Status of ZHH analysis

Taikan Suehara
(ICEPP, U. Tokyo)

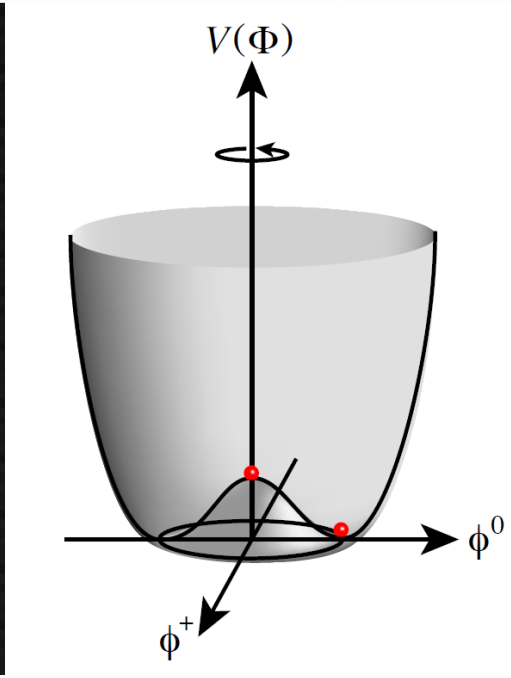
J. Tian(KEK), T. Tanabe (Tokyo),
K. Fujii(KEK) and all ILD colleagues

The only probe for Higgs potential: self coupling

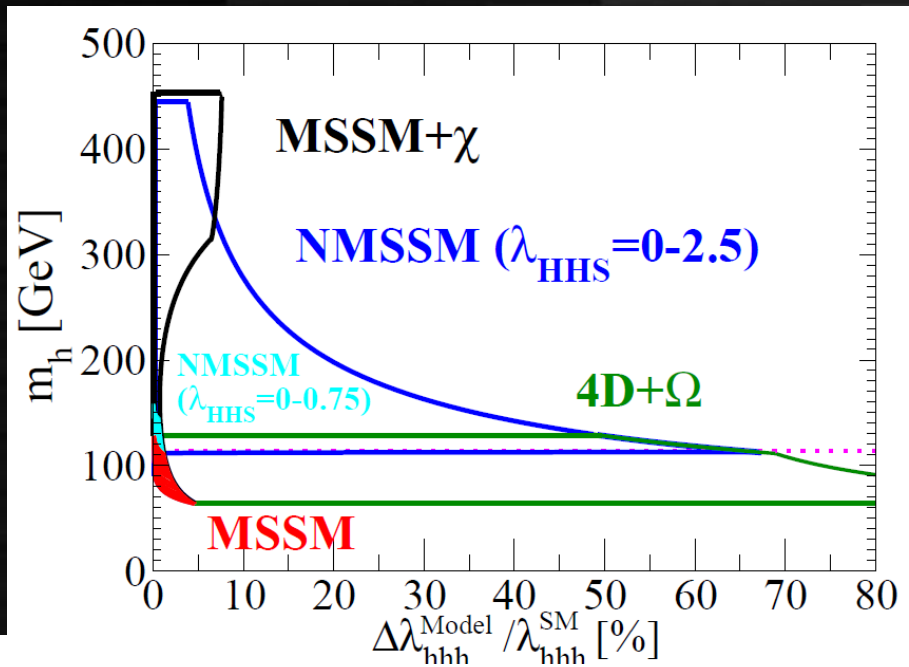
SM force

Lagrangian term	example
Gauge force	QCD, electroweak
Yukawa force	Higgs-fermion
Higgs force	Higgs self-coupling

- The last force in SM
- A good probe for BSM with ~30% accuracy

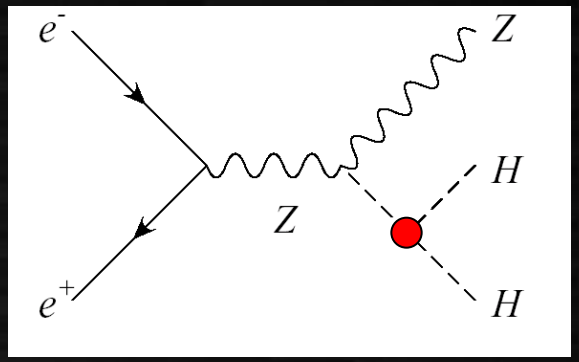


$$V(\Phi) = \mu^2|\Phi|^2 + \lambda|\Phi|^4 + \text{h.c.}, \qquad \mu^2 < 0, \lambda > 0$$

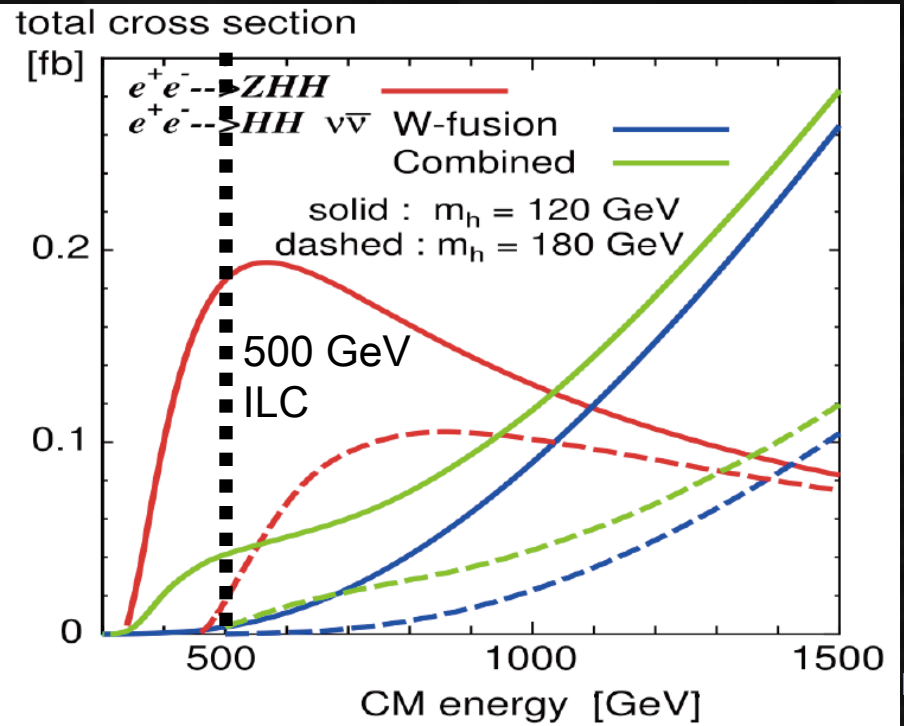


Wo SUSY case: Kanemura et al. (2011)

ZHH in 500 GeV ILC



Double Higgs-strahlung:
largest xsec around 500 GeV



m_H=120 GeV

Decay mode	BR.	# events in 2 ab^{-1}
qqbbbb	32%	146
ννbbbb	9%	42
qqbbWW*->qqbbqqqq	6%	28
llbbbb	4%	19
qqbbWW*->qqbbqqlν	3%	14
qqbbWW*->qqbblνqq	3%	14
others	43%	194
tt -> bbqqqq		~800,000
ZZZ, ZZH -> qqbbbb		~600

Tiny cross section of 0.2fb
(and only half contribute to
self coupling diagram)
Background (top-pair, ZZH etc.)
must be very strongly suppressed

Previous result by Junping

ALCPG 2011

put all together (preliminary)

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

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

we are interested in:

A. the combined significance of ZHH excess.

hhh coupling sensitivity of 57% … Need to improve!

