Pseudorapidity and transverse-momentum distributions of charged particles in proton-proton collisions at $\sqrt{s} = 13$ TeV

ALICE Collaboration

Abstract

The pseudorapidity ($\eta$) and transverse-momentum ($p_T$) distributions of charged particles produced in proton-proton collisions are measured at the centre-of-mass energy $\sqrt{s} = 13$ TeV. The pseudorapidity distribution in $|\eta| < 1.8$ is reported for inelastic events and for events with at least one charged particle in $|\eta| < 1$. The pseudorapidity density of charged particles produced in the pseudorapidity region $|\eta| < 0.5$ is $5.31 \pm 0.18$ and $6.46 \pm 0.19$ for the two event classes, respectively. The transverse-momentum distribution of charged particles is measured in the range $0.15 < p_T < 20$ GeV/$c$ and $|\eta| < 0.8$ for events with at least one charged particle in $|\eta| < 1$. The evolution of the transverse momentum spectra of charged particles is also investigated as a function of event multiplicity. The results are compared with calculations from PYTHIA and EPOS Monte Carlo generators.

*See Appendix A for the list of collaboration members
1 Introduction

After a two-year long shutdown, the Large Hadron Collider (LHC) at CERN restarted its physics programme in June 2015 with proton-proton collisions at \( \sqrt{s} = 13 \) TeV, the highest centre-of-mass energy reached so far in laboratory. The measurement of the inclusive production of charged hadrons in high-energy proton-proton interactions is a key observable to characterise the global properties of the collision, in particular whenever the collision energy increases significantly. Particle production at collider energies originates from the interplay of perturbative (hard) and non-perturbative (soft) QCD processes. Soft scattering processes and parton hadronisation dominate the bulk of particle production at low transverse momenta and can only be modelled phenomenologically. Hence, these measurements provide constraints for a better tuning of models and event generators for hadron-collider and cosmic-ray physics [1].

We present the pseudorapidity (\( \eta \)) and transverse-momentum (\( p_T \)) distributions of primary charged particles measured in proton-proton collisions at the centre-of-mass energy \( \sqrt{s} = 13 \) TeV with the ALICE detector [2] at the LHC [3]. Primary particles are defined as prompt particles produced in the collisions, including all decay products, with the exception of those from weak decays of strange particles. Similar measurements have been performed by ALICE in proton-proton (pp), proton-lead (p–Pb) and lead-lead (Pb–Pb) collisions collected during the previous LHC run at lower energies [4–14]. The pseudorapidity distribution is measured at central rapidity in \( |\eta| < 1.8 \). The measurements reported here have been obtained for inelastic events (INEL) and events having at least one charged particle produced with \( p_T > 0 \) in the pseudorapidity interval \( |\eta| < 1 \) (INEL>0). Similar results were recently published by the CMS Collaboration for INEL events [15]. The transverse-momentum distribution of charged particles is measured in the range \( 0.15 < p_T < 20 \text{ GeV/c} \) and \( |\eta| < 0.8 \) for INEL>0 events. The evolution of the transverse momentum spectra of charged particles is also investigated as a function of event multiplicity. The data have been compared to calculations from models commonly used at the LHC.

2 The ALICE detector and data collection

A comprehensive description of the ALICE experimental setup can be found in [2,16]. The main detectors utilised for the analysis presented here are the Inner Tracking System (ITS), the Time-Projection Chamber (TPC), the V0 counters and the ALICE Diffractive (AD) detector. The ITS and TPC detectors, which are located inside a solenoidal magnet providing a magnetic field of 0.5 T, are used for primary-vertex and track reconstruction. The V0 counters and the AD detector are employed for triggering and for background suppression.

The ITS is composed of six cylindrical layers of high-resolution silicon tracking detectors. The innermost layers consist of two arrays of hybrid Silicon Pixel Detectors (SPD) located at radii 3.9 and 7.6 cm from the beam axis and covering respectively \( |\eta| < 2.0 \) and \( |\eta| < 1.4 \) for particles emerging from the nominal interaction point \((z = 0 \text{ cm})\). The TPC is a large cylindrical drift detector of radial and longitudinal size of about \( 85 < r < 250 \text{ cm} \) and \( -250 < z < 250 \text{ cm} \), respectively. The active volume of nearly 90 m\(^3\) is filled with an Ar-CO\(_2\) (88-12%) gas mixture and is divided in two halves by a central high-voltage membrane maintained at \(-100 \text{ kV}\). The two end-caps are each equipped with 36 multi-wire proportional chambers with cathode pad readout, comprising a total of 558000 readout channels. The V0 counters are two scintillator hodoscopes placed on either side of the interaction region at \( z = 3.3 \text{ m} \) and \( z = -0.9 \text{ m} \), covering the pseudorapidity regions \( 2.8 < \eta < 5.1 \) and \(-3.7 < \eta < -1.7 \), respectively. The AD detector was integrated in ALICE during the LHC shutdown before Run 2 to enhance the capabilities of the experiment to tag diffractive processes and low \( p_T \) events [17]. It consists of two double layers of scintillation counters placed far from the interaction region, on both sides: one in the ALICE cavern at \( z = 17.0 \text{ m} \) and one in the LHC tunnel at \( z = -19.5 \text{ m} \). The pseudorapidity coverage of the two AD arrays is \( 4.8 < \eta < 6.3 \) and \(-7.0 < \eta < -4.9 \), respectively.

The data were collected after the startup of LHC Run 2 in June 2015. Beams consisting of 39 bunches...
were circulating in the machine, with about $8 \times 10^9$ protons per bunch. In the ALICE interaction region, 15 pairs of bunches were colliding, leading to a luminosity of about $5 \times 10^{27} \text{cm}^{-2}\text{s}^{-1}$. This value corresponds to a rate of about 350 Hz for inelastic proton-proton collisions. The probability that a recorded event contains more than one collision was estimated to be around $10^{-3}$, which is consistent with the fraction of events containing more than one distinct vertex and tagged as pileup. The luminous region had an RMS width of about 5 cm in the $z$ direction and about 85 $\mu$m in the transverse direction. The data were collected using a minimum-bias trigger requiring a hit in either the V0 scintillators or in the AD arrays. The events were recorded in coincidence with signals from two beam pick-up counters each positioned on either side of the interaction region to tag the arrival of proton bunches from both directions. Control triggers taken for various combinations of beam and empty buckets were used to measure beam-induced and accidental backgrounds. The contamination from background events is removed offline by using the timing information from the V0 and the AD detectors, which have a time resolution better than 1 ns. Background events are also rejected by exploiting the correlation between the number of clusters of pixel hits and the number of tracklets (short track segments pointing to the primary vertex) in the SPD. From the analysis of control triggers it is estimated that the remaining background fraction in the sample is less than $10^{-4}$ and can be neglected.

3 Event selection and data analysis

About 1.5 million events pass the minimum-bias selection criteria. Events used for the data analysis are further required to have a valid reconstructed vertex within $|z| < 10$ cm. All corrections are calculated using a sample of about 4 million Monte Carlo events from the PYTHIA 6 [18] (Perugia-2011 [19]) event generator with particle transport performed via a GEANT3 [20] simulation of the ALICE detector.

The analysis technique employed for the measurement of the charged-particle pseudorapidity distribution is based on the reconstruction of tracklets, which are built using the position of the reconstructed primary vertex and two hits, one on each SPD layer. Details on the algorithm for tracklet reconstruction are described in [4]. This technique effectively allows to reconstruct charged particles with $p_T$ above the 50 MeV/$c$ cut-off determined by particle absorption in the material. The charged-particle pseudorapidity density is obtained from the measured distribution of tracklets $dN_{\text{tracklets}}/d\eta$ as $dN_{\text{ch}}/d\eta = \alpha(1 - \beta) dN_{\text{tracklets}}/d\eta$. The correction $\alpha$ accounts for the acceptance and efficiency for a primary particle to produce a tracklet, while $\beta$ is the contamination of reconstructed tracklets from combinations of hits not produced by the same primary particle. Both correction factors are determined as a function of the $z$ position of the primary vertex and the pseudorapidity of the tracklet from detector simulations and are found to be on average 1.5 and 0.01, respectively. The vertex position requirement results in an effective $|\eta| < 1.8$ coverage. Differences in strange-particle content between data and simulations, observed at lower beam energies [21, 22], are taken into account by scaling the strangeness production in the Monte Carlo event sample by a factor 1.85 (strangeness correction), resulting in a further contamination correction of about 1%.

