Top quark pair production near the threshold

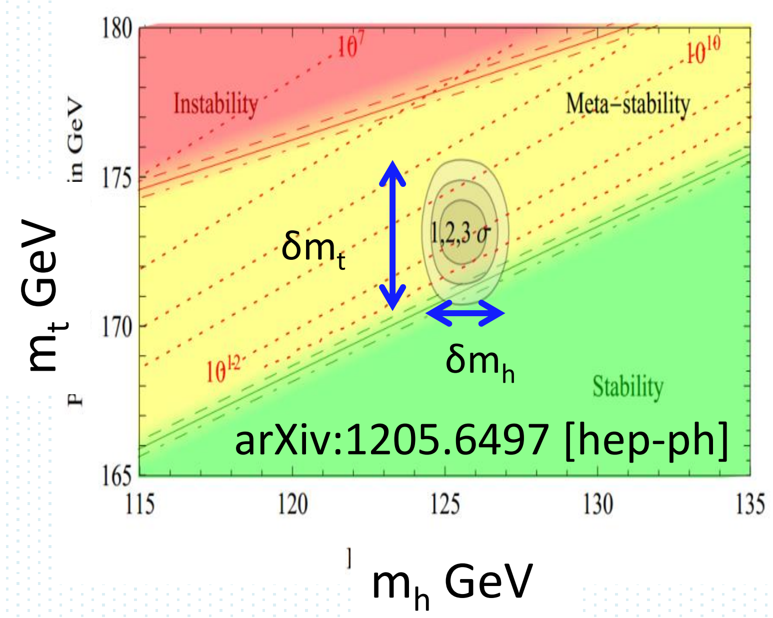
5th March. 2014 @ Top physics at LC, Paris

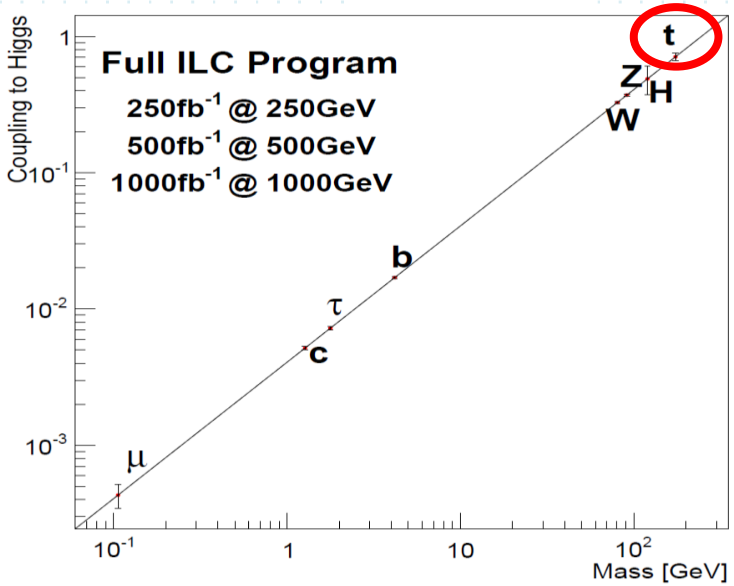
Tomohiro Horiguchi
A. Ishikawa, K. Fujii[1], T. Suehara[2], Y. Kiyo[3], Y. Sumino, H. Yamamoto
Tohoku Univ. , [1]KEK, [2]Kyushu Univ. [3]Juntendo Univ.

arXiv:1205.6497 [hep-ph]

Target around 350GeV

- Top mass(m_t)
  - Important input parameter
  - $\overline{\text{MS}}$ scheme mass ($m_t^{\overline{MS}}$)
    - ✓ $m_t^{\overline{MS}} = 160\ ^{+5}_{-4}$ GeV (PDG)
  - Potential subtracted mass (m_t^{PS})
- Decay width(Γ_t)
  - anomalous coupling
  - exotic decay
- Top yukawa coupling(y_t)
  - Test of higgs mechanism
- α_s
- QCD wave function

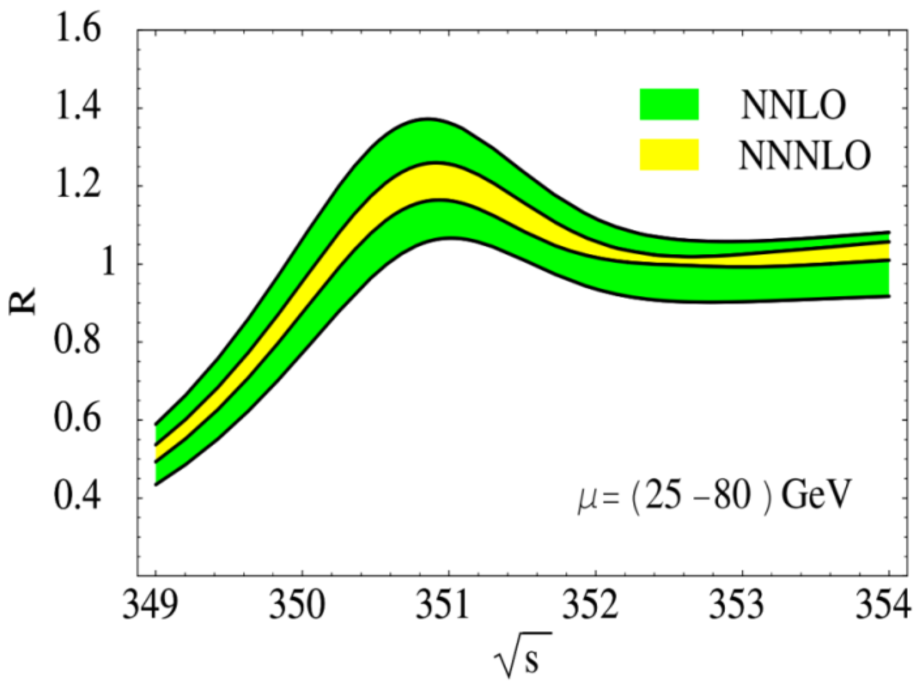




σ_{tt} Measurement

Near the threshold region of top pair production ($\sqrt{s}$=2m_t), the energy dependence of σ_{tt} is large. And σ_{tt} depend on fundamental parameters. Then, using threshold scan technic, measuring σ_{tt} precisely and fitting it, these parameters are determined !!

