SUSY Digs up a Buried Higgs

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Introduction

- Search for SM-like Higgs at hadron collider is well-studied
- But Higgs decay maybe non-standard
  - Higgs with mass < 114 GeV may not be excluded by LEP II data
  - h -> 2 light pseudo-scalars -> 4j

    Dermisek & Gunion (2005)

    Chang,Fox,Weiner(2006)
  - LEP II bound as low as 82 GeV

Introduction

- not unusual in models with extended Higgs sector
  - NMSSM: h-> 2a -> 2b, 2tau — Dermisek, Gunion (2005)
  - Buried/Charming Higgs: h->2η-> 4g, 4c — Bellazzini,Caski,Falkowski,Weiler(2009, 2010)
  - many others — Luty,Phalen,Pierce(2010), Carpenter, Kaplan, Rhee(2008)
- Hadronic final states -> Higgs would be buried by QCD background

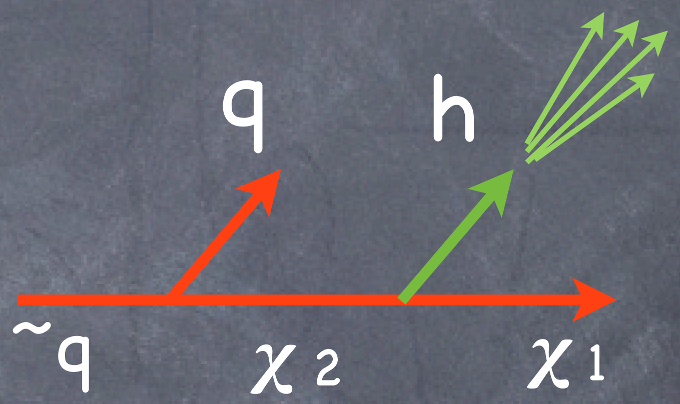
How to search?

- distinguish Higgs jets from QCD jets
  - jet substructure — Falkowski,Krohn,Shelton,Thalapillil,Wang(2010) Chen,Nojiri,Sreethawong(2010)
- Our approach: consider Higgs produced in new physics events (supersymmetry in our analysis) — A. Martin's talk
  - SM background significantly reduced by requiring large MET +multi-jets +Large H_T
  - how well can this improve the Higgs discovery
  - h->bb search in SUSY events shows it is quite promising

Kribs,Martin,Roy,Spannowsky(2009,2010)

Higgs from SUSY Cascade

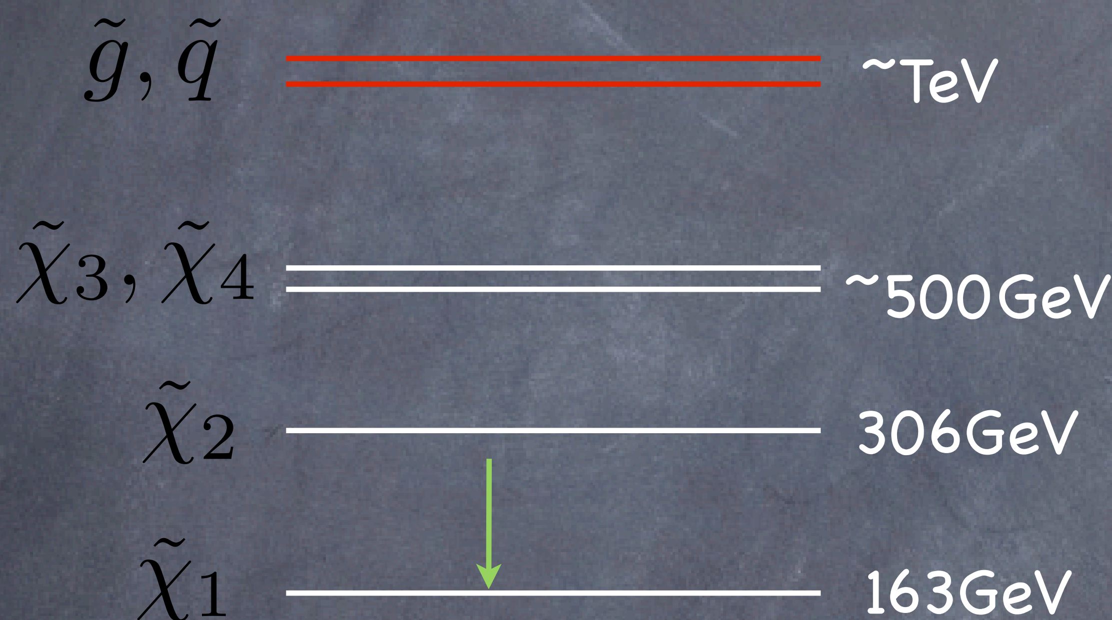
- Higgs produced in cascade decay of heavy exotic particles
  - ~t2 -> ~t1 + h
  - little cascade: $\chi_2 \rightarrow \chi_1 + h$
  - big cascade: $\chi_3/\chi_4 \rightarrow \chi_1/\chi_2 + h$



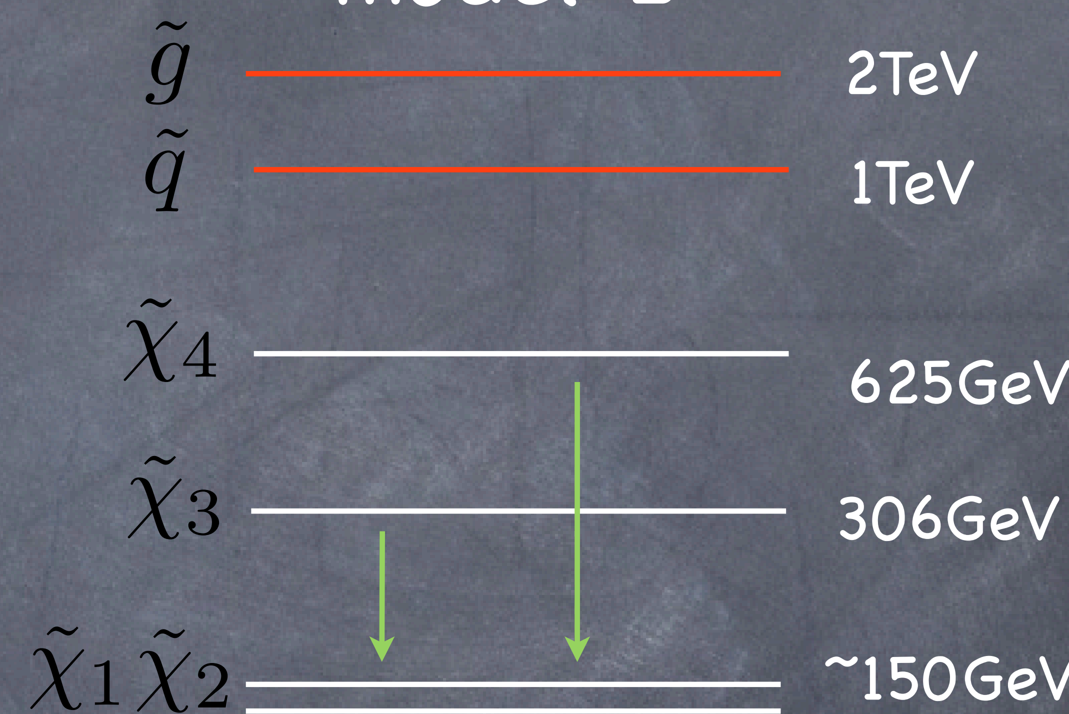
- cascade decay initiated from colored particles -- gluino/squark --> Large rate
- Higgs would be boosted if mass difference in the decay is large enough

