update on Higgs self-coupling study @ ILC

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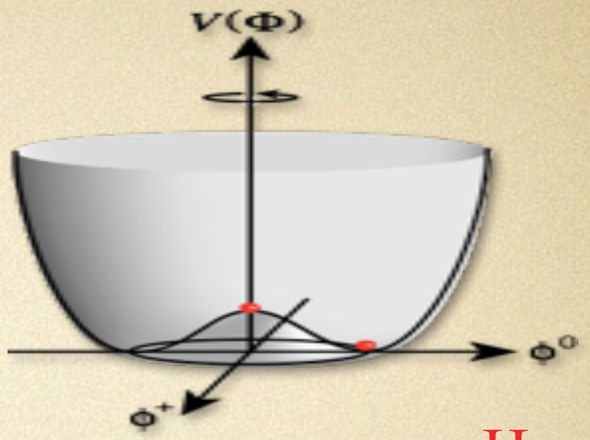
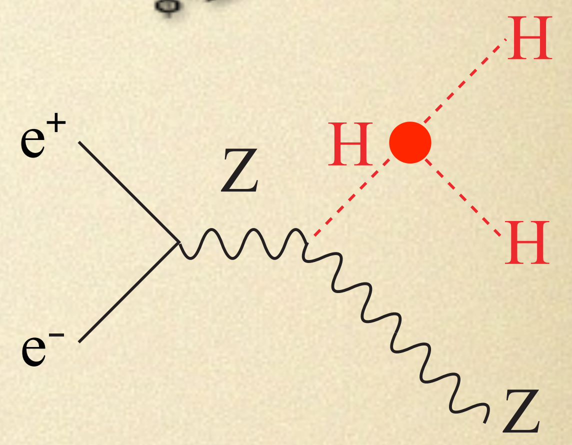
ILD Meeting 2014, Sep. 6-9, 2014 @ Oshu

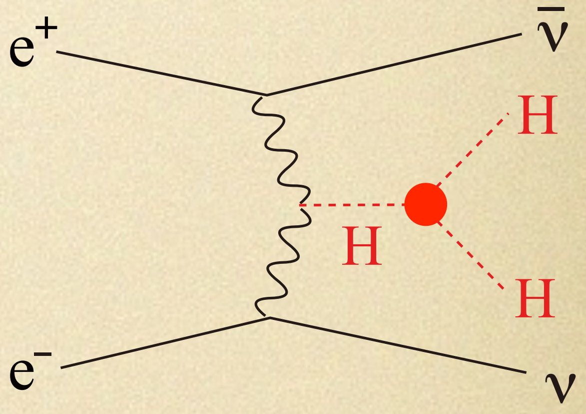
status



- ☑ DBD benchmark analysis: ZHH @ 500 GeV
- ☑ SGV fast simulation analysis: $\nu\nu$HH @ 1 TeV
- ☑ DBD benchmark analysis: $\nu\nu$HH @ 1 TeV
- ☑ LC-REP-2013-003



- updating analysis with mH=125 GeV
- impact of overlay from $\gamma\gamma$->hadrons
- impact of beam polarisations
- 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



ILC white paper: Higgs Self-coupling Projections

(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)

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

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

Extrapolation works, slightly conservative

Scenario A: $HH \to bbbb$

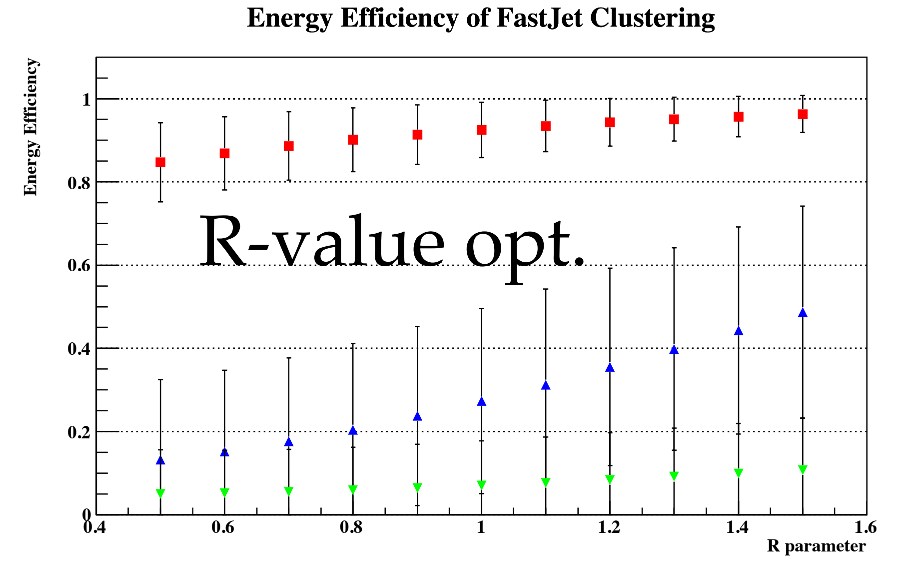
Scenario B: with $HH \to bbWW^*$, ≈ 20% improvement

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!

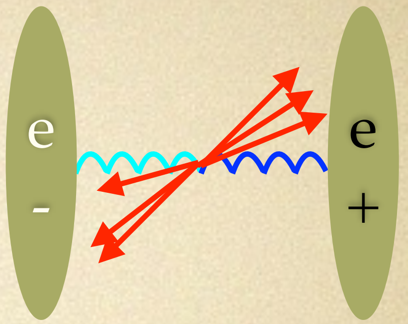
Effect of $\gamma\gamma$-overlay?

effect of overlay and strategy of removal


Energy Efficiency of FastJet Clustering

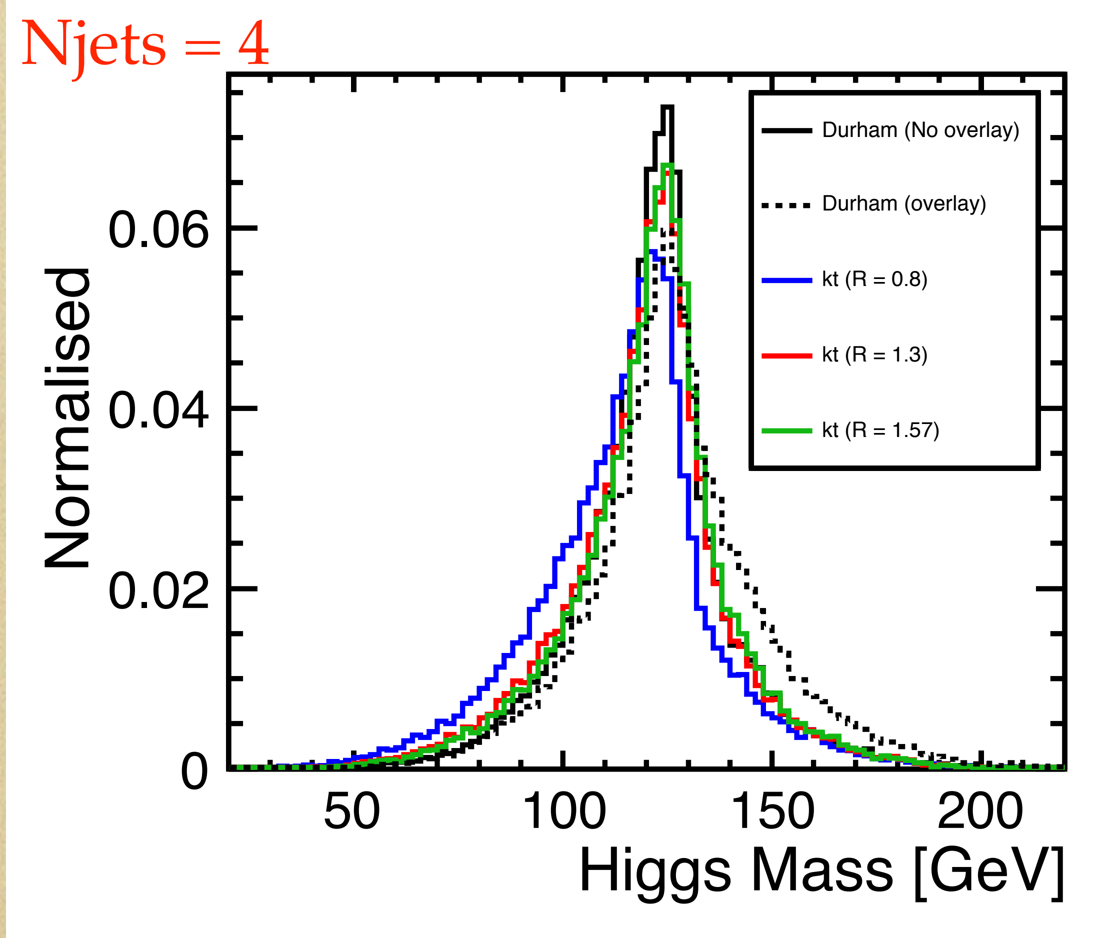
R-value opt.

<N> = 1.7 (1.2) @ 500 GeV

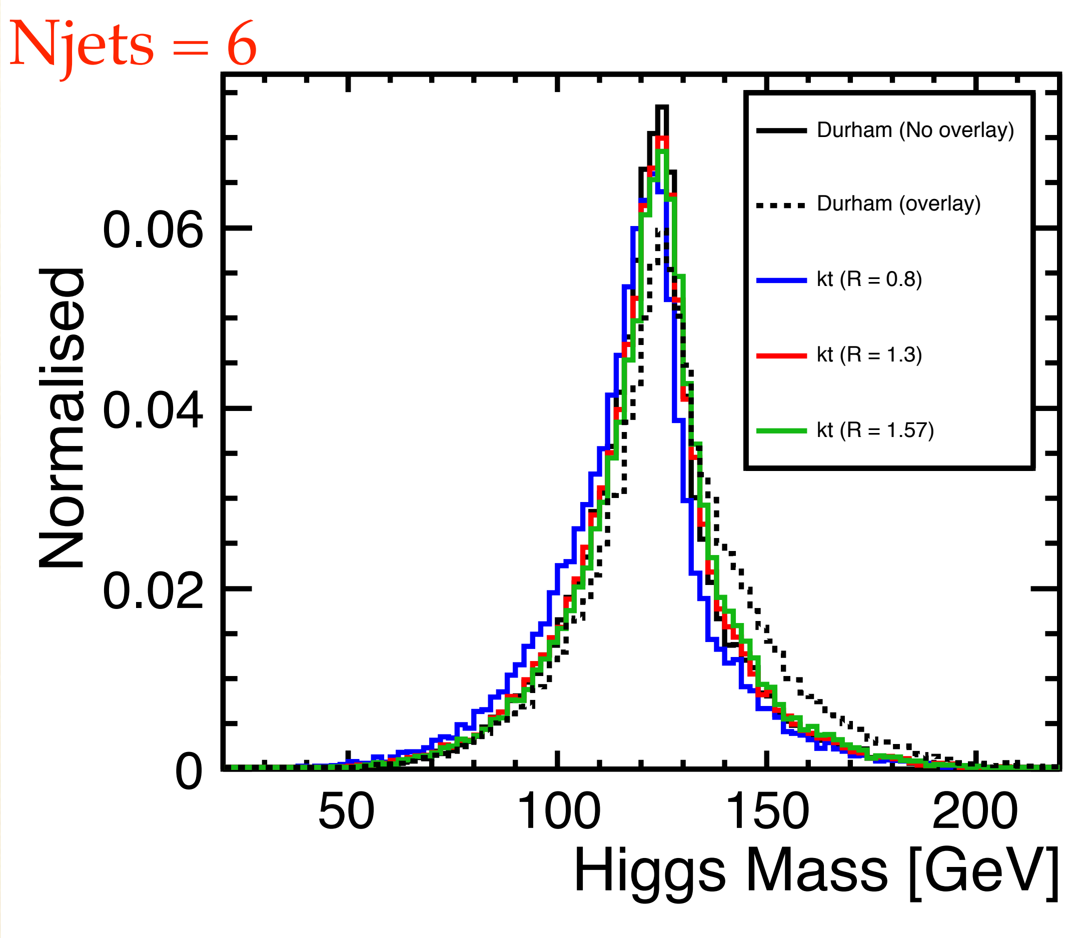


- exclusive kt algorithm.
- optimization: R-value and Njets.
- new method based on MVA being developed.

