Study of photon-associated Higgs production at the ILC

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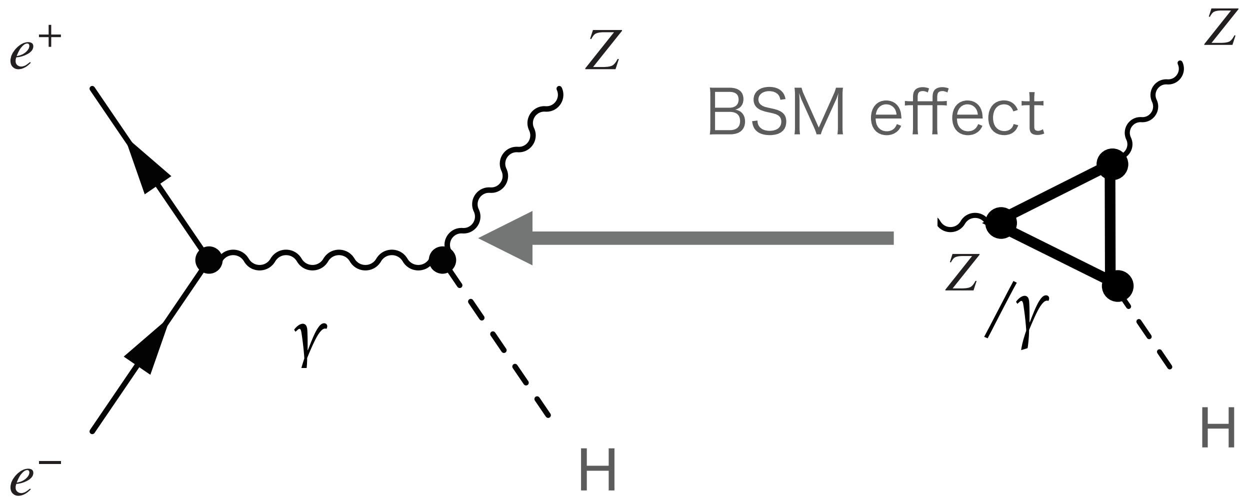
2021.7.14(Wed) @Software&Analysis mtg

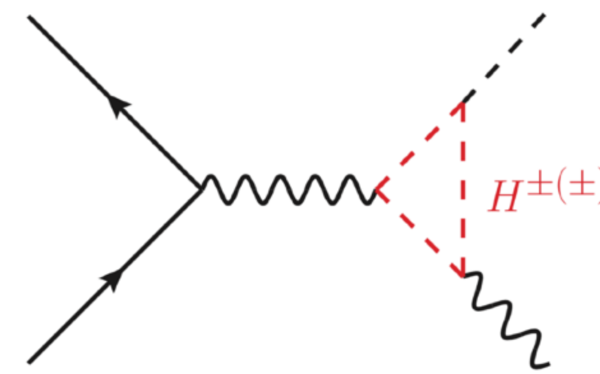
1.Motivation

To find new physics via Hγγ and HγZ couplings

Higgs to γZ coupling in the Standard Model (SM) is a loop induced coupling.
→We expect BSM amplitude can be larger than SM amplitude.



e.g.： Inert Triplet Model



Mawatari, et al, arXiv:1808.10268

This process can be also useful to constrain the dimension 6 EFT operators which can introduce effective anomalous hγZ and hγγ couplings.

Q. H. Cao, et al, arXiv:1505.00654 [hep-ph]

Any deviation of the coupling constants from SM signals new physics.

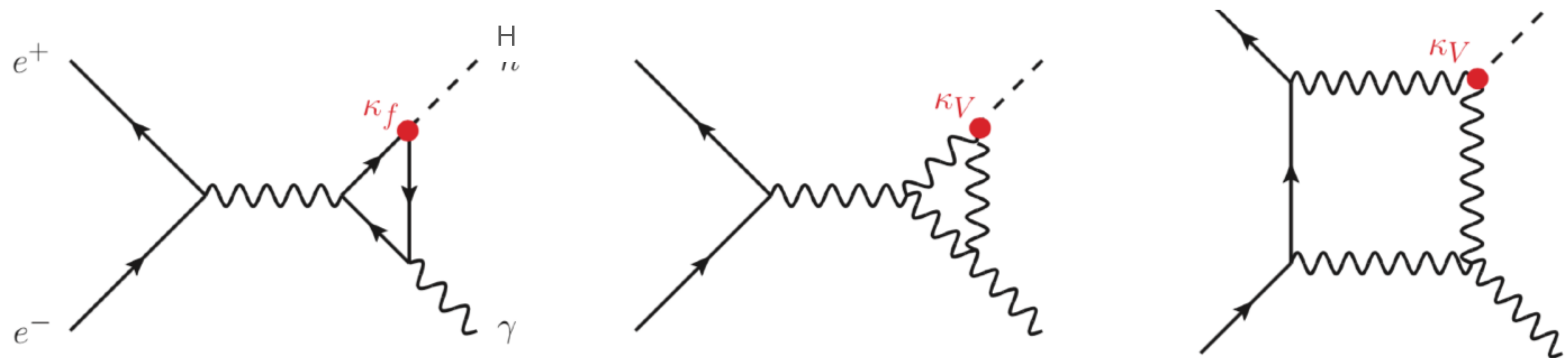
h→bb

h→WW*
semi leptonic

2. Theoretical framework for our analysis

SM one-loop predictions

The main Feynman diagrams



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SM cross sections by one loop calculation:

e⁻ e⁺

σ_{SM}=0.35 fb for (-100%,+100%)

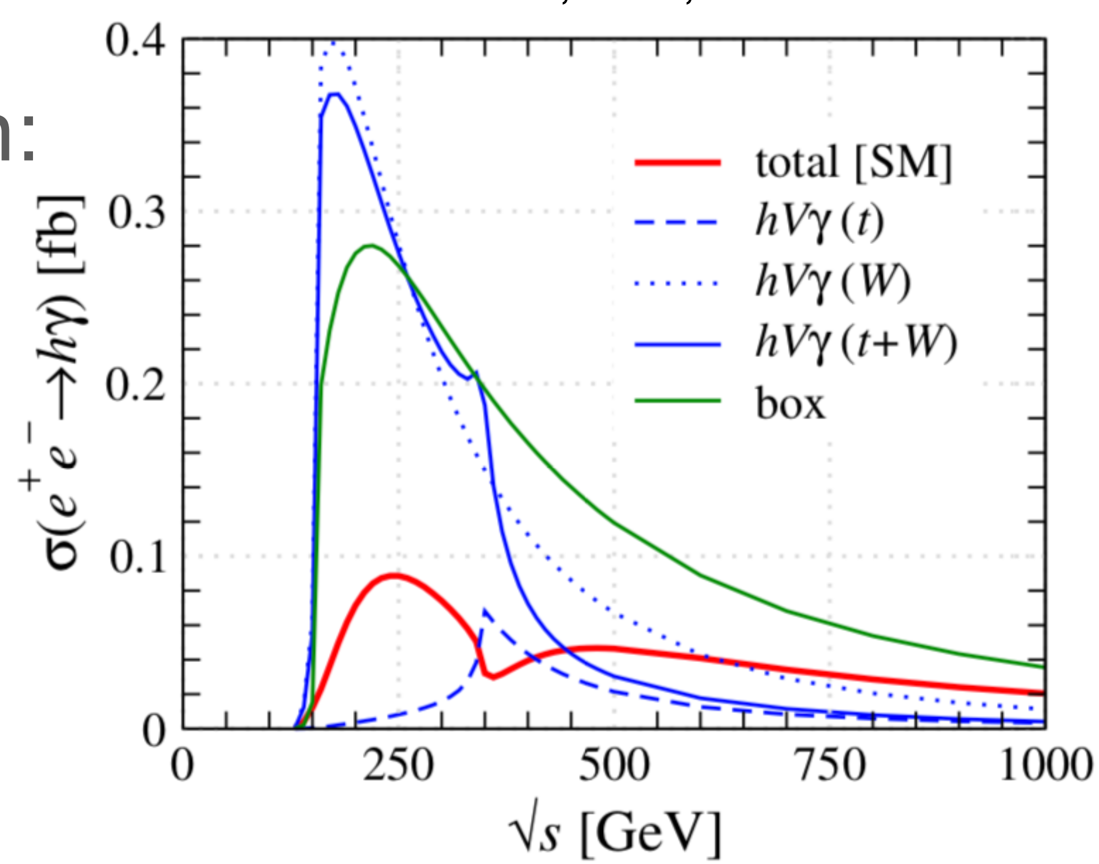
σ_{SM}=0.016 fb for (+100%,-100%)

σ_{SM}=**0.20 fb** for (-80%,+30%)

$\sqrt{s}$ = 250 GeV

Small !

