Measurements of Top quark Mass, Width and Yukawa coupling near threshold at the ILC

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- Update of ttbar σ_{tt} study
  - Measurements of m_t, Γ_t and y_t
- A_{FB} study
  - Measurements of Γ_t and α_s

σ_{tt}
(Measurements of "m_t", "Γ_t" and "y_t")

σ_{tt} Measurement

Since near the threshold of top pair production ($\sqrt{s}$=2m_t), the energy dependence of σ_{tt} is large, measuring the σ_{tt} precisely and fitting it, fundamental parameters are determined.

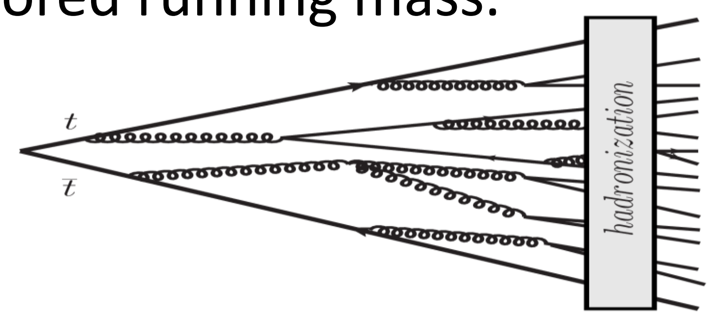
◎Well-defined mass

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

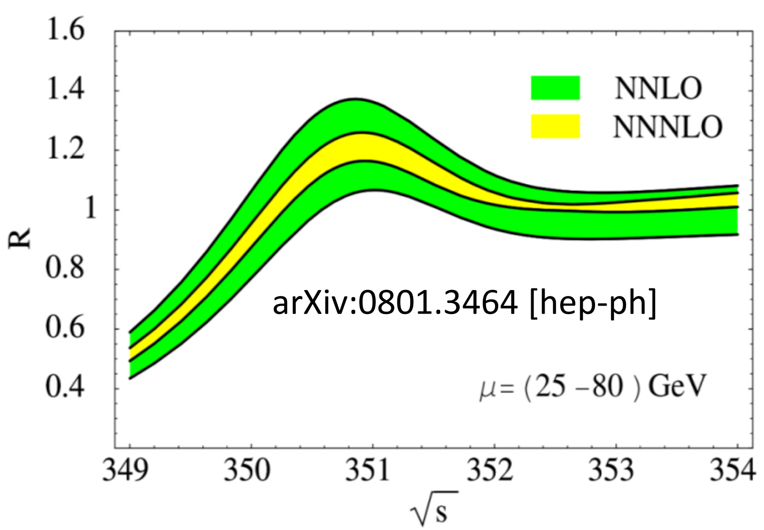
Here potential subtracted(PS) mass

Phys.Lett. B434 (1998) 115-125

Invariant mass from three jets is hard to interpret to theoretical favored running mass.



◎Theoretical σ_{tt}



$\delta\sigma/\sigma$(theoretical) ~ 4-5 %

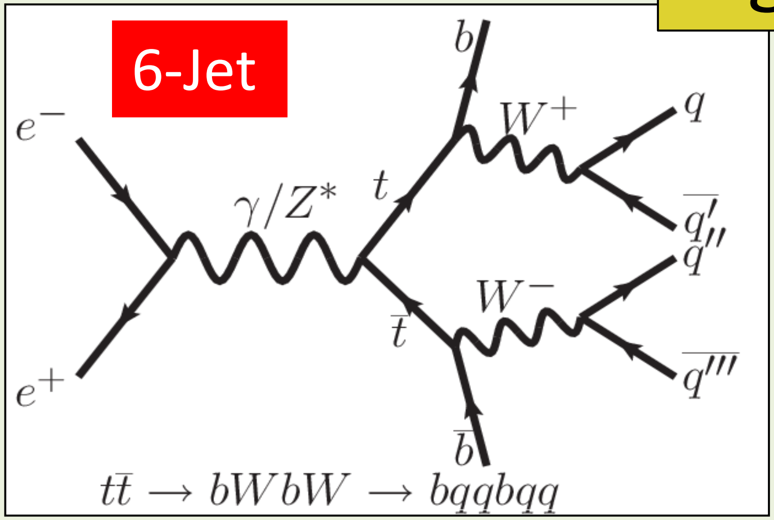
For prediction of m_t with precision of 100 MeV requires $\delta\sigma/\sigma$ ~ 2%