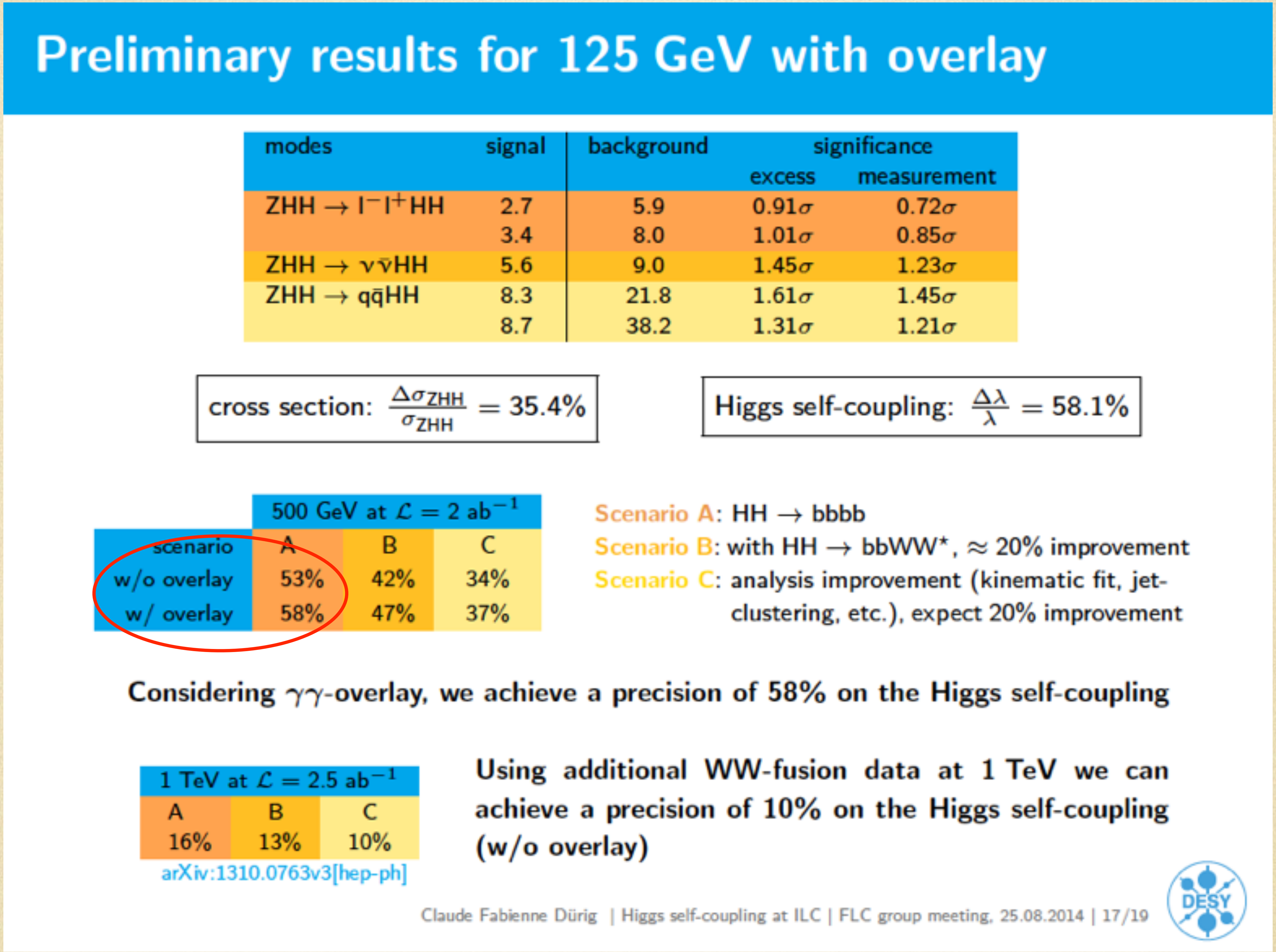
Njets = 4



Njets = 6



impact of overlay on self-coupling



Preliminary results for 125 GeV with overlay

modes	signal	background	significance excess	significance measurement
ZHH → l^-l^+HH	2.7	5.9	0.91σ	0.72σ
	3.4	8.0	1.01σ	0.85σ
ZHH → $\nu\bar{\nu}$HH	5.6	9.0	1.45σ	1.23σ
ZHH → $q\bar{q}$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 $\mathcal{L} = 2\ \text{ab}^{-1}$		
scenario	A	B	C
w/o overlay	53%	42%	34%
w/ overlay	58%	47%	37%

Scenario A: HH → bbbb
Scenario B: with HH → bbWW*, ≈ 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 $\mathcal{L} = 2.5\ \text{ab}^{-1}$		
A	B	C
16%	13%	10%

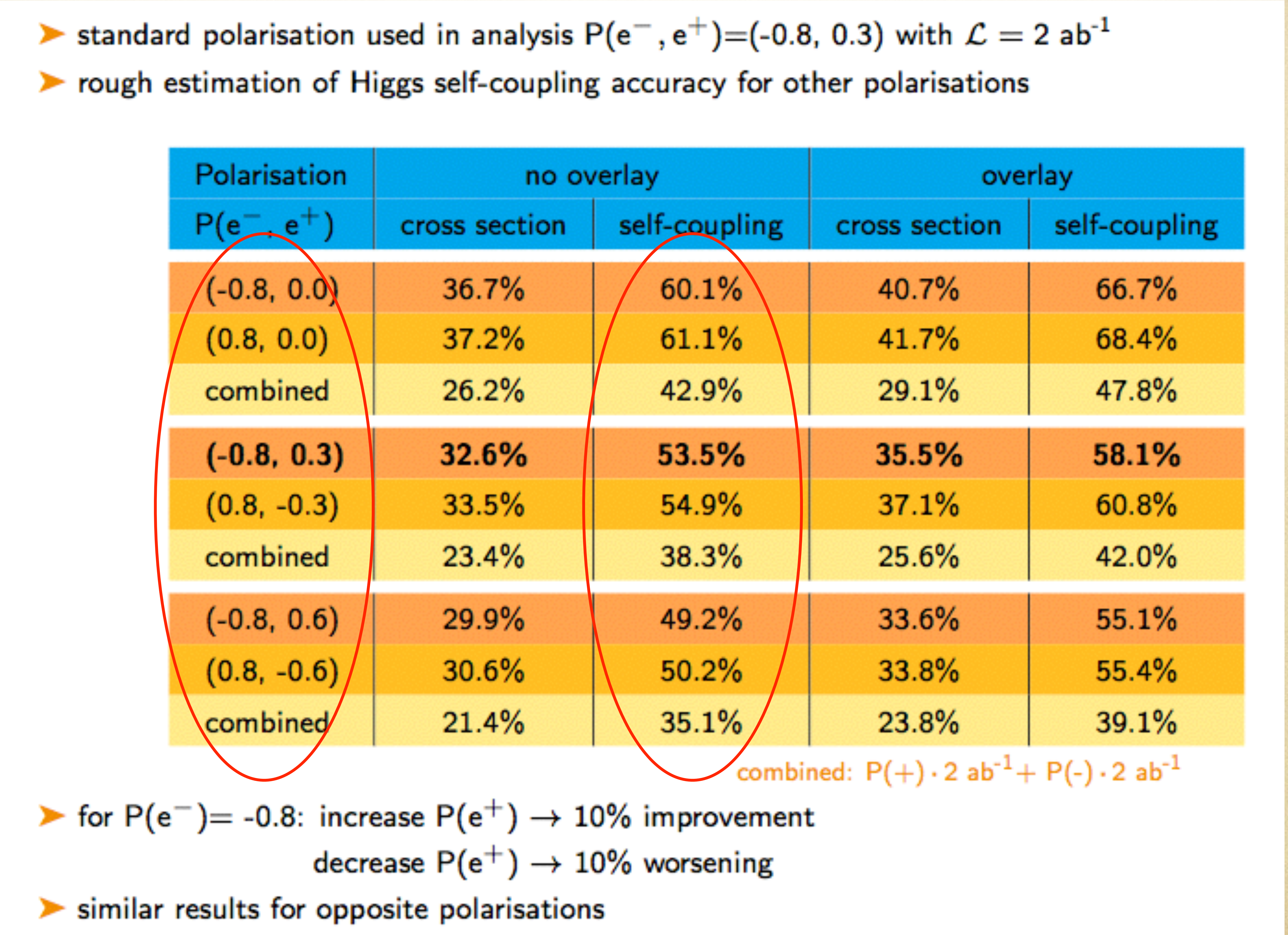
arXiv:1310.0763v3[hep-ph]

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

Claude Fabienne Dürig | Higgs self-coupling at ILC | FLC group meeting, 25.08.2014 | 17/19

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.

impact of beam polarisations



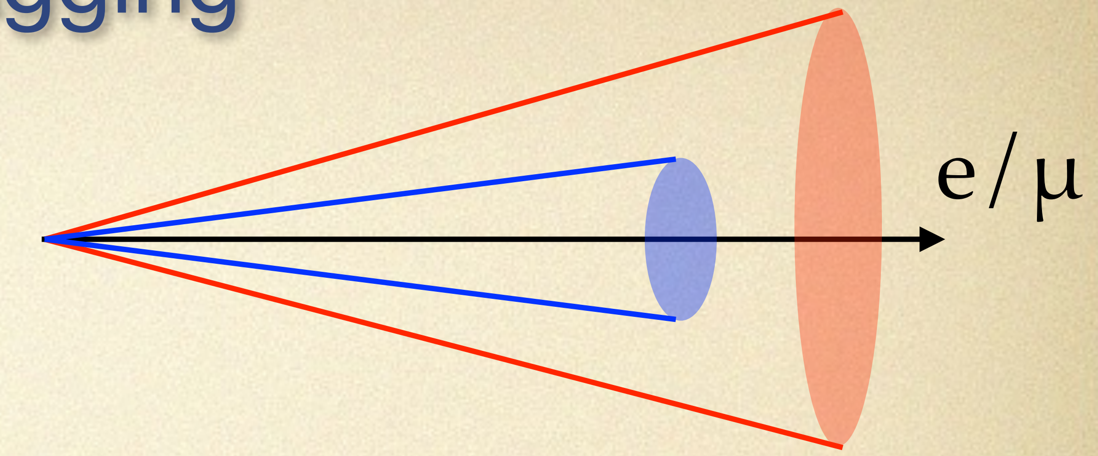
- standard polarisation used in analysis P(e^-, e^+)=(-0.8, 0.3) with $\mathcal{L} = 2$ ab^{-1}
- rough estimation of Higgs self-coupling accuracy for other polarisations

Polarisation	no overlay		overlay	
P(e^-, e^+)	cross section	self-coupling	cross section	self-coupling
(-0.8, 0.0)	36.7%	60.1%	40.7%	66.7%
(0.8, 0.0)	37.2%	61.1%	41.7%	68.4%
combined	26.2%	42.9%	29.1%	47.8%
(-0.8, 0.3)	**32.6%**	**53.5%**	**35.5%**	**58.1%**
(0.8, -0.3)	33.5%	54.9%	37.1%	60.8%
combined	23.4%	38.3%	25.6%	42.0%
(-0.8, 0.6)	29.9%	49.2%	33.6%	55.1%
(0.8, -0.6)	30.6%	50.2%	33.8%	55.4%
combined	21.4%	35.1%	23.8%	39.1%

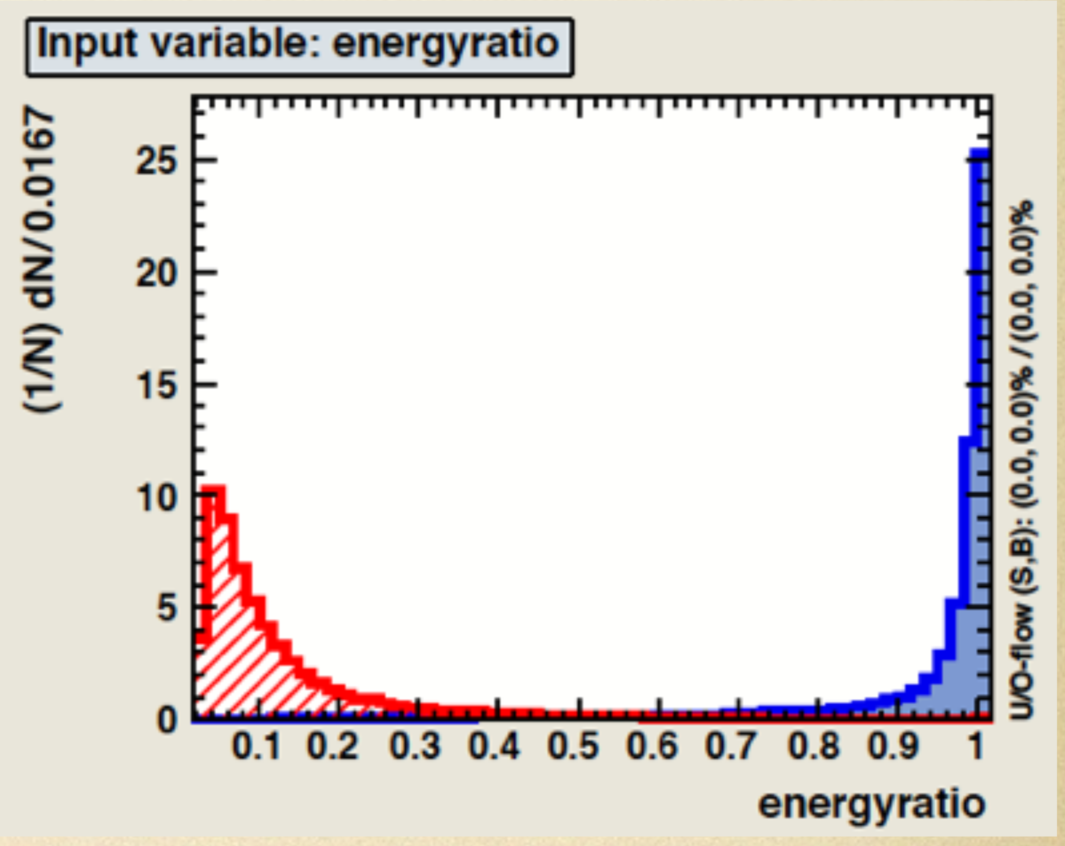
combined: P(+) · 2 ab^{-1} + P(-) · 2 ab^{-1}

- for P(e^-)= -0.8: increase P(e^+) → 10% improvement
  decrease P(e^+) → 10% worsening
- similar results for opposite polarisations

isolated lepton tagging



- ☑ general lepton identification: different fractions of energy deposited in ECAL, HCAL and Yoke.
- ☑ isolation requirement: effect of neighbour 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).



