Study of Higgs Self-couplings at ILC

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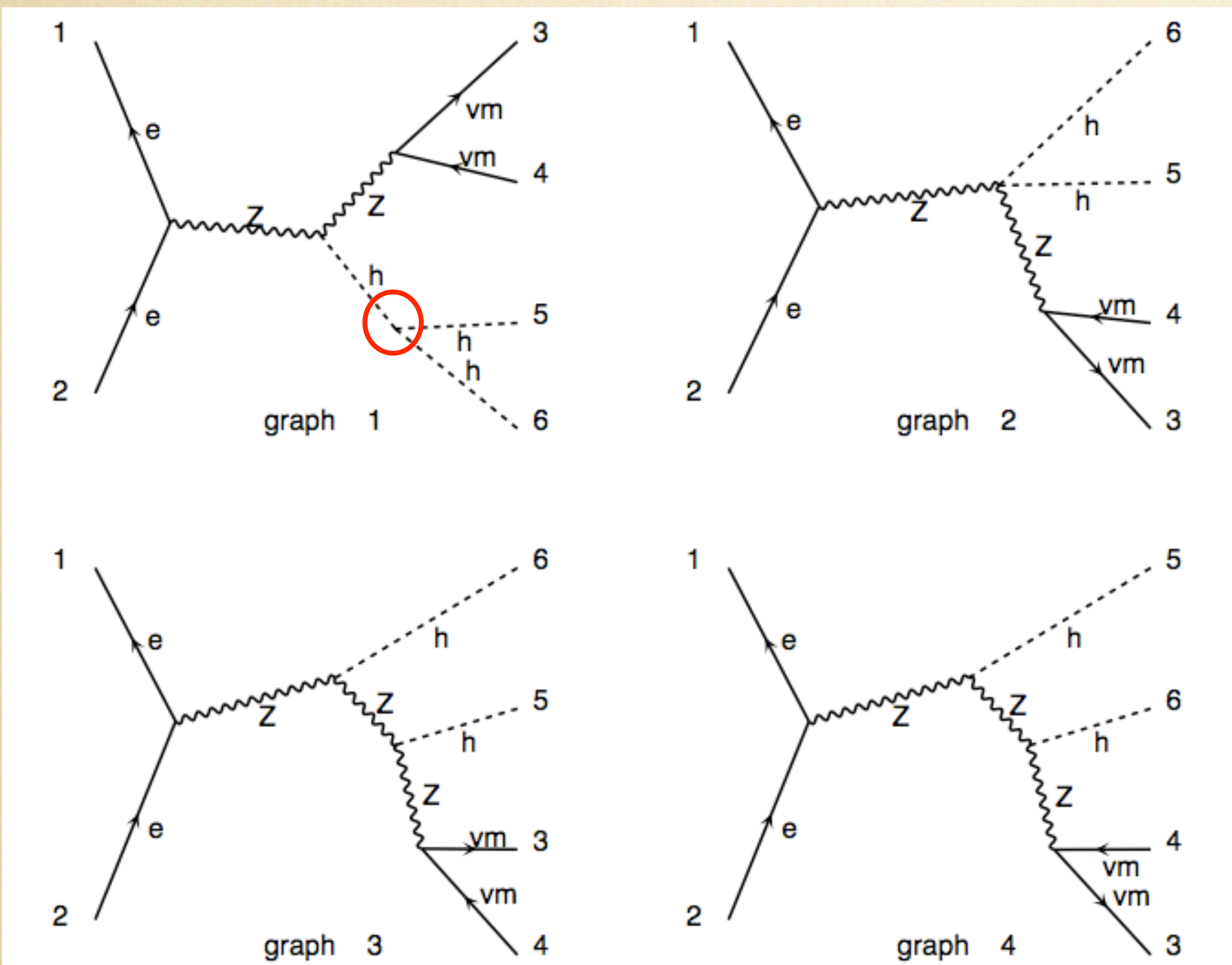
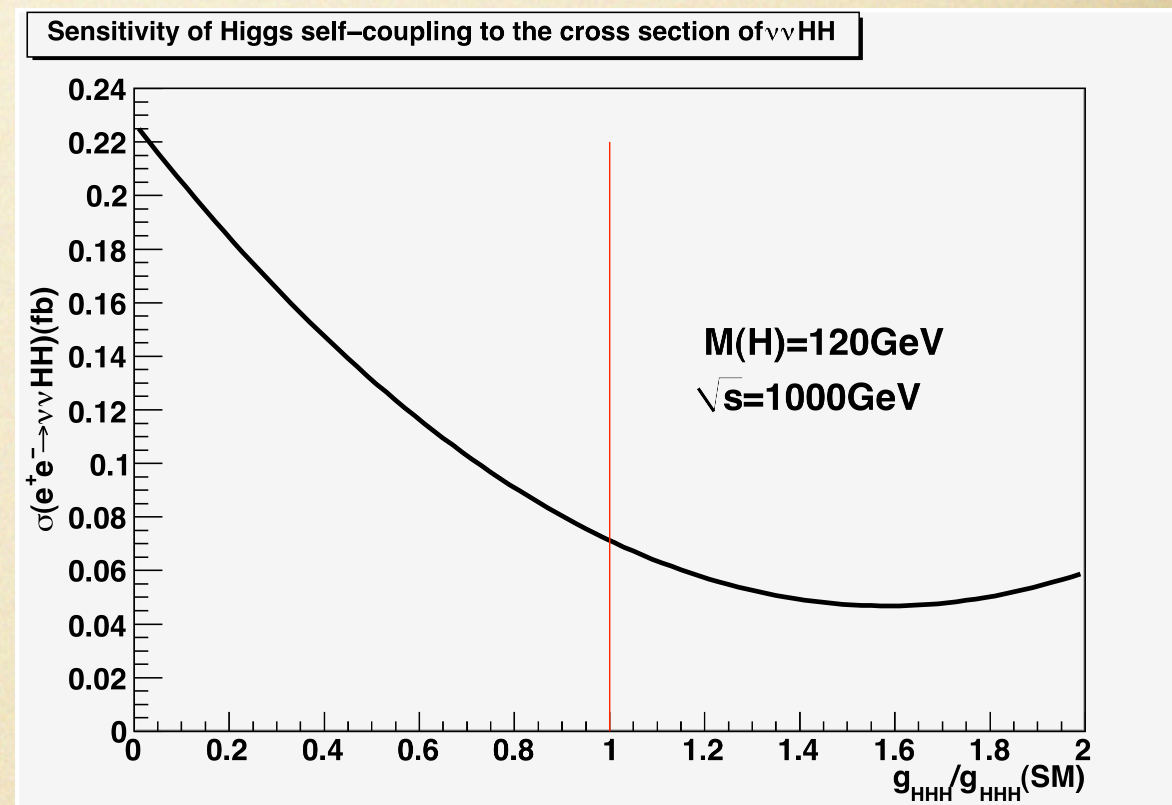
$$e^- + e^+ \to \nu\bar{\nu}HH$$ (fast simulation)

$\sigma = 71.3$ ab @Ecm $= 1$TeV

ISR
No BeamStrahlung





$$\frac{\Delta\lambda}{\lambda} = 0.85\frac{\Delta\sigma}{\sigma}$$

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

previous!

