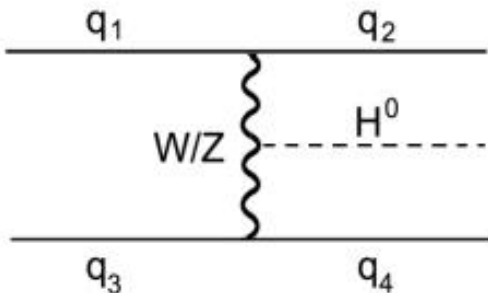
Physics at TeV Colliders Workshop
Higgs production and decays Working Group
Les Houches, 22/06/2007

$gg \rightarrow H^0$ background to qqH^0: ALPGEN+PYTHIA studies

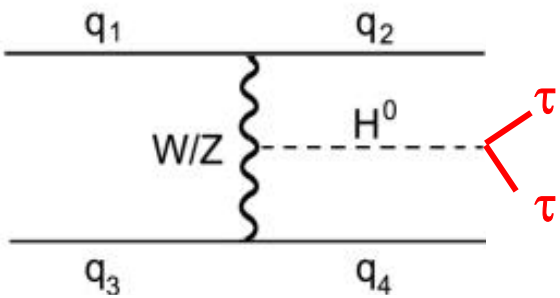
Mónica L. Vázquez Acosta (CERN)

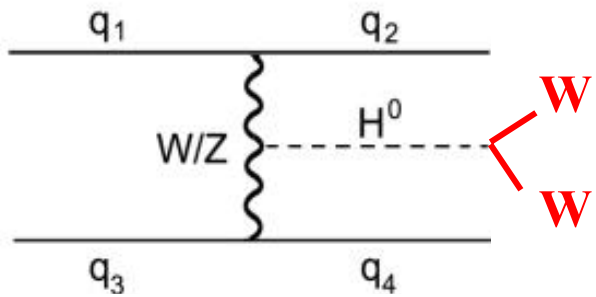
Alexander Nikitenko (Imperial College of London)

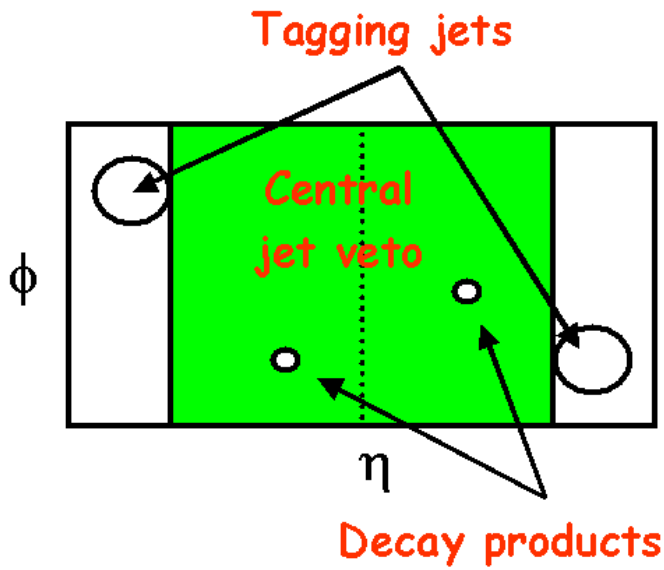
Higgs Production via Vector Boson Fusion



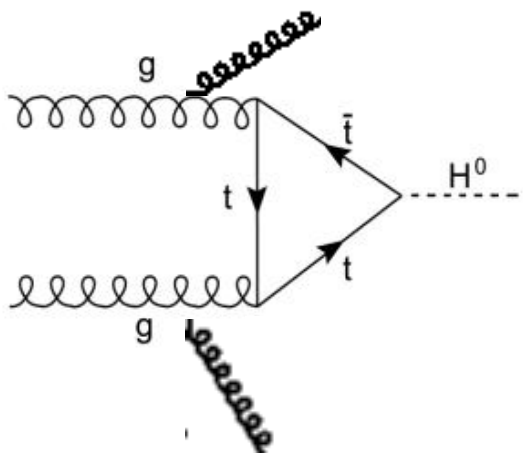
Distinct topology of final state (two forward jets with little extra hadronic activity and the decay products of the Higgs). Background expected small.







Ratio of cross section of VBF Higgs to different decay channels can be used to determine Higgs Couplings. Some uncertainties will cancel out.

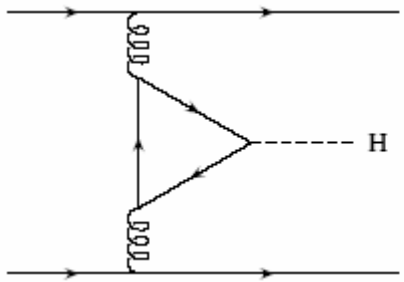


GOAL OF THIS STUDY:

Estimate the contamination of gg→H production with initial and final state radiation with the same topology as VectorBosonFusion Higgs events (qqH).

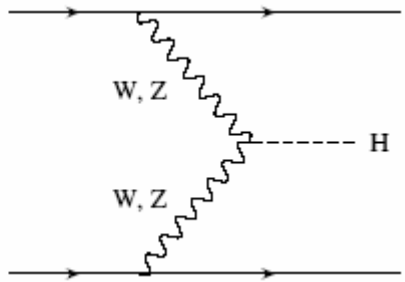
Distinguish between VBF and Gluon Fusion?

gg→H (gluon fusion)

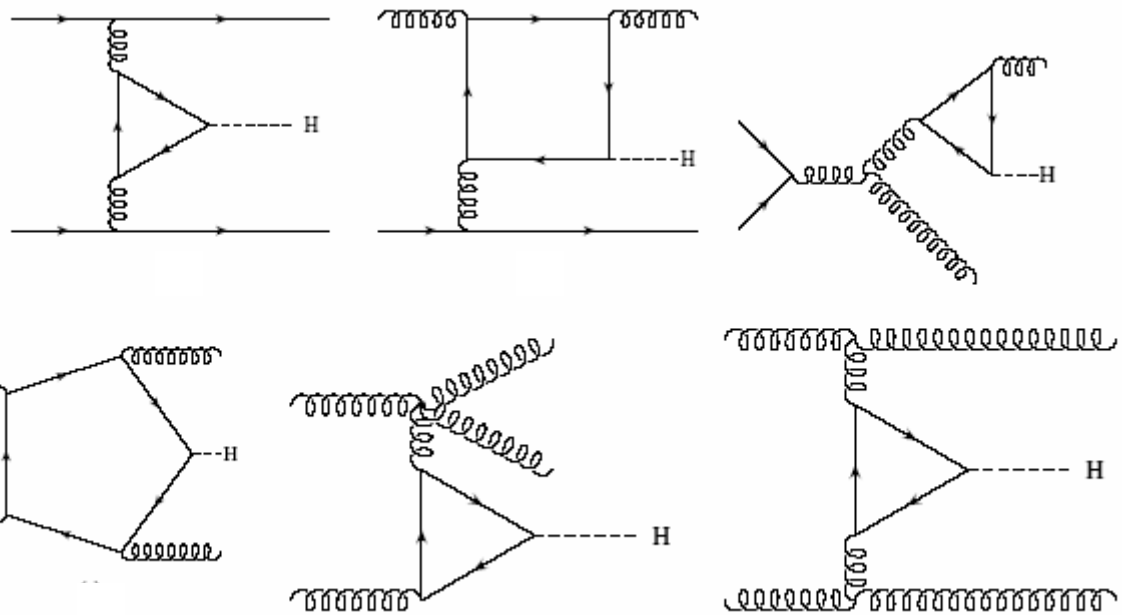


vs.

qqH (Vector Boson Fusion)



Diagrams of gg→H with two partons in the final state



LO MonteCarlo programs used

PYTHIA 6.409:

estimate qqH (VectorBosonFusion) cross section

Old parton-showers used

Hadron Level Study

ALPGEN v2.06 (May 19 2006):

estimate H+jets ggH contribution

- **Fixed order Matrix Element calculation**
- **H+jets with gg→H process only**
- **Pythia used for parton-shower simulation**

Higgs parameters:

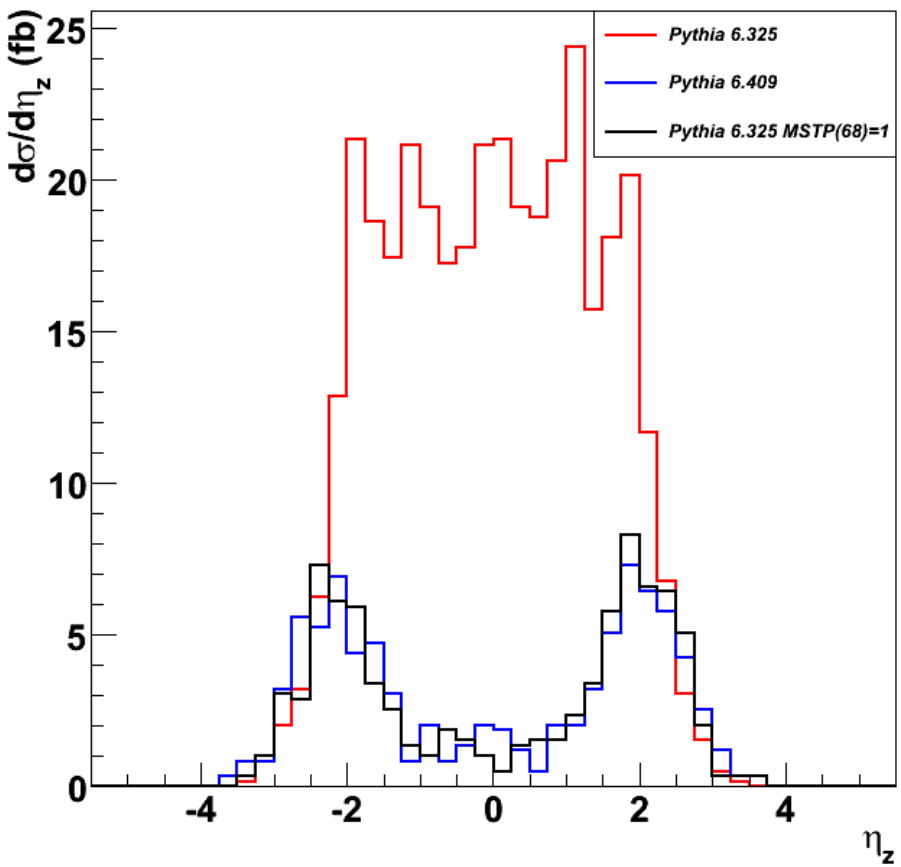
- $m_H = 120$ GeV
- $H \rightarrow ZZ \rightarrow 4\nu$: **decay forced to avoid jets from Higgs decays**

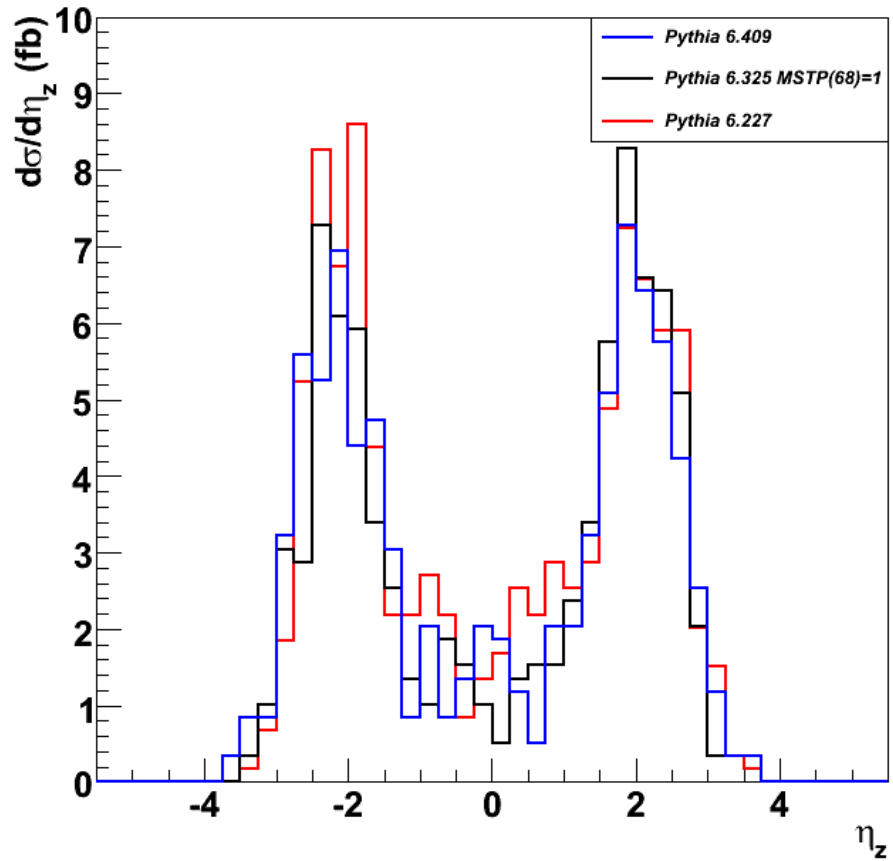
  Branching fraction not taken into account in final cross sections

Pythia Simulation of qqH comparison of v6.227(PTDRII), 6.325, 6.409

$\eta_Z = \eta^{jet3} - 0.5(\eta^{jet1} + \eta^{jet2})$

Pythia 6.325: set parameter MSTP(68)=1





Explanation of difference with old parton showers seen in Pythia 6.325 (T. Sjostrand)

Maximum evolution scale for showers was set to s-hat instead of order of m_W^2

Much larger scale allows more third-jet production & spread over a larger rapidity range

ALPGEN H+jets GENERATION

ALPGEN Parameters

- $p_{T,jet} > 20$ GeV, $|\eta_{jet}| < 5.0$, $\Delta r_{jj} > 0.5$
- Ickkw 1 (CKKW scale setting procedure needed for jet matching)
- CTEQ5L, $Q^2 = m_H^2 + p_{t,jets}^2$

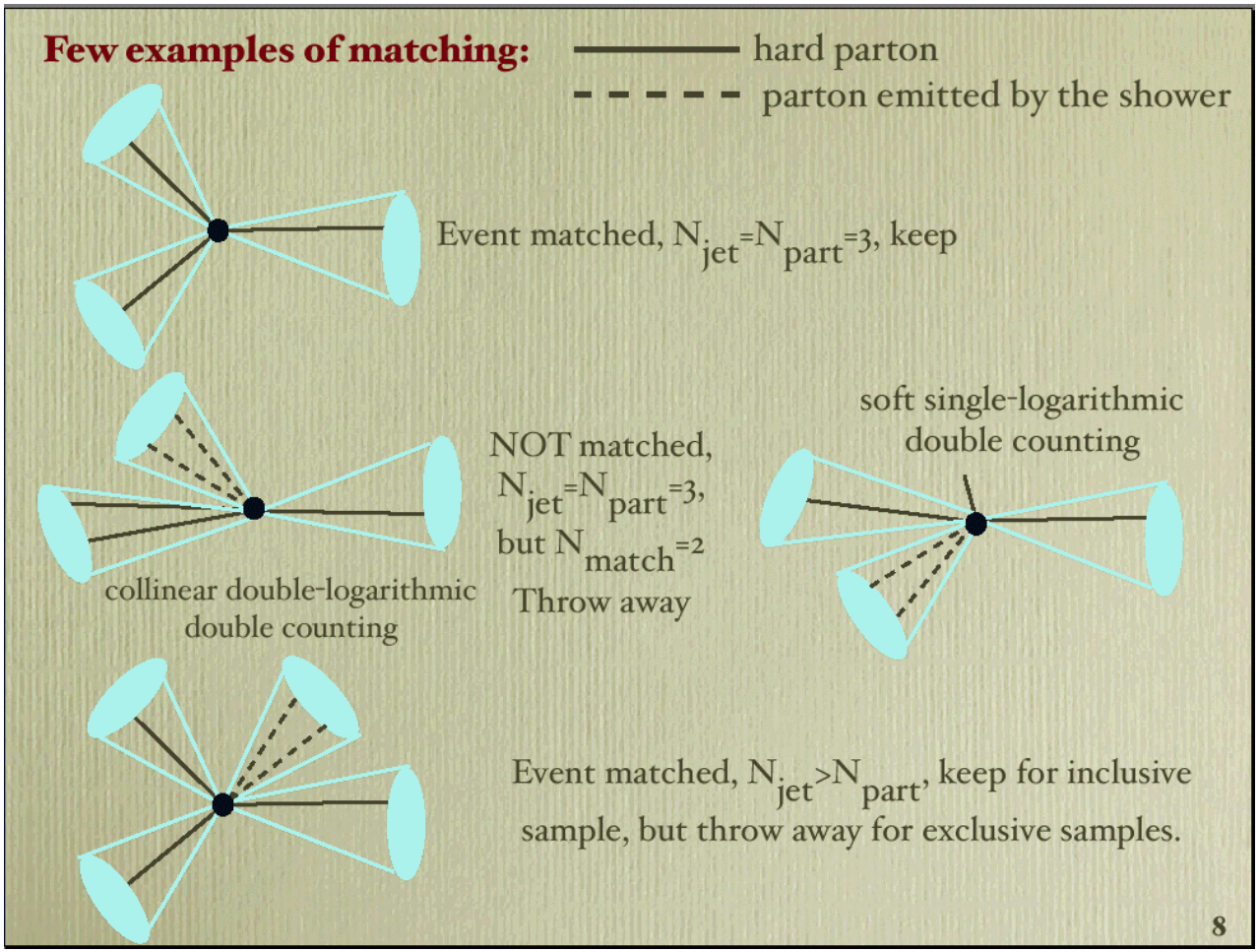
ALPGEN soft VBF preselection of two highest pt partons (j1,j2)

- $M_{j1j2} > 600$ GeV
- $\Delta\eta^{jet1,2} > 4$

	Events	VBF preselection	partonic σ(pb)
H + 1 jet	6392242	No	19.54
H + 2 jets	26825	Yes	0.693
H + 3 jets	5513	Yes	0.574
H + 4 jets	1326	Yes	0.355

MLM Matching procedure

Match hard partons with hadron level jets after pythia parton-showering
Procedure avoids double-counting



