ILCにおける$e^+e^-\to\gamma H$を使った$H\gamma Z$結合の研究

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

Yumi Aoki(SOKENDAI), Junping Tian(Tokyo Univ.)
, Keisuke Fujii(KEK),
Sunghoon Jung(Seoul National Univ.),
Junghwan Lee(Seoul National Univ.),

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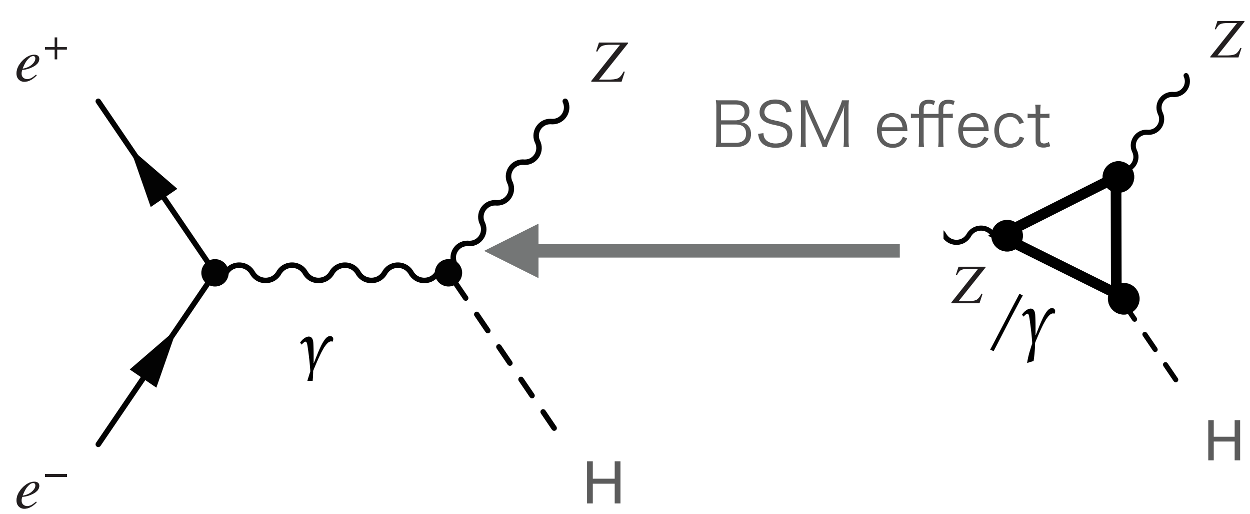
Contents

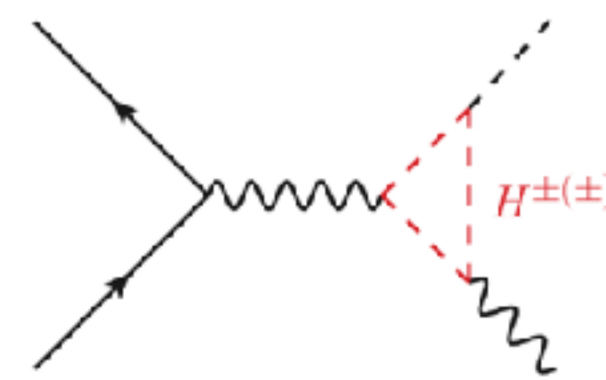
1.Motivation

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.

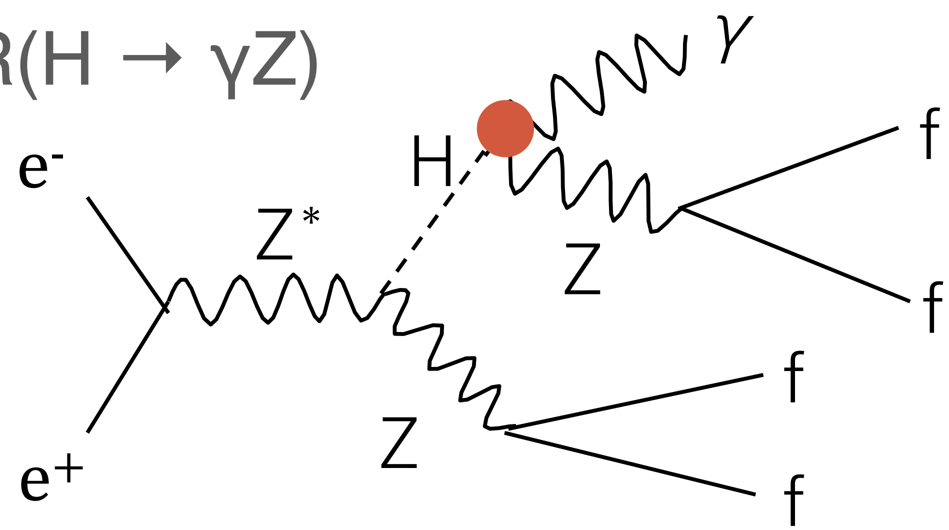
Q. H. Cao, et al, arXiv:1505.00654 [hep-ph]

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

2.Two ways to measure HγZ coupling

Higgs decay

BR(H → γZ)

