Top electroweak coupling study using di-muonic state at $\sqrt{s} = 500$ GeV, ILC

ILD Analysis/Software Meeting

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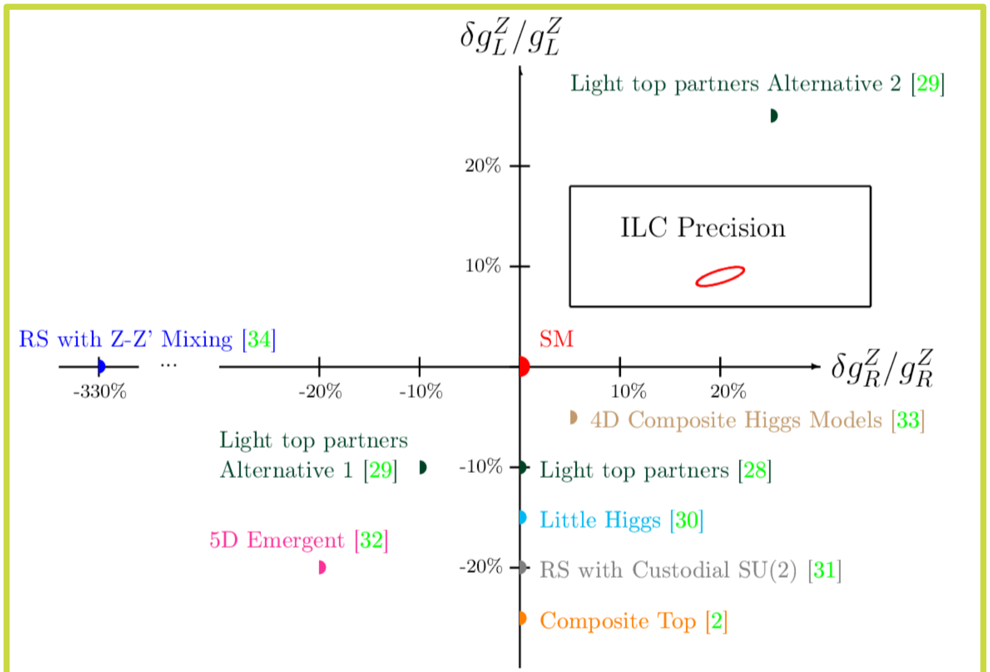
Top electroweak coupling

The top quark mass is comparable with the electroweak symmetry breaking scale. One can speculate that top quark plays a special role for the EWSB, in such composite models. Therefore 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]

Matrix element method

The most efficient method when all the kinematics can be reconstructed.

- Result of previous study shows that the 10 form factors can be fitted simultaneously at less than a percent precision.

Statistical uncertainties and correlation with the SM LO as normalization

Kheim, E.K. Kurihara, Le Diberder: arXiv:1503:04247

$\mathcal{R}e\ \delta\tilde{F}_{1V}^{\gamma}$	$\mathcal{R}e\ \delta\tilde{F}_{1V}^{Z}$	$\mathcal{R}e\ \delta\tilde{F}_{1A}^{\gamma}$	$\mathcal{R}e\ \delta\tilde{F}_{1A}^{Z}$	$\mathcal{R}e\ \delta\tilde{F}_{2V}^{\gamma}$	$\mathcal{R}e\ \delta\tilde{F}_{2V}^{Z}$	$\mathcal{R}e\ \delta\tilde{F}_{2A}^{\gamma}$	$\mathcal{R}e\ \delta\tilde{F}_{2A}^{Z}$	$\mathcal{I}m\ \delta\tilde{F}_{2A}^{\gamma}$	$\mathcal{I}m\ \delta\tilde{F}_{2A}^{Z}$
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

500 GeV&500 fb^{-1} Polarization 50/50 between ±80% and ±30%

Emi Kou (LAL-Orsay)
LFC 15, Trento,
7-11 Sep. 2015

This result is at parton level ignoring the detector effect, ISR and so on.

