update of matrix element package and its application

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status of matrix element method

- package of MEM tools for full simulation studies available in latest ilcsoft-v01-17-06: **Physsim-v00-01**
- basic verification done; principle demonstrated in first application for e+e- —> eeH via ZZ-fusion
- **update: more e+e- processes implemented; added some new features**
- **look at more applications: leptonic recoil mass; Higgs self-coupling**
- **a new proposal to recover ISR in beam direction**

svn co https://svnsrv.desy.de/basic/physsim/Physsim/trunk

what Physsim package provides

- **hellib:** C++ version of HELAS (by K. Fujii), subroutines to calculate generic parts of one Feynman diagram, i.e. wave function, vertex, propagator, amplitude, etc.);
- **LCME:** implementation of matrix element calculation for specific e+e- processes, i.e. e+e- —> ZH, ννH, ZZ, etc.
- **example processors** to calculate ME in marlin framework

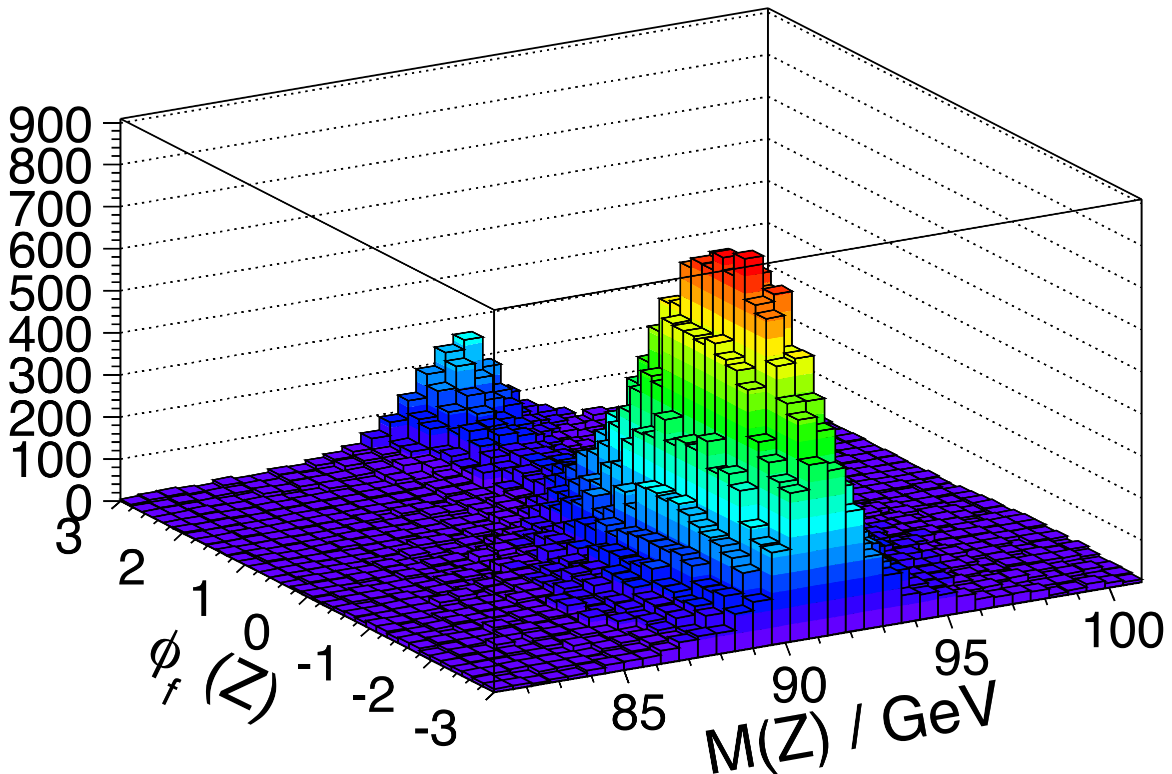
what Physsim does not provide

- radiative correction
- automatically generate all possible Feynman diagrams for given final states
- integrate ME with detector transfer function or unmeasured kinematics (yet-to-be supported)

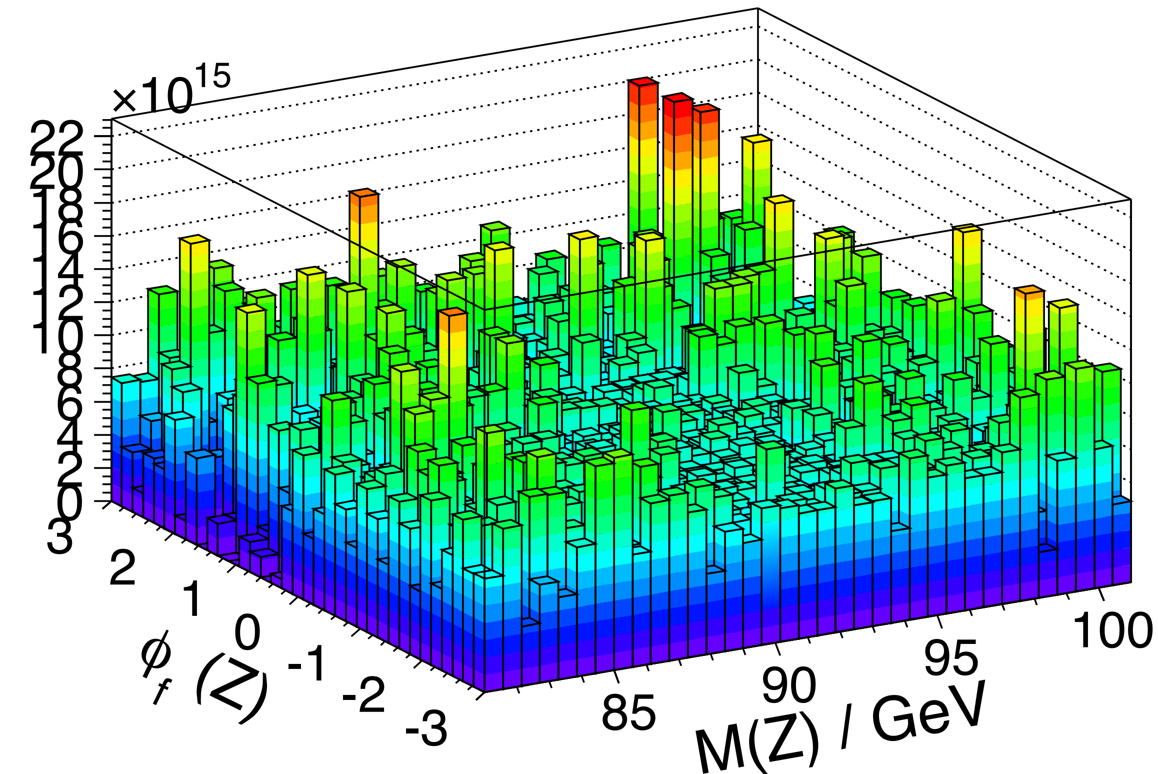
$$L(\mathbf{p}_i^{\mathrm{vis}}|\mathbf{a}) = \frac{1}{\sigma_{\mathbf{a}}}[\prod_{j\in\mathrm{inv.}}\int\frac{d^3p_j}{(2\pi)^3 2E_j}][\prod_{k\in\mathrm{vis.}}\int\frac{d^3p_k}{(2\pi)^3 2E_k}W_i(\mathbf{p}_i^{\mathrm{vis}}|p_k,\mathbf{a})]|M(p_j,p_k;\mathbf{a})|^2$$

reminder: method to verify calculated matrix element

original events



weighted by $\frac{1}{|\mathrm{ME}|^2}$



(ZHH @ 500 GeV)

