Off-shell Interpretations TF

NLO effects in VBF off-shell production

Martina Javurkova[1], Rafael Coelho Lopes de Sá[1], Lailin Xu[2]

[1]University of Massachusetts-Amherst

[2] Brookhaven National Laboratory

TH Uncertainties Meeting

22/10/2020

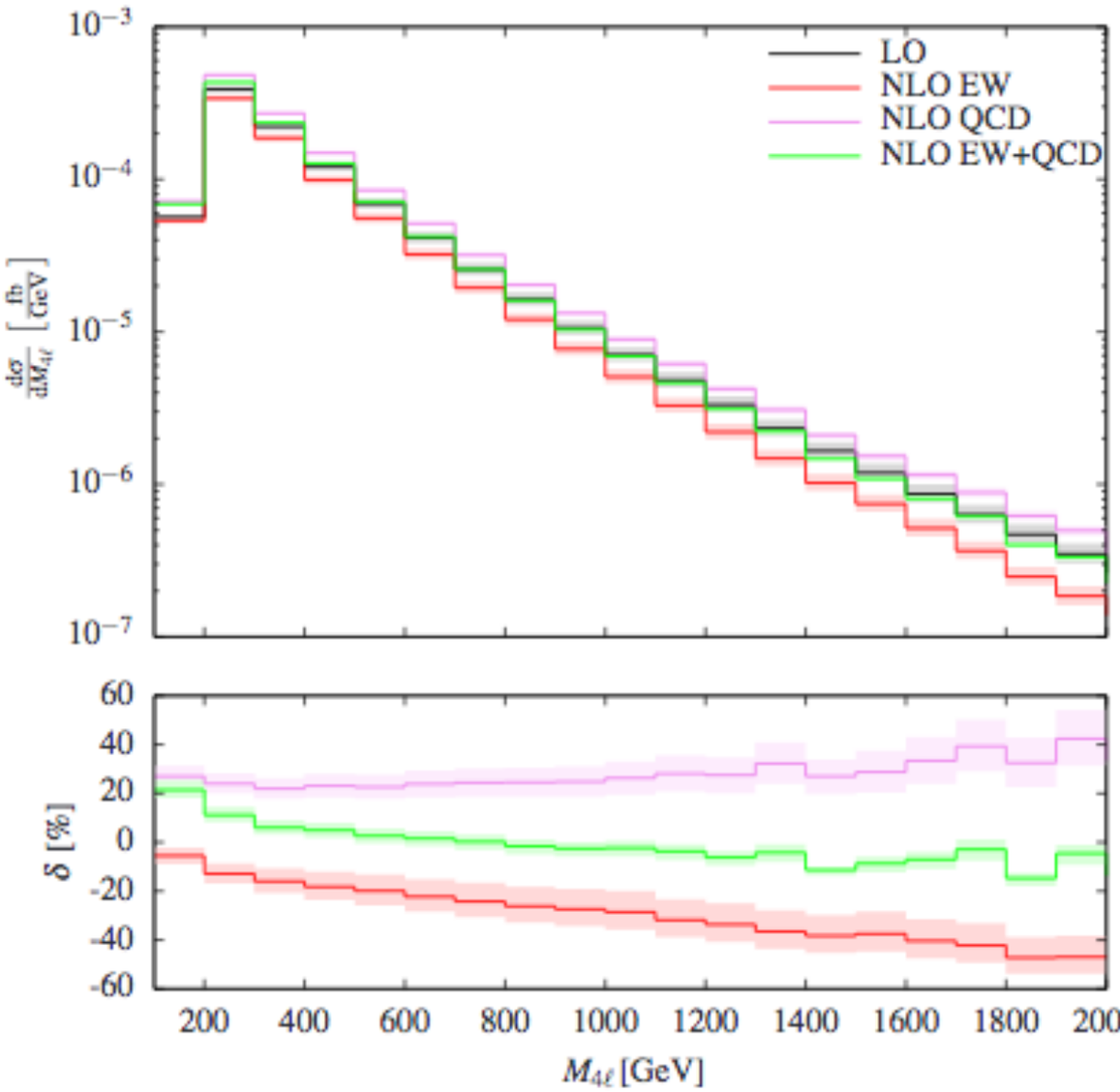
HO corrections to the VBF processes

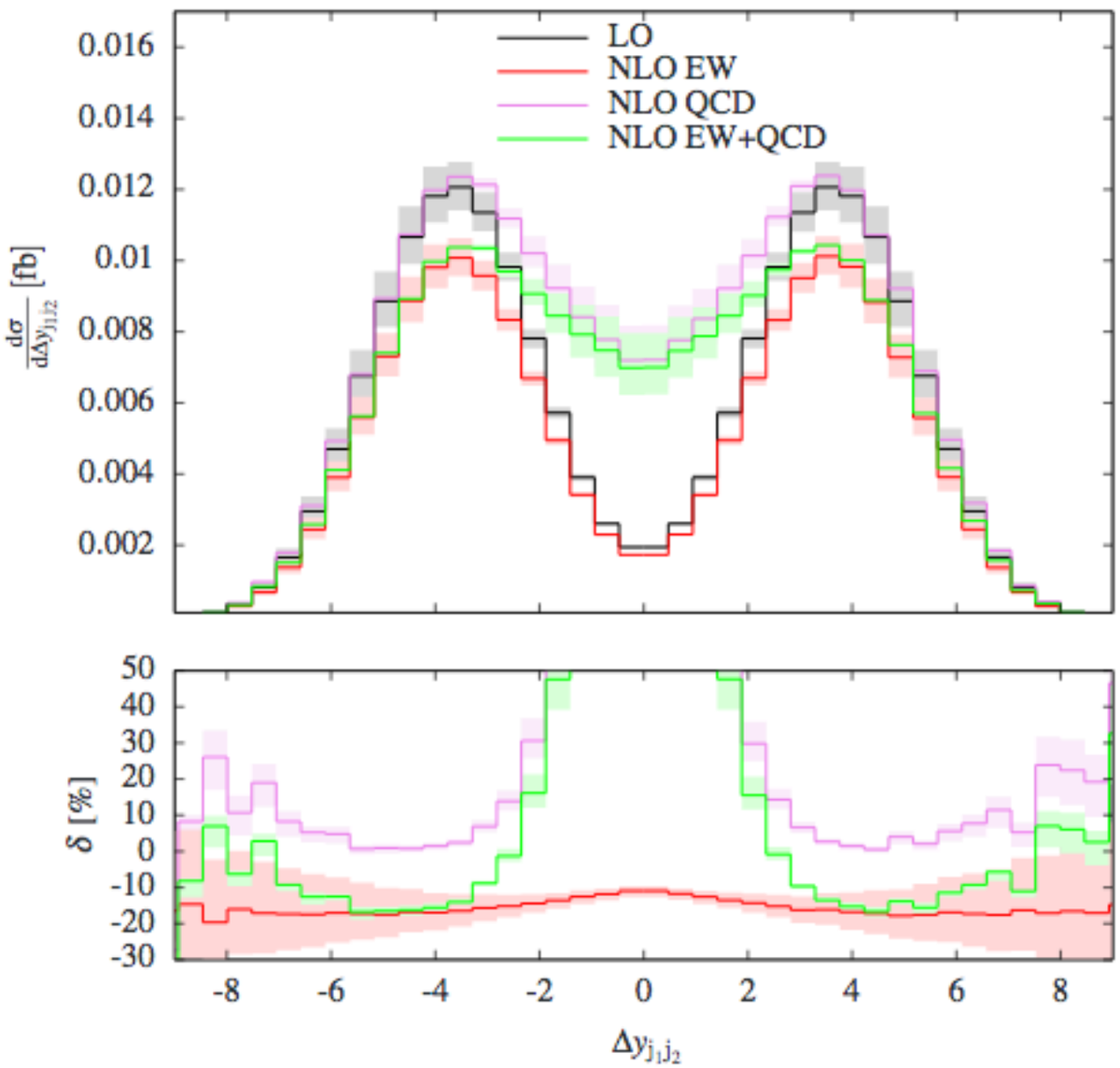
- Contribution from the VBF process is not negligible
- Sensitive to the VBF signal strength
- Samples generated with MadGraph5 at the LO
- What are the effects of HO corrections?

