

Study of Higgs Self-couplings at ILC

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status of ZHH full simulation

- succeeded in running mokka and marlin on grid (Thanks Miyamoto-san), now about 1K CPUs can be used ---> 0.5M events/day
- samples with statistics of higher than 2 ab^{-1} for llcc, vvbb ($\sim 2\text{M}$) are generated and analyzed. confirmed to have no contamination finally.
- new background llh (not included in previous llbb background) is checked. no contribution at $\sim 2 \text{ ab}^{-1}$.
- estimating the errors of expected signal and background events. not very stable, still have large fluctuation.

error of expected value

| | no cuts | final cuts |
|-----------|---------|------------|
| generated | M0 | M |
| expected | N0 | N |

Expected value:

$$N = \frac{N_0}{M_0} M$$

Error of expected value:

$$\delta N = \frac{N_0}{M_0} \delta M = \frac{N_0}{M_0} \sqrt{M} = \sqrt{\frac{N_0}{M_0}} \sqrt{N}$$

$$\frac{\delta N}{N} = \sqrt{\frac{N_0}{M_0}} \frac{1}{\sqrt{N}}$$

especially when N is small (our case), we have to improve the error by increasing M0 significantly:

$$\frac{\delta N}{N} = 10\%$$

$$N = 5 \rightarrow M_0 = 10N_0$$

$$e^+ + e^- \rightarrow ZHH \rightarrow (l\bar{l})(b\bar{b})(b\bar{b}) \rightarrow 2 \text{ leptons} + 4 \text{ bjets}$$

Polarization: $(e^-, e^+) = (-0.8, 0.3)$

$$\int L dt = 2 \text{ ab}^{-1}$$

| | signal | background |
|------------|--------|------------|
| N | 6.4 | 6.5 |
| Error of N | 0.10 | 0.6 |

| | |
|--------|------|
| eebb | 0.42 |
| mmbb | 0.36 |
| eebbbb | 0.08 |
| mmbbbb | 0.06 |
| eebbh | 0.07 |
| mmbbh | 0.06 |
| llqqh | 0.10 |

increase

eebb: $6.7 \text{ ab}^{-1} \rightarrow 9.4 \text{ ab}^{-1}$

mmbb: $5.6 \text{ ab}^{-1} \rightarrow 11.0 \text{ ab}^{-1}$

| | signal | background |
|------------|--------|------------|
| N | 6.4 | 7.5 |
| Error of N | 0.10 | 0.6 |

not very stable!

significance: $1.72\sigma \rightarrow 1.65\sigma$

$2.10\sigma \rightarrow 1.98\sigma$

| | |
|------|------|
| eebb | 0.37 |
| mmbb | 0.48 |

$$e^+ + e^- \rightarrow ZHH \rightarrow (\nu\bar{\nu})(b\bar{b})(b\bar{b}) \rightarrow \nu\bar{\nu} + 4 \text{ bjets}$$

Polarization: $(e^-, e^+) = (-0.8, 0.3)$

$$\int L dt = 2 \text{ ab}^{-1}$$

| | signal | background |
|------------|--------|------------|
| N | 5.0 | 6.0 |
| Error of N | 0.15 | 1.5 |

| | |
|----------|------|
| bbbb | 0.62 |
| tauvbbcs | 1.38 |
| vvbbbb | 0.12 |
| vvbbh | 0.08 |

increase

bbbb: $7 \text{ ab}^{-1} \rightarrow 20 \text{ ab}^{-1}$
 tauvbbcs: $2 \text{ ab}^{-1} \rightarrow 12.0 \text{ ab}^{-1}$

| | signal | background |
|------------|--------|------------|
| N | 5.0 | 7.8 |
| Error of N | 0.15 | 0.9 |

not very stable!

significance: $1.41\sigma \rightarrow 1.29\sigma$
 $1.72\sigma \rightarrow 1.53\sigma$

| | |
|----------|------|
| bbbb | 0.43 |
| tauvbbcs | 0.77 |

one issue (gluon emission)

