Parton Shower Uncertainties

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MCnet

PHYSICS AT THE TERA SCALE
Helmholtz Alliance

Parton shower uncertainties

- MC prediction better be accurate to minimise bias.
- Important theory error for all measurements.
- Old school:

$$\sigma = |\text{Pythia} - \text{Herwig}|$$

- Modern event generators offer more.

Parton shower uncertainties

Some uncertainties

- pdf errors (usually treated as separate issue).
- Perturbative expansion, vary μ_R, μ_F.
- Parton shower
  - Evolution variables (run different showers).
  - Initial conditions (usually constrained by soft phase).
- Matching/merging scales.
  May indicate higher order/subleading log effects.
- Hadronization. Modelling/tuning error.
- Underlying Event. Modelling/tuning error.

Try to quantify.

See also Sherpa and Vincia, e.g.

[Hoeche, Krauss, Schönherr, Siegert, JHEP 1209 049]

Parton shower uncertainties

Note, no correlations included,
all uncertainties only observed one-by-one.

All variations done independently.

After all, already done so in tuning.

Full story too involved. Good starting point.

Outline

Go through errors for particular example.

$Z+1$ jet. Herwig++/Matchbox builtin.

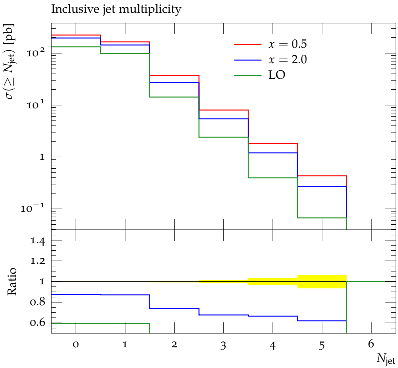
Some observables:

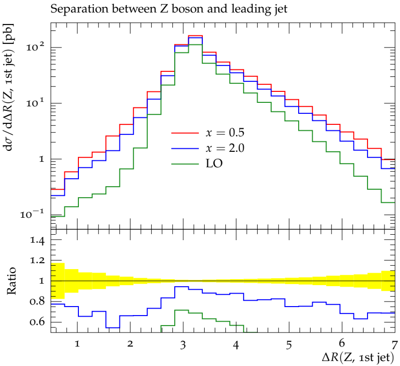
- p_T(jet 1, 2). Parton shower, soft physics at low end.
- Mass(jet 1,2). Parton shower and soft effects.
- Inclusive jet multiplicity. Parton shower and higher orders.
- $\Delta R(Z, \text{jet } 1)$. Very sensitive to shower, NLO.
  (cut off at π in absence of parton shower.)

[SG, S. Plätzer, work in progress]

Hard matrix element

Vary μ_R, μ_F by factor 2 simultaneously.





Sizable variation. NLO corrections large as well.

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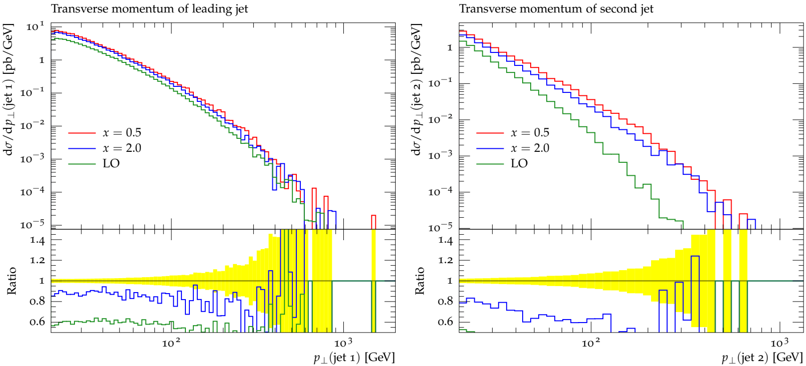


Sizable variation. NLO corrections large as well.