- Lately published paper https://arxiv.org/pdf/2009.00411.pdf shows that NLO QCD and EW corrections to the full process may be significant
  - Different phase-space region w.r.t. our H4l off-shell analysis
    - No requirement on the $m_{4\ell}$
    - Cut on the two leading jets: $m_{jj} > 100$ GeV

QCD and EW corrections to the VBF processes

- Corrections have been derived for the full process (signal + background + interference)
- QCD corrections exceed 20%
- EW corrections can reach -40% in the high-energy tails of distributions

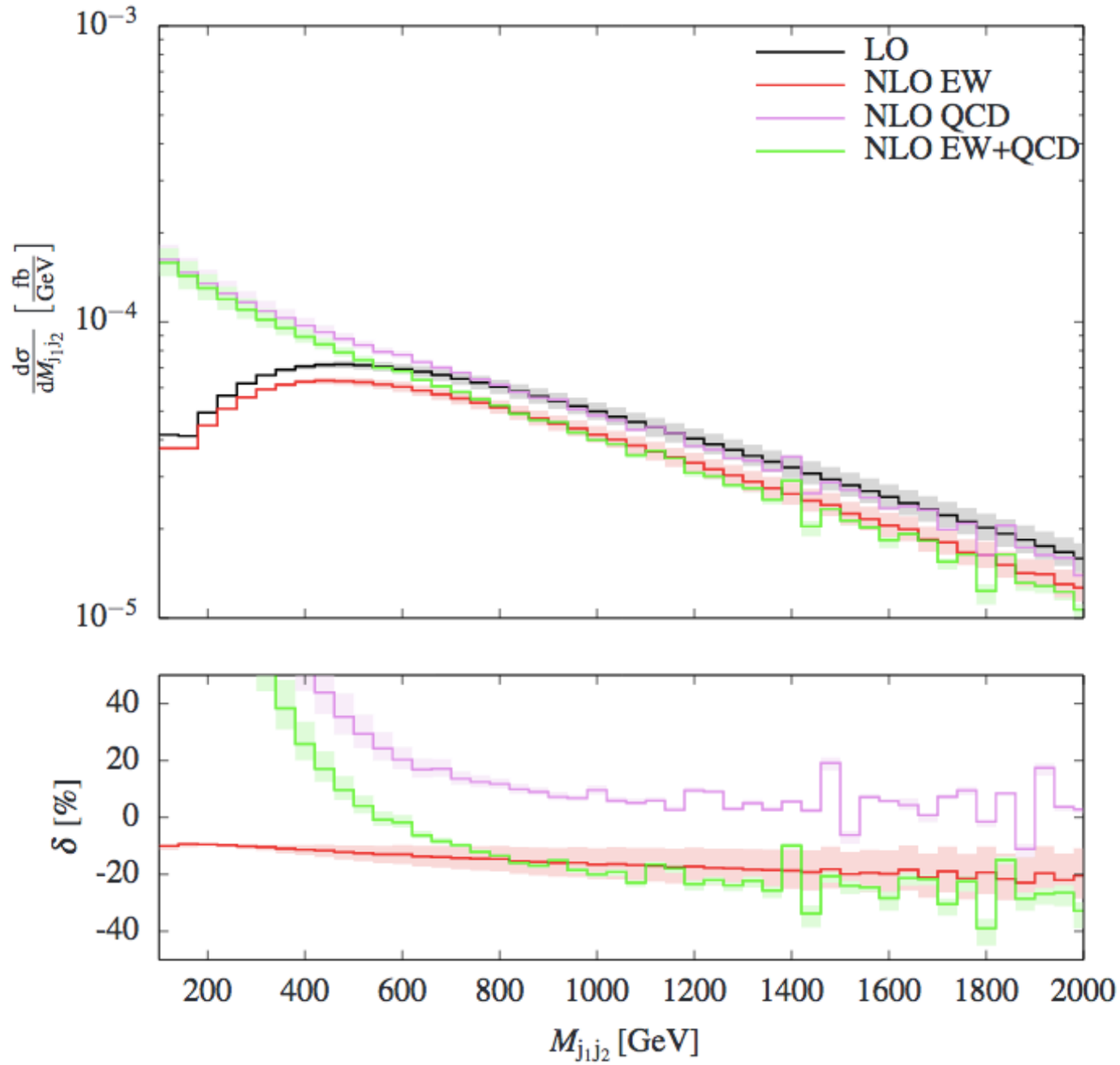




QCD and EW corrections to the VBF processes (II)

- Difference is mainly due to the fact that the computation is done for a rather inclusive phase-space region

- Massive vector boson decaying hadronically cannot become resonant due to $m_{jj} > 100$ GeV cut



QCD NLO generation of the VBF signal process

1. Generated **signal VBF events in the s-channel (VBF and VH)** with MadGraph5 at the NLO in QCD

   - **generate p p > z h > j j e+ e- mu+ mu- QCD=0 QED=6 [QCD]**
   - **add process p p > w+ h > j j e+ e- mu+ mu- QCD=0 QED=6 [QCD]**
   - **add process p p > w- h > j j e+ e- mu+ mu- QCD=0 QED=6 [QCD]**

2. Showered with Pythia8 using a dipole-recoil scheme

3. Compared to the LO VBF events using Rivet tool

   - Two SFOS lepton pairs within Z-mass window
   - Off-shell region: $220 < m_{4\ell} < 2000$ GeV

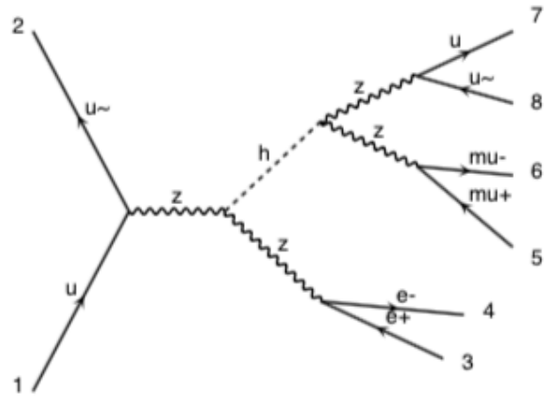
QCD NLO generation of the VBF signal process (II)

- We have decided to use this syntax rather than a more generic one p p > h > j j e+ e- mu+ mu- QCD=0 QED=6 [QCD]
  - To reduce the effect of VBS approximation https://arxiv.org/pdf/1803.07943.pdf
- Dipole-recoil scheme corrects for the default Pythia8 settings which produce too much radiation in the central region of rapidity for VBS processes
  - May not be compatible with the NLO calculation https://cds.cern.ch/record/2655303/files/ATL-PHYS-PUB-2019-004.pdf

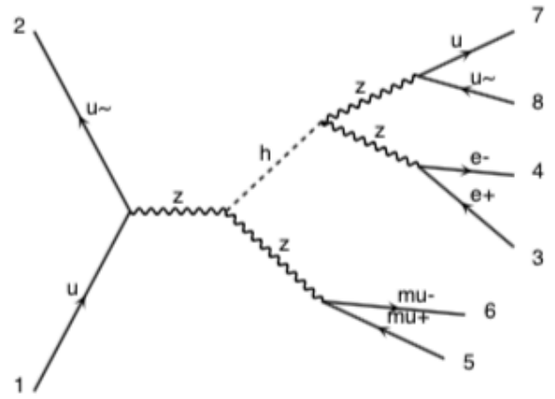
Feynman diagrams

- LO Feynman diagrams for uu~ and ud~ processes are the same as the born diagrams for the NLO calculation

