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

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Outline

- Introduction to ILC
- Motivation of ILC
- Higgs Two Doublet Model
- Motivation for Charged Higgs Search at ILC
- Analysis Strategy
- Status
- Plan
- Summery

Higgs Two Doublet Model (H2DM)

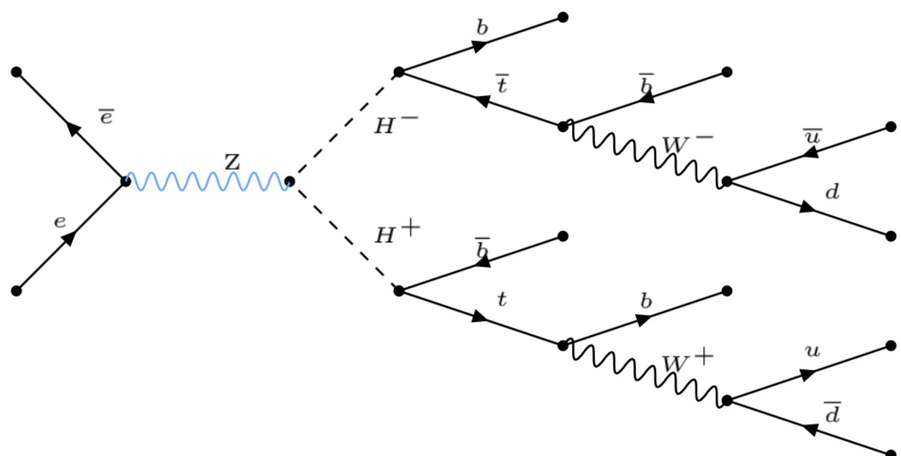
- Favorable in SUSY
  - Main motivation – hierarchy problem (Higgs mass correction in SM to ∼16 digits)
  - Dark matter, Gauge coupling unification (GUT)
- No conjugated potential in SUSY
  - To give mass to up and down type fermions –> two Higgs doublets
  - 8 degrees of freedom -> 5 Higgs bosons
  - 2 charged Higgs bosons (H+H-)

Motivation for Charged Higgs Search at ILC

- e^+e^--Collider very sensitive (up to kin. Limit)
- Light Higgs 125 GeV -> decoupling limit
  - Heavy Higgs to weak gauge boson coupling small
  - Makes fermion final state most promising
  - Hardly visible at LHC
- Very simple and well defined prosess
  - e+e- -> H+H-

Analysis Strategy

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



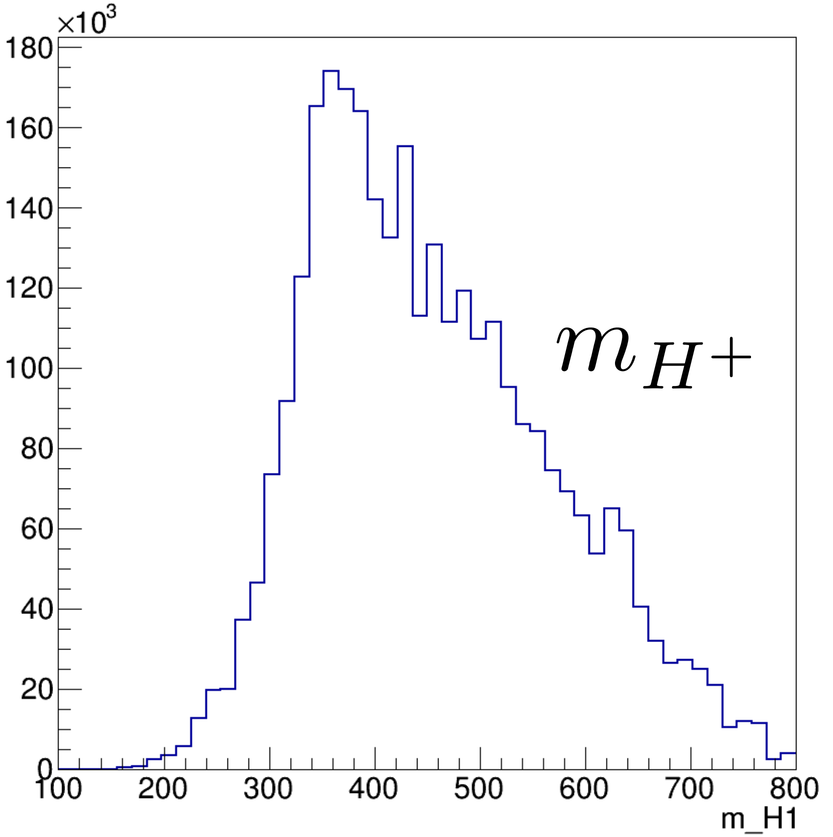
Analysis Strategy - Chi^2

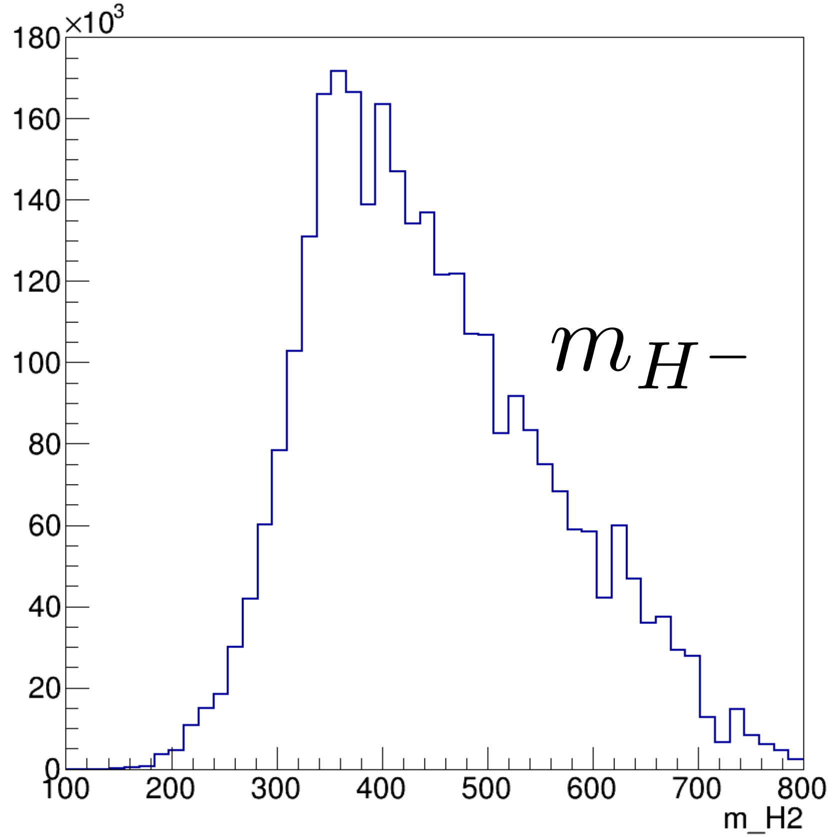
- Jet pairing has 40320 combinations
- With b tag consideration –> 576 combinations
- without exchanging jets from a given W-boson
  without exchanging H+ and H-
  -> 36 combination
- For mass measurement the mass of $H^\pm$ can not be fixed

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

$$+ \left(\frac{m_{j_6 j_7 j_8} - M_t}{\sigma_t} \right)^2 + \left(\frac{m_{j_3 j_4} - M_W}{\sigma_W} \right)^2 + \left(\frac{m_{j_7 j_8} - M_W}{\sigma_W} \right)^2$$

