Measuring the top Yukawa coupling at 500 GeV ILC

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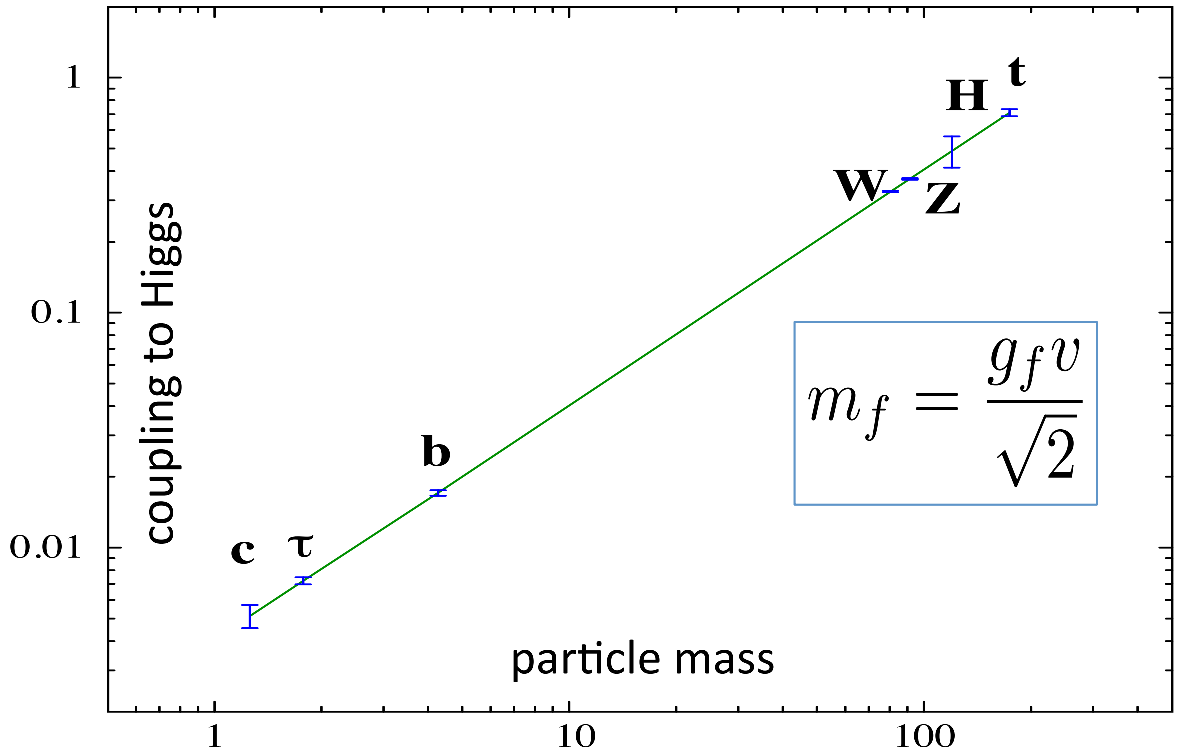
motivation (1)

- verification of EWSB & mass generation is a critical task which must be done before BSM physics can be established
- ILC is an ideal probe for measuring the couplings related to the Higgs (self-coupling, Yukawa coupling)



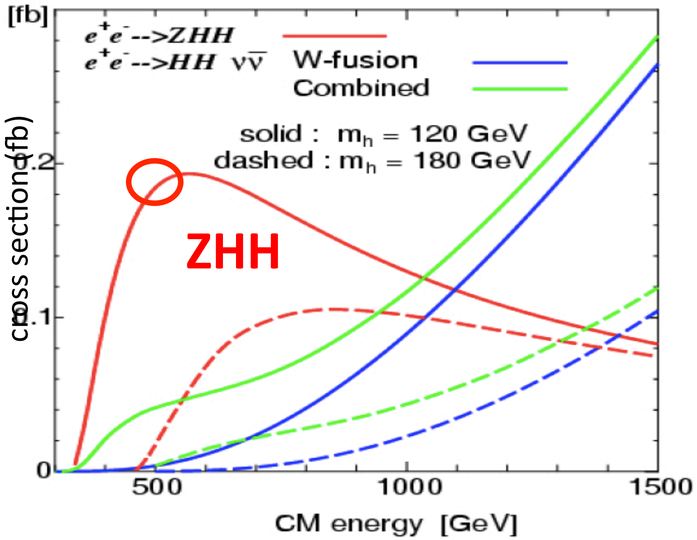
motivation (2)

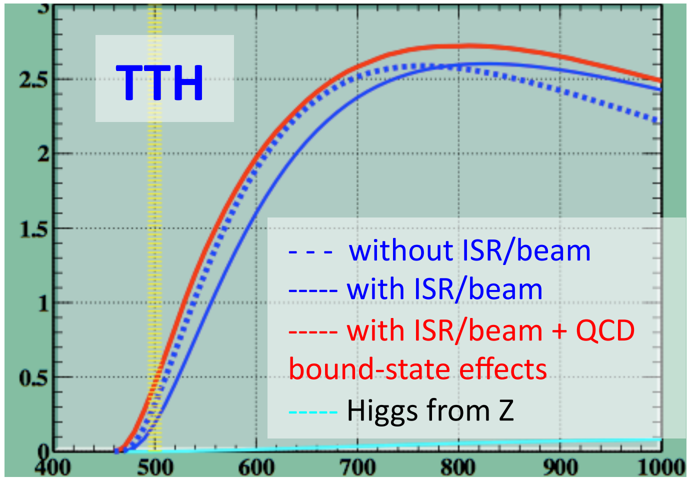
well-known energy thresholds for ILC:
(m_H=120 GeV)

