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Future of VBF? Challenges.

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Particle Physics — University of Vienna

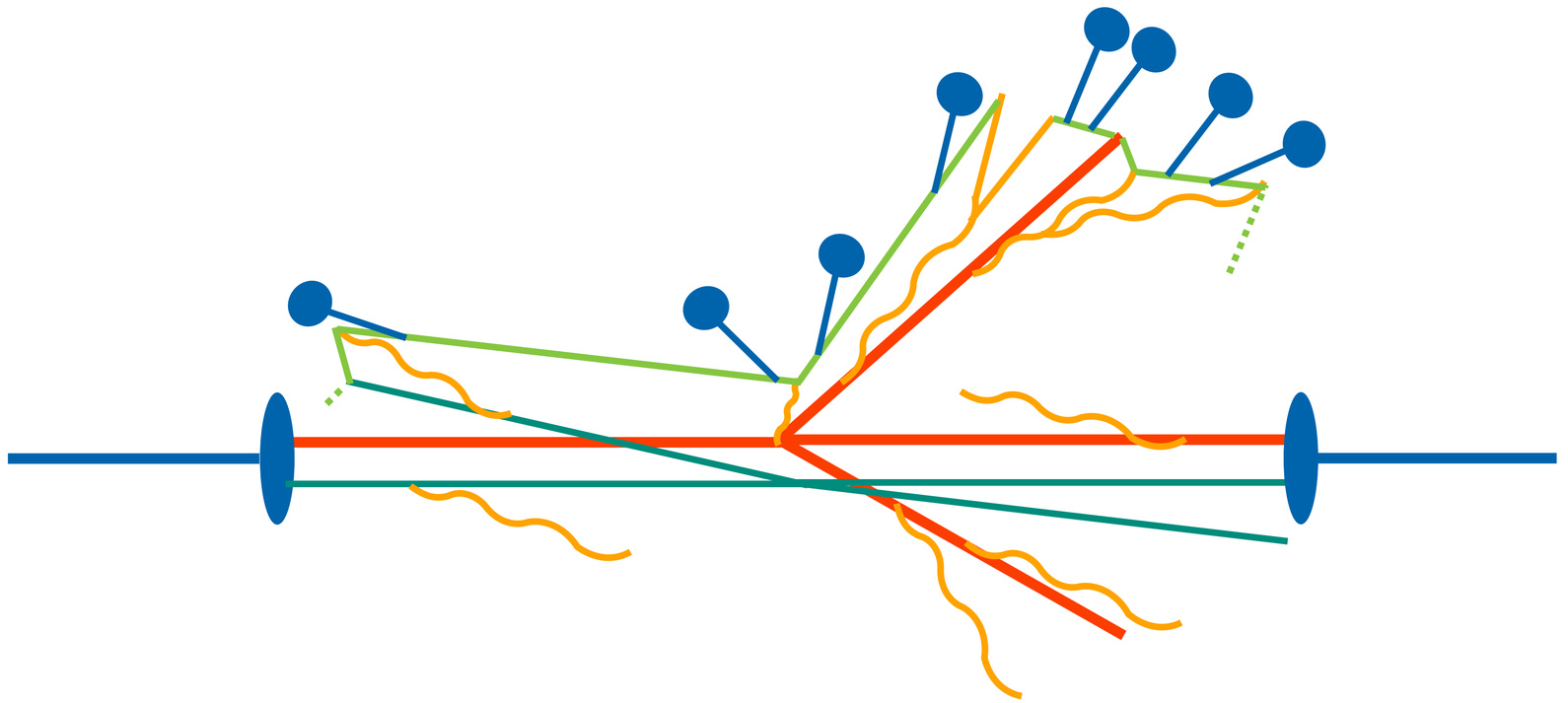
At the
Past, Present and Future of VBF workshop
CERN/Online | 21 October 2022

Motivation

How do we, most **accurately**, describe VBF/VBS final states?

- Complexity in final states (parton showers, decays, definition of final states)?
- "Contamination" from soft physics?
- Interferences and description of radiation patterns (non-factorizable contributions, loose cuts)?
- Are there issues in matching and merging (the "generation cuts" problem)?
- Pushing towards a few percent: electroweak, hadronization, ….

Multi-purpose event generators

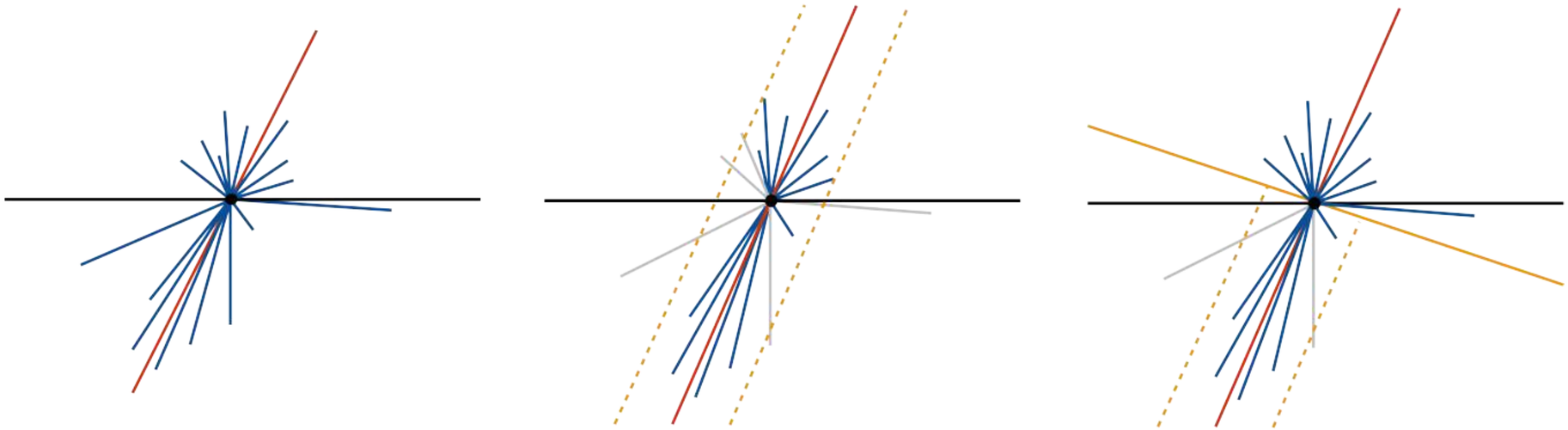


$$\mathrm{d}\sigma \sim \mathrm{L} \times \mathrm{d}\sigma_H(Q) \times \mathrm{PS}(Q \to \mu) \times \mathrm{MPI} \times \mathrm{Had}(\mu \to \Lambda) \times \ldots$$

More to parton showers

Silvia & Christian have already done a terrific job at summarising most of fixed order corrections and matching.

Accuracy of Parton Showers



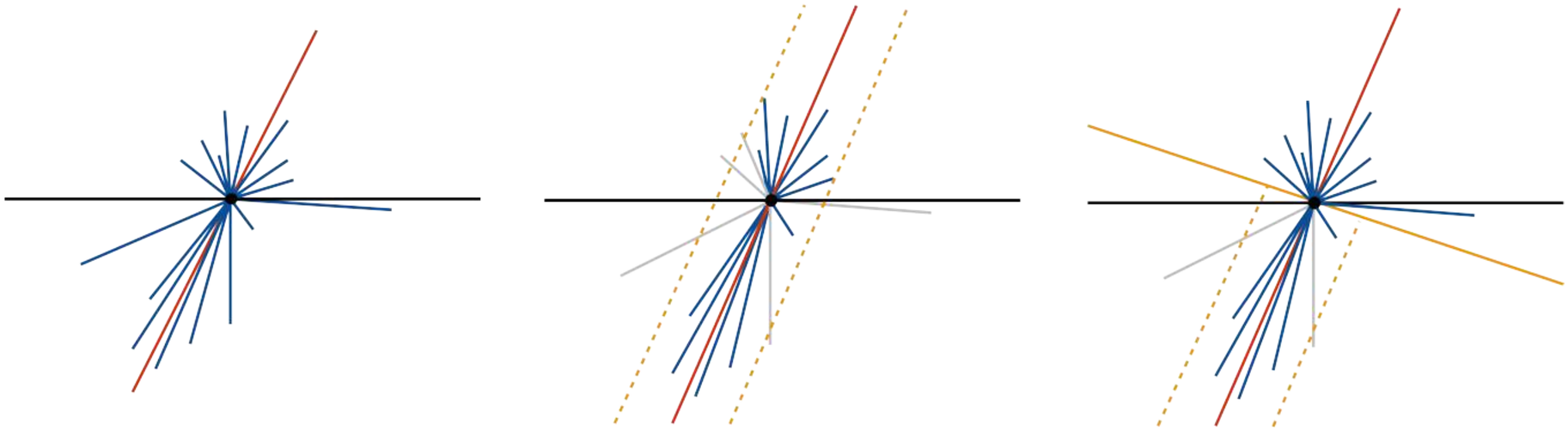
Global event shapes from coherent branching

$$H(\alpha_s) \times \exp\left(Lg_1(\alpha_s L) + g_2(\alpha_s L) + \alpha_s g_3(\alpha_s L) + \ldots\right)$$

LL — qualitative NLL — quantitative NNLL — precision

$$\alpha_s L \sim 1$$

Accuracy of Parton Showers



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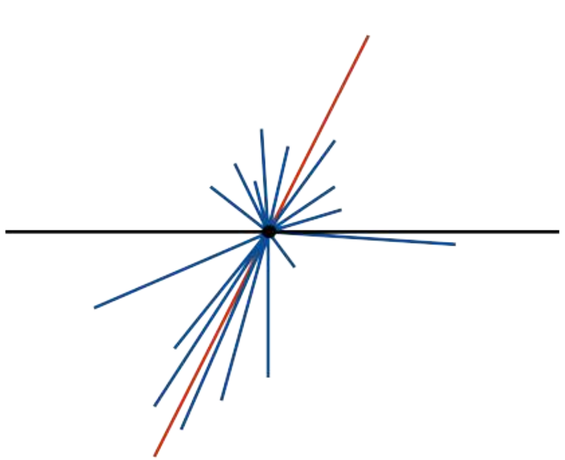
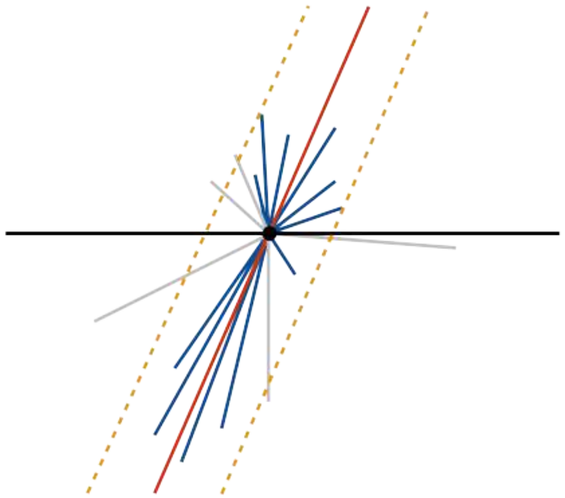
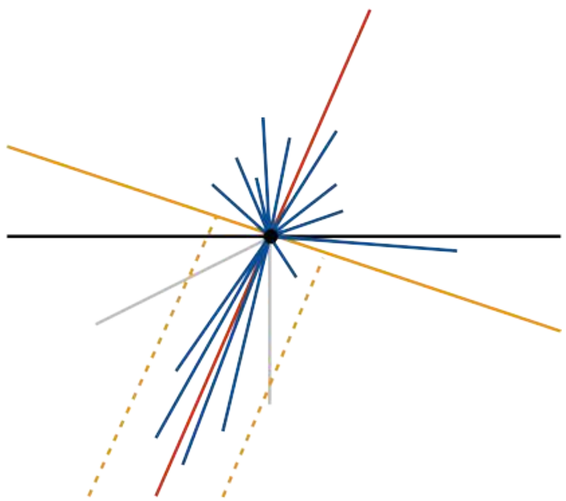


