Top Yukawa coupling measurement

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on behalf of TTH subgroup
in ILC Physics group

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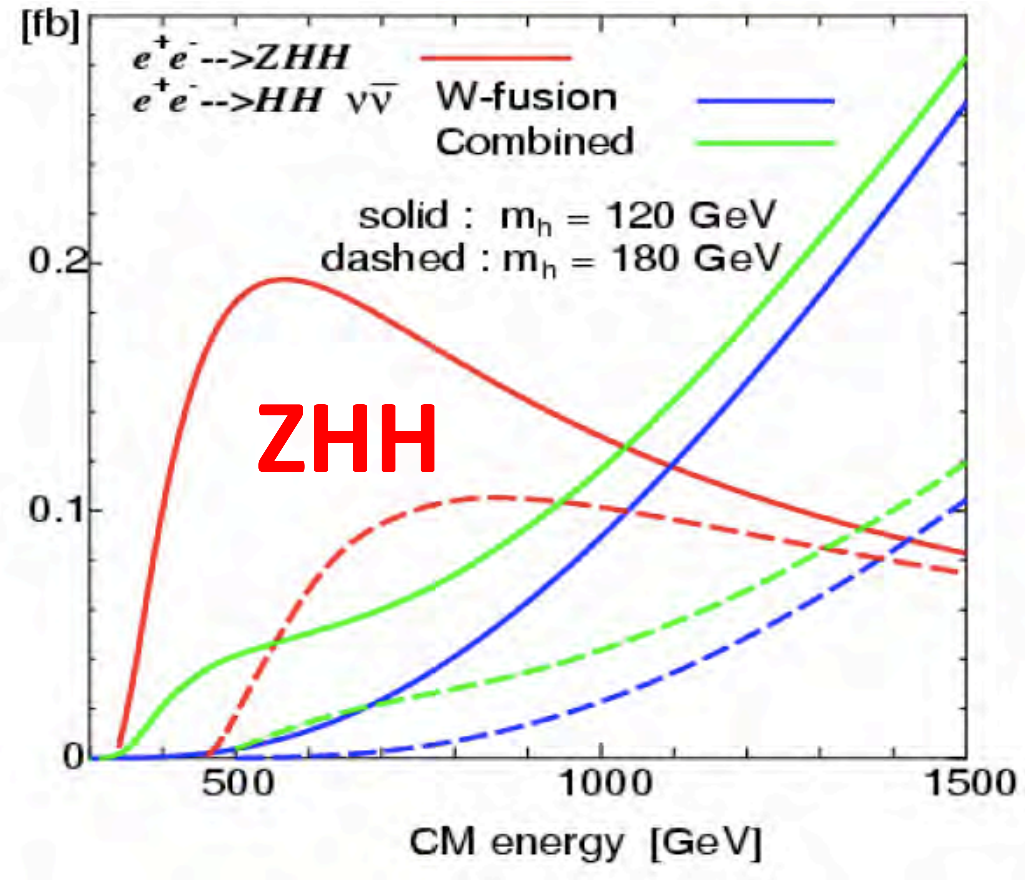
Motivation

Higgs coupling measurements are critical missions for the ILC

- Higgs self coupling ⟶ Junping's talk
- Higgs fermion coupling



Higgs self coupling will be tested at ~ **500** GeV where e+e- -> ZHH cross section attains its maximum.

Our motivation is to measure Top-Yukawa coupling at **500 GeV (1st stage of ILC)** concurrently to measuring Higgs self coupling.

Measurement of top-Yukawa coupling at 500 GeV

Past work estimated the measurement accuracy around E_{cm} = 700 ~ 800 GeV where the cross section reaches maximum.

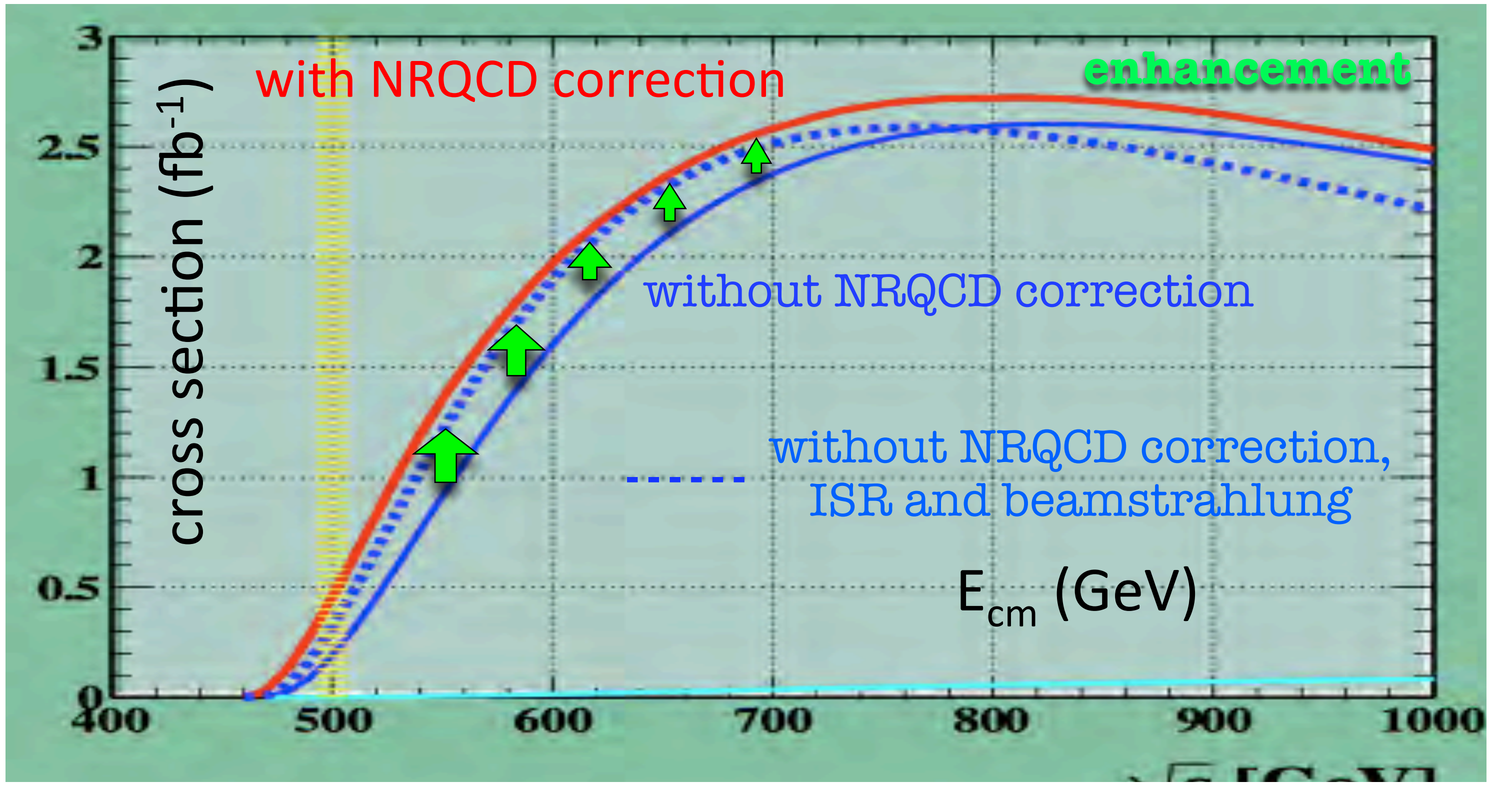
At 500 GeV, Cross section is smaller than 1 fb!

