Measurement of HWW coupling and Higgs total width @ ILC

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precision HVV coupling

unitarity in VV—>VV scattering will be violated, if there’s no scalar providing hVV coupling

in SM: $$g_{HVV} = \frac{2m_V^2}{v}$$ saturated by one H

generally: $$\sum_i g_{h_iVV}^2 = \frac{4m_V^4}{v^2} \qquad \frac{g_{h_iWW}}{g_{h_iZZ}} = \frac{m_W^2}{m_Z^2}$$

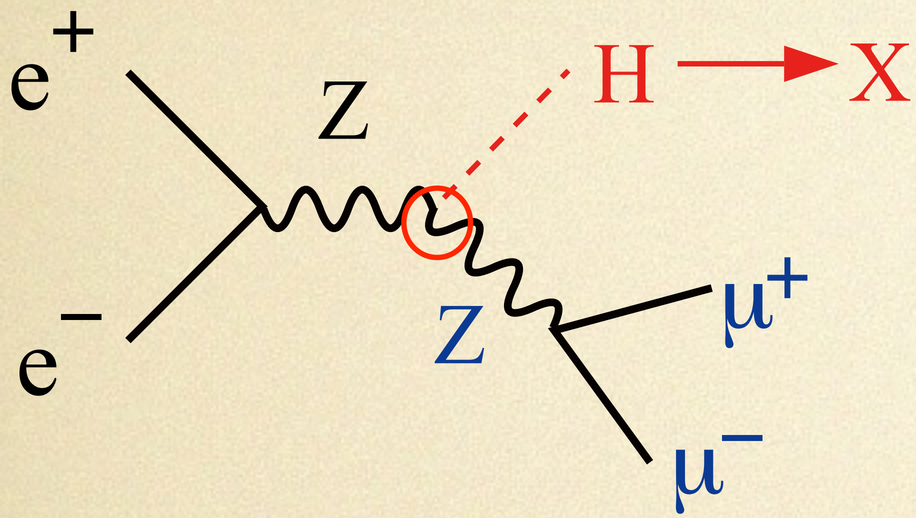
unitarity & CP-conserving: $$g_{h_iVV} \leq g_{HVV}$$

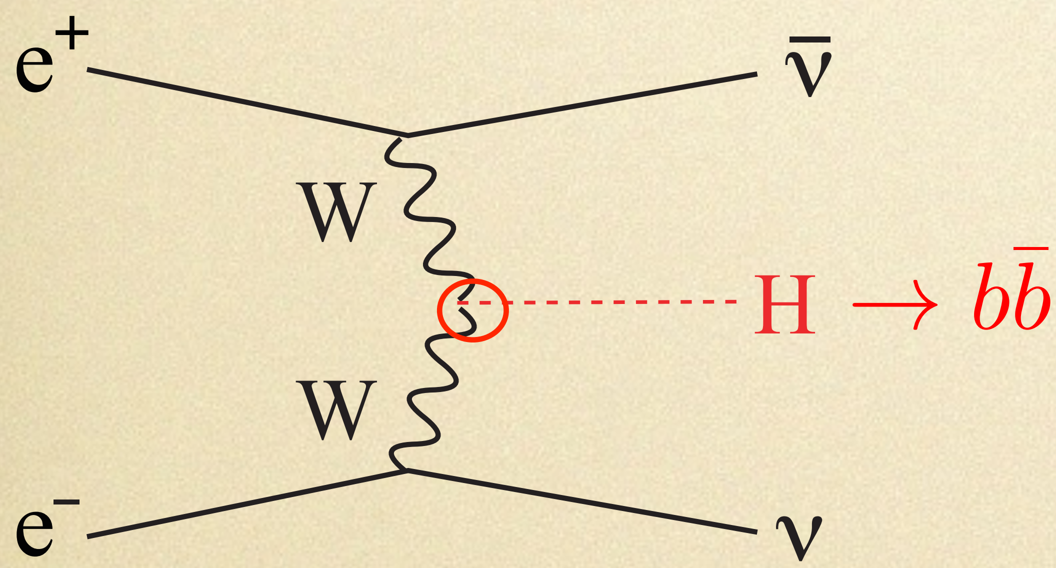
if deviation (<1) observed: hint of additional scalar bosons

if deviation (>1) observed: hint of CP-violation in Higgs sector

cf: ILC Higgs White Paper

HVV coupling @ ILC





neutrinos can't be directly reconstructed —> recoil technique not working for ννH.

$$Y_1 = \sigma_{ZH} \propto g^2_{HZZ}$$

$$Y_2 = \sigma_{\nu\bar{\nu}H} \cdot \mathrm{Br}(H \to b\bar{b}) \propto g^2_{HWW} \cdot \mathrm{Br}(H \to b\bar{b})$$

$$Y_3 = \sigma_{ZH} \cdot \mathrm{Br}(H \to b\bar{b}) \propto g^2_{HZZ} \cdot \mathrm{Br}(H \to b\bar{b})$$

Y_2/Y_3 gives accurate test of g_{HWW}/g_{HZZ}, and with g_{HZZ} gives absolute normalization of g_{HWW}.

$$g_{HZZ} \propto \sqrt{Y_1}$$

$$g_{HWW} \propto \sqrt{\frac{Y_2}{Y_3}} \cdot g_{HZZ} \propto \sqrt{\frac{Y_1 Y_2}{Y_3}}$$

WW-fusion production fully activated: 14 fb @ 250 GeV ---> 150 fb @ 500 GeV

Y_2 @ 500 GeV is today's topic

simulation setup

(DBD softwares, thank A. Miyamoto for preparing all signal samples)

Polarization: (e-,e+)=(-0.8,+0.3) $E_{\mathrm{cm}} = 500\mathrm{GeV}, M_H = 125\mathrm{GeV}$ $\int \mathrm{L} = 500\ \mathrm{fb}^{-1}$

	Cross Section / fb	Expected Events	Generated
vvh (WW fusion)	1.49×10^{2}	7.47×10^{4}	1.88×10^{5}
vvh (ZH)	2.04×10^{1}	1.02×10^{4}	4.64×10^{4}
4f_sznu_sl	5.59×10^{2}	2.79×10^{5}	4.71×10^{4}
4f_sw_sl	4.85×10^{3}	2.43×10^{6}	4.07×10^{5}
4f_zz_sl	3.66×10^{2}	1.83×10^{5}	4.18×10^{4}
4f_ww_sl	5.56×10^{3}	2.78×10^{6}	4.45×10^{5}
4f_sze_sl	1.88×10^{3}	9.41×10^{5}	2.73×10^{5}
6f_yyveev	1.21×10^{1}	6.05×10^{3}	4.80×10^{3}
6f_yyvelv	4.74×10^{1}	2.37×10^{4}	1.76×10^{4}
6f_yyvllv	4.74×10^{1}	2.36×10^{4}	1.76×10^{4}
Total BG	1.34×10^{4}	6.68×10^{6}	

$$e^+ + e^- \to \nu\bar{\nu}H \to \nu\bar{\nu}(b\bar{b})$$

full simulation @ 500GeV

pre-selection:

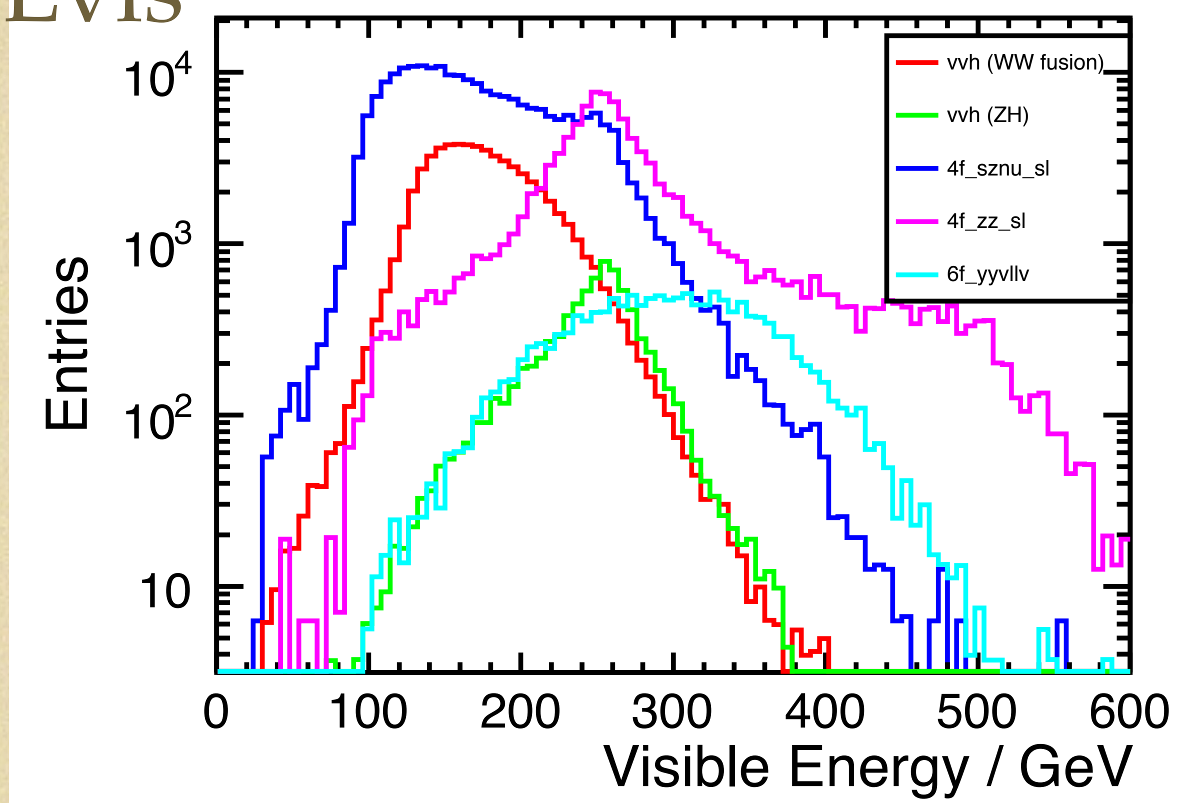
- anti-kt jet-clustering to remove the very forward overlaid particles
- reject the events with isolated electron or muon
- two jets clustering and flavor tagging, each with more than 8 particles

final-selection:

