ATLAS measurements of soft particle production and diffraction

Šárka Todorova-Nová (On behalf of the ATLAS Collaboration)

Tufts University, Medford MA, USA

Abstract.
The ATLAS Collaboration has measured a wide range of properties of soft particle production in $\sqrt{s}$=900 GeV and $\sqrt{s}$=7 TeV proton-proton collisions at the Large Hadron Collider (LHC). These include forward-backward and azimuthal correlations, azimuthal ordering of hadron production, underlying event properties and their dependence on aspects of the hard scattering process. The inelastic and diffractive cross sections have also been measured, using particle forward flow and rapidity gaps. Many of these measurements are used to develop and tune models for soft particle production.

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INCLUSIVE PARTICLE SPECTRA

The measurements of soft particle production test various phenomenological models of the hadron production and serve as input for the adjustment of model parameters.

The measurement of the charged multiplicity and of the inclusive p_T and pseudorapidity distribution [1], one of the first ATLAS [2] publication based on initial LHC data, revealed significant discrepancies between the observed distributions and the Monte-Carlo (MC) predictions (see Fig. 1). Although these discrepancies were to a large extent cured by subsequent retuning of the model parameters (AMBT2 tune [3]), a completely satisfactory understanding of the physics processes involved in soft particle production has not yet been achieved. A selection of recent ATLAS publications investigating various aspects of the problematics is presented below.

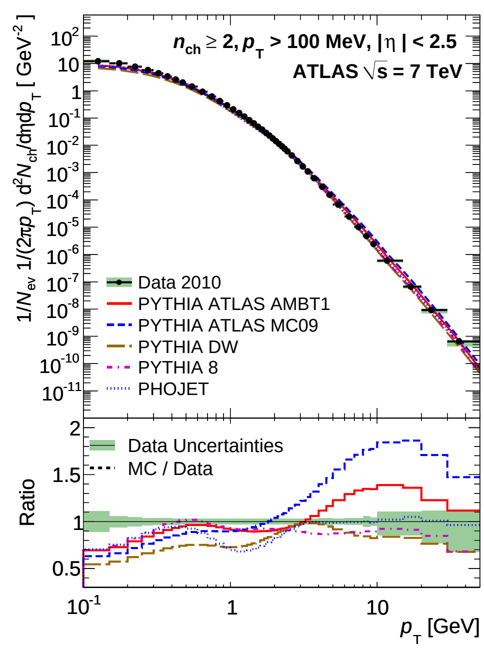


FIGURE 1.: Inclusive transverse momentum distribution of charged particles [1].

DIFFRACTIVE PROCESSES

ATLAS measured the dependence of the inelastic cross section on the forward rapidity gap $\Delta\eta^F$ [4] measured from the edge of the calorimeter acceptance $|\eta| < 4.9$. As shown in Fig. 2a), none of the available models describes the data over the whole gap range.

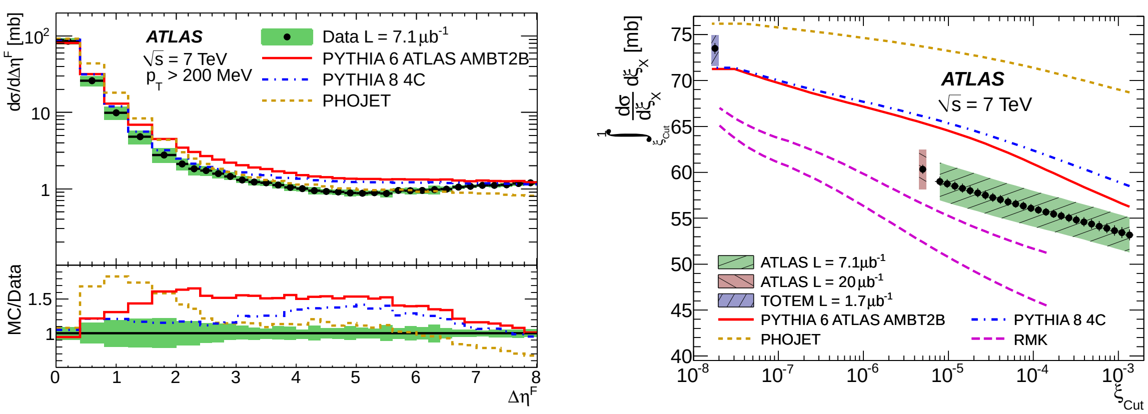
The slope of the distribution at large gap sizes, dominated by the single diffractive (SD) contribution, was used to extract a value of the Pomeron intercept

$$\alpha(0) = 1.058 \pm 0.003(stat) \pm 0.034(syst). \tag{1}$$

For SD process, the rapidity gap $\Delta\eta$ between the scattered proton (at $\eta \simeq \pm 8.9$) and the dissociated hadron system X is closely related to the mass of the system M_X

$$\Delta\eta^F \simeq \Delta\eta - 4,\ \Delta\eta \simeq -\ln\xi_X,\ \xi_X = \frac{M_X^2}{s}. \tag{2}$$

Figure 2b) shows the measured inelastic cross section integrated over $\xi_X < \xi_{\rm cut}$ compared with previous ATLAS measurement [5] and with the measurement done by the TOTEM Collaboration [6]. The MC models fail to describe the $\xi_{\rm cut}$ dependence, in particular the steep rise of the cross section at low ξ_X.

