Looking at the photoproduction of massive gauge bosons at the LHeC

Magno V. T. Machado

Instituto de Fisica - GFPAE Group
UFRGS, Porto Alegre. Brazil

DIS2013 Conference. Marseille.
April 22-27 (2013)

Outline

- Motivation
- Photoproduction of massive gauge bosons in the SM: $W^{\pm}$, Z (γ^*)
- Present some estimates for future LHeC
- Beyond SM: anomalous coupling $WW\gamma$
- Conclusions

Refs.:

C. Brenner Mariotto, MVTM, Phys. Rev. D 86, 033009 (2012)
C. Brenner Mariotto, MVTM, Phys. Rev. D 87, 054028 (2013)

Motivation

- LHeC: It will open a new kinematic window - γp CM energy can reach up to 1.4 TeV ($\sqrt{s} \gg$ 200 GeV @ HERA) - small-x physics and many other physics studies
- W and Z production @ LHC: important tests of SM and beyond
- W, Z photoproduction: cleaner than in pp collisions
- Despite of great sucesses of SM, the non abelian self-couplings of W, Z and photon remains poorly measured up to now
- In this contribution, we also investigate the $WW\gamma$ coupling.

Main goal

- Study photoproduction of massive gauge bosons at future LHeC energies.
- Present estimates of production cross sections and number of events, W^+W^- asymmetries...
  - in SM
  - beyond SM... W photoproduction

  $\Rightarrow$ Investigating anomalous form factors in $WW\gamma$ vertex

Photoproduction of $W^{\pm}$ bosons in SM

- The cross section for the subprocess $\gamma q_i \to W q_j$ is composed of the direct and resolved-photon production, $\hat{\sigma} = \hat{\sigma}_{dir} + \hat{\sigma}_{res}$.
- The direct part of the cross section then reads

$$\sigma_{dir}(\gamma p \to W^{\pm} X) = \int_{x_p^m}^{1} dx_p \sum_{q,\bar{q}} f_{q/p}(x_p, Q^2)\, \hat{\sigma}_W(\hat{s}),$$

- $f_{q/p}$ are the proton PDFs, $x_p^m = M_W^2/s$ and $\hat{s} = x_p s$.
- Here, C and P parity conserving effective Lagrangian for two charged W-boson and one photon interactions.
- The motivation is to use the W photoproduction cross section as a test of the $WW\gamma$ vertex.
- Two dimensionless parameters, κ and λ, related to the magnetic dipole and electric quadrupole moments, $\mu_W = \frac{e}{2m_W}(1 + \kappa + \lambda)$ and $Q_W = -\frac{e}{m_W^2}(\kappa - \lambda)$. [In SM: $\kappa = 1$ and $\lambda = 0$].

Photoproduction of $W^{\pm}$ bosons in SM

- The direct-photon contribution reads:

$$
\begin{aligned}
\hat{\sigma}_W &= \sigma_0\{|V_{q_i q_j}|^2\{(|e_q|-1)^2(1-2\hat{z}+2\hat{z}^2)\log(\frac{\hat{s}-M_W^2}{\Lambda^2}) \\
&- [(1-2\hat{z}+2\hat{z}^2)-2|e_q|(1+\kappa+2\hat{z}^2)+\frac{(1-\kappa)^2}{4\hat{z}} \\
&- \frac{(1+\kappa)^2}{4}]\log\hat{z}+[(2\kappa+\frac{(1-\kappa)^2}{16})\frac{1}{\hat{z}} \\
&+ (\frac{1}{2}+\frac{3(1+|e_q|^2)}{2})\hat{z}+(1+\kappa)|e_q|-\frac{(1-\kappa)^2}{16} \\
&+ \frac{|e_q|^2}{2}](1-\hat{z})-\frac{\lambda^2}{4\hat{z}^2}(\hat{z}^2-2\hat{z}\log\hat{z}-1) \\
&+ \frac{\lambda}{16\hat{z}}(2\kappa+\lambda-2)[(\hat{z}-1)(\hat{z}-9)+4(\hat{z}+1)\log\hat{z}]\},
\end{aligned}
$$

Photoproduction of $W^{\pm}$ bosons in SM

- Notation in previous slide:
  $\sigma_0 = \frac{\alpha G_F M_W^2}{\sqrt{2}\hat{s}}$, $\hat{z} = M_W^2/\hat{s}$.
- Λ^2 is the cutoff scale in order to regularize the $\hat{u}$-pole of the collinear singularity for massless quarks.
- The quantity V_{ij} is the Cabibbo-Kobayashi-Maskawa (CKM) matrix and e_q is the quark charge.
- In numerics, we use PDG values for electroweak parameters.
- In addition, $Q^2 = m_W^2$ and CTEQ (proton) + GRV (photon).

