LCWS 2000, FNAL

SPIN CORRELATIONS & AZIMUTHAL ANGULAR DEPENDENCE in $e^+e^- \to t\bar{t}$

- Yuichiro Kiyo
- Tohoku Univ, Japan

- Jiro Kodaira, Kazushige Morii
- Hiroshima, Japan

hep-ph/0008065

INTRODUCTION

- Our Motivation to study top quark:

  → Better understanding of SM.
  → Search for hints of "Physics Beyond the SM."

☆ Remarkable Propeties for top quark are

- t decays before hadronization
  (Bigi, Dokshitzer, Khoze, Kühn, Zerwas ('86))
- Sizable angular correlations between decay products and spin of top.
  (Jezabek, Kühn ('84~))

- In '96 Parke and Shadmi showed
  " Top quark spins are uniquely determined in the spin basis named "Off-diagonal Basis" in $e^+e^- \to t_s \bar{t}_{\bar{s}_t}$. "
  (PLB387, 199 ('96))

Namely top quarks produced in $e^+_{R/L} e^-_{R/L}$ are almost pure spin state!!

In this talk, we investigate the spin & angular correlations in $e^+e^- \to t\bar{t} \to X_t \bar{X}_t$ including QCD corrections & anomalous coupling in γ/Z-$t\bar{t}$ vertex.

(Production far above the $t\bar{t}$ threshold, e.g. $\sqrt{s} = 400$ GeV)

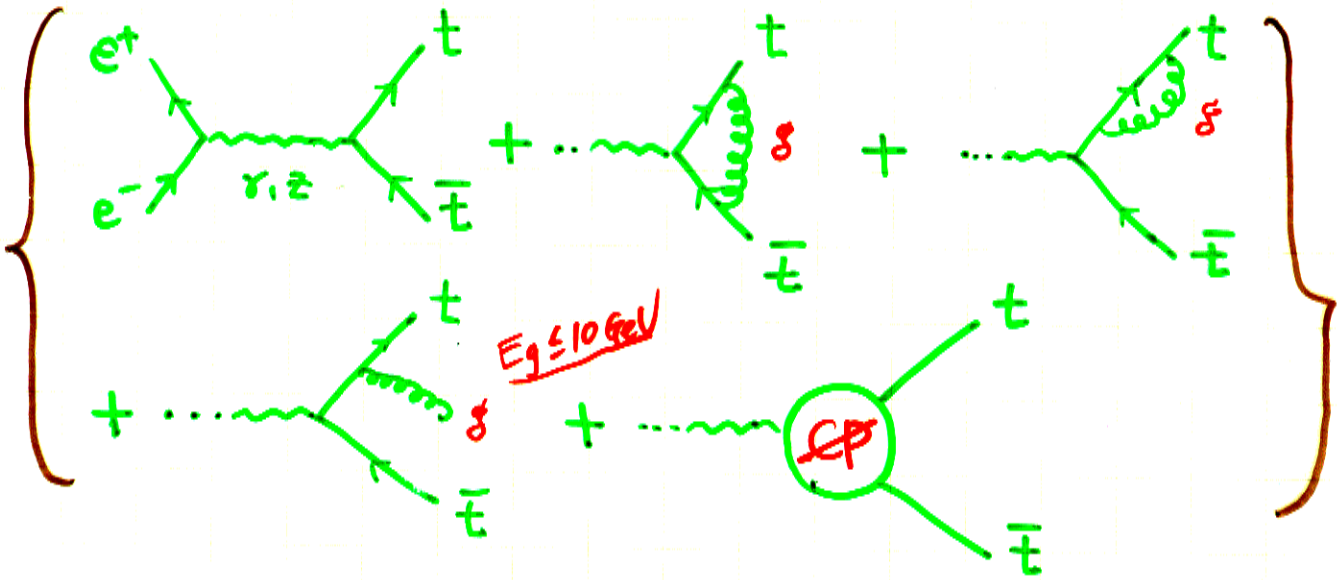
PLAN OF MY TALK

✓ 0. INTRODUCTION

1. Anomalous Couplings & QCD Corr.
2. "Off-diagonal" Basis & Production Cross Sections.
3. Distribution of Decay Products of Polarized Top Quarks.
4. Summary

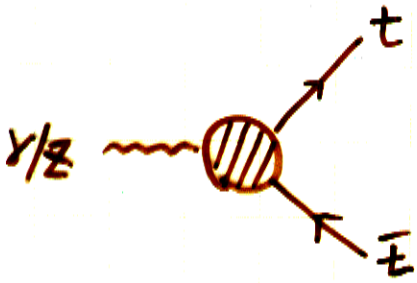
Anomalous Couplings & QCD Corr.

