measuring the top Yukawa coupling at the ILC at E_{cm} = 500 GeV

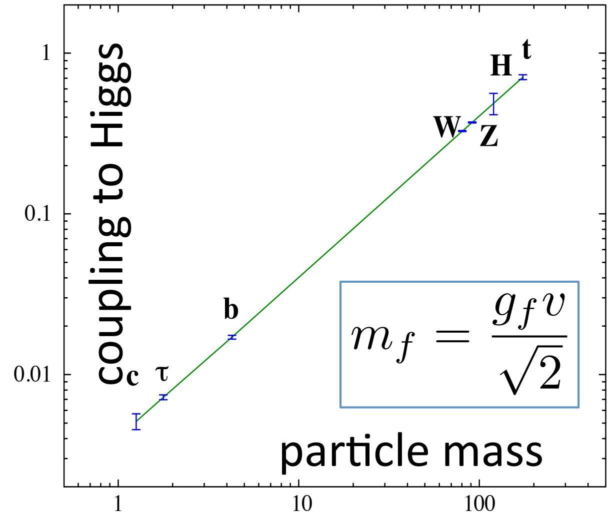
R. Yonamine (Sokendai), T. Tanabe (Tokyo), K. Ikematsu, K. Fujii,
Y. Kiyo (KEK), Y. Sumino (Tohoku), S. Uozumi (KNU), H. Yokoya (CERN)

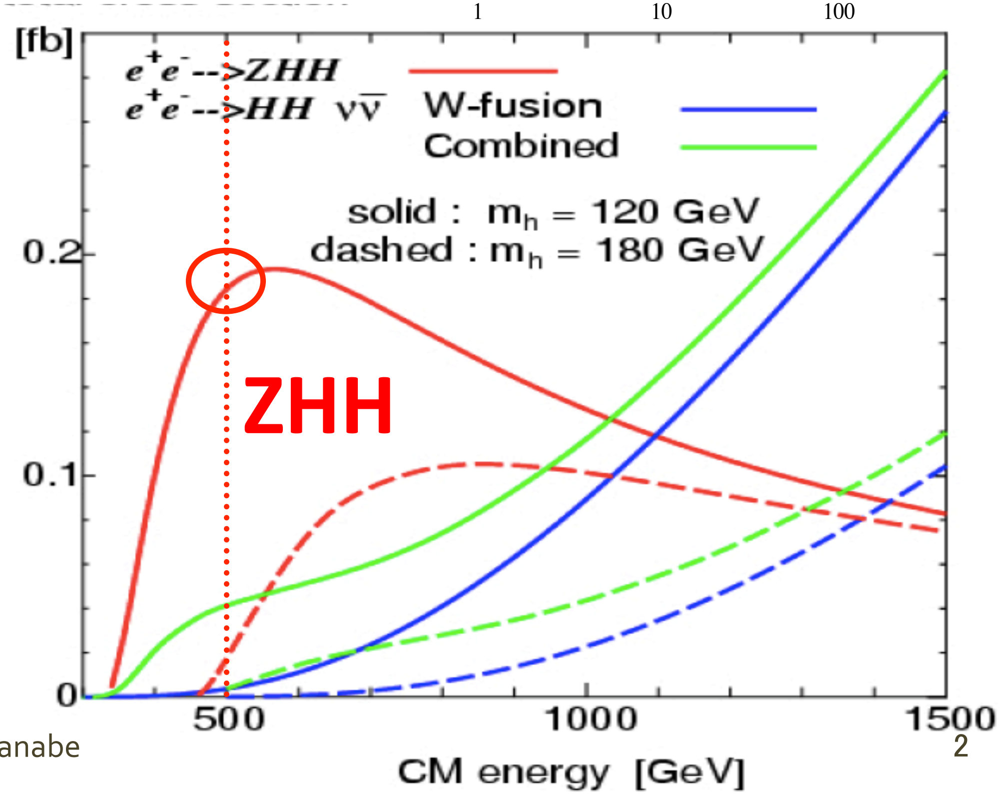
March 28, 2010

Linear Collider Workshop, Beijing

motivation

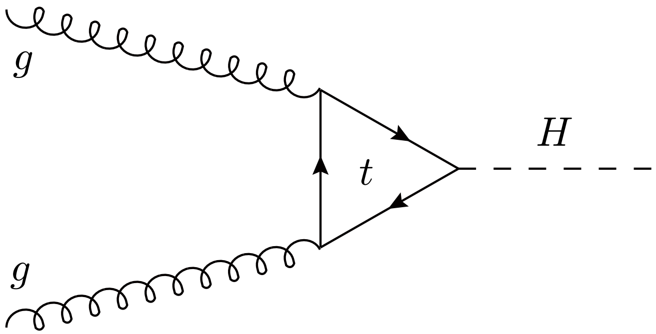
- although spontaneous symmetry breaking has been a huge success, its verification (discovery of Higgs) is yet to be realized
- once the Higgs is discovered, the precise measurements of its mass, spin, and interactions will be needed to confirm the EWSB and mass generation
- a critical mission for the ILC is the Higgs coupling measurements (HHH and ttH)
  - ZHH xsec attains its maximum at ~500 GeV
- we investigate the feasibility of measuring the ttH coupling concurrent to the HHH coupling (E_{cm}=500 GeV)