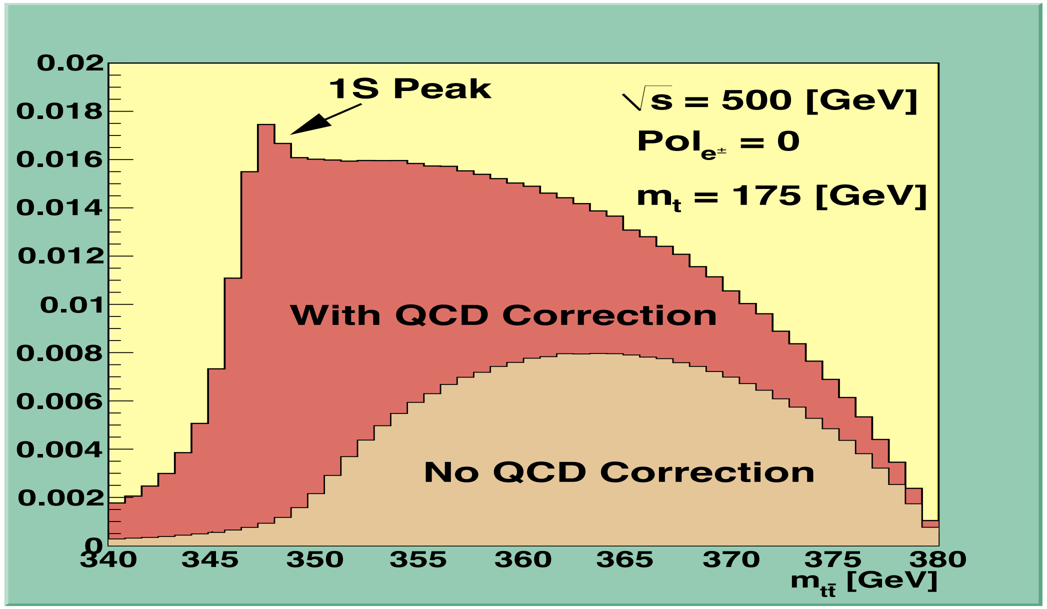
250 GeV: ZH
350 GeV: top pair
500 GeV: ZHH & ttH

ttH measurement is possible due to *QCD bound-state effects* which enhance the cross section

(Note: this also enhances ttZ; ttg* is not enhanced because tt in this case is not a color singlet)



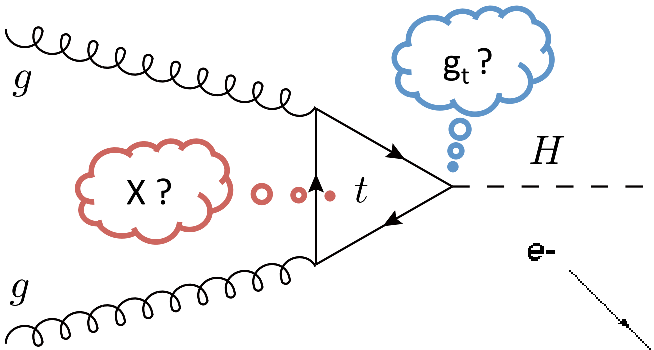


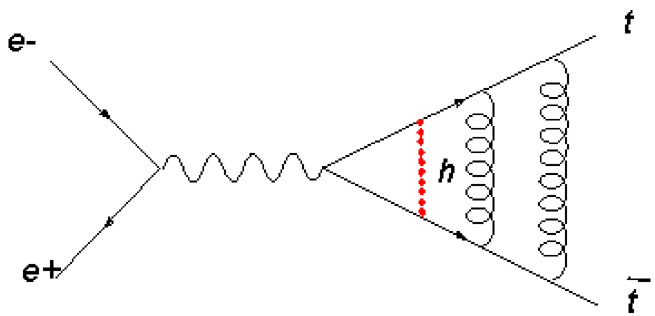


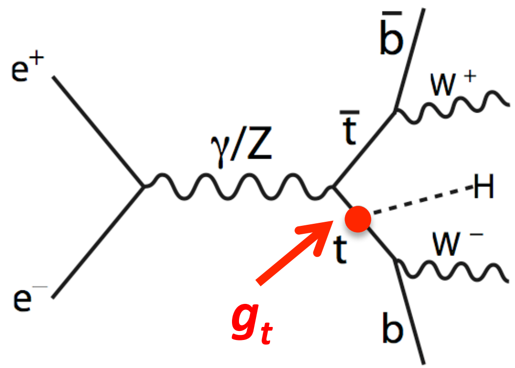
Based on Farrell & Hoang, PRD74, 014008 (2006)

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)
  - but: 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 E_{CM}=700-800 GeV ILC; we show this for E_{CM}=500 GeV
  - direct measurement at LHC using H->ττ has been proposed but it can only measure σ x BR(H->ττ)