(We assume in this study
M_{top} = 175 GeV
M_H = 120 GeV)

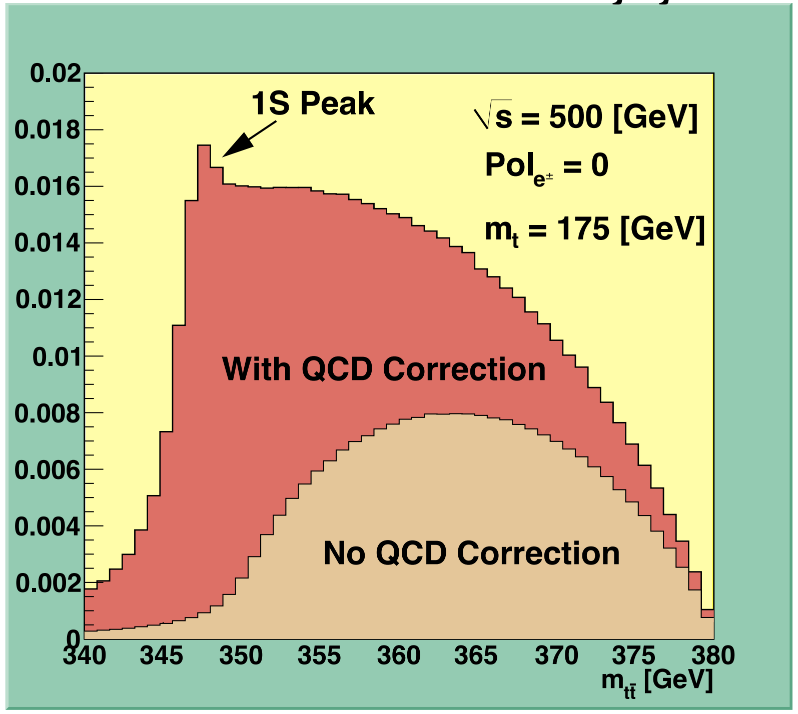
tt threshold correction enhances ttH production (and also ttZ)

This makes it possible to perform the direct g_t measurement at 500 GeV

Cross section of ttH



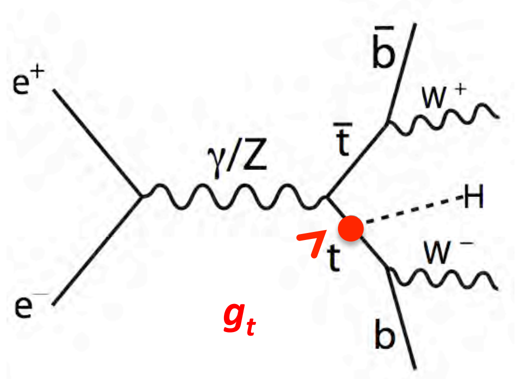
Invariant mass dist. for tt sysytem



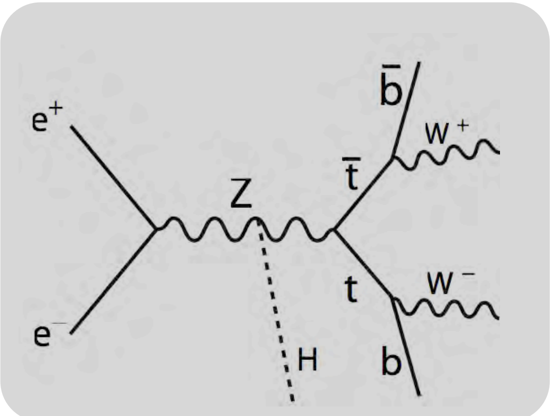
Feature of signal process (e+e- -> ttH)

At E_{cm} = 500 GeV, ttH production is dominated by s-channel γ / Z exchange.

e+e- -> ttH



contains g_t → This is what we want.



does NOT contains g_t

There is contribution to ttH from Higgs-strahlung. This diagram doesn't contain top-Yukawa coupling. But its contribution is negligible because of small cross section.

→ **This measurement is a counting experiment.**

If we assume H --> bb, the signal are divided into three modes according to W decays.

- 8-Jet
- 1-lepton + 6-jet
- 2-lepton + 4-jet

(H -> bb : 68% assuming M_H = 120 GeV)

Main backgrounds

(1) **ttZ** followed by Z -> bb (15%)

same final state (t t Z -> bW bW bb)

--> irreducible background

tt threshold correction enhances σ_{ttz} from 0.7fb to 1.3fb

(2) **ttg*** followed by g* -> bb

same final state (t t g* -> bW bW bb) --> irreducible background

(3) **tbW**

huge cross section (~ 600fb)
hard gluon emission from bottom quarks in tt process mimic signal
(Since the tail of tt enters as background of ttH, it is important to include non-resonant contribution(tbW))
even a tiny fraction of mis-reconstruction or b-tagging failure leads to significant background contamination.

The other possible backgrounds ?