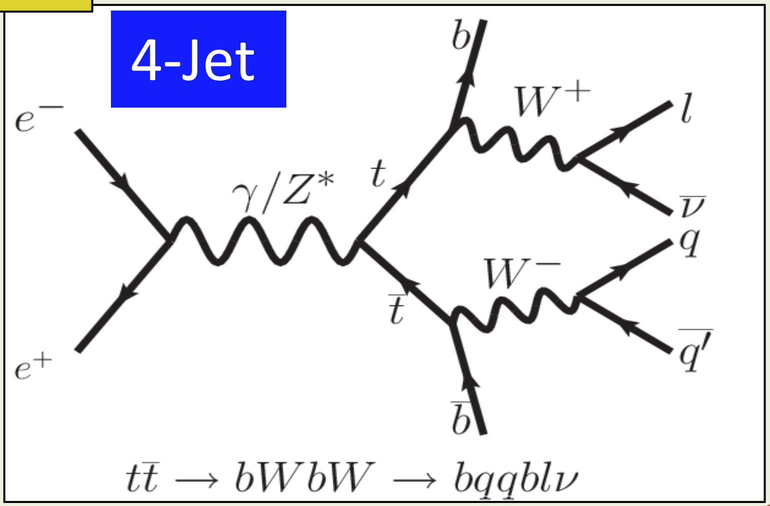
Simulation set up

Top quark mass	174 GeV
$\sqrt{s}$ (threshold scan)	341 - 350GeV (every 1 GeV, 10 points)
Polarization	$\mathrm{p}(\mathrm{e}^+, \mathrm{e}^-) = (-30\%, +80\%), (+30\%, -80\%)$ (In this talk, I call them "Right" and "Left")
Integrated Luminosity	5 fb^{-1} (each $\sqrt{s}$ & pol, total 100fb^{-1})
Event Generation	Physsim (LO ,QCD enhancement, on ISR/ beamstralung/beam energy spread)
Simulation	ILD_01_v05 (DBD ver.)

Signal and background

Signal

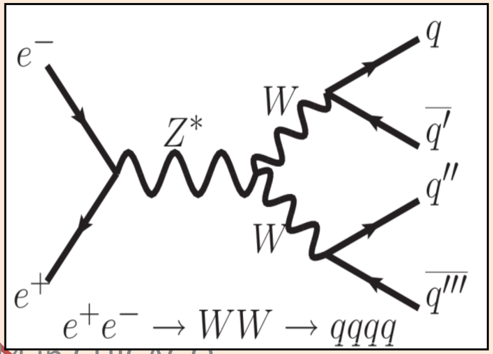


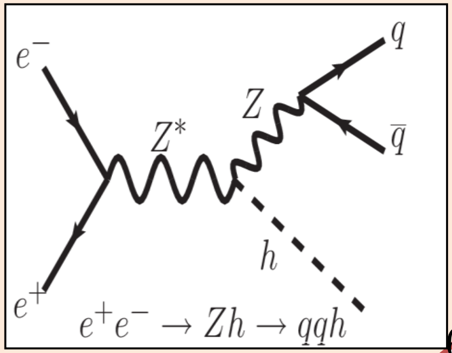


Branching Ratio	
6-Jet	45%
4-Jet	44%
2-Jet	11%

background

SM bkg. which have 4 or 6 fermions in final state Main bkg. : WW, ZZ, ZH





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

Reconstruction method	6-Jet	4-Jet
Isolated Lepton(l_{iso}) finding using cone energy cut ($\cos\theta_{cone}$> 0.96, P_{track}> 15 GeV, E_{cone}< 10 GeV)	# of l_{iso} = 0	# of l_{iso} = 1
Jet clustering using Durham algorithm	6jets	4jets
Extraction of 2 b-likeness jets		
Reconstruction of top quark pair and finding the best candidate by χ^2 from invariant mass	(b+q+q') × 2	(b+q+q') & (b+l_{iso}+ν)

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

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

Selection Table @ √s= 350GeV

Table : 6-Jet Left handed

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

(e+,e-)=(+30,-80%)	tt6j	tt4j	tt2j	SM bkg.	S_{6j}	ε_{6j}
Generated	1643	1583	381	0.13M	4.4	100
# of lepton = 0	1590	353	18	0.11M	5.0	96.8
btag > 0.09 × 2	1499	330	17	19336	10.3	91.2
Thrust<0.825	1439	285	11	2447	22.3	87.6
Evis>300 GeV	1424	61	0	1092	28.0	86.6
m_t>107 GeV × 2	1383	37	0	492	31.6	84.1
# of pfos>84	1376	33	0	442	32.0	83.8
y45> 0.0012 y56 >0.0006	1362	31	0	392	32.2	82.9
Sphericity>0.22	1347	24	0	329	**32.7**	**82.0**

