Role of polarization in probing chiral structure of heavy gauge bosons at an $e^+e^-$ collider

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Outline

- Introduction
- Description of the Model
- Numerical Analysis
- Results and Discussion
- Conclusion
The Standard model describes all the fundamental particles of nature and their dynamics.

Being a successful renormalizable chiral gauge theory, it is based on the gauge symmetry $SU(3)_C \times SU(2)_L \times U(1)_Y$.

However, it is difficult to understand within the SM why the electroweak scale is much smaller than the Planck scale.

$$m_h \approx 100\,\text{GeV} \ll M_{Pl}$$

The large ratios of the masses and mixings of the SM fermions are also remain unexplained within the SM.

A simple mechanism based on the warped extra dimensions could address some of these hierarchy problems.
Description of the Model

- In the original framework of RS model, all the SM particles (including all the fermions and gauge bosons) were localized near the IR brane whereas the graviton propagating in the bulk.

- The hierarchy problems can be solved in the RS model by allowing all the SM fermions and gauge bosons to propagate in the bulk except the Higgs boson, which has to be localized near the IR(TeV) brane.

- The key feature of the RS model is the Kaluza-Klein excitations of the SM gauge bosons in addition to those of the graviton.

- Due to the presence of new particles, there are new contributions to the FCNC processes and EWPT, which can be solved by the introduction of custodial symmetry in this model.
The electroweak bulk gauge symmetry of the RS model is

$$SU(2)_L \times SU(2)_R \times U(1)_X$$

The model has three additional neutral gauge bosons $A_1$, $Z_1$, $Z_X$ and two charged ones $W^\pm_L$, $W^\pm_R$.

The couplings of the gauge KK modes to the light fermions are enhanced (suppressed) compared to the SM gauge couplings due to the overlap of the corresponding profiles in the extra dimensions.

In the neutral gauge boson sector, the KK $Z$ and KK photon are

$$A_{\mu}^{(n)} = \sin\theta_W W_{\mu L}^{3(n)} + \cos\theta_W B_{\mu}^{(n)}$$

$$Z_{\mu}^{(n)} = \cos\theta_W W_{\mu L}^{3(n)} - \sin\theta_W B_{\mu}^{(n)}$$
The hypercharge gauge boson KK modes and the neutral gauge boson $Z_X$ KK modes are

$$B^{(n)}_\mu = \sin \theta' W^{3(n)}_{\mu R} + \cos \theta' X^{(n)}_\mu$$

$$Z^{(n)}_{\mu X} = \cos \theta' W^{3(n)}_{\mu R} - \sin \theta' X^{(n)}_\mu$$

The photon, $Z$ KK and $Z_X$ KK masses are given by

$$M_{A_1,Z_1} = m_{KK}$$

$$M_{Z_{X_1}} \approx 0.981 m_{KK}$$

The mixing angles and couplings are related through

$$g_Z = g_L / \cos \theta_W$$

$$g'_Z = g_R / \cos \theta'$$

with $g_L = g_R = e / \sin \theta_W$
The process $e^+e^- \rightarrow t\bar{t}$ recieves contribution from the following Feynman diagrams.

- The top quark is allowed to decay, where $t$ dominantly decays to $Wb$ and $W$ decays to $\nu l$. 
The asymmetries and observables may depend on the couplings of the electron with the neutral gauge bosons. Hence the use of beam polarization may improve the sensitivities of some of the asymmetries/observables.

As $Z_1$, $Z_X$ couples differently to left and right handed top and bottom quarks, we present the deviation of the left and right handed couplings of the RS model to that of the SM.

We have considered here the total production cross section and the obtained corresponding significance. The analysis is done both for polarized and unpolarized beams.

The significance is

$$S = \frac{|\sigma_{NP} - \sigma_{SM}|}{\Delta \sigma}$$

where $\Delta \sigma = \sqrt{\frac{\sigma_{SM}}{\mathcal{L}} + \epsilon^2 \sigma_{SM}^2}$
The total production cross section both for polarized and unpolarized beams.
Significance of the total cross section both in polarized and unpolarized case.
The polarization of top quark is given by
\[ P_{\text{top}} = \frac{\sigma^R - \sigma^L}{\sigma^R + \sigma^L} \]

Significance for the top quark polarization is
\[ S = \frac{|A_{NP} - A_{SM}|}{\Delta A} \]
where \((\Delta A)^2 = \frac{1-A_{SM}^2}{\sigma_{SM} L} + \frac{\epsilon^2}{2} (1 - A_{SM}^2)^2\)

Top forward-backward asymmetry is defined as
\[ A^{t\bar{t}}_{FB} = \frac{\sigma(cos\theta_t > 0) - \sigma(cos\theta_t < 0)}{\sigma(cos\theta_t > 0) + \sigma(cos\theta_t < 0)} \]
where \(\theta_t\) is the polar angle of top quark.
The deviation of RS model couplings from the SM couplings for top quark and electron.
Top polarization and its sensitivity for unpolarized beams.
Polar angle distribution

\[ \frac{d\sigma}{d\cos \theta_t} \] [pb]

\( \cos \theta_t \)

SM

\( m_{kk} = 3 \text{ TeV} \)

\( m_{kk} = 2 \text{ TeV} \)

Polar angle distributions of top and antitop.
Forward-backward asymmetry of top quark for both unpolarized and polarized beams.
Polar angle distributions of decay leptons.

Polar angle distributions of the decay charged leptons.
Azimuthal angle distributions of decay charged leptons.

\[ \frac{d\sigma}{d\phi^{\pm}} \] for different values of $m_{kk} = 3$ TeV.
The right handed couplings of top quark in comparison to the left handed one is more sensitive to new physics.

As the new gauge bosons couple differently to $t_L$ and $t_R$, the net polarization of the produced top is different from the SM. The top polarization serves as a window to the chiral structure of the new physics couplings.

The forward backward asymmetry of the given process deviates from the SM with the increase of $\sqrt{s}$. Use of beam polarization improves the sensitivity further.
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