W*W*/Z*Z -> ttbb small contribution (< 0.01fb)

qq (5 flavors), WW, ZZ, ZH have different signature from ttH signal.

- can be separated with 4×b tagging, event shape cut and mass cut

} Small contribution

We generated signal(ttH) and main backgrounds (ttZ, ttg*, tbW).

Analysis of Fast Simulation data

Cut flow (**6Jet + lepton**, lumi. = 1 ab^{-1}, beam polarization (-0.8,+0.3))

Cut	ttH(6J+L)	ttH (8J, 4J+2L)	tbW(inc. tt)	ttZ	ttg* (g* -> bb)	significance
no cut	282	358	980739	2407	1160	0.28
Single isolated lepton	180	49	340069	791	398	0.31
thrust < 0.77	146	37.7	144999	617	266	0.38
$Y_{5\to4}$ > 0.005	126	25.8	12297.7	416	114	1.1
4×b-tagging	49.0	4.2	172.9	53.3	37.8	2.8
mass cut	39.5	1.6	23.0	33.9	13.2	3.7

H -> bb (68%) Z->bb (15%)

Analysis of Fast Simulation data

Cut flow (**8Jet**, lumi. = 1 ab^{-1}, beam polarization (-0.8,+0.3))

Cut	ttH(6J+L)	ttH (8J, 4J+2L)	tbW(inc. tt)	ttZ	ttg* (g^* -> bb)	significance
no cut	290	351	980739	2407	1160	0.29
Single isolated lepton	266	92.2	589716	1351	701	0.35
thrust < 0.77	168	46.7	107227	818	312	0.51
$Y_{5\to4}$ > 0.005	114	13.3	4048	350	67.1	1.7
4×b-tagging	66.6	6.9	443	77.6	39.8	2.6
mass cut	50.1	0.4	75.6	47.6	14.1	3.7

H -> bb (68%) Z->bb (15%)

Analysis of Fast Simulation data

Combined significance 5.2

Combined $\Delta g_t/g_t$ 9.6 %

Assuming
- E_{cm} = 500 GeV
- luminosity 1 ab^{-1}
- polarized beams (-0.8, +0.3)
- M_H = 120 GeV
- M_{top} = 175 GeV

See details in Phys.Rev.D84:014033,2011

Analysis of Full Detector Simulation data

We have just started.

Our first goal

Compare the results with fast simulation

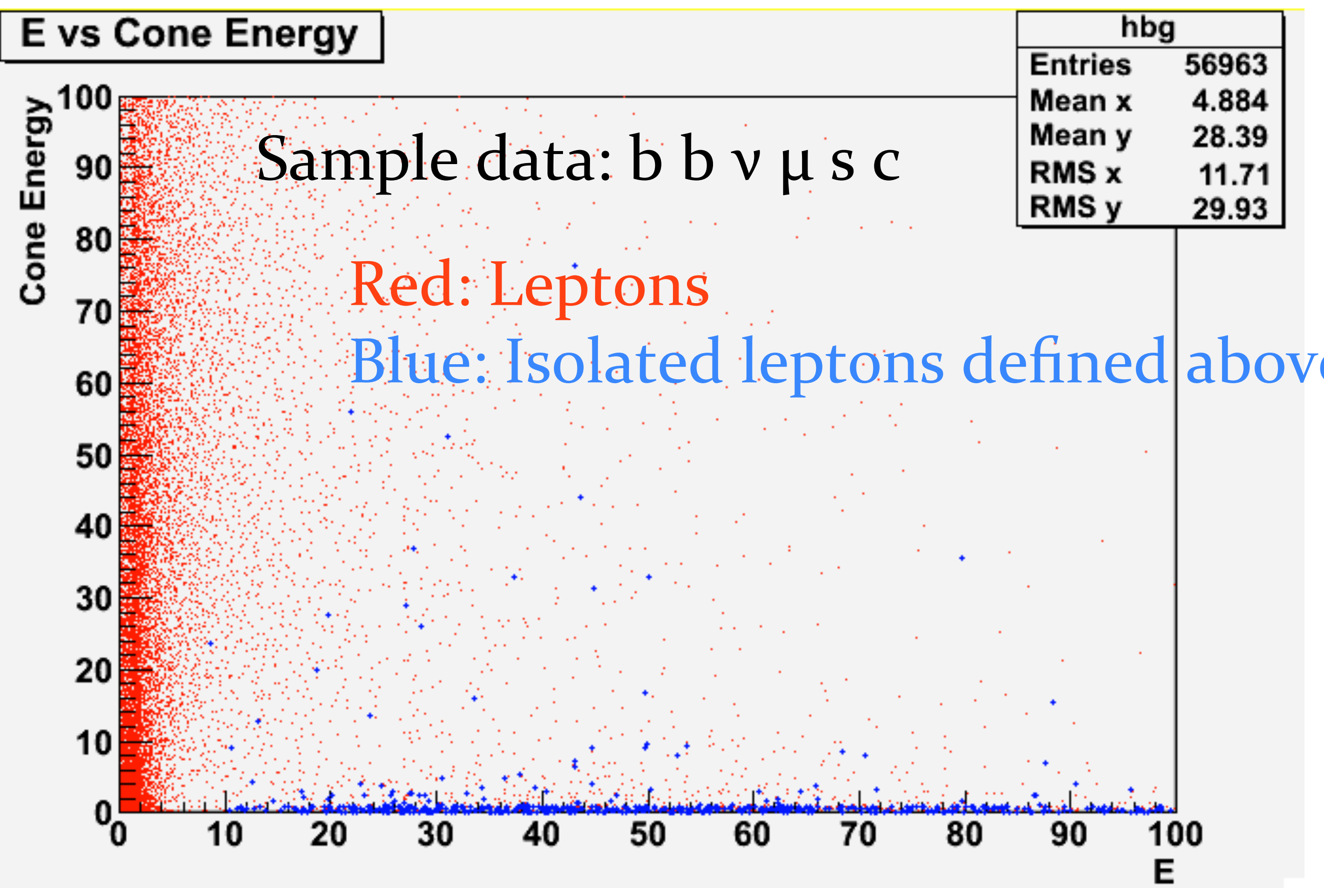
- E_{cm} = 500 GeV
- luminosity 1 ab^{-1}
- polarized beams (-0.8, +0.3)
- M_H = 120 GeV
- M_{top} = 175 GeV

What we need?

