universität wien

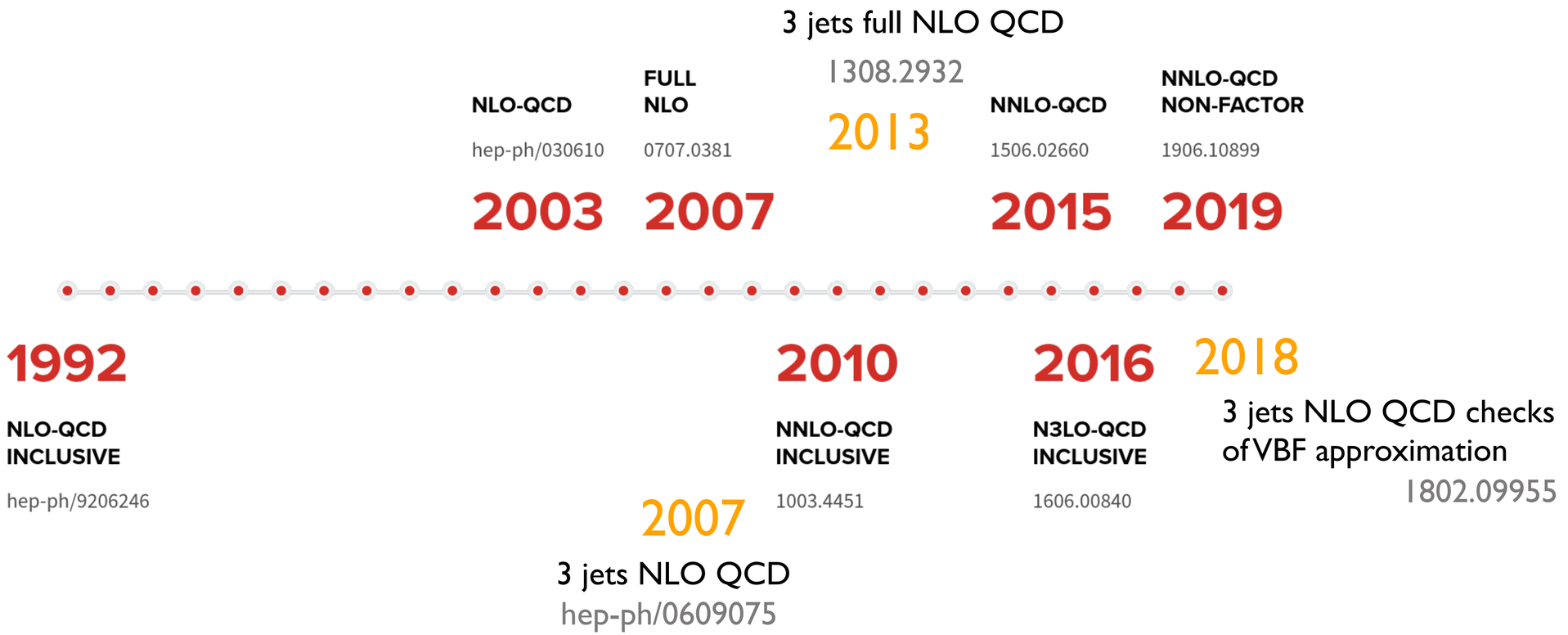
MC (QCD) challenges in VBF/VBS

Simon Plätzer
Particle Physics — University of Vienna

at the
SM@LHC conference
Remote | 9 November 2020

A personal selection.

If fixed order was enough



See talk by Melnikov for VBF related developments

Karlberg — VBSCAN Helsinki meeting
Additions by Plätzer

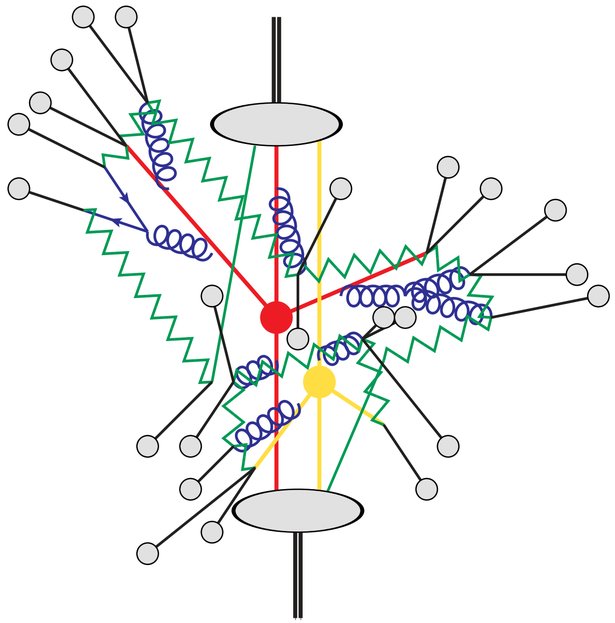
PP collisions are more complex

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



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

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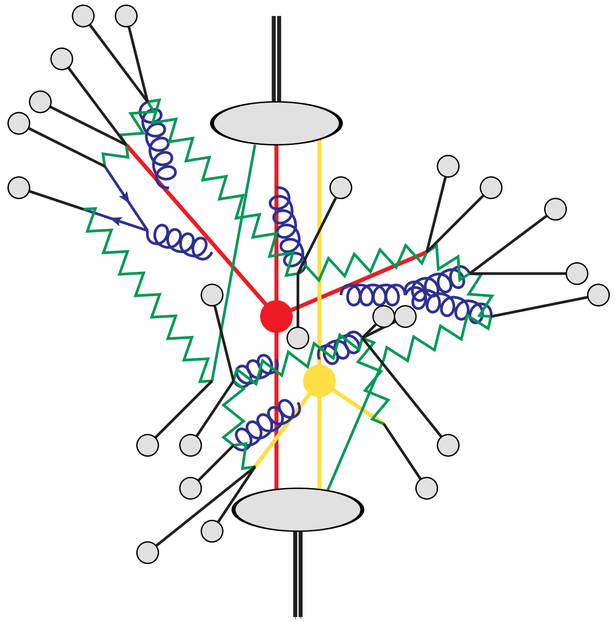
All challenged by VBF/VBS!

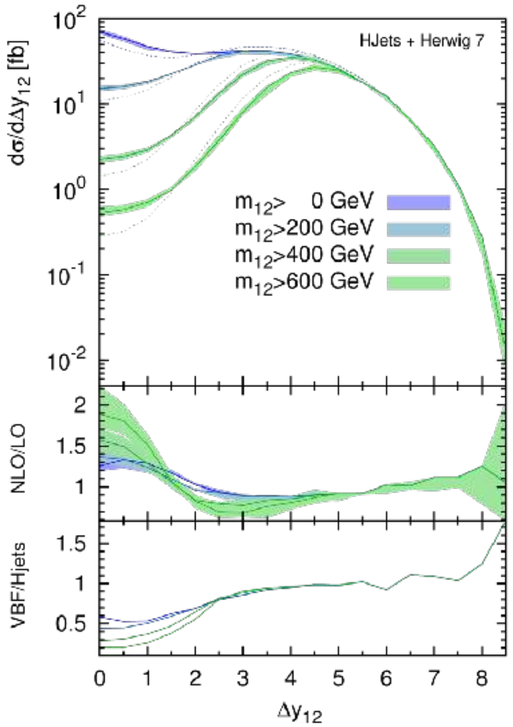


$$\mathrm{d}\sigma \sim \mathrm{d}\sigma_{\mathrm{hard}}(Q) \times \mathrm{PS}(Q \to \mu) \times \mathrm{Had}(\mu \to \Lambda) \times \ldots$$

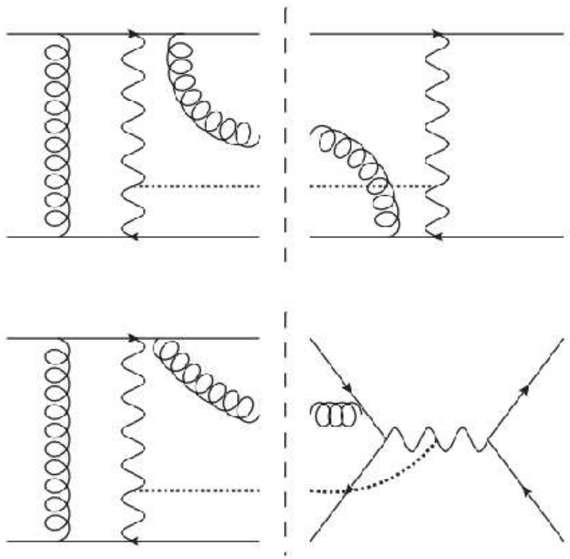
Fixed order and the VBF approximation

Approximation at NLO: acceptable in tight VBF selection.
Challenge is in using full calculations throughout, and for anomalous couplings etc.

[Ballestero et al. — Eur.Phys.J.C 78 (2018) 8, 671]



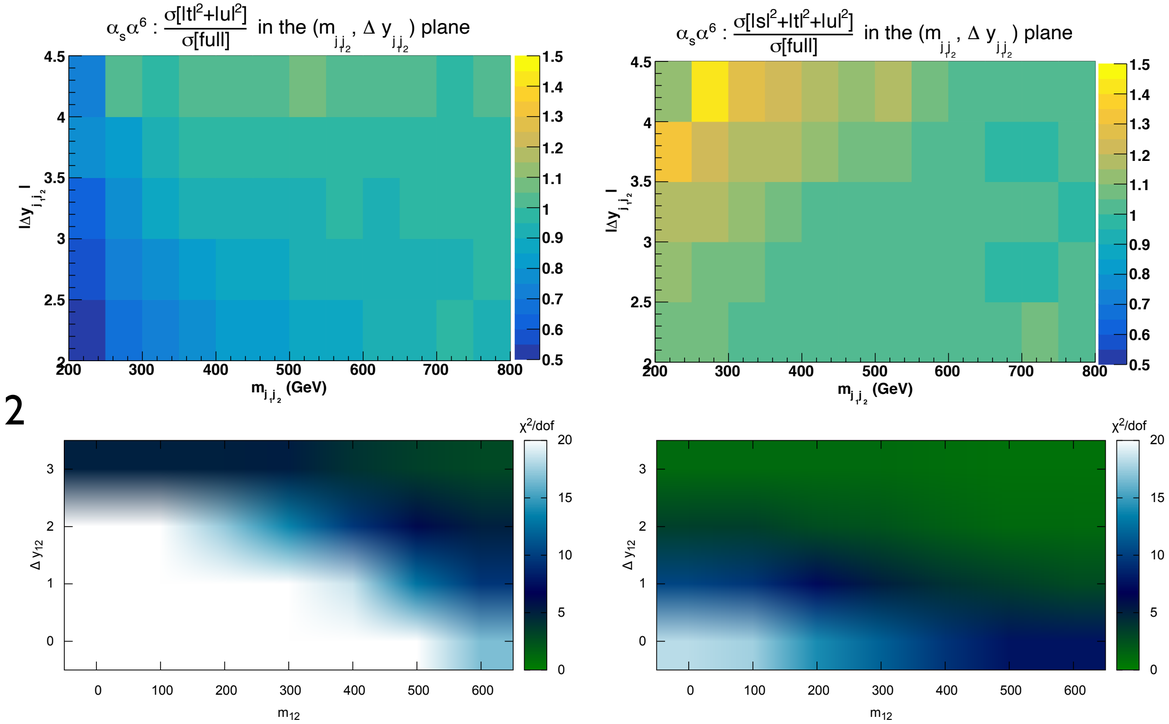
"non-factorizable"



