liu[149], X. Liu[113b], Y. Liu[112b,112c], Y. Liu[165], 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[159], K. Lohwasser[143], E. Loiacono[123], J.D. Lomas[21], I. Longarini[163], R. Longo[24b,24a,am], A. Lopez Solis[13], N.A. Lopez-canelas[7], N. Lorenzo Martinez[4], A.M. Lory[109], M. Losada[118a], G. Löschcke Centeno[4], X. Lou[14,112c], P.A. Love[91], M. Lu[65], S. Lu[130], Y.J. Lu[152], H.J. Lubatti[141], C. Luci[74a,74b], F.L. Lucio Alves[112a], F. Luehring[67], B.S. Lunday[130], O. Lundberg[148], J. Lunde[37], N.A. Luongo[6], M.S. Lutz[159], A.B. Lux[26], D. Lynn[30], R. Lysak[133], V. Lysenko[134],

E. Lytken [98], V. Lyubushkin [38], T. Lyubushkina [38], M.M. Lyukova [149], H. Ma [30], K. Ma [61], L.L. Ma [113b], W. Ma [61], Y. Ma [113b], J.C. MacDonald [100], 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 [143], M. Maheshwari [33], V. Maiboroda [65], A. Maio [132a,132b,132d], K. Maj [85a], O. Majersky [47], S. Majewski [125], A. Makita [157], N. Makovec [65], V. Maksimovic [16], B. Malaescu [129], J. Malamant [127], 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 [150], I. Mandić [93], L. Manhaes de Andrade Filho [81a], I.M. Maniatis [172], J. Manjarres Ramos [89], D.C. Mankad [172], A. Mann [109], T. Manoussos [37], M.N. Mantinan [39], S. Manzoni [37], L. Mao [142a], X. Mapekula [34c], A. Marantis [156], R.R. Marcelo Gregorio [1], G. Marchiori [5], C. Marcon [70a], E. Maricic [16], M. Marinescu [47], S. Marium [47], M. Marjanovic [122], A. Markhoos [53], M. Markovitch [65], M.K. Maroun [103], M.C. Marr [146], G.T. Marsden [101], Z. Marshall [18a], S. Marti-Garcia [166], J. Martin [96], T.A. Martin [136], 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 [136], G. Martinovicova [135], 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], T. Masubuchi [126], T.T. Mathew [125], J. Matousek [135], D.M. Mattern [48], K. Mauer [47], J. Maurer [28b], T. Maurin [58], A.J. Maury [65], B. Maček [93], C. Mavungu Tsava [102], A.E. May [101], E. Mayer [40], R. Mazini [34j], S.M. Mazza [138], E. Mazzeo [37], J.P. Mc Gowan [168], S.P. Mc Kee [106], C.C. McCracken [167], E.F. McDonald [105], L.F. Mcelhinney [91], J.A. Mcfayden [150], R.P. McGovern [130], R.P. Mckenzie [34j], D.J. Mclaughlin [96], S.J. McMahon [136], C.M. Mcpartland [92], R.A. McPherson [168,ab], S. Mehlhase [109], A. Mehta [92], D. Melini [166], 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 [156], C. Merlassino [68a,68c], C. Meroni [70a,70b], J. Metcalfe [6], A.S. Mete [6], E. Meuser [100], C. Meyer [67], J-P. Meyer [137], Y. Miao [112a], R.P. Middleton [136], M. Mihovilovic [65], L. Mijović [51], G. Mikenberg [172], M. Mikestikova [133], M. Mikuž [93], H. Mildner [100], A. Milic [37], D.W. Miller [39], E.H. Miller [147], A. Milov [172], D.A. Milstead [46a,46b], T. Min [112a], I.A. Minashvili [153b], A.I. Mincer [119], 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 [170], V.A. Mitsou [166], Y. Mitsumori [111], P.S. Miyagawa [94], R. Mizuhiki [84], T. Mkrtchyan [37], M. Mlinarevic [96], T. Mlinarevic [96], M. Mlynarikova [135], L. Mlynarska [85a], C. Mo [142a], S. Mobius [20], M.H. Mohamed Farook [114], S. Mohapatra [41], M.F. Mohd Soberi [51], S. Mohiuddin [123], G. Mokgatitswane [34j], R. Mole [21], L. Moleri [172], U. Molinatti [128], L.G. Mollier [20], B. Mondal [133], S. Mondal [135], K. Mönig [47], E. Monnier [102], L. Monsonis Romero [166], A. Montella [46a,46b], M. Montella [121], 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 [166], C. Moreno Martinez [55], J.M. Moreno Perez [23b], P. Morettini [56b], S. Morgenstern [62a], M. Morii [60], M. Morinaga [157], F. Morodei [74a,74b], P. Moschovakos [37], B. Moser [53], M. Mosidze [153b], T. Moskalets [44], P. Moskvitina [115], C.J. Mosomane [34b], J. Moss [32], T. Motta Quirino [81d], A. Moussa [36d], Y. Moyal [172,k], H. Moyano Gomez [13], E.J.W. Moyse [103], T.G. Mroz [86], S. Muanza [102], M. Mucha [25], J. Mueller [131], D. Muller [145], G.A. Mullier [164], A.J. Mullin [33], J.J. Mullin [50], A.C. Mullins [44], A.E. Mulski [60], D.P. Mungo [159], D. Munoz Perez [123], F.J. Munoz Sanchez [101], W.J. Murray [170,136], E. Musajan [61], M. Muškinja [93], C. Mwewa [47], A.J. Myers [8], G. Myers [106], M. Myska [134], B.P. Nachman [147], K. Nagai [128], K. Nagano [82], R. Nagasaka [157], 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 [126], E.A. Narayanan [44],
Y. Narukawa [157], L. Nasella [70a,70b], S. Nasri [118b], C. Nass [25], G. Navarro [23a], A. Nayaz [19],
S. Nechaeva [24b,24a], F. Nechansky [133], L. Nedic [128], A. Negri [72a,72b], M. Negrini [24b],
C. Nellist [116], C. Nelson [104], K. Nelson [106], S. Nemecek [133], M. Nessi [37,g], M.S. Neubauer [165],
J. Newell [92], P.R. Newman [21], Y.W.Y. Ng [165], B. Ngair [118a], H.D.N. Nguyen [108],
J.D. Nichols [122], R. Nicolaidou [137], J. Nielsen [138], M. Niemeyer [54], J. Niermann [37],
N. Nikiforou [37], I. Nikolic-Audit [129], P. Nilsson [30], G. Ninio [155], A. Nisati [74a], R. Nisius [110],
N. Nitika [172], E.K. Nkadimeng [34b], T. Nobe [157], D. Noll [147], T. Nommensen [151],
M.B. Norfolk [143], B.J. Norman [35], L.C. Nosler [18a], M. Noury [36a], J. Novak [93], T. Novak [93],
P. Novotny [172], R. Novotny [134], L. Nozka [124], K. Ntekas [37], D. Ntounis [147],
N.M.J. Nunes De Moura Junior [81b], J. Ocariz [129], I. Ochoa [132a], A. Odella Rodriguez [13],
S. Oerdek [47], J.T. Offermann [39], A. Ogrodnik [86], A. Oh [101], C.C. Ohm [148], H. Oide [82],
M.L. Ojeda [37], Y. Okumura [157], L.F. Oleiro Seabra [132a], 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 [140],
A. Onofre [132a,132e,e], P.U.E. Onyisi [11], M.J. Oreglia [39], D. Orestano [76a,76b], R. Orlandini [76a,76b],
R.S. Orr [159], L.M. Osojnak [41], Y. Osumi [111], G. Otero y Garzón [31], H. Otono [88],
M. Ouchrif [36d], F. Ould-Saada [127], T. Ovsiannikova [141], M. Owen [58], R.E. Owen [136],
S.A. Oyeniran [114], V.E. Ozcan [22a], F. Ozturk [86], N. Ozturk [8], S. Ozturk [80], H.A. Pacey [128],
K. Pachal [160a], 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 [136], H.D. Pandya [1], H. Pang [137], P. Pani [47], G. Panizzo [68a,68c],
L. Panwar [129,w], L. Paolozzi [21], S. Parajuli [165], 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], 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 [135], C.I. Pazos [162],
