# Study of Higgs Self-coupling at ILC

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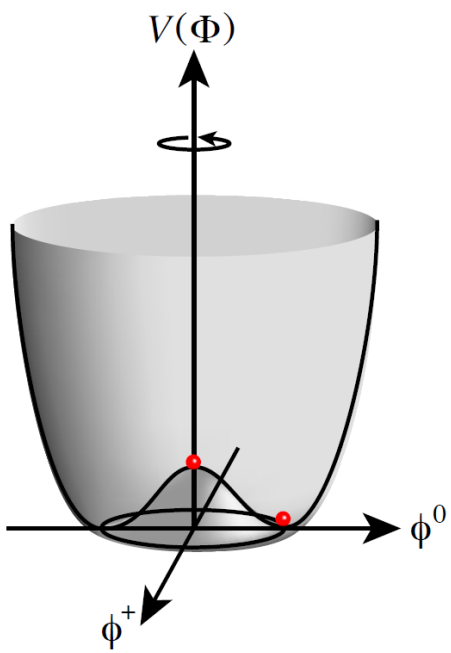
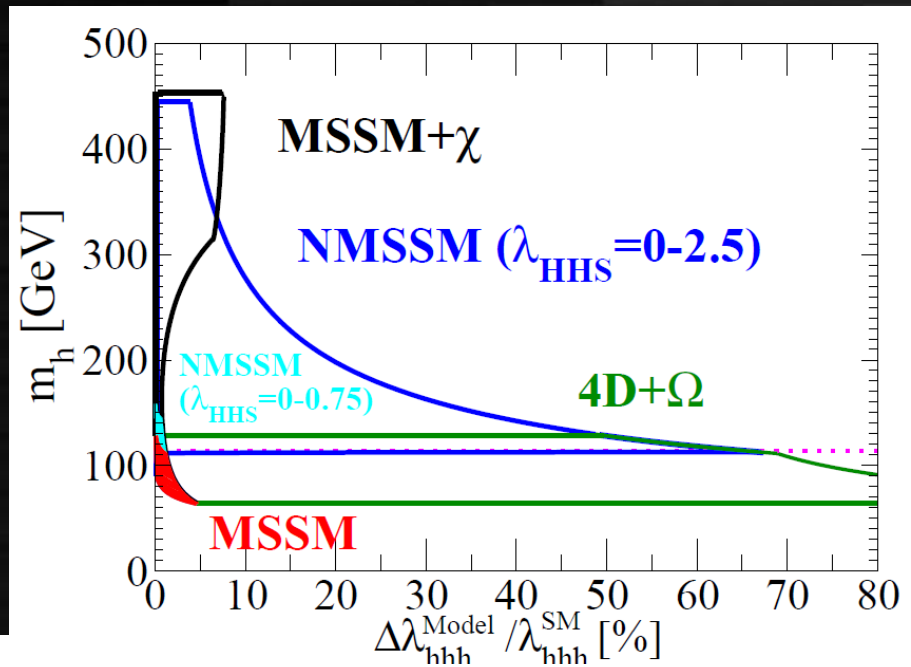
# The only probe for Higgs potential: self coupling