Raw mass distribution





Reconstructed H^+ and H^- mass with uncorrected clustering and chi^2 pairing

Analysis Strategy - Chi^2

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

Beam background removed

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

Analysis Strategy - Chi^2

- Choose σ from pairing with generator information
- Optimize for c for maximal pairing efficiency

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

$$+ c_t \left(\frac{m_{j_6 j_7 j_8} - M_t}{\sigma_t} \right)^2 + c_w \left(\frac{m_{j_3 j_4} - M_W}{\sigma_W} \right)^2 + c_w \left(\frac{m_{j_7 j_8} - M_W}{\sigma_W} \right)^2$$

$$\sigma_H = \sigma_t = 80\ GeV,\ \sigma_W = 48\ GeV$$

Analysis Strategy - Chi^2

- Choose σ from pairing with generator information
- Optimize for c for maximal pairing efficiency

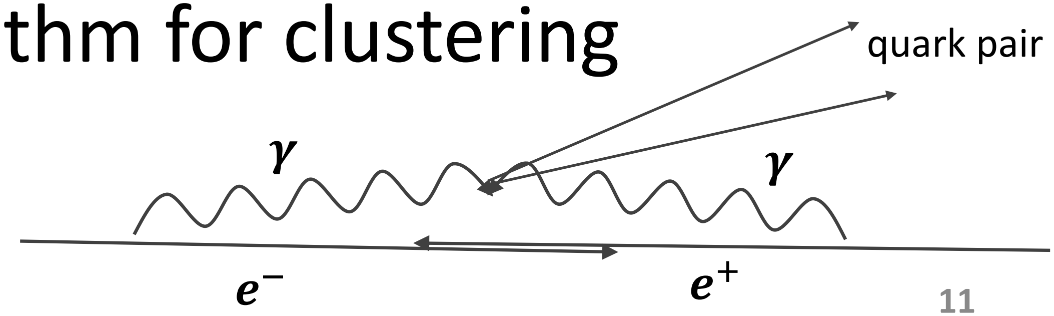
$$\chi^2 = c_H \left| \frac{(m_{j_1 j_2 j_3 j_4})^2 - (m_{j_5 j_6 j_7 j_8})^2}{2\sigma_{H^+}^2} \right| + c_t \left(\frac{m_{j_2 j_3 j_4} - M_t}{\sigma_t} \right)^2$$

$$+ c_t \left(\frac{m_{j_6 j_7 j_8} - M_t}{\sigma_t} \right)^2 + c_w \left(\frac{m_{j_3 j_4} - M_W}{\sigma_W} \right)^2 + c_w \left(\frac{m_{j_7 j_8} - M_W}{\sigma_W} \right)^2$$

$$+ c_{\cos\theta_{HH}} \left(\frac{1 - \cos\theta_{HH}}{\sigma_{\cos\theta_{HH}}} \right)^2 + c_{\theta_{HH}} \left(\frac{\theta_{HH}}{\sigma_{\theta_{HH}}} \right)^2 + c_E \left(\frac{E_{H^-} - E_{H^+}}{\sigma_E} \right)^2 + c_p \left(\frac{\vec{p} - \vec{p}_{H^+}}{\sigma_p} \right)^2$$

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 – kt Algorithm (beam background removal)

- Calculate the distance between to all tracks

$$d_{ij} = \min(p_{Ti}^2, p_{Tj}^2)\frac{\Delta R_{ij}}{R}$$

with $\Delta R_{ij} = (\eta_i - \eta_j)^2 + (\phi_i - \phi_j)^2$

η pseudo rapidity, ϕ azimuth

- Find smallest d_{ij}
- If $d_{ij} < d_{iB} = p_{Ti}^2$ merge tracks, if not remove Track (B: Beam)
  - Remove particles that are closer to the beam than to the closest track i
- Continue to step one until there are only the requested number of jets

Analysis Strategy – Durham Algorithm (jet clustering)

- Calculate the distance between to all tracks

$$v_{ij} = 2(1 - \cos\theta_{ij})$$

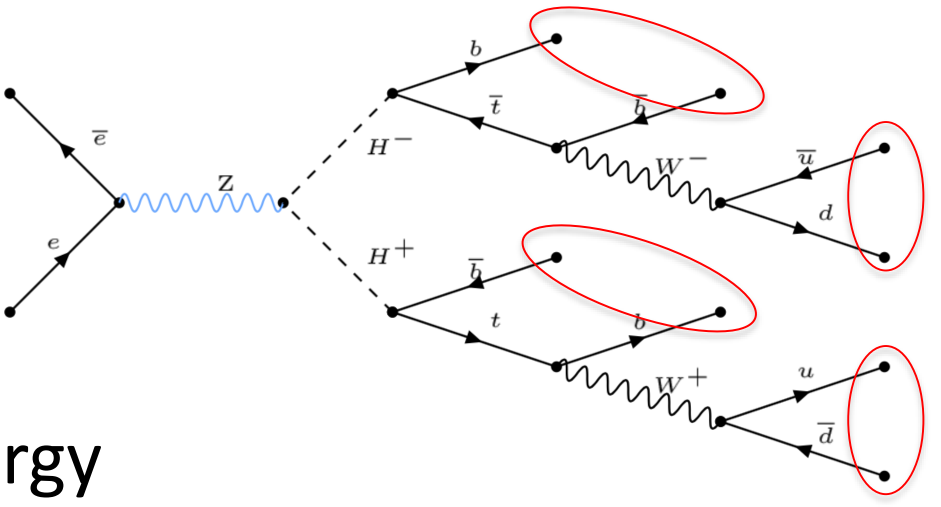
  with θ_{ij} angle between tracks
- Find smallest v_{ij}
- If $\min(E_i, E_j)v_{ij} < y_{\mathrm{cut}}$ merge tracks
  if not next higher v_{ij}
- If there are no tracks to merge left,
  increase y_{cut} until requested number of jets are found

Analysis Strategy – Check clustering

- Recover for every reconstructed track the origin particle from Monte Carlo Simulation
- Recover initial state parent
- Can only recover color singlet
- Four color singlets
- Major fraction of jet: correctly clustered energy
- Minor fractions of jet: missclustered energy