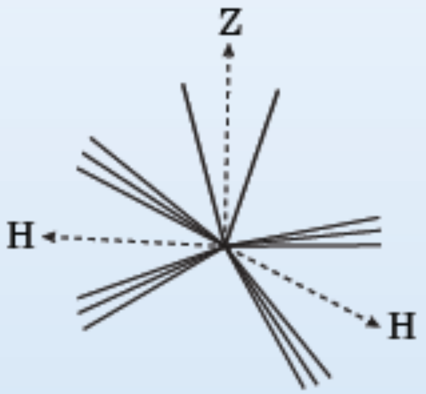
Eff (%)	eeHH	μμHH	bbbb	eνbbqq	μνbbqq
NEW	87.0	89.1	0.0017	0.32	0.020
DBD	85.7	88.4	0.028	1.44	0.10
LoI	81.9	85.4	0.43	2.71	1.94

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

kinematic fitting

Benjamin Hermberg (DESY)

Lepton channel



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

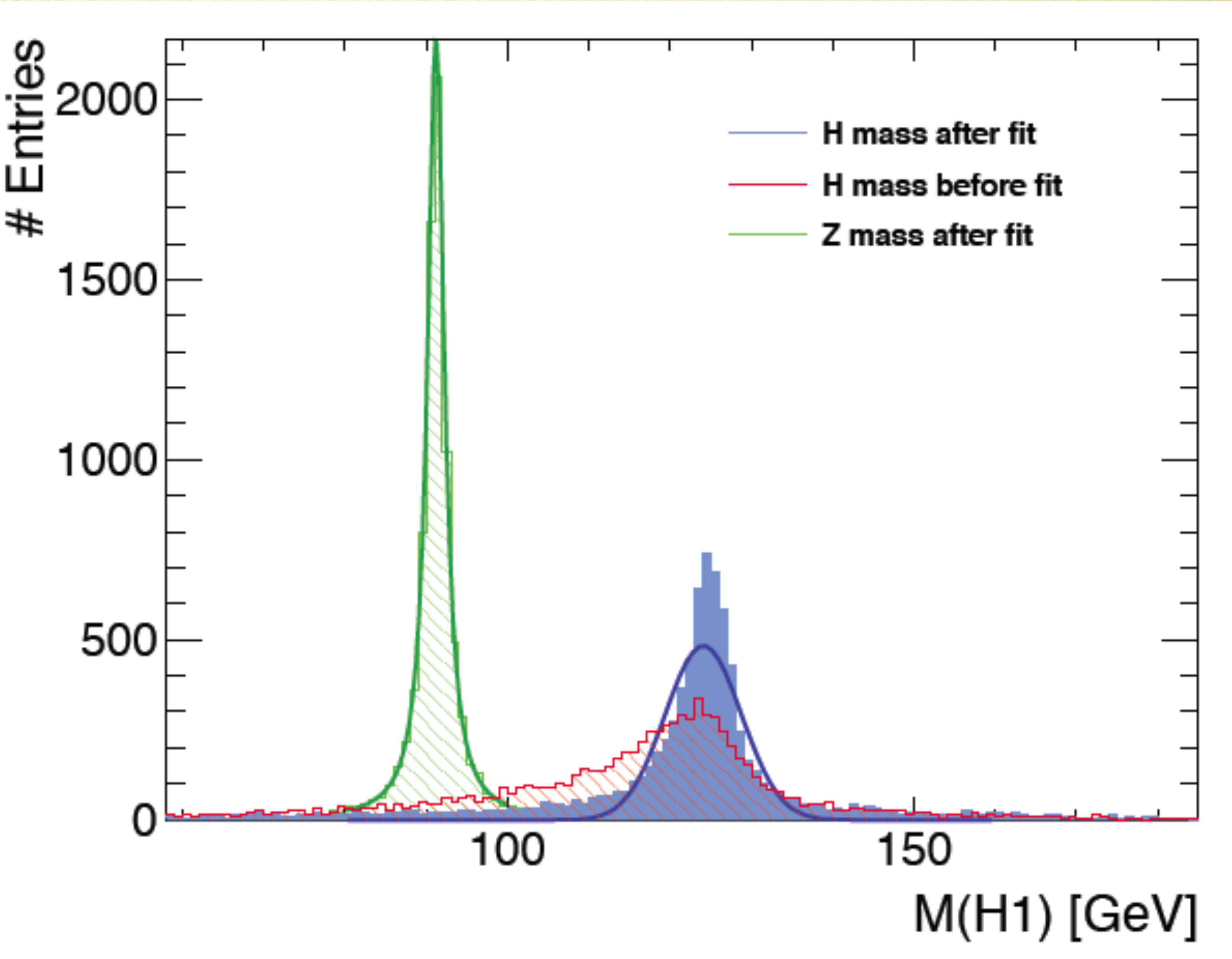
2 Leptons + 4 Jets

$$M_{ll} = M_Z$$

$$M_{j_1j_2} = M_{j_3j_4}$$

$$\sum E_J + \sum E_l = \sqrt{s}$$

$$\sum \vec{p} = 0$$

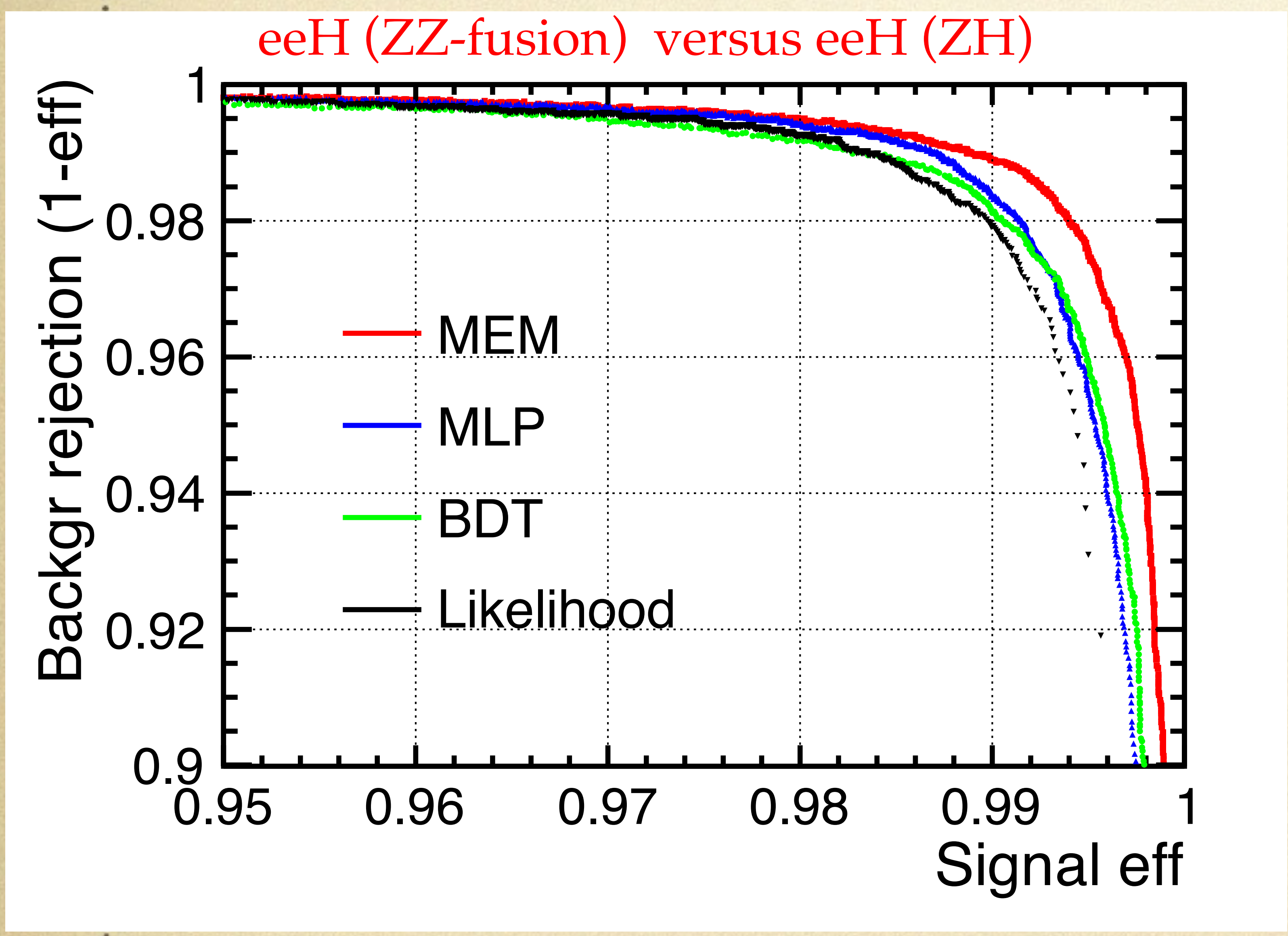


very promising!
much better Higgs mass resolution,
going to check with background

recent development of Matrix Element tools

(approach the true likelihood of each event)

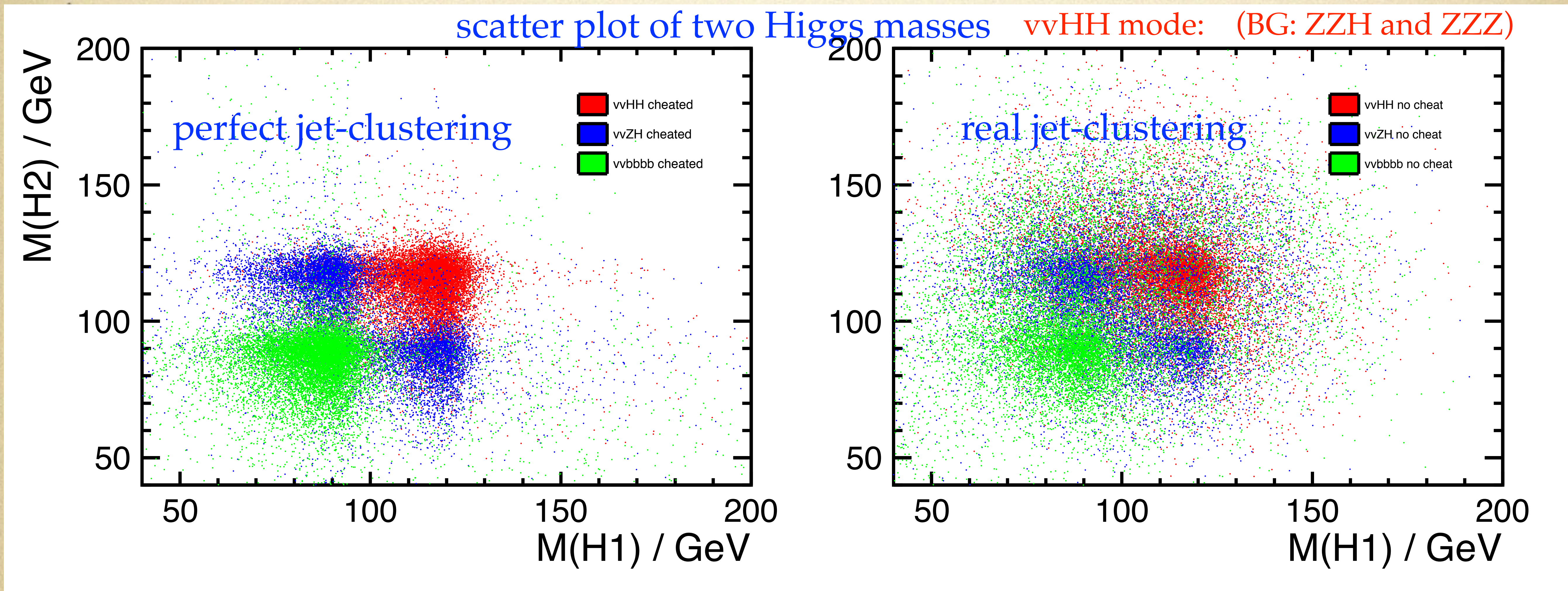
JT@AWLC14



- showed very encouraging improvement in ZZ-fusion analysis.
- going to be applied to event weighting 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?


scatter plot of two Higgs masses vvHH mode: (BG: ZZH and ZZZ)

