Measurement of $e^+e^- \rightarrow \nu_e\nu_e H$ (H->WW*->qqqq) at future leptonic Colliders

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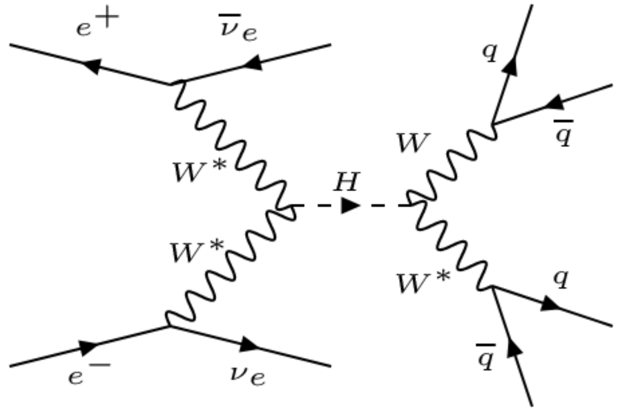
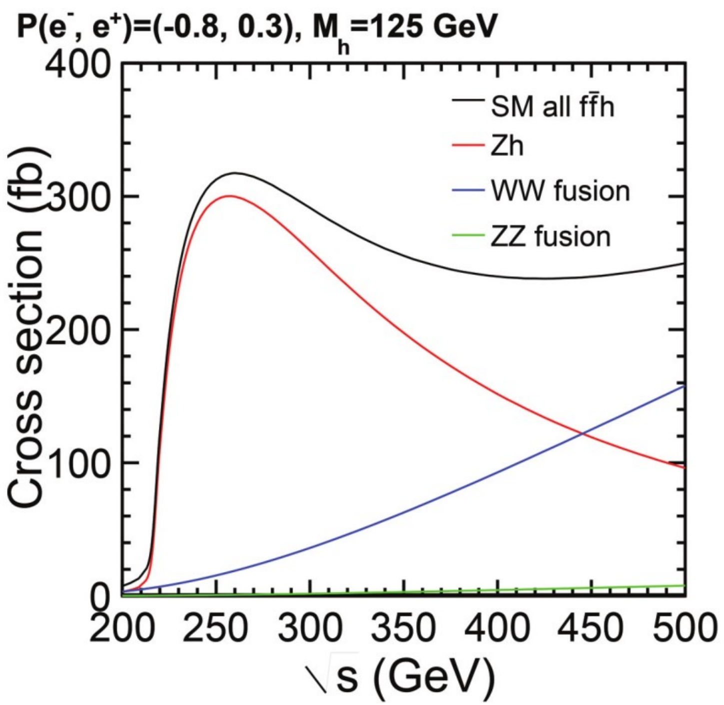
Studied channel





$$N_S \propto g_{HWW}^4 \quad \rightarrow \quad \frac{\Delta g_{HWW}}{g_{HWW}} = \frac{1}{4}\frac{\sqrt{N_S + N_B}}{N_S}$$

$$BR(H \rightarrow WW^*) = 21.5\%$$

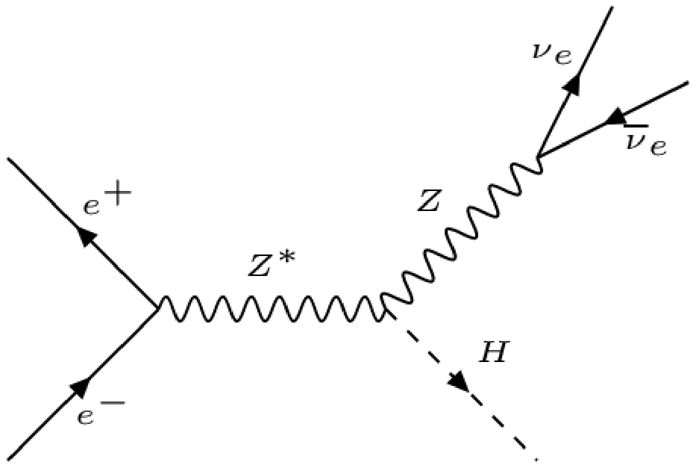
Channels	Cross section (fb)
$\nu_e\overline{\nu}_e H \rightarrow WW^* \rightarrow q\bar{q}q\bar{q}$	3.43
2 fermions leptonic	12983
2 fermions hadronic	77324
4 fermions leptonic	10424
4 fermions hadronic	16800
4 fermions semileptonic	19529

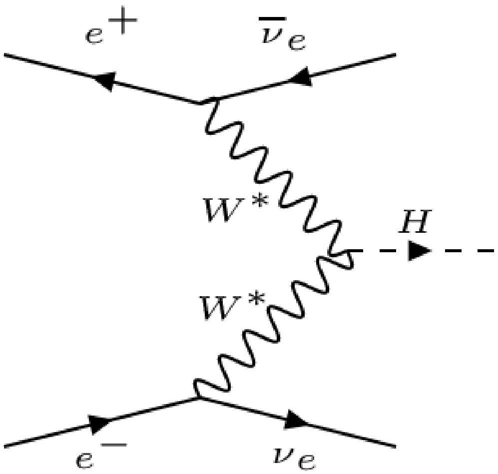
- Low number of signal events expected :
  - For ILC at 250 GeV (900 fb^{-1}): ~ 3000 events

Studied channel

- ILD with l5_o1_v02 model
  - with background overlay

- The $\nu_e\nu_e H$ production files contains the contribution from both Higgsstrahlung and W-fusion (+interference)
  - ~45 % of events from W-fusion
  - It is not possible to distinguish between those both channels

