Jet Substructure as a new Higgs Search
at the LHC

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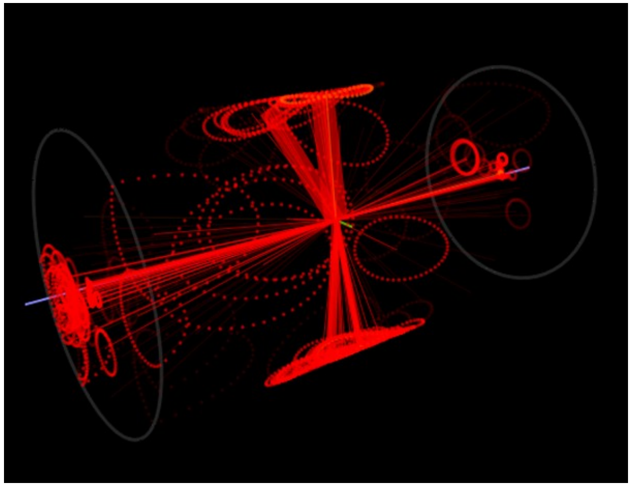

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Low Mass Higgs Search

- A low mass SM Higgs is hardish to discover at LHC
- Main production/decay channel $gg \rightarrow H \rightarrow bb$ swamped by large backgrounds
- Forced into a smaller production cross-section and/or a smaller branching ratio to find a cleaner signal
- At the Tevatron ZH/WH are two of the main channels for a low mass Higgs discovery
- Considered impossible at the LHC
- But would also give access to ZH and WH couplings (as well as discovering the Higgs...)

Associated Higgs Production

- Production of H in association with W or Z
- In the ATLAS TDR considered impossible
- Small S/B
- Detector acceptance
- Issues with systematics, control of background shapes
- “very difficult ... even under the most optimistic assumptions”

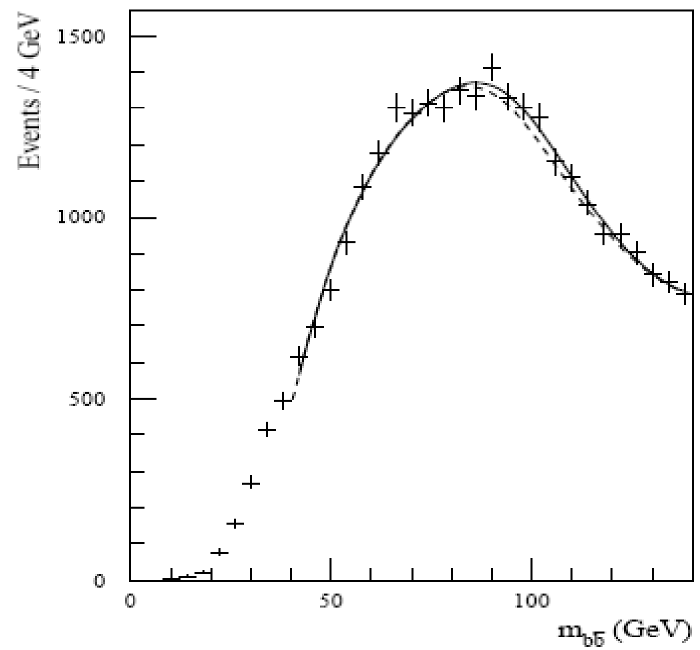


Figure 19-7 Expected *WH* signal with $H \rightarrow b\bar{b}$ above the summed background for m_H = 100 GeV and for an integrated luminosity of 30 fb^{-1}. The dashed line represents the shape of the background.

Associated Higgs Production

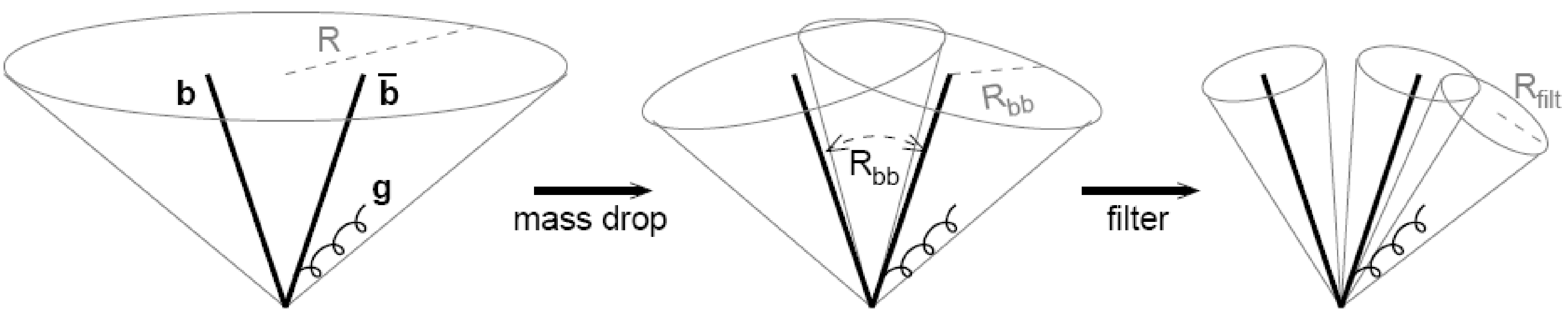
- However if we go to high pT things simplify
  - Simpler event topology
  - Most of cross-section within acceptance
  - No more backgrounds at the same intrinsic scale
- Cutting at 200GeV does throw away 95% of our signal events
- Boosted Higgs decay gives two b-quarks, frequently very close together
  - Must carefully consider hadronic reconstruction

Jet Substructure

- If a highly boosted Higgs decays, often reconstruct a single high pT massive jet in the event
- As well as high mass, such jets have distinctive structure due to the relatively hard splitting of the Higgs decay
- Pure QCD processes can emulate this but they tend not to
- Previous work in this area includes "y-scale" approach using kT algorithm (see talk by E. Oczan in 30 minutes)