$$\sigma_{tt} \propto f(\sqrt{s}, m_t, \Gamma_t, \alpha_s, y_t, m_h)$$



σ/δσ(theoretical) ~ 4-5 %

arXiv:0801.3464 [hep-ph]
M. Beneke, Y. Kiyo and K. Schuller,

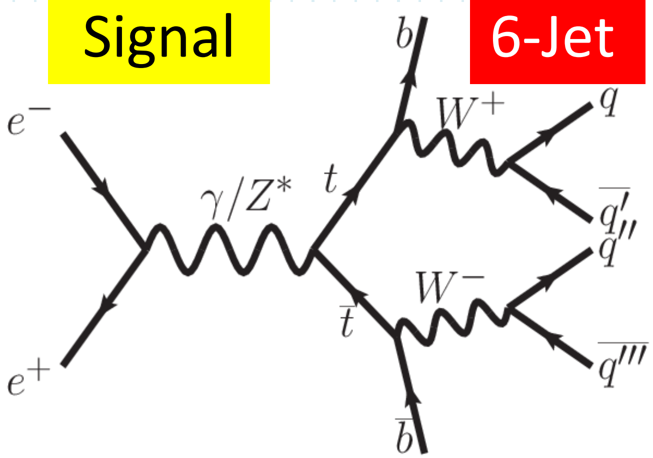
Simulation set up

Top quark mass	174 GeV
$\sqrt{s}$ (threshold scan)	341 - 350GeV (every 1 GeV, 10 points)
Polarization	$\mathrm{p(e^+, e^-) = (-30\%, +80\%), (+30\%, -80\%)}$ (In this talk, I call them "Right" and "Left")
Integrated Luminosity	5 fb^{-1} (each $\sqrt{s}$ & pol, total 100fb^{-1}) ※Running schedule around 350GeV is not determined.
Event Generation	Physsim (LO ,no higgs exchange/on QCD enhancement, on ISR/ beamstralung/beam energy spread)
Simulation	ILD_01_v05 (DBD ver.)

Signal and background

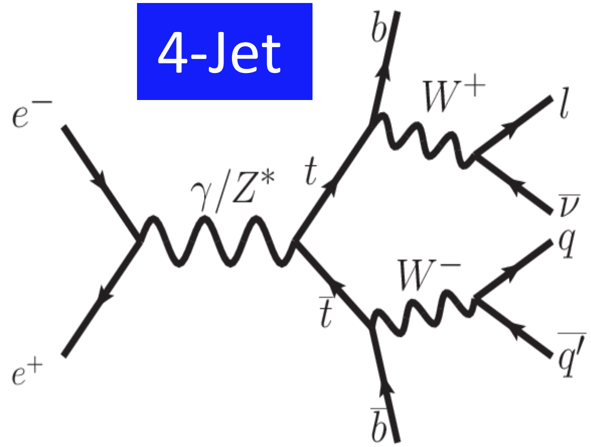
Signal

6-Jet



$t\bar{t} \rightarrow bWbW \rightarrow bqqbqq$

4-Jet



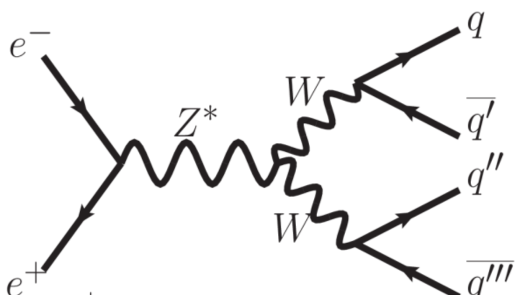
$t\bar{t} \rightarrow bWbW \rightarrow bqqbl\nu$

