Measuring the Higgs Branching Ratio into Photon Pairs at the ILC

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General Meeting

2014 Jan. 18

Initial Comments

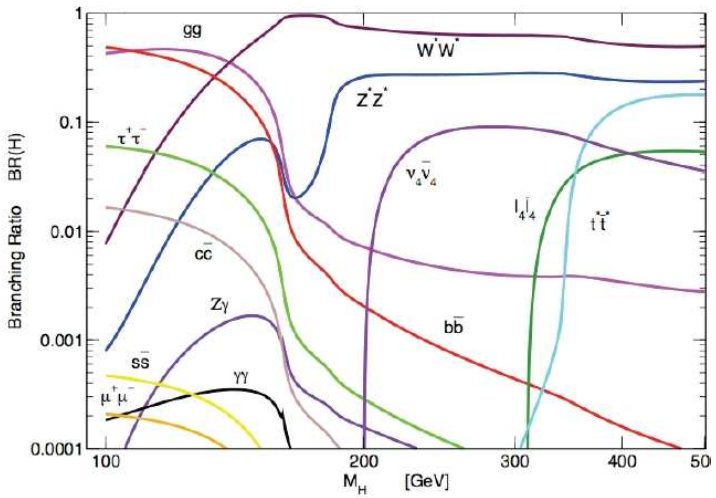
- No much progress since last Tokyo LCWS13.
  - Studying origin of low preselection efficiency ($< 90\%$).
  - Reoptimazing final selection with TMVA (in progress).

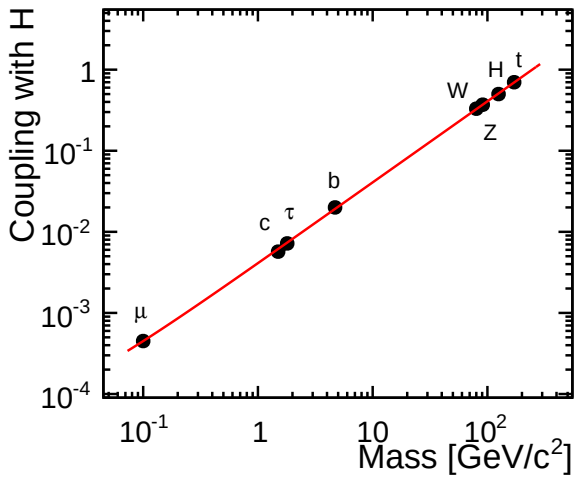
Outline

- Introduction
- Analysis
  - Results
- Conclusion

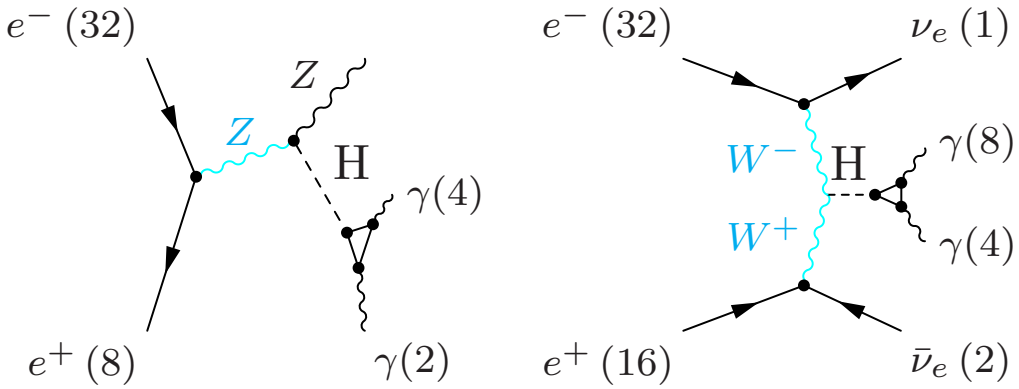
Branching Ratio Measurements

- Studying the Higgs properties important part of the ILC physics programme.
- Mass of $\approx 125\ \mathrm{GeV}/c^2$ $\rightarrow$ we are sensitive to many H decays.
  - Makes possible to test the linear coupling mass relation.
  - Makes possible to study rare Higgs decays via loop.
    - Even if no new heavy particles are observed, they will affect the branching fraction of these rare decays.





$H \to \gamma\gamma$



external Z in the left hand plot decaying to: $Z \to l^+l^-$, $Z \to \nu\bar{\nu}$, $Z \to q\bar{q}$ (*)

Very small ratio: Br$(H \to \gamma\gamma) = 0.228$ %

- Main Background: qq$\gamma\gamma$, $\nu\nu\gamma\gamma$
  - High statistics samples generated, simulated, reconstructed with same tools as DBD samples.
- $\sigma(mainback)/\sigma(signal)$
  - 1000 GeV: $\approx$ 50$(= 44/0.9)$ $(\nu\bar{\nu}H)$, $\approx 930(= 38/0.041)$ $(q\bar{q}H)$
  - 500 GeV: $\approx$ 110$(= 42/0.39)$ $(\nu\bar{\nu}H)$, $\approx 410(= 65/0.16)$ $(q\bar{q}H)$
  - 250 GeV: $\approx 400(= 71/0.18)$ $(\nu\bar{\nu}H)$, $\approx 560(= 265/0.47)$ $(q\bar{q}H)$
  - On blue color currently analyzed modes (WW-fusion processes only).

