Top electroweak couplings at $\sqrt{s}$ =500 GeV the ILC

Workshop on Top physics at the LC 2016

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Outline

- **Introduction**
- **Forward backward asymmetry study (Semi-leptonic analysis)**
  - Cause of migration effect
- **Matrix element method study (Di-leptonic analysis)**
  - Selection for the Di-leptonic channel

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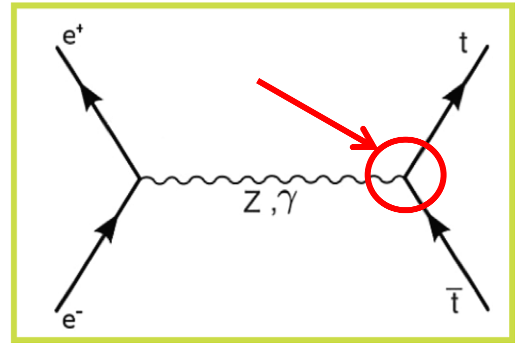
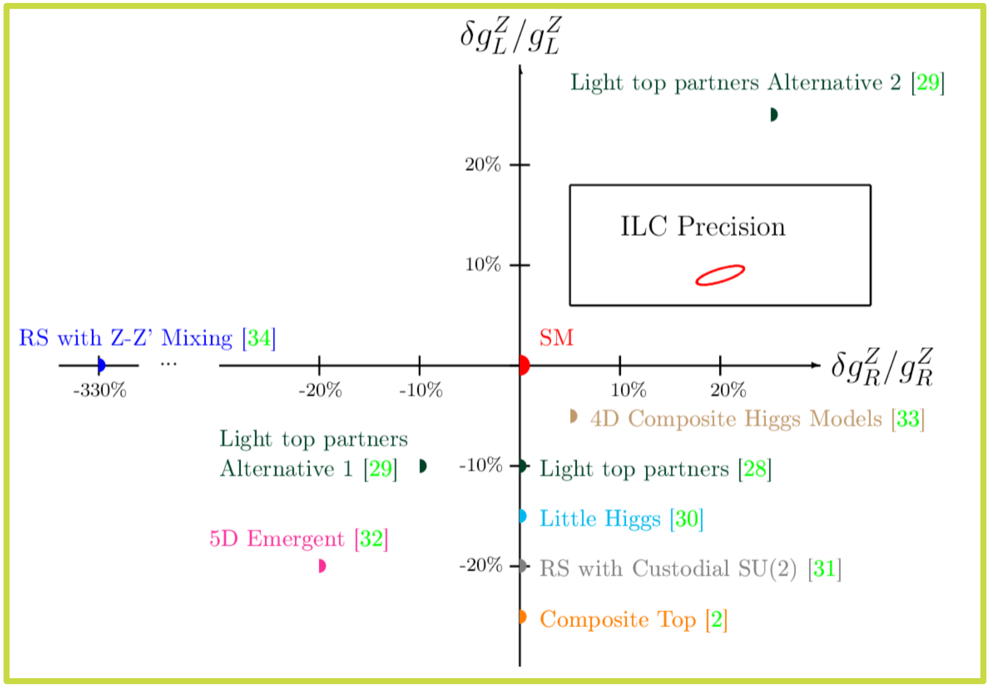
Motivation

The top quark mass is comparable with the electroweak symmetry breaking scale. Top quark may be related to new physics behind EWSB, such as composite models, so top quark electroweak coupling is a good probe of new physics.





Plots show the predicted deviations from the Standard model of Z^0couplings to t_L and t_R in composite models

Precision expected at the ILC will allow to distinguish between models.

arXiv:1505.06020 [hep-ph]

Top quark pair production at the ILC

Top quark pair production is one of the important channels of the ILC.

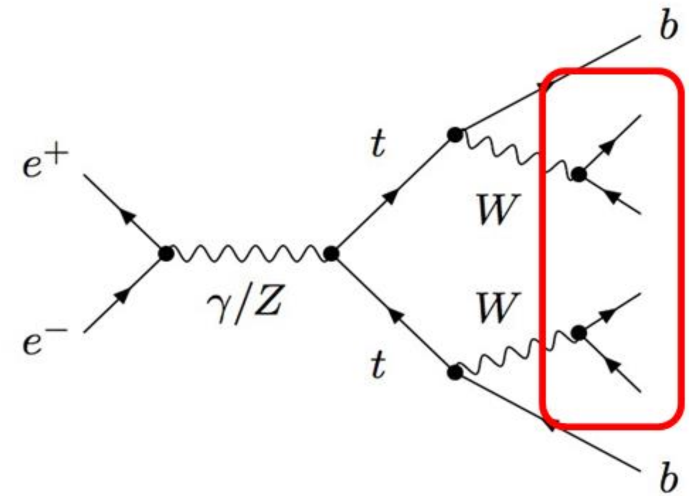
Top quark decays to bW at ~100%

→Three different final states in top pair:

(1) Fully hadronic : $t\bar{t} \rightarrow bq\bar{q}bq\bar{q}$ *(46.2%)*

(2) Semi leptonic : $t\bar{t} \rightarrow bq\bar{q}bl\nu_l$ *(43.5%)*

(3) Di leptonic : $t\bar{t} \rightarrow bl\nu_l bl\nu_l$ *(10.3%)*



Depending on the analysis, suitable final state should be chosen.

e.g.) Forward backward asymmetry study → semi-leptonic

Matrix element method study → di-leptonic

→Ultimately, all final states should be used for analysis.

