QCD effects in VBF/VBS

Simon Plätzer
Particle Physics — University of Vienna

at the
VBSCAN WG1 Periodic Meeting
Remote | 26 June 2020

If fixed order was enough

1992
NLO-QCD INCLUSIVE
hep-ph/9206246

2003
NLO-QCD
hep-ph/030610

2007
FULL NLO
0707.0381

2007
3 jets NLO QCD
hep-ph/0609075

2010
NNLO-QCD INCLUSIVE
1003.4451

2013
3 jets full NLO QCD
1308.2932

2015
NNLO-QCD
1506.02660

2016
N3LO-QCD INCLUSIVE
1606.00840

2018
3 jets NLO QCD checks of VBF approximation
1802.09955

2019
NNLO-QCD NON-FACTOR
1906.10899

Karlberg — Helsinki meeting
Additions by Plätzer

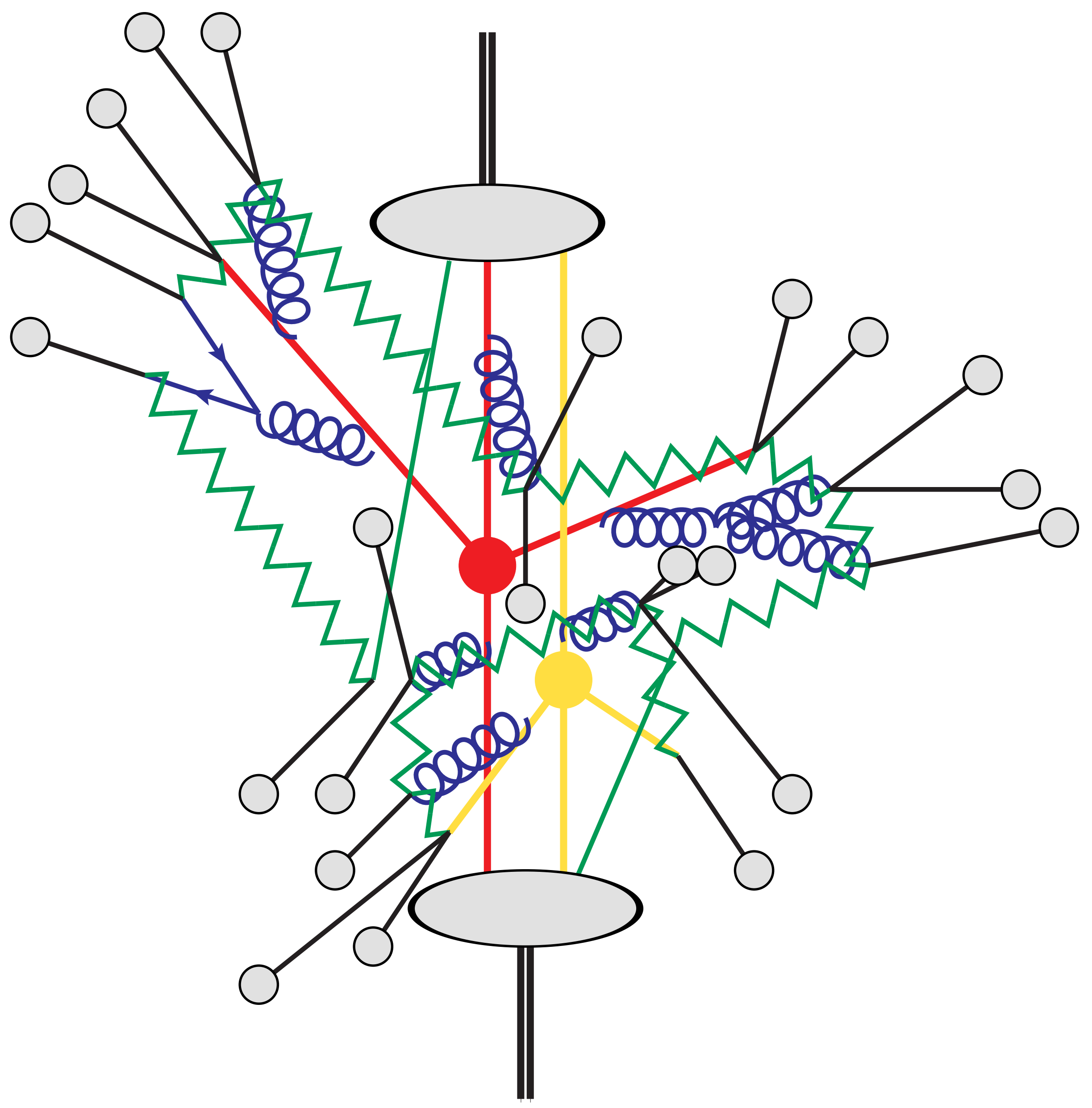
PP collisions are more complex

QCD description of collider reactions:
Complexity challenges precision.

Hard partonic scattering:
NLO QCD routinely

Jet evolution — parton showers:
NLL sometimes, mostly unclear

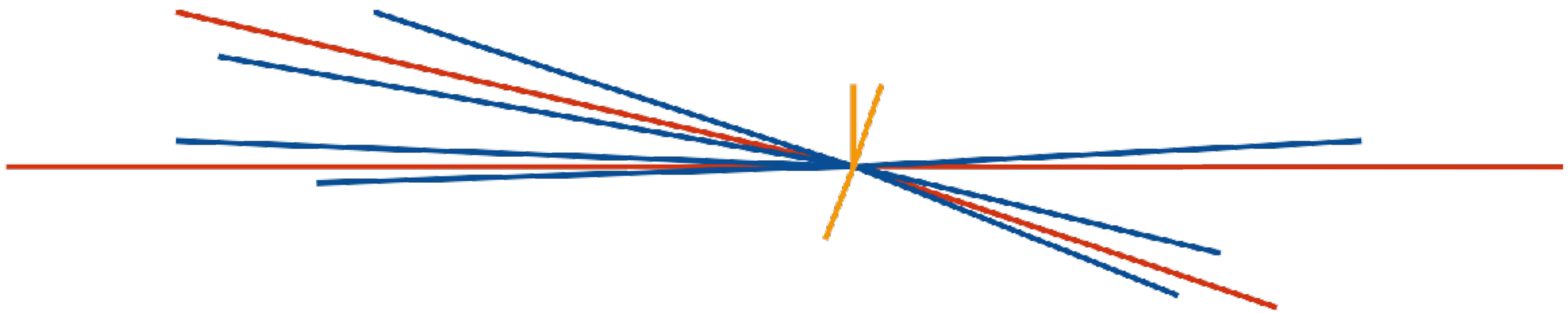
Multi-parton interactions
Hadronization



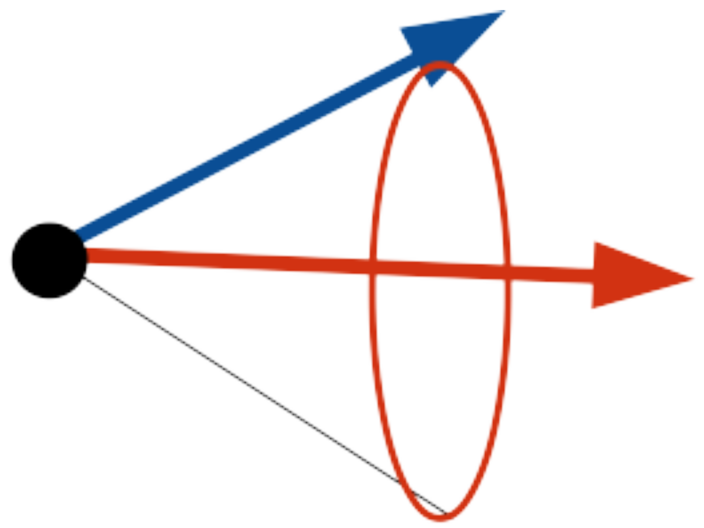
$$d\sigma \sim d\sigma_{\text{hard}}(Q) \times \text{PS}(Q \to \mu) \times \text{Had}(\mu \to \Lambda) \times \ldots$$

QCD Coherence

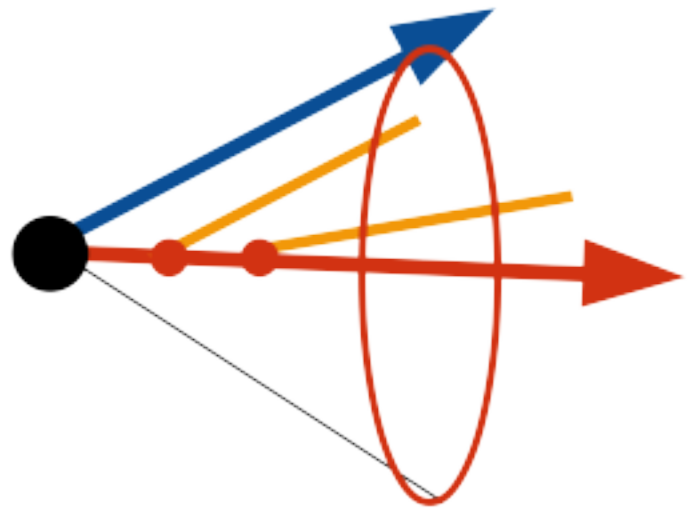
Coherent emission of soft large angle gluons from systems of collinear partons.



Central design behind parton branching algorithms, reason for global observables at NLL.



constructive interference
in each collinear region

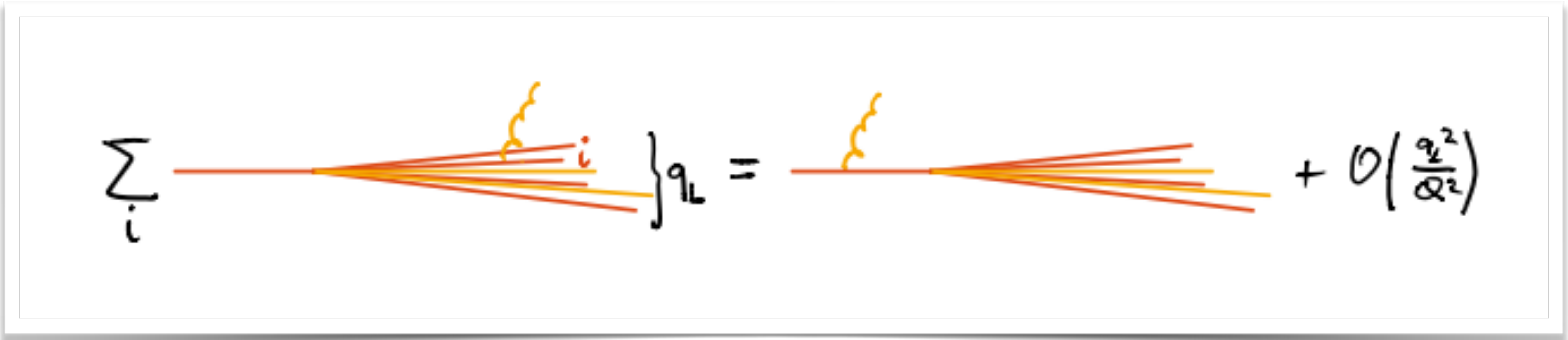


branchings
order in ~ angle

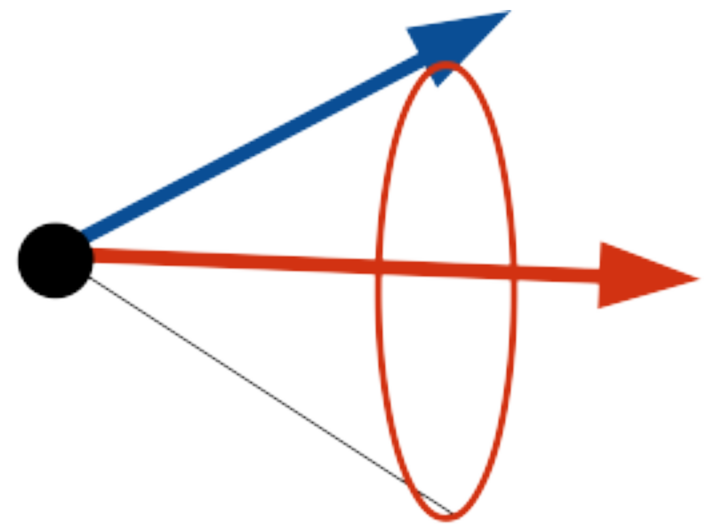
dipoles
order in ~ p_T

QCD Coherence

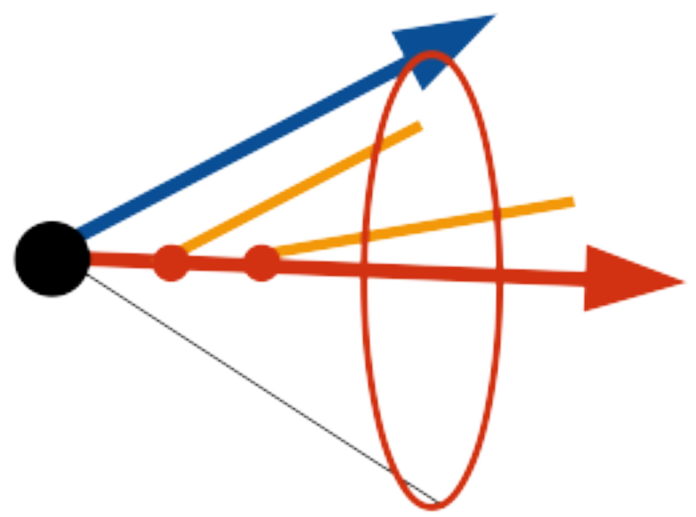
Coherent emission of soft large angle gluons from systems of collinear partons.



Central design behind parton branching algorithms, reason for global observables at NLL.



constructive interference
in each collinear region

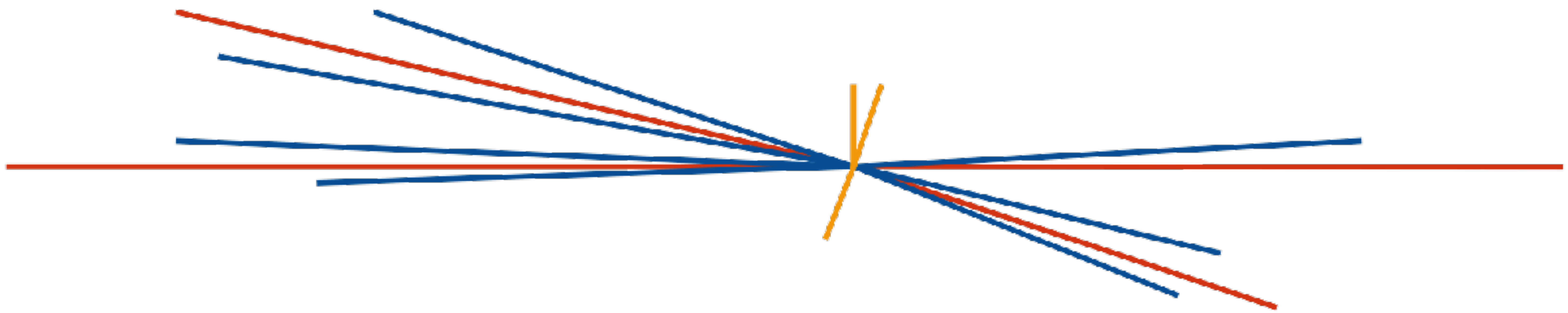


branchings
order in ~ angle

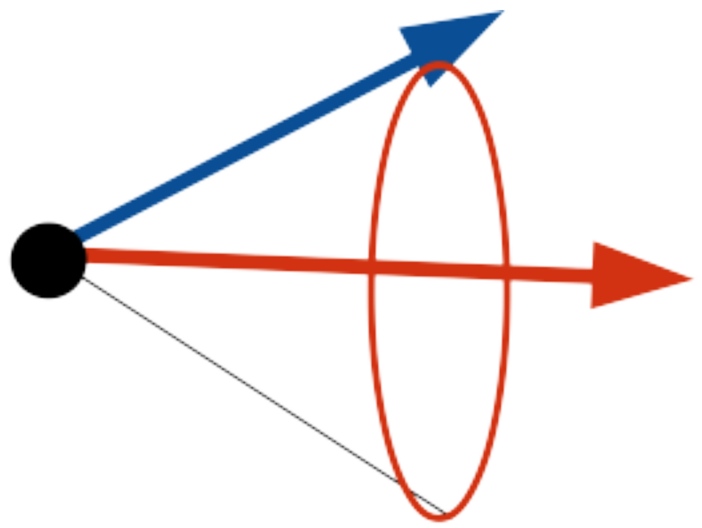
dipoles
order in ~ p_T

QCD Coherence

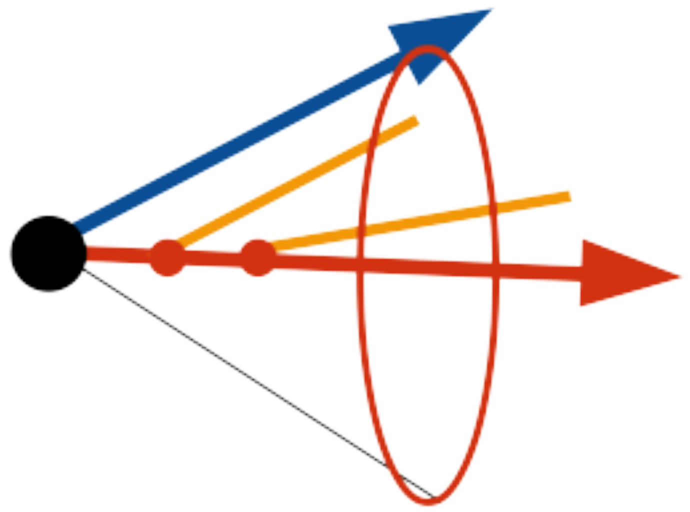
Coherent emission of soft large angle gluons from systems of collinear partons.