M. Pedersen [127], R. Pedro [132a], O. Penc [133], C.C. Penelaud [129], S. Peng [15], G.D. Penn [175],
B.S. Peralva [81d], A.P. Pereira Peixoto [141], L. Pereira Sanchez [147], 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 [134],
A.R. Petri [70a,70b], T. Petru [135], M. Pettee [18a], A. Petukhov [80], K. Petukhova [37], R. Pezoa [139g],
L. Pezzotti [24b,24a], G. Pezzullo [175], L. Pfaffenbichler [37], A.J. Pfleger [78], T.M. Pham [173],
T. Pham [105], P.W. Phillips [136], G. Piacquadio [149], E. Pianori [18a], F. Piazza [125], R. Piegaia [31],
D. Pietreanu [28b], A.D. Pilkington [101], M. Pinamonti [68a,68c], J.L. Pinfold [2], G. Pinheiro Matos [41],
B.C. Pinheiro Pereira [132a], J. Pinol Bel [13], A.E. Pinto Pinoargote [129], L. Pintucci [68a,68c],
K.M. Piper [150], A. Pirttikoski [55], D.A. Pizzi [35], L. Pizzimento [63b], A. Plebani [33],
M.-A. Pleier [30], V. Pleskot [135], E. Plotnikova [38], G. Poddar [94], R. Poettgen [98], L. Poggioli [129],
S. Polacek [135], G. Polesello [72a], A. Poley [146], A. Polini [24b], C.S. Pollard [170], Z.B. Pollock [121],
E. Pompa Pacchi [122], N.I. Pond [96], D. Ponomarenko [67], L. Pontecorvo [37], S. Popa [28a],
G.A. Popeneciu [28d], A. Poreba [37], D.M. Portillo Quintero [160a], S. Pospisil [134], M.A. Postill [143],
P. Postolache [28c], K. Potamianos [170], P.A. Potepa [85a], I.N. Potrap [38], C.J. Potter [33], H. Potti [151],
J. Poveda [166], M.E. Pozo Astigarraga [37], R. Pozzi [37], A. Prades Ibanez [75a,75b], S.R. Pradhan [143],
J. Pretel [168], D. Price [101], M. Primavera [69a], L. Primomo [68a,68c], M.A. Principe Martin [99],
R. Privara [124], T. Procter [85b], M.L. Proffitt [141], N. Proklova [130], 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 [128], Y. Qin [13],
T. Qiu [51], A. Quadt [54], M. Queitsch-Maitland [101], G. Quetant [55], R.P. Quinn [167],

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[130], N.P. Rapheeha[34j], H. Rasheed[28b], A. Rastogi[18a], S. Rave[100], S. Ravera[56b,56a], B. Ravina[37], I. Ravinovich[172], M. Raymond[37], A.L. Read[127], N.P. Readioff[143], D.M. Rebuzzi[72a,72b], A.S. Reed[58], K. Reeves[27], D. Reikher[37], A. Rej[48], C. Rembser[37], H. Ren[61], M. Renda[28b], F. Renner[47], A.G. Rennie[58], M. Repik[55], A.L. Rescia[56b,56a], S. Resconi[70a], M. Ressegotti[56b], S. Rettie[116], W.F. Rettie[35], M.M. Revering[33], O.L. Rezanova[38], P. Reznicek[135], H. Riani[36d], N. Ribaric[50], B. Ricci[68a,68c], E. Ricci[77a,77b], R. Richter[110], E. Richter-Was[85b], M. Ridel[129], S. Ridouani[36d], P. Riedler[37], E.M. Riefel[46a,46b], J.O. Rieger[116], M. Rimoldi[34c], L. Rinaldi[24b,24a], P. Rincke[164,54], G. Ripellino[164], I. Riu[13], J.C. Rivera Vergara[168], F. Rizatdinova[123], E. Rizvi[94], B.R. Roberts[39], S.S. Roberts[138], 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[127], R.A. Rojas[37], Z. Rokavec[93], C.P.A. Roland[129], A. Romaniouk[78], E. Romano[72a,72b], M. Romano[24b], N. Rompotis[92], L. Roos[129], S. Rosati[74a], L. Roscher[47], B.J. Rosser[39], E. Rossi[128], E. Rossi[71a,71b], L.P. Rossi[60], L. Rossini[53], R. Rosten[121], 