Status of parton showers

Stefan Prestel

(DESY)

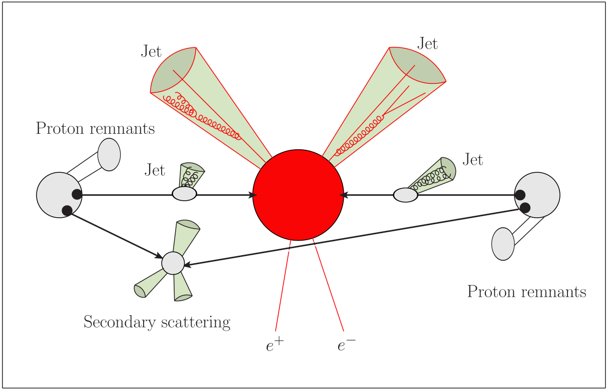
QCD Tools for LHC Physics: From 8 to 14 TeV - What's needed and why?

Fermilab, November 14-15, 2013

Outline

- Parton shower event generators, parton shower types
- Improving the splitting kernels
- Status of different parton showers
- Open issues

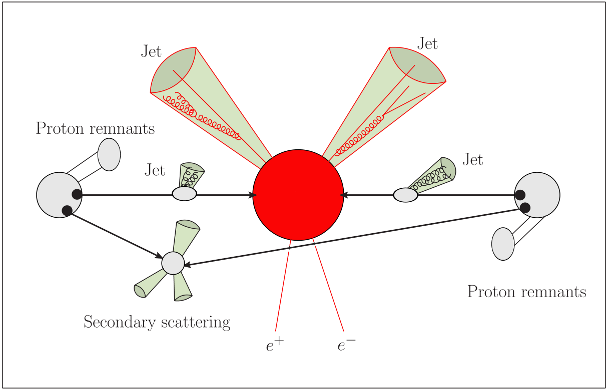
Hadronic events



Event generators need to model

- Hard interactions,
- (inital or final state) radiation,
- multipe scatterings and beam remnants,
- hadronisation and hadron decays.

Hadronic events



Event generators need to model

- Hard interactions, ←Perturbative improvements possible.
- (inital or final state) radiation, ←Perturbative improvements possible.
- multipe scatterings and beam remnants,
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Parton showers

- model the radiation cascade.
- facilitate a perturbative resummation of dominant logs.
- are interfaced to non(?)-perturbative generator components.
- need to "be okay" many different data sets.

Status: Formally only LL for inclusive observables.

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The end... thanks for your time.

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- need to "be okay" many different data sets.

Status: Formally only LL for inclusive observables.

But parton showers contains many improvements that are necessary to

(a) allow a matching to fixed-order
(b) help to describe data

In what way are parton showers better than LL?

Parton showers

How do we derive a parton shower?

(a) From collinear limit $\rightarrow$ DGLAP showers
(PYTHIA6-Q^2, Herwig++-Θ, KRKMC showers, WHIZARD showers)

(b) From soft limit $\rightarrow$ Dipole antenna showers
(ARIADNE, VINCIA, ANTS)

(c) From NLO calculations $\rightarrow$ Partitioned dipole showers
(SHERPA CS shower, Herwig++ dipole shower, PYTHIA8)

Real parton showers are an admixture of these approaches (e.g. HERWIRI started from HERWIG[1], and introduced soft-IR-improved splitting kernels).

[1] Phys.Lett.B685(2010)283, Phys.Rev.D81(2010)076008, Phys.Lett.B719(2013)367, arXiv:1305.0023

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Real parton showers are an admixture of these approaches (e.g. HERWIRI started from HERWIG[1], and introduced soft-IR-improved splitting kernels).

