Study of Higgs Self-couplings at ILC

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motivation

SM: $\tilde{\lambda} = \lambda = \lambda_{SM} = \frac{m_H^2}{2v^2}$

Higgs Potential: $V(\eta_H) = \frac{1}{2} m_H^2 \eta_H^2 + \lambda v \eta_H^3 + \frac{1}{4} \tilde{\lambda} \eta_H^4$

physical Higgs field

mass term

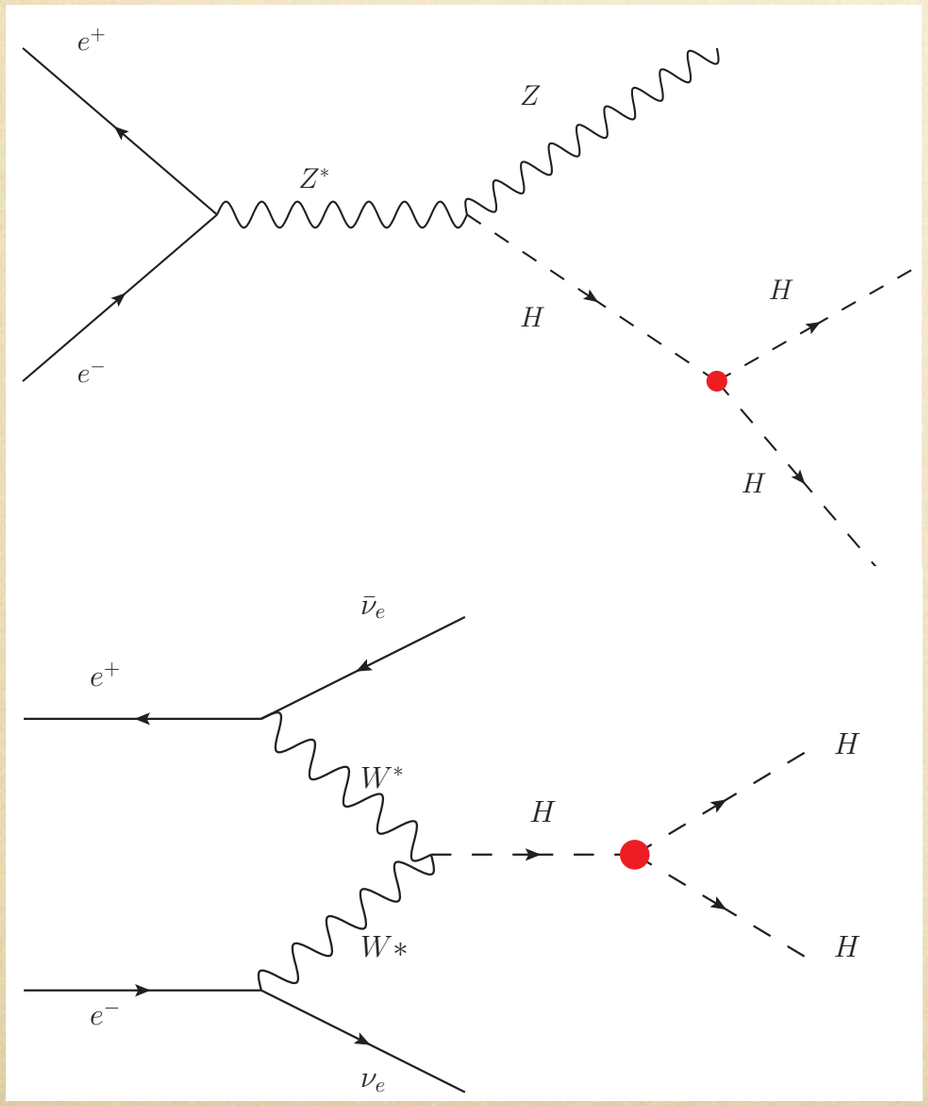
trilinear coupling

