

# A simulation study of heavy Higgs bosons decaying to jets at high energy regions of the ILC

by Christian Drews

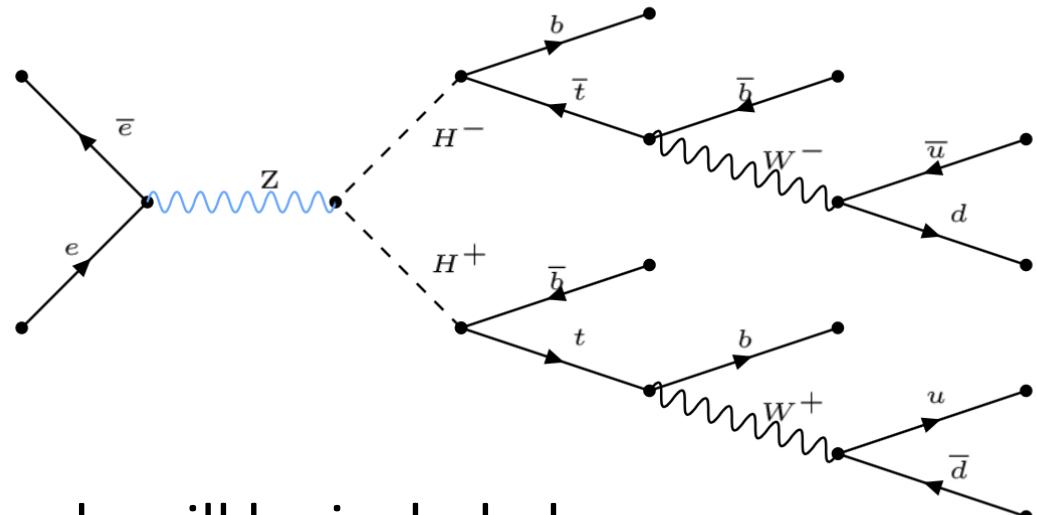
2017.04.28

Academic advisors: Professor Hitoshi Yamamoto (Tohoku Uni.)  
Professor Arno Straessner (TU Dresden)