Improvement expected with new tools - LCFIPlus

- New vertex finder
- Jet clustering with vertex
- Single track vertex finder for b-tagging
- Optimized input variables

for details, refer to Tomohiko's talk in the morning
and my slides in KILC12 / software pre-meeting yesterday

LCFIPlus (1) jet clustering

Multi-jet environment

- presence of low energy jets
- Hard gluon emission

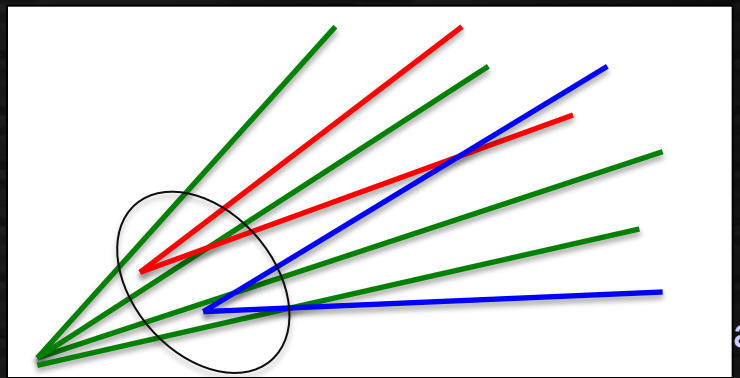
→ mistakes jet reconstruction, especially 2 b-jets combined into 1

→ degradation in b-counting

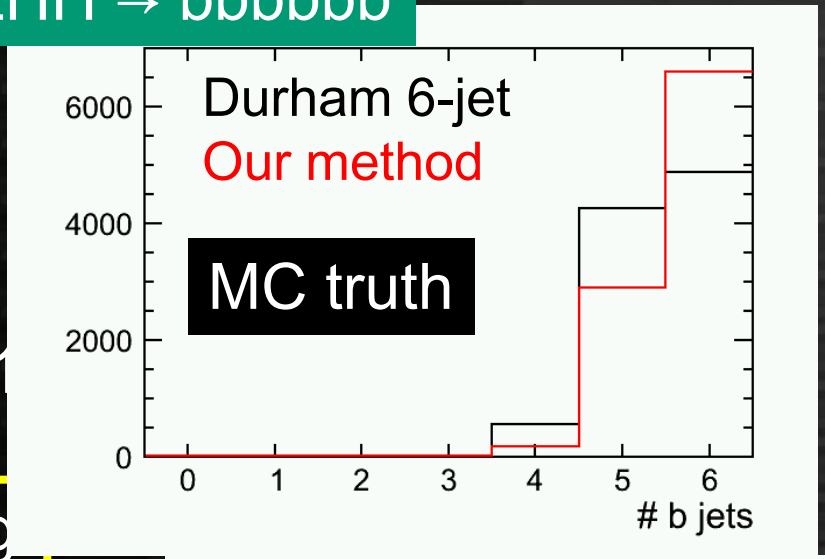
Jet clustering based on vertex finding

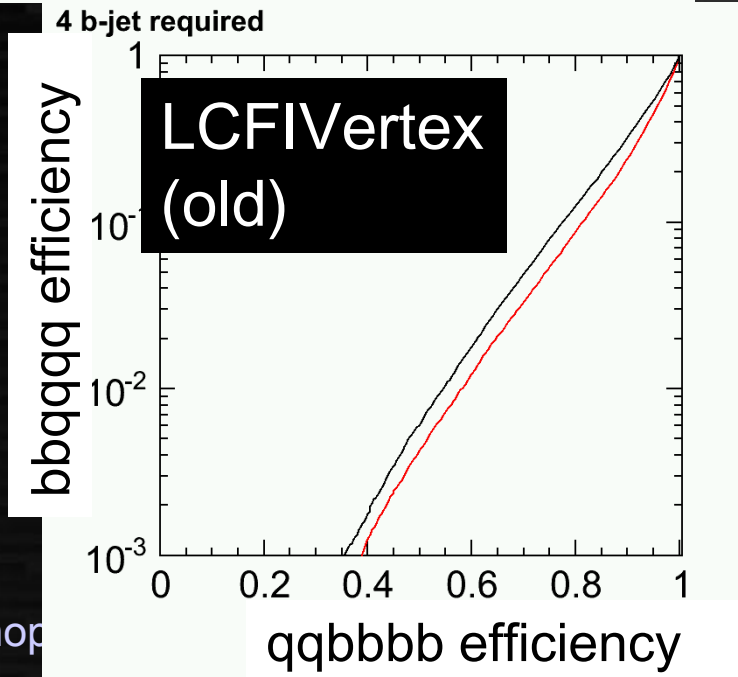
- Avoid combining jet-seeds with vertices into one jet

→ b-counting efficiency improved

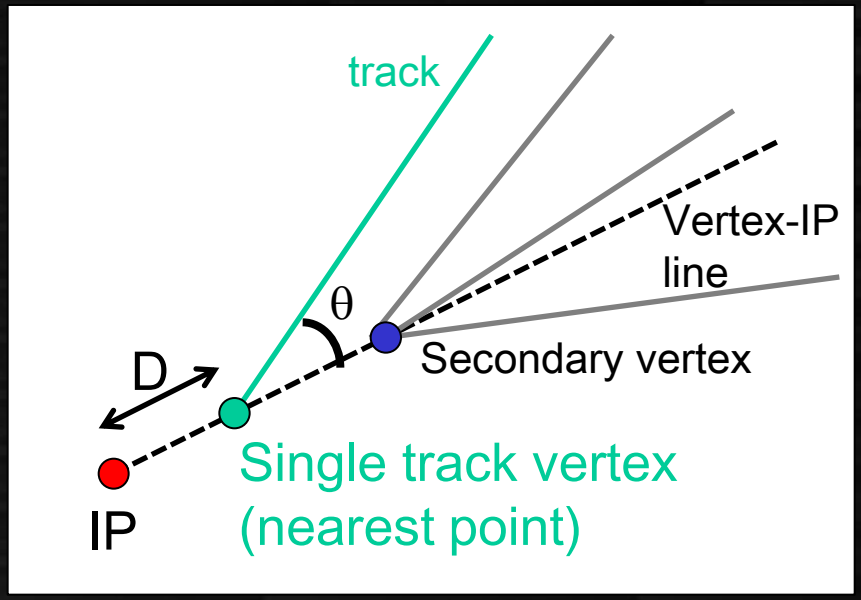


ZHH → bbbbbb





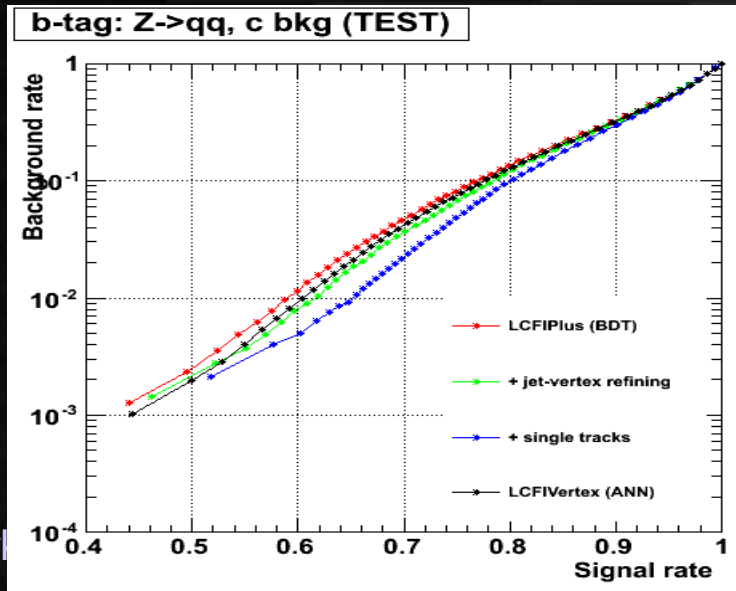
LCFIPlus (2) Single track vertex



- Normal vertex finder needs at least 2 tracks -> loose single track vertices
- Single track vertices can be found by using direction of cascaded vertex
- They contribute to the b-tagging efficiency