Once we have a parton shower, we include improvements to match onto fixed-order results:

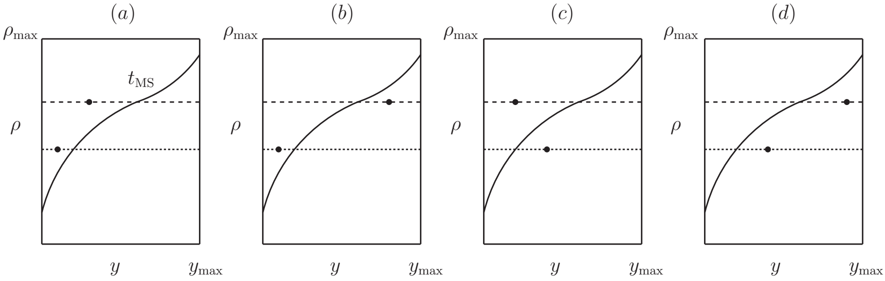
- ME centric view: Add PS to ME, amend PS where necessary (e.g. improved Sudakov for MC@NLO, truncated showers)
- PS centric view: Take PS, correct some configurations to ME (e.g. ME corrections, PS reweighting)

. . . a better shower is always a better starting point.

[1] Phys.Lett.B685(2010)283, Phys.Rev.D81(2010)076008, Phys.Lett.B719(2013)367, arXiv:1305.0023

Use improved and "old" showers simultaneously, switch to "old" shower when improved shower no longer needed.

One example: Truncated shower for METS merging.



ME-centric improvements

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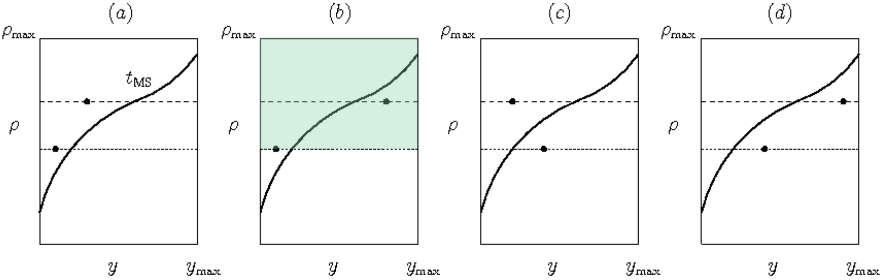

Truncated shower

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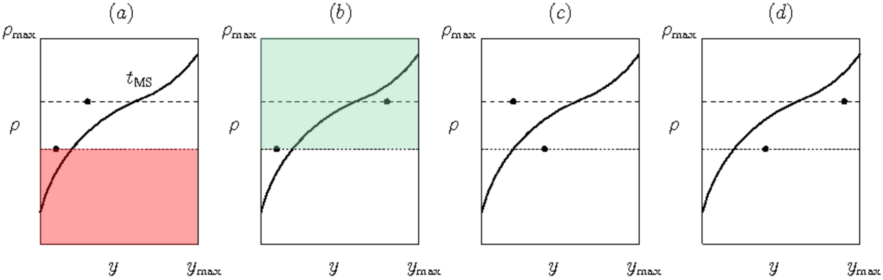

Truncated shower

Standard shower

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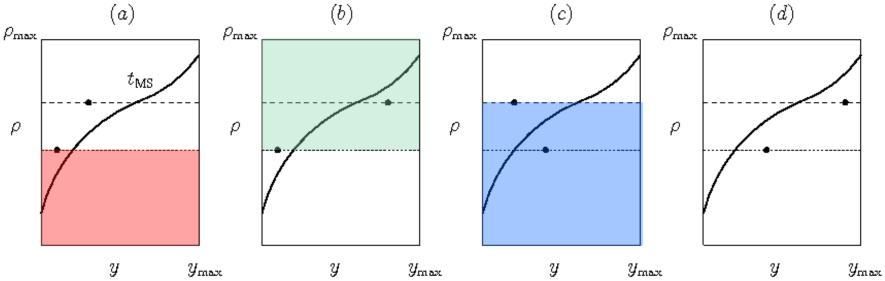


Truncated shower

Standard shower

Vetoed shower

ME-centric improvements

Use improved and "old" showers simultaneously, switch to "old" shower when improved shower no longer needed.

