Precision measurement of Higgs to gauge bosons couplings @ ILC 500

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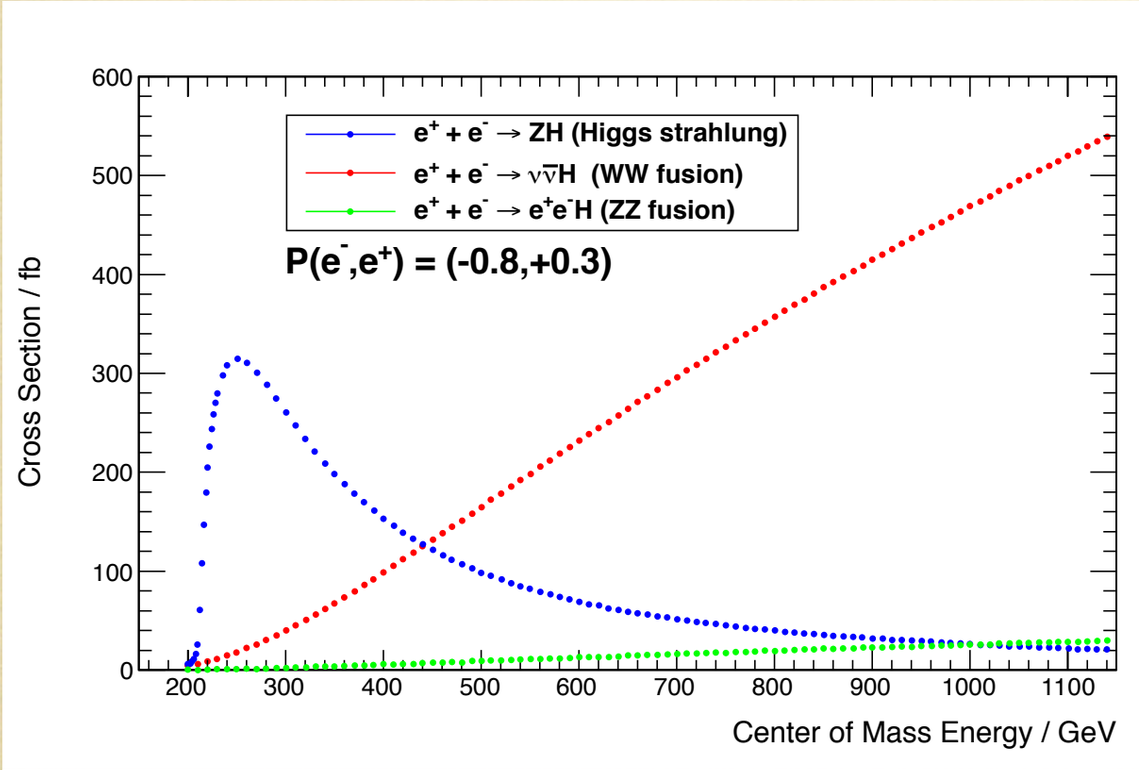
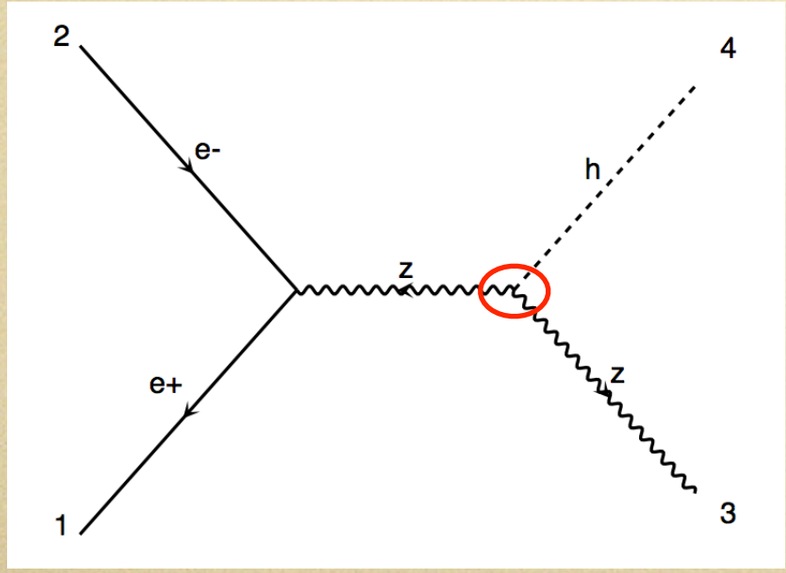
outline

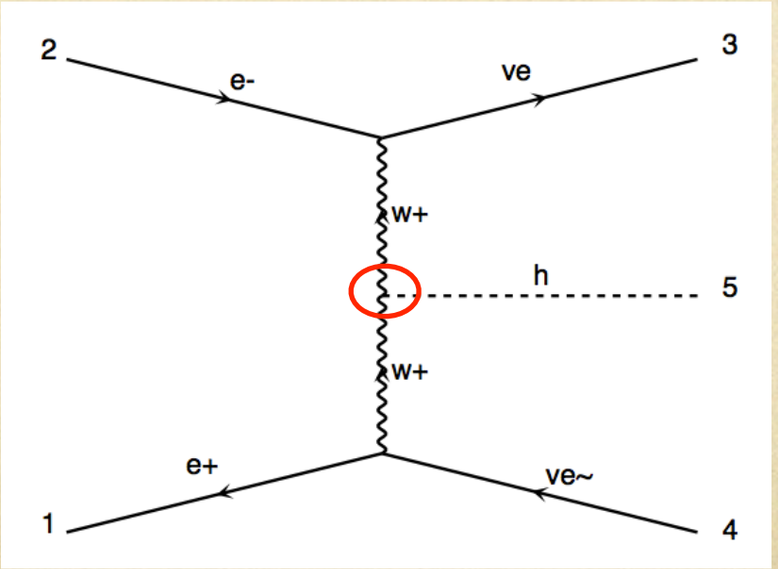
- WWH, ZZH coupling measurement @ 500 GeV
- testing Higgs coupling to $W_L W^*_L$ (both longitudinal)

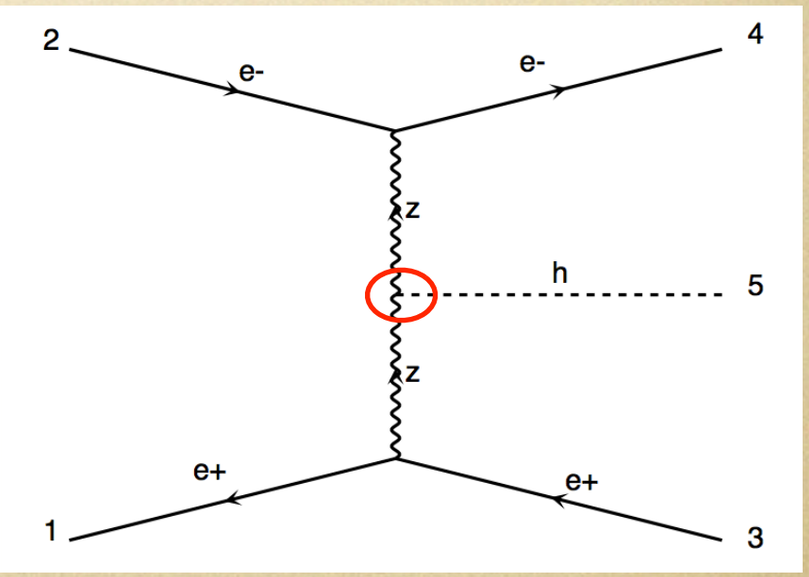
motivation of WWH, ZZH precision measurement



- two of fundamental Higgs couplings
- crucial test of SU(2) gauge symmetry
- precision measurement: SM or NP
- **dominant Higgs production**, bases of all other Higgs properties measurements

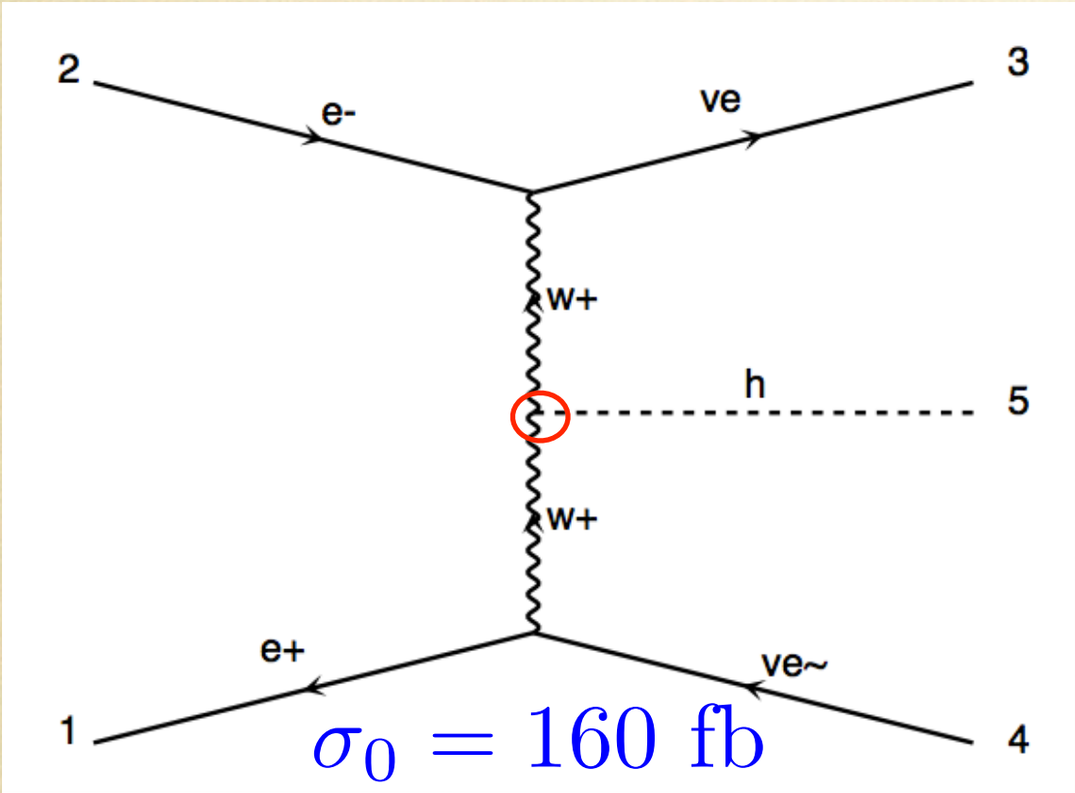






WWH coupling measurement using WW fusion process

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



$E_{\rm cm} = 500{\rm GeV}, M_H = 120{\rm GeV}$

- large cross section at 500 GeV (10 times of that at 250), large integrated luminosity
- independent with Higgs to WW branching ratio measurement, together offering the precision measurement of Higgs total width
- full simulation based on LoI framework of ILD
- main background: vvZ, ZH, WW, eeZ

$$\Gamma_{\rm tot} = \frac{\Gamma_{H\to WW}}{{\rm Br}(H\to WW)}$$

$$\frac{\delta g_{WWH}}{g_{WWH}} = \frac{1}{2}\sqrt{(\frac{\delta\sigma}{\sigma})^2 + (\frac{\delta{\rm Br}(H\to b\bar{b})}{{\rm Br}(H\to b\bar{b})})^2}$$

signal and backgrounds

Polarization: (e-,e+)=(-0.8,+0.3) $E_{\rm cm} = 500{\rm GeV}, M_H = 120{\rm GeV}$ $\int {\rm L} = 500\ {\rm fb}^{-1}$

	Cross Section	Expected	Generated
vvh (WW fusion)	1.60×10^{2}	7.98×10^{4}	2.73×10^{5}
vvh (ZH)	2.06×10^{1}	1.03×10^{4}	5.26×10^{4}
vvbb	1.55×10^{2}	7.77×10^{4}	2.32×10^{5}
vvcc	1.35×10^{2}	6.75×10^{4}	1.85×10^{5}
lvqq	1.04×10^{4}	5.18×10^{6}	1.64×10^{6}
lvlvbb	9.16×10^{1}	4.58×10^{4}	1.20×10^{5}
lvbbqq	4.11×10^{2}	2.06×10^{5}	7.96×10^{5}
eeh	1.21×10^{1}	6.04×10^{3}	4.58×10^{4}
llbb	1.82×10^{2}	9.12×10^{4}	3.16×10^{4}
llcc	7.59×10^{2}	3.80×10^{6}	2.91×10^{6}
Total BG	1.21×10^{4}	6.06×10^{6}	

