Higgs Self-Coupling Measurement at the ILC.

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Overview

- Higgs self-coupling analysis with new Higgs mass $m_{\mathrm{H}} = 125$ GeV samples
- ZHH at $\sqrt{s} = 500\ \mathrm{GeV}$, assuming $\mathcal{L} = 2\ \mathrm{ab}^{-1}$
- beam polarisation $P(e^{+}, e^{-}) = (0.3, -0.8)$
- analysis strategy identical to LC-REP-2013-003 by Junping Tian
- **new:** consider low-p_T $\gamma\gamma \rightarrow$ hadrons beam induced background
- **status update of analysis presented at AWLC 2014**

  Higgs self-coupling for $\mathrm{m_H} = 120$ GeV: 44%
  extrapolation to $\mathrm{m_H} = 125$ GeV: 53%

  Higgs self-coupling for $\mathrm{m_H} = 125$ GeV without overlay: 52%
  with overlay: 59.4%

- **today:** update on overlay removal $\longrightarrow$ $\nu\nu HH$ search channel

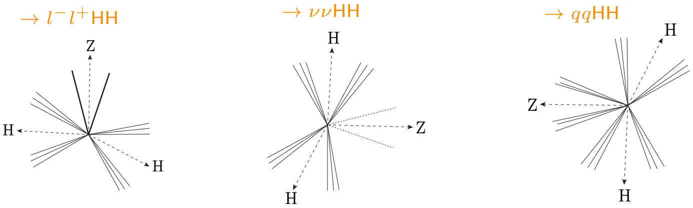
Analysis strategy $e^+e^- \rightarrow ZHH$ at $\sqrt{s} = 500$ GeV

Perform analysis for $m_H = 125$ GeV without and with overlay and investigate the differences

analysis strategy identical to *LC-REP-2013-003*

NEW low p_T $\gamma\gamma \rightarrow$ hadrons background

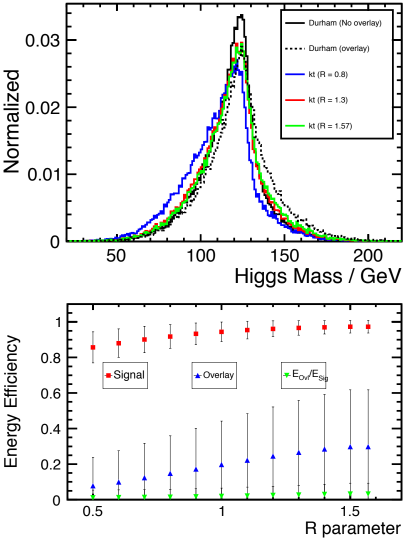
- virtual photons which got radiated off the primary beam electrons
- real photons due to bremsstrahlung and synchrotron radiation



Event selection:

1. isolated lepton selection or rejection
2. $\gamma\gamma$-overlay removal
3. cluster particles into jets and get flavor tag information
4. pair jets to form signal bosons
5. each dominant background is suppressed by training a separate neural net

Removal of low-p_T $\gamma\gamma \rightarrow$ hadrons background



- low-p_T $\gamma\gamma \rightarrow$ hadrons overlaid events per interaction:

  $$< N_{\gamma\gamma} >= 1.7$$

  (ILD/SiD standard, but overestimated)

- apply **FastJetClustering:**

  k_TExclusiveNJets

  which R-value?

- for R ≥ 1.2 almost no increase in signal efficiency but in overlay
- best recovery of bare evts R $= 1.3$
- use only reconstructed particles in the clustered jets for analysis

'Old' results and status of analysis

measurement at $\sqrt{s}$ =500 GeV, $\mathcal{L}$ =2 ab^{-1} and P(e^+e^-) = (0.3,-0.8)