Hard matrix element

- See effects of NLO calculation.
- Assess remaining uncertainty from NLO calculation.
- Good to have in order to gauge further uncertainties.
- Example

```
cd /Herwig/MatrixElements/Matchbox
set PPFactory:RenormalizationScaleFactor 2.0
set PPFactory:FactorizationScaleFactor 2.0
```

Parton shower

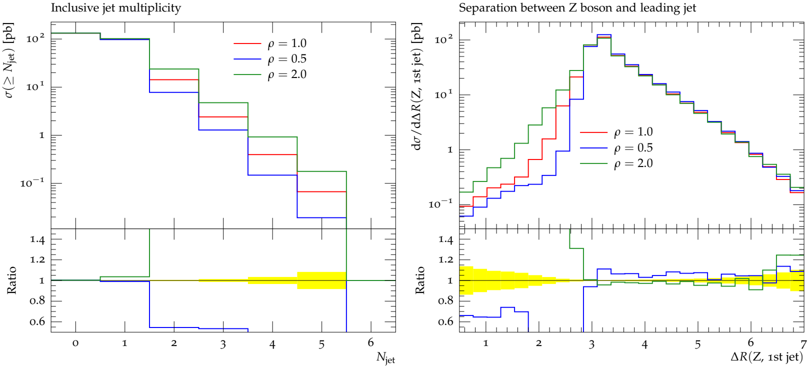
Only LO runs.

Initial scale particularly important. Often given by further constraints (e.g. soft phase space in Herwig).

Vary parton shower type/choice of evolution variables.
[Similar: evolution/kin scale choices in Sherpa, Vincia.]

Parton shower initial conditions

Parton shower initial scale $(\times 2)$ or $(\times 1/2)$
(normally fixed by phase space constraints).



Very senstitive where only parton shower is used (of course).

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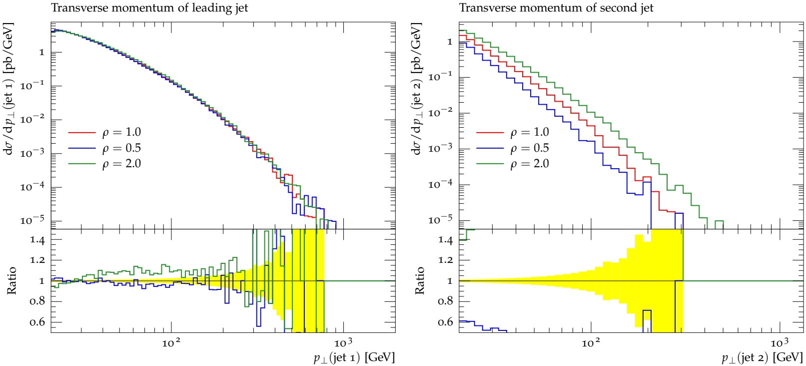

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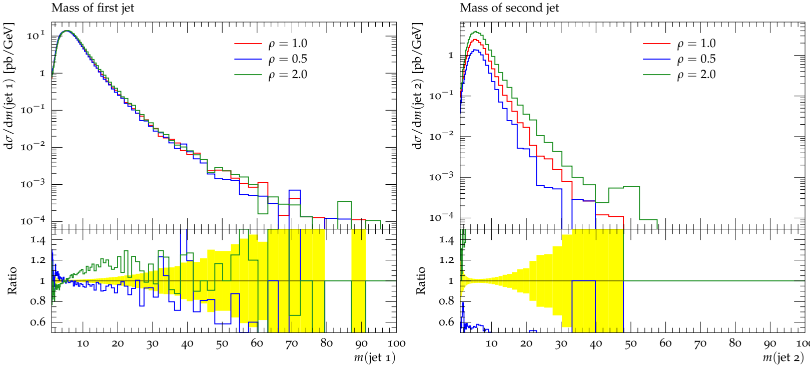


Very senstitive where only parton shower is used (of course).