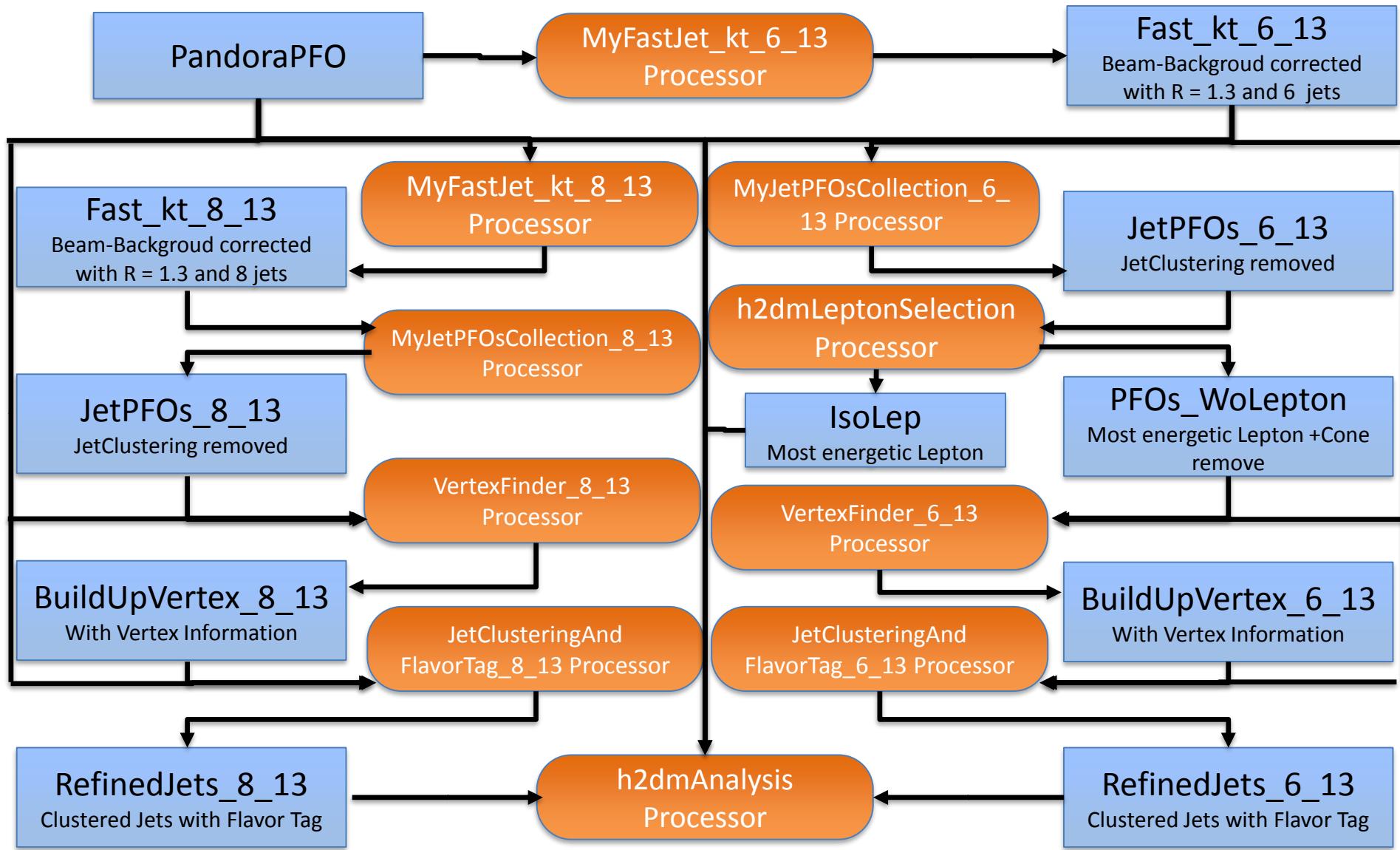


# Analysis Strategy

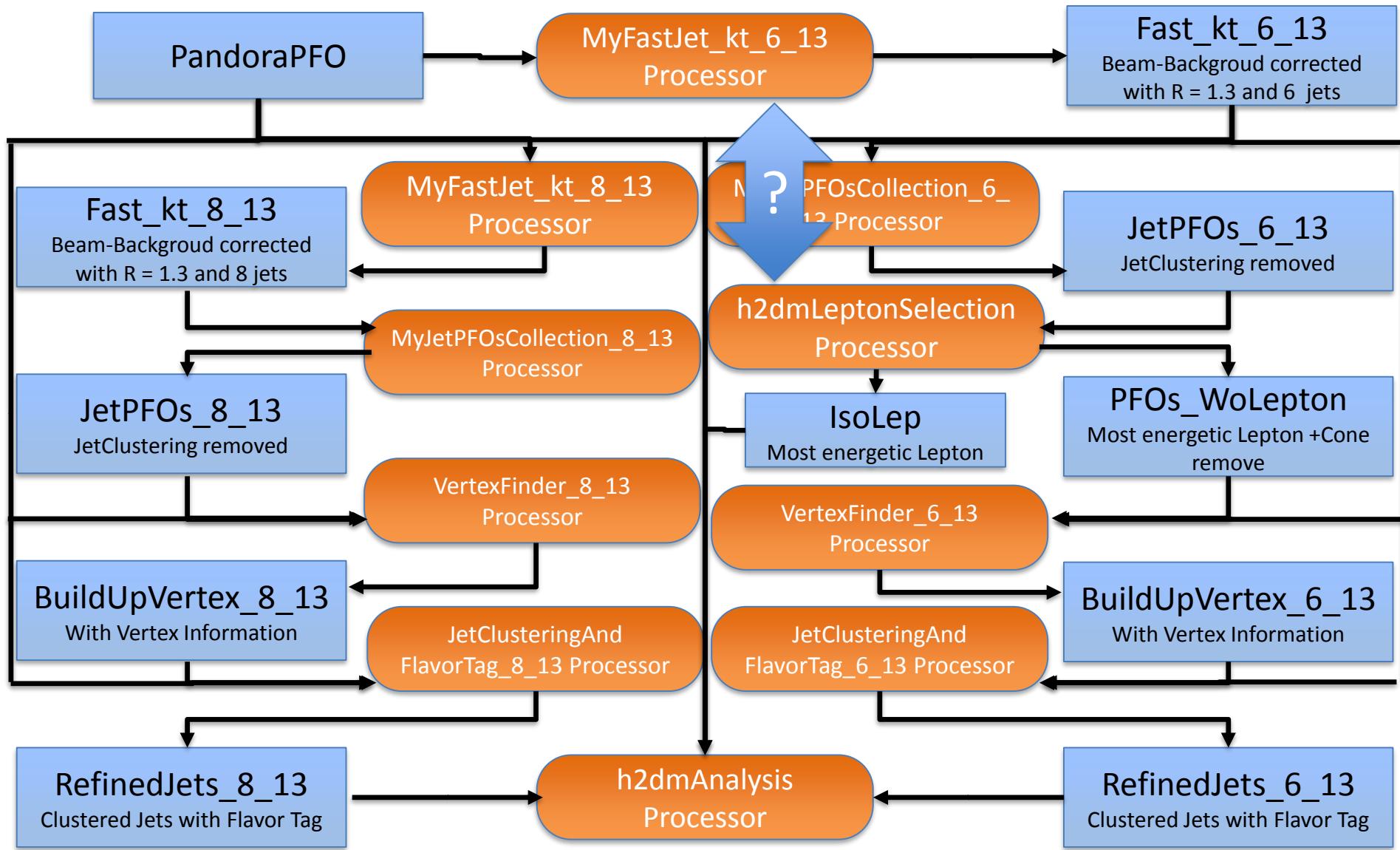
- $m_{H^\pm} = 350 \text{ GeV}$
- $e^+e^- \rightarrow H^+H^- \rightarrow tb\bar{t}b \rightarrow Wbb\bar{W}bb \xrightarrow{W \rightarrow 2 \text{ jets}} 8 \text{ jets}$
- Pairing 4 jets with lowest b tag to W mass
- Pairing 5<sup>th</sup> and 6<sup>th</sup> jet to top mass
- Pairing other jets to same invariant mass
- Background:
  - ttH/ttZ/ttg  $\rightarrow ttbb$
  - tt  $\rightarrow bWbW$
  - HA  $\rightarrow bbbb$  (SUSY)
- Later semi-leptonic mode will be included
  - One W  $\rightarrow l\nu$  (6 jets + lepton)



# Analysis Strategy – Add Semi-leptonic



# Analysis Strategy – Add Semi-leptonic



# Analysis Strategy – Lepton selection

- Pfo has charge
- $E_{\text{con}}^2 \leq 6 * (E_{\text{pfo}} - 15)$
- $E_{\text{con}} = \text{Sum}(E_i [\cos(\alpha(p_i, p_{\text{pfo}})) \geq 0.98])$
- Now I am looking at other ways to select leptons
- 63 % correctly selected (quite good (33 % tau))
- Should I make an effort to select taus?

# Analysis Strategy - Chi<sup>2</sup>

- Lorentz vector for neutrino p\_ny
  - $p_{\text{vis}} = \text{Sum}(p_{\text{pfos}})$  (Do I need a cut off Energy?)
  - $p_{\text{CMS}} = (1000, 0, 0, 0)$  (Do I need the crossing angle?)
  - $p_{\text{ny}} = (p_{\text{CMS}} - p_{\text{vis}})$
- Should I fix neutrino-lepton-system to W-mass?

# Analysis Strategy - Chi<sup>2</sup>

- Jet pairing has 40320 combinations
- With b tag consideration → 576 combinations
- without exchanging jets from a given W-boson  
without exchanging H+ and H-  
→ 36 combination
- For mass measurement the mass of H<sup>±</sup> can not be fixed

$$\chi^2 = \left| \frac{(m_{j_1 j_2 j_3 j_4})^2 - (m_{j_5 j_6 j_7 j_8})^2}{2\sigma_{H^+}^2} \right| + \left( \frac{m_{j_2 j_3 j_4} - M_t}{\sigma_t} \right)^2 + \left( \frac{m_{j_6 j_7 j_8} - M_t}{\sigma_t} \right)^2 + \left( \frac{m_{j_3 j_4} - M_W}{\sigma_W} \right)^2 + \left( \frac{m_{j_7 j_8} - M_W}{\sigma_W} \right)^2$$

# Status

- Ready for Analysis:
  - Semi-leptonic pairing
  - Pairing optimization is set up
  - Best R search for jet clustering is set up
- Close to ready for Analysis:
  - Lepton finder optimization is partially set up
- Waiting for new data samples  
Semi-leptonic and with beam strahlung and ISR

