Matching of W+jets in MadEvent and Pythia

Johan Alwall

SLAC

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Outline

Jet matching – ME vs. PS

Matrix elements

1. Fixed order calculation
2. Computationally expensive
3. Limited number of particles
4. Valid when partons are hard and well separated
5. Quantum interference correct
6. Needed for multi-jet description

Parton showers

1. Resums logs to all orders
2. Computationally cheap
3. No limit on particle multiplicity
4. Valid when partons are collinear and/or soft
5. Partial quantum interference through angular ordering
6. Needed for hadronization/ detector simulation

Matrix element and Parton showers complementary approaches
Both necessary in high-precision studies of multijet processes

Need to combine without double-counting

Jet matching schemes

The simple idea behind matching

- Use matrix element description for well separated jets, and parton showers for collinear jets
- Phase-space cutoff to separate regions

$\Longrightarrow$ No double-counting between jet multiplicities

Difficulties

- Get smooth transition between regions
- No/small dependence from precise cutoff
- No/small dependence from largest multiplicity sample

How to accomplish this

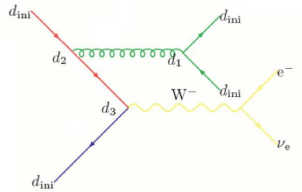
- CKKW matching (Catani, Krauss, Kuhn, Webber)
- MLM matching (M.L. Mangano)
- (Interesting newcomers: SCET Schwartz, GenEvA Bauer, Tackman, Thaler)

CKKW matching

Catani, Krauss, Kuhn, Webber [hep-ph/0109231], Krauss [hep-ph/0205283]

Imitate parton shower procedure for matrix elements

1. Choose a cutoff scale d_{ini}
2. Generate multiparton event with $d_{\text{min}} = d_{\text{ini}}$
3. Cluster event with k_T algorithm to find "parton shower history"
4. Use $d_i \simeq k_T^2$ in each vertex as scale for α_s
5. Weight event with Sudakov factor $\Delta(d_i, d_j)$ for each parton line between vertices i and j
6. Shower event, allowing only emissions with $k_T < d_{\text{ini}}$ ("vetoed shower")
7. For highest multiplicity sample, use $\min(d_i)$ of event as d_{ini}

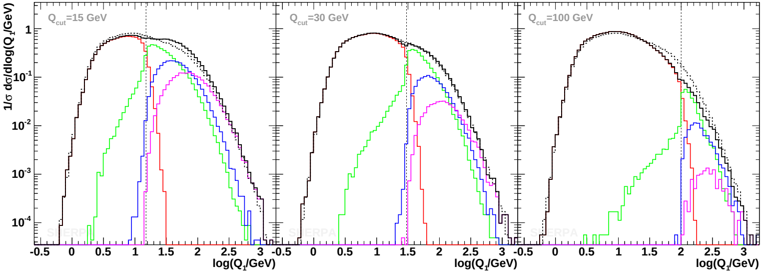


Boost-invariant k_T measure:

$$\begin{cases} d_{iB} = p_{T,i}^2 \\ d_{ij} = \min(p_{T,i}^2, p_{T,j}^2) R(i,j) \end{cases}$$

$$R(i,j) = \cosh \Delta\eta_{ij} - \cos \Delta\phi_{ij}$$

- Final-state showers:
  Combination of NLL Sudakov factors and vetoed NLL showers guarantees independence of q_{ini} to NLL order
- Initial-state showers: Proof by example (Sherpa)
- Problem in practice: No NLL shower implementation!
  (Sherpa uses Pythia-like showers and adapted Sudakovs)



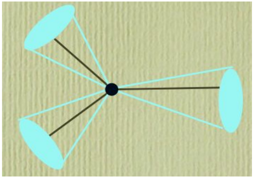
Differential $0 \to 1$ jet rate by Sherpa in $pp \to Z +$ jets for three different d_{ini}, compared to averaged reference curve [hep-ph/0503280]

MLM matching

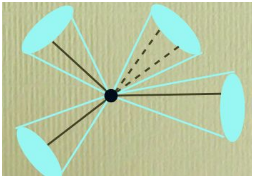
M.L. Mangano [2002, Alpgen home page, arXiv:0706.2569]

Use shower hardness to separate ME/PS

1. Generate multiparton event with cut on jet p_T, η and ΔR
2. Cluster event and use k_T^2 for α_s scale (as in CKKW)
3. Shower event (using Pythia or Herwig)
4. Collect showered partons in cone jets with $p_{T,\mathrm{min}}(jet) > p_{T,\mathrm{min}}(parton)$
5. Keep event only if each jet corresponds to one parton ("matched")
6. For highest multiplicity sample, allow extra jets with $p_T < p_{Tmin}^{\mathrm{parton}}$



