a new method for Higgs mass measurement

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introduction: issues in m_H measurement

- one source of systematic errors (parametric) for precision coupling measurements
  - $\delta\Gamma_W=2\delta_W=14\delta m_H$; $\delta\Gamma_Z=2\delta_Z=15\delta m_H$ (arXiv:1404.0319)
- leptonic recoil: Δm_H=527 MeV at Ecm=500 GeV with 500 fb^{-1} (arXiv:1604.07524)
  - systematic error to partial width: $\delta\Gamma_{W/Z}$ ~ 6%
  - much larger than statistical error ~ 3%
- one of the main reasons that running at 250 GeV is needed
- another ongoing method: direction reconstruction using H —>bb, apply full kinematic fitting (A.Ebrahimi at LCWS15)

idea of a new method for m_H

strategy

- e+e- —> ZH, Z—>ff, H—>bb/cc/gg
- use only directions of two jets from Higgs, leaving two jet energies as free parameters
- use only conservations of Px and Py —> resolve two parameters

advantage

- not sensitive to beamstrahlung/ISR, which are the main issue in leptonic recoil method at high Ecm
- resolution of jet direction better than jet energy
- not (less) effected by asymmetric resolution of b-jet energy

analytic results

In process $e^+e^- \to ZH,\ Z \to f\bar{f},\ H \to b\bar{b}/c\bar{c}/gg$, using conservation of $\sum_i (p_x, p_y)_i = 0$

$$p_1 \sin\theta_1 \cos\phi_1 + p_2 \sin\theta_2 \cos\phi_2 = p_x \quad (1)$$

$$p_1 \sin\theta_1 \sin\phi_1 + p_2 \sin\theta_2 \sin\phi_2 = p_y \quad (2)$$

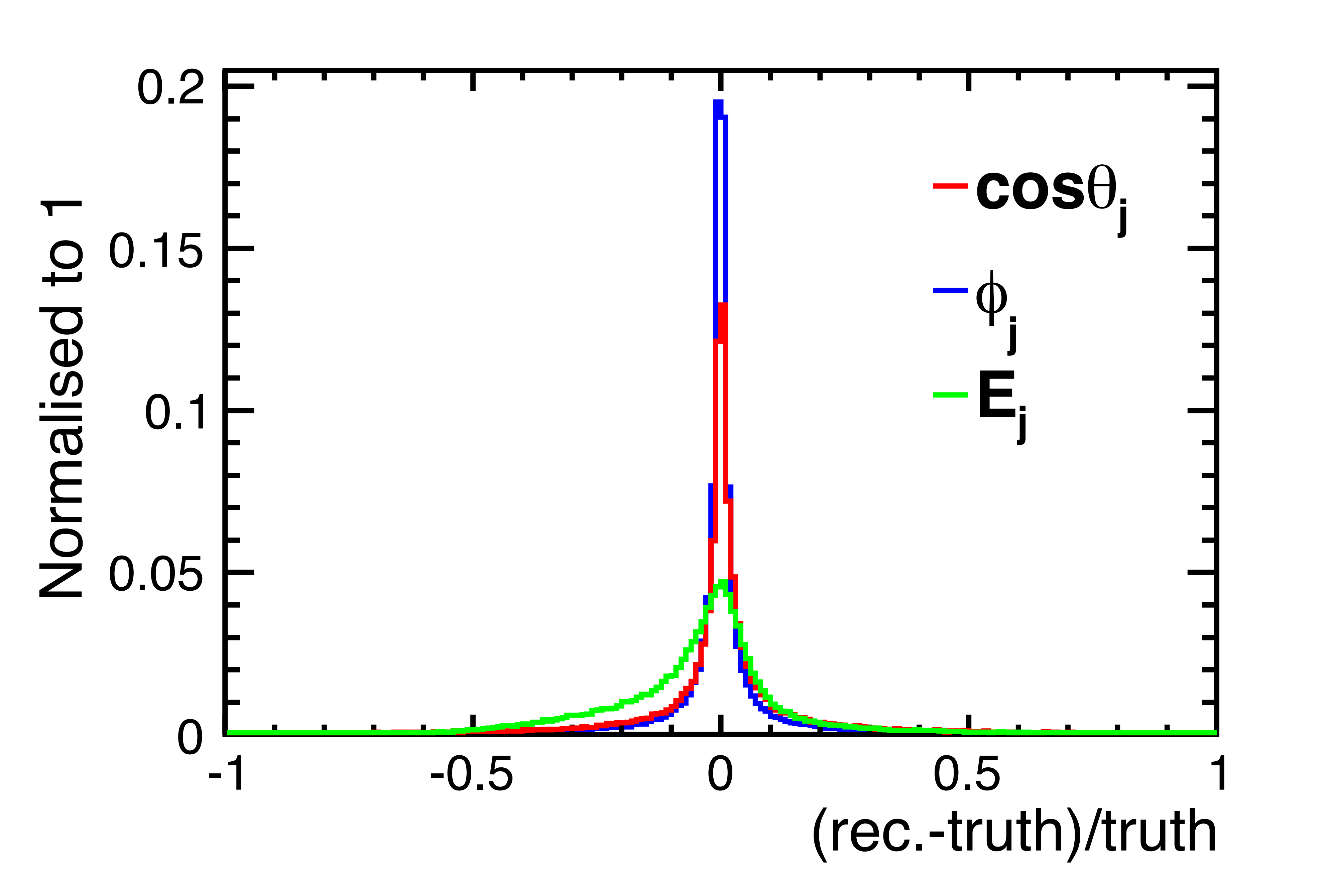
where index 1 and 2 are for two jets from H decay, p_x and p_y are transverse recoil vector against $Z \to f\bar{f}$. Values obtained from direct measurement are used for all variables except p_1 and p_2 which can be obtained by solving the two equations.

