

S O K E N D A I



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

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

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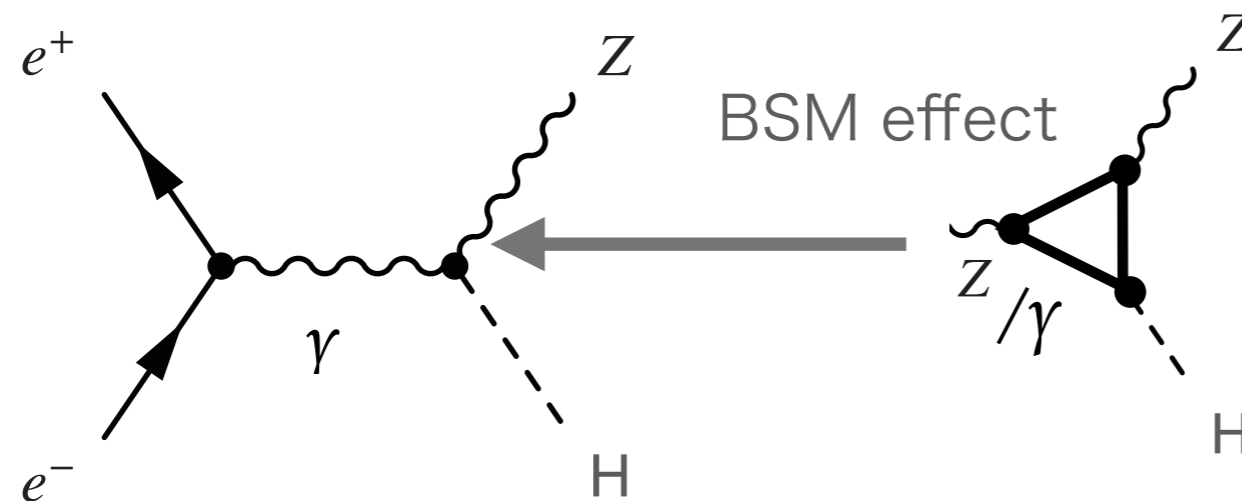
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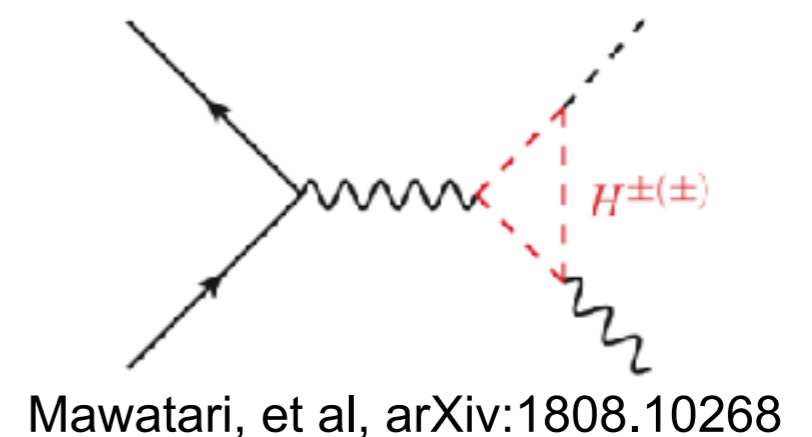
1. Motivation

To find new physics via $H\gamma\gamma$ and $H\gamma Z$ 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



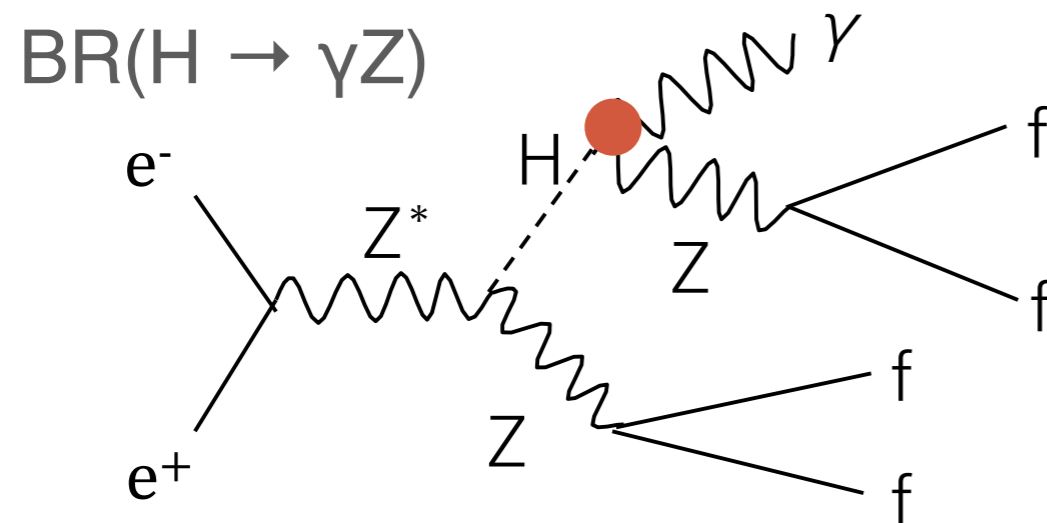
This process can be also useful to constrain the dimension 6 EFT operators which can introduce effective anomalous $h\gamma Z$ and $h\gamma\gamma$ couplings.

