Higgs Self-coupling Status and Prospects

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ZHH and ILC: our motivation

ZHH is not included in benchmark, but…

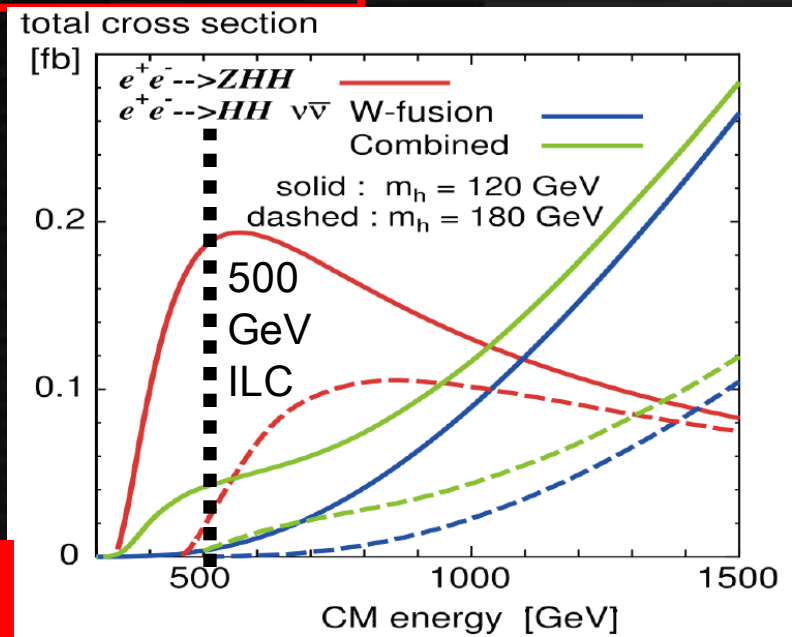
- ZHH is the only probe for the last piece of SM: Higgs Force
- LHC seems almost impossible to investigate it in case of light Higgs (even at 3000 fb^{-1})
  -> strong motivation of building 500 GeV ILC!

SM force

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

ZHH is very difficult, even in ILC…

- Extremely small cross section of 0.2fb (and half from non-self coupling diagram)
- Huge background, complicated final states, hard to separate



Have to gather effort for ZHH analysis!

Timeline for ZHH analysis

- 2001 Tesla TDR: 13% σ, 22% λ_{hhh} in 1000 fb^{-1}
  - Hard gluon treatment was wrong…
- 2008 ILD LoI: 95% σ in 500 fb^{-1}
- 2011 ILD (J. Tian): 32% σ, 57% λ_{hhh} in 2000 fb^{-1}
- Our tools development (2010 – present)
  - Vertex-based jet clustering
    - expect to raise ttbar separation performance > 10%
  - Single track vertex finder
  - LCFIPlus optimization
- First analysis using those tools are ongoing
  - started last week in fact…

Previous result by Junping

ALCPG 2011

put all together (preliminary)