NLO with matching



NLL with coherent branching
Issues in dipole showers



Issues in coherent branching
LL with dipole showers

Strictly only in the 2-jet limit for global observables.
Non-globals always fine with dipoles in large-N limit but mind $\alpha_s N^2 \sim 1$

[Dasgupta, Dreyer, Hamilton, Monni, Salam et al. — JHEP 09 (2018) 033, …]
[Hoang, Plätzer, Samitz — JHEP 1810 (2018) 200]
[Bewick, Ferrario, Richardson, Seymour — JHEP 04 (2020) 019]

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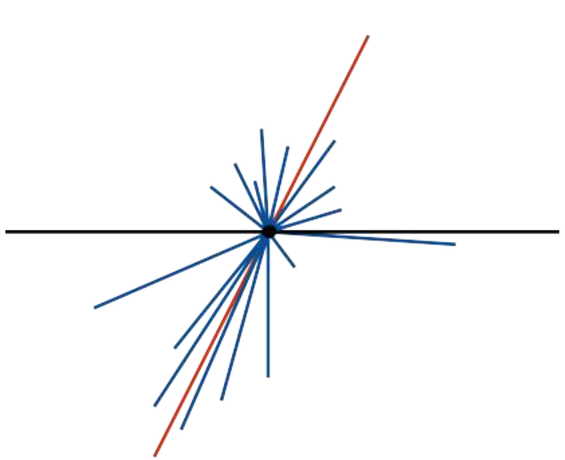

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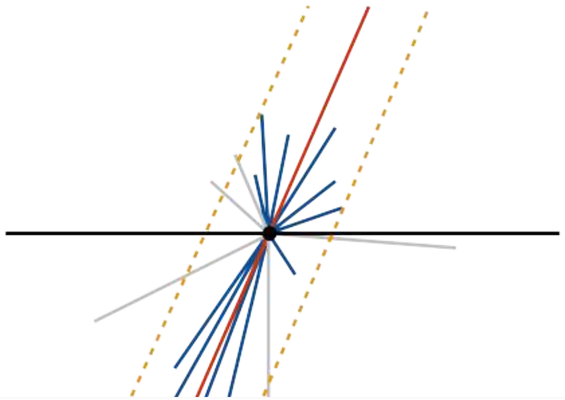

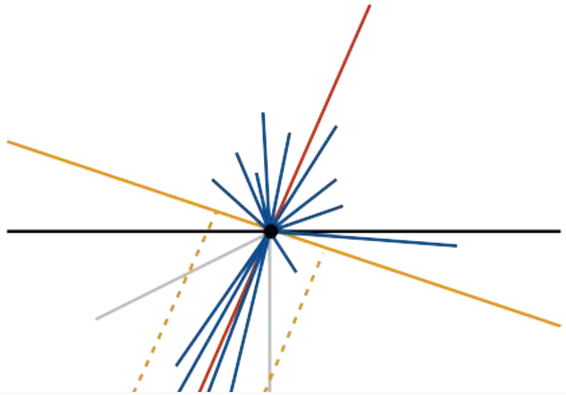

Dipole showers reproducing coherent branching:
NLL & NLC global, LL & LC non-global

[Dasgupta, Dreyer, Hamilton, Monni, Salam —PRL 125 (2020) 5]
[Forshaw, Holguin, Plätzer – JHEP 09 (2020) 014 & EPC C81 (2021) 4]
recently also implemented in Sherpa

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Colour in VBF/VBS

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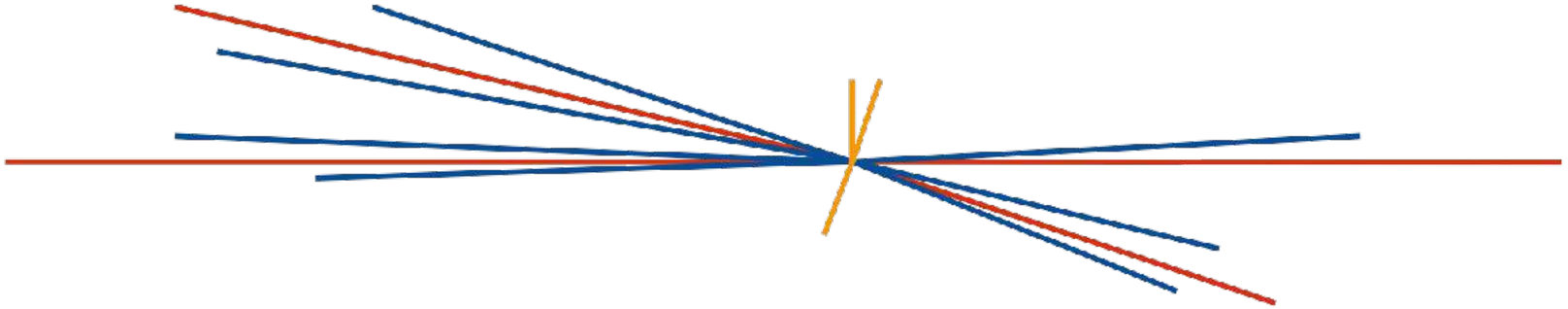
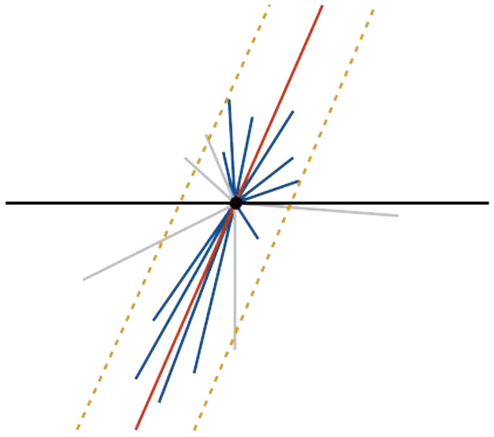
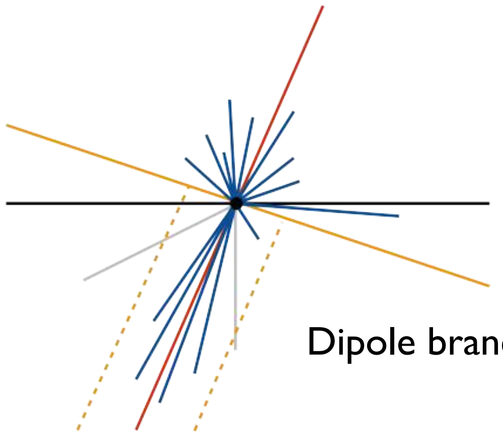
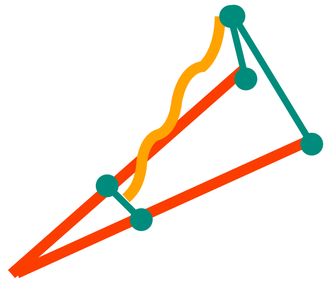
Coherent emission of soft large angle gluons from systems of collinear partons.





Parton branchings order in angle:
Driven by QCD coherence, recoils
at the end of showering.





Dipole branchings order in transverse momentum:
Driven by large-N colour flow.
Allow to conserve momentum locally.

"Bad" recoil choices can destroy this pattern even if everything else is right.

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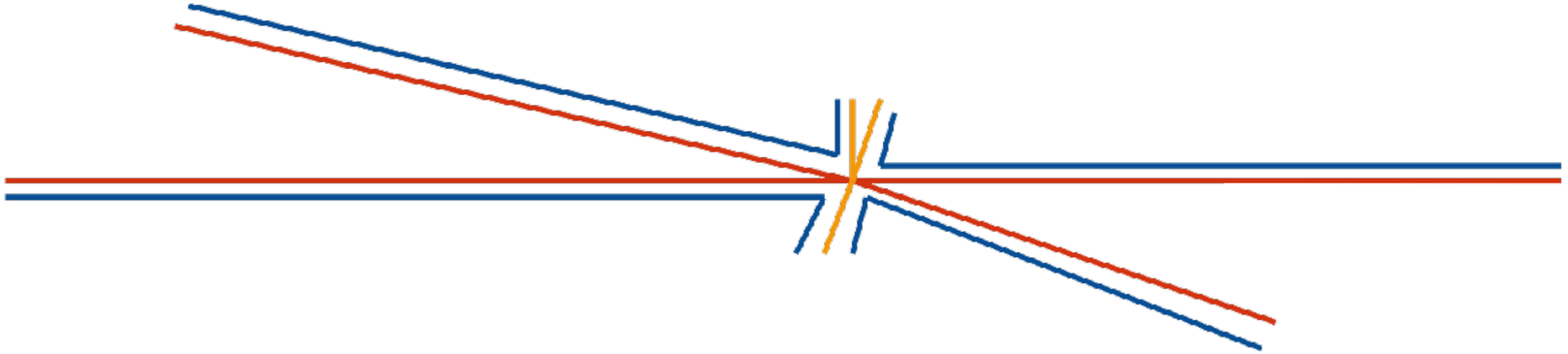

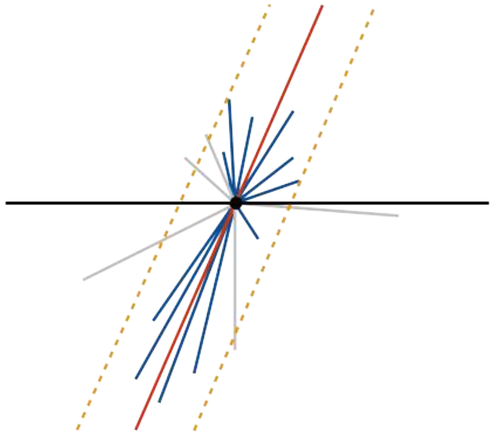

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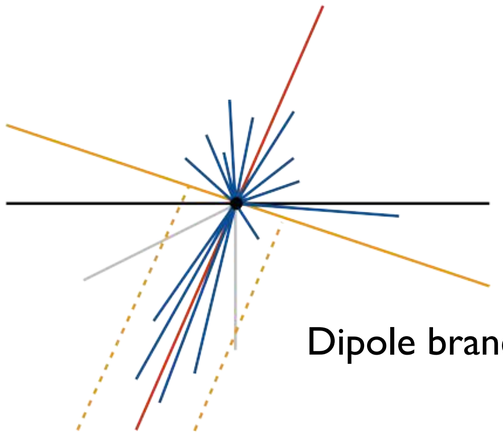

