Search for anomalous coupling in top decay at hadron colliders

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Introduction

At Tevatron,
The top property measurements are the next round studies.

At LHC,
The top is the "controlled sample" (may often be a backgrounds).

Understanding of top properties require Full kinematical reconstruction:

(Physics) ⇨ Good tests of the anomaly beyond SM.

(Experiment) ⇨ Likelihood Fitting in event-by-event basis;
May useful to compensate the jet energy calibration (etc) each other.

In this WS, would be discussed about understanding of top physics in experiment and theoretical views.

W polarization and top spin in top correlation

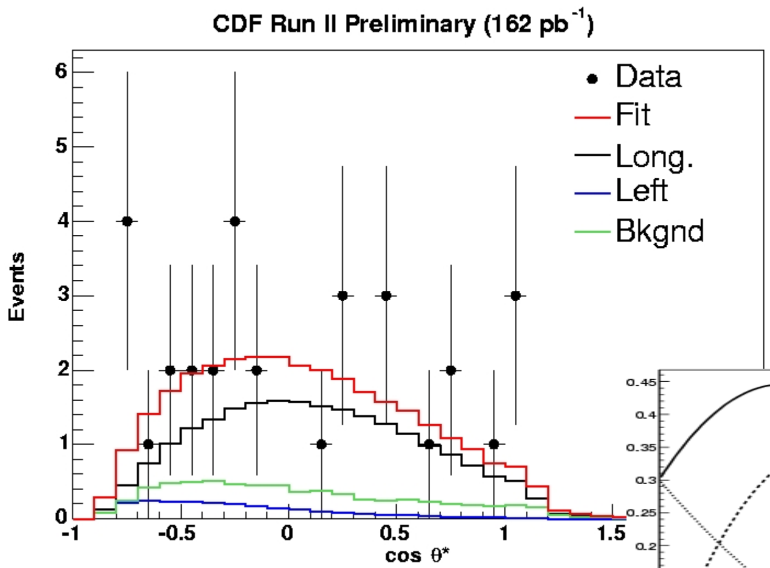
CDF RunII Preliminary:

W helicity measurement from top decay :

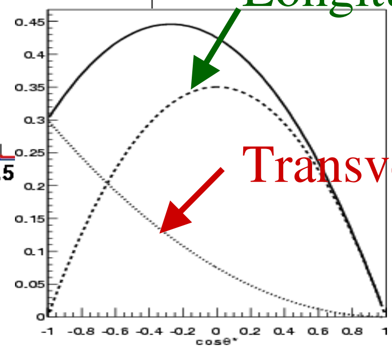
a) cosθ : $F_0 = 0.89^{+0.30}_{-0.34}(stat.) \pm 0.17(syst.)$ (@162 pb^{-1})

b) lepton p_T : $F_0 = 0.27^{+0.35}_{-0.21}(stat.) \pm 0.17(syst.)$ (@193 pb^{-1})

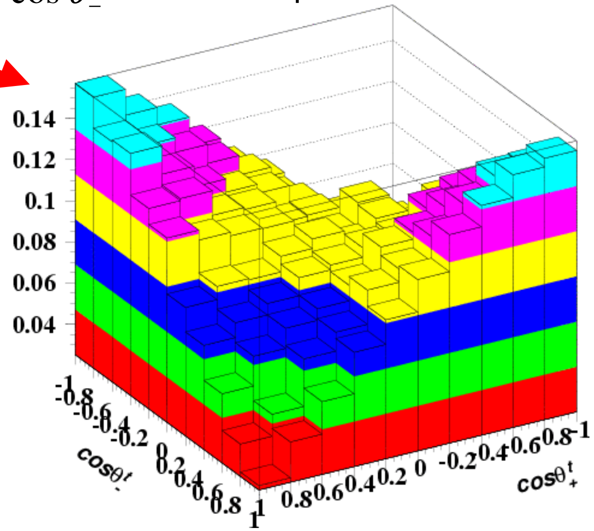
spin correlation : not yet for public.



$$\cos\theta^* \cong \frac{2m_{lb}^2}{m_T^2 - m_W^2} - 1$$



$$\frac{1}{\sigma}\frac{d^2\sigma}{d\cos\theta_+ d\cos\theta_-} = \frac{1 - C\cos\theta_+\cos\theta_-}{4}$$



Search for anomalous coupling in top decay

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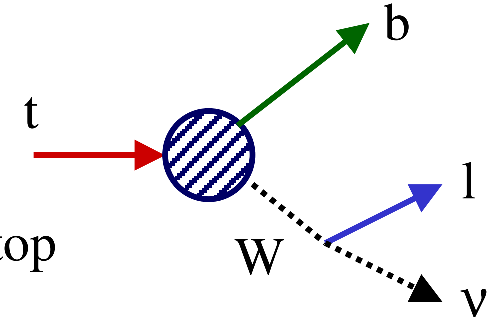
With the on-shell W mass and bottom massless limit, the coupling for top-decay depends only on 2(+2) form factors.

$$\left\{\begin{aligned}
\Gamma^{\mu}_{Wtb} &= -\frac{g_W}{\sqrt{2}} V_{tb}\, \bar{u}(p_b) \left[\gamma^{\mu} \boxed{f_1^L} P_L - \frac{i\sigma^{\mu\nu} p_{W\nu}}{M_W} \boxed{f_2^R} P_R \right] u(p_t) \quad \text{for top} \\
\bar{\Gamma}^{\mu}_{W\bar{t}\bar{b}} &= -\frac{g_W}{\sqrt{2}} V_{tb}^{*}\, \bar{v}(p_{\bar{t}}) \left[\gamma^{\mu} \boxed{\bar{f}_1^L} P_L - \frac{i\sigma^{\mu\nu} p_{W\nu}}{M_W} \boxed{\bar{f}_2^L} P_L \right] v(p_{\bar{b}}) \quad \text{for anti-top}
\end{aligned}\right.$$



where $P_L = (1 - \gamma_5) / 2$ and $P_R = (1 + \gamma_5) / 2$.

