EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

Submitted to: Phys. Rev. Lett.

CERN-EP-2023-036
March 31, 2023

Measurement of the Sensitivity of Two-Particle Correlations in pp Collisions to the Presence of Hard Scatterings

The ATLAS Collaboration

A key open question in the study of multi-particle production in high-energy pp collisions is the relationship between the "ridge" – observed azimuthal correlations between particles in the underlying event that extend over all rapidities – and hard or semi-hard scattering processes. In particular, it is not known whether jets or their soft fragments are correlated with particles in the underlying event. To address this question, two-particle correlations are measured in pp collisions at $\sqrt{s}$ = 13 TeV using data collected by the ATLAS experiment at the LHC, with an integrated luminosity of 15.8 pb^{-1}, in two different configurations. In the first case, charged particles associated with jets are excluded from the correlation analysis, while in the second case, correlations are measured between particles within jets and charged particles from the underlying event. Second-order flow coefficients, v_2, are presented as a function of event multiplicity and transverse momentum. These measurements show that excluding particles associated with jets does not affect the measured correlations. Moreover, particles associated with jets do not exhibit any significant azimuthal correlations with the underlying event, ruling out hard processes contributing to the ridge.

In heavy-ion collisions, two-particle correlations (2PC) in relative azimuthal angle with large pseudorapidity [1] separation show distinct long-range correlations [2–12]. These long-range correlations are a simple manifestation of the single-particle anisotropies, v_n, that originate from the hydrodynamic expansion of the quark-gluon plasma (QGP) produced in these collisions. The v_n are defined by parameterizing the azimuthal distribution of produced particles as:

$$\frac{dN}{d\phi} \propto \left(1 + 2\sum_{n=1}^{\infty} v_n \cos(n(\phi - \Psi_n))\right), \tag{1}$$

where ϕ is the azimuthal angle of the particle momentum and v_n and Ψ_n are the magnitude and phase of the n^{th}-order anisotropy, see Refs. [4, 10] and references therein.

Because of their hydrodynamic origin in nucleus-nucleus (A+A) collisions, such long-range correlations were not expected in smaller colliding systems such as proton–nucleus (p+A) or proton–proton (pp) collisions, where collective phenomena were not commonly expected to develop. However, measurements by CMS showed the presence of such long-range correlations, known as the "ridge," in high-multiplicity pp collisions [13]. Further investigations by ATLAS [9, 14, 15] have demonstrated that these long-range correlations in pp collisions are produced from single-particle anisotropies similar to those in heavy-ion collisions. These long-range correlations have been interpreted as evidence of collective effects similar to those seen in heavy-ion collisions. However, some authors have proposed that the ridge is primarily composed of hard partons scattering off of a dense gluonic state [16–20], implying that much of the correlation structure associated with the ridge should be associated with hard- or semi-hard scattering processes. Previous measurements [21] have shown that the ridge is unmodified in pp collisions producing a Z boson, but no direct measurement in pp collisions of the correlation between jets or their fragments and the underlying event has yet been performed, while such a correlation has been observed in p+Pb collisions [22, 23].

This Letter presents 2PC measurements in pp collisions at a center-of-mass energy ($\sqrt{s}$) of 13 TeV, using the ATLAS detector at the LHC. The measurements are performed with two different particle-pair selections. The first case explores correlations between tracks that are not jet constituents, while the second case measures correlations between tracks that are constituents of jets and tracks that are well-separated from jets. Similar measurements in p+Pb collisions have shown significant non-zero v_2 for low [23] and high [22] transverse momentum (p_{T}) particles generated in hard processes. Correlations are also measured in events that are explicitly selected by requiring the presence or absence of low-p_{T} jets. These measurements can address whether or not the presence of jets affects the ridge, and if the particles from jets exhibit azimuthal correlations with particles from the underlying event and therefore contribute to the ridge.

The measurements presented here are performed using the ATLAS [24] inner detector (ID), minimum-bias trigger scintillators (MBTS), calorimeters and the trigger and data acquisition systems [25]. The ID records charged-particle trajectories within the pseudorapidity range $|\eta| < 2.5$ using a combination of silicon pixel detectors including the "insertable B-layer" (IBL) [26, 27], silicon microstrip detectors (SCT), and a straw-tube transition radiation tracker (TRT), all immersed in a 2 T axial magnetic field [1, 28]. The ATLAS calorimeter system consists of a liquid argon (LAr) electromagnetic calorimeter covering $|\eta| < 3.2$, a steel–scintillator sampling hadronic calorimeter covering $|\eta| < 1.7$, a LAr hadronic calorimeter covering $1.5 < |\eta| < 3.2$, and two LAr electromagnetic and hadronic forward calorimeters (FCal) covering $3.2 < |\eta| < 4.9$. The ATLAS trigger system [29] consists of a Level-1 (L1) trigger implemented using a combination of dedicated electronics and programmable logic, and a software-based high-level trigger

(HLT). An extensive software suite [30] 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.

The data were collected during Run 2 of the LHC (2015–2018), with an average collision rate per bunch crossing (μ) of less than 3, and an integrated luminosity of 15.8 pb^{-1}. The data used here were recorded using multiple minimum-bias, high-multiplicity, and jet triggers, which are described in Ref. [31]. Additional offline requirements are imposed on the events selected by the triggers. The events are required to have a reconstructed vertex with $|z| < 100$ mm. To suppress events with more than one pp collision in the same bunch crossing, events are required to have only one reconstructed vertex. Pileup events where the vertices from multiple collisions are sufficiently close such that they are reconstructed as a single vertex are not removed by the one vertex requirement. However, such merged events typically have a broader distribution for the longitudinal impact parameter of tracks relative to the vertex ($|z_0 \sin(\theta)|$). Such events are reduced by requiring that the standard deviation of $|z_0 \sin(\theta)|$ for all tracks in an event is less than 0.25 mm.

The reconstruction and performance of tracks and primary vertices in the ID are described in Refs. [32–34]. The specific track selection criteria can be found in Ref. [31]. The track reconstruction efficiencies $\epsilon(p_{\mathrm{T}}, \eta)$ are obtained using Monte Carlo (MC) generated events that are passed through a GEANT4 [35] simulation [36] of the ATLAS detector and reconstructed using the procedures applied to the data. The efficiency varies between 69% and 87% as a function of η and p_{T}.

Jets used in this analysis are reconstructed using the anti-k_t algorithm [37] with a radius parameter of 0.4. The inputs to jet reconstruction are “particle flow objects” as detailed in Ref. [38]. Jets are calibrated to the hadronic scale using scale factors obtained from MC simulations specifically derived for low-μ data. Additional *in situ* corrections [39] are applied, which account for differences in the jet response between the MC samples and data. One issue in this analysis is that the modulation in the soft particles in the event (Eq. (1)) biases the jet p_{T} in a manner that depends on its orientation relative to the Ψ_n. This affects the measurements of the correlations between jet-fragments and the underlying event (UE) particles (discussed in detail below). To mitigate this effect, instead of selecting jets based on their p_{T}, selections are made on the following groomed quantity:

$$p_{\mathrm{T}}^{\mathrm{G}} = \left| \sum_{\text{constituents}} \boldsymbol{p}_{\mathrm{T}}^{> 4\ \mathrm{GeV}} \right|, \tag{2}$$

where the sum runs over all the jet constituents with $p_{\mathrm{T}} > 4$ GeV, which considerably reduces the number of UE particles within the jet, and makes this bias negligible, as shown in Ref. [31].

In previous ATLAS measurements of 2PCs in p+Pb [40, 41] and pp [14, 15, 21] collisions, events were quantified by $N_{\mathrm{ch}}^{\mathrm{rec}}$: the total number of reconstructed tracks with $p_{\mathrm{T}} > 0.4$ GeV, passing the track selections discussed above. In this analysis, a slight modification is made to ensure that the event activity is not biased by the presence of jets, and only reflects the soft multiplicity in the event. The number of constituent tracks in jets with $p_{\mathrm{T}}^{\mathrm{G}} > 15$ GeV is subtracted from the measured multiplicity, and the corrected quantity, $N_{\mathrm{ch}}^{\mathrm{rec,corr}}$, is used to represent the event activity. While counting the constituent tracks of jets, the $p_{\mathrm{T}} > 4$ GeV requirement is not imposed on the tracks. Additionally, this correction is offset by the average number of UE tracks within the jet cone. This offset is estimated by measuring the average number of tracks, as a function of η and ϕ, that are in a $R = 0.4$ cone in events with similar multiplicity and trigger conditions.

In 2PC measurements, the distribution of particle-pairs in relative azimuthal angle $\Delta\phi = \phi^{\mathrm{a}} - \phi^{\mathrm{b}}$ are measured. The labels a and b denote the two particles in the pair. In evaluating the correlation functions, the tracks are weighted by the inverse of their reconstruction efficiency, $1/\epsilon(p_{\mathrm{T}}, \eta)$. To suppress short-range correlations, the particles are required to have a pseudorapidity separation of $|\Delta\eta| > 2$. In pp collisions, back-to-back dijets also make a significant contribution to the 2PCs. To remove this contribution, a template-fit method [14, 15, 21] is employed in which the measured 2PC is described by a fit having two components. The first component accounts for the dijet contribution, $C^{\mathrm{periph}}(\Delta\phi)$, which is measured using low-multiplicity events (called the "peripheral reference"). This analysis uses the $N_{\mathrm{ch}}^{\mathrm{rec,corr}}$ interval of 10–30 to build C^{periph}. The second component accounts for the bulk contribution with a relative harmonic modulation, $C^{\mathrm{ridge}}(\Delta\phi)$. The 2PC can then be described as:

$$\begin{aligned} C(\Delta\phi) &= FC^{\mathrm{periph}}(\Delta\phi) + G\left(1 + 2\sum_{n=2} v_{n,n}\cos(n\Delta\phi)\right) \\ &\equiv FC^{\mathrm{periph}}(\Delta\phi) + C^{\mathrm{ridge}}(\Delta\phi), \end{aligned} \quad (3)$$

where F and $v_{n,n}$ are fit parameters and G is fixed by the requirement that the integrals of the fit and $C(\Delta\phi)$ are equal. The Fourier moments, $v_{n,n}$, obtained from the template-fit quantify the strength of the long-range correlation. It is demonstrated in Refs. [14, 15] that the $v_{n,n}$ in pp collisions obtained from Eq. (3) factorize as $v_{n,n}(p_{\mathrm{T}}^{\mathrm{a}}, p_{\mathrm{T}}^{\mathrm{b}}) = v_n(p_{\mathrm{T}}^{\mathrm{a}})v_n(p_{\mathrm{T}}^{\mathrm{b}})$, where v_n is the single particle anisotropy (Eq. (1)). Thus, $v_n(p_{\mathrm{T}}^{\mathrm{b}})$ is obtained as $v_n(p_{\mathrm{T}}^{\mathrm{b}}) = v_{n,n}(p_{\mathrm{T}}^{\mathrm{a}}, p_{\mathrm{T}}^{\mathrm{b}})/\sqrt{v_{n,n}(p_{\mathrm{T}}^{\mathrm{a}}, p_{\mathrm{T}}^{\mathrm{a}})}$.

This Letter studies how the presence of a hard-scattering affects the structure of the long-range correlation of UE particles (quantified by the v_n), and also investigates whether tracks that are constituents of jets (jet-fragment) exhibit any azimuthal correlation with the UE. To get an unbiased set of UE tracks for the correlation analysis, the UE tracks used in the 2PC are required to be separated from all $p_{\mathrm{T}}^{\mathrm{G}} > 15$ GeV jets in the event by at least one unit in η. These tracks are referred as h^{UE} in this study. This approach has previously been used in studies of p+Pb collisions [22]. Subsequently, correlations are studied between particle-pairs where both particles are from the UE, or pairs where one particle is from the UE and the other particle is a jet constituent (h^{J}). Five classes of correlations are studied in this Letter:

- *h-h*: Standard 2PC [14, 15] without applying any rejection of tracks around jets.
- $h^{UE} - h^{UE}$(*AllEvents*): 2PC where both tracks are h^{UE}. About 14% of *h-h* 2PC pairs are removed by the abovementioned rejection.
- $h^{UE} - h^{UE}$(*NoJets*): 2PC using events with no jets with $p_{\mathrm{T}}^{\mathrm{G}} > 15$ GeV.
- $h^{UE} - h^{UE}$(*WithJets*): 2PC using events with at least one jet with $p_{\mathrm{T}}^{\mathrm{G}} > 15$ GeV.
- $h^{UE} - h^{J}$: 2PC performed between h^{UE} and h^{J} (for jets with $p_{\mathrm{T}}^{\mathrm{G}} > 40$ GeV).

These classes are not mutually exclusive. Specifically, the $h^{UE} - h^{UE}$(*NoJets*) and $h^{UE} - h^{UE}$(*WithJets*) classes add up to the $h^{UE} - h^{UE}$(*AllEvents*) class. The $h^{UE} - h^{J}$ class has no overlapping particle-pairs with the ones in the $h^{UE} - h^{UE}$(*AllEvents*), $h^{UE} - h^{UE}$(*NoJets*), and $h^{UE} - h^{UE}$(*WithJets*) classes. The *h-h* class is identical to the measurements performed in the previous ATLAS publications [14, 15], and is used as a reference with which other classes are compared. The $h^{UE} - h^{UE}$(*AllEvents*) class is used to study the effect of removing jets-associated tracks from the long-range correlations. The $h^{UE} - h^{UE}$(*WithJets*) and $h^{UE} - h^{UE}$(*NoJets*) classes contrast how the presence or absence of jets in an event affect the 2PC, even when the tracks associated with the jets are not used in the 2PC. Finally, the $h^{UE} - h^{J}$ class is used to study whether the jet-fragments also exhibit long-range correlations with the UE. To measure the $h^{UE} - h^{J}$ correlations, one of the tracks in the 2PC is selected from the constituents of a $p_{\mathrm{T}}^{\mathrm{G}} > 40$ GeV jet, while the other is an UE track. To prevent any possible biases to the shape of the 2PC from split and nearby jets, an isolation requirement is imposed that no jets with $p_{\mathrm{T}}^{\mathrm{G}} > 15$ GeV are present within a $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$ of one unit from the $p_{\mathrm{T}}^{\mathrm{G}} > 40$ GeV jet. Since jets usually occur in pairs, a matched recoil jet with $p_{\mathrm{T}}^{\mathrm{G}} > 15$ GeV is required to be present in the event located at $|\Delta\phi| > 5\pi/6$ from the first jet. The requirement of a matched recoil jet ensures that all the h^{UE} used in the 2PC are also separated from the recoil jet. This consequently reduces possible biases from dijet pairs to the $h^{UE} - h^{J}$ 2PC. The $h^{UE} - h^{J}$ 2PC requires some additional steps in the construction of the correlation functions. It may happen that some constituents of jets originate in the UE, leading to a contribution of combinatorial pairs in the 2PC. These combinatorial pairs, by construction, have the same correlation as those where both the tracks are from the UE. The contribution of such pairs is removed by the following technique. For each event that contributes to the $h^{UE} - h^{J}$ correlation, a separate 2PC is made using another event with similar vertex position and multiplicity. In this event, one track is picked from an η-ϕ region that is within $R = 0.4$ cone of the jet-axis and the other track is picked from the same η range as in the $h^{UE} - h^{J}$ event. This combinatorial 2PC is then subtracted from the $h^{UE} - h^{J}$ 2PC.

Statistical uncertainties in the measured 2PCs are evaluated using a bootstrapping procedure previously used in Ref. [42]. Systematic uncertainties in the v_2 measurements are estimated by varying different aspects of the analysis. For the template-fit procedure, the $N_{\mathrm{ch}}^{\mathrm{rec,corr}}$ multiplicity range for the peripheral reference selection was varied from the nominal 10–30 to 10–40 and 20–40 [31] and the change in the v_2 values is included as a systematic uncertainty. For the multiplicity dependence, this uncertainty for the v_2 is 0.01 (absolute) for the $h^{UE} - h^{J}$ class and is typically within 2% for the other classes. This uncertainty is fully correlated across all multiplicity intervals and is the dominant uncertainty for the $h^{UE} - h^{J}$ class. Uncertainties in the tracking efficiency are propagated into the measured v_2. This uncertainty on the v_2 is less than 0.5%, and is estimated by varying the efficiency up and down within its uncertainties ($\sim \pm 3\%$) [43], and re-evaluating the v_2. The systematic uncertainty due to non-primary tracks is estimated by varying the selection criteria for transverse and longitudinal impact parameters, resulting in a 0.5% change in v_2. The 2PC analyses often use event-mixing [4, 10] to estimate and correct the 2PCs for the detector's pair acceptance. This correction is quite small, and the full effect of the correction is included as a systematic uncertainty. As discussed previously, the events used in this analysis are required to have the standard deviation of $|z_0 \sin(\theta)|$ for the tracks in an event to be smaller than 0.25 mm, to reduce pileup. Conservatively, the entire effect of this selection, which varies with multiplicity but is typically within 1%, is taken to be a systematic uncertainty associated with pileup effects.

Figure 1 compares the 2PCs for all classes, except the $h^{UE} - h^{UE}(AllEvents)$ class. The figure also shows the template fits including the components of the fits. In general, the template fits describe the 2PCs quite well. A near-side ridge is visible for the h-h, $h^{UE} - h^{UE}(WithJets)$ and $h^{UE} - h^{UE}(NoJets)$ cases, while the $C^{\mathrm{periph}}(\Delta\phi)$ appears to describe the full distribution in the $h^{UE} - h^{J}$ case.