→More realistic study is required !

Setting of this study

Sample

The top pair production di-muonic state; $t\bar{t} \to b\bar{b}\mu^+\mu^-\nu\bar{\nu}$ at $\sqrt{s}$ = 500 GeV

Situation

✓ The hadronization of b and $\bar{b}$ quark

✓ The detector effect (the ILD full simulation)

× ISR and beamsstrahlung

× gluon emission from top quark

× γγ → hadrons background

Topics

- **b-jet reconstruction**
  - Thrust axis method
  - Deviation of energy of b-jet
- **Kinematical reconstruction of top quark**
  - Strategy
  - χ^2 algorithm
- **Fit of the form factor with matrix element method**
  - Status report

1. b-jet reconstruction

Kinematics of b-jets :

- Direction is used for kinematical reconstruction of top quark
- Energy is just used to select optimal solution

  (The detail will be described in a later slide.)

Sub-topics

- Thrust axis method for reconstruction of direction of b-jets
- Deviation of energy of b-jets

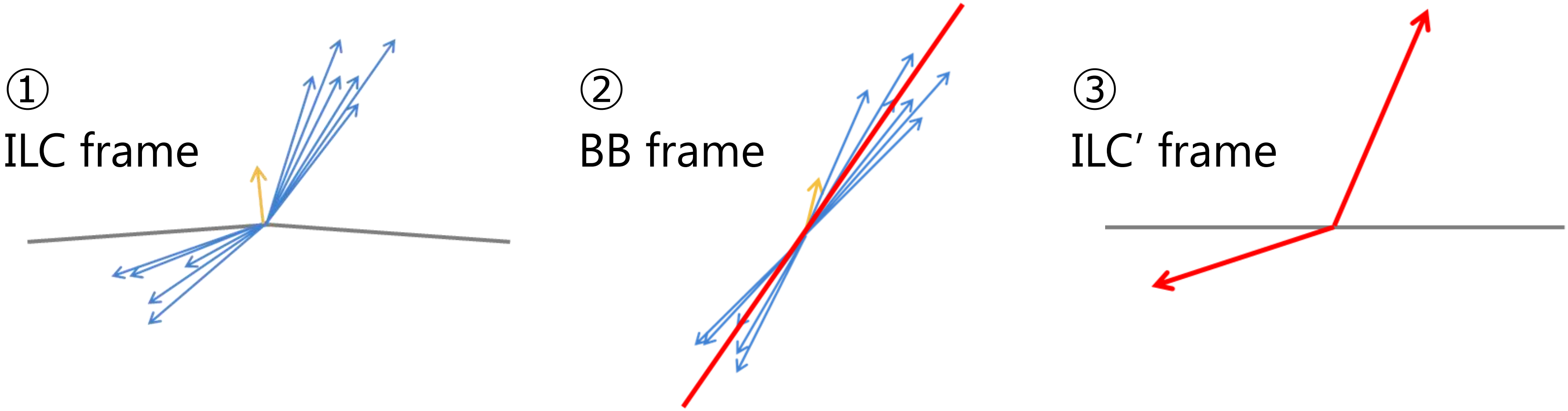
Thrust axis method

① Collect all hadronized particles from b and $\bar{b}$ quark and photons from isolated leptons in the ILC frame

② Boost them to their rest frame and calculate thrust axis in this frame (defined as the BB frame in this slide)