(*) On red the reconstructed modes on this Analysis (no $Z \to l^+l^-$).

Samples

- SM samples: DBD samples (det. model ILD_o1_v05).
- Signal and main background samples created with same tools as SM samples.
- All samples include the beam induced background ($\gamma\gamma \rightarrow$ hadrons).

Processes (500 GeV)	σ [fb]	L[ab^{-1}]
$\nu\nu$H	0.39	202
qqH	0.16	498.7
$\nu\nu\gamma\gamma$	41.6	16.9
qq$\gamma\gamma$	64.8	10.8
2f	26400	0.125
4f	32400	0.10
aa_4f	210	0.53
5f	143	0.57
6f	1180	0.40

Processes (1000 GeV)	σ [fb]	L[ab^{-1}]
$\nu\nu$H	0.92	64.4
qqH	0.0405	1931
$\nu\nu\gamma\gamma$	43.9	135.8
qq$\gamma\gamma$	37.8	111
2f	7780.0	0.068
4f	310000	0.042
3f	283000	0.021
aa_4f	1130	0.091
6f	693	7.13

Analysis

Strategy

Signal Topology

- Two large energy photons.
- Large missing energy because the two missing neutrino.

Loose Preselection (*)

- Two large photons ($E > 25$ GeV) with invariant mass $|M(\gamma,\gamma) - 125| < 30\ \mathrm{GeV/c^2}$
  - Recovered FSAR using standard ILD procedure.
- $\not{E} > 90$ GeV

- Additional cuts to reject 2f,4f hadronic contributions.
- Final selection using TMVA.

(*) Preselection Efficiencies < 90 % (currently under investigation).