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

full simulation @ 500GeV

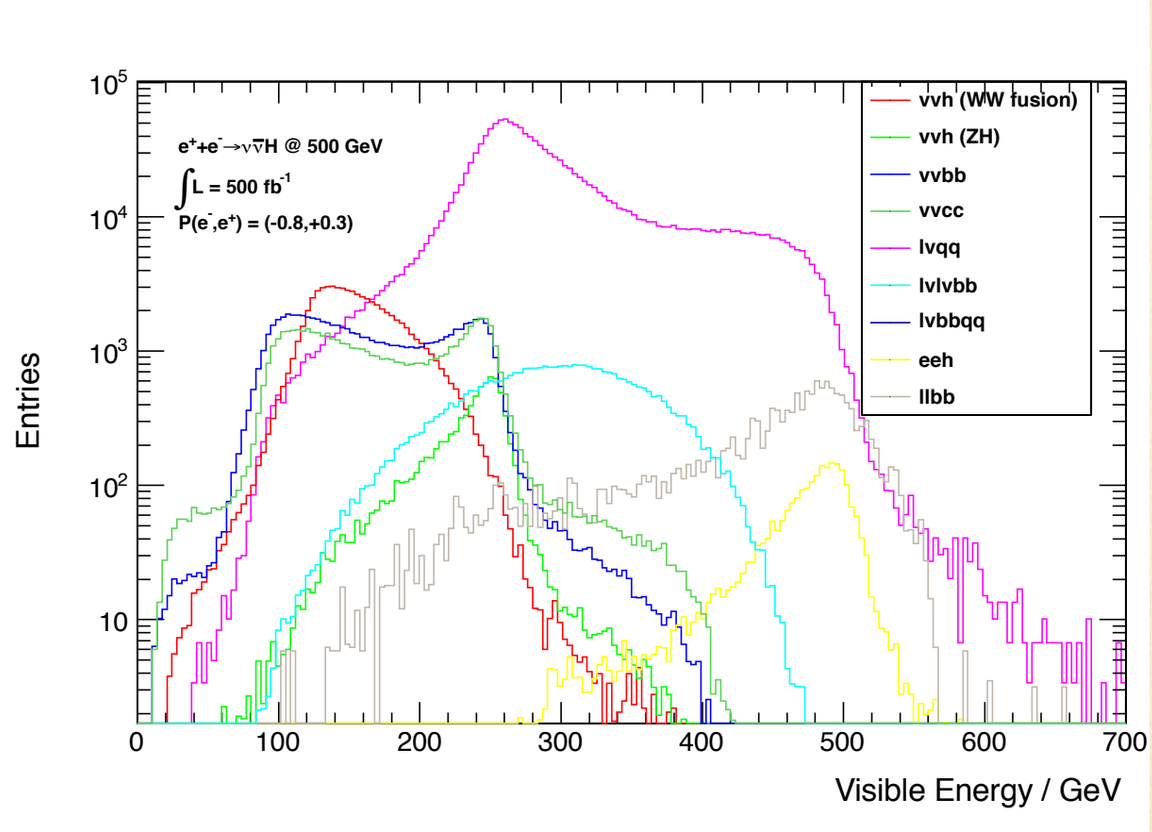
pre-selection:

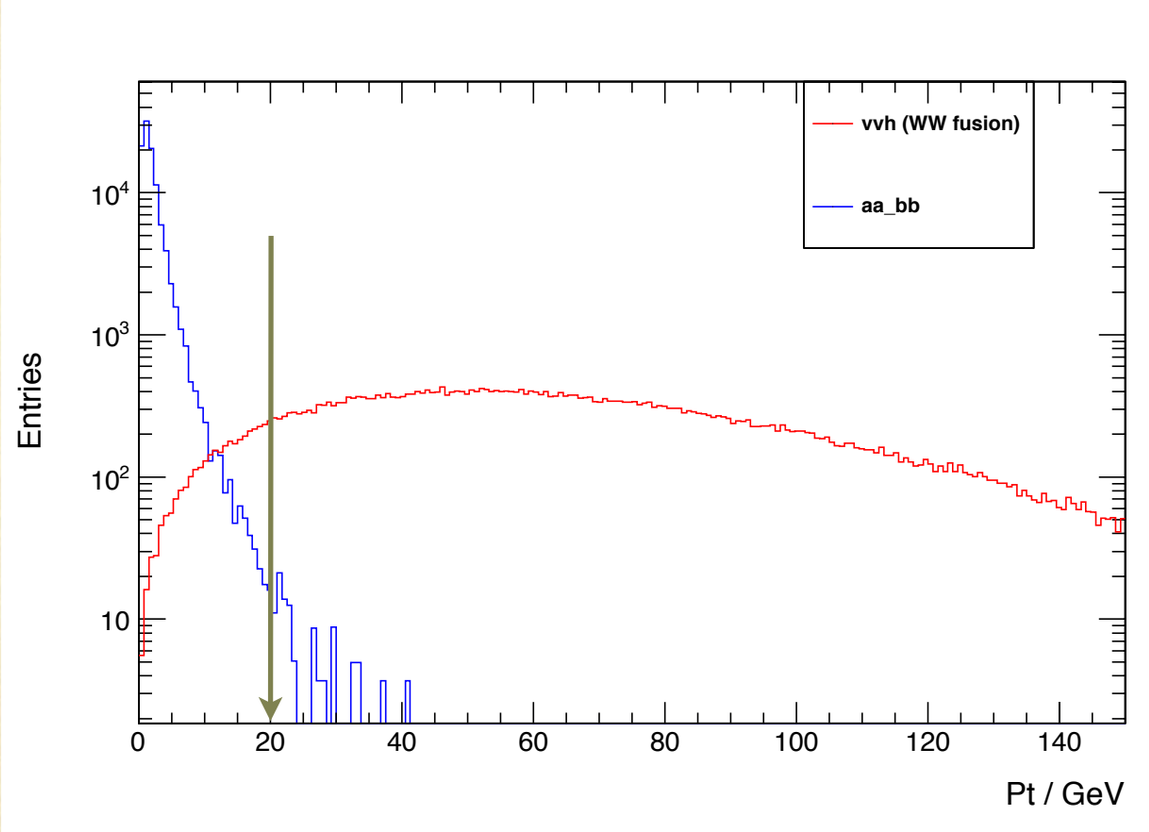
- two jets, each with more than 8 particles

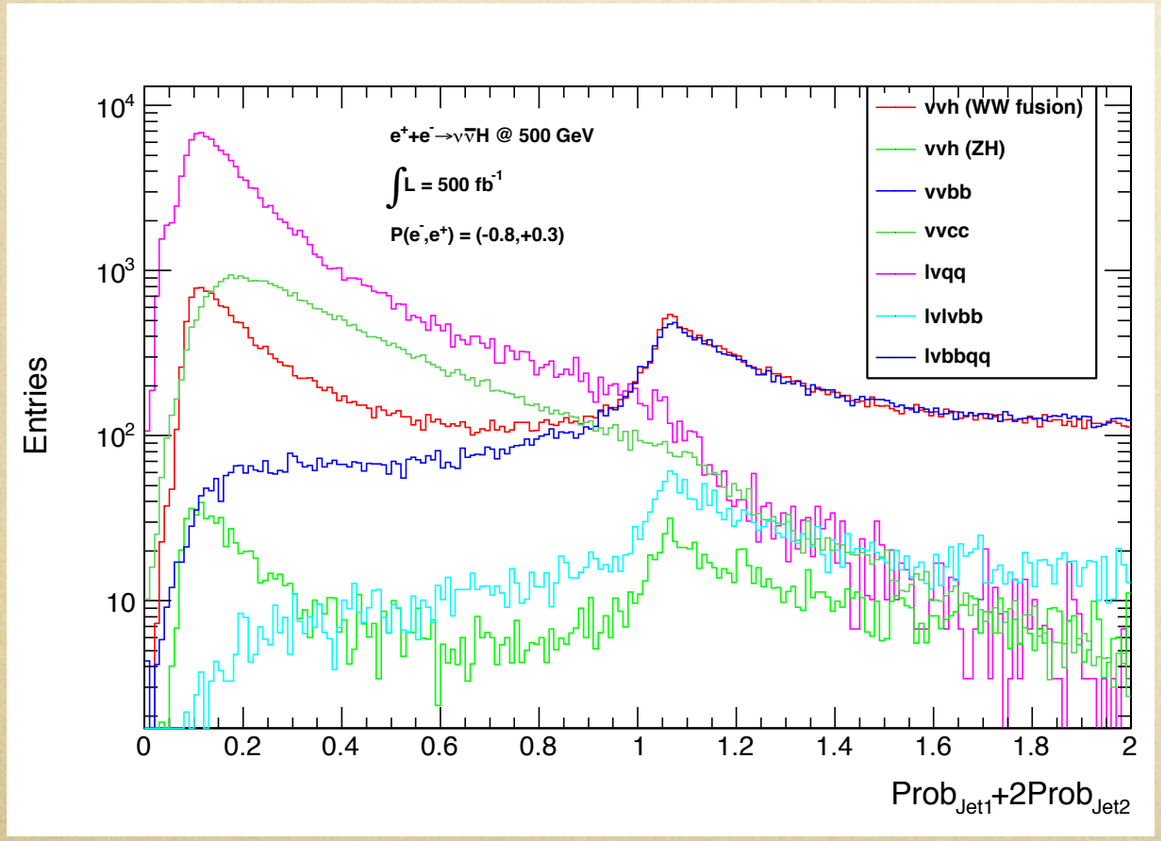
final-selection:

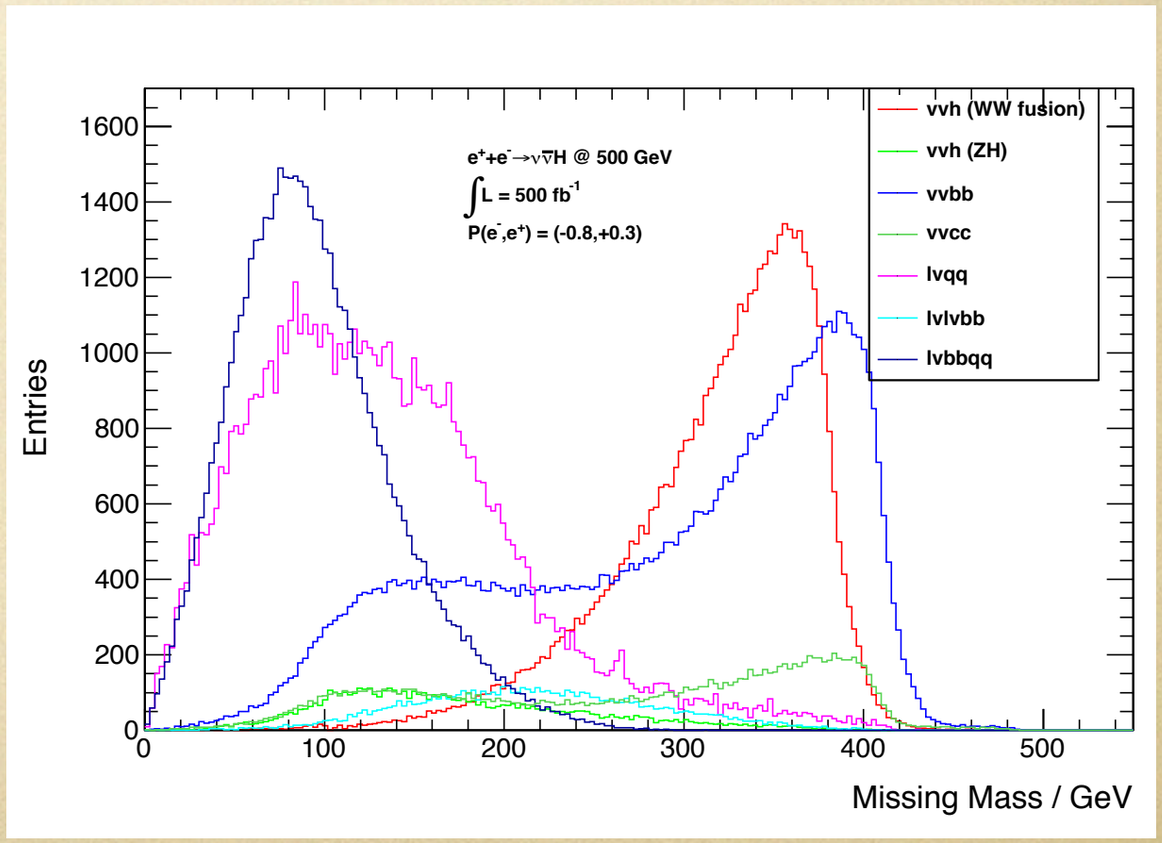
- Visible energy: (100, 230) GeV Pt > 20 GeV (cut1)
- Isolate lepton rejection: P(Lmax) < 2*Econe + 20 (cut2)
- B-tagging: Prob(Jet1) + 2Prob(Jet2) > 0.6 (cut3)
- Missing mass (Z rejection): > 220 GeV (cut4)
- Higgs mass: (98, 140) GeV (cut5)