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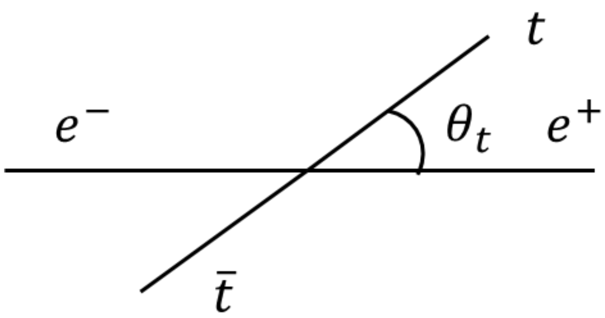
Forward backward asymmetry using semi-leptonic channel

Forward backward asymmetry, A_{FB}

One of the main observables sensitive to the chiral structure

$$A_{FB} = \frac{N(\cos\theta_t > 0) - N(\cos\theta_t < 0)}{N(\cos\theta_t > 0) + N(\cos\theta_t < 0)}$$



The advantage of the semi-leptonic channel

The presence of an isolated lepton tells us charge information of top.

Since there are hadronic top and leptonic top, we can determine the top quark direction and charge.

⇔direction is determined by top hadronic decaying

charge of this top is determined by charge of isolated lepton

Reconstruction of top quark decaying hadronic

- Isolated lepton (e,μ) finding using cone cut: #iso_lep =1
- Suppressing the overlay background using k_T algorithm
- 4-Jets clustering using Durham algorithm
- 2 b-likeness jets were found (LCFIPlus package)
- Reconstruction of top quark decaying hadronic
- Minimizing the χ^2 to select the better combination of b and W;

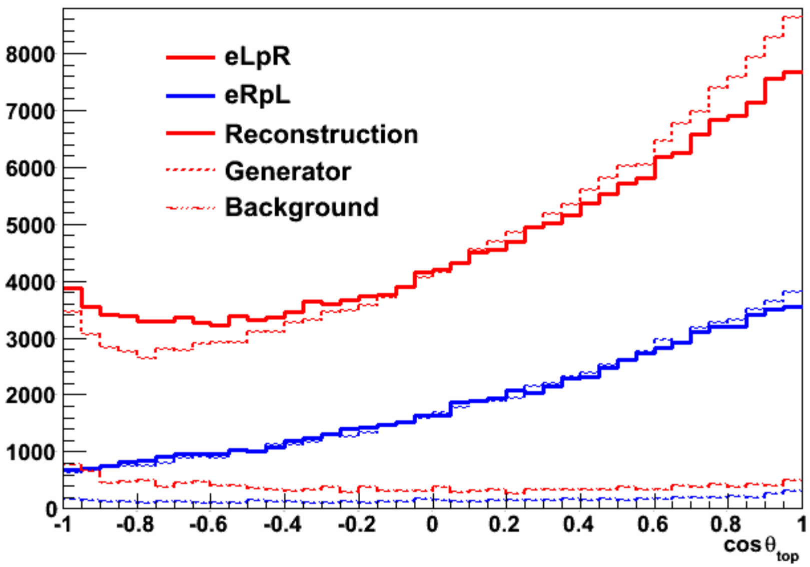
$$\chi^2 = \left(\frac{\gamma_t - 1.403}{\sigma_{\gamma_t}}\right)^2 + \left(\frac{p_b^* - 67.4}{\sigma_{p_{b^*}}}\right)^2 + \left(\frac{\cos\theta_{bW} - 0.23}{\sigma_{\cos\theta_{bW}}}\right)^2$$

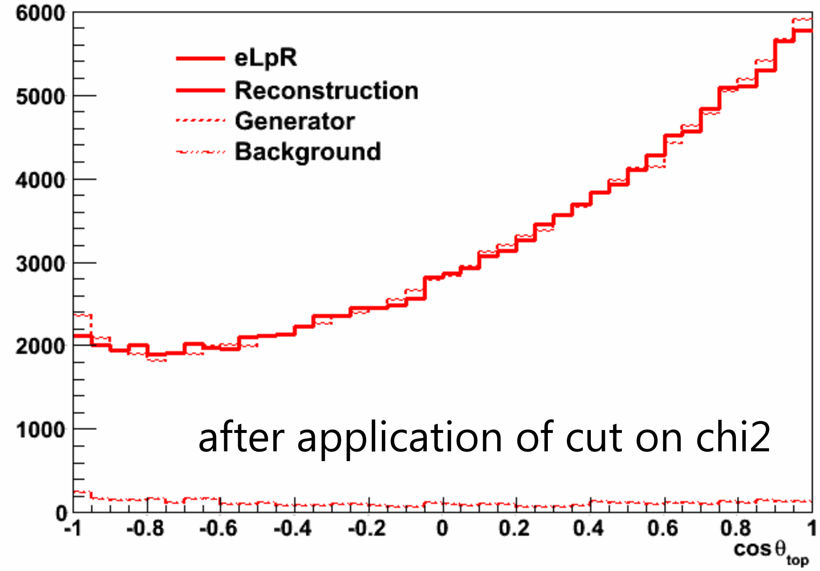
γ_t : the Lorentz factor of top quark ($\gamma_t = E_t/m_t$)

