Cross sections and diffraction in PYTHIA 8

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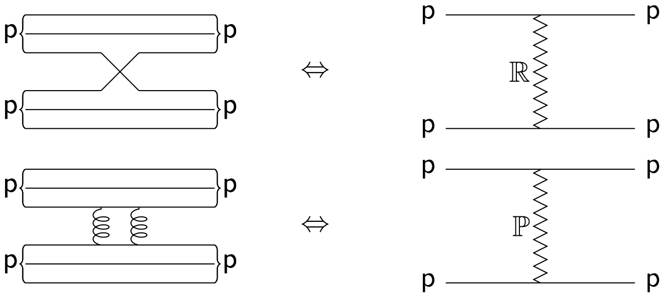
- Goals
- Regge theory intro
- Total and elastic cross sections
- Diffraction cross sections
- Conclusion and outlook

Goals

- Better description of the total and elastic cross sections at LHC energies
  (PYTHIA currently is too low)
- Better description of elastic differential cross section
  (PYTHIA currently only exponential)
- Better description of diffractive (differential) cross sections
  (none of the models available in PYTHIA currently describes all aspects of data)
- Include possibility for producing truly hard QCD and electroweak particles in diffractive events
  (only soft with small tail of hard QCD available in PYTHIA before).
  See arXiv:1512.05525 [hep-ph].

Regge theory intro

Old-school scattering theory describing particle collisions, eg. pp elastic scattering.
Can be described in a diagrammatic way, similar to Feynman diagrams in QFT.

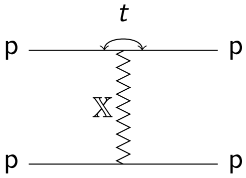


We can construct propagators for $\mathbb{X}$ and vertex rules for $\mathbb{X}\mathrm{p}$, $\mathbb{XXX}$ etc. ($\mathbb{X} = \mathbb{R}, \mathbb{P}$).

Regge theory intro

Neglecting Couloumb scattering, amplitude for elastic scattering at lowest order is

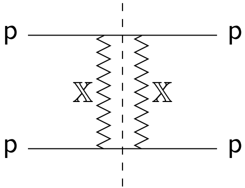
$A_{\mathrm{el}} =$



$\sim F^2(t) \cdot G_{\mathbb{X}}(\frac{s}{s_0}, t)$

And the cross section

$\sigma_{\mathrm{el}} \sim$

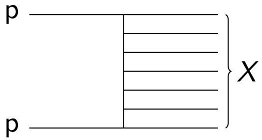


$\sim F^4(t) \cdot |G_{\mathbb{X}}(\frac{s}{s_0}, t)|^2$

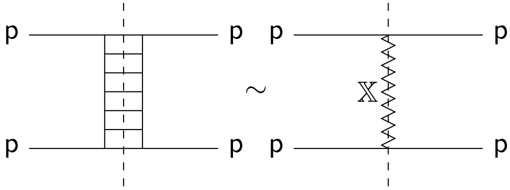
Regge theory intro

The amplitude for pp→anything is

$$A(\mathrm{pp} \to X) =$$



$$\sigma_{\mathrm{tot}} \sim$$



$$\sim F^2(0)\, G_{\mathbb{X}}\left(\frac{s}{s_0}, 0\right)$$

Amplitudes and cross sections for various processes, eg. elastic, total and diffractive processes, can be constructed with these form factors, propagators and vertices from Regge theory, to various degrees of complexity.

Total and elastic cross sections

- Old Donnachie-Landshoff parametrization does not describe measured cross sections at the LHC.

$$\sigma_{\mathrm{tot}}^{\mathrm{DL,\,old}} = X\, s^{\alpha_{\mathbb{P}}(0)-1} + Y\, s^{\alpha_{\mathbb{R}}(0)-1}$$

- Pythia currently only includes simple exponential fallof in $\frac{\mathrm{d}\sigma_{\mathrm{el}}}{\mathrm{d}t}$, and do not fully describe LHC data.

$$\frac{\mathrm{d}\sigma_{\mathrm{el}}}{\mathrm{d}t} = \frac{\sigma_{\mathrm{tot}}^2}{16\pi}\exp(B_{\mathrm{el}}\,t)$$

- Various parametrizations of differential elastic cross section available from different authors.
- Two chosen: COMPETE parametrization from PDGs Review of particle physics 2014 (RPP), DL-based parametrization from Appleby et.al. (ABMST).

