update on Higgs self-coupling study @ ILC

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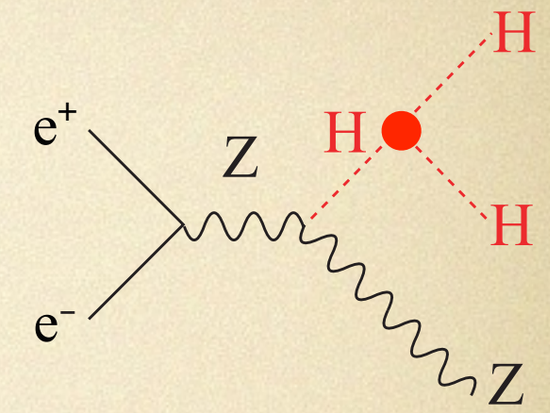
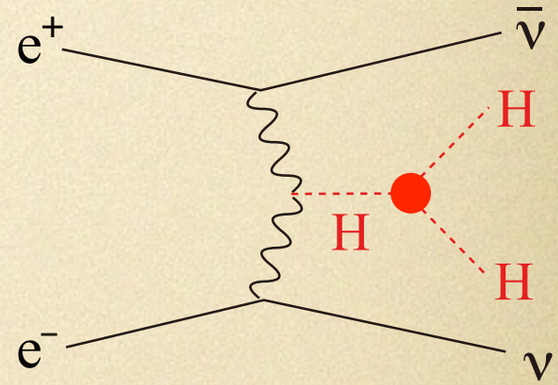
status

- DBD benchmark analysis: ZHH @ 500 GeV
- SGV fast simulation analysis: ννHH @ 1 TeV
- DBD benchmark analysis: ννHH @ 1 TeV
- LC



- updating analysis with mH=125 GeV
- impact of overlay from γγ->hadrons
- improving analysis technique / strategy
  - isolated lepton tagging
  - kinematic fitting
  - optimize cuts for coupling instead of cross section
  - matrix element method and color-singlet-jet-clustering



reminder: Higgs Self-coupling Projections @ ILC

(full simulation done w/ mH = 120 GeV, extrapolated to mH = 125 GeV)

500 GeV: 500 (1600) fb^{-1}
1 TeV: 1000 (2500) fb^{-1}

P(e-,e+)=(-0.8,+0.3) @ 250, 500 GeV
P(e-,e+)=(-0.8,+0.2) @ 1 TeV

$\Delta\lambda_{HHH}/\lambda_{HHH}$	500 GeV			500 GeV + 1 TeV		
Scenario	A	B	C	A	B	C
Baseline	104%	83%	66%	26%	21%	17%
LumiUP	58%	46%	37%	16%	13%	10%

Scenario A (done): HH-->bbbb, full simulation done
Scenario B (done): adding HH-->bbWW*, full simulation done (M.Kurata) (M.Kurata), ~20% relative improvement
Scenario C (ongoing): color-singlet clustering, matrix element method, kinematic fitting, flavor tagging, expected ~20% relative improvement (conservative)

if positron polarisation 30%(20%) --> 60%(40%), gain relatively 10% improvement

J. Tian, LC-REP-2013-003 M. Kurata @ ECFA2013 C.Duerig @ AWLC14

Preliminary results for 125 GeV without overlay

- m_H= 120 GeV results extrapolated to 125 GeV give a precision of 53% on Higgs self-coupling
- preliminary results without overlay

modes	signal	background	significance	
			excess	measurement
$ZHH \to l^-l^+HH$	3.0	4.3	1.16σ	0.91σ
	3.3	6.0	1.12σ	0.91σ
$ZHH \to \nu\bar{\nu}HH$	5.2	6.9	1.63σ	1.37σ
$ZHH \to q\bar{q}HH$	9.2	20.9	1.82σ	1.64σ
	7.7	23.5	1.45σ	1.31σ

cross section: $\frac{\Delta\sigma_{ZHH}}{\sigma_{ZHH}} = 32.6\%$

Higgs self-coupling: $\frac{\Delta\lambda}{\lambda} = 53\%$

	500 GeV at $\mathcal{L} = 2$ ab^{-1}		
scenario	A	B	C
extrapolated	53%	42%	34%
full analysis	53%	42%	34%

Extrapolation works, slightly conservative

Scenario A: $HH \to bbbb$

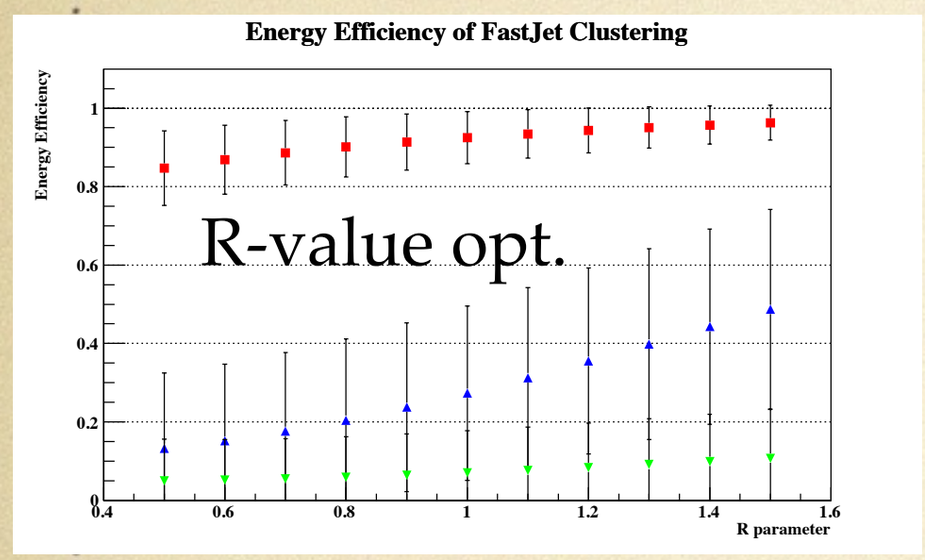
Scenario B: with $HH \to bbWW^*$, $\approx$ 20% improvement

Scenario C: analysis improvement (kinematic fit, jet-clustering, etc.), expect 20% improvement

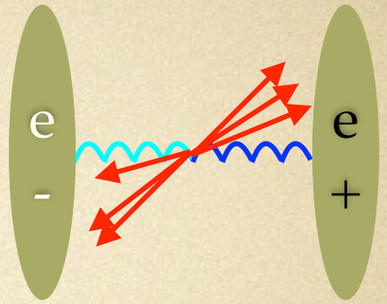
We achieve a precision of 53% on the Higgs self-coupling for $m_H = 125$ GeV!

Effect of $\gamma\gamma$-overlay?