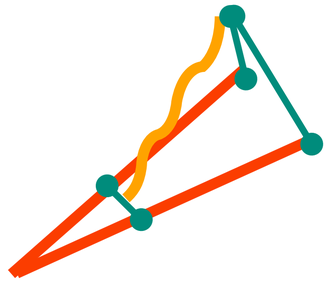

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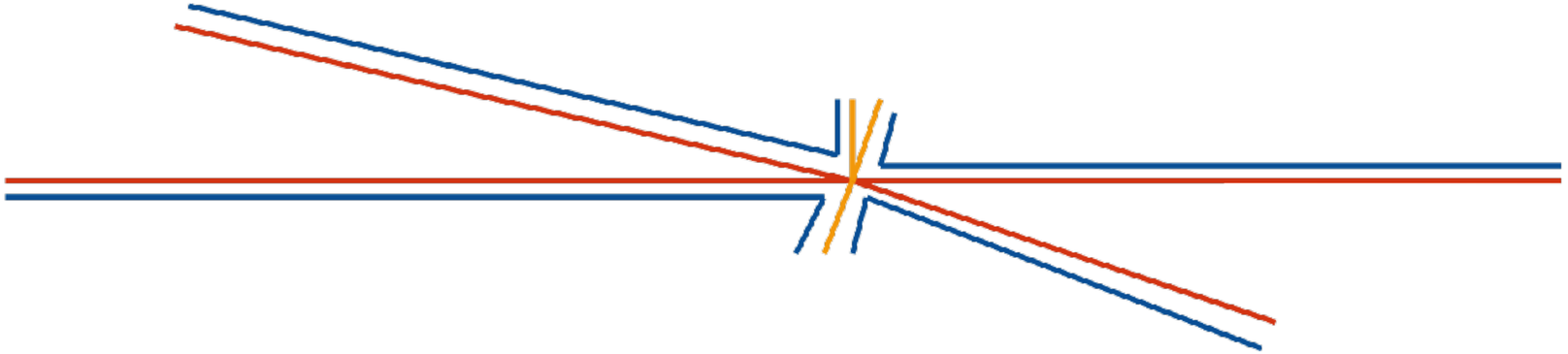

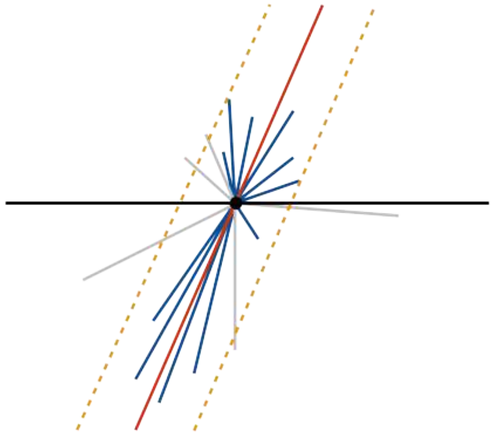

Parton branchings order in angle:
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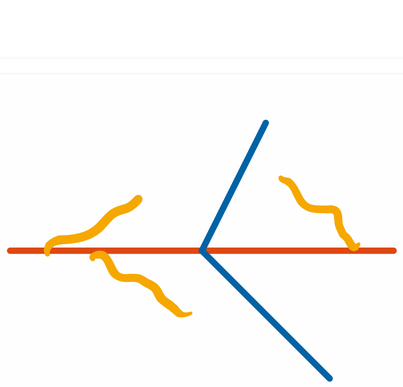
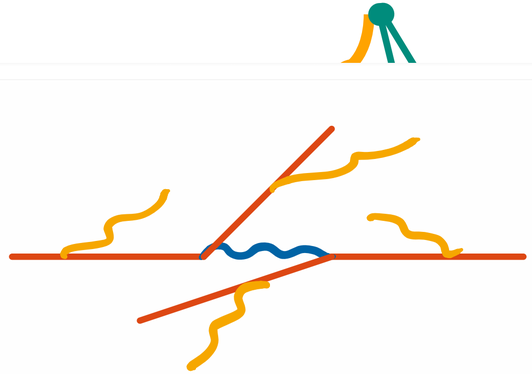
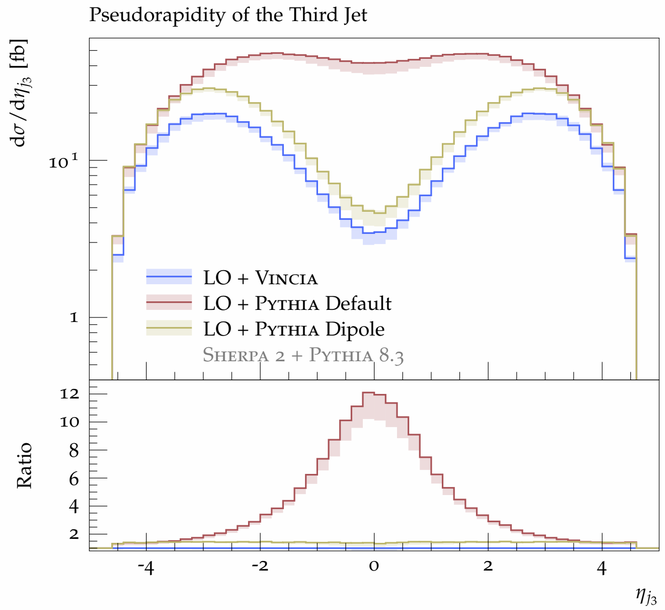




II dipoles substantially different from IF ones.

"Bad" recoil choices can destroy this pattern even if everything else is right.

Colour in VBF/VBS



[Höche, Mrenna, Payne, Preuss, Skands — arXiv:2106.10987]
similar findings earlier in
[Jäger, Karlberg, Plätzer, Scheller, Zaro — EPJ C80 (2020) 756]
[Ballestero et al. — Eur.Phys.J.C 78 (2018) 8, 671]

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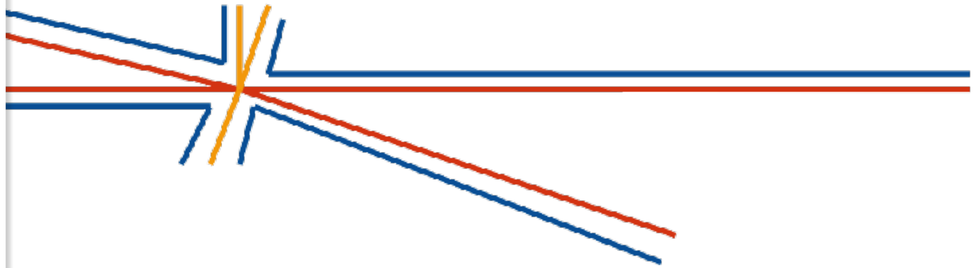

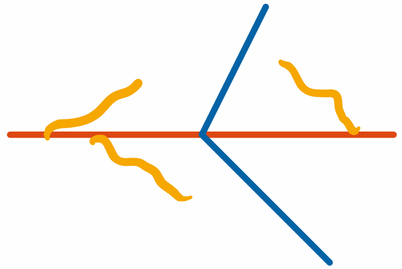

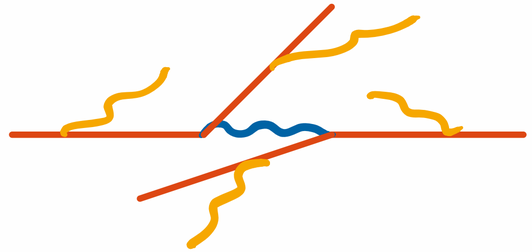

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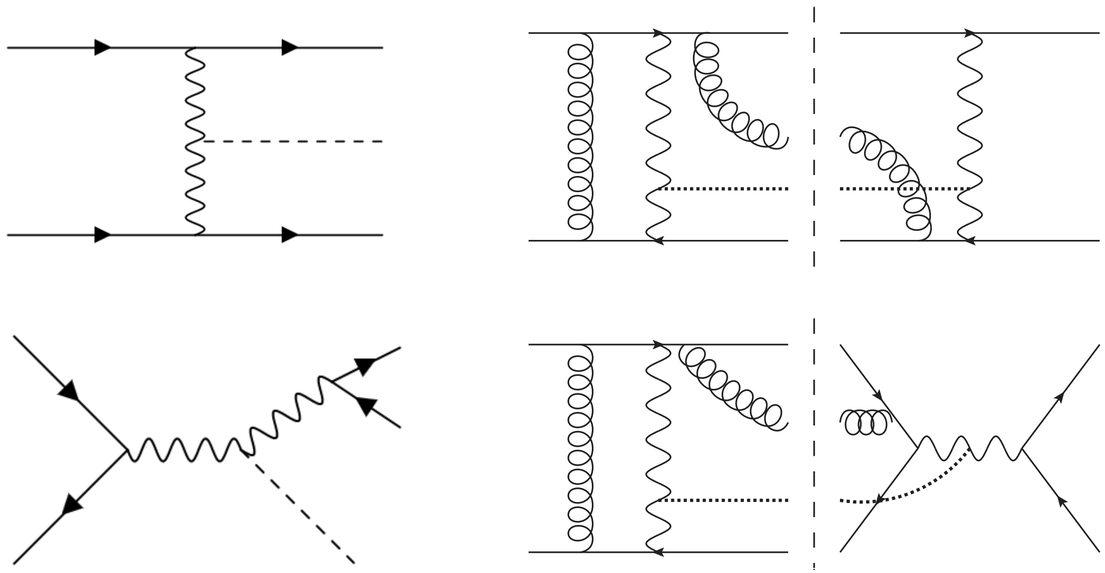
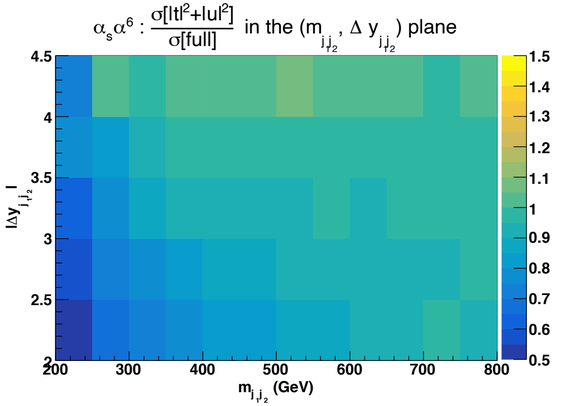
Colour in VBF/VBS

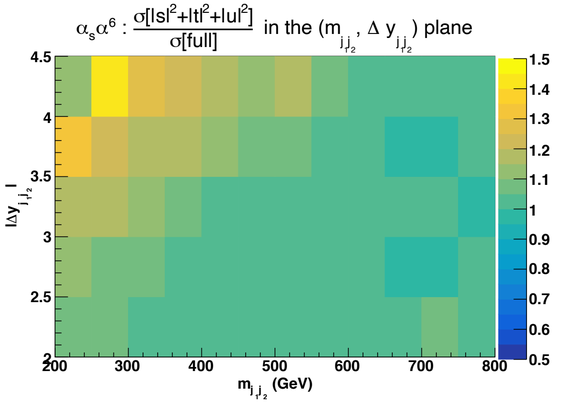
In essence, coherence is about getting interferences right — for more than two (three) partons we inevitably need to resort to the large-N limit.



