new method for measurement of the Higgs boson mass at e+e-

Junping Tian (U' of Tokyo)

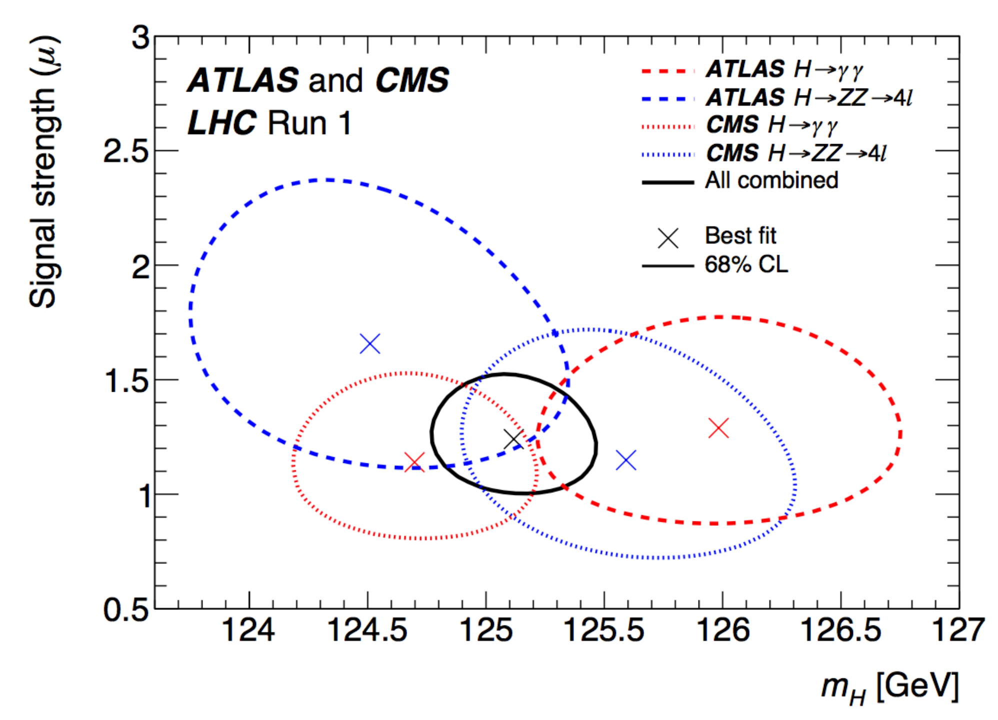
International Workshop on High Energy Circular Electron Positron Collider @ IHEP, Nov. 6-8, 2017

introduction: methods to measure Higgs mass

- at LHC: direct reconstruction from decay, e.g. H—>γγ or H—>ZZ—>4l

$$m_H^{\rm Run1} = 125.09 \pm 0.21({\rm stat}) \pm 0.11({\rm sys}){\rm GeV}$$

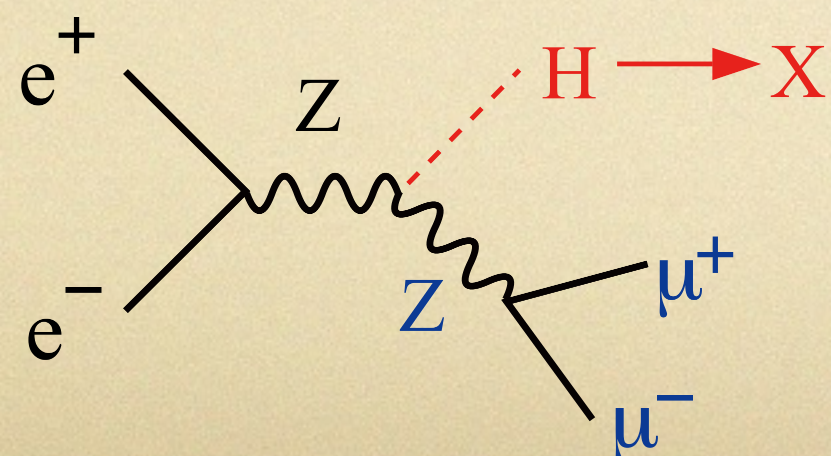
1503.07589

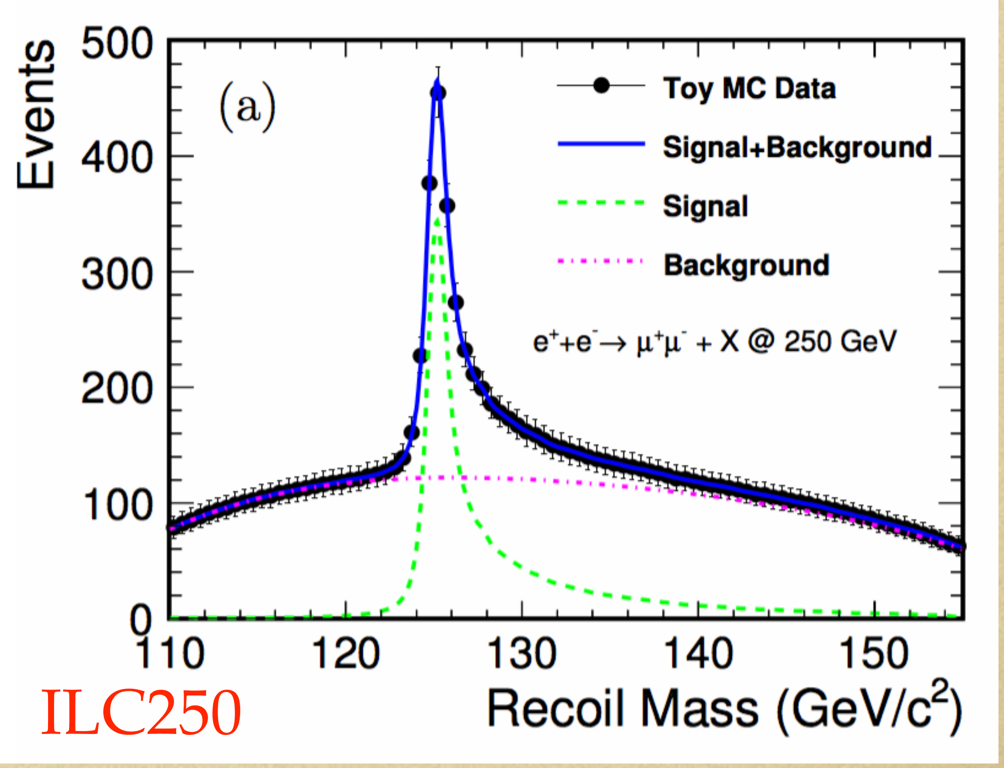


- at e+e-: recoil mass against Z—>ll

$$\Delta m_H^{\rm H20} = 14{\rm MeV}$$

1604.07524





introduction: why δm_H is important

- partial widths of H->ZZ*/WW* is very sensitive to the Higgs boson mass (due to phase space)
- δm_H becomes one main source of systematic errors for theory prediction of Γ(H->ZZ) and Γ(H->WW)

1404.0319

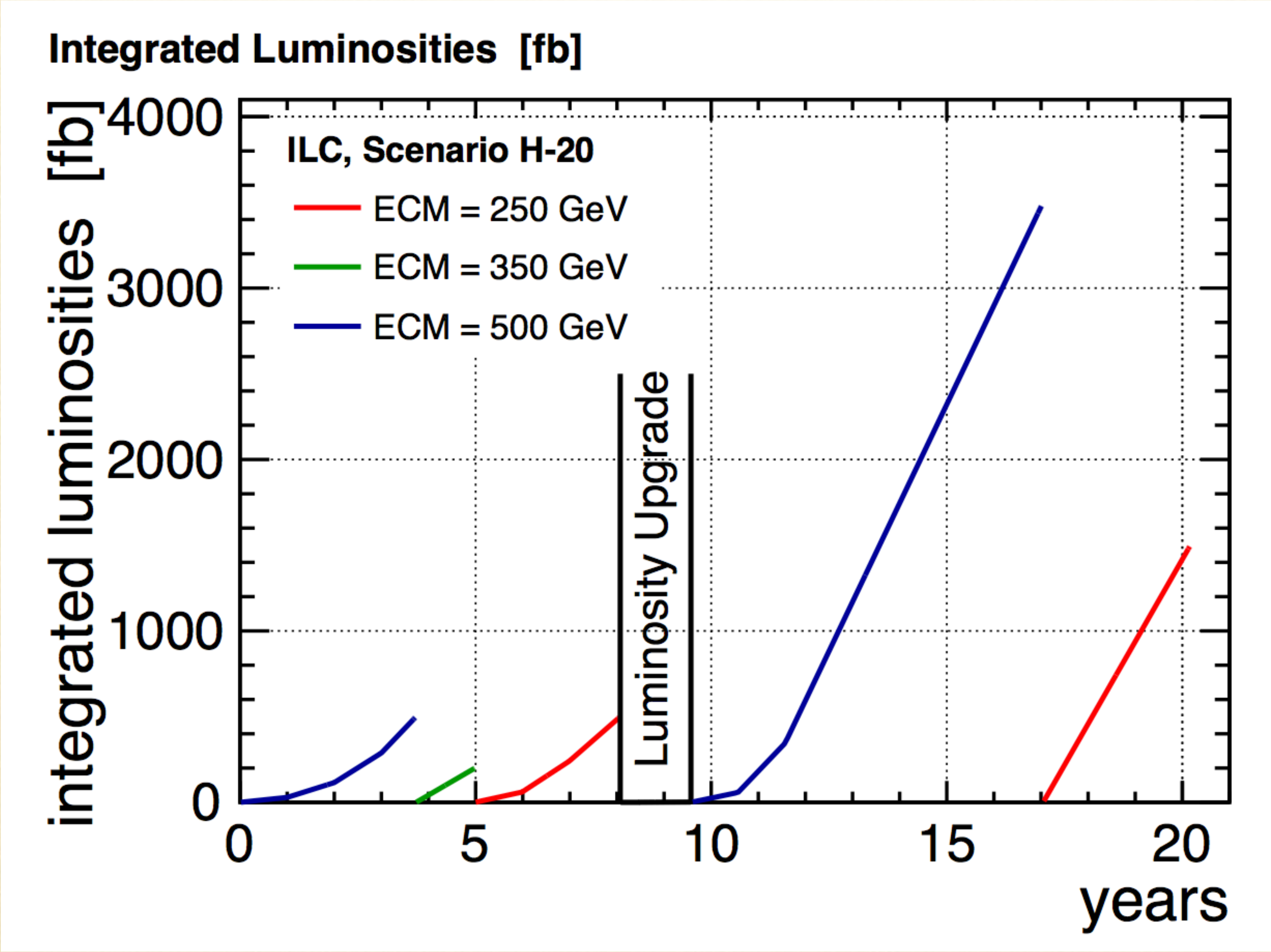
$$\delta_W = 6.9 \cdot \delta m_H \qquad \delta_Z = 7.7 \cdot \delta m_H$$

e.g. if Δm_H = 200 MeV —> δ_Z ~ 1.2% (>> other sources)

