NLO Merging using HJets

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Overview

Simulation Tools and Matrix Elements

Herwig 7 https://herwig.hepforge.org

- General purpose event generator
- Parton showers, hadronization, MPI modeling
- NLO Merging

HJets++ https://hjets.hepforge.org

- Add-on module to Herwig 7
- Full calculation for electroweak Higgs boson plus jets production

VBFNLO https://www.itp.kit.edu/vbfnlo

- Interfaced to Herwig 7
- VBF approximation

Example Herwig 7 Input File

```
# -*- ThePEG-repository -*-

##################################################
## Herwig/Merging example input file
##################################################

##################################################
## Collider type
##################################################

read snippets/DipoleMerging.in
read snippets/PPCollider.in
read snippets/MonacoSampler.in

##################################################
## Beam energy sqrt(s)
##################################################

cd /Herwig/EventHandlers
set EventHandler:LuminosityFunction:Energy 13000*GeV
set EventHandler:Weighted On

##################################################
## Process selection
##################################################

## Note that event generation may fail if no matching matrix element has
## been found.  Coupling orders are with respect to the Born process,
## i.e. NLO QCD does not require an additional power of alphas.
```

```
## Select the process
## You may use identifiers such as p, pbar, j, l, mu+, h0 etc.

do MergingFactory:Process p p -> h0 j j [ j j ]

set MergingFactory:NLOProcesses 2

read Chunk-settings.in

#set MergingFactory:Chunk 10
#set MergingFactory:ChunkPart 1
#
# Set the merging scale deviding the parton shower
# from the matrix element region in phase space.
set Merger:MergingScale 25.*GeV
set Merger:MergingScaleSmearing 0.1


# The following line clear a preweighter
# that is not working for Higgs as here
# pt and HT are 0 before the shower.
# See other merging files for more information.
clear MergingFactory:Preweighters

# The next line can switch of hadronization
# and MPI modelling. Use with care!!
read Matchbox/PQCDLevel.in
```

Example Herwig 7 Input File

```
#read Matchbox/VBFDiagramsOnly.in

##################################################
## Matrix element library selection
##################################################

## Select a generic tree/loop combination or a
## specialized NLO package

# read Matchbox/MadGraph-GoSam.in
# read Matchbox/MadGraph-MadGraph.in
# read Matchbox/MadGraph-NJet.in
# read Matchbox/MadGraph-OpenLoops.in
read HJets.in
#read Matchbox/VBFNLO.in

## Uncomment this to use ggh effective couplings
## currently only supported by MadGraph-GoSam and
## MadGraph-Openloops

#read Matchbox/HiggsEffective.in
cd /Herwig/MatrixElements/Matchbox/Amplitudes
#set OpenLoops:HiggsEff Yes
#set MadGraph:Model heft

##################################################
## Cut selection
## See the documentation for more options
##################################################
```

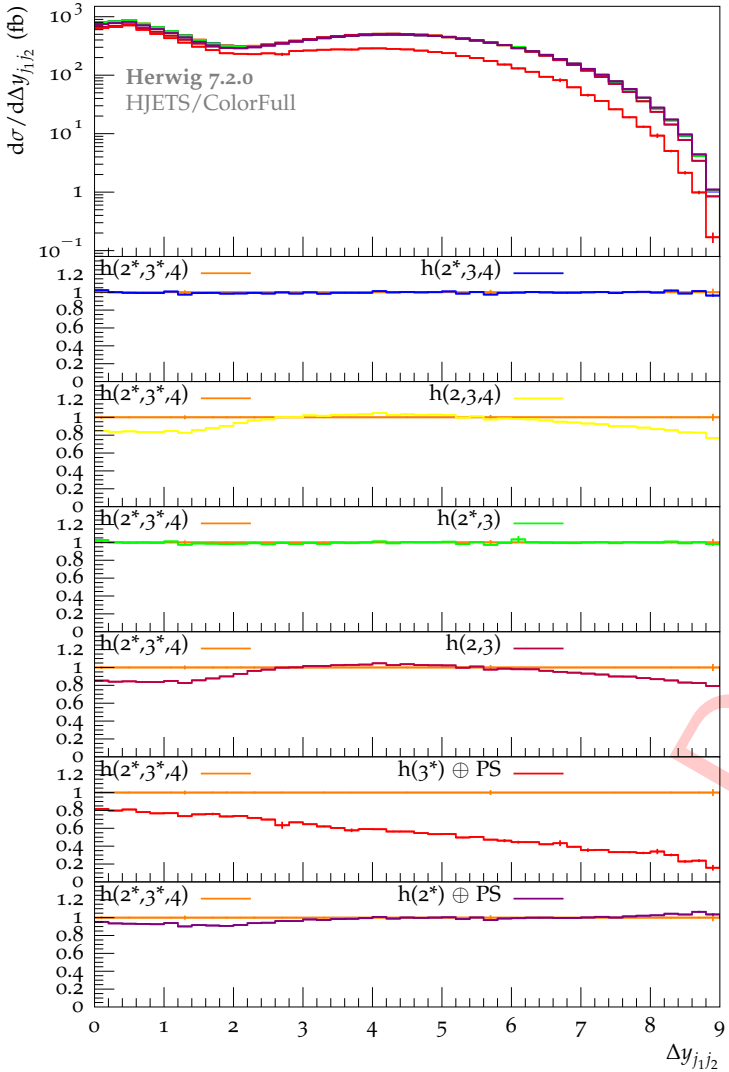
```
##################################################
## Analyses
##################################################

cd /Herwig/Analysis
## Write HepMC events. Modify the PrintEvent interface for your needs.
# insert /Herwig/Generators/EventGenerator:AnalysisHandlers 0 HepMCFile

## Setup the Rivet analysis:
read snippets/Rivet.in
insert Rivet:Analyses 0 MC_H2JETS_04_INC
insert Rivet:Analyses 1 MC_H2JETS_04_TIGHT
insert Rivet:Analyses 2 MC_H2JETS_04_LOOSE
insert Rivet:Analyses 3 MC_H_KTSPLITTINGS
insert Rivet:Analyses 4 MC_H2JETS_07_INC
insert Rivet:Analyses 5 MC_H2JETS_07_TIGHT
insert Rivet:Analyses 6 MC_H2JETS_07_LOOSE

#insert Rivet:Analyses 4 MC_VBFH_LHCHXSWG
## Here we collected a various Rivet analysis for Higgs at LHC
## at the 8 TeV. (The collection might not be complete.)
#read Merging/LHC8-H-Analysis.in

read HJets-settings.in

##################################################
## Save the generator
##################################################
```

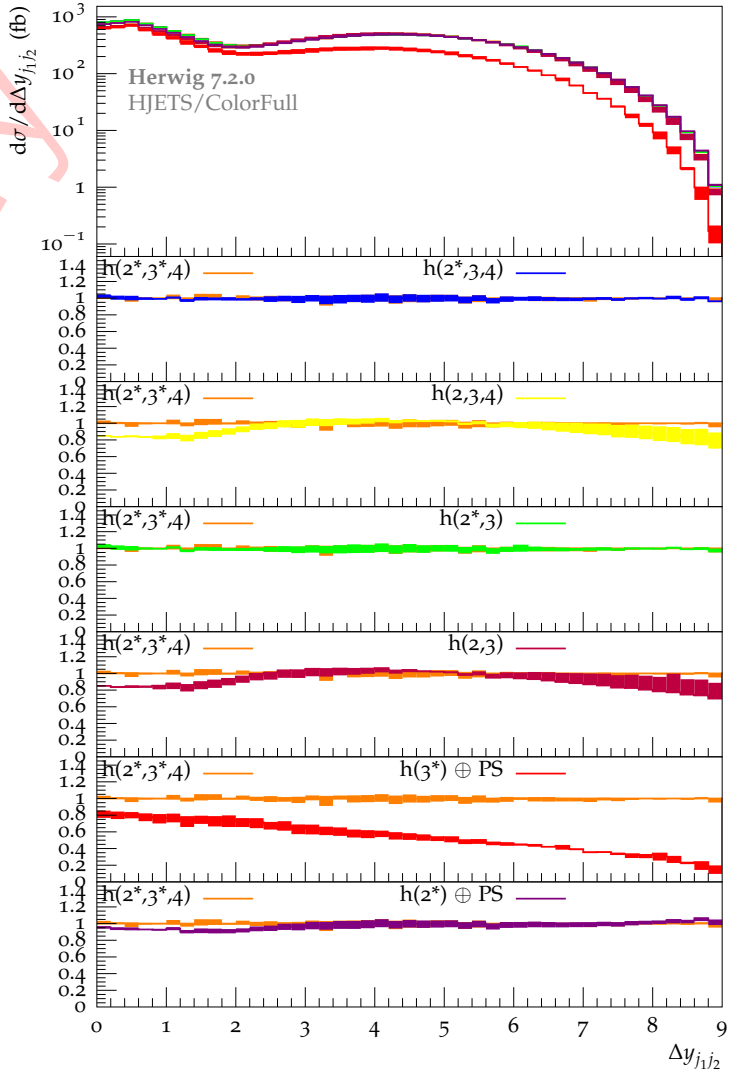
Input Parameters and Event Selection Cuts

- CMS Energy of Collider and Beam Type: pp LHC (13 TeV).
- PDF set (LHAPDF): PDF4LHC15_nnlo_100_pdfas.
- Factorization and renormalization scales set to HT(jets), $\mu_R^2 = \mu_F^2 = (\sum_i p_T^i)^2$
- Anti-k_T Jet clustering (R=0.4) using FastJet, at least two jets with $p_{T,jets} > 25$ GeV.
- Matched results use a MC@NLO type matching. No hadronization or MPI have been included in the simulations.
- The tight selection cuts is defined as

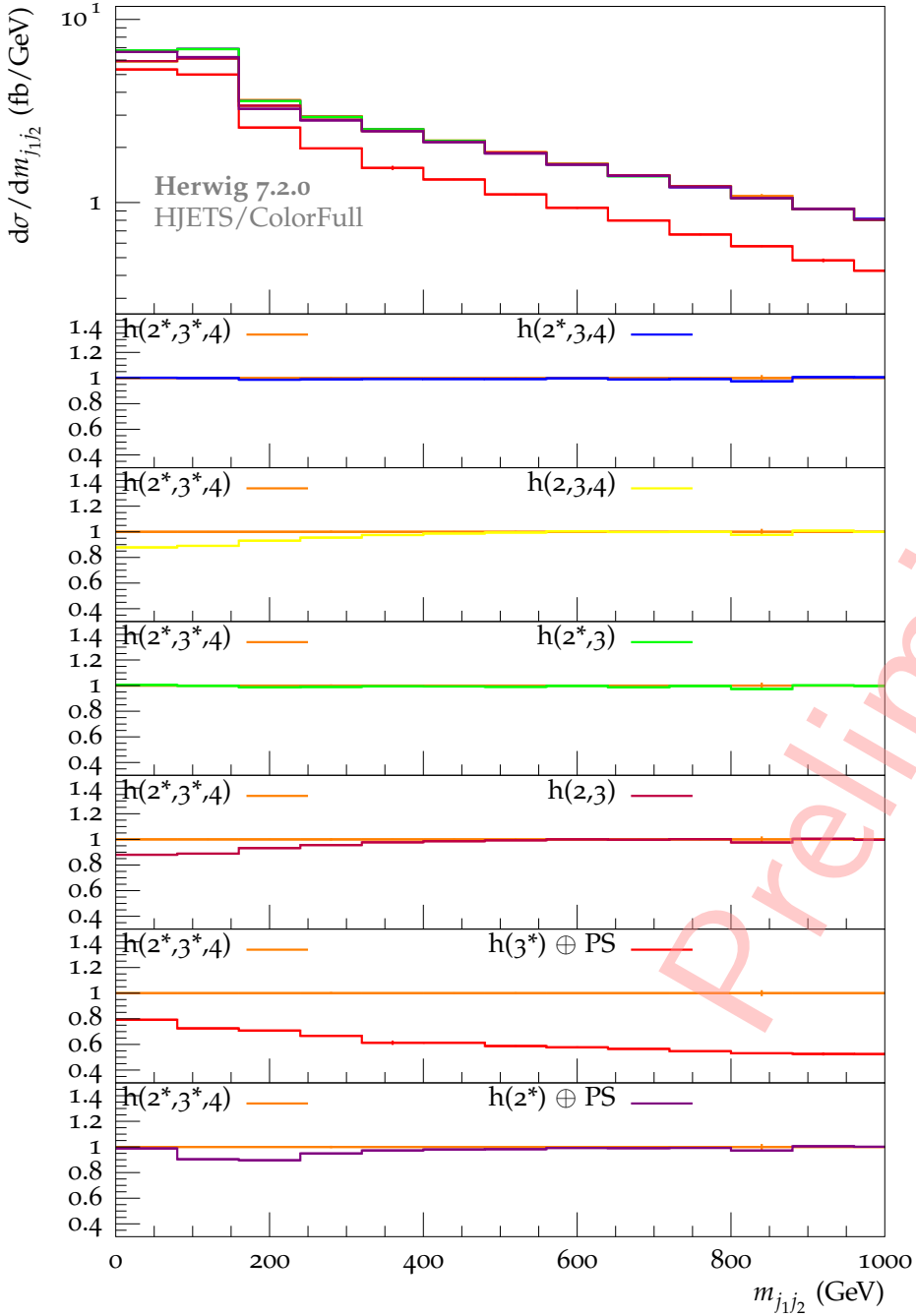
$$m_{j_1 j_2} > 600 \text{ GeV}, \quad \Delta y_{j_1 j_2} > 4.5, \quad y_{j_1} \cdot y_{j_2} < 0. \tag{1}$$