NNH: $\mathrm{H} \to \gamma\gamma$ 500 GeV

$\nu\bar{\nu}\mathrm{H}$, 500 GeV

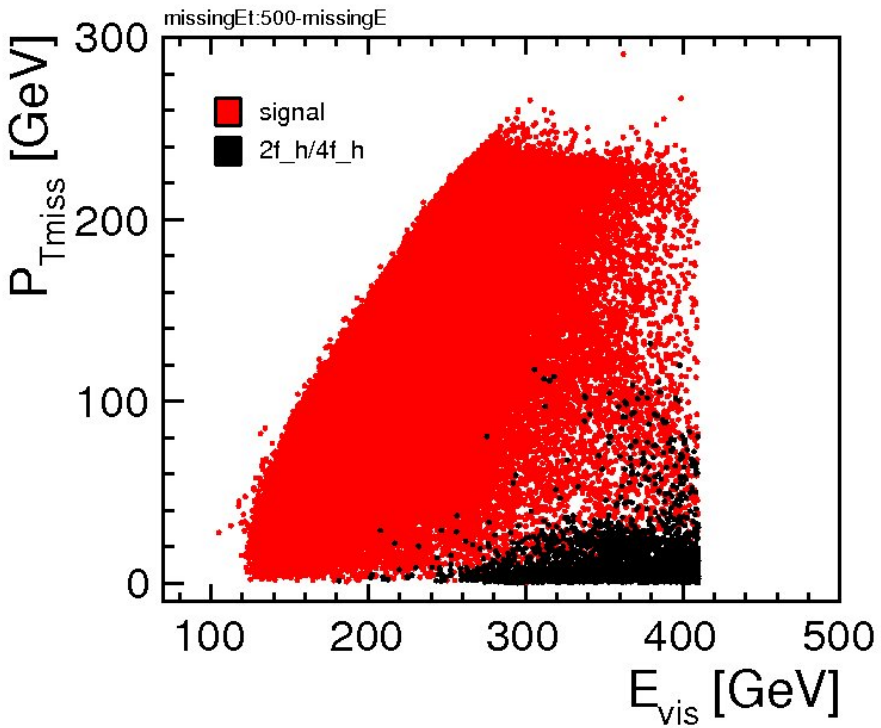
NNH: $H \to \gamma\gamma$ 500 GeV

Background Rejection

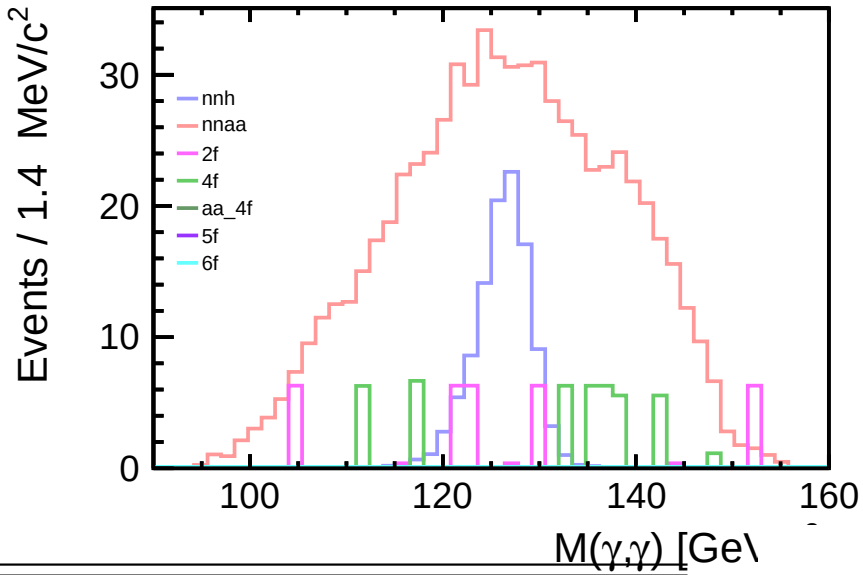
- Exploit correlation on some variables (coneE, E) $\not{E}_T$, E_{vis}).
- Added event thrust information.
- After reject other contributions, using TMVA to separate signal from main background.

BDT Variables

- $\cos(\gamma, \gamma)$
- $\cos(\theta_\gamma)$
- $P_T(\gamma_1)+P_T(\gamma_2)$
- energyH
- principleThrust
- cosThrustAxis
- oblateness
- $\cos(\theta_{\not{P}})$

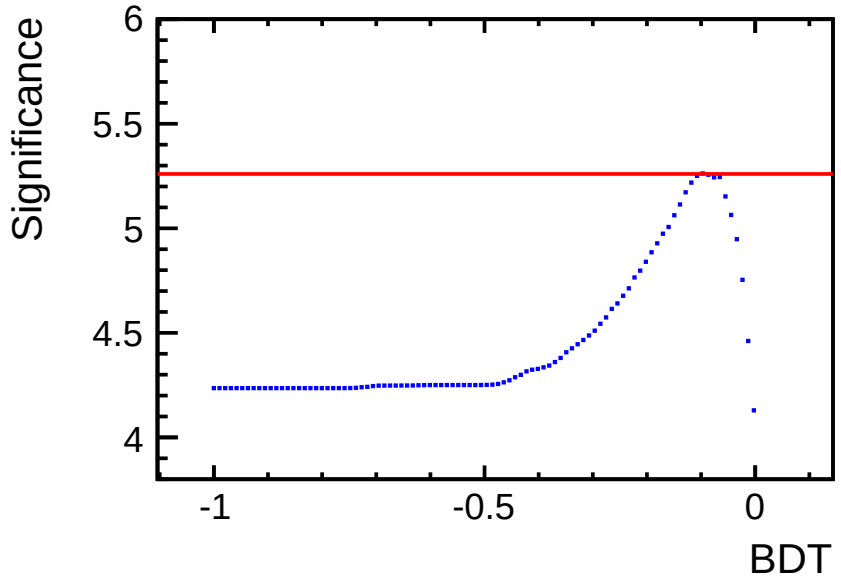


NNH: $H \to \gamma\gamma$ 500 GeV



1	Preselection
2	(coneE_m $<$ 3.76+0.066*E_m) & (coneE_l $<$ 0.0545+0.092*E_l)
3	$\not{E}_T >$ -326 + 1.25*E_{vis}
4	$\lvert\cos(\theta^*_\gamma)\rvert < 0.98$
5	$\cos(\theta_\gamma) < 0.98$
6	$\text{coneE}(\gamma_1) + \text{coneE}(\gamma_2) < 8$
7	$\not{M} > 140\ \text{GeV}/c^2$
8	BDT $>$ -0.1
9	$120 < M(\gamma,\gamma) < 132\ \text{GeV}/c^2$

- Significance: 5.3
- E_m (E_l): photon from di-photon system with highest (lowest) energy.



Cut Flow NNH 500

Process	signal	vvaa	2f	4f	aa_4f	5f	6f	Signf
Cross Section	0.387	41.6	2.64e+04	3.24e+04	210	143	1.18e+03	
Expected	193	2.08e+04	1.32e+07	1.62e+07	1.05e+05	7.17e+04	5.89e+05	
Generated	7.83e+04	7.02e+05	3.3e+06	3.27e+06	1.11e+05	8.16e+04	4.74e+05	
Cut1	169	8.07e+03	2.9e+04	5.33e+04	75	75.5	350	0.56
Cut2	166	7.5e+03	7.37e+03	1.15e+04	21.5	19.2	64.9	1.02
Cut3	164	7.01e+03	1.3e+03	3.76e+03	7.54	5.56	12.7	1.48
Cut4	162	6.71e+03	1.05e+03	3.35e+03	6.55	5.55	12.6	1.52
Cut5	156	4.41e+03	744	1.41e+03	1.93	4.2	6.85	1.9
Cut6	152	4.23e+03	175	257	0	0	0.0177	2.19
Cut7	134	3.07e+03	121	162	0	0	0	2.27
Cut8	107	696	33	44	0	0	0	3.6
Cut9	103	260	19	0	0	0	0	5.3