ILC 250: Δm_H = 14 MeV —> δ_Z ~ 0.1%

note: δ_Z is relative error for HZZ coupling, which is defined as 1/2 of relative error of partial width of H->ZZ*

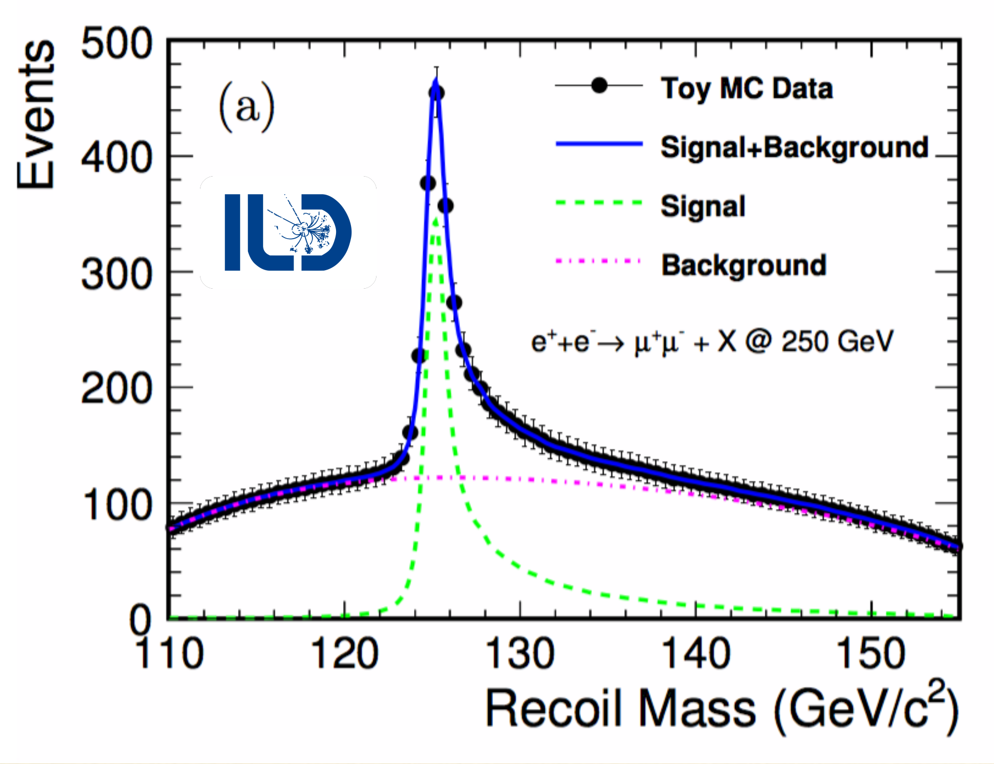
introduction: the motivation for a new method



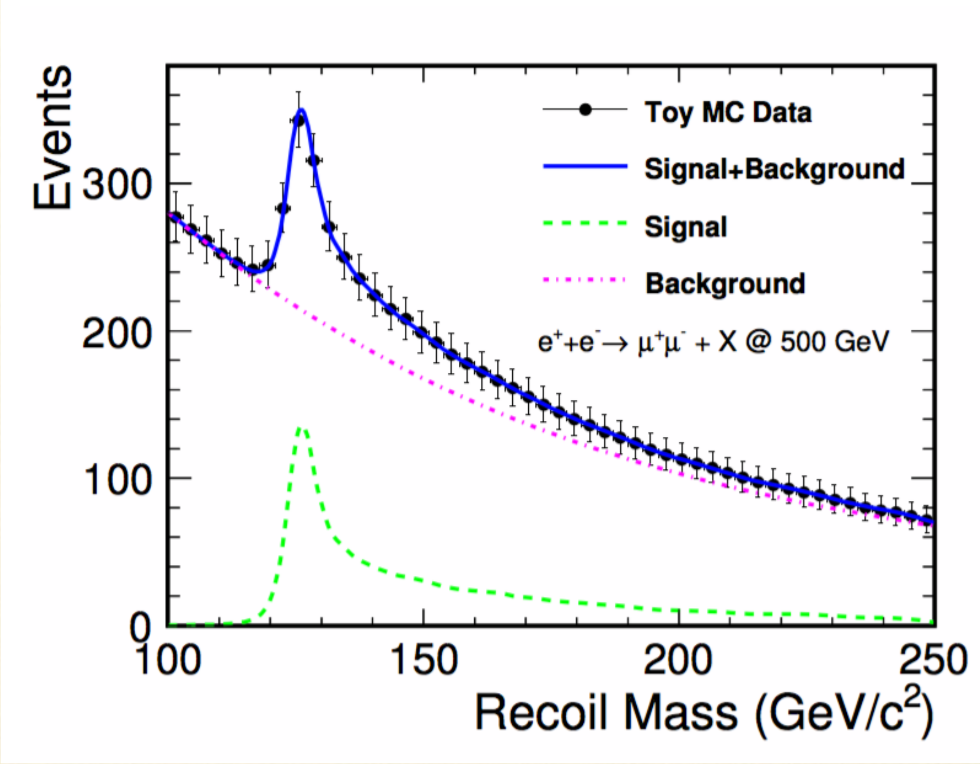
ILC H20: why, for significant fraction of time, the 500 GeV machine is running at 250 GeV? (was really a pity to me)

introduction: the motivation for a new method

at Ecm=250 GeV: Δm_H = 14 MeV



at Ecm=500 GeV: Δm_H = 218 MeV



1604.07524

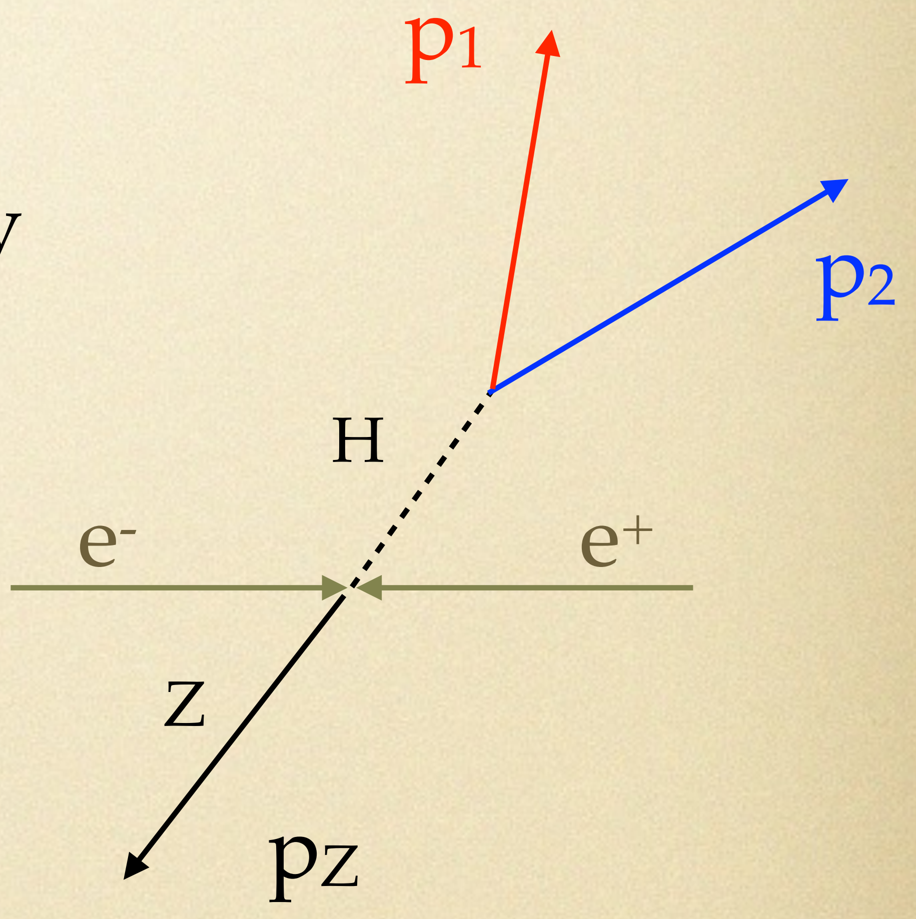
can we improve Δm_H at e.g. $\sqrt{s}$ >= 500 GeV?