Pre-selection:

- number of reconstructed particle (E>0.1GeV) >= 40
- number of isolated lepton = 0
- force all the particles to four jets
- combine the four jets by minimizing

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

constraint implied in the pre-selection:

|M(bb)-M(H)| < 80 GeV

previous!

preliminary results

no beam polarization $E_{\rm cm} = 1000\text{GeV}, M_H = 120\text{GeV}$ $\int Ldt = 2\text{ab}^{-1}$

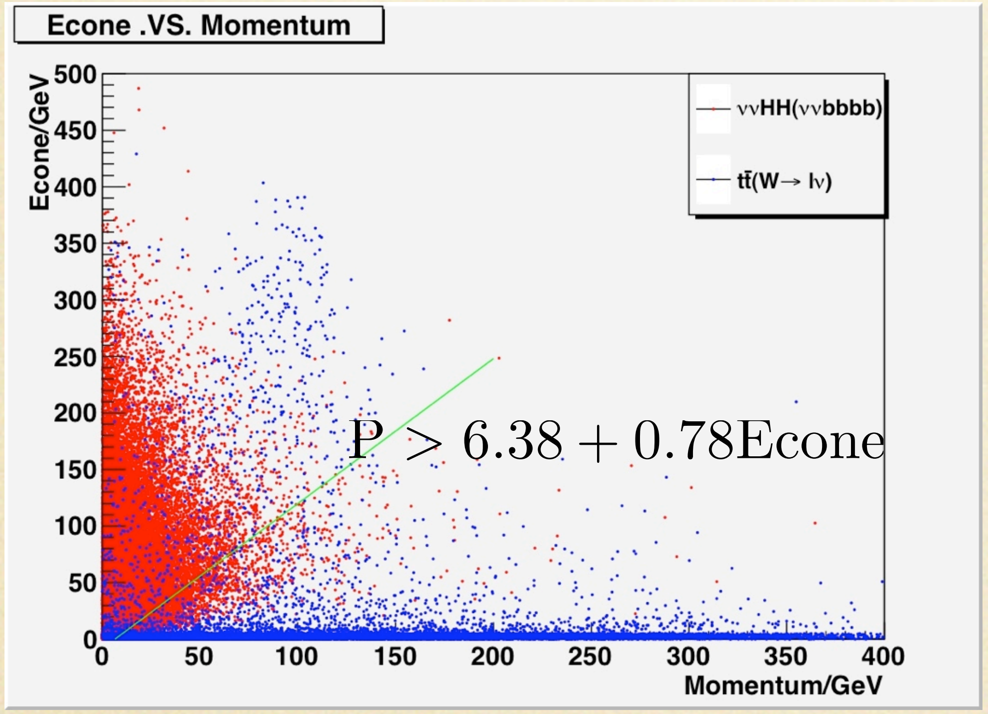
	υυHH(υυbbbb)	tt-bar	WWZ	ZZZ	ZZH	ννZZ	ννWW	ttH	υυZH
MC	500K	500K	500K	500K	500K	50K	50K	50K	50K
expected	142.6(63.4)	377600	123400	1664	700	12100	30200	4960	2500
pre-selection	101.3(54.4)	146603	25653.6	586.1	219.4	5812	13658	134.2	1452
Evis<600	96.8(51.9)	25764.4	10361.4	310.3	119.8	5638	13237	57.8	1379
mvatt>0.8	25.1(15.0)	302.1	58.5	1.25	1.26	120.8	161	1.19	89.0
noff4>0	10.2(8.58)	31.0	2.22	0.08	0.20	6.8	0	0.50	12.8
noff3>2	7.18(6.72)	5.29	0.25	0.05	0.10	4.11	0	0.20	6.90
mjet4>2	7.10(6.71)	1.51	0	0.05	0.10	4.11	0	0.20	6.85

analysis strategy changed

- the previous non isolated lepton criterion is a bit tighter (85%) as a pre-selection. we used a new looser one (98%).
- in order to suppress the υυZZ and υυZH background, we need better mass resolution. there are two factors which effect the resolution: miss jet clustering and wrong jet pairing. first we defined a quantity to tag the jet, and then we can evaluate the wrong pairing possibility of a specified jet pairing algorithm.
- a new jet pairing algorithm based on the likelihood of the invariant mass of jet pairs was used.
- previously, we only trained the neural-net for tt-bar background, now we trained another neural-net for υυZZ and υυZH.

criterion of isolated lepton

previous:



red: all the particles from signal vvbbbb
blue: leptons from the semi-leptonic decay of tt-bar