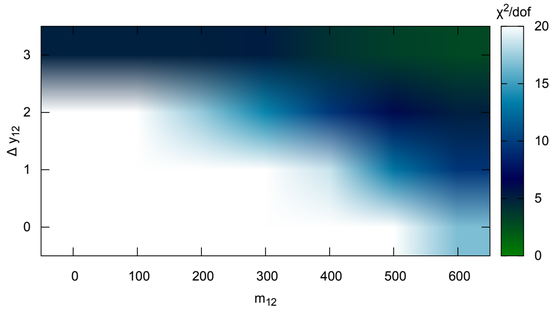
no s channels

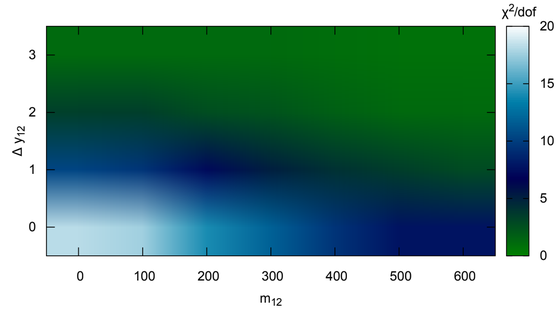


s channels in approximation



Δy_{12}





m_{12}

s channels un-suppressed

s channels vetoed

Beyond fixed-order largely uncharted territory.

[Campanario, Figy, Plätzer, Rauch, Schichtel, Sjödahl – PRD 98 (2018) 033]
[Ballestero et al. — Eur.Phys.J.C 78 (2018) 8, 671]

Colour in VBF/VBS

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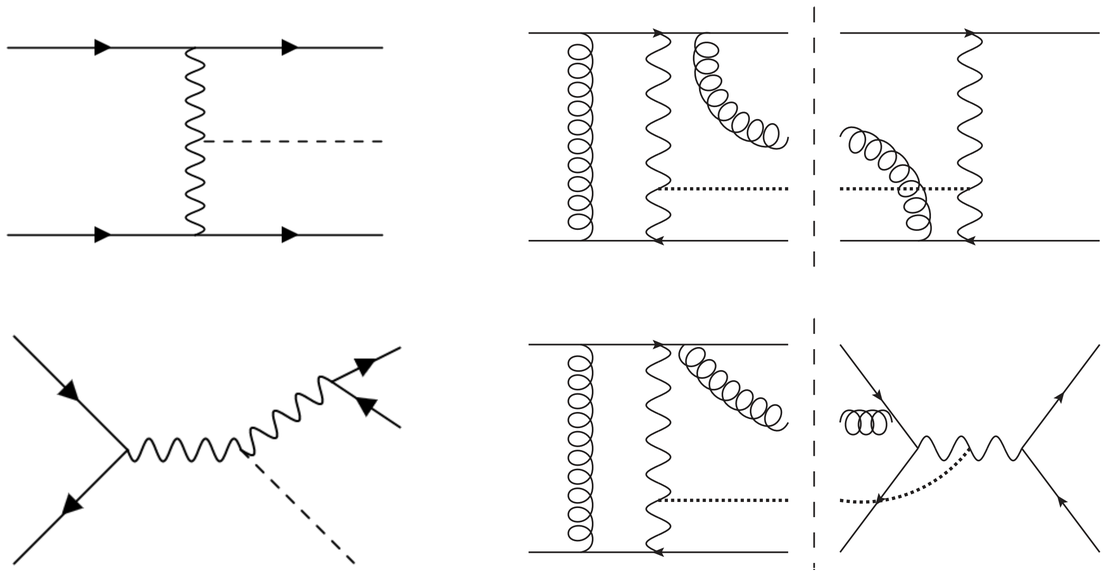

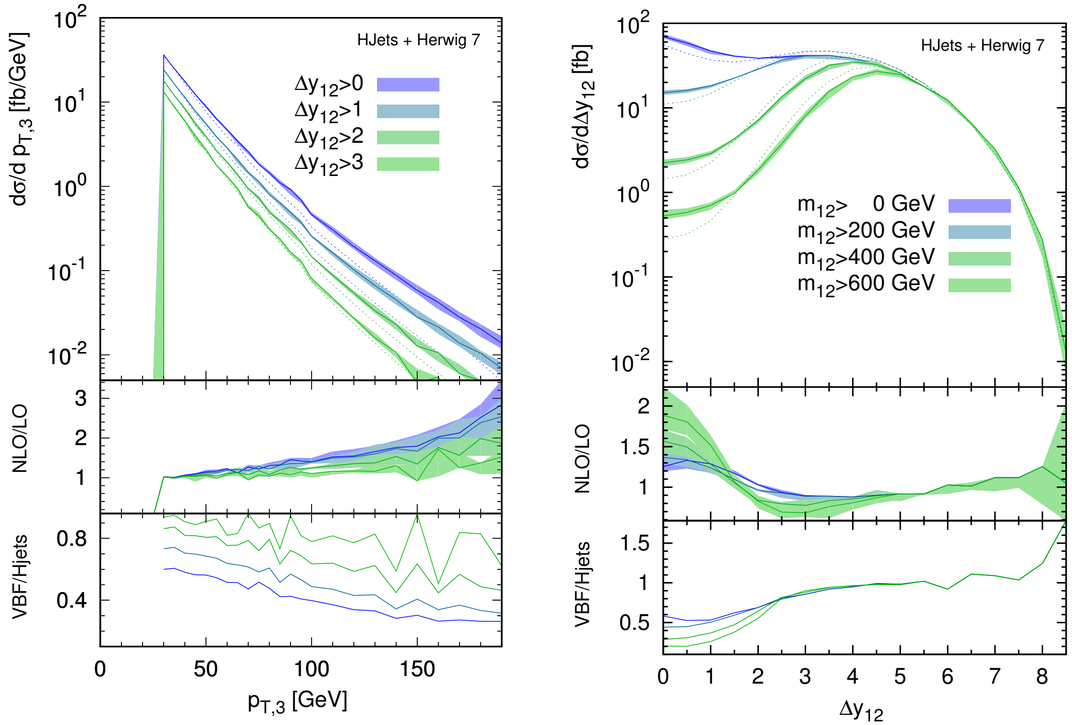

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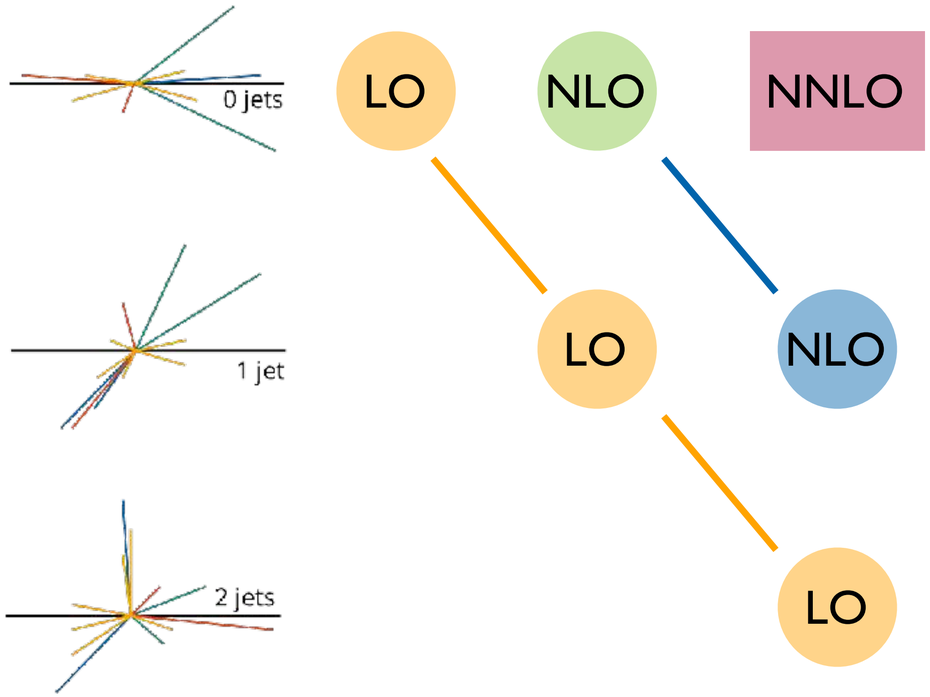
Challenges for Matching and Merging

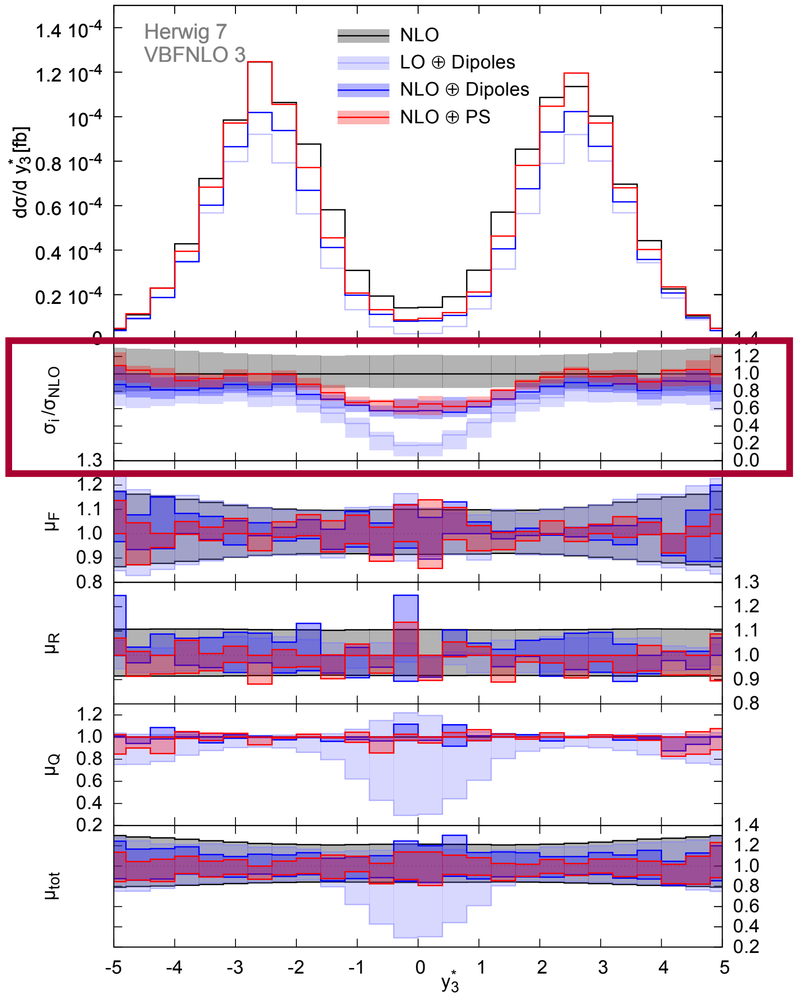
Jets at Born level:

- Generation cut uncertainties: what NLO calculation are we actually matching to?!
- Merging algorithms specifically challenged — solved within modified unitarized merging.