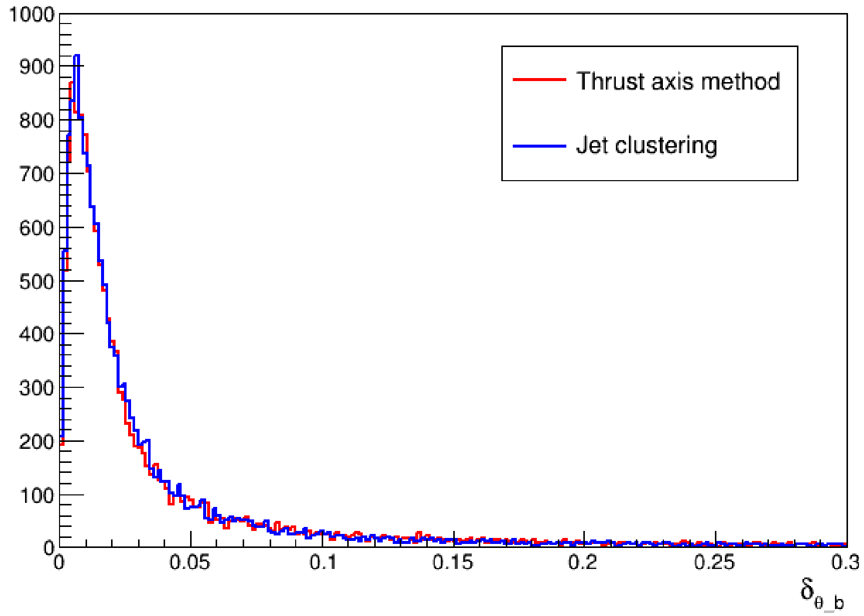
③ Boost the vectors along thrust axis to the ILC′ frame

(ILC′ frame : the frame in which head-on-collision occurs)



Comparison two method

The figure shows the δ_{θ_b}, the angle between truth direction of b-quark and reconstructed direction.



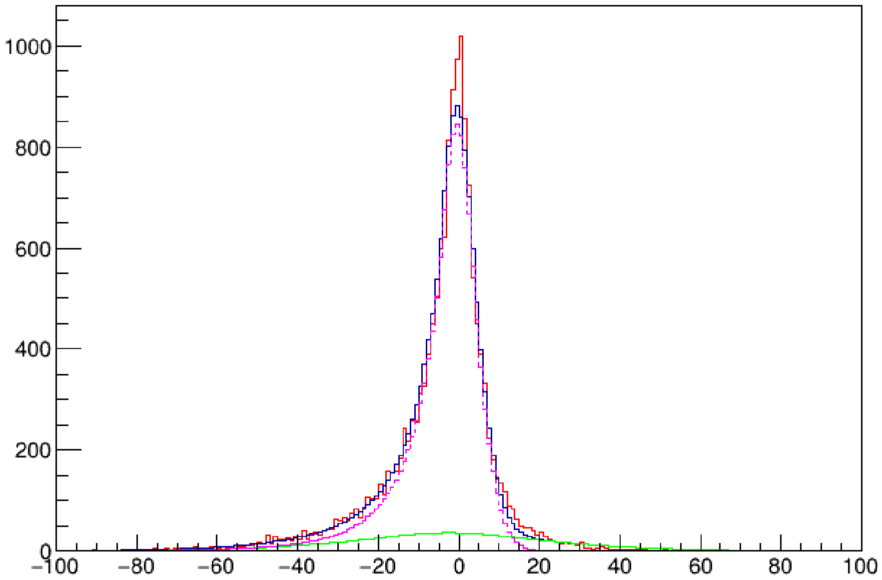
Red : Thrust axis method

Blue : Jet clustering

Two methods produce almost same precision for direction of b-quark.

→We select the thrust axis method so far.

Deviation of energy of b-jet



Deviation of energy of b-jet

(using thrust axis method)

Red : Original

Blue : Fitted

(Blue is a sum of Pink and Green)

To estimate the b-jet energy resolution we use multiple Crystal Ball functions for fitting.

$$CB(x|\alpha, n, \mu, \sigma) = \begin{cases} N \exp\left(-\frac{x^2-\mu}{2\sigma^2}\right), & \frac{x-\mu}{\sigma} > -\alpha \\ N \cdot A \cdot \left(B - \frac{x-\mu}{\sigma}\right), & \frac{x-\mu}{\sigma} < -\alpha \end{cases}$$