idea of a new method for measurement of m_H

(talk at LCWS16)

strategy

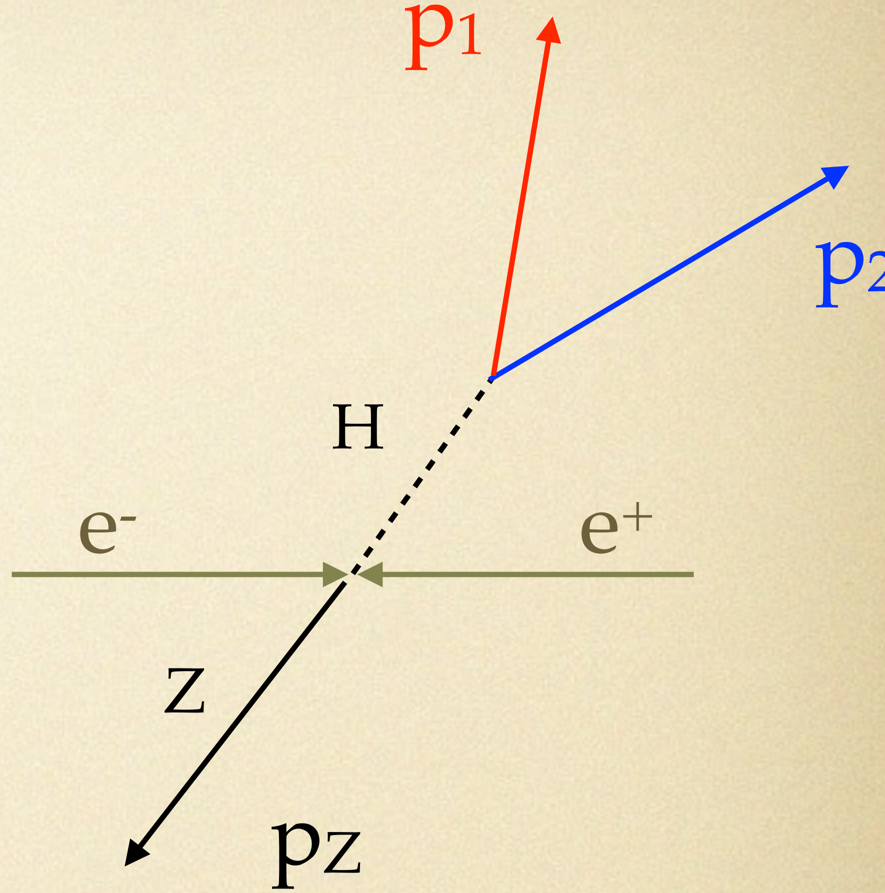
- require momentum balance only in transverse direction
- use measured jet direction, but not energy
- two constraints -> two unknown (p1, p2)



advantage

- insensitive to beam energy
- insensitive to beamstrahlung/ISR
- insensitive to (b)-jet energy resolution

analytic results



$$p_1 \sin\theta_1 \cos\phi_1 + p_2 \sin\theta_2 \cos\phi_2 = p_x$$

$$p_1 \sin\theta_1 \sin\phi_1 + p_2 \sin\theta_2 \sin\phi_2 = p_y$$

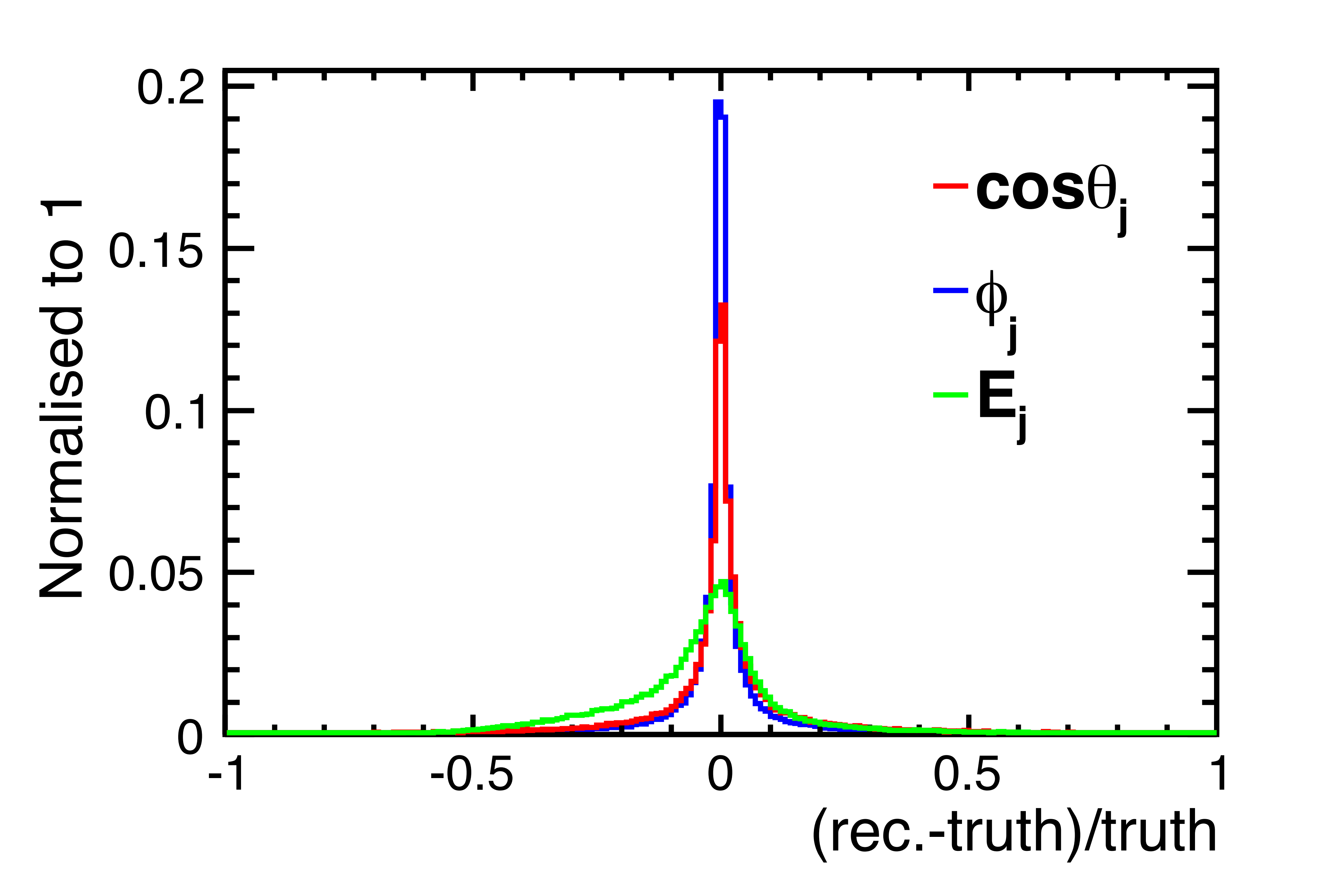
(px, py: measured from pZ)

$$\begin{pmatrix} p_1 \\ p_2 \end{pmatrix} = \frac{p_t}{\sin\phi} \begin{pmatrix} \frac{\sin(\phi-\phi_2)}{\sin\theta_1} \\ \frac{\sin(\phi_1-\phi)}{\sin\theta_2} \end{pmatrix}$$

$$\phi = \phi_1 - \phi_2 \qquad p_t = \sqrt{p_x^2 + p_y^2}$$

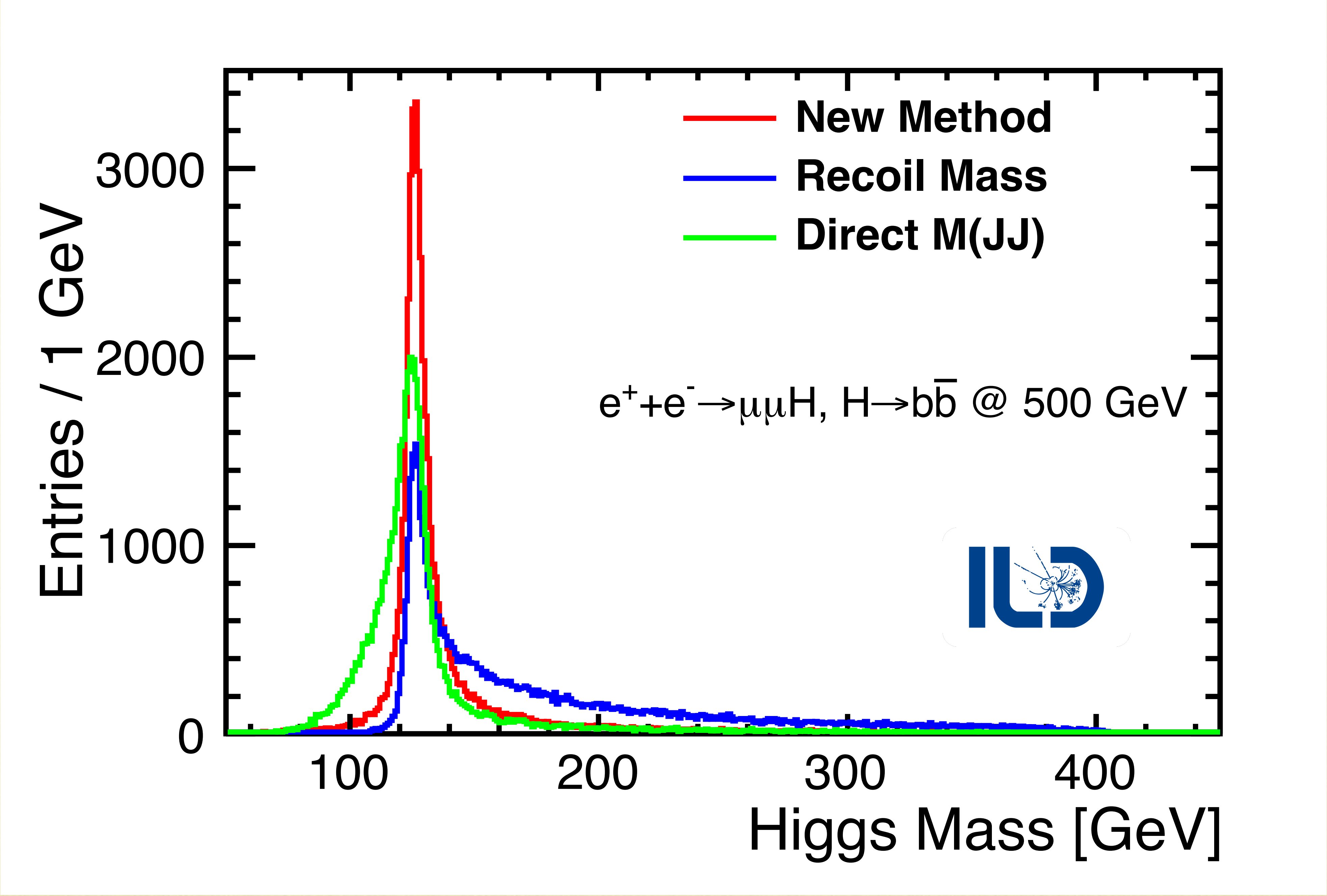
results for full simulation — resolutions