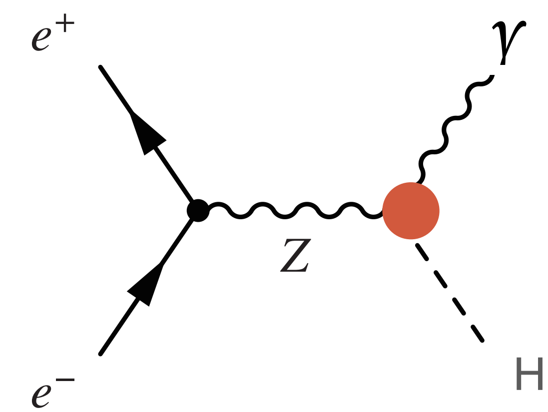


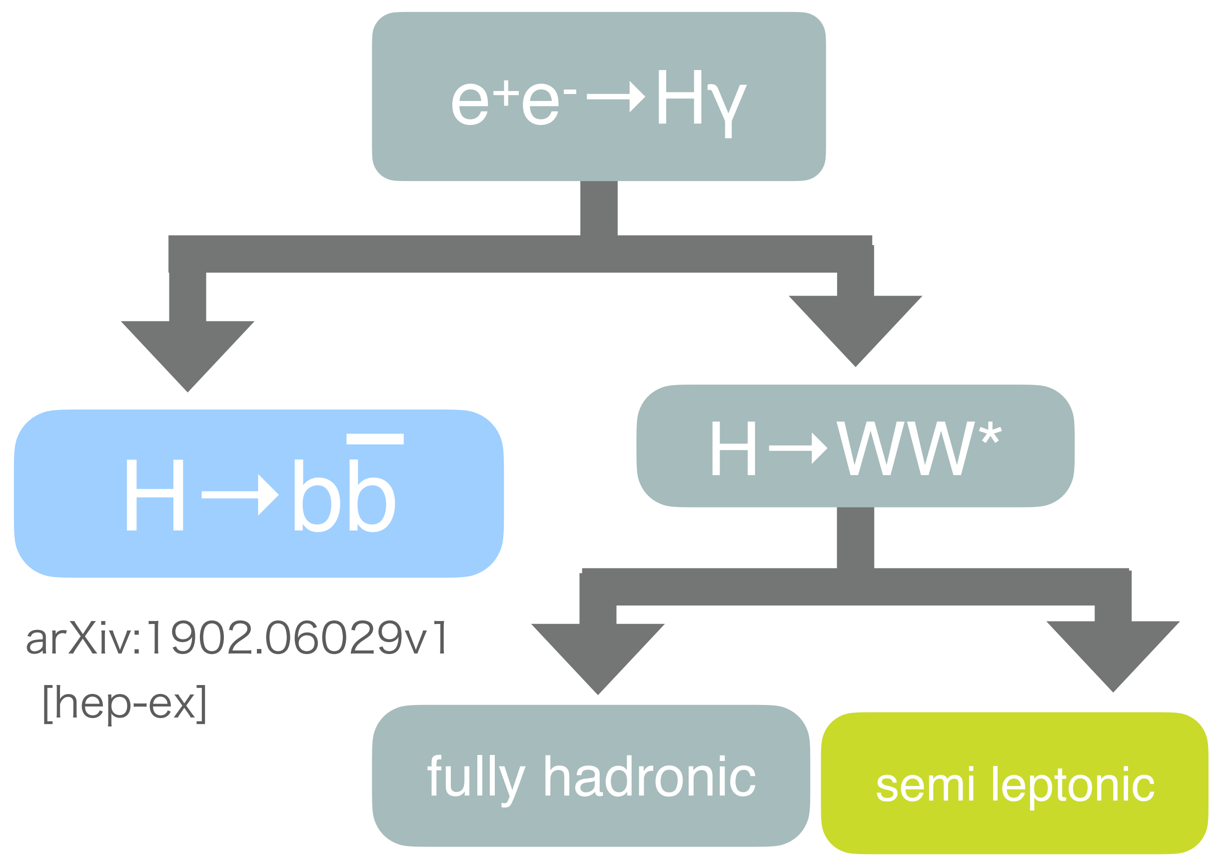
final state	BR
mmqqγ	4.7%
eeqqγ	4.7%
nnqqγ	28.0%
qqqqγ	48.9%
others	13.7%

by Kazuki Fujii at LCWS2018

Higgs production

σ（$e^+e^- \to H\gamma$）





arXiv:1902.06029v1 [hep-ex]

arXiv:2002.07164 [hep-ex]

