Flavor Changing Neutral Current interaction in single top quark production at ep-collider.

=FCNC Top=

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Contents

Contents

Contents

Contents

- Introduction
- Single *Top* production through $e^- p \to e^- t$
- Density Matrix formalism and construction of Polarization Observables for top quark:
  - Polarization observables for spin-$\frac{1}{2}$ Fermion.
- Event Generation and Analysis at Detector:
  - Distributions of various kinematic variables

Introduction

- The *Top quark*, being the heaviest fundamental particle discovered till date, decays before any possible hadronization could occur.

  • $\Gamma_t \approx 2.0 \pm 0.5\ GeV \Rightarrow \tau_t (= \frac{\hbar}{\Gamma_t}) \approx 10^{-25}$ sec

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- The absence of QCD effect in its decay $\to$ spin/polarization of the top is carried to the decay products (leptonic decay of W).

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- In this presentation I will be talking more on FCNC couplings in top quark sector.
- The FCNC in the top quark sector within the strict context of the Standard Model (SM) are known to be extremely rare.
  SM limits : $\mathrm{BR}(t \to Zu(c)) \approx 10^{-17}(10^{-14})$ and $\mathrm{BR}(t \to \gamma u(c)) \approx 10^{-16}(10^{-14})$.

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- Expt. bounds : excludes a $B(t \to Zq) > 5 \times 10^{-4}$ at the 95% CL.

SM predictions and Expt. possibilities for FCNC in *Top* sector

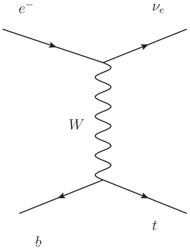
• CMS search for single top quark production channel:
$t + Z$, at $\sqrt{s} = 7$ TeV , $\mathcal{L} = 5 fb^{-1}$

$$\mathcal{L}_{tqV} = \sum_{q=u,c} \frac{g_W}{\sqrt{2}c_W} \frac{\kappa_{zqt}}{\Lambda} \bar{t}\sigma^{\mu\nu} q_\nu [z_L P_L + z_R P_R] q Z_\mu + h.c.$$

Limits: On the tensor couplings of the tqZ vertex as $\frac{\kappa_{Zut}}{\Lambda} < 0.45\ TeV^{-1}$, $B(t \to Zu) \leq 0.51\%$ and $\frac{\kappa_{Zct}}{\Lambda} < 2.27\, TeV^{-1}$, $B(t \to Zc) \leq 11.40\%$, for $z_L = 1$ and $z_R = 0$. • CMS search for FCNC in top quark decay:
• $t\bar{t} \to Zq + W^- b$, $(W \to l^- \nu,\ Z \to l^+ l^-)$, 19.7 fb^{-1} at $\sqrt{s}$ =8 TeV. No excess, was seen in the observed number of events relative to the standard model prediction.
Thus a combination of the above search excludes a $B(t \to Zq) > 0.05\%$ at the 95% confidence level.

Top production at $e^- p$ Collider

- Unexplored top phenomena atHERA(DIS) because $\sqrt{S} \simeq 315$ GeV $\rightarrow$ Makes the cross section small.
- The study of top quark(specially single top) at LHC or ILC suffers heavily because of QCD background; but better at proposed FCC−he.
- Not the case for FCC−he($\sqrt{S} \simeq 4.9$ TeV), makes differences in looking beyond HERA.
- At FCC−he the Single top produced through tWb-vertex :

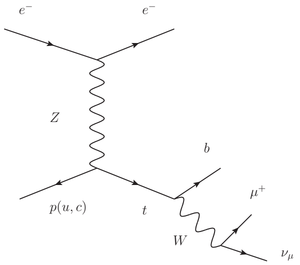


$\sigma(e^- p \rightarrow \nu_e t) \simeq 4$ pb (within SM).

Single *Top* production through $e^- p \to e^- t$

- The other possibility:
- FCNC vertex mediated by a γ or a Z-boson.
- Which will alter only possible t-channel production of single top quark at FCC$-$he.

Signal Process : $e^- p \to e^- t,\ (t \to W^+ b,\ W^+ \to \mu^+ \nu_\mu)$



Choice of leptonic decay of top quark makes sure, there exist only one missing particle(ν_l).
Also gives us handle to study kinematic distributions of the e^- comming out of the primary vertex.