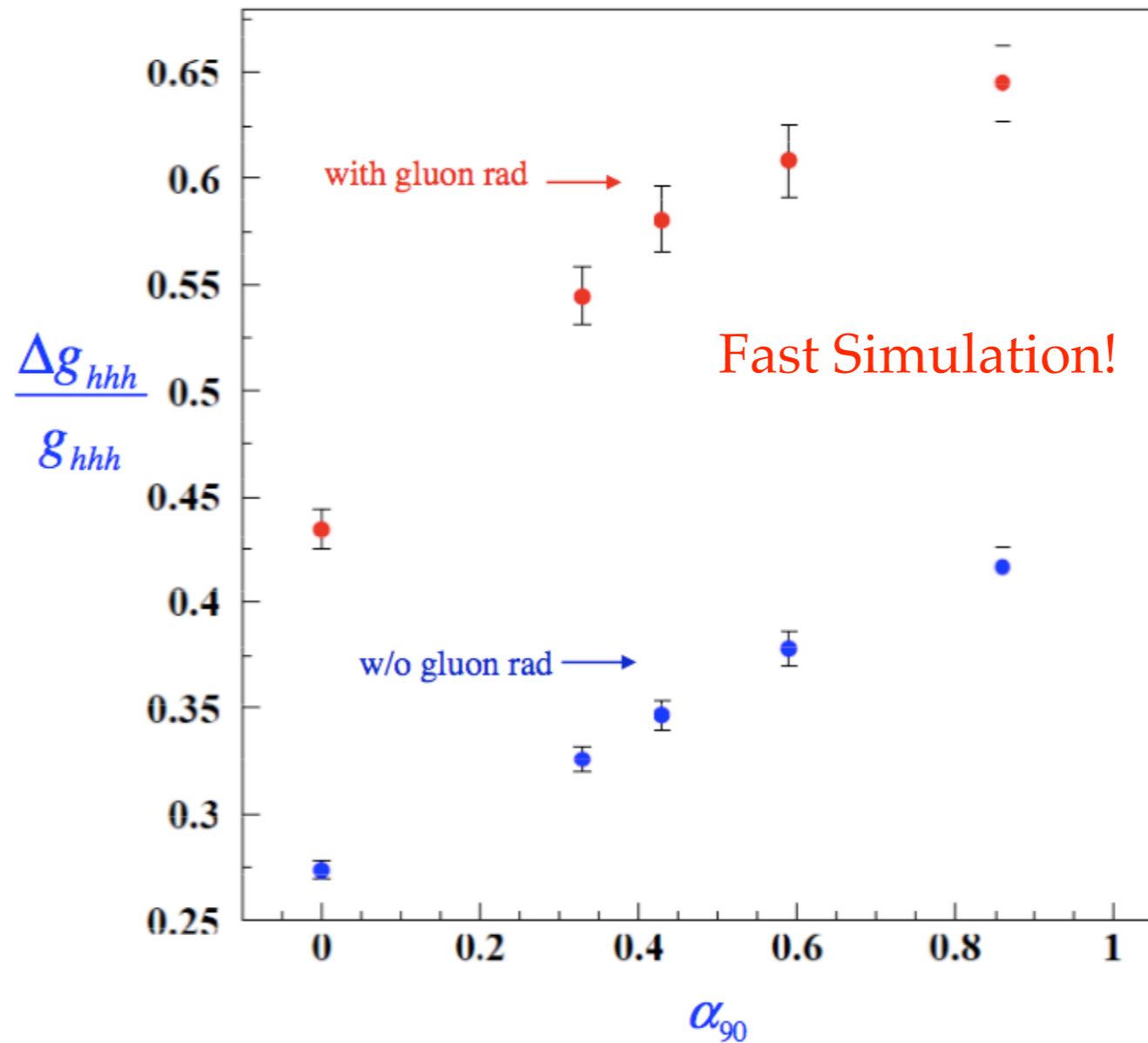
$$\text{BR}(H \rightarrow b\bar{b})=0.678$$

$$e^+e^- \rightarrow ZHH \\ \rightarrow qqbb\bar{b}\bar{b}$$

$$\sqrt{s} = 500 \text{ GeV}$$

$$L = 2000 \text{ fb}^{-1}$$

$$\Delta E/\sqrt{E} = 60\% \rightarrow 30\% \\ \text{equiv to } 1.4 \times \text{Lumi}$$



From Tim's talk
@ LCWS07

whizard-1.40 used by LoI didn't include the gluon emission. higher version included it. need to estimate this affection.

next to do

- qqHH modes still need to be optimized, though still have no idea how to further improve the bbc_{sdu} suppression.
- increase statistics as more as possible to make the result stable ($\sim 20 \text{ ab}^{-1}$).
- estimate the gluon emission affection.
- give a more statistical reasonable accuracy of coupling.

backup

combined result (preliminary)