Keep



Discard unless highest multiplicity

Differences between CKKW and MLM

- CKKW scheme: Assumes intimate knowledge of and modifications to parton shower. Needs analytical form for parton shower Sudakovs.
- MLM scheme: Effective Sudakov suppression directly from parton shower
- However: MLM not sensitive to parton types of internal lines (remedied by pseudoshower approach, see below)
- Factorization scale: In CKKW jet resolution scale, in MLM central scale.
- Highest multiplicity treatment – less obvious in MLM than in CKKW
- MLM only for hadronic collisions (so far)

CKKW with pseudoshowers

Lönnblad [hep-ph/0112284] (ARIADNE)
Mrenna, Richardsson [hep-ph/0312274]

- Apply parton shower stepwize to clustered event, reject event if too hard emission
- Apply vetoed parton shower as in the CKKW approach

Matching in MadGraph / MadEvent

J.A. et al. [arXiv:0706.2569], [*work in progress*]
(*cf.* Mrenna, Richardsson [hep-ph/0312274])

- CKKW scheme (for Sherpa showers) (with S. Höche)
- MLM scheme (Pythia showers, old & new)
- MLM scheme with k_T jets (Pythia showers, old & new)
- "Shower k_T scheme" (Pythia showers, new)

Details of MadEvent k_T MLM scheme

1. Generate multiparton event with k_T clustering cutoff d_{cut}
2. Cluster event and use k_T for α_s scale
3. Shower event with Pythia
4. Perform jet clustering with k_T algorithm, $d_{\text{min}}(jet) > d_{\text{cut}}$
5. Match clustered jets to partons ($d(\text{jet}, \text{parton}) < d_{\text{min}}(jet)$)
6. Discard events where jets not matched
7. For highest multiplicity sample, jets matched if $d(\text{jet}, \text{parton}) < d_{\text{min}}(\text{parton}, \text{parton})$

Advantages with k_T jets

- Immediate comparison with CKKW scheme
- One matching parameter ($d_{\text{min}}^{\text{jet}}$ vs. $p_{T,\text{min}}, \Delta R_{\text{min}}$)
- Easy to check smoothness by plotting jet rates d_{jet}
- Allows to use "shower k_T scheme"
- Allows straightforward investigations of parton showers

Shower k_T scheme

- Keep/reject event based on k_T of hardest shower emission (as reported by Pythia)
- Highest multiplicity treatment as in CKKW, use min d_{parton} as cutoff
- No jet clustering
- No need of "fiducial region", can use $k_T^{\text{match}} = d_{\text{cut}}^{\text{ME}}$
- Need similar k_T definitions in ME and PS (only "new", p_T-ordered showers at present)

Old and New Pythia showers

Parton showers

- Sudakov form factors for non-branching probability between scales

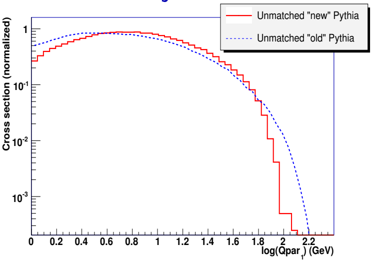
$$\Delta(t_1, t_2) = \exp\left\{ -\int_{t_2}^{t_1} \frac{dt'}{t'} \int_{\epsilon(t)}^{1-\epsilon(t)} dz \frac{\alpha_s(t)}{2\pi} \widehat{P}(z) \right\}$$

- QCD splitting functions $P_{a \to b}(z)$ for z distribution
- Different choice of evolution variable t
  $\Longrightarrow$ "Old" Pythia showers: Q^2
  $\Longrightarrow$ "New" Pythia showers: p_T^2 (dipole-inspired)
- Can give quite different distributions

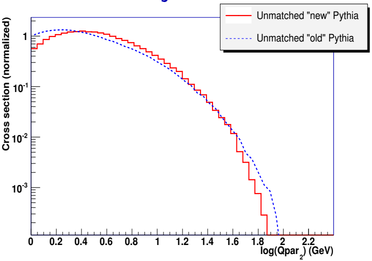
Comparisons between old and new Pythia showers