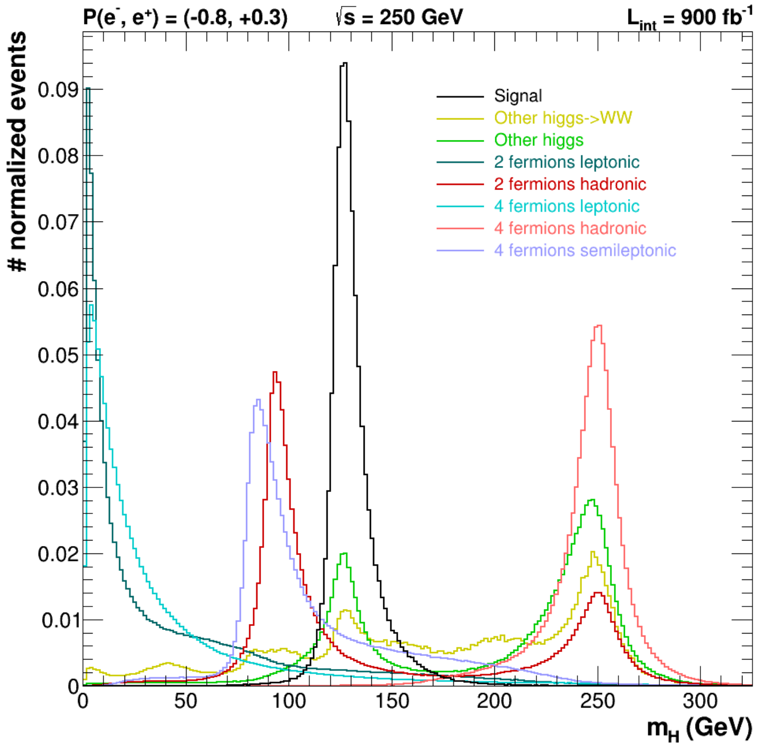


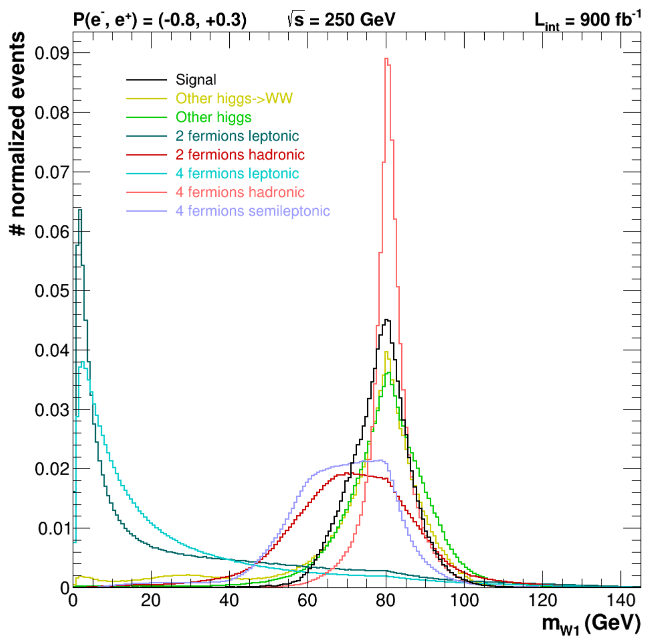


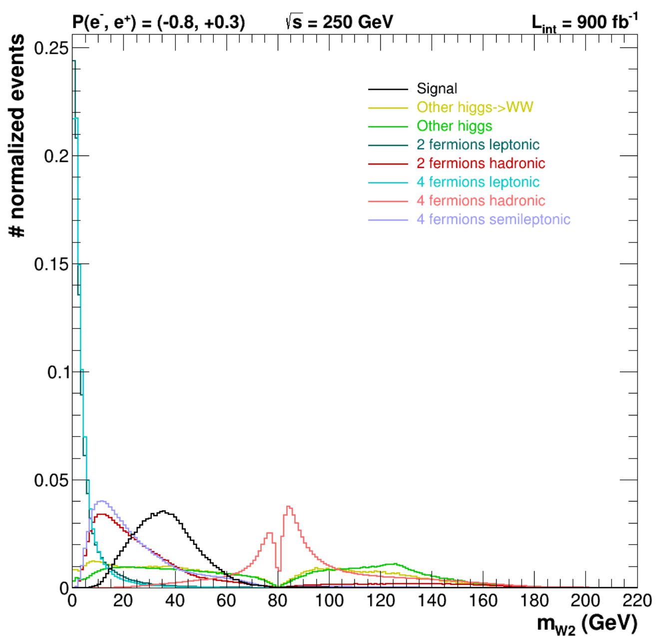
Event reconstruction

- Durham jet algorithm
- Event forced into 4-jets
- Jet pair with mass closest to W mass is tagged as on-shell W boson
- The 2 remaining jets are tagged as off-shell W* boson

- Event rejected if :
  - at least one isolated lepton is found
  - higgs mass < 70 GeV or > 200 GeV