The Procedure

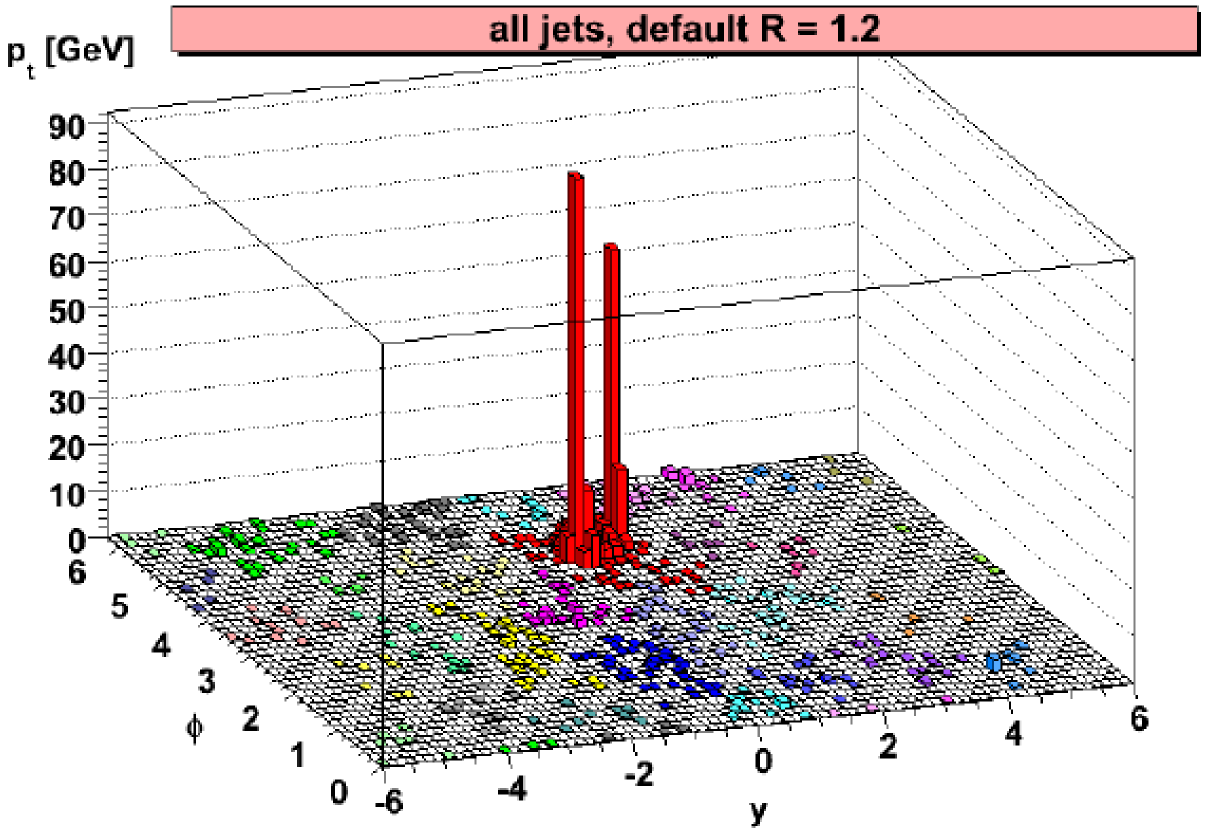
- Using the Cambridge-Aachen jet algorithm
  - Recombines closest pair of objects in the event up to R
- When finding a jet that passes a pT cut
  - Clustering can be undone one step at a time
  - Reverse clustering until a large drop in mass is observed
  - Check this splitting is not too asymmetric
  - Recluster remaining constituents with smaller R



$pp \to ZH \to \nu\bar{\nu}b\bar{b}$, @14 TeV, $m_H = 115$ GeV

SIGNAL

Herwig 6.510 + Jimmy 4.31 + FastJet 2.3



These slides pirated from an excellent talk by G. Salam at SUSY08

Zbb BACKGROUND

Cluster event, C/A, R=1.2

arbitrary norm.

$pp \to ZH \to \nu\bar{\nu}b\bar{b}$, @14 TeV, $m_H = 115$ GeV

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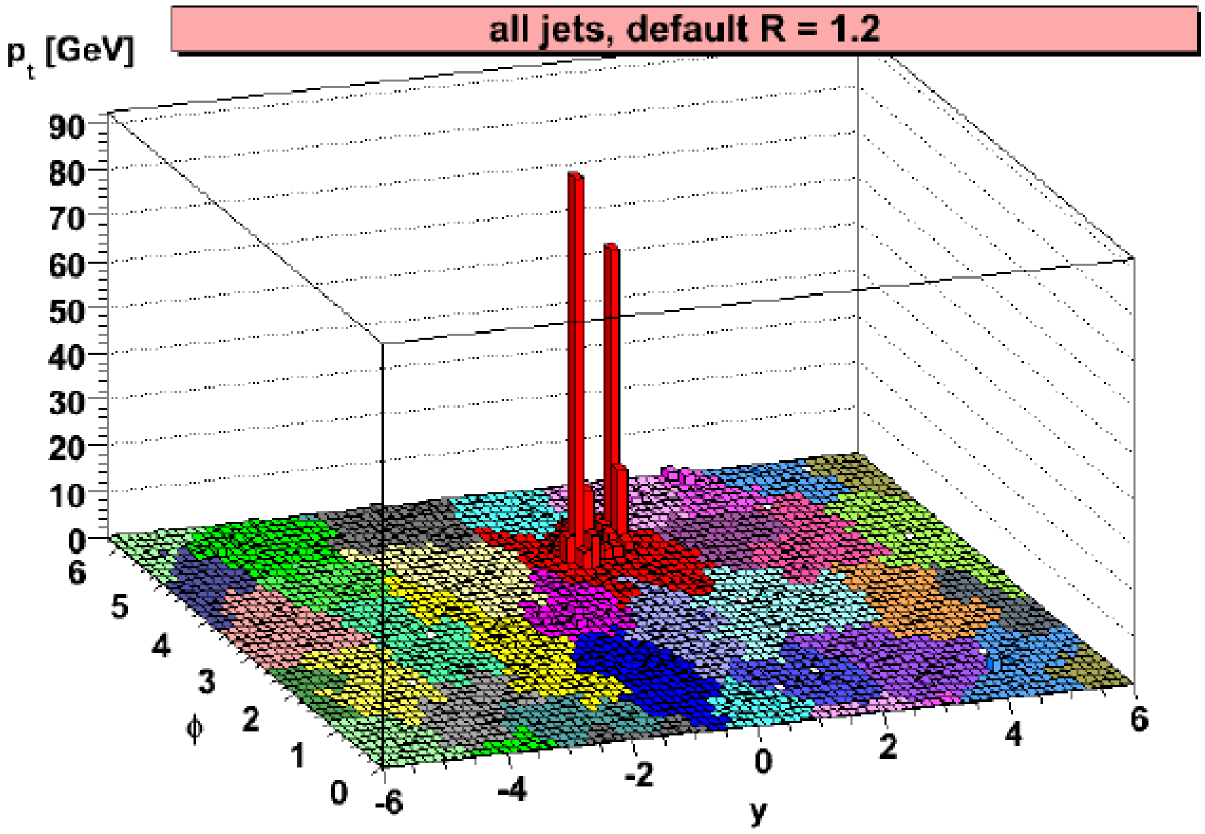

Zbb BACKGROUND

Fill it in, → show jets more clearly

arbitrary norm.