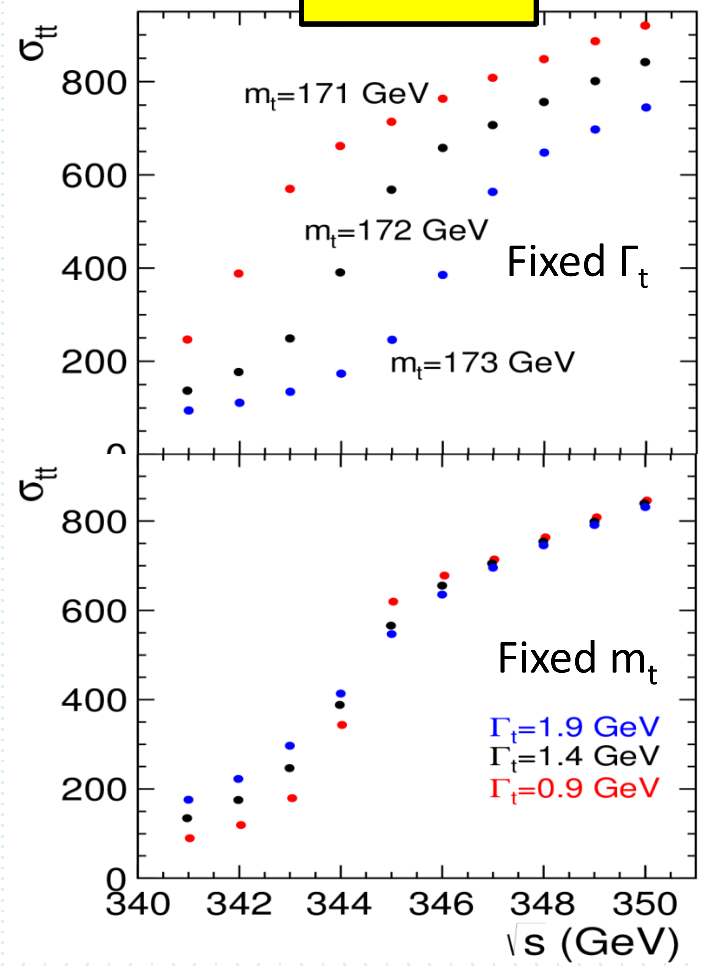
√s=350 GeV	$S_{n\text{-}Jet}$	$\varepsilon_{n\text{-}Jet}$
6-Jet (e+,e-)=(-30, +80%)	23.5	84.6
4-Jet (e+,e-)=(+30, -80%)	31.0	66.3
4-Jet (e+,e-)=(-30, +80%)	21.9	68.2

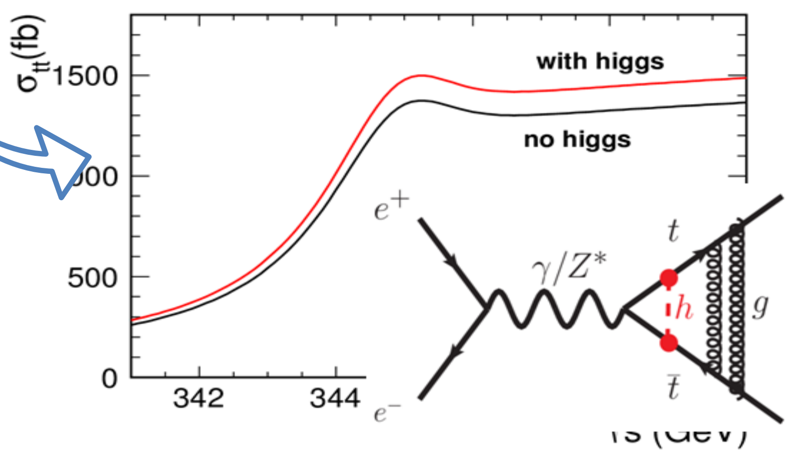
toyMC to extract m_t, Γ_t, y_t

- **<u>Preparing the Templates:</u>**
  - Theoretical σ_{tt} is convoluted using luminosity spectrum.
  - Making the template by changing m_t^{PS} and Γ_t / Fixed α_s (=0.12)
- **<u>Fitting to σ_{tt}:</u>**
  - Since the measurement of δy_t is extracted from normalization of σ_{tt}, the normalization is used for σ_{tt} fit.
  - By using the templates, σ_{tt}s are fitted to extract y_t, m_t and Γ_t simultaneously.

new

Template





AGO

Fit Result

Stat. Error (m_t, Γ_t :MeV/y_t:%)	6-Jet			4-Jet		
	m_t^{PS}	Γ_t	y_t	m_t^{PS}	Γ_t	y_t
Left(50fb^{-1})	47	65	9.6	52	71	11
Right(50fb^{-1})	68	94	14	75	106	16
Left (50fb^{-1}) + Right(50fb^{-1})	**39**	**53**	**7.9**	**43**	**59**	**9.1**

Combined ALL

m_t^{PS}(GeV)	Γ_t(GeV)	y_t
172±0.029	1.4±0.039	5.9 %

Systematic err.

- Theoretical err.
  δm_t~100MeV
- Luminosity spectrum
  δm_t~80MeV

Ph.D thesis F. Gournaris (2009)

◎PS→$\overline{\text{MS}}$

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

$m_t^{\overline{MS}}$ = 163.800±0.028 (stat.)(GeV)

Comparison of (2+1) param fits and 3 param fits

previous result : **2D fit** of m_t and Γ_t, y_t is measured individually.
New result : **3D fit** of m_t, Γ_t and y_t.