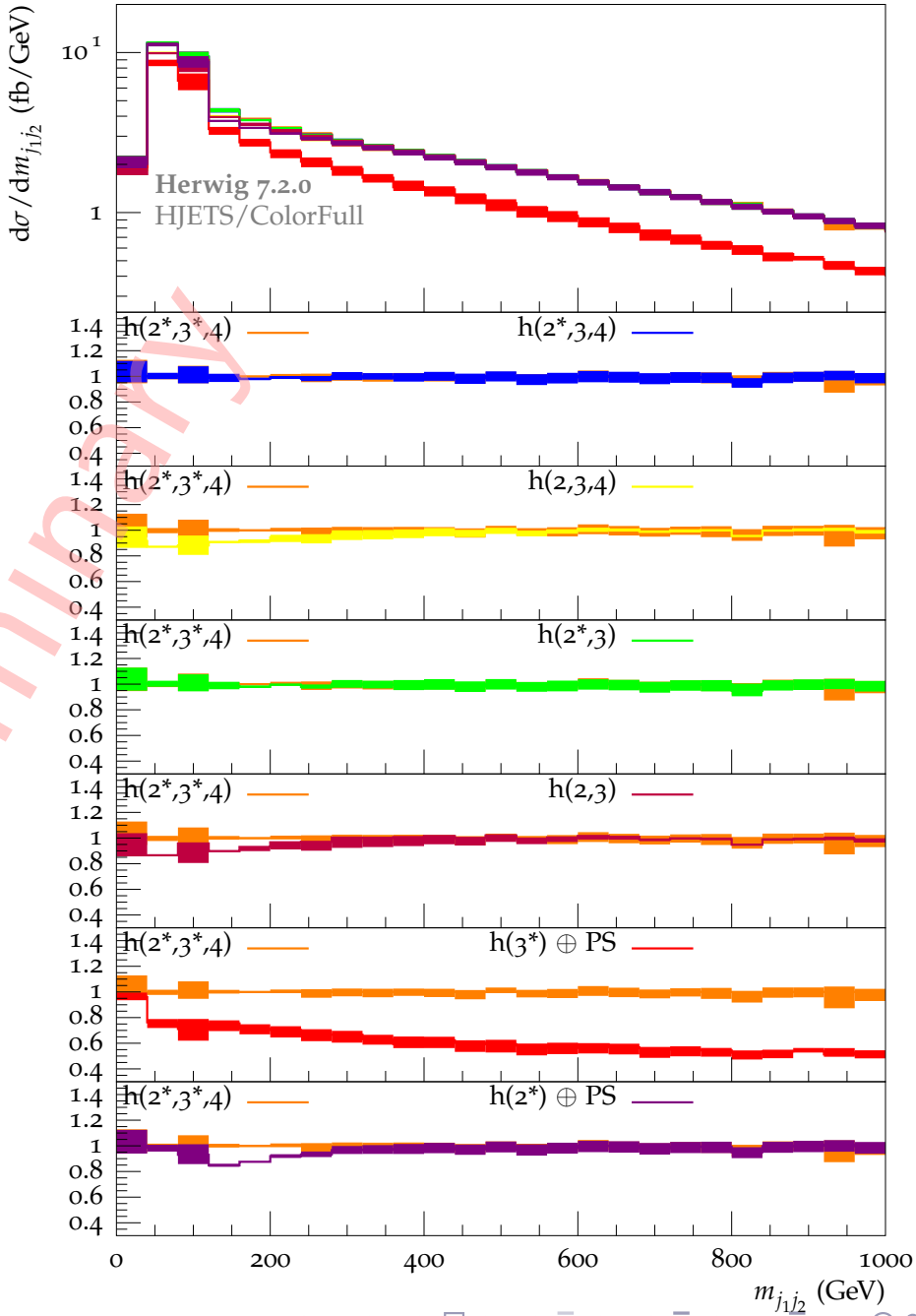
Merged NLO H2j, NLO H3j, LO H4j Results[1]