[Bellm, Gieseke, Plätzer — EPJ C78 (2018) 244]
[Chen, Figy, Plätzer — EPJ C82 (2022) 8]



Merging & matching
NLO merging

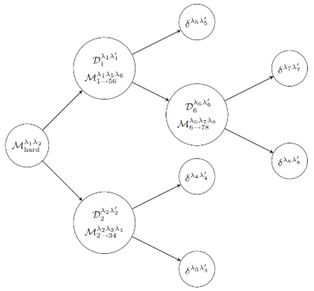


[Rauch, Plätzer – EPJ C77 (2017) 293]

Correlations and measurements

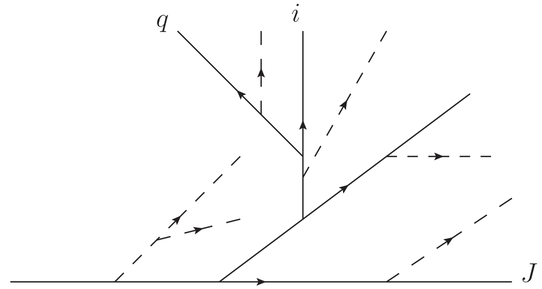
Spin and colour correlations need to be propagated through the shower — definition of final states becomes important possibly including and beyond hadronization models.

Spin correlations in traditional shower algorithms largely understood.

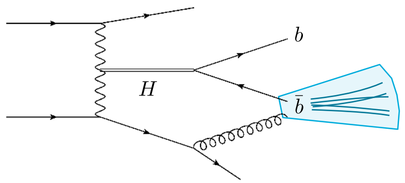


[Webster, Richardson - Eur.Phys.J.C 80 (2020) 2]
[Karlberg, Salam, Scyboz, Verheyen — Eur.Phys.J.C 81 (2021) 8, 681]

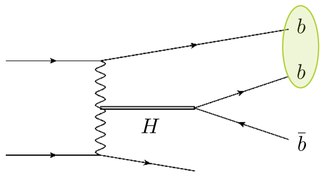
Dynamic colour charges crucial in newer coherent branching algorithms.



[Forshaw, Holguin, Plätzer — EPJ C81 (2021) 4]
[Hamilton, Medves, Salam, Scyboz, Soyez — JHEP 03 (2021) 041]



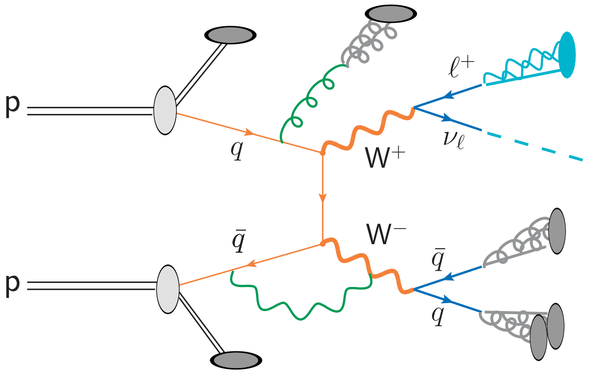
Jet-clustering breaks factorization



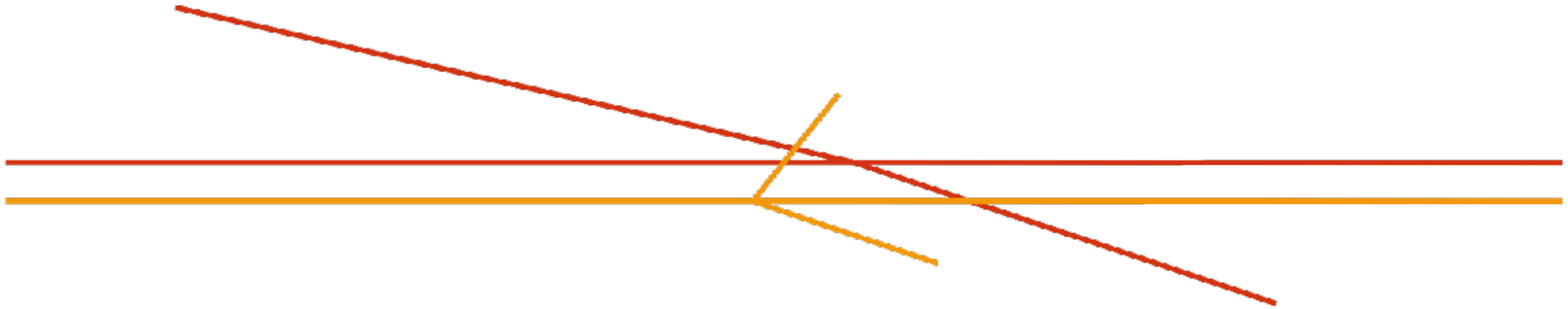
B-tagging breaks factorization

Looking at VBF processes from a polarization perspective

Giovanni Pelliccioli
Max-Planck-Institut für Physik

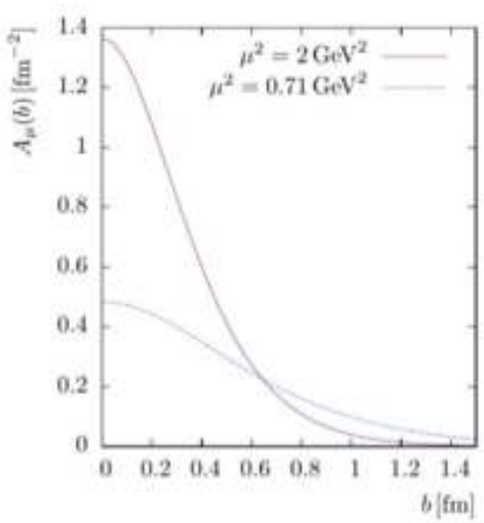


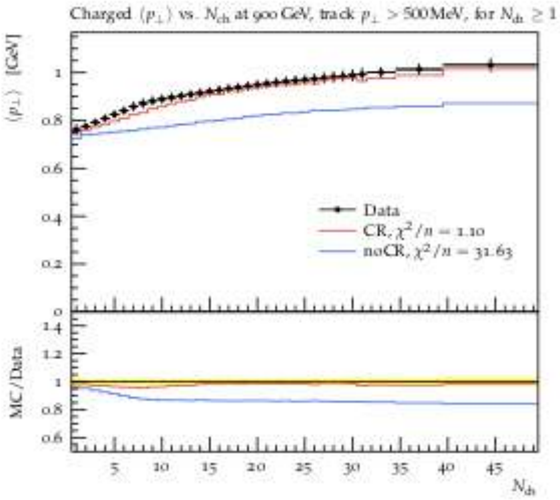
MPI & Colour Reconnection



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.

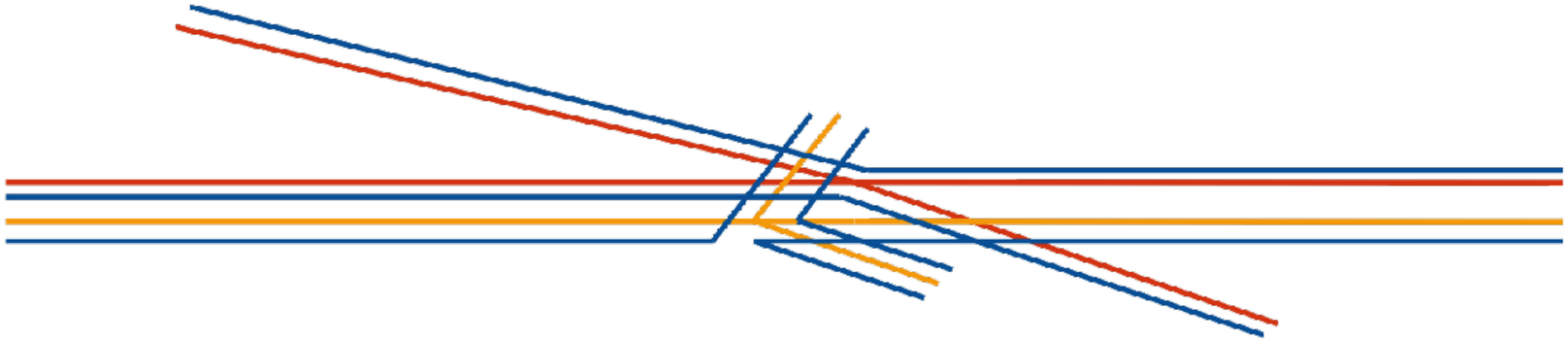




[Gieseke, Kirchgaesser, Plätzer – EPJ C 78 (2018) 99]

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

MPI & Colour Reconnection



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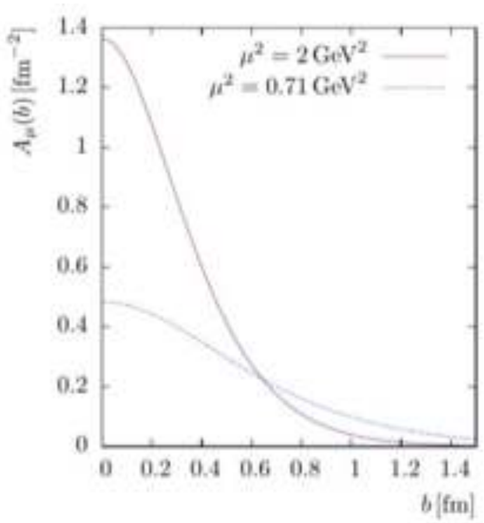