ϕ_F: azimuthal angle defined in Z rest frame of fermion from Z—>ff

note: try to switch off ISR and beam beam strahlung for verification

update of package

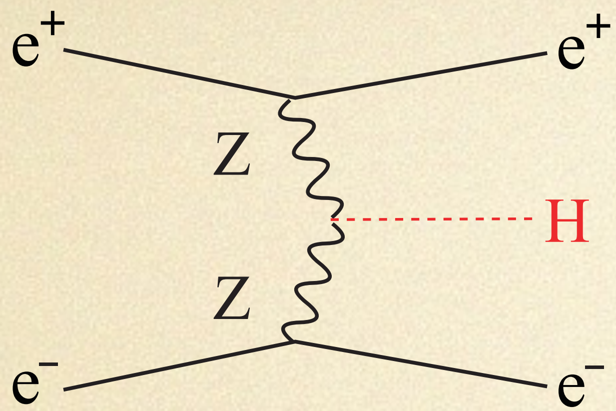
(to be committed in this week)

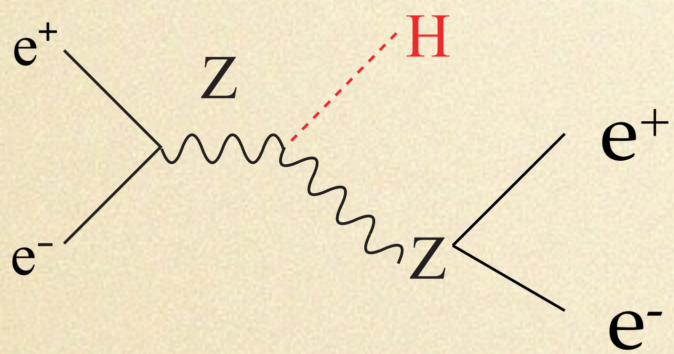
- more processes implemented
  - previous: ZH, ννH (VBF), eeH (VBF), ZHH, ννHH (VBF)
  - new: ZZ, WW, eeZ, ZZZ, ZZH
  - on the way: ννZ (VBF), ttH, WWH
- new features
  - switch to allow Z not decay, i.e. for ZZ as background in recoil mass analysi
  - switch to allow Higgs decay, i.e. add Breit-Wigner structure only or full ME
  - be able to select Feynman diagrams, i.e. in ZHH case, four diagrams.
  - switch to return differential cross (default) or amplitude squared only
  - support for anomalous couplings (gHZZ, gHWW)

$$\mathcal{L}_{\mathrm{HWW}} = 2M_W^2\left(\frac{1}{v}+\frac{a}{\Lambda}\right) H\, W_\mu^+ W^{-\mu} + \frac{b}{\Lambda} H\, W_{\mu\nu}^+ W^{-\mu\nu} + \frac{\tilde{b}}{\Lambda} H\, \epsilon^{\mu\nu\sigma\tau} W_{\mu\nu}^+ W_{\sigma\tau}^-$$

reminder

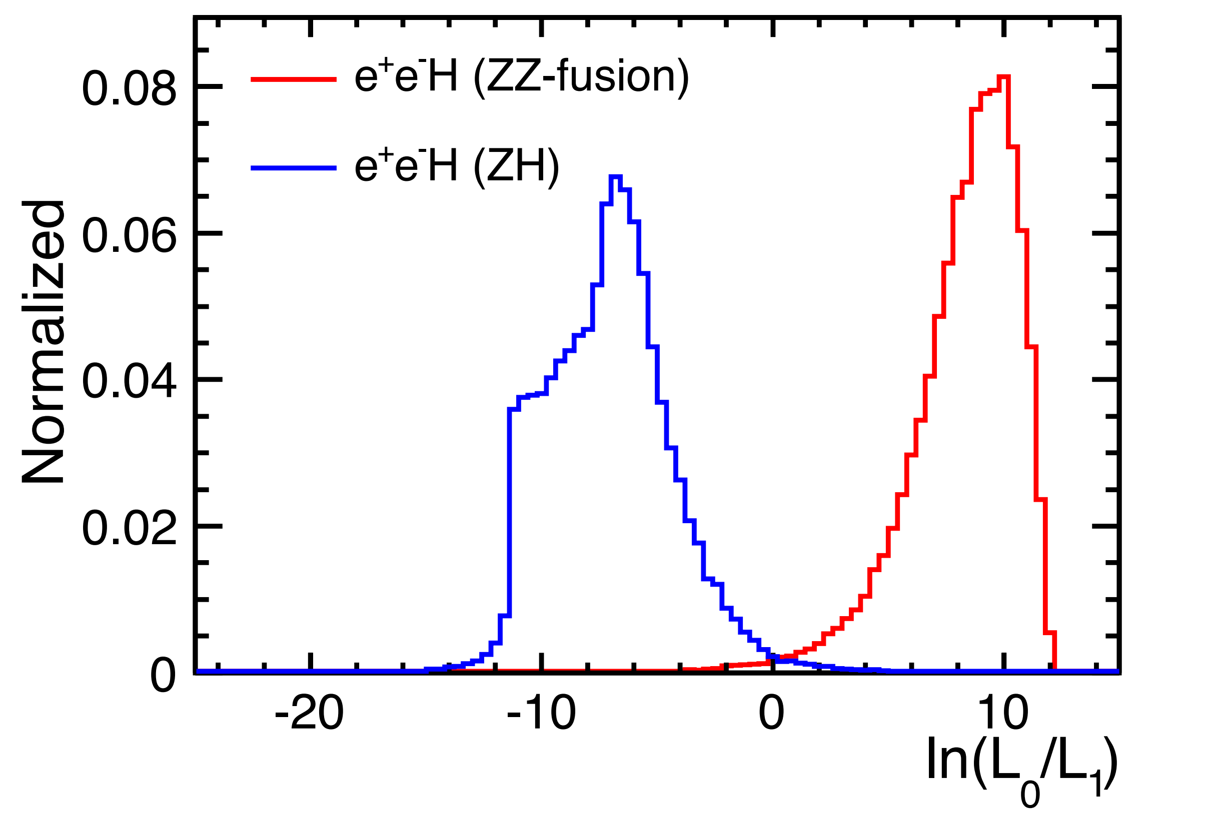
application (I): e+e- —> e+e-H



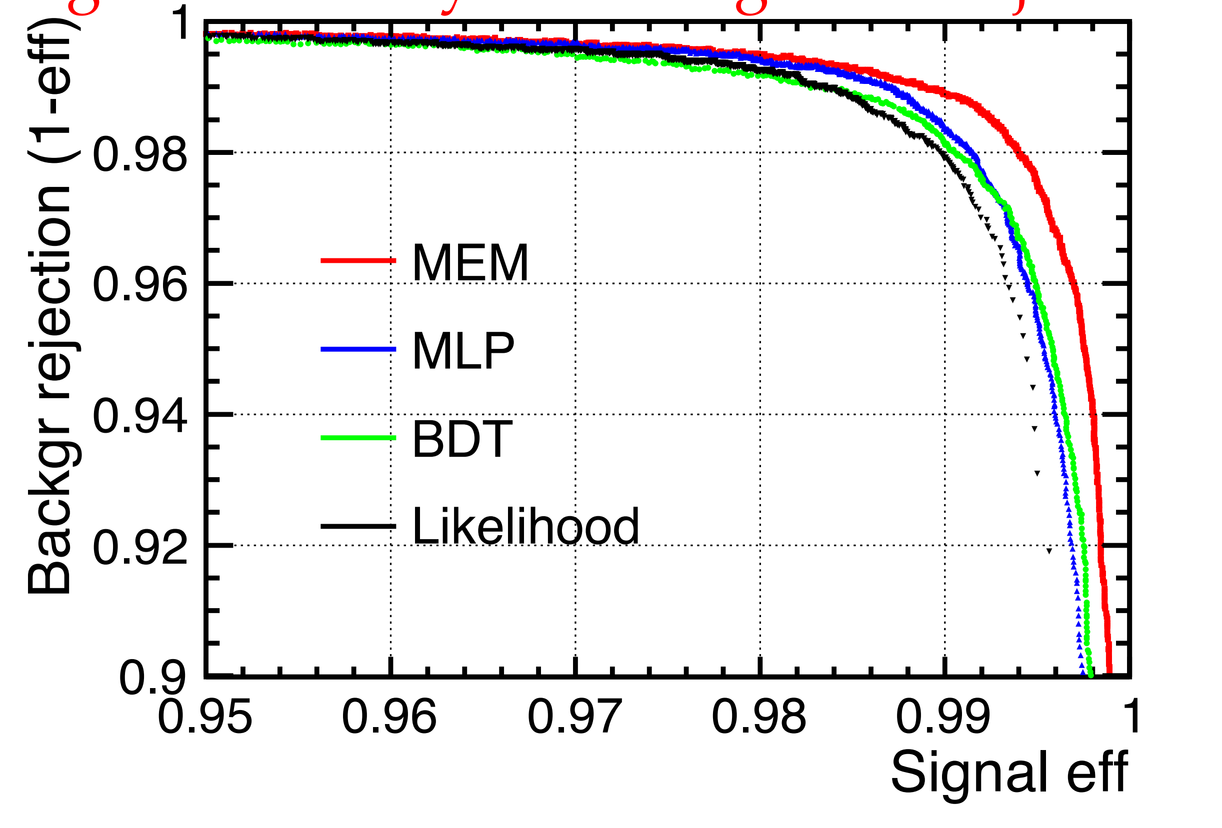


- simplest application, same final states, generator level
- principle's confirmed that ME ratio provides the best separation between ZH and eeH.