$$\begin{pmatrix} p_1 \\ p_2 \end{pmatrix} = \frac{1}{\sin^2\phi} \begin{pmatrix} \frac{1}{\sin\theta_1}[(\cos\phi_1 - \cos\phi\cos\phi_2)p_x + (\sin\phi_1 - \cos\phi\sin\phi_2)p_y] \\ \frac{1}{\sin\theta_2}[(\cos\phi_2 - \cos\phi\cos\phi_1)p_x + (\sin\phi_2 - \cos\phi\sin\phi_1)p_y] \end{pmatrix} \quad (7)$$

where $\phi = \phi_1 - \phi_2$,

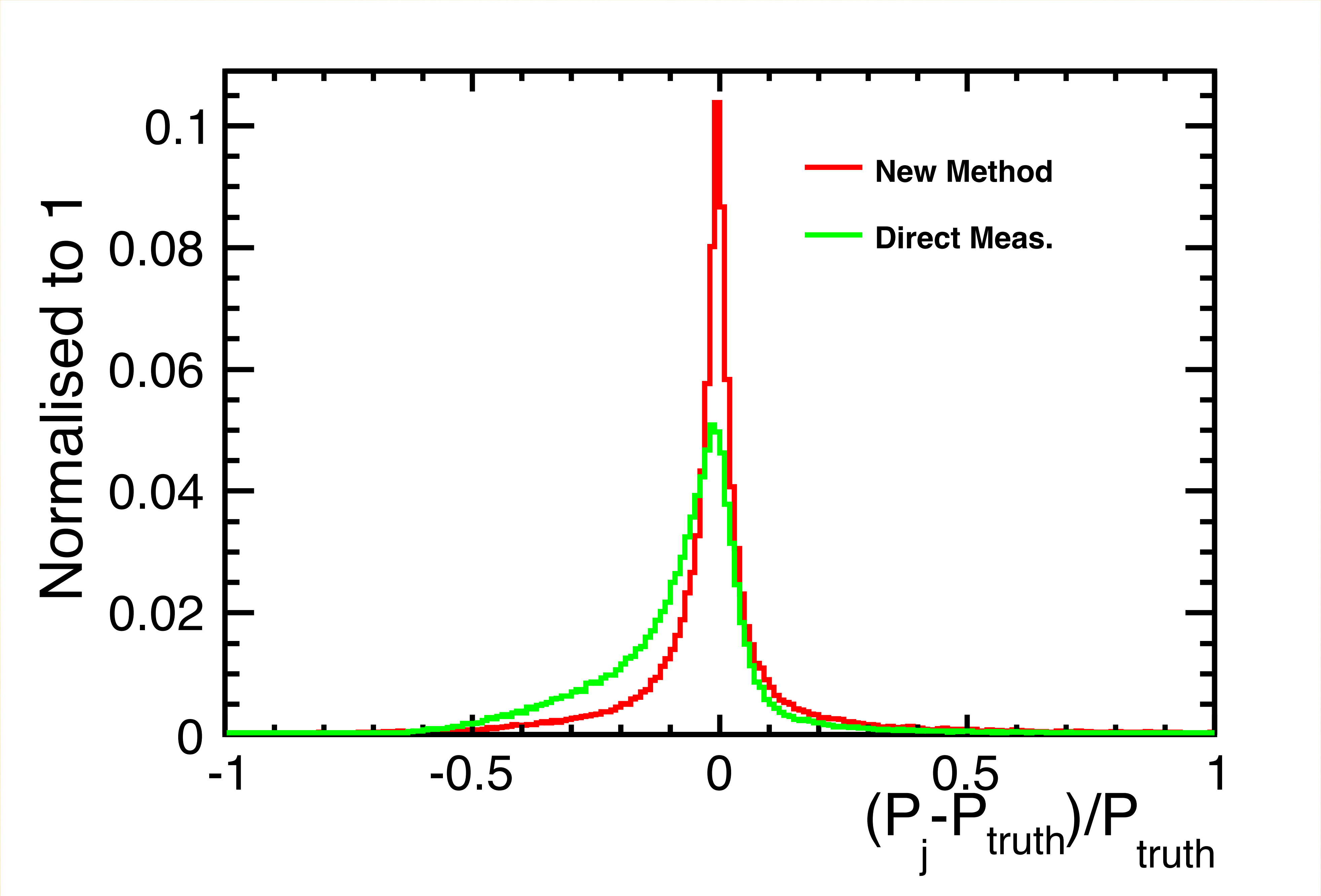
results for full simulation — resolutions