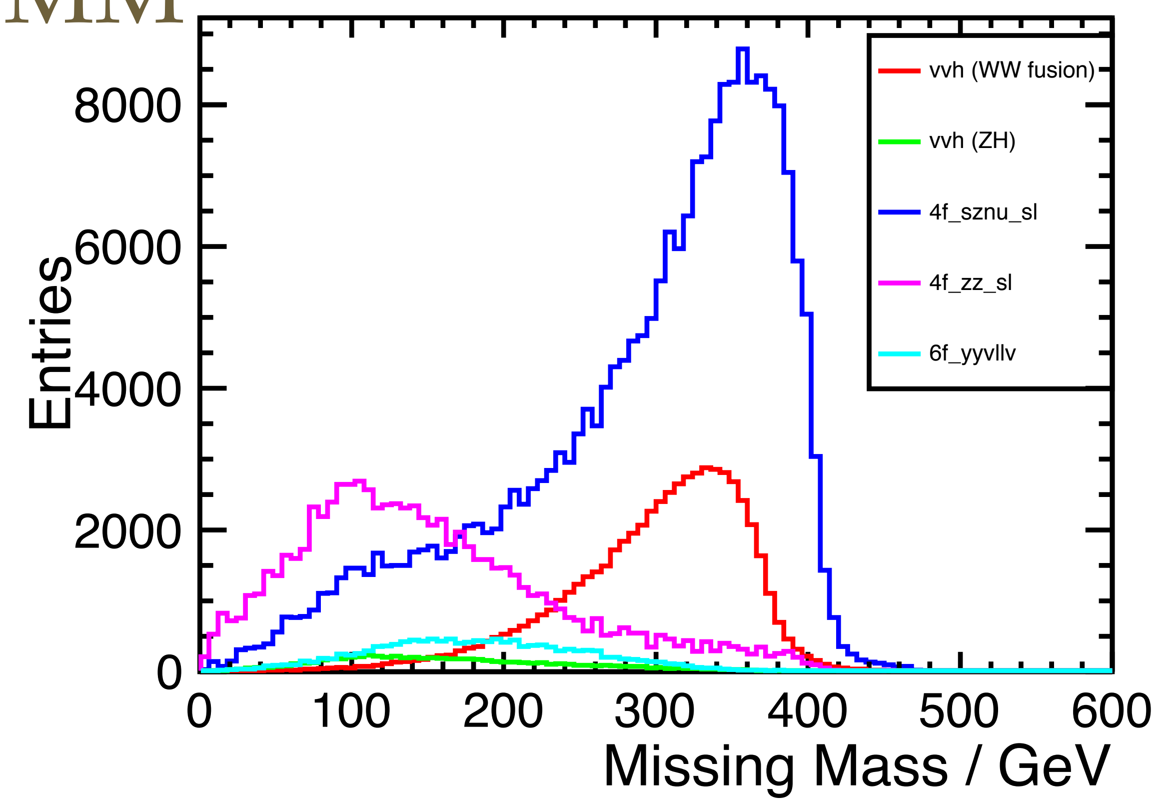
- Visible energy: (100, 300) GeV   Pt > 20 GeV (cut1)
- Isolate lepton rejection: P(Lmax) < 2*Econe + 20 (cut2)
- B-tagging: Prob(Jet1) + 2Prob(Jet2) > 0.92 (cut3)
- Missing mass (Z rejection): > 172 GeV (cut4)
- Higgs mass: (100, 143) GeV (cut5)

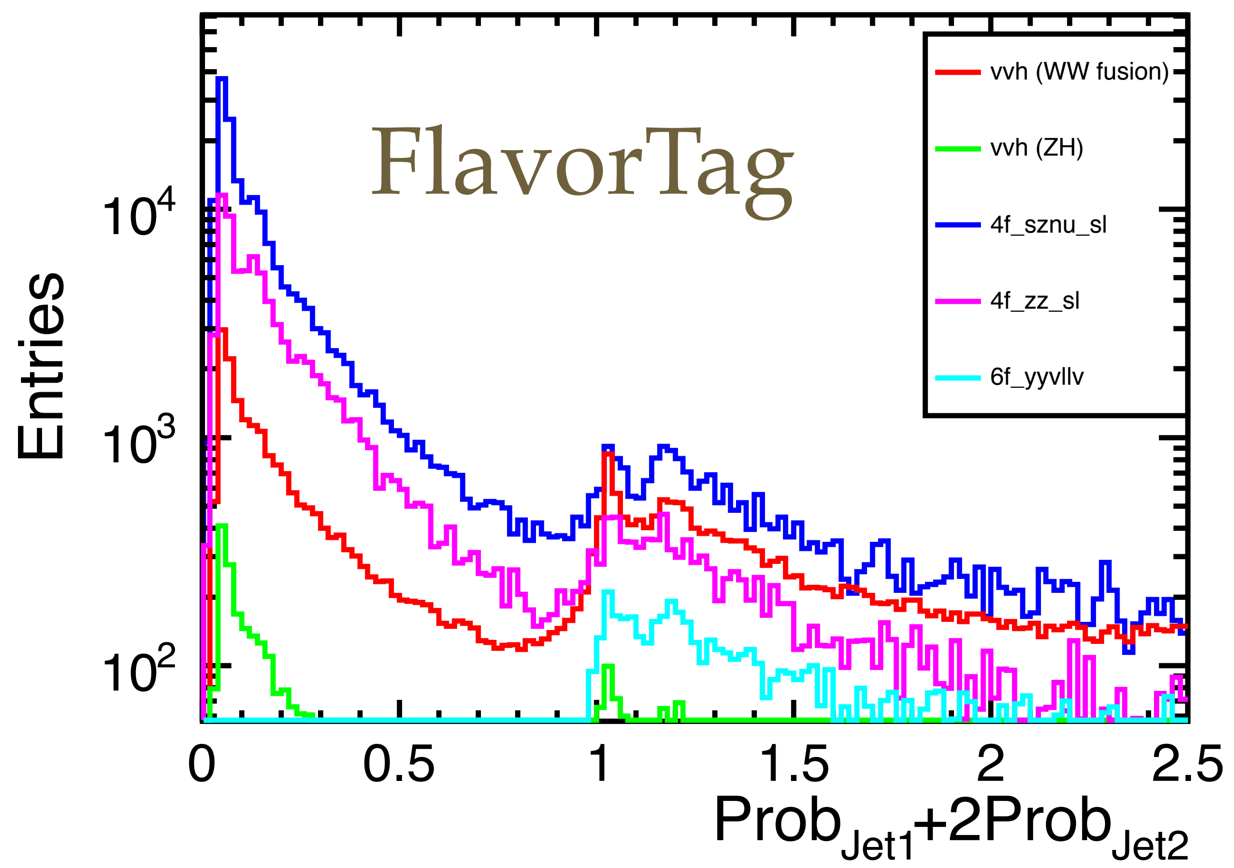
several distributions

Evis

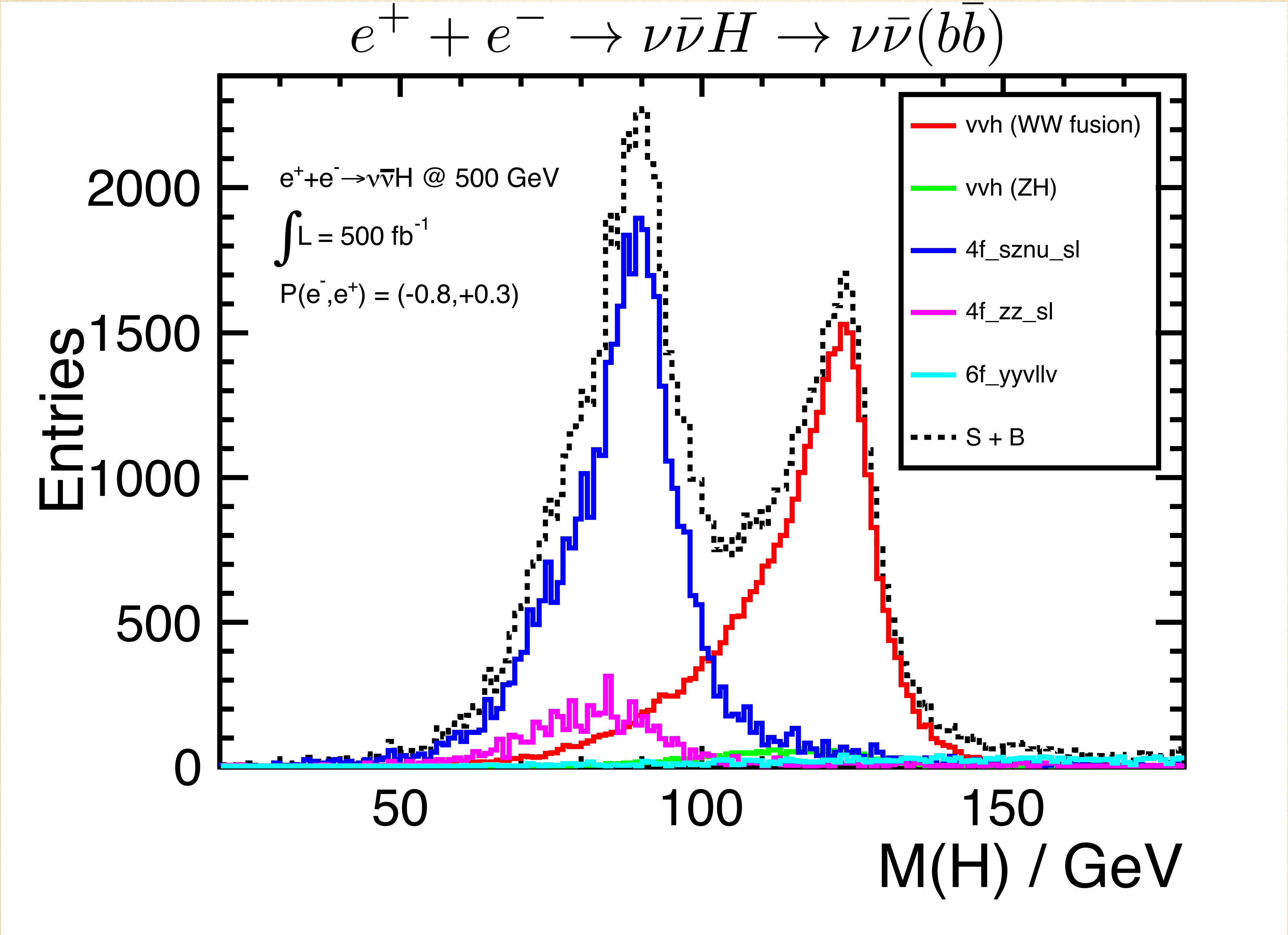


MM





Higgs Mass (after the preceding 4 cuts)



100 GeV < M(H) < 143 GeV

signal and backgrounds (reduction table)

$$e^+ + e^- \to \nu\bar{\nu}H \to \nu\bar{\nu}(b\bar{b})$$

Polarization: (e-,e+)=(-0.8,+0.3) $E_{\rm cm} = 500{\rm GeV}, M_H = 125{\rm GeV}$ $\int {\rm L} = 500\ {\rm fb}^{-1}$

