Study of Top Pair Production Near Threshold

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Targets

The targets of ILC around Ecm 350 GeV !!

Today's topic

1. top mass
   → In Pole, $\overline{\mathrm{MS}}$ & potential subtracted schemes
2. top width
3. top yukawa coupling
4. α_s
5. QCD wave function of top pair system

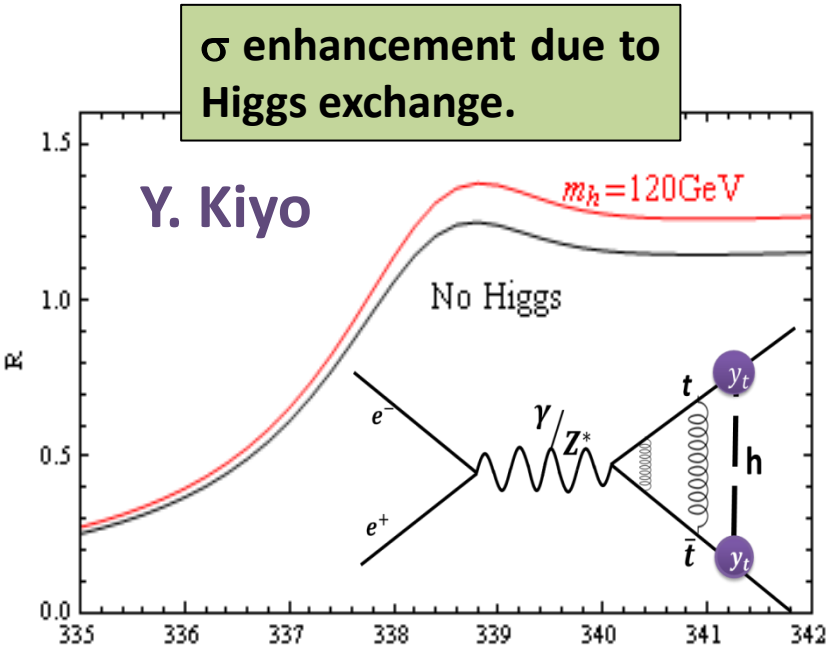
Top Yukawa, Mass & Width from ttbar Cross Section

The total cross section of top pair production near threshold depends on following parameters. If we can measure the cross section precisely and fit it, fundamental parameters are determined !!

$$\sigma = f(\sqrt{s}, m_t, \Gamma_t, \alpha_s, m_h, y_t)$$

Especially, at near threshold we can define potential subtracted(PS) mass** which is insensitive to long-distance physics.

** arXiv:hep-ph/9804241



Contribution of Higgs exchange diagram to total cross section is about 9%.
So if we can measure total cross section precisely, we can extract **top Yukawa coupling** before going to Ecm=500GeV. (note. Current theoretical uncertainty in the cross section is about 4% and I hope this will be improved in coming 10 years)

Condition of the Analysis

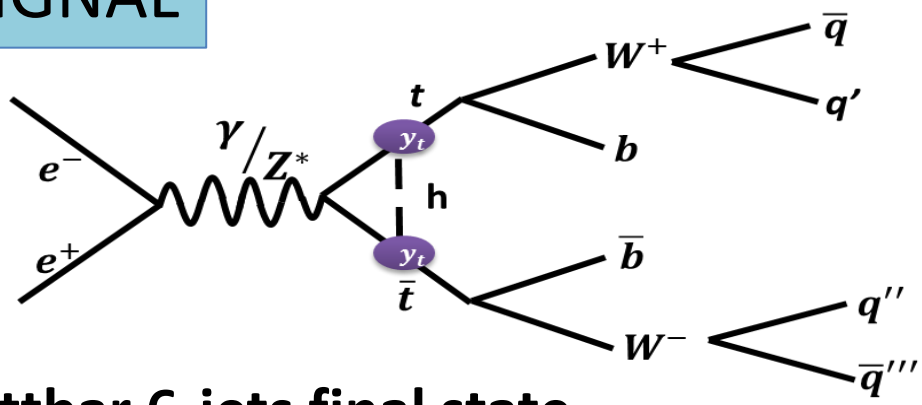
Simulation

Top mass (pole mass)	174 GeV
Ecm (using threshold scan)	340 - 350GeV (every 1 GeV)
Polarization	(e^-, e^+)=(-0.8, +0.3) (+0.8, -0.3)
Integrated luminosity	10 fb^{-1} (each Ecm and polarization)
Top pair generator	Physsim (LO ,On QCD enhancement, no higgs exchange, on ISR/beamstralung)

Full simulation with the ILD detector is performed.