The transverse-momentum distribution is measured from tracks reconstructed using the information from the ITS and TPC detectors. Candidate tracks are selected with cuts on the number of space points used for tracking and on the quality of the track fit, as well as on the distance of closest approach to the reconstructed vertex. Details on the track-reconstruction algorithm and quality cuts can be found in [10, 11, 14]. The requirements applied for track selection result in an effective $|\eta| < 0.8$ acceptance. The efficiency for track reconstruction and selection depends on the particle type and it is known that PYTHIA 6 does not reproduce correctly the particle fractions measured at $\sqrt{s} = 7$ TeV. A reweighting of the Monte Carlo efficiencies for each species with the relative abundances measured in minimum-bias pp collisions at $\sqrt{s} = 7$ TeV [21, 22] is performed. The overall primary charged-particle reconstruction efficiency for $|\eta| < 0.8$ increases sharply from 34% at 150 MeV/$c$, reaches 73% at 0.8 GeV/$c$, decreases moderately to 67% for $p_T = 2$ GeV/$c$ and rises again to reach a saturation value of 74% at 10 GeV/$c$. 

$\eta$ and $p_T$ distributions of charged particles in pp at $\sqrt{s} = 13$ TeV

ALICE Collaboration
η and \( p_T \) distributions of charged particles in pp at \( \sqrt{s} = 13 \) TeV

ALICE Collaboration

|                        | \( \frac{dN_{ch}}{d\eta} \) | \( \frac{dN_{ch}}{dp_T} \) |
|------------------------|-------------------------------|-----------------------------|
|                        | INEL                         | INEL > 0                    | 0.15             | 20 GeV/c         |
| Background events and pileup | negligible                  | negligible                  |                  |                 |
| Normalisation          | 2.8                          | 2.3                         | 1.8              | 5.6             |
| Detector acceptance and efficiency | 1.5                          | 1.8                         | 0.1              | 1.5             |
| Material budget        | 0.1                          | 1.5                         | 0.2              | 0.2             |
| Track(let) selection criteria | negligible                  | 1.5                         | 0.2              | 0.2             |
| Particle composition   | 0.2                          | 0.3                         | 2.4              |                 |
| Weak decays of strange hadrons | 0.5                          | 3.4                         | 0.4              |                 |
| Zero-\( p_T \) extrapolation | 1.0                          | not applicable              |                  |                 |
| Total (\( \eta, p_T \) dependent) | 1.9                          | 4.4                         | 6.8              |                 |
| Total                  | 3.4                          | 3.0                         | 5.0              | 7.2             |

Table 1: Summary of the relative systematic uncertainties (expressed in %) contributing to the measurement of the charged-particle pseudorapidity and transverse-momentum distributions. The values for the \( \frac{dN_{ch}}{d\eta} \) analysis are reported separately for the INEL and INEL > 0 classes. For the \( \frac{dN_{ch}}{dp_T} \) analysis the \( p_T \) dependence is summarised with the values at 0.15 and 20 GeV/c for the INEL > 0 class.

The minimum around 2 GeV/c arises due to the azimuthal segmentation of the TPC readout chambers. Tracks of moderate \( p_T \), which may not have enough hits in adjacent azimuthal sectors, do not pass the selection criteria. Finally, the residual contamination from secondary particles is subtracted from the spectrum; this contamination, estimated from Monte Carlo simulations, is 7% for our lowest \( p_T \) bin and decreases below 1% for \( p_T > 2 \) GeV/c.

4 Systematic uncertainties

A summary of the contributions to the relative systematic uncertainties of the charged-particle pseudorapidity and transverse-momentum distributions is reported in Tab. 1.

One of the main contributions to the normalisation of the results comes from the limited knowledge of cross-sections and kinematics of diffractive processes. For proton-proton collisions at \( \sqrt{s} = 13 \) TeV there is not yet any experimental information available about diffractive processes, therefore trigger and event-selection efficiency corrections are solely based on previous experimental data at lower collision energies and simulations with Monte Carlo event generators. The corresponding systematic uncertainty has been evaluated by varying the fractions of single-diffractive (SD) and double-diffractive (DD) events produced by PYTHIA 6 (Perugia-2011) by \( \pm 50\% \) of their nominal values at \( \sqrt{s} = 13 \) TeV. The resulting contribution to the systematic uncertainties for INEL and INEL > 0 events is estimated to be about 2% and 1.2%, respectively. To estimate systematic uncertainties associated to the model dependence of the normalisation correction we employed PYTHIA 8 [23] (Monash-2013 [24]), which shows large differences both in the multiplicity and transverse-momentum distributions of charged particles with respect to PYTHIA 6, especially in diffractive events [25]. A difference of about 0.4% and 2% is observed for INEL and INEL > 0 events, respectively. Finally, an uncertainty of 2% has been estimated by varying the offline event-selection criteria applied to the trigger detectors which only affects the normalisation of the INEL sample.

The systematic uncertainties for the transverse-momentum distribution analysis are evaluated in a similar way as in previous analyses of pp [9,10], p–Pb [11,12], and Pb–Pb [14] data. The dominant sources of uncertainty are the track selections, the efficiency corrections and, for low \( p_T \), the contamination from weak decays of strange hadrons. The systematic uncertainties for the pseudorapidity distribution...
analysis are discussed in the following. The uncertainty in detector acceptance and efficiency is estimated to be about 1.5%, determined from the change of the multiplicity at a given $\eta$ by varying the range of the $z$ position of the vertex and performing the measurement in different runs. The material budget in the ALICE central barrel $|\eta| < 1$ is known with a precision of about 5% [16]. The corresponding systematic uncertainty, obtained by varying the material budget in the simulation, is estimated to be about 0.1% and is negligibly small compared to the other sources. The sensitivity to tracklet selection criteria was estimated varying the selection requirements and is negligible. The uncertainty due to the particle composition is estimated to be about 0.2% and was determined by changing the relative fractions of charged kaons and protons with respect to charged pions produced by the Monte Carlo generator by $\pm 30\%$. The uncertainty resulting from the subtraction of the contamination from weak decays of strange hadrons is estimated to amount to about 0.5% by varying the strangeness correction by $\pm 30\%$. The uncertainty due to the correction down to zero $p_T$ is estimated to be about 1% by varying the amount of particles below the 50 MeV/$c$ low-$p_T$ cutoff by $^{+100\%}_{-50\%}$.