Figure 2 shows the multiplicity dependence of the v_2 for all five 2PC classes. The v_2 values for the h-h case vary weakly with multiplicity, as previously reported in Refs. [14, 15]. The v_2 values in the $h^{UE} - h^{UE}(AllEvents)$, $h^{UE} - h^{UE}(NoJets)$, and $h^{UE} - h^{UE}(WithJets)$ cases, are all consistent with the h-h result. This demonstrates that removing tracks associated with jets does not impact the long-range UE correlations, and nor does the presence (or absence) of jets in an event. Within uncertainties, the v_2 values in the $h^{UE} - h^{J}$ case are consistent with zero. The mean v_2 for the $h^{UE} - h^{J}$ correlations over the 40–150 multiplicity range is $-0.009 \pm 0.010(\text{statistical}) \pm 0.014(\text{systematic})$. This indicates that particles produced in hard scattering processes (with $p_{\mathrm{T}}^{\mathrm{G}} > 40$ GeV) do not contribute significantly to the long-range correlation observed in pp collisions. Figure 3 shows the p_{T}-dependence of the v_2. The differential $v_2(p_{\mathrm{T}})$ values in the $h^{UE} - h^{UE}(AllEvents)$, $h^{UE} - h^{UE}(NoJets)$ and $h^{UE} - h^{UE}(WithJets)$ cases are found to be consistent with the h-h case. Again, within uncertainties, the $h^{UE} - h^{J}$ v_2 values are consistent with zero,

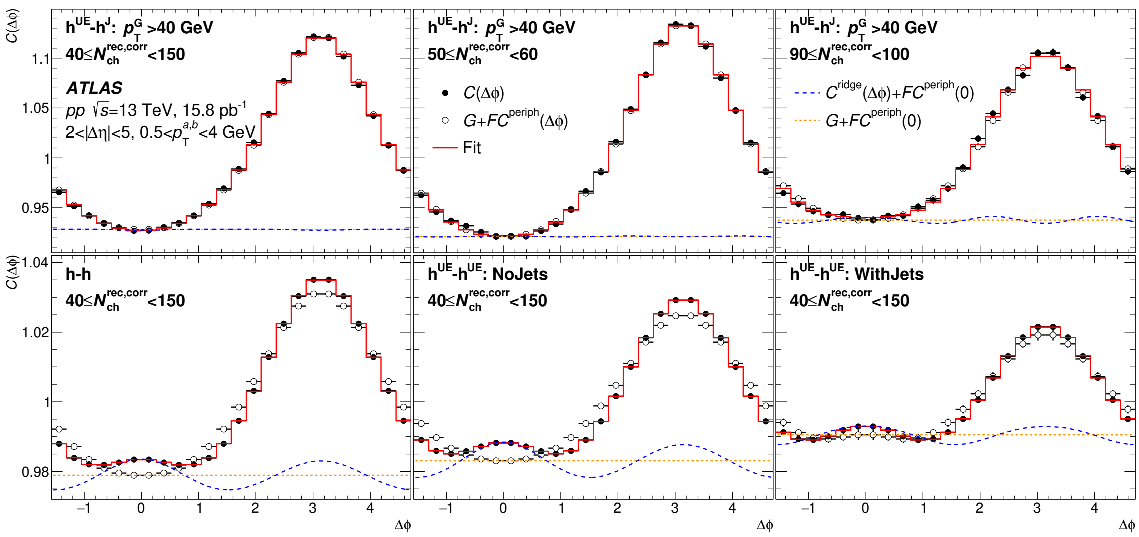

Figure 1: Template-fits to the two-particle correlations in $\Delta\phi$. Events with $10 \leq N_{\mathrm{ch}}^{\mathrm{rec,corr}} < 30$ are used as the peripheral reference. The solid points indicate the measured 2PC, the open circles show the scaled and shifted peripheral reference, and the continuous line shows the fit. The dashed line shows the second-order harmonic component, and the dotted line shows the pedestal of the fit shifted up by $FC^{\mathrm{periph}}(0)$. The top row corresponds to different multiplicity intervals for the $h^{UE} - h^{J}$ class. The left, center and right panels in the bottom row correspond to the *h*-*h*, $h^{UE} - h^{UE}(NoJets)$, and $h^{UE} - h^{UE}(WithJets)$ classes, respectively, for the 40–150 multiplicity interval.

across the entire measured p_{T} range. The findings drawn from the p_{T} dependence are consistent with those from the multiplicity dependence, and similarly demonstrate that the presence or absence of jets has no influence on the flow of the UE and that there are no correlations between jet-fragments and the UE. The features of the v_2 values discussed above do not show any systematic variation with the jet selections, for example the $p_{\mathrm{T}}^{\mathrm{G}}$ thresholds, used in the analysis [31].

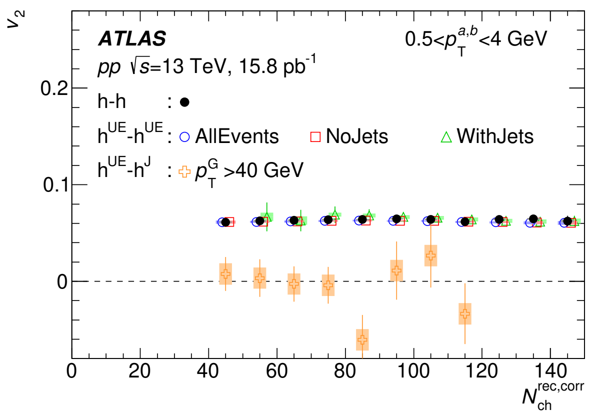

Figure 2: The multiplicity dependence of v_2 for $2 < |\Delta\eta| < 5$. Events with $10 \leq N_{\mathrm{ch}}^{\mathrm{rec,corr}} < 30$ are used as the peripheral reference. Jets with $p_{\mathrm{T}}^{\mathrm{G}} > 15$ GeV are used to classify the $h^{UE} - h^{UE}(NoJets)$ and $h^{UE} - h^{UE}(WithJets)$ samples. The data point for the $h^{UE} - h^{UE}(WithJets)$ case has a particularly large statistical uncertainty in the 40–50 multiplicity interval and is not shown. The data-points for the $h^{UE} - h^{UE}(AllEvents)$, $h^{UE} - h^{UE}(NoJets)$, and $h^{UE} - h^{UE}(WithJets)$ samples are slightly shifted along the x-axis for clarity. The error bars and bands correspond to statistical and systematic uncertainties, respectively.

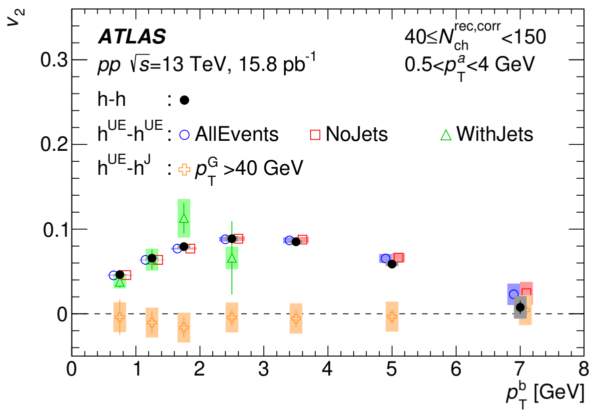

Figure 3: The $p_{\mathrm{T}}^{\mathrm{b}}$ dependence of the v_2 obtained for the 40–150 multiplicity interval for $2 < |\Delta\eta| < 5$. Events with $10 \leq N_{\mathrm{ch}}^{\mathrm{rec,corr}} < 30$ are used as the peripheral reference. Jets with $p_{\mathrm{T}}^{\mathrm{G}} > 15$ GeV are used to classify the $h^{UE} - h^{UE}(NoJets)$ and $h^{UE} - h^{UE}(WithJets)$ samples. The data-points for the h-h sample are drawn at the nominal values while the data-points for the $h^{UE} - h^{UE}(AllEvents)$, $h^{UE} - h^{UE}(NoJets)$, and the highest $p_{\mathrm{T}}^{\mathrm{b}}$ point of $h^{UE} - h^{J}$ samples are shifted slightly for clarity. The error bars and bands correspond to statistical and systematic uncertainties, respectively.

In conclusion, this Letter studies long-range 2PCs in pp collisions when rejecting tracks in the vicinity of jets, and the correlations between jet constituent tracks and tracks from the UE. The 2PCs are analyzed using a template-fit procedure, previously developed by ATLAS [15], which extracts second-order Fourier coefficients (v_2) of the anisotropy. These results demonstrate that the magnitude of the v_2 is not affected when removing tracks associated with jets, or by the presence or absence of jets in the event. The v_2 measured with correlations between jet constituents with $p_{\mathrm{T}} < 8$ GeV and UE tracks are consistent with zero within uncertainties. These features are observed both in the v_2 multiplicity and p_{T} dependence.

The observation that fragments of high-p_T jets in pp collisions do not have measurable long-range azimuthal correlations with the UE, and that the production of Z bosons [21] or jets does not significantly influence the long-range correlations between UE particles, suggest a complete "factorization" between hard-scattering processes and the physics responsible for the ridge. Further studies are needed to extend this measurement to higher p_T to compare with previous measurements in p+Pb collisions [22] where such factorization is broken. This Letter provides important insights into the origin of the long-range correlations observed in pp collisions and offers new fundamental input to theoretical models.

Acknowledgements

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

We 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; BMBF, HGF and MPG, Germany; GSRI, Greece; RGC and Hong Kong SAR, China; ISF and Benoziyo Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; NWO, Netherlands; RCN, Norway; MEiN, Poland; FCT, Portugal; MNE/IFA, Romania; MESTD, Serbia; MSSR, Slovakia; ARRS and MIZŠ, Slovenia; DSI/NRF, South Africa; MICINN, Spain; SRC and Wallenberg Foundation, Sweden; SERI, SNSF and Cantons of Bern and Geneva, Switzerland; MOST, Taiwan; TENMAK, Türkiye; STFC, United Kingdom; DOE and NSF, United States of America. In addition, individual groups and members have received support from BCKDF, CANARIE, Compute Canada and CRC, Canada; PRIMUS 21/SCI/017 and UNCE SCI/013, 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; Norwegian Financial Mechanism 2014-2021, Norway; NCN and NAWA, Poland; La Caixa Banking Foundation, CERCA Programme Generalitat de Catalunya and PROMETEO and GenT Programmes Generalitat Valenciana, Spain; Göran Gustafssons Stiftelse, Sweden; The Royal Society and Leverhulme Trust, United Kingdom.

The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN, the ATLAS Tier-1 facilities at TRIUMF (Canada), NDGF (Denmark, Norway, Sweden), CC-IN2P3 (France), KIT/GridKA (Germany), INFN-CNAF (Italy), NL-T1 (Netherlands), PIC (Spain), ASGC (Taiwan), 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. [44].

References

[1] *ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the centre of the detector and the z-axis along the beam pipe. The x-axis points from the IP to the centre of the LHC ring, and the y-axis points upwards. Cylindrical 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 $\eta = -\ln\tan(\theta/2)$. Angular distance is measured in units of $\Delta R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$.

[2] ALICE Collaboration, *Harmonic decomposition of two-particle angular correlations in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV*, Phys. Lett. B **708** (2012) 249, arXiv: 1109.2501 [nucl-ex].

[3] CMS Collaboration, *Centrality dependence of dihadron correlations and azimuthal anisotropy harmonics in PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV*, Eur. Phys. J. C **72** (2012) 2012, arXiv: 1201.3158 [hep-ex].

[4] ATLAS Collaboration, *Measurement of the azimuthal anisotropy for charged particle production in $\sqrt{s_{NN}} = 2.76$ TeV lead–lead collisions with the ATLAS detector*, Phys. Rev. C **86** (2012) 014907, arXiv: 1203.3087 [hep-ex].

[5] ATLAS Collaboration, *Measurement of event-plane correlations in $\sqrt{s_{NN}} = 2.76$ TeV lead–lead collisions with the ATLAS detector*, Phys. Rev. C **90** (2014) 024905, arXiv: 1403.0489 [hep-ex].

[6] ATLAS Collaboration, *Measurement of flow harmonics with multi-particle cumulants in Pb+Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV with the ATLAS detector*, Eur. Phys. J. C **74** (2014) 3157, arXiv: 1408.4342 [hep-ex].

[7] ATLAS Collaboration, *Measurement of the centrality and pseudorapidity dependence of the integrated elliptic flow in lead–lead collisions at $\sqrt{s_{NN}} = 2.76$ TeV with the ATLAS detector*, Eur. Phys. J. C **74** (2014) 2982, arXiv: 1405.3936 [hep-ex].

[8] ATLAS Collaboration, *Measurement of the distributions of event-by-event flow harmonics in lead–lead collisions at $\sqrt{s_{NN}} = 2.76$ TeV with the ATLAS detector at the LHC*, JHEP **11** (2013) 183, arXiv: 1305.2942 [hep-ex].

[9] ATLAS Collaboration, *Measurement of multi-particle azimuthal correlations in pp, p+Pb and low-multiplicity Pb+Pb collisions with the ATLAS detector*, Eur. Phys. J. C **77** (2017) 428, arXiv: 1705.04176 [hep-ex].

[10] ATLAS Collaboration, *Measurement of the azimuthal anisotropy of charged particles produced in $\sqrt{s_{NN}} = 5.02$ TeV Pb+Pb collisions with the ATLAS detector*, Eur. Phys. J. C **78** (2018) 997, arXiv: 1808.03951 [hep-ex].

[11] STAR Collaboration, *Elliptic flow from two- and four-particle correlations in Au+Au collisions at $\sqrt{s_{\mathrm{NN}}} = 130$ GeV*, Phys. Rev. C **66** (2002) 034904, arXiv: nucl-ex/0206001 [nucl-ex].

[12] PHENIX Collaboration, *Measurement of the higher-order anisotropic flow coefficients for identified hadrons in Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV*, Phys. Rev. C **93** (2016) 051902, arXiv: 1412.1038 [nucl-ex].

[13] CMS Collaboration, *Observation of long-range, near-side angular correlations in proton–proton collisions at the LHC*, JHEP **09** (2010) 091, arXiv: 1009.4122 [hep-ex].

[14] ATLAS Collaboration, *Observation of Long-Range Elliptic Azimuthal Anisotropies in $\sqrt{s} = 13$ and 2.76 TeV pp Collisions with the ATLAS Detector*, Phys. Rev. Lett. **116** (2016) 172301, arXiv: 1509.04776 [hep-ex].

[15] ATLAS Collaboration, *Measurements of long-range azimuthal anisotropies and associated Fourier coefficients for pp collisions at $\sqrt{s} = 5.02$ and 13 TeV and p+Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with the ATLAS detector*, Phys. Rev. C **96** (2017) 024908, arXiv: 1609.06213 [hep-ex].

[16] A. Dumitru, K. Dusling, F. Gelis, J. Jalilian-Marian, T. Lappi, et al., *The Ridge in proton-proton collisions at the LHC*, Phys. Lett. B **697** (2011) 21, arXiv: 1009.5295 [hep-ph].

[17] K. Dusling and R. Venugopalan, *Azimuthal collimation of long range rapidity correlations by strong color fields in high multiplicity hadron-hadron collisions*, Phys. Rev. Lett. **108** (2012) 262001, arXiv: 1201.2658 [hep-ph].

[18] E. Gotsman, E. Levin, and I. Potashnikova, *A CGC/saturation approach for angular correlations in proton–proton scattering*, Eur. Phys. J. C **77** (2017) 632, arXiv: 1706.07617 [hep-ph].

[19] K. Dusling, M. Mace, and R. Venugopalan, *Parton model description of multiparticle azimuthal correlations in pA collisions*, Phys. Rev. D **97** (2018) 016014, arXiv: 1706.06260 [hep-ph].

[20] T. Altinoluk and N. Armesto, *Particle correlations from the initial state*, Eur. Phys. J. A **56** (2020), arXiv: 2004.08185 [hep-ph].

[21] ATLAS Collaboration, *Measurement of long-range two-particle azimuthal correlations in Z-boson tagged pp collisions at $\sqrt{s} = 8$ and 13 TeV*, Eur. Phys. J. C **80** (2020) 64, arXiv: 1906.08290 [hep-ex].

[22] ATLAS Collaboration, *Transverse momentum and process dependent azimuthal anisotropies in $\sqrt{s_{NN}} = 8.16$ TeV p+Pb collisions with the ATLAS detector*, Eur. Phys. J. C **80** (2020) 73, arXiv: 1910.13978 [hep-ex].

[23] ALICE Collaboration, *Azimuthal anisotropy of jet particles in p-Pb and Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV*, (2022), arXiv: 2212.12609 [nucl-ex].

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

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

[26] ATLAS Collaboration, *ATLAS Insertable B-Layer Technical Design Report*, ATLAS-TDR-19; CERN-LHCC-2010-013, 2010, URL: https://cds.cern.ch/record/1291633, Addendum: ATLAS-TDR-19-ADD-1; CERN-LHCC-2012-009, 2012, URL: https://cds.cern.ch/record/1451888.

[27] B. Abbott et al., *Production and Integration of the ATLAS Insertable B-Layer*, JINST **13** (2018) T05008, arXiv: 1803.00844 [physics.ins-det].

[28] ATLAS Collaboration, *The ATLAS Inner Detector commissioning and calibration*, Eur. Phys. J. C **70** (2010) 787, arXiv: 1004.5293 [hep-ex].

[29] ATLAS Collaboration, *Performance of the ATLAS Trigger System in 2010*, Eur. Phys. J. C **72** (2012) 1849, arXiv: 1110.1530 [hep-ex].

[30] ATLAS Collaboration, *The ATLAS Collaboration Software and Firmware*, ATL-SOFT-PUB-2021-001, 2021, URL: https://cds.cern.ch/record/2767187.