effect of overlay and strategy of removal

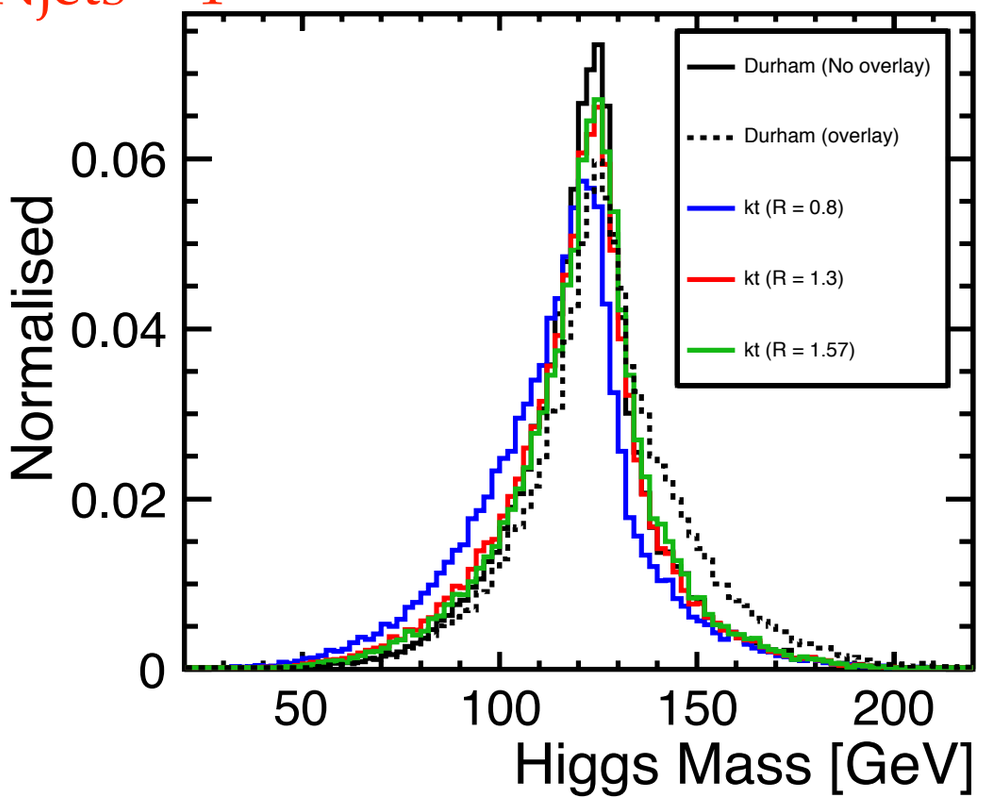


<N> = 1.7 (1.2) @ 500 GeV

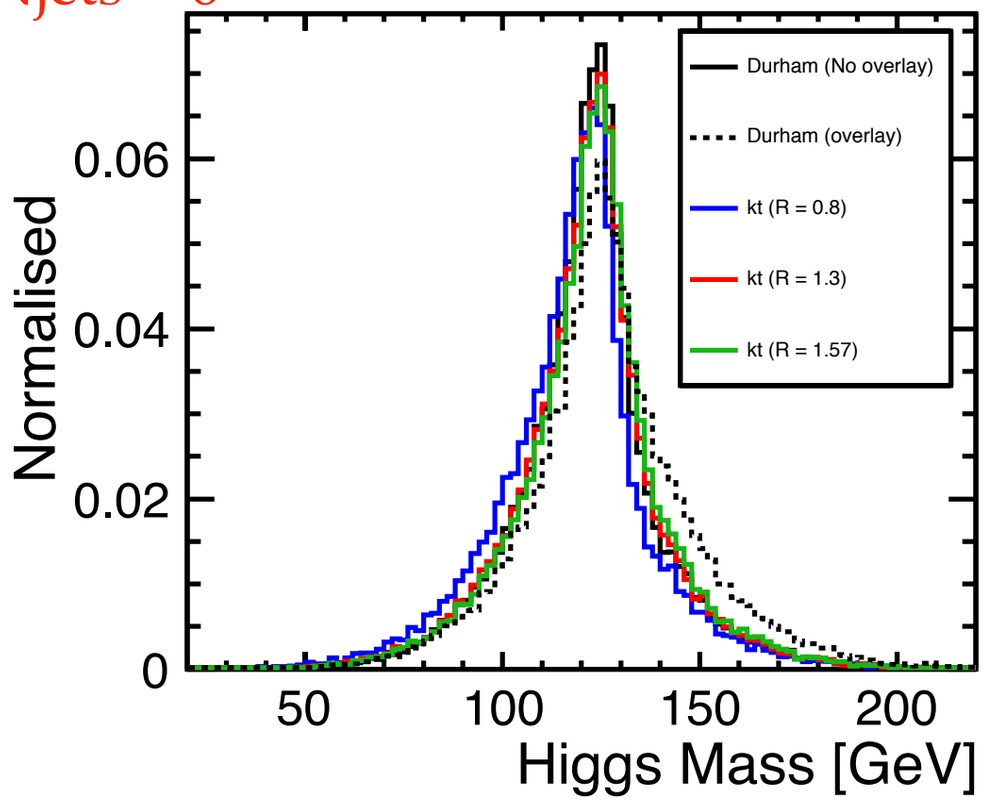


- exclusive kt algorithm.
- optimization: R-value and Njets.
- new method based on MVA being developed.

Njets = 4



Njets = 6



impact of overlay on self-coupling

Preliminary results for 125 GeV with overlay

modes	signal	background	significance	
			excess	measurement
$ZHH \to l^- l^+ HH$	2.7	5.9	0.91σ	0.72σ
	3.4	8.0	1.01σ	0.85σ
$ZHH \to \nu\bar{\nu}HH$	5.6	9.0	1.45σ	1.23σ
$ZHH \to q\bar{q}HH$	8.3	21.8	1.61σ	1.45σ
	8.7	38.2	1.31σ	1.21σ

cross section: $\frac{\Delta\sigma_{ZHH}}{\sigma_{ZHH}} = 35.4\%$

Higgs self-coupling: $\frac{\Delta\lambda}{\lambda} = 58.1\%$

	500 GeV at $\mathcal{L} = 2\ ab^{-1}$		
scenario	A	B	C
w/o overlay	53%	42%	34%
w/ overlay	58%	47%	37%

Scenario A: $HH \to bbbb$
Scenario B: with $HH \to bbWW^*$, $\approx$ 20% improvement
Scenario C: analysis improvement (kinematic fit, jet-clustering, etc.), expect 20% improvement

Considering $\gamma\gamma$-overlay, we achieve a precision of 58% on the Higgs self-coupling

1 TeV at $\mathcal{L} = 2.5\ ab^{-1}$		
A	B	C
16%	13%	10%

arXiv:1310.0763v3[hep-ph]

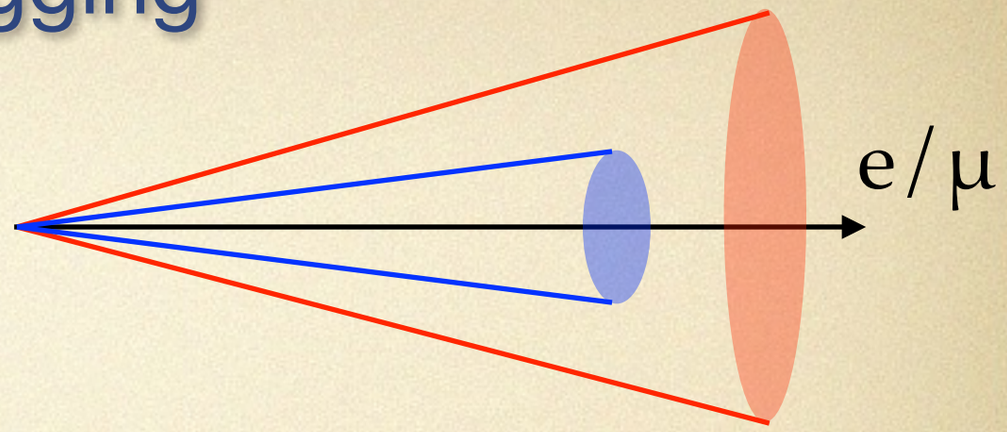
Using additional WW-fusion data at 1 TeV we can achieve a precision of 10% on the Higgs self-coupling (w/o overlay)