Total and elastic cross sections

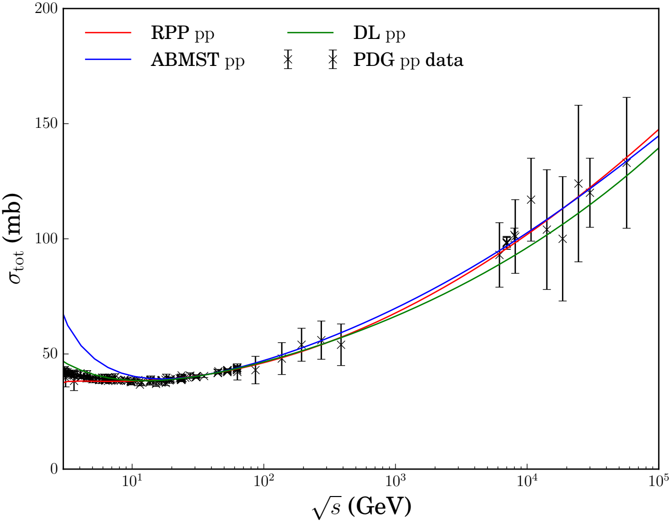
$$A_{\mathrm{pp}}^{\mathrm{ABMST}} = \sum_{i=1}^{4} A_i(s,t) + A_{ggg}$$

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

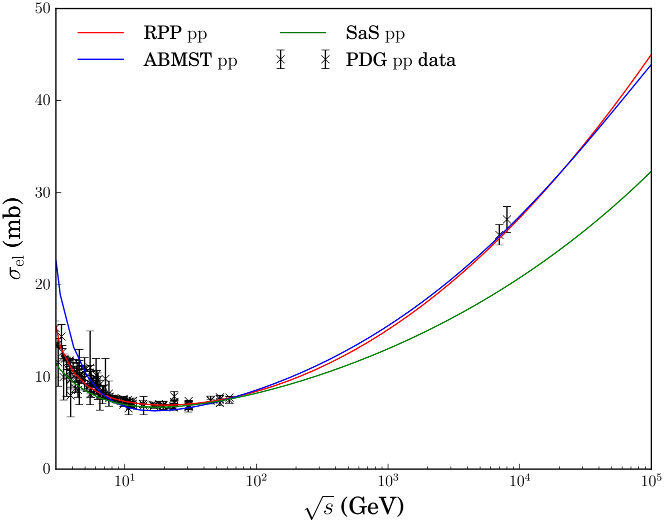
$$A_{\mathrm{pp}}^{\mathrm{RPP}} = \sum_{i=1}^{6} F_+^i + F_-^i$$

- 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_-).