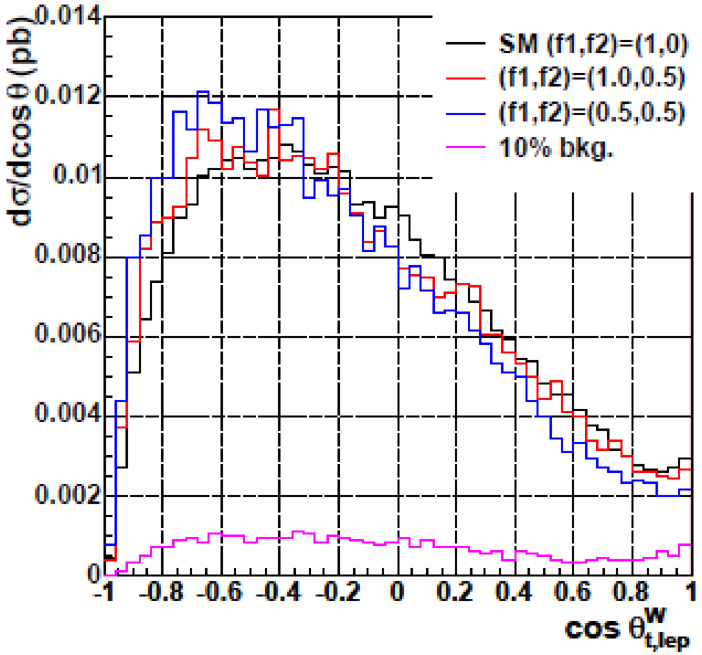
If $f_1^L = \bar{f}_1^L$ and $f_2^R = \bar{f}_2^L$, CP conservation, otherwise, CP violation.

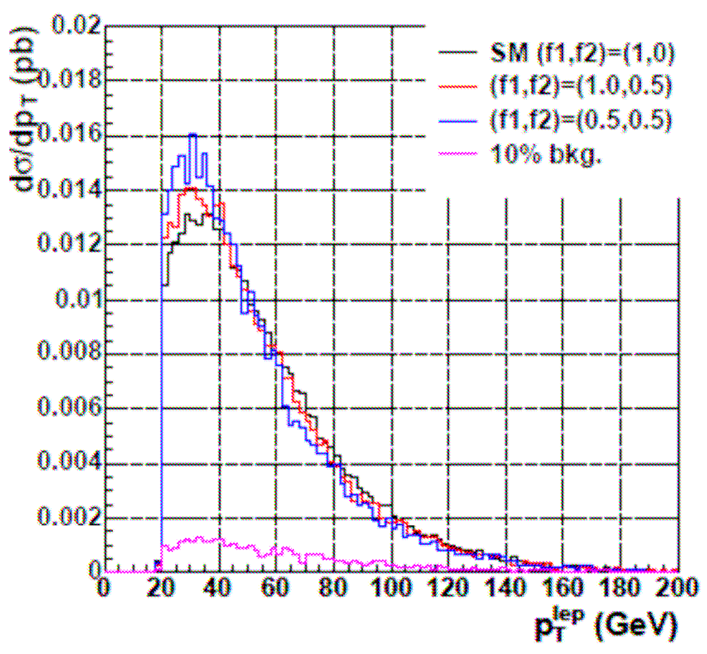
The parameters are characterize by just two parameters.

This formula was embedded into GRACE system for hadron collider (GR@PPA).

Kinematical shape

The anomalous coupling is insensitive to the ordinal top kinematics analysis from W helicity measurements.

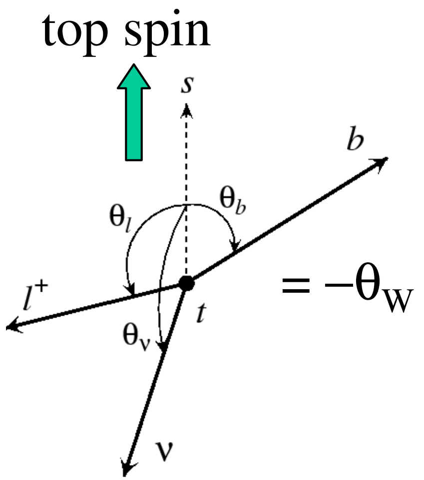




We need the advanced kinematical distribution which enhances those anomalous couplings.

Advance kinematical distribution (I)

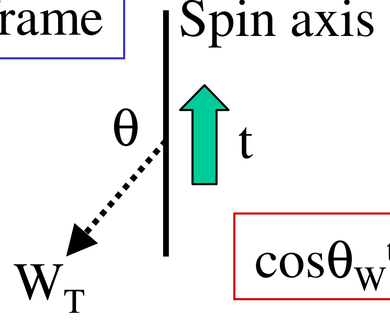
Differential decay distribution from polarized top-quark for f_{1L}=1(tree level),



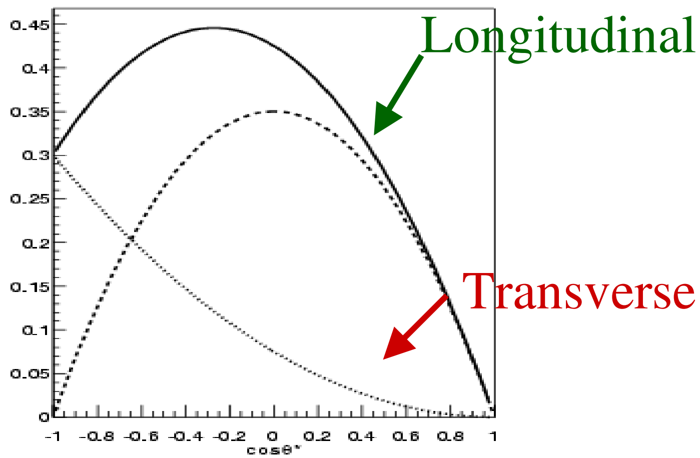
$$\frac{d\Gamma(t_{\uparrow} \to bl\nu)}{d\cos\theta_W d\cos\theta_l d\phi_l} = A\left| -\left(f_{2R} + \frac{m_t}{m_W}\right)\cos\left(\frac{\theta_W}{2}\right)\sin\theta_l + \left(1 + f_{2R}\frac{m_t}{m_W}\right)e^{-i\phi_l}\sin\left(\frac{\theta_W}{2}\right)(1-\cos\theta_l)\right|^2$$

Anomalous coupling (f_2) enhances transverse component of W boson.

