Status of tth analysis

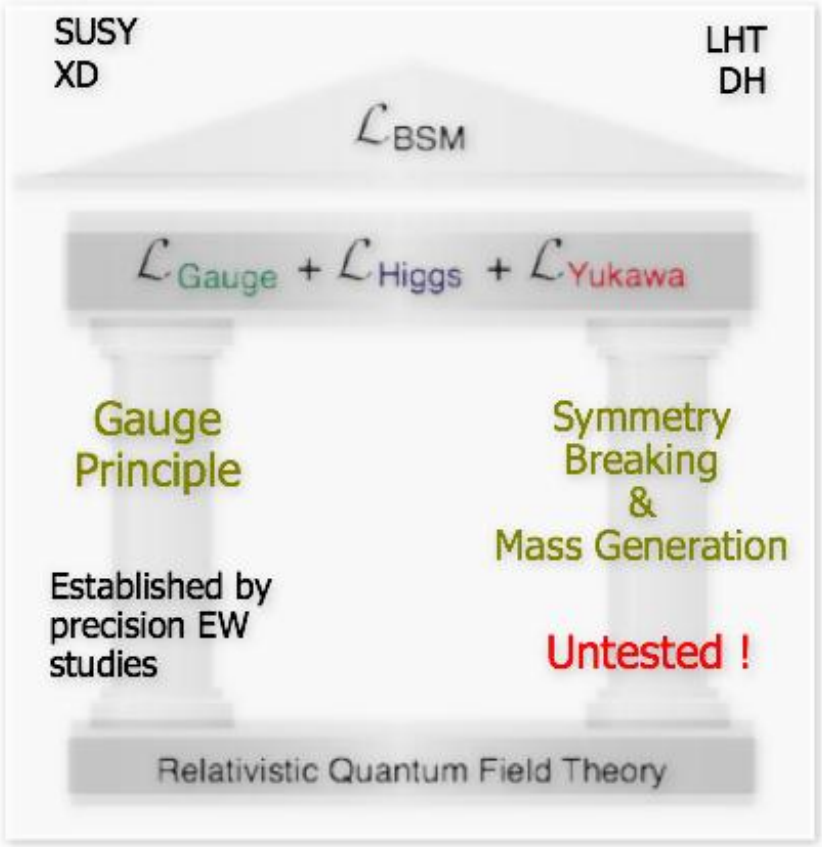
1. √s=500 GeV
2. √s=1 TeV
3. MC requests

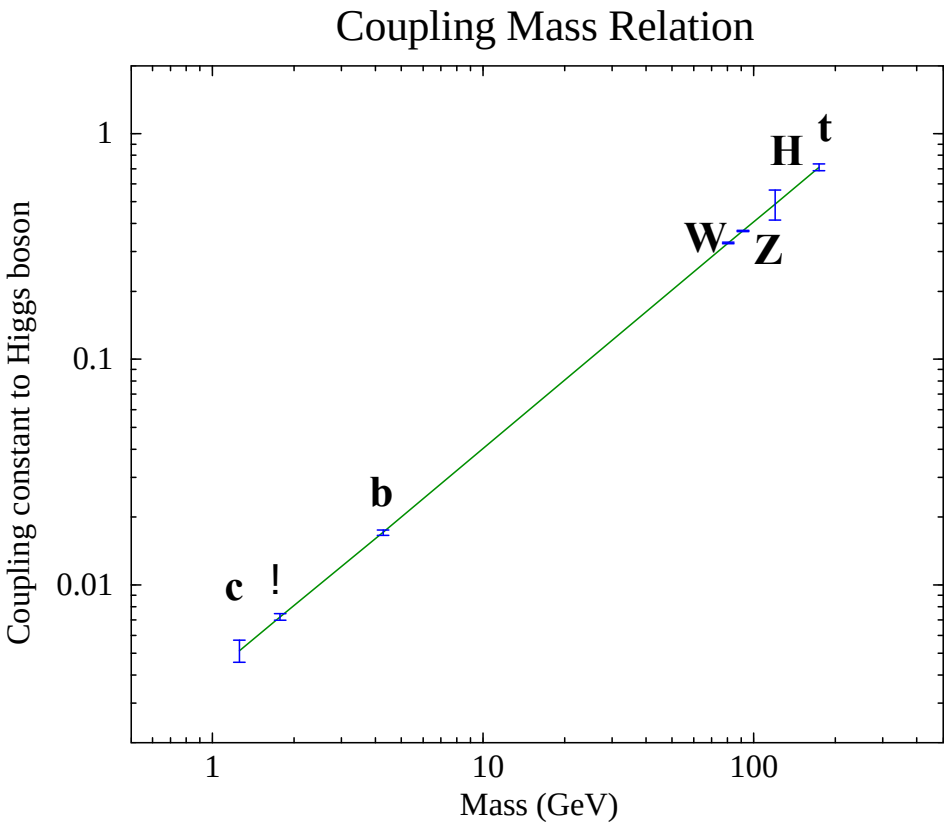
R. Yonamine, **T. Tanabe**, K. Fujii
T. Price, H. Tabassam, N. Watson, V. Martin

ILD Workshop, Kyushu University
May 23, 2012

Main Motivations

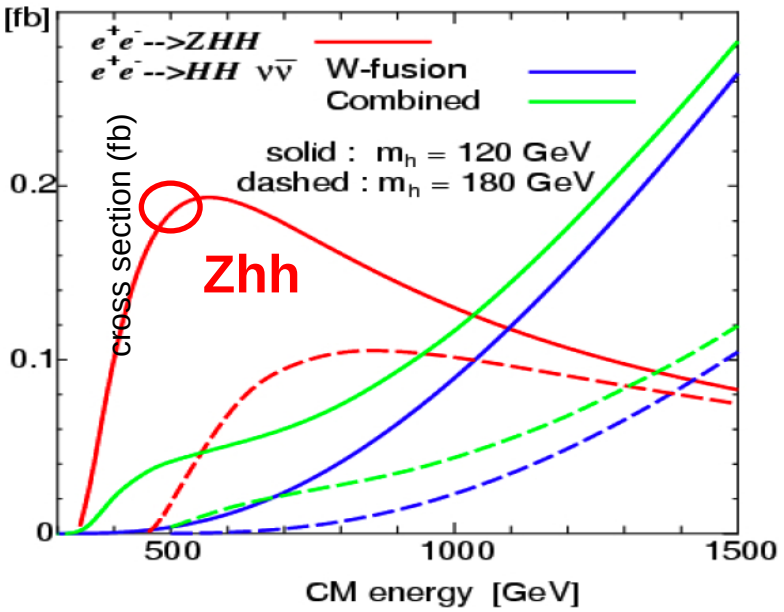
- We must verify the origin of **EWSB** and the **mass generation** mechanism, which must be done before BSM physics can be established.
- Given the hint of a light Higgs at the LHC (we will assume mh=120 GeV), ILC becomes an ideal probe for measuring the Higgs couplings to the gauge bosons and fermions. Our focus: **top Yukawa coupling.**