A more recent example of PS improvements for ME matching are coloured showers for MC@NLO. For this, remember:

$$\widetilde{B}_n = B_n + V_n + I_n + \int \left(D^A - D^S\right)$$

$$\sigma^{\text{MC@NLO}} = \widetilde{B}_n \left[\Delta^A(p_{\perp min}) + \int \frac{D^A}{B_n} \Delta^A(p_\perp)\right] + \int \left[R - D^A\right]$$

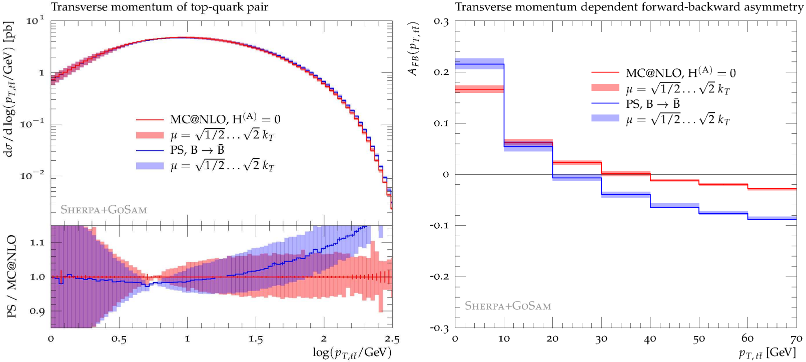
⇒ For finite $\int \left(D^A - D^S\right)$ without approximations, D^A needs to have all subleading divergences.

This also includes subleading colour terms!

Subleading colour treatment have been introduced in SHERPA and HERWIG++/MATCHBOX.

Coloured MC@NLO dipole showers in SHERPA

Do $1/N_c$ corrections make a difference?



- Effect of sub-leading color corrections typically $\mathcal{O}(10\%)$
- In most cases also well within parton shower uncertainty
- Can have larger impact on some observables, e.g. $A_{FB}(p_T)$

Slide ©Stefan Höche, see also JHEP 1209 (2012) 049, Phys.Rev. D88 (2013) 014040

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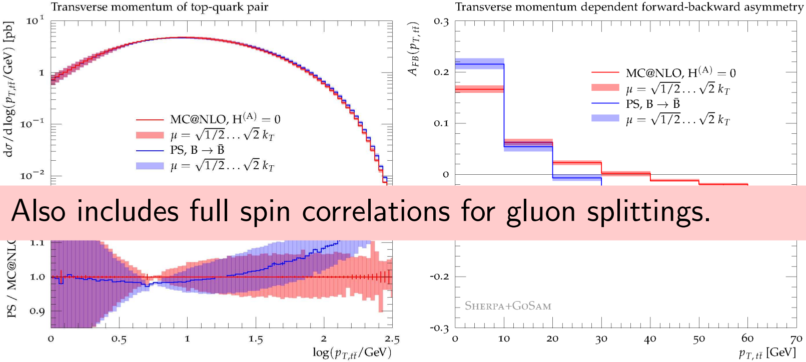

Also includes full spin correlations for gluon splittings.

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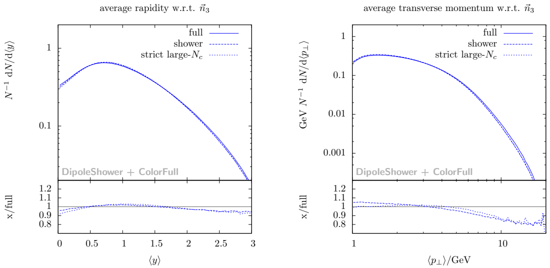
Slide ©Stefan Höche, see also JHEP 1209 (2012) 049, Phys.Rev. D88 (2013) 014040

First steps towards higher orders in N_c.

Include virtual colour rearranging terms in shower evolution.
Studied for gaps between jets. [A. Schofield, M. Seymour – JHEP 1201 (2012) 078]

Correct single emission pattern by full colour correlations.
'Colour matrix element corrections' first studied for LEP.