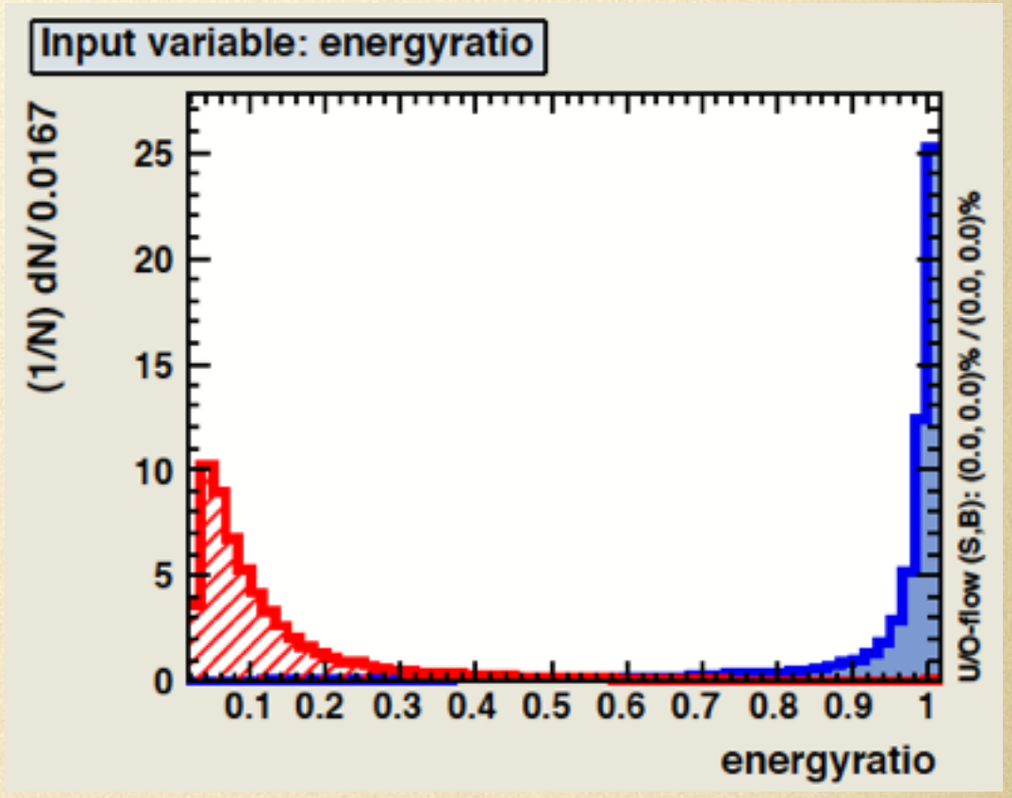
DESY

it has a significant impact (8% worse); particularly with few more overlaid particles, some background can be more like signal; we still need look into some detail to improve this; on the other hand, <N> of overlay is over estimated, we still have hope to recover.

isolated lepton tagging

- general lepton identification: different fractions of energy deposited in ECAL, HCAL and Yoke.
- isolation requirement: effect of neighbor particles (now defined by two cones, one small, one large); from primary vertex.
- multivariate method is used to get the best efficiency / purity; output classifier (tagging) is kept for following optimization.
- shower shape not yet used (start point, lateral distribution), helpful for charged pion suppression.
- isolation still not ultimately optimized: infinity layers of cones (energy ratio .vs. cone angle).





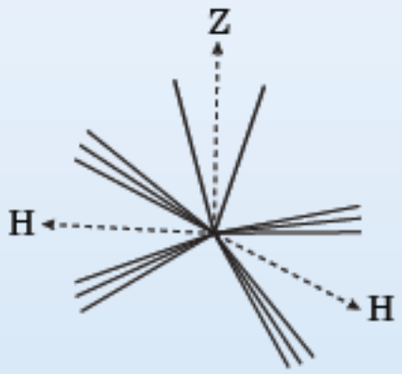
Eff (%)	eeHH	μμHH	bbbb	evbbqq	μvbbqq
NEW	87.0	89.1	0.0017	0.32	0.020
DBD	85.7	88.4	0.028	1.44	0.10
LoI	81.9	85.4	0.43	2.71	1.94

incorporate with Kurata-san's study on shower profile; still room to improve

kinematic fitting

Benjamin Hermberg (DESY)