Central design behind parton branching algorithms, reason for global observables at NLL.



constructive interference
in each collinear region

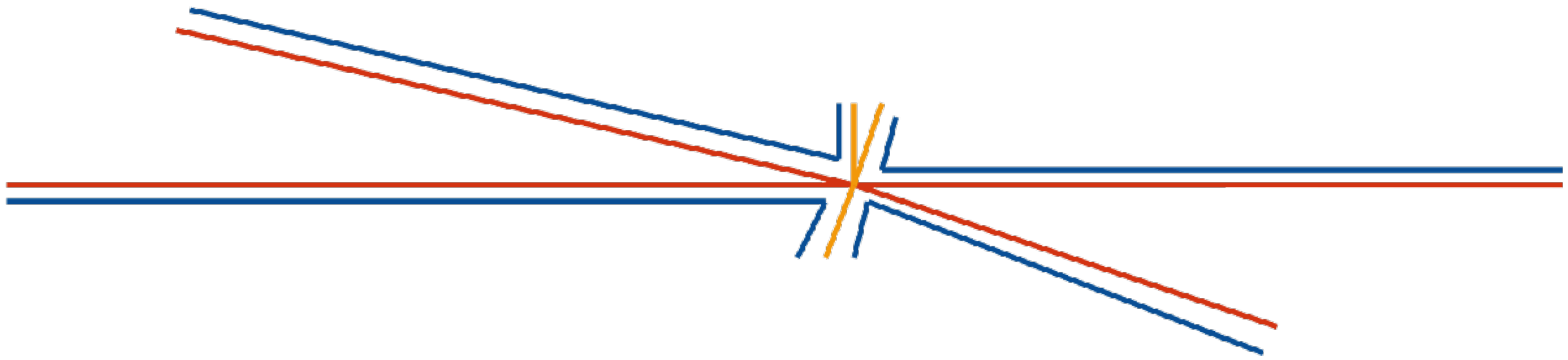


branchings
order in ~ angle

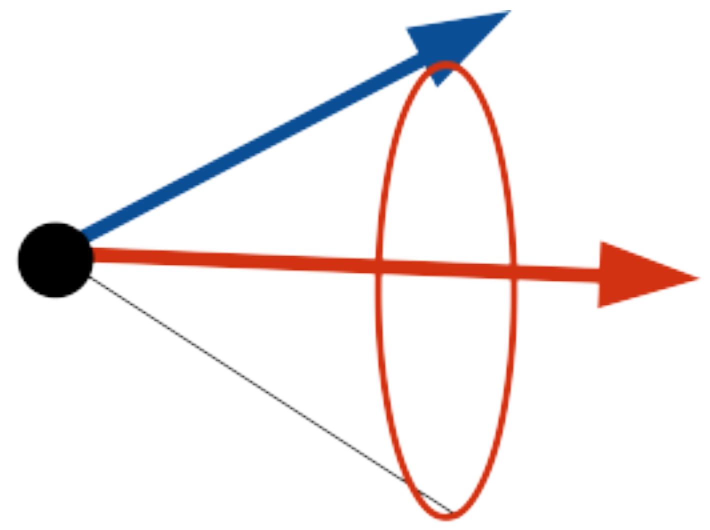
dipoles
order in ~ p_T

QCD Coherence

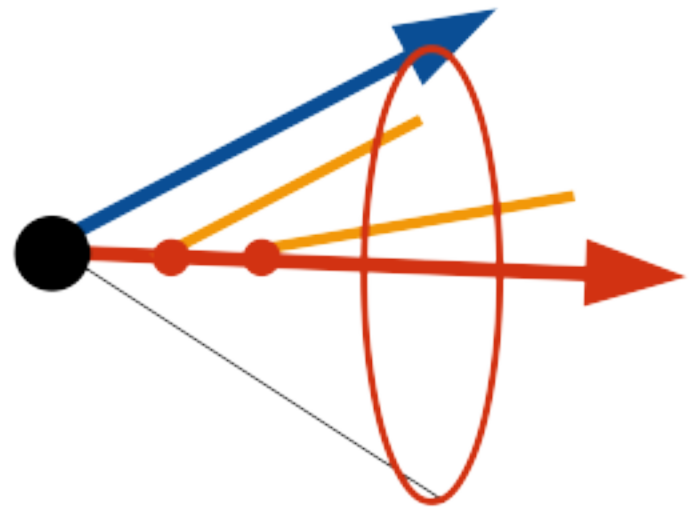
Coherent emission of soft large angle gluons from systems of collinear partons.



Central design behind parton branching algorithms, reason for global observables at NLL.



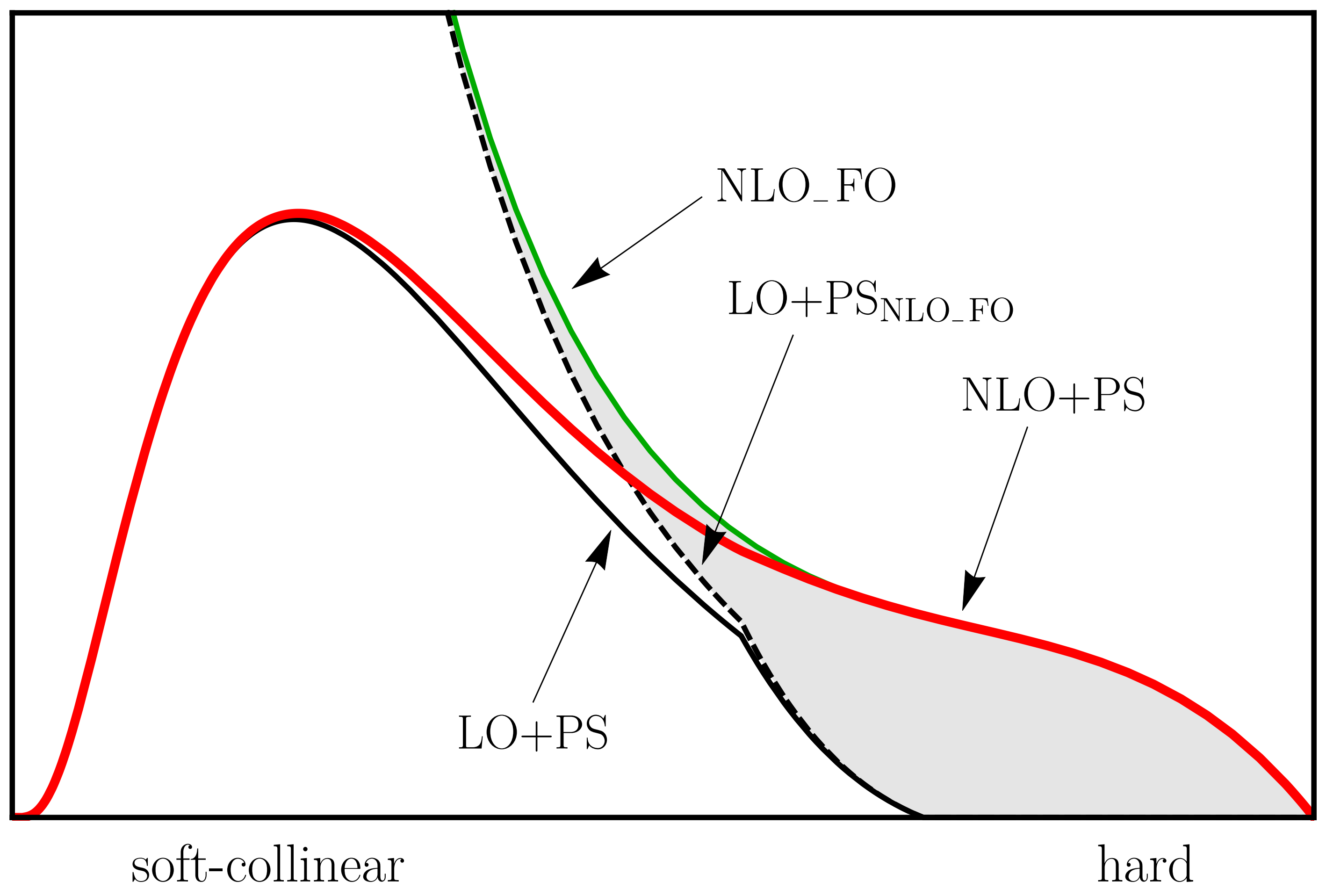
constructive interference
in each collinear region

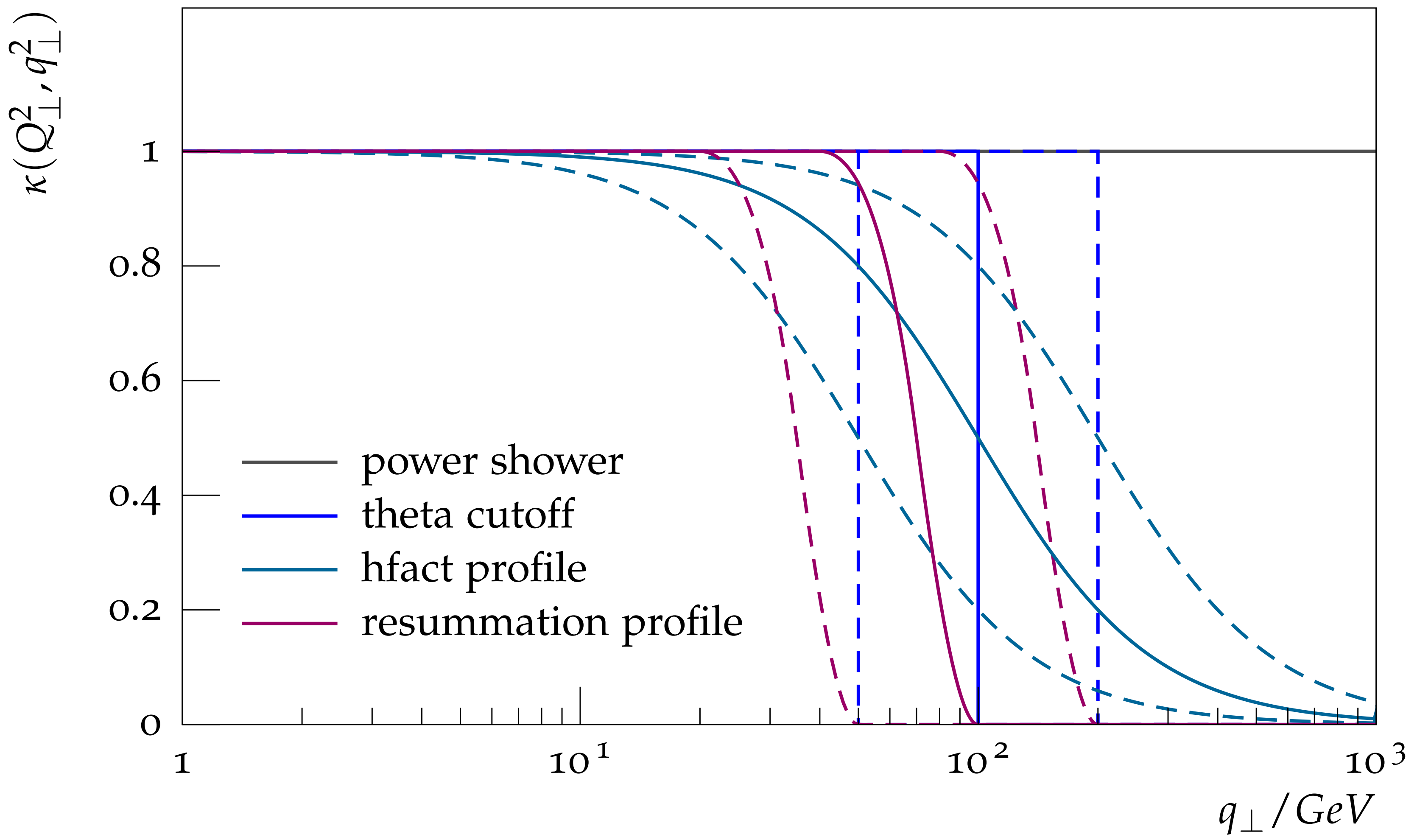


branchings
order in ~ angle

dipoles
order in ~ p_T

Fixed Order, Parton Showers and Variations

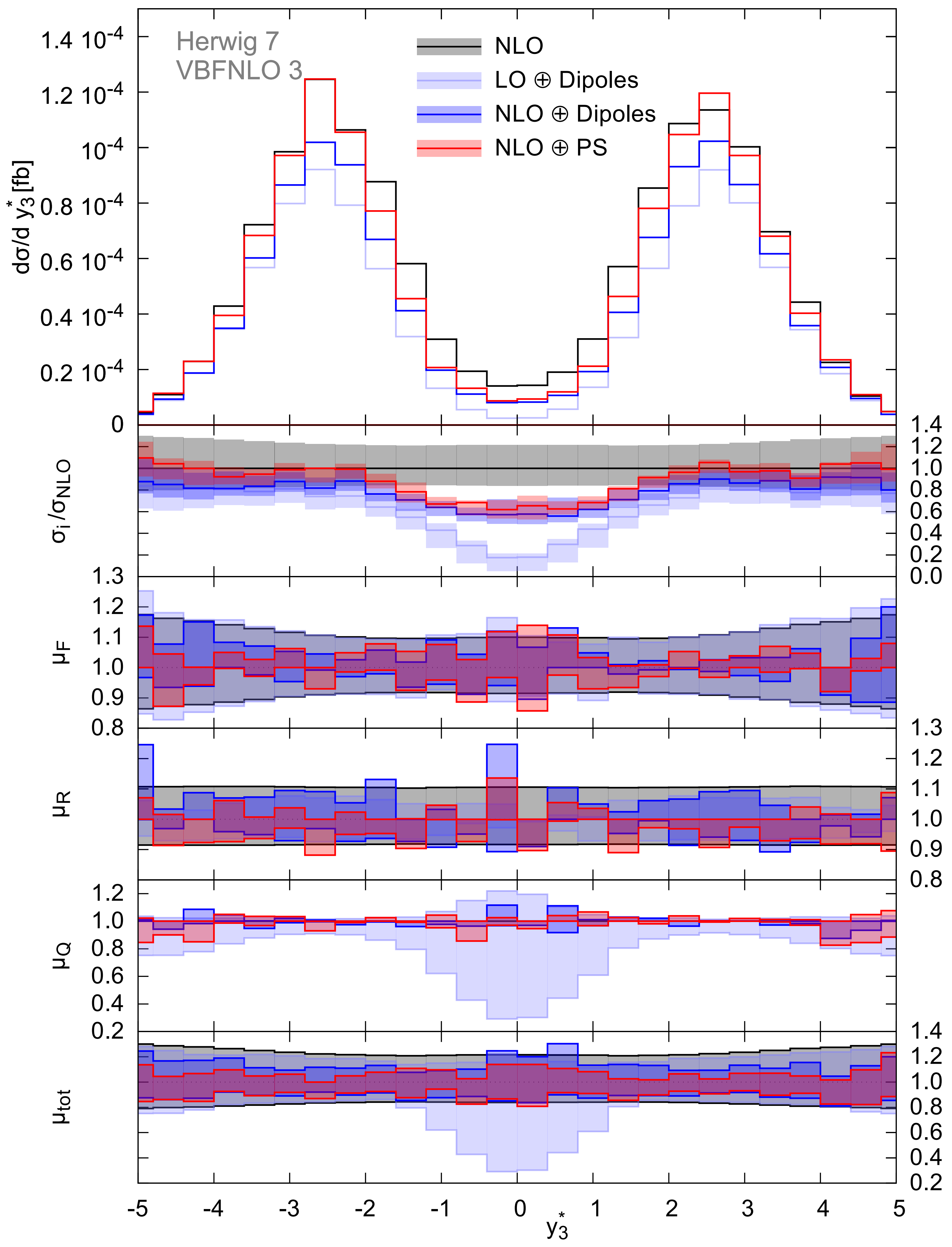




Need to switch off shower evolution at a scale of the order of the hard process scale.

As with all scale choices this is anything from unique.

Functional from of smearing has significant impact on reliability of hard scale variations.



