Fun with Monte Carlo Generators
in
Weak Boson Fusion/Scattering

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www.ippp.dur.ac.uk

Disclaimer: this is a personal selection of things that could be done in HiggsTools

… therefore I will

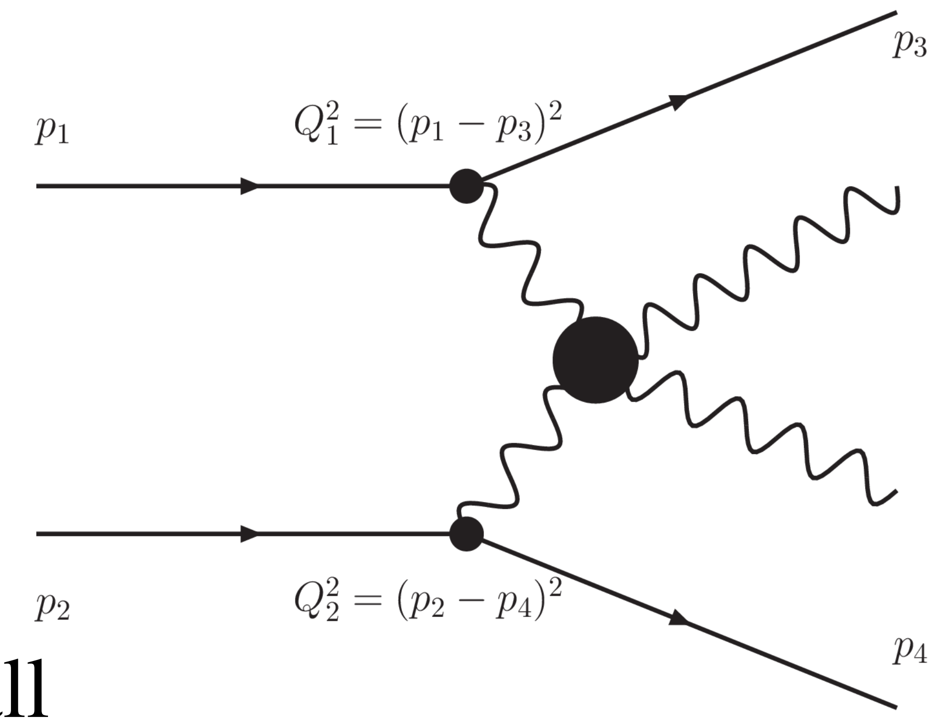
- ➔ not aim at presenting “everything”
- ➔ focus on some dominant features and tools
- ➔ briefly discuss the things that I find interesting
- ➔ try to work out some ideas for systematic checks and work that could be done

Weak Boson Fusion/Scattering:

General thoughts

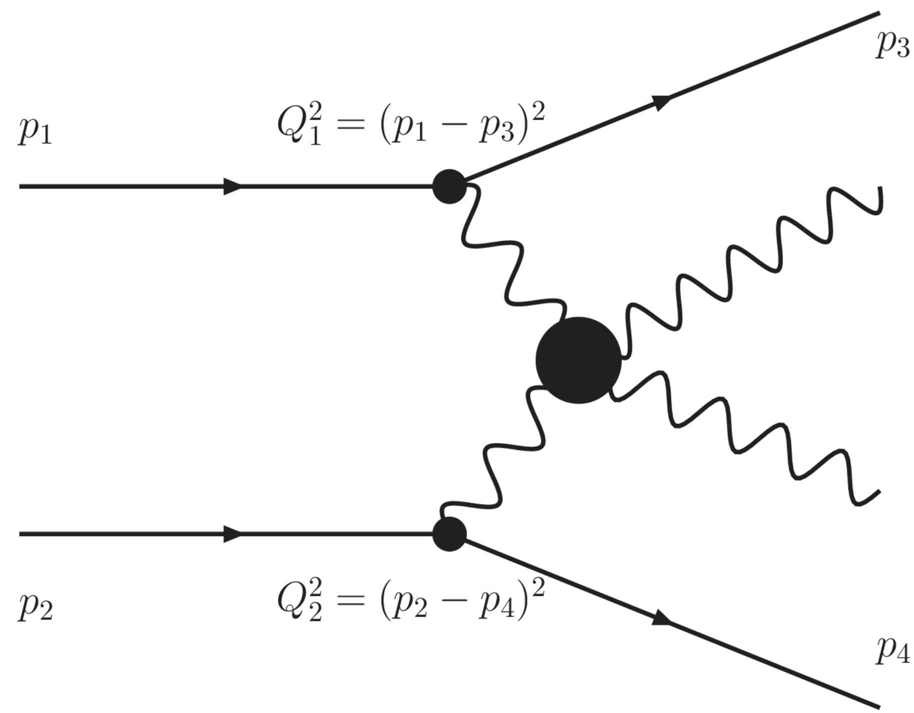
Dynamical picture of WBF

- quark-initiated process with colour-less t-channel exchange
- think of "double-DIS"
- two QCD scales $Q_{1,2}$
- combine $Q^2 = Q_1 Q_2$
- HO effects typically small with QCD ~ EW corrections (but opposite sign)



Dynamical picture of WBF (cont'd)

- angular ordering: forward tag jets + rapidity gap, populated by produced system
- great for S/B
- main Bck: QCD
- EW non-negligible
- sizeable interferences in high-mass regime



- Initial valence quarks drivers in this regime

WBF signal at NNLO

Size of NNLO corrections

(recent paper by Cacciari et al., 1506.02660)

- NNLO corrections surprisingly large

  (at least to my taste)

- "funny" scale choice

	$\sigma^{(\text{no cuts})}$ [pb]	$\sigma^{(\text{VBF cuts})}$ [pb]
LO	$4.032\,^{+0.057}_{-0.069}$	$0.957\,^{+0.066}_{-0.059}$
NLO	$3.929\,^{+0.024}_{-0.023}$	$0.876\,^{+0.008}_{-0.018}$
NNLO	$3.888\,^{+0.016}_{-0.012}$	$0.826\,^{+0.013}_{-0.014}$

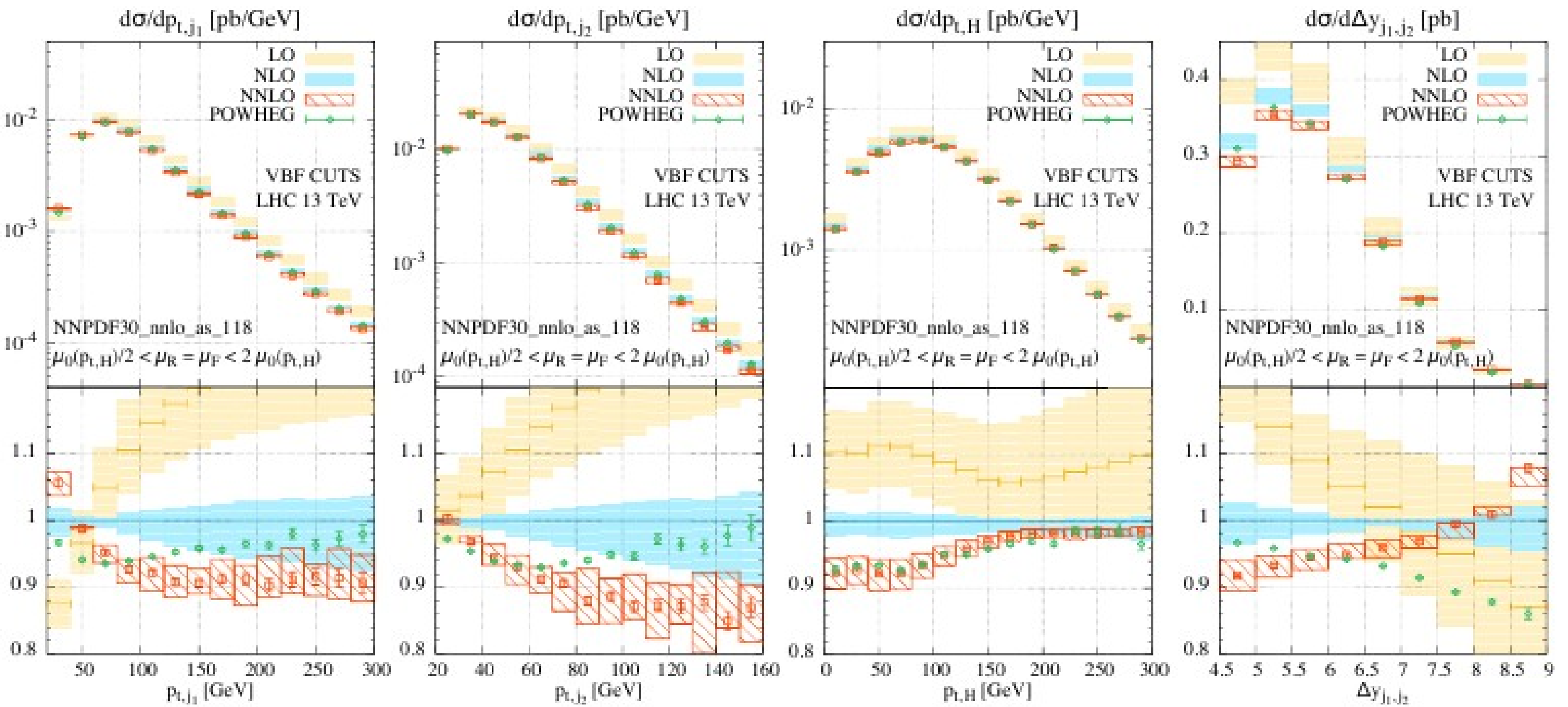
- strong dependence on cuts and kinematics

