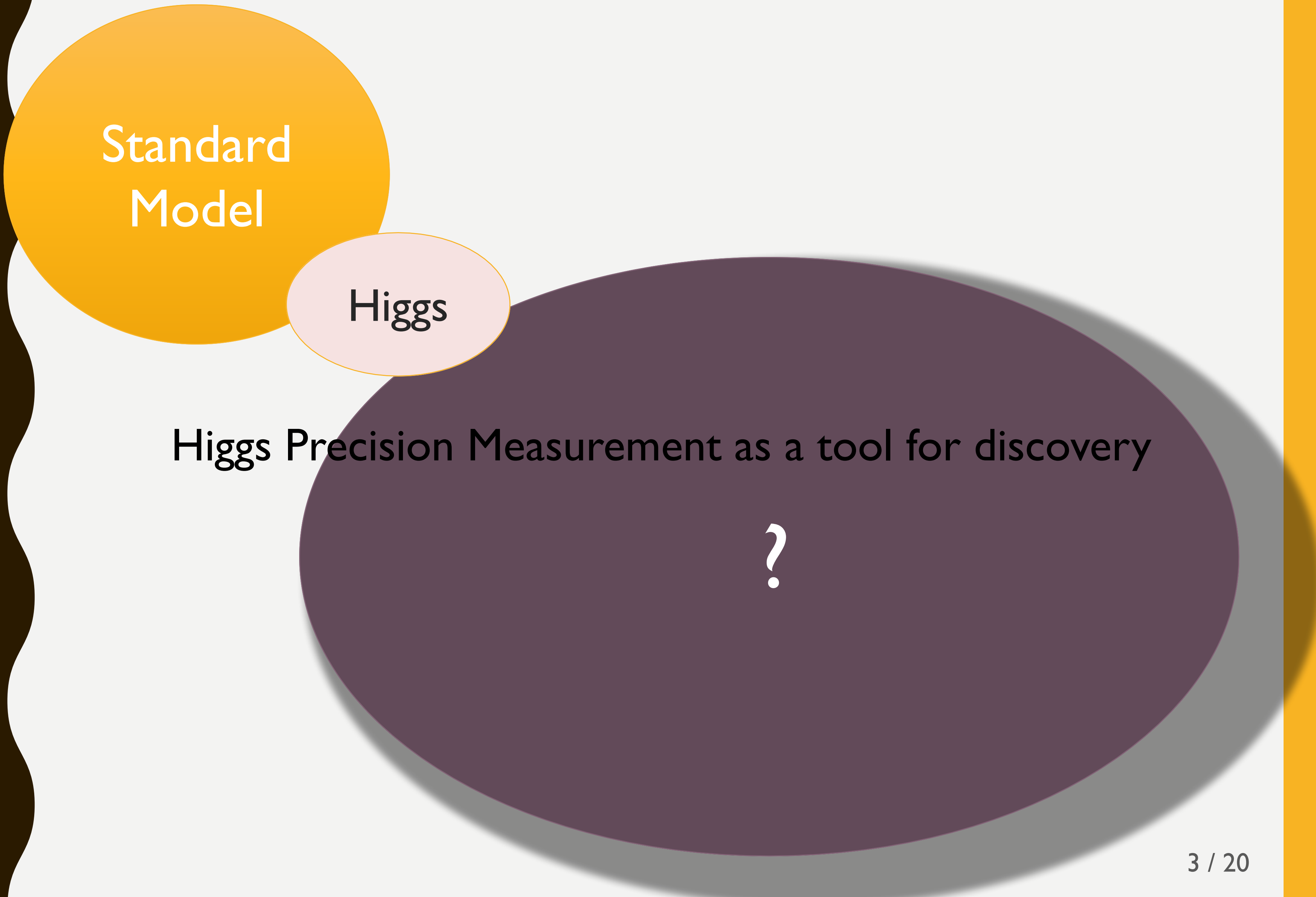
AWLC@SLAC, June 26th 2017

Zhuoni Qian

HIGGS PRODUCTION THROUGH ZZ FUSION CHANNEL AT THE ILC

CONTENTS:


Standard Model
Higgs
Higgs Precision Measurement as a tool for discovery
?