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

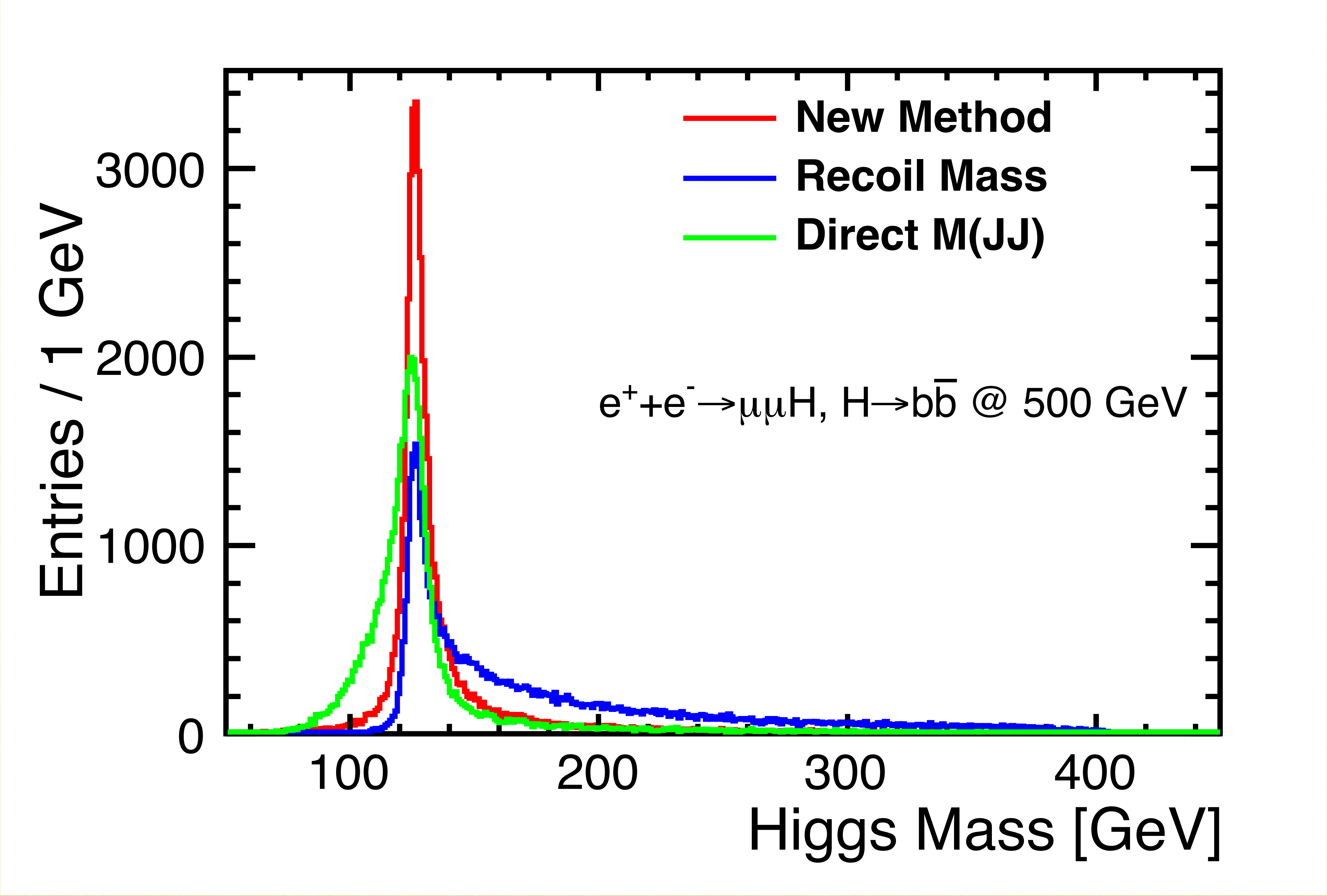


comparison between resolved P and directly measured P

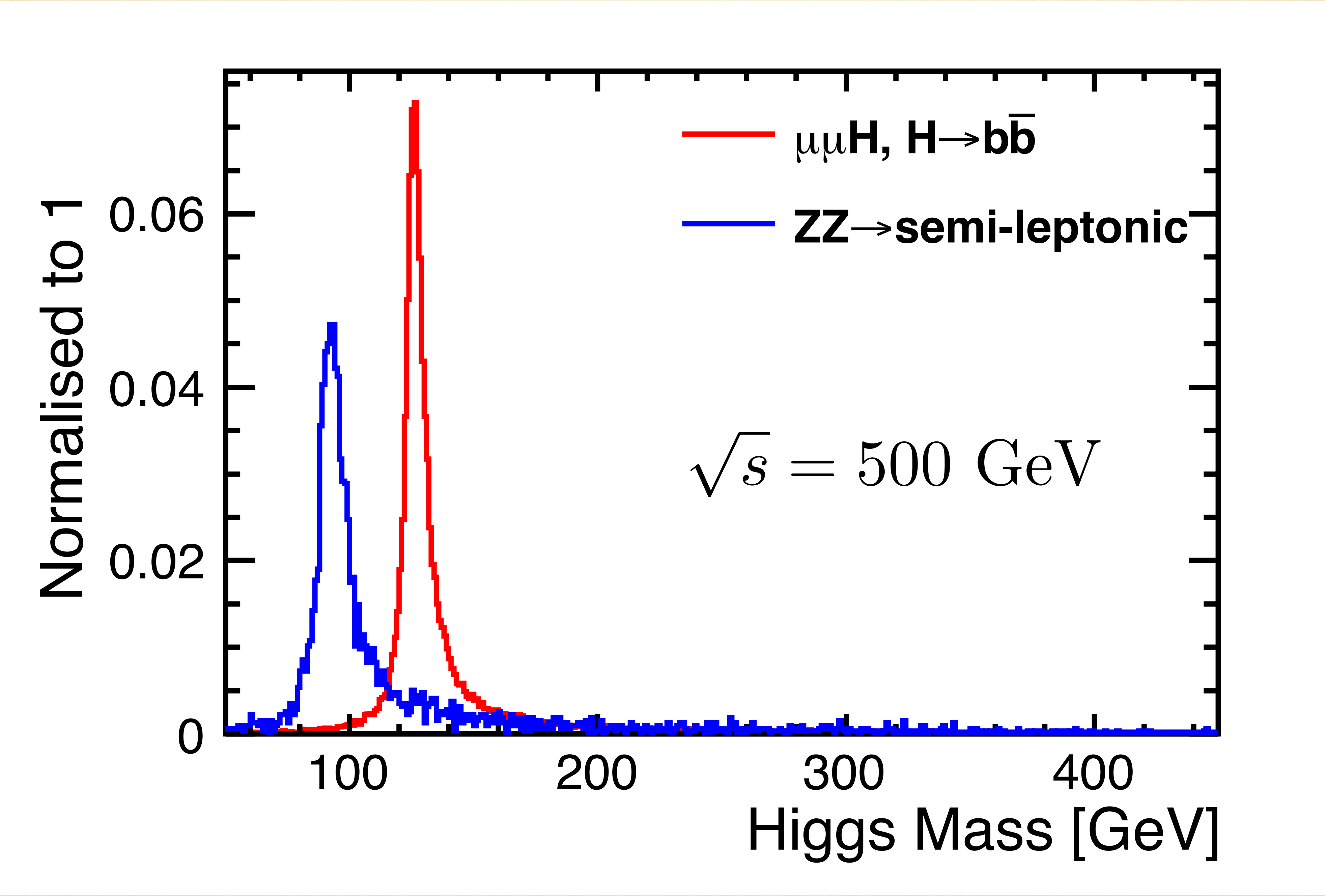
$\sqrt{s} = 500\ \mathrm{GeV} \qquad e^+e^- \to \mu\mu H, H \to b\bar{b}$