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 $H\gamma Z$ coupling

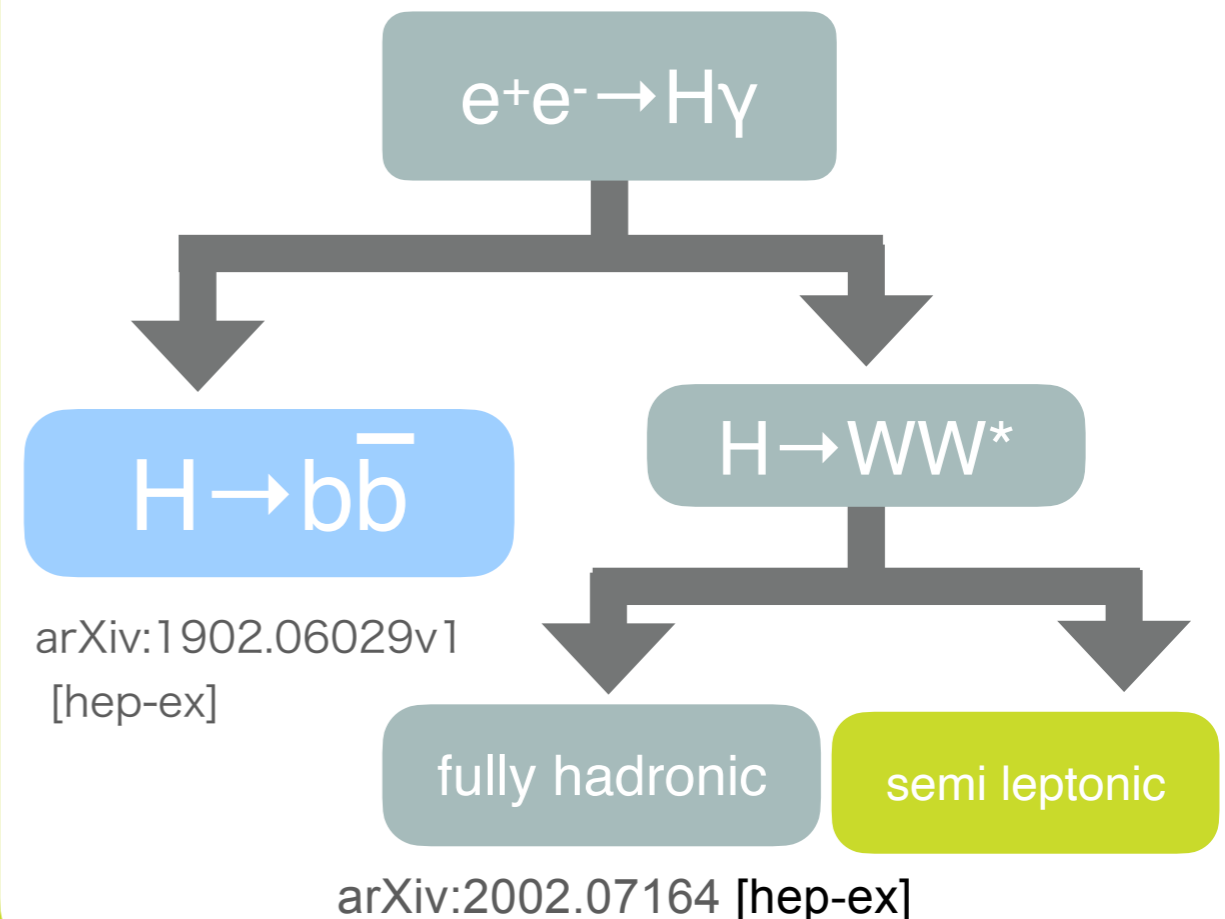
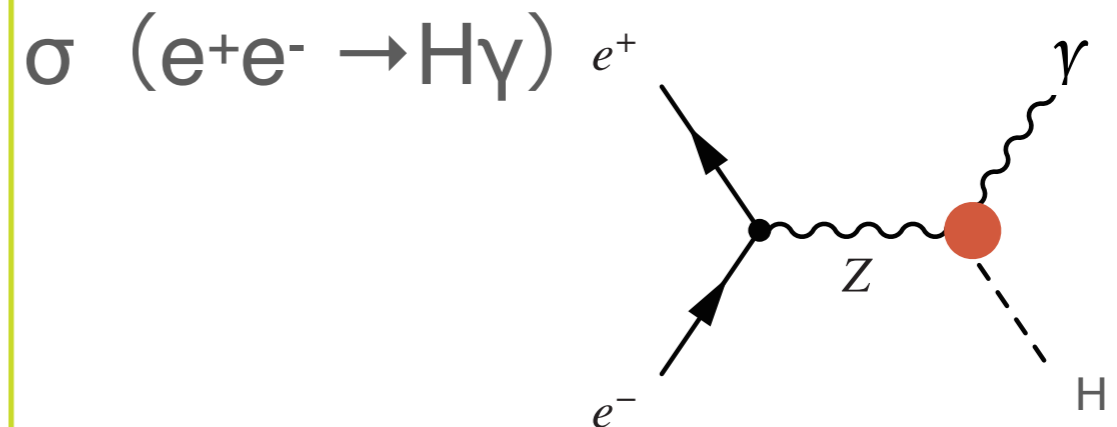
Higgs decay



final state	BR
mmqq γ	4.7%
eeqq γ	4.7%
nnqq γ	28.0%
qqqq γ	48.9%
others	13.7%

by Kazuki Fujii at LCWS2018

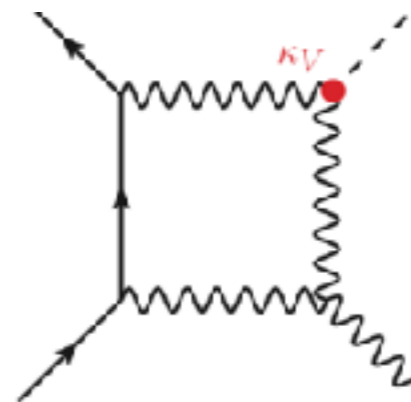
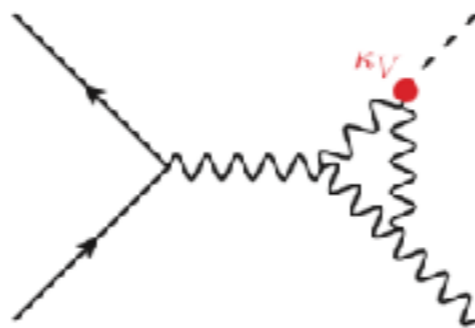
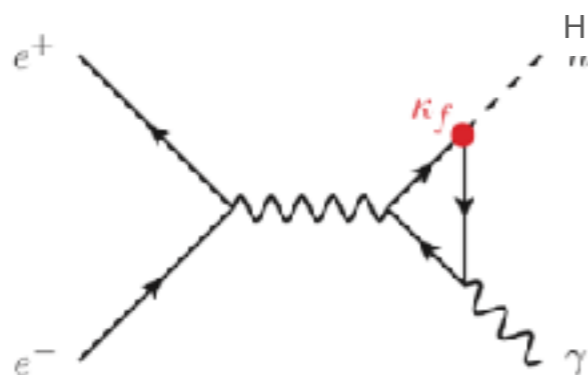
Higgs production



