Charged-Particle Multiplicity Density at Midrapidity in Central Pb-Pb Collisions at $\sqrt{s_{NN}} = 2.76$ TeV

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The first measurement of the charged-particle multiplicity density at midrapidity in Pb-Pb collisions at a center-of-mass energy per nucleon pair $\sqrt{s_{NN}} = 2.76$ TeV is presented. For an event sample corresponding to the most central 5% of the hadronic cross section, the pseudorapidity density of primary charged particles at midrapidity is $1584 \pm 4(\text{stat}) \pm 76(\text{syst})$, which corresponds to $8.3 \pm 0.4(\text{syst})$ per participating nucleon pair. This represents an increase of about a factor 1.9 relative to pp collisions at similar collision energies, and about a factor 2.2 to central Au-Au collisions at $\sqrt{s_{NN}} = 0.2$ TeV. This measurement provides the first experimental constraint for models of nucleus-nucleus collisions at LHC energies.

The theory of strong interactions, quantum chromodynamics (QCD), predicts a phase transition at high temperature between hadronic matter, where quarks and gluons are confined inside hadrons, and a deconfined state of matter, the quark-gluon plasma. A new frontier in the study of QCD matter opened with the first collisions of ^{208}Pb ions in November 2010, at the Large Hadron Collider (LHC) at CERN. These collisions are expected to generate matter at unprecedented temperatures and energy densities in the laboratory.

The first step in characterizing the system produced in these collisions is the measurement of the charged-particle pseudorapidity density, which constrains the dominant particle production mechanisms and is essential to estimate the initial energy density. The dependence of the charged-particle multiplicity density on energy and system size reflects the interplay between hard parton-parton scattering processes and soft processes. Predictions of models that successfully describe particle production at RHIC vary by a factor of 2 at the LHC [1,2].

This Letter reports the measurement of the charged-particle pseudorapidity density produced in Pb-Pb collisions at the LHC, utilizing data taken with the ALICE detector [3] at a center-of-mass energy per nucleon pair $\sqrt{s_{NN}} = 2.76$ TeV. The primary charged-particle density, $dN_{\text{ch}}/d\eta$, in central (small impact parameter) Pb-Pb collisions is measured in the pseudorapidity interval $|\eta| \equiv |-\ln \tan(\theta/2)| < 0.5$, where θ is the polar angle between the charged-particle direction and the beam axis (z). We define primary particles as prompt particles produced in the collision, including decay products, except those from weak decays of strange particles.

The present measurement extends the study of particle densities in nucleus-nucleus collisions into the TeV regime. We make comparisons to model predictions [4–16] and to previous measurements in nucleus-nucleus collisions at lower energies at the SPS and RHIC [17–25], as well as to pp and $p\bar{p}$ collisions over a wide energy range [26–32]. Our measurement provides new insight into particle production mechanisms in high energy nuclear collisions and enables more precise model predictions for a wide array of other observables in nuclear collisions at the LHC.

A detailed description of the ALICE experiment is given in Ref. [3]. Here, we briefly describe the detector components used in this analysis. The silicon pixel detector (SPD) is the innermost part of the inner tracking system. It consists of two cylindrical layers of hybrid silicon pixel assemblies positioned at radial distances of 3.9 and 7.6 cm from the beam line, with a total of 9.8×10^6 pixels of size 50×425 μm^2, read out by 1200 electronic chips. The SPD coverage for particles originating from the center of the detector is $|\eta| < 2.0$ and $|\eta| < 1.4$ for the inner and outer layers, respectively. Each chip provides a fast signal if at least one of its pixels is hit. The signals from the 1200 chips are combined in a programmable logic unit which supplies a trigger signal. The fraction of SPD channels active during data taking was 70% for the inner and 78% for the outer layer. The VZERO detector consists of two arrays of 32 scintillator tiles placed at distances $z = 3.3$ m and $z = -0.9$ m from the nominal interaction point, covering the full azimuth within $2.8 < \eta < 5.1$ (VZERO-A) and $-3.7 < \eta < -1.7$ (VZERO-C). Both the amplitude and the time signal in each scintillator are recorded. The VZERO time resolution is better than 1 ns, allowing discrimination of beam-beam collisions from background events produced upstream of the experiment. The