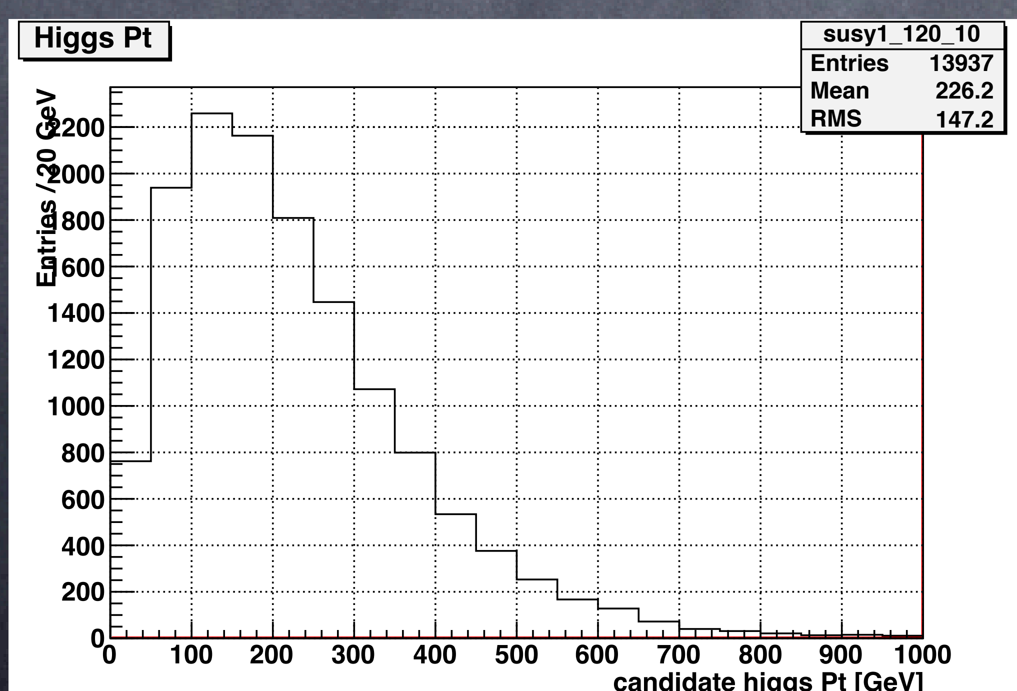
Benchmark Scenarios

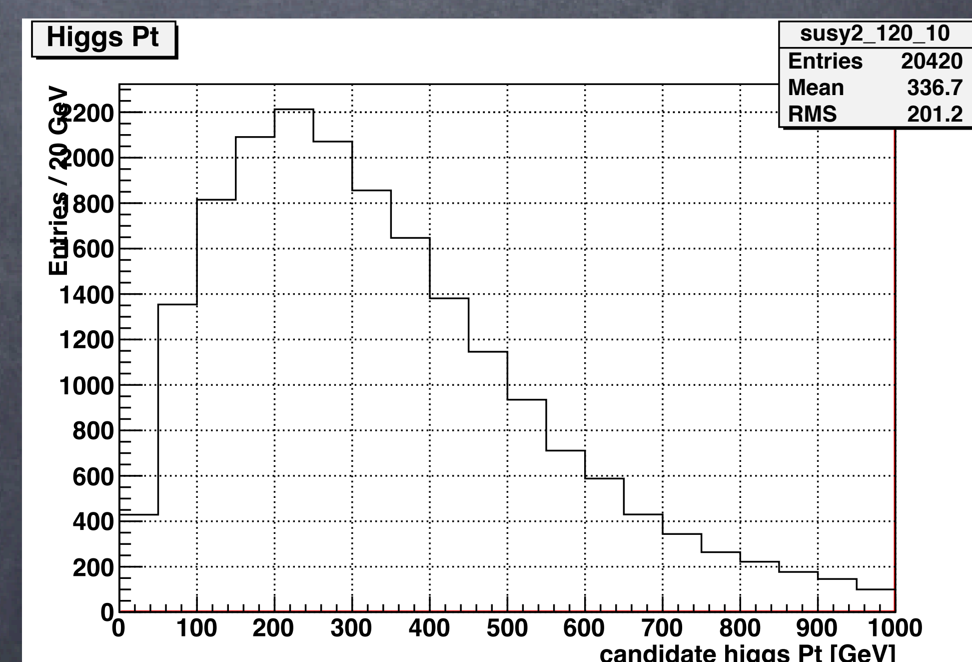
model 1



model 2







Procedure

- Inclusive production of squark and gluino
- SUSY event selection cuts
- Look for candidate Higgs jets
- Search for bump in the jet mass distribution
- Consider four different mass assignments: mh=100, 120 GeV, meta = 10, 30 GeV

Simulation

- Events generated and showered in Pythia 6.4
- Include ISR/FSR, MPI using "DW" tune
- inclusive jet : Cambridge/Aachen with R=0.5 (Fastjet)

  0.1x0.1 granularity
- Preselection cuts:
  - MET > 200 GeV
  - N(jet) >2
  - Pt(j1) > 180, Pt(j2) > 110 GeV
  - Ht > 500 GeV
- SM background significantly reduced

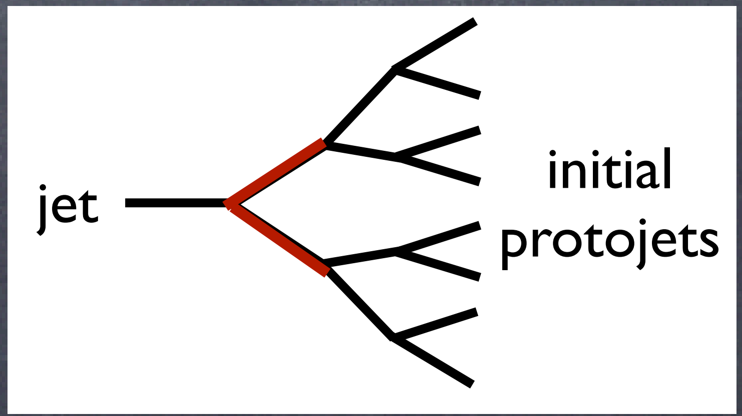
	model 1	model 2
$\sigma(\tilde{g},\tilde{q})$	2.5 pb	0.41 pb
$\mathrm{BR}(\tilde{q}_L \to h)$	30%	22%
$\mathrm{BR}(\tilde{q}_L \to Z)$	3%	25%
$\mathrm{BR}(\tilde{q}_L \to W)$	64%	48%
$\sigma \cdot \mathrm{BR}(h)$	0.29 pb	0.04 pb
$\sigma \cdot \mathrm{BR}(h+W/Z)$	0.47 pb	0.1 pb
$\sigma \cdot \mathrm{BR}(W/Z)$	1.04 pb	0.23 pb

Higgs jet tagging

- H->bb studied by Butterworth,Davison,Rubin,Salam (BDRS algorithm)
    - cluster particles into "fat jets"
    - uncluster fat jets -> check if satisfy "mass drop" and symmetric splitting
    - if not uncluster the heavier one until jet pt < 50 or no smaller structure

$$m_{j1} < \mu m_j$$

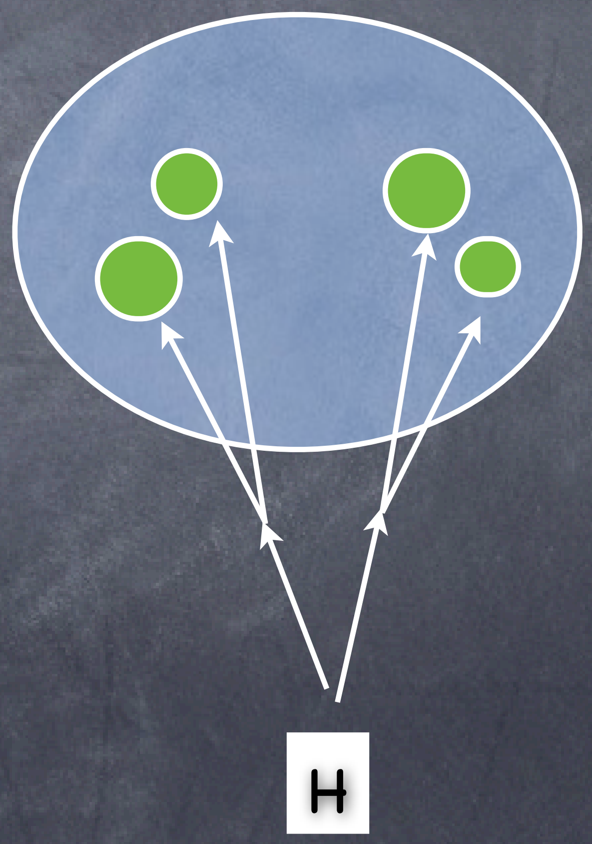
$$y \equiv \min(p_{t\,j_1}^2, p_{t\,j_2}^2)/m_j^2 \, \Delta R_{j_1,j_2}^2 > y_{cut}$$