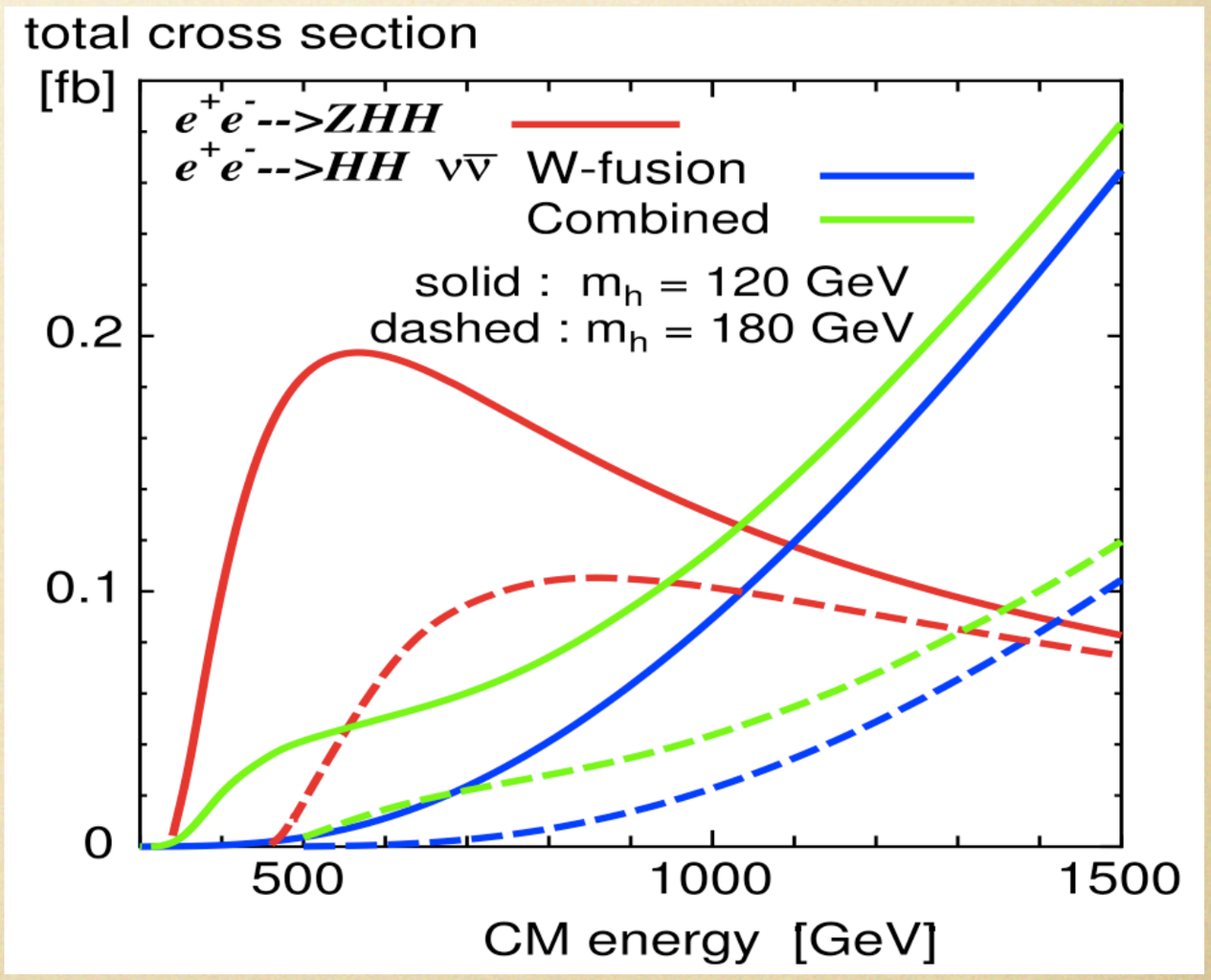
quartic Higgs coupling, which is difficult to measure at both LHC and ILC, even SLHC!

- a new interaction (non-gauge interaction).
- the non-trivial probe of the Higgs potential, offer a direct independent determination.
- accurate test of this coupling may reveal the extended nature of Higgs sector, like 2HDM and SUSY.
- difficult to measure at LHC for a light Higgs.