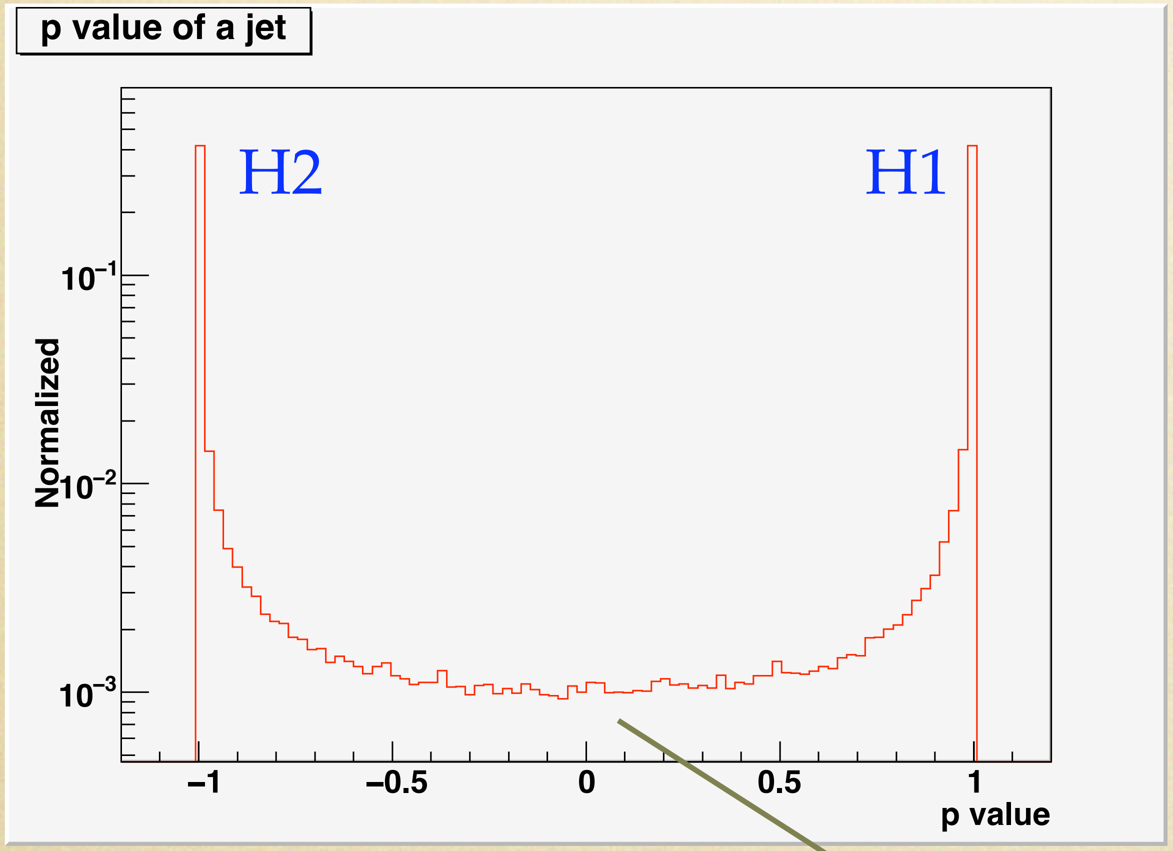
coefficients from Fisher method in TMVA

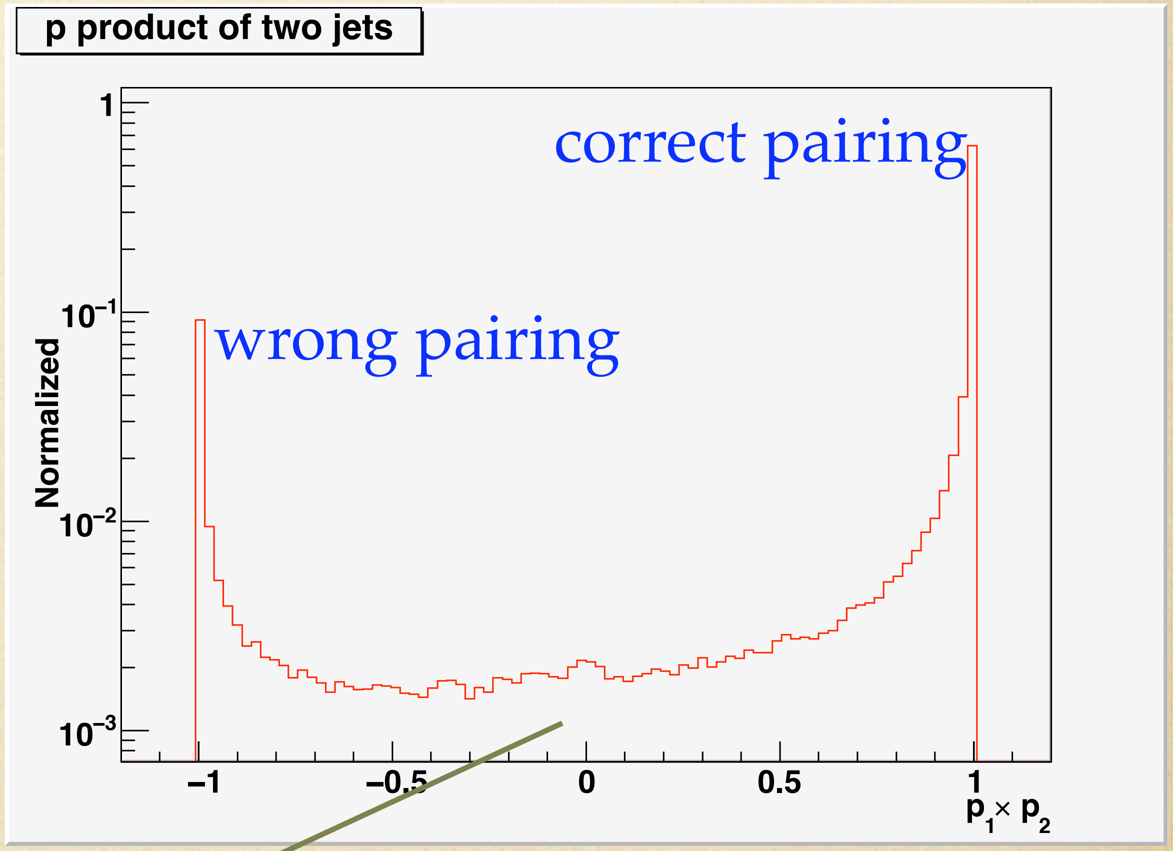
now: Econe < 20 GeV && P > 20 GeV

tagging of color singlet id for a jet

- for signal events, the four b jets come from two color singlets: H1 and H2.
- for each track in a jet, by using the truth information we can know which color singlet it comes from.
- for a jet, we can count the number of tracks and the sum of energy belongs to H1 and H2 respectively.
- define a quantity: $$p = \frac{n_1 E_1 - n_2 E_2}{n_1 E_1 + n_2 E_2}$$
- if $p > 0$, the jet comes from H1, otherwise H2.

typical distributions of p value and product of two p values





miss jet clustering

usual jet pairing algorithm(χ^2)

minimizing $\chi^2 = \frac{(M(j_1, j_2) - M_H)^2}{\sigma^2_{H_1}} + \frac{(M(j_3, j_4) - M_H)^2}{\sigma^2_{H_2}}$ $M_H = 120 GeV$ $\sigma_H = 6 GeV$

	ννHH(ννbbbb)
MC	22224
pre-selection	21391(96.2%)
p1×p2×p3×p4 > 0	19404
p1×p2 > 0	15500(79.9%)

probability of correct pairing

two issues:

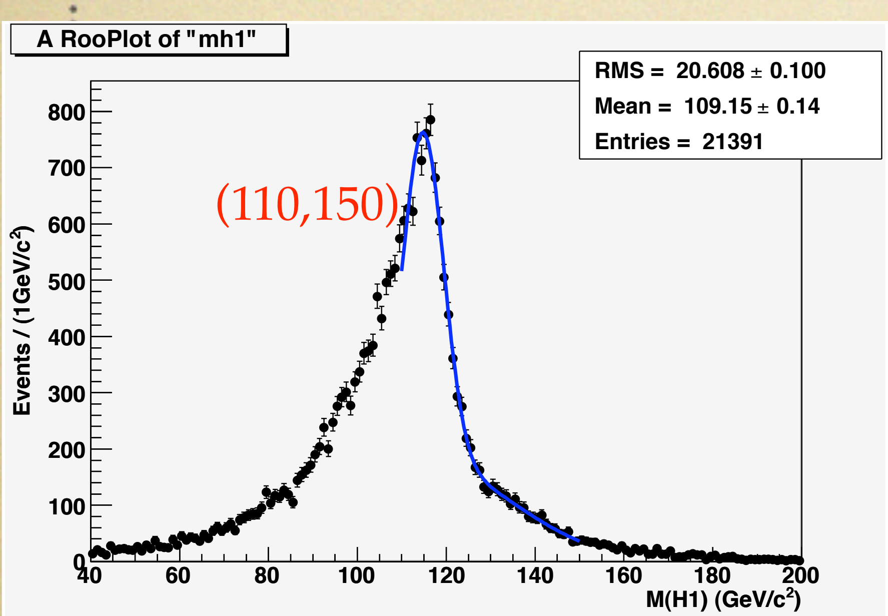
(i) the central value of invariant mass is not at 120 (115)

