CMS: minimum bias studies

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Abstract

The early data from LHC will allow the first look at minimum bias p-p collisions initially at the center-of-mass energies of 10 and later 14 TeV. The plans of the CMS collaboration to measure cross sections and differential yields of charged particles (unidentified or identified) and neutrals produced in inelastic p-p collisions at 14 TeV are presented. The tracking of charged particles will be possible down to about 100 MeV/c, with good efficiency and negligible fake rate. The yield of charged kaons and protons can be extracted for total momenta below 0.8 and 1.5 GeV/c, respectively. Comparisons of the results to theoretical models are also discussed.

1 Introduction

The CMS experiment at the LHC is a general purpose detector designed to explore physics at the TeV energy scale [6, 8]. It has a large acceptance and hermetic coverage. The various subdetectors are: a silicon tracker with pixels and strips ($|\eta| < 2.4$); electromagnetic ($|\eta| < 3$) and hadronic ($|\eta| < 5$) calorimeters; and muon chambers ($|\eta| < 2.4$) [5]. The acceptance is further extended with forward detectors: CASTOR ($5.2 < |\eta| < 6.6$) and Zero Degree Calorimeters ($|\eta_{neutrals}| > 8.3$). CMS detects leptons and both charged and neutral hadrons. This example analysis uses 2 million inelastic p-p collisions. They have been generated by the PYTHIA event generator [10].

2 Minimum bias triggers

In case of very low initial intensity the events can be taken by a special high level trigger, requiring at least one or two reconstructed tracks in the pixel detector. This trigger has very low bias and an efficiency of about 88% for inelastic p-p collisions. Another type of trigger will be based on counting towers, with energy above the detector noise level, in both forward hadronic calorimeters (HF, $3 < |\eta| < 5$). A minimal number of hits (1, 2 or 3) will be required on one or on both sides [3]. The efficiency of this single-sided trigger for inelastic p-p collisions is about 89%. The double-sided trigger is less efficient (about 59%), but it is also less sensitive to beam-gas background (Fig. 1-left). Once the luminosity is high enough, events can also be taken with the so called zero-bias trigger based on a random clock each bunch crossing.

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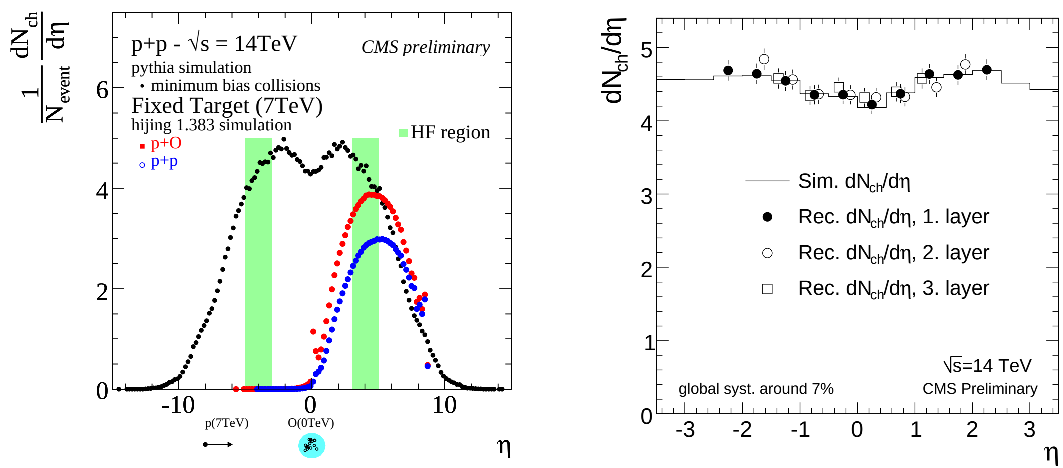

Fig. 1: Left: The number of charged particles per unit pseudo-rapidity for minimum bias collisions compared to beam gas collisions occurring at the center of the detector. Right: Charged particle $dN_{ch}/d\eta$ distributions from generated (histogram) and reconstructed (symbols) p-p events at 14 TeV. Error bars show the statistical errors corresponding to 5000 events.

3 Charged particle rapidity density

Charged hadrons with p_T larger than 30 MeV/c can leave hits in the layers of the pixel detector. Its fine segmentation and small occupancies allow for the measurement of the η distribution of charged hadrons by counting the number of reconstructed hits [2]. With help of the length of the pixel hit clusters in beam direction, the position of the interaction vertex can be estimated. It also helps to remove background hits at higher η if their size is incompatible with the found vertex position. The number of detected hits has to be corrected for non-primary origin: looping particles, secondaries, decay products. A systematic error of 7% is expected (Fig. 1-right). The method is attractive since it does not need particle tracking and it is insensitive to the alignment of the tracker.