[Rauch, Plätzer – EPJ C77 (2017) 293]

[Bellm, Nail, Plätzer, Schichtel, Siodmok – EPJ C76 (2016) 665]

[Rauch et al. For VBSCAN study – EPJ C78 (2018) 671]

Benchmarks for VBF Higgs production

universität wien

[Jäger, Karlberg, Plätzer, Scheller, Zaro — 2003.12435]

Jets $p_{\mathrm{T,j}} > 25\,\mathrm{GeV}$ $|\eta_{\mathrm{j}}| < 4.5$ **Scale** $\mu_0^2 = \frac{M_{\mathrm{H}}}{2}\sqrt{\left(\frac{M_{\mathrm{H}}}{2}\right)^2 + p_{T,H}^2}$

Baseline: tight VBF selection $\eta_{j_1} \cdot \eta_{j_2} < 0$ $|\Delta\eta_{\mathrm{j_1 j_2}}| > 4.5$ $m_{\mathrm{j_1 j_2}} > 600\,\mathrm{GeV}$

Loose selection to test impact of VBF approximation $|\Delta\eta_{j_1 j_2}| > 1$ $m_{j_1 j_2} > 200$ GeV

Plethora of matching and shower setups

generator	matching	SMC	shower recoil	used in Sec. 4.2
VBFNLO+Herwig7/Matchbox	$\oplus$	HERWIG 7.1.5	global ($\tilde{q}$) / local (dipole)	✓ ($\tilde{q}$)
HJets+Herwig7/Matchbox	$\oplus$	HERWIG 7.1.5	global ($\tilde{q}$) / local (dipole)	
MadGraph5_aMC@NLO 2.6.1	$\oplus$	HERWIG 7.1.2	global	✓
MadGraph5_aMC@NLO 2.6.1	$\oplus$	PYTHIA 8.230	global	
POWHEG BOX V2	$\otimes$	PYTHIA 8.240	local (dipole)	✓
POWHEG BOX V2	$\otimes$	PYTHIA 8.240	global	
POWHEG BOX V2	$\otimes$	HERWIG 7.1.4	global ($\tilde{q}$)	

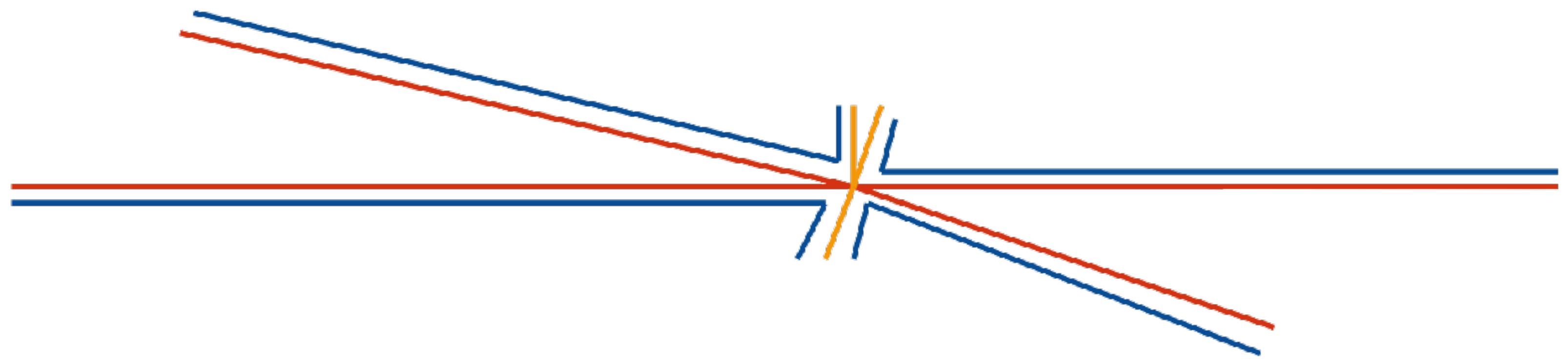
Comparison between tools

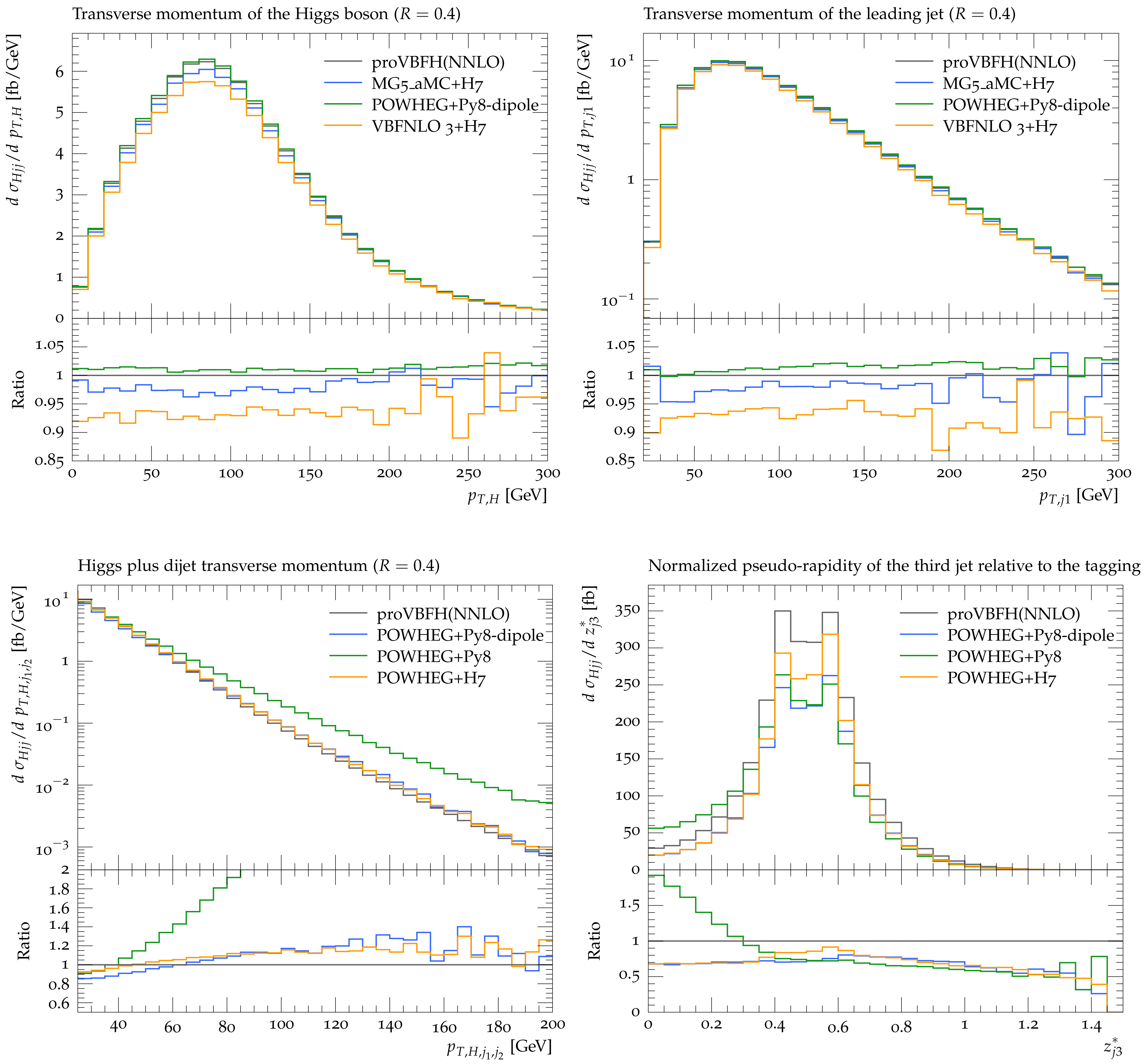
[Jäger, Karlberg, Plätzer, Scheller, Zaro — 2003.12435]

Different setups agree well in tight VBF selection, if colour flow respected.

Herwig seems somewhat less 'jetty', but all consistent within 10%, shapes of hard spectra not altered.

Pythia global recoil not compatible with other results. Pythia dipole recoil NLO matching only available via Powheg.



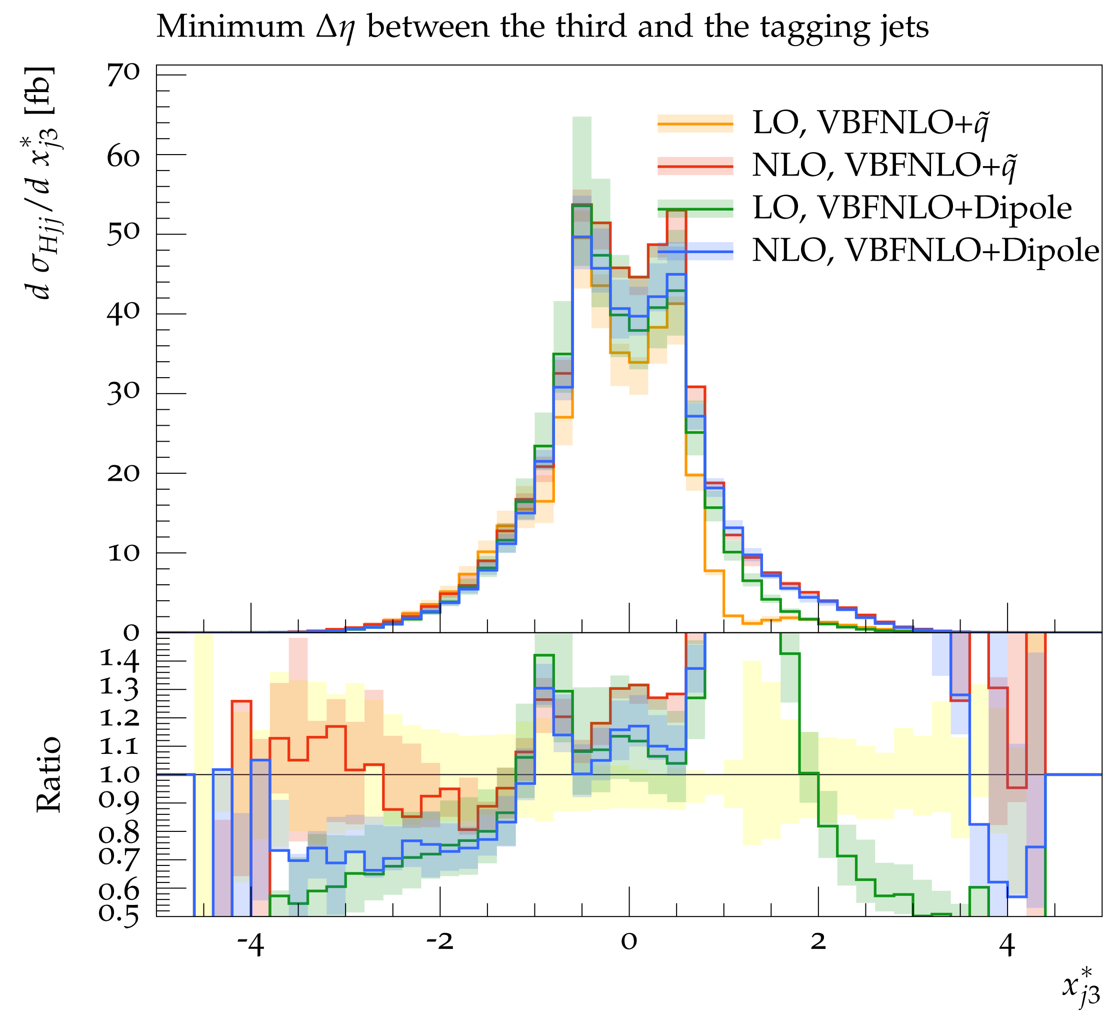


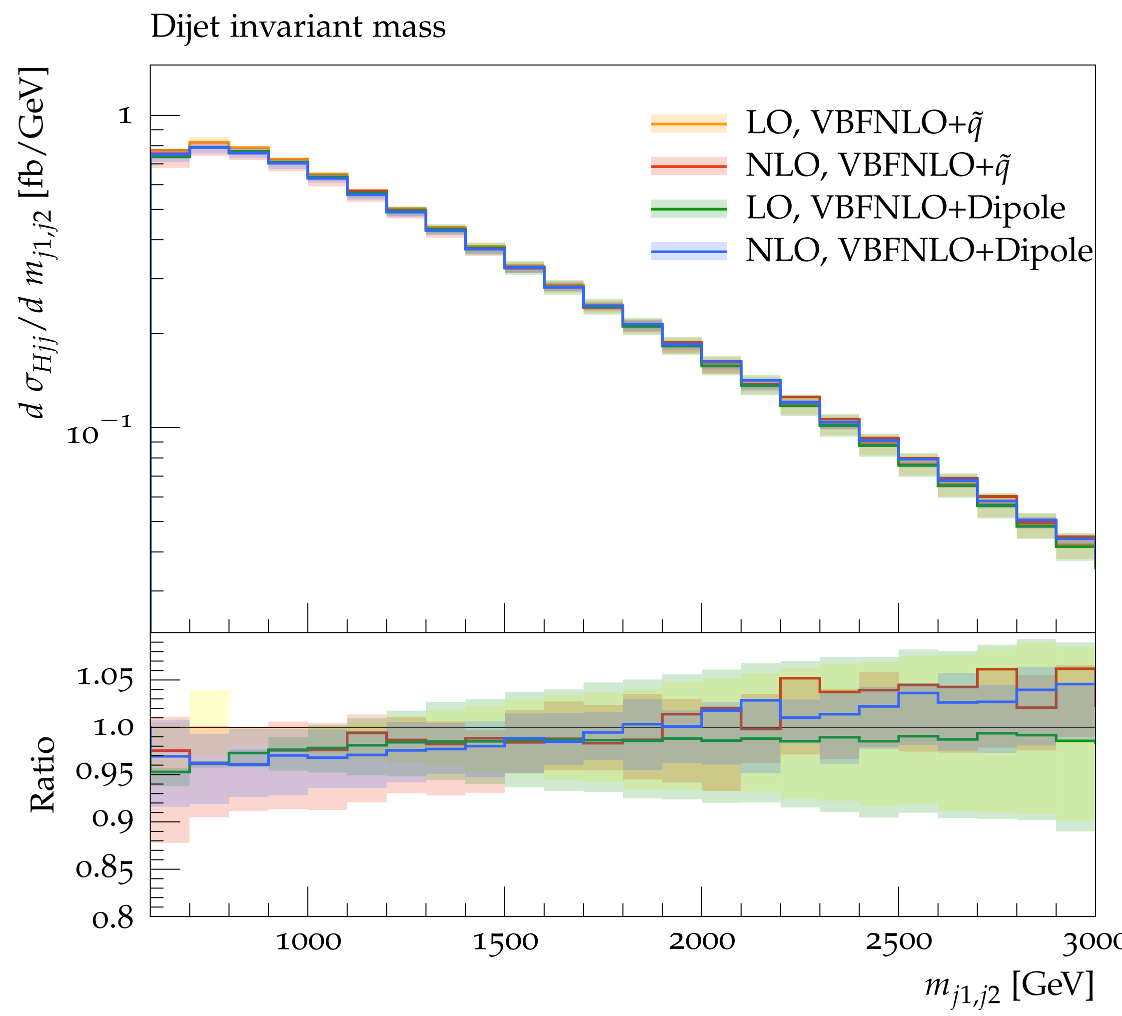
Shower Variations and Jet Radius Dependence

[Jäger, Karlberg, Plätzer, Scheller, Zaro — 2003.12435]

Still significant shower variations shedding light on jet activity after showering, otherwise distributions stable at NLO+PS.

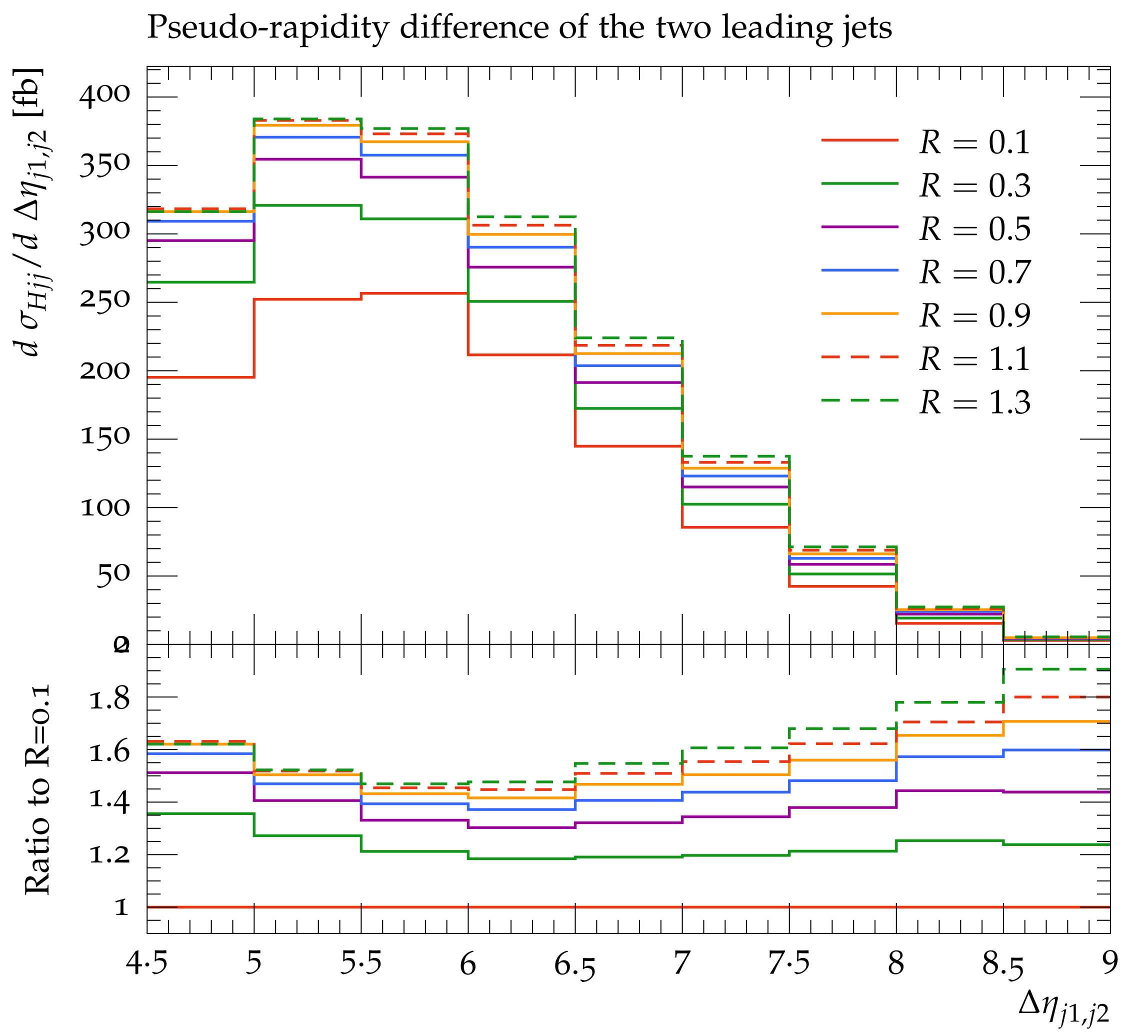
More careful investigation of shower scale profiles and cut migration needed.