Signal and Background

SIGNAL

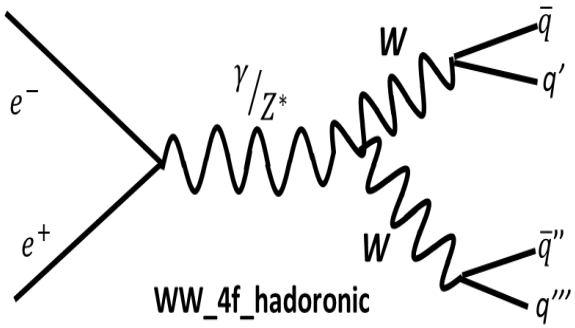


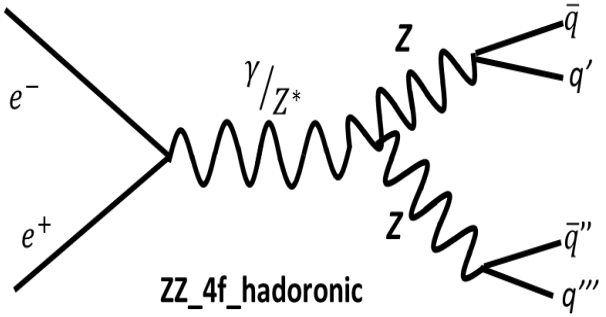
ttbar 6-jets final state

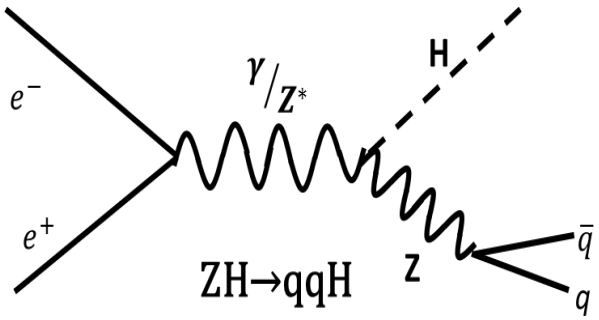
Branching Ratio	
6-jets	45%
$4\mathrm{j}1l1\nu$	44%
$2\mathrm{j}2l2\nu$	11%

Main BG.

$$ee \rightarrow WW\ (\rightarrow qq'q''q''')\ \ q = (u,d,s,c,b)$$
$$\rightarrow\ ZZ\ \ (\rightarrow q\bar{q}q'\bar{q}')$$
$$\rightarrow\ ZH\ \ (\rightarrow qq\,\mathrm{H})$$