This analysis is very challenging.



※For unpolarized beam

Destructive interference

3.Experimental Method

The effective field theory (EFT) Lagrangian (model-independent)

effective hγZ coupling   effective h$\gamma\gamma$ coupling

$$L_{\gamma H} = L_{\rm SM} + \frac{\zeta_{AZ}}{v} A_{\mu\nu} Z^{\mu\nu} H + \frac{\zeta_A}{2v} A_{\mu\nu} A^{\mu\nu} H$$

$A_{\mu\nu}$, $Z_{\mu\nu}$: field strength tensors   v: vacuum expectation value

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cross section of e+e- —> γH

$$\frac{\sigma_{\gamma H}}{\sigma_{SM}} = 1 - 273\zeta_A - 201\zeta_{AZ} \quad \text{(eLpR)}$$

$$\frac{\sigma_{\gamma H}}{\sigma_{SM}} = 1 + 492\zeta_A - 311\zeta_{AZ} \quad \text{(eRpL)}$$

Since ζ_A is already constrained by measurement of H→ γγ branching ratio at LHC, we can extract ζ_{AZ} parameter by just measuring cross section for a single beam polarization.

4. Simulation framework

Event generation

- $\sqrt{s}$=250 GeV
  Integrated Luminosity: 2000 fb^{-1}
  (900 fb^{-1} each for Left / Right handed pol.)
- background : 2f,4f (DBD sample)
- ISR and Beamstrahlung effects are included

Detector simulation

- ILD full simulation (Mokka)
- Geant4 based, realistic detailed detector model

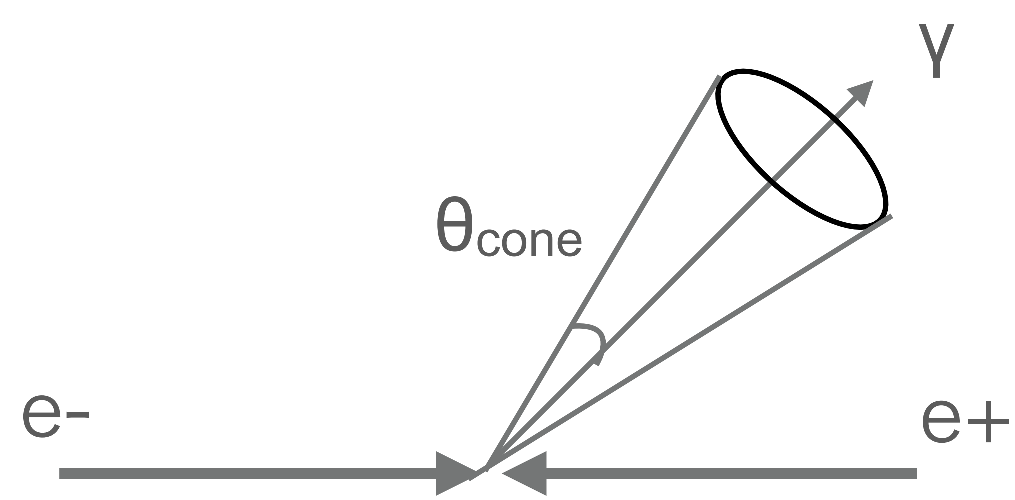
Event reconstruction

- Full reconstruction chain from detector signals to 4-vectors
  (iLCSoft v01-16-02/ MarlinReco, PandoraPFA, LCFI+, Isolated photon finder, jet clustering)

Event selection

- $E_\gamma > 50$ GeV

9. Pre-Event selection



- Isolated photon
  - ➤ Photon ID
  - ➤ $E_\gamma > 50$ GeV

※The split photon clusters within a small cone are recovered

➤ ($\cos\theta_{cone}$=0.998)