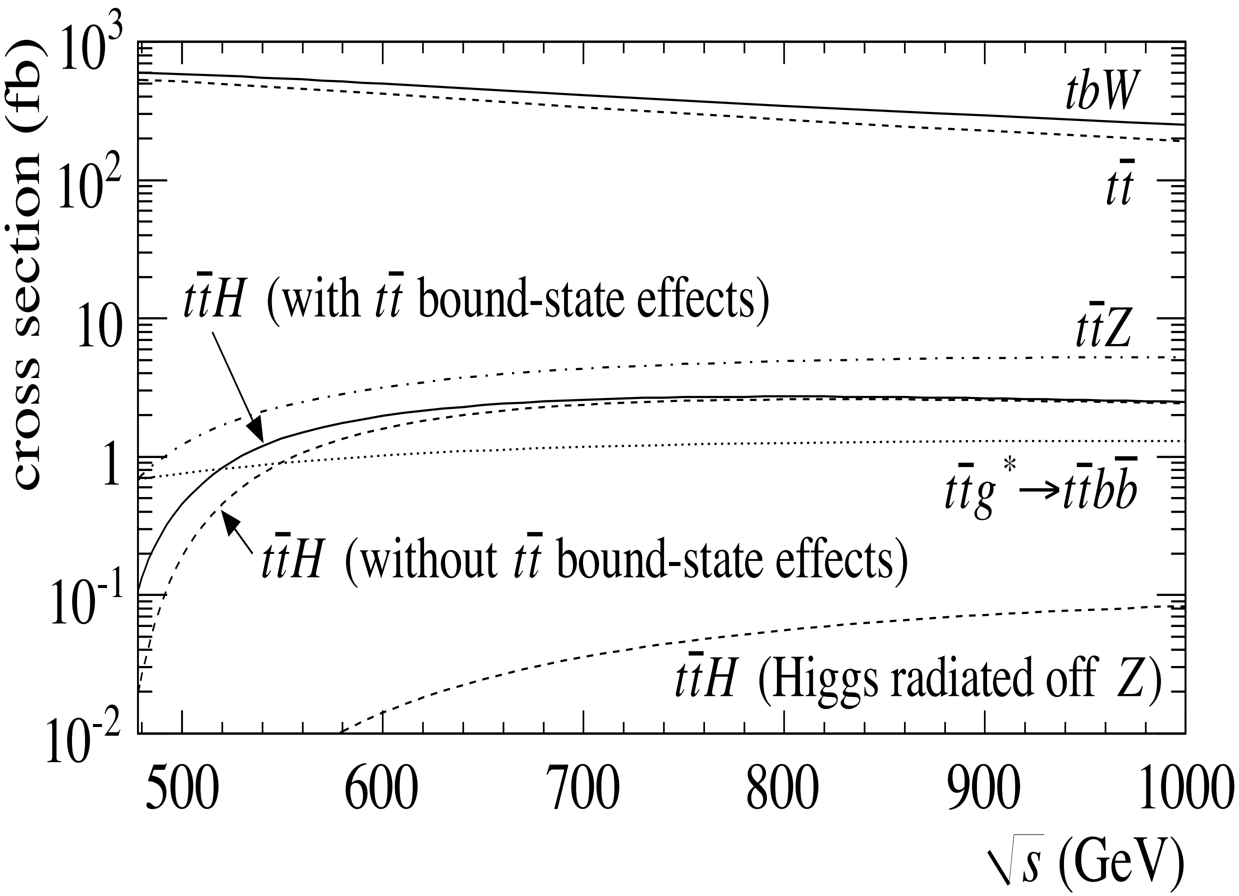


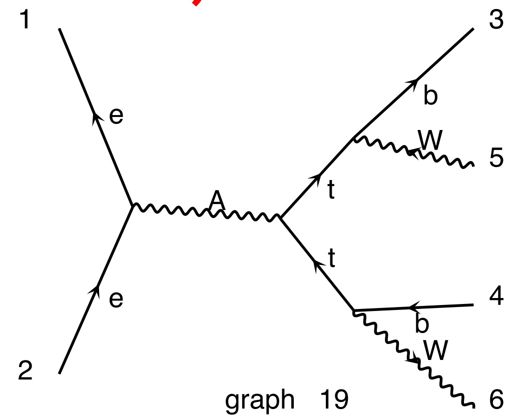


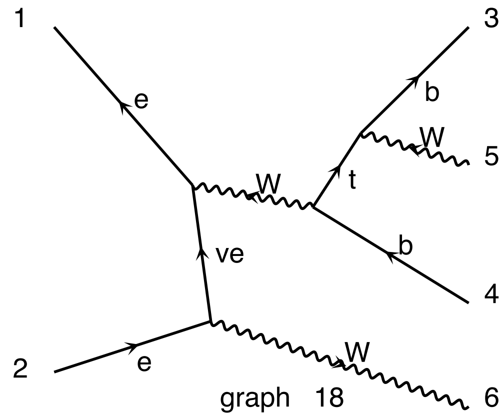


signal & background

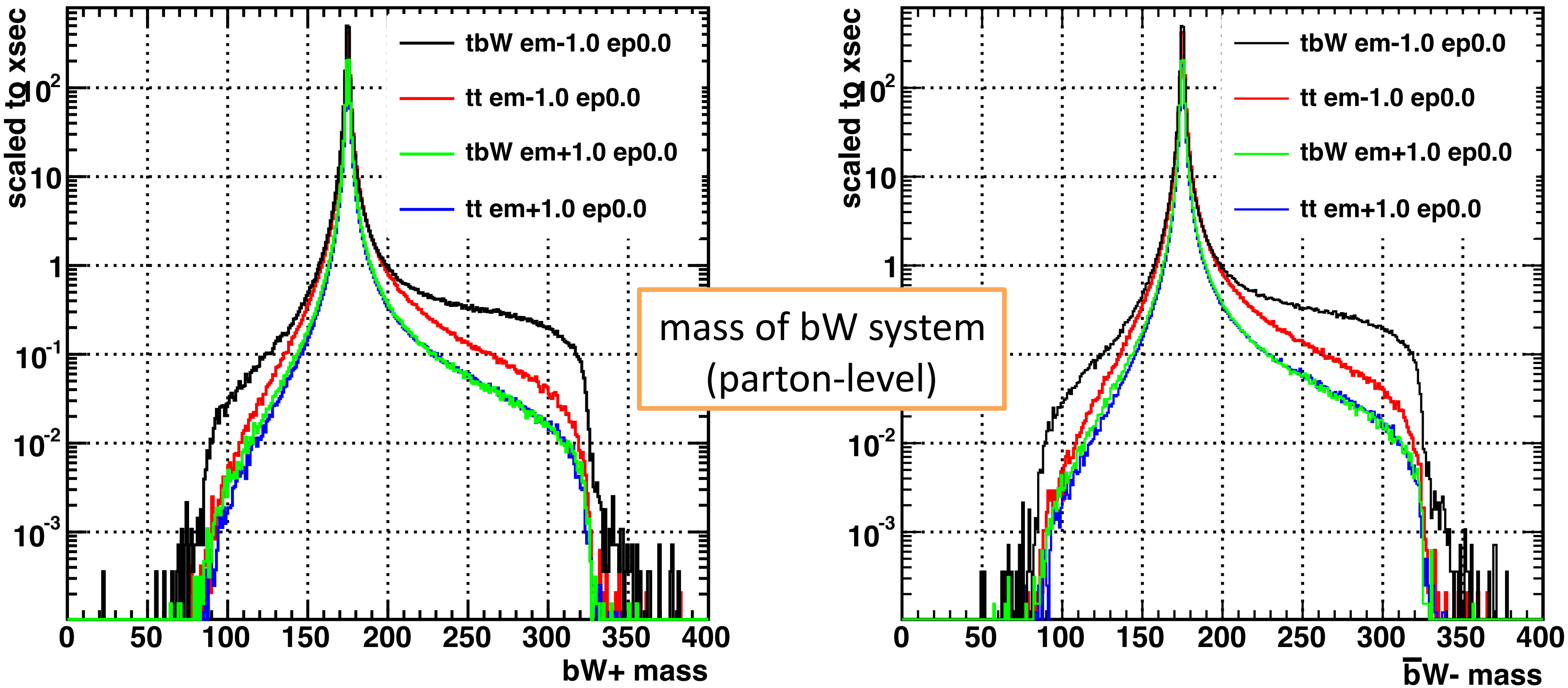
- **signal:** ttH -> bWbWbb (0.45 fb for 6-jet + lepton & 8-jet modes)
- **main background:**
  ttg* (g*->bb, ~1 fb), ttZ -> ttbb (~0.2 fb), **tbW (~600 fb)**



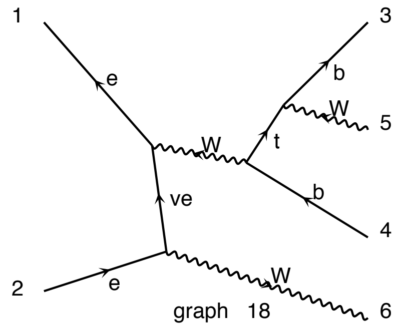




tbW events



- jet combinatorial effects & misidentification of b-jets result in significant background
  - tail of distribution is important
- WW* enhances the tbW tails for $e^-_L e^+_R$



analysis framework

- physsim: event generator
  - helicity amplitude by HELAS; phase space integration
  - ISR & beamstrahlung included
  - ttbar threshold correction to ttH & ttZ
  - dedicated ttg generator
- pythia: parton shower & hadronization