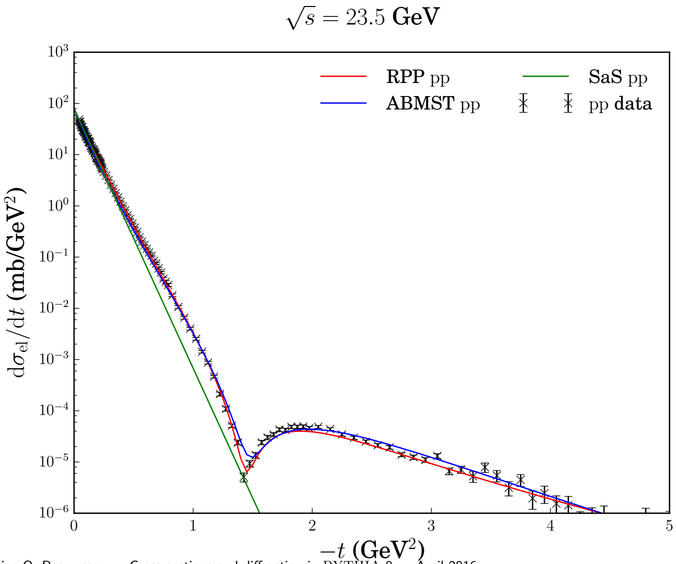
Total and elastic cross sections



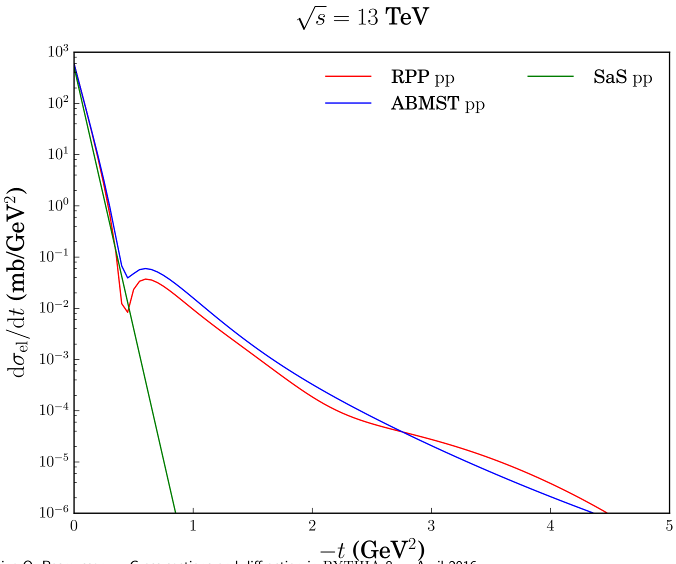
Total and elastic cross sections



Total and elastic cross sections

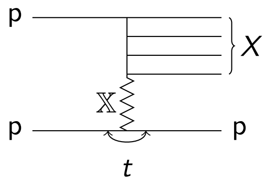


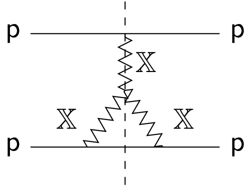
Total and elastic cross sections



Diffractive cross sections

The single diffractive amplitude can be constucted similarly

$A_{\mathrm{SD}} =$ 

$\sigma_{\mathrm{SD}} \sim$ 

and obtain

$$\sigma_{\mathrm{SD}} \sim F^2(0)|G_{\mathbb{X}}(\frac{M_X^2}{s_0}, 0)|^2 \cdot g_{\mathbb{XXX}}^2 \cdot F^4(t)|G_{\mathbb{X}}(\frac{s}{M_X^2}, t)|^4$$

The fractional momentum loss of the proton is $\xi = \frac{M_X^2}{s}$.

Diffractive cross sections

Default in PYTHIA: Schuler-Sjöstrand parametrization (SaS)

$$\frac{\mathrm{d}\sigma_{\mathrm{SD}}^2}{\mathrm{d}t\mathrm{d}\xi} = \frac{g_{\mathbb{PPP}}}{16\pi}\frac{\beta_{\mathrm{p}\mathbb{P}}^3}{\xi}\exp(B_{\mathrm{SD}}t)F_{\mathrm{SD}}$$

where

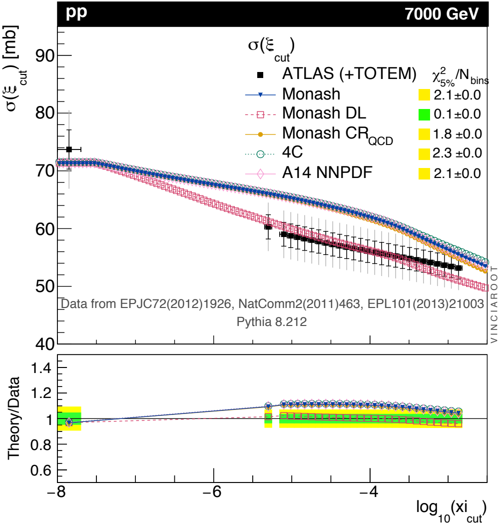
$$\beta_{\mathrm{p}\mathbb{P}}^2 = X_{\mathrm{pp}}\, s_{\mathrm{ref}}^{\epsilon_{\mathbb{P}}}$$