4 Charged particle spectra, particle identification

Both pixel and strip silicon tracker detectors are used for the reconstruction of charged particles. With a modified hit triplet finding algorithm the pixel detector can be employed for the reconstruction of low p_T charged particles [1, 8, 9]. The acceptance of the method extends down to 0.1, 0.2 and 0.3 GeV/c in p_T for pions, kaons and protons, respectively. The obtained pixel tracks are used for finding and fitting the primary vertex or vertices [4, 6, 7]. The found vertices are reused, ensuring that the track comes from an interaction point. This brings the fake track rate down to per mille levels. The measured shape of tracker hits is compared to the dimensions predicted from the local direction of the trajectory. This filter helps to eliminate incompatible trajectory candidates at an early stage. At the end, the trajectory is refitted with the primary vertex constraint.

The hadron spectra are corrected for particles of non-primary origin. Their main source is

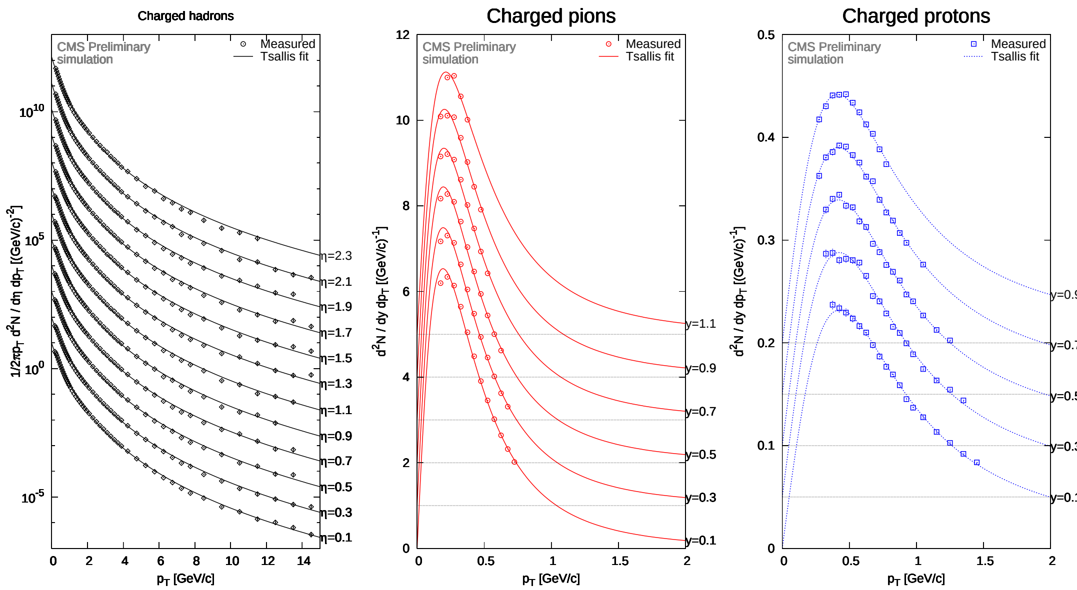

Fig. 2: Selection of particle spectra. Left: Measured invariant yields of charged hadrons in the range $0 < |\eta| < 2.4$. Right: Measured differential yields of identified charged pions and protons in the range $0 < |y| < 1.2$. Measured values and empirical fit functions are plotted, with a series of 0.2 unit wide bins. Values are successively multiplied by 10 or shifted for clarity.

the feed-down from weakly decaying resonances. While the correction is around 2% for pions, it can go up to 15% for protons with $p_T \approx 0.3\ \mathrm{GeV}/c$. The resonances K^0_S, Λ and $\overline{\Lambda}$ can be extracted from the measured data.

Charged particles can be singly identified or their yields can be extracted (identification in the statistical sense) using deposited energy in the pixel and strip silicon tracker, with help of the truncated mean estimator [1]. The distribution of $\log \mathrm{d}E/\mathrm{d}x$ can be successfully fitted in slices of momentum. The fit function is a sum of properly scaled Gaussians for each particle species: here pions, kaons and protons are assumed. The relative resolution of $\mathrm{d}E/\mathrm{d}x$ for tracks with average number of hits ($\sim$15) is around 5-7%. The yield of kaons can be extracted if $p < 0.8\ \mathrm{GeV}/c$ and that of protons if $p < 1.5\ \mathrm{GeV}/c$. Both limits correspond to approximately 3σ separation.