Parton shower initial conditions

Unphysical variation of initial condition (in Herwig).

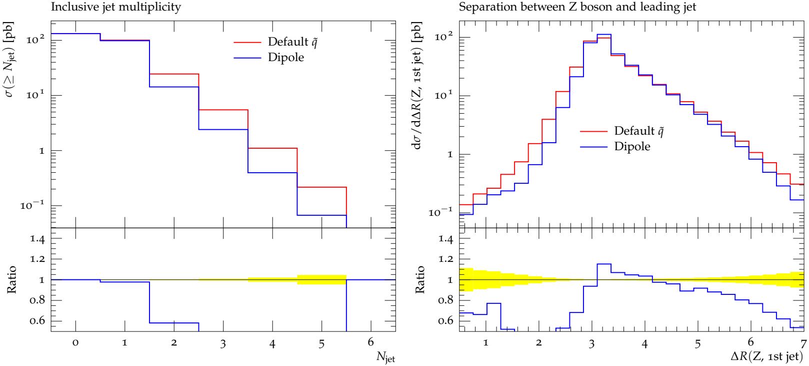
Shows where result depends strongly on parton shower while ME domintated parts are insensitive.

Example:

```
cd /Herwig/DipoleShower/
set DipoleShowerHandler:HardScaleFactor 2.0
```

Parton shower type

Switch from Dipole shower to default $\tilde{q}$ shower.



Again, differences in parton shower domain,
dipole shower less, slightly fatter jets.

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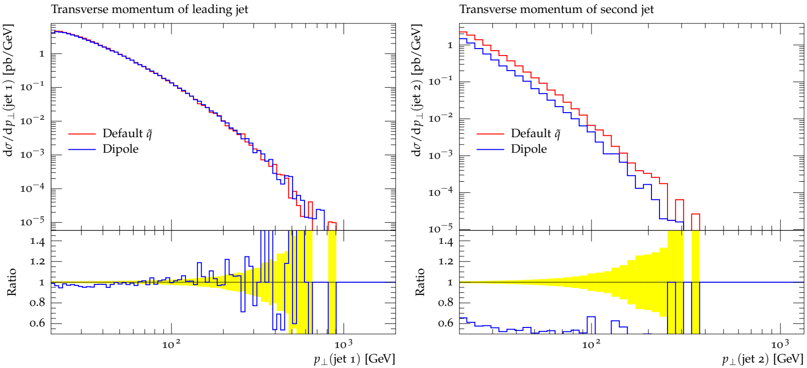

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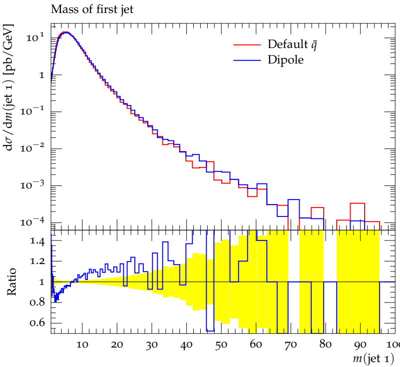
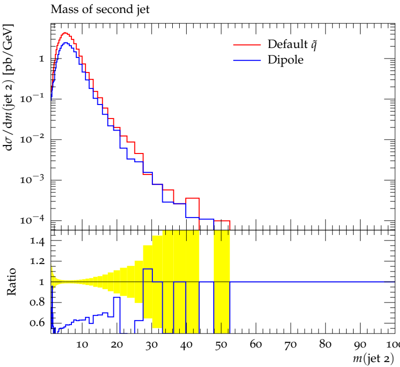




Again, differences in parton shower domain,
dipole shower less, slightly fatter jets.

Parton shower type

Systematic error of parton shower.

Extrapolation out of the strict soft and collinear limits.