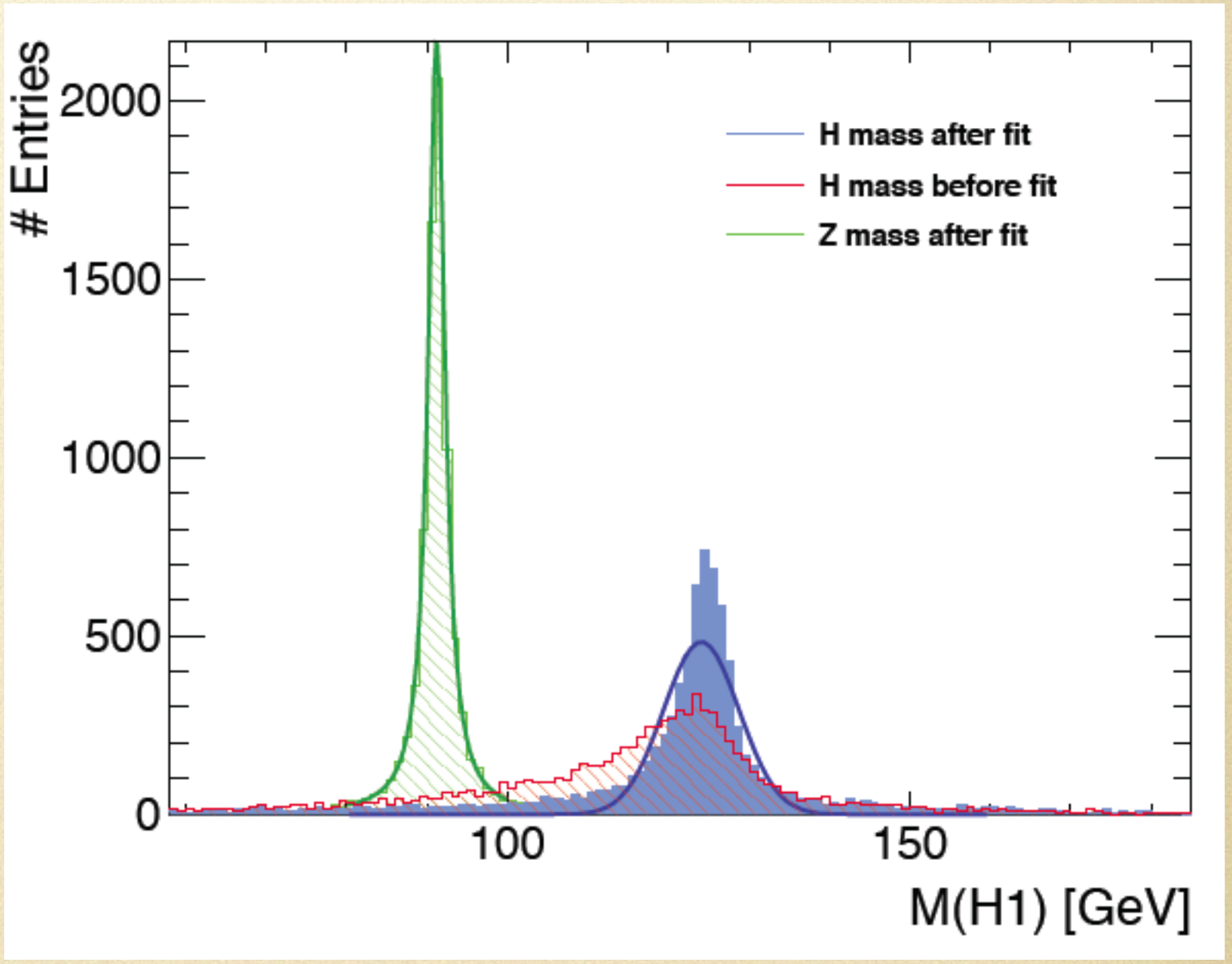
Lepton channel



$$e^+e^- \to ZHH \to l\bar{l}HH$$

2 Leptons + 4 Jets

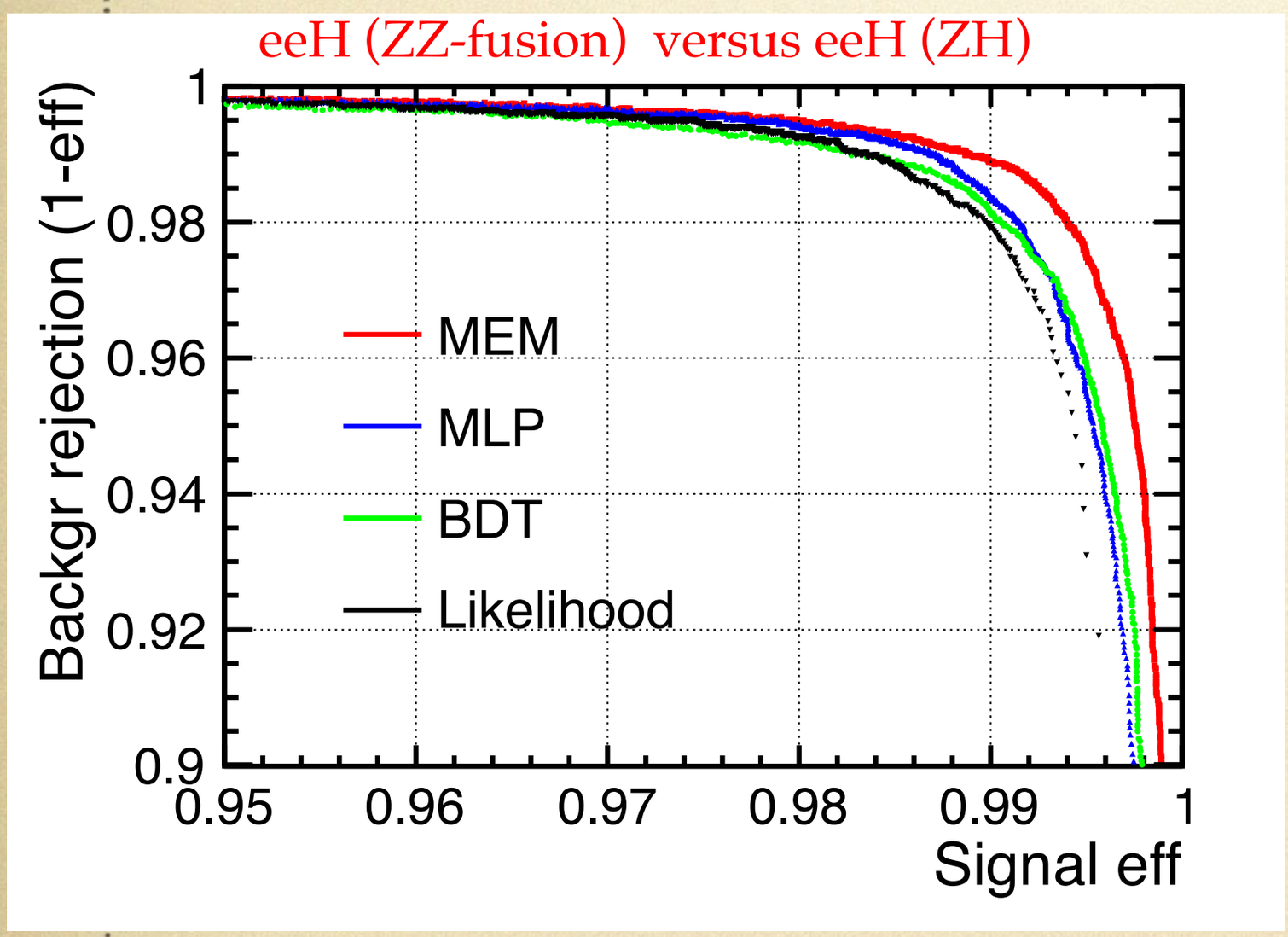
$$M_{ll} = M_Z$$
$$M_{j_1 j_2} = M_{j_3 j_4}$$
$$\sum E_J + \sum E_l = \sqrt{s}$$
$$\sum \vec{p} = 0$$



much better Higgs mass resolution,
going to check with background

recent development of Matrix Element tools

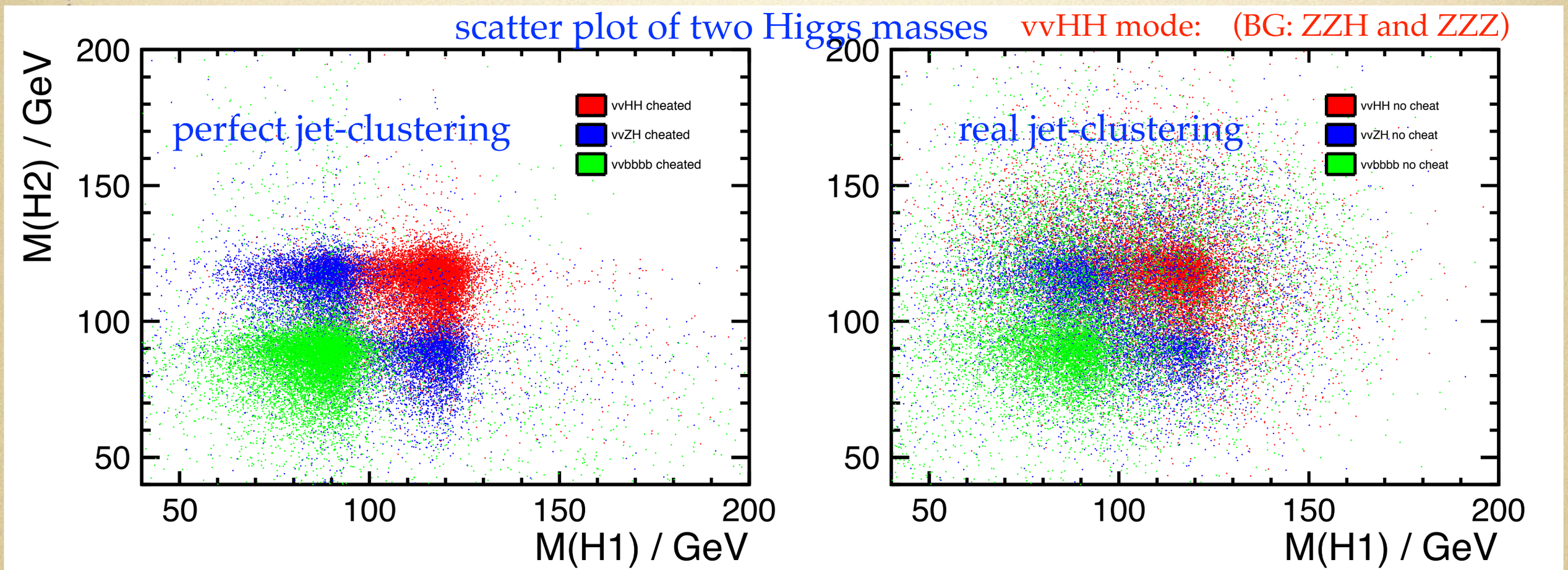
(approach the true likelihood of each event)



- showed very encouraging improvement in ZZ-fusion analysis.
- going to be applied to event waiting in ZHH analysis (to increase sensitivity from self-coupling diagram).
- would be really exciting if we can apply to color-singlet-jet-clustering (see following slides)

(developed for full detector simulation, available in latest ilcsoft release v01-17-06)

what's wrong with current jet-clustering?



- the mis-clustering of particles degrades significantly the separation between signal and BG.
- it is studied that using perfect color-singlet-jet-clustering can improve $\delta\lambda/\lambda$ by 40%!

how to approach perfect jet-clustering?

(idea of a mini-jet based jet-clustering algorithm)

- find vertex before clustering then merge particles from same vertex —> better flavor tagging performance. (implemented in LCFI+)

- early stage of jet-clustering —> find all mini-jet : suppose the traditional clustering algorithm can work well with very small y-values.

- combine the mini-jets: ideally we need matrix element at parton shower level! tentatively, reconstruct the decay plane of each color singlet, mini-jets from one same color singlet should have smaller Pt relative to the decay plane.