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

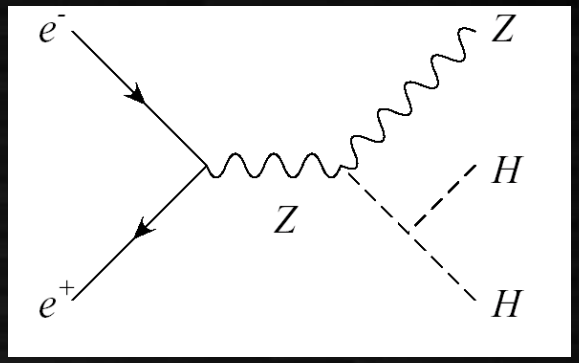


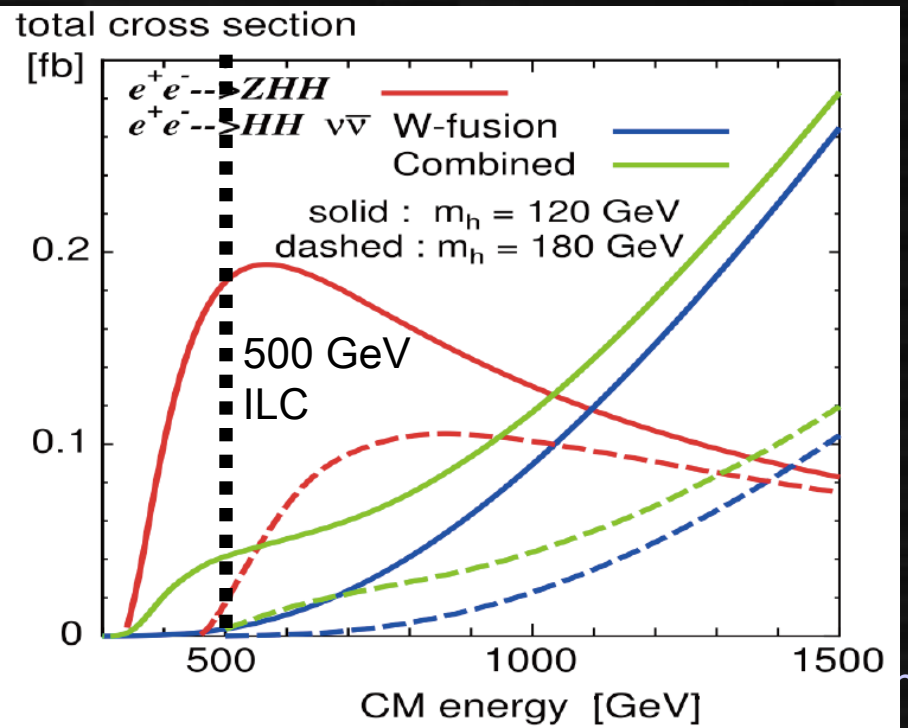

$$V(\Phi) = \mu^2|\Phi|^2 + \lambda|\Phi|^4 + \text{h.c.}, \qquad \mu^2 < 0, \lambda > 0$$

ra, 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!

# Recent progress in reconstruction

- Jet clustering with vertex
- Single track vertex finder for b-tagging

- Issue fixed in MC simulation
  B-baryon life is set to 0 in LoI samples
  -> degrades b-tagging efficiency