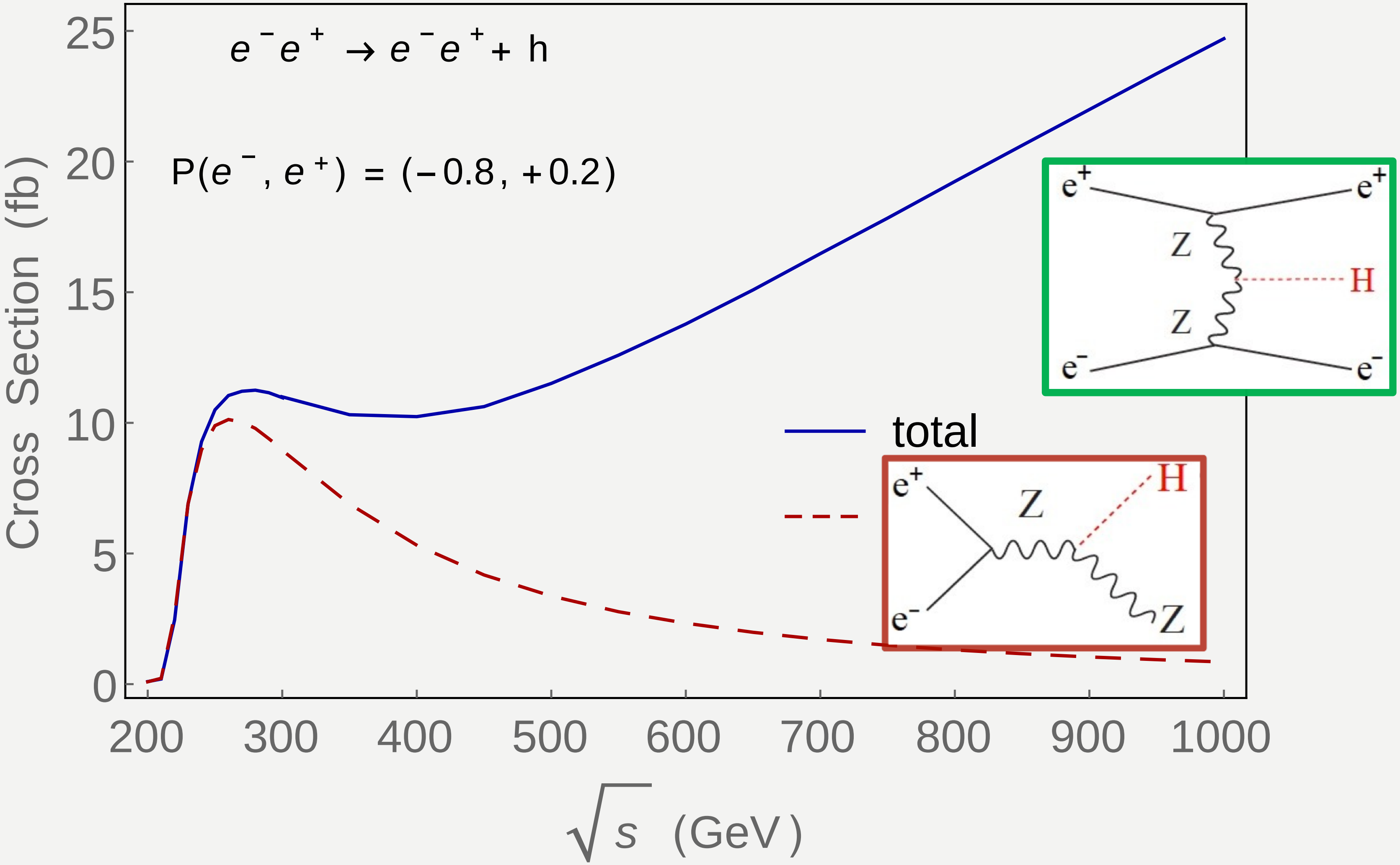
Higgs coupling modification in these models, in %

	Model	$b\bar{b}$	$c\bar{c}$	gg	WW	$\tau\tau$	ZZ	$\gamma\gamma$	$\mu\mu$
1	MSSM [21]	+4.8	-0.8	- 0.8	-0.2	+0.4	-0.05	+0.1	+0.3
2	Type II 2HD [22]	+10.1	-0.2	-0.2	0.0	+9.8	0.0	+0.1	+9.8
3	Type X 2HD [22]	-0.2	-0.2	-0.2	0.0	+7.8	0.0	0.0	+7.8
4	Type Y 2HD [22]	+10.1	-0.2	-0.2	0.0	-0.2	0.0	0.1	-0.2
5	Little Higgs w. T-parity [24]	0.0	0.0	-6.1	-2.5	0.0	-2.5	-1.5	0.0
6	Little Higgs w. T-parity [25]	-7.8	-4.6	-3.5	-1.5	-7.8	-1.5	-1.0	-7.8
7	Higgs-Radion [26]	-1.5	- 1.5	10.	-1.5	-1.5	-1.5	-1.0	-1.5
8	Higgs Singlet [27]	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5