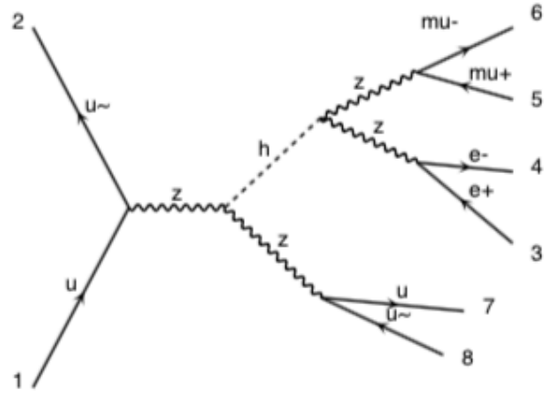
- NLO Feynman diagrams



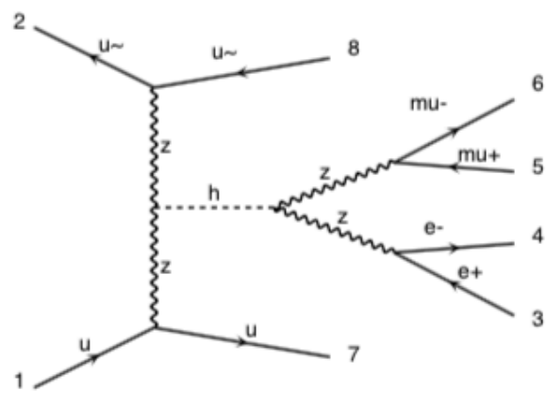
born diagram 1 QCD=0, QED=6



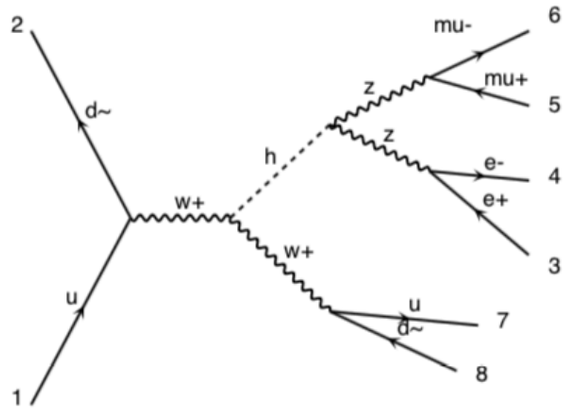
born diagram 2 QCD=0, QED=6



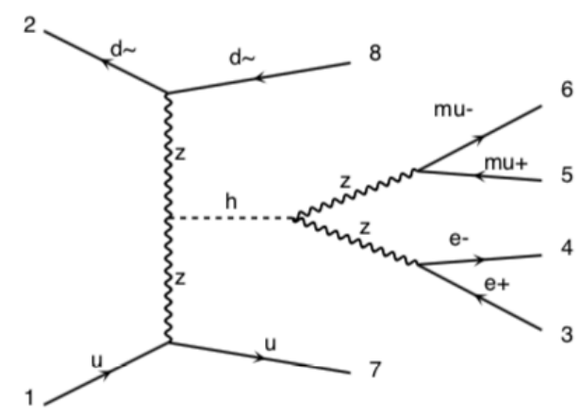
born diagram 3 QCD=0, QED=6



born diagram 4 QCD=0, QED=6



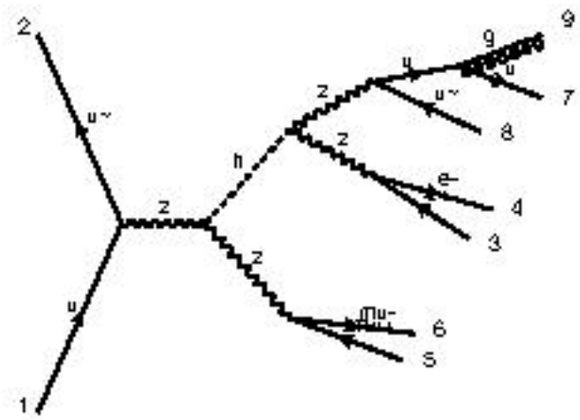
born diagram 1 QCD=0, QED=6



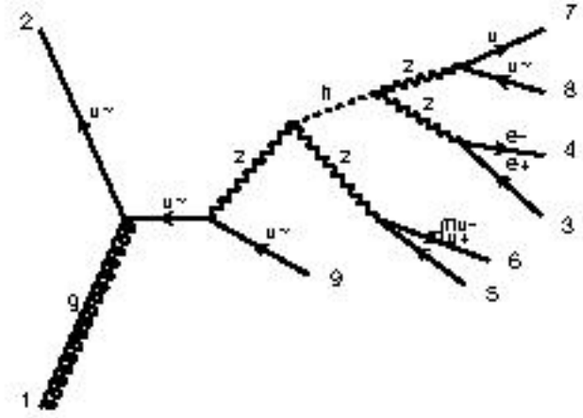
born diagram 2 QCD=0, QED=6

Feynman diagrams

- LO Feynman diagrams for uu~ and ud~ processes are the same as the born diagrams for the NLO calculation