$H \to 2\eta \to 4j$

Low mass η (10GeV)

- two hard subjets, one-to-one corresponds to 2eta
- Similar to $H \to 2b$, use BDRS algorithm, but without b-tagging
- Filtering -- recluster with $R_{sub} = \min(R_{12}/2, 0.3)$, take leading 3 subjets



What's special ?

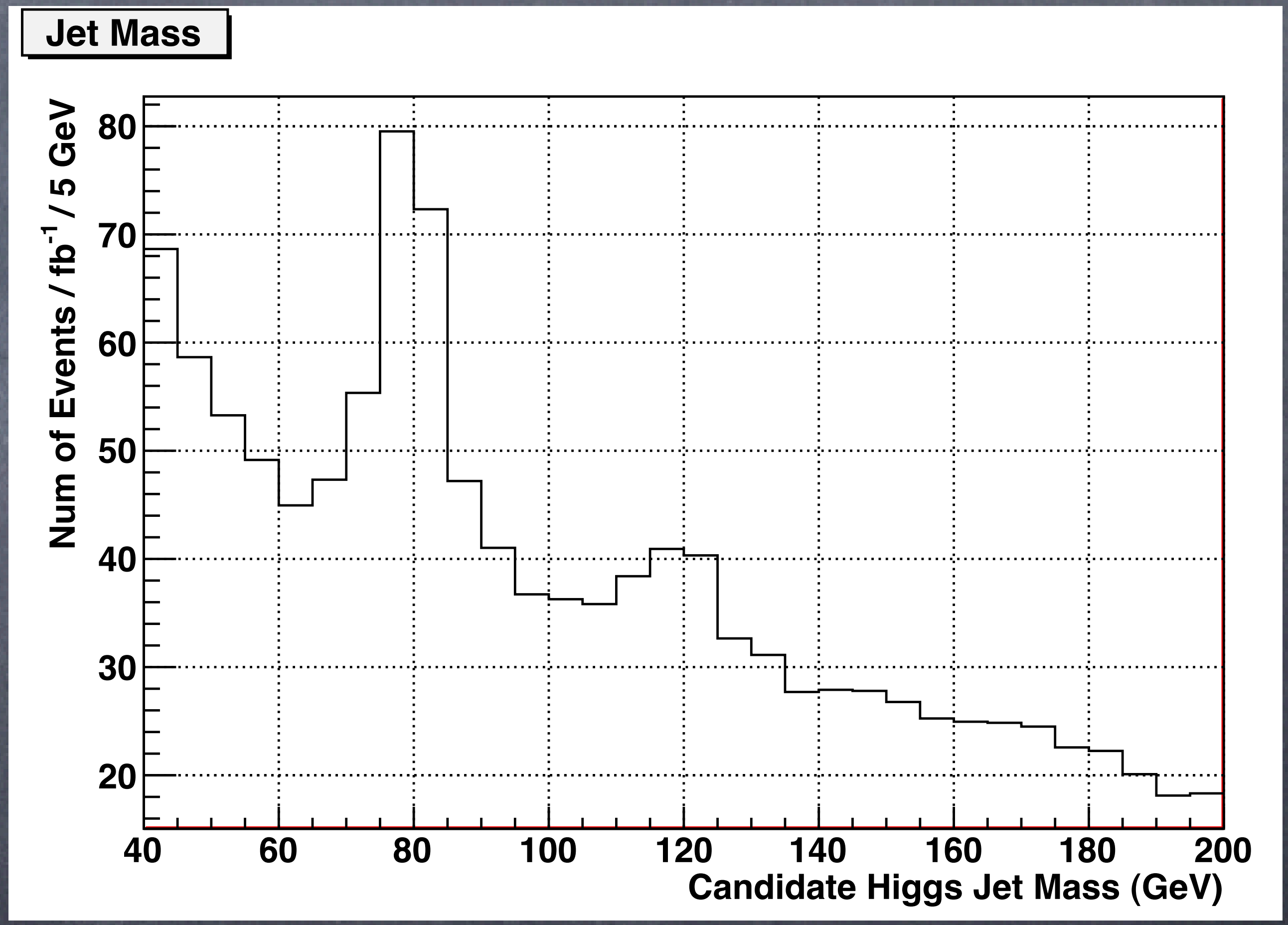
- Events are busy: many other jets from decay of gluino/squark, W/Z, Top
- Contamination from other partons could lead to failure of mass drop and symmetric splitting requirements -> lower the tagging efficiency
- broadening the mass peak

Higgs mass distribution

BDRS only

- use Cambridge/Aachen algorithm with R=1.2 cone size (Fastjet)
- μ=0.667, y_{cut} = (0.3)^2