Other methods in other generators:

- Vincia uses different evolution variables and momentum prescriptions.
- Different variables for the dipole shower phase space in Sherpa.

Example:

```
set LHCHandler:CascadeHandler
   /Herwig/DipoleShower/DipoleShowerHandler
```

or leave default shower switched on.

NLO matching

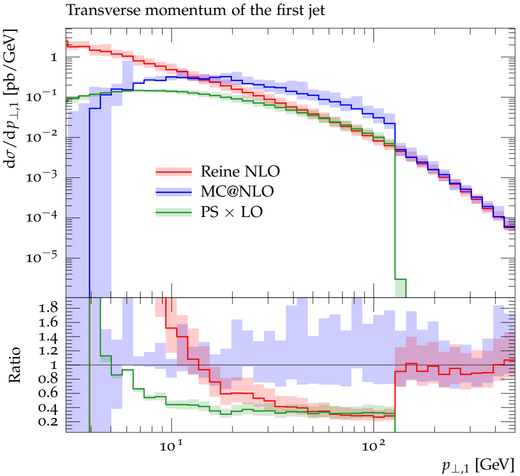
MC@NLO like matching: upper scale of parton shower = boundary between real matrix element and parton shower.

Induces uncontrolled higher order terms

Can be large at the next highest order (NNLO in this case). Good example (with bad behaviour) is Higgs production (large K factors).

NLO 'raw' matching example

Example: transverse momentum of 1st jet in h^0 production.



[Diplomarbeit B. Zimmermann, KIT 2013]

NLO 'raw' matching example

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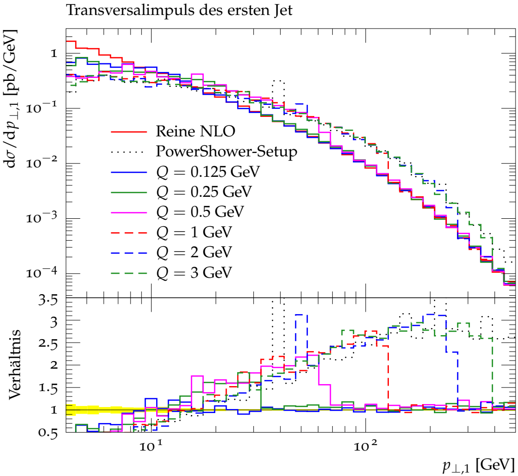

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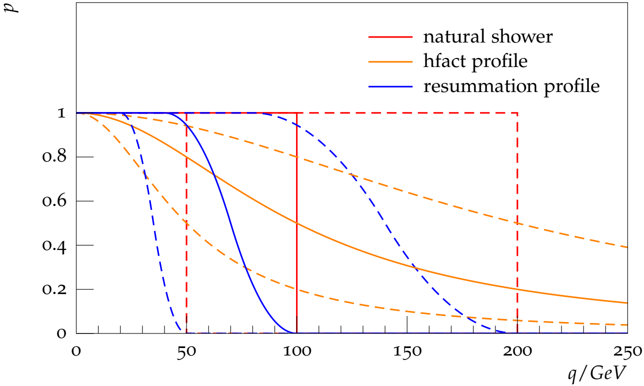
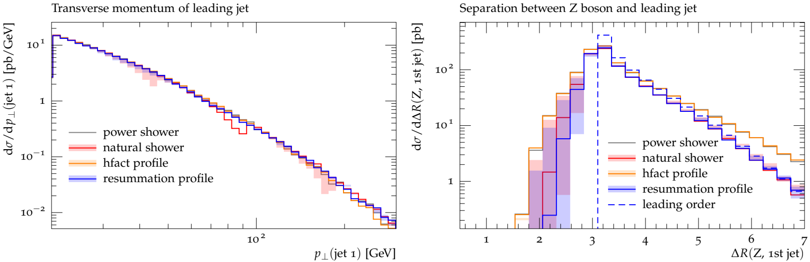
NLO matching example



Smoothly interpolate between ME and resummation domains.