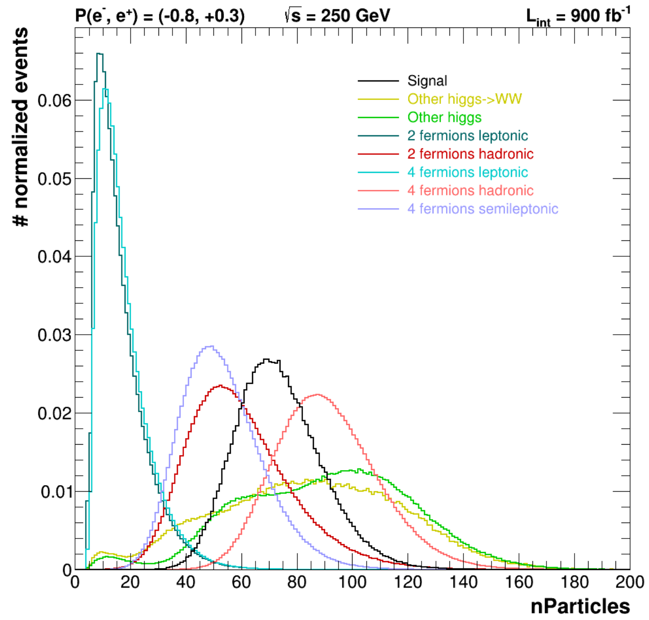


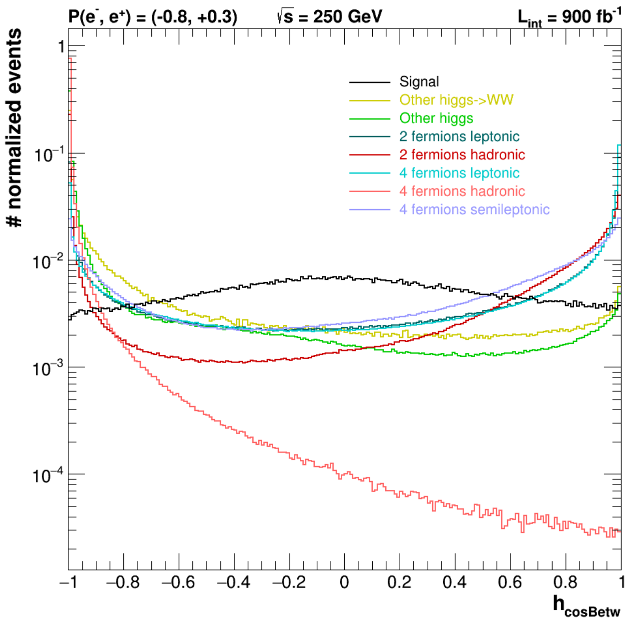


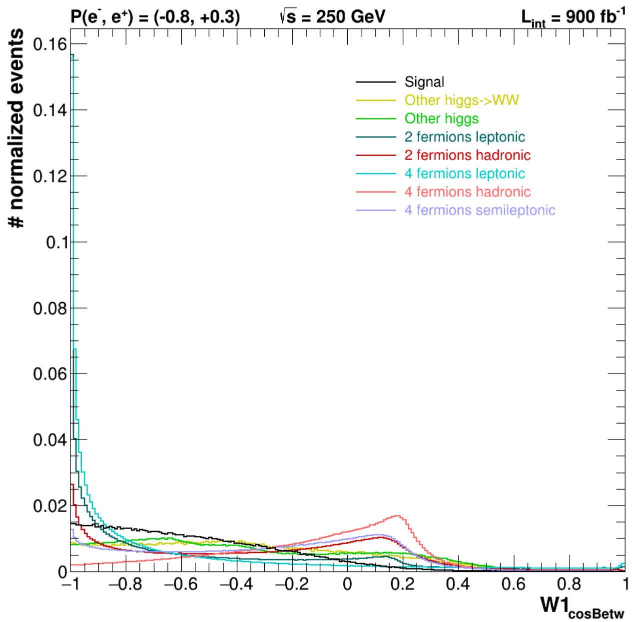


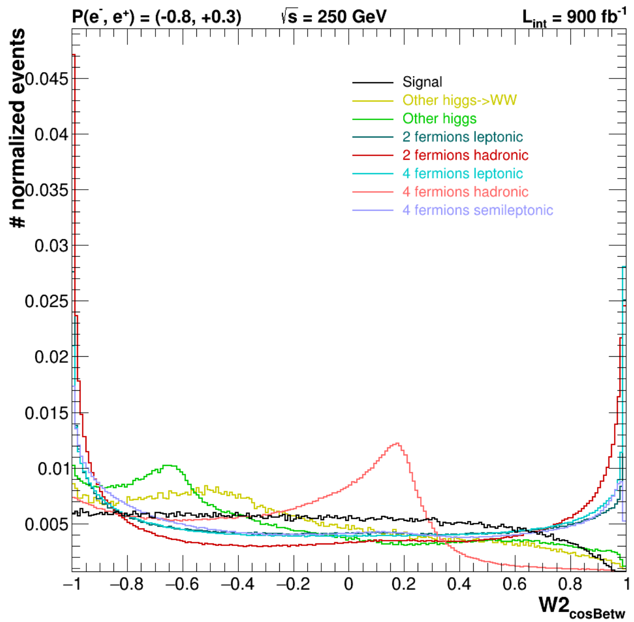
BDT input

- Number of reconstructed particles
- higgs energy, higgs pt, higgs mass
- Cosine of the angle between on-shell and off-shell W
- On-shell W energy, pt, mass
- Off-shell W energy, pt, mass
- Cosine of angle between the 2 jets tagged as on-shell W
- Cosine of angle between the 2 jets tagged as off-shell W



