SOFT QCD RESULTS FROM ATLAS AND CMS

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The ATLAS and CMS Collaborations have measured properties of minimum bias events and have determined characteristics of the underlying event in proton-proton collisions at three LHC centre-of-mass energies. Comparisons to common phenomenological models and partially to other experiments have been made. The production of the strange particles $K_{S}^{0}$, $\Lambda$ and $\Xi$ is discussed. Particle correlation studies, in particular Bose-Einstein as well as long- and short-range angular correlations in proton-proton and lead ion events are explained.

1 Properties of minimum bias events

Ideally minimum bias events are those recorded with a totally inclusive trigger. The exact definition depends on the experiment. Usually minimum bias only refers to non-single-diffractive (NSD) events. In ATLAS\(^1\) and CMS\(^2\) similar minimum bias trigger detectors are used. ATLAS has two stations of Minimum Bias Trigger Scintillators (MBTS) located upstream and downstream at $z = \pm 3.56$ m from the nominal collision vertex in the pseudorapidity intervals $2.09 < |\eta| < 2.82$ and $2.82 < |\eta| < 3.84$. CMS has Beam Scintillator Counters (BSC) at $z = \pm 10.86$ m within $3.23 < |\eta| < 4.65$. Both experiments also use signals from a beam pick-up based timing system (BPTX) at $z = \pm 175$ m with a time resolution of 200 ps in their minimum bias trigger.

Transverse momentum spectra of charged particles have been measured in a large range of $p_T$. Fig. 1 shows results from the CMS experiment and comparisons to CDF data\(^3\). Calorimeter-based transverse energy triggers have been used in the high-$p_T$-region instead of the normal minimum bias trigger. The data are fully corrected. The inclusive invariant cross-section expressed as a function of the scaling variable $x_T = 2p_T/\sqrt{s}$ is given by Eq. 1

$$\frac{d^3\sigma}{dp^3} = \frac{F(x_T)}{p_T^{n(x_T,\sqrt{s})}} = \frac{F'(x_T)}{\sqrt{s}^{n(x_T,\sqrt{s})}} \tag{1}$$

Minimum bias pseudorapidity and multiplicity distributions as measured by ATLAS\(^4\) are depicted in Fig. 2. The rapidity plateau extends to $|\eta| \approx 1$ for both centre-of-mass energies of 0.9 and 7 TeV, however, there is an increase of almost a factor of two in its height. No Monte Carlo tune describes the multiplicity distribution shown in Fig. 2: well.

2 Underlying event studies

The underlying event (UE) comprises all particles except those from a given hard interaction of interest. It has components from multiple semi-hard parton scattering processes and soft...
components from beam-beam remnants. The dominant momentum flow defines three regions in the plane transverse to the incoming beams. It is given by the direction of the highest-$p_T$ track in ATLAS, whereas in CMS the leading track jet is used instead. The region within an azimuthal angle difference of $|\Delta \phi| < 60^\circ$ with respect to the leading object is called the toward region, and the one opposite ($|\Delta \phi| > 120^\circ$) the away region. The area in between, the transverse region, is the one that is most sensitive to the UE.

ATLAS and CMS measured various properties of charged particles in the UE such as multiplicity and transverse momentum distributions. Multiplicity and $\Sigma p_T$ densities as a function of the leading-$p_T$ entity were also studied. There is a strong growth of UE activity with $\sqrt{s}$.

Figure 1: $x_T$ scaling curves (a), inclusive invariant cross-section (b)

Figure 2: Minimum bias pseudorapidity distributions at $\sqrt{s} = 0.9$ TeV (a) and 7 TeV (b), multiplicity distribution at $\sqrt{s} = 7$ TeV (c)

Figure 3: Underlying event multiplicities (a), average scalar momentum sum (b), multiplicity density ratio (c)

Fig. 3a shows the increase of the number of events for centre-of-mass energies from 0.9 to 7 TeV.
as a function of multiplicity for the transverse region. The average scalar momentum sum rises sharply till 8 GeV due to the increase of multiple parton interaction activity, followed by a slow increase thereafter (Fig. 3b). The distributions in Fig. 3 are well reproduced by the PYTHIA Z1 Monte Carlo tune.\textsuperscript{2}

The charged particle multiplicity density in the transverse region is plotted in Fig. 4a. Compared to minimum bias there is about two times more activity in the UE. All Monte Carlo models underestimate the multiplicity. Figs. 4b and 4c show the increase of the UE $p_T$ by about 20% from 0.9 to 7 TeV, well reproduced by a variety of models.

3 Strangeness production

The production of the strange hadrons $K_0^0$, $\Lambda$ and $\Xi$ has been studied.\textsuperscript{5} The mass peaks have been reconstructed, as shown in Fig. 5a for the $\Xi^-$. Production rates have been measured as functions of rapidity and transverse momentum. The $p_T$ distributions extend from practically zero to 10 GeV for $K_0^0$ (Fig. 5b) and 6 GeV for $\Xi^-$. The increase in production of strange particles from 0.9 to 7 TeV is approximately consistent with results for charged particles described above, but the rates exceed the predictions by up to a factor of three (Fig. 5c). This deficiency probably originates from parameters regulating the frequency of s-quarks appearing in color strings.

4 Particle correlations

Pairs of same-sign charged particles with four-momentum difference $Q$ in the region $0.02 \text{ GeV} < Q < 2 \text{ GeV}$ are analysed to study Bose-Einstein correlations.\textsuperscript{6} The radius of the effective
space-time region emitting bosons with overlapping wave functions increases with multiplicity, whereas the correlation strength decreases. Both decrease with increasing momentum difference \( k_T \). Anticorrelations between same-sign charged particles are observed for \( Q \) values above the signal region, which can be seen in Fig. 6, showing the double ratio \( R(Q) \)\(^{11} \).

Figure 6: Radius \( r \) (a), correlation strength \( \lambda \) (b), double ratio showing anticorrelations (c)

Near-side long-range particle correlations in proton data have first been reported by CMS\(^{11} \). A ridge, a pronounced structure in high-multiplicity events for rapidity and azimuth differences of \( 2.0 < |\Delta \eta| < 4.8 \) and \( \Delta \phi \approx 0 \) has been found. Long- and short-range correlations in ion data have also been studied\(^{12} \). The correlation functions of the 0-5% most central collisions show characteristic features not present in minimum bias proton interactions (Fig. 7). The ridge is most evident for \( p_T \)’s of the trigger particle between 2 and 6 GeV, but disappears at high \( p_T \).

Figure 7: Short-range (0 < |\Delta \eta| < 1) and long-range (2 < |\Delta \eta| < 4) correlations in lead ion data

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