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Particle Production and Diffraction in ATLAS

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On behalf of the ATLAS Collaboration

PLHC Vancouver, 4th-9th June 2012

Introduction

Why soft QCD?

- Useful for validating and tuning models of particle production
- Help to deal with pile-up, soft backgrounds for other processes
- Insight into the physics of hadronic cross-sections and hadron formation

Measuring soft QCD at ATLAS

Soft QCD measurements rely heavily on

- **Inner tracking detectors**: sensitive to charged particles with $p_{\mathrm{T}} > 100$ MeV and $|\eta| < 2.5$
- **Electromagnetic and hadronic calorimeters**: sensitive to electrons/photons and hadrons that have $E_{\mathrm{T}} >$ a few hundred MeV and $|\eta| < 4.9$.
- **MinBias events**: inclusive collisions triggered by scintillators ($2.1 < |\eta| < 3.8$)

ATLAS measurements

- K^0_S and Λ production
- Rapidity gap cross-sections
- Two particle angular correlations
- Forward-backward correlations
- Azimuthal ordering of charged hadrons
- Underlying event in charged-particle jet events

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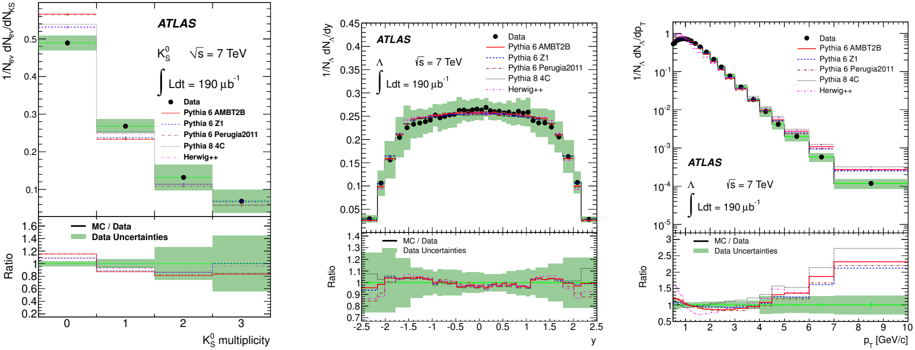
K^0_S and Λ production

PRD 85 (2012) 012001

- K^0_S and Λ candidates identified by fitting pairs of opposite-sign tracks to a common vertex and cutting on
  - transverse flight distance between primary (PV) and secondary (SV) vertices
  - the pointing angle, between the particle momentum and the PV→SV vector
- Signal extracted in each bin of p_{T} and η by fitting invariant mass distribution.
- Data corrected for detector inefficiency



Rapidity gap cross-sections

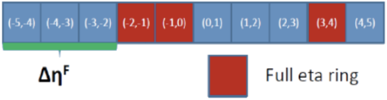
EPJ C72 (2012) 1926

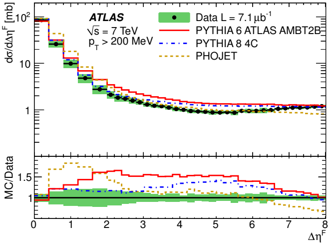
Detector-level gap algorithm

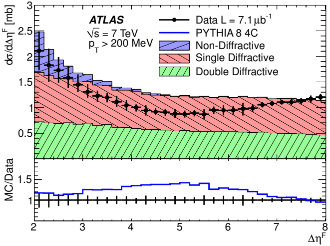
- Detector divided into η-rings for $|\eta| < 4.9$
- Ring is empty (for a given p_{T}^{cut}) if no
  - track with $p_{\mathrm{T}} > p_{\mathrm{T}}^{cut}$ and $|\eta| < 2.5$
  - calorimeter cluster with $p_{\mathrm{T}} > p_{\mathrm{T}}^{cut}$ and E above noise threshold

Measurement definition

- Inelastic cross-section as a function of the **forward rapidity gap size** ($\Delta\eta_F$)
- Forward gap defined as largest span of empty rings from edge of calorimeter
- Measurement corrected to particle-level (gap defined using stable particles)
- Tests proportions of ND, SD+DD components







Rapidity gap cross-sections

EPJ C72 (2012) 1926

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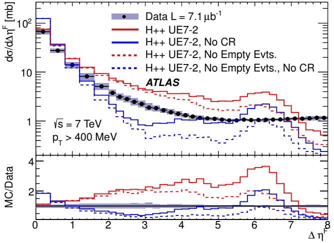
Inelastic cross-section