→Left events except photon

- ➤ 2jet clustering (Durham)
- ➤ Flavor tagged（LCFI+）

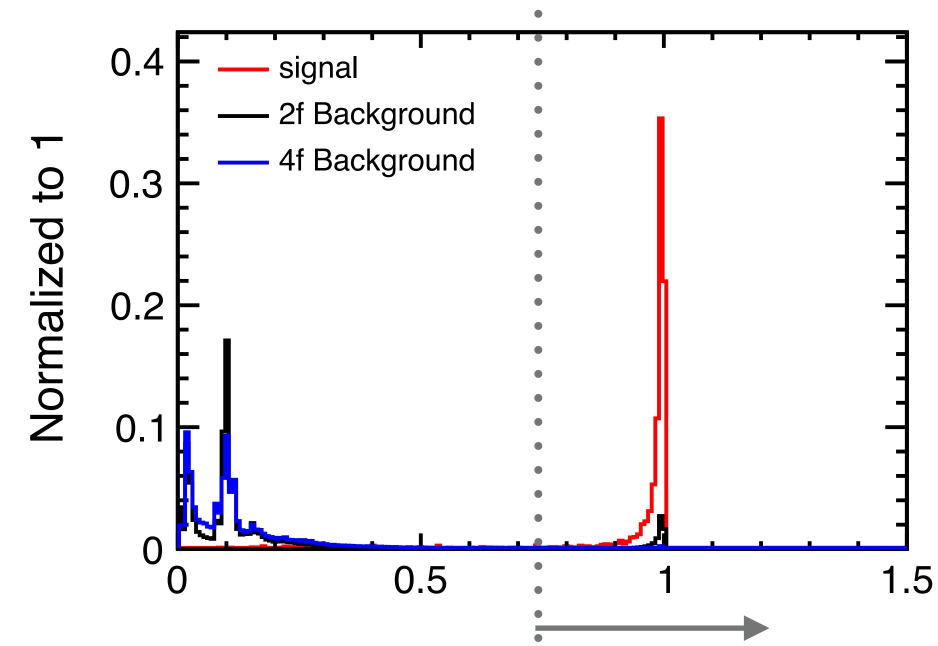
For h→WW* semi-leptonic,

number of decay w to qq=1

5. Analysis - Event selection

Signal: $e^+e^- \to \gamma H \to \gamma(b\bar{b})$

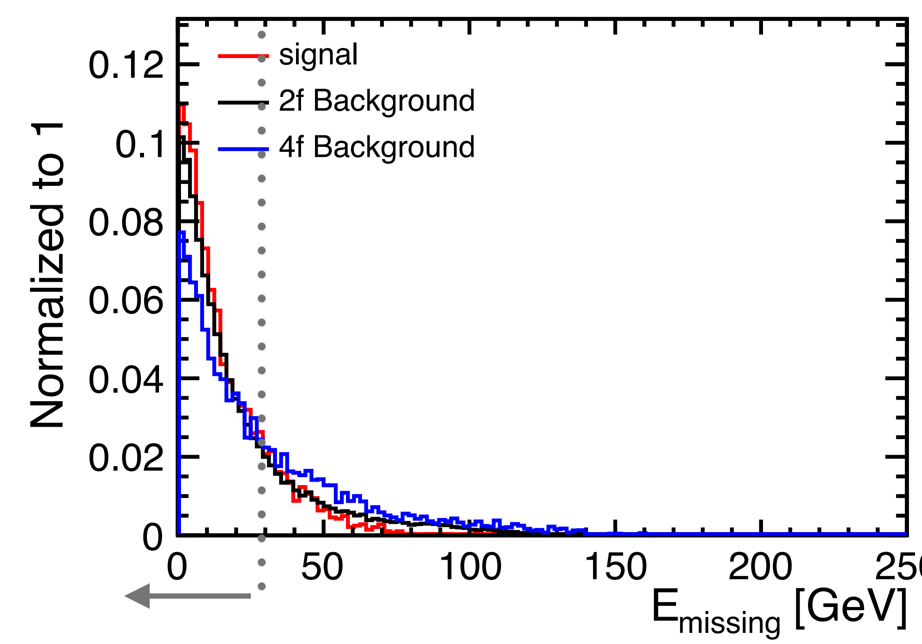
Cut 1: b likeliness1>0.77



Signal signatures

1. Isolated monochromatic photon with energy 93 GeV
2. 2 b jets
3. m(bb) (invariant mass) = Higgs mass

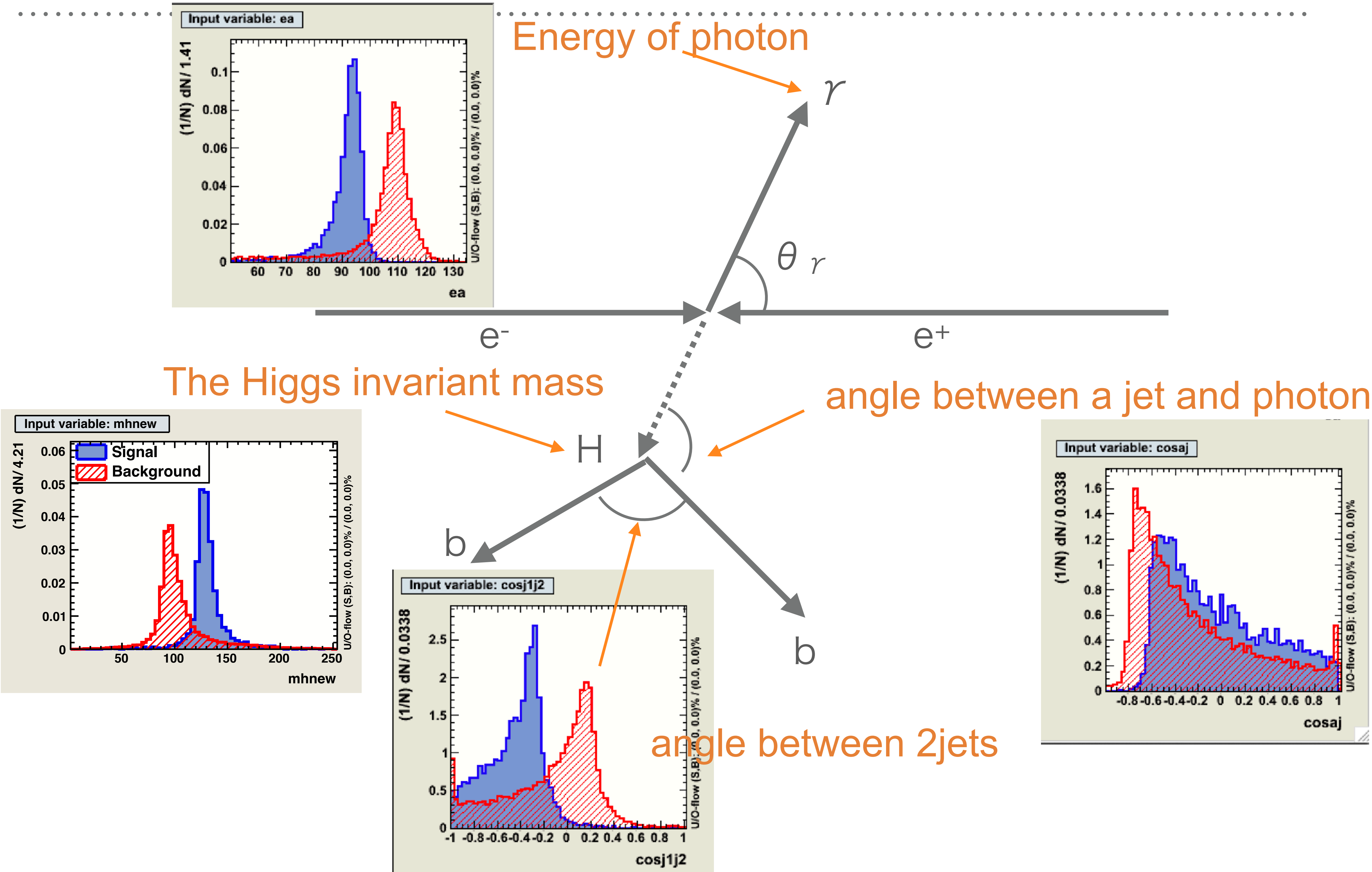
Cut 2: missing energy<35 GeV



Main backgrounds

$e^+e^- \to \gamma Z \to \gamma qq$

5. Analysis - Input variables for MVA



5. Analysis - Reduction table

Left	total bg	Signal	Significance
Expected	1.4×10^{8}	107	0.01
Pre selection	2.9×10^{7}	100	0.02
b likeliness>0.77	2.2×10^{6}	90	0.06
$E_{mis}<35$	1.9×10^{6}	82	0.06
mvabdt > 0.025	19583	34	0.24
$-0.92<\cos\theta_{\gamma}<0.92$	12422	29	**0.26**

Right	total bg	Signal	Significance
Expected	7.8×10^{7}	11.2	0.001
Pre selection	2.3×10^{7}	10.3	0.002
b likeliness>0.77	1.5×10^{6}	9.4	0.008
$E_{mis}<35$	1.3×10^{6}	8.4	0.007
mvabdt > 0.025	1.0×10^{4}	3.4	0.034
$-0.92<\cos\theta_{\gamma}<0.92$	5.9×10^{3}	3.0	**0.039**

$$significance \quad \frac{N_s}{\sqrt{N_s + N_B}}$$

N_S: # of signal

N_B: # of bg

5. Analysis - Event selection1

Signal: $e^+e^- \to \gamma h \to \gamma(WW^*)$ →γ 2j lν

one W decays hadronically (W_1), and another decays leptonically(W_2)

Signal signatures

1. Isolated monochromatic photon with energy 93 GeV
2. 2 jets that originated from the hadronically decayed W

Cut1. # of charged particle in jets >3

3. the sum of four momenta of the 2 jets, the lepton and leptin neutrino is consistent with Higgs hypothesis,

Main backgrounds $e^+e^- \to W^+W^-(\gamma)$

5. Analysis - Event selection2

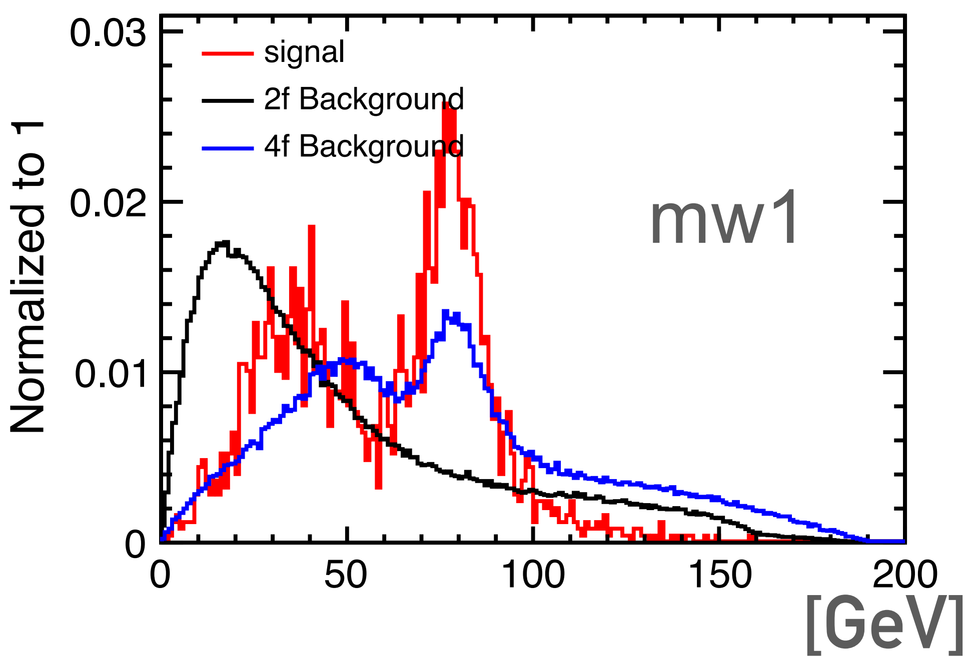
Signal: $e^+e^- \to \gamma h \to \gamma(WW^*)$ →γ 2j lν

