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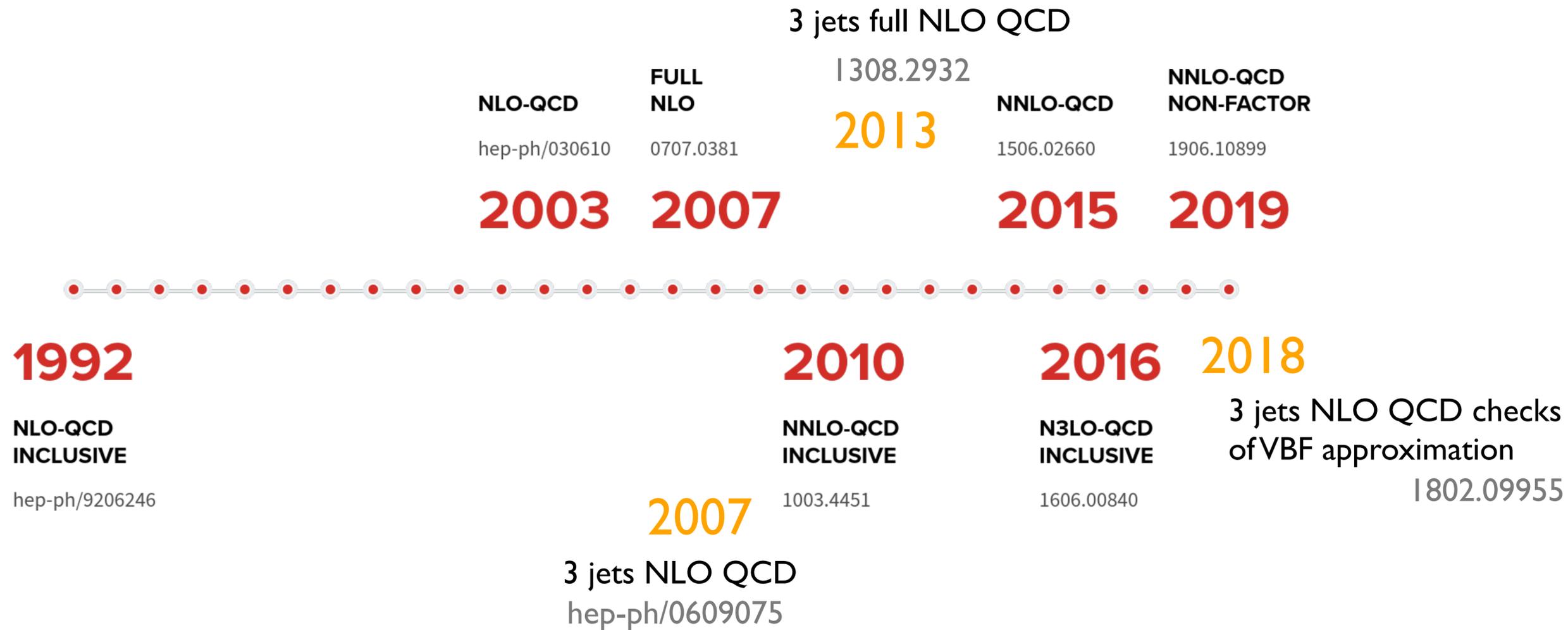
(Soft) QCD effects in VBF/VBS

Simon Plätzer
Particle Physics — University of Vienna

at the
HXSWG General Meeting
Remote | 9 November 2020

[See Yacine's talk tomorrow on STXS VBF/VH bins]

If fixed order was enough



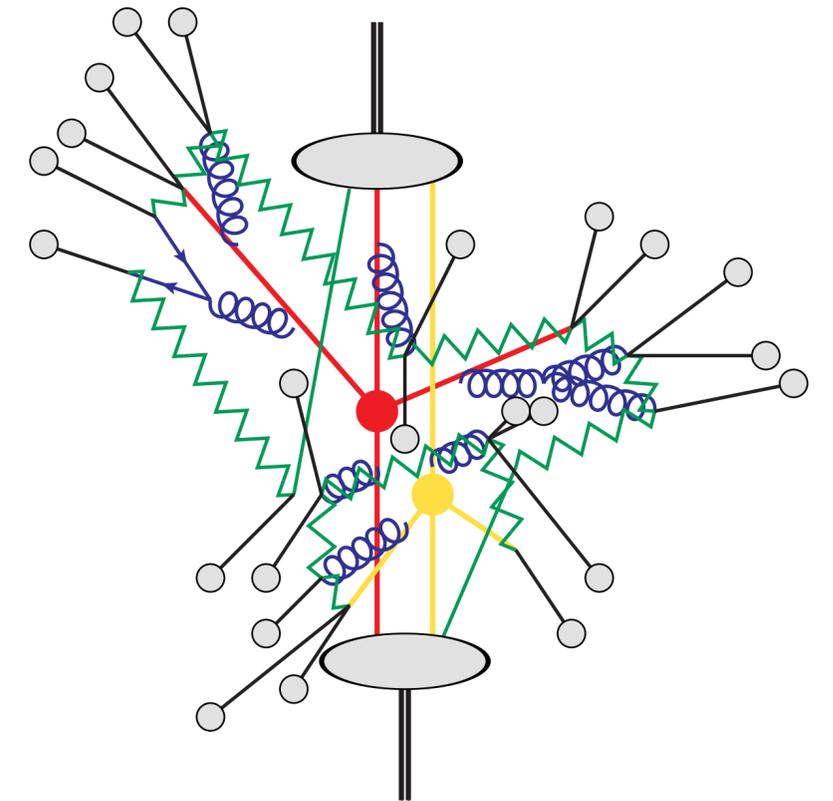
PP collisions are more complex

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



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

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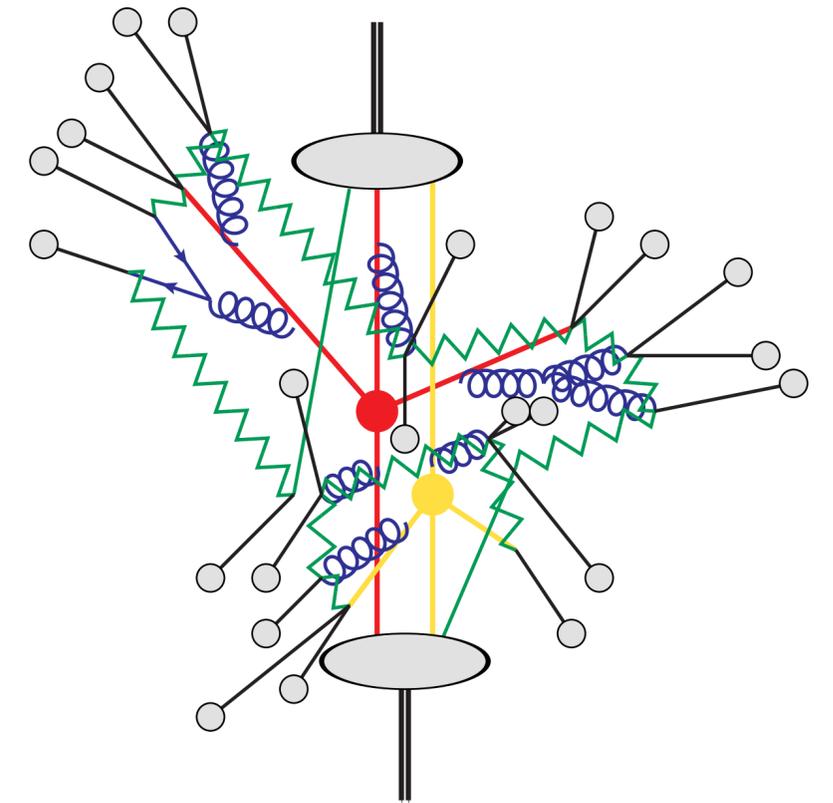
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[Jäger, Karlberg, Plätzer, Scheller, Zaro — 2003.12435]
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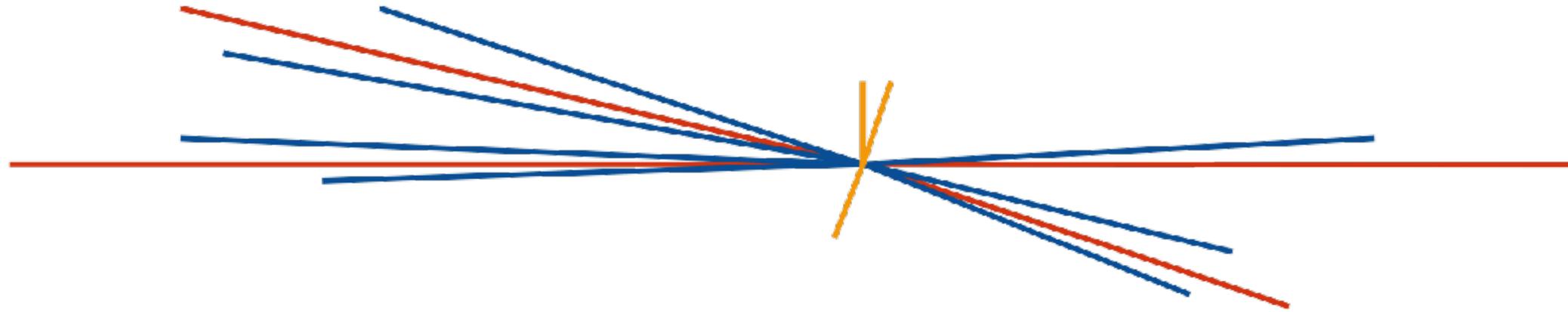
[Bittrich, Kirchgaesser, Papaefstathiou, Plätzer, Todt — in preparation]

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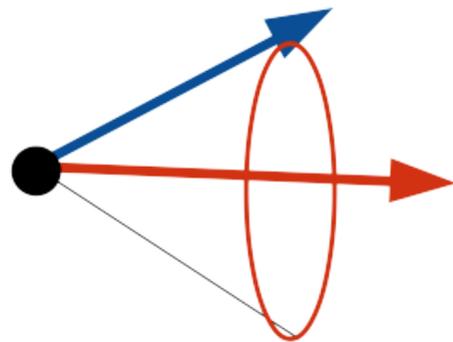


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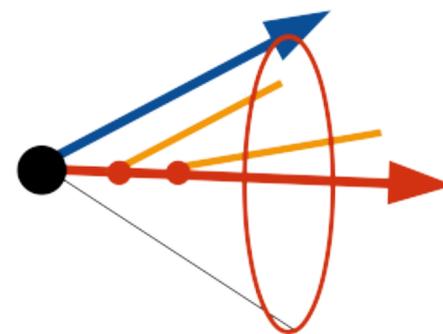
Coherent emission of soft large angle gluons from systems of collinear partons.



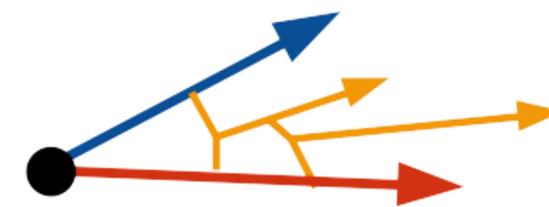
Parton branching algorithms: dipoles vs angular ordered, recoils closely tied to accuracy.



constructive interference
in each collinear region

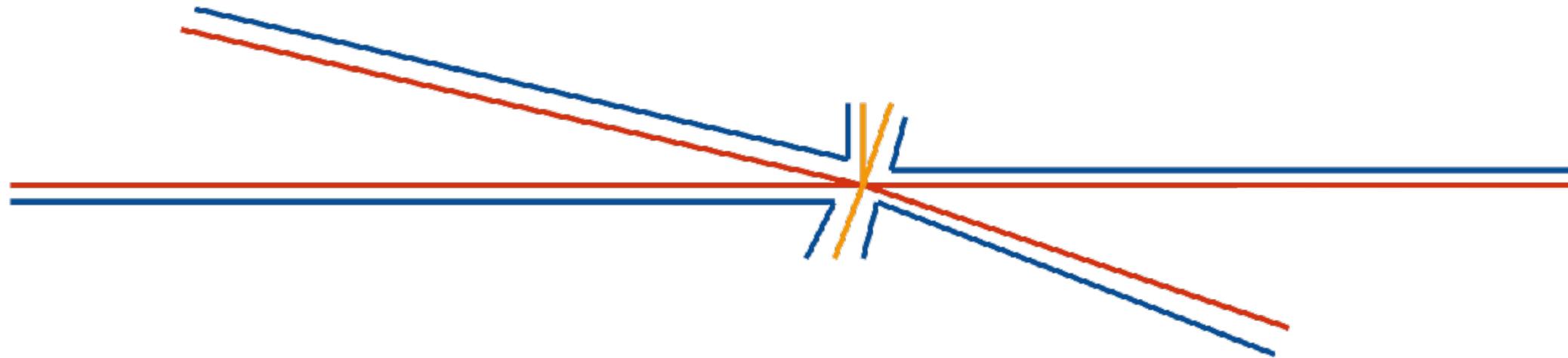


branchings
order in \sim angle

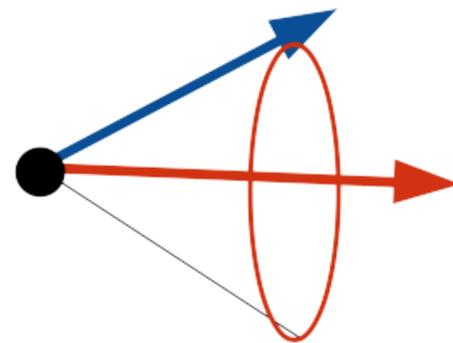


dipoles
order in $\sim p_T$

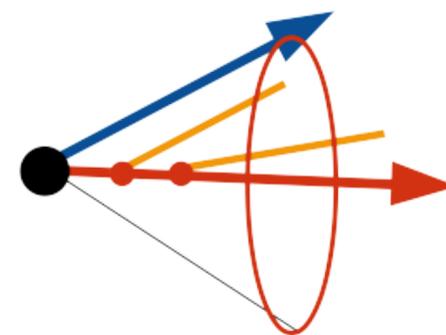
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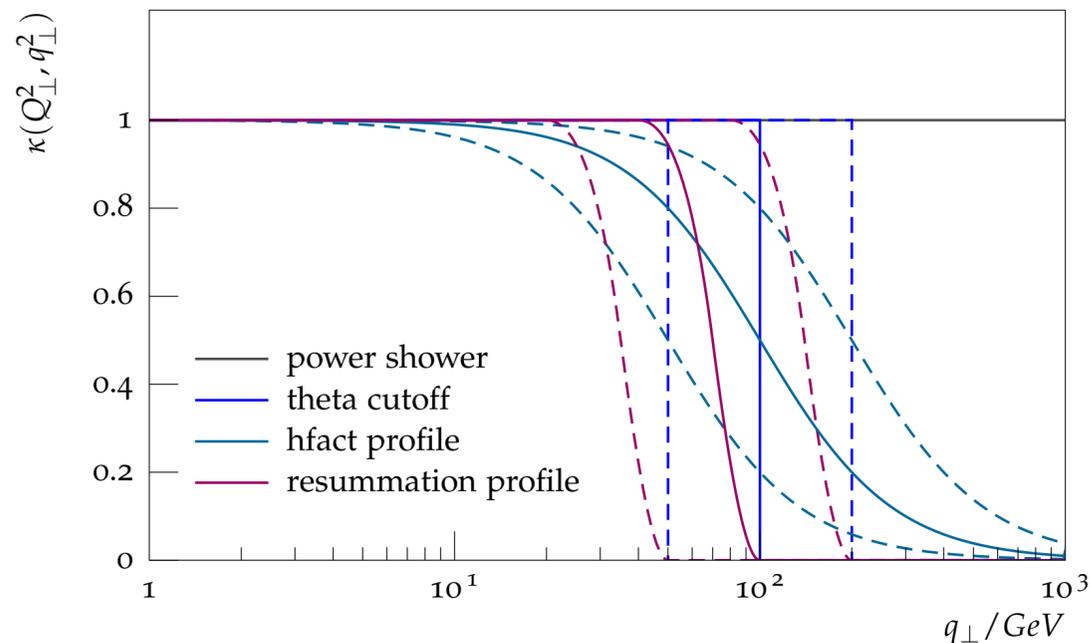
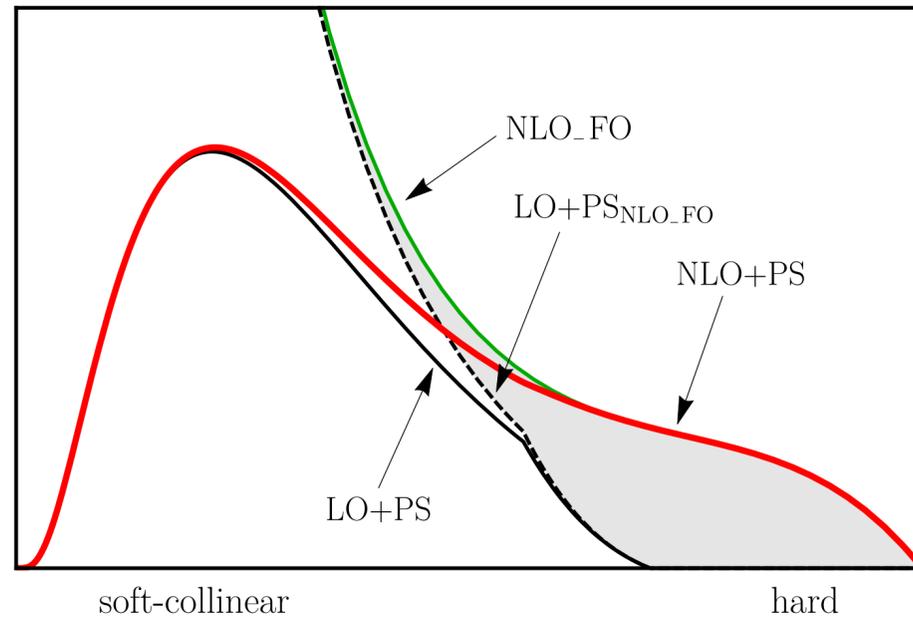