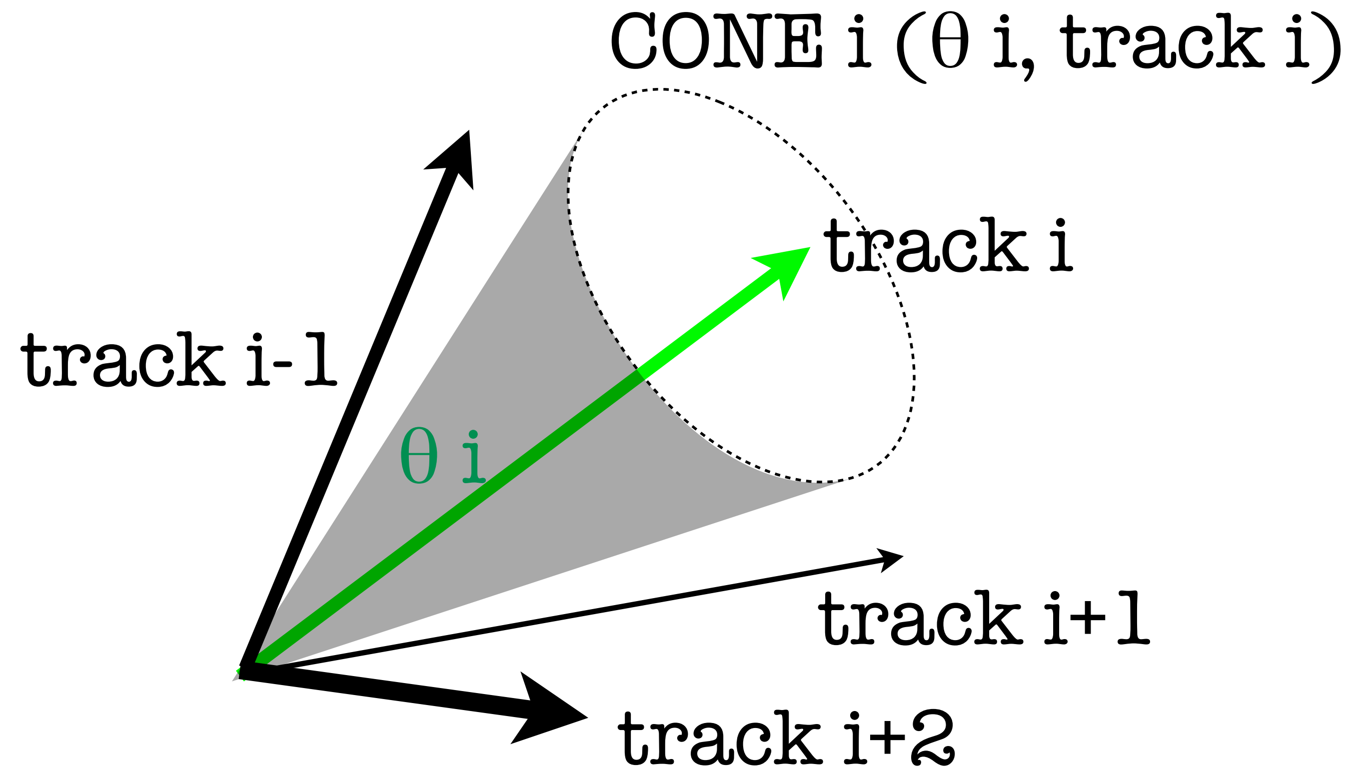
Detector simulation data
Most background are already available, which are used in LOI studies.
ttH and ttZ are needed to prepare by ourselves considering QCD correction effect.
Analysis
Isolated lepton finder processor

Analysis code is under preparing ...

Energy and Cone Energy scatter plot
which is useful to find isolated leptons



Cone energy



Cone energy is defined as the
energy of the tracks in the cone.

Summay

The fast simulation study shows that
~10% accuracy on top-Yukawa coupling is achievable.

Assuming
- E_{cm} = 500 GeV
- luminosity 1 ab^{-1}
- polarized beams (-0.8, +0.3)
- M_H = 120 GeV
- M_{top} = 175 GeV

Plans

Full simulation
Finish preparation of the analysis code
Prepare the full simulated data (ttH, ttZ)
Optimize the cut value

Fast simulation
M_H ~ 140 GeV (Considering H--> WW*)

Backup

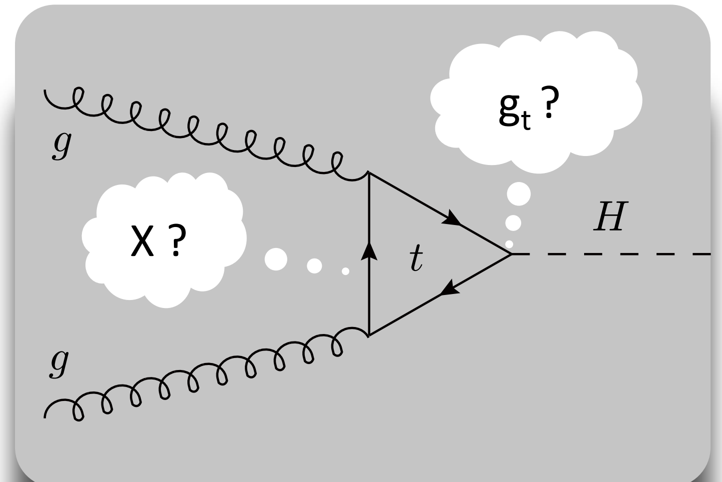
Top-Yukawa coupling $<$ indirect measurement / direct measurement

•indirect measurement

The Higgs sector offers a broad range of possibilities for new physics ...

There is a possibility of a new particle X being in the loop.

It is difficult to distinguish X loop and top loop!