several distributions

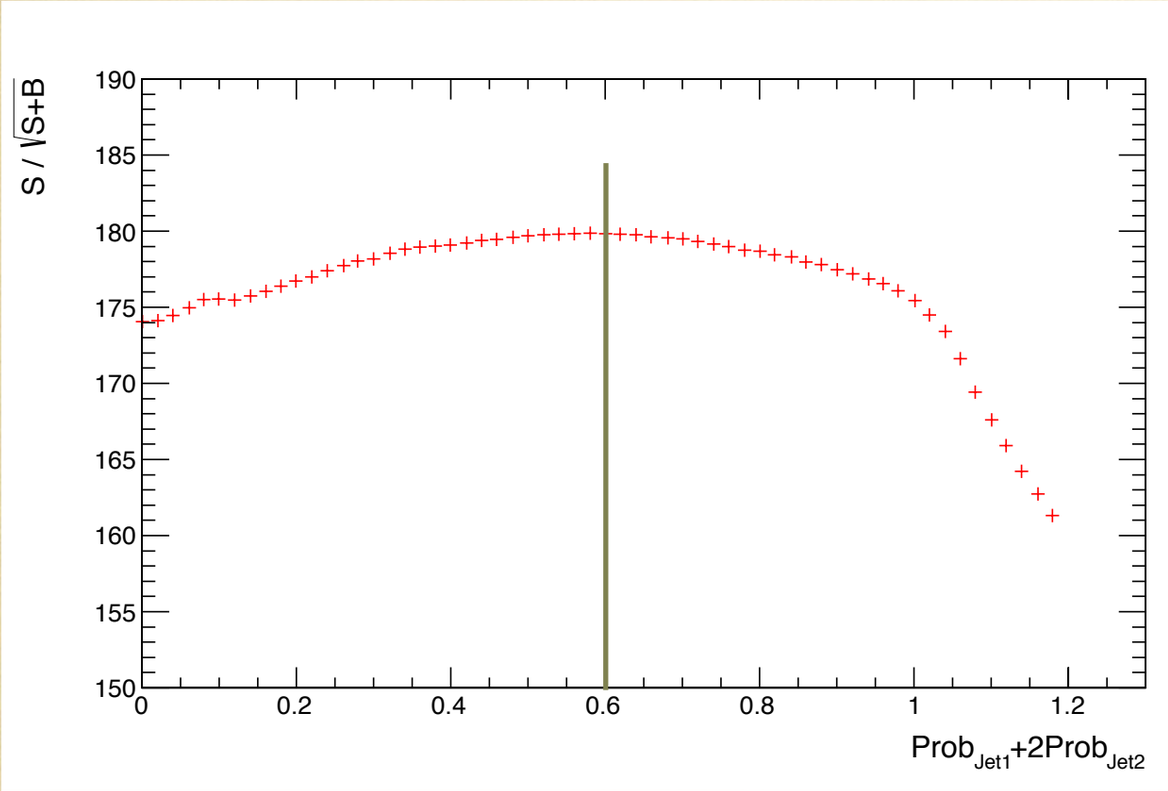


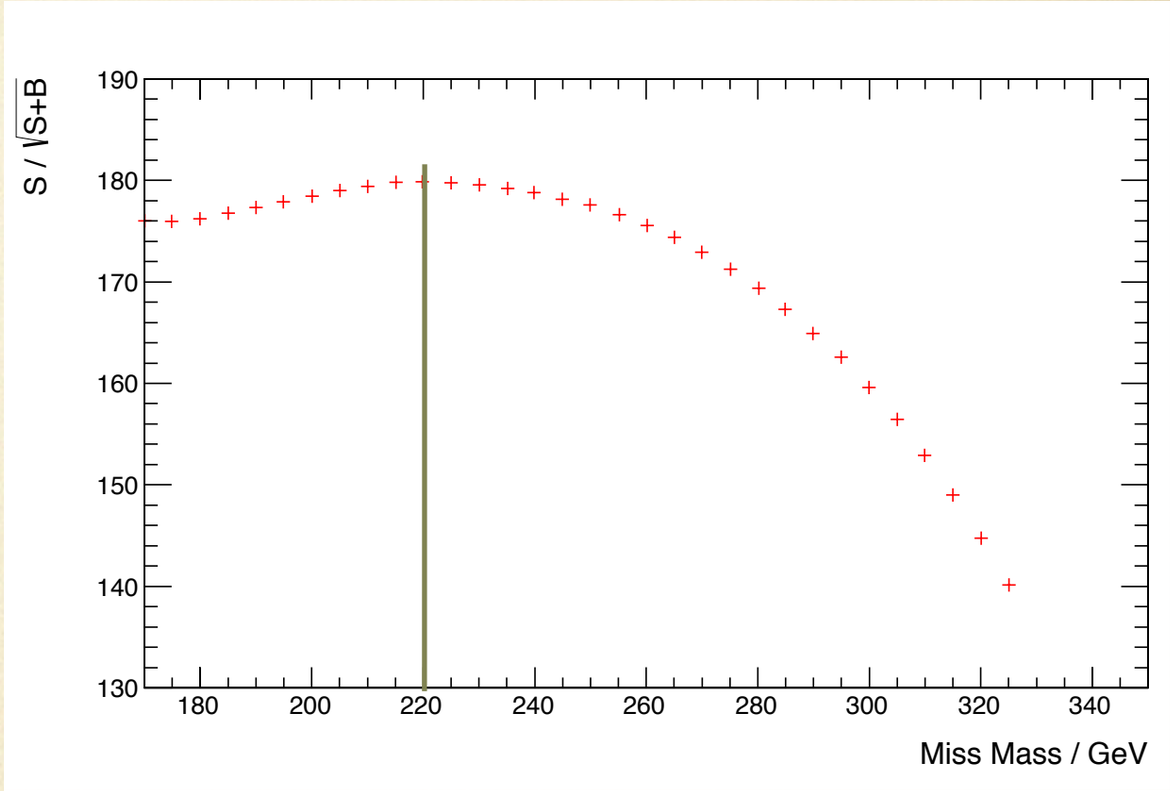


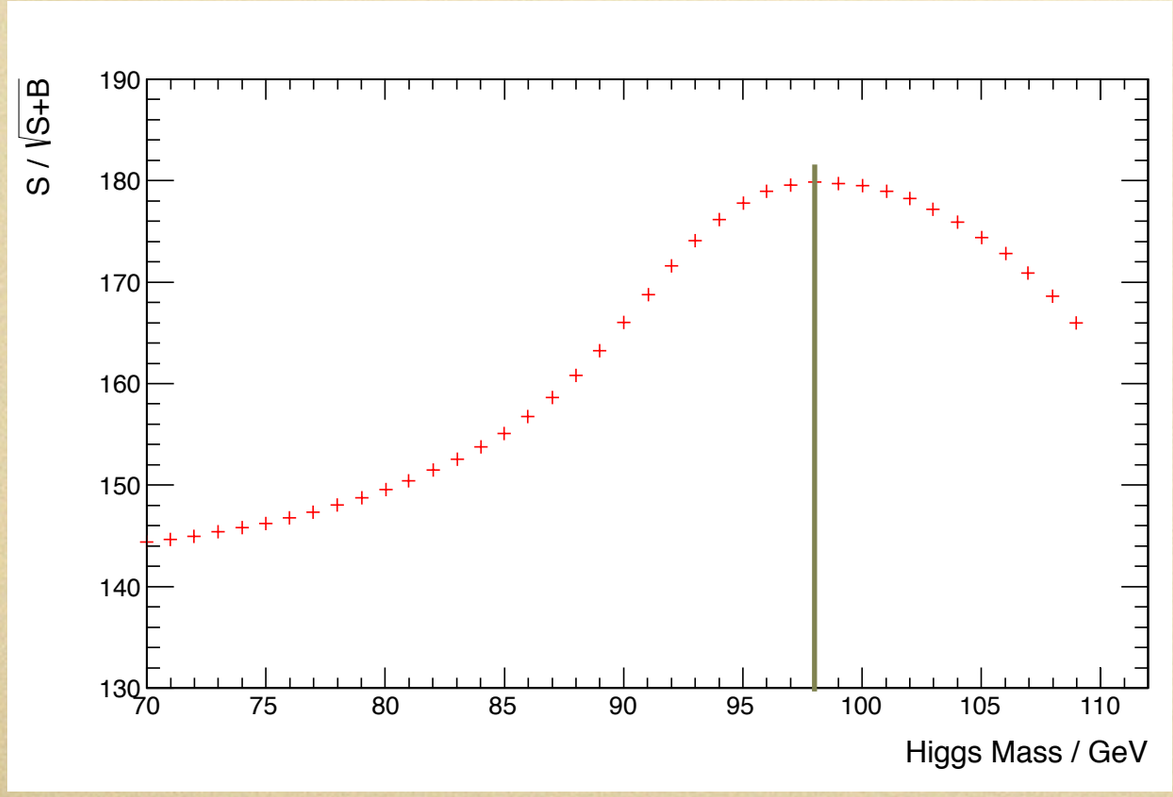


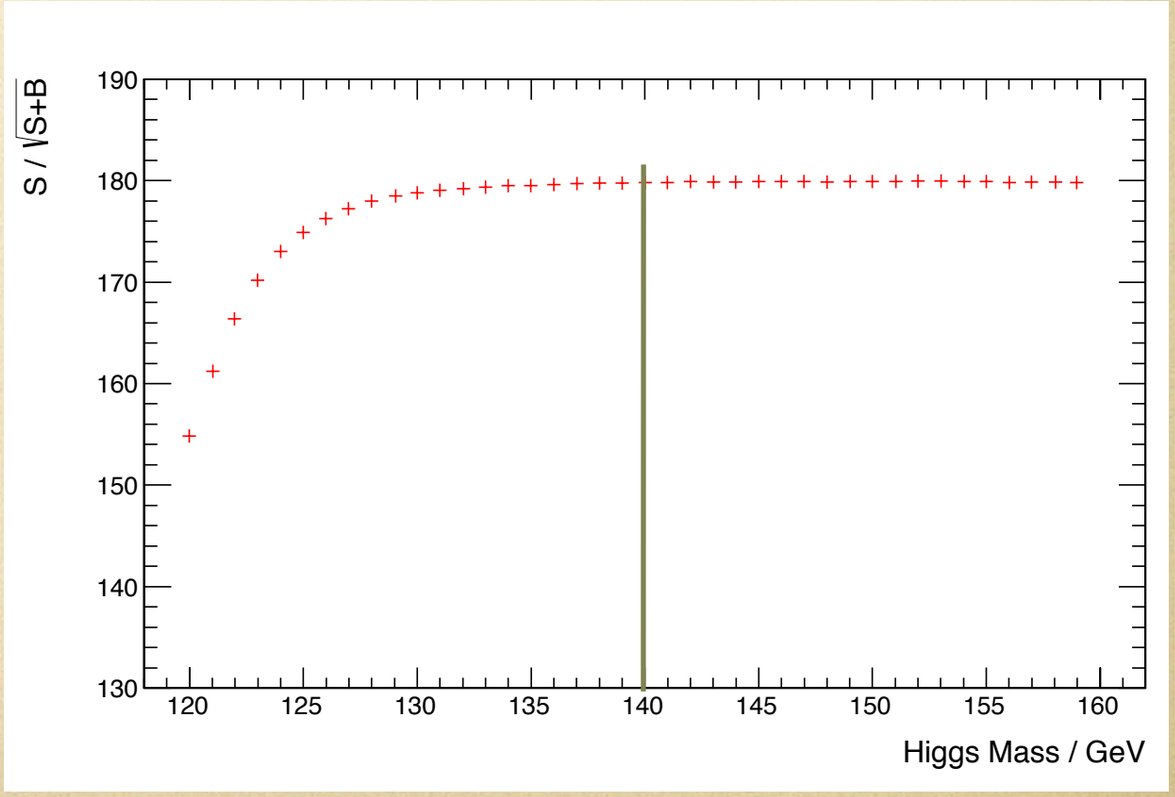


cut optimization



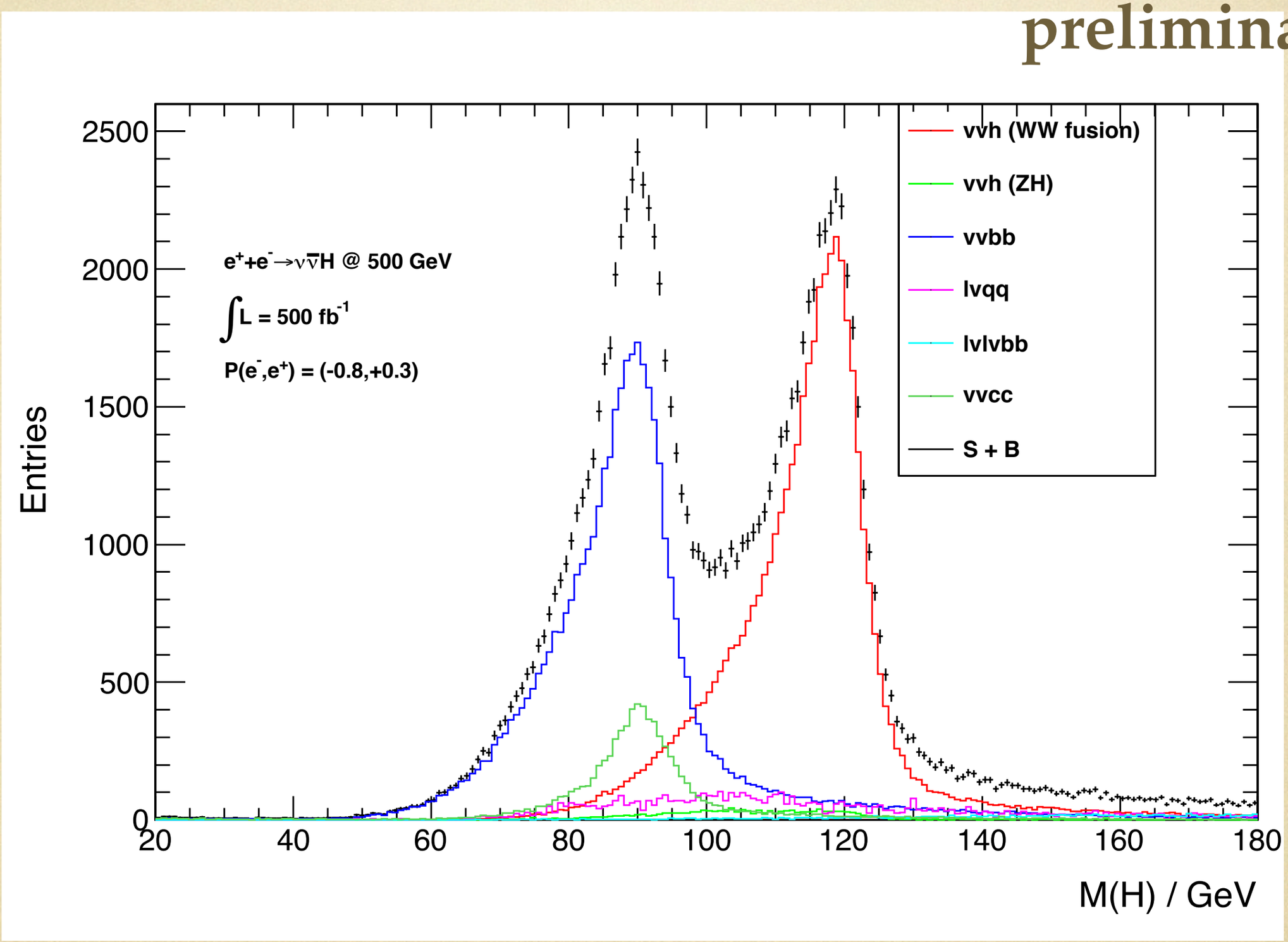






Higgs Mass (after the preceding 4 cuts)

preliminary



98 GeV < M(H) < 140 GeV: $\frac{S}{\sqrt{S+B}} = 175$

signal and backgrounds (reduction table)

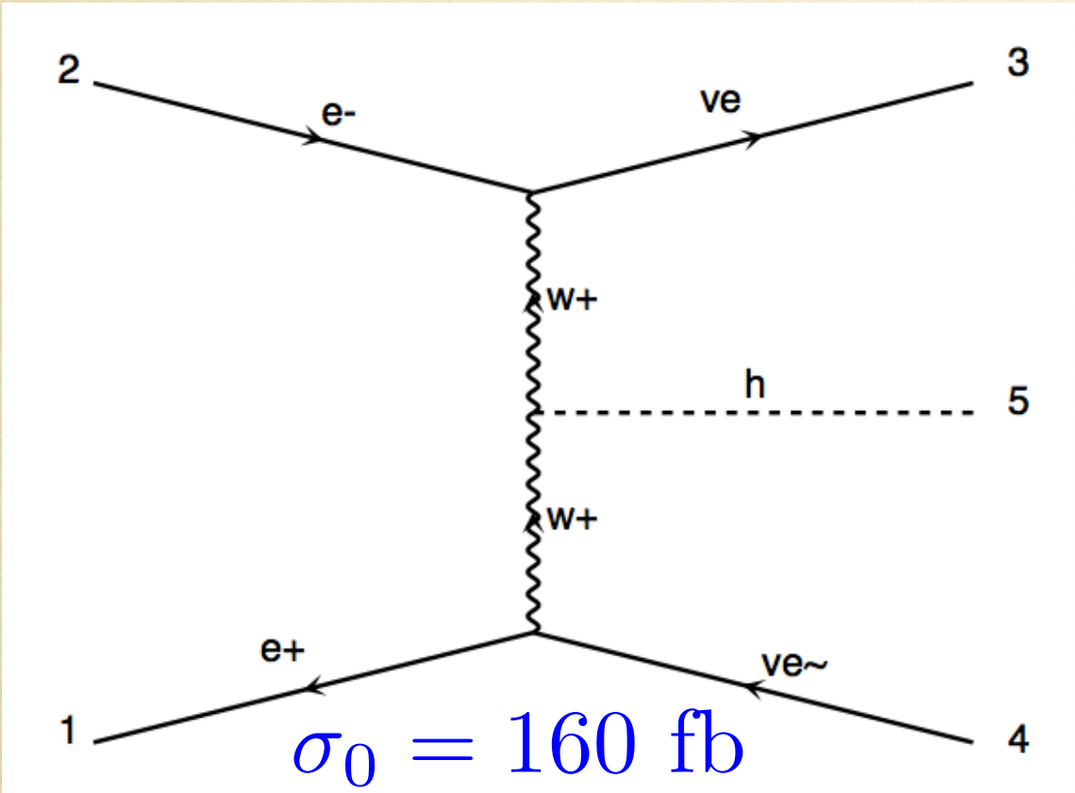
preliminary

Polarization: (e-,e+)=(-0.8,+0.3) $E_{\rm cm} = 500{\rm GeV}, M_H = 120{\rm GeV}$ $\int {\rm L} = 500\ {\rm fb}^{-1}$

	Expected	pre-selction	cut1	cut2	cut3	cut4	cut5
vvh (WW fusion)	7.98×10^4	68992	60647	59030	44973	43552	37976
vvh (ZH)	1.03×10^4	8546	3168	2972	2361	1508	1026
vvbb	7.77×10^4	72822	47911	47356	44436	38288	4542
vvcc	6.75×10^4	60070	37074	36962	8412	7173	1038
lvqq	5.18×10^6	1451030	116889	79187	8175	4515	2236
lvlvbb	4.58×10^4	35891	5116	2035	1932	1909	413
lvbbqq	2.06×10^5	199058	137	114	96.6	94.9	0.35
eeh	6.04×10^3	2379	0.30	0	0	0	0
llbb	9.12×10^4	17145	175	132	125	102	65.4
llcc	3.80×10^6	87840	131	84.2	39.4	31.6	3.89