We discuss the spin correlations and angular dependence in $e^+e^- \to t\bar{t} \to X_t \bar{X}_t$ including anomalous coupling. Then QCD corrections should be included to detect "small signals" in the distribution of decay products for $t\bar{t}$.



$\otimes$ $t, \bar{t}$ Decay Density Matrix.

Parametrization: $t\bar{t}$-Z/γ vertex.



Radiative Corr

$$= g_V \left\{ Q_L^V \gamma_\mu L + Q_R \gamma_\mu R + \frac{(t-\bar{t})_\mu}{2m_t} \left[G_L^V L + G_R^V R \right] \right\}$$

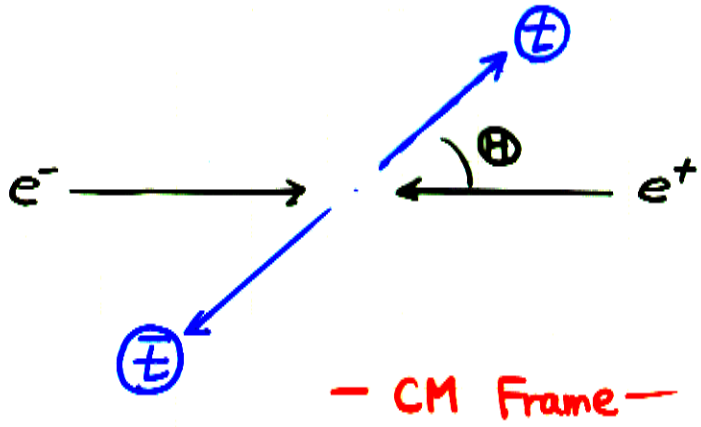
$$G_R^{\gamma,Z} - G_L^{\gamma,Z} \equiv i f_3^{\gamma,Z}$$