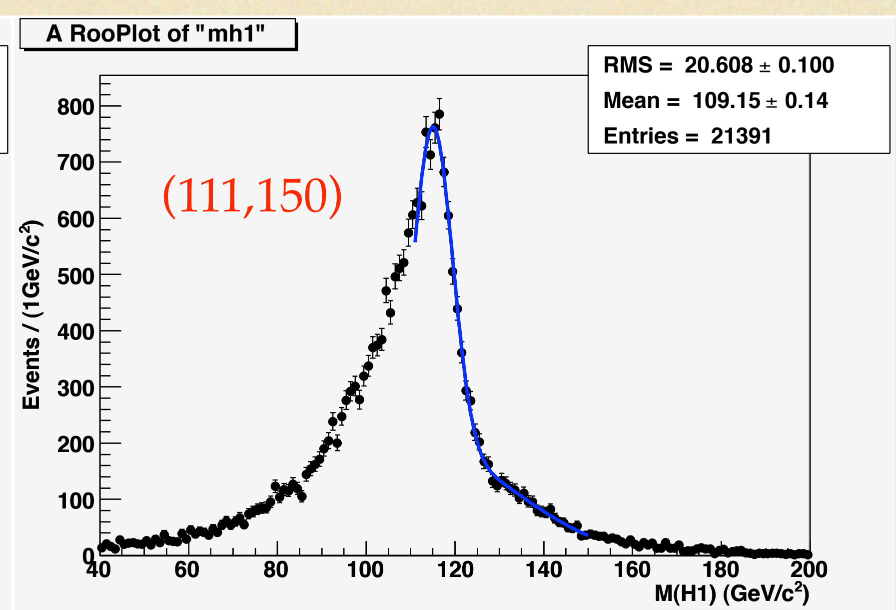
(ii) the distribution of invariant mass is no longer a Gaussian, the resolution is not well defined, especially for resonance with natural width, like Z

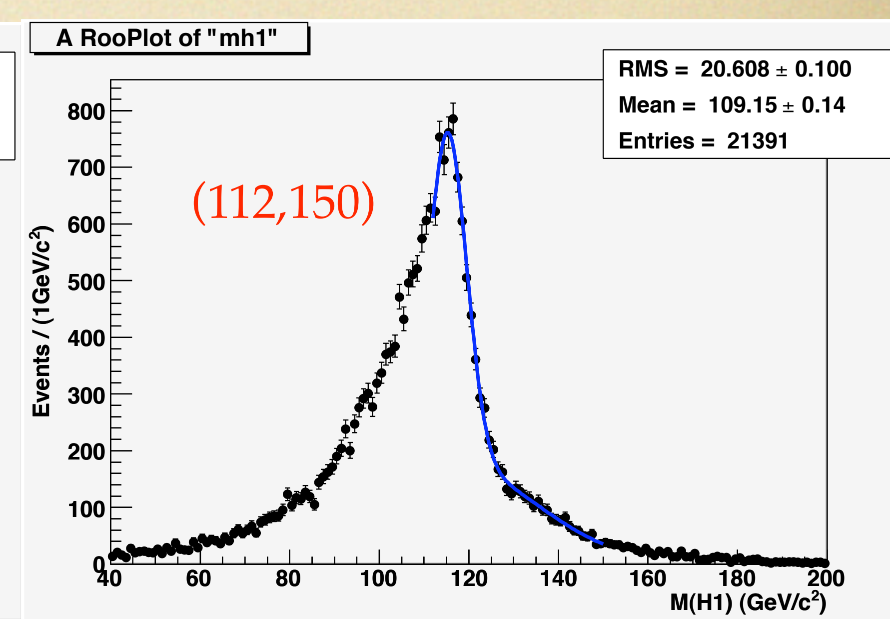
Higgs mass resolution

dependence with fitting range

m±δm,σ±δσ	130	150	170
110	114.8±0.1, 4.4±0.4	114.8±0.1, 4.6±0.1	114.7±0.1, 4.9±0.1
111	115.1±0.1, 3.9±0.3	115.0±0.1, 4.4±0.1	115.0±0.2, 4.8±0.2
112	115.3±0.1, 3.5±0.3	115.3±0.2, 4.2±0.2	115.1±0.2, 4.7±0.2







a new jet paring algorithm(likelihood)

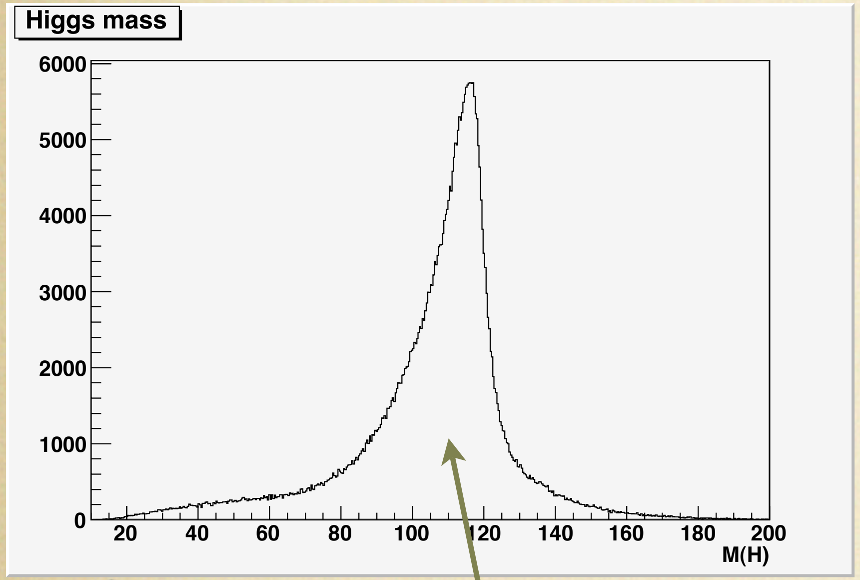
(i) estimate the p.d.f of M(j1,j2), M(j3,j4) in the case of correct pairing (using truth information of the four jets we can do the correct paring): non-parametric kernal estimation

(ii) define the likelihood of the real pairing: $L = f(M_{12})f(M_{34})$

and the corresponding χ^2 : $\chi^2 = -lnL = -ln(f(M_{12})) - ln(f(M_{34}))$

(iii) choose the pair which has the smallest χ^2

kernel estimation (binned)