	Expected	pre-selction	cut1	cut2	cut3	cut4	cut5
vvh (fusion)	7.47×10^4	59698	54529	54048	35598	34278	29199 (28598)
vvh (ZH)	1.02×10^4	7839	7301	7224	4863	1951	1512
4f_sznu_sl	2.79×10^5	234259	203489	202977	44943	39125	3957
4f_sw_sl	2.43×10^6	228436	135164	121791	1495	911	132
4f_zz_sl	1.83×10^5	102172	60684	59865	13036	5736	461
4f_ww_sl	2.78×10^6	653997	287428	250944	3851	1145	176
4f_sze_sl	9.41×10^5	65011	1311	1259	91.1	40.7	5.51
6f_yyveev	6.05×10^3	931	306	104	96.6	87.4	20.4
6f_yyvelv	2.37×10^4	5450	2425	1116	997	907	237
6f_yyvllv	2.36×10^4	8009	4272	2813	2556	2383	674
BG	6.68×10^6	1.31×10^6	702379	648094	71929	52285	7176
significance		35	43.3	44.6	106	114	150

$$\frac{S}{\sqrt{S+B}} = \frac{28598}{\sqrt{29199+7176}} = 150 \qquad \frac{\delta(\sigma\cdot{\rm Br})}{\sigma\cdot{\rm Br}} = 0.667\%$$

LoI result 0.60%, extrapolation in DBD 0.661%

HWW coupling

$$g_{HWW} \propto \sqrt{\frac{Y_2}{Y_3}} \cdot g_{HZZ} \propto \sqrt{\frac{Y_1 Y_2}{Y_3}}$$

$\Delta g_{HWW}/g_{HWW}$	250 GeV	+ 500 GeV
Baseline	4.8%	1.2%
LumiUP	2.3%	0.58%

Higgs total width Γ_H

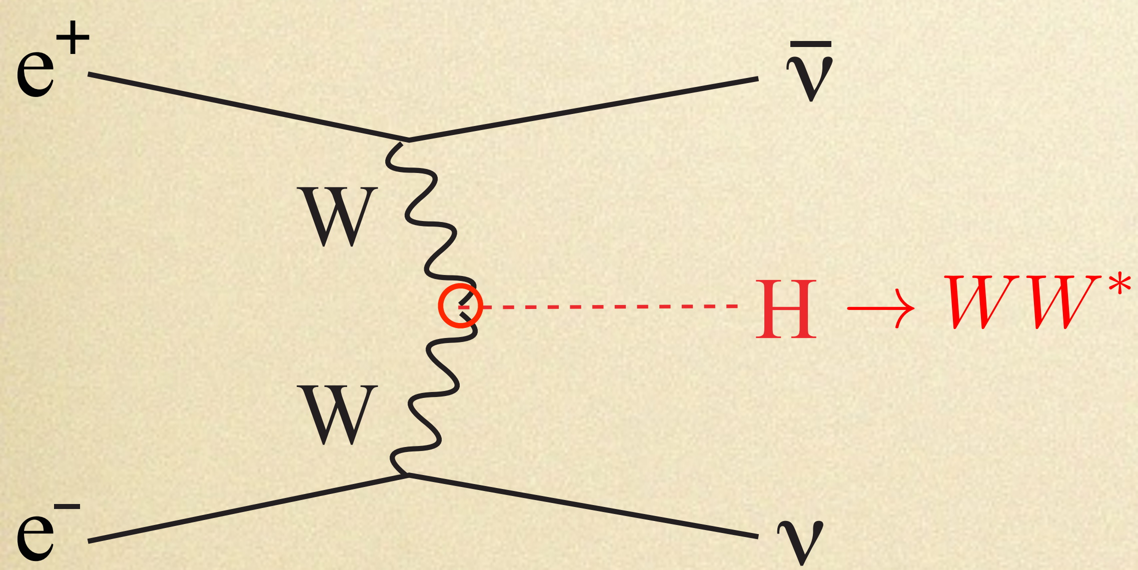
model free, one of the great advantages of ILC

$$\Gamma_H = \frac{\Gamma_{HZZ}}{\mathrm{Br}(H \to ZZ^*)} \propto \frac{g^2_{HZZ}}{\mathrm{Br}(H \to ZZ^*)}$$

Br(H->ZZ*) very small, not very precisely measured

$$\Gamma_H = \frac{\Gamma_{HWW}}{\mathrm{Br}(H \to WW^*)} \propto \frac{g^2_{HWW}}{\mathrm{Br}(H \to WW^*)}$$

better option



$$Y_4 = \sigma_{\nu\bar{\nu}H} \cdot \mathrm{Br}(H \to WW^*) \propto \frac{g^4_{HWW}}{\Gamma_0}$$

Y_4 and g_{HWW} gives Higgs total width --> absolute normalization of other couplings.

$$\Gamma_H \propto \frac{g^4_{HWW}}{Y_4} \propto \frac{Y_1^2 Y_2^2}{Y_3^2 Y_4}$$

any obvious deviation on Γ_H —> new Higgs decay modes

two methods to measure Y_4: full hadronic or semi-leptonic decay of WW*

$$e^+ + e^- \to \nu\bar{\nu}H \to \nu\bar{\nu}(WW^*) \to \nu\bar{\nu}qqqq$$

full simulation @ 500GeV

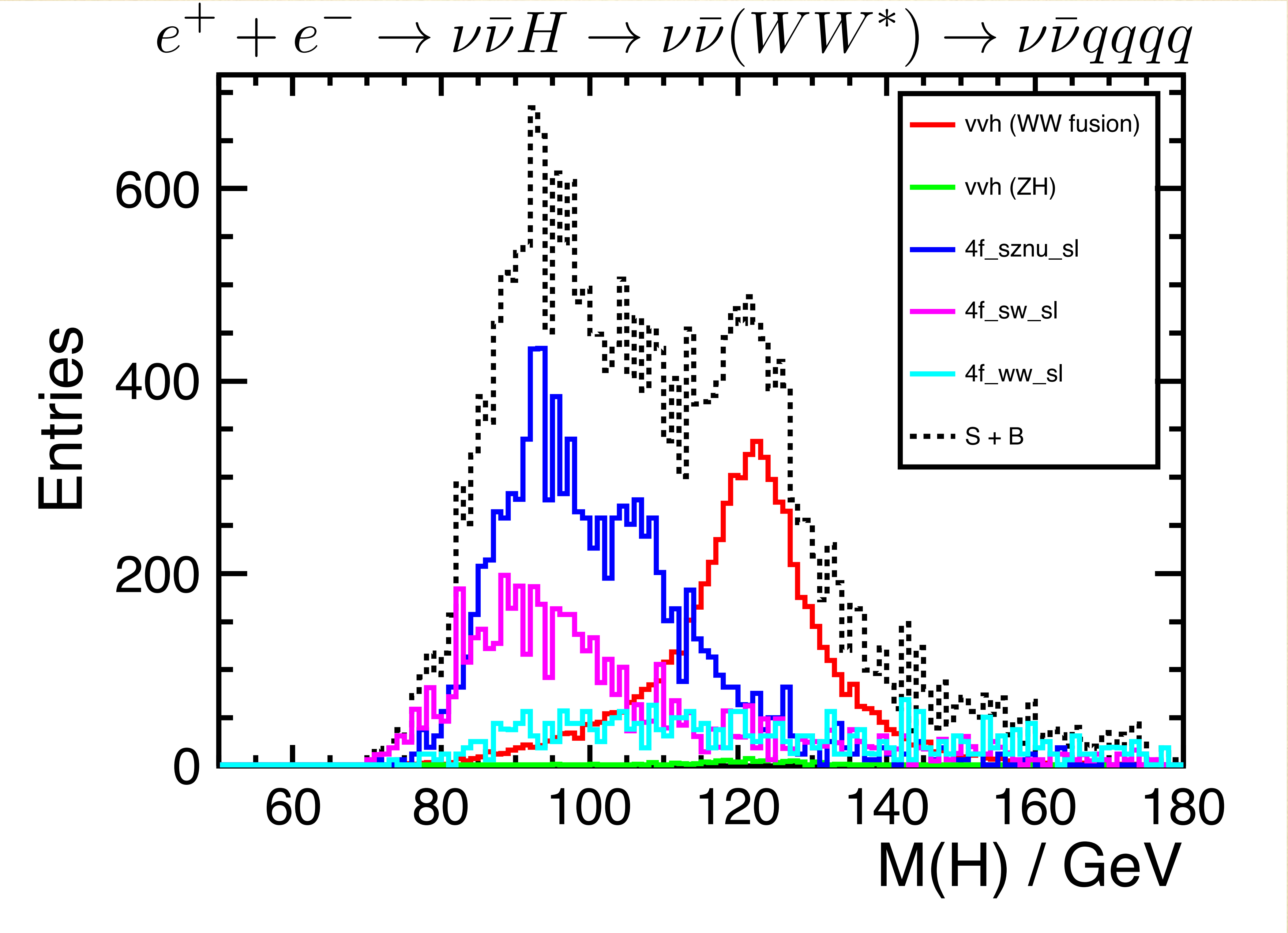
pre-selection:

- MVA to remove the very forward overlaid particles (see backup)
- reject the events with isolated electron or muon
- four jets clustering and flavor tagging, No. of PFOs >= 40 (7,6,5,4)

final-selection:

- Y34 > 0.0026, Y23 > 0.0076 (cut1)
- Evis < 230 GeV, Pt > 20 GeV, MissingMass > 200 GeV (cut2)
- Isolate lepton rejection: P(Lmax) < 2*Econe + 9. (cut3)
- b-jet rejection: (btag1+2btag2<0.7, btag3+2btag4<0.14) (cut4)
- 54 < M(W1) < 94, 11 < M(W2) < 64 (cut5)
- Higgs mass: (114, 142) GeV (cut6)

Higgs Mass (after the preceding 5 cuts)



114 GeV < M(H) < 142 GeV

signal and backgrounds (reduction table)

$$e^+ + e^- \to \nu\bar{\nu}H \to \nu\bar{\nu}(WW^*) \to \nu\bar{\nu}qqqq$$

Polarization: (e-,e+)=(-0.8,+0.3) $E_{\rm cm} = 500\text{GeV}, M_H = 125\text{GeV}$ $\int L = 500\ \text{fb}^{-1}$

	Expected	pre-selction	cut1	cut2	cut3	cut4	cut5	cut6
vvh (fusion)	7.47×10^4	42373	14461	11684	11315	7415	6746	4970(3136)
vvh (ZH)	1.02×10^4	5497	911	240	232	144	120	86.8
4f_sznu_sl	2.79×10^5	140092	23016	18123	17841	14157	9675	1308
4f_sw_sl	2.43×10^6	220670	40715	11746	11383	11013	5317	778
4f_zz_sl	1.83×10^5	57640	7041	722	690	546	342	65.1
4f_ww_sl	2.78×10^6	416386	46390	4816	4149	3934	2965	806
4f_sze_sl	9.41×10^5	45911	19160	38.4	38.4	32.1	8.56	0
6f_yyveev	6.05×10^3	52.5	35.7	9.24	0.02	0	0	0
6f_yyvelv	2.37×10^4	703	498	102	45.6	9.51	5.78	3.88
6f_yyvllv	2.36×10^4	2025	1420	358	252	30.4	26.6	7.6
BG	6.68×10^6	8.89×10^5	139185	36156	34632	29866	18462	3055
significance		6.8	13.4	19.4	19.5	21	24.6	35

$$\frac{S}{\sqrt{S+B}} = \frac{3136}{\sqrt{4970+3055}} = 35 \qquad \frac{\delta(\sigma\cdot\text{Br})}{\sigma\cdot\text{Br}} = 2.8\%$$