Event (91.2GeV)	0 vtx	1 vtx	1vtx + 1 single	2 vtx
bb	20144	37562	13951	28343
cc	55143	43869	647	213
qq (uds)	98225	1680	44	51

Number of vertices in 100 k events



But…

Preliminary

Energy (GeV)	Modes	signal	background	significance	
				excess (I)	measurement (II)
500	$ZHH \to (l\bar{l})(b\bar{b})(b\bar{b})$	6.4	6.7	2.1σ	1.7σ
500	$ZHH \to (\nu\bar{\nu})(b\bar{b})(b\bar{b})$	5.2	7.0	1.7σ	1.4σ
500	$ZHH \to (q\bar{q})(b\bar{b})(b\bar{b})$	8.5(7.6)	11.7(22.2)	2.2σ(1.5)	1.9σ(1.3)
		16.6(14.7)	129(143)	1.4σ(1.2)	1.3σ(1.2)

Blue: with LCFIPlus

By repeating previous analysis, performance is rather degraded!

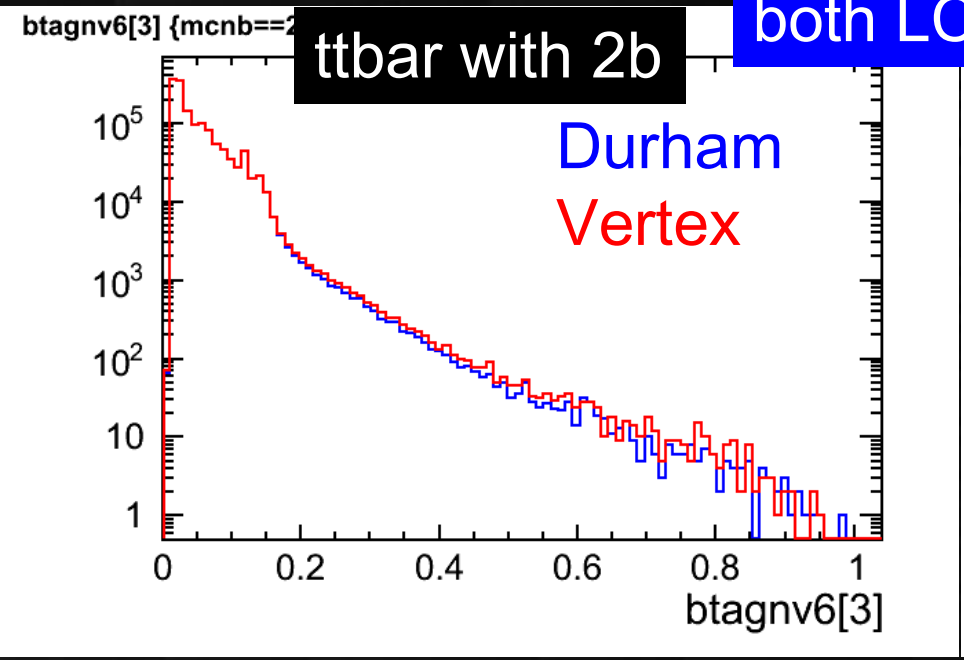
- Analysis has to be retuned?
- More essential problem?

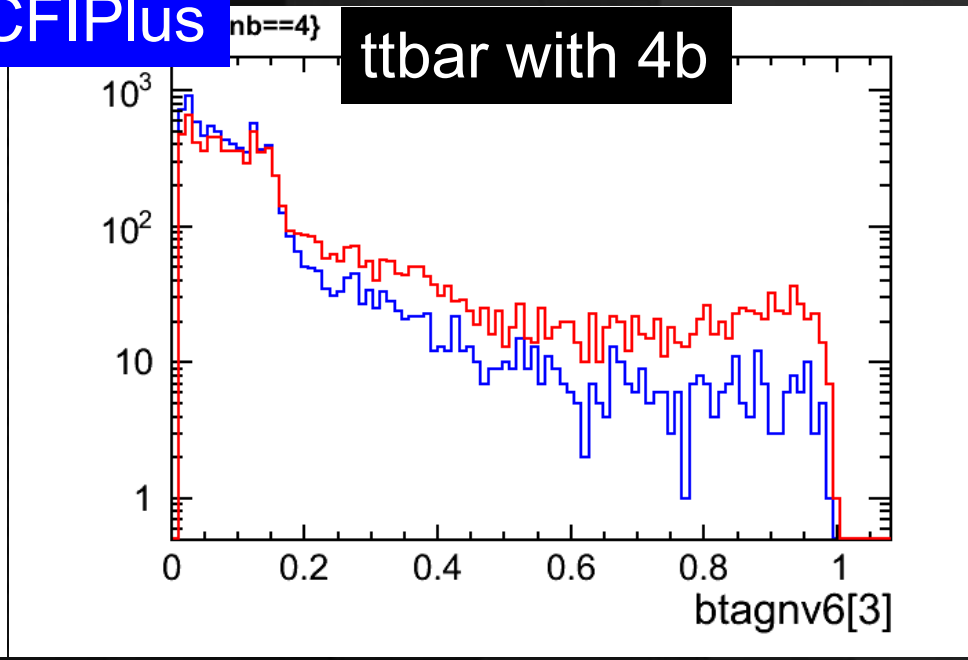
tt + g -> ttbb

preliminary

Fourth largest b-likeness among 6-jets – expected to be 0 for 2b

both LCFIPlus





small difference

large difference (2x – 3x)

