Probing anomalous $WW\gamma$ Triple Gauge Bosons Coupling at LHeC

Speaker: Ruibo Li

Zhejiang Institute of Modern Physics
Zhejiang University

In collaborated with Xiao-Min Shen, Kai Wang, Tao Xu, Liangliang Zhang and Guohuai Zhu, arXiv:1711.05607

Outline

- Effective Lagrangian
  - CP properties
- Existing study
- Search Strategy
  - $e^- p \to e^- Wj$ Channel
  - Total cross-section
  - Kinematic differential distributions: $\cos\theta_{\mu W}$, $\Delta\phi_{ej}$
  - Reconstruction of events
  - Estimation of sensitivity: χ^2 method
- Results

Effective Lagrangian

$$
\begin{aligned}
\mathcal{L}_{TGC}/g_{WWV} \quad = \quad & ig_{1,V}(W^+_{\mu\nu}W^-_\mu V_\nu - W^-_{\mu\nu}W^+_\mu V_\nu) + i\kappa_V W^+_\mu W^-_\nu V_{\mu\nu} + \frac{i\lambda_V}{M_W^2}W^+_{\mu\nu}W^-_{\nu\rho}V_{\rho\mu} \\
& + g_5^V \epsilon_{\mu\nu\rho\sigma}(W^+_\mu \overleftrightarrow{\partial}_\rho W^-_\nu)V_\sigma - g_4^V W^+_\mu W^-_\nu(\partial_\mu V_\nu + \partial_\nu V_\mu) \\
& + i\tilde{\kappa}_V W^+_\mu W^-_\nu \tilde{V}_{\mu\nu} + \frac{i\tilde{\lambda}_V}{M_W^2}W^+_{\lambda\mu}W^-_{\mu\nu}\tilde{V}_{\nu\lambda}
\end{aligned}
$$

- g_4^V: C and CP violation, P conservation;
- g_5^V: C and P violation, CP conservation;
- $\tilde{\kappa}_V$ and $\tilde{\lambda}_V$: P and CP violation, C conservation;
- $g_{1,V}$,κ_V and λ_V: C, P and CP conservation.

$$
\lambda_\gamma = \lambda_Z, \Delta\kappa_Z = \Delta g_{1,Z} - \tan^2\theta_W \Delta\kappa_\gamma
$$

Only 3 independent aTGCs parameters(CP conservation): $\Delta g_{1,Z}$, $\Delta\kappa_\gamma$ and λ_γ.

Existing Study

- WW pair production@LEP/LHC: 1302.3415, 1703.06095, 1706.01702;
- Experimental bounds:

aTGC	LEP	CMS, 8 TeV	ATLAS, 8 TeV	SM
$\Delta\kappa_\gamma$	[-0.099, 0.066]	[-0.044, 0.063]	[-0.061, 0.064]	0
λ_γ	[-0.059, 0.017]	[-0.011, 0.011]	[-0.013, 0.013]	0

Table 1: 95% C.L. limits on $\Delta\kappa_\gamma$ and λ_γ at LEP and LHC. These bounds are from single parameter fittings. LHC measurement of WW/WZ pair production in semi-leptonic decay channel with an integrated luminosity of 19 ab^{-1}(CMS) and 20.2 ab^{-1}(ALTAS) give the above abounds. arXiv:1302.3415, 1703.06095, 1706.01702

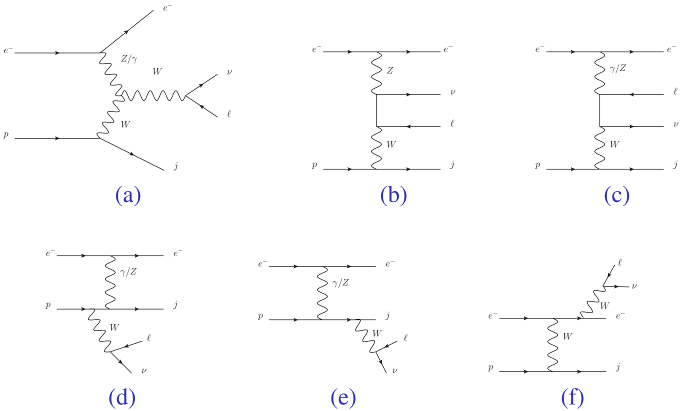
- single γ production@LHeC: 1405.6056, 1406.7696, FCC-DRAFT-ACC-2016-017;