Differential jet rates in W production at the Tevatron

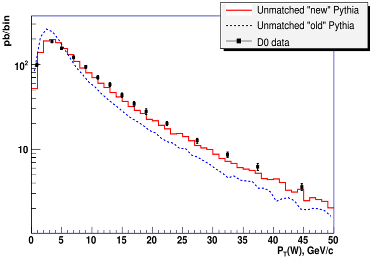
$0 \rightarrow 1$ jet rate

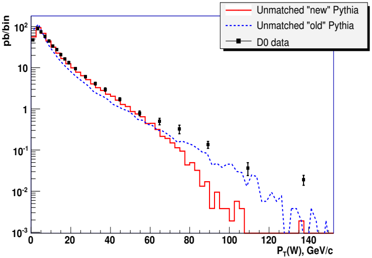


$1 \rightarrow 2$ jet rate



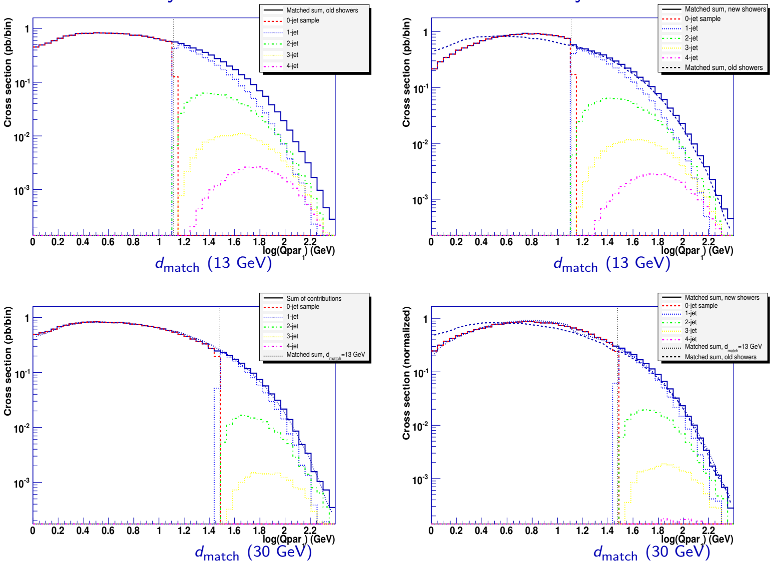
$p_T(W)$ in W production at the Tevatron





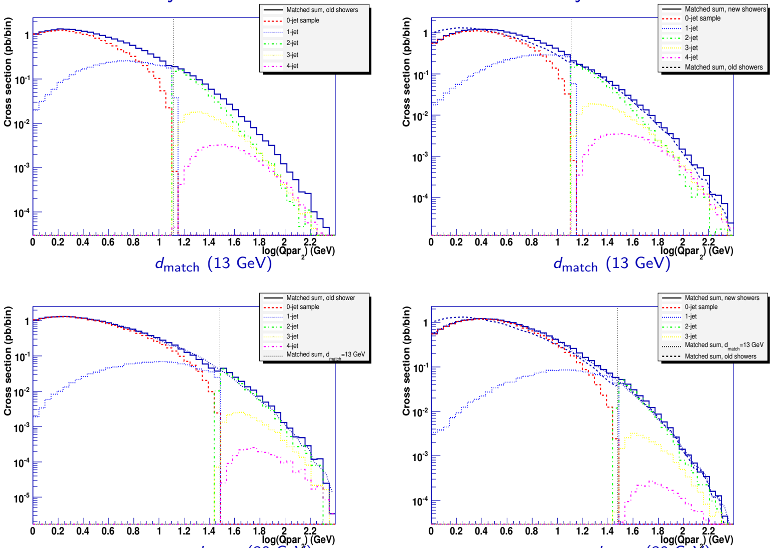
Impact of shower on matching

“Old” Pythia showers — “New” Pythia showers



Differential 0 → 1 jet rate

"Old" Pythia showers — "New" Pythia showers



d_{match} (13 GeV) — d_{match} (13 GeV)

d_{match} (30 GeV) — d_{match} (30 GeV)

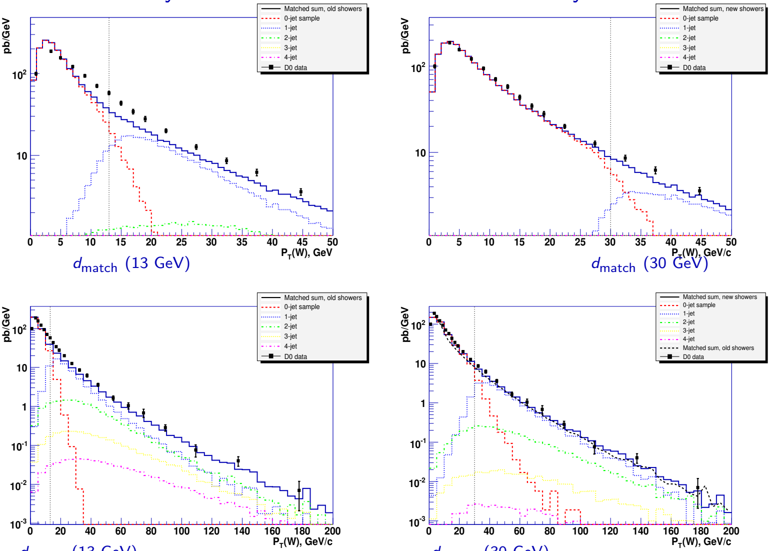
Differential 1 → 2 jet rate

Old showers smooth for small cutoff, new showers for larger cutoff

$p_T(W)$ at the Tevatron

"Old" Pythia showers

"New" Pythia showers



d_{match} (13 GeV)

d_{match} (30 GeV)

d_{match} (13 GeV)

d_{match} (30 GeV)