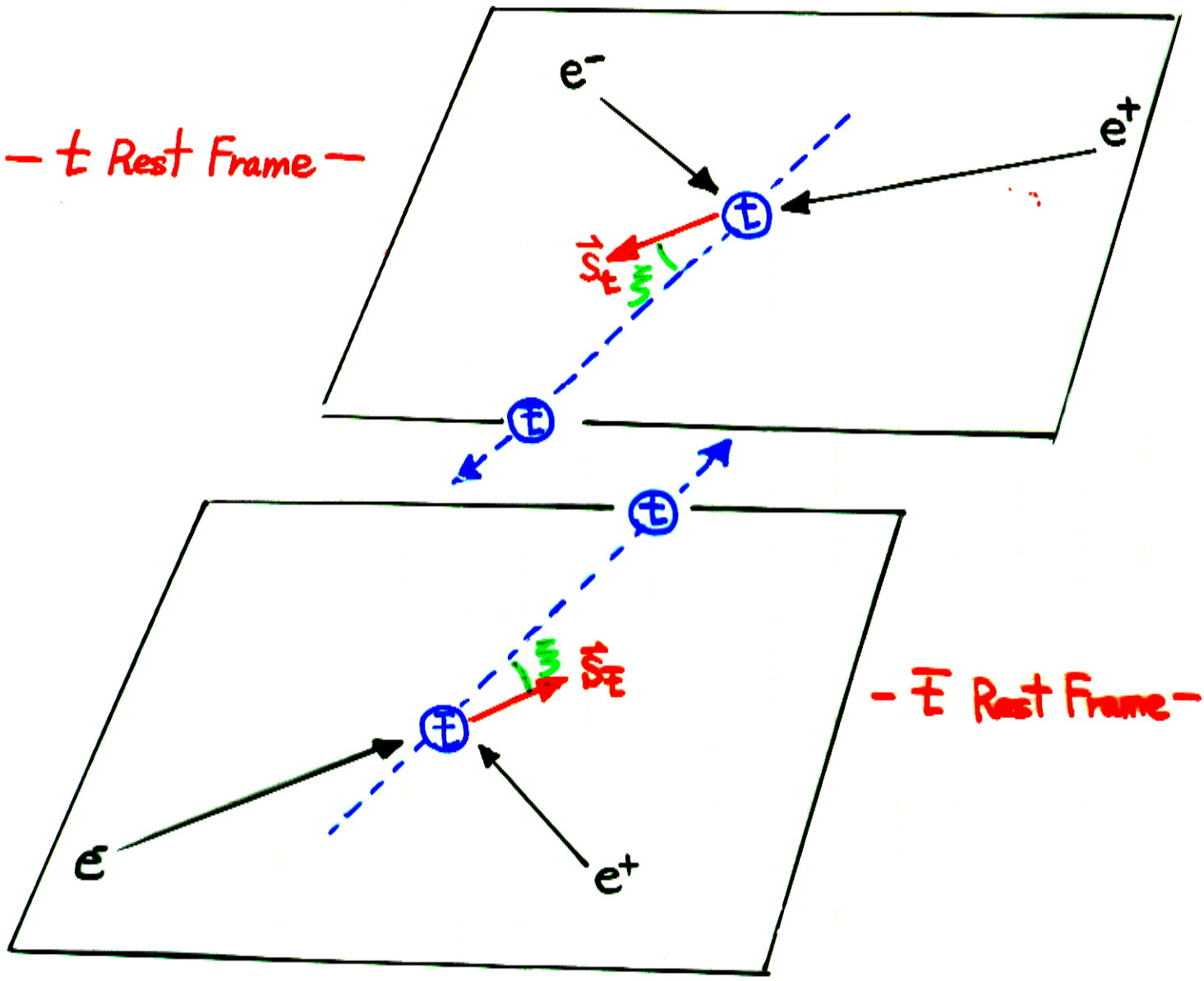
: $\not{CP}$ form factor (EDM, WDM)

In this talk we take all the couplings as SM one (including QCD corr) except for EDM/WDM couplings.

$t\bar{t}$ Production & "Off-Diagonal" Spin Basis in e^+e^- Annihilation

■ SPIN BASIS FOR $t.\bar{t}$ (Park, Shadmi '96) PLB387,199.





Production Amplitude for $e^+e^- \to t\bar{t}$

- $M(e^-_L e^+_R \to t_\uparrow \bar{t}_\uparrow, t_\downarrow \bar{t}_\downarrow)$

$$= \mp 4\pi\alpha \left[A_{LR} \cos\xi - B_{LR} \sin\xi \right]$$
$$+ \text{QCD Corr} \quad \pm i E_{LR}$$

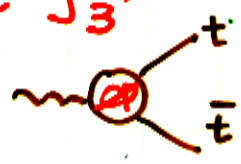
- $M(e^-_L e^+_R \to t_\uparrow \bar{t}_\downarrow, t_\downarrow \bar{t}_\uparrow)$

$$= 4\pi\alpha \left[A_{LR} \sin\xi + B_{LR} \cos\xi \pm D_{LR} \right]$$
$$+ \text{QCD Corr}$$

※ A_{LR}, B_{LR}, D_{LR} are function of $\sqrt{s}$, Θ

- $A_{LR} \sim -0.72 \sin\Theta$
- $B_{LR} \sim -0.20 - 0.82 \cos\Theta$
- ⋮
- $E_{LR} \sim f_3^{\gamma, Z}$