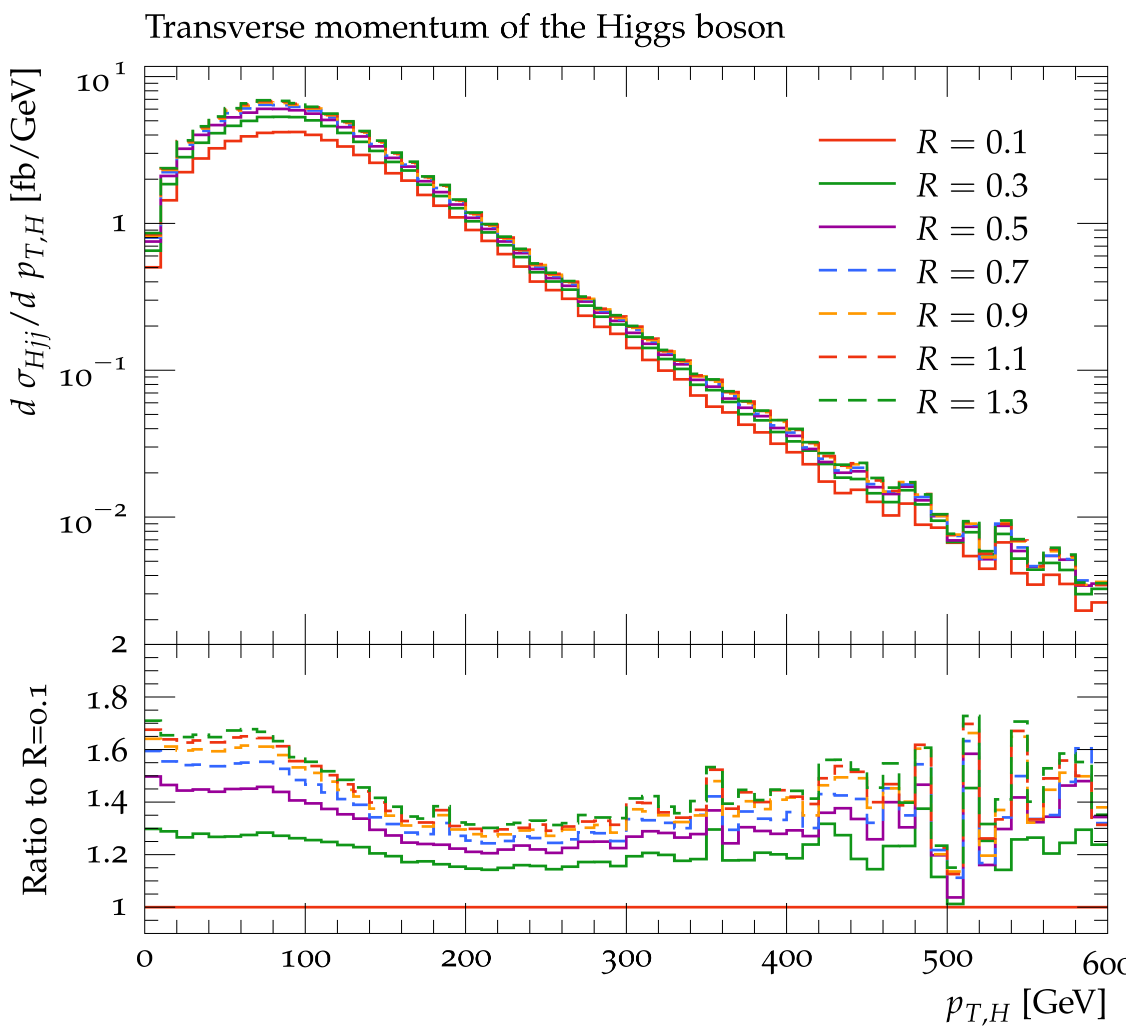




Jet radius dependence shows expected perturbative behaviour.

Need to confront with perturbative variations and soft QCD.





Perturbative scales and R see LH jet study
[Bellm et al. — EPJ C80 (2020) 93]

Shower Variations and Jet Radius Dependence

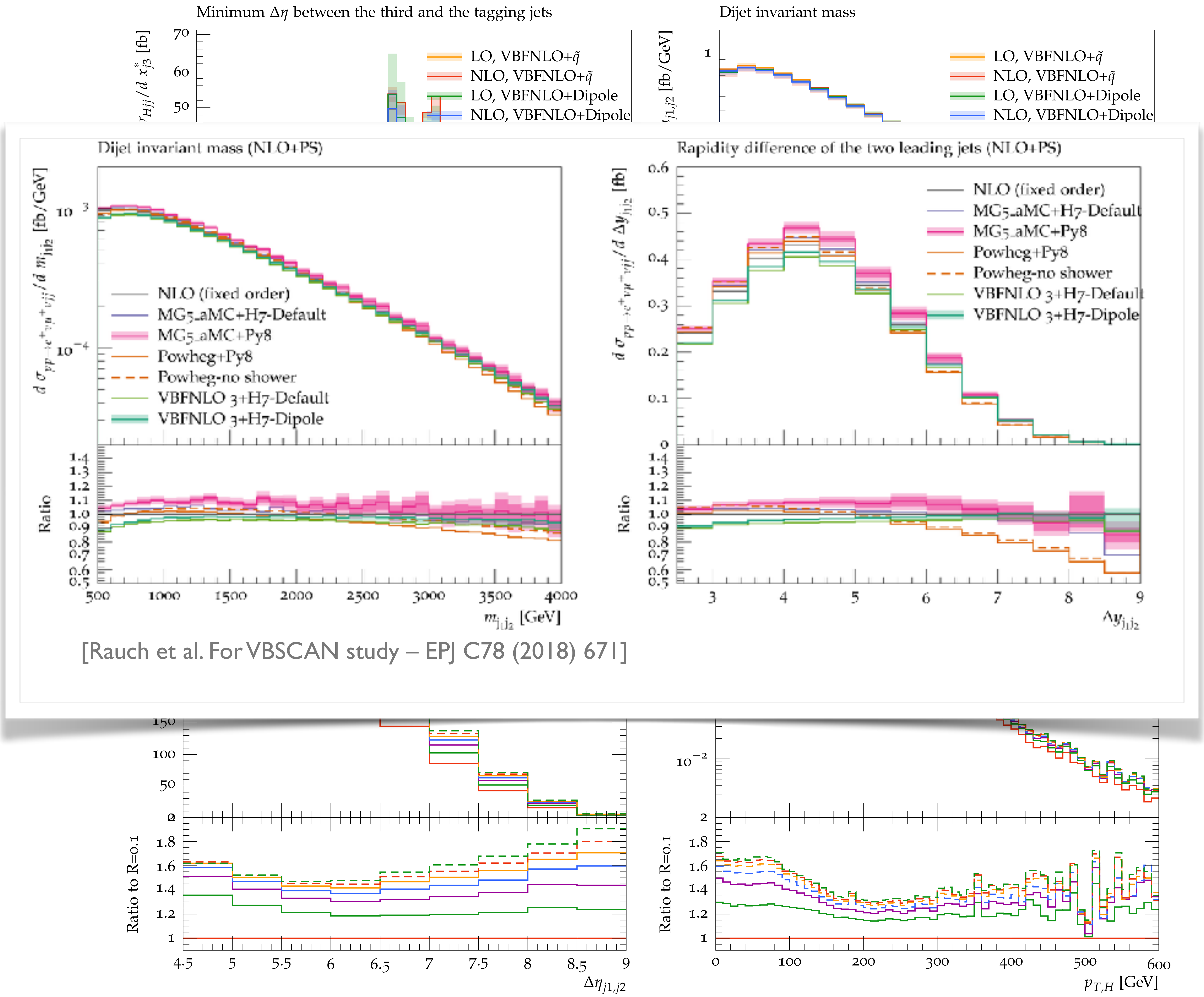
[Jäger, Karlberg, Plätzer, Scheller, Zaro — 2003.12435]

Still significant shower variations shedding light on jet activity after showering, otherwise distributions stable at NLO+PS.

More careful investigation of shower scale profiles and cut migration needed.

Jet radius dependence shows expected perturbative behaviour.

Need to confront with perturbative variations and soft QCD.



[Rauch et al. For VBSCAN study – EPJ C78 (2018) 671]

Perturbative scales and R see LH jet study
[Bellm et al. — EPJ C80 (2020) 93]

Shower Variations and Jet Radius Dependence

Still significant shower variations shedding light on jet activity after showering, otherwise distributions stable at NLO+PS.

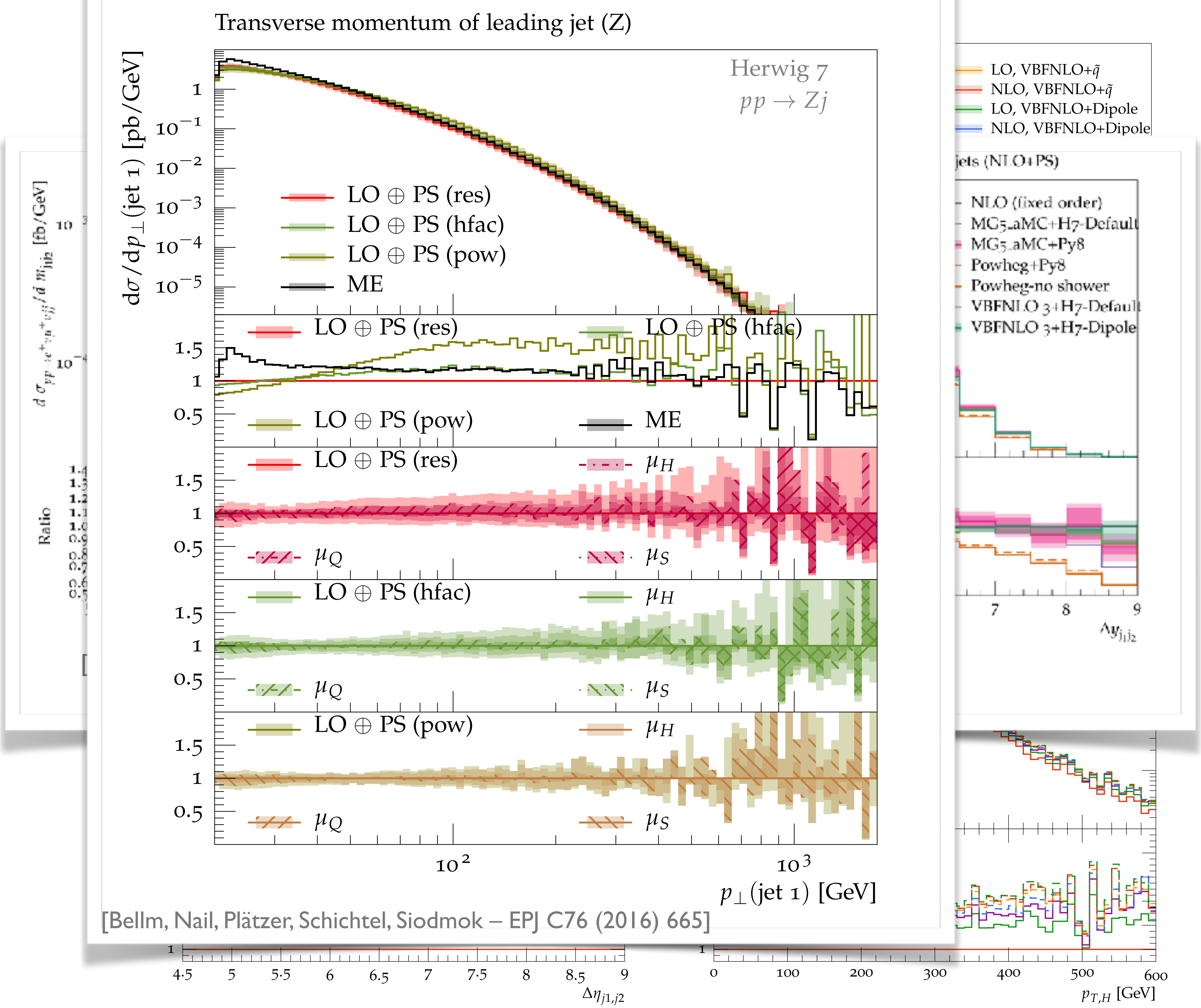
More careful investigation of shower scale profiles and cut migration needed.

Jet radius dependence shows expected perturbative behaviour.

Need to confront with perturbative variations and soft QCD.

Perturbative scales and R see LH jet study
[Bellm et al. — EPJ C80 (2020) 93]

[Jäger, Karlberg, Plätzer, Scheller, Zaro — 2003.12435]



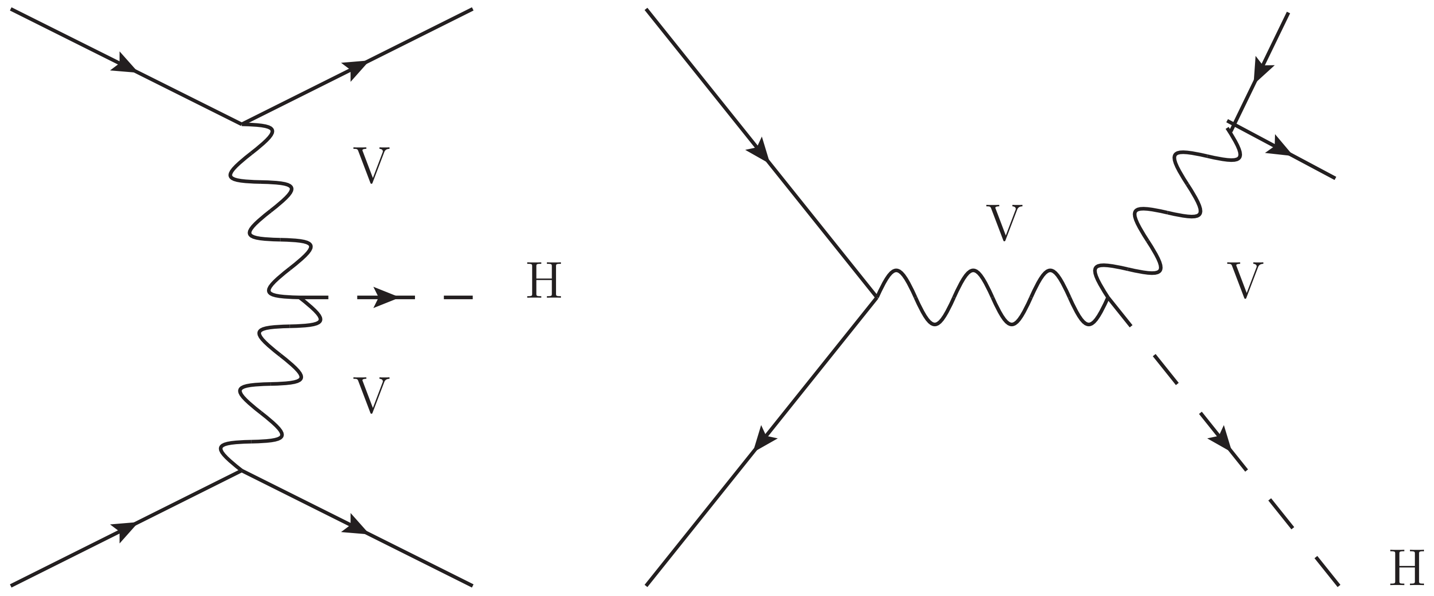
[Bellm, Nail, Plätzer, Schichtel, Siodmok – EPJ C76 (2016) 665]