BG	6.06×10^6	1934780	210603	168842	65578	53621	9324
significance	32.2	48.7	116	124	135	140	175

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

Polarization: (e-,e+)=(-0.8,+0.3) $E_{\rm cm} = 500{\rm GeV}, M_H = 120{\rm GeV}$



$$\sigma = \sigma_0(\nu\bar{\nu}H) \cdot {\rm Br}(H \to b\bar{b})$$

$$\frac{\delta\sigma}{\sigma} = 0.57\%$$

$$\frac{\delta g_{WWH}}{g_{WWH}} = \frac{1}{2}\sqrt{(\frac{\delta\sigma}{\sigma})^2 + (\frac{\delta{\rm Br}(H \to b\bar{b})}{{\rm Br}(H \to b\bar{b})})^2}$$

$$\frac{\delta{\rm Br}({\rm H} \to {\rm b}\bar{\rm b})}{{\rm Br}({\rm H} \to {\rm b}\bar{\rm b})} = 2.7\%$$

$$\frac{\delta\sigma_0}{\sigma_0} = 2.8\% \qquad \frac{\delta g_{\rm WWH}}{g_{\rm WWH}} = 1.4\%$$

precision: Br(H-->WW) ~ 4%

Higgs width ---> $\frac{\delta\Gamma_{\rm tot}}{\Gamma_{\rm tot}} \approx 5\%$

limited by the error of Higgs recoil mass measurement

ZZH coupling @ 500 GeV

full simulation ongoing

	250 GeV	500 GeV
$ZH \to e^+e^-H$	10.5 fb	3.29 fb
$ZH \to \mu^+\mu^-H$	10.5 fb	3.29 fb
e^+e^-H (ZZ fusion)	-	8.81 fb

resolution drop at 500 GeV!