"s channel"

no s channels

s channels in approximation



Δy12

m12

s channels un-suppressed

s channels vetoed

[Campanario, Figy, Plätzer, Sjödahl – PRL 111 (2013) 211802]

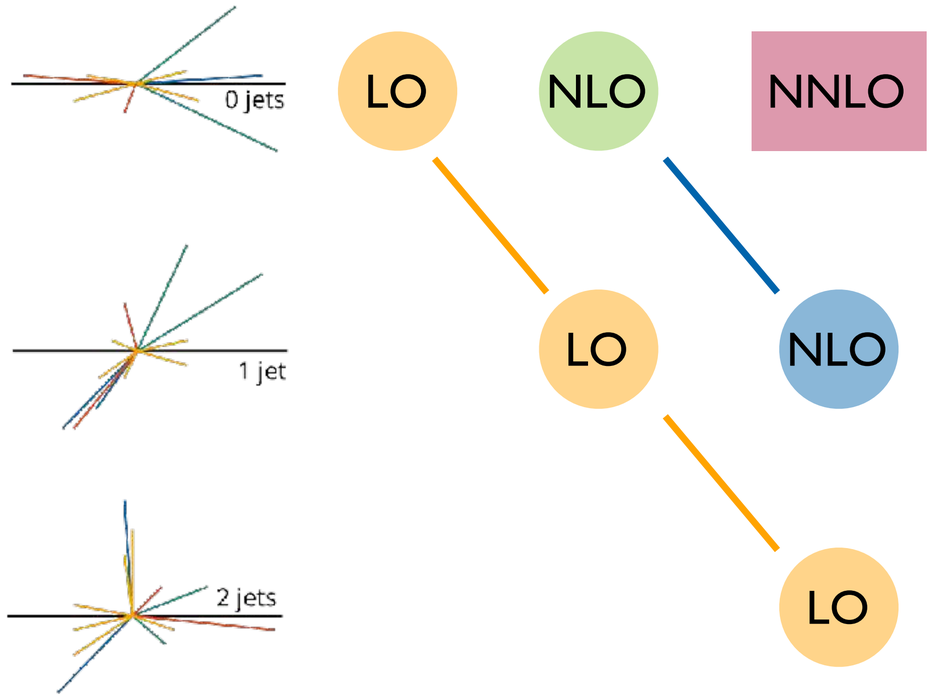
[Campanario, Figy, Plätzer, Rauch, Schichtel, Sjödahl – PRD 98 (2018) 033]

Challenges for Matching and Merging

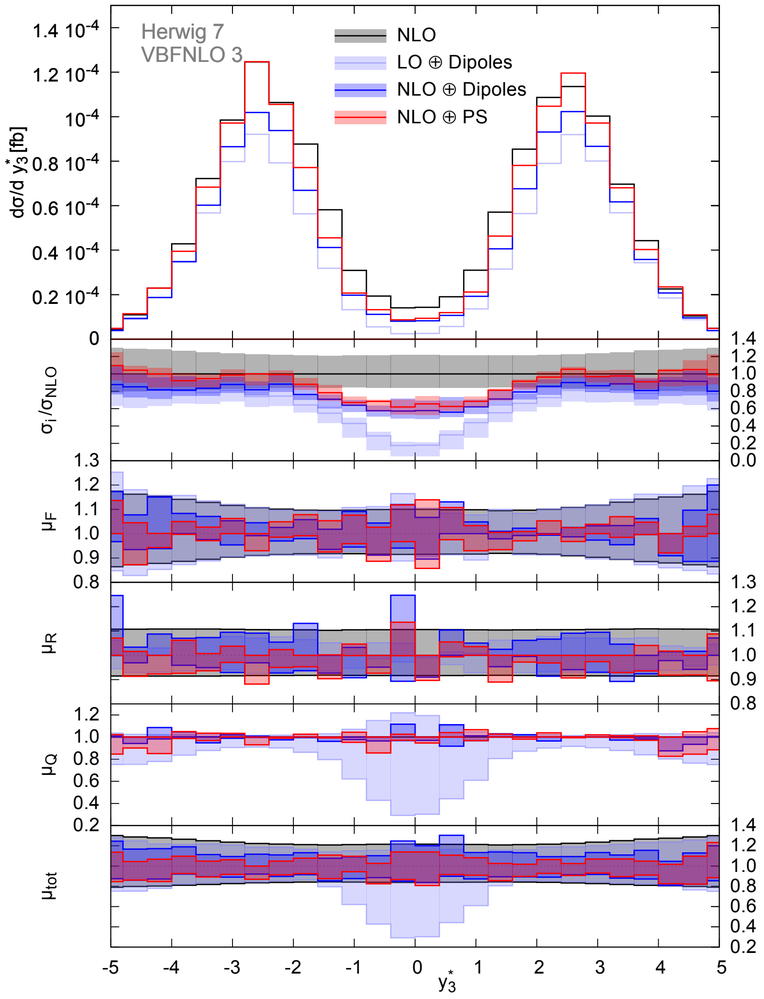
Jets at Born level:

- Generation cut uncertainties
- Merging algorithms specifically challenged — solved within modified unitarized merging.

[Bellm, Gieseke, Plätzer — EPJ C78 (2018) 244]



Merging & matching
NLO merging



[Rauch, Plätzer – EPJ C77 (2017) 293]

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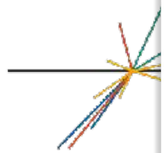
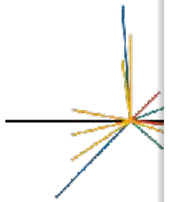
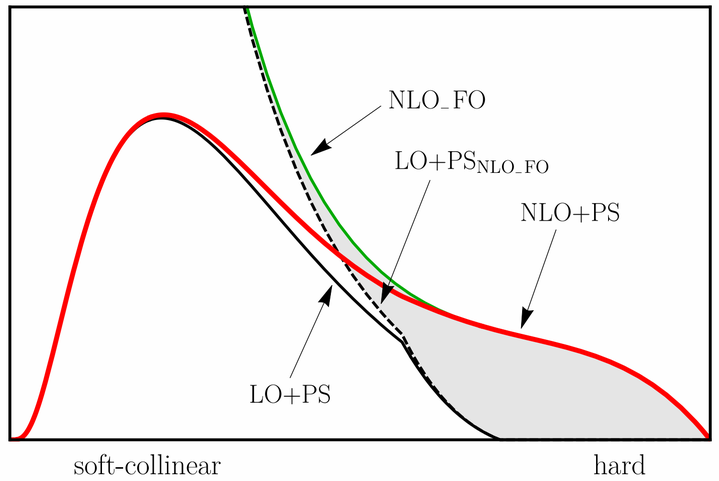
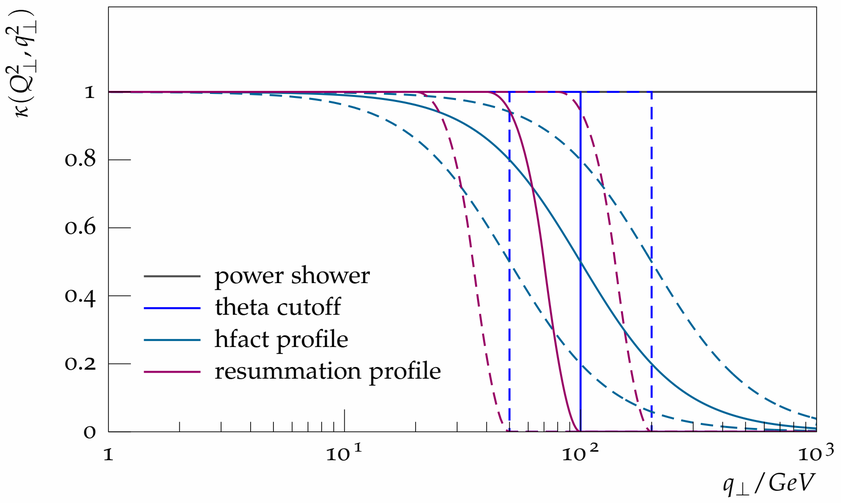
  modifie







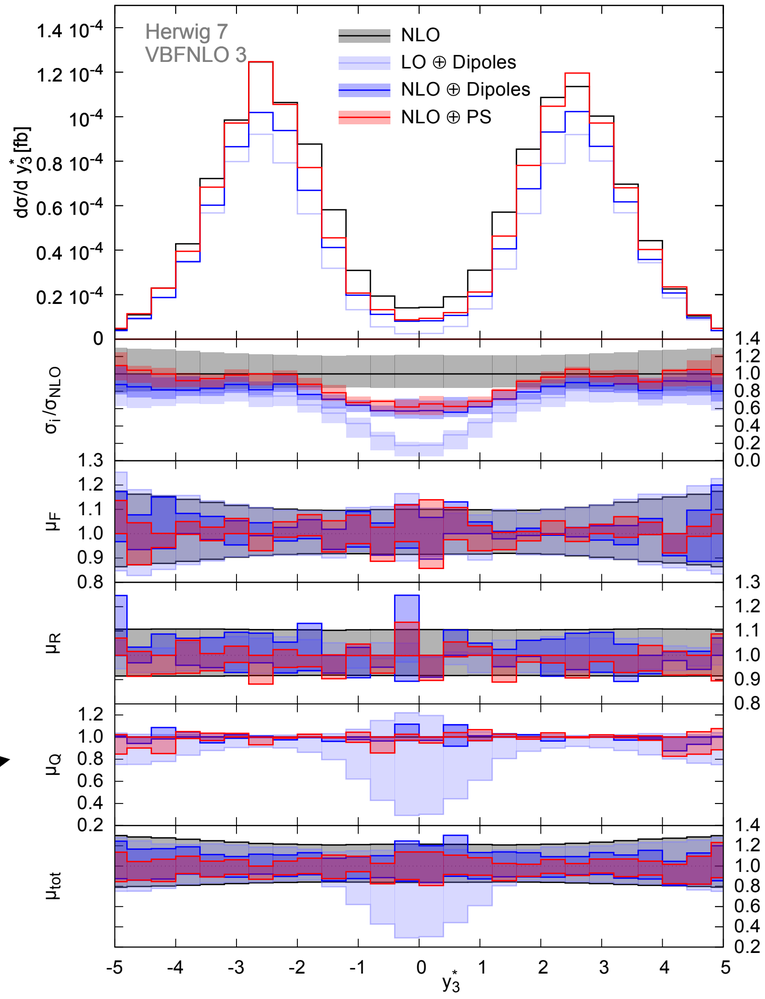


[Bellm, Nail, Plätzer, Schichtel, Siodmok – EPJ C76 (2016) 665]