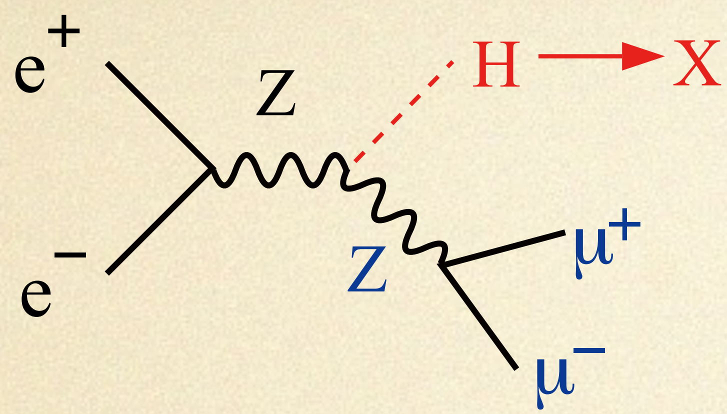
ratio of ME

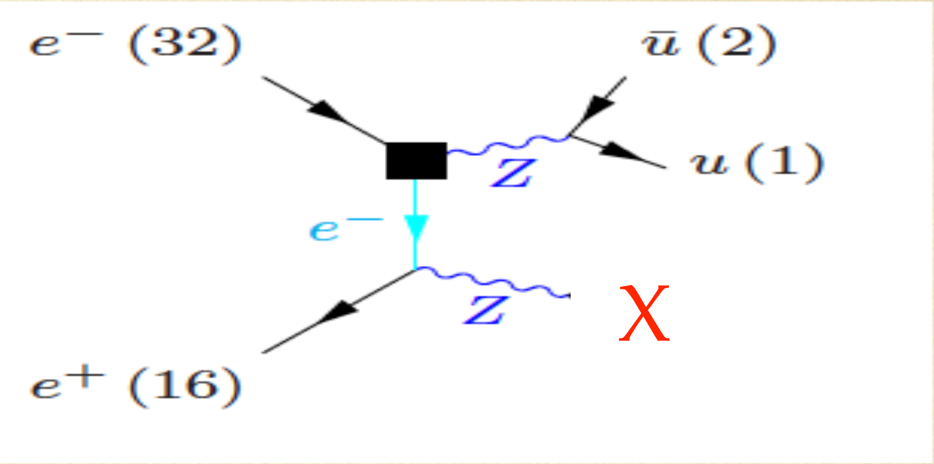


signal efficiency .vs. background rejection



application (II): recoil mass analysis





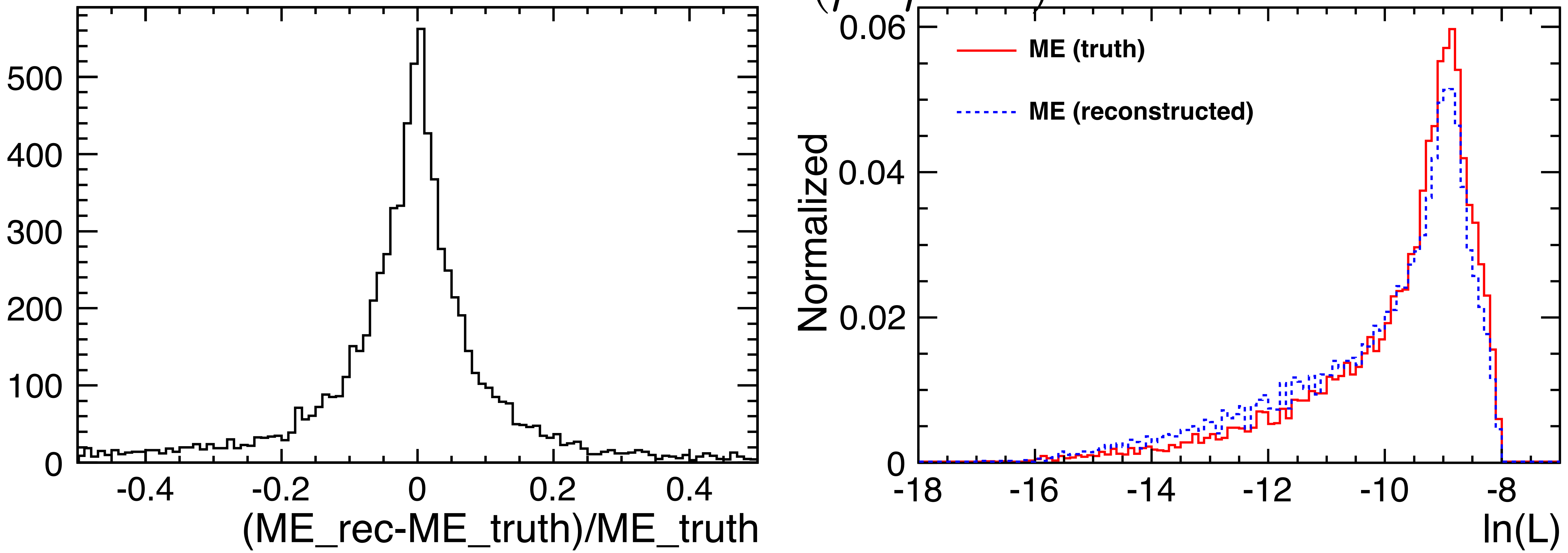
- based on fully simulated and reconstructed samples
- for purpose, first tried without ISR and BS
- momentum of two muons are precisely measured, momentum of Higgs can be well determined as well by recoil technique
- therefore matrix element for this process can be precisely reconstructed
- to separate with ZZ background, Higgs propagator is included in ME, without assuming any decay mode, and one Z decay is switched off and is replaced by Z propagator only in ZZ

$$\mathrm{M} = \mathrm{M}(\mu^+\mu^- H)\frac{1}{p_H^2 - m_H^2 + i m_H \Gamma_H}$$

matrix element: reconstructed .vs. truth

(w/o ISR and beam strahlung)