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

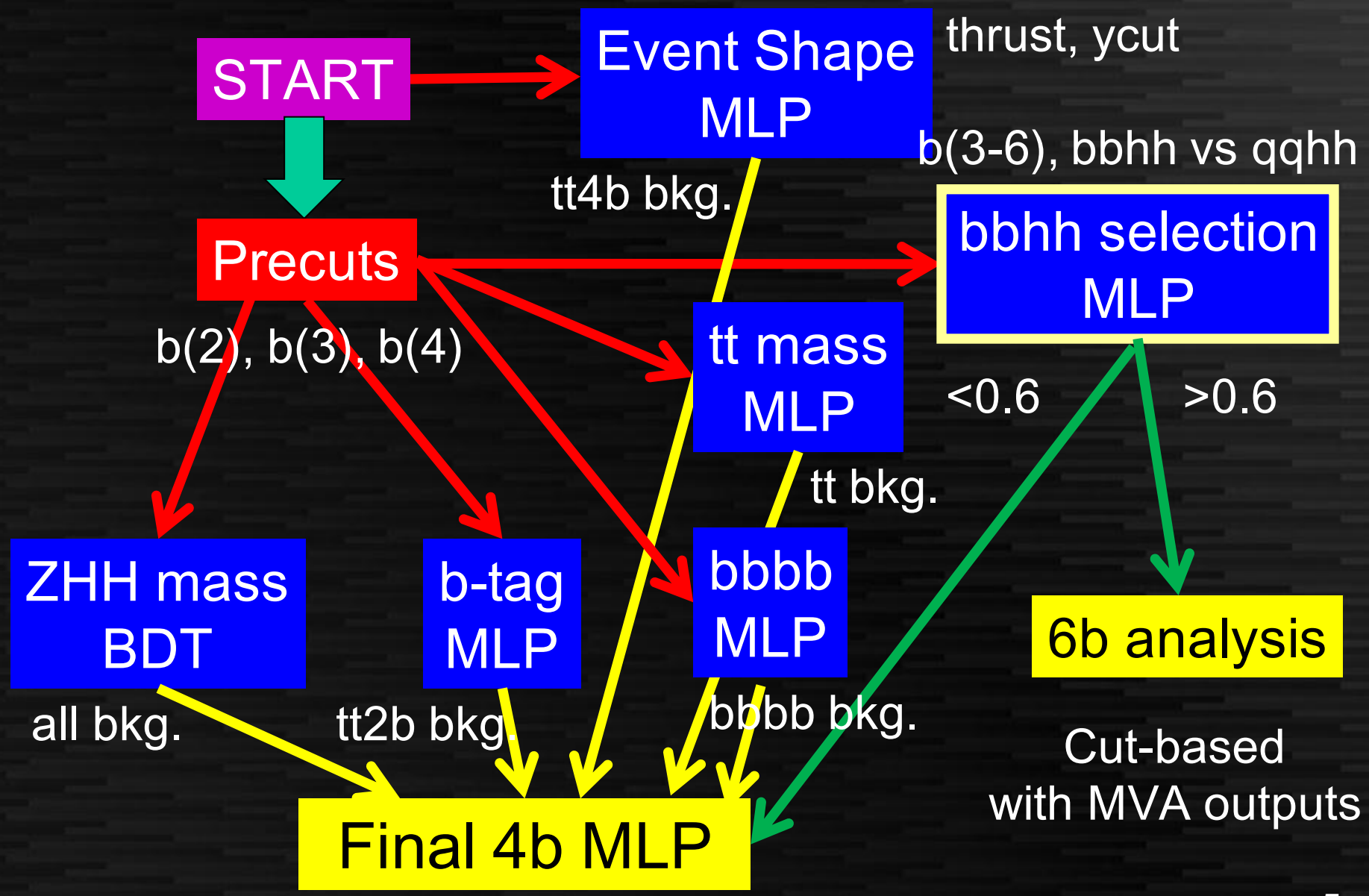
Energy (GeV)	Modes	signal	background	significance	
				excess (I)	measurement (II)
500	$ZHH \to (l\bar{l})(b\bar{b})(b\bar{b})$	6.4	6.7	2.1σ	1.7σ
500	$ZHH \to (\nu\bar{\nu})(b\bar{b})(b\bar{b})$	5.2	7.0	1.7σ	1.4σ
500	$ZHH \to (q\bar{q})(b\bar{b})(b\bar{b})$	8.5	11.7	2.2σ	1.9σ
		16.6	129	1.4σ	1.3σ

we are interested in:

A. the combined significance of ZHH excess.
B. the combined precision of measured ZHH cross section.

Current status(1)

Events are divided to 3 parts for 2-stage MVA



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 MVA1	1.4	13.8	141	0.3	4.8	9.6	23	45
Final MVA2	0.2	5.3	10.1	0.0	1.0	2.6	5.1	6.7
Final MVA3	0.1	3.1	1.7	0.0	0.4	1.2	2.4	2.0

- Unfortunately not so good result yet…
- bbbb & ttqq cuts are not optimized
  - many room for improvements
- Need better separators for ttbar

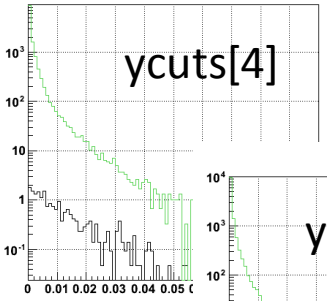
bbhh mode

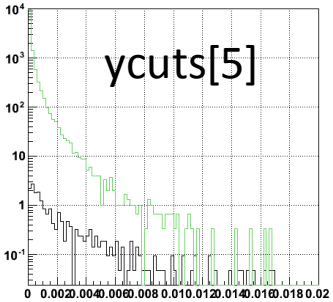
To ensure no overlap with 4b mode, apply the following selection

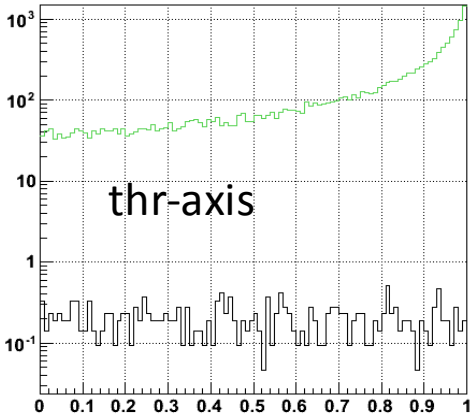
- lbbhh>0.60 (ensure no overlap with 4b mode)