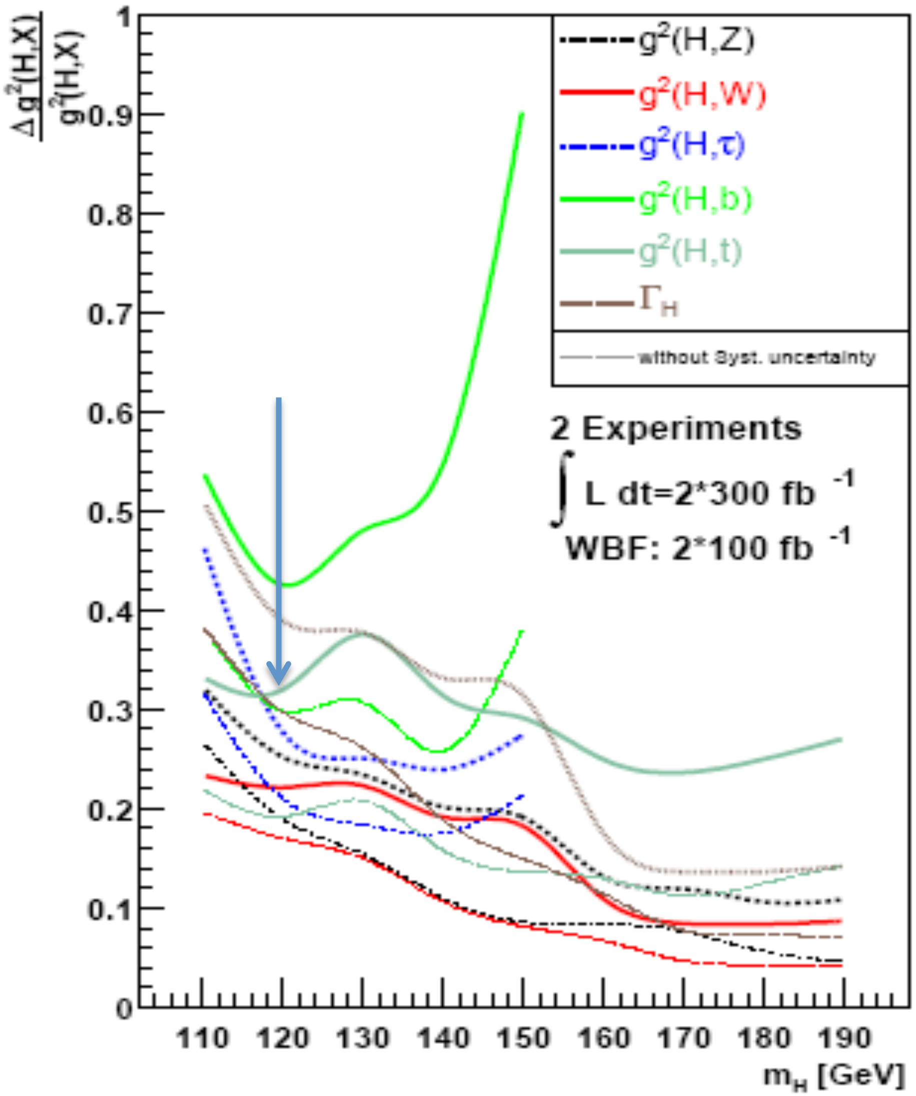


situation at LHC

- at the LHC, direct measurement of the top Yukawa coupling (pp->ttH) is thought to be impossible due to too much background
- through indirect measurement involving gluon fusion with a top loop,

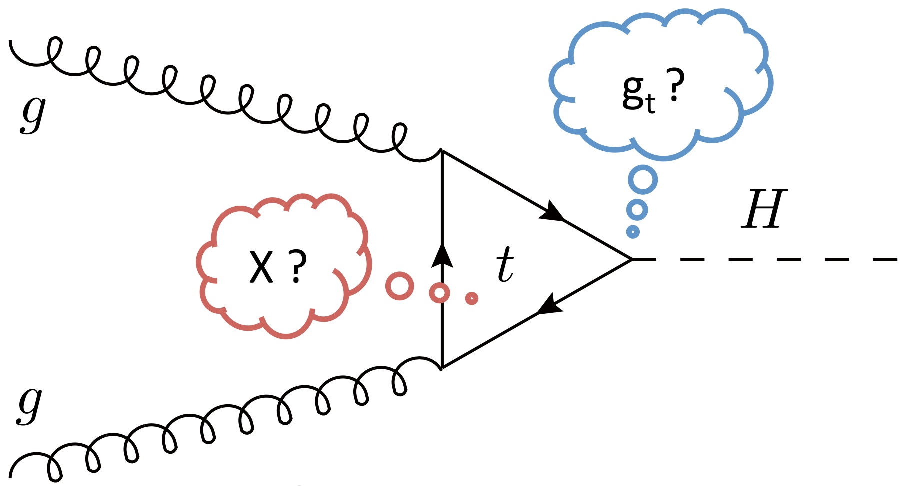


g_t measurement precision is estimated to be ~15% for M_H=120 GeV with 2 x 300 fb^{-1} data