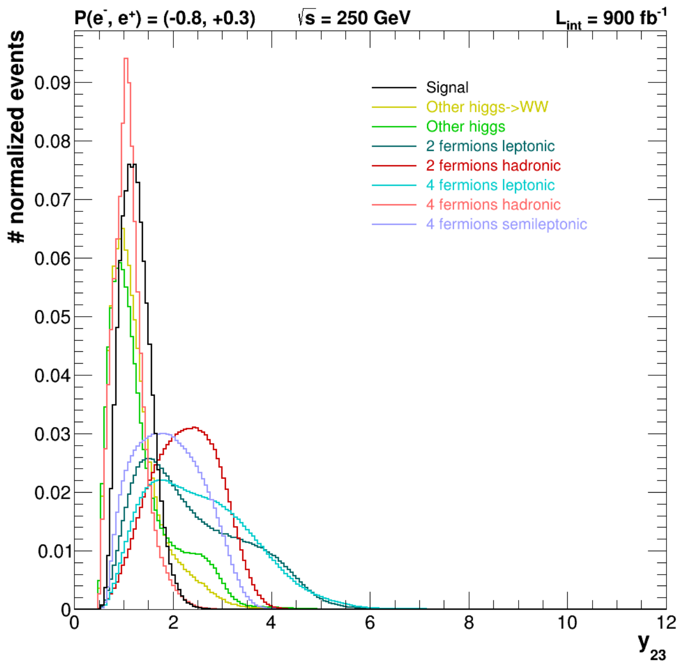


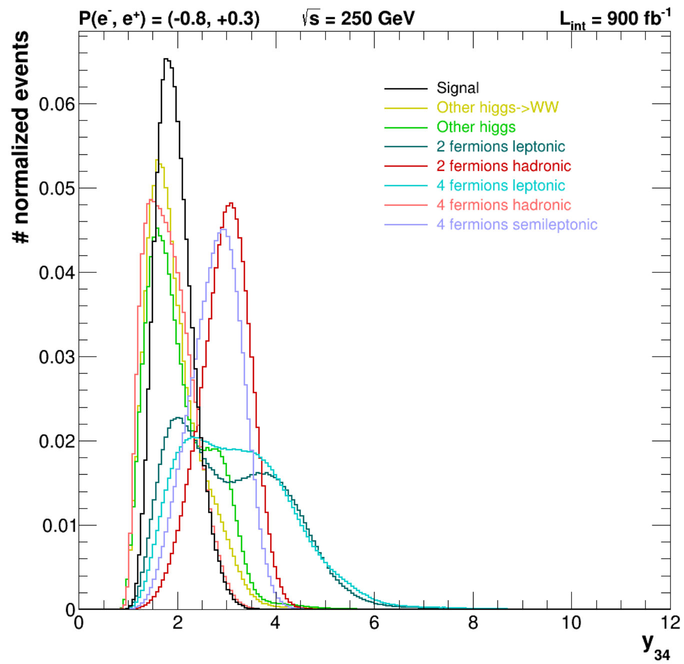




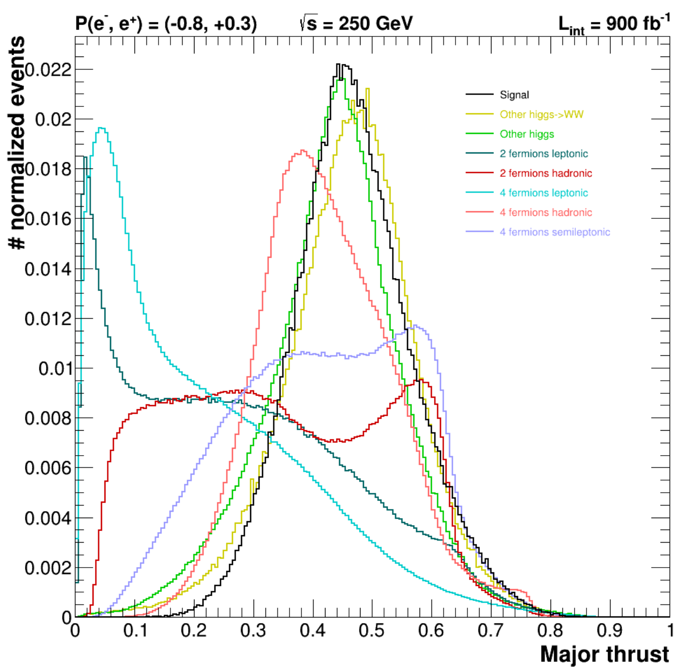
BDT input

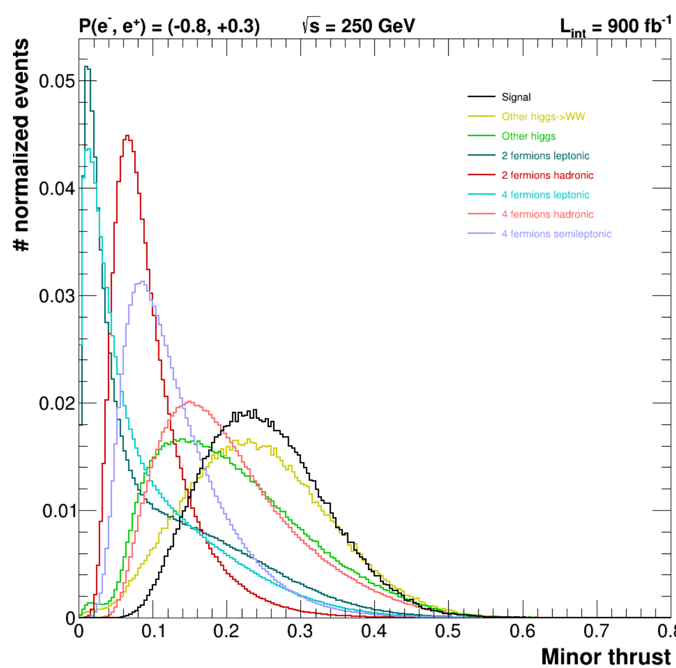
- Jet parameters :
  - -log10(y12)
  - -log10(y23)
  - -log10(y34)
  - -log10(y45)
  - -log10(y56)
  - -log10(y67)