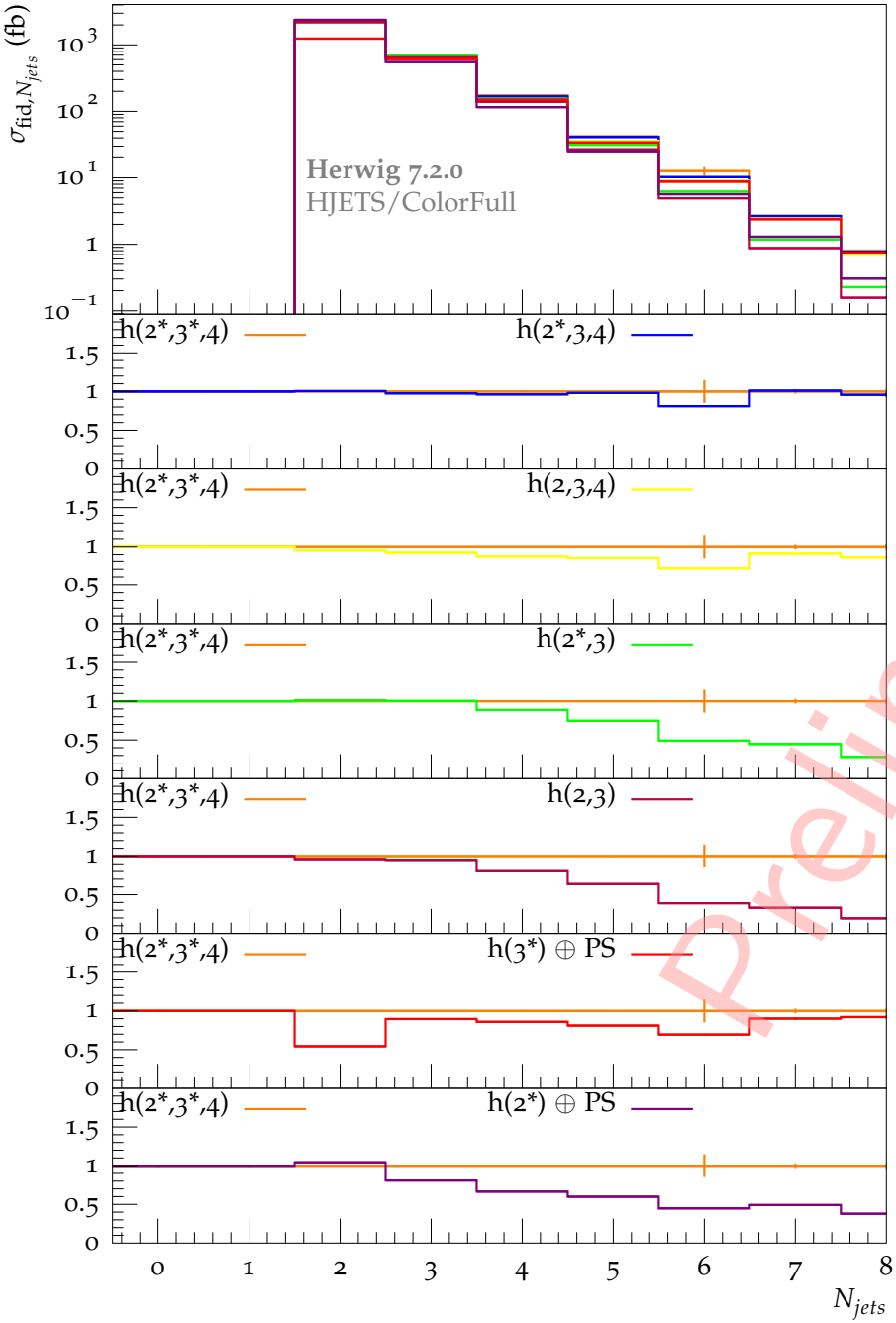


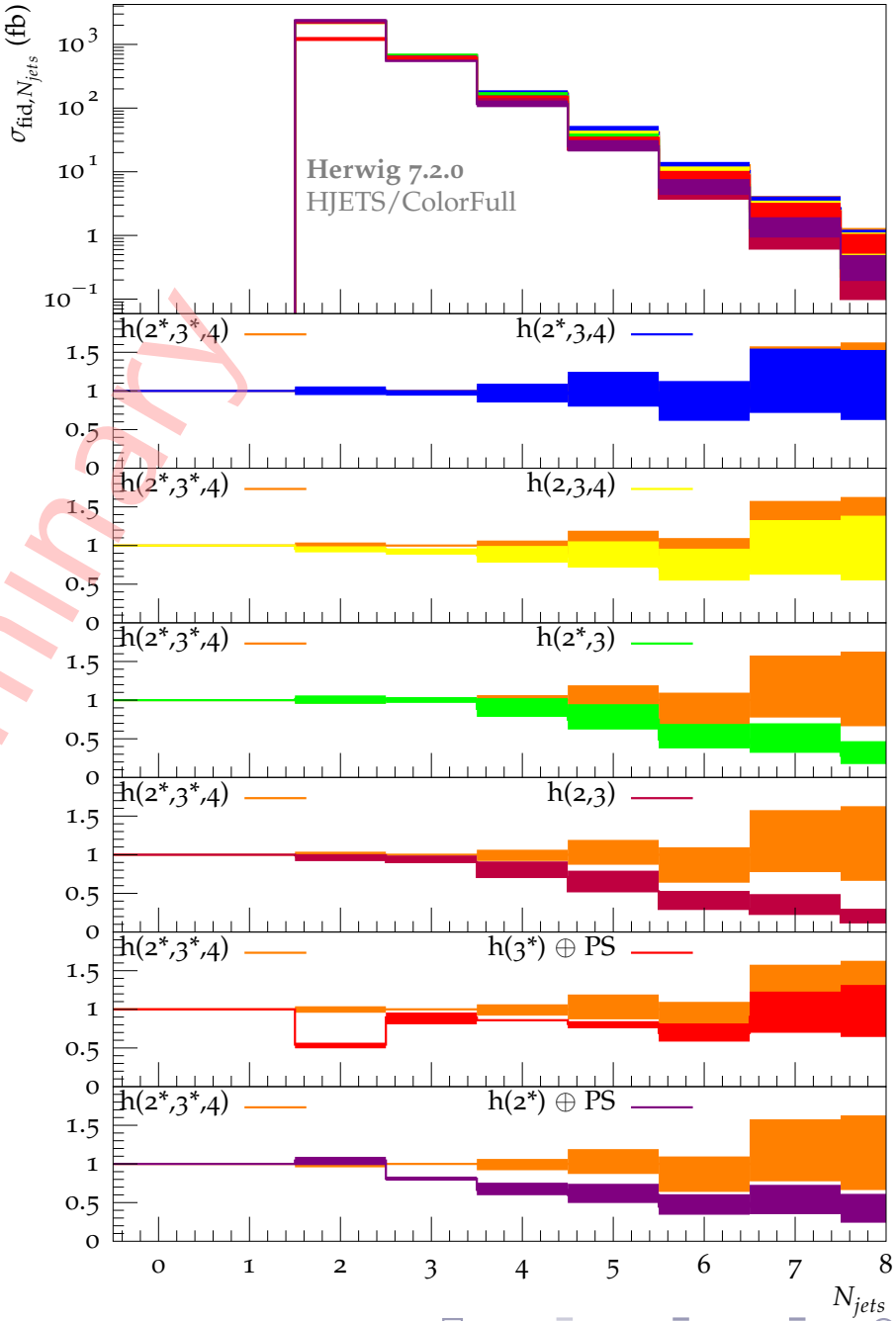


[1] In collaboration with Terrance Figy and Simon Platzer







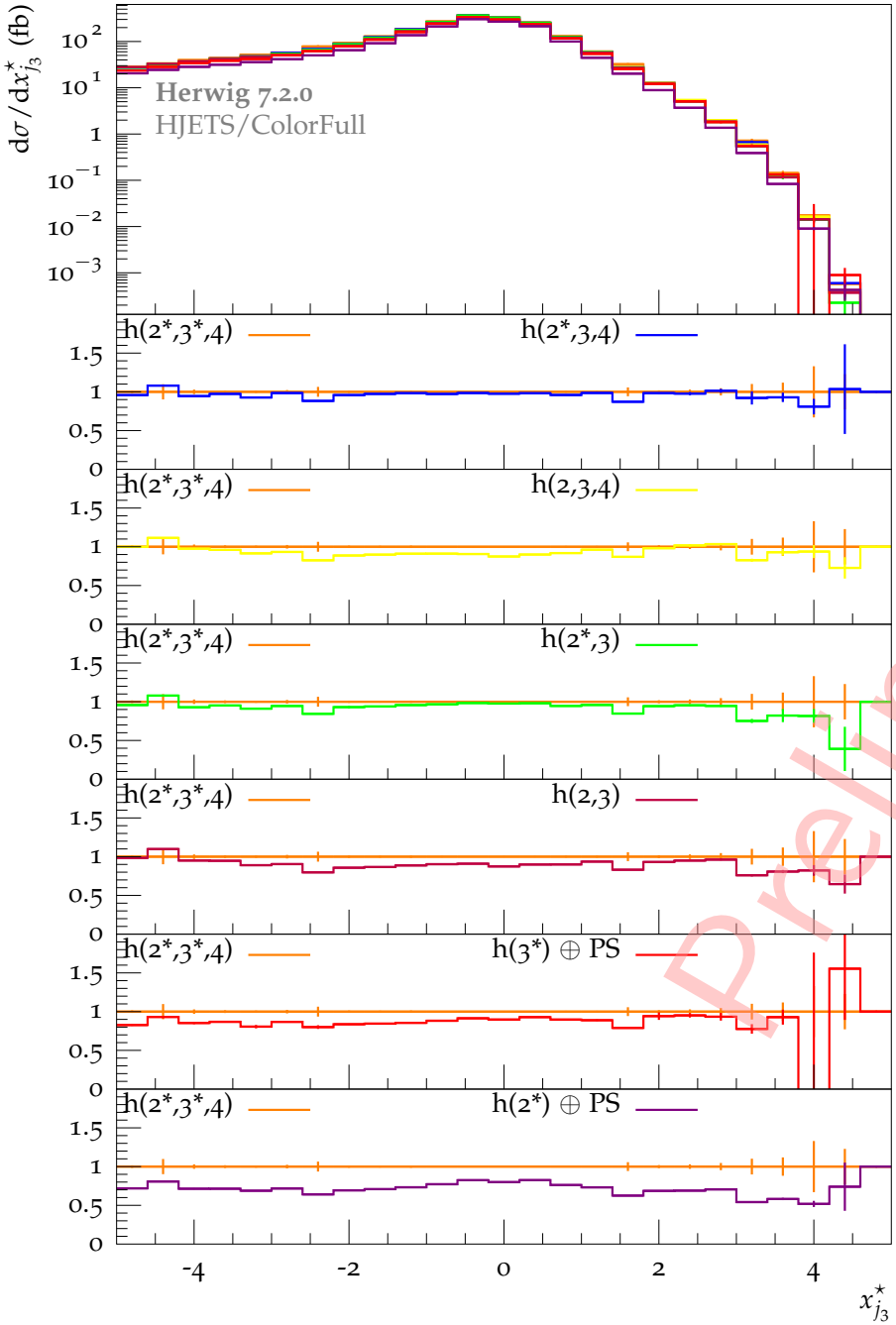


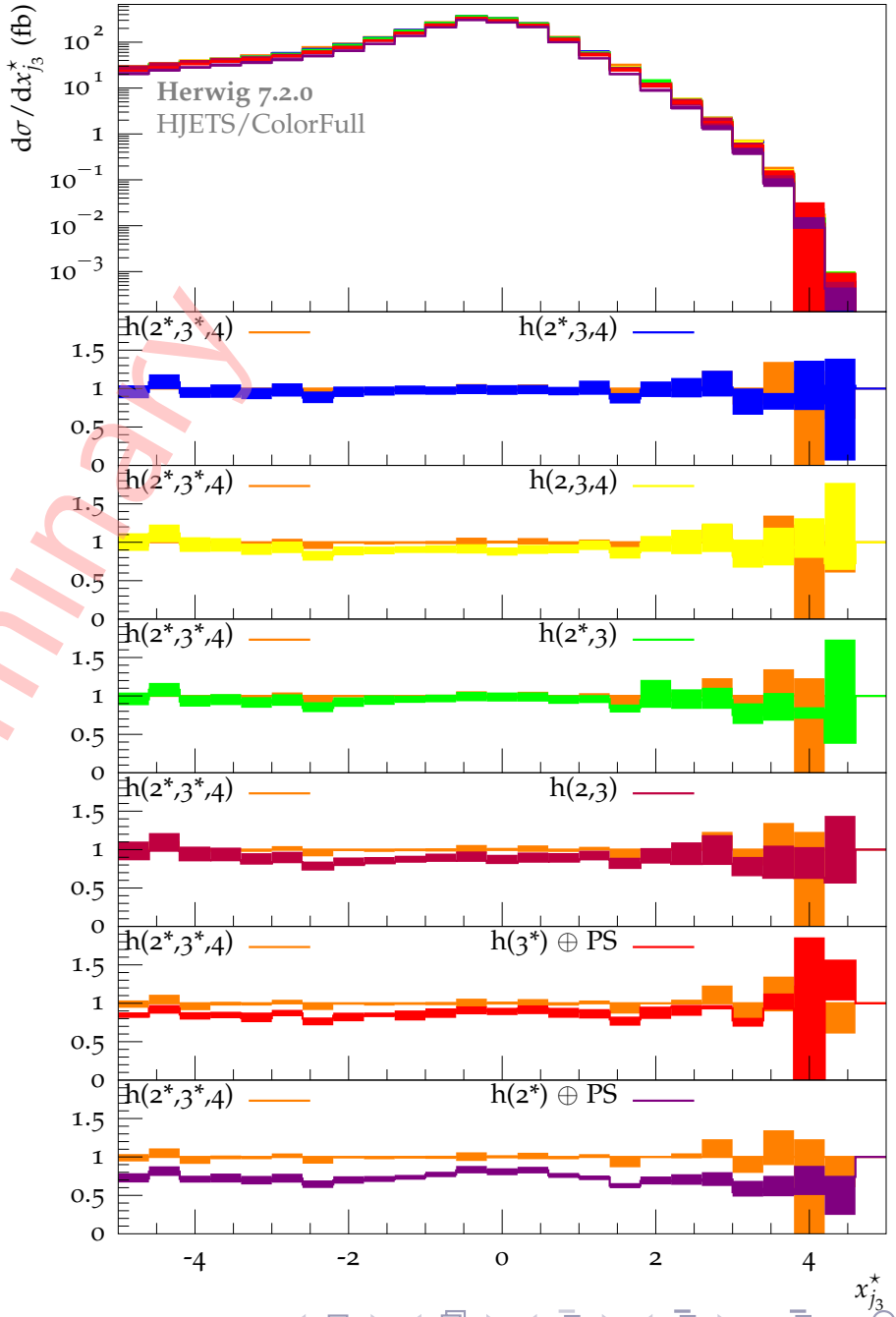
- The Zeppenfeld variable is defined as

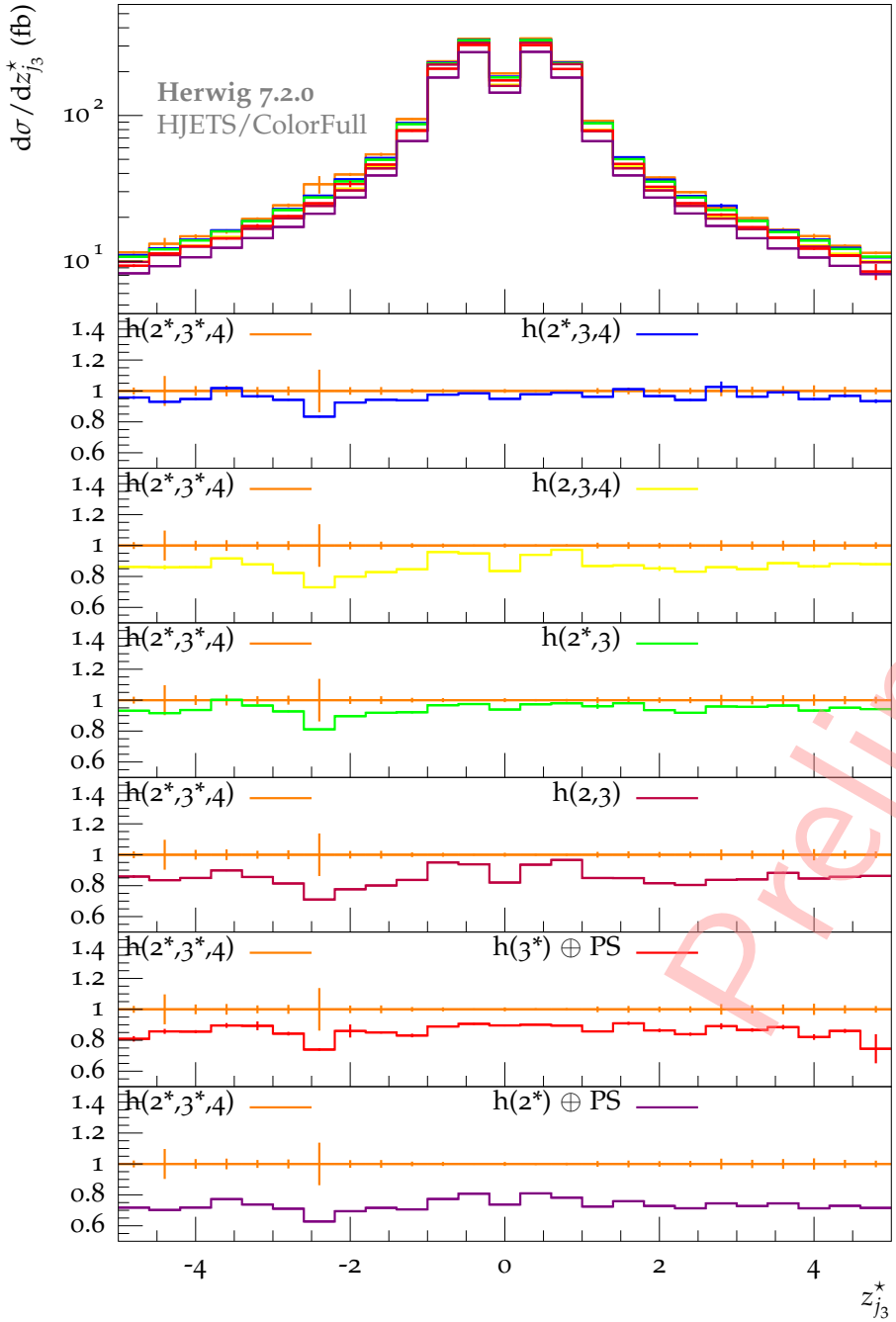
$$z^*_{j_3} = \frac{y_{j_3} - \frac{y_{j_1}+y_{j_2}}{2}}{|\Delta y_{j_1 j_2}|}. \tag{2}$$