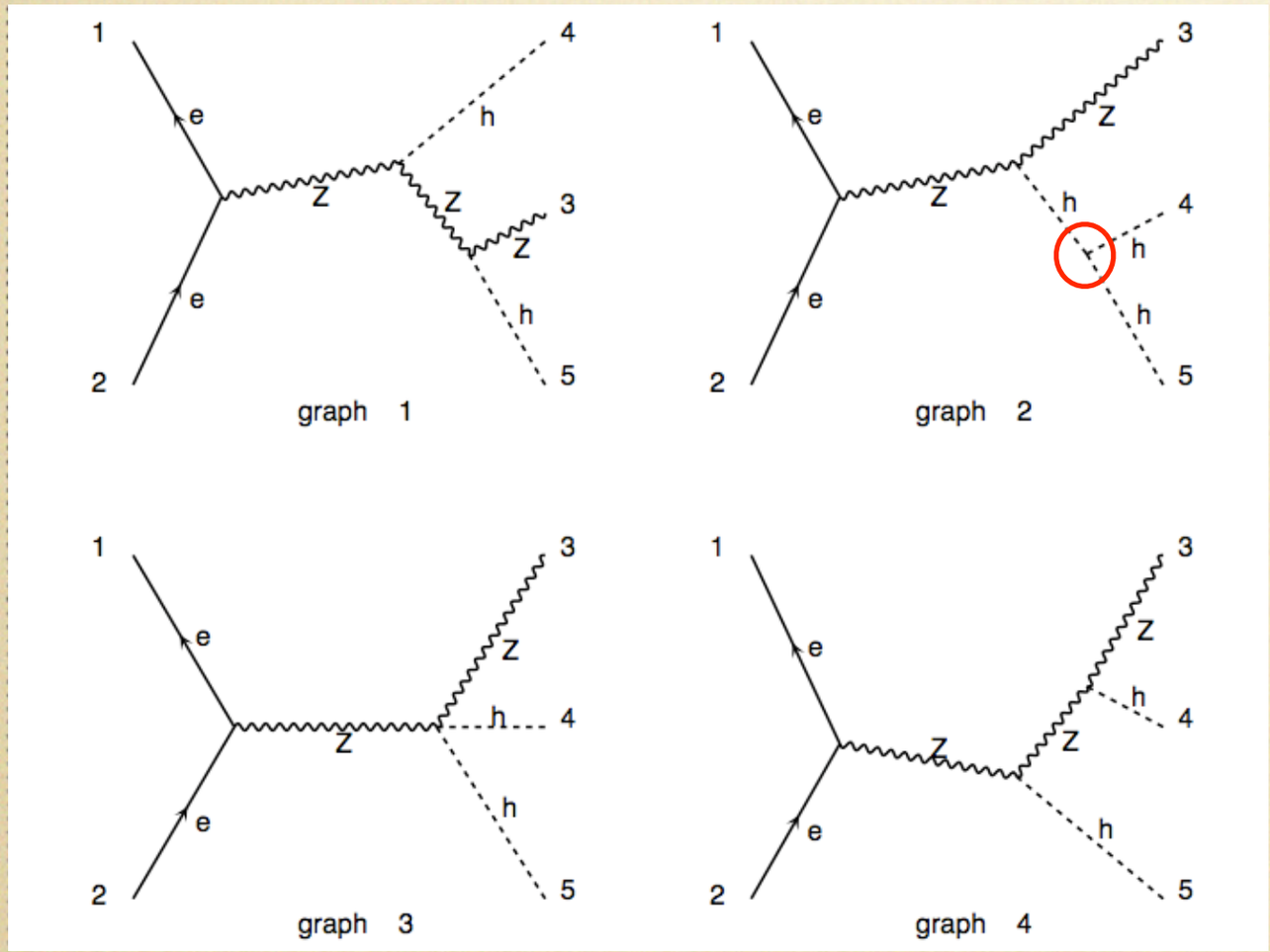
Measurement of the trilinear Higgs self-coupling @ ILC