	(2 + 1) param fit	3 param fit
m_t	19 MeV	29 MeV
Γ_t	38 MeV	39 MeV
y_t	4.6%	5.9%

Correlation coefficients

	(2 + 1) param fit	3 param fit
m_t vs Γ_t	0.52	0.57
m_t vs y_t	-	0.72
Γ_t vs y_t	-	0.33

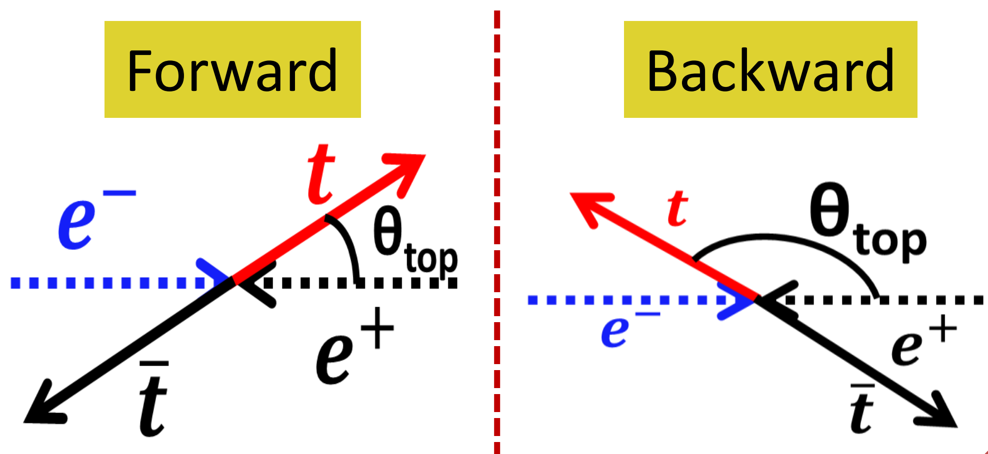
A_{FB}
(Measurement of "Γ_t", "α_s")

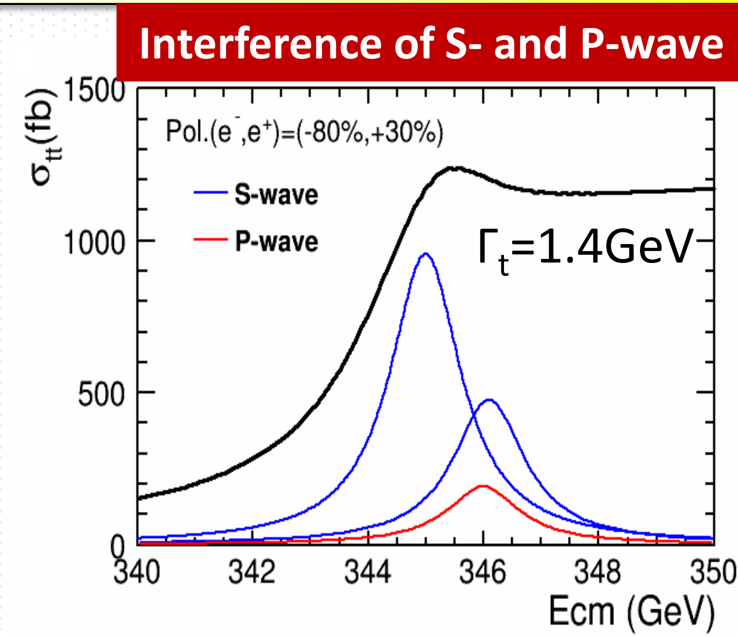
A_{FB} near ttbar threshold

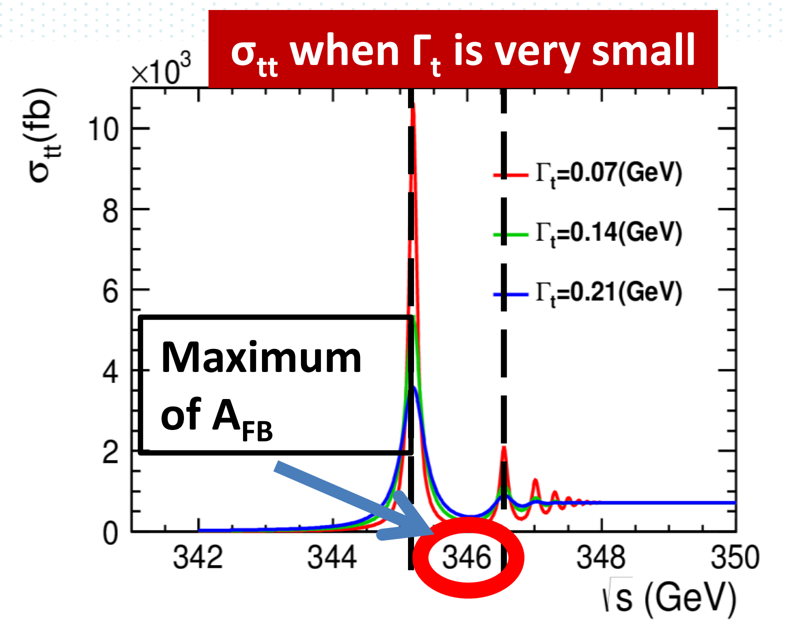
★Forward backward asymmetry of top quark (A_{FB})