perfect jet-clustering

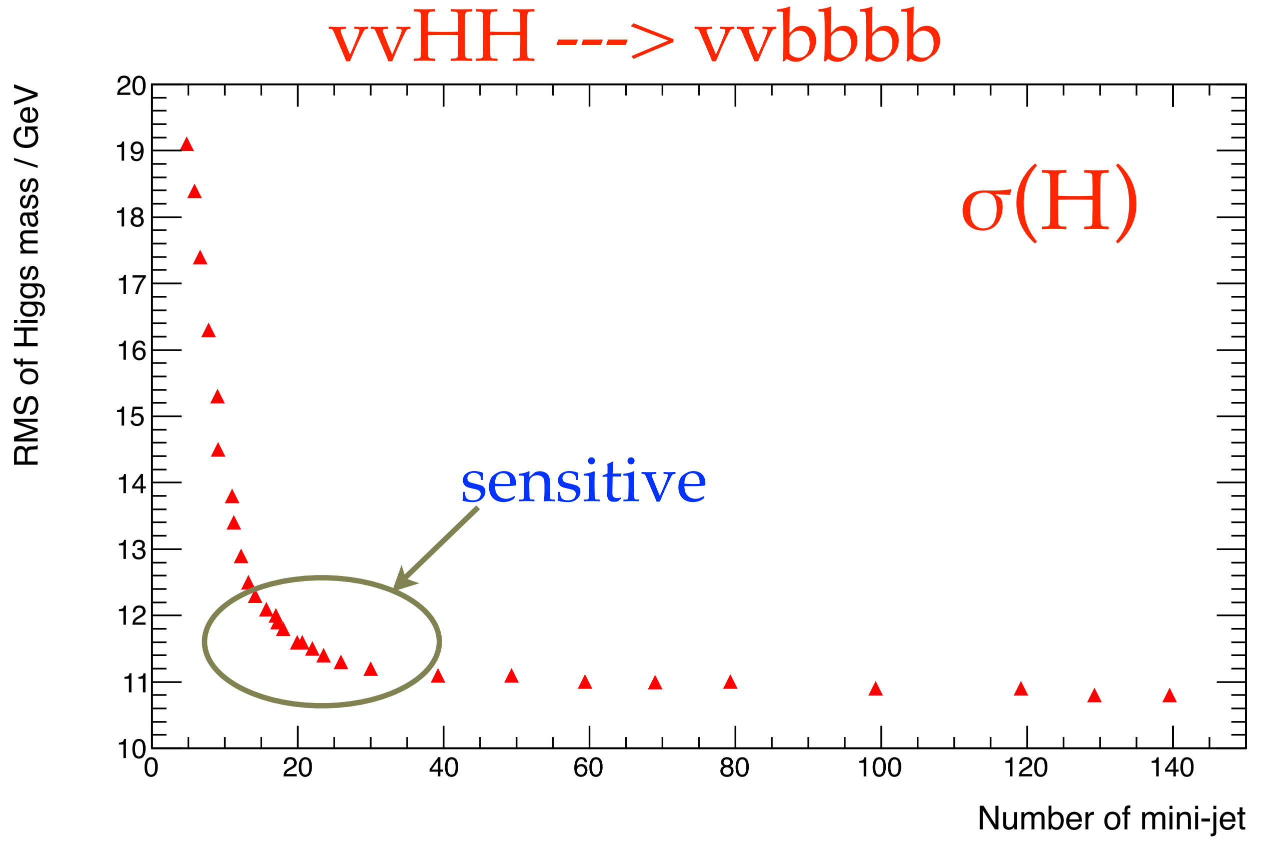
real jet-clustering

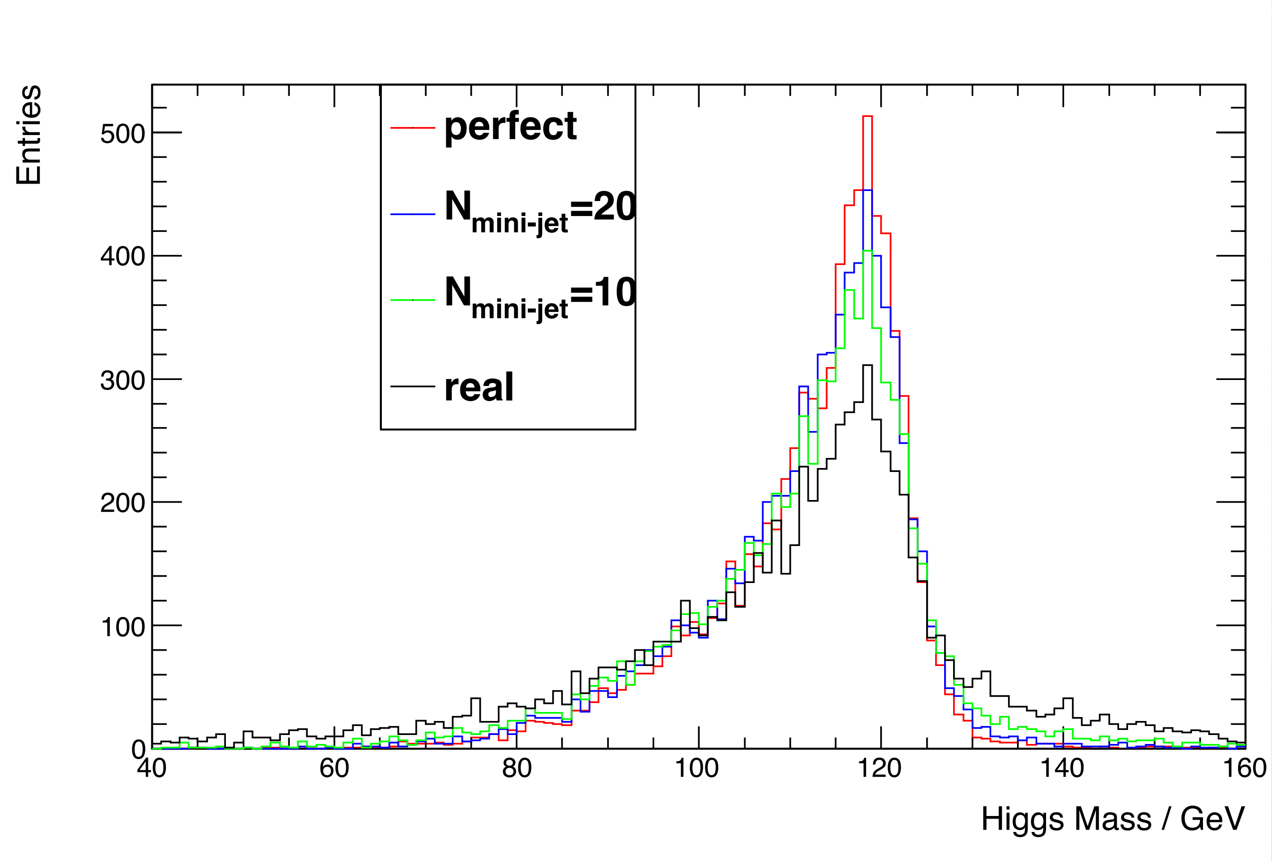
- the mis-clustering of particles degrades significantly the separation between signal and BG.
- it is studied that using perfect color-singlet-jet-clustering can improve $\delta\lambda/\lambda$ by 40%!

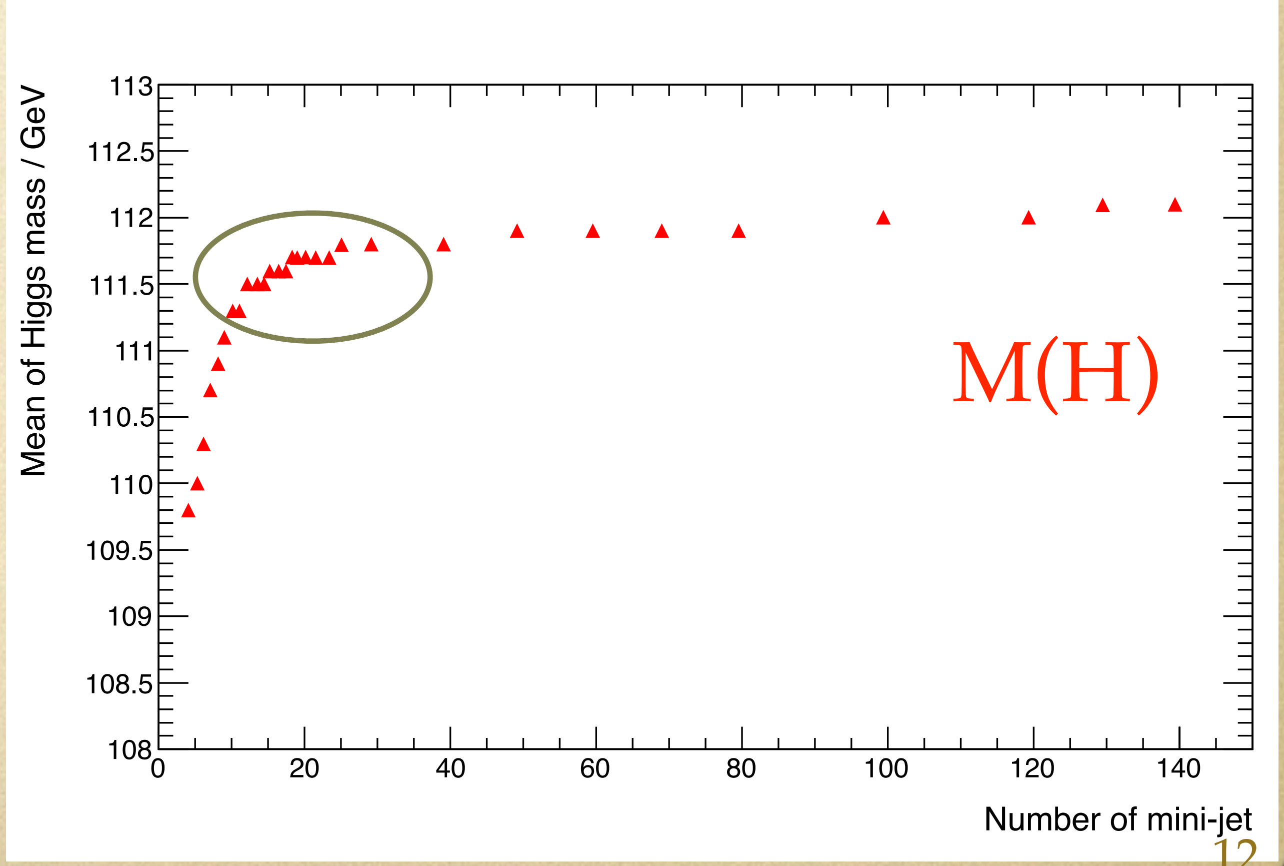
how to approach perfect jet-clustering?

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

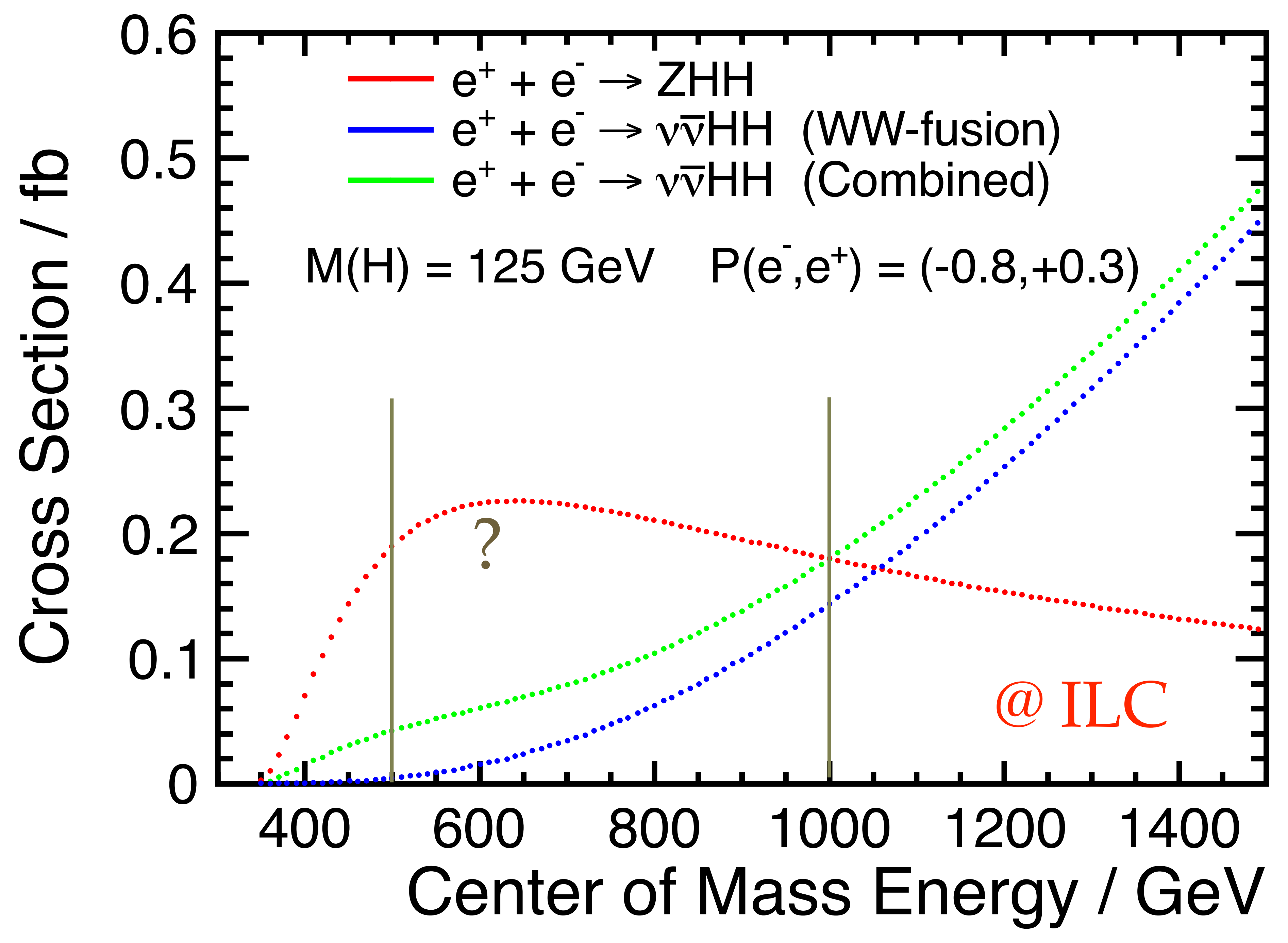
- find vertex before clustering then merge particles from same vertex (LCFI+)
- early stage of jet-clustering —> find all mini-jet : suppose the traditional clustering algorithm can work well with very small y-values.
- combine the mini-jets: ideally we need matrix element at parton shower level!







