Diffraction in PYTHIA 8

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- Goals
- pp framework
- $\gamma\mathrm{p}$ and $\gamma\gamma$ framework
- Hard diffraction in ep
- Conclusion and outlook

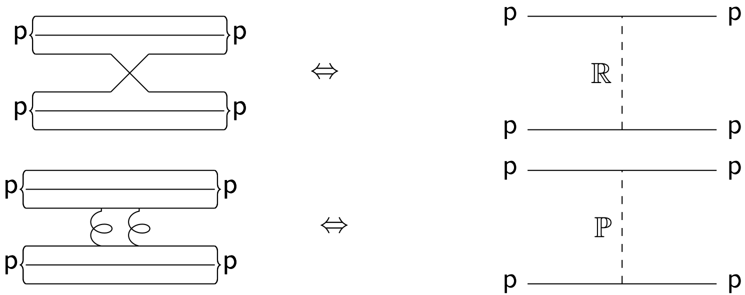
Goals

- Improve and extend pp and $\mathrm{p\overline{p}}$ cross sections:
  Total, elastic, diffractive topologies
  (with T. Sjöstrand [TS])
- Implement $\gamma\mathrm{p}$ and $\gamma\gamma$ cross sections:
  Total, elastic, diffractive topologies
  (with TS)
- Extend $\gamma\mathrm{p}$ framework to ep collisions
  (with I. Helenius [IH])
- Extend hard diffraction framework to ep collisions
  (with IH)

Soft diffraction based on MPI framework - only QCD processes.
Hard diffraction uses internal PYTHIA MEs - all processes available.

Regge theory

All cross sections are described within the Regge framework:



Complexity of model depends on the number of exchanges allowed.

High complexity needed for total and elastic (differential) cross sections to describe data, less needed for diffractive topologies.

pp total & elastic

Pythia 8 description of Schuler-Sjöstrand and Donnachie-Landshoff (SaS+DL) parametrization does not describe measured cross sections at the LHC.

$$\sigma_{\mathrm{tot}}^{\mathrm{DL}} = X\, s^{\alpha_{\mathbb{P}}(0)-1} + Y\, s^{\alpha_{\mathbb{R}}(0)-1}$$
$$\frac{\mathrm{d}\sigma_{\mathrm{el}}}{\mathrm{d}t} = \frac{\sigma_{\mathrm{tot}}^2}{16\pi}\exp(B_{\mathrm{el}}t)$$

Two new parametrisations implemented:

- COMPETE parametrization from PDG
  [PDG 2016] (corrected for misprints)
- DL-based parametrization from Appleby et.al. (ABMST).
  [EPJ C76 (2016) 520]

pp total & elastic

$$A_{\mathrm{el}}^{\mathrm{ABMST}} = \sum_{i=1}^{4} A_i(s,t) + A_{ggg}$$

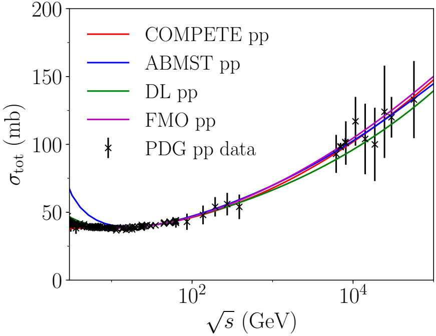
- Hard $\mathbb{P}$.
- Soft $\mathbb{P}$.
- f_2, a_2 trajectory.
- ρ, ω trajectory.
- Triple-gluon.

