Karlsruhe Institute of Technology

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PHYSICS AT THE TERA SCALE Helmholtz Alliance

Comparison of Pythia, vbfnlo and Herwig++ for the vector boson fusion channel

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Outline

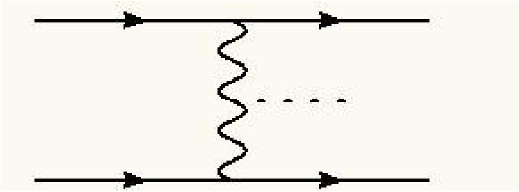
- **The VBF signal**
- **Generators used**
- **ME level – pythia and vbfnlo**
- **3rd jet / central jet**
- **Conclusion / Outlook**

Vector Boson Fusion

Vector Boson Fusion is a promising Higgs production process

The kinematic signature is given by two hard jets, one forward and one backward in rapidity, with a big gap between them

This gap should be visible at hadron level, since the process is a color singlet exchange



So for the study of this channel it is important to investigate this gap after parton shower, hadronization and underlying event

Since this is strongly model dependent (only models available for parton shower, hadronization and underlying event), different generators should be compared

Setup for generation

vbfnlo – Matrix element generator optimized for the VBF process

- developed by the group of D. Zeppenfeld
- also does NLO calculations
- available at www-itp.uni-karlsruhe.de/vbfnlo

Pythia

- ZZ fusion and W^+W^- fusion
- Higgs boson decays in 2 taus
- m_{Higgs} = 120 GeV
- no further cuts at generator level

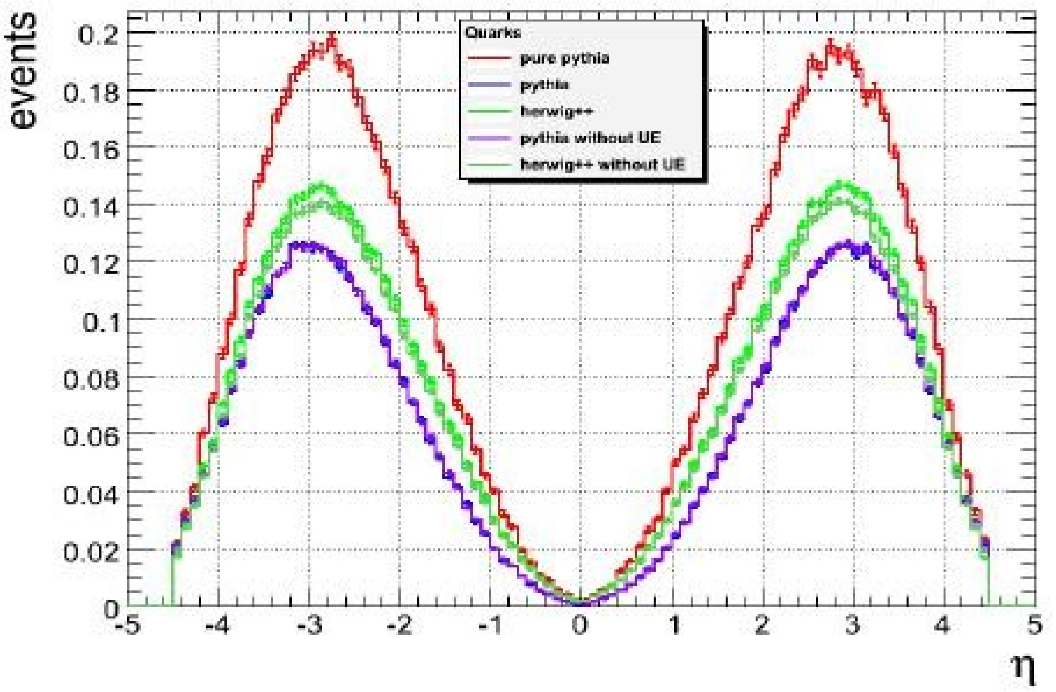
vbfnlo (LO)

- Higgs boson decays in 2 taus
- m_{Higgs} = 120 GeV
- soft VBF cuts
- showering with Pythia and Herwig++

Selection cuts after generation:

- the two hardest genJets (sisCone5) fulfilling the vbf cuts are used as tagging jets:
  opp. hemispheres, $\Delta\eta_{jets} > 4.0$, $p_T > 20$ GeV, $|\eta| < 4.5$, $m_{inv}^{Dijet} > 600$ GeV
- taus inside rapidity gap of quarks, p_T>20GeV, η<2.5, ΔR(jet,tau)>0.6
- ΔR(gen_jet; Outgoing Taus) < 0.2 are assumed as jet from tau decay
- highest p_T GenJet left is the 3rd jet
- highest p_T GenJet left which is between the two tagging jets is the central jet

Matrix elements - naïve comparison



color scheme:

vbfnlo with pythia showering
vbfnlo with herwig++ showering
vbfnlo with pythia showering w/o UE
vbfnlo with herwig++ showering w/o UE
pythia with pythia showering

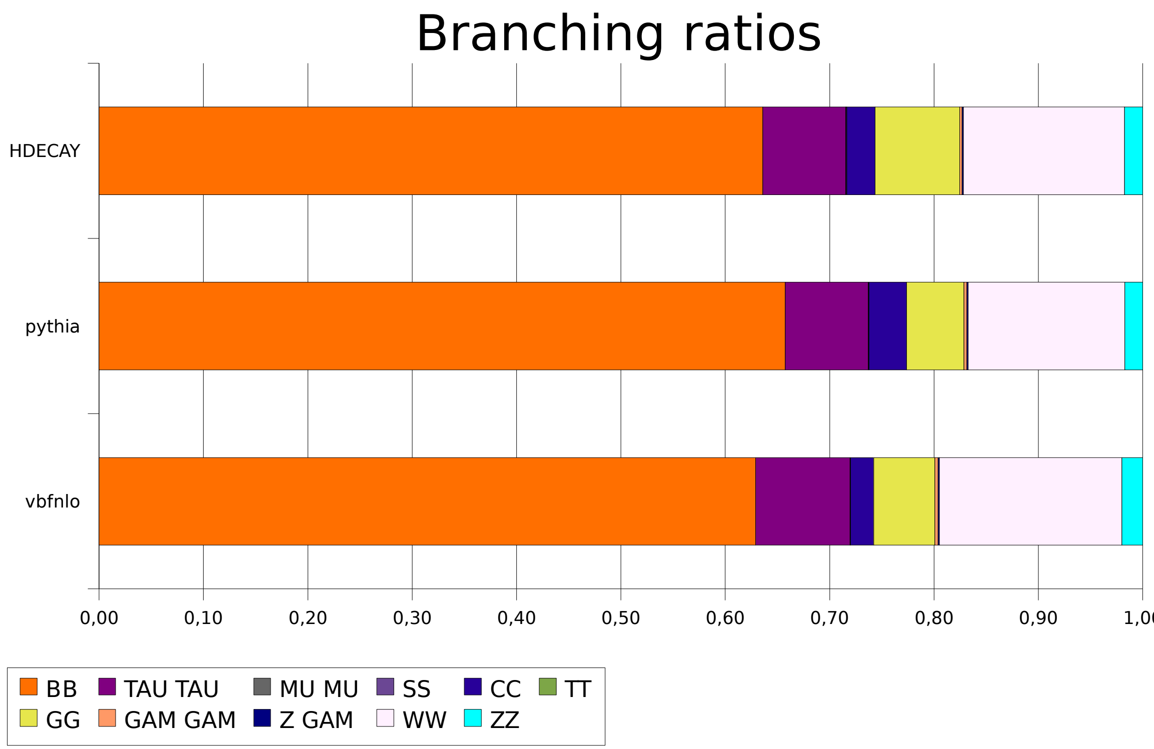
The pure Pythia sample (ME and showering done by Pythia) yields a much higher cross section than the samples made with vbfnlo

The problem (now resolved) stemmed from outdated input parameter for the Higgs branching – new vbfnlo version includes updated parameters

Brancing ratios, updated

The branching ratio of the Higgs is strongly dependent on the mass of the decay products