Branching Ratio	
6-Jet	45%
4-Jet	44%
2-Jet	11%

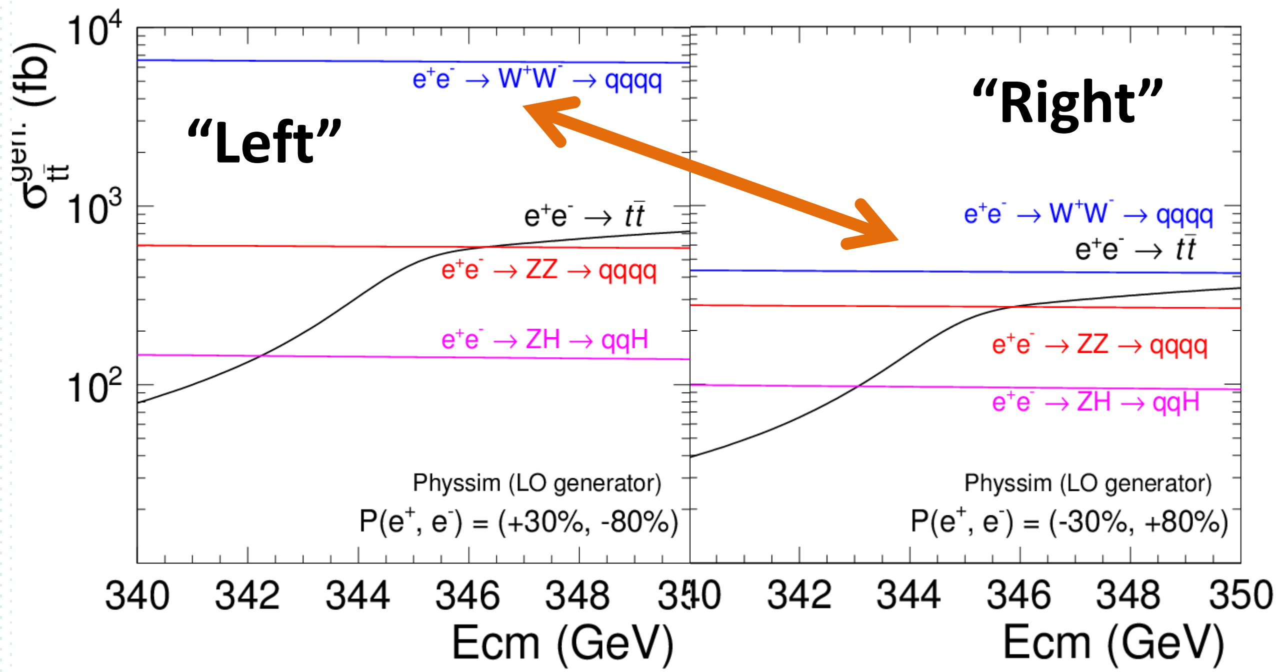
background

SM bkg. which have 4 or 6 fermions in final state

Main bkg. : WW, ZZ, ZH



$e^+e^- \rightarrow WW \rightarrow qqqq$



Top Quark Reconstruction (6-Jet & 4-Jet)

Reconstruction method	6-Jet	4-Jet
Suppressing the background overlay using anti-k_T algorithm (R=0.7)		
Isolated Lepton(l_{iso}) finding using cone energy cut	# of l_{iso} = 0	# of l_{iso} = 1
Jet clustering using Durham algorithm	Cluster to 6jets	Cluster to 4jets
2 b-likeness Jets were found using LCFIPlus	-	-
Reconstruction of two W bosons	$q_1 + q_2$ & $q_3 + q_4$	q_1+q_2 & $l_{iso}+\nu$
Reconstruction of two top quarks	-	-
Minimizing the χ^2	①	②

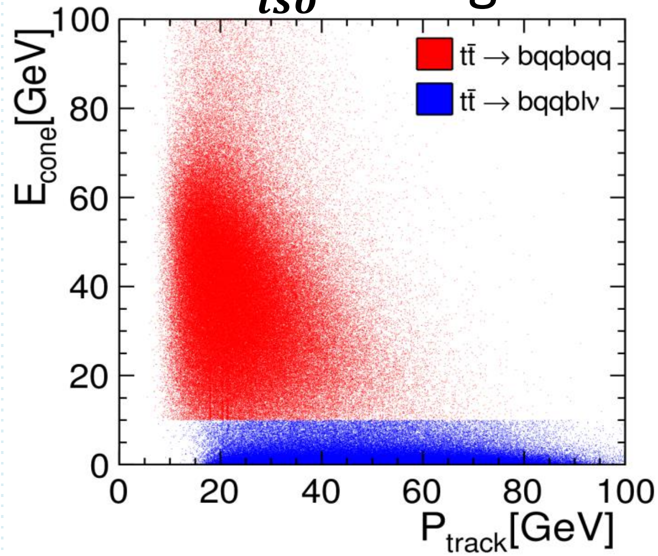
①

$$\chi^2_{6-\mathrm{Jet}} = \frac{(m_{3j^a\mathrm{reco.}} - m_t)^2}{\sigma_t^2} + \frac{(m_{3j^b\mathrm{reco.}} - m_t)^2}{\sigma_t^2} + \frac{(m_{2j^a\mathrm{reco.}} - m_w)^2}{\sigma_w^2} + \frac{(m_{2j^b\mathrm{reco.}} - m_w)^2}{\sigma_w^2}$$

②

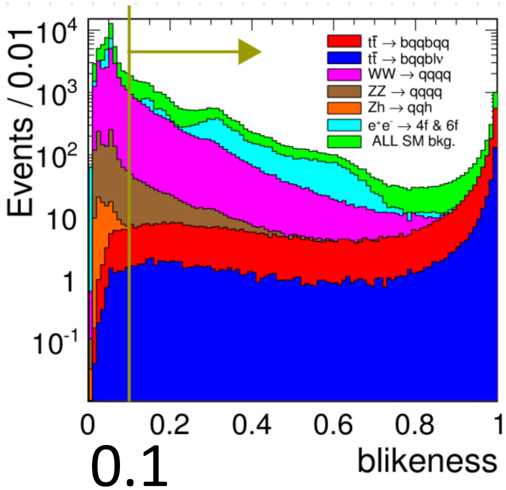
$$\chi^2_{4-\mathrm{Jet}} = \frac{(m_{3j\mathrm{reco.}} - m_t)^2}{\sigma_t^2} + \frac{(m_{jl\nu\mathrm{reco.}} - m_t)^2}{\sigma_t^2} + \frac{(m_{2j\mathrm{reco.}} - m_w)^2}{\sigma_w^2}$$

l_{iso} finding

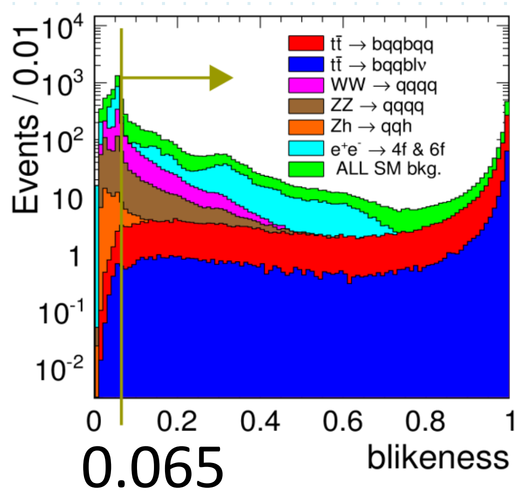


Event Selection(only 6-Jet)