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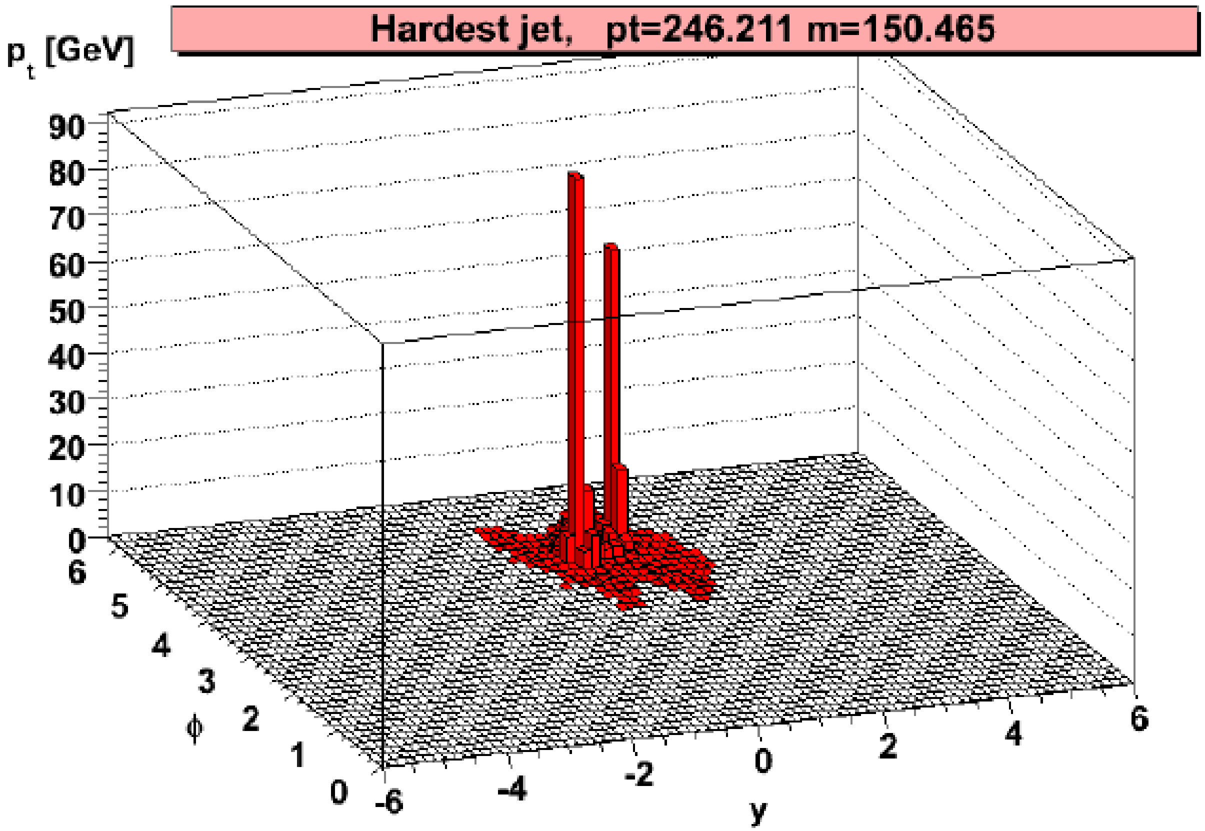
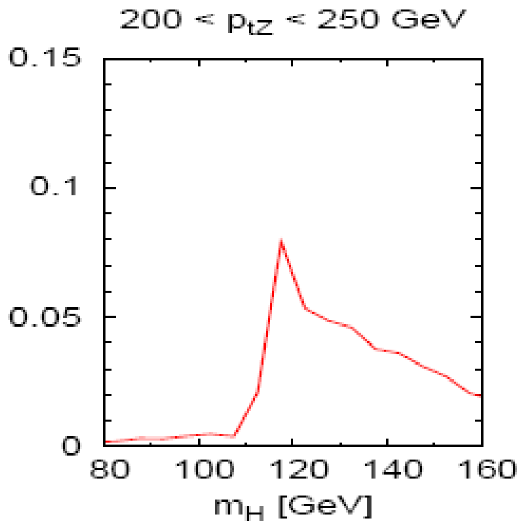
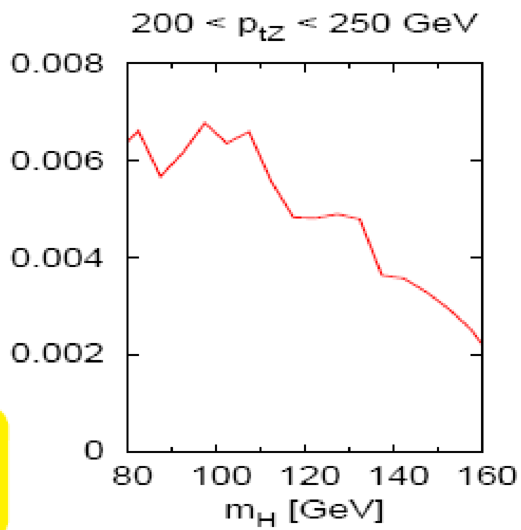


SIGNAL



Zbb BACKGROUND



Consider hardest jet, $m = 150$ GeV

arbitrary norm.

$pp \to ZH \to \nu\bar{\nu}b\bar{b}$, @14 TeV, $m_H = 115$ GeV

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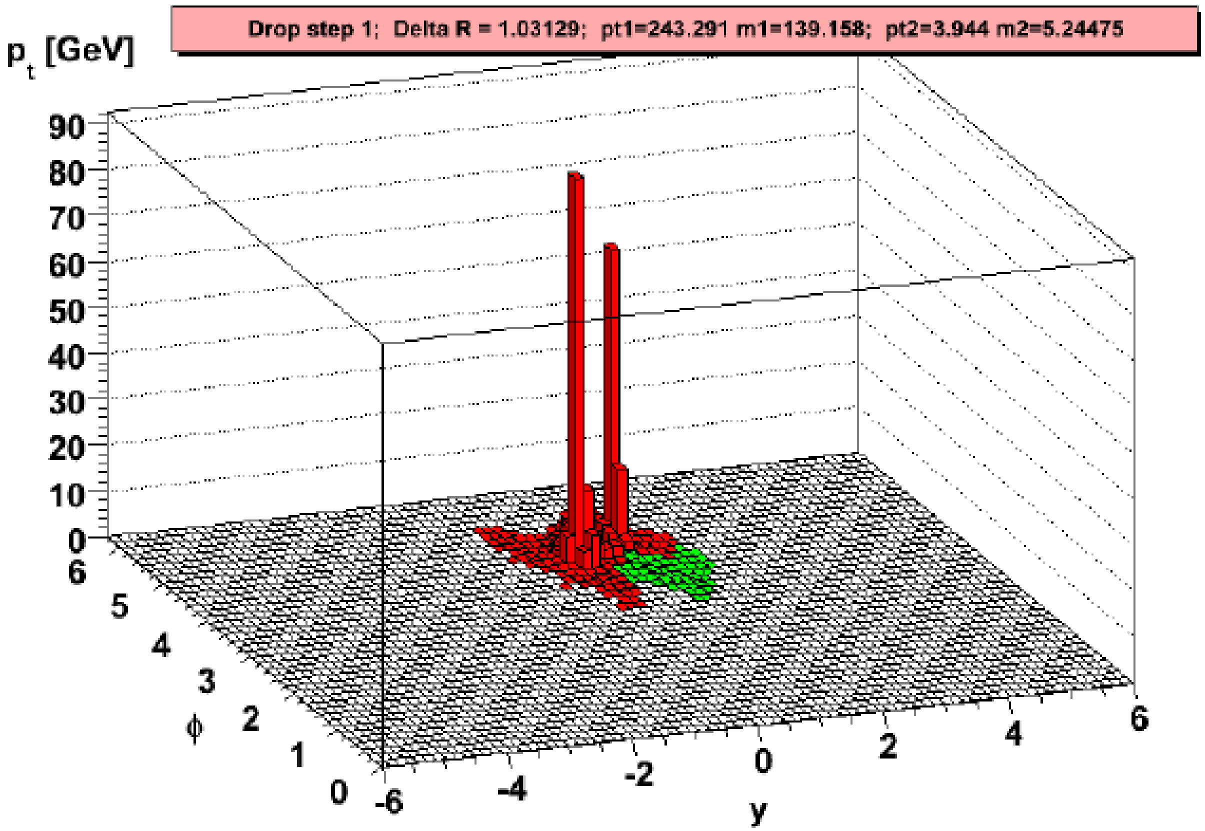