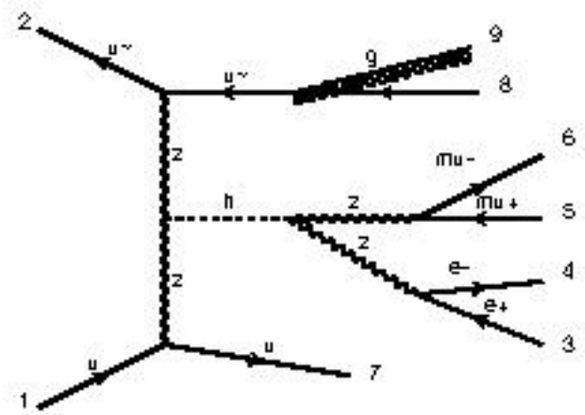


real diagram 2 QCD=1, QED=6

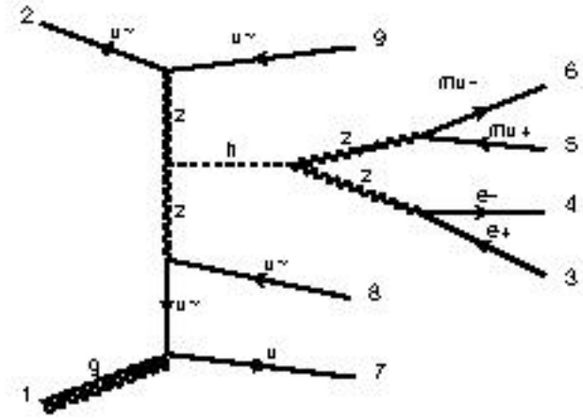


real diagram 2 QCD=1, QED=6

- NLO Feynman diagrams



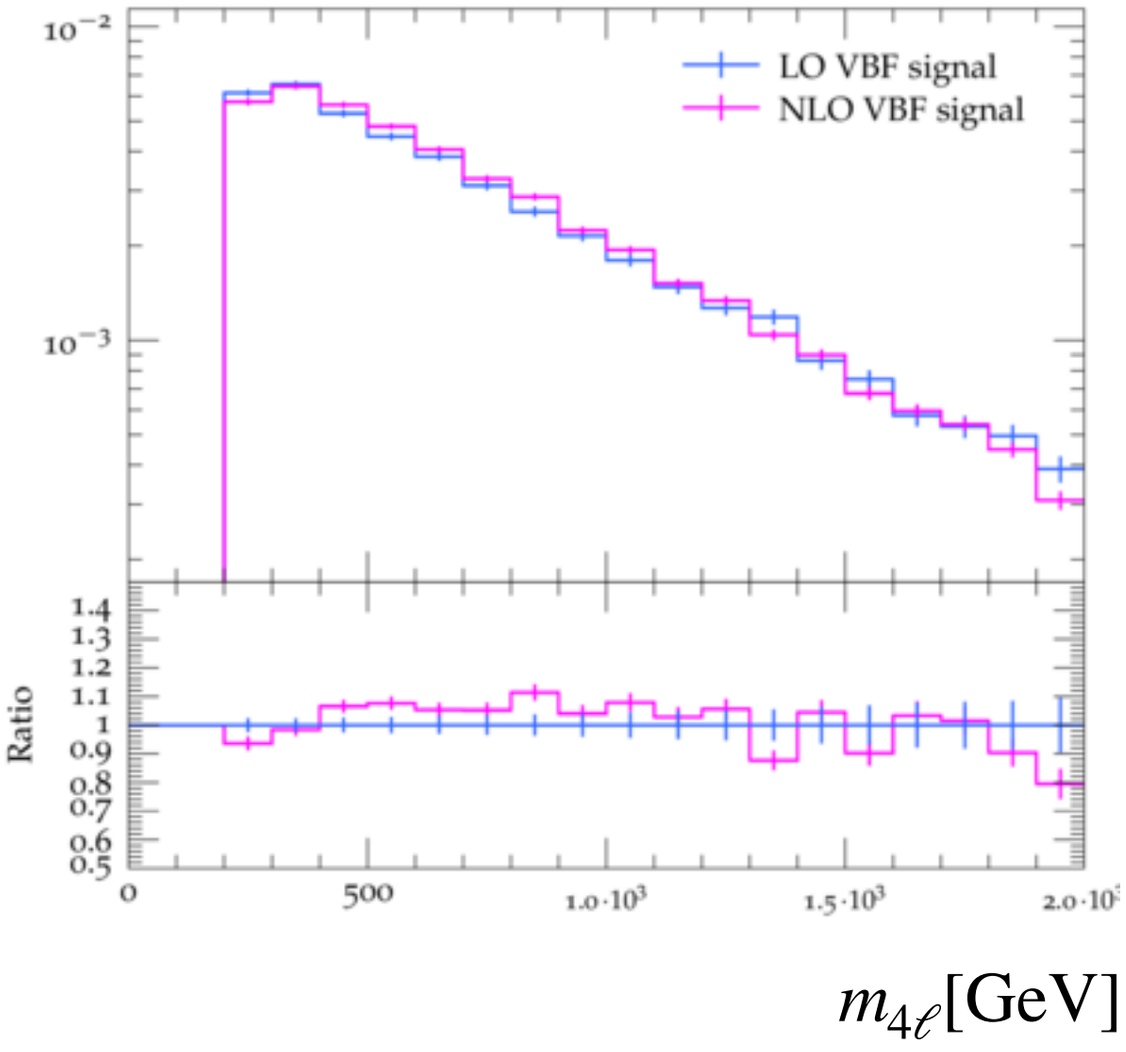
real diagram 8 QCD=1, QED=6

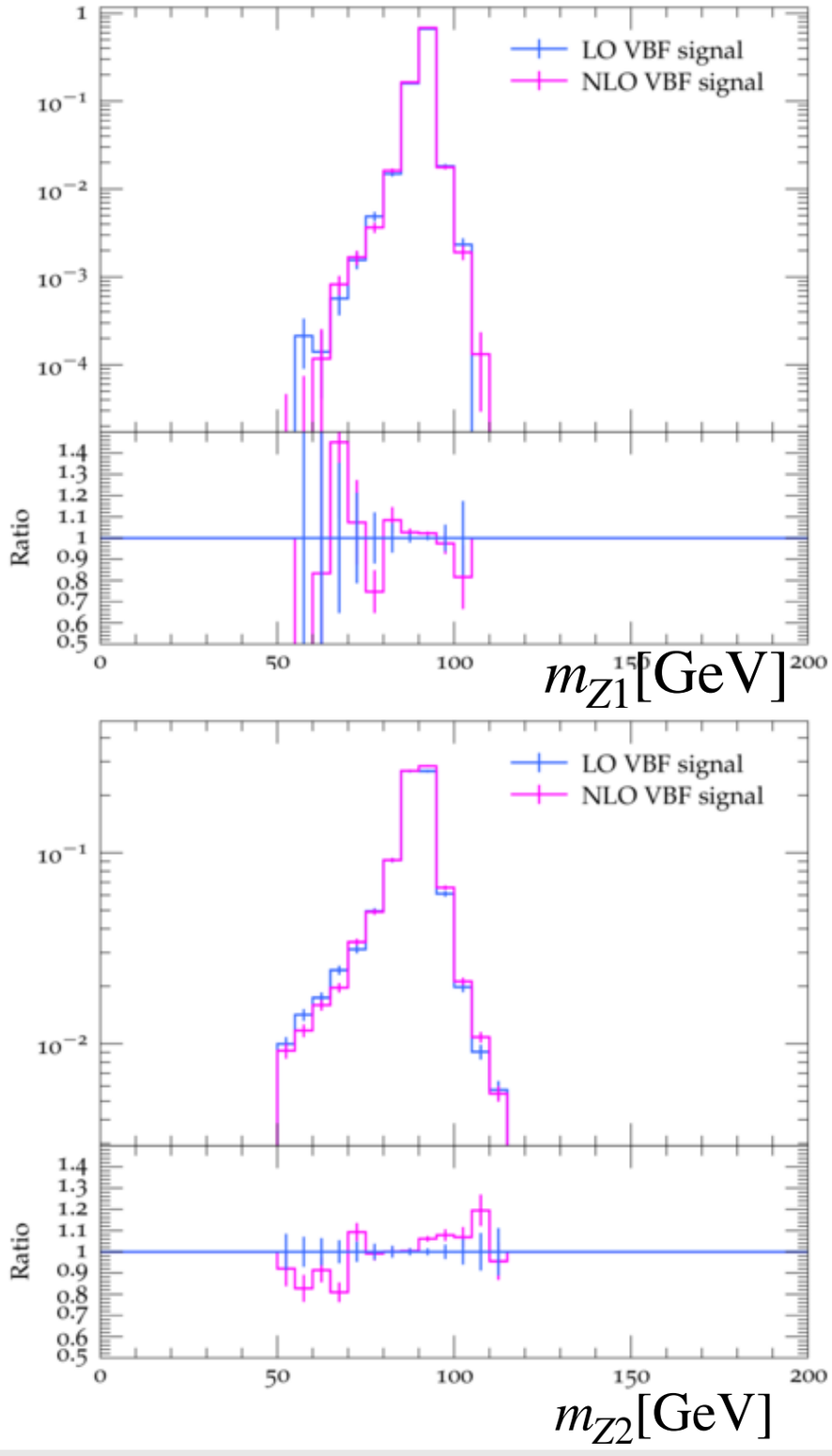


real diagram 8 QCD=1, QED=6

Lepton distributions in the inclusive region

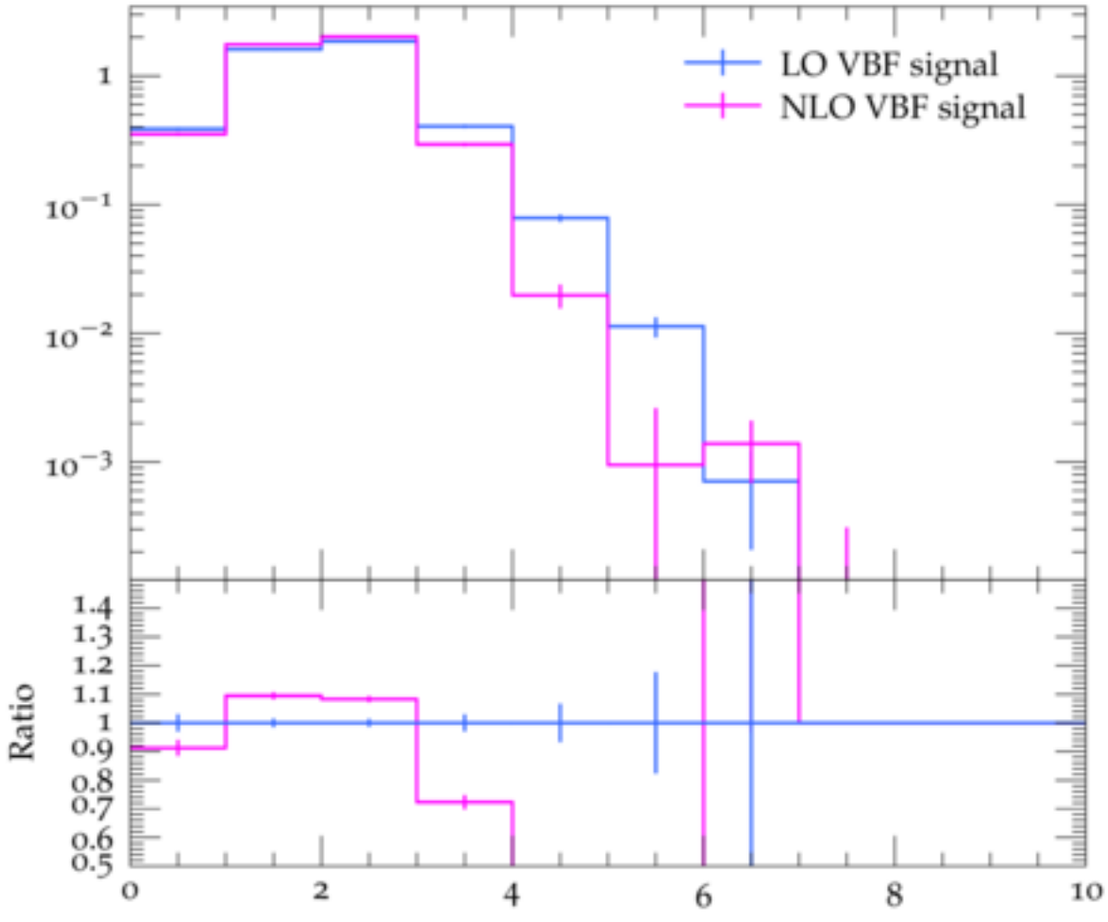
- 2M NLO events compared to 100k LO events
- $220 < m_{4\ell} < 2000$ GeV
- Nice agreement

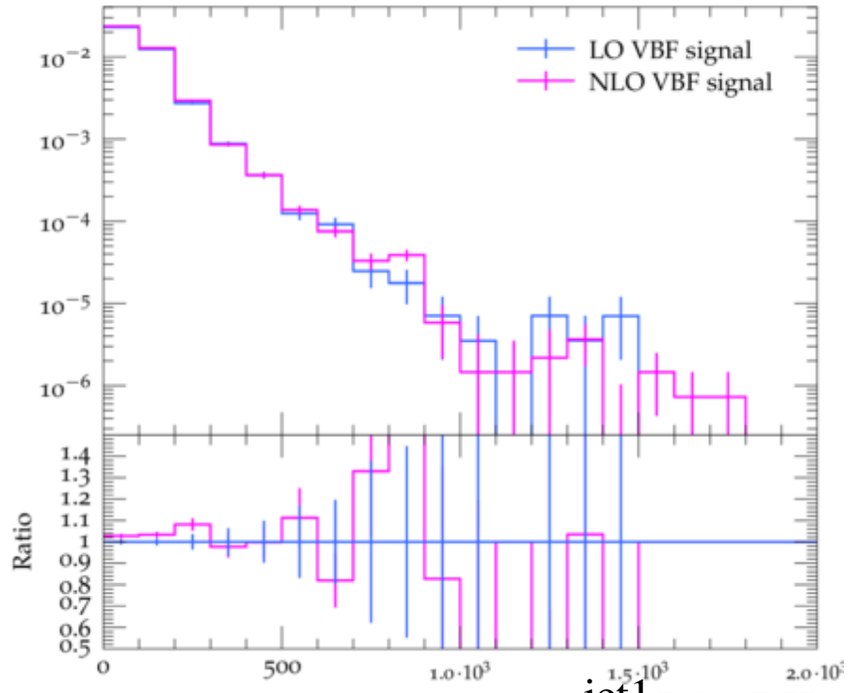


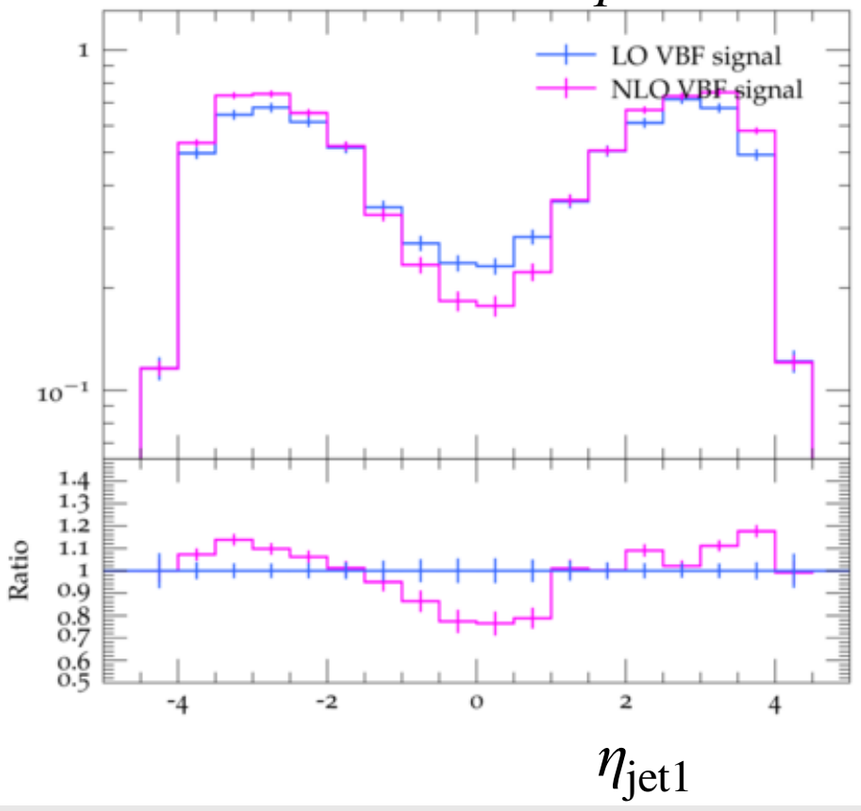


Jet distributions in the inclusive region

- 2M NLO events compared to 100k LO events
- $220 < m_{4\ell} < 2000$ GeV
- Difference in the jet multiplicities and the jet rapidity