5 Results

Figure 1 shows the average charged-particle density distribution $\langle dN_{ch}/d\eta \rangle$ measured in INEL and INEL$>0$ events in the pseudorapidity range $|\eta| < 1.8$. The data points have been symmetrised averaging the results obtained in $\pm \eta$, which were consistent within statistical uncertainties. The corresponding pseudorapidity densities in $|\eta| < 0.5$ are $5.31 \pm 0.18$ and $6.46 \pm 0.19$, respectively. The pseudorapidity density for the INEL$>0$ events is also measured in $|\eta| < 1$ for direct comparison with INEL$>0$ results reported by ALICE at lower energies [5] and is $6.61 \pm 0.20$. Also shown in Fig. 1 are the results recently published by the CMS Collaboration for inelastic collisions [15], which agree, within the uncertainties, with the measurement presented here. We compared our measurement to Monte Carlo calculations performed with PYTHIA 6 [18] (Perugia-2011 [19]), PYTHIA 8 [26] (Monash-2013 [24]) and

Fig. 1: Average pseudorapidity density of charged particles as a function of $\eta$ produced in pp collisions at $\sqrt{s} = 13$ TeV. The ALICE results are shown in the normalisation classes INEL and INEL$>0$ and compared to Monte Carlo calculations [18, 19, 24, 26–28] and to the results from the CMS Collaboration [15]. The uncertainties are the quadratic sum of statistical and systematic contributions.
Fig. 2: Charged-particle pseudorapidity density measured in the central pseudorapidity region $|\eta| < 0.5$ for INEL and INEL > 0 events [4–6, 15, 29–33]. The uncertainties are the quadratic sum of statistical and systematic contributions. The lines are power-law fits of the energy dependence of the data and the grey bands represent the standard deviation of the fits.

EPOS LHC [27, 28] in both the INEL and INEL > 0 event classes. PYTHIA 6 calculations are in better agreement with the data than PYTHIA 8 in both classes, with PYTHIA 8 being higher than the data by about 12% (7%) in INEL events and about 7% (3%) in INEL > 0 events at $\eta \sim 0$ ($\eta \sim 1.5$). EPOS LHC calculations are about 7% (4%) and about 7% (5%) higher than the data in INEL and INEL > 0 events, respectively, at $\eta \sim 0$ ($\eta \sim 1.5$). In Fig. 2 we show a compilation of results on pseudorapidity density of charged particles measured in $|\eta| < 0.5$ for the INEL and INEL > 0 results at different proton-proton collider energies [4–6, 15, 29–33]. The energy dependence of $\langle dN_{ch}/d\eta \rangle$ is parametrised by the power law as $s^b$ fitted to data, where $a$ and $b$ are free parameters. By combining the data at lower energies with ALICE and CMS results at $\sqrt{s} = 13$ TeV, we obtain $b = 0.103(2)$ and $b = 0.111(4)$ for INEL and INEL > 0 event classes, respectively. Notice that the fit results assume that uncertainties at different centre-of-mass energies are independent, which is not strictly the case.

Figure 3 presents the measured $p_T$ spectrum and its comparison with calculations with PYTHIA 6 (Perugia-2011), PYTHIA 8 (Monash-2013) and EPOS LHC. For bulk particle production, the mechanism of colour reconnection is an important one in the PYTHIA models (see discussion below and in ref. [34]). EPOS is a model based on the Gribov-Regge theory at parton level [27]. Collective (flow-like) effects are incorporated in the EPOS3 version [35] and treated via parametrisations in the EPOS LHC version [28]. These event generators, benefitting from the tuning performed on the LHC data in Run 1, describe the $p_T$ spectrum reasonably well, although not in detail. It is interesting to note that both PYTHIA 8 and EPOS LHC models show a similar pattern in the ratio to data with discrepancies up to 20% and that PYTHIA 6 overestimates particle production at high $p_T$.

Figure 4 shows the ratio of transverse-momentum spectra of charged particles at $\sqrt{s} = 13$ TeV and 7 TeV. The published data at $\sqrt{s} = 7$ TeV [10] were for INEL events. We have recalculated the normalisation of the spectrum to correspond to INEL > 0 events in a similar manner as done for $\sqrt{s} = 13$ TeV. The

$^1$Calculations performed with CRMC package version 1.5.3.
Fig. 3: Invariant charged-particle yield as a function of $p_T$ normalised to INEL>0 events. The data are compared to Monte Carlo calculations [18, 19, 24, 26–28]. For the ratio of models (MC) and data (lower panel) the systematic and total uncertainties of the data are shown as grey bands.

The correlation of the particle mean transverse momentum ($\langle p_T \rangle$) with the multiplicity of the event ($N_{ch}$) first observed at the Sp¯¯pS collider [35], has been studied by many experiments at hadron colliders in pp(¯¯p) covering collision energies from $\sqrt{s} = 31$ GeV up to 7 TeV [9, 37–44]. The increase of $\langle p_T \rangle$ with $N_{ch}$ in the central rapidity region observed in all experiments could be reproduced in the PYTHIA event generator only if a mechanism of hadronisation with colour reconnections (CR) is considered [34, 45–47]. A connection between CR and features of collective flow has been conjectured in [48]. In heavy-ion collisions, collective flow is established as a genuine space-time evolution of a fireball, while CR in PYTHIA is a mechanism invoked for hadronisation. The relevance of the CR-flow conjecture is currently investigated further [49]. A mechanism involving collective string hadronisation is also used in the EPOS model [28].

Figure 5 shows the ratio of spectra measured in three intervals of multiplicity to the inclusive (INEL>0) spectrum. For this ratio, the spectra were normalised by the integral prior to dividing. The selection is performed on the multiplicity measured in the same kinematic region as the spectrum, $|\eta| < 0.8$ and $0.15 < p_T < 20$ GeV/c, using the measured track multiplicity $N_{ch}^{acc}$ for data and the true value of $N_{ch}$ known in Monte Carlo events. For INEL>0 events, $\langle N_{ch}^{acc} \rangle = 6.73$ (and, from the spectrum in Fig. 3
η and \( p_T \) distributions of charged particles in pp at \( \sqrt{s} = 13 \) TeV

ALICE Collaboration

![Graph showing ratio of transverse-momentum spectra in INEL>0 events at \( \sqrt{s} = 13 \) and 7 TeV. The boxes represent the systematic uncertainties. The data are compared to Monte Carlo calculations [18, 19, 24, 26–28].](image)

\[ \langle N_{ch} \rangle = 9.41 \pm 0.38 \] for data and \( \langle N_{ch} \rangle = 10.13 \) for PYTHIA 8 and \( \langle N_{ch} \rangle = 9.97 \) for EPOS LHC events. The low-multiplicity interval corresponds to \( N_{ch} (N_{acc}^{ch}) \) smaller than the average value in INEL>0 events, \( \langle N_{ch} \rangle (\langle N_{acc}^{ch} \rangle) \), the medium-multiplicity interval covers between \( \langle N_{ch} \rangle (\langle N_{acc}^{ch} \rangle) \) and twice \( \langle N_{ch} \rangle (\langle N_{acc}^{ch} \rangle) \), while the high-multiplicity interval includes all events with \( N_{ch} (N_{acc}^{ch}) \geq 2 \langle N_{ch} \rangle (\langle N_{acc}^{ch} \rangle) \). Given that the measurement efficiency of the \( p_T \) spectrum for INEL>0 events with \( N_{ch} = 1 \) is about 50%, the data is slightly biased for the lowest multiplicity interval. This leads to a slight hardening of the measured spectrum, but the magnitude of the spectral shape change, of a few percent, is clearly smaller than the observed difference between data and models. The systematic uncertainties of the measured spectra cancel out completely in the ratios. A residual contribution, not estimated at this stage, is that of the contamination from strange-particle decays.

It is known that the increase of \( \langle p_T \rangle \) as a function of multiplicity is moderate [44]. The data in Fig. 5 show that the correlation of the spectrum with multiplicity is prominent for the whole \( p_T \) range and in particular that it is stronger at high \( p_T \). In first order, this correlation arises naturally from jets, giving the leading high-\( p_T \) hadron and a significant contribution to multiplicity. The general features seen in the data, which are similar to those first seen at \( \sqrt{s} = 0.9 \) TeV [9], are reproduced by PYTHIA 8 and EPOS LHC fairly well, but some disagreements are noticeable too, in particular in the \( p_T \) region of a few GeV/c. This is more prominent for EPOS LHC. It was shown earlier [44] that both EPOS LHC and PYTHIA 8 reproduce well, although slightly overpredicting, the correlation of \( \langle p_T \rangle \) with \( N_{ch} \). The present data on spectral shape highlight some deficiencies in both models concerning the description of spectral shapes as a function of multiplicity.