3. Theoretical framework for our analysis

SM one-loop predictions

The main Feynman diagrams



Mawatari, et al, arXiv:1808.10268

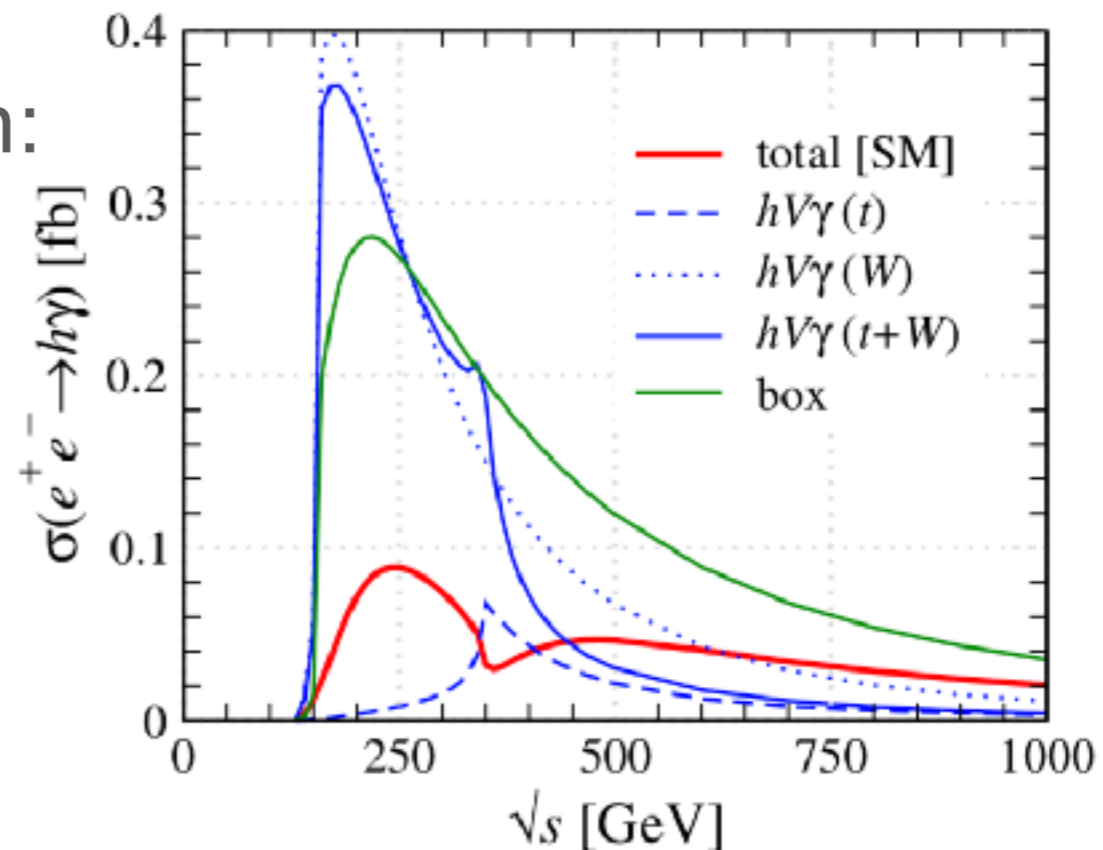
SM cross sections by one loop calculation:

$\sigma_{SM} = 0.35 \text{ fb}$ for $(-100\%, +100\%)$
 $\sigma_{SM} = 0.016 \text{ fb}$ for $(+100\%, -100\%)$

$\sigma_{SM} = \mathbf{0.20 \text{ fb}}$ for $(-80\%, +30\%)$
 $\sqrt{s} = 250 \text{ GeV}$