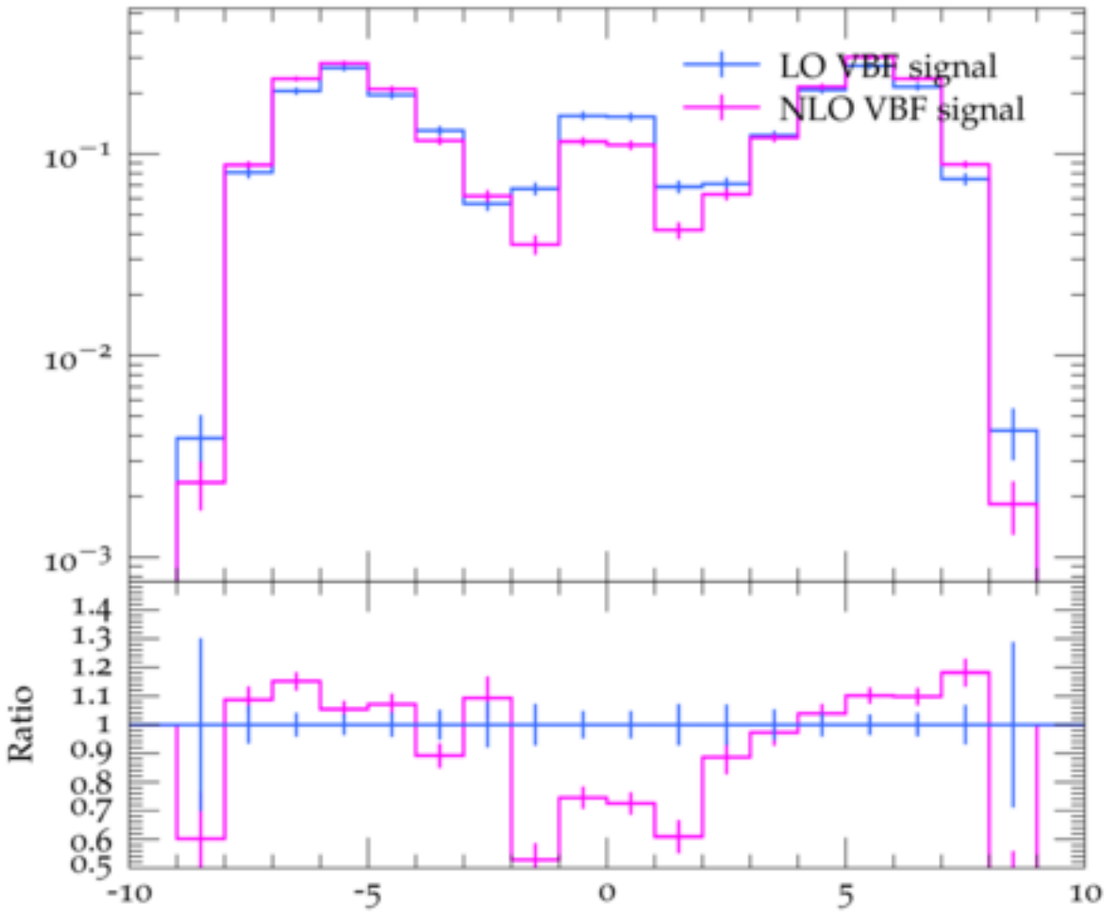




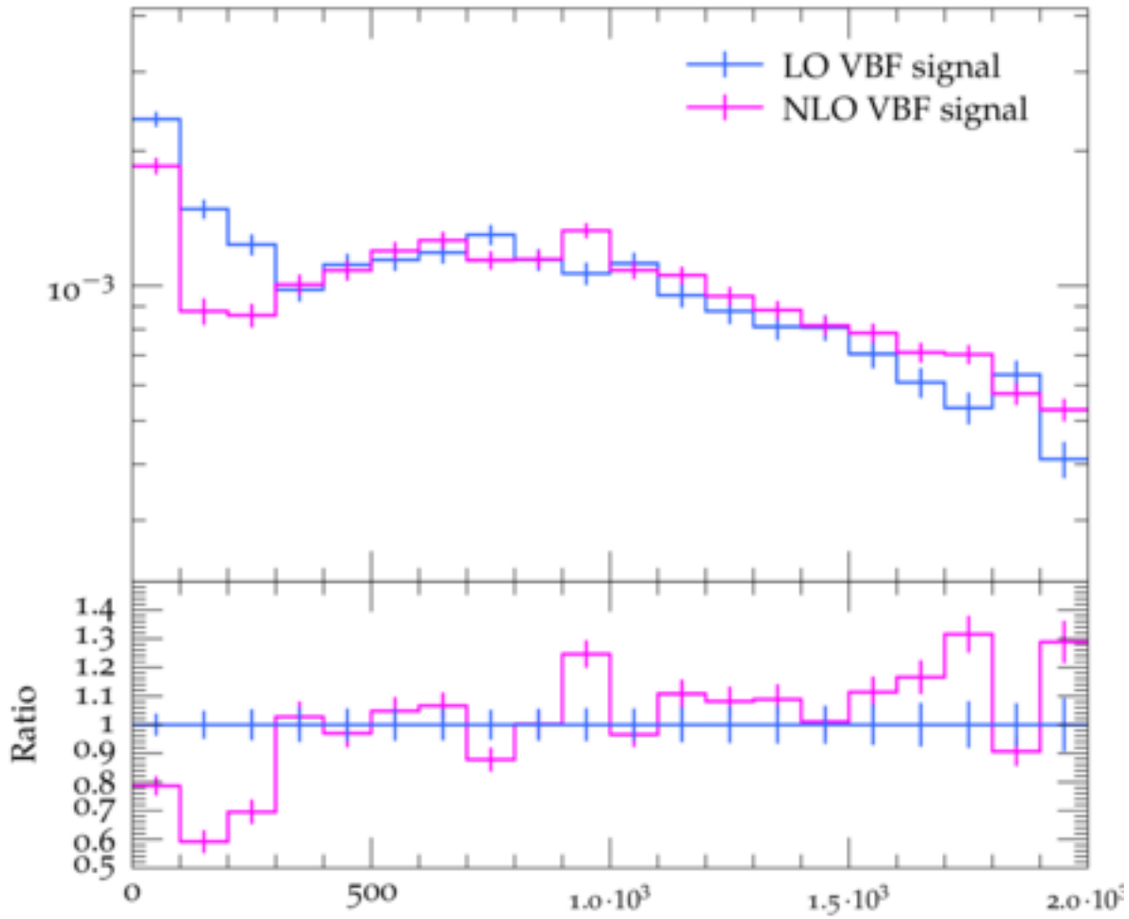


Dijet distributions in $N_{\text{jets}} \geq 2$ region

- VBF-enriched region with at least two jets
- Nice agreement in VBF region defined $\Delta\eta_{jj} > 4$
- Difference in central $\Delta\eta_{jj}$ (ggF region) and low m_{jj} regions