Single *Top* production through $e^- p \to e^- t$

- Effective Field Theory (EFT). Lagrangian for FCNC via $tZq(u,c)$:

$$
\begin{aligned}
-\mathcal{L}_{\rm tqZ} =& \frac{g}{2c_W}\bar{q}\gamma^\mu(X^L_{qt}P_L + X^R_{qt}P_R)tZ_\mu \\
&+ \frac{g}{2c_W}\bar{q}\frac{i\sigma^{\mu\nu}q_\nu}{m_t}(\kappa^L_{qt}P_L + \kappa^R_{qt}P_R)tZ_\mu + \mathrm{H.c},
\end{aligned}
$$

where $q_\nu = p_t - p_q$ is the outgoing boson momentum in the process.

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- In this report, we considered each type of couplings separately and try to make distinction between one type of couplings from the other by looking at various distributions of the final state particles.

Single *Top* production through $e^- p \to e^- t$

signal : $e^- p \to e^- t,\ (t \to W^+ b,\ W^+ \to \mu^+ \nu_\mu)$, E($e^-$) =120 GeV and E($p$) =50,000 GeV; $X_{qt} = \kappa_{qt} = 1$.

Coupling	Electron beam polarization		
	No Pol.	-80% Pol.	+80% Pol.
	σ(fb)	σ(fb)	σ(fb)
X^L_{ut}	2141.54	2633.40	1649.64
X^R_{ut}	2027.73	2265.81	1790.43
κ^L_{ut}	1513.15	1896.47	1130.68
κ^R_{ut}	1514.40	1662.40	1365.84
X^L_{ct}	730.02	918.75	541.41
X^R_{ct}	696.89	757.65	636.13
κ^L_{ct}	364.41	489.42	239.32
κ^R_{ct}	328.94	325.64	332.48

Single *Top* production through $e^- p \to e^- t$

Background: For a complete study we tried to keep as many possible backgrounds for the study of the signal process. We divide the backgrounds into the following three category:
(a) Hadronic decay of the top quark: $\nu_e W^- \bar{b}$, $\nu_e jjj$, $\nu_e cjj$, $\nu_e c\bar{c}j$, $\nu_e b\bar{b}j$, $\nu_e \bar{c}(\bar{c} \to W^- \bar{s})$,
(b) Leptonic decay of the top quark: $\ell^- \bar{\nu}_\ell \nu_e j$, $\ell^- \bar{\nu}_\ell \nu_e c/\bar{c}$, $\ell^- \bar{\nu}_\ell \nu_e b/\bar{b}$, $e^- \ell^- \bar{\nu}_\ell c$,$e^- \ell^- \bar{\nu}_\ell j$,
(c) photo-production.

Density Matrix formalism and construction of Polarization Observables for top quark

- The invariant amplitude square :

$$\overline{|\mathcal{M}|^2} = \frac{\pi\delta(P_t^2 - m_t^2)}{\Gamma_t m_t} \sum_{\lambda,\lambda'} \rho(\lambda,\lambda')\Gamma(\lambda,\lambda')$$

- The polarization matrix

$$P(\lambda,\lambda') = \frac{1}{\sigma_{\text{prod}}} \int \rho(\lambda,\lambda') d\Omega_{\text{prod}}$$

$$P(\lambda,\lambda') = \frac{1}{2} \begin{bmatrix} 1 + P_z & P_x - iP_y \\ P_x + iP_y & 1 - P_z \end{bmatrix}$$

- The decay density matrix

$$\Gamma(\lambda,\lambda') = \frac{1}{2} \begin{bmatrix} 1 + \alpha\cos\theta & \alpha\sin\theta e^{i\phi} \\ \alpha\sin\theta e^{-i\phi} & 1 - \alpha\cos\theta \end{bmatrix}$$

Polarization observables for spin-$\frac{1}{2}$ Fermion

- $$\frac{1}{\sigma_{\rm tot}}\frac{d\sigma_{\rm tot}}{d\Omega} = \frac{1}{4\pi}[1 + \alpha P_z \cos\theta + \alpha P_x \sin\theta\cos\phi - \alpha P_y \sin\theta\sin\phi],$$

  θ and ϕ are the polar angle and Azimuthal orientation of the final state fermion(b-quark or μ^+ or ν_μ), in the rest frame of top quark.