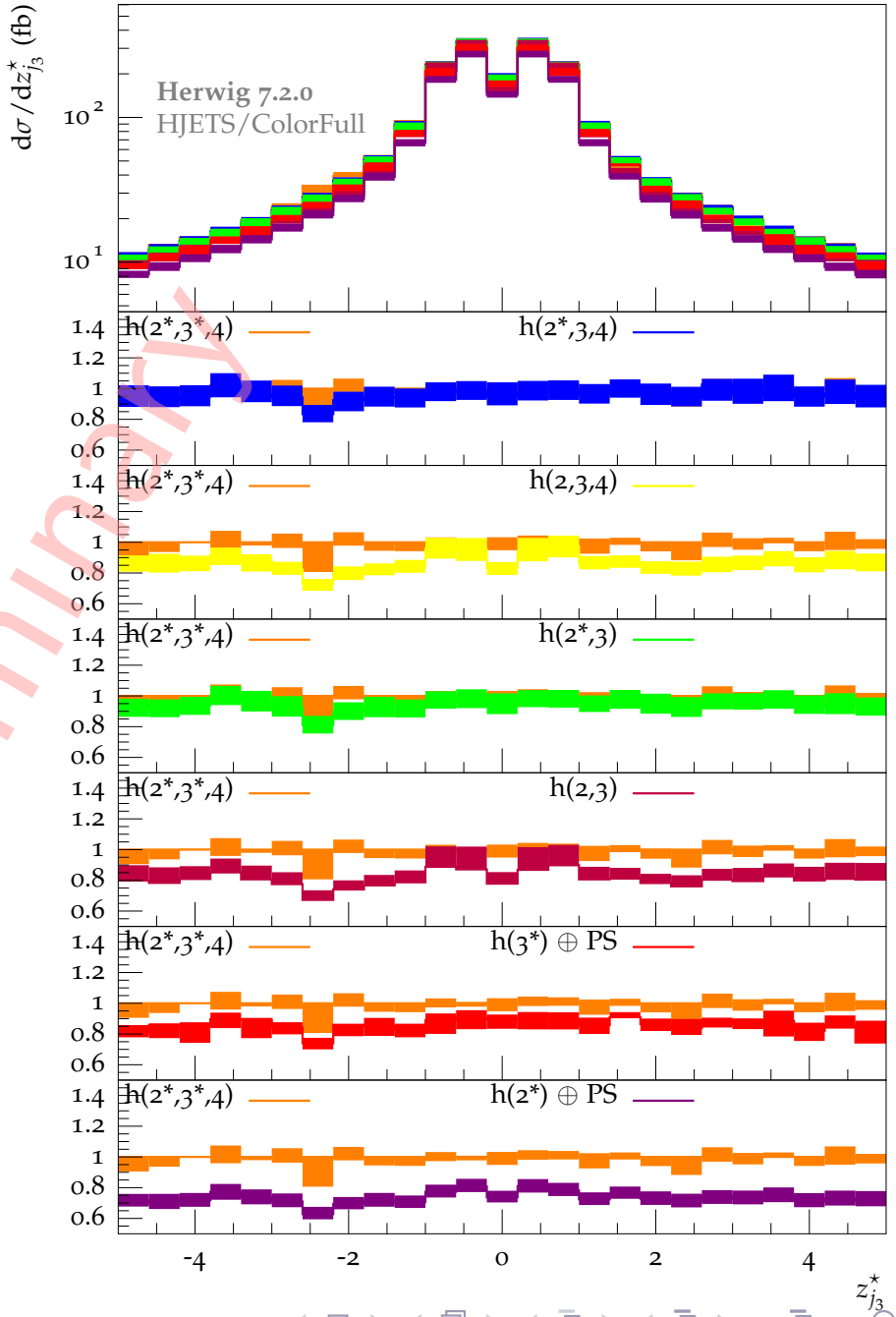
- The minimum rapidity difference of the third jet with respect to the two leading jets is defined as

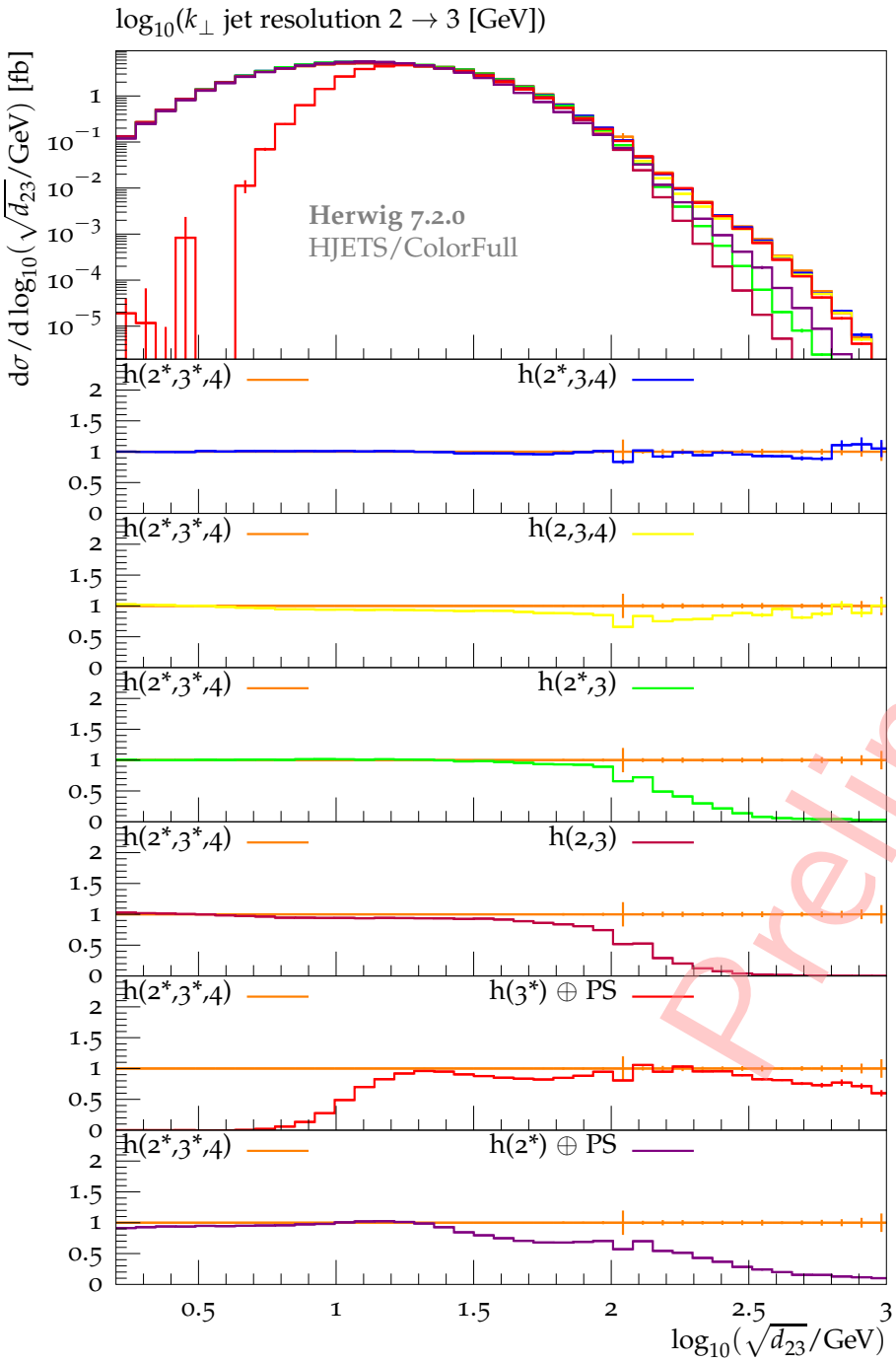
$$x^*_{j_3} = min\{|y_{j_1} - y_{j_3}|, |y_{j_2} - y_{j_3}|\}. \tag{3}$$

