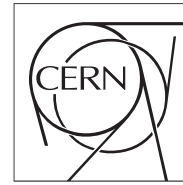


The Compact Muon Solenoid Experiment
Conference Report

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland



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Measurement of charged particle spectra in pp collisions at CMS

Luca Mucibello on behalf of the CMS Collaboration

Abstract

Two analyses proposed by the CMS Collaboration for the study of minimum bias data are presented. One versatile method is based on track reconstruction, while a second one is based on single hit counting offering a complementary measure for differential pseudorapidity distribution.

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1 Introduction

Charged hadron spectra in proton-proton collisions are important observables providing information on particle production mechanisms. Interesting new scaling properties have been recently discovered by the CDF Collaboration at the Tevatron collider [1] and will be compared to higher energies at the LHC.

The so called minimum bias events (mostly non-single diffractive inelastic interactions [2]) will constitute 65% of the total LHC cross section: at design luminosity each process of interest will be contaminated by a pile up of 19 minimum bias collisions on average. A good description of minimum bias events will improve our knowledge of background levels associated to many physics processes and will help in describing the complex nature of the radiation environment in which LHC's detector systems will operate [3].

2 Track reconstruction method

The CMS silicon pixel subdetector [4] is a fully silicon based detector made up of 64 million sensors in a rectangular shape of $150 \times 100 \mu\text{m}^2$ and with a thickness of $290 \mu\text{m}$. Three barrel layers and two disks for each end-cap regions surround the nominal interaction point at a few centimetres. In combination with a low occupancy, it is capable of reconstructing low transverse momenta p_T tracks, which is crucial in the study of minimum bias events.

The standard pixel hit triplet finding algorithm [5] initially constructs hit pairs and then predicts the range of possible coordinates of the third hit. Hit triplet are the basis of the seed generation, after which the track is propagated towards the outer silicon strip tracker layers. A linear extrapolation for the seeding is optimized for speed and good efficiency at higher momenta but, as shown in Fig. 1, fails in the description of the $p_T < 0.9 \text{ GeV}/c$ range highly populated by minimum bias events.

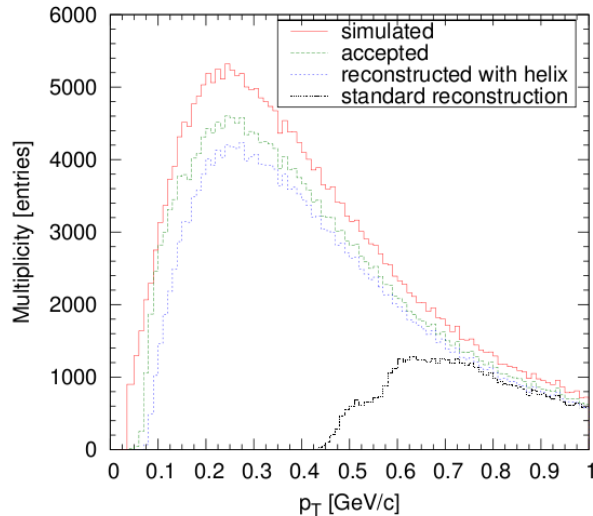


Figure 1: Transverse momentum distribution of simulated tracks (solid red), tracks falling in the tracker acceptance (green dashed) and reconstructed charged particles. For comparison the result of the new helix method (dotted blue) and the standard one are shown.

On the basis of the standard track reconstruction, a specific algorithm has been developed for low p_T tracks [6] considering the charge particles propagating on helices in the practically constant magnetic field of the pixel region. Few other constraints are added, such as the requirement of leaving a hit in the outermost pixel layer and selecting tracks coming from a certain cylinder around the nominal interaction vertex. A uniform acceptance and efficiency are already reached for p_T values of 0.1, 0.2 and 0.3 GeV/c respectively for pions, kaons and protons which are the most abundant particles produced. With a hit filter based on the relation between the track incidence angle and the geometrical shape of the energy deposits, the fake rate is kept below 0.5% for $\eta \simeq 0$ and well below 1% for $p_T > 0.16 \text{ GeV}/c$. The algorithm provides a pseudorapidity bias free measure, with an excellent η resolution. The p_T

measurement results to be affected by systematic errors: the resolution depends on η , p_T and particle type, showing an average of 2% for high p_T .