B likeness cut using LCFIPlus



6-Jet Left

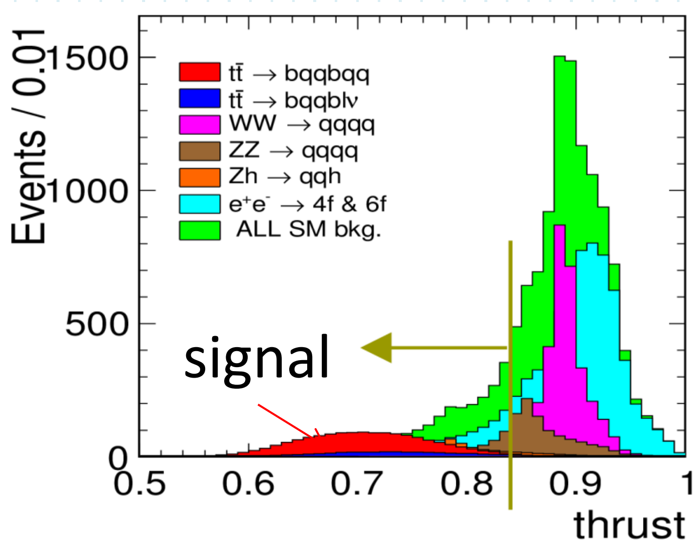


6-Jet Right

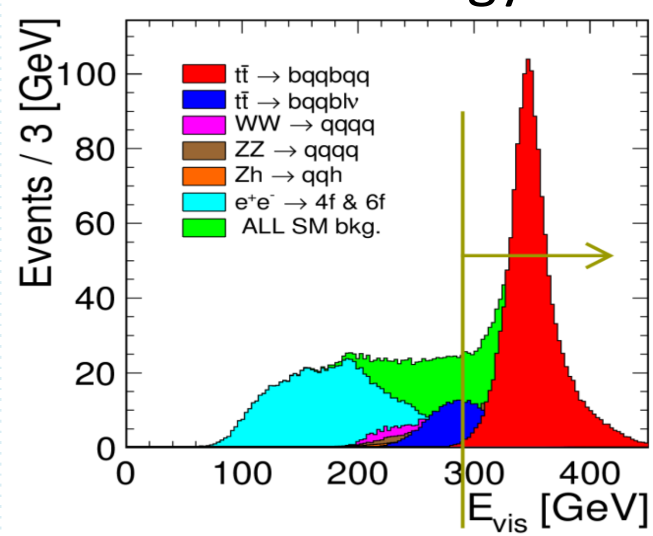
Other cut

- **Missing Pt**
- **Top quark mass**
- **Y value (applied to only 6-Jet)**
- **# of particle**

Thrust cut



Visible Energy



Selection Table 6-Jet @350GeV

$$\int \mathcal{L}(t)dt = 5(\mathrm{fb}^{-1}) \quad S = \frac{N_{Sig}}{\sqrt{N_{Sig} + N_{BG.}}}$$

Left	tt6j	tt4j	tt2j	WW	ZZ	ZH	6f+4f	S_{6j}
Generated	1643	1583	381	32664	3004	694	71691	4.9
# of lepton = 0	1592	357	19	32079	2957	638	39983	5.7
btag > 0.1 × 2	1515	340	18	3601	1398	471	7399	12.5
Thrust<0.84	1485	313	13	398	433	383	1084	23.2
Evis>290 GeV	1481	159	1	218	310	309	90	29.2
missPt<38GeV	1473	72	0	217	307	303	80	29.7
m_t>100 GeV × 2	1467	69	0	180	253	255	63	30.7
y45> 0.0015 y56 >0.0007	1419	45	0	68	71	80	36	34.2
# of pfos>86	1406	38	0	45	59	73	33	34.6