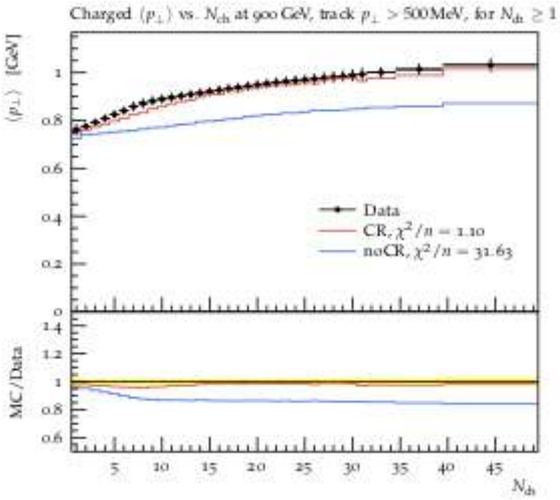

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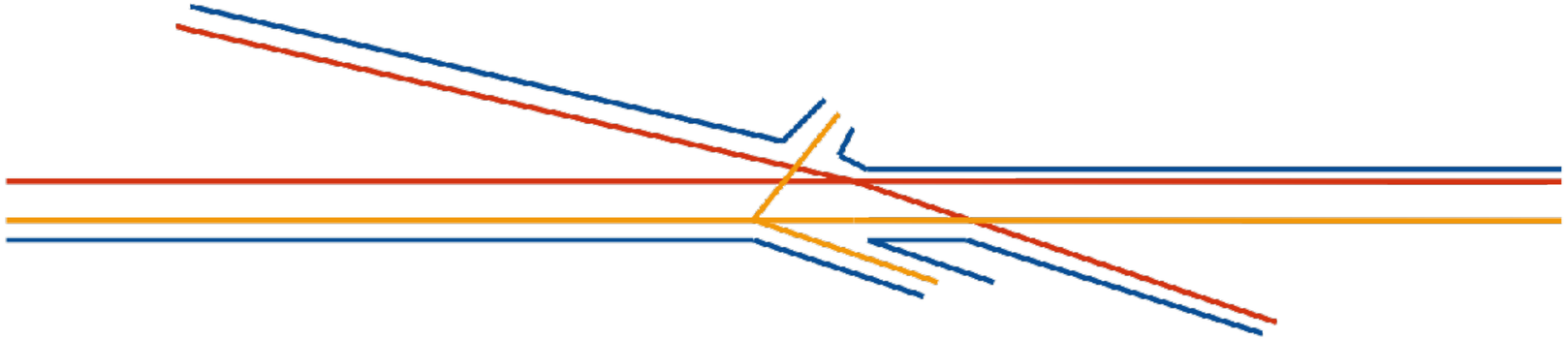
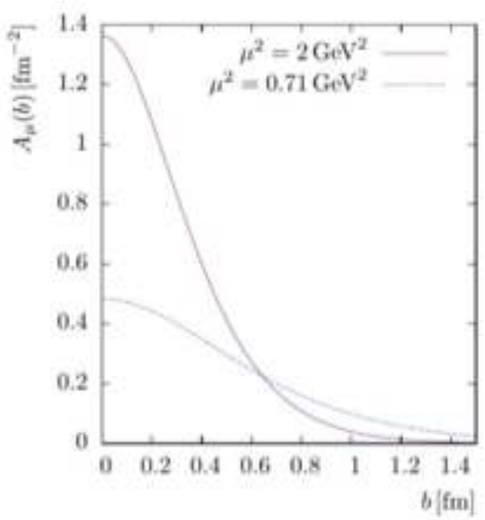
[Gieseke, Röhr, Siodmok – EPJ C 72 (2012) 2225]

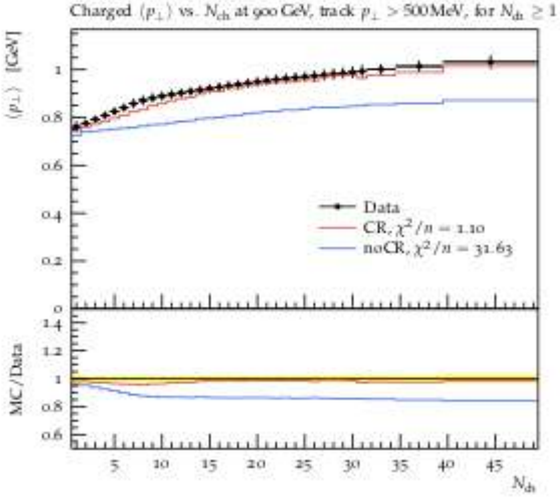
MPI & Colour Reconnection



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

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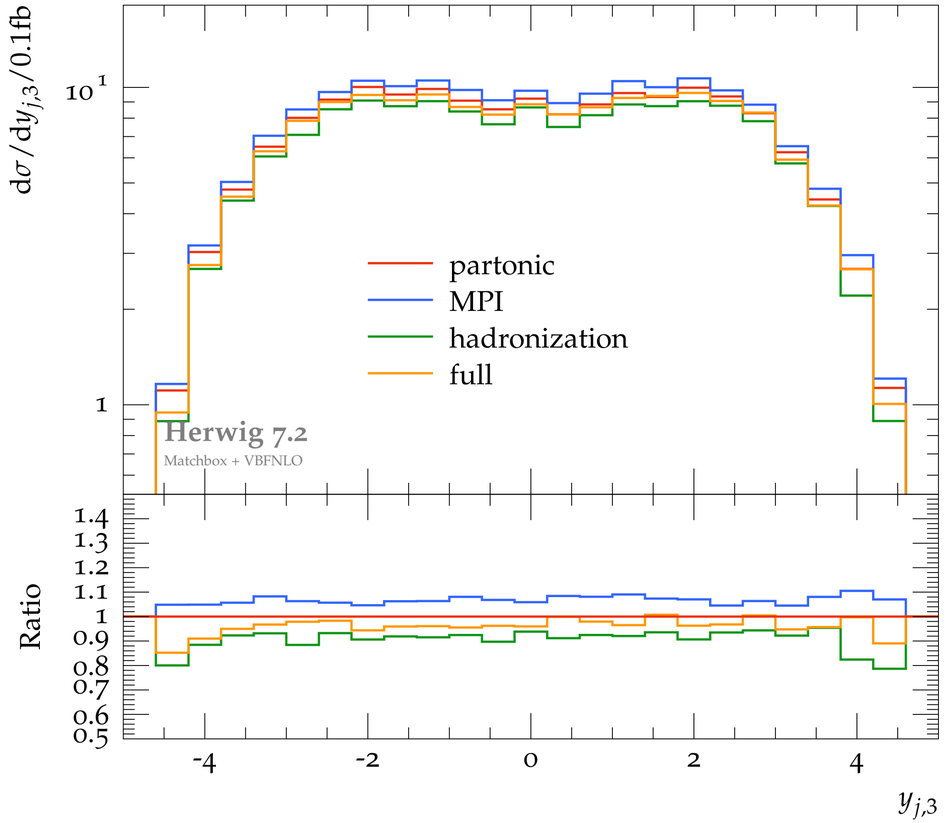
[Bittrich, Kirchgaesser, Papaefstathiou, Plätzer, Todt — EPJ C82 (2022) 9]

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.

MPI & Colour Reconnection

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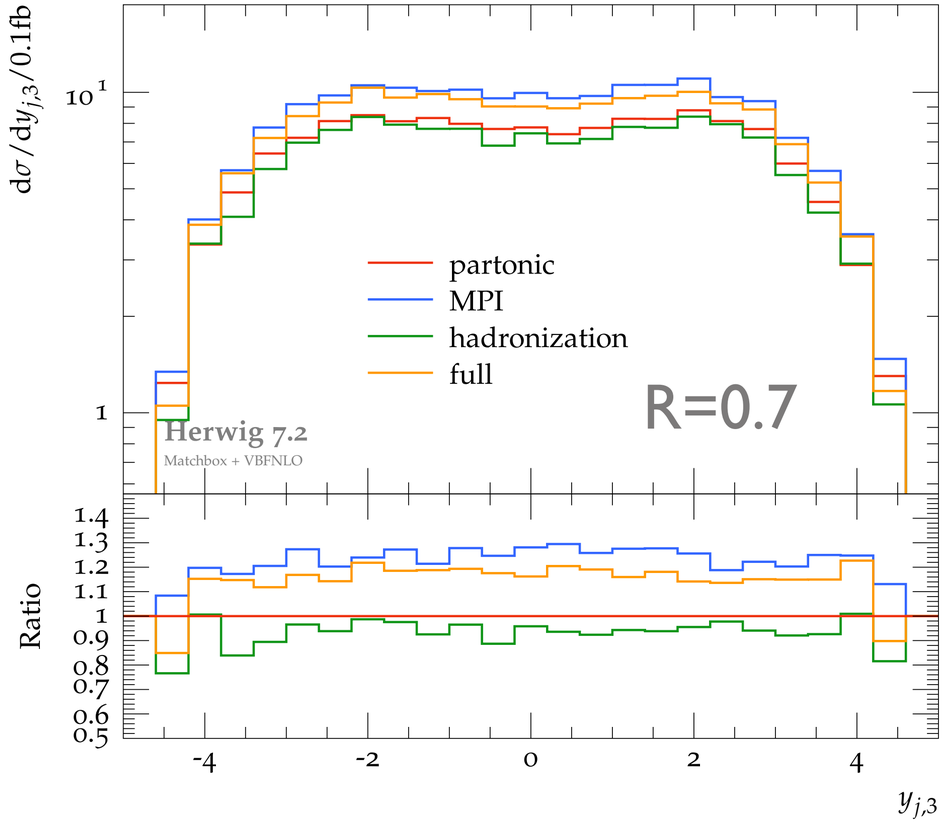

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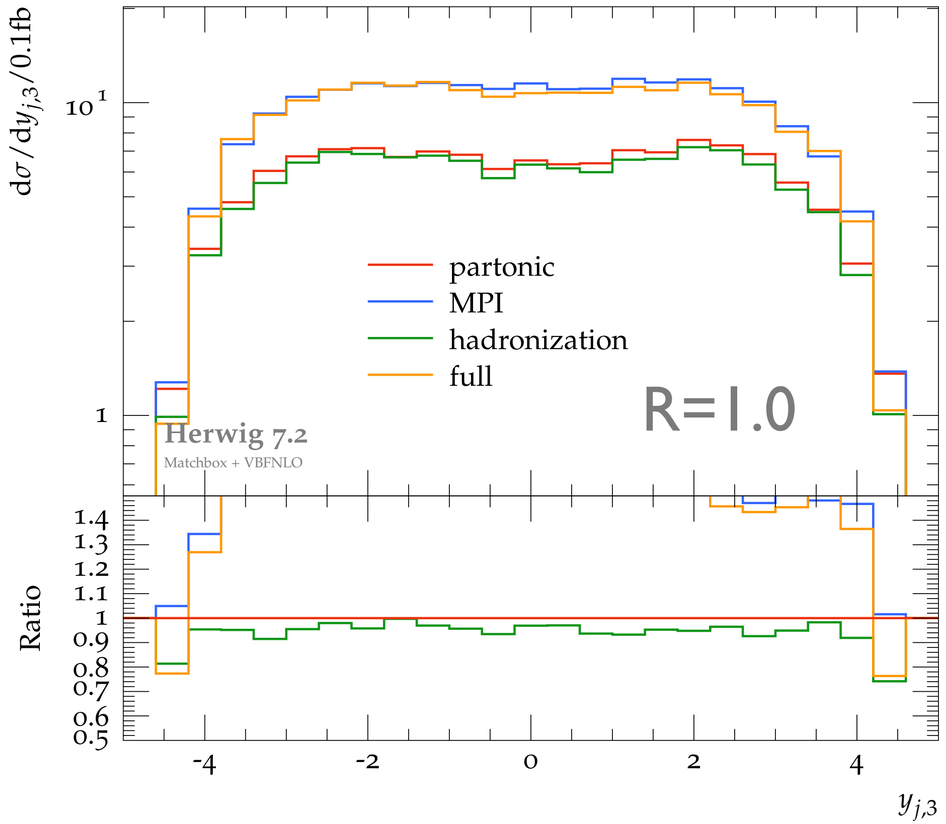
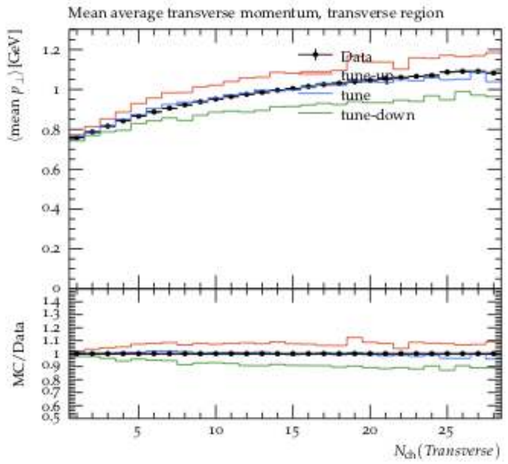


Benchmark is VBF Z production, but findings should be ~ universal.