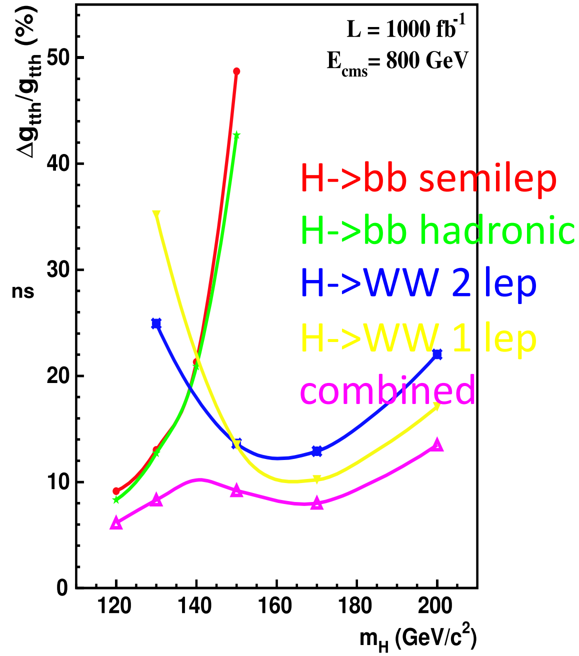
indirect measurement

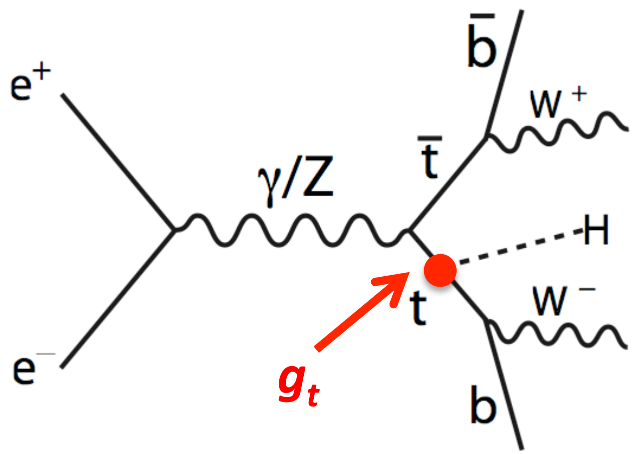
- the Higgs sector offers a broad range of possibilities for new physics; consider the scenario in which an anomaly in the Higgs production cross section is found.
- could it be due to…
  - an anomaly in the top Yukawa coupling itself?
  - a manifestation of a new particle X in the loop?
- difficult to distinguish these two with an indirect measurement !!

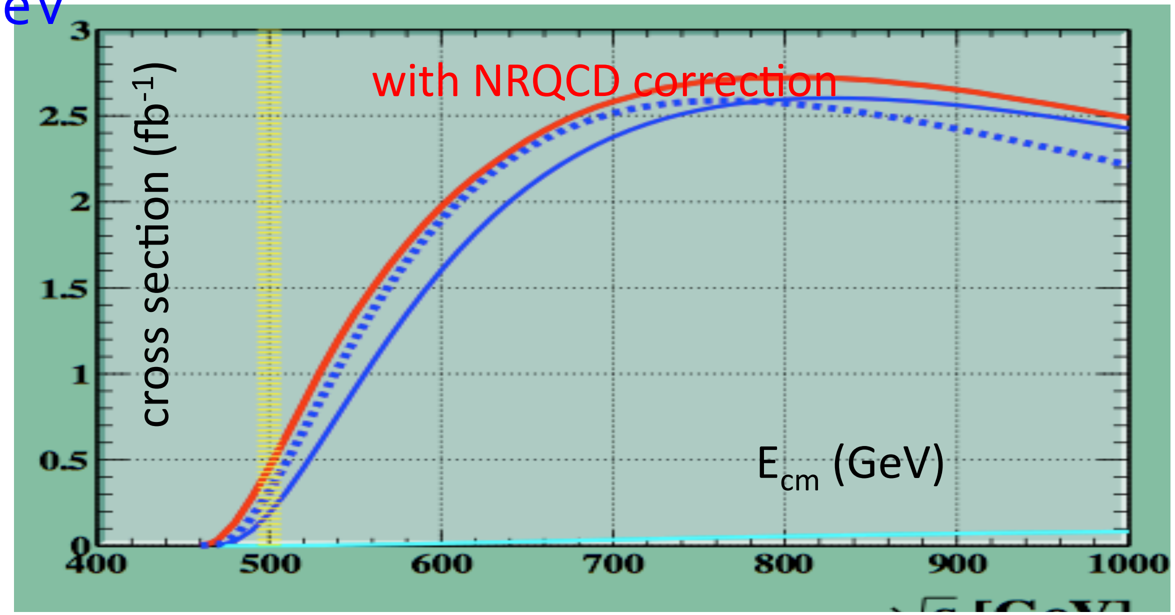


top Yukawa coupling @ ILC

- direct top Yukawa coupling measurement!
- past work estimated the measurement accuracy around E_{cm} = 700-800 GeV where the cross section reaches maximum
- the aim of this study is to demonstrate the feasibility of this measurement at E_{cm}=500 GeV
  - lower xsec due to lower E_{cm}
  - but the ttbar threshold correction enhances the ttH production (and also ttZ and ttg*)
- this makes it possible to perform the direct g_t measurement at E_{cm}=500 GeV