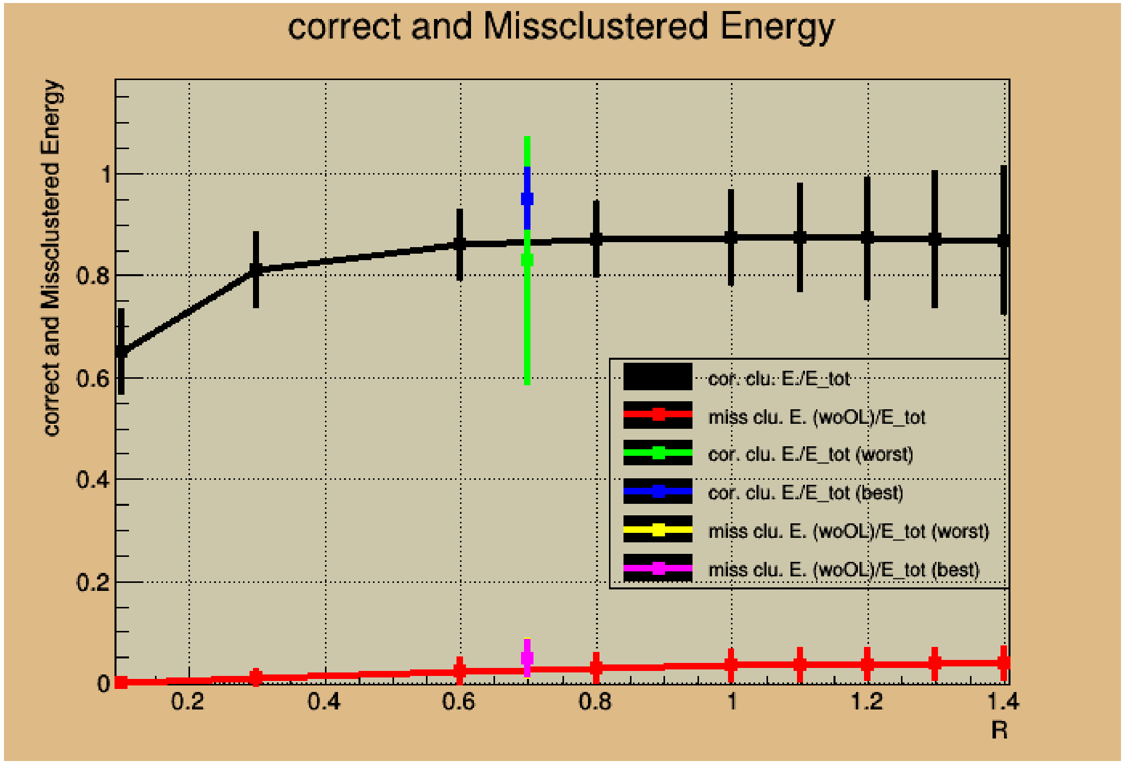
Analysis Strategy – Check clustering

- Recover for every reconstructed track the origin particle from Monte Carlo Simulation
- Recover initial state parent
- Can only recover color singlet
- Here: 4 color singlets
- Major fraction of jet: correctly clustered energy
- Minor fractions of jet: mis-clustered energy

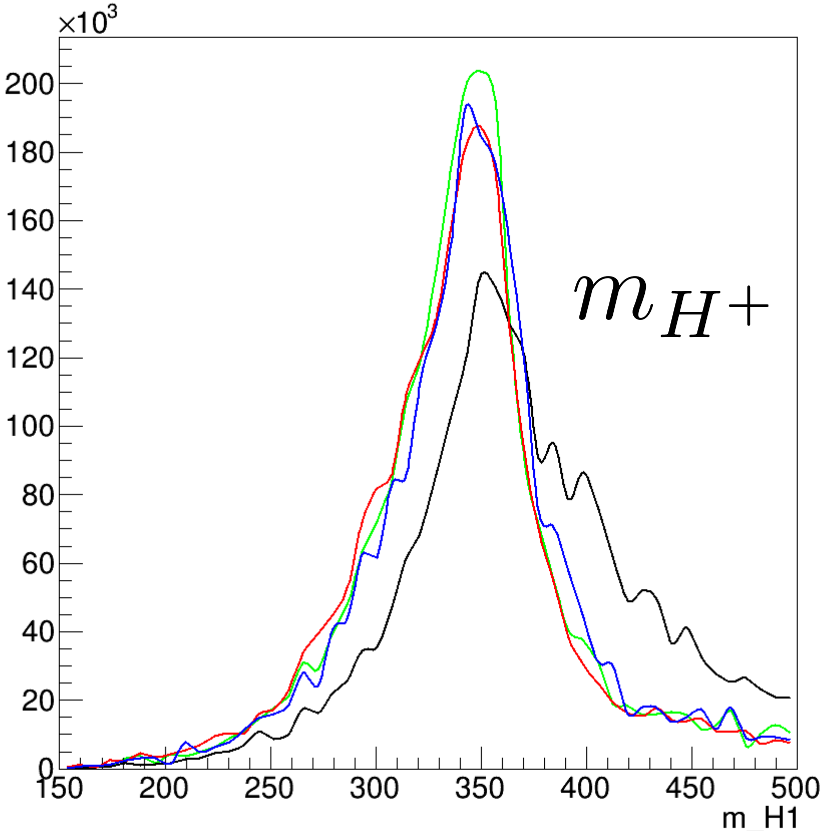


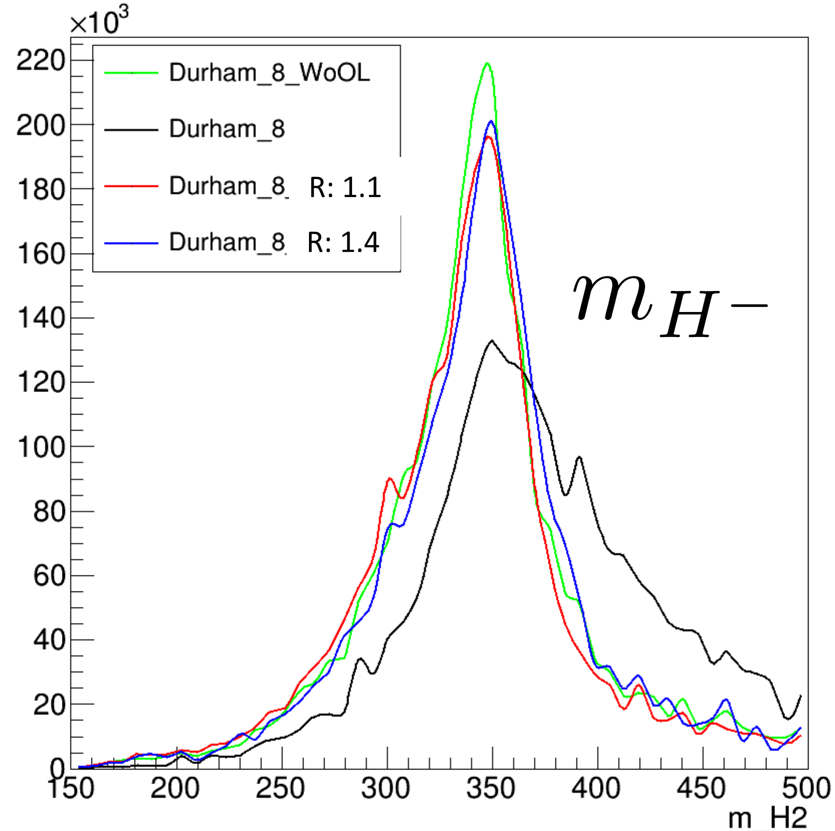
Analysis Strategy - Find R for kt-Algorithm

- Correctly clustered and missclustered energy over total energy
- X-axes generalized radius R
- Error bars spread of the distribution