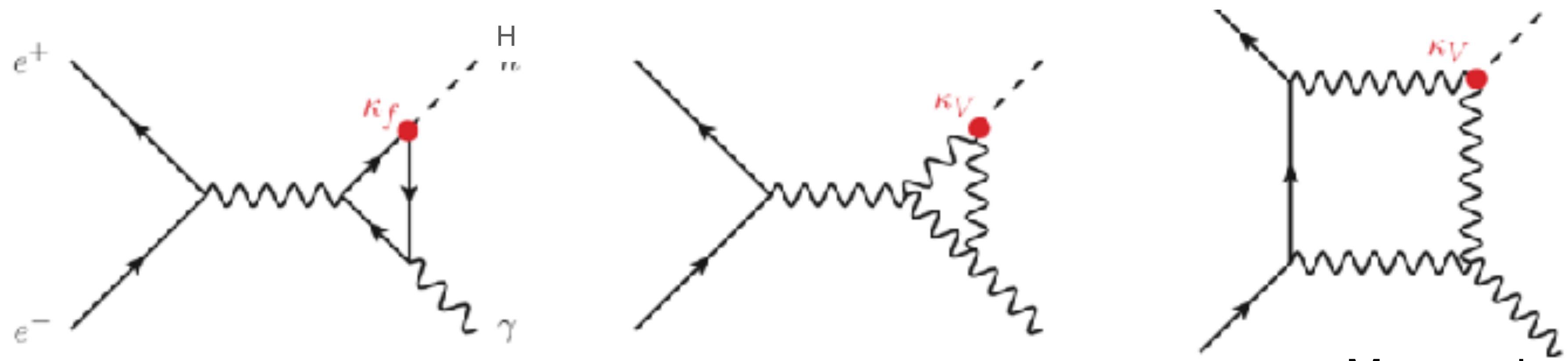
h→bb

h→WW*
semi leptonic

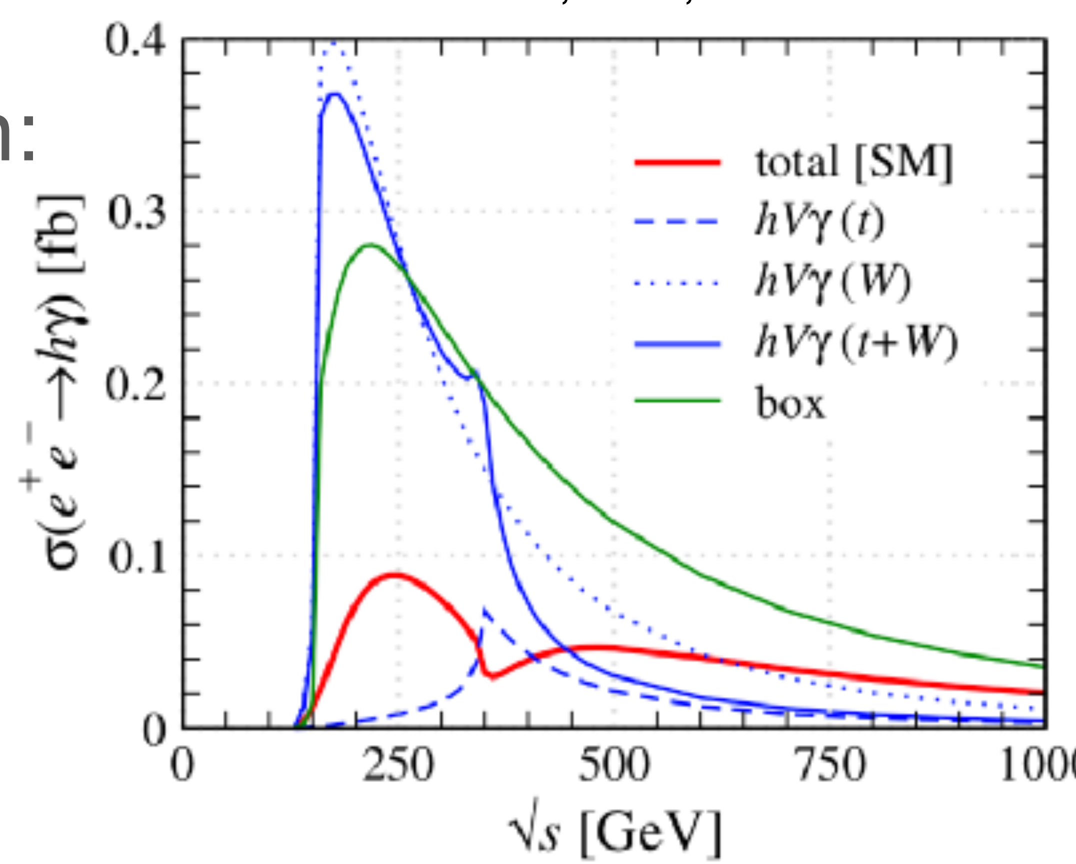
3. Theoretical framework for our analysis

SM one-loop predictions

The main Feynman diagrams



Mawatari, et al, arXiv:1808.10268



※For unpolarized beam

Destructive interference

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 !

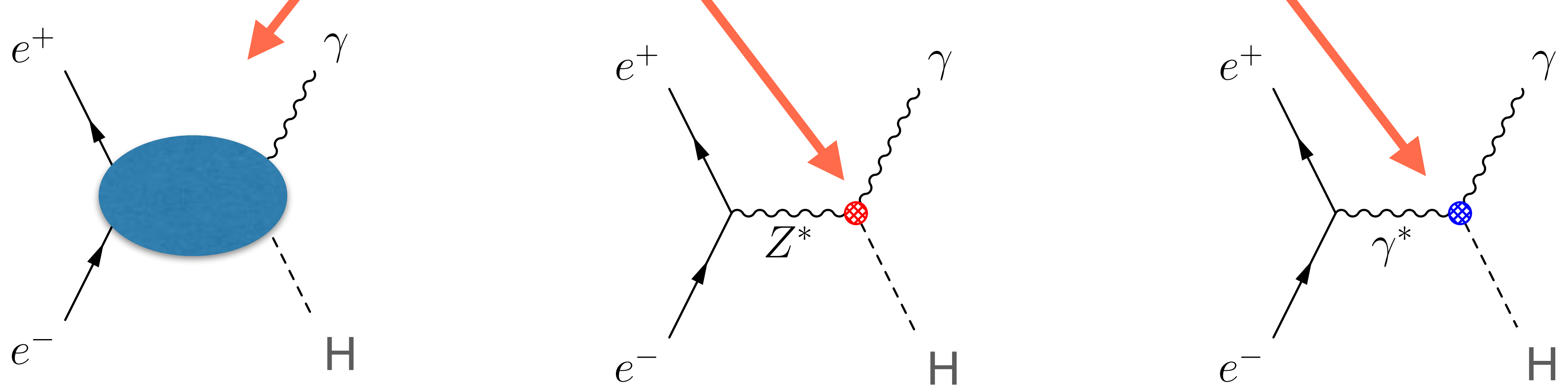
This analysis is very challenging.

3. Theoretical framework for our analysis

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

effective hγZ coupling   effective hγγ coupling

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



Phys.Rev. D94 (2016) 095015

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

Since ζ_A is already constrained by measurement of $H \to \gamma\gamma$ 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} for Left handed)
- background : 2f,4f (DBD sample)
- ISR and Beamstrahlung effects are included