assuming: $250\ \mathrm{fb}^{-1}$ @ 250 GeV $500\ \mathrm{fb}^{-1}$ @ 500 GeV

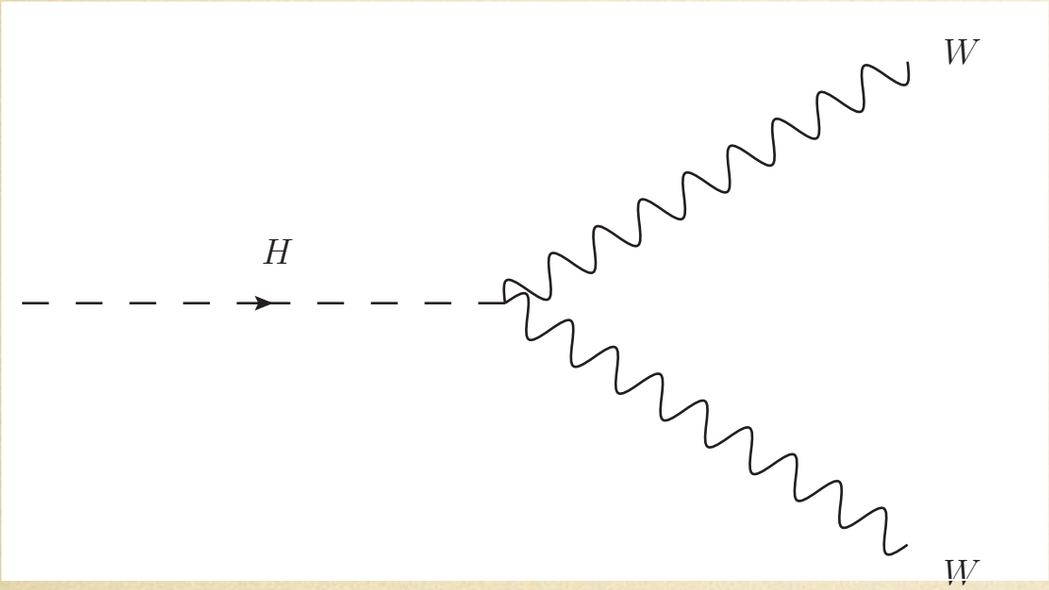
statistically, gain a fact of 2.5

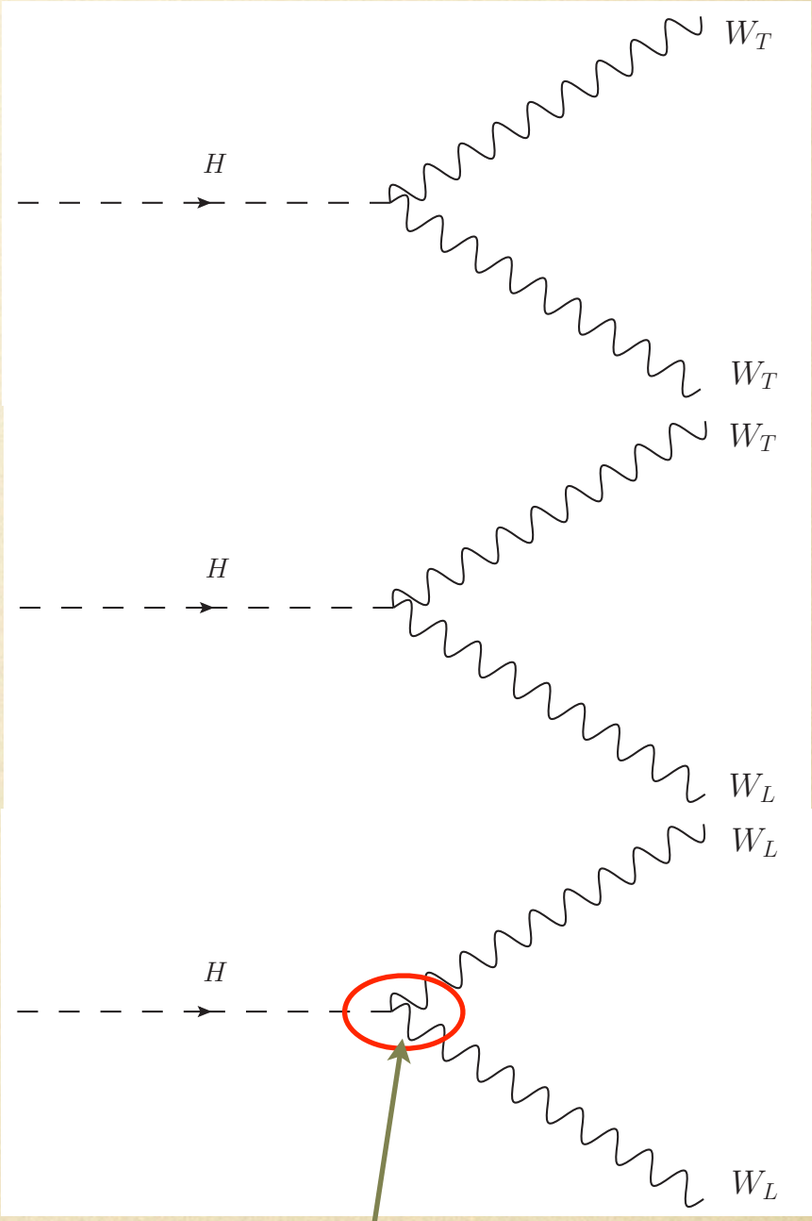
$$\frac{\delta\sigma_0(ZH)}{\sigma_0(ZH)} \longrightarrow 1.6\%$$

(LoI: 2.5%)

$$\frac{\delta g_{\mathrm{ZZH}}}{g_{\mathrm{ZZH}}} \to 0.80\% \qquad \frac{\delta g_{\mathrm{WWH}}}{g_{\mathrm{WWH}}} \to 0.85\%$$

possibility of testing Higgs potential using $H \dashrightarrow W_L W_L$





sensitive to Higgs potential

- select the Higgs to WW* events
- measure the polarization of each W, using the decay angular distribution
- estimate the fraction of both W are longitudinal

$$e^+ + e^- \to \nu\bar{\nu}H \to \nu\bar{\nu}(WW^*) \to \nu\bar{\nu} + 4\text{jets}$$

- study at 500 GeV, as part of the Higgs task group analyses (Higgs to WW* @ 250 GeV by Ono-san).
- only use the full hadronic mode ---> both the two W decay planes can be reconstructed
- full simulation based on LoI framework of ILD
- main background: vvZ, WW, vvWW, **vvH to other**

pre-selection:

- four jets, each at least 5 particles, totally at least 40 particles

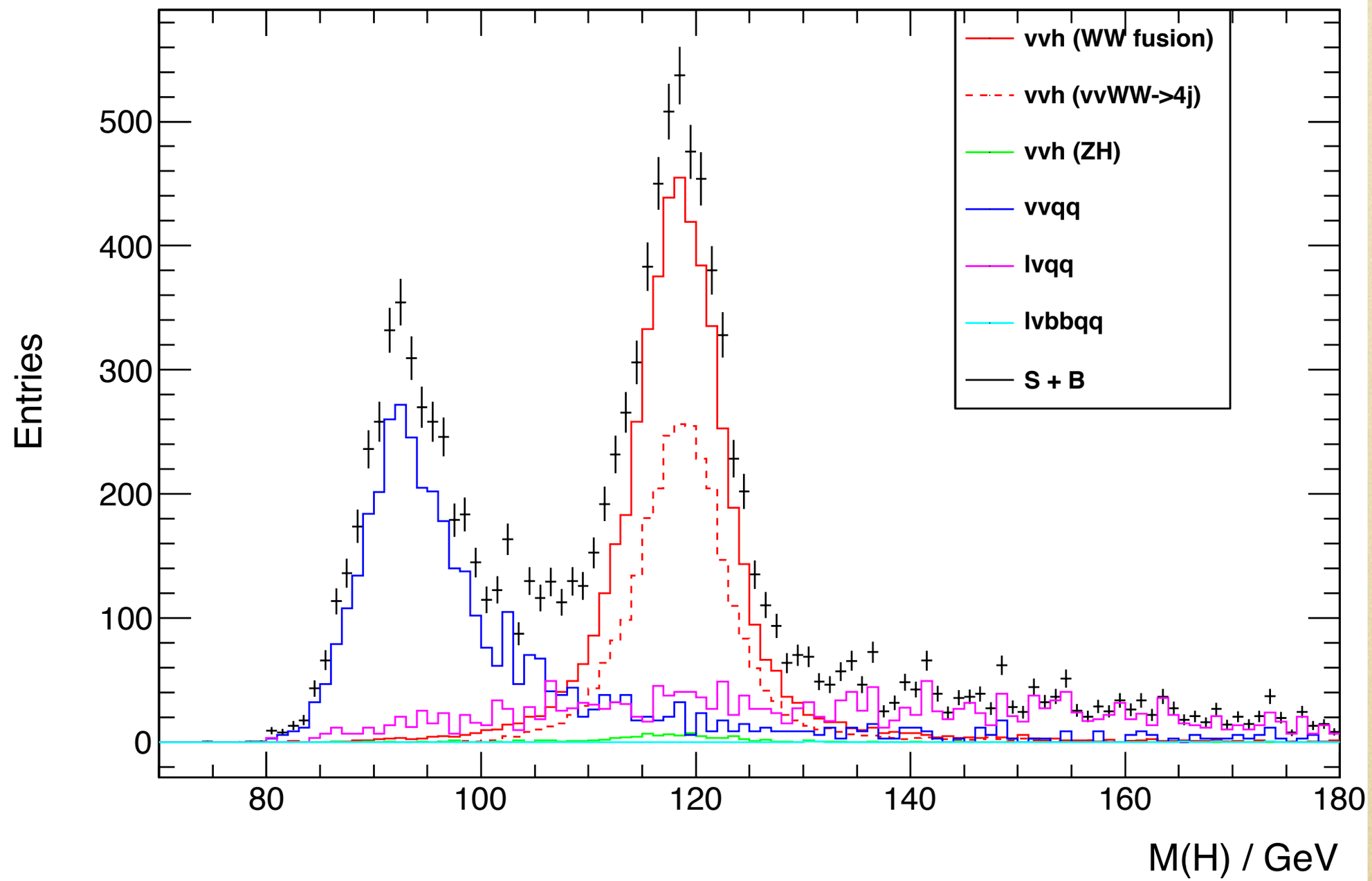
final-selection:

- Ycut > 0.002 (cut1)
- Visible energy: (120, 250) GeV, Pt > 20 GeV (cut2)
- Isolate lepton rejection: P(Lmax) < 2*Econe + 20 (cut3)
- b-jet rejection: Prob(Jet1) + 2Prob(Jet2) < 0.6 (cut4)
- Missing mass (Z rejection): > 220 GeV (cut5)
- 60 < M(W1) <90, 10 < M(W2) < 60 (cut6)
- Higgs mass: (98, 140) GeV (cut7)

Higgs Mass (after the preceding 6 cuts)

preliminary

$$e^+ + e^- \to \nu\bar{\nu}H \to \nu\bar{\nu}(WW^*) \to \nu\bar{\nu} + 4\text{jets}$$



signal and backgrounds (reduction table)

preliminary

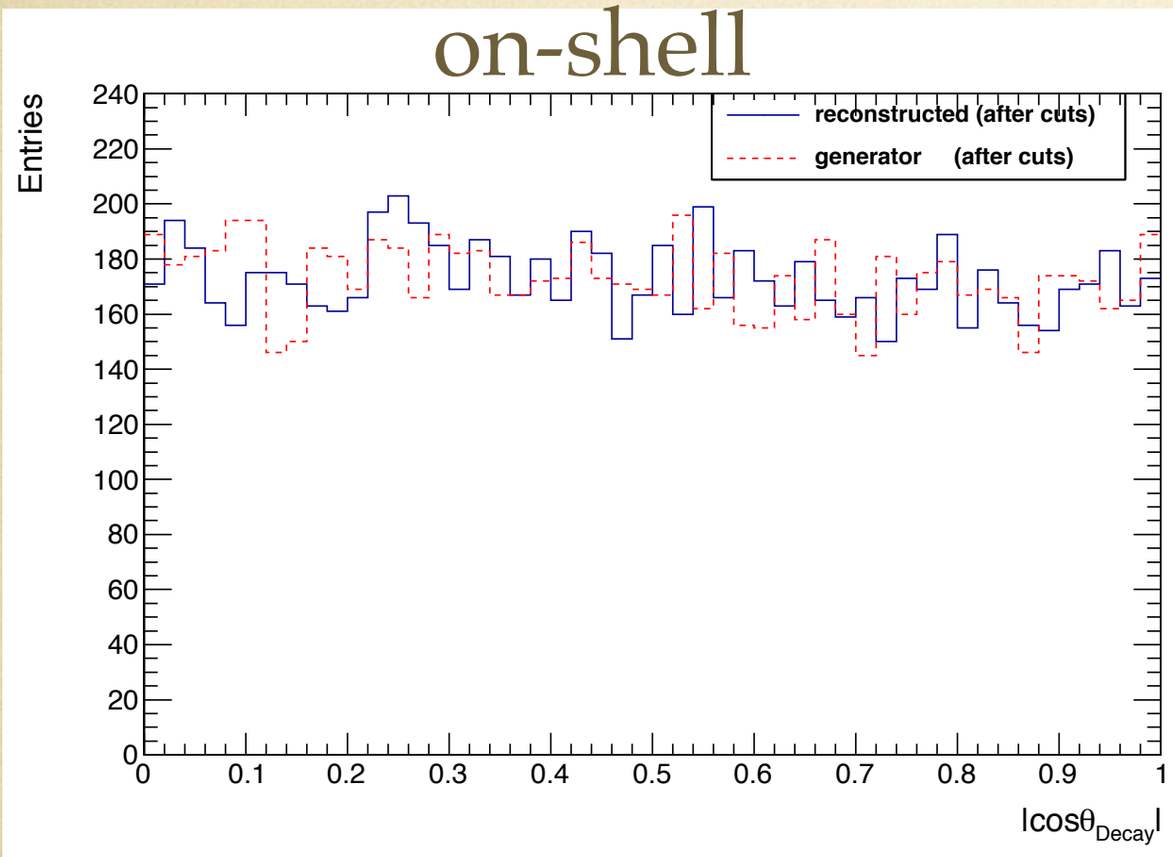
Polarization: (e-,e+)=(-0.8,+0.3) $E_{\rm cm} = 500{\rm GeV}, M_H = 120{\rm GeV}$ $\int {\rm L} = 500\ {\rm fb}^{-1}$

