Study of diffraction processes at the LHC

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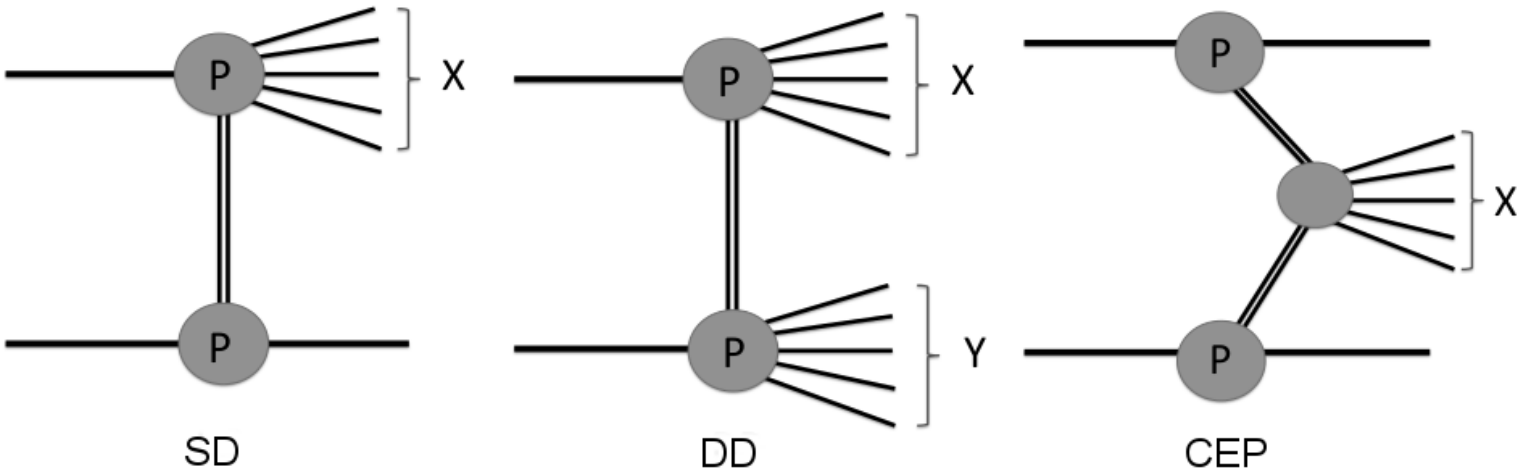
Content

Diffraction



- **Single diffraction** - most frequent, one of the p is rescattered, other one dissociates into the system X, rescattered p and system X are separated by a large rapidity gap
- **Double diffraction** - both protons are dissociated
- **Central diffraction** - double pomeron exchange and central exclusive production

Soft and hard diffraction

- Pomeron - object carrying quantum numbers of vaccuum, colorless
- Processes with small transferred momenta - **soft scale**
  - Fenomenological models based on Regge theory
  - Interaction is described as an exchange of Regge trajectory

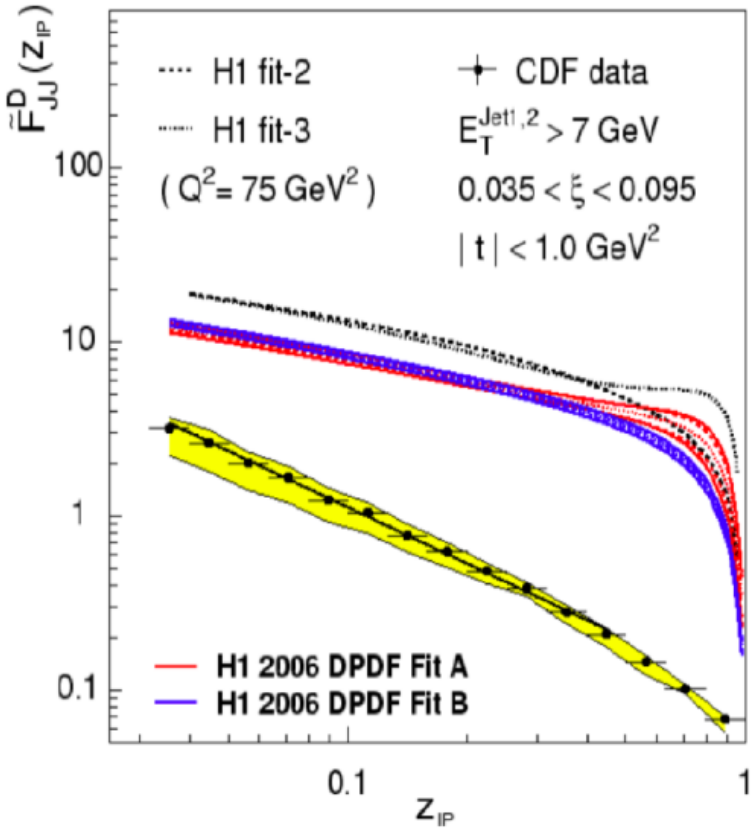
$$\alpha(t) = \alpha(0) + \alpha' t$$

  - For $\alpha(0) < 1$ we are talking about pomeron
- Processes with large momentum tranfer - **hard scale**
  - Perturbative theory can be used
  - Pomeron = composed object with an inner structure
  - One can measure diffractive parton distribution functions (DPDF)
  - Cross-section of a certain process can be written as

