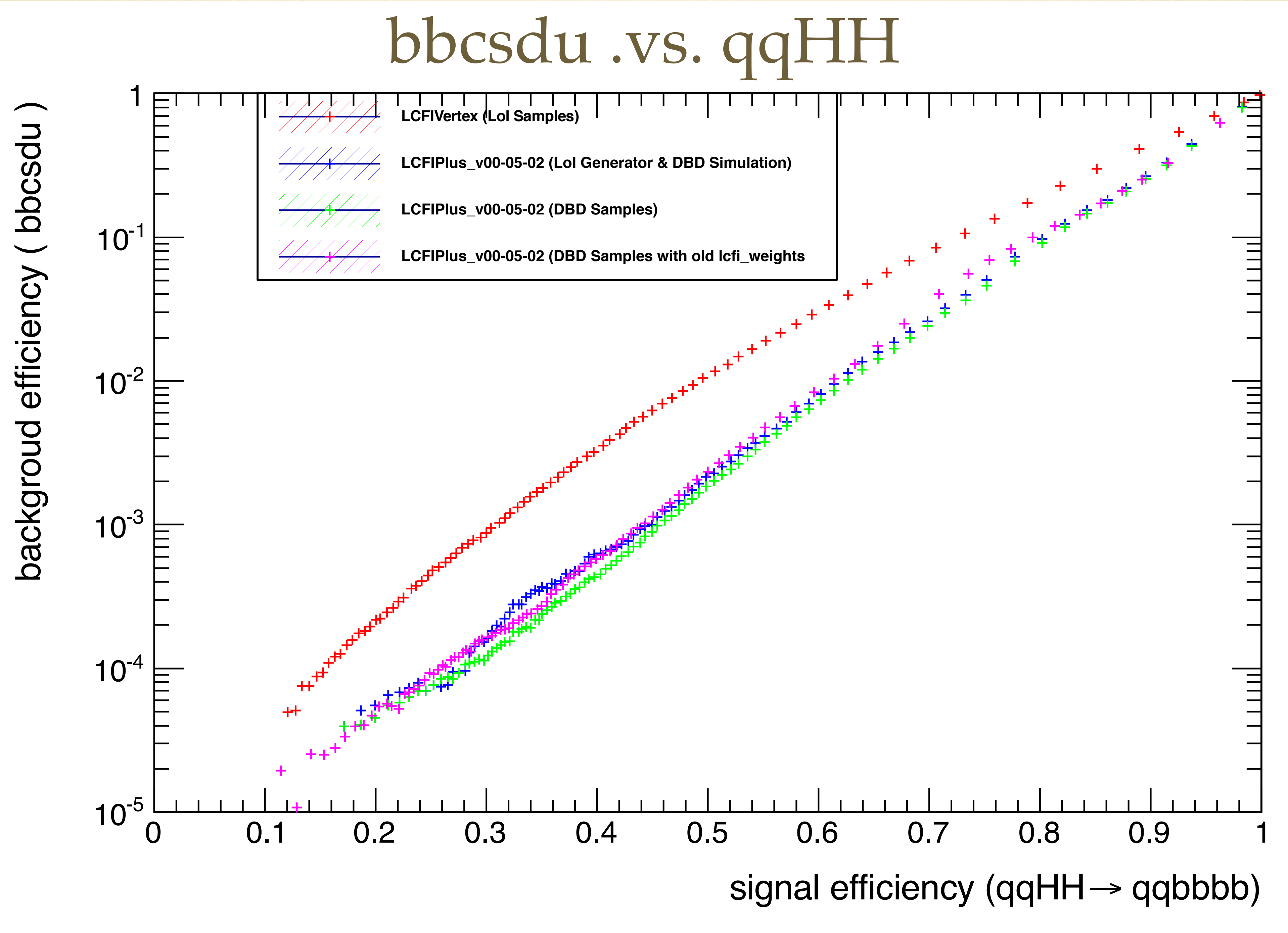
Status of Higgs self-coupling analysis

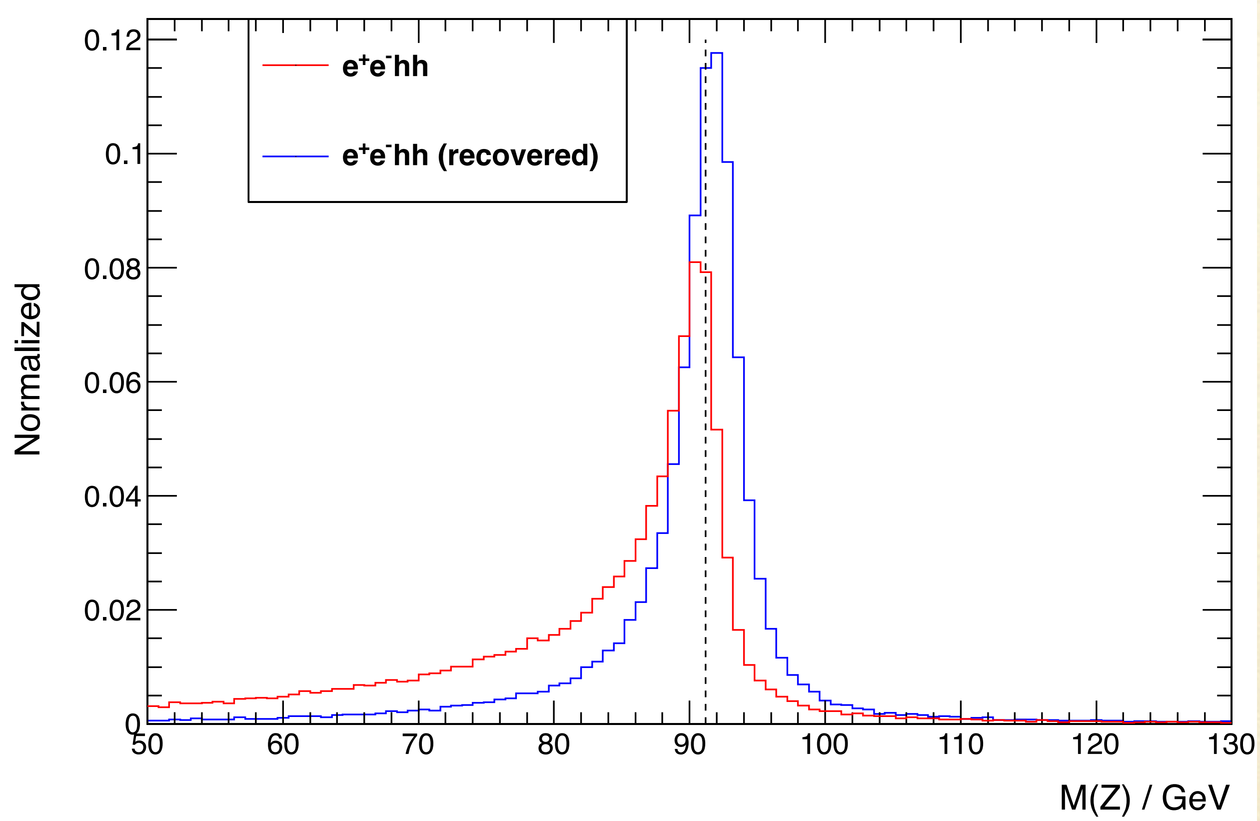
Junping Tian (KEK)