comparison of different methods for Higgs mass

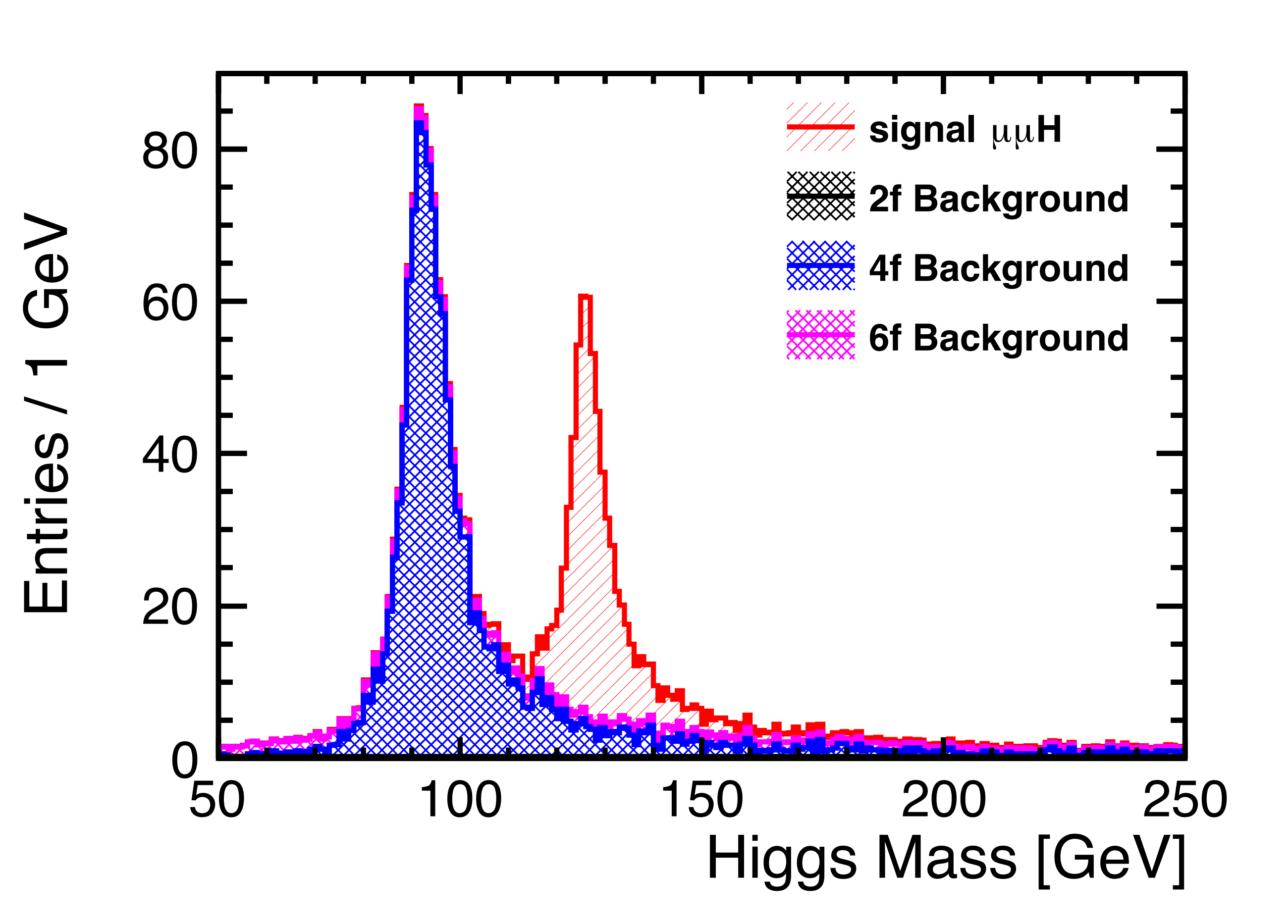


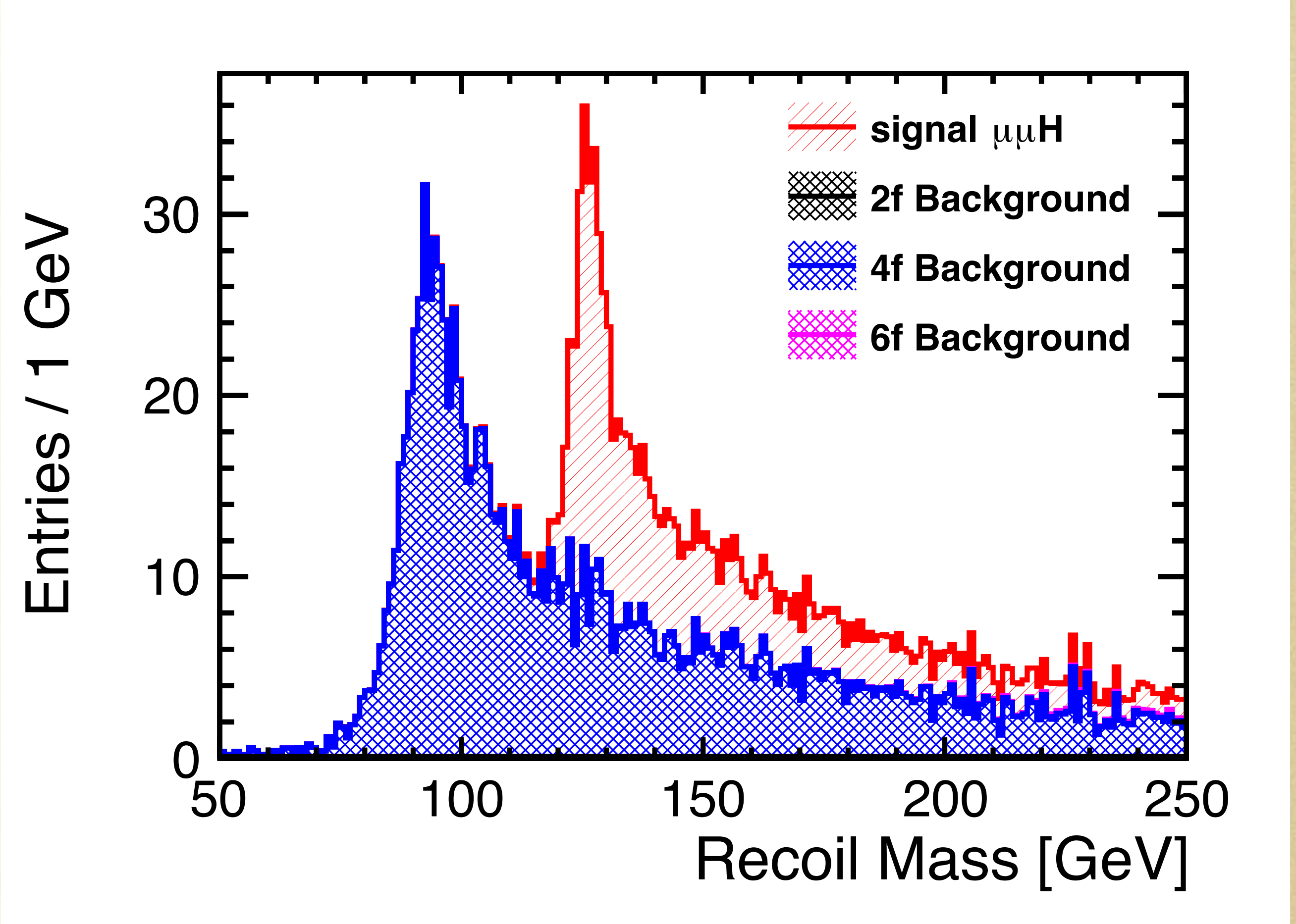
effect on background: new method doesn't depend on mass



results for full simulation — including full SM background

$\sqrt{s} = 500$ GeV $\quad e^+e^- \to \mu\mu H, H \to b\bar{b} \quad \int L dt = 500$ fb^{-1} $\quad P(e^-, e^+) = (-0.8, +0.3)$