impact of centre-of-mass energies



key issue: interference

$$\sigma = \lambda^2 S + \lambda I + B$$

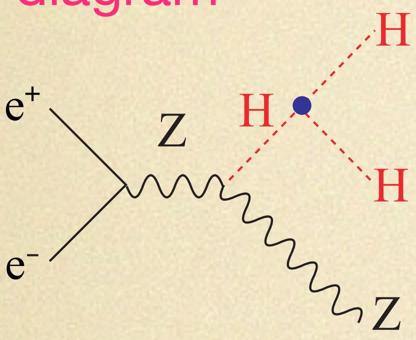
@ 500 GeV

@ 1 TeV

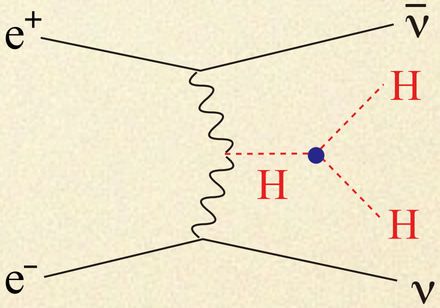
key issue: interference

$$\sigma = \lambda^2 S + \lambda I + B$$

Signal
diagram



Signal
diagram



@ 500 GeV

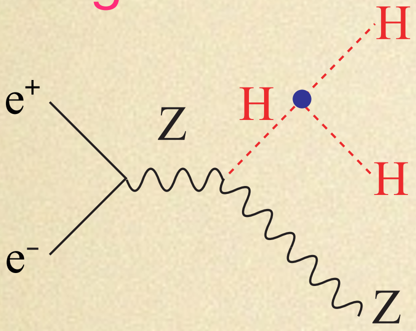
@ 1 TeV

key issue: interference

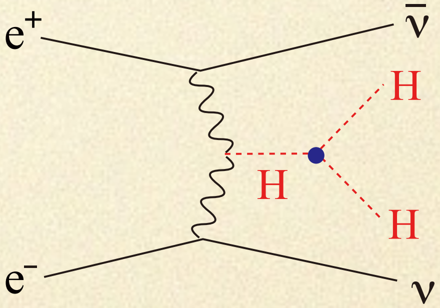
$$\sigma = \lambda^2 S + \lambda I + B$$

$$\frac{\Delta\lambda}{\lambda} = 0.5 \cdot \frac{\Delta\sigma}{\sigma}$$

Signal diagram



Signal diagram



$\sigma_{ZHH} \sim 0.018$ fb

$\sigma_{\nu\nu HH} \sim 0.16$ fb

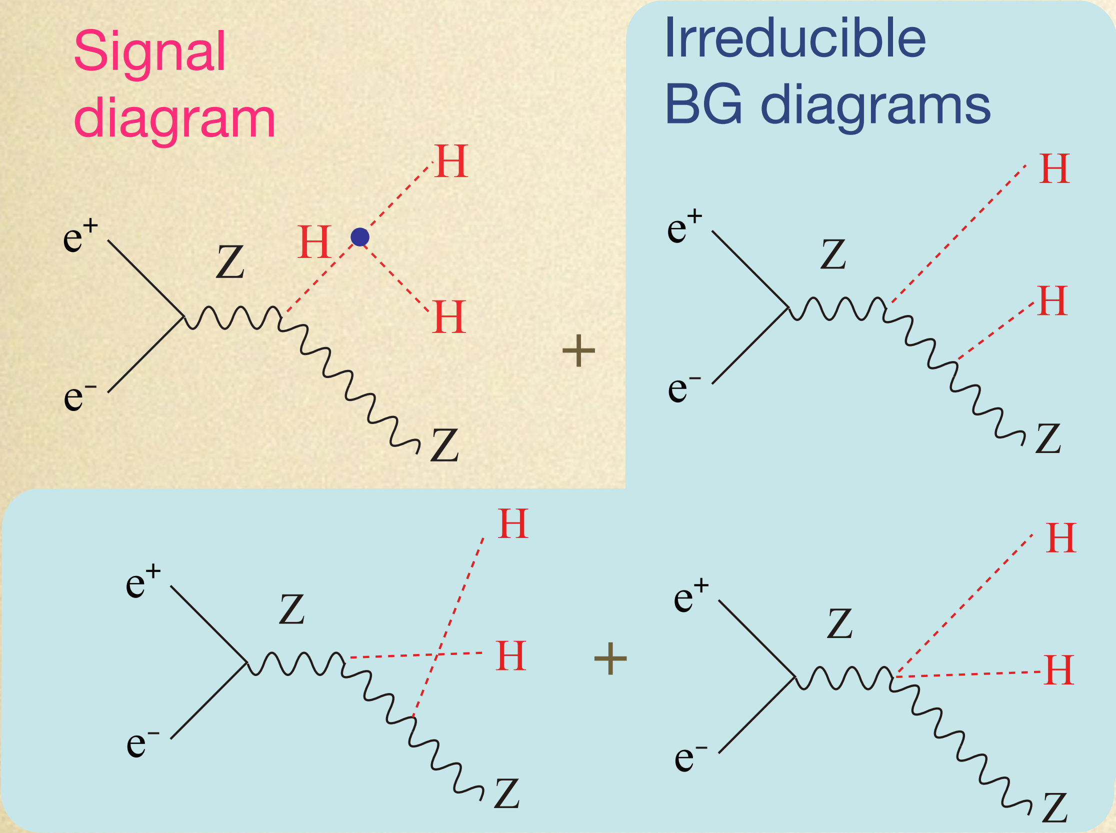
@ 500 GeV

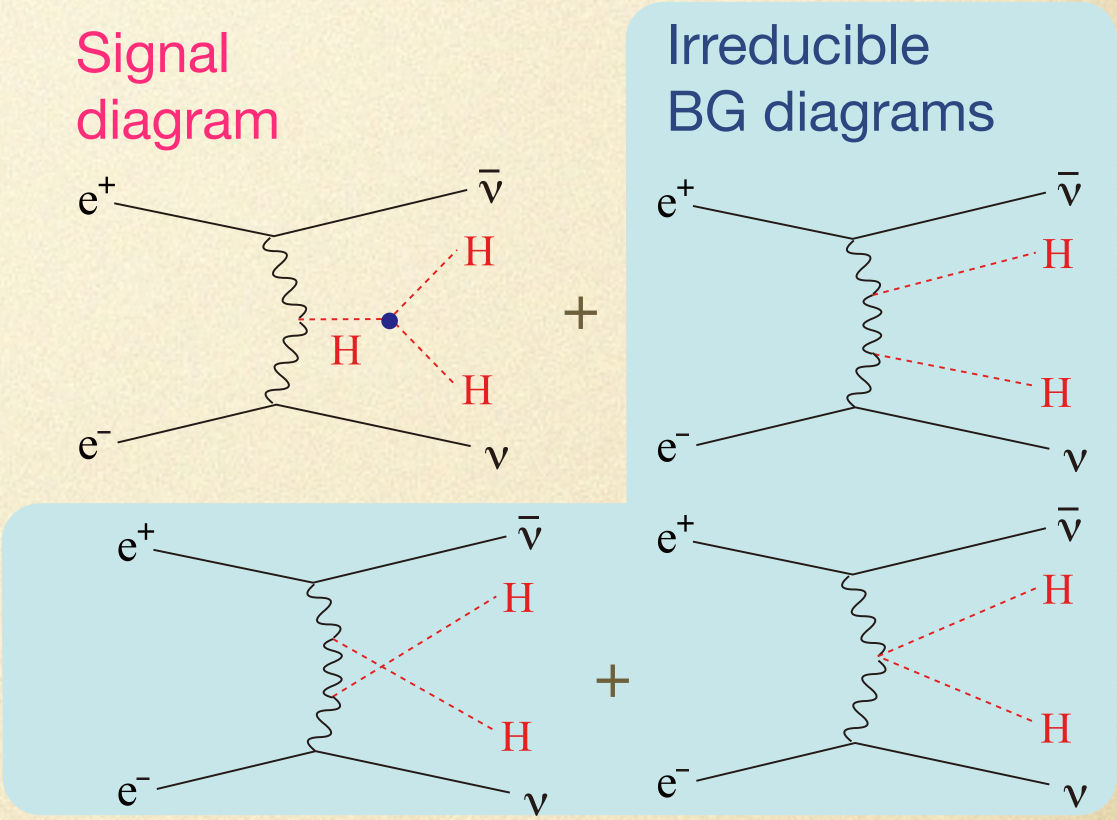
@ 1 TeV

key issue: interference

$$\sigma = \lambda^2 S + \lambda I + B$$

$$\frac{\Delta\lambda}{\lambda} = 0.5 \cdot \frac{\Delta\sigma}{\sigma}$$





$\sigma_{ZHH} \sim 0.018$ fb

$\sigma_{\nu\nu HH} \sim 0.16$ fb

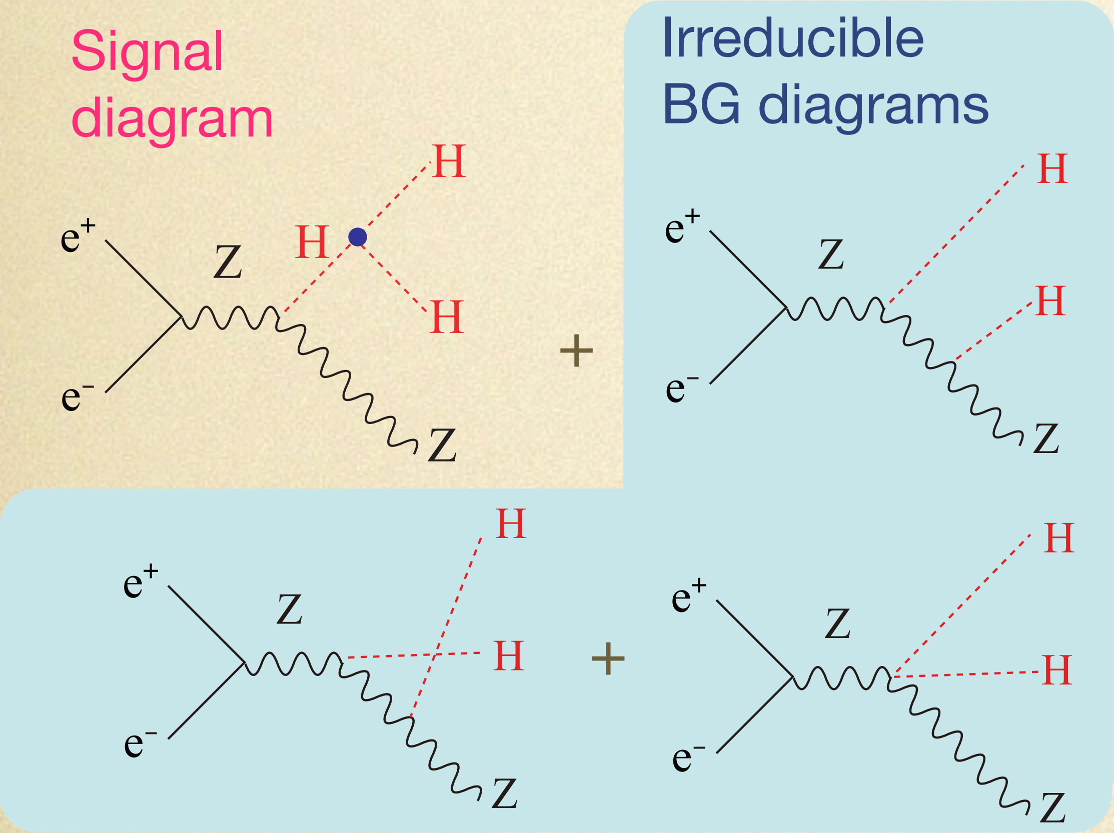
@ 500 GeV

@ 1 TeV

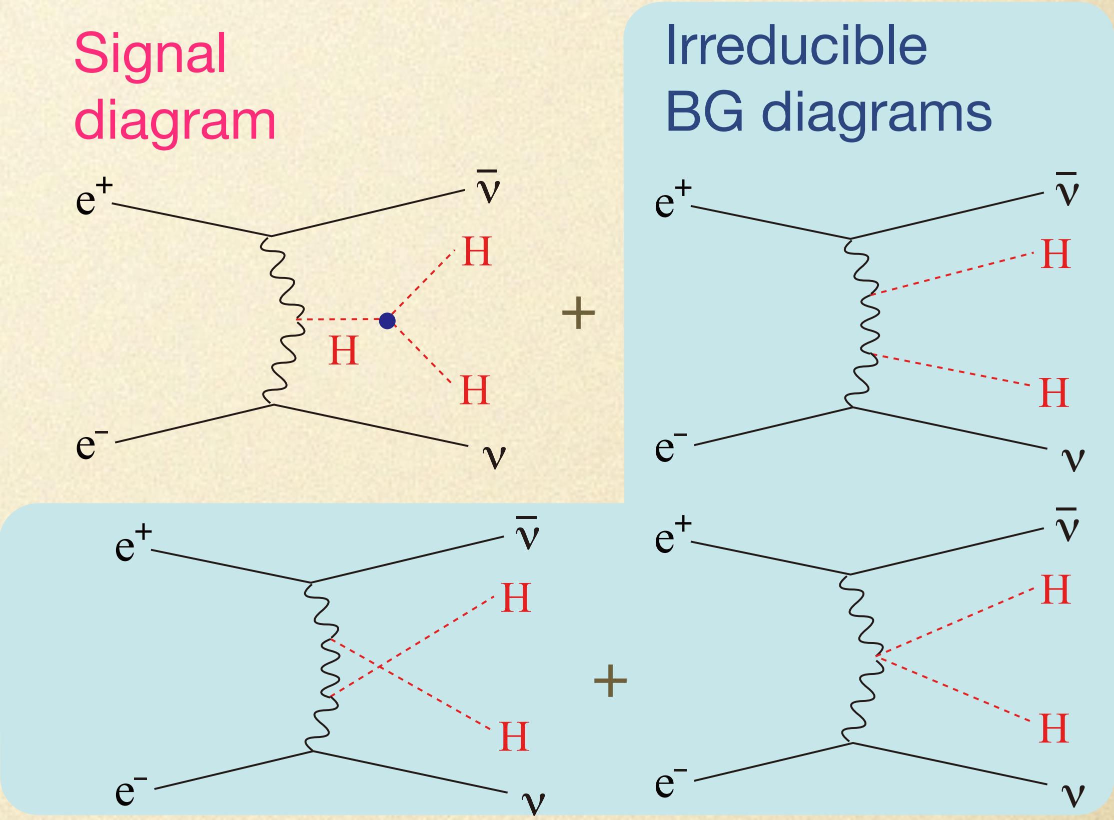
key issue: interference

$$\sigma = \lambda^2 S + \lambda I + B$$

$$\cancel{\frac{\Delta\lambda}{\lambda} = 0.5 \cdot \frac{\Delta\sigma}{\sigma}}$$


