# Study of Higgs Self-couplings at ILC

**J. Tian** (Tsinghua U.)

Y. Takubo (Tohuko U.)

K. Fujii (KEK)

Y. Gao (Tsinghua U.)

# status

- updates on the vvHH analysis: changed cuts

(Previous)

# preliminary results (cut based)

no beam polarization $E_{\mathrm{cm}} = 500\mathrm{GeV}, M_H = 120\mathrm{GeV}$ $\int Ldt = 2\mathrm{ab}^{-1}$

| normalized | MC | expected | pre-selection | Evis<380 | MissPt>40 80<MissM<200 | Npfos>60 | Thrust<0.85 \|Cos\|<0.8 | \|M(H1)-115\|<15 \|M(H2)-110\|<15 | Btagging |
|---|---|---|---|---|---|---|---|---|---|
| ννhh(ννbbbb) | 37587 | 67.7(30.2) | 53.6(27.5) | 51.1(26.2) | 35.3(19.7) | 30.0(18.2) | 23.3(14.0) | 12.0(7.77) | 1.81(1.80) |
| ννbbbb | 10000 | 50.5 | 45.1 | 44.3 | 20.3 | 16.9 | 8.44 | 0.93 | 0.23 |
| ννbbH | 10000 | 60.0 | 50.6 | 49.1 | 33.5 | 29.4 | 20.4 | 3.58 | 0.64 |
| bbcsdu | 405727 | 230600 | 144791 | 3068 | 326 | 298 | 250 | 29.6 | 0 |
| bbuddu | 231600 | 116200 | 71800 | 1389 | 130 | 114 | 96.8 | 12.5 | 0 |
| qqbb | 29637 | 183700 | 152382 | 26547 | 1509 | 650 | 135 | 13.5 | 0 |
| bbbb | 27491 | 23900 | 19205 | 2790 | 129 | 96.5 | 12.2 | 0.87 | 0.87 |
| llbb | 31585 | 316000 | 63940 | 10405 | 1411 | 10.0 | 0 | 0 | 0 |
| ννbb | 30001 | 150000 | 22219 | 22059 | 7355 | 795 | 160 | 15.0 | 0 |
| evbbqq | 318926 | 159200 | 23022 | 13280 | 6994 | 4606 | 3295 | 676 | 0 |
| μvbbqq | 318926 | 159200 | 21983 | 14989 | 8204 | 5648 | 4044 | 818 | 0 |
| τvbbqq | 159175 | 159200 | 124264 | 80514 | 52561 | 34166 | 24531 | 4613 | 1.00 |

1.8 signal events,   2.7 background events:       1.2σ

# preliminary results (cut based)

(New)

