Improved Parton Showers at Large Transverse Momenta

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Overview

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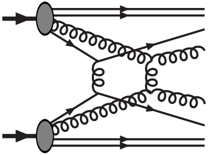
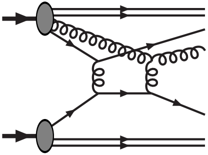
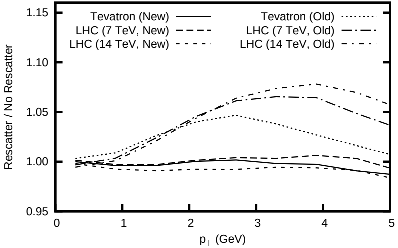
Rescattering

- R. Corke and T. Sjöstrand, “Multiparton Interactions and Rescattering,” arXiv:0911.1909 [hep-ph], to appear in JHEP.
- Already scattered partons allowed to scatter again as part of interleaved MPI framework





- No “smoking-gun” signatures, but evidence of some effects



Matching with POWHEG

- POWHEG (Nason et al.) generates hardest emission ($p_\perp$) with a Sudakov

$$\mathrm{d}\sigma = \bar{B}(v) d\Phi_v \left[\frac{R(v,r)}{B(v)} \exp\left(- \int_{p_\perp} \frac{R(v,r)}{B(v)} \right) d\Phi_r \right]$$

- PYTHIA shower variable inspired by lightcone kinematics

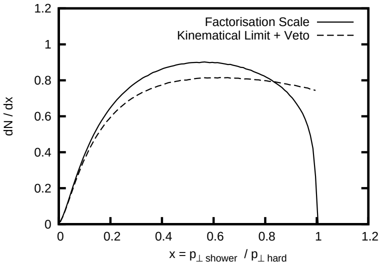
$$\text{ISR:} \quad p^2_{\perp\mathrm{evol}} = (1-z)Q^2 \quad > \quad (1-z)Q^2 - \frac{Q^4}{m^2_{ar}} = p^2_\perp$$

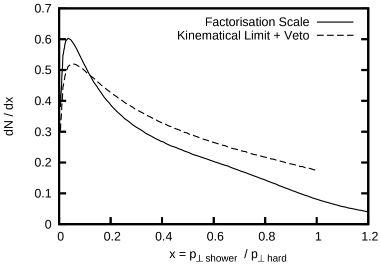
- $p_\perp$ relative to the emitting parton
- What scale to begin the shower?
  - ISR: $p_{\perp\mathrm{max}} = k * p_{\perp\mathrm{fac}}$ (but $p_\perp < p_{\perp\mathrm{evol}}$)
  - FSR: $p_{\perp\mathrm{max}} = k * p_{\perp\mathrm{fac}}$ (but $p_\perp$ relative to outgoing parton)
  - Alternative: start showers at high $p_{\perp\mathrm{evol}}$ and veto emissions above kinematic POWHEG scale
  - Even after a shower emission beneath the POWHEG scale, small chance that a subsequent emission may again be harder
- Start with top pair production
- Bottom pair production to come; any further issues?

Matching with POWHEG

Top Pair Production

- Study the kinematic $p_\perp$ ratio of the first shower emission to POWHEG emission
- Ratios stay below unity for ISR, but some area of phase space not covered
- Ratios greater than unity for FSR due to different frame

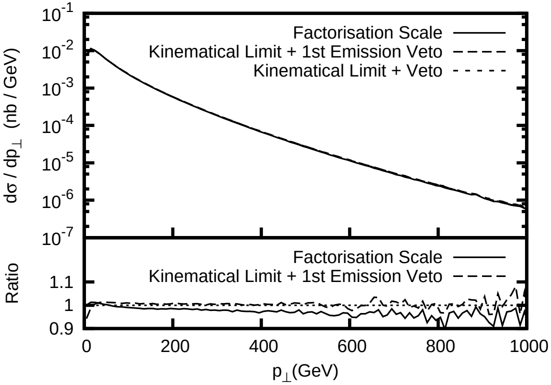




Matching with POWHEG

Top Pair Production

- Veto only first emission or all emissions?
- Use final $p_\perp$ of top pair to gauge size of effects
- Less than 10% difference between factorisation scale and veto scheme
- Almost no difference when vetoing subsequent emissions



