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# Rapidity Gaps and Multiple Interactions

- Introduction
- Gaps vs. Multiple Interactions
- Available Generators
- How to Generate Gaps
- Conclusions

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**2001.04.20**
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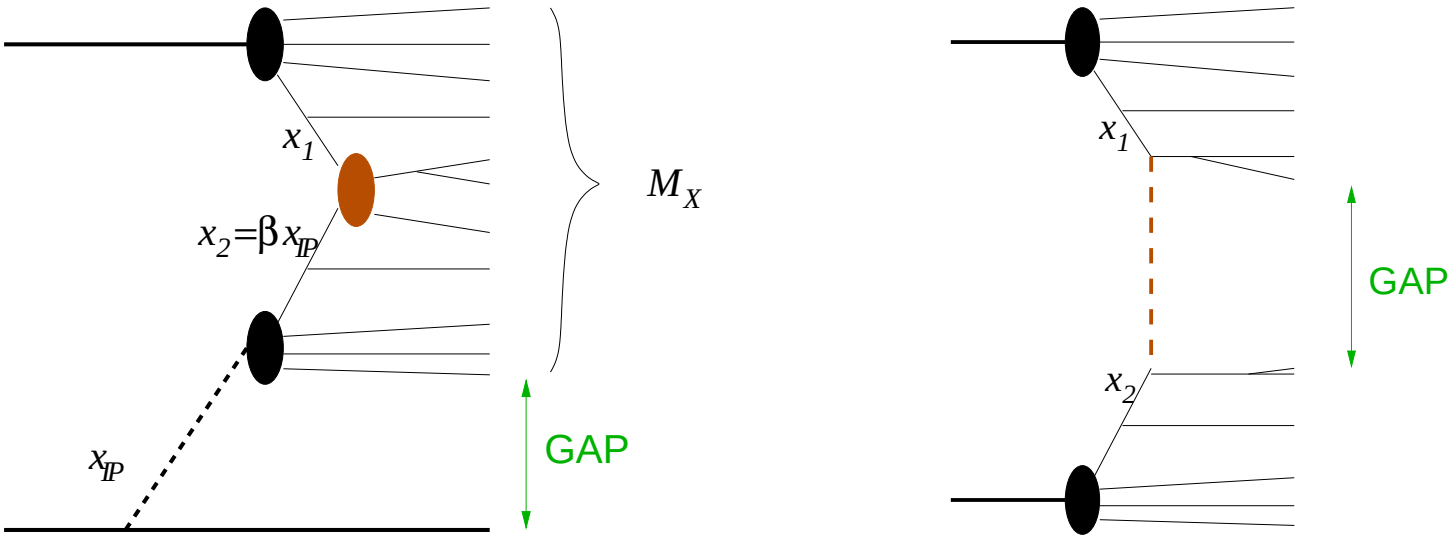
- The pomeron is intimately connected with small-$x$ evolution.
- The pomeron is intimately connected to multiple interactions.
- The interplay between the hard and soft pomeron may give insight into the interplay between perturbative and non-perturbative QCD.
- ...

# Gaps everywhere




Single Diffraction, Double Diffraction, Gaps between jets.

Identified by rapidity gaps or by detecting the diffracted proton.

# Hera vs. Tevatron

H1/ZEUS have measured $F_2^{D3}$.