  (next slide)

- naive question: is this a result of hard emissions – or phrased differently: could this have been anticipated from multijet-merged samples

Size of NNLO corrections

(recent paper by Cacciari et al., 1506.02660)



Production of

same-sign W bosons ($W^{\pm}W^{\pm}$)

Role of H in same-sign V's

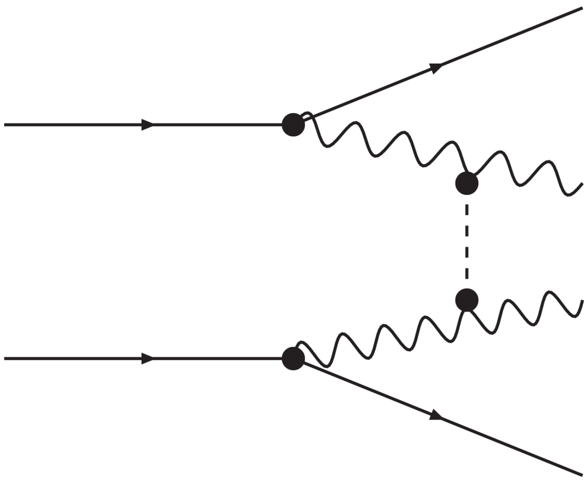
- Test coupling of H to VV in different kinematic regime
  (*t*-channel, see next slide)
- independent of NWA
  → measure width Γ_H
- see recent paper
  (by Ellis et al., 1502.02990)