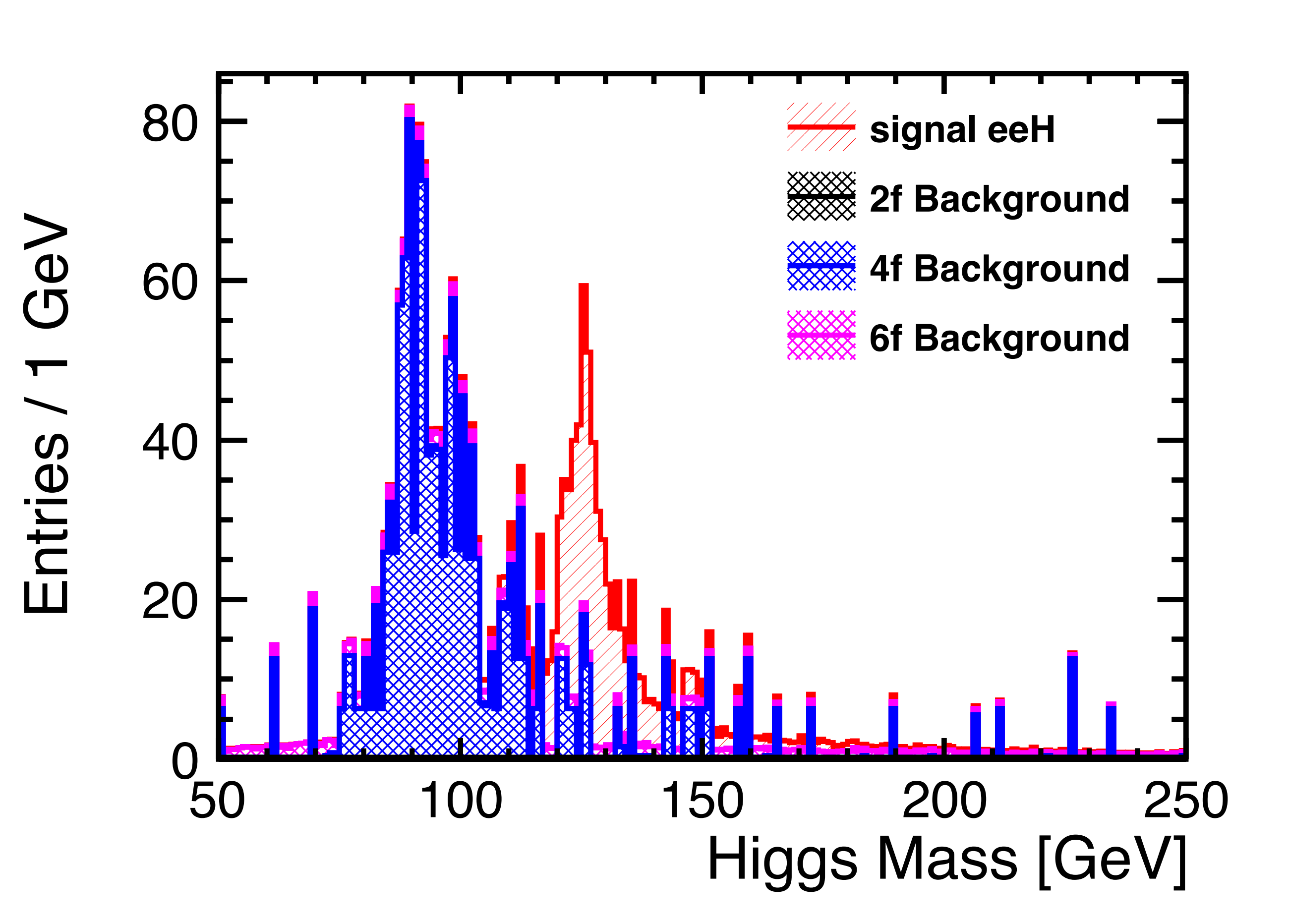


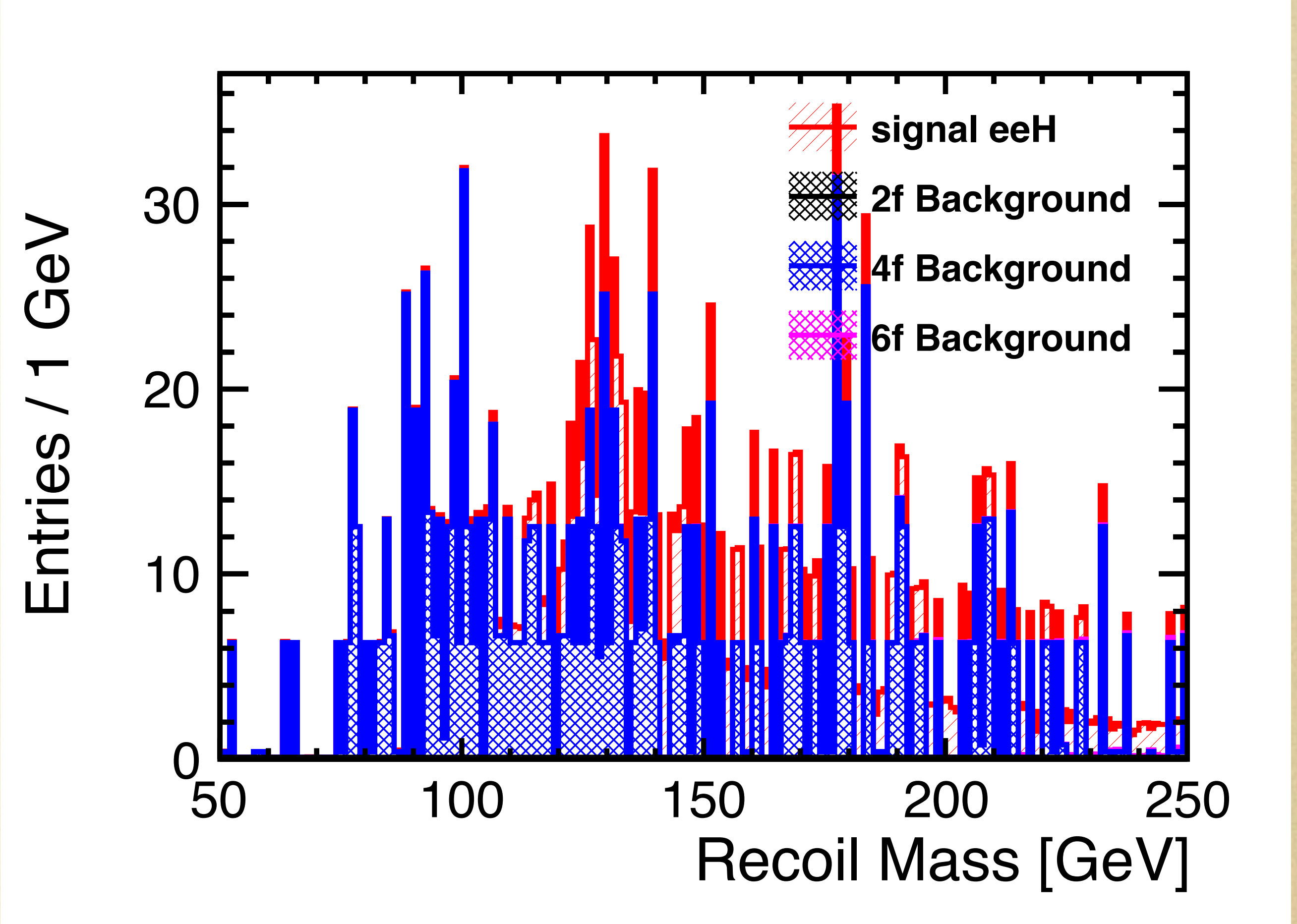
$\Delta m_H \sim 230$ MeV

(previous leptonic recoil: $\Delta m_H \sim 592$ MeV)

results for full simulation — including full SM background

$\sqrt{s} = 500$ GeV $\quad e^+e^- \to eeH, H \to b\bar{b} \quad \int L\mathrm{d}t = 500\ \mathrm{fb}^{-1} \quad P(e^-, e^+) = (-0.8, +0.3)$





$\Delta m_H \sim 325$ MeV

(previous leptonic recoil: $\Delta m_H \sim 1160$ MeV)

summary & next step

- a new method for mH measurement is proposed for higher Ecm
- take advantage of good resolution on jet direction, and not be effected by beamstrahlung/ISR (good benchmark for detector optimisation)
- preliminary results available for Z—>μμ/ee, combined ΔmH ~ 188 MeV with 500 fb-1 at 500 GeV, a factor ~ 3 better than leptonic recoil
- systematic to $\delta\Gamma_W$ ~ 2% already achievable (statistical error 3%)
- next step: include Z—>qq (light quark pairs); systematic errors due to hadronisation for jet direction and jet mass
- if Δm_H can be further reduced by a factor of 2, then coupling measurements at higher Ecm only will not be limited by Δm_H