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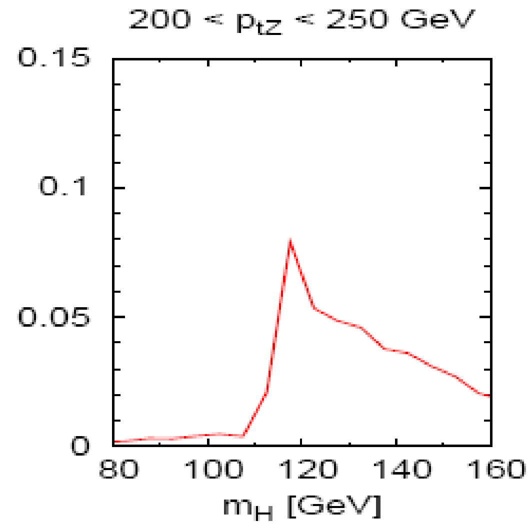
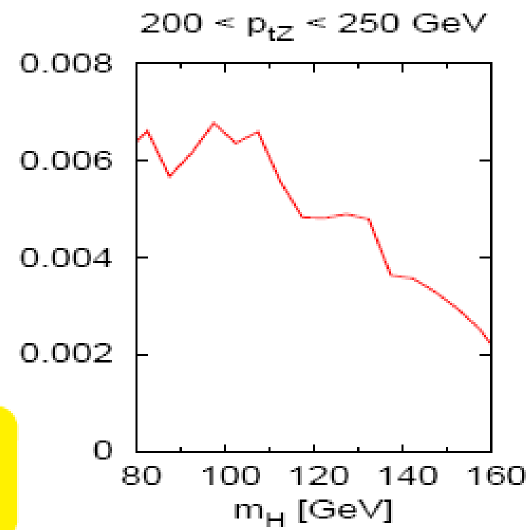


Zbb BACKGROUND

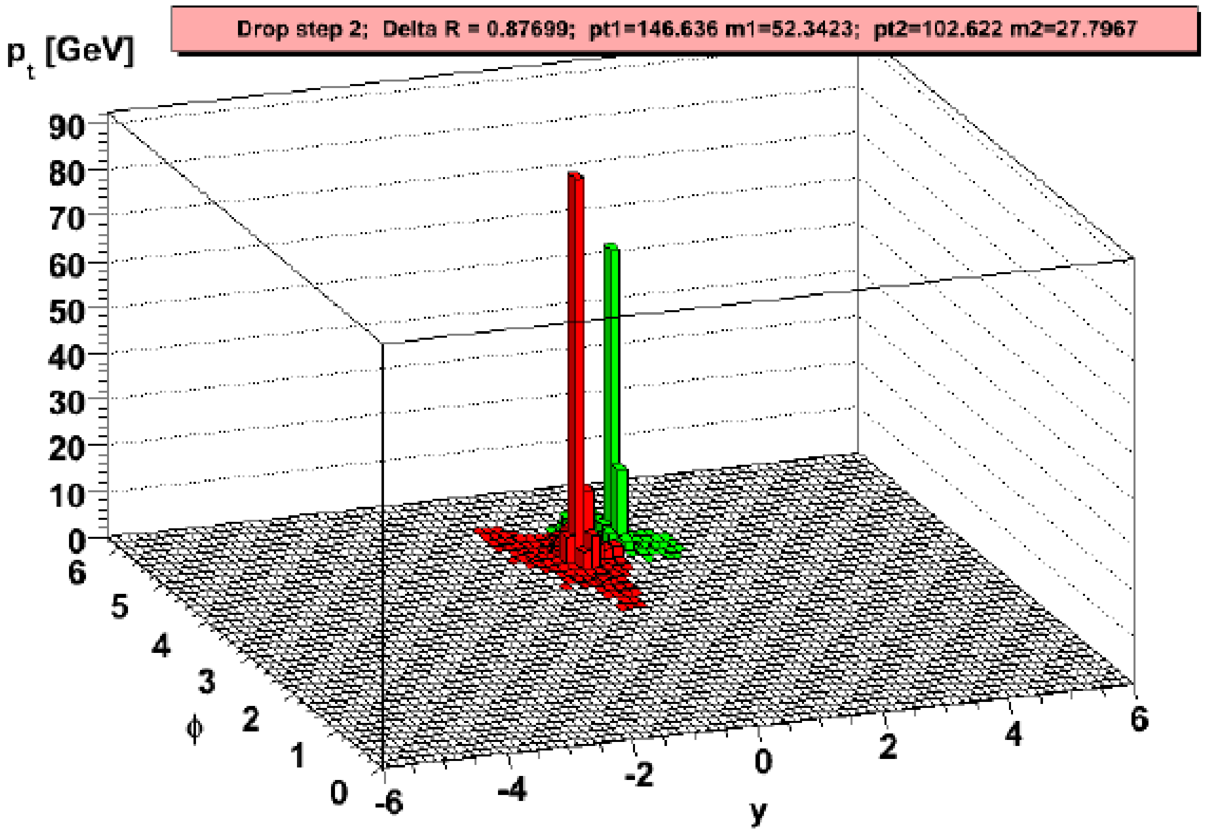


split: $m = 150$ GeV, $\frac{\max(m_1, m2)}{m} = 0.92 \to$ repeat

arbitrary norm.

