Study of HγZ coupling using $e^+e^- \to \gamma H$ at the ILC

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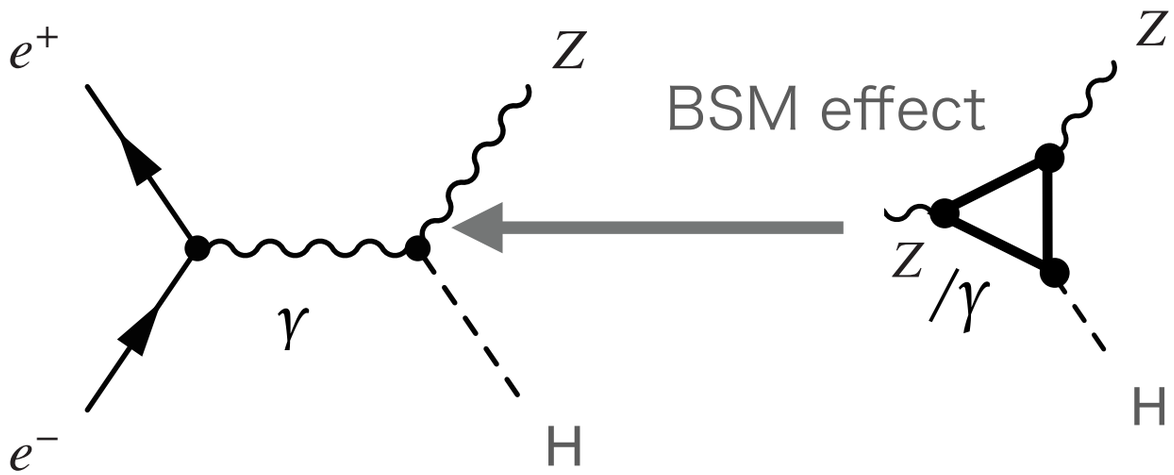
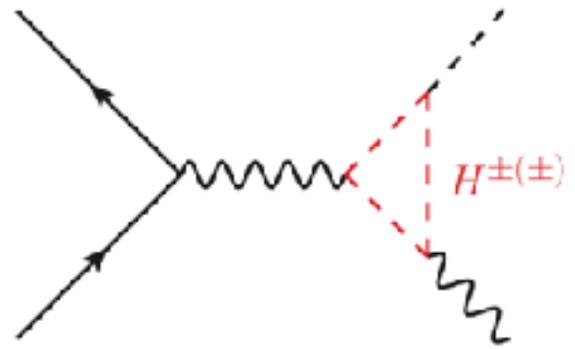
1.Motivation

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.

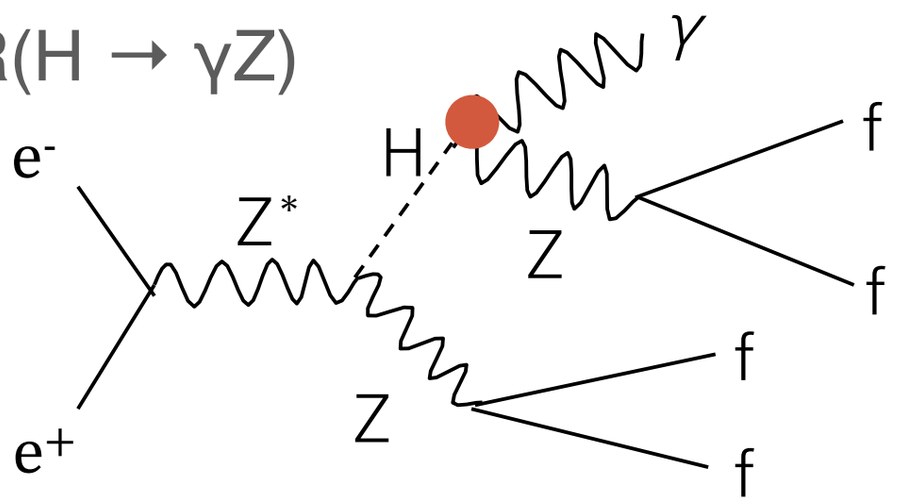
Q. H. Cao, et al, arXiv:1505.00654 [hep-ph]

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

2.Two ways to measure HγZ coupling

Higgs decay

BR(H → γZ)