- Since top has large Γ_t, we can measure A_{FB} by interfering the resonance of S- and P- wave.
- The level split which is separation of two resonances depends on α_s.

$$A_{FB} \equiv \frac{N(cos\theta_{top} > 0) - N(cos\theta_{top} < 0)}{N(cos\theta_{top} > 0) + N(cos\theta_{top} < 0)}$$

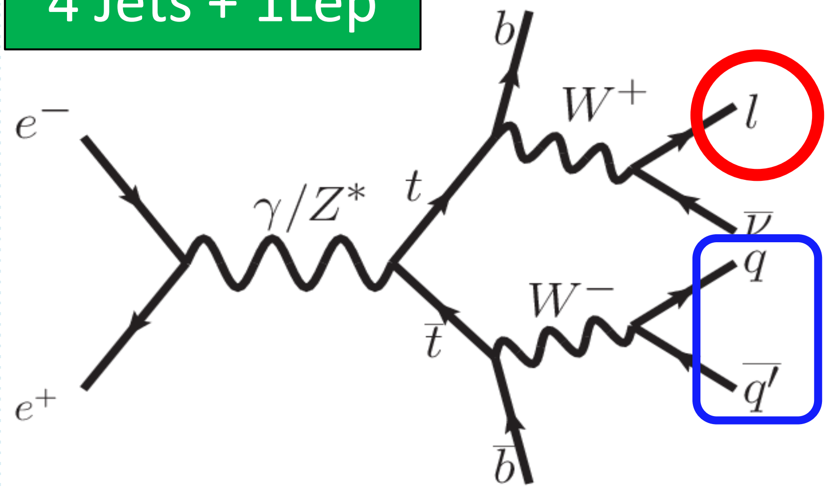






Analysis method and MC Set up

Signal
4 Jets + 1Lep



$t\bar{t} \to bWbW \to bqbl\nu$

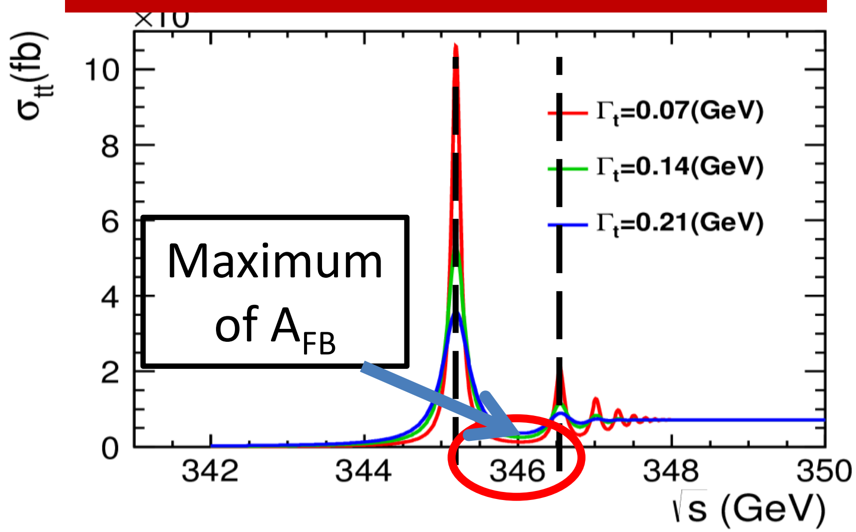
○Semi-leptonic side

Since charge tag of jets is too difficult, isolated lepton is used for ID of top or anti-top.

○Hadronic side

Since leptonic decayed top quark has missing 4-vector, hadronic decayed one is used to determined angle of top quark.