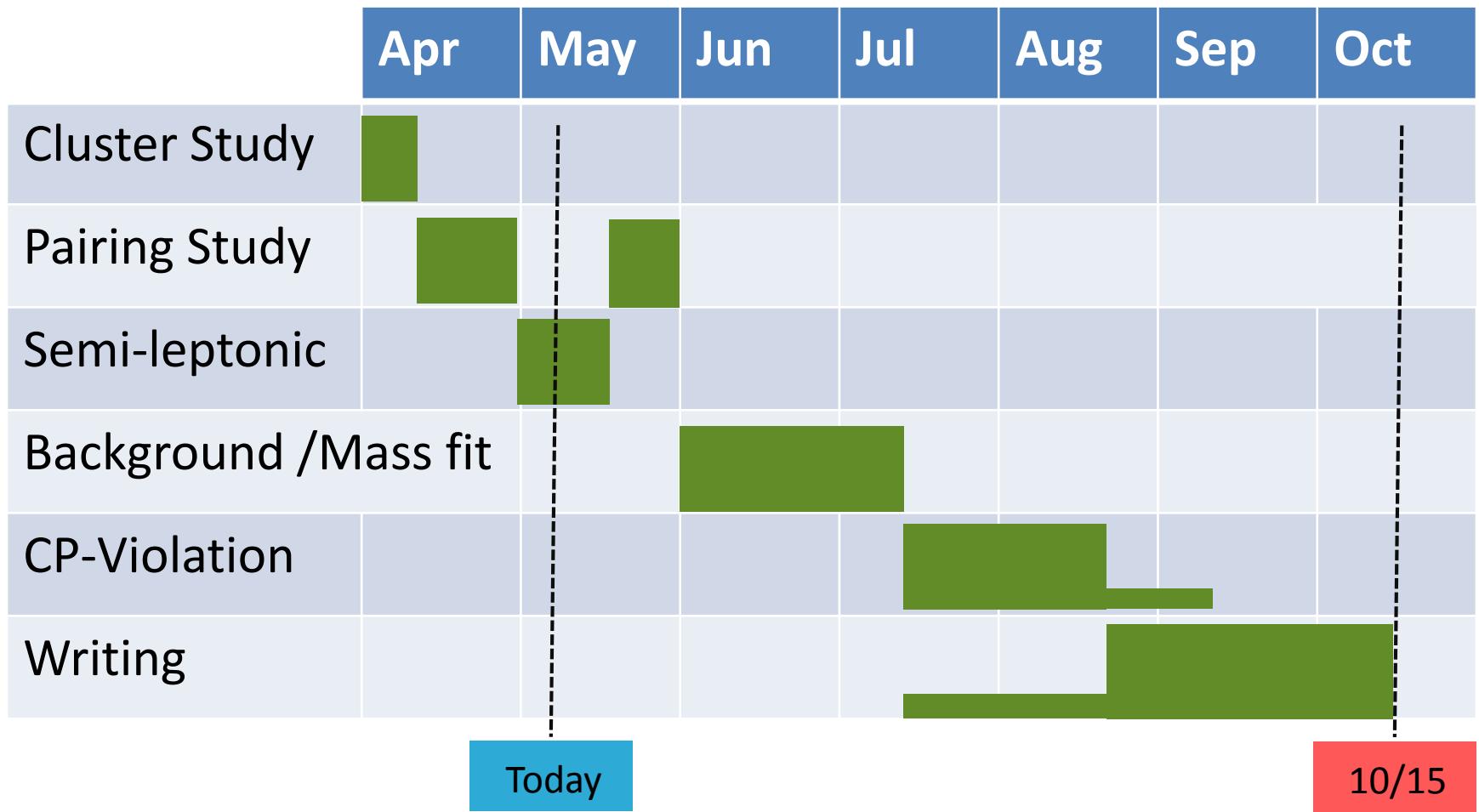
# Analysis Strategy - Chi<sup>2</sup>

- Choose  $\sigma$  from pairing with generator information
- Optimize for  $c$  for maximal pairing efficiency

$$\begin{aligned}\chi^2 = & c_H \left| \frac{(m_{j_1 j_2 j_3 j_4})^2 - (m_{j_5 j_6 j_7 j_8})^2}{2\sigma_{H^+}^2} \right| + c_t \left( \frac{m_{j_2 j_3 j_4} - M_t}{\sigma_t} \right)^2 \\ & + c_t \left( \frac{m_{j_6 j_7 j_8} - M_t}{\sigma_t} \right)^2 + c_w \left( \frac{m_{j_3 j_4} - M_W}{\sigma_W} \right)^2 + c_w \left( \frac{m_{j_7 j_8} - M_W}{\sigma_W} \right)^2\end{aligned}$$

$$\sigma_H = \sigma_t = 80 \text{ GeV}, \quad \sigma_W = 48 \text{ GeV}$$

# Schedule



# Plan

- Apply kt-algorithm on jet pairing
- Check Chi^2 Pairing with 3D display
- Background study with cuts
- Goal:
  - mass fit -> mass resolution measurement
  - Detection efficiency
    - > cross section times branching ratio
- Bonus:
  - Research how to distinguish H+ and H-
  - Study of CP-violation measurement

# Backup

# Analysis Strategy - Chi<sup>2</sup>

	w/o overlay	R: 1.3	with overlay	
B-tag efficiency	44.6	42.5	38.0	the 4 b-jets have highest b-tag in the event
Clustering works well	50.7	49.4	40.2	For every color singlet there are 2 jets with a major fraction from this singlet
Clustering works	95.8	95.6	92.5	Clustering works well + one color singlet has only one jet with a major fraction from this singlet
Pairing works	27.8	25.0	17.2	Jet pairing agrees with major color singlet fraction in jet

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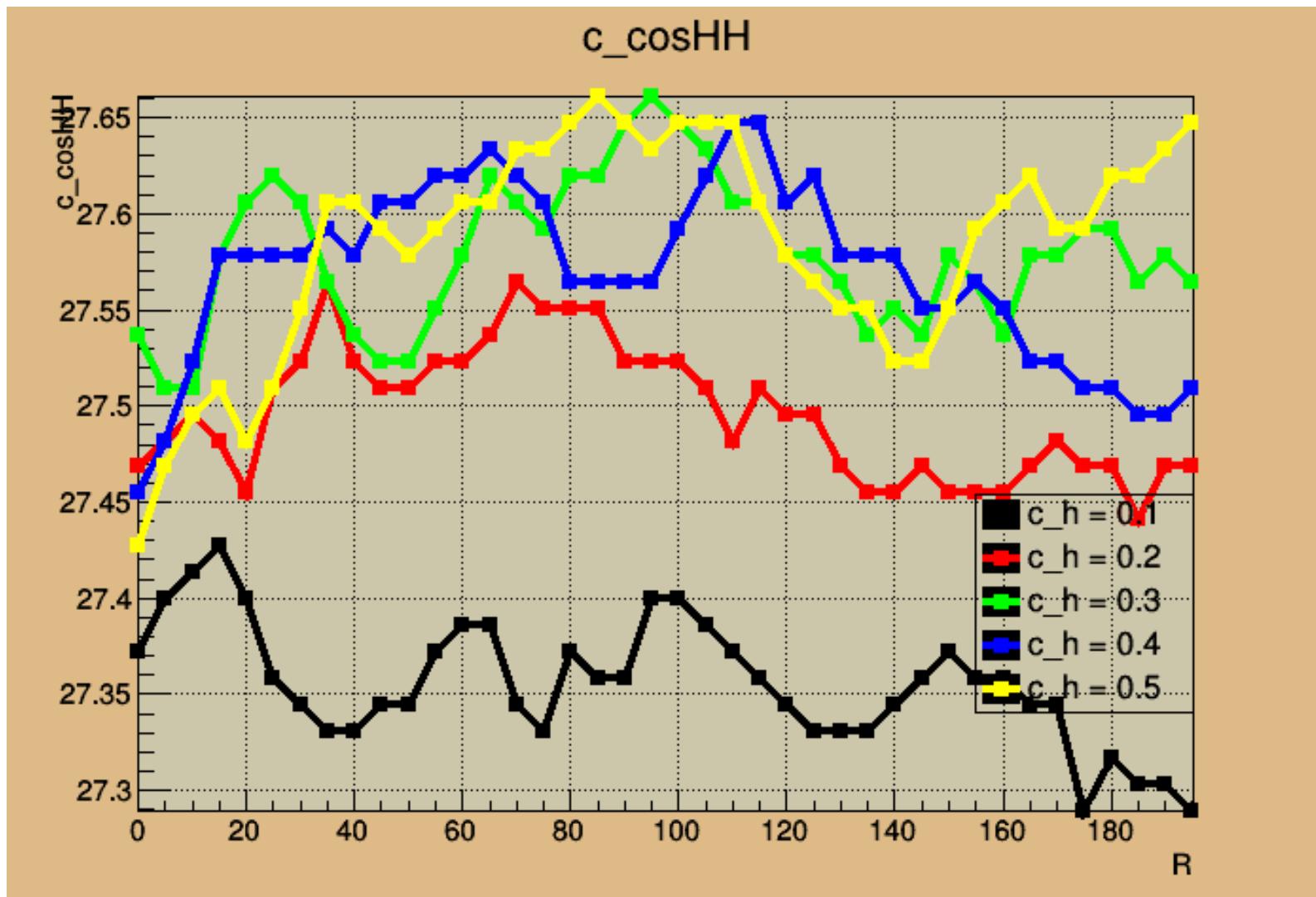
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# Analysis Strategy - Chi<sup>2</sup>

- First test optimization for c\_H and c\_cos
- c\_H ~ 0.2 / c\_cos ~ 30 ( $\sigma_{\text{cos}} = 1$ )
- Pairing efficiency 25 -> 27.5 %