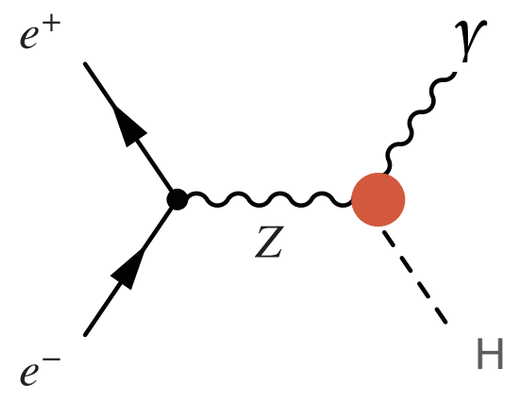


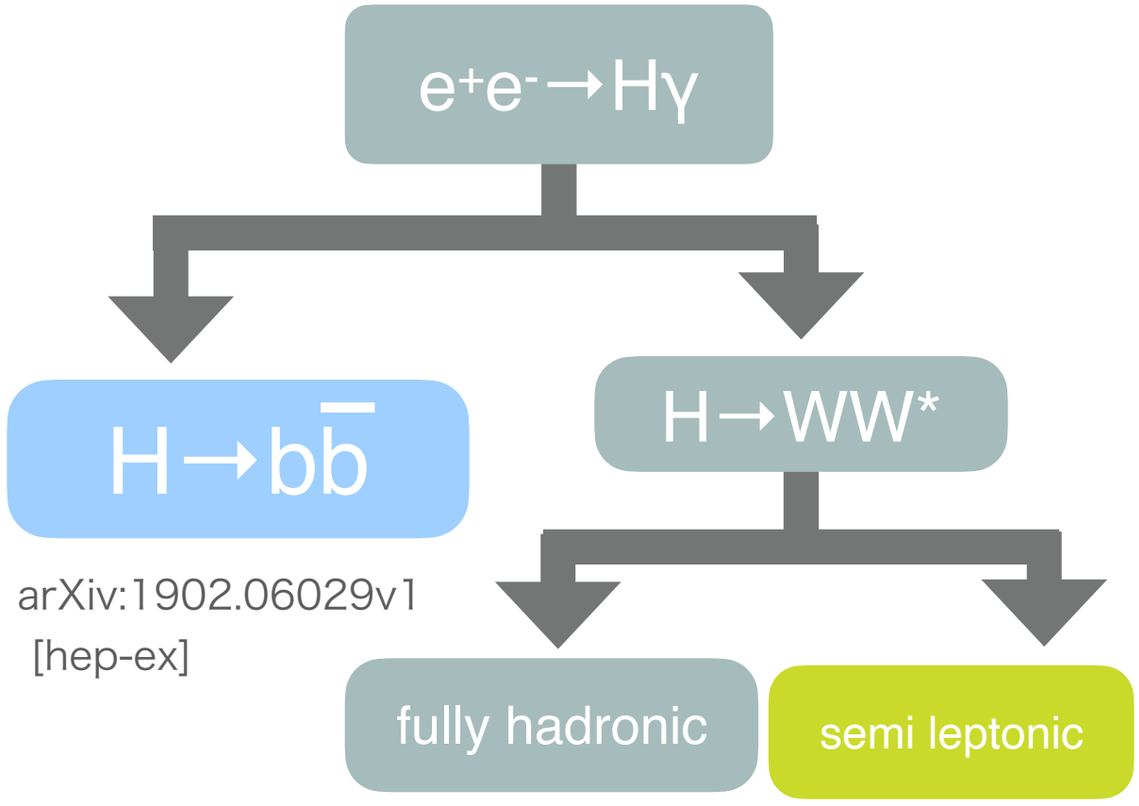
final state	BR
mmqqγ	4.7%
eeqqγ	4.7%
nnqqγ	28.0%
qqqqγ	48.9%
others	13.7%

by Kazuki Fujii at LCWS2018

Higgs production

σ（e+e- →Hγ）





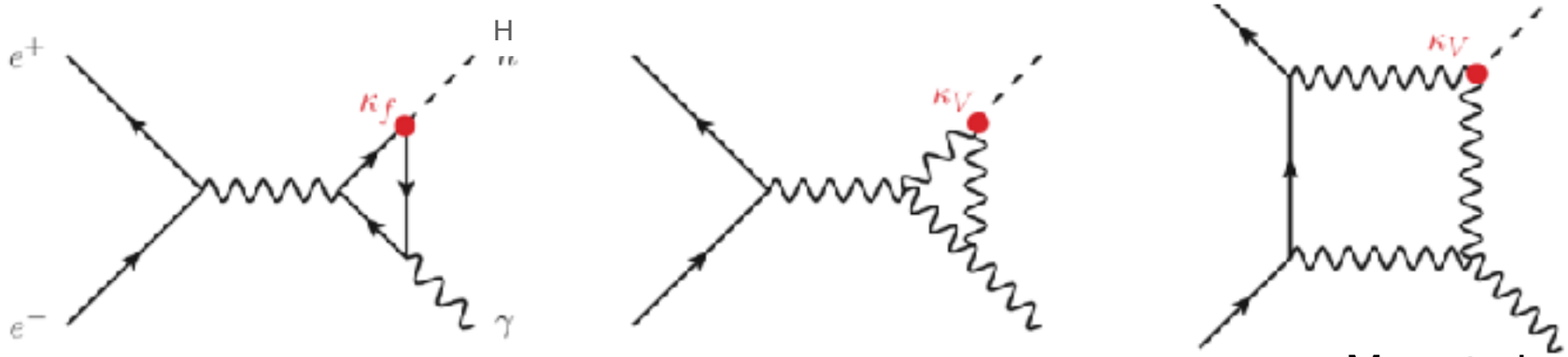
arXiv:1902.06029v1 [hep-ex]

arXiv:2002.07164 [hep-ex]

3. 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%)