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[154], A. Rubio Jimenez[166], V.H. Ruelas Rivera[19], T.A. Ruggeri[1], A. Ruggiero[128], A. Ruiz-Martinez[166], A. Rummler[37], G.B. Rupnik Boero[37], N.A. Rusakovich[38], S. Ruscelli[48], H.L. Russell[168], G. Russo[138], J.P. Rutherfoord[7], S. Rutherford Colmenares[119], M. Rybar[135], P. Rybczynski[85a], A. Ryzhov[44], F. Safai Tehrani[74a], S. Saha[1], B. Sahoo[172], A. Saibel[166], B.T. Saifuddin[122], M. Saimpert[137], I. Sainz Saenz Diez[62a], G.T. Saito[81c], M. Saito[157], T. Saito[157], A. Sala[70a,70b], O.T. Salin[65], A. Salnikov[147], J. Salt[166], A. Salvador Salas[155], F. Salvatore[150], A. Salzburger[37], D. Sammel[53], E. Sampson[91], D. Sampsonidis[156,d], D. Sampsonidou[125], M.A.A. Samy[58], J. Sánchez[166], V. Sanchez Sebastian[166], H. Sandaker[127], C.O. Sander[47], J.A. Sandesara[173], M. Sandhoff[174], C. Sandoval[23b], L. Sanfilippo[62a], D.P.C. Sankey[136], T. Sano[87], A. Sansar[22c], A. Sansoni[52], M. Santana Queiroz[18b], L. Santi[37], C. Santoni[40], H. Santos[132a,132b], L. Santos Pereira Trigo[47], E. Sanzani[24b,24a], K.A. Saoucha[83b], J.G. Saraiva[132a,132d], J. Sardain[7], S. Sarkar[50], O. Sasaki[82], K. Sato[161], C. Sauer[37], E. Sauvan[4], P. Savard[159,aj], R. Sawada[157], C. Sawyer[136], L. Sawyer[97], A.M. Sayed[27], C. Sbarra[24b], A. Sbrizzi[24b,24a], R. Scaglioni[72a,72b], T. Scanlon[96], J. Schaarschmidt[141], U. Schäfer[100], A.C. Schaffer[65,44], D. Schaile[109], R.D. Schamberger[149], C. Scharf[19], M.M. Schefer[20], D. Scheirich[135], M. Schernau[139f], C. Scheulen[55], C. Schiavi[56b,56a], M. Schioppa[43b,43a], S. Schlenker[37], T. Schlomer[54], J. Schmeing[174], C.R. Schmidt[49], E. Schmidt[110], M.A. Schmidt[174], K. Schmieden[25], C. Schmitt[100], N. Schmitt[100], S. Schmitt[47], N.A. Schneider[109], L. Schoeffel[137], A. Schoening[62b], P.G. Scholer[35], E. Schopf[145], M. Schott[25], S. Schramm[55], T. Schroer[55], H-C. Schultz-Coulon[62a], M. Schumacher[53], B.A. Schumm[138], Ph. Schune[137], H.R. Schwartz[7], A. Schwartzman[147], T.A. Schwarz[106], Ph. Schwemling[137], R. Schwienhorst[107], F.G. Sciacca[20], A. Sciandra[30], G. Sciolla[27], S.A. Scoville[131], F. Scuri[73a], C.D. Sebastiani[37], K. Sedlaczek[117], A. Sehrawat[139b], S.C. Seidel[114], B.D. Seidlitz[41], C. Seitz[47], J.M. Seixas[81b], G. Sekhniaidze[71a], L. Selem[129], N. Semprini-Cesari[24b,24a], A. Semushin[176], V. Senthilkumar[116], L. Serin[65], M. Sessa[71a,71b], H. Severini[122], F. Sforza[56b,56a], A. Sfyrla[55], Q. Sha[14], H. Shaddix[117], A.H. Shah[33], R. Shaheen[148], J.D. Shahinian[130], M. Shamim[37], L.Y. Shan[14], M. Shapiro[18a], A. Sharma[37], A.S. Sharma[167], P. Sharma[30], K. Shaw[150], S.M. Shaw[101], D. Shemyakin[172], Q. Shen[14], D.J. Sheppard[146], 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[127], B. Shrestha[122], S. Shrestha[121,aq], I. Shreyber[38], M.J. Shroff[104], P. Sicho[133], A.M. Sickles[165], 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[150], 