LoI result 3.0%, extrapolation in DBD 2.6%

$$e^+ + e^- \to \nu\bar{\nu}H \to \nu\bar{\nu}(WW^*) \to \nu\bar{\nu}l\nu qq$$

full simulation @ 500GeV
samples with DBD software

pre-selection:

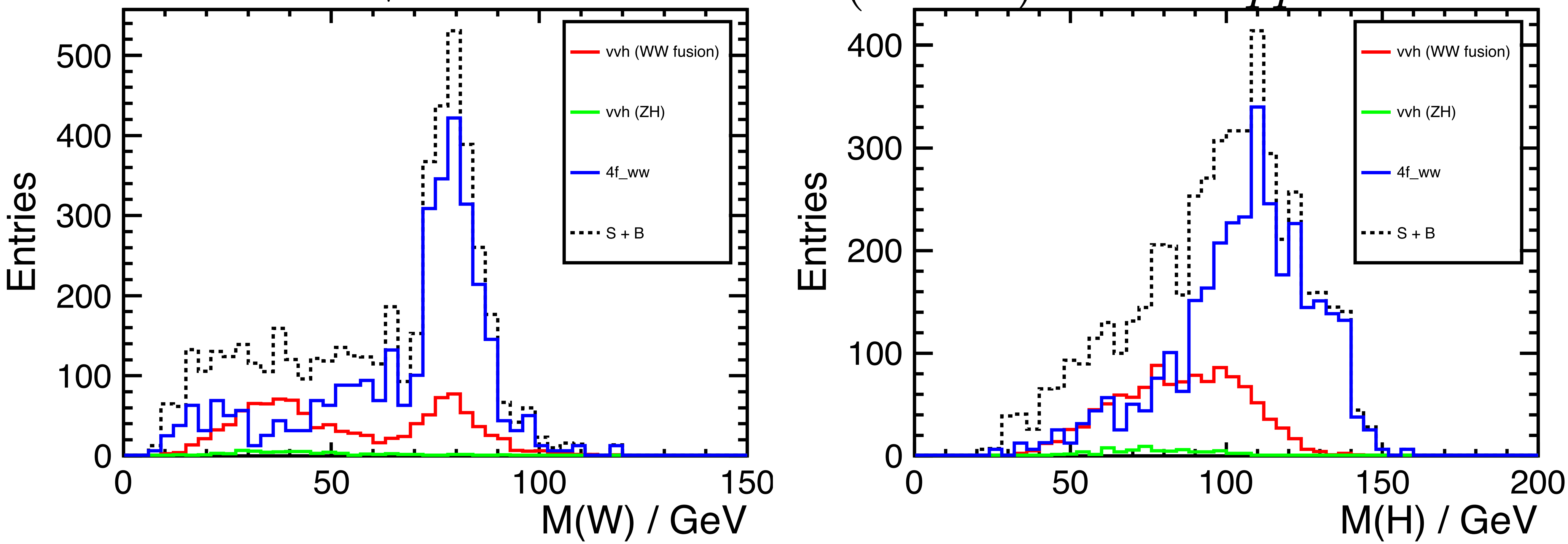
- select one isolated electron or muon (BS and FSR recovered)
- MVA to remove the very forward overlaid particles
- two jets clustering and flavor tagging, each jet at least two charged high Pt (>500 MeV) particles (to either suppress τ from Z or W, or overlay contamination)

final-selection:

- separate to two categories, muon-type or electron-type, which have very different background contamination and hence selection optimization.
- require large missing energy and large missing Pt (to suppress full hadronic background).
- use flavor tagging to suppress events with b-jets.
- cut on angle between W and lepton, recoil mass of one W (to suppress the dominant background WW).
- cut on electron polar angle (to suppress ee or eν fusion background), also angle between electron and jet (to suppress mis-tagged electron).
- Higgs mass cut

Higgs mass and W mass

$$e^+ + e^- \rightarrow \nu\bar{\nu}H \rightarrow \nu\bar{\nu}(WW^*) \rightarrow \nu\bar{\nu}l\nu qq$$



$$e^+ + e^- \to \nu\bar{\nu}H \to \nu\bar{\nu}(WW^*) \to \nu\bar{\nu}l\nu qq$$

Polarization: (e-,e+)=(-0.8,+0.3) $E_{\rm cm} = 500\text{GeV}, M_H = 125\text{GeV}$ $\int \text{L} = 500\ \text{fb}^{-1}$

muon-category:

#Signal	#Background	significance
1002 (982)	2187	17.4σ

electron-category:

#Signal	#Background	significance
879 (858)	2528	14.7σ

combined: 22.8σ $\frac{\Delta(\sigma \cdot \text{Br})}{\sigma \cdot \text{Br}} = 4.4\%$

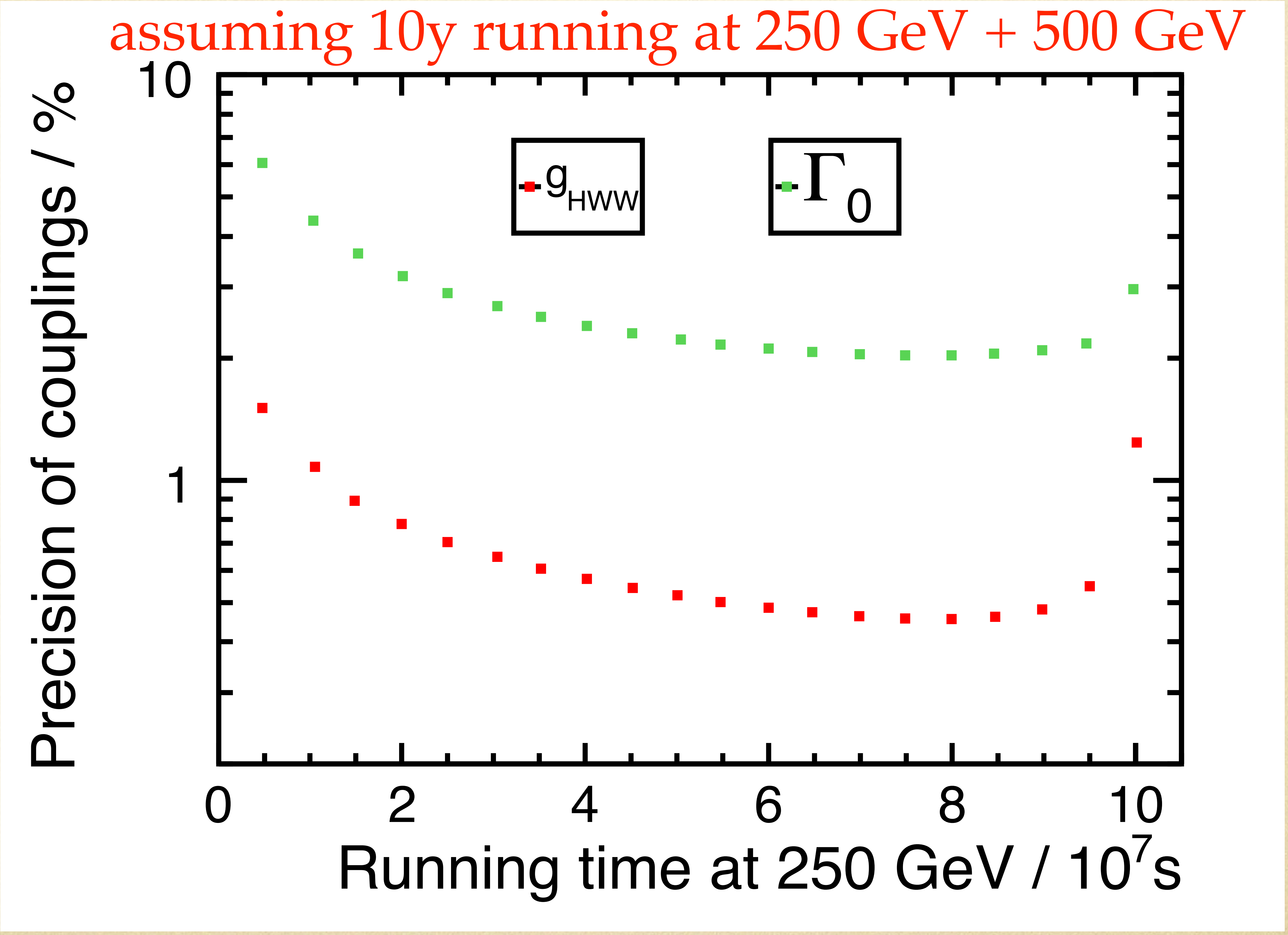
comparable with WW*-->qqqq (2.8%), together giving accuracy of σBr(WW*) 2.4%