p_b^* : the momentum of b quark in the rest frame of top quark

θ_{bW}: the angle between the b quark and the W boson in lab frame

Angular distribution of top quark





Right-handed electron case (eRpL), Blue line

Good agreement with generator

Left-handed electron case (eLpR), Red line

Considerable migrations of events passing from the forward hemisphere to the backward one. → **Migration effect**.

Solution of migration effect

*Application of a cut on χ^2

*Reconstruction of b quark charge

→**Good agreement with generator**

but efficiency falls down

Causes of the migration effect

Main problem through reconstruction process: Miss association of b and W.

(250fb-1)	true association	miss association
eLpR	75586 (84.3%)	14109 (15.7%)
eRpL	30286 (84.1%)	5712 (15.9%)

The fraction of miss association in reconstructed events is ~16%

Although the fraction of miss association in reconstructed events is almost same for both cases, migration effect happens in only case of eLpR

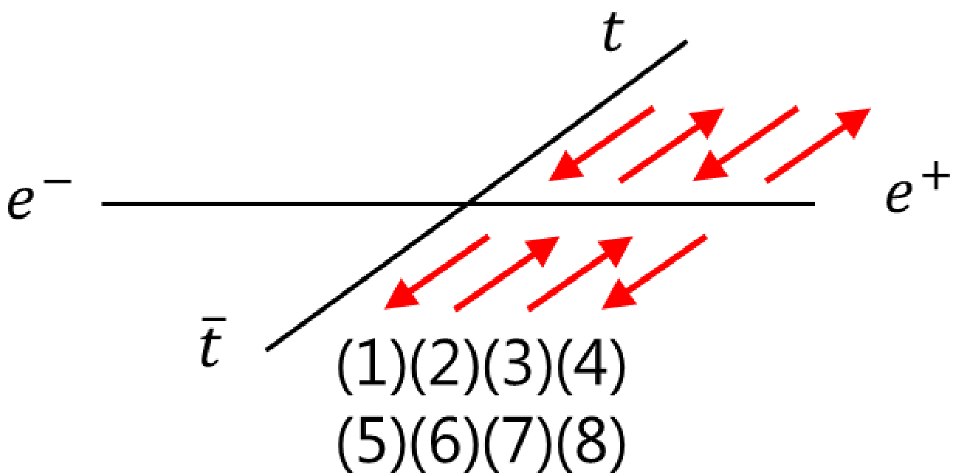
→ The kinematic features depend on the initial polarization

∗ Relation between $e\bar{e}$ and $t\bar{t}$ ∗ Relation between t and bW^+

Relation between $e\bar{e}$ and $t\bar{t}$

- The angular dependence (i.e. $\cos\theta_t$) of each amplitude is determined by angular momentum conservation

$$M(e_L\bar{e}_R \to t_L\bar{t}_R) \propto (1+\cos\theta_t) \quad (1)$$
$$M(e_L\bar{e}_R \to t_R\bar{t}_L) \propto (1-\cos\theta_t) \quad (2)$$
$$M(e_L\bar{e}_R \to t_L\bar{t}_L) \propto \sin\theta_t \quad (3)$$
$$M(e_L\bar{e}_R \to t_R\bar{t}_R) \propto \sin\theta_t \quad (4)$$
$$M(e_R\bar{e}_L \to t_L\bar{t}_R) \propto (1-\cos\theta_t) \quad (5)$$
$$M(e_R\bar{e}_L \to t_R\bar{t}_L) \propto (1+\cos\theta_t) \quad (6)$$
$$M(e_R\bar{e}_L \to t_L\bar{t}_L) \propto \sin\theta_t \quad (7)$$
$$M(e_R\bar{e}_L \to t_R\bar{t}_R) \propto \sin\theta_t \quad (8)$$



- The amplitudes depend on helicity of $e\bar{e}$ and $t\bar{t}$

→ eLpR: Many events with t_L at $\cos\theta_t$ ~1 (1), Small events with t_R at $\cos\theta_t$ ~-1 (2)

→ eRpL: Many events with t_R at $\cos\theta_t$ ~1 (4), Small events with t_L at $\cos\theta_t$ ~-1 (3)