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[122], M. Slawinska[86], I. Slazyk[17], I. Sliusar[127], V. Smakhtin[172], B.H. Smart[136], S.Yu. Smirnov[139b], Y. Smirnov[34c], O. Smirnova[98], J.L. Smith[101], M.B. Smith[35], R. Smith[147], H. Smitmanns[100], M. Smizanska[91], K. Smolek[134], P. Smolyanskiy[134], A.A. Snesarev[38], H.L. Snoek[116], R.M. Snyder[50], S. Snyder[30], R. Sobie[168,ab], A. Soffer[155], C.A. Solans Sanchez[37], E.Yu. Soldatov[38], U. Soldevila[166], A.A. Solodkov[34j], S. Solomon[27], A. Soloshenko[38], O.V. Solovyanov[40], P. Sommer[49], A. Sopczak[134], A.L. Sopio[51], F. Sopkova[29b], J.D. Sorenson[114], I.R. Sotarriva Alvarez[140], V. Sothilingam[62a], O.J. Soto Sandoval[139c,139b], S. Sottocornola[67], R. Soualah[83a], D. South[47], N. Soybelman[172], S. Spagnolo[69a,69b], A.S. Spellman[125], D. Sperlich[53], B. Spisso[71a,71b], L. Splendori[102], M. Spousta[135], 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[138], J. Stark[89], P. Staroba[133], P. Starovoitov[83b], R. Staszewski[86], C. Stauch[109], G. Stavropoulos[45], A. Stefl[37], A. Stein[100], P. Steinberg[30], B. Stelzer[146,160a], H.J. Stelzer[131], O. Stelzer[160a], H. Stenzel[57], T.J. Stevenson[150], G.A. Stewart[47], G. Stoicea[28b], M. Stolarski[132a], S. Stonjek[110], A. Straessner[49], J. Strandberg[148], S. Strandberg[46a,46b], M. Stratmann[174], M. Strauss[122], T. Strebler[102], P. Strizenec[29b], R. Ströhmer[169], D.M. Strom[125], R. Stroynowski[44], A. Strubig[46a,46b], S.A. Stucci[30], B. Stugu[17], J. Stupak[122], N.A. Styles[47], D. Su[147], S. Su[61], X. Su[61], D. Suchy[29a], A.D. Sudhakar Ponnu[54], L. Sudit[172], Y. Sue[82], K. Sugizaki[130], D.M.S. Sultan[128], L. Sultanaliyeva[25], S. Sultansoy[3b], S. Sun[173], W. Sun[14], S. Sundar Raman[167], N. Sur[98], J.P. Surdutovich[121], N. Suri Jr[175], M.R. Sutton[150], M. Svatos[133], P.N. Swallow[33], S.N. Swatman[37], M. Swiatlowski[160a], A. Swoboda[37], I. Sykora[29a], M. Sykora[135], T. Sykora[135], D. Ta[100], K. Tackmann[47,y], A. Taffard[163], R. Tafirout[160a], Y. Takubo[82], M. Talby[102], N.M. Tamir[155], A. Tanaka[157], J. Tanaka[157], R. Tanaka[65], M. Tanasini[149], Z. Tao[167], S. Tapia Araya[139g], S. Tapprogge[100], A. Tarek Abouelfadl Mohamed[37], S. Tarem[154], K. Tariq[14], G. Tarna[37], G.F. Tartarelli[70a], M.J. Tartarin[142b], P. Tas[135], M. Tasevsky[133], E. Tassi[43b,43a], A.C. Tate[165], Y. Tayalati[36e,aa], G.N. Taylor[105], W. Taylor[160b], R.J. Taylor Vara[166], A.S. Tegetmeier[89], P. Teixeira-Dias[95], J.J. Teoh[159], K. Terashi[157], J. Terron[99], S. Terzo[13], M. Testa[52], R.J. Teuscher[159,ab], A. Thaler[78], T. Theveneaux-Pelzer[102], J.P. Thomas[21], E.A. Thompson[18a], P.D. Thompson[21], E. Thomson[130], R.E. Thornberry[30], T.M. Thory-Rao[21], C.N. Thotamuna Wijewardhana[149], C. Tian[61], Y. Tian[55], V. Tikhomirov[80], Yu.A. Tikhonov[38], D. Timoshyn[135], E.X.L. Ting[1], P. Tipton[175], A. Tishelman-Charny[30], K. Todome[140], S. Todorova-Nova[135], L. Toffolin[68a,68c], M. Togawa[82], J. Tojo[88], S. Tokár[29a], O. Toldaiev[67], G. Tolkachev[102], M. Tomoto[82], L. Tompkins[147], E. Torrence[125], H. Torres[89], D.I. Torres