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VZERO also provides a trigger signal. The zero degree
calorimeters (ZDCs) measure the energy of spectators
(noninteracting nucleons) in two identical detectors, lo-
cated ± 114 m from the interaction point. Each ZDC con-
sists of two quartz fiber sampling calorimeters: a neutron
calorimeter positioned between the two beam pipes down-
stream of the first machine dipole that separates the two
charged-particle beams and a proton calorimeter posi-
tioned externally to the outgoing beam pipe. The energy
resolution at beam energy is estimated to be 11% for the
neutron and 13% for the proton calorimeter, respectively.

For the data analyzed, beams of four bunches, with about
10^7 Pb ions per bunch, collided at $\sqrt{s_{NN}} = 2.76$ TeV, with
an estimated luminosity of 5×10^{23} cm^{-2} s^{-1}. The trigger
was configured for high efficiency for hadronic events,
requiring at least two out of the following three conditions:
(i) two pixel chips hit in the outer layer of the SPD, (ii) a
signal in VZERO-A, (iii) a signal in VZERO-C. The
threshold in the VZERO detector corresponds approxi-
mately to the energy deposition of a minimum ionizing
particle. The luminous region had a rms width of 5.9 cm in
the longitudinal direction and 50 μm in the transverse
direction. The estimated luminosity corresponds to a had-
ronic collision rate of about 4 Hz. The observed rate was
about 50 Hz, mainly due to electromagnetically induced
processes [33]. These processes have very large cross
sections at LHC energies but generate very low multiplic-
ities and therefore do not contribute to the high particle
multiplicities of interest for the present analysis. The trig-
ger rate without beam was negligible and the rate in
coincidence with bunches of only one beam was about
1 Hz. This beam background is eliminated from the trig-
gered event sample using the VZERO timing information,
as well as the correlation between the number of tracks
reconstructed in the time projection chamber and the num-
ber of hits in the SPD.

Off-line event characterization utilizes global event ob-
servables that are intrinsically correlated over different
regions of phase space through the initial collision geome-
try. Figure 1 (upper) shows the measured correlation be-
tween the energy deposited in the ZDC and the sum of
amplitudes in the VZERO detector. The VZERO response
is proportional to the event multiplicity, and the ZDC
energy to the number of noninteracting nucleons close to
beam rapidity. As events become more central, with
smaller impact parameter, they generate larger multiplicity
in VZERO and less energy forward in the ZDC. This
behavior is understood based on collision geometry and
nuclear breakup [34]. For small ZDC response the VZERO
signal has two distinct values corresponding to peripheral
and central collisions. However, the VZERO signal alone
can be used to discriminate on centrality. Figure 1 (lower)
shows the distribution of the VZERO amplitude for all
triggered events after beam background removal. The dis-
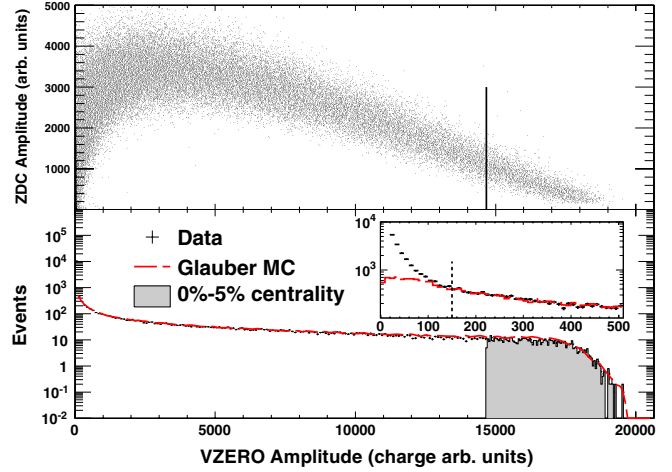tribution is fit using the Glauber model [35] to describe the