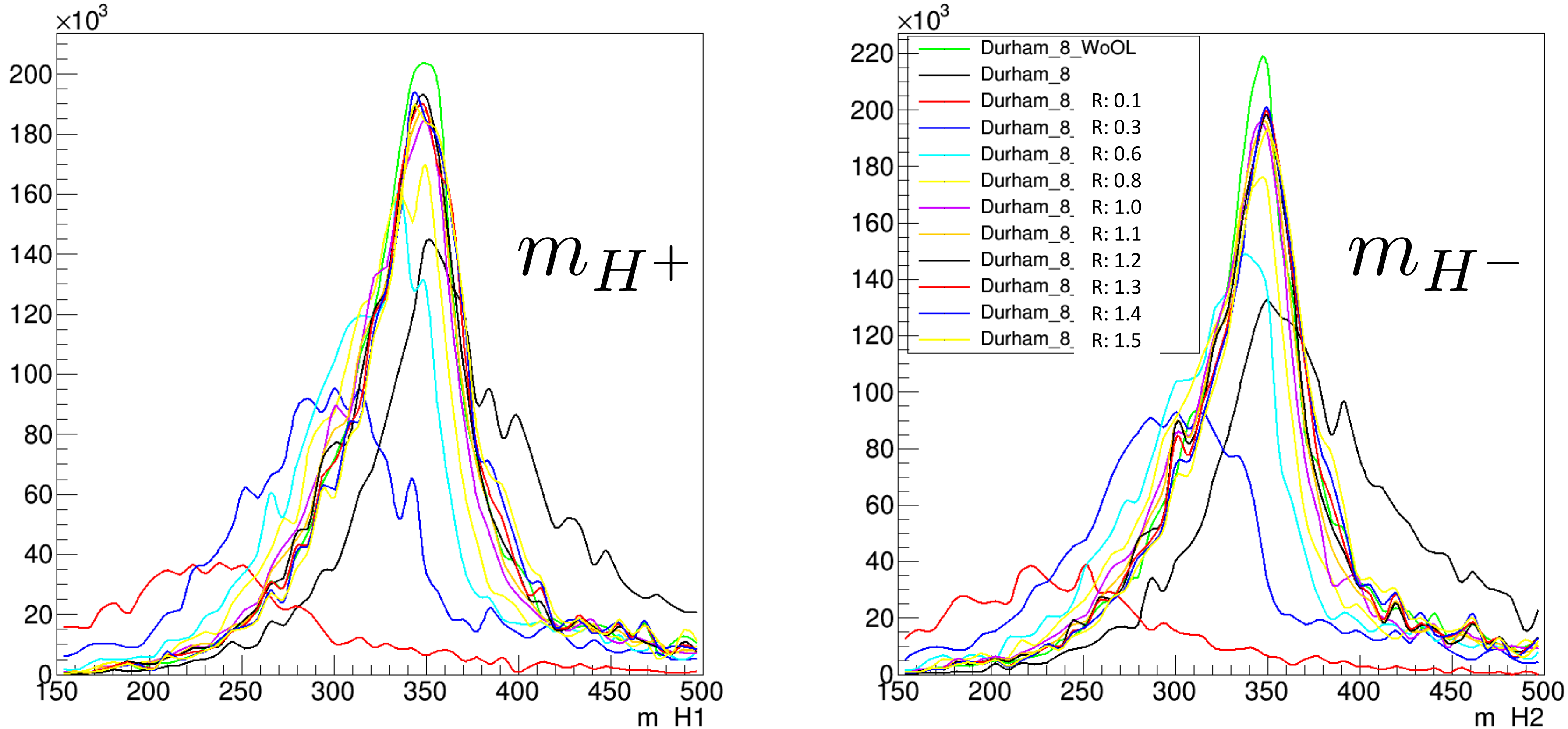
Analysis Strategy - Find R for kt-Algorithm





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

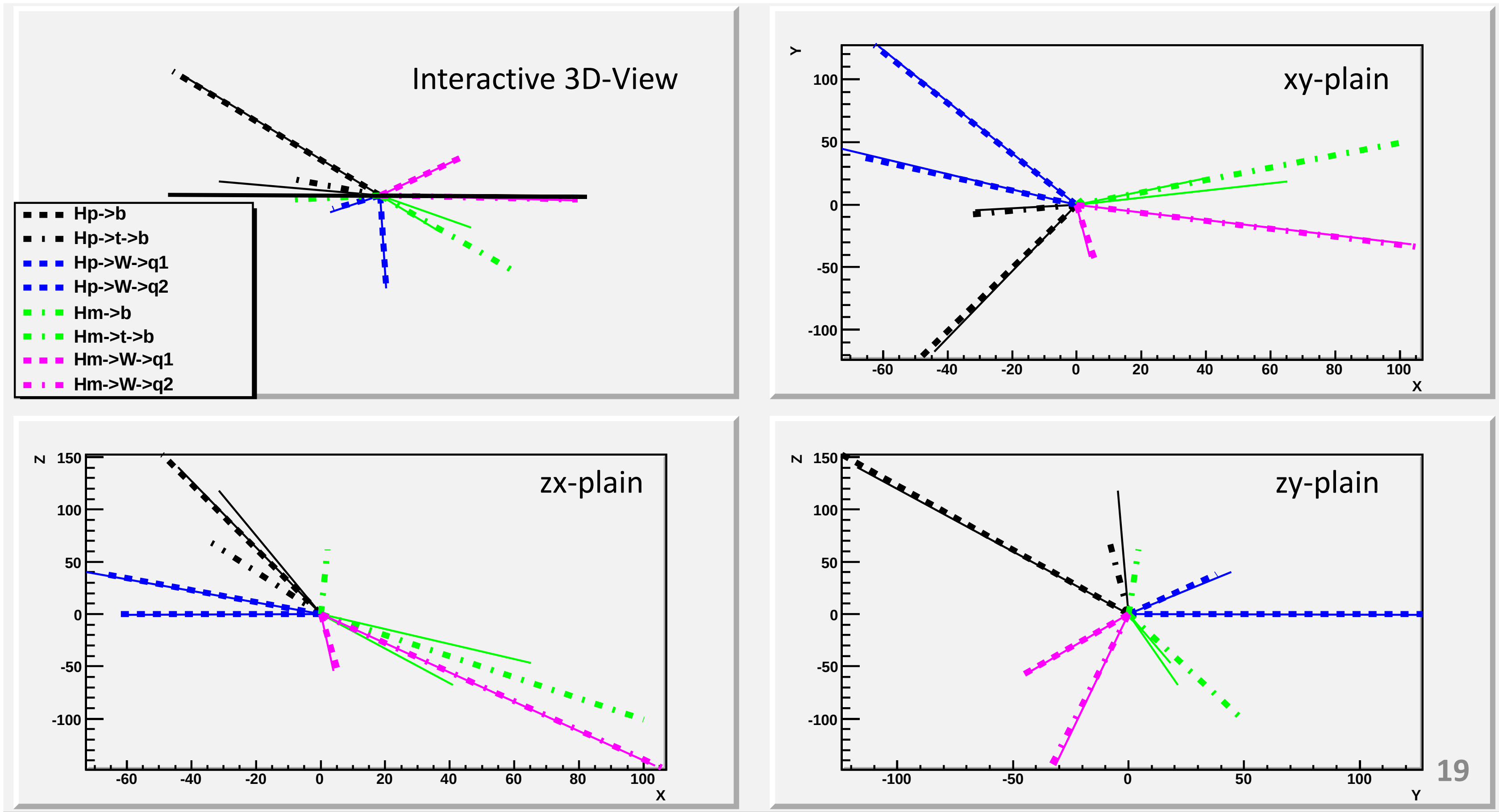
Analysis Strategy - Find R for kt-Algorithm