※ $\sqrt{s} = 400\,\text{GeV}$



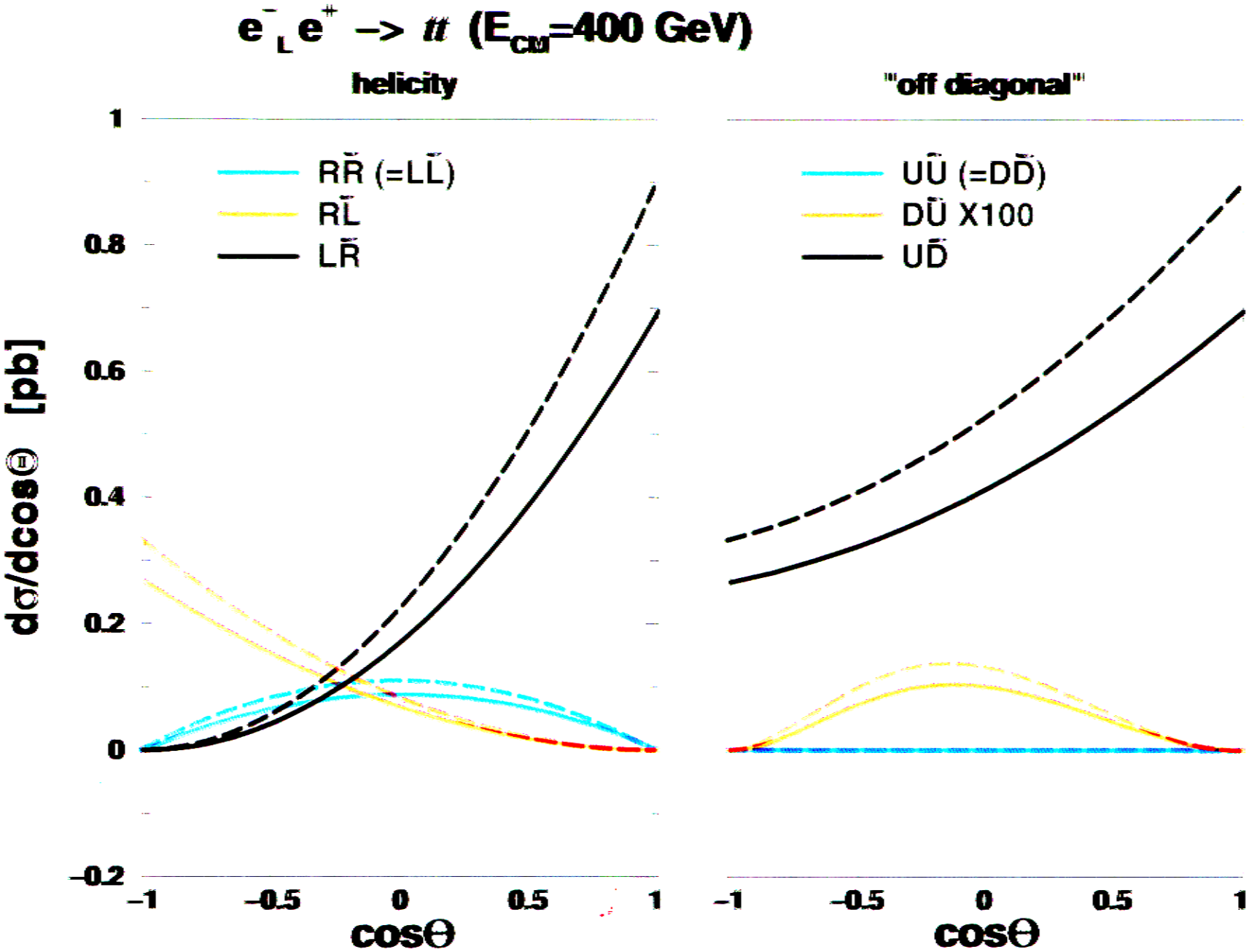
☆ There remain Freedom to choose spin axis, $\vec{s} \Leftrightarrow \xi$.

$$A_{LR} \cos\xi - B_{LR} \sin\xi = 0 \Leftrightarrow \tan\xi = A_{LR}/B_{LR}$$

- Off-diagonal Basis; Parke, Shadmi ('96)
- QCD Corr to OD Basis; Kodaira, Nasuno, Parke ('99)

$$M(e^-_L e^+_R \to t_\uparrow \bar{t}_\uparrow, t_\downarrow \bar{t}_\downarrow) \stackrel{d}{=} 0.$$

This is the "Off-Diagonal" Basis.