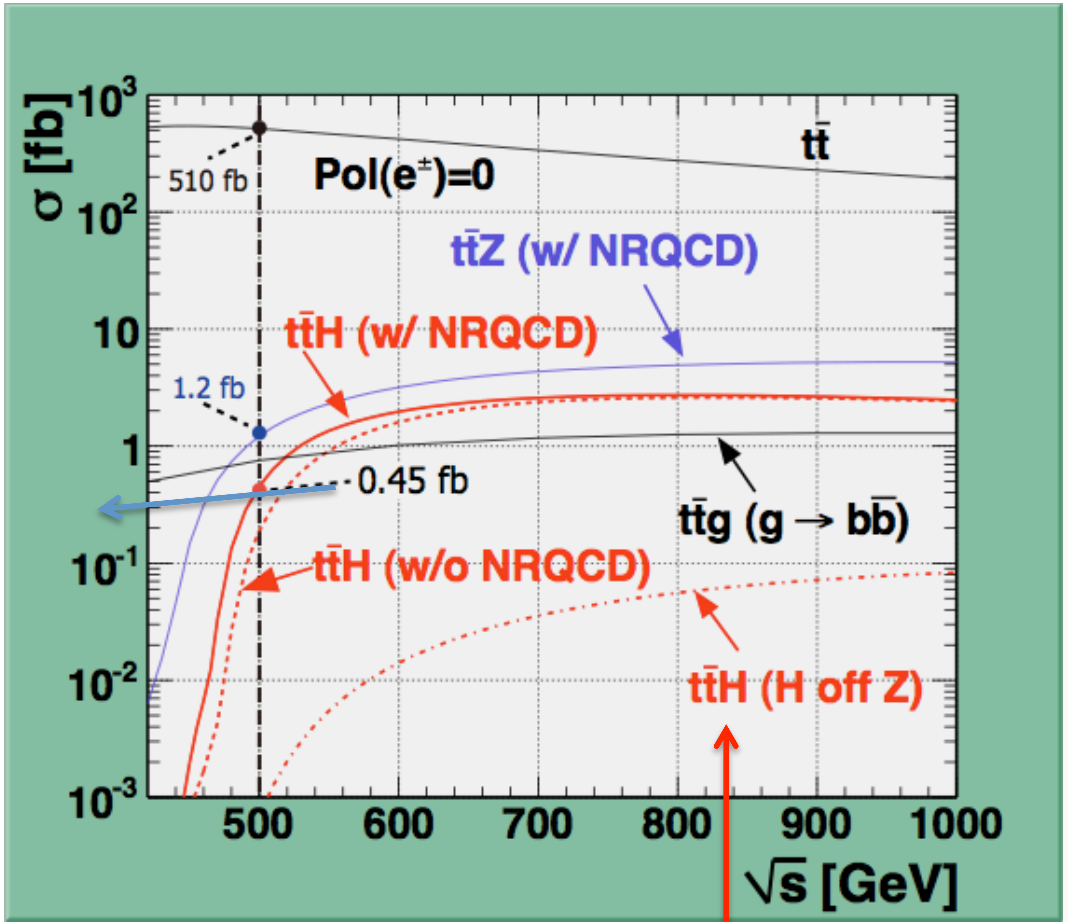






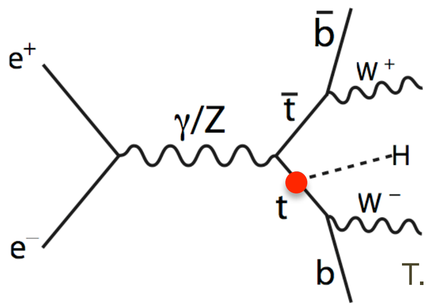
signal process: e+e- -> ttH

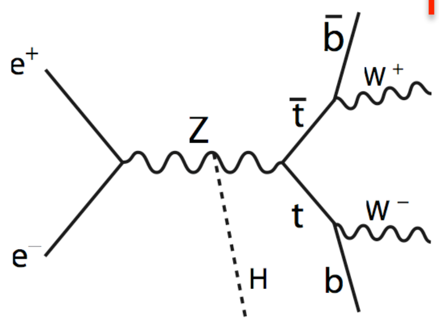
- event signature:
  - ttH -> bW^+bW^-bb
  - 8-jet, 1-lepton + 6-jet, and 2-lepton + 4-jet (H->bb: 68%)
- at E_{cm}=500 GeV, ttH production is dominated by γ/Z exchange
  - Higgs-strahlung contribution is negligible (tiny xsec)
  - can determine g_t by event counting
- small signal cross section (< 1fb)
  - further reduced by ISR and beamstrahlung
- after ttbar threshold correction: σ_{ttH} = 0.45 fb (no beam pol.)