Photoproduction of $W^{\pm}$ bosons

- The resolved-photon part of the cross section can be calculated using the usual electroweak formula for the $q_\gamma q_p \to W^{\pm}$ fusion process, $\hat{\sigma}(q_i \bar{q}_j \to W) = \frac{\sqrt{2}\pi}{3} G_F m_W^2 |V_{ij}|^2 \delta(x_i x_j s_{\gamma p} - m_W^2)$.

$$\sigma_{res}(\gamma p \to W^{\pm} X) = \frac{\pi\sqrt{2}}{3\,s} G_F m_W^2 |V_{ij}|^2 \int_{x_\gamma^m}^{1} \frac{dx_\gamma}{x_\gamma}$$

$$\times \sum_{q_i, q_j} f_{q_i/p}(\frac{m_W^2}{xs}, Q_p) \left[f_{q_j/\gamma}(x_\gamma, Q_\gamma^2) - \tilde{f}_{q_j/\gamma}(x_\gamma, Q_\gamma^2) \right],$$

- In order to avoid double counting on the leading logarithmic level, one subtracts the pointlike part of the photon structure function (photon splitting at large x),
$\tilde{f}_{q/\gamma}(x, Q_\gamma^2) = \frac{3\alpha e_q^2}{2\pi}[x^2 + (1-x)^2] \log(Q_\gamma^2/\Lambda^2)$.

Photoproduction of Z bosons

- Similar calculation can be done for the Z boson photoproduction.
- Here, we focus on the SM prediction.
- The direct part of the Z-photoproduction cross section then reads

$$\sigma_{dir}(\gamma p \to Z^0 X) = \int_{x_p^m}^{1} dx_p \sum_{q,\bar{q}} f_{q/p}(x_p, Q^2)\, \hat{\sigma}_Z(\hat{s}),$$

- $f_{q/p}$ are the proton PDFs and $x_p^m = m_Z^2/s$.
- The direct-photon contribution reads as:

$$\begin{aligned} \hat{\sigma}_Z &= \frac{\alpha G_F M_Z^2}{\sqrt{2}\,\hat{s}}\, g_q^2 e_q^2 \left[\left(1 - 2\hat{z} + 2\hat{z}^2\right) \log\left(\frac{\hat{s} - M_Z^2}{\Lambda^2}\right) \right. \\ &+ \left. \frac{1}{2}\left(1 + 2\hat{z} - 3\hat{z}^2\right) \right], \end{aligned}$$

- $\hat{z} = M_Z^2/\hat{s}$ and $g_q^2 = \frac{1}{2}(1 - 4|e_e|x_W + 8e_q^2 x_W^2)$, with $x_W = 0.23$.

Photoproduction of Z bosons

- The resolved-photon part of the cross section stands for the subprocess $q\bar{q} \to Z^0$, and it is written as

$$\sigma_{res}(\gamma p \to Z^0 X) = \frac{\pi\sqrt{2}}{3\,s} G_F m_W^2 g_q^2 \int_{x_\gamma^m}^{1} \frac{dx_\gamma}{x_\gamma}$$

$$\times \quad \sum_q f_{\bar{q}/p}\left(\frac{m_Z^2}{xs}, Q_p\right)\left[f_{q/\gamma}(x_\gamma, Q_\gamma^2) - \tilde{f}_{q/\gamma}(x_\gamma, Q_\gamma^2)\right].$$

Results: energy dependence

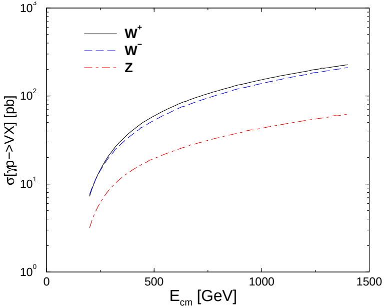


Figure : Cross sections for the production of massive $W^{\pm}$ and Z^0 gauge bosons as a function of the CM energy.

- The dependence is like $\sigma_V \propto W_{\gamma p}^{1.3}$, with SM coupling.

Results: number of events at LHeC

- Photon-proton total cross sections times branching ratio of $W \to \mu\nu$ and also for the Z^0 boson with a corresponding branching ratio of $Z^0 \to \mu^+\mu^-$ (SM).
- The number of events $N_{ev} = \sigma(ep \to V + X) BR(V \to \mu\nu/\mu^+\mu^-) L_{int}$.
- At this point we consider the acceptance in the leptonic channel as 100%.
- The photoproduction cross section is calculated by convoluting the Weizsäcker-Williams spectrum

$$f_{\gamma/e}(y) = \frac{\alpha}{2\pi}\left[\frac{1+(1-y)^2}{y}\log\frac{Q^2_{max}}{Q^2_{min}} - 2m_e^2 y\left(\frac{1}{Q^2_{min}} - \frac{1}{Q^2_{max}}\right)\right]$$

- Here, $Q^2_{min} = m_e^2 y/(1-y)$ and we impose a cut of $Q^2_{max} = 0.01$.