$\sqrt{s} = 500\ \mathrm{GeV}$ $\quad e^+e^- \to \mu\mu H, H \to b\bar{b}$ $\quad$ w/o overlay



comparison between momentum of jets and b-quarks

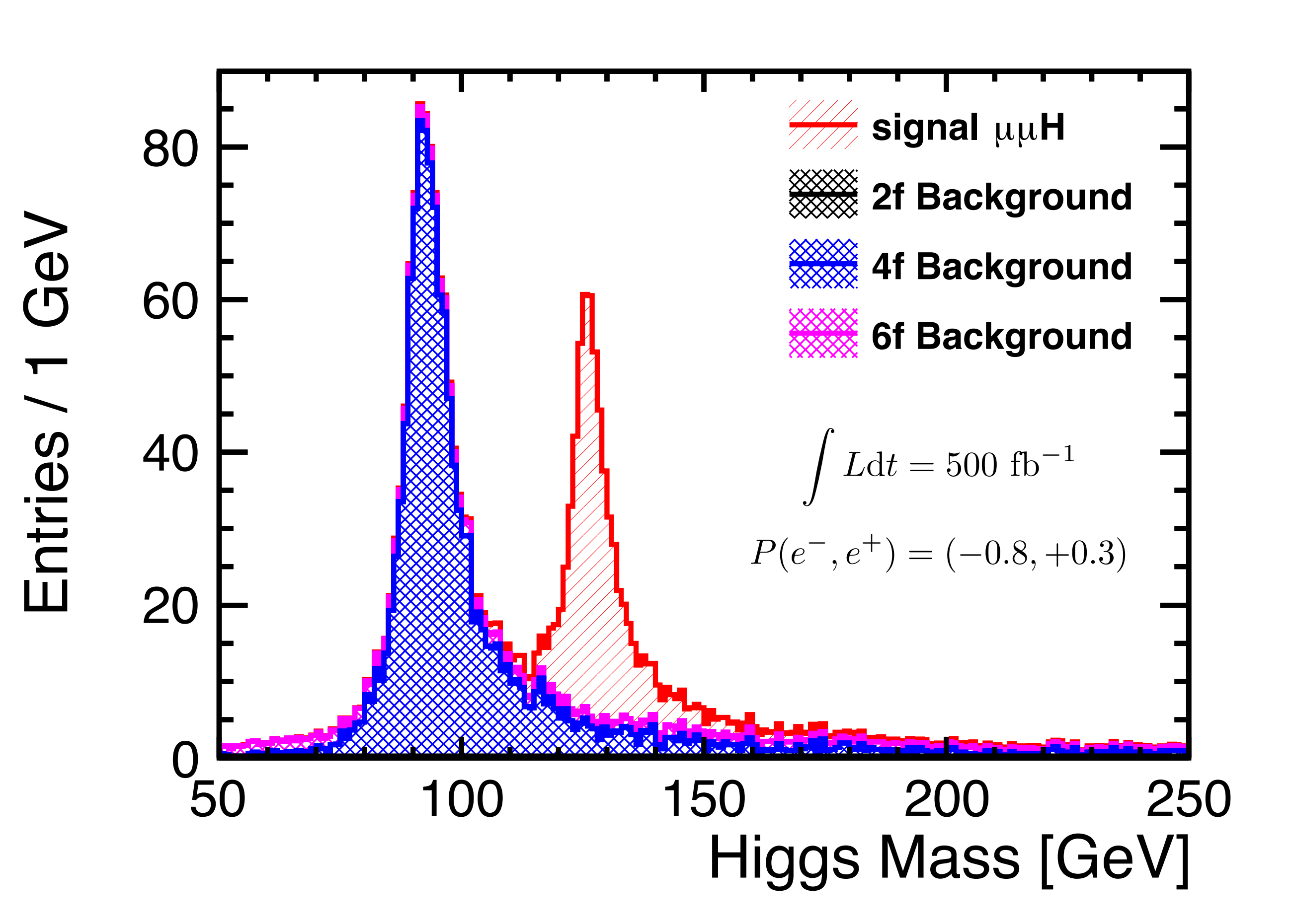
performance of new method (compared with others)