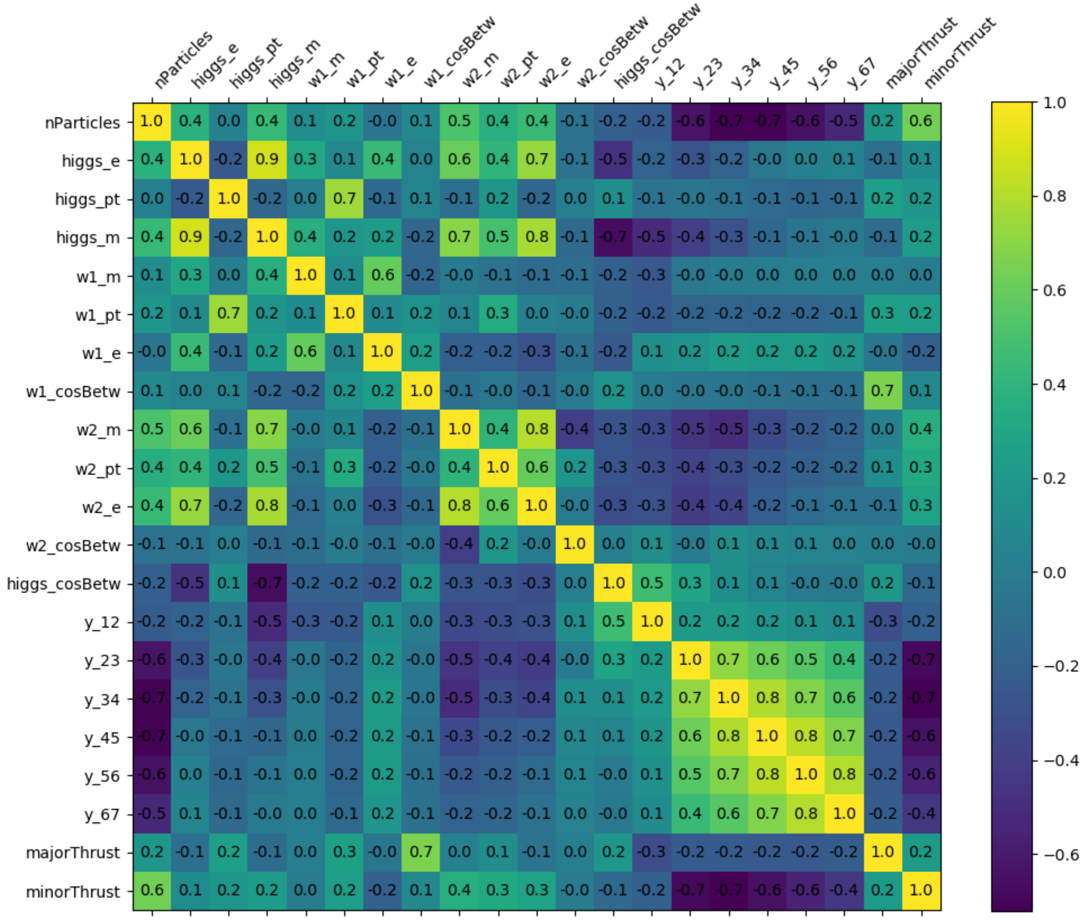
- Event shape variables :
  - Major thrust
  - Minor thrust