thin

J C78 (2018) 244]

matching
ging



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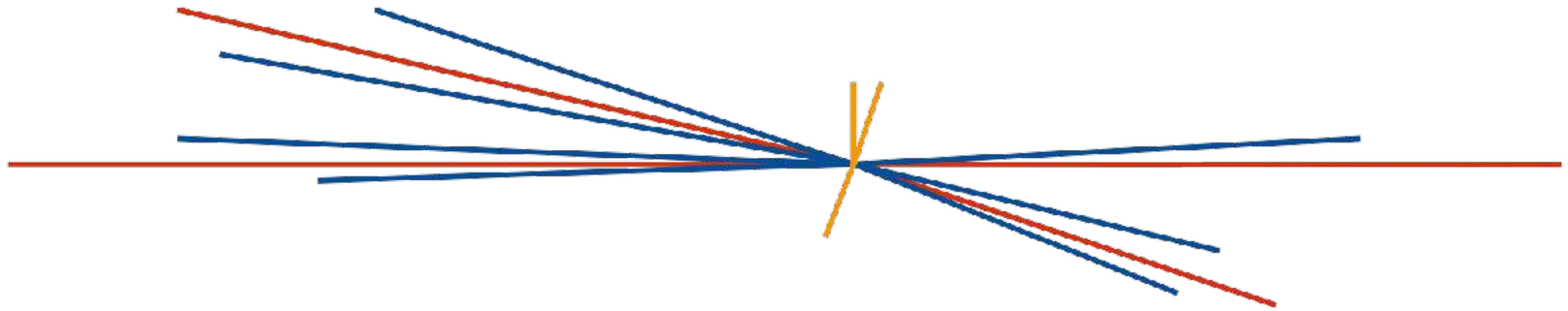
Colour in VBS/VBF

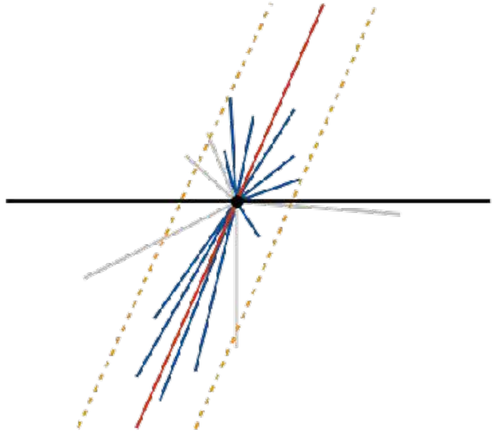
Coherent emission of soft large angle gluons from systems of collinear partons.



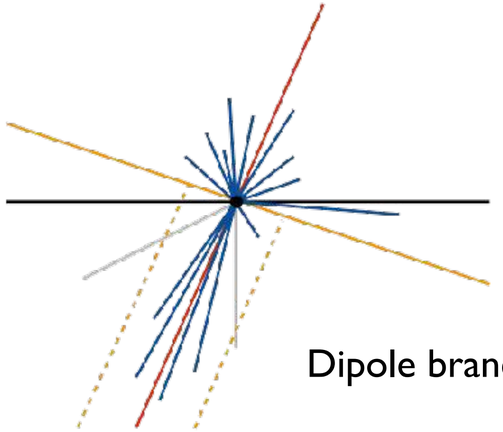
Parton showers: dipoles vs angular ordered, issues of accuracy.

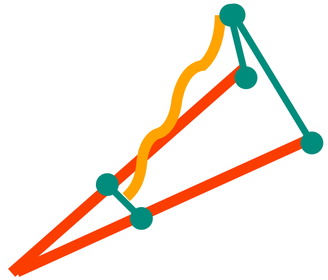
[Salam et al. — JHEP 09 (2018) 033]
[Forshaw, Holguin, Plätzer – JHEP 09 (2020) 014]

See Prestel's talk



Parton branchings order in angle:
accurate for global observables.





Dipole branchings order in transverse momentum:
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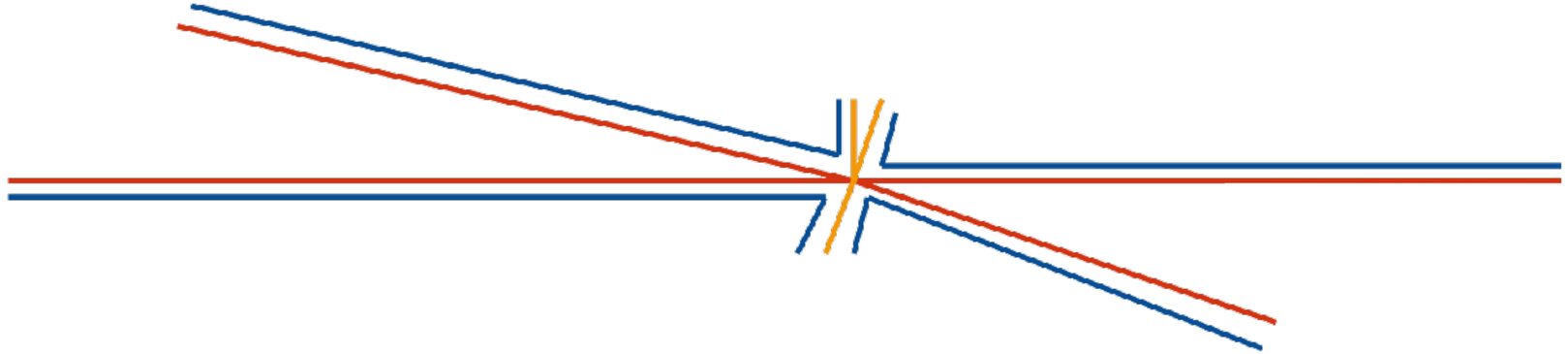

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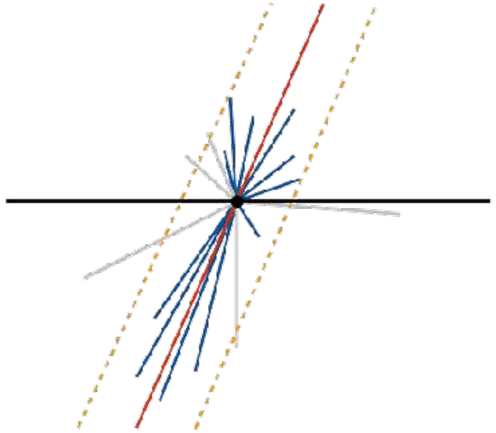

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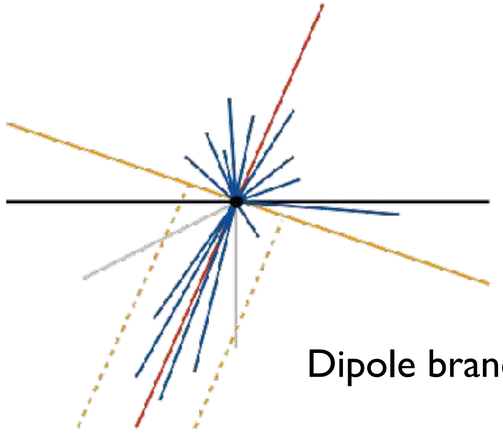

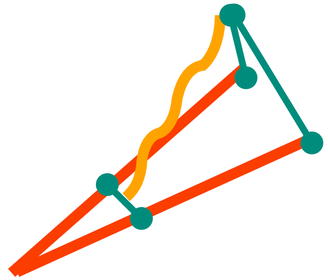

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Benchmarks for VBF Higgs production

[Jäger, Karlberg, Plätzer, Scheller, Zaro — EPJ C80 (2020) 756]

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

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)	✓
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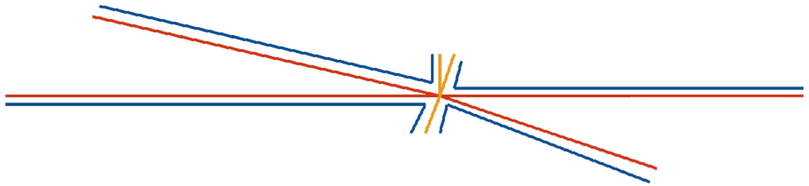
Comparison between tools

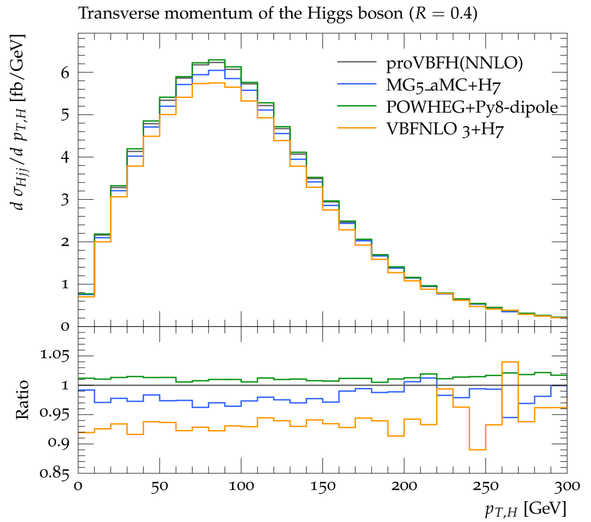
[Jäger, Karlberg, Plätzer, Scheller, Zaro — EPJ C80 (2020) 756]

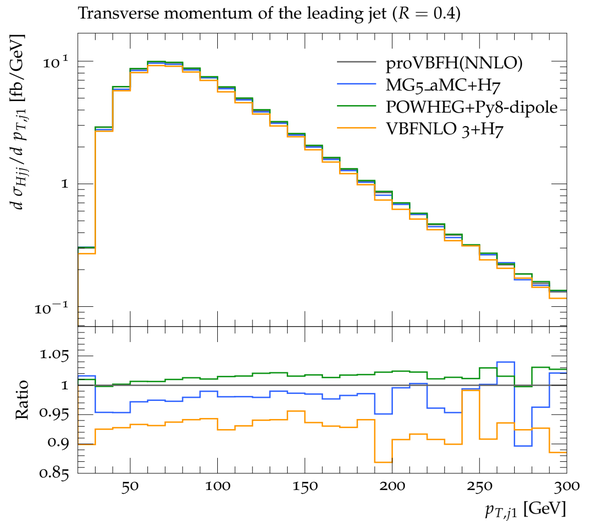
Different setups agree well in tight VBF selection, if colour flow respected.