$$\mathrm{d}\sigma = \sum_i f_i^D(x, Q^2, \xi, t) * \mathrm{d}\sigma_i(x, Q^2)$$

$$f_i^D(x, Q^2, \xi, t) = f_{\mathbb{P}}(\xi, t) \cdot f_i^{\mathbb{P}}(x, Q^2)$$

  - Measurements at HERA $\rightarrow$ predictions for $p\bar{p}$ interactions at Tevatron



- Suppression by the factor 10 $\rightarrow$ DPDF are not process independent
- Factor S^2 - probability that soft interactions do not spoil the gap
- $S^2 \approx 0.1$ for SD processes with 2 jets at Tevatron, same estimation was made for the LHC
- CMS measurements - $S^2(\mathrm{LO}) \approx 0.12 \pm 0.04$ and $S^2(\mathrm{NLO}) \approx 0.08 \pm 0.04$
- ATLAS measurements - $S^2 \approx 0.16 \pm 0.04(\mathrm{stat.}) \pm 0.08(\mathrm{exp.sys.})$

Summary on important relations

- **Fractional momentum loss of the incident proton**: $\xi = \frac{(P-P')\cdot q}{P\cdot q}$
- **Transferred four-momentum squared**: $t = (E - E')^2 - (\vec{p} - \vec{p}')^2$
- **Invariant mass of the dissociated system**:

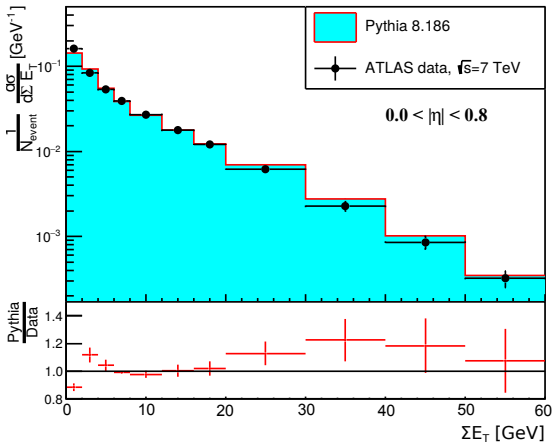
$$M_X = \sqrt{\left(\sum_i E_i\right)^2 - \left(\sum_i \vec{p_i}\right)^2} = \sqrt{s\xi}$$

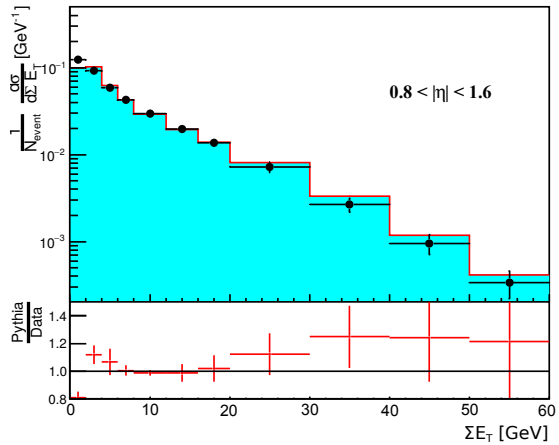
- **Pseudorapidity**: $\eta = -\ln\tan\left(\frac{\theta}{2}\right)$
- **Large rapidity gap** (LRG): region in pseudorapidity devoid of any hadronic activity, size of the gap is taken from the edge of the detector to the first registered particle