Detector simulation

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

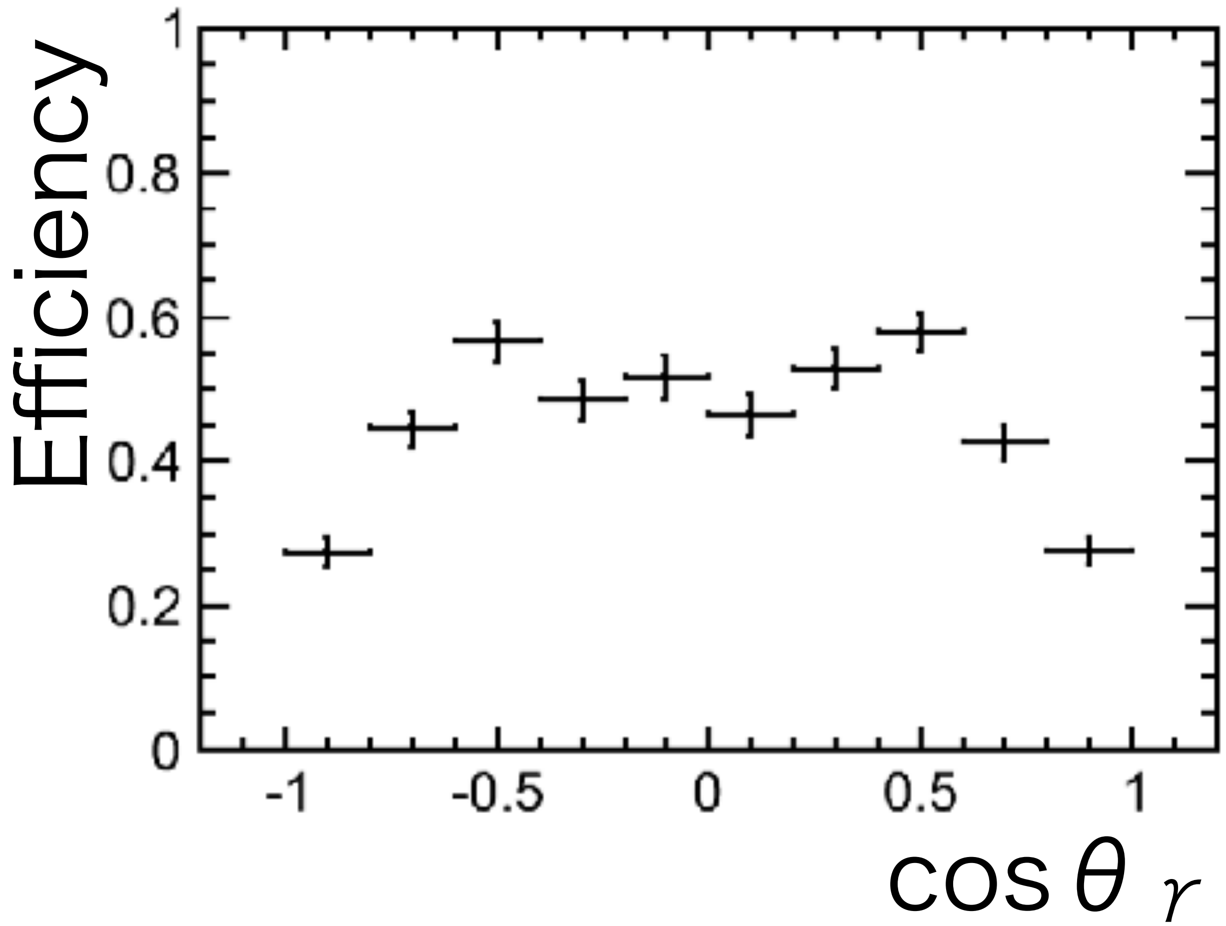
Event reconstruction

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

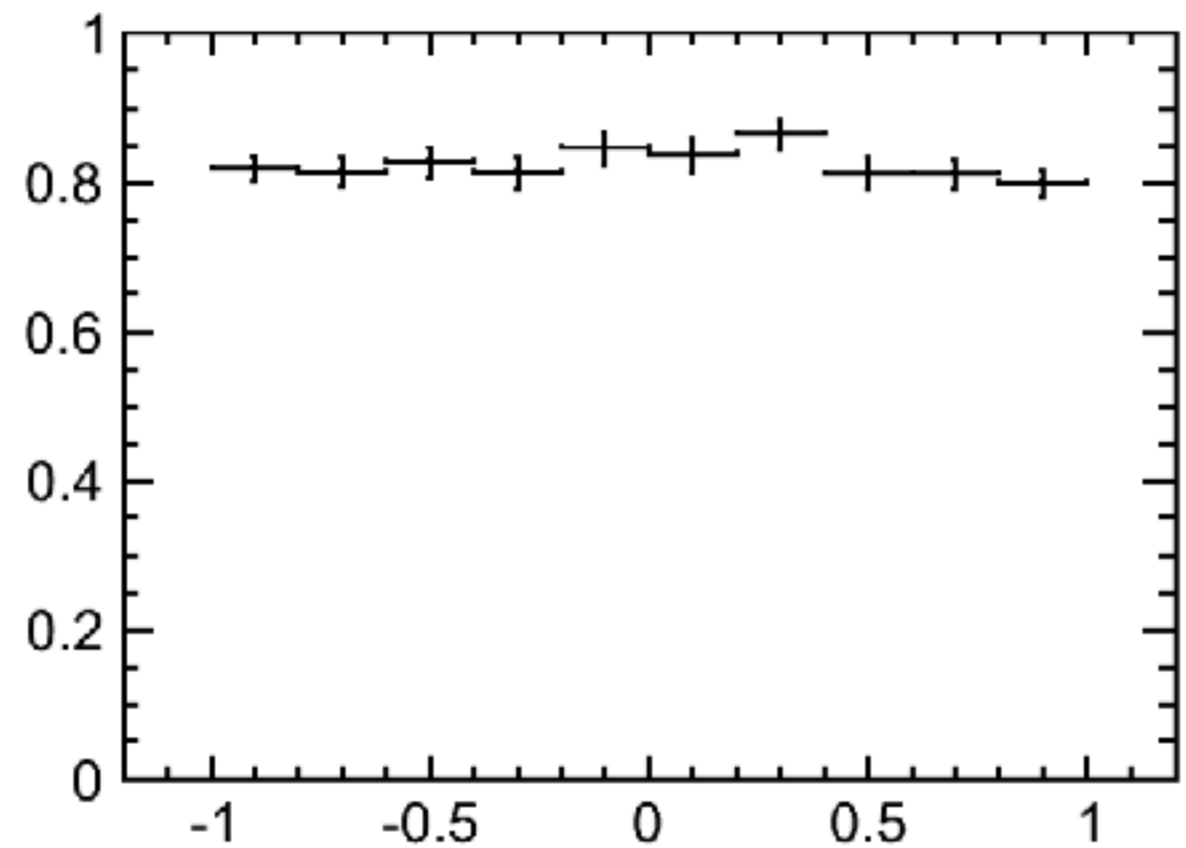
Event selection

- $E_\gamma >$ 50 GeV

cosθγ Distribution(bb)