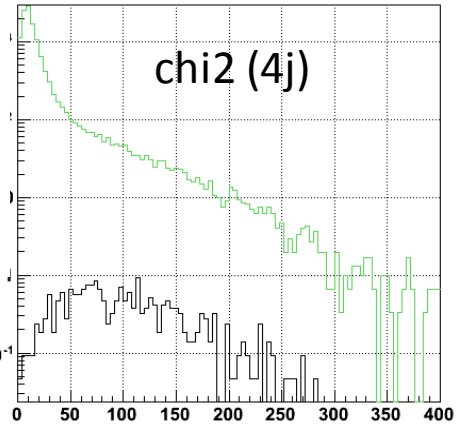
Event selection is performed using:

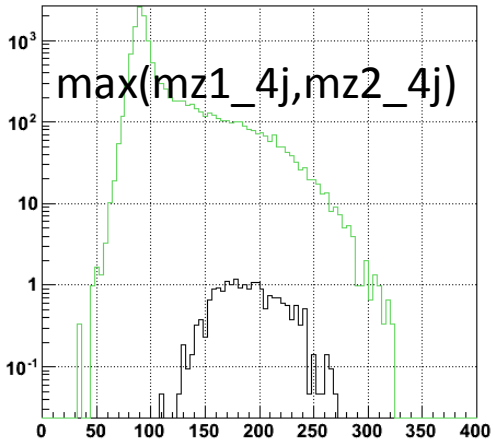
- lzhh>-0.4 && lzhh<0.05
- thrust < 0.9
- |cos θthrust |<0.95
- ycut[5]>0.00072 && ycut[5]<0.055
- chi2_4j > 15
- max(mz1_4j,mz2_4j)>100
- btag[3]>0.5 (in addition to the pre-selection)
- 90<mH1,2<140, 70<mZ<140











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

Problems in current analysis(1)

- Mokka B-baryon lifetime fix
  - B-baryons immediately decay in LoI sample
    - B-baryon fraction: ~10% of all b decay
  - Suffers much in 4b/6b counting

	bbhh	bbhhnew	qqhh	qqhhnew	tt	ZZZ-6b	ZZZ-4b	ZZh
Final MVA1	1.4	1.5	13.8	20.8	141	0.3	4.8	9.6
Final MVA2	0.2	0.5	5.3	8.8	10.1	0.0	1.0	2.6
Final MVA3	0.1	0.2	3.1	5.1	1.7	0.0	0.4	1.2

Significant! (~50%)

Need to re-produce all samples!!
…or use B-baryon cut in MC … may cause bias

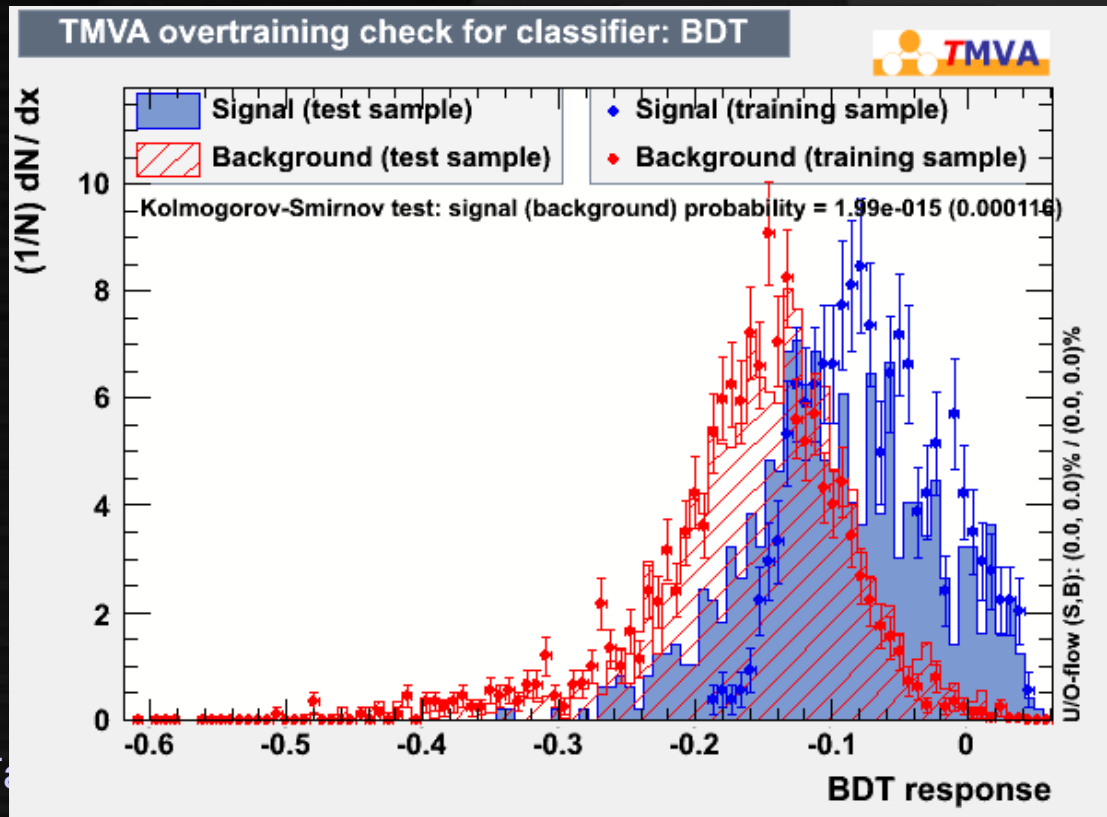
Problems in current analysis(2)