Signal diagram

Irreducible BG diagrams


Signal diagram

Irreducible BG diagrams

~~$\sigma_{ZHH} \sim 0.018$ fb~~

$\sigma_{ZHH} \sim 0.19$ fb

$$\frac{\Delta\lambda}{\lambda} = 1.7 \cdot \frac{\Delta\sigma}{\sigma}$$

@ 500 GeV

~~$\sigma_{\nu\nu HH} \sim 0.16$ fb~~

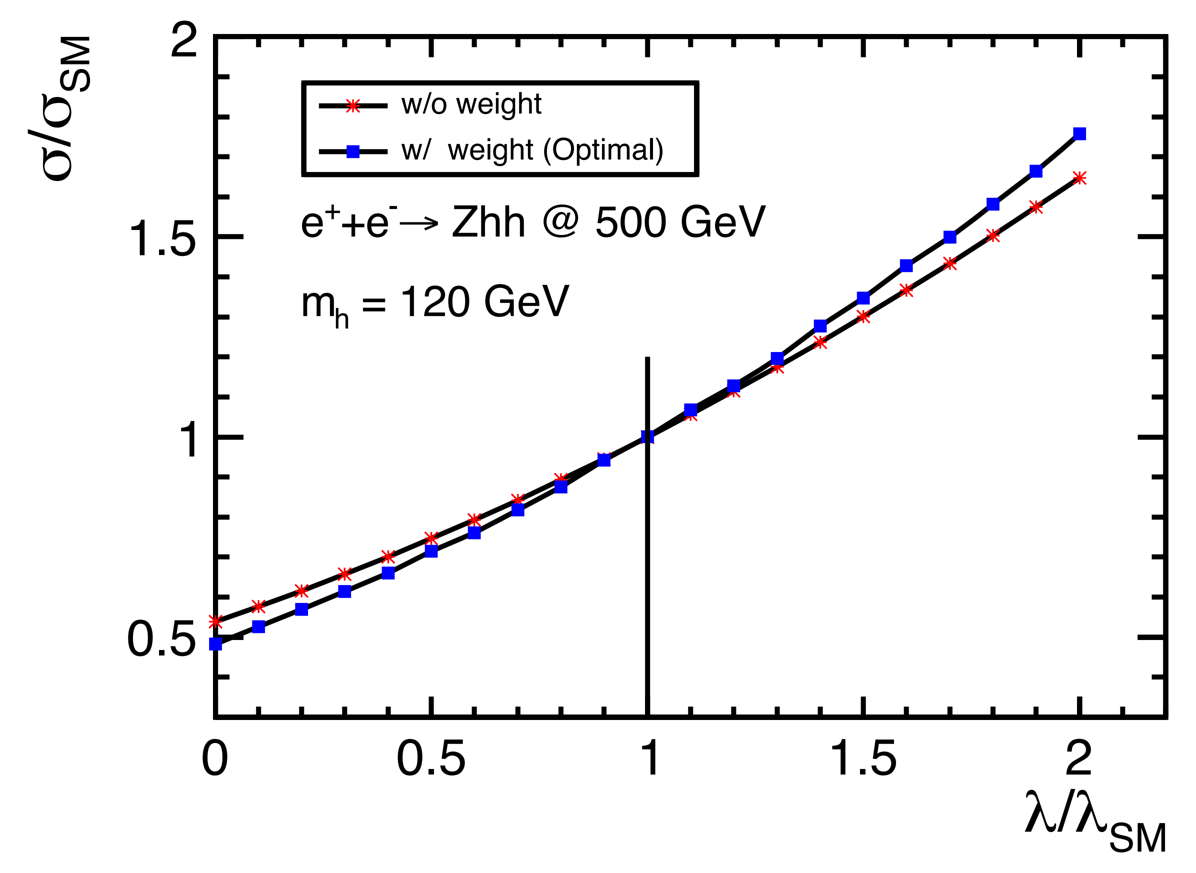
$\sigma_{\nu\nu HH} \sim 0.14$ fb

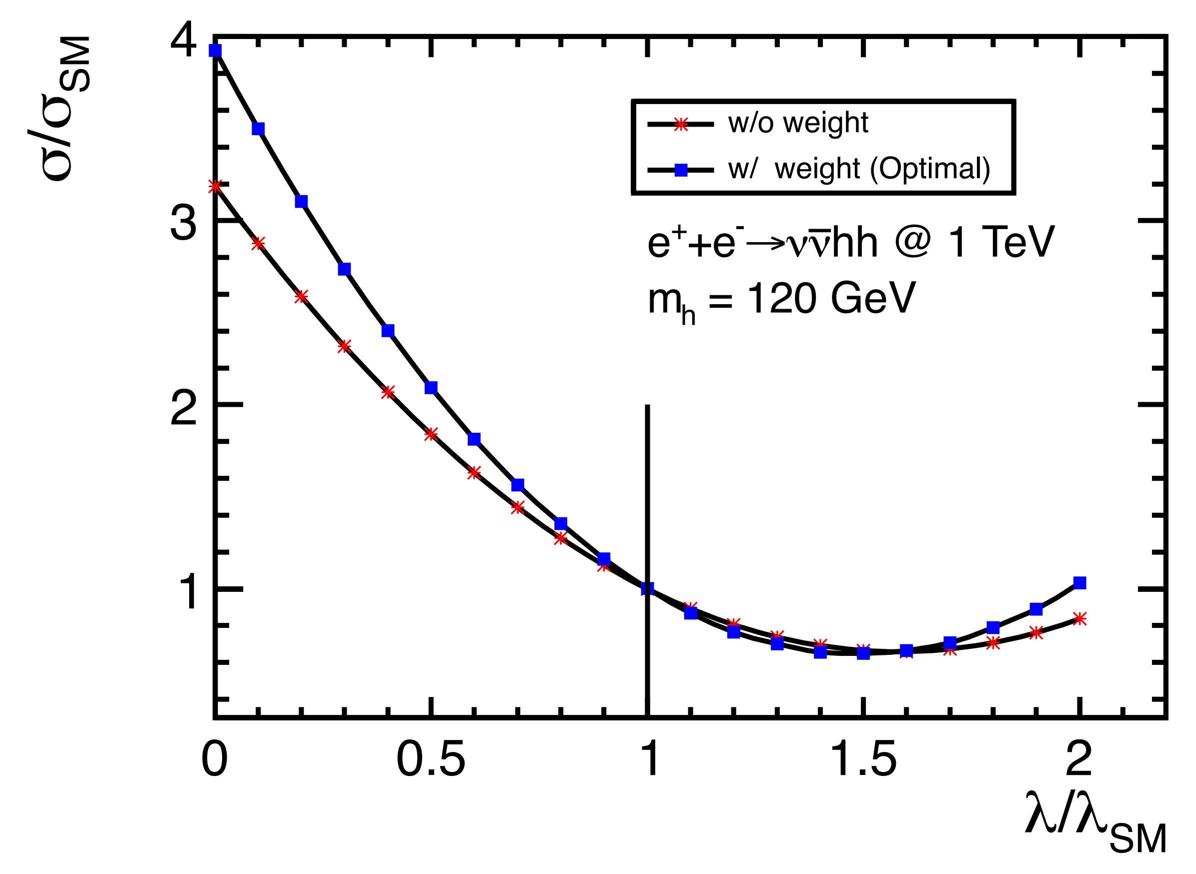
$$\frac{\Delta\lambda}{\lambda} = 0.8 \cdot \frac{\Delta\sigma}{\sigma}$$

@ 1 TeV

key issue: interference

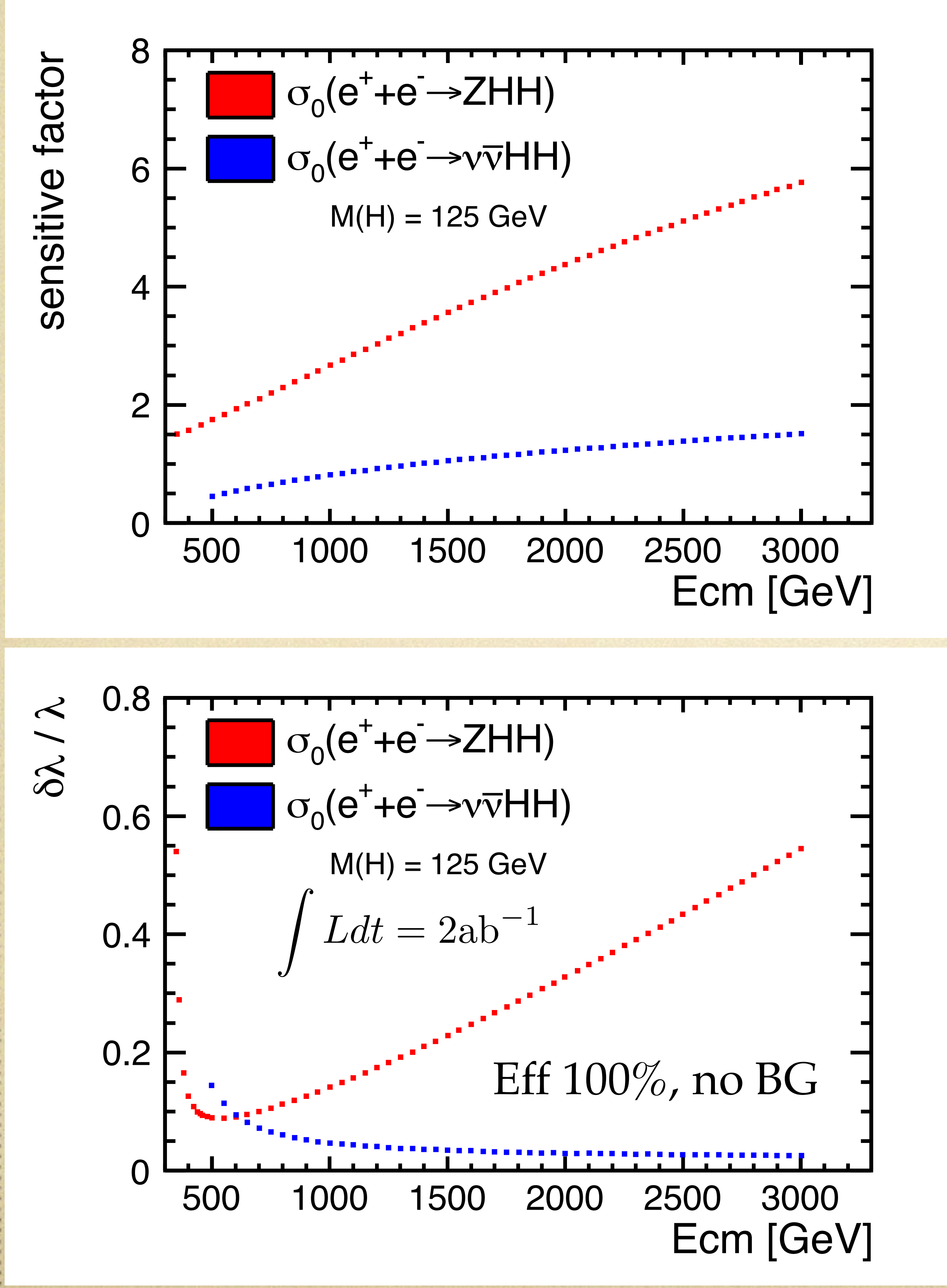
$$\sigma = \lambda^2 S + \lambda I + B$$





(with proper weighting sensitivity factor can be improved by ~10%)

impact of centre-of-mass energies



$$\frac{\Delta\lambda}{\lambda} = \mathrm{F} \cdot \frac{\Delta\sigma}{\sigma}$$

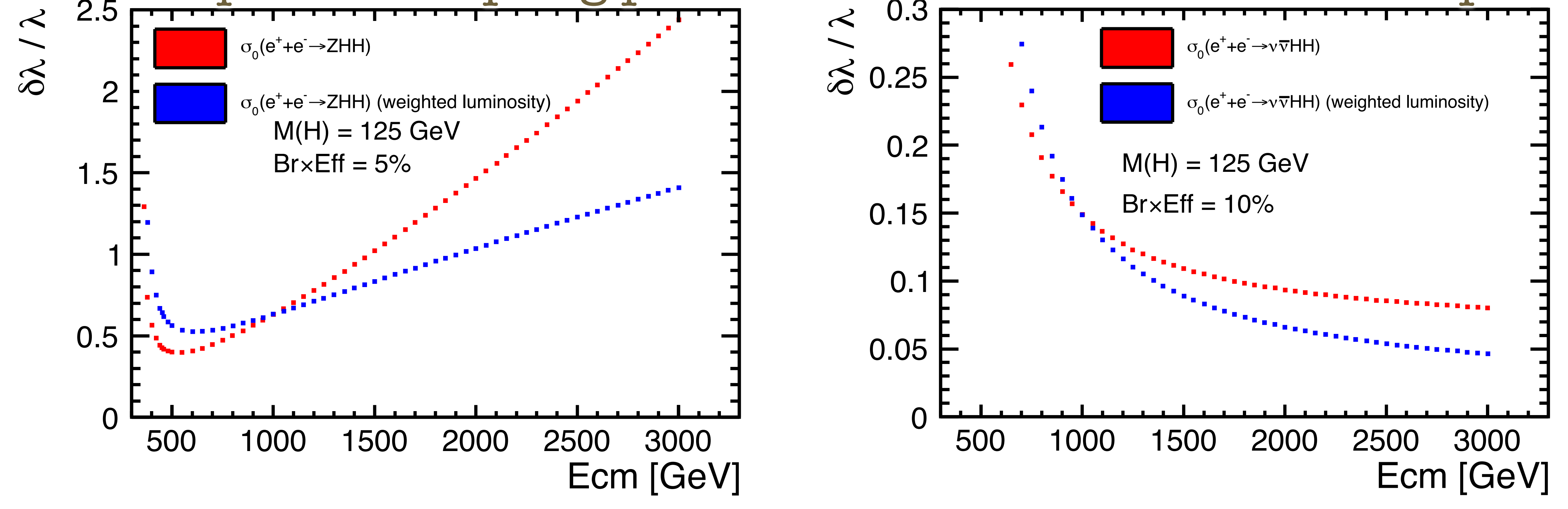
Factor increases quickly as going to higher energy