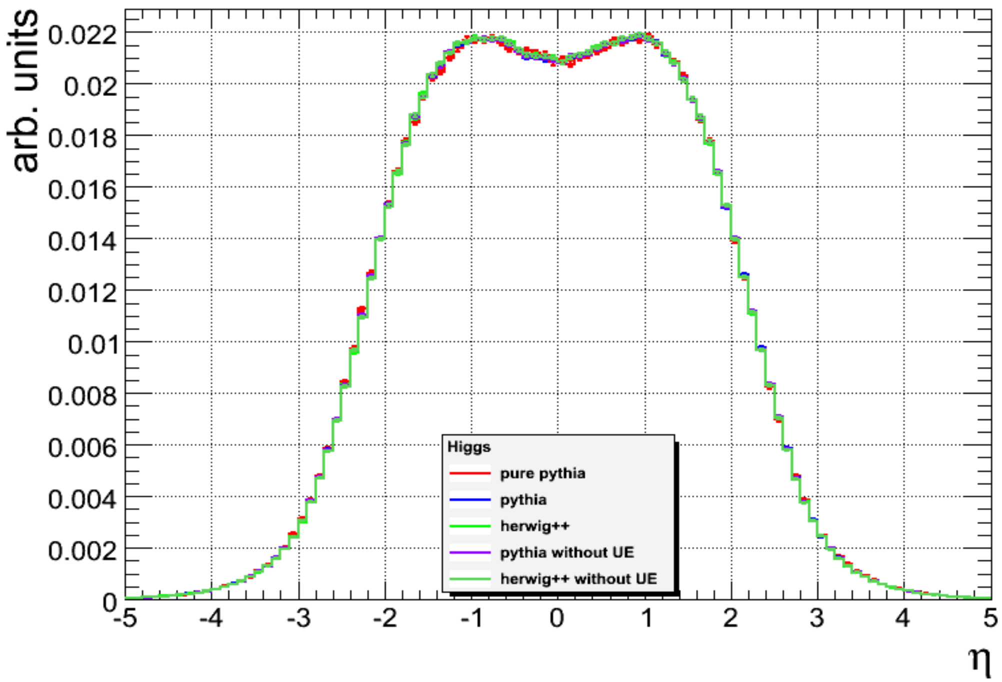
For m_{Higgs} = 120 GeV the major decay channel is H to bb, so the b-mass is a crucial input parameter



Branching ratios with updated parameters, HDECAY, Pythia and vbfnlo

Still some small differences remaining

Matrix element level



shape of different kinematic distributions agree within statistical uncertainties on parton level

Example:

Rapidity distribution for the Higgs at Matrix element level

color scheme:

vbfnlo with pythia showering
vbfnlo with herwig++ showering
vbfnlo with pythia showering w/o UE
vbfnlo with herwig++ showering w/o UE
pythia with pythia showering

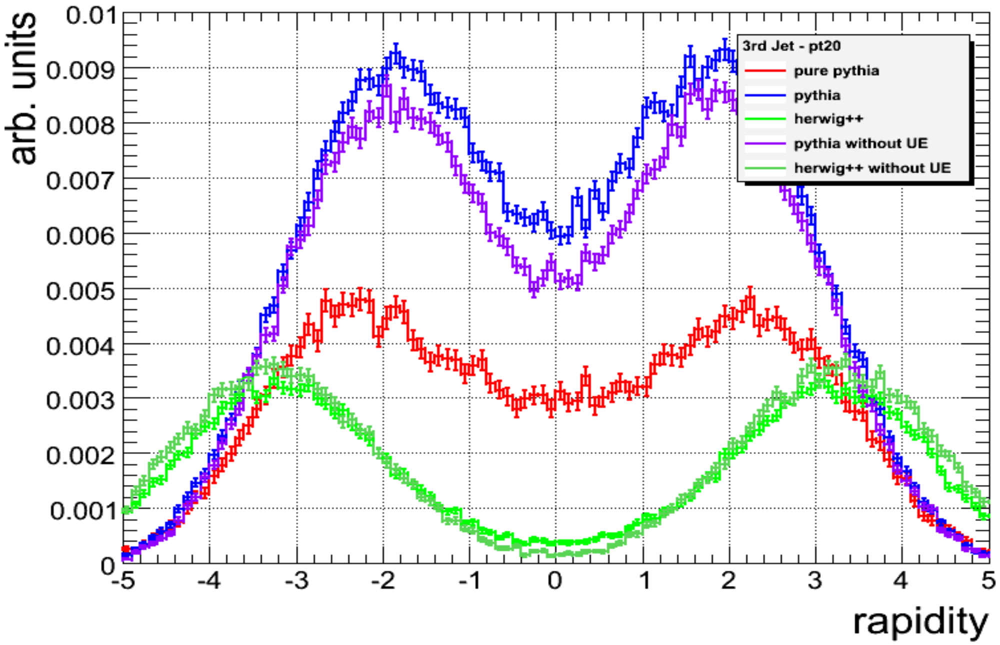
Third Jet

The VBF process at ME is characterized by a central region free of hadronic activiy

Parton shower, hadronization, underlying event fill this region to some extent

The simulation is therefore strongly model dependent

rapidity of 3[rd] jet, p_T > 20 GeV



Some problems with Pythia+vbfnlo, difference to pure pythia, probably due to scale choices for the ME, work in progress

color scheme:
vbfnlo with pythia
vbfnlo with herwig++
vbfnlo with pythia w/o UE
vbfnlo with herwig++ w/o UE
pure pythia

Third Jet, y*

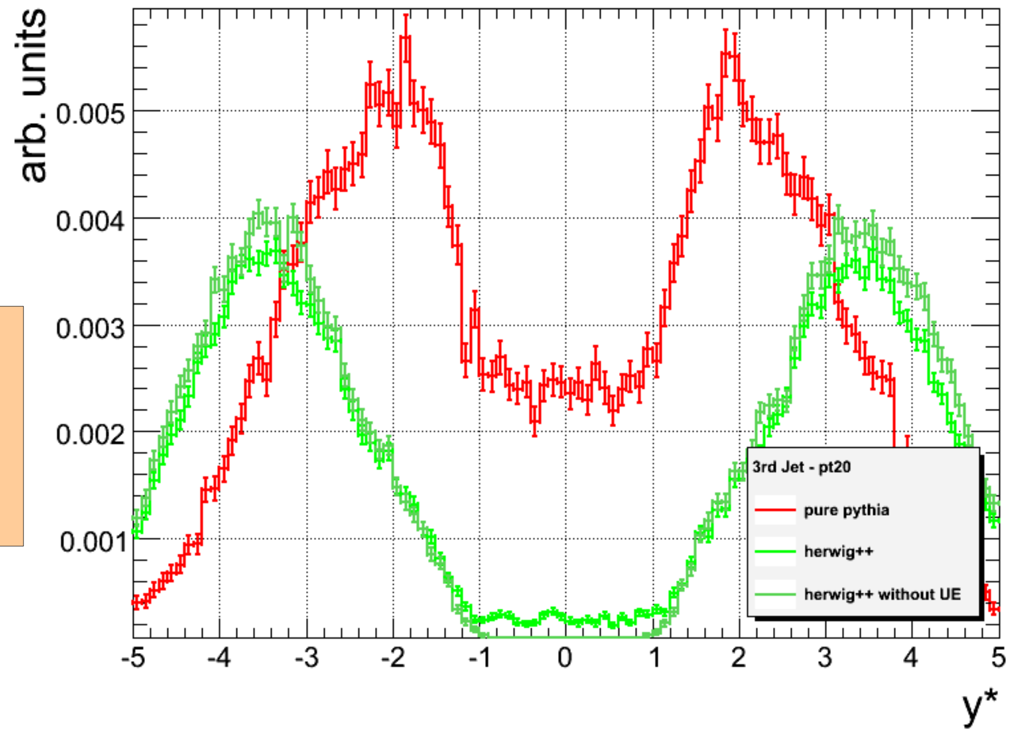
To see the position of the 3rd jet relative to the two tagging jets, y* is introduced:

$$y^* = y_3 - \frac{1}{2} \cdot (y_1 + y_2)$$

Main difference:

Shower and Hadronization model used in Pythia and Herwig++

y* of 3rd jet, p_T > 20 GeV



color scheme:
vbfnlo with herwig++
vbfnlo with herwig++ w/o UE
pure pythia

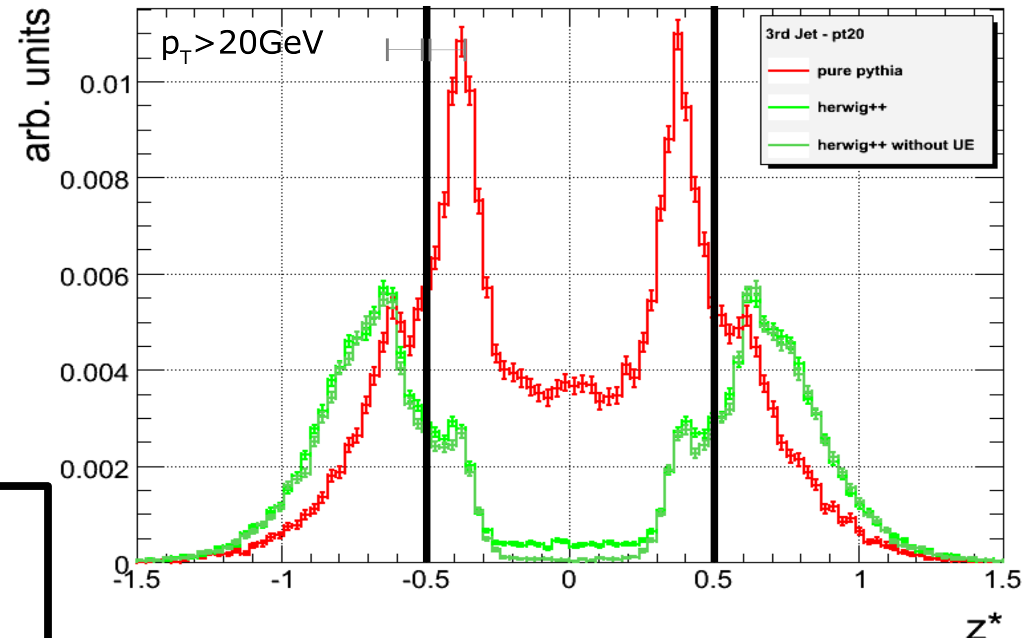
Third Jet

Normalizing y* to the size of the rapidity gap shows more clearly where the 3rd jet lies

$$z^* = \frac{y^*}{|y_1 - y_2|}$$

If the 3rd jet has the same rapidity as a tagging jet,
$z^* = \pm 1/2$
3rd jet between the tagging jets
$|z^*| < 1/2$
3rd jet outside the tagging jets
$|z^*| > 1/2$

z* of 3rd jet, p_T > 20 GeV

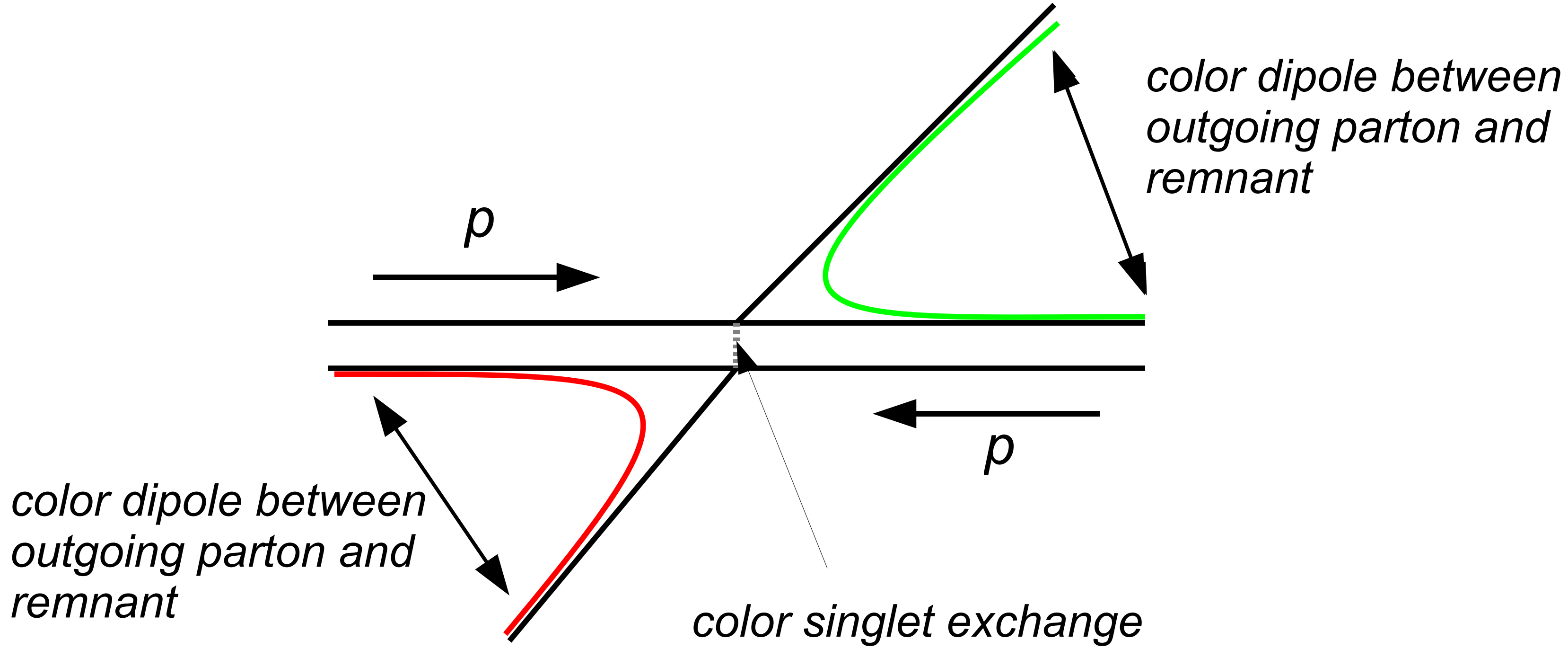


The peaks near ±½ can be explained by the jet finder

Pythia and Herwig++ disagree strongly in their predicition!!

Parton Shower formalism

What behavior of the third jet would we expect from the parton shower?

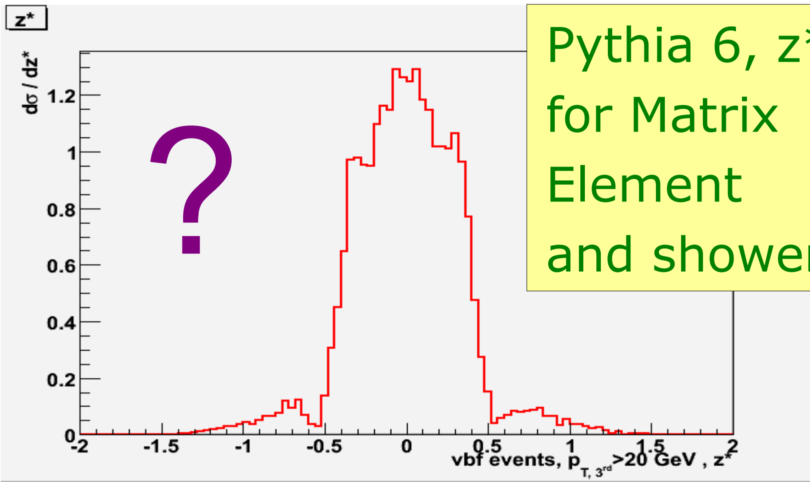


In the parton shower additional partons are emitted between color dipoles to yield smaller resulting dipoles