$$B_{\mathrm{SD}}(s) = 2b_{\mathrm{p}} - 2\alpha'_{\mathbb{P}}\ln(\xi)$$

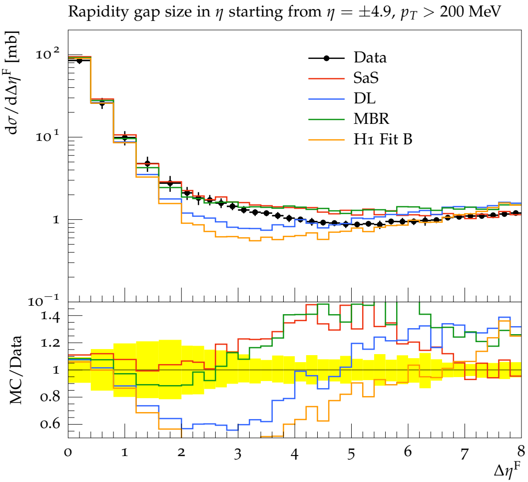
$$F_{\mathrm{SD}} = (1-\xi)\left(1 + \frac{c_{\mathrm{res}}M_{\mathrm{res}}^2}{M_{\mathrm{res}}^2 + \xi\, s}\right)$$

and $\sqrt{s_{\mathrm{ref}}} = 20$ GeV, $g_{\mathbb{PPP}} \simeq 0.318\,\mathrm{mb}^{1/2}$, $b_{\mathrm{p}} = 2.3$,
$c_{\mathrm{res}} = 2$ and $M_{\mathrm{res}} = 2$ GeV.
Additional options available.

Diffractive cross sections



Diffractive cross sections



Diffractive cross sections

New implementation: ABMST parametrization

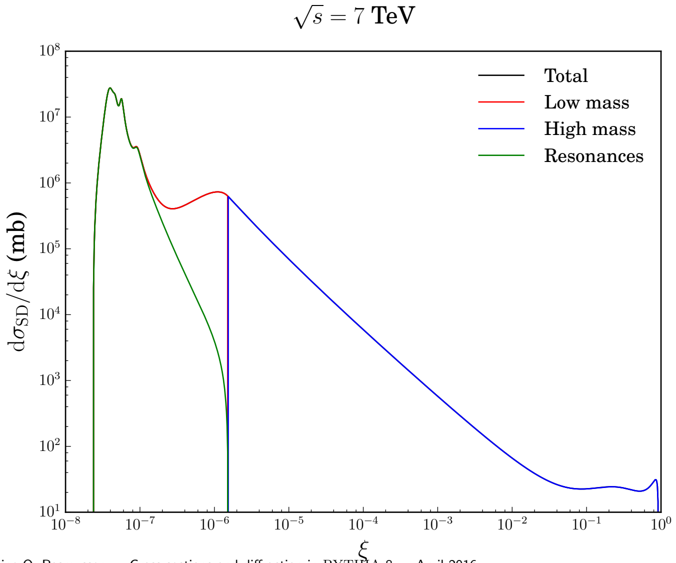
$M_X > M_{\mathrm{cut}}$

$$\frac{\mathrm{d}\sigma^2_{\mathrm{SD}}}{\mathrm{d}t\mathrm{d}\xi} = g_{\mathbb{PPP}} s^{\epsilon_{\mathbb{P}}} \xi^{\alpha_{\mathbb{P}}(0)-2\alpha_{\mathbb{P}}(t)} + g_{\mathbb{PPR}} s^{\epsilon_{\mathbb{R}}} \xi^{\alpha_{\mathbb{R}}(0)-2\alpha_{\mathbb{P}}(t)} + g_{\mathbb{RRP}} s^{\epsilon_{\mathbb{P}}} \xi^{\alpha_{\mathbb{P}}(0)-2\alpha_{\mathbb{R}}(t)} + g_{\mathbb{RRR}} s^{\epsilon_{\mathbb{R}}} \xi^{\alpha_{\mathbb{R}}(0)-2\alpha_{\mathbb{R}}(t)} + \frac{g^2_{\pi\pi\mathrm{p}}}{16\pi^2} \frac{|t|}{(t-m_\pi^2)^2} F^2(t) \cdot \xi^{1-\alpha_\pi(t)} \sigma_{\pi^0\mathrm{p}}(s\xi)$$