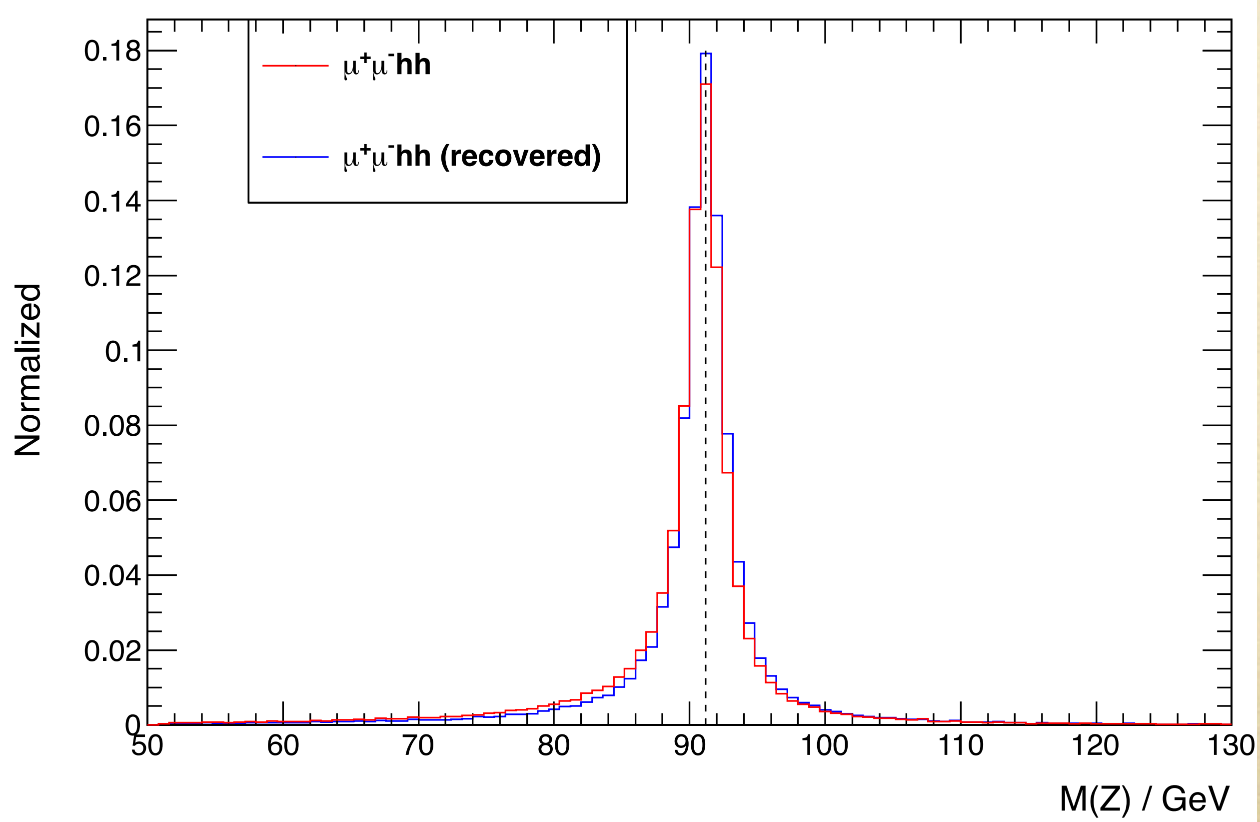
Nov. 16 @ Physics Meeting

flavor tagging performance in qqHH mode



Isolated lepton selection (llHH)





(Etot = Eecal + Ehcal)

	electron ID	muon ID
✦	Eecal / Etot > 0.9	Eyoke > 1.2
✦	0.5 < Etot / P < 1.3	Etot / P < 0.3
✦	from primary vertex	from primary vertex
✦	P > 12.2 + 0.87Econe	P > 12.6 + 4.62Econe

BS and FSR recovery adapted from ZFinder

efficiency of two isolated lepton selection
(much better for DBD)

Eff (%)	eeHH	μμHH	bbbb	eνbbqq	μνbbqq
DBD	85.7	88.4	0.028	1.44	0.10
LoI	81.9	85.4	0.43	2.71	1.94

$$e^+ + e^- \to ZHH \to (l\bar{l})(b\bar{b})(b\bar{b}) \to l\bar{l} + 4 \text{ bjets}$$

full simulation @ 500GeV

✦generator: Whizard 1.95
✦simulation: ilcsoft-v01-14-01
✦reconstruction: ilcsoft-v01-16
✦flavor tagging: LCFIPlus

pre-selection:

- two isolated-charged-leptons
- 4-jets clustering (LCFIPlus, Durham)
- combine the six jets by minimizing

$$\chi^2 = \frac{(M(b,\bar{b}) - M_H)^2}{\sigma^2_{H_1}} + \frac{(M(b,\bar{b}) - M_H)^2}{\sigma^2_{H_2}} + \frac{(M(l,\bar{l}) - M_Z)^2}{\sigma^2_Z}$$

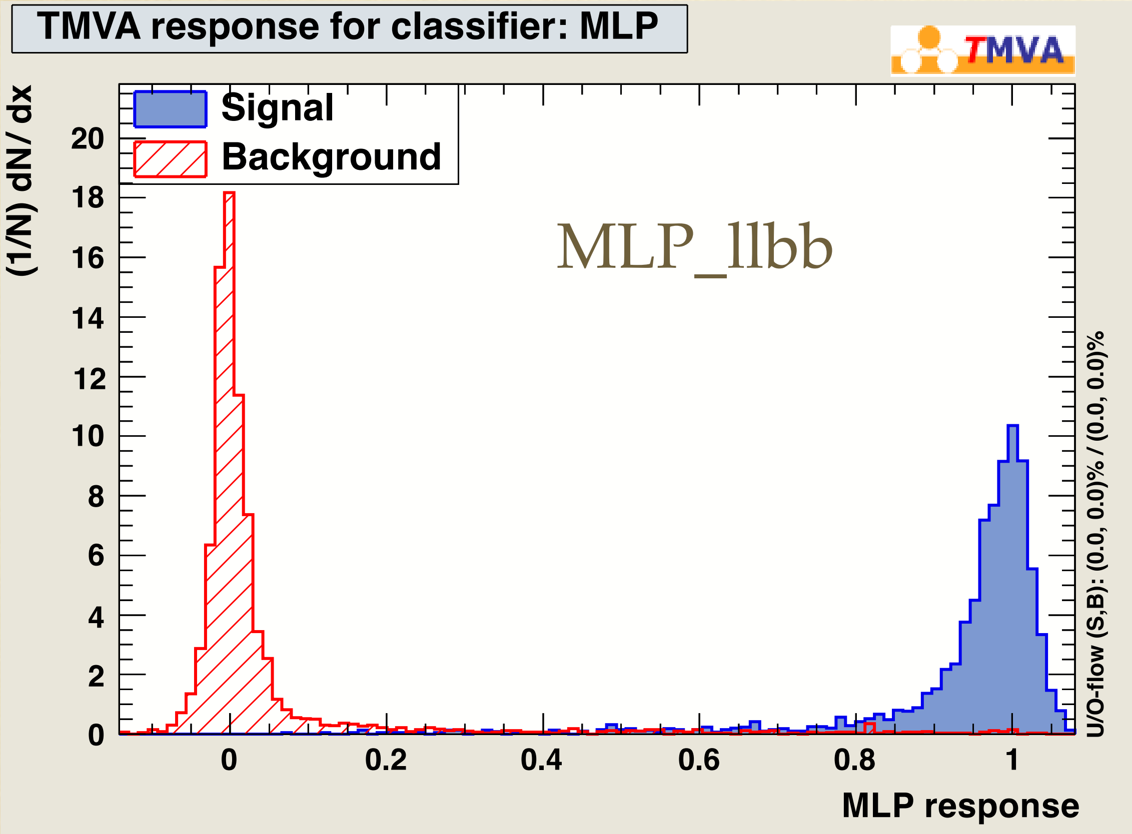
requirement implied in the pre-selection:

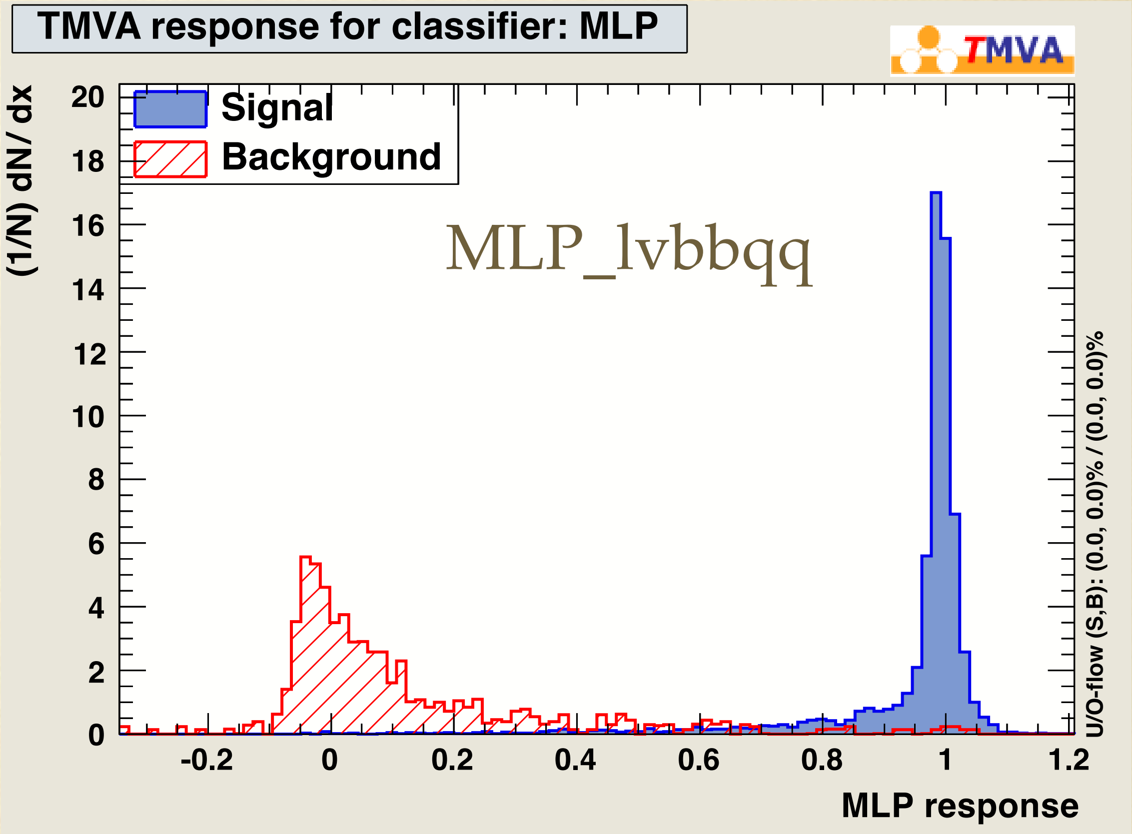
- |M(ll) - M(Z)| < 40 GeV

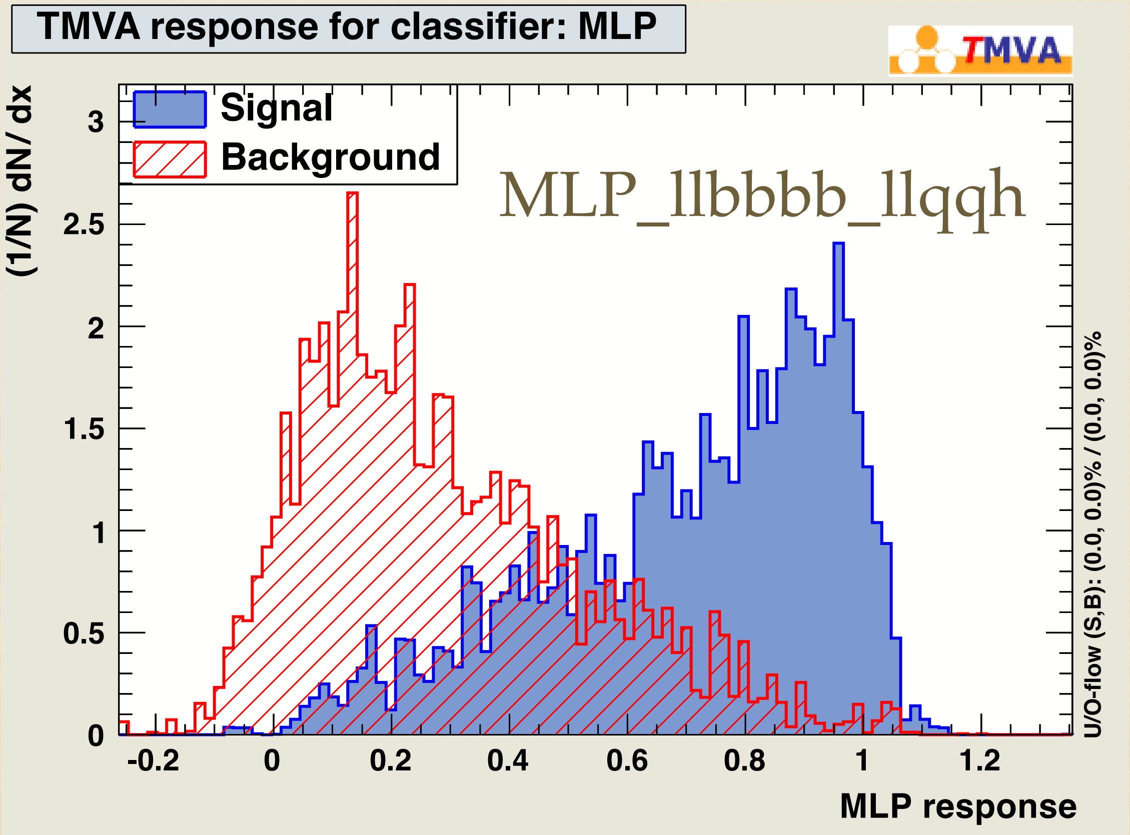
final selection:

- separate to two categories: electron-type and muon-type
- train the neural-nets, each event is also reconstructed as from ZZ, tt-bar, ZZZ and ZZH, and various variables are input to NN
- optimize cuts on NN-output and b-tagging

neural-net output (llHH)







preliminary

P(e-,e+)=(-0.8,+0.3)

reduction table

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

(muon-type)

$\int Ldt = 2{\rm ab}^{-1}$

normalized	expected	MC	pre-selection	ltype = 13	Econ12+4EconC12<60 PLep1+PLep2>80 |M(ll)-M(Z)|<27	MLP_llbb>0.53	MLP_lvbbqq>0.2	Bmax3>0.16	MLP_llbbbb >0.52
llhh(llbbbb)	46.5(19.3)	3.88×10^5	26.5(11.0)	13.3(5.53)	13.0(5.38)	10.6(5.24)	10.4(5.23)	5.76(4.79)	4.47(3.76)
eebb	2.84×10^5	4.18×10^6	3950	0	0	0	0	0	0
μμbb	4.96×10^4	1.00×10^6	1944	1943	1750	73.3	72.8	7.28	2.33
eνbbqq	2.48×10^5	1.51×10^6	2437	0	0	0	0	0	0
μνbbqq	2.46×10^5	1.48×10^6	239	215	95.7	65.7	33.3	2.78	0
τνbbqq	2.46×10^5	1.35×10^6	156	7.76	2.62	1.82	0.80	0	0
bbqqqq	6.24×10^5	3.90×10^6	107	1.09	0	0	0	0	0
bbbb	4.02×10^4	1.02×10^6	5.84	0.08	0	0	0	0	0
llbbbb(ZZZ)	69.5	1.06×10^5	15.0	7.57	7.10	5.92	5.90	5.38	1.29
llqqh(ZZH)	157	6.30×10^4	138	69.7	68.4	54.3	54.0	12.8	2.36
BG	1.74×10^6	1.46×10^7	8992	2244	1924	201	167	28.2	5.97

muon-type: nS = 4.5, nB = 6.0 ~ 1.2σ

preliminary

P(e-,e+)=(-0.8,+0.3)

reduction table

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

(electron-type)