6 Conclusions

We have reported the measurement of the pseudorapidity and transverse-momentum distributions of charged particles produced in proton-proton collisions at \( \sqrt{s} = 13 \) TeV with the ALICE detector at LHC. The pseudorapidity distribution is measured for two normalisation classes: inelastic events (INEL) and events having at least one charged particle in the pseudorapidity interval \( |\eta| < 1 \) (INEL>0). The charged-
Fig. 5: Ratios of transverse-momentum distributions of charged particles in three intervals of multiplicities to the respective one for inclusive (INEL > 0) collisions. The spectra were normalized by the integral prior to division. The data are compared to Monte Carlo calculations [24, 26, 28].

Particle densities in $|\eta| < 0.5$ are $5.31 \pm 0.18$ and $6.46 \pm 0.19$, respectively. The transverse-momentum distribution is measured in the range $0.15 < p_T < 20$ GeV/c and $|\eta| < 0.8$ for INEL > 0 events. The spectrum is significantly harder than at $\sqrt{s} = 7$ TeV and shows rich features when correlated with the charged-particle multiplicity measured in the same kinematic region. The results are found to be in fair agreement with the expectations from lower energy extrapolations and with the calculations from PYTHIA and EPOS Monte Carlo generators, but not in all details. Both models exhibit a slightly more pronounced hardening of the $p_T$ distributions with collision energy than the data for transverse momenta above a few GeV/c.

Acknowledgements

The ALICE Collaboration would like to thank all its engineers and technicians for their invaluable contributions to the construction of the experiment and the CERN accelerator teams for the outstanding performance of the LHC complex. The ALICE Collaboration gratefully acknowledges the resources and support provided by all Grid centres and the Worldwide LHC Computing Grid (WLCG) collaboration. The ALICE Collaboration acknowledges the following funding agencies for their support in building and running the ALICE detector: State Committee of Science, World Federation of Scientists (WFS) and Swiss Fonds Kidagan, Armenia; Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Financiadora de Estudos e Projetos (FINEP), Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP); National Natural Science Foundation of China (NSFC), the Chinese Ministry of Education (CMOE) and the Ministry of Science and Technology of China (MSTC); Ministry of Education and Youth of the Czech Republic; Danish Natural Science Research Council, the Carlsberg Foundation and the Danish National Research Foundation; The European Research Council under the European Community’s Seventh Framework Programme; Helsinki Institute of Physics and the Academy of Finland; French CNRS-IN2P3, the ‘Region Pays de Loire’, ‘Region Alsace’, ‘Region Auvergne’ and CEA, France; German Bundesministerium fur Bildung, Wissenschaft, Forschung und
η and $p_T$ distributions of charged particles in pp at $\sqrt{s} = 13$ TeV

ALICE Collaboration

Technologie (BMBF) and the Helmholtz Association; General Secretariat for Research and Technology, Ministry of Development, Greece; National Research, Development and Innovation Office (NKFIH), Hungary; Department of Atomic Energy and Department of Science and Technology of the Government of India; Istituto Nazionale di Fisica Nucleare (INFN) and Centro Fermi - Museo Storico della Fisica e Centro Studi e Ricerche “Enrico Fermi”, Italy; MEXT Grant-in-Aid for Specially Promoted Research, Japan; Joint Institute for Nuclear Research, Dubna; National Research Foundation of Korea (NRF); Consejo Nacional de Cienca y Tecnologia (CONACyT), Dirección General de Asuntos del Personal Académico(DGAPA), México, Amerique Latine Formation academique - European Commission (ALFA-EC) and the EPLANET Program (European Particle Physics Latin American Network); Stichting voor Fundamenteel Onderzoek der Materie (FOM) and the Nederlandse Organisatie voor Wetenschappelijk Onderzoek (NWO), Netherlands; Research Council of Norway (NFR); National Science Centre, Poland; Ministry of National Education/Institute for Atomic Physics and National Council of Scientific Research in Higher Education (CNCS/UEFISCDI), Romania; Ministry of Education and Science of Russian Federation, Russian Academy of Sciences, Russian Federal Agency for Science and Innovations and The Russian Foundation for Basic Research; Ministry of Education of Slovakia; Department of Science and Technology, South Africa; Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas (CIEMAT), E-Infrastructure shared between Europe and Latin America (EELA), Ministerio de Economía y Competitividad (MINECO) of Spain, Xunta de Galicia (Consellería de Educación), Centro de Aplicaciones Tecnológicas y Desarrollo Nuclear (CEADEN), Cubaenergía, Cuba, and IAEA (International Atomic Energy Agency); Swedish Research Council (VR) and Knut & Alice Wallenberg Foundation (KAW); Ukraine Ministry of Education and Science; United Kingdom Science and Technology Facilities Council (STFC); The United States Department of Energy, the United States National Science Foundation, the State of Texas, and the State of Ohio; Ministry of Science, Education and Sports of Croatia and Unity through Knowledge Fund, Croatia; Council of Scientific and Industrial Research (CSIR), New Delhi, India; Pontificia Universidad Católica del Perú.

References

[1] D. d’Enterria, R. Engel, T. Pierog, S. Ostapchenko, and K. Werner, “Constraints from the first LHC data on hadronic event generators for ultra-high energy cosmic-ray physics,” *Astropart. Phys.* 35 (2011) 98–113, arXiv:1101.5596 [astro-ph.HE].

[2] ALICE Collaboration, K. Aamodt et al., “The ALICE experiment at the CERN LHC,” *JINST* 3 (2008) S08002.

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

[4] ALICE Collaboration, K. Aamodt et al., “Charged-particle multiplicity measurement in proton-proton collisions at $\sqrt{s}$ = 0.9 and 2.36 TeV with ALICE at LHC,” *Eur. Phys. J.* C68 (2010) 89–108, arXiv:1004.3034 [hep-ex].

[5] ALICE Collaboration, K. Aamodt et al., “Charged-particle multiplicity measurement in proton-proton collisions at $\sqrt{s}$ = 7 TeV with ALICE at LHC,” *Eur. Phys. J.* C68 (2010) 345–354, arXiv:1004.3514 [hep-ex].

[6] ALICE Collaboration, K. Aamodt et al., “Charged-particle multiplicities in proton-proton collisions at $s = 0.9$ to 8 TeV, with ALICE at the LHC,” arXiv:1509.07541 [nucl-ex].

[7] ALICE Collaboration, B. Abelev et al., “Pseudorapidity density of charged particles in $p + Pb$ collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV,” *Phys. Rev. Lett.* 110 no. 3, (2013) 032301, arXiv:1210.3615 [nucl-ex].
η and \( p_T \) distributions of charged particles in pp at \( \sqrt{s} = 13 \text{ TeV} \)

[8] \textbf{ALICE} Collaboration, K. Aamodt \textit{et al.}, “Charged-particle multiplicity density at mid-rapidity in central \( \text{Pb-Pb} \) collisions at \( \sqrt{s_{NN}} = 2.76 \text{ TeV} \),” \textit{Phys. Rev. Lett.} \textbf{105} (2010) 252301, arXiv:1011.3916 [nucl-ex]

[9] \textbf{ALICE} Collaboration, K. Aamodt \textit{et al.}, “Transverse momentum spectra of charged particles in proton-proton collisions at \( \sqrt{s} = 900 \text{ GeV} \) with ALICE at the LHC,” \textit{Phys. Lett.} \textbf{B693} (2010) 53–68, arXiv:1007.0719 [hep-ex]

[10] \textbf{ALICE} Collaboration, B. Abelev \textit{et al.}, “Energy Dependence of the Transverse Momentum Distributions of Charged Particles in pp Collisions Measured by ALICE,” \textit{Eur. Phys. J.} \textbf{C73} no. 12, (2013) 2662, arXiv:1307.1093 [nucl-ex]