FIG. 1 (color online). Upper panel: Correlation of ZDC and
the VZERO response in hadronic collisions. Lower
panel: Distribution of the sum of amplitudes in the VZERO
scintillator tiles (black histogram); inset shows the low ampli-
tude part of the distribution. The gray (red) line shows the fit of
the Glauber calculation to the measurement. The fit was per-
formed above the cut indicated in the inset, avoiding the region
at low amplitudes dominated by the electromagnetic processes.
The shaded area corresponds to the most central 5% of hadronic
collisions.

collision geometry and a negative binomial distribution to
describe particle production [34]. In addition to the two
parameters of the negative binomial distribution, there is
one free parameter that controls the power-law dependence
of particle production on the number of participating nu-
cleons (N_{part}). To avoid the region contaminated by elec-
tromagnetic processes, which constitutes over 90% of the
triggered events, the fit is restricted to the VZERO ampli-
tude region above 150, where the trigger for hadronic
collisions is fully efficient. The fraction of the hadronic
cross section from the model fit corresponding to this cut,
87%, allows the determination of the cross section percen-
tile for any more-central VZERO cut by integrating the
measured distribution. The most central 5% fraction of the
hadronic cross section was determined in this way.

The analysis is based on the VZERO event selection as
described above. Among the triggered sample of about
650 000 events, 3615 events correspond to the most central
5% of the hadronic cross section, indicated by the shaded
region in Fig. 1 (lower). The first step in the measurement
of the charged-particle multiplicity is the determination of
the primary vertex position by correlating hits in the two
SPD layers. All events in the central sample are found to
have a well-constrained primary vertex. To minimize edge
effects at the limit of the SPD acceptance we have only
used events with reconstructed vertex at $|z_{vtx}| < 7$ cm,
reducing the sample to 2711 events. Tracklet candidates
[25] are formed using information on the position of the
primary vertex and of hits on the SPD layers. A tracklet is
defined by a pair of hits, one on each SPD layer. Using the

reconstructed vertex as the origin, we calculate the differences in azimuthal ($\Delta\varphi$, bending plane) and polar ($\Delta\theta$, nonbending direction) angles for pairs of hits [31]. Only hit combinations satisfying a selection on the sum of the squares of $\Delta\varphi$ and $\Delta\theta$, each normalized to its estimated resolution (60 mrad in $\Delta\varphi$ and $25\sin^2\theta$ mrad in $\Delta\theta$), are selected as tracklets. If multiple tracklet candidates share a hit, only the combination with the smallest sum of squares of $\Delta\varphi$ and $\Delta\theta$ is kept. The cut imposed on $\Delta\varphi$ efficiently selects charged particles with transverse momentum (p_t) above 50 MeV/c. Particles below 50 MeV/c are mostly absorbed by material.

The charged-particle pseudorapidity density $dN_{ch}/d\eta$ is obtained from the number of tracklets within $|\eta| < 0.5$ according to $dN_{ch}/d\eta = \alpha \times (1 - \beta)dN_{tracklets}/d\eta$, where α is the correction factor for the acceptance and efficiency for a primary track to generate a tracklet and β is the probability to form a background tracklet from uncorrelated hits. The corrections α and β are determined as a function of the z position of the primary vertex and the pseudorapidity of the tracklet. The simulations used to calculate the corrections are based on the HIJING [36] event generator and a GEANT3 [37] model of the detector response. Three different methods have been used to estimate the combinatorial background.