Parton Showers at Large Transverse Momenta

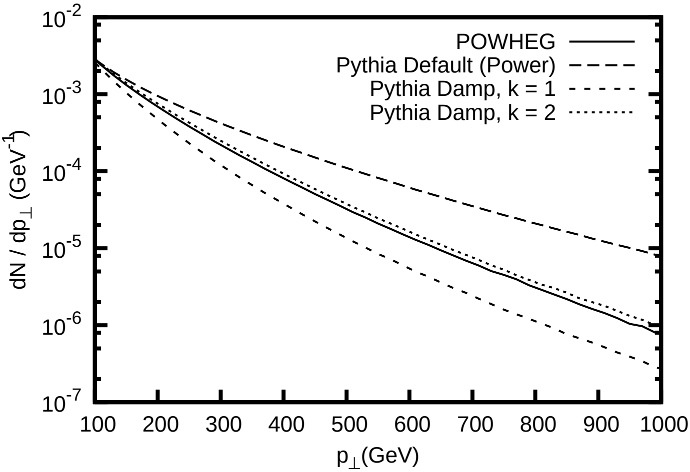
- Aim to provide good default behaviour for any process, even when higher order corrections not available
- Top pair production
  - Large top mass; neglect FSR
  - Power shower ($p^2_{\perp\mathrm{max}} = s$) overestimates high-$p_\perp$ tail
  - Wimpy shower ($p^2_{\perp\mathrm{max}} = M^2$) underestimates high-$p_\perp$ tail
- Something in between? Consider $\mathrm{gg} \to \mathrm{t\bar{t}g}$
  - Small $p_{\perp\mathrm{g}}$: approximate as $\mathrm{g} \to \mathrm{gg} + \mathrm{gg} \to \mathrm{t\bar{t}} \implies \frac{\mathrm{d}p^2_{\perp\mathrm{g}}}{p^2_{\perp\mathrm{g}}}$ falloff
  - Large $p_{\perp\mathrm{g}}$: approximate as $\mathrm{g} \to \mathrm{t\bar{t}} + \mathrm{gt} \to \mathrm{gt} \implies \frac{\mathrm{d}p^2_{\perp\mathrm{g}}}{p^4_{\perp\mathrm{g}}}$ falloff
- Ansatz for damping the high-$p_\perp$ shower tail

$$\frac{\mathrm{d}\mathcal{P}_{\mathrm{ISR}}}{\mathrm{d}p^2_\perp} \propto \frac{1}{p^2_\perp} \frac{kM^2}{kM^2 + p^2_\perp}$$

- Expect this to be valid for production of coloured final states
  - Coherence between initial and final state

Parton Showers at Large Transverse Momenta

- Compare damped PYTHIA against POWHEG



Parton Showers at Large Transverse Momenta

- For top pairs, can compare against "correct" answer
- For other processes, use MadEvent to get a rough idea of corrections
- Generate probability of emissions as

$$\frac{\mathrm{d}\sigma_R}{\sigma_0} \exp\left(-\int \frac{\mathrm{d}\sigma_R}{\sigma_0}\right)$$