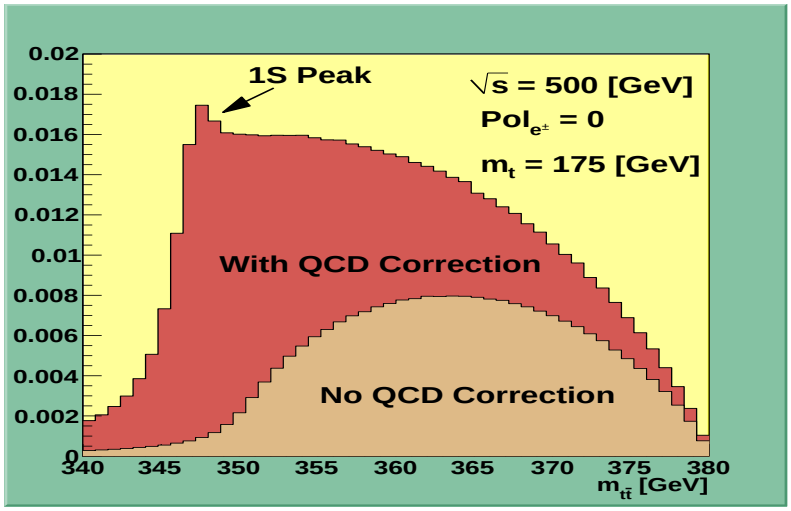


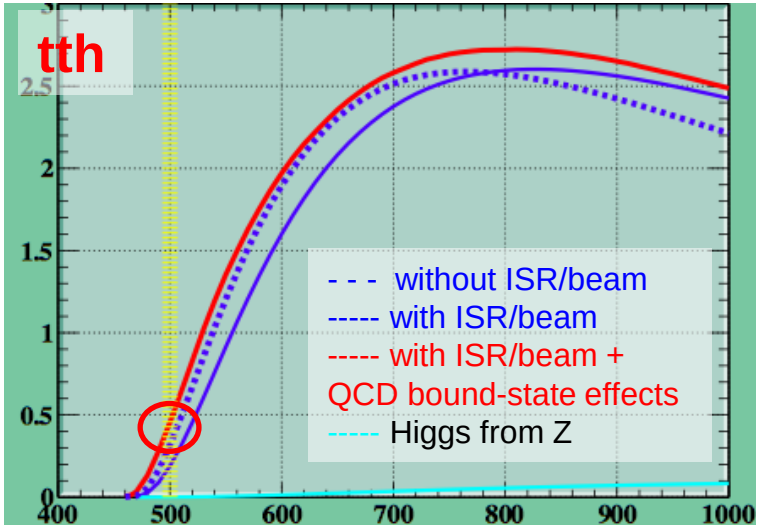


Motivations at √s=500 GeV

- Well-known energy thresholds for ILC:
  - **250 GeV: Zh** (m_h=120 GeV)
  - **350 GeV: top pair**
  - **500 GeV: Zhh & tth**
- y_t measurement possible at 500 GeV due to **QCD bound-state effects** (enhancement near the production threshold)
- Fast simulation result: **10% statistical precision on y_t** [Phys. Rev. D 84, 014033 (2011)]
  - Next: full simulation to increase confidence



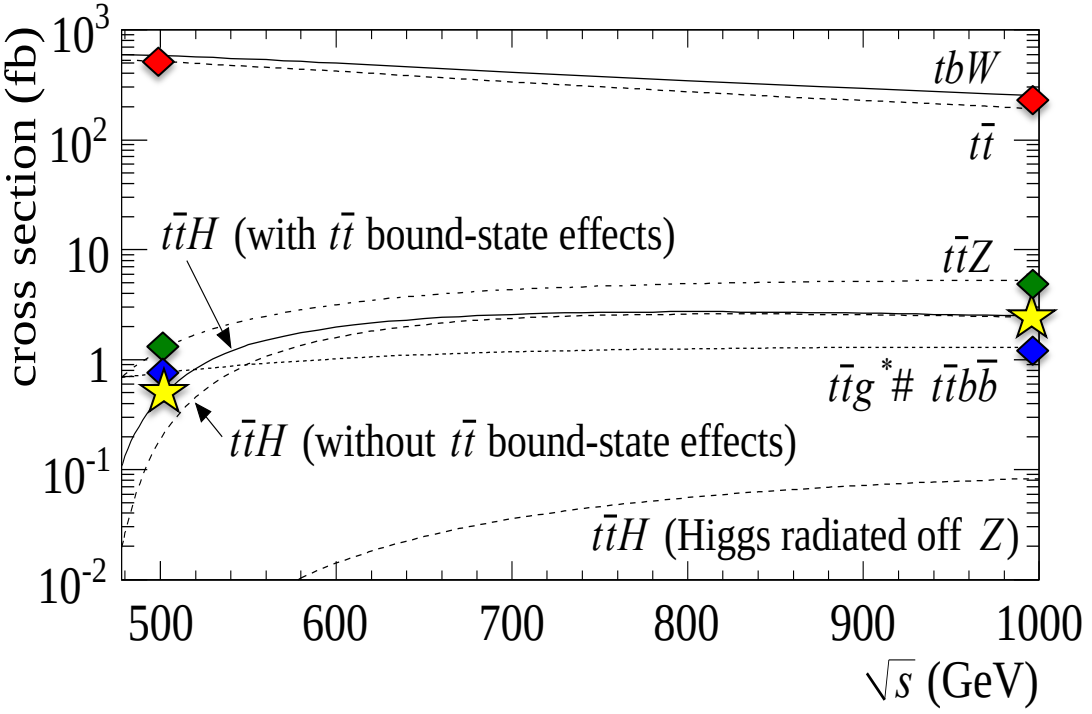




Note: ttZ is also enhanced. But ttg* is not enhanced because tt system is not a color singlet.

Signal & background

- **Signal:**
  - ★ **tth → bWbWbb**
    - 6 jet + lepton mode
    - 8 jets mode
- **Main backgrounds:**
  - ◆ **ttg* → ttbb → bWbWbb**
  - ◆ **ttZ → ttbb → bWbWbb**
  - ◆ **tt → bWbW**
  - – off-resonant contributions important !



Motivations at √s=1 TeV

- **Detector benchmark process for DBD**
- Should be better measurement at higher energy:
  - – Signal cross section increases (peaks around 800 GeV)
    - (QCD bound-state effects become negligible)
  - – ttZ and ttg*→ttbb also increase but **tt → bWbW decreases**

Software tools

	500 GeV	1 TeV
Event Generator	tth, ttZ, ttg*→ttbb: physsim	
	tt: LOI 6f (Whizard)	**STILL MISSING !**
Detector Simulation	Geant4 9.3p02 Mokka 07-06-p02	Geant4 9.5 Mokka 07-07-p06
Detector Model	ILD_00	ILD_o1_v0X
Event Reconstruction	LOI reconstruction: PandoraPFA SatoruJetFinder LCFIVertex	ilcsoft v01-13-05: PandoraPFANew MarlinFastJet LCFIVertex

Still using old tools/samples in some places.
They will be updated to the validated tools for DBD.