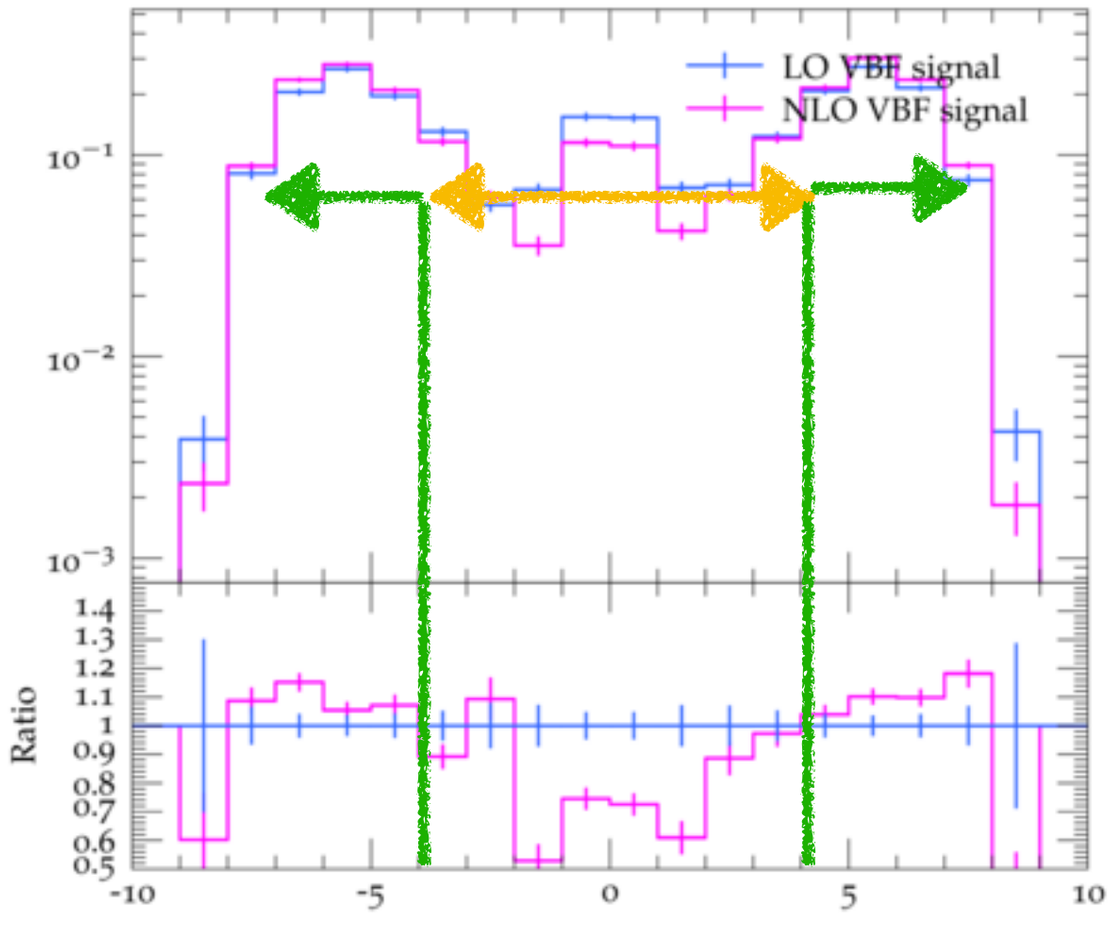
$\Delta\eta_{jj}$



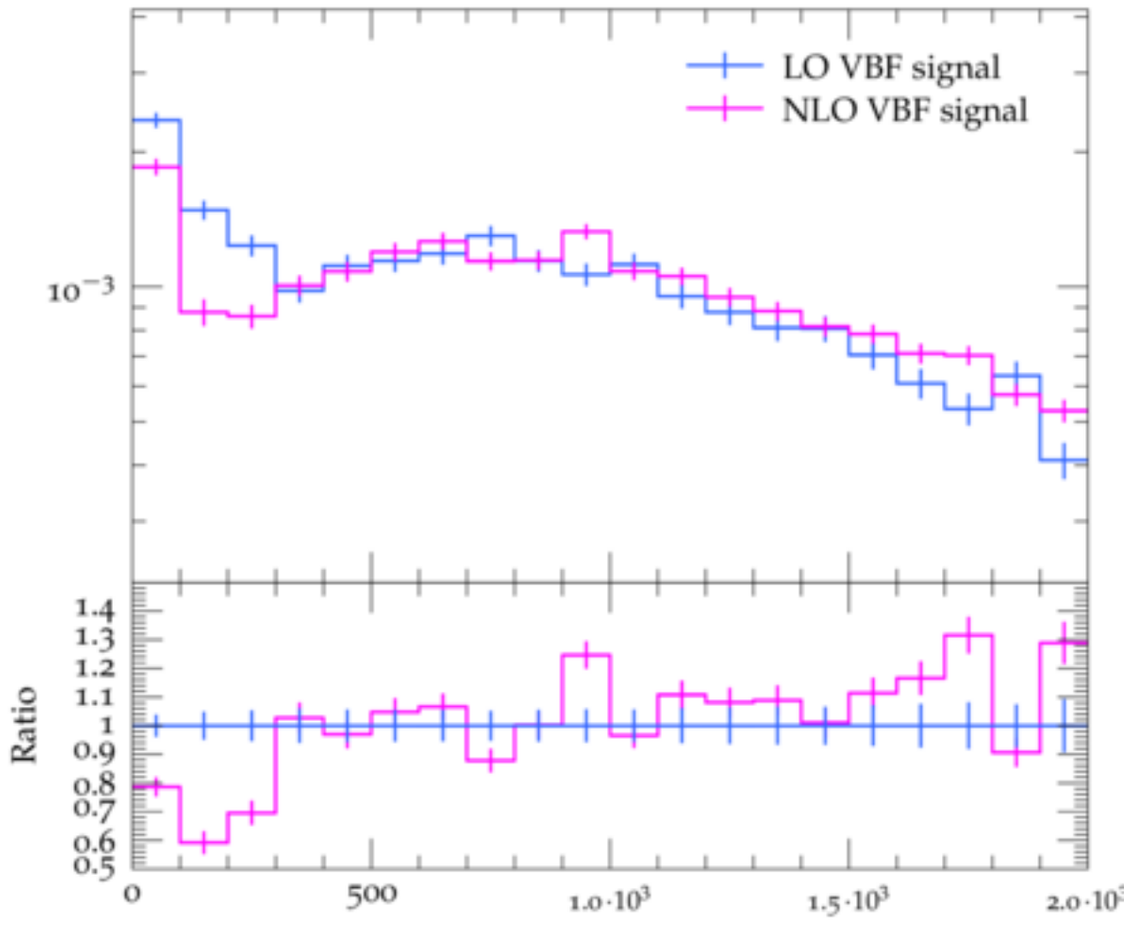
m_{jj}[GeV]

Dijet distributions in $N_{\text{jets}} \geq 2$ region

- VBF-enriched region with at least two jets
- Nice agreement in VBF region defined $\Delta\eta_{jj} > 4$
- Difference in $\Delta\eta_{jj}$ (ggF region) and m_{jj} (low mass) distributions