MLM matching parameters:

- **Etclus: 20 GeV**
- **Rclus = 0.5**
- **Etaclmax = 5.0**
- **Iexc = 1 (exclusive)**
  0 (inclusive)

Final VBF Hadron Level Cuts

VBF phase space selection:

- $E_T^{jet1,2} > 30$ GeV
- $\eta^{jet1,2} < 4.5$
- $M_{j1j2} > 1000$ GeV
- $\Delta\eta^{jet1,2} > 4.5$
- $\eta^{jet1} * \eta^{jet2} < 0$

Hadron Level Cuts (Pythia particle level)

Central jet veto:

- $E_T^{jet,central} > 30$ GeV
- $\eta^{jet,min}+0.5 < \eta^{jet,central} < \eta^{jet,max}-0.5$

Underlying Event Tunes in Pythia

UE Parameters

ISR Parameters

Intrinsic KT

Parameter	Tune A	Tune DWT
MSTP(81)	1	1
MSTP(82)	4	4
PARP(82)	2.0 GeV	1.9409 GeV
PARP(83)	0.5	0.5
PARP(84)	0.4	0.4
PARP(85)	0.9	1.0
PARP(86)	0.95	1.0
PARP(89)	1.8 TeV	1.96 TeV
PARP(90)	0.25	0.16
PARP(62)	1.0	1.25
PARP(64)	1.0	0.2
PARP(67)	4.0	2.5
MSTP(91)	1	1
PARP(91)	1.0	2.1
PARP(93)	5.0	15.0

R. Field

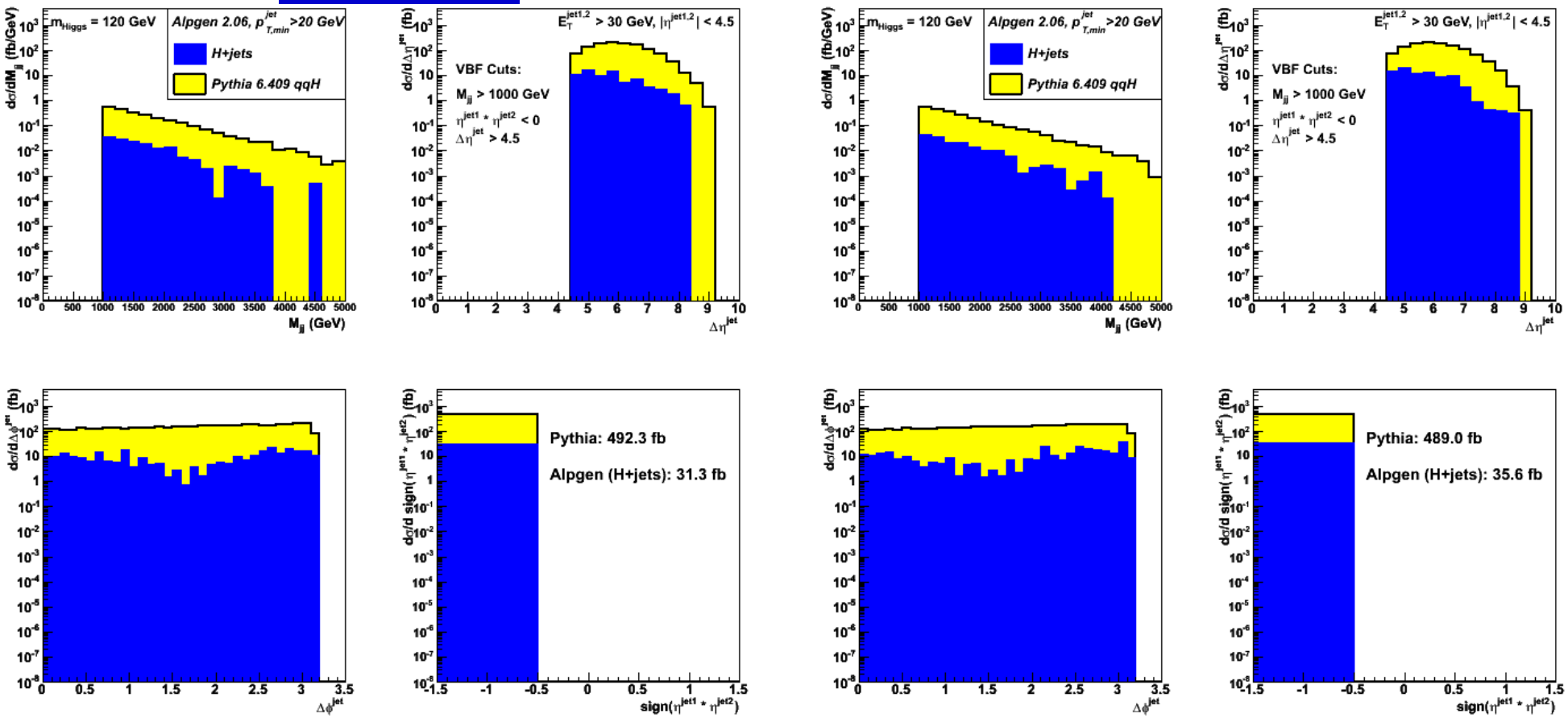
ALPGEN v 2.06 + Pythia 6.409
MLM Match Efficiency

UE:TUNE DWT	Tried	Selected	σ (mb)	MLM match	match efficiency
ALPGEN H + 1 jets	329196	100000	$5.936 \cdot 10^{-09}$	exclusive	0.30
ALPGEN H + 2 jets	26825	2307	$5.969 \cdot 10^{-11}$	exclusive	0.09
ALPGEN H + 3 jets	5513	333	$3.473 \cdot 10^{-11}$	exclusive	0.06
ALPGEN H + 4 jets	1326	224	$6.005 \cdot 10^{-11}$	inclusive	0.17

UE:TUNE A	Tried	Selected	σ (mb)	MLM match	match efficiency
ALPGEN H + 1 jets	298517	100000	$6.546 \cdot 10^{-09}$	exclusive	0.33
ALPGEN H + 2 jets	26825	2418	$6.257 \cdot 10^{-11}$	exclusive	0.09
ALPGEN H + 3 jets	5513	334	$3.484 \cdot 10^{-11}$	exclusive	0.06
ALPGEN H + 4 jets	1326	283	$7.593 \cdot 10^{-11}$	inclusive	0.21