The main method to estimate the combinatorial background β relies on the event simulation using a sample of events with similar multiplicities (SPD hits) as in the real data. In Fig. 2 the $\Delta\varphi$ distribution for candidate tracklets is compared for data and simulation. The distributions are very similar, practically identical in the background dominated tails. The second method is based on the injection of random background hits in the real event, in order to evaluate the probability of creating fake tracklets by combinatorics. In the third method events are modified by rotating hits in the inner SPD layer by 180° in φ, thereby destroying real correlations, but preserving global event features. In all cases, the absolute amount of combinatorial
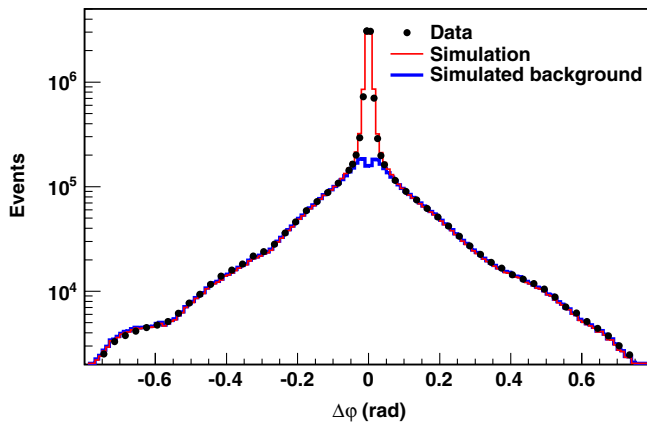

FIG. 2 (color online). Distribution of the azimuthal separation ($\Delta\varphi$) of all candidate tracklets in data, simulation, and the background contribution that is estimated from the simulation.

background is obtained by matching the tracklet and background distributions in the tails. For the main method, which ideally provides both the shape and the normalization, an adjustment of 1% is needed to match the tails. The estimated combinatorial background is about 14%. In order to account for the effect of the correlated background, the same background subtraction procedure is also applied to the simulation (i.e., without relying on the event generator information). The correction for the acceptance and efficiency, α, is obtained by the ratio of the number of generated primary charged particles to the number of reconstructed tracklets after subtraction of the combinatorial background. In this way, α accounts for geometrical acceptance, detector and reconstruction efficiencies, contamination by weak decay products of strange particles, conversions, secondary interactions, and undetected particles below 50 MeV/c transverse momentum. The overall correction factor α varies slightly depending on vertex position and η, and is about 2.

We have considered the following sources of systematic uncertainties: background subtraction estimated as 2% by comparing the results of different methods; particle composition estimated as 1% by changing the relative abundances of protons, pions, kaons by a factor of 2; contamination by weak decays estimated as 1% by changing the relative contribution of the yield of strange particles by a factor of 2; low-p_t extrapolation estimated as 2% by varying the amount of undetected particles at low p_t by a factor of 2; event generator estimated as 2% by using HIJING [36] with and without jet quenching, as well as DPMJET [38] for the corrections; centrality definition estimated as 3% by using an alternative event selection based on the SPD hit multiplicities, and by varying the range of the Glauber model fit. All other sources of systematic errors considered (tracklet cuts, vertex cuts, material budget, detector efficiency, background events) were found to be negligible. The total systematic errors amounts to 4.8%. Independent cross-checks performed using tracks reconstructed in the time projection chamber and the inner tracking system yield results consistent within the systematic uncertainty.

In order to compare bulk particle production in different collision systems and at different energies, and to compare with model calculations, the charged-particle density is scaled by the number of participating nucleons, determined using the Glauber model fit described above (Fig. 1). The average number of participants for the 5% most central events is found to be $\langle N_{part}\rangle = 381$ with a rms of 18 and a systematic uncertainty of 1%. The systematic uncertainty was obtained by varying the parameters of the Glauber calculation within the experimental uncertainty and by $\pm 8\%$ around 64 mb for the nucleon-nucleon cross section, by using different fit ranges, and by comparing results obtained for different centrality variables (SPD hits or combined use of the ZDC and VZERO signals).
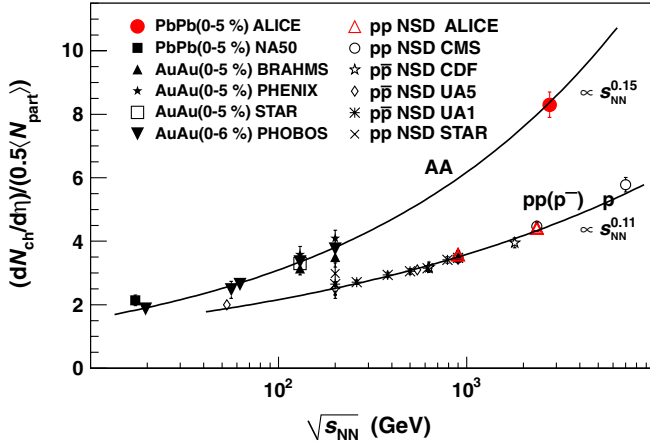
FIG. 3 (color online). Charged-particle pseudorapidity density per participant pair for central nucleus-nucleus [17–25] and nonsingle diffractive pp ($p\bar{p}$) collisions [26–32], as a function of $\sqrt{s_{NN}}$. The solid lines $\propto s_{NN}^{0.15}$ and $\propto s_{NN}^{0.11}$ are superimposed on the heavy-ion and pp ($p\bar{p}$) data, respectively.