[31] *See Supplemental Material at [URL will be inserted by publisher] for details of the triggers, track selection criteria, systematic uncertainties related to the peripheral reference, an explanation of how the groomed $p_{\mathrm{T}}^{\mathrm{G}}$ removes the underlying-event bias and, cross-checks related to the jet selections.*

[32] T. Cornelissen et al., *The new ATLAS track reconstruction (NEWT)*, Journal of Physics: Conference Series **119** (2008) 032014.

[33] A. Salzburger on behalf of the ATLAS Collaboration, *Optimisation of the ATLAS Track Reconstruction Software for Run-2*, J. Phys. Conf. Ser. **664** (2015) 072042.

[34] ATLAS Collaboration, *The Optimization of ATLAS Track Reconstruction in Dense Environments*, ATL-PHYS-PUB-2015-006, 2015, URL: https://cds.cern.ch/record/2002609.

[35] S. Agostinelli et al., *GEANT4: A simulation toolkit*, Nucl. Instrum. Meth. A **506** (2003) 250.

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

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

[38] 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].

[39] 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** (2020) 689, arXiv: 2007.02645 [hep-ex].

[40] ATLAS Collaboration, *Observation of Associated Near-Side and Away-Side Long-Range Correlations in $\sqrt{s_{NN}} = 5.02$ TeV Proton–Lead Collisions with the ATLAS Detector*, Phys. Rev. Lett. **110** (2013) 182302, arXiv: 1212.5198 [hep-ex].

[41] ATLAS Collaboration, *Measurement of long-range pseudorapidity correlations and azimuthal harmonics in $\sqrt{s_{NN}} = 5.02$ TeV proton–lead collisions with the ATLAS detector*, Phys. Rev. C **90** (2014) 044906, arXiv: 1409.1792 [hep-ex].

[42] ATLAS Collaboration, *Two-particle azimuthal correlations in photonuclear ultraperipheral Pb+Pb collisions at* 5.02 *TeV with ATLAS*, Phys. Rev. C **104** (2021) 014903, arXiv: 2101.10771 [hep-ex].

[43] ATLAS Collaboration, *Measurement of the azimuthal anisotropy of charged-particle production in Xe+Xe collisions at $\sqrt{s_{NN}} = 5.44$ TeV with the ATLAS detector*, Phys. Rev. C **101** (2020) 024906, arXiv: 1911.04812 [hep-ex].

[44] ATLAS Collaboration, *ATLAS Computing Acknowledgements*, ATL-SOFT-PUB-2021-003, 2021, URL: https://cds.cern.ch/record/2776662.

Appendix

A Supplemental Material Allowed by Journal to Accompany Online Version of Paper

A.1 Detailed trigger description

Multiple triggers were used to record the data and can broadly be classified into three categories. The first category of triggers selects a set of minimum-bias events through a L1 trigger that requires a signal in at least one MBTS counter, and a second trigger that requires at least one reconstructed track with $p_{\mathrm{T}} > 0.2$ GeV at the HLT. The second category is a set of high-multiplicity triggers that apply a L1 requirement on either the transverse energy (E_{T}) in the calorimeters or a hit in at least one MBTS counter on each side, and an HLT requirement on the multiplicity of HLT-reconstructed tracks with $p_{\mathrm{T}} > 0.4$ GeV that is associated with the reconstructed vertex with the highest multiplicity in the event. The third is a set of triggers that enhance the rate of jets. These include a set of triggers that require a jet at L1 and at the HLT, and another set of triggers that require a minimum threshold on the total E_{T} in the calorimeter at L1.

A.2 Detailed track selection criteria

The criteria used to select tracks include the requirements of $p_{\mathrm{T}} > 0.4$ GeV and $|\eta| < 2.5$, a hit in the IBL or a hit in the pixel layer next to the IBL, and a minimum of six hits in the SCT. Additionally, the transverse impact parameter of the track relative to the average beam position, and the longitudinal impact parameter of the track relative to the vertex are both required to be less than 1.5 mm. To remove tracks with mis-measured p_{T} due to interactions with the material or other effects, the track-fit χ^2 probability is required to be larger than 0.01 for tracks having $p_{\mathrm{T}} > 10$ GeV.

A.3 Multiplicity distributions

Figure 4 shows the distribution of $N_{\mathrm{ch}}^{\mathrm{rec,corr}}$ for the events in the h-h, $h^{UE}-h^{UE}(AllEvents)$, $h^{UE}-h^{UE}(NoJets)$, $h^{UE}-h^{UE}(WithJets)$, and $h^{UE}-h^{J}$ cases. The default peripheral reference in the template-fits is constructed using the events in the 10–30 multiplicity interval. The average minimum-bias multiplicity of reconstructed charged-particle tracks in 13 TeV pp collisions in ATLAS is ~ 20, and the default range for the peripheral reference is taken to be a ± 10 window around this mean value. Alternative peripheral references built from the 10–40 and 20–40 multiplicity intervals are used to evaluate systematic uncertainties, where the lower and upper multiplicity ranges are increased by 10 from the default interval. The 0–10 multiplicity interval, is excluded from the peripheral references as 1) the $h^{UE}-h^{UE}(WithJets)$ and $h^{UE}-h^{J}$ cases have very few events at these low multiplicities, and 2) such low multiplicity are likely to contain a significant contribution from diffractive events.

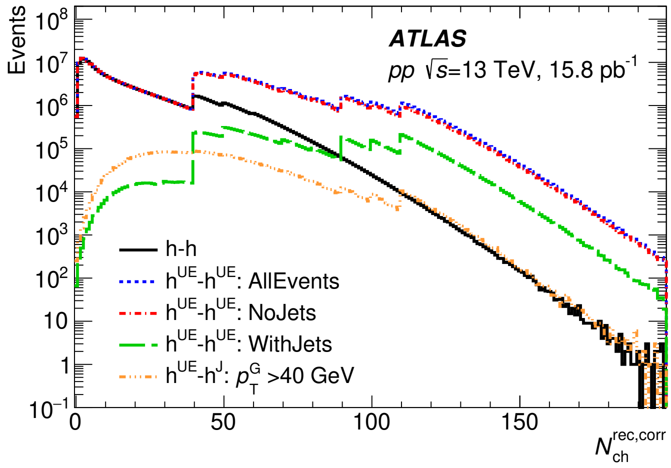

Figure 4: The distribution of $N_{\text{ch}}^{\text{rec,corr}}$ for the $\sqrt{s}$ = 13 TeV pp data used in this analysis. The different lines denote the h-h, $h^{UE} - h^{UE}(AllEvents)$, $h^{UE} - h^{UE}(NoJets)$, $h^{UE} - h^{UE}(WithJets)$, and $h^{UE} - h^{J}$ cases. The discontinuities in the distributions correspond to different high-multiplicity trigger thresholds.

A.4 Pythia 8 Embedding

This section motivates the choice of the 4 GeV requirement used in Eq. (2) to remove the bias from the UE modulation on the jet selection. The effect of UE modulation on the jet selection is estimated by a toy Pythia 8 embedding study. The Pythia 8 events are simulated using the Monash 2013 tune with multi-parton interaction off and initial-state radiation on. Jet reconstruction is performed on these generated events, using the anti-k_{T} clustering algorithm with a radius parameter of 0.4. The jets thus produced are called *generated-jets* hereafter. The generated events are filtered by requiring the events to have a generated-jet with p_{T} greater than 15 GeV and a balanced generated-jet with $p_{\text{T}} > 10$ GeV and $|\Delta\phi| > 5\pi/6$ relative to the first jet. The generated (stable[1]) particles are embedded onto minimum bias data events. After the embedding, jets are reconstructed using the embedded particles and the original particle flow objects [38] present in the data-event, using the anti-k_{T} clustering algorithm with a radius parameter of 0.4. These jets are called *embedded-jets* hereafter. Similar jet clustering is also done using only the particle flow objects in the minimum-bias data used in the embedding study. These jets are called *data-jets* hereafter.

The embedded-jets are required to match a generated-jet with $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} < 0.1$. The embedded-jets are also required to be separated from data-jets by $\Delta R > 0.8$. The p_{T} of the embedded-jets is always larger than the p_{T} of the matched generated-jet as the particle flow objects in the data always push up the p_{T}. The issue of concern for this analysis is that this increase in the p_{T} is dependent on the azimuthal angle that the jet makes with the second-order event-plane, due to the modulation in the UE. To visualize the bias from the UE modulation, the difference between the azimuthal angle of the embedded-jet, ϕ^{jet}, and the second-order event plane angle, Ψ_2^{Data}, is plotted in Figure 5. The Ψ_2 angle is calculated using particles from the data events only, excluding particles within one unit in η around any data-jets with p_{T} greater than 15 GeV. Since Pythia 8 events are uncorrelated with the data event onto which they are embedded, the distribution of $\phi^{\text{jet}} - \Psi_2^{\text{Data}}$ is, by construction, constant for the generated-jets. However, for the embedded-jets the corresponding distribution is modulated, as shown in Figure 5.

[1] The generated particles that are not decayed further by Pythia 8 are called stable here.

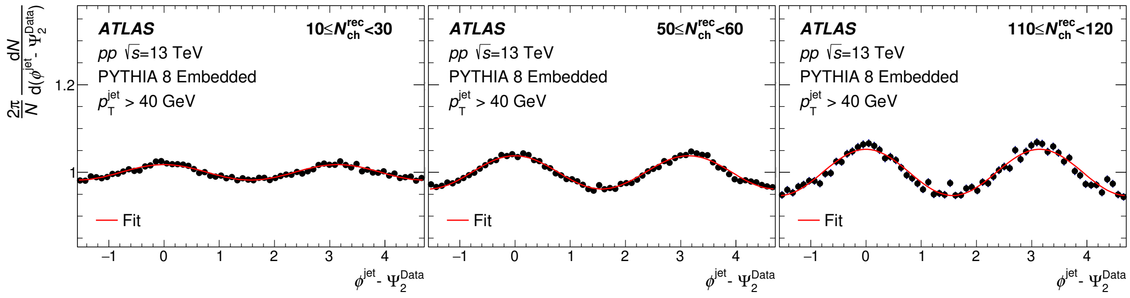

Figure 5: The distribution of $\phi^{\rm jet} - \Psi_2^{\rm Data}$ for the embedded jets. The continuous line indicates a Fourier fit to the distribution that includes a 2$^{\rm nd}$ order modulation. The different panels correspond to different multiplicity intervals.

Since the modulation effects are dominated by low $p_{\rm T}$ particles, grooming the jets to remove soft particles can remove the UE bias. A groomed jet $p_{\rm T}$ definition is proposed here, by summing the $p_{\rm T}$ of jet constituents with $p_{\rm T}$ greater than a particular threshold X:

$$p_{\rm T}^{\rm G} = \left|\sum \boldsymbol{p}_{\rm T}^{> \rm X\ GeV}\right|, \tag{4}$$

Figure 6 shows the $\phi^{\rm jet} - \Psi_2^{\rm Data}$ using different values of the threshold X in Eq. (4). The modulation in the distribution systematically decreases with increasing X, and is nearly gone for $X = 4$ GeV.

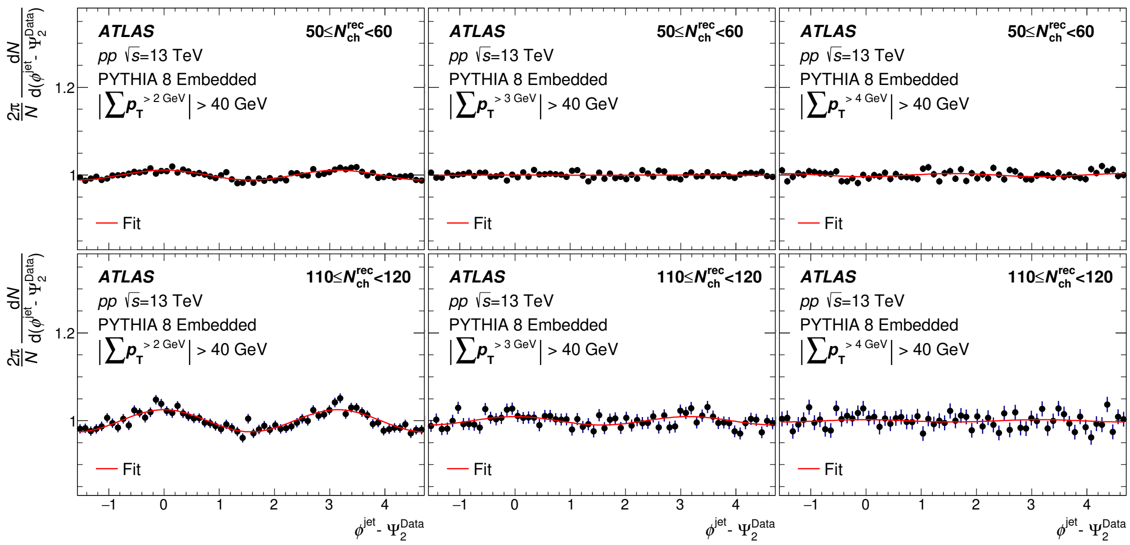

Figure 6: The distribution of $\phi^{\rm jet} - \Psi_2^{\rm Data}$ for the embedded jets. The continuous line indicates a Fourier fit to the distribution that includes a 2$^{\rm nd}$ order modulation. From left to right, the three panels in each row correspond to increasing thresholds X (in Eq. (4)) of 2 GeV, 3 GeV, and 4 GeV. The top (bottom) row corresponds to the 50–60 (110–120) multiplicity interval.

A.5 Cross checks on jet selections used in the analysis

This section discusses several checks that are made to test the sensitivity of the results on the jet selections used in the analysis.

- The sensitivity of the $h^{UE} - h^{J}$ v_2 measurements to the $p_{\mathrm{T}}^{\mathrm{G}}$ selection is evaluated by varying the $p_{\mathrm{T}}^{\mathrm{G}}$ selection threshold from the nominal value of 40 GeV to 35 GeV and 50 GeV.
- The sensitivity of the v_2 to the p_{T} threshold applied on the jet constituents in Eq. (2) is checked by raising it from its default value of 4 GeV to 4.5 GeV.
- The sensitivity of results to the choice of the jet $p_{\mathrm{T}}^{\mathrm{G}}$ used to isolate the h^{UE} tracks is investigated by increasing the threshold from its nominal value of 15 GeV to 20 GeV.
- As stated in the Letter as isolation requirement is imposed on the $p_{\mathrm{T}}^{\mathrm{G}} > 40$ GeV jets in the $h^{UE} - h^{J}$ correlations. This isolation requirement requires that there are no $p_{\mathrm{T}}^{\mathrm{G}} > 15$ GeV jets within $\Delta R = 1$ of the $p_{\mathrm{T}}^{\mathrm{G}} > 40$ GeV jets used in the $h^{UE} - h^{J}$ correlation analysis. As a cross-check the measurements are repeated with this isolation requirement removed.

For all these cases no significant variation is observed in the measurements, and the results with these variations are consistent with the nominal ones within the quoted systematic and statistical uncertainties.