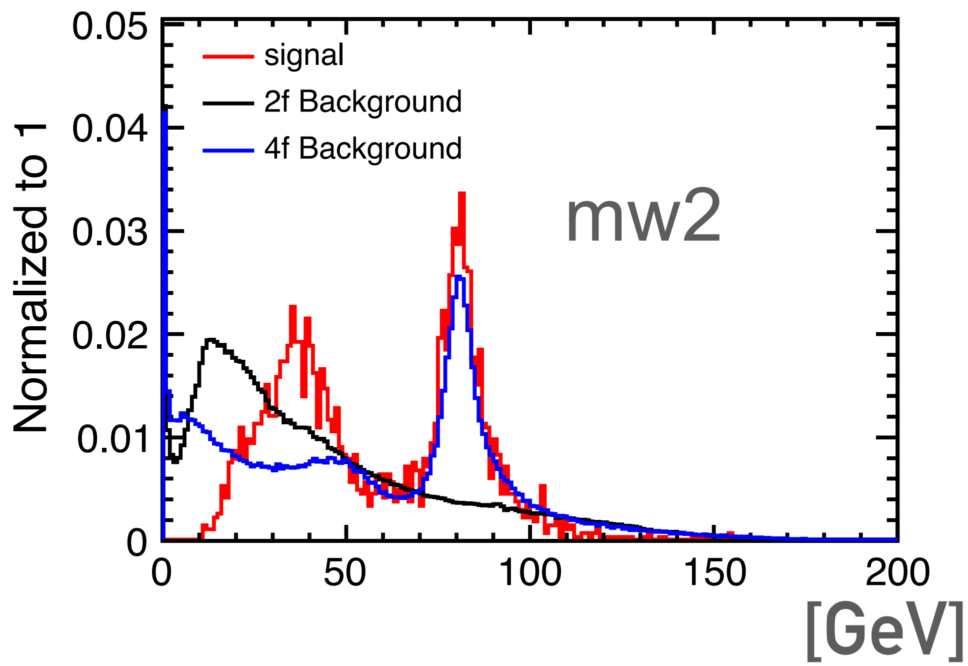
one W decays hadronically (W_1), and another decays leptonically(W_2)

Signal signatures

4. either one of the 2 jets or the lepton-neutrino systems has an invariant mass consistent with the on-sell W hypothesis

Cut2. |mw1-80.4|<10 GeV or |mw2-80.4|<9.4 GeV

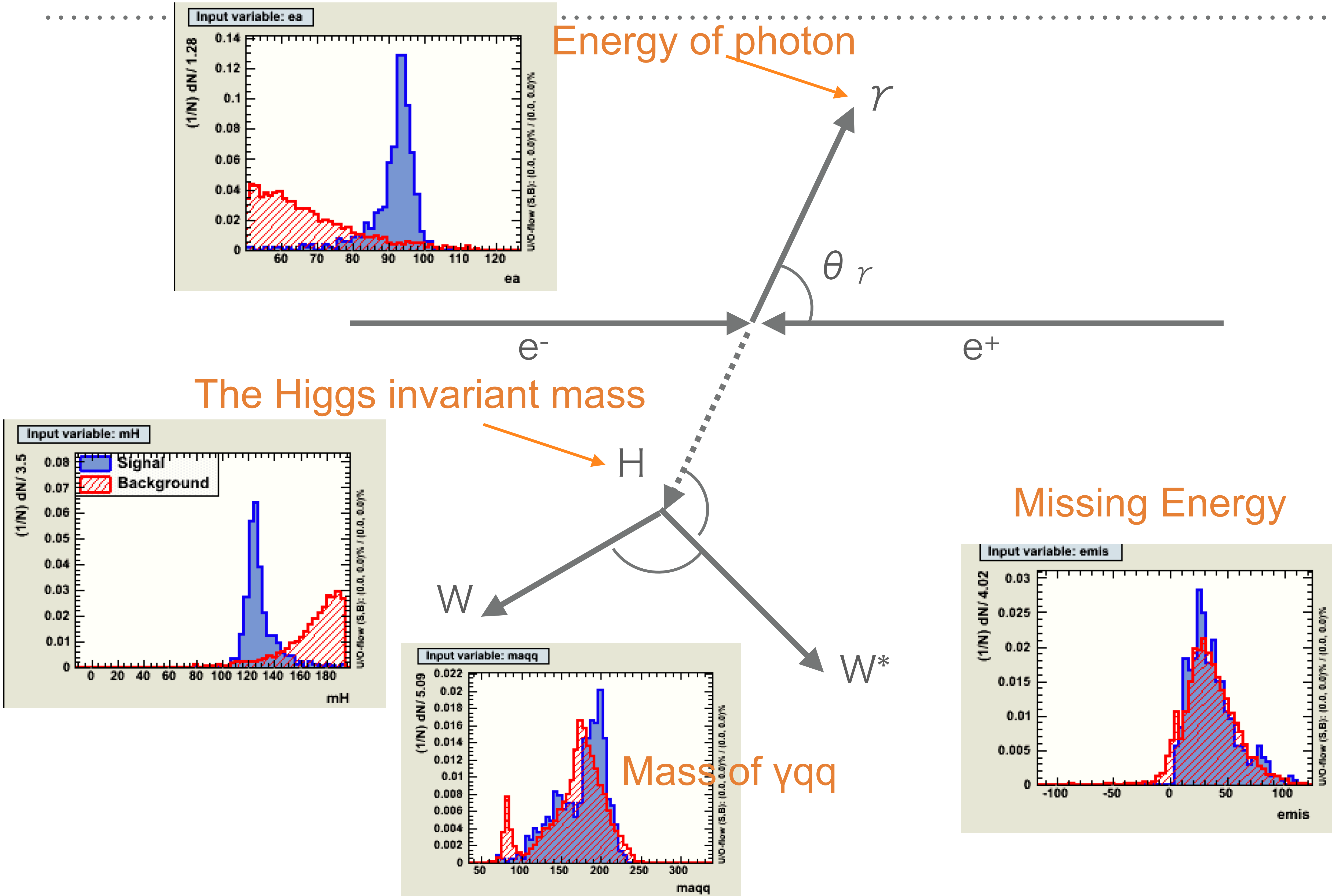




5.there are no b-quark jets

Cut3. b likeliness<0.77

5. Analysis - Input variables for MVA



5. Analysis - Reduction table and upper limit

Left	total bg	Signal	Significance
Expected	1.4×10^{8}	18.0	0.003
Pre selection	1.3×10^{7}	10.5	0.004
# of charged particle >3	3.1×10^{5}	5.4	0.010
|mw1-80.4|<10 GeV or |mw2-80.4|<9.4 GeV	1.9×10^{5}	3.7	0.009
b likeliness<0.77	1.8×10^{5}	3.7	0.009
mvabdt>0.1	41	1.0	0.16
$-0.93<\cos\theta_\gamma<0.93$	8	0.9	**0.31**

Right	total bg	Signal	Significance
Expected	7.8×10^{7}	1.9	0.000
Pre selection	1.2×10^{7}	2.0	0.000
# of charged particle >3	8.6×10^{4}	1.5	0.002
|mw1-80.4|<10 GeV or |mw2-80.4|<9.4 GeV	3.2×10^{4}	0.4	0.002
b likeliness<0.77	2.6×10^{5}	0.4	0.002
mvabdt>0.1	74	0.1	0.01
$-0.93<\cos\theta_\gamma<0.93$	5	0.1	**0.04**

5. Analysis - Uncertainty due to finite MC statistics

We conservatively re-estimated the numbers of remaining background events with high weights (= low statistics) and re-evaluated signal significance.