σ_{tt} when Γ_t is very small

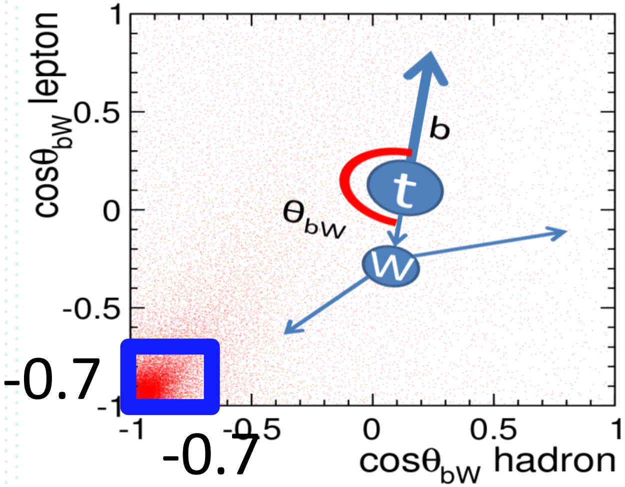


Set up

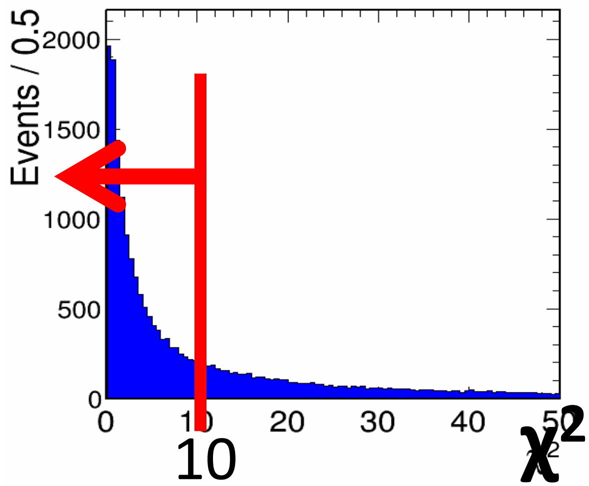
BKG. : SM bkg.
√s = 346 GeV (between S- and P- wave)
$\mathcal{L}$ = 50fb^{-1} (e+,e-) = (+0.3, -0.8)
$\mathcal{L}$ = 50fb^{-1} (e+,e-) = (-0.3, +0.8)

Reconstruction of top quark

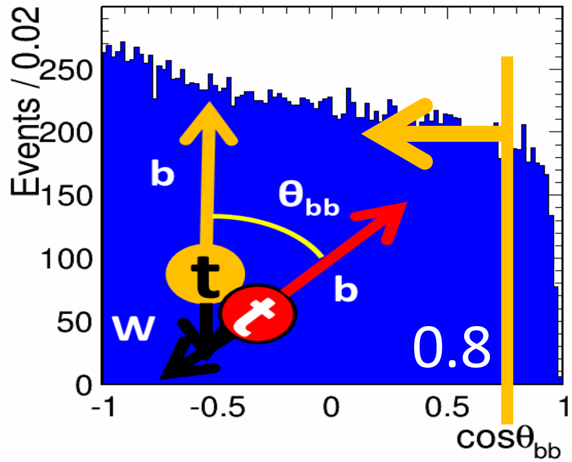
Angle of b and W at rest frame



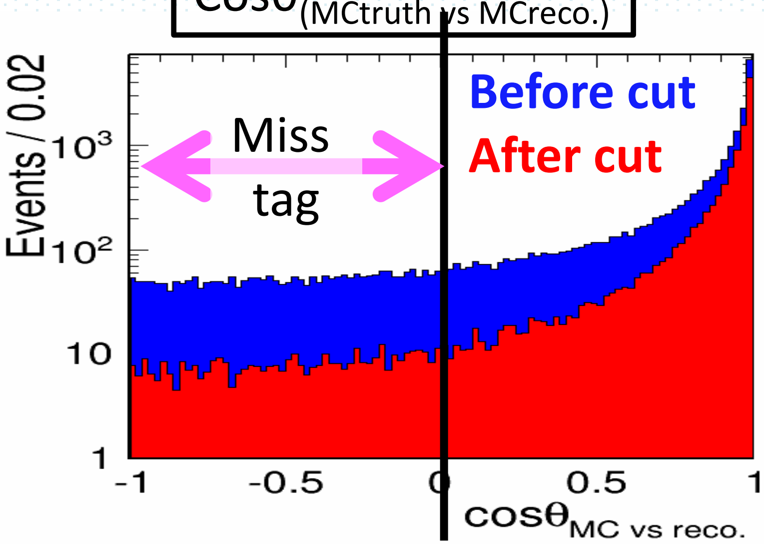
X^2 from mass



Closeness of 2 b quarks



Cosθ(MCtruth vs MCreco.)



$$\chi^2 = \frac{(m_t - m_{3j})^2}{\sigma_t^2} + \frac{(m_t - m_{jl\nu})^2}{\sigma_t^2} + \frac{(m_w - m_{2j})^2}{\sigma_w^2}$$

Cut for top ID

$\cos\theta_{bW}<-0.7$, $X^2<10$, $\cos\theta_{bb}<0.8$

Misreconstruction is reduced.

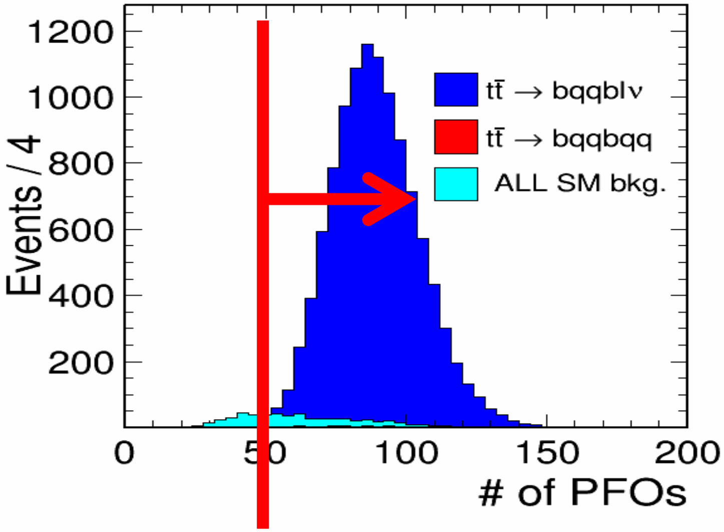
13% ⇒ 3.7 %

Background suppression

- For maximizing the significance (S_{top}), bkg. are rejected.

$$S_{top} = \frac{N_{signal}}{\sqrt{N_{signal} + N_{bkg.}}}$$

- # of PFOs is used except top tagging cut (previous page).