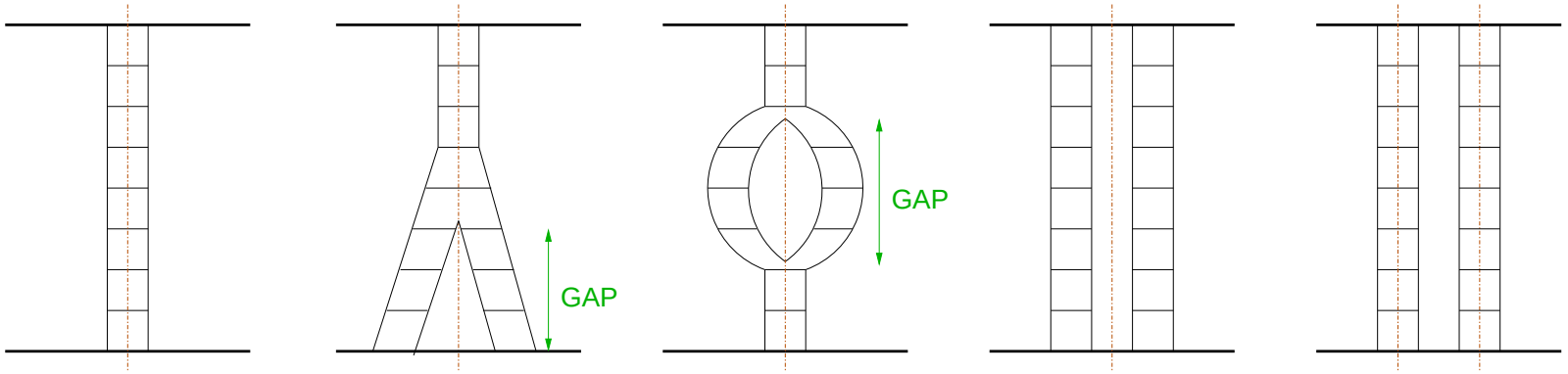
Assuming factorization we can extract a pomeron flux and parton densities of the pomeron.

Taking this pomeron to predict diffraction at the Tevatron fails. The gap fractions are overestimated by orders of magnitude.

If there is a pomeron it does not factorize in $\mathrm{p\bar{p}}$.

But we can try to find an approximate factorization by introducing a gap survival probability.

# Gaps vs. Multiple Interactions

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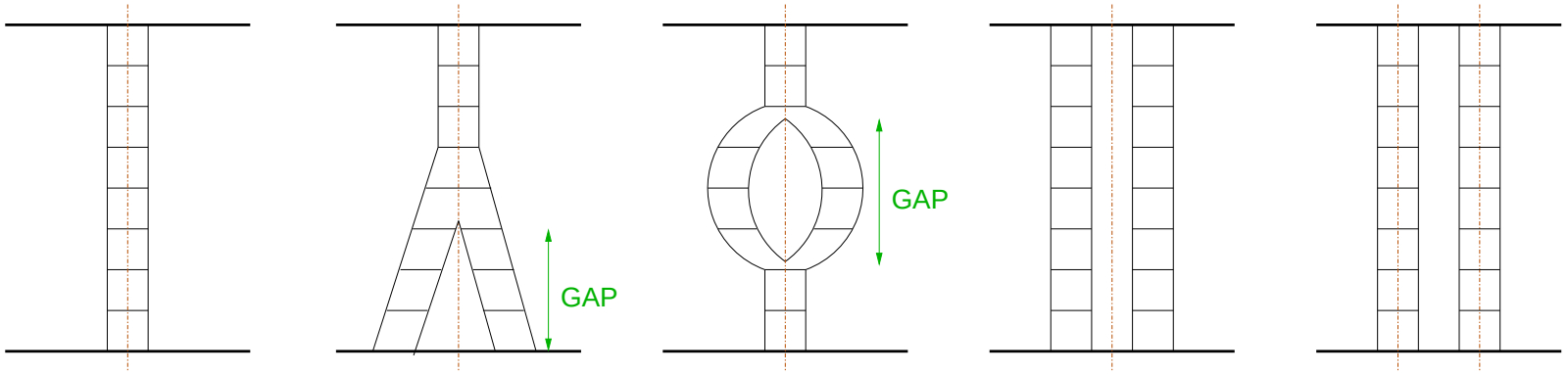
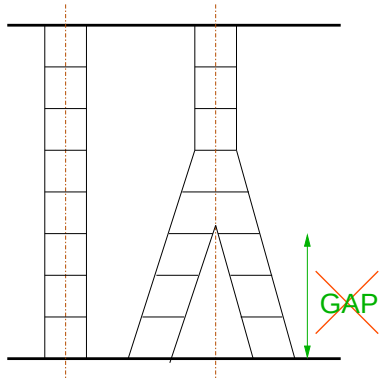



Diffraction and multiple interactions are intimately related

Any additional scattering will destroy a produced gap.



This also means that triggering on a rapidity gap is a veto against multiple interactions.

Since multiple interactions contribute to the underlying event, the jet energies must be corrected differently in gap events as compared to standard events.