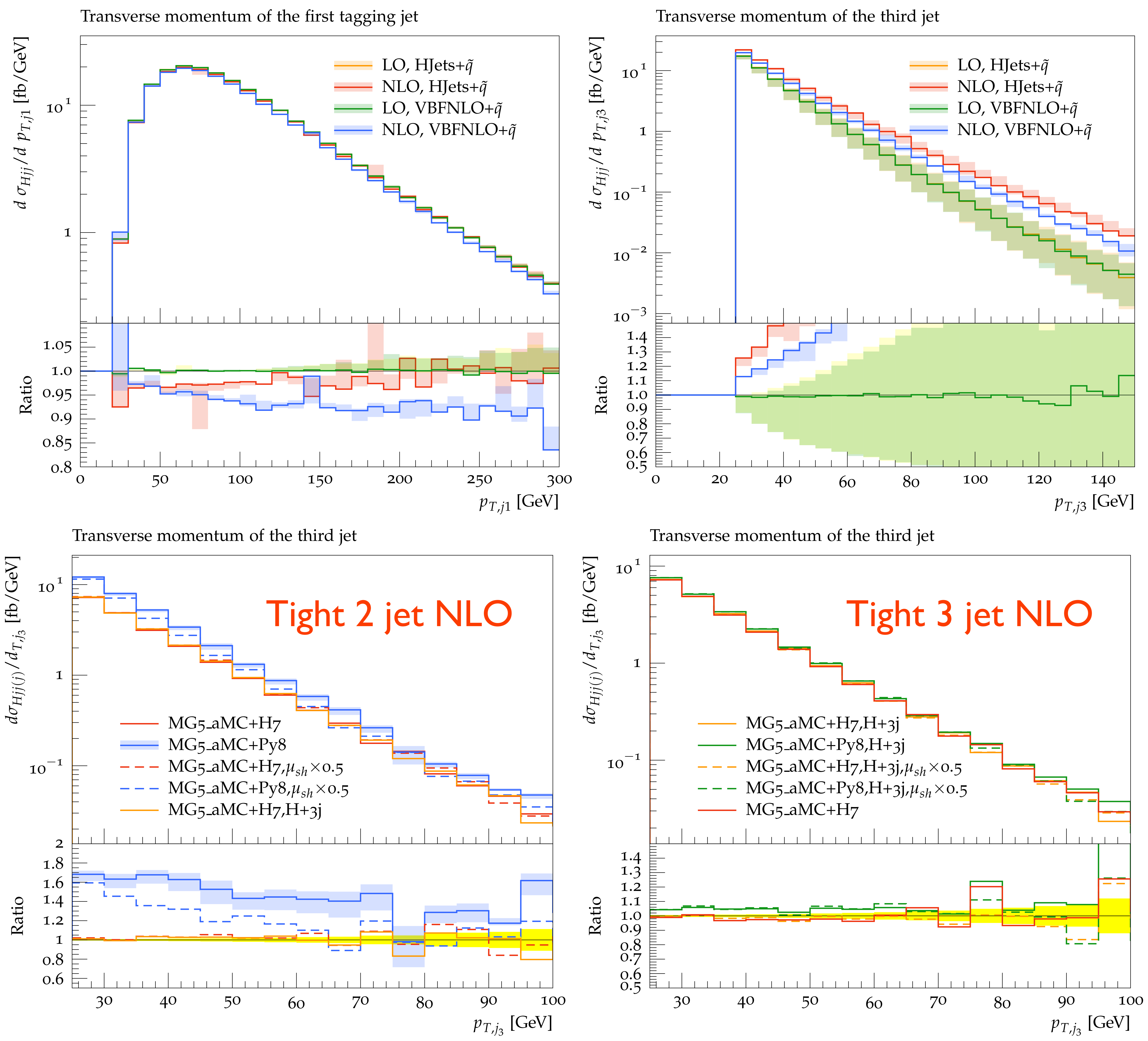
Third Jet & Impact of VBF Approximation

[Jäger, Karlberg, Plätzer, Scheller, Zaro — 2003.12435]

In loose setup we see significant deviations between VBF approximation and full calculation available from HJets + Herwig 7 / Matchbox.

$$|\Delta\eta_{j_1 j_2}| > 1 \qquad m_{j_1 j_2} > 200\ \text{GeV}$$



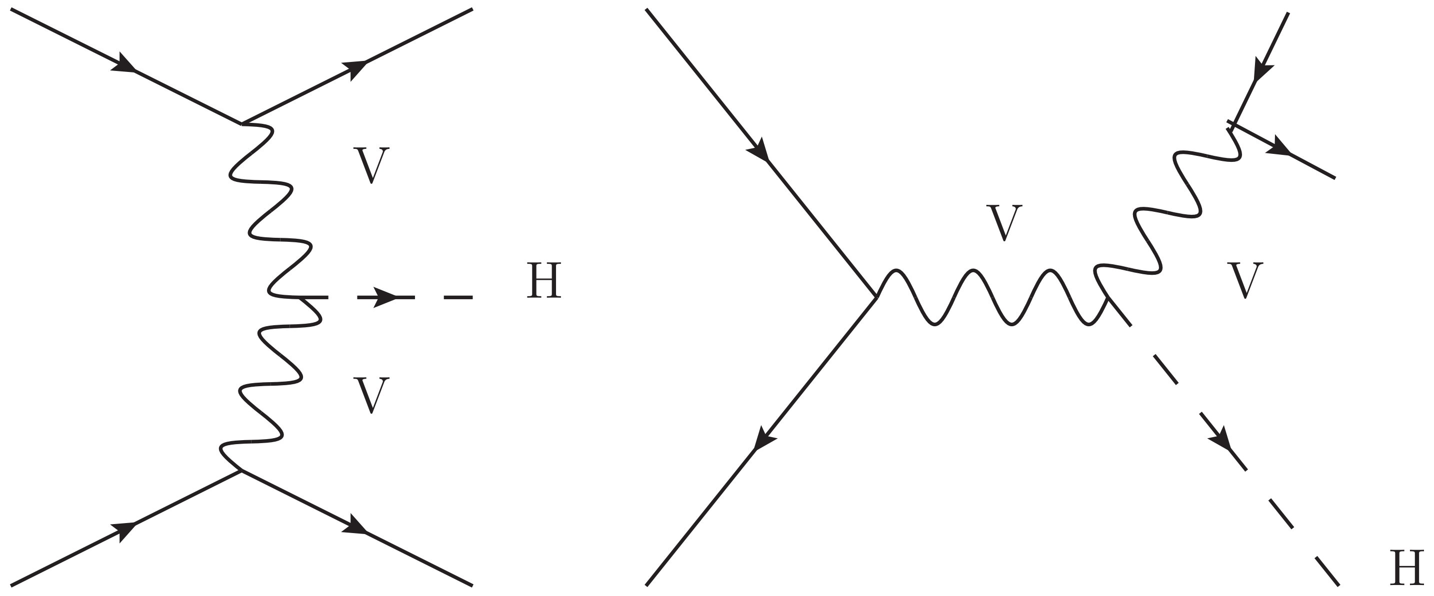


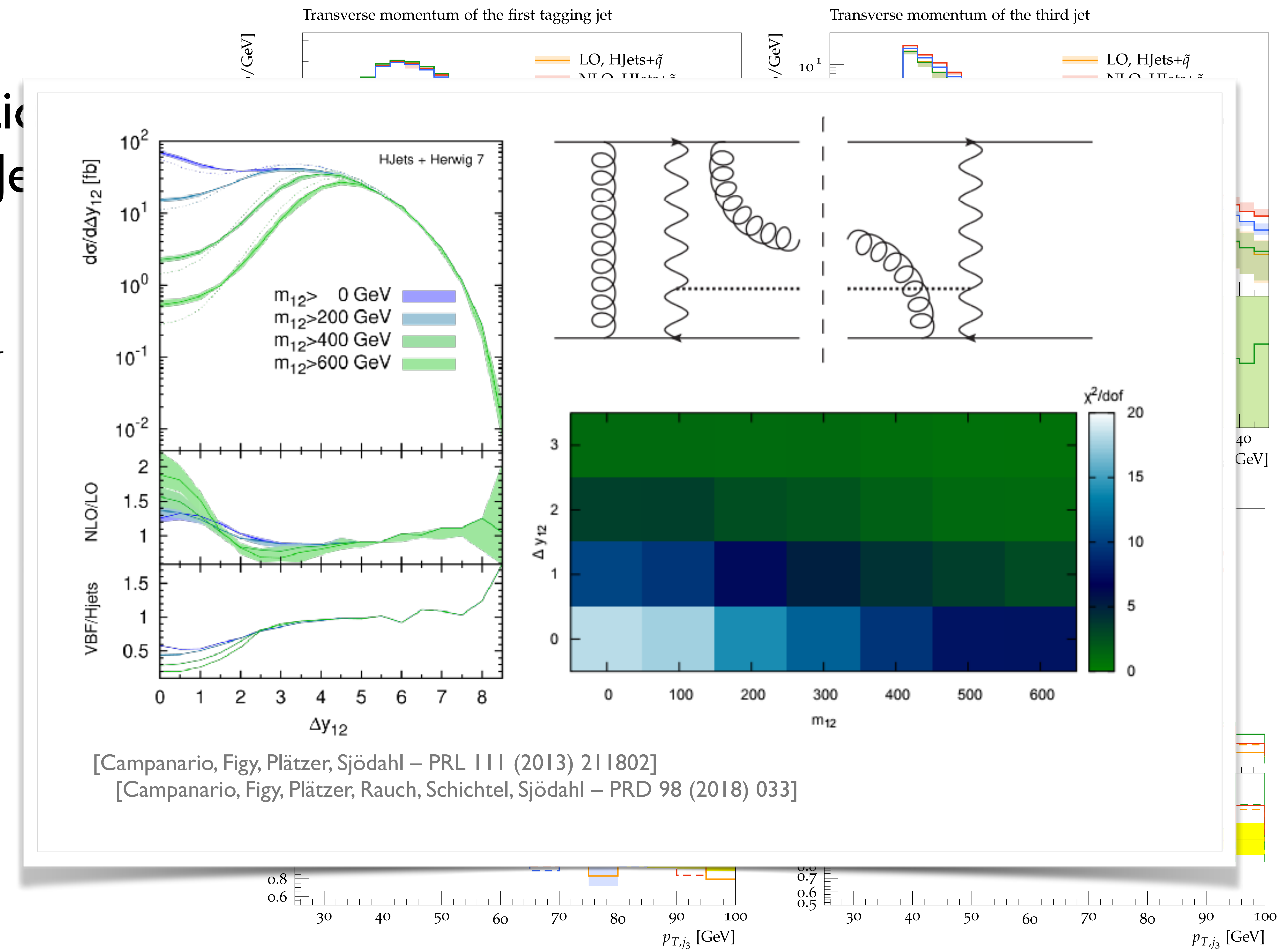
Third Jet & Impact of VBF Approximation

[Jäger, Karlberg, Plätzer, Scheller, Zaro — 2003.12435]

In loose setup we see significant deviations between VBF approximatio[n] and full calculation available from HJe[ts] Herwig 7 / Matchbox.

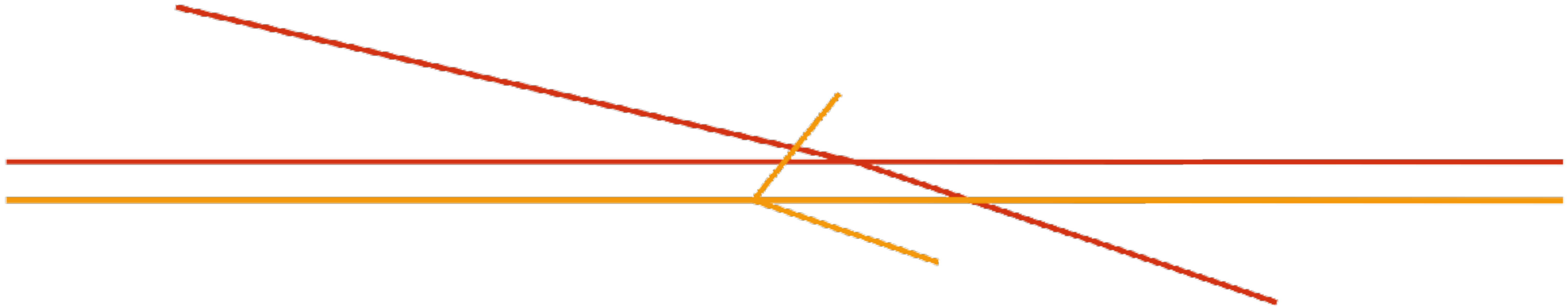
$$|\Delta\eta_{j_1 j_2}| > 1 \qquad m_{j_1 j_2} > 200\ \text{GeV}$$





[Campanario, Figy, Plätzer, Sjödahl – PRL 111 (2013) 211802]
[Campanario, Figy, Plätzer, Rauch, Schichtel, Sjödahl – PRD 98 (2018) 033]

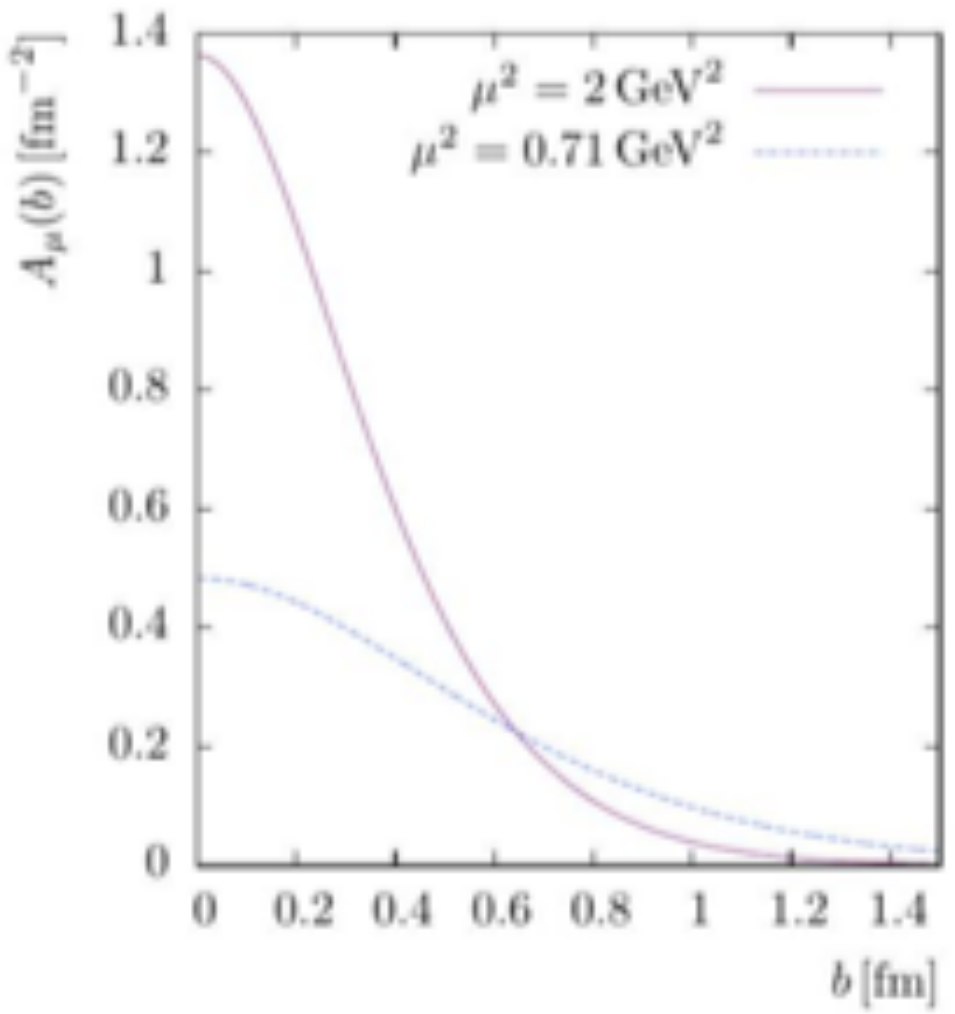
MPI & Colour Reconnection

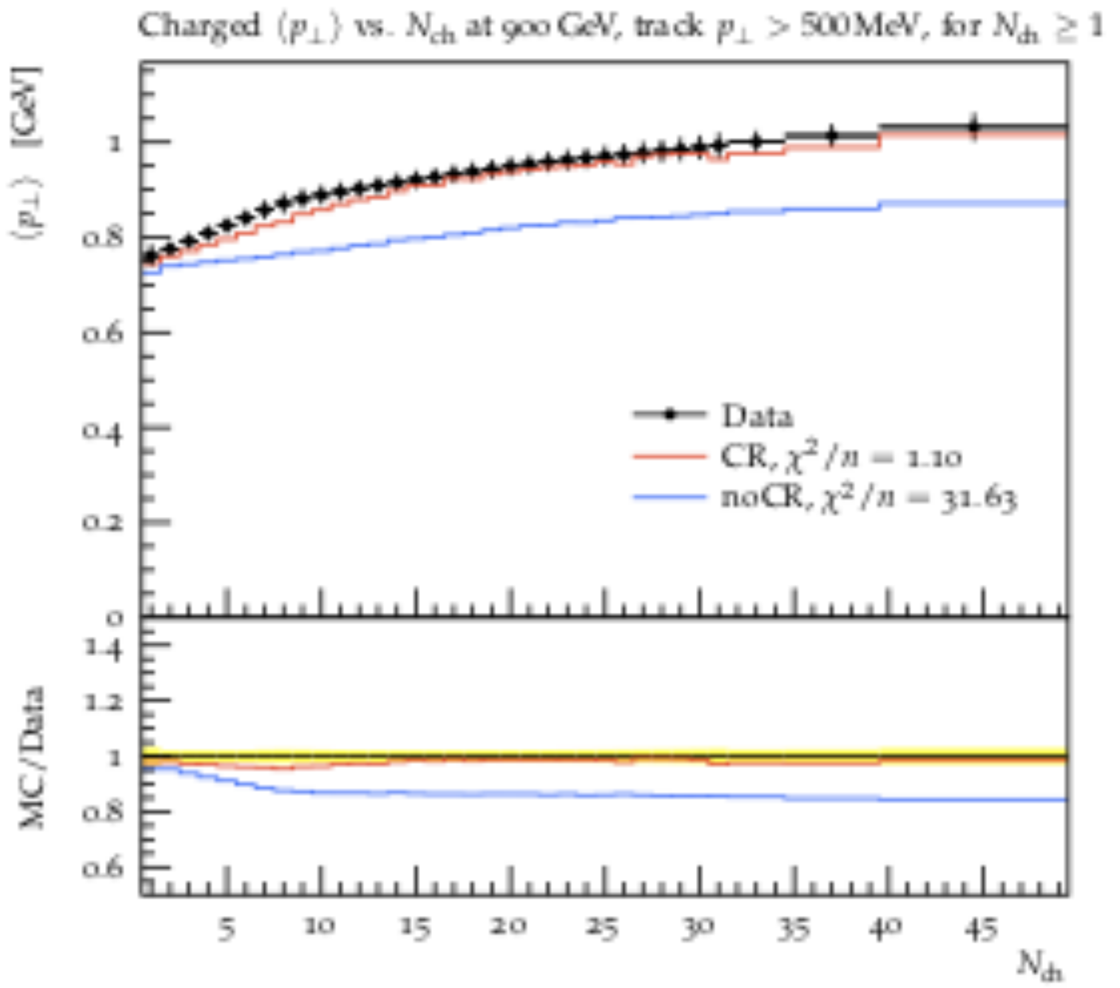


Assume some matter distribution in the proton, and effective multiplicity distribution of additional scatters.