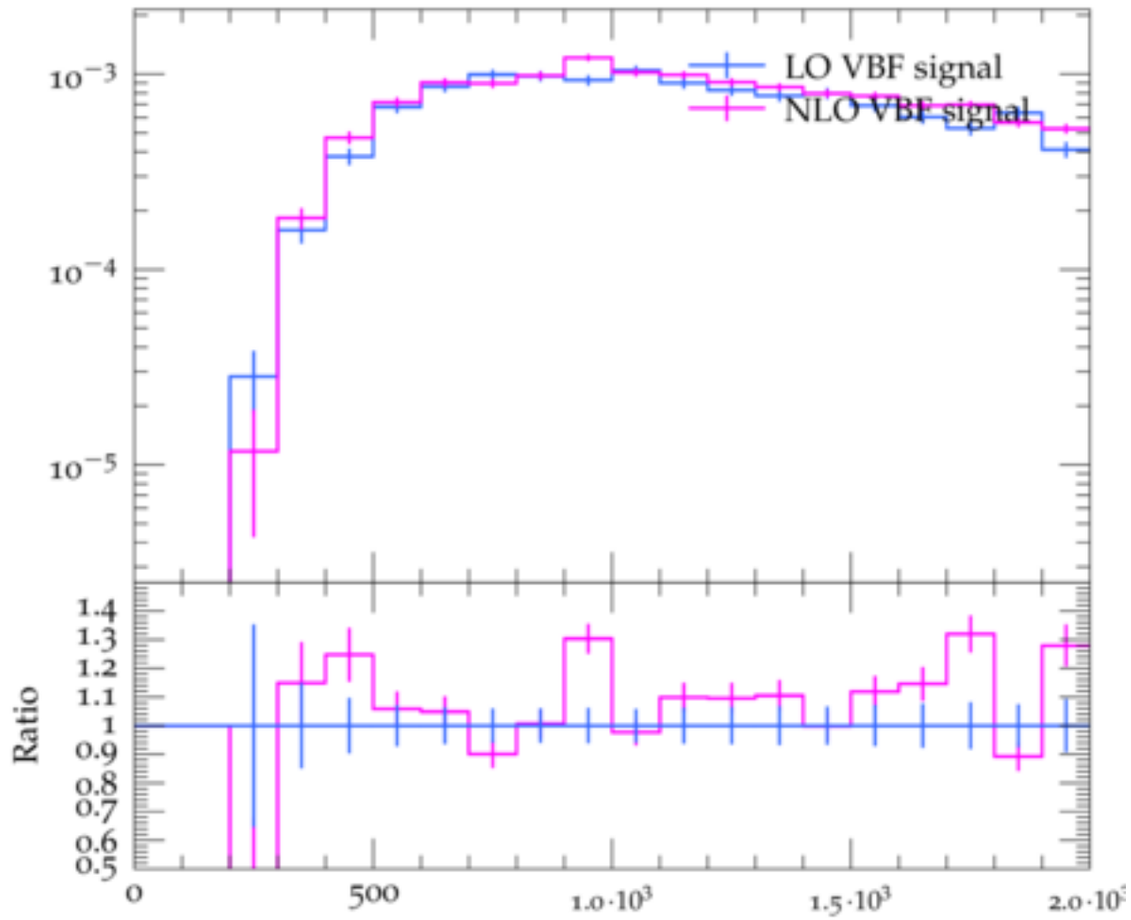
$\Delta\eta_{jj}$



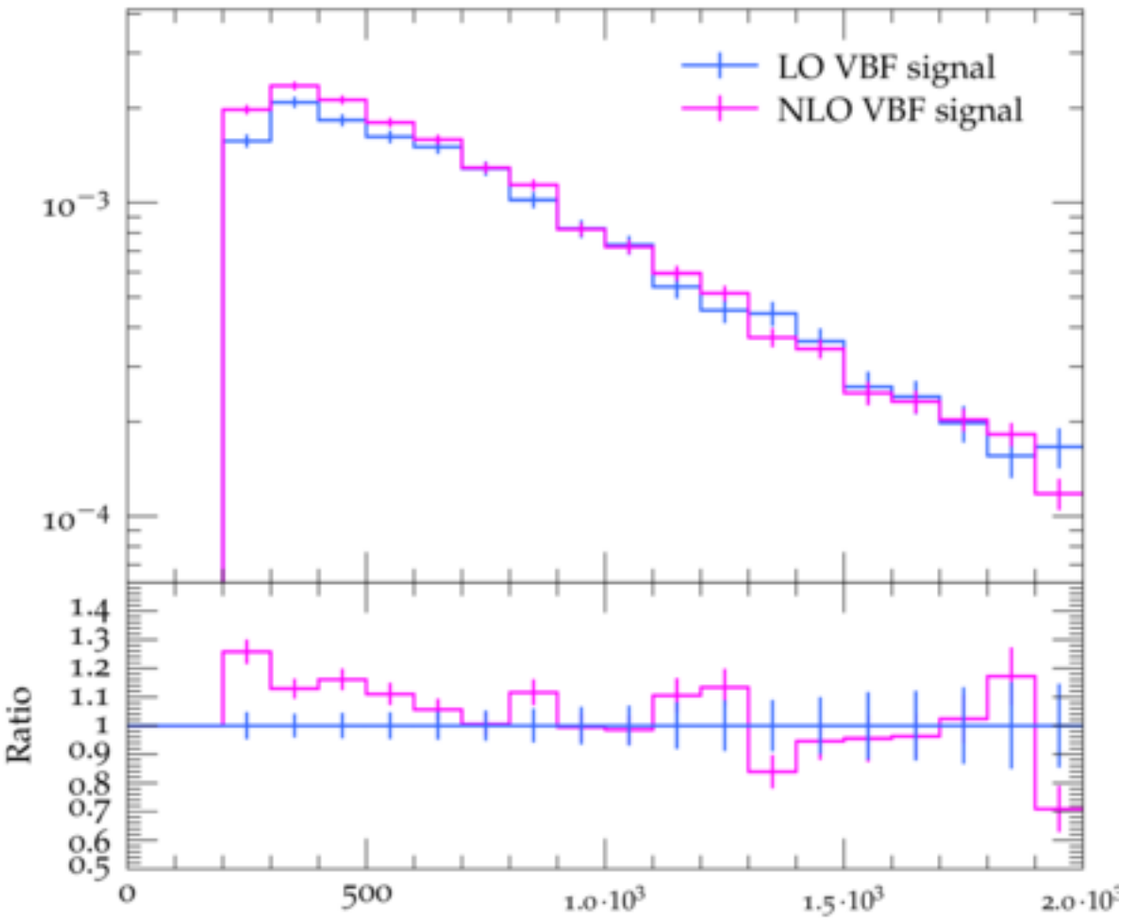
m_{jj}[GeV]

VBF signal region

- VBF-enriched region with at least two jets and $\Delta\eta_{jj} > 4$
- Nice agreement in m_{jj} distribution
- Small difference in low $m_{4\ell}$ region



m_{jj}[GeV]



$m_{4\ell}$[GeV]

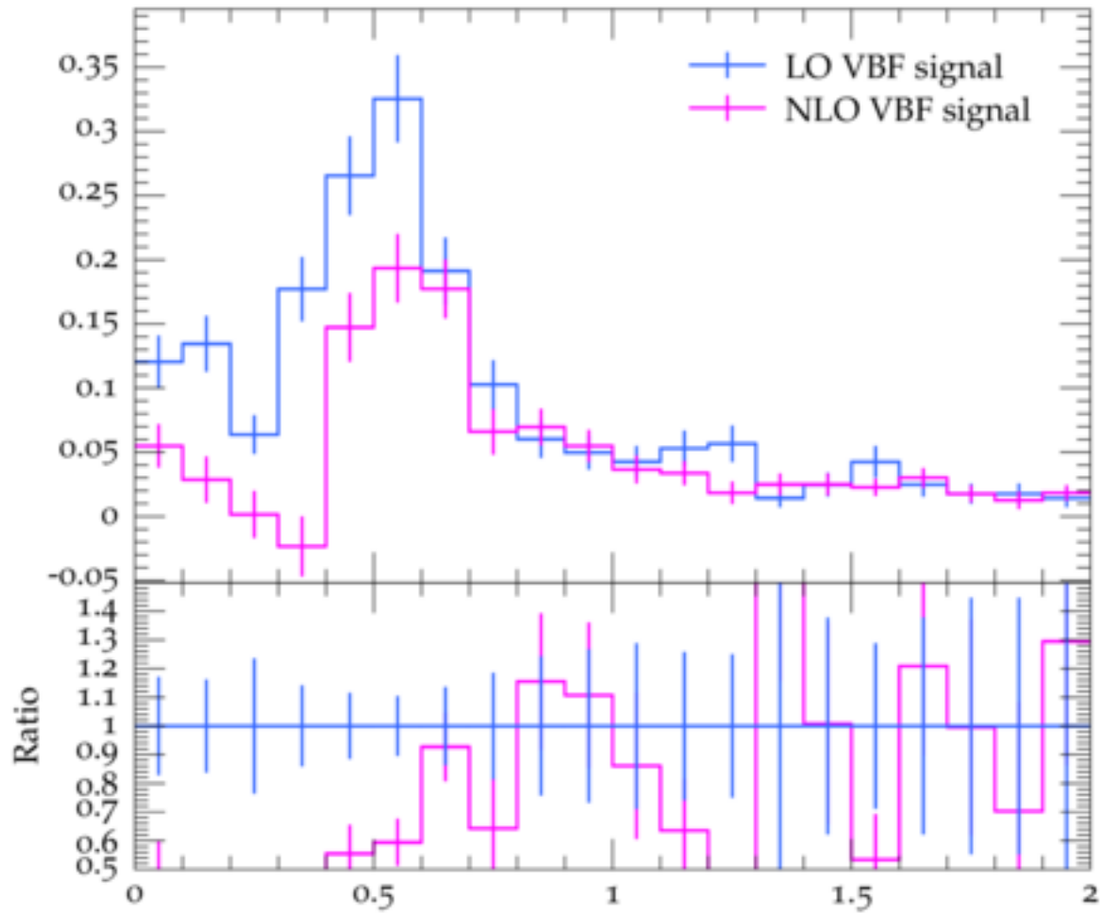
Region with more than 3 jets

- Dipole shower corrects for the default Pythia8 settings which produce too much radiation in the central region of rapidity for VBS processes

- Zeppenfeld variable for the third jes sensitive to the rapidity distribution of additional radiation

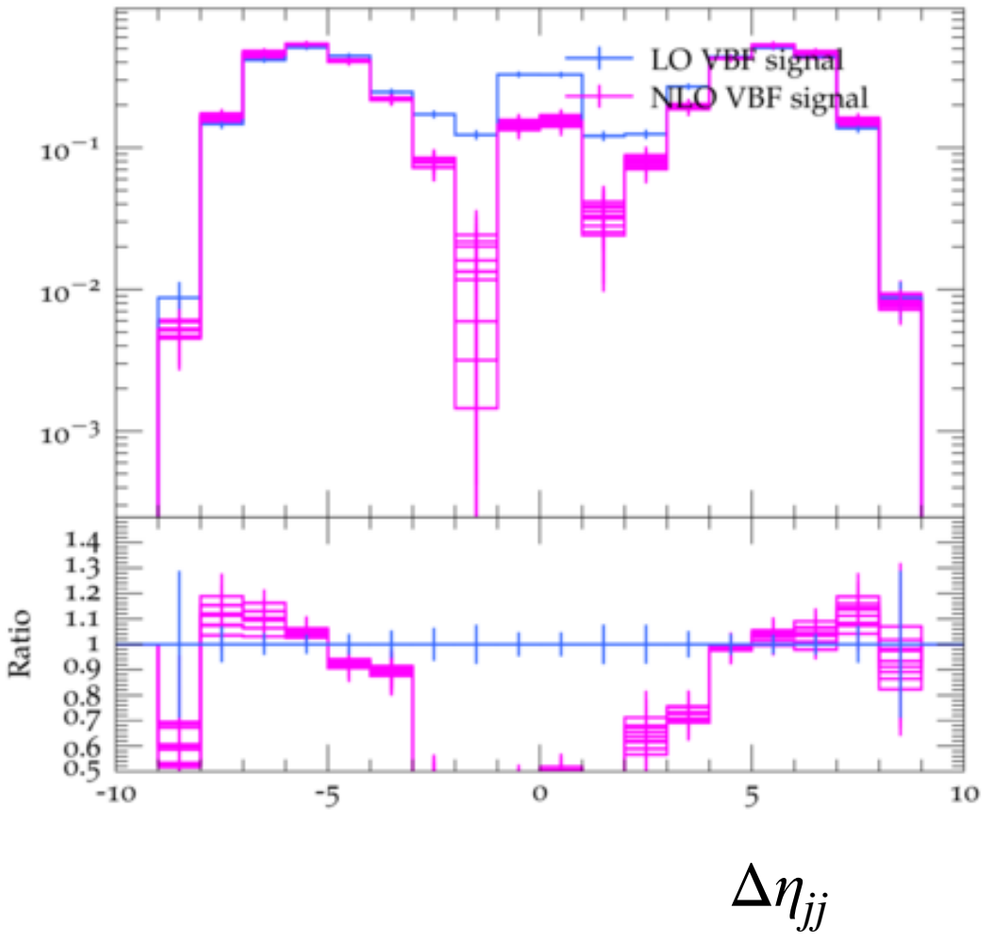
$$z_3 = \frac{\eta_{\text{jet3}} - 0.5(\eta_{\text{jet1}} + \eta_{\text{jet2}})}{|\eta_{\text{jet1}} - \eta_{\text{jet2}}|}$$

  - small values: the third jet is central
  - large values: the third jet is found at large rapidity



z_3

What about theoretical systematic uncertainties?



