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Soft QCD Measurements at 900 GeV and 7 TeV with ATLAS

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Abstract

We present results on charged particle production in proton-proton collisions at the Large Hadron Collider and center of mass energies $\sqrt{s}$ = 900 GeV and 7 TeV in the ATLAS Detector. Charged tracks are measured with high precision in the inner tracking system; track multiplicities, transverse momentum spectrum and the average track transverse momentum as a function of track multiplicity are compared to phenomenological models describing the soft QCD processes participating in the interaction. Although all models approximately describe the data, none show complete agreement, with the deviation between data and Monte Carlo becoming more significant at the the higher center of mass energy and for higher track transverse momentum. These data have been used in the determination of a new optimised model which provides a much improved description of the data.

Keywords: soft QCD, minimum bias, ATLAS

1. Introduction

We present first results from the ATLAS experiment on soft QCD processes in proton-proton collisions at center of mass energies of 900 GeV and 7 TeV using the ATLAS detector [1] at the Large Hadron Collider (LHC) [2]. The total cross section for proton-proton interactions includes the sum of the elastic cross section, the single and double diffractive cross section, and the hard core. The hard core itself has two components: the hard scattering process which results in partons emitted with large momentum transverse to the direction of the incoming proton beams, which can be described in perturbative QCD, and a non-perturbative soft component which is the subject of this analysis. It has an interesting phenomenology including beam remnants, multiple parton interactions and color recombination [3] as well as the modeling of the initial state radiation. An accurate understanding of the soft core is important for precision measurements of many physics processes to be studied at the LHC, such as experimental biases in jet triggers, and "pile-up" when several proton-proton collisions occur in the same bunch crossing. These processes must be precisely accounted for in measurements of the top mass, the jet energy scale and, for example, in evaluating the impact of isolation cuts in particle identification.

In this paper, charged tracks are measured and used to study observables which are sensitive to the physics of soft QCD (the so-called underlying event): the track multiplicity and transverse momentum spectrum as well as the mean transverse momentum of charged tracks as a function of the track multiplicty.

The ATLAS detector is one of the two large general purpose detectors at the LHC. An inner tracking system embedded in a 2 tesla solenoidal field is used to measure the momentum of charged particles emitted from collisions with a resolution of ∼1% for a transverse momentum of 1 GeV. The tracking system is surrounded by calorimetry with an acceptance in pseudorapidity[1], $|\eta| < 4.9$. The muon spectrometer lies outside the calorimeter system and comprises precision chambers embedded in a toroidal magnetic field. The measurements described below make use of tracks found in the inner detector (ID) which is shown in Fig. 1. The ID consists of three sub-detectors covering the rapidity range $|\eta| < 2.5$. At inner radii, the pixel layers provide high precision independent space points, and the silicon central tracker (SCT) using microstrip sensors provides stereo pairs. At

[1] The ATLAS reference system is a cartesian right-handed coordinate system, with the nominal collision point at the origin. The azimuthal angle ϕ (radians) is measured around the beam axis, and the polar angle θ is the angle measured with respect to the z-axis. The pseudorapidity is defined as $\eta = -\ln \tan \theta/2$. p_T is the track momentum transverse to the beam direction.

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outer radii, the Transition Radiation Tracker provides approximately 36 layers of (r,ϕ) hits depending on the location of the track. Also of relevence to this analysis, scintillator counters (the MBTS) are located on either side of the interaction point and cover the region $2.09 < |\eta| < 3.84$. These are the principal elements of the trigger used to record interactions of interest for this analysis. More details on the ATLAS detector can be found in [1].

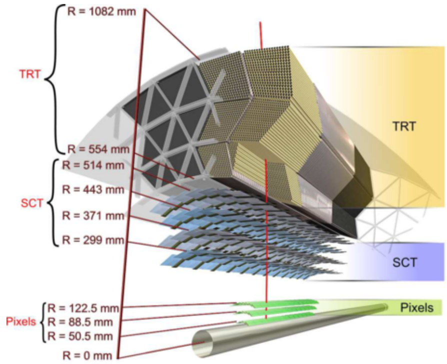

Figure 1: Cartoon showing the layout of the ATLAS tracking system.

2. Trigger and event selection

The data used in the analysis comprise ~445K events taken at $\sqrt{s}$ =900 GeV and ~400K events at $\sqrt{s}$ =7 TeV. Events were recorded if at least one MBTS counter fired on either side of the detector. The use of a single sided trigger avoids the need to model diffractive processes in computing efficiencies. Tracks with transverse momentum $p_T > 100$ MeV were reconstructed offline, and these tracks were used to reconstruct event vertices if ≥2 such tracks are found. Each event was required to have a reconstructed event vertex, no additional primary interaction, and at least one track passing the following selection cuts:

- $p_T > 500$ MeV, $|\eta| < 2.5$
- >1 hits in pixel and >6 in the SCT tracking systems
- transverse impact parameter $|d_0|$ <1.5mm
- longitudinal impact parameter $|z_0| \cdot sin\theta$ <1.5mm

The trigger efficiency was determined from analysis of randomly triggered events to be ~99.5%. The residual backgrounds are small or negligible: cosmic ray background $< 10^{-6}$; beam backgrounds < 0.1%; multiple interactions (pileup) < 0.01%.

Track reconstruction efficiencies were determined from Monte Carlo simulated events using full detector simulation and reconstruction. A key issue is the description of the material in the tracking volume, which was tuned in the simulation to match the data. The efficiency as a function of η averaged over all tracks with $p_T > 500$ MeV increases from ~0.65 for $|\eta| = 2.5$ to a plateau value of ~0.85 in the region $|\eta| < 1$. The efficiency as a function of p_T averaged over all tracks with $|\eta| < 2.5$ increases rapidly from an efficiency of 0.75 for p_T ~500 MeV to approximately 0.9 for tracks with p_T ~10 GeV. The Monte Carlo is also used to correct the observed distributions for contributions from non-primary tracks, such as from decays of K_s and Λ using the impact parameter distributions obtained via generator level information as shown in Fig. 2. The measured track distributions are corrected back to particle-level, namely stable charged particles with a lifetime $> 3 \cdot 10^{-11}$s, by inverting the efficiency corrections parameterised as a function of p_T and η and correcting for non-primary backgrounds. More details on the determination of efficiencies and backgrounds can be found in [4].

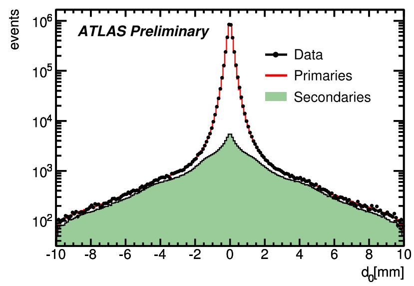

Figure 2: Impact parameter distributions in Monte Carlo events for primary and secondary charged particles.

3. Particle multiplicity and transverse momentum distributions

The charged particle multiplicity distribution, $\frac{1}{N_{ev}}\frac{dN_{ch}}{d\eta}$, is shown in Fig. 3 as a function of η for $\sqrt{s}$ =900 GeV, and in Fig. 4 for $\sqrt{s}$ =7 TeV. The curves shown are Monte Carlo predictions using the PYTHIA [5] event generator using models tuned to a wide range of experimental measurements. The tune, ATLAS MC09, is a tune by ATLAS to CDF data using the p_T-ordered shower and colour recombination model [6]. The DW tune [7] is a tune to CDF Run II data using maximal initial state radiation and virtuality ordered showering. The Perugia tune [8] also uses the p_T-ordered shower