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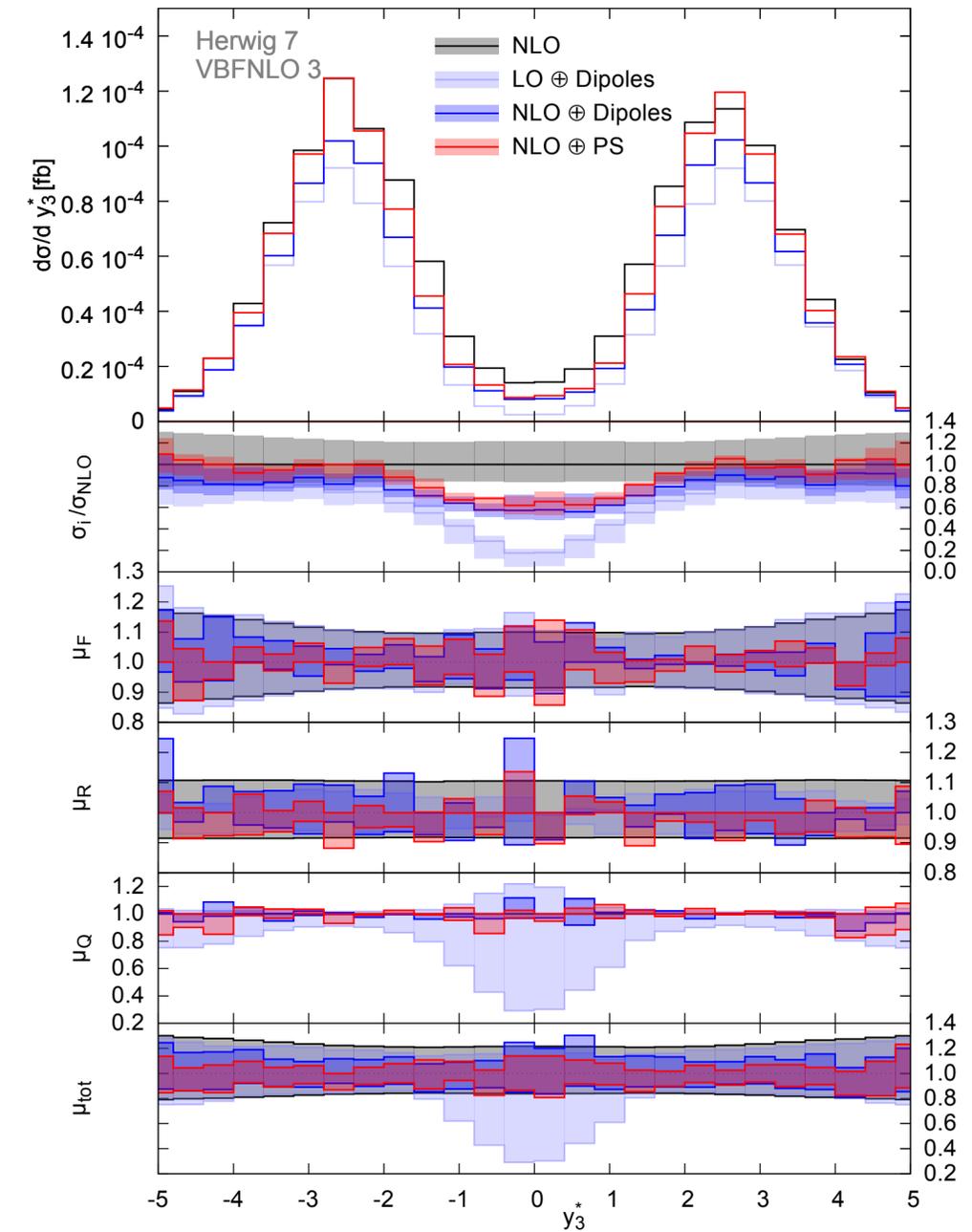
Fixed Order, Parton Showers and Variations



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 form 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]

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

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

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

**Plethora of
matching and
shower setups**

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

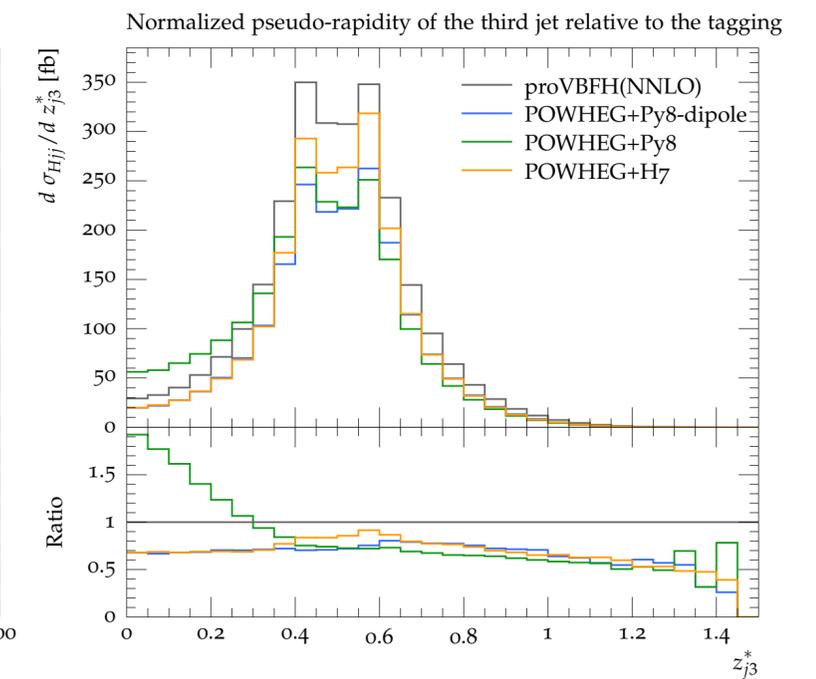
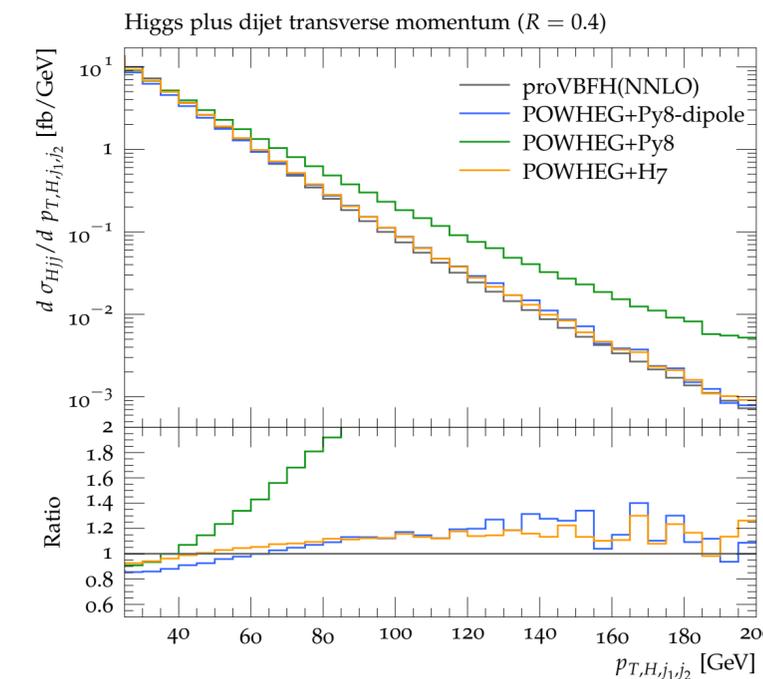
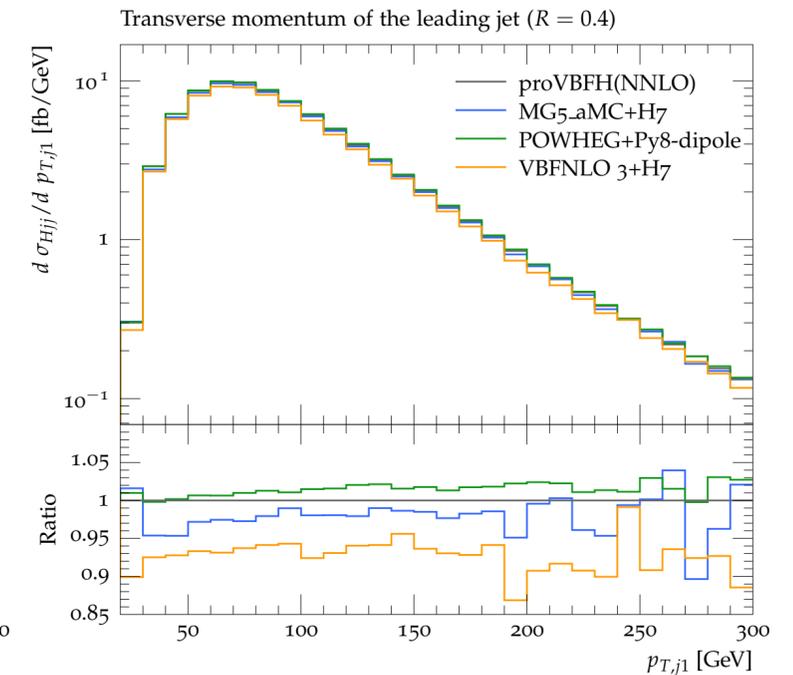
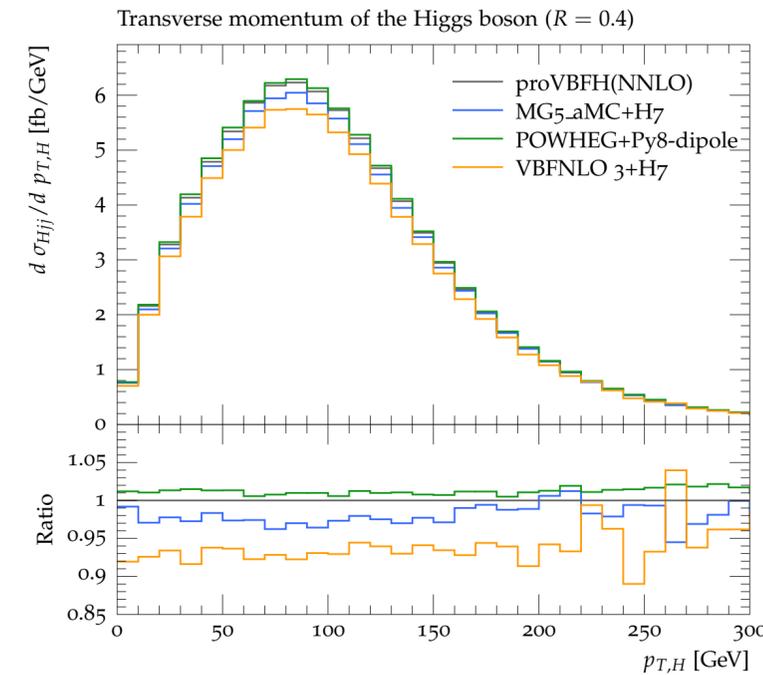
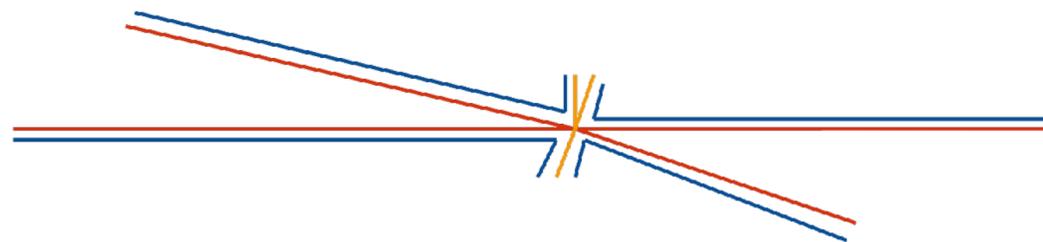
Comparison between tools

[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]

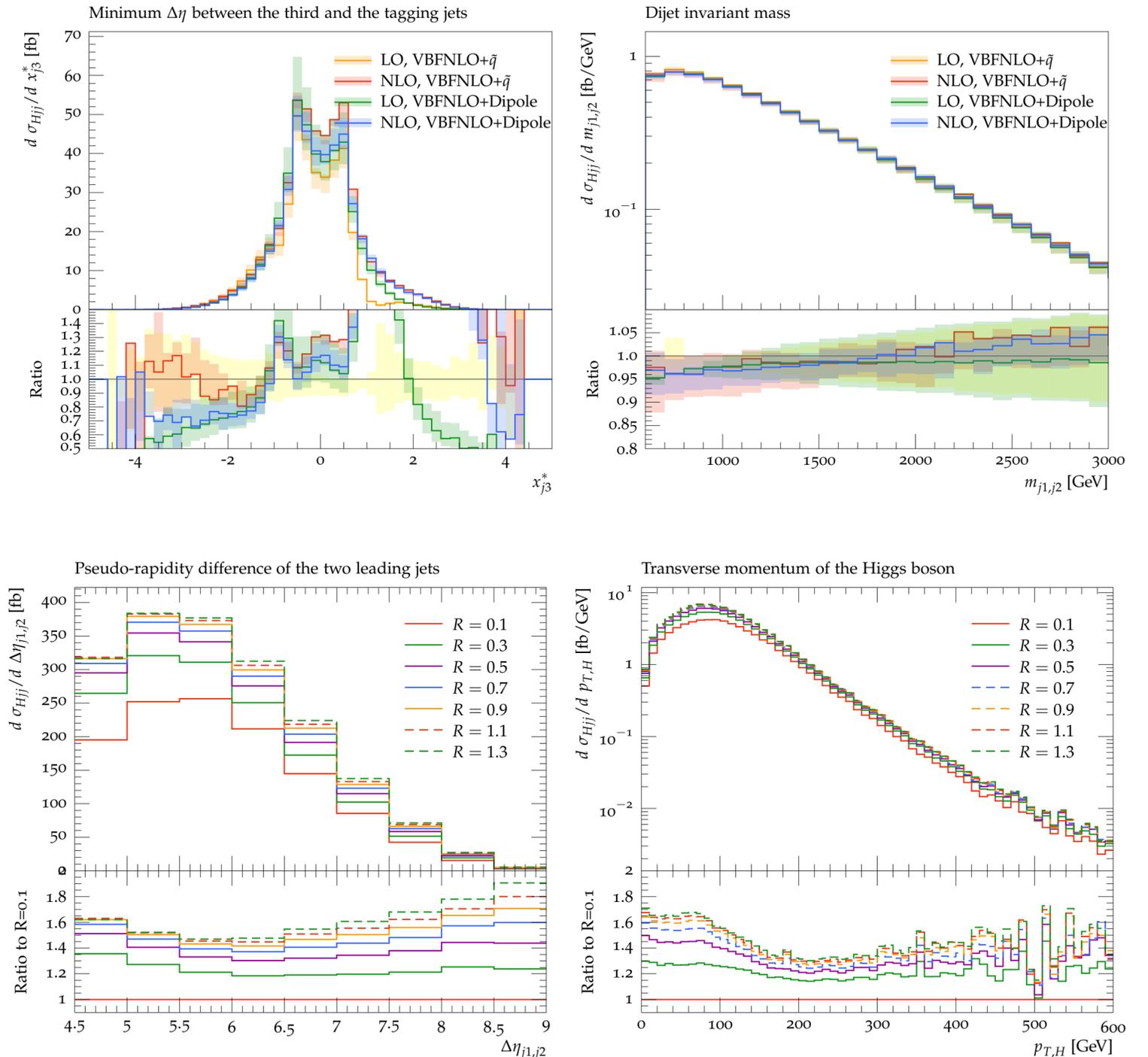
Still significant shower variations shedding light on jet activity after showering, otherwise distributions stable at NLO+PS.