We use $\sigma_{jet} E_b^X$ with two parameters σ_{jet} and X instead of σ

Kinematical reconstruction

Strategy of the kinematical reconstruction

- **There are 8 unknown kinematics in this state**

  (= the momenta of two neutrinos and energy of b-jets)

  The precision of energy of b-jets is not enough for kinematical reconstruction

- **Impose 8 constraints** (= initial state constraints and $m_t, m_{\bar{t}}, m_{W^+}, m_{W^-}$)

  → Solutions are obtained in terms of (θ_t, ϕ_t) (→ $(\theta_t, \phi_t, m_t, m_{\bar{t}}, m_{W^+}, m_{W^-})$)

  It is not unique solution since the equation is nonlinear. Furthermore an ambiguity of b-charge remains. → **Typically 4 solutions per event.**

- **Select optimal solution**

  Compare energy of b-quarks between reconstructed and measured.

χ^2 algorithm #1

1. Define the χ^2_μ ;

$$\chi^2_\mu = \chi^2_{\mu^+} + \chi^2_{\mu^-}, \quad \chi^2_{\mu^\pm} = \left(\frac{E^{**}_{\mu^\pm}(\theta_t, \phi_t, m_t, m_{\bar{t}}, m_{W^+}, m_{W^-}) - m_{W^\pm}/2}{\sigma\left[E^{**}_{\mu^\pm}\right]}\right)^2$$

The energy of $\mu^\pm$ in the $W^\pm$ rest frame, $E^{**}_{\mu^\pm}$, must be equal to $m_{W^\pm}/2$ and it can be written by six parameters $(\theta_t, \phi_t, m_t, m_{\bar{t}}, m_{W^+}, m_{W^-})$.

2. Define the δ^2_b;

$$\delta^2_b = -2\log L_b - 2\log L_{\bar{b}}\,, \;\; L_b = \mathrm{CB}\left(E^{\mathrm{meas.}}_b - E^{\mathrm{rec.}}_b(\theta_t, \phi_t, m_t, m_{\bar{t}}, m_{W^+}, m_{W^-})\right)$$

Although the energy of b quarks can be only poorly measured, we can eliminate b-charge ambiguity by comparing the measured energy to the reconstructed energy.

3. Compound $\chi^2_{\mathrm{tot.}}$; $\chi^2_{\mathrm{tot.}} = \chi^2_\mu + \delta^2_b$

One minimizes the $\chi^2_{\mathrm{tot.}}$ to obtain optimal solution in terms of $(\theta_t, \phi_t, m_t, m_{\bar{t}}, m_{W^+}, m_{W^-})$.

χ^2 algorithm #2

We used the reconstructed direction of b-jets as constant.

→ Add 4 angles $(\theta_b, \phi_b, \theta_{\bar{b}}, \phi_{\bar{b}})$ for the fitting parameters

→ Add constraints of 4 angles $(\theta_b, \phi_b, \theta_{\bar{b}}, \phi_{\bar{b}})$ to $\chi^2_{\mathrm{tot.}}$ as below;

$$\chi^2_{\mathrm{direction}} = \chi^2_{\theta_b} + \chi^2_{\phi_b} + \chi^2_{\theta_{\bar{b}}} + \chi^2_{\phi_{\bar{b}}}, \qquad \chi^2_{\theta_b} = \left(\frac{\theta_b^{\mathrm{meas.}} - \theta_b}{\sigma[\theta_b^{\mathrm{meas.}}]}\right)^2$$

$(\chi^2_{\phi_b}, \chi^2_{\theta_{\bar{b}}}, \chi^2_{\phi_{\bar{b}}}$ are same as $\chi^2_{\theta_b})$

$$(\chi^2_{\mathrm{tot.}})' = \chi^2_{\mathrm{tot.}} + \chi^2_{\mathrm{direction}}$$