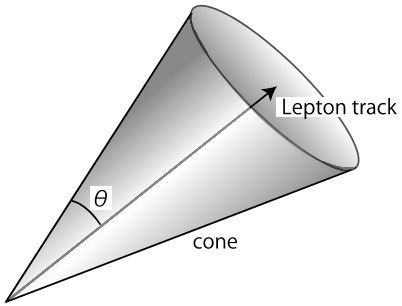
Analysis Conditions

Target luminosity: 1 ab-1 (both 500 GeV and 1 TeV)
Polarizations: nominal polarizations (-0.8,+0.2-0.3)

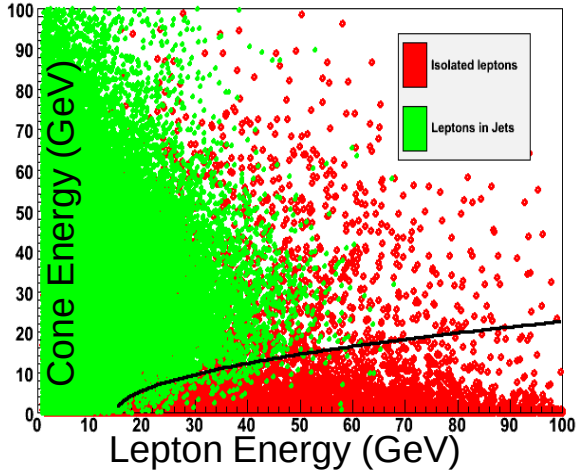
Event Selection

Fast simulation results based on the following variables:

Isolated Leptons



cos θ < 0.98



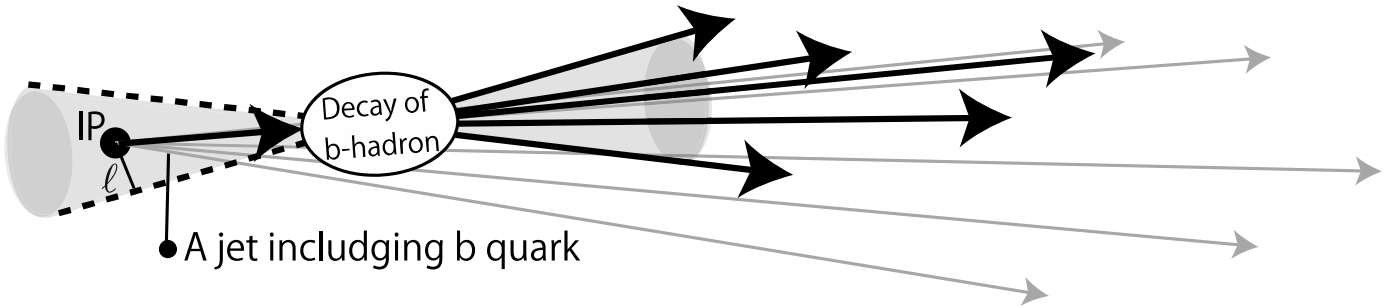
Event Shape (thrust)

$$T = \max_{|\hat{n}|=1} \frac{\sum_i |\hat{n} \cdot \vec{p}_i|}{\sum_i |\vec{p}_i|}$$

Jet Finding thresholds

$$Y_{ij} = \frac{\min(E_i^2, E_j^2)(1 - \cos\theta_{ij})}{E_{\mathrm{CM}}^2}$$

b tagging

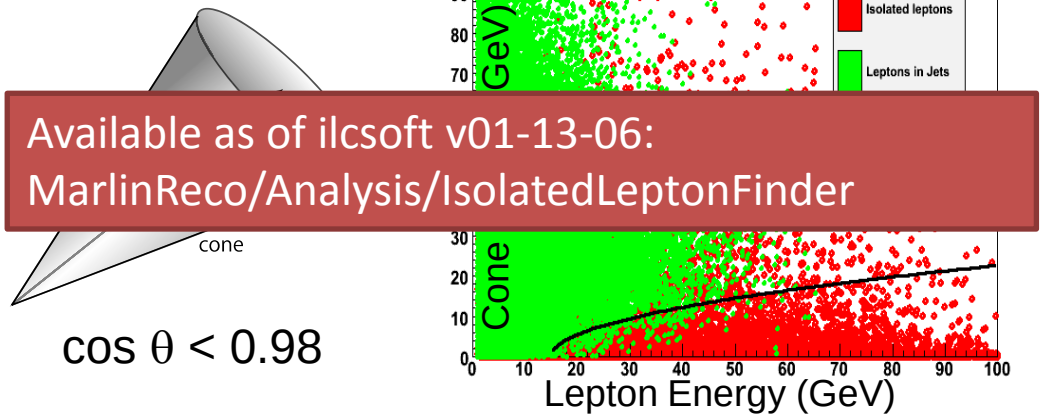


+ mass reconstruction based on jet combination selection.

Event Selection

Full simulation:

Isolated Leptons



Available as of ilcsoft v01-13-06:
MarlinReco/Analysis/IsolatedLeptonFinder

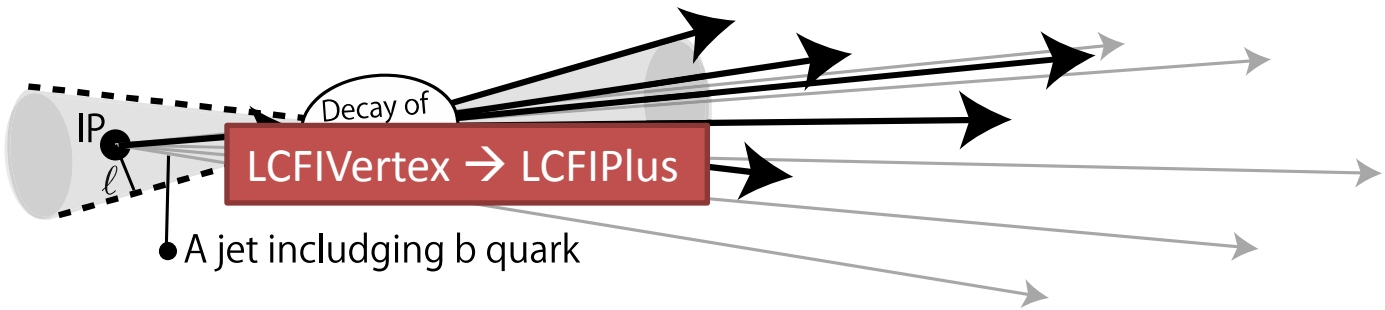
Event Shape (thrust)

$$T = \max_{|\hat{n}|=1} \frac{\sum_i |\hat{n} \cdot \vec{p}_i|}{\sum_i |\vec{p}_i|}$$