The ATLAS Collaboration

G. Aad[102], B. Abbott[120], K. Abeling[55], N.J. Abicht[49], S.H. Abidi[29], A. Aboulhorma[35e], H. Abramowicz[151], H. Abreu[150], Y. Abulaiti[117], A.C. Abusleme Hoffman[137a], B.S. Acharya[69a,69b,n], C. Adam Bourdarios[4], L. Adamczyk[85a], L. Adamek[155], S.V. Addepalli[26], J. Adelman[115], A. Adiguzel[21c], T. Adye[134], A.A. Affolder[136], Y. Afik[36], M.N. Agaras[13], J. Agarwala[73a,73b], A. Aggarwal[100], C. Agheorghiesei[27c], A. Ahmad[36], F. Ahmadov[38,z], W.S. Ahmed[104], S. Ahuja[95], X. Ai[62a], G. Aielli[76a,76b], M. Ait Tamlihat[35e], B. Aitbenchikh[35a], I. Aizenberg[168], M. Akbiyik[100], T.P.A. Åkesson[98], A.V. Akimov[37], D. Akiyama[167], N.N. Akolkar[24], K. Al Khoury[41], G.L. Alberghi[23b], J. Albert[164], P. Albicocco[53], G.L. Albouy[60], S. Alderweireldt[52], M. Aleksa[36], I.N. Aleksandrov[38], C. Alexa[27b], T. Alexopoulos[10], A. Alfonsi[114], F. Alfonsi[23b], M. Algren[56], M. Alhroob[120], B. Ali[132], H.M.J. Ali[91], S. Ali[148], S.W. Alibocus[92], M. Aliev[37], G. Alimonti[71a], W. Alkakhi[55], C. Allaire[66], B.M.M. Allbrooke[146], J.F. Allen[52], C.A. Allendes Flores[137f], P.P. Allport[20], A. Aloisio[72a,72b], F. Alonso[90], C. Alpigiani[138], M. Alvarez Estevez[99], A. Alvarez Fernandez[100], M.G. Alviggi[72a,72b], M. Aly[101], Y. Amaral Coutinho[82b], A. Ambler[104], C. Amelung[36], M. Amerl[101], C.G. Ames[109], D. Amidei[106], S.P. Amor Dos Santos[130a], K.R. Amos[162], V. Ananiev[125], C. Anastopoulos[139], T. Andeen[11], J.K. Anders[36], S.Y. Andrean[47a,47b], A. Andreazza[71a,71b], S. Angelidakis[9], A. Angerami[41,ac], A.V. Anisenkov[37], A. Annovi[74a], C. Antel[56], M.T. Anthony[139], E. Antipov[145], M. Antonelli[53], D.J.A. Antrim[17a], F. Anulli[75a], M. Aoki[83], T. Aoki[153], J.A. Aparisi Pozo[162], M.A. Aparo[146], L. Aperio Bella[48], C. Appelt[18], A. Apyan[26], N. Aranzabal[36], C. Arcangeletti[53], A.T.H. Arce[51], E. Arena[92], J-F. Arguin[108], S. Argyropoulos[54], J.-H. Arling[48], A.J. Armbruster[36], O. Arnaez[4], H. Arnold[114], Z.P. Arrubarrena Tame[109], G. Artoni[75a,75b], H. Asada[111], K. Asai[118], S. Asai[153], N.A. Asbah[61], J. Assahsah[35d], K. Assamagan[29], R. Astalos[28a], S. Atashi[159], R.J. Atkin[33a], M. Atkinson[161], N.B. Atlay[18], H. Atmani[62b], P.A. Atmasiddha[106], K. Augsten[132], S. Auricchio[72a,72b], A.D. Auriol[20], V.A. Austrup[101], G. Avolio[36], K. Axiotis[56], G. Azuelos[108,ae], D. Babal[28b], H. Bachacou[135], K. Bachas[152,q], A. Bachiu[34], F. Backman[47a,47b], A. Badea[61], P. Bagnaia[75a,75b], M. Bahmani[18], A.J. Bailey[162], V.R. Bailey[161], J.T. Baines[134], C. Bakalis[10], O.K. Baker[171], E. Bakos[15], D. Bakshi Gupta[8], R. Balasubramanian[114], E.M. Baldin[37], P. Balek[85a], E. Ballabene[23b,23a], F. Balli[135], L.M. Baltes[63a], W.K. Balunas[32], J. Balz[100], E. Banas[86], M. Bandieramonte[129], A. Bandyopadhyay[24], S. Bansal[24], L. Barak[151], M. Barakat[48], E.L. Barberio[105], D. Barberis[57b,57a], M. Barbero[102], G. Barbour[96], K.N. Barends[33a], T. Barillari[110], M-S. Barisits[36], T. Barklow[143], P. Baron[122], D.A. Baron Moreno[101], A. Baroncelli[62a], G. Barone[29], A.J. Barr[126], J.D. Barr[96], L. Barranco Navarro[47a,47b], F. Barreiro[99], J. Barreiro Guimarães da Costa[14a], U. Barron[151], M.G. Barros Teixeira[130a], S. Barsov[37], F. Bartels[63a], R. Bartoldus[143], A.E. Barton[91], P. Bartos[28a], A. Basan[100], M. Baselga[49], A. Bassalat[66], M.J. Basso[155], C.R. Basson[101], R.L. Bates[59], S. Batlamous[35e], J.R. Batley[32], B. Batool[141], M. Battaglia[136], D. Battulga[18], M. Bauce[75a,75b], M. Bauer[36], P. Bauer[24], L.T. Bazzano Hurrell[30], J.B. Beacham[51], T. Beau[127], P.H. Beauchemin[158], F. Becherer[54], P. Bechtle[24], H.P. Beck[19,p], K. Becker[166], A.J. Beddall[21d], V.A. Bednyakov[38], C.P. Bee[145], L.J. Beemster[15], T.A. Beermann[36], M. Begalli[82d,82d], M. Begel[29], A. Behera[145], J.K. Behr[48], J.F. Beirer[55], F. Beisiegel[24], M. Belfkir[116b], G. Bella[151], L. Bellagamba[23b], A. Bellerive[34], P. Bellos[20], K. Beloborodov[37], N.L. Belyaev[37], D. Benchekroun[35a], F. Bendebba[35a], Y. Benhammou[151], M. Benoit[29], J.R. Bensinger[26], S. Bentvelsen[114],

L. Beresford[48], M. Beretta[53], E. Bergeaas Kuutmann[160], N. Berger[4], B. Bergmann[132], J. Beringer[17a], G. Bernardi[5], C. Bernius[143], F.U. Bernlochner[24], F. Bernon[36,102], T. Berry[95], P. Berta[133], A. Berthold[50], I.A. Bertram[91], S. Bethke[110], A. Betti[75a,75b], A.J. Bevan[94], M. Bhamjee[33c], S. Bhatta[145], D.S. Bhattacharya[165], P. Bhattarai[26], V.S. Bhopatkar[121], R. Bi[29,ag], R.M. Bianchi[129], G. Bianco[23b,23a], O. Biebel[109], R. Bielski[123], M. Biglietti[77a], T.R.V. Billoud[132], M. Bindi[55], A. Bingul[21b], C. Bini[75a,75b], A. Biondini[92], C.J. Birch-sykes[101], G.A. Bird[20,134], M. Birman[168], M. Biros[133], T. Bisanz[49], E. Bisceglie[43b,43a], D. Biswas[141], A. Bitadze[101], K. Bjørke[125], I. Bloch[48], C. Blocker[26], A. Blue[59], U. Blumenschein[94], J. Blumenthal[100], G.J. Bobbink[114], V.S. Bobrovnikov[37], M. Boehler[54], B. Boehm[165], D. Bogavac[36], A.G. Bogdanchikov[37], C. Bohm[47a], V. Boisvert[95], P. Bokan[48], T. Bold[85a], M. Bomben[5], M. Bona[94], M. Boonekamp[135], C.D. Booth[95], A.G. Borbély[59], I.S. Bordulev[37], H.M. Borecka-Bielska[108], L.S. Borgna[96], G. Borissov[91], D. Bortoletto[126], D. Boscherini[23b], M. Bosman[13], J.D. Bossio Sola[36], K. Bouaouda[35a], N. Bouchhar[162], J. Boudreau[129], E.V. Bouhova-Thacker[91], D. Boumediene[40], R. Bouquet[5], A. Boveia[119], J. Boyd[36], D. Boye[29], I.R. Boyko[38], J. Bracinik[20], N. Brahimi[62d], G. Brandt[170], O. Brandt[32], F. Braren[48], B. Brau[103], J.E. Brau[123], R. Brener[168], L. Brenner[114], R. Brenner[160], S. Bressler[168], D. Britton[59], D. Britzger[110], I. Brock[24], G. Brooijmans[41], W.K. Brooks[137f], E. Brost[29], L.M. Brown[164,l], L.E. Bruce[61], T.L. Bruckler[126], P.A. Bruckman de Renstrom[86], B. Brüers[48], D. Bruncko[28b,*], A. Bruni[23b], G. Bruni[23b], M. Bruschi[23b], N. Bruscino[75a,75b], T. Buanes[16], Q. Buat[138], D. Buchin[110], A.G. Buckley[59], M.K. Bugge[125], O. Bulekov[37], B.A. Bullard[143], S. Burdin[92], C.D. Burgard[49], A.M. Burger[40], B. Burghgrave[8], O. Burlayenko[54], J.T.P. Burr[32], C.D. Burton[11], J.C. Burzynski[142], E.L. Busch[41], V. Büscher[100], P.J. Bussey[59], J.M. Butler[25], C.M. Buttar[59], J.M. Butterworth[96], W. Buttinger[134], C.J. Buxo Vazquez[107], A.R. Buzykaev[37], G. Cabras[23b], S. Cabrera Urbán[162], D. Caforio[58], H. Cai[129], Y. Cai[14a,14e], V.M.M. Cairo[36], O. Cakir[3a], N. Calace[36], P. Calafiura[17a], G. Calderini[127], P. Calfayan[68], G. Callea[59], L.P. Caloba[82b], D. Calvet[40], S. Calvet[40], T.P. Calvet[102], M. Calvetti[74a,74b], R. Camacho Toro[127], S. Camarda[36], D. Camarero Munoz[26], P. Camarri[76a,76b], M.T. Camerlingo[72a,72b], D. Cameron[125], C. Camincher[164], M. Campanelli[96], A. Camplani[42], V. Canale[72a,72b], A. Canesse[104], M. Cano Bret[80], J. Cantero[162], Y. Cao[161], F. Capocasa[26], M. Capua[43b,43a], A. Carbone[71a,71b], R. Cardarelli[76a], J.C.J. Cardenas[8], F. Cardillo[162], T. Carli[36], G. Carlino[72a], J.I. Carlotto[13], B.T. Carlson[129,r], E.M. Carlson[164,156a], L. Carminati[71a,71b], A. Carnelli[135], M. Carnesale[75a,75b], S. Caron[113], E. Carquin[137f], S. Carrá[71a,71b], G. Carratta[23b,23a], F. Carrio Argos[33g], J.W.S. Carter[155], T.M. Carter[52], M.P. Casado[13,i], M. Caspar[48], E.G. Castiglia[171], F.L. Castillo[4], L. Castillo Garcia[13], V. Castillo Gimenez[162], N.F. Castro[130a,130e], A. Catinaccio[36], J.R. Catmore[125], V. Cavaliere[29], N. Cavalli[23b,23a], V. Cavasinni[74a,74b], Y.C. Cekmecelioglu[48], E. Celebi[21a], F. Celli[126], M.S. Centonze[70a,70b], K. Cerny[122], A.S. Cerqueira[82a], A. Cerri[146], L. Cerrito[76a,76b], F. Cerutti[17a], B. Cervato[141], A. Cervelli[23b], G. Cesarini[53], S.A. Cetin[21d], Z. Chadi[35a], D. Chakraborty[115], M. Chala[130f], J. Chan[169], W.Y. Chan[153], J.D. Chapman[32], E. Chapon[135], B. Chargeishvili[149b], D.G. Charlton[20], T.P. Charman[94], M. Chatterjee[19], C. Chauhan[133], S. Chekanov[6], S.V. Chekulaev[156a], G.A. Chelkov[38,a], A. Chen[106], B. Chen[151], B. Chen[164], H. Chen[14c], H. Chen[29], J. Chen[62c], J. Chen[142], M. Chen[126], S. Chen[153], S.J. Chen[14c], X. Chen[62c], X. Chen[14b,ad], Y. Chen[62a], C.L. Cheng[169], H.C. Cheng[64a], S. Cheong[143], A. Cheplakov[38], E. Cheremushkina[48], E. Cherepanova[114], R. Cherkaoui El Moursli[35e], E. Cheu[7], K. Cheung[65], L. Chevalier[135], V. Chiarella[53], G. Chiarelli[74a], N. Chiedde[102], G. Chiodini[70a], A.S. Chisholm[20], A. Chitan[27b], M. Chitishvili[162], M.V. Chizhov[38],

K. Choi[11], A.R. Chomont[75a,75b], Y. Chou[103], E.Y.S. Chow[114], T. Chowdhury[33g], K.L. Chu[168], M.C. Chu[64a], X. Chu[14a,14e], J. Chudoba[131], J.J. Chwastowski[86], D. Cieri[110], K.M. Ciesla[85a], V. Cindro[93], A. Ciocio[17a], F. Cirotto[72a,72b], Z.H. Citron[168], M. Citterio[71a], D.A. Ciubotaru[27b], B.M. Ciungu[155], A. Clark[56], P.J. Clark[52], J.M. Clavijo Columbie[48], S.E. Clawson[48], C. Clement[47a,47b], J. Clercx[48], L. Clissa[23b,23a], Y. Coadou[102], M. Cobal[69a,69c], A. Coccaro[57b], R.F. Coelho Barrue[130a], R. Coelho Lopes De Sa[103], S. Coelli[71a], H. Cohen[151], A.E.C. Coimbra[71a,71b], B. Cole[41], J. Collot[60], P. Conde Muiño[130a,130g], M.P. Connell[33c], S.H. Connell[33c], I.A. Connelly[59], E.I. Conroy[126], F. Conventi[72a,af], H.G. Cooke[20], A.M. Cooper-Sarkar[126], A. Cordeiro Oudot Choi[127], F. Cormier[163], L.D. Corpe[40], M. Corradi[75a,75b], F. Corriveau[104,x], A. Cortes-Gonzalez[18], M.J. Costa[162], F. Costanza[4], D. Costanzo[139], B.M. Cote[119], G. Cowan[95], K. Cranmer[169], D. Cremonini[23b,23a], S. Crépé-Renaudin[60], F. Crescioli[127], M. Cristinziani[141], M. Cristoforetti[78a,78b], V. Croft[114], J.E. Crosby[121], G. Crosetti[43b,43a], A. Cueto[99], T. Cuhadar Donszelmann[159], H. Cui[14a,14e], Z. Cui[7], W.R. Cunningham[59], F. Curcio[43b,43a], P. Czodrowski[36], M.M. Czurylo[63b], M.J. Da Cunha Sargedas De Sousa[62a], J.V. Da Fonseca Pinto[82b], C. Da Via[101], W. Dabrowski[85a], T. Dado[49], S. Dahbi[33g], T. Dai[106], C. Dallapiccola[103], M. Dam[42], G. D'amen[29], V. D'Amico[109], J. Damp[100], J.R. Dandoy[128], M.F. Daneri[30], M. Danninger[142], V. Dao[36], G. Darbo[57b], S. Darmora[6], S.J. Das[29], S. D'Auria[71a,71b], C. David[156b], T. Davidek[133], B. Davis-Purcell[34], I. Dawson[94], H.A. Day-hall[132], K. De[8], R. De Asmundis[72a], N. De Biase[48], S. De Castro[23b,23a], N. De Groot[113], P. de Jong[114], H. De la Torre[107], A. De Maria[14c], A. De Salvo[75a], U. De Sanctis[76a,76b], A. De Santo[146], J.B. De Vivie De Regie[60], D.V. Dedovich[38], J. Degens[114], A.M. Deiana[44], F. Del Corso[23b,23a], J. Del Peso[99], F. Del Rio[63a], F. Deliot[135], C.M. Delitzsch[49], M. Della Pietra[72a,72b], D. Della Volpe[56], A. Dell'Acqua[36], L. Dell'Asta[71a,71b], M. Delmastro[4], P.A. Delsart[60], S. Demers[171], M. Demichev[38], S.P. Denisov[37], L. D'Eramo[40], D. Derendarz[86], F. Derue[127], P. Dervan[92], K. Desch[24], C. Deutsch[24], F.A. Di Bello[57b,57a], A. Di Ciaccio[76a,76b], L. Di Ciaccio[4], A. Di Domenico[75a,75b], C. Di Donato[72a,72b], A. Di Girolamo[36], G. Di Gregorio[5], A. Di Luca[78a,78b], B. Di Micco[77a,77b], R. Di Nardo[77a,77b], C. Diaconu[102], F.A. Dias[114], T. Dias Do Vale[142], M.A. Diaz[137a,137b], F.G. Diaz Capriles[24], M. Didenko[162], E.B. Diehl[106], L. Diehl[54], S. Díez Cornell[48], C. Diez Pardos[141], C. Dimitriadi[24,160], A. Dimitrievska[17a], J. Dingfelder[24], I-M. Dinu[27b], S.J. Dittmeier[63b], F. Dittus[36], F. Djama[102], T. Djobava[149b], J.I. Djuvsland[16], C. Doglioni[101,98], J. Dolejsi[133], Z. Dolezal[133], M. Donadelli[82c], B. Dong[107], J. Donini[40], A. D'Onofrio[77a,77b], M. D'Onofrio[92], J. Dopke[134], A. Doria[72a], N. Dos Santos Fernandes[130a], M.T. Dova[90], A.T. Doyle[59], M.A. Draguet[126], E. Dreyer[168], I. Drivas-koulouris[10], A.S. Drobac[158], M. Drozdova[56], D. Du[62a], T.A. du Pree[114], F. Dubinin[37], M. Dubovsky[28a], E. Duchovni[168], G. Duckeck[109], O.A. Ducu[27b], D. Duda[52], A. Dudarev[36], E.R. Duden[26], M. D'uffizi[101], L. Duflot[66], M. Dührssen[36], C. Dülsen[170], A.E. Dumitriu[27b], M. Dunford[63a], S. Dungs[49], K. Dunne[47a,47b], A. Duperrin[102], H. Duran Yildiz[3a], M. Düren[58], A. Durglishvili[149b], B.L. Dwyer[115], G.I. Dyckes[17a], M. Dyndal[85a], S. Dysch[101], B.S. Dziedzic[86], Z.O. Earnshaw[146], G.H. Eberwein[126], B. Eckerova[28a], S. Eggebrecht[55], M.G. Eggleston[51], E. Egidio Purcino De Souza[127], L.F. Ehrke[56], G. Eigen[16], K. Einsweiler[17a], T. Ekelof[160], P.A. Ekman[98], S. El Farkh[35b], Y. El Ghazali[35b], H. El Jarrari[35e,148], A. El Moussaouy[35a], V. Ellajosyula[160], M. Ellert[160], F. Ellinghaus[170], A.A. Elliot[94], N. Ellis[36], J. Elmsheuser[29], M. Elsing[36], D. Emeliyanov[134], Y. Enari[153], I. Ene[17a], S. Epari[13], J. Erdmann[49], P.A. Erland[86], M. Errenst[170], M. Escalier[66], C. Escobar[162], E. Etzion[151], G. Evans[130a], H. Evans[68], L.S. Evans[95], M.O. Evans[146], A. Ezhilov[37], S. Ezzarqtouni[35a], F. Fabbri[59],