FIG. 4 (color online). Comparison of this measurement with model predictions. Dashed lines group similar theoretical approaches.

We measure a density of primary charged particles at midrapidity $dN_{ch}/d\eta = 1584 \pm 4\text{(stat)} \pm 76\text{(syst)}$. Normalizing per participant pair, we obtain $dN_{ch}/d\eta/ (0.5\langle N_{part}\rangle) = 8.3 \pm 0.4\text{(syst)}$ with negligible statistical error. In Fig. 3, this value is compared to the measurements for Au-Au and Pb-Pb, and nonsingle diffractive pp and $p\bar{p}$ collisions over a wide range of collision energies [17–32]. It is interesting to note that the energy dependence is steeper for heavy-ion collisions than for pp and $p\bar{p}$ collisions. For illustration, the curves $\propto s_{NN}^{0.15}$ and $\propto s_{NN}^{0.11}$ are shown superimposed on the data. A significant increase, by a factor 2.2, in the pseudorapidity density is observed at $\sqrt{s_{NN}} = 2.76$ TeV for Pb-Pb compared to $\sqrt{s_{NN}} = 0.2$ TeV for Au-Au. The average multiplicity per participant pair for our centrality selection is found to be a factor 1.9 higher than that for pp and $p\bar{p}$ collisions at similar energies.

Figure 4 compares the measured pseudorapidity density to model calculations that describe RHIC measurements at $\sqrt{s_{NN}} = 0.2$ TeV, and for which predictions at $\sqrt{s_{NN}} = 2.76$ TeV are available. Empirical extrapolation from lower energy data [4] significantly underpredicts the measurement. Perturbative-QCD-inspired Monte Carlo event generators, based on the HIJING model tuned to 7 TeV pp data without jet quenching [5], on the dual parton model [6], or on the ultrarelativistic quantum molecular dynamics model [7], are consistent with the measurement. Models based on initial-state gluon density saturation have a range of predictions depending on the specific implementation [8–12] and exhibit a varying level of agreement with the measurement. The prediction of a hybrid model based on hydrodynamics and saturation of final-state phase space of scattered partons [13] is close to the measurement. A hydrodynamic model in which multiplicity is scaled from $p + p$ collisions overpredicts the measurement [14], while
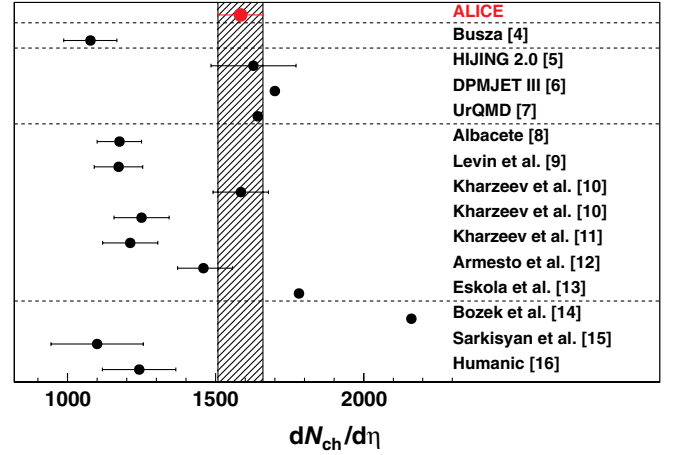
a model incorporating scaling based on Landau hydrodynamics underpredicts the measurement [15]. Finally, a calculation based on modified PYTHIA and hadronic rescattering [16] underpredicts the measurement.