# Recent progress (1) jet clustering

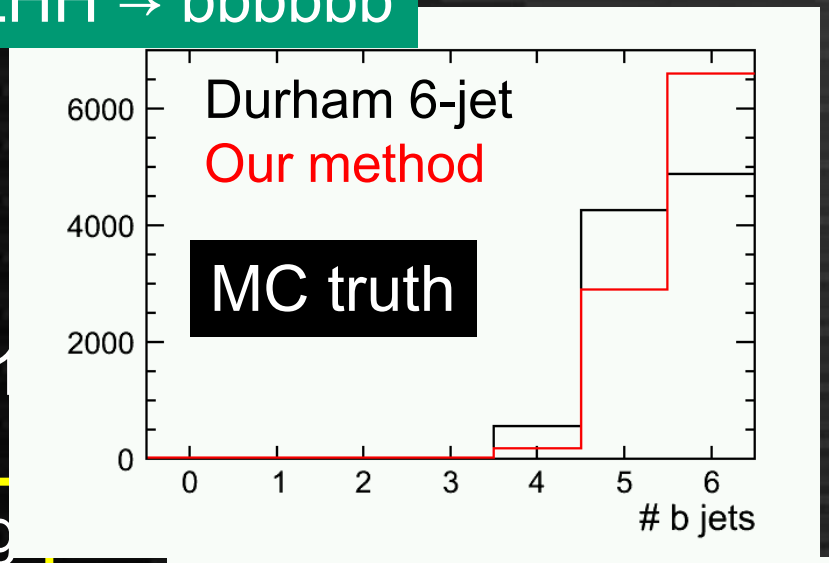
Multi-jet environment

- presence of low energy jets
- Hard gluon emission

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

→ degradation in b-counting

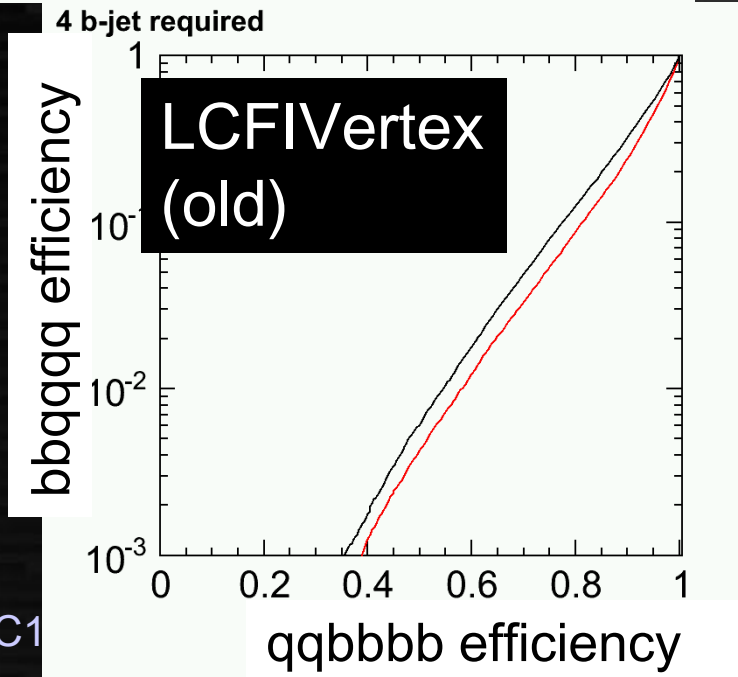
ZHH → bbbbbb

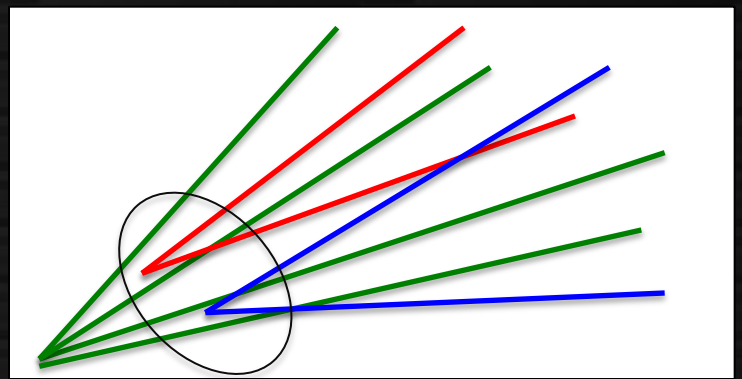



Jet clustering based on vertex finding

- Avoid combining jet-seeds with vertices into one jet

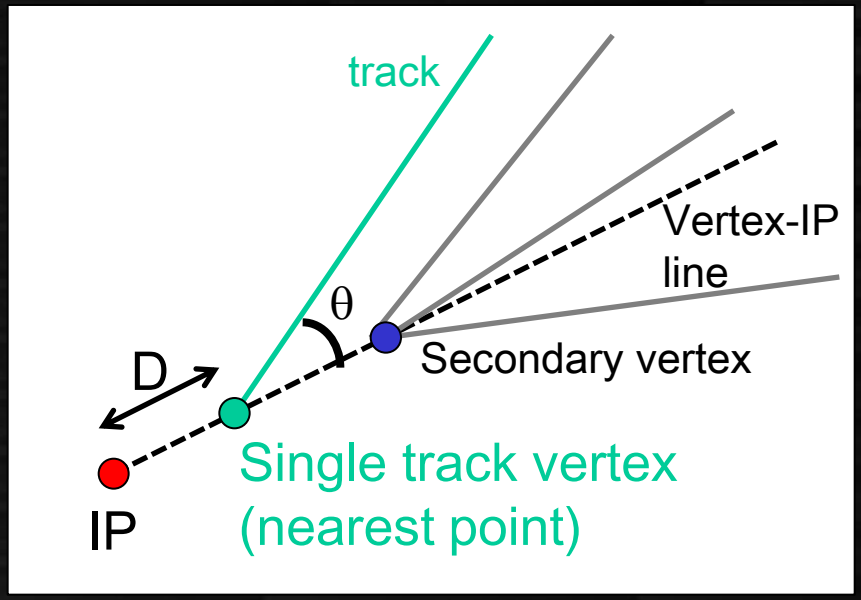
→ b-counting efficiency improved



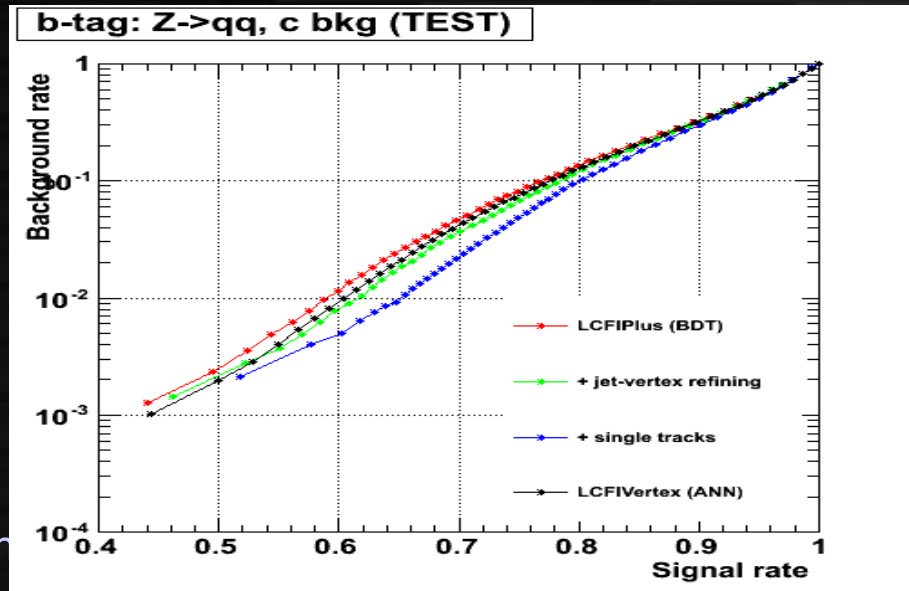
Suehara, TILC1

# 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%) |



# Analysis revived … last week

- With new tools
- Optimization efforts for jet-pairing
- (LoI sample now – without B-baryon fix)