[S. Plätzer, M. Sjödahl – JHEP 1207 (2012) 042]

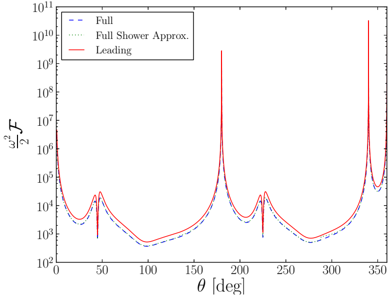


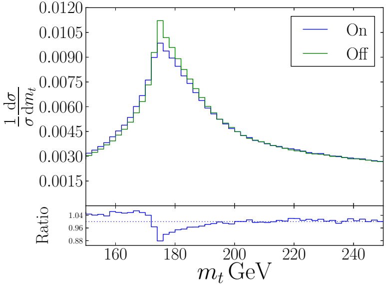
Relative orientation of soft particles to hard three-jet system very sensitive.

Multiscale Showering.

Improve shower algorithm for soft gluons in multi-scale problems.
Particularly relevant in decays of heavy coloured particles (masses, widths, IR cutoff).

[P. Richardson, D.E. Winn – in preparation]





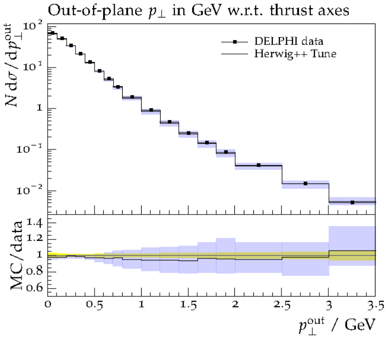
Double gluon emission pattern in $gg \to t\bar{t}$ and impact of correction on the top mass.

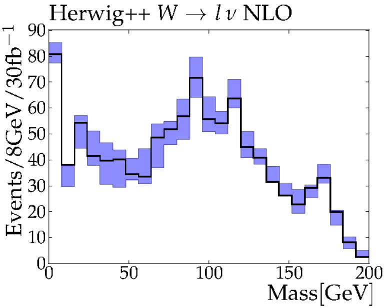
Eigentunes.

[P. Richardson, D.E. Winn – Eur.Phys.J. C72 (2012) 2178]

Eigentunes for Herwig++ similar to PDF error sets.

Investigate impact on jet substructure analysis (including $H \to b\bar{b}$ POWHEG).





Antenna showers

. . . or: why was ARIADNE looking so good?

- Antennae quite naturally include coherence effects.
- Fewer antennea compared to partitioned dipoles ($\rightarrow$ antenna showers should be very efficient).
- Antennae lend themselves to ME corrections (less partial fractioning of ME corrections is necessary, on-shell kinematics as for all dipole showers, the $\mathrm{q\bar{q}g}$ antenna is the Z$\rightarrow$ $\mathrm{q\bar{q}g}$ ME).

Antenna showers: SHERPA

Antenna shower in SHERPA

Slide ©Korinna Zapp

Motivation

- coherent radiation off colour dipole
- local recoil compensation
- relation to antenna subtraction

Status

- ANTenna Shower (ANTS) implemented (WK kernels)

  Winter & Krauss, JHEP **0807** (2008) 040

- two kinematics mappings: WK & antenna mapping

  Gehrmann-De Ridder, Gehrmann, Glover & Heinrich, JHEP **0711** (2007) 058
  Daleo, Gehrmann & Maitre, JHEP **0704** (2007) 016