no beam polarization    $E_{\rm cm} = 500\,\text{GeV}, M_H = 120\,\text{GeV}$    $\int L dt = 2\,\text{ab}^{-1}$
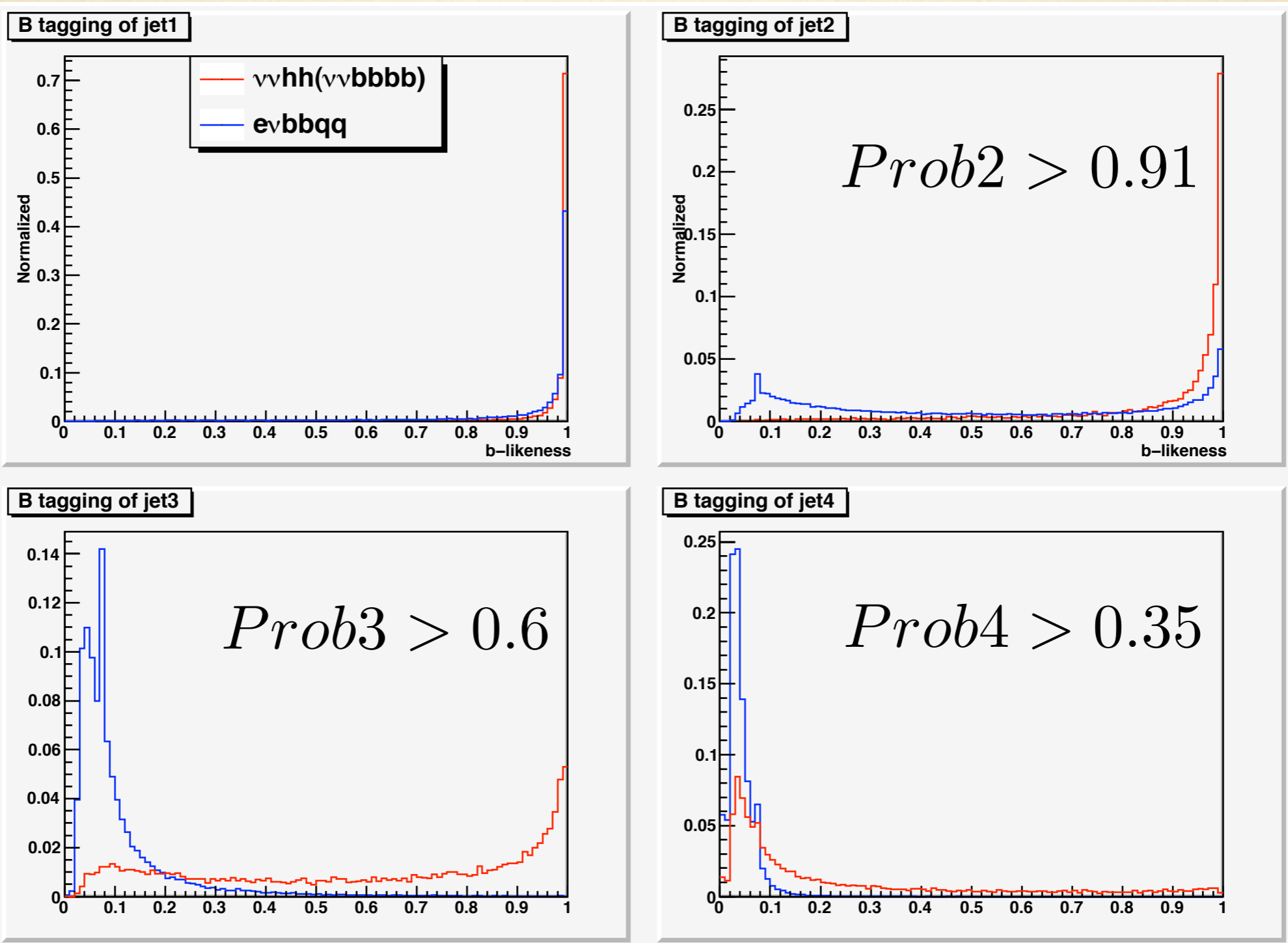
| normalized | MC | expected | pre-selection | Evis<390 | MissPt>25 70<MissM<220 | Npfos>60 | Thrust<0.88 \|Cos1st\|<0.9 | Y65<0.003 | plmax<25 | \|M(H1)-120\|<15 \|M(H2)-115\|<15 | Btagging |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ννhh(ννbbbb) | 45000 | 67.7(30.2) | 53.6(27.3) | 52.4(26.7) | 42.8(23.4) | 35.6(21.5) | 31.8(19.1) | 29.2(18.2) | 26.8(16.6) | 13.4(8.77) | 2.43(2.41) |
| ννbbbb | 30000 | 50.5 | 45.0 | 44.6 | 27.2 | 22.7 | 15.5 | 15.2 | 13.9 | 1.22 | 0.30 |
| ννbbH | 23670 | 60.0 | 50.6 | 50.0 | 41.1 | 35.8 | 29.4 | 28.2 | 26.1 | 3.20 | 0.66 |
| bbcsdu | 405727 | 230600 | 144791 | 4895 | 1192 | 1079 | 956.0 | 474.0 | 438.2 | 43.2 | 0 |
| bbuddu | 231600 | 116200 | 71800 | 2249 | 495.2 | 437.5 | 380.3 | 191.2 | 176.1 | 20.1 | 0 |
| bbcssc | 230721 | 115600 | 73663 | 2737 | 700 | 641.8 | 572.2 | 293.6 | 272.6 | 26.6 | 0 |
| qqbb | 29637 | 183700 | 152382 | 29518.1 | 4608 | 1935 | 534.6 | 500.8 | 466.9 | 60.9 | 0 |
| bbbb | 25000 | 23900 | 19280 | 3346 | 447.4 | 338.4 | 57.4 | 55.4 | 45.9 | 1.91 | 0 |
| llbb | 31585 | 316000 | 63940 | 10405 | 1411 | 10.0 | 10.0 | 10.0 | 0 | 0 | 0 |
| ννbb | 30001 | 150000 | 22219 | 22134 | 9585 | 970.0 | 225.0 | 225.0 | 10.0 | 0 | 0 |
| eνbbqq | 318926 | 159200 | 23022 | 14752 | 9280 | 6016 | 5209 | 4786 | 2286 | 421.3 | 0 |
| μνbbqq | 318926 | 159200 | 21983 | 16492 | 10800 | 7402 | 6306 | 5773 | 2474 | 461.2 | 0 |
| τνbbqq | 159175 | 159200 | 124264 | 89785 | 70570 | 45830 | 39078 | 35346 | 29612 | 5357 | 0 |