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]



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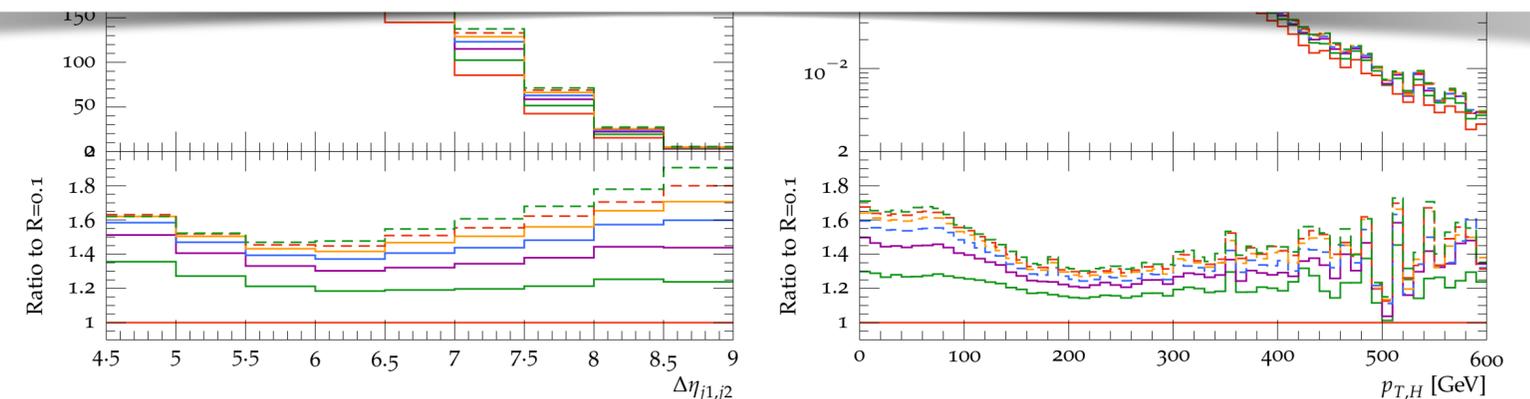
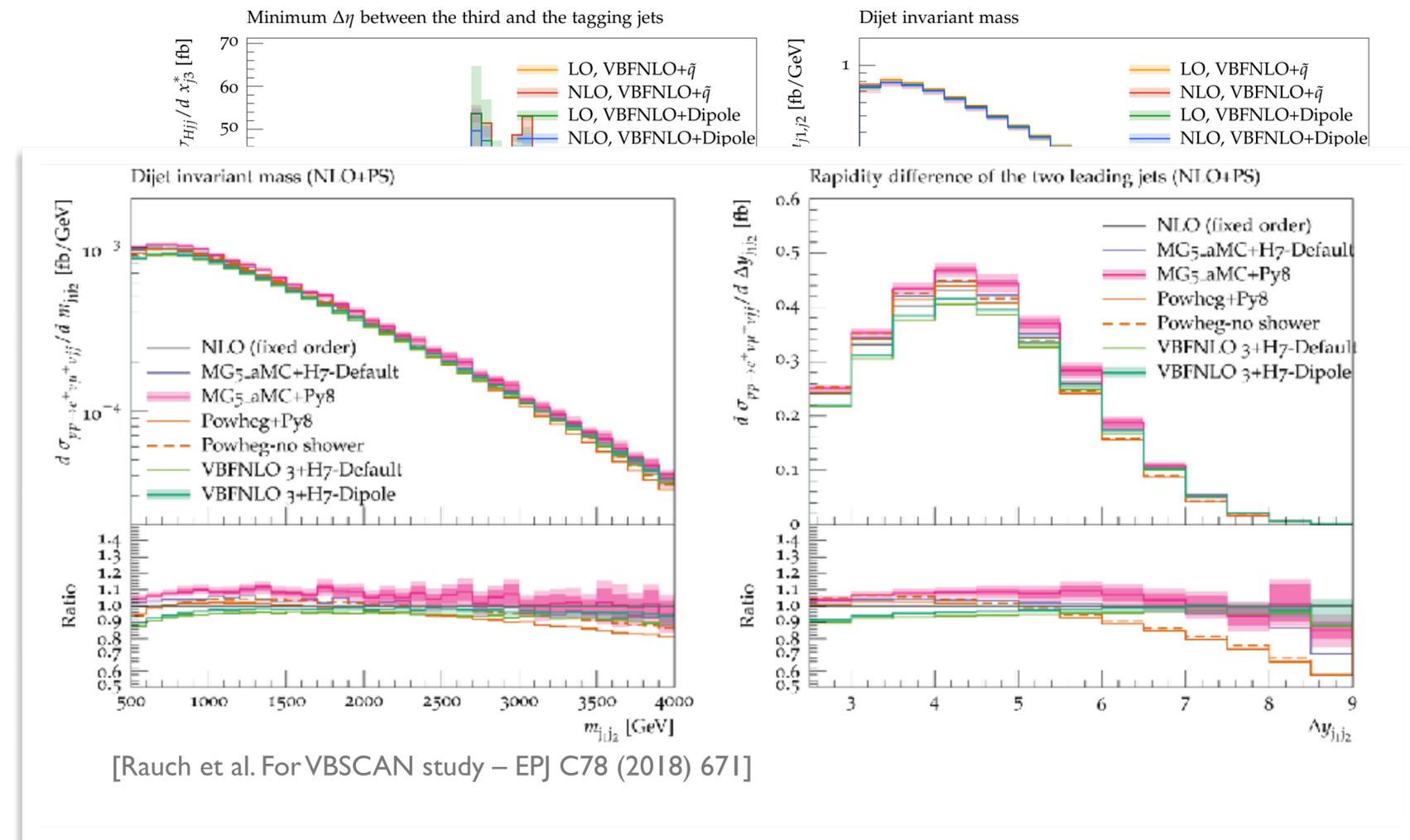
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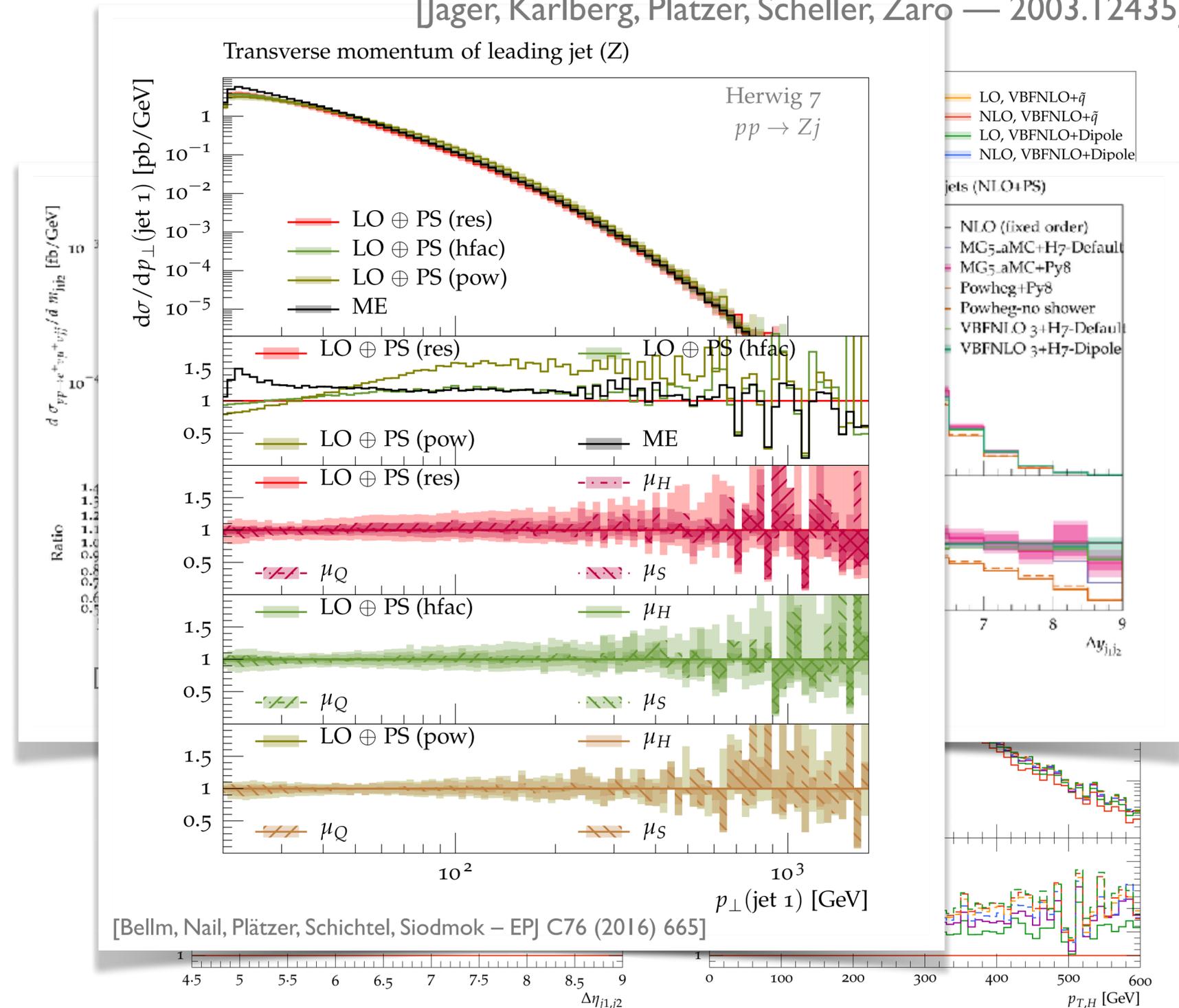
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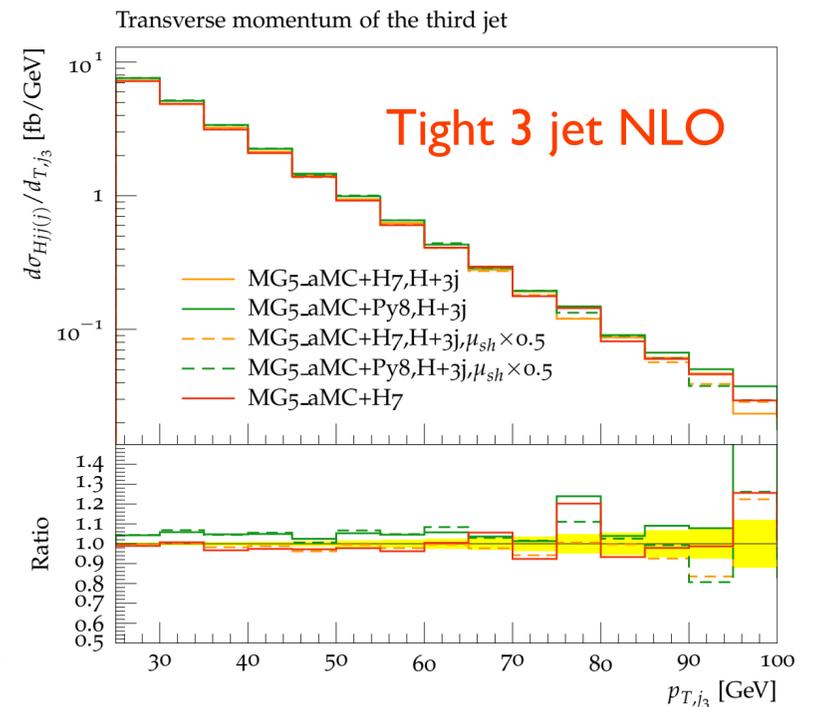
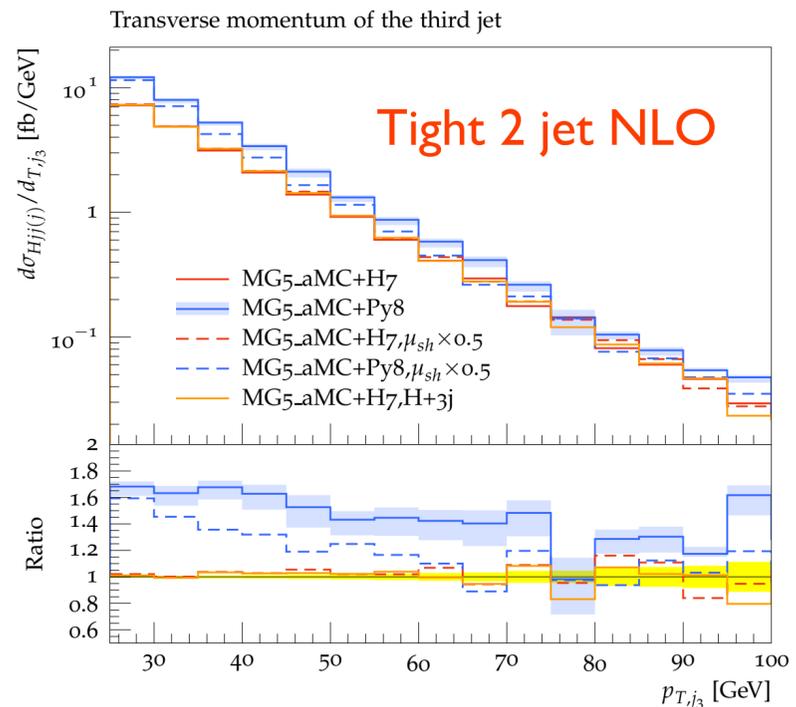
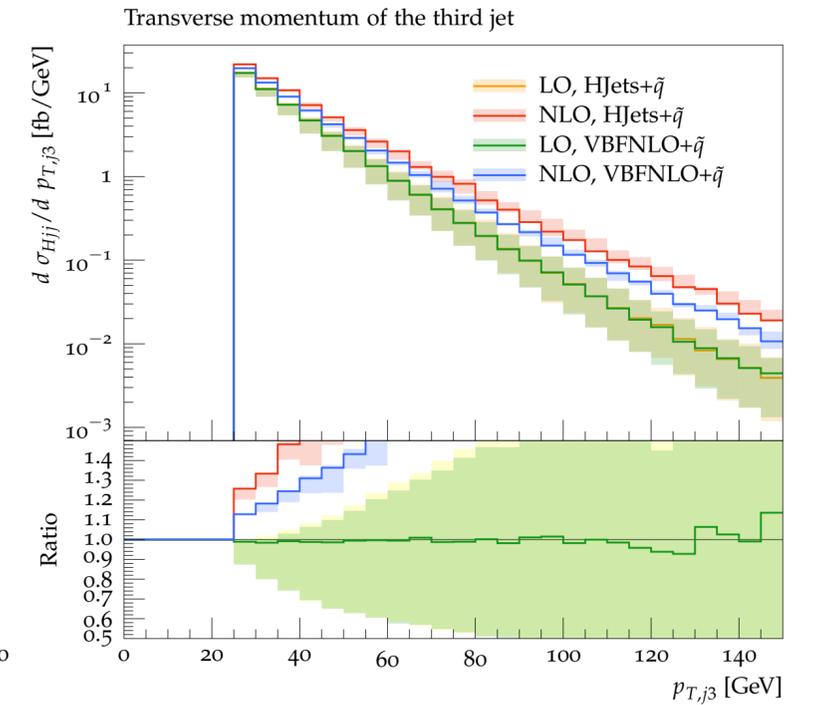
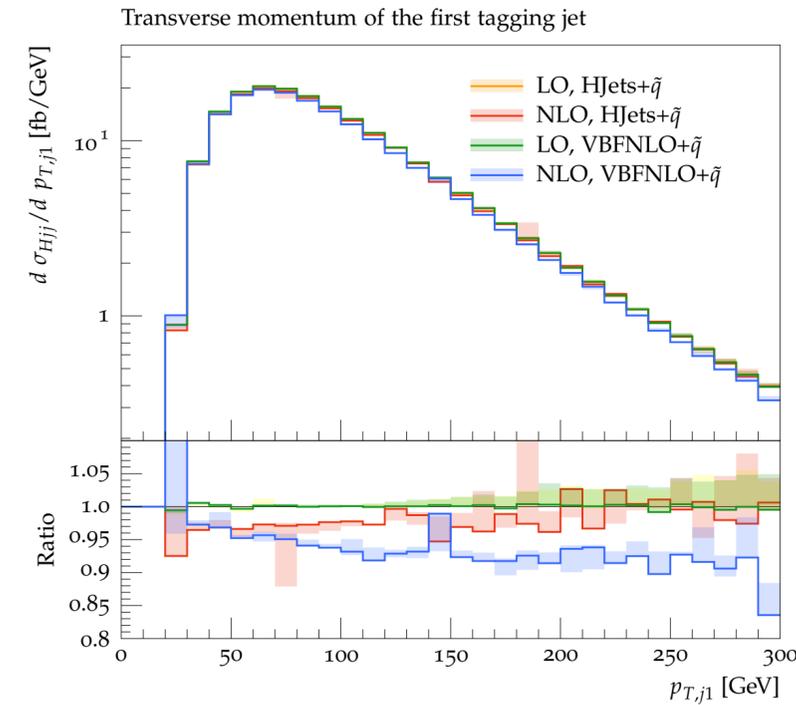
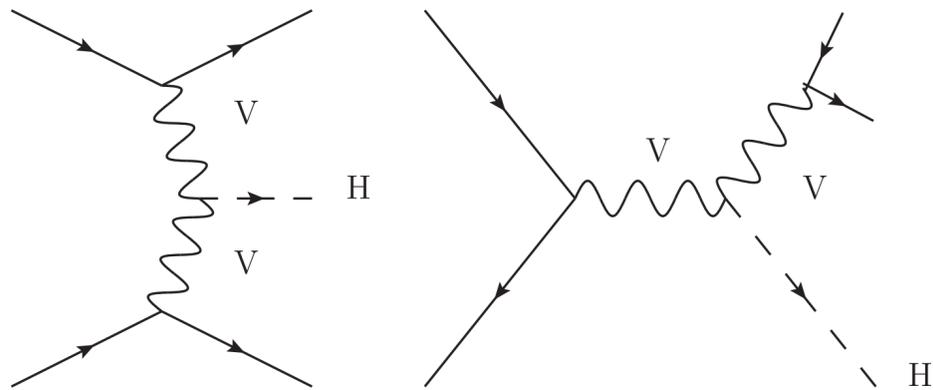