Jet Finding thresholds

$$Y_{ij} = \frac{\min(E_i^2, E_j^2)(1 - \cos\theta_{ij})}{E_{\mathrm{CM}}^2}$$

b tagging



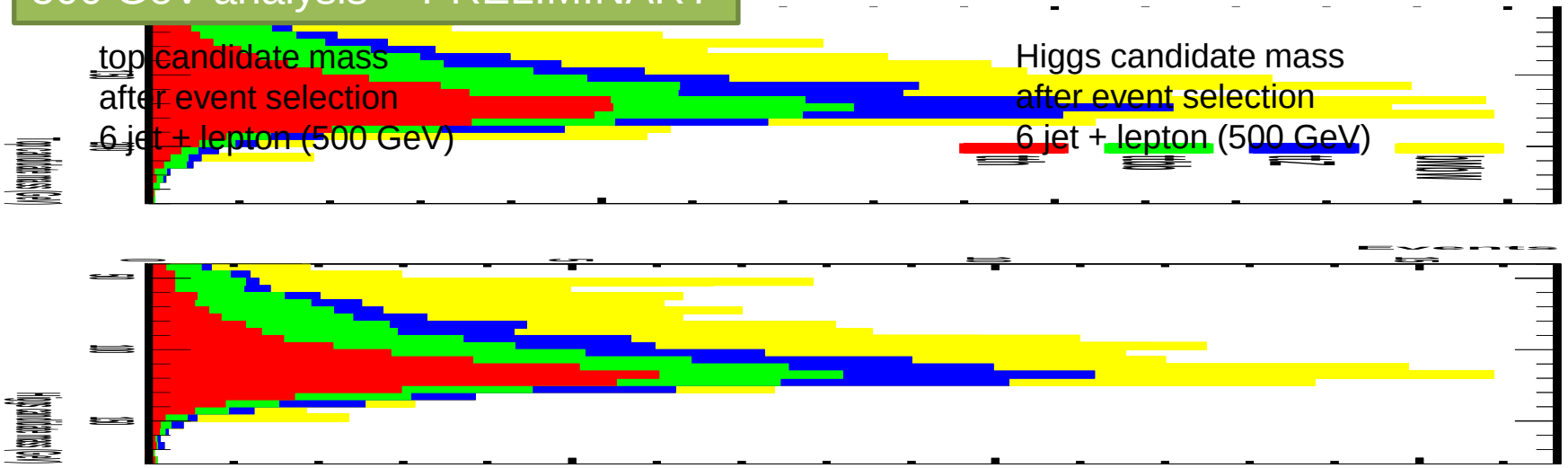
LCFIVertex → LCFIPlus

+ mass reconstruction based on jet combination selection.

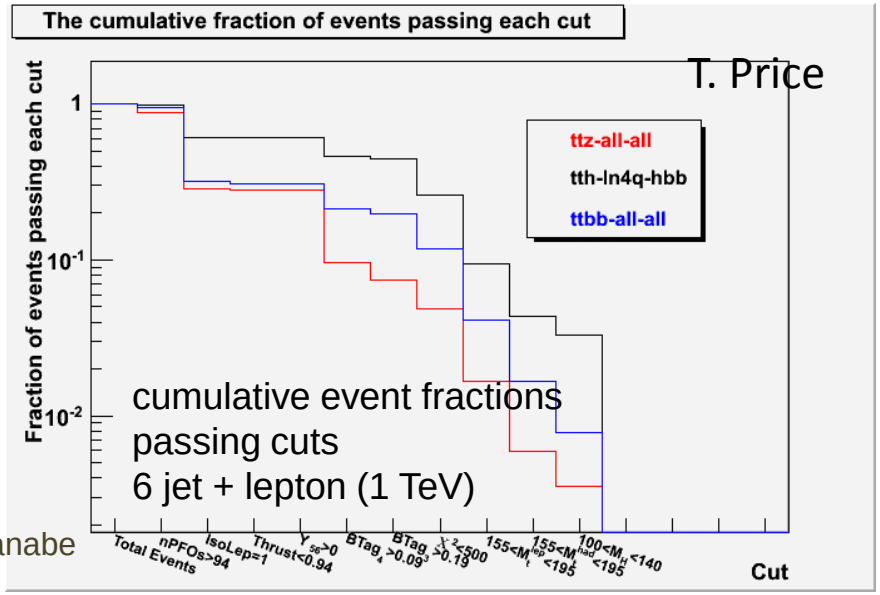
+ MarlinKinfit

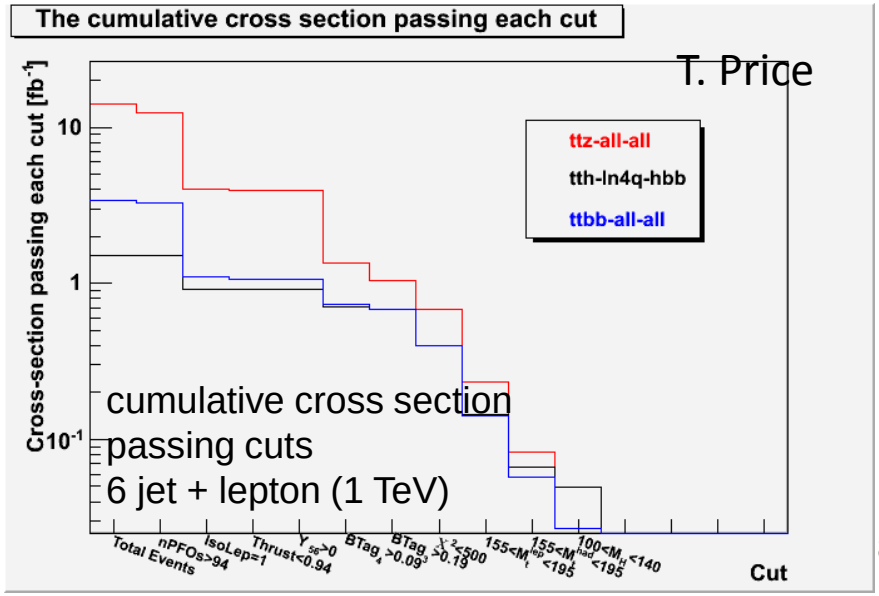
Preliminary Results

500 GeV analysis -- PRELIMINARY



1 TeV analysis -- PRELIMINARY





Sample requests for tth analysis

- **500 GeV samples are generated & simulated at KEK clusters**
  - tth/ttZ/ttg* event generators ready
  - **tt (6f) event generator not yet available**

- **1 TeV samples are/will be made by central mass production**

- **For tth, ttZ, ttbb processes at 1 TeV**
  - would like: **4 ab-1 (#events ~ 50,000) simulated**
  - 10 ab-1 (#events ~ 260,000) **already generated**

- **For ttbar (6f) processes at 1 TeV**
  - **samples not yet available !!**
    - too late to decide preselections at this stage
  - 6f is also a background for other analysis (nunuH)
  - will therefore request simulation without preselections
  - **2 ab-1, ~1 million events simulated & generated**

tth, ttZ, ttbb samples @ 1 TeV

A. Miyamoto

Process	beam-pol	processID	xsec(fb)	Nev@2ab-1	DBD (L80R20)	DBD (L80R30)	Max(F,G)
Ptth-6q-hbb	eL.pR	I106401	1.8002	3601	1945	2107	2107
Ptth-6q-hbb	eR.pL	I106402	0.8098	1620	65	57	65
Ptth-6q-hnonbb	eL.pR	I106403	1.0403	2081	1124	1218	1218
Ptth-6q-hnonbb	eR.pL	I106404	0.4680	936	38	33	38
Pttbb-6q-all	eL.pR	I106405	1.5606	3122	1686	1827	1827
Pttbb-6q-all	eR.pL	I106406	0.6910	1383	56	49	56
Pttz-6q-all	eL.pR	I106407	6.3878	12776	6900	7474	7474
Pttz-6q-all	eR.pL	I106408	1.9891	3979	160	140	160
Ptth-ln4q-hbb	eL.pR	I106409	1.7338	3468	1873	2029	2029
Ptth-ln4q-hbb	eR.pL	I106410	0.7801	1561	63	55	63
Ptth-ln4q-hnonbb	eL.pR	I106411	1.0020	2004	1083	1173	1173
Ptth-ln4q-hnonbb	eR.pL	I106412	0.4508	902	37	32	37
Pttbb-ln4q-all	eL.pR	I106413	1.5074	3015	1629	1764	1764
Pttbb-ln4q-all	eR.pL	I106414	0.6666	1334	54	47	54
Pttz-ln4q-all	eL.pR	I106415	6.1520	12304	6645	7198	7198
Pttz-ln4q-all	eR.pL	I106416	1.9164	3833	154	135	154
Total					23512	25338	25417

x2

Requesting 2 ab-1 for tth, ttZ, ttbb (without 2l+2nu channels), total of ~25,000 events.
Samples already available (thanks to Akiya) on the Grid at: /grid/ilc/prod/ilc/mc-dbd

x2 for training: ~50,000 events (6f events not included here)