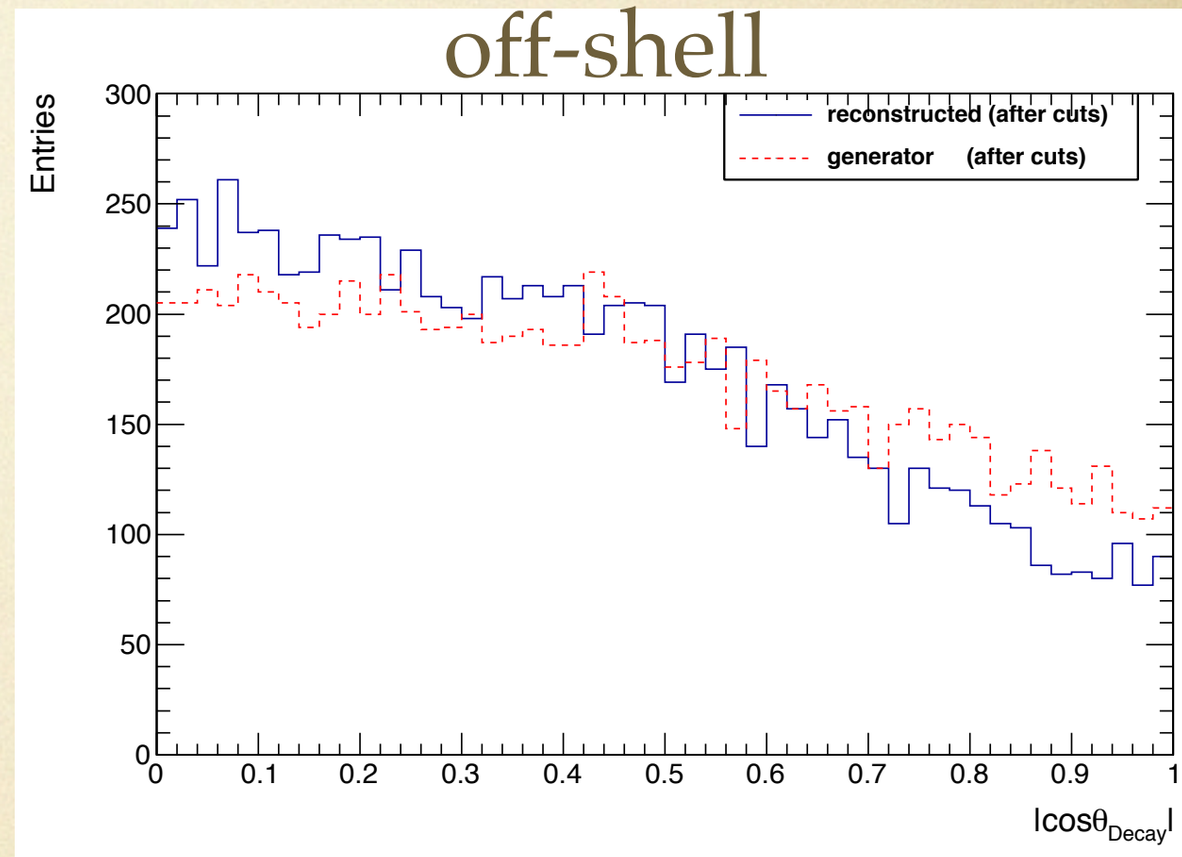
	Expected	pre-selction	cut1	cut2	cut3	cut4	cut5	cut6	cut7
vvh (vv4j)	5137	4609	3987	3624	3619	3131	2976	2755	2514
vvh (fusion)	7.98×10^4	51306	17258	14326	14207	5966	5664	4996	4442
vvh (ZH)	1.03×10^4	6098	1031	658	643	294	102	85.5	70.4
vvbb	7.77×10^4	46308	8569	3372	3348	218	198	65.8	13.2
vvcc	6.75×10^4	31311	5757	2630	2622	1943	1731	734	82.2
vvqq	2.22×10^5	90220	18494	9212	9188	8780	7840	3763	368
lvqq	5.18×10^6	676053	119963	15836	10727	8972	4420	2721	614
lvlvbb	4.58×10^4	7246	5996	1605	780	25.5	24.0	12.2	0.55
lvbbqq	2.06×10^5	140570	138560	512	420	21.8	17.5	4.66	0
BG	6.28×10^6	1020453	304903	33907	27775	20274	14348	7398	1149
significance	2.05	4.45	7.02	16.5	17.7	19.3	21.0	24.7	33.6

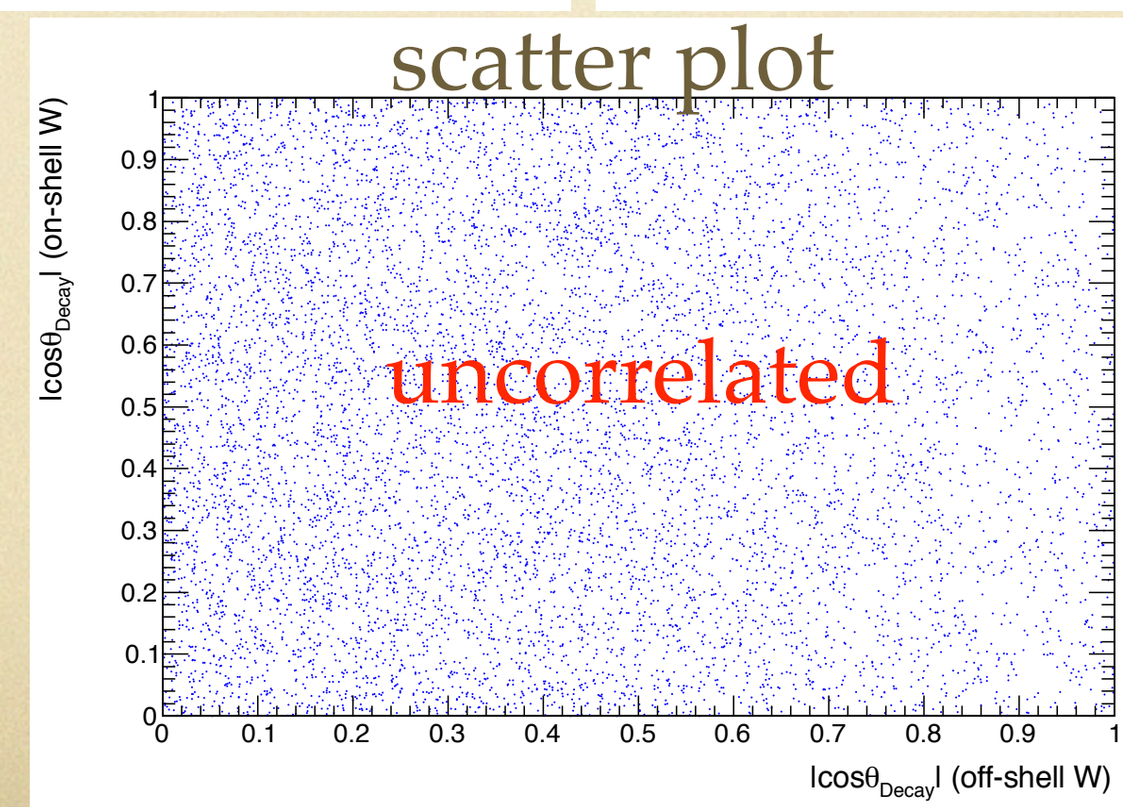
$$\frac{S}{\sqrt{S+B}} = \frac{2514}{\sqrt{4442+1149}} = 33.6 \qquad \frac{\delta(\sigma_0 \cdot {\rm Br}(H \to WW^*))}{\sigma_0 \cdot {\rm Br}} \approx 3.0\%$$

W decay angular distribution (after cuts)

(signal only)





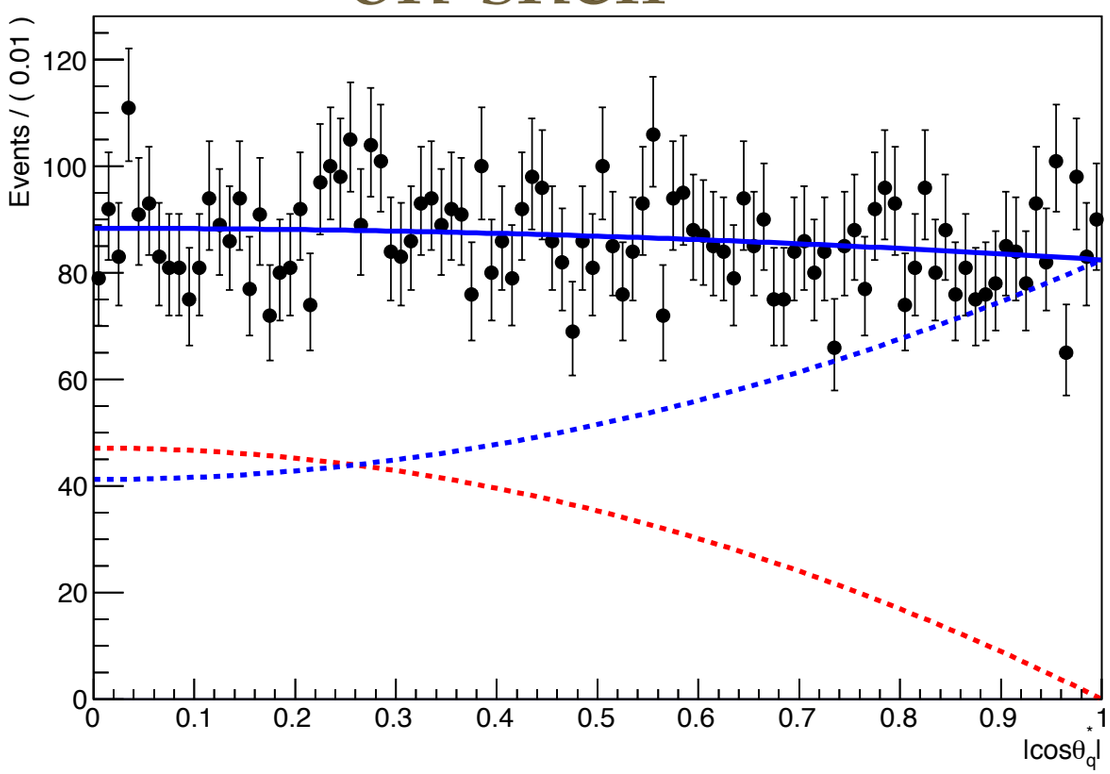


W decay angular distribution (fitting)

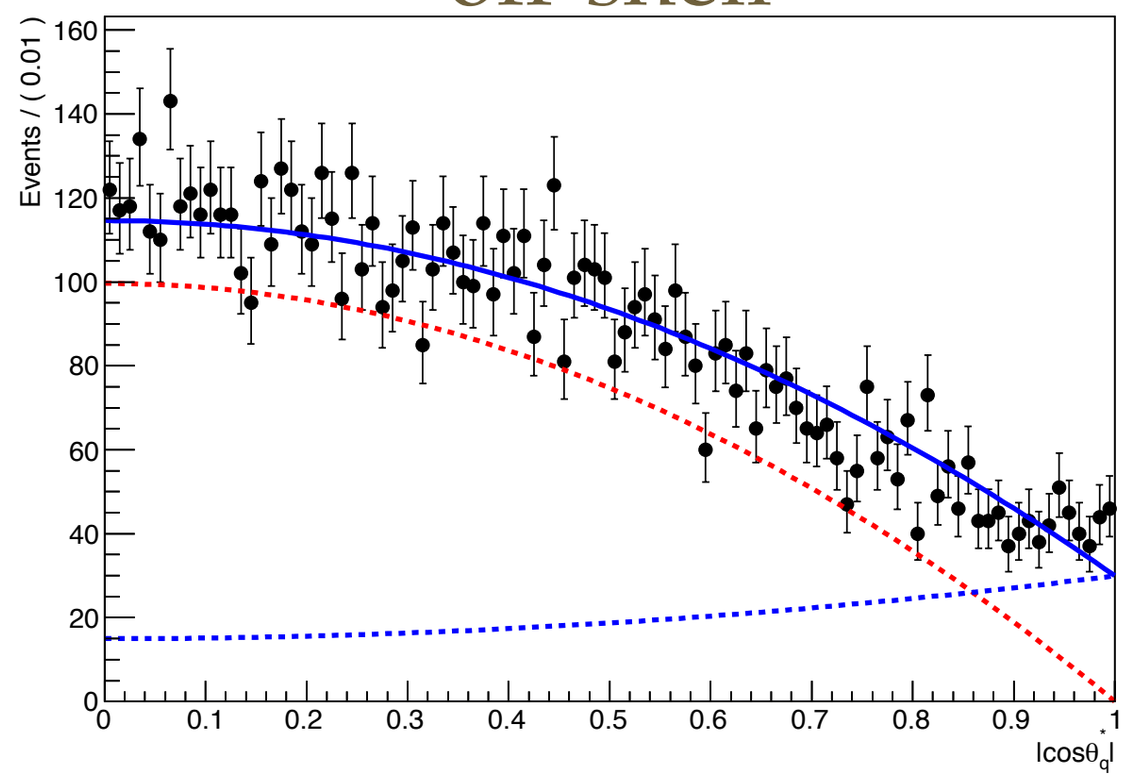
$$\frac{1}{N}\frac{dN}{d|\cos\theta_q^*|} = f_\pm \frac{3}{4}(1+|\cos\theta_q^*|^2) + f_0\frac{3}{2}(1-|\cos\theta_q^*|^2)$$

f+, f-, f0: fraction corresponding to the helicity +1, -1, 0

on-shell



off-shell



$$f_0 = 0.364 \pm 0.016$$

$$f_0 = 0.769 \pm 0.012$$

fraction of polarization

after selection

preliminary

fraction	W_TW_T	W_TW_L	W_LW_L
reconstructed	14.7%	57.0%	28.3%
generator	25.1%	52.9%	22.0%

$$\frac{N(H \to W_L W_L)}{\sqrt{S+B}} = \frac{2514 * 28.3\%}{\sqrt{4442+1149}} = 9.5$$