model 1



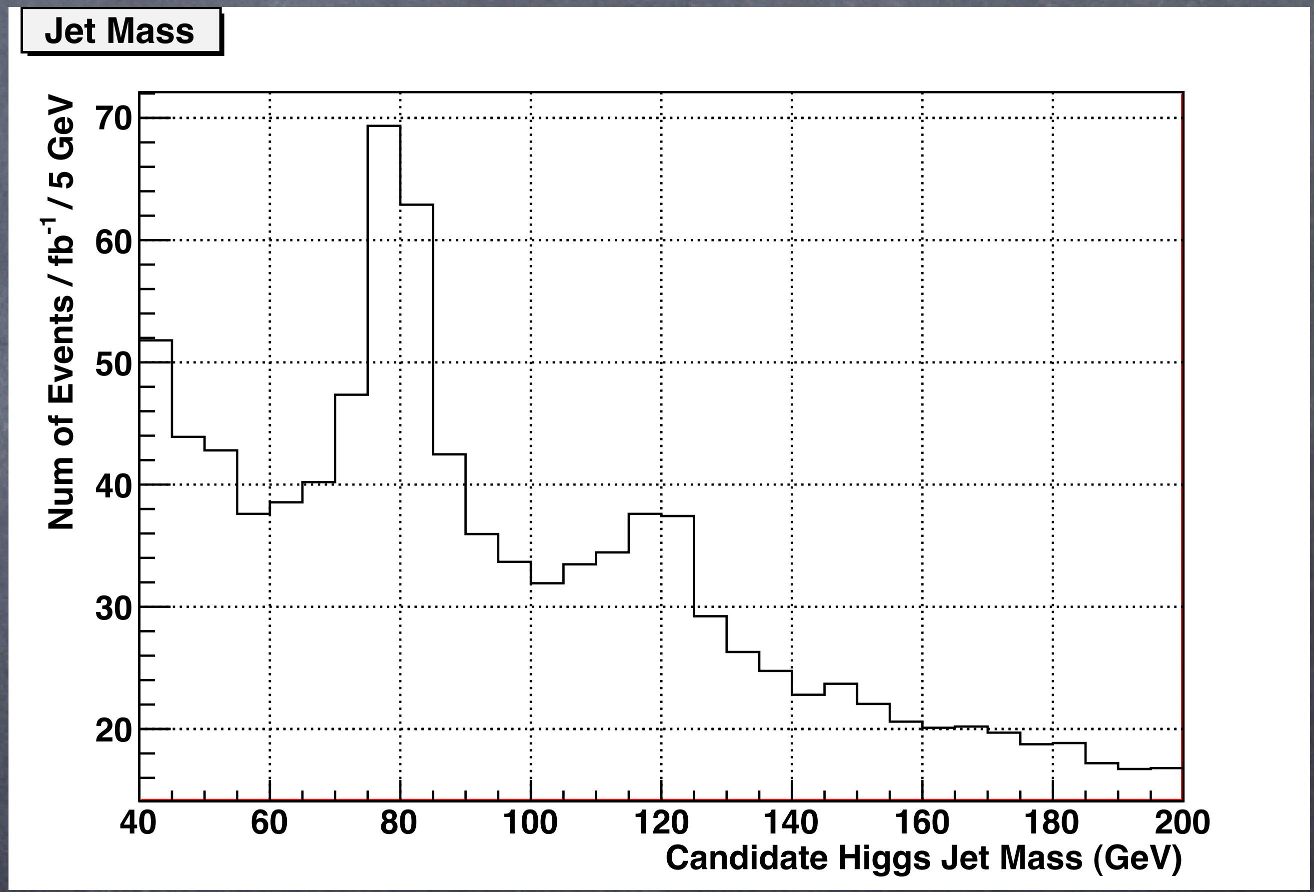
$$m_h = 120, m_\eta = 10\text{GeV}$$

Higgs mass distribution

model 1

BDRS only

- use Cambridge/Aachen algorithm with R=1.5 cone size (Fastjet)
- μ=0.4, y_{cut} = (0.3)^2



$$m_h = 120, m_\eta = 10\text{GeV}$$

Reduce SUSY background

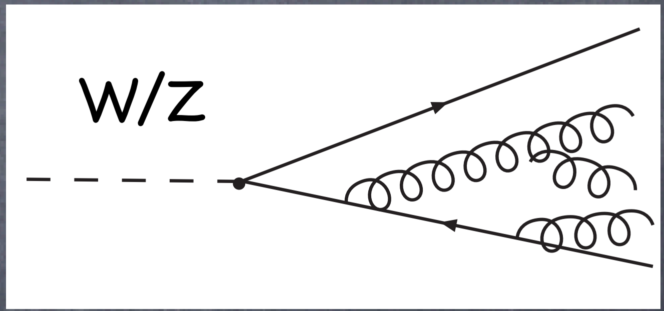
- W/Z and combinatoric background model dependent, not subtractable -- reduce as much as possible using jet substructure

- Additional substructure variables

Falkowski,Krohn,Shelton,Thalapillil,Wang(2010)

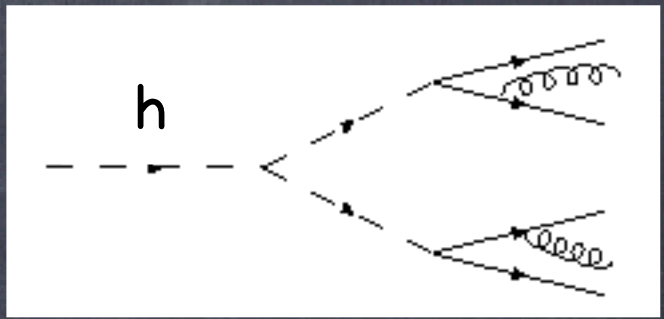
  - Mass democracy

$$\alpha_{\mathrm{MD}} \equiv \frac{\min(m_{j1}, m_{j2})}{\max(m_{j1}, m_{j2})}$$