Summary and Outlook

- **Progress** in 500 GeV and 1 TeV analyses
  - Good coverage in man power
  - Analysis chain in place, using existing tools and samples
  - Switch to centrally produces samples & validated tools when available
  - Collaboration with SiD analysts starts in June

- **MC request summary:**
  - ~50k events (total for tth, ttZ, ttbb, 4ab-1 each)
  - ~1M events (ttbar, 2ab-1)

Backup Slides

Impact on y_t accuracy

- our fast simulation at 500 GeV shows S/B is ~O(1)
  - roughly expect 6x (2x) increase in signal (background) at 1 TeV
- statistical accuracy of δyt/yt = 0.5*sqrt(S+B)/S
  - calculate relative error on this number from MC statistics of S and B

(S,B) at 1 ab-1	δyt/yt	Lumi = 1 ab-1		Lumi = 2 ab-1	
		S error	B error	S error	B error
(50,100)	12%	17%	3.3%	12%	2.4%
(100,50)	6.1%	13%	2.4%	9.4%	1.7%
(100,100)	7.1%	13%	2.5%	8.8%	1.8%
(100,200)	8.7%	12%	2.4%	8.3%	1.7%
(200,100)	4.3%	9.4%	1.7%	6.7%	1.2%
(200,200)	5.0%	8.8%	1.8%	6.3%	1.3%

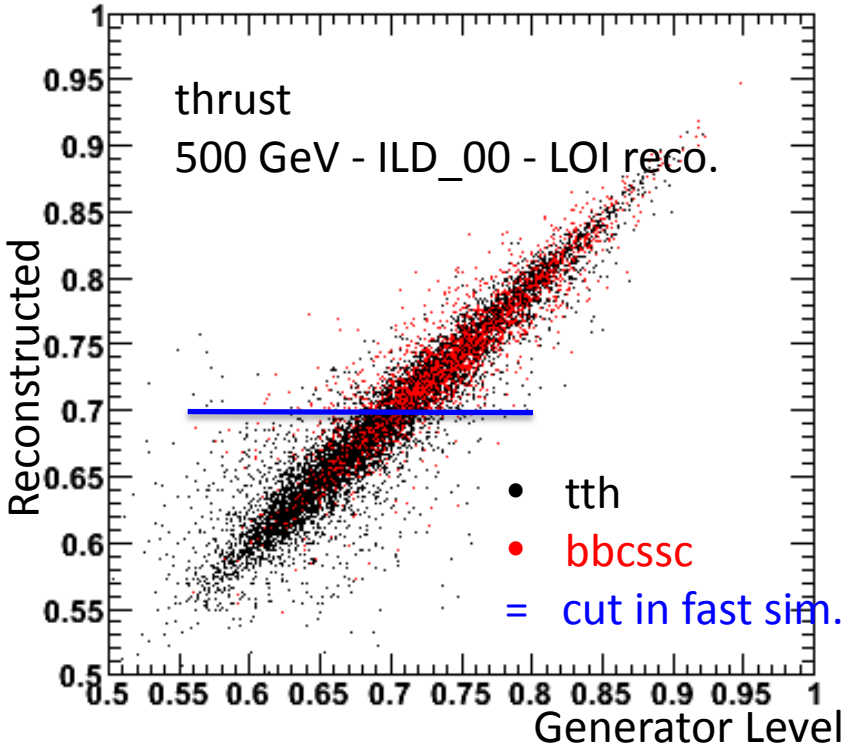
For <10% relative error on top Yukawa, would like 2 ab-1 for S; 1 ab-1 for B sufficient.

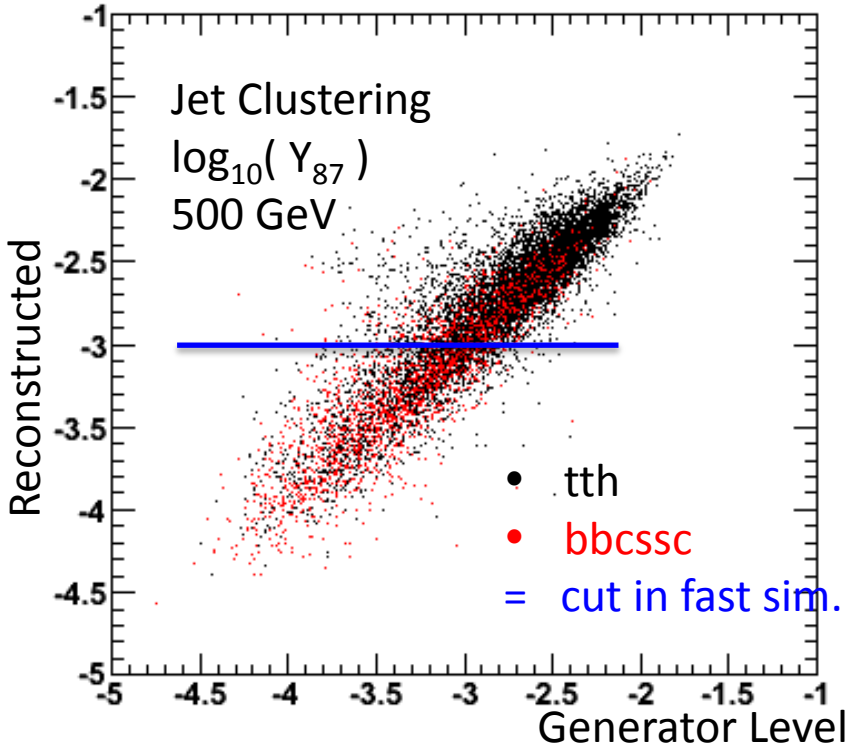
500 GeV fast simulation	$t\bar{t}H(6j)$	tbW	$t\bar{t}Z$	$t\bar{t}g^*(b\bar{b})$
no cuts	282.3	980738.5	2406.9	1159.6
single isolated lepton	179.6	340069.0	790.6	397.7
thrust < 0.77	145.7	144999.0	616.7	266.0
$Y_{5\to4} > 0.005$	125.5	12297.7	416.2	113.7
b-tagging	49.0	172.9	53.3	37.8
mass cuts	39.5	23.0	33.9	13.2

process	xsec (fb) @ 500 GeV	xsec (fb) @ 1 TeV
tth	0.45	2.5
ttZ	1.2	5.2
ttbb	0.75	1.3
tbW	580	250