$$\mathrm{M} = \mathrm{M}(\mu^+\mu^- H)$$

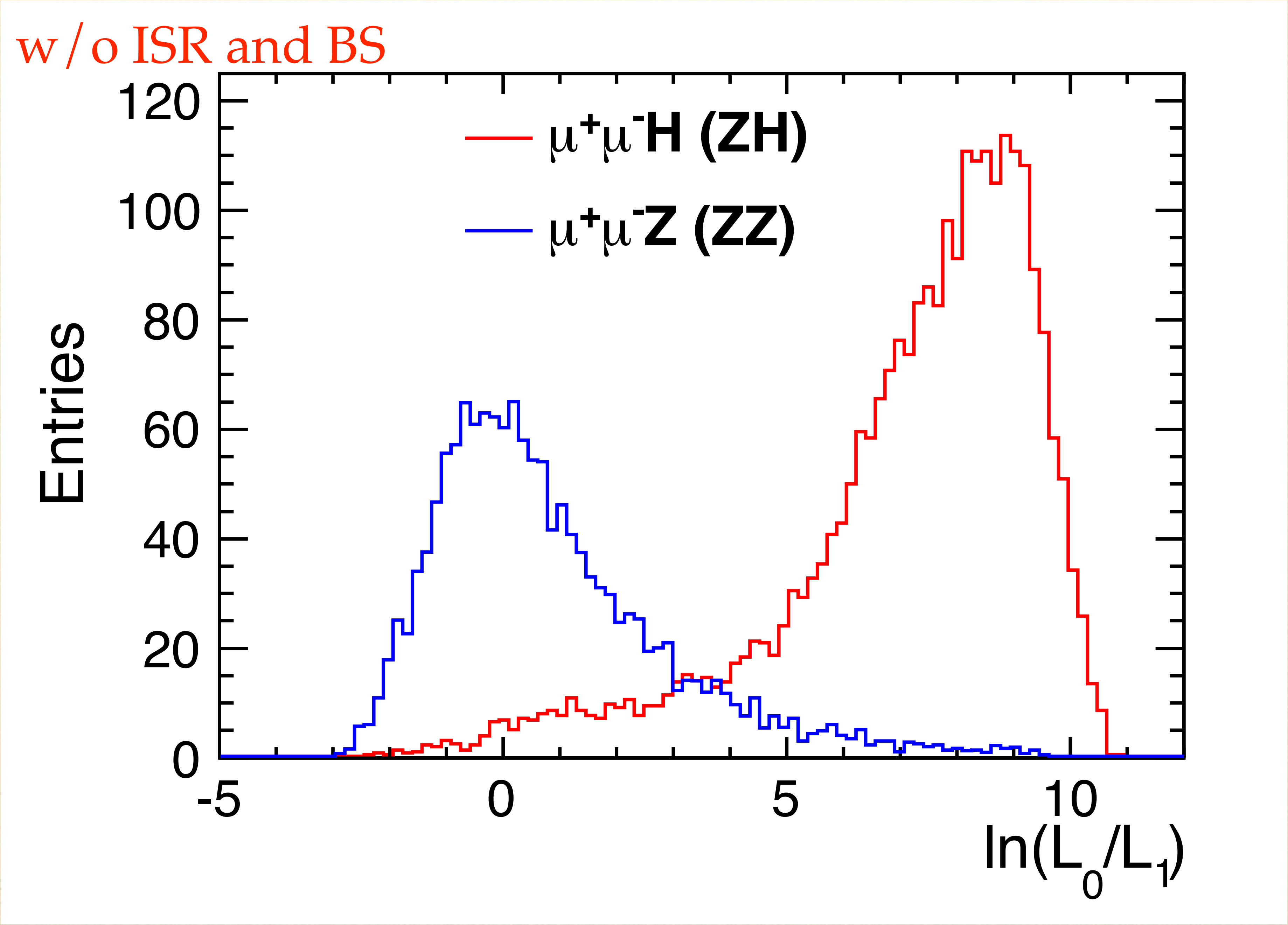


ME can be reconstructed with a resolution ~5%

matrix element: signal .vs. background (ZZ)

(normalized to expected number of events w/ 250 fb^{-1})

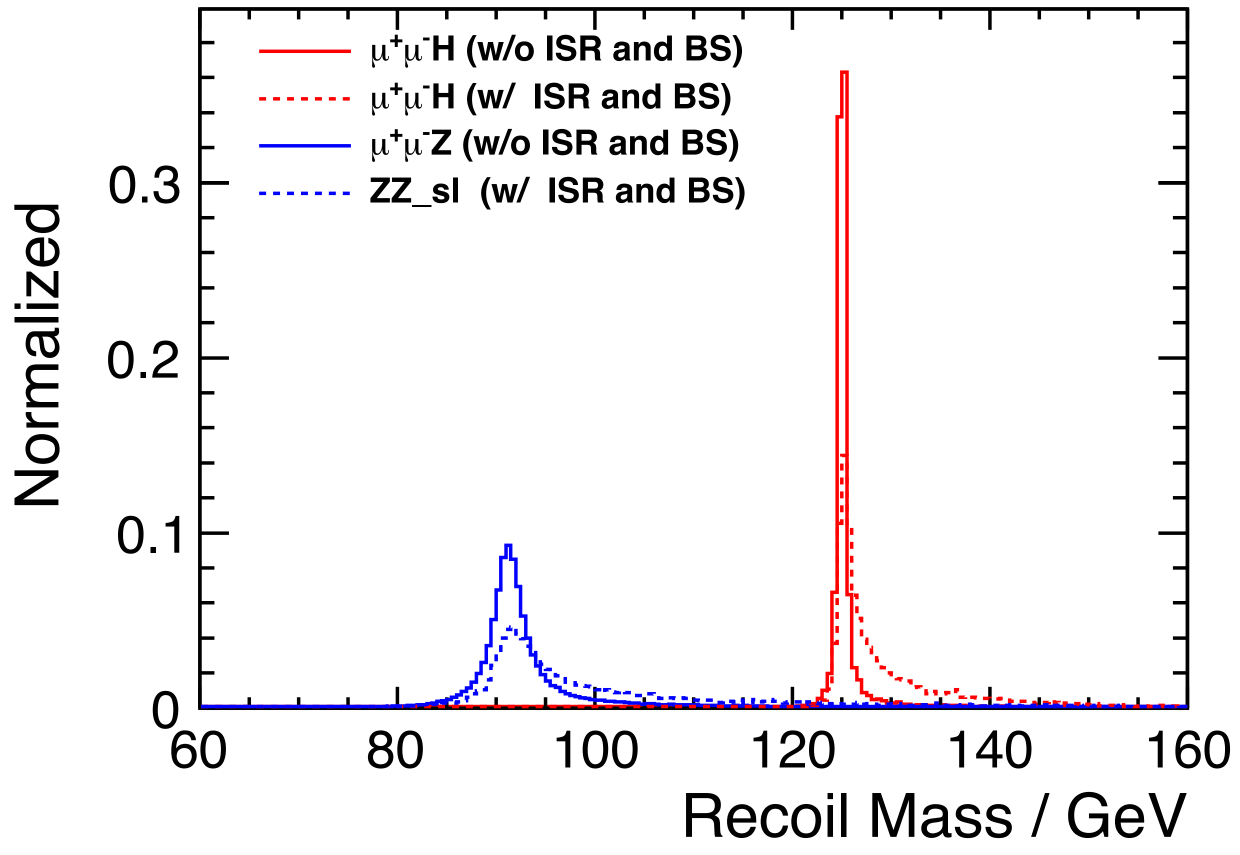
$$M = M(\mu^+\mu^- H)\frac{1}{p_H^2 - m_H^2 + i m_H \Gamma_H} \Bigg/ M = M(\mu^+\mu^- Z)\frac{1}{p_Z^2 - m_Z^2 + i m_Z \Gamma_Z}$$