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

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

effective $h\gamma Z$ coupling effective $h\gamma\gamma$ coupling

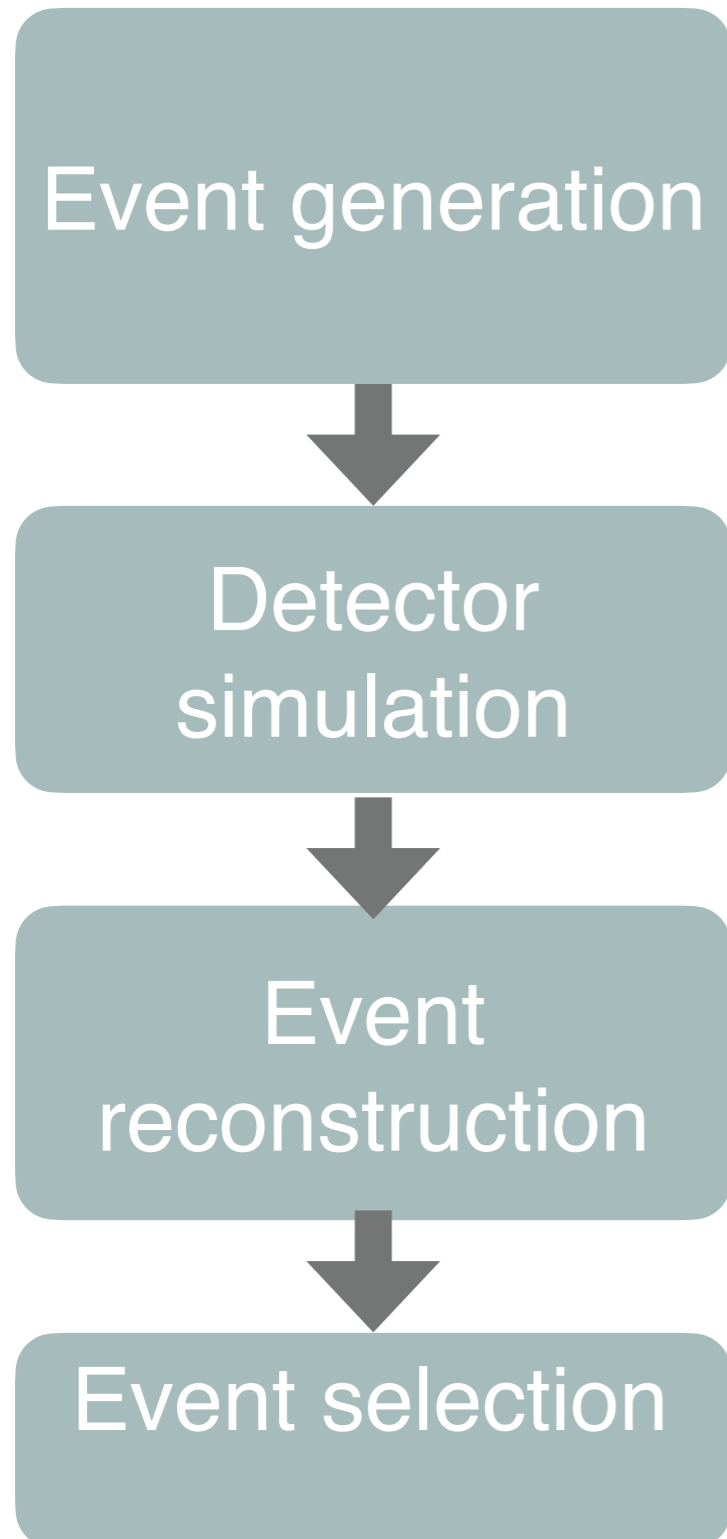
Phys.Rev. D94 (2016) 095015

$A_{\mu\nu}, Z_{\mu\nu}$: field strength tensors

v : vacuum expectation value

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

4. Simulation framework



- $\sqrt{s}=250$ GeV
Integrated Luminosity: 2000 fb⁻¹
(900 fb⁻¹ for Left handed)
- background : 2f,4f (DBD sample)
- ISR and Beamstrahlung effects are included
- **ILD full simulation (Mokka)**
- Geant4 based, realistic detailed detector model
- Full reconstruction chain from detector signals to 4-vectors
(iLCSoft v01-16-02/ MarlinReco, PandoraPFA, LCFI+, Isolated photon finder, jet clustering)
- $E_\gamma > 50$ GeV

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

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

N_s : Number of signal N_B : Number of background

Reduction table

	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
$E_{\text{mis}} < 35$	1.9×10^6	82	0.06
mvabdt > 0.0126	8996	34	0.36

→ 95% C.L upper limit

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

$$= 0.35 + 4.59 \times 0.35 \text{ [fb]} \quad (\text{Significance} = 0.36 \text{ for SM})$$

$$= 1.96 \text{ [fb]} \quad (\text{Left handed beam polarization case})$$

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
$ m_{w1} - 80.4 < 10$ GeV or $ m_{w2} - 80.4 < 9.4$ GeV	184537	3.6	0.008
$b_{max1} < 0.77$	175417	3.6	0.008
$m_{vabdt} > 0.068$	40	1.7	0.27

→ 95% C.L upper limit

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

Significance = 0.27 for SM

$$= 0.35 + 6.07 \times 0.35 \text{ [fb]}$$

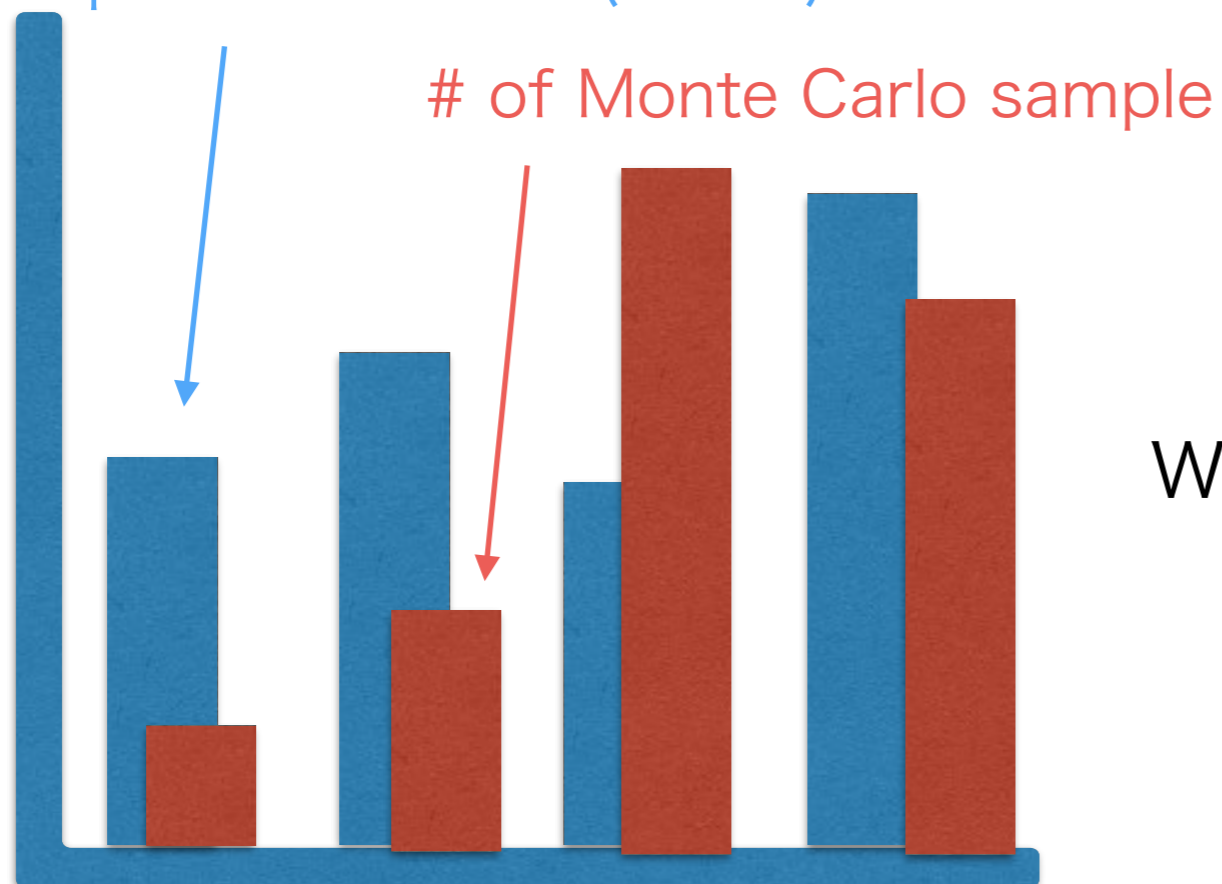
$$= 2.48 \text{ [fb]} \quad (\text{Left handed})$$

