Diffraction and rapidity gap measurements with ATLAS

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Introduction

- Diffraction = processes containing large rapidity gaps
- Dominated by soft processes => phenomenological description based on Regge theory - exchange of object with quantum numbers of vacua – Pomeron
- Described in variables $\xi=M^2/s$, $t$
- MC models based on triple pomeron approach parameterised as:

  \[ \frac{d\sigma^{SD}}{d\xi dt} \propto \xi^{1-2\alpha_{IP}(t)} e^{\beta t} \]

  \[ \alpha_{IP}(t) = \alpha_{IP}(0) + \alpha_{IP}'(0)t \]
Motivation and goals

• Direct measurement of $d\sigma/d\xi$ without proton taggers is not possible due to small detector acceptance

• We measured rapidity gaps at first LHC runs with low instantaneous luminosity

• Correlation between gaps and $\xi$, $\Delta\eta \approx -\ln(\xi)$, allows to constrain diffractive models

• Measurement of $d\sigma/d\Delta\eta$ corrected to level of stable particles with $p_T > 200, 400, 600, 800$ MeV tests hadronisation and UE models.
ATLAS detector I.

Calorimeter:

- Large coverage $|\eta|<4.9$
- Using calorimeter clusters for gap definition
- Additional conditions applied on cells to reduce noise ($E/\sigma > \sim 5.5$) => requires well describe noise dist. by MC.
- Using EM, HEC and FCal sub-detectors – cell noise well described by Gaussian distribution
- TileCal was not used due to different cell noise distribution.
ATLAS detector II.

Inner Detector:
- Coverage $|\eta| < 2.5$
- Consists of Pixel Detector, Silicon Strip Tracker and Transition Radiation Tracker.
- Using tracks for gap definition (in combination with calo. clusters)

Minimum Bias Trigger Scintillator (MBTS):
- Two discs symmetrically positioned 3 m from IP.
- Coverage $2.1 < |\eta| < 3.8$.
- Used for event selection:
  - single online hit
  - two offline hits in order to reduce noise contribution
Experimental rapidity gap definition

- **Forward Rapidity Gap** $\Delta \eta^F = $ largest distance from the edge of the detector ($\eta = \pm 4.9$) to first calorimeter cluster or track with $p_T > 200, 400, 600, 800$ MeV
Measured (uncorrected) rapidity gap distribution

- Exponential fall at small $\Delta \eta^F$ typical for ND events
- Plateau for $\Delta \eta^F > 3$ suggests presence of diffractive events
- Suppression at $\Delta \eta^F > 8$ caused by low trigger efficiency (large corrections from MC) => the results presented for $\Delta \eta^F < 8$
Rapidity gap cross section for $p_T>200$ MeV

- All MCs predict dominant contribution of ND at $\Delta \eta^F < 3$, with exponential decreasing behaviour due to fluctuations in hadronisation.
- Large gaps created only by SD and DD (with $M_\gamma < 7$ GeV)
Rapidity gap cross section for $p_T > 200$ MeV

- Overall precision between 8% (large gaps) and 20% ($\Delta\eta_F \sim 1.5$)
- Different prediction for various MC models
- Pythia8 good description at small gaps
- Phojet overestimates gaps $\Delta\eta_F < 1.5$ but reasonable description of large gaps
- Data exhibit slope in between Pythia8 DL (higher slope) and rest of MCs (smaller slope) at $\Delta\eta_F > 5$
Estimation of pomeron intercept $\alpha_p(0)$ in Donnachie-Landshoff model

- Using DL model implementation in Pythia8 to fit $\alpha_p(0)$ in data

Default DL:

$$
\frac{d\sigma^{SD}}{d\zeta dt} \propto \zeta^{1-2\alpha_{IP}(t)} e^{bt} \\
\alpha_{IP}(t) = \alpha_{IP}(0) + \alpha_{IP}' t \\
\alpha_{IP}(0) = 1.085 \\
\alpha_{IP}' = 0.25
$$