Higgs total width Γ_H

$$\Gamma_H \propto \frac{g^4_{HWW}}{Y_4} \propto \frac{Y_1^2 Y_2^2}{Y_3^2 Y_4}$$

$\Delta\Gamma_H/\Gamma_H$	250 GeV	+ 500 GeV
Baseline	11%	5.0%
LumiUP	5.4%	2.5%

Staged Running

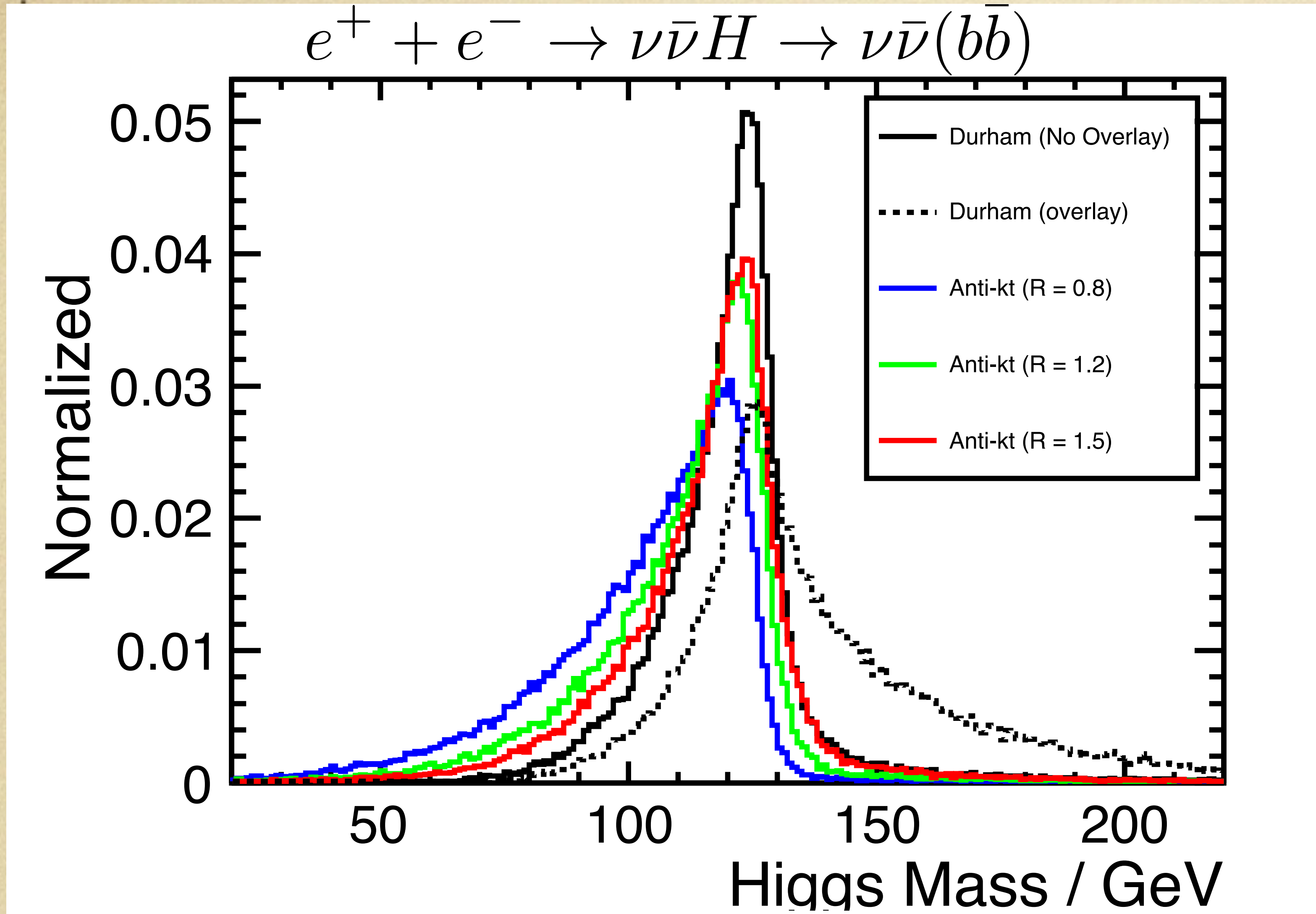


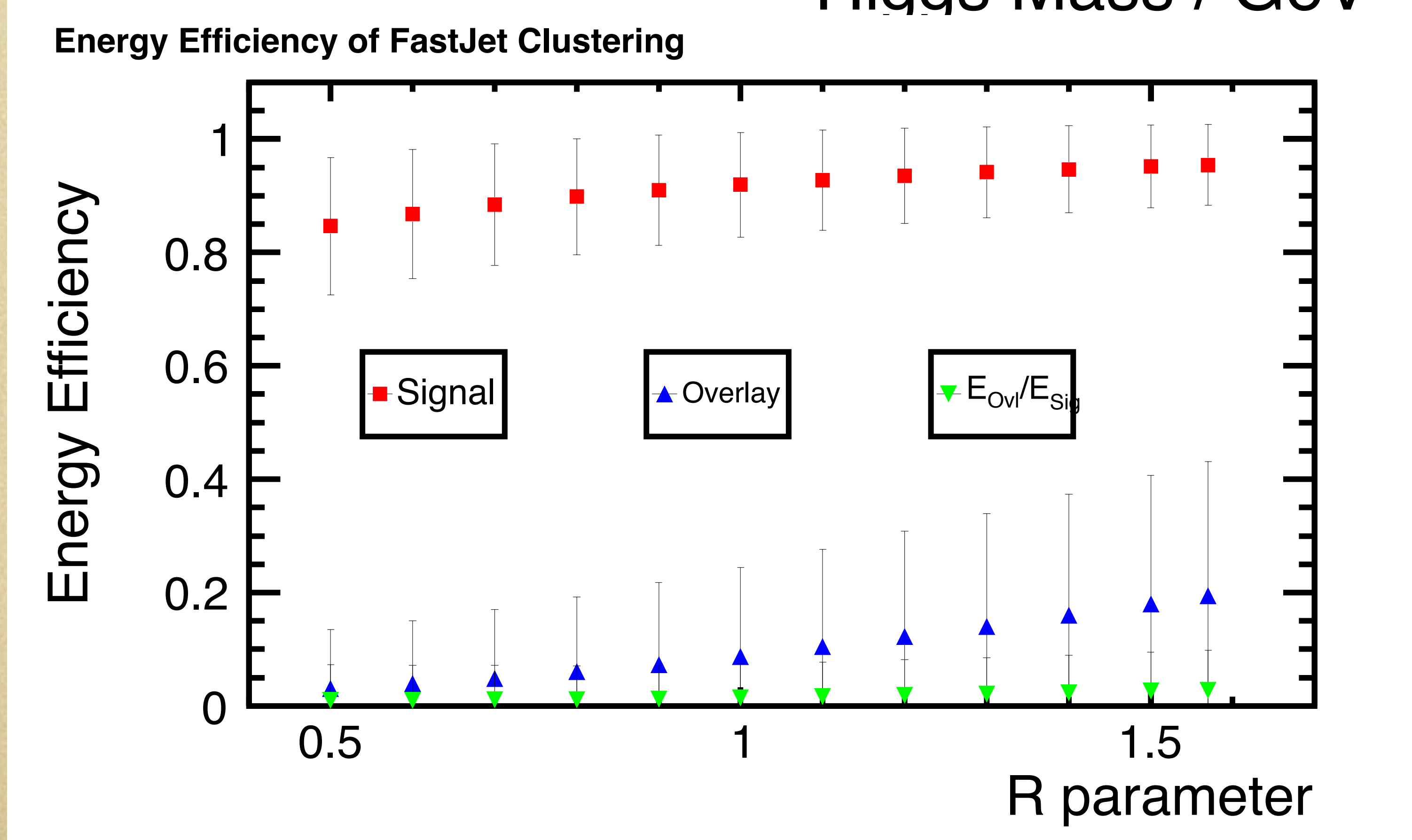
summary

- deviations on HWW coupling and Higgs total width are strong signal to new physics, and can be measured model independently at ILC.

- to get HWW coupling as good as HZZ coupling, going up to 500 GeV is essential for fully employing WW-fusion channel, where both HWW coupling and Higgs total width can be significantly improved by a factor of ~4.