1	Preselection
2	(coneE_m $<$ 3.76+0.066*E_m) & (coneE_l $<$ 0.0545+0.092*E_l)
3	$\not{E}_T >$ -326 + 1.25*E_{vis}
4	$\lvert\cos(\theta^*_\gamma)\rvert < 0.98$
5	$\cos(\theta_\gamma) < 0.98$
6	$\text{coneE}(\gamma_1) + \text{coneE}(\gamma_2) < 8$
7	$\not{M} > 140\ \text{GeV}/c^2$
8	BDT $>$ -0.1
9	$120 < M(\gamma,\gamma) < 132\ \text{GeV}/c^2$

- The low efficiency (87.6%) after preselection is under study.
- Possible sources are:
  - Photon conversions.
  - One photon escape to beam pipe / one photon less than 25 GeV.

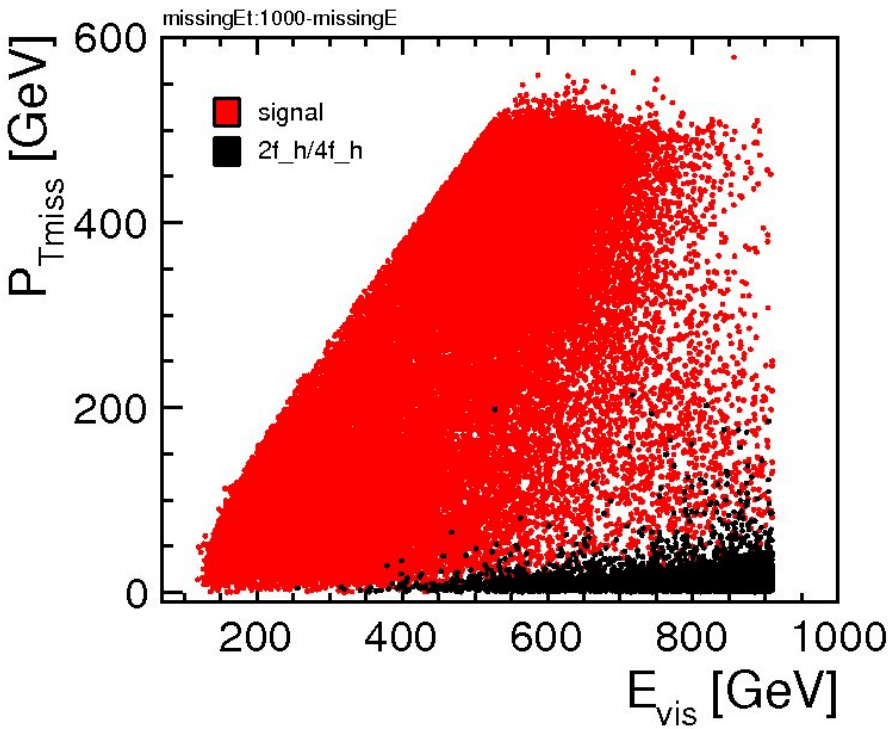
NNH: $\mathrm{H} \to \gamma\gamma$ 1000 GeV