Expect mostly emission in the forward region for the VBF channel

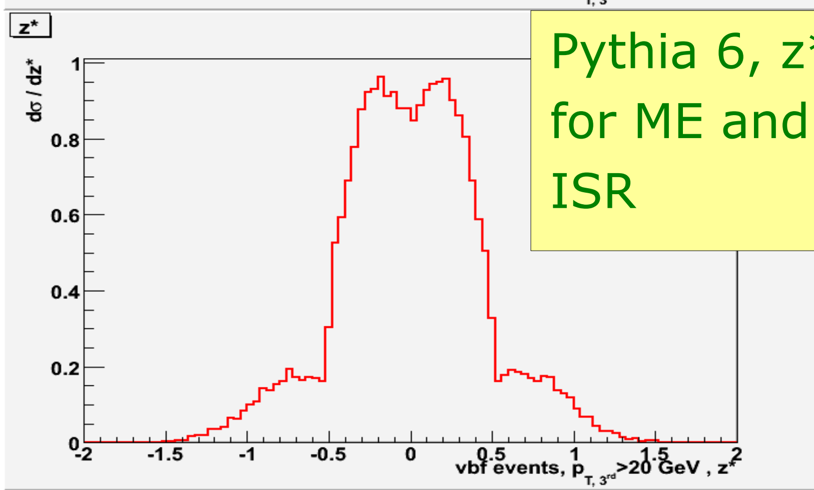
Shower details, Pythia

The difference between Herwig++ and Pythia stems from the parton shower, in Pythia 6 the the shower mostly fills the central region



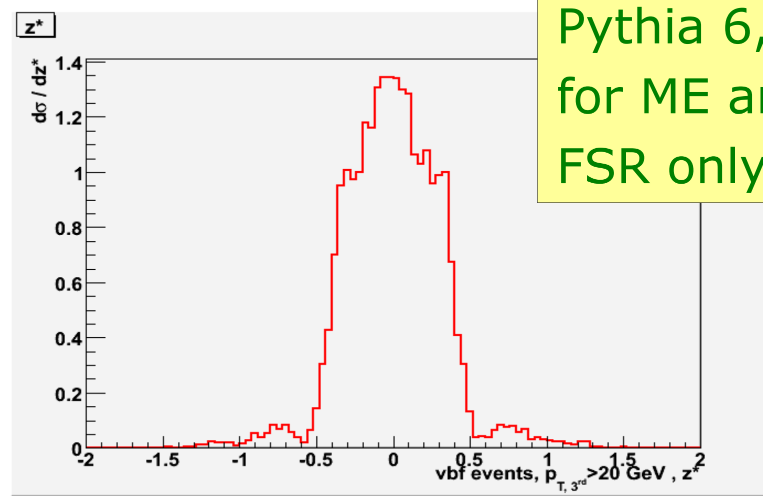
Pythia 6, z* for Matrix Element and shower

So the shower does not work as expected



Pythia 6, z* for ME and ISR

The shower model for Pythia 8 has changed and shows a better behavior for the FSR



Pythia 6, z* for ME and FSR only

Shower details, Pythia

Comment of Torbjörn Sjöstrand on the hadronic activity inside the gap region:

> **"The [shower] formalism is not specifically set up to cover this kind of somewhat special topologies, so it could well miss some suppression that ought to have been there**. This has been noted by other people previously, so does not come as a big surprise. **In that sense I would agree that the Pythia result is overly pessimistic**, if you want the presence of a rapidity gap as a signal."

So our findings seem to be expected by Torbjörn.

Central Jets

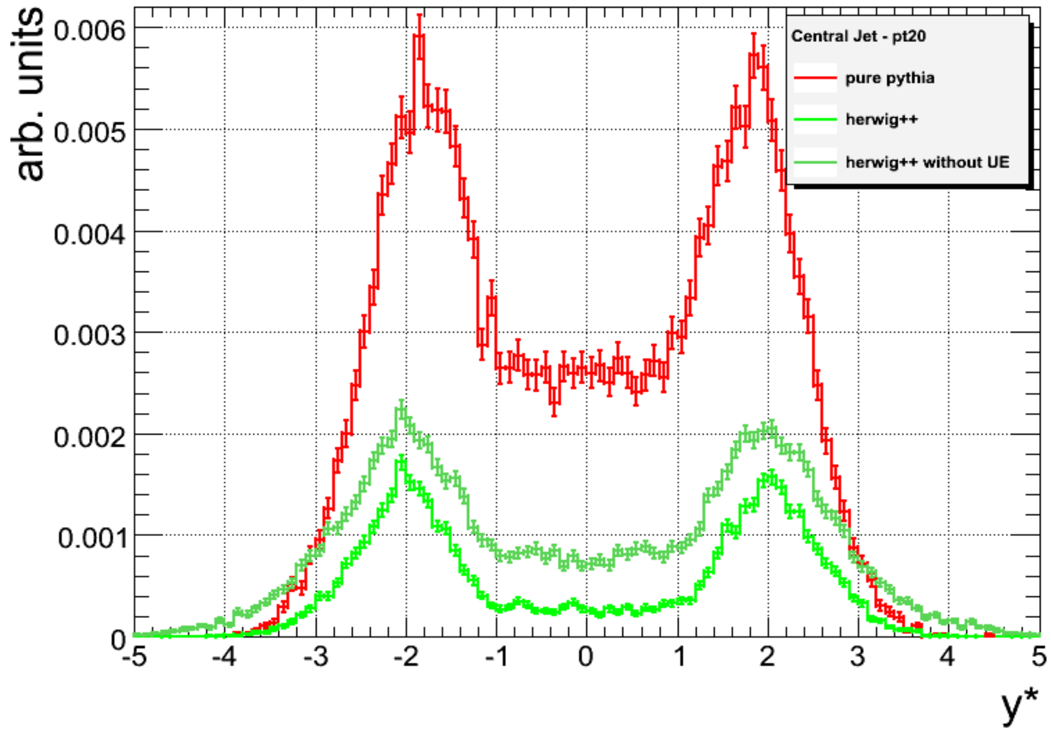
The position of additional jets relative to the tagging jets is crucial for the visibility of the signal

Only jets falling in the rapidity gap are a problem, events with hard central jets should be vetoed

→ The hardest jet falling between the two tagging jets in rapidity is examined in the following to check the difference between Pythia and Herwig++

Central Jets, y*

color scheme:
- vbfnlo with herwig++ w/o UE
- vbfnlo with herwig++
- pure pythia



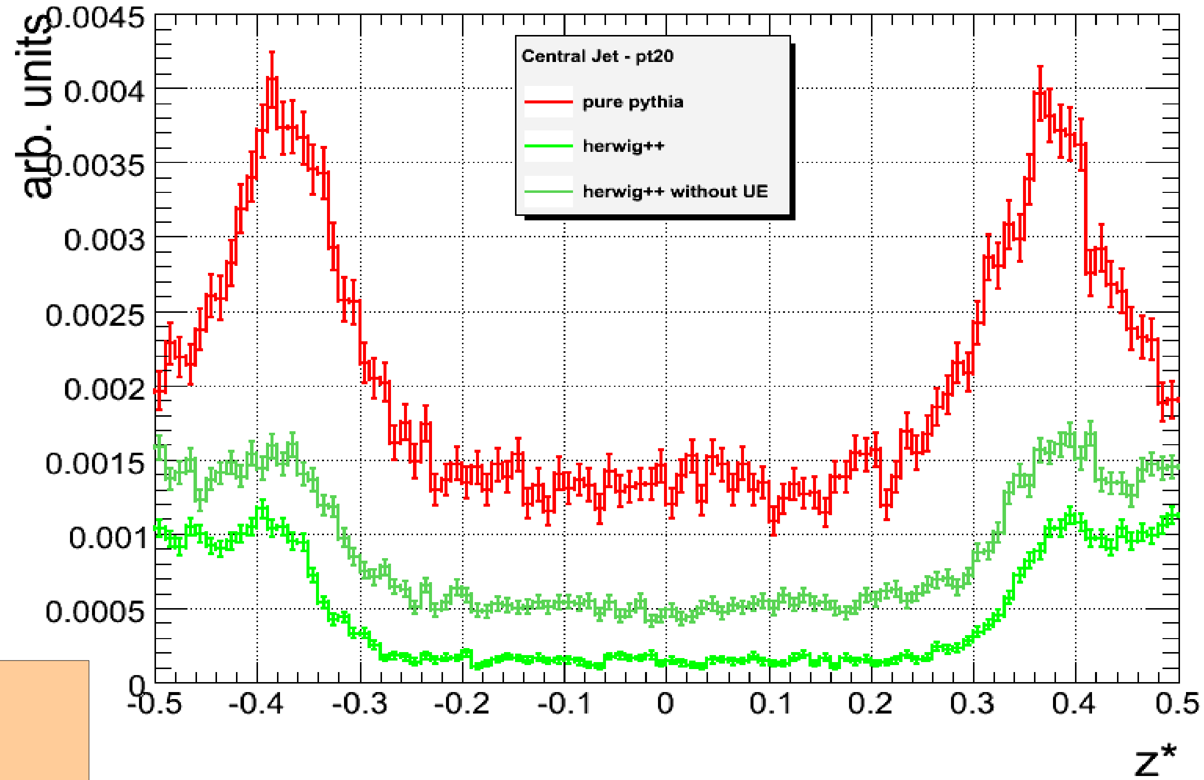
$$y^* = y_3 - \frac{1}{2} \cdot (y_1 + y_2)$$