In summary, we have measured the charged-particle pseudorapidity density at midrapidity in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, for the most central 5% fraction of the hadronic cross section. We find $dN_{ch}/d\eta = 1584 \pm 4\text{(stat)} \pm 76\text{(syst)}$, corresponding to $8.3 \pm 0.4\text{(syst)}$ per participant pair. These values are significantly larger than those measured at RHIC, and indicate a stronger energy dependence than measured in pp collisions. The result presented in this Letter provides an essential constraint for models describing high energy nucleus-nucleus collisions.

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[1] S. Abreu et al., J. Phys. G **35**, 054001 (2008).

[2] N. Armesto, arXiv:0903.1330.

[3] K. Aamodt et al. (ALICE Collaboration), JINST **3**, S08002 (2008).

[4] W. Busza, J. Phys. G **35**, 044040 (2008).

[5] W.-T. Deng, X.-N. Wang, and R. Xu, arXiv:1008.1841.

[6] F. W. Bopp, R. Engel, J. Ranft, and S. Roesler, arXiv:0706.3875.

[7] M. Mitrovski, T. Schuster, G. Graf, H. Petersen, and M. Bleicher, Phys. Rev. C **79**, 044901 (2009).

[8] J. L. Albacete, arXiv:1010.6027.

[9] E. Levin and A. H. Rezaeian, Phys. Rev. D **82**, 054003 (2010).

[10] D. Kharzeev, E. Levin, and M. Nardi, Nucl. Phys. **A747**, 609 (2005).

[11] D. Kharzeev, E. Levin, and M. Nardi, arXiv:0707.0811.

[12] N. Armesto, C. A. Salgado, and U. A. Wiedemann, Phys. Rev. Lett. **94**, 022002 (2005).

[13] K. J. Eskola, P. V. Ruuskanen, S. S. Rasanen, and K. Tuominen, Nucl. Phys. **A696**, 715 (2001).

[14] P. Bozek, M. Chojnacki, W. Florkowski, and B. Tomasik, Phys. Lett. B **694**, 238 (2010).

[15] E. K. G. Sarkisyan and A. S. Sakharov, arXiv:1004.4390.

[16] T. J. Humanic, arXiv:1011.0378.

[17] M. C. Abreu et al. (NA50 Collaboration), Phys. Lett. B **530**, 43 (2002).

[18] C. Adler et al. (STAR Collaboration), Phys. Rev. Lett. **87**, 112303 (2001).

[19] I. G. Bearden et al. (BRAHMS Collaboration), Phys. Lett. B **523**, 227 (2001).

[20] I. G. Bearden et al. (BRAHMS Collaboration), Phys. Rev. Lett. **88**, 202301 (2002).

[21] K. Adcox et al. (PHENIX Collaboration), Phys. Rev. Lett. **86**, 3500 (2001).

[22] B. B. Back et al. (PHOBOS Collaboration), Phys. Rev. Lett. **85**, 3100 (2000).

[23] B. B. Back et al. (PHOBOS Collaboration), Phys. Rev. Lett. **87**, 102303 (2001).

[24] B. B. Back et al., Phys. Rev. Lett. **91**, 052303 (2003).

[25] B. Alver et al., arXiv:1011.1940.

[26] C. Albajar et al., Nucl. Phys. **B335**, 261 (1990).

[27] K. Alpgard et al., Phys. Lett. B **112**, 183 (1982).

[28] G. J. Alner et al., Z. Phys. C **33**, 1 (1986).

[29] B. I. Abelev et al., Phys. Rev. C **79**, 034909 (2009).

[30] F. Abe et al., Phys. Rev. D **41**, 2330 (1990).

[31] K. Aamodt et al. (ALICE Collaboration), Eur. Phys. J. C **68**, 89 (2010).