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  θ and ϕ are the polar angle and Azimuthal orientation of the final state fermion(b-quark or μ^+ or ν_μ), in the rest frame of top quark.
- Construction of asymmetries:

$$A_x = \frac{1}{\sigma}\left[\int_{\theta=0}^{\theta=\pi}\int_{\phi=-\frac{\pi}{2}}^{\phi=\frac{\pi}{2}}\frac{d\sigma}{d\Omega}d\Omega - \int_{\theta=0}^{\theta=\pi}\int_{\phi=\frac{\pi}{2}}^{\phi=3\frac{\pi}{2}}\frac{d\sigma}{d\Omega}d\Omega\right]$$

$$= \frac{\sigma(\cos\phi>0)-\sigma(\cos\phi<0)}{\sigma(\cos\phi>0)+\sigma(\cos\phi<0)} \equiv \frac{P_x}{2}, \qquad (1)$$

$$A_y \equiv \frac{\sigma(\sin\phi>0)-\sigma(\sin\phi<0)}{\sigma(\sin\phi>0)+\sigma(\sin\phi<0)} = \frac{P_y}{2}, \qquad (2)$$

$$A_z \equiv \frac{\sigma(\cos\theta>0)-\sigma(\cos\theta<0)}{\sigma(\cos\theta>0)+\sigma(\cos\theta<0)} = \frac{P_z}{2}. \qquad (3)$$

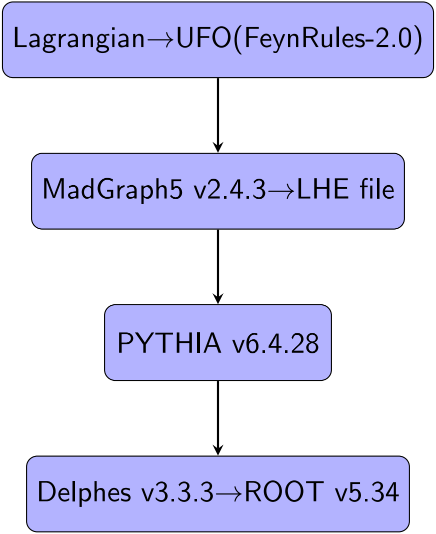
Polarization observables for spin-$\frac{1}{2}$ Fermion

- Values of Asymmetries from partonic event : θ and ϕ being polar and azimuthal orientation of μ^+ in top rest frame.

Coupling	Electron beam Polarization								
	0%			-100%			+100%		
	A_x	A_y	A_z	A_x	A_y	A_z	A_x	A_y	A_z
X_{ut}^L	-0.08029	-0.00166	-0.46445	-0.09254	-0.00219	-0.45745	-0.05936	0.00173	-0.47966
X_{ut}^R	0.05138	-0.00177	0.47359	0.04143	0.00033	0.48618	0.06677	-0.00161	0.46215
κ_{ut}^L	0.02637	3e-05	0.48257	0.0255	-0.00245	0.4788	0.03561	0.00303	0.48667
κ_{ut}^R	-0.06421	0.00208	-0.47771	-0.06821	0.00331	-0.48116	-0.0683	0.00214	-0.47331
X_{ct}^L	-0.13976	0.00229	-0.42701	-0.15471	-0.00037	-0.41511	-0.10733	-0.00042	-0.46167
X_{ct}^R	0.08783	-0.00353	0.44257	0.06711	0.00163	0.46463	0.10371	0.00087	0.4194
κ_{ct}^L	0.005	0.00204	0.47272	-0.00572	-0.00296	0.47268	0.01805	-0.00041	0.47774
κ_{ct}^R	-0.05597	0.0006	-0.46383	-0.07145	-0.00048	-0.46896	-0.04458	-0.0005	-0.46358

Table: Table showing the mean value of the asymmetric observables (at parton level) for different polarization of the initial e^--beam of the collider. Here θ_l and ϕ_l are the Polar angle and Azimuthal orientation of the μ^+ in the rest frame of top quark. All coupling values set to unity.