Third Jet & Impact of VBF Approximation

[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.

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

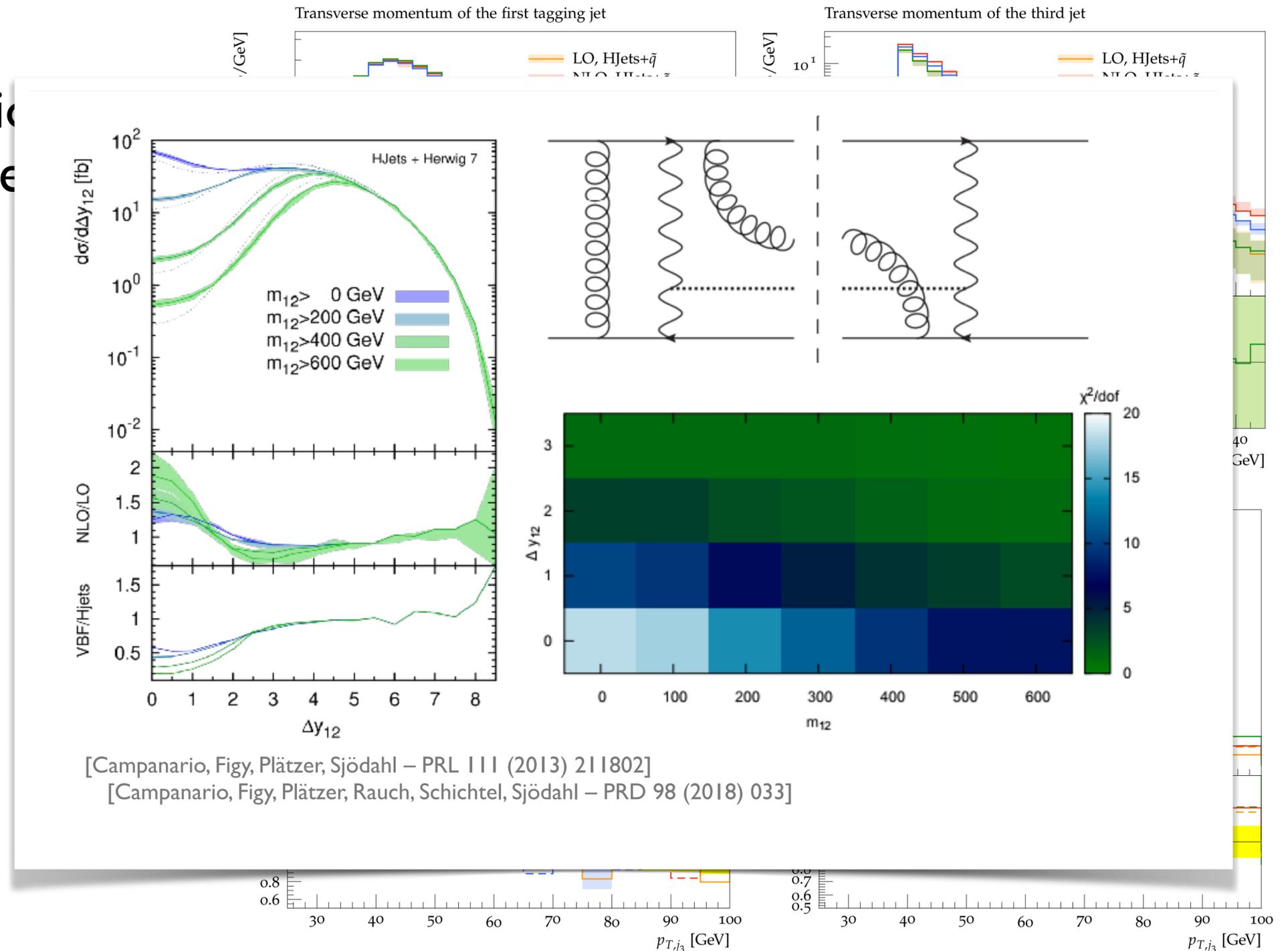
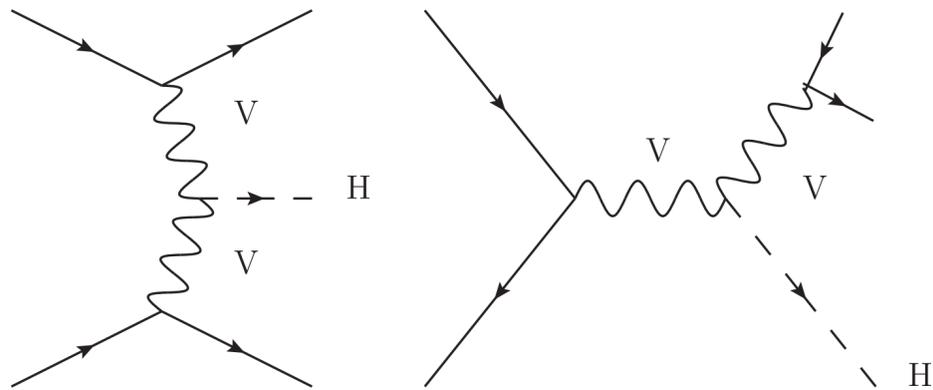


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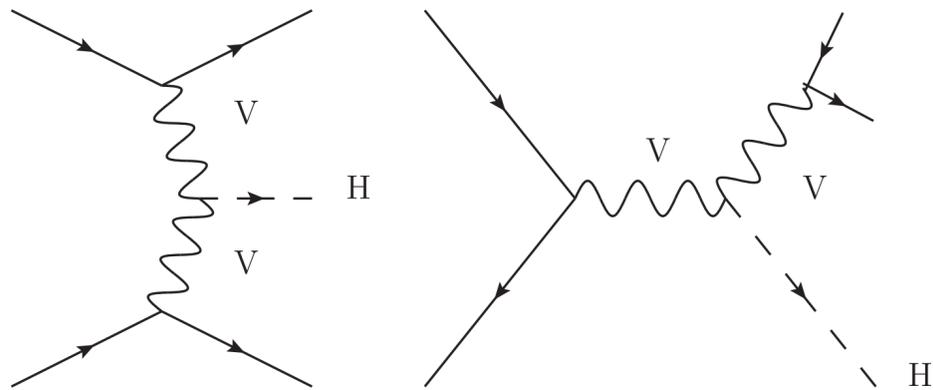
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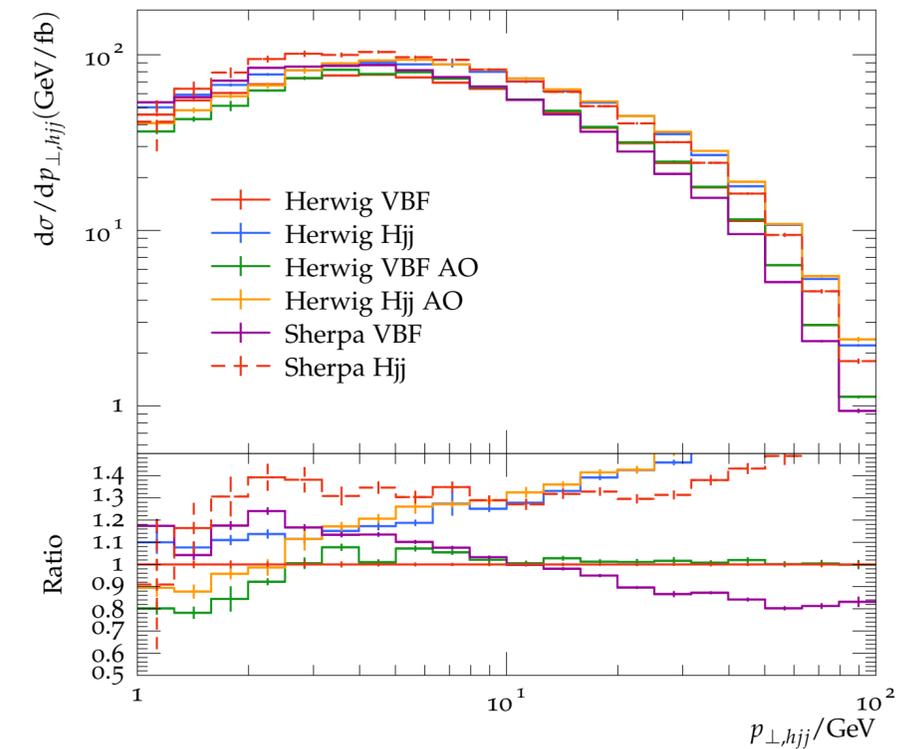
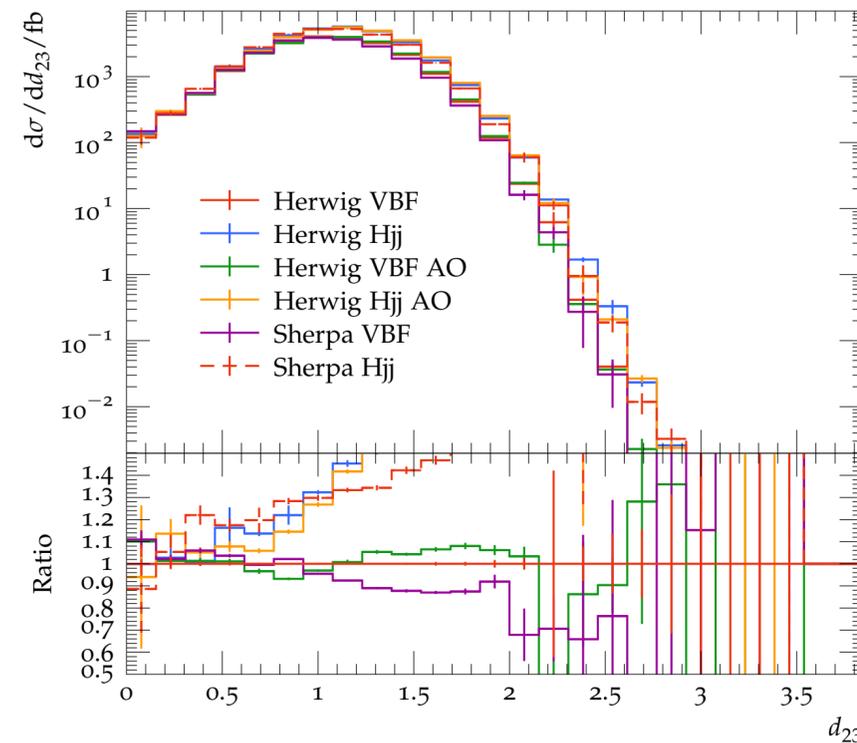


More perturbative studies underway in following up on Les Houches 2019: Powheg, Herwig and Sherpa.

Detailed investigation in various kinematic regions, shower differences beyond matching, VBF approximation.