Preselections

tth is to be studied in (1) 6 jets + lepton mode, and (2) 8 jets mode.
main cuts in the analysis: event shape, jet clustering thresholds, b-tagging





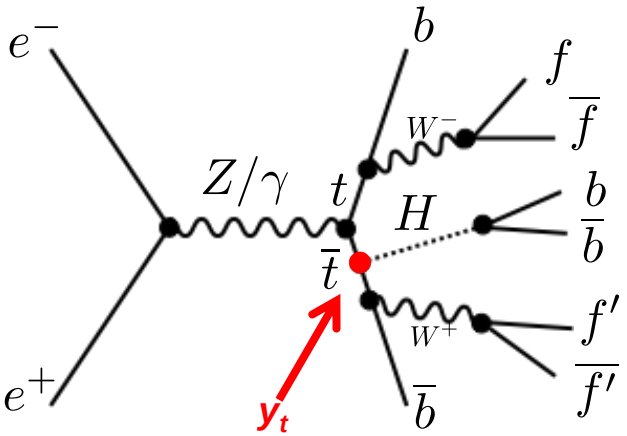
Generator-level particles: generator status =1, not created in simulation,
neutrino veto, cosTheta<0.997, pT>0.1
Reconstructed Particles: same cosTheta & pT cuts

Some safe cuts may be possible, need more detailed study by analysts.
→ propose to let analysts generate large statistics background samples

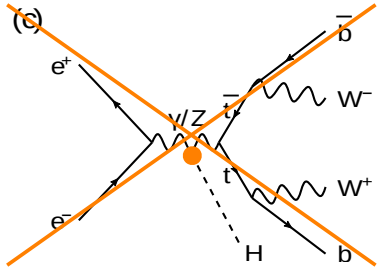
Evaluate accuracy of y_t

= Accuracy of e+e- → tth cross section

$$\frac{\Delta g_t^2}{g_t^2} = \frac{\Delta \sigma_{t\bar{t}H}}{\sigma_{t\bar{t}H}}$$



Higgs strahlung off Z negligible



Estimate the statistical uncertainty.

$$\left(\frac{\Delta \sigma_{t\bar{t}H}}{\sigma_{t\bar{t}H}}\right)^2 = \boxed{\frac{S+B}{S^2}} + \left(\frac{\Delta B_{\mathrm{syst}}}{S}\right)^2 + \left(\frac{\Delta \mathcal{L}}{\mathcal{L}}\right)^2 + \left(\frac{\Delta \epsilon}{\epsilon}\right)^2$$

Statistical Uncertainty

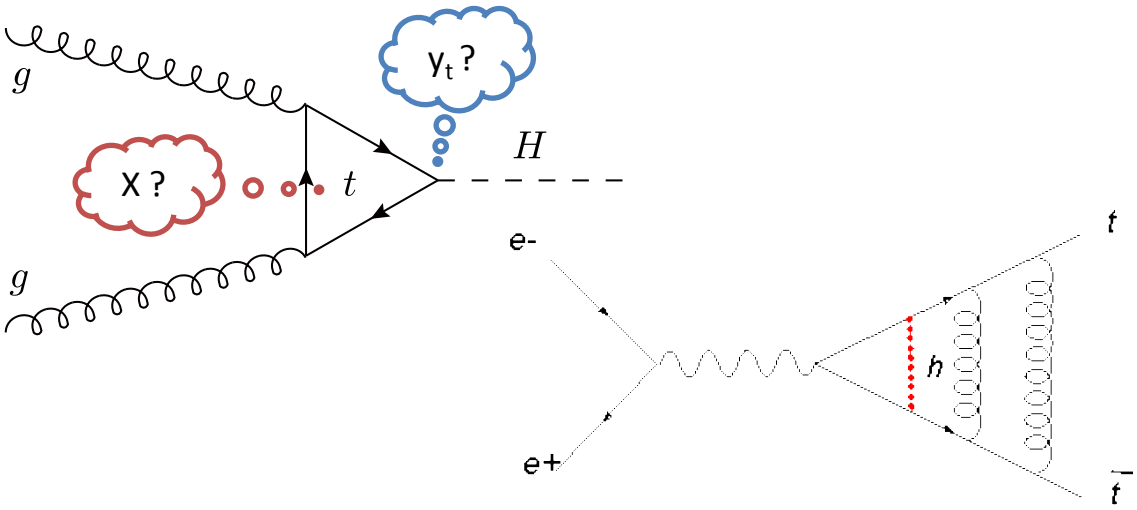
Background Shape Systematics

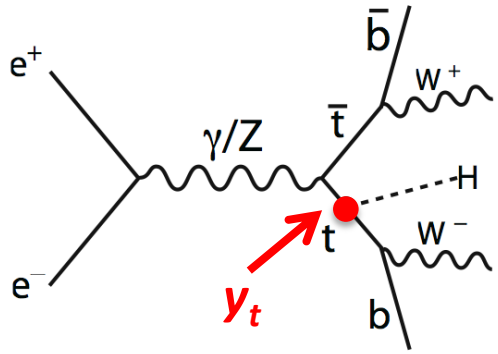
Luminosity Systematics

Analysis Systematics

Indirect vs. direct measurement

- Indirect measurement of top Yukawa is possible at the ttbar threshold and also at the **LHC via gluon fusion** to ttbar (but the jet background makes it challenging)
  - if an anomaly is found in the production rate, one cannot distinguish (1) the coupling anomaly or (2) the presence of a new particle in the loop
- Need direct measurement; feasibility already shown for √s=700-800 GeV ILC; we show this for √s=500 GeV
  - direct measurement at LHC using h-> | | has been proposed but it can only measure ∫ x BR(h-> | |)





Summary of cuts (fast simulation)