Facility		ILC	
$\sqrt{s}$ (GeV)	250	500	1000
$\int \mathcal{L}dt$ (fb^{-1})	250	+500	+1000
$P(e^-, e^+)$	$(-0.8, +0.3)$	$(-0.8, +0.3)$	$(-0.8, +0.2)$
Γ_H	12%	5.0%	4.6%
κ_γ	18%	8.4%	4.0%
κ_g	6.4%	2.3%	1.6%
κ_W	4.9%	1.2%	1.2%
κ_Z	1.3%	1.0%	1.0%
κ_μ	91%	91%	16%
κ_τ	5.8%	2.4%	1.8%
κ_c	6.8%	2.8%	1.8%
κ_b	5.3%	1.7%	1.3%
κ_t	–	14%	3.2%
BR_{inv}	0.9%	$< 0.9\%$	$< 0.9\%$

$$\kappa_Z = \frac{g_{ZZH}}{g_{ZZH}^{SM}}$$

Snowmass Higgs Report (2013)



$e^-e^+ \to e^-e^+ + h$
$P(e^-, e^+) = (-0.8, +0.2)$
Cross Section (fb)
25
20
15
10
5
0
200
300
400
500
600
700
800
900
1000
$\sqrt{s}$ (GeV)
total
e+
e-
Z
H

SIMULATION

- Whizard 1.95 (ISR, Beam-strahlung) and Pythia6
- SGV – fast detector simulation

- Signal: ee > ee + h
- Background: ee > ee + X , ee > ee + X X , etc.

$$E_\gamma > 10 \ \text{GeV}, \quad \theta_\gamma > 6^\circ$$

$$m_{\gamma\ell} > 4 \ \text{GeV}$$

$$m_{\ell\ell} > 4 \ \text{GeV}$$

TREATING $ee + \gamma$

- In the Higgs rest frame, veto isolated photon that has,

$$E_\gamma > 65\text{GeV}$$

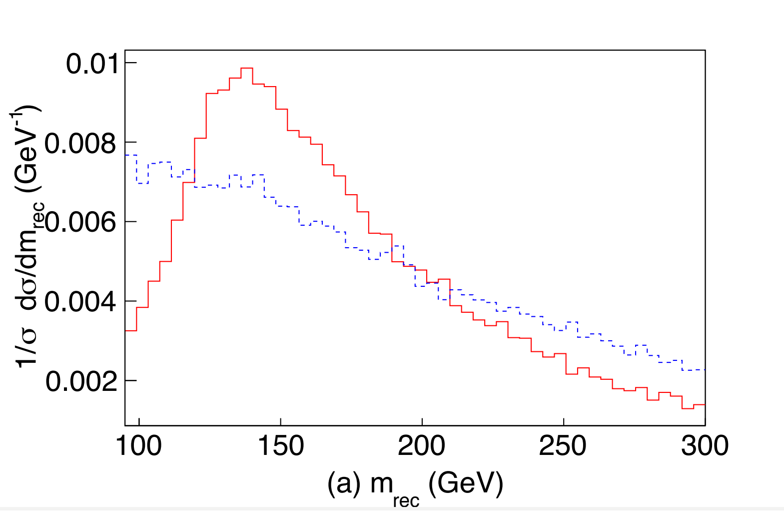
Cuts (fb)	Generator level	$m_{\text{rec}},\ m_{ee}$	$p_{T(ee)}$	Veto isolated single γ
e^-e^+h (500 GeV)	11.5	4.11	3.48	3.48
$e^-e^+\gamma$ (500 GeV)	165000	317	67.2	1.32
e^-e^+h (1 TeV)	24.1	9.75	8.49	8.18
$e^-e^+\gamma$ (1 TeV)	175000	1570	344	4.73

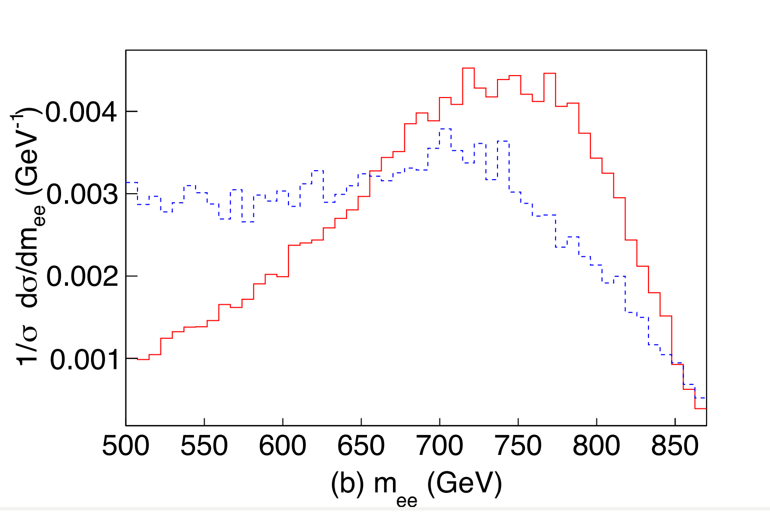
DISTRIBUTION AND CUT ANALYSIS

500 GeV (-0.8, +0.3)

Cut 1:

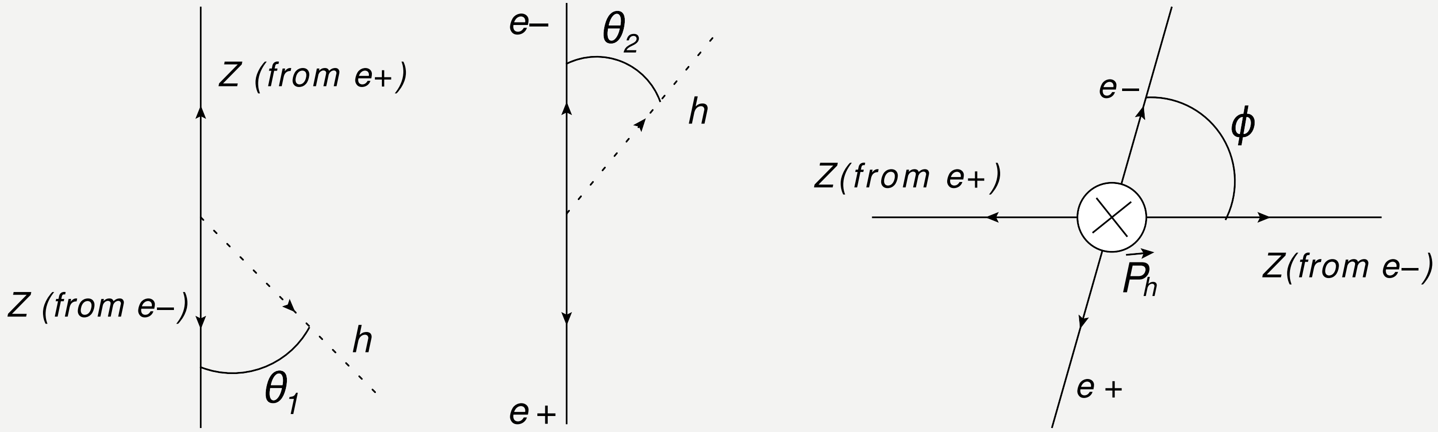
$$122 \text{ GeV} < m_{\text{rec}} < 145 \text{ GeV}$$
$$110 \text{ GeV} < m_{ee} < 370 \text{ GeV}$$
$$p_{T(ee)} > 40 \text{ GeV}$$
$$\text{veto 1 isolated photon}$$