contains g_t

$\sigma_{ttH} \propto g_t^2$

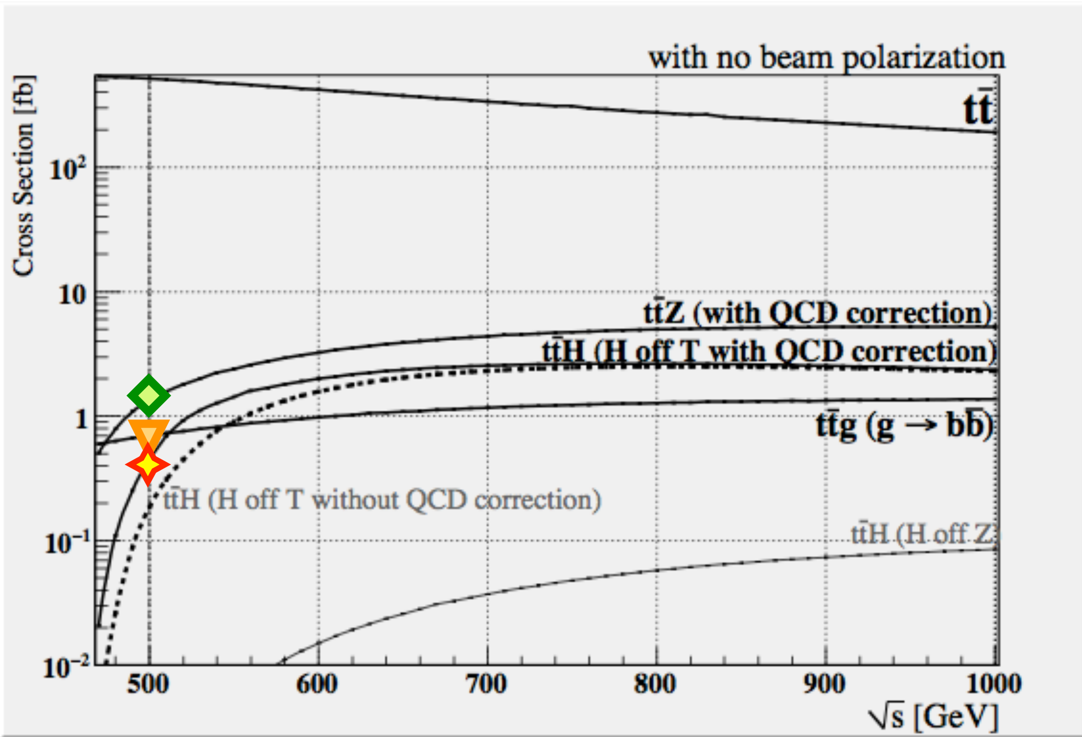




does not contain g_t

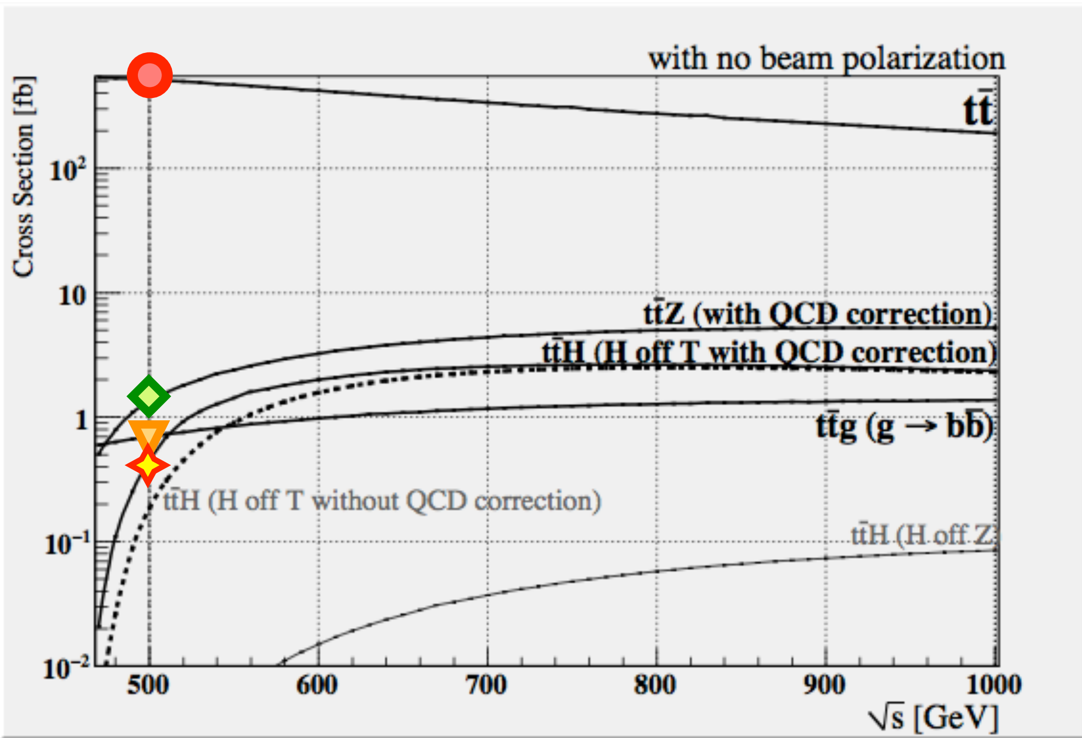
(almost) irreducible background: ttZ, ttg*

- irreducible background (same final state: ttbb -> bqq blνbb)
- electroweak: ttZ -> ttbb (Z -> bb: 15%) ~ 0.2fb with no beam polarization
  - ttbar threshold correction enhances σ_{ttz} from 0.7fb to 1.3fb
- electroweak: W*W*/ZZ* -> ttbb: small contribution (< 0.01fb)
- QCD: ttg* -> ttbb (g* -> bb: dominant) ~ 0.7fb with no beam polarization
- separate using M_{bb} vs. M_{Higgs}



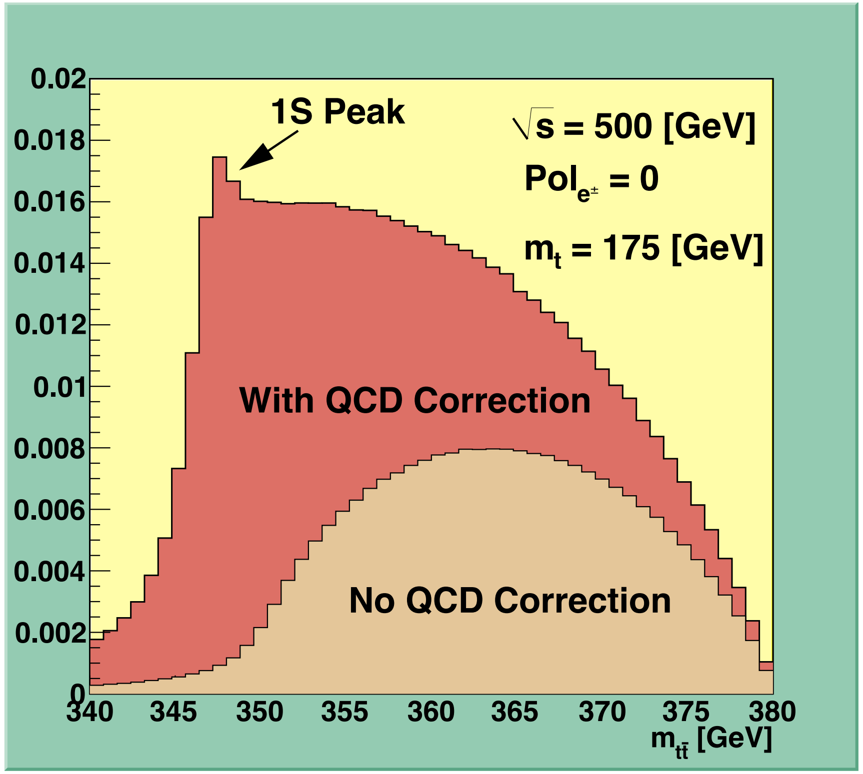
reducible background: ttbar

- reducible background but huge cross section: ~500 fb (no beam pol.)
  - hard gluon emission from bottom quarks mimic signal
  - even a tiny fraction of mis-reconstruction or b-tagging failure may lead to significant background contribution
- qq (5 flavors): ~4pb, found to be negligible with 4x b-tag
- WW: ~8pb, negligible with 4x b-tag; ZZ: ~0.58pb, negligible cross section



analysis framework

- physsim: event generator
  - full helicity amplitude calculation using HELAS; MC phase space integration / final-state particles
  - ISR & beamstrahlung included
  - ttbar threshold correction to ttH/ttZ
  - dedicated ttg generator with correct color strings
  - ttbar
- pythia: parton shower & hadronization
- JSF: fast detector simulation