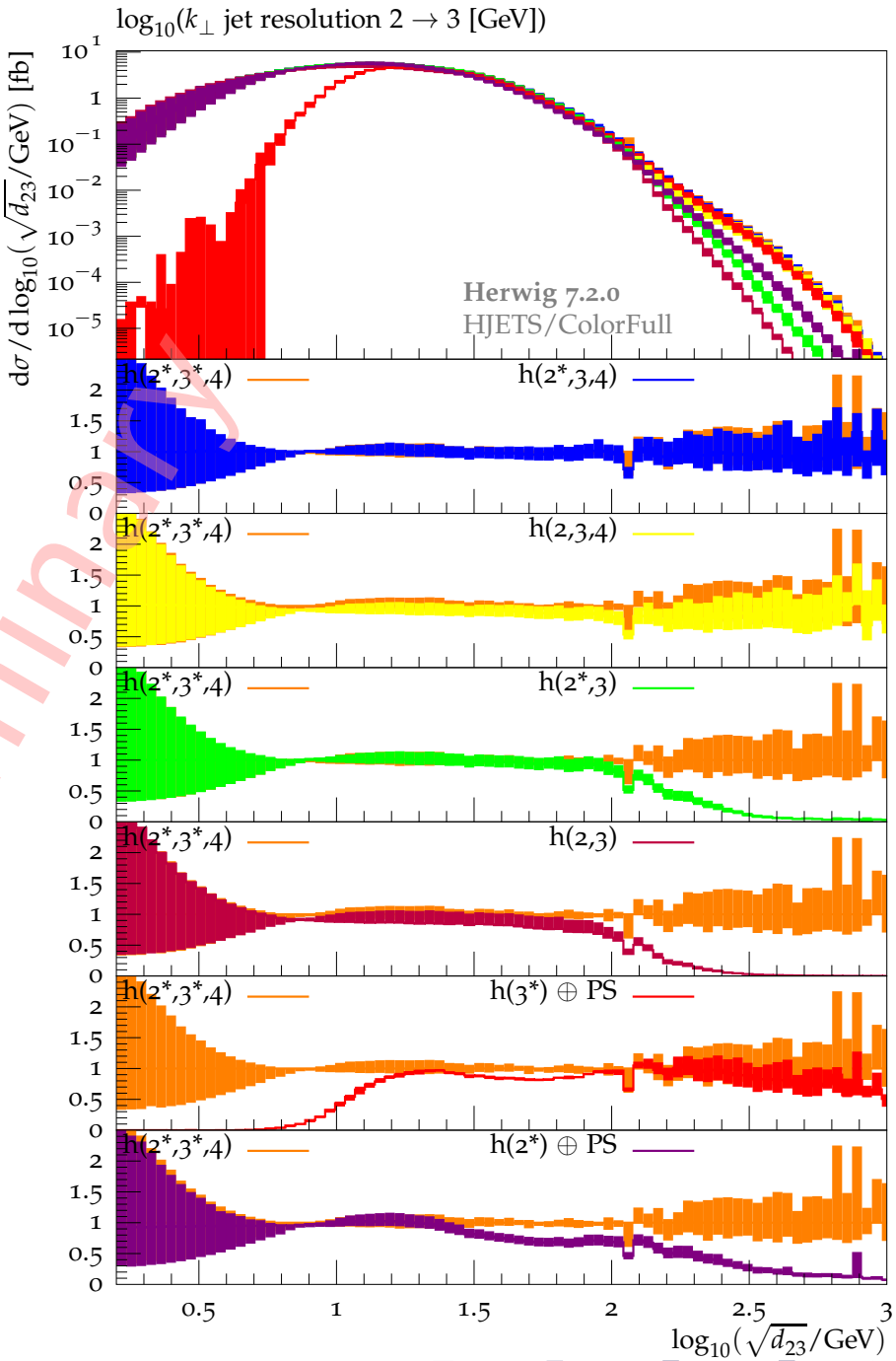


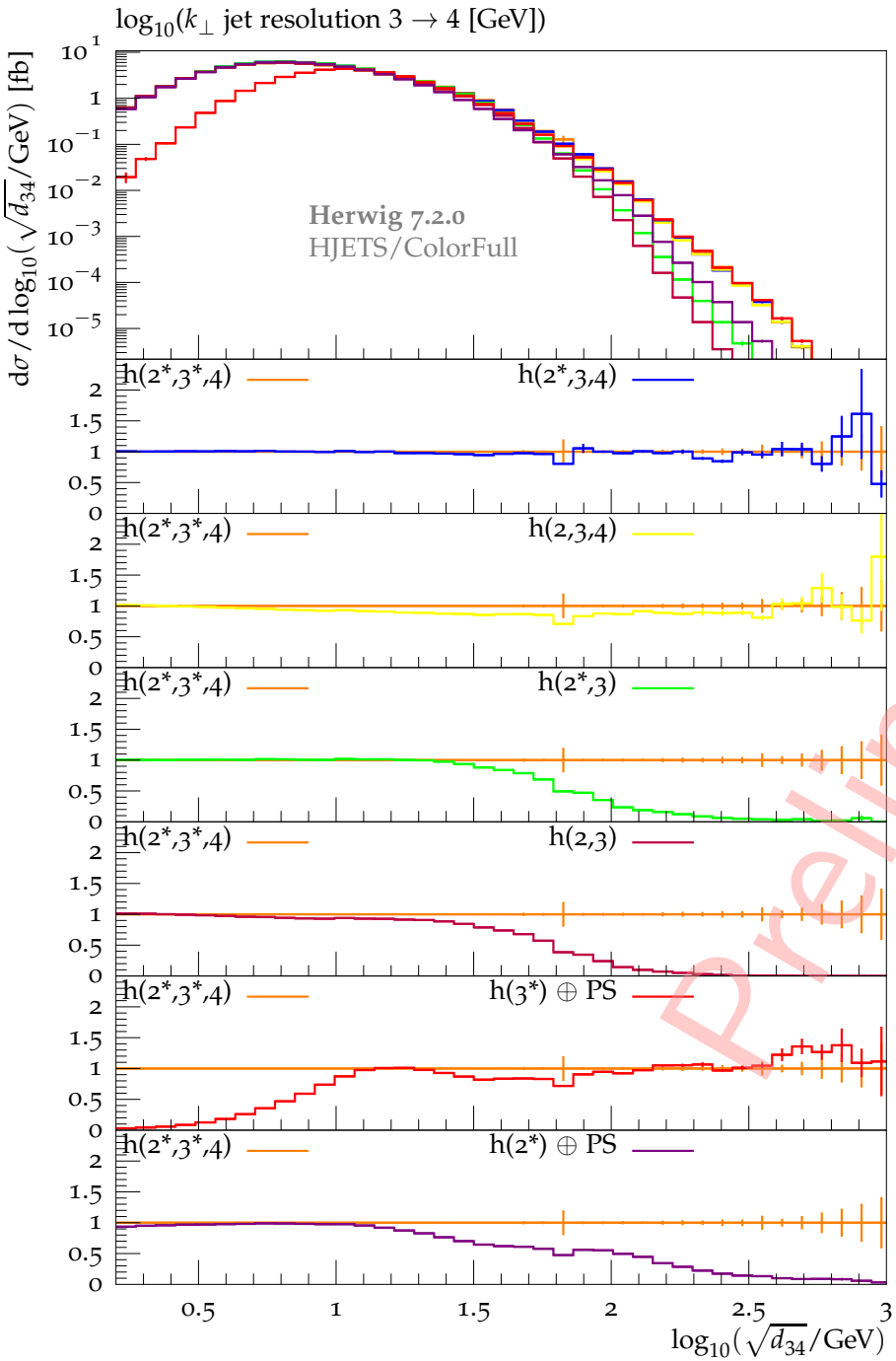


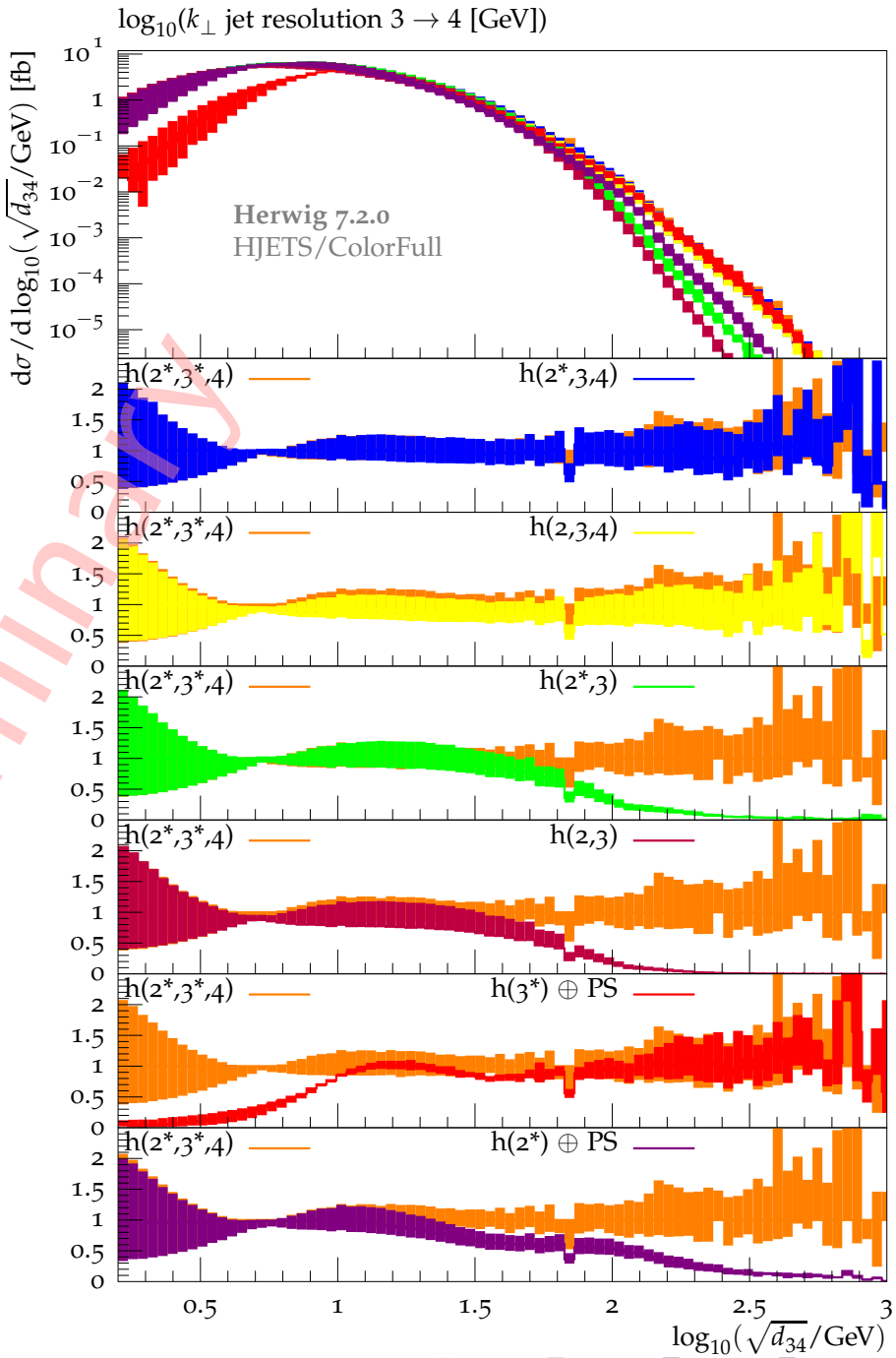




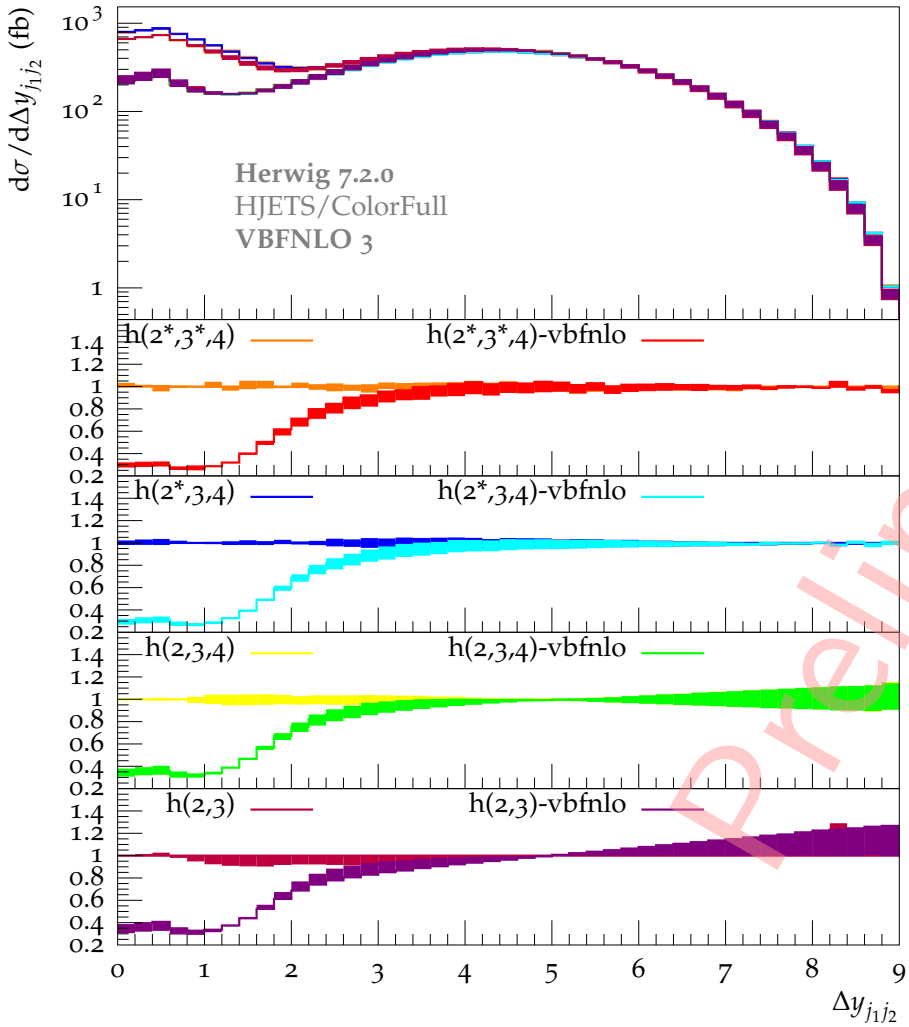