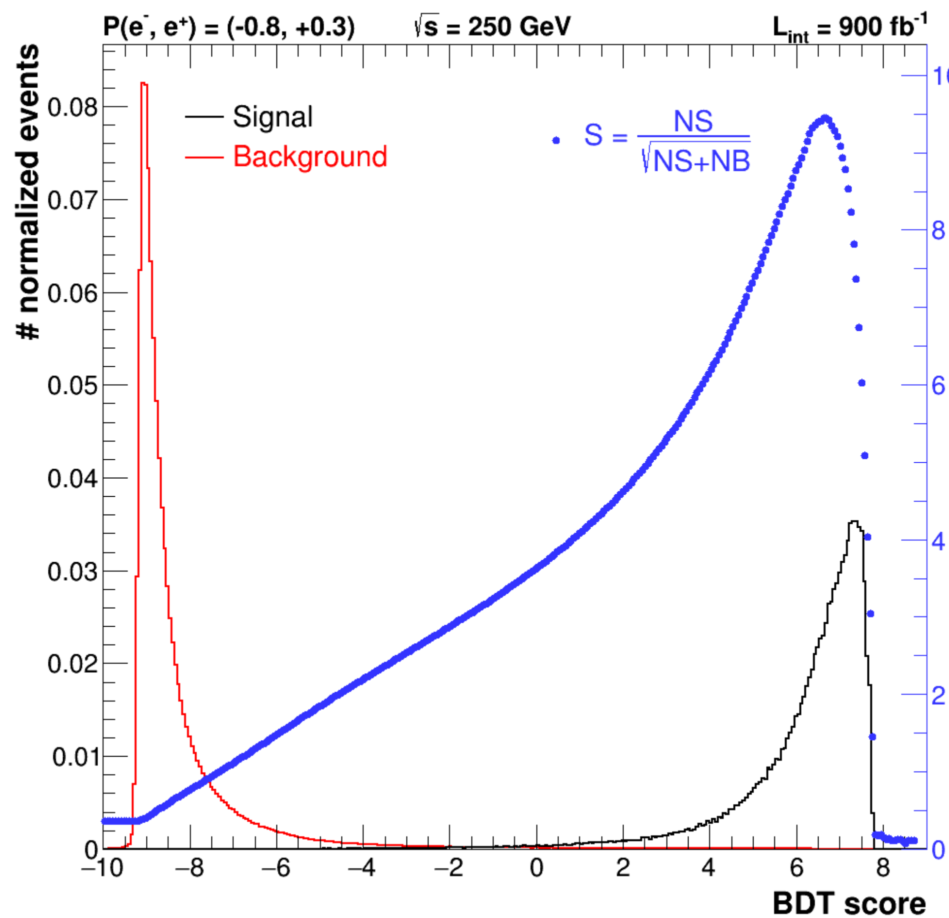




BDT output

- scikit-learn
- HistGradientBoostingClassifier(max_iter=300, max_depth=None, max_leaf_nodes=70, learning_rate=0.2, n_iter_no_change=20, validation_fraction=0.3)