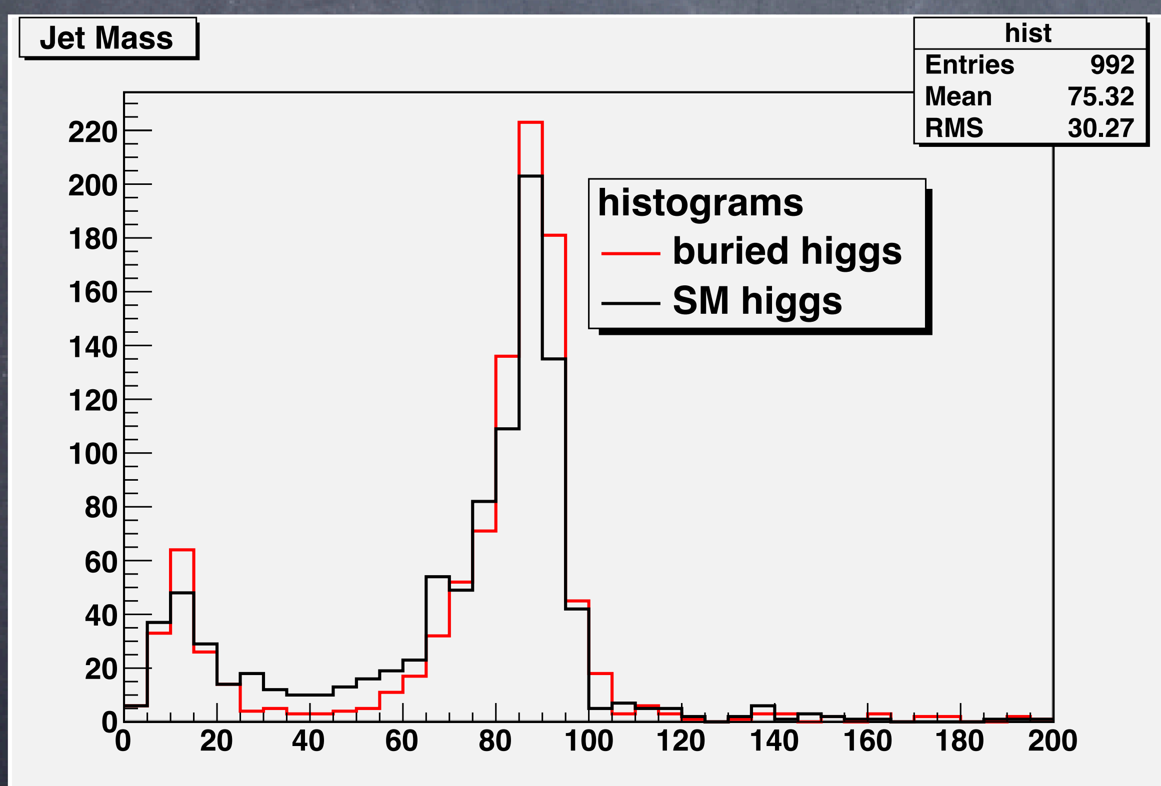


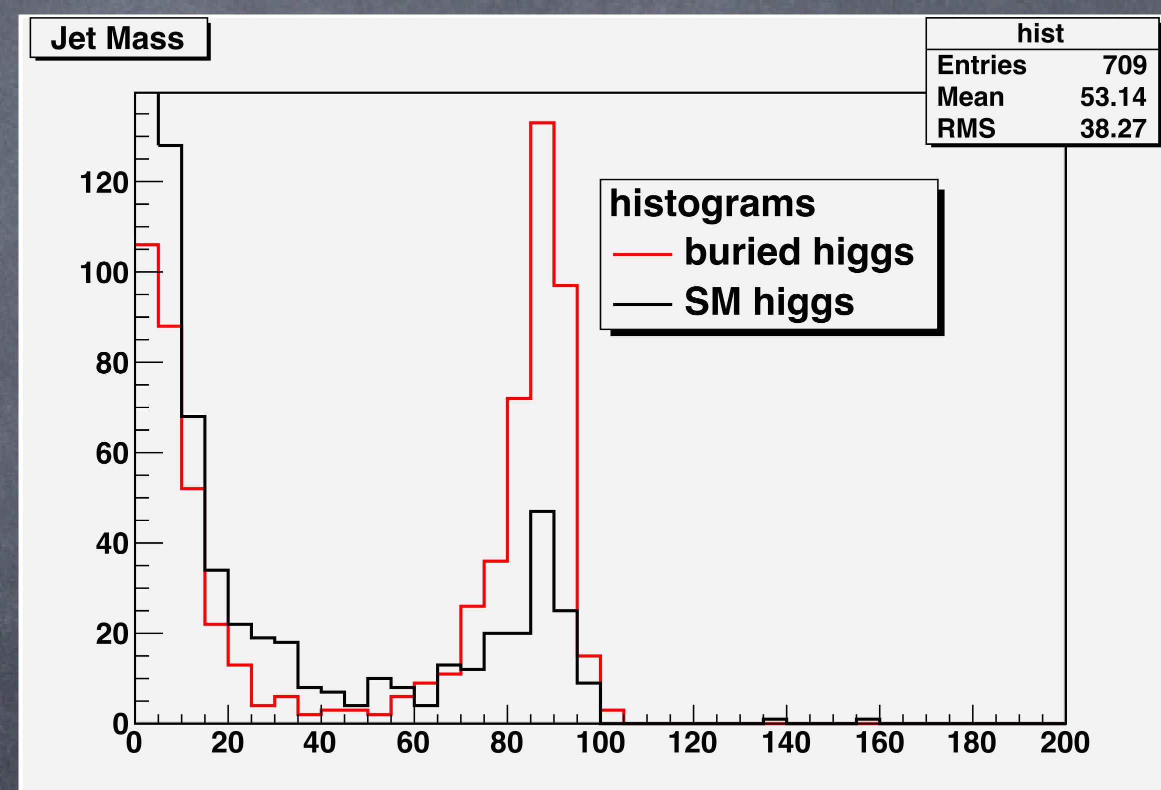
  - Flow variable

$$\beta_{\mathrm{flow}} \equiv \frac{p_{T,j3}}{p_{T,j1} + p_{T,j2}}, \quad \text{if} \quad p_{T,j3} > p_T^{min}.$$



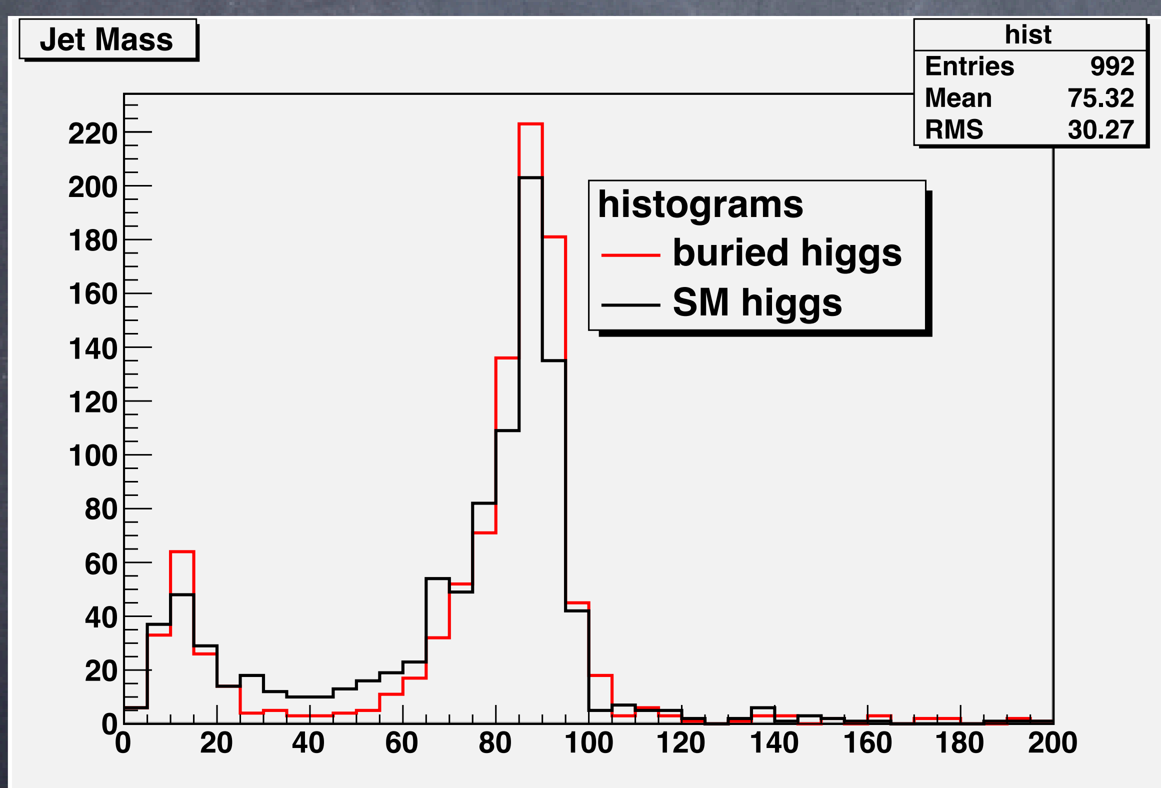
- Test SM production hZ : h->2b vs h->4j