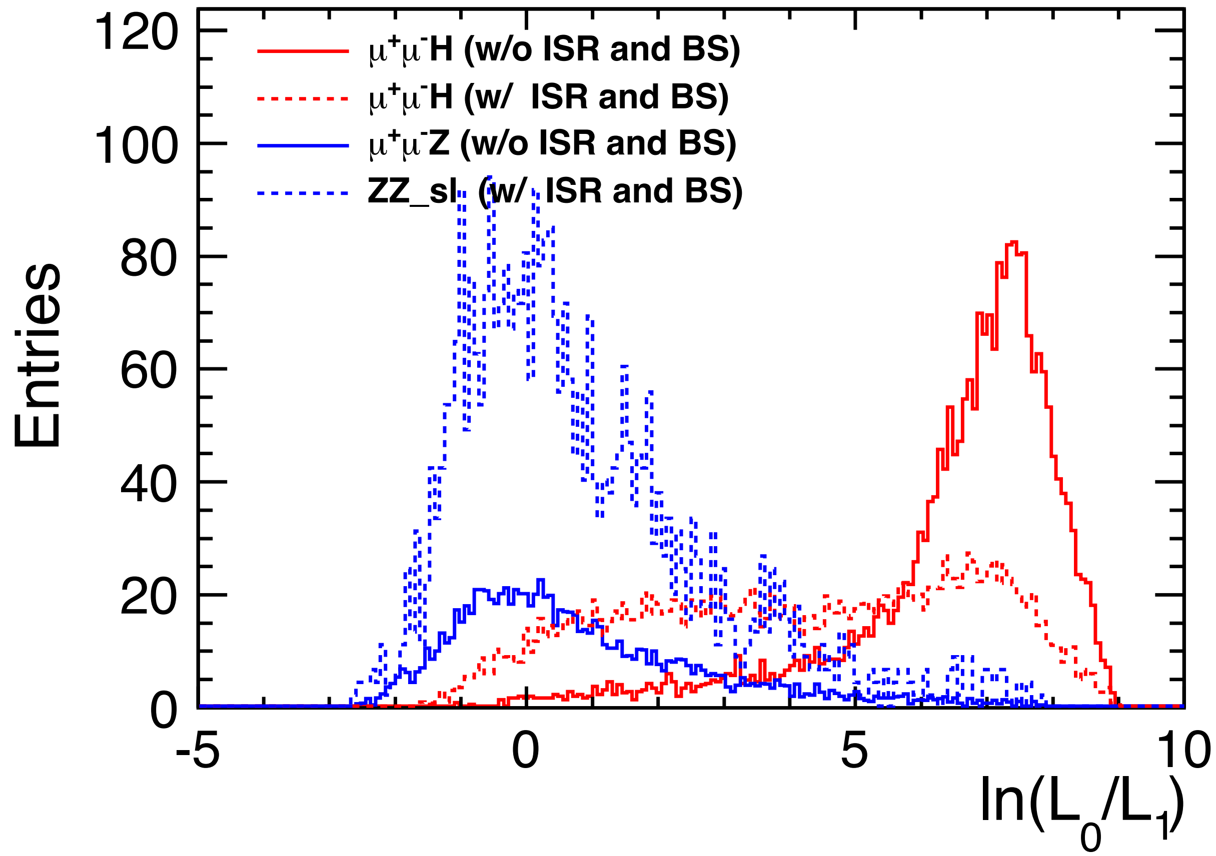
without any other selection except recoil mass > 110 GeV, already very well separated

including everything: ISR + beam spectrum

normalized to 1



normalized to <E> @ 250 fb-1



ISR + BS significantly degraded the separation power against ZZ

any chance to recover ISR and BS?

proposal to recover ISR

- ☑ ISR enters detector: identification (see T. Tomita's study, eff ~ 90%)
- ☐ what if ISR goes to beam pipe? (dominant)

4 unknown: 3 P_{H} + 1 P_{γ}

4C —> we can resolve it!

$$|P_z(\gamma)| = |P(\gamma)|$$

$$P_y(H) = -P_y(Z); \quad P_x(H) = \sqrt{s}\sin\frac{\theta}{2} - P_x$$

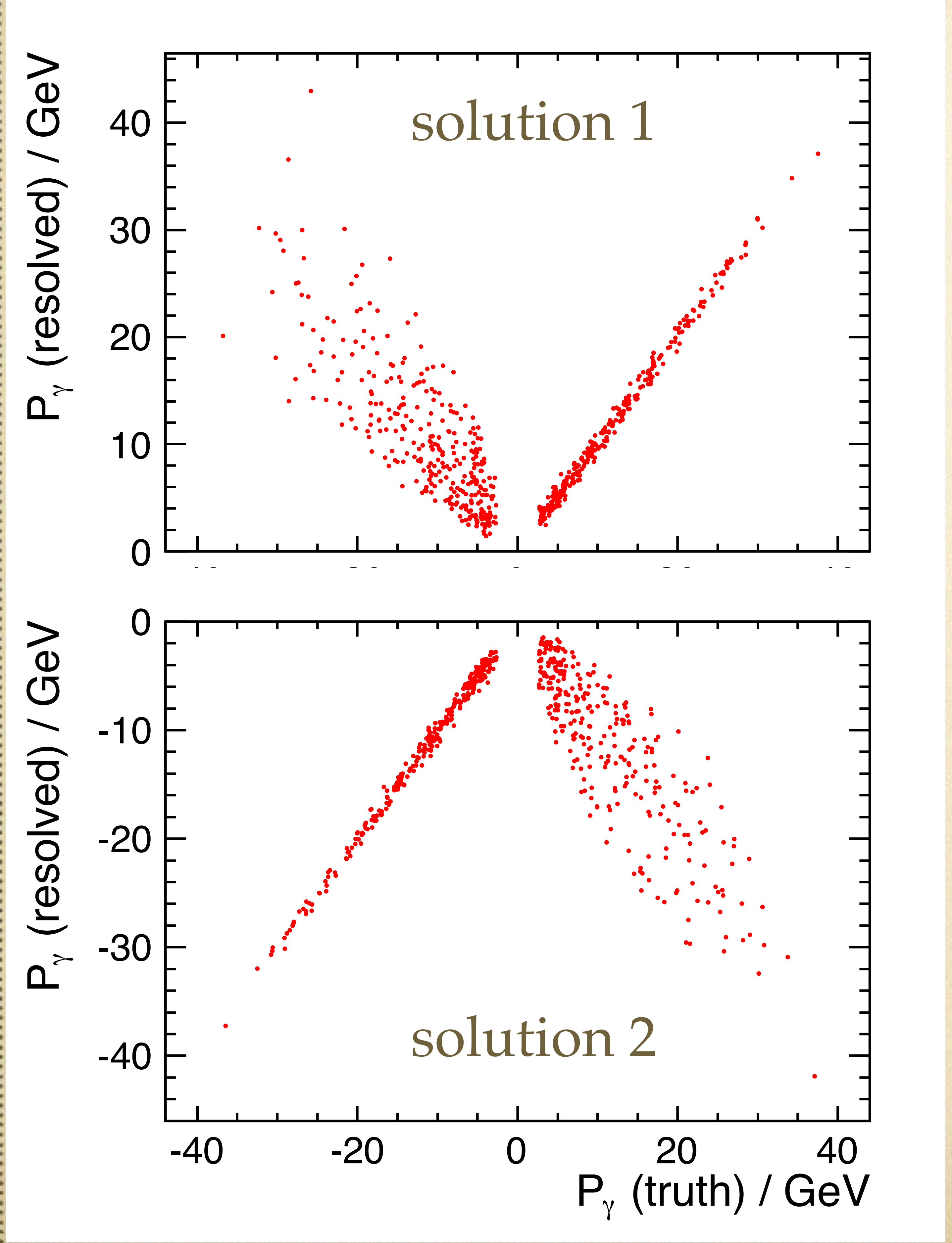
$$P_z(H) = -(P_z(Z) + P_z(\gamma))$$

$$E(Z) + \sqrt{P_t^2(H) + P_z^2(H) + m^2(H)} + |P(\gamma)| = \sqrt{s}$$

$$P(\gamma) = \frac{s\cos^2\frac{\theta}{2} - 2\sqrt{s}(E(Z) - P_x(Z)\sin\frac{\theta}{2}) + m^2(H) - m^2(Z)}{2[P_z(Z) \pm (\sqrt{s} - E(Z))]}$$