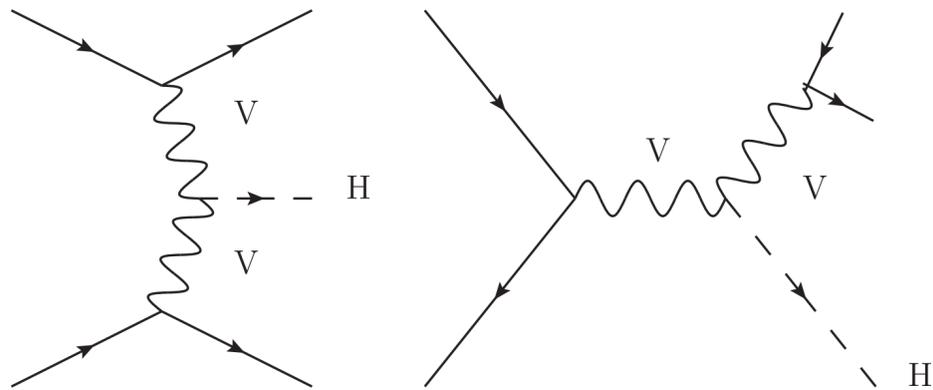
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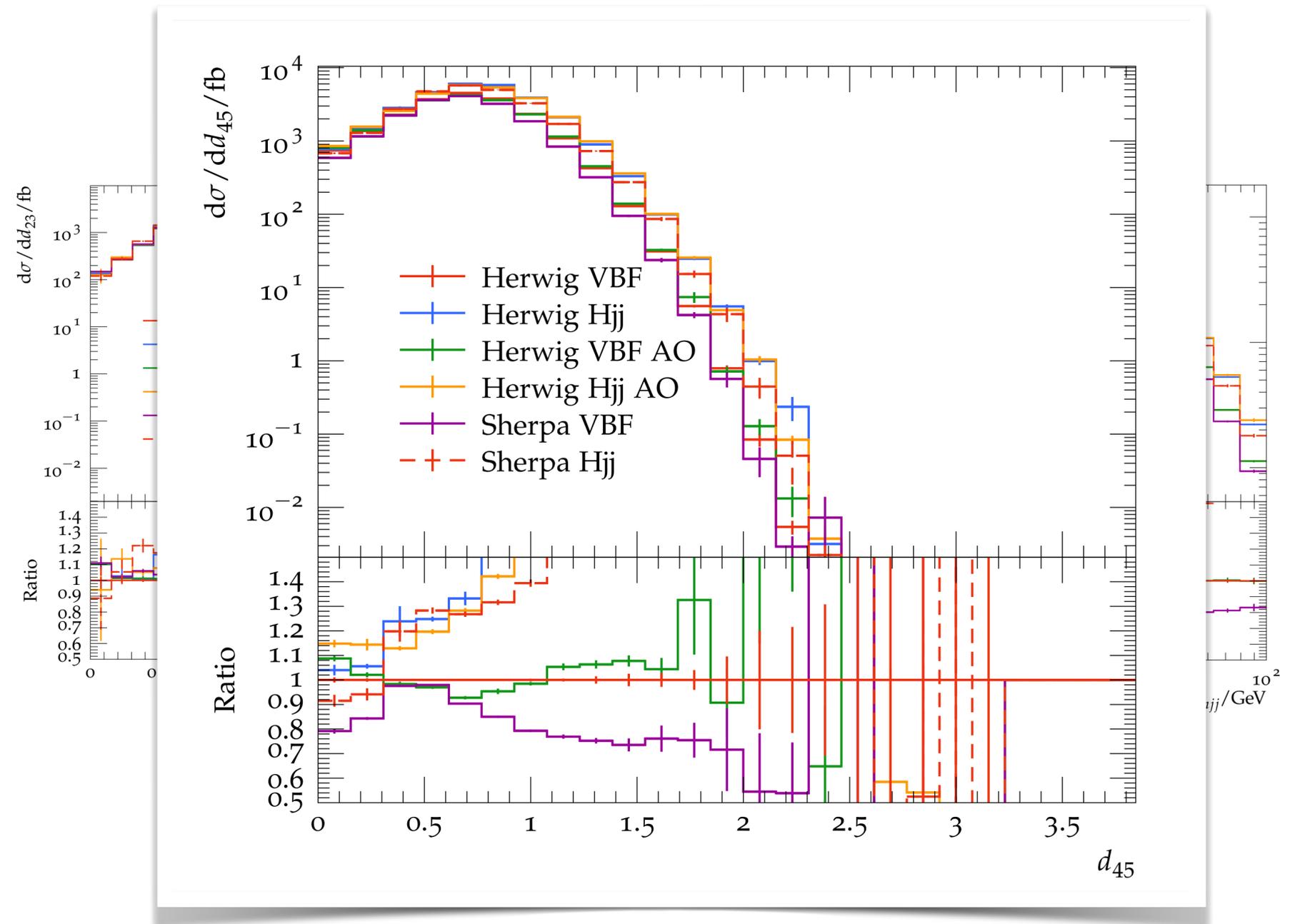
More Perturbative Studies

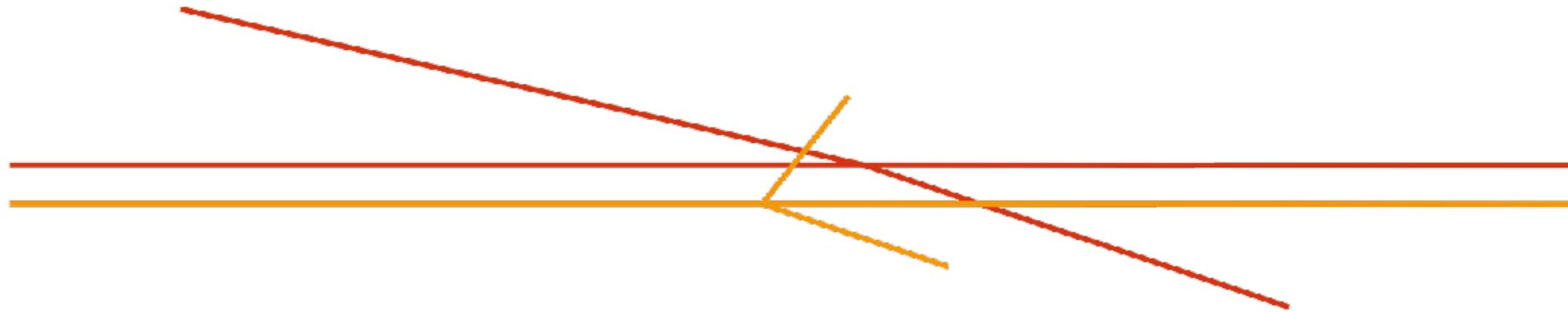
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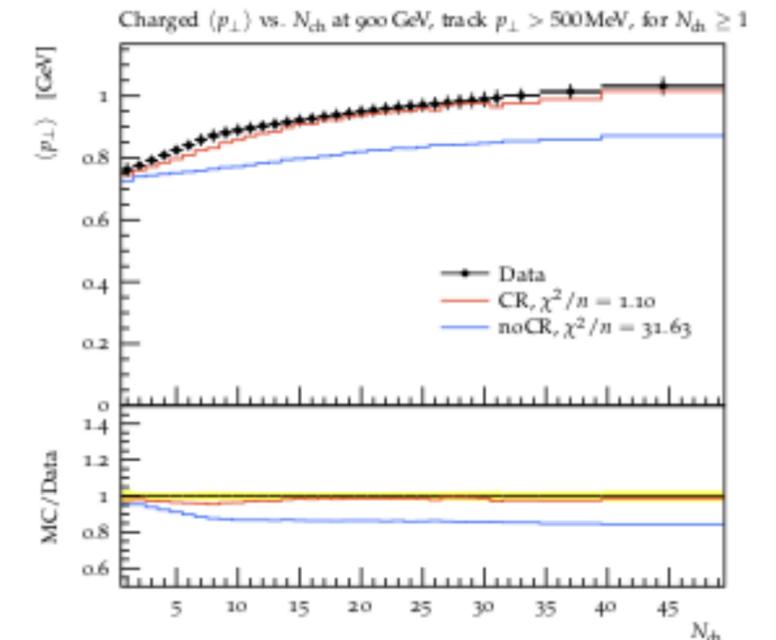
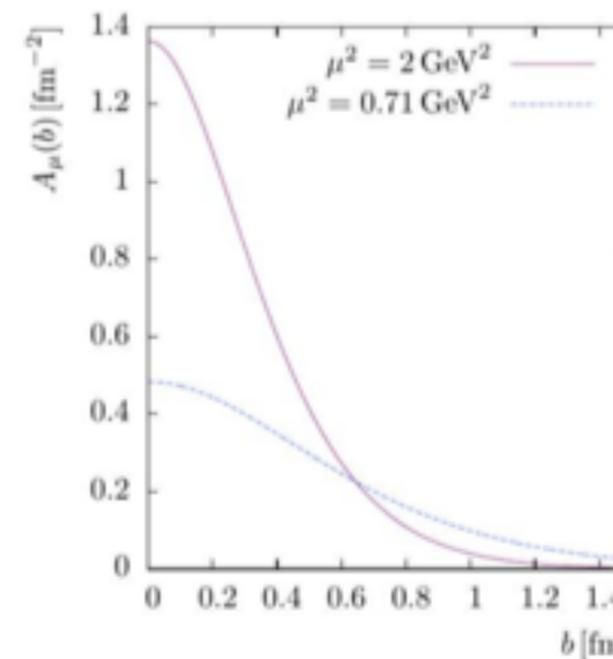
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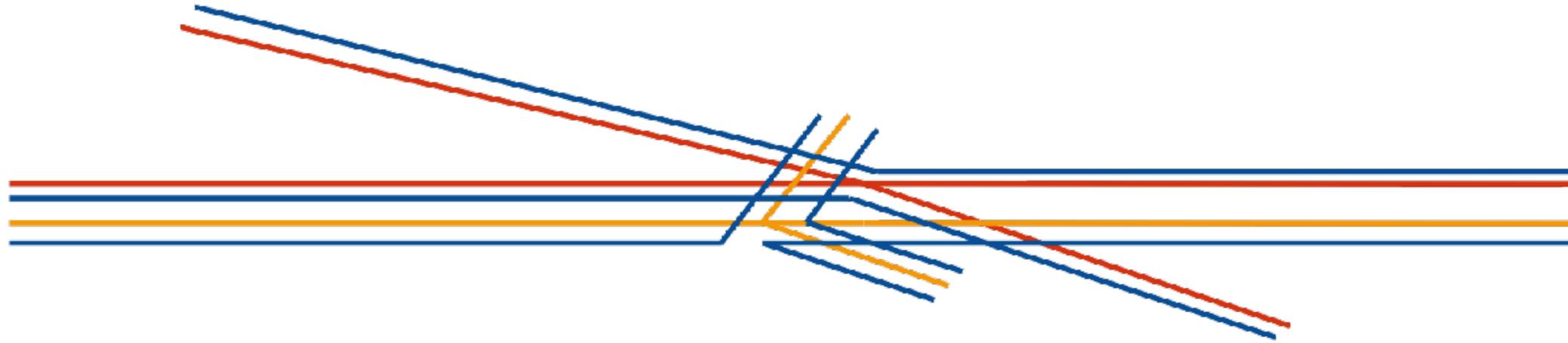




Assume some matter distribution in the proton, and effective multiplicity distribution of additional scatters.

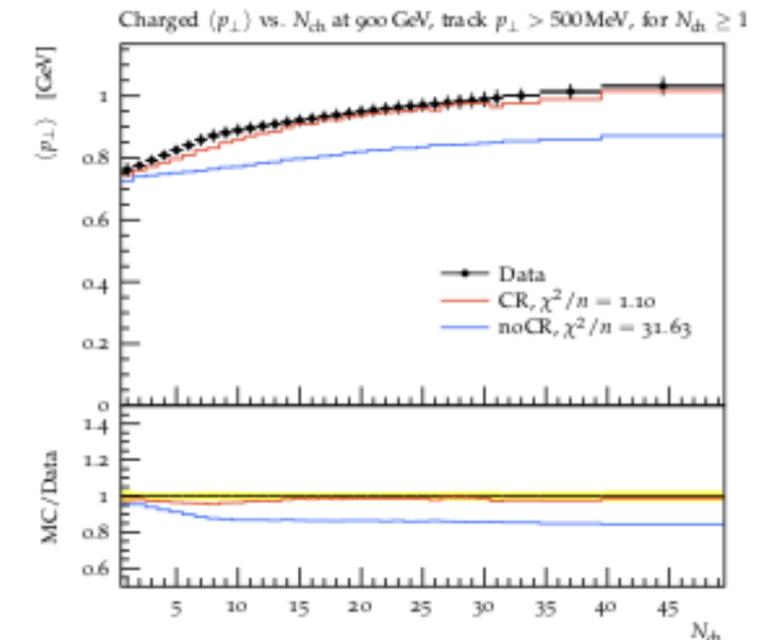
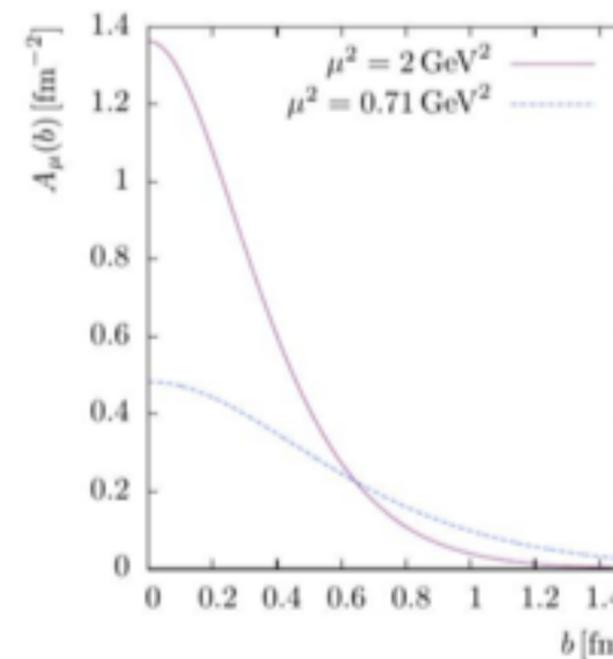
Colour reconnection crucial to describe MinBias and UE data: lack of knowledge about colour correlations.