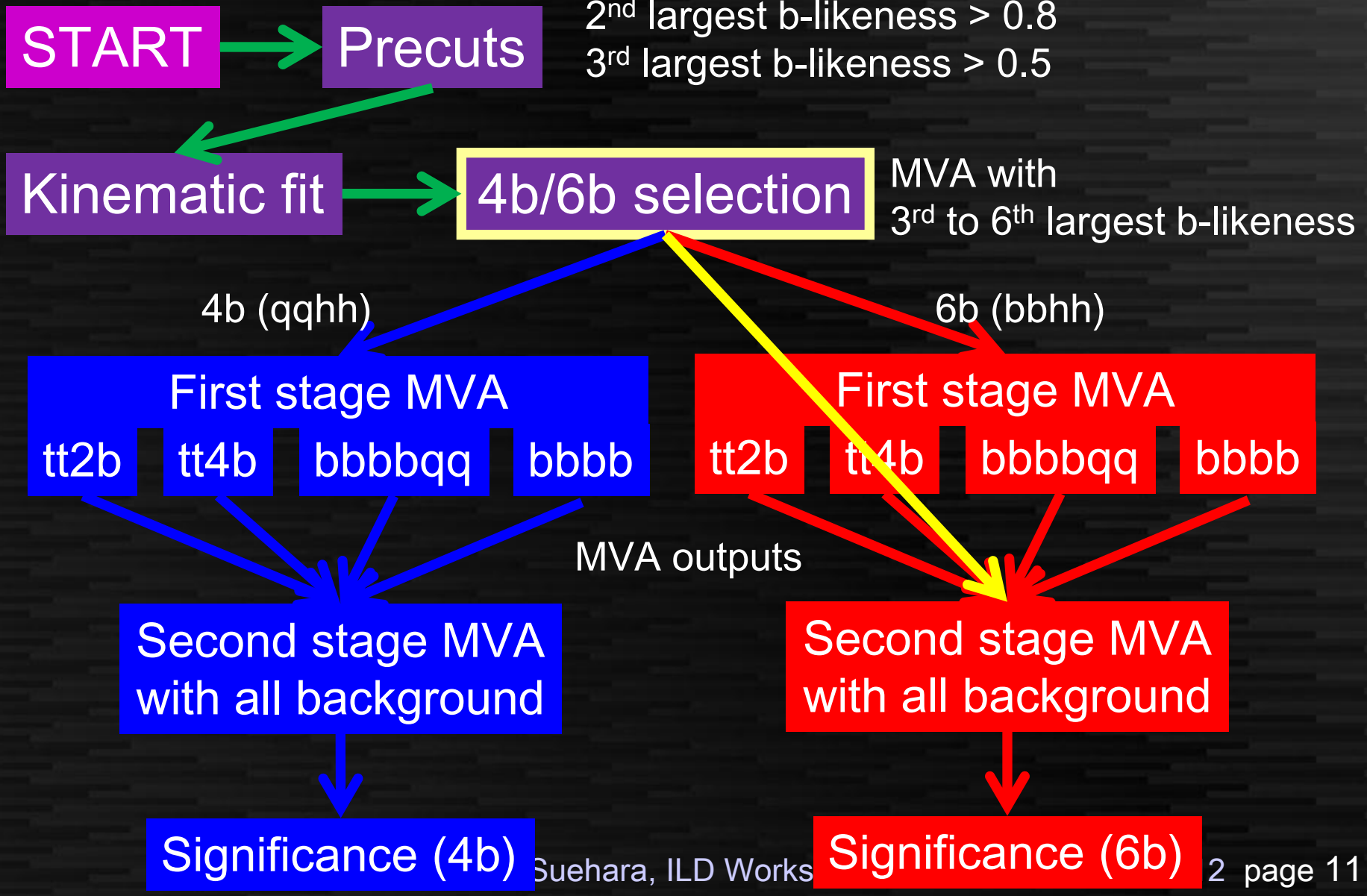
- gluon to bb jets are preferentially reconstructed in Vertex-Jets
  - more tt background in qqhh analysis
- Need to be suppressed

New analysis started

- Latest LCFIPlus
- Optimize variables to suppress ttg
- Try many other ideas
- Cross-check to Junping's analysis

Analysis overview

Events are divided to 3 parts for 2-stage MVA



Kinmatic fits with mass constraints

- Currently 8 types of constraints (under tuning)
  - KF1: Zhh with 6-jets, Z & h mass fixed
  - KF2: Zhh with 6-jets, Z mass fixed, h float
  - KF6: Zhh with 6-jets, Z & h float
    - Assume 2-jets with least b-likeness form Z
  - KF3: tt->bWbW with 6-jets, W & t float
  - KF8: tt->bWbW with Durham 6-jets, W & t float
  - KF4: tt->bWbWb with 7-jets, W fixed, t float
    - KF4-1: gluon from W, KF4-2: gluon from b, KF4-3: gluon from t
    - select one of KF4-(1,2,3) by probability
  - KF7: tt->bWbWbb with 8-jets, W fixed, t float
    bb with the least mass combined into one -> 7-jets
  - KF5: ZZ with 4-jets, Z float