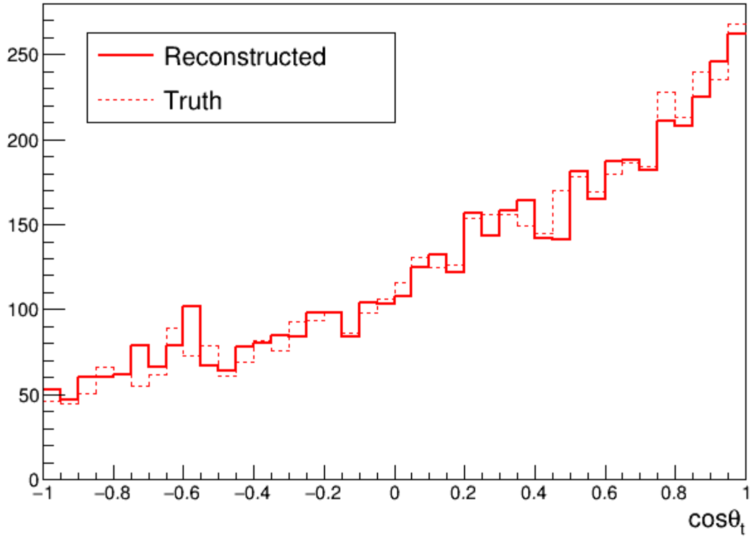
Then we can use $(\chi^2_{\mathrm{tot.}})'$ instead of $\chi^2_{\mathrm{tot.}}$.

Kinematical reconstruction : Results

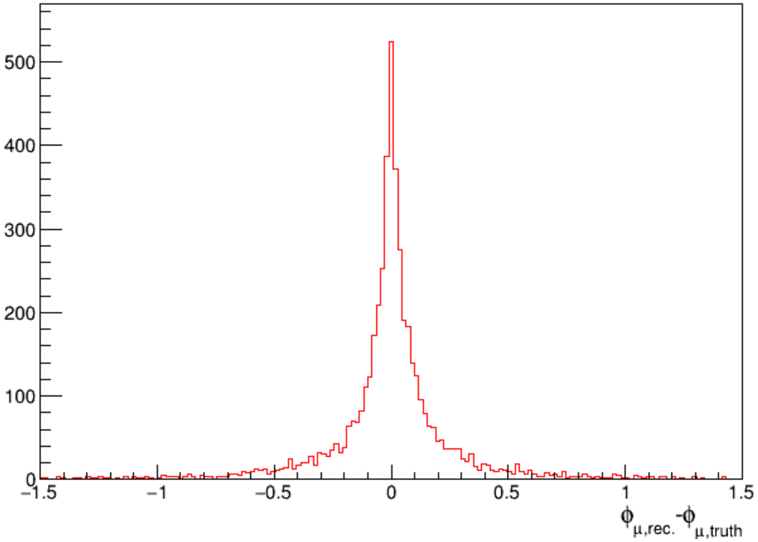
Reconstructed particles are used in terms of helicity angles for fit form factors:

$$\cos\theta_t\,,\cos\theta_{W^+}\,,\phi_{W^+},\cos\theta_{\mu^+}\,,\phi_{\mu^+},\cos\theta_{W^-}\,,\phi_{W^-},\cos\theta_{\mu^-}\,,\phi_{\mu^-}$$

eg.) $\cos\theta_t$



eg.) $\phi_{\mu^+,rec.} - \phi_{\mu^+,truth}$



The ratio of wrong assignment of b-quark is only 2.1 % !

BUT we use truth values as seeds for minimization for now.

Status of the 10 form factors fit

Δ_{F1}	-0.0067 $\pm$ 0.0082
Δ_{F2}	0.035 $\pm$ 0.017
Δ_{F3}	-0.056 $\pm$ 0.012
Δ_{F4}	0.035 $\pm$ 0.018
Δ_{F5}	-0.022 $\pm$ 0.026
Δ_{F6}	0.042 $\pm$ 0.045
Δ_{F7}	-0.0081 $\pm$ 0.015
Δ_{F8}	0.010 $\pm$ 0.032
Δ_{F9}	0.013 $\pm$ 0.024
Δ_{F10}	-0.010 $\pm$ 0.022

(Preliminary)

5000 events, after cut on the $\chi^2_{\mathrm{tot.}}$ to keep ~83% of the events.