- QuickSim: fast detector simulation
  - semi-realistic PFA reconstruction

Detector	Performance	Coverage
Vertex detector	$\sigma_b = 7.0 \oplus (20.0/p)/\sin^{3/2}\theta \mu m$	$\lvert\cos\theta\rvert \leq 0.90$
Central drift chamber	$\sigma_{P_T}/P_T = 1.1 \times 10^{-4} p_T \oplus 0.1\%$	$\lvert\cos\theta\rvert \leq 0.95$
EM calorimeter	$\sigma_E/E = 15\%/\sqrt{E} \oplus 1\%$	$\lvert\cos\theta\rvert \leq 0.90$
Hadron calorimeter	$\sigma_E/E = 40\%/\sqrt{E} \oplus 2\%$	$\lvert\cos\theta\rvert \leq 0.90$

process	cross-section (fb)	generated number of events	equivalent luminosity (ab^{-1})
ttH	1.24	50,000	40.3
ttZ	4.04	50,000	12.4
ttg* -> ttbb	1.93	50,000	25.9
tbW	1633.	10,000,000	6.1
ttH	0.540	50,000	92.6
ttZ	1.324	50,000	37.8
ttg* -> ttbb	0.859	50,000	58.2
tbW	700.	10,000,000	14.3

e-/e+ pol. = (-1.0, +1.0) (green rows)

e-/e+ pol. = (+1.0, -1.0) (orange rows)