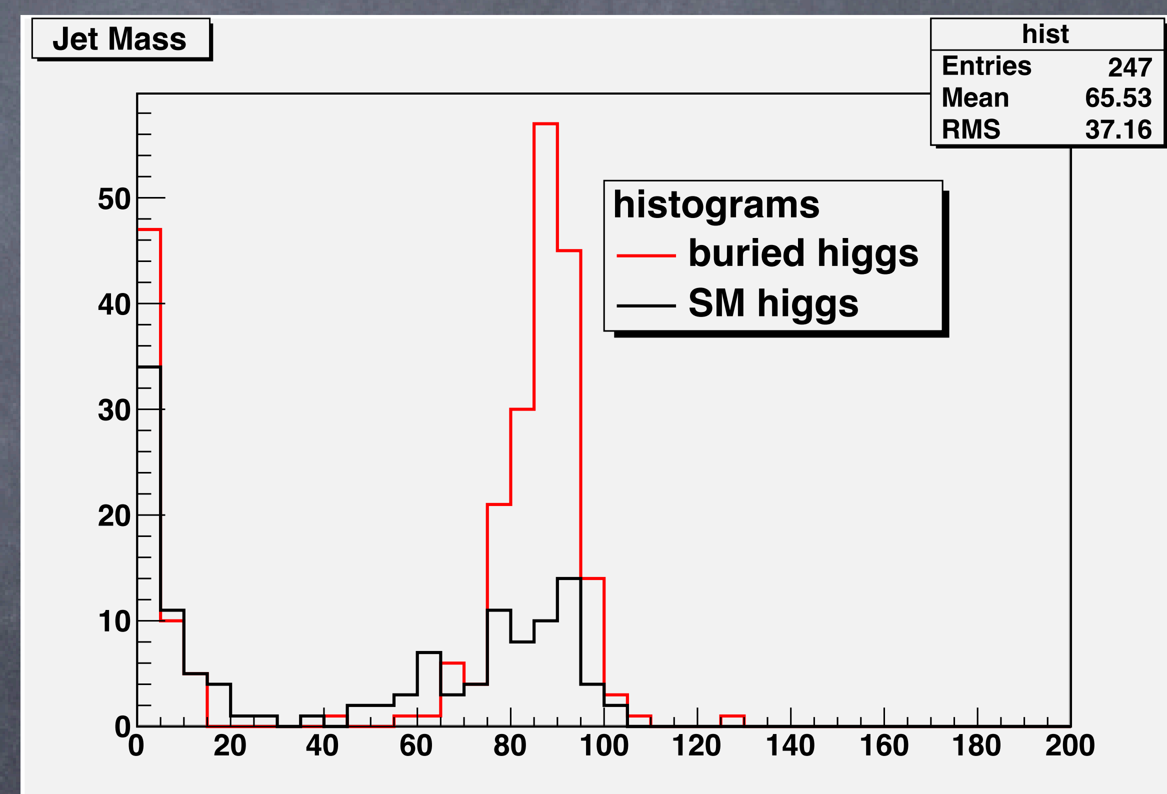




$$\alpha > 0.7$$

- Test SM production hZ : h->2b vs h->4j



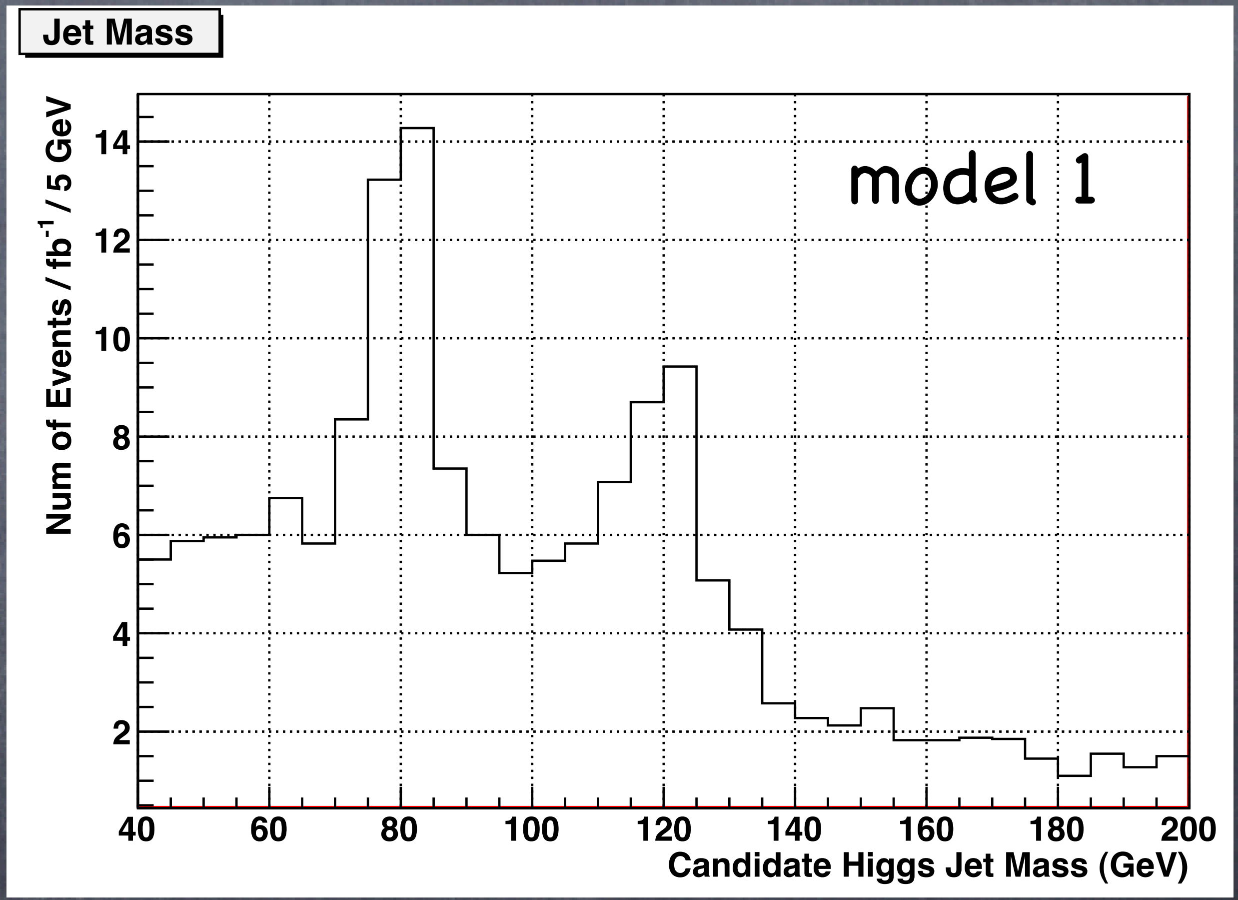


$$\alpha > 0.7 \quad \beta > 0.005$$

Higgs mass distribution

BDRS +
Mass democracy + flow cut

m_h, m_η	$(120, 10)$
R	1.2
μ	0.667
$\alpha_{\rm MD}$	> 0.7
$\beta_{\rm flow}$	$< 2\%$
$p_T^{\rm min}$	2.0