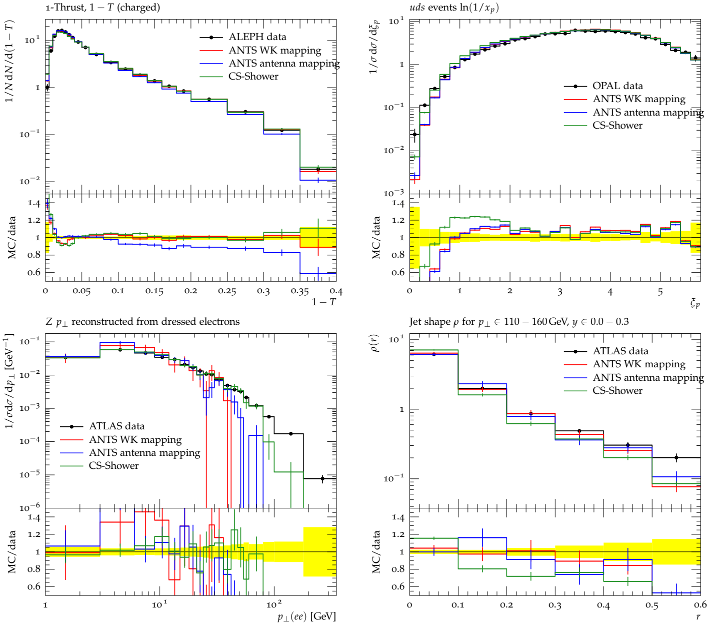
- needs validation & tuning

Future plans

- implement antenna kernels
- matching & merging

ANTS: preliminary results

Slide ©Korinna Zapp



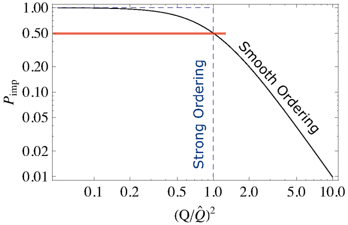
Antenna showers: VINCIA

Motivation:

- ◇ Coherence, PS is a very efficient phase space generator.
- ◇ PS-centric matching approach: Have PS that fills full phase space
  . . . then correct with full matrix elements.

Smooth Ordering

Giele, Kosower, Skands, PRD 84 (2011) 054003



$$P_{\rm strong} = \Theta\left(\hat{p}_\perp^2 - p_\perp^2\right)$$

$$P_{\rm smooth} = \frac{\hat{p}_\perp^2}{\hat{p}_\perp^2 + p_\perp^2} \otimes \underbrace{\frac{1}{p_\perp^2}}_{A_{2\to3}}$$

Strongly Ordered Limit

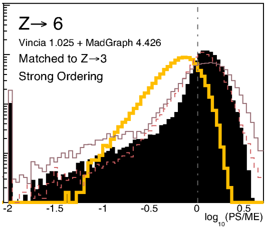
$$\frac{1}{p_\perp^2}\left(1 - \mathcal{O}\left(\frac{p_\perp^2}{\hat{p}_\perp^2}\right)\right)$$

Strongly Unordered

$$\frac{\hat{p}_\perp^2}{p_\perp^4}\left(1 - \mathcal{O}\left(\frac{\hat{p}_\perp^2}{p_\perp^2}\right)\right)$$

NB: Antenna Phase Spaces still nested
(antenna masses strongly ordered and decreasing)

Strong Ordering



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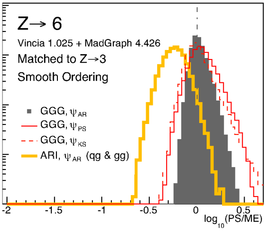
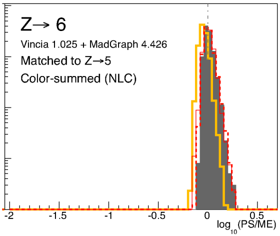


Smooth with ME corrs



Z→6: PS/ME Ratio in a flat phase-space scan (log(PS/ME)=0 is good)

New aspects of VINCIA

Larkoski, Lopez-Villarejo, Skands, PRD87(2013)054033

Helicity-dependence for relativistic partons

Can use a single helicity ME as radiation function

Dominant = MHV (easiest to evaluate) + NMHV + …
Note: Helicity ≠ Polarization (azimuthal corrs only via ME corrections)

Full 2nd order corrections

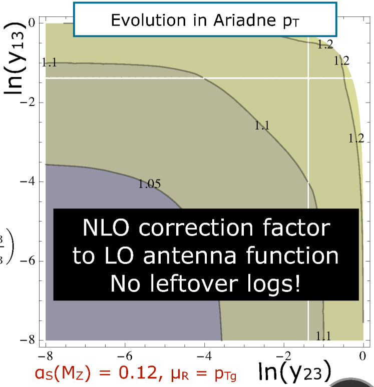
One-loop Z→3 matrix element:
= singularities + logs + finite pieces