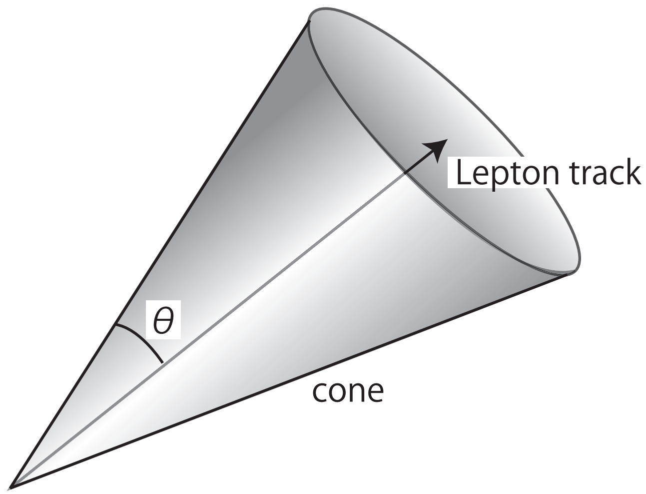
(target integrated luminosity = 1 ab^{-1})

analysis strategy

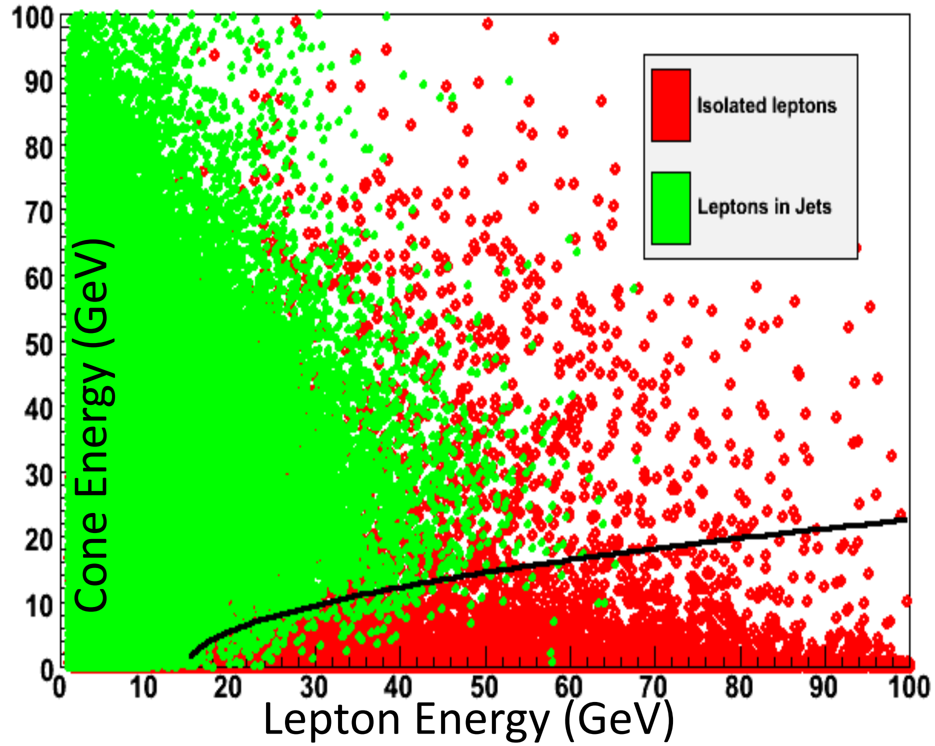
- analysis mode:
  - (i) 8-jet mode: 45%
  - (ii) 6-jet + lepton mode (*e or μ*): 29%
  - (iii) 4-jet + 2-lepton mode (*ee*, *eμ*, or *μμ*): 5% (we don't reconstruct)
- Higgs reconstructed in bb mode (68%)
- cut-and-count analysis
- event selection based on:
  - identification/rejection of isolated leptons
  - event shape variables
  - b-tagging of jets
  - combination of jets into top & Higgs candidates
  - invariant mass

lepton selection / rejection

- lepton identification by MC information (assumes 100% efficiency & purity for E>15 GeV leptons)
- distinguish isolated leptons & leptons from jets by using the energy sum of the particles around the lepton candidate (cone energy) versus the lepton energy
- 2-D selection (rejection) of isolated leptons for the 6-jet + lepton analysis (8-jet analysis)



cos θ < 0.98



event shape

- use the thrust variable to discriminate signal from background (peaks at 1 for dijet events)

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

jet clustering

- use the Durham jet clustering algorithm to force the event into the 6 or 8 jet topology (after removing the isolated leptons)

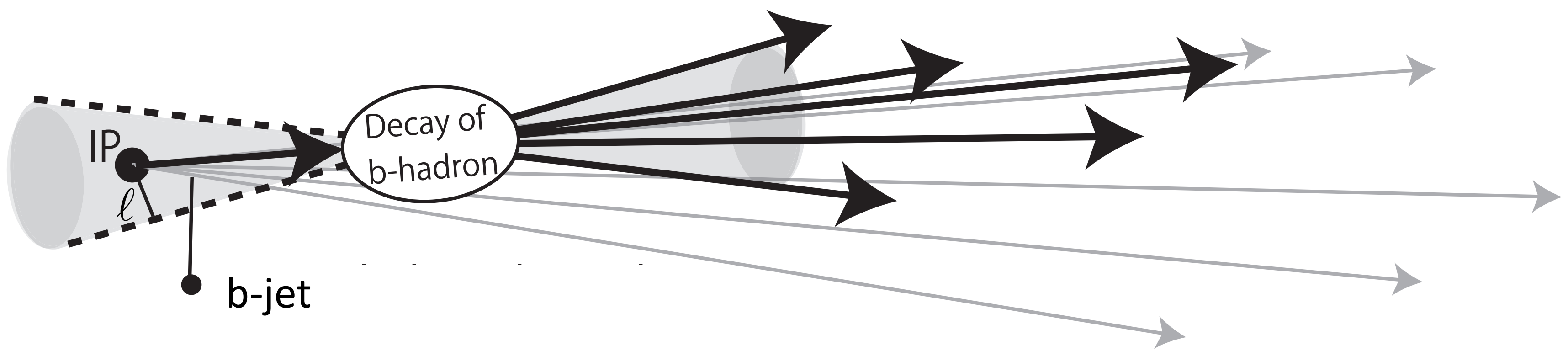
$$Y_{ij} = \frac{\max(E_i^2, E_j^2)(1 - \cos\theta_{ij})}{E_{\mathrm{CM}}^2}$$