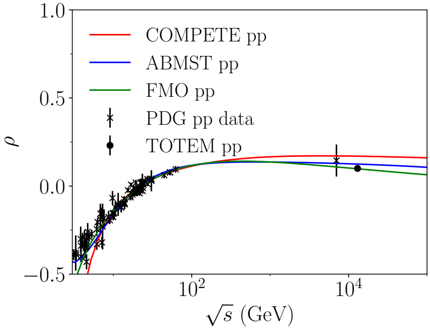
$$A_{\mathrm{el}}^{\mathrm{COMPETE}} = \sum_{i=1}^{6} F_+^i + F_-^i$$

- Froissaron (F_+^H).
- Maximal $\mathbb{O}$ (F_-^{MO}).
- $\mathbb{P}$, $\mathbb{O}$ poles (F_+^P, F_+^O).
- f_2, a_2 and ρ, ω trajectories (F_+^R, F_-^R).
- $\mathbb{PP}$, $\mathbb{RP}$, $\mathbb{OP}$ cuts (F_+^{PP}, $F_\pm^{RP}$, F_-^{OP}).
- Triple-gluon exchanges (N_+, N_-).

pp total & elastic

$$\sigma_{\text{tot}} = N\,\text{Im}[A_{\text{el}}(s,0)] \qquad \rho = \text{Re}[A_{\text{el}}(s,0)]/\text{Im}[A_{\text{el}}(s,0)]$$



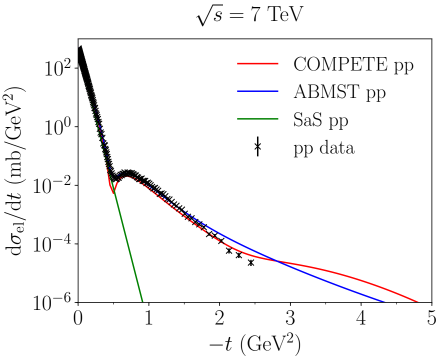


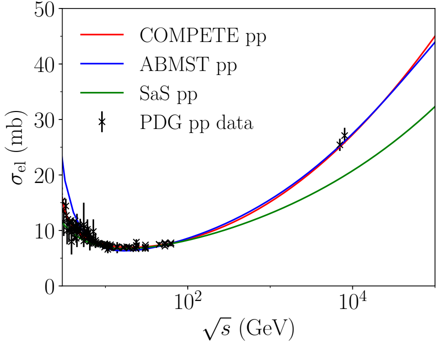
- FMO not implemented in Pythia
- New models improve description of σ_{tot} and ρ (const. in SaS, not shown).

MCnet

pp total & elastic

$$\frac{\mathrm{d}\sigma_{\mathrm{el}}}{\mathrm{d}t} = N\,A_{\mathrm{el}}(s,t) \qquad \sigma_{\mathrm{el}} = \int \mathrm{d}t \frac{\mathrm{d}\sigma_{\mathrm{el}}}{\mathrm{d}t}$$



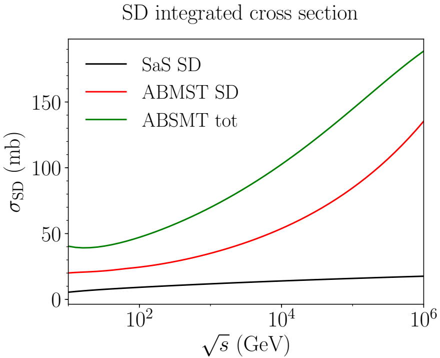


- Coulomb term can be included in all models
- New models improve description of (differential) cross sections

pp diffractive

- SaS provides a description for single, double and central diffraction using a single Pomeron.
- COMPETE model provides no description here.
- ABMST provides a desctription for single diffraction using two exchanges: A Pomeron and a Reggeon. Also includes sophisticated model for low-mass resonances.
- We have extended ABMST to double and central diffraction.
- A modified version of the ABMST description is also available, fixing some unwanted features of the original ABMST description.