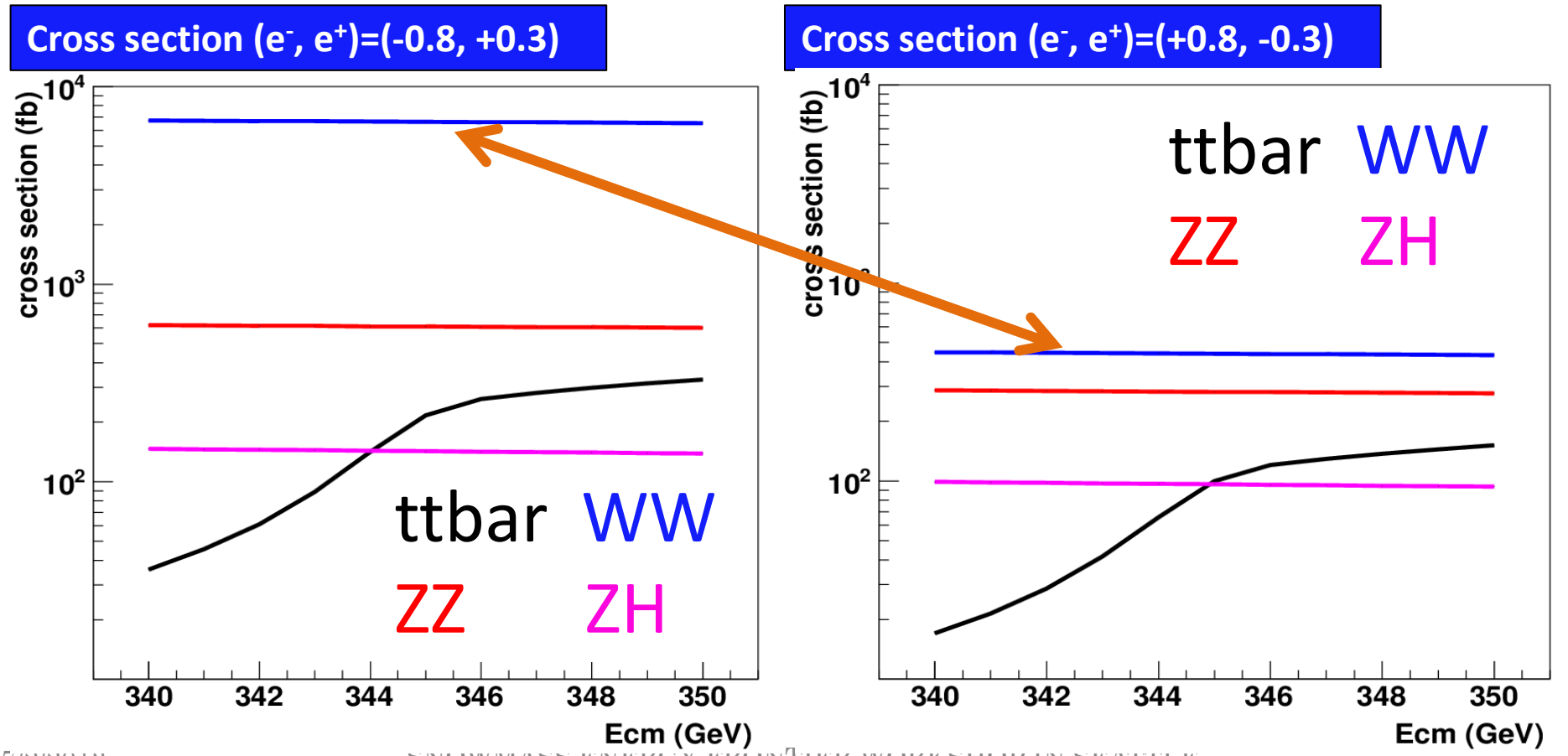




For future plan, we will add WWZ, ZZZ, tbW.

Cross Section of ttbar and BG.

Since QCD theory is well-known at the threshold region, measuring the energy dependence of the cross section, we can determine the fundamental physics parameters. And since left-handed and right-handed top quarks have different SU(2) and U(1) charges, the cross section has difference between left- and right-handed polarizations.

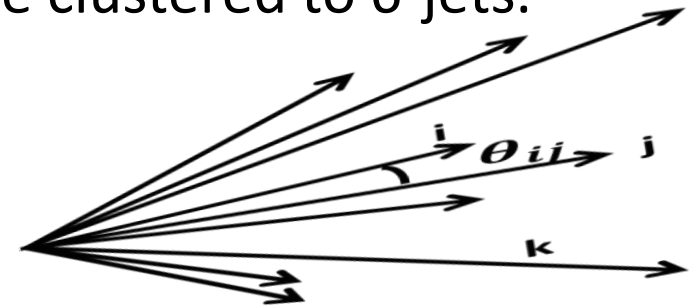


Analysis

Reconstruction

① Using Durham algorism, objects are clustered to 6-jets.

$$Y_{ij} = \frac{2E_iE_j(1-cos\theta_{ij})}{{E_{vis}}^2}$$



② b quark tagging × 2
Most b like jet and second most b like jet are selected.

③ Two Ws are reconstructed from remaining 4-jets.

④ top quarks are reconstructed by pairing W and b.

⑤ The best candidate of jet combination is selected by minimizing χ^2 from W and top mass.

$$\chi^2 = \frac{(M_{2j}-M_{W_1})^2}{\sigma_{W_1}} + \frac{(M_{2j}-M_{W_2})^2}{\sigma_{W_2}} + \frac{(M_{3j}-M_{t_1})^2}{\sigma_{t_1}} + \frac{(M_{3j}-M_{t_2})^2}{\sigma_{t_2}}$$

Selections

Maximizing the significance of top pair to 6-jets final state, these selections were applied.

First, for suppressing the large backgrounds, WW and ZZ, we tagged b quarks, and applied thrust cut.

And for suppressing 4-jets + 1-lepton, isolated lepton veto and visible energy cut are used.

Finally, we use Durham y values for 5 to 6 jets and 6 to 7 jets, y56 and y67.