backup

In process $e^+e^- \to ZH,\ Z \to f\bar{f},\ H \to b\bar{b}/c\bar{c}/gg$, using conservation of $\sum_i (p_x, p_y)_i = 0$

$$p_1 \sin\theta_1 \cos\phi_1 + p_2 \sin\theta_2 \cos\phi_2 = p_x \tag{1}$$

$$p_1 \sin\theta_1 \sin\phi_1 + p_2 \sin\theta_2 \sin\phi_2 = p_y \tag{2}$$

where index 1 and 2 are for two jets from H decay, p_x and p_y are transverse recoil vector against $Z \to f\bar{f}$. Values obtained from direct measurement are used for all variables except p_1 and p_2 which can be obtained by solving the two equations.

$$\begin{pmatrix} \cos\phi_1 & \cos\phi_2 \\ \sin\phi_1 & \sin\phi_2 \end{pmatrix} \begin{pmatrix} \sin\theta_1 & 0 \\ 0 & \sin\theta_2 \end{pmatrix} \begin{pmatrix} p_1 \\ p_2 \end{pmatrix} = \begin{pmatrix} p_x \\ p_y \end{pmatrix} \tag{3}$$

Define $A = \begin{pmatrix} \cos\phi_1 & \cos\phi_2 \\ \sin\phi_1 & \sin\phi_2 \end{pmatrix}$, $C = \begin{pmatrix} \sin\theta_1 & 0 \\ 0 & \sin\theta_2 \end{pmatrix}$. C^{-1} is easy, to get A^{-1},

$$A^T A = \begin{pmatrix} 1 & \cos\phi \\ \cos\phi & 1 \end{pmatrix} \equiv B, \tag{4}$$