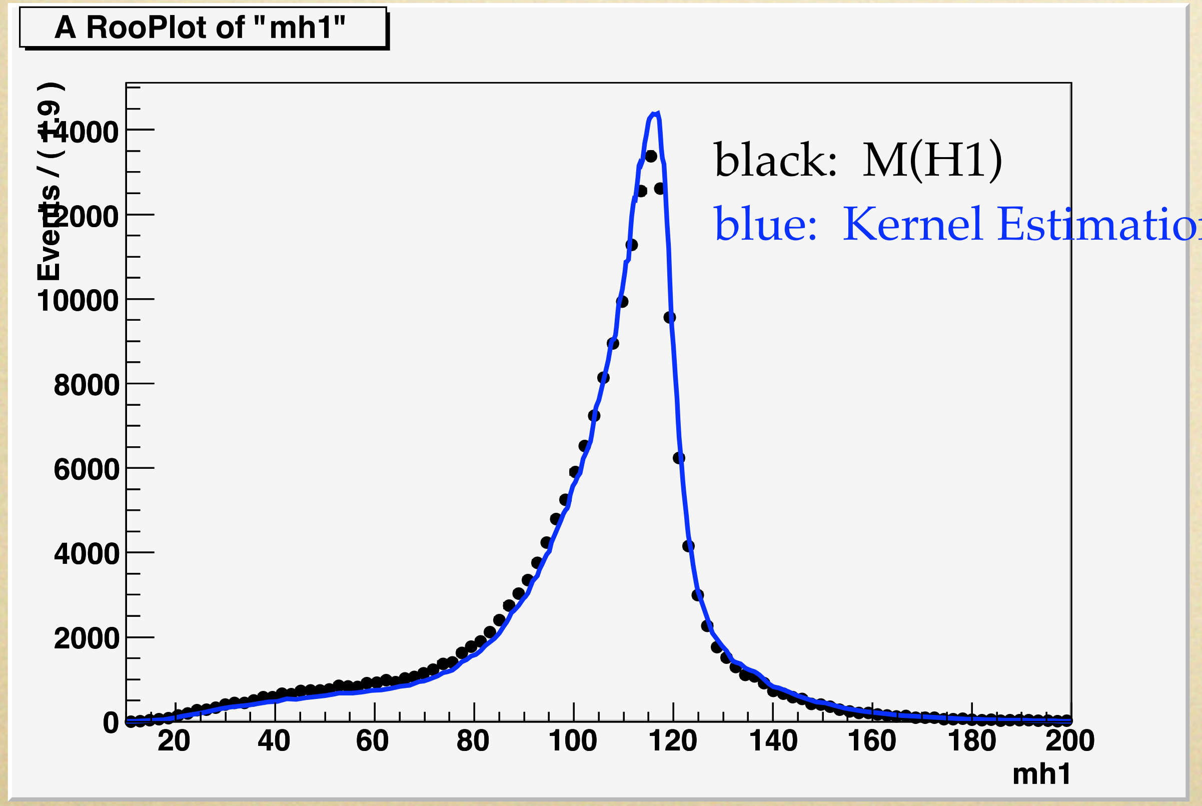


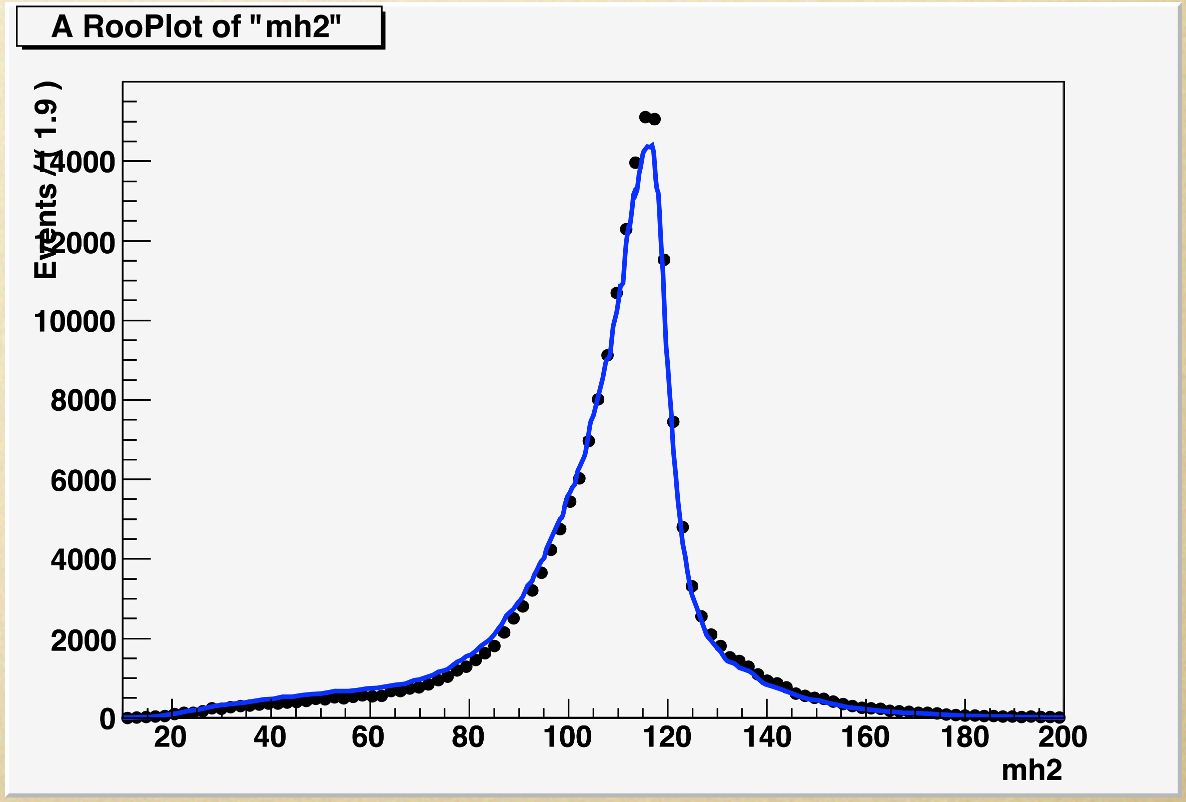
histogram of merged M(H1) and M(H2)