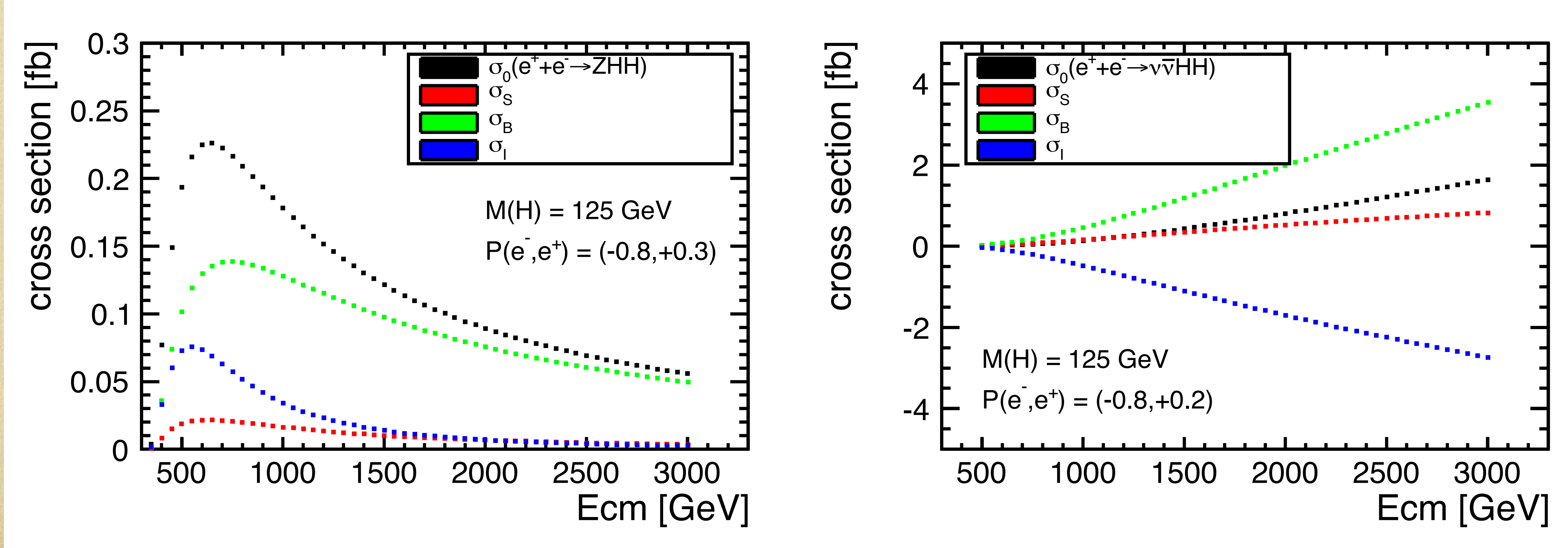
for ZHH, the expected optimal energy ~ 500 GeV (rather flat at 500 — 600 GeV)

for $\nu\nu$HH, expected precision improves slowly as going to higher energy

impact of centre-of-mass energies

expected coupling precision with more realistic setup





impact of centre-of-mass energies

- for ZHH process, 500 GeV is still the optimal energy.
- we do gain significantly from vvHH @ 1 TeV, where sensitivity factor is much smaller than that in ZHH.
- new baseline running scenario is up to 500 GeV, what would we expect?
- with 5500 fb^{-1} @ 500 GeV, we expect 25% precision on self-coupling based on already-done analyses; conservatively, 20% is achievable with improved techniques.
- reminder: 75% @ LoI —> 44% @ DBD (mH=120GeV, $2\mathrm{ab}^{-1}$)
- with 1 TeV upgrade: $\delta\lambda/\lambda < 10\%$

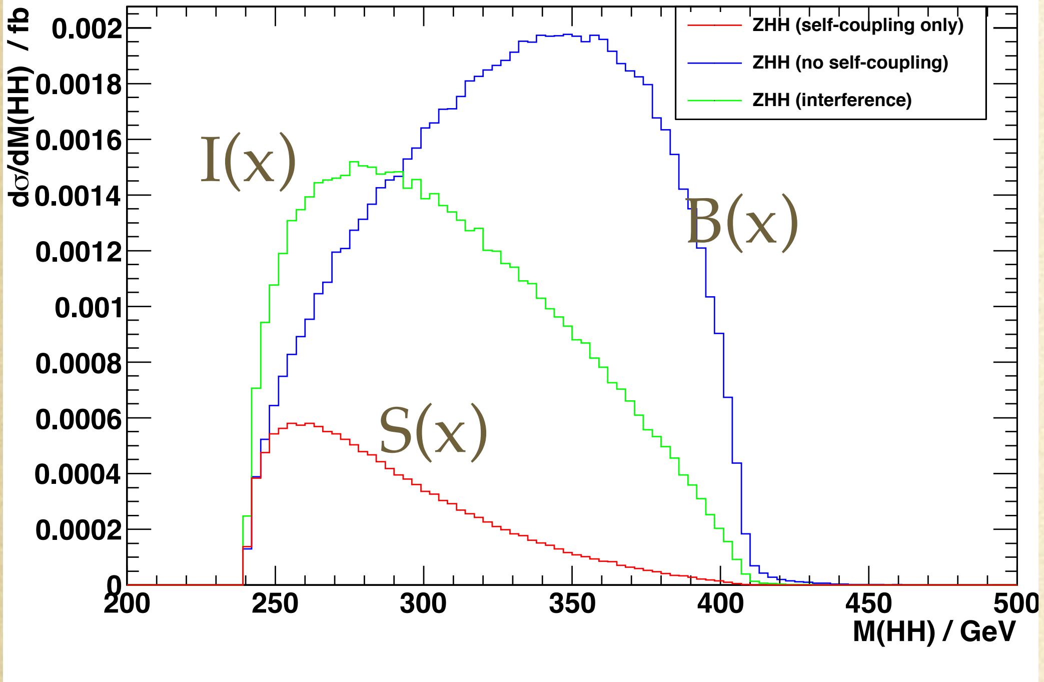
summary and next step

- it is one of the fundamental physics goal to measure λ_{HHH} at the future collider; 10% precision is achievable at 1 TeV ILC.
- current focus is to improve analysis at 500 GeV.
- quite lots of efforts ongoing: kinematic fitting, isolated lepton tagging, jet clustering and jet pairing, optimisation strategy
- and don't forget flavor tagging…
- as planned, at some point we should publish our results, instead of waiting for all techniques available.

Backup

new weighting method to enhance the coupling sensitivity

differential cross-section



$$\frac{\mathrm{d}\sigma}{\mathrm{d}x} = B(x) + \lambda I(x) + \lambda^2 S(x)$$

irreducible

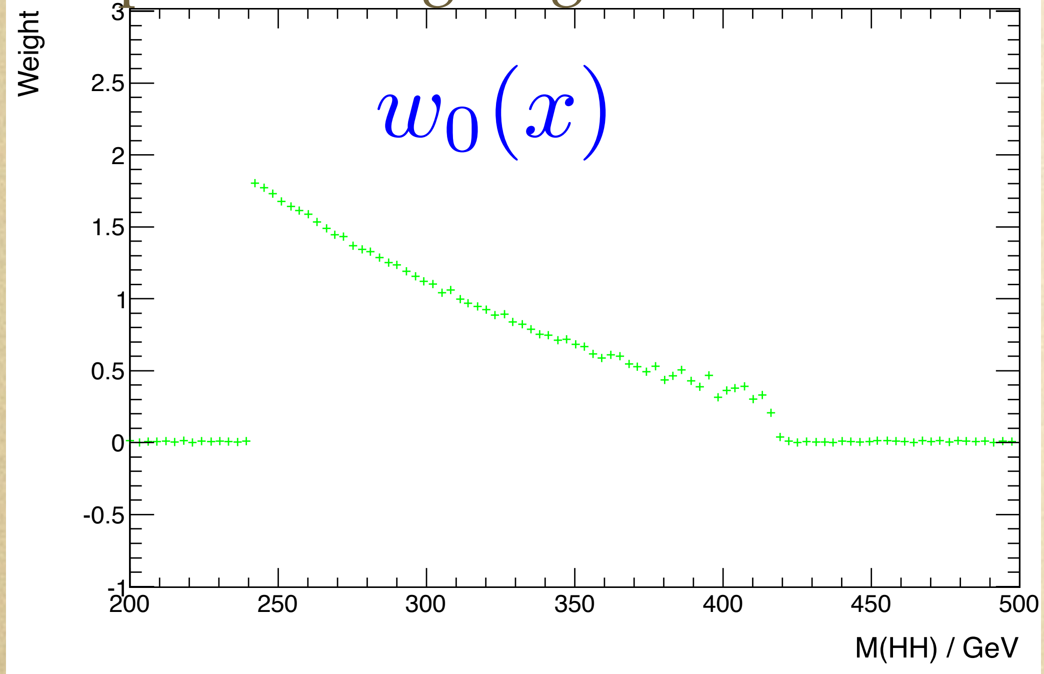
interference

self-coupling

observable: weighted cross-section

$$\sigma_w = \int \frac{\mathrm{d}\sigma}{\mathrm{d}x} w(x)\mathrm{d}x$$

optimal weighing function



equation of the optimal w(x) (variance principle):

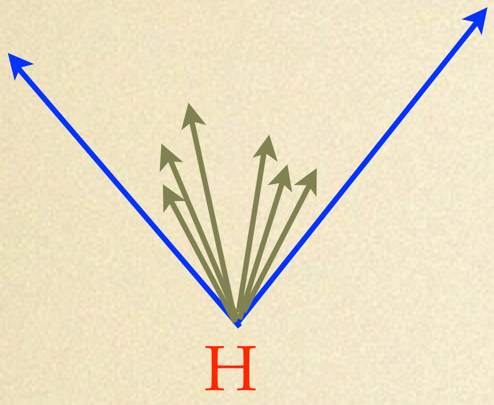
$$\sigma(x)w_0(x)\int (I(x)+2S(x))w_0(x)\mathrm{d}x = (I(x)+2S(x))\int \sigma(x)w_0^2(x)\mathrm{d}x$$

general solution:

$$w_0(x) = c\cdot\frac{I(x)+2S(x)}{\sigma(x)}$$

c: arbitrary normalization factor

decay plane



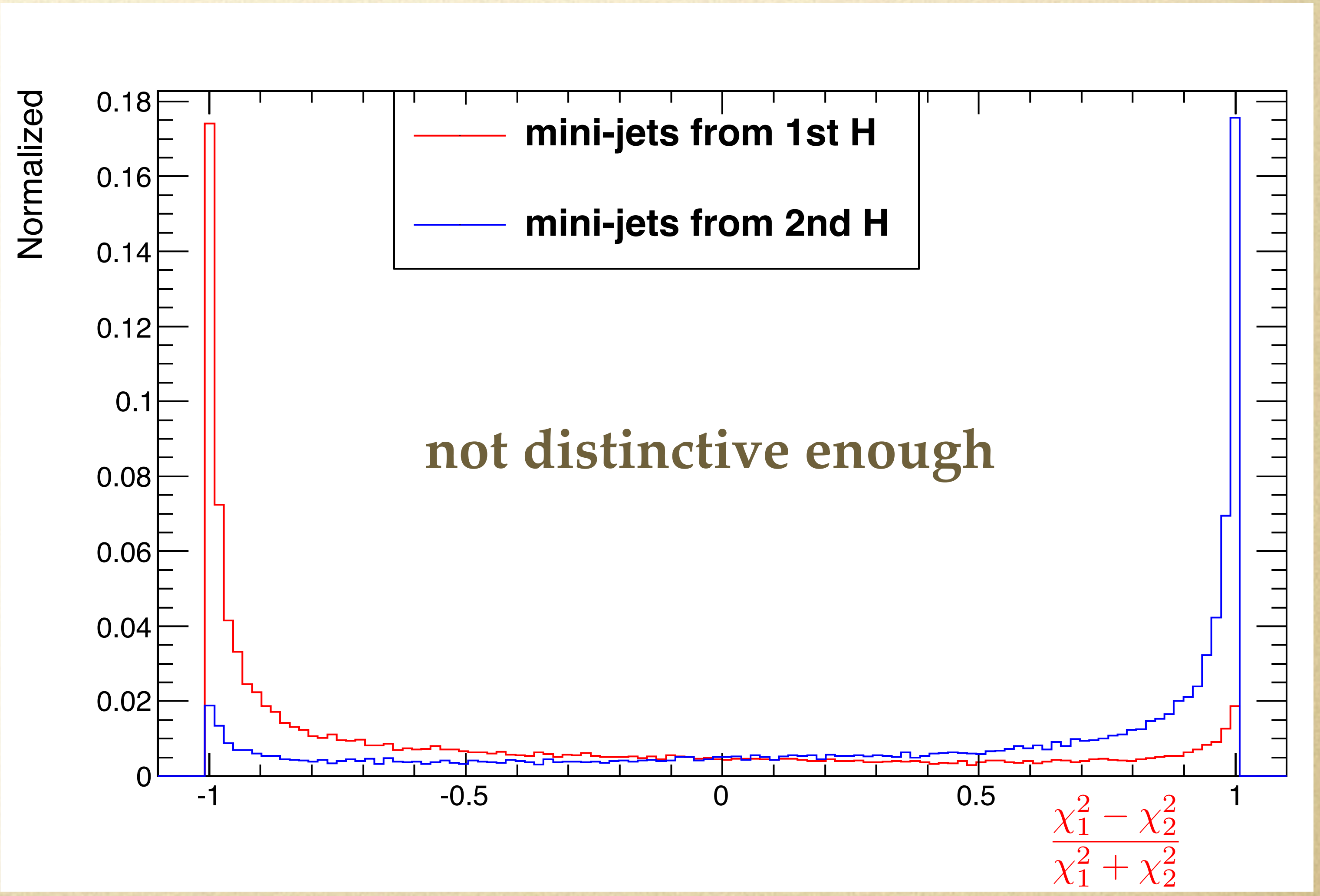
particles from one same color singlet
should be around the decay plane