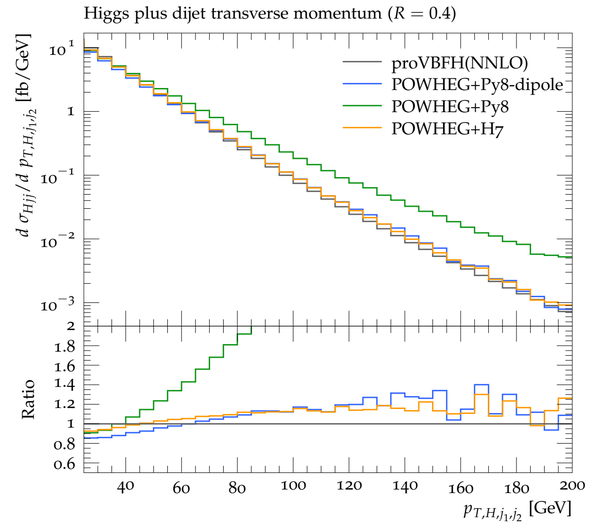
Herwig seems somewhat less ‘jetty’, but all consistent within 10%, shapes of hard spectra not altered.

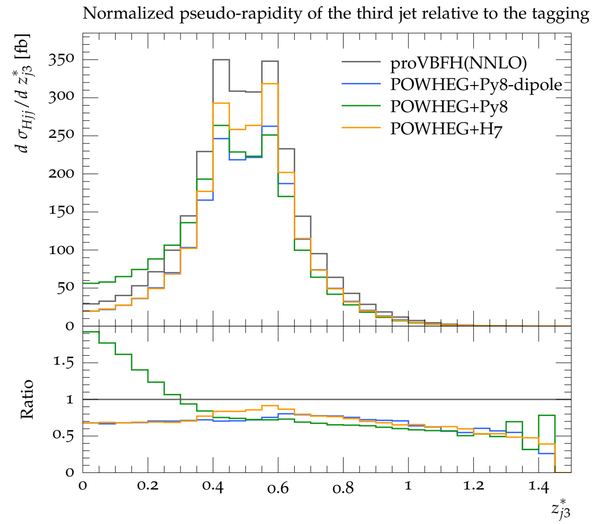
Pythia global recoil not compatible with other results. Pythia dipole recoil NLO matching only available via Powheg.











Shower Variations and Jet Radius Dependence

[Jäger, Karlberg, Plätzer, Scheller, Zaro — EPJ C80 (2020) 756]

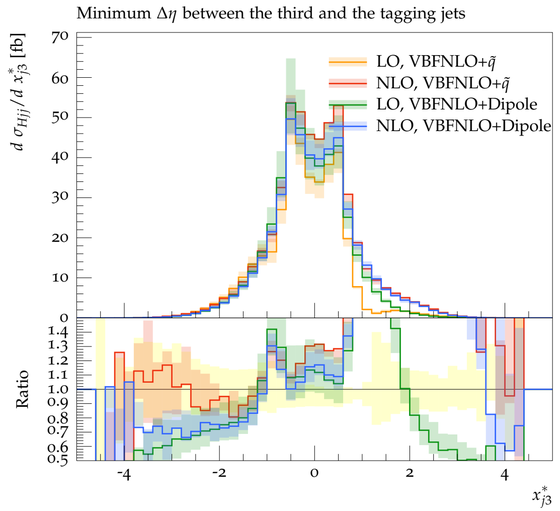
Still significant shower variations shedding light on jet activity after showering, otherwise distributions stable at NLO+PS.

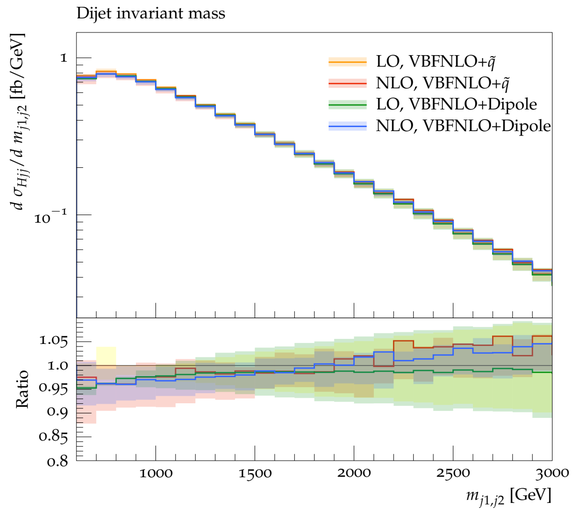
More careful investigation of shower scale profiles and cut migration needed.

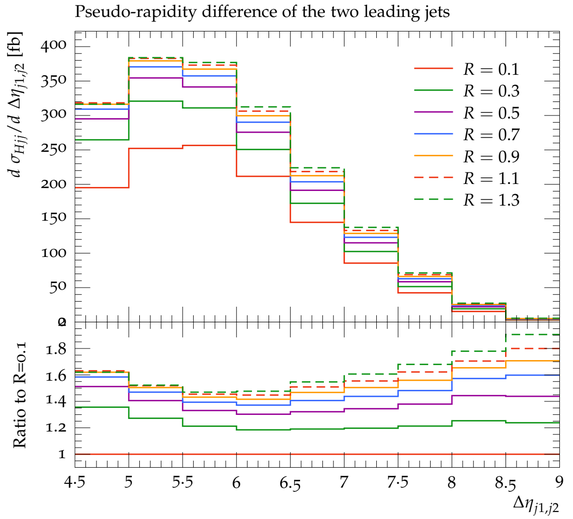
Jet radius dependence shows expected perturbative behaviour.

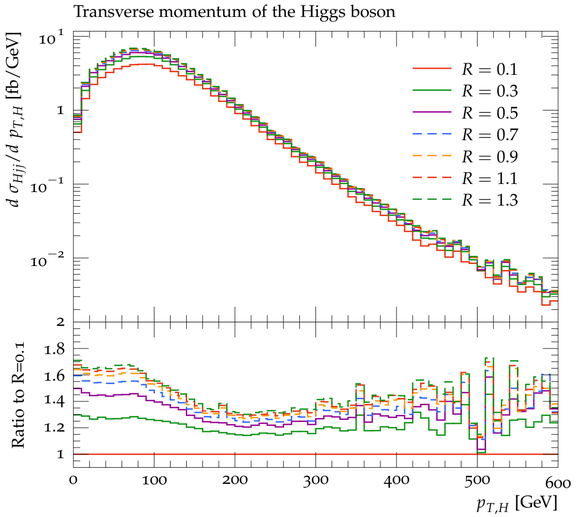
Need to confront with perturbative variations and soft QCD.

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









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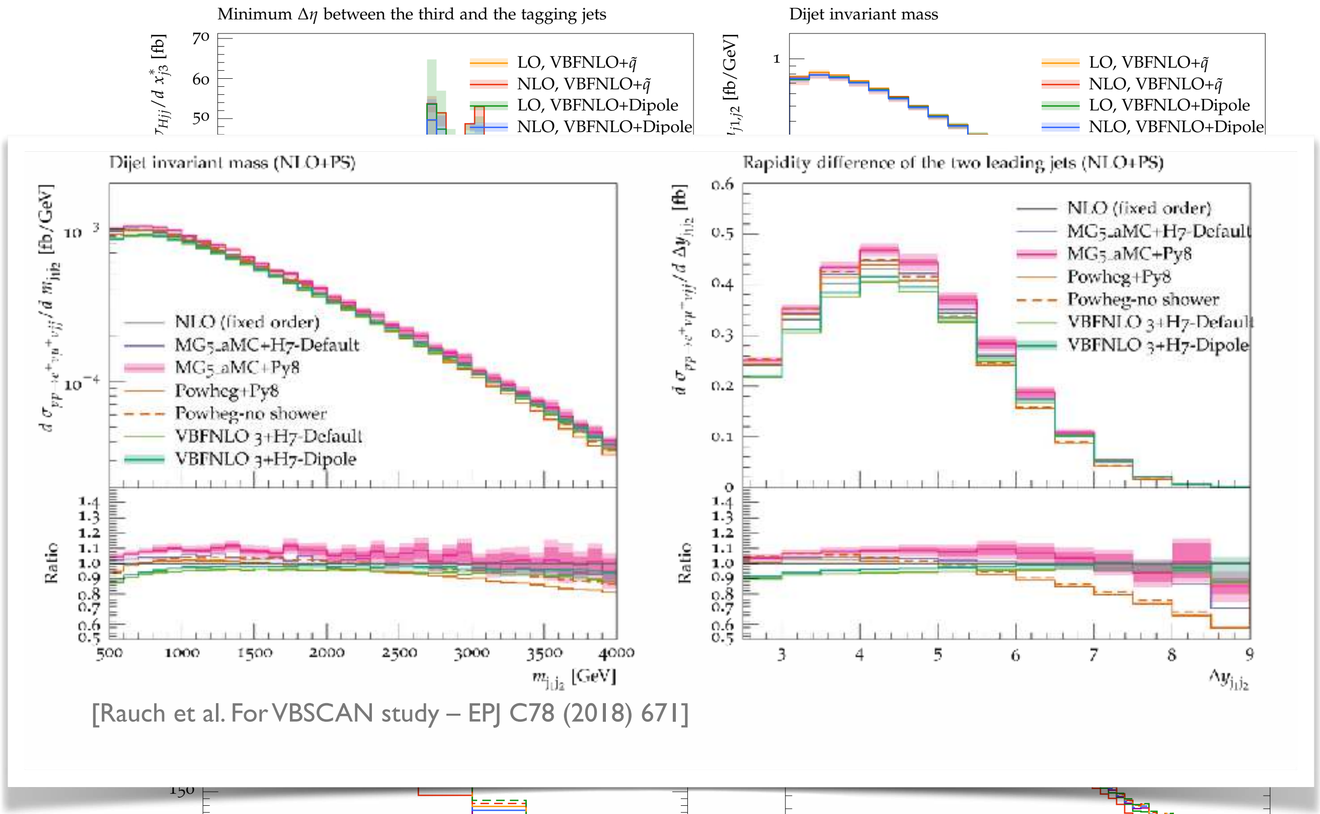
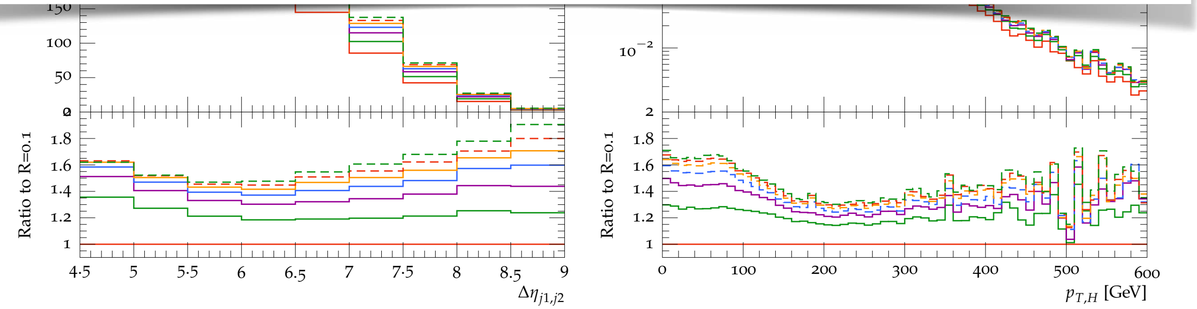