[SG, S. Plätzer, work in progress.]

NLO matching example

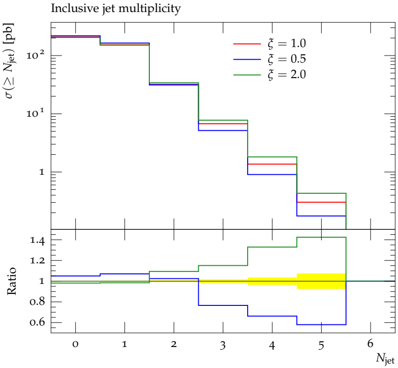


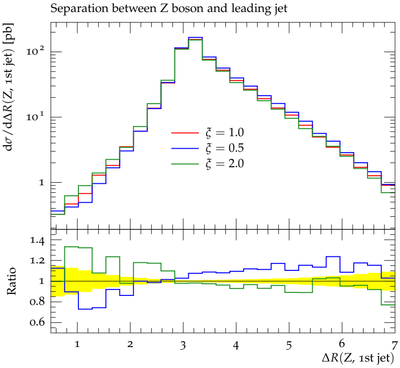
LO ME with parton shower to show effect on soft gluons.

Uncertainty estimates quite different.

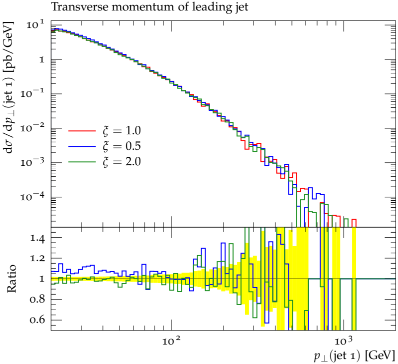
[SG, S. Plätzer, work in progress.]

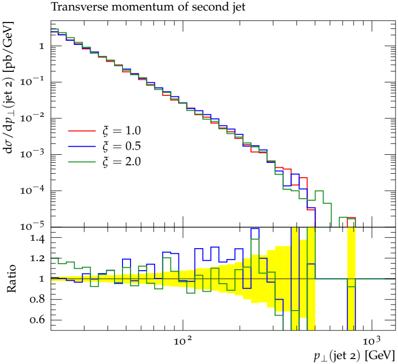
NLO matching scale





NLO matching scale





Uncertainty small but still sizable
with ME dominated observables.

Hadronization

Old school:

$$|\text{Pythia} - \text{Herwig}|$$

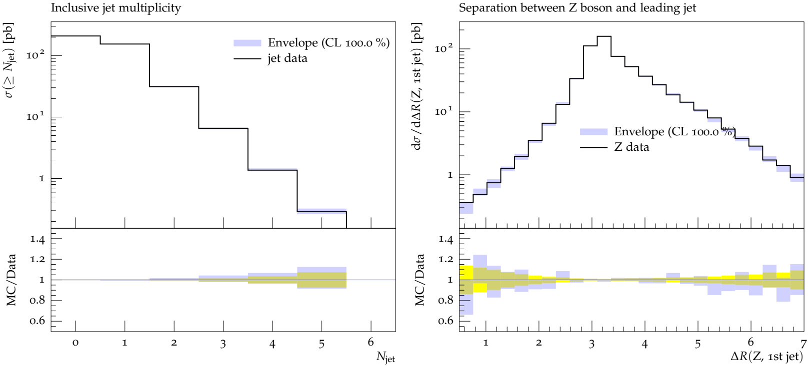
Completely non-perturbative, little insight on true theory error.

Some idea about sensitivity to data is obtained with eigentune variations (similar to pdf errors).

Size of variation some matter of taste.