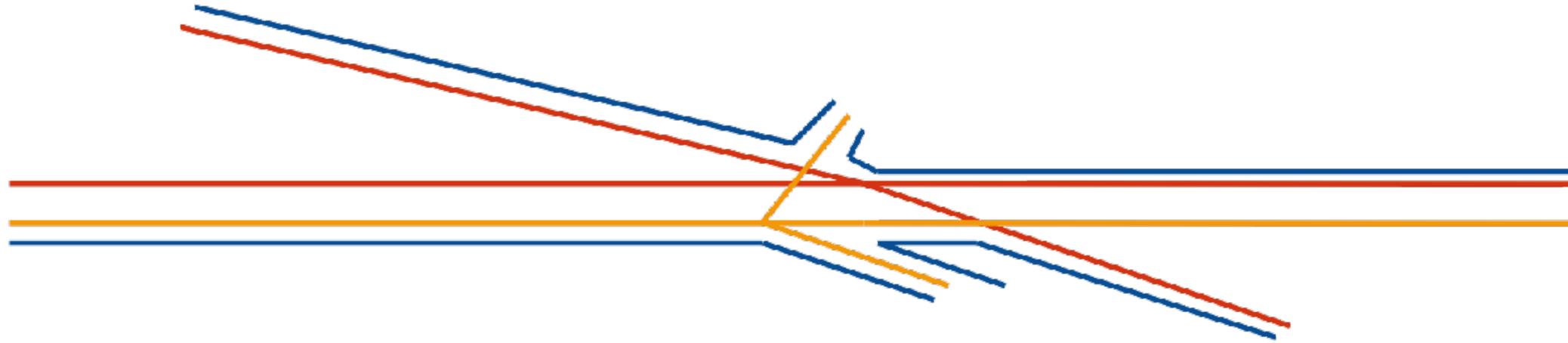




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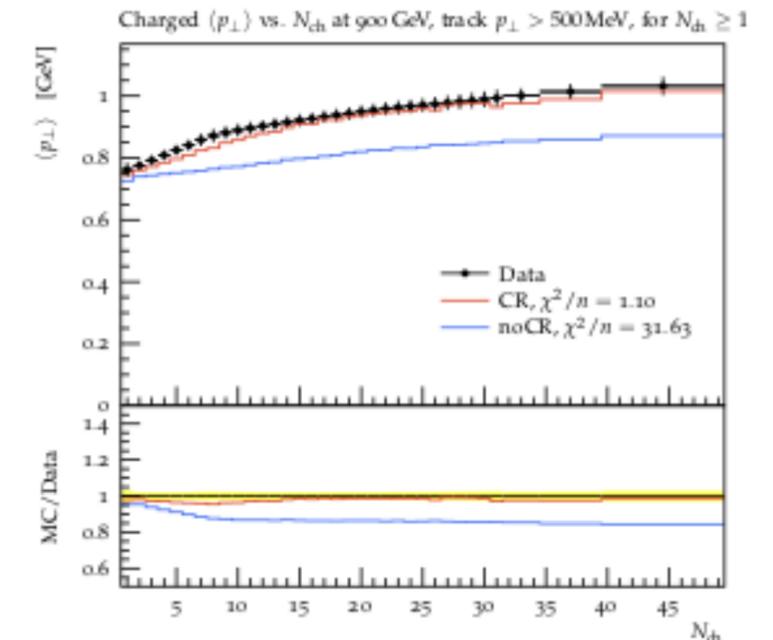
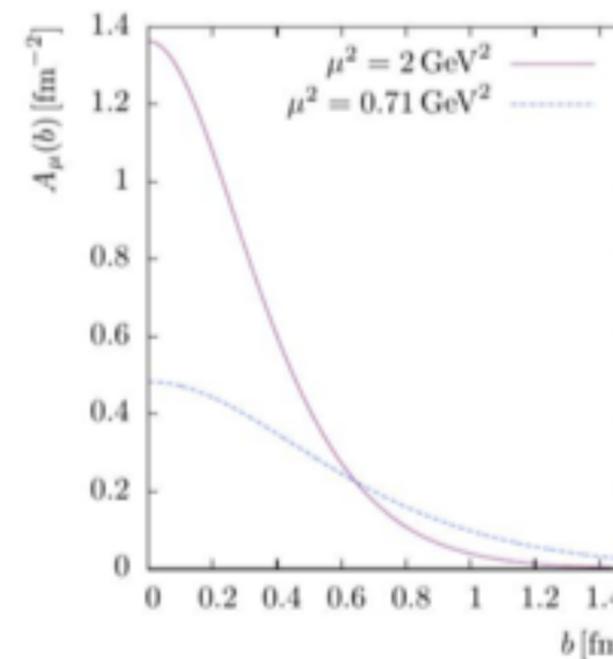
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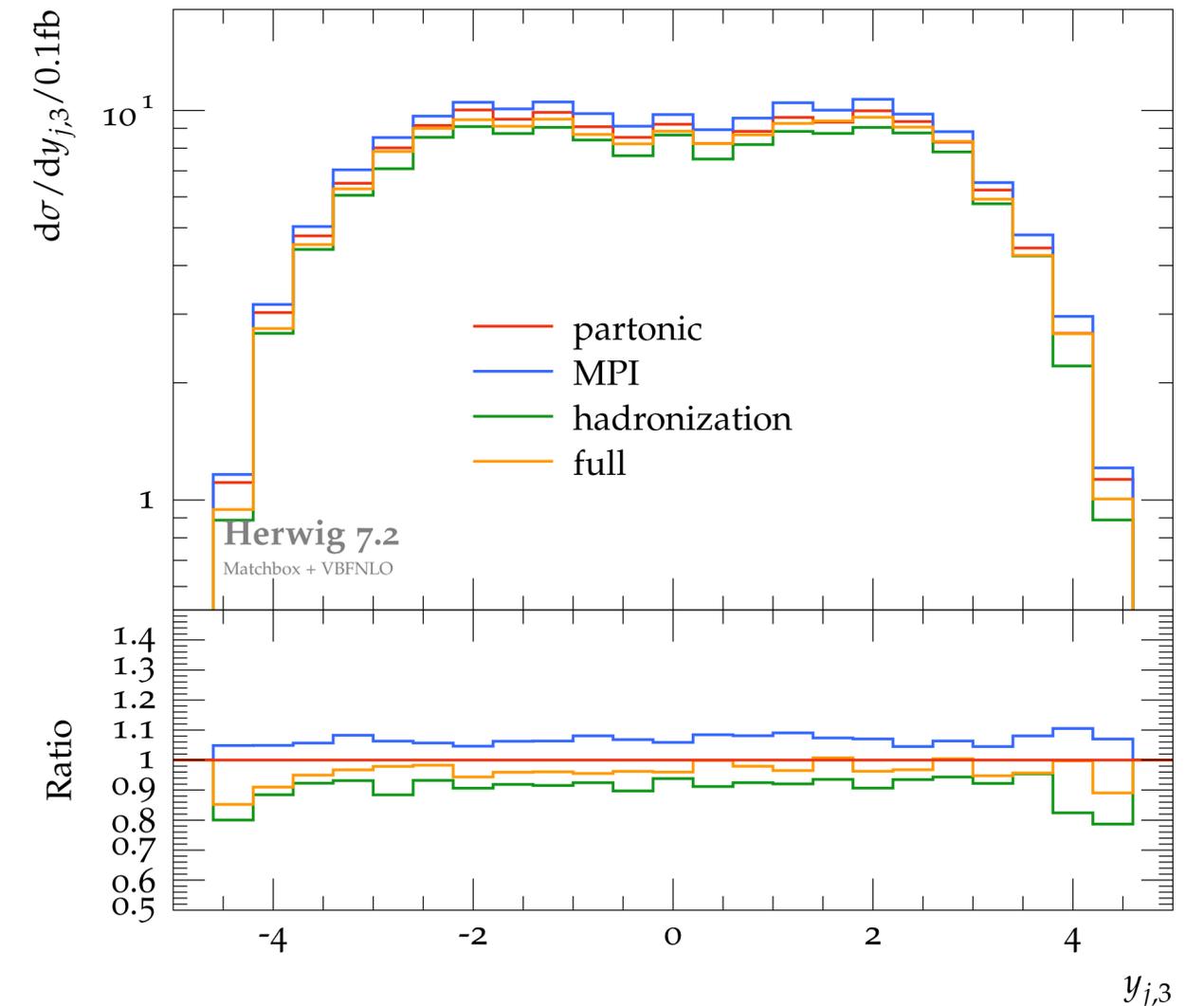
Soft QCD effects are not absent: significant impact on interjet activity and jet shapes.

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

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



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

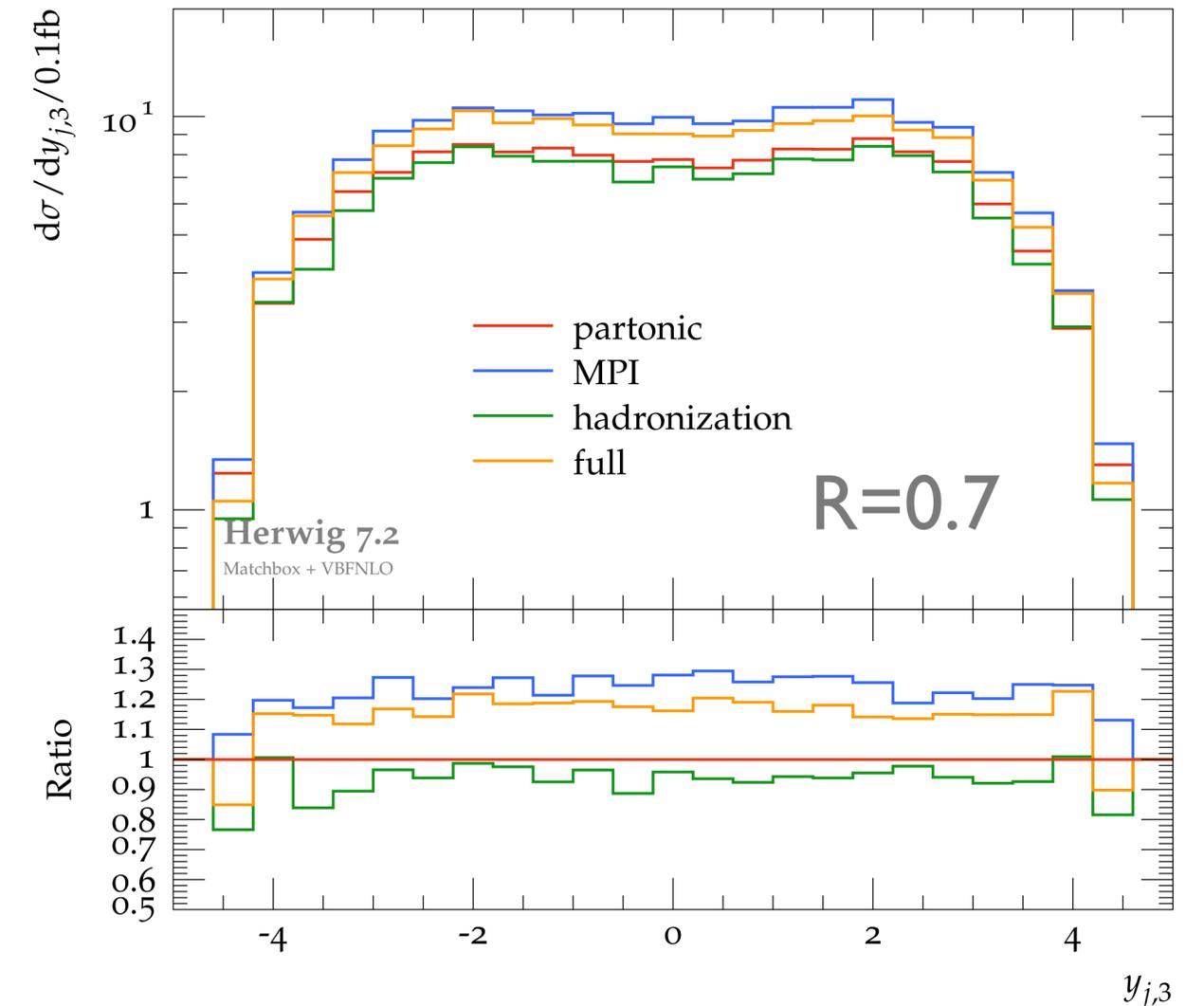
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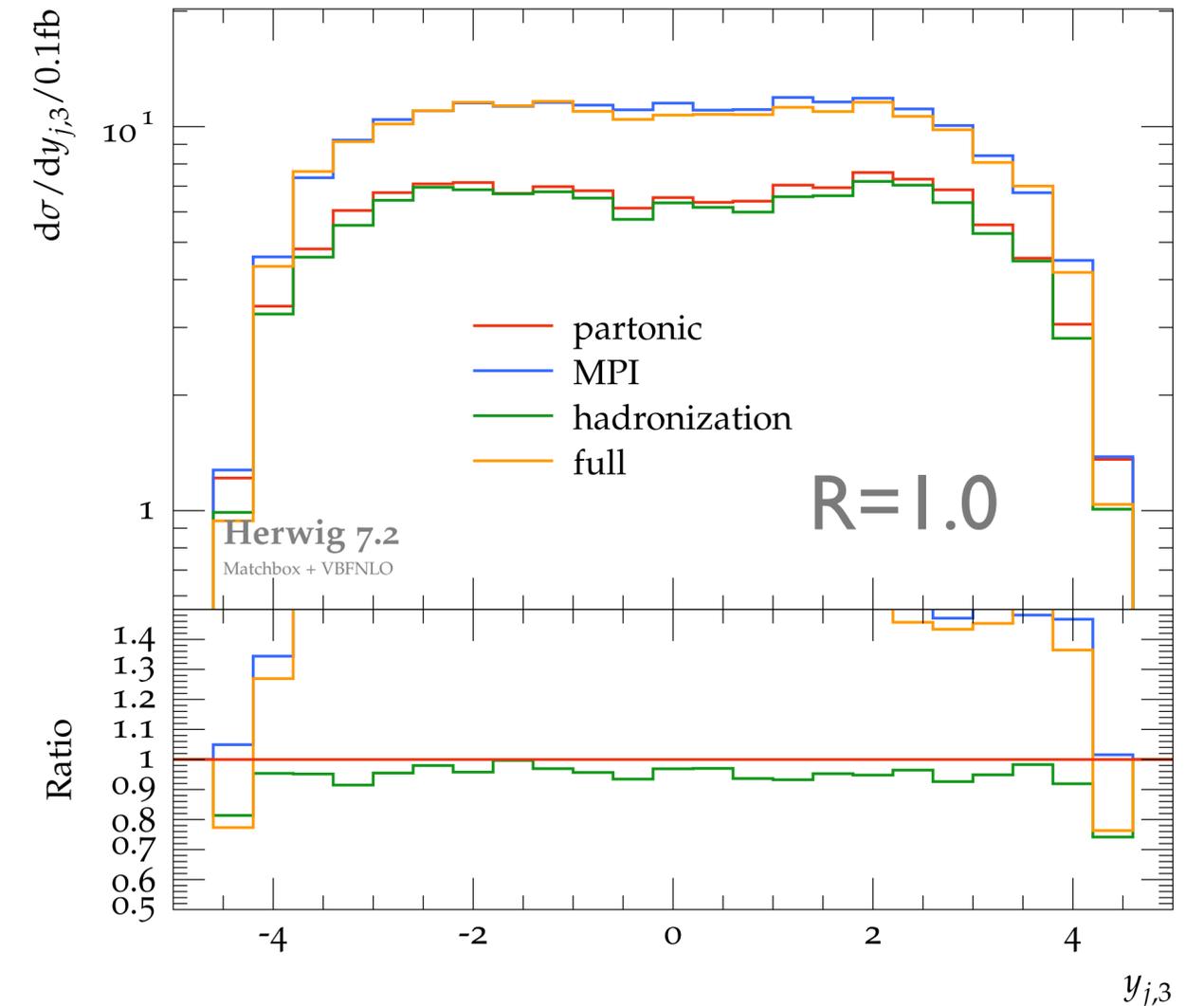
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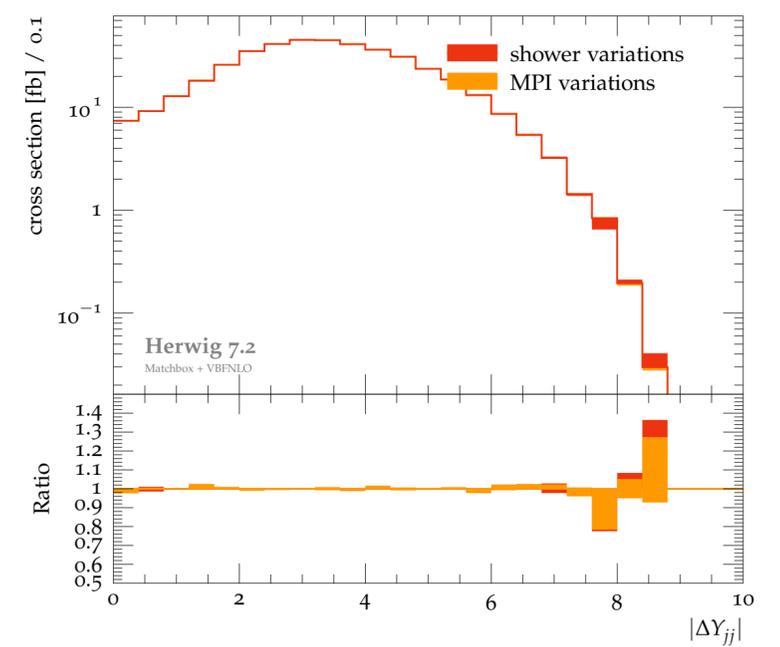
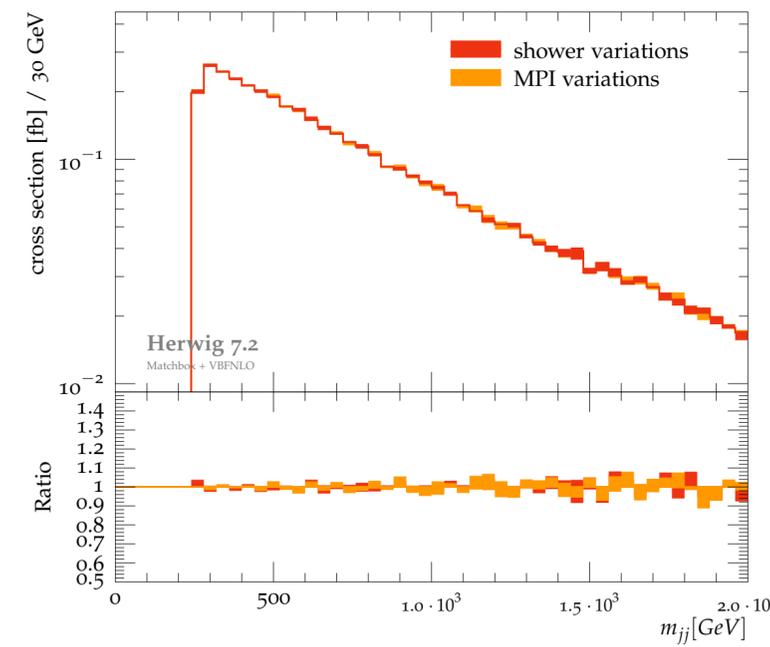
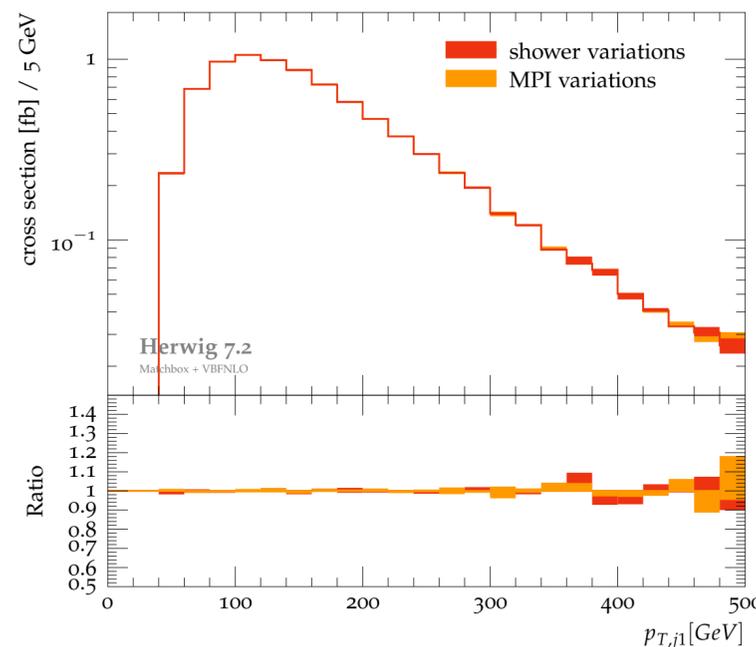
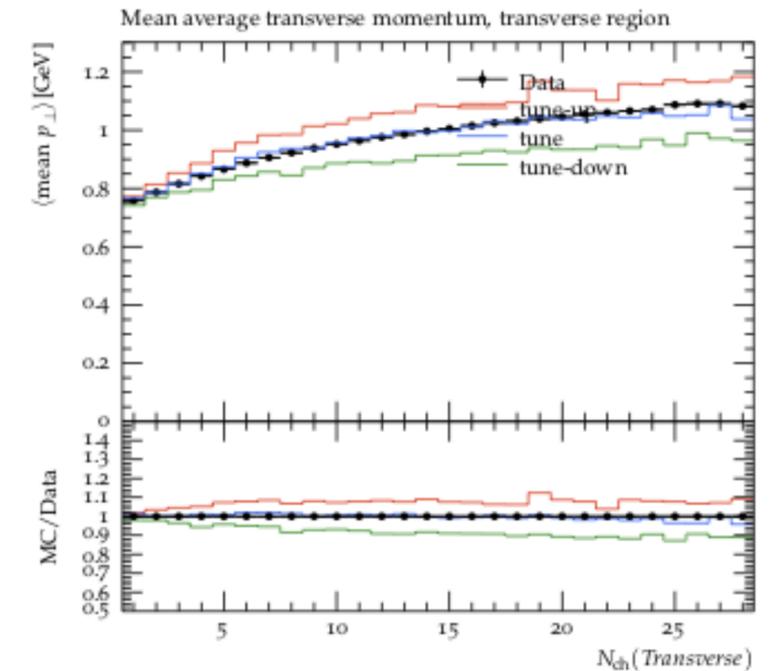
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Strategy