L. Fabbri [23b,23a], G. Facini [96], V. Fadeyev [136], R.M. Fakhrutdinov [37], S. Falciano [75a], L.F. Falda Ulhoa Coelho [36], P.J. Falke [24], J. Faltova [133], C. Fan [161], Y. Fan [14a], Y. Fang [14a,14e], M. Fanti [71a,71b], M. Faraj [69a,69b], Z. Farazpay [97], A. Farbin [8], A. Farilla [77a], T. Farooque [107], S.M. Farrington [52], F. Fassi [35e], D. Fassouliotis [9], M. Faucci Giannelli [76a,76b], W.J. Fawcett [32], L. Fayard [66], P. Federic [133], P. Federicova [131], O.L. Fedin [37,a], G. Fedotov [37], M. Feickert [169], L. Feligioni [102], D.E. Fellers [123], C. Feng [62b], M. Feng [14b], Z. Feng [114], M.J. Fenton [159], A.B. Fenyuk [37], L. Ferencz [48], R.A.M. Ferguson [91], S.I. Fernandez Luengo [137f], J.A. Fernandez Pretel [54], M.J.V. Fernoux [102], J. Ferrando [48], A. Ferrari [160], P. Ferrari [114,113], R. Ferrari [73a], D. Ferrere [56], C. Ferretti [106], F. Fiedler [100], A. Filipčič [93], E.K. Filmer [1], F. Filthaut [113], M.C.N. Fiolhais [130a,130c,c], L. Fiorini [162], W.C. Fisher [107], T. Fitschen [101], P.M. Fitzhugh [135], I. Fleck [141], P. Fleischmann [106], T. Flick [170], L. Flores [128], M. Flores [33d], L.R. Flores Castillo [64a], L. Flores Sanz De Acedo [36], F.M. Follega [78a,78b], N. Fomin [16], J.H. Foo [155], B.C. Forland [68], A. Formica [135], A.C. Forti [101], E. Fortin [36], A.W. Fortman [61], M.G. Foti [17a], L. Fountas [9], D. Fournier [66], H. Fox [91], P. Francavilla [74a,74b], S. Francescato [61], S. Franchellucci [56], M. Franchini [23b,23a], S. Franchino [63a], D. Francis [36], L. Franco [113], L. Franconi [48], M. Franklin [61], G. Frattari [26], A.C. Freegard [94], W.S. Freund [82b], Y.Y. Frid [151], N. Fritzsche [50], A. Froch [54], D. Froidevaux [36], J.A. Frost [126], Y. Fu [62a], M. Fujimoto [118], E. Fullana Torregrosa [162,*], K.Y. Fung [64a], E. Furtado De Simas Filho [82b], M. Furukawa [153], J. Fuster [162], A. Gabrielli [23b,23a], A. Gabrielli [155], P. Gadow [48], G. Gagliardi [57b,57a], L.G. Gagnon [17a], E.J. Gallas [126], B.J. Gallop [134], K.K. Gan [119], S. Ganguly [153], J. Gao [62a], Y. Gao [52], F.M. Garay Walls [137a,137b], B. Garcia [29,ag], C. García [162], A. Garcia Alonso [114], A.G. Garcia Caffaro [171], J.E. García Navarro [162], M. Garcia-Sciveres [17a], G.L. Gardner [128], R.W. Gardner [39], N. Garelli [158], D. Garg [80], R.B. Garg [143], J.M. Gargan [52], C.A. Garner [155], S.J. Gasiorowski [138], P. Gaspar [82b], G. Gaudio [73a], V. Gautam [13], P. Gauzzi [75a,75b], I.L. Gavrilenko [37], A. Gavrilyuk [37], C. Gay [163], G. Gaycken [48], E.N. Gazis [10], A.A. Geanta [27b], C.M. Gee [136], C. Gemme [57b], M.H. Genest [60], S. Gentile [75a,75b], S. George [95], W.F. George [20], T. Geralis [46], P. Gessinger-Befurt [36], M.E. Geyik [170], M. Ghneimat [141], K. Ghorbanian [94], A. Ghosal [141], A. Ghosh [159], A. Ghosh [7], B. Giacobbe [23b], S. Giagu [75a,75b], P. Giannetti [74a], A. Giannini [62a], S.M. Gibson [95], M. Gignac [136], D.T. Gil [85b], A.K. Gilbert [85a], B.J. Gilbert [41], D. Gillberg [34], G. Gilles [114], N.E.K. Gillwald [48], L. Ginabat [127], D.M. Gingrich [2,ae], M.P. Giordani [69a,69c], P.F. Giraud [135], G. Giugliarelli [69a,69c], D. Giugni [71a], F. Giuli [36], I. Gkialas [9,j], L.K. Gladilin [37], C. Glasman [99], G.R. Gledhill [123], M. Glisic [123], I. Gnesi [43b,f], Y. Go [29,ag], M. Goblirsch-Kolb [36], B. Gocke [49], D. Godin [108], B. Gokturk [21a], S. Goldfarb [105], T. Golling [56], M.G.D. Gololo [33g], D. Golubkov [37], J.P. Gombas [107], A. Gomes [130a,130b], G. Gomes Da Silva [141], A.J. Gomez Delegido [162], R. Gonçalo [130a,130c], G. Gonella [123], L. Gonella [20], A. Gongadze [38], F. Gonnella [20], J.L. Gonski [41], S. González de la Hoz [162], S. Gonzalez Fernandez [13], R. Gonzalez Lopez [92], C. Gonzalez Renteria [17a], R. Gonzalez Suarez [160], S. Gonzalez-Sevilla [56], G.R. Gonzalvo Rodriguez [162], R.Y. González Andana [52], L. Goossens [36], P.A. Gorbounov [37], B. Gorini [36], E. Gorini [70a,70b], A. Gorišek [93], T.C. Gosart [128], A.T. Goshaw [51], M.I. Gostkin [38], S. Goswami [121], C.A. Gottardo [36], M. Gouighri [35b], V. Goumarre [48], A.G. Goussiou [138], N. Govender [33c], I. Grabowska-Bold [85a], K. Graham [34], E. Gramstad [125], S. Grancagnolo [70a,70b], M. Grandi [146], V. Gratchev [37,*], P.M. Gravila [27f], F.G. Gravili [70a,70b], H.M. Gray [17a], M. Greco [70a,70b], C. Grefe [24], I.M. Gregor [48], P. Grenier [143], C. Grieco [13], A.A. Grillo [136], K. Grimm [31], S. Grinstein [13,u], J.-F. Grivaz [66], E. Gross [168], J. Grosse-Knetter [55], C. Grud [106], J.C. Grundy [126], L. Guan [106], W. Guan [169], C. Gubbels [163], J.G.R. Guerrero Rojas [162], G. Guerrieri [69a,69b], F. Guescini [110], R. Gugel [100], J.A.M. Guhit [106], A. Guida [18], T. Guillemin [4], E. Guilloton [166,134], S. Guindon [36], F. Guo [14a,14e], J. Guo [62c],

L. Guo [48], Y. Guo [106], R. Gupta [48], S. Gurbuz [24], S.S. Gurdasani [54], G. Gustavino [36], M. Guth [56], P. Gutierrez [120], L.F. Gutierrez Zagazeta [128], C. Gutschow [96], C. Gwenlan [126], C.B. Gwilliam [92], E.S. Haaland [125], A. Haas [117], M. Habedank [48], C. Haber [17a], H.K. Hadavand [8], A. Hadef [100], S. Hadzic [110], J.J. Hahn [141], E.H. Haines [96], M. Haleem [165], J. Haley [121], J.J. Hall [139], G.D. Hallewell [102], L. Halser [19], K. Hamano [164], H. Hamdaoui [35e], M. Hamer [24], G.N. Hamity [52], E.J. Hampshire [95], J. Han [62b], K. Han [62a], L. Han [14c], L. Han [62a], S. Han [17a], Y.F. Han [155], K. Hanagaki [83], M. Hance [136], D.A. Hangal [41,ac], H. Hanif [142], M.D. Hank [128], R. Hankache [101], J.B. Hansen [42], J.D. Hansen [42], P.H. Hansen [42], K. Hara [157], D. Harada [56], T. Harenberg [170], S. Harkusha [37], M.L. Harris[103], Y.T. Harris [126], J. Harrison [13], N.M. Harrison [119], P.F. Harrison[166], N.M. Hartman [143], N.M. Hartmann [109], Y. Hasegawa [140], A. Hasib [52], S. Haug [19], R. Hauser [107], C.M. Hawkes [20], R.J. Hawkings [36], Y. Hayashi [153], S. Hayashida [111], D. Hayden [107], C. Hayes [106], R.L. Hayes [114], C.P. Hays [126], J.M. Hays [94], H.S. Hayward [92], F. He [62a], M. He [14a,14e], Y. He [154], Y. He [127], N.B. Heatley [94], V. Hedberg [98], A.L. Heggelund [125], N.D. Hehir [94], C. Heidegger [54], K.K. Heidegger [54], W.D. Heidorn [81], J. Heilman [34], S. Heim [48], T. Heim [17a], J.G. Heinlein [128], J.J. Heinrich [123], L. Heinrich [110], J. Hejbal [131], L. Helary [48], A. Held [169], S. Hellesund [16], C.M. Helling [163], S. Hellman [47a,47b], C. Helsens [36], R.C.W. Henderson[91], L. Henkelmann [32], A.M. Henriques Correia[36], H. Herde [98], Y. Hernández Jiménez [145], L.M. Herrmann [24], T. Herrmann [50], G. Herten [54], R. Hertenberger [109], L. Hervas [36], M.E. Hesping [100], N.P. Hessey [156a], H. Hibi [84], S.J. Hillier [20], J.R. Hinds[107], F. Hinterkeuser [24], M. Hirose [124], S. Hirose [157], D. Hirschbuehl [170], T.G. Hitchings [101], B. Hiti [93], J. Hobbs [145], R. Hobincu [27e], N. Hod [168], M.C. Hodgkinson [139], B.H. Hodkinson [32], A. Hoecker [36], J. Hofer [48], T. Holm [24], M. Holzbock [110], L.B.A.H. Hommels [32], B.P. Honan [101], J. Hong [62c], T.M. Hong [129], B.H. Hooberman [161], W.H. Hopkins [6], Y. Horii [111], S. Hou [148], A.S. Howard [93], J. Howarth [59], J. Hoya [6], M. Hrabovsky [122], A. Hrynevich [48], T. Hryn'ova [4], P.J. Hsu [65], S.-C. Hsu [138], Q. Hu [41], Y.F. Hu [14a,14e], S. Huang [64b], X. Huang [14c], Y. Huang [62a], Y. Huang [14a], Z. Huang [101], Z. Hubacek [132], M. Huebner [24], F. Huegging [24], T.B. Huffman [126], C.A. Hugli [48], M. Huhtinen [36], S.K. Huiberts [16], R. Hulsken [104], N. Huseynov [12,a], J. Huston [107], J. Huth [61], R. Hyneman [143], G. Iacobucci [56], G. Iakovidis [29], I. Ibragimov [141], L. Iconomidou-Fayard [66], P. Iengo [72a,72b], R. Iguchi [153], T. Iizawa [83,ab], Y. Ikegami [83], N. Ilic [155], H. Imam [35a], M. Ince Lezki [56], T. Ingebretsen Carlson [47a,47b], G. Introzzi [73a,73b], M. Iodice [77a], V. Ippolito [75a,75b], R.K. Irwin [92], M. Ishino [153], W. Islam [169], C. Issever [18,48], S. Istin [21a], H. Ito [167], J.M. Iturbe Ponce [64a], R. Iuppa [78a,78b], A. Ivina [168], J.M. Izen [45], V. Izzo [72a], P. Jacka [131,132], P. Jackson [1], R.M. Jacobs [48], B.P. Jaeger [142], C.S. Jagfeld [109], P. Jain [54], G. Jäkel [170], K. Jakobs [54], T. Jakoubek [168], J. Jamieson [59], K.W. Janas [85a], A.E. Jaspan [92], M. Javurkova [103], F. Jeanneau [135], L. Jeanty [123], J. Jejelava [149a,aa], P. Jenni [54,g], C.E. Jessiman [34], S. Jézéquel [4], C. Jia[62b], J. Jia [145], X. Jia [61], X. Jia [14a,14e], Z. Jia [14c], Y. Jiang[62a], S. Jiggins [48], J. Jimenez Pena [13], S. Jin [14c], A. Jinaru [27b], O. Jinnouchi [154], P. Johansson [139], K.A. Johns [7], J.W. Johnson [136], D.M. Jones [32], E. Jones [48], P. Jones [32], R.W.L. Jones [91], T.J. Jones [92], R. Joshi [119], J. Jovicevic [15], X. Ju [17a], J.J. Junggeburth [36], T. Junkermann [63a], A. Juste Rozas [13,u], M.K. Juzek [86], S. Kabana [137e], A. Kaczmarska [86], M. Kado [110], H. Kagan [119], M. Kagan [143], A. Kahn[41], A. Kahn [128], C. Kahra [100], T. Kaji [167], E. Kajomovitz [150], N. Kakati [168], I. Kalaitzidou [54], C.W. Kalderon [29], A. Kamenshchikov [155], S. Kanayama [154], N.J. Kang [136], D. Kar [33g], K. Karava [126], M.J. Kareem [156b], E. Karentzos [54], I. Karkanias [152], O. Karkout [114], S.N. Karpov [38], Z.M. Karpova [38], V. Kartvelishvili [91], A.N. Karyukhin [37], E. Kasimi [152], J. Katzy [48], S. Kaur [34], K. Kawade [140], T. Kawamoto [135], E.F. Kay [36], F.I. Kaya [158], S. Kazakos [107], V.F. Kazanin [37], Y. Ke [145], J.M. Keaveney [33a],

R. Keeler [164], G.V. Kehris [61], J.S. Keller [34], A.S. Kelly[96], J.J. Kempster [146], K.E. Kennedy [41], P.D. Kennedy [100], O. Kepka [131], B.P. Kerridge [166], S. Kersten [170], B.P. Kerševan [93], S. Keshri [66], L. Keszeghova [28a], S. Ketabchi Haghighat [155], M. Khandoga [127], A. Khanov [121], A.G. Kharlamov [37], T. Kharlamova [37], E.E. Khoda [138], T.J. Khoo [18], G. Khoriauli [165], J. Khubua [149b], Y.A.R. Khwaira [66], M. Kiehn [36], A. Kilgallon [123], D.W. Kim [47a,47b], Y.K. Kim [39], N. Kimura [96], A. Kirchhoff [55], C. Kirfel [24], F. Kirfel [24], J. Kirk [134], A.E. Kiryunin [110], C. Kitsaki [10], O. Kivernyk [24], M. Klassen [63a], C. Klein [34], L. Klein [165], M.H. Klein [106], M. Klein [92], S.B. Klein [56], U. Klein [92], P. Klimek [36], A. Klimentov [29], T. Klioutchnikova [36], P. Kluit [114], S. Kluth [110], E. Kneringer [79], T.M. Knight [155], A. Knue [54], R. Kobayashi [87], S.F. Koch [126], M. Kocian [143], P. Kodyš [133], D.M. Koeck [123], P.T. Koenig [24], T. Koffas [34], M. Kolb [135], I. Koletsou [4], T. Komarek [122], K. Köneke [54], A.X.Y. Kong [1], T. Kono [118], N. Konstantinidis [96], B. Konya [98], R. Kopeliansky [68], S. Koperny [85a], K. Korcyl [86], K. Kordas [152,e], G. Koren [151], A. Korn [96], S. Korn [55], I. Korolkov [13], N. Korotkova [37], B. Kortman [114], O. Kortner [110], S. Kortner [110], W.H. Kostecka [115], V.V. Kostyukhin [141], A. Kotsokechagia [135], A. Kotwal [51], A. Koulouris [36], A. Kourkoumeli-Charalampidi [73a,73b], C. Kourkoumelis [9], E. Kourlitis [6], O. Kovanda [146], R. Kowalewski [164], W. Kozanecki [135], A.S. Kozhin [37], V.A. Kramarenko [37], G. Kramberger [93], P. Kramer [100], M.W. Krasny [127], A. Krasznahorkay [36], J.W. Kraus [170], J.A. Kremer [100], T. Kresse [50], J. Kretzschmar [92], K. Kreul [18], P. Krieger [155], S. Krishnamurthy [103], M. Krivos [133], K. Krizka [20], K. Kroeninger [49], H. Kroha [110], J. Kroll [131], J. Kroll [128], K.S. Krowpman [107], U. Kruchonak [38], H. Krüger [24], N. Krumnack[81], M.C. Kruse [51], J.A. Krzysiak [86], O. Kuchinskaia [37], S. Kuday [3a], S. Kuehn [36], R. Kuesters [54], T. Kuhl [48], V. Kukhtin [38], Y. Kulchitsky [37,a], S. Kuleshov [137d,137b], M. Kumar [33g], N. Kumari [102], A. Kupco [131], T. Kupfer[49], A. Kupich [37], O. Kuprash [54], H. Kurashige [84], L.L. Kurchaninov [156a], O. Kurdysh [66], Y.A. Kurochkin [37], A. Kurova [37], M. Kuze [154], A.K. Kvam [103], J. Kvita [122], T. Kwan [104], N.G. Kyriacou [106], L.A.O. Laatu [102], C. Lacasta [162], F. Lacava [75a,75b], H. Lacker [18], D. Lacour [127], N.N. Lad [96], E. Ladygin [38], B. Laforge [127], T. Lagouri [137e], S. Lai [55], I.K. Lakomiec [85a], N. Lalloue [60], J.E. Lambert [164,l], S. Lammers [68], W. Lampl [7], C. Lampoudis [152,e], A.N. Lancaster [115], E. Lançon [29], U. Landgraf [54], M.P.J. Landon [94], V.S. Lang [54], R.J. Langenberg [103], O.K.B. Langrekken [125], A.J. Lankford [159], F. Lanni [36], K. Lantzsch [24], A. Lanza [73a], A. Lapertosa [57b,57a], J.F. Laporte [135], T. Lari [71a], F. Lasagni Manghi [23b], M. Lassnig [36], V. Latonova [131], A. Laudrain [100], A. Laurier [150], S.D. Lawlor [95], Z. Lawrence [101], M. Lazzaroni [71a,71b], B. Le[101], E.M. Le Boulicaut [51], B. Leban [93], A. Lebedev [81], M. LeBlanc [36], F. Ledroit-Guillon [60], A.C.A. Lee[96], S.C. Lee [148], S. Lee [47a,47b], T.F. Lee [92], L.L. Leeuw [33c], H.P. Lefebvre [95], M. Lefebvre [164], C. Leggett [17a], G. Lehmann Miotto [36], M. Leigh [56], W.A. Leight [103], W. Leinonen [113], A. Leisos [152,t], M.A.L. Leite [82c], C.E. Leitgeb [48], R. Leitner [133], K.J.C. Leney [44], T. Lenz [24], S. Leone [74a], C. Leonidopoulos [52], A. Leopold [144], C. Leroy [108], R. Les [107], C.G. Lester [32], M. Levchenko [37], J. Levêque [4], D. Levin [106], L.J. Levinson [168], M.P. Lewicki [86], D.J. Lewis [4], A. Li [5], B. Li [62b], C. Li[62a], C-Q. Li [62c], H. Li [62a], H. Li [62b], H. Li [14c], H. Li [62b], K. Li [138], L. Li [62c], M. Li [14a,14e], Q.Y. Li [62a], S. Li [14a,14e], S. Li [62d,62c,d], T. Li [5,b], X. Li [104], Z. Li [126], Z. Li [104], Z. Li [92], Z. Li [14a,14e], Z. Liang [14a], M. Liberatore [48], B. Liberti [76a], K. Lie [64c], J. Lieber Marin [82b], H. Lien [68], K. Lin [107], R.E. Lindley [7], J.H. Lindon [2], A. Linss [48], E. Lipeles [128], A. Lipniacka [16], A. Lister [163], J.D. Little [4], B. Liu [14a], B.X. Liu [142], D. Liu [62d,62c], J.B. Liu [62a], J.K.K. Liu [32], K. Liu [62d,62c], M. Liu [62a], M.Y. Liu [62a], P. Liu [14a], Q. Liu [62d,138,62c], X. Liu [62a], Y. Liu [14d,14e], Y.L. Liu [106], Y.W. Liu [62a], J. Llorente Merino [142], S.L. Lloyd [94], E.M. Lobodzinska [48], P. Loch [7], S. Loffredo [76a,76b], T. Lohse [18], K. Lohwasser [139], E. Loiacono [48], M. Lokajicek [131], J.D. Lomas [20], J.D. Long [161],