Top rest frame



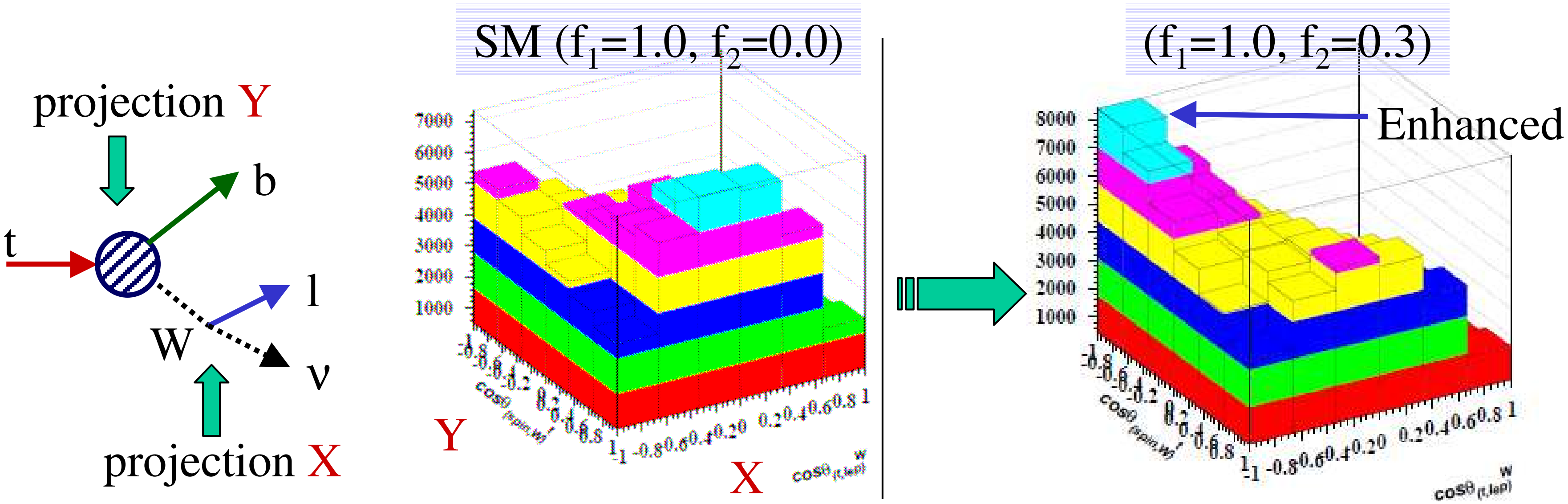
$\cos\theta_W{}^t \sim -1$



Advanced kinematical distribution (II)

The idea is to make 2D plot to enhance the W_T distribution.

X : $\cos\theta_{(top,lep)}^{W}$: angle between top and lepton on W rest frame.
Y : $\cos\theta_{(spin,W)}^{top}$: angle between top spin and W on top rest frame.



Clearly, we can see the excess in (-1,-1) region.

The reconstruction of top spin axis is the KEY in this analysis.

Advanced kinematical distribution (III)

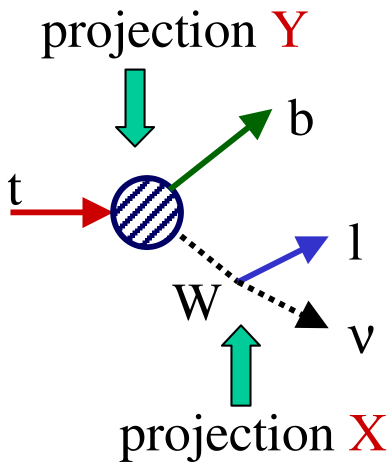
We take "Helicity basis" for the top spin axis.

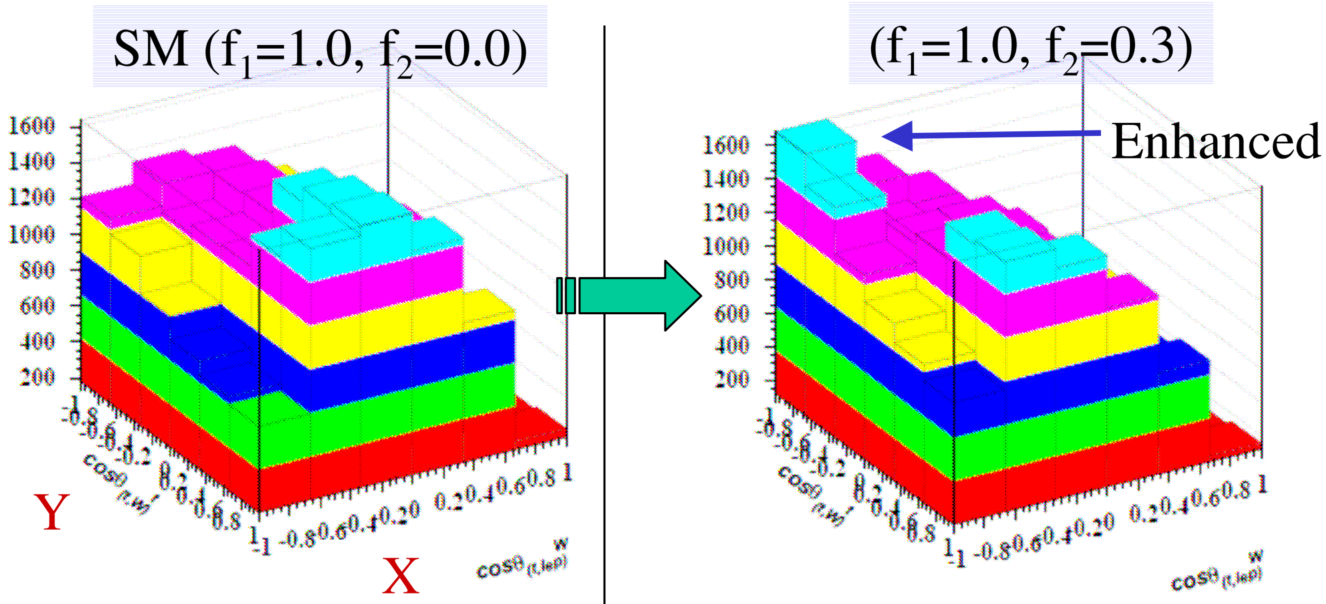
top spin axis ⟹ $-\vec{p}(\bar{t})$

Actually, hadronic-top on the leptonic-top CM frame.