6. Background study

Propose : Estimate Monte Carlo fluctuation

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

Expect # of event ($2ab-1$)



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

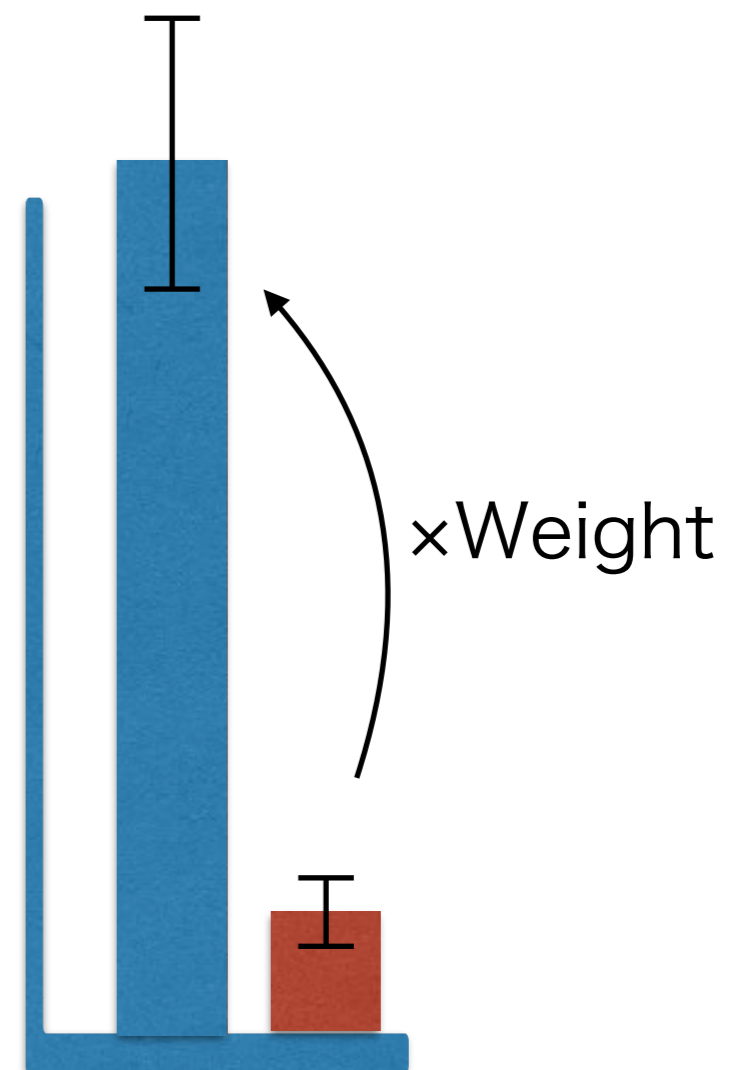
What is the problem?