The difference is small ($\sim 1$GeV), but on a steeply falling $E_\perp$ spectrum it can make a noticeable difference in the gap fractions.

It is important to use event generators to estimate the effects of multiple interactions, hadronization etc.

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- HERWIG
- POMWIG
- PYTHIA
- POMPYT
- SCI/GAL
- ARIADNE

# HERWIG

(Marchesini, Webber, . . . )

hepwww.rl.ac.uk/theory/seymour/herwig/

Includes high-$t$ diffraction with hard BFKL pomeron exchange.

Has soft underlying events, but ordinary multiple interactions can be included with JIMMY (Butterworth, Forshaw, Seymour, Walker), www.hep.ucl.ac.uk/JetWeb/JIMMY/.

No rapidity gaps from soft pomerons (although created lots of rapidity gaps due to strange remnant treatment.)

# POMWIG

(Cox, Forshaw, www.hep.man.ac.uk/∼coxb/pomwig)

Add-on to HERWIG to include single and double diffraction using a factorized pomeron model.

Implements H1 pomeron parton densities.

Possible to use pomeron flux with scale-dependent intercept.

Also includes Reggeons

Does not work with JIMMY (yet).

# Pythia

(Sjöstrand, www.thep.lu.se/∼torbjorn/Pythia.html)

Does not include (hard) diffraction.

But has an advanced multiple-interactions mechanism which can be used to estimate gap survival probabilities (and other corrections) by looking at other colour singlet (photon) exchange interactions.

Should be easy (?) to modify the photo-production mechanism to use pomerons instead.

# POMPYT

(Bruni, Edin, Ingelman, www3.tsl.uu.se/thep/pompyt/)

Uses PYTHIA (unfortunately version 5) to generate pomeron–hadron collisions, using a factorized pomeron model.

Several pomeron (and Reggeon) parton densities and fluxes are implemented.

Includes (old) multiple interactions of PYTHIA, but only between the colliding pomeron and proton – not between proton and anti-proton.

# Soft Colour Interactions

(Edin, Rathsman, Ingelman, www3.tsl.uu.se/thep/MC/scigal/)

Add-on to PYTHIA which allows for colour reconnections after the parton-shower stage according to the Soft Colour Interaction model and/or the so-called Generalized Area Law.

Can be run with Multiple Interactions in PYTHIA.

Despite the very simple model, it can describe rapidity gaps both at HERA and Tevatron, as well as e.g. high-$p_\perp$ charmonium production at the Tevatron.

# Ariadne

(yours truly, www.thep.lu.se/∼leif/ariadne)

Pomeron inspired model using the ratio between diffractive and total parton densities to trigger a special remnant treatment giving rapidity gaps (possibly on both sides).

Difficult to implement pomeron parton densities and fluxes. Has not been tuned.

Can be used to estimate hadronization corrections etc.

# How to generate Gaps

Since there are no complete generators this is far from straight forward. We have to combine the abilities of several generators and patch things together.

Two case studies:

- Diffractive W-production
- Gaps between jets

# Diffractive W-production

Also diffractive anything production

The non-diffractive reference sample is easy – just use PYTHIA or HERWIG.

For the diffractive signal, use POMPYT or POMWIG.

For diffractive jets, switch on multiple interactions, but remember that the $p\mathbb{P}$ collisions are at lower energies, so there are less MI's.

To estimate the gap survival probability use e.g. PYTHIA with MI to obtain the probability of having no additional scatterings between the $p$ and $\bar{p}$ (almost any process will do since almost any additional scattering will destroy the gap)

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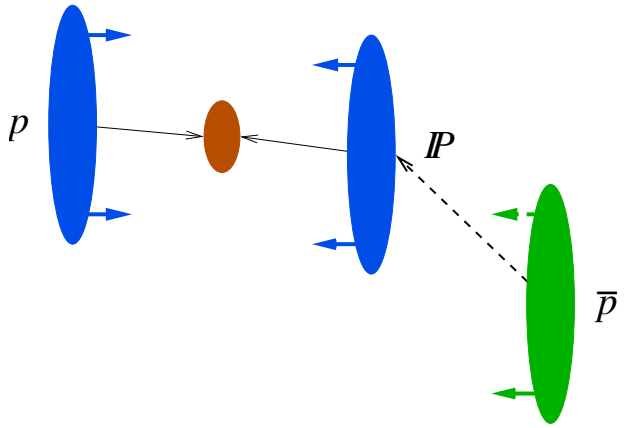
- A diffractive $p\bar{p}$ collision may be more peripheral than a non-diffractive one...