where $\phi = \phi_1 - \phi_2$, and B^{-1} can be easily calculated as

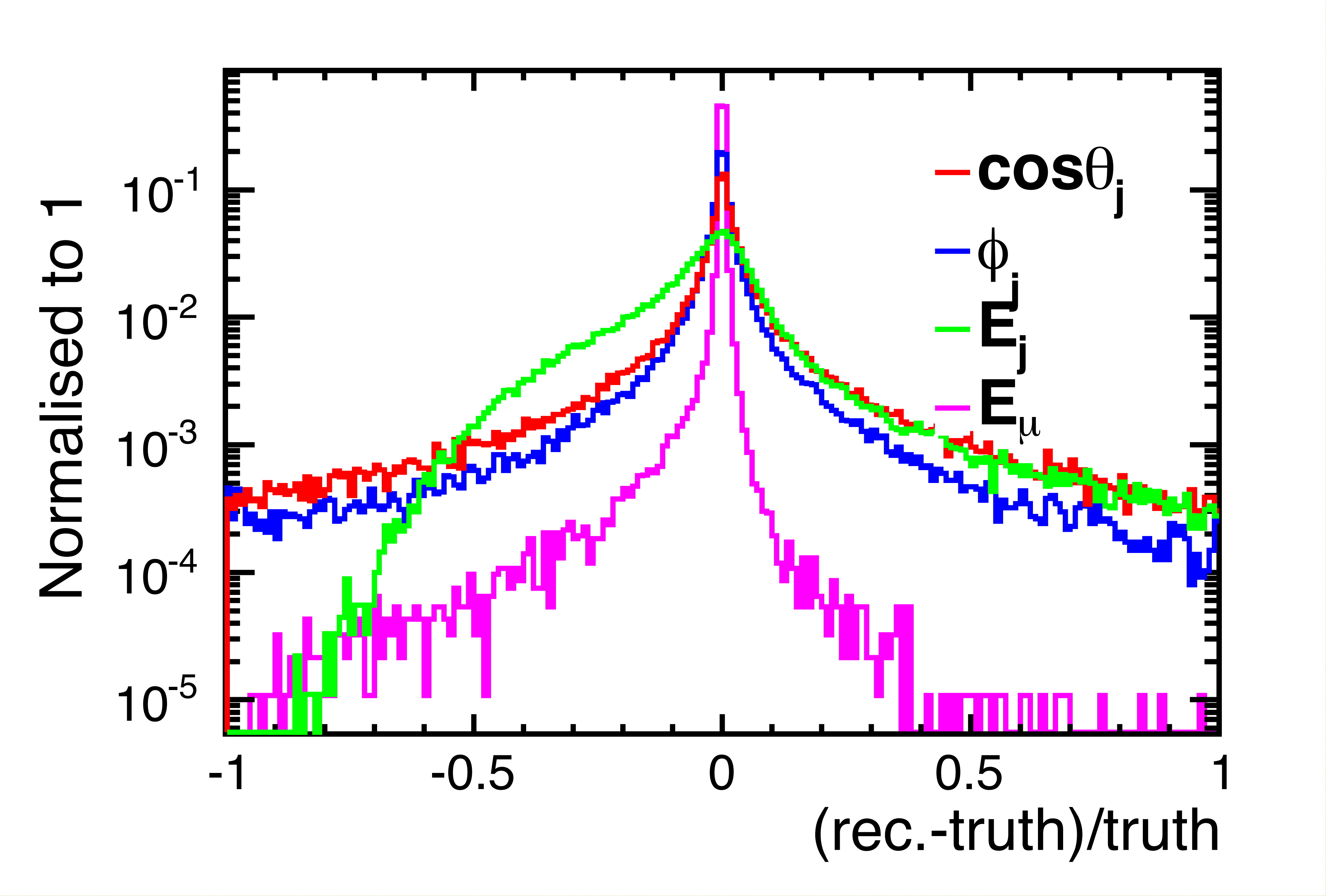
$$B^{-1} = \frac{1}{\sin^2\phi} \begin{pmatrix} 1 & -\cos\phi \\ -\cos\phi & 1 \end{pmatrix}. \tag{5}$$

Then A^{-1} can be calculated as

$$\begin{aligned} A^{-1} = B^{-1}A^T &= \frac{1}{\sin^2\phi} \begin{pmatrix} 1 & -\cos\phi \\ -\cos\phi & 1 \end{pmatrix} \begin{pmatrix} \cos\phi_1 & \sin\phi_1 \\ \cos\phi_2 & \sin\phi_2 \end{pmatrix} \\ &= \frac{1}{\sin^2\phi} \begin{pmatrix} \cos\phi_1 - \cos\phi\cos\phi_2 & \sin\phi_1 - \cos\phi\sin\phi_2 \\ -\cos\phi\cos\phi_1 + \cos\phi_2 & -\cos\phi\sin\phi_1 + \sin\phi_2 \end{pmatrix}. \end{aligned} \tag{6}$$

Then p_1 and p_2 are resolved as

$$\begin{pmatrix} p_1 \\ p_2 \end{pmatrix} = \frac{1}{\sin^2\phi} \begin{pmatrix} \frac{1}{\sin\theta_1}[(\cos\phi_1 - \cos\phi\cos\phi_2)p_x + (\sin\phi_1 - \cos\phi\sin\phi_2)p_y] \\ \frac{1}{\sin\theta_2}[(\cos\phi_2 - \cos\phi\cos\phi_1)p_x + (\sin\phi_2 - \cos\phi\sin\phi_1)p_y] \end{pmatrix} \tag{7}$$



Normalised to 1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
-1
-0.5
0
0.5
1
(rec.-truth)/truth
$\cos\theta_j$
ϕ_j
E_j
E_μ