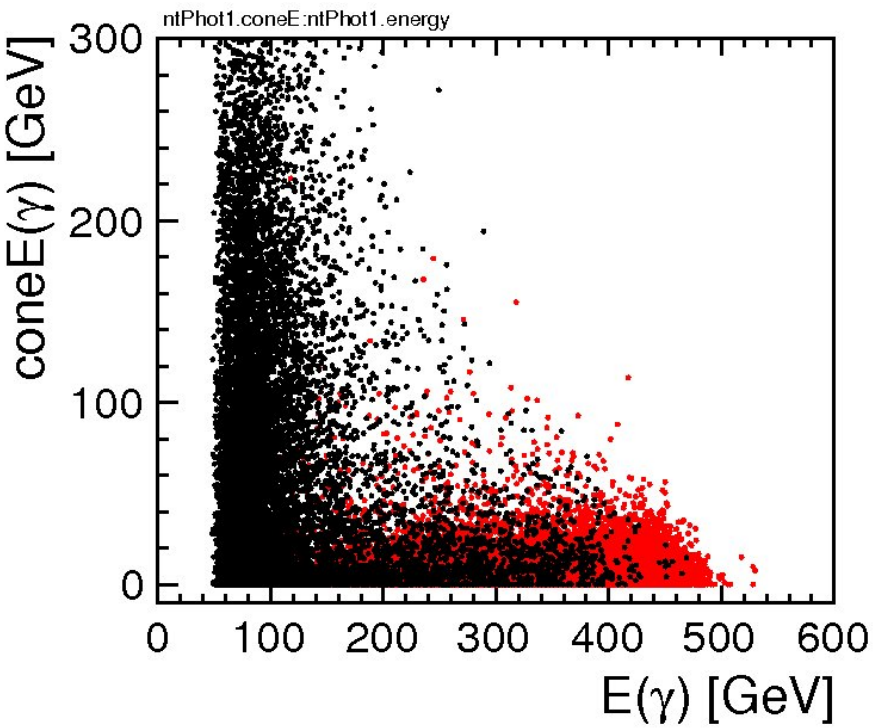
$\nu\bar{\nu}\mathrm{H}$, 1000 GeV

NNH: $H \to \gamma\gamma$ 1000 GeV

1	Preselection
2	$\not{E}_T > -474 + 0.985 * E_{vis}\ \mathrm{GeV/c^2}$
3	($coneEm < 1.60 + 0.064 * Em$) && ($coneEl < 0.44 + 0.092 * El$) (*)
4	MLP > 0.133

(*) Em (El) γ from di-photon system with highest (lowest) E.

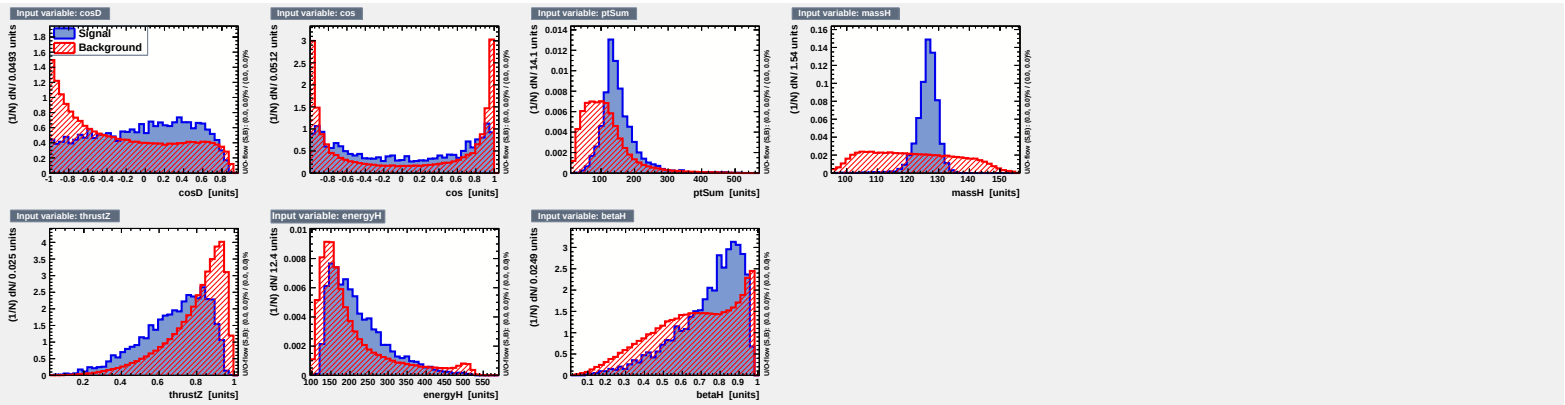




TMVA trainning

Input vars

- $\cos(\gamma,\gamma)$
- $\cos(\theta_\gamma)$
- $P_T(\gamma_1)+P_T(\gamma_2)$
- thrust (on Z-axis)
- energyH
- $\beta(H)$
- $M(\gamma,\gamma)$



NNH: $H \to \gamma\gamma$ 1000 GeV Cut Flow

Process	signal	vvaa	2f	4f	3f	aa_4f	6f	Signf
Cross Section	0.922	43.9	7.78e+03	3.1e+05	2.83e+05	1.13e+03	693	-
Expected	922	4.39e+04	7.78e+06	3.1e+08	2.83e+08	1.13e+06	6.93e+05	-
Generated	5.94e+04	5.96e+06	5.19e+05	1.3e+07	6.01e+06	1.03e+05	4.94e+06	-
Cut1	770	1.49e+04	4.73e+04	3.36e+05	1.71e+05	4.99e+03	8.11e+03	1.01
Cut2	757	1.41e+04	5.09e+03	8.55e+04	5.39e+04	1.68e+03	1.05e+03	1.88
Cut3	724	1.13e+04	1.19e+03	2.76e+04	1.75e+04	47	150	2.99
Cut4	496	675	1.7	142	24.3	0	0.3	13.6

1	Preselection
2	$\not{E}_T > 474 + 0.985 * E_{vis}\ \mathrm{GeV/c^2}$
3	$(coneEm < 1.60 + 0.064 * Em)$ && $(coneEl < 0.44 + 0.092 * El)$ (*)
4	MLP > 0.133

(*) Em (El) γ from di-photon system with highest (lowest) E.