- We use a b-dependent variables to be included in MVA (eg. masses in flavor-constrained jet pairing)
  - Need precut with b-tagging

-> Statistics limited (now O(1000))

  - MVA training is not sufficient

Need more samples for powerful MVA



Samples needed

Mainly needed for MLP/BDT training:

- Signal (ZHH): < 1M, easy
- ZZH, ZZZ, ttqq, bbbb, ZH: < 1M, easy
- ttbar – largest problem, may need ~10M
  - Statistics needed because precut of b-tag reduces ttbar sample to ~0.1% before training
- If we include H->WW*, need other events

Since it is not benchmark, we plan to run simulation on these samples in new KEKCC locally
(now ~1000 cores usually available, ~2000 in weekend)
But may need more generator samples…

Prospects

- Many other ideas for improvements
  - g->bb suppression cuts (main bkg. in ttbar)
  - Jet clustering/pairing ideas
    - Color Singlet clustering
    - Mass Constrained clustering
    - Kinematic fit
  - ZVKIN
  - H -> WW* inclusion
  - Vertex charge

We hope we can fix new result in 2-3 months

Backup

Recent progress (1) jet clustering

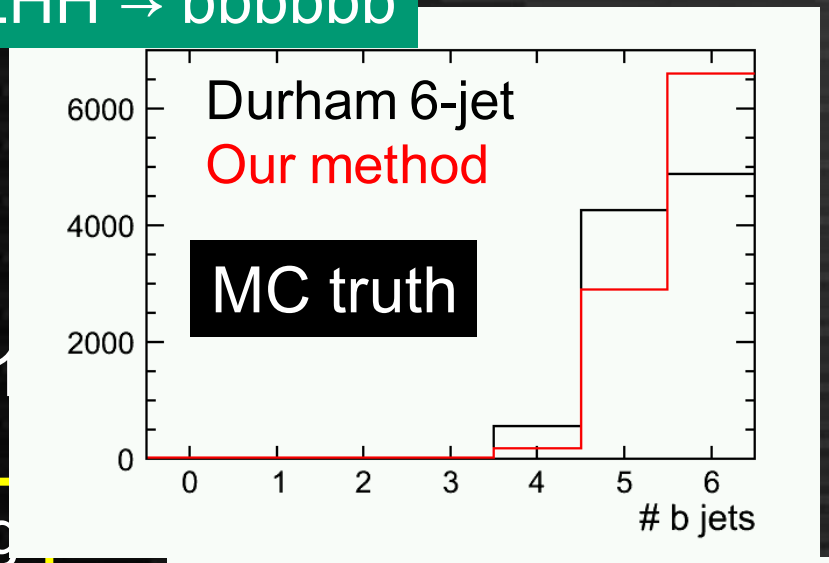
Multi-jet environment

- presence of low energy jets
- Hard gluon emission

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

→ degradation in b-counting

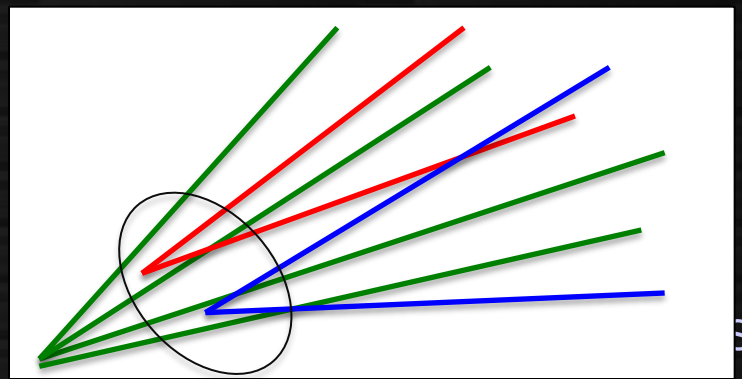
ZHH → bbbbbb

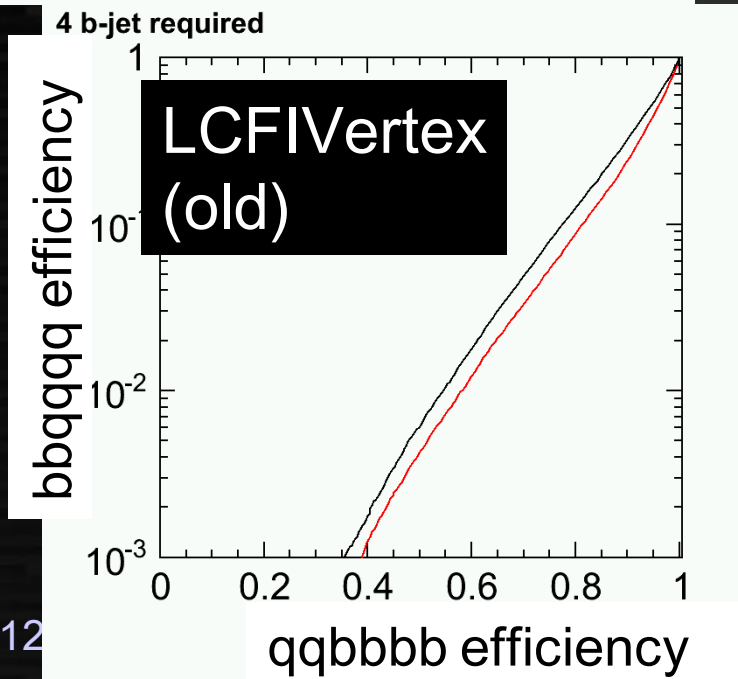


Jet clustering based on vertex finding

- Avoid combining jet-seeds with vertices into one jet

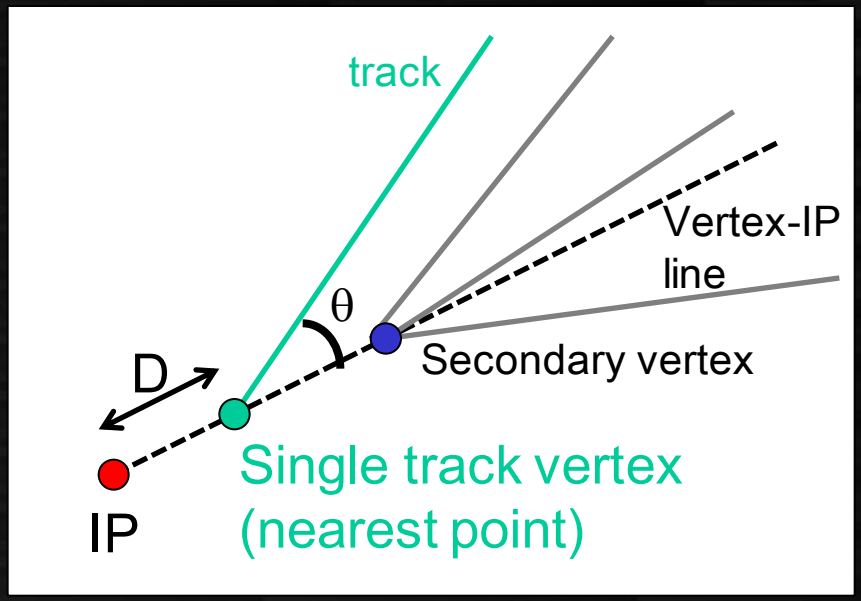
→ b-counting efficiency improved





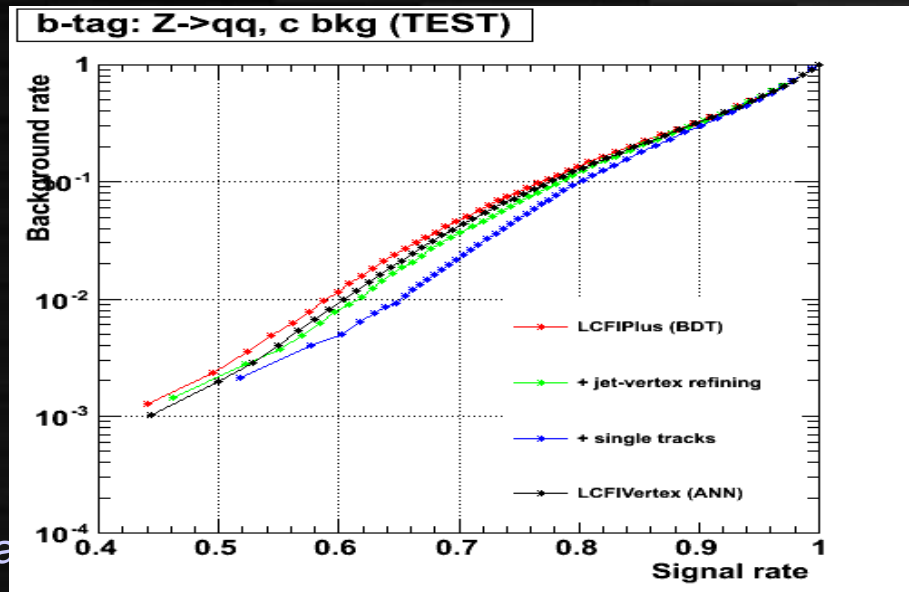
Suehara, TILC12

Progress (2) Single track vertex



- Normal vertex finder needs > 2 tracks
  -> loose many vertices
- Single track vertex can be found by using other vertex direction
- Improves b-tagging performance