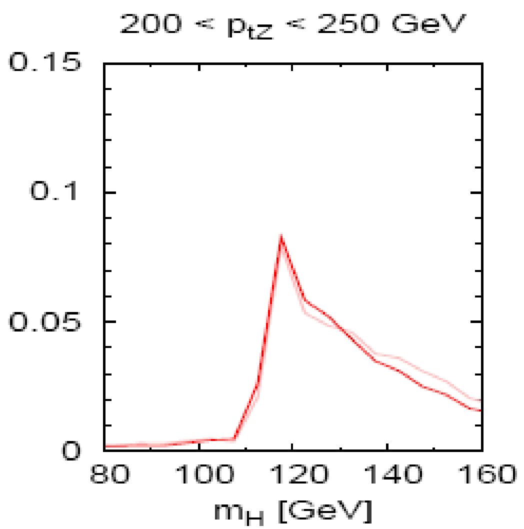
$pp \to ZH \to \nu\bar{\nu}b\bar{b}$, @14 TeV, $m_H = 115$ GeV

Herwig 6.510 + Jimmy 4.31 + FastJet 2.3

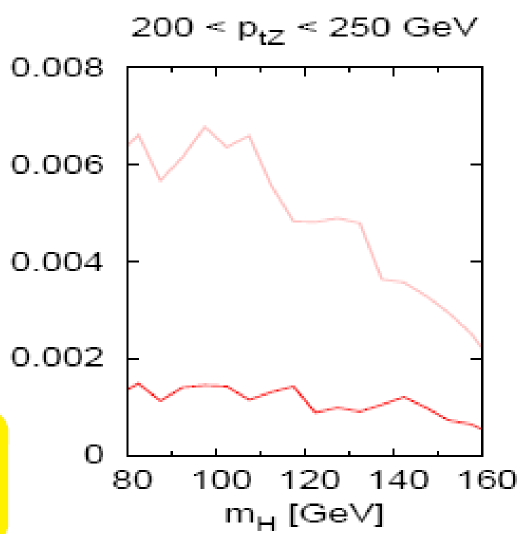


split: $m = 139$ GeV, $\frac{\max(m_1, m2)}{m} = 0.37 \to$ mass drop

SIGNAL



Zbb BACKGROUND



arbitrary norm.

$pp \to ZH \to \nu\bar{\nu}b\bar{b}$, @14 TeV, $m_H = 115$ GeV

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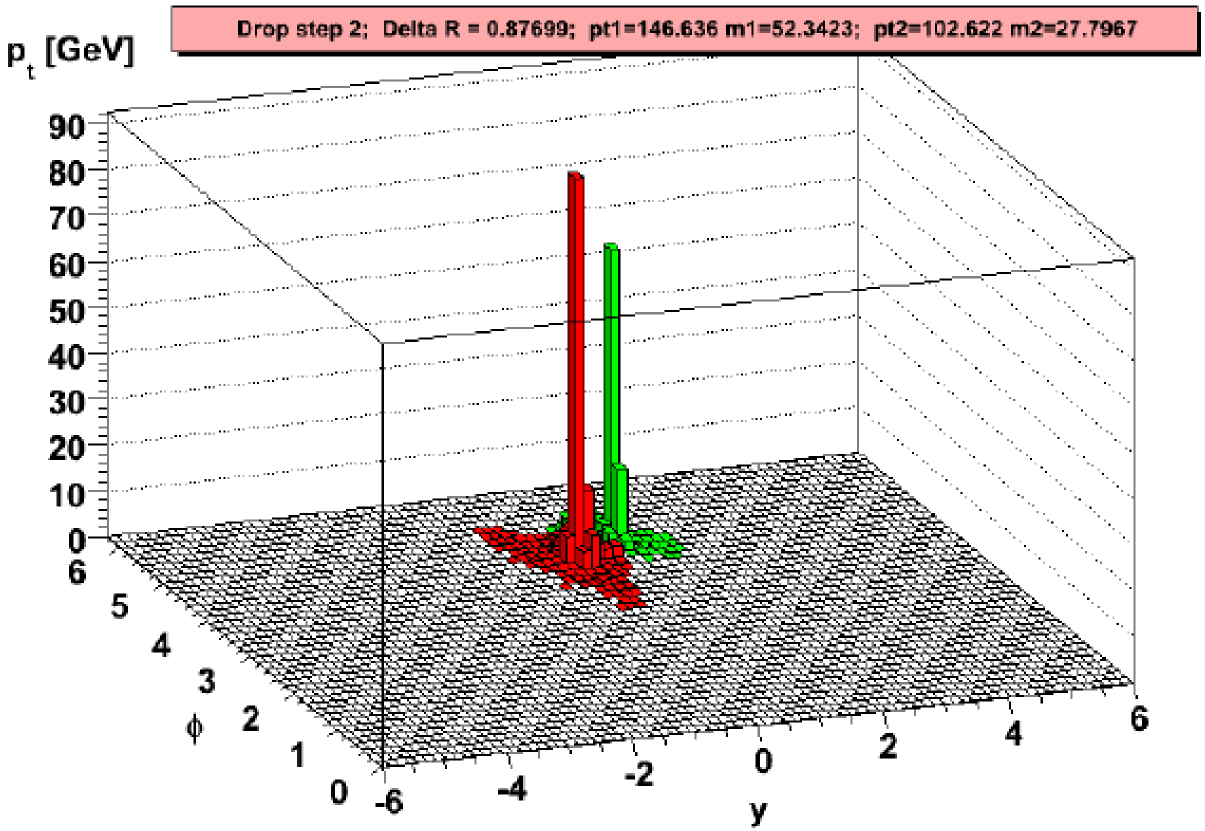
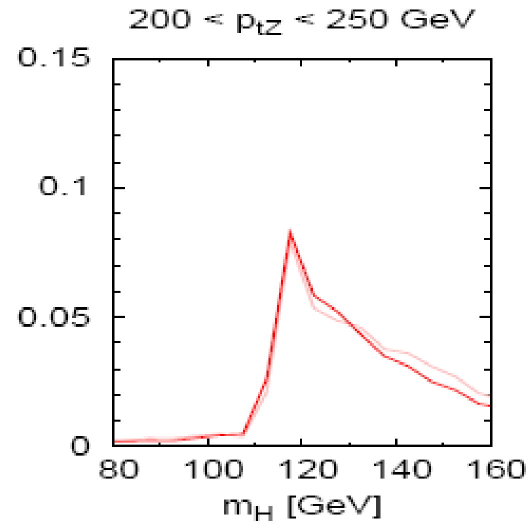
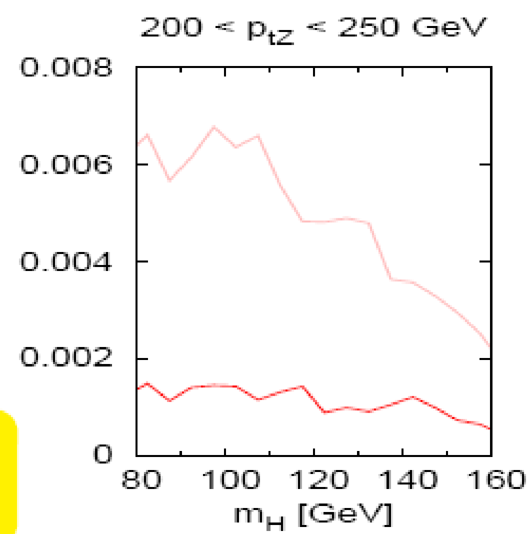


check: $y_{12} \simeq \frac{p_{t2}}{p_{t1}} \simeq 0.7 \to$ OK + 2 b-tags (anti-QCD)

SIGNAL



Zbb BACKGROUND



arbitrary norm.