- flavor tagging information of the mini-jets and invariant mass can be used to suppress the wrong combinations: one color singlet with more than two b-jets; much different mass to the possible color singlets (mainly W,Z,H)

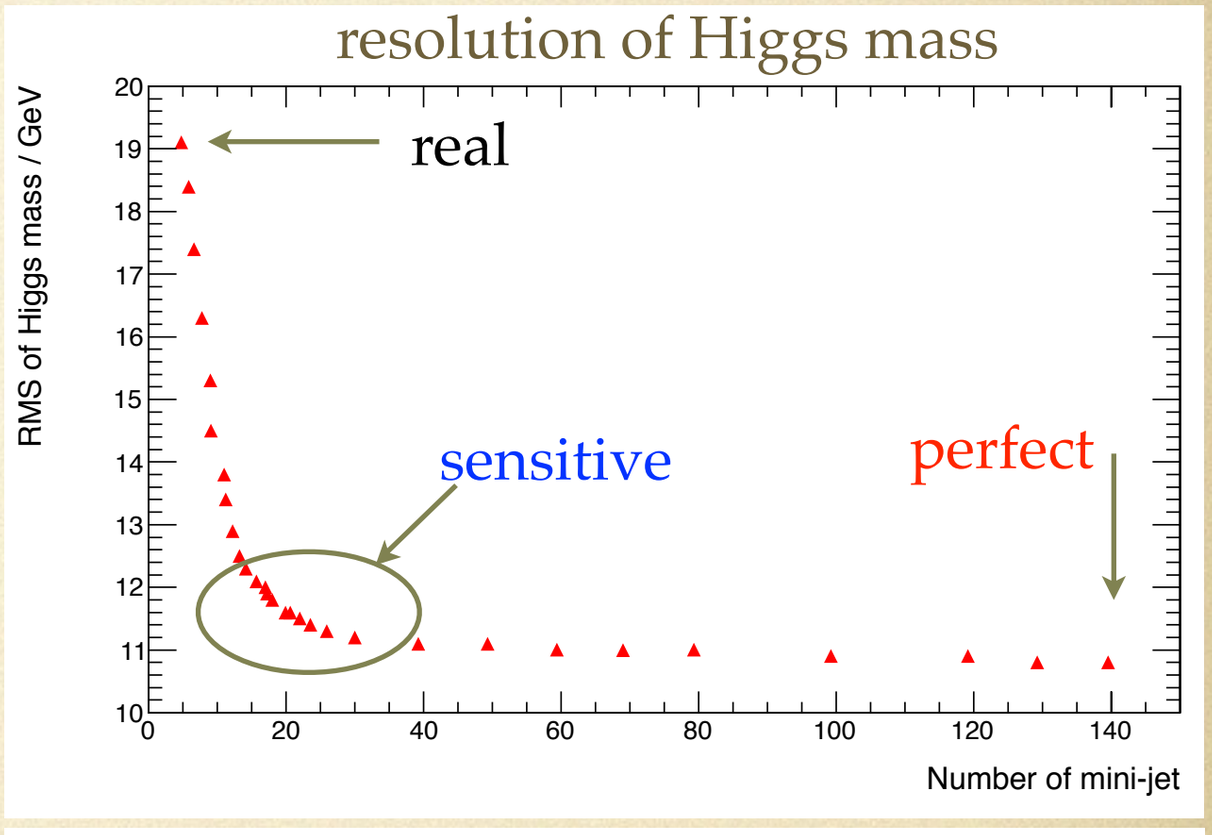
a first look: until when those mini-jets are still good?

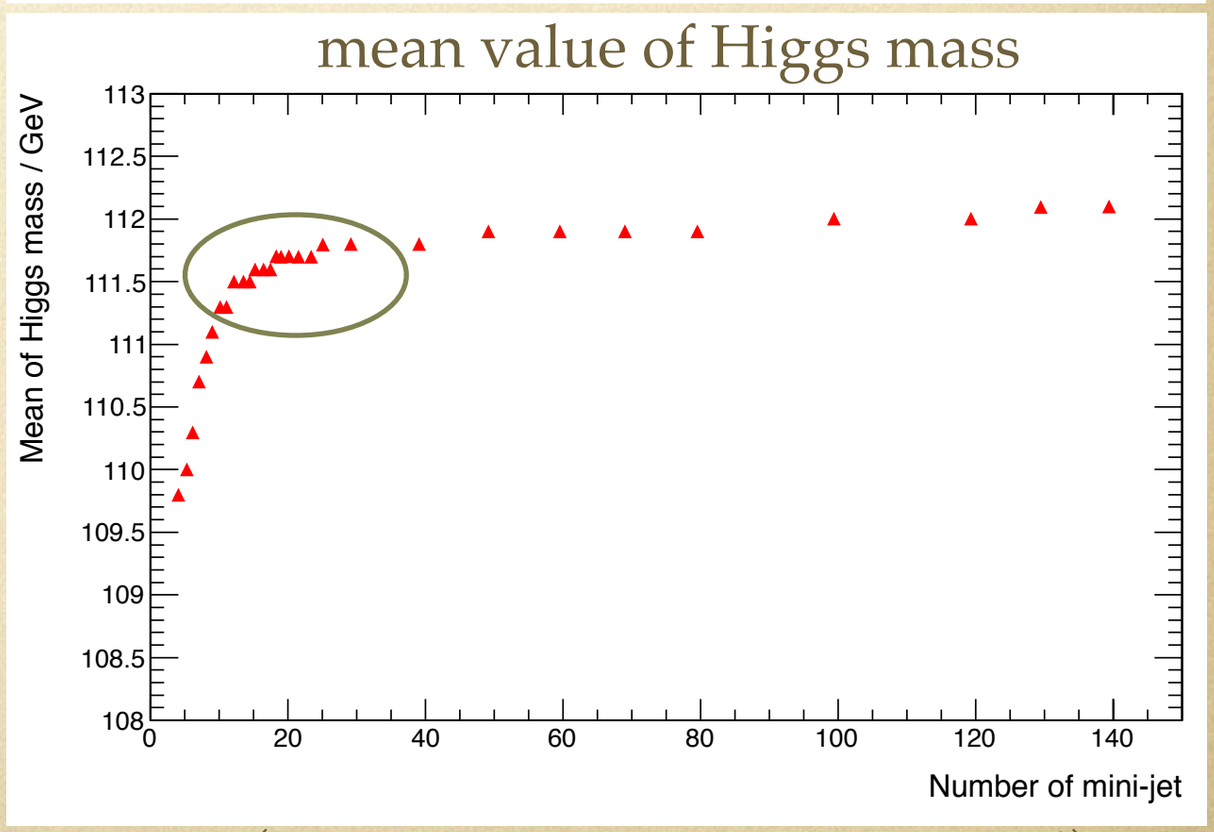
- Would the mini-jet be pure enough?
- When would the mini-jet clustering appropriately stop?