X : $\cos\theta_{(top,lep)}^{W}$: angle between top and lepton on W rest frame.

Y : $\cos\theta_{(anti\text{-}top,W)}^{top}$: angle between anti-top and W on top rest frame.



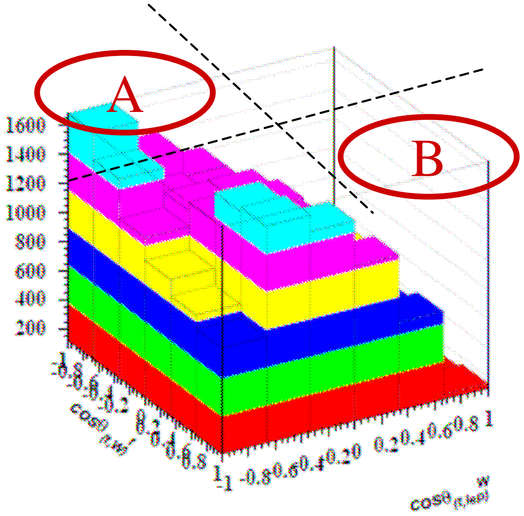


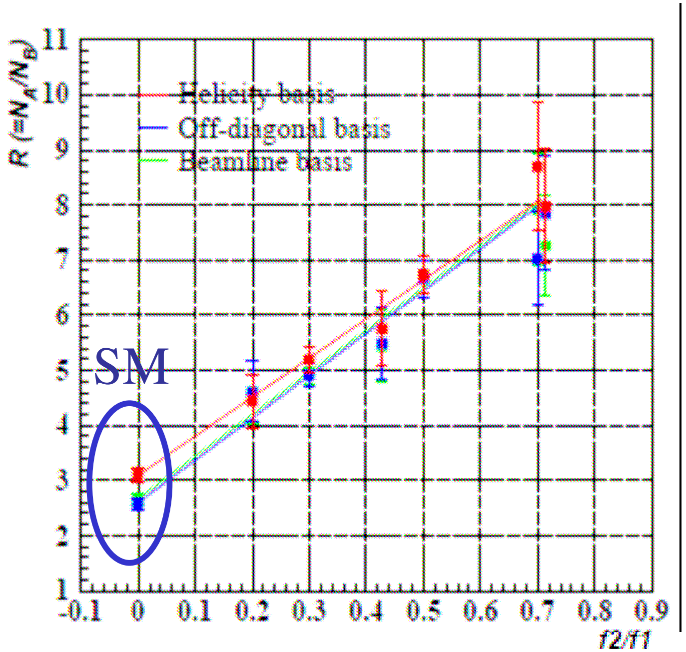
This is our final distribution which we would like to measure.

Sensitivity for the anomalous coupling

As the first guess, we define the sensitivity factor,

$R \equiv N_A/N_B$.





N_A: number of events in (-1,-1) region
N_B: number of events in (+1,+1) region

Different spin basis are also shown, although they are not reconstructable in this analysis.

The ratio R is approximately proportional to the f2/f1 against various choices of f1 and f2. This slope is the discrimination power to the coupling parameters.

Event Reconstruction (L+4jets)

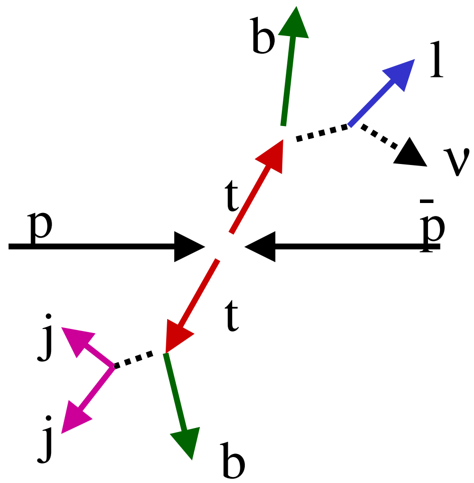
Event reconstruction is crucial for this analysis.

Kinematical variables with 6-body final state :

➡ 16 free parameters.

With 4-momentum conservation and massless condition of neutrino in lepton + 4 jets channel :

➡ 5 free parameters.



{ Most ambiguity factor : Energy of jets ; 4
Boost vector : Pz ; 1

➡ Likelihood function

Likelihood function : DO reconstruction event by event

$$L = \prod_{i=1}^{4} P^{i}_{E_T}(E_T^{obs.}, E_T^{i}) \cdot P_{\Gamma_{W+}} \cdot P_{\Gamma_{W-}} \cdot P_{\Gamma t} \cdot P_{\Gamma \bar{t}} \cdot P_{PDF}$$

jet E_T response function

W and top mass constrain with Breit Wigner mass

constrain by PDF ($x_{1(2)}=(E_{CM}\pm Pz_{CM})/2E_{beam}$)

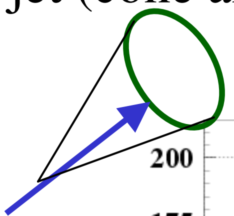
Jet Response Function

Measure the difference between input parton and observed jet.

First approximation : Gaussian distribution neglecting the tail effect.