y* spectrum of hardest central jet, p_T > 20 GeV

Central Jets, z*

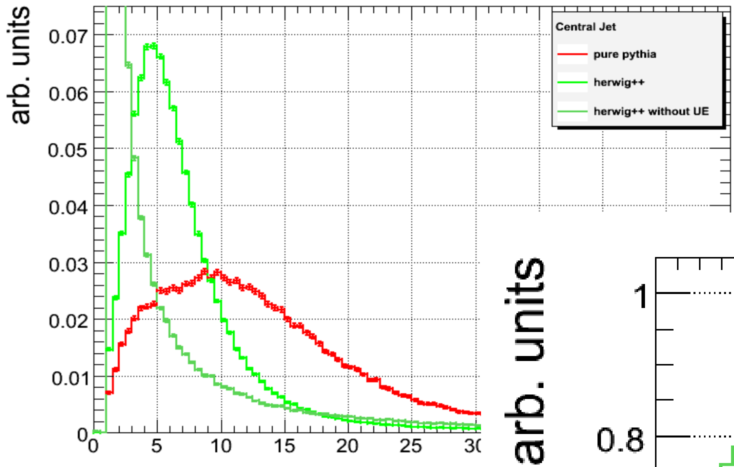
z* spectra of hardest central jet, $p_T > 20$ GeV

$$z^* = \frac{y^*}{|y_1 - y_2|}$$

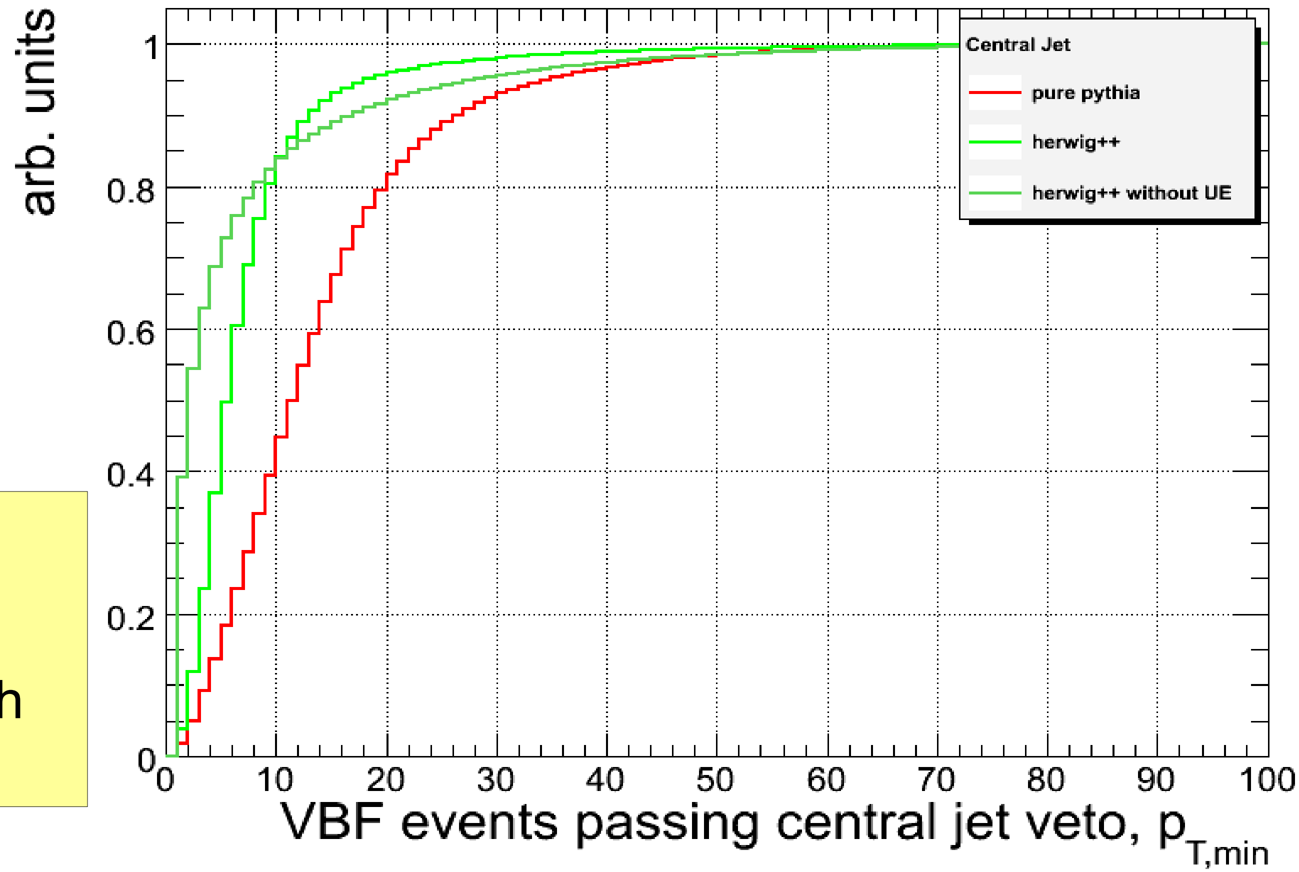


color scheme:
vbfnlo with herwig++ w/o UE
vbfnlo with herwig++
pure pythia

Central Jet Veto efficiency



The pT spectrum of the hardest central jet can be used to obtain a Central Jet Veto Efficiency – Herwig++ and Pythia differ



Veto Efficiency: fraction of VBF events passing a central jet veto with given p_T

Conclusion and Outlook

The analysis of the VBF channel depends strongly on the presence of a rapidity gap between two tagging jets free of hard hadronic activity

The behavior of this rapidity gap is simulated by models like parton shower, hadronization and underlying event