$pp \to ZH \to \nu\bar{\nu}b\bar{b}$, @14 TeV, $m_H = 115$ GeV

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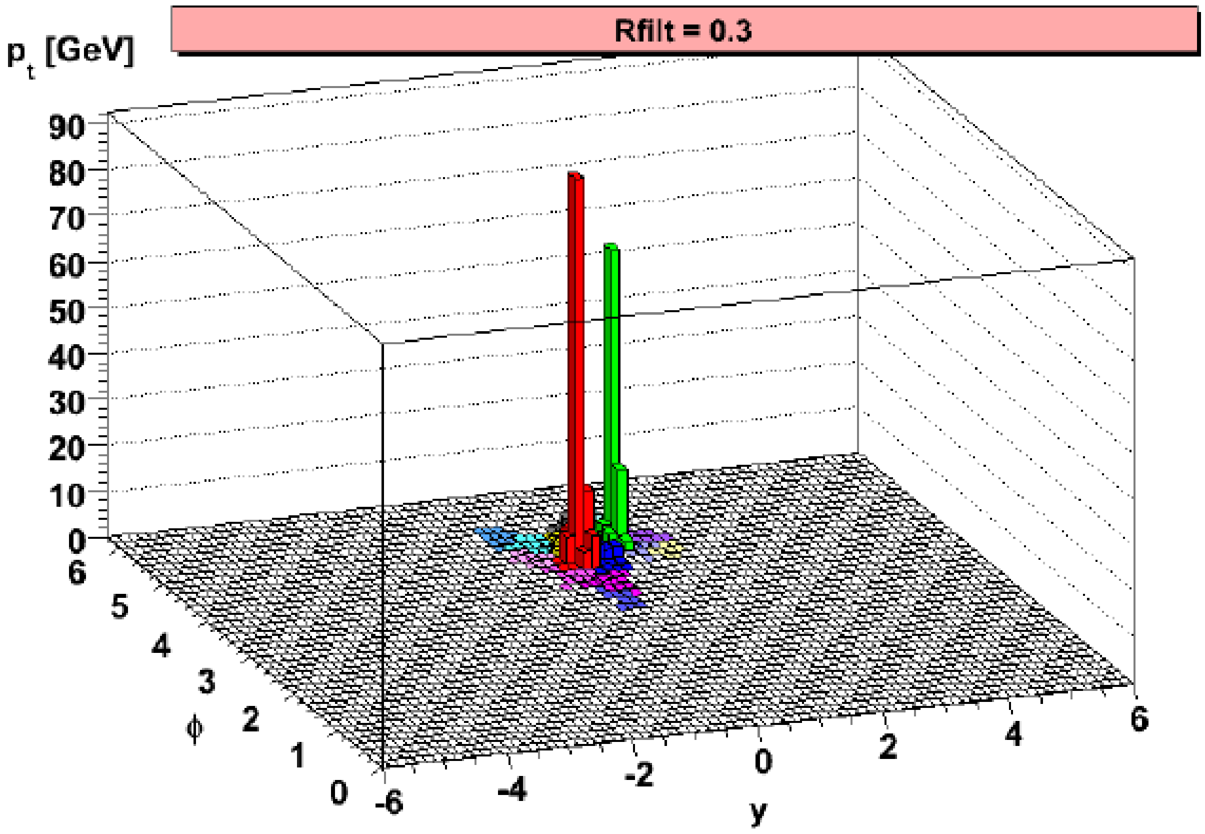
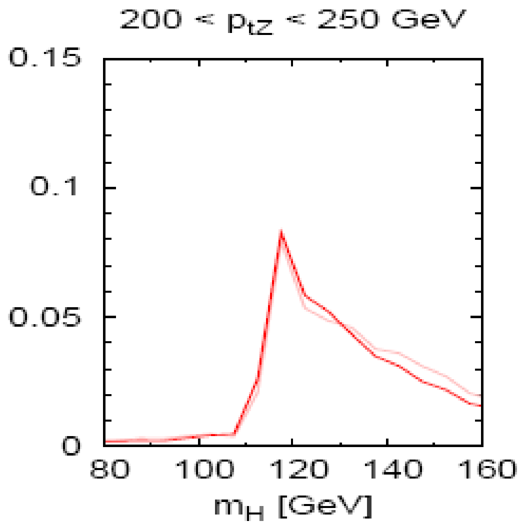
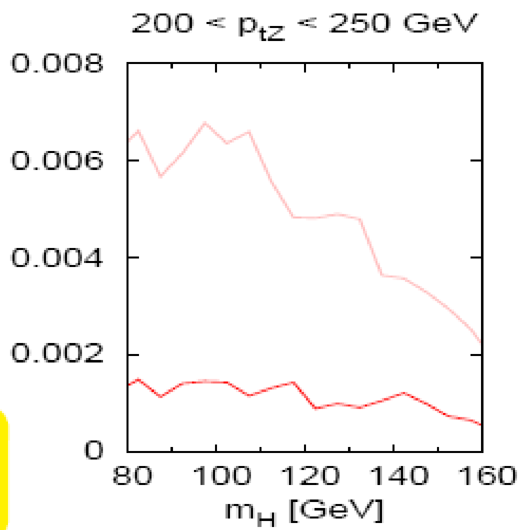