Left handed
btag1 > 0.1, btag2 > 0.1
Thrust <0.84
of isolated leptons = 0
Visible Energy > 310 GeV
y56 > 0.001, y67 >0.0001

Right handed
btag1 > 0.07, btag2 > 0.07
Thrust <0.83
of isolated leptons = 0
Visible Energy > 305 GeV
y56 > 0.001, y67 >0.0001

Cut table @350GeV Left-Handed

tt → 6jets cut based analysis table at Center of Mass Energy 350(GeV).

Luminosity = 10 fb^{-1} , polarization **e(-80%)p(+30%)**

Significance ; $S = \frac{signal}{\sqrt{signal+background}}$

	Signal	Background					
Ecm=350(GeV)	tt6j	tt4j+1l	tt2j+2l	WW	ZZ	ZH	S_{6j}
No cut	3288	3167	763	65328	6008	1389	11.6
btag × 2	3136	3004	725	7567	2832	982	23.2
Thrust<0.84	3090	2882	645	867	917	815	32.2
# of lepton = 0	3071	495	20	864	915	792	39.2
Evis>310 GeV	3044	185	1	432	572	571	43.9
y56 > 0.001 y67 >0.0001	2880	127	0	134	126	142	49.3

Statistical error for cross section is 1/49.3= 2.0%

Cut table @350GeV Right-Handed

tt → 6jets cut based analysis table at Center of Mass Energy 350(GeV).

Luminosity = 10 fb^{-1} , polarization **e(+80%)p(-30%)**

Significance ; $S = \frac{signal}{\sqrt{signal+background}}$

Signal ↓ | Background

Ecm=350(GeV)	tt6j	tt4j+1l	tt2j+2l	WW	ZZ	ZH	S_{6j}
No cut	1572	1515	365	4326	2773	937	14.7
btag × 2	1547	1483	356	1165	1585	720	18.7
Thrust<0.83	1512	1404	308	118	323	563	23.3
# of lepton = 0	1503	241	9	118	322	543	28.7
Evis>305 GeV	1496	105	0	59	185	409	31.5
y56 > 0.001 y67 >0.0001	1417	72	0	18	47	108	34.8

Statistical error for cross section is 1/34.8= 2.9%

TOP YUKAWA

Statistical Error of Top Yukawa

Summing the events in all the center of mass energy, the statistical errors of the cross section and top yukawa coupling were estimated. Because of 9% enhancement by exchanging higgs boson, we can estimate the statistical error of top yukawa from following formula.

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

Top mass and width are fixed.

Statistical error	Left	Right	Combined
Cross section	0.84%	1.2%	
Top yukawa	5.0%	7.1%	4.2%

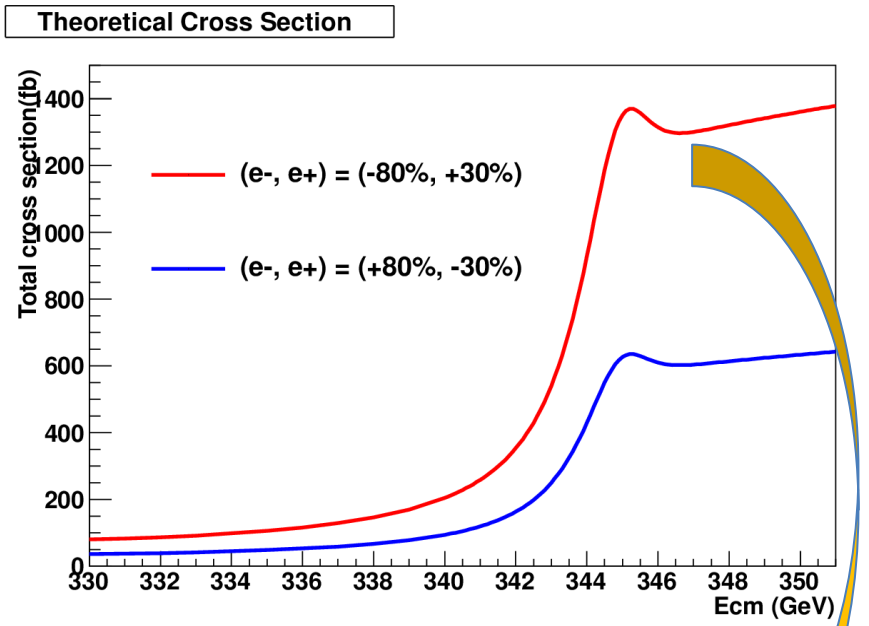
If we can combine 6-jets analysis with 4-jets one , the expected statistical error of top yukawa might be reduced to about **3 %.**