gg→H & qqH Cross Section Comparison after VBF cuts

Tune DWT | **Pythia 6.409** | **Tune A**



Contribution of gg→H to qqH ~ 6%

σ(PYTHIA qqH) = 492.3 fb

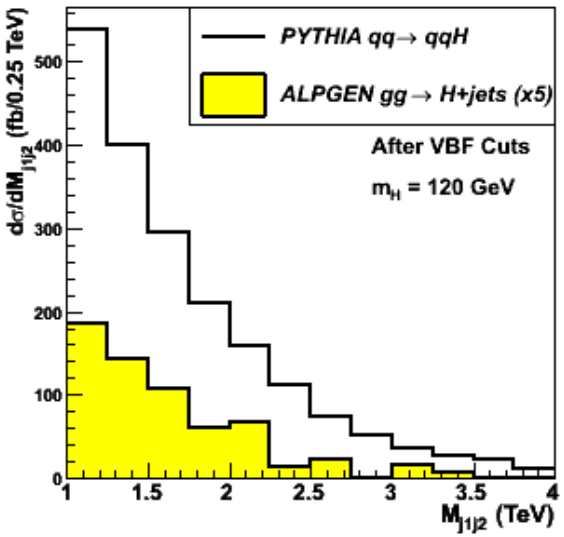
σ(ALPGEN H+jets) = 31.3 fb

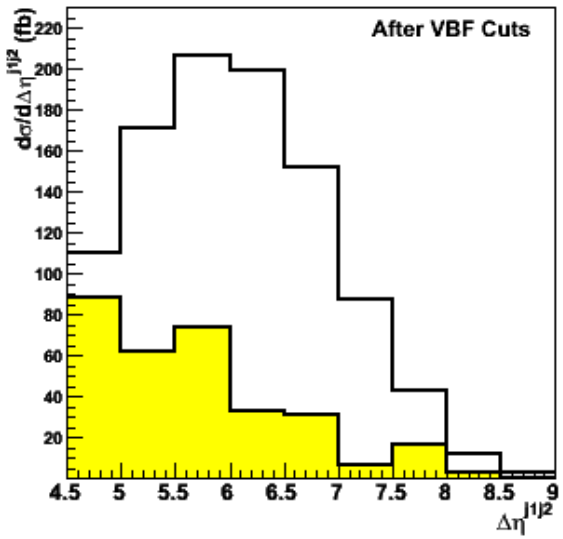
Contribution of gg→H to qqH ~ 7%

σ(PYTHIA qqH) = 489.0 fb

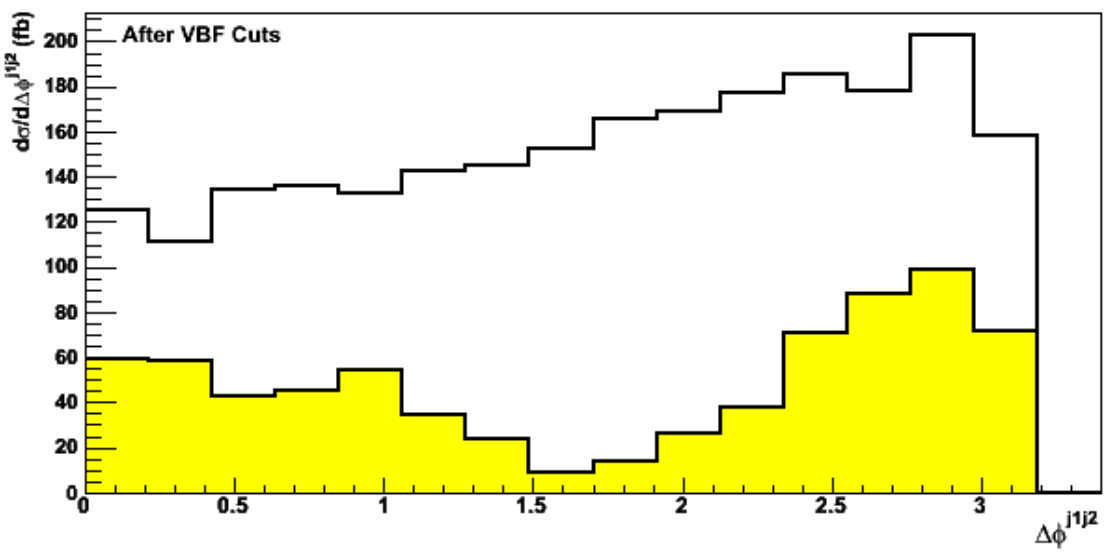
σ(ALPGEN H+jets) = 35.6 fb

gg→H & qqH Cross Section Comparison after VBF cuts





Tune DWT



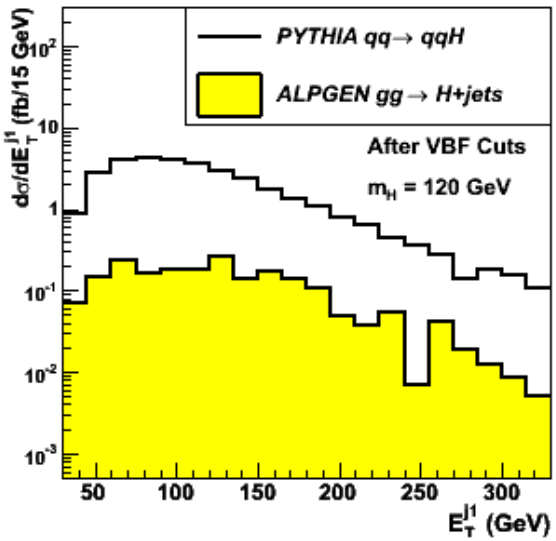
Contribution of gg→H to qqH

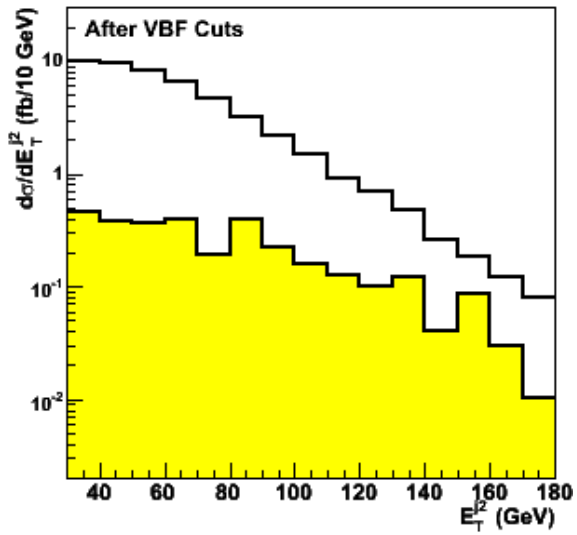
~ 6%

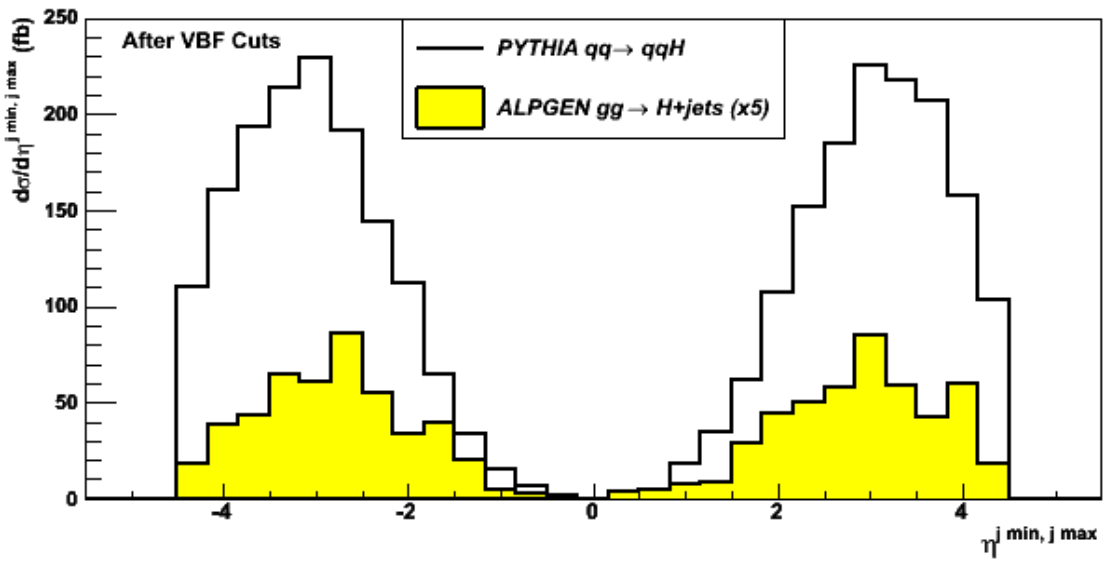
σ(PYTHIA qqH) = 492.3 fb

σ(ALPGEN H+jets) = 31.3 fb

Tagging Jet distributions after VBF cuts