Take in cos θ γ in MVA

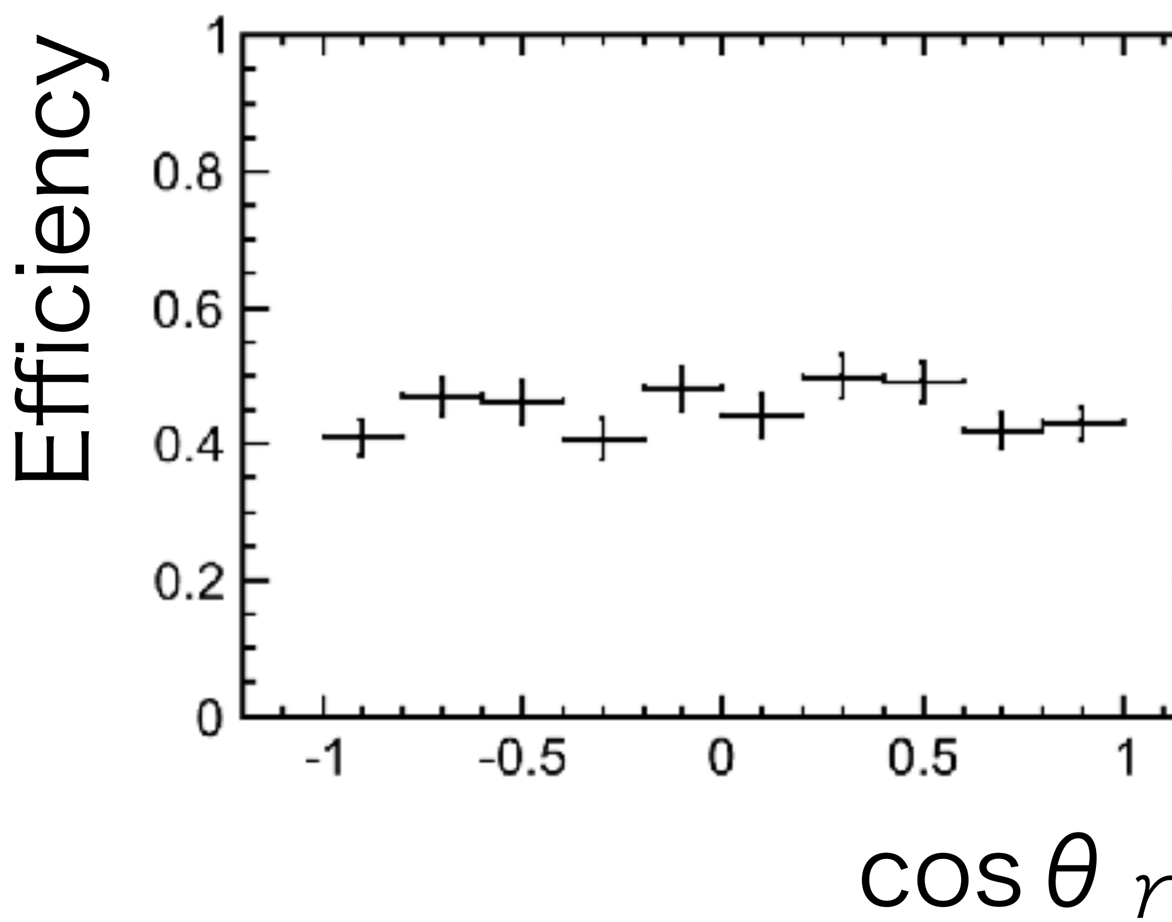


Take out cos θ γ from MVA

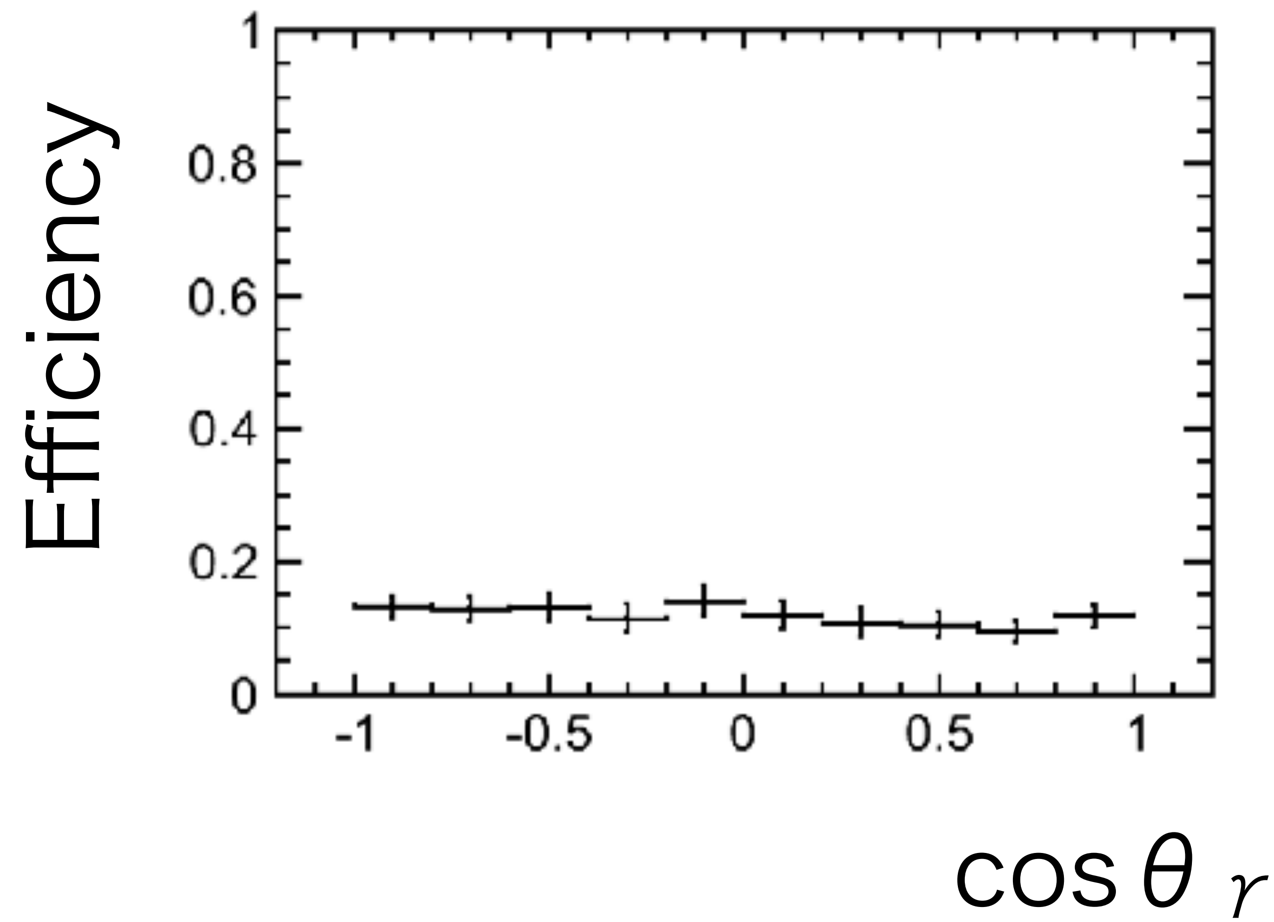
→ Check significant again

cosθγ Distribution(WW* sl)

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



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



→ Check significant again

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
btag>0.77	2.2×10^{7}	90	0.06
$E_{mis}<35$	1.9×10^{6}	82	0.06
mvabdt > -0.02(optimized)	36354	52	0.27
<cos<0.92	22356	47	0.31

→95% C.L upper limit

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

= 0.35 + 5.29 × 0.35 [fb] (Significance = 0.31 for SM)

=2.20 [fb] (Left 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 particle>1	7.1×10^{6}	10.0	0.004
# of charged particle >3	306997	5.1	0.009
|mw1-80.4|<10 GeV or |mw2-80.4|<9.4 GeV	184537	3.6	0.008
bmax1<0.77	175417	3.6	0.008
mvabdt>-0.05(optimized)	58	1.2	0.16
-0.93<cos<0.93	23	1.1	0.24

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

Significance = 0.24 for SM

= 0.35 + 6.83 × 0.35 [fb]

=2.74 [fb] (Left handed)

8. Summary

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

- signal significance **0.31σ** for SM at $\sqrt{s}$=250 GeV, 900 fb^{-1}.($h \to bb$)

  0.24σ for SM at $\sqrt{s}$=250 GeV, 900 fb^{-1}.($h \to WW^*$ semi-leptonic)

- Calculate background upper limit statistically

- Check the cosθγ distribution for confirm method validity

Next step

- Right handed case should be analyzed
- Understand the role of this measurement in a global EFT analysis.