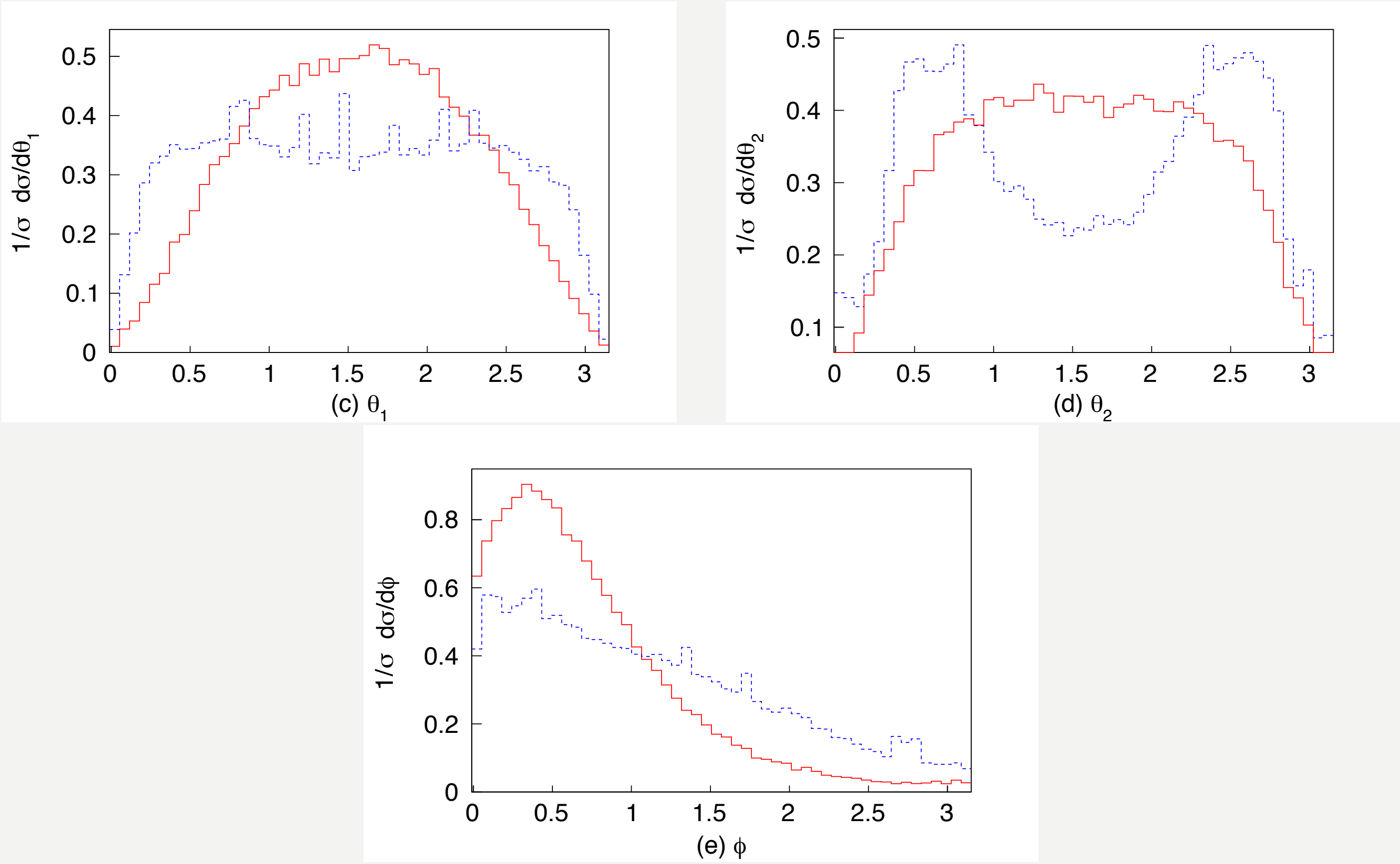


ANGULAR DISTRIBUTION:

- θ_1 is the angle between the boosted momentum of the outgoing e+e- pair and the beam-line.
- θ_2 is the angle between the outgoing e- in e-e+ rest frame and the momentum of e+e- pair in the lab frame.
- ϕ_3 is the azimuthal angle of the outgoing e- relative to the plane defined by the outgoing e+e- pair and the beam-line in the lab frame.



DISTRIBUTION AND CUT ANALYSIS



Cut 2:

$$\phi < 1.5$$

SIGNAL & BACKGROUND PROCESSES

- Cross sections (fb)

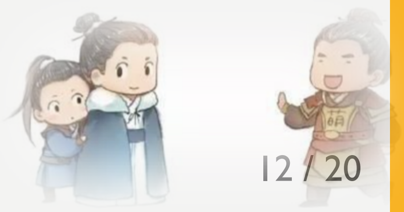
$$\frac{\delta\sigma}{\sigma} = \frac{\sqrt{N_s + N_b}}{N_s}$$

Process	Generator level (fb)	Cut 1 (fb)	Cut 2 (fb)
$ee \to eeh$(Signal)	11.5	3.48	3.11
$ee \to ee\nu_e\nu_e$	659	23.9	16.0
$ee \to ee\nu_{\mu,\tau}\nu_{\mu,\tau}$	78.6	1.02	0.70
$ee \to eeqq$	1850	9.33	6.88
$ee \to eell$	4420	5.18	4.42
$ee \to ee\gamma\gamma$	1640	1.18	0.60
$ee \to ee\gamma$	165 000	1.32	0.66
Total background	174 000	41.9	29.2
$\delta\sigma/\sigma$	$\cdots$	8.7%	8.2%