$$\mathcal{P}oles\left(A_3^1(1_q,3_g,2_{\bar q})\right) = 2\left(\mathbf{I}^{(1)}_{qg}(\epsilon,s_{13}) + \mathbf{I}^{(1)}_{qg}(\epsilon,s_{23}) - \mathbf{I}^{(1)}_{q\bar q}(\epsilon,s_{123})\right) A_3^0(1,3,2)\ ,$$

$$\mathcal{F}inite\left(A_3^1(1_q,3_g,2_{\bar q})\right) = -\left(R(y_{13},y_{23}) + \frac{5}{3}\log y_{13} + \frac{5}{3}\log y_{23}\right) A_3^0(1,3,2)$$
$$+\frac{1}{s_{123}} + \frac{s_{12}+s_{23}}{2s_{123}s_{13}} + \frac{s_{12}+s_{13}}{2s_{123}s_{23}} - \frac{s_{13}}{2s_{123}(s_{12}+s_{13})}$$
$$-\frac{s_{23}}{2s_{123}(s_{12}+s_{23})} + \frac{\log y_{13}}{s_{123}}\left(2 - \frac{1}{2}\frac{s_{13}s_{23}}{(s_{12}+s_{23})^2} + 2\frac{s_{13}-s_{23}}{s_{12}+s_{23}}\right)$$
$$+\frac{\log y_{23}}{s_{123}}\left(2 - \frac{1}{2}\frac{s_{13}s_{23}}{(s_{12}+s_{13})^2} + 2\frac{s_{23}-s_{13}}{s_{12}+s_{13}}\right)\ ,$$

$$R(y,z) = \log y \log z - \log y \log(1-y) - \log z \log(1-z) + \frac{\pi^2}{6} - \mathrm{Li}_2(y) - \mathrm{Li}_2(z)$$

"Antenna Subtraction at NNLO"
Gehrmann-de Ridder, Gehrmann, Glover, JHEP09(2005)056



Hartgring, Laenen, Skands, JHEP10(2013)127

Note: any coherent LL shower should get the singularities right.
The rest goes beyond LL

+ Uncertainties

Automated uncertainties

Evaluated on the fly

by explicit variations

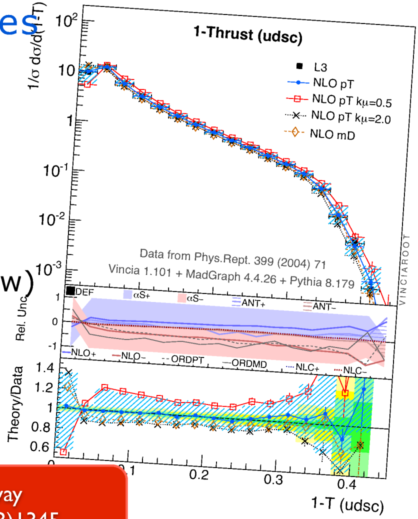
branching by branching

→ Vector of weights

Central weight is unity (unw)

+ 11 alternative weights

- μR variations
- Subleading antenna terms
- pT vs mD evolution
- Subleading colour



Disclaimer: formalism for pp still underway
see Ritzmann, Kosower, Skands, PLB718(2013)1345

Analytic Parton Showers

cf. JHEP1204(2012)013 (and Phys.Rev.D76(2007)114017)

- conventional parton showers:
  - trial splittings
  - if not allowed reject or manually altered
  - probabilities incalculable
- *analytic parton showers*
  - ensure that either
    - only allowed branchings are generated
    - or probability of rejection is calculable
  - possible to reweight events after they are simulated

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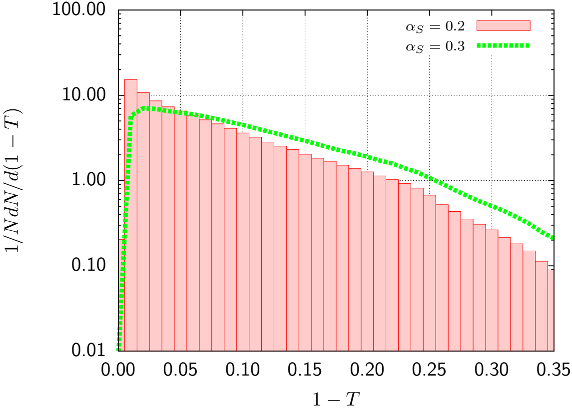
WHIZARD approach: Remove veto of disallowed kinematics after momentum reshuffling by performing $1 \to 3$ and $2 \to 4$ splittings.
$\Rightarrow$ "PS cross section" is known. Reweighting possible.