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	$\sigma_E/E = 40\%/\sqrt{E} \oplus 2\%$	$\lvert\cos\theta\rvert \leq 0.90$

data samples

process	xsec (fb)	generated events	equivalent luminosity (ab^{-1})
ttH	1.24	50,000	40.3
ttZ	4.04	50,000	12.4
ttg (g->bb)	1.93	50,000	25.9
tt	1440.	7,000,000	4.9
ttH	0.540	50,000	92.6
ttZ	1.324	50,000	37.8
ttg (g->bb)	0.859	50,000	58.2
tt	618	7,000,000	11.3

e-/e+ polarization = (-1.0, +1.0)

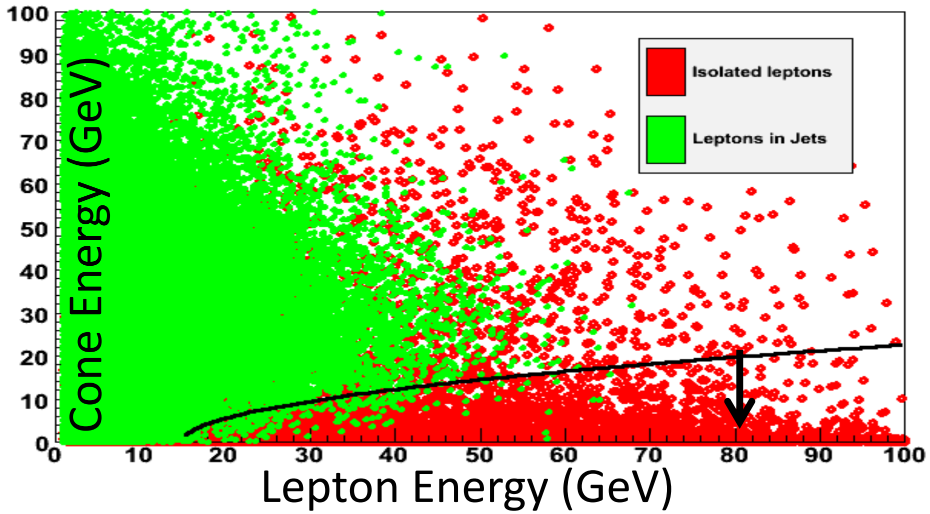
e-/e+ polarization = (+1.0, -1.0)

event selection

6-jet & 1-lepton mode	8-jet mode

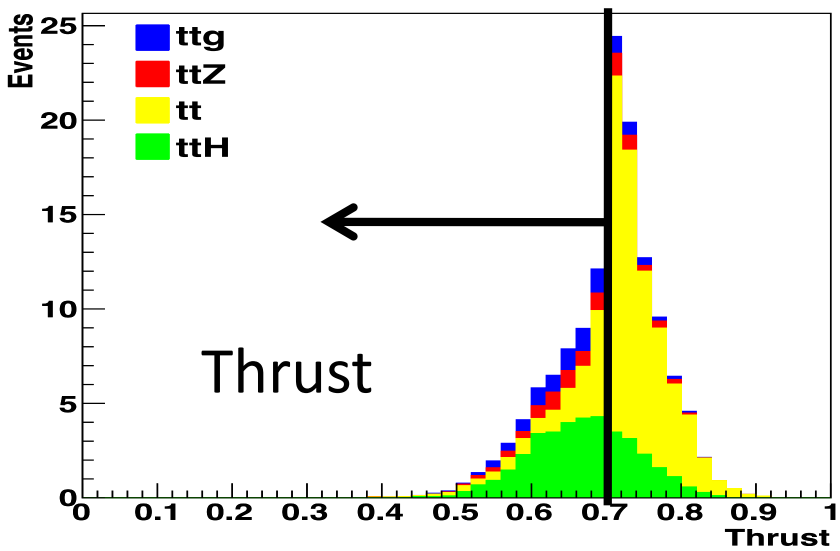
6-jet & 1-lepton mode

- find 1 isolated energetic e/mu
- force 6-jet (4 b-jets + 2 jets)
- choose jet combination consistent with
  - ttH = bWbWbb = bqqblnubb
- mass cut & thrust cut



8-jet mode

- force 8-jet (4 b-jets + 4 jets)
- choose jet combination consistent with
  - ttH = bWbWbb = bqqbqqbb
- mass cut & thrust cut



preliminary

cut flow: 1 lepton + 6 jets

beam pol: (±0.0, ±0.0)	ttH	tt	ttZ	ttg	significance
No Cut	449.0	514075	1340	697.5	0.625
Thrust Cut < 0.9	448.5	504263	1337	694.8	0.630
Isolated lepton = 1	159.6	175513	439.1	240.9	0.380
Y_{cut} value cut(0.0003) before Force 6J	154.8	65213	384.2	209.8	0.603
b-tagging(loose(2,2), tight(2.5,4)) && $\lvert M - M_{Higgs}\rvert > \lvert M - M_Z\rvert$ for Higgs candidate	49.4	615.7	37.7	43.3	1.809
top Mass Cut > 140 GeV && Thrust cut < 0.78 && Y_{cut} value cut (log10(ycut_f4j) > -2.3)	30.2	16.1	19.5	8.8	3.497

beam pol: (-0.8, +0.3)	ttH	tt	ttZ	ttg	significance
No Cut	759.3	863503	2406	1160	0.815
Thrust Cut < 0.9	758.4	847025	2401	1155	0.822
Isolated lepton = 1	270.8	294796	787.7	395.7	0.498
Y_{cut} value cut(0.0003) before Force 6J	262.7	109572	689.4	344.1	0.789
b-tagging(loose(2,2), tight(2.5,4)) && $\lvert M - M_{Higgs}\rvert > \lvert M - M_Z\rvert$ for Higgs candidate	84.0	1033.8	67.5	72.2	2.369
top Mass Cut > 140 GeV && Thrust cut < 0.78 && Y_{cut} value cut (log10(ycut_f4j) > -2.3)	51.1	26.6	34.5	14.1	4.547