Some small biases are observed (eg. Δ_{F3}) at few percent level

→ **No show stopper yet !!!**

→ Should be corrected by accounting for detector effects in $|M|^2$

Summary and Plan for LCWS

- Matrix element method is the most efficient method when all the kinematics can be reconstructed.
- Thrust axis method produced almost the same precision for direction of b-jets as jet clustering.
- All kinematics of this state are obtained with a good accuracy from kinematical reconstruction.
- Although there are small biases, the hadronization and detector effect don't affect for fit of form factors too match.

- Plan to fit 1 form factor instead of 10 and assess it using forward backward asymmetry of top quark.

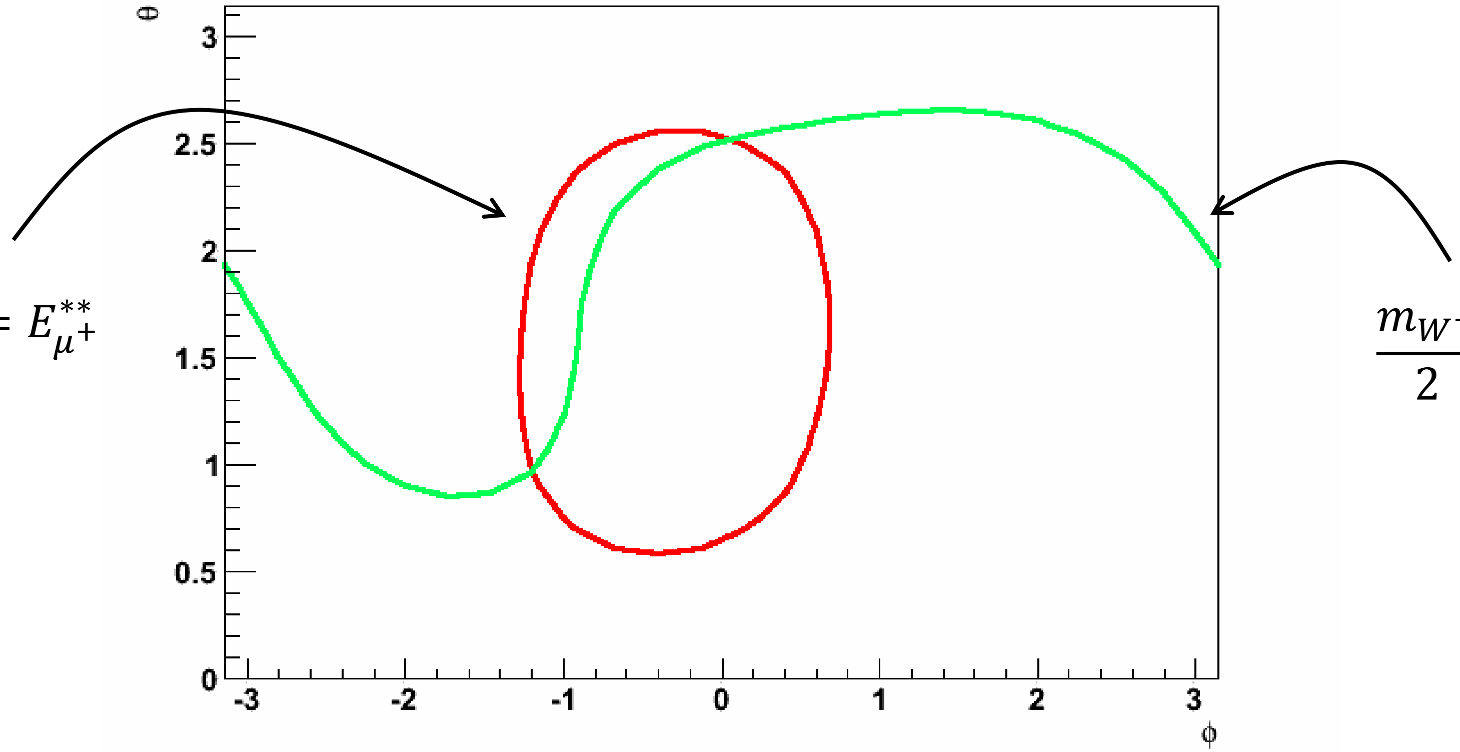
Back up

Kinematical constraints

In the W rest frame, the energy of isolated lepton is equal to $m_W/2$

(with ignoring ISR and bremsstrahlung)

$$\frac{m_{W^+}}{2} = E^{**}_{\mu^+}$$

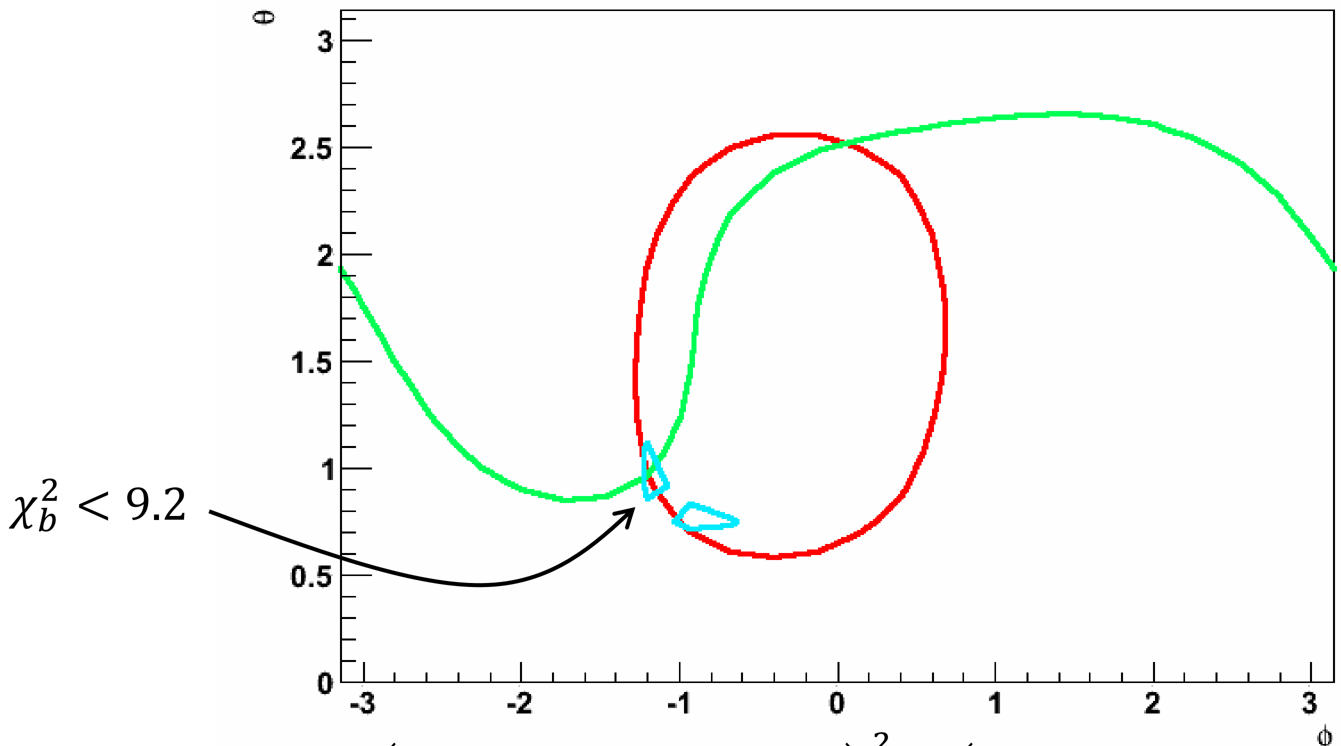


$$\frac{m_{W^-}}{2} = E^{**}_{\mu^-}$$

Measurements of b-quark energies

To select a right solution, we can use the measurement of b-jets energy.