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)
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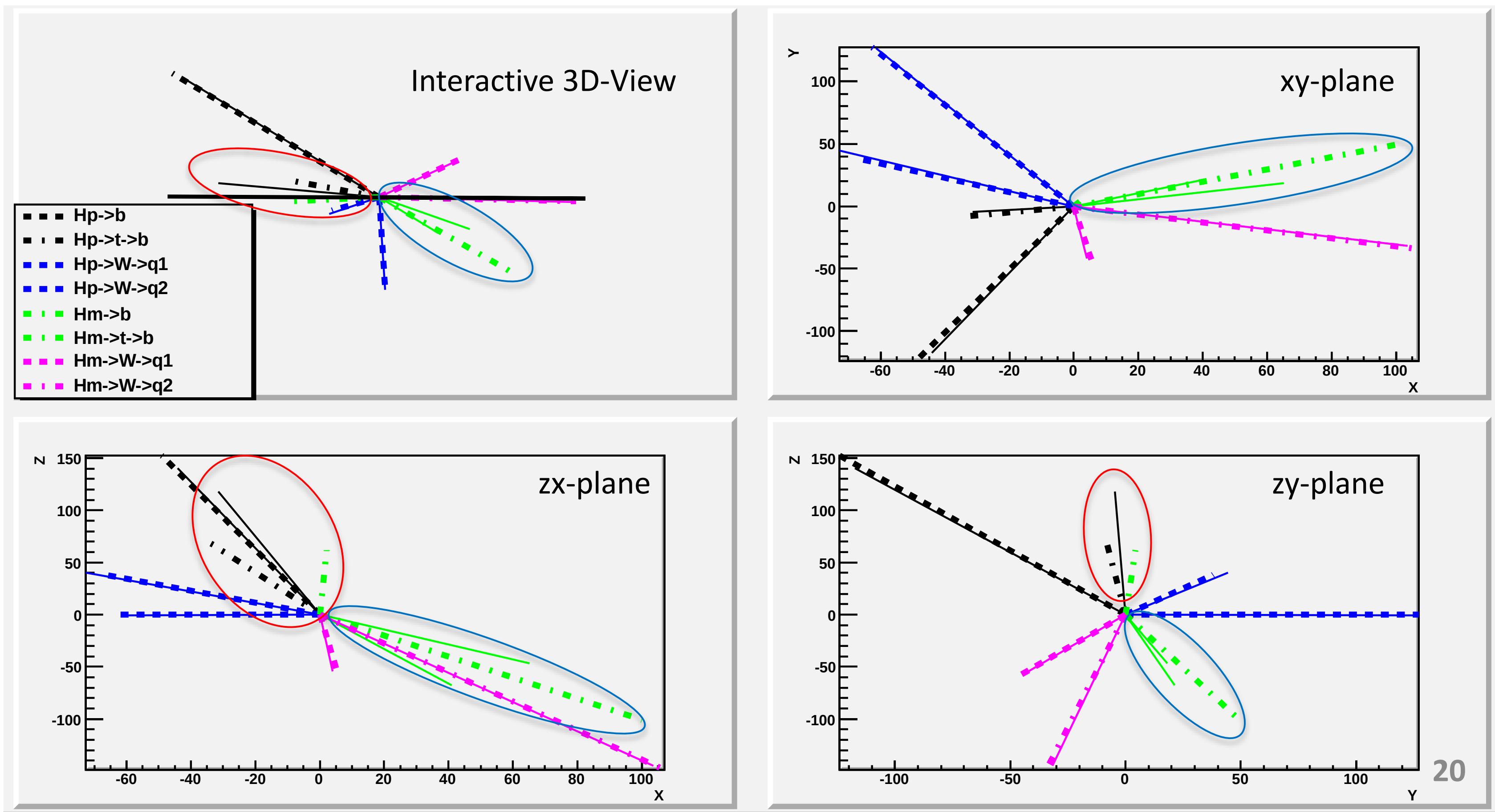


Analysis Strategy - CP Violation

- Possible to measure in this channel
- Through decay with CP violating SUSY loops
- δ between 0.20 and 0.02 for tan(β) between 5 and 30
- Semi-leptonic mode better suitable

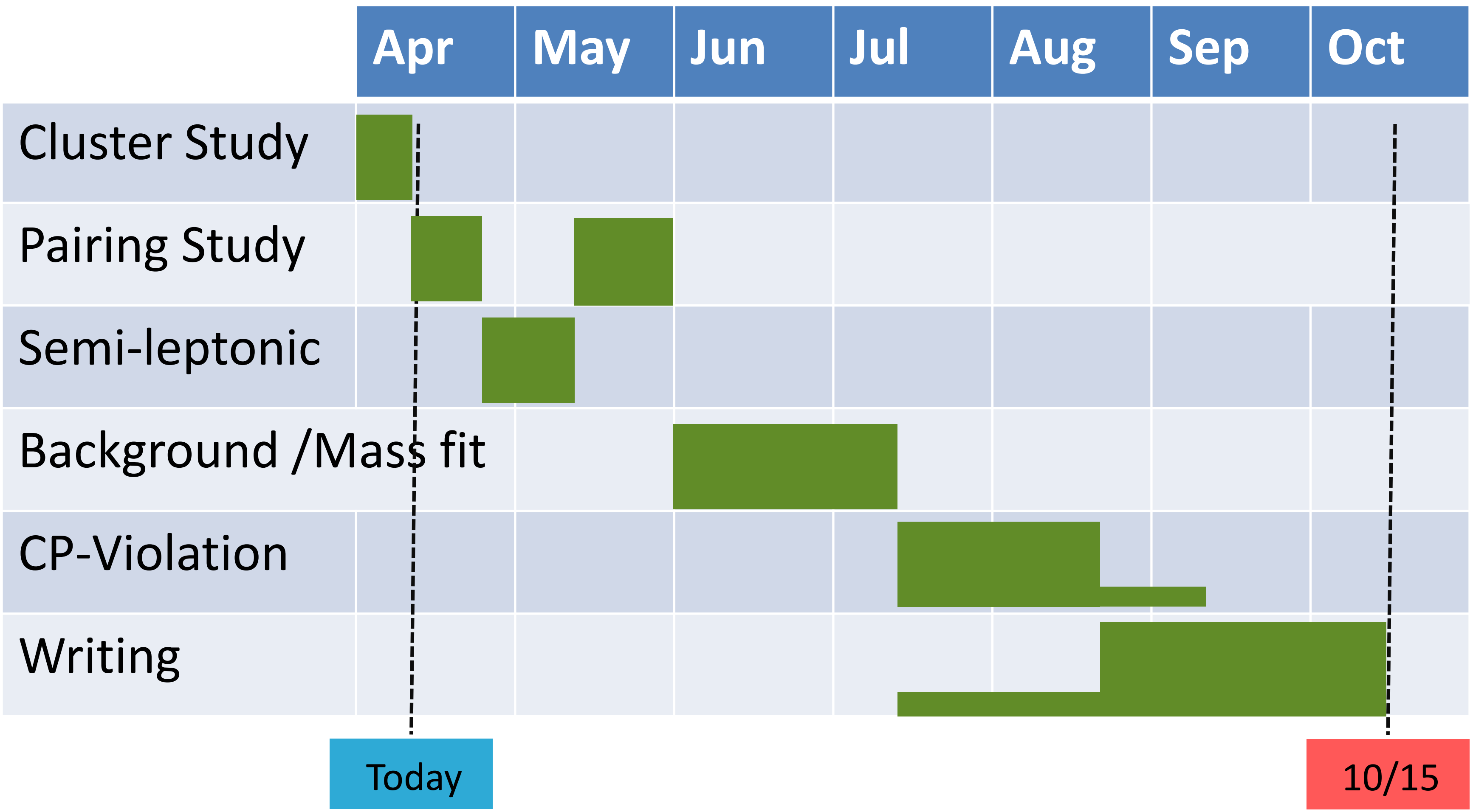
$$\delta^{CP}_{f\overline{f}'} \propto \frac{1}{\tan\beta}$$

$$\delta^{CP}_{f\overline{f}'} = \frac{BR(H^+ \to f\overline{f}') - BR(H^- \to \overline{f}f')}{BR(H^+ \to f\overline{f}') + BR(H^- \to \overline{f}f')}$$