For the aim of the present analysis, reconstructed tracks are collected in bins of pseudorapidity and transverse momenta, $N(\eta, p_T)$, to correct for the effects of fake rate, multiple counting, algorithmic efficiency and geometrical acceptance. The measured triple differential invariant yield:

$$E \frac{d^3N}{dp^3} = \frac{d^3N}{d\phi dy dp_T} = \frac{1}{2\pi p_T} \frac{d^2N}{dy dp_T} = \frac{1}{2\pi p_T} \frac{E}{p} \frac{d^2N}{d\eta dp_T},$$

in terms of rapidity y or pseudorapidity η , is then fitted by a reparametrization of a Tsallis function in order to properly describe the low p_T thermal behavior and the high p_T empirical power law tail:

$$E \frac{d^3N}{dp^3} = \frac{dN}{dy} \frac{(n-1)(n-2)}{2\pi n T [nT + (n-2)m]} \left[1 + \frac{E_T(p_T)}{nT} \right]^{-n}.$$

The advantage of this procedure is to directly obtain the integrated dN/dy distribution from the fit. The method is shown to properly describe the high p_T tails for both unidentified and identified hadrons and the low p_T range for identified particles¹. Below $p_T \simeq 2$ GeV/ c the fit fails to describe the distributions of unidentified particles: in this range the strategy of summing the measured differential yields down to the lowest accessible p_T value of 0.2 GeV/ c and then thermally fit down to zero is taken. The 8% systematic error of spectra measurements is dominated by the model dependent estimate of the fraction of collisions missed by the trigger. In the case of the zero-bias trigger scenario [8], the number of events without a reconstructed track can only be estimated using a physical model.

Information on the differential inelastic pp cross-section $d\sigma$ can be easily obtained multiplying the yield by the cross section of the process:

$$d\sigma = \frac{dN}{\Delta N_{ev}} \cdot \sigma = \frac{dN}{\Delta N_{ev}} \cdot \frac{\Delta N_{ev}}{L\Delta t} = \frac{dN}{L\Delta t},$$

with ΔN_{ev} the number of events, with the known measuring time Δt and the luminosity L measured by independent monitors with an expected precision of 1% [9]. In this result there is an advantageous cancellation of uncertainties for measured events ΔN_{ev} .

With 1.9 million events expected after one month of data taking, invariant spectra, cross-section and differential yields of charged particles (unidentified or identified pions, kaons and protons) in pp collisions at $\sqrt{s} = 14$ TeV can be measured with good precision, as shown in Fig 2. Several follow-up analysis are possible, such as comparison at low and high p_T to theoretical models and previous experimental results, study of multiplicity distributions, studies of multiplicity and energy dependence of central rapidity density and average transverse momentum. Figure 3 is taken as an example of such results and comparisons.

3 Hit counting method

A minimum p_T of 75 MeV/ c is needed for a particle to reach the third pixel layer and being subsequently reconstructed. The limit decreases to 30 MeV/ c for a particle to reach just the first layer. On this basis, an independent and complementary method has been studied for measuring the pseudorapidity distribution of charged particle counting hits in the first pixel layer [11]. A second advantage of such approach comes from the fact that its precision is not limited by a detailed description of the pixel detector alignment, configuring the analysis as an ideal candidate for the start-up phase of data acquisition.

Apart from primary particles, pixel clusters can be produced by the passage of secondaries and loopers. Secondaries are considered to be particles generated from interaction of primaries in the beam pipe material and particles decayed previously then reaching the first detection layer. Loopers are particles with approximately $p_T < 800$ MeV/ c not reaching calorimetry and moving on helical trajectories for more than half a turn. A selection optimized for a reduction of these backgrounds has been designed based on the observation that primary particles deposit energy dE/dx in the silicon with an average

¹Charged particles can be identified singly or their yields can be extracted (identification in the statistical sense) using deposited energy in the pixel and strip silicon tracker [7]. Pions and kaons yields can be obtained for $p < 0.8$ GeV/ c , while that for protons are available even up to $p \approx 1.5$ GeV/ c .