Relation of t and bW^+

- Coupling of W boson and fermions is V-A structure in the Standard model

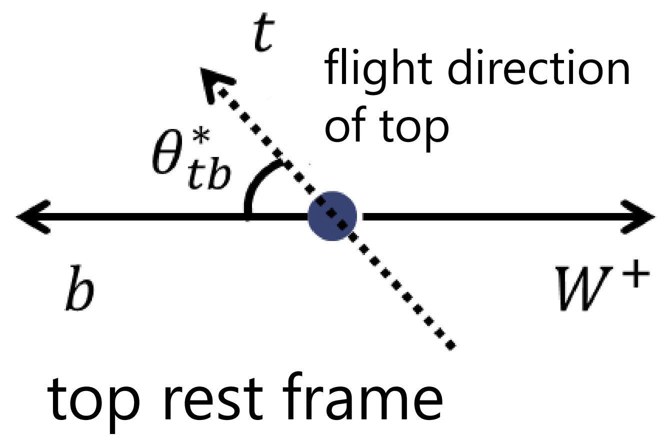
→b quark tends to be emitted in opposite direction of top quark spin

(for t_L flight direction of top, for t_R opposite direction of flight direction)

In terms of $\cos\theta^*_{tb}$ we can translate it as follows;

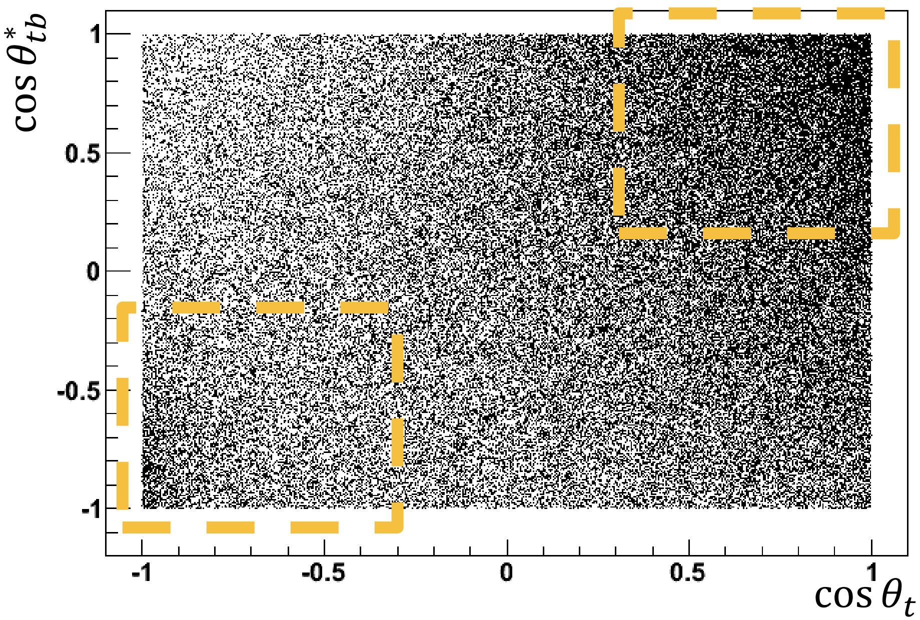
→ t_L: Many events at $\cos\theta^*_{tb}$ ~1