$\int Ldt = 2{\rm ab}^{-1}$

normalized	expected	MC	pre-selection	ltype = 11	Econ12+4EconC12<90 $\vert M(ll)-M(Z)\vert<32$	MLP_llbb>0.56	MLP_lvbbqq>0.81	Bmax3>0.19	MLP_llbbbb >0.5
llhh(llbbbb)	46.5(19.3)	3.88×10^5	26.5(11.0)	13.1(5.50)	12.3(5.18)	10.1(5.02)	8.60(4.57)	4.64(4.08)	3.73(3.30)
eebb	2.84×10^5	4.18×10^6	3950	3950	2762	75.4	57.8	3.88	0.81
μμbb	4.96×10^4	1.00×10^6	1944	0.74	0.10	0	0	0	0
eνbbqq	2.48×10^5	1.51×10^6	2437	2437	928	675	25.7	1.93	0.46
μνbbqq	2.46×10^5	1.48×10^6	239	24.5	0.52	0.36	0	0	0
τνbbqq	2.46×10^5	1.35×10^6	156	148	38.6	30.3	1.50	0.25	0
bbqqqq	6.24×10^5	3.90×10^6	107	106	3.93	3.93	1.04	0.16	0.16
bbbb	4.02×10^4	1.02×10^6	5.84	5.76	0.10	0	0	0	0
llbbbb(ZZZ)	69.5	1.06×10^5	15.0	7.42	6.69	5.44	4.68	4.18	0.97
llqqh(ZZH)	157	6.30×10^4	138	68.1	65.0	51.1	46.9	9.92	1.93
BG	1.74×10^6	1.46×10^7	8992	6748	3806	842	138	20.3	4.32

electron-type: nS = 3.7, nB = 4.3 $\sim 1.1\sigma$

Status of DBD analysis

preliminary

P(e-,e+)=(-0.8,0.3) $e^+ + e^- \rightarrow ZHH$ $M(H) = 120\text{GeV}$ $\int Ldt = 2\text{ab}^{-1}$

Energy (GeV)	Modes	signal	background	significance	
				excess (I)	measurement (II)
500	$ZHH \rightarrow (l\bar{l})(b\bar{b})(b\bar{b})$	3.7	4.3	1.5σ	1.1σ
		4.5	6.0	1.5σ	1.2σ
500	$ZHH \rightarrow (\nu\bar{\nu})(b\bar{b})(b\bar{b})$	-	-	-	-
500	$ZHH \rightarrow (q\bar{q})(b\bar{b})(b\bar{b})$	12.4	11.0	3.1σ	2.7σ
		21.4	89.9	2.2σ	2.0σ

- qqHH mode only, significance is already as same as using all modes in LoI
- llHH mode into two categories is helpful
- vvHH still ongoing
- samples @ 500 GeV are more or less ready

samples request for vvHH @ 1TeV

(http://www-jlc.kek.jp/jlc/sites/default/files/users/tianjp/samples_1TeV.list)

id	name	type	ecm	P1	P2	Lumi(existed)	x-sec	Nrequest
35815	6f_yyxylv	6f_ttbar	1000.0	L	R	1000.0	116.427	700000
35816	6f_yyxylv	6f_ttbar	1000.0	R	L	999.998	37.3211	60000
35807	6f_yyvlyx	6f_ttbar	1000.0	L	R	1000.0	115.979	700000
35808	6f_yyvlyx	6f_ttbar	1000.0	R	L	999.987	37.3065	60000
35811	6f_yyxyev	6f_ttbar	1000.0	L	R	999.997	68.5022	400000
35812	6f_yyxyev	6f_ttbar	1000.0	R	L	999.986	18.6593	40000
35795	6f_yyveyx	6f_ttbar	1000.0	L	R	999.995	67.5343	400000
35796	6f_yyveyx	6f_ttbar	1000.0	R	L	999.982	18.6453	40000
35819	6f_yyuyyu	6f_ttbar	1000.0	L	R	1000.0	84.596	500000
35820	6f_yyuyyu	6f_ttbar	1000.0	R	L	999.983	27.5005	40000
35823	6f_yyuyyc	6f_ttbar	1000.0	L	R	1000.0	84.5818	500000
35824	6f_yyuyyc	6f_ttbar	1000.0	R	L	1000.02	27.5085	40000
35827	6f_yycyyu	6f_ttbar	1000.0	L	R	999.995	84.4265	500000
35828	6f_yycyyu	6f_ttbar	1000.0	R	L	1000.0	27.484	40000
35831	6f_yycyyc	6f_ttbar	1000.0	L	R	1000.0	84.9759	500000
35832	6f_yycyyc	6f_ttbar	1000.0	R	L	1000.01	27.5846	40000

~4.5M

DESY group will help generate the tt-bar type background.

I will generate signal and ZZZ/ZZH background.

backup

analysis strategy and status

$e^+ + e^- \rightarrow ZHH$ @ $500\ GeV$

main backgrounds in each mode:

- llHH: llbb (ZZ, γZ, bbZ), lνbbqq (tt-bar), llbbbb (ZZZ/ZZH) preliminary
- ννHH: bbbb (ZZ, γZ, bbZ), τνbbqq (tt-bar), ννbbbb (ZZZ/ZZH) ongoing
- qqHH: bbbb (ZZ, γZ, bbZ), bbqqqq (tt-bar), qqbbbb (ZZZ/ZZH) preliminary

after isolated-lepton selection (or rejection) and jet-clustering, a neural-net is trained for each dominant background process (in total 9)

to make the result stable, high statistics is necessary

main improvements to the LoI analysis:

- better flavor tagging (tracking, PFA, LCFIPlus, B-baryon fixed)
- better lepton selection (muon detector, vertex constrained, bremsstrahlung and FSR recovered)

$$e^+ + e^- \to ZHH \to (q\bar{q})(b\bar{b})(b\bar{b}) \to q\bar{q} + 4 \text{ bjets}$$

full simulation @ 500GeV

pre-selection:

✦generator: Whizard 1.95
✦simulation: ilcsoft-v01-14-01
✦reconstruction: ilcsoft-v01-16
✦flavor tagging: LCFIPlus