[32] V. Khachatryan et al. (CMS Collaboration), J. High Energy Phys. 02 (2010) 041.

[33] G. Baur, K. Hencken, D. Trautmann, S. Sadovsky, and Y. Kharlov, Phys. Rep. **364**, 359 (2002).

[34] M. L. Miller, K. Reygers, S. J. Sanders, and P. Steinberg, Annu. Rev. Nucl. Part. Sci. **57**, 205 (2007).

[35] B. Alver, M. Baker, C. Loizides, and P. Steinberg, arXiv:0805.4411.

[36] X.-N. Wang and M. Gyulassy, Phys. Rev. D **44**, 3501 (1991).

[37] R. Brun et al., CERN Program Library Long Write-up, W5013, GEANT Detector Description and Simulation Tool, 1994.

[38] S. Roesler, R. Engel, and J. Ranft, arXiv:hep-ph/0012252.

K. Aamodt,[1] B. Abelev,[2] A. Abrahantes Quintana,[3] D. Adamová,[4] A. M. Adare,[5] M. M. Aggarwal,[6] G. Aglieri Rinella,[7] A. G. Agocs,[8] S. Aguilar Salazar,[9] Z. Ahammed,[10] A. Ahmad Masoodi,[11] N. Ahmad,[11] S. U. Ahn,[12,b] A. Akindinov,[13] D. Aleksandrov,[14] B. Alessandro,[15] R. Alfaro Molina,[9] A. Alici,[16,c] A. Alkin,[17] E. Almaráz Aviña,[9] T. Alt,[18] V. Altini,[19] S. Altinpinar,[20] I. Altsybeev,[21] C. Andrei,[22] A. Andronic,[20] V. Anguelov,[23,d]