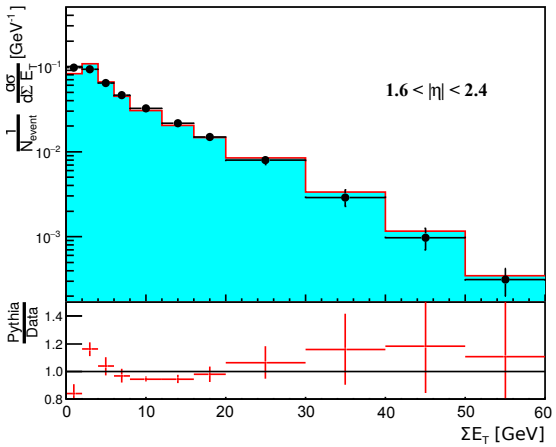
$$\Delta\eta \approx -\ln\xi$$

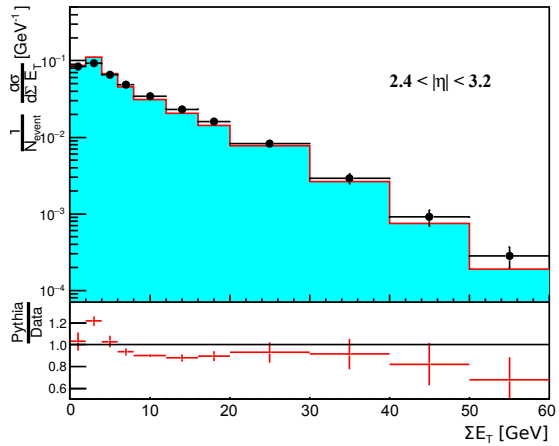
Transverse energy flow through the ATLAS detector

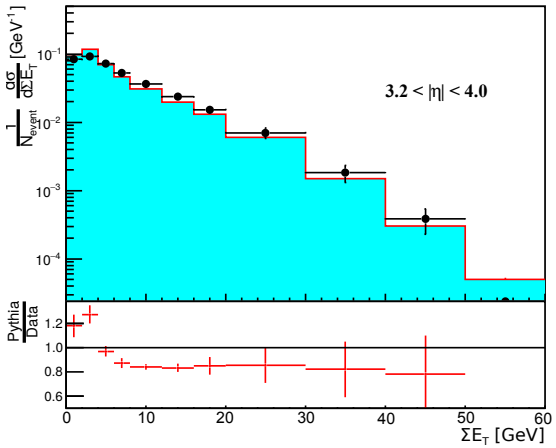
- Does the Pythia 8 describe published ATLAS data correctly? Are the jet constituents well described?
- Measurements of the **transverse energy sum** distribution at the ATLAS experiment for low luminosities of the beam.
- Minimum bias dataset - events containing at least 2 charged particles with $p_T > 250\ \mathrm{MeV}$ and $|\eta| < 2.5$
- $\sum E_T$ - sum of the E_T of all stable neutral particles with $p > 200\ \mathrm{MeV}$ and all stable charged particles with $p > 500\ \mathrm{MeV}$
- **Transverse energy density**
  $E_T^{density} = \left\langle \frac{\mathrm{d}^2 \sum E_T}{\mathrm{d}\eta \mathrm{d}\phi} \right\rangle \approx \frac{1}{N_{event}} \cdot \frac{1}{2\Delta\eta} \cdot \frac{1}{\Delta\phi} \cdot \sum_{x<|\eta|<y} (\sum E_T)$
- Six regions of pseudorapidity in $0.0 < |\eta| < 4.8$

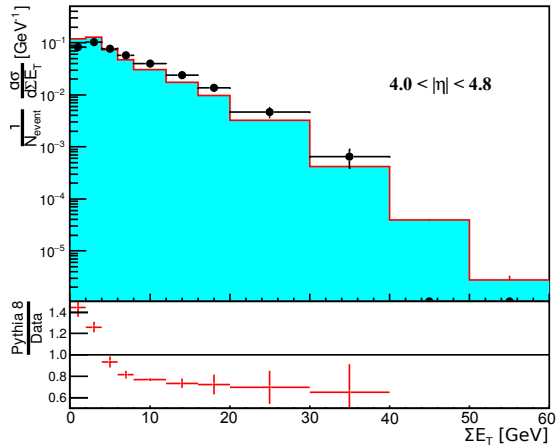

Pythia 8.186
ATLAS data, √s=7 TeV
0.0 < |η| < 0.8
Pythia / Data
ΣE_T [GeV]

