Matching Matrix Elements and Interleaved Showers

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Outline

- Introduction
- Example: 1 jet above a scale ρ_c.
- Multiple interactions and matrix element merging.
- Phase space constraints and merging.
- Other uncertainties and conclusions.

Introduction

Problem: When describing soft/collinear and hard jets together, virtues of both fixed order and resummation are needed, since

- ME accurate to fixed order far away from phase space boundaries, but breaks down e.g. in infrared region.
- PS constructed to work in collinear region, with some improvements for soft gluon resummation.

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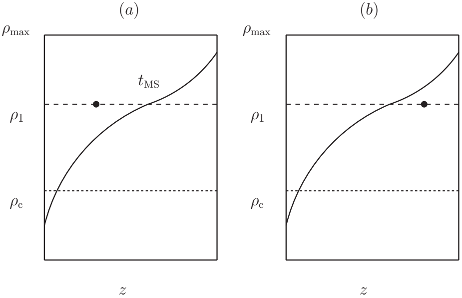
- This introduces another problem: Cut dependence.
  → Use identical normalisation for +1 jet and +0 jet ME, and add samples.
- This means reweighting the matrix element with α_s factors (for running α_s in the PS), PDF ratios (for backward evolution) and no-emission probabilities (no emissions above the scale of the first emission).

One jet above ρ_c

(ρ: evolution p_T

z: Auxiliary variables

t_{ms}: Merging scale)



Take (a) from +1 jet matrix element $|\mathcal{M}_{S_{+1}}|^2$. Reweight with the PS weight, i.e. pick this state with weight

$$\left[x_1 f_1(x_1,\mu_1)\alpha_s(\mu_R)\,|\mathcal{M}_{S_{+1}}|^2\right] d\Phi_1^{\mathrm{ME}} \times w_{Path} \times \frac{x_0 f_0(x_0,\rho_0)}{x_1 f_1(x_1,\mu_1)}$$

$$\times \quad \frac{\alpha_s(\rho_1)}{\alpha_s(\mu_R)} \frac{x_1 f_1(x_1,\rho_1)}{x_0 f_0(x_0,\rho_1)} \Pi_{S_{+0}}(x_0,\rho_0,\rho_1)\Pi_{S_{+1}}(x_1,\rho_1,\rho_c)$$

Take (b) from +0 jet matrix element $|\mathcal{M}_{S_{+0}}|^2$, with one shower splitting, i.e. with weight

$$\left[x_0 f_0(x_0,\mu_0)\,|\mathcal{M}_{S_{+0}}|^2\right] d\Phi_0^{\mathrm{ME}} \times \frac{x_0 f_0(x_0,\rho_0)}{x_0 f_0(x_0,\mu_0)}$$

$$\times \quad \alpha_s(\rho_1)\frac{x_1 f_1(x_1,\rho_1)}{x_0 f_0(x_0,\rho_1)} P\left(\frac{x_0}{x_1}\right) d\Phi_1^{\mathrm{PS}} \Pi_{S_{+0}}(x_0,\rho_0,\rho_1)\Pi_{S_{+1}}(x_1,\rho_1,\rho_c)$$

Recap: Lessons from one jet above ρ_c

The dependence on the cut t_{MS} vanishes if

$$\left|\mathcal{M}_{S_{+1,me}}\right|^2 d\Phi_1^{\mathrm{ME}} w_{Path} = \left|\mathcal{M}_{S_{+0,me}}\right|^2 d\Phi_0^{\mathrm{ME}} P\left(\frac{x_0}{x_1}\right) d\Phi_1^{\mathrm{PS}} \quad (1)$$

and

$$\begin{aligned} & \Pi_{S_{+0,rec}}(x_0,\rho_0,\rho_1)\Pi_{S_{+1,me}}(x_1,\rho_1,\rho_c) \\ = \quad & \Pi_{S_{+0,me}}(x_0,\rho_0,\rho_1)\Pi_{S_{+1,ps}}(x_1,\rho_1,\rho_c) \end{aligned} \quad (2)$$

For (1), make the PS splitting kernels and the PS phase space resemble the ME as closely as possible.
For (2)

- Get state S_{+0} as correct as possible by using (inverted) PS momentum mapping.
- Use shower to produce no-emission probabilities $\Pi_{S_{+i,rec}} = \Pi_{S_{+i,me}} = \Pi_{S_{+i,ps}} = \Pi_{S_{+i}}$.