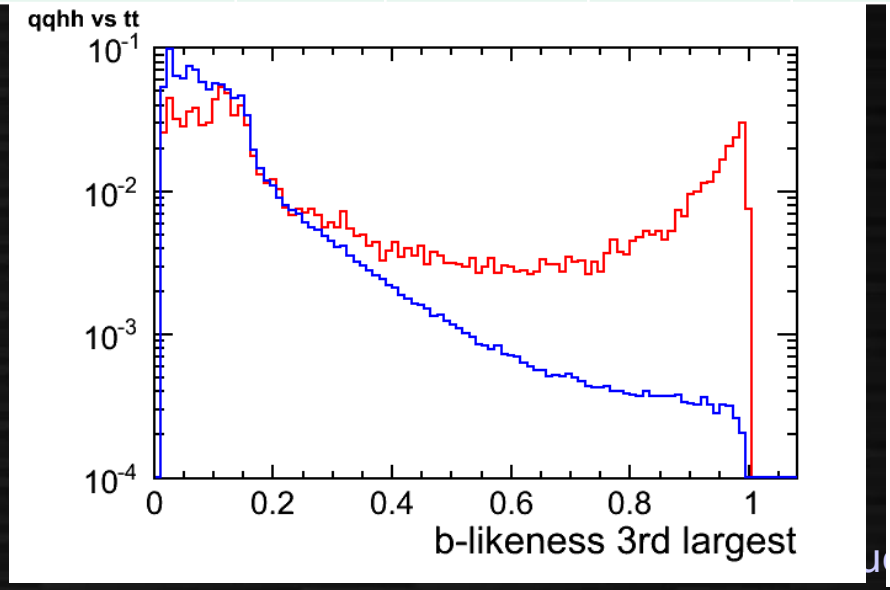
Event	0 vtx	1 vtx	>= 2 vtx
bb normal	322	1052	426(24%)
bb +single	322	459	1019(57%)
cc normal	1003	779	18(1.0%)
cc +single	1003	715	82(4.6%)