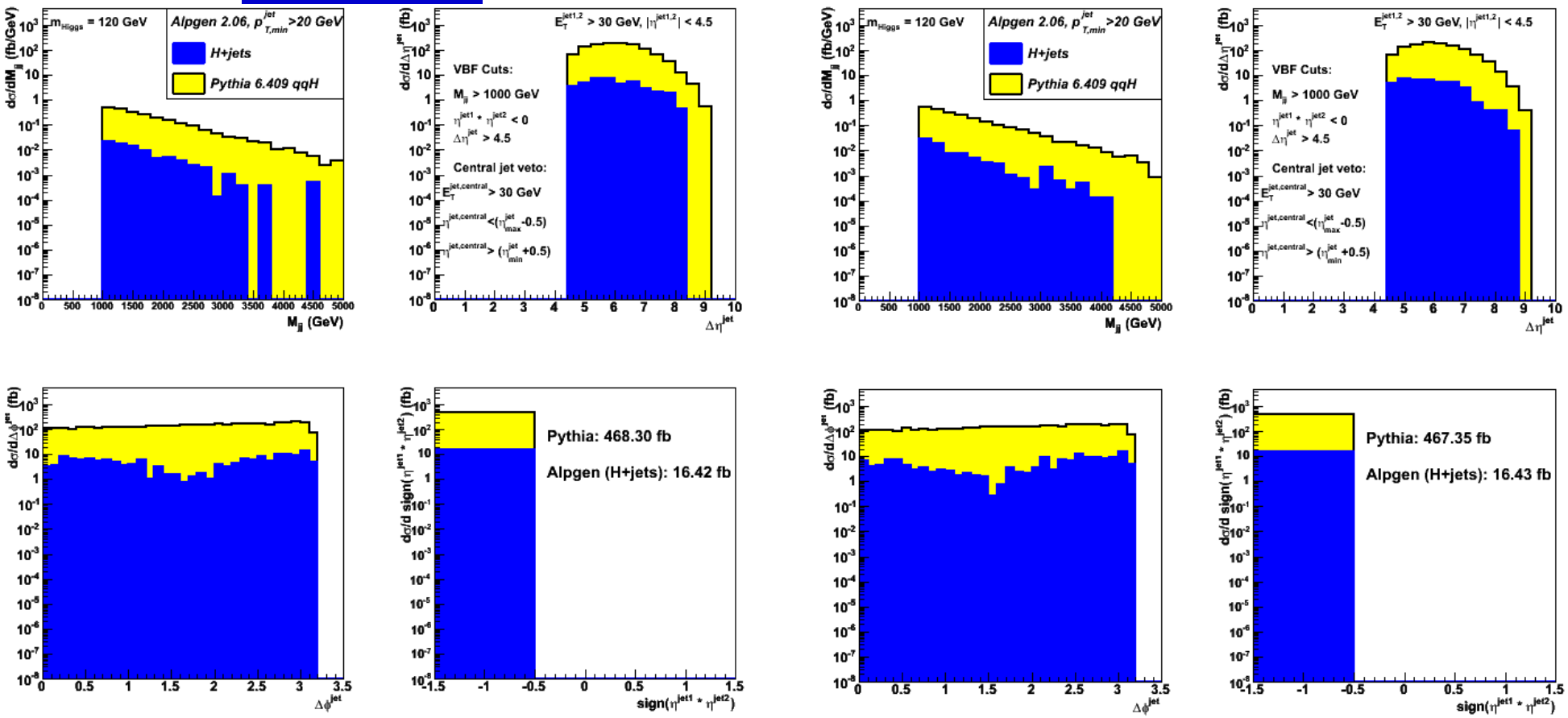






gg→H & qqH Cross Section Comparison after VBF cuts & Central Jet Veto

Tune DWT | **Pythia 6.409** | **Tune A**



Contribution of gg→H to qqH ~ 4%

σ(PYTHIA qqH) = 468.30 fb

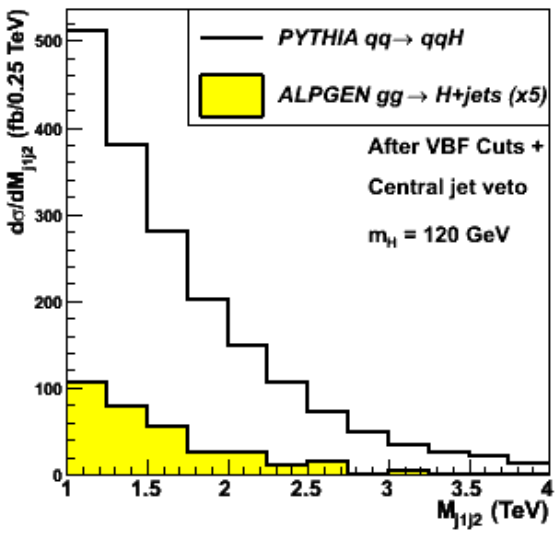
σ(ALPGEN H+jets) = 16.42 fb

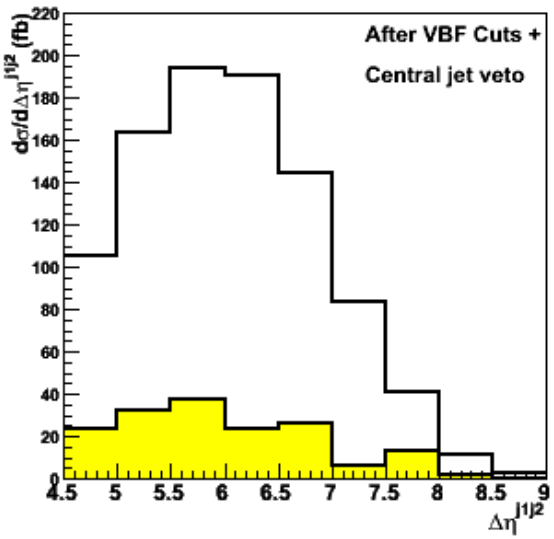
Contribution of gg→H to qqH ~ 4%

σ(PYTHIA qqH) = 467.35 fb

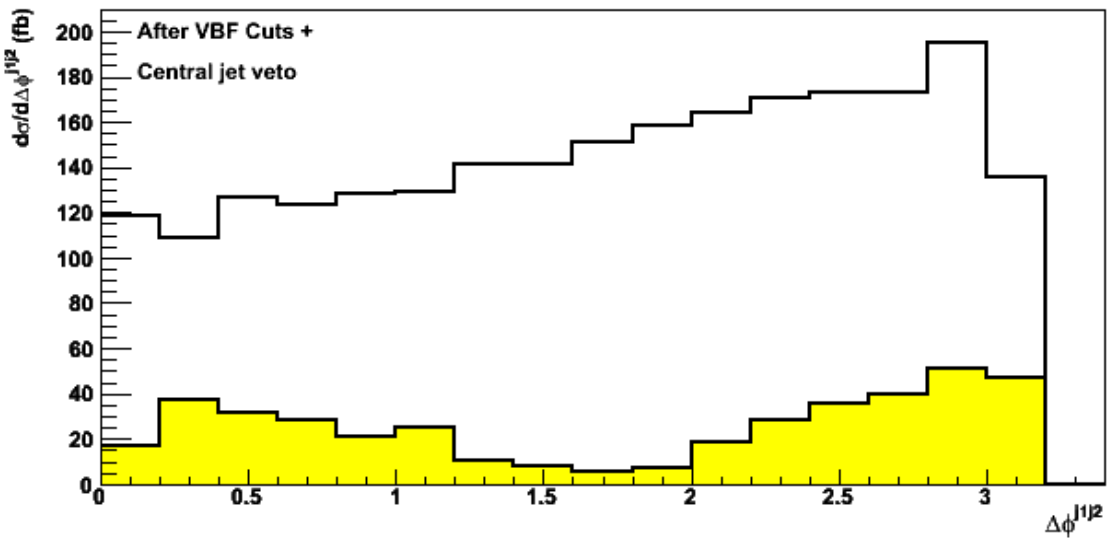
σ(ALPGEN H+jets) = 16.43 fb

gg→H & qqH Cross Section Comparison after VBF cuts





Tune DWT



Contribution of gg→H to qqH

~ 4%

σ(PYTHIA qqH) = 468.30 fb

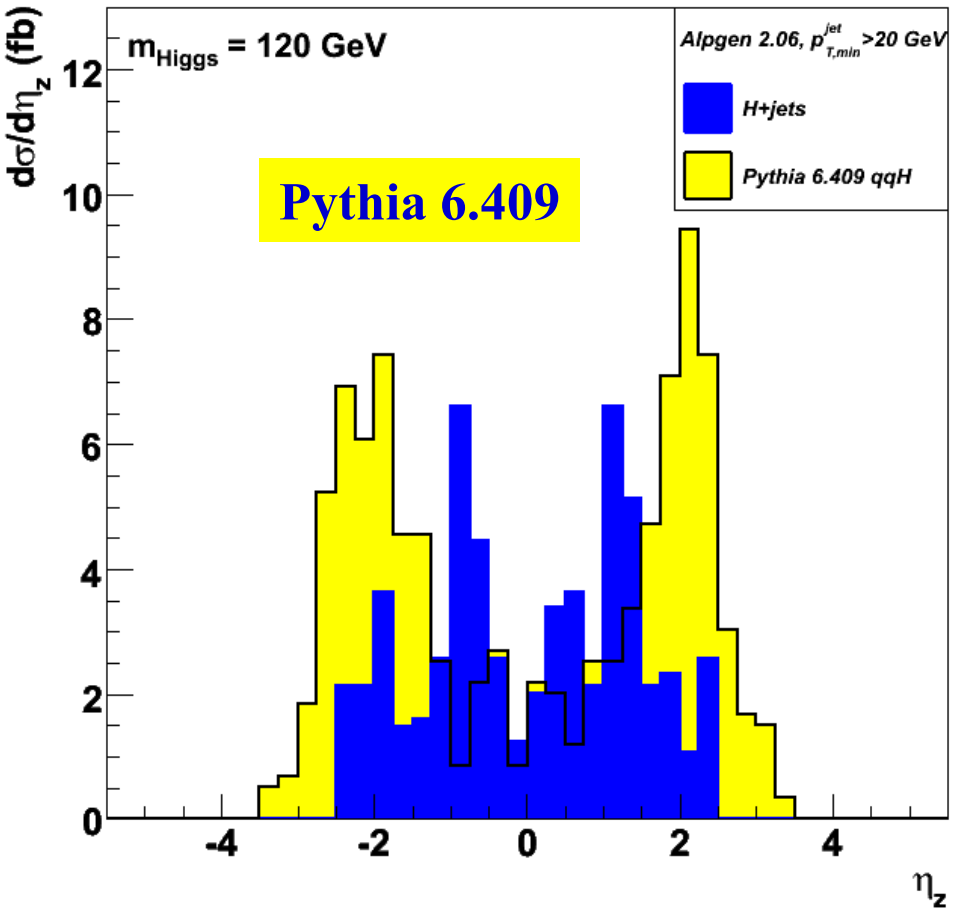
σ(ALPGEN H+jets) = 16.42 fb

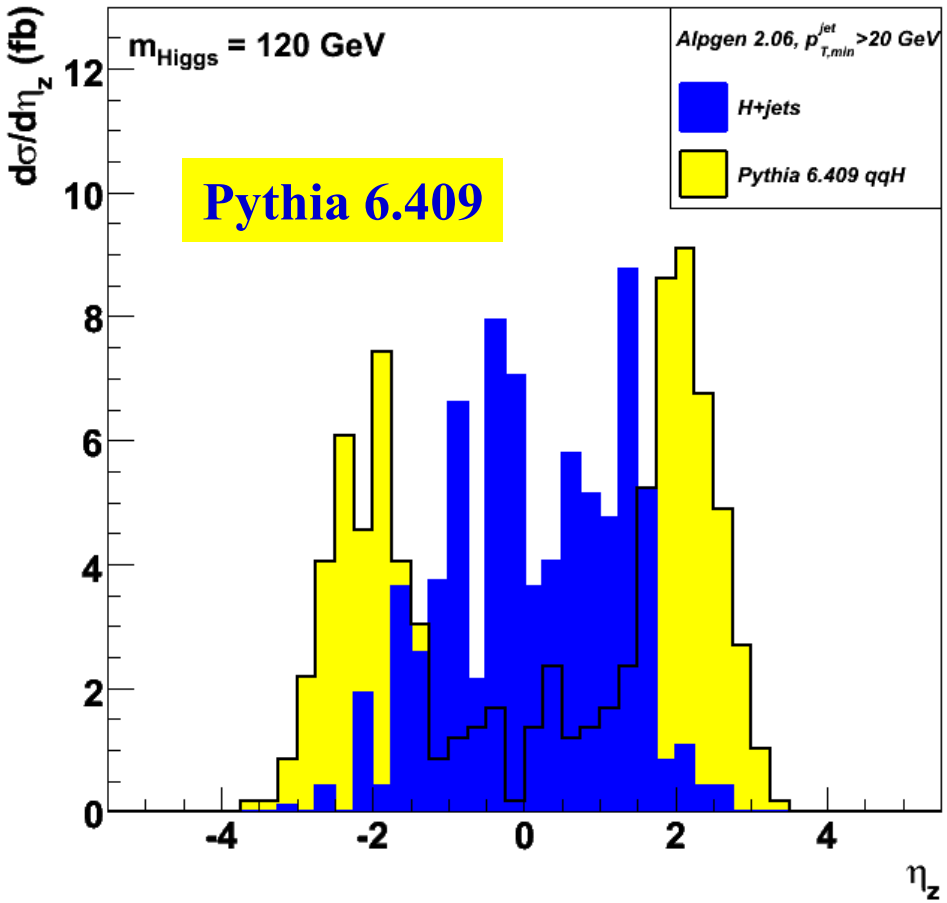