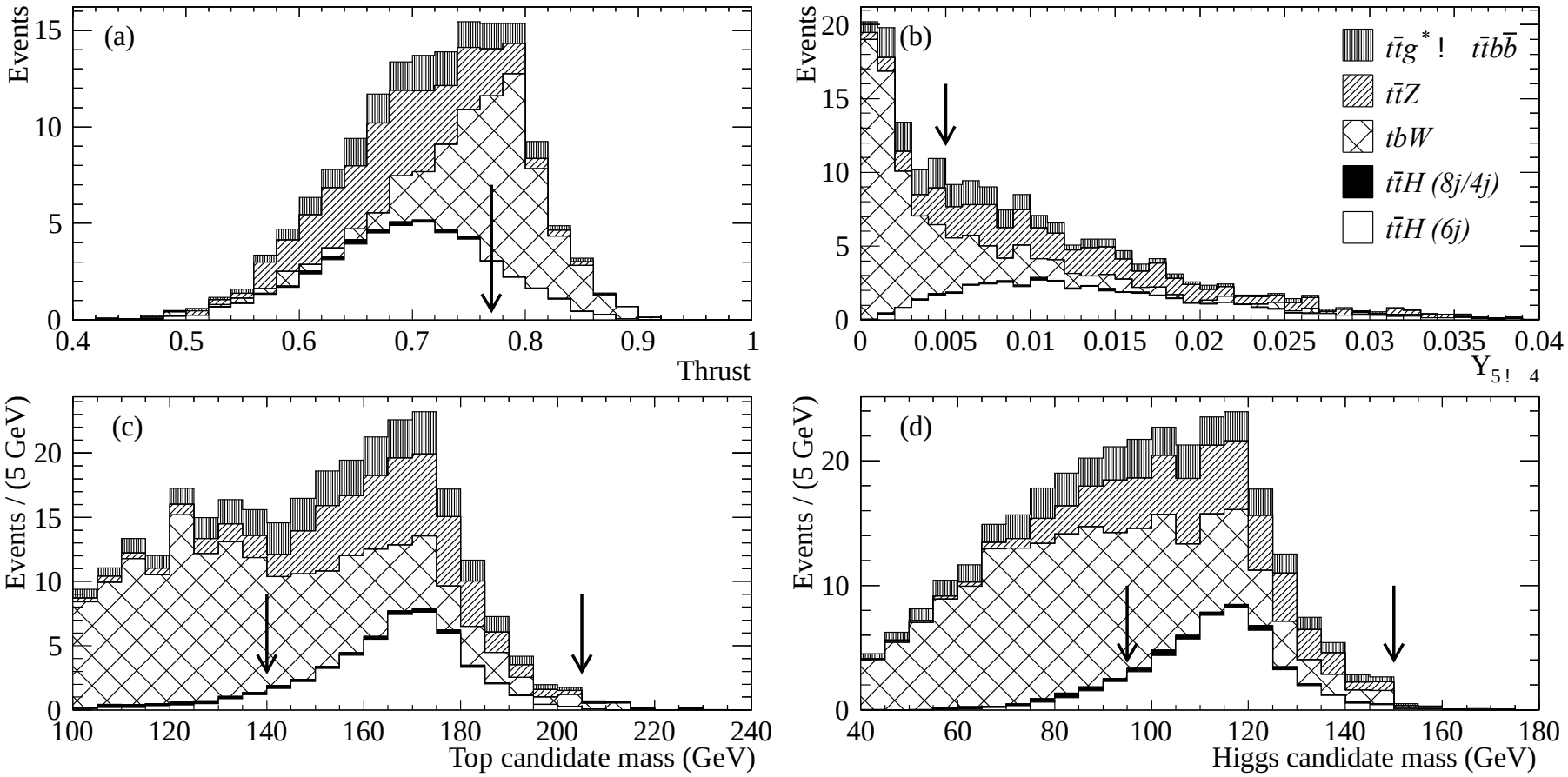
cut	6-jet + lepton	8-jet
number of isolated lepton	1	0
thrust	< 0.77	< 0.7
jet clustering	$Y_{5->4} > 0.005$	$Y_{8->7} > 0.00080$
b-tagging	4x b-jets	4x b-jets
top mass (GeV)	$140 < m_t < 205$	$140 < m_H < 215$
higgs mass (GeV)	$95 < m_t < 150$	$80 < m_H < 150$

6-jet + lepton cut flow (fast simulation)

cut \ sample	ttH (6J)	ttH (8J/4J)	tt	ttZ	ttg^{*} -> ttbb	significance
no cuts	282.	358.	980739.	2407.	1160.	0.3
# isolated lepton = 1	180.	49.0	340069.	791.	398	0.3
thrust < 0.77	146.	37.7	144999.	617.	266.	0.4
$Y_{5->4}$ > 0.005	126.	25.8	12298.	416.	114.	1.1
4x btag	49.0	4.2	173.	53.3	37.8	2.8
mass cuts	39.5	1.6	23.0	33.9	13.2	3.7

lumi = $1ab^{-1}$, polarized beams

6-jet + lepton analysis (fast simulation)



Scaled to 1 ab^{-1}

Beam polarization (Pol(e-),Pol(e+)) = (-0.8,+0.3)

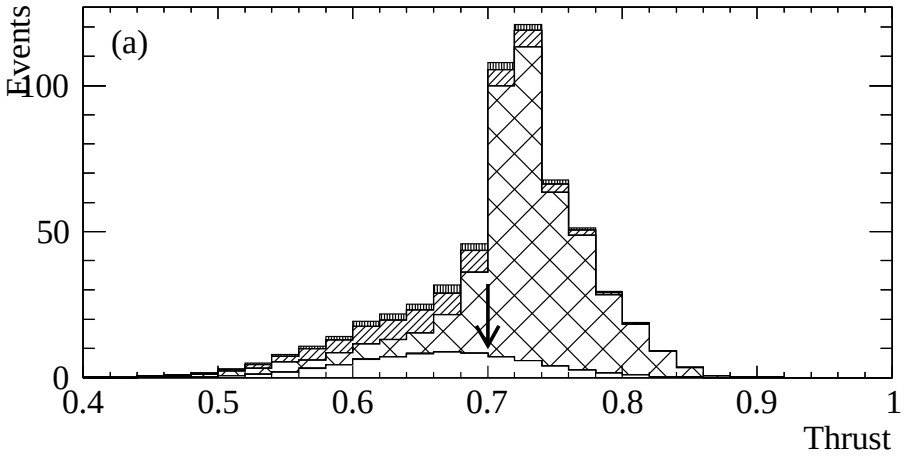
All other cuts applied.

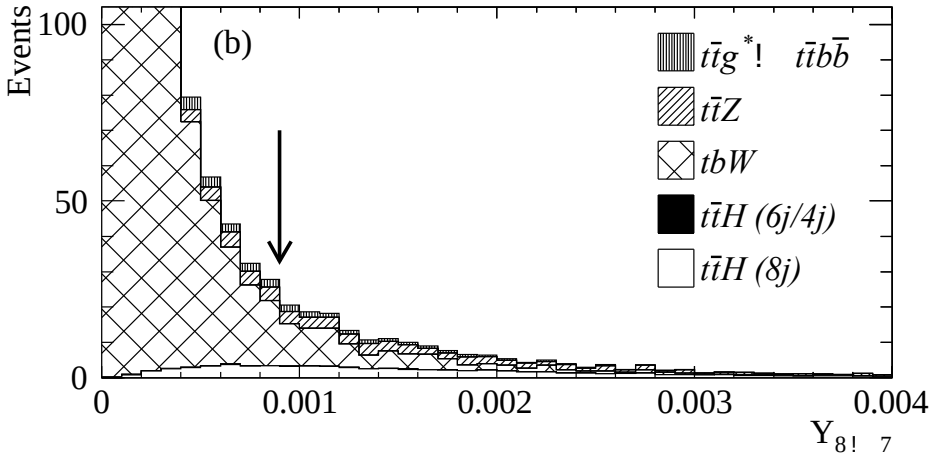
8-jet cut flow (fast simulation)