Colour reconnection crucial to describe MinBias and UE data: lack of knowledge about colour correlations.

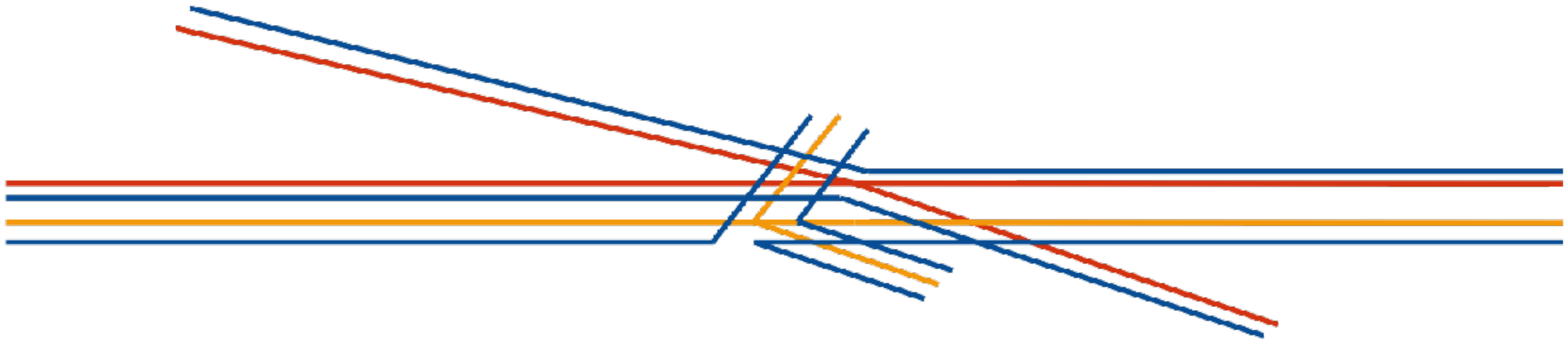
[Gieseke, Kirchgaesser, Plätzer – EPJ C 78 (2018) 99]





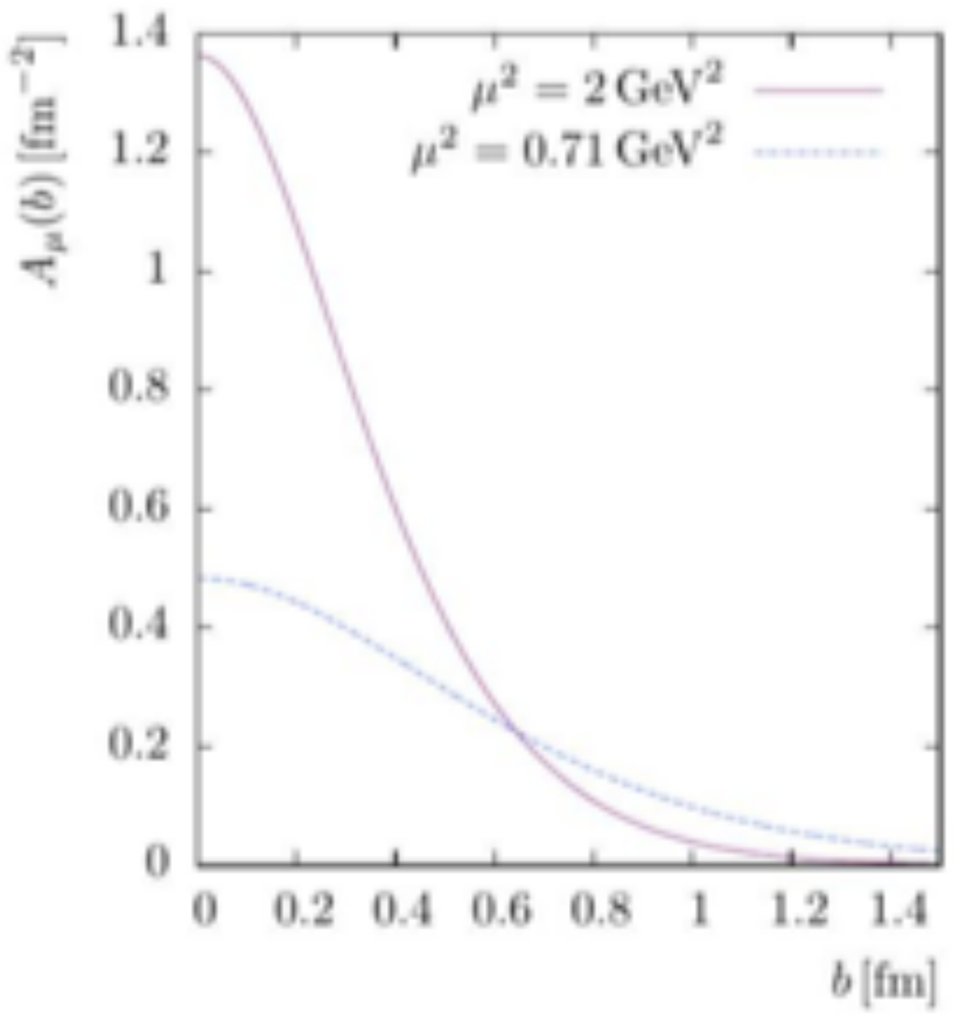
[Gieseke, Röhr, Siodmok – EPJ C 72 (2012) 2225]

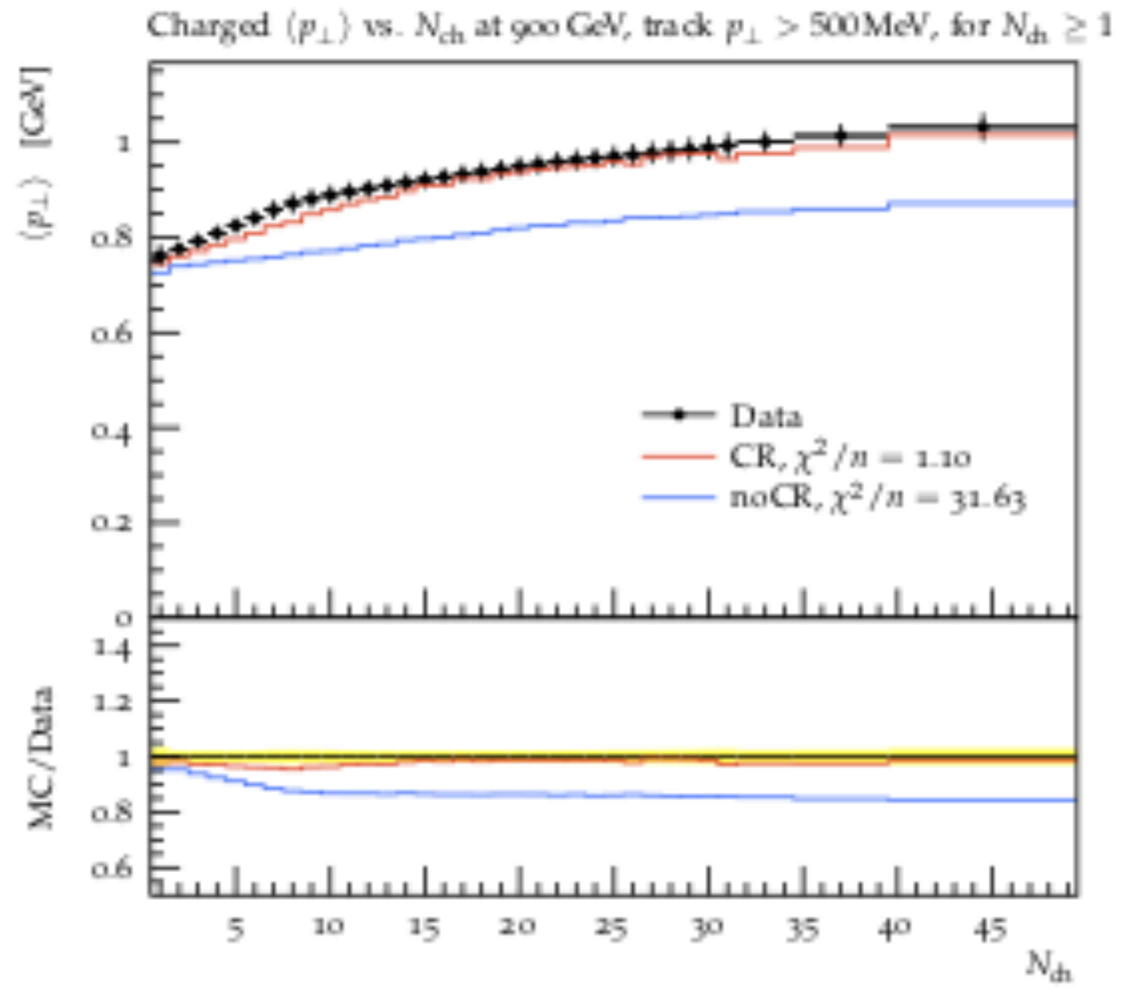
MPI & Colour Reconnection



Assume some matter distribution in the proton, and effective multiplicity distribution of additional scatters.

Colour reconnection crucial to describe MinBias and UE data: lack of knowledge about colour correlations.

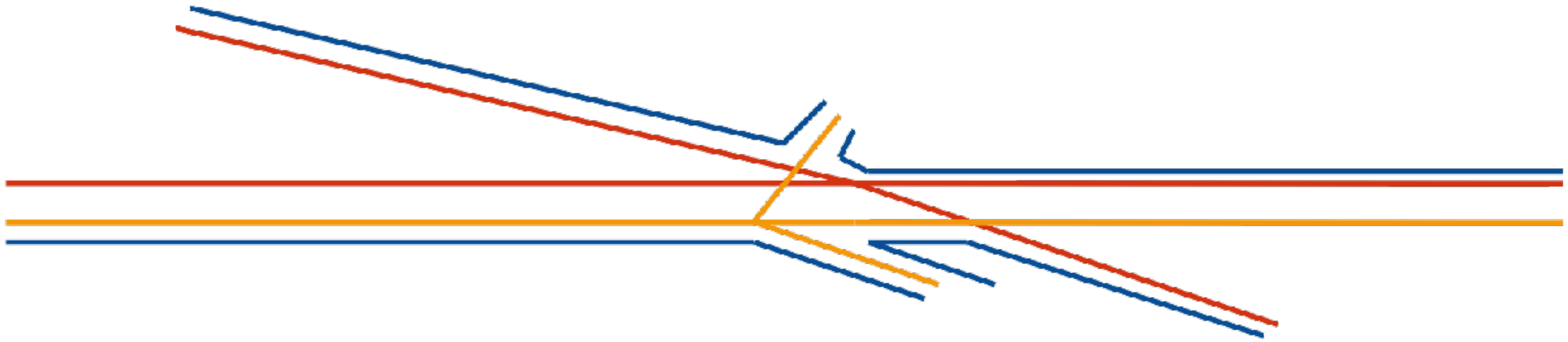




[Gieseke, Kirchgaesser, Plätzer – EPJ C 78 (2018) 99]

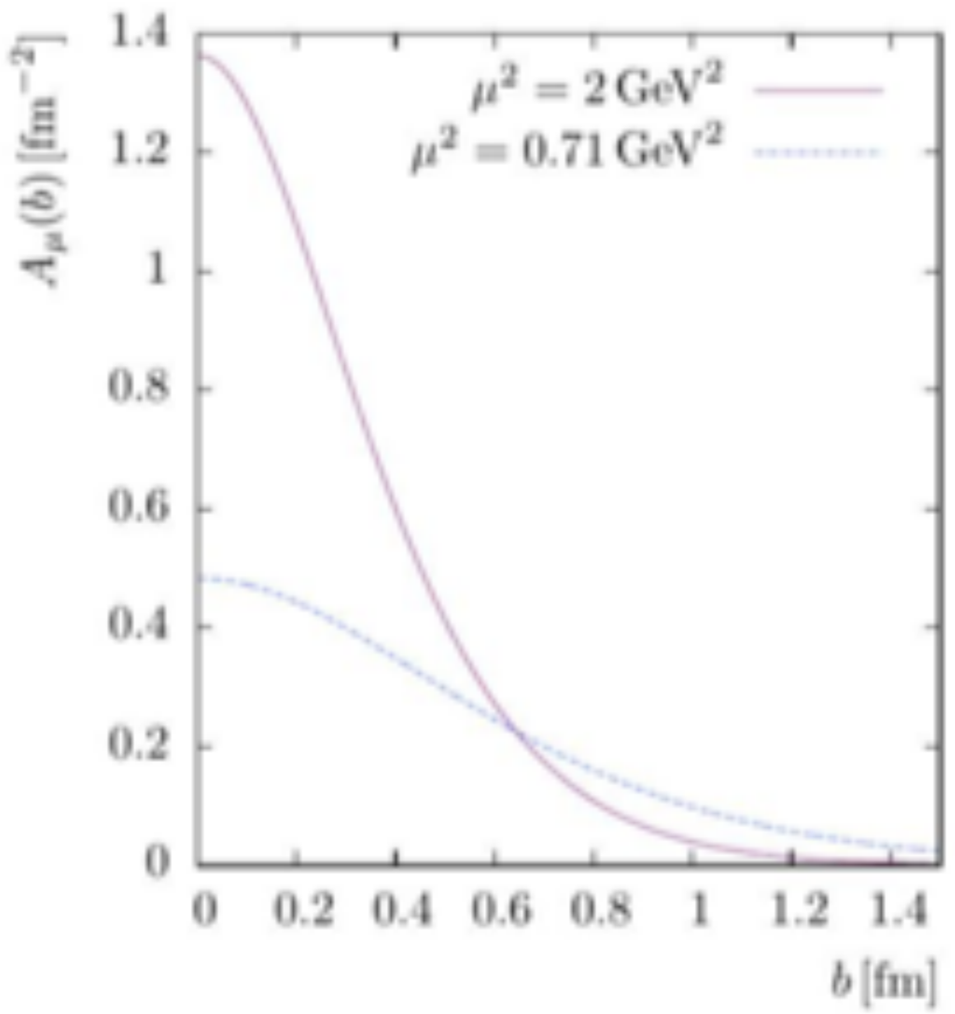
[Gieseke, Röhr, Siodmok – EPJ C 72 (2012) 2225]

MPI & Colour Reconnection

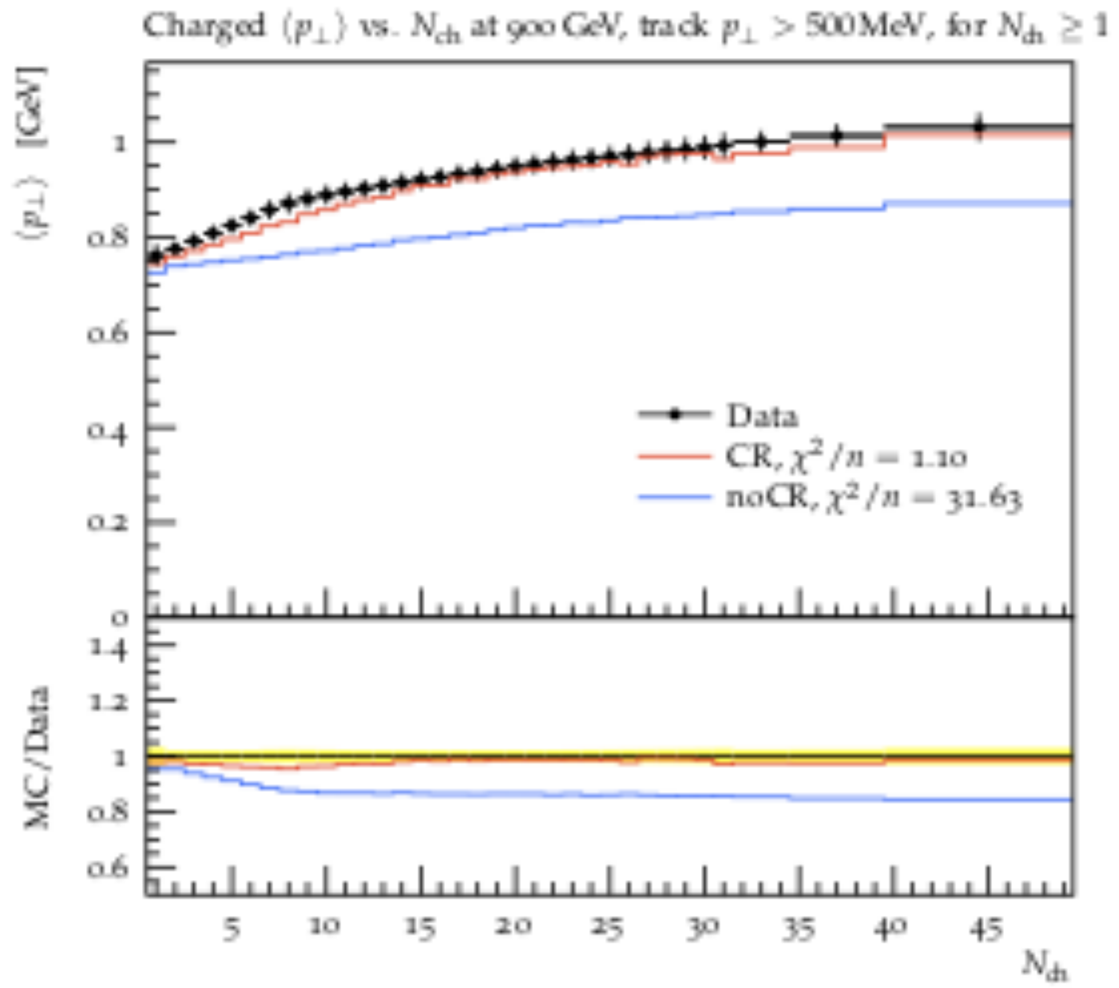


Assume some matter distribution in the proton, and effective multiplicity distribution of additional scatters.