→ t_R: Many events at $\cos\theta^*_{tb}$ ~-1

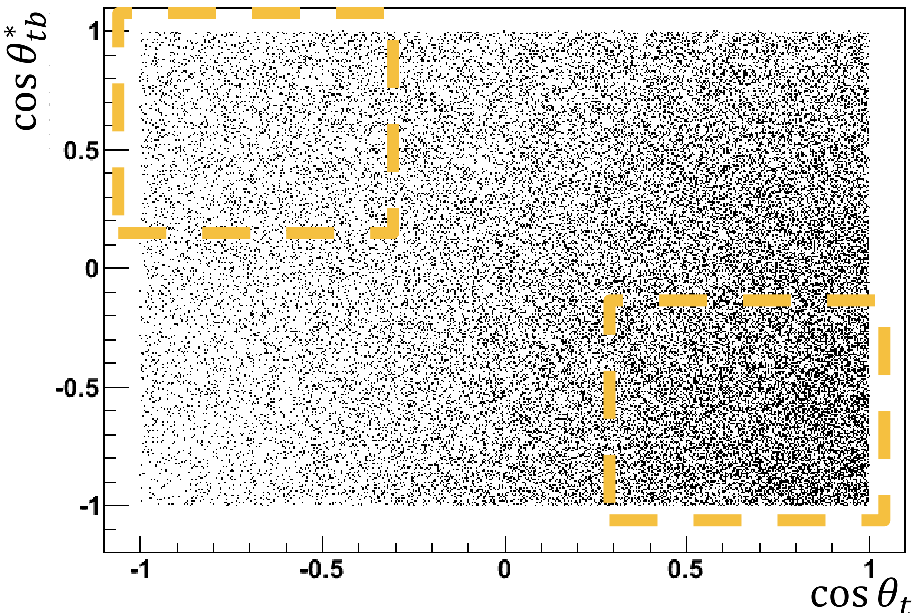


Correlation between $\cos\theta_t$ and $\cos\theta^*_{tb}$ at generator level

eLpR



eRpL



eLpR: Large peak at $\cos\theta_t$ ~1 and $\cos\theta^*_{tb}$ ~1 for t_L

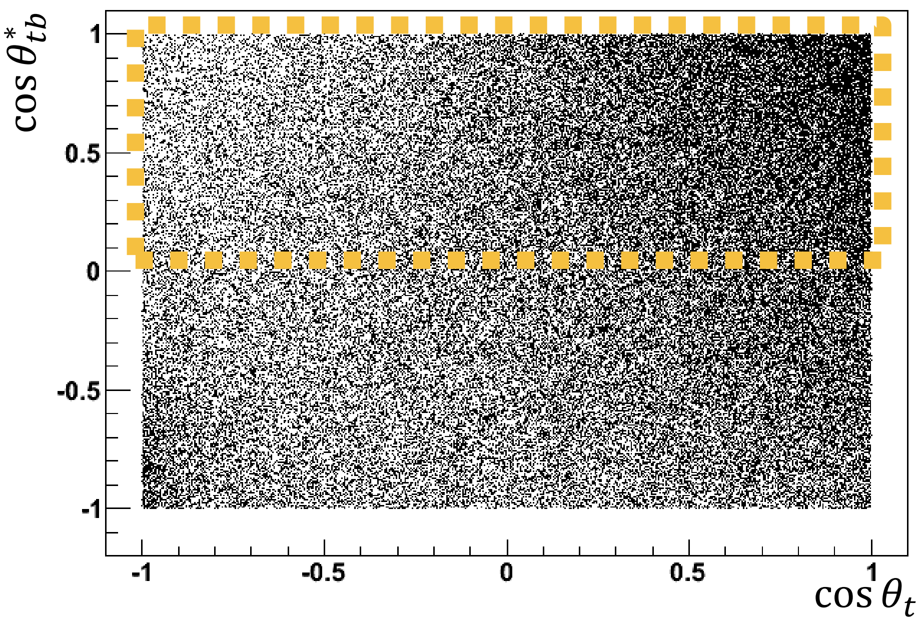
Small peak at $\cos\theta_t$ ~-1 and $\cos\theta^*_{tb}$ ~-1 for t_R

eRpL: Large peak at $\cos\theta_t$ ~1 and $\cos\theta^*_{tb}$ ~1 for t_R

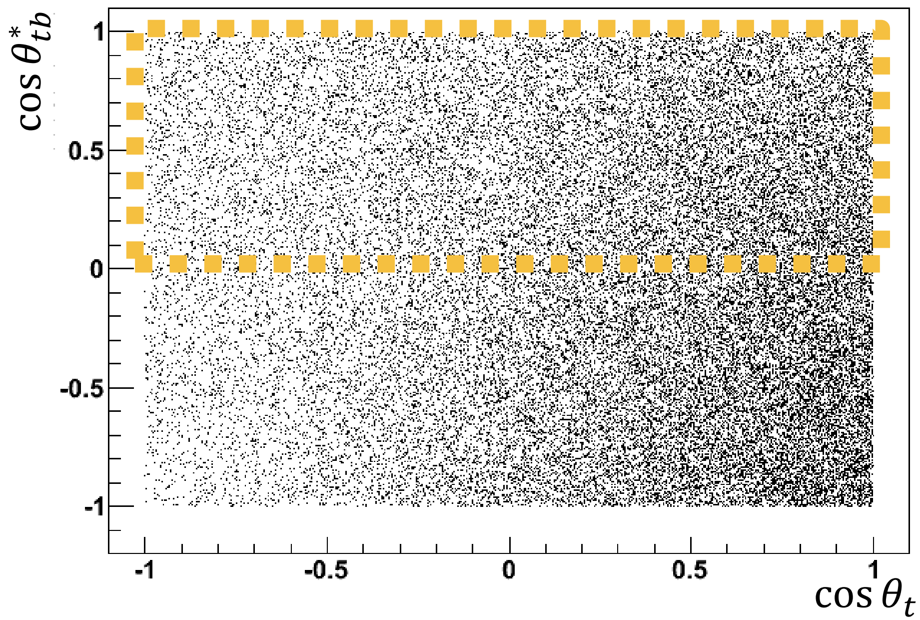
(Small peak at $\cos\theta_t$ ~-1 and $\cos\theta^*_{tb}$ ~-1 for t_L)