Central Jet Veto: Zeppenfeld plot

Tune DWT

$\eta_z = \eta^{jet3} - 0.5(\eta^{jet1} + \eta^{jet2})$

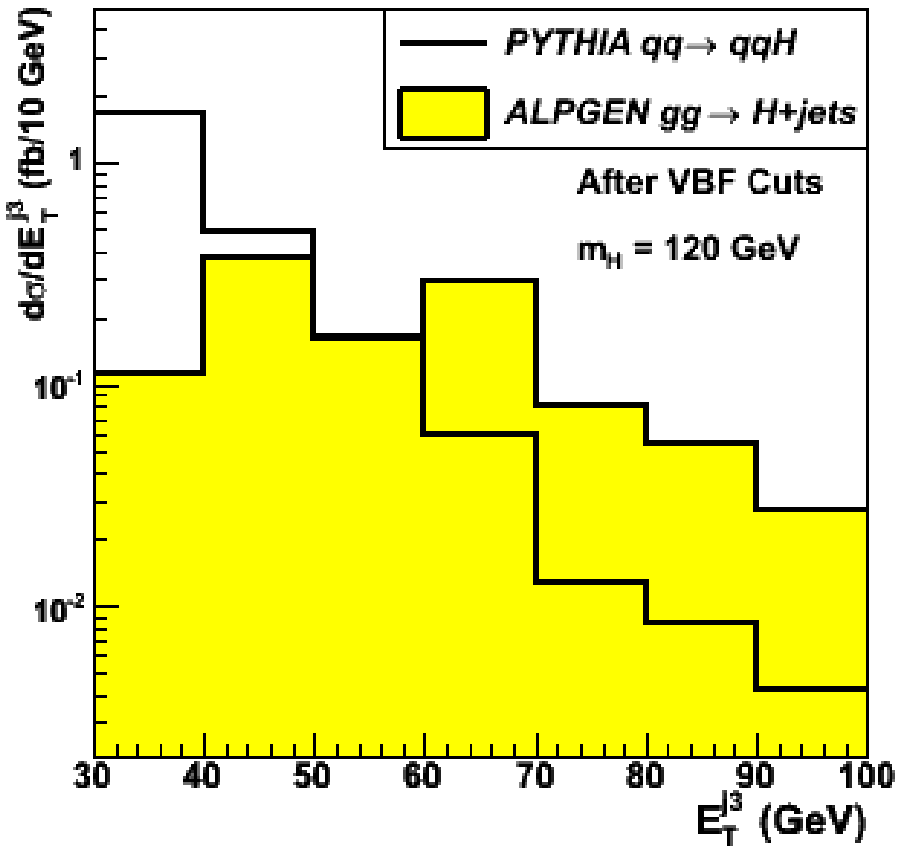
Tune A

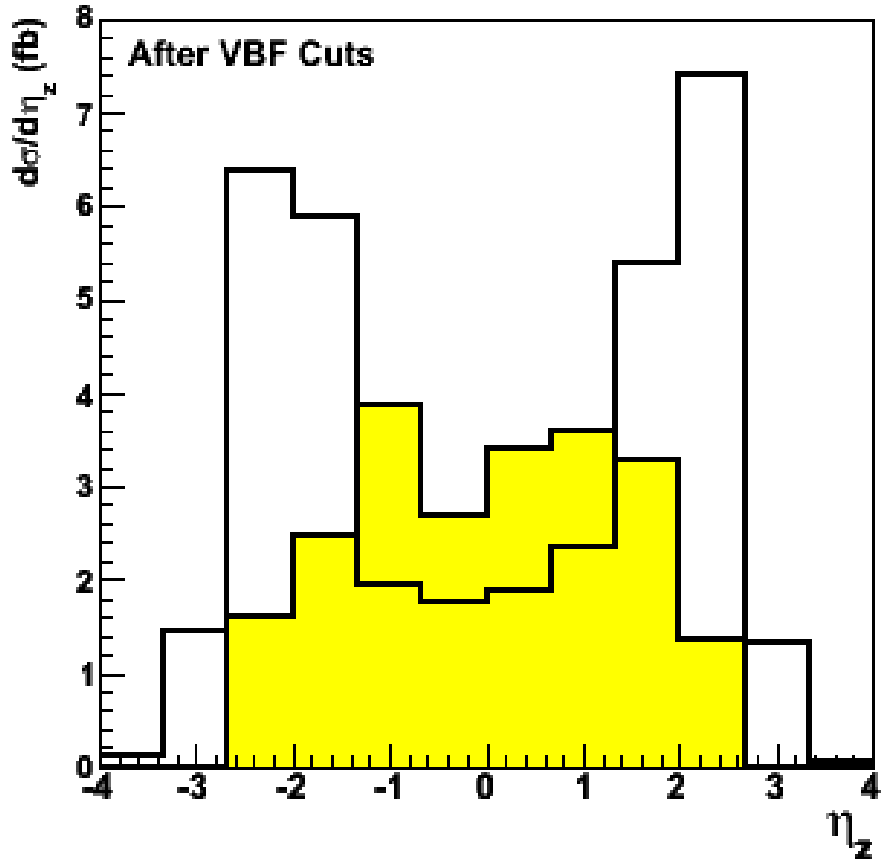




qqH has a clear peak structure compared to H+jets coming from QCD radiation of gg→H

Central Jet Veto: Zeppenfeld plot





qqH has a clear peak structure compared to H+jets coming from QCD radiation of gg→H

ALPGEN: Result Stability Check

VBF selection:

- $E_T^{jet1,2} > 30$ GeV, $\eta^{jet1,2} < 4.5$
- $M_{j1j2} > 1000$ GeV, $\Delta\eta^{jet1,2} > 4.5$
- $\eta^{jet1} * \eta^{jet2} < 0$

Central jet veto:

- $E_T^{jet,central} > 30$ GeV
- $\eta^{jet,min}+0.5 < \eta^{jet,central} < \eta^{jet,max}-0.5$