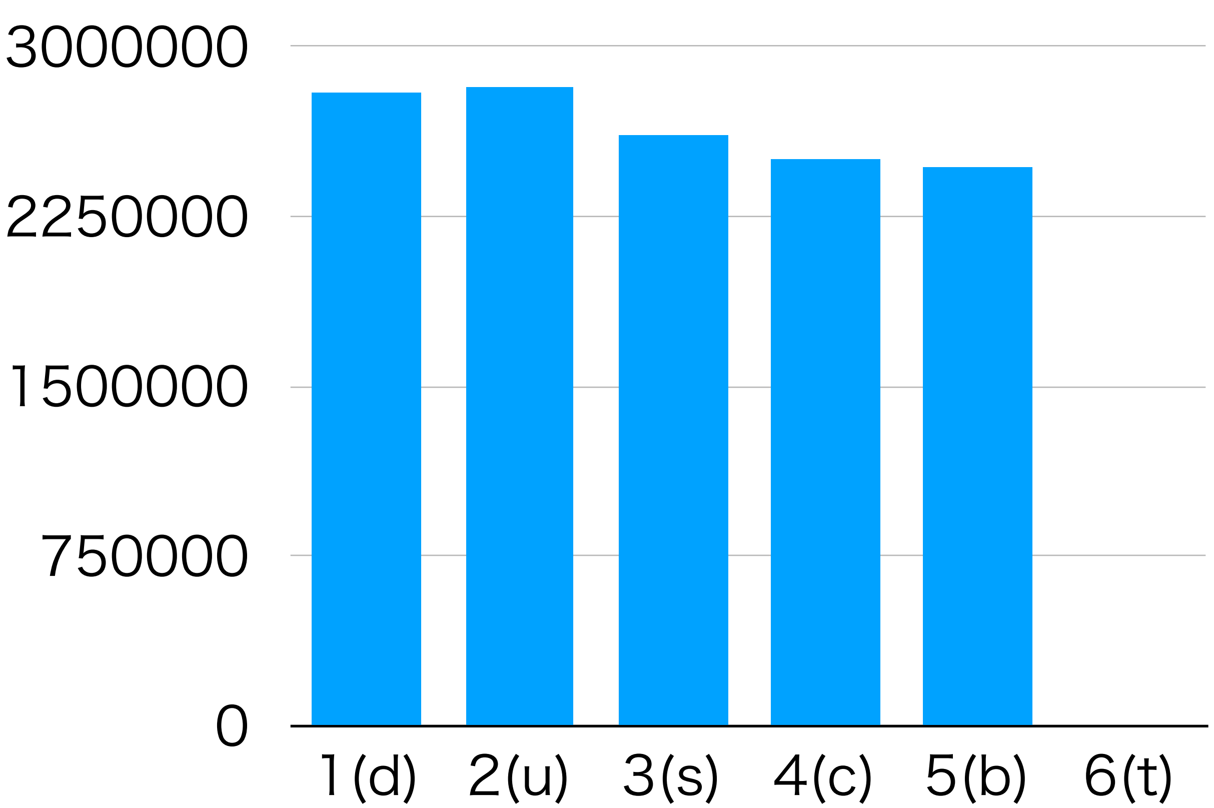
		total bg	Signal	Significance	95% C.L upper limit on σγH (fb)
h→bb Left	Nominal	12422	29	0.29	2.6
	Conservative	13488	29	0.25	2.7
h→bb Right	Nominal	5946	3	0.04	0.7
	Conservative	7204	3	0.04	0.8
h→WW* Left	Nominal	8	0.9	0.31	2.2
	Conservative	92	0.9	0.09	6.5
h→WW* Right	Nominal	5	0.1	0.01	0.7
	Conservative	21	0.1	0.02	1.2

5. Analysis - Uncertainty due to finite MC statistics

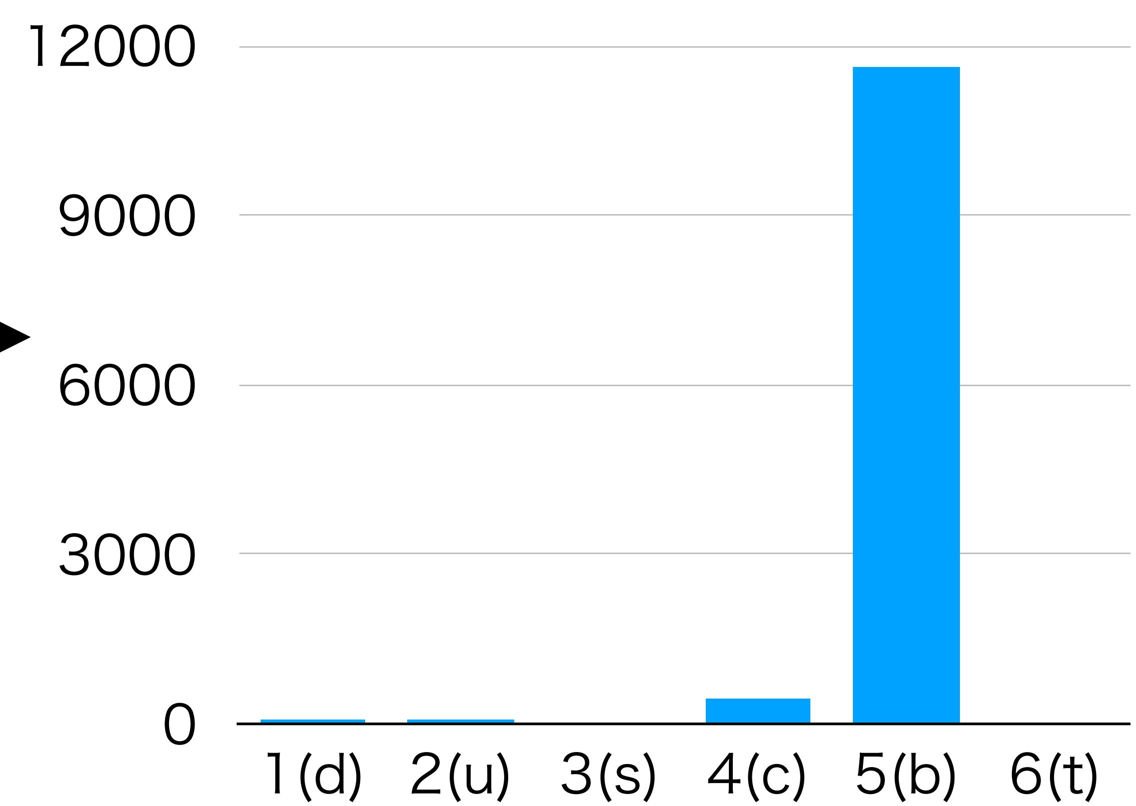
Is there any room to improve significance

by improving flavor tagging?

Before cuts



After cuts



By flavor cut (b-tag > 0.77), quarks other than b are cut off

→There is few room to improve significance

6. Combined result - Each polarization

95% C.L upper limit
(e-,e+=-100,+100)

$$\sigma_{\gamma H} = \sigma_{SM} + \frac{1.64}{\text{significance}}\sigma_{SM}$$

Left handed

H→bb Significance = 0.26 for SM

H→WW (Semi-leptonic) Significance = 0.31 for SM

Combined Significance = 0.40 for SM

$\sigma_{\gamma H}^{L} < 1.8$ fb (95% C.L upper limit)

Right handed

H→bb Significance = 0.039 for SM

H→WW (Semi-leptonic) Significance = 0.042 for SM

Combined Significance = 0.06 for SM

$\sigma_{\gamma H}^{R} < 0.5$ fb (95% C.L upper limit)

6. Combined result - conversion to ζ_{AZ}

$$L_{\gamma H} = L_{\rm SM} + \frac{\zeta_{AZ}}{v} A_{\mu\nu} Z^{\mu\nu} H + \frac{\zeta_A}{2v} A_{\mu\nu} A^{\mu\nu} H$$

Left handed Combined Significance = 0.40 for SM

5.1 > $\frac{\sigma_{\gamma H}}{\sigma_{SM}} = 1 - 273\zeta_A - 201\zeta_{AZ}$ >0 asume ζ_A =0

-0.020< ζ_{AZ} <0.005

Right handed Combined Significance = 0.06 for SM

28.3 > $\frac{\sigma_{\gamma H}}{\sigma_{SM}} = 1 + 492\zeta_A - 311\zeta_{AZ}$ >0 asume ζ_A =0

-0.088< ζ_{AZ} <0.0032

7. Summary

We have performed a full simulation study of $e^+e^- \to H\gamma$ at 250 GeV ILC, using ILD detector and full 1-loop SM amplitudes.