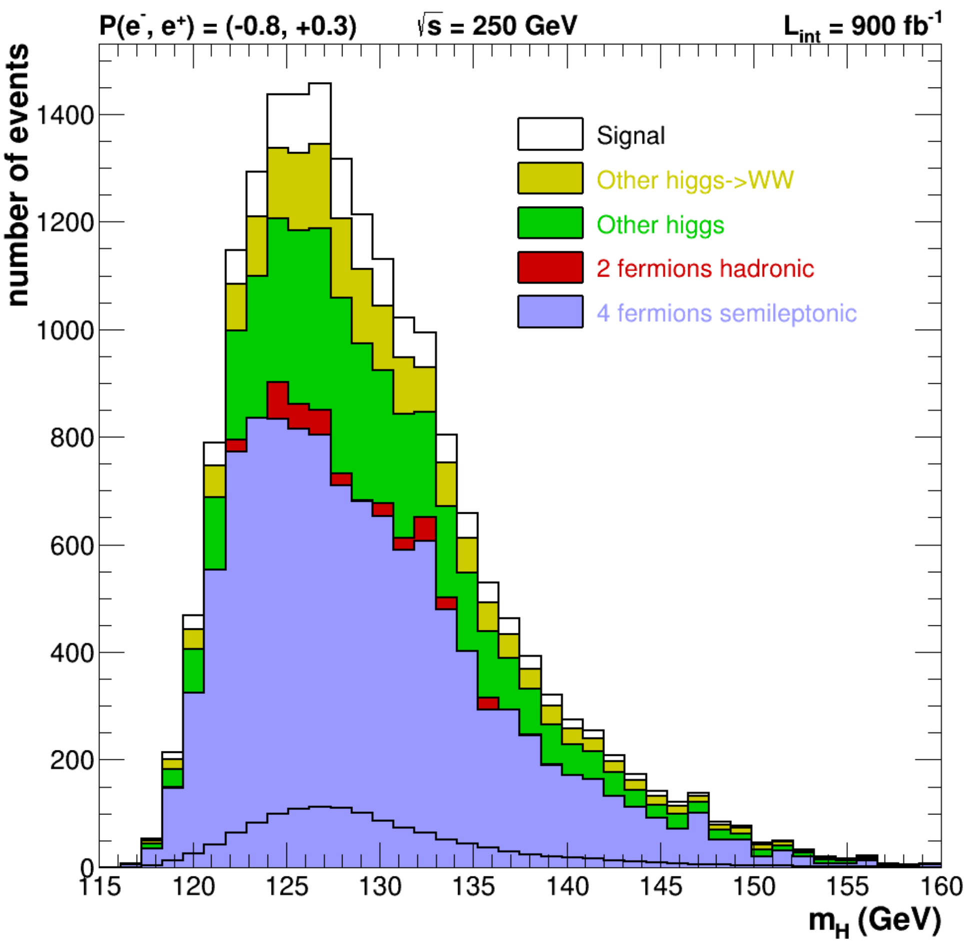




- Best significance : 9.45 for BDT cut = 6.66

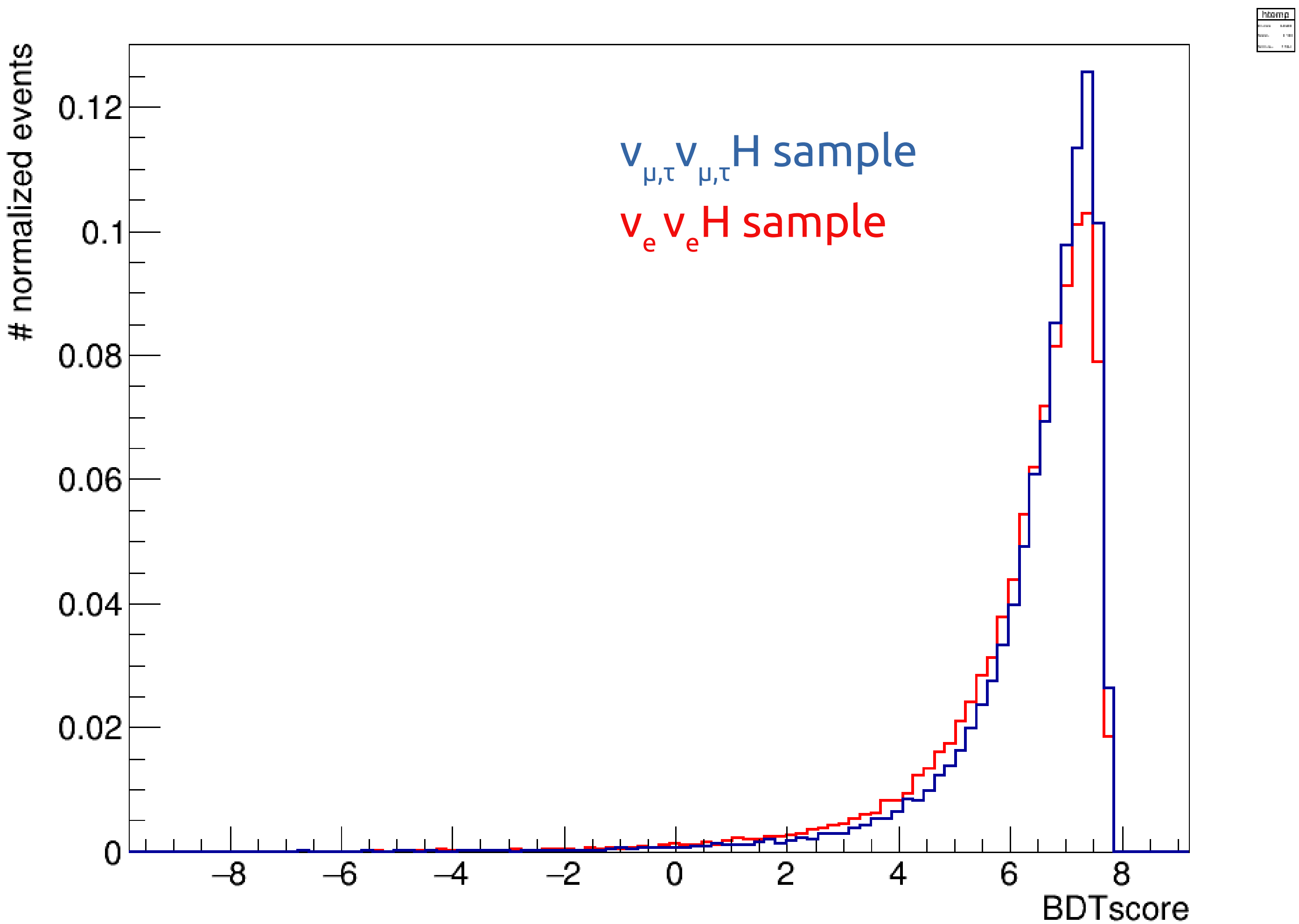
Final selection

- ILD case
  - 900 fb^{-1} at P(e$^-$,e$^+$)=(-80 %,+30%)
- ~ 1300 signal events expected after selection
  - But this includes both higgsstrahlung and W-fusion events
  - 41.68 % signal selection efficiency, but what about the W-fusion events selection efficiency ?
  - The higgsstrahlung events selection efficiency is measured with the $\nu_{\mu,\tau}\nu_{\mu,\tau}H$ events (no W-fusion here)
    - → 50.8 % selection efficiency
  - This gives roughly a 30 % selection of W-fusion events -> only 420 W-fusion events remaining, which means a true significance of 3.05 (not very exciting...)



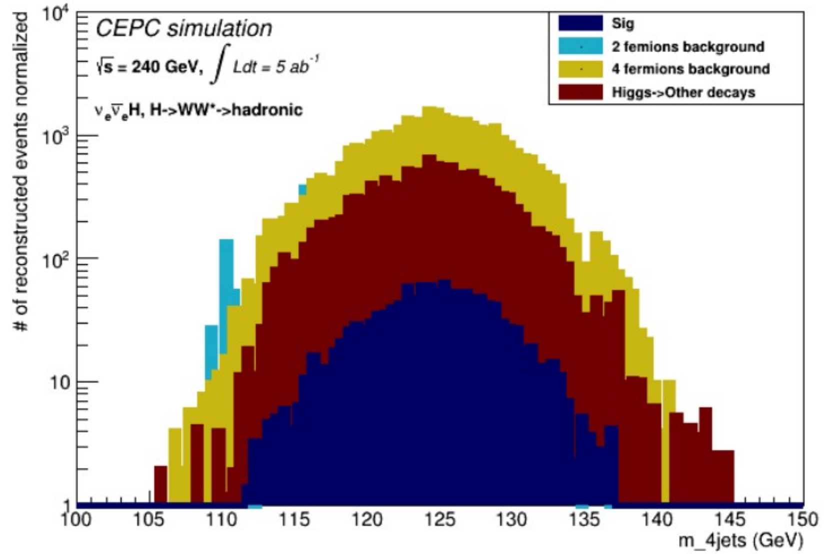
Channels	Events expected	Events selected	Selection %
Signal	3116	1299	41.68 %
Other Higgs → WW*	57950	1854	3.199 %
Other Higgs	223997	4009	1.79 %
2 fermions leptonic	11684593	0	0 %
2 fermions hadronic	69591936	345	$4.952.10^{-4}$ %
4 fermions leptonic	9381313	1	$1.597.10^{-5}$ %
4 fermions hadronic	15120406	50	$3.318.10^{-4}$ %
4 fermions semileptonic	17576134	11327	$6.445.10^{-2}$ %

- The BDT tends to select more the higgsstrahlung events than the W-fusion events.
- I cannot avoid this for the moment, because the signal sample contains both
- Will need a dedicated W-fusion sample to improve BDT accuracy