Methdology for Detector Level Analysis :



Detector Level Analysis :

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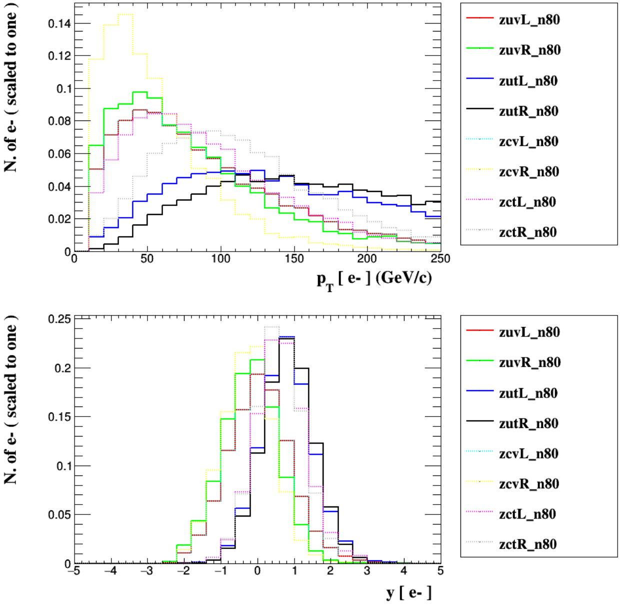
- **Cut Based Analysis:**
- Both for signal and background, we have selected two sets of cuts : basic cuts and number cuts.
- Basic cuts : $P_T(l) > 10$, $P_T(j, b) > 20$, $|\eta| < 5.0$, $\Delta R(j, b, l) > 0.4$ are selected.

Coupling	Electron beam polarization					
	0%		-80%		+80%	
	σ(fb)	σ(fb) for $N_{e^-,b,\mu^+} = 1$	σ(fb)	σ(fb) for $N_{e^-,b,\mu^+} = 1$	σ(fb)	σ(fb) for $N_{e^-,b,\mu^+} = 1$
X^L_{ut}	2141.54	674.70	2633.40	846.00	1649.64	501.80
X^R_{ut}	2027.73	663.60	2265.81	728.70	1790.43	599.00
κ^L_{ut}	1513.15	447.80	1896.47	577.50	1130.68	316.10
κ^R_{ut}	1514.40	434.50	1662.40	459.10	1365.84	409.80
X^L_{ct}	730.02	313.70	918.75	398.90	541.41	229.50
X^R_{ct}	696.89	300.80	757.65	326.20	636.13	276.10
κ^L_{ct}	364.41	153.42	489.42	208.20	239.32	97.88
κ^R_{ct}	328.94	138.66	325.64	135.80	332.48	142.91

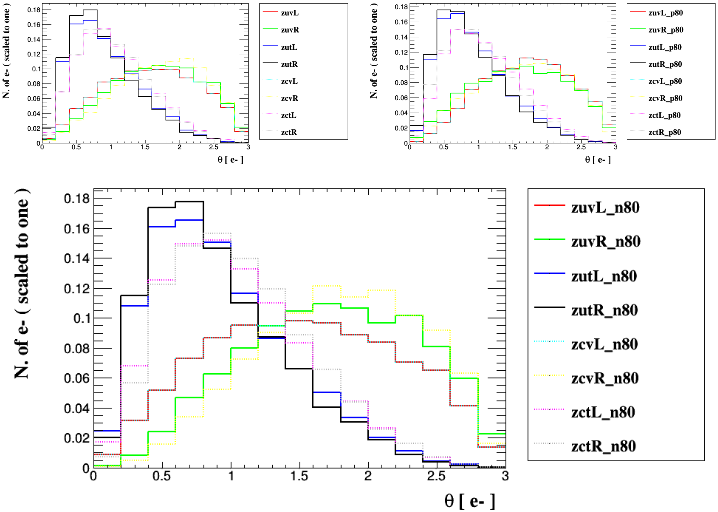
Detector Level Analysis :