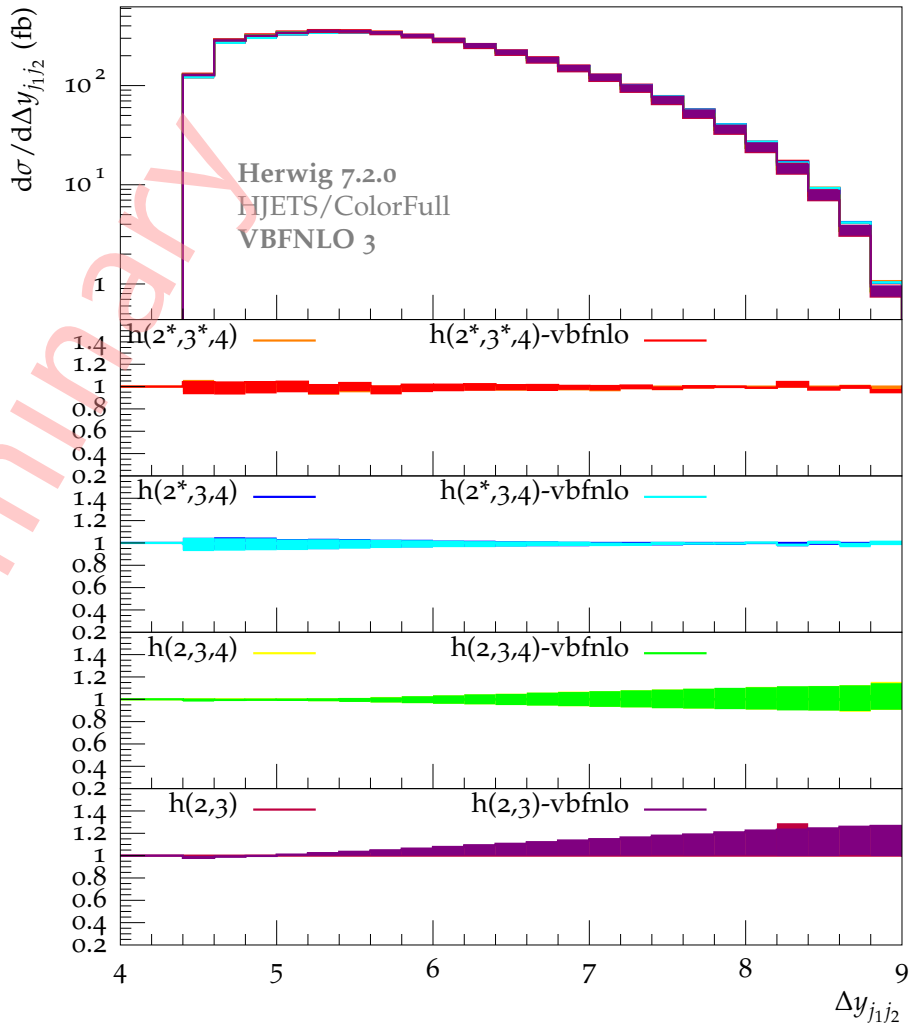




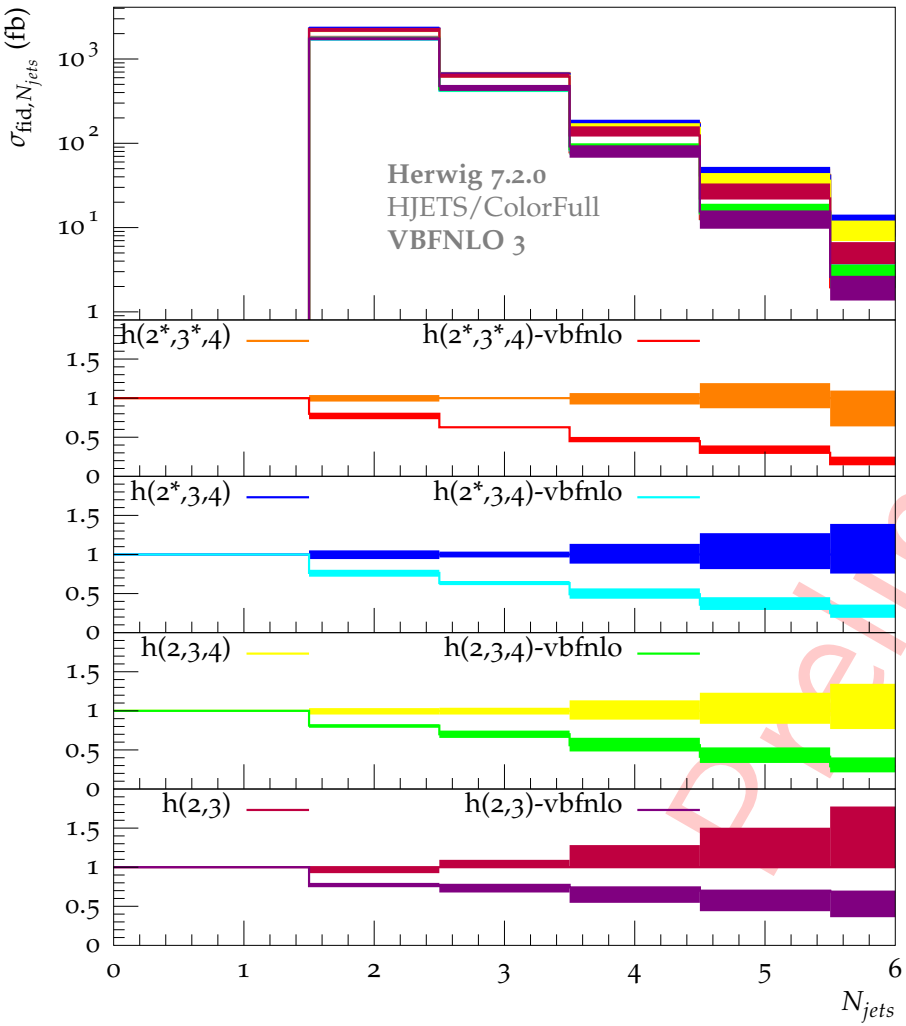


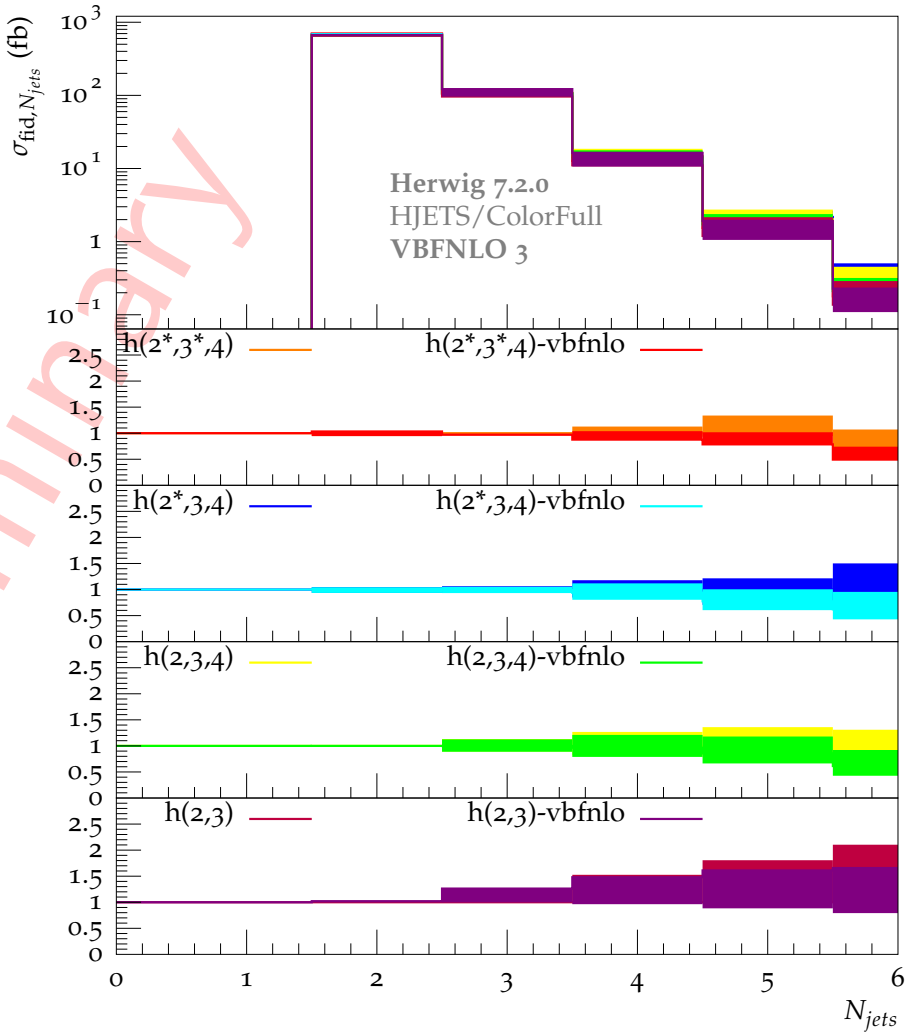
HJets vs.VBFNLO Preliminary Results[2]