SIGNAL



Zbb BACKGROUND

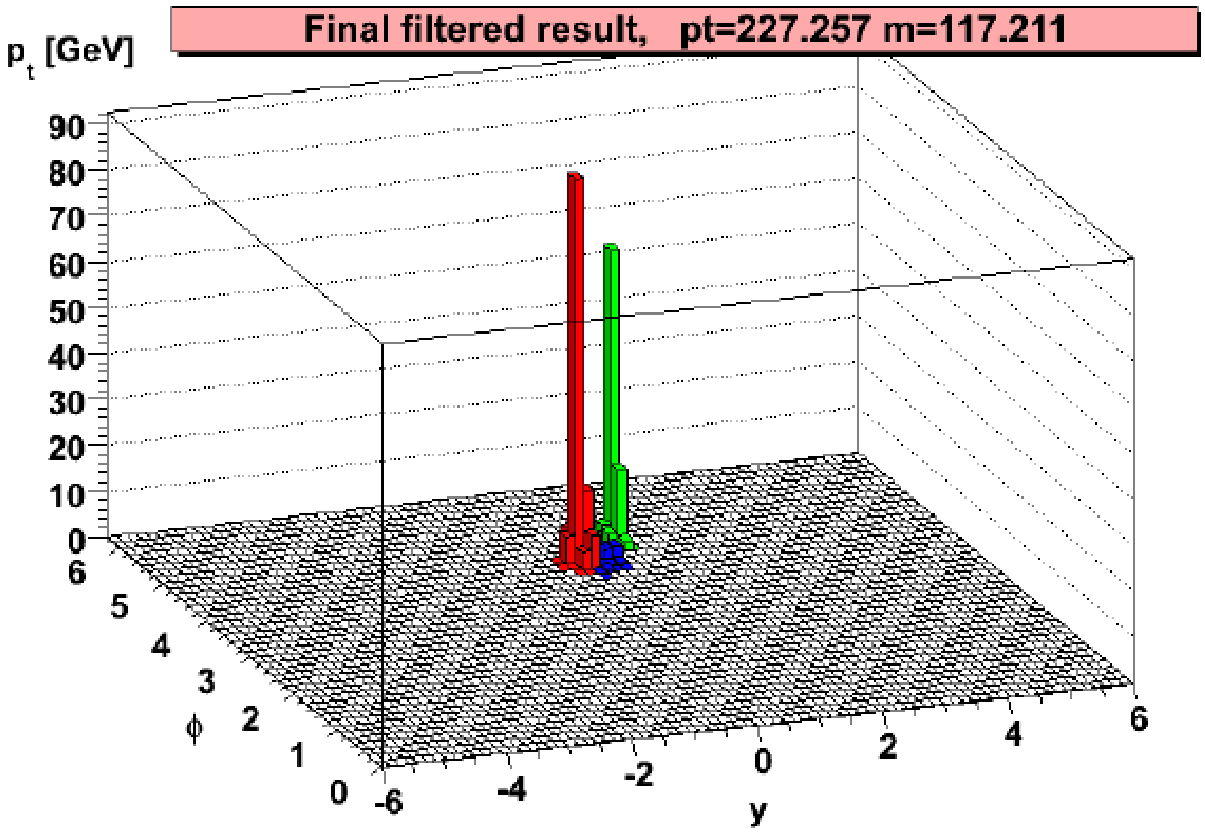


$R_{filt} = 0.3$

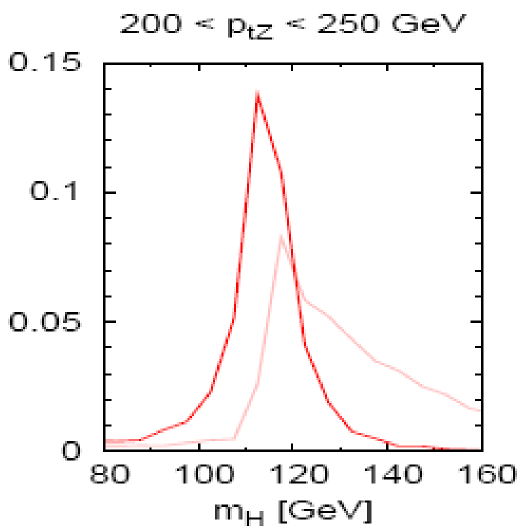
arbitrary norm.

$pp \to ZH \to \nu\bar{\nu}b\bar{b}$, @14 TeV, $m_H = 115$ GeV

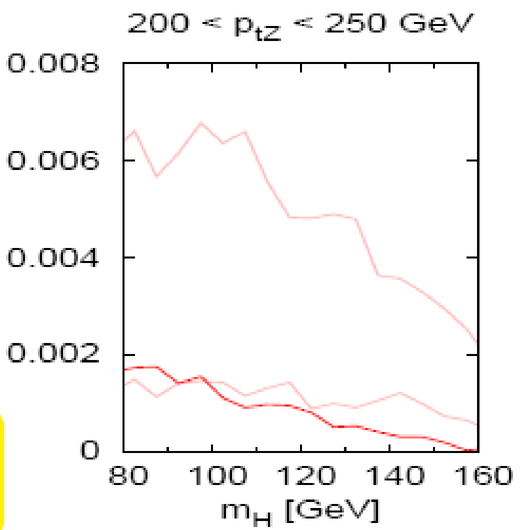
Herwig 6.510 + Jimmy 4.31 + FastJet 2.3



SIGNAL



Zbb BACKGROUND



$R_{filt} = 0.3$: take 3 hardest, **m = 117 GeV**

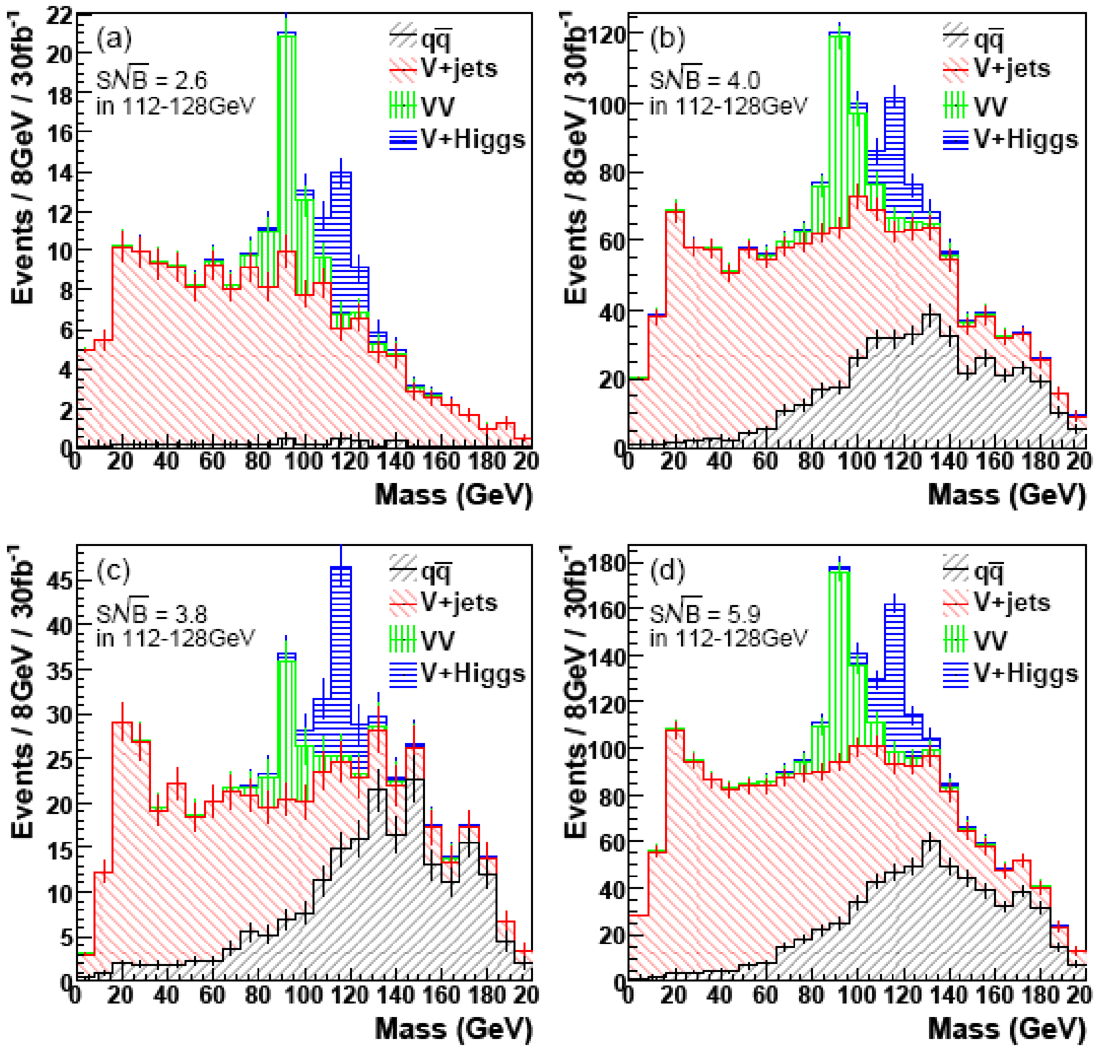
arbitrary norm.