I. Longarini[159], L. Longo[70a,70b], R. Longo[161], I. Lopez Paz[67], A. Lopez Solis[48], J. Lorenz[109], N. Lorenzo Martinez[4], A.M. Lory[109], O. Loseva[37], X. Lou[47a,47b], X. Lou[14a,14e], A. Lounis[66], J. Love[6], P.A. Love[91], G. Lu[14a,14e], M. Lu[80], S. Lu[128], Y.J. Lu[65], H.J. Lubatti[138], C. Luci[75a,75b], F.L. Lucio Alves[14c], A. Lucotte[60], F. Luehring[68], I. Luise[145], O. Lukianchuk[66], O. Lundberg[144], B. Lund-Jensen[144], N.A. Luongo[123], M.S. Lutz[151], D. Lynn[29], H. Lyons[92], R. Lysak[131], E. Lytken[98], V. Lyubushkin[38], T. Lyubushkina[38], M.M. Lyukova[145], H. Ma[29], K. Ma[62a], L.L. Ma[62b], Y. Ma[121], D.M. Mac Donell[164], G. Maccarrone[53], J.C. MacDonald[100], R. Madar[40], W.F. Mader[50], J. Maeda[84], T. Maeno[29], M. Maerker[50], H. Maguire[139], V. Maiboroda[135], A. Maio[130a,130b,130d], K. Maj[85a], O. Majersky[48], S. Majewski[123], N. Makovec[66], V. Maksimovic[15], B. Malaescu[127], Pa. Malecki[86], V.P. Maleev[37], F. Malek[60], M. Mali[93], D. Malito[95,o], U. Mallik[80], S. Maltezos[10], S. Malyukov[38], J. Mamuzic[13], G. Mancini[53], G. Manco[73a,73b], J.P. Mandalia[94], I. Mandić[93], L. Manhaes de Andrade Filho[82a], I.M. Maniatis[168], J. Manjarres Ramos[102], D.C. Mankad[168], A. Mann[109], B. Mansoulie[135], S. Manzoni[36], A. Marantis[152], G. Marchiori[5], M. Marcisovsky[131], C. Marcon[71a,71b], M. Marinescu[20], M. Marjanovic[120], E.J. Marshall[91], Z. Marshall[17a], S. Marti-Garcia[162], T.A. Martin[166], V.J. Martin[52], B. Martin dit Latour[16], L. Martinelli[75a,75b], M. Martinez[13,u], P. Martinez Agullo[162], V.I. Martinez Outschoorn[103], P. Martinez Suarez[13], S. Martin-Haugh[134], V.S. Martoiu[27b], A.C. Martyniuk[96], A. Marzin[36], D. Mascione[78a,78b], L. Masetti[100], T. Mashimo[153], J. Masik[101], A.L. Maslennikov[37], L. Massa[23b], P. Massarotti[72a,72b], P. Mastrandrea[74a,74b], A. Mastroberardino[43b,43a], T. Masubuchi[153], T. Mathisen[160], J. Matousek[133], N. Matsuzawa[153], J. Maurer[27b], B. Maček[93], D.A. Maximov[37], R. Mazini[148], I. Maznas[152], M. Mazza[107], S.M. Mazza[136], E. Mazzeo[71a,71b], C. Mc Ginn[29], J.P. Mc Gowan[104], S.P. Mc Kee[106], E.F. McDonald[105], A.E. McDougall[114], J.A. Mcfayden[146], R.P. McGovern[128], G. Mchedlidze[149b], R.P. Mckenzie[33g], T.C. Mclachlan[48], D.J. Mclaughlin[96], K.D. McLean[164], S.J. McMahon[134], P.C. McNamara[105], C.M. Mcpartland[92], R.A. McPherson[164,x], S. Mehlhase[109], A. Mehta[92], D. Melini[150], B.R. Mellado Garcia[33g], A.H. Melo[55], F. Meloni[48], A.M. Mendes Jacques Da Costa[101], H.Y. Meng[155], L. Meng[91], S. Menke[110], M. Mentink[36], E. Meoni[43b,43a], C. Merlassino[126], L. Merola[72a,72b], C. Meroni[71a], G. Merz[106], O. Meshkov[37], J. Metcalfe[6], A.S. Mete[6], C. Meyer[68], J-P. Meyer[135], R.P. Middleton[134], L. Mijović[52], G. Mikenberg[168], M. Mikestikova[131], M. Mikuž[93], H. Mildner[100], A. Milic[36], C.D. Milke[44], D.W. Miller[39], L.S. Miller[34], A. Milov[168], D.A. Milstead[47a,47b], T. Min[14c], A.A. Minaenko[37], I.A. Minashvili[149b], L. Mince[59], A.I. Mincer[117], B. Mindur[85a], M. Mineev[38], Y. Mino[87], L.M. Mir[13], M. Miralles Lopez[162], M. Mironova[17a], A. Mishima[153], M.C. Missio[113], T. Mitani[167], A. Mitra[166], V.A. Mitsou[162], O. Miu[155], P.S. Miyagawa[94], Y. Miyazaki[89], A. Mizukami[83], T. Mkrtchyan[63a], M. Mlinarevic[96], T. Mlinarevic[96], M. Mlynarikova[36], S. Mobius[19], K. Mochizuki[108], P. Moder[48], P. Mogg[109], A.F. Mohammed[14a,14e], S. Mohapatra[41], G. Mokgatitswane[33g], L. Moleri[168], B. Mondal[141], S. Mondal[132], G. Monig[146], K. Mönig[48], E. Monnier[102], L. Monsonis Romero[162], J. Montejo Berlingen[13,83], M. Montella[119], F. Montereali[77a,77b], F. Monticelli[90], S. Monzani[69a,69c], N. Morange[66], A.L. Moreira De Carvalho[130a], M. Moreno Llácer[162], C. Moreno Martinez[56], P. Morettini[57b], S. Morgenstern[36], M. Morii[61], M. Morinaga[153], A.K. Morley[36], F. Morodei[75a,75b], L. Morvaj[36], P. Moschovakos[36], B. Moser[36], M. Mosidze[149b], T. Moskalets[54], P. Moskvitina[113], J. Moss[31,m], E.J.W. Moyse[103], O. Mtintsilana[33g], S. Muanza[102], J. Mueller[129], D. Muenstermann[91], R. Müller[19], G.A. Mullier[160], A.J. Mullin[32], J.J. Mullin[128], D.P. Mungo[155], D. Munoz Perez[162], F.J. Munoz Sanchez[101], M. Murin[101], W.J. Murray[166,134],

A. Murrone [71a,71b], J.M. Muse [120], M. Muškinja [17a], C. Mwewa [29], A.G. Myagkov [37,a], A.J. Myers [8], A.A. Myers[129], G. Myers [68], M. Myska [132], B.P. Nachman [17a], O. Nackenhorst [49], A.Nag Nag [50], K. Nagai [126], K. Nagano [83], J.L. Nagle [29,ag], E. Nagy [102], A.M. Nairz [36], Y. Nakahama [83], K. Nakamura [83], K. Nakkalil [5], H. Nanjo [124], R. Narayan [44], E.A. Narayanan [112], I. Naryshkin [37], M. Naseri [34], S. Nasri [116b], C. Nass [24], G. Navarro [22a], J. Navarro-Gonzalez [162], R. Nayak [151], A. Nayaz [18], P.Y. Nechaeva [37], F. Nechansky [48], L. Nedic [126], T.J. Neep [20], A. Negri [73a,73b], M. Negrini [23b], C. Nellist [114], C. Nelson [104], K. Nelson [106], S. Nemecek [131], M. Nessi [36,h], M.S. Neubauer [161], F. Neuhaus [100], J. Neundorf [48], R. Newhouse [163], P.R. Newman [20], C.W. Ng [129], Y.W.Y. Ng [48], B. Ngair [35e], H.D.N. Nguyen [108], R.B. Nickerson [126], R. Nicolaidou [135], J. Nielsen [136], M. Niemeyer [55], J. Niermann [55,36], N. Nikiforou [36], V. Nikolaenko [37,a], I. Nikolic-Audit [127], K. Nikolopoulos [20], P. Nilsson [29], I. Ninca [48], H.R. Nindhito [56], G. Ninio [151], A. Nisati [75a], N. Nishu [2], R. Nisius [110], J-E. Nitschke [50], E.K. Nkadimeng [33g], S.J. Noacco Rosende [90], T. Nobe [153], D.L. Noel [32], T. Nommensen [147], M.B. Norfolk [139], R.R.B. Norisam [96], B.J. Norman [34], J. Novak [93], T. Novak [48], L. Novotny [132], R. Novotny [112], L. Nozka [122], K. Ntekas [159], N.M.J. Nunes De Moura Junior [82b], E. Nurse[96], J. Ocariz [127], A. Ochi [84], I. Ochoa [130a], S. Oerdek [160], J.T. Offermann [39], A. Ogrodnik [133], A. Oh [101], C.C. Ohm [144], H. Oide [83], R. Oishi [153], M.L. Ojeda [48], Y. Okazaki [87], M.W. O'Keefe[92], Y. Okumura [153], L.F. Oleiro Seabra [130a], S.A. Olivares Pino [137d], D. Oliveira Damazio [29], D. Oliveira Goncalves [82a], J.L. Oliver [159], M.J.R. Olsson [159], A. Olszewski [86], Ö.O. Öncel [54], D.C. O'Neil [142], A.P. O'Neill [19], A. Onofre [130a,130e], P.U.E. Onyisi [11], M.J. Oreglia [39], G.E. Orellana [90], D. Orestano [77a,77b], N. Orlando [13], R.S. Orr [155], V. O'Shea [59], L.M. Osojnak [128], R. Ospanov [62a], G. Otero y Garzon [30], H. Otono [89], P.S. Ott [63a], G.J. Ottino [17a], M. Ouchrif [35d], J. Ouellette [29], F. Ould-Saada [125], M. Owen [59], R.E. Owen [134], K.Y. Oyulmaz [21a], V.E. Ozcan [21a], N. Ozturk [8], S. Ozturk [21d], H.A. Pacey [32], A. Pacheco Pages [13], C. Padilla Aranda [13], G. Padovano [75a,75b], S. Pagan Griso [17a], G. Palacino [68], A. Palazzo [70a,70b], S. Palestini [36], J. Pan [171], T. Pan [64a], D.K. Panchal [11], C.E. Pandini [114], J.G. Panduro Vazquez [95], H. Pang [14b], P. Pani [48], G. Panizzo [69a,69c], L. Paolozzi [56], C. Papadatos [108], S. Parajuli [44], A. Paramonov [6], C. Paraskevopoulos [10], D. Paredes Hernandez [64b], T.H. Park [155], M.A. Parker [32], F. Parodi [57b,57a], E.W. Parrish [115], V.A. Parrish [52], J.A. Parsons [41], U. Parzefall [54], B. Pascual Dias [108], L. Pascual Dominguez [151], F. Pasquali [114], E. Pasqualucci [75a], S. Passaggio [57b], F. Pastore [95], P. Pasuwan [47a,47b], P. Patel [86], U.M. Patel [51], J.R. Pater [101], T. Pauly [36], J. Pearkes [143], M. Pedersen [125], R. Pedro [130a], S.V. Peleganchuk [37], O. Penc [36], E.A. Pender[52], H. Peng [62a], K.E. Penski [109], M. Penzin [37], B.S. Peralva [82d,82d], A.P. Pereira Peixoto [60], L. Pereira Sanchez [47a,47b], D.V. Perepelitsa [29,ag], E. Perez Codina [156a], M. Perganti [10], L. Perini [71a,71b,*], H. Pernegger [36], A. Perrevoort [113], O. Perrin [40], K. Peters [48], R.F.Y. Peters [101], B.A. Petersen [36], T.C. Petersen [42], E. Petit [102], V. Petousis [132], C. Petridou [152,e], A. Petrukhin [141], M. Pettee [17a], N.E. Pettersson [36], A. Petukhov [37], K. Petukhova [133], A. Peyaud [135], R. Pezoa [137f], L. Pezzotti [36], G. Pezzullo [171], T.M. Pham [169], T. Pham [105], P.W. Phillips [134], G. Piacquadio [145], E. Pianori [17a], F. Piazza [71a,71b], R. Piegaia [30], D. Pietreanu [27b], A.D. Pilkington [101], M. Pinamonti [69a,69c], J.L. Pinfold [2], B.C. Pinheiro Pereira [130a], A.E. Pinto Pinoargote [135], K.M. Piper [146], A. Pirttikoski [56], C. Pitman Donaldson[96], D.A. Pizzi [34], L. Pizzimento [76a,76b], A. Pizzini [114], M.-A. Pleier [29], V. Plesanovs[54], V. Pleskot [133], E. Plotnikova[38], G. Poddar [4], R. Poettgen [98], L. Poggioli [127], I. Pokharel [55], S. Polacek [133], G. Polesello [73a], A. Poley [142,156a], R. Polifka [132], A. Polini [23b], C.S. Pollard [166], Z.B. Pollock [119], V. Polychronakos [29], E. Pompa Pacchi[75a,75b], D. Ponomarenko [113], L. Pontecorvo [36], S. Popa [27a], G.A. Popeneciu [27d], A. Poreba [36], D.M. Portillo Quintero[156a], S. Pospisil[132], M.A. Postill[139], P. Postolache[27c], K. Potamianos[166], P.P. Potepa[85a], I.N. Potrap[38], C.J. Potter[32], H. Potti[1], T. Poulsen[48], J. Poveda[162], M.E. Pozo Astigarraga[36], A. Prades Ibanez[162], D. Price[101], M. Primavera[70a], M.A. Principe Martin[99], R. Privara[122], T. Procter[59], M.L. Proffitt[138], N. Proklova[128], K. Prokofiev[64c], G. Proto[110], S. Protopopescu[29], J. Proudfoot[6], M. Przybycien[85a], W.W. Przygoda[85b], J.E. Puddefoot[139], D. Pudzha[37], D. Pyatiizbyantseva[37], J. Qian[106], D. Qichen[101], Y. Qin[101], T. Qiu[52], A. Quadt[55], M. Queitsch-Maitland[101], G. Quetant[56], G. Rabanal Bolanos[61], D. Rafanoharana[54], F. Ragusa[71a,71b], J.L. Rainbolt[39], J.A. Raine[56], S. Rajagopalan[29], E. Ramakoti[37], K. Ran[48,14e], N.P. Rapheeha[33g], H. Rasheed[27b], V. Raskina[127], D.F. Rassloff[63a], S. Rave[100], B. Ravina[55], I. Ravinovich[168], M. Raymond[36], A.L. Read[125], N.P. Readioff[139], D.M. Rebuzzi[73a,73b], G. Redlinger[29], A.S. Reed[110], K. Reeves[26], J.A. Reidelsturz[170,s], D. Reikher[151], A. Rej[141], C. Rembser[36], A. Renardi[48], M. Renda[27b], M.B. Rendel[110], F. Renner[48], A.G. Rennie[59], S. Resconi[71a], M. Ressegotti[57b,57a], S. Rettie[36], J.G. Reyes Rivera[107], B. Reynolds[119], E. Reynolds[17a], O.L. Rezanova[37], P. Reznicek[133], N. Ribaric[91], E. Ricci[78a,78b], R. Richter[110], S. Richter[47a,47b], E. Richter-Was[85b], M. Ridel[127], S. Ridouani[35d], P. Rieck[117], P. Riedler[36], M. Rijssenbeek[145], A. Rimoldi[73a,73b], M. Rimoldi[48], L. Rinaldi[23b,23a], T.T. Rinn[29], M.P. Rinnagel[109], G. Ripellino[160], I. Riu[13], P. Rivadeneira[48], J.C. Rivera Vergara[164], F. Rizatdinova[121], E. Rizvi[94], B.A. Roberts[166], B.R. Roberts[17a], S.H. Robertson[104,x], M. Robin[48], D. Robinson[32], C.M. Robles Gajardo[137f], M. Robles Manzano[100], A. Robson[59], A. Rocchi[76a,76b], C. Roda[74a,74b], S. Rodriguez Bosca[63a], Y. Rodriguez Garcia[22a], A. Rodriguez Rodriguez[54], A.M. Rodríguez Vera[156b], S. Roe[36], J.T. Roemer[159], A.R. Roepe-Gier[136], J. Roggel[170], O. Røhne[125], R.A. Rojas[103], C.P.A. Roland[68], J. Roloff[29], A. Romaniouk[37], E. Romano[73a,73b], M. Romano[23b], A.C. Romero Hernandez[161], N. Rompotis[92], L. Roos[127], S. Rosati[75a], B.J. Rosser[39], E. Rossi[126], E. Rossi[72a,72b], L.P. Rossi[57b], L. Rossini[48], R. Rosten[119], M. Rotaru[27b], B. Rottler[54], C. Rougier[102], D. Rousseau[66], D. Rousso[32], A. Roy[161], S. Roy-Garand[155], A. Rozanov[102], Y. Rozen[150], X. Ruan[33g], A. Rubio Jimenez[162], A.J. Ruby[92], V.H. Ruelas Rivera[18], T.A. Ruggeri[1], A. Ruggiero[126], A. Ruiz-Martinez[162], A. Rummler[36], Z. Rurikova[54], N.A. Rusakovich[38], H.L. Russell[164], G. Russo[75a,75b], J.P. Rutherfoord[7], S. Rutherford Colmenares[32], K. Rybacki[91], M. Rybar[133], E.B. Rye[125], A. Ryzhov[44], J.A. Sabater Iglesias[56], P. Sabatini[162], L. Sabetta[75a,75b], H.F-W. Sadrozinski[136], F. Safai Tehrani[75a], B. Safarzadeh Samani[146], M. Safdari[143], S. Saha[164], M. Sahinsoy[110], M. Saimpert[135], M. Saito[153], T. Saito[153], D. Salamani[36], A. Salnikov[143], J. Salt[162], A. Salvador Salas[13], D. Salvatore[43b,43a], F. Salvatore[146], A. Salzburger[36], D. Sammel[54], D. Sampsonidis[152,e], D. Sampsonidou[123], J. Sánchez[162], A. Sanchez Pineda[4], V. Sanchez Sebastian[162], H. Sandaker[125], C.O. Sander[48], J.A. Sandesara[103], M. Sandhoff[170], C. Sandoval[22b], D.P.C. Sankey[134], T. Sano[87], A. Sansoni[53], L. Santi[75a,75b], C. Santoni[40], H. Santos[130a,130b], S.N. Santpur[17a], A. Santra[168], K.A. Saoucha[139], J.G. Saraiva[130a,130d], J. Sardain[7], O. Sasaki[83], K. Sato[157], C. Sauer[63b], F. Sauerburger[54], E. Sauvan[4], P. Savard[155,ae], R. Sawada[153], C. Sawyer[134], L. Sawyer[97], I. Sayago Galvan[162], C. Sbarra[23b], A. Sbrizzi[23b,23a], T. Scanlon[96], J. Schaarschmidt[138], P. Schacht[110], D. Schaefer[39], U. Schäfer[100], A.C. Schaffer[66,44], D. Schaile[109], R.D. Schamberger[145], C. Scharf[18], M.M. Schefer[19], V.A. Schegelsky[37], D. Scheirich[133], F. Schenck[18], M. Schernau[159], C. Scheulen[55], C. Schiavi[57b,57a], E.J. Schioppa[70a,70b], M. Schioppa[43b,43a], B. Schlag[143], K.E. Schleicher[54], S. Schlenker[36], J. Schmeing[170], M.A. Schmidt[170], K. Schmieden[100], C. Schmitt[100], S. Schmitt[48], L. Schoeffel[135], A. Schoening[63b], P.G. Scholer[54], E. Schopf[126], M. Schott[100], J. Schovancova[36],