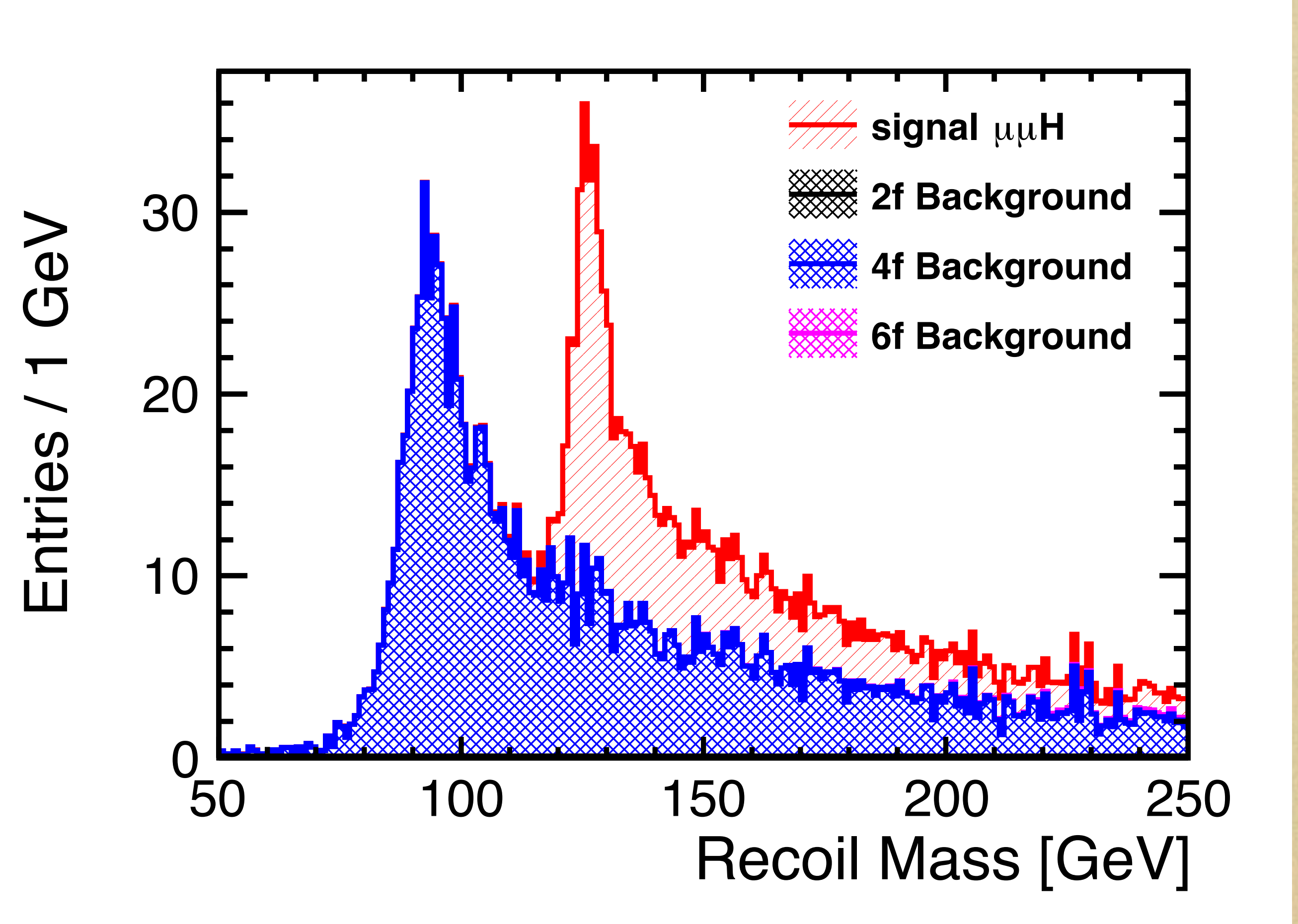


ILD full simulation

results for full simulation — including full SM background

$\sqrt{s} = 500$ GeV $\qquad e^+e^- \to \mu\mu H, H \to b\bar{b}$





new method

$\Delta m_H \sim 70$ MeV

recoil method

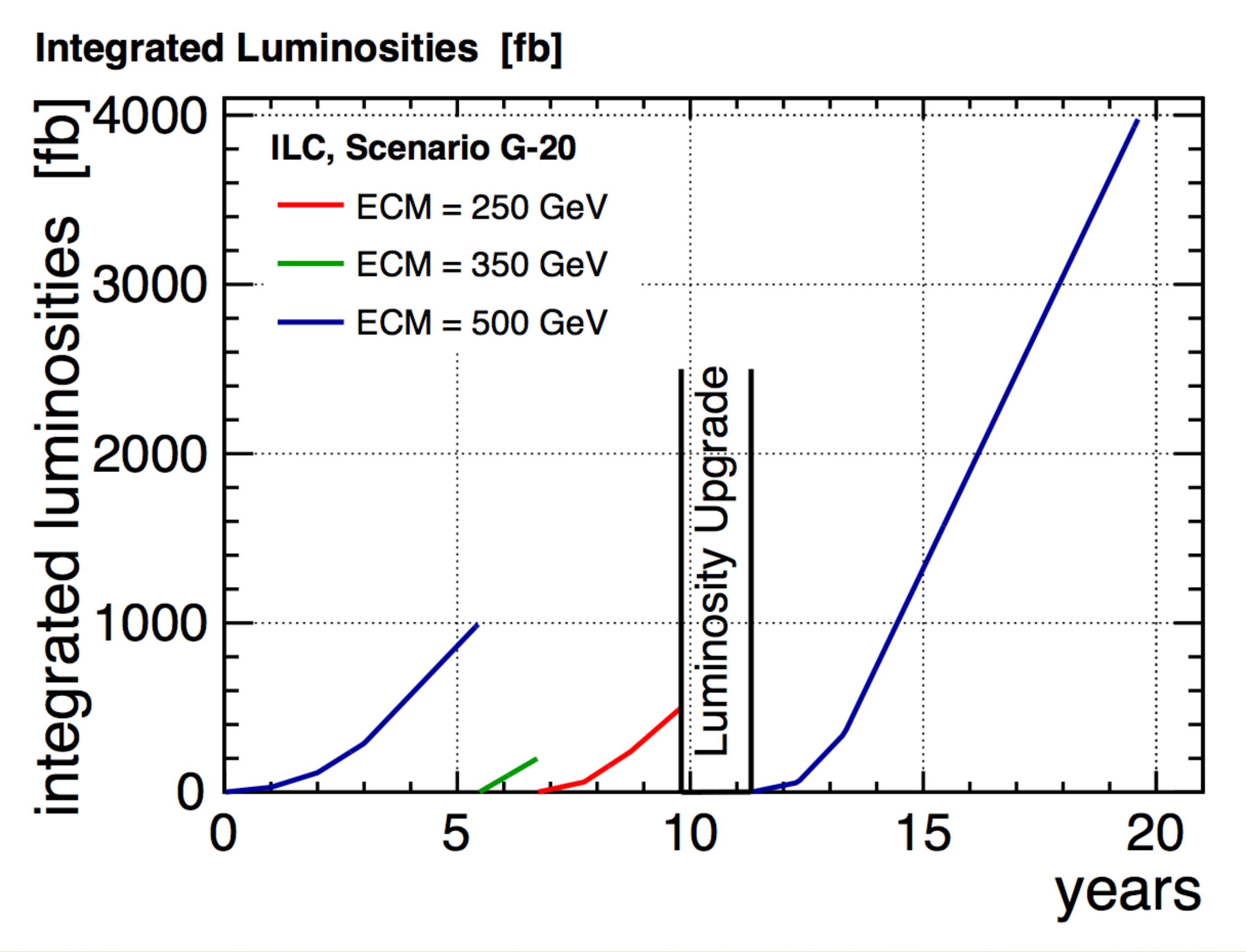
$\Delta m_H \sim 218$ MeV

(leptonic channels & only 500 GeV data in H20)

back to LCWS16

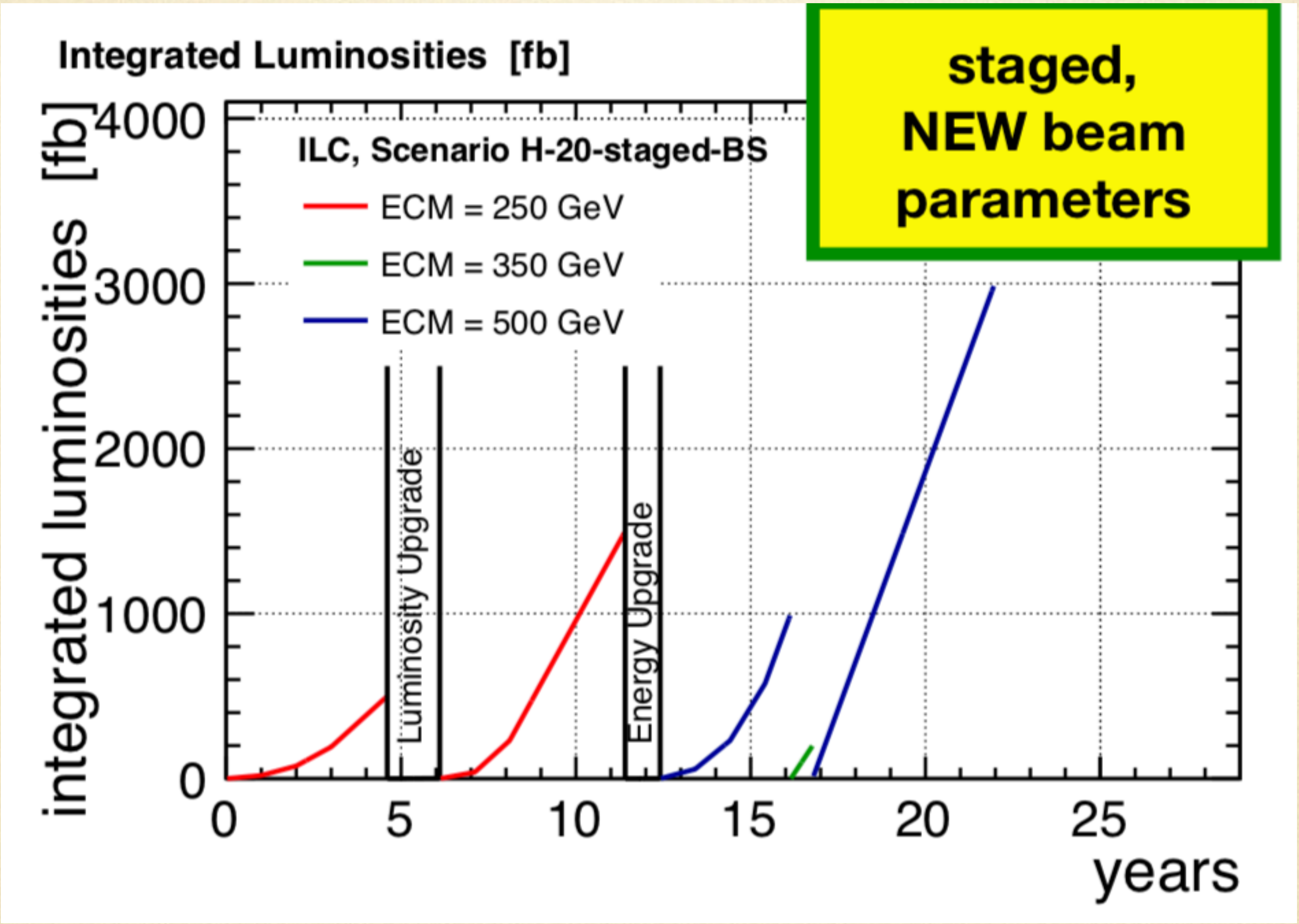
- new method:very promising m_H measurement at 500 GeV
- was about to include Z->qq channel
- maybe we can forgot about 250 GeV running

e.g. some variation of G-20



another news from LCWS16

- we would have to run ILC at √s = 250 GeV first anyway…



J.List @ LCWS17

in that case, isn't recoil method good enough?

in fact, I did forget about my study of new method

higher luminosity at 250 GeV

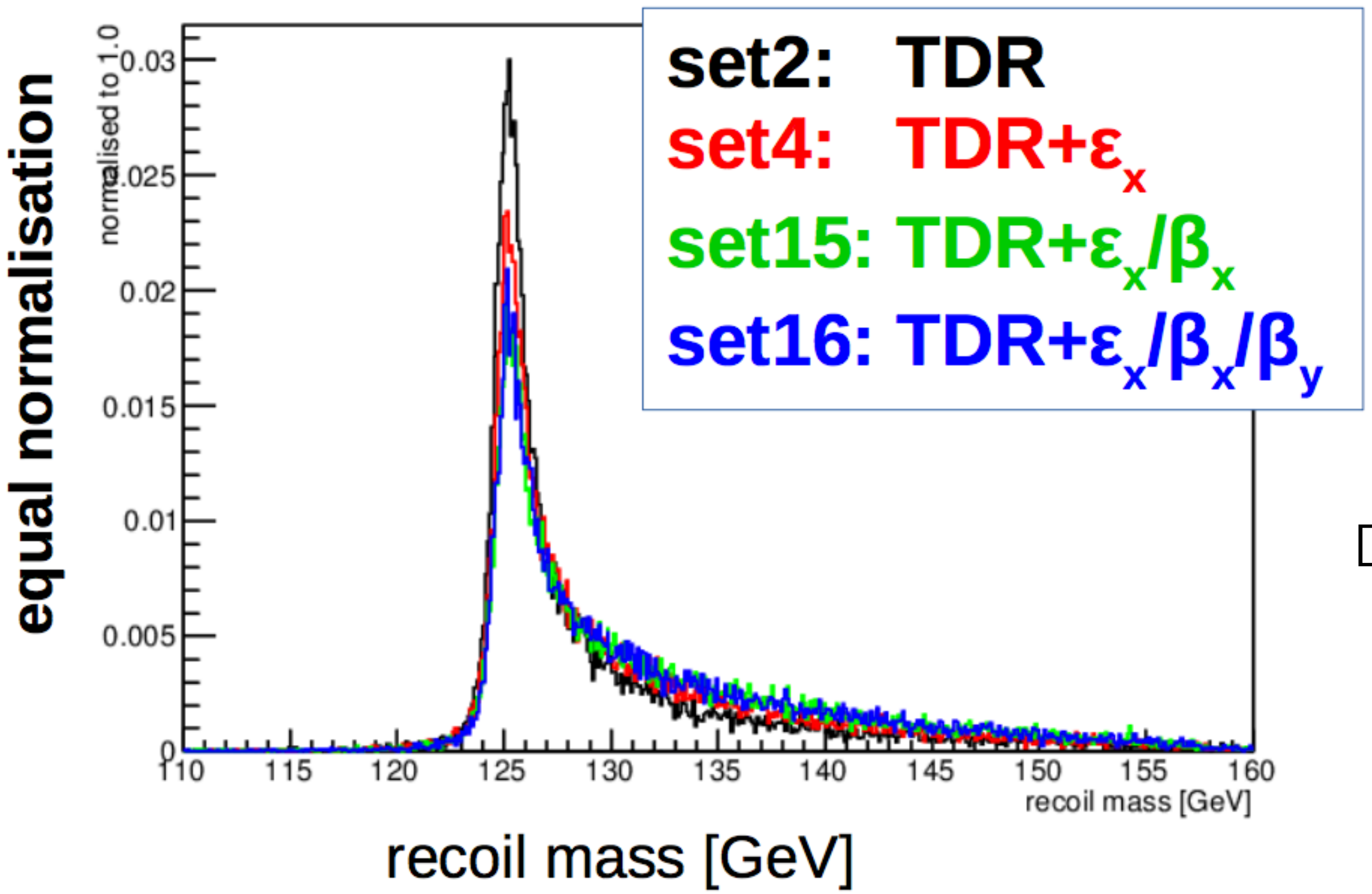
K.Yokoya @ AWLC 2017

$$\mathcal{L} \approx C \frac{P_B}{E} \sqrt{\frac{\delta_{BS}}{\epsilon_{y,n}}} \min\left(1, \sqrt{\sigma_z/\beta_y}\right)$$