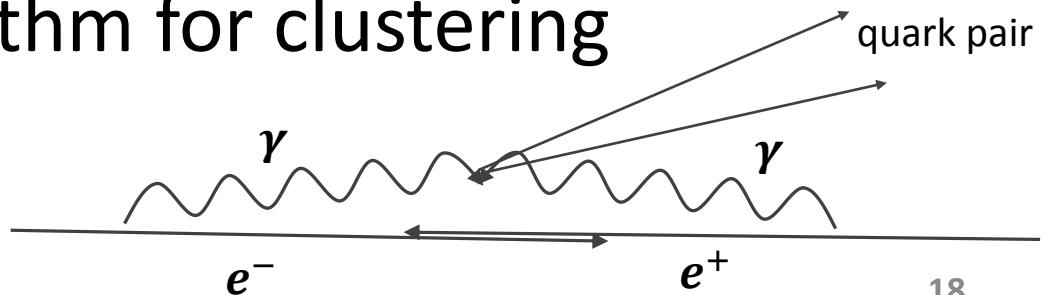
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# Analysis Strategy - Chi<sup>2</sup>

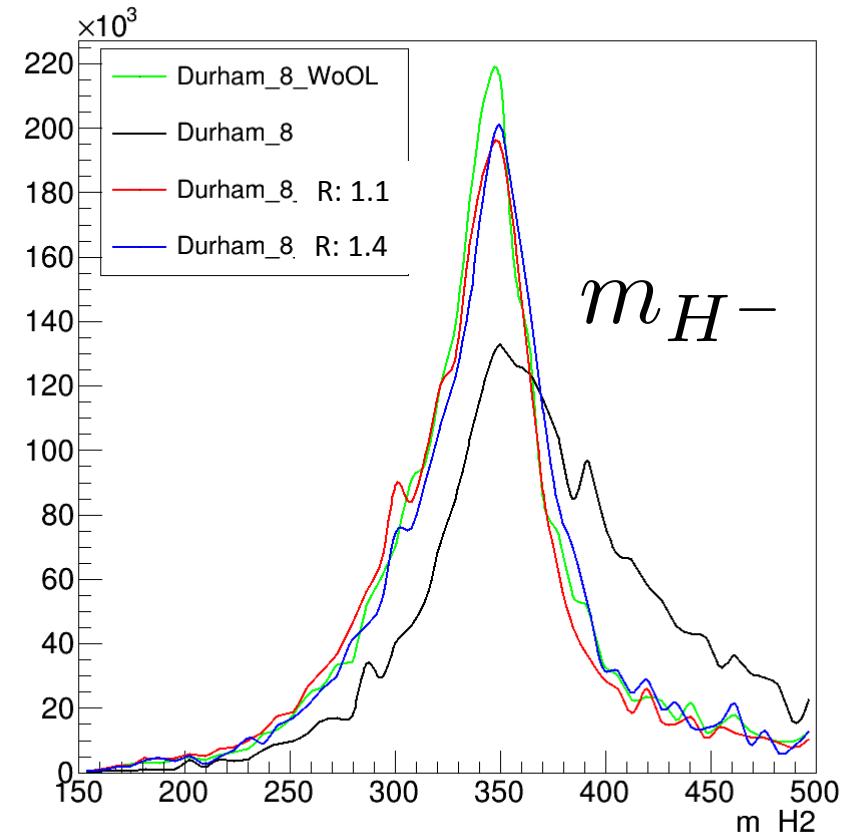
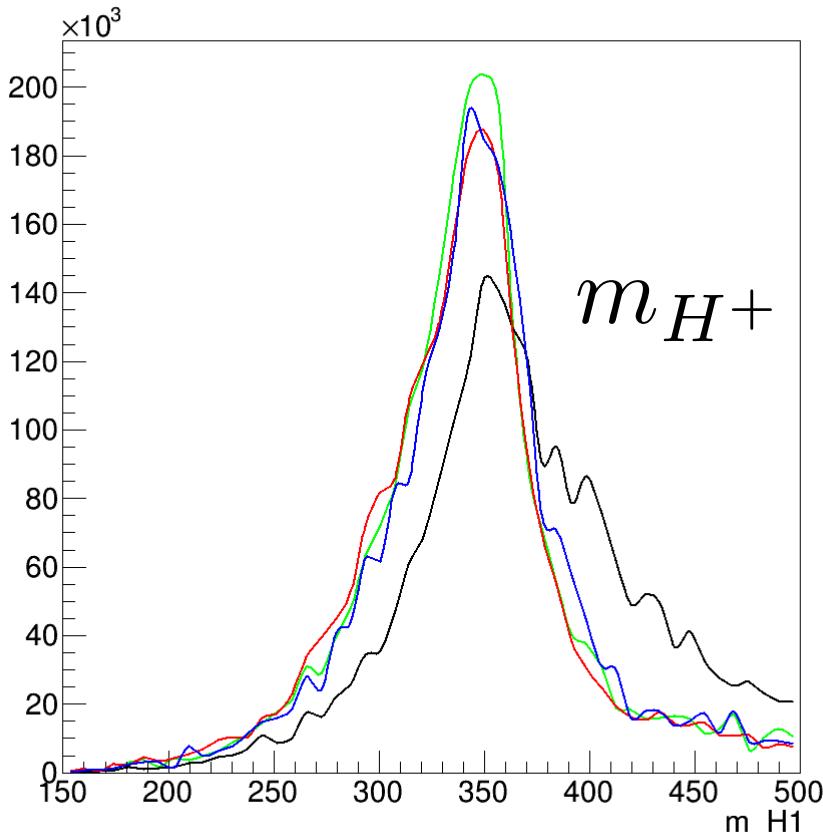


# Analysis Strategy – Beam Background

- In average 1.7 beam background events per bunch crossing
- Has major influence on jet clustering
- Use kt-algorithm from fastjet package to reduce background
  - R: Generalized radius of jets
  - Vary R to optimal mass resolution
- Use Durham algorithm for clustering