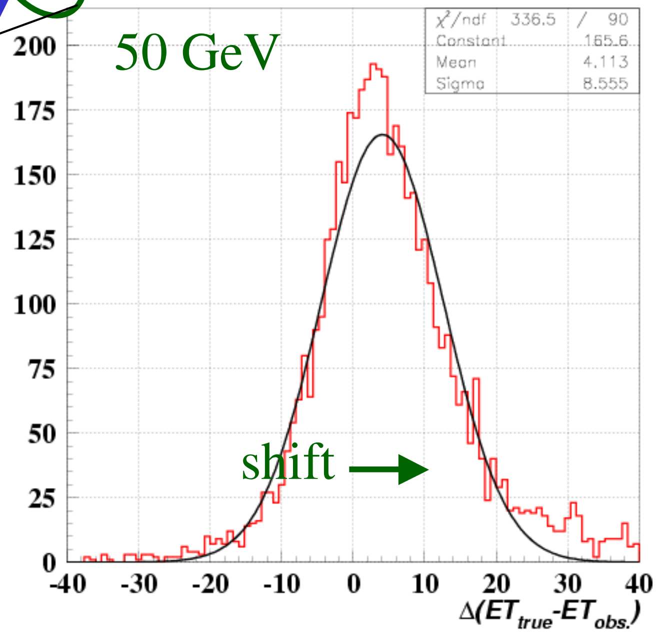
Also, neglecting geometrical dependence.

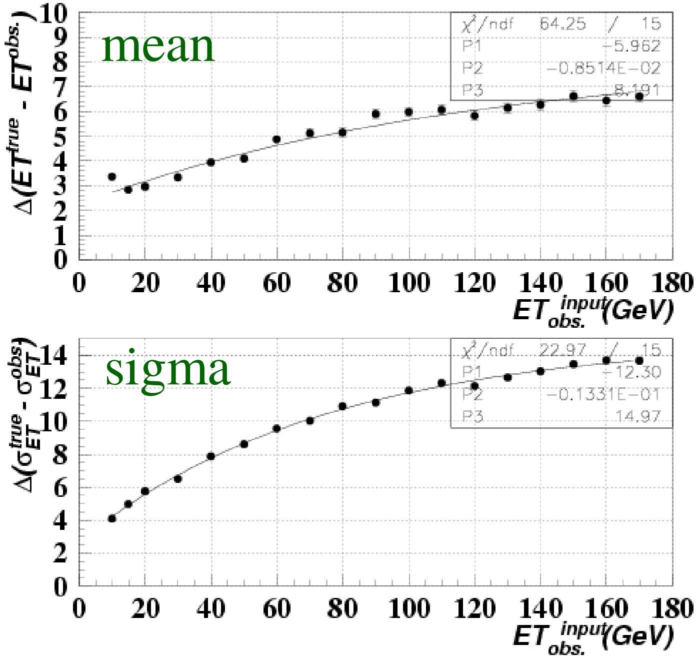
jet (cone algo. R=0.4)



parton

$$P_{ET}^{i}(E_T,\phi,\eta) \longrightarrow P_{ET}^{i}(E_T)$$





B-Jet response function is measured separately.

Mass Distributions

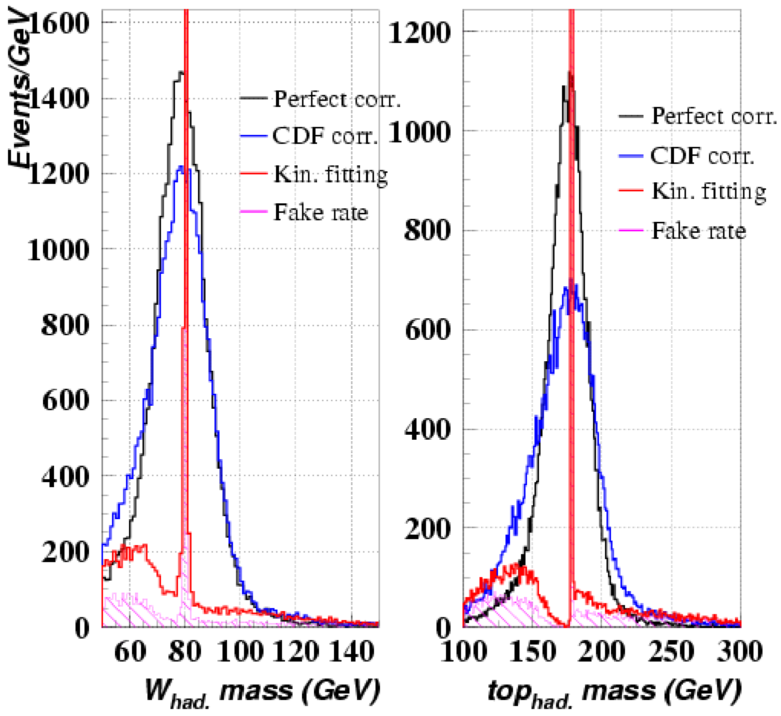
Comparison :

1) perfect correction : $E_T^{true} / E_T^{obs.} \vec{E}_j$
   using parton level info.
2) mean corr. : $E_T^{mean} / E_T^{obs.} \vec{E}_j$
   uniform correction.
3) Likelihood fitting : $E_T^{fit} / E_T^{obs.} \vec{E}_j$
   no boundary condition.
   fake rate ≈ 30 %

Assuming no combinatorial bkg.
→ right combination.
Force leptonic-W mass constrain.

Cuts :

For lepton,
$P_T > 20$ GeV , $|\eta| < 1.0$
For b-jets,
$E_T^{uncorr.}(R=.4) > 15$ GeV , $|\eta| < 1.0$
For jets,
$E_T^{uncorr.}(R=.4) > 15$ GeV , $|\eta| < 2.4$
no requirement for the jet-jet(lep.) separation.



