Forward physics in Herwig++

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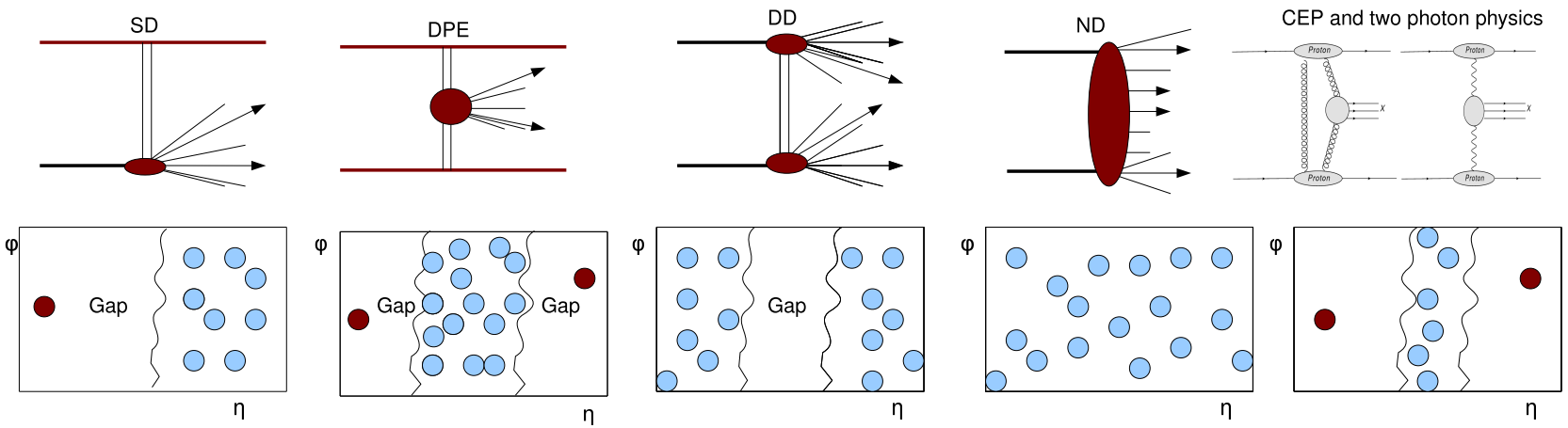
Forward physics at LHC

- Forward physics: processes in which particles are created at small polar angles i.e. high rapidities.
- LHC plans to have rich forward physics program:
  - ATLAS: LUCID, ZDC, ALFA, AFP
  - CMS: CASTOR, ZDC, FP420
  - TOTEM
- Highlights in forward physics which are going to be studied:
  - Total cross section and elastics scattering
  - Soft & Hard diffraction
  - Exclusive production of new mass states
  - Low-x Dynamics
  - Two-photon interactions and peripheral collisions
  - New Forward Physics phenomena

Introduction

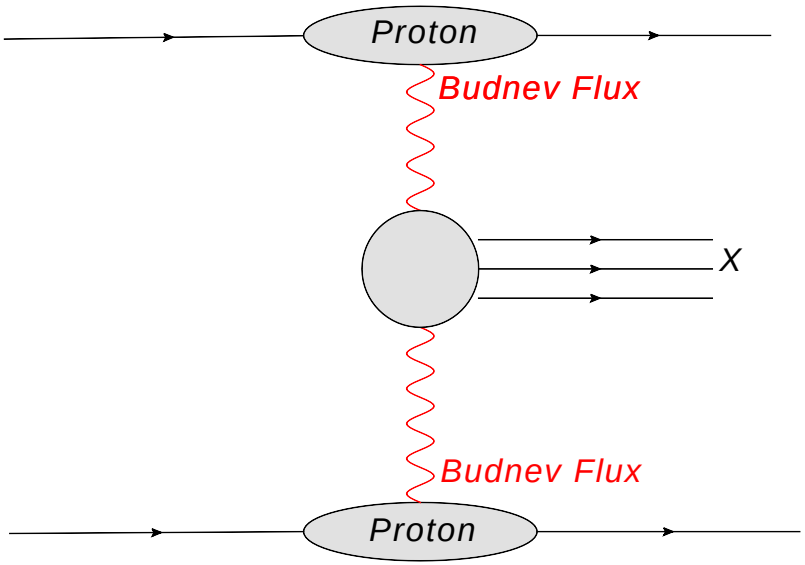
- Herwig++ has been being extended for some of the most interesting forward physics processes:
  - Two photon physics
  - Hard diffraction: Single Diffraction, Double Pomeron Exchange and Central Exclusive Production