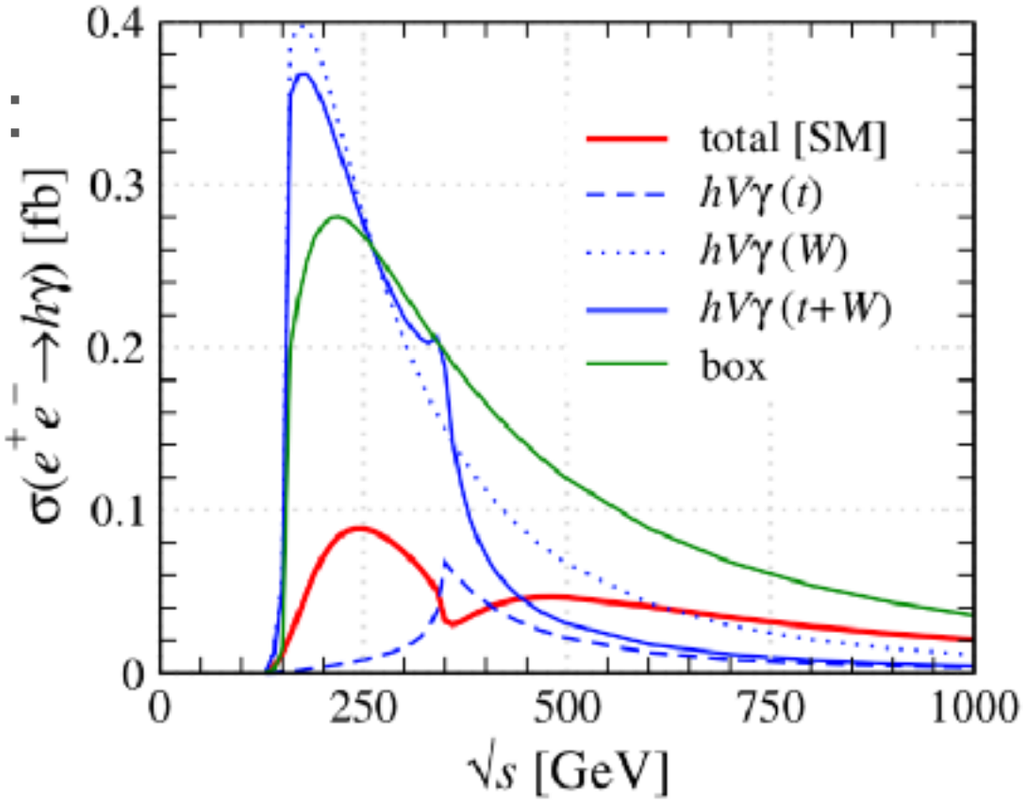
σ_{SM}=0.016 fb for (+100%,-100%)

σ_{SM}=**0.20 fb** for (-80%,+30%)

$\sqrt{s}$ = 250 GeV

Small !

This analysis is very challenging.



※For unpolarized beam

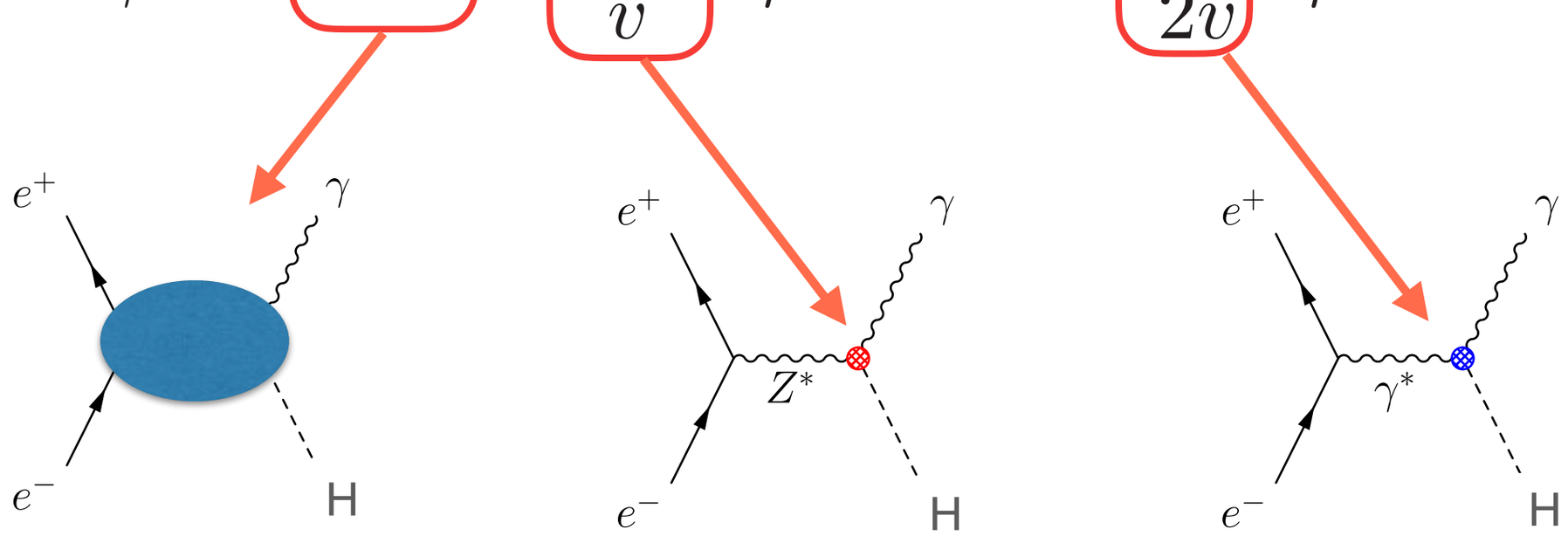
Destructive interference

3. Theoretical framework for our analysis

The effective field theory (EFT) Lagrangian to include new physics contributions to the $e^+e^- \rightarrow H\gamma$ cross section model-independently

effective h γ Z coupling　　effective h γ γ coupling

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



Phys.Rev. D94 (2016) 095015

Aμν, Zμν : field strength tensors　　v: vacuum expectation value

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

- √s=250 GeV
  Integrated Luminosity: 2000 fb^{-1}
  (900 fb^{-1} for Left handed / Right handed)
- 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