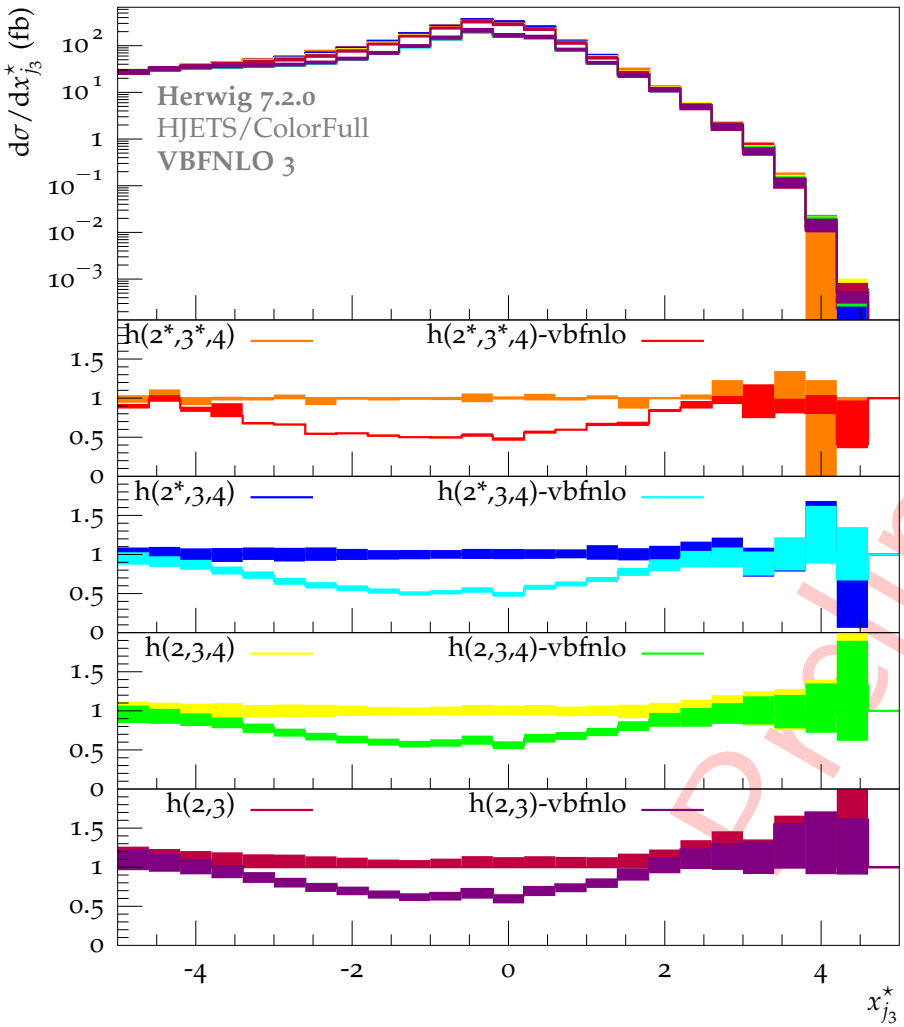


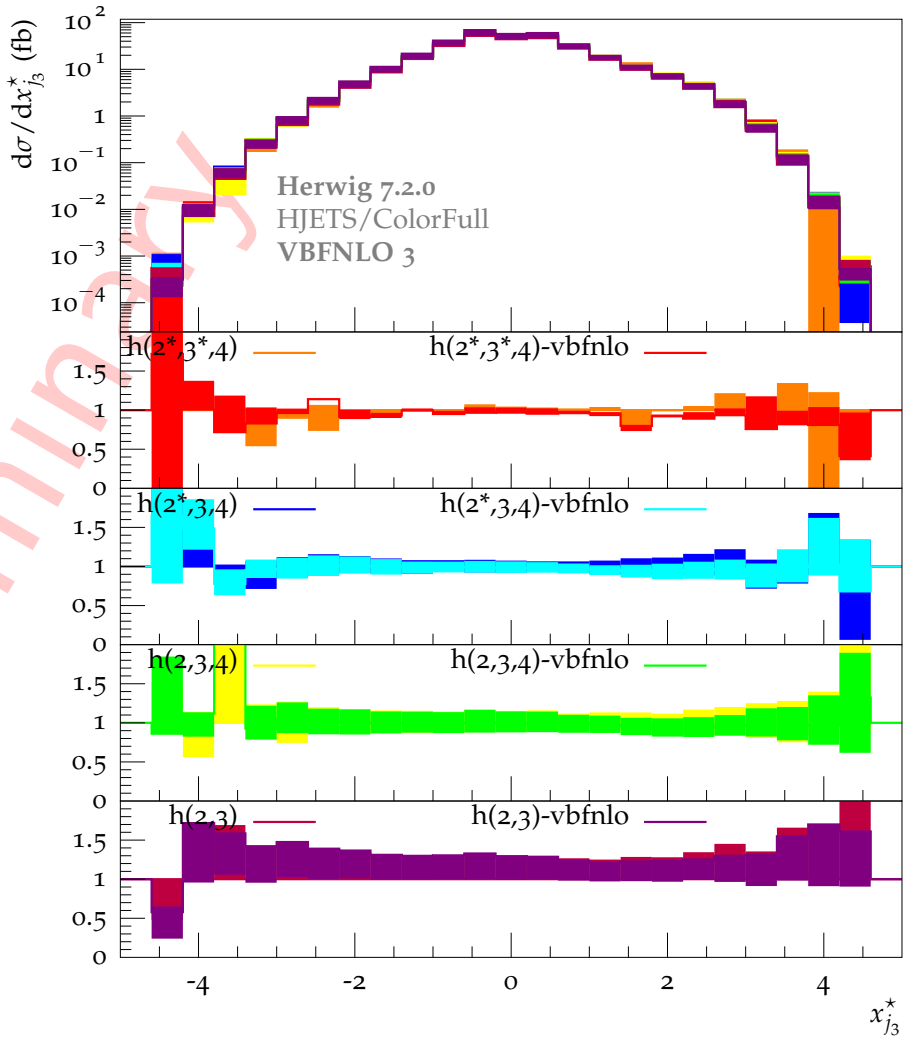


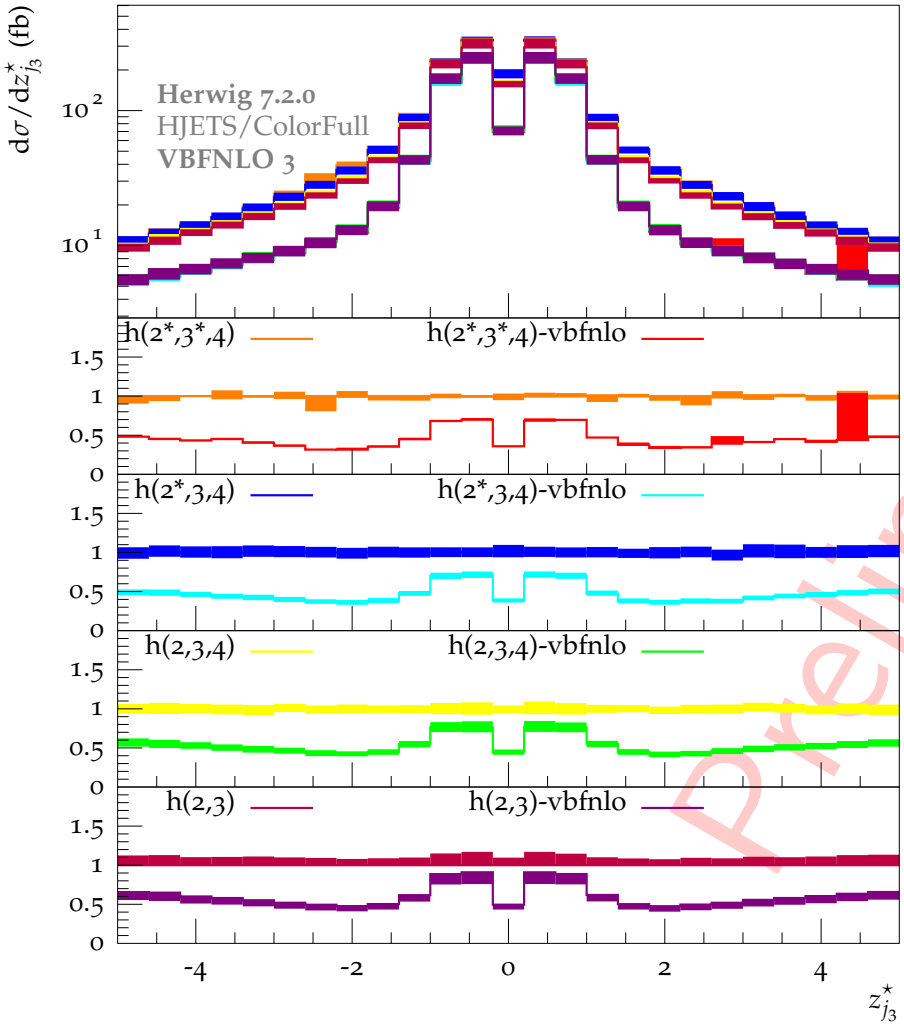
[2] In collaboration with Terrance Figy and Simon Platzer

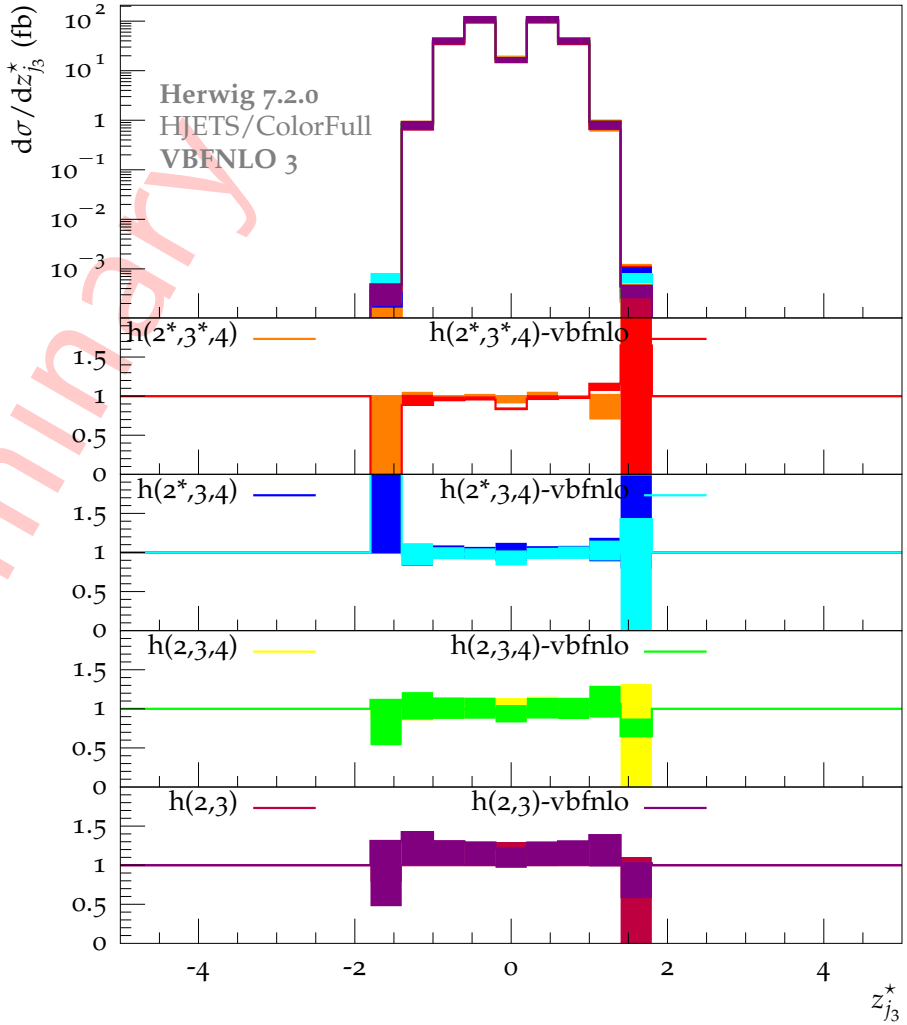


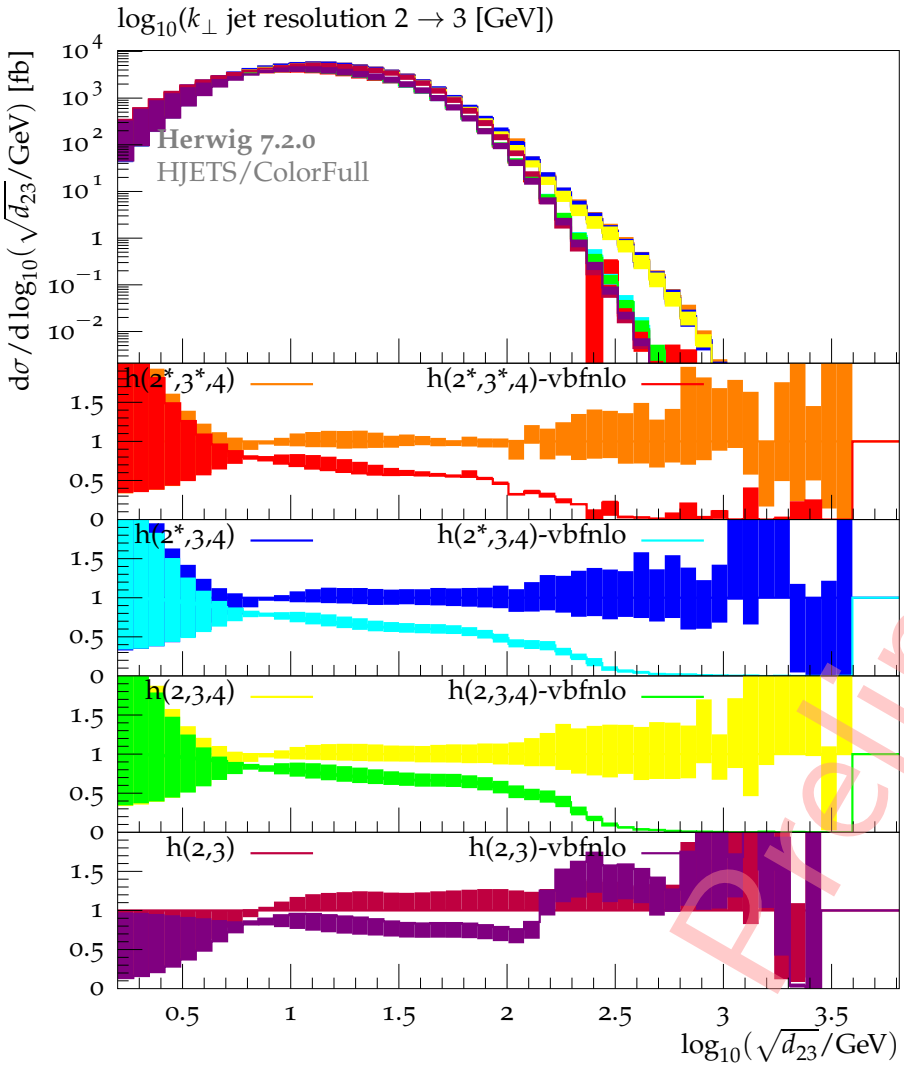


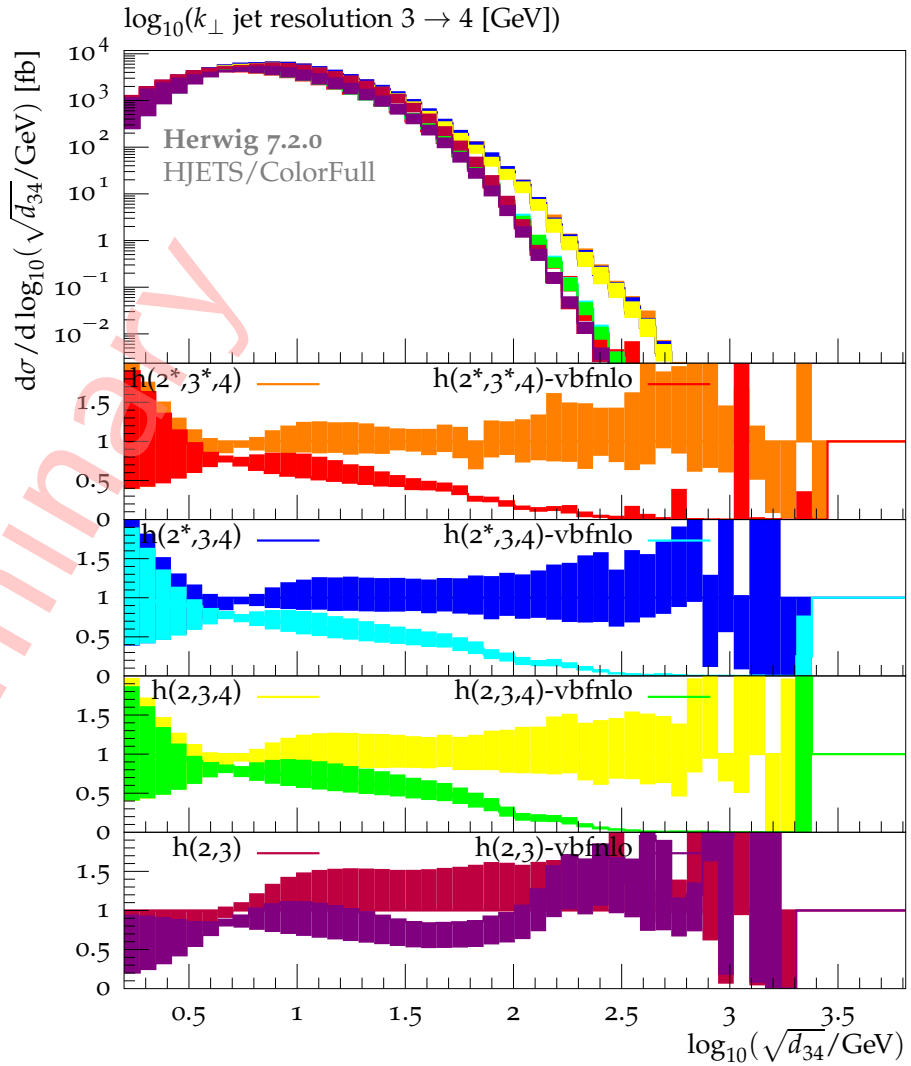












Summary

- We have shown merged NLO H2j, NLO H3j, LO H4j results using Herwig 7.
- There is difference between VBF calculation and full calculation. After applying tight selection cuts, two results has agreement.