Tune DWT

after VBF cut

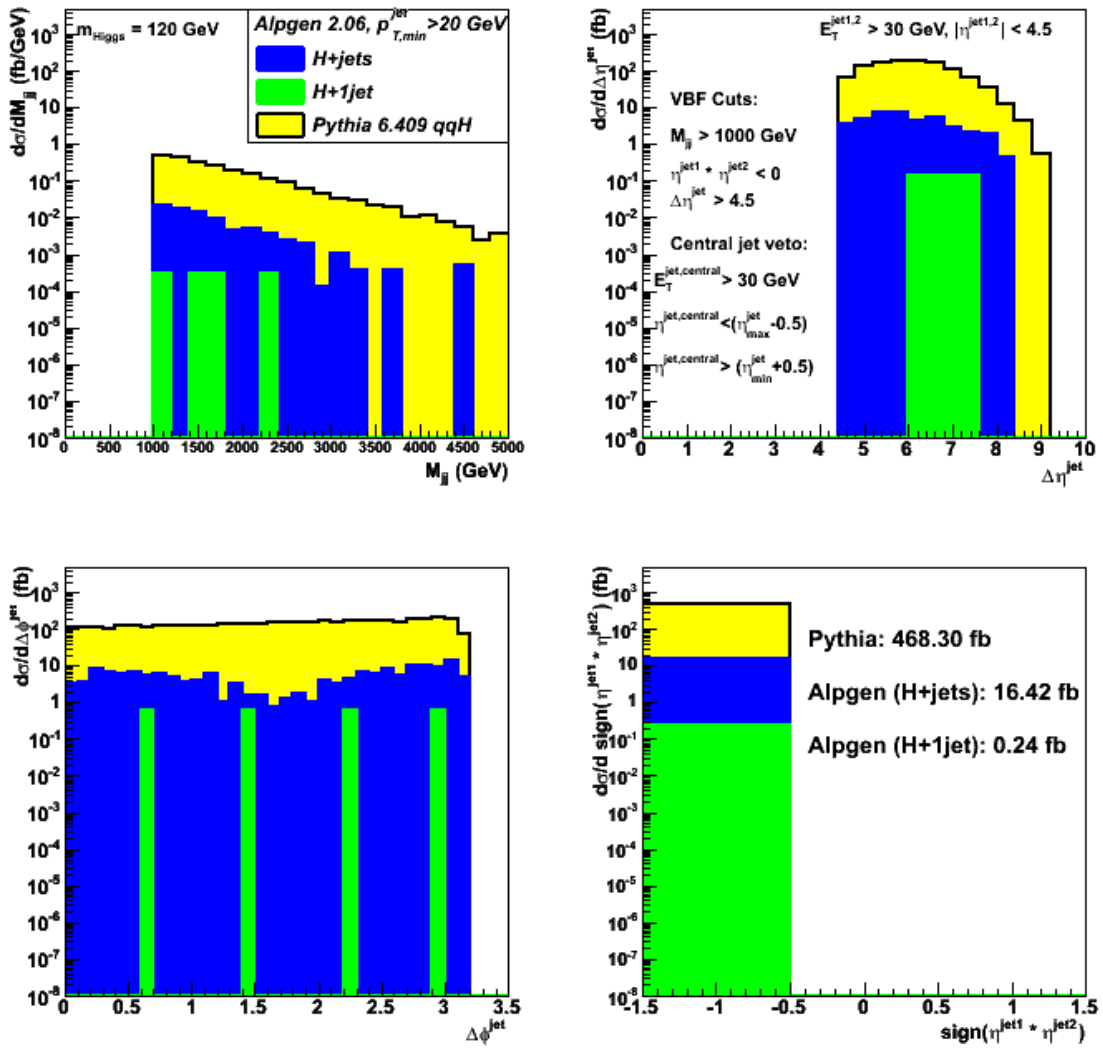
	H+jets: σ(fb)	ggH/qqH
VBF Preselection in the ALPGEN generation:		
H+1jet(exc)+H+2jet(exc)+H+3jet(exc)+H+4jet(inc)	31.3	0.06
H+1jet(exc)+H+2jet(exc)+H+3jet(inc)	39.8	0.08

after VBF cut & central jet veto

VBF Preselection in the ALPGEN generation:		
H+1jet(exc)+H+2jet(exc)+H+3jet(exc)+H+4jet(inc)	16.4	0.04
H+1jet(exc)+H+2jet(exc)+H+3jet(inc)	20.0	0.04
Inclusive ALPGEN generation:		
H+1jet(exc)+H+2jet(exc)+H+3jet(inc)	24.6	0.05

Contribution of H+1jet
VBF cuts + jet veto

Contribution of H+1jet: ~1%



H + 2 jets Parton-level calculation
D. Zeppenfeld

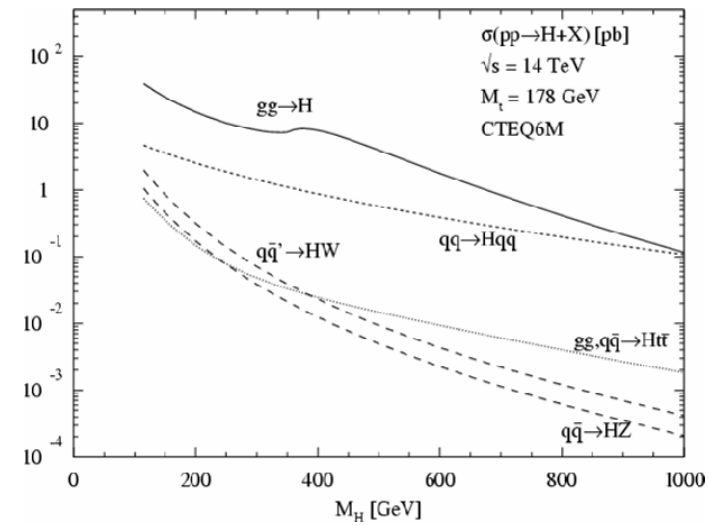
- INCLUSIVE cuts to define $H + 2$ jets

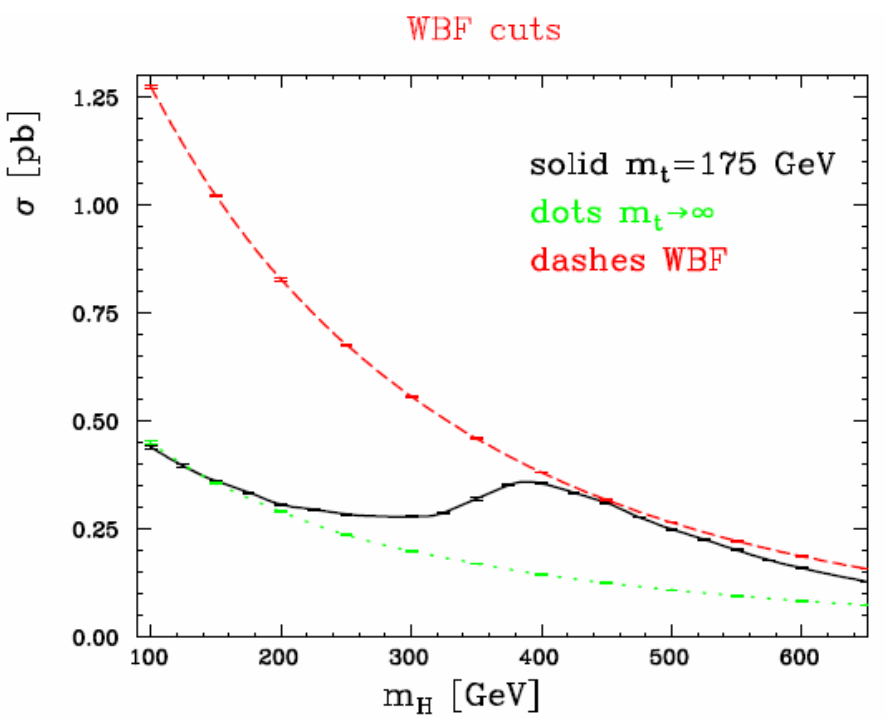
$$p_{T j} > 20\,\text{GeV} \qquad |\eta_j| < 5 \qquad R_{jj} = \sqrt{(\eta_{j_1} - \eta_{j_2})^2 + (\phi_{j_1} - \phi_{j_2})^2} > 0.6$$

- WBF cuts to enhance WBF over gluon fusion

  In addition to the previous ones, we impose

$$|\eta_{j_1} - \eta_{j_2}| > 4.2 \qquad \eta_{j_1} \cdot \eta_{j_2} < 0 \qquad m_{jj} > 600\,\text{GeV}$$





Dieter's numbers for m_H=120 GeV

σ(VBF) $\approx$ 1.2 pb

σ(ggH) $\approx$ 0.4 pb

σ(ggH) / σ(VBF) $\approx$ 0.3

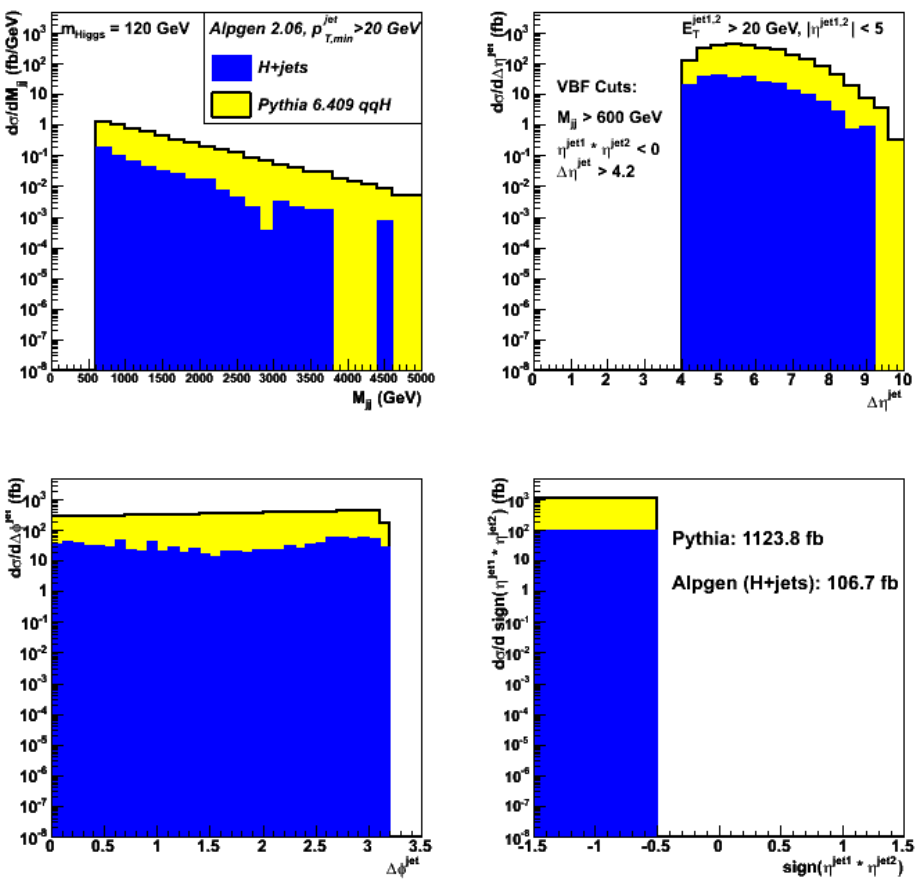
Comparison to H + 2 jets Parton-level calculation