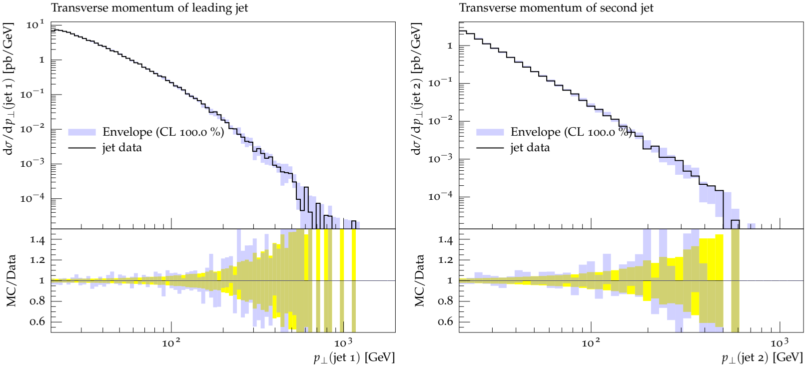
Caveat: only catches tuning uncertainty.

Hadronization



Little impact on jetty observables. Error too small?

Hadronization



Little impact on jetty observables. Error too small?

Hadronization

Little impact on jetty observables. Error too small?
To be taken with a large grain of salt.

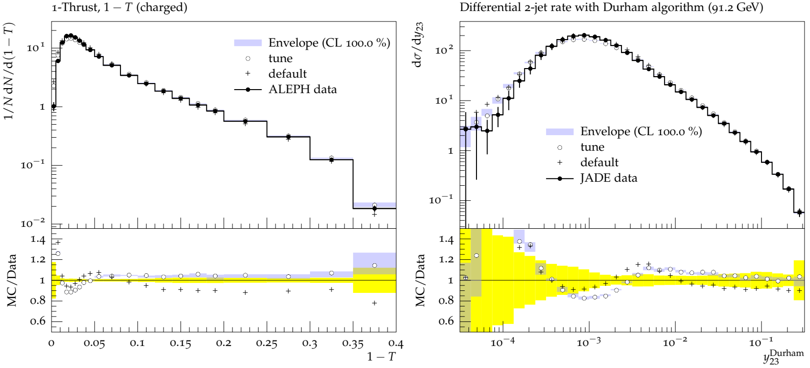
Size of bands somewhat arbitrary.
Needs multiple consistency checks.

Attempt to get real error estimate, though.

Our (jetty) observables:
Very small impact from hadronization.

Hadronization at LEP

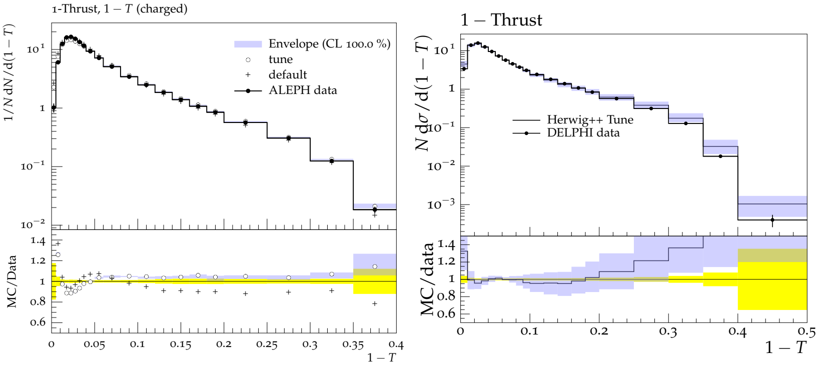
Comparison to Herwig++ dipole shower LEP ($q\bar{q}$ at NLO).



[N. Fischer, Master thesis, KIT 2013.]

Hard to believe such a small hadronization error.
Experience shows large sensitivity in low y_{ij} region.

Hadronization at LEP



[Richardson, Winn, EPJC C72, 2178]

Suggestion to choose $\Delta\chi^2 = 10$.

Underlying event

Situation similar to hadronization.