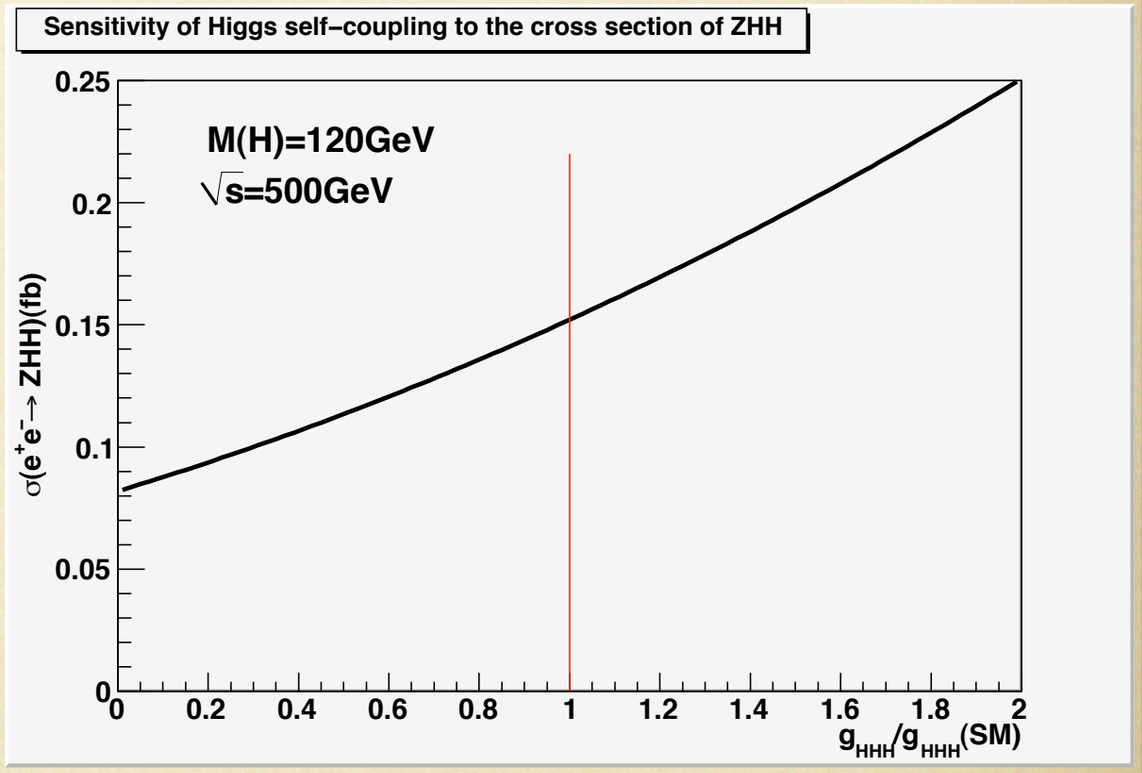
- double Higgs-strahlung (dominate at lower energy)
- WW fusion (dominate at higher energy)





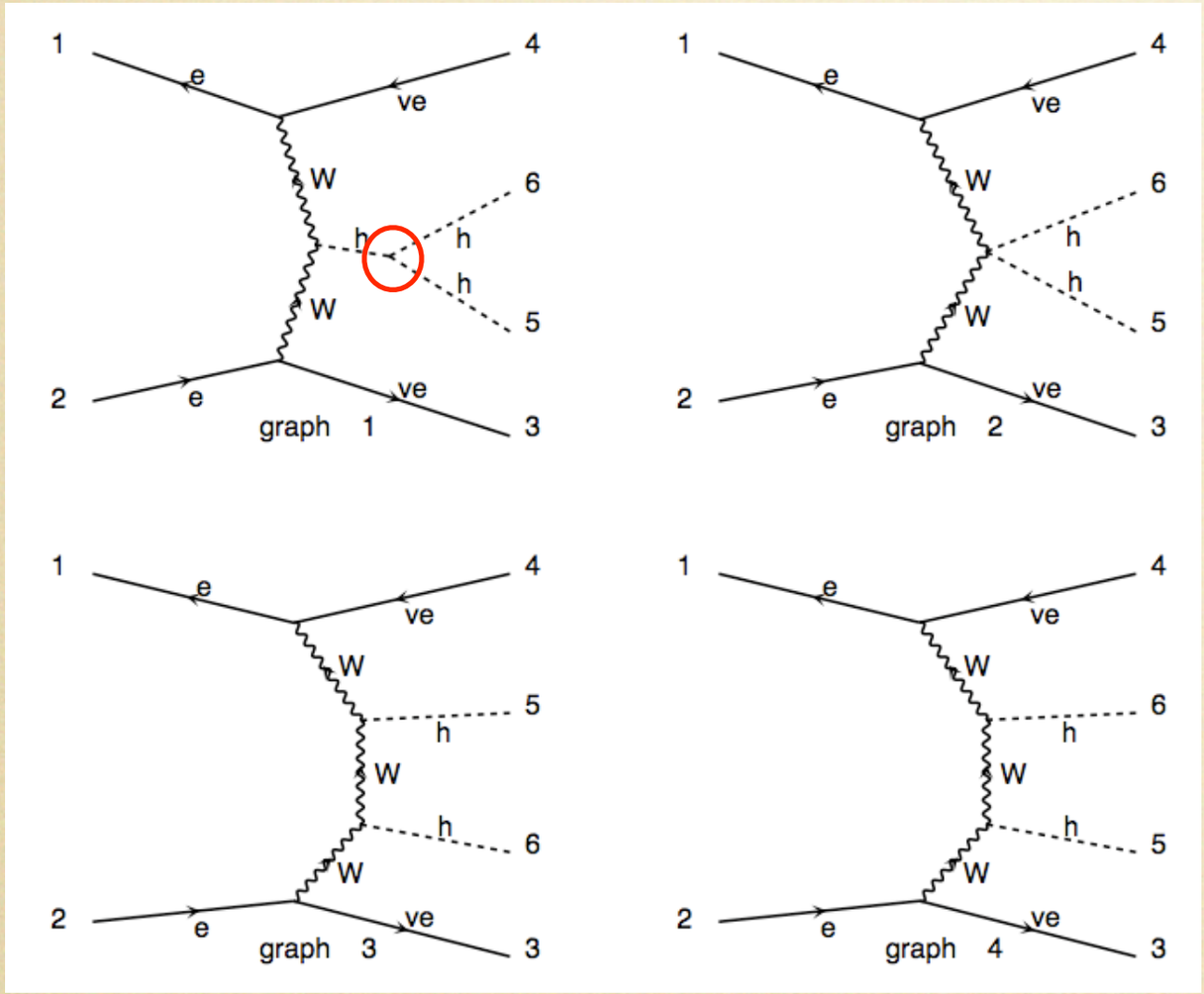
sensitivity of Higgs self-coupling to the cross section of ZHH