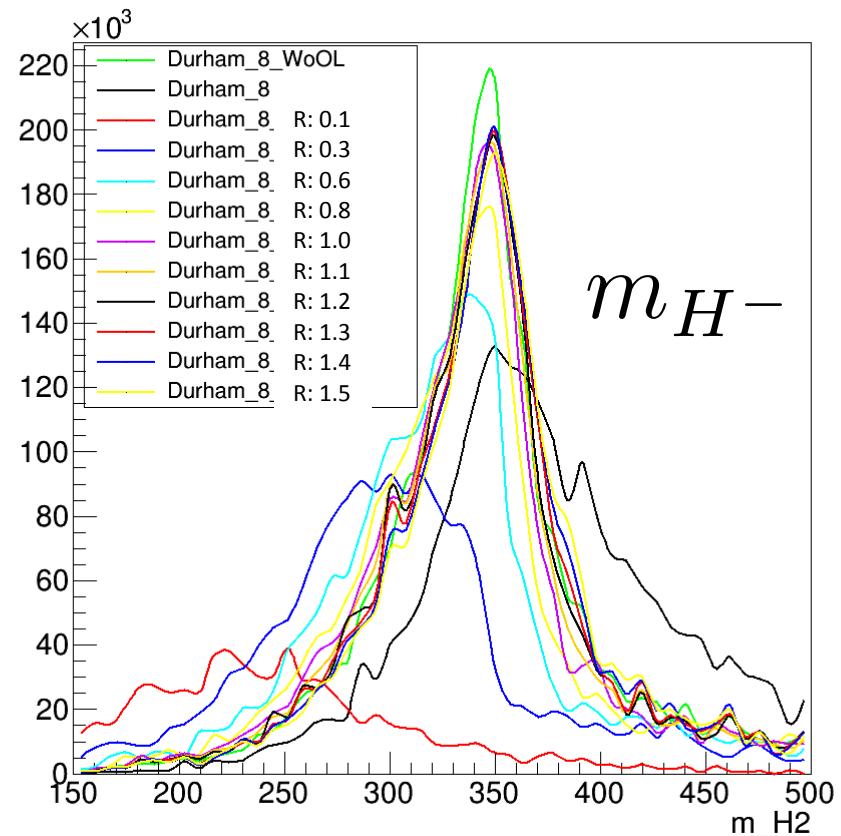
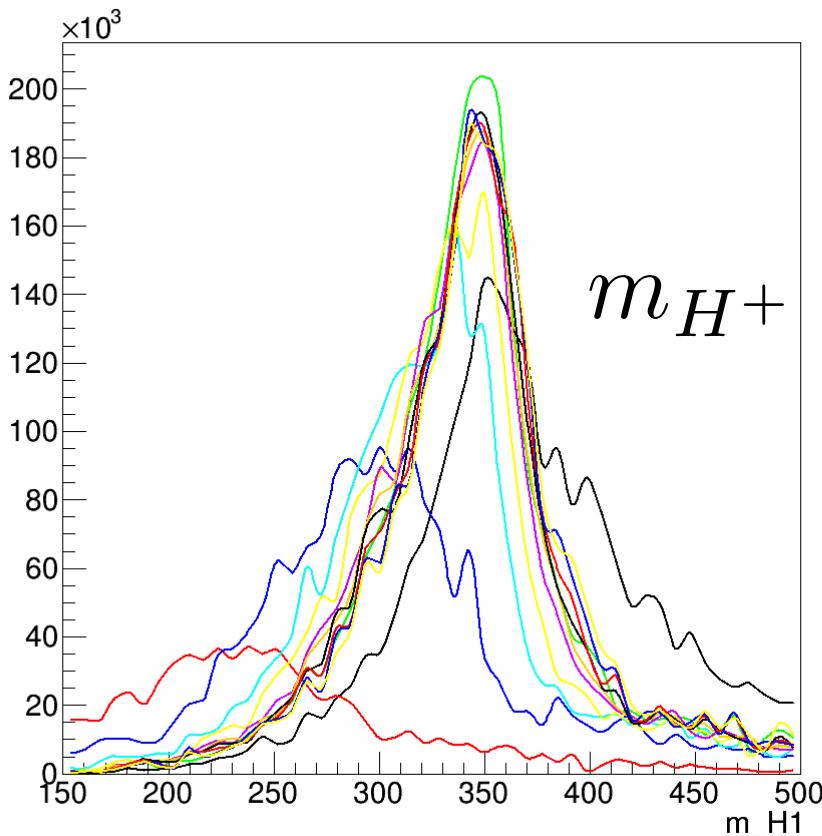


# Analysis Strategy - Find R for kt-Algorithm



Reconstructed  $H^+$  and  $H^-$  mass with realistic clustering and pairing with generator information

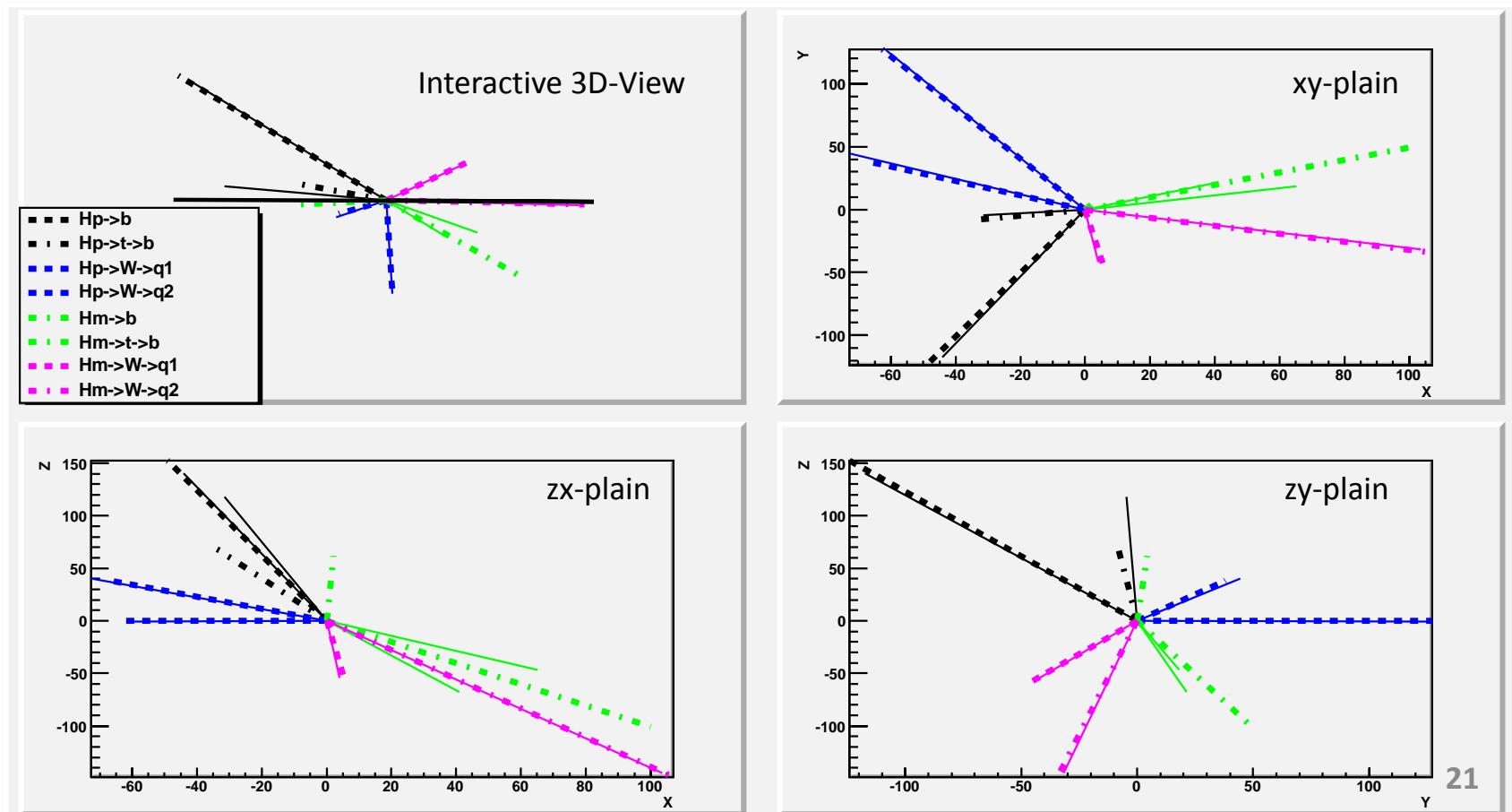
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Reconstructed  $H^+$  and  $H^-$  mass with realistic clustering and pairing with generator information