- isolated-charged-leptons rejected
- 6-jets clustering (LCFIPlus, Durham)
- combine the six jets by minimizing, and require the b tagging

$$\chi^2 = \frac{(M(b,\bar{b}) - M_H)^2}{\sigma^2_{H_1}} + \frac{(M(b,\bar{b}) - M_H)^2}{\sigma^2_{H_2}} + \frac{(M(q,\bar{q}) - M_Z)^2}{\sigma^2_Z}$$

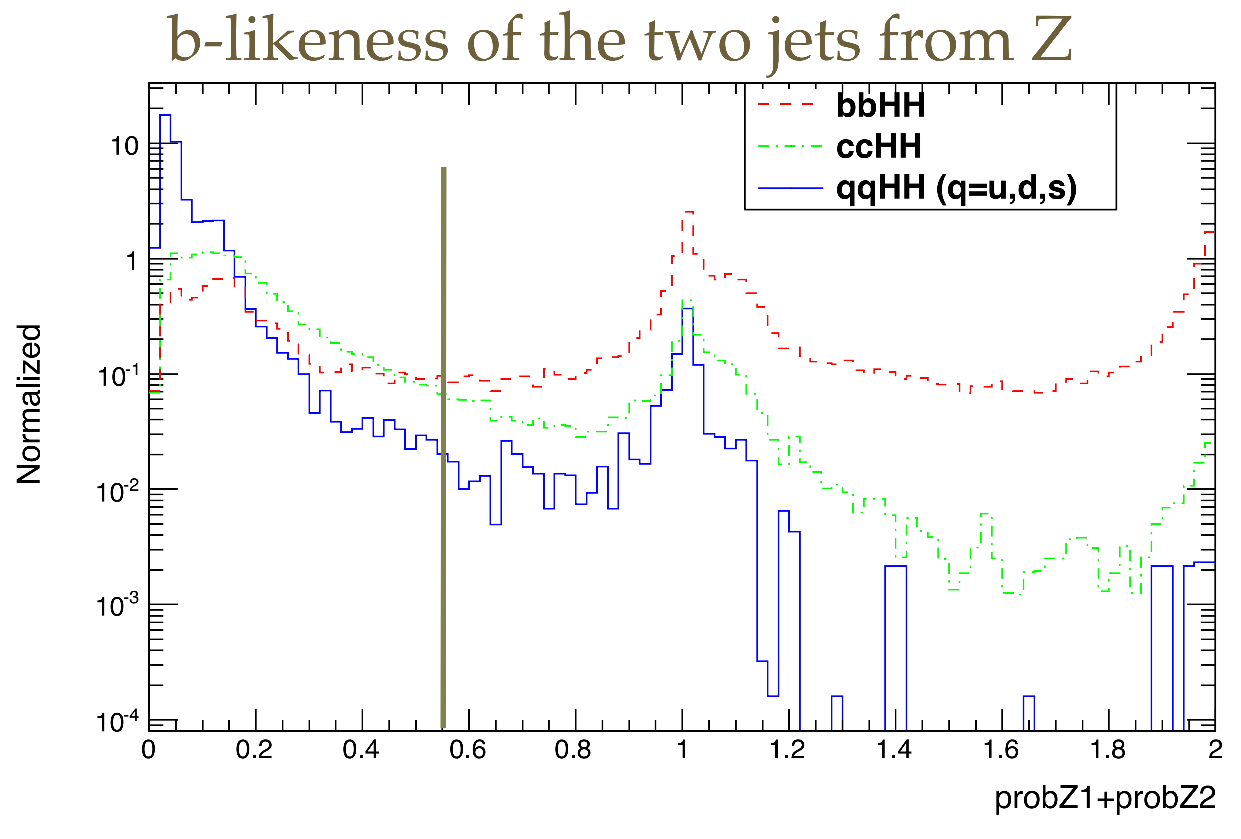
requirement implied in the pre-selection:

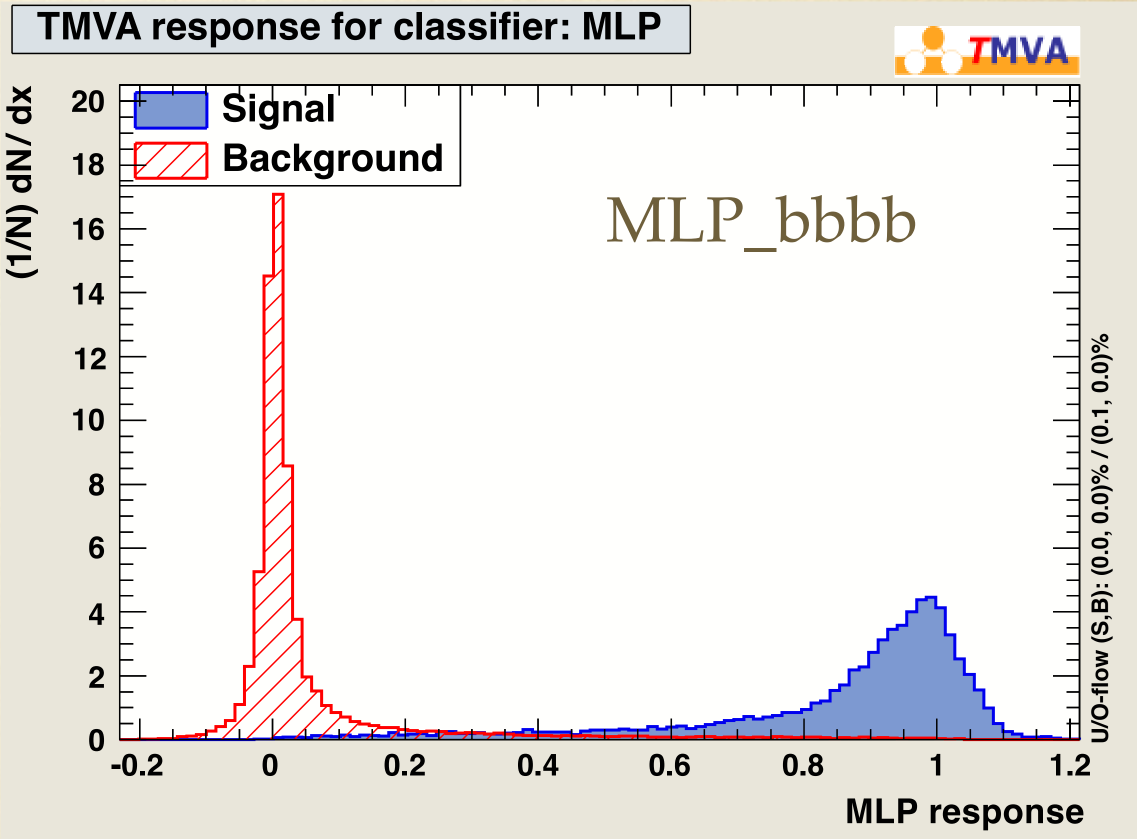
- b-tagged four jets from two Higgs (b-likeness > 0.16)