- Non-final result: still has
  many rooms for improvements

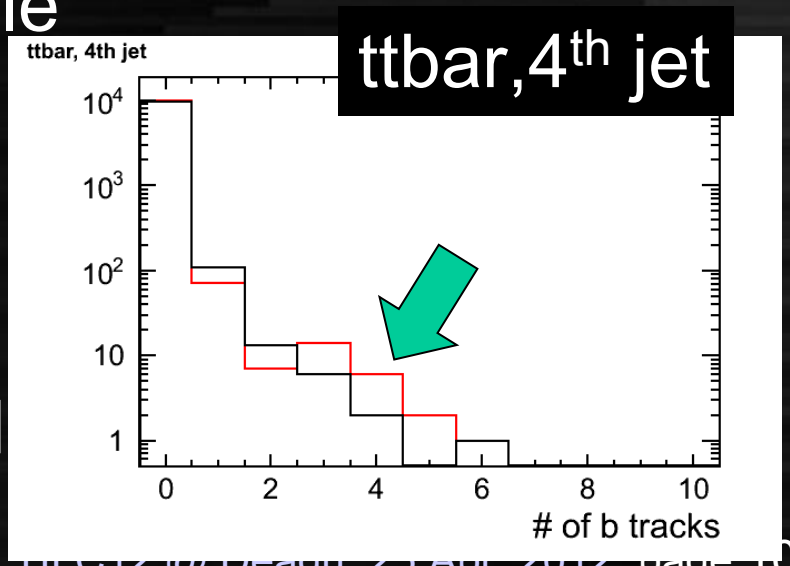
# ZHH analysis – basic strategy

- 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

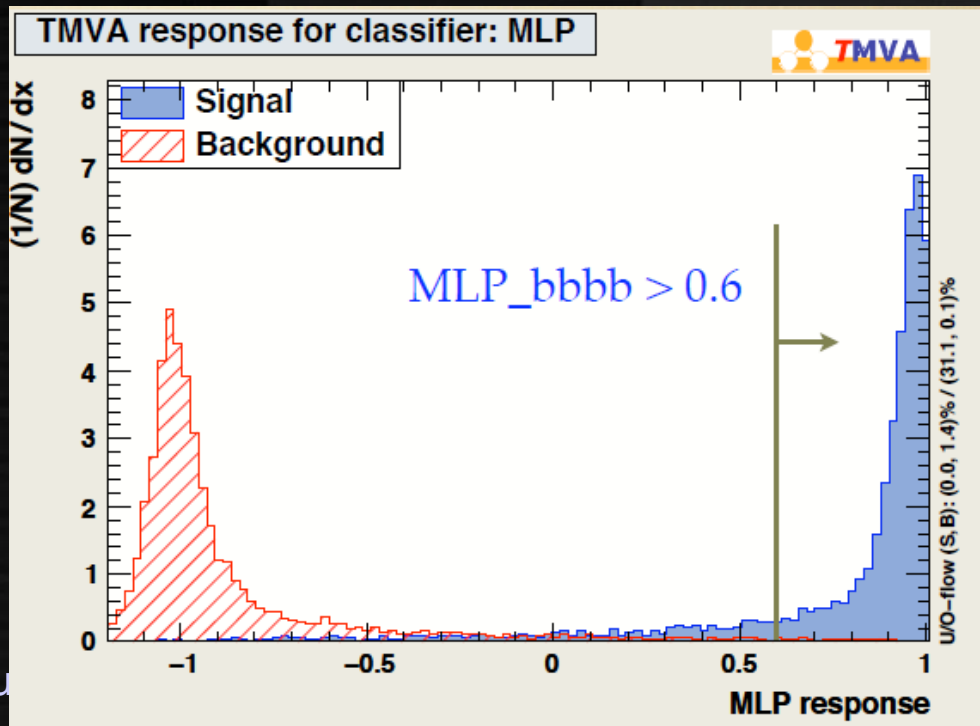
# Background (1) ttbar

- 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

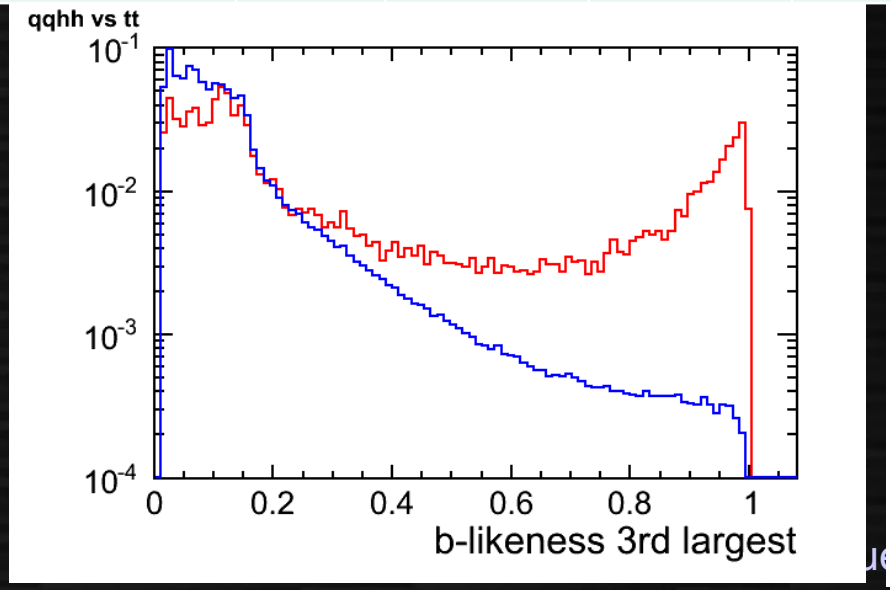
- Irriducible by b-tag for
  ZZZ -> qqbbbb, ZZh -> qqbbbb
- Separation possible by separating Z/H mass
  - Need to suppress pairing background
- ZZ, ttqq, lnbbqq
  - Not fully optimized yet in our analysis
  - Junping's result shows good separation