Arza[139g], E. Torres Reoyo[166], E. Torró Pastor[166], M. Toscani[31], C. Tosciri[39], M. Tost[11], D.R. Tovey[143], T. Trefzger[169], P.M. Tricarico[13], A. Tricoli[30], I.M. Trigger[160a], S. Trincaz-Duvoid[129], D.A. Trischuk[168], A. Tropina[38], D. Truncali[75a,75b], L. Truong[34c], M. Trzebinski[86], A. Trzupek[86], F. Tsai[149], A. Tsiamis[156], P.V. Tsiareshka[38], S. Tsigaridas[160a], A. Tsirigotis[156,t], V. Tsiskaridze[153a], E.G. Tskhadadze[153a], H.F. Tsoi[130], Y. Tsujikawa[87], V. Tsulaia[18a], K. Tsuri[120], D. Tsybychev[149], Y. Tu[63b], A. Tudorache[28b], V. Tudorache[28b], S.B. Tuncay[128], S. Turchikhin[56b,56a], I. Turk Cakir[3a], R. Turra[70a], T. Turtuvshin[38,ac], P.M. Tuts[41],

Y. Uematsu [82], F. Ukegawa [161], P.A. Ulloa Poblete [139c,139b], G. Unal [37], A. Undrus [30], J. Urban [29b], P. Urrejola [139e], G. Usai [8], R. Ushioda [158], M. Usman [108], F. Ustuner [51], Z. Uysal [80], V. Vacek [134], 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 [166], E. Valiente Moreno [166], A. Vallier [89], J.A. Valls Ferrer [166], D.R. Van Arneman [116], R. Van Den Broucke [129], 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 [135], M. Vanadia [75a,75b], U.M. Vande Voorde [148], W. Vandelli [37], E.R. Vandewall [147], D. Vannicola [155], R. Vari [74a], M. Varma [175], E.W. Varnes [7], C. Varni [85a], D. Varouchas [65], L. Varriale [166], K.E. Varvell [151], M.E. Vasile [28b], A. Vasileiadou[9], L. Vaslin[82], M.D. Vassilev [147], A. Vasyukov [38], L.M. Vaughan [123], R. Vavricka[135], T. Vazquez Schroeder [13], J. Veatch [32], V. Vecchio [101], M.J. Veen [103], I. Veliscek [30], I. Velkovska [93], L.M. Veloce [159], F. Veloso [132a,132c], A.G. Veltman [51], S.H. Venetianer [162], 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 [147], M. Vessella [163], M.C. Vetterli [146,aj], A. Vgenopoulos [100], N. Viaux Maira [139g,af], L. Vicenik [134], T. Vickey [143], O.E. Vickey Boeriu [143], G.H.A. Viehhauser [128], L. Vigani [62b], M. Vigl [110], M. Villa [24b,24a], M. Villaplana Perez [166], E.M. Villhauer[39], E. Vilucchi [52], M. Vincent [166], M.G. Vincter [35], A. Visibile [116], A. Visive [116], C. Vittori [162], I. Vivarelli [24b,24a], M.I. Vivas Albornoz [47], E. Voevodina [110], F. Vogel [109], J.C. Voigt [49], P. Vokac [134], Yu. Volkotrub [85b], L. Vomberg [25], E. Von Toerne [25], B. Vormwald [37], K. Vorobev [50], M. Vos [166], K. Voss [145], M. Vozak [37], L. Vozdecky [122], N. Vranjes [16], M. Vranjes Milosavljevic [16], M. Vreeswijk [116], N.K. Vu [112a], R. Vuillermet [37], O. Vujinovic [100], I. Vukotic [39], I.K. Vyas [35], J.F. Wack [33], A. Wada [111], S. Wada [161], C. Wagner[147], J.M. Wagner [18a], W. Wagner [174], S. Wahdan [174], H. Wahlberg [90], C.H. Waits [122], J. Walder [136], R. Walker [109], K. Walkingshaw Pass [58], W. Walkowiak [145], A. Wall [130], E.J. Wallin [98], T. Wamorkar [147], K. Wandall-Christensen [166], A. Wang [61], A.Z. Wang [138], 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 [152], S. Wang [14], T. Wang [115], T. Wang [61], W.T. Wang [128], X. Wang [165], X. Wang [142a], X. Wang [47], Y. Wang [149], Y. Wang [114], Z. Wang [106], Z. Wang [14], Z. Wang[63b], C. Wanotayaroj [82], A. Warburton [104], A.L. Warnerbring [145], S. Waterhouse [96], A.T. Watson [21], H. Watson [51], M.F. Watson [21], E. Watton [37], G. Watts [141], B.M. Waugh [96], J.M. Webb [53], C. Weber [30], M.S. Weber [20], C. Wei [61], Y. Wei [53], A.R. Weidberg [128], E.J. Weik [119], J. Weingarten [48], C. Weiser [53], C.J. Wells [47], T. Wenaus [30], T. Wengler [37], N.S. Wenke[110], N. Wermes [25], M. Wessels [62a], A.M. Wharton [91], A.S. White [37], A. White [8], M.J. White [1], D. Whiteson [163], L. Wickremasinghe [126], W. Wiedenmann [173], M. Wielers [136], R. Wierda [148], 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 [125], B.T. Winter [53], M. Wittgen[147], M. Wobisch [97], T. Wojtkowski[59], Z. Wolffs [116], J. Wollrath[37], M.W. Wolter [86], H. Wolters [132a,132c], M.C. Wong[138], 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 [159], C. Wu [21], J. Wu [157], M. Wu [112b], M. Wu [115], S.L. Wu [173], S. Wu [14,an], X. Wu [61], Y.Q. Wu [159], 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 [125], I. Xiotidis [37], D. Xu [14], H. Xu [61], L. Xu [61], R. Xu [130], T. Xu [106], W. Xu[112a], Y. Xu [141], Z. Xu [51], R. Xue [131], B. Yabsley [151], S. Yacoob [11], Y. Yamaguchi [82], E. Yamashita [157], H. Yamauchi [161], T. Yamazaki [18a], Y. Yamazaki [84], S. Yan [58], Z. Yan [103], C. Yang [18a], H.J. Yang [142a], H.T. Yang [61], S. Yang [61], X. Yang [37], X. Yang [14], Y. Yang [157], Y. Yang[61], W-M. Yao [18a], C.L. Yardley [150], J. Ye [14], S. Ye [30], X. Ye [61], I. Yeletskikh [38], B. Yeo [18b], M.R. Yexley [96], T.P. Yildirim [128], K. Yorita [171], C.J.S. Young [37], C. Young [147], I.N.L. Young [58], N.D. Young[125], Y. Yu [61], J. Yuan [14,112c,an], M. Yuan [106], R. Yuan [142b], 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 [166], S. Zambito [55], J. Zang [157], R. Zanzottera [70a,70b], O. Zaplatilek [134], E. Zaya [148], C. Zeitnitz [174], H. Zeng [14], D.T. Zenger Jr [27], T. Ženiš [29a], S. Zenz [94], D. Zerwas [65], W. Zhan [61], B. Zhang [170], D.F. Zhang [143], 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 [141], Y. Zhang [96], Y. Zhang [61], Y. Zhang [112a], Z. Zhang [18a], Z. Zhang [113b], Z. Zhang [65], H. Zhao [141], T. Zhao [113b], Y. Zhao [35], Z. Zhao [61], Z. Zhao [61], A. Zhemchugov [38], J. Zheng [112a], K. Zheng [165], L. Zheng [113b], X. Zheng [61], Z. Zheng [147], D. Zhong [165], B. Zhou [106], B. Zhou [142b,142a], N. Zhou [142a], Y. Zhou [15], Y. Zhou [112a], Y. Zhou[7], Z. Zhou [61], J. Zhu [106], X. Zhu[142b], Y. Zhu [142a], X. Zhuang [14], K. Zhukov [67], P. Ziakas [4], N.I. Zimine [38], J. Zinsser [62b], M. Ziolkowski [145], L. Živković [16], A. Zoccoli [24b,24a], K. Zoch [37], A. Zografos [37], T.G. Zorbas [143], 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]Département 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)]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][(a)]New York University Abu Dhabi, Abu Dhabi;[(b)]United Arab Emirates University, Al Ain; United Arab Emirates.