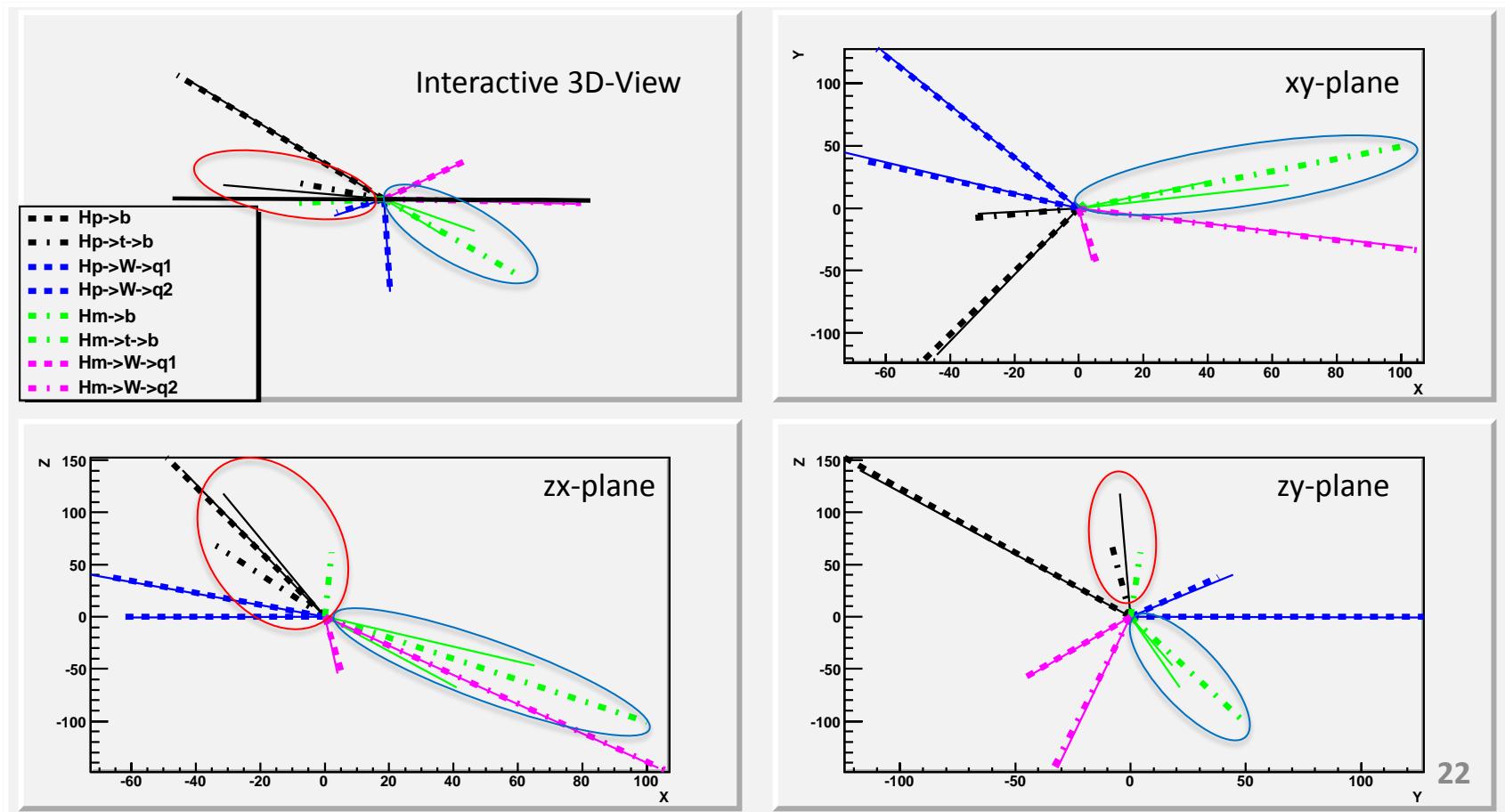
# Analysis Strategy - 3D display

- Event by event view of reconstructed jets (solid line) and generator quarks (dashed line)
- To analyze and check clustering and pairing



# Analysis Strategy - 3D display

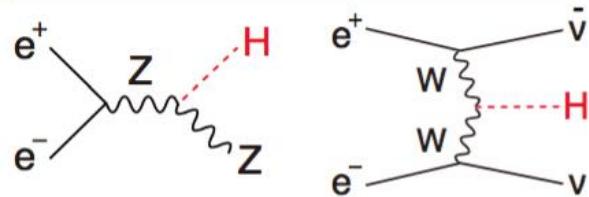
- Event by event view of reconstructed jets (solid line) and generator quarks (dashed line)
- To analyze and check clustering and pairing



# Higgs Recoil – Copied from Keisuke Fuji

At LHC all the measurements are  $\sigma \times BR$  measurements.

At ILC all but the  $\sigma$  measurement using recoil mass technique is  $\sigma \times BR$  measurements.

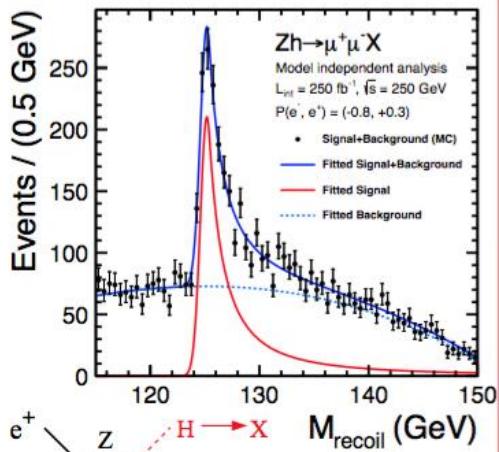


$$g_{HAA}^2 \propto \Gamma(H \rightarrow AA) = \Gamma_H \cdot BR(H \rightarrow AA)$$

$\sigma \times BR$

BR

g coupling

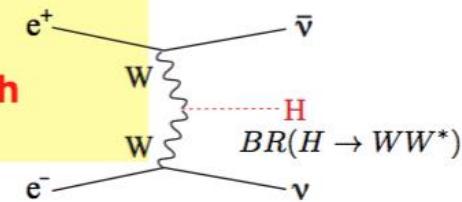


$$M_X^2 = (p_{CM} - (p_{\mu^+} + p_{\mu^-}))^2$$

Can detect even if Higgs decays invisibly!

$\sigma$   
from recoil mass

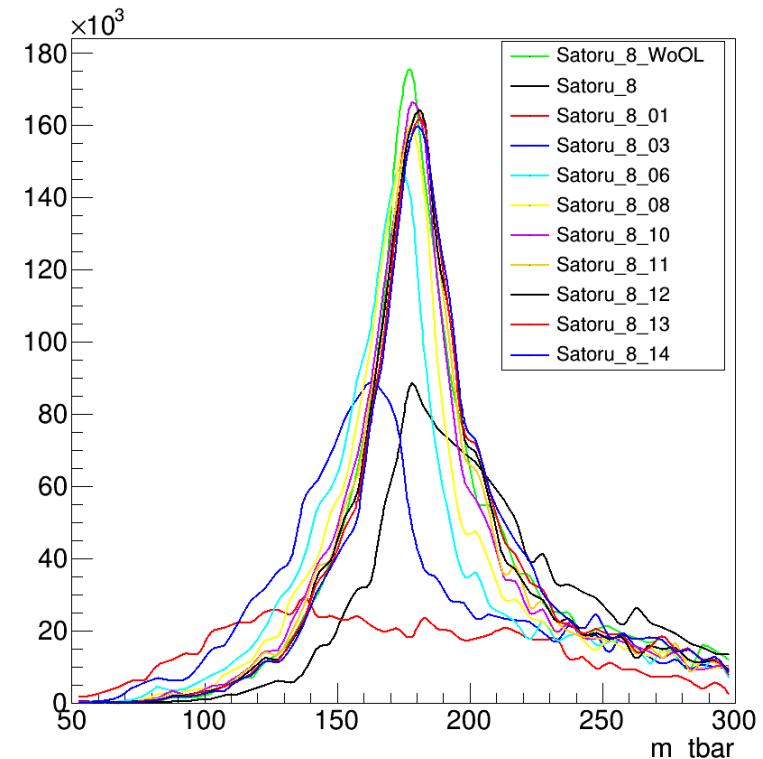
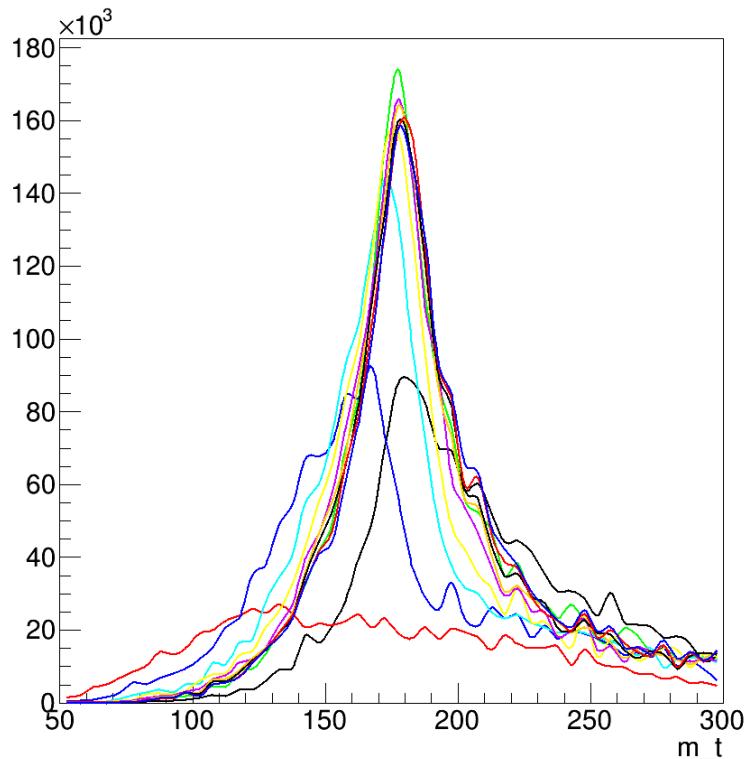
$\Gamma_H$   
Total width