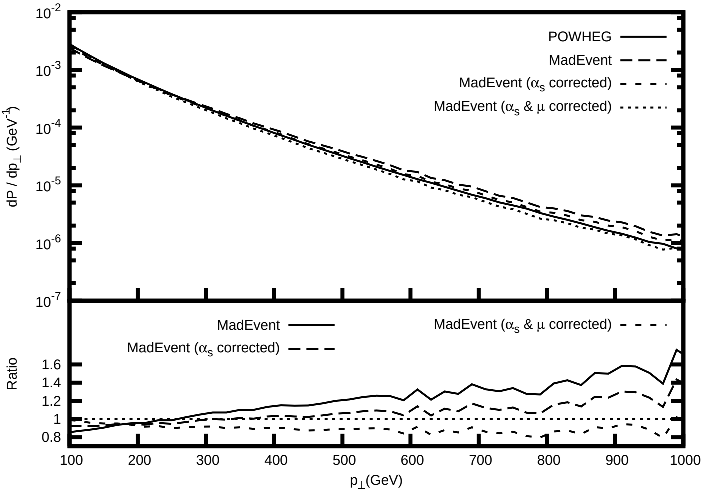
- No NLO prefactor, but assuming differences are small, qualitative comparisons can be made
- Corrections for renormalisation/factorisation scales

$$\frac{\alpha_s(p_\perp^2)}{\alpha_s(M^2)} \qquad \frac{x_1 f_1(x_1, p_\perp^2) * x_2 f_2(x_2, p_\perp^2)}{x_1 f_1(x_1, M^2) * x_2 f_2(x_2, M^2)}$$

- Test with top pairs
- No damping for W/Z pair production required
- MSSM squark/gluino production as a further check

Parton Showers at Large Transverse Momenta

- Compare approximate MadEvent prescription against POWHEG



Conclusions

- Slight mismatch in POWHEG and PYTHIA scales
- Little difference in top pair production

- Study a damping of the high-$p_\perp$ tail of the PYTHIA shower
- Good agreement for top pairs
- MadEvent + approximate Sudakov prescription for further checks

- Work in progress

PYTHIA 8 Status

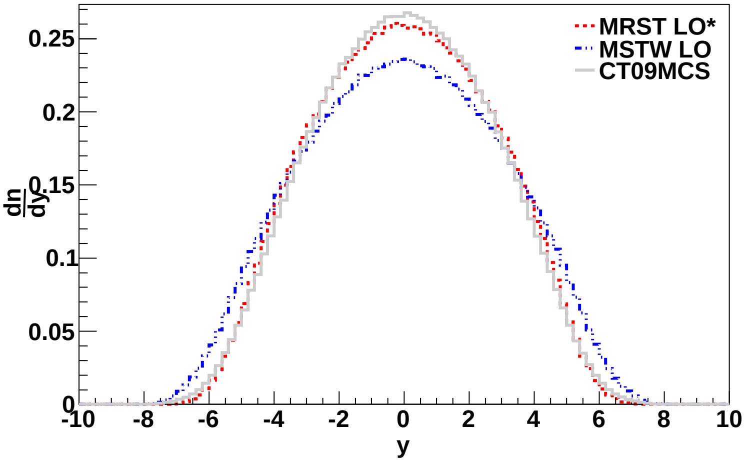
- PYTHIA 8.135 now released
- Full update history within package

- Rescattering option now available
- Possibility to veto individual ISR/FSR emissions

- Static member methods eliminated (Settings, ParticleData and Rndm)
- Only interface to LHAPDF remains static (Fortran interface)

- 10 new proton PDF sets (with Tomas Kasemets)
  - MRST LO* (2007)
  - MRST LO** (2008)
  - MSTW 2008 LO (central member)
  - MSTW 2008 NLO (central member)
  - CTEQ6L
  - CTEQ6L1
  - CTEQ6.6 (NLO, central member)
  - CT09MC1
  - CT09MC2
  - CT09MCS

- Testing and comparisions of different PDF sets underway

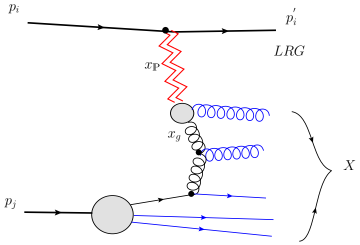


PYTHIA 8 Status

Diffraction

- New framework for high-mass diffractive events (with Sparsh Navin)
- Follows the approach of Pompyt (P. Bruni, A. Edin and G. Ingelman)
- Total diffractive cross sections parameterised as before
- Introduce pomeron flux $f_{\mathbb{P}/p}(x_{\mathbb{P}}, t)$

$$x_{\mathbb{P}} = \frac{E_{\mathbb{P}}}{E_p}, \quad t = (p_i - p_i^{'})^2, \quad M_X^2 = x_{\mathbb{P}} s$$