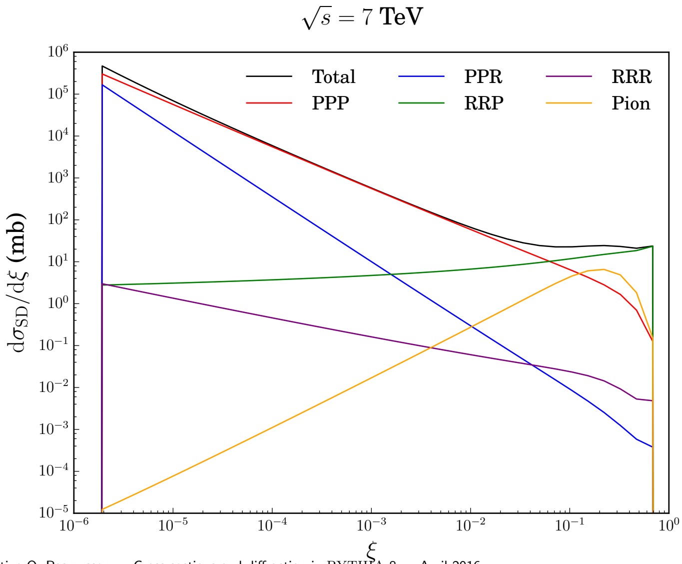
$M_X < M_{\mathrm{cut}}$

$$\frac{\mathrm{d}\sigma^2_{\mathrm{SD}}}{\mathrm{d}t\mathrm{d}\xi} = a(t,s)(\xi-\xi_{\mathrm{t}})^2 + b(s,t)(\xi-\xi_{\mathrm{t}}) - \frac{\mathrm{d}\sigma^2_{\mathrm{HM}}(\xi_{\mathrm{c}},t,s)}{\mathrm{d}t\mathrm{d}\xi} \frac{\xi-\xi_{\mathrm{t}}}{\xi_{\mathrm{c}}-\xi_{\mathrm{t}}} + \frac{\exp(13.5(t+0.05))}{\xi} \cdot \sum_{l=1}^{4} \frac{c_l m_l \Gamma_l}{(s\xi-m_l^2)^2+(m_l\Gamma_l)^2}$$

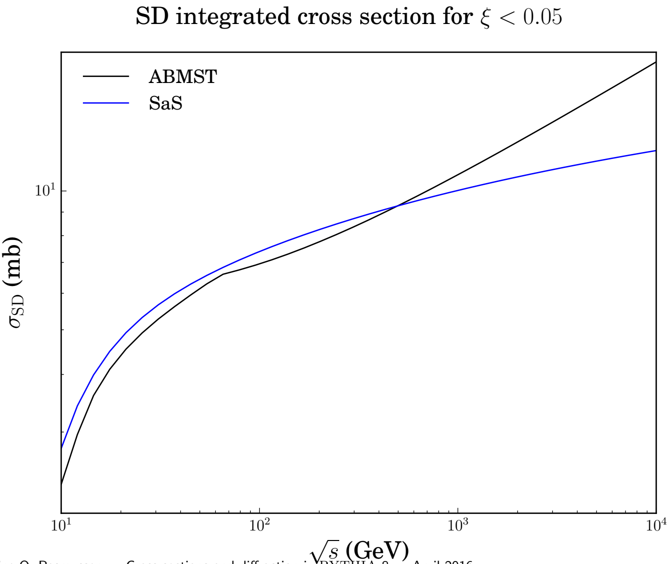
Diffractive cross sections



Diffractive cross sections



Diffractive cross sections



Conclusion and outlook

- Implemented two new parametrizations of the total and elastic cross sections in PYTHIA 8.
- Implemented new parametrization of SD cross sections.
- Compare the new SD parametrization to LHC data.
- Invent description for double- and central diffraction close to ABMST description.
- Implement alternative scenario, keeping ABMST good points, but with different high-energy behavior.