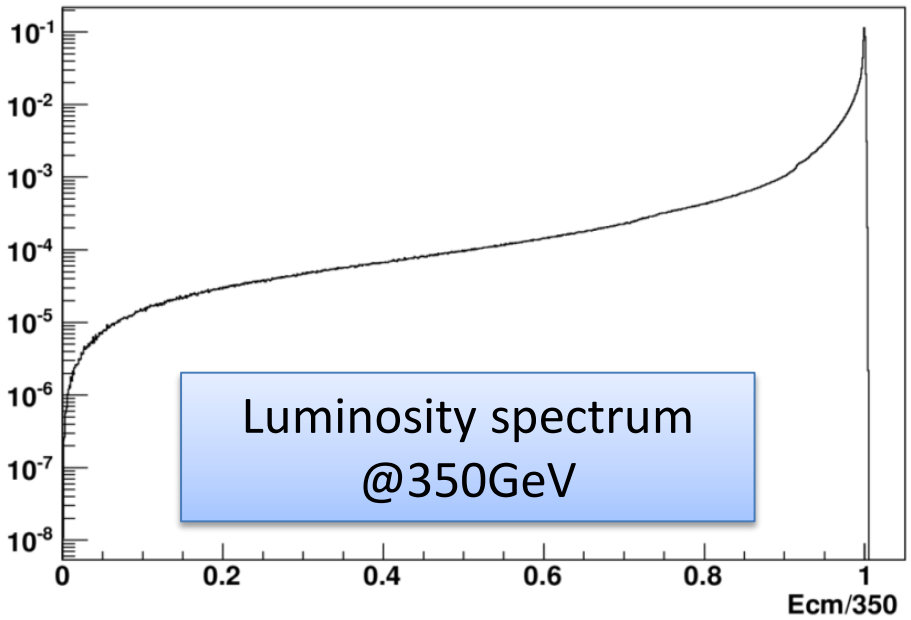
Top Mass & Width

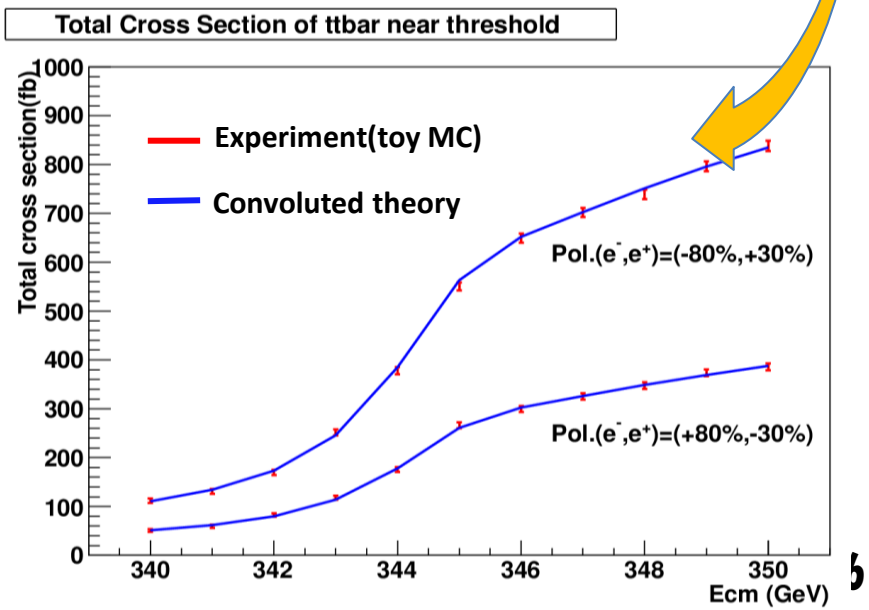
Fitting the Cross Section

To take into account the beam energy spread, ISR, and beamstrahlung effects, theoretical cross section is convoluted with luminosity spectrum. This is done at each Ecm , top mass and width to make cross section tables.