b-tagging

- identify b-jets via their large impact parameter significance (IPS) of secondary tracks.
- b-tagging criteria:
  - **tight (6J+L)**: require 4 tracks with IPS >2.5
  - **tight (8J)**: require 2 tracks with IPS>3.0
    - efficiency: 47%, fake rate: c-jet 3.2%, uds-jet 0.1%
  - **loose**: require 2 tracks with IPS >2.0
    - efficiency: 80%, fake rate: c-jet 40%, uds-jet 0.5%

efficiency & fake rate estimated on Z->qq sample @ 91.2 GeV

- event selection:
  - tight b + loose b for Higgs candidate
  - tight b for at least one top, loose b for the other top



jet combination

- choose the jet combination which is most consistent with the ttH mass hypothesis is chosen by minimizing the following "chi-squared" value:

$$\chi^2 = \frac{(m_{2j} - M_H)^2}{\sigma_H^2} + \frac{(m_{2j} - M_{W_1})^2}{\sigma_{W_1}^2} + \frac{(m_{3j} - M_{t_1})^2}{\sigma_{t_1}^2} + \left\{ \frac{(m_{2j} - M_{W_2})^2}{\sigma_{W_2}^2} + \frac{(m_{3j} - M_{t_2})^2}{\sigma_{t_2}^2} \right\}_{8j}$$

summary of cuts

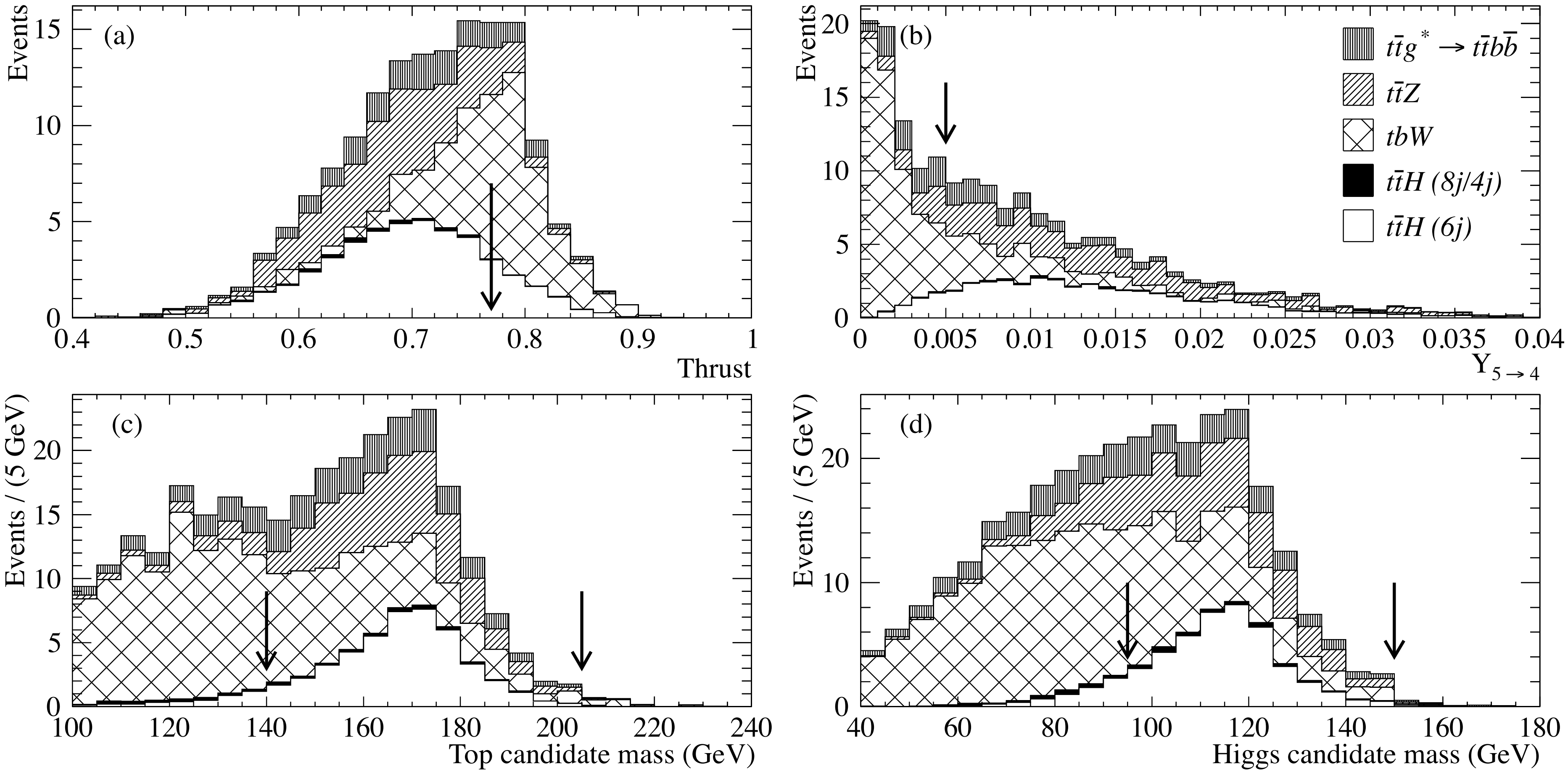
cut	6-jet + lepton	8-jet
number of isolated lepton	1	0
thrust	< 0.77	< 0.7
jet clustering	$Y_{5\text{->}4} > 0.005$	$Y_{8\text{->}7} > 0.00080$
b-tagging	4x b-jets	4x b-jets
top mass (GeV)	$140 < m_t < 205$	$140 < m_H < 215$
higgs mass (GeV)	$95 < m_t < 150$	$80 < m_H < 150$