[Rauch et al. For VBSCAN study – EPJ C78 (2018) 671]



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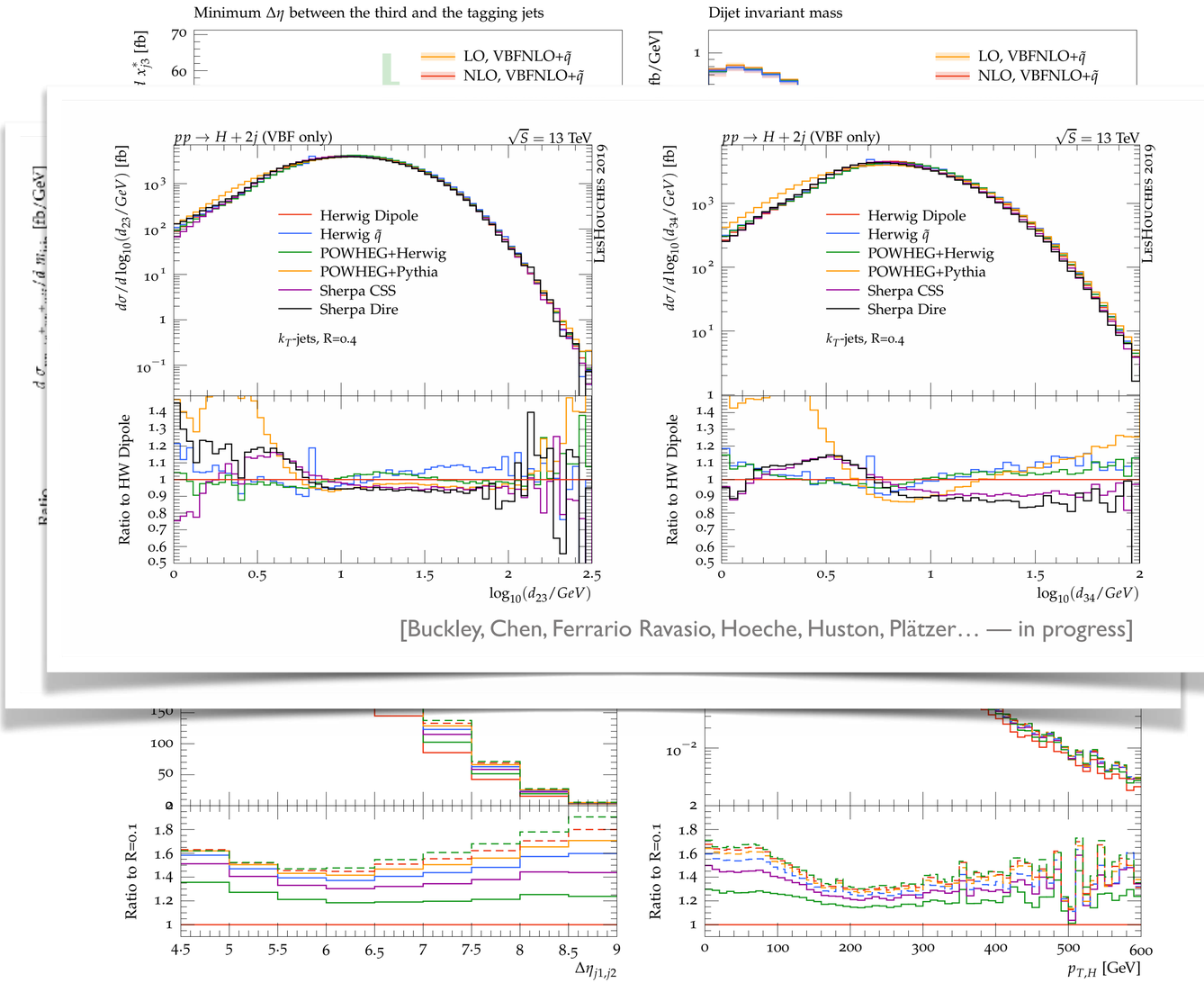
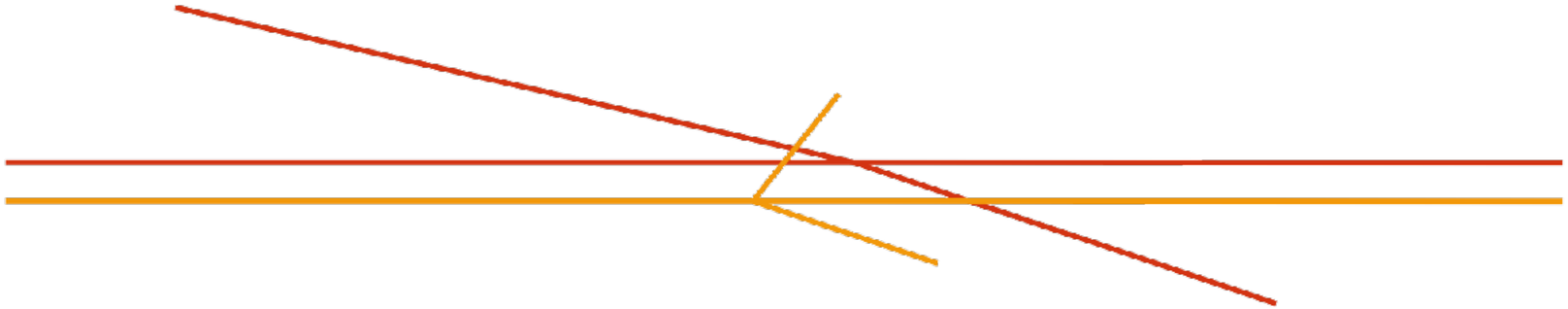


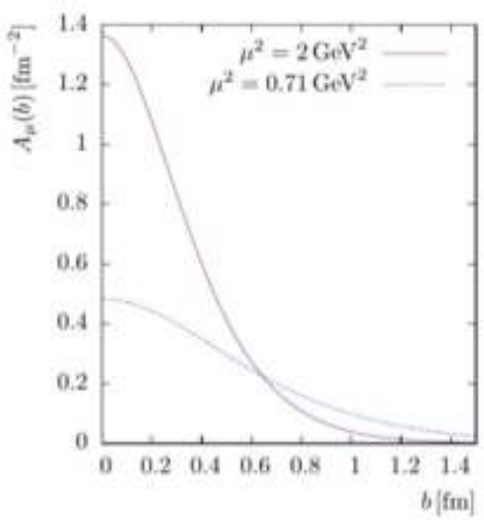
[Buckley, Chen, Ferrario Ravasio, Hoeche, Huston, Plätzer… — in progress]

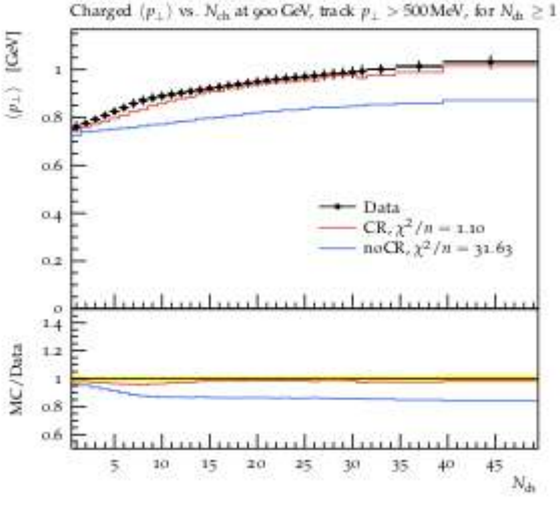
MPI & Colour Reconnection



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]

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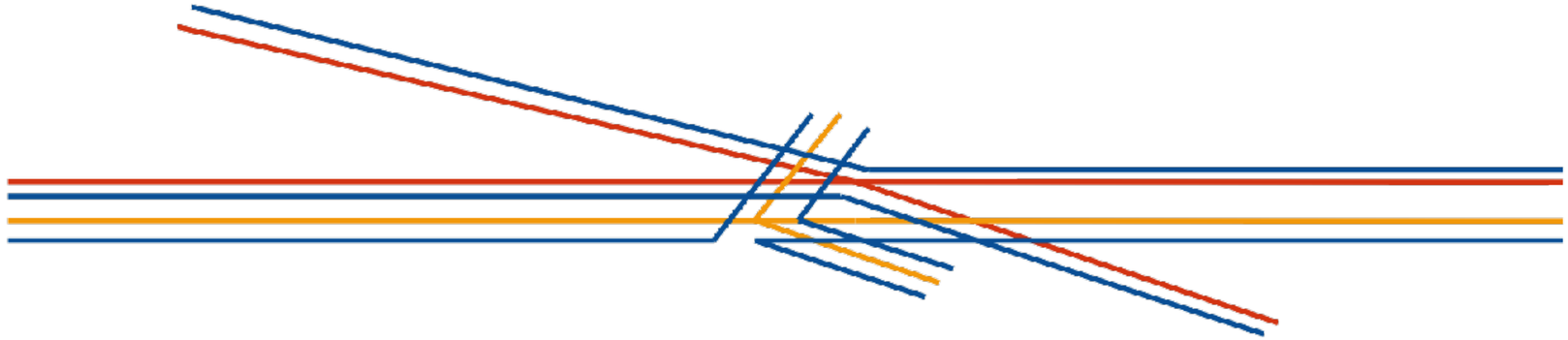