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

transverse momentum
relative to the decay plane

vvHH ---> vvbbbb

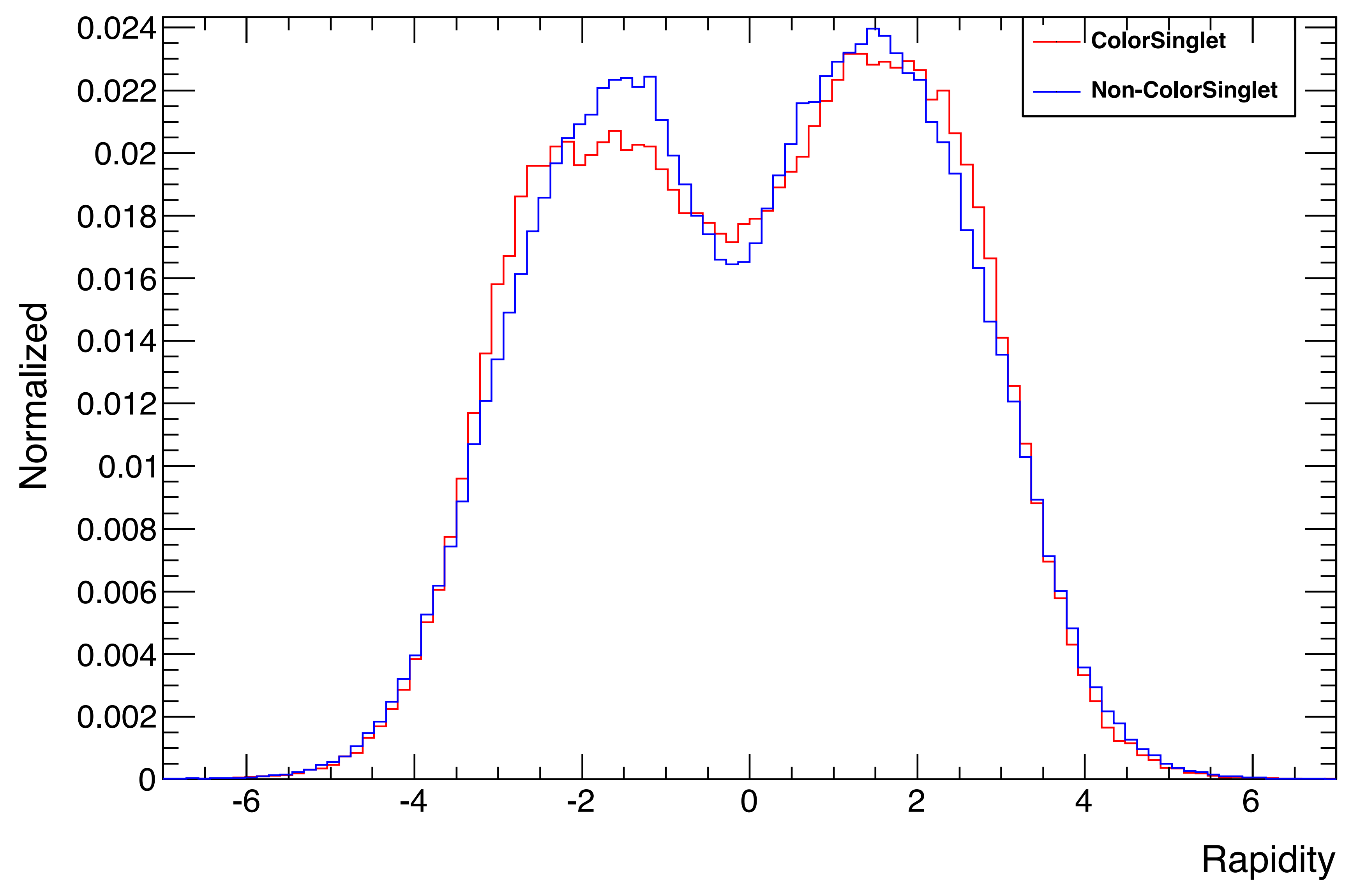
- using the realistic Duhram algorithm for the mini-jet clustering, stop when there are 20 mini-jets left.
- calculate the chi2 for each mini-jet, there are two decay planes, we get two chi2 for each mini-jet. (currently the two decay planes are decided by cheating)



not distinctive enough

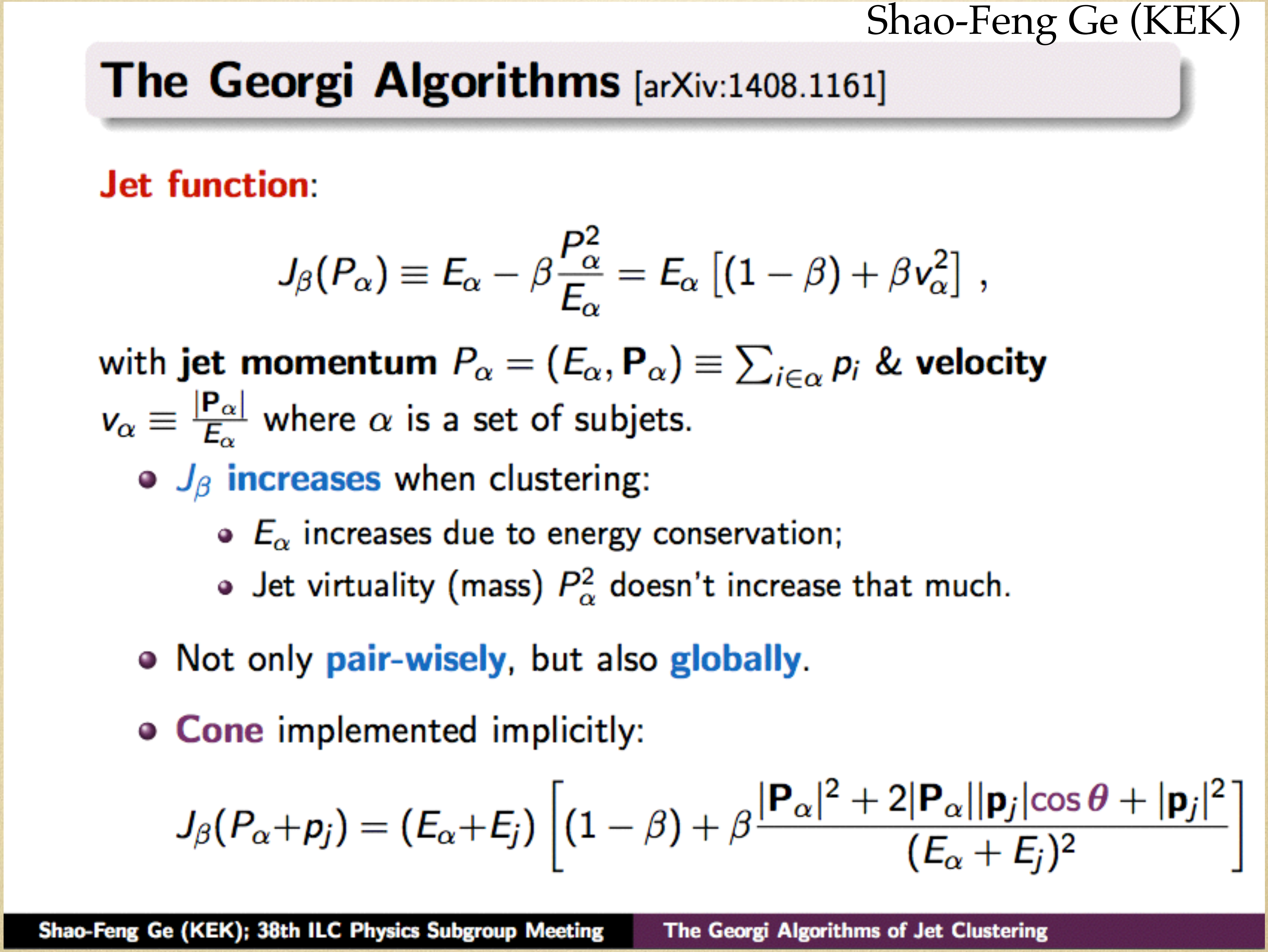
rapidity gap? (reconstructed)

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



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

Shao-Feng Ge (KEK)



The Georgi Algorithms [arXiv:1408.1161]

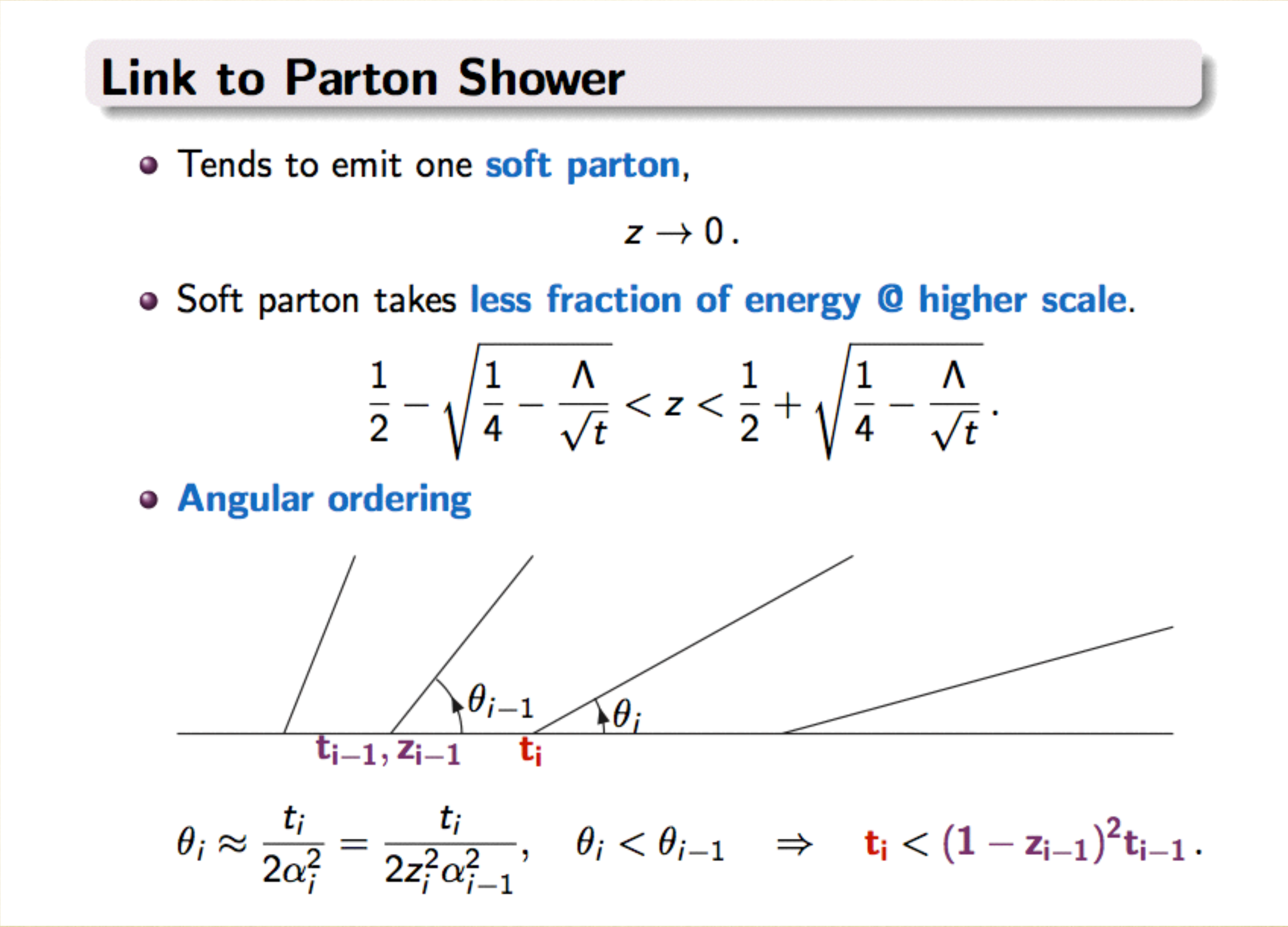
Jet function:

$$J_\beta(P_\alpha) \equiv E_\alpha - \beta \frac{P_\alpha^2}{E_\alpha} = E_\alpha \left[(1-\beta) + \beta v_\alpha^2\right] ,$$

with **jet momentum** $P_\alpha = (E_\alpha, \mathbf{P}_\alpha) \equiv \sum_{i \in \alpha} p_i$ & **velocity** $v_\alpha \equiv \frac{|\mathbf{P}_\alpha|}{E_\alpha}$ where α is a set of subjets.

- J_β **increases** when clustering:
  - E_α increases due to energy conservation;
  - Jet virtuality (mass) P_α^2 doesn't increase that much.
- Not only **pair-wisely**, but also **globally**.
- **Cone** implemented implicitly:

$$J_\beta(P_\alpha + p_j) = (E_\alpha + E_j) \left[(1-\beta) + \beta \frac{|\mathbf{P}_\alpha|^2 + 2|\mathbf{P}_\alpha||\mathbf{p}_j|\cos\theta + |\mathbf{p}_j|^2}{(E_\alpha + E_j)^2}\right]$$



Link to Parton Shower

- Tends to emit one **soft parton**,

$$z \to 0\,.$$

- Soft parton takes **less fraction of energy @ higher scale**.

$$\frac{1}{2} - \sqrt{\frac{1}{4} - \frac{\Lambda}{\sqrt{t}}} < z < \frac{1}{2} + \sqrt{\frac{1}{4} - \frac{\Lambda}{\sqrt{t}}}\,.$$

- **Angular ordering**

$$\theta_i \approx \frac{t_i}{2\alpha_i^2} = \frac{t_i}{2z_i^2\alpha_{i-1}^2}\,, \quad \theta_i < \theta_{i-1} \quad \Rightarrow \quad \mathbf{t_i} < (\mathbf{1} - \mathbf{z_{i-1}})^2\mathbf{t_{i-1}}\,.$$