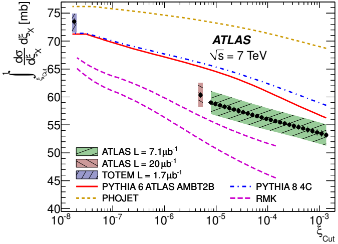
- HERWIG++ has no diffraction breakdown
- Structure based on hadronization model
- Weird shape - sensitive to hadronization model
- Three values of p_T^{cut} : 200, 400, 800 MeV

Measurement can be used to constrain differential contributions and hadronization



Cross-section as a function of ξ_{cut}

- $\xi_X = M_X^2/s$, ξ_{cut} is a minimum
- Corresponds to an integral of the above plot
- More low mass SD than in theory → more low mass diffraction
- Shown by steepness of ATLAS → TOTEM transition



Two Particle Angular Correlations

arXiv:hep-ex/1203.3549

Why correlations?

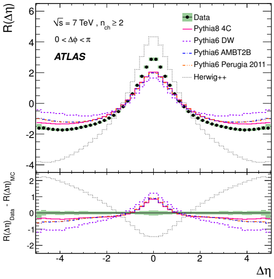
- Correlations between final state particles indicate a common origin for their production.
- Pattern of correlations can be complicated - MC generators need to describe this

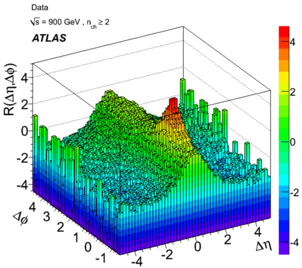
$\Delta\eta$ and $\Delta\phi$ correlations

- Foreground - **Intra-event**
- Background - **Inter-event**
- Measure F/B

$$R = \frac{\langle (N_{ch}-1)F(N_{ch},\Delta\eta,\Delta\phi)\rangle}{B(\Delta\eta,\Delta\phi)} - \langle N_{ch}-1\rangle$$

- Fully corrected for detector effects
- Observed number of charged tracks corrected using a trail-blazing technique (HBOM)





Forward-backward Correlations

arXiv:hep-ex/1203.3100

Forward-backward correlations

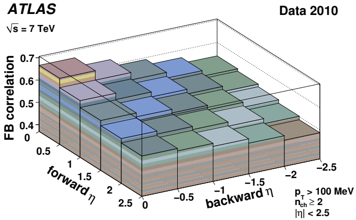
Correlations between the forward and backward regions for

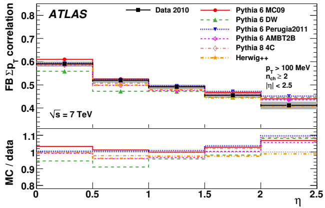
- Charged particle multiplicity
- Total transverse momentum of charged particles

Forward-backward multiplicity correlation

$$\rho^n_{fb} = \frac{\langle (n_f - \langle n_f \rangle)(n_b - \langle n_b \rangle) \rangle}{\sqrt{\langle (n_f - \langle n_f \rangle)^2 \rangle \langle (n_b - \langle n_b \rangle)^2 \rangle}}$$

- First measurement of summed-p_T correlations
- Data corrected for detector effects using multiple regression - would otherwise reduce correlations
- Latest MC tunes reproduce the correlations in data





Azimuthal ordering of charged hadrons

arXiv:hep-ex/1203.0419

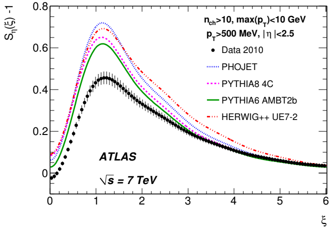
Angular correlations

- Spectral analysis of correlations between the longitudinal and transverse components of charged hadrons

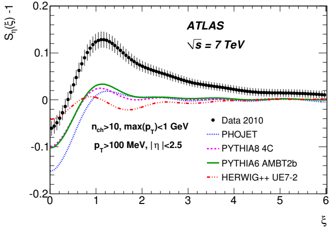
Angular correlation spectrum

$$S_\eta(\xi) = \frac{1}{N_{ev}} \sum_{event} \frac{1}{n_{ch}} \left| \sum_{i \neq j} \cos\left(\xi \Delta\eta_{ij} - \Delta\phi_{ij}\right) \right|^2$$

- Data corrected for detector inefficiencies and the measurement is presented at particle level
- Too much correlation in typical MCs, for high-p_{T} charged particles (top), but too little correlation for low-p_{T} charged particles (bottom).