Kodaira, Nasuno, Parke (199)

Park, Shadmi ('96)

Distribution of Decay Products of Polarized Top Quarks

We combine production and decay density matrix: The cross section for $e^+e^- \to t\bar{t} \to X_t \bar{X}_t$ is given by convolution of production & decay density matrices.

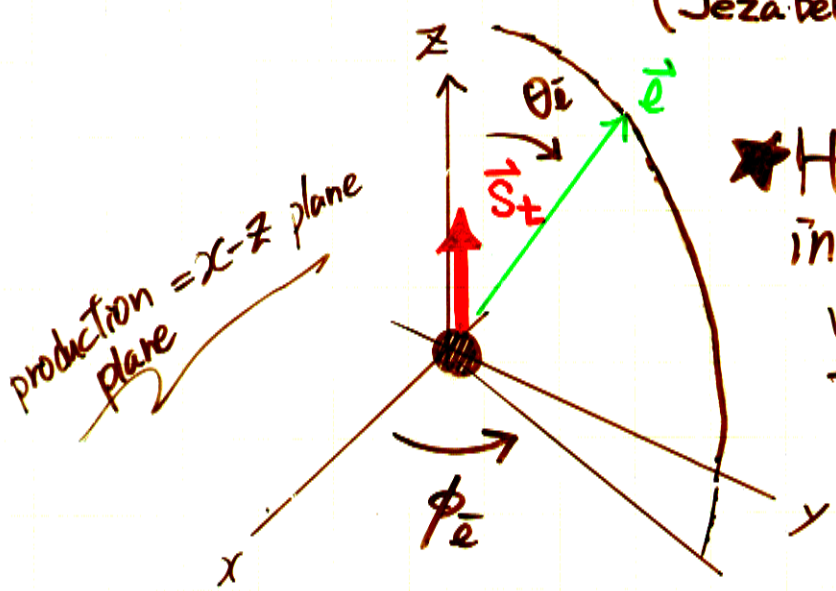
$$\boxed{d\sigma(e^+e^- \to t\bar{t} \to X_t \bar{X}_t) \propto \sum_{\substack{s_t, \bar{s}_t \\ s_t', \bar{s}_t' = \uparrow\downarrow}} M(e^+e^- \to t_s \bar{t}_{\bar{s}}) M^*(e^+e^- \to t_{s'} \bar{t}_{\bar{s}'}) \times \tau_{s_t s_t'} \, \tau_{\bar{s}_t \bar{s}_t'}}$$

For charged lepton : $t \to \ell \nu b$

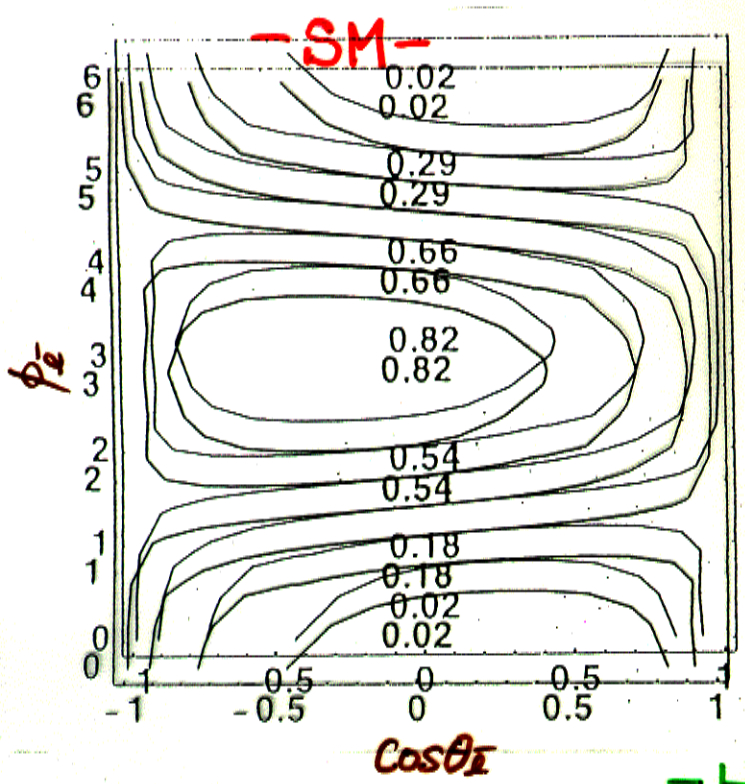
$$\tau_{s_t s_t'} = M(t_s) M^*(t_{s'}) \propto \begin{array}{c|cc} & t_\uparrow & t_\downarrow \\ \hline t_\uparrow & 1 + \cos\theta_{\bar{\ell}} & \sin\theta \, e^{i\phi_{\bar{\ell}}} \\ t_\downarrow & \sin\theta \, e^{-i\phi_{\bar{\ell}}} & 1 - \cos\theta_{\bar{\ell}} \end{array}$$