- Vary colour reconnection and MPI parameters to stay within $\sim 10\%$ agreement of typical tuning observables
- Vary perturbative scales, specifically shower hard scale
- Full NLO+PS study including shower variations

Tagging jet
distributions
mostly stable



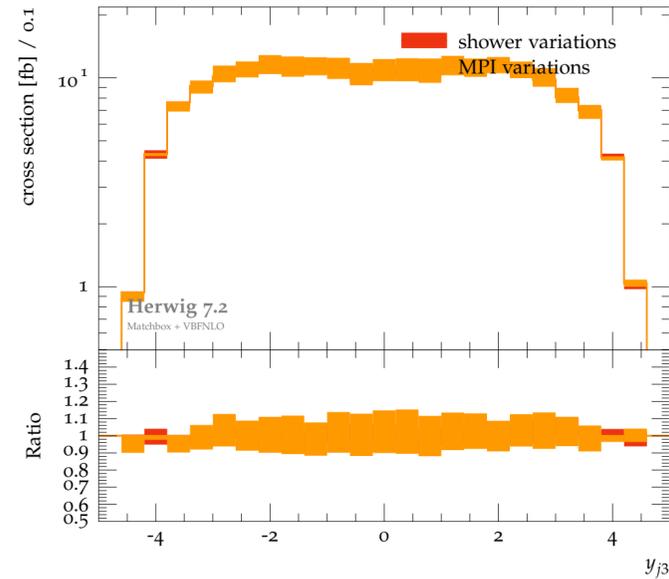
Model variation surprises

Loose selection, $R=1.0$

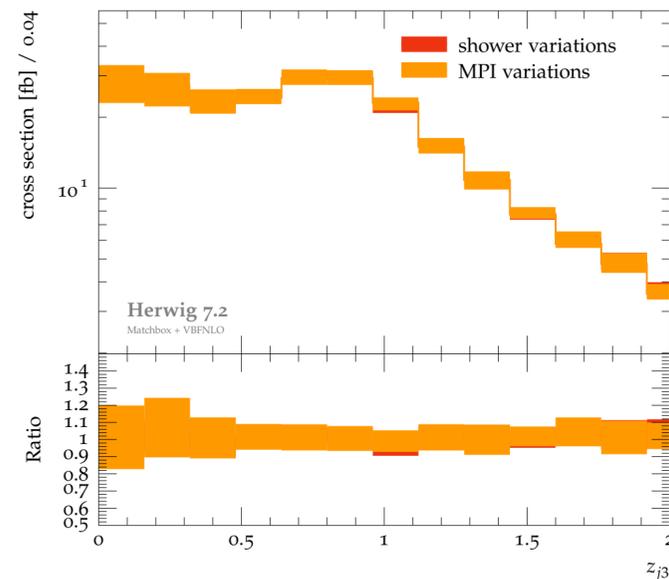
Loose selection, $R=0.7$

Tight selection, $R=0.7$

Third jet rapidity



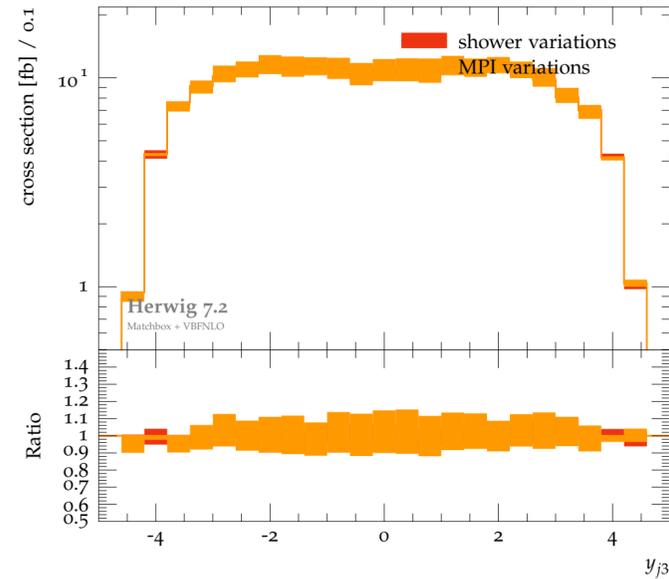
Third jet z



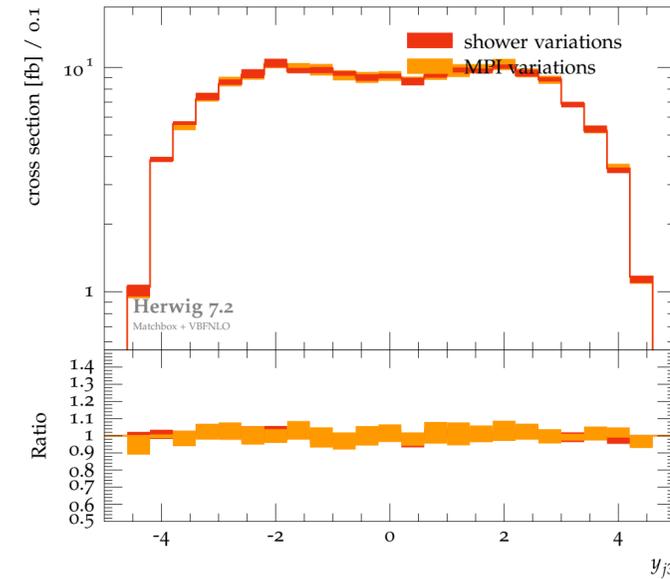
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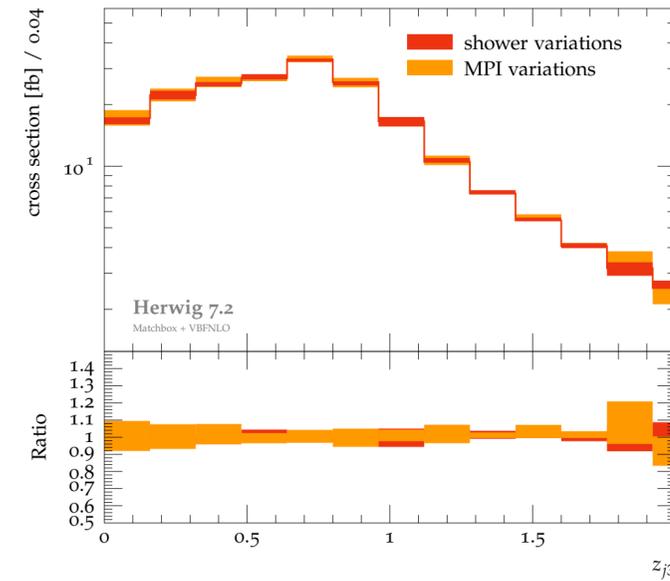
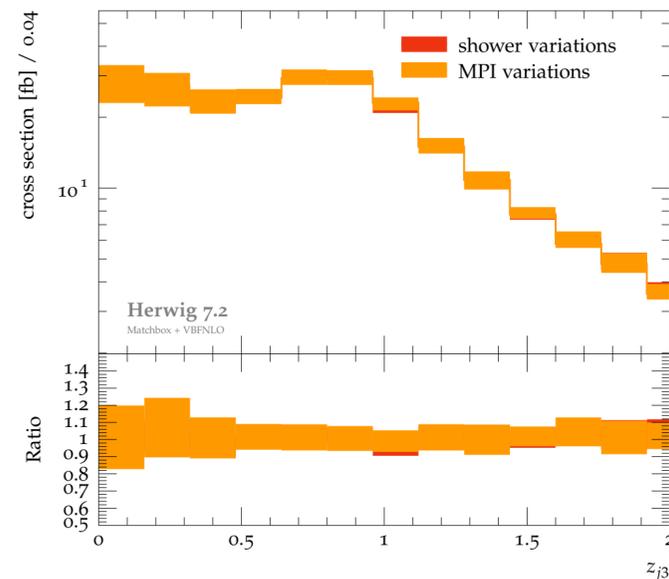


Loose selection, $R=0.7$



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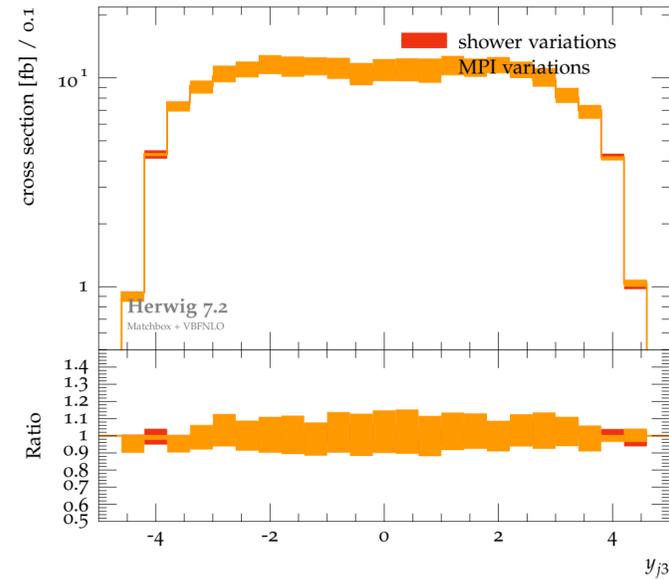
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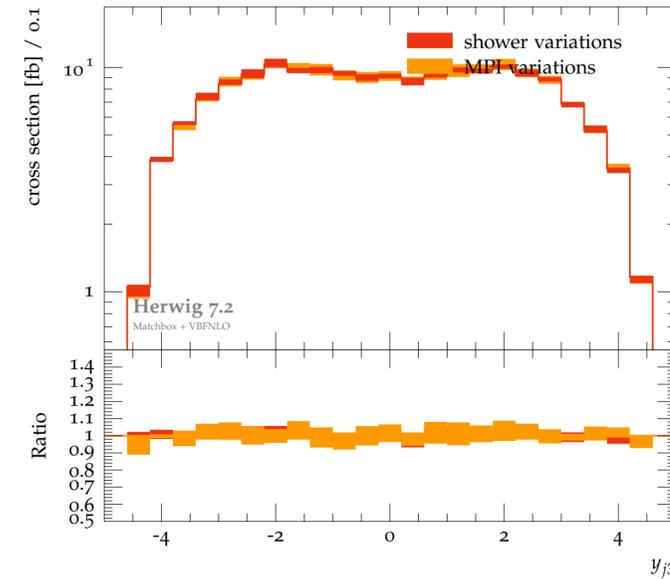
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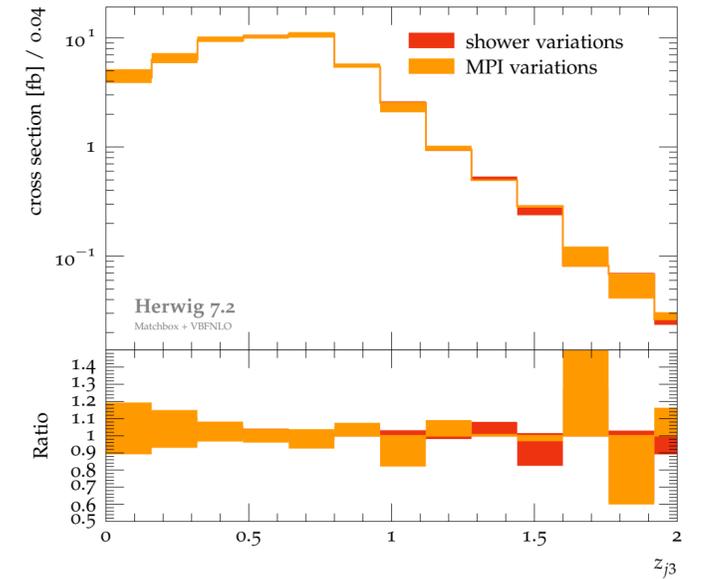
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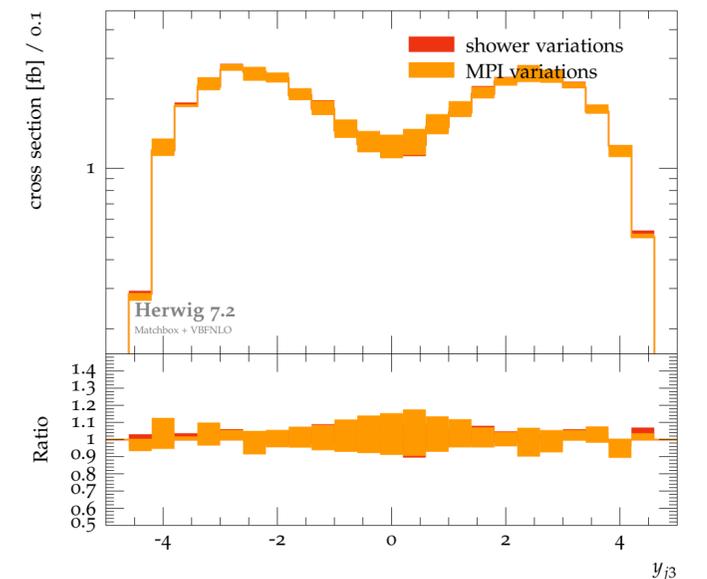
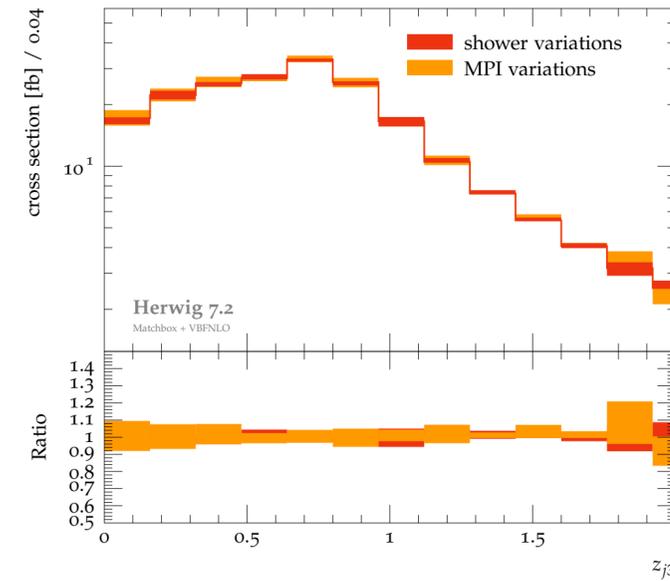
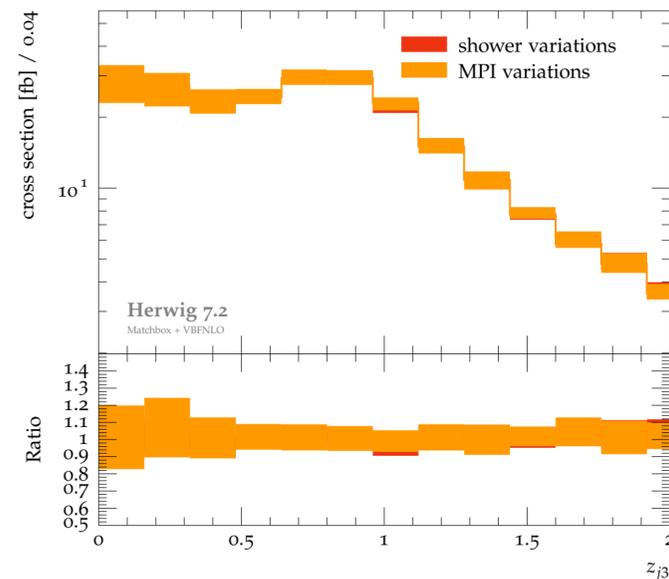
Loose selection, $R=0.7$