ThePEG structure

- Herwig++ is based on thePEG framework: the Toolkit for High Energy Physics Event Generation.
- ThePEG provides all the infrastructure that does not depend on the physics models. Each HERWIG++ class inherits from ThePEG abstract class and provides specific model implementation.
- ThePEG has repository which keeps all the building blocks of the EventGenerator and connections between them (as Matrix elements, PDF functions, hadronization handlers, beam properties etc.).
- User setups all the building blocks and their properties easily together via the text inputfile.

Two photon physics



Budnev flux:

$$dN = \frac{\alpha}{\pi}\frac{dE_\gamma}{E_\gamma}\frac{dQ^2}{Q^2}\left[(1-\frac{E_{gamma}}{E})(1-\frac{Q^2}{Q^2})F_E + \frac{E_\gamma^2}{E^2}F_M\right]$$

$$F_M = G_M^2$$

$$F_E = (4m_p^2 G_E^2 + Q^2 G_M^2)/(4m_p^2 + Q^2)$$

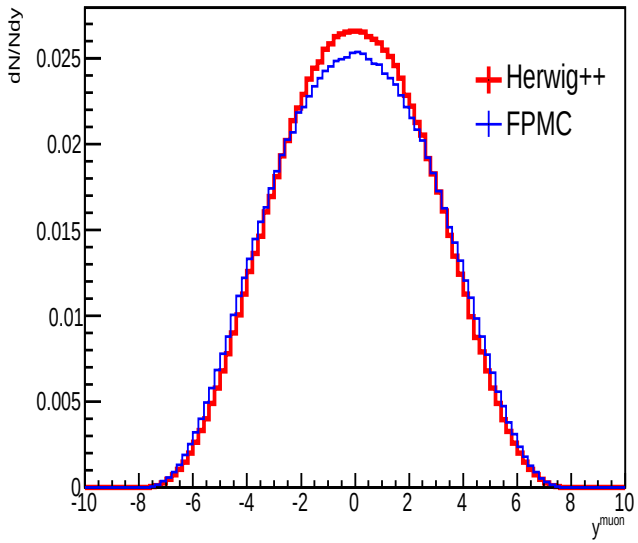
$$G_E^2 = G_M^2/\mu_p^2 = (1 + Q^2/Q_0^2)$$

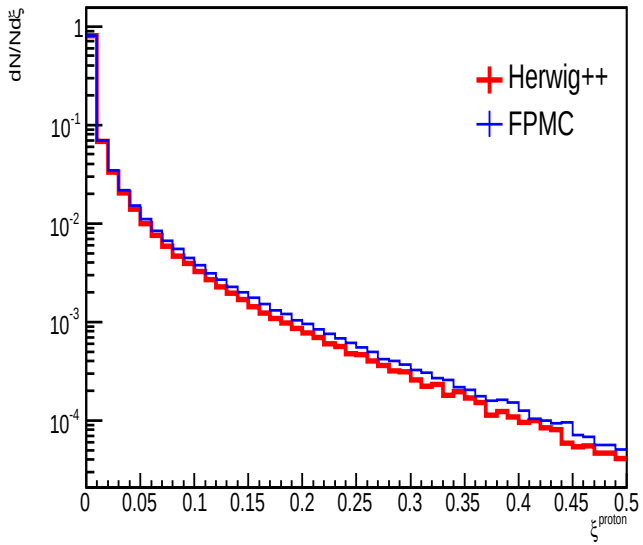
where $\mu_p^2 = 7.78$ and $Q_0^2 = 0.71$ GeV^2