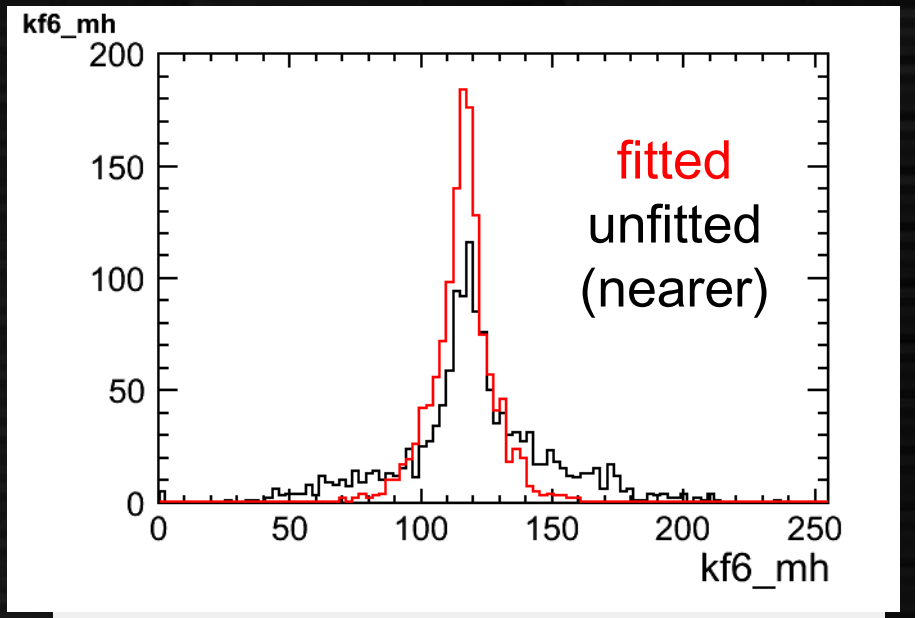
Zhh, ZZh, ZZZ separation

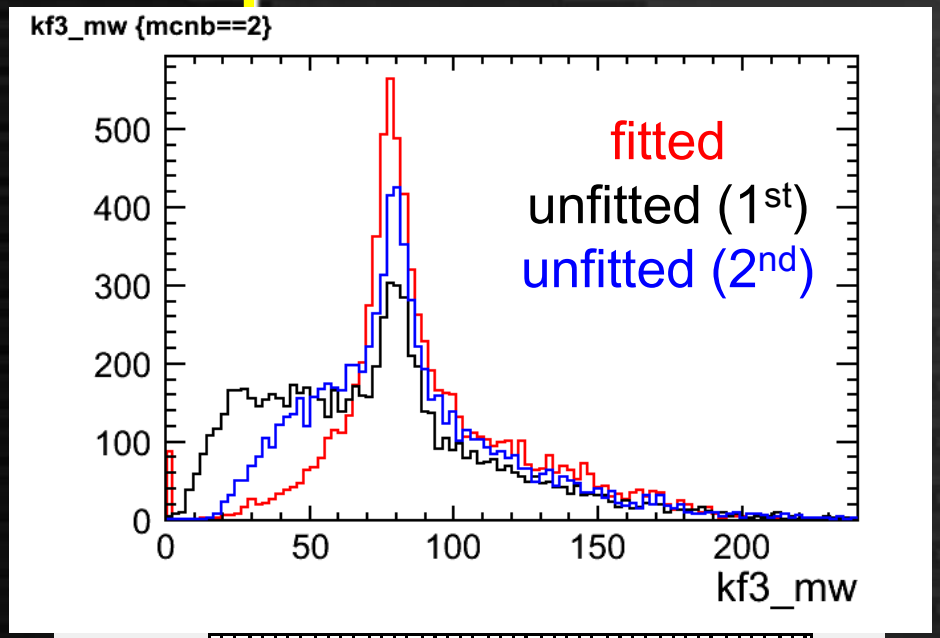
tt, ttg separation

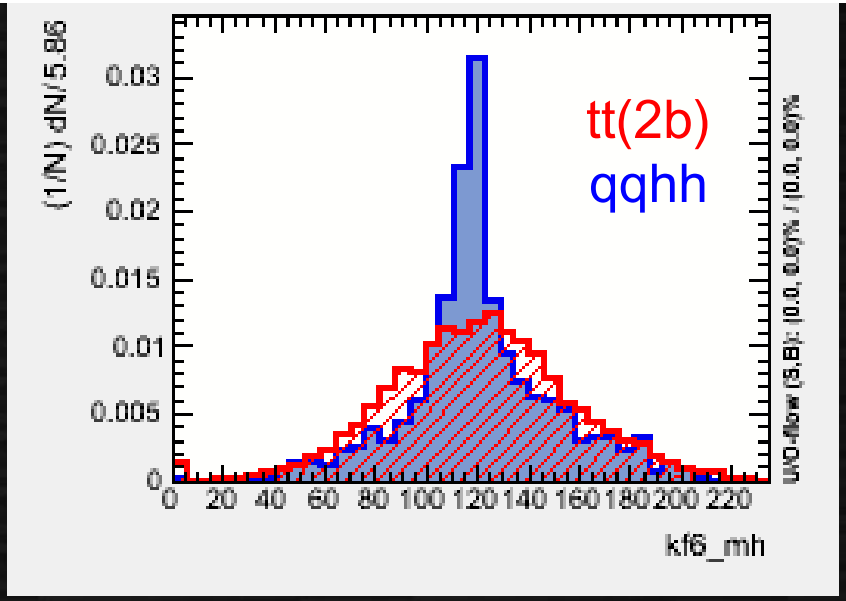
ZZ separation

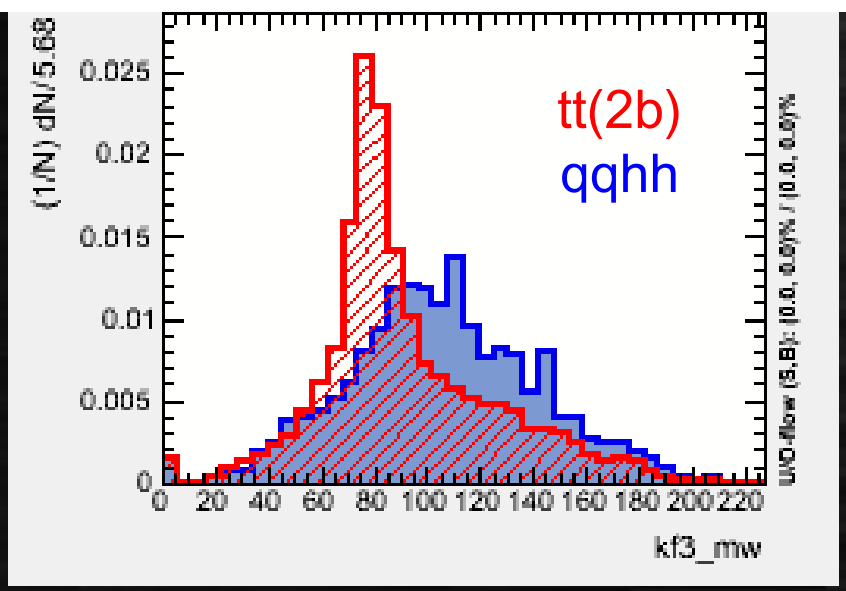
Using MarlinKinfit

Kinematic fit plots









MVA selection: overview

First stage: single background each

4b analysis

b-likeness order is important

- bbbb: ycuts, thrust, Z mass, KF5 (ZZ), KF6 (Zhh), N tracks
- tt(2b): btag, ctag, bb angle, KF1 (Zhh), KF3 (tt2b), KF6
- tt(4b): btag, btag (Durham), ctag (7j), ycuts, thrust, N tracks, angle 8-jets, KF6, KF4 (tt4b-7j),KF7 (tt4b-8j)
- ZZZ/ZZh: Zhh mass (unfit), KF1, KF3, KF6

6b analysis

b-likeness itself is more important

- bbbb: ycuts, thrust, Z mass, N tracks, KF5 (ZZ), KF1, KF2 (Zhh), btag
- tt(2b): btag, ctag, bb angle, KF2 (Zhh), KF3 (tt2b), N tracks
- tt(4b): btag, btag (Durham), ctag, ycuts, thrust, N tracks, angle 8-jets, KF1, KF2, KF4 (7j) KF7 (8j)
- ZZZ/ZZh: N tracks, btag, KF1, KF2
- bbhh: btag

Second stage MVA: combine likeness of first stage with all background with proper weight

Current result

preliminary

Significances are obtained by changing threshold of final MVA

4b

sult:												
bbhh.root	31.88	14.81	7.64	5.02	3.33	2.34	1.78	1.08	0.75	0.52	0.14	0.05
qqhh.root	63.20	56.35	36.33	26.68	21.28	17.53	13.74	9.66	7.45	4.83	2.25	0.84
tt.root	13001.59	11085.33	762.13	225.44	75.71	30.28	18.51	10.09	3.36	1.68	1.68	0.00
tt.root	1872.51	1583.14	412.19	171.60	75.71	45.42	25.24	10.09	3.36	1.68	0.00	0.00
ttqq.root	78.21	66.46	14.10	6.27	3.79	2.48	1.31	0.78	0.39	0.13	0.00	0.00
bbbb.root	2925.40	2012.65	181.15	79.92	41.96	26.31	13.32	5.66	3.00	0.33	0.00	0.00
zzz-6b.root	10.72	8.73	3.47	1.94	1.21	0.78	0.48	0.23	0.12	0.05	0.02	0.00
zzz-4b.root	62.78	54.46	21.73	11.99	7.05	4.34	2.65	1.42	0.71	0.29	0.07	0.00
qqqqh.root	74.73	60.48	29.88	19.59	13.26	9.39	6.66	3.99	2.10	0.78	0.36	0.06
signal	71.17	43.97	31.69	24.61	19.88	15.52	10.74	8.20	5.34	2.39	0.89	
background	14871.24	1424.66	516.75	218.67	119.00	68.16	32.27	13.05	4.95	2.13	0.06	
significance (S+N)	0.58	1.15	1.35	1.58	1.69	1.70	1.64	1.78	1.67	1.12	0.91	
significance (N)	0.58	1.17	1.39	1.66	1.82	1.88	1.89	2.27	2.40	1.64	3.64	

sig (S+N): 1.70, sig (N): 1.88

6b

sult:												
bbhh.root	31.88	16.41	12.94	10.55	8.81	7.41	6.42	5.72	4.88	3.52	1.88	0.14
qqhh.root	63.20	6.05	3.89	2.20	1.41	1.08	0.66	0.47	0.28	0.05	0.00	0.00
tt.root	13001.59	168.24	42.06	15.14	10.09	5.05	3.36	1.68	1.68	1.68	0.00	0.00
tt.root	1872.51	188.43	68.98	26.92	15.14	11.78	10.09	5.05	3.36	1.68	0.00	0.00
ttqq.root	78.21	5.35	1.83	1.18	0.78	0.39	0.13	0.00	0.00	0.00	0.00	0.00
bbbb.root	2925.40	233.77	26.97	14.32	8.32	4.00	3.00	3.00	2.66	0.67	0.00	0.00
zzz-6b.root	10.72	1.68	0.82	0.42	0.27	0.18	0.09	0.06	0.04	0.03	0.01	0.00
zzz-4b.root	62.78	6.54	3.06	1.71	1.19	0.88	0.53	0.33	0.21	0.10	0.04	0.00
qqqqh.root	74.73	12.72	8.97	6.63	5.10	4.14	3.15	2.85	2.22	1.56	0.93	0.00
signal	22.46	16.83	12.75	10.22	8.49	7.08	6.19	5.16	3.56	1.88	0.14	
background	616.73	152.70	66.31	40.90	26.40	20.36	12.97	10.18	5.72	0.99	0.00	
significance (S+N)	0.89	1.29	1.43	1.43	1.44	1.35	1.41	1.32	1.17	1.11	0.38	
significance (N)	0.90	1.36	1.57	1.60	1.65	1.57	1.72	1.62	1.49	1.89	inf	

sig (S+N): 1.44, sig (N): 1.65

Comparison of result

- Junping's previous result (qqhh)
  - Measurement (S=1): $1.9\sigma + 1.3\sigma \rightarrow 2.3\sigma$
  - Excess (S=0): $2.2\sigma + 1.4\sigma \rightarrow 2.6\sigma$
- New result preliminary
  - Measurement (S=1): $1.70\sigma + 1.44\sigma \rightarrow 2.22\sigma$
  - Excess (S=0): $1.88\sigma + 1.65\sigma \rightarrow 2.50\sigma$