Back up

Reduction table(bb)

	total bg	Signal	Significance
Expected	1.4×10^8	107	0.01
Pre selection	2.9×10^7	100	0.02
btag>0.77	2.2×10^7	90	0.06
$E_{mis}<35$	1.9×10^6	82	0.06
mvabdt > 0.0126	8996	34	0.36

	total bg	Signal	Significance
Expected	1.4×10^8	107	0.01
Pre selection	2.9×10^7	100	0.02
btag>0.77	2.2×10^7	90	0.06
$E_{mis}<35$	1.9×10^6	82	0.06
mvabdt > -0.02(not optimized)	36354	52	0.27

Preliminary

	total bg	Signal	Significance
Expected	1.4×10^8	18.0	0.003
Pre selection	1.3×10^7	11.0	0.004
# of particle>1	7.1×10^6	10.0	0.004
# of charged particle >3	306997	5.1	0.009
|mw1-80.4|<10 GeV or |mw2-80.4|<9.4 GeV	184537	3.6	0.008
bmax1<0.77	175417	3.6	0.008
mvabdt>0.068	40	1.7	0.27

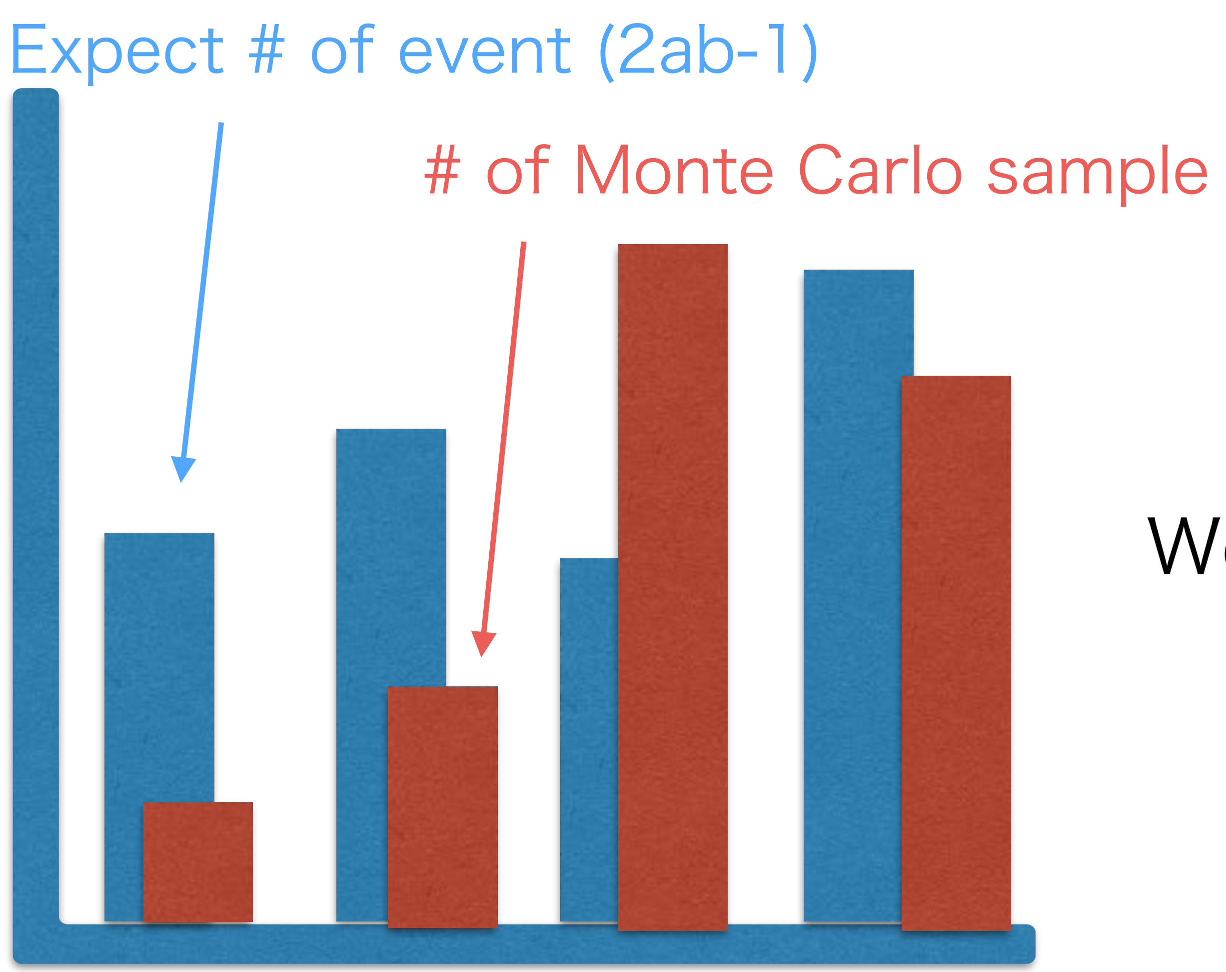
↓ Take out $\cos\theta\ \gamma$ from mva

	total bg	Signal	Significance
Expected	1.4×10^8	18.0	0.003
Pre selection	1.3×10^7	11.0	0.004
# of particle>1	7.1×10^6	10.0	0.004
# of charged particle >3	306997	5.1	0.009
|mw1-80.4|<10 GeV or |mw2-80.4|<9.4 GeV	184537	3.6	0.008
bmax1<0.77	175417	3.6	0.008
mvabdt>0.05(not optimized)	58	1.2	0.16

6. Background study

Propose : Estimate Monte Calro fluctuation

We can't make Monte Calro samples amount of 2ab-1 because some sample is huge. → Define "Weight"



$$\text{Weight} = \frac{\text{Expect \# of event (2ab-1)}}{\text{\# of Monte Carlo sample}}$$