New Generator

Old

Implemented with only EFT

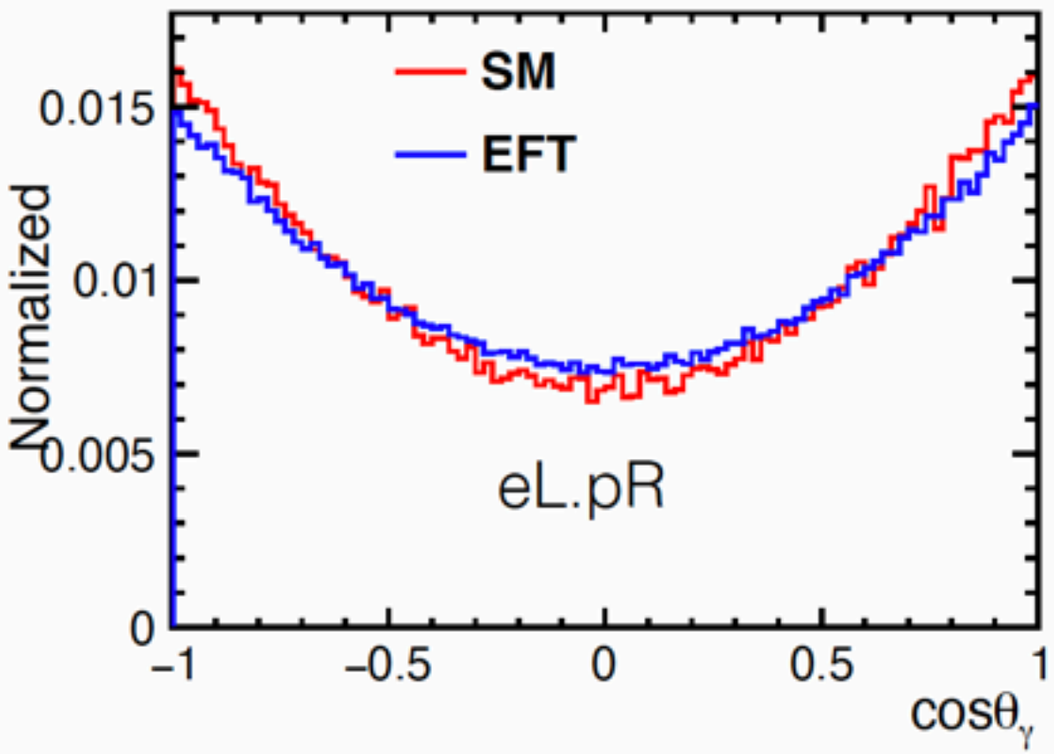
(without SM loop)