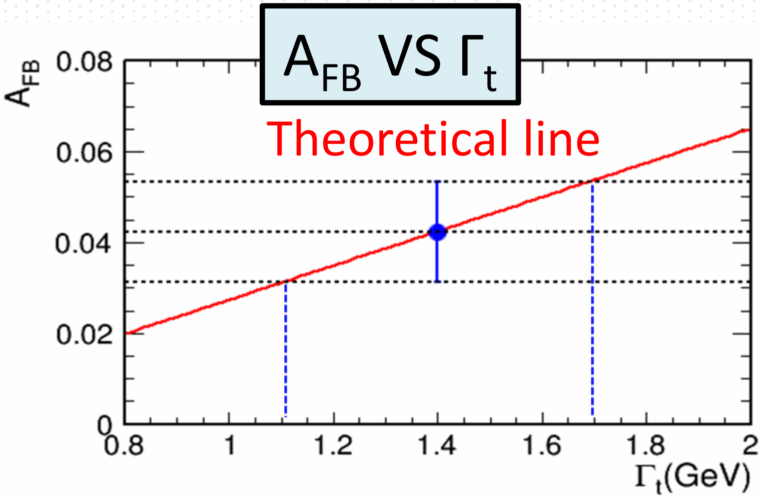
Left 50fb^{-1}	tt4j	tt6j	tt2j	SM bkg.	S_{top}	Efficiency
Gen.	12619	13101	3039	1 M	12.2	100
# of l_{iso} = 1	9648	418	909	0.3M	16.9	76.5
$\cos\theta_{bW}$<-0.7	8989	397	834	0.2M	18.4	71.2
X^2<10	6856	65	164	13134	48.2	54.3
$\cos\theta_{bb}$<0.8	4881	3	6	271	67.9	38.7
# of PFOs > 50	4872	3	4	182	**68.5**	**38.6**

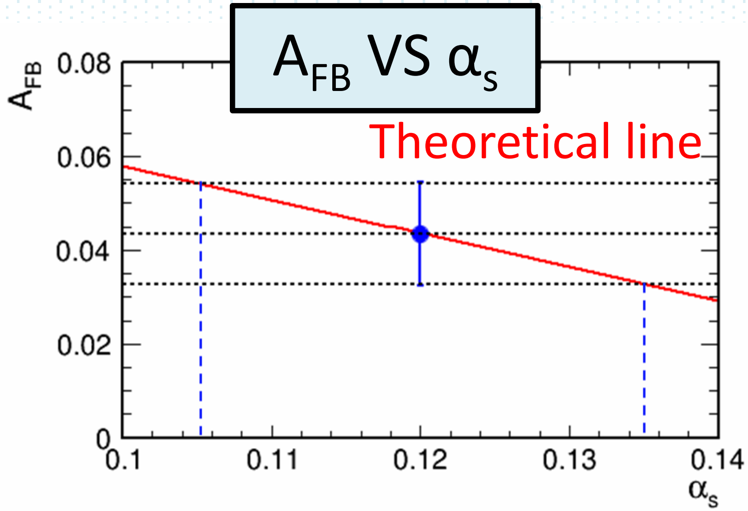
Γ_t and α_s measurement

From the 1σ error, we estimate the accuracy of Γ_t and α_s.

Center value is A_{FB}= 0.0427

50 fb^{-1}	# of events (NNLO)	δA_{FB}
Left handed	5537	0.013
Right handed	2564	0.020
Left + Right (100 fb^{-1})	8101	0.011





Red lines show theoretical line assuming polarization of $(e^+, e^-)=(0,0)$.
Theoretical calculation for polarized case is not calculated.
In the future when ILC will be built, theorists will calculate it.

$\mathcal{L}$ = 100 fb^{-1} $\delta\Gamma_t$ = 290 MeV, $\delta\alpha_s$ = 0.015

Summary

- σ_{tt} measurement (mass, width, yt)
  - Simultaneous fit to extract m_t, Γ_t and y_t was performed.
  - Integrated luminosity : 5 fb^{-1} × 20 points, total 100 fb^{-1}
  - We can measure at δm_t^{PS} = 29 MeV, $\delta\Gamma_t$ = 39 MeV and δy_t = 5.9 % with 3D fit.