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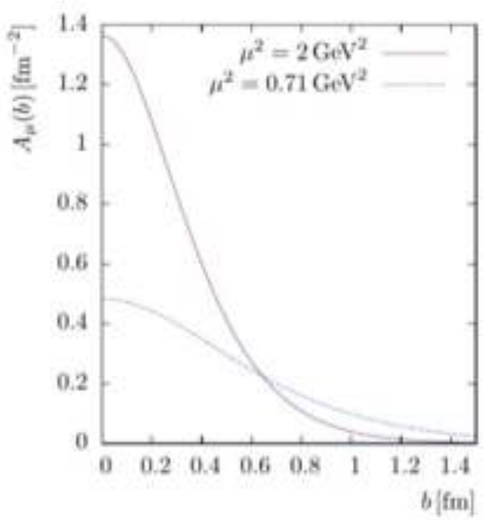

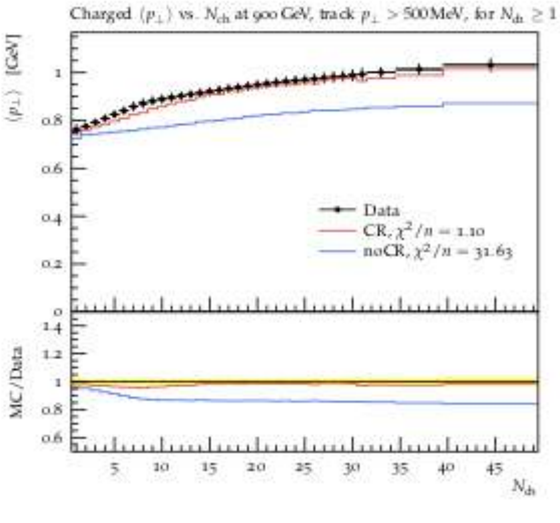

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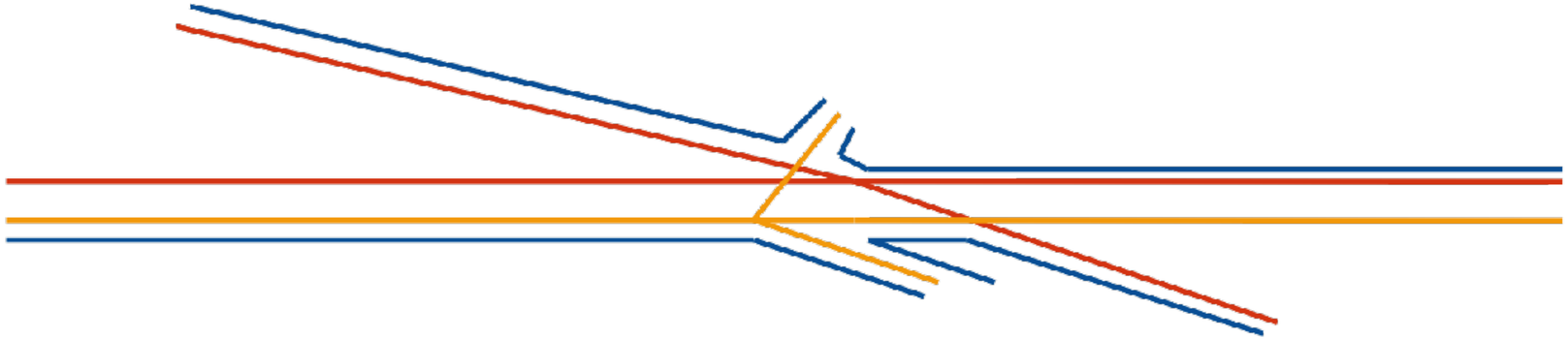

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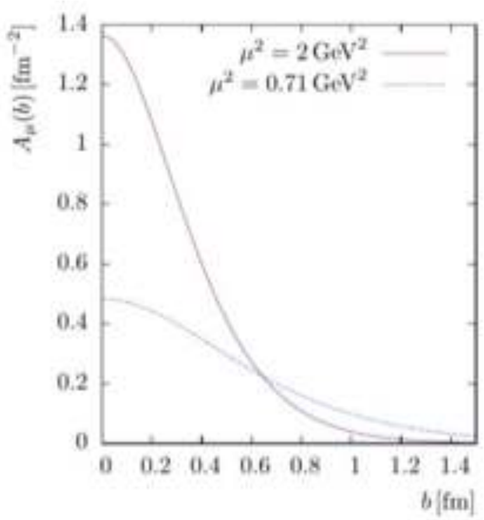
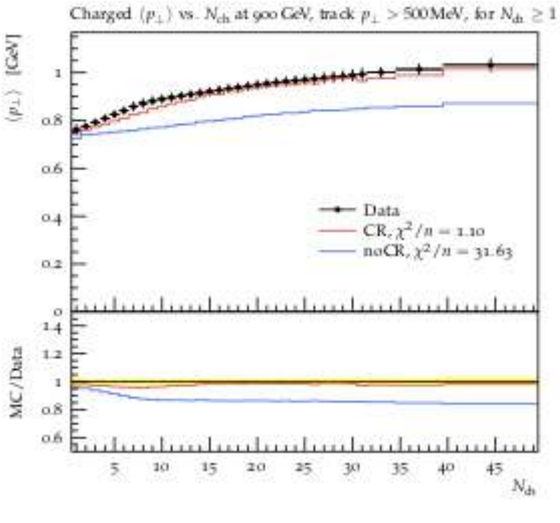




[Gieseke, Kirchgaesser, Plätzer – EPJ C 78 (2018) 99]

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

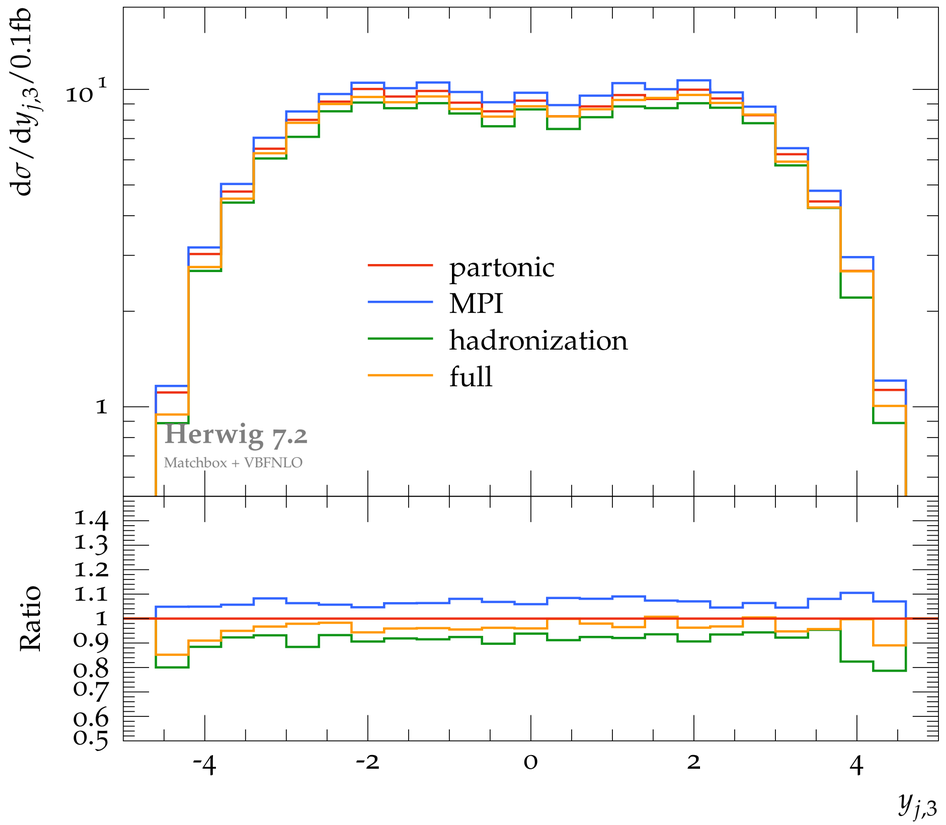
MPI & Colour Reconnection

[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.

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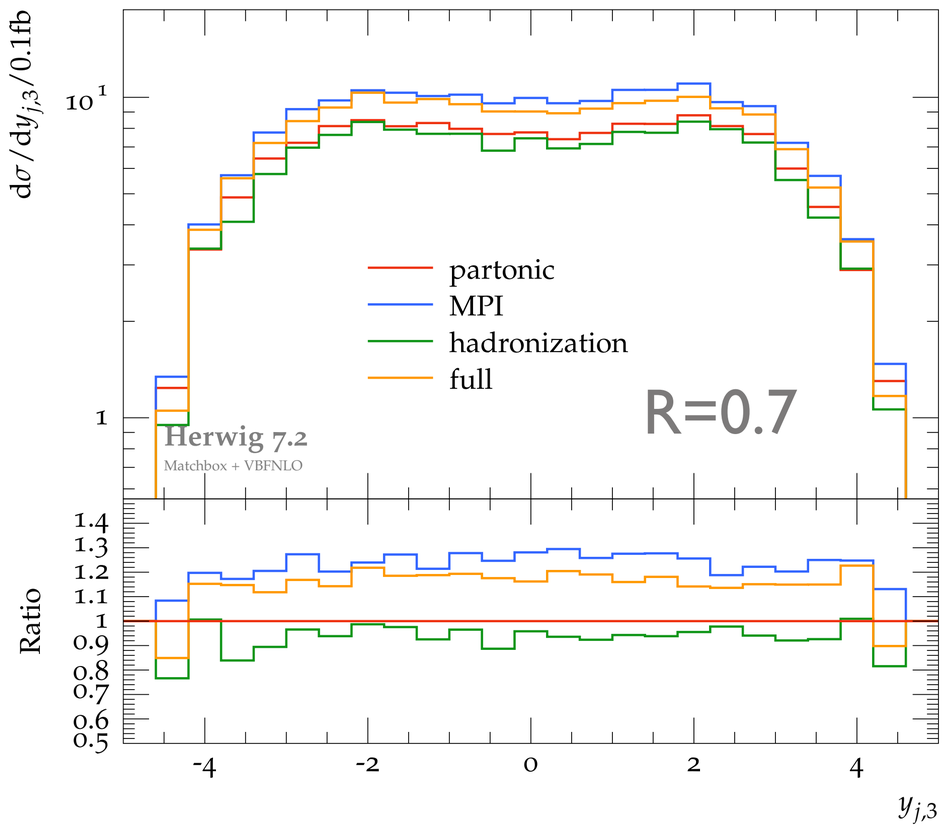