- NLO events have been generated with renormalisation and factorisation scale variations
- Working on adding PDF uncertainties
- NB: Plot done with the previous syntax (generate p p > h > j j e+ e- mu+ mu- QCD=0 QED=6)

- QCD scale variations cover differences in the VBF region

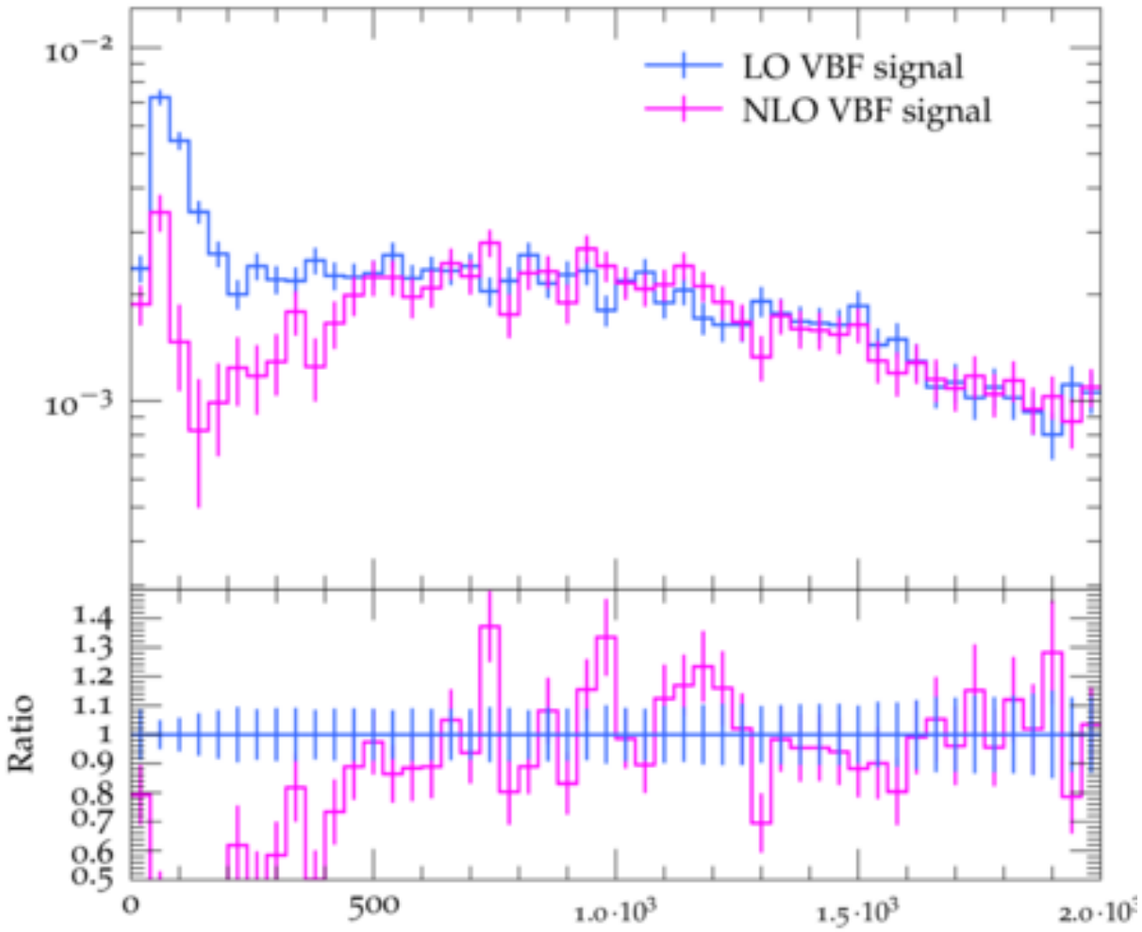
Conclusions & Topics for discussion

- Small difference in the VBF region
- Difference is more significant in the ggF region
  - Will be checked with Herwig shower
- Do we need HO corrections?
  - Should we generate the full process ourselves?
    - Would pure QCD NLO corrections be relevant?
  - May the authors of the paper https://arxiv.org/pdf/2009.00411.pdf provide QCD and EW corrections?
    - In our region of the phase space
    - For all the samples that we need

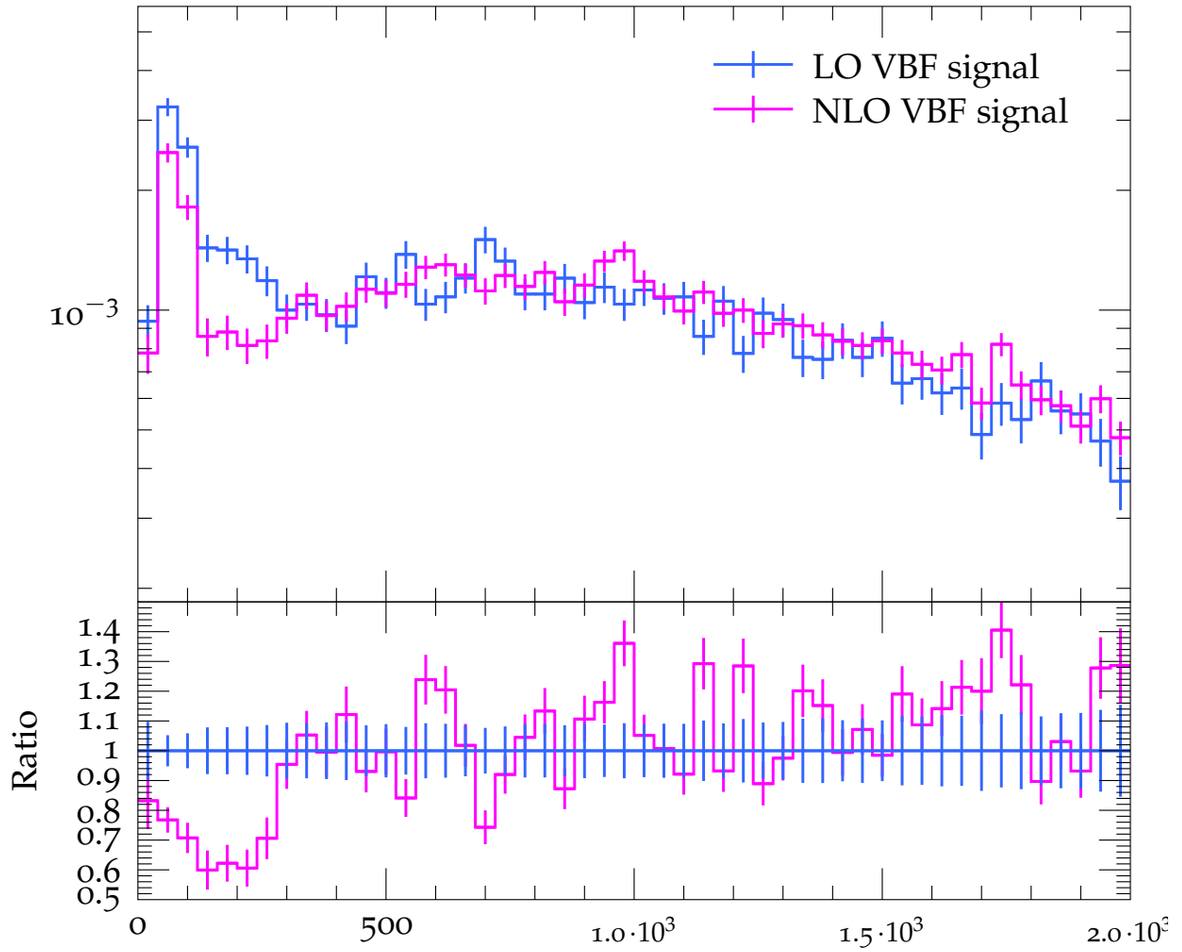
Backup

Comparing the effect of using different syntax

- p p > h > j j e+ e- mu+ mu- QCD=0 QED=6 [QCD] (left)
- p p > v h > j j e+ e- mu+ mu- QCD=0 QED=6 [QCD] (right)



m_{jj}[GeV]



m_{jj}[GeV]

Region with more than 3 jets

- https://cds.cern.ch/record/2655303/files/ATL-PHYS-PUB-2019-004.pdf