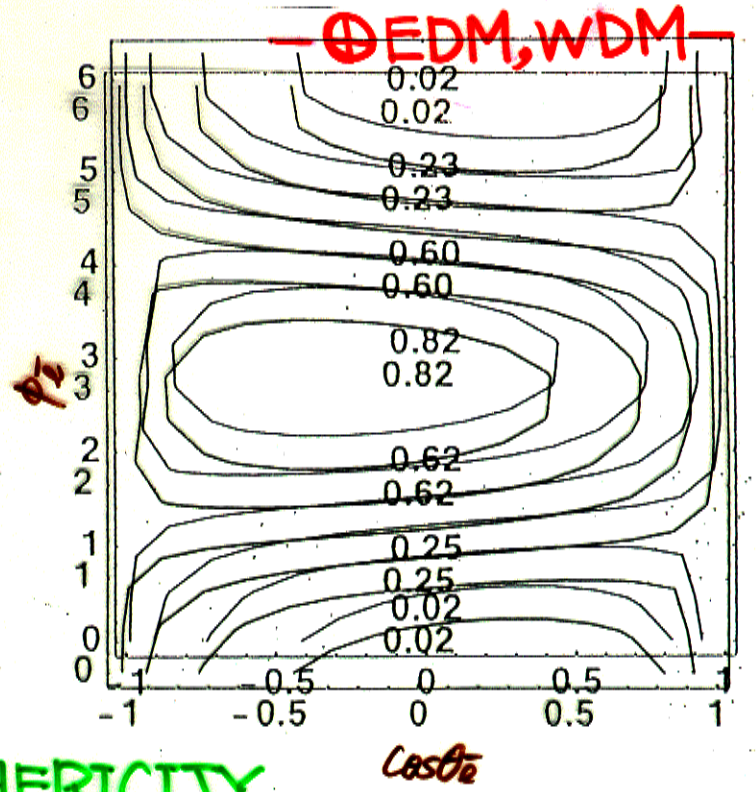
"OD"

(Jezabek, Kühn, Czarnecki, (89))



★ Here we take a frame in which z-axis coincide with spin axis of the top quark.