- **preliminary results for 'no overlay' case:**

modes	signal	background	significance	
			excess	measurement
ZHH → l^-l^+HH	3.0	4.3	1.16σ	0.91σ
	3.3	6.0	1.12σ	0.91σ
ZHH → $\nu\bar{\nu}$HH	5.4	7.0	1.72σ	1.45σ
ZHH → $q\bar{q}$HH	9.1	21.3	1.78σ	1.61σ
	9.0	34.7	1.41σ	1.30σ

significance: 3.8σ

cross-section:
$\frac{\delta\sigma_{ZHH}}{\sigma_{ZHH}}$ = 32.6%

Higgs self-coupling:
$\frac{\delta\lambda}{\lambda}$ = 52.5%

- **preliminary results for 'overlay' case:**

modes	signal	background	significance	
			excess	measurement
ZHH → l^-l^+HH	2.4	4.0	0.94σ	0.72σ
	3.2	7.0	1.01σ	0.83σ
ZHH → $\nu\bar{\nu}$HH	3.8	4.0	1.53σ	1.22σ
ZHH → $q\bar{q}$HH	8.3	22.3	1.59σ	1.44σ
	8.7	39.3	1.29σ	1.19σ

significance: 2.9σ

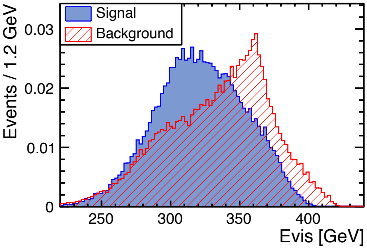
cross-section:
$\frac{\delta\sigma_{ZHH}}{\sigma_{ZHH}}$ = 36.2%

Higgs self-coupling:
$\frac{\delta\lambda}{\lambda}$ = 59.4%

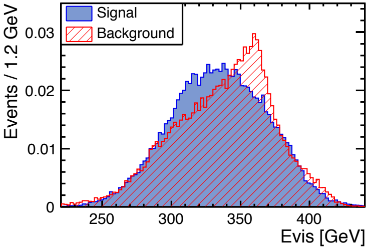
Problem in $\nu\nu HH$: Evis in neural net training

- three neural nets: bbbb, lvbbqq, vvbbbb
- visible energy input variable for bbbb vs signal

'no overlay'



'overlay'



- shift to higher visible energies for signal in overlay case?

Problem in $\nu\nu$HH: Evis in neural net training

- just for signal sample? $\longrightarrow$ check other samples ✔

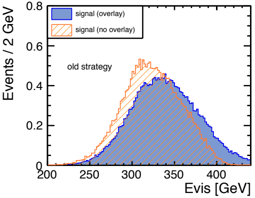
  bbbb
  vvbb
  lvbbqq
  vvqqh
  vvbbbb
  bbqqqq

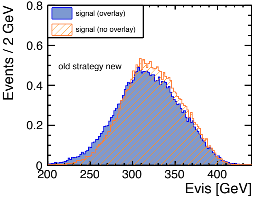
- overlay removal before/after isolated lepton finding? ✔
- FastJetClustering $\longrightarrow$ correct R-value? ✔
- FastJetClustering $\longrightarrow$ Number of jets?

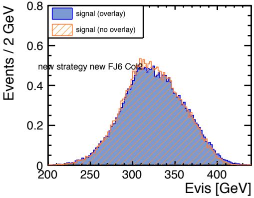
Example distribution

	old	correct collection FastJet Njets = 4	correct collection FastJet Njets = 6

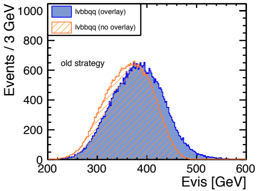
signal $\nu\nu HH$

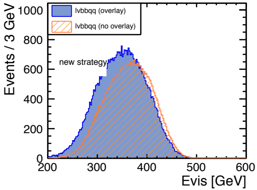


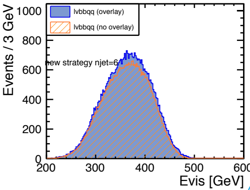




background $l\nu bbqq$







neutrino channel: optimised cuts

optimised with overlay

- **cut1**:
  $E_{vis} < 362\text{ GeV} + 0.83 \cdot P_t^{miss}$,
  $M_Z < 60\text{ GeV}$
- **cut2**:
  $\text{npfos}_{min} > 8$,
  $\text{M(HH)} < 217\text{ GeV}$,
  $99\text{ GeV} < \text{M(H1)} < 146\text{ GeV}$,
  $91\text{ GeV} < \text{M(H2)} < 139\text{ GeV}$
- **cut3**: MVAbbbb > 0.90
- **cut4**: MVAlvqqqq > 0.74
- **cut5**: MVAvvbbbb > 0.31
- **cut6**: bmax3 + bmax4 > 1.08