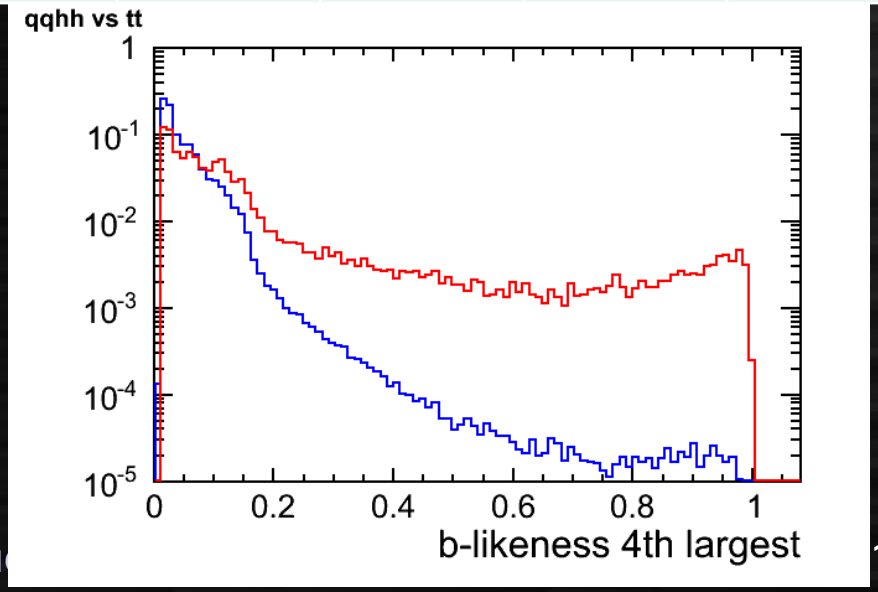


B-tag precut

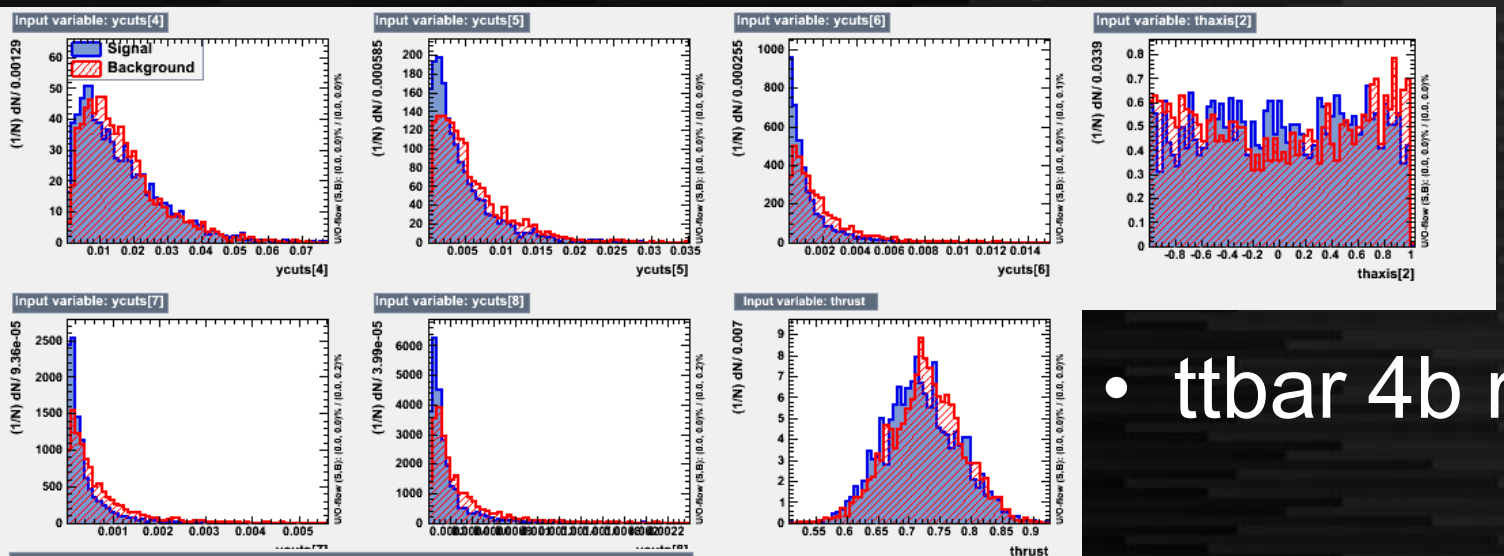
Jets are sorted by descending order of b-likeness

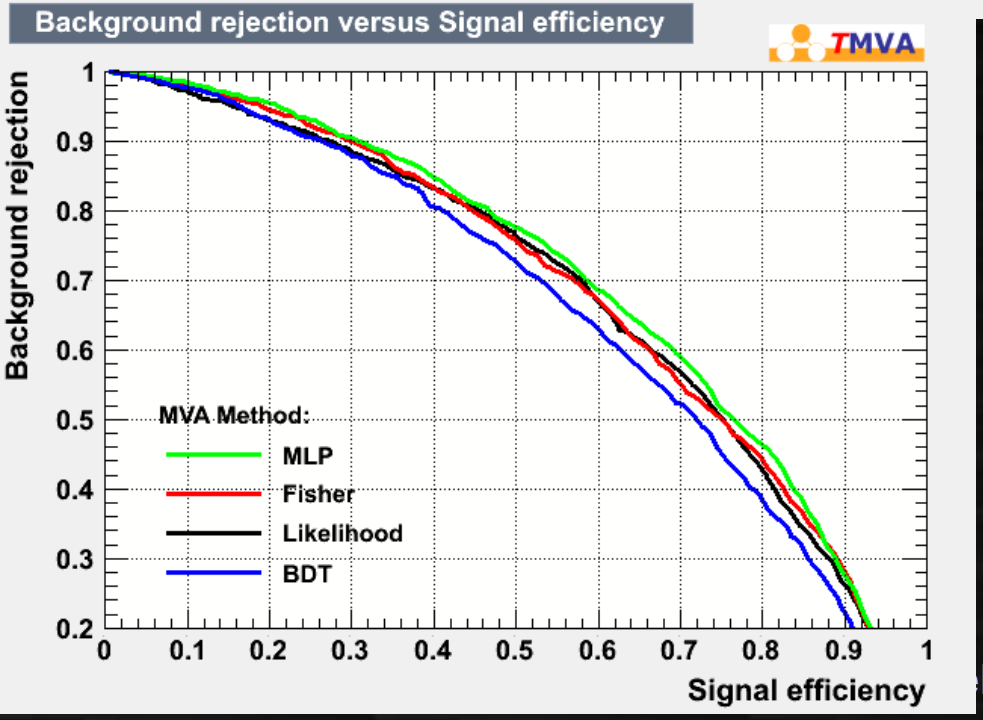
	bbhh	qqhh	tt	ZZZ-6b	ZZZ-4b	ZZh	ttqq	bbbb
No cut	27	111	800000	12.5	146	381	2169	40824
b(2)>0.8	25	89	282493	11.5	109	152	987	28749
b(2)>0.8 b(3)>0.6	23	61	11036	10.2	71	63	263	18151
b(2)>0.8 b(3)>0.6 b(4)>0.2	21	37	2298 (880: #b=4)	9.4	43	40	153	13004