Results: number of events at LHeC

Table : The photon-proton cross sections times branching ratios $\sigma(\gamma p \to W^{\pm}X) \times BR(W^{+} \to \mu\nu)$ and $\sigma(\gamma p \to Z^{0}X) \times BR(Z^{0} \to \mu^{+}\mu^{-})$ in units of pb. The number of events N_{ev} is also presented at an integrated luminosity 10 fb^{-1}.

V	$\sigma(\gamma p \to V\,X) \times BR$	N_{ev}
W^{+}	24	1.2×10^{4}
W^{-}	24	1.2×10^{4}
Z^{0}	2.1	1.1×10^{3}

Investigating physics beyond SM

- Certain properties of the W bosons, such as μ_W and Q_W, play a role in the interaction vertex $WW\gamma$. They can be written in terms of parameters κ, λ values for those parameters at tree level[1].
- In W photoproduction one has a unique scenario to test it.

$$
\begin{aligned}
\frac{\Gamma_{\mu\nu\rho}(p_1,p_2,p_3)}{e} = & \left[g_{\mu\nu}\left(p_1 - p_2 - \frac{\lambda}{M_W^2}[(p_2\cdot p_3)p_1 - (p_1\cdot p_3)p_2]\right)_\rho \right. \\
& + g_{\mu\rho}\left(\kappa p_3 - p_1 + \frac{\lambda}{M_W^2}[(p_2\cdot p_3)p_1 - (p_1\cdot p_2)p_3]\right)_\nu \\
& + g_{\nu\rho}\left(p_2 - \kappa p_3 - \frac{\lambda}{M_W^2}[(p_1\cdot p_3)p_2 - (p_1\cdot p_2)p_3]\right)_\mu \\
& \left. + \frac{\lambda}{M_W^2}\left(p_{2\mu}p_{3\nu}p_{1\rho} - p_{3\mu}p_{1\nu}p_{2\rho}\right)\right]
\end{aligned}
$$

[1] K. Hagiwara, R.D. Peccei, D. Zeppenfeld and K. Hikasa, Nucl. Phys. B282, 253 (1987).

Anomalous coupling

- In the photoproduction of $W^{\pm}$ bosons, the direct contribution σ_{dir} involves the generalized $WW\gamma$ vertex.

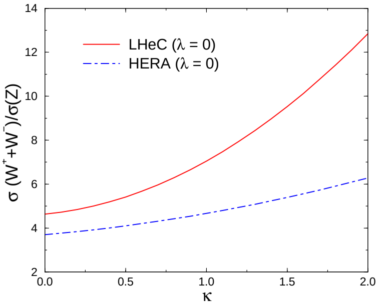
Table : The number of muon plus neutrino events coming from the W^+ decay for distinct choices for the parameters κ and λ presented at an integrated luminosity of 10 fb^{-1}.

κ	λ	$\sigma(\gamma p \to W^+ X) \times BR$ [pb]	N_{ev}
0	0	16	8×10^3
1	0	24	1.2×10^4
2	0	44	2.2×10^4
1	1	61	3.1×10^4
1	2	172	8.5×10^4

Results on the ratios @ LHeC

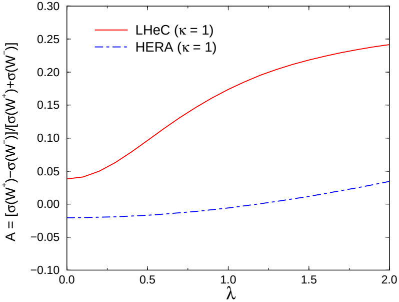
- In order to get rid of normalization uncertainties, one can take the ratios $\sigma_W^{\pm}/\sigma_Z$ to test the $WW\gamma$ vertex.
- To do this we propose the study of the following observable:

$$R_{W/Z}(\kappa,\lambda;\sqrt{s}) = \frac{\sigma_{W^+} + \sigma_{W^-}}{\sigma_Z}$$



Results on the ratios @ LHeC

- Another observable that could be studied is the W^+W^- asymmetry: $A(\kappa, \lambda; \sqrt{s}) = \frac{(\sigma_{W^+} - \sigma_{W^-})}{(\sigma_{W^+} + \sigma_{W^-})}$.



- sensitivity with the κ and λ: SM X new physics...
- W^+W^- asymmetry depends strongly on the κ and λ parameters

Conclusions

- In this work in progress, we study the massive gauge photoproduction @ LHeC.
- Extended γp energy ($E_{CM} \simeq 1.3\ TeV$) will allow to go beyond HERA studies, including small-x, γ and proton structure
- New kinematic window to confirm SM and/or discover new physics
- We present estimates of $W^{\pm}$, Z photoproduction @ LHeC
- Possibility to test non-abelian self-couplings of W, Z and γ, and access new physics. Here we investigate the sensitivity with the anomalous form factors, κ and λ, in some ratios and asymmetries which could be measured
- This 'little extension' of LHC (ep machine) could provide many new insights of SM physics and beyond