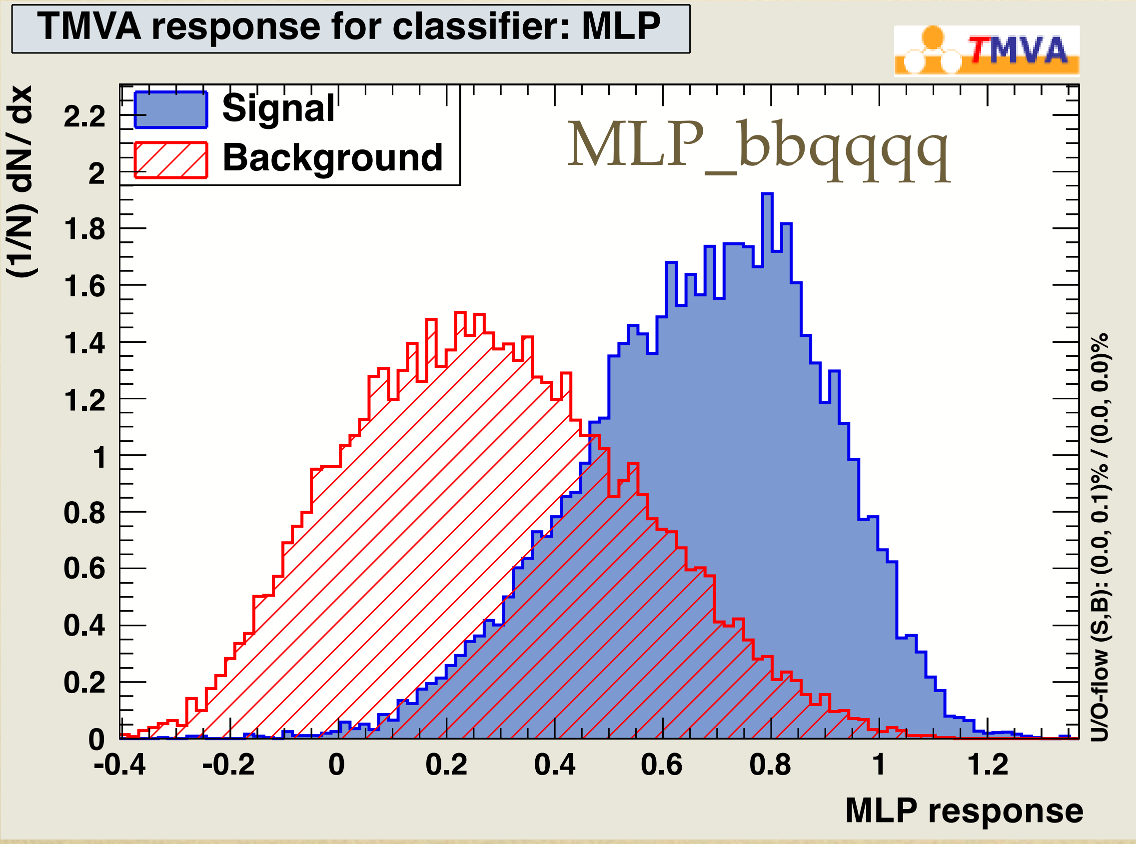
final selection:

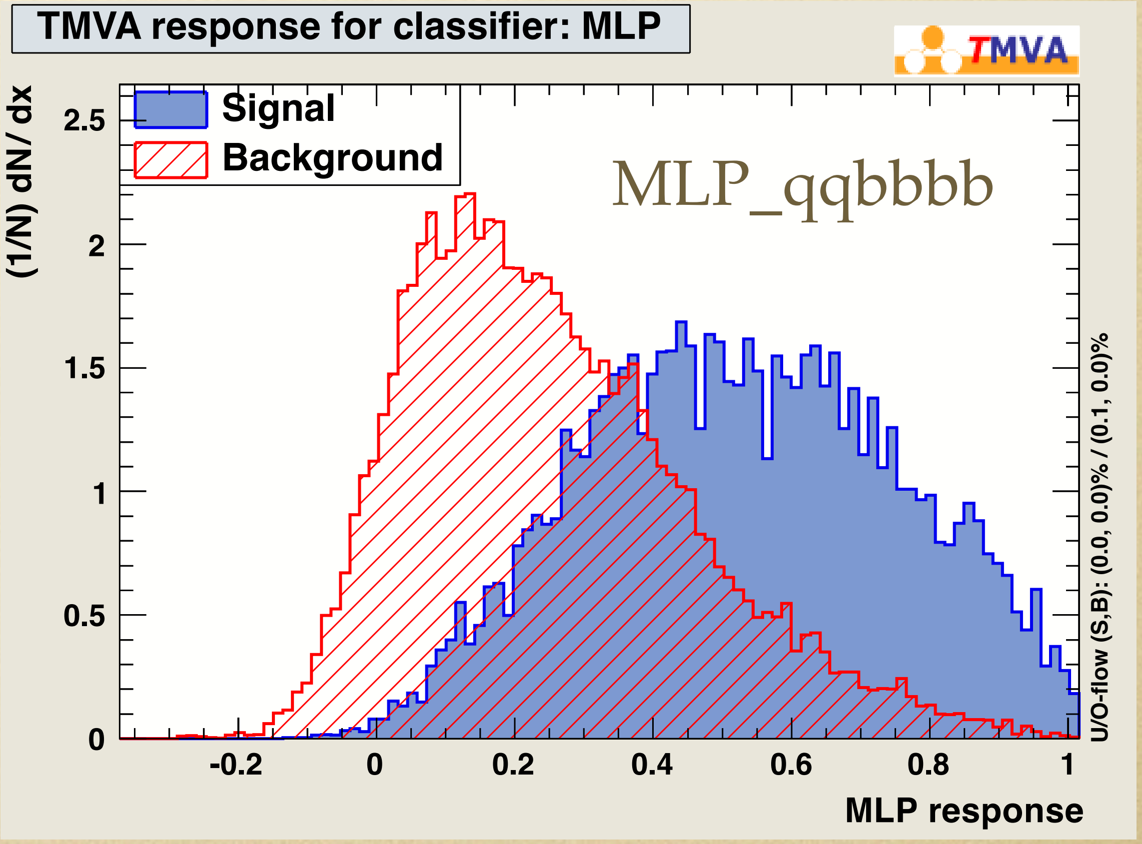
- separate to two categories: bbHH dominant and light qqHH dominant
- train the neural-nets, each event is also reconstructed as from ZZ, tt-bar, ZZZ and ZZH, and various variables are input to NN
- optimize the cuts on NN-output and tighter b-tagging