$$F(x) = \frac{1}{N}\sum_{j=1}^{m} n_j G(x; t_j, h_j)$$

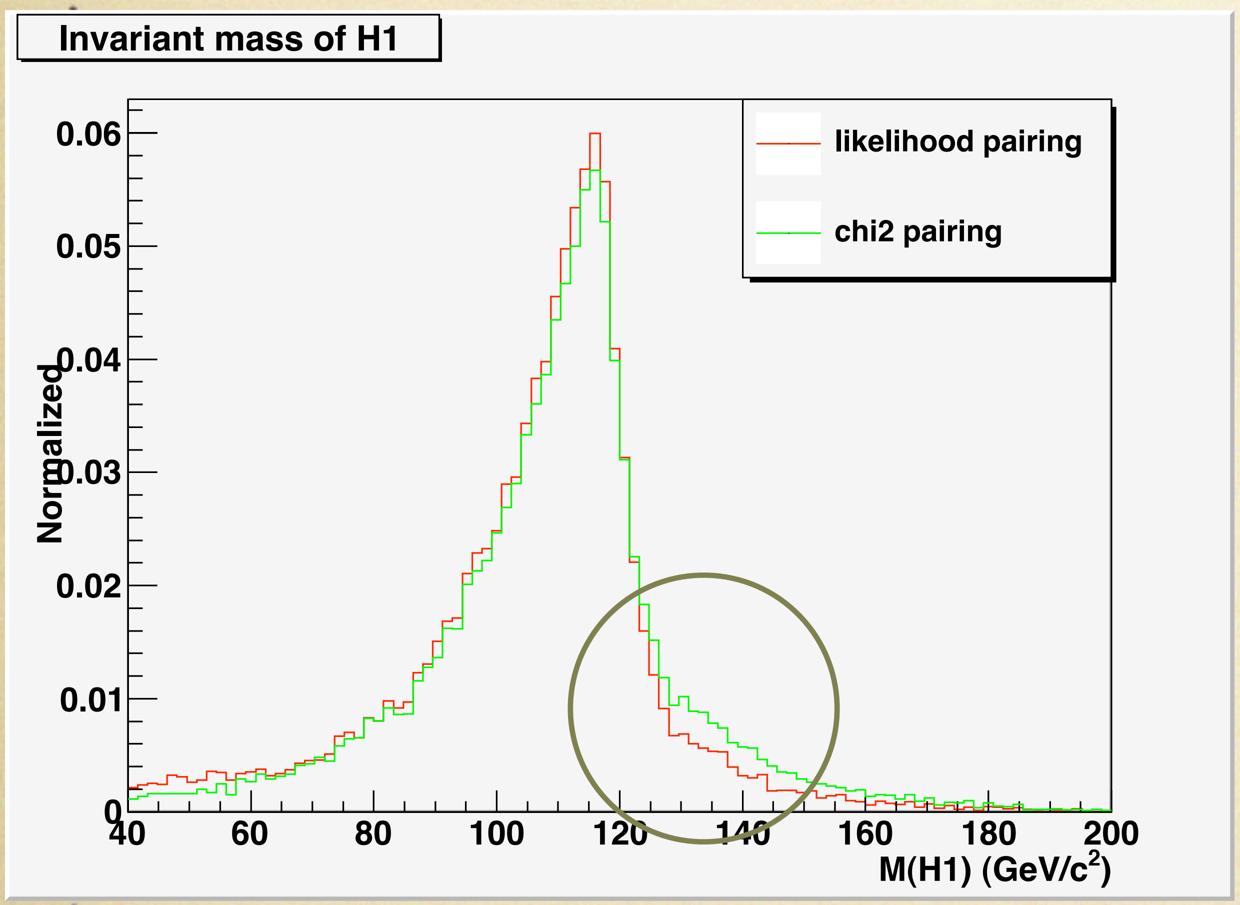
$$h_j = (\frac{4}{3})^{1/5} N^{-1/5} \Delta x \sqrt{\frac{N}{n_j}}$$

- N : total number of events
- nj: number of events in that bin
- m: number of bins
- Δx: bin width
- tj: center of that bin
- hj: resolution of that bin
- G(x; tj, hj): Gaussian Kernel





comparison of two jet pairing algorithms



ννHH(ννbbbb)	χ^2	likelihood
MC	22224	222246
pre-selection	21391(96.2%)	21446
p1×p2×p3×p4 > 0	19404	19449
p1×p2 > 0	15500(79.9%)	16629(85.4%)

probability of correct pairing

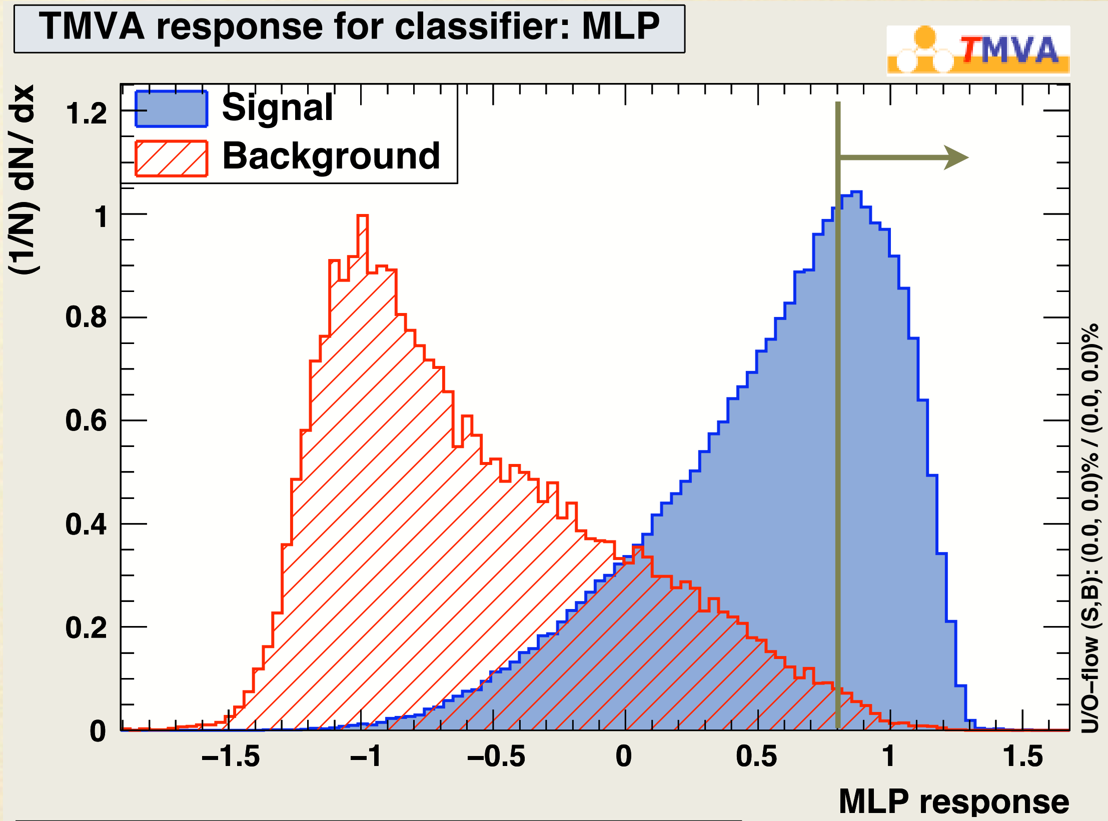
we also pair the jets under the hypothesis of ννZZ and ννZH. the invariant masses of Z and H in each hypothesis also could be used to suppress the backgrounds.