Comparable result now
  - need further improvement

LoI -> new sample

b-baryon lifetime is set to 0 in LoI samples
- very important in 4b/6b analysis
(b-baryon ~ 10% -> 40-60% of 4b/6b events include at least one b-baryon)

very preliminary

4b result:												
bbhh.root	31.88	14.81	7.64	5.02	3.33	2.34	1.78	1.08	0.75	0.52	0.14	0.05
bbhhnew.root	39.85	16.89	9.73	6.24	4.42	2.99	2.03	1.35	0.78	0.32	0.16	0.00
qqhh.root	63.20	56.35	36.33	26.68	21.28	17.53	13.74	9.66	7.45	4.83	2.25	0.84
qqhhnew.root	75.71	66.33	47.05	36.58	30.13	24.76	20.12	15.05	10.76	6.21	3.01	0.95
tt.root	13001.59	11085.33	762.13	225.44	75.71	30.28	18.51	10.09	3.36	1.68	1.68	0.00
tt.root	1872.51	1583.14	412.19	171.60	75.71	45.42	25.24	10.09	3.36	1.68	0.00	0.00
ttnew.root	16162.61	13724.81	1194.52	292.54	146.27	73.13	24.38	24.38	24.38	0.00	0.00	0.00
ttnew.root	2803.47	2096.51	609.45	341.29	170.65	97.51	24.38	24.38	24.38	0.00	0.00	0.00
signal	71.17	43.97	31.69	24.61	19.88	15.52	10.74	8.20	5.34	2.39	0.89	
signal (new)	83.22	56.78	42.82	34.55	27.76	22.15	16.40	11.53	6.53	3.17	0.95	
background	14871.24	1424.66	516.75	218.67	119.00	68.16	32.27	13.05	4.95	2.13	0.06	
background (new)	18024.09	2054.31	753.54	384.17	213.94	73.18	60.84	55.08	1.59	0.45	0.06	
significance (S+N)	0.58	1.15	1.35	1.58	1.69	1.70	1.64	1.78	1.67	1.12	0.91	
significance (N)	0.58	1.17	1.39	1.66	1.82	1.88	1.89	2.27	2.40	1.64	3.64	
significance (new, S+N)	0.62	1.24	1.52	1.69	1.79	2.27	1.87	1.41	2.29	1.67	0.95	
significance (new, N)	0.62	1.25	1.56	1.76	1.90	2.59	2.10	1.55	5.18	4.74	3.88	

- background is replaced to new in ttbar only
- ttbar statistics is VERY short (weight = 24.38)
- MVA training is done in old sample

KEKCC is recently crowded: may need grid partially for ttbar

Need to replace to new sample!

Other improvements expected

- More training sample (ttbar!)
  - MVA suffers very much from short statistics
  - Optimization difficult in current statistics
    - statistical fluctuation is too large
- Optimization of analysis
- Optimization (more) of b-tagging
- Many ideas to be implemented
  - Color singlet jet clustering
  - Mass constrained jet clustering
  - and so on…

Summary

- After developing jet clustering and vertex finder, we got a first step to incorporate those improvements to real ZHH analysis.
  - One problem in tt + g->bb
- Intense 1-month analysis efforts have not yet obtained satisfactory results
- Intense efforts will continue, to obtain concrete results in 2-3 months
- Higgs self coupling performance is one of the key in ILC promotion over LHC. Workers / advises are very welcome!

Backup

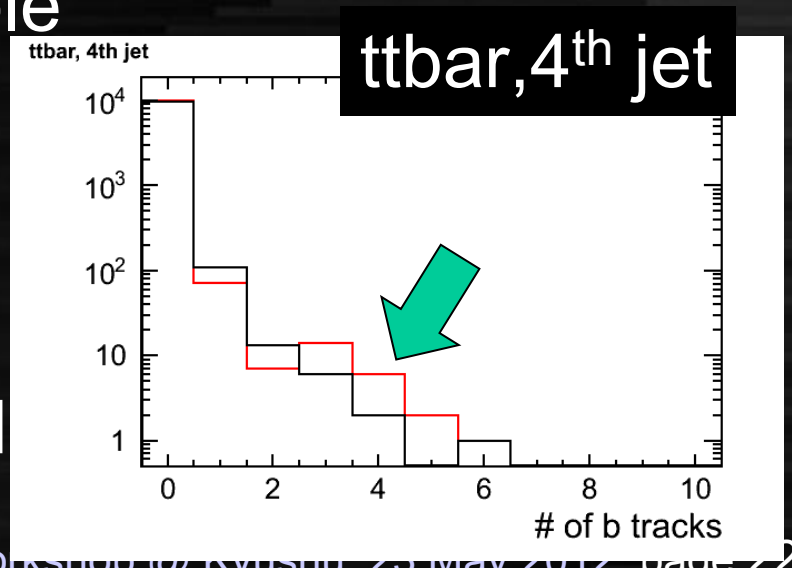
ZHH analysis – basic strategy

- Signal: Zhh -> qqhh: 138 events in 2ab-1
  - bbhh: 27 events
    - Powerful separation by b-tagging
    - Difficult mass reconstruction
  - Non-bb qqhh: 111 events
    - Z mass reconstruction by non-b tagged jets
    - Suffered from huge tt background
      - Mainly ttg -> ttbb

Event identification totally different:
prefer independent analysis for bbhh & qqhh