Results: Reweighting



LEP @ 91 GeV

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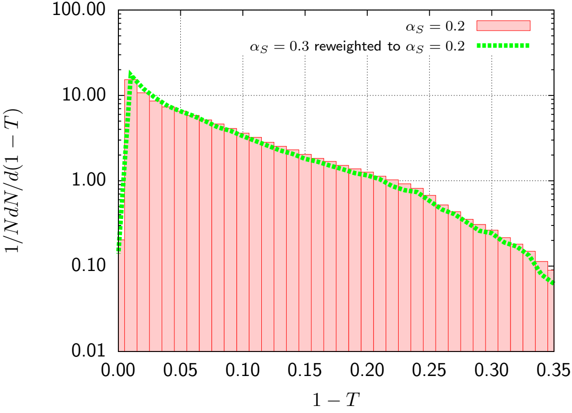

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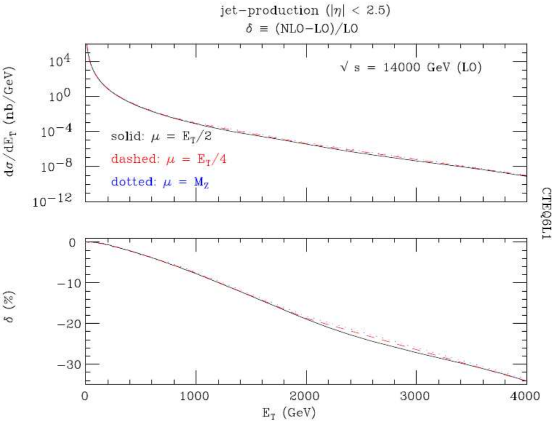
Electroweak corrections to showers?



Nucl.Phys.B759(2006)50

- ◇ Weak correction is $\sim \alpha_w \ln^2(\hat{s}/M_w)$.
- ◇ Is W/Z-boson radiation a necessary ingredient for TeV-jets?

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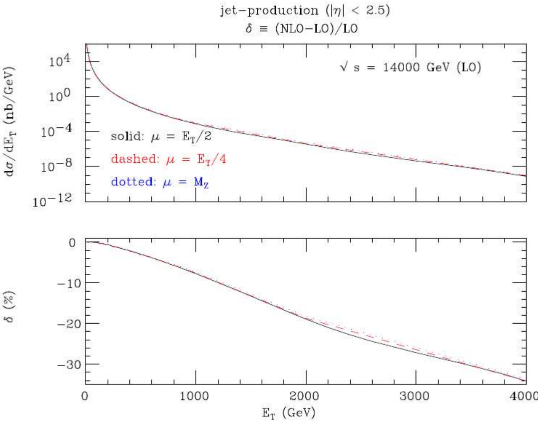

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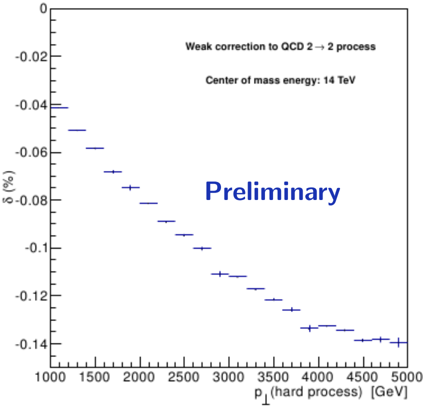
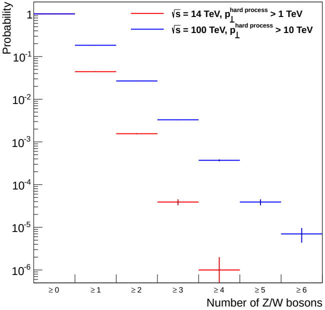
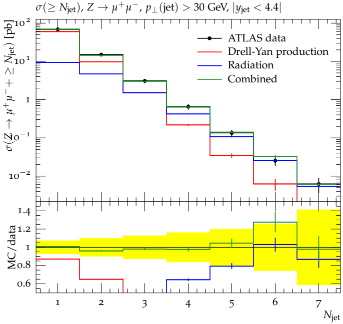