$$\delta_{BS} = \left\langle -\frac{\Delta E}{E} \right\rangle \approx 0.836 \frac{N^2 r_e^3 \gamma}{\sigma_z \sigma_x^2}, \qquad \sigma_x = \sqrt{\frac{\epsilon_{x,n} \beta_x^*}{\gamma}}$$

- luminosity can be increased by higher δ_{BS} (beamstrahlung energy loss, which is 1% at TDR)
- higher δ_{BS} can be achieved by smaller $\varepsilon_{x,n}$ or β_x^*
- set of new beam parameters with smaller $\varepsilon_{x,n}$ is being tried —> x1.6 higher luminosity is promising
- if works —> can further try smaller β_x^*

impact of higher beamstrahlung



D.Jeans @ AWLC 2017

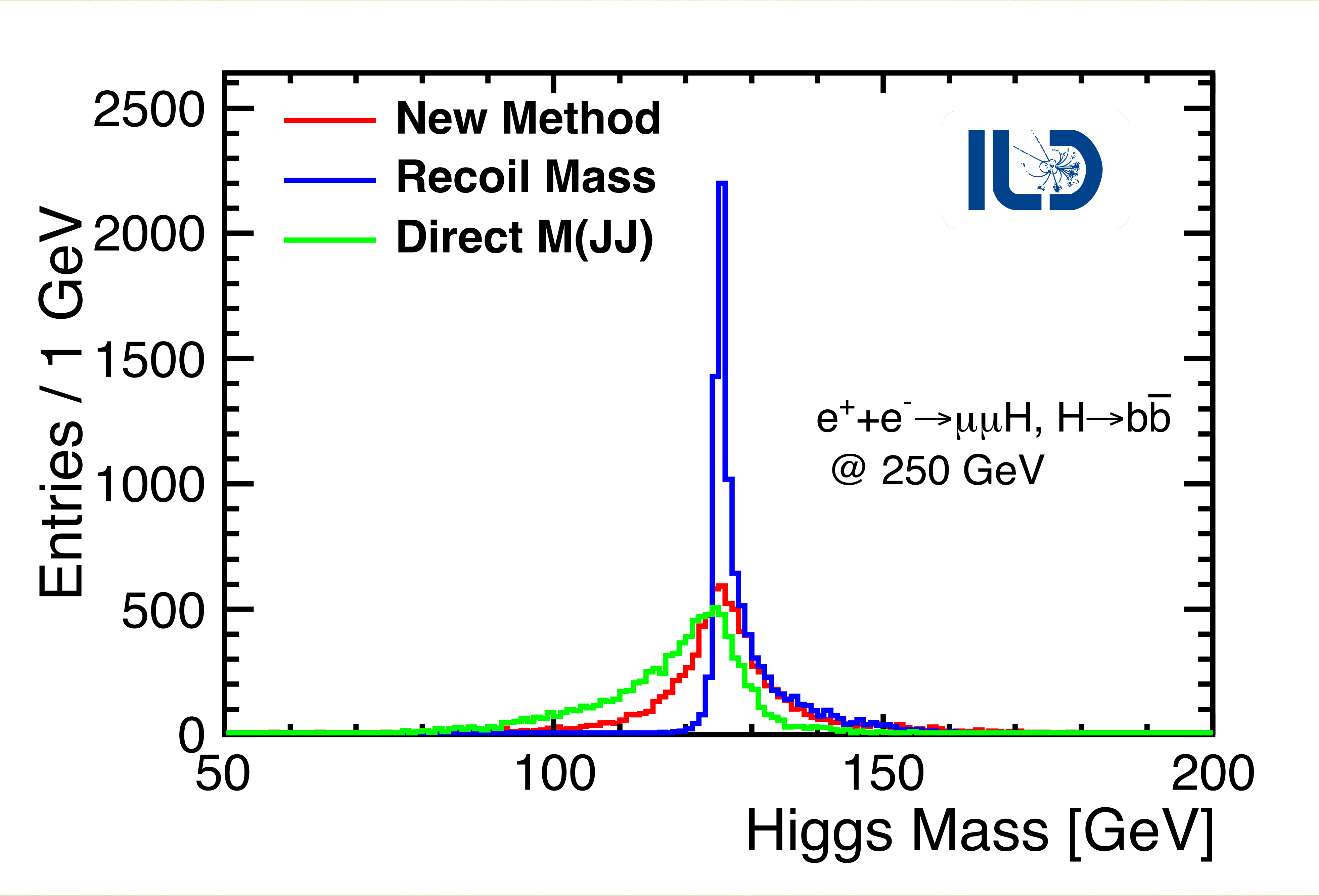
- set4 : Δm_H larger by ~25%
- set15/16: Δm_H larger by ~50%

—> ILC250: Δm_H ~ 20 MeV for new beam parameters

new motivation of the new method

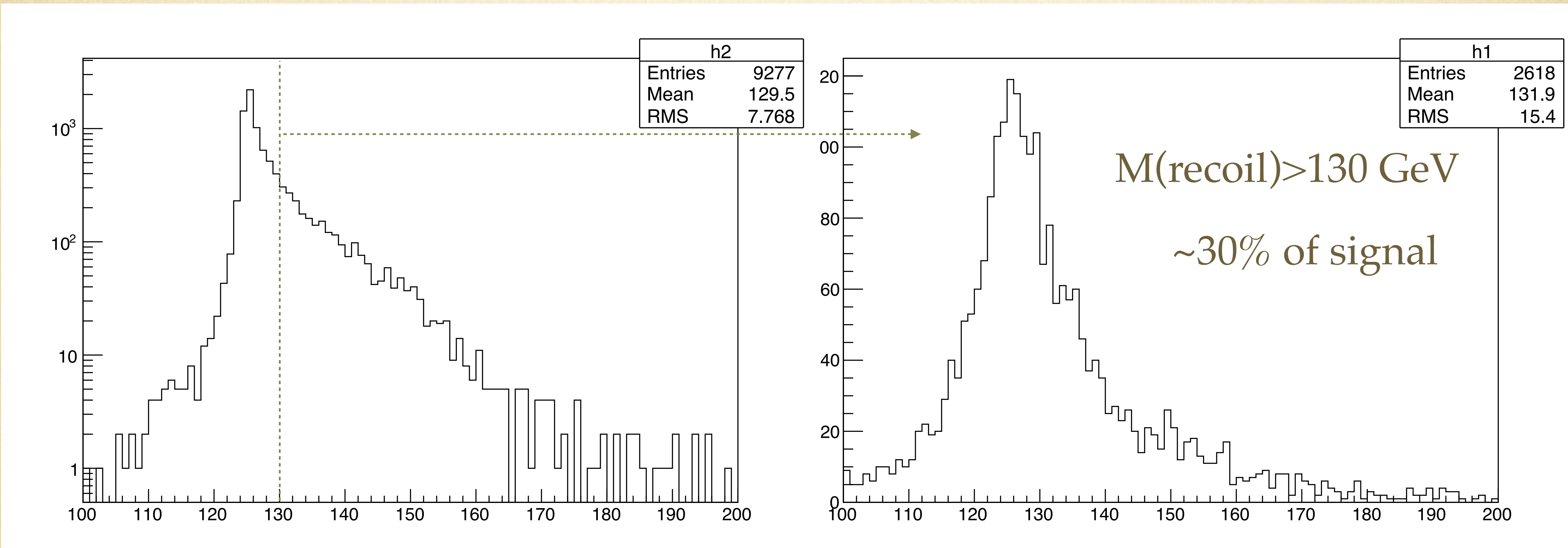
- insensitive to the beam energy —> complementary in terms of systematic errors ☑ CEPC
- insensitive to beamstrahlung/ISR —> improve statistical error by applying the new method to those events with large beamstrahlung/ISR, e.g. a combined approach ☑ CEPC
- might be useful, in supporting new beam parameters with even higher luminosity at 250 GeV
- improve separation between signal background ☑ CEPC