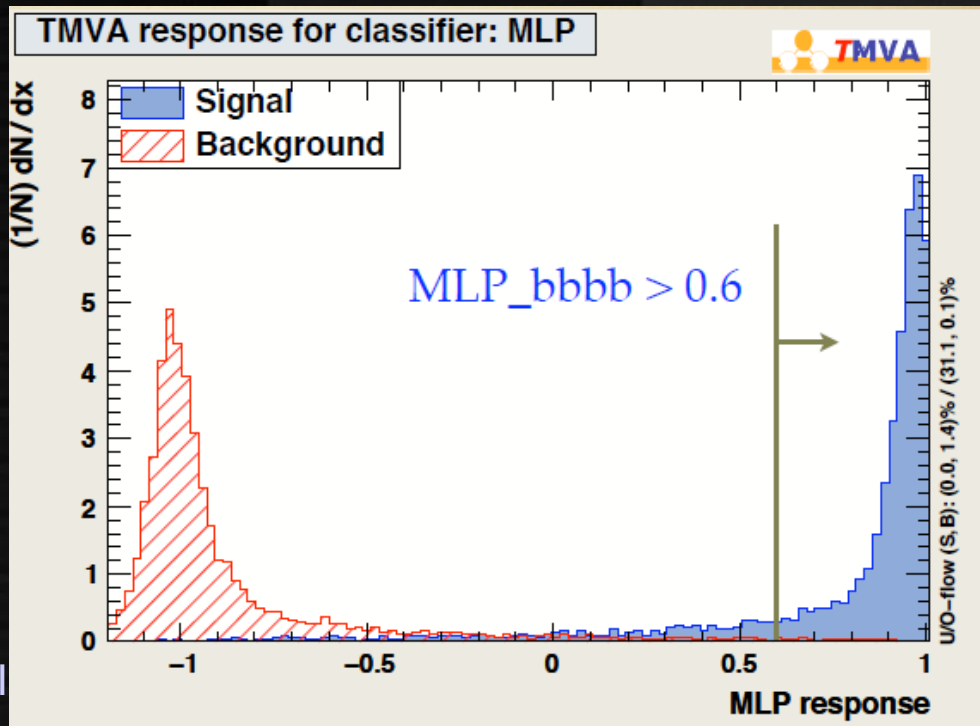
Background (1) ttbar

- HUGE: ~800000 (remind signal: 138)
  - Basic cut: b-tag 3rd & 4th jets
- Some (~0.5% in our sample) includes hard gluon emission with g->bb (fake 4-b jets)
  - Unfortunately enhanced in our jet clustering
  - Virtually 8-jet: ycut variable & thrust useful
- ttbar / W mass reconstruction
  - Many pairing background
  - Not so efficient now



Background(2) ZZZ, ZZH, ZZ

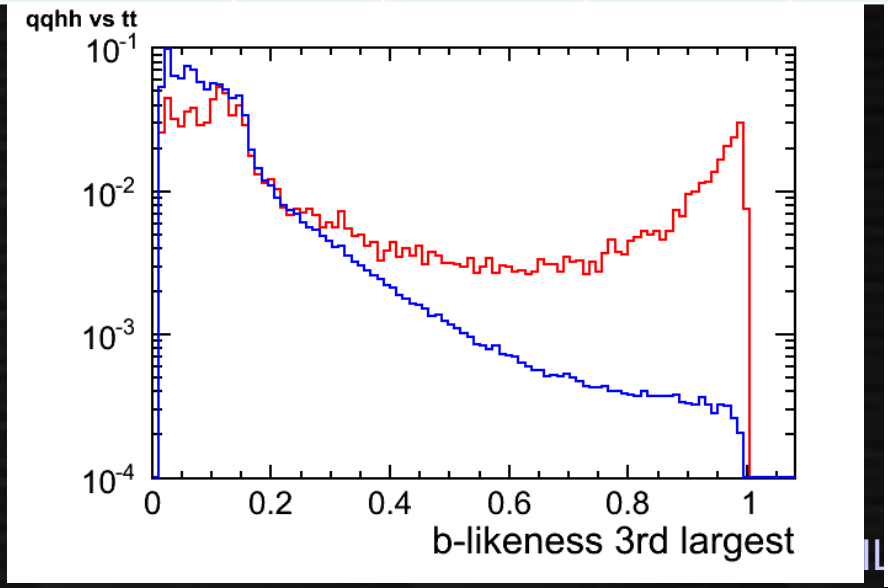
- Irriducible by b-tag for
  ZZZ -> qqbbbb, ZZh -> qqbbbb
- Separation possible by separating Z/H mass
  - Need to suppress pairing background
- ZZ, ttqq, lnbbqq
  - Not fully optimized yet in our analysis
  - Junping's result shows good separation

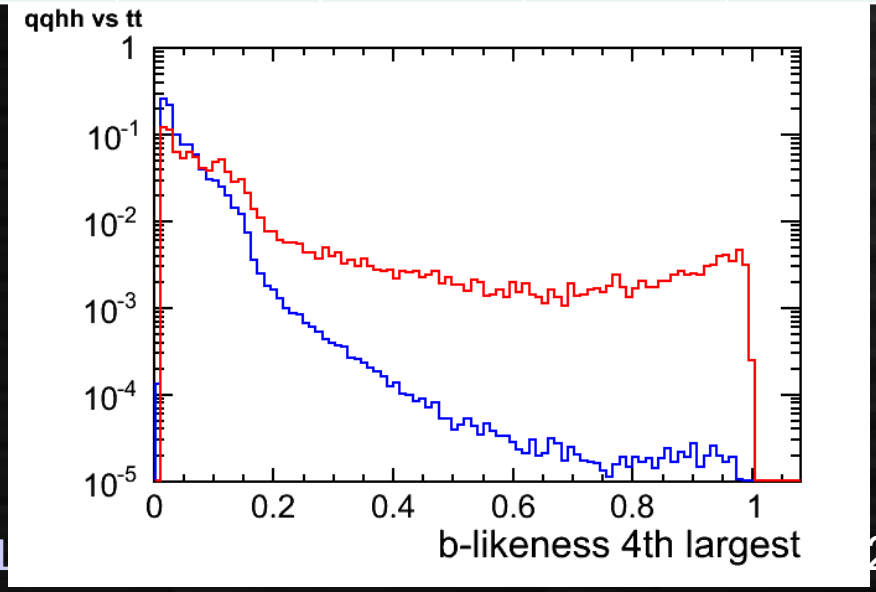


B-tag precut

Jets are sorted by descending order of b-likeness

	bbhh	qqhh	tt	ZZZ-6b	ZZZ-4b	ZZh	ttqq	bbbb
No cut	27	111	800000	12.5	146	381	2169	40824
b(2)>0.8	25	89	282493	11.5	109	152	987	28749
b(2)>0.8 b(3)>0.6	23	61	11036	10.2	71	63	263	18151
b(2)>0.8 b(3)>0.6 b(4)>0.2	21	37	2298 (880: #b=4)	9.4	43	40	153	13004