Validation

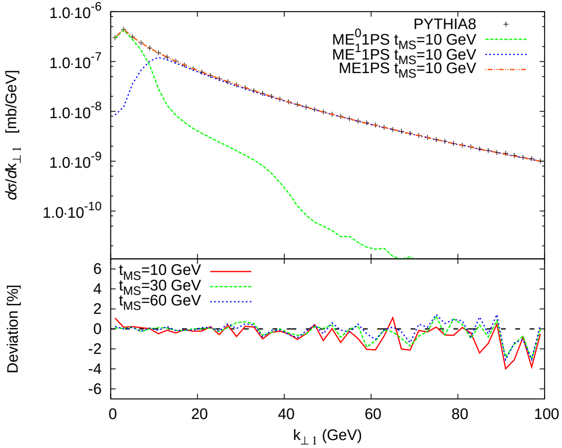


Figure: Transverse momentum of the first jet in W + 1 jet in pp collisions at $E_{CM} = 7000$ GeV, for different merging scale values. Jet defined with $k_\perp$ algorithm as implemented in `fastjet` with $D = 0.4$. Lower inset shows the ratio to default, ME-corrected PYTHIA8.

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MPI in PYTHIA8

In PYTHIA, MPI are interleaved with spacelike showers.
MPI are 2→2 QCD splittings, which are then showered. At low scales, the splittings are regularised by

$$\frac{d\sigma}{d\rho} \approx \frac{\alpha_s^2(\rho)}{\rho^2} \longrightarrow \frac{\alpha_s^2(\rho+\rho_0)}{(\rho+\rho_0)^2} \ ,$$

so that the probability for picking a MPI is shifted to

$$\alpha_s(\rho)\ P_{mpi}\ \frac{d\rho}{\rho} \longrightarrow \alpha_s(\rho+\rho_0)\ P_{mpi}\ \frac{d\rho}{\rho+\rho_0}$$

Since MPI and ISR evolve interleaved, the same shift is done in the spacelike showers.

Combining merging and MPI

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Change the trial shower steps:

- When trial showering off reclustered state, just treat MPI identical to radiation.
- When trial showering off the ME state, only veto if QCD radiation from the hard interaction was above t_{MS}.

MEPS + MPI plots

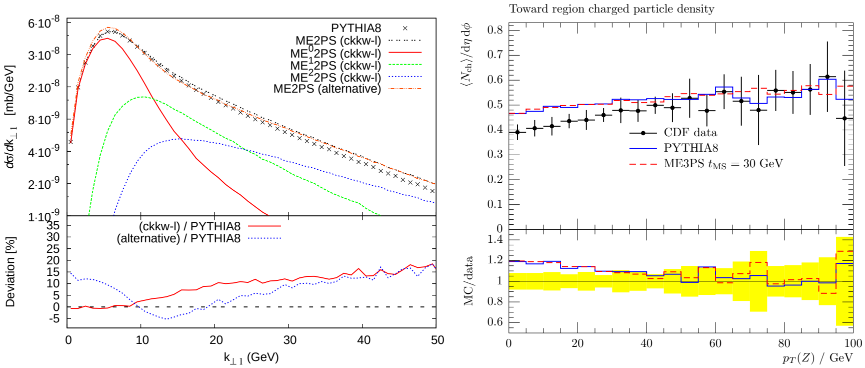

Figure: Left Panel: Transverse momentum of the first jet in Z + jets in pp collisions at $E_{CM} = 7000$ GeV, for two different MPI treatments. Right Panel: Toward region charged particle density in Drell-Yan events, as measured by CDF.