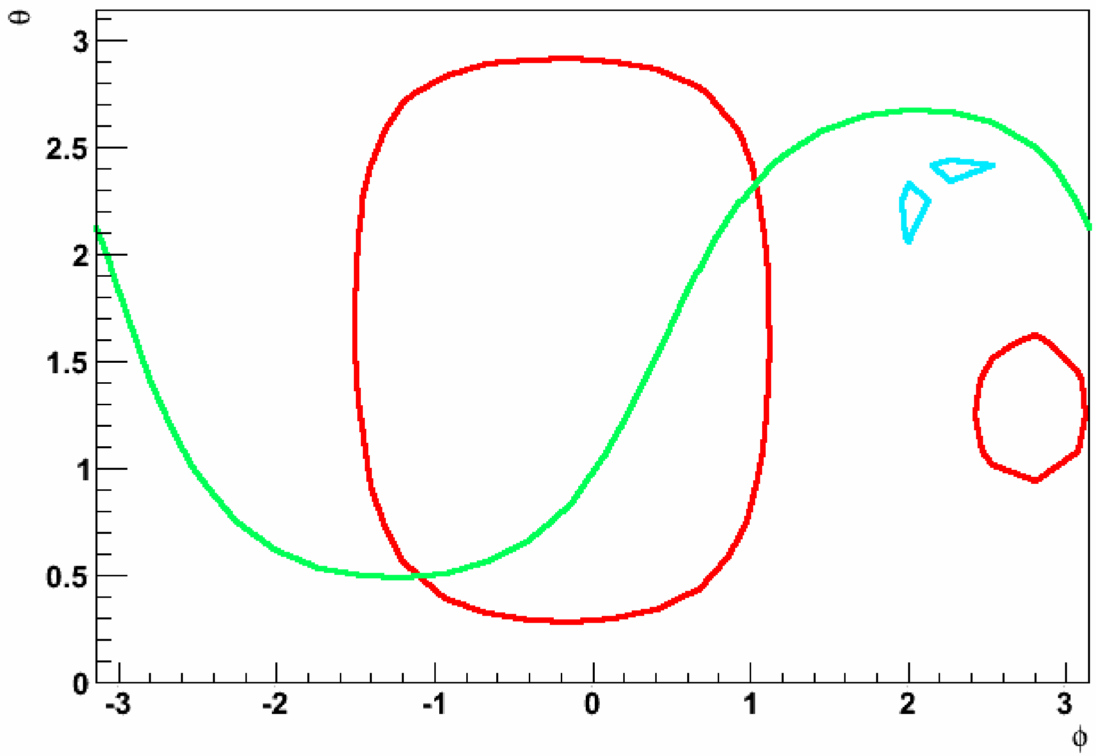
(Because this figure is at parton level, the χ_b^2 doesn't make sense.)



$$\chi_b^2(\phi_t, \theta_t) = \left(\frac{E_{b,mes} - E_{b,reco}(\phi_t, \theta_t)}{\sigma_j \sqrt{E_{b,mes}}}\right)^2 + \left(\frac{E_{\bar{b},mes} - E_{\bar{b},reco}(\phi_t, \theta_t)}{\sigma_j \sqrt{E_{\bar{b},mes}}}\right)^2$$

Miss combination of b-quarks

When we use the anti-b direction for the top reconstruction, the measurements of energy of b-jets excludes this combination.



Flow of analysis

- Reconstruction of two muons
- Reconstruction of two b-jets
  - Thrust axis method
  - Jet clustering (LCFIPlus)
- Kinematical reconstruction of top quark
- Fit of the form factors with matrix element method