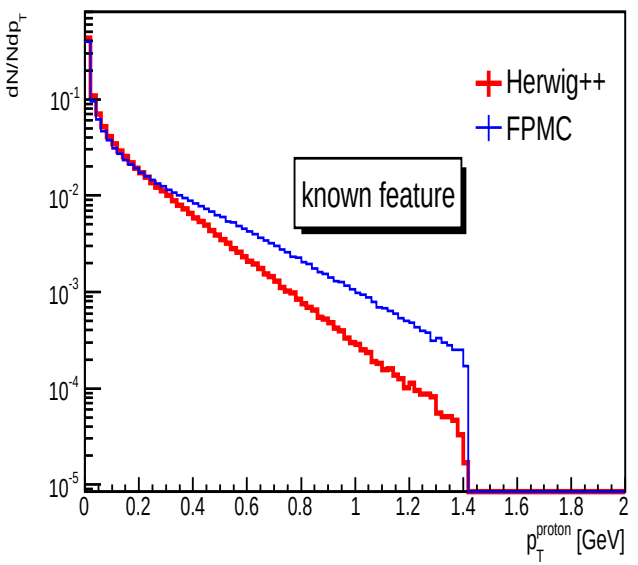
Two photon physics

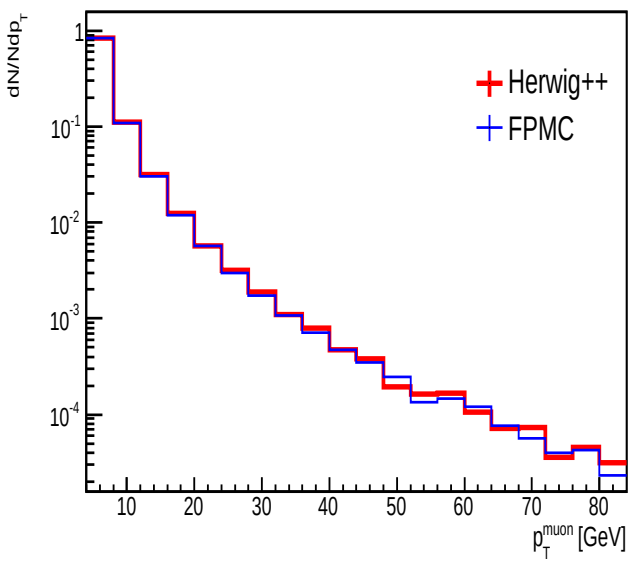
- Budnev flux implemented.
- Available SM processes: dilepton production, W boson production, dijet production
- Extension for beyond standard model processes can be easily done.
- Two photon physics validated against FPMC (Forward Physics Monte Carlo, `www.cern.ch/fpmc`, arXiv:0903.3861), see next slides.

Distributions $pp \longrightarrow p + \gamma\gamma + p \longrightarrow p + \mu\mu + p$