$e^-p \to e^-Wj$ Channel

- total cross-section: previously discussed (1406.7696, hep-ph/0004089......)
- azimuthal angle $\Delta\phi_{ej}$: measure the CP nature of Higgs couplings (hep-ph/0105325)
- polar angle $\cos\theta_{\mu W}$: contains W polarization information directly which we want!
  - someone defines polar angle between W boson or W boson decay production and the incoming particle, which also contains polarization information but has a dependence on polarized state of the incoming particle. (Nucl.Phys.B325.1989.253-274, 1501.01380, 1507.02238)

To illustrate the feature, we first focus on the μ^+ decay of W boson:

$$e^- p \to e^- W^+ j, W \to \mu^+ \nu_\mu$$



Note: Due to large suppression from the Z boson mass, the results are insensitive to WWZ couplings. Therefore, we only consider γ propagator diagrams!

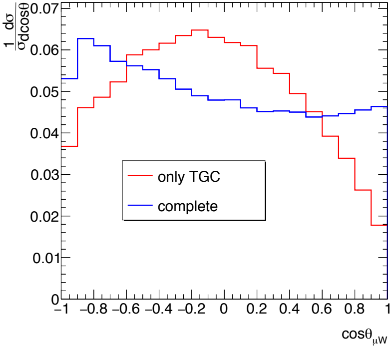
Only (e) contains TGC vertex (longitudinal polarized W dominates) $\Rightarrow$ unitarity violation

(f)–(j) are included $\Rightarrow$ large cancellation between the longitudinal components $\Rightarrow$ unitarity restoration

Spontaneously symmetry breaking
↓
Longitudinal polarization contribution
↓
Unitarity problem

$\Leftrightarrow$

Ward-Takahashi Identity
↓
Goldstone boson equivalence principle

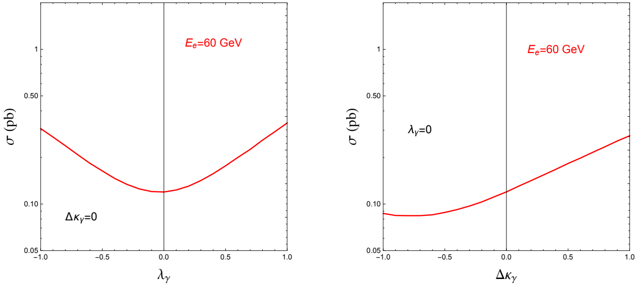


TGC is related to the polarization information. We can choose some kinematic observables containing W polarization information to probe aTGC contributions!

total cross-section

The cross-sections and detector simulations are implemented by *MadGraph*5v2.4.2, *Pythia*6.420 and *Delphes*3.3.0.(including off-shell W boson contributions)

Basic cuts:
$|\eta_{\ell,j}| < 5$,
$\Delta R_{\ell\ell} > 0.4$,
$\Delta R_{\ell j} > 0.4$,
$P_{T\ell} > 10$ GeV,
$P_{Tj} > 20$ GeV.
In SM, $\sigma_{tot} = 0.120$ pb

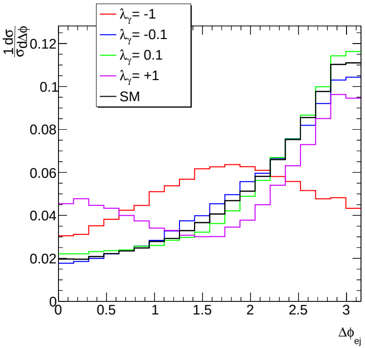


(g) (h)

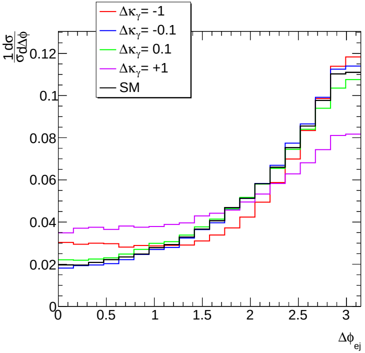
- $\Delta\kappa_\gamma$: interference term is dominant.
- λ_γ: interference term is overshadowed by the contribution purely coming from the 6-dimension anomalous term when $\sqrt{\hat{s}} \geq 500$ GeV. (1601.01380)

Kinematic differetial distributions

- $\Delta\phi_{ej}$: the azimuthal angle $\Delta\phi_{ej}$ is defined on the ej plane in Lab frame.
- $\cos\theta_{\mu W}$: $\theta_{\mu W}$ is the angle between the W boson and the μ^+ defined in W boson CM frame(contains W polarization information).