Analysis

- Perform a hadron level analysis (no detector simulation) but try to make cuts and windows of reasonable values given our knowledge of ATLAS
- Generate samples of HZ, HW, WW, WZ, ZZ, $t\bar{t}$, single top, W+jets, Z+jets with Herwig
- Try to select three types of event
  - ZH with Z→ll
  - ZH with Z→νν
  - WH with W→lν
- Then look for Higgs candidate jets, split, filter and plot the mass

Some Results

- Plot mass of Higgs candidates for each channel
- Summed in (d)
- Can observe peak at Higgs mass
- Peak at Z mass provides important calibration channel

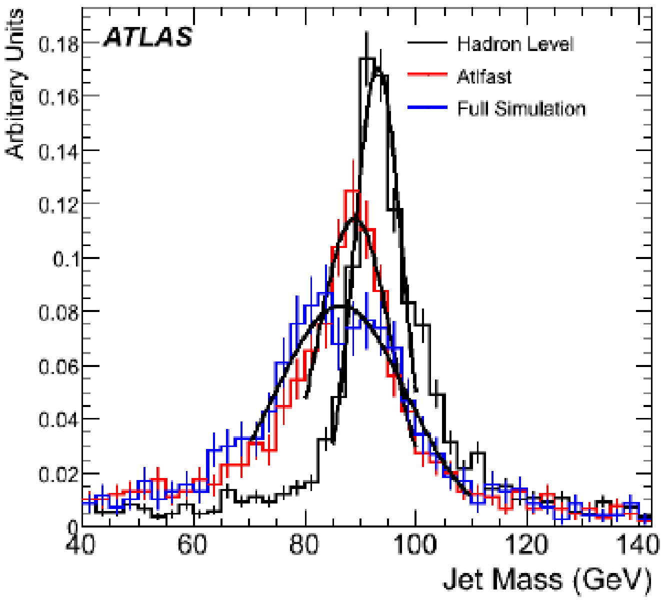


Interpretation

- It seems that at high pT VH→bb can be recovered as a more promising Higgs search at the LHC
- Many unknowns in terms of detector performance
- Merits further study
  - Jet mass performance
  - B-tagging performance
- Good news for us is that for jet mass, ATLAS should outperform CMS by factor of ~2

ATLAS Performance

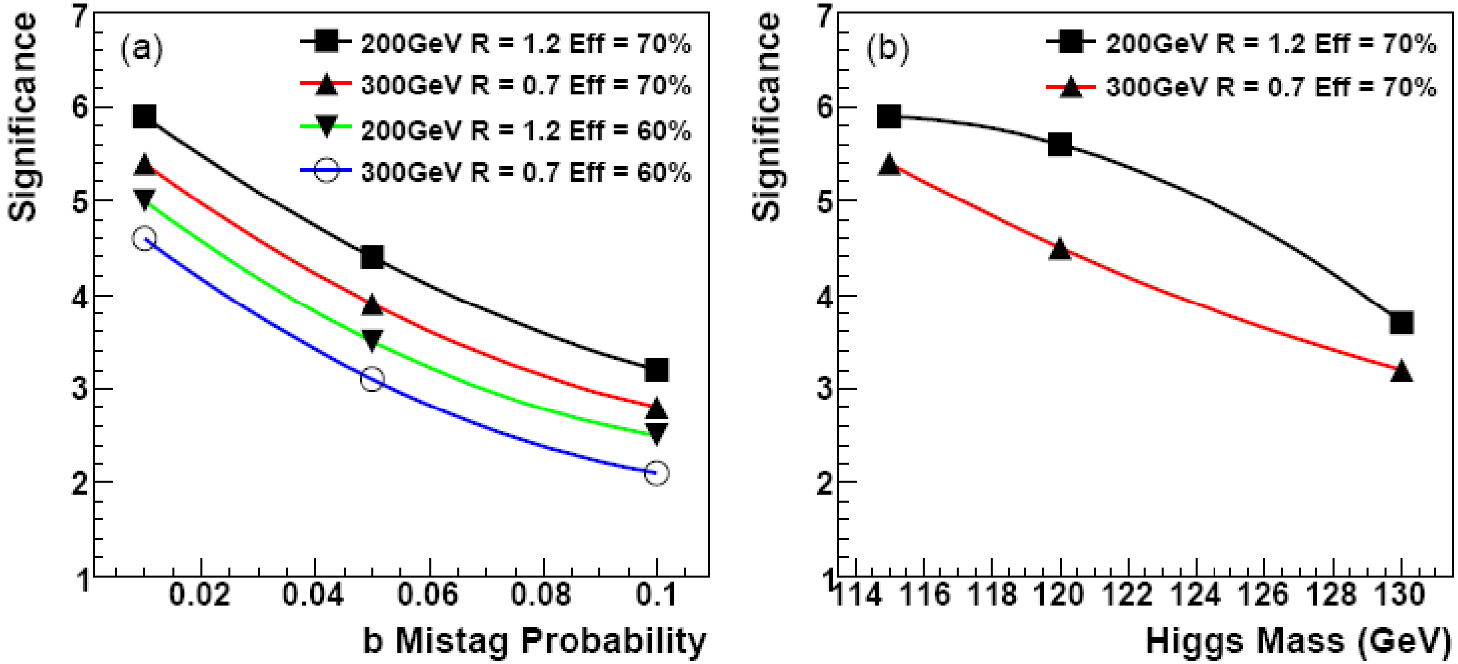
- Studied jet mass resolution previously for kT jets with R=0.6 and found ~8GeV for jets with mass O(100GeV)
- Studied again for C/A 1.2 jets with this splitting/filtering procedure and find ~11GeV in similar mass region
- Similar to our assumptions
  - Window of 16GeV
- Need to study effect of b decays
- B-tagging work ongoing



Conclusions

- This study implies that VH→bb is actually a more promising search channel than previously believed at ATLAS
- Could provide the only way to access the HZ and HW couplings directly
- Detector performance now being evaluated

Dependence on Higgs Mass



Different Jet Algorithms

Jet definition	σ_S/fb	σ_B/fb	$S/\sqrt{B \cdot \text{fb}}$
C/A, $R = 1.2$, MD-F	0.57	0.51	0.80
$K_\perp$, $R = 1.0$, y_{cut}	0.19	0.74	0.22
SISCone, $R = 0.8$	0.49	1.33	0.42

TABLE I: Cross section for signal and the Z+jets background in the leptonic Z channel for $200 < p_{TZ}/\text{GeV} < 600$ and $110 < m_J/\text{GeV} < 125$, with perfect b-tagging; shown for our jet definition, and other standard ones at near optimal R values.

With Weaker b-tagging