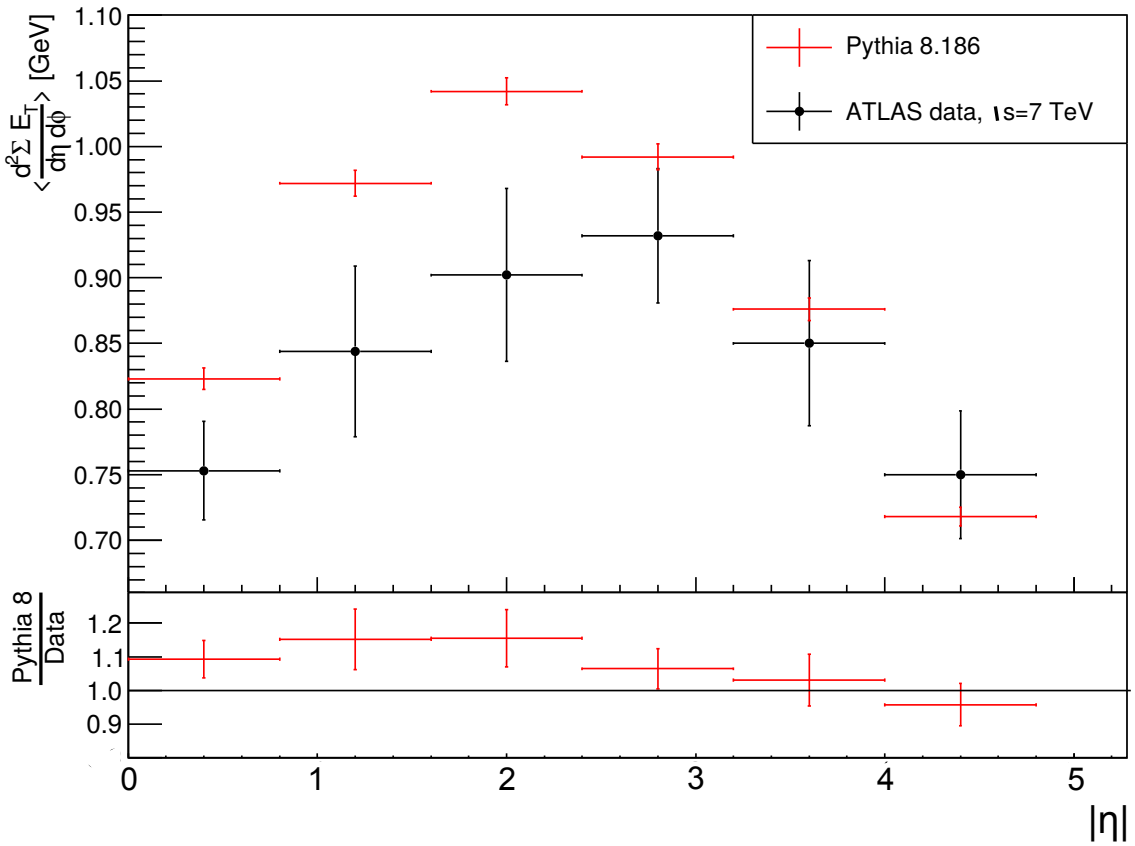

0.8 < |η| < 1.6
Pythia / Data
ΣE_T [GeV]


1.6 < |η| < 2.4
Pythia / Data
ΣE_T [GeV]


2.4 < |η| < 3.2
Pythia / Data
ΣE_T [GeV]


3.2 < |η| < 4.0
Pythia / Data
ΣE_T [GeV]

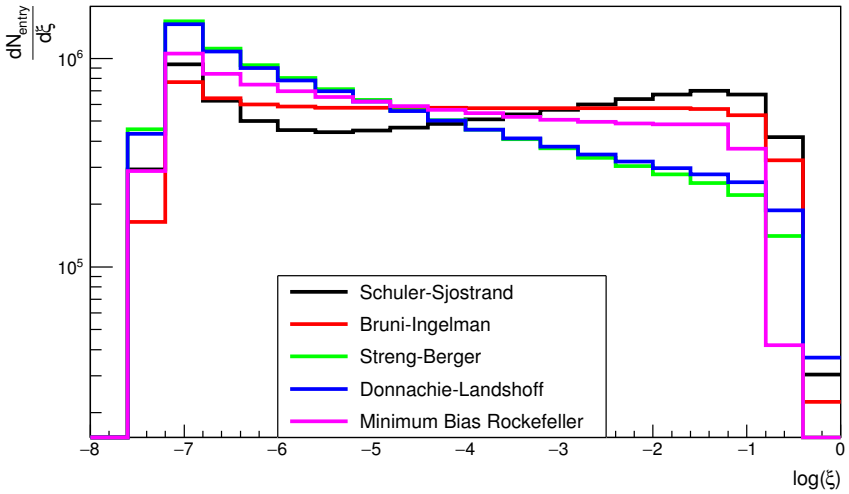

4.0 < |η| < 4.8
Pythia 8 / Data
ΣE_T [GeV]