- ◇ Weak correction is $\sim \alpha_w \ln^2(\hat{s}/M_w)$.
- ◇ Is W/Z-boson radiation a necessary ingredient for TeV-jets?
- ◇ Idea: Implement W/Z-shower off QCD processes, and check!

Electroweak showers in PYTHIA: Preliminary results

- Effect of weak emissions in high $p_{\perp}$-jets.
- Possible to give a better description of the W/Z+jets production than the normal PS?
- Needed step to be able to recluster all PS histories in the merging/matching approach.





Electroweak showers in PYTHIA: Preliminary results

Uses s- or $u+t$-channel ME's as splitting probabilities. Multiple boson emissions very rare.

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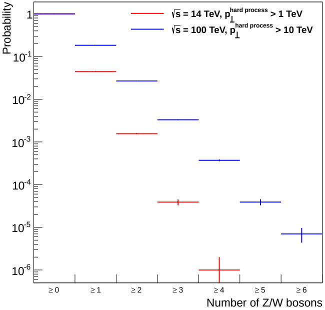

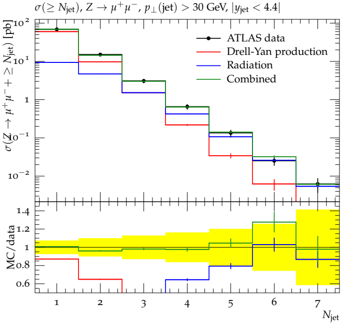

Open issues

There has been a lot of work on showers in the last few years - most of it under the radar. Here some questions:

1. Is there / what is the connection to CSS resummation? How accurate is the PS?
   Problem: How to factor in recoil effects?

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[1] Question © Z. Nagy

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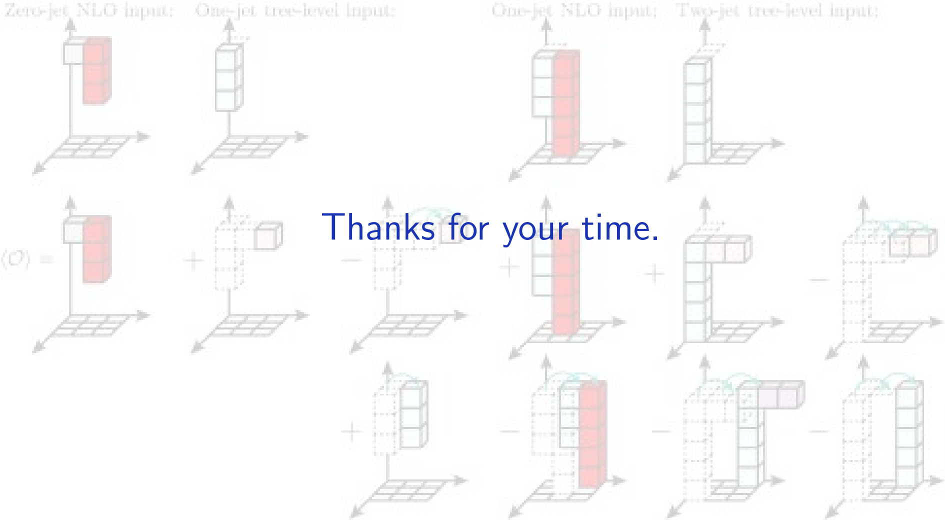
...and many more non-perturbative (?) issues!
Is σ_{eff} universal? What about "The ridge"? What's wrong with identified flavours @ LHC? Strings vs. clusters?

[1] Question © Z. Nagy



Thanks for your time.