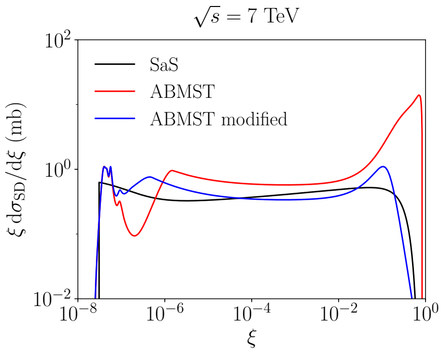
pp diffractive

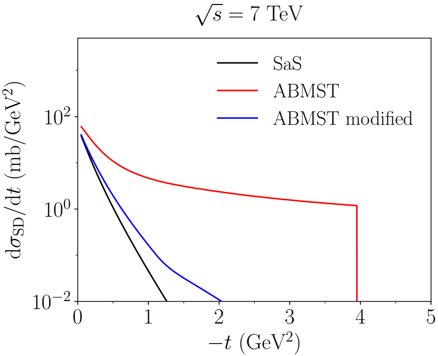


Unwanted features:

- SD cross section too large
- Model leaves very little room for other processes

pp diffractive

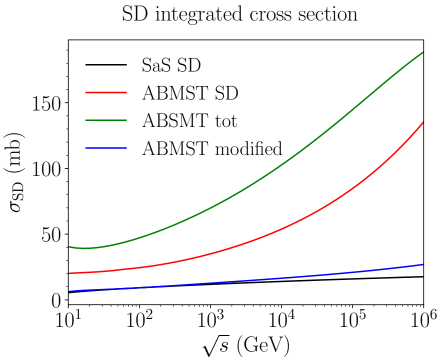




Unwanted features:

- ABMST model has too much high-mass activity
- ABMST model has large dip between low-mass resonances and high-mass desciption
- ABMST model becomes constant at large t

pp diffractive

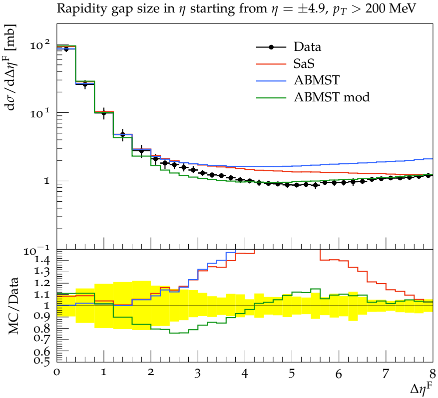


- ABMST modified gives more reasonable results
- SaS is too large at LHC energies, hence ABMST (modified) might also be

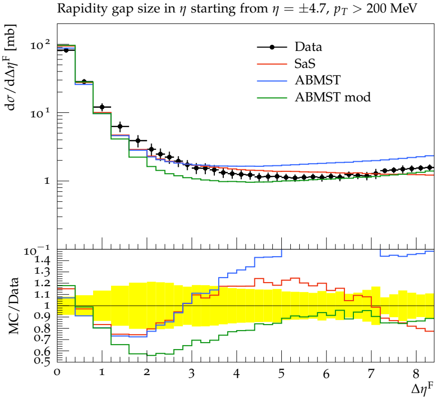
pp diffractive

Preliminary results:

ATLAS 2012:



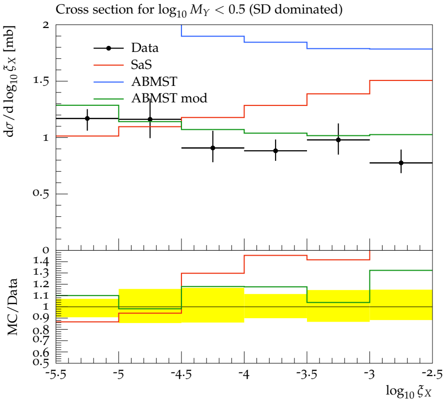
CMS 2015:



pp diffractive

Preliminary results:

CMS 2015:



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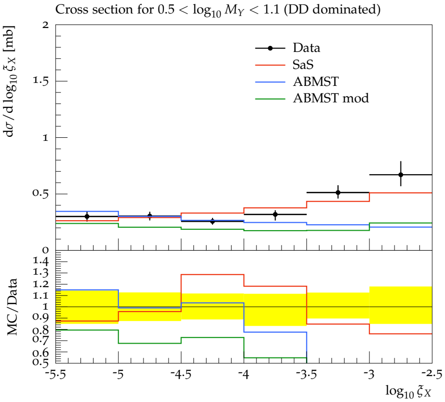
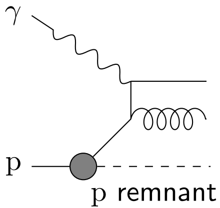
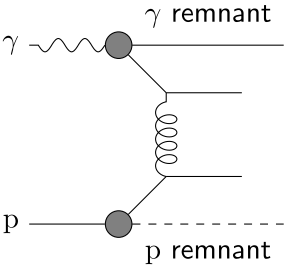