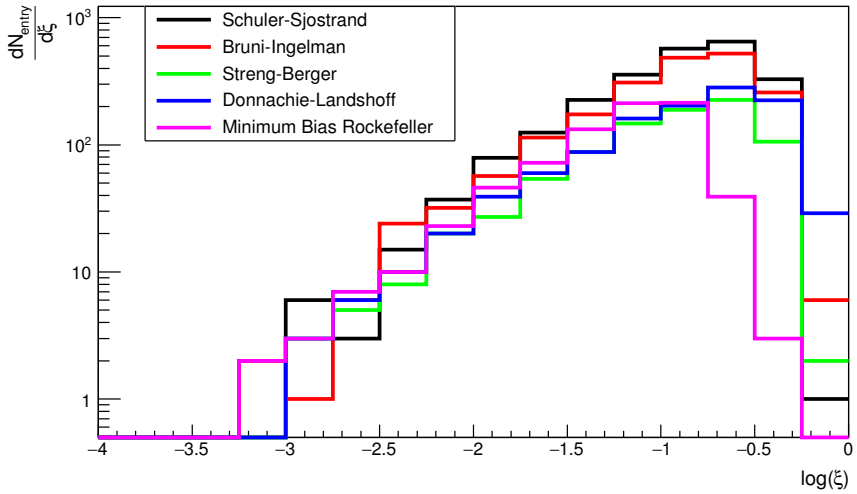
- Differencies between the Pythia 8 model and the ATLAS data are within 20% for both transverse energy sum and the transverse energy density.

Pomeron flux

Inclusive



Dijet



- ξ distributions for 5 different pomeron fluxes
- Comparison of the inclusive and dijet cases in single diffractive events.
- Dijet requirement: At least two jets with $p_T > 20\ \mathrm{GeV}$, anti-$\mathrm{k_t}$ algorithm with the jet radius $R = 0.6$ was used for the reconstruction.
- Cases with high ξ are preferred in dijet events.
- MBR flux was used for the next analysis

Invariant mass of the dissociated system and particle multiplicity

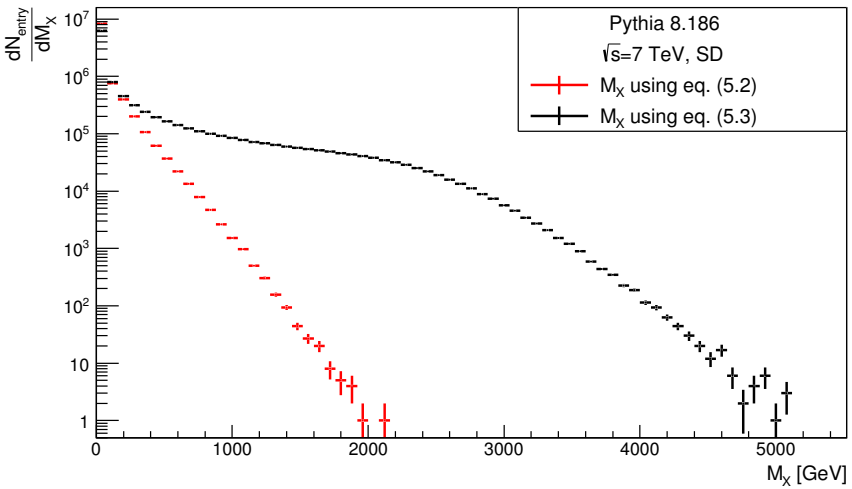
- Comparison of the single, double and non-diffractive processes in inclusive and dijet events.
- Comparison of the two methods of M_X calculation used in single diffractive events.

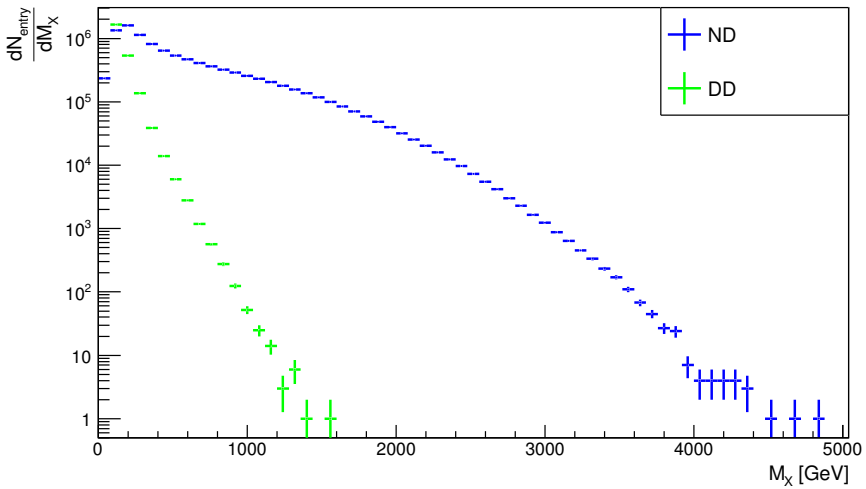
$$M_X = \sqrt{\left(\sum_i E_i\right)^2 - \left(\sum_i \vec{p}_i\right)^2} \tag{1}$$

$$M_X = \sqrt{s\xi} \tag{2}$$

- Only particles with $|\eta| < 4.9$ and $p_T > 200\ \mathrm{MeV}$ were accepted.
- Dijet requirement: At least two jets with $p_T > 20\ \mathrm{GeV}$, anti-$\mathrm{k_t}$ algorithm with the jet radius $R = 0.6$ was used for the reconstruction.