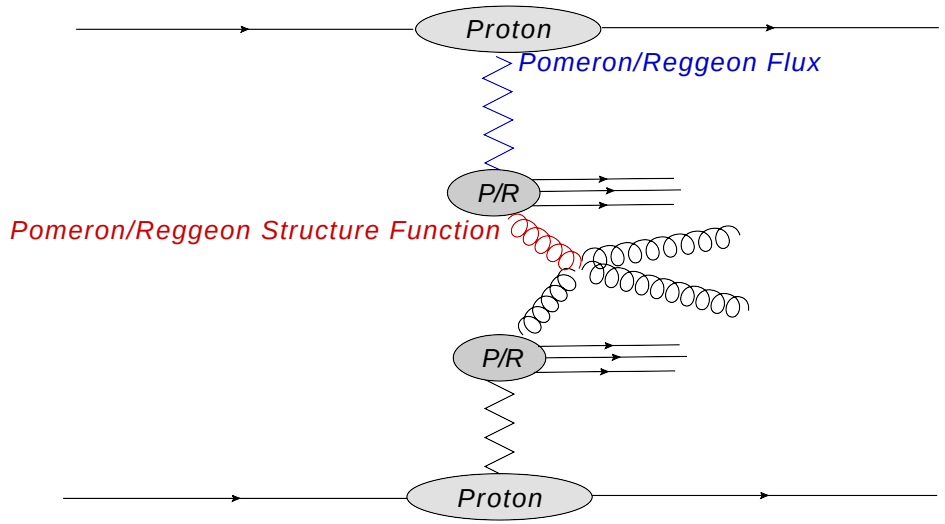


Cross Section $pp \longrightarrow p + \gamma\gamma + p \longrightarrow p + \mu\mu + p$

p_T	Herwig++	FPMC
3 GeV	47.2 pb	48.9 pb
5 GeV	13.2 pb	13.5 pb
10 GeV	2.20 pb	2.22 pb
30 GeV	1.09×10^{-2} pb	1.09×10^{-2} pb
50 GeV	2.48×10^{-3} pb	2.49×10^{-3} pb

Cross sections of dimuon production for various p_T cuts at $\sqrt{s} = 14$ TeV with $x_{min} = 0$, $x_{max} = 1$ and $Q^2 = 2$ GeV^2

Inclusive diffraction: Ingelman-Schlein model



- Cross section:

$$\sigma(PP \to PPXY) = \sum_{i,j} \iint dx_1 dx_2 f_i^D(x_1, Q_1^2) f_j^D(x_2, Q_2^2) \hat{\sigma}(x_1, Q_1^2, x_2, Q_2^2)$$

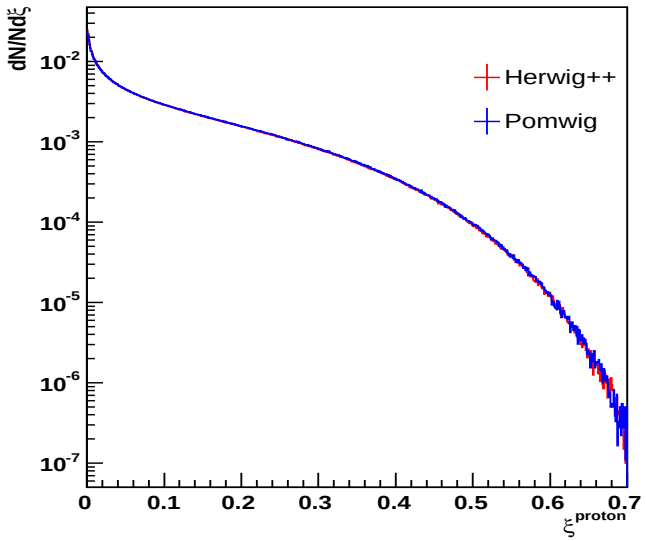
$$f_i^D(x, Q^2) = f_{\mathbb{P}}(t, x_P) f_i^{\mathbb{P}}(Q^2, x) + f_{\mathbb{R}}(t, x_R) f_i^{\mathbb{R}}(Q^2, x)$$

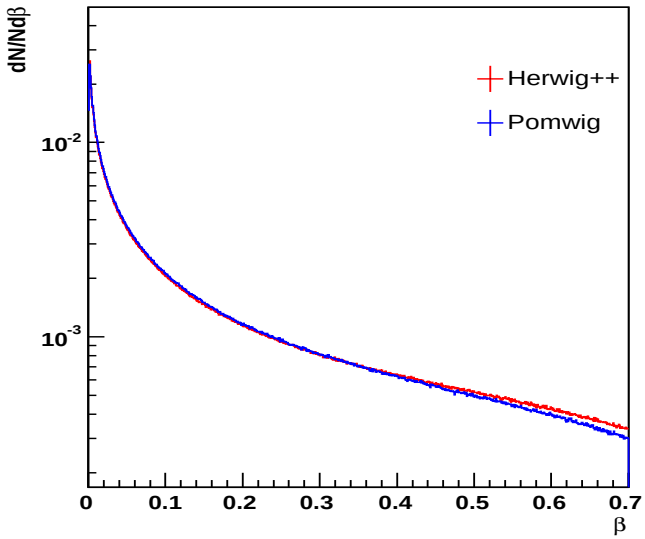
- Pomeron/Reggeon flux: $f_{\mathbb{P}}(t, x_P) = A e^{\beta_p t} / x^{2(\alpha(0) - \alpha' t) - 1}$
- Pomeron/Reggeon structure function: $f_i^{\mathbb{P}}(Q^2, x)$