Event shape MLP



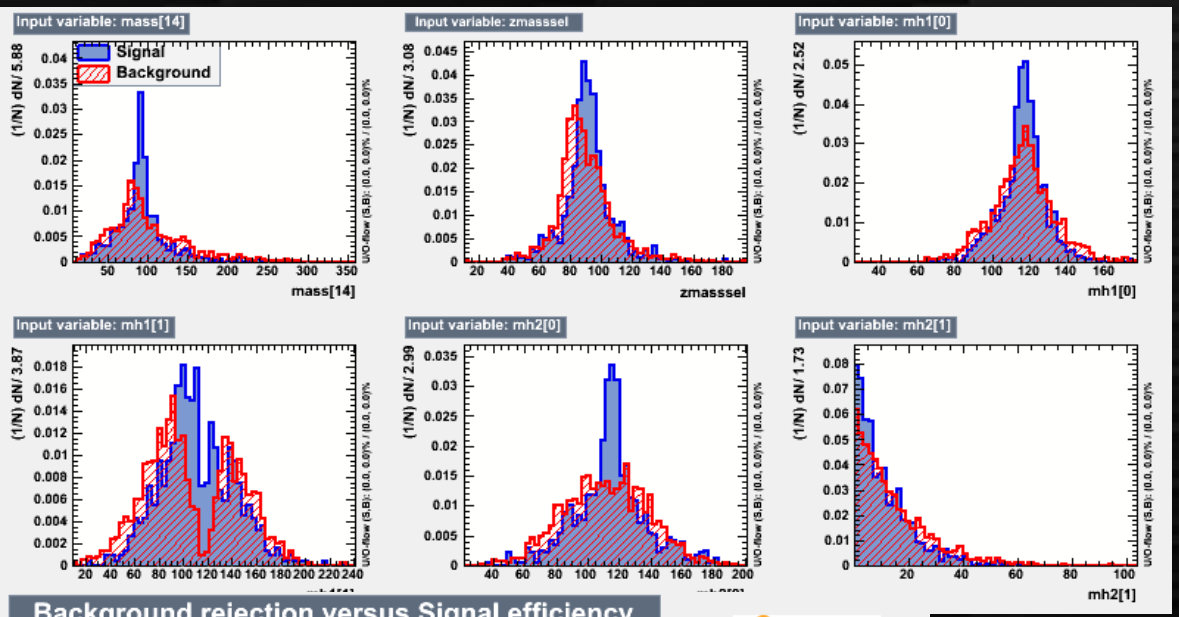


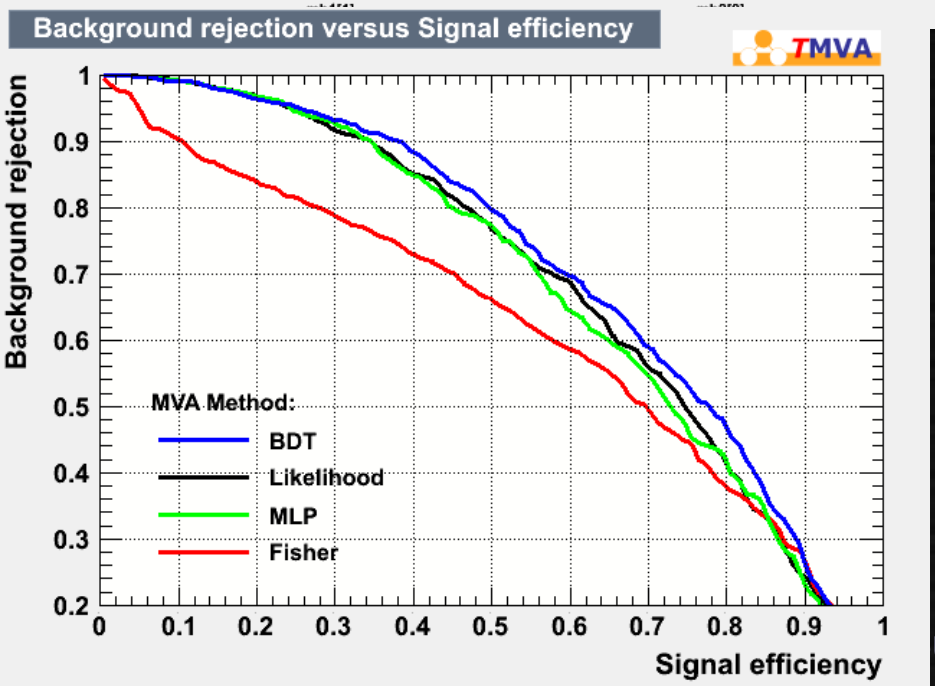
- ttbar 4b rejection
- Jet clustering y threshold (4,5,6,7,8 jet)
- thrust
- Z thrust axis

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…