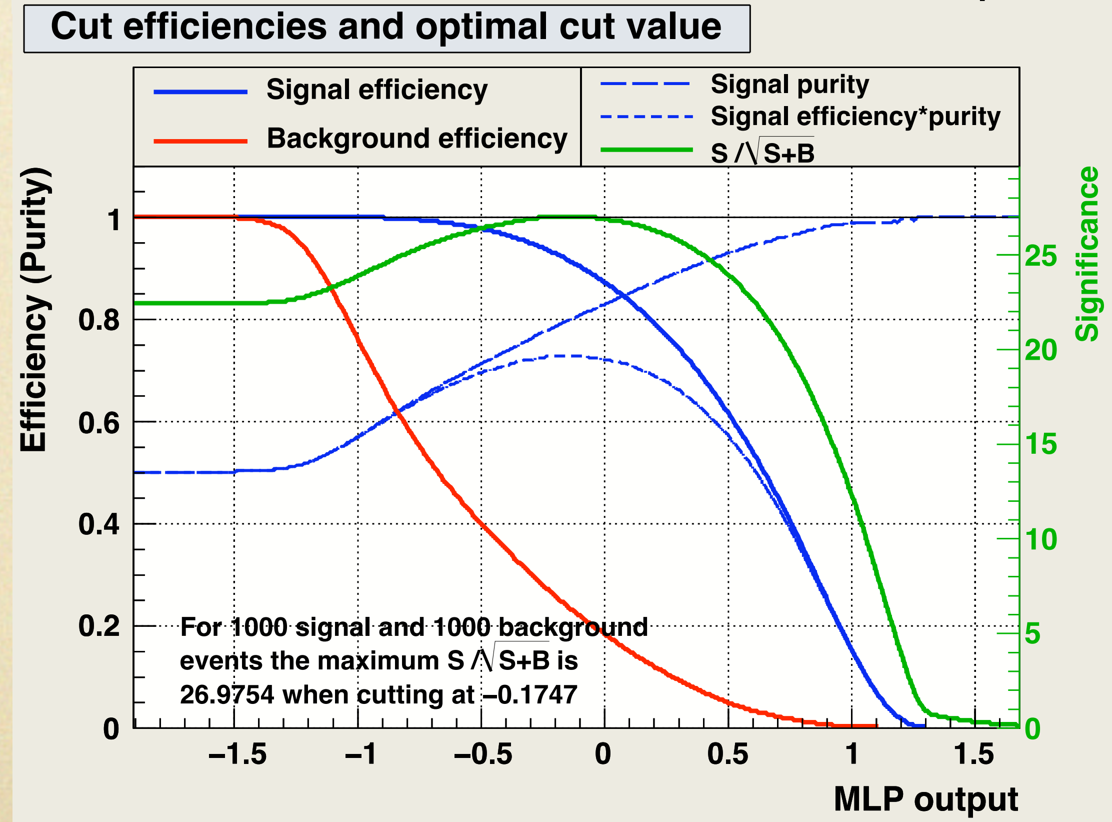
suppression of tt-bar

input:

- M(H1)
- M(H2)
- Y value
- Miss Pt
- Cosθ(hh)
- Npart4

	ννHH(ννbbbb)	tt-bar
MC	500K	500K
expected	142.6(63.4)	377600
pre-selection	115.8(61.1)	160971
Evis<600	110.8(58.3)	32326