Pythia and Herwig++ differ significantly in their prediction of central jets

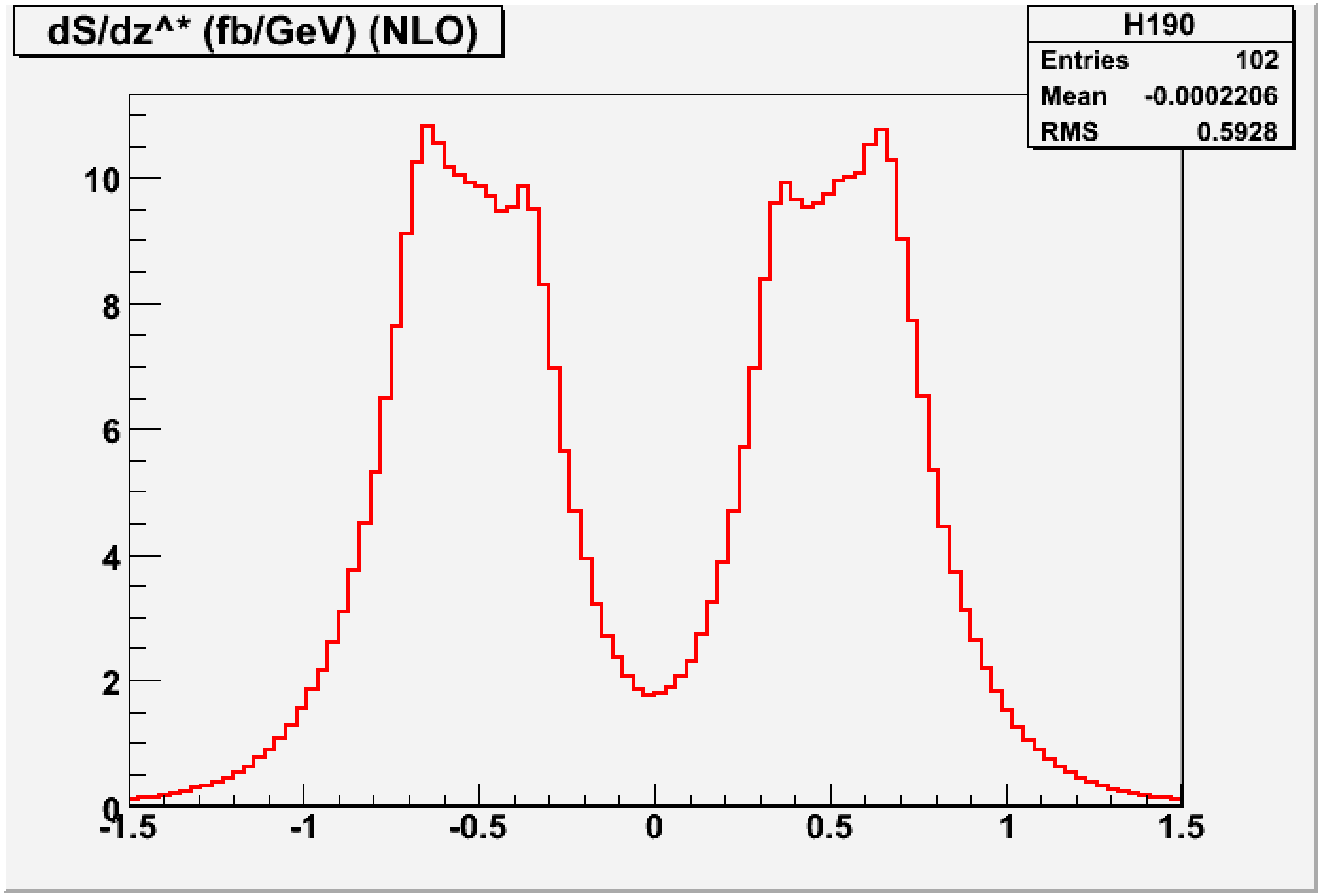
Work in progress – we are collaborating with the groups of D.Zeppenfeld (Theory, vbfnlo) and S.Gieseke (Herwig++)

Herwig++ suggests re-evaluation of signal selection and efficiency determination (Work in progress in Karlsruhe group)

Only data may resolve this issue!

Backup

Third jet in NLO calculation

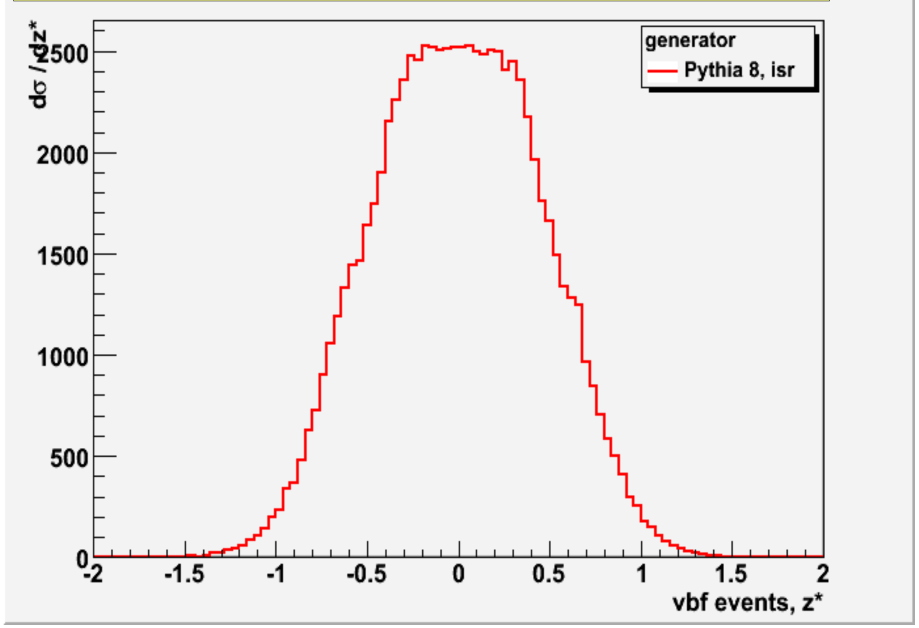


z* with real emission from the NLO calculation, $p_{T,3\ jet}$ > 20 GeV

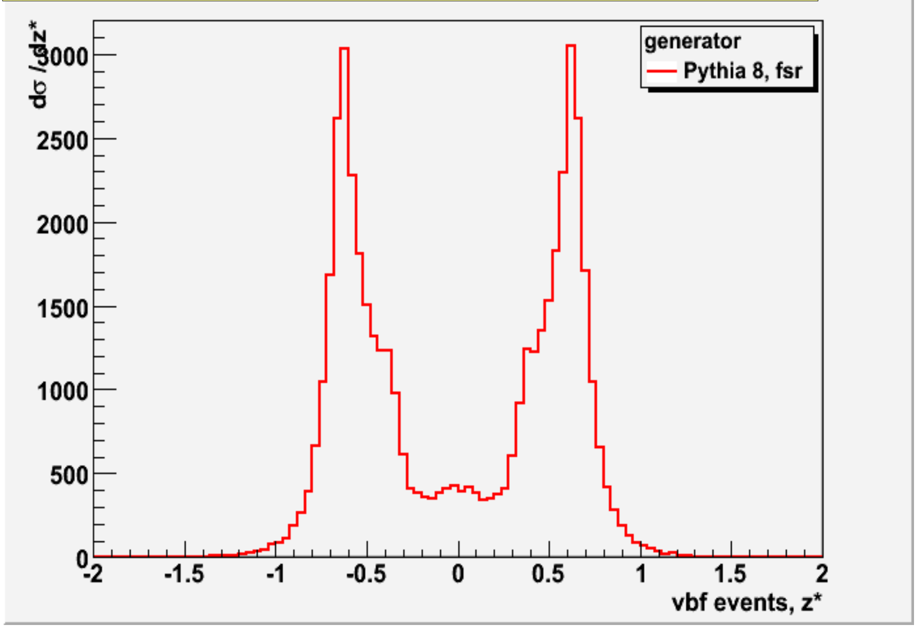
Shower details, Pythia 8

In Pythia 8 the Initial State Radiation in Pythia produces a lot of activity in the central region, the Final State Radiation behaves more like expected in our case

Pythia 8, z* for Matrix Element and Initial State Radiation only



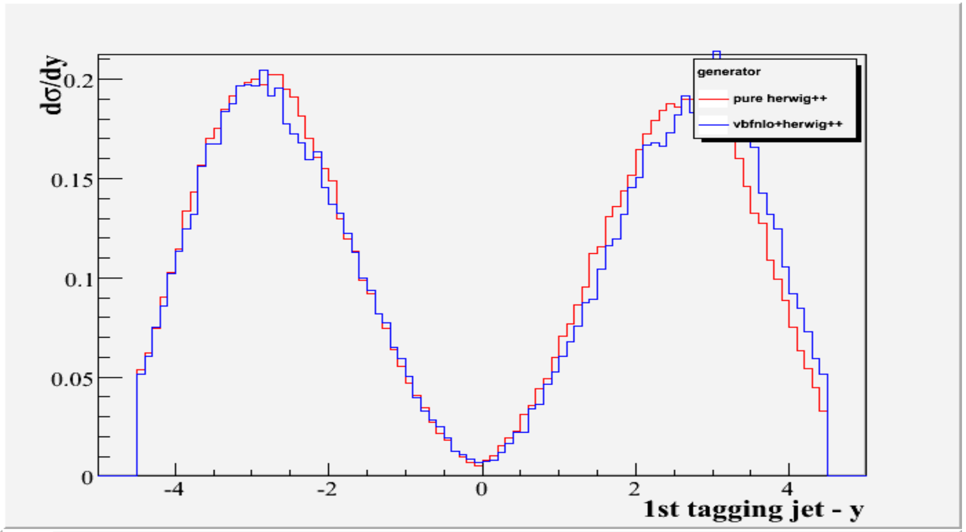
Pythia 8, z* for Matrix Element and Final State Radiation only