Correlation between $\cos\theta_t$ and $\cos\theta^*_{tb}$ at generator level

eLpR



eRpL

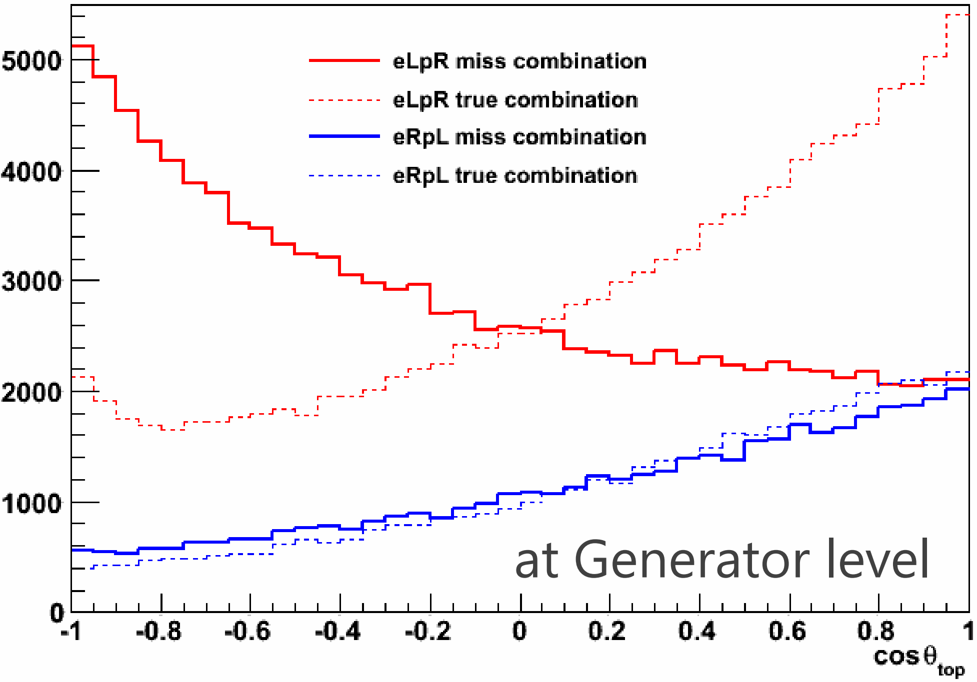


In case that b quark is emitted in direction of top quark (i.e. $\cos\theta^*_{tb} \sim 1$),

b quark is energetic and W is almost at rest in the lab frame.

→**Miss association of b and W can flip the direction of reconstructed top quark.**

The angular distribution of true and miss association



Right-handed electron case (eRpL), Blue line

Little difference between true and miss associated distributions

Left-handed electron case (eLpR), Red line

Miss association changes angular distribution significantly

Cause of migration effect

Even though the rate of miss association is almost same for the both cases, angular distribution is changed by miss association of b and W in the case of eLpR

→**The migration effect happens in only the case of eLpR**

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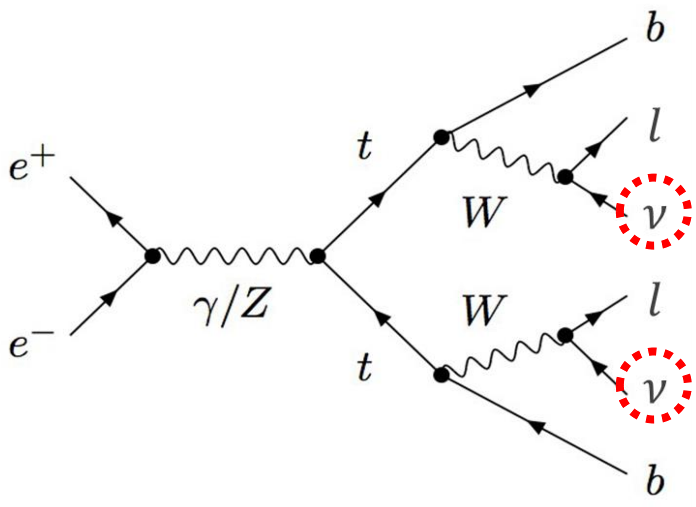
Di-leptonic analysis for matrix element method

Matrix element method

The most efficient method when all the kinematics can be reconstructed

→Use the di-leptonic final state to have a full kinematical information



We can obtain these information;

*Directions of isolated leptons and b quarks

*Energy of isolated leptons

*(Energy of b quarks)

From the kinematical reconstruction ,

we can recover missing neutrinos

Di-leptonic analysis for matrix element method

Results of statistical uncertainties and correlation at generator with SM LO

P.H. Kheim et al: arXiv: 1503:04247

$\mathcal{R}\mathrm{e}\,\delta\tilde{F}^{\gamma}_{1V}$	$\mathcal{R}\mathrm{e}\,\delta\tilde{F}^{Z}_{1V}$	$\mathcal{R}\mathrm{e}\,\delta\tilde{F}^{\gamma}_{1A}$	$\mathcal{R}\mathrm{e}\,\delta\tilde{F}^{Z}_{1A}$	$\mathcal{R}\mathrm{e}\,\delta\tilde{F}^{\gamma}_{2V}$	$\mathcal{R}\mathrm{e}\,\delta\tilde{F}^{Z}_{2V}$	$\mathcal{R}\mathrm{e}\,\delta\tilde{F}^{\gamma}_{2A}$	$\mathcal{R}\mathrm{e}\,\delta\tilde{F}^{Z}_{2A}$	$\mathcal{I}\mathrm{m}\,\delta\tilde{F}^{\gamma}_{2A}$	$\mathcal{I}\mathrm{m}\,\delta\tilde{F}^{Z}_{2A}$
0.0037	−0.18	−0.09	+0.14	+0.62	−0.15	0	0	0	0
	0.0063	+.14	−0.06	−0.13	+0.61	0	0	0	0
		0.0053	−0.15	−0.05	+0.09	0	0	0	0
			0.0083	+0.06	−0.04	0	0	0	0
				0.0105	−0.19	0	0	0	0
					0.0169	0	0	0	0
						0.0068	−0.15	0	0
							0.0118	0	0
								0.0069	−0.17
									0.0100

$\sqrt{s}$ =**500 GeV,500 fb-1,** $P(e^-,e^+) = (\mp\mathbf{0.8}, \pm\mathbf{0.3})$

less than one percent precision achieved with parton level study

→I study the same technique including detector simulation.