S/N	5.67
δσ/σ	2.9%

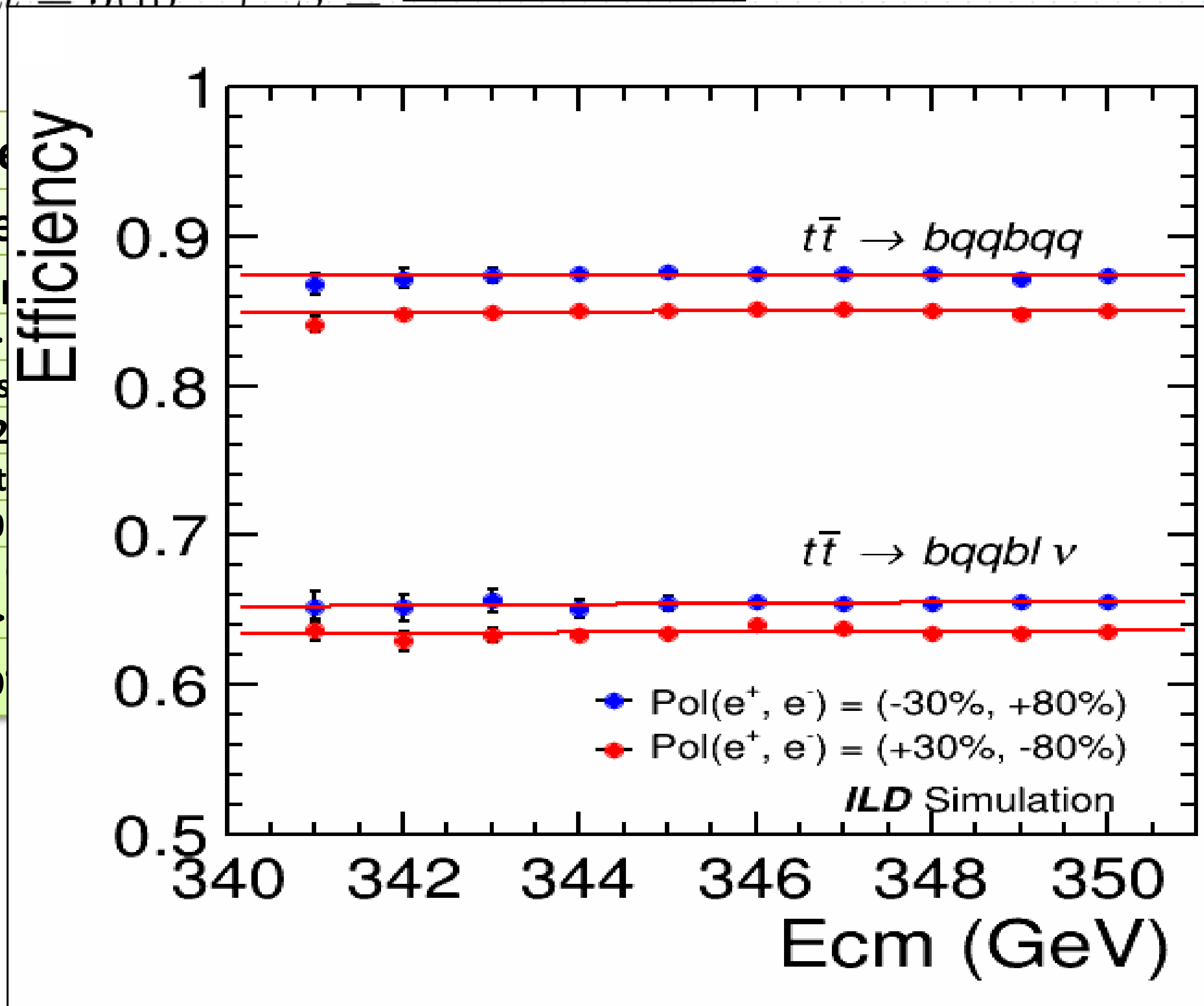
6f: 6 fermion final state except ttbar

Selection Table 6-Jet @350GeV

$\int \mathcal{L}(t)dt = 5(\mathrm{fb}^{-1})$ $S = \frac{N_{Sig}}{\ldots}$

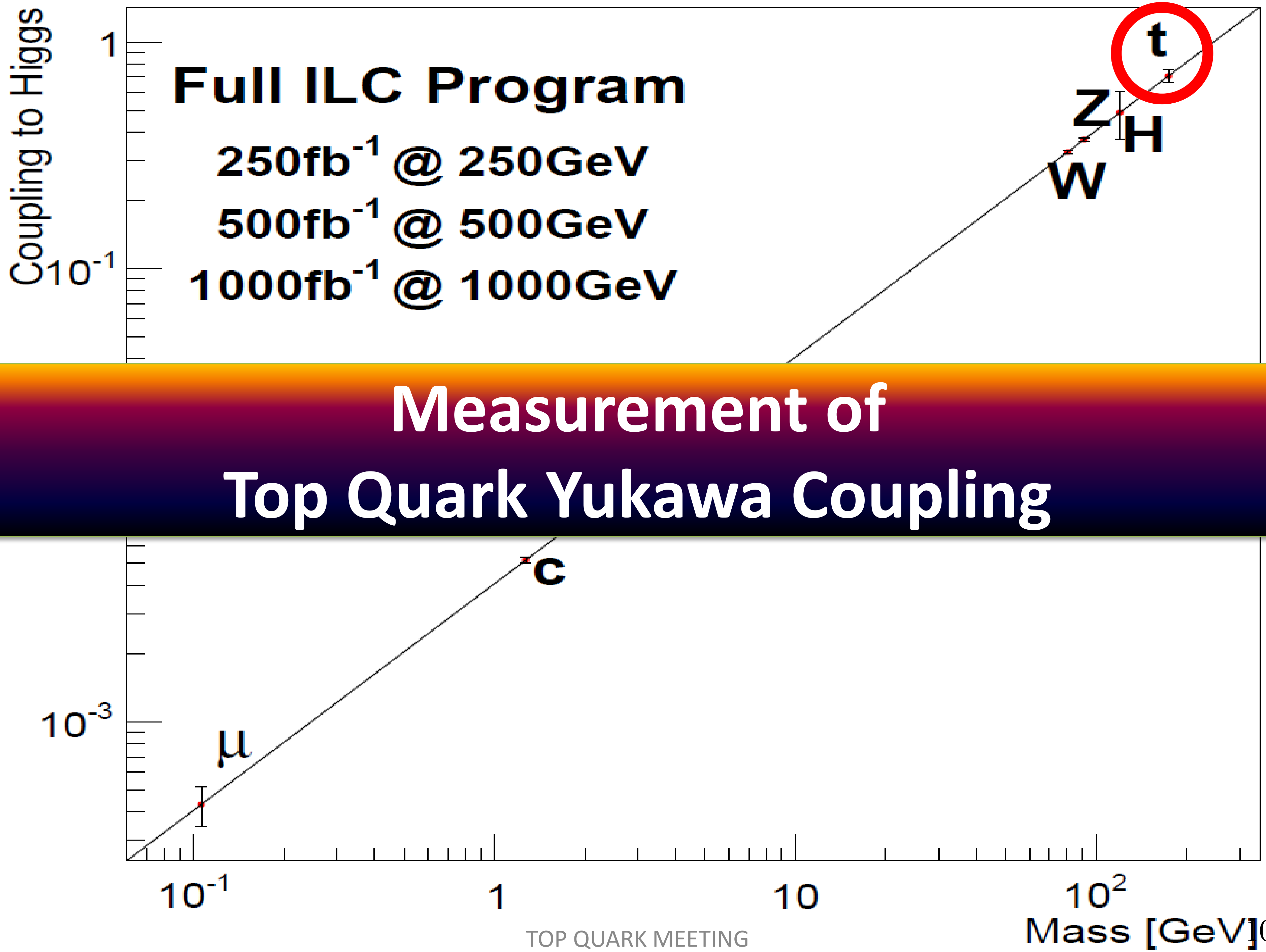
Le	S_{6j}
Gene	4.9
# of lep	5.7
btag >	12.5
Thrus	23.2
Evis>2	29.2
missPt	29.7
m_t>100	30.7
y45> y56 >	34.2
# of p	34.6