[11] \textbf{ALICE} Collaboration, B. Abelev \textit{et al.}, “Energy Dependence of the Transverse Momentum Distributions of Charged Particles in pp Collisions Measured by ALICE,” \textit{Eur. Phys. J.} \textbf{C73} no. 12, (2013) 2662, arXiv:1307.1093 [nucl-ex]

[12] \textbf{ALICE} Collaboration, B. Abelev \textit{et al.}, “Center-of-Mass Energy Dependence of the Transverse Momentum Distributions of Charged Particles in \( p-Pb \) Collisions Measured by ALICE,” \textit{Eur. Phys. J.} \textbf{C74} no. 9, (2014) 3054, arXiv:1405.2737 [nucl-ex]

[13] \textbf{ALICE} Collaboration, B. Abelev \textit{et al.}, “Suppression of Charged Particle Production at Large Transverse Momentum in Central \( \text{Pb-Pb} \) Collisions at \( \sqrt{s_{NN}} = 2.76 \text{ TeV} \),” \textit{Phys. Lett.} \textbf{B696} (2011) 30–39, arXiv:1012.1004 [nucl-ex]

[14] \textbf{ALICE} Collaboration, B. Abelev \textit{et al.}, “Centrality dependence of charged particle production at large transverse momentum in \( \text{Pb-Pb} \) collisions at \( \sqrt{s_{NN}} = 2.76 \text{ TeV} \),” \textit{Phys. Lett. B} \textbf{720} (2013) 52–62, arXiv:1208.2711 [hep-ex]

[15] \textbf{CMS} Collaboration, V. Khachatryan \textit{et al.}, “Pseudorapidity distribution of charged hadrons in proton-proton collisions at \( \sqrt{s} = 13 \text{ TeV} \),” \textit{Phys. Lett. B751} (2015) 143–163, arXiv:1507.05915 [hep-ex]

[16] \textbf{ALICE} Collaboration, B. Abelev \textit{et al.}, “Performance of the ALICE Experiment at the CERN LHC,” \textit{Int. J. Mod. Phys.} \textbf{A29} (2014) 1430044, arXiv:1402.4476 [nucl-ex]

[17] M. Akbiyik \textit{et al.}, “LHC Forward Physics,” \textit{CERN-PH-LHCC-2015-001} (2015).

[18] T. Sjöstrand, S. Mrenna, and P. Z. Skands, “PYTHIA 6.4 Physics and Manual,” \textit{JHEP} \textbf{05} (2006) 026, arXiv:hep-ph/0603175 [hep-ph]

[19] P. Z. Skands, “Tuning Monte Carlo Generators: The Perugia Tunes,” \textit{Phys. Rev.} \textbf{D82} (2010) 074018, arXiv:1005.3457 [hep-ph]

[20] R. Brun, F. Carminati, and S. Giani, “GEANT Detector Description and Simulation Tool.”

[21] \textbf{ALICE} Collaboration, J. Adam \textit{et al.}, “Measurement of pion, kaon and proton production in proton-proton collisions at \( \sqrt{s} = 7 \text{ TeV} \),” \textit{Eur. Phys. J. C} \textbf{75} no. 5, (2015) 226, arXiv:1504.00024 [nucl-ex]

[22] \textbf{ALICE} Collaboration, B. Abelev \textit{et al.}, “Multi-strange baryon production in pp collisions at \( \sqrt{s} = 7 \text{ TeV} \) with ALICE,” \textit{Phys. Lett. B} \textbf{712} (2012) 309–318, arXiv:1204.0282 [nucl-ex]

[23] T. Sjöstrand, S. Mrenna, and P. Z. Skands, “A Brief Introduction to PYTHIA 8.1,” \textit{Comput. Phys. Commun.} \textbf{178} (2008) 852–867, arXiv:0710.3820 [hep-ph]
\( \eta \) and \( p_T \) distributions of charged particles in pp at \( \sqrt{s} = 13 \) TeV

ALICE Collaboration

[24] P. Z. Skands, S. Carrazza, and J. Rojo, “Tuning PYTHIA 8.1: the Monash 2013 Tune,” Eur. Phys. J. C74 no. 8, (2014) 3024 [arXiv:1404.5630 [hep-ph]]

[25] S. Navin, “Diffraction in Pythia,” arXiv:1005.3894 [hep-ph]

[26] T. Sjöstrand, S. Ask, J. R. Christiansen, R. Corke, N. Desai, et al., “An Introduction to PYTHIA 8.2,” Comput. Phys. Commun. 191 (2015) 159–177 [arXiv:1410.3012 [hep-ph]]

[27] H. J. Drescher, M. Hladik, S. Ostapchenko, T. Pierog, and K. Werner, “Parton based Gribov-Regge theory,” Phys. Rept. 350 (2001) 93–289 [arXiv:hep-ph/0007198 [hep-ph]]

[28] T. Pierog, I. Karpenko, J. Katzy, E. Yatsenko, and K. Werner, “EPOS LHC: test of collective hadronization with LHC data,” arXiv:1306.0121 [hep-ph]

[29] Aachen-CERN-Heidelberg-Munich Collaboration, W. Thome et al., “Charged Particle Multiplicity Distributions in p p Collisions at ISR Energies,” Nucl. Phys. B129 (1977) 365.

[30] UA5 Collaboration, G. J. Alner et al., “Scaling of Pseudorapidity Distributions at c.m. Energies Up to 0.9-TeV,” Z. Phys. C33 (1986) 1–6.

[31] UA5 Collaboration, K. Alpgard et al., “Comparison of \( p\bar{p} \) and pp Interactions at \( \sqrt{s} = 53 \)-GeV,” Phys. Lett. B112 (1982) 183.

[32] UA5 Collaboration, G. J. Alner et al., “UA5: A general study of proton-antiproton physics at \( \sqrt{s} = 546 \)-GeV,” Phys. Rept. 154 (1987) 247–383.

[33] PHOBOS Collaboration, B. Alver et al., “Phobos results on charged particle multiplicity and pseudorapidity distributions in Au+Au, Cu+Cu, d+Au, and p+p collisions at ultra-relativistic energies,” Phys. Rev. C83 (2011) 024913 [arXiv:1011.1940 [nucl-ex]]

[34] T. Sjöstrand, “Colour reconnection and its effects on precise measurements at the LHC,” in Proceedings, 48th Rencontres de Moriond on QCD and High Energy Interactions, pp. 247–251. 2013. arXiv:1310.8073 [hep-ph]

[35] K. Werner, B. Guiot, I. Karpenko, and T. Pierog, “Analysing radial flow features in p-Pb and p-p collisions at several TeV by studying identified particle production in EPOS3,” Phys. Rev. C 89 (2014) 064903 [arXiv:1312.1233 [nucl-th]]

[36] UA1 Collaboration, G. Arnison et al., “Transverse Momentum Spectra for Charged Particles at the CERN Proton anti-Proton Collider,” Phys. Lett. B 118 (1982) 167.

[37] ABCDHW Collaboration, A. Breakstone et al., “Multiplicity dependence on the average transverse momentum and of the particle source size in pp interactions at \( \sqrt{s} = 62, 44 \) and 31 GeV,” Z. f. Physik C 33(3) (1987) 333.

[38] UA1 Collaboration, C. Alhajar et al., “A Study of the General Characteristics of \( p\bar{p} \) Collisions at \( \sqrt{s} = 0.2 \)-TeV to 0.9-TeV,” Nucl. Phys. B335 (1990) 261–287.

[39] E735 Collaboration, T. Alexopoulos et al., “Multiplicity dependence of the transverse-momentum spectrum for centrally produced hadrons in antiproton-proton collisions at \( \sqrt{s} = 1.8 \) TeV,” Phys. Rev. Lett. 60 (Apr, 1988) 1622–1625.