6-jet + lepton cut flow

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
$Y_{5\text{->}4}$ *> 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



Scaled to 1 ab^{-1}

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

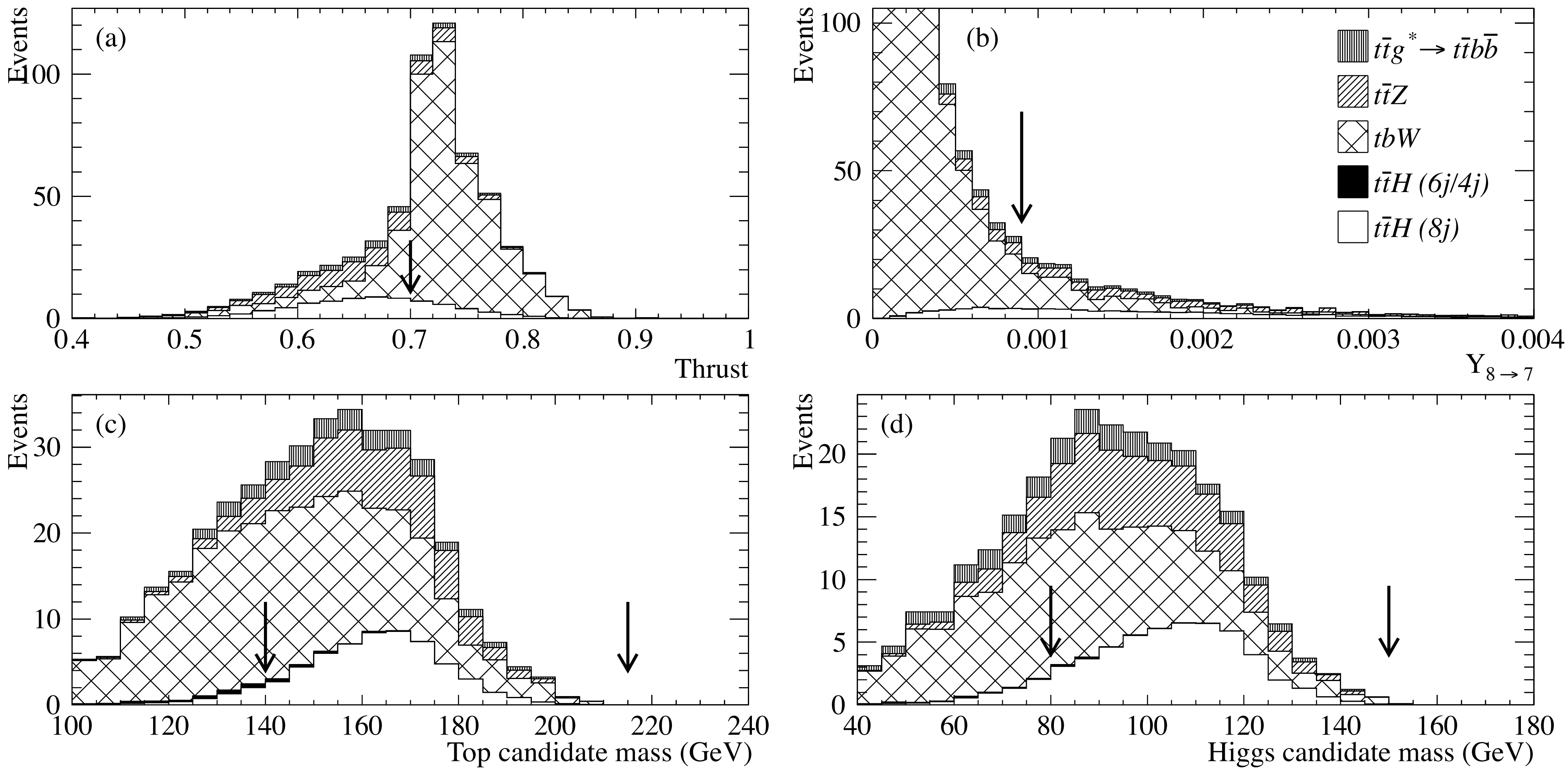
All other cuts applied.