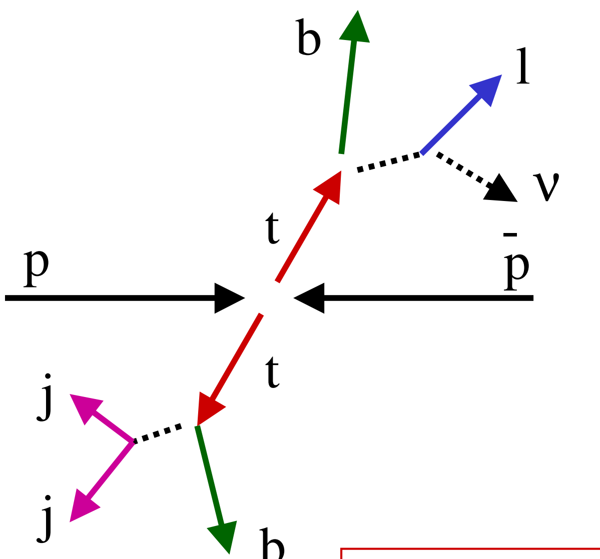
Kinematical reconstruction

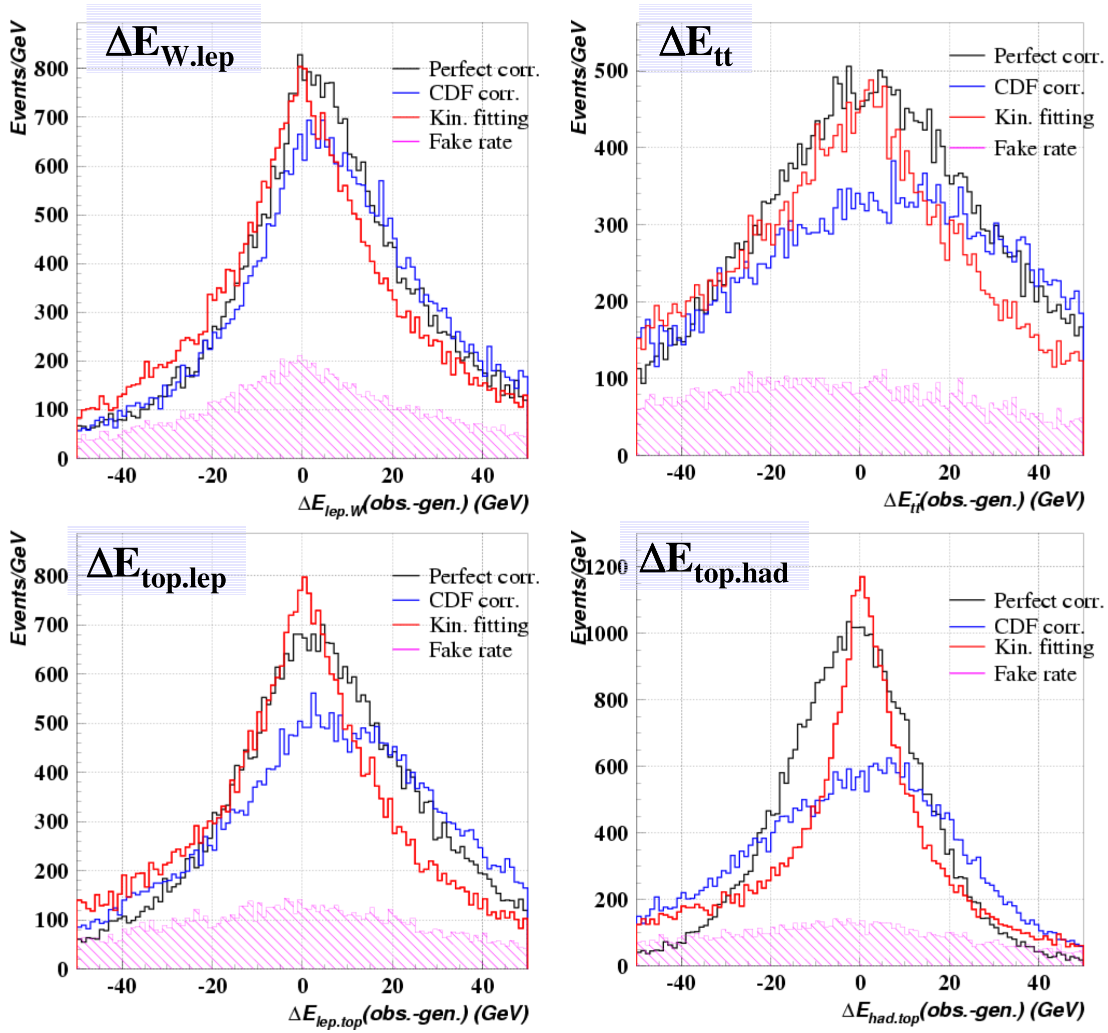
Three strategies are compared :

1) prefect correction
2) mean correction
3) kinematical fitting

Plots are showing :

ΔE_i (obs. – gen.) (GeV)



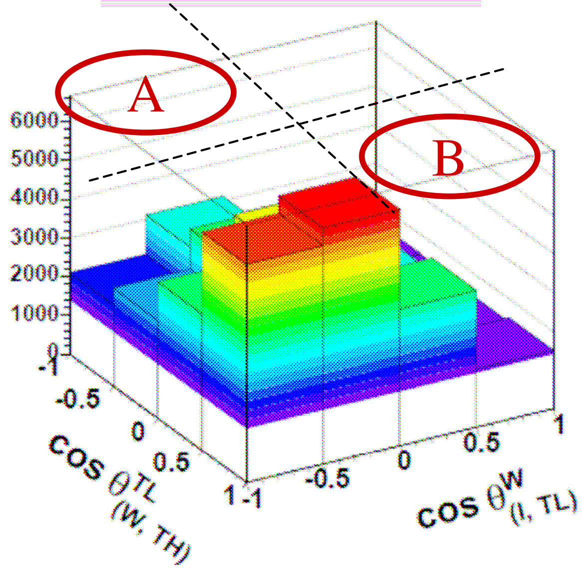


The kinematical fitting well reproduce the event topology.

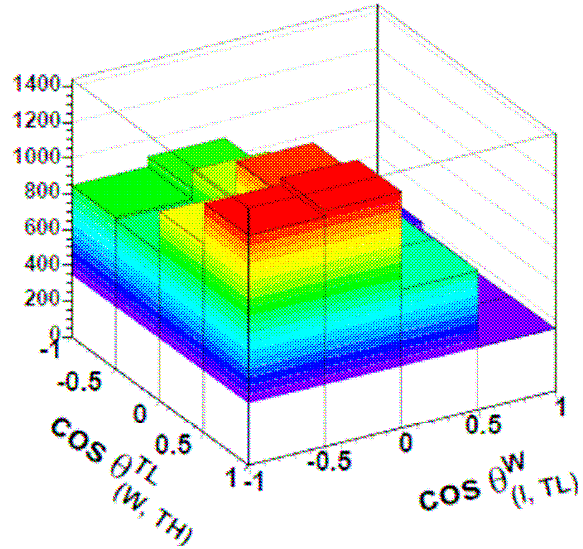
Signal sensitivity (I)

The number of events in (-1,-1) region are increasing with the coupling parameters.