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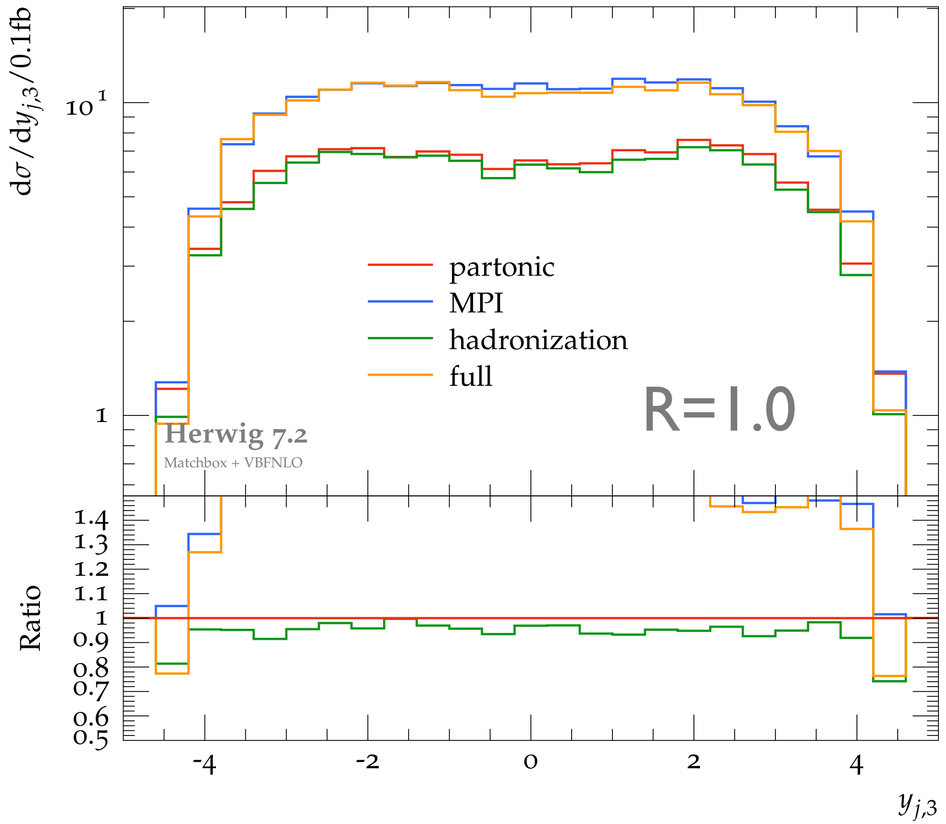


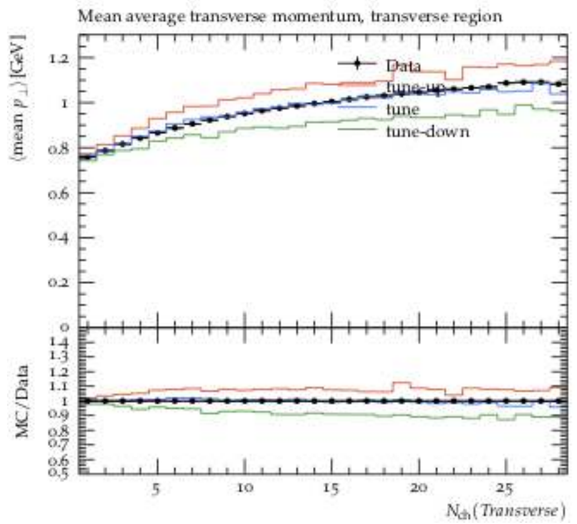
Benchmark is VBF Z production, but findings should be ~ universal.

Model variations

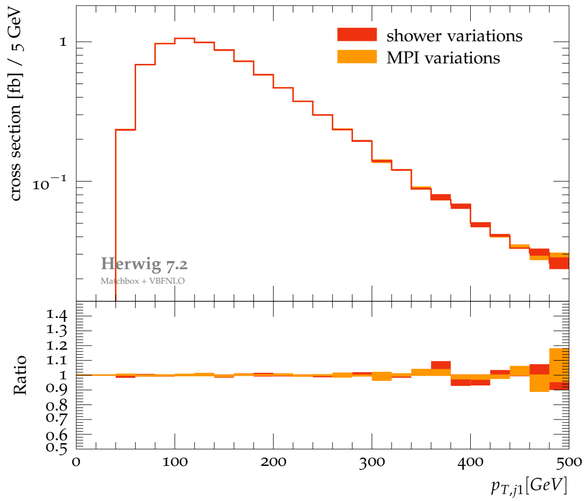
[Bittrich, Kirchgaesser, Papaefstathiou, Plätzer, Todt — in progress]

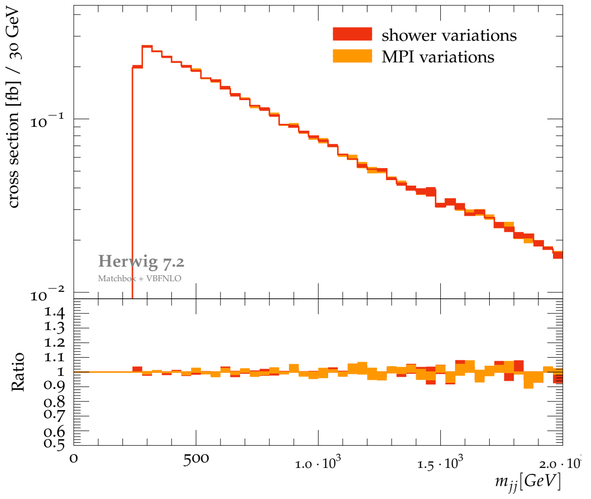
Strategy

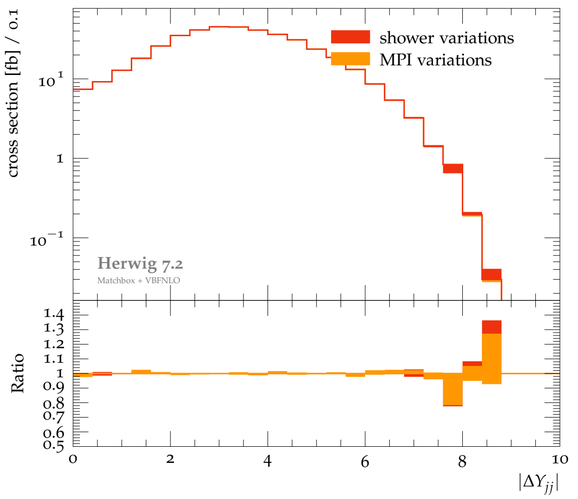
- Vary colour reconnection and MPI parameters to stay within ~ 10% agreement of typical tuning observables
- Vary perturbative scales, specifically shower hard scale
- Full NLO+PS study including shower variations



Tagging jet distributions mostly stable







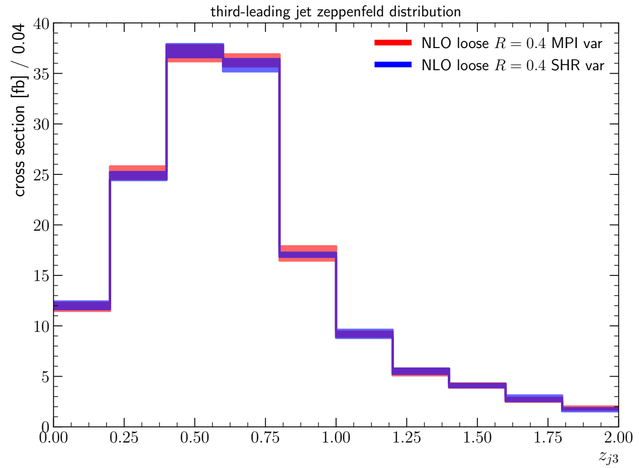
Model variations

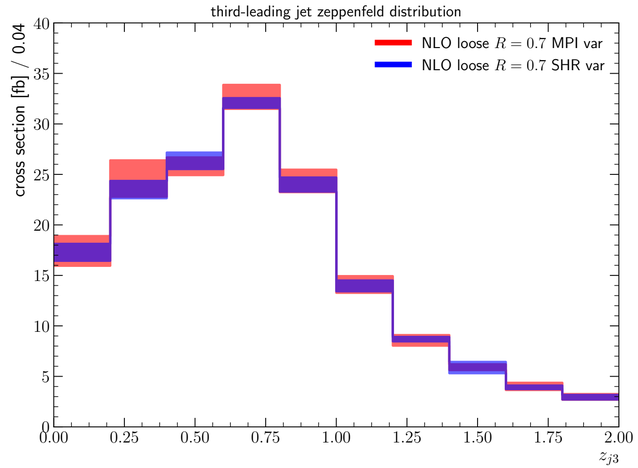
Third jet Zeppenfeld variable between perturbative and MPI variations.

R=0.4

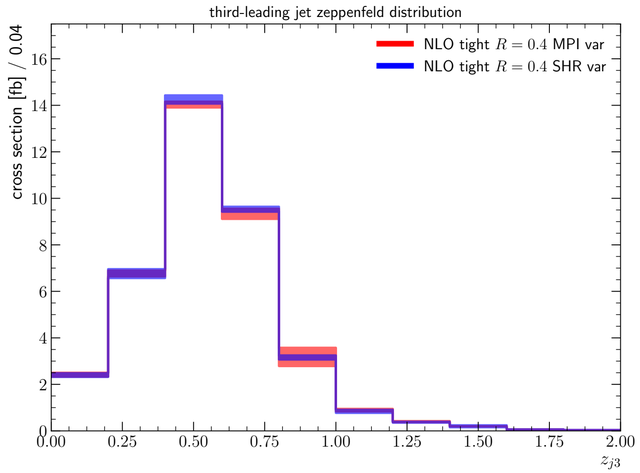
R=0.7

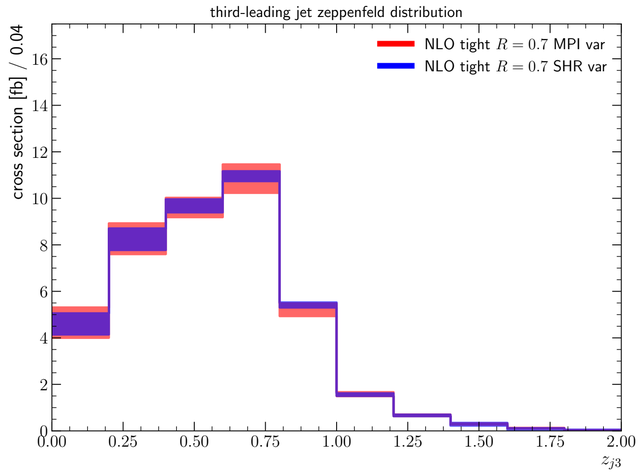
Loose selection





Tight selection





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

Jet vetos & Non-global Observables

[Liu, Melnikov, Penin]

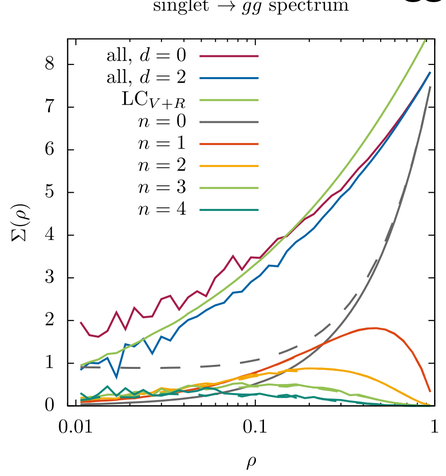
Jet vetos beyond leading-N and Glauber phases require amplitude level evolution.