Status

- Pairing optimization in prosess
- Best R for jet clustering
  - For charged Higgs between 1.1 and 1.4 (Impact on pairing has to be studied)
  - Around 1.0 for tth samples (consistent with older study at 1TeV (R = 1.2))
- Data samples were (finally) generated successfully
- Analyses environment is set and partially tested on tth samples

Schedule


Apr
May
Jun
Jul
Aug
Sep
Oct
Cluster Study
Pairing Study
Semi-leptonic
Background /Mass fit
CP-Violation
Writing
Today
10/15

Plan

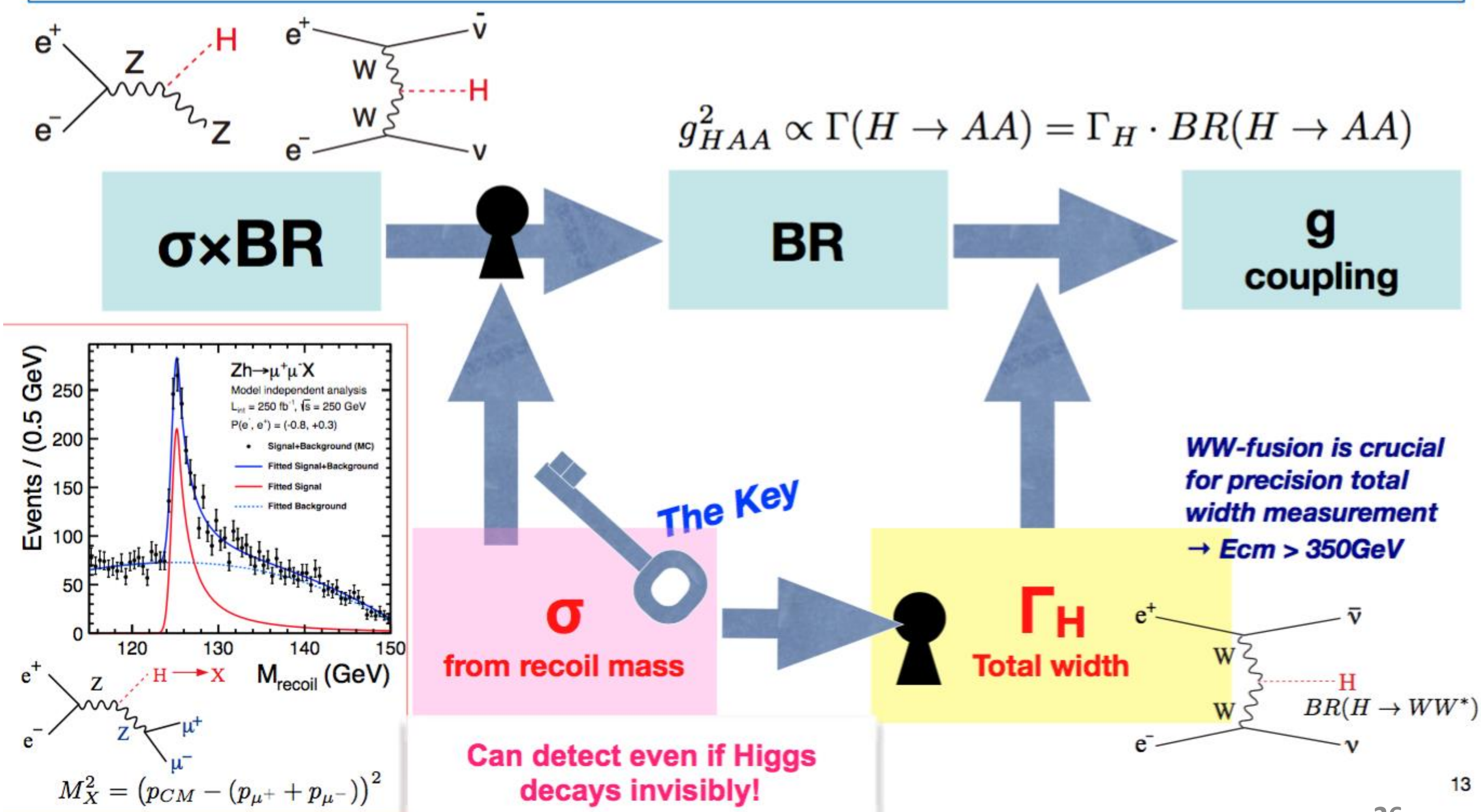
- Apply kt-algorithm on jet pairing
- Check Chi^2 Pairing with 3D display
- Develop extra conditions for pairing
- Include semi-leptonic mode (6 jets)
- Background study with cuts
- Goal:
  - mass fit -> mass resolution measurement
  - Detection efficiency
    -> cross section times branching ratio
- Bonus:
  - Research how to distinguish H+ and H-
  - Study of CP-violation measurement