Polarization: $(e_1, e_+) = (-0.8, 0.3)$ $e^+ + e^- \rightarrow ZHH$ $M(H) = 120\text{GeV}$ $\int Ldt = 2\text{ab}^{-1}$

| Energy (GeV) | Modes | signal | | background | | significance | |
|--------------|--|--------|------|------------|----|--------------|------------------|
| | | | | | | excess (I) | measurement (II) |
| 500 | $ZHH \rightarrow (l\bar{l})(b\bar{b})(b\bar{b})$ | 6.4 | | 6.5 | | 2.1σ | 1.7σ |
| 500 | $ZHH \rightarrow (\nu\bar{\nu})(b\bar{b})(b\bar{b})$ | 5.0 | | 6.0 | | 1.7σ | 1.4σ |
| 500 | $ZHH \rightarrow (q\bar{q})(b\bar{b})(b\bar{b})$ | 6.5 | 11.5 | 6.8 | 86 | 2.7σ | 2.6σ |
| 500 | combined | | | | | 4.6σ | 4.1σ |

accuracy for cross section: $\sim 25\%$

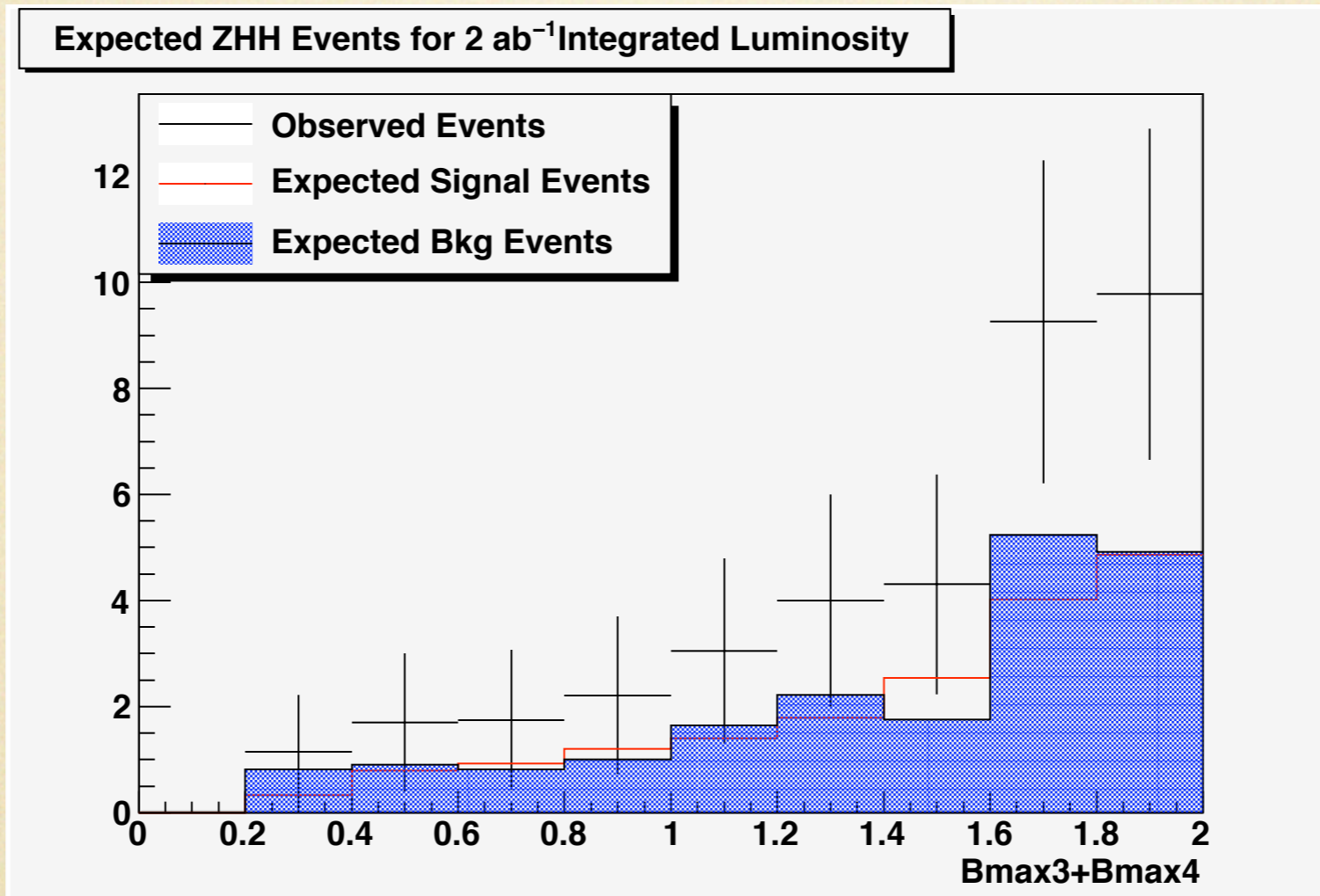
accuracy for self coupling: $\sim 45\%$

LoI: $\sim 180\%$ for cross section, $\sim 90\%$ assuming a better b tagging (500fb^{-1})

Expected ZHH events and backgrounds

$$N_S = 17.9$$

$$N_B = 19.3$$



B_{max3}, B_{max4} :

3rd and 4th largest
b-likeness of the four
jets from two Higgs