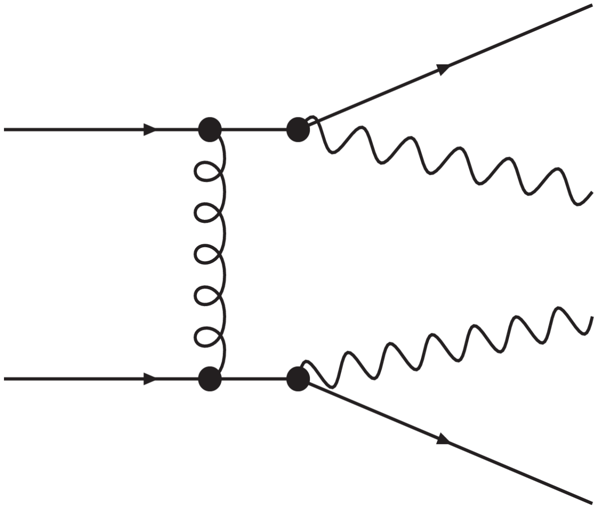
Process	Nominal process	Cut	σ [fb] $O(\alpha^6)$	Factor	Events in 100 fb^{-1}
$pp \to e^-\mu^+\nu_\mu\bar{\nu}_e jj$	W^-W^+	$m_T^{WW} > 300$ GeV	0.2378	x4	95
$pp \to \nu_e e^+\nu_\mu\mu^+ jj$	W^+W^+	$m_T^{WW} > 300$ GeV	0.1358	x2	27
$pp \to e^-\bar{\nu}_e\mu^-\bar{\nu}_\mu jj$	W^-W^-	$m_T^{WW} > 300$ GeV	0.0440	x2	9
$pp \to \nu_e e^+\mu^-\mu^+\mu^+ jj$	W^+Z	$m_T^{WZ} > 300$ GeV	0.0492	x4	20
$pp \to e^-\bar{\nu}_e\mu^-\mu^+ jj$	W^-Z	$m_T^{WZ} > 300$ GeV	0.0242	x4	10
$pp \to l^-l^+\nu_l\bar{\nu}_l jj$	ZZ	$m_T^{ZZ} > 300$ GeV	0.0225	x6	14
$pp \to l^-l^+\nu_l\bar{\nu}_l jj$	ZZ	$m_T^{WW} > 300$ GeV	0.0181	x6	11
$pp \to e^-e^+\mu^-\mu^+ jj$	ZZ	$m_{4l} > 300$ GeV	0.0218	x2	4

Process	Nominal process	Cut	σ [fb] $O(\alpha^4\alpha_s^2)$	Factor	Events in 100 fb^{-1}
$pp \to e^-\mu^+\nu_\mu\bar{\nu}_e jj$	W^-W^+	$m_T^{WW} > 300$ GeV	0.2227	x4	89
$pp \to \nu_e e^+\nu_\mu\mu^+ jj$	W^+W^+	$m_T^{WW} > 300$ GeV	0.0079	x2	2
$pp \to e^-\bar{\nu}_e\mu^-\bar{\nu}_\mu jj$	W^-W^-	$m_T^{WW} > 300$ GeV	0.0025	x2	0
$pp \to \nu_e e^+\mu^-\mu^+\mu^+ jj$	W^+Z	$m_T^{WZ} > 300$ GeV	0.0916	x4	37
$pp \to e^-\bar{\nu}_e\mu^-\mu^+ jj$	W^-Z	$m_T^{WZ} > 300$ GeV	0.0454	x4	18
$pp \to l^-l^+\nu_l\bar{\nu}_l jj$	ZZ	$m_T^{ZZ} > 300$ GeV	0.0143	x6	9
$pp \to l^-l^+\nu_l\bar{\nu}_l jj$	ZZ	$m_T^{WW} > 300$ GeV	0.0118	x6	7
$pp \to e^-e^+\mu^-\mu^+ jj$	ZZ	$m_{4l} > 300$ GeV	0.0147	x2	3

Production modes at leading order

- in general:
  W^+-pairs favoured over W^--pairs
  (valence quarks dominant)
- EW production vs. QCD mode
  (no interference – colour structure)
- curious observation: quarks in FS,
  but no (jet-) cuts necessary
- cross-sections a few fb





Higher orders

- NLO corrections calculated for QCD and EW (?)
- to check:
  - size of QCD-EW interference at NLO
  - available tools
- in Sherpa: need loop-amplitudes

(OpenLoops/GoSam/Blackhat/...)

S/B interference

Assume VV $\to$ 4leptons as final state

- lots of diagrams, with and without resonant V's: ultimately this is qq $\to$ qq+4l.
- typically NLO corrections more cumbersome (I do not know of any complete calculation)
- important: look at size of these non-resonant graphs $\to$ I think a LO check with typical cuts is enough
- notabene: same is true for WBF $(H \to \tau\tau)$ etc.
- also: can check some HO effects through simulating with LO multijet merging