bkg processes	Cross section σ in fb			
	0%	-80%	+80%	for $N_{e^-,b,\mu^+} = 1$ with any pol.
$p\ e^- \rightarrow e^-\ j\ j\ j$	270968.8	338711.0	338100.0	0.0
$p\ e^- \rightarrow e^-\ \ell^-(\ell^+)\ \bar{\nu}_\ell(\nu_\ell)\ c(\bar{c})$	49.8	62.3	39.5	0.13
$p\ e^- \rightarrow e^-\ \ell^-\ \bar{\nu}_\ell\ j$	246.1	283.13	149.6	0.0
$p\ e^- \rightarrow \ell^-\ \bar{\nu}_\ell\ \nu_e\ b(\bar{b})$	516.8	646.3	76.0	0.02
$p\ e^- \rightarrow \ell^-\ \bar{\nu}_\ell\ \nu_e\ c(\bar{c})$	15.1	19.6	3.2	0.0
$p\ e^- \rightarrow \ell^-\ \bar{\nu}_\ell\ \nu_e\ j$	294.6	368.2	57.4	0.0
$p\ e^- \rightarrow \nu_e\ b\ \bar{b}\ j$	487.0	560.0	78.5	0.0
$p\ e^- \rightarrow \nu_e\ c\ \bar{c}\ j(3flav)$	441.8	539.0	88.6	0.0
$p\ e^- \rightarrow \nu_e\ c(\bar{c})\ j\ j(3flav)$	11808.0	14760.0	10580.0	0.0
$p\ e^- \rightarrow \nu_e\ j\ j\ j$	42789.0	50491.0	5005.0	0.0
$p\ e^- \rightarrow \ell^-\ b\ b(\bar{b})\ \bar{b}$	190.5	209.596	58.0	0.04
$p\ e^- \rightarrow \ell^-\ j\ b\ \bar{b}$	32770.0	32749.4	32700.0	0.0
$p\ e^- \rightarrow \ell^-\ j\ b(\bar{b})$	13459.0	13750.6	13710.0	0.0
$p\ e^- \rightarrow \ell^-\ j\ j\ b(\bar{b})$	3414.5	3544.71	3050.6	0.0
$p\ e^- \rightarrow \ell^-\ \ell^-\ \ell^+\ b(\bar{b})$	1.18	1.48	1.4	0.05
$p\ e^- \rightarrow \ell^-\ \ell^-\ \ell^+\ j$	54.5	90.653	8.6	0.0
$p\ e^- \rightarrow \nu_\ell\ \ell^-\ \ell^+\ j\ j$	65.8	147.79	98.7	0.0
$p\ e^- \rightarrow \bar{\nu}_\ell(\nu_\ell)\ \ell^-\ \ell^-(\ell^+)\ j$	486.8	628.012	73.7	0.0
$p\ e^- \rightarrow \nu_\ell\ \nu_\ell\ \bar{\nu}_\ell\ j$	131.3	197.349	25.8	0.0
$p\ a \rightarrow j\ j\ b(\bar{b})$	29015.0	29073.0	29073.0	0.0
$p\ a \rightarrow \ell^+\ \ell^-\ \bar{b}$ $p\ a \rightarrow \nu_\ell\ \bar{\nu}_\ell\ b(\bar{b})$	17.8	17.8	17.8	0.02
$p\ a \rightarrow \ell^-\ \ell^+\ j\ j$ $p\ a \rightarrow \ell^-\ \ell^+\ b(\bar{b})\ j(b)$ $p\ a \rightarrow \ell^-\ \ell^+\ \bar{b}\ j$	87.0	87.87	87.8	0.0
$p\ a \rightarrow \nu_\ell\ \bar{\nu}_\ell\ b(\bar{b})\ j(b)$ $p\ a \rightarrow \nu_\ell\ \bar{\nu}_\ell\ b\ \bar{b}$	1.8	1.853	1.8	0.0 0.0
$p\ a \rightarrow \nu_\ell\ \bar{\nu}_\ell\ j\ j$	51.5	52.45	52.5	0.0
$p\ a \rightarrow \nu_\ell\ \bar{\nu}_\ell\ \ell^-\ \ell^+\ b(\bar{b})$	1.29	1.33	2.0	0.08
$p\ a \rightarrow \nu_\ell\ \bar{\nu}_\ell\ \ell^-\ \ell^+\ j$	1.2	1.048	1.1	0.0

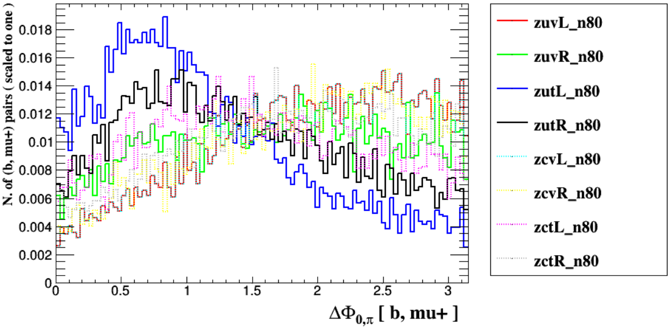
Electron P_T and Y Distributions :



Electron θ Distributions : For various pol. of e^{-}-beam



$\Delta\phi(b, \mu^+)$ Distributions :



The distributions of the azimuthal angle between final state particles as shown in figure gives a clear picture between vectorial and tensorial couplings present in the *top* quark production.

Thank You