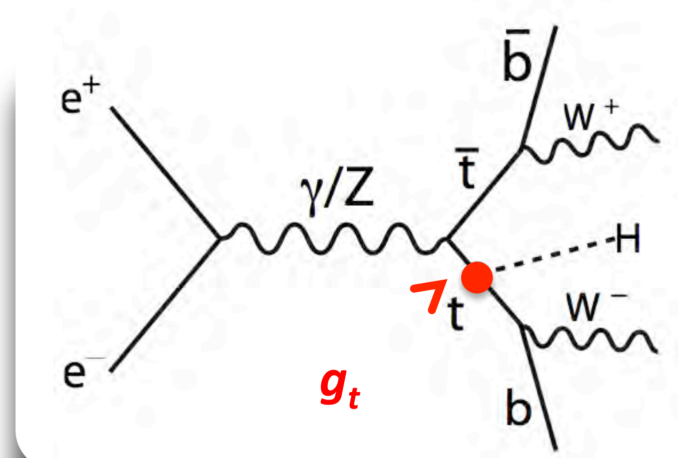


gg -> ttH @ LHC

•direct measurement

promising at ILC !!

main decay mode (H -> bb 68%) can be used



e+e- -> ttH @ ILC

Analysis Framework

- Event generator : physsim
  - full helicity amplitude calculation by HELAS
  - MC phase space integration by BASES/SPRING

  ISR & beamstrahlung are included

  NRQCD correction for ttH and ttZ is included

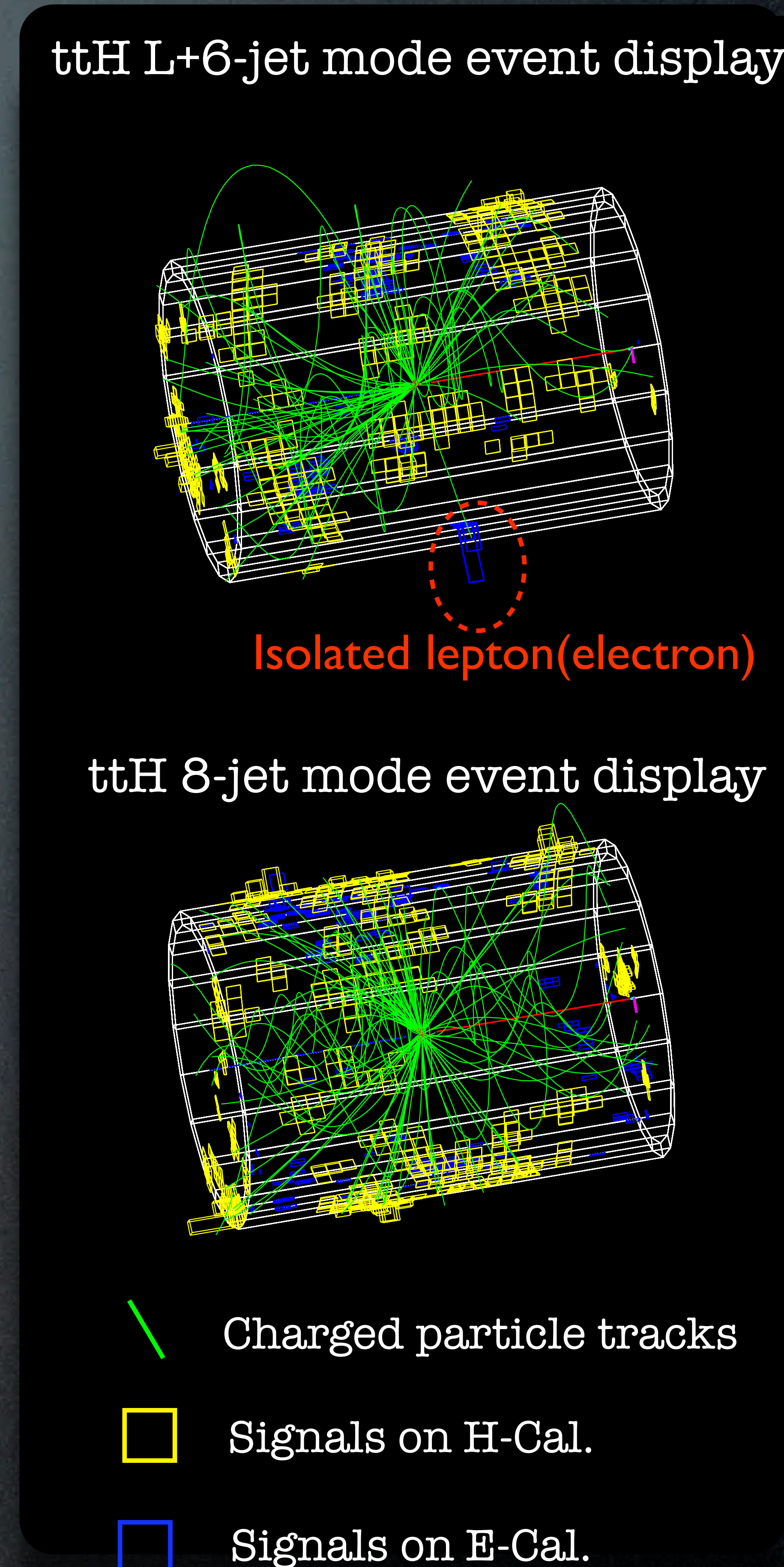
  Dedicated ttg generator with correct color strings