- The low efficiency (83.5%) after preselection is under study.
- Possible sources are:
  - Photon conversions.
  - One photon escape to beam pipe / one photon less than 25 GeV.

Summary / Plan

- Studying the Higgs branching ratios is an important topic at the ILC.
- Significant deviations from the SM predictions in the branching ratio of rare Higgs decays (via loop) would be a clear sign of new physics.

$\mathrm{H} \to \gamma\gamma$

- We have analyzed the process $\nu\bar{\nu}\mathrm{H}(\mathrm{H} \to \gamma\gamma\ )$ for the ILD detector.
- We estimate $\frac{\Delta(\sigma \cdot Br)}{\sigma \cdot Br}$ as follows:
  - 18.9 % at 500 GeV $(500\ \mathrm{fb}^{-1})$
  - 7.4 % at 1000 GeV $(1000\ \mathrm{fb}^{-1})$.

Plan

Plan $\mathrm{H} \to \gamma\gamma$

- Finish $\mathrm{H} \to \gamma\gamma$ analysis.
- Write documentation note.
- Write paper.

Longer Term: $\mathrm{H} \to \mathrm{Z}\gamma$

- Need some discussion with generator experts if i plan to do it.
- It seems `Whizard` v1 not suitable for generate such process.
- `Whizard` v2? `GRACE`? Good options but ...
  - Lack of module describing ILC beam polarisation.

Back Up Slides

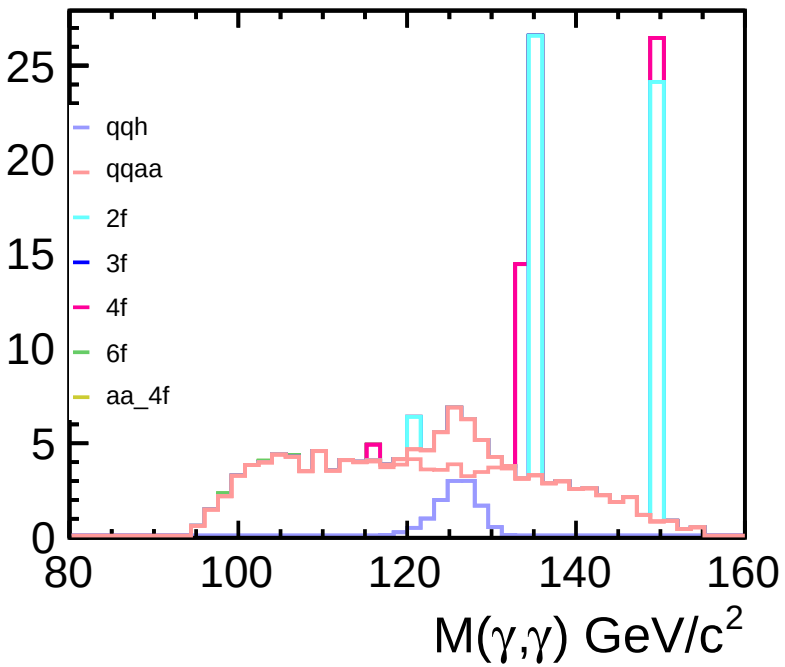
Back Up

QQH: $\mathrm{H} \to \gamma\gamma$ 1000 GeV

$\mathrm{q\bar{q}H}$, 1000 GeV

QQH: $H \to \gamma\gamma$ 1000 GeV

1	Preselection
2	missing mass $< 200\ \mathrm{GeV}/c^2$
3	cos(γ,γ) > 0.65
4	coneE(γ) < 20 GeV
5	$\lvert cos(\theta)\rvert < 0.85$
6	P_T(H) >350 GeV
7	$\not{E} <$ 100 GeV
8	$120 < M(\gamma,\gamma) < 132\ \mathrm{GeV}/c^2$