scaled to 1 ab^{-1}

mass: 1 lepton + 6 jets

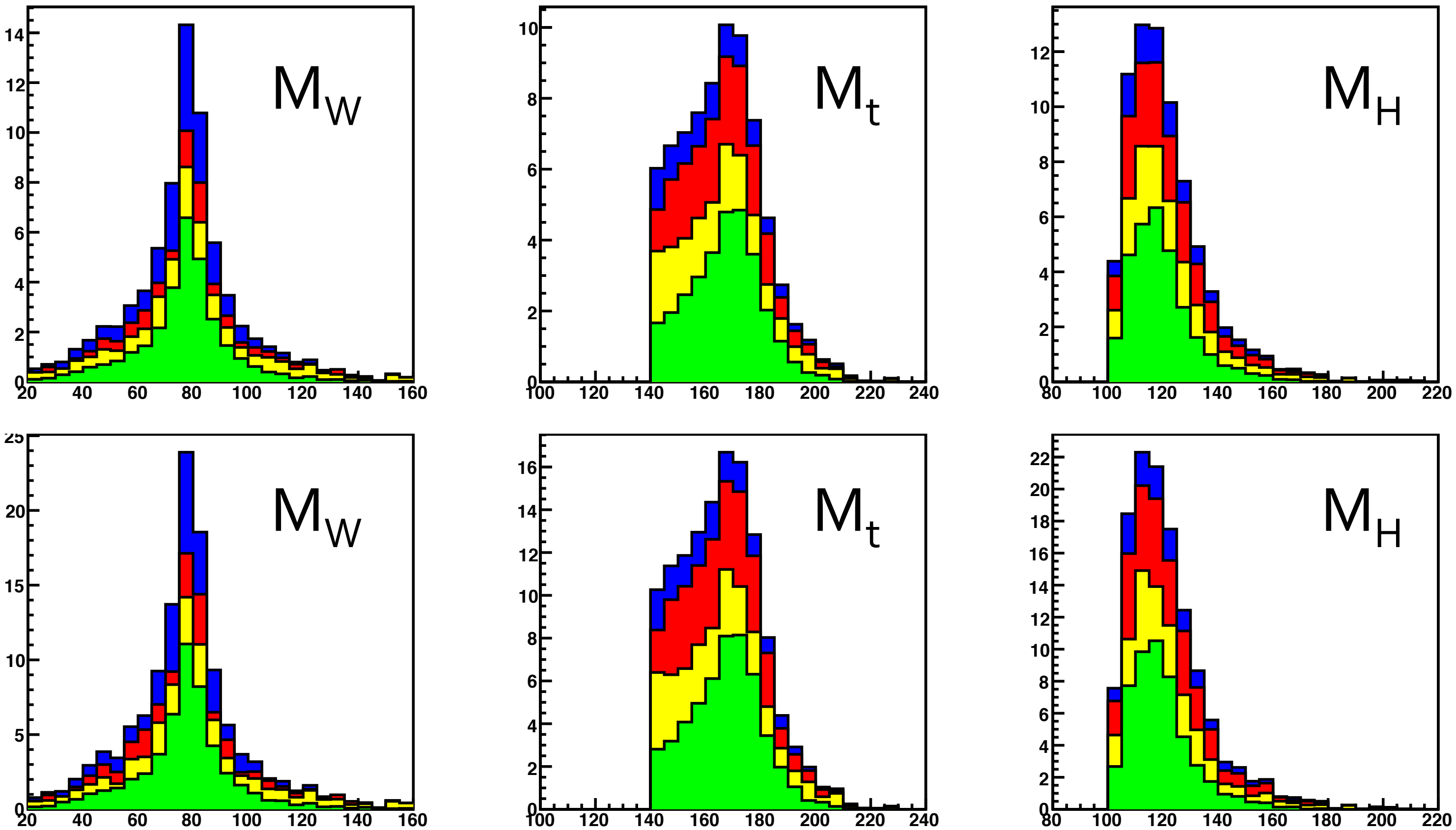
preliminary

1 ab^{-1}

(±0.0, ±0.0)

- ttg
- ttZ
- tt
- ttH

(-0.8, +0.3)



Polarization	S / B	S / √(S+B)	$\Delta g_t / g_t$
(0.0, 0.0)	30.2 / 44.4	3.50	14.3%
(-0.8, +0.3)	51.2 / 75.2	4.55	11.0%

(stat. error only)

cut flow: 8 jets

preliminary

beam pol: (±0.0, ±0.0)	ttH	tt	ttZ	ttg	significance
No cut	445.2	516912.7	1338.8	697.4	0.62
$N_{trk} > 25$	445.1	515716.6	1338.0	697.4	0.62
E_{vis}>300GeV	430.2	460838.9	1210.6	650.8	0.63
$P_{t,vis}$<100GeV	423.1	426059.5	1179.8	612.0	0.65
$Y_{jet} > 0.001$	407.2	201768.7	1073.1	529.9	0.90
$E_{jet} > 5$ GeV	404.5	198164.9	1062.1	526.0	0.90
btag & mass cut	31.2	131.3	18.2	7.5	2.28
thrust < 0.7	20.7	25.1	13.5	4.7	2.59

beam pol: (-0.8,+0.3)	ttH	tt	ttZ	ttg	significance
No cut	744.7	869867.8	2405.2	1159.4	0.80
$N_{trk} > 25$	744.6	867851.9	2403.8	1159.4	0.80
E_{vis}>300GeV	719.8	775599.7	2174.2	1085.4	0.82
$P_{t,vis}$<100GeV	707.8	717008.2	2118.9	1022.1	0.83
$Y_{jet} > 0.001$	681.3	339451.8	1926.9	881.0	1.16
$E_{jet} > 5$ GeV	676.9	333392.1	1907.7	874.5	1.17
btag & mass cut	52.3	220.9	32.6	12.9	2.93
thrust < 0.7	34.8	41.2	24.6	7.5	3.35