γp, $\gamma\gamma$ framework

- Photoproduction already included in Pythia (IH + TS)
- Automatic mixing between processes.



- Direct: Photon initiator of hard process
- No MPIs, but FSR and ISR for hadron



- VMD/anomalous: Photon fluctuates into hadronic state before hard process
- PDFs describe partonic structure of hadronic state
- MPIs, FSR and ISR for both sides

γp, $\gamma\gamma$ framework

- New: Extended framework to elastic and diffractive VMD processes using the SaS model.

$$\gamma + \mathrm{p} \rightarrow V + \mathrm{p} \qquad \gamma + \gamma \rightarrow V_1 + V_2$$
$$\gamma + \mathrm{p} \rightarrow X + \mathrm{p} \qquad \gamma + \gamma \rightarrow X + V_2$$
$$\gamma + \mathrm{p} \rightarrow V + X \qquad \gamma + \gamma \rightarrow V_1 + X$$
$$\gamma + \mathrm{p} \rightarrow X_1 + X_2 \qquad \gamma + \gamma \rightarrow X_1 + X_2$$

- New: Hard diffraction model from pp extended to γp and $\gamma\gamma$.

[CR+IH+TS]

ep framework

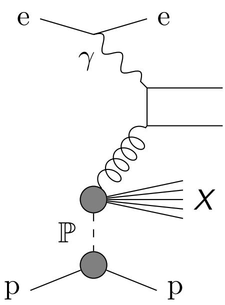
DIS:

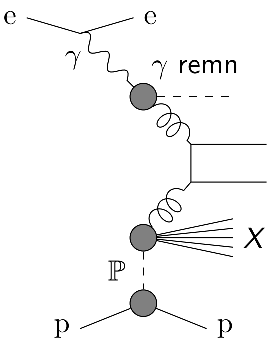
- High virtuality photon
- Available with new dipoleRecoil shower [TS + B.Cabouat] or DIRE [S. Höche, S. Prestel]
- Diffractive dijet cross sections described by NLO calculations.

Photoproduction:

- Low virtuality photon
- Photon may fluctuate into hadronic state (VMD / anomalous)
- Factorize γ flux and setup $\gamma \mathrm{p}$ system
- NLO calculations overshoot diffractive dijet data.

Hard diffraction in ep



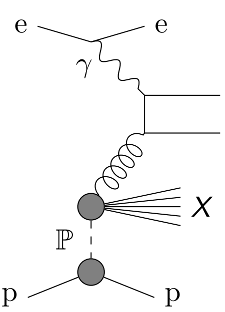


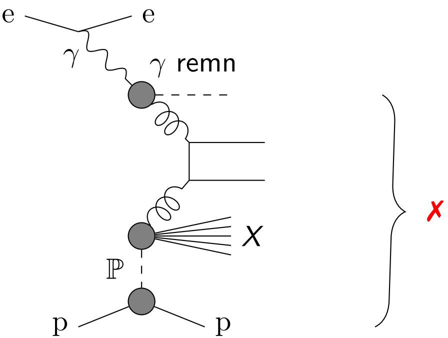
- Tentative diffractive probability based on dPDF to PDF ratio