Circular colliders case

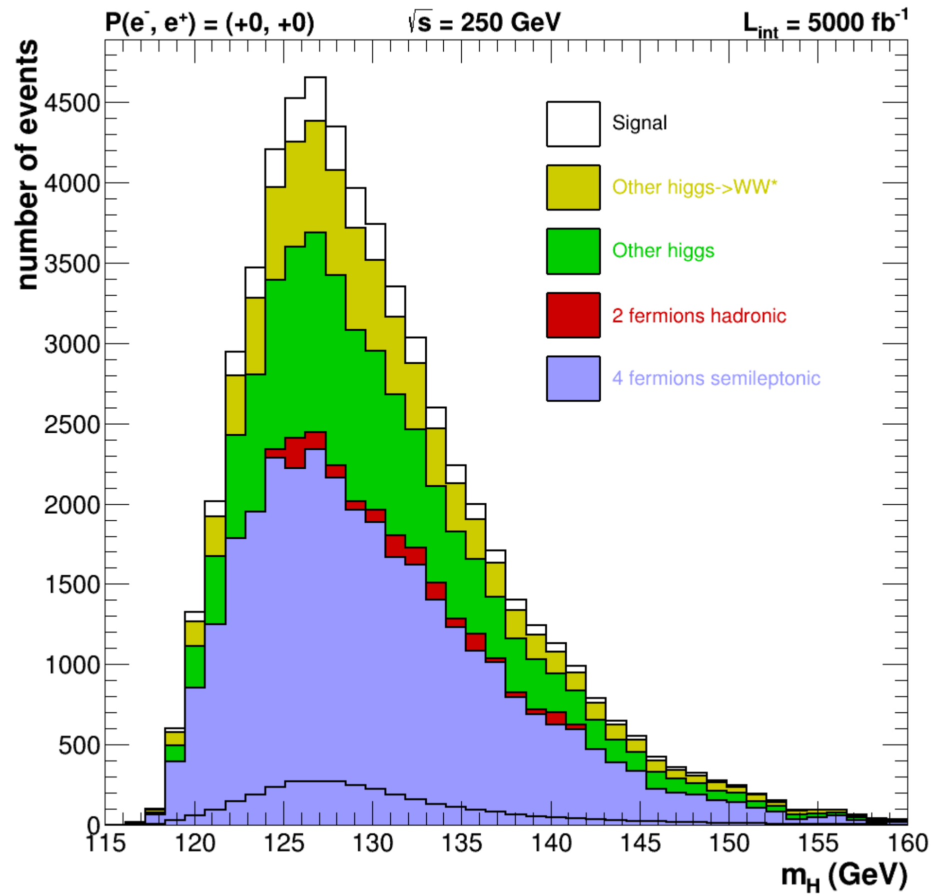
- Bing Liu results for CEPC :
  - 5000 fb^{-1} at 240 GeV
  - $N_S / \sqrt{(N_S+N_B)} = 11.17$
    - N_S still includes both HZ and W-fusion events
  - Better significance can be obtained because no cut on isolated leptons were used (this improved a lot the rejection of semileptonic events in my case)



process	Cross section (fb)	$\varepsilon_{pre}(\%)$	$\varepsilon_{final}(\%)$
Signal	0.60	78.10	42.97
Higgs→ other decays	203.06	7.33	1.34
two-fermion backgrounds: $q\bar{q}$			
$e^-e^+ \to q\bar{q}$	54106.86	0.6	4.60×10^{-03}
four-fermion backgrounds: ZZ			
ZZ_h	516.67	0.117	5.93×10^{-03}
ZZ_sl	556.49	2.52	0.13
four-fermion backgrounds: WW			
WW_h	3825.46	0.045	2.76×10^{-03}
WW_sl	4846.99	0.403	0.11
four-fermion backgrounds: ZZ or WW			
ZZ or WW_h	3217.87	0.049	2.51×10^{-03}
four-fermion backgrounds: single Z			
SZE_sl	316.04	0.574	3.00×10^{-03}
SZNU_sl	145.62	3.14	0.18
four-fermion backgrounds: single W			
SW_sl	2612.62	1.25	0.02

Circular colliders case

- To roughly simulate the results we can obtain with a circular collider, using the same ILD files
  - Set the target polarisation to $P(e^-,e^+)=(0,0)$ and 5000 fb^{-1} integrated luminosity
  - $N_S / \sqrt{(N_S+N_B)} = 13.11$
  - 3217 « signal » events selected, ~1000 W-fusion events selected
  - This would give (considering only W-fusion events):
  - $N_S / \sqrt{(N_S+N_B)} = 4.23$
    - → 5.9 % precision on g_{HWW}



Channels	Events expected	Events selected	Selection %
Signal	7410	3217	43.42 %
Other Higgs → WW*	217436	8447	3.885 %
Other Higgs	825219	14773	1.79 %
2 fermions leptonic	46971244	11	$2.433.10^{-5}$ %
2 fermions hadronic	247977696	1258	$5.075.10^{-5}$ %
4 fermions leptonic	38946308	4	$9.602.10^{-6}$ %
4 fermions hadronic	37037352	131	$3.535.10^{-5}$ %
4 fermions semileptonic	46752016	32402	$6.931.10^{-2}$ %

Conclusion

- g_{HWW} measurement through the $e^+e^- \to \nu_e\nu_e H$ ($H \to WW^* \to qqqq$) channel seems hard at 240/250 GeV
  - Despite the $g4_{HWW}$ dependancy, the cross section is simply too low
  - 5.9 % precision for $5000 fb^{-1}$ in circular colliders
- The BDT accuracy can be improved with a pure W-fusion sample, but i do not expect miracles