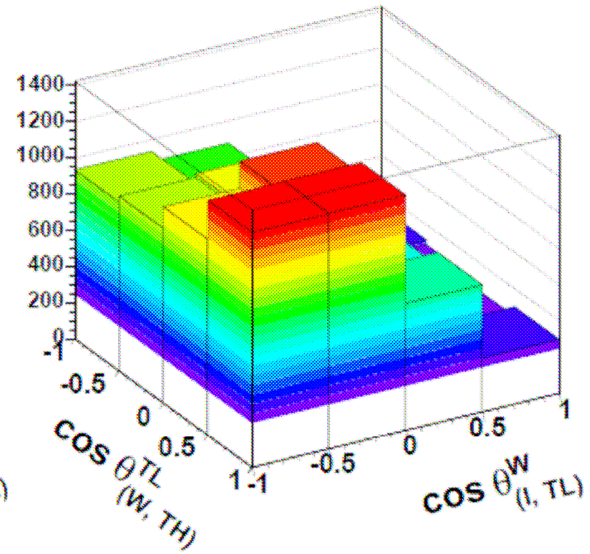
Standard Model



(f_1,f_2)=(1.0,0.5)



(f_1,f_2)=(0.5,0.5)

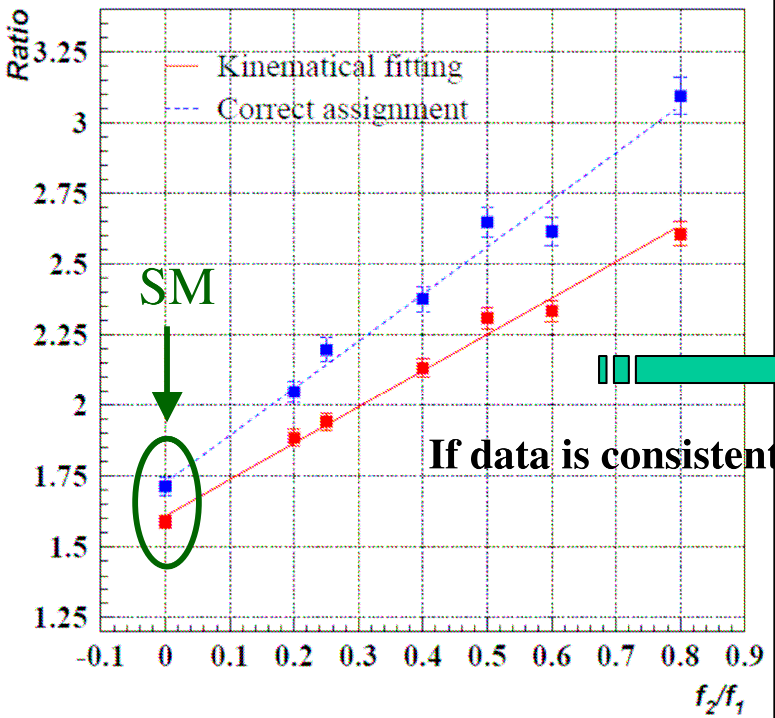


Sensitivity of Anomalous Coupling

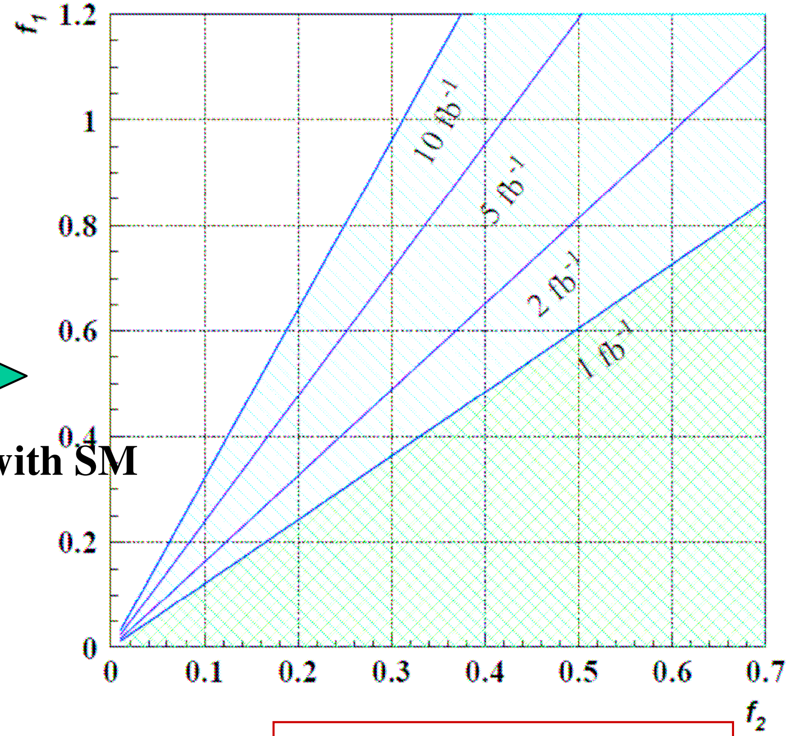
Ratio = N_A / N_B

95% confidence level

Stat. Error only
ε_b=25%



If data is consistent with SM



The Ratio simply depends on the (f_2 / f_1), in spite of various parameters of f_1 and f_2 .

$f_2/f_1 > 0.8$ @ 1 fb^{-1}
> 0.3 @ 10 fb^{-1}

Reduction of the fake rate should improve the discovery/exclude reach.

Summary

Anomalous coupling in top decay was studied :

1) Embedded this coupling into Monte Carlo event generator,
2) Found a kinematical distribution enhanced by the anomalous coupling,
3) Signal shape and sensitivity was studied.

We found :

1) Sensitivity $R \equiv N_A/N_B$ can be reproduced almost linear relation to the anomalous coupling parameters f_1 and f_2 in reconstructed signal and parton level. The discrimination power is now 1.2.