- Parton shower & hadronization: pythia

- Fast detector simulation: JSF

Detector parameters

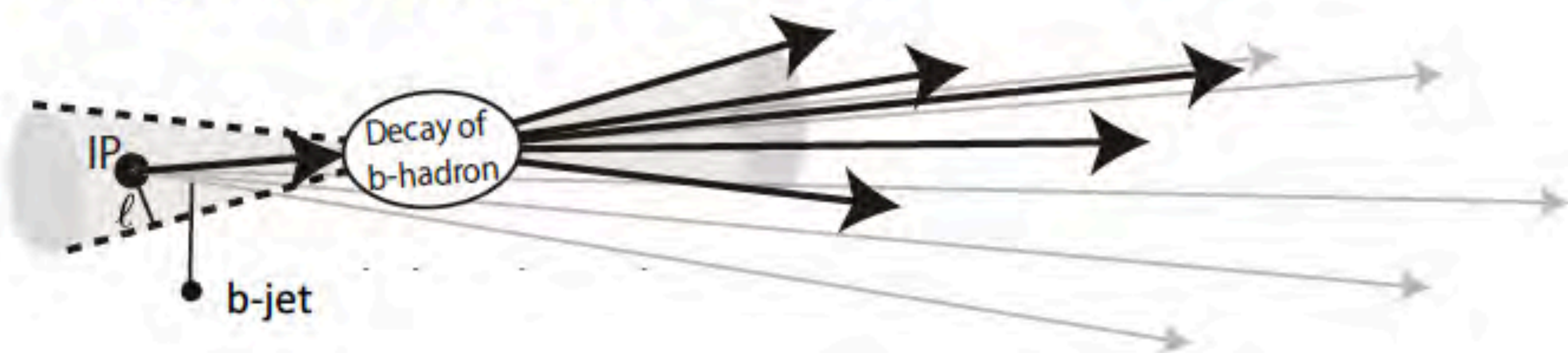
Detector	Performance	Coverage
Vertex detector	$\sigma_b = 7.0 \oplus (20.0/p)/\sin^{3/2}\theta \mu m$	$\lvert\cos\theta\rvert \leq 0.90$
Central drift chamber	$\sigma_{P_T}/P_T = 1.1 \times 10^{-4} p_T \oplus 0.1\%$	$\lvert\cos\theta\rvert \leq 0.95$
EM calorimeter	$\sigma_E/E = 15\%/\sqrt{E} \oplus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



b-tagging

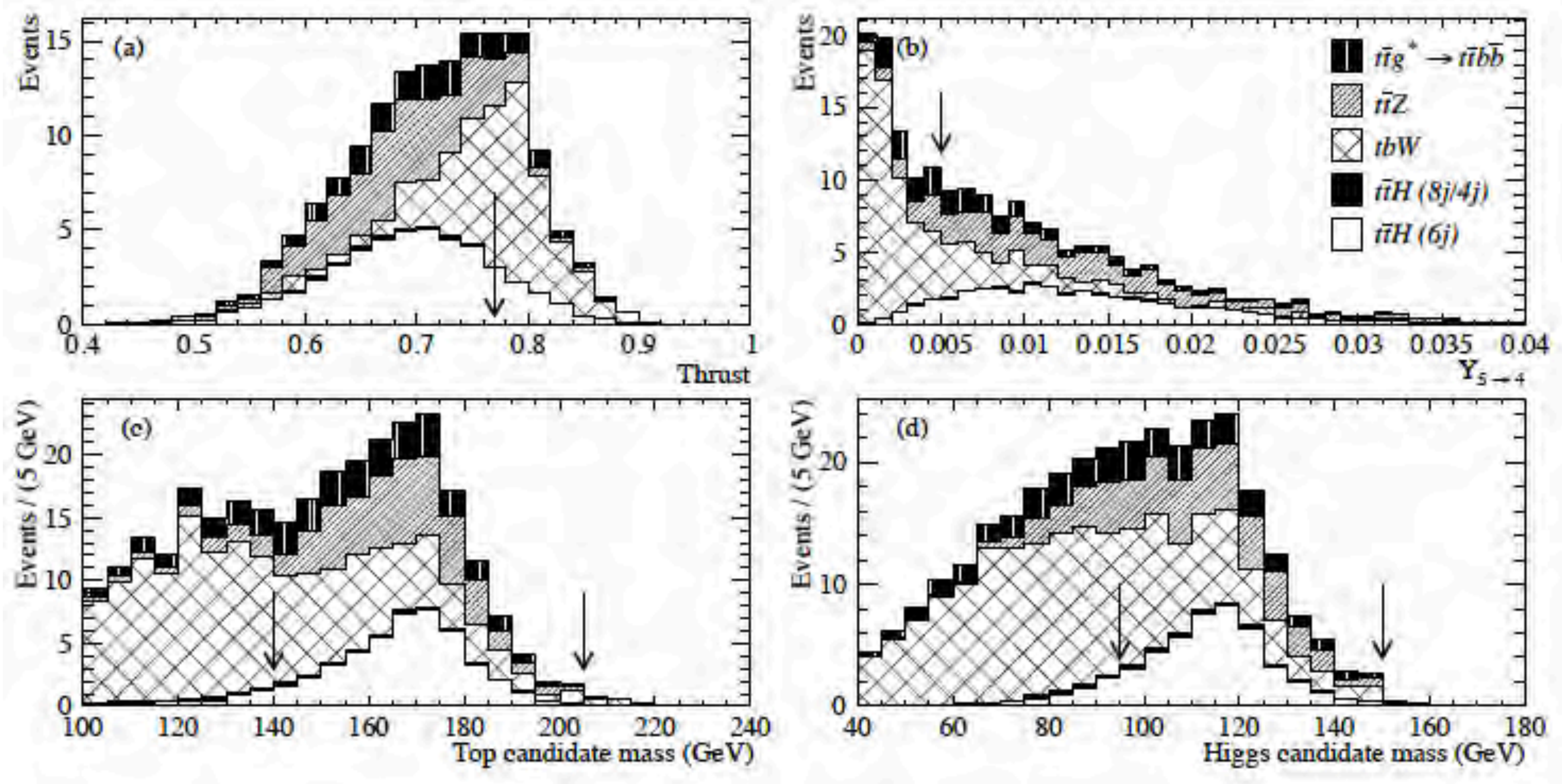
- identify b-jets via their large impact parameter significance (IPS) of secondary tracks.
- b-tagging criteria:
  - **tight (6J+L)**: require 4 tracks with IPS >2.5
  - **tight (8J)**: require 2 tracks with IPS>3.0
    - efficiency: 47%, fake rate: c-jet 3.2%, uds-jet 0.1%
  - **loose**: require 2 tracks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