Propose : Estimate Monte Carlo fluctuation

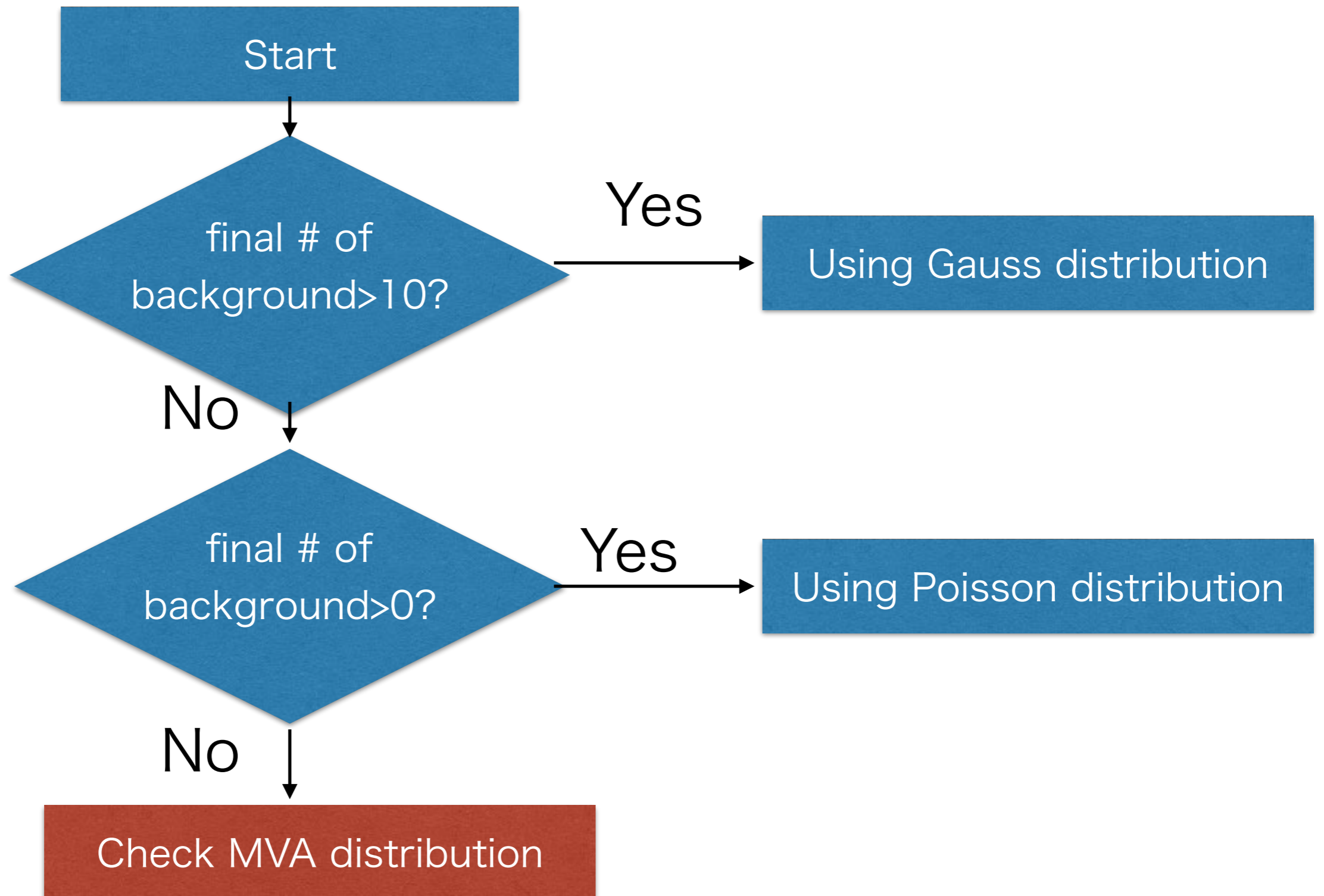
$$\text{Weight} = \frac{\text{Expect \# of event (2ab-1)}}{\text{\# of Monte Carlo sample}}$$

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

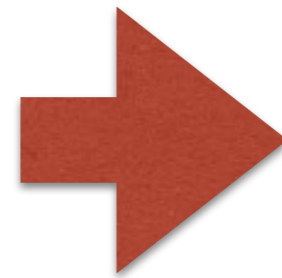
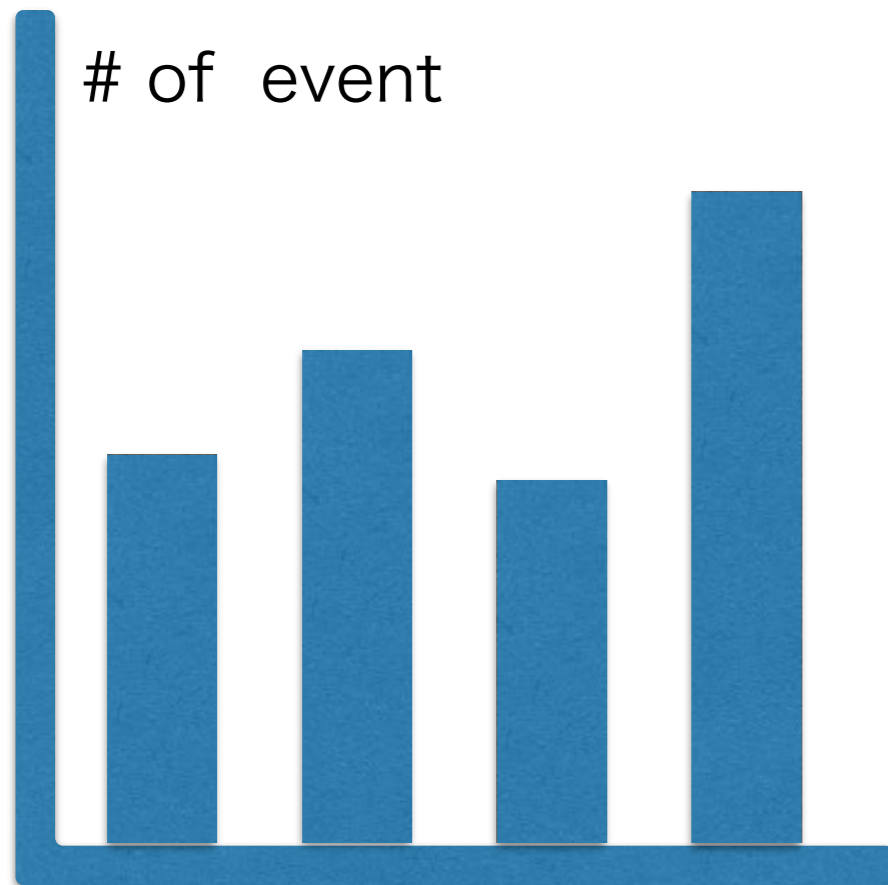
→ When we calculate the number of background at the worst case (upper limit), we should correct this effect.