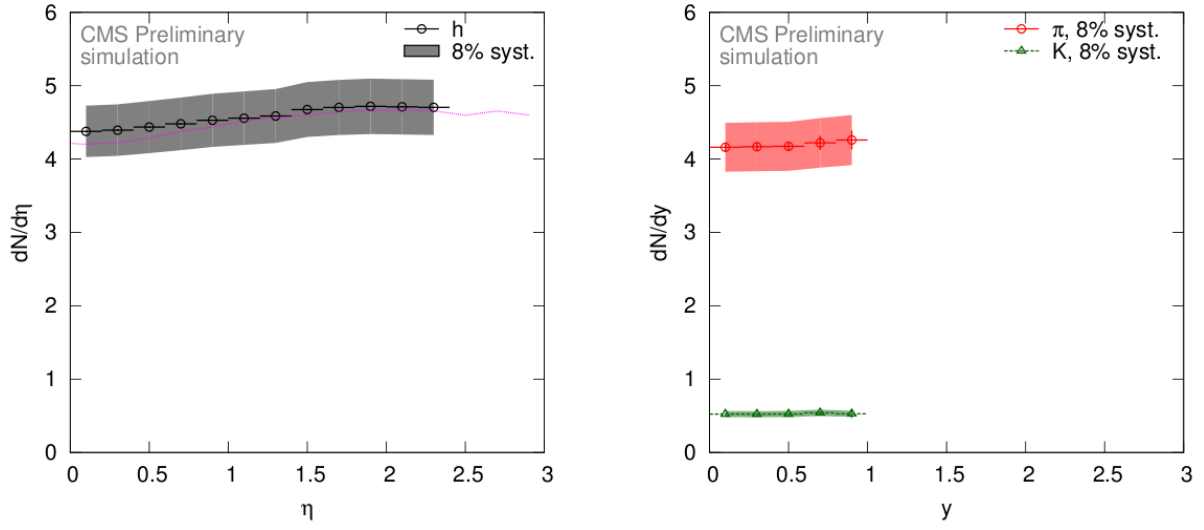


Figure 2: Left: Pseudorapidity density distribution of charged hadrons. The distribution from simulated tracks is given by the purple curve for comparison. Right: Rapidity distribution of charged pions and kaons. Estimated systematic error bands (8%) are also shown.

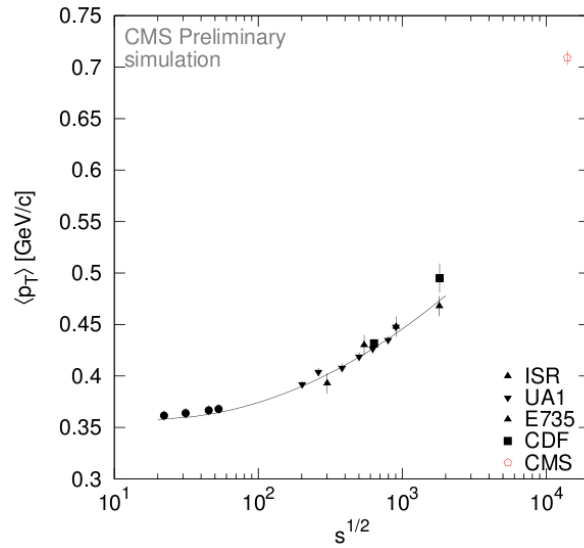


Figure 3: Energy dependence of average transverse momentum of unidentified charged hadrons at $\eta \approx 0$. Data of other experiments and fit are taken from [10]. The result of the CMS track reconstruction analysis is shown with red pentagon.

proportional to $\cosh \eta$ and Landau distributed around the mean, while there is no strict relation between crossing angle and pseudorapidity for background particles. The cluster pseudorapidity is calculated with respect to a fitted vertex using pixel triplet information.

From PYTHIA [12] Monte Carlo simulation we compute the conversion ratio $\chi(\eta, M) = H^{MC}(\eta, M)/T^{MC}(\eta, M)$ between selected hits $H^{MC}(\eta, M)$ and number of tracks $T^{MC}(\eta, M)$, with M the hit multiplicity per event. This ratio is not strongly model dependent since it mainly contains information on the detector geometry. Having the measured number of hits $H^{real}(\eta, M)$ and the number of events passing the selections $E_t^{real}(M)$, it is possible to obtain the differential pseudorapidity distribution per pseudorapidity and multiplicity M bins: $\frac{dN}{d\eta}(\eta, M) = \frac{1}{\chi(\eta, M)} \frac{H^{real}(\eta, M)}{E_t^{real}(M)}$.