References

[1] Campanario, Francisco, et al. "Stress-testing the VBF approximation in multijet final states." arXiv preprint arXiv:1802.09955 (2018).

[2] Campanario, Francisco, et al. "Electroweak Higgs boson plus three jet production at next-to-leading-order QCD." Physical review letters 111.21 (2013): 211802.

[3] Figy, Terrance, Vera Hankele, and Dieter Zeppenfeld. "Dominant next-to-leading order QCD corrections to Higgs plus three jet production in vector-boson fusion." Journal of High Energy Physics 2008.02 (2008): 076.

[4] de Florian, Daniel, et al. "Handbook of LHC Higgs cross sections: 4. Deciphering the nature of the Higgs sector." arXiv. org (2016).

References

[1] Jäger, Barbara, et al. "Parton-shower effects in Higgs production via vector-boson fusion." The European Physical Journal C 80.8 (2020): 1-16.

[2] Bellm, Johannes, Stefan Gieseke, and Simon Plätzer. "Merging NLO multi-jet calculations with improved unitarization." The European Physical Journal C 78.3 (2018): 1-31.

[3] Rauch, Michael, and Simon Plätzer. "Parton-shower matching systematics in vector-boson-fusion WW production." The European Physical Journal C 77.5 (2017): 1-10.

[4] Bellm, Johannes, et al. "Herwig 7.2 release note." The European Physical Journal C 80 (2020): 1-13.

[5] Plätzer, Simon, and Stefan Gieseke. "Dipole showers and automated NLO matching in Herwig++." The European Physical Journal C 72.11 (2012): 1-19.

Thank You!

Back up slides

$$\sigma_{NLO}^{matched} = \int_n \left(d\sigma_{LO} + d\sigma_{virt}\right) \tag{4}$$

$$= \int_n \int_1 \left(d\sigma_{PS} - d\sigma_{sub}\right) \tag{5}$$

$$= \int_{n+1} \left(d\sigma_R - d\sigma_{PS}\right) \tag{6}$$

More details see: https://arxiv.org/pdf/1605.07851.pdf
https://arxiv.org/pdf/1912.06509.pdf
https://arxiv.org/pdf/1109.6256.pdf

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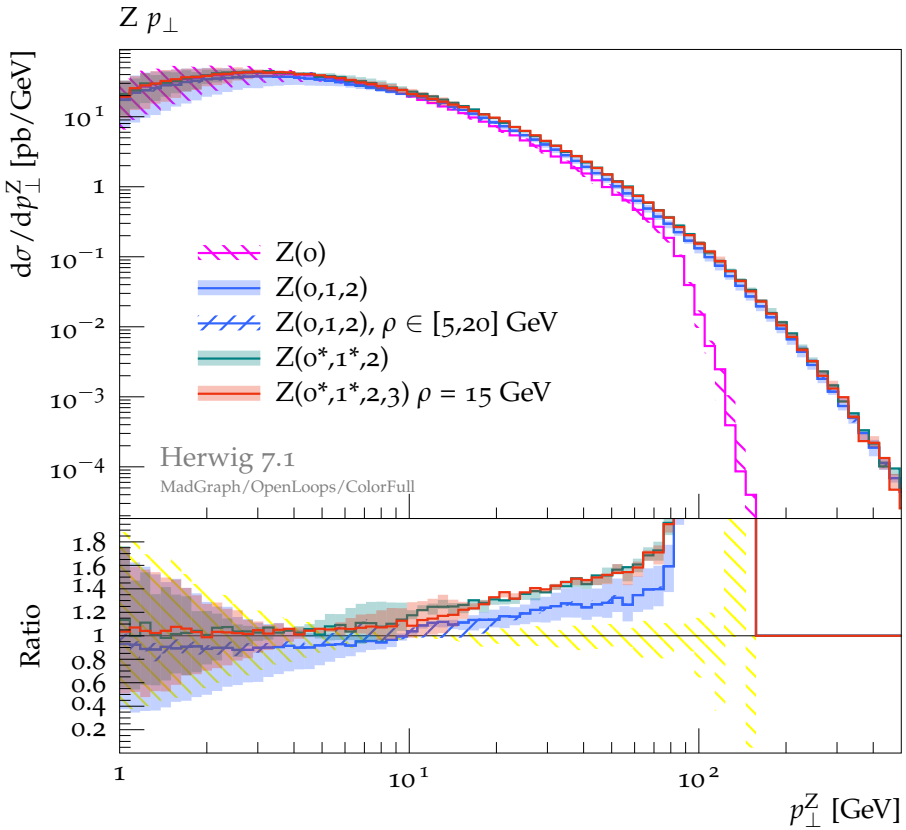

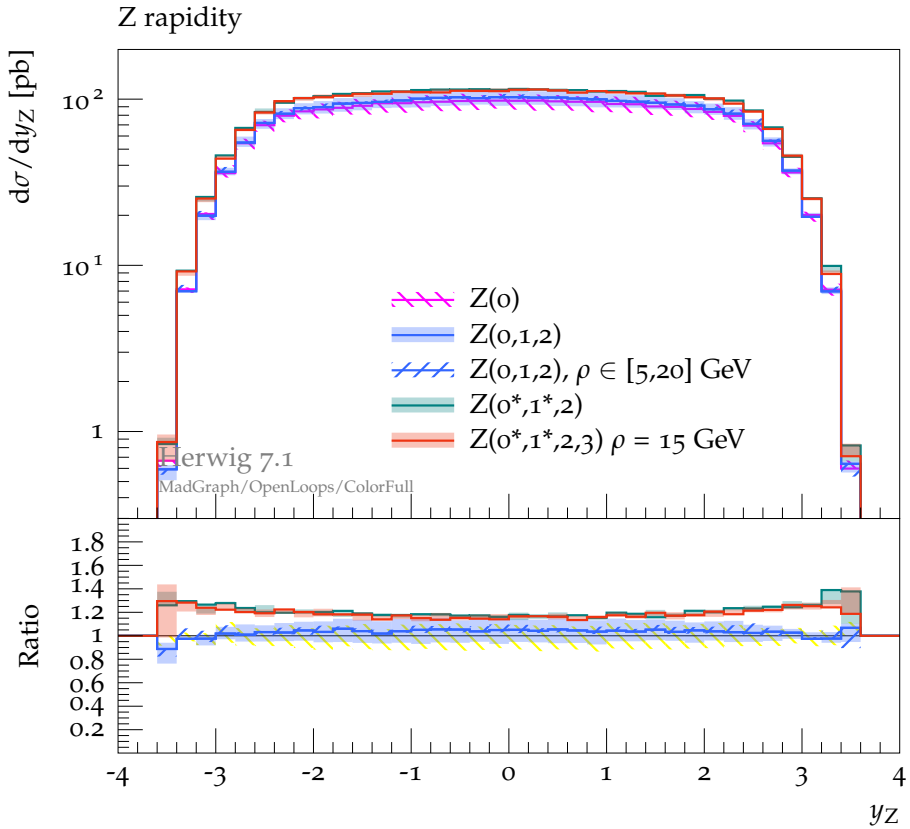

see https://arxiv.org/pdf/1705.06700.pdf

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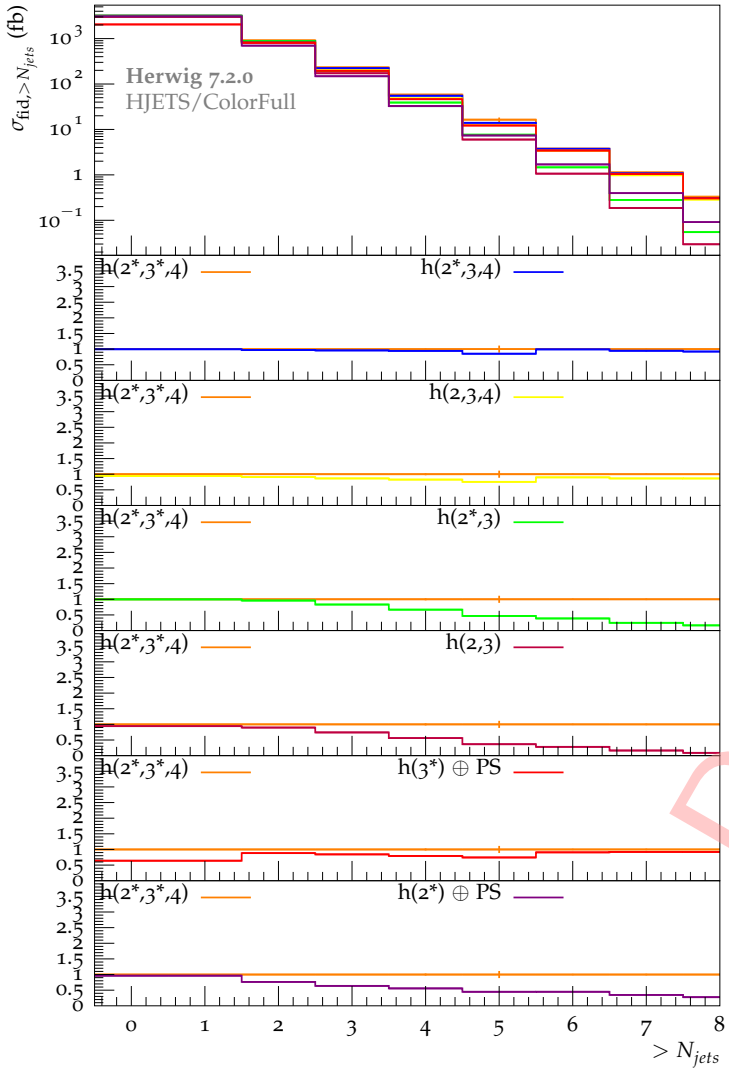

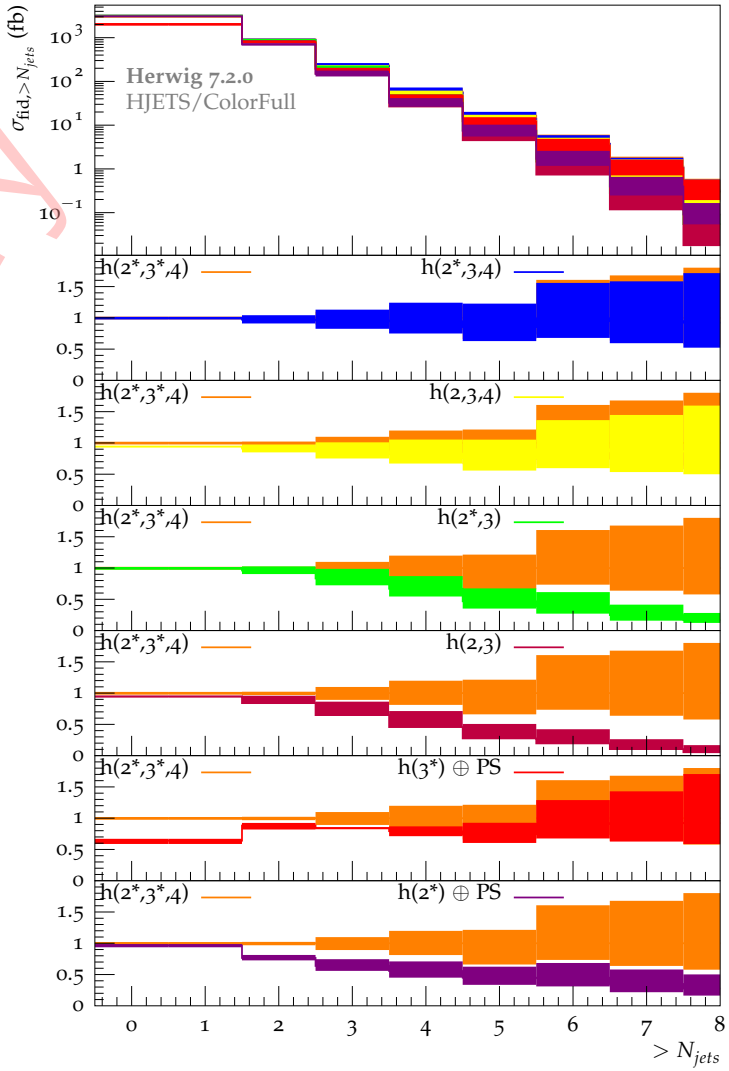

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