S. Schramm [56], F. Schroeder [170], T. Schroer [56], H-C. Schultz-Coulon [63a], M. Schumacher [54], B.A. Schumm [136], Ph. Schune [135], A.J. Schuy [138], H.R. Schwartz [136], A. Schwartzman [143], T.A. Schwarz [106], Ph. Schwemling [135], R. Schwienhorst [107], A. Sciandra [136], G. Sciolla [26], F. Scuri [74a], C.D. Sebastiani [92], K. Sedlaczek [115], P. Seema [18], S.C. Seidel [112], A. Seiden [136], B.D. Seidlitz [41], C. Seitz [48], J.M. Seixas [82b], G. Sekhniaidze [72a], S.J. Sekula [44], L. Selem [60], N. Semprini-Cesari [23b,23a], D. Sengupta [56], V. Senthilkumar [162], L. Serin [66], L. Serkin [69a,69b], M. Sessa [76a,76b], H. Severini [120], F. Sforza [57b,57a], A. Sfyrla [56], E. Shabalina [55], R. Shaheen [144], J.D. Shahinian [128], D. Shaked Renous [168], L.Y. Shan [14a], M. Shapiro [17a], A. Sharma [36], A.S. Sharma [163], P. Sharma [80], S. Sharma [48], P.B. Shatalov [37], K. Shaw [146], S.M. Shaw [101], A. Shcherbakova [37], Q. Shen [62c,5], P. Sherwood [96], L. Shi [96], X. Shi [14a], C.O. Shimmin [171], Y. Shimogama [167], J.D. Shinner [95], I.P.J. Shipsey [126], S. Shirabe [56,h], M. Shiyakova [38], J. Shlomi [168], M.J. Shochet [39], J. Shojaii [105], D.R. Shope [125], S. Shrestha [119,ah], E.M. Shrif [33g], M.J. Shroff [164], P. Sicho [131], A.M. Sickles [161], E. Sideras Haddad [33g], A. Sidoti [23b], F. Siegert [50], Dj. Sijacki [15], R. Sikora [85a], F. Sili [90], J.M. Silva [20], M.V. Silva Oliveira [29], S.B. Silverstein [47a], S. Simion [66], R. Simoniello [36], E.L. Simpson [59], H. Simpson [146], L.R. Simpson [106], N.D. Simpson [98], S. Simsek [21d], S. Sindhu [55], P. Sinervo [155], S. Singh [155], S. Sinha [48], S. Sinha [101], M. Sioli [23b,23a], I. Siral [36], E. Sitnikova [48], S.Yu. Sivoklokov [37,*], J. Sjölin [47a,47b], A. Skaf [55], E. Skorda [98], P. Skubic [120], M. Slawinska [86], V. Smakhtin [168], B.H. Smart [134], J. Smiesko [36], S.Yu. Smirnov [37], Y. Smirnov [37], L.N. Smirnova [37,a], O. Smirnova [98], A.C. Smith [41], E.A. Smith [39], H.A. Smith [126], J.L. Smith [92], R. Smith [143], M. Smizanska [91], K. Smolek [132], A.A. Snesarev [37], S.R. Snider [155], H.L. Snoek [114], S. Snyder [29], R. Sobie [164,x], A. Soffer [151], C.A. Solans Sanchez [36], E.Yu. Soldatov [37], U. Soldevila [162], A.A. Solodkov [37], S. Solomon [26], A. Soloshenko [38], K. Solovieva [54], O.V. Solovyanov [40], V. Solovyev [37], P. Sommer [36], A. Sonay [13], W.Y. Song [156b], J.M. Sonneveld [114], A. Sopczak [132], A.L. Sopio [96], F. Sopkova [28b], V. Sothilingam [63a], S. Sottocornola [68], R. Soualah [116c], Z. Soumaimi [35e], D. South [48], S. Spagnolo [70a,70b], M. Spalla [110], D. Sperlich [54], G. Spigo [36], M. Spina [146], S. Spinali [91], D.P. Spiteri [59], M. Spousta [133], E.J. Staats [34], A. Stabile [71a,71b], R. Stamen [63a], M. Stamenkovic [114], A. Stampekis [20], M. Standke [24], E. Stanecka [86], M.V. Stange [50], B. Stanislaus [17a], M.M. Stanitzki [48], B. Stapf [48], E.A. Starchenko [37], G.H. Stark [136], J. Stark [102], D.M. Starko [156b], P. Staroba [131], P. Starovoitov [63a], S. Stärz [104], R. Staszewski [86], G. Stavropoulos [46], J. Steentoft [160], P. Steinberg [29], B. Stelzer [142,156a], H.J. Stelzer [129], O. Stelzer-Chilton [156a], H. Stenzel [58], T.J. Stevenson [146], G.A. Stewart [36], J.R. Stewart [121], M.C. Stockton [36], G. Stoicea [27b], M. Stolarski [130a], S. Stonjek [110], A. Straessner [50], J. Strandberg [144], S. Strandberg [47a,47b], M. Strauss [120], T. Strebler [102], P. Strizenec [28b], R. Ströhmer [165], D.M. Strom [123], L.R. Strom [48], R. Stroynowski [44], A. Strubig [47a,47b], S.A. Stucci [29], B. Stugu [16], J. Stupak [120], N.A. Styles [48], D. Su [143], S. Su [62a], W. Su [62d], X. Su [62a,66], K. Sugizaki [153], V.V. Sulin [37], M.J. Sullivan [92], D.M.S. Sultan [78a,78b], L. Sultanaliyeva [37], S. Sultansoy [3b], T. Sumida [87], S. Sun [106], S. Sun [169], O. Sunneborn Gudnadottir [160], M.R. Sutton [146], H. Suzuki [157], M. Svatos [131], M. Swiatlowski [156a], T. Swirski [165], I. Sykora [28a], M. Sykora [133], T. Sykora [133], D. Ta [100], K. Tackmann [48,v], A. Taffard [159], R. Tafirout [156a], J.S. Tafoya Vargas [66], R. Takashima [88], E.P. Takeva [52], Y. Takubo [83], M. Talby [102], A.A. Talyshev [37], K.C. Tam [64b], N.M. Tamir [151], A. Tanaka [153], J. Tanaka [153], R. Tanaka [66], M. Tanasini [57b,57a], Z. Tao [163], S. Tapia Araya [137f], S. Tapprogge [100], A. Tarek Abouelfadl Mohamed [107], S. Tarem [150], K. Tariq [14a], G. Tarna [102,27b], G.F. Tartarelli [71a], P. Tas [133], M. Tasevsky [131], E. Tassi [43b,43a], A.C. Tate [161], G. Tateno [153], Y. Tayalati [35e,w], G.N. Taylor [105], W. Taylor [156b], H. Teagle [92], A.S. Tee [169], R. Teixeira De Lima [143],

P. Teixeira-Dias[95], J.J. Teoh[155], K. Terashi[153], J. Terron[99], S. Terzo[13], M. Testa[53], R.J. Teuscher[155,x], A. Thaler[79], O. Theiner[56], N. Themistokleous[52], T. Theveneaux-Pelzer[102], O. Thielmann[170], D.W. Thomas[95], J.P. Thomas[20], E.A. Thompson[17a], P.D. Thompson[20], E. Thomson[128], Y. Tian[55], V. Tikhomirov[37,a], Yu.A. Tikhonov[37], S. Timoshenko[37], D. Timoshyn[133], E.X.L. Ting[1], P. Tipton[171], S.H. Tlou[33g], A. Tnourji[40], K. Todome[23b,23a], S. Todorova-Nova[133], S. Todt[50], M. Togawa[83], J. Tojo[89], S. Tokár[28a], K. Tokushuku[83], O. Toldaiev[68], R. Tombs[32], M. Tomoto[83,111], L. Tompkins[143], K.W. Topolnicki[85b], E. Torrence[123], H. Torres[102], E. Torró Pastor[162], M. Toscani[30], C. Tosciri[39], M. Tost[11], D.R. Tovey[139], A. Traeet[16], I.S. Trandafir[27b], T. Trefzger[165], A. Tricoli[29], I.M. Trigger[156a], S. Trincaz-Duvoid[127], D.A. Trischuk[26], B. Trocmé[60], C. Troncon[71a], L. Truong[33c], M. Trzebinski[86], A. Trzupek[86], F. Tsai[145], M. Tsai[106], A. Tsiamis[152,e], P.V. Tsiareshka[37], S. Tsigaridas[156a], A. Tsirigotis[152,t], V. Tsiskaridze[155], E.G. Tskhadadze[149a], M. Tsopoulou[152,e], Y. Tsujikawa[87], I.I. Tsukerman[37], V. Tsulaia[17a], S. Tsuno[83], O. Tsur[150], K. Tsuri[118], D. Tsybychev[145], Y. Tu[64b], A. Tudorache[27b], V. Tudorache[27b], A.N. Tuna[36], S. Turchikhin[38], I. Turk Cakir[3a], R. Turra[71a], T. Turtuvshin[38,y], P.M. Tuts[41], S. Tzamarias[152,e], P. Tzanis[10], E. Tzovara[100], K. Uchida[153], F. Ukegawa[157], P.A. Ulloa Poblete[137c,137b], E.N. Umaka[29], G. Unal[36], M. Unal[11], A. Undrus[29], G. Unel[159], J. Urban[28b], P. Urquijo[105], G. Usai[8], R. Ushioda[154], M. Usman[108], Z. Uysal[21b], L. Vacavant[102], V. Vacek[132], B. Vachon[104], K.O.H. Vadla[125], T. Vafeiadis[36], A. Vaitkus[96], C. Valderanis[109], E. Valdes Santurio[47a,47b], M. Valente[156a], S. Valentinetti[23b,23a], A. Valero[162], E. Valiente Moreno[162], A. Vallier[102], J.A. Valls Ferrer[162], D.R. Van Arneman[114], T.R. Van Daalen[138], A. Van Der Graaf[49], P. Van Gemmeren[6], M. Van Rijnbach[125,36], S. Van Stroud[96], I. Van Vulpen[114], M. Vanadia[76a,76b], W. Vandelli[36], M. Vandenbroucke[135], E.R. Vandewall[121], D. Vannicola[151], L. Vannoli[57b,57a], R. Vari[75a], E.W. Varnes[7], C. Varni[17a], T. Varol[148], D. Varouchas[66], L. Varriale[162], K.E. Varvell[147], M.E. Vasile[27b], L. Vaslin[40], G.A. Vasquez[164], F. Vazeille[40], T. Vazquez Schroeder[36], J. Veatch[31], V. Vecchio[101], M.J. Veen[103], I. Veliscek[126], L.M. Veloce[155], F. Veloso[130a,130c], S. Veneziano[75a], A. Ventura[70a,70b], A. Verbytskyi[110], M. Verducci[74a,74b], C. Vergis[24], M. Verissimo De Araujo[82b], W. Verkerke[114], J.C. Vermeulen[114], C. Vernieri[143], P.J. Verschuuren[95], M. Vessella[103], M.C. Vetterli[142,ae], A. Vgenopoulos[152,e], N. Viaux Maira[137f], T. Vickey[139], O.E. Vickey Boeriu[139], G.H.A. Viehhauser[126], L. Vigani[63b], M. Villa[23b,23a], M. Villaplana Perez[162], E.M. Villhauer[52], E. Vilucchi[53], M.G. Vincter[34], G.S. Virdee[20], A. Vishwakarma[52], A. Visibile[114], C. Vittori[36], I. Vivarelli[146], V. Vladimirov[166], E. Voevodina[110], F. Vogel[109], P. Vokac[132], J. Von Ahnen[48], E. Von Toerne[24], B. Vormwald[36], V. Vorobel[133], K. Vorobev[37], M. Vos[162], K. Voss[141], J.H. Vossebeld[92], M. Vozak[114], L. Vozdecky[94], N. Vranjes[15], M. Vranjes Milosavljevic[15], M. Vreeswijk[114], N.K. Vu[62d,62c], R. Vuillermet[36], O. Vujinovic[100], I. Vukotic[39], S. Wada[157], C. Wagner[103], J.M. Wagner[17a], W. Wagner[170], S. Wahdan[170], H. Wahlberg[90], R. Wakasa[157], M. Wakida[111], J. Walder[134], R. Walker[109], W. Walkowiak[141], A. Wall[128], T. Wamorkar[6], A.Z. Wang[169], C. Wang[100], C. Wang[62c], H. Wang[17a], J. Wang[64a], R.-J. Wang[100], R. Wang[61], R. Wang[6], S.M. Wang[148], S. Wang[62b], T. Wang[62a], W.T. Wang[80], X. Wang[14c], X. Wang[161], X. Wang[62c], Y. Wang[62d], Y. Wang[14c], Z. Wang[106], Z. Wang[62d,51,62c], Z. Wang[106], A. Warburton[104], R.J. Ward[20], N. Warrack[59], A.T. Watson[20], H. Watson[59], M.F. Watson[20], E. Watton[59,134], G. Watts[138], B.M. Waugh[96], C. Weber[29], H.A. Weber[18], M.S. Weber[19], S.M. Weber[63a], C. Wei[62a], Y. Wei[126], A.R. Weidberg[126], E.J. Weik[117], J. Weingarten[49], M. Weirich[100], C. Weiser[54], C.J. Wells[48], T. Wenaus[29], B. Wendland[49], T. Wengler[36], N.S. Wenke[110], N. Wermes[24], M. Wessels[63a], K. Whalen[123], A.M. Wharton[91], A.S. White[61], A. White[8], M.J. White[1], D. Whiteson[159],