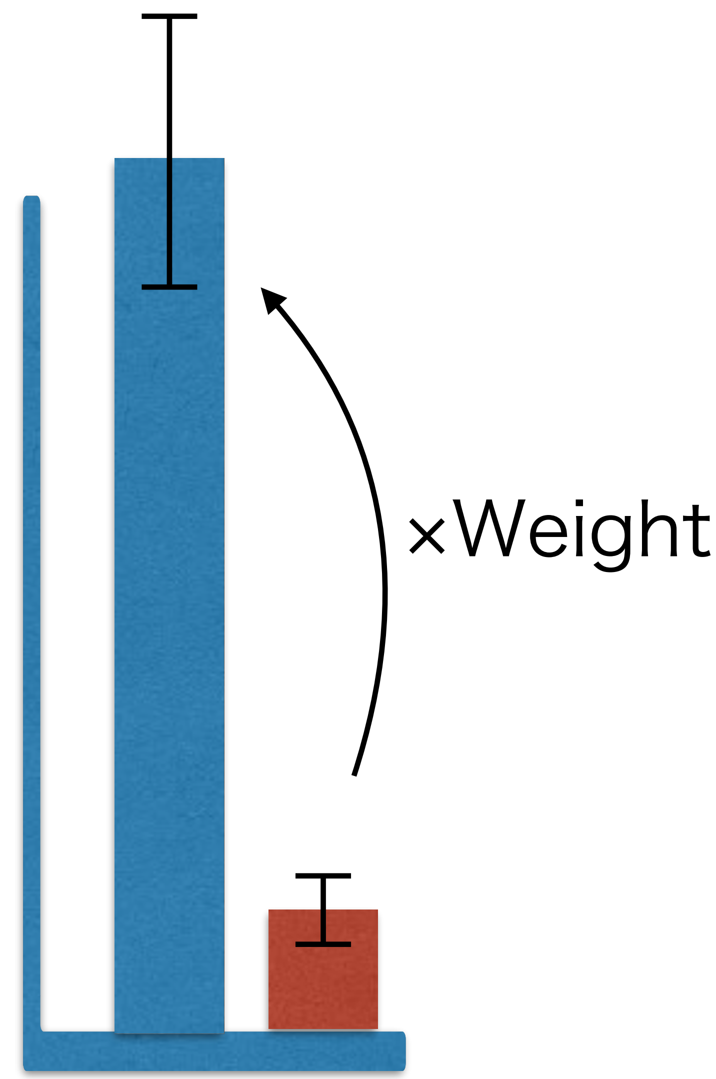
What is the problem?

Propose : Estimate Monte Calro fluctuation

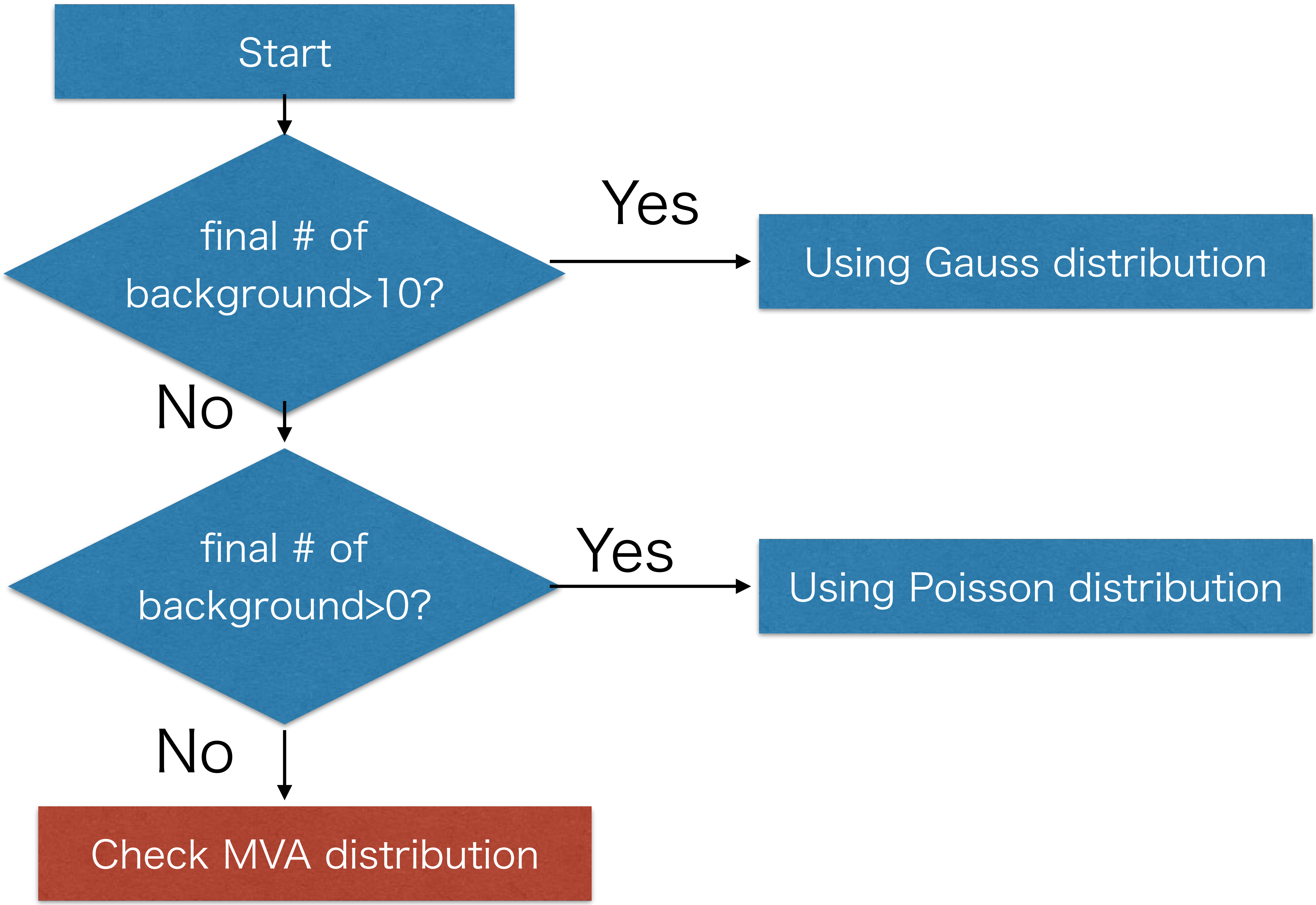
$$\text{Weight} = \frac{\text{Expect \# of event (2ab-1)}}{\text{\# of Monte Carlo sample}}$$