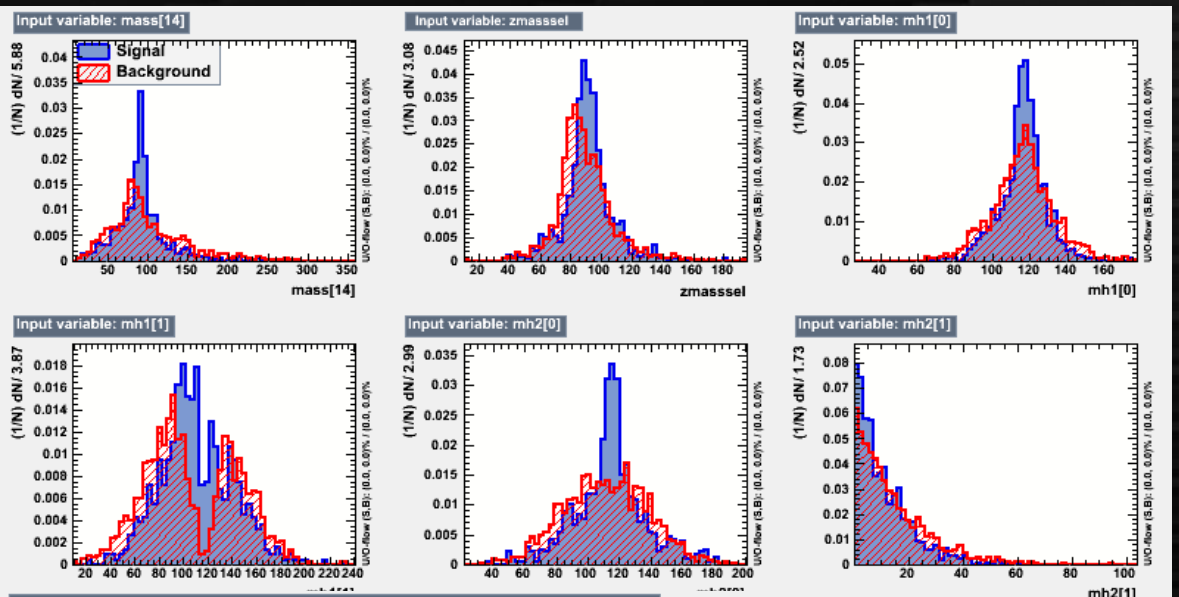


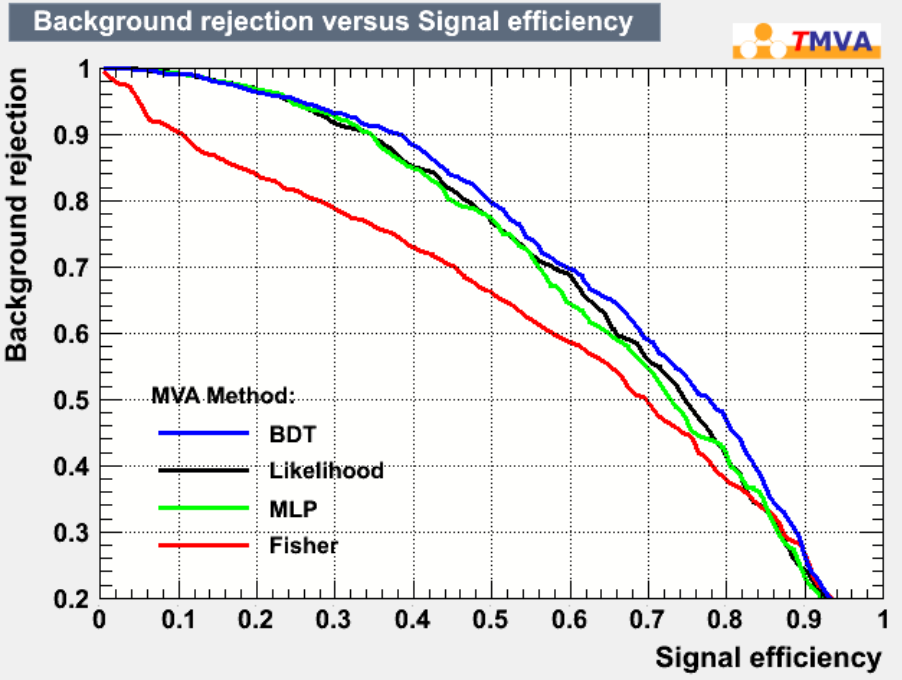


ZHH mass pairing for 4b analysis

- Jet pairing with b-tagging values
  1. Z selection
     - Examine mass of least-b-likeness 2 jets
       if m_Z +/- 10 GeV, accepted as Z candidate
     - Otherwise, 3rd least jet is examined (3 combination)
  2. Higgs selction
     - Two higgs from remaining four jets
     - Pairing using Higgs mass (nearest pair)
     - Pairing without Higgs mass (use mass difference between two jet-pairs
     - Both masses put to MVA

ZHH mass MLP





- tt, ZZH, ZZZ combined bkg.
- Moderate separation seen
- Apparently short statistics – need preselections for more…

Tentative 4b analysis result

	bbhh	qqhh	tt	ZZZ-6b	ZZZ-4b	ZZh	ttqq	bbbb
No cut	27	111	800000	12.5	146	381	2169	40824
Precut	21	37	2298 (880)	9.4	43	40	153	13004
4b part	7.5	37	2212	3.9	40	33	140	10232
Final MVA	1.7	12.6	56	0.6	6.5	10.1	14.8	-

- Unfortunately not so good result yet…
- Still have many room for improvement
  - Top mass reconstruction not successful
  - bbbb rejection (should be possible)
  - …

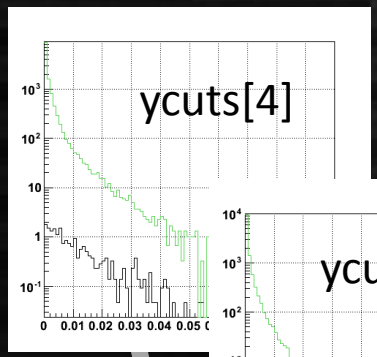
bbhh mode

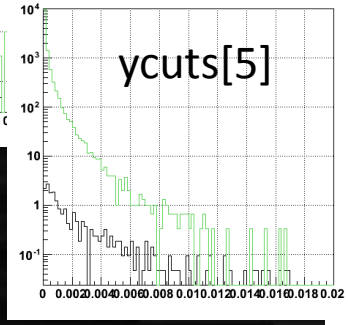
To ensure no overlap with 4b mode, apply the following selection

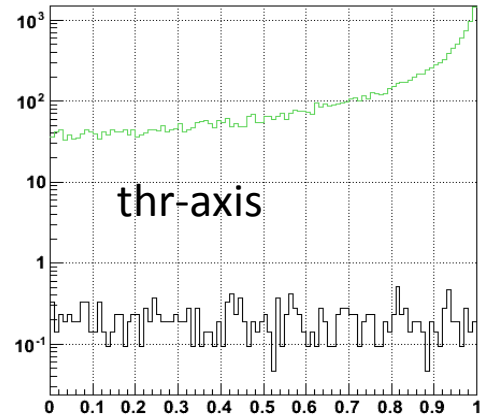
- lbbhh>0.60 (ensure no overlap with 4b mode)

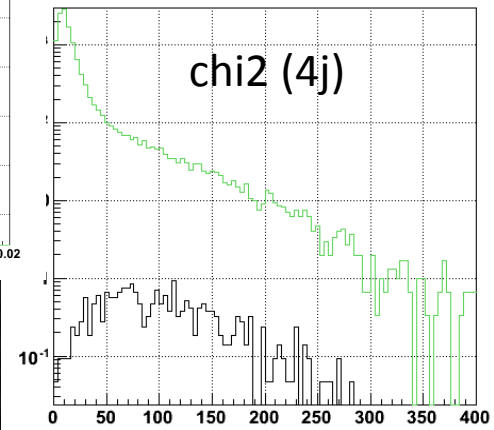
Event selection is performed using:

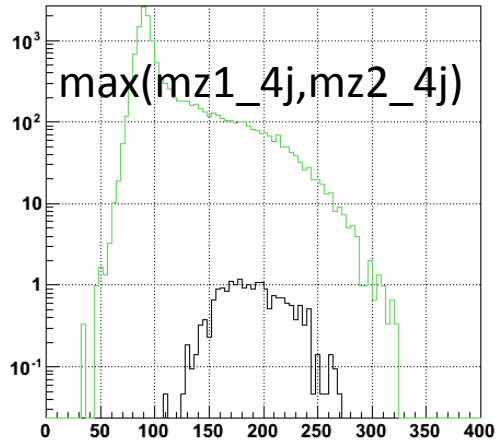
- lzhh>-0.4 && lzhh<0.05
- thrust < 0.9
- |cos θthrust |<0.95
- ycut[5]>0.00072 && ycut[5]<0.055
- chi2_4j > 15
- max(mz1_4j,mz2_4j)>100
- btag[3]>0.5 (in addition to the pre-selection)
- 90<mH1,2<140, 70<mZ<140











bbhh	11.7
qqhh	1.5
qqqqh	4.9
6f	52
zzz(4b)	1.4
zzz(6b)	2.8
ttqq	4.4
bbbb	15