performance of new method: single approach at 250 GeV



a possible combined approach

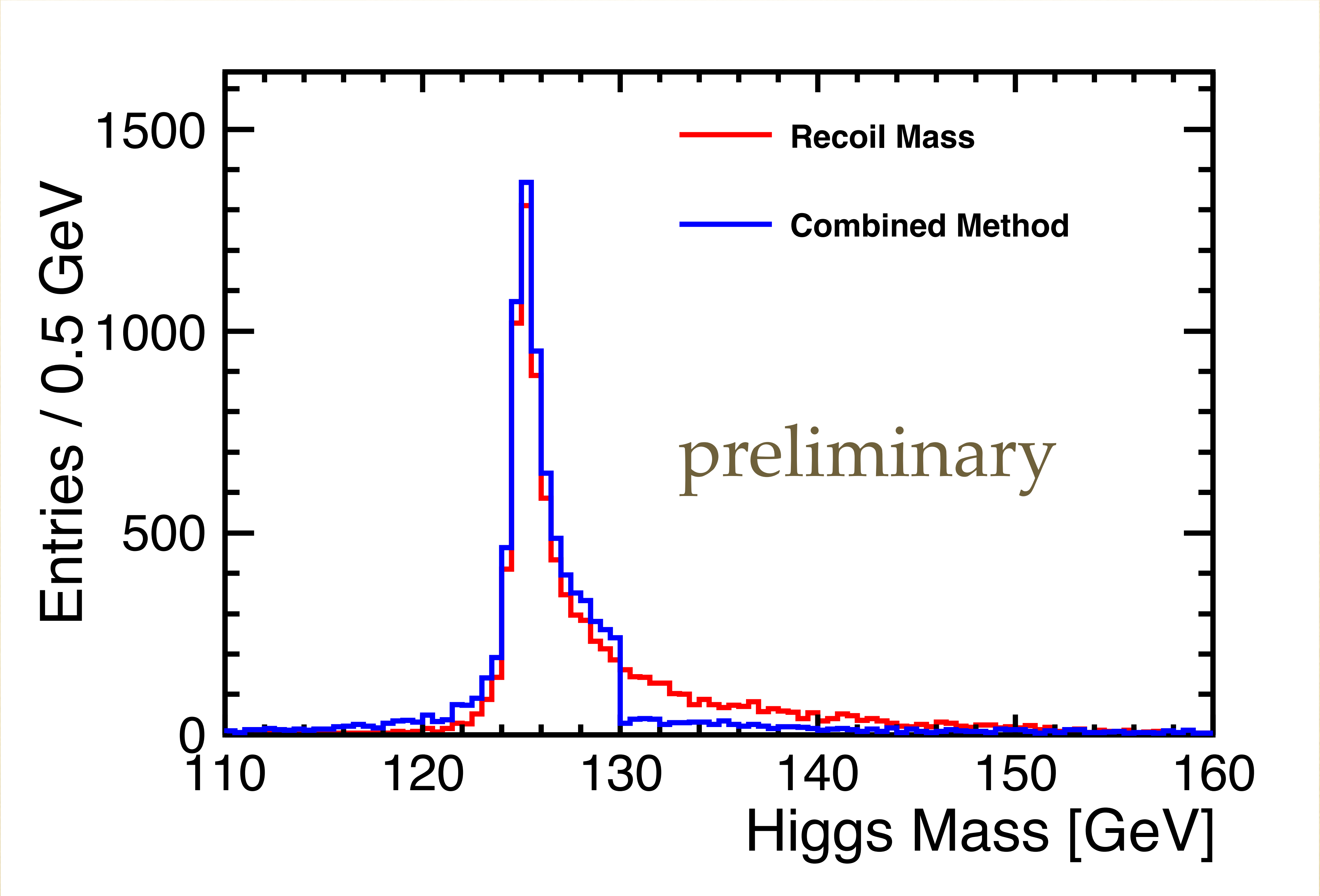
$\sqrt{s} = 250$ GeV $\quad e^+e^- \to \mu\mu H, H \to b\bar{b}$



M(recoil) M(new)

a possible combined approach

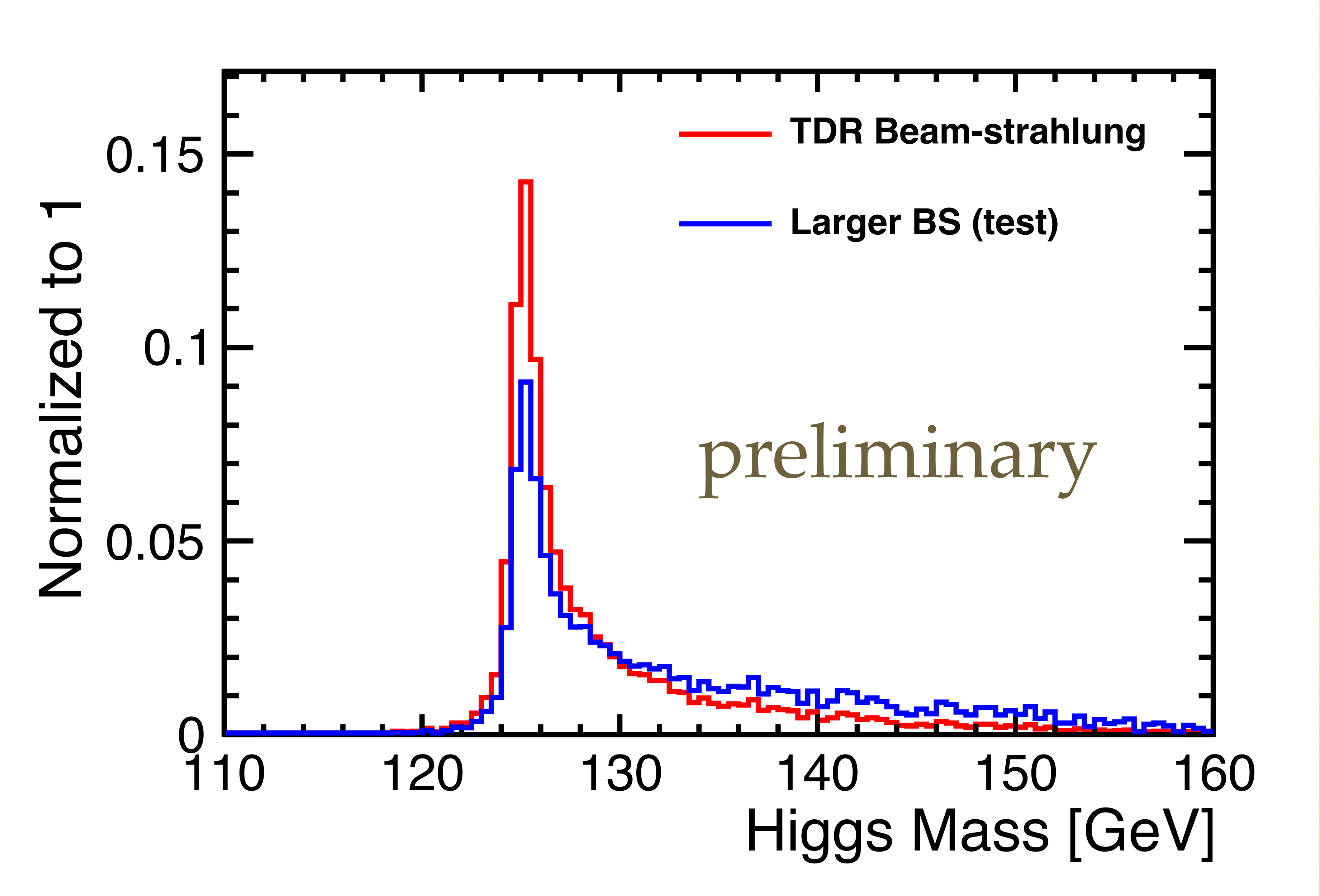
$\sqrt{s} = 250 \text{ GeV}$ $e^+e^- \to \mu\mu H, H \to b\bar{b}$



~10% increase of events in peak area, for free

test for higher beam-strahlung

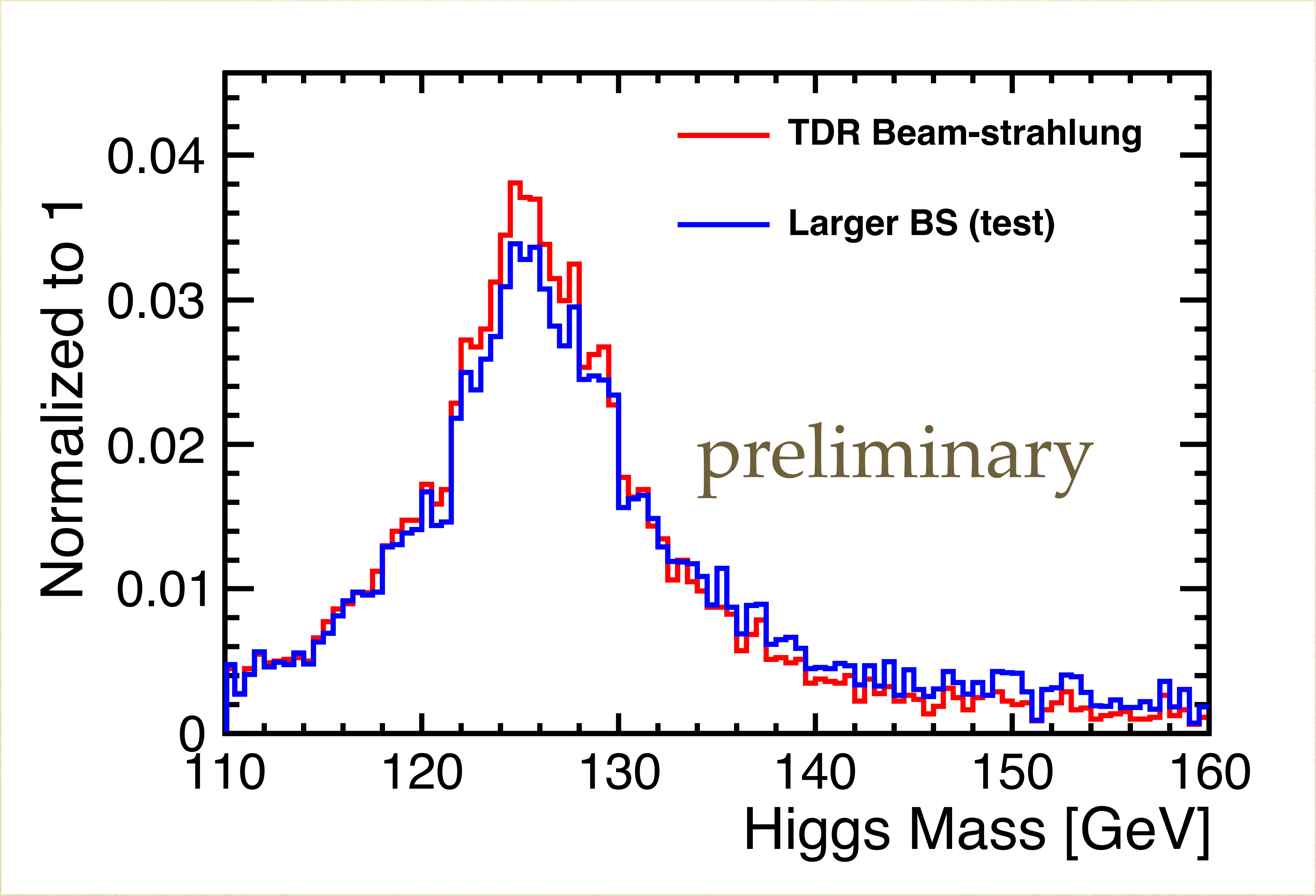
$\sqrt{s} = 250 \text{ GeV}$ $\qquad e^+e^- \to \mu\mu H, H \to b\bar{b}$