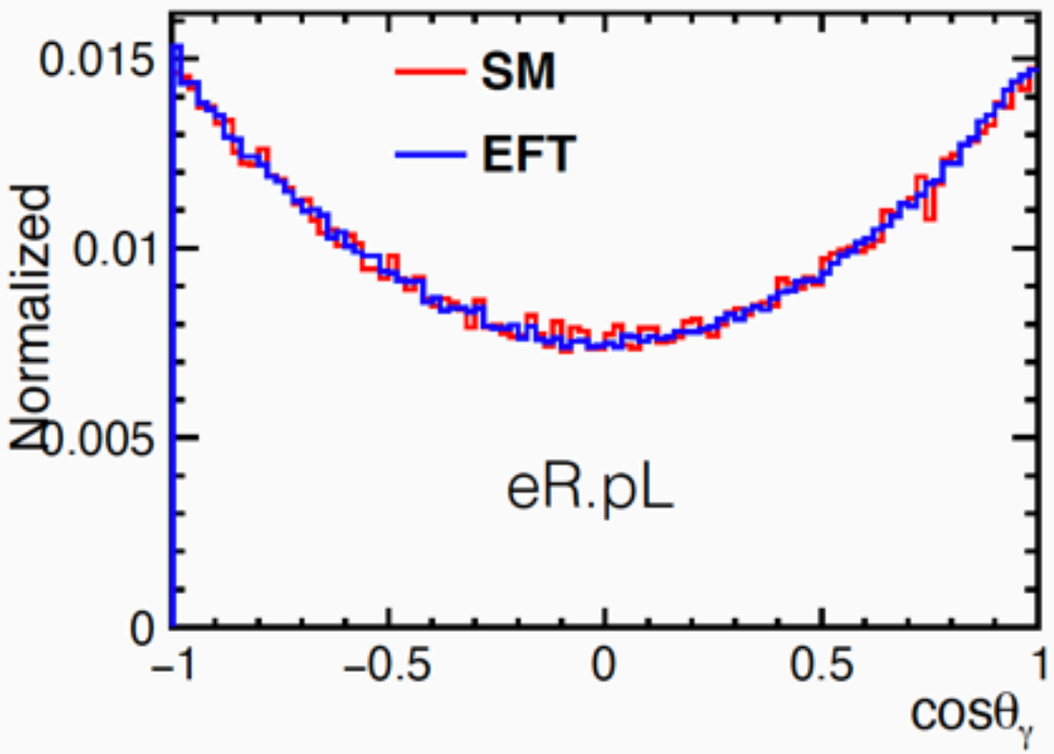
New

Implemented parameterized SM differential cross section

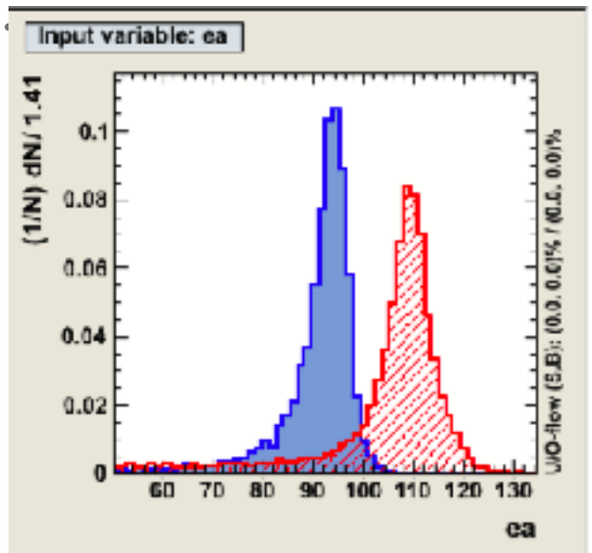
→impact of ISR on total cross section is also naturally taken into account

angular distribution:

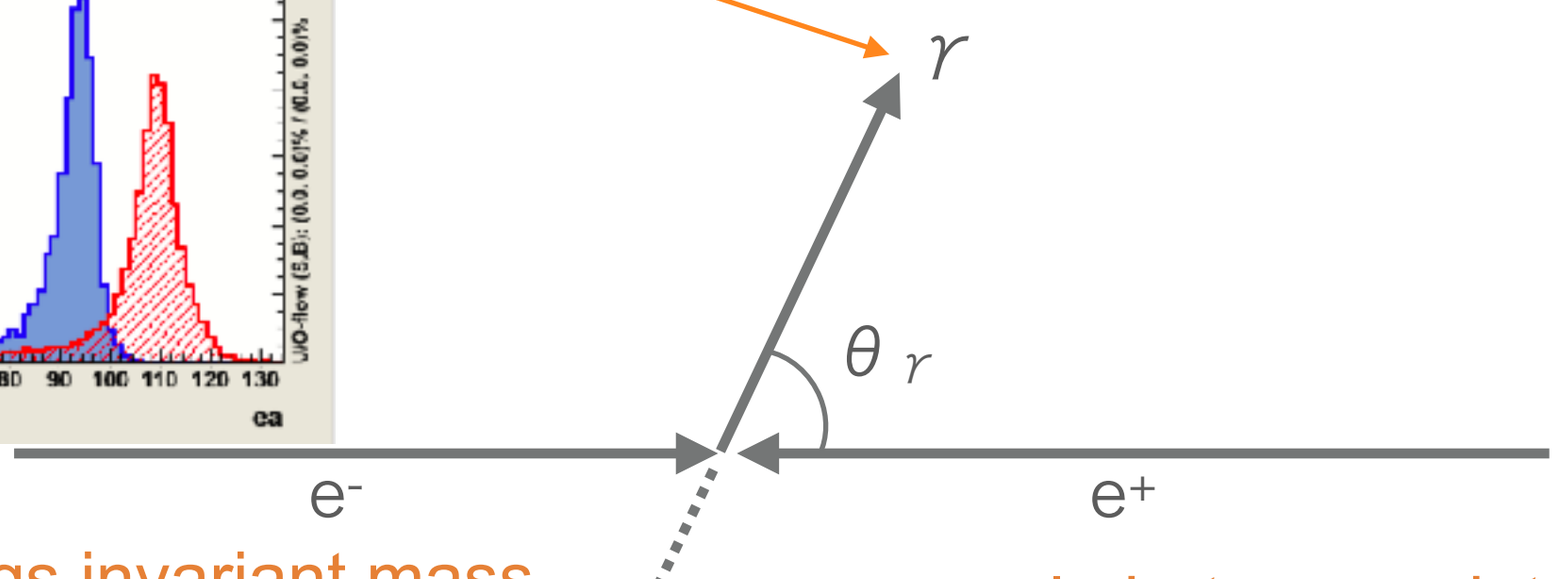




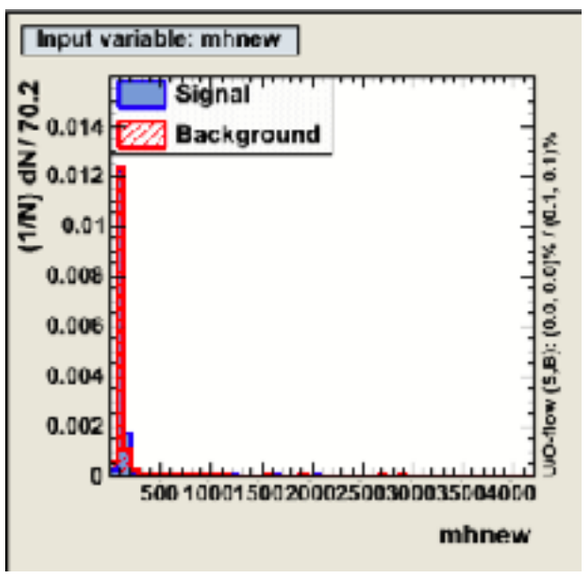
5. Analysis - Input variables for MVA

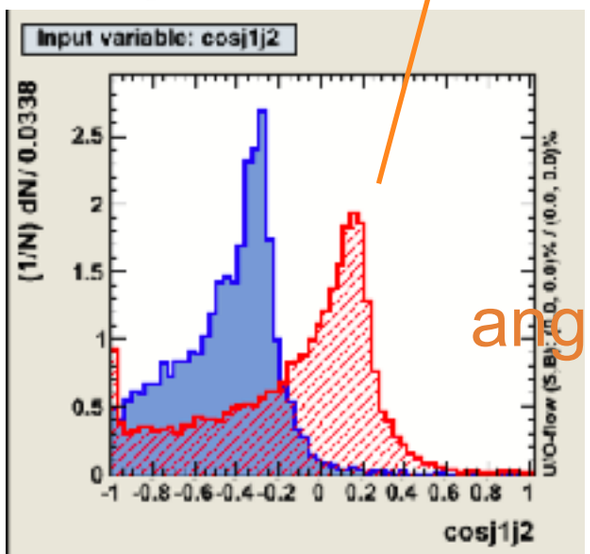


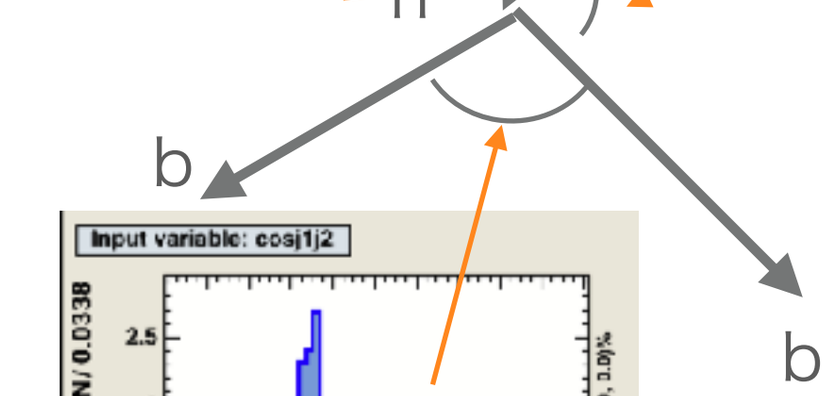
Energy of photon



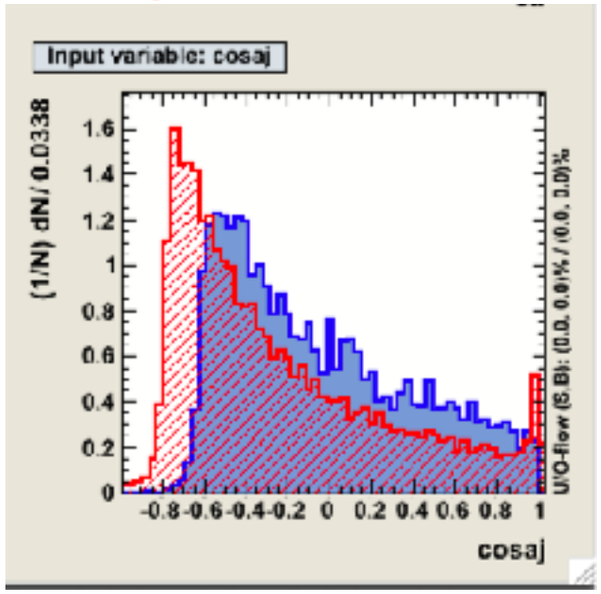
The Higgs invariant mass





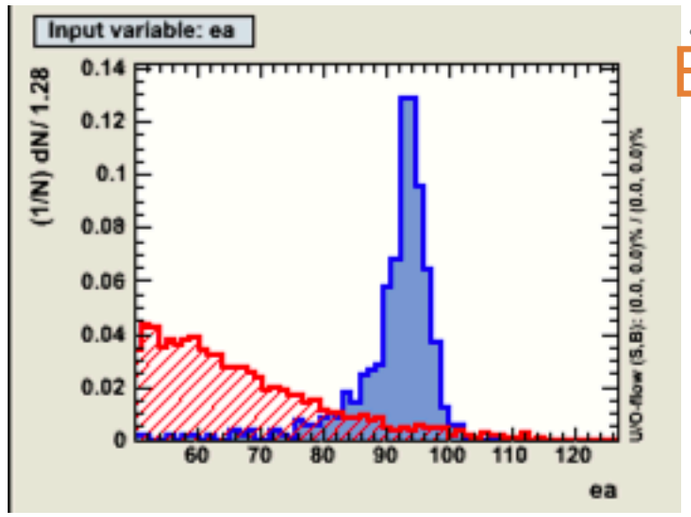


angle between a jet and photon

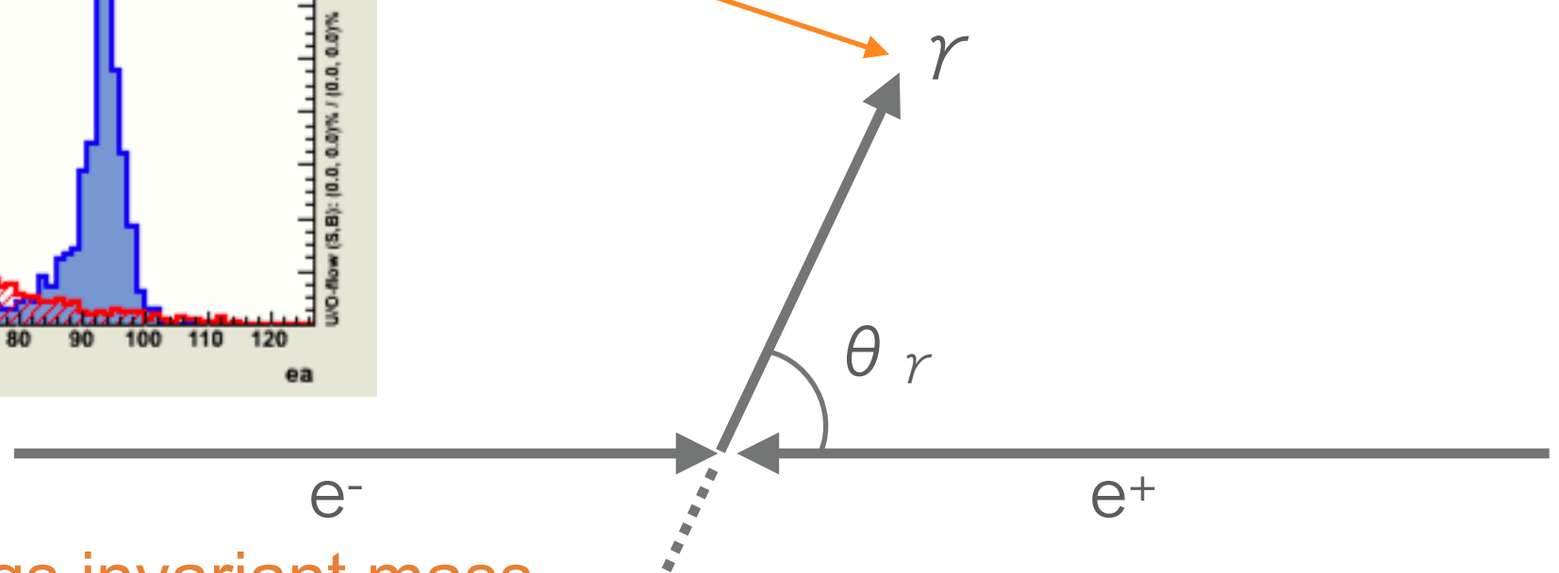


angle between 2jets

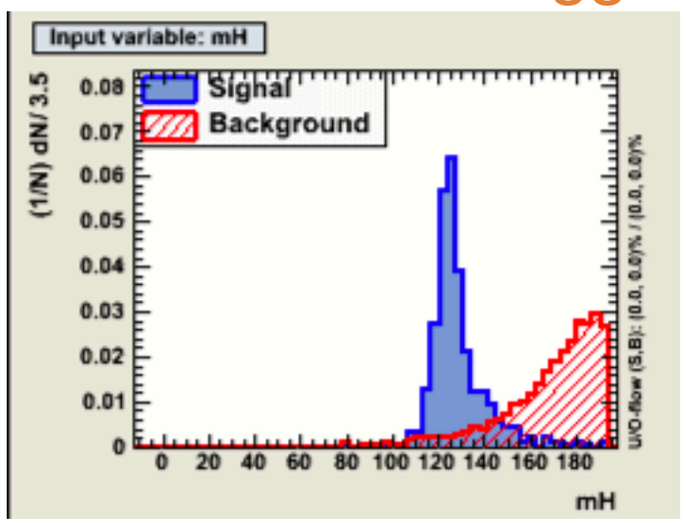
5. Analysis - Input variables for MVA

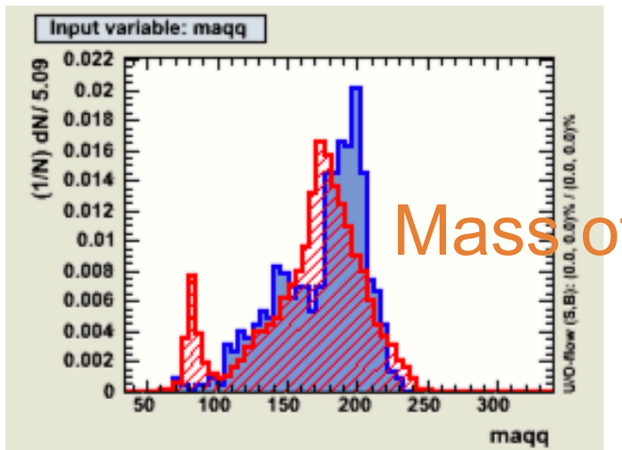


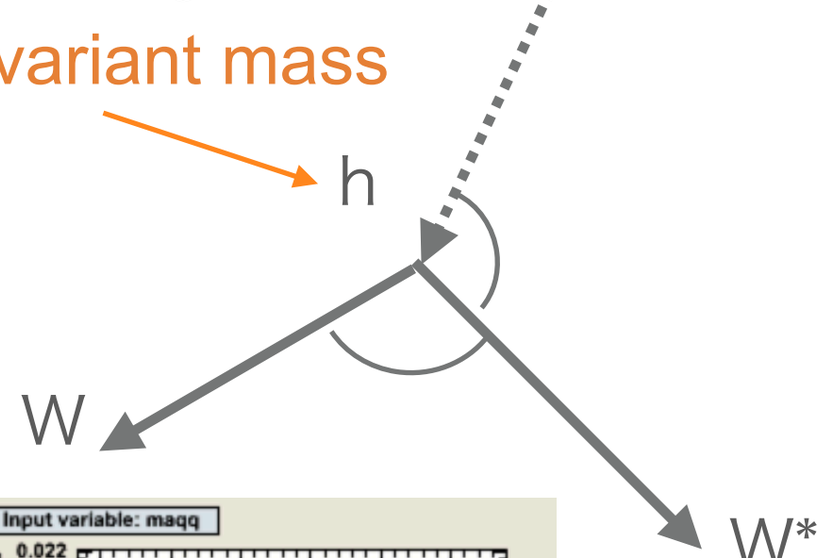
Energy of photon



The Higgs invariant mass

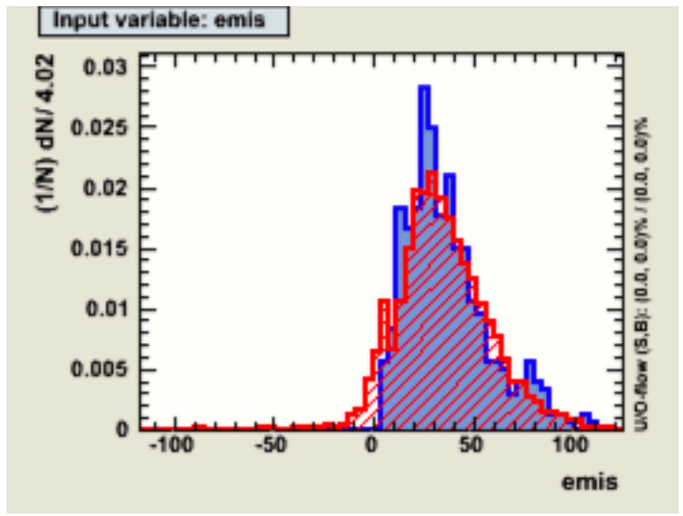






Mass of γqq

Missing Energy



5. Analysis - Result of h→bb (Left handed)

Reduction table

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

N_s:Number of signal N_B:Number of background

	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	2.2×10^7	90	0.06
E_{mis}<35	1.9×10^6	82	0.06
mvabdt > 0.025	34814	48	0.26
$-0.92<\cos\theta_\gamma<0.92$	21257	43	0.29

Preliminary

Dominant background : $e^+e^- \rightarrow \gamma Z \rightarrow \gamma qq$

→95% C.L upper limit $\sigma_{\gamma H} = \sigma_{SM} + \frac{1.64}{\text{significance}}\sigma_{SM}$