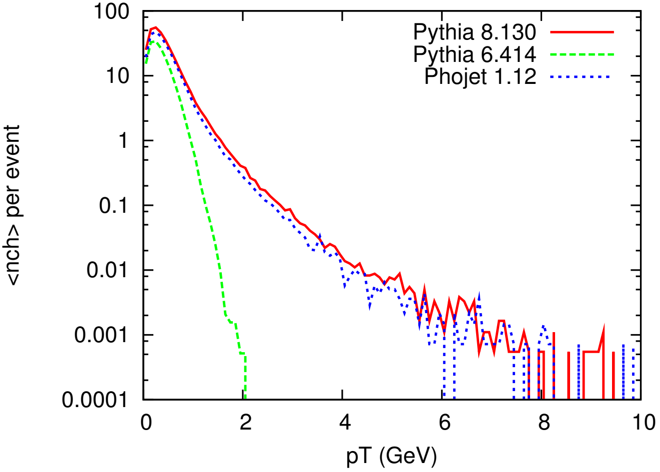
- Factorise proton-pomeron hard scattering

$$f_{p_1/p}(x_1, Q^2)\, f_{p_2/\mathbb{P}}(x_2, Q^2)\, \frac{\mathrm{d}\hat{\sigma}}{\mathrm{d}\hat{t}}$$

- Existing PYTHIA machinery used to simulate interaction
- Initialise MPI framework for a set of different diffractive mass values; interpolate in between

- $M_X \leq 10\,\mathrm{GeV}$: original longitudinal string description used
- $M_X > 10\,\mathrm{GeV}$: new perturbative description used
- Four parameterisations of the pomeron flux available
- Five choices for pomeron PDFs
  - Q^2-independent parameterisations, $x_{\mathbb{P}}\, f(x_{\mathbb{P}}) = N\, x_{\mathbb{P}}^{a}\, (1 - x_{\mathbb{P}})^{b}$
  - Pion PDF (one built in, others through LHAPDF)
  - H1 NLO fits: 2006 Fit A, 2006 Fit B and 2007 Jets
- Single and double diffraction included
- Central diffraction a future possibility
- Still to be tuned

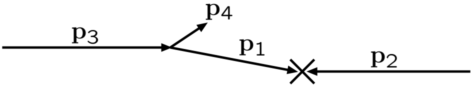
- Comparisons to PYTHIA 6 and PHOJET have been made e.g. $p_\perp$ distribution of single diffractive events



Backup

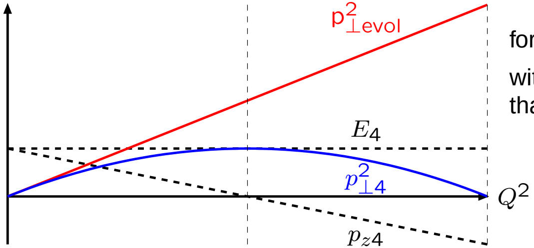
Transverse momentum definition(s)

Study kinematics of $3 \to 1 + 4$ in rest frame of $3 + 2$:



$$(p_1 + p_2)^2 = \widehat{s}$$
$$(p_3 + p_2)^2 = \frac{\widehat{s}}{z} = \widehat{s}'$$

$$p_{3,2} = \frac{\sqrt{\widehat{s}'}}{2}(1; 0, 0, \pm 1)$$
$$p_4 = \left(\frac{\sqrt{\widehat{s}'}}{2}(1-z); \sqrt{(1-z)Q^2 - \frac{Q^4}{\widehat{s}'}}, 0, \frac{\sqrt{\widehat{s}'}}{2}\left(1 - z - \frac{2Q^2}{\widehat{s}'}\right) \right)$$



for fixed $\widehat{s}$ and $z = 1/2$,

with units such that $E_4 = 1$