backup





overlay

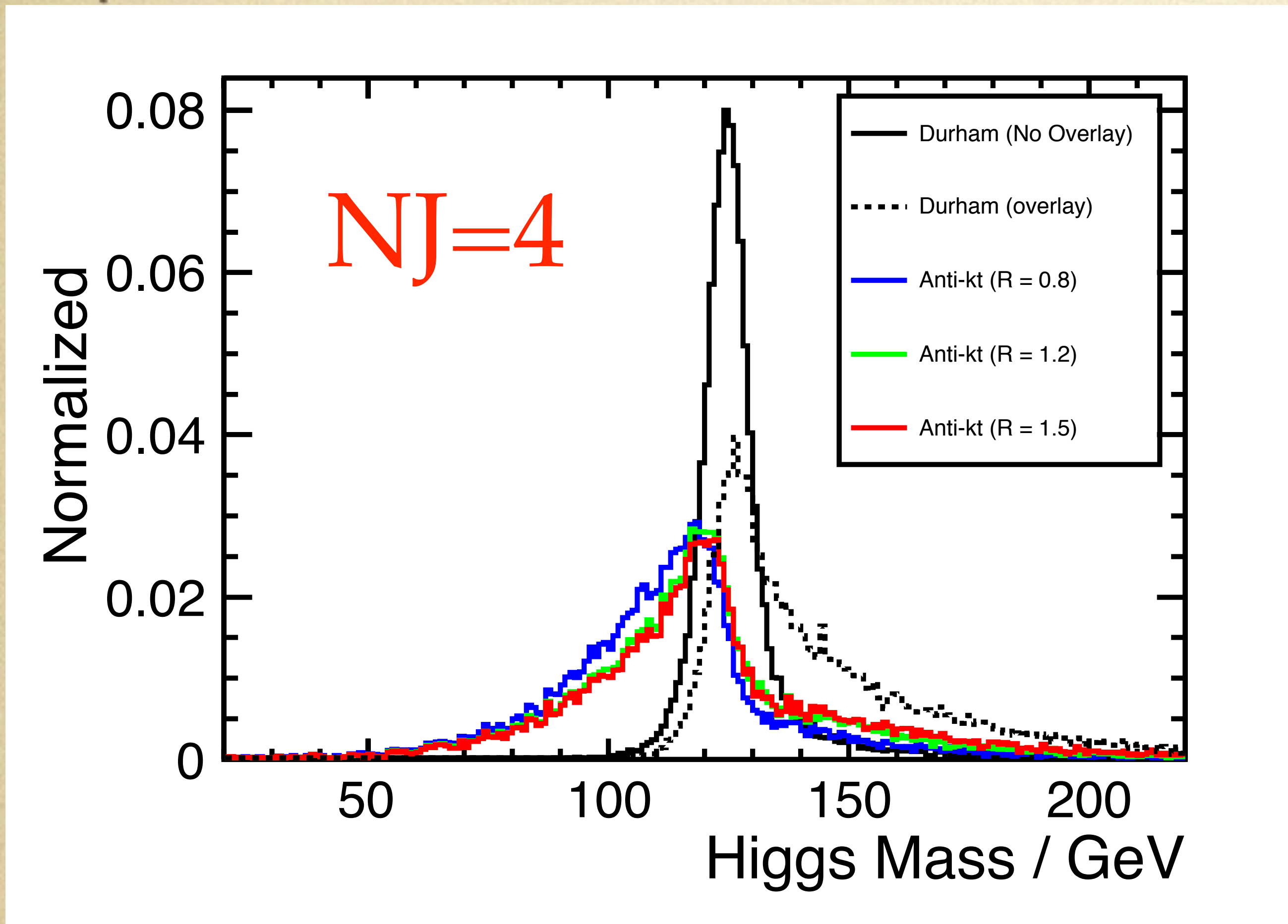
optimization of anti-kt jet clustering

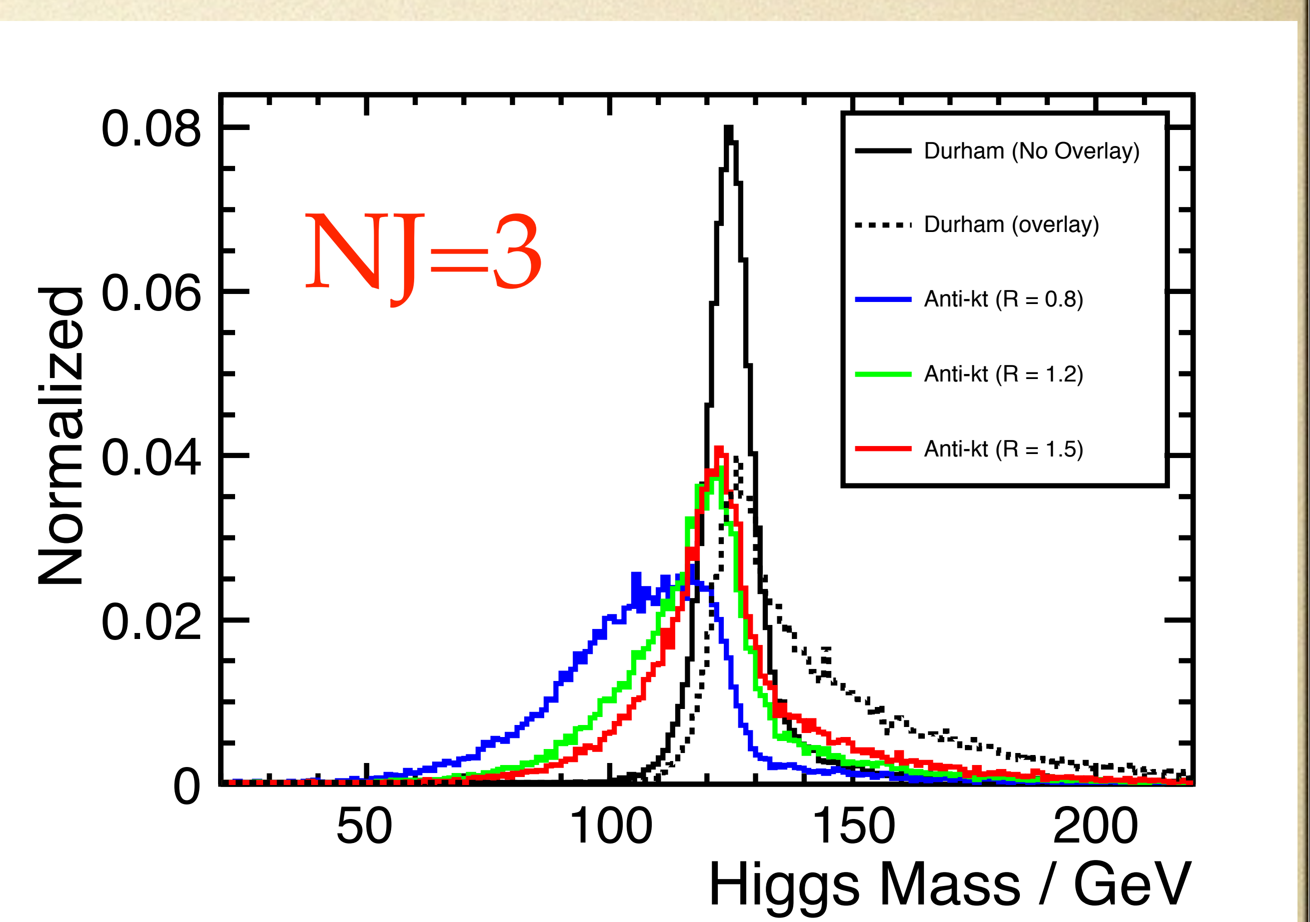
Max No. of Jets = 2

R = 1.5

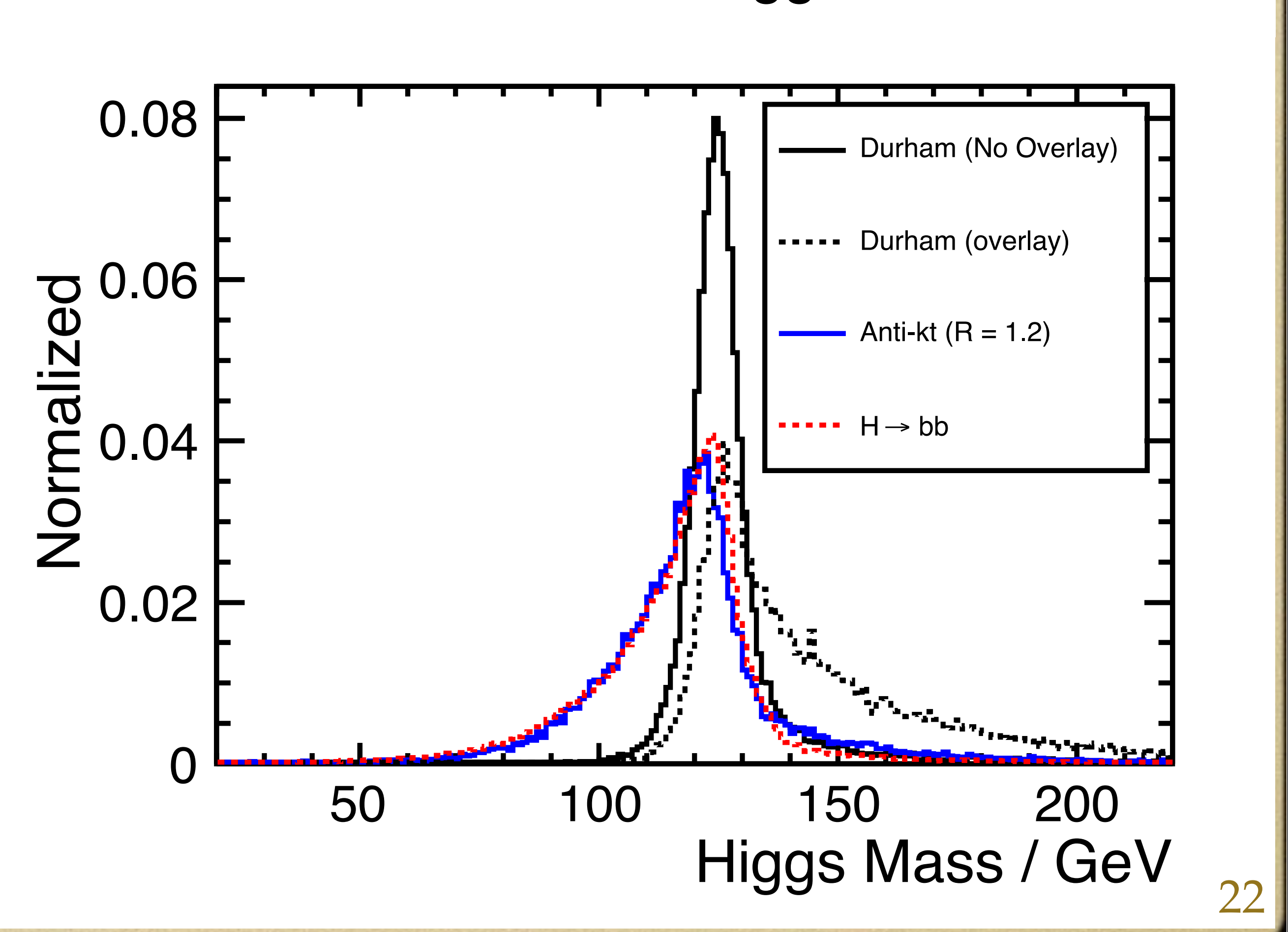
~95% signal
~18% overlay
~97% purity

$$e^+ + e^- \to \nu\bar{\nu}H \to \nu\bar{\nu}(WW^*) \to \nu\bar{\nu}qqqq$$