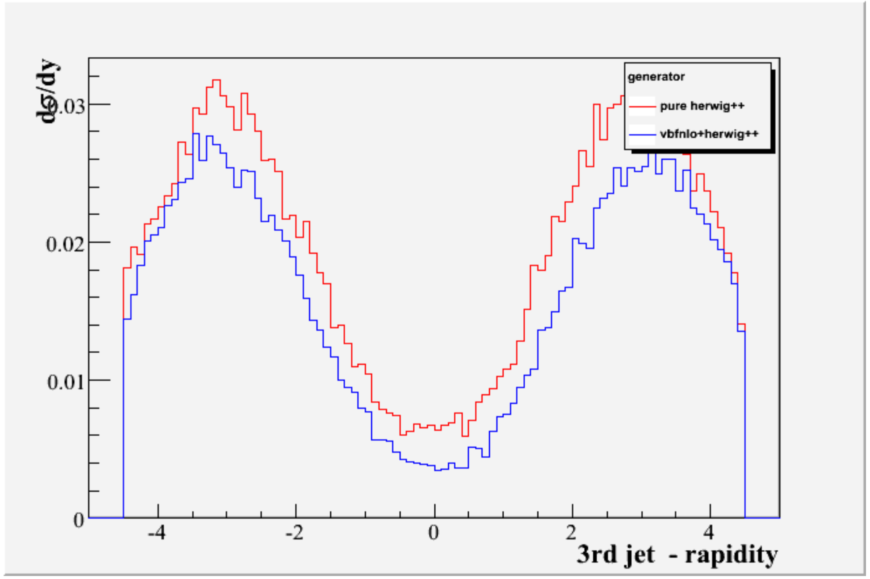


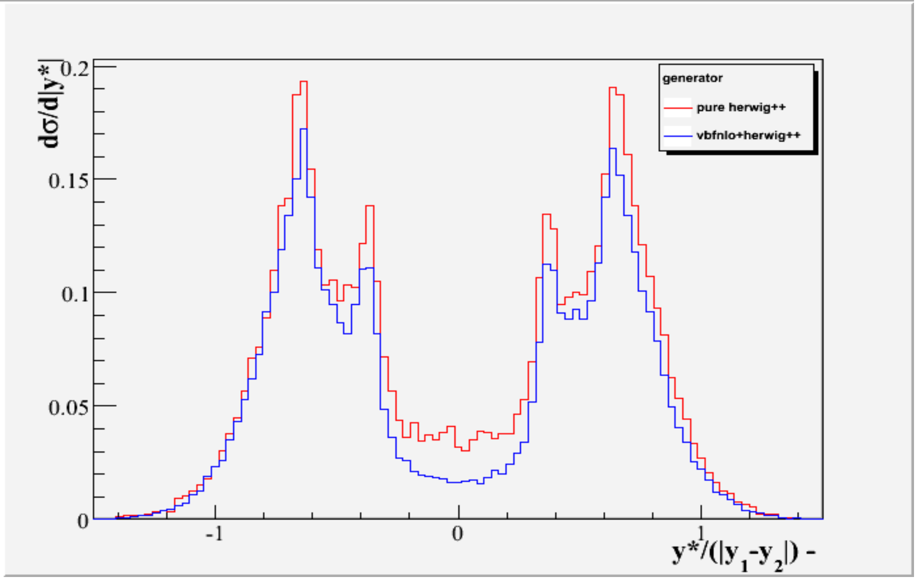
Preliminary: Coming Herwig++ ME

The VBF matrix element for Herwig++ is currently under development, not tuned yet