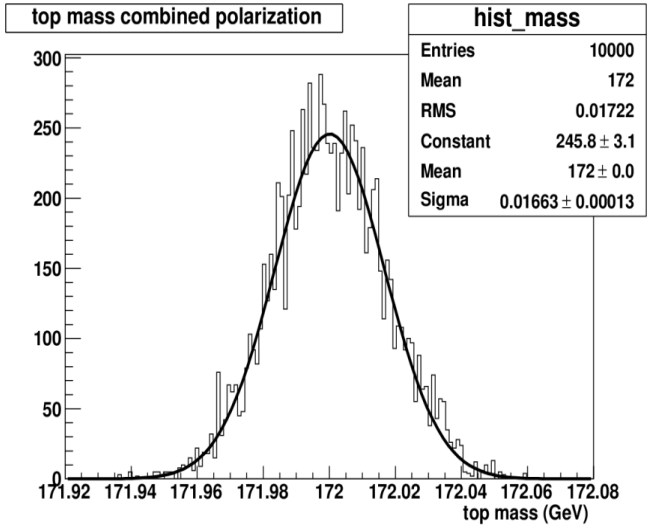
10000 toy MC experiments for 11 Ecm points are generated and fitted with the function according to the tables by floating the mass and width (y_t is fixed).

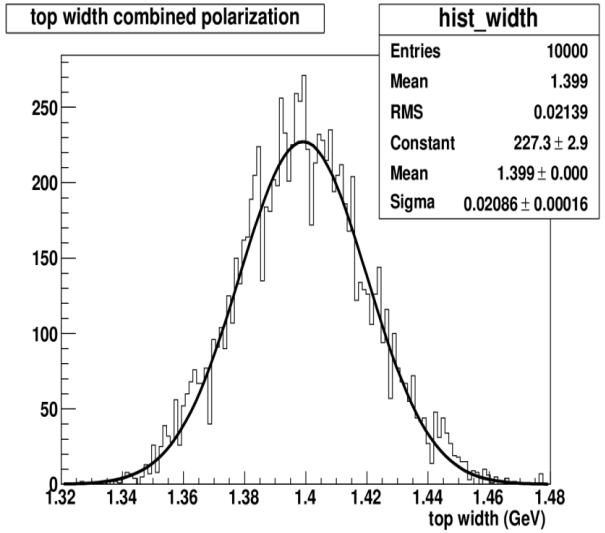


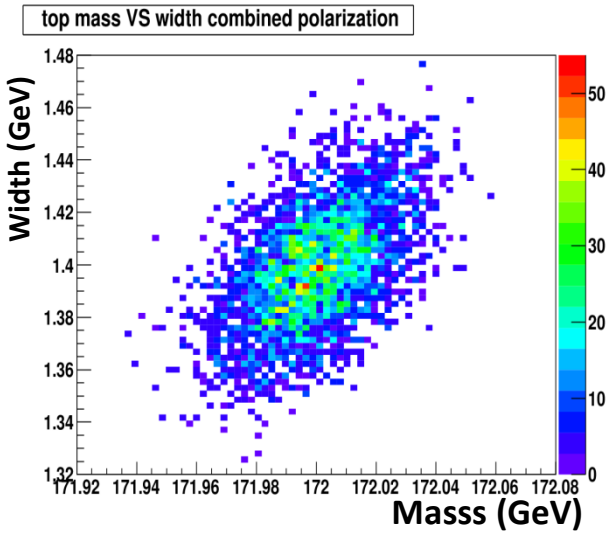




Fit Result







	PS Mass(GeV)	Width(GeV)
Left(110fb^{-1})	172.000±0.021	1.400±0.025
Right(110fb^{-1})	172.000±0.030	1.399±0.037
Left (110fb^{-1}) + Right(110fb^{-1})	172.000±0.017	1.399±0.021

α_s(Mz)	PDG 0.1184 ±0.0007 (0.6%)	Future? 0.1184±0.00012 (0.1%)
$\overline{MS}$mass(GeV)	163.80±0.016(stat)±0.054(α_s) ± …	163.80±0.016(stat)±0.009(α_s)±…

From PS mass to $\overline{MS}$ mass $\quad \overline{MS}mass \sim M_{PS} - \frac{4}{3\pi}(M_{PS} - 20)\alpha_s + \cdots$

SUMMARY & PLAN

<SUMMARY>

- We have estimated the statistical error of top yukawa coupling and the accuracy of top mass and width using 6-jets final state for each polarization at ILC.
- The estimated statistical error of top yukawa coupling is 4.2%.
- The accuracy of $\overline{MS}mass$ is 16MeV (stat) + 54 MeV($\boldsymbol{\alpha_s}$)
  - If the systematic error in $\boldsymbol{\alpha_s}$ is reduced to 0.1%, the corresponding systematic becomes 54 → 9 MeV.
- The accuracy of width is 21 MeV.

<PLAN>

- Estimation of top yukawa coupling by fitting.
- 4-jets + 1-l study will be started which double the statistics.