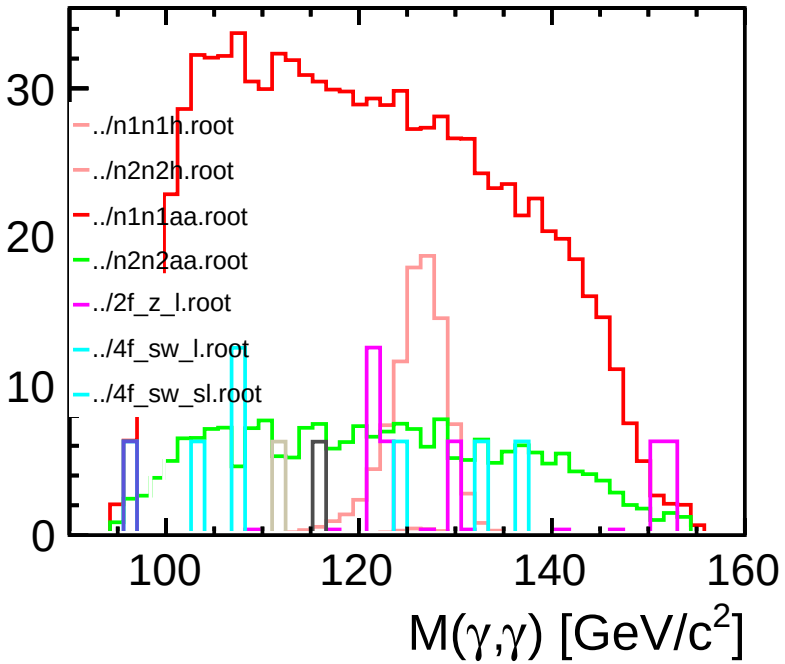


- Significance: 1.85

QQH: $H \to \gamma\gamma$ 1000 GeV Cut Flow

Process	signal	vvaa	2f	4f	3f	aa_4f	6f	Signf
Cross Section	0.0405	37.8	7.78e+03	3.1e+05	2.83e+05	1.13e+03	698	-
Expected	40.5	3.78e+04	7.78e+06	3.1e+08	2.83e+08	1.13e+06	6.98e+05	-
Generated	7.82e+04	4.19e+06	5.26e+05	1.3e+07	6.01e+06	1.13e+05	4.93e+06	-
Cut1	34.5	1.43e+04	2.78e+05	1.74e+06	1.07e+06	1.02e+04	5.44e+04	0.0194
Cut2	29	1.14e+04	2.2e+05	1.12e+06	6.48e+05	3.88e+03	4.55e+04	0.0203
Cut3	21.7	2.92e+03	1.53e+04	3.83e+04	2.26e+04	65.1	211	0.0771
Cut4	19.3	1.99e+03	3.17e+03	1.46e+04	9.82e+03	0	39.7	0.112
Cut5	16.6	249	78.5	90.8	0	0	3.65	0.795
Cut6	13.4	119	50	22	0	0	0.339	0.933
Cut7	12.5	113	48.3	14.5	0	0	0.339	0.912
Cut8	11.9	27.6	1.72	0	0	0	0	1.85

NNH: $H \to \gamma\gamma$ 500 GeV (Cut based Analysis)



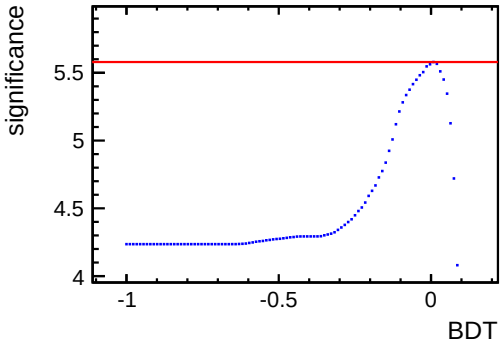
- Significance: 4.3

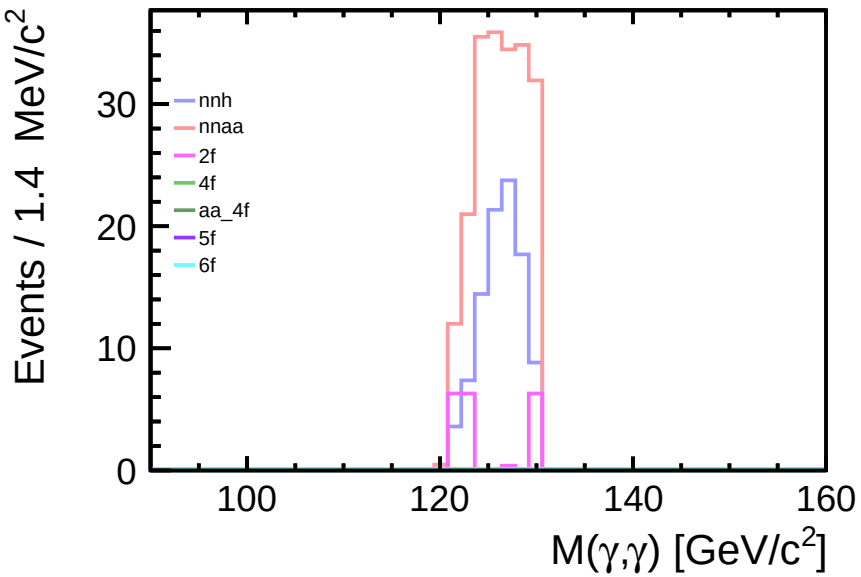
1	Preselection
2	$M\!\!\!/ > 140\ \mathrm{GeV}/c^2$
3	$E\!\!\!/_T > 20$ GeV
4	$E\!\!\!/ > 250$ GeV
5	$\cos(\gamma_1,\gamma_2) > -0.85$
6	coneE(γ) < 10 GeV
7	$P_T(\gamma_1) + P_T(\gamma_2) >= 100$ GeV
8	$120 < M(\gamma,\gamma) < 132\ \mathrm{GeV}/c^2$