2.4 signal events,  1.0 background events:    1.9σ

# B tagging for the four jets

LCFIVertex Processor

jets are ordered by the b-likeness from higher to lower

# different poloarization

no beam polarization $\qquad E_{\rm cm} = 500{\rm GeV}, M_H = 120{\rm GeV} \qquad \int Ldt = 2{\rm ab}^{-1}$

| normalized | MC | expected | pre-selection | final |
|---|---|---|---|---|
| vvhh(vvbbbb) | 45000 | 67.7(30.2) | 53.6(27.3) | 2.43(2.41) |
| vvbbbb | 30000 | 50.5 | 45.0 | 0.30 |
| vvbbh | 23670 | 60.0 | 50.6 | 0.66 |

excess significance:  1.91σ

beam polarization: P(e-,e+) = (-80%,+30%)

| normalized | MC | expected | pre-selection | final |
|---|---|---|---|---|
| vvhh(vvbbbb) | 45000 | 109.9(49.0) | 83.2(42.5) | 3.70(3.67) |
| vvbbbb | 30000 | 105.2 | 94.1 | 0.61 |
| vvbbh | 23670 | 92.7 | 78.2 | 1.03 |

excess significance:  2.36σ

# combined result of full simulation

beam polarization: P(e-,e+) = (-80%,+30%)

$$e^+ + e^- \rightarrow ZHH \quad e^+ + e^- \rightarrow \nu\nu HH \quad M(H) = 120\text{GeV} \quad \int Ldt = 2\text{ab}^{-1}$$

| Energy (GeV) | Modes | signal | background | significance |
|---|---|---|---|---|
| 500 | $ZHH \rightarrow (l\bar{l})(b\bar{b})(b\bar{b})$ | 4.7 | 2.3 | 2.6σ |
| 500 | $ZHH \rightarrow (\nu\bar{\nu})(b\bar{b})(b\bar{b})$ | 3.7 | 1.6 | 2.4σ |
| 500 | $ZHH \rightarrow (q\bar{q})(b\bar{b})(b\bar{b})$ | 26.4 | 153 | 2.0σ |

combining strategy:

- for each mode, we can calculate the p value which is the probability for that greater or equal than the expected number of events are backgrounds.

- multiply the three p values to be the final p value

- calculate 1-p and convert to gaussian significance

excess significance:

combining first two modes: 3.8σ

combining all three modes: 4.4σ

## two definitions for significance

$$1 - p = \int_{-\infty}^{\mu\sigma} N(0,1)$$

$$1 - p = \int_{-\mu\sigma}^{\mu\sigma} N(0,1) \quad \text{(now used)}$$

# summary for ννHH analysis

$$e^+ + e^- \rightarrow ZHH \rightarrow (\nu\bar{\nu})HH$$

- with carefully adjusted cuts, all the backgrounds except ννbbbb and ννbbh are eliminated. significance increased 1.2σ --> 1.9σ

- with polarization (e-,e+)=(-0.8,+0.3), significance increased 1.9σ --> 2.4σ

- combined significance increased to 4.4σ

- next step: optimize the cuts and try to adjust the neural-net for ννHH analysis

backup

# significance

$$p(n \geq m) = \sum_{n=m}^{\infty} \frac{\nu^n e^{-\nu}}{n!} = 1 - \sum_{n=0}^{m-1} \frac{\nu^n e^{-\nu}}{n!}$$