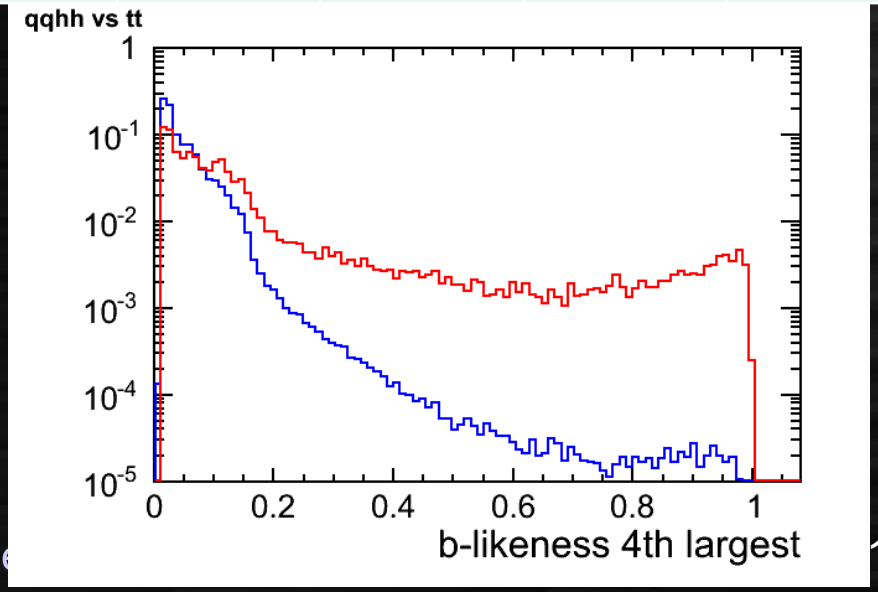


# B-tag precut

Jets are sorted by descending order of b-likeness

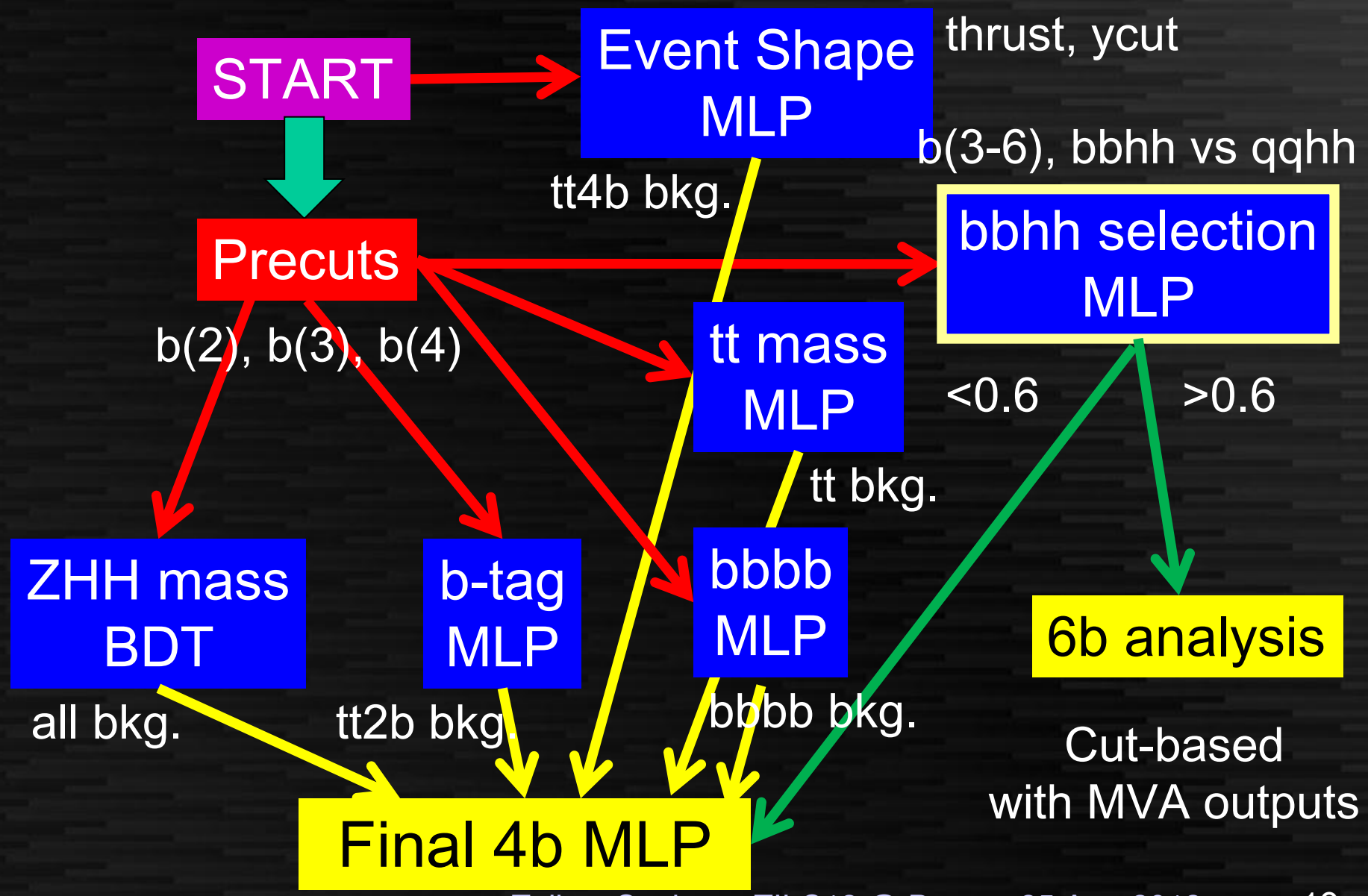
| | bbhh | qqhh | tt | ZZZ-6b | ZZZ-4b | ZZh | ttqq | bbbb |
|---|---|---|---|---|---|---|---|---|
| No cut | 27 | 111 | 800000 | 12.5 | 146 | 381 | 2169 | 40824 |
| b(2)>0.8 | 25 | 89 | 282493 | 11.5 | 109 | 152 | 987 | 28749 |
| b(2)>0.8<br>b(3)>0.6 | 23 | 61 | 11036 | 10.2 | 71 | 63 | 263 | 18151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