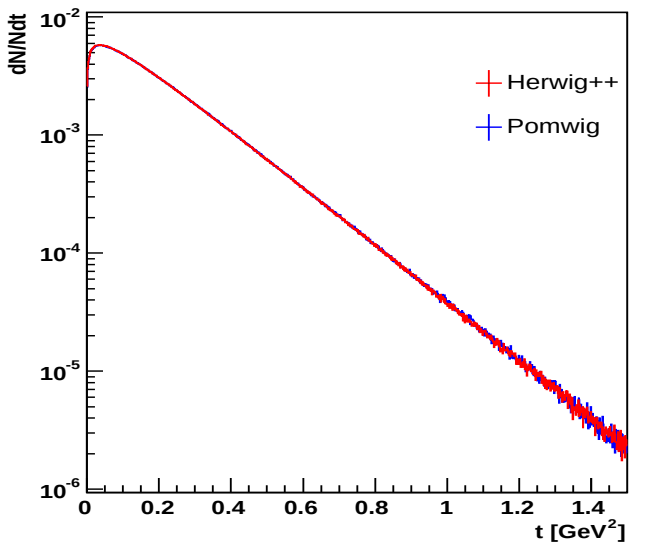
Current implementation

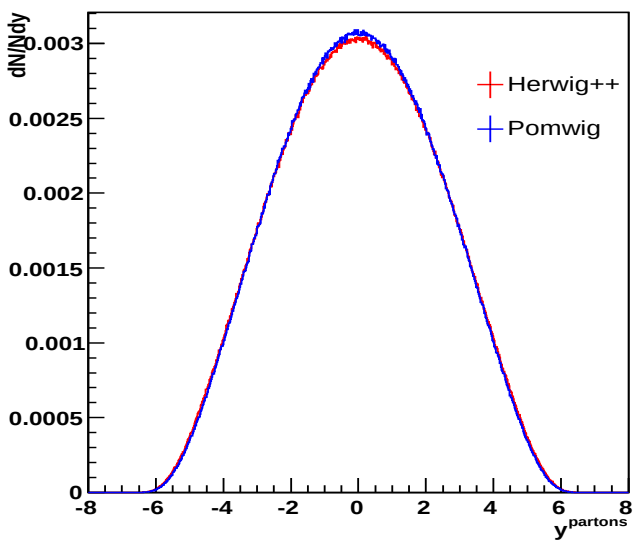
- Sum of pomeron and reggeon contributions implemented.
- Default value of pomeron and reggeon fluxes are given by the PDF fits. They can be also varied by user.
- Pomeron structure functions from HERA measurement: 2006 (fit A and fit B), 2007.
- The PDFs can be freezed or extrapolated outside of their boundaries.
- In case of reggeon, pion structure function is used.
- Pomeron composed either from the valence gluons (default option) or from $q\bar{q}$ pairs.
- Reggeon has only $q\bar{q}$ structure which is consistent with pion.
- Gap survival probability is not included.
- Comparison was done with POMWIG (the most established event generator for hard diffraction, `http://www.pomwig.com`).