5.67
2.9%



6f: 6 fermion final state except ttbar

Measurement of Top Quark Yukawa Coupling



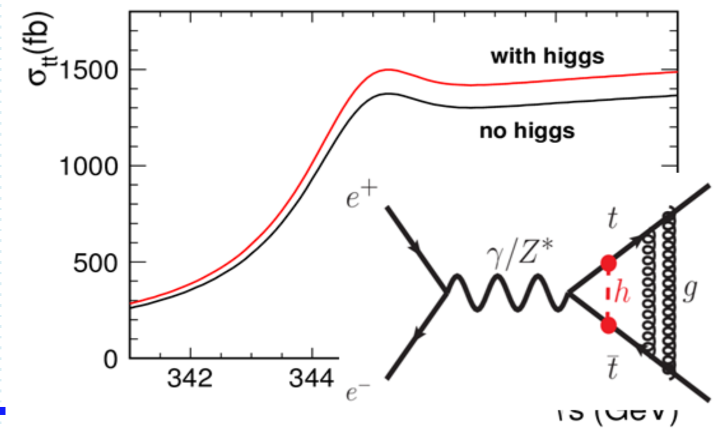
The Statistical Error of y_t

Using the significances of the all $\sqrt{s}$ (341 – 350 GeV) for each polarization, the statistical error of y_t is estimated.

The cross section is enhanced about 9% by exchanging the Higgs boson !!

$$\sigma_{tt} \propto \left| \mathcal{M}_{w/o\ higgs} + y_t^2 \mathcal{M}_{w/\ higgs} \right|^2$$

$$\frac{\delta y_t}{y_t} \sim \frac{109 \times \frac{1}{2} \times \frac{\delta\sigma}{\sigma}}{9}$$



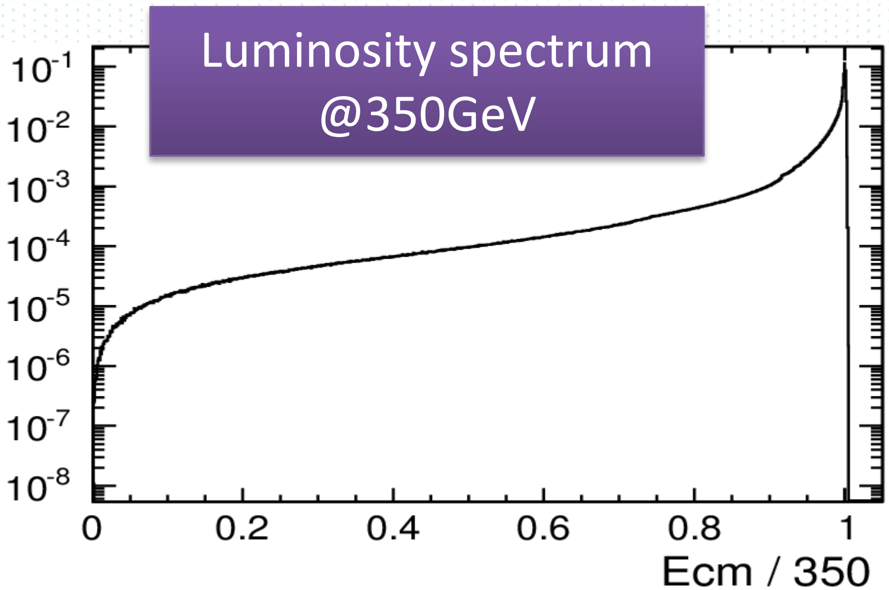
Stat. Error (50 fb^{-1})	6-Jet (Left)	6-Jet (Right)	4-Jet (Left)	4-Jet (Right)	6-Jet + 4-Jet (Left)	6-Jet + 4-Jet (Right)	Combined (100 fb^{-1})
$\frac{\delta\sigma}{\sigma}$	1.2%	1.7%	1.3%	1.9%	0.9%	1.3%	
$\frac{\delta y_t}{y_t}$	7.2%	10.2%	7.8%	11%	5.3%	7.5%	**4.3%**