C. Anson,[24] T. Antičić,[25] F. Antinori,[26] P. Antonioli,[27] L. Aphecetche,[28] H. Appelshäuser,[29] N. Arbor,[30] S. Arcelli,[16]
A. Arend,[29] N. Armesto,[31] R. Arnaldi,[15] T. Aronsson,[5] I. C. Arsene,[20] A. Asryan,[21] A. Augustinus,[7] R. Averbeck,[20]
T. C. Awes,[32] J. Äystö,[33] M. D. Azmi,[11] M. Bach,[18] A. Badalà,[34] Y. W. Baek,[12] S. Bagnasco,[15] R. Bailhache,[29]
R. Bala,[35,e] R. Baldini Ferroli,[36] A. Baldisseri,[37] A. Baldit,[38] F. Baltasar Dos Santos Pedrosa,[7] J. Bán,[39] R. Barbera,[40]
F. Barile,[19] G. G. Barnaföldi,[8] L. S. Barnby,[41] V. Barret,[38] J. Bartke,[42] M. Basile,[16] N. Bastid,[38] B. Bathen,[43]
G. Batigne,[28] B. Batyunya,[44] C. Baumann,[29] I. G. Bearden,[45] H. Beck,[29] I. Belikov,[46] F. Bellini,[16] R. Bellwied,[47,f]
E. Belmont-Moreno,[9] S. Beole,[35] I. Berceanu,[22] A. Bercuci,[22] E. Berdermann,[20] Y. Berdnikov,[48] C. Bergmann,[43]
L. Betev,[7] A. Bhasin,[49] A. K. Bhati,[6] L. Bianchi,[35] N. Bianchi,[50] C. Bianchin,[26] J. Bielčík,[51] J. Bielčíková,[4]
A. Bilandzic,[52] E. Biolcati,[35] A. Blanc,[38] F. Blanco,[53] F. Blanco,[54] D. Blau,[14] C. Blume,[29] M. Boccioli,[7] N. Bock,[24]
A. Bogdanov,[55] H. Bøggild,[45] M. Bogolyubsky,[56] L. Boldizsár,[8] M. Bombara,[57] C. Bombonati,[26] J. Book,[29]
H. Borel,[37] A. Borissov,[47] C. Bortolin,[26,g] S. Bose,[58] F. Bossú,[35] M. Botje,[52] S. Böttger,[23] B. Boyer,[59]
P. Braun-Munzinger,[20] L. Bravina,[60] M. Bregant,[61,h] T. Breitner,[23] M. Broz,[62] R. Brun,[7] E. Bruna,[5] G. E. Bruno,[19]
D. Budnikov,[63] H. Buesching,[29] K. Bugaiev,[17] O. Busch,[64] Z. Buthelezi,[65] D. Caffarri,[26] X. Cai,[66] H. Caines,[5]
E. Calvo Villar,[67] P. Camerini,[61] V. Canoa Roman,[7,i] G. Cara Romeo,[27] F. Carena,[7] W. Carena,[7] F. Carminati,[7]
A. Casanova Díaz,[50] M. Caselle,[7] J. Castillo Castellanos,[37] V. Catanescu,[22] C. Cavicchioli,[7] J. Cepila,[51] P. Cerello,[15]
B. Chang,[33] S. Chapeland,[7] J. L. Charvet,[37] S. Chattopadhyay,[58] S. Chattopadhyay,[10] M. Cherney,[68] C. Cheshkov,[69]
B. Cheynis,[69] E. Chiavassa,[15] V. Chibante Barroso,[7] D. D. Chinellato,[70] P. Chochula,[7] M. Chojnacki,[71]
P. Christakoglou,[71] C. H. Christensen,[45] P. Christiansen,[72] T. Chujo,[73] C. Cicalo,[74] L. Cifarelli,[16] F. Cindolo,[27]
J. Cleymans,[65] F. Coccetti,[20] J.-P. Coffin,[46] S. Coli,[15] G. Conesa Balbastre,[50,j] Z. Conesa del Valle,[28,k]
P. Constantin,[64] G. Contin,[61] J. G. Contreras,[75] T. M. Cormier,[47] Y. Corrales Morales,[35] I. Cortés Maldonado,[76]
P. Cortese,[77] M. R. Cosentino,[70] F. Costa,[7] M. E. Cotallo,[53] E. Crescio,[75] P. Crochet,[38] E. Cuautle,[78] L. Cunqueiro,[50]
G. D Erasmo,[19] A. Dainese,[79,l] H. H. Dalsgaard,[45] A. Danu,[80] D. Das,[58] I. Das,[58] K. Das,[58] A. Dash,[81] S. Dash,[15]
S. De,[10] A. De Azevedo Moregula,[50] G. O. V. de Barros,[82] A. De Caro,[83] G. de Cataldo,[84] J. de Cuveland,[18]
A. De Falco,[85] D. De Gruttola,[83] N. De Marco,[15] S. De Pasquale,[83] R. De Remigis,[15] R. de Rooij,[71] P. R. Debski,[86]
E. Del Castillo Sanchez,[7] H. Delagrange,[28] Y. Delgado Mercado,[67] G. Dellacasa,[77,1] A. Deloff,[86] V. Demanov,[63]
E. Dénes,[8] A. Deppman,[82] D. Di Bari,[19] C. Di Giglio,[19] S. Di Liberto,[87] A. Di Mauro,[7] P. Di Nezza,[50] T. Dietel,[43]
R. Divià,[7] Ø. Djuvsland,[1] A. Dobrin,[47,m] T. Dobrowolski,[86] I. Domínguez,[78] B. Dönigus,[20] O. Dordic,[60] O. Driga,[28]
A. K. Dubey,[10] J. Dubuisson,[7] L. Ducroux,[69] P. Dupieux,[38] A. K. Dutta Majumdar,[58] M. R. Dutta Majumdar,[10]
D. Elia,[84] D. Emschermann,[43] H. Engel,[23] H. A. Erdal,[88] B. Espagnon,[59] M. Estienne,[28] S. Esumi,[73] D. Evans,[41]
S. Evrard,[7] G. Eyyubova,[60] C. W. Fabjan,[7,n] D. Fabris,[89] J. Faivre,[30] D. Falchieri,[16] A. Fantoni,[50] M. Fasel,[20]
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