Distributions $pp \longrightarrow p + dijet + p$









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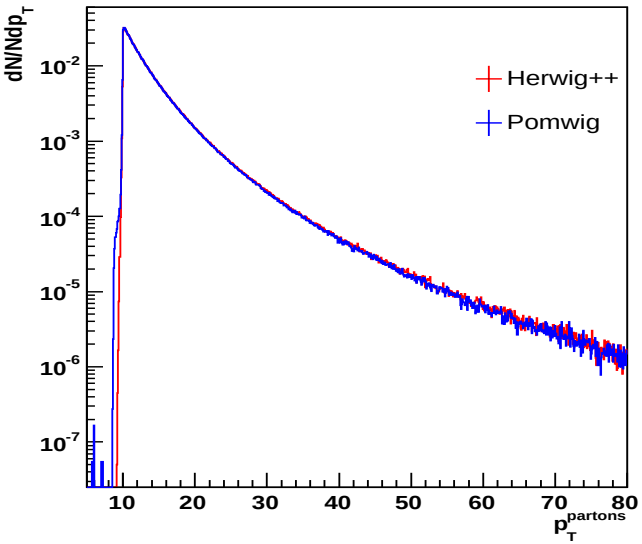

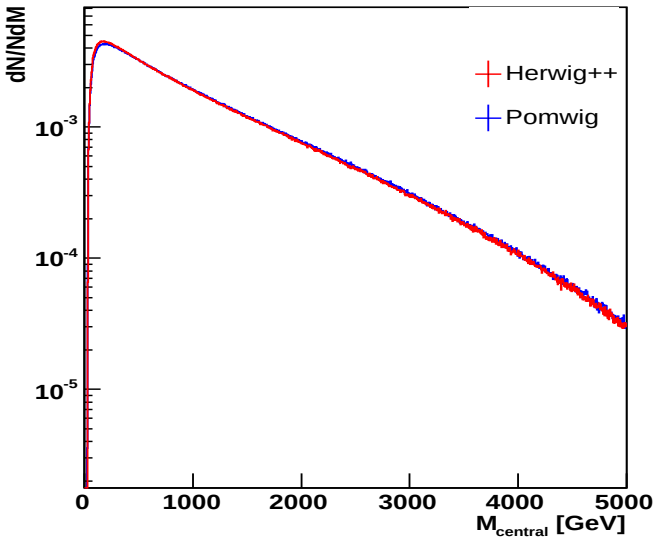

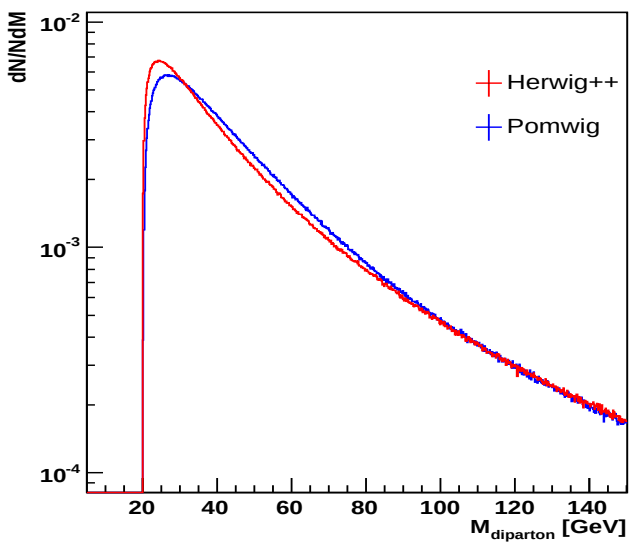

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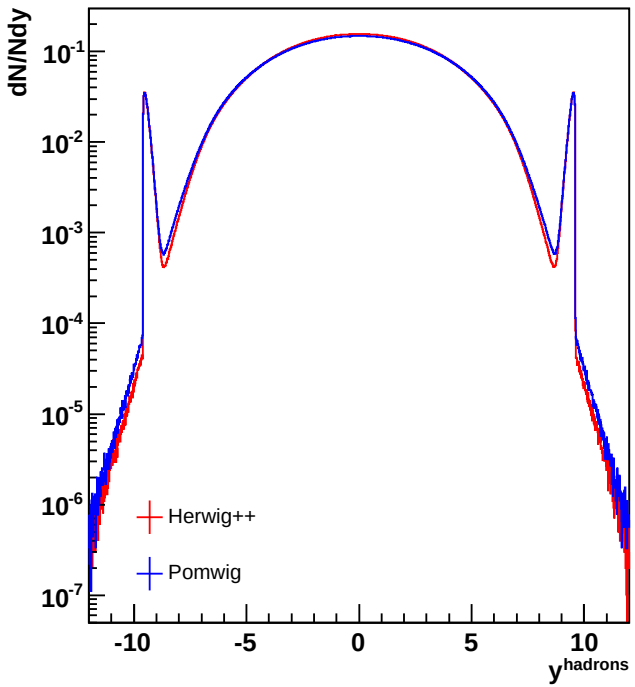
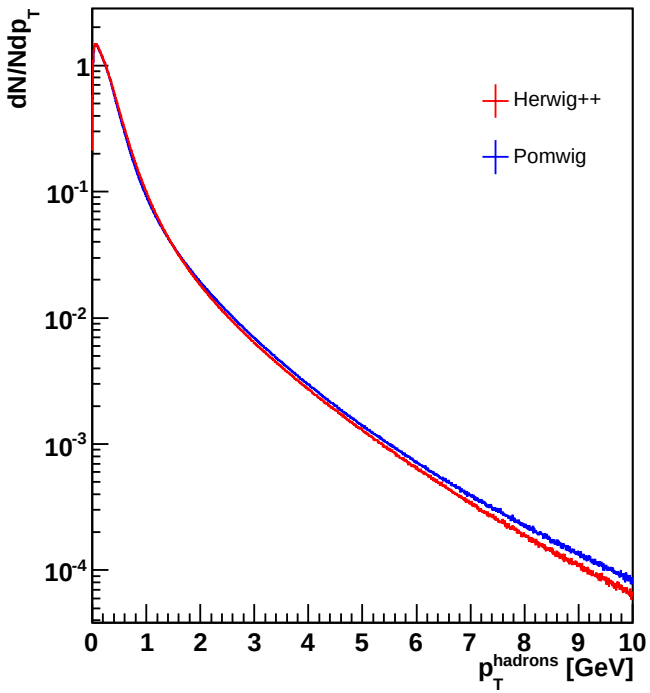




- Feature in POMWIG: proton has mass of the electron $\longrightarrow$ wrong rapidity distributions of survived protons, influence on the t distribution.

Cross Section $pp \longrightarrow p + dijet + p$

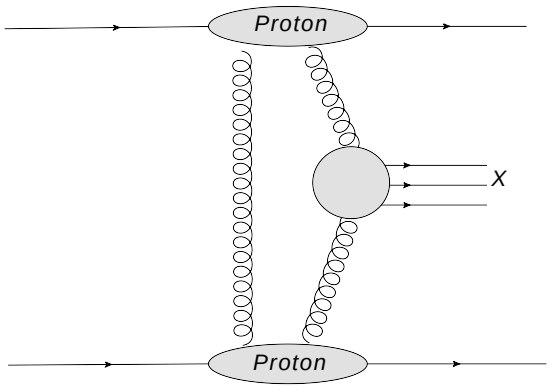
p_T	Herwig++	Pomwig
10 GeV	9.63×10^4 nb	9.56×10^4 nb
20 GeV	7.49×10^3 nb	7.49×10^3 nb
30 GeV	1.55×10^3 nb	1.54×10^3 nb
40 GeV	2.83×10^2 nb	2.81×10^2 nb

Cross sections of dijet production for various p_T cuts at $\sqrt{s} = 14$ TeV with $x_{min} = 10^{-7}$, $x_{max} = 1$ H1 2006 Fit A.

Summary

- Framework for two photon physics was implemented.
- It provides dilepton and W production.
- More processes can be added if necessary.
- Tested against FPMC.
- Following hard diffraction processes will be available in next Herwig++ release :
  - Single Diffraction: dijet production
  - Double Pomeron Exchange: dijet production, Higgs production
- Tested against POMWIG.

Outlook



- Finish validation and final tunning of the two photon physics and hard diffraction.
- Work on CEP has been started.
- KMR model will be used for CEP.
- Higgs and dijet production will be implemented first.