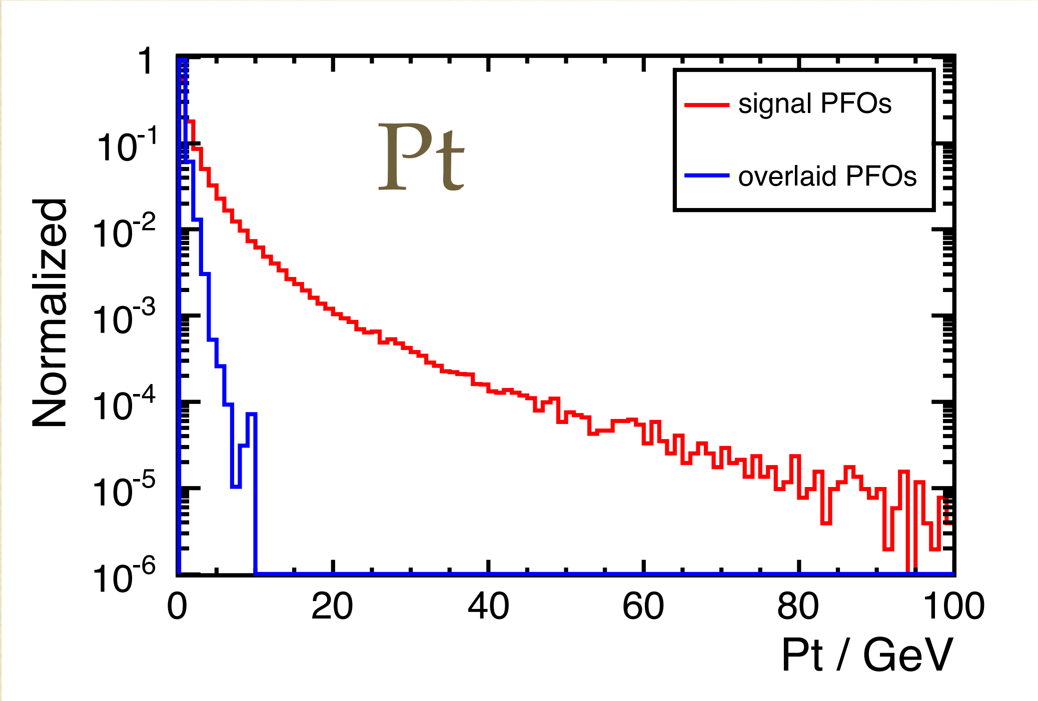


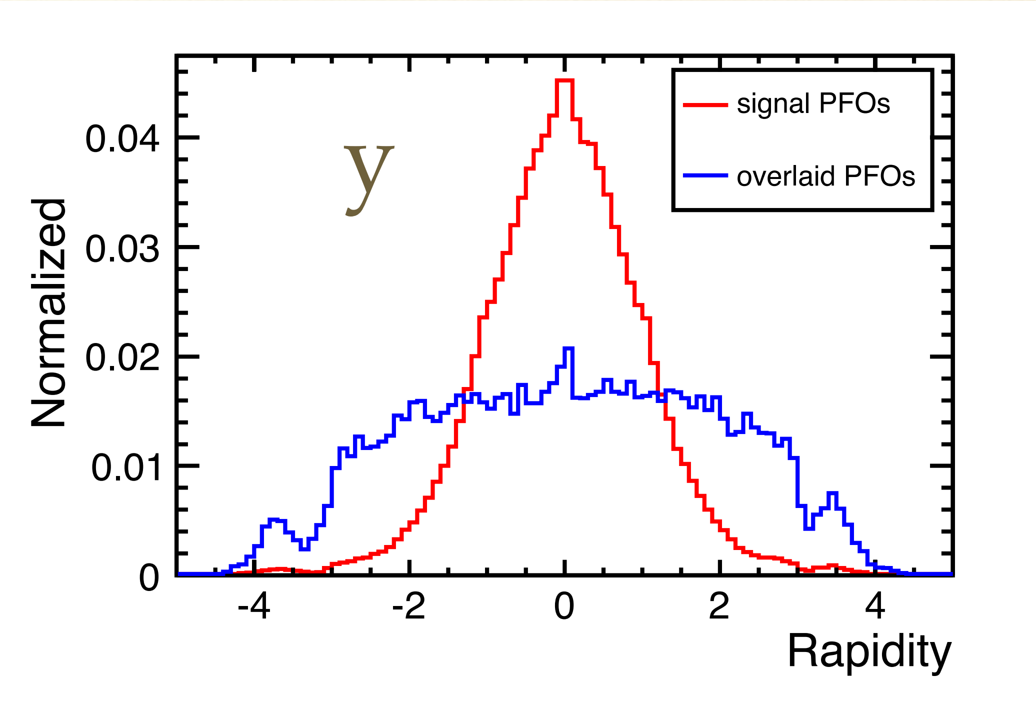


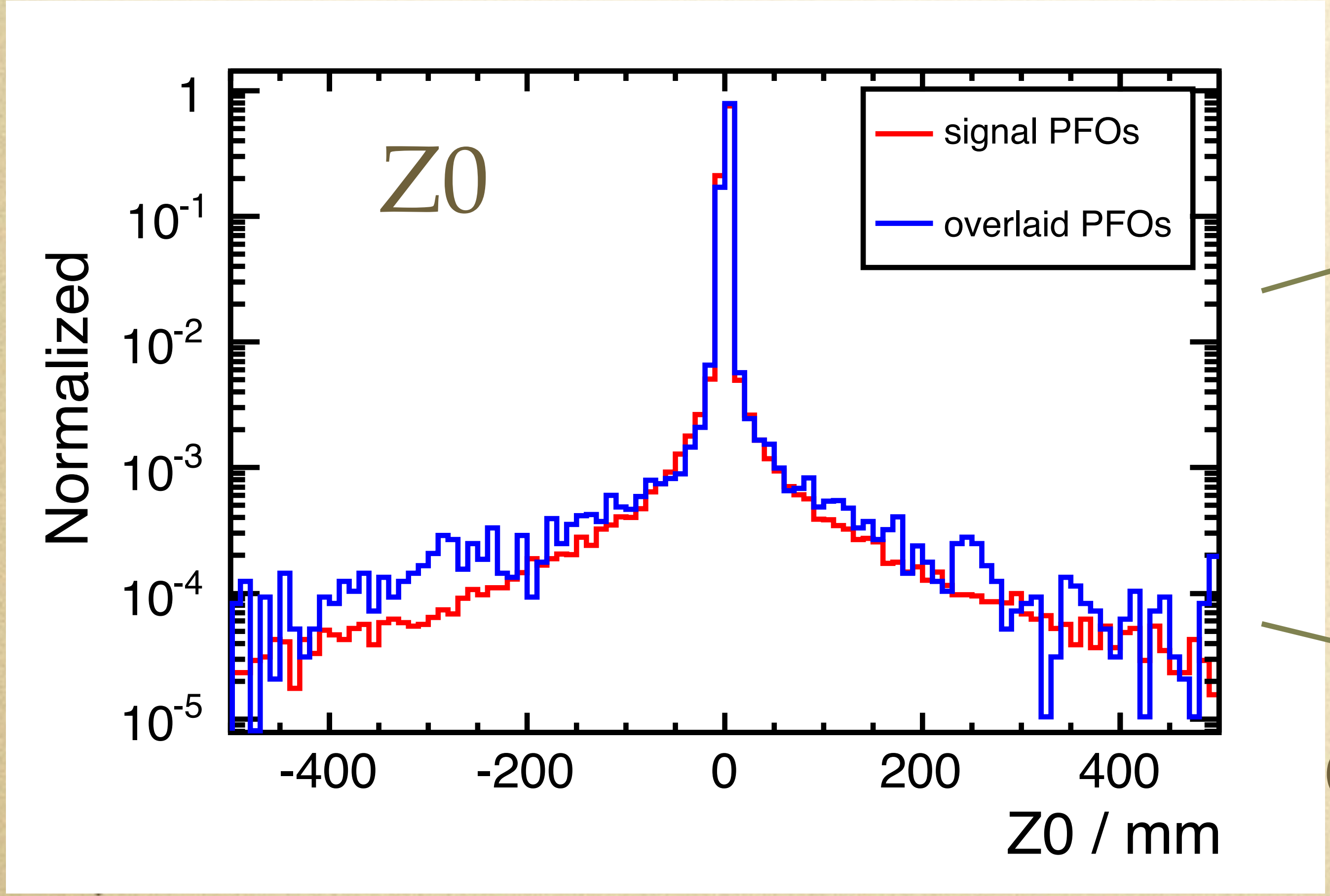
- resolution is much worse with overlay for H-->WW*
- Anti-kt with max no. of jets 3 works better than 4
- resolution with NJ=3 is already as "good" as H-->bb case