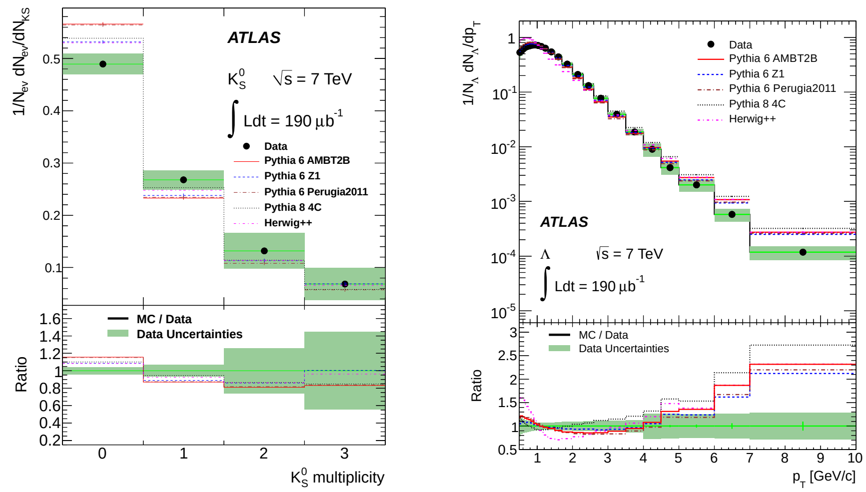


(a) (b)

FIGURE 2. (a) Forward rapidity gap distribution [4]. (b) The inelastic cross section measured by ATLAS and TOTEM Collaborations [4, 5, 6].

EXCLUSIVE HADRON PRODUCTION

K_S^0 and Λ production has been measured in [7] using a cut on transverse flight distance between primary and secondary vertices and on the pointing angle of the reconstructed resonance candidates. The production rate of K_S^0 is found to be somewhat underestimated (Fig. 3a) and the tail of the transverse momentum of the Λ baryon is significantly overestimated (Fig. 3b) by the models.



(a) (b)

FIGURE 3. (a) The measured production rate of the K^0_S resonance. (b) The transverse momentum distribution of the Λ baryon [7].

PARTICLE DENSITIES

The multiple parton interactions contributing to the so-called underlying event activity can be studied through the measured particle production in regions separated from the leading track/jet in the event. ATLAS measured the azimuthal correlations between the charged particles and the leading track [8]. The models tend to overestimate the particle flow around the leading track and to underpopulate the phase space regions away from the leading track, as shown in Fig. 4. The analysis also comprises the measurement of forward-backward correlations in multiplicity and summed transverse momentum between symmetrically defined pseudorapidity intervals.

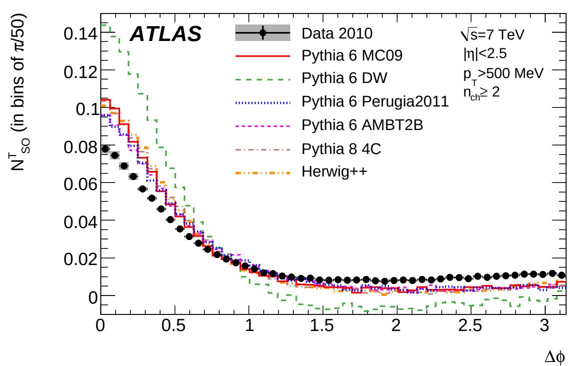
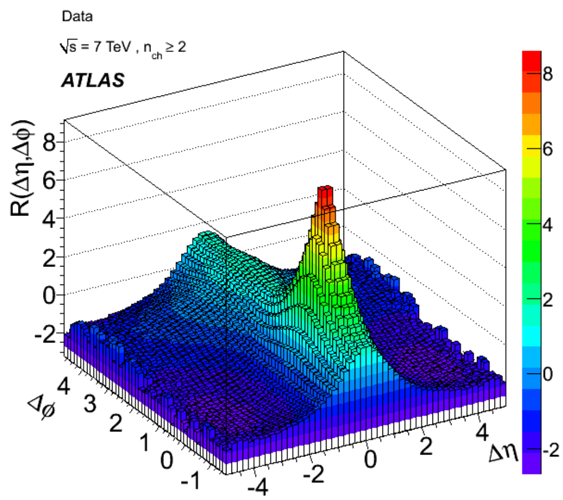


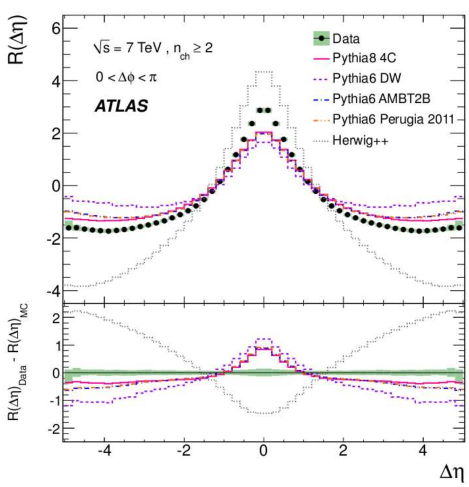
FIGURE 4.: Distribution of the azimuthal opening angle between charged particles and the leading track, after subtraction of distributions from the same and the opposite hemisphere [8].