Measurement of Top Quark “Mass” and “Width”

Fit - convolution -

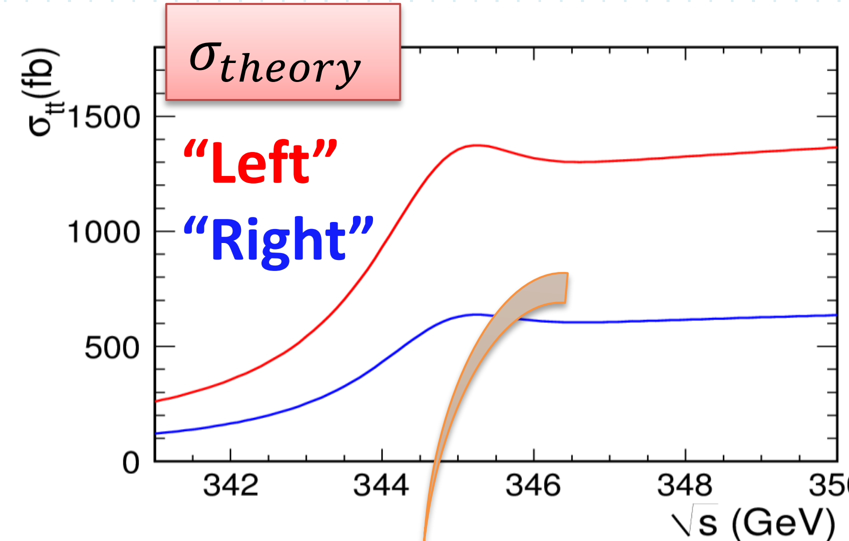
◎We must consider "Beam effects" around threshold.

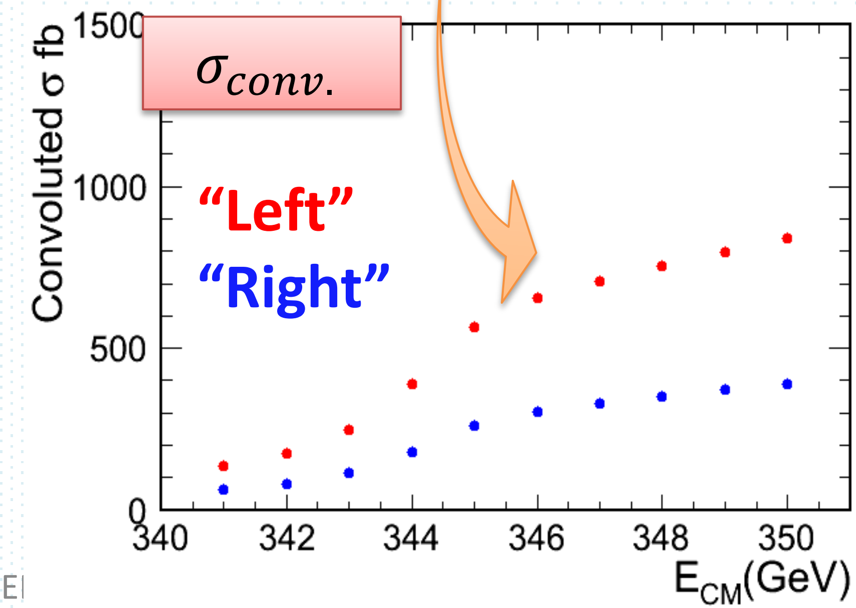
Using luminosity spectrum,
theoretical cross section is convoluted.



$$\sigma_{conv.}(\sqrt{s}) = \int \mathcal{L}(t)\sigma_{th}(t)dt$$

$\mathcal{L}$: luminosity spectrum, $\sqrt{s}$: nominal, σ_{th}: theoretical σ,
$\sigma_{conv.}$: convoluted σ, t(=$\sqrt{s'/s}$) where $\sqrt{s'}$ is collision energy