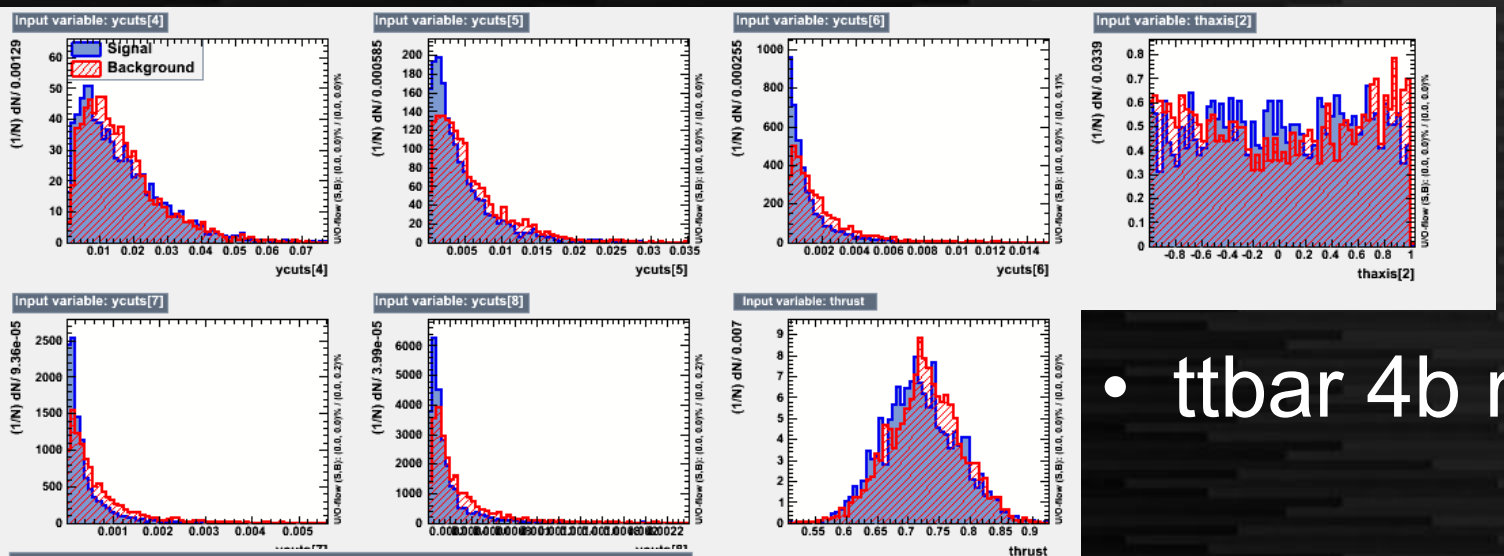



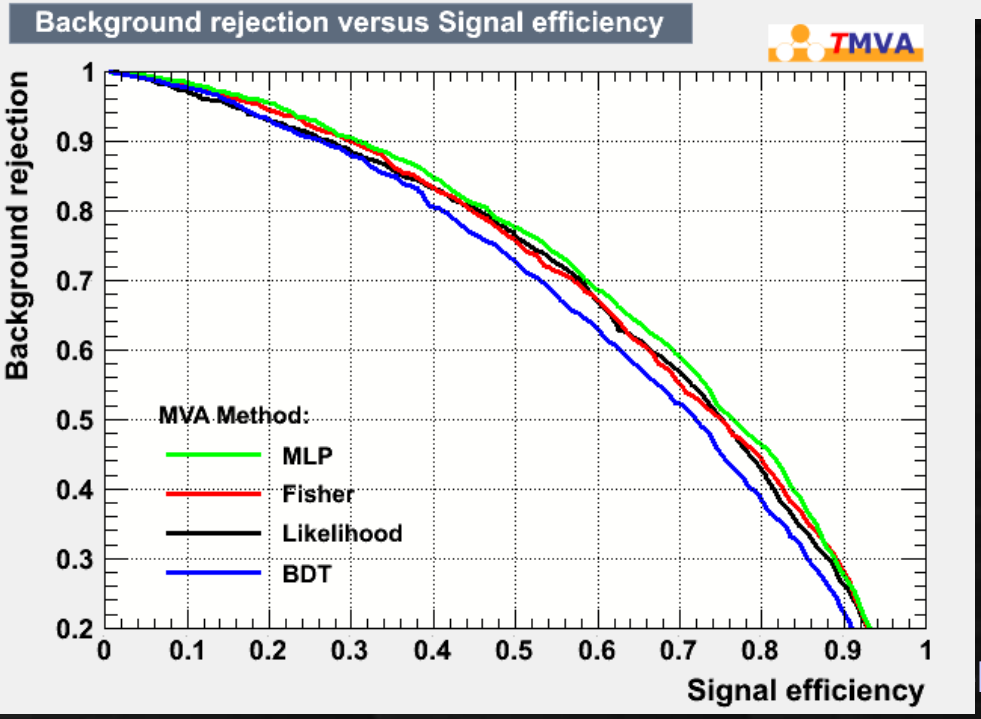
# Selection overview

Events are divided to 3 parts for 2-stage MVA



# Event shape MLP



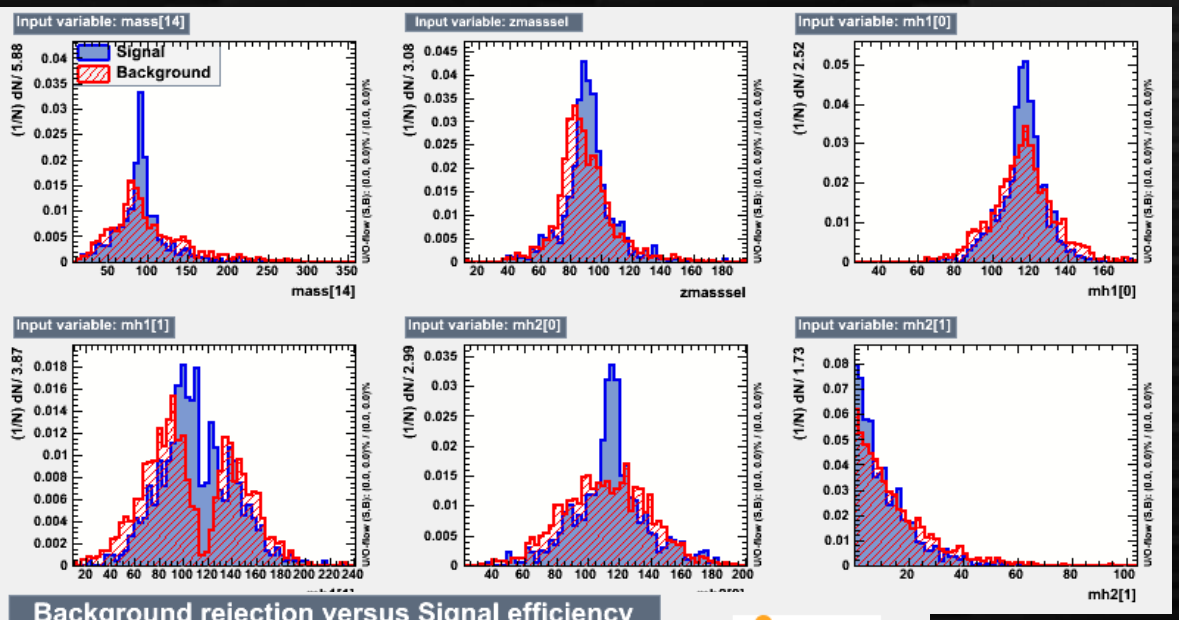



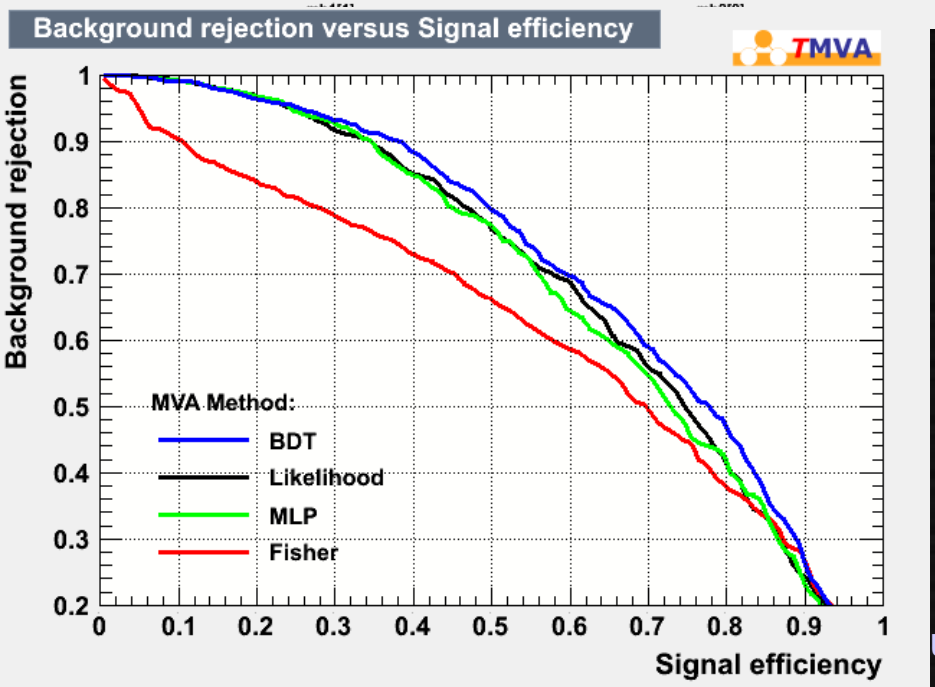

- ttbar 4b rejection
- Jet clustering y threshold (4,5,6,7,8 jet)
- thrust
- Z thrust axis

# 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…

# 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)
  - …

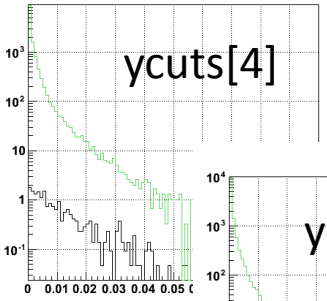