Model variations

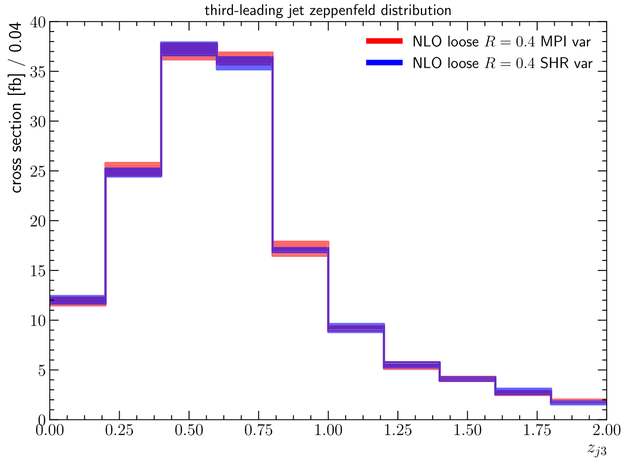
Strategy

- Vary colour reconnection and MPI parameters to stay within ~ 10% agreement of typical tuning observables
- Vary perturbative scales, specifically shower hard scale

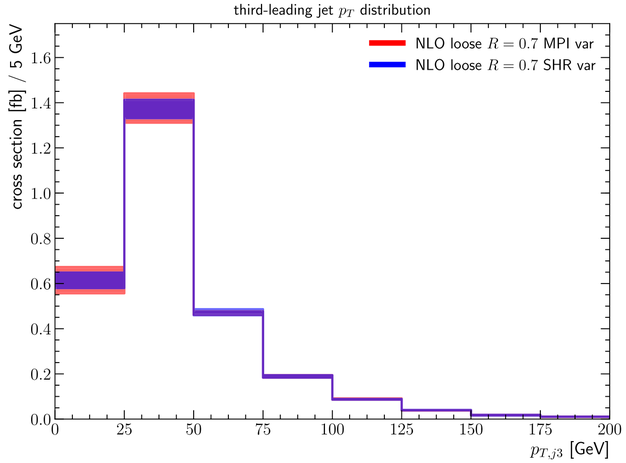


Loose selection

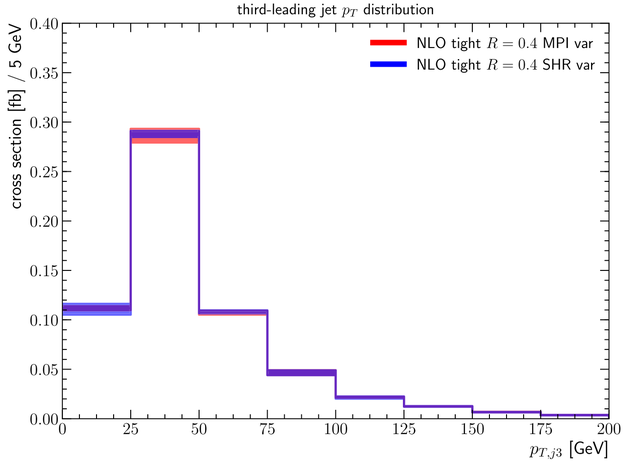
R=0.4

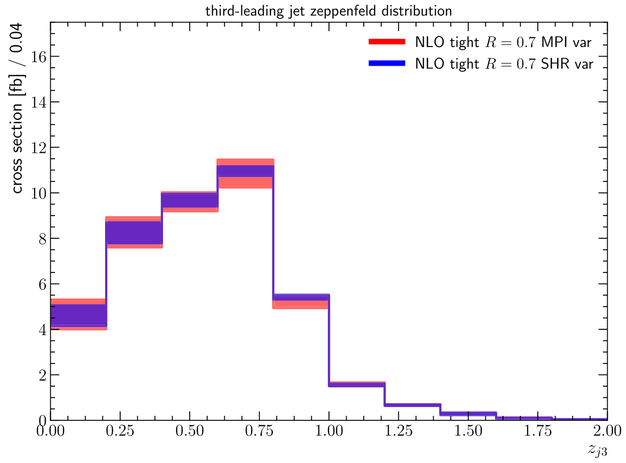


R=0.7



Tight selection





[Bittrich, Kirchgaesser, Papaefstathiou, Plätzer, Todt — EPJ C82 (2022) 9]

High-energy effects and related challenges

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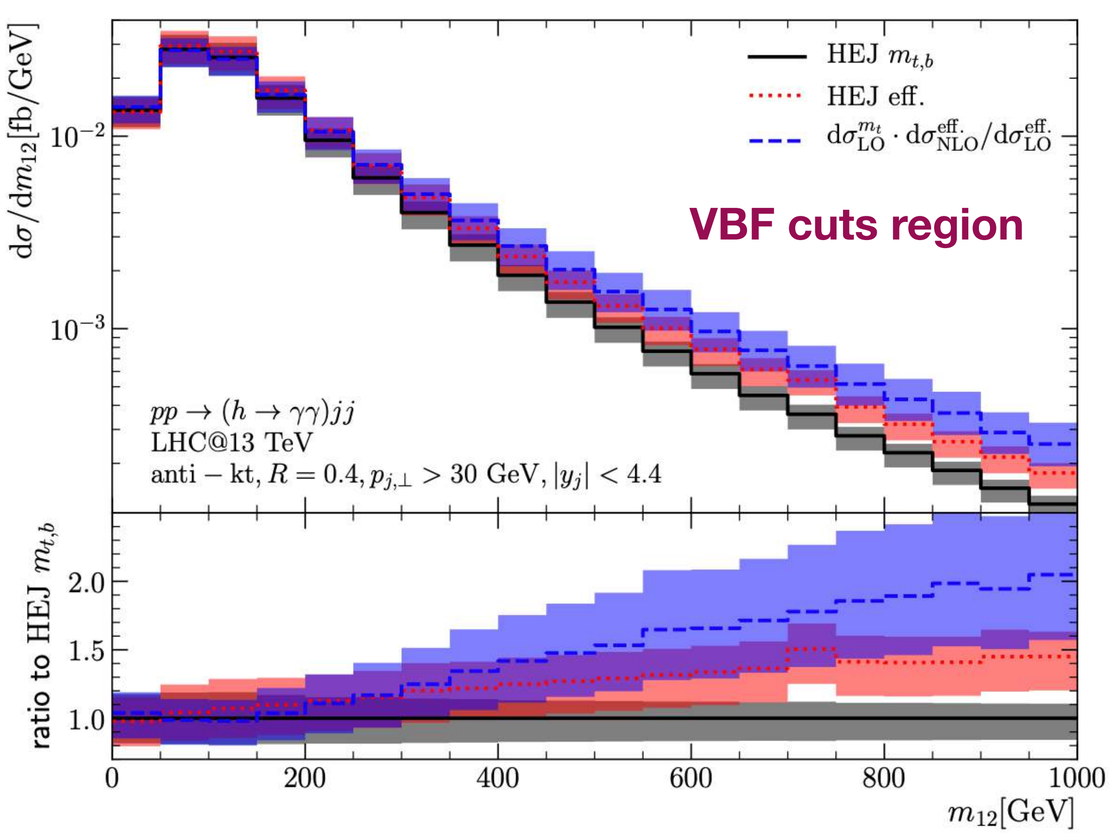
VBF cut region is special in terms of kinematics:
Need to control HE effects in both ggf and VBF.

HEJ Applied to Inclusive H+jets Production

Jérémy Paltrinieri
University of Edinburgh

How do we extrapolate this outside of the multi-Regge dominated region, what about interferences?



Colour Evolution in VBF & ggf

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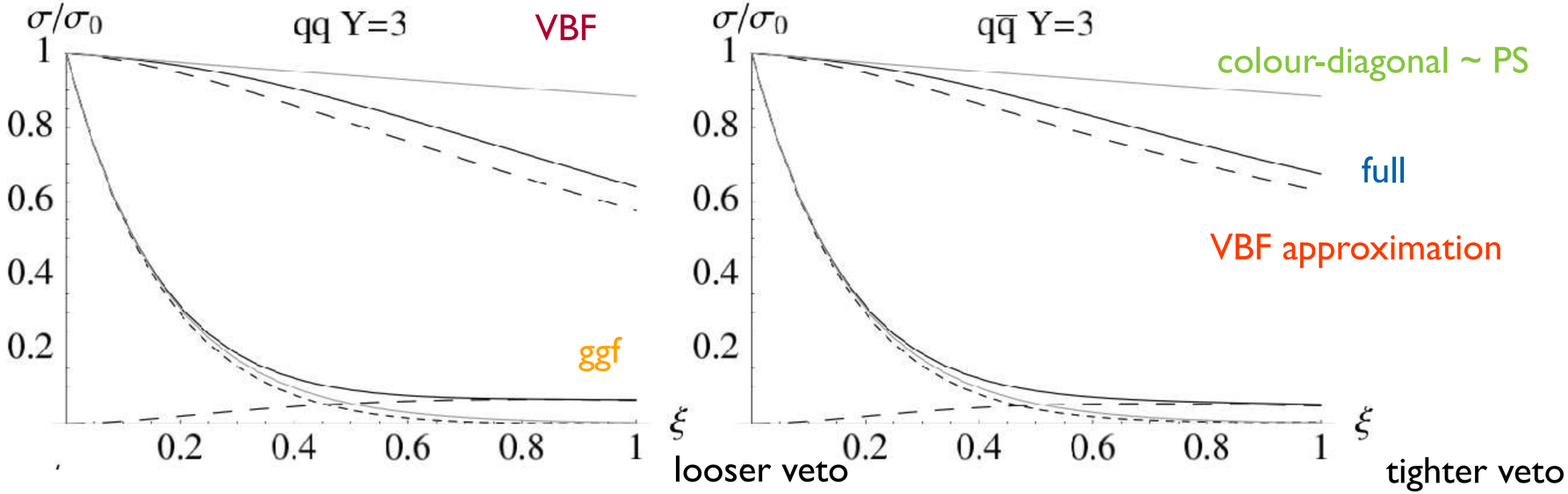
Parton showers with colour matrix element corrections can account for subleading N effects from real emissions.

[Plätzer, Sjödahl – JHEP 1207 (2012) 042]
[Plätzer, Sjödahl, Thoren – JHEP 11 (2018) 009]
[Höche, Reichelt — Phys.Rev.D 104 (2021) 3, 034006]

Virtual exchanges can be resummed at fixed jet multiplicity.

[Forshaw, Sjödahl — JHEP 09 (2007) 119]



Neither one gives a complete picture.