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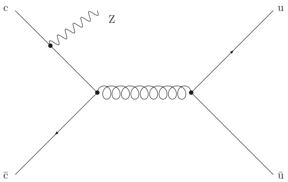
Unordered phase space points

In some cases, no ρ-ordered histories can be found, since the full ME phase space is larger than the ordered PS phase space. Including Sudakov suppression for unordered histories is ambiguous.



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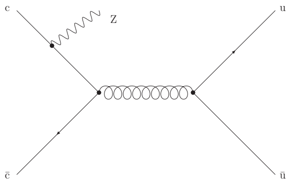
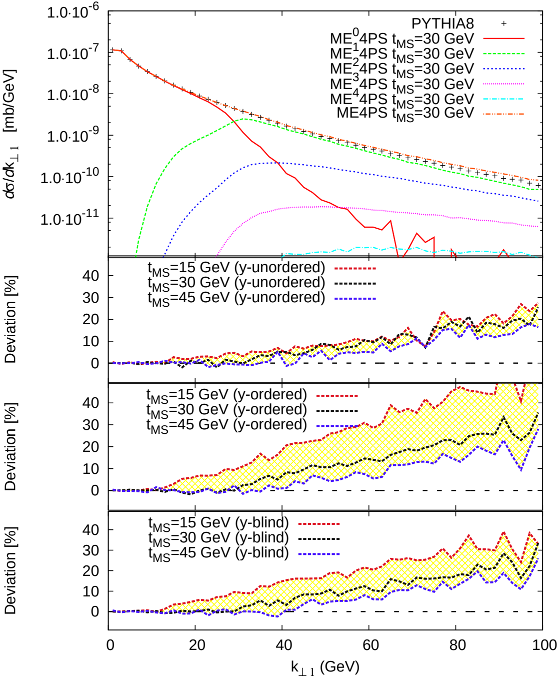


We can change the meaning of "ordered" by including additional ordering constraints (= constraining phase space region in which the PS is valid). This can help investigating this ambiguity.

Some preferably unordered configurations can have large influence on specific observables, e.g. the topology above gives a large contribution to high H_T-bins.



PYTHIA8
ME^0 4PS t_MS=30 GeV
ME^1 4PS t_MS=30 GeV
ME^2 4PS t_MS=30 GeV
ME^3 4PS t_MS=30 GeV
ME^4 4PS t_MS=30 GeV
ME4PS t_MS=30 GeV
dσ/dk⊥1 [mb/GeV]
1.0·10^-6
1.0·10^-7
1.0·10^-8
1.0·10^-9
1.0·10^-10
1.0·10^-11
t_MS=15 GeV (y-unordered)
t_MS=30 GeV (y-unordered)
t_MS=45 GeV (y-unordered)
t_MS=15 GeV (y-ordered)
t_MS=30 GeV (y-ordered)
t_MS=45 GeV (y-ordered)
t_MS=15 GeV (y-blind)
t_MS=30 GeV (y-blind)
t_MS=45 GeV (y-blind)
Deviation [%]
0
10
20
30
40
0
20
40
60
80
100
k⊥1 (GeV)

Other uncertainties. . .

- We construct all possible histories. Different prescriptions to pick histories give sub-leading, small differences.
- We can encounter incomplete histories, i.e. where parton flavours do not allow any clustering to PS states. These will be added as new processes. Cross sections for such states are typically small, so that no differences are found when changing their treatment, but . . .
- We allow user-defined merging scale *definitions*. Differences are small (?).

Conclusions

- For a consistent description of the shape of soft/collinear and hard jets, our method of choice is MEPS merging.
- We have implemented the CKKW-L method in PYTHIA8 (public since version 8.157).
- The inclusion of MPI is conceptually straight-forward. Our implementation does not change the UE description of PYTHIA.
- PYTHIA allows changing what is called shower accuracy. MEPS gives a good handle to estimate the shortcomings of the shower.
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Thank you for your time.

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