# bbhh mode

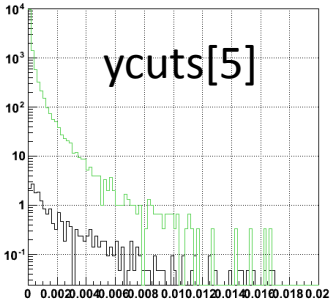
To ensure no overlap with 4b mode, apply the following selection

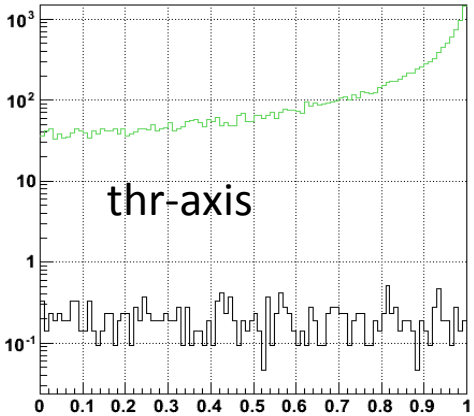
- lbbhh>0.60 (ensure no overlap with 4b mode)

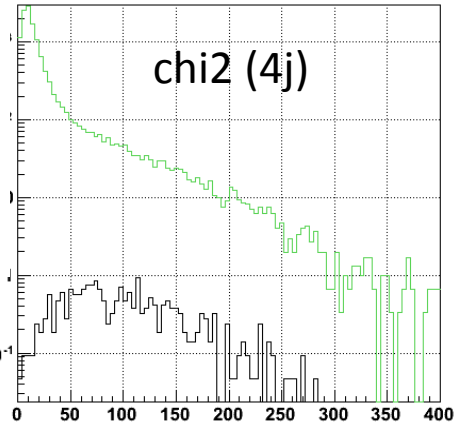
Event selection is performed using:

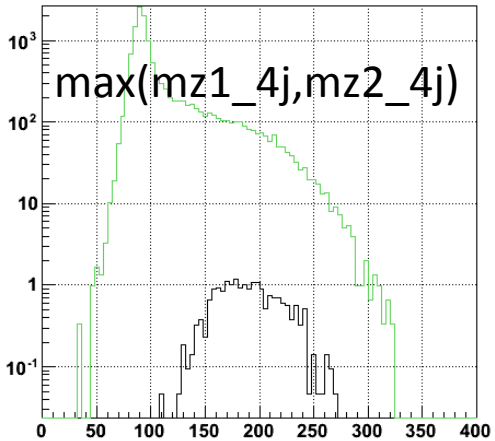
- lzhh>-0.4 && lzhh<0.05
- thrust < 0.9
- |cos θthrust |<0.95
- ycut[5]>0.00072 && ycut[5]<0.055
- chi2_4j > 15
- max(mz1_4j,mz2_4j)>100
- btag[3]>0.5 (in addition to the pre-selection)
- 90<mH1,2<140, 70<mZ<140




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

# Prospects

- Many things to do…
  - More training sample (significant)
  - Mokka B-baryon fix incorporation (significant)
  - Color Singlet clustering
  - Mass Constrained clustering
  - Kinematic fit
  - ZVKIN
  - H -> WW* inclusion
  - Vertex charge
  - and so on….

# Summary

- After developing jet clustering and vertex finder, we got a first step to incorporate those improvements to real ZHH analysis.
- Intense 1-week 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!