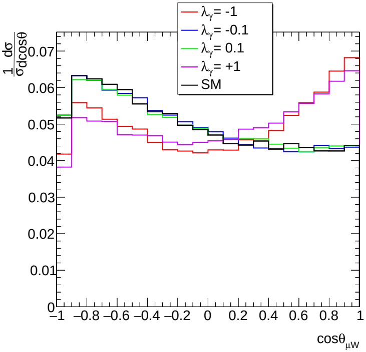


(i)

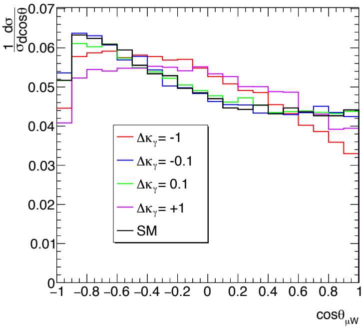


(j)

$\lambda_\gamma \Rightarrow$ enhancement transverse polarization $\Rightarrow$ peak: $\cos\theta_{\mu W} = -1 \rightarrow +1$
$\Delta\kappa_\gamma \Rightarrow$ enhancement longitudinal polarization $\Rightarrow$ peak: $\cos\theta_{\mu W} = -1 \rightarrow 0$



(k)



(l)

Reconstruction of events

Nontrivial!

There is one invisible neutrino in the final state and z-direction momentum conservation cannot be used as a result of the unknown Bjorken x

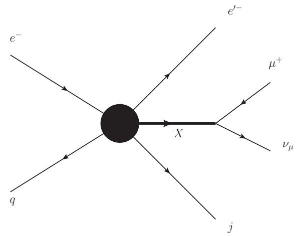
We define the e^- beam direction is the z-direction.

- 1. use the W boson invariant mass and massless neutrino.
  - problem: two solutions for the invisible neutrino.
  - solution: assume the neutrino with momentum more parallel with muon is the W decay product.
- 2. use energy and z-direction momentum conservation conditions.

$$p^z_{\nu_\mu} = \frac{(2E_e - E_{e'j\mu} - p^z_{e'j\mu})^2 - (p^T_{\nu_\mu})^2}{2(2E_e - E_{e'j\mu} - p^z_{e'j\mu})}$$

  - advantage: only single accurate solution for the invisible neutrino.

- 3. use the recoil mass M_X (on-shell W dominant).



$$M_X^2 = \hat{s} + M_{e'j}^2 - 2E_{e'j}(E_q + E_e) + 2p_{e'j}^z(E_e - E_q)$$

$$x = \frac{M_W^2 - M_{e'j}^2 + 2E_e(E_{e'j} - p_{e'j}^z)}{2E_p(2E_e - E_{e'j} - p_{e'j}^z)}$$

  - advantage-1: restore z-direction momentum conservation condition.
  - advantage-2: don't need any information of the invisible neutrino.

Detector level
(Full simulation):
Pythia+Delphes

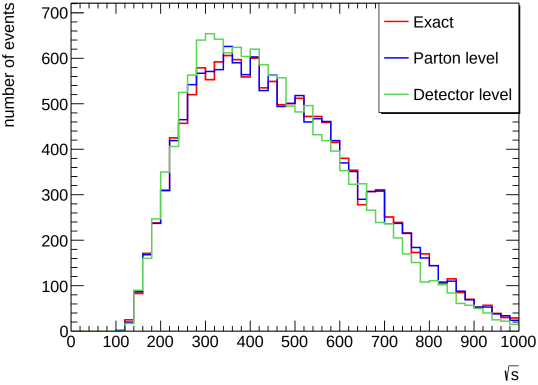


Figure 1: Comparison of partonic collision energy $\sqrt{\hat{s}}$ distributions of exact value(red), parton level value(blue) and detector level value(green)

Criteria: Vetoing second or more hard jets, 30% survival probaility

Estimation of sensitivity: χ^2 method

$$\chi^2 \equiv \sum_i \left(\frac{N_i^{BSM} - N_i^{SM}}{\sqrt{N_i^{SM}}} \right)^2,$$

- $\sum_i N_i^{SM} = \frac{10M}{10}$ to reduce MC fluctuation;
- $\sum_i N_i^{BSM} = 1M$;
- ten bins and 95% C.L.;
- $\frac{1}{\sqrt{N_i^{SM}}}$ is the statistic uncertainty. We neglect the systematic uncertainty and N_i^{SM} theoretical uncertainty here.

Why we focus on μ^+ decay subchannel?

Other channels:

- $\ell = e^+$: additional backgrounds–neutral bosons decay to e^+e^- pair;
- $\ell = e^-$:
  - the mis-tagging rate between the e^- from W and the scattered beam: 7%;
  - neutral current DIS events in e^- channel are potential source of background.
- $\ell = \mu^-$: potential to be combined

Therefore we expect the μ^+ channel to be more sensitive to aTGCs than others.