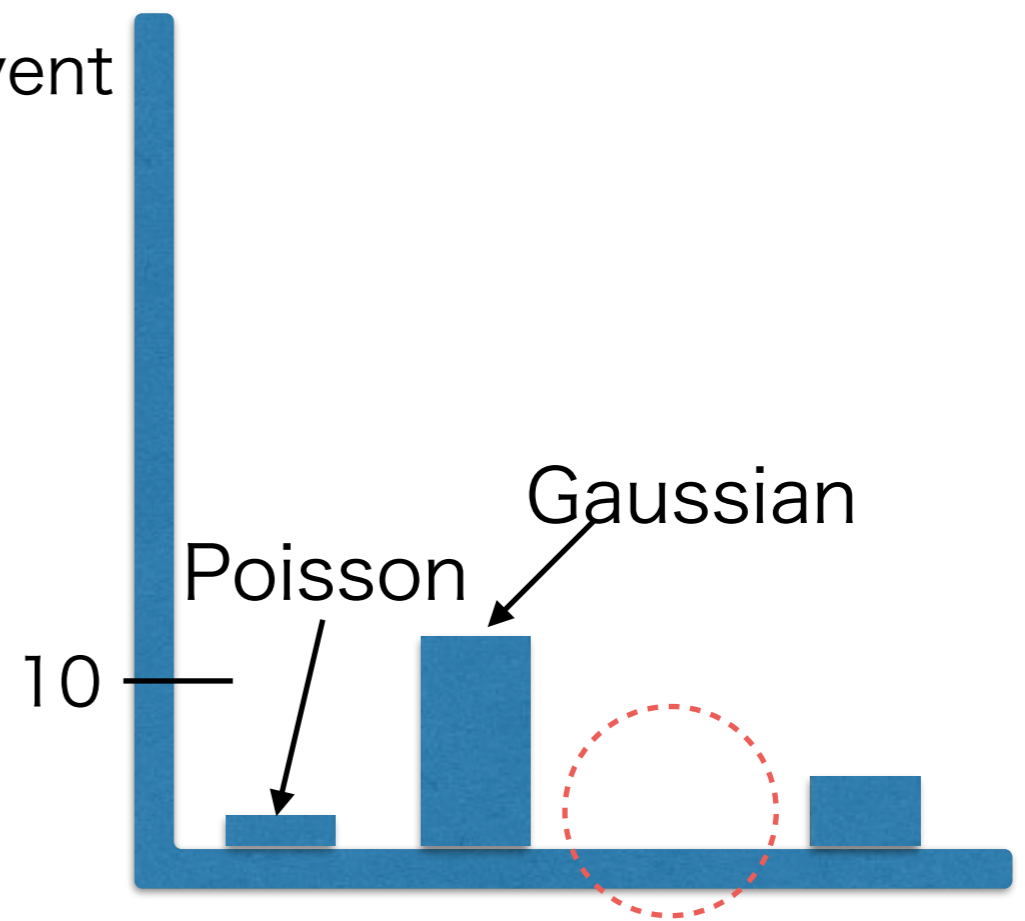
Analysis Flow



Before cut (Just after the precut)



After cut



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
$h \rightarrow bb$	8996	10418
$h \rightarrow WW(\text{semi-leptonic})$	40	50

7. Method Validity

We assume no difference between SM and BSM $\cos \theta_r$ distribution

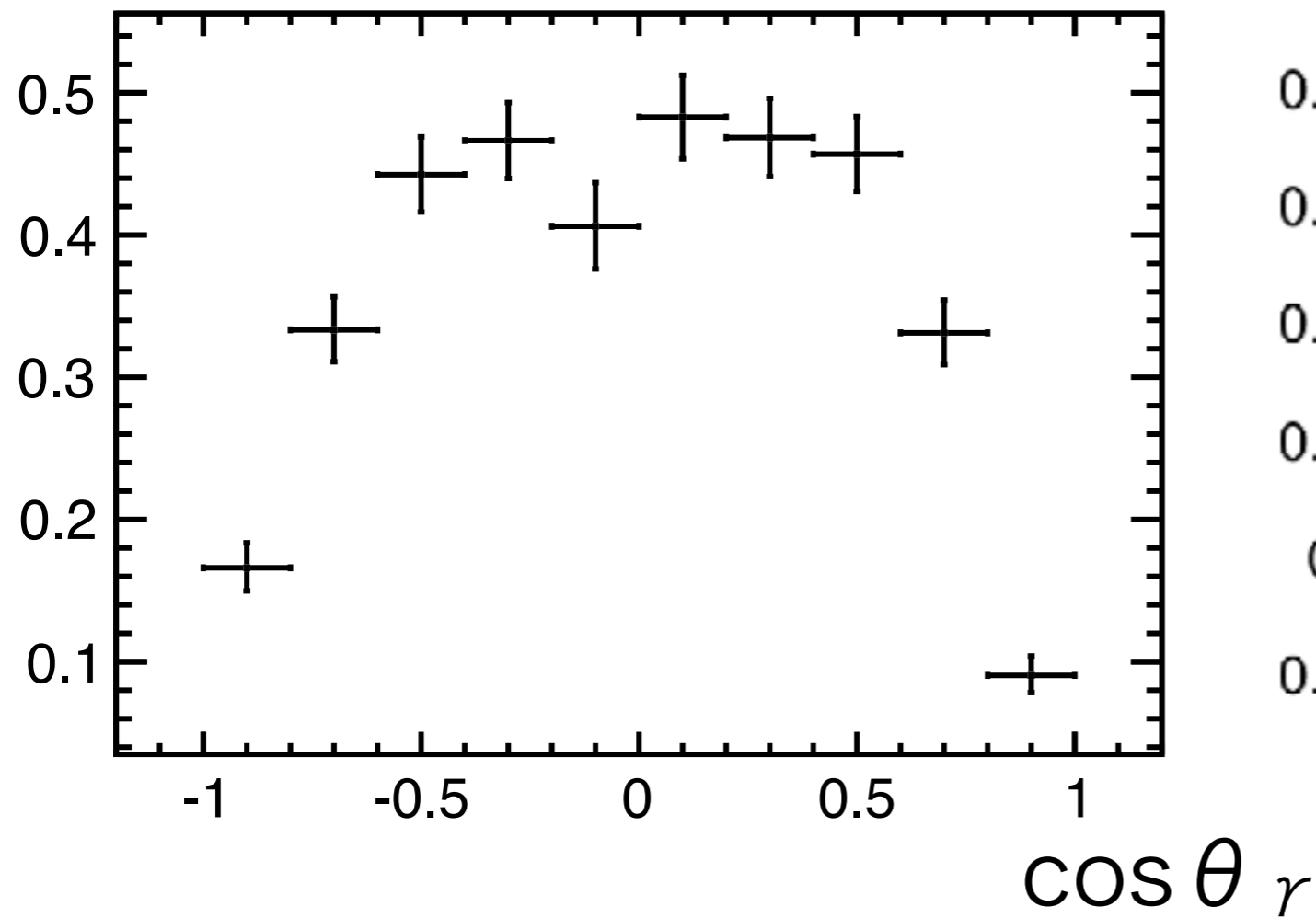
$$d\sigma = \frac{1}{2s\beta} \sum_{s_1, s_2} w_{s_1}, w_{s_2} \underbrace{|T_{SM} + T_{BSM}(\zeta_{AZ}, \zeta_A)|^2}_{|T_{SM}|^2 + 2 \operatorname{Re}(T_{SM}^* T_{BSM}(\zeta_A, \zeta_{AZ})) + \cancel{|T_{BSM}|^2}} d\Phi_2$$