first trial a different way to remove overlay

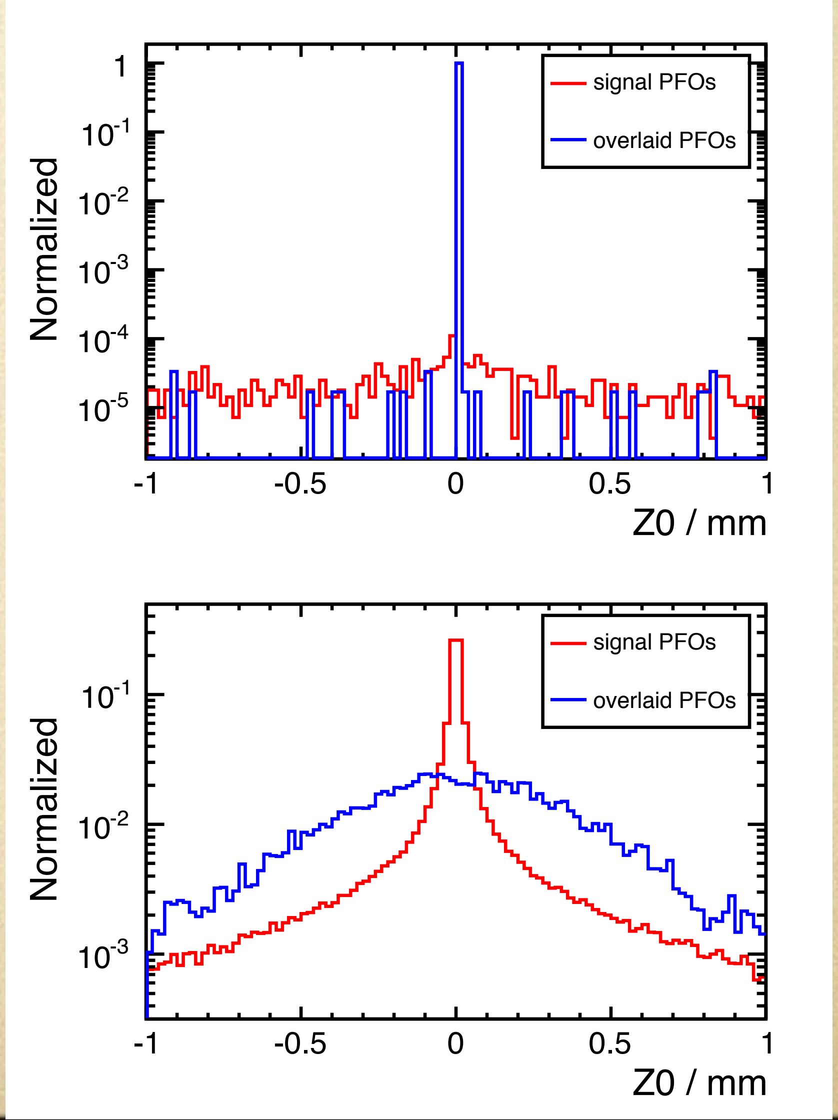




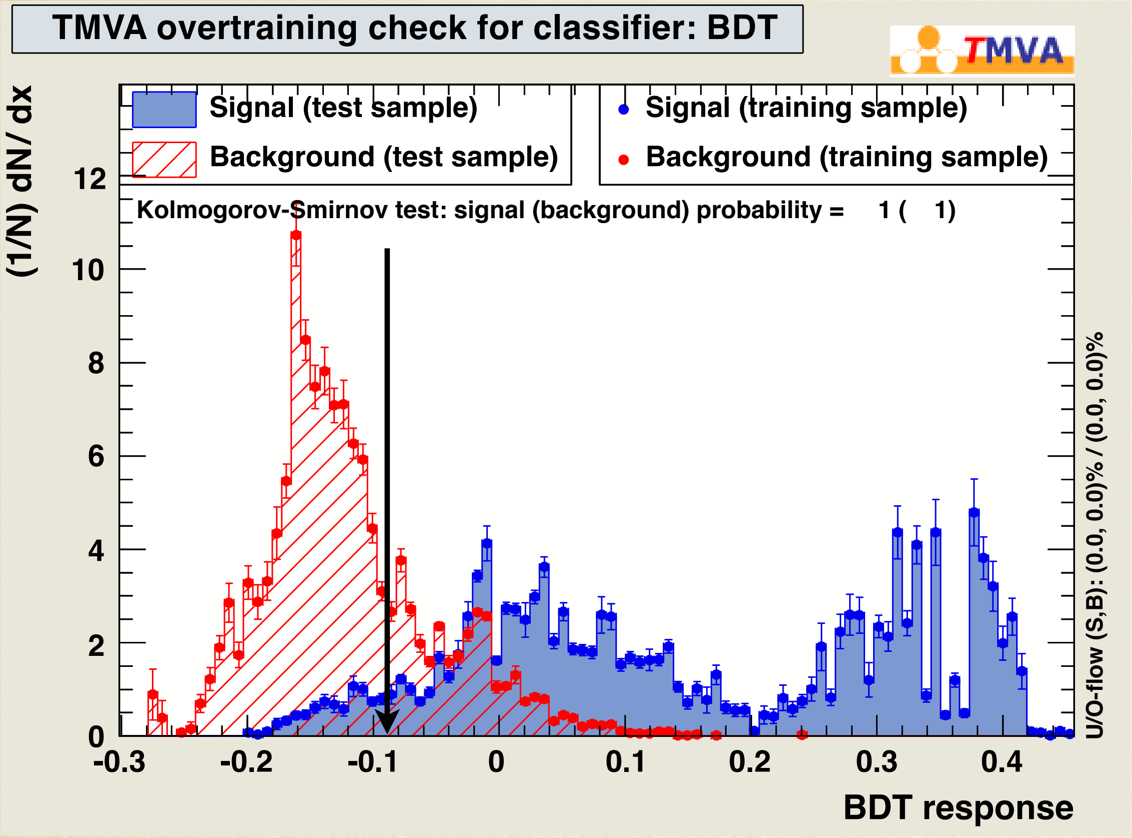


Neutral

Charged

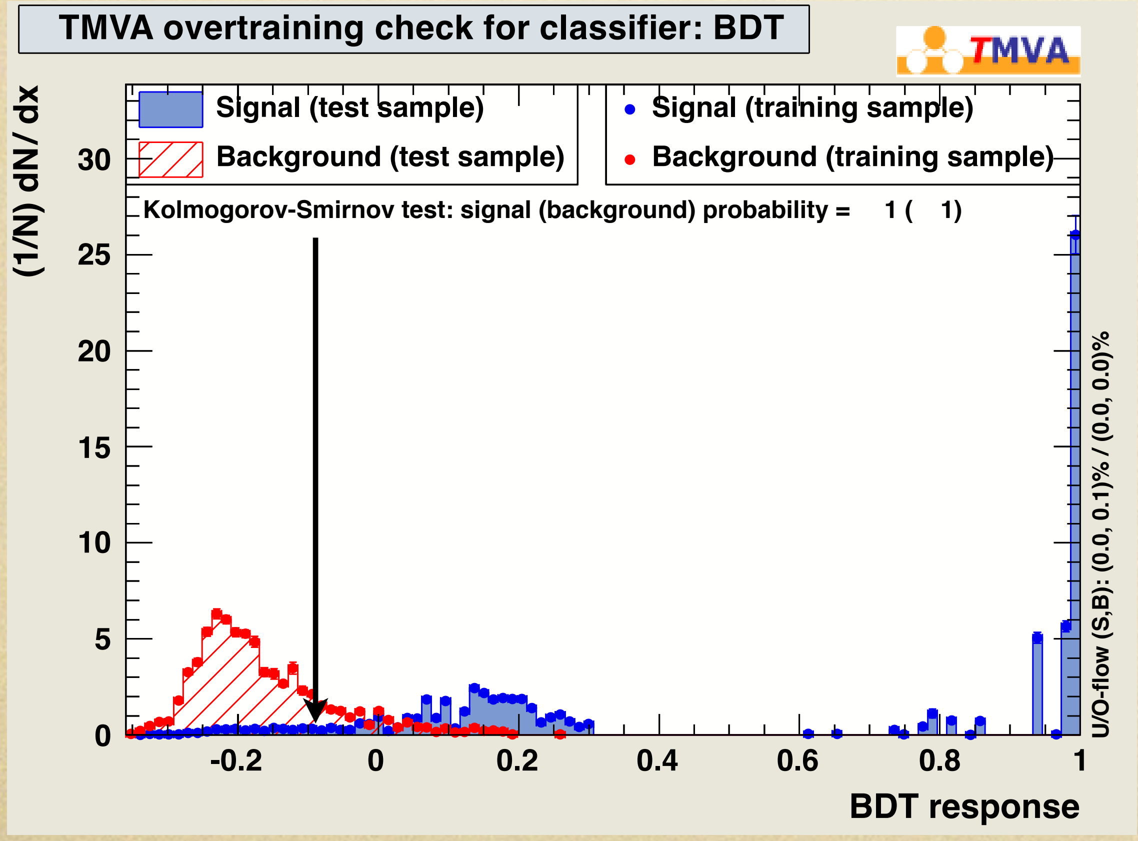


use MVA to identify overlaid particle



category 1: neural or large z0

input: Pt, Rapidity

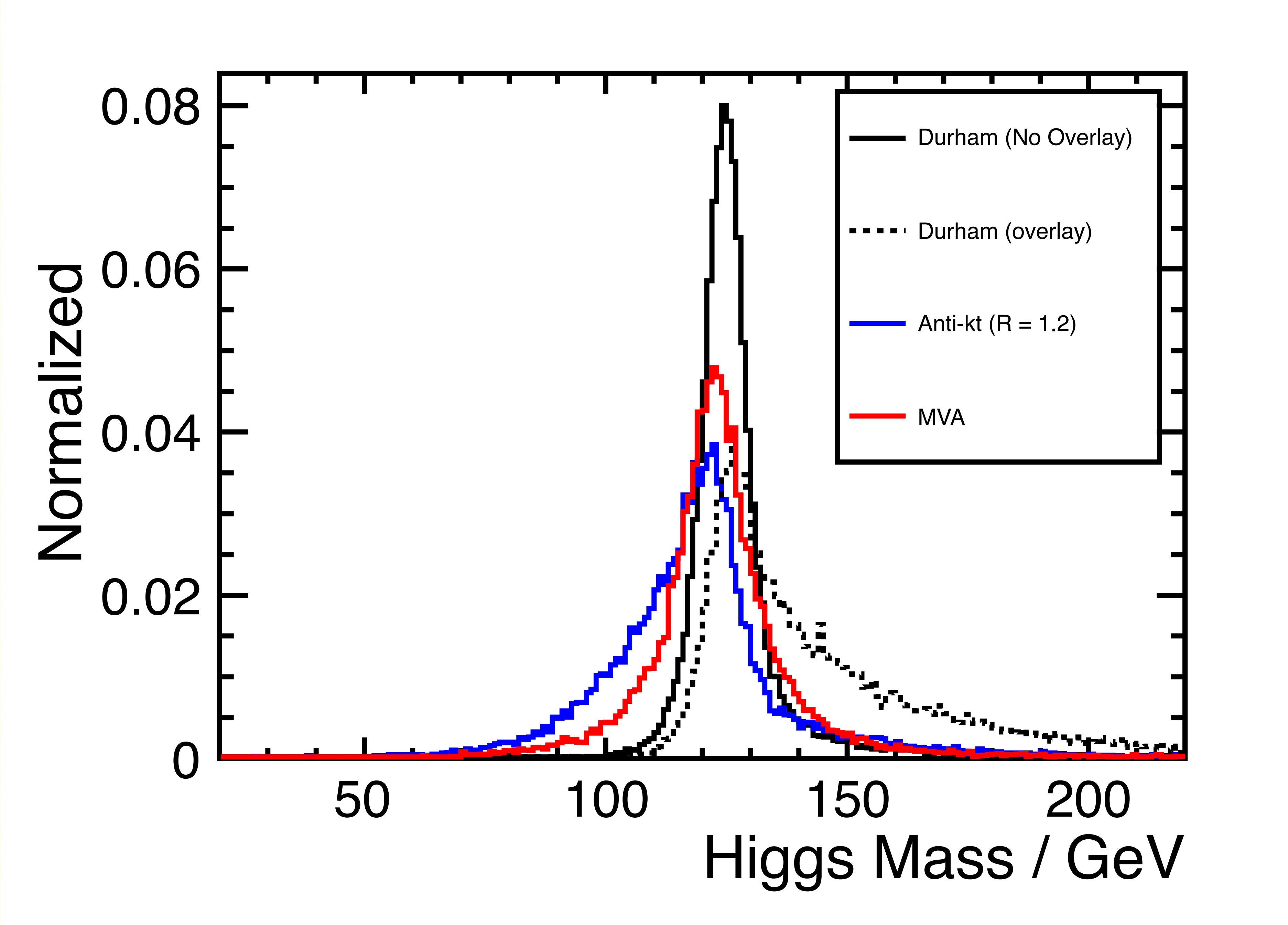


category 2: charged and small z0

input: Pt, Rapidity, z0

each PFO weighted by energy in both cases

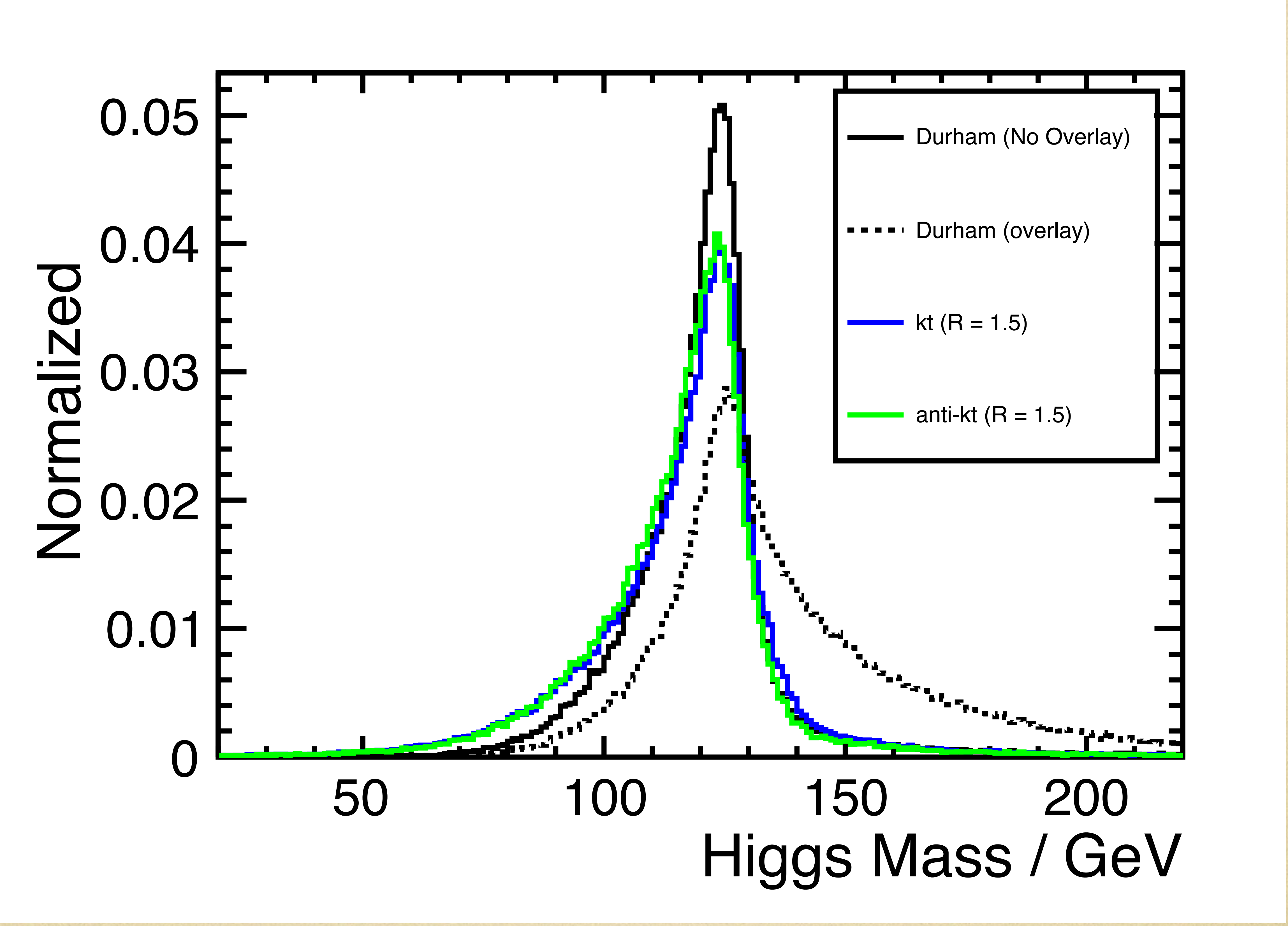
$$e^+ + e^- \to \nu\bar{\nu}H \to \nu\bar{\nu}(WW^*) \to \nu\bar{\nu}qqqq$$



~94% signal
~23% overlay
~98% purity

looks working, better resolution than anti-kt algorithm

ideas of new useful variables are very welcome!


Normalized
0.05
0.04
0.03
0.02
0.01
0
50
100
150
200
Higgs Mass / GeV
Durham (No Overlay)
Durham (overlay)
kt (R = 1.5)
anti-kt (R = 1.5)