these can be tested supposing we can combine the mini-jets perfectly

vvHH ---> vvbbbb

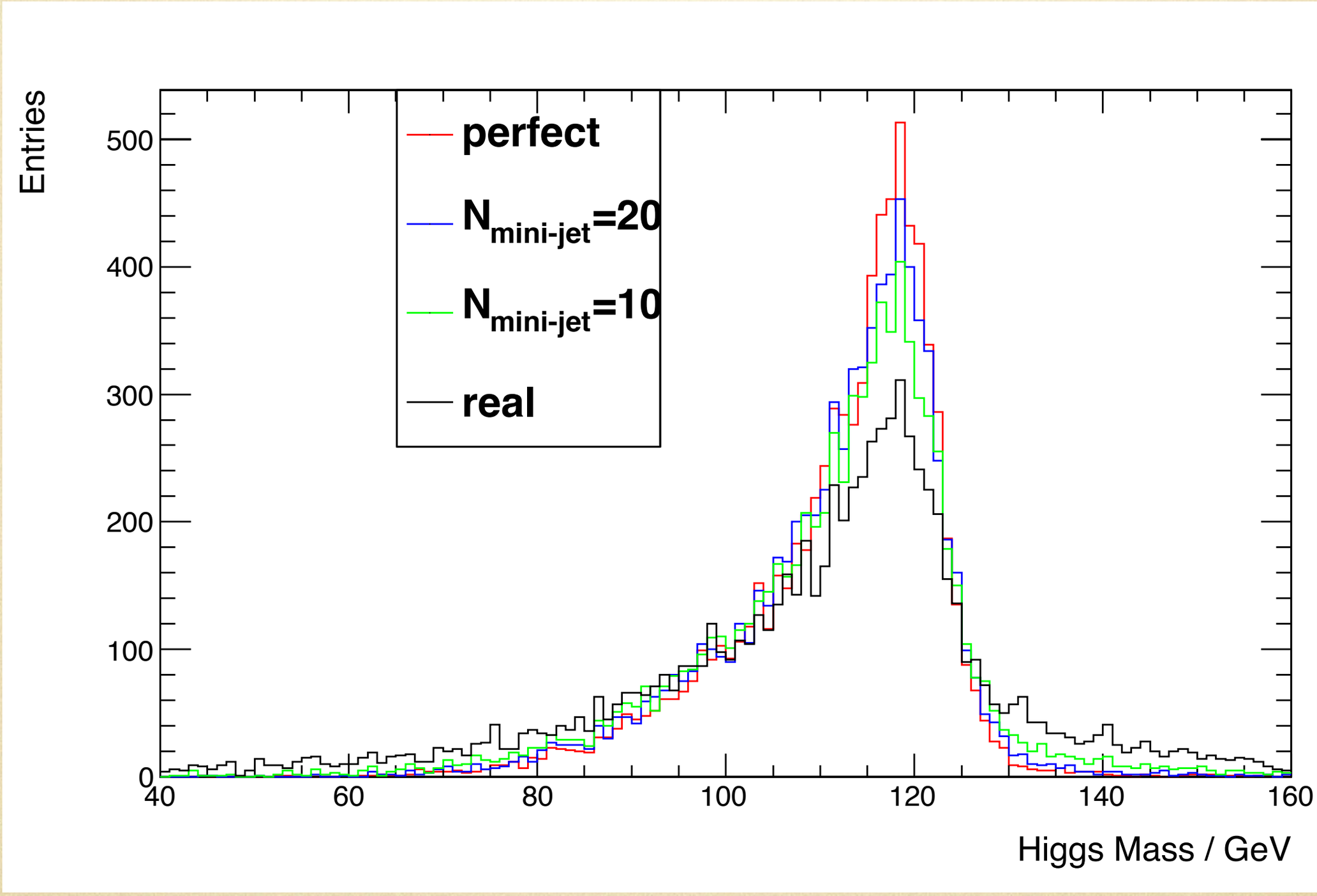
- using the realistic Duhram algorithm for the mini-jet clustering, stop when there are fixed number of mini-jets remained.
- combine the mini-jets with MC information, check the performance of Higgs reconstruction





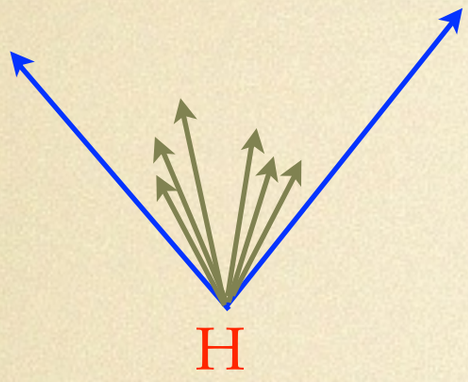
(two Higgs masses are merged)

a first look: Higgs mass



what kind of color-singlet information can help jet-clustering?