8-jet cut flow

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
$Y_{8\text{->}7} > 0.0009$	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



Scaled to 1 ab^{-1}

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

All other cuts applied.

results

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 Δg_t / g_t
(0.0, 0.0)	4.0	**12%**
(-0.8, +0.3)	5.2	**9.6%**

conclusions

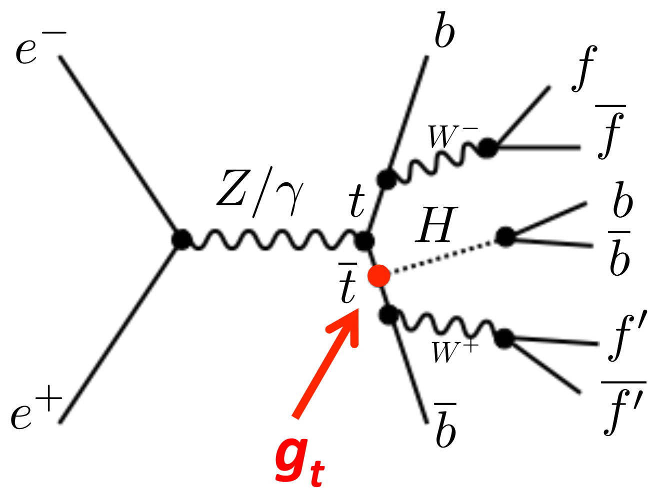
- our fast simulation study shows that, with
  - **m_{Higgs} = 120 GeV**
  - **ILC (500 GeV)**
  - **nominal beam polarizations (-0.8, +0.3)**
  - **Lumi = 1 ab^{-1}**

  the top Yukawa coupling can be measured with **10%** statistical accuracy
- for increased confidence in this results, a study with full detector simulation should be performed, which is the target of our next study
- we will also try to meet the demands of the DBD benchmark which asks for the same analysis at E_{CM} = 1 TeV for the ILD detector

backup

purpose of study

- Evaluate the accuracy of g_t
  E_{cm}=500 GeV, m_H = 120 GeV, H -> bb (68%)



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

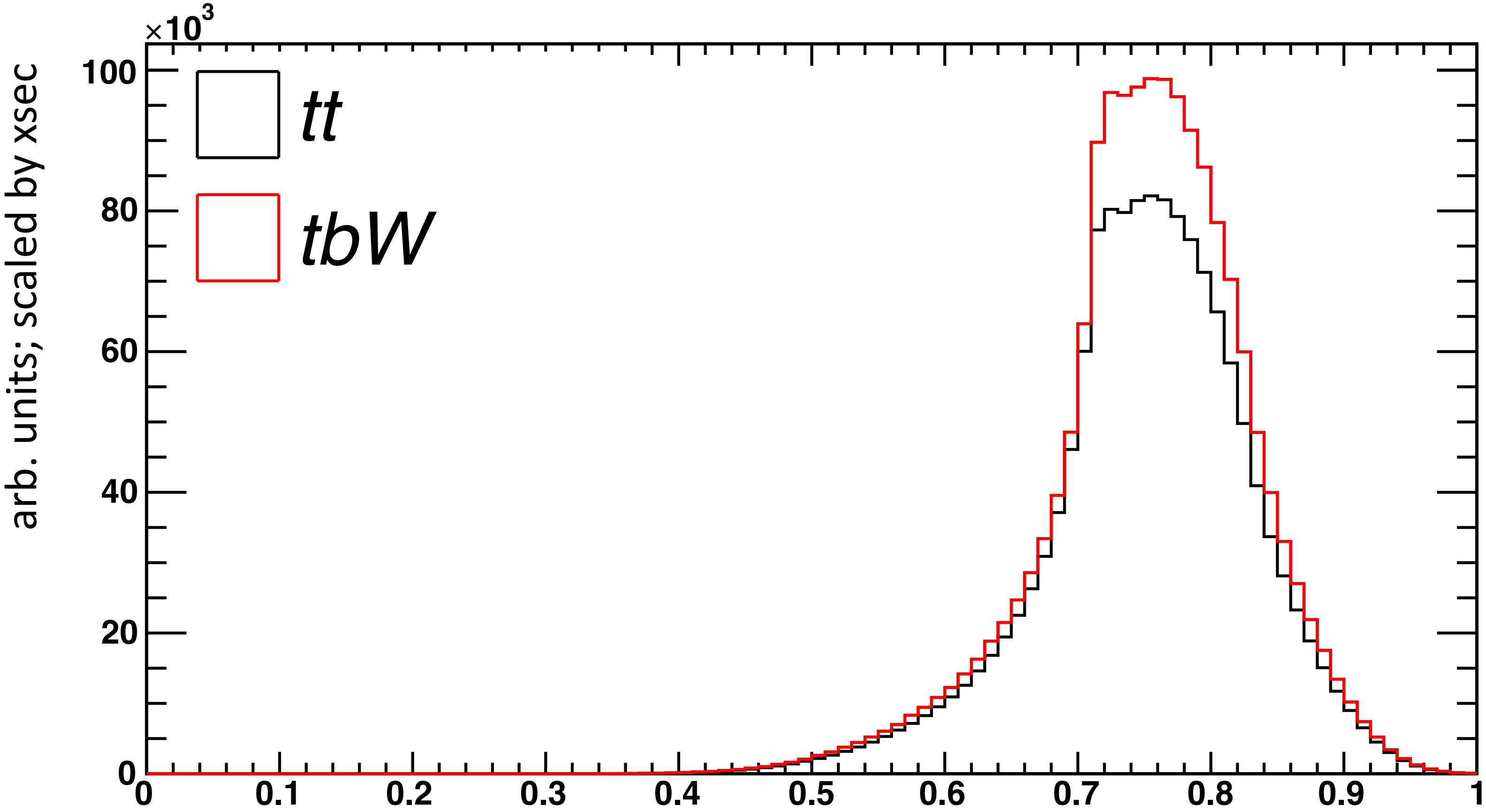
= accuracy of e^+e^- -> ttH cross-section.

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

Statistical Uncertainty | Background Shape Systematic | Uncertainty of Integrated Luminosity | Uncertainty of Event Reco.

Estimate the statistical uncertainty.

comparison of thrust distribution



TT is included within TBW (GOOD)