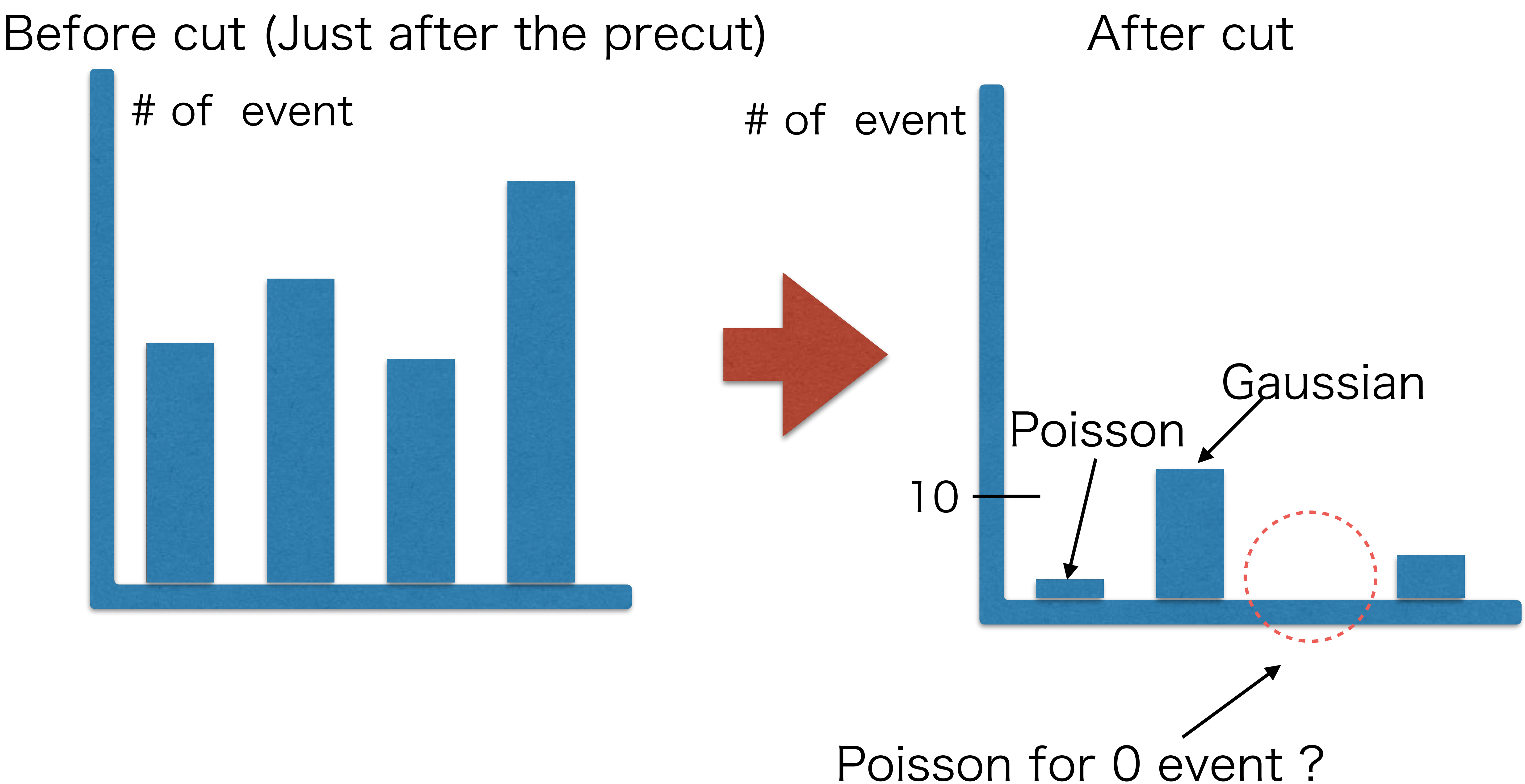
If a sample has huge weight (few Monte Carlo samples), its error seems over estimated.

→ When we calculate the number of background at the worst case (upper limit), we should correct this effect.



Analysis Flow




Before cut (Just after the precut)
# of event
After cut
# of event
Gaussian
Poisson
10
Poisson for 0 event ?

For 0 background

Most background is suppressed by MVA, so I estimate how MVA suppress backgrounds

Before cut	After MVA cut
2422.2	66.5
95.7	2.7
29.5	0.0

$$\text{MVA suppression ratio} = \frac{\text{\# of event after cut}}{\text{\# of event before cut}}$$

※ If the number of event after cut is 0, we ignore this event (regard 0)

Upper limit = calculated upper limit by poisson ×MVA suppression ratio

※ 95% upper limit

Result

	avarage # of bg	upper limit of bg
h→bb	8996	10418
h→WW(semi-leptonic)	40	50

7.Method Validity

We assume no difference between SM and BSM $\cos\theta_{\gamma}$ distribution

$$d\sigma = \frac{1}{2s\beta}\sum_{s_1,s_2} w_s, w_{s2}\left|T_{SM} + T_{BSM}(\zeta_{AZ},\zeta_A)\right|^2 d\Phi_2$$

$$\left|T_{SM}\right|^2 + 2\,\mathrm{Re}(T^*_{sM}T_{BSM}(\zeta_A,\zeta_{Az})) + \cancel{\left|T_{BSM}\right|^2}$$

$$\frac{d\sigma}{d\cos\theta} = \frac{d\sigma_{SM}}{d\cos\theta} + \zeta_A\frac{d\sigma_{BSM}}{d\cos\theta}(\zeta_A = 1,\zeta_{AZ} = 0) + \zeta_{AZ}\frac{d\sigma_{BSM}}{d\cos\theta}(\zeta_A = 0,\zeta_{AZ} = 1)$$

$$N = \mathscr{L}\int\frac{d\sigma}{d\cos\theta}\eta(\cos\theta)d\cos\theta$$

$$= \mathscr{L}\left[\int\frac{d\sigma_{SM}}{d\cos\theta}\eta(\cos\theta)d\cos\theta + \int\frac{d\sigma_{BSM}}{d\cos\theta}(\zeta_A = 1,\zeta_{AZ} = 0)\eta(\cos\theta)d\cos\theta\zeta_A\right. -$$

$$\left. + \int\frac{d\sigma_{BSM}}{d\cos\theta}(\zeta_A = 0,\zeta_{AZ} = 1)\eta(\cos\theta)d\cos\theta\zeta_{AZ}\right]$$