Perspective :

1) We may have more room to test the top property using the kinematical info.
2) Naïve guess: 2~3 times better than cosθ measurement at LHC.

Note :

In LHC, need to study spin reconstruction. (tt, tt+jets)

MCatNLO v.s. ME gen.(7-bdy; LO)

Advanced kinematical distribution (III')

We have to rely on the effective spin axis because the top quark

- has large mass (173GeV),
- is pair-produced with high momentum (p_T ~ 100GeV).

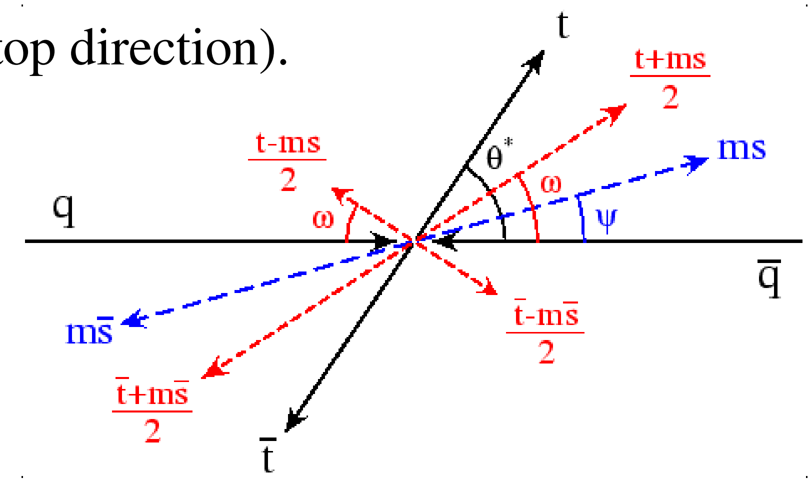
Effective spin basis: (defined on top CM frame)

Helicity basis: $-\vec{p}(\bar{t})$ (just anti-top direction).

Beamline basis: $\vec{s}_t \cdot p_Z(beam)$

Off-diagonal basis:

$$\vec{s}_t \cdot \tan\psi = \vec{s}_t \cdot \frac{\beta^2 \cos\theta^* \sin\theta^*}{1-\beta^2 \sin^2\theta^*}$$



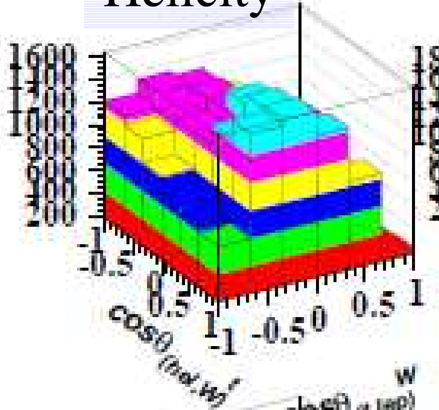
where $\vec{s}_t \cdot \vec{s}_{\bar{t}} = -1$ (top spin correlation).

Note that only "Helicity basis" is reconstructable in this analysis.

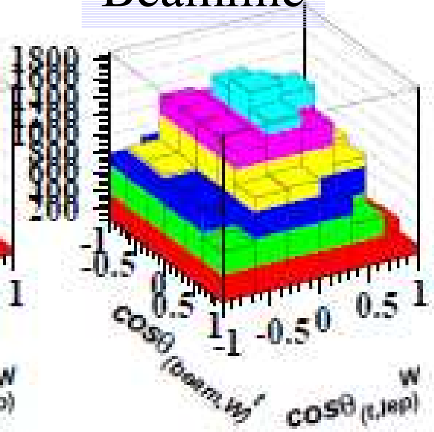
Advanced kinematical distribution (IV')

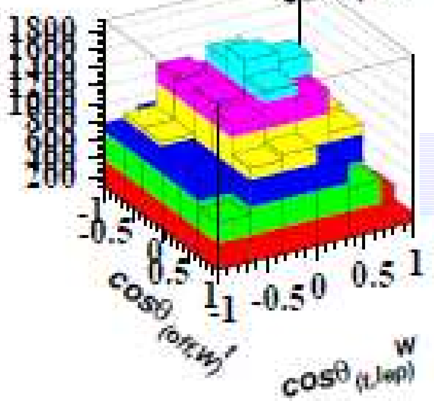
Standard Model

Helicity



Beamline

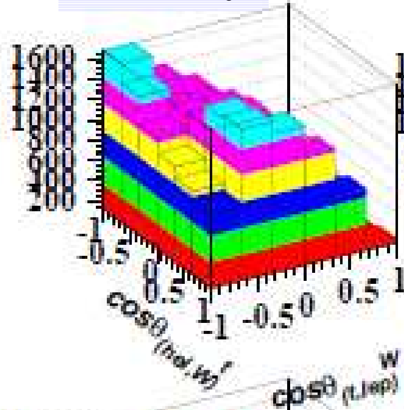




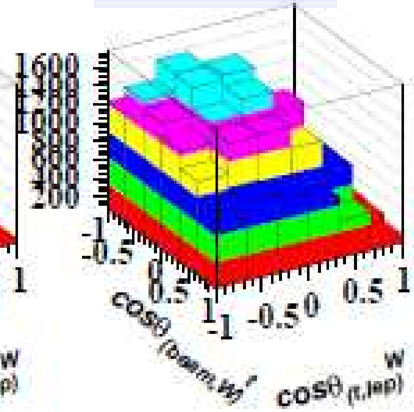
Off-diagonal

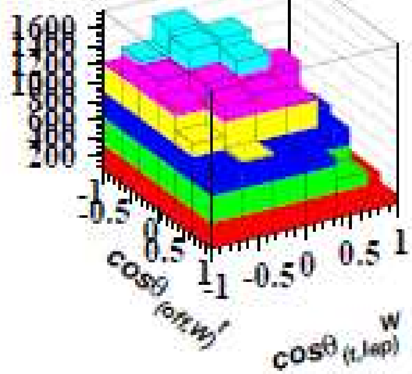
$(f_1,f_2)=(1.0,0.3)$

Helicity



Beamline





Off-diagonal

Actually, the region (-1,-1) is enhanced!!