=2.3 [fb] （Left handed beam polarization case）

5. Analysis - Result of h→bb (Right handed)

Reduction table

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

N_s:Number of signal N_B:Number of background

	total bg	Signal	Significance
Expected	77667900	6.4	0.001
Pre selection	23220500	5.9	0.001
b likeliness>0.77	1461840	5.3	0.004
E_{mis}<35	1264340	4.9	0.004
mvabdt > 0.025	19923	2.9	0.021
-0.92<cosθ_γ<0.92	11986	2.6	0.023

Preliminary

→95% C.L upper limit $\sigma_{\gamma H} = \sigma_{SM} + \frac{1.64}{\text{significance}}\sigma_{SM}$

= 1.6 [fb] （Right handed beam polarization case）

5. Analysis - Reduction table

	total bg	Signal	Significance
Expected	1.4×10^{8}	18.0	0.003
Pre selection	1.3×10^{7}	11.0	0.004
# of charged particle >3	306997	5.4	0.010
|mw1-80.4|<10 GeV or |mw2-80.4|<9.4 GeV	184537	3.7	0.009
b likeliness<0.77	175276	3.7	0.009
mvabdt>0.1	214	1.8	0.12
$-0.93<\cos\theta_{\gamma}<0.93$	35	1.6	0.26

Preliminary

Dominant background : $e^+e^- \rightarrow W^+W^-$

→95% C.L upper limit $\sigma_{\gamma H} = \sigma_{SM} + \dfrac{1.64}{\text{significance}}\sigma_{SM}$

=2.6 [fb] （Left handed）

5. Analysis - Reduction table (Right handed)

