Hard diffraction in PYTHIA8

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- PYTHIA8
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- Conclusion and outlook
PYTHIA8 is a general purpose event generator for high-energy collisions.

It attempts to describe all parts.

[Figure: T. Sjöstrand]
And does a fairly good job for most of the physics:

Figures from MCPlots: [mcplots.cern.ch]
PYTHIA8

Currently 8 authors (incl. 3 post-docs and 2 PhD students).

New main features as of version 8.2:

• New models of colour reconnections
  (J. Christiansen, P. Skands + T. Sjöstrand)

• Variety of matching and merging schemes
  (S. Prestel + L. Lönnblad)

Ongoing work:

• New PDF for photons for $e^+e^-$ studies
  (I. Helenius + T. Sjöstrand)

• New model for hard diffraction
  (C. Rasmussen + T. Sjöstrand)

An Introduction to PYTHIA8.2

Soft diffraction

The soft diffractive PYTHIA8 machinery is based on the Ingelman-Schlein picture of a Pomeron as a hadronlike state.

\( pp \) and \( PP \) collisions are here developed to also include the interleaved parton evolution of MPI, ISR and FSR.

MPI gives a smooth merging of hard jets and soft events.
Soft diffraction

Low-mass region: $M_X \leq 10 \text{ GeV.}$

- Represent $M_X$ as longitudinal string
- Probability to take out a gluon or quark from Pomeron: $\frac{P(q)}{P(g)} = \frac{N}{M^p}$, $p$ tunable
- Quark = 1 string, gluon = 2 strings
- No ISR, FSR, MPI
- Fragment with Lund String fragmentation model

High mass region: $M_X > 10 \text{ GeV.}$

- Based on Ingelman-Schlein approach
- Set up $\mathbb{P}p$ system
- MPI machinery decide interactions
- Includes interleaved MPI, ISR, FSR evolution in $\mathbb{P}p$ system
- Now includes 7 models for Pomeron flux and 5 for Pomeron PDF
Soft diffraction

$\sigma_{SD}$ with Pomeron-based parametrisation of Schuler-Sjöstrand:

$$\frac{d^2\sigma_{SD}}{dt \, dM^2} = \frac{g_3^P}{16\pi} \beta_A^P \beta_B^P \frac{1}{M^2} \exp(B_{SD} t) F_{SD}$$

MPI activity in SD tuned to give approximately same amount as in ND:

$$\langle n_{MPI} \rangle(ND) \sim \frac{\sigma_{\text{hard}}}{\sigma_{ND}} \Rightarrow$$

$$\langle n_{MPI} \rangle(SD) \sim \frac{\sigma_{\text{hard}}(\text{No gap survival})}{\sigma_{pp}(\text{No gap survival})} = \frac{\sigma_{\text{hard}}}{\sigma_{pp}^{\text{eff}}}$$

with $\sigma_{pp}^{\text{eff}} = 10 \text{ mb}$, tunable.

Gap always survives, as MPI not allowed between Pomerons hadron-remnant and other hadronic remnant.

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Soft diffraction

$p_T$ distribution for SD events at 7 TeV. From S. Navin [arXiv:1005.3894[hep-ph]].

From MCPlots [mcplots.cern.ch]
Hard diffraction

Objective: Given a hard scattering, \( ab \rightarrow cd \), what is the probability for this to have been created in a diffractive process?

Available: Parton id, \( x \) and \( Q^2 \).

Method: Evaluate the diffractive structure function and use dynamical gap survival.

Assumption 1: The hadronic PDFs can be split into non-diffractive and diffractive.

\[
f_i(x, Q^2) = f_i^{\text{ND}}(x, Q^2) + F_i^{\text{D}}(x, Q^2)
\]

Assumption 2: The diffractive structure function factorises.

\[
F_i^{\text{D}}(x, Q^2) = \int_x^1 \frac{d\xi}{\xi} \int_{t_{\text{min}}}^{t_{\text{max}}} dt \, f_{P/p}(\xi, t) \, f_{i/P}(x/\xi, Q^2)
\]
**Hard diffraction**

Only flux is \( t \)-dependent, hence we integrate \( t \) out:

\[
f_{p/p}(\xi) = \int_{t_{\text{min}}}^{t_{\text{max}}} dt \ f_{p/p}(\xi, t)
\]

with mass-dependent limits, \( t = t(m_A^2, m_B^2, m_{A'}^2, X, m_{X(B')}) \).