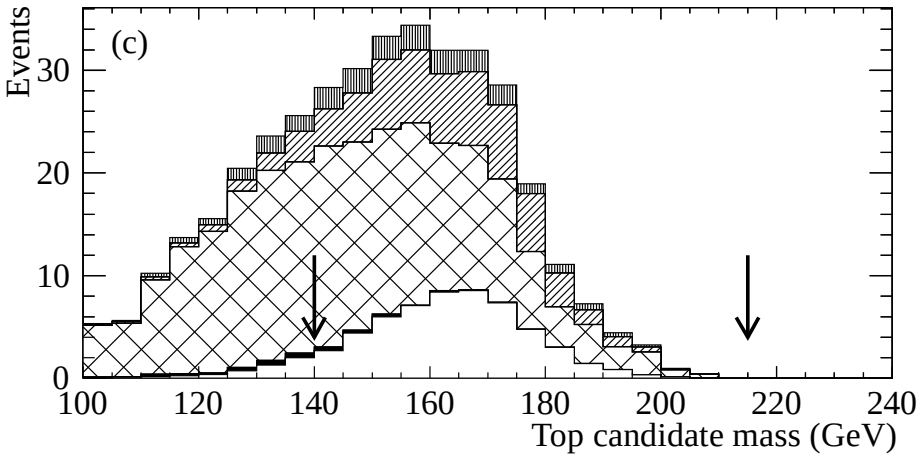
cut \ sample	ttH (6J)	ttH (8J/4J)	tt	ttZ	ttg^{*} -> ttbb	significance
no cuts	290.	358.	980739.	2406.	1160.	0.3
# isolated lepton = 0	266.	92.2	589716.	1351.	701.	0.3
thrust < 0.7	168.	46.7	107227.	818.	312.	0.5
$Y_{8->7} > 0.0009$	114.	13.3	4048.	350.	67.1	1.7
4x btag	66.6	6.9	443.	77.6	39.8	2.6
mass cuts	50.1	0.4	75.6	47.6	14.1	3.7

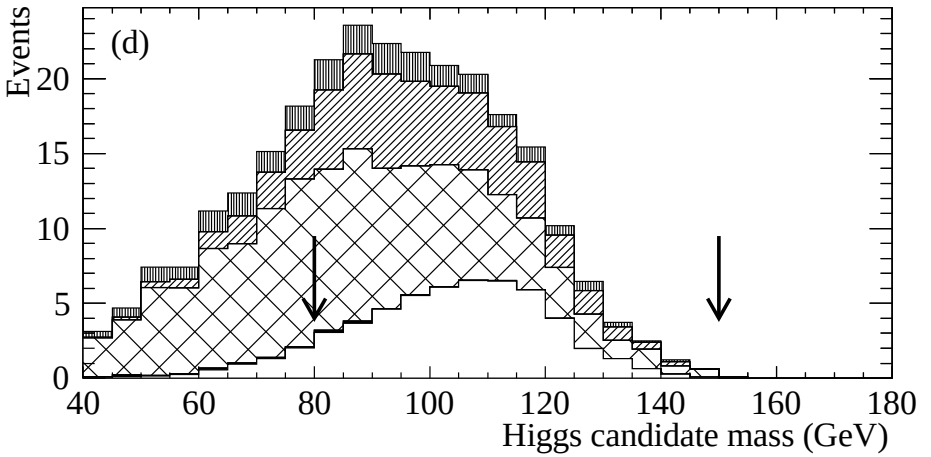
lumi = $1ab^{-1}$, polarized beams

8-jet analysis (fast simulation)









Scaled to 1 ab^{-1}

Beam polarization (Pol(e-),Pol(e+)) = (-0.8,+0.3)

All other cuts applied.

results (fast simulation)

beam pol.(e-, e+)	6 jet + lepton	8 jet
(0.0, 0.0)	2.9	2.8
(-0.8, +0.3)	3.7	3.7

beam pol. (e-, e+)	combined significance	combined $\Delta g_t / g_t$
(0.0, 0.0)	4.0	**12%**
(-0.8, +0.3)	5.2	**9.6%**

ILC500
Lumi = 1 ab^{-1}
P(e-,e+)=(-0.8,+0.3)

preliminary results

PRD 84, 014033 (2011)

Fast Sim	*tth*	*ttZ*	*ttbb*	*tbW*
6 jet + lepton	280 → 40	2400 → 34	1200 → 13	9.8×10^5 → 23
8 jet	290 → 34	2400 → 48	1200 → 14	9.8×10^5 → 76

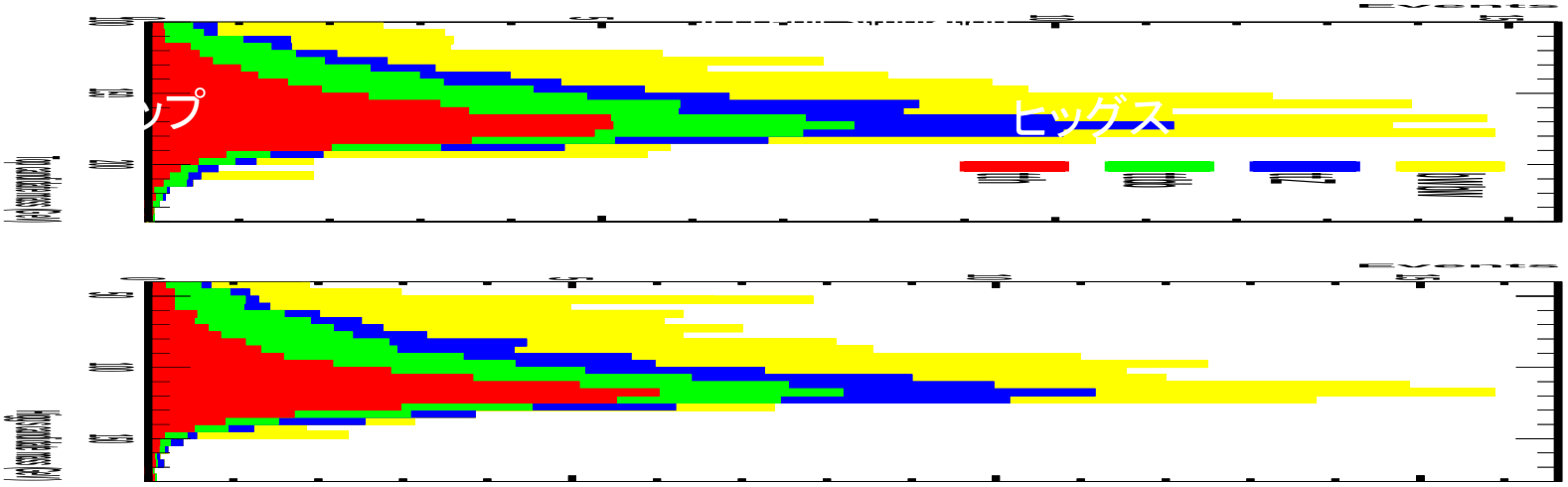
Preliminary

ttZ: mistake found in QCD correction, fixed xsec below

Full Sim	*tth*	*ttZ*	*ttbb*	*bWbW*
6 jet + lepton	280 → 28	1900 → 16	1200 → 13	9.1×10^5 → 19
8 jet	290 → 34	1900 → 24	1200 → 14	9.1×10^5 → 33

- 6 jet: S/sqrt(S+B) = 28/sqrt(28+16+13+19) = 3.21 sigma
- 8 jet: S/sqrt(S+B) = 34/sqrt(34+24+14+33) = 3.32 sigma
- Assuming Gaussian errors, combined significance is 4.60
- Relative uncertainty on y_t is 0.5/(uncertainty in xsec) = 0.5/4.60 = 0.11

6 jet + lepton



8 jet