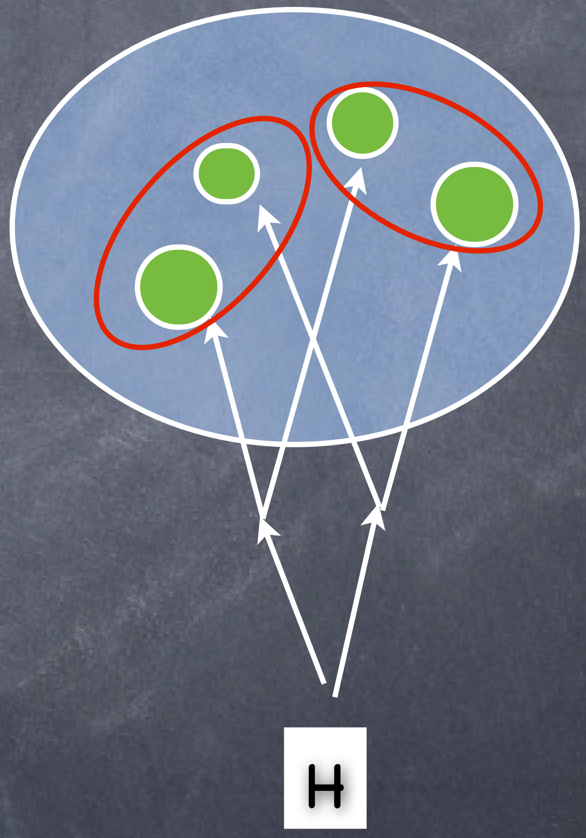
reduce 75% W/Z, but 30% for Higgs

$m_h = 120, m_\eta = 10\text{GeV}$

H-> 2η -> 4j

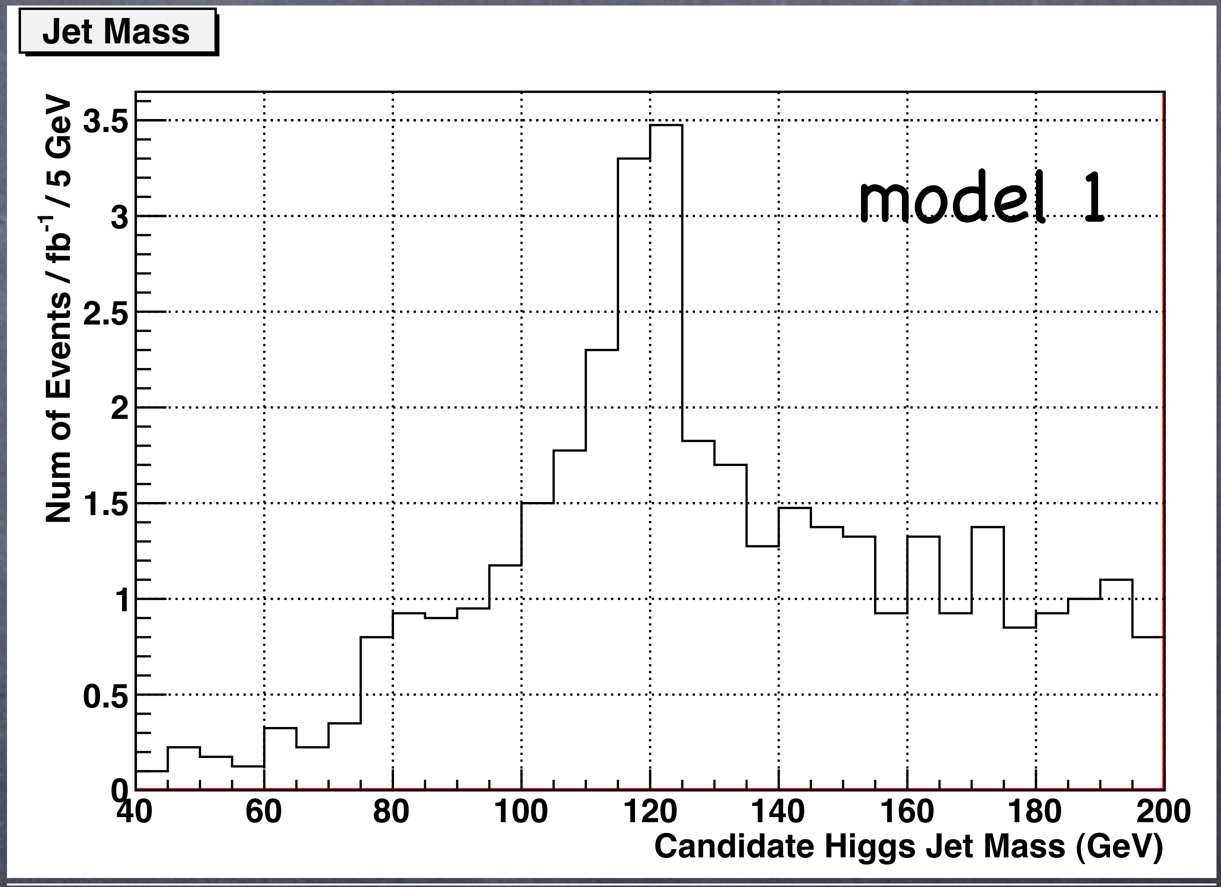
High mass η (30GeV)

- more four-prong decay, not always one-to-one correspond to 2η from the first unclustering
- again BDRS algorithm should work to tag the Higgs
- Easier to separate from W/Z -- cut on num of subjets



Higgs mass distribution

- Cambridge/Aachen with R=1.0 cone size
- μ=0.667, y_{cut} = (0.3)^2
- Mass democracy cut : alpha > 0.4
- Recluster the tagged fat jet with Rsub = 0.25 Require n(subjet) > 3 with Pt > 15 GeV

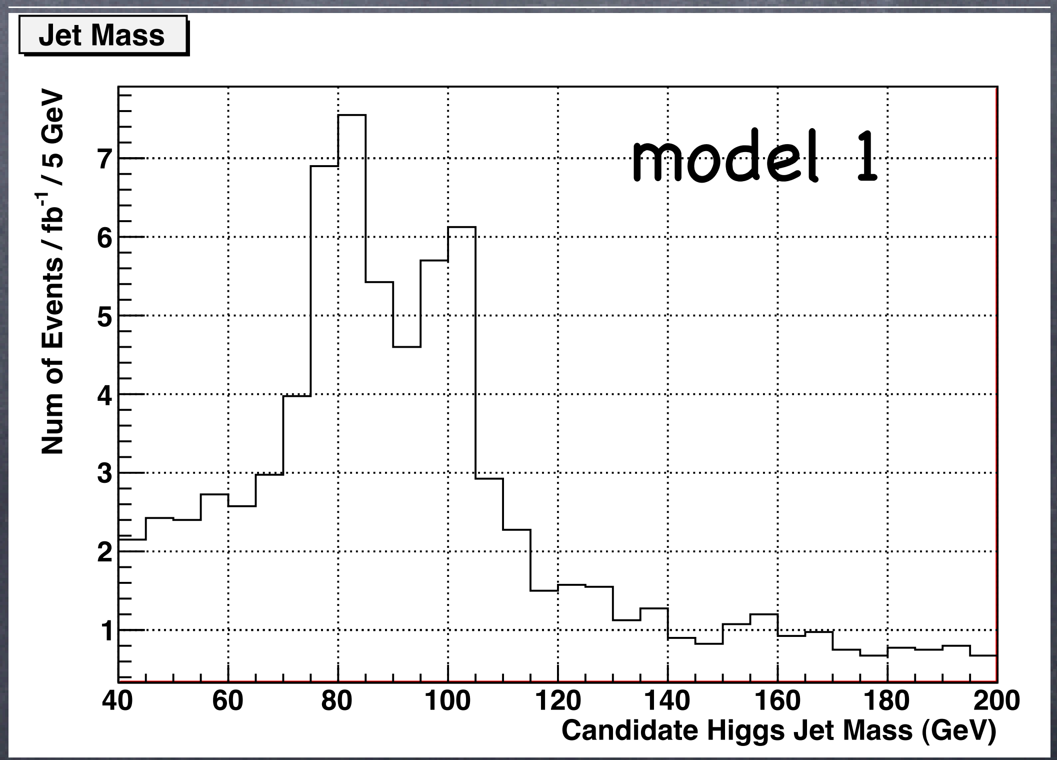


$$m_h = 120, m_\eta = 30\text{GeV}$$

Lighter higgs (100 GeV)

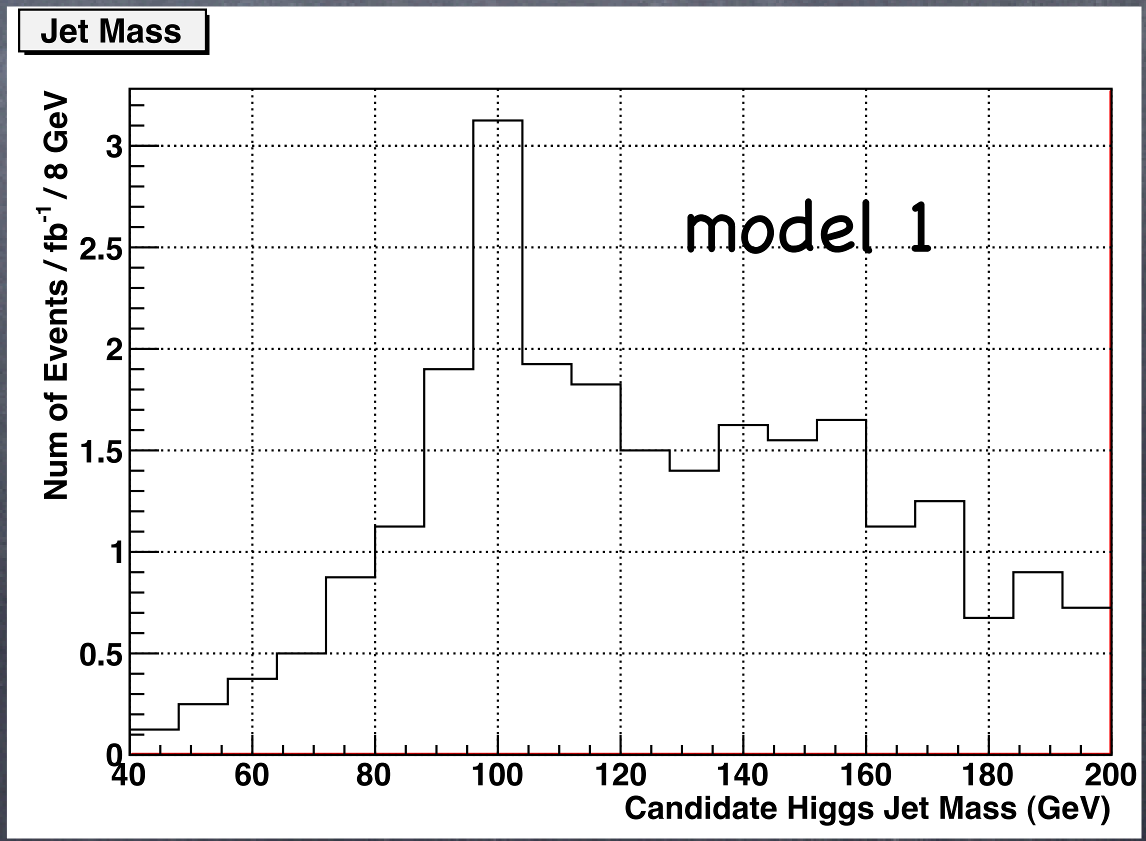
- Even more difficult, the Higgs peak and W/Z peak has significant overlap
- meta=10GeV, the interfere is strong. But the Higgs peak is still visible
- harder cuts, but reduce higgs tag fficiency too much