optimised without overlay

- **cut1**:
  $E_{vis} < 364\text{ GeV} + 0.83 \cdot P_t^{miss}$,
  $M_Z < 60\text{ GeV}$
- **cut2**:
  $\text{npfos}_{min} > 5$,
  $\text{M(HH)} < 238\text{ GeV}$,
  $101\text{ GeV} < \text{M(H1)} < 139\text{ GeV}$,
  $89\text{ GeV} < \text{M(H2)} < 135\text{ GeV}$
- **cut3**: MVAbbbb > 0.86
- **cut4**: MVAlvqqqq > 0.72
- **cut5**: MVAvvbbbb > 0.48
- **cut6**: bmax3 + bmax4 > 1.08

neutrino channel: cutflow table

without overlay

with overlay

	$\nu\nu$bb	eνbbqq	$\mu\nu$bbqq	$\tau\nu$bbqq	bbqqqq	bbbb	$\nu\nu$bbbb	$\nu\nu$qqh	bgrd	signal ($\nu\nu$4b)
expected	272802	248454	245936	245708	624060	40234.3	97.1	447.0	$1.7 \cdot 10^6$	80.1
preselection	951.2	1677.9	1410.3	36246.8	62172.9	30830.4	82.2	71.0	133443	28.3 (22.6)
	994.5	2018.2	1670.4	39845.2	71838.3	30835.5	81.5	74.9	147358	28.5 (22.4)
cut1	908.3	837.4	825.6	24231.6	1382.8	3934.9	80.7	68.9	32270.2	27.5 (21.9)
	869.8	961.2	916.2	25059.5	2368.9	3894.1	78.7	69.9	34218.5	27.4 (21.5)
cut2	16.5	203.9	209.6	5315.7	257.6	376.3	8.1	18.8	6406.6	16.5 (14.5)
	11.7	281.5	291.2	6459.3	697.6	498.2	12.1	23.5	8275.1	16.3 (14.3)
cut3	8.4	171.5	175.2	4286.4	87.9	11.7	4.8	14.5	4760.6	14.2 (12.5)
	5.5	226.6	223.5	4910.7	153.6	10.8	7.5	18.2	5556.7	13.3 (11.7)
cut4	3.5	29.1	38.8	511.2	32.2	6.4	2.8	6.7	630.8	10.8 (9.8)
	4.9	37.1	44.6	606.7	46.6	5.8	4.1	8.1	758.2	11.3 (10.1)
cut5	2.1	23.9	32.9	430.8	31.6	5.9	1.3	4.5	533.3	9.7 (8.7)
	4.9	37.1	34.9	523.9	45.9	5.1	2.1	6.0	653.5	10.6 (9.5)
cut6	0	0.2	0.3	1.5	0	2.6	0.6	1.7	6.9	5.2 (5.1)
	0	0	0	3.6	0	2.2	0.9	2.1	9.0	5.6 (5.5)

Results and current status of analysis

measurement at $\sqrt{s}$ =500 GeV, $\mathcal{L}$ =2 ab^{-1} and P(e^+e^-) = (0.3,-0.8)

- **preliminary results for 'no overlay' case:**

modes	signal	background	significance	
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ZHH → $\nu\bar{\nu}$HH	5.2	6.9	1.63σ	1.37σ
	5.4	7.0	1.72σ	1.45σ
ZHH → $q\bar{q}$HH	9.1	21.3	1.78σ	1.61σ
	9.0	34.7	1.41σ	1.30σ

significance: 3.74σ

cross-section:
$\frac{\delta\sigma_{ZHH}}{\sigma_{ZHH}} = 32.8\%$

Higgs self-coupling:
$\frac{\delta\lambda}{\lambda} = 53.8\%$

- **preliminary results for 'overlay' case:**

modes	signal	background	significance	
			excess	measurement
ZHH → l^-l^+HH	2.4	4.0	0.94σ	0.72σ
	3.2	7.0	1.01σ	0.83σ
ZHH → $\nu\bar{\nu}$HH	5.6	9.0	1.45σ	1.23σ
	3.8	4.0	1.53σ	1.22σ
ZHH → $q\bar{q}$HH	8.3	22.3	1.59σ	1.44σ
	8.7	39.3	1.29σ	1.19σ