$\alpha_p(0)$ responsible for slope of the distribution at large $\Delta\eta^F$

- Fit result $\alpha_p(0) = 1.058 \pm 0.003\text{(Stat.)} + (0.034 - 0.039)\text{(Syst.)}$
- Result is consistent with the default DL value due to large model uncertainty

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Rapidity gap cross section for $p_T > 400, 600, 800$ MeV

- Increasing $p_T$ cut produces larger rapidity gaps
- Sensitivity to hadronic fluctuation at different $p_T$ thresholds
Rapidity gap cross section for $p_T > 400, 600, 800$ MeV

- $p_T > 400$ MeV keeps similar behaviour as $p_T > 200$ MeV. ND contribution relevant up to $\Delta \eta^F < 3$
- Particle production for $p_T > 600$ MeV starts to be rare => ND events produce very large gaps by fluctuations
• Testing of H++ MinBias model containing different hadronisation – cluster model
• **H++ MinBias contains only ND model** – production of large rapidity gaps
• Does not follow exponential decrease at large gaps – bump at $\Delta \eta^F \sim 6$
• This feature present with colour reconnection on/off
• Similar features occur for higher $p_T$ cuts.
Integrated inelastic cross section

- Integrated cross section $\int_{\xi_{\text{cut}}}^{1} \frac{d\sigma}{d\xi_x} d\xi_x$ is obtained from the MC prediction due to strong correlation $\Delta \eta = -\ln(\xi_x)$
- Small correction is applied to include particles with $p_T < 200$ MeV and for hadronisation fluctuations
- Error is dominated by uncertainty on luminosity measurement
- Result is compared with recent TOTEM measurement and previous ATLAS measurement which was done using MBTS trigger
- Models fail to describe evolution from low $\xi_x$ (TOTEM data) to large $\xi_x$ (ATLAS data) - KMR model has better shape description than the others
Conclusions

• ATLAS measured rapidity gap distributions $d\sigma/d\Delta\eta_F$ for different $p_T$ cuts $p_T > 200, 400, 600, 800$ MeV
• Observed plateau in gap distribution suggests presence of diffractive processes.
• Pomeron intercept in DL model was fitted at large gaps. The result is compatible with default DL value.
• Small gaps are sensitive to fluctuation in hadronisation. Different hadronisation and UE models has been compared with data. Herwig++ produces very large gaps in ND processes.
• Using MC prediction we obtained integrated inelastic cross section as a function of $\xi$ variable. This allows direct comparison of our measurement with different experiments and various models
• For further details see ATLAS Paper: arXiv:1201.2808
Backup slides
Corrections for experimental effects

- Measured rapidity gap distribution corrected for detector effects to level of stable hadrons

\[
\frac{d\sigma(\Delta\eta^F)}{d\Delta\eta^F} = \frac{A(\Delta\eta^F)}{\Delta\eta_{\text{ring}}} \cdot \frac{N(\Delta\eta^F) - N_{\text{BG}}(\Delta\eta^F)}{\varepsilon(\Delta\eta^F) \times \mathcal{L}}
\]

- \(N(\Delta\eta^F)\) measured distribution
- \(N_{\text{BG}}(\Delta\eta^F)\) beam induced background
- \(\varepsilon(\Delta\eta^F)\) trigger efficiency, estimated from MC
- \(A(\Delta\eta^F)\) corrections for detector effects – using Bayesian unfolding
- \(\Delta\eta_{\text{ring}}\) bin size
- \(\mathcal{L}\) luminosity = 7.1 ± 0.2 \(\mu\text{b}^{-1}\) (400 kevents)
Corrections for detector effects

- Matrix used in Bayesian unfolding
Systematic uncertainties

• Effect of various systematic uncertainties has been included: cluster energy scale, MC model uncertainty, tracking efficiency, luminosity measurement, MBTS trigger eff.

• Overall precision between 8% (large gaps) and 20% ($\Delta\eta_F \sim 1.5$)