[40] STAR Collaboration, J. Adams et al., “The Multiplicity dependence of inclusive \( p_T \) spectra from pp collisions at \( \sqrt{s} = 200 \) GeV,” Phys. Rev. D 74 (2006) 032006 [arXiv:nucl-ex/0606028 [nucl-ex]].
\( \eta \) and \( p_T \) distributions of charged particles in pp at \( \sqrt{s} = 13 \text{ TeV} \) ALICE Collaboration

[41] **CDF** Collaboration, T. Aaltonen et al., “Measurement of particle production and inclusive differential cross sections in pp collisions at \( \sqrt{s} = 1.96 \text{ TeV} \),” *Phys. Rev. D* 79 (2009) 112005 arXiv:0904.1098 [hep-ex].

[42] **CMS** Collaboration, V. Khachatryan et al., “Charged particle multiplicities in pp interactions at \( \sqrt{s} = 0.9, 2.36, \text{ and } 7 \text{ TeV} \),” *JHEP* 1101 (2011) 079 arXiv:1011.5531 [hep-ex].

[43] **ATLAS** Collaboration, G. Aad et al., “Charged-particle multiplicities in pp interactions measured with the ATLAS detector at the LHC,” *New J. Phys.* 13 (2011) 053033 arXiv:1012.5104 [hep-ex].

[44] **ALICE** Collaboration, B. Abelev et al., “Multiplicity dependence of the average transverse momentum in pp, p-Pb, and Pb-Pb collisions at the LHC,” *Phys. Lett. B* 727 (2013) 371–380 arXiv:1307.1094 [nucl-ex].

[45] P. Z. Skands and D. Wicke, “Non-perturbative QCD effects and the top mass at the Tevatron,” *Eur. Phys. J. C* 52 (2007) 133–140 arXiv:hep-ph/0703081 [HEP-PH].

[46] R. Corke and T. Sjöstrand, “Interleaved Parton Showers and Tuning Prospects,” *JHEP* 1103 (2011) 032 arXiv:1011.1759 [hep-ph].

[47] R. Corke and T. Sjöstrand, “Multiparton Interactions with an x-dependent Proton Size,” *JHEP* 1105 (2011) 009 arXiv:1101.5953 [hep-ph].

[48] A. Ortiz, P. Christiansen, E. Cuautle, I. Maldonado, and G. Paic, “Color reconnection and flow-like patterns in pp collisions,” *Phys. Rev. Lett.* 111 no. 4, (2013) 042001 arXiv:1303.6326 [hep-ph].

[49] C. Bierlich and J. R. Christiansen, “Effects of Colour Reconnection on Hadron Flavour Observables,” arXiv:1507.02091 [hep-ph].
A The ALICE Collaboration

J. Adamo, D. Adamová, M.M. Aggarwal, G. Aglieri Rinella, M. Agnesi, N. Agrawal, Z. Ahammed, S.U. Ahn, S. Alioli, A. Akindinov, S.N. Alani, D. Aleksandrov, B. Alessandria, D. Alexandre, A. Alfacchi I.R.M. Almarza, I. Almeida, T. Alt, S. Altinpinar, I. Altisent, I. Alves Garcia Prad, M. Andrei, A. Andronico, V. Anguelov, J. Anielisk, T. Antić, F. Antinori, P. Antonioli, L. Aphecetche, E. Appelshäuser, S. Arcellis, R. Arnal, O.W. Arnold, I.C. Arsenel, M. Arslanov, B. Auffinger, A. Augoustakis, R. Averbuch-27, M.D. Azimi, A. Badane, Y.W. Bae, S. Bagnasco, R. Bailhache, R. Balica, S. Balasubramanian, A. Baldi, A. Bala, C. Baranov, R.C. Baranov, A.M. Baranov, R. Barbera, F. Barilari, G.G. Barndoff, L.S. Barnby, V. Barre, P. Bartalini, K. Bartl, J. Barik, E. Barsch, M. Basile, N. Bastid, S. Basu, B. Bather, G. Batignani, A. Battista Canevascini, B. Bayatyn, P.C. Batzinger, I.G. Bearden, H. Beck, C. Beddall, N.K. Behra, I. Belikov, F. Bellini, F. Bello, H. Bello Martine, R. Bellwied, R. Belmont, E. Belmore, V. Belyaev, G. Bencivenni, S. Beol et, I. Berceanu, A. Bercuc, Y. Berndt, D. Berenyi, R.A. Bernet, D. Berzan, L. Betev, A. Bhasin, I.R. Bhat, A.K. Bhat, B. Bhattacharjee, J. Bhoni, L. Bianchi, N. Bianchi, C. Bianchi, I. Bičel, J. Bičelj, I. Bičeljčikov, A. Bilandžija, R. Biswa, S. Biswas, S. Biegel, J.T. Blaizot, D. Blaž, C. Blum, F. Bock, A. Bogdanov, H. Bőggild, L. Boldizsár, M. Bombard, J. Book, H. Bore, A. Borris, M. Boris, F. Boss, E. Böttger, C. Bourjau, P. Braun-Munzinger, F. Brezger, M. Breiten, T.A. Brelie, T.A. Browning, M. Brož, E.J. Brügger, E. Brun, I.G. Brundo, D. Budnikov, H. Buesching, S. Bufalino, P. Bunc, O. Busch, D. Buthelezi, J.B. Butler, J.T. Buxtor, D. Caffarri, X. Ca, H. Caines, L. Calero Dad, A. Caliva, E. Calvo Villa, P. Camerini, F. Carena, W. Caren, F. Carneccia, J. Castillo Castellanos, J.A. Castrod, E.A. Custodio, C. Ceballos Sanchez, J. Cepila, P. Cerezo, L. Cerka, B. Chau, S. Chapelopoulos, M. Chartier, J.L. Charvet, S. Chattopadhyaya, S. Chattopadhyaya, P. Chelnokov, M. Chernyak, B. Cheshkov, P. Chiyini, V. Chivante Barros, D.D. Chinellato, S. Choudhur, P. Chochula, K. Choo, M. Chojnacki, S. Choudhury, P. Christakogl, C.H. Christensen, C. Christiansen, T. Chud, S.U. Chung, H. Cicalo, I.L. Cifarelli, J. Cindolo, H.J. Cleymans, F. Colamar, D. Collell, A. Collo, C. Colocci, G. Conesa Balbo, Z. Conesa del Vall, M.E. Connors, J.G. Contreras, J.M. Crompt, Y. Corraula, M. Cortés Maldonado, P. Cortés, M.R. Cosentino, F. Costi, P. Croce, R. Cruz Albin, S. Cuautle, L. Cunqueiro, T. Dahms, D. Daines, A. Danu, D. Dasi, I. Dasi, S. Dasi, D. De Buhr, S. De Carli, G. de Catala, J. De Cuveland, A. De Falco, D. De Gruttola, B. De Haan, N. De Marc, S. De Pasquale, A. Deisting, J. Deloff, E. Dénès, C. Deplanche, V. Dinh-Ha, T. Di Baran, A. Di Maur, S.P. Di Nezza, M.A. Diaz Corcher, H. Dieter, P. Dillenseger, R. Divi, O. Djuesvd, A. Dobrin, F. Domenicos, D. Döning, O. Dordi, D. Drozhzhova, A.K. Dubo, A. Dubl, D. Ducou, J. Dupieux, R.J. Ehler, D. Eli, H. Engel, E. Epple, B. Erasmus, I. Erdem, F. Erhardt, B. Espagnon, M. Estienne, N. Esumi, J. Eum, D. Evan, S. Evdokimov, G. Eyyubova, F. Labbe, J. Fabbri, T. J. Faivre, A. Fannon, M. Faschi, F. Feldkamp, A. Feliciello, G. Feofilov, E. Ferrerén, A. Fernández Téllez, G.E. Ferreira, A. Ferrer, A. Festa, V.G. Feuillard, J. Figiel, M.A.S. Figueroedo, D. Filchagin, D. Finoge, F.M. Fiona, E.M. Fiore, M.G. Fleci, M. Floris, S. Foerth, M. Foka, S. Fokin, E. Fragiacomo, A. Francesc, O. Frankenfeld, U. Fuch, C. Furger, A. Furl, M. Fusco Girard, J.J. Gaardh, M. Gagliardi, A.M. Gago, M. Galli, D.R. Gandhagarad, P. Gano, C. Gas, C. Garbatov, E. Garcia-Solís, C. Gargiulo, P. Gasil, E.F. Gauge, M. Germain, A. Gheata, M. Gheata, P. Ghos, S.K. Ghosh, P. Gianotti, G. Giubellini, G. Giubelini, E. Gladysz-Dziadus, P. Gläßer, D.M. Gömez Corral, A. Gomez Ramirez, R. Gonzalez, R. Gonzalez-Zamora, S. Gorbonov, L. Górilčík, S. Gotová, V. Grabs, O.A. Grachov, L.K. Graczykowski, K.L. Graham, A. Grebili, A. Grigori, G. Grigoris, V. Grigoriev, A. Grigoryan, S. Grigoryan, B. Grinoy, N. Grips, J.M. Gronfeld, J.F. Groote-Oostinghorst, J.-Y. Grosset, R. Gross, E. Guber, R. Guerra, B. Guzman, K. Gubrander, T. Gunji, A. Gupta, R. Guti, R. Haak, O. Halan, C. Hajiadak, M. Haiduc, H. Hamagak, G. Hamal, J.W. Harri, A. Haro, H. Hatzifotiadi, S. Hayash, S.T. Heck, M. Heide, H. Helstrup, A. Herhelegui, G. Herrera Corra, B.A. Hes, K.F. Hettla, D. Hillel, B. Hippolyte, R. Hososk, P. Hristos, M. Huang, T.J. Human, N. Hussain, T. Hussan, D. Hutte, D.S. Hwang, R. Ilka, M. Inaba, M. Ippolito, V. Ivanov, V. Ivanov
η and pT distributions of charged particles in pp at $\sqrt{s} = 13$ TeV