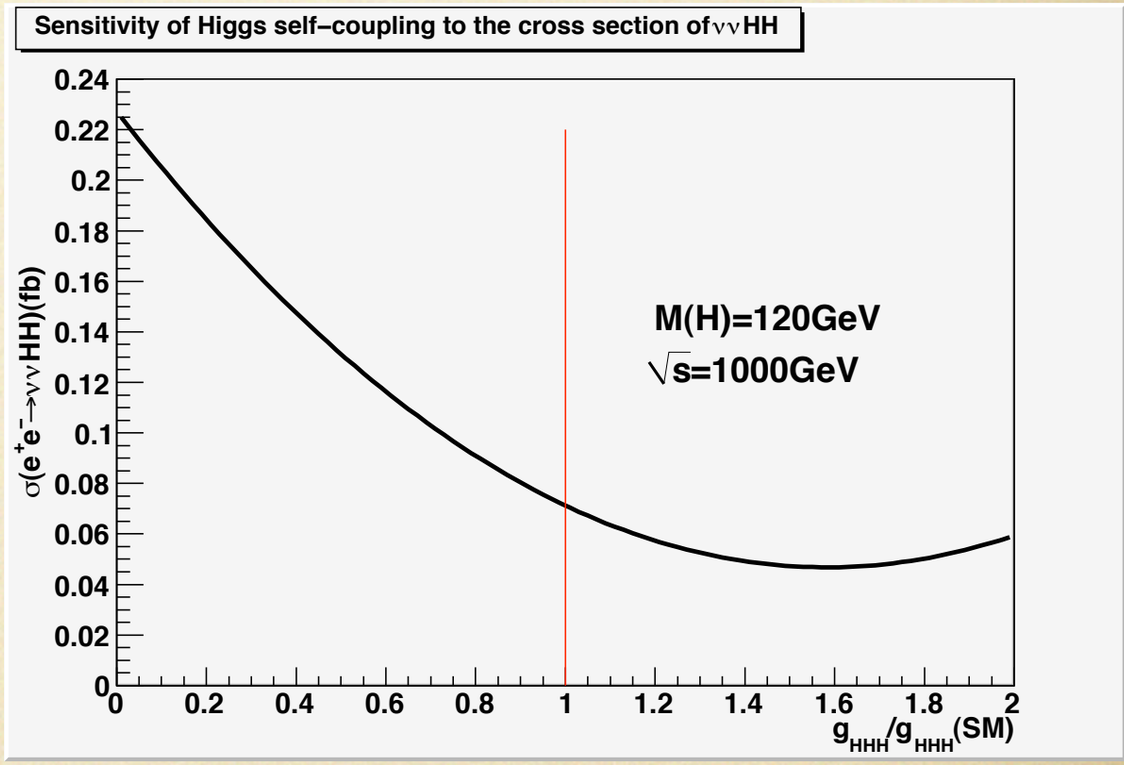




$$\frac{\Delta\lambda}{\lambda} = 1.8\frac{\Delta\sigma}{\sigma}$$

sensitivity of Higgs self-coupling to the cross section of $\upsilon\upsilon$HH





$$\frac{\Delta\lambda}{\lambda} = 0.85\frac{\Delta\sigma}{\sigma}$$

Fast Simulation

set up: JSF framework

- Generator: Physsim

  i. helicity amplitudes are calculated by HELAS

  ii. phase space integration and four momentum generation are performed by BASES/SPRING

  iii. parton showering and hadronization are carried out by PYTHIA

- Simulator: JSFQuickSimulator

  - GLD geometry and detector performance related parameters are implemented (GLD V4')

initial state radiation, beam width, beamstrahlung, w/o beam polarization

Full Simulation

set up: Marlin framework

- Generator: Whizard
- Simulator: Mokka
  - ILD geometry and detector performance related parameters are implemented
- Reconstruction and Analysis: Marlin

initial state radiation, beam width, beamstrahlung, w/ beam polarization

status of the simulation

(preliminary)

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

Energy (GeV)	Modes	Fast Simulation	Full Simulation
500	$ZHH \to (l\bar{l})(b\bar{b})(b\bar{b})$	2.5σ	3.6σ
500	$ZHH \to (\nu\bar{\nu})(b\bar{b})(b\bar{b})$	0.8σ	1.3σ
500	$ZHH \to (q\bar{q})(b\bar{b})(b\bar{b})$	2.0σ	2.0σ
500	$ZHH \to (q\bar{q})(b\bar{b})(WW^*)$	0.05σ	-
1,000	$\nu\bar{\nu}HH \to (\nu\bar{\nu})(b\bar{b})(b\bar{b})$	2.5σ	-

- from LCWS2010, full simulations of llHH and ννHH were investigated (today's topic).
- qqHH analysis was presented at ALCPG09 by Takubo-san.
- improvement in full simulation comes from b tagging and background specification.

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

full simulation @ 500GeV

pre-selection:

- two isolated charged leptons (the pair nearest to Z mass is selected)
- force the other particles(PFOs) to four jets
