Early Measurements of Bulk Observables in CMS

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Abstract. With the large acceptance and excellent granularity of its tracking system, the CMS experiment is well-equipped to explore the bulk properties of the quark-gluon plasma with the first Pb+Pb collisions recorded at the LHC. Given the twenty-fold increase in collision energy compared to previous experiments, CMS measurements will be a powerful test of parton saturation, jet quenching, and hydrodynamic models, which have been successful in describing many features of particle production at RHIC. In preparation for early measurements of charged multiplicity, transverse-momentum spectra, and two-particle angular correlations, the corresponding measurements performed on p+p collision data are reviewed.

1. Introduction
The large increase in collision energy from existing measurements at RHIC ($\sqrt{s_{NN}} = 0.2$ TeV) to future measurements at the LHC ($\sqrt{s_{NN}} = 2.76$ TeV) ensures that the bulk properties of the produced QGP, accessible from the very first Pb+Pb collisions, will be exciting and perhaps unexpected. In these proceedings, three specific early Pb+Pb measurements are addressed: charged particle multiplicity, transverse momentum spectra, and two-particle correlations. For each, the corresponding first CMS measurements, performed on 10 - 200k p+p collisions at $\sqrt{s} = 0.9$, 2.36, and 7 TeV, are presented and the implications for Pb+Pb running discussed.

These bulk measurements of charged particle distributions are primarily reliant on the silicon pixel and strip detectors [1], which reside in a 3.8 T magnetic field and cover the pseudorapidity range $|\eta| < 2.4$ with full azimuthal acceptance. The performance of the CMS tracking system has been well-understood since the first 0.9 TeV collisions in 2009, showing excellent agreement with detector simulations [2].

A common minimum bias event selection was applied for the first CMS p+p measurements of bulk QCD properties (details in Ref. [3]). The detector readout was triggered by a single hit paddle in the Beam Scintillator Counters (BSC), coincident with the passing of a proton bunch indicated by the Beam Pick-up Timing for the eXperiments (BPTX) devices. To preferentially select non-single-diffractive (NSD) events, at least one forward calorimeter (HF) tower with $E > 3$ GeV in each of the forward and backward hemispheres was required. Further selections were made on the timing of BSC hits to reject beam backgrounds. Finally, a valid primary vertex reconstructed from pixel tracks was required.

2. Charged Particle Multiplicity
The $dN_{ch}/d\eta$ distributions for p+p collisions at $\sqrt{s} = 0.9$, 2.36, and 7 TeV [3][4] were obtained using three methods based on the counting of (1) reconstructed clusters in the pixel barrel detector; (2) pixel tracklets composed of pairs of clusters in different pixel barrel layers; and (3)
tracks reconstructed in the full tracker volume, combining the pixel and strip hits. The three different methods, which are sensitive to different systematic effects, are compared in Fig. 1 for the three collision energies. The results of the three methods were then weighted by their uncorrelated errors and averaged (not shown).

**Figure 1.** Reconstructed $dN_{ch}/d\eta$ distributions obtained from the cluster counting, tracklet and tracking methods, in p+p collisions at 0.9, 2.36 and 7 TeV. The error bars include systematic uncertainties, excluding those common to all the methods.

In Fig. 2 the collision energy dependence of the midrapidity yield is shown compared to lower energy data and the predictions of a number of models. The $dN_{ch}/d\eta$ values measured at the LHC energies are consistent with the trend, but the increase with energy is significantly steeper than predicted by most models. The steeper-than-expected energy dependence in p+p collisions has interesting implications for Pb+Pb collisions, where predictions of the multiplicity vary by as much as a factor of three [6]. Unless the ratio of Pb+Pb to p+p multiplicities is significantly smaller than the trend observed at lower energies, the new LHC multiplicity measurements suggest that the lowest Pb+Pb estimates ($dN_{ch}/d\eta \approx 1000$ at 5.5 TeV) are disfavored.

**3. Transverse Momentum Spectra**

In addition to the charged multiplicity measurements, the transverse momentum ($p_T$) spectra have been measured by CMS at all three LHC collision energies [3, 4]. The spectra shown in Fig. 3 are well-described up to $p_T = 6$ GeV/c by the empirical Tsallis fit functions, which simultaneously capture the exponential behavior at low $p_T$ and the power-law behavior at high $p_T$. As expected, the spectra are significantly harder at the highest collision energy. Preliminary results from the high-statistics spectra analysis ($p_T$ out to 140 GeV/c), which were mentioned at the conference, have since been made public [7]. The resulting spectra are consistent with expectations from leading-order QCD and $x_T$-scaling and show a significant...
power to discriminate between various MC tunes that vary among themselves by as much as a factor of two.

![Figure 3. Measured yield of charged hadrons for $|\eta| < 2.4$ with systematic uncertainties (symbols) at $\sqrt{s} = 0.9$, 2.36 and 7 TeV. Lines represent empirical fits based on the Tsallis function described in Ref. [4].](image)

The charged particle spectrum in p+p collisions is an important reference for future CMS measurements of high-$p_T$ particle suppression in the dense QCD medium produced in Pb+Pb collisions. At RHIC, the sizable suppression of high-$p_T$ spectra, compared to the superposition of a corresponding number of p+p collisions, was one of the first indications of strong final-state medium effects on particle production. It is similarly expected to be one of the first measurements at the LHC, where first-year statistics should allow measurements to 50-60 GeV/c. Again, expectations on the scale and the $p_T$ dependence of the suppression vary by large factors [5]. By interpolating between the 0.9, 2.36, and 7 TeV measurements, the systematics of the 2.76 TeV p+p reference can be significantly better constrained, improving the discriminating power of the Pb+Pb measurement to various jet quenching scenarios.

4. Two-particle Correlations

Angular correlations between final-state particles are related to the hadronization process responsible for their production. From studying various MC models, it is apparent that QCD string fragmentation results in a roughly Gaussian $\Delta \eta$ correlation that is similar for all $\Delta \phi$ and peaked at $\Delta \eta = 0$. Conversely, dijets result in a characteristic ‘near-side’ peak centered at $\Delta \phi = \Delta \eta = 0$ and an ‘away-side’ structure around $\Delta \phi = \pi$ that is swept out over the observable range of $\Delta \eta$. The correlations between particles with $0.1 < p_T < 5.0$ GeV/c, measured by CMS in minimum bias collisions at all three p+p energies [9], are less ‘jet-like’ than PYTHIA (shown for 7 TeV in Figs. [4] and [5] but not as ‘string-like’ as, e.g., HERWIG++ (not shown).

As was done at lower energies [10], the strength and spatial extent of the $\Delta \eta$ correlation structure can be characterized in terms of an effective cluster size and width. The new CMS measurements are consistent with the trend of slowly increasing cluster size with collision energy, significantly exceeding what is seen in PYTHIA.

In heavy-ion collisions at RHIC, two-particle correlations have yielded a wealth of information on the physics of jet quenching, elliptic flow, and much more. The large $\Delta \eta$ acceptance of the CMS tracker will be particularly advantageous for exploring correlations in heavy ions. For example, based on the same two-particle correlation technique discussed above, it is possible to
extract the relative contributions of ‘flow’ and ‘non-flow’ in two-particle correlations for many years the dominant uncertainty on elliptic flow.

5. Summary

CMS is an excellent detector for studying minimum bias QCD and heavy-ion physics. First p+p measurements have now been published at $\sqrt{s} = 0.9$, 2.36, and 7 TeV. These results will provide an important reference for future heavy-ion measurements of bulk observables, which will already be possible with only a few tens of thousands of events (or about fifteen minutes of colliding beams).

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