In the default MI model of PYTHIA, the probability of additional scatterings depends on the transverse overlap of the colliding hadrons.

Large scale sub-processes gives large overlap and a large probability of additional scatterings. Smaller scales corresponds to less overlap and less MI's.




For W-production, the relevant scale is $m_W^2$. But that is for the overlap between the $p$ and $I\!P$ and additional scatterings there will not destroy the gap.

The overlap between the $p$ and $\bar{p}$ may be governed by the momentum transfer in the pomeron which is small $t < 1$ GeV$^2$.

Using POMWIG to generate diffractive W's with the H1 pomeron and Reggeon parton densities and a large pomeron intercept.

Using PYTHIA MI's for small scale photon exchange, the gap survival can be as high as 60%

We[†] get a diffractive to non-diffractive ratio for the Tevatron at 1.67% to be compared to the CDF value of $1.15 \pm 0.55\%$

[†] Cox, Forshaw, Lönnblad, hep-ph/0012310

# Gaps between Jets

BFKL-pomeron exchange is so far only implemented in HERWIG. It does not, however, work well with JIMMY, but that's OK since MI's are vetoed by the gap requirement.

In the ratio to non-diffractive events, the denominator is normal di-jet events (with MI's). Except that there is a large rapidity difference between the jets and there are no generators available which can generate such evolution.

Using HERWIG to generate BFKL-pomeron exchange using a fixed $\alpha_s$ in the pre-factors ($\alpha_s^4$) ($I\!P$–gluon vertices are not normal vertices)

Using PYTHIA with MI's to estimate jet corrections and gap survival (hard photon exchange gives $\approx$20%)

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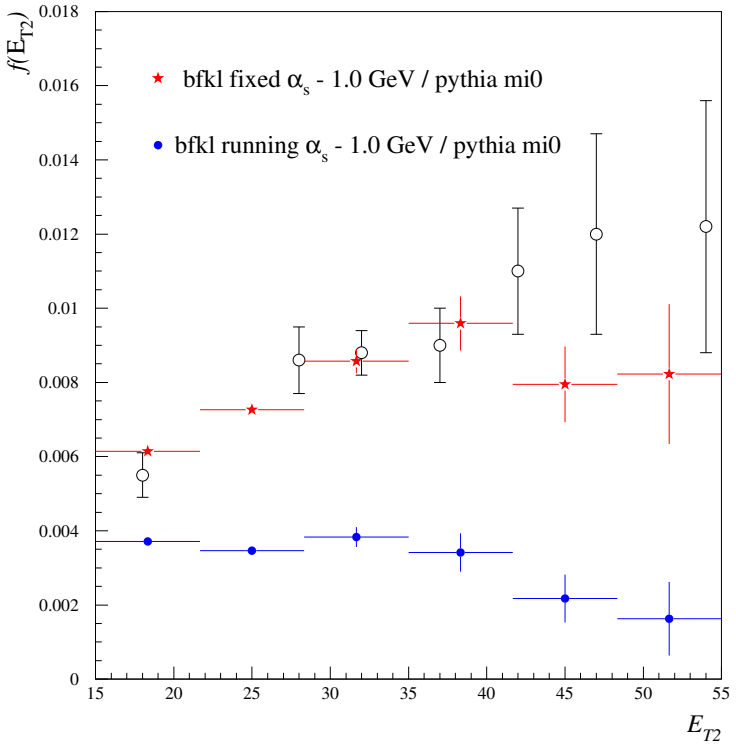
Cox, Forshaw, Lönnblad, JHEP 10(1999) 023



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- There is no single-generator solution for simulating rapidity gap events.
- Be careful when using pomeron PDF's – they have to match the flux for which they have been extracted.
- Reggeon exchange need not be negligible.
- Rapidity gaps and gap survival is connected with multiple interactions – we need to understand multiple interactions better.