Jet vetos & Non-global Observables

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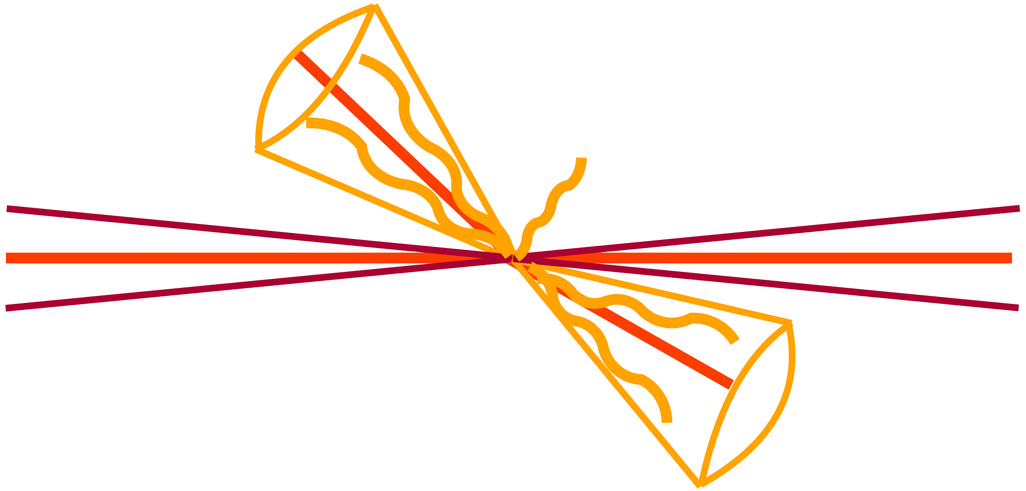
Jet vetos beyond leading-N and Glauber phases require amplitude level evolution.

[Liu, Melnikov, Penin]

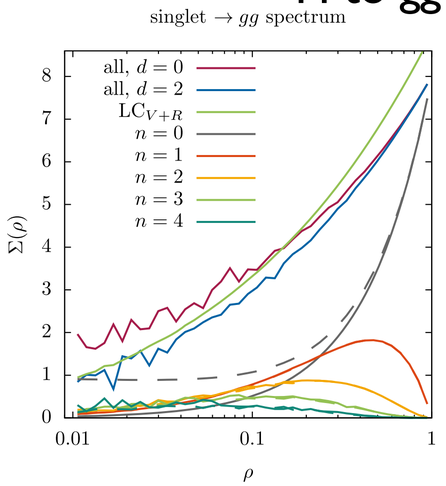
[Forshaw, Holguin, Plätzer – JHEP 1908 (2019) 145]



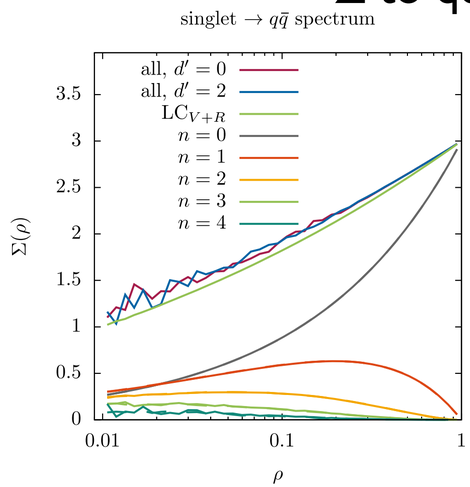
Recent results on jet vetos from CVolver on jet vetos in e+e- collisions.

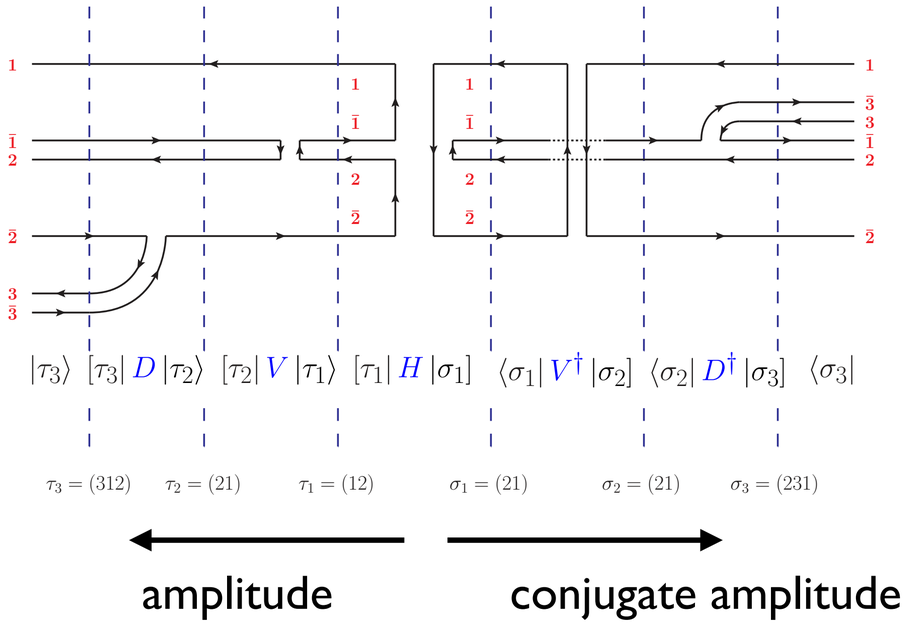
[De Angelis, Forshaw, Plätzer — PRL 126 (2021) 11]

H to gg



Z to qq



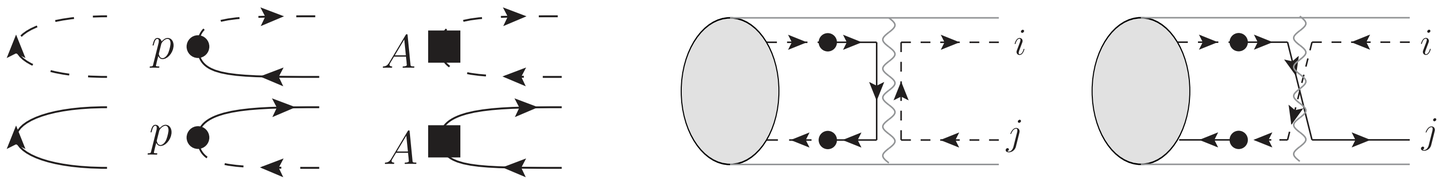


Complementary approach through Langevin dynamics, but not in form of an event generator.

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

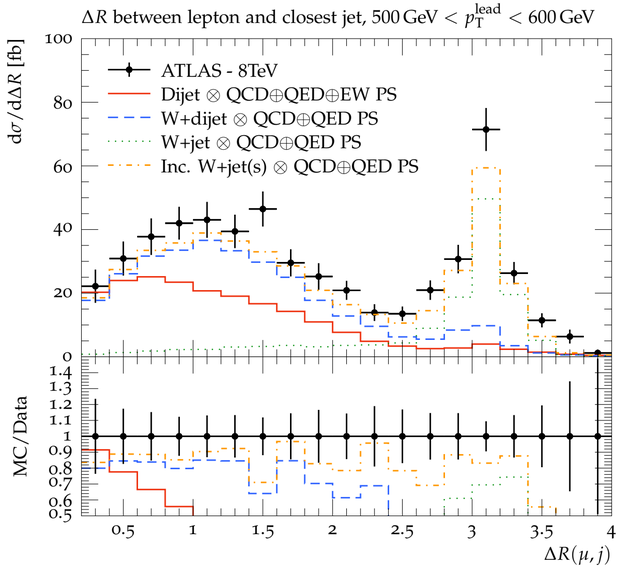
Electroweak (amplitude) evolution

Amplitudes evolve in chirality & isospin, recoil even more important.



[Plätzer, Sjödahl — arXiv:2204.03258]

- More differential knowledge and higher energies will require a coherent treatment of the full Standard Model.
- Might resolve conceptual issues in defining VBF/VBS processes themselves.
- VBF/VBS at lepton colliders!

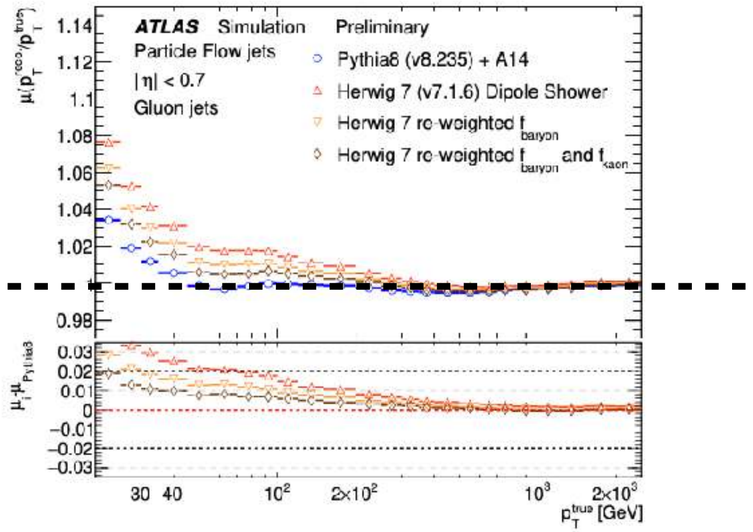


Start to build EW showers, but understanding their structure is far from the level we have for QCD.

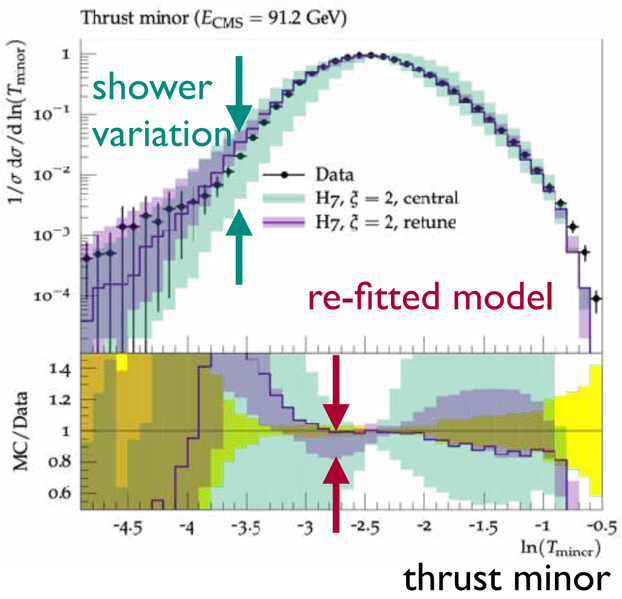
[Masouminia, Richardson — arXiv:2108.10817]
[Christiansen, Sjöstrand, Bauer, Webber, Brooks, Verheyen, Skands ….]

Last not least: Hadronization models?!

relative deviation of
measured jet momentum



[ATLAS-PUB-2022-021]



[Bellm, Lönnblad, Plätzer, Prestel, Samitz, Siodmok — Les Houches 2017]
[Hoang, Plätzer, Samitz — '18 …]

We cannot look at shower uncertainties in isolation, nor can we ignore other soft physics models.

Summary

VBF is among those processes which challenge predictions **at all scales and all levels of detail.**

We should not rest assured on fixed order (possibly matched) studies.

We should not think, that we have a full command of event generator uncertainties and an understanding of their physics down to the percent level — this really is what we are progressing with now.

Thank you!

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