Reverse Polarization, reduce dominant background

$ee \to eeh$ 60%

$ee \to WW \to ee\nu_e\nu_e$ 6%

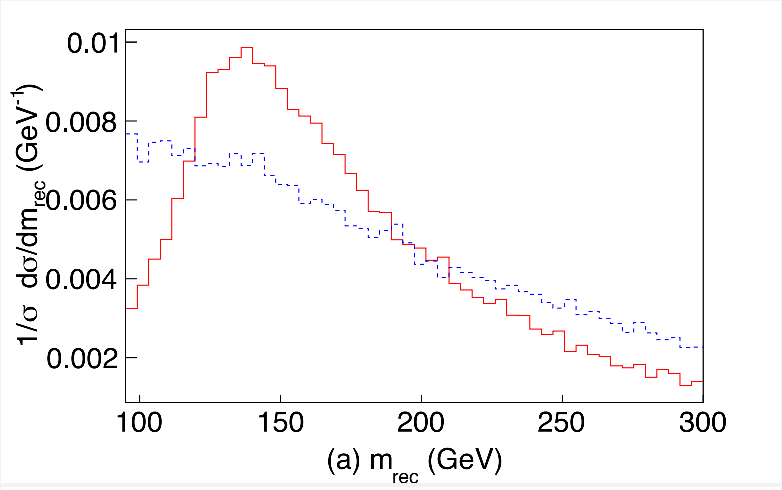


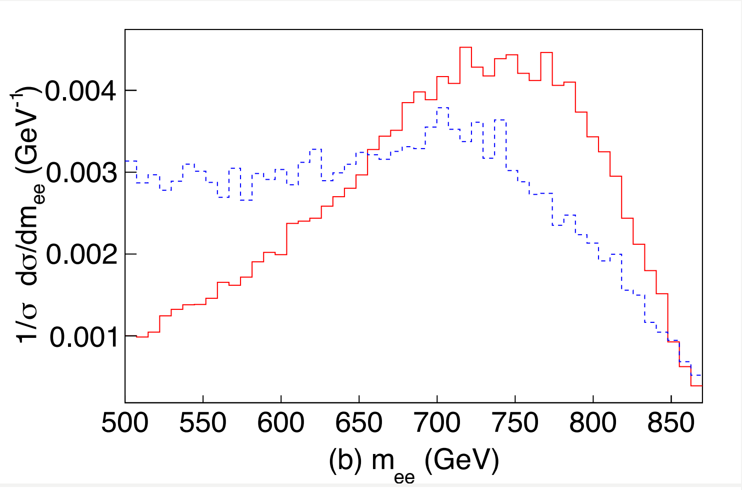
DISTRIBUTION AND CUT ANALYSIS

1000 GeV (-0.8, +0.2)

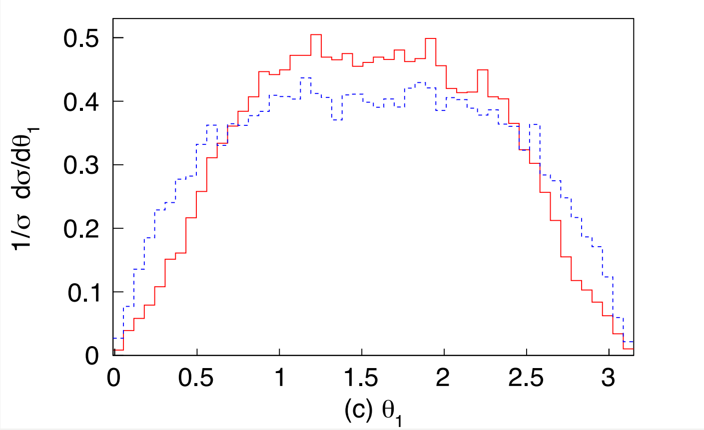
Cut 1:

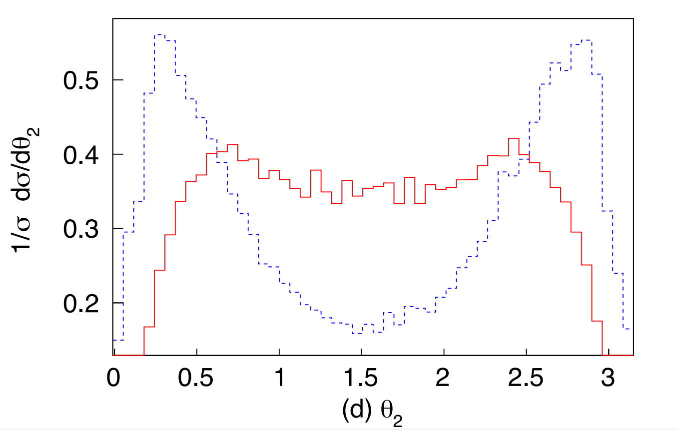
$$95 \ \text{GeV} < m_{\text{rec}} < 300 \ \text{GeV}$$
$$500 \ \text{GeV} < m_{ee} < 870 \ \text{GeV}$$
$$p_{T(ee)} > 50 \ \text{GeV}$$
$$\text{veto 1 isolated photon}$$