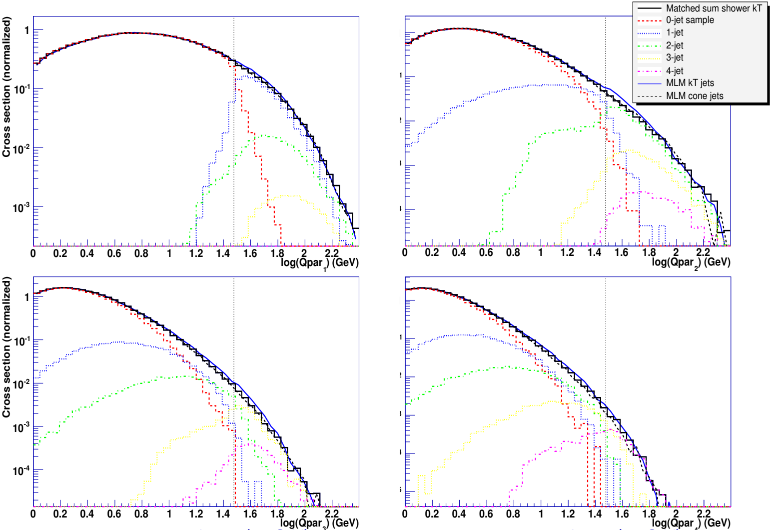
Tail well described by both, but head best by new shower

Summary of shower impact

- Different showers have very different behavior, especially at low k_T
- Strongly affects matching – need different treatment (e.g. cutoffs) for different showers
- Matching stabilizes tail, but overall normalization is strongly affected by shower
  $\Longrightarrow$ Normalizing overall cross section to e.g. NLO value dangerous
- New pythia showers seem to agree better with W/Z data – but why "step" in matching for low k_T?

"Shower k_T" scheme

Comparison with k_T and cone jet MLM schemes



d_{match} (30 GeV) d_{match} (30 GeV)

Excellent agreement with MLM methods

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Matching ME+Pythia

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Jet matching schemes

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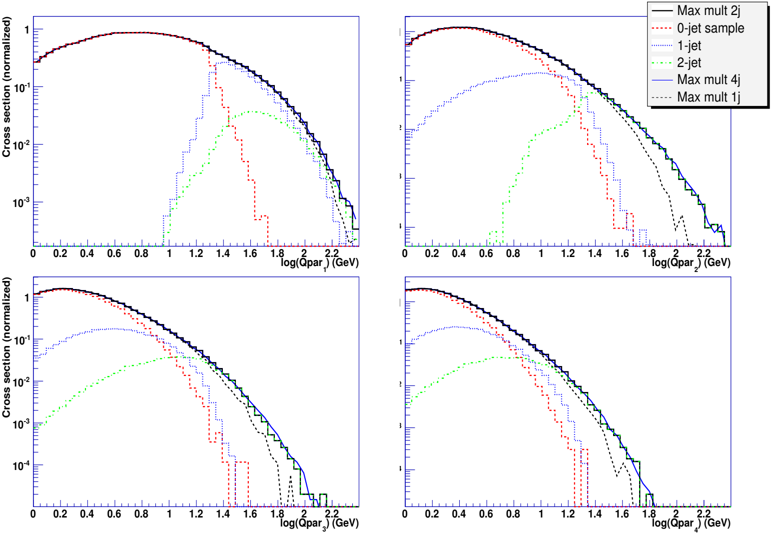
Conclusions

Dependence on highest multiplicity



Surprisingly small dependence with “shower k_T” method!

Conclusions

- Have presented investigation of shower and scheme dependence for the benchmark case W + jets
- Shower dependence larger than expected (should be equivalent for small k_T!?)
- Needs care with e.g. cutoff values (p_T or k_T)
- New "shower k_T" scheme presented, with many nice properties:
  $\longrightarrow$ More efficient than standard MLM since no "fiducial region" needed
  $\longrightarrow$ Agrees with MLM schemes
  $\longrightarrow$ Remarkable insensitivity to highest multiplicity sample
  $\longrightarrow$ No need for special treatment of e.g. top or b quarks
- So far only for "new" Pythia shower