	total bg	Signal	Significance
Expected	77667900	1.1	0.000
Pre selection	12315600	2.2	0.000
# of charged particle >3	86237	1.9	0.001
|mw1-80.4|<10 GeV or |mw2-80.4|<9.4 GeV	32304	0.2	0.001
b likeliness<0.77	26083	0.2	0.001
mvabdt>0.1	161	0.1	0.008
-0.93<cosθ$_\gamma$<0.93	52	0.1	0.013

Preliminary

→95% C.L upper limit $\sigma_{\gamma H} = \sigma_{SM} + \frac{1.64}{\text{significance}}\sigma_{SM}$

= 2.8 [fb] （Right handed）

MC uncertainty

There is MC statistics errors →We estimated Monte Calro fluctuation

h→bb

	total bg	Signal	Significance
After all cuts	24423	43.0	0.27

→95% C.L upper limit $\sigma_{\gamma H} = \sigma_{SM} + \frac{1.64}{\text{significance}}\sigma_{SM}$

~2.5 [fb] （Left handed）

h→WW*
semi leptonic

	total bg	Signal	Significance
After all cuts	101	1.6	0.16

→95% C.L upper limit $\sigma_{\gamma H} = \sigma_{SM} + \frac{1.64}{\text{significance}}\sigma_{SM}$

~3.9 [fb] （Left handed）

6. Combined result

Left handed

H→bb Significance = 0.29 for SM

H→WW (Semi-leptonic) Significance = 0.26 for SM

Combined **σγH < 1.8 fb** (95% C.L upper limit)

Right handed

H→bb Significance = 0.023 for SM

H→WW (Semi-leptonic) Significance = 0.013 for SM

Combined **σγH < 1.4 fb** (95% C.L upper limit)