$$P_{\mathrm{D}} = F^{\mathrm{D}}(x_g, Q^2)/f_{\mathrm{p}}(x_g, Q^2)$$

- Gap survival introduced with MPI framework

Hard diffraction in ep





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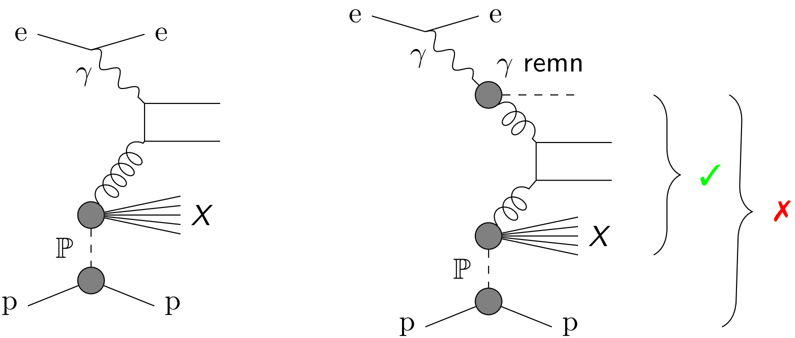

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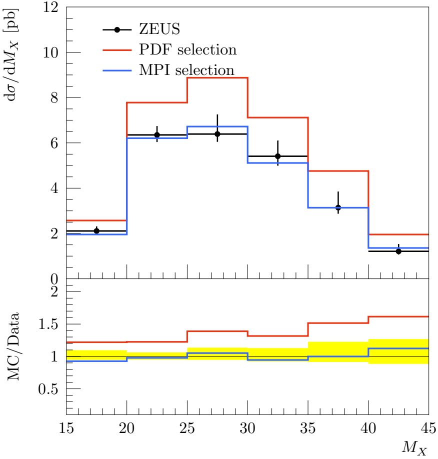
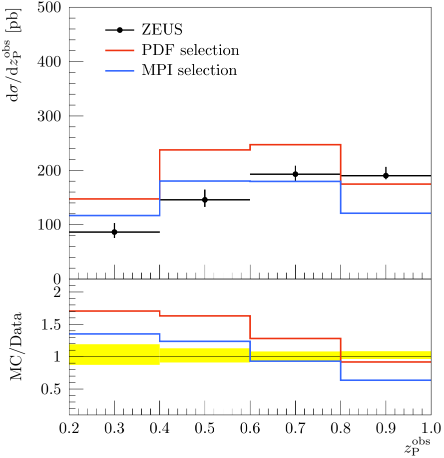
Hard diffraction in ep

- ZEUS diffractive dijet analysis [ZEUS: Eur.Phys.J C55, 177-191(2008)]
- $Q_\gamma^2 < 1.\ \text{GeV}^2$, $|\eta_{j1,j2}| < 1.5$, $E_T^{1(2)} > 7.5(6.5)$ GeV
- H1 Fit B LO dPDF and flux
- Tentative probability overshoots
- MPI gap survival gives good agreement

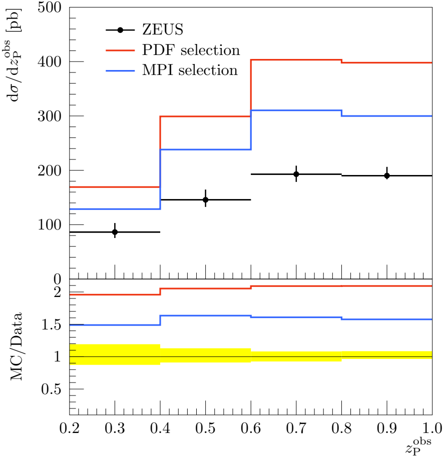


Hard diffraction in ep

H1 Fit B LO:



H1 Fit A NLO:



High sensitivity to dPDF and flux, but promising results.

Conclusion and outlook

In PYTHIA 8.235:

- New models for total and elastic pp cross sections available.
- New models for diffractive pp cross sections available.
- Elastic and diffractive cross sections for $\gamma\mathrm{p}$ and $\gamma\gamma$.
- Hard diffraction for ep

Future plans:

- Exptend elastic and diffractive $\gamma\mathrm{p}$ and $\gamma\gamma$ to γ from e.
- Merging of DIS and photoproduction
- Extend from ep to $\mathrm{e}A$ with Angantyr