n.b.: there are two possible solutions! and Higgs mass has to be known

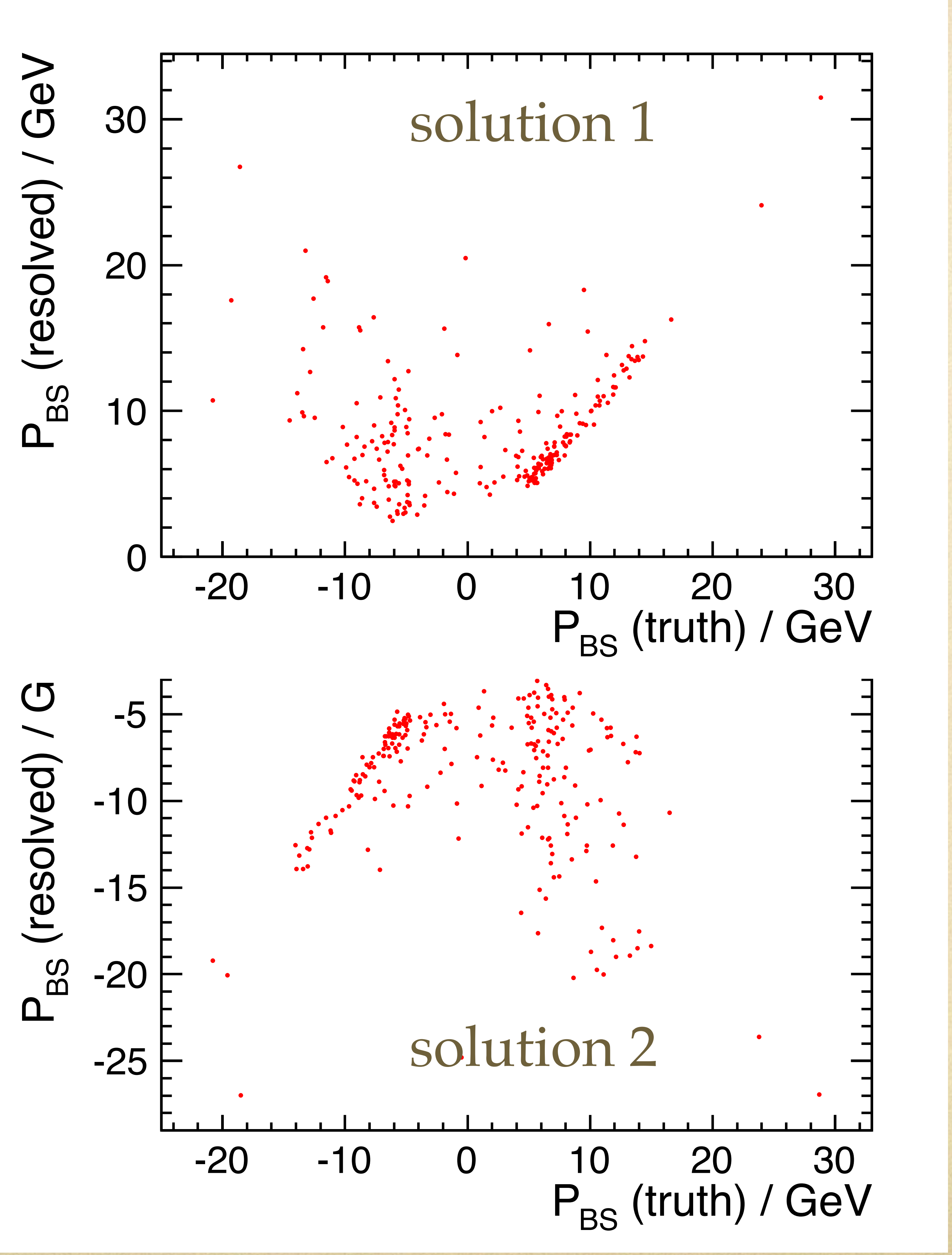
resolve ISR: events with one hard ISR (>3 GeV)



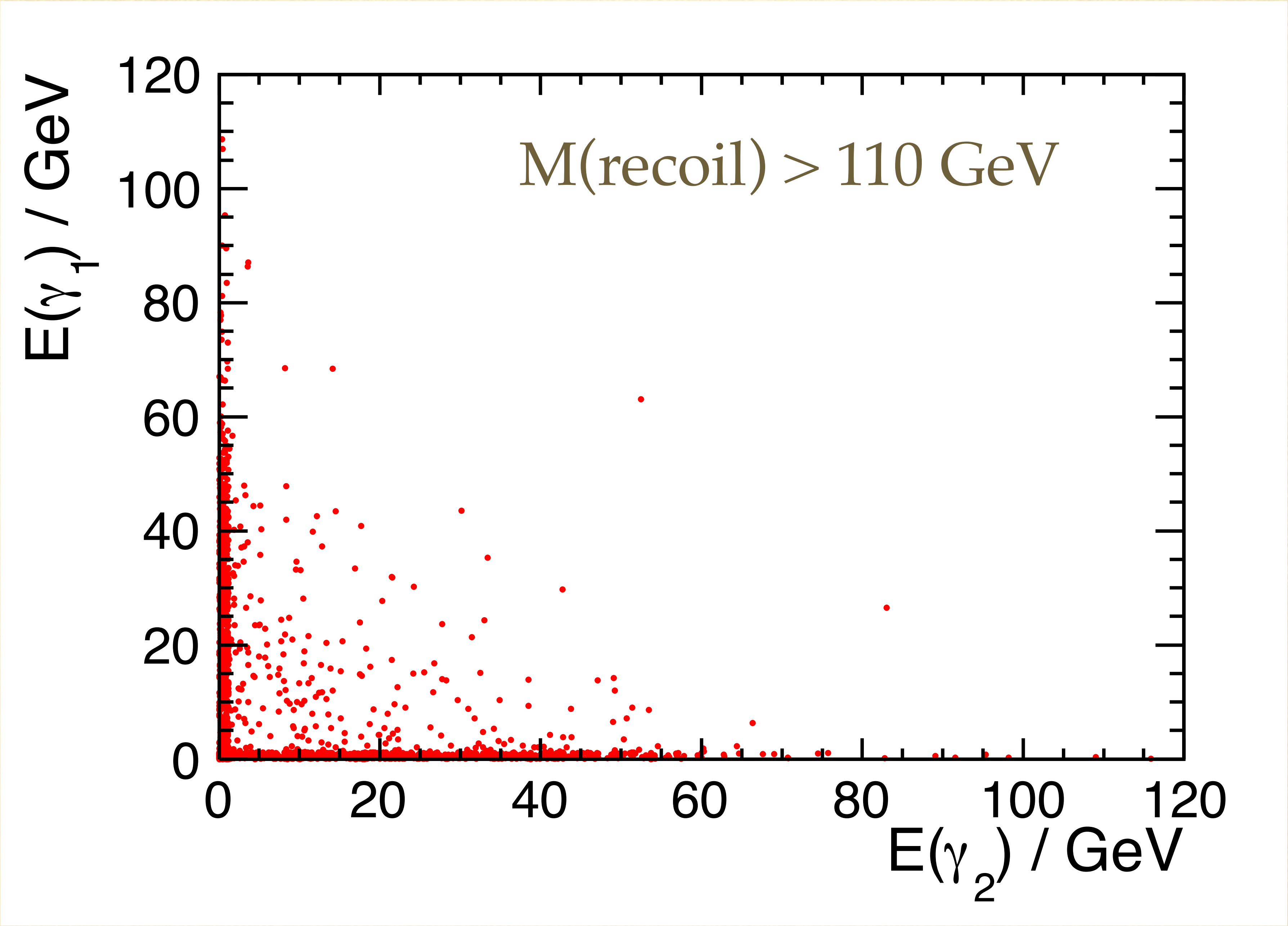
- two solutions correspond to +z or -z direction of ISR momentum
- both are allowed by kinematics, and ME in both cases show no difference
- therefore overall ME has to be sum of those two ME.

is also possible to resolve beamstrahlung?