Tight selection, $R=0.7$



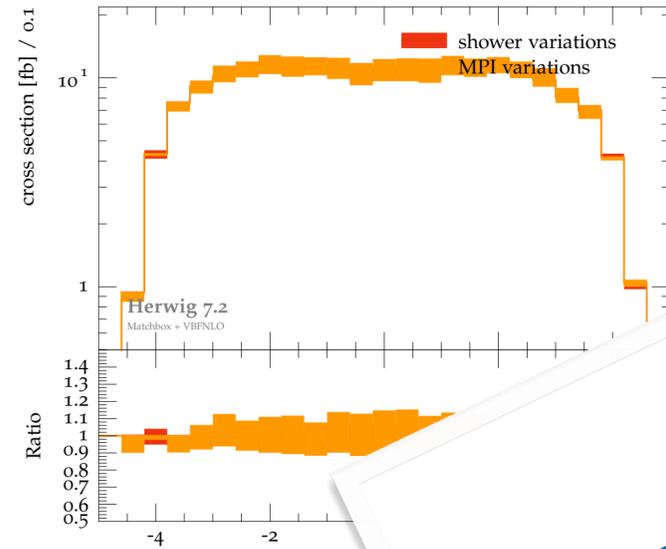
Third jet z



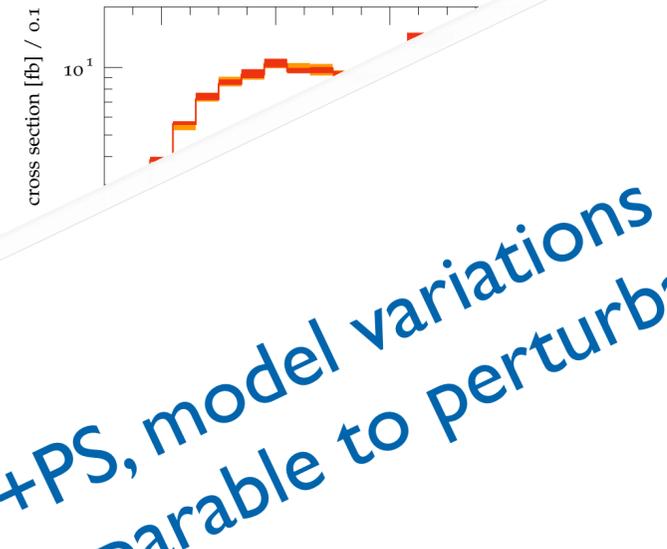
Model variation surprises

Third jet rapidity

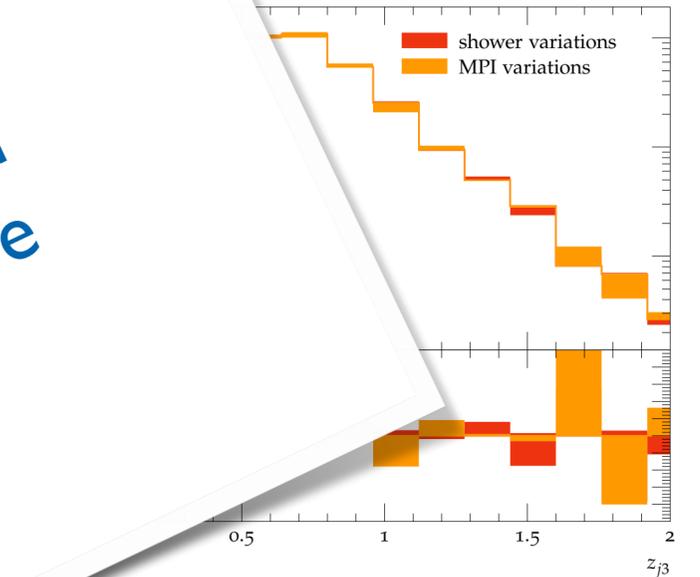
Loose selection, $R=1.0$



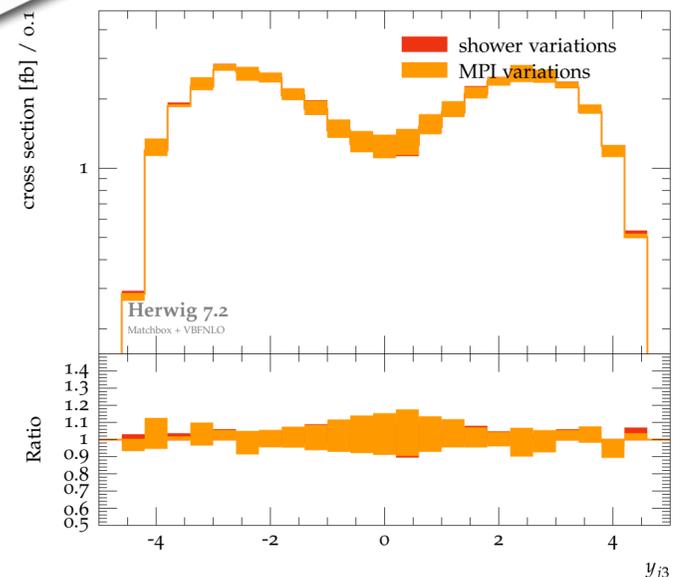
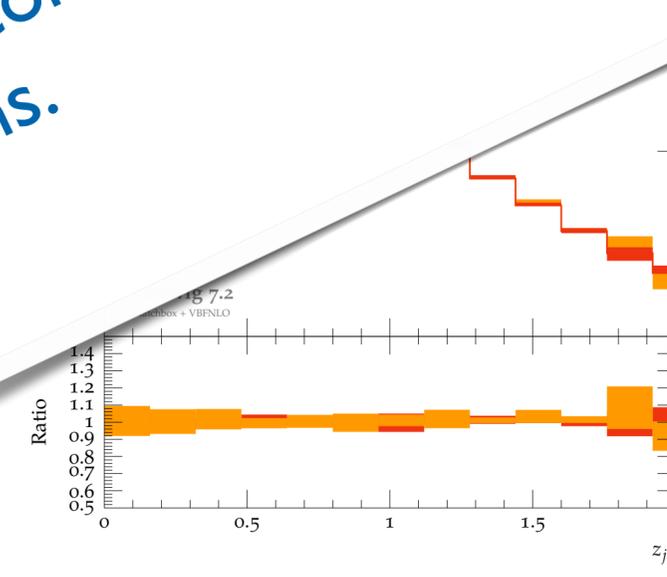
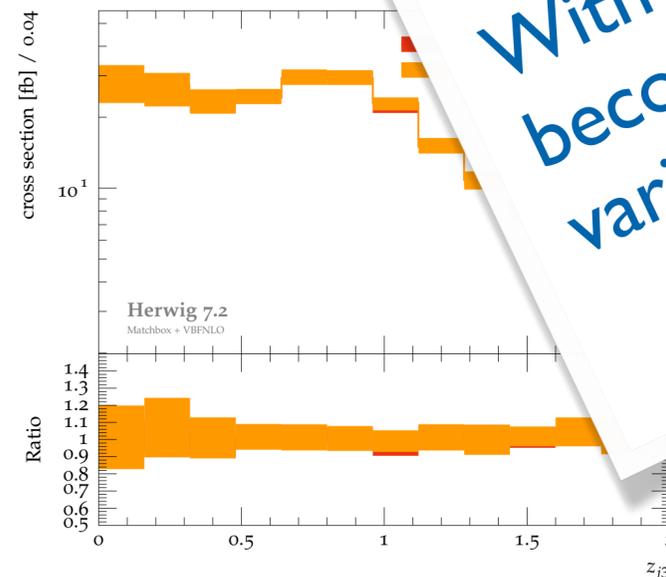
Loose selection, $R=0.7$



Light selection, $R=0.7$



Third jet z



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

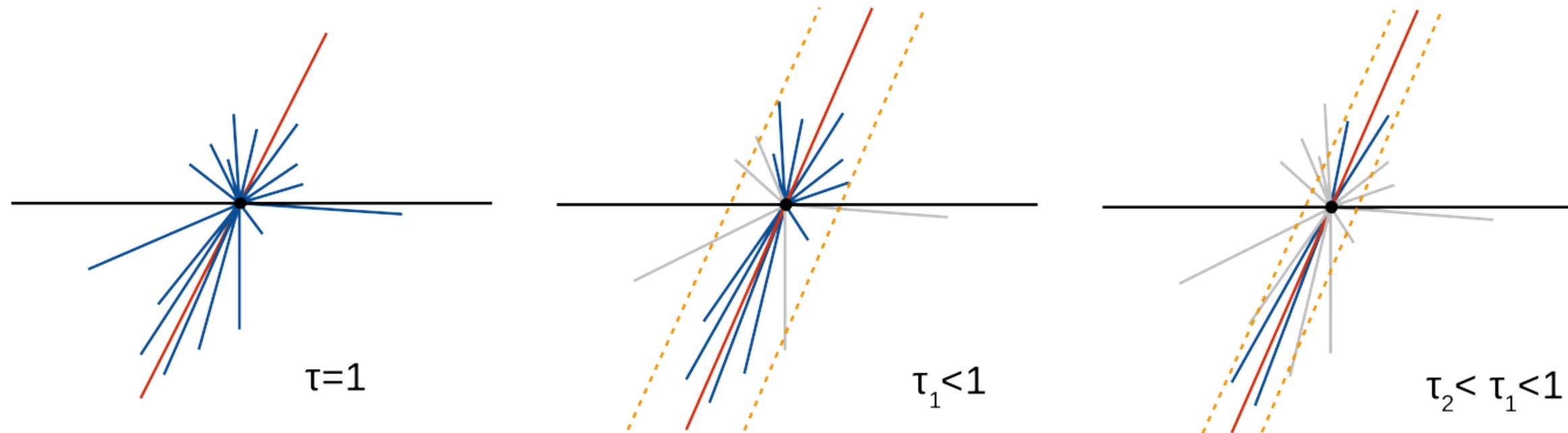
NLO+PS tools are in good shape for VBF and VBS, though uncertainties remain at the 10% level in between different algorithms for hard spectra. VBF specifically sensitive to colour coherence and recoil effects.

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.

Should not forget about more recent development on Glauber exchanges.

Thank you!



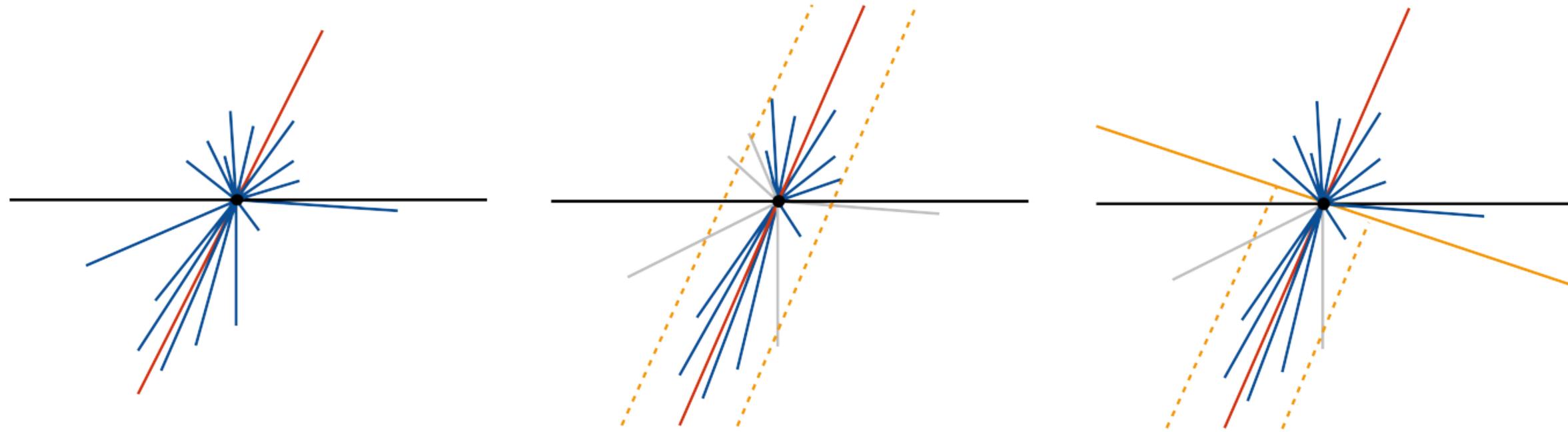
Resummation of observables which globally measure deviations from 2-jet limit.

[n jets in large-N limit]

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

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

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



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.