scaled to 1 ab^{-1}

mass: 8 jets

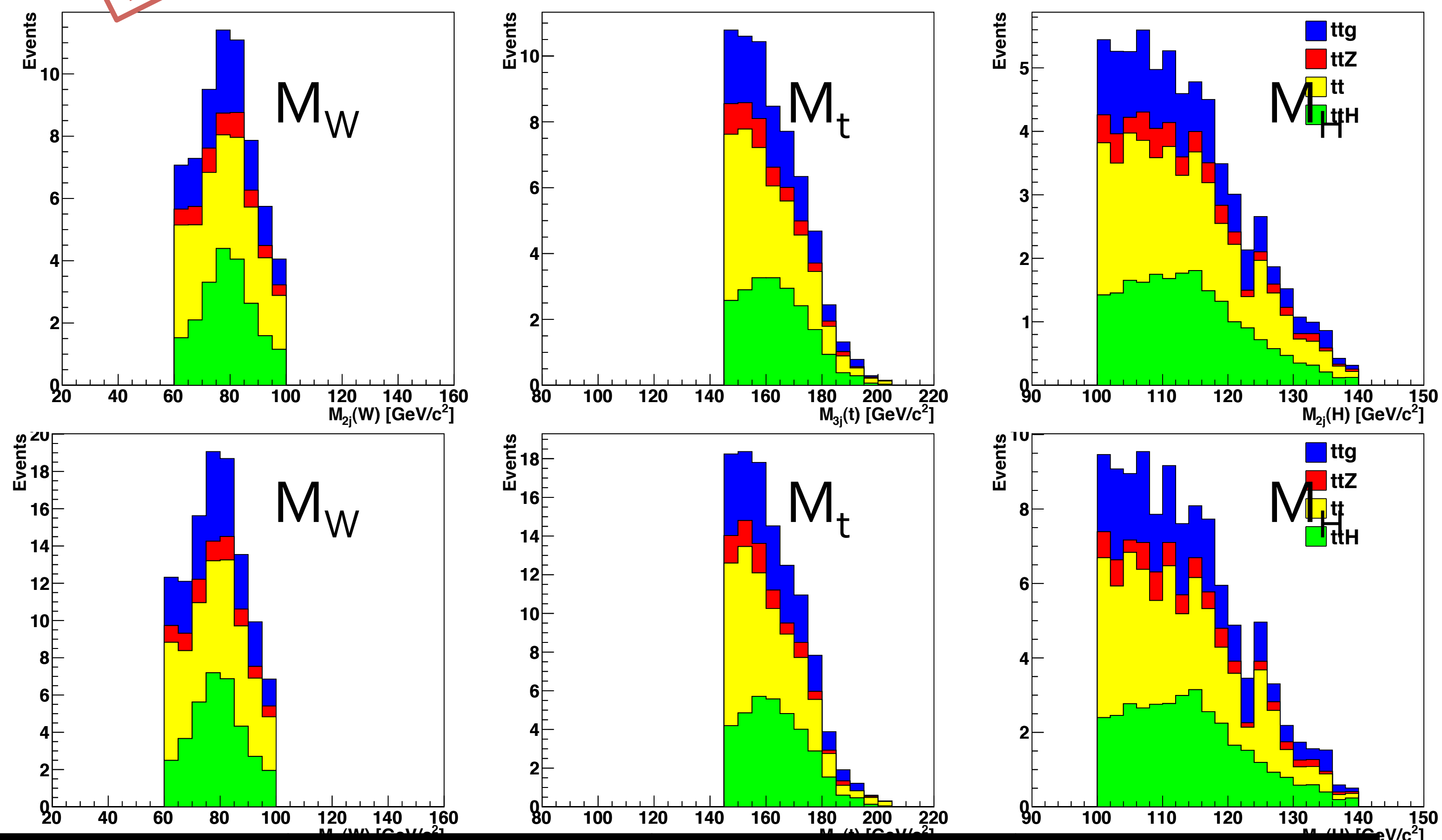
preliminary

1 ab^{-1}

(±0.0, ±0.0)

ttg
ttZ
tt
ttH

(-0.8, +0.3)



Polarization	S / B	S / √(S+B)	$\Delta g_t / g_t$
(0.0, 0.0)	20.7 / 43.3	2.59	19.3%
(-0.8, +0.3)	34.8 / 73.3	3.35	14.9%

(stat. error only)

combined significance

preliminary

1 ab^{-1}

Polarization (e-,e+)	6 Jet + Lepton S / B	8 Jet S / B
(±0.0, ±0.0)	30.2 / 44.4	20.7 / 43.3
(-0.8, +0.3)	51.2 / 75.2	34.8 / 73.3

Polarization (e-,e+)	6 Jet + Lepton S/√(S+B)	8 Jet S/√(S+B)	Combined Significance	Combined $\Delta g_t / g_t$
(±0.0, ±0.0)	3.50	2.59	4.35	11.5
(-0.8, +0.3)	4.55	3.35	5.65	8.8

(stat. error only)

summary & plans

- given:
  - E_{cm} = 500 GeV
  - 1 ab^{-1}
  - polarized beams (-0.8, +0.3)
- fast simulation studies suggests ~10% accuracy on g_t is achievable
  - concurrent to HHH coupling measurement
- future plans
  - move to full simulation
    - use high performance flavor-tagging: LCFIVertex
    - full SM background scan
  - submit fast simulation results for publication

backup

equations

Arbitrary Polarization from Purely Polarized Beams

$$\sigma(e^+e^- \to X) = \frac{1}{4}[(1+P_{e^-})(1-P_{e^+})\sigma(e_L^+e_R^- \to X)$$
$$+ (1-P_{e^-})(1+P_{e^+})\sigma(e_R^+e_L^- \to X)]$$

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

equations

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

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

Combining Significances

$$\mathcal{S}_{\rm combined} = \sqrt{\sum_i (\mathcal{S}_i)^2}$$