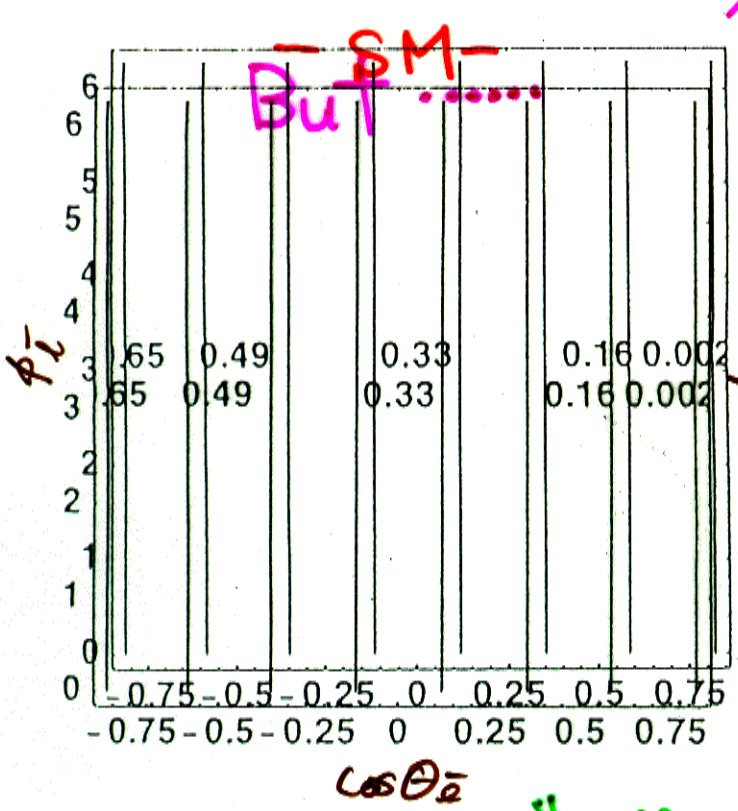


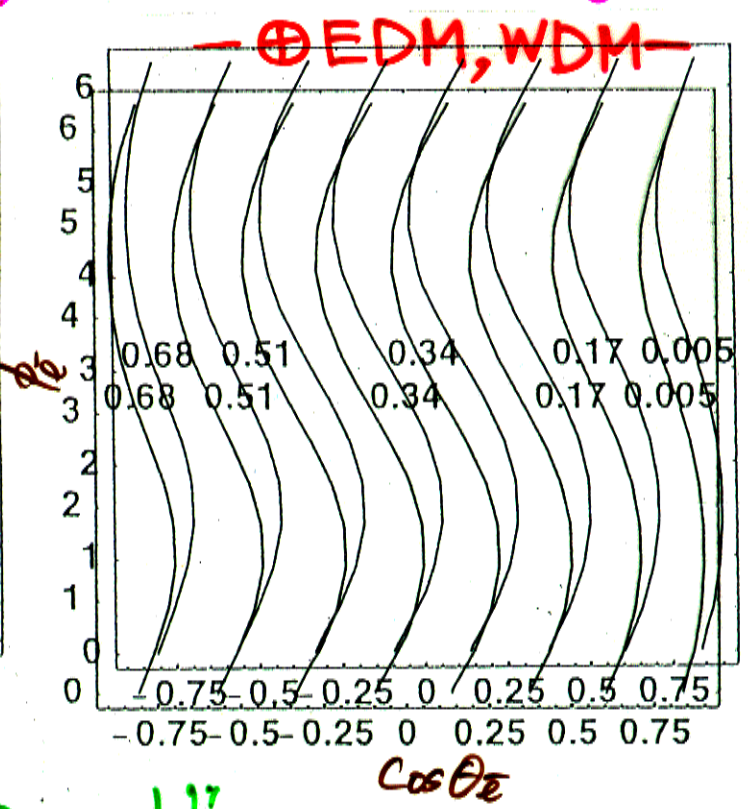
-HERICITY BASIS-

=Distribution of Decaying Charged Lepton in $t \to \bar{\ell} b \nu$=

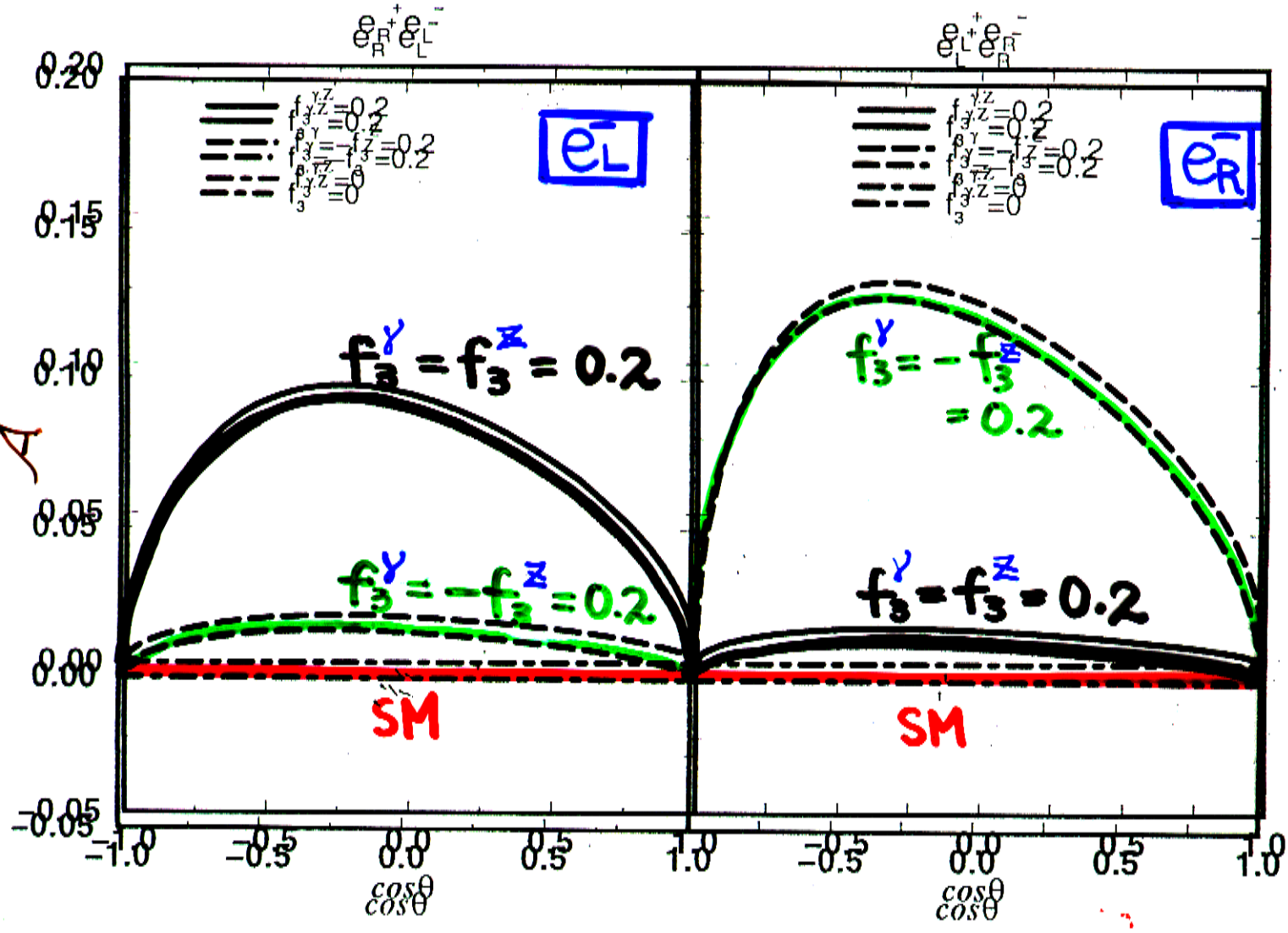
Hard to identify the effect at a glance!!

But.....





"Off-Diagonal"



In order to show the effect of EDM/WDM coupling, define asymmetry with respect to azimuthal angle $\phi_{\bar{\ell}}$:

$$A(\Theta) = \frac{\left(\int_0^{\pi} d\phi_{\bar{\ell}} - \int_{\pi}^{2\pi} d\phi_{\bar{\ell}}\right) \frac{d\sigma(e^+e^- \to t\bar{t} \to \bar{\ell} + \cdots)}{d\cos\Theta \, d\phi_{\bar{\ell}}}}{(\quad = \quad) + (\quad = \quad)}$$

※ asy. induced by QCD corr is tiny!

Summary

- Study of the $t\bar{t}$ production & subsequent decay

We found the large azimuthal asymmetry for decaying lepton from polarized top quark in OD basis:

- 10% asy. for $|f_3^{r.s}| \sim 0.2$
- Asy. induced by QCD corr is tiny (< 0.5 %)

(1.5 % asy in helicity basis)

It is interesting if we can see characteristic distribution of the decay product from top quark experimentally.