L. Wickremasinghe[124], W. Wiedenmann[169], C. Wiel[50], M. Wielers[134], C. Wiglesworth[42], D.J. Wilbern[120], H.G. Wilkens[36], D.M. Williams[41], H.H. Williams[128], S. Williams[32], S. Willocq[103], B.J. Wilson[101], P.J. Windischhofer[39], F.I. Winkel[30], F. Winklmeier[123], B.T. Winter[54], J.K. Winter[101], M. Wittgen[143], M. Wobisch[97], Z. Wolffs[114], R. Wölker[126], J. Wollrath[159], M.W. Wolter[86], H. Wolters[130a,130c], A.F. Wongel[48], S.D. Worm[48], B.K. Wosiek[86], K.W. Woźniak[86], S. Wozniewski[55], K. Wraight[59], C. Wu[20], J. Wu[14a,14e], M. Wu[64a], M. Wu[113], S.L. Wu[169], X. Wu[56], Y. Wu[62a], Z. Wu[135], J. Wuerzinger[110], T.R. Wyatt[101], B.M. Wynne[52], S. Xella[42], L. Xia[14c], M. Xia[14b], J. Xiang[64c], X. Xiao[106], M. Xie[62a], X. Xie[62a], S. Xin[14a,14e], J. Xiong[17a], D. Xu[14a], H. Xu[62a], L. Xu[62a], R. Xu[128], T. Xu[106], Y. Xu[14b], Z. Xu[52], Z. Xu[14a], B. Yabsley[147], S. Yacoob[33a], N. Yamaguchi[89], Y. Yamaguchi[154], E. Yamashita[153], H. Yamauchi[157], T. Yamazaki[17a], Y. Yamazaki[84], J. Yan[62c], S. Yan[126], Z. Yan[25], H.J. Yang[62c,62d], H.T. Yang[62a], S. Yang[62a], T. Yang[64c], X. Yang[62a], X. Yang[14a], Y. Yang[44], Z. Yang[62a], W-M. Yao[17a], Y.C. Yap[48], H. Ye[14c], H. Ye[55], J. Ye[44], S. Ye[29], X. Ye[62a], Y. Yeh[96], I. Yeletskikh[38], B.K. Yeo[17a], M.R. Yexley[96], P. Yin[41], K. Yorita[167], S. Younas[27b], C.J.S. Young[54], C. Young[143], Y. Yu[62a], M. Yuan[106], R. Yuan[62b,k], L. Yue[96], M. Zaazoua[62a], B. Zabinski[86], E. Zaid[52], T. Zakareishvili[149b], N. Zakharchuk[34], S. Zambito[56], J.A. Zamora Saa[137d,137b], J. Zang[153], D. Zanzi[54], O. Zaplatilek[132], C. Zeitnitz[170], H. Zeng[14a], J.C. Zeng[161], D.T. Zenger Jr[26], O. Zenin[37], T. Ženiš[28a], S. Zenz[94], S. Zerradi[35a], D. Zerwas[66], M. Zhai[14a,14e], B. Zhang[14c], D.F. Zhang[139], J. Zhang[62b], J. Zhang[6], K. Zhang[14a,14e], L. Zhang[14c], P. Zhang[14a,14e], R. Zhang[169], S. Zhang[106], T. Zhang[153], X. Zhang[62c], X. Zhang[62b], Y. Zhang[62c,5], Y. Zhang[96], Z. Zhang[17a], Z. Zhang[66], H. Zhao[138], P. Zhao[51], T. Zhao[62b], Y. Zhao[136], Z. Zhao[62a], A. Zhemchugov[38], K. Zheng[161], X. Zheng[62a], Z. Zheng[143], D. Zhong[161], B. Zhou[106], H. Zhou[7], N. Zhou[62c], Y. Zhou[7], C.G. Zhu[62b], J. Zhu[106], Y. Zhu[62c], Y. Zhu[62a], X. Zhuang[14a], K. Zhukov[37], V. Zhulanov[37], N.I. Zimine[38], J. Zinsser[63b], M. Ziolkowski[141], L. Živković[15], A. Zoccoli[23b,23a], K. Zoch[56], T.G. Zorbas[139], O. Zormpa[46], W. Zou[41], L. Zwalinski[36].

[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, Univ. 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(a)]Institute of High Energy Physics, Chinese Academy of Sciences, Beijing;[(b)]Physics Department, Tsinghua University, Beijing;[(c)]Department of Physics, Nanjing University, Nanjing;[(d)]School of Science, Shenzhen Campus of Sun Yat-sen University;[(e)]University of Chinese Academy of Science (UCAS), Beijing; China.

[15]Institute of Physics, University of Belgrade, Belgrade; Serbia.
[16]Department for Physics and Technology, University of Bergen, Bergen; Norway.
[17(a)]Physics Division, Lawrence Berkeley National Laboratory, Berkeley CA;[(b)]University of California, Berkeley CA; United States of America.
[18]Institut für Physik, Humboldt Universität zu Berlin, Berlin; Germany.
[19]Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern; Switzerland.
[20]School of Physics and Astronomy, University of Birmingham, Birmingham; United Kingdom.
[21(a)]Department of Physics, Bogazici University, Istanbul;[(b)]Department of Physics Engineering, Gaziantep University, Gaziantep;[(c)]Department of Physics, Istanbul University, Istanbul;[(d)]Istinye University, Sariyer, Istanbul; Türkiye.
[22(a)]Facultad de Ciencias y Centro de Investigaciónes, Universidad Antonio Nariño, Bogotá;[(b)]Departamento de Física, Universidad Nacional de Colombia, Bogotá;[(c)]Pontificia Universidad Javeriana, Bogota; Colombia.
[23(a)]Dipartimento di Fisica e Astronomia A. Righi, Università di Bologna, Bologna;[(b)]INFN Sezione di Bologna; Italy.
[24]Physikalisches Institut, Universität Bonn, Bonn; Germany.
[25]Department of Physics, Boston University, Boston MA; United States of America.
[26]Department of Physics, Brandeis University, Waltham MA; United States of America.
[27(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)]University Politehnica Bucharest, Bucharest;[(f)]West University in Timisoara, Timisoara;[(g)]Faculty of Physics, University of Bucharest, Bucharest; Romania.
[28(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.
[29]Physics Department, Brookhaven National Laboratory, Upton NY; United States of America.
[30]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.
[31]California State University, CA; United States of America.
[32]Cavendish Laboratory, University of Cambridge, Cambridge; United Kingdom.
[33(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)]University of South Africa, Department of Physics, Pretoria;[(f)]University of Zululand, KwaDlangezwa;[(g)]School of Physics, University of the Witwatersrand, Johannesburg; South Africa.
[34]Department of Physics, Carleton University, Ottawa ON; Canada.
[35(a)]Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies - Université Hassan II, 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.
[36]CERN, Geneva; Switzerland.
[37]Affiliated with an institute covered by a cooperation agreement with CERN.
[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]Physics Department, University of Texas at Dallas, Richardson TX; United States of America.
[46]National Centre for Scientific Research "Demokritos", Agia Paraskevi; Greece.
[47][(a)]Department of Physics, Stockholm University;[(b)]Oskar Klein Centre, Stockholm; Sweden.
[48]Deutsches Elektronen-Synchrotron DESY, Hamburg and Zeuthen; Germany.
[49]Fakultät Physik , Technische Universität Dortmund, Dortmund; Germany.
[50]Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden; Germany.
[51]Department of Physics, Duke University, Durham NC; United States of America.
[52]SUPA - School of Physics and Astronomy, University of Edinburgh, Edinburgh; United Kingdom.
[53]INFN e Laboratori Nazionali di Frascati, Frascati; Italy.
[54]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg; Germany.
[55]II. Physikalisches Institut, Georg-August-Universität Göttingen, Göttingen; Germany.
[56]Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève; Switzerland.
[57][(a)]Dipartimento di Fisica, Università di Genova, Genova;[(b)]INFN Sezione di Genova; Italy.
[58]II. Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen; Germany.
[59]SUPA - School of Physics and Astronomy, University of Glasgow, Glasgow; United Kingdom.
[60]LPSC, Université Grenoble Alpes, CNRS/IN2P3, Grenoble INP, Grenoble; France.
[61]Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge MA; United States of America.
[62][(a)]Department of Modern Physics and State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei;[(b)]Institute of Frontier and Interdisciplinary Science and Key Laboratory of Particle Physics and Particle Irradiation (MOE), Shandong University, Qingdao;[(c)]School of Physics and Astronomy, Shanghai Jiao Tong University, Key Laboratory for Particle Astrophysics and Cosmology (MOE), SKLPPC, Shanghai;[(d)]Tsung-Dao Lee Institute, Shanghai; China.
[63][(a)]Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg;[(b)]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg; Germany.
[64][(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.
[65]Department of Physics, National Tsing Hua University, Hsinchu; Taiwan.
[66]IJCLab, Université Paris-Saclay, CNRS/IN2P3, 91405, Orsay; France.
[67]Centro Nacional de Microelectrónica (IMB-CNM-CSIC), Barcelona; Spain.
[68]Department of Physics, Indiana University, Bloomington IN; United States of America.
[69][(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.
[70][(a)]INFN Sezione di Lecce;[(b)]Dipartimento di Matematica e Fisica, Università del Salento, Lecce; Italy.
[71][(a)]INFN Sezione di Milano;[(b)]Dipartimento di Fisica, Università di Milano, Milano; Italy.
[72][(a)]INFN Sezione di Napoli;[(b)]Dipartimento di Fisica, Università di Napoli, Napoli; Italy.
[73][(a)]INFN Sezione di Pavia;[(b)]Dipartimento di Fisica, Università di Pavia, Pavia; Italy.
[74][(a)]INFN Sezione di Pisa;[(b)]Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa; Italy.
[75][(a)]INFN Sezione di Roma;[(b)]Dipartimento di Fisica, Sapienza Università di Roma, Roma; Italy.
[76][(a)]INFN Sezione di Roma Tor Vergata;[(b)]Dipartimento di Fisica, Università di Roma Tor Vergata,

Roma; Italy.
[77(a)]INFN Sezione di Roma Tre;[(b)]Dipartimento di Matematica e Fisica, Università Roma Tre, Roma; Italy.
[78(a)]INFN-TIFPA;[(b)]Università degli Studi di Trento, Trento; Italy.
[79]Universität Innsbruck, Department of Astro and Particle Physics, Innsbruck; Austria.
[80]University of Iowa, Iowa City IA; United States of America.
[81]Department of Physics and Astronomy, Iowa State University, Ames IA; United States of America.
[82(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; Brazil.
[83]KEK, High Energy Accelerator Research Organization, Tsukuba; Japan.
[84]Graduate School of Science, Kobe University, Kobe; Japan.
[85(a)]AGH University of Science and Technology, 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]Kyoto University of Education, Kyoto; Japan.
[89]Research Center for Advanced Particle Physics and Department of Physics, Kyushu University, Fukuoka ; Japan.
[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]School 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]Department of Physics and Astronomy, University of New Mexico, Albuquerque NM; United States of America.
[113]Institute for Mathematics, Astrophysics and Particle Physics, Radboud University/Nikhef, Nijmegen; Netherlands.

[114]Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam; Netherlands.
[115]Department of Physics, Northern Illinois University, DeKalb IL; United States of America.
[116(a)]New York University Abu Dhabi, Abu Dhabi;[(b)]United Arab Emirates University, Al Ain;[(c)]University of Sharjah, Sharjah; United Arab Emirates.
[117]Department of Physics, New York University, New York NY; United States of America.
[118]Ochanomizu University, Otsuka, Bunkyo-ku, Tokyo; Japan.
[119]Ohio State University, Columbus OH; United States of America.
[120]Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman OK; United States of America.
[121]Department of Physics, Oklahoma State University, Stillwater OK; United States of America.
[122]Palacký University, Joint Laboratory of Optics, Olomouc; Czech Republic.
[123]Institute for Fundamental Science, University of Oregon, Eugene, OR; United States of America.
[124]Graduate School of Science, Osaka University, Osaka; Japan.
[125]Department of Physics, University of Oslo, Oslo; Norway.
[126]Department of Physics, Oxford University, Oxford; United Kingdom.
[127]LPNHE, Sorbonne Université, Université Paris Cité, CNRS/IN2P3, Paris; France.
[128]Department of Physics, University of Pennsylvania, Philadelphia PA; United States of America.
[129]Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh PA; United States of America.
[130(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, Universidade do Minho, Braga;[(f)]Departamento de Física Teórica y del Cosmos, Universidad de Granada, Granada (Spain);[(g)]Instituto Superior Técnico, Universidade de Lisboa, Lisboa; Portugal.
[131]Institute of Physics of the Czech Academy of Sciences, Prague; Czech Republic.
[132]Czech Technical University in Prague, Prague; Czech Republic.
[133]Charles University, Faculty of Mathematics and Physics, Prague; Czech Republic.
[134]Particle Physics Department, Rutherford Appleton Laboratory, Didcot; United Kingdom.
[135]IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette; France.
[136]Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz CA; United States of America.
[137(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)]Instituto de Alta Investigación, Universidad de Tarapacá, Arica;[(f)]Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso; Chile.
[138]Department of Physics, University of Washington, Seattle WA; United States of America.
[139]Department of Physics and Astronomy, University of Sheffield, Sheffield; United Kingdom.
[140]Department of Physics, Shinshu University, Nagano; Japan.
[141]Department Physik, Universität Siegen, Siegen; Germany.
[142]Department of Physics, Simon Fraser University, Burnaby BC; Canada.
[143]SLAC National Accelerator Laboratory, Stanford CA; United States of America.
[144]Department of Physics, Royal Institute of Technology, Stockholm; Sweden.
[145]Departments of Physics and Astronomy, Stony Brook University, Stony Brook NY; United States of America.

[146]Department of Physics and Astronomy, University of Sussex, Brighton; United Kingdom.
[147]School of Physics, University of Sydney, Sydney; Australia.
[148]Institute of Physics, Academia Sinica, Taipei; Taiwan.
[149](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.
[150]Department of Physics, Technion, Israel Institute of Technology, Haifa; Israel.
[151]Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv; Israel.
[152]Department of Physics, Aristotle University of Thessaloniki, Thessaloniki; Greece.
[153]International Center for Elementary Particle Physics and Department of Physics, University of Tokyo, Tokyo; Japan.
[154]Department of Physics, Tokyo Institute of Technology, Tokyo; Japan.
[155]Department of Physics, University of Toronto, Toronto ON; Canada.
[156](a)TRIUMF, Vancouver BC;(b)Department of Physics and Astronomy, York University, Toronto ON; Canada.
[157]Division of Physics and Tomonaga Center for the History of the Universe, Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba; Japan.
[158]Department of Physics and Astronomy, Tufts University, Medford MA; United States of America.
[159]Department of Physics and Astronomy, University of California Irvine, Irvine CA; United States of America.
[160]Department of Physics and Astronomy, University of Uppsala, Uppsala; Sweden.
[161]Department of Physics, University of Illinois, Urbana IL; United States of America.
[162]Instituto de Física Corpuscular (IFIC), Centro Mixto Universidad de Valencia - CSIC, Valencia; Spain.
[163]Department of Physics, University of British Columbia, Vancouver BC; Canada.
[164]Department of Physics and Astronomy, University of Victoria, Victoria BC; Canada.
[165]Fakultät für Physik und Astronomie, Julius-Maximilians-Universität Würzburg, Würzburg; Germany.
[166]Department of Physics, University of Warwick, Coventry; United Kingdom.
[167]Waseda University, Tokyo; Japan.
[168]Department of Particle Physics and Astrophysics, Weizmann Institute of Science, Rehovot; Israel.
[169]Department of Physics, University of Wisconsin, Madison WI; United States of America.
[170]Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal; Germany.
[171]Department of Physics, Yale University, New Haven CT; United States of America.
[a] Also Affiliated with an institute covered by a cooperation agreement with CERN.
[b] Also at APC, Université Paris Cité, CNRS/IN2P3, Paris; France.
[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 High Energy Physics, Peking University; China.
[e] Also at Center for Interdisciplinary Research and Innovation (CIRI-AUTH), Thessaloniki ; Greece.
[f] Also at Centro Studi e Ricerche Enrico Fermi; Italy.
[g] Also at CERN, Geneva; Switzerland.
[h] Also at Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève; Switzerland.
[i] Also at Departament de Fisica de la Universitat Autonoma de Barcelona, Barcelona; Spain.
[j] Also at Department of Financial and Management Engineering, University of the Aegean, Chios; Greece.
[k] Also at Department of Physics and Astronomy, Michigan State University, East Lansing MI; United States of America.
[l] Also at Department of Physics and Astronomy, University of Victoria, Victoria BC; Canada.

[m] Also at Department of Physics, California State University, Sacramento; United States of America.
[n] Also at Department of Physics, King's College London, London; United Kingdom.
[o] Also at Department of Physics, Royal Holloway University of London, Egham; United Kingdom.
[p] Also at Department of Physics, University of Fribourg, Fribourg; Switzerland.
[q] Also at Department of Physics, University of Thessaly; Greece.
[r] Also at Department of Physics, Westmont College, Santa Barbara; United States of America.
[s] Also at Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal; Germany.
[t] Also at Hellenic Open University, Patras; Greece.
[u] Also at Institucio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona; Spain.
[v] Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg; Germany.
[w] Also at Institute of Applied Physics, Mohammed VI Polytechnic University, Ben Guerir; Morocco.
[x] Also at Institute of Particle Physics (IPP); Canada.
[y] Also at Institute of Physics and Technology, Ulaanbaatar; Mongolia.
[z] Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku; Azerbaijan.
[aa] Also at Institute of Theoretical Physics, Ilia State University, Tbilisi; Georgia.
[ab] Also at KEK, High Energy Accelerator Research Organization, Tsukuba; Japan.
[ac] Also at Lawrence Livermore National Laboratory, Livermore; United States of America.
[ad] Also at The Collaborative Innovation Center of Quantum Matter (CICQM), Beijing; China.
[ae] Also at TRIUMF, Vancouver BC; Canada.
[af] Also at Università di Napoli Parthenope, Napoli; Italy.
[ag] Also at University of Colorado Boulder, Department of Physics, Colorado; United States of America.
[ah] Also at Washington College, Chestertown, MD; United States of America.
[*] Deceased