Backup

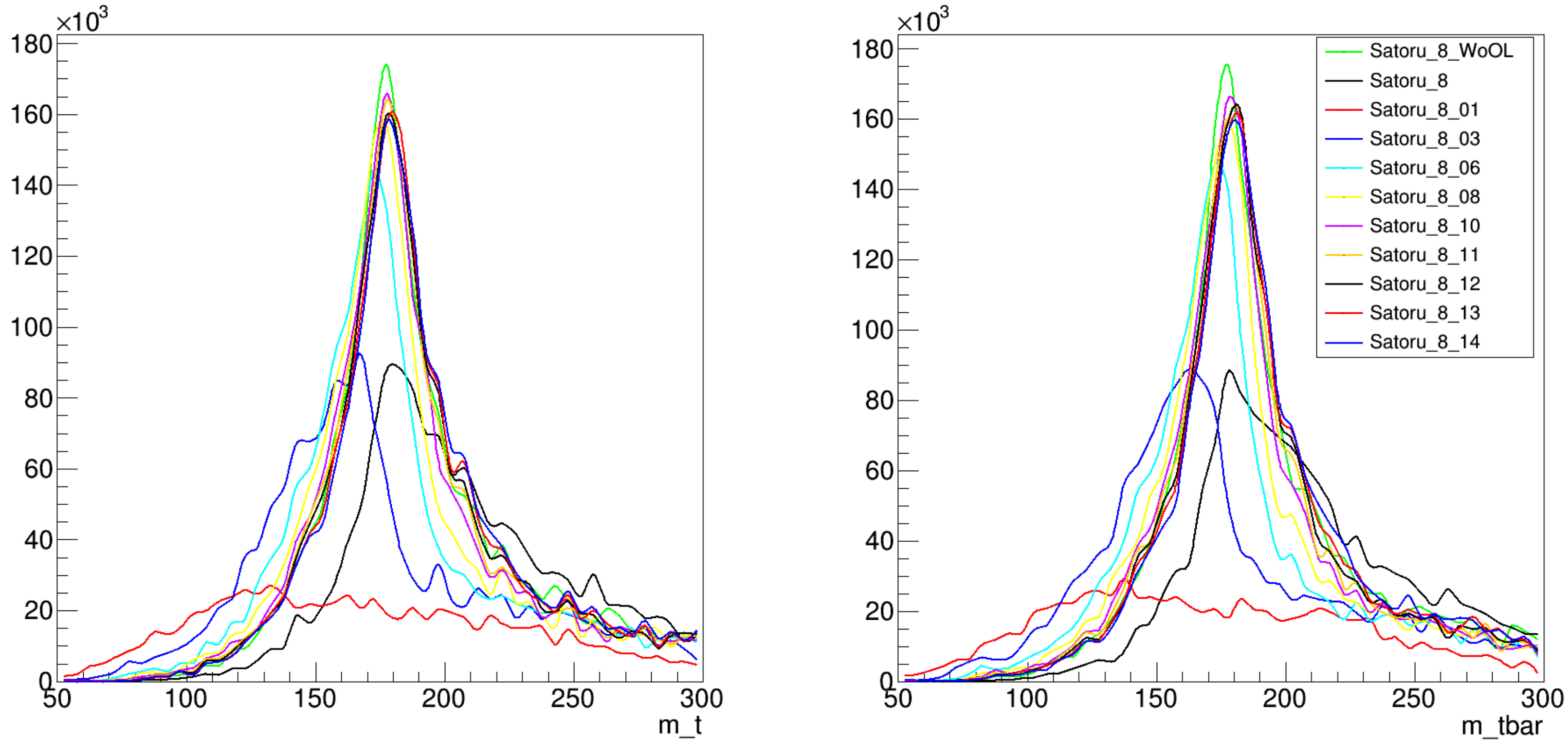
Higgs Recoil – Copied from Keisuke Fuji

At LHC all the measurements are σ×BR measurements.

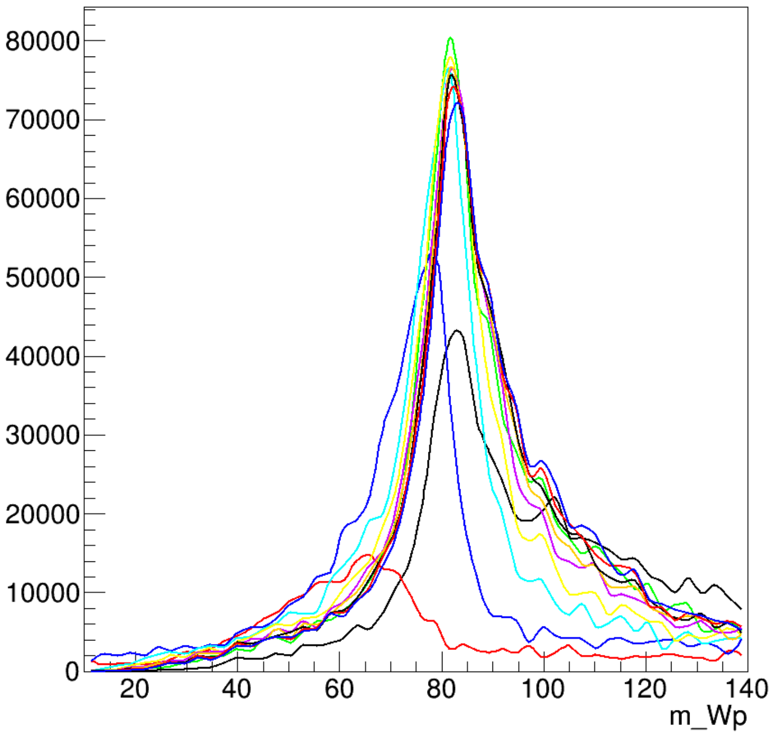
At ILC all but **the σ measurement using recoil mass technique** is σ×BR measurements.

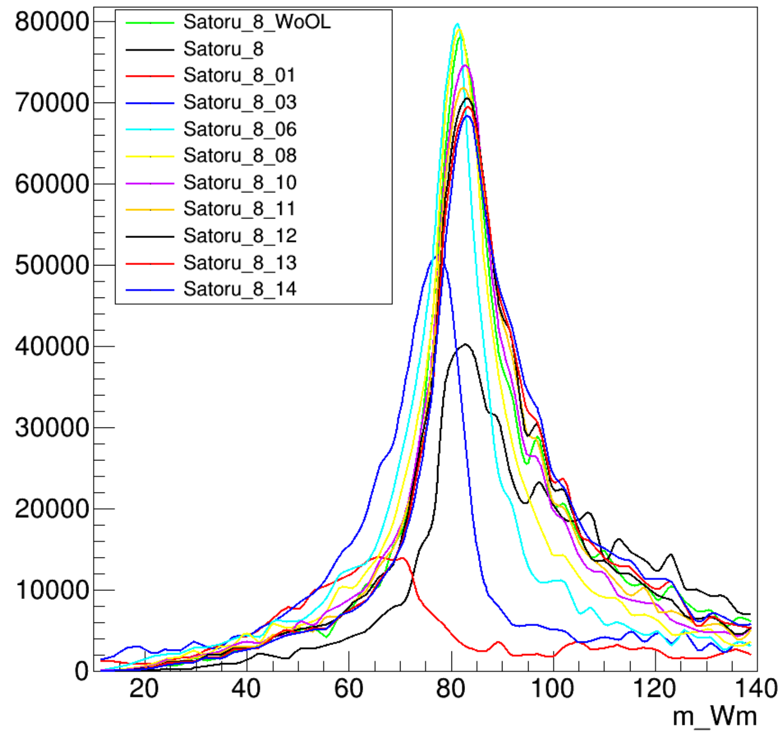


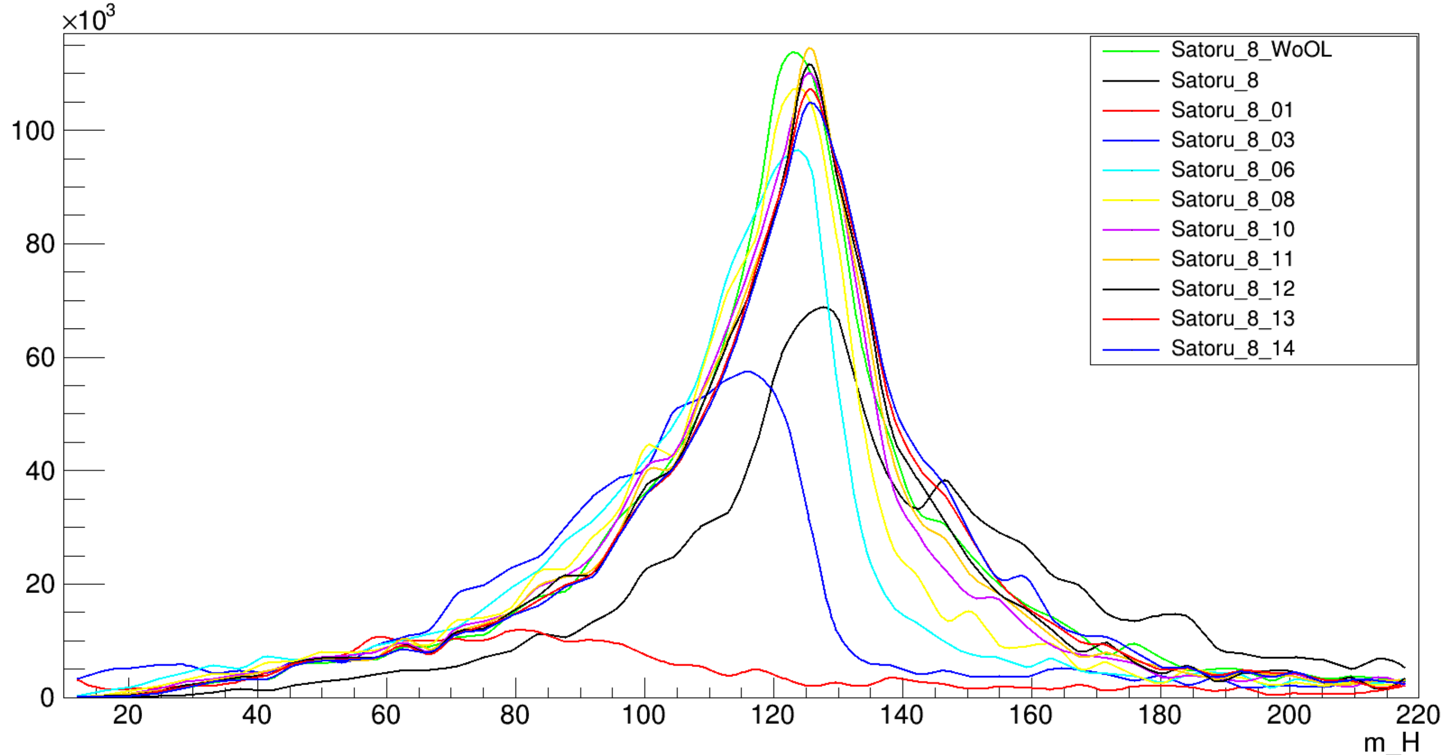
Analysis Strategy - Find R for kt-Algorithm