significance: 3.36σ

cross-section:
$\frac{\delta\sigma_{ZHH}}{\sigma_{ZHH}} = 35.6\%$

Higgs self-coupling:
$\frac{\delta\lambda}{\lambda} = 58.4\%$

BACKUP SLIDES

neutrino channel: old optimised cuts

optimised with overlay

- **cut1**:
  $E_{vis} < 372$ GeV $+ 0.83 \cdot P_t^{miss}$,
  $M_Z < 60$ GeV
- **cut2**:
  npfos$_{min} > 10$,
  M(HH) < 200 GeV,
  103 GeV $<$ M(H1) < 141 GeV,
  103 GeV $<$ M(H2) < 136 GeV
- **cut3**: MVAbbbb > 0.93
- **cut4**: MVAlvqqqq > 0.73
- **cut5**: MVAvvbbbb > 0.3
- **cut6**: bmax3 + bmax4 > 1.1

optimised without overlay

- **cut1**:
  $E_{vis} < 364$ GeV $+ 0.83 \cdot P_t^{miss}$,
  $M_Z < 60$ GeV
- **cut2**:
  npfos$_{min} > 6$,
  M(HH) < 200 GeV,
  100 GeV $<$ M(H1) < 139 GeV,
  91 GeV $<$ M(H2) < 134 GeV
- **cut3**: MVAbbbb > 0.93
- **cut4**: MVAlvqqqq > 0.66
- **cut5**: MVAvvbbbb > 0.56
- **cut6**: bmax3 + bmax4 > 1.08

neutrino channel: old cutflow table

without overlay

with overlay

	$\nu\nu bb$	$e\nu bbqq$	$\mu\nu bbqq$	$\tau\nu bbqq$	bbqqqq	bbbb	$\nu\nu bbbb$	$\nu\nu qqh$	bgrd	signal ($\nu\nu 4b$)
expected	272802	248454	245936	245708	624060	40234.3	97.1	447.0	$1.7 \cdot 10^6$	80.1
preselection	545.4	1787.7	1480.9	37410.7	65529	31292	81.9	72.3	138200	28.5 (22.7)
	992.8	1996.6	1661.7	38659.3	69698	30922	80.9	74.6	144086	28.4 (22.4)
cut1	481.0	894.1	867.4	25002.4	1443.6	3943.2	80.5	70.1	32782.4	27.7 (22.0)
	862.4	989.7	929.3	24532.0	1247.8	3552.6	77.8	69.2	32260.9	26.6 (20.9)
cut2	6.7	208.0	225.3	5161.1	252.8	382.9	9.7	19.6	6266.3	16.8 (14.8)
	5.6	163.7	154.3	2951.7	270.5	211.5	4.8	8.6	3770.8	11.6 (10.4)
cut3	4.3	181.5	196.8	4325.4	121.6	13.3	6.4	15.9	4865.2	14.9 (13.1)
	2.4	110.9	112.1	1938.3	61.7	4.1	2.4	6.4	2238.4	8.6 (7.7)
cut4	4.3	34.5	45.3	602.9	42.8	7.7	4.1	8.5	750.3	11.8 (10.6)
	2.4	44.1	45.8	624.5	38.0	3.3	1.9	4.7	764.7	7.5 (6.8)
cut5	3.1	24.9	35.1	454.7	41.9	6.5	1.4	4.4	527.0	9.9 (8.9)
	2.4	37.3	39.8	568.3	36.9	3.1	1.3	4.1	693.3	7.1 (6.4)
cut6	0	0	0	1.6	0.1	3.0	0.6	1.7	7.0	5.4 (5.3)
	0	0	0	0.6	0.1	1.3	0.6	1.4	4.0	3.8 (3.8)

Excess and measurement significance

excess significance: assuming there is no signal, the probability of observing events equal or more than the expected number of events $(N_S + N_B)$

$$p = \int_{N_S+N_B}^{\infty} f(x; N_B) dx$$

in case of large statistics: $\frac{N_S}{\sqrt{N_B}}$

measurement significance: assuming signal exists, the probability of observing events equal or less than the expected number of background events (N_B)

$$p = \int_{-\infty}^{N_B} f(x; N_S + N_B) dx$$

in case of large statistics: $\frac{N_S}{\sqrt{N_S+N_B}}$

convert to gaussion significance (s):

$$1 - p = \int_{-\infty}^{s\sigma} N(x; 0, 1) dx$$