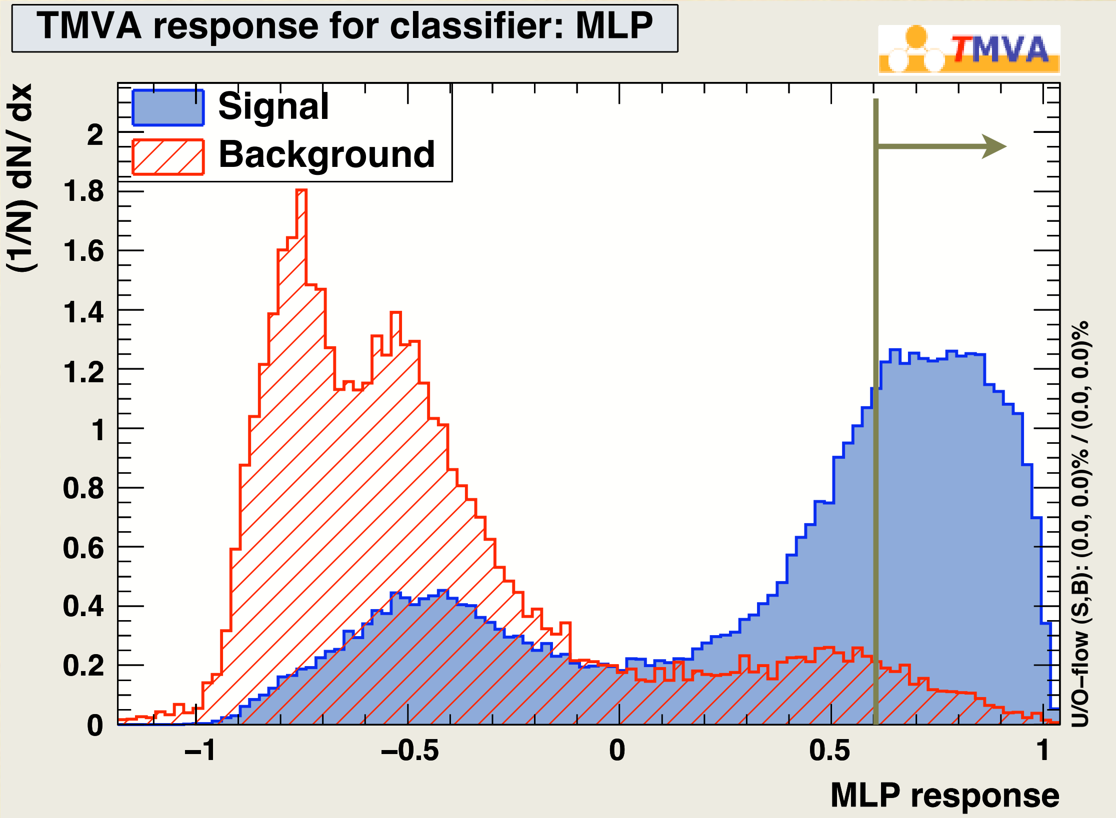


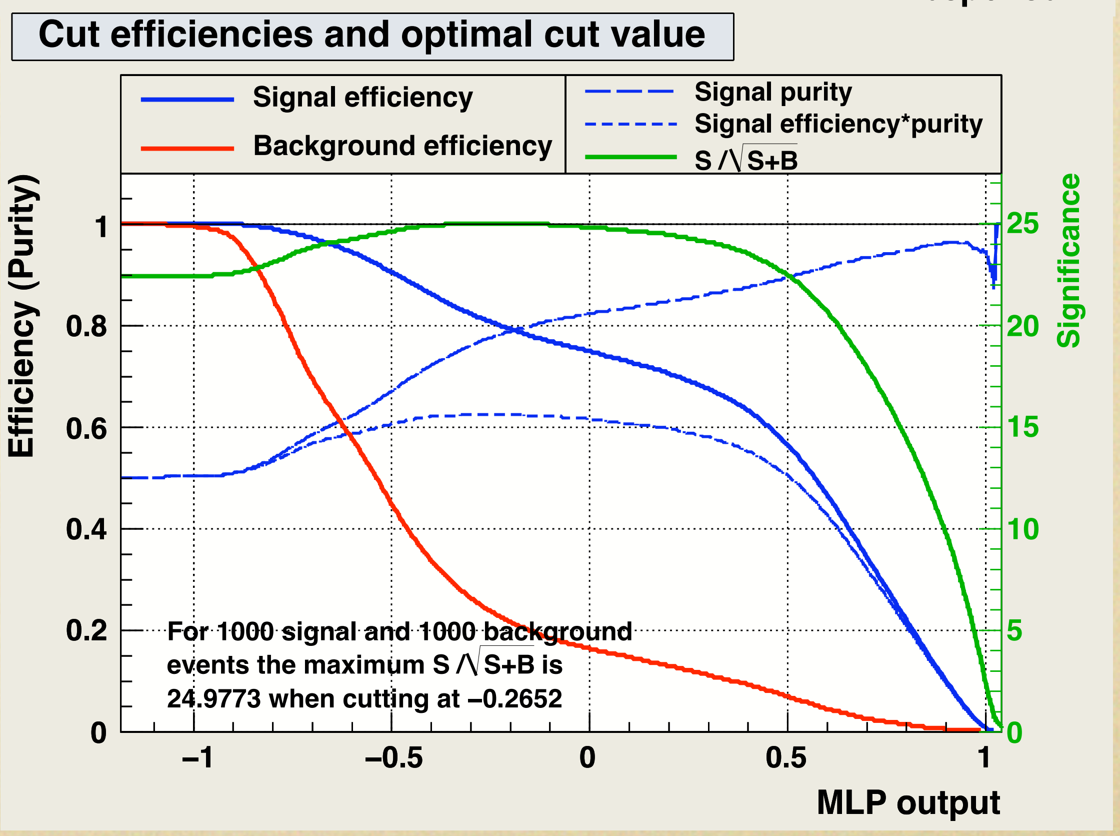
suppression of ννZZ and ννZH

input:

M(Z1)_ννZZ
M(Z2)_ννZZ
M(Z)_ννZH
M(H)_ννZH
decay angles of H1 and H2

	υυHH (υυbbbb)	ννZZ	ννZH
MC	500K	500K	500K
expected	142.6(63.4)	12100	2500
pre-selection	115.8(61.1)	6112	1620
Evis<600	110.8(58.3)	5932	1548
mvatt>0.8	33.0(20.7)	140.0	159.8





preliminary results

no beam polarization $E_{\rm cm} = 1000 {\rm GeV}, M_H = 120 {\rm GeV}$ $\int L dt = 2 {\rm ab}^{-1}$

	υυHH(υυbbbb)	tt-bar	WWZ	ZZZ	ZZH	ννZZ	ννWW	ttH	υυZH
MC	500K	500K	500K	500K	500K	500K	50K	50K	500K
expected	142.6(63.4)	377600	123400	1664	700	12100	14048	4960	2500
pre-selection	115.8(61.1)	160971	27772	609.2	239.7	6112	13626	184.3	1620
Evis<600	110.8(58.3)	32326	11512	330.2	134.8	5932	171.5	89.2	1548
mvatt>0.8	33.0(20.7)	376.8	57.5	1.95	2.42	140.0	4.83	2.38	159.8
mvazzzh>0.6	20.6(12.8)	182.8	17.0	0.45	0.60	6.32	0	1.78	22.0
noff4>0 noff3>2	6.17(5.8)	3.78	0	0.02	0.05	0.36	0	0.40	2.16
mjet4>2 econe>0.1	5.95(5.62)	1.51	0	0.02	0.04	0.36	0	0.20	2.04

summary

$\nu\nu HH$:	5.9
tt-bar:	3.9

i. excess significance: 2.5σ

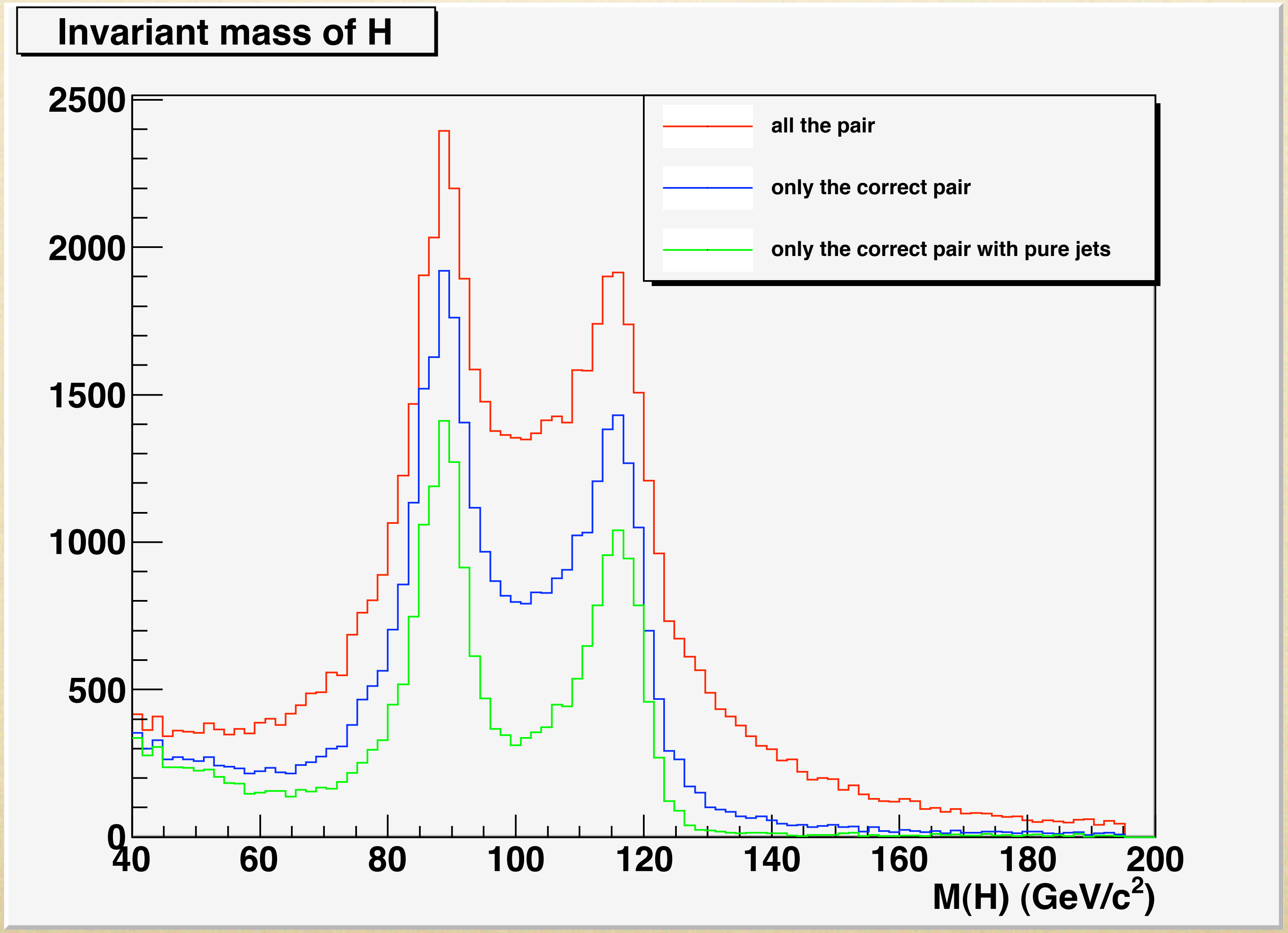
ii. precision for Higgs self-coupling: 45%

back up

μμZH background

sources of contamination:

(i) mass resolution
(ii) pari combination
(iii) jet clustering



invariant mass of each jet