- signal significance and upper limit of σγH for SM at $\sqrt{s}$=250 GeV, 900 fb^{-1}

(Left handed) Significance = 0.40 for SM

σγH < 1.8 fb (95% C.L upper limit)

(Right handed) Significance = 0.06 for SM

σγH < 0.5 fb (95% C.L upper limit)

- Conversion to ζ_{AZ}

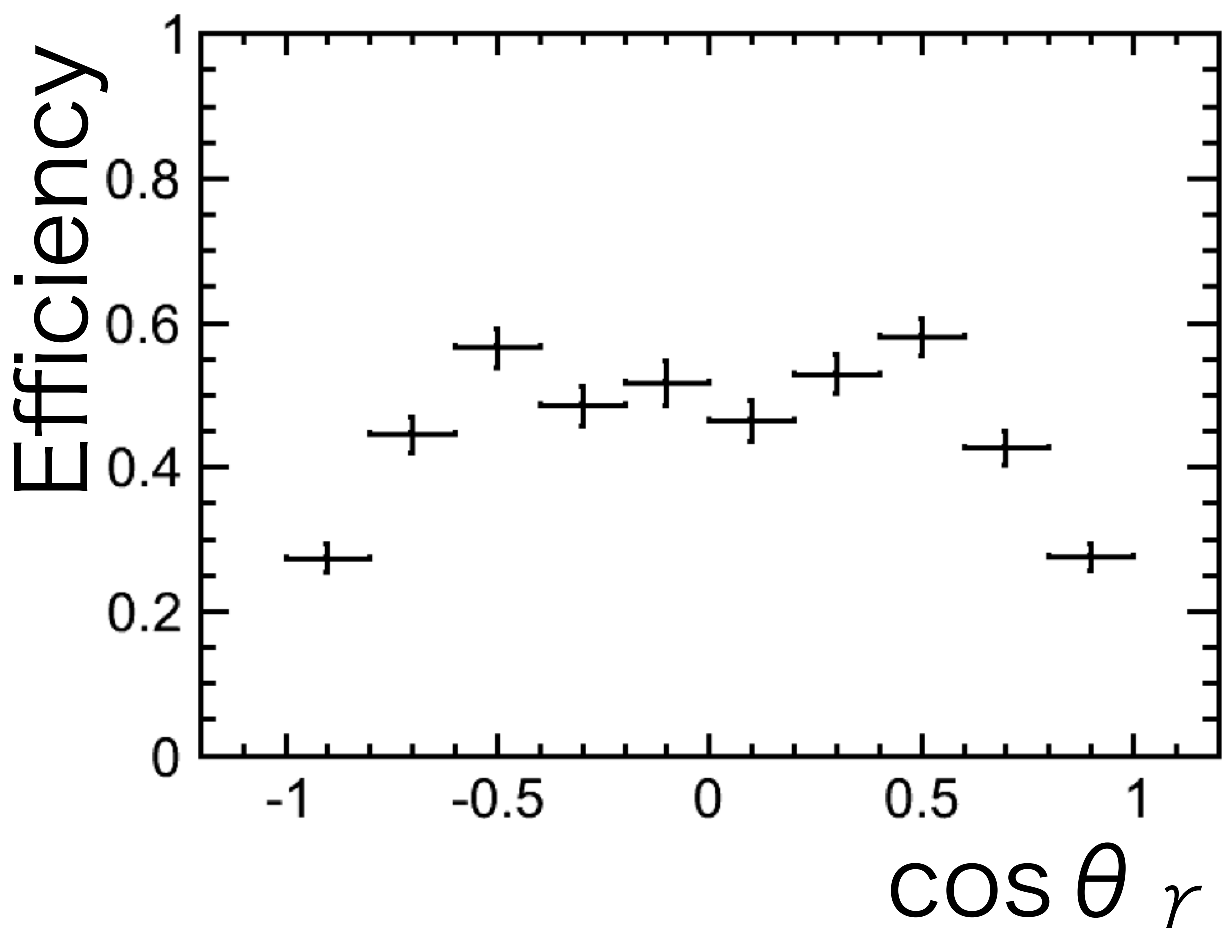
(Left handed) $-0.020 < \zeta_{AZ} < 0.005$

(Right handed) $-0.088 < \zeta_{AZ} < 0.0032$

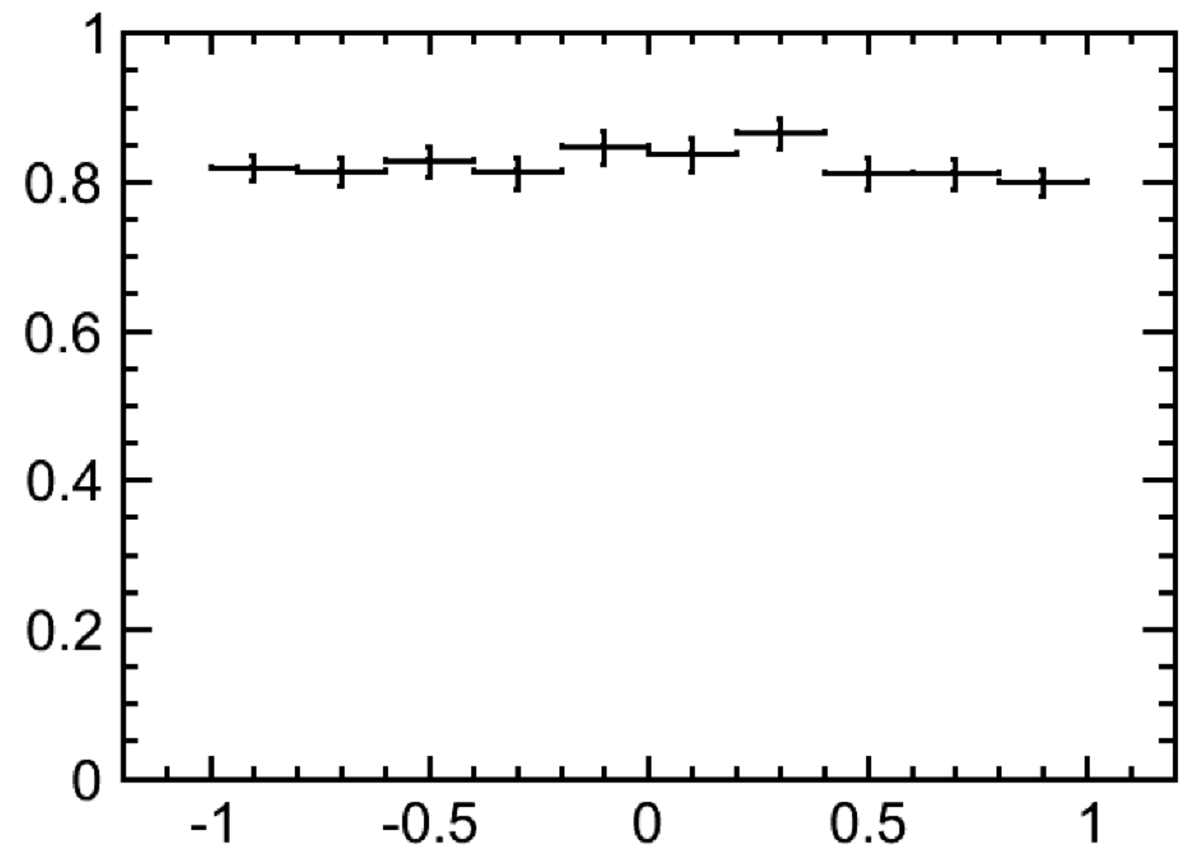
→ Discuss constraint on hγZ, concrete models, electron Yukawa coupling

Back up

cosθγ Distribution(bb)