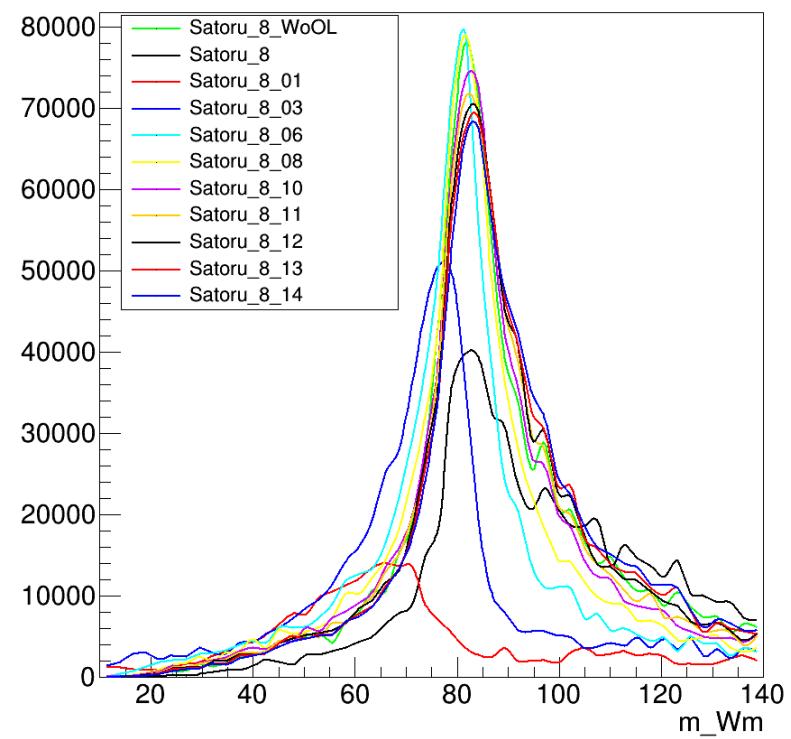
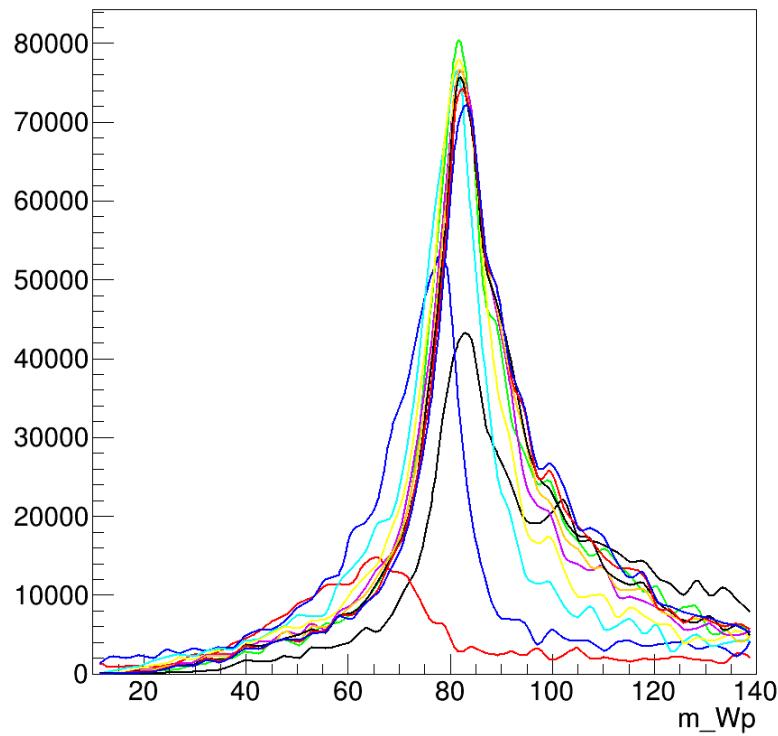
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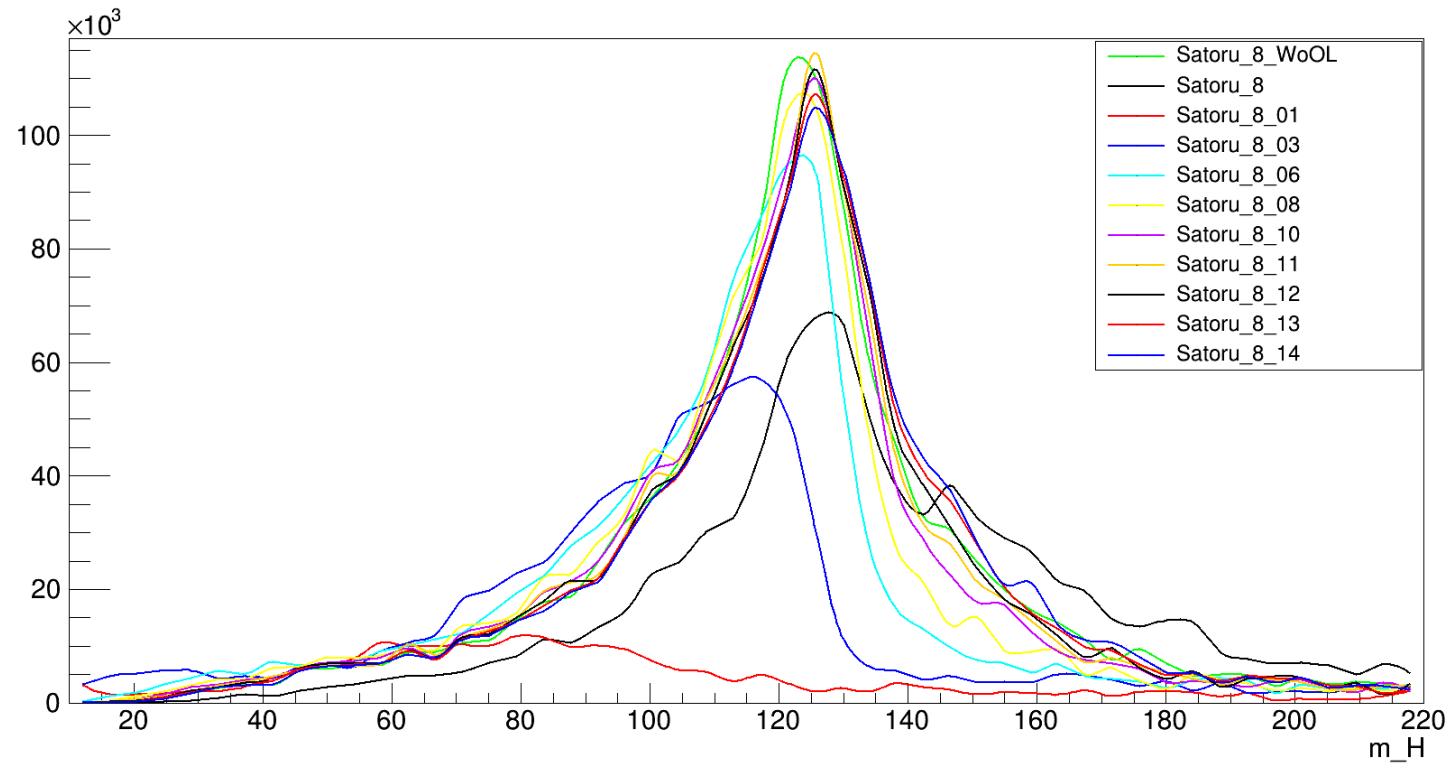
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# Analysis Strategy - Find R for kt-Algorithm