[119]Department of Physics, New York University, New York NY; United States of America.
[120]Ochanomizu University, Otsuka, Bunkyo-ku, Tokyo; Japan.
[121]Ohio State University, Columbus OH; United States of America.
[122]Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman OK; United States of America.

[123]Department of Physics, Oklahoma State University, Stillwater OK; United States of America.
[124]Palacký University, Joint Laboratory of Optics, Olomouc; Czech Republic.
[125]Institute for Fundamental Science, University of Oregon, Eugene, OR; United States of America.
[126]Graduate School of Science, University of Osaka, Osaka; Japan.
[127]Department of Physics, University of Oslo, Oslo; Norway.
[128]Department of Physics, Oxford University, Oxford; United Kingdom.
[129]LPNHE, Sorbonne Université, Université Paris Cité, CNRS/IN2P3, Paris; France.
[130]Department of Physics, University of Pennsylvania, Philadelphia PA; United States of America.
[131]Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh PA; United States of America.
[132][(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.
[133]Institute of Physics of the Czech Academy of Sciences, Prague; Czech Republic.
[134]Czech Technical University in Prague, Prague; Czech Republic.
[135]Charles University, Faculty of Mathematics and Physics, Prague; Czech Republic.
[136]Particle Physics Department, Rutherford Appleton Laboratory, Didcot; United Kingdom.
[137]IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette; France.
[138]Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz CA; United States of America.
[139][(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.
[140]Department of Physics, Institute of Science, Tokyo; Japan.
[141]Department of Physics, University of Washington, Seattle WA; United States of America.
[142][(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.
[143]Department of Physics and Astronomy, University of Sheffield, Sheffield; United Kingdom.
[144]Department of Physics, Shinshu University, Nagano; Japan.
[145]Department Physik, Universität Siegen, Siegen; Germany.
[146]Department of Physics, Simon Fraser University, Burnaby BC; Canada.
[147]SLAC National Accelerator Laboratory, Stanford CA; United States of America.
[148]Department of Physics, Royal Institute of Technology, Stockholm; Sweden.
[149]Departments of Physics and Astronomy, Stony Brook University, Stony Brook NY; United States of America.
[150]Department of Physics and Astronomy, University of Sussex, Brighton; United Kingdom.
[151]School of Physics, University of Sydney, Sydney; Australia.
[152]Institute of Physics, Academia Sinica, Taipei; Taiwan.
[153][(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.
[154]Department of Physics, Technion, Israel Institute of Technology, Haifa; Israel.
[155]Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv; Israel.
[156]Department of Physics, Aristotle University of Thessaloniki, Thessaloniki; Greece.
[157]International Center for Elementary Particle Physics and Department of Physics, University of Tokyo, Tokyo; Japan.
[158]Graduate School of Science and Technology, Tokyo Metropolitan University, Tokyo; Japan.
[159]Department of Physics, University of Toronto, Toronto ON; Canada.
[160(a)]TRIUMF, Vancouver BC;[(b)]Department of Physics and Astronomy, York University, Toronto ON; Canada.
[161]Division of Physics and Tomonaga Center for the History of the Universe, Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba; Japan.
[162]Department of Physics and Astronomy, Tufts University, Medford MA; United States of America.
[163]Department of Physics and Astronomy, University of California Irvine, Irvine CA; United States of America.
[164]Department of Physics and Astronomy, University of Uppsala, Uppsala; Sweden.
[165]Department of Physics, University of Illinois, Urbana IL; United States of America.
[166]Instituto de Física Corpuscular (IFIC), Centro Mixto Universidad de Valencia - CSIC, Valencia; Spain.
[167]Department of Physics, University of British Columbia, Vancouver BC; Canada.
[168]Department of Physics and Astronomy, University of Victoria, Victoria BC; Canada.
[169]Fakultät für Physik und Astronomie, Julius-Maximilians-Universität Würzburg, Würzburg; Germany.
[170]Department of Physics, University of Warwick, Coventry; United Kingdom.
[171]Waseda University, Tokyo; Japan.
[172]Department of Particle Physics and Astrophysics, Weizmann Institute of Science, Rehovot; Israel.
[173]Department of Physics, University of Wisconsin, Madison WI; United States of America.
[174]Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal; Germany.
[175]Department of Physics, Yale University, New Haven CT; United States of America.
[176]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