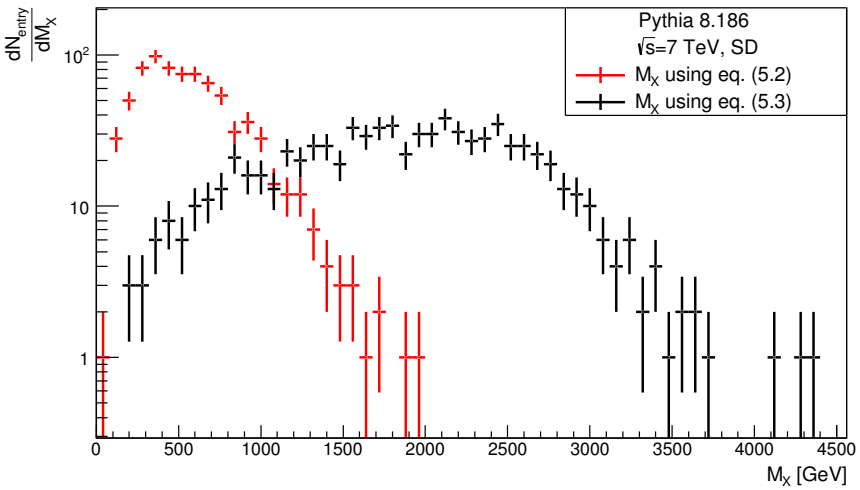
Invariant mass - inclusive

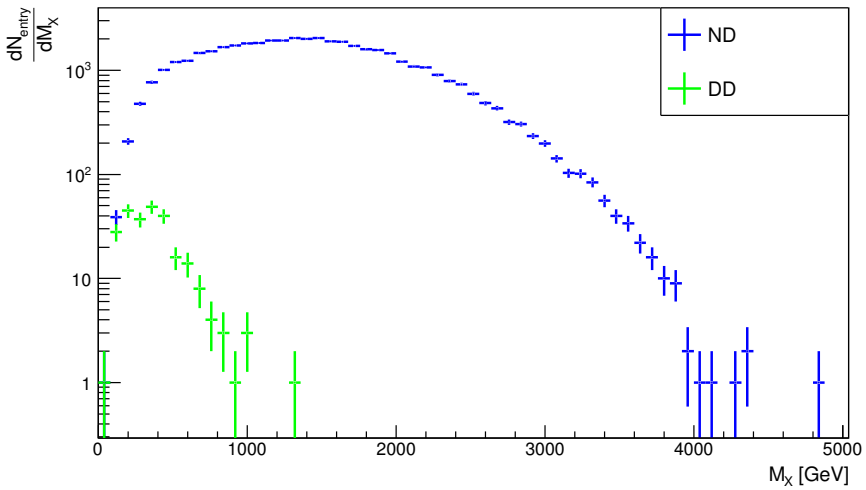




- Big size of the uncovered forward region outside the central detector.
- Decreasing tendency of $M_X \rightarrow$ processes with low M_X are prefered.
- DD events show similar tendency as SD ones.