Colour reconnection crucial to describe MinBias and UE data: lack of knowledge about colour correlations.



[Gieseke, Kirchgaesser, Plätzer – EPJ C 78 (2018) 99]



[Gieseke, Röhr, Siodmok – EPJ C 72 (2012) 2225]

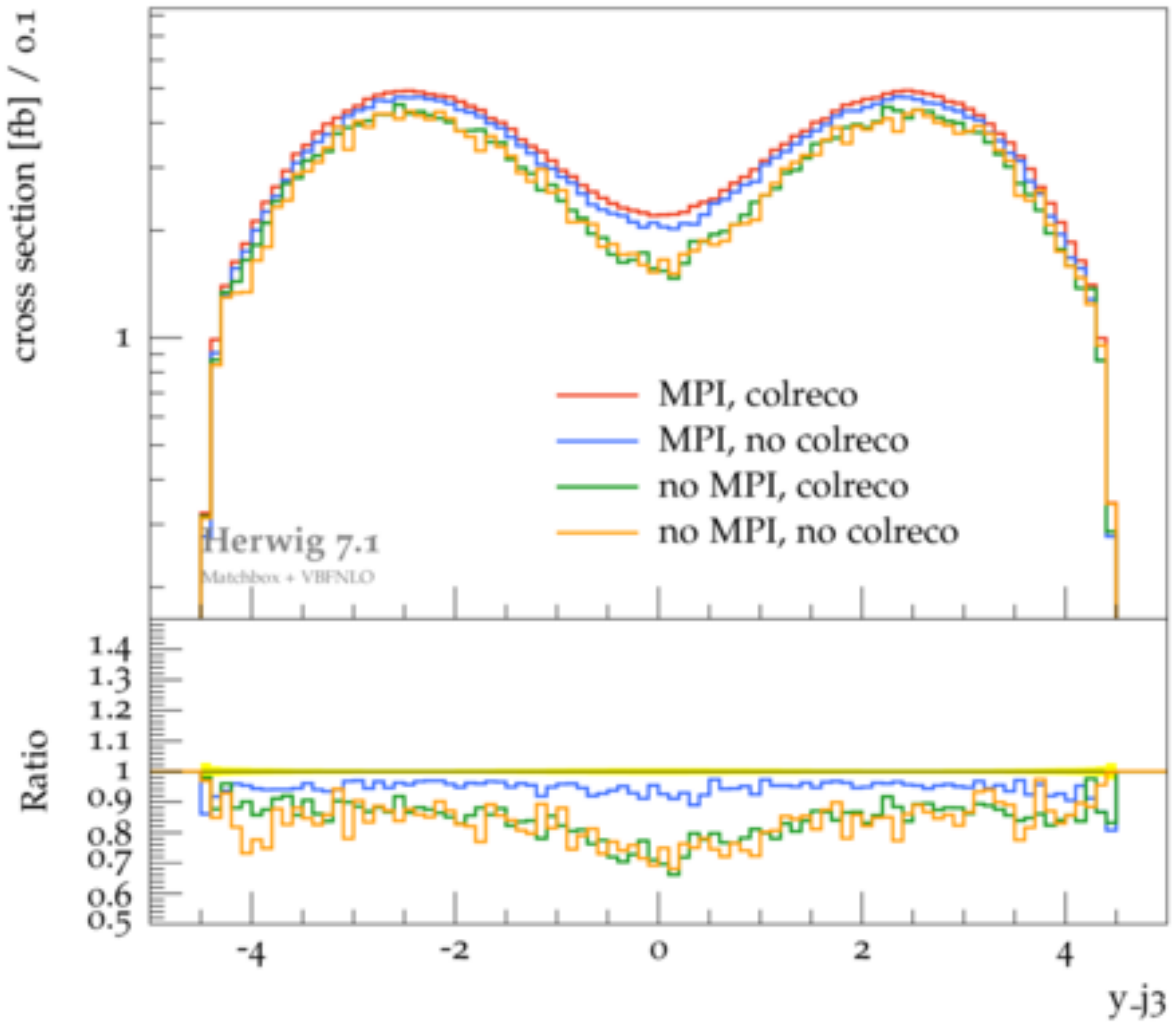
MPI & Colour Reconnection

[Bittrich, Kirchgaesser, Papaefstathiou, Plätzer, Todt — in progress]

Soft QCD effects are not absent: significant impact on interjet activity and jet shapes. On/off exercise will only hint at their relative importance.

Questions to be raised:

- Quantify impact (and how certain that is)
- Determine interplay with perturbative variations and models
- Watch out for lack of perturbative dynamics beyond current NLO+PS



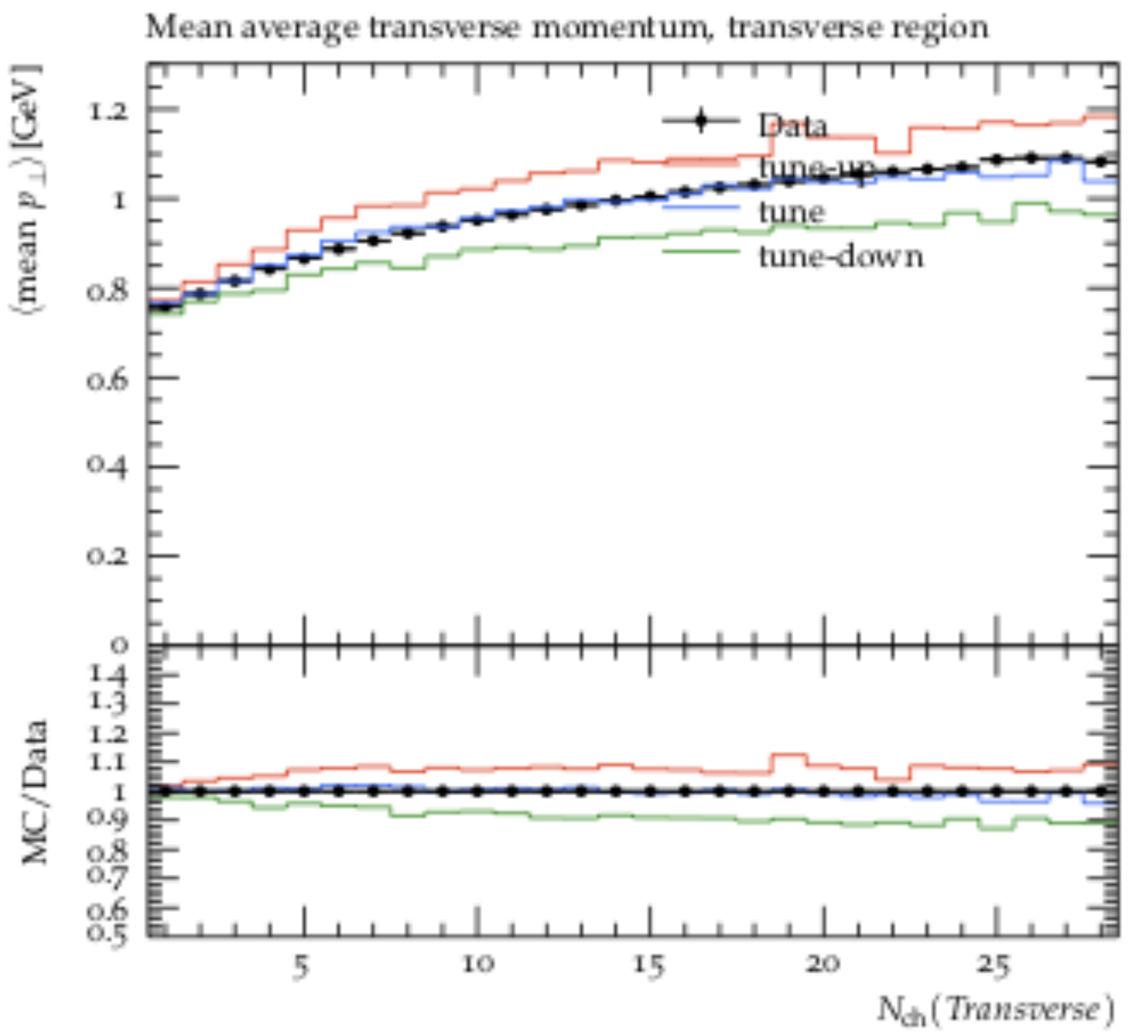
Benchmark is VBF Z production, but findings should be ~ universal.

Model variations

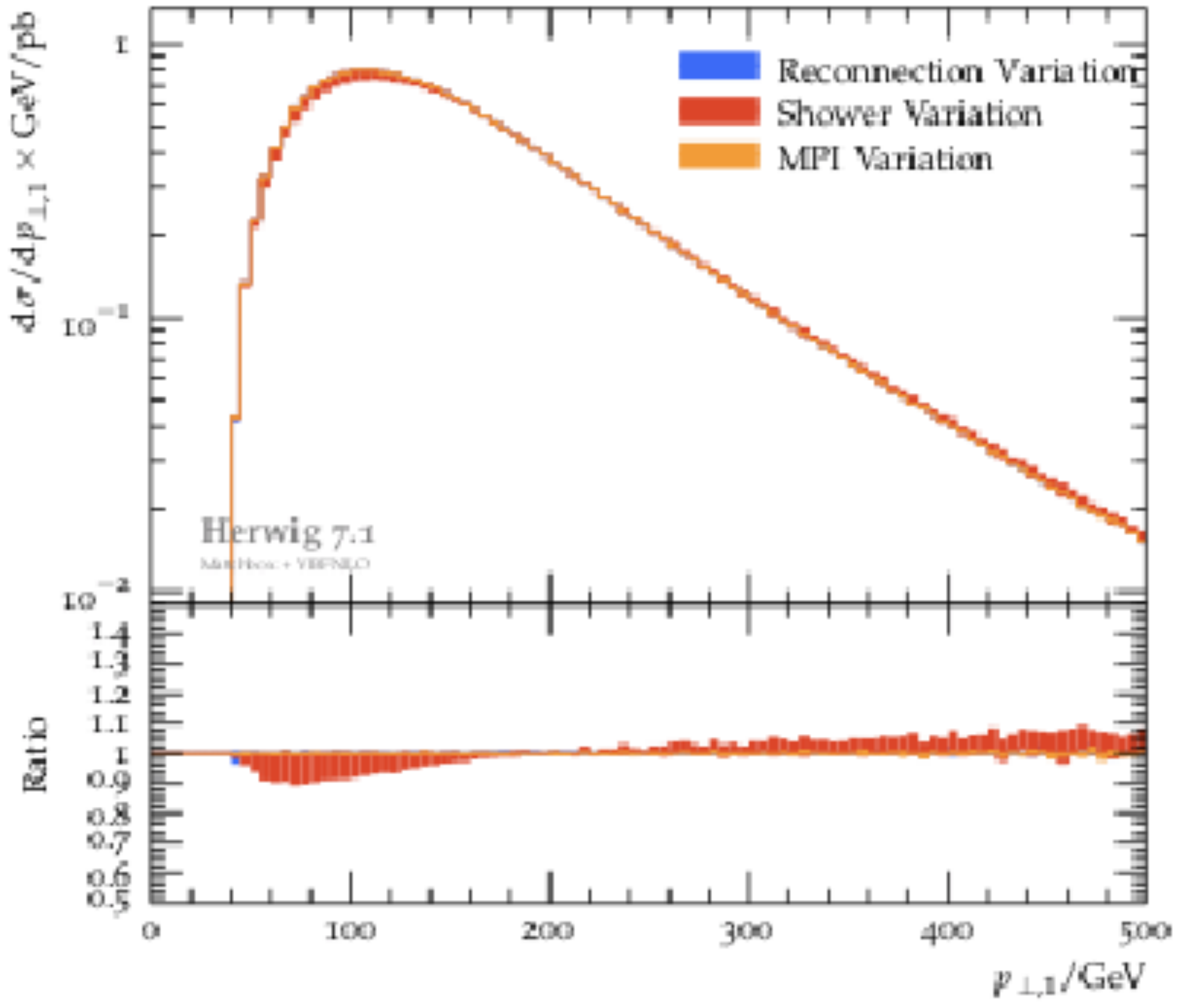
[Bittrich, Kirchgaesser, Papaefstathiou, Plätzer, Todt — in progress]