First I would show the selection of the di-leptonic final state.

Analysis process of selection for di-leptonic channel

- Isolated lepton (e,μ) finding using cone cut: #iso_lep =2
- Suppressing the overlay background using k_T algorithm
- 2-Jets clustering using Durham algorithm (LCFIPlus package)
- 2 b-likeness jets were found (LCFIPlus package)

(Reconstruction events from their kinematics. → Not yet)

→Selection study for di-leptonic final state

Samples : DBD samples, ILCSOFT: v01-16-p05

Selection for di-leptonic channel

$$\sqrt{s} = 500\ \text{GeV},\ 500\ \text{fb}^{-1},\ \text{P}(e^-, e^+) = (-0.8, +0.3)$$

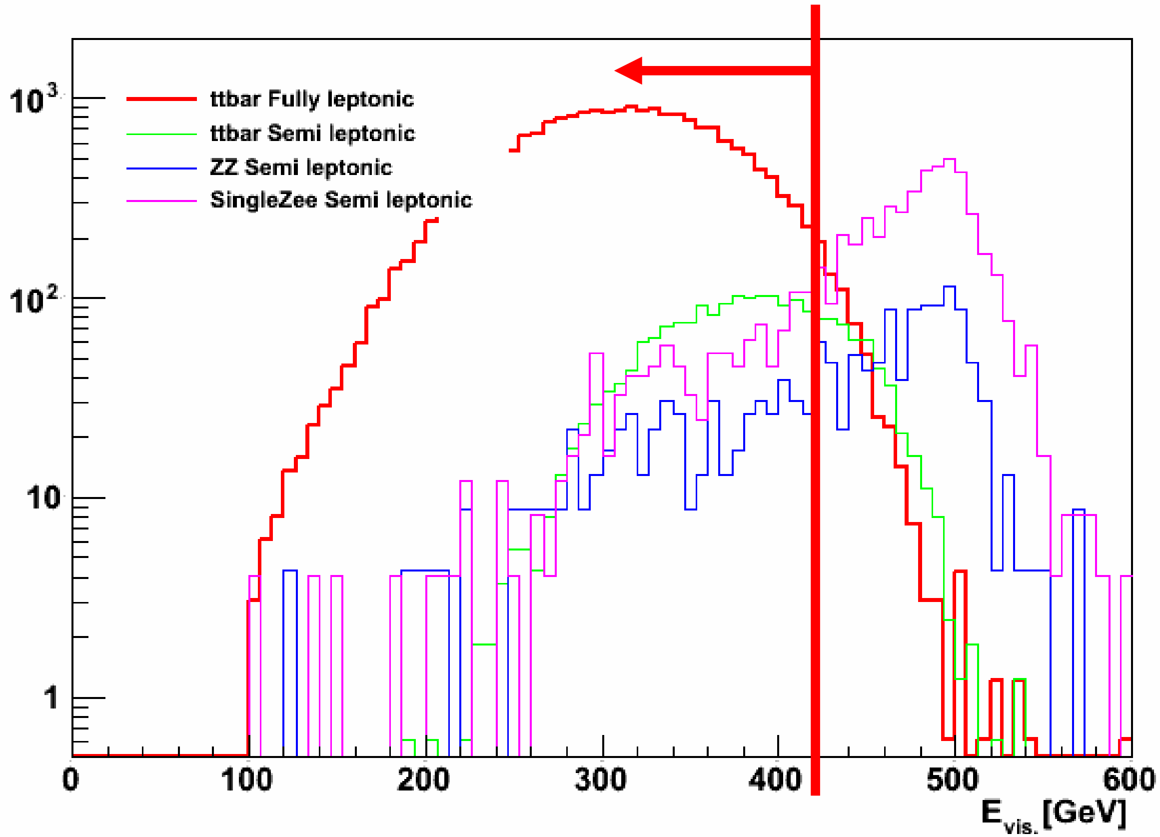
$500\ \text{fb}^{-1}$ (-0.8,+0.3)	ttbar Di-leptonic (Signal)	ttbar Semi-leptonic	ZZ Semi-leptonic	Single Z ee	Others
Generated	53289 (100%)	208505 (100%)	183053 (100%)	941270 (100%)	14939285 (100%)
# of lepton = 2	25482 (47.8%)	2716 (1.30%)	28343 (15.5%)	97536 (10.362%)	48064 (0.3217%)
b-tag1 > 0.8 or b-tag2 > 0.8	22278 (41.8%)	2029 (0.973%)	5110 (2.79%)	13942 (1.48%)	1823 (0.01220%)
Thrust < 0.9	21612 (40.6%)	2022 (0.970%)	1524 (0.833%)	5727 (0.608%)	333 (0.0022%)