Results

- Single-parameter fitting: $\mathcal{L} = 1\ ab^{-1}$

variable / parameter	μ^+ decay, $E_e = 60$ GeV		μ^+ decay, $E_e = 140$ GeV		
	$\cos\theta_{\mu^+W^+}$	$\Delta\phi_{ej}$	$\cos\theta_{\mu^+W^+}$	$\Delta\phi_{ej}$	SM
λ_γ	—	[-0.0074, 0.0062]	—	[-0.0038, 0.002]	0
$\Delta\kappa_\gamma$	[-0.005, 0.0058]	[-0.0057, 0.0061]	[-0.0032, 0.0029]	[-0.0023, 0.0026]	0

variable / parameter	μ^- decay, $E_e = 60$ GeV		μ^- decay, $E_e = 140$ GeV		
	$\cos\theta_{\mu^-W^-}$	$\Delta\phi_{ej}$	$\cos\theta_{\mu^-W^-}$	$\Delta\phi_{ej}$	SM
λ_γ	—	[-0.011, 0.011]	—	[-0.0027, 0.0051]	0
$\Delta\kappa_\gamma$	[-0.0078, 0.0078]	[-0.0075, 0.008]	[-0.005, 0.0029]	[-0.0041, 0.0051]	0

Table 2: The 95% C.L. bound on aTGC λ_γ and $\Delta\kappa_\gamma$, obtained from the kinematic observables $\cos\theta_{\mu^\pm W^\pm}$ and $\Delta\phi_{ej}$ at LHeC with $E_e = 60$ and 140 GeV. The results listed are from single-parameter fitting when the other one is fixed to its SM value. The "—" in the table means this bound is no better than the ones from LEP.

- Two-parameter fitting: $\mathcal{L} = 1\ ab^{-1}$

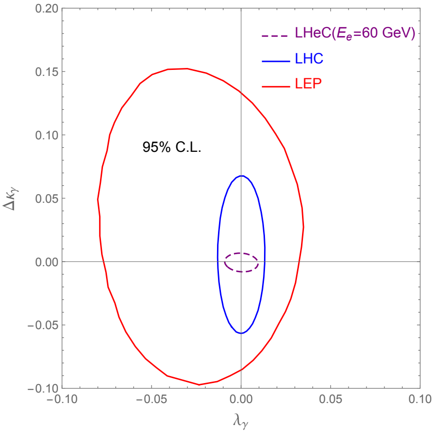


Figure 2: Two-parameter fitting results of aTGC bounds at 95% C.L. for LHeC, LHC and LEP.

The above results are all obtained via pure partonic level study. To achieve the same results in a full simulation(*Pythia* and *Delphes*), one expects about threefold integrated luminosity with 30% survival probability criteria.

- Theoretical uncertainty:
  PDF variation 0.6%(*NNPDF23_nlo_as_0119*) ⇒ 0.15%∼0.2% with LHeC PDF sets

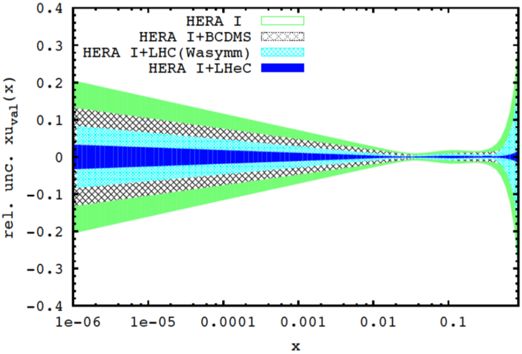


Figure 3: Comparison of the up valence quark distribution of different colliders.1206.2913(LHeC Study Group)

Conclusion

- The sensitivity to λ_γ and $\Delta\kappa_\gamma$ could reach $\mathcal{O}(10^{-3})$ when $\mathcal{L} = 1\ ab^{-1}$ based on χ^2-method at parton level with the expectation of more precise PDFs at future LHeC, while in a full simulation the integrated luminosity need to be increased to 2-3 ab^{-1} to consistent the result.
- There's also a significant improvement in constraining $\Delta\kappa_\gamma$ parameter because the observables we choose are sensitive to the enhancement in longitudinal polarization.

We hope:

- Combine the μ^+ and μ^- subchannels.
- Utilize more technical analysis method: consider the joint distribution of $\Delta\phi_{ej}$ and W boson polarization.
- Complementary studies with different electron beam polarizations.