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



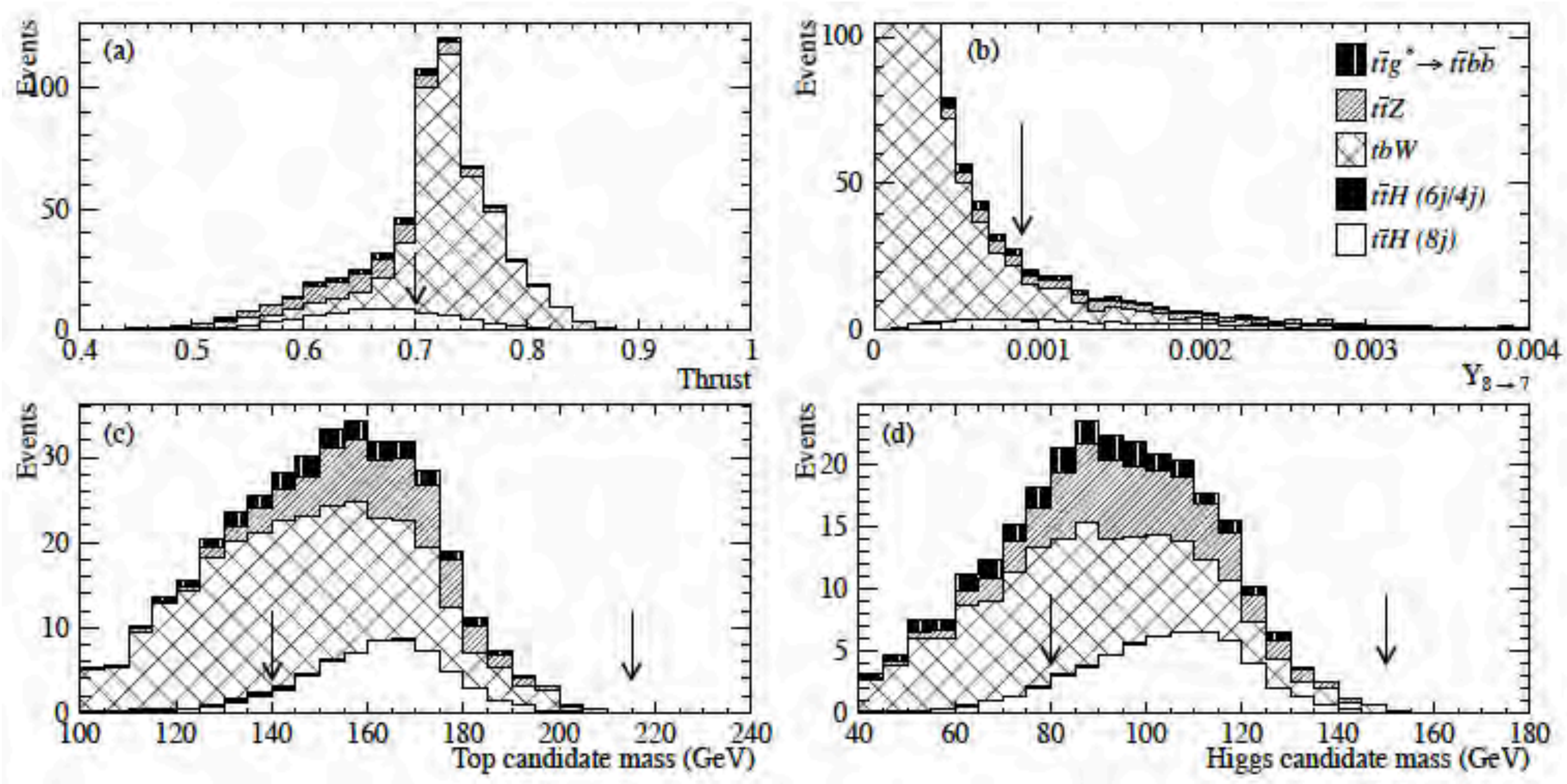
Background reduction

1 lepton + 6 jet mode

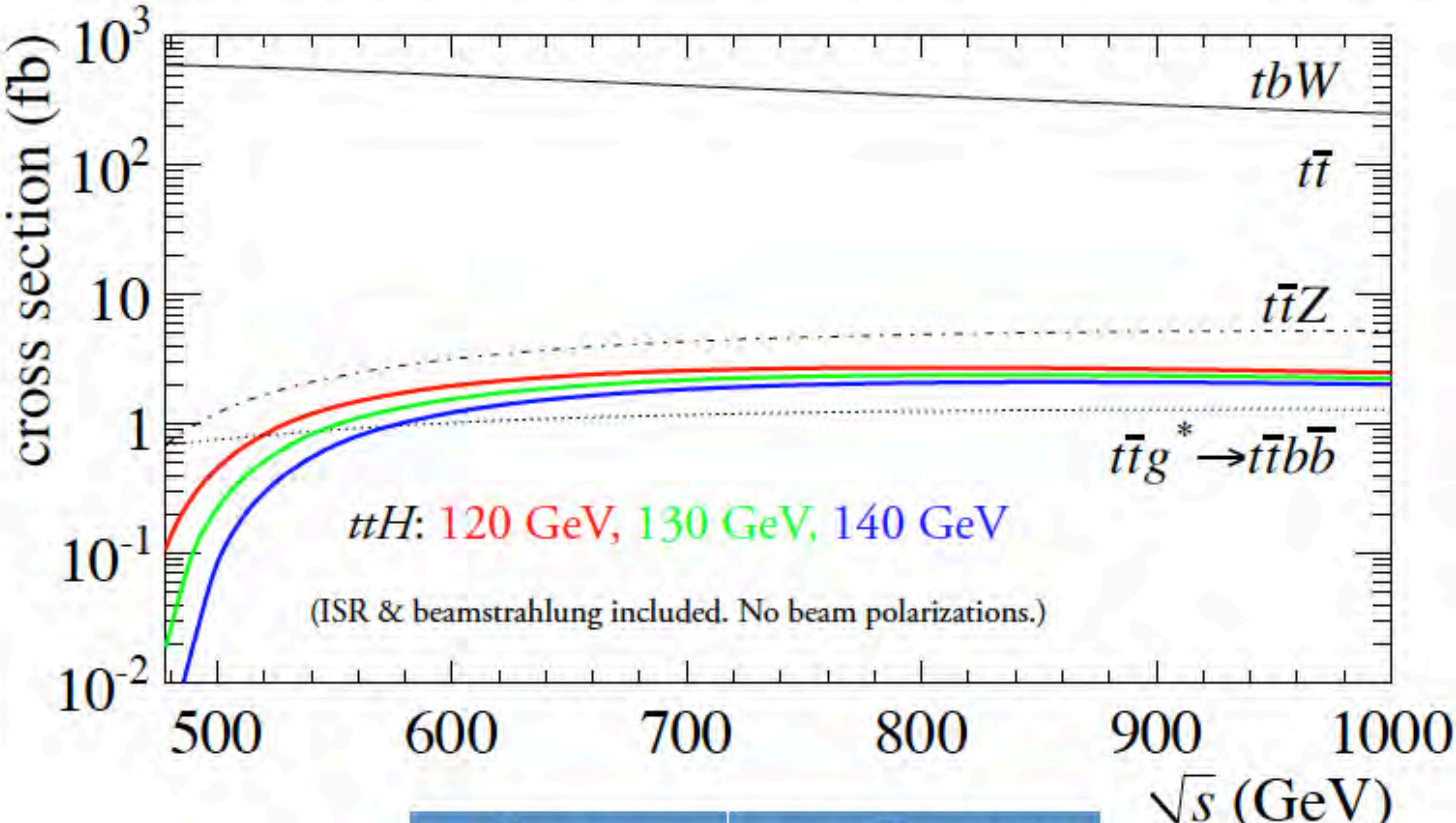


Background reduction

8 jet mode

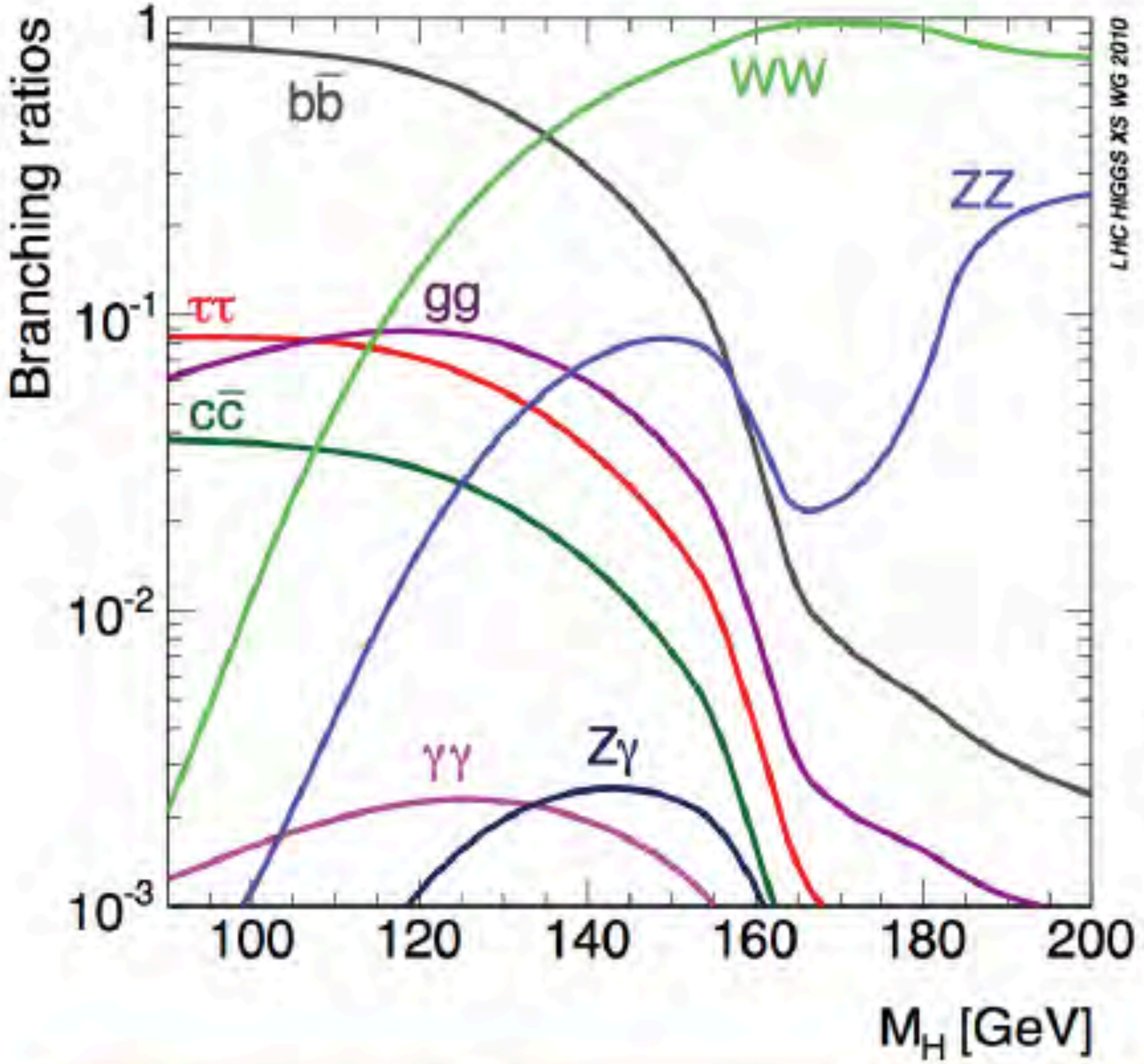


ttH cross section



Higgs mass	e+e- -> *ttH* cross section
120 GeV	0.454 fb
130 GeV	0.224 fb
140 GeV	0.084 fb

Higgs branching ratio



Higgs mass	BF(H->bb)	BF(H->WW)
120 GeV	67.9%	13.2%
130 GeV	52.7%	28.7%
140 GeV	34.4%	48.3%

Thrust

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

Y value for jet clustering (Durham)

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

For Jet combination

1 lepton + 6 jet analysis

$$\chi^2 = \left(\frac{m_{j_1 j_2} - M_H}{\sigma_H}\right)^2 + \left(\frac{m_{j_3 j_4 j_5} - M_t}{\sigma_t}\right)^2 + \left(\frac{m_{j_3 j_4} - M_W}{\sigma_W}\right)^2$$

8 jet analysis

$$\chi^2 = \left(\frac{m_{j_1 j_2} - M_H}{\sigma_H}\right)^2 + \left(\frac{m_{j_3 j_4 j_5} - M_t}{\sigma_t}\right)^2 + \left(\frac{m_{j_6 j_7 j_8} - M_t}{\sigma_t}\right)^2 + \left(\frac{m_{j_3 j_4} - M_W}{\sigma_W}\right)^2 + \left(\frac{m_{j_6 j_7} - M_W}{\sigma_W}\right)^2$$