From the Monte Carlo simulation one can calculate the M -dependent efficiency of the event selection $\epsilon(M) = E_t^{MC}(M)/E^{MC}(M)$, as the ratio between the number of events passing the selection cut $E_t^{MC}(M)$ and the total number of generated events $E^{MC}(M)$. This results finally in the pseudorapidity spectrum:

$$\frac{dN_{ch}}{d\eta} = \frac{\sum_M E_t^{real} \cdot \frac{1}{\epsilon(M)} \cdot \frac{dN}{d\eta}(\eta, M)}{\sum_M E_t^{real} \cdot \frac{1}{\epsilon(M)}},$$

shown in Fig. 4 (left). It is also possible to evaluate the $dN_{ch}/d\eta$ distributions for various bins of multiplicity M . The height of the pseudorapidity plateau rises with increasing M , while the width of the plateau decrease, as can be seen from Fig. 4 (right).

The systematic error of 8% reported in the bands of Fig. 4 originates from two main sources: modeling and vertexing. The model (simulation) uncertainty of the correction factors described above was determined by varying independently the average multiplicity and average p_T by 50% around the nominal value. The vertexing uncertainty was estimated by replacing the fitted vertex by the nominal interaction point.

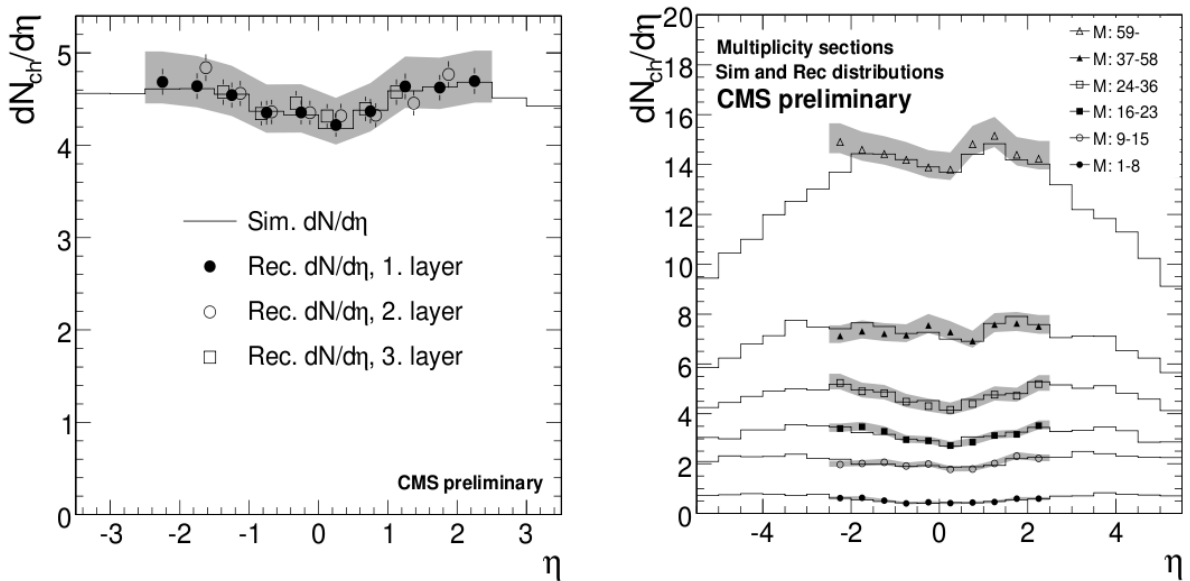


Figure 4: Left: charged particle $dN_{ch}/d\eta$ distributions from simulated (histogram) and reconstructed (symbols) pp events at 14 TeV, different symbols correspond to each of the three pixel layers used for the hit counting method. Error bars show statistical errors using 5000 events. Right: charged particle $dN_{ch}/d\eta$ distribution in six bins of multiplicity M for the first pixel layer.

In conclusion, a robust and simple method has been developed to measure the pseudorapidity distribution of charged particles. With ten thousand events, obtained in the first days of data taking at low luminosity and in absence of pile-up, this measurement will be one of the first providing quantitative information about soft hadron production at the new energy frontier opened by the LHC.

Acknowledgments

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