- detector resolution, **Y value cut** and **jet clustering** can affect the reconstructed fraction after selection

- for 500 fb^{-1} (2 ab^{-1}), we have about 1000 (4000) H--->W_LW_L events. These events could be used for Higgs potential study (ongoing).

summary (I)

- one analysis using WW fusion process vvH (H-->bb) @ 500 GeV is performed, the WWH coupling can be measured to 1.4%.
- still limited by the Higgs recoil mass measurement. analysis using ZH/eeH @ 500 GeV is ongoing to increase the ZZH coupling precision.
- using WWH coupling measurement and Higgs to WW branching ratio measurement, the total width of Higgs can be determined to the precision of 5%

summary (II)

- one analysis using WW fusion process vvH (H-->WW*-->4jets) @ 500 GeV is performed, precision of Higgs to WW* branching ratio can be measured to ~ 4%.

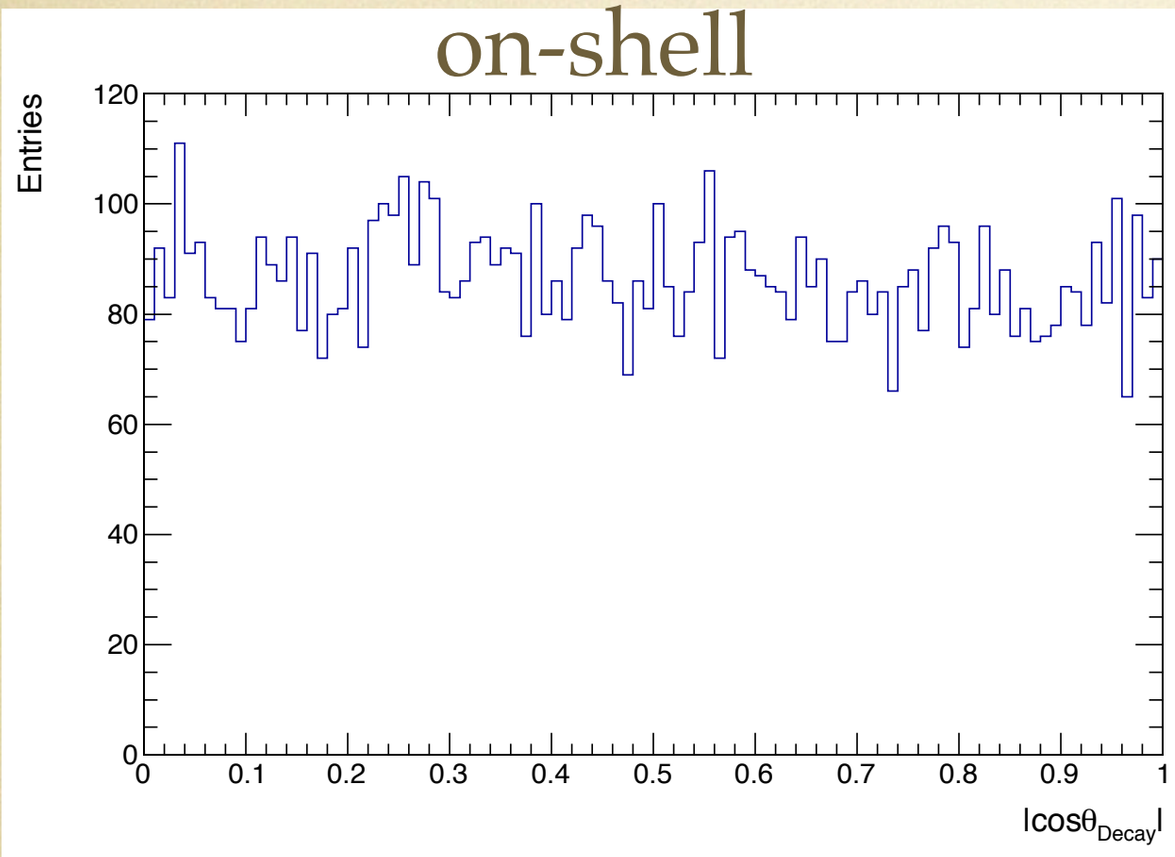
- using the hadronic decay of W, the measurement of polarization of W is possible. different polarization combinations are estimated according to the decay angular distribution. ~28.3% both longitudinal W bosons.

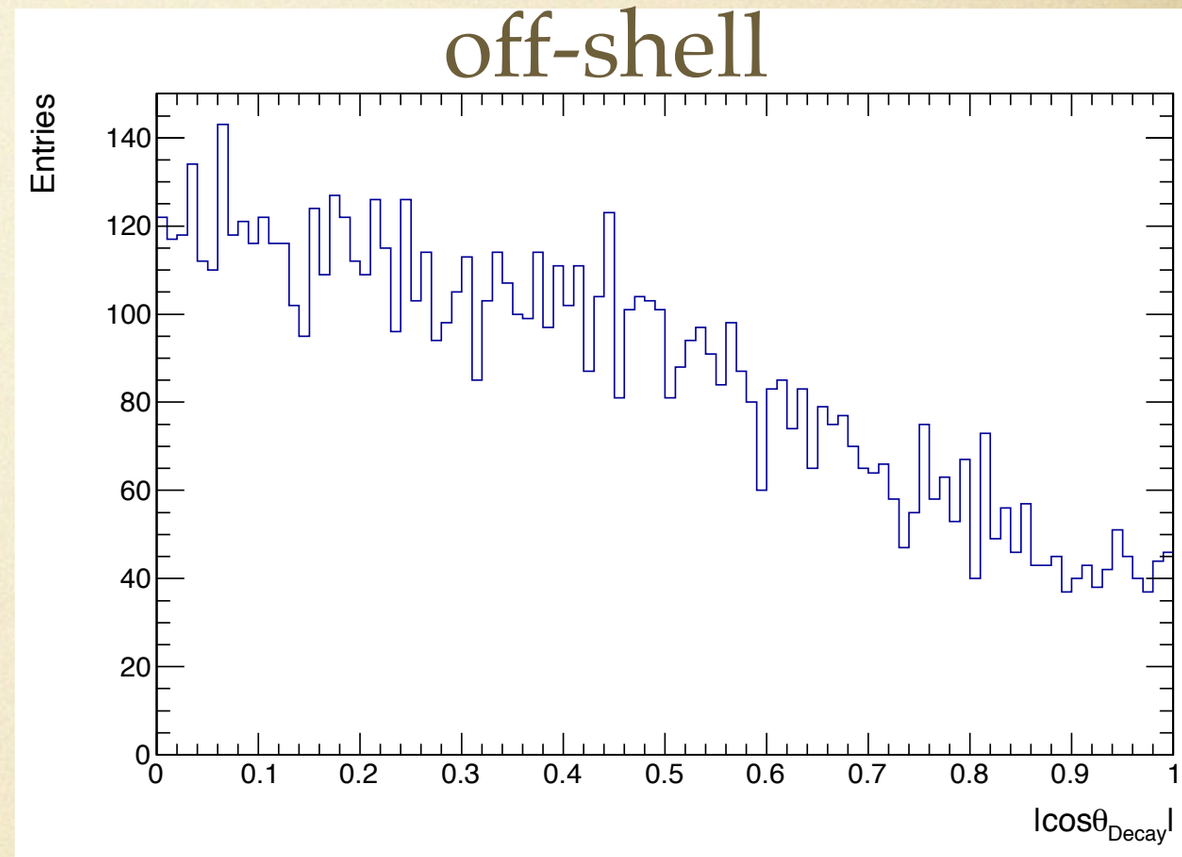
- H-->$W_L W_L$ is sensitive to Higgs potential, this analysis can select a quite large sample used to test the new physics effect.

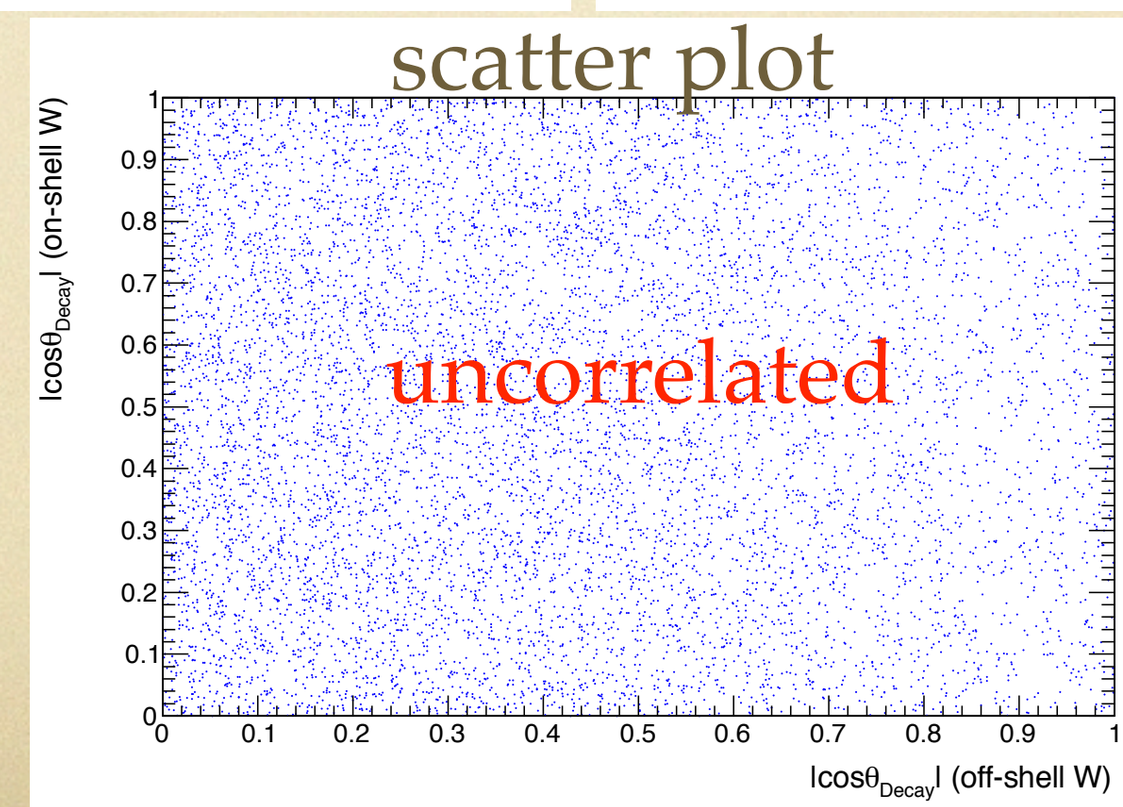
backup

W decay angular distribution (after cuts)

(signal only)