Nonetheless, quite good agreement with vbfnlo after showering

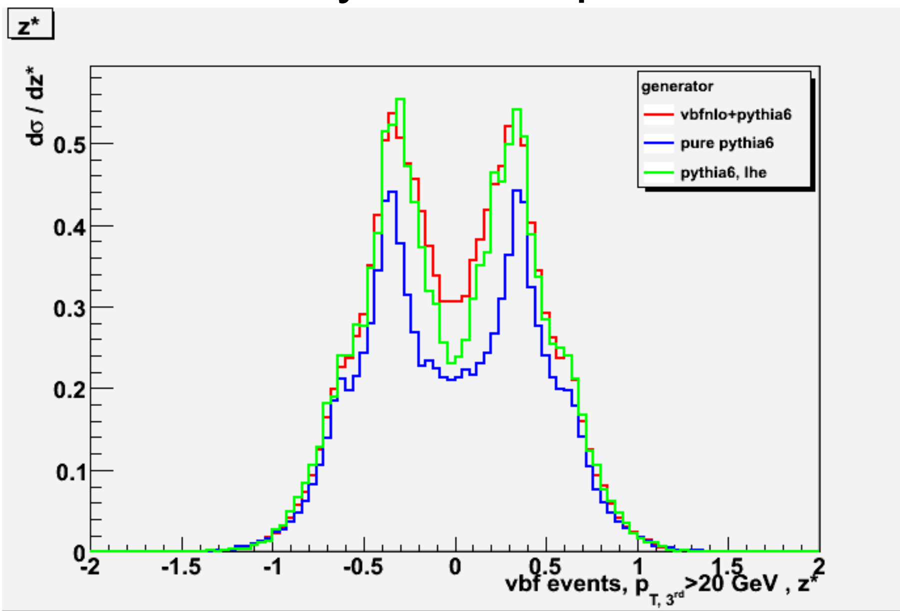


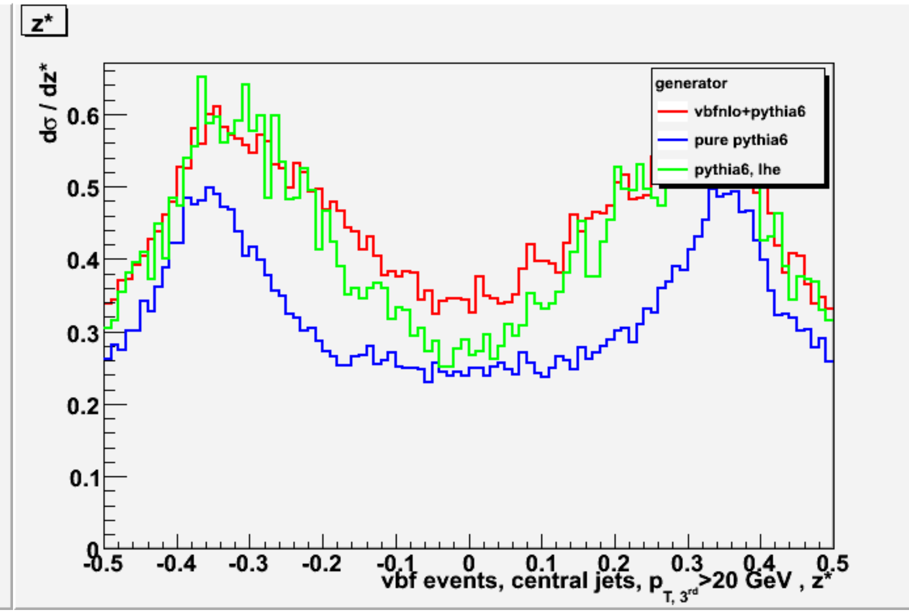




Pythia standalone

Standalone Pythia comparison of internal and external Matrix elements





z* for the third jet

z* for the hardest central jet

Visible difference in the distributions, as yet unclear why this is the case

color scheme:
vbfnlo + pythia
pure Pythia
Pythia -> Les Houches file -> Pythia

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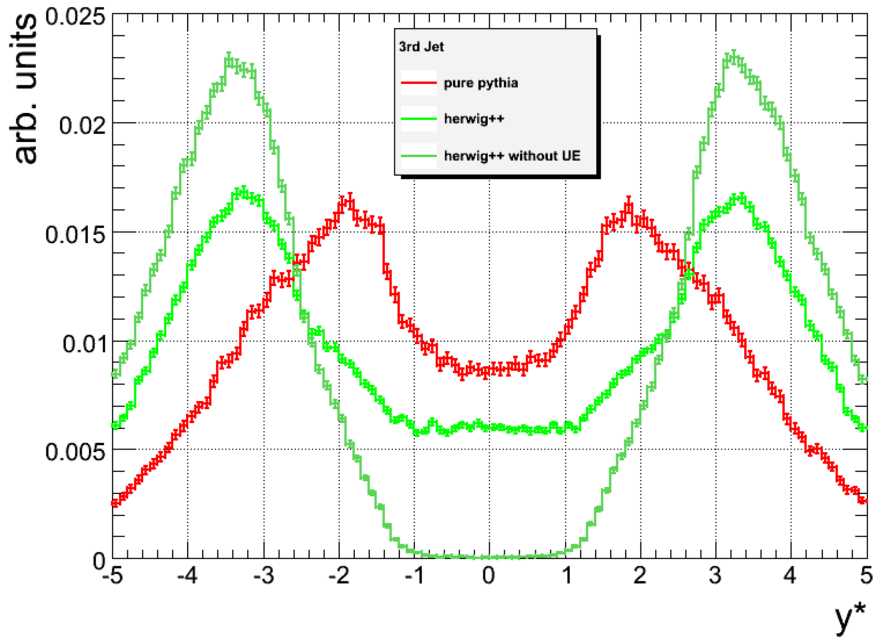
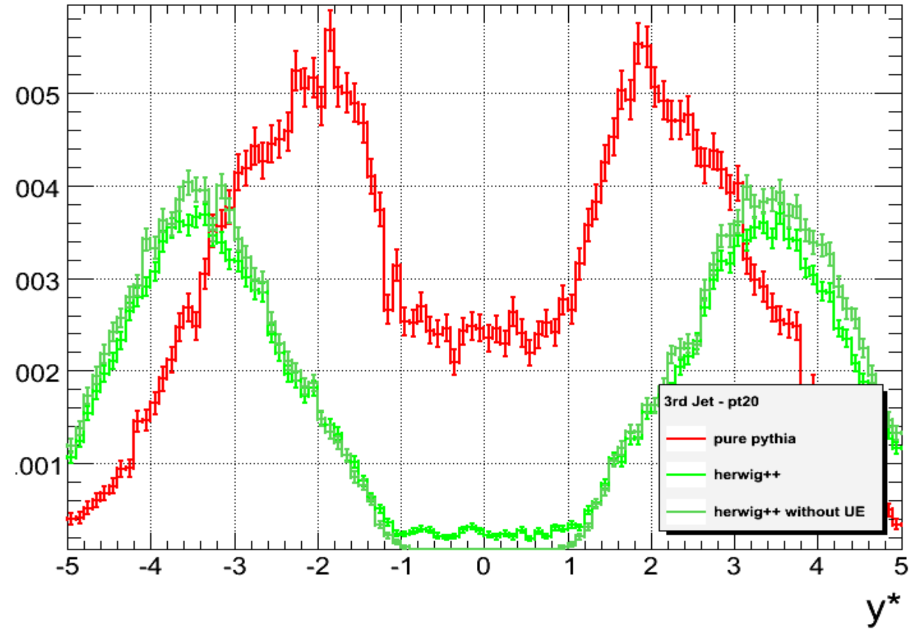
Third jet, y*



y* without p_T cut

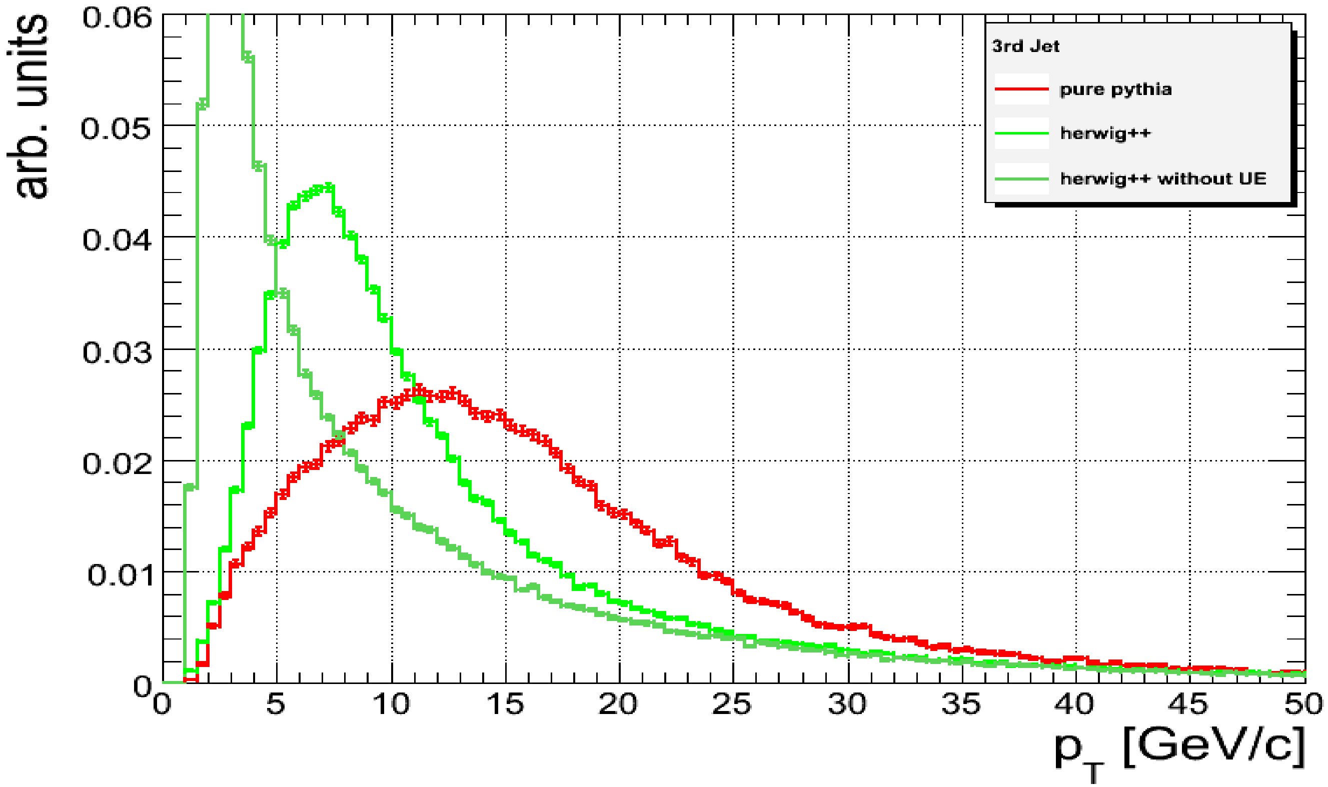


y* with p_T > 20 GeV

Normalized to fraction of VBF events

color scheme:
vbfnlo with herwig++
vbfnlo with herwig++ w/o UE
pure pythia (as off. prod.)

Third jet, p_T



3[rd] jet, p_T

color scheme:
vbfnlo with herwig++
vbfnlo with herwig++ w/o UE
pure pythia (as off. prod.)

Setup for generation

Pythia (LO)

- ZZ fusion and W^+W^- fusion
- Higgs boson decays in 2 taus
- m_{Higgs} = 120 GeV
- no further cuts at generator level
- 7.200.000 events, σ = 335 fb
- showering with Pythia

vbfnlo (LO)

- Higgs boson decays in 2 taus
- m_{Higgs} = 120 GeV
- soft VBF cuts:
  - quarks in opposite hemispheres, $\Delta\eta_{quarks} > 2.0$, $p_T > 10$ GeV, $|\eta| < 5$, $m_{inv}^{Diquark} > 400$GeV
  - taus fall between quarks
  - taus: $p_T > 20$ GeV, $|\eta| < 2.5$
- showering with Pythia and Herwig++