![Diagram showing hard diffraction](image)

The probabilities for either sides to be diffractive are

\[
P_B = F^D(x_a, Q^2)/f_p(x_a, Q^2)
\]

\[
P_A = F^D(x_b, Q^2)/f_p(x_b, Q^2)
\]
Hard diffraction

\[ F_1^D(x, Q^2) \text{ with Schuler-Sjostrand flux, } Q^2 = 100 \text{ GeV}^2 \]

The diffractive structure function.
Hard diffraction

Dynamical gap survival:

\[ p \rightarrow X \rightarrow p' \]

SD \( ab \rightarrow X \) process with beam remnants from both proton and Pomeron.
Hard diffraction

Dynamical gap survival:

- Evaluate $f_p(x, Q^2)$ and $F^D(x, Q^2)$
- $F^D/f_p \gtrsim \text{rndm}$?
  - no $\sim 90\%$
  - yes $\sim 10\%$

- Prelim. diffractive
- Trial evolution
- nMPI $> 1$?
  - yes $\sim 8\%$
  - no $\sim 2\%$

- Non-diffractive
- Diffractive

Additional suppression factor. Can this explain discrepancies btw. HERA and Tevatron?
Diffractive dijet production at the Tevatron.

(a) The ratio SD/ND dijet events at $\sqrt{s} = 1.8$ and $\sqrt{s} = 1.96$ TeV from CDF [Phys.Rev.D86.(2012) 032009].

(b) The diffractive structure function measured at $\sqrt{s} = 1.8$ TeV from CDF [Phys.Rev.Lett.84.(2000) 5043]
Preliminary studies

$E_{T}^{*} = \frac{(E_{T}^{\text{MinBias}} + E_{T}^{\text{MPI-unchecked SD}})}{2}$

$\eta^{*} = \frac{(\eta^{\text{MinBias}} + \eta^{\text{MPI-checked SD}})}{2}$

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Preliminary studies

Events too hard ⇒ ratio not steep enough.
We need to suppress hardest events.

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Preliminary studies

**Solutions:** New Pomeron fluxes and/or PDFs.

**Test:** Suppress Pomeron PDFs.

Suppression with $(1 - x)^p$  
Suppression with $x^{-p}$
Preliminary studies

<table>
<thead>
<tr>
<th></th>
<th>$p\bar{p} \to \text{Gap} + W$</th>
<th>$p\bar{p} \to \text{Gap} + Z$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>D0</strong></td>
<td>$(0.89^{+0.19}_{-0.17})%$</td>
<td>$(1.44^{+0.61}_{-0.52})%$</td>
</tr>
<tr>
<td><strong>CDF</strong></td>
<td>$p\bar{p} \to \bar{p}' + W$</td>
<td>$p\bar{p} \to \bar{p}' + Z$</td>
</tr>
<tr>
<td></td>
<td>$(1.0\pm0.11)%$</td>
<td>$(0.88\pm0.22)%$</td>
</tr>
<tr>
<td><strong>PYTHIA8 MPI-checked</strong></td>
<td>$p\bar{p} \to \bar{p}' + W$</td>
<td>$p\bar{p} \to \bar{p}' + Z$</td>
</tr>
<tr>
<td></td>
<td>$\sim 1.7%$</td>
<td>$\sim 2%$</td>
</tr>
</tbody>
</table>

Fractions are too large.

Conclusion

• We have developed a new model for hard diffraction with dynamical gap survival
• Model is implemented in PYTHIA8, publicly available (but still being tested)
• Model gives a factor $\sim 2$ larger fractions for diffractive W/Z than observed
• Kinematical distributions disagree with CDF data - we obtain too hard events
• Development of new Pomeron flux and/or PDF might solve the problems. On to-do list for Autumn
• LHC studies on to-do list. Comparison to eg. CMS feasibility studies [CMS PAS DIF-07-002].