Invariant mass - dijets

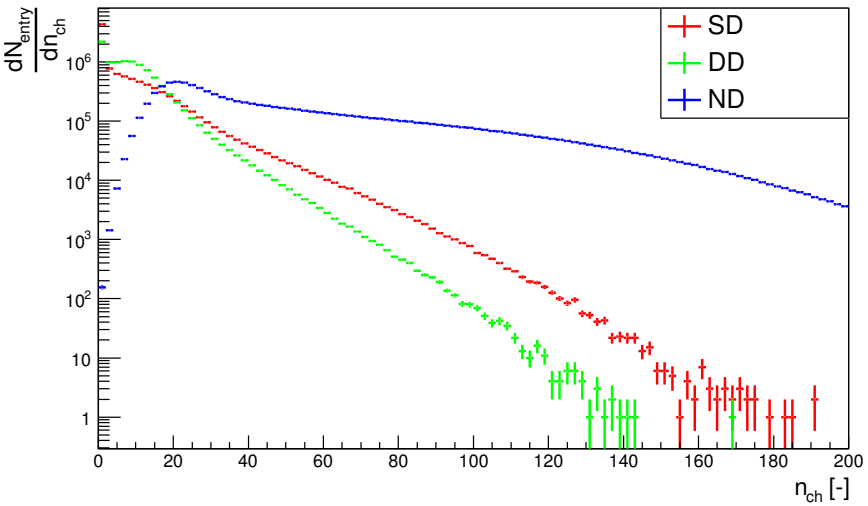




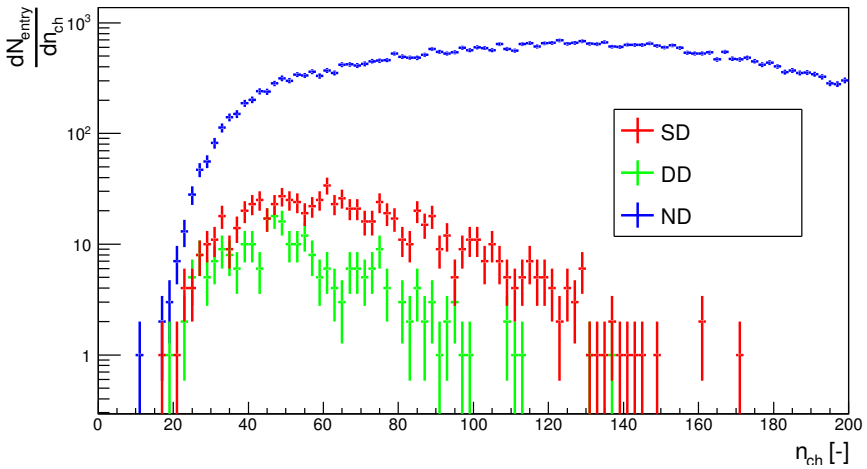
- Difference between two calculation methods of M_X is similar to the inclusive case.
- Events with very low M_X are deeply suppressed in SD, DD and also ND events.
- Presence of jets requires more particles in an event or particles with high p_T.

Particle multiplicity

Inclusive



Dijet

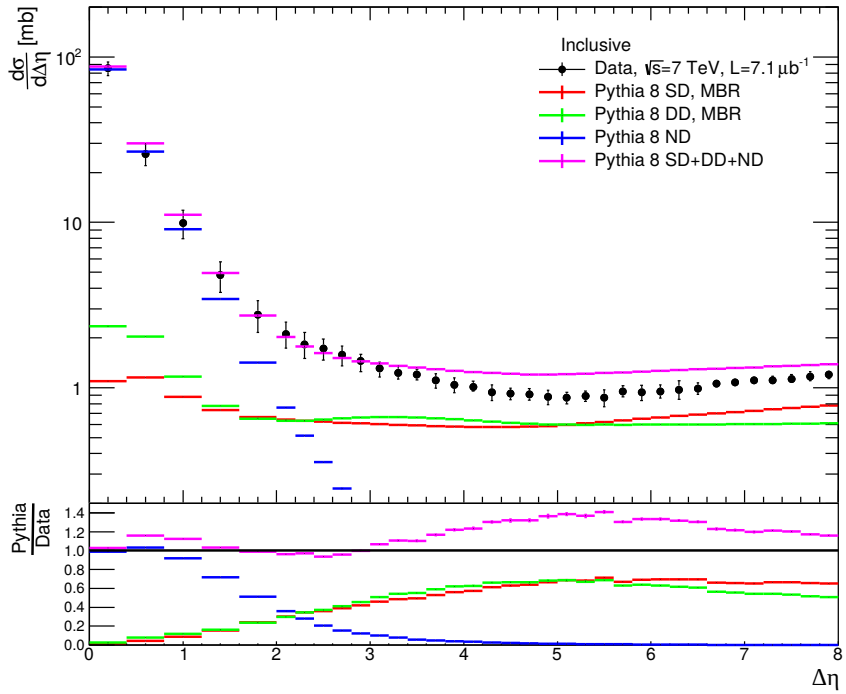


- Maximum in very low values of n_{ch} in diffractive events, for ND events maximum is shifted toward higher values - caused by the presence of the rapidity gap in diffractive processes.
- Suppression of lower values of n_{ch} due to cut for jets.