The measured invariant yields of charged hadrons are shown in Fig. 2-left, as a function of p_T, in narrow η bins. (Results refer to the sum of positively and negatively charged particles. Symmetric positive and negative η bins are also added.) Measured differential yields of identified charged pions and protons are shown in Fig. 2-right. The obtained invariant yields were fitted by the Tsallis function [11], a function that successfully combines and describes both the low p_T exponential and the high p_T power-law behaviors. The pseudorapidity distribution of charged hadrons is shown in Fig. 3-left. The energy dependence of some measured quantities can also be studied (Fig. 3-right). The curve shows a quadratic fit on data points of other experiments [12].

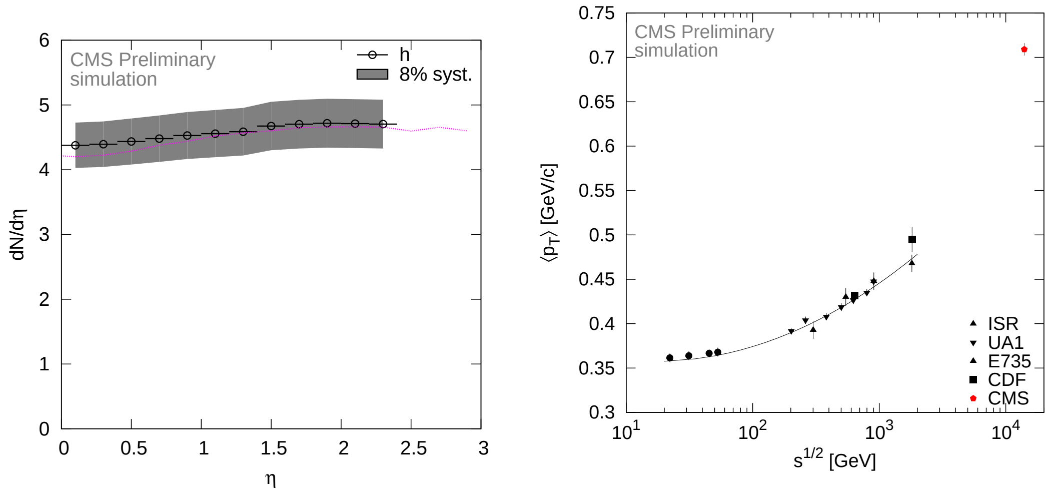

Fig. 3: Left: Pseudorapidity density distribution of charged hadrons. The distribution from simulated tracks is given by the purple curve for comparison. Right: Energy dependence of average transverse momentum of unidentified charged hadrons at $\eta \approx 0$. The result of this analysis is shown with red pentagons.

5 Conclusions

In summary, spectra and yields of charged and neutral particles (unidentified and identified) produced in inelastic proton-proton collisions can be measured with good precision with the CMS tracker. They will help to improve the QCD understanding of p-p collisions.

Acknowledgment

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References

[1] Measurement of charged hadron spectra in proton-proton collisions at $\sqrt{s}$ = 14 tev. *CMS PAS*, QCD-07-001.

[2] Pseudorapidity distributions of charged hadrons in minimum bias p-p collisions at 14 tev. *CMS PAS*, QCD-08-004.

[3] Zero bias and hf-based minimum-bias triggering for pp collisions at 14 tev in cms. *CMS PAS*.

[4] W. Adam, B. Mangano, T. Speer, and T. Todorov. Track reconstruction in the cms tracker. *CMS Note*, 2006041.

[5] R. Adolphi et al. The CMS experiment at the CERN LHC. *JINST*, 0803:S08004, 2008.

[6] G. L. Bayatian et al. CMS technical design report, volume II: Physics performance. *J. Phys.*, G34:995–1579, 2007.

[7] S. Cucciarelli, M. Konecki, D. Kotliński, and T. Todorov. Track reconstruction, primary vertex finding and seed generation with the pixel detector. *CMS Note*, 2006026.

[8] David G. d'Enterria (Ed.) et al. CMS physics technical design report: Addendum on high density QCD with heavy ions. *J. Phys.*, G34:2307–2455, 2007.

[9] Ferenc Sikler. Low p(T) hadronic physics with CMS. *Int. J. Mod. Phys.*, E16:1819–1825, 2007.

[10] Torbjorn Sjostrand, Stephen Mrenna, and Peter Skands. PYTHIA 6.4 Physics and Manual. *JHEP*, 05:026, 2006.

[11] Constantino Tsallis. Possible Generalization of Boltzmann-Gibbs Statistics. *J. Stat. Phys.*, 52:479–487, 1988.

[12] Thomas S. Ullrich. Experimental summary on global observables, hadron spectra and ratios. *Nucl. Phys.*, A715:399–411, 2003.