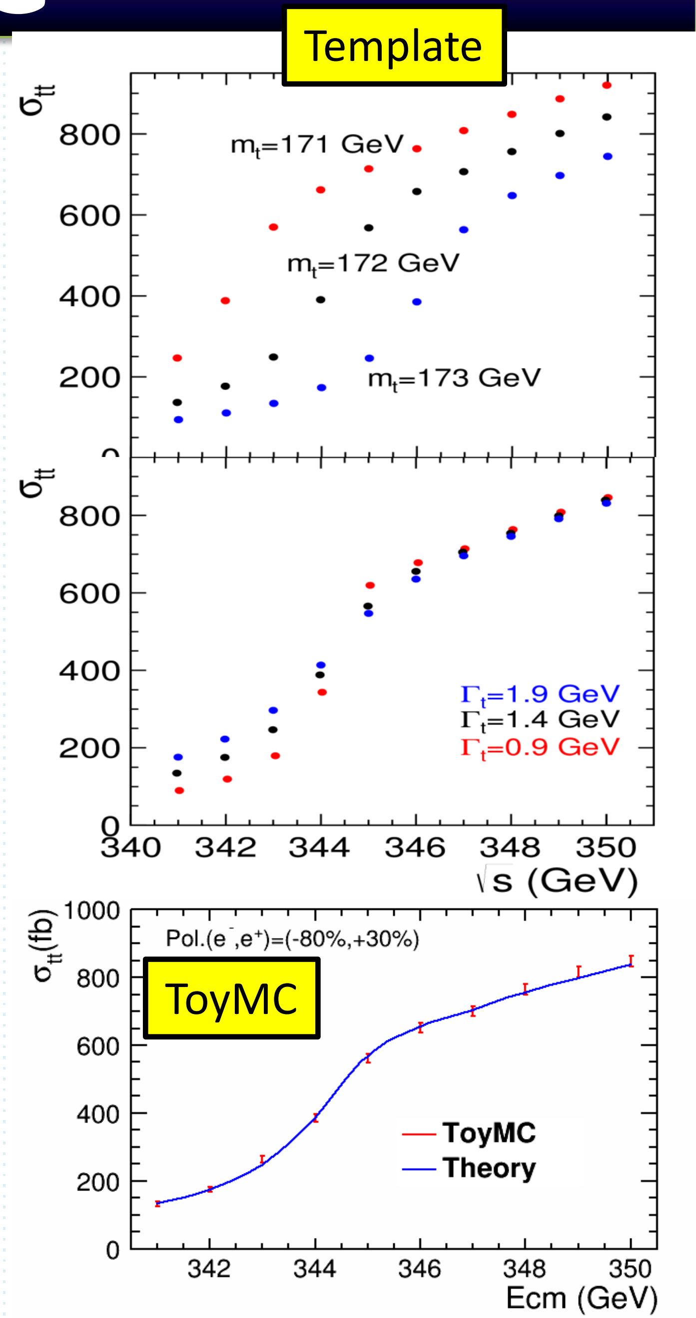




Fit -toyMC

- **Setting the Template:**
  - Floating m_t^{PS}, Γ_t and $\sqrt{s}$ / Fixed α_s and y_t
  - The center value (m_t^{PS}, Γ_t) = (172.000, 1.400)
  - Since αs will be determined by lattice QCD calculation in the future, here we make the template of m_t and Γ_t.

- **Fitting the σ_{tt}:**
  - σ_{tt} is scaled from LO to NNLO calculation.
  - Interpolating m_t and Γ_t, σ_{tt}s are fitted at each center of mass energy.
  - Using all center of mass energies (341 – 350 GeV), m_t and Γ_t are optimized.



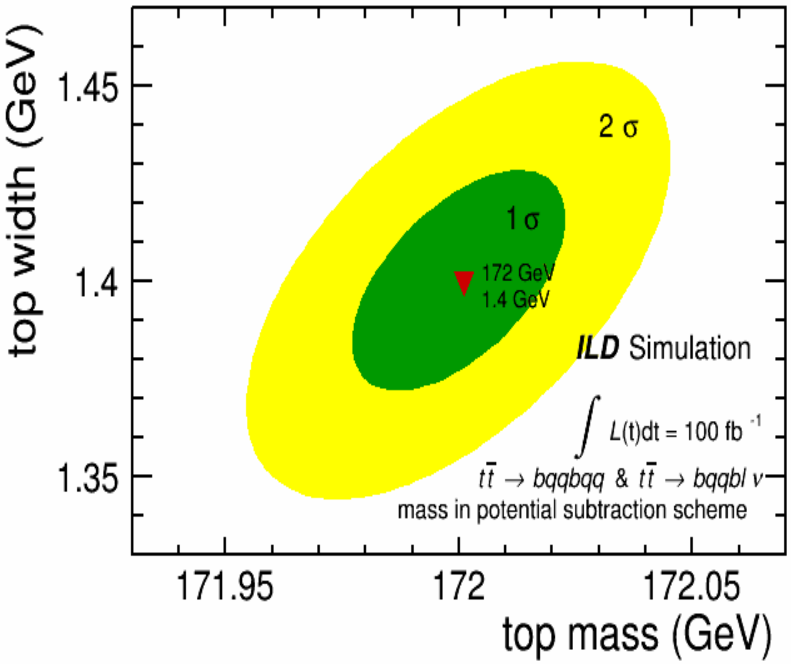
Fit -Result-

Stat. Error (MeV)	6-Jet		4-Jet	
	m_t^{PS}	Γ_t	m_t^{PS}	Γ_t
Left($50fb^{-1}$)	28	40	33	48
Right($50fb^{-1}$)	42	63	48	67
Left ($50fb^{-1}$) + Right($50fb^{-1}$)	**23**	**34**	**27**	**39**

Center value: $m_t^{PS} = 172.000$ GeV, $\Gamma_t = 1.400$ GeV

Combined ALL

m_t^{PS}(GeV)	Γ_t(GeV)
172.001±0.018	1.399±0.026



◎PS→$\overline{MS}$

$$m_t^{\overline{MS}} \sim m_t^{PS} - \frac{4}{3\pi}(m_t^{PS} - 20)\alpha_s + \ldots$$

$m_t^{\overline{MS}}$ = 163.800±0.017 (stat.)(GeV)

Summary

- σ_{tt} measurement
  - Since σ_{tt} depend on the fundamental parameters such as y_t, m_t and Γ_t, we can determine these precisely by measuring it.
  - We have estimated the statistical error of y_t, m_t and Γ_t with 6-Jet and 4-Jet final state for two polarization at the ILC.
  - Integrated luminosity : 5 fb^{-1} × 20 points, total 100 fb^{-1}

σ_{tt} measurement	
$\Delta y_t/y_t$	**4.3 %**
m_t^{PS}	172.001 ± **0.018** (GeV)
$m_t^{\overline{MS}}$	163.800 ± **0.017** (GeV)
Γ_t	1.399 ± **0.026** (GeV)

- For future plan, we will estimate the sensitivity of width measurement using A_{FB}

backup

A_{FB} Measurement

- The main contribution of A_{FB} come from the interference of vector and axial-vector vertices.
  - Since top has large decay width, the interference with S- and P-wave is controlled by Γ_t
  - The level split which is separation with 1S- and 2P-resonance is depend on α_s.