Rapidity gaps

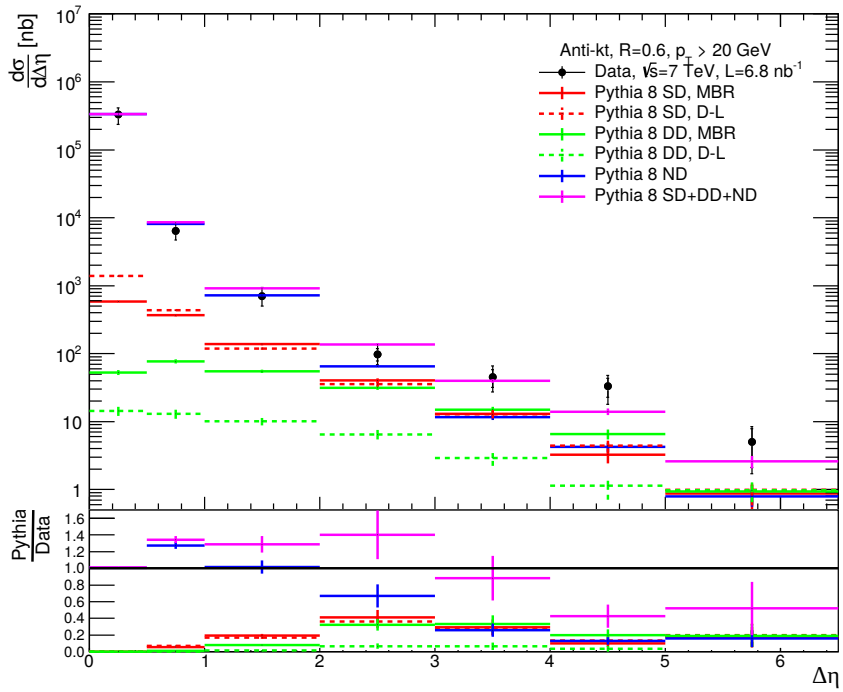
- Inelastic differential cross-section in forward RG size for inclusive and dijet cases - comparison with the ATLAS data, predictions of Pythia 8.186 fo SD, DD and ND component of the cross-section.
- In inclusive events only particles with $|\eta| < 4.9$ and $p_T > 200\ \mathrm{MeV}$ were accepted.
- Different conditions on particles in dijet cases - gap is defined as a region of pseudorapidity devoid of neutral particles with $p > 200\ \mathrm{MeV}$ and charged particles with $p > 500\ \mathrm{MeV}$ or $p_T > 200\ \mathrm{MeV}$
- Dijet requirement: At least two jets with $p_T > 20\ \mathrm{GeV}$, anti-$\mathrm{k_t}$ algorithm with the jet radius $R = 0.6$ was used for the reconstruction.
- ND contribution normalized by the factor of 0.75 in dijet case.

Inclusive [4]



- In low $\Delta\eta$ ND component form the main contribution to the inelastic cross-section and falls exponentially to $\Delta\eta \approx 3$.
- SD and DD processes form the main contribution to the inelastic cross-section for high values of $\Delta\eta$
- Plateau and consecutive rise of the cross-section are observed.

Dijet [5]



- All components of the inelastic cross-section show exponential fall towards high values of $\Delta\eta \rightarrow$ caused by the reduced phase space due to the presence of jets.
- Model is in good accordance with the data for $\Delta\eta < 4$.
- No S^2 factor was needed for SD events - will be compared with Pythia 8.2 model.

Conclusion

- Comparison of Pythia 8 predictions with the ATLAS data for $\sum E_T$ and $E_T^{density}$ distributions - observed differencies are within 20%.
- Comparison of diffraction properties in inclusive and dijet events for ξ, M_X (two different calculation methods) and n_{ch} distributions.
- Comparison of the SD and DD with non-diffractive events for M_X and n_{ch} distributions.
- Predictions of Pythia 8 for differential cross-section for SD, DD and ND events and their sum in inclusive and dijet cases, comparison with published ATLAS data.
- Predictions for inclusive events are in accordance with the data up to $\Delta\eta \approx 3$, for higher values of $\Delta\eta$ Pythia 8 predictions are slightly overestimated.
- Predictions for dijet events with D-L flux are in accordance with the data, especially for low values of $\Delta\eta$.
- There is no need to apply the S^2 factor in this particular model, i.e. $S^2 = 1.0$ - will be compared with Pythia 8.2 model with dynamical generation of the gap survival probability.

Thank you for your attention.

Reference

- M. Arneodo and M. Diehl, *Diffraction for non-believers*, 2005.
- V. Kůs, *Study of diffractive processes at the ATLAS experiment*, Doctoral thesis, 2015.
- ATLAS Collaboration, *Measurements of the pseudorapidity dependence of the total transverse energy in proton-proton collisions at* $\sqrt{s} = 7\ \mathrm{TeV}$ *with the ATLAS*, J. High Energ. Phys. (2012) 2012:33.
- ATLAS Collaboration, *Rapidity gap cross sections measured with the ATLAS detector in pp collisions at* $\sqrt{s} = 7\ \mathrm{TeV}$, Eur.Phys. J. C72 (2012) 1926.
- ATLAS Collaboration, *Dijet production in* $\sqrt{s} = 7\ \mathrm{TeV}$ *pp collisions with large rapidity gaps at the ATLAS experiment*, Phys.Lett. B754 (2016) 214-234.