Reconstructed top and anti top mass with realistic clustering and pairing with generator information (with tth samples)


80000
70000
60000
50000
40000
30000
20000
10000
0
20
40
60
80
100
120
140
m_Wp


Satoru_8_WoOL
Satoru_8
Satoru_8_01
Satoru_8_03
Satoru_8_06
Satoru_8_08
Satoru_8_10
Satoru_8_11
Satoru_8_12
Satoru_8_13
Satoru_8_14
80000
70000
60000
50000
40000
30000
20000
10000
0
20
40
60
80
100
120
140
m_Wm



×10^3
100
80
60
40
20
0
20
40
60
80
100
120
140
160
180
200
220
m_H
Satoru_8_WoOL
Satoru_8
Satoru_8_01
Satoru_8_03
Satoru_8_06
Satoru_8_08
Satoru_8_10
Satoru_8_11
Satoru_8_12
Satoru_8_13
Satoru_8_14

Analysis Strategy - Chi^2

- Testing with tth -> bqqbqqbb (same final state)
- Makes 40320 combinations
- With b tag consideration –> 576 combinations
- without jet 3 and 4, 7 and 8, 6 and 2, … -> 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

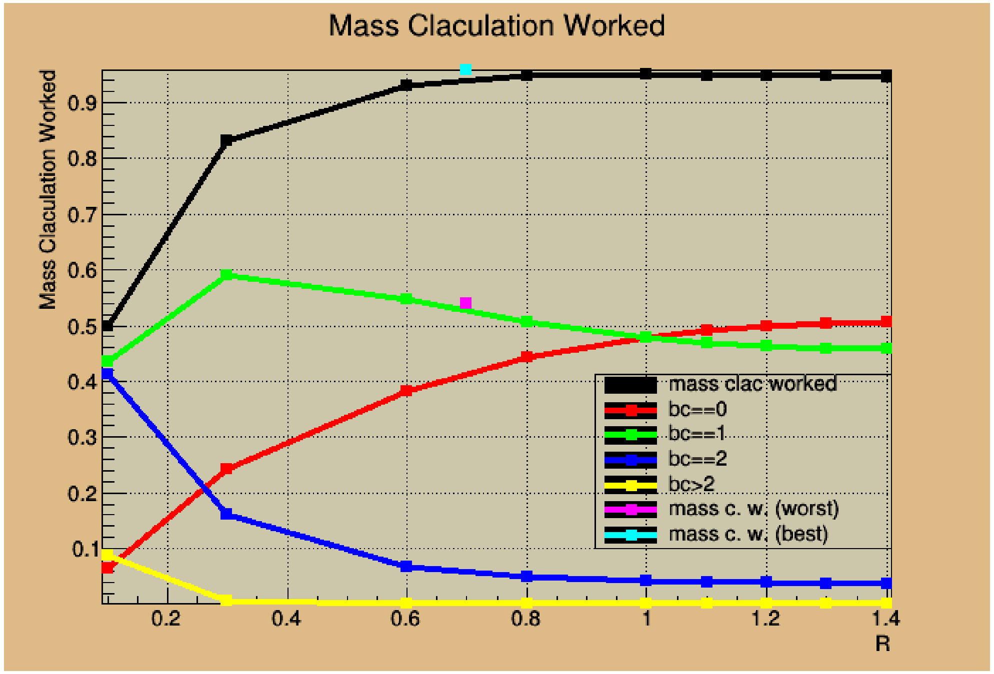
- Retracing pfo to MC part
- Separation of Colorsinglet
- Pairing Jets

- Correcting

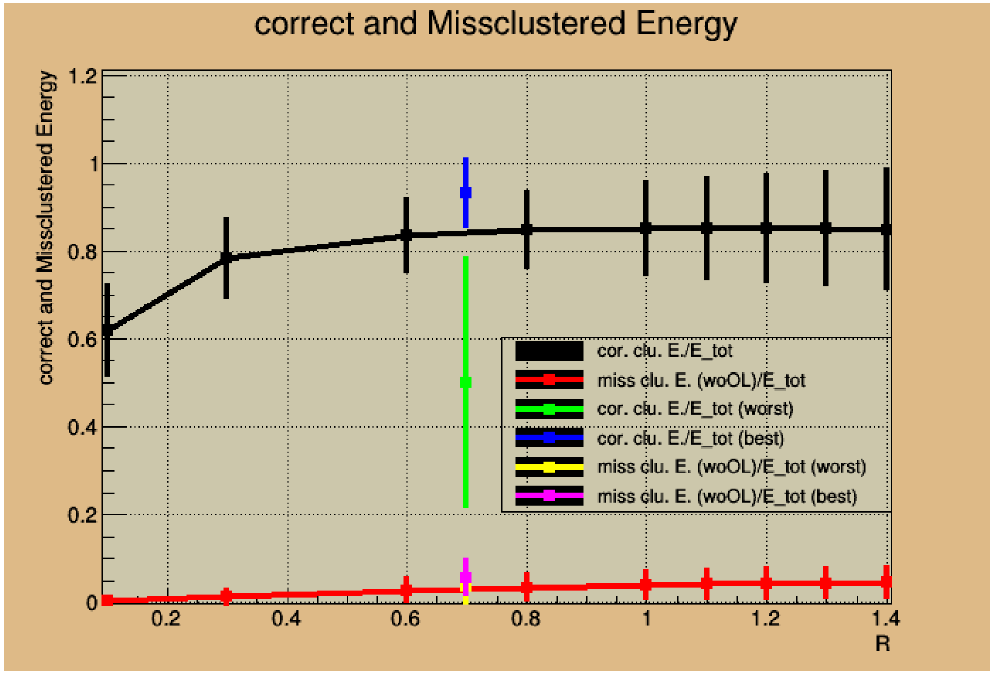
	CS1 (%)	CS2 (%)
Jet1	60	40
Jet2	55	45
Jet3	99	1
Jet4	0	100

Mass Calculation Worked

- bc == 1 means one correction is nesseary
- I only correct ones because correcting more then ones is difficult



Correctly and Missclustered Energy



Different Algorithms

- RefinedJets from LFCIplus