recoil mass method

test for higher beam-strahlung

$\sqrt{s} = 250 \text{ GeV}$ $\quad e^+e^- \to \mu\mu H, H \to b\bar{b}$



new method

summary & next step

- m_H measurement is important: Δm_H=14 MeV -> 0.1% systematic error for HZZ, HWW couplings
- a new method for m_H measurement is proposed
  - insensitive to beam energy, beamstrahlung/ISR
  - a factor of 3 better at √s >= 500 GeV than recoil method
  - a combined approach is promising at √s = 250 GeV
- next step: include Z—>qq; systematic errors, e.g. jet direction and jet mass; apply to new beam parameters

backup

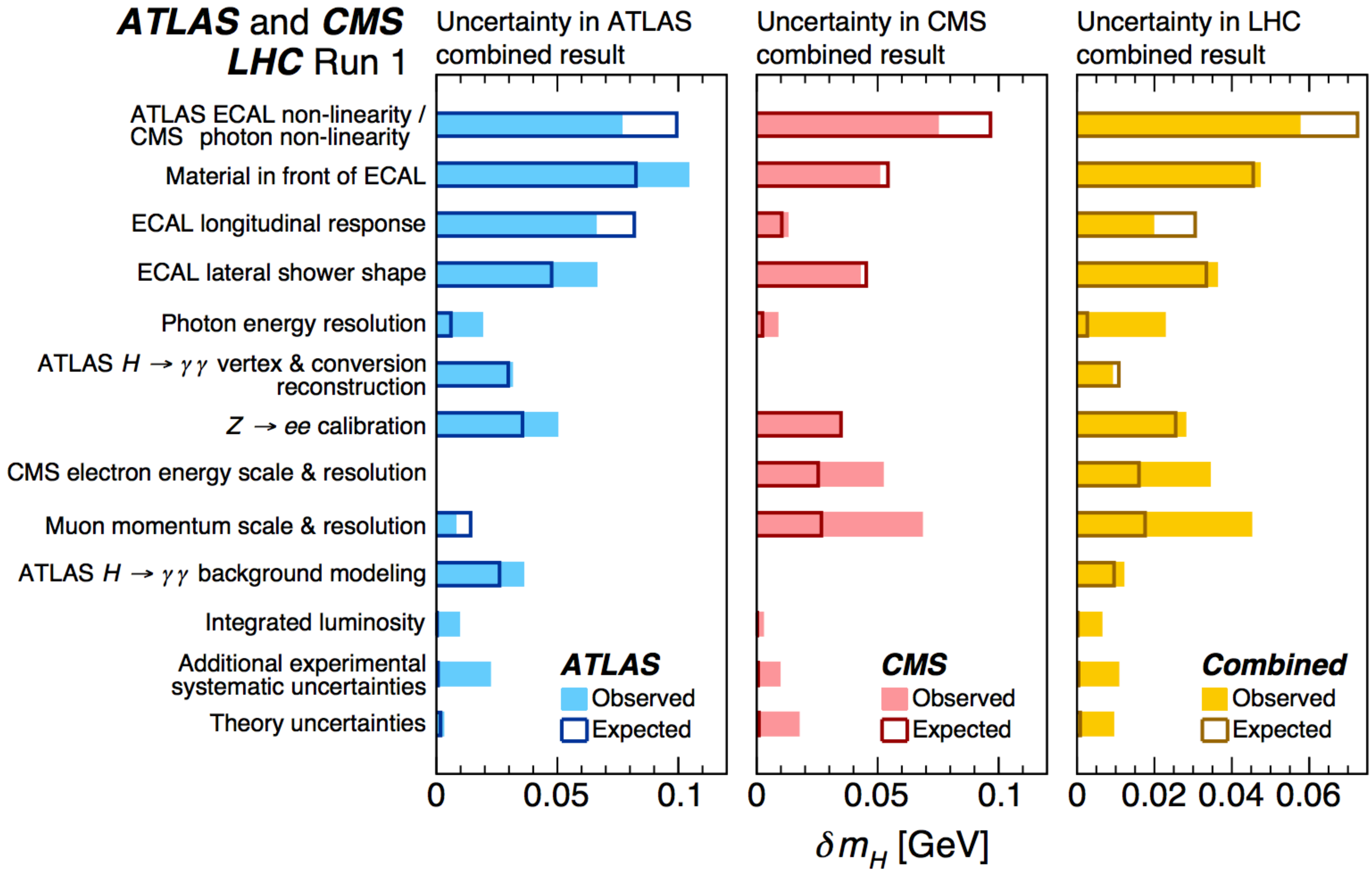
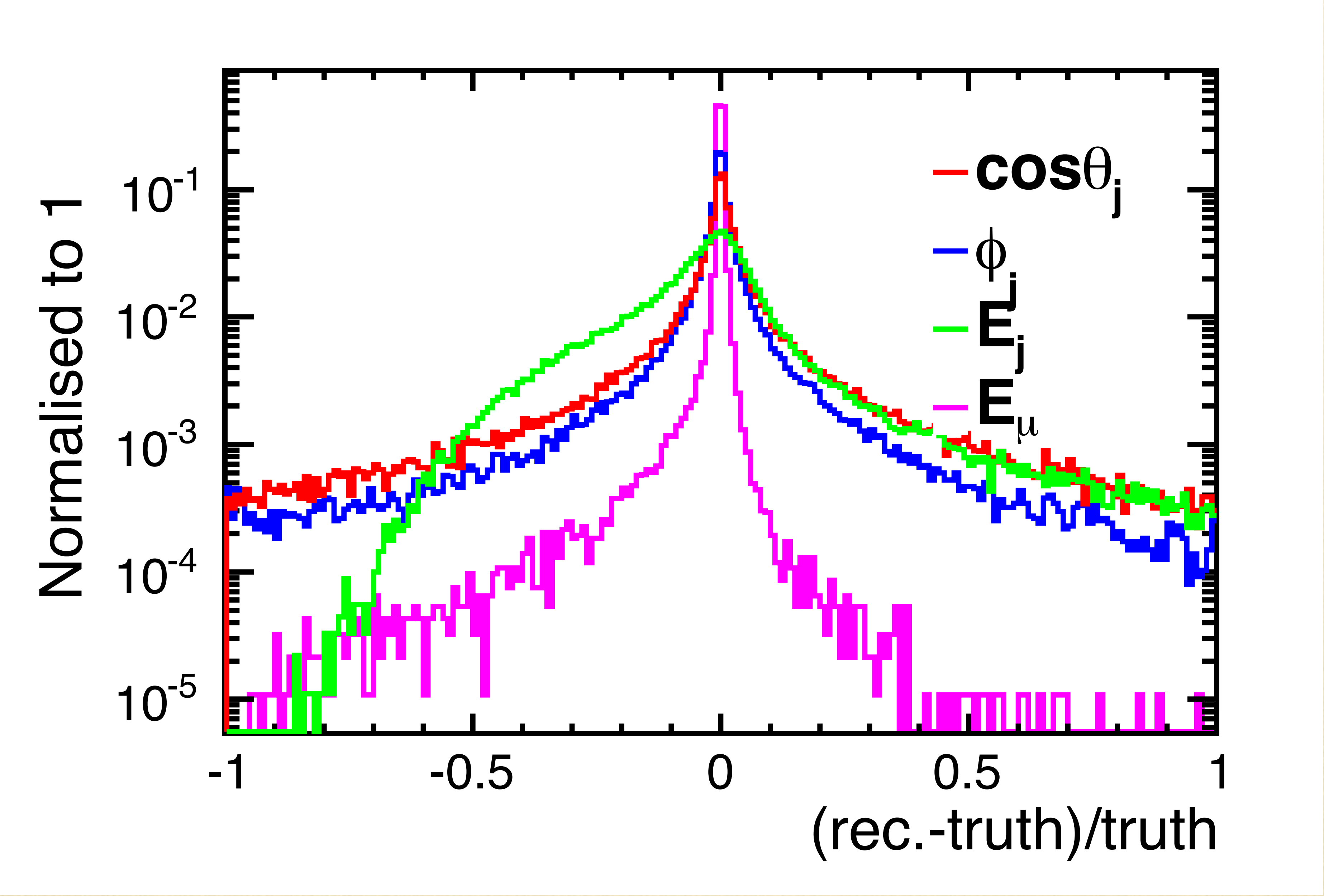


Figure 3: The impacts δm_H (see text) of the nuisance parameter groups in Table 1 on the ATLAS (left), CMS (center), and combined (right) mass measurement uncertainty. The observed (expected) results are shown by the solid (empty) bars.

$\sqrt{s} = 500\ \mathrm{GeV} \qquad e^+e^- \to \mu\mu H, H \to b\bar{b}$



$\sqrt{s} = 250\ \text{GeV} \qquad e^+e^- \rightarrow \mu\mu H, H \rightarrow b\bar{b}$