R	1.2
μ	0.667
α_{MD}	> 0.7
β_{flow}	$< 2\%$
p_T^{min}	2.0



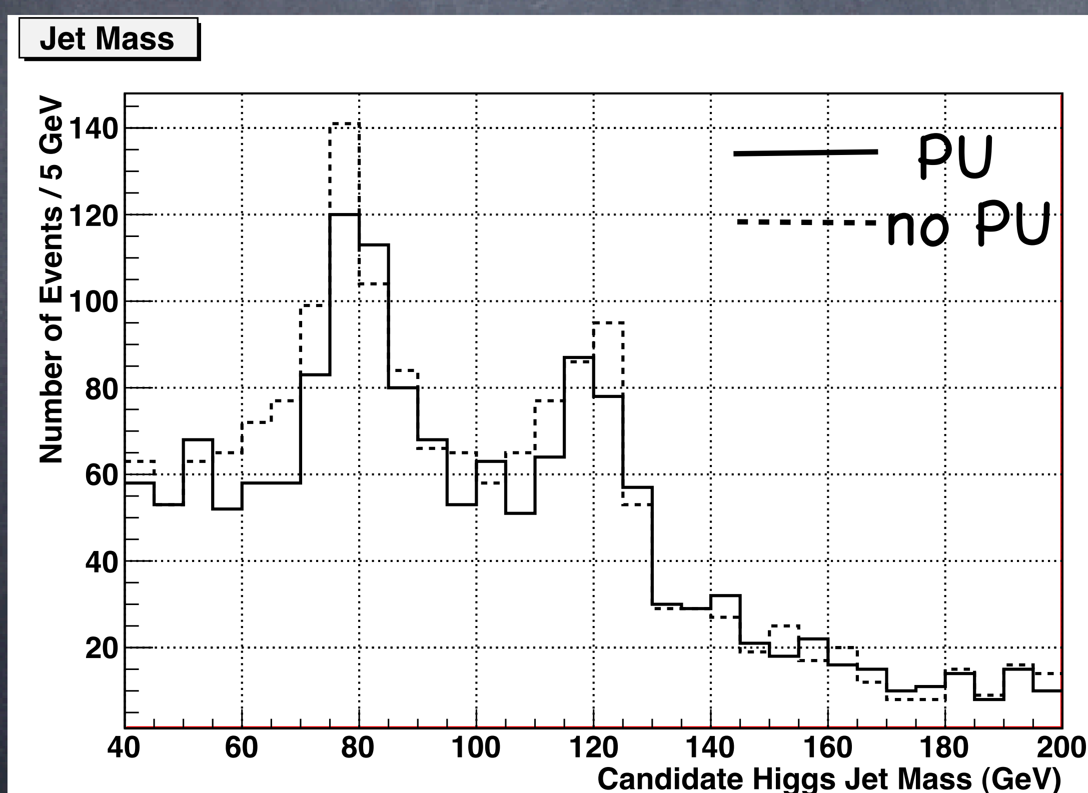
Lighter higgs (100 GeV)

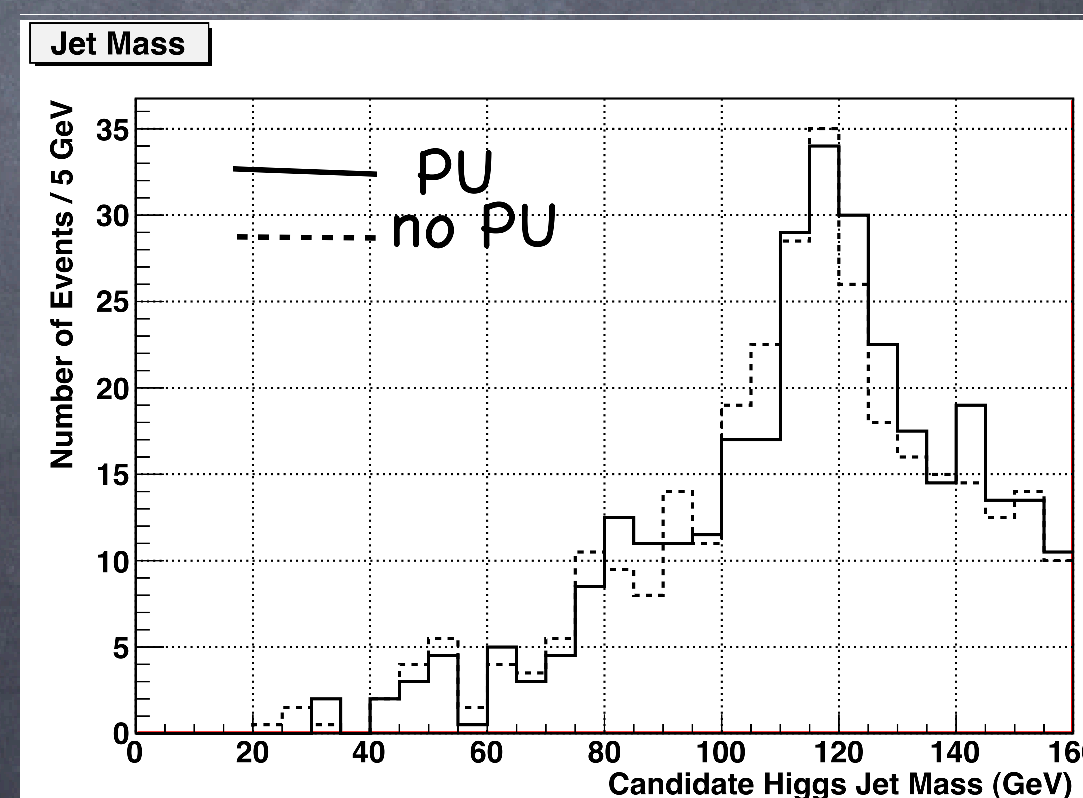
- meta=30GeV, much cleaner since W/Z can be significantly reduced
- R=0.9, μ=0.5, y_{cut} = (0.3)^2
- Mass democracy cut : alpha > 0.4
- Recluster the tagged fat jet with R_{sub} = 0.25 Require n(subjet) > 3 with Pt > 17 GeV



Pile-up effects

- Average 3 Pile-up events
- Qualitatively the same





Discussion

- Variation in the tagging algorithms may improve the efficiency
- h-> 4j, no b-tagging, suppress faking from W/Z is important, especially for low Higgs mass
- discrimination power may be improved with other variables
  - N-subjettiness, jet pull, plannar flow ...
  - Multivariable analysis
  - Difficulty: too many jets in the Higgs event

Conclusion

- Look for Higgs to 4jets in new physics events can be more superior than in SM channels: QCD background can be significantly reduced.
- Jet substructure can be used to tag Higgs against other jets in the signal events
- Discovery can be achieved much earlier compare to using SM production channels (10-30 1/fb)
- light Higgs with mass close to W/Z is challenging. Multi-variables maybe helpful.