ALICE Collaboration

V. Izucheva, P.M. Jacob, M.B. Jadhav, S. Jadlovský, J. Jadlovský, C. Jahnel, M.J. Jakubowska, J.H. Jang, J.A. Jankowiak, J.P.H.S. Jayarathna, C. Jen, S. Jen, R.T. Jimenez Bustamante, P.G. Jones, A. Jung, A. Jusko, J. Kalinvala, A. Kalweit, J. Kann, V. Kaplin, S. Karch, A. Karasu Uysal, O. Karavichev, T. Karavichev, L. Karayan, E. Karpechev, U. Kebschull, R. Keide, D.L.D. Keijders, M. Keil, M. Mohsin Khan, P. Khan, S.A. Khan, A. Khanzadeev, Y. Kharkhori, B. Kilen, B. Kim, D.W. Kim, D.J. Kim, D. Kim, H. Kim, S.J. Kim, S. Kim, S. Kim, T. Kim, S. Kirsch, I. Kiselev, S. Kissel, A. Kisiel, G. Kiss, J.L. Klav, C. Klein, J. Klein, P. Klein, C. Klebingat, S. Klewe, A. Kluge, M.L. Kniechev, A.G. Knospe, T. Kobayashi, C. Koba, M. Kofarago, T. Kollegger, A. Kolozyvar, V. Kondratiev, N. Kondratiev, E. Kondratiev, A. Konyukh, M. Kopytov, V. Korol, M. Kowalczyk, G. Koyithatta Meethaleveedu, I. Králík, A. Kravčáková, M. Kreuz, M. Krivda, F. Krivel, E. Krysanov, M. Krzwicki, A.M. Kubera, V. Kučera, C. Kuhl, P.G. Kujić, A. Kumor, J. Kuma, I. Kumar, S. Kumar, P. Kurashvili, A. Kurepiš, A.B. Kurepin, A. Kuraykin, M.J. Kweon, S. Kwon, S.L. La Pointe, P. La Rocca, P. Ladrón de Guevara, I. Lagana, Fernandez, I. Lakomo, R. Lango, C. Lari, A. Lardeu, A. Lattuca, E. Laut, R. Lee, L. Leardini, G.R. Le, S. Le, F. Lehe, R.C. Lemmon, V. Lenton, E. Leonardi, L. León, Monzón, H. León Vargues, M. Leoncini, M. Lévy, A. Levai, I. Lev, R. Lepoutre, E. Lévy, A. Letov, S. Lindau, V. Lindstrøm, C. Lippmann, H.M. Ljunggren, D.F. Lodato, P.I. Lowe, E. Lópe, O. López Terre, A. Low, S. Luettig, M. Lunardon, G. Luparelli, T.H. Lutfi, A. Maevsky, M. Magee, S. Mahajan, S.M. Mahmoos, A. Maire, R.D. Majik, M. Malac, I. Maldonado Cervante, L. Malinina, D. Mal’Kevich, P. Malzacher, A. Mamonov, V. Manke, F. Mans, V. Manzari, M. Marchionno, F. Marschon, J. Mars, G.V. Margaglioti, A. Margotti, J. Margutt, A. Martin, C. Markarian, M. Marquard, N.A. Martin, J. Martin Blanco, P. Martinengo, M.I. Martínez, G. Martínez García, M. Martínez Pedregal, A. Mass, S. Massicchio, M. Masers, A. Mason, L. Massacrè, A. Mastroserio, A. Matyi, A. Mayer, M. Mazzer, A.M. Mazza, D. Mcdonald, F. Meddi, M. Medeiros, Y. Melikyan, A. Menchaca-Rocha, E. Meninno, J. Mercado Pérez, M. Mereke, Y. Miakes, M.M. Mieskolainen, K. Mikhailov, L. Milandr, M. Milosev, J. Milosev, L. Milan, M. Minervini, A. Mischke, A.N. Mishra, D. Miškowjiec, J. Mitra, C.M. Mitra, N. Mohammad, B. Mohanty, F. Moneta, L. Molnar, S. Monsalve, A. Montemayor, R.J. Reed, A. Moretto, D. Mcdonald, J. Morel, S. Morozov, A. Morozov, S. Mostafa, T. Mousemati, M. Moussa, S. Muhuri, M. Mukherjee, P. Mukherjee, J.D. Mulligan, M.G. Munho, R.H. Munz, S. Murru, L. Musol, M. Musis, B. Naik, R. Nair, B.K. Nandi, R. Nani, E. Nappi, M.U. Nan, H. Natal da Luz, C. Nataltassi, S.R. Navarro, K. Nayak, T.K. Nayak, S. Nazarenko, A. Nedosekin, L. Neller, F. Ni, M. Nicacci, S. Nicosia, S. Niedziela, B.S. Nielse, S. Nikolaev, S. Nikolaj, V. Nikolai, F. Noferini, P. Nomokono, G. Nooren, J.C.C.C. Nori, A. Norman, A. Nyanin, J. Nyström, H. Oeschler, C. Ol, J.F. Olmos, A. Ohlson, S.W. Okauf, T. Okubo, T. Olajai, J. Olajak, J. Olennic, A.C. Oliveira Da Silva, M.H. Oliveira, J. Onderwaet, C. Oppedisano, R. Oravčev, A. Ortiz Velasquez, A. Oskarsson, J. Otwinowski, S. Oya, M. Ozdemir, Y. Pachmayr, P. Pagani, G. Paoletti, S.K. Park, S. Park, G.K. Park, D.P. Pardey, P. Papcu, V. Papic, J.G.S. Pappalardo, P. Parejko, W.J. Parodi, S. Parma, A. Passfied, V. Paticchie, R.N. Patrafü, B. Paul, H. Peitz, T. Peitzmann, H. Pereira da Costa, E. Pereira da Oliveira Filho, D. Peresunko, L. Peres, E. Perez, Lezam, V. Peskov, Y. Pestov, V. Petráček, V. Petro, M. Petroev, C. Pettit, S. Pian, M. Pikna, P. Pillo, O. Pinzetta, L. Pinský, D.B. Piyarathna, M. Ploskon, M. Planinc, J. Pluta, S. Pochoybov, P.L.M. Podesta-Lerm, M.G. Poghosyan, B. Polichtchouk, N. Poljak, W. Poosonawat, A. Pop, P. Portebou-Housa, J. Porte, J. Pospisil, S.K. Prasad, R. Preghenell, E. Priolo, C.A. Pruneau, C. Pscchenikov, F. Puccio, G. Puddu, P. Pujahari, V. Puni, J. Putschke, H. Qvigstad, A. Rachvetski, S. Rah, S. Rajput, J. Raß, A. Rakotozamfindraz, L. Ramelli, A. Rami, R. Ranilawa, S. Ranilawa, S.S. Räsänen, B.T. Rascani, D. Rathez, K.F. Rea, S.S. Rea, J.R. Ree, A. Rehman, I.P. Reichelt, F. Reid, L. Ren, R. Renfordt, A.R. Reolof, A. Reshetin, J.P. Revol, K. Reygers, V. Riabov, R.A. Ricci, T. Richer, M. Richter, P. Riedel, W. Riege, F. Rigg, C. Riste, E. Rocco, M.Rodriguez Cahuntz, A. Rodriguez Manso, K. Roel, E. Rogochay, D. Rohr, D. Röhrich, R. Romiti, F. Ronchetti, B.S. Roncalles, L. Ronflett, P. Rosset, A. Ross, M. Roukoutakis, F. Roukoutakis, A. Roy, C. Roy, P. Roy, A.J. Rubio Monter, R. Ru, R. Russo, E. Ryabinin, Y. Ryabov.
Affiliation notes