some distributions (qqHH)









preliminary

reduction table

(probZ1+probZ2 > 0.56)

P(e-,e+)=(-0.8,+0.3)

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

$\int Ldt = 2\mathrm{ab}^{-1}$

normalized	expected	MC	pre-selection	probZ1+probZ2>0.56	MissPt < 60	MLP_bbbb>0.74	MLP_bbqqqq>0.34	MLP_qqbbbb>0.0	Bmax3>0.82 Bmax4>0.21
qqhh(qqbbbb)	310(129)	3.73×10^5	111(85.3)	26.7(23.0)	25.9(22.8)	20.6(18.8)	20.1(18.4)	20.0(18.3)	12.4(11.8)
bbbb	4.02×10^4	7.19×10^5	22889	2289	2253	9.04	8.06	7.94	3.32
lvbbqq	7.40×10^5	3.56×10^6	17240	357	172	8.47	6.69	6.69	0.03
qqbbbb	140	3.03×10^4	82.3	13.6	13.5	7.43	6.96	3.94	2.36
bbuddu	1.56×10^5	8.87×10^5	565	11.2	11.2	8.82	6.73	6.73	0.73
bbcsdu	3.12×10^5	1.26×10^6	6109	86.8	86.4	61.6	44.6	44.1	2.41
bbcssc	1.56×10^5	1.17×10^6	12456	256	254	177	126	125	4.71
qqqqH(ZZH)	381	not available yet							
ttqq	2169	not available yet							
BG			59342	3013	2790	273	199	197	11.0

bbHH dominant: nS = 12.4, nB = 11.0 ~ 2.7σ

samples of ZZH and ttqq are already available, to be added soon

preliminary

P(e-,e+)=(-0.8,+0.3)

reduction table

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

(probZ1+probZ2 < 0.56)

$\int Ldt = 2\text{ab}^{-1}$

normalized	expected	MC	pre-selection	probZ1+probZ2<0.56	MissPt < 60	MLP_bbbb>0.63	MLP_bbqqqq>0.55	MLP_qqbbbb>0.15	Bmax3>0.85 Bmax4>0.43
qqhh(qqbbbb)	310(129)	3.73×10^5	111(85.3)	84.3(62.3)	80.9(61.8)	66.9(53.5)	45.9(37.7)	44.5(36.6)	21.4(18.6)
bbbb	4.02×10^4	7.19×10^5	22889	20600	20282	152	62.9	53.5	25.6
lvbbqq	7.40×10^5	3.56×10^6	17240	16884	7937	536	115	105	1.36
qqbbbb	140	3.03×10^4	82.3	68.7	68.3	42.5	20.7	14.9	7.03
bbuddu	1.56×10^5	8.87×10^5	565	554	550	434	105	99.2	11.3
bbcsdu	3.12×10^5	1.26×10^6	6109	6022	5987	4559	977	917	25.4
bbcssc	1.56×10^5	1.17×10^6	12456	12200	12115	9181	1655	1556	19.2
qqqqH(ZZH)	381	not available yet							
ttqq	2169	not available yet							
BG			59342	56329	46939	14906	2936	2745	89.9

light qqHH dominant: nS = 21.4, nB = 89.9 ~ 2.0σ

result of LoI analysis

@ALCPG11

- focus on the ZHH @ 500 GeV, M(H) = 120 GeV.
- three decay modes of ZHH (Z-->ll, vv, qq, H-->bb) are investigated, based on ILD full simulation.
- neural-net methods are used to improve the background suppression.
- effects of different beam polarizations are checked.

P(e-,e+)=(-0.8,0.3)

$$e^+ + e^- \rightarrow ZHH$$

$M(H) = 120\text{GeV}$ $\int Ldt = 2\text{ab}^{-1}$

Energy (GeV)	Modes	signal	background	significance	
				excess (I)	measurement (II)
500	$ZHH \rightarrow (l\bar{l})(b\bar{b})(b\bar{b})$	6.4	6.7	2.1σ	1.7σ
500	$ZHH \rightarrow (\nu\bar{\nu})(b\bar{b})(b\bar{b})$	5.2	7.0	1.7σ	1.4σ
500	$ZHH \rightarrow (q\bar{q})(b\bar{b})(b\bar{b})$	8.5	11.7	2.2σ	1.9σ
		16.6	129	1.4σ	1.3σ

$$\sigma_{ZHH} = 0.22 \pm 0.07 \quad \text{fb}$$

precision of cross section: **32%**

precision of Higgs self-coupling: **57%**