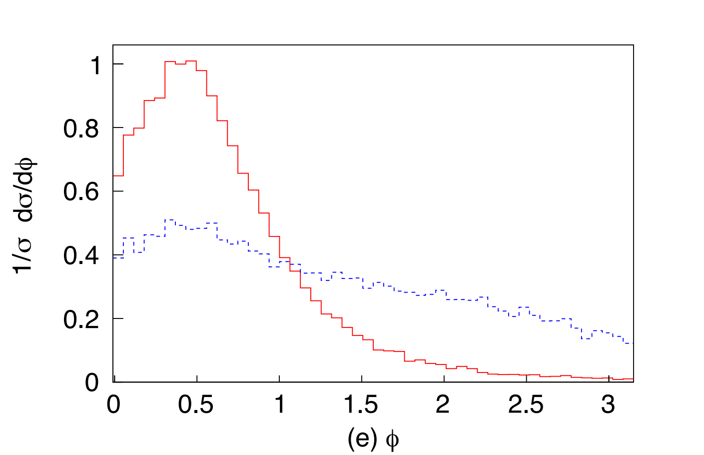




DISTRIBUTION AND CUT ANALYSIS







Cut 2:

$$0.14 < \theta_2 < 3.0$$

$$\phi < 1.5$$

SIGNAL & BACKGROUND PROCESSES

- Cross sections (fb)

$$\frac{\delta\sigma}{\sigma} = \frac{\sqrt{N_s + N_b}}{N_s}$$

Process	Generator level (fb)	Cut 1(fb)	Cut 2(fb)
$ee \to eeh$(Signal)	24.1	8.18	7.52
$ee \to ee\nu_e\nu_e$	978	31.5	17.2
$ee \to ee\nu_{\mu,\tau}\nu_{\mu,\tau}$	93.9	3.24	1.64
$ee \to eeqq$	2830	24.1	13.6
$ee \to eell$	6690	13.7	10.8
$ee \to ee\gamma\gamma$	3180	2.68	1.10
$ee \to ee\gamma$	175 000	4.73	2.28
Total background	189 000	80.0	46.6
$\delta\sigma/\sigma$	$\cdots$	3.6%	3.1%

MULTI-DIMENSIONAL LOG-LIKELIHOOD:

$$LL(\mathbf{n};\boldsymbol{\nu}) = 2\sum_{i=1}^{N_{\mathrm{bins}}}[\ n_i\ ln(\frac{n_i}{\nu_i}) + \nu_i - n_i]$$

(Definition based on Poisson distribution in each bin)

Where in each bin:

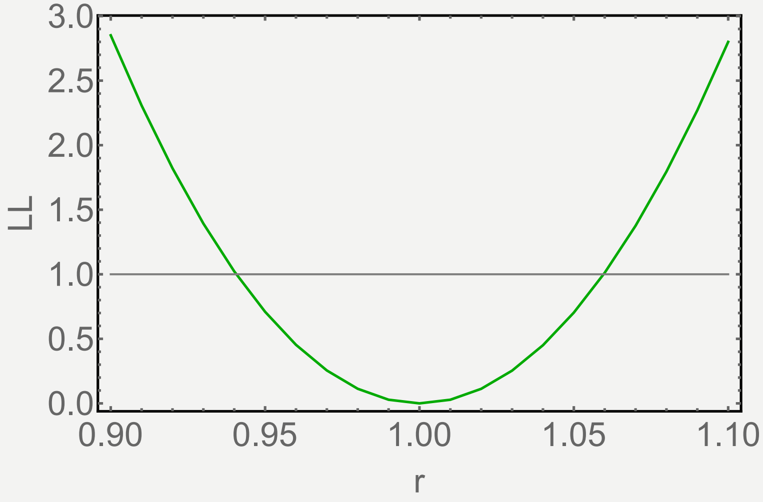
- vi = expected value , background + signal
- ni = background + r*signal

$$\{m_{\mathrm{rec}},\ \ m_{\mathrm{ee}},\ \ \theta_1, \theta_2, \phi\}$$

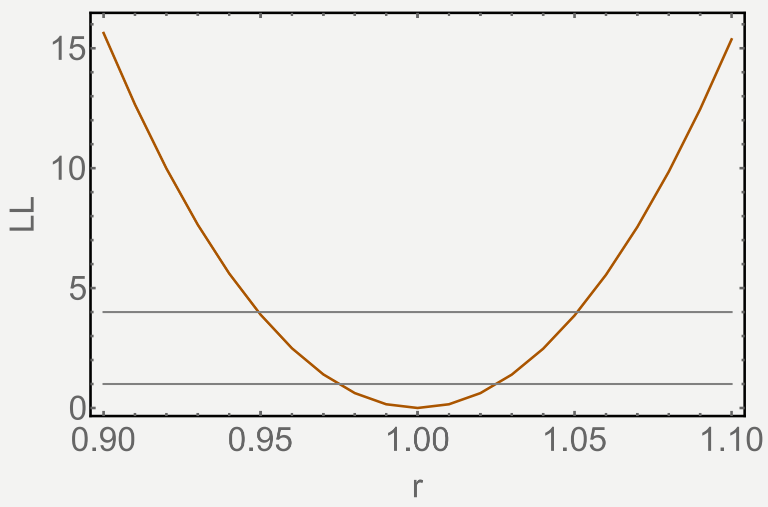
- 5^5 = 3125 bins Multi-Dimensional Analysis (MVA)

MVA RESULTS:

500 GeV



1000 GeV



- An average of 0.1 events / bin will still give good results
- Compare three independently generated data.