- combine the four jets by minimizing

$$\chi^2 = \frac{(M(b,\bar{b}) - M_H)^2}{\sigma^2_{H_1}} + \frac{(M(b,\bar{b}) - M_H)^2}{\sigma^2_{H_2}} + \frac{(M(l,\bar{l}) - M_Z)^2}{\sigma^2_Z}$$

do not effect minimization

requirement implied in the pre-selection:

- |M(ll)-M(Z)| < 40 GeV
- |M(jj)-M(H)| < 80 GeV

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

final selection:

- divide all the backgrounds to four kinds: non-leptonic, jets poor, semi-leptonic, two leptons four b jets

- for non-leptonic backgrounds (bbcsdu): add tighter cuts on the cone energy of leptons

- for jets poor backgrounds (llbb): train a neural-net with Y value, thrust, axis of thrust, numbers of PFOs in each jet

- for semi-leptonic backgrounds (lvbbqq): train a neural-net with missing energy, b tagging, energy and cone energy of the slower lepton, angle between two most like b jets

- for two leptons four b jets backgrounds (llbbbb): train a neural-net with two Higgs masses, features of t-channel events

preliminary results

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

normalized	MC	expected	pre-selection	econe1+econe2<30 econec1+econec2<10	80<mz<100	mvallqq>0.8	mvalvbbqq>0.8	mvallbbbb>0.5
llhh(llbbbb)	19700	21.18(9.5)	17.50(7.83)	15.67(7.30)	13.82(6.21)	10.47(5.78)	7.37(5.19)	4.93(3.55)
bbhh	8000	46.2	0.55	0.23	0.058	0.046	0.029	0.023
cchh	8000	36.2	0.48	0.31	0.069	0.064	0.0058	0.0058
llbbbb	10924	25.64	9.31	7.79	6.18	4.12	3.67	0.50
bbbbbb	19998	6.9	0.034	0	0	0	0	0
bbcsdu	405727	230600	328.5	1.14	0	0	0	0
bbcssc	230701	115600	166.9	0	0	0	0	0
bbuddu	231600	116200	158.0	0.50	0.50	0.50	0	0
qqbb	29637	207600	343.2	0	0	0	0	0
qqcc	20672	103400	40.02	0	0	0	0	0
qqqq	21934	156000	78.2	0	0	0	0	0
lvbbqq	796313	477600	8369.1	1052.7	214.8	112.9	0.5	0
llbb	31585	316000	12856.1	5692.7	3531.7	30.01	10.00	0
llcc	290907	1434800	12414.2	5617.7	3447.6	118.4	0	0