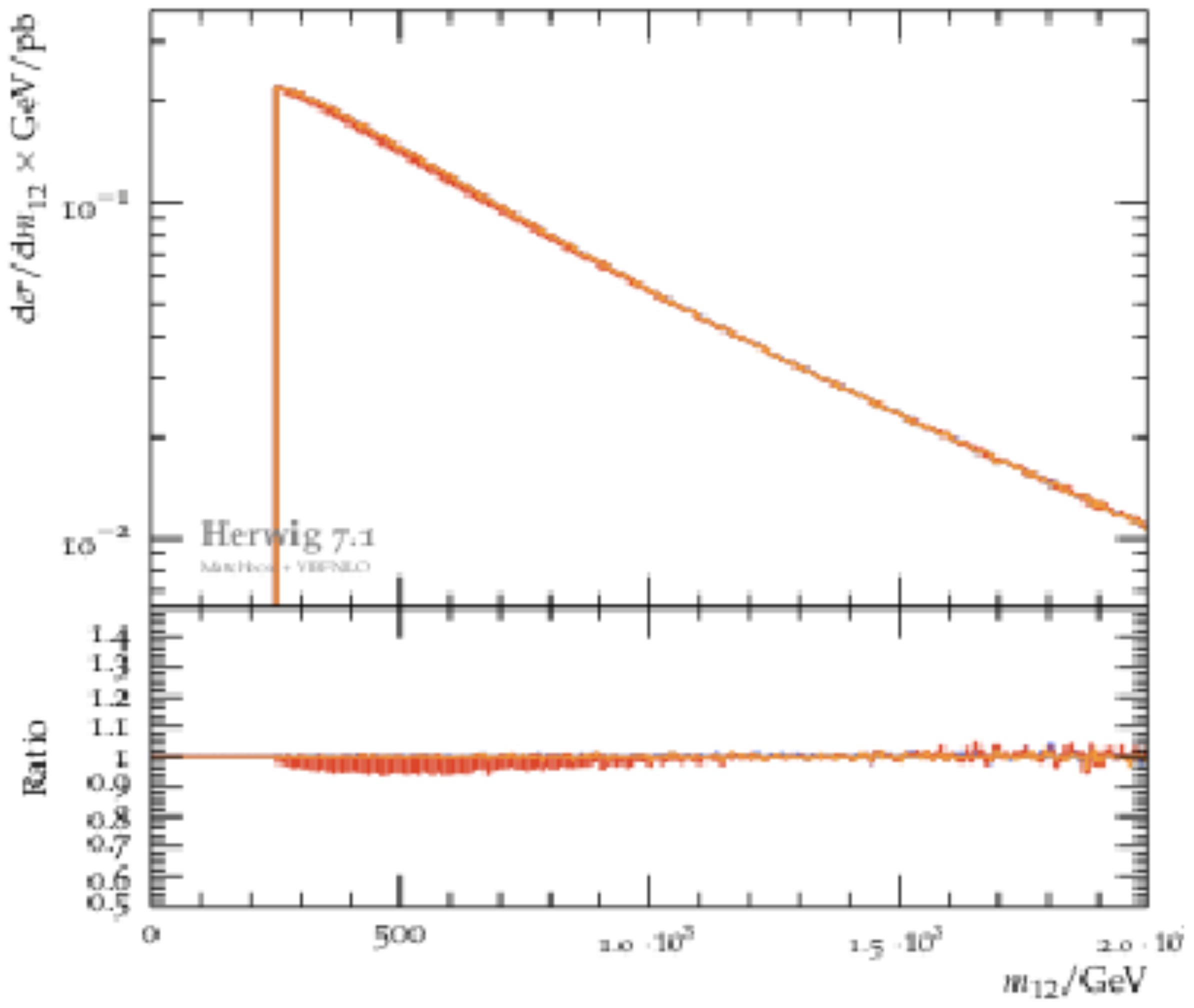
Strategy

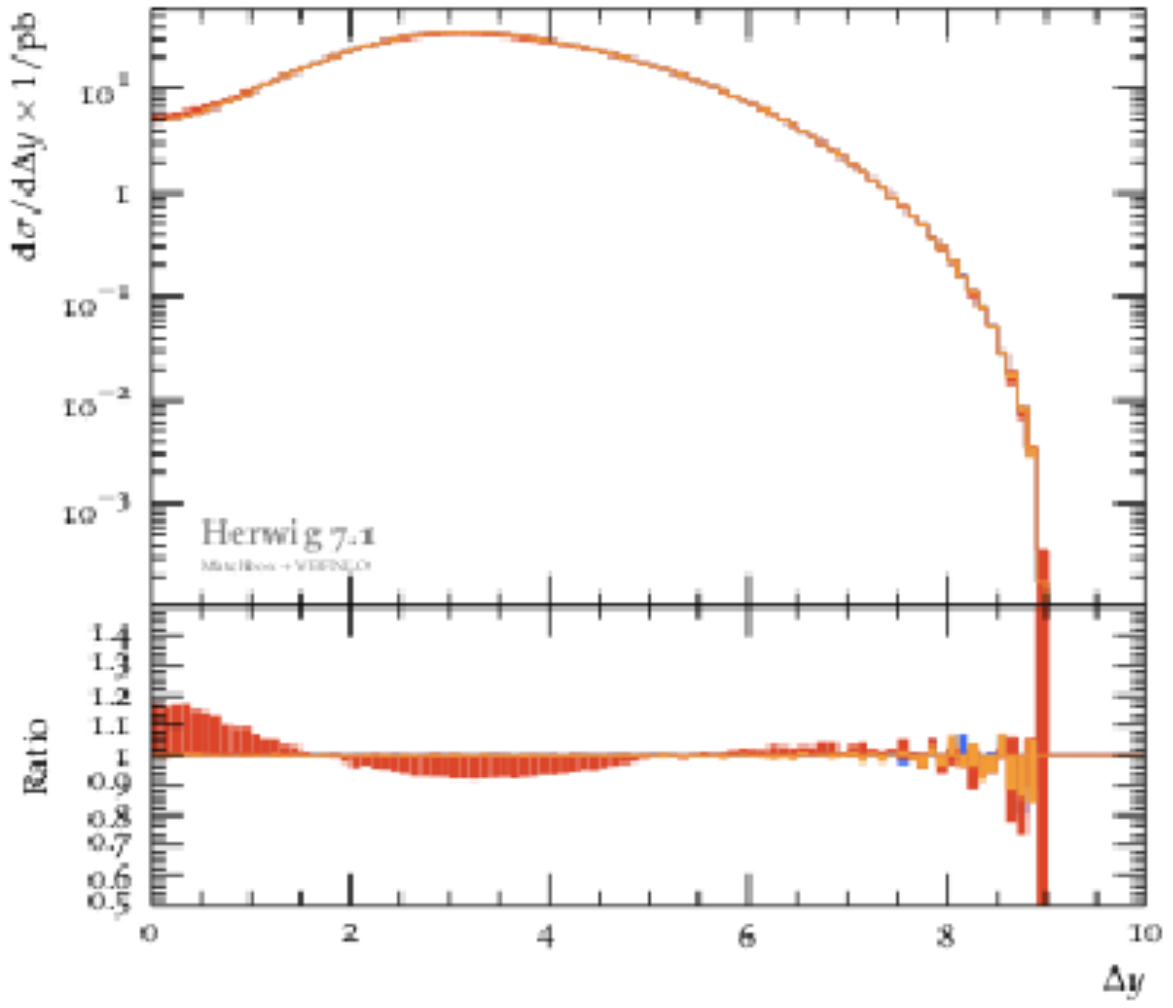
- Vary colour reconnection and MPI parameters to stay within ~ 10% agreement of typical tuning observables
- Vary perturbative scales, specifically shower hard scale
- Examples are LO+PS, but we have a full NLO+PS study in the pipeline



Tagging jet distributions mostly stable





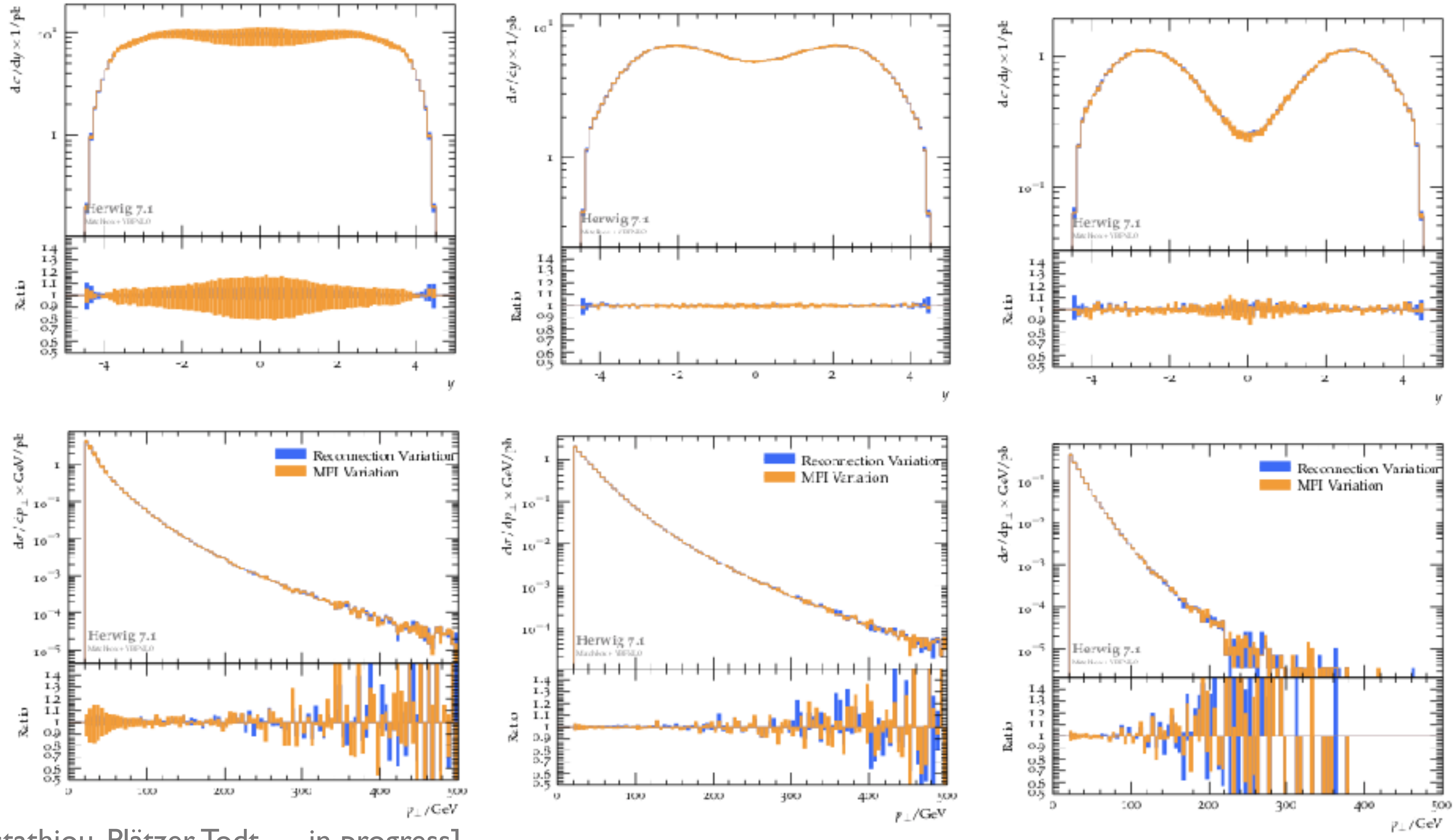


Model variations

Loose selection, R=1.0 | Loose selection, R=0.4 | Tight selection, R=0.4

Third jet rapidity

Third jet pt



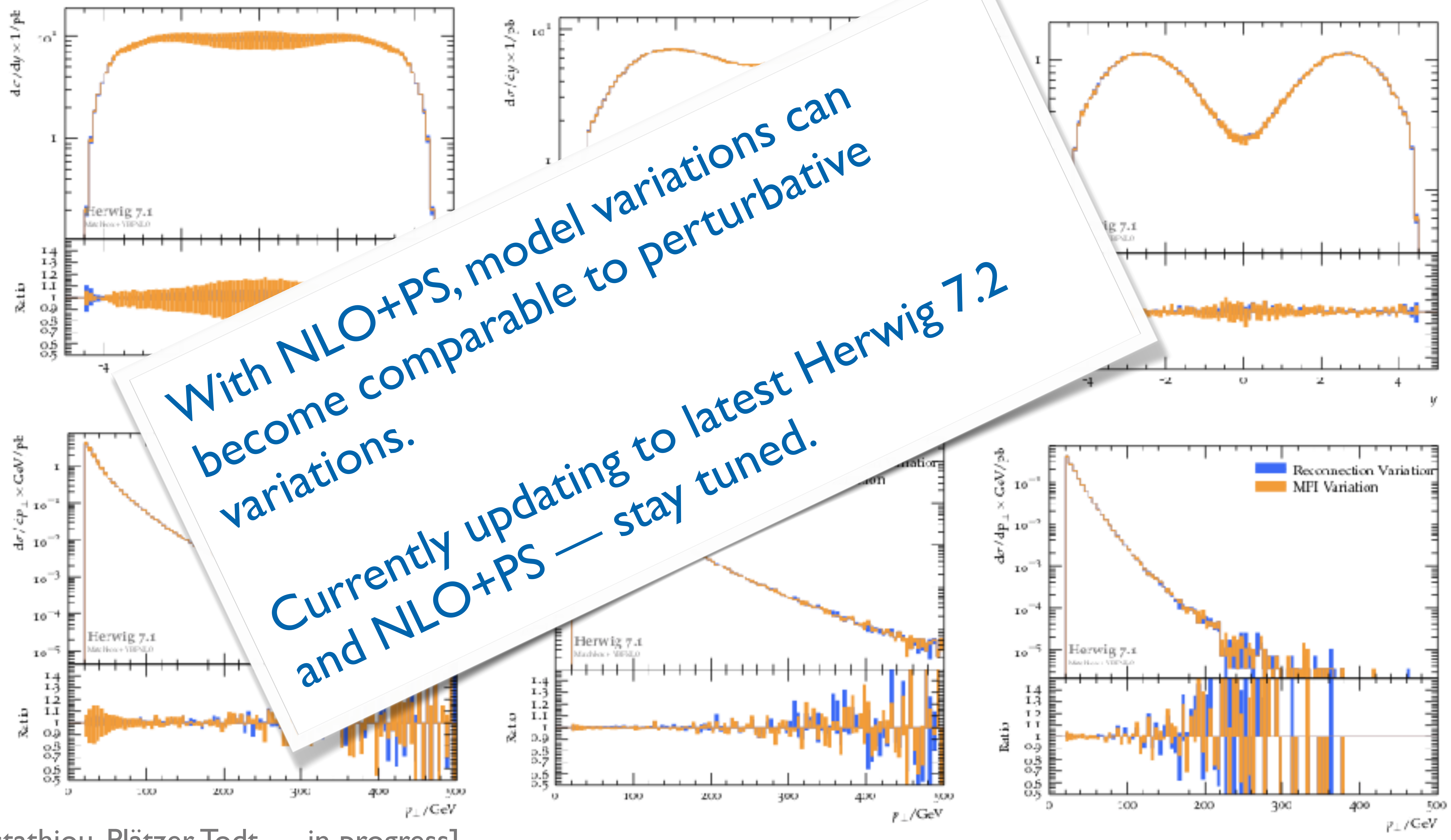
[Bittrich, Kirchgaesser, Papaefstathiou, Plätzer, Todt — in progress]

Model variations

Loose selection, R=1.0 | Loose selection, R=0.4 | Tight selection, R=0.4

Third jet rapidity

Third jet pt



With NLO+PS, model variations can become comparable to perturbative variations.

Currently updating to latest Herwig 7.2 and NLO+PS — stay tuned.

[Bittrich, Kirchgaesser, Papaefstathiou, Plätzer, Todt — in progress]

Summary

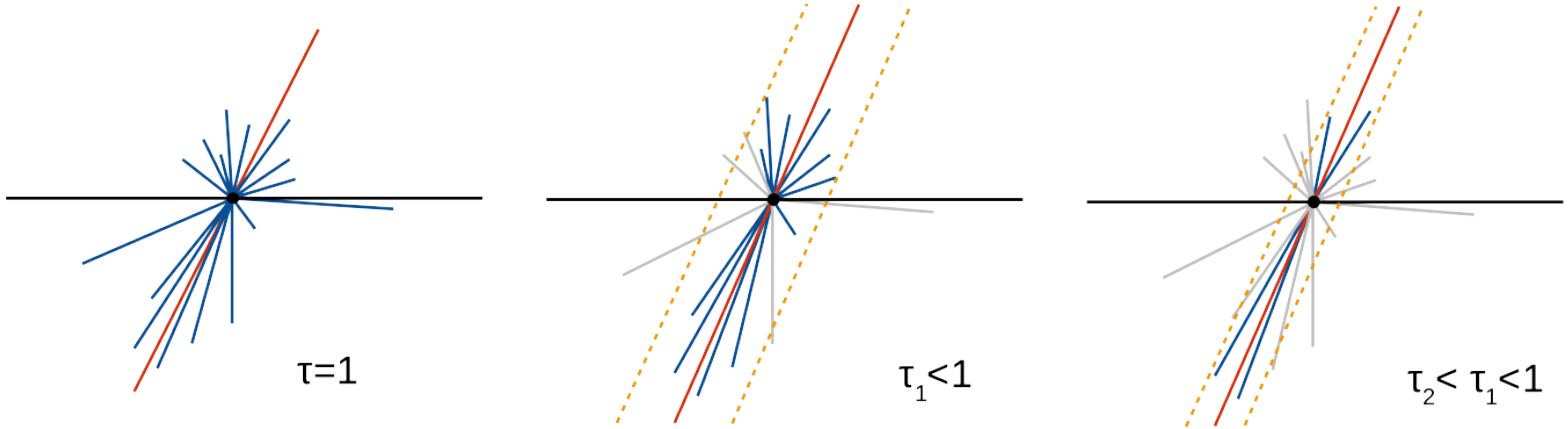
NLO+PS tools are in good shape for VBF and VBS, though uncertainties remain at the 10% level in between different algorithms for hard spectra. VBF specifically sensitive to colour coherence and recoil effects.

VBF approximation is under control for a tight selections, but can become significant impact for loose(r) selections — that not meaning 'inclusive'.

Perturbative variations at this level now need to be confronted with soft QCD effects from multi-parton interactions and hadronization.

Thank you!

Coherent branching



Resummation of observables which globally measure deviations from 2-jet limit.

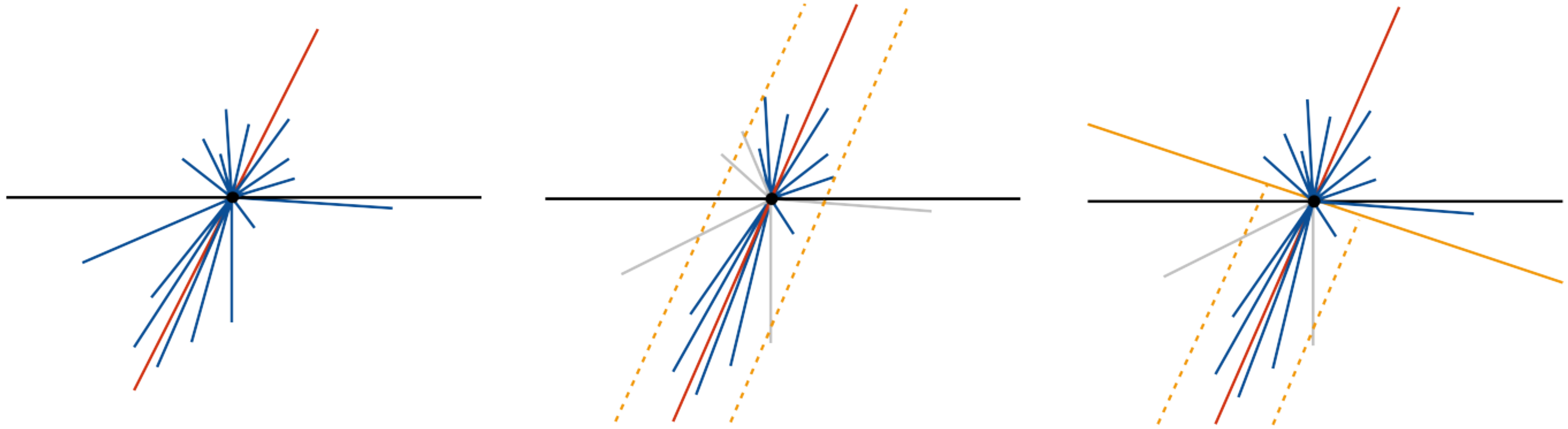
[n jets in large-N limit]

Initial conditions & kinematics crucial to get large-angle soft radiation right.

$$P_{qq}\left[\alpha_s, z\right] = \frac{\alpha_s C_F}{2\pi}\frac{1+z^2}{1-z} = \frac{\alpha_s C_F}{2\pi}\left[\frac{2}{1-z} - (1+z)\right]$$

$$\frac{\mathrm{d}\tilde{q}^2}{\tilde{q}^2}\mathrm{d}z\frac{2}{1-z} \sim \frac{n\cdot\bar{n}}{n\cdot q_i\; q_i\cdot n}\frac{\mathrm{d}^3k_i}{2E_i}$$

Non-global Observables



No global measure of deviation from jet configuration:
Coherent branching fails, full complexity of amplitudes strikes back.

If non-global bit is isolated can use dipole cascades to resum in the large-N limit.

[Dasgupta, Salam, Banfi, Marchesini, Smye, Becher et al. …]