decay plane



particles from one same color singlet
should be around the decay plane

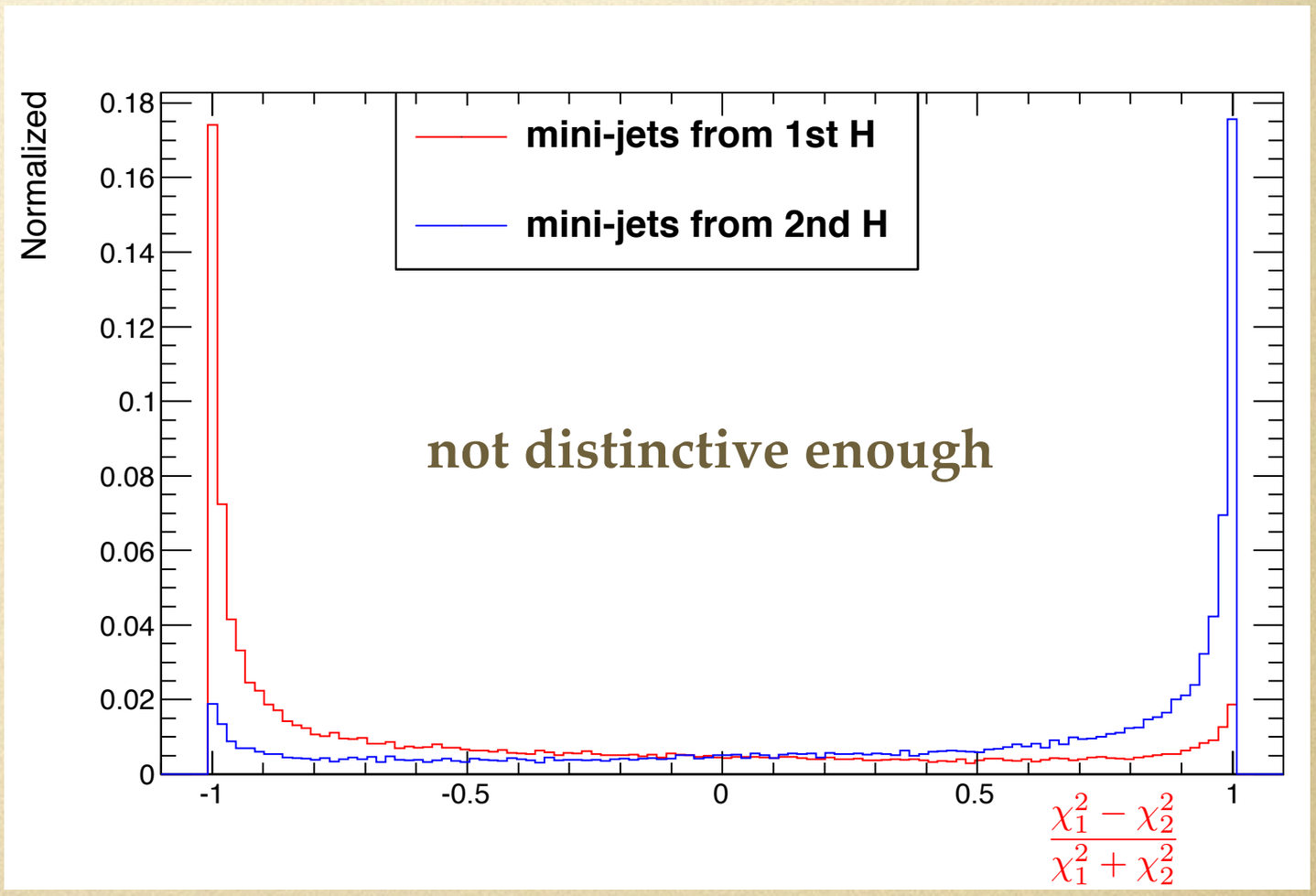
$$\chi^2 = P_t^2$$

transverse momentum
relative to the decay plane

vvHH ---> vvbbbb

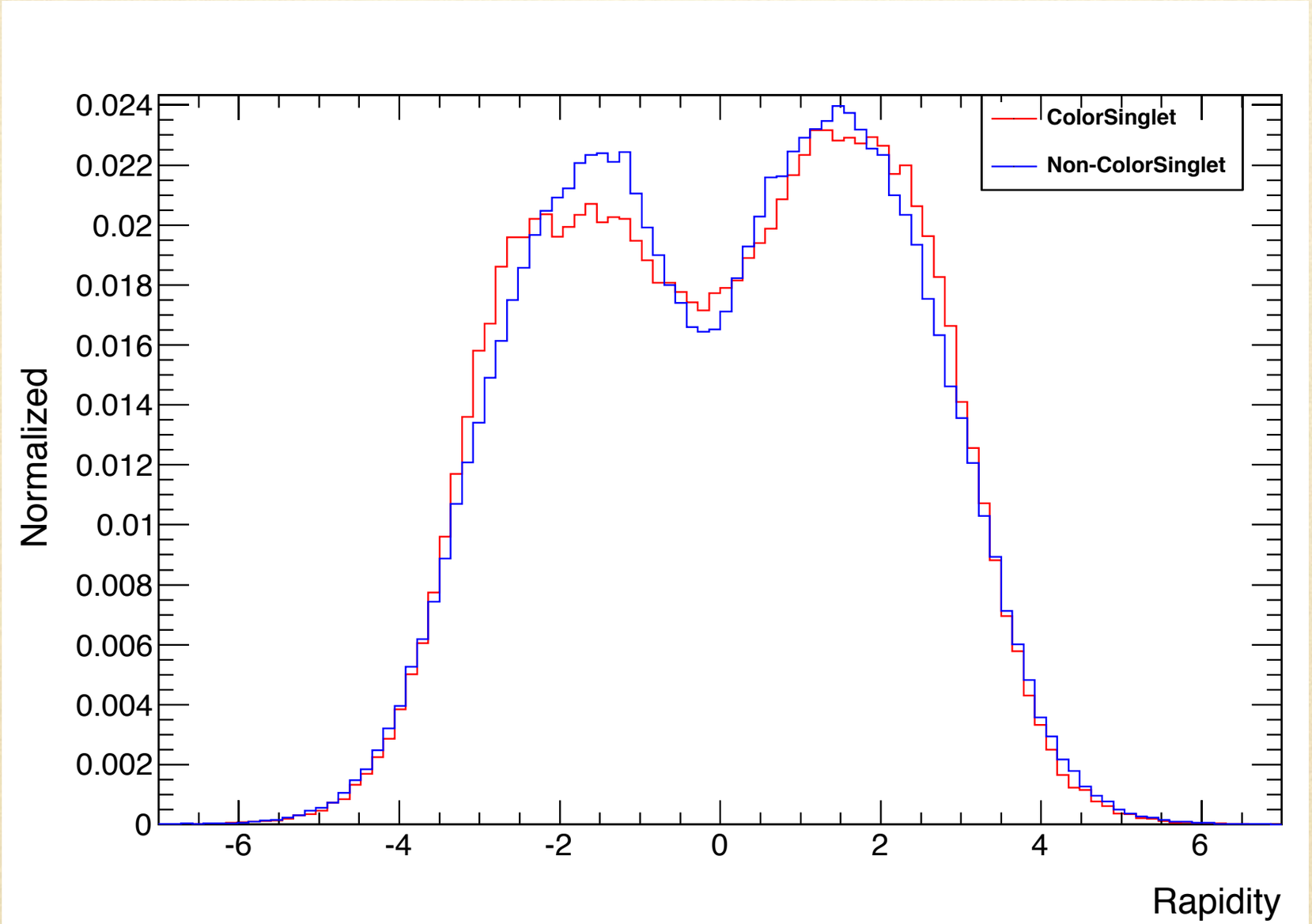
- using the realistic Duhram algorithm for the mini-jet clustering, stop when there are 20 mini-jets left.

- calculate the chi2 for each mini-jet, there are two decay planes, we get two chi2 for each mini-jet. (currently the two decay planes are decided by cheating)



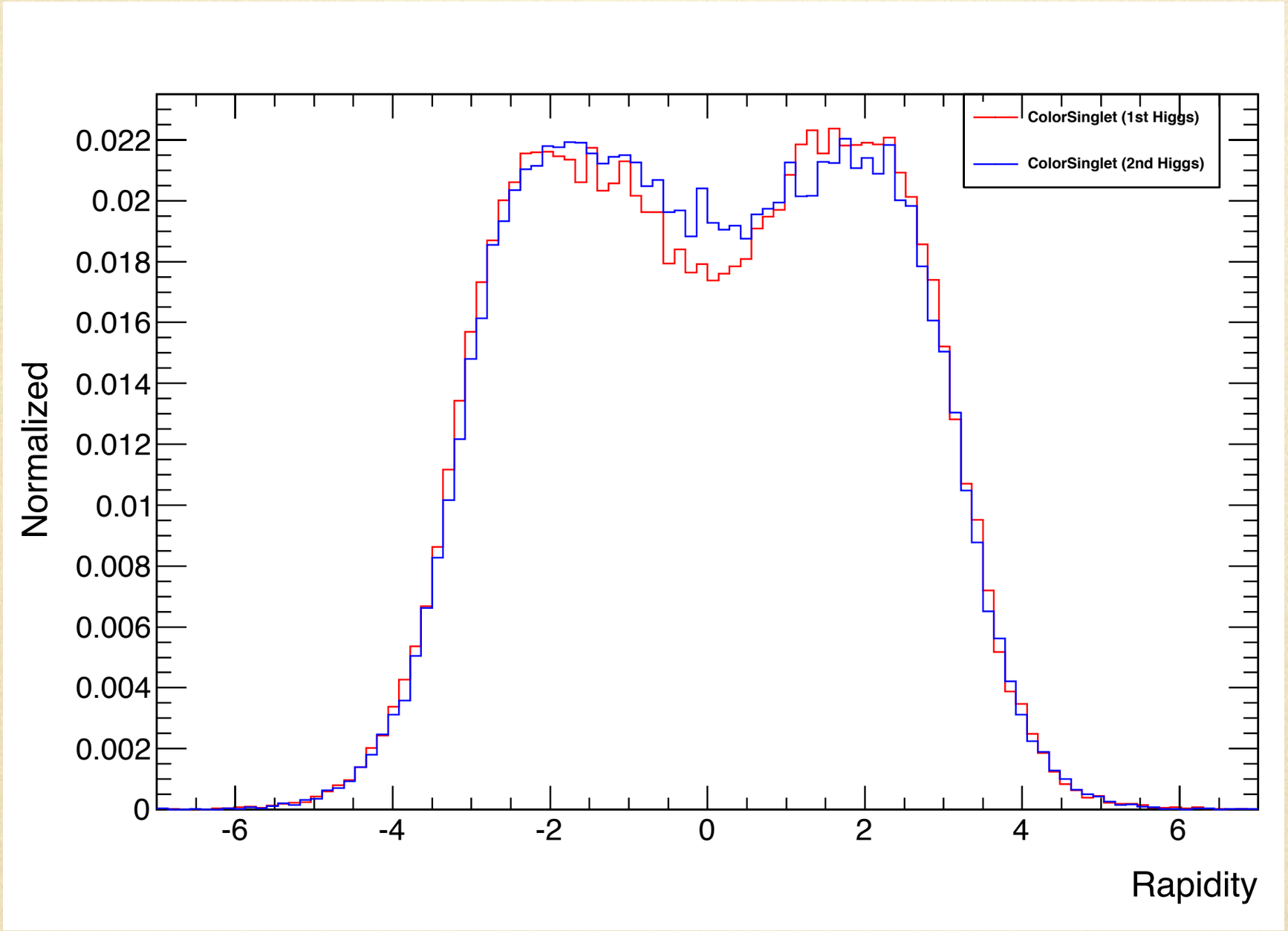
rapidity gap? (reconstructed)

decay frame (one of the b momentum as z-axis)