Reconstructed top and anti top mass with realistic clustering and pairing with generator information  
(with  $t\bar{t}$  samples)





# Analysis Strategy - Chi<sup>2</sup>

- Testing with  $t\bar{t} \rightarrow b\bar{q}qb\bar{q}bb$  (same final state)
- Makes 40320 combinations
- With b tag consideration  $\rightarrow 576$  combinations
- without jet 3 and 4, 7 and 8, 6 and 2, ...  $\rightarrow 36$  combination

$$\chi^2 = \left| \frac{(m_{j_1 j_2})^2 - (m_h)^2}{\sigma_h} \right| + \left( \frac{m_{j_3 j_4 j_5} - M_t}{\sigma_t} \right)^2 + \left( \frac{m_{j_6 j_7 j_8} - M_t}{\sigma_t} \right)^2 + \left( \frac{m_{j_3 j_4} - M_W}{\sigma_W} \right)^2 + \left( \frac{m_{j_7 j_8} - M_W}{\sigma_W} \right)^2$$

# Analysing Jetclustering with MC information

- Retracking pfo to MC part
- Separation of Colorsinglet
- Pairing Jets

	CS1 (%)	CS2 (%)
Jet1	0	100
Jet2	100	0
Jet3	100	0
Jet4	0	100

# Analysing Jetclustering with MC information

- Retracking pfo to MC part
- Separation of Colorsinglet
- Pairing Jets

	CS1 (%)	CS2 (%)
Jet1	15	85
Jet2	55	45
Jet3	99	1
Jet4	0	100

# Analysing Jetclustering with MC information

- Retracking pfo to MC part
- Separation of Colorsinglet
- Pairing Jets

	CS1 (%)	CS2 (%)
Jet1	60	40
Jet2	55	45
Jet3	99	1
Jet4	0	100

# Analysing Jetclustering with MC information

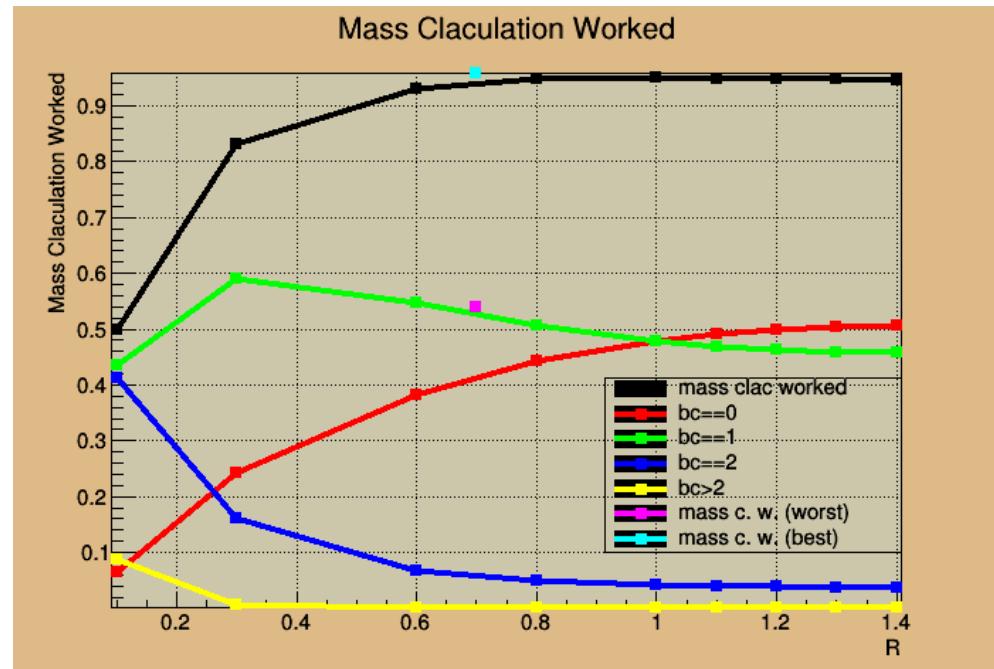
- Retracing pfo to MC part
- Separation of Colorsinglet
- Pairing Jets

- Correcting

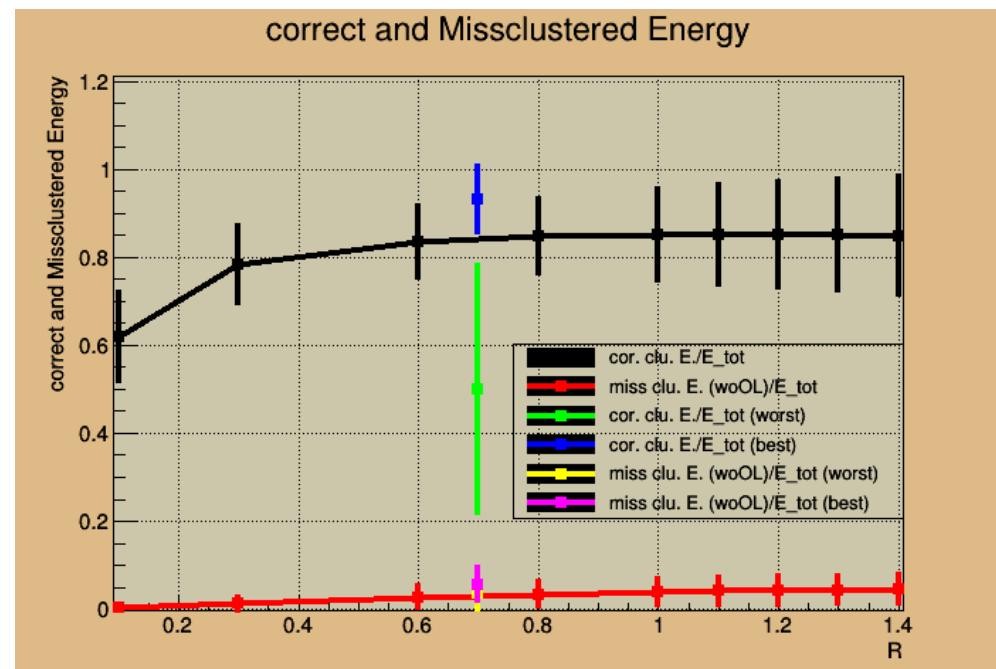
	CS1 (%)	CS2 (%)
Jet1	60	40
Jet2	55	45
Jet3	99	1
Jet4	0	100

# Mass Calculation Worked

- $bc == 1$  means one correction is necessary
- I only correct ones because correcting more than ones is difficult



# Correctly and Missclustered Energy



# Different Algorithms

- RefinedJets from LFCIplus