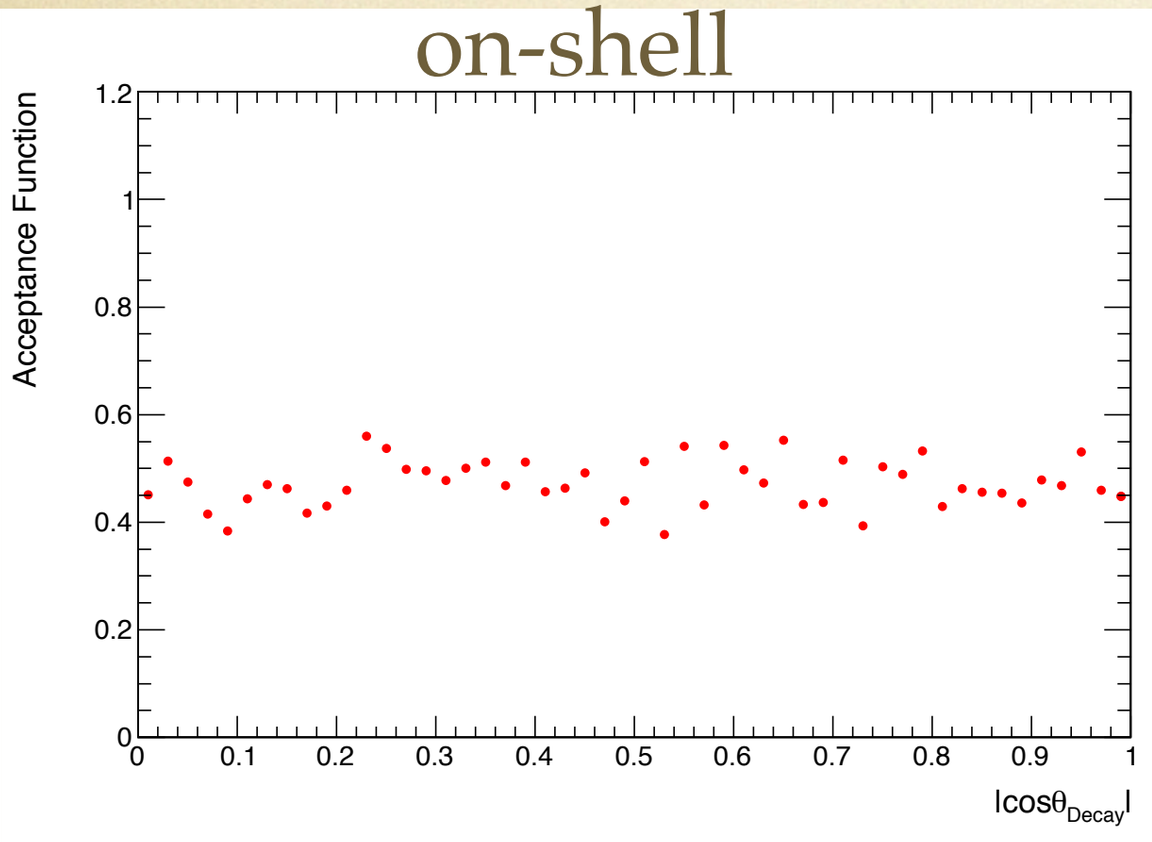


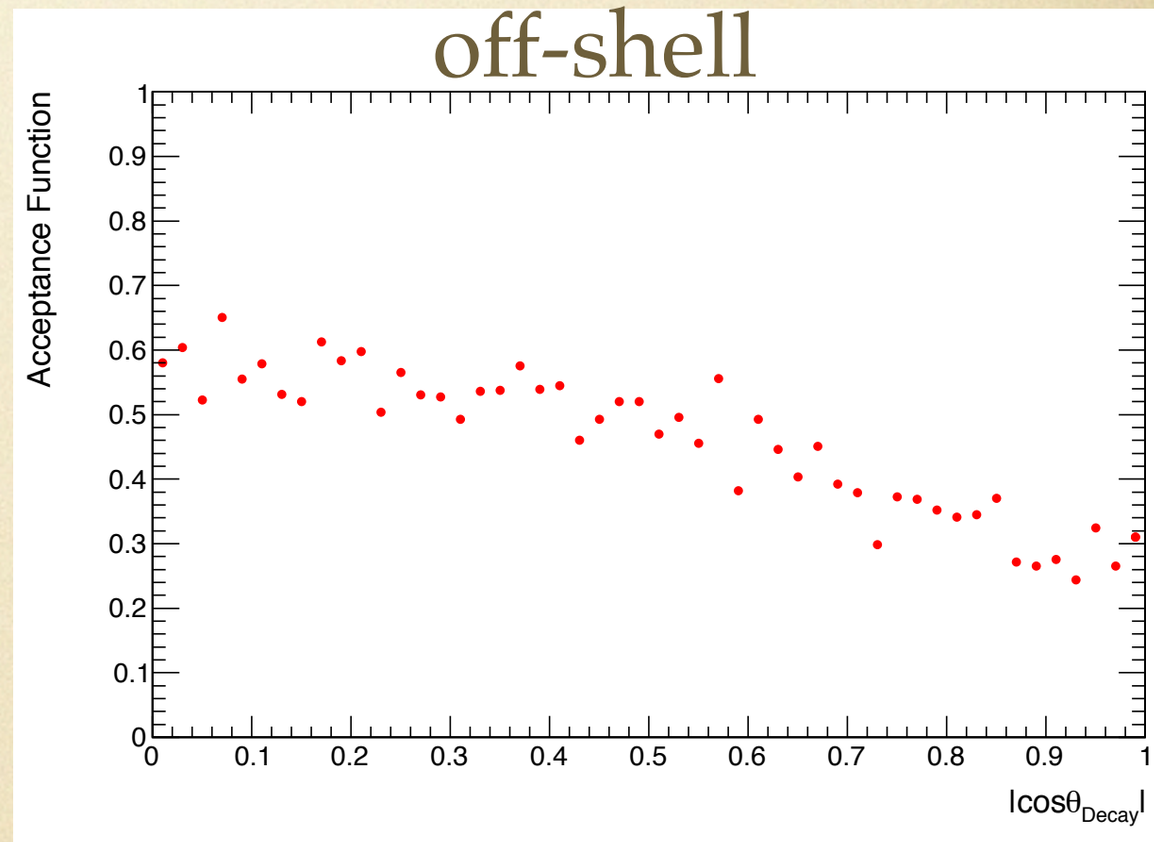




total acceptance function

$$\text{acceptance function} = \frac{\text{reconstructed after all cuts}}{\text{generated before any cuts}}$$





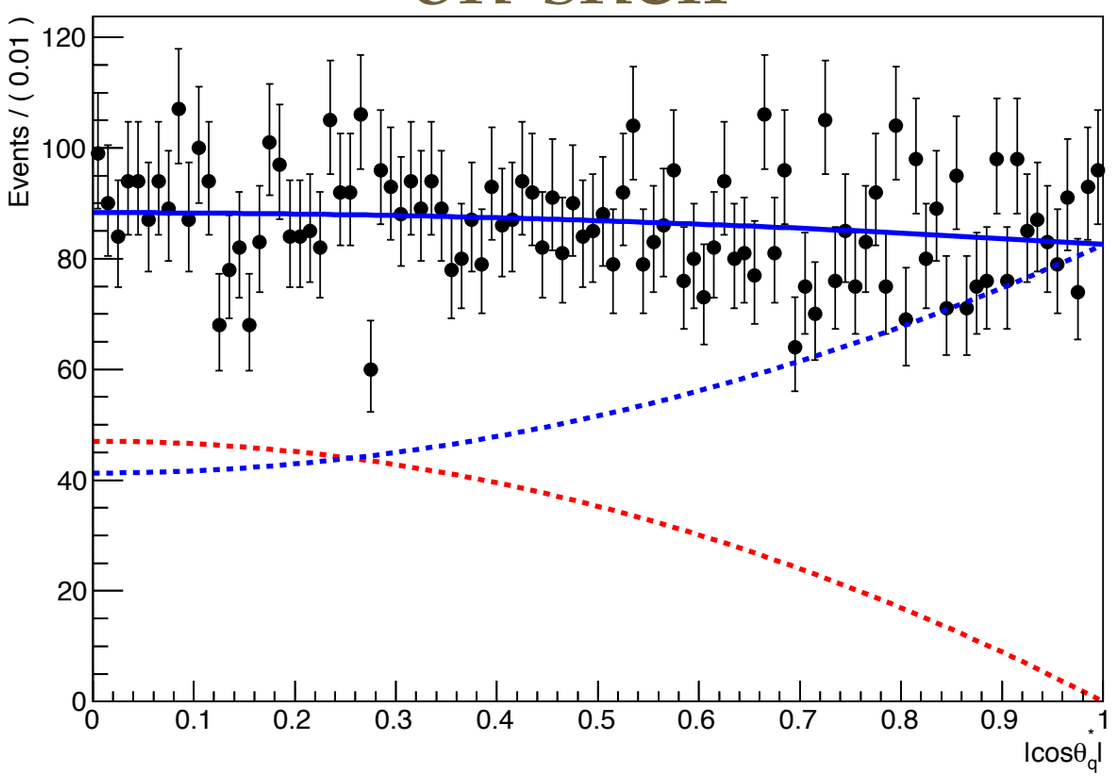
- detector resolution
- **Y value cut**
- **Jet clustering**

W decay angular distribution (fitting)

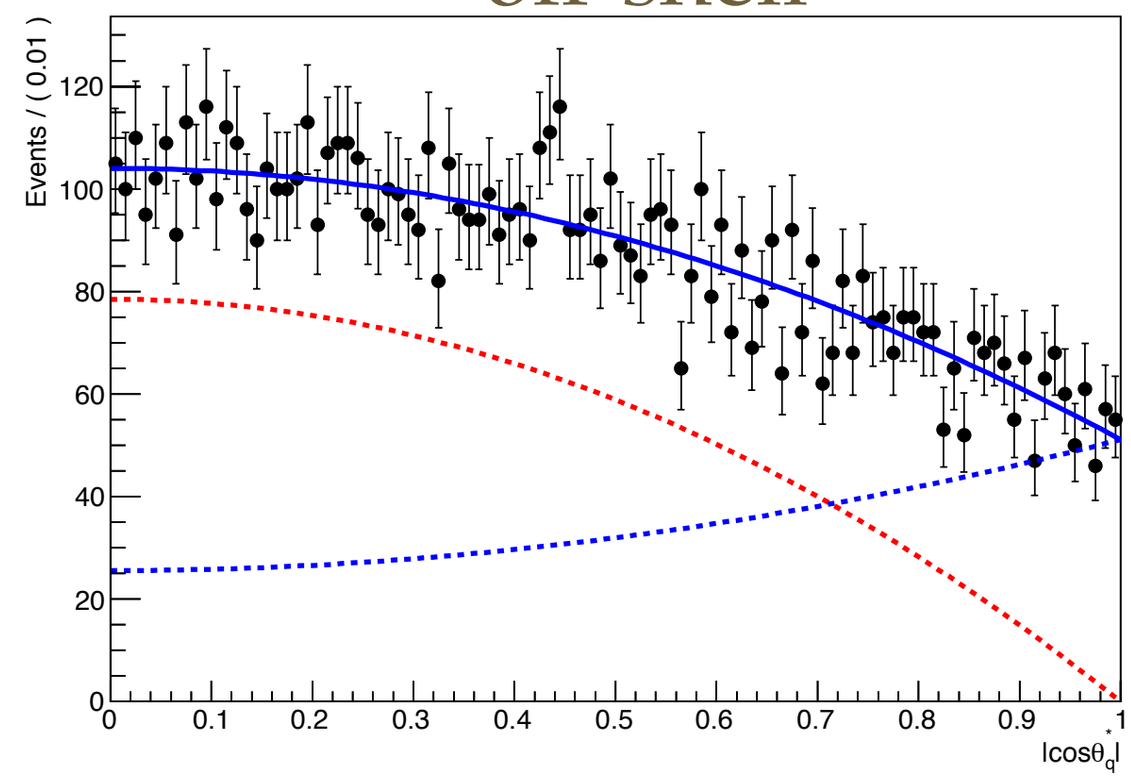
(generator information after cuts)

equivalently, same as the data corrected by the total acceptance function

on-shell



off-shell



$$f_0 = 0.363 \pm 0.016$$

$$f_0 = 0.606 \pm 0.014$$