A recent measurement of the characteristics of the underlying event and their dependence on the properties of the leading jet in the event [9], in particular the jet transverse momentum and the clusterization parameter, provides a detailed information for fine-tuning of the MC models.

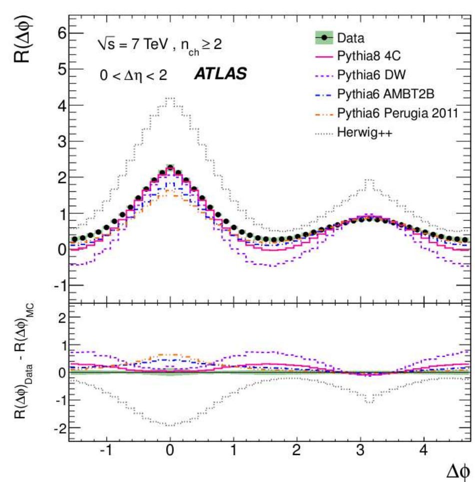
Particle correlations reflect the dynamics of the particle production and provide an important test of the modelling of the soft particle production. ATLAS has measured the inclusive two-particle angular correlations [10] with help of a multiplicity independent 2-dimensional correlation function (Fig. 5a) using a reference sample constructed from pairs of particles from different events. The comparison between the data and models of the correlation function integrated over the azimuthal angle, resp. over a given pseudorapidity interval, is shown in Figs. 5b and 5c. None of the models fully describes the shape of the measured correlation function.



(a)



(b)



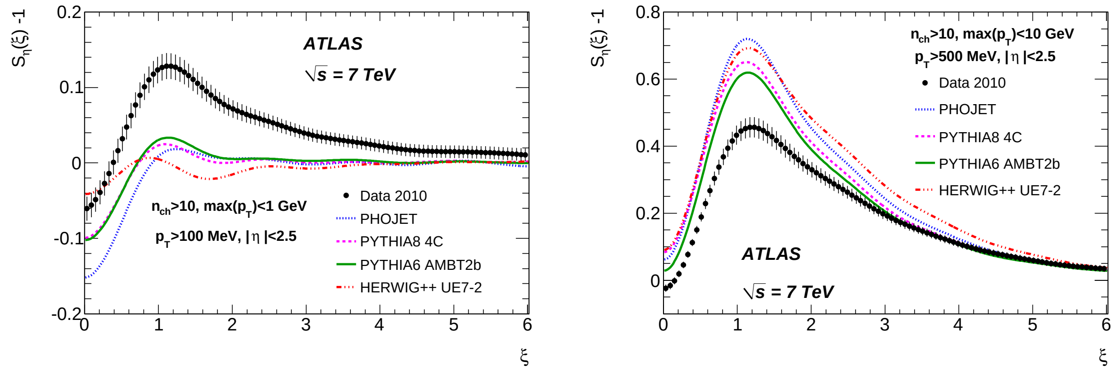
(c)

FIGURE 5. Top:(a) The two-particle correlation function [10]. Bottom: The correlation function integrated over the azimuthal angle difference (b) and over the $0 < \Delta\eta < 2$ range (c).

ATLAS also performed a spectral analysis of correlations between longitudinal and transverse components of the momentum of charged particles, driven by the search for phenomena related to the structure of the QCD field [11].

Fig. 6 shows the measurement of the power spectrum S_η defined as

$$S_\eta(\xi) = 1 + \frac{1}{N_{\text{ev}}} \sum_{\text{event}} \frac{1}{n_{\text{ch}}} \sum_{\text{i}\neq\text{j}} \cos(\xi \Delta\eta_{\text{ij}} - \Delta\phi_{\text{ij}}), \tag{3}$$



(a) (b)

FIGURE 6. The S_η power spectrum measured in a phase-space region restricted by the cut on $\max(\mathrm{p_T}) < 1$ GeV (a) and with the low $\mathrm{p_T}$ cut raised from 100 MeV to 500 MeV (b) [11]. The measurements have different sensitivity to the hadronization effects.

where ξ stands for a parameter, $\Delta\eta$ and $\Delta\phi$ are the differences in pseudorapidity and the azimuthal angle. The power spectrum is normalized to the number of charged particles in the event n_{ch} and to the number of events N_{ev}. In the phase space region most sensitive to the hadronization effects (Fig. 6a), the data show a significant amount of correlations not present in the MC models. On the other hand, reducing the content of soft particles in the sample with an increased $\mathrm{p_T}$ threshold leads to an overestimate of the shape of the power spectrum by all models (Fig. 6b). The latter behaviour is probably related to the overestimate of the particle flow around the leading track mentioned above (Fig. 4) but the origin of discrepancies and the interplay between contributing physics phenomena is not yet understood.

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