Cut Flow NNH 500

Process	signal	vvaa	2f	4f	aa_4f	5f	6f	Signf
Cross Section	0.387	41.6	2.64e+04	3.24e+04	210	143	1.18e+03	
Expected	193	2.08e+04	1.32e+07	1.62e+07	1.05e+05	7.17e+04	5.89e+05	
Generated	7.83e+04	7.02e+05	3.3e+06	3.27e+06	1.11e+05	8.16e+04	4.74e+05	
Cut1	169	7.68e+03	2.9e+04	5.3e+04	75	75.5	350	0.562
Cut2	147	5.54e+03	9.59e+03	9.86e+03	21.6	13.6	37	0.924
Cut3	137	4.53e+03	5.73e+03	6.77e+03	9.82	6.55	30.4	1.05
Cut4	123	3.35e+03	1.32e+03	1.83e+03	5.84	3.84	19.6	1.51
Cut5	120	3.08e+03	193	347	0.984	0.000977	1.35	1.96
Cut6	101	1.32e+03	80.8	93.8	0	0	0	2.52
Cut7	94.3	339	25.9	6.29	0	0	0	4.37

Mass in the BDT Trainning ($H \to \gamma\gamma$ 500 GeV)

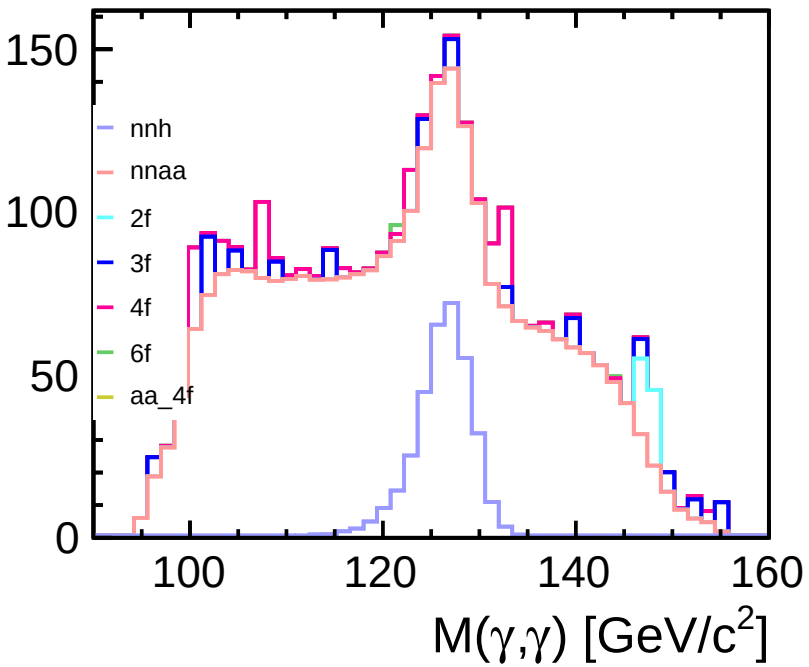




- Including massH in the BDT trainning no significant improve (S $\approx$ 5.4).

NNH: $H \to \gamma\gamma$ 1000 GeV (Cut based Analysis)

1	Preselection
2	missing mass $> 400\ \mathrm{GeV}/c^2$
3	$\lvert cos(\theta)\rvert < 0.95$
4	coneE(γ) < 20 GeV
5	P_T(H) >40 GeV
6	$P_T(\gamma_1)+P_T(\gamma_2)>55$GeV
7	n charged PFO $<= 15$
8	$120 < M(\gamma,\gamma) < 132\ \mathrm{GeV}/c^2$



- Significance: 10.2

NNH: $H \to \gamma\gamma$ 1000 GeV Cut Flow

Process	signal	vvaa	2f	4f	3f	aa_4f	6f	Signf
Cross Section	0.922	43.9	7.78e+03	3.1e+05	2.83e+05	1.13e+03	693	-
Expected	922	4.39e+04	7.78e+06	3.1e+08	2.83e+08	1.13e+06	6.93e+05	-
Generated	5.94e+04	5.96e+06	5.19e+05	1.3e+07	6.01e+06	1.03e+05	4.94e+06	-
Cut1	770	1.49e+04	4.73e+04	3.36e+05	1.71e+05	4.99e+03	8.11e+03	1.01
Cut2	714	1.3e+04	5.84e+03	9.45e+04	7.03e+04	2.51e+03	453	1.65
Cut3	595	4.74e+03	3.31e+03	1.48e+04	9.08e+03	1.67e+03	279	3.2
Cut4	591	4.69e+03	214	1.47e+03	662	20.6	14	6.76
Cut5	513	3.73e+03	144	922	458	0	8.14	6.75
Cut6	513	3.67e+03	144	913	452	0	8.14	6.8
Cut7	348	2.51e+03	46.5	256	111	0	3.32	6.08
Cut8	325	626	0	52.8	18.1	0	2.69	10.2