Take in cos θ γ in MVA

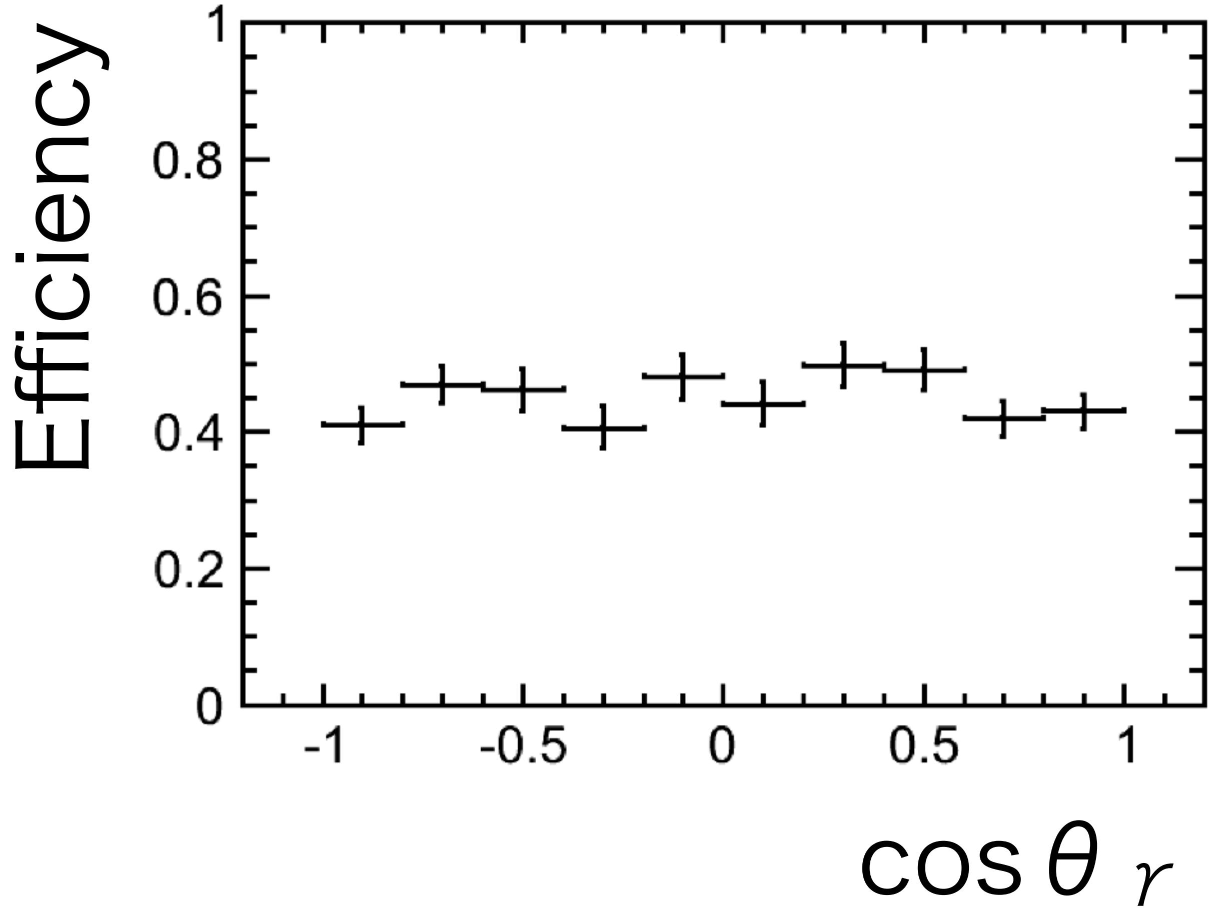


Take out cos θ γ from MVA

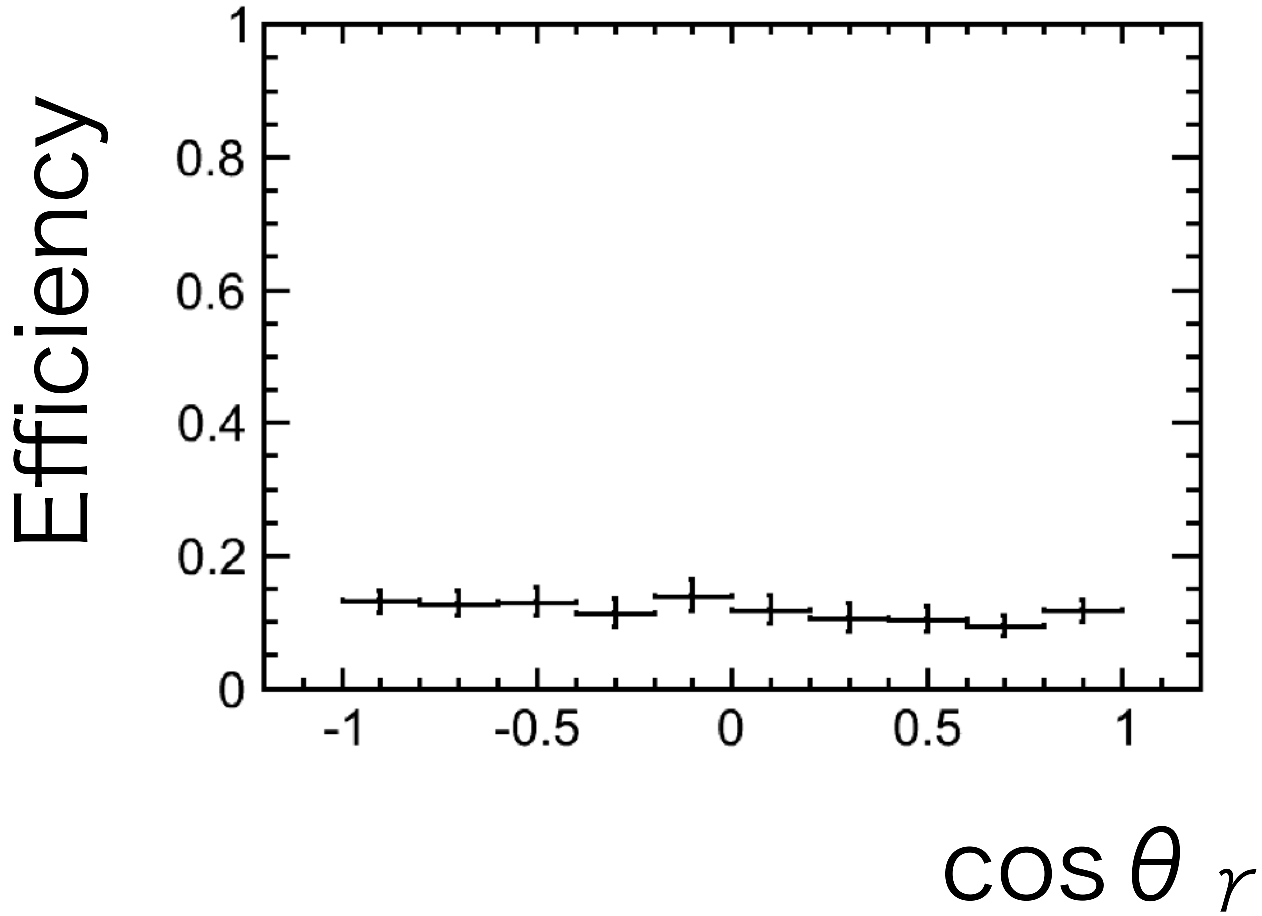
→ Check significant again

cosθγ Distribution(WW* sl)

Take in $\cos\theta_\gamma$ in MVA



Take out $\cos\theta_\gamma$ from MVA



→ Check significant again

4. Simulation framework - New Generator

Old

Implemented with EFT coefficients matched to SM $h\to\gamma\gamma$ / γZ loop calculations

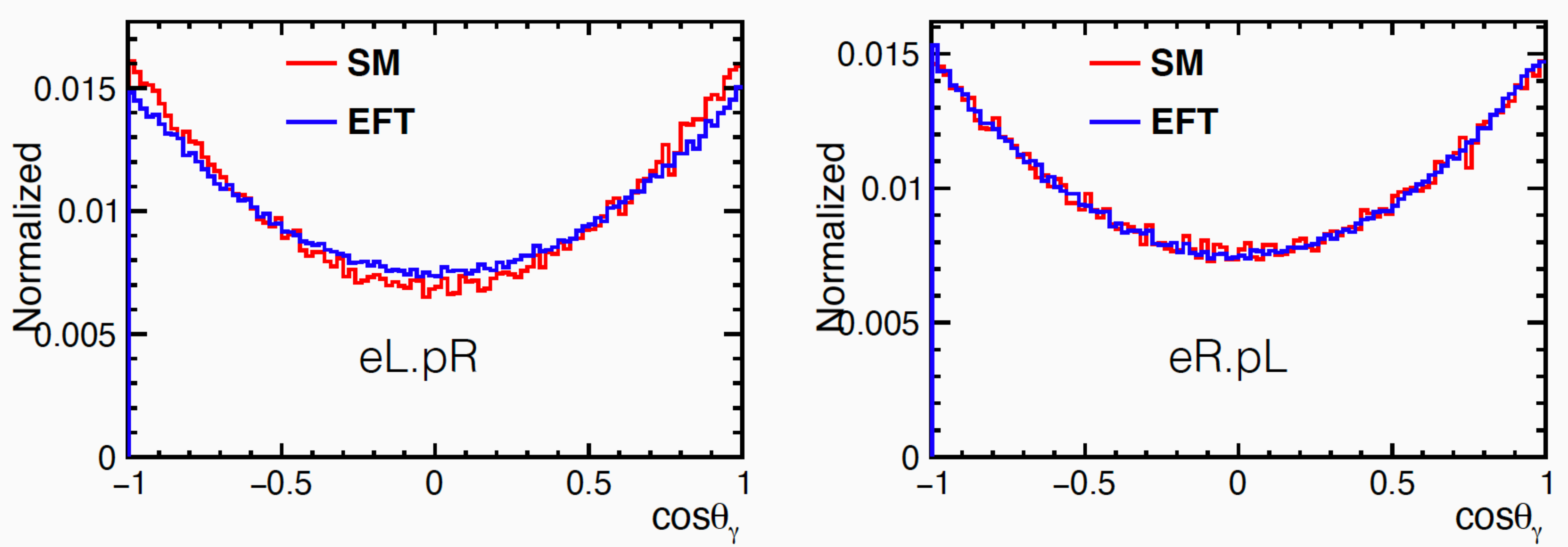
(without SM loop)