[Forshaw, Holguin, Plätzer – JHEP 1908 (2019) 145]

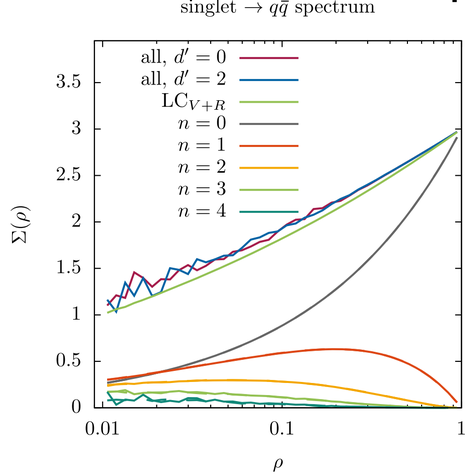
Recent results on jet vetos from CVolver on jet vetos in e+e- collisions.

[De Angelis, Forshaw, Plätzer — PRL 126 (2021) 11]

H to gg

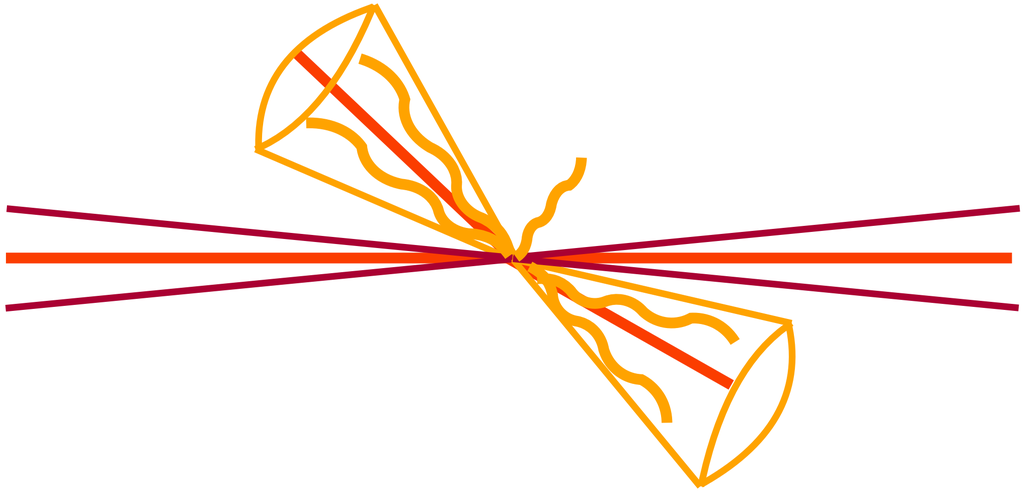


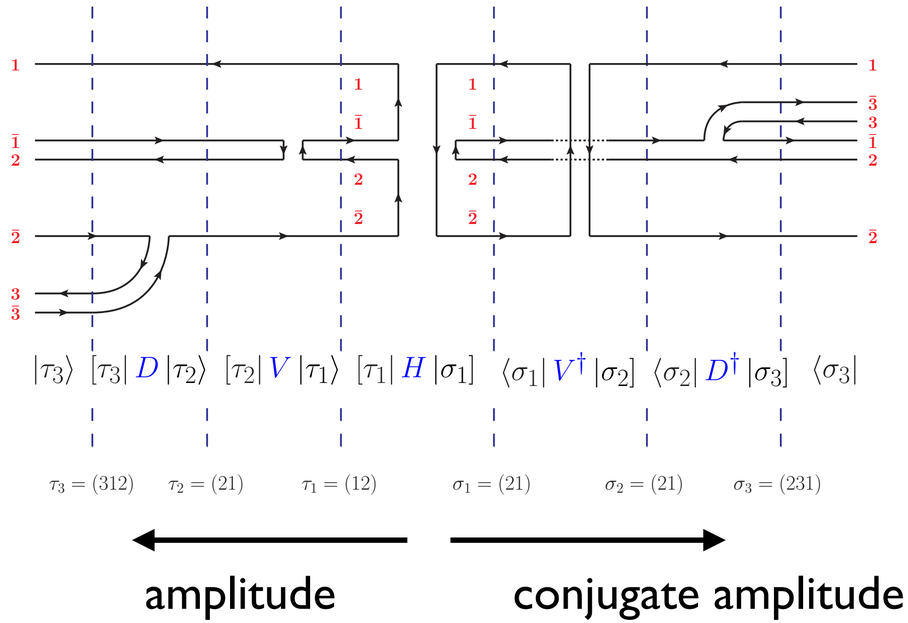
Z to qq



Complementary approach through Langevin dynamics, but not in form of an event generator.

[Hatta et al. — Nucl.Phys.B 962 (2021) 115273]





Summary & Outlook

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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.

Shower accuracy remains an open question at the interplay of global & non-global observables — initial conditions and recoils crucial.

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.

Significant development towards subleasing-N effects and account of interferences.
Challenges in hard process definition: electroweak showers?

Thank you!

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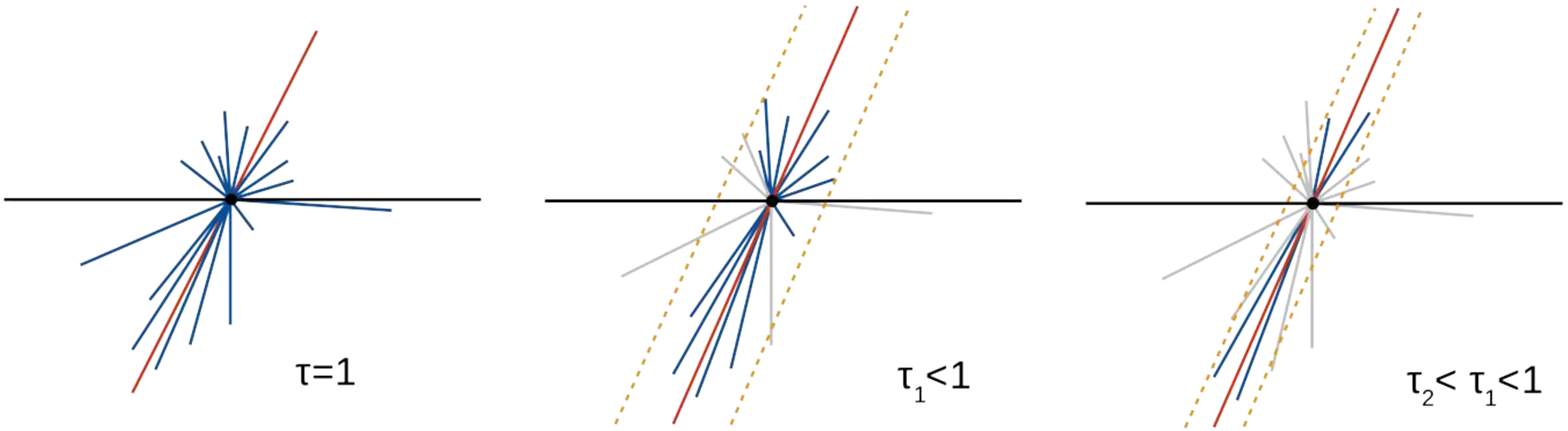
Coherent branching



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

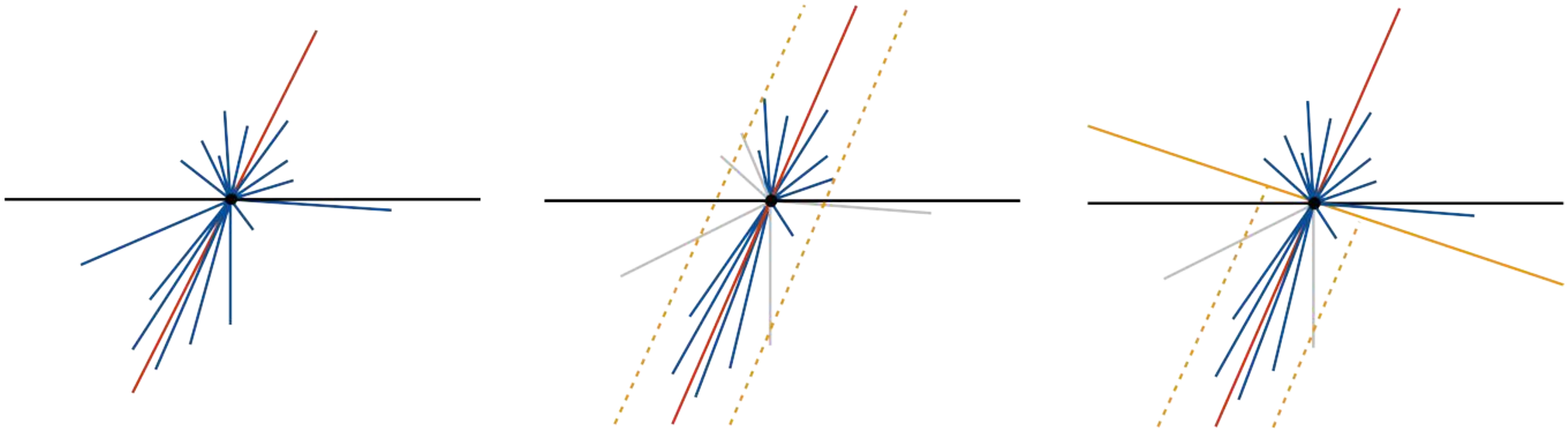
[n jets in large-N limit]

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

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

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

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. …]