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

(preliminary)

- 4.93 signal events with 0.50 background events:
  - ZHH excess significance: 3.6σ
  - 68% confidence level: $5.4^{+3.5}_{-2.3}$ 54% for cross section
  - precision for Higgs self-coupling: 97%

- llbbH not considered: as rough estimation, 1.0 event could be involved.

- statistics of llbb backgrounds is not enough (we are generating more samples)

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

full simulation @ 500GeV

pre-selection:

- no isolated charged leptons
- force the particles(PFOs) to four jets
- combine the four jets by minimizing

$$\chi^2 = \frac{(M(b,\bar{b}) - M_H)^2}{\sigma^2_{H_1}} + \frac{(M(b,\bar{b}) - M_H)^2}{\sigma^2_{H_2}}$$

requirement implied in the pre-selection:

- $|M(jj)-M(H)| < 80$ GeV

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

final selection:

- adding constraints on Missing Energy, Missing Pt and Missing Mass.
- requiring the Number of Particles in each jet to be greater than 10 and Total Number of Particles to be greater than 60.
- for one of the dominant backgrounds (bbbb): train a neural-net with Thrust, Axis of Thrust, Maximum Momentum of three bosons, Pole Angle of Maximum Momentum and Invariant Masses of Higgs.
- for another dominant backgrounds (lvbbqq): train a neural-net with Axis of Thrust, Y value in case of 5 jets, Higgs Masses, Reconstructed W mass and Top mass.
- b tagging requirement: order the four jets with the b likeness, add constraints on the last two b likeness.

preliminary results (cut based)

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

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	59.3							
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
μνbbqq	318926	159200	21983	14989	8204	5648	4044	818	0
τνbbqq	159175	159200	124264	80514	52561	34166	24531	4613	1.00

1.8 signal events, 2.1 background events: 0.91σ

preliminary results (neural-net based)

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

normalized	MC	expected	pre-selection	Evis<380	MissPt>40 80<MissM<200	Npfos>60	MLP_bbbb>0.8	MLP_lvbbqq>0.5	Btagging
νννh(νννbbbb)	37587	67.7(30.2)	53.6(27.5)	51.1(26.2)	35.3(19.7)	30.0(18.2)	22.7(13.7)	11.1(7.69)	1.95(1.94)
νννbbbb	10000	50.5	45.1	44.3	20.3	16.9	4.22	1.33	0.37
νννbbH	10000	59.3							
bbcsdu	405727	230600	144791	3068	326	298	159	9.66	0
bbuddu	231600	116200	71800	1389	130	114	61.2	4.52	0
qqbb	29637	183700	152382	26547	1509	650	67.7	13.5	0
bbbb	27491	23900	19205	2790	129	96.5	5.22	0	0
llbb	31585	316000	63940	10405	1411	10.0	0	0	0
νννbb	30001	150000	22219	22059	7355	795	45.0	15.0	0
eνbbqq	318926	159200	23022	13280	6994	4606	2614	236	0
μνbbqq	318926	159200	21983	14989	8204	5648	3178	294	0.50
τνbbqq	159175	159200	124264	80514	52561	34166	19032	1817	0

1.9 signal events, 0.9 background events: 1.3σ

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

(preliminary)

- bbbb, vvbbbb and lvbbqq became the dominant backgrounds.
- vvbbH not considered. (using ZZH generator with physsim, still under investigation)

- cut based: 1.8 signal, 2.1 background ---> 0.9σ
- neural-net based: 1.9 signal, 0.9 background ---> 1.3σ

summary

- double strahlung process ZHH @ 500 GeV is possible to search the Higgs Self-Coupling signature.

- ZZH background is not considered yet for both llHH and ννHH analyses. Generating full simulation sample of ZZH by using Physsim is the next plan.

- we will finalize each analysis and combine them in the near future.

backup

significance

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