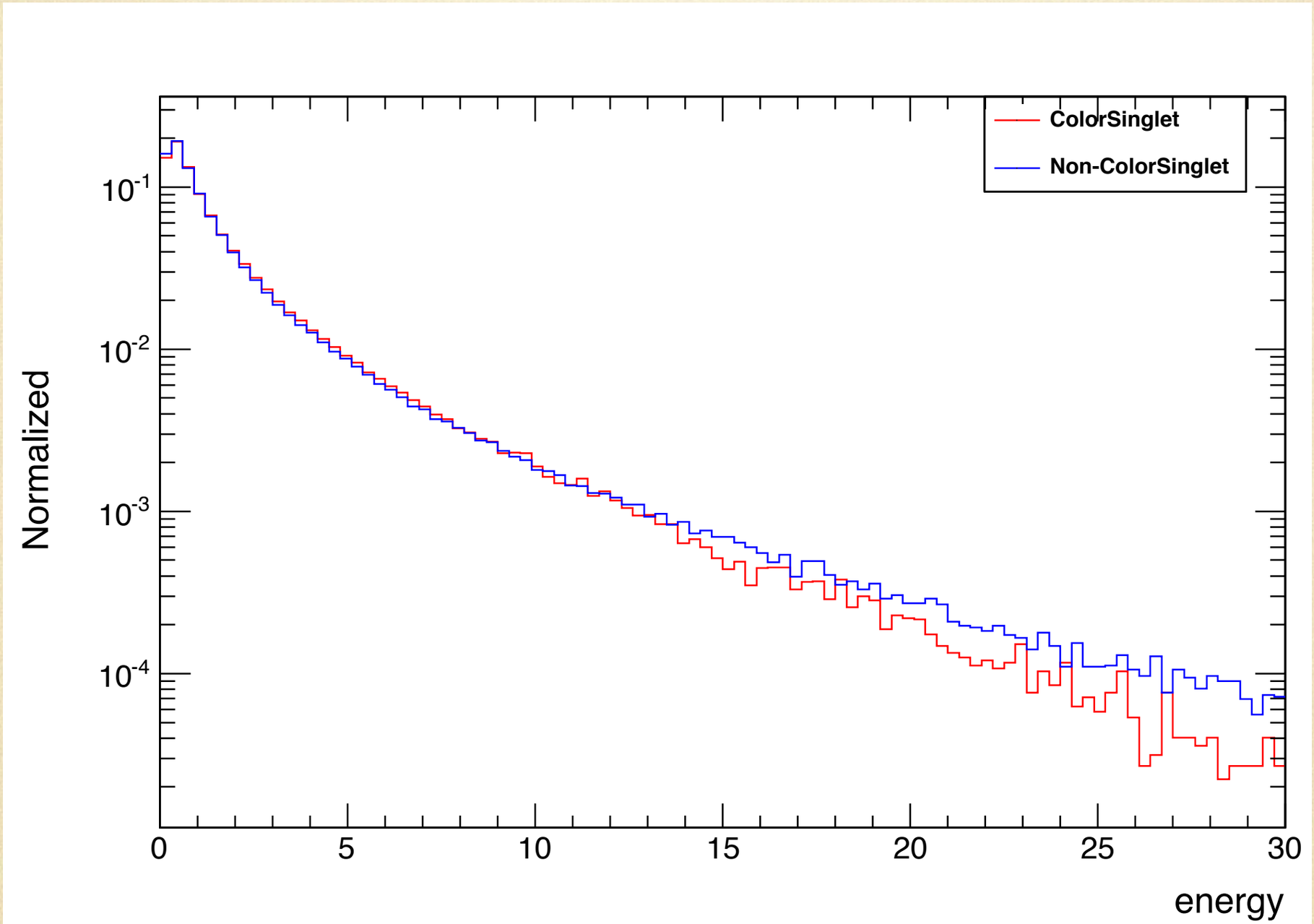
- perfect jet-clustering for vvHH events
- rapidity of every particle in the jet pair

rapidity gap? (MC truth)



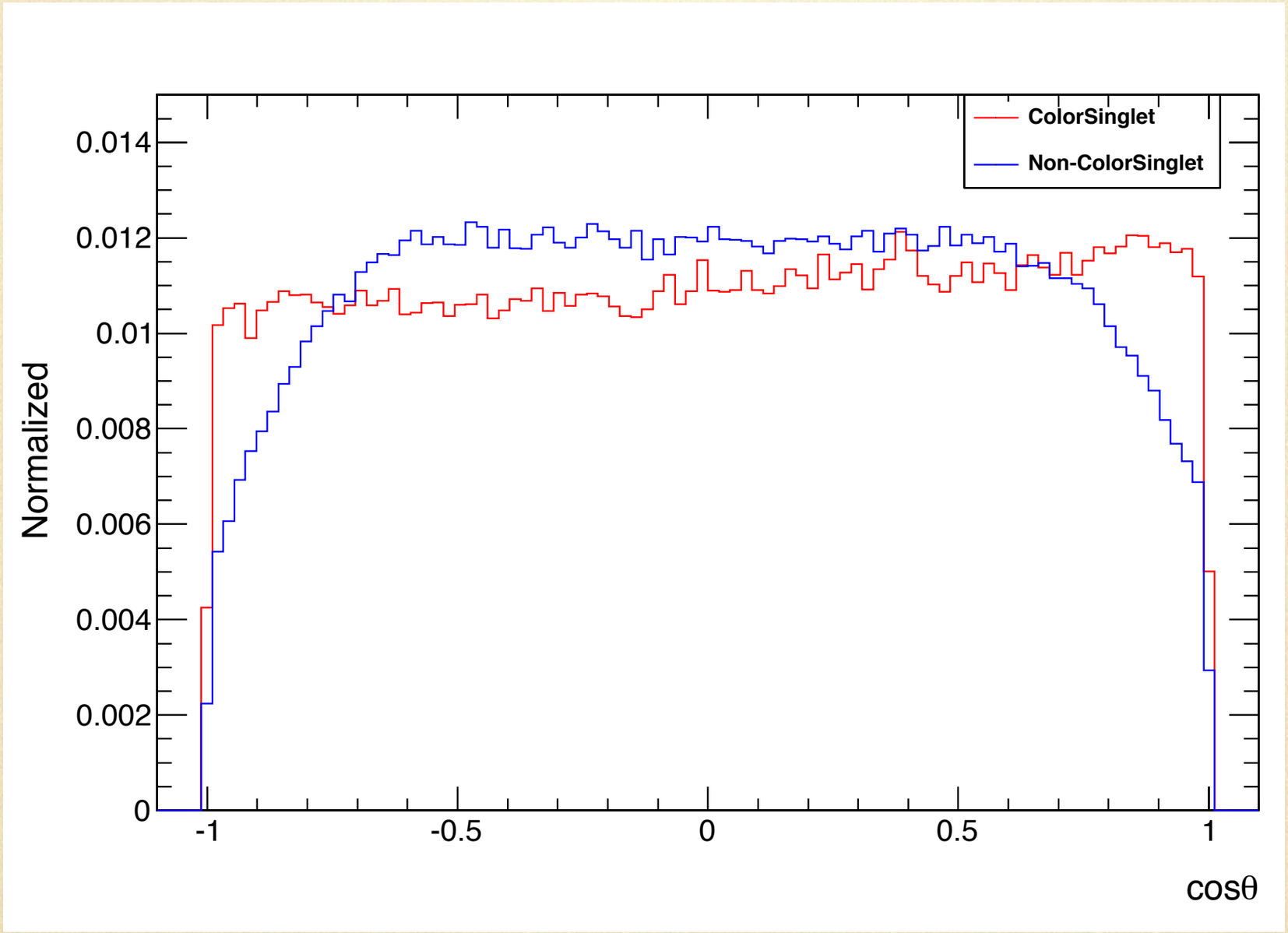
- two color-singlet
- color correlation not implemented in MC?

energy (reconstructed)



- not different?

polar angular (reconstructed)



- helicity frame (Higgs momentum as z-axis)
- forward-backward asymmetry?
- gap for the non-color-singlet system

next about the combination ...

- realistic algorithm of reconstructing the two decay plane.

$$\chi^2 = \sum_i P_t^2$$

i: can count for all mini-jets or all particles in mini-jets

- adding the suppression factor

$$e^{-(N_b-1)(N_b-2)}$$

- implement the likelihood including more characteristics

  rapidity gap, angular correlation,
  matrix element at parton shower , etc.

looks challenging, but definitely worth pursuing

happy to hear more from talk by Shao-feng this after noon

summary and next step

- measuring Higgs self-coupling is one of the fundamental task for the future Linear Collider; 10% precision is achievable eventually with 1 TeV run; however, precision at 500 GeV is still limited (though significantly improved since LoI).

- updated analysis with mH=125 GeV confirmed well previous results with extrapolation; overlay removal still needs be improved; optimization strategy can be improved by using newly developed matrix element tool.

- quite lots of efforts ongoing to improve analysis technique: kinematic fitting, isolated lepton tagging, jet clustering and jet pairing

- and don't forget flavor tagging…

- as planned, at some point we should publish our results, instead of waiting for all techniques available.