(a) High p_{T} enhanced



(b) Low p_{T} enhanced

Azimuthal ordering of charged hadrons

arXiv:hep-ex/1203.0419

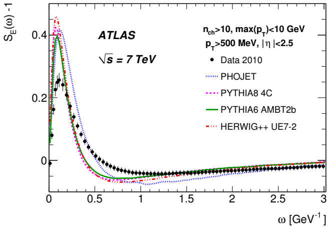
Energy/angular correlation spectrum

$$S_E(\omega) = \frac{1}{N_{ev}} \sum_{event} \frac{1}{n_{ch}} \left| \sum_{i \neq j} \cos\left(\omega \Delta X_{ij} - \Delta \phi_{ij}\right) \right|^2$$

for $X_j = 0.5 E_j + \sum_{k=0}^{k<j} E_k$

Interpretation

- Large disagreement in all correlation spectra
- MC is well above/below data
  - increase UE: less correlation, MC goes down (top looks better)
  - increase ISR: more correlation, MC goes up (bottom looks better)
  - problems for MC tuning - can't just turn usual handles and fit all data



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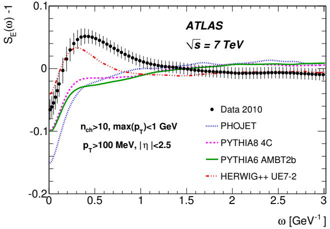


(b) Low p_{T} enhanced

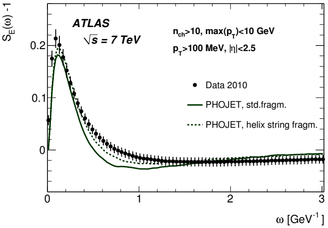
Azimuthal ordering of charged hadrons

arXiv:hep-ex/1203.0419

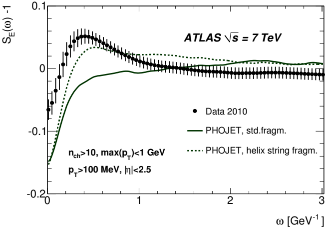
Model: helix-ordered gluon chain

- Helix-like structured gluon field at end of parton shower
- Azimuthal direction of hadron p_{T} coincides with helix string phase
- Imposes correlations between adjacent break-up points along string
- Induces strong correlations between angular and p_{T} orderings

- Correlations poorly described by conventional hadron-production model
- Some features consistent with string fragmentation from helix-ordered gluon chain
- Ordered fragmentation effects could improve soft particle production/hadronization models



(a) Inclusive



(b) Low p_{T} enhanced

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Underlying event in charged-particle jet events

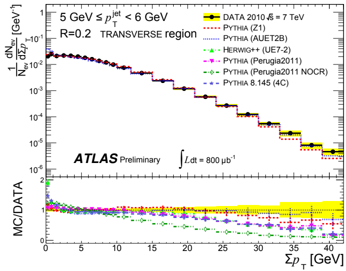
CERN-PH-EP-2012-148

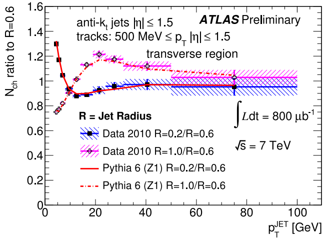
Underlying event

- Any hadronic activity not associated with hard scattering process
- Not possible to unambiguously assign particles to the hard scatter or UE

Observables

- Multiplicity and $\sum p_\mathrm{T}$ for charged particles
- **Leading jet**: highest p_T anti-k$_\mathrm{t}$ jet with $p_\mathrm{T} > 4$ GeV and $|\eta| < 1.5$
- **Transverse region**: $\pi/3 < |\phi^{particle} - \phi^{jet}| \leq 2\pi/3$
- Different anti-k$_\mathrm{t}$ R-parameters





- PYTHIA 6 (AUET2B) shows reasonable agreement
- Other generators need additional tuning of soft-QCD parameters
- Choice of hard scatter affects UE distributions!

Summary

K^0_S and Λ

- K^0_S distributions agree well with MC
- Λ p_{T} distribution shows substantial disagreement

Rapidity gap cross-sections

- PYTHIA, PHOJET better than HERWIG++
- Larger low mass SD contribution than in theory

Two particle angular correlations

- PYTHIA much better than HERWIG++ (string/cluster model)
- Large disagreements seen between data and MC

Summary

Forward-backward correlations

- Latest MC tunes perform well

Azimuthal ordering

- Large disagreement in all correlation spectra
- Helix-ordered gluon chain may improve things

Underlying event in charged particle jet events

- PYTHIA 6 shows reasonable agreement
- Other MC generators need additional tuning
- UE quantities depend on definition of hard scatter