Main background：ttbar semi-leptonic, ZZ semi-leptonic and Single Z ee

Cut on the visible energy

The visible energy of the signal is smaller because of two missing neutrinos

$$E_{vis} < 420 \text{ GeV}$$



Current results of cut study of di-leptonic analysis

$500\ \mathrm{fb}^{-1}$ (-0.8,+0.3)	ttbar di-leptonic (Signal)	ttbar Semi-leptonic	ZZ semi-leptonic	Single Z ee
Generated	53289 (100%)	208505 (100%)	183053 (100%)	941270 (100%)
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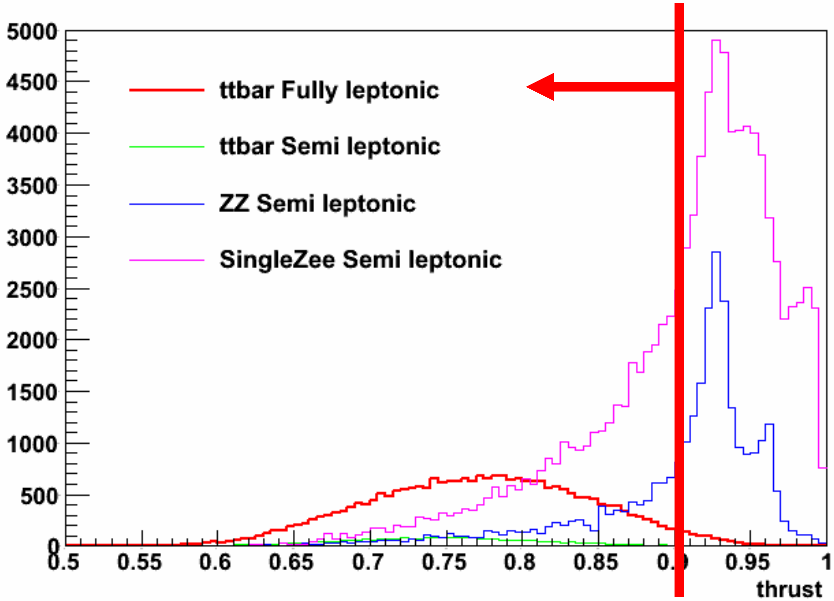
Thrust < 0.9	21612 (40.6%)	2022 (0.970%)	1524 (0.833%)	5727 (0.608%)
Evis< 420	20958 (39.3%)	1252 (0.600%)	502 (0.274)	1114 (0.118%)

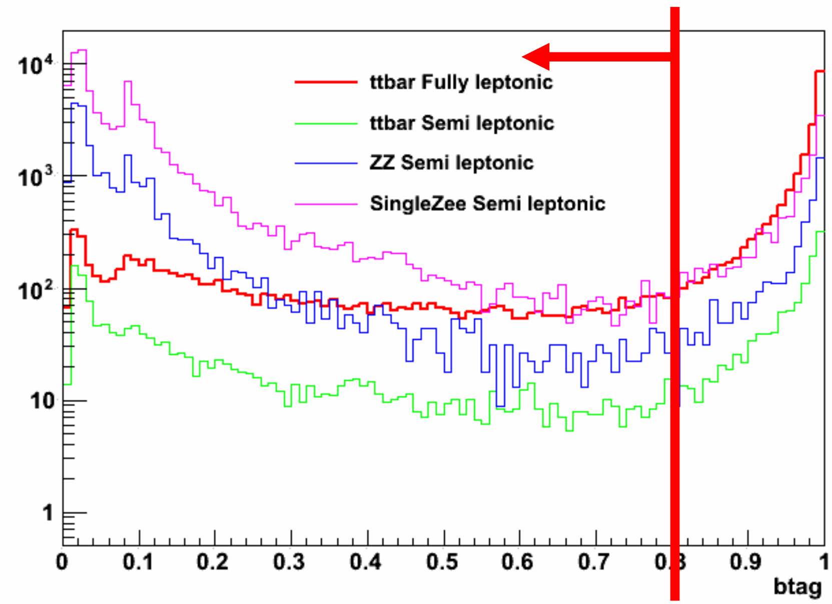
Efficiency = 39.3%, Significance $(N_{sig.}/\sqrt{N_{sig.}+N_{bkg.}})$ = 135.8

Summary

- **Forward backward asymmetry study (Semi-leptonic analysis)**
  - Migration effect is main problem for A_{FB} study
  - Only in the case for eLpR, migration effect happens frequently since the W tends to be almost at rest.
- **Matrix element method study (Di-leptonic analysis)**
  - Selection study is first trial for di-leptonic analysis.

Backup





Thrust < 0.9

b-tag1 < 0.8