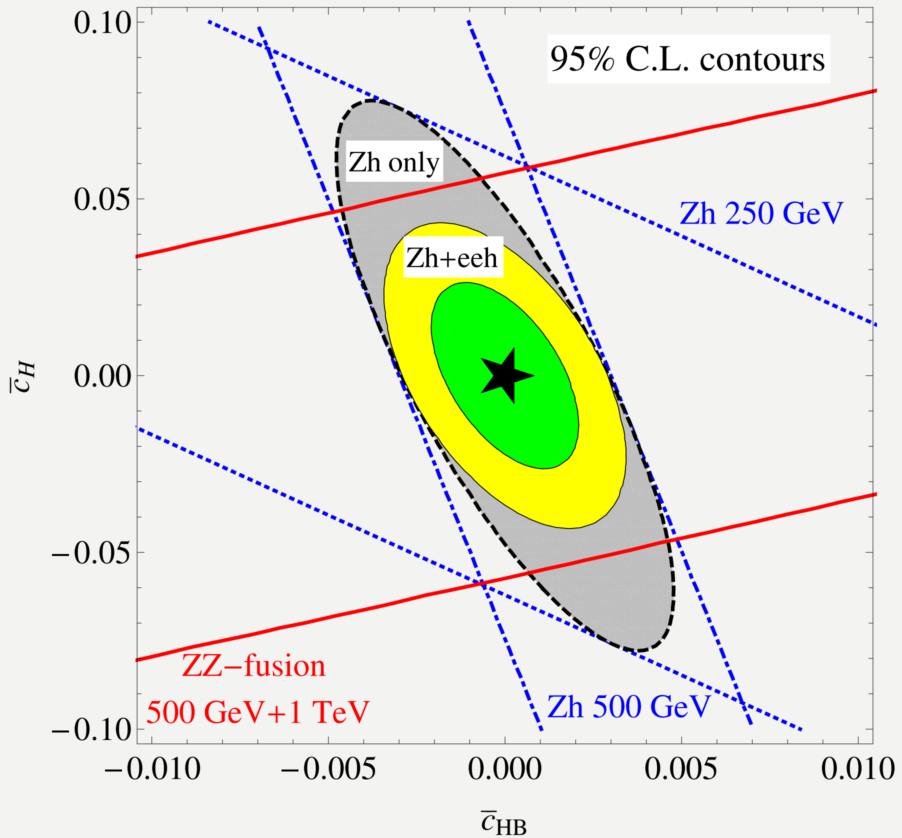
RESULTS SUMMARY

Relative error %	ILC 250+500		ILC 250+500+1000	
$\delta\sigma_{Zh}$	6.0%		2.5%	
Improvement		With HL-LHC		With HL-LHC
Γ	$4.8 \to 4.7$	$4.8 \to 4.6$	$4.5 \to 3.7$	$4.5 \to 3.7$
g_Z	$0.99 \to 0.94$	$0.99 \to 0.94$	$0.98 \to 0.75$	$0.98 \to 0.75$
g_W	$1.1 \to 1.1$	$1.1 \to 1.1$	$1.1 \to 0.89$	$1.1 \to 0.88$
g_b	$1.5 \to 1.5$	$1.5 \to 1.5$	$1.3 \to 1.2$	$1.3 \to 1.1$

Table 6. The improvement on selected coupling precisions by incorporating our ZZ fusion analysis from a typical 10-parameter model-independent fit. We show both the ILC exclusive results and ILC combined with the optimistic CMS HL-LHC input [27]. For details of fitting scheme and combination scheme, see Ref. [16]. The results for ILC 250/500/1000 (GeV) assume 250/500/1000 fb^{-1} integrated luminosities.

CONSTRAIN BSM SPACE

$$\mathcal{O}_H = \partial^\mu(\phi^\dagger\phi)\partial_\mu(\phi^\dagger\phi), \qquad \mathcal{O}_{HB} = g' D^\mu\phi^\dagger D^\nu\phi B_{\mu\nu},$$



Constraints from ZZ fusion 500 GeV, 1 TeV Contribution