→

New

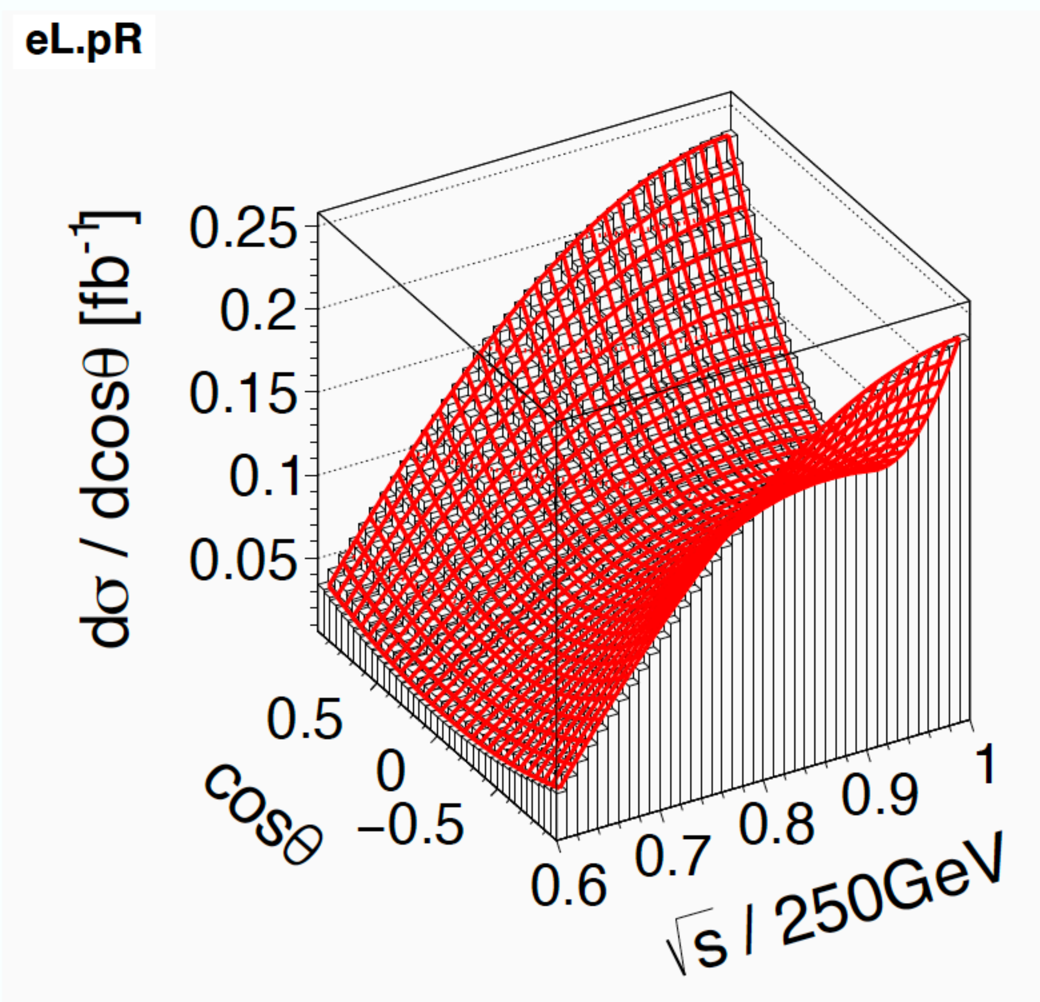
Implemented with full SM 1-loop calculations

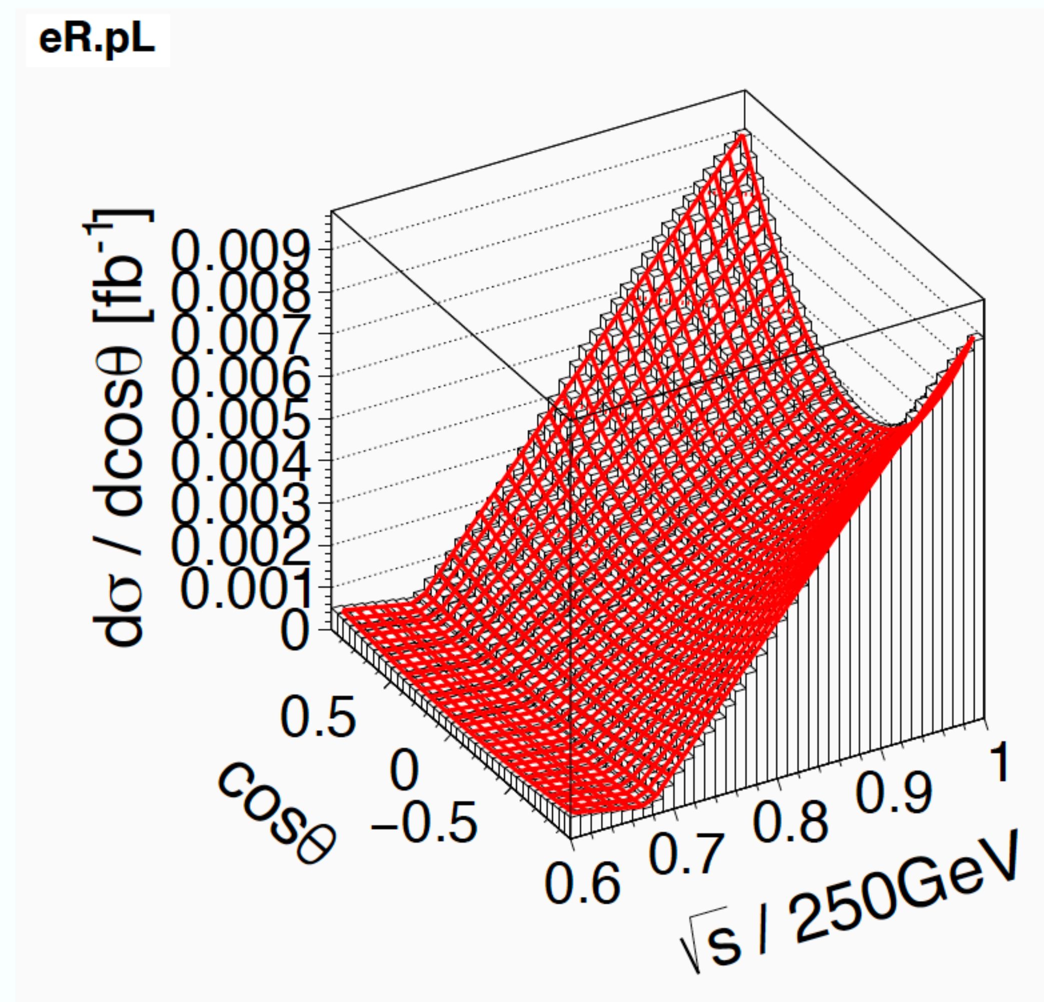
angular distribution:



new event generator

- earlier generator was implemented with only EFT, without SM loop
- what's new is an implementation of parameterized SM differential cross section, by which impact of ISR on total cross section is also naturally taken into account





Lego: numerical calculation; Mesh: polynomial parameterization