events without hard ISR (< 1 MeV), but with reduced Ecm (> 5 GeV)



role of ISR in case of background ZZ

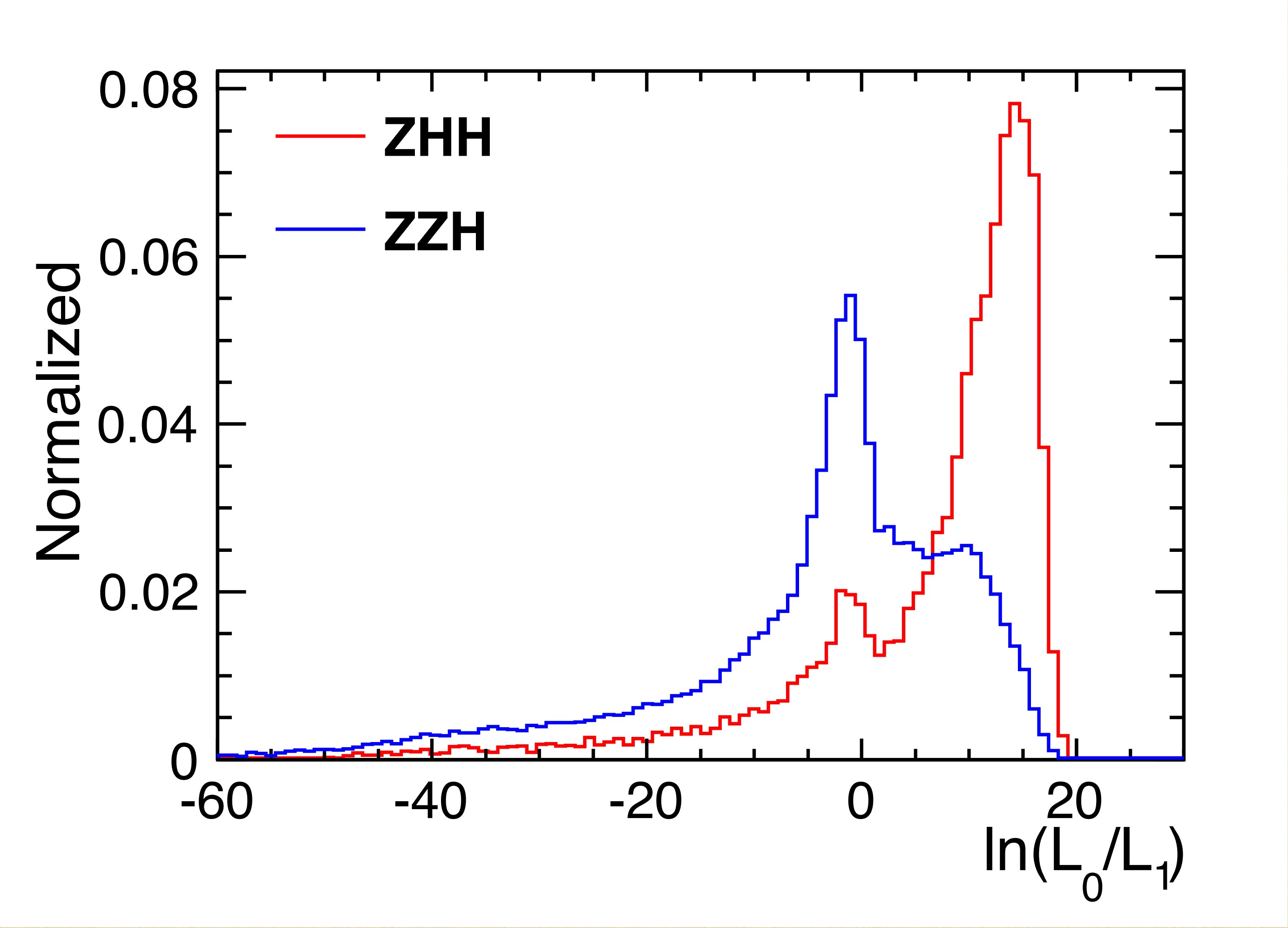


ISR is the main reason to have recoil mass > 110 GeV

analysis including ISR recover for both ZH and ZZ is ongoing

application (III): Higgs self-coupling

- see previous slides by Claude
- now ME for both ZHH and ZZH are available
- from the ratio, it looks quite promising
- ME can also applied for jet-pairing



summary and next step

- ME tools have been developed and verified by first look, but still during "principle" stage; application to complete analysis would be very welcome.

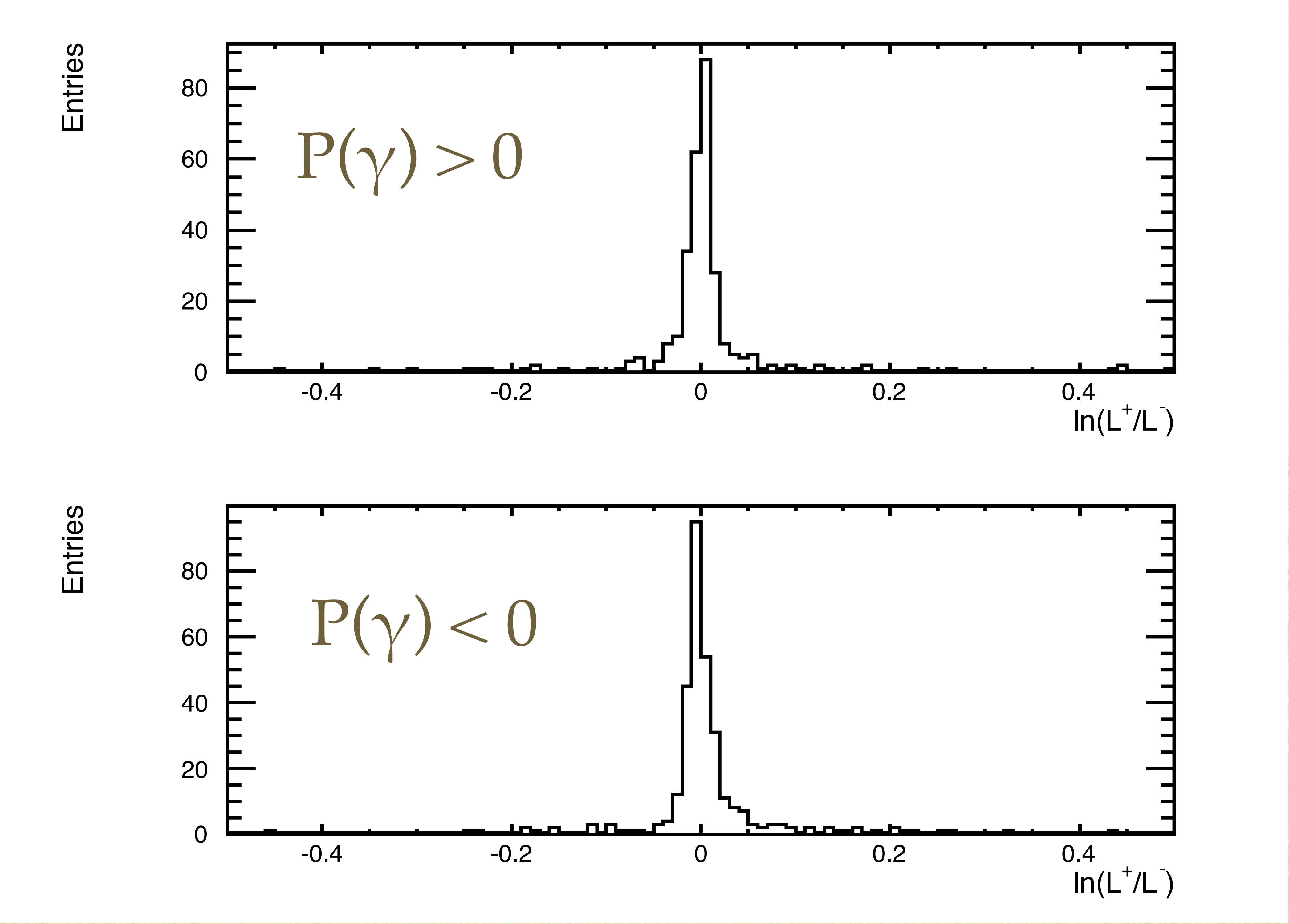
- ME indeed can be reconstructed very precisely at the ILC; event selection will be much simplified using MEM.

- ISR in recoil analysis can be resolved to help get better ME; and to use Higgs propagator, in principle we need know Higgs mass first, which can be obtained by fitting recoil mass (note: to get mass more cuts on decay part can be applied); to improve $\sigma(ZH)$ measurement would then be main purpose of using MEM.