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

$$\begin{aligned} N &= \mathcal{L} \int \frac{d\sigma}{d \cos \theta} \eta(\cos \theta) d \cos \theta \\ &= \mathcal{L} \left[\int \frac{d\sigma_{SM}}{d \cos \theta} \eta(\cos \theta) d \cos \theta + \int \frac{d\sigma_{BSM}}{d \cos \theta} (\zeta_A = 1, \zeta_{AZ} = 0) \eta(\cos \theta) d \cos \theta \zeta_A - \right. \\ &\quad \left. + \int \frac{d\sigma_{BSM}}{d \cos \theta} (\zeta_A = 0, \zeta_{AZ} = 1) \eta(\cos \theta) d \cos \theta \zeta_{AZ} \right] \end{aligned}$$

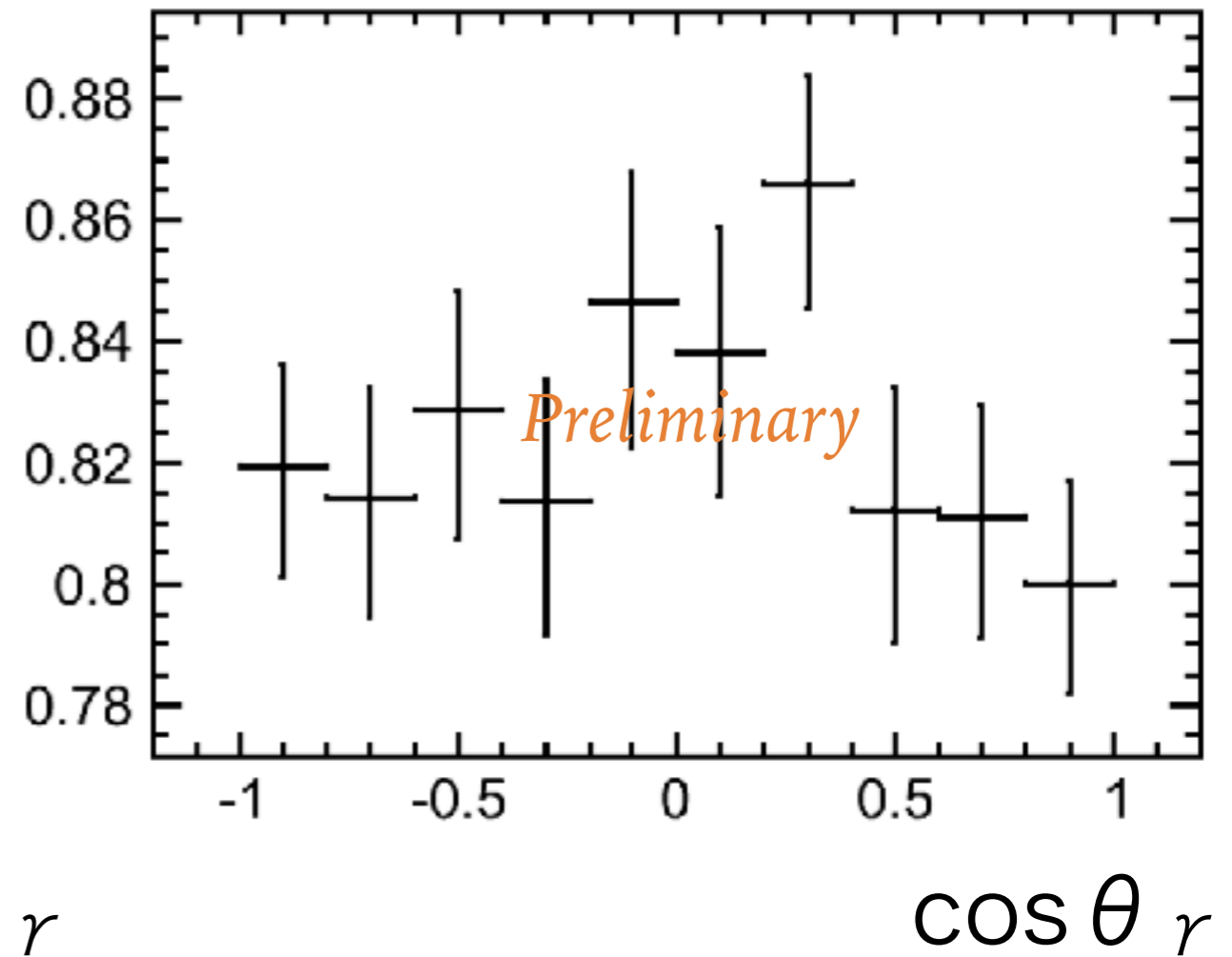
$\cos\theta_\gamma$ Distribution

Efficiency



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

Efficiency



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

8. Summary

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

- signal significance **0.36 σ** for SM at $\sqrt{s}=250$ GeV, 900 fb⁻¹. ($h \rightarrow bb$)
0.27 σ for SM at $\sqrt{s}=250$ GeV, 900 fb⁻¹. ($h \rightarrow WW^*$ semi-leptonic)
- Calculate background upper limit statistically
- Check the $\cos\theta_\gamma$ distribution for confirm method validity

Next step

- Check $\cos\theta_\gamma$ distribution
- Right handed case should be analyzed
- Understand the role of this measurement in a global EFT analysis.