1 Deceased

Also at: Georgia State University, Atlanta, Georgia, United States

Also at: Also at Department of Applied Physics, Aligarh Muslim University, Aligarh, India

Also at: M.V. Lomonosov Moscow State University, D.V. Skobeltsyn Institute of Nuclear Physics, Moscow, Russia

Collaboration Institutes

1 A.I. Alifyanikyan National Science Laboratory (Yerevan Physics Institute) Foundation, Yerevan, Armenia

2 Benemérita Universidad Autónoma de Puebla, Puebla, Mexico

3 Bogolyubov Institute for Theoretical Physics, Kiev, Ukraine

4 Bose Institute, Department of Physics and Centre for Astroparticle Physics and Space Science (CAPSS), Kolkata, India

5 Budker Institute for Nuclear Physics, Novosibirsk, Russia

6 California Polytechnic State University, San Luis Obispo, California, United States

7 Central China Normal University, Wuhan, China

8 Centre de Calcul de l’IN2P3, Villeurbanne, France

9 Centro de Aplicaciones Tecnológicas y Desarrollo Nuclear (CEADEN), Havana, Cuba
\( \eta \) and \( p_T \) distributions of charged particles in pp at \( \sqrt{s} = 13 \) TeV

ALICE Collaboration

10 Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain
11 Centro de Investigación y de Estudios Avanzados (CINVESTAV), Mexico City and Mérida, Mexico
12 Centro Fermi - Museo Storico della Fisica e Centro Studi e Ricerche “Enrico Fermi”, Rome, Italy
13 Chicago State University, Chicago, Illinois, USA
14 China Institute of Atomic Energy, Beijing, China
15 Commissariat à l’Energie Atomique, IRFU, Saclay, France
16 COMSATS Institute of Information Technology (CIIT), Islamabad, Pakistan
17 Departamento de Física de Partículas and IGFAE, Universidad de Santiago de Compostela, Santiago de Compostela, Spain
18 Department of Physics and Technology, University of Bergen, Bergen, Norway
19 Department of Physics, Aligarh Muslim University, Aligarh, India
20 Department of Physics, Ohio State University, Columbus, Ohio, United States
21 Department of Physics, Sejong University, Seoul, South Korea
22 Department of Physics, University of Oslo, Oslo, Norway
23 Dipartimento di Elettrontica ed Elettronica del Politecnico, Bari, Italy
24 Dipartimento di Fisica dell’Università ‘La Sapienza’ and Sezione INFN Rome, Italy
25 Dipartimento di Fisica dell’Università and Sezione INFN, Cagliari, Italy
26 Dipartimento di Fisica dell’Università and Sezione INFN, Trieste, Italy
27 Dipartimento di Fisica dell’Università and Sezione INFN, Turin, Italy
28 Dipartimento di Fisica e Astronomia dell’Università and Sezione INFN, Bologna, Italy
29 Dipartimento di Fisica e Astronomia dell’Università and Sezione INFN, Catania, Italy
30 Dipartimento di Fisica e Astronomia dell’Università and Sezione INFN, Padova, Italy
31 Dipartimento di Fisica ‘E.R. Caianiello’ dell’Università and Gruppo Collegato INFN, Salerno, Italy
32 Dipartimento di Scienze e Innovazione Tecnologica dell’Università del Piemonte Orientale and Gruppo Collegato INFN, Alessandria, Italy
33 Dipartimento Interateneo di Fisica ‘M. Merlin’ and Sezione INFN, Bari, Italy
34 Division of Experimental High Energy Physics, University of Lund, Lund, Sweden
35 Eberhard Karls Universität Tübingen, Tübingen, Germany
36 European Organization for Nuclear Research (CERN), Geneva, Switzerland
37 Excellence Cluster Universe, Technische Universität München, Munich, Germany
38 Faculty of Engineering, Bergen University College, Bergen, Norway
39 Faculty of Mathematics, Physics and Informatics, Comenius University, Bratislava, Slovakia
40 Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague, Prague, Czech Republic
41 Faculty of Science, P.J. Šafárik University, Košice, Slovakia
42 Faculty of Technology, Buskerud and Vestfold University College, Vestfold, Norway
43 Frankfurt Institute for Advanced Studies, Johann Wolfgang Goethe-Universität Frankfurt, Frankfurt, Germany
44 Gangneung-Wonju National University, Gangneung, South Korea
45 Gauhati University, Department of Physics, Guwahati, India
46 Helsinki Institute of Physics (HIP), Helsinki, Finland
47 Hiroshima University, Hiroshima, Japan
48 Indian Institute of Technology Bombay (IIT), Mumbai, India
49 Indian Institute of Technology Indore, Indore (IITI), India
50 Inha University, Incheon, South Korea
51 Institut de Physique Nucléaire d’Orsay (IPNO), Université Paris-Sud, CNRS-IN2P3, Orsay, France
52 Institut für Informatik, Johann Wolfgang Goethe-Universität Frankfurt, Frankfurt, Germany
53 Institut für Kernphysik, Johann Wolfgang Goethe-Universität Frankfurt, Frankfurt, Germany
54 Institut für Kernphysik, Westfälische Wilhelms-Universität Münster, Münster, Germany
55 Institut Pluridisciplinaire Hubert Curien (IPHC), Université de Strasbourg, CNRS-IN2P3, Strasbourg, France
56 Institute for Nuclear Research, Academy of Sciences, Moscow, Russia
57 Institute for Subatomic Physics of Utrecht University, Utrecht, Netherlands
58 Institute for Theoretical and Experimental Physics, Moscow, Russia
59 Institute of Experimental Physics, Slovak Academy of Sciences, Košice, Slovakia
60 Institute of Physics, Academy of Sciences of the Czech Republic, Prague, Czech Republic
$\eta$ and $p_T$ distributions of charged particles in pp at $\sqrt{s} = 13$ TeV

ALICE Collaboration