Tune DWT

Pythia 6.409

VBF phase space selection (hadron level):

- $E_T^{jet1,2} > 20$ GeV, $\eta^{jet1,2} < 5$
- $\Delta\eta^{jet1,2} > 4.2$, $\eta^{jet1} * \eta^{jet2} < 0$, $M_{j1j2} > 600$ GeV



VBF presel. ALPGEN generation used:

H+1jet(exc)+H+2jet(exc)+
H+3jet(exc)+H+4jet(inc)

Dieter's parton level numbers:

$\sigma(VBF) \approx 1.2$ pb

$\sigma(ggH) \approx 0.4$ pb

$\sigma(ggH) / \sigma(VBF) \approx 0.3$

Hadron level cross sections:

σ(Pythia qqH) = 1123.8 fb

σ(Alpgen H+jets) = 106.7 fb

$\sigma(ggH)/ \sigma(VBF) \approx 0.09$

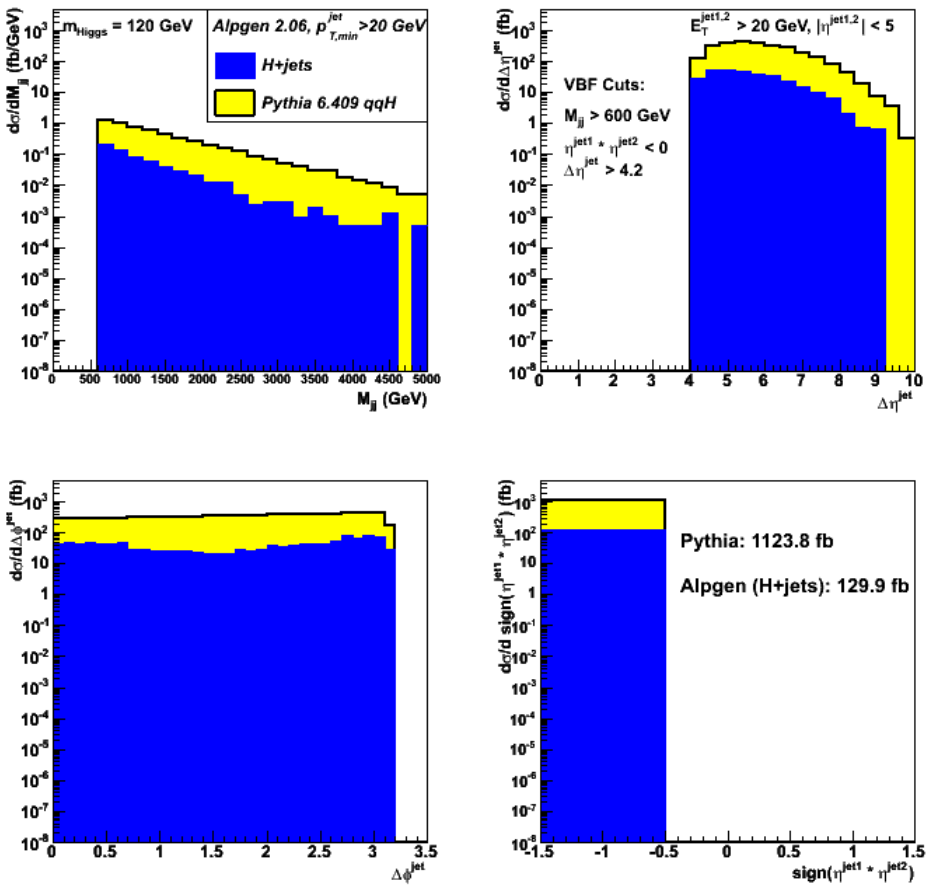
Comparison to H + 2 jets Parton-level calculation

Tune DWT

Pythia 6.409

VBF phase space selection (hadron level):

- $E_T^{jet1,2} > 20$ GeV, $\eta^{jet1,2} < 5$
- $\Delta\eta^{jet1,2} > 4.2$, $\eta^{jet1} * \eta^{jet2} < 0$, $M_{j1j2} > 600$ GeV



VBF presel. ALPGEN generation used:
H+1jet(exc)+H+2jet(exc)+H+3jet(inc)

Dieter's parton level numbers:

$\sigma(VBF) \approx 1.2$ pb

$\sigma(ggH) \approx 0.4$ pb

$\sigma(ggH) / \sigma(VBF) \approx 0.3$

Hadron level cross sections:

σ(Pythia qqH) = 1123.8 fb

σ(Alpgen H+jets) = 129.9 fb

$\sigma(ggH)/ \sigma(VBF) \approx 0.12$

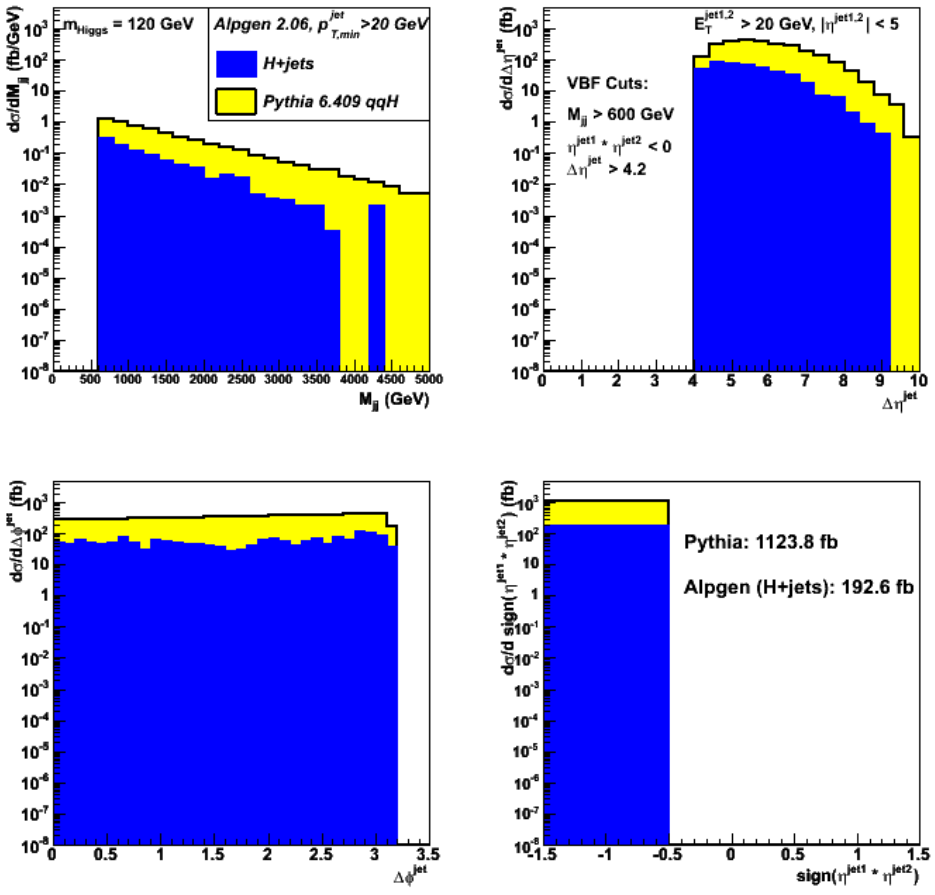
Comparison to H + 2 jets Parton-level calculation

Tune DWT

Pythia 6.409

VBF phase space selection (hadron level):

- $E_T^{jet1,2} > 20$ GeV, $\eta^{jet1,2} < 5$
- $\Delta\eta^{jet1,2} > 4.2$, $\eta^{jet1} * \eta^{jet2} < 0$, $M_{j1j2} > 600$ GeV



Inclusive ALPGEN generation used:
H+1jet(exc)+H+2jet(exc)+H+3jet(inc)

Dieter's parton level numbers:

$\sigma(VBF) \approx 1.2$ pb

$\sigma(ggH) \approx 0.4$ pb

$\sigma(ggH) / \sigma(VBF) \approx 0.3$

Hadron level cross sections:

σ(Pythia qqH) = 1123.8 fb

σ(Alpgen H+jets) = 192.6 fb

$\sigma(ggH)/ \sigma(VBF) \approx 0.17$

Summary

- **First look at H+jets in the latest ALPGEN version v2.06 which contains the gg→H contribution**

- **PYTHIA 6.409 qqH sample and ALPGEN v2.06 H+jets sample are compared with final Vector Boson Fusion selection and Central Jet Veto at Hadron Level**

- **Tune A and Tune DWT of the underlying event in PYTHIA give similar results**

- **The contribution of gg→H +QCD-radiation events is estimated to be ~4% of the qqH sample with final VBF selection and Central Jet Veto**