- promising for Higgs self-coupling

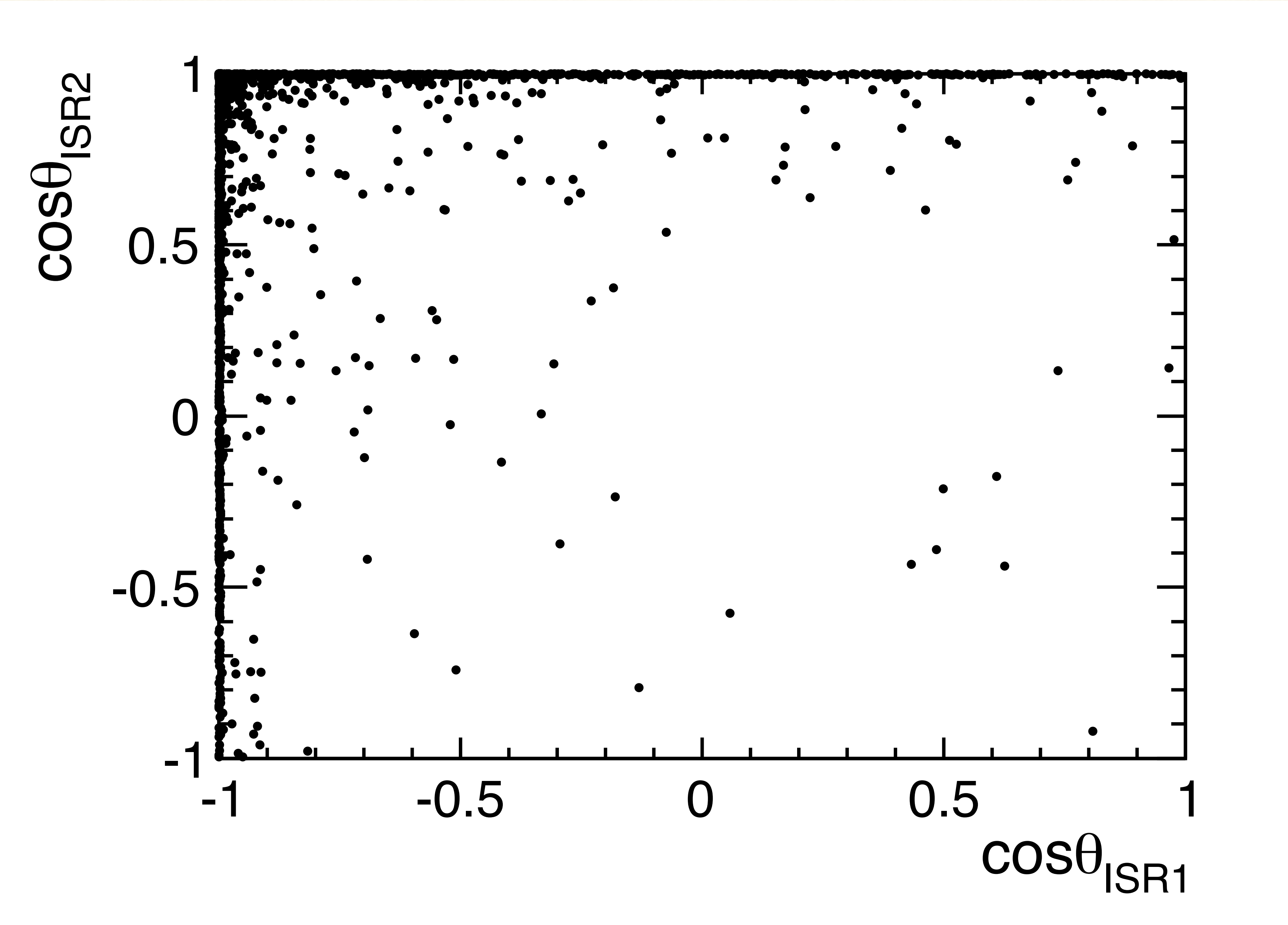
back up

compare the matrix elements for both solutions



both solutions seem allowed

angular distribution of ISR (by whizard 2 ISR kept)

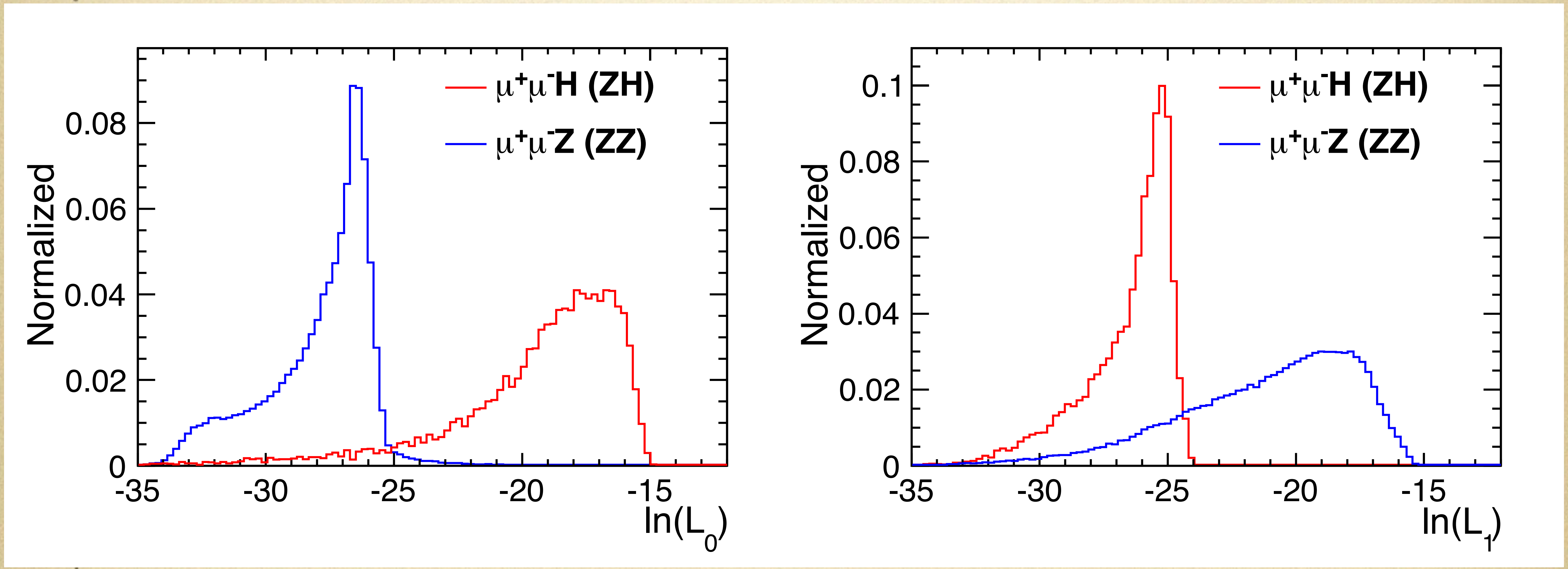


$|\cos\theta_1| > 0.999$ or $|\cos\theta_2| > 0.999$ ~93%

$|\cos\theta_1| < 0.999$ and $|\cos\theta_2| < 0.999$ ~7%

matrix element: signal .vs. background (ZZ)

$$\mathrm{M} = \mathrm{M}(\mu^+\mu^- H)\frac{1}{p_H^2 - m_H^2 + im_H\Gamma_H} \qquad \mathrm{M} = \mathrm{M}(\mu^+\mu^- Z)\frac{1}{p_Z^2 - m_Z^2 + im_Z\Gamma_Z}$$



verification

$$L(\mathbf{p}_i^{\mathrm{vis}}|\mathbf{a}) = \frac{1}{\sigma_{\mathbf{a}}}[\prod_{j\in \mathrm{inv.}} \int \frac{d^3p_j}{(2\pi)^3 2E_j}][\prod_{k\in \mathrm{vis.}} \int \frac{d^3p_k}{(2\pi)^3 2E_k} W_i(\mathbf{p}_i^{\mathrm{vis}}|p_k,\mathbf{a})]|M(p_j,p_k;\mathbf{a})|^2$$

- stdhep events are generated without any ISR and BS, helicity combinations of both initial and final states can be controlled.
- detector transfer function ($W(p_i | p_k, a)$) becomes a delta function, and no invisible variables. (test with MC information).
- ME calculated for each event in this way should be as same as the ME used in event generation (as event weights).
- to verify the calculated ME, if each event is weighted by ($1./|ME|^2$), all variables should be uniformly distributed.