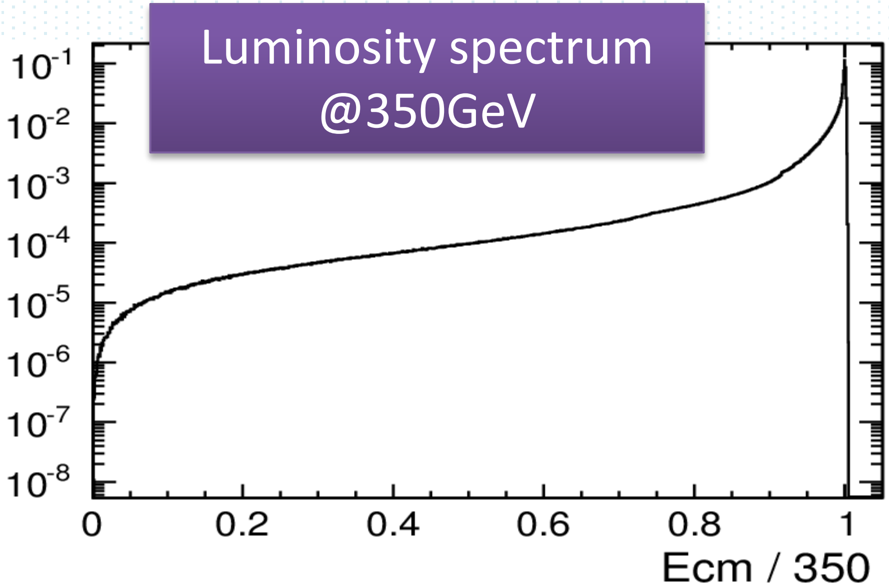
- A_{FB} measurement
  - Near ttbar threshold, A_{FB} measurement is sensitive to Γ_t and α_s.
  - At √s=346 GeV where A_{FB} is maximum, δA_{FB} of top quark were measured and $\delta\Gamma_t$ and $\delta\alpha_s$ are estimated.
  - If we accumulate $\mathcal{L}$ = 100 fb^{-1}, we can measure at Γ_t = 290 MeV and $\delta\alpha_s$ = 0.015.
  - Theoretical predictions of A_{FB} vs Γ_t and α_s for polarized case exist but not calculated numerically.

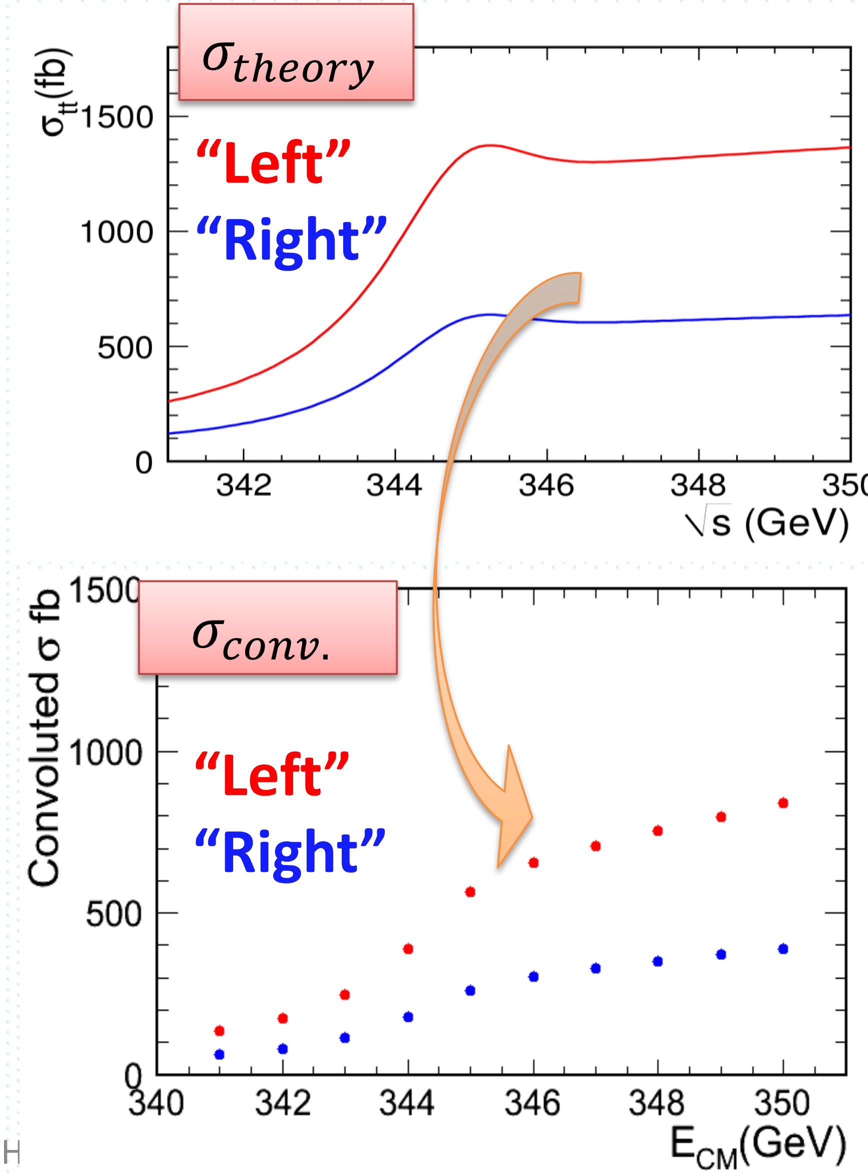
backup

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