Related signal: VH

Tri-lepton final states in VH

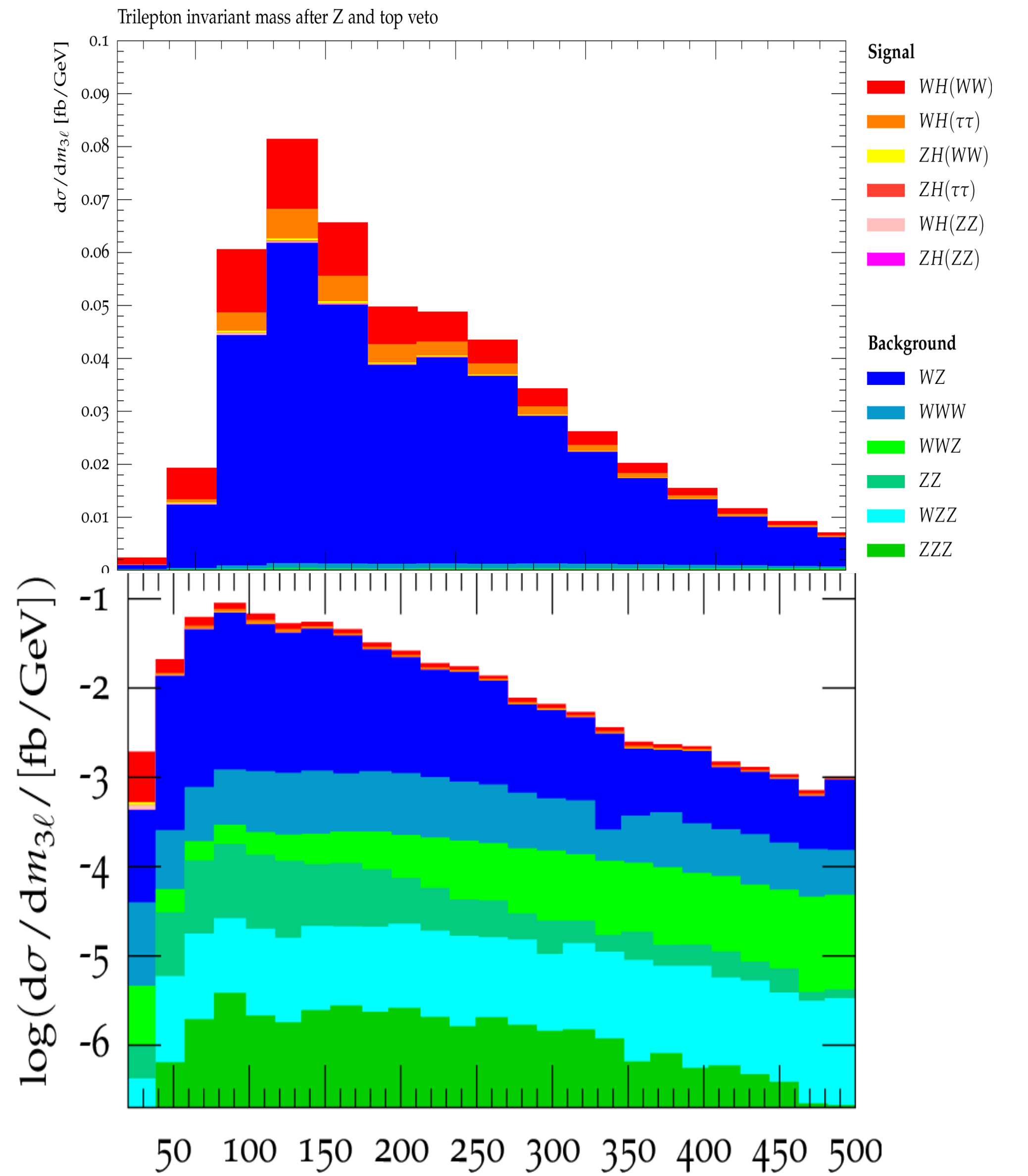
- personal bias

  (plots with Sherpa)

- no interference with WBF (leptons!)

- simple signal: plots to the right at 8 TeV, multijet-merged@NLO

- Check at 13 TeV, boosted regime?



Tools

Possible tools

- VBFNLO at FO (not sure about link to shower)
- Madgraph5 (with and without aMC@NLO) + shower program (Pythia, Herwig)
- Sherpa (with or without loop provider)

- important: run more than one MC code