- Tuning errors (eigentunes)
- Alternatively, "tune" UE to

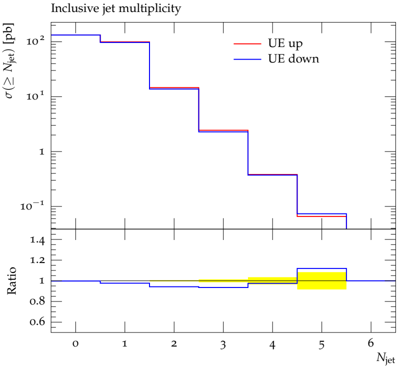
$$\text{data} + \sigma = (\text{UE up}), \qquad \text{data} - \sigma = (\text{UE down})$$

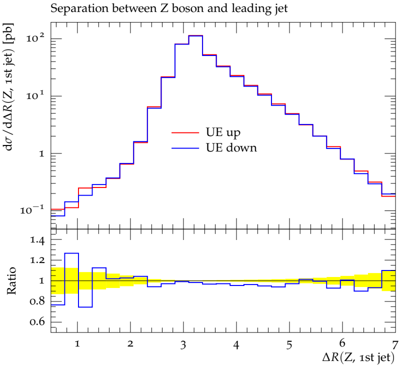
  Get error band from runs with these inputs.

(No real tune done here, varied $p_{\perp,\min}$ by eye, good enough).

Turning off UE may lead to crazy results.

Underlying event





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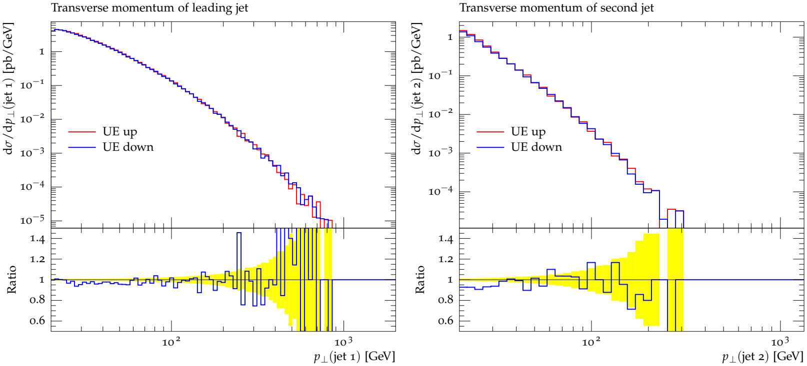
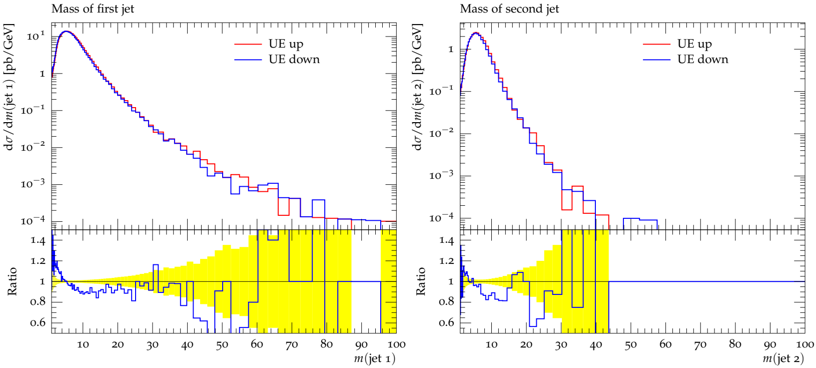


Sizable contribution from UE.

Underlying event



Sizable contribution from UE.

Conclusions

Many ways to estimate uncertainties from MCs themselves.

Perturbative domain offers various scales to vary.
Implications of subleading logarithms.

Non-perturbative physics largely tune-dependent.
Impact of parameter sensitivity by eigentune-like variations.