Diffractive Z^0 photoproduction in electromagnetic interactions at the LHC

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Outline

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- Model for Z^0 photoproduction - color dipole approach
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Short Motivation

- The LHC will explore physics at TeV scale, opening a new territory where ground-breaking discoveries are expected.
- One primary goal of LHC is the search/study of the discrimination among models for physics beyond of the SM.
- An important physics signal/background to a number of processes indicating the presence of new physics is the production of Z^0 boson.
- Z^0 produced copiously in pp and AA collisions at the LHC, decaying after into lepton pairs or hadrons.
- Hadronic Z^0 decays are expected to be difficult to identify (strong background of QCD multi-jet production).
- Z^0 factory at the LHC, which allows for high-statistics measurement in final states with leptons.

Short Motivation

- We consider the exclusive Z^0 photoproduction in electromagnetic interactions in pp and AA collisions.
- This process is characterized by the photon - hadron interaction, with the photon stemming from the electromagnetic field of one of the two colliding hadrons.
- It is a clean environment characterized by two rapidity gaps between the Z^0 and the outgoing hadrons which can be detected in forward proton detectors.

$$\sigma(h_1 h_2 \rightarrow h_1 Z^0 h_2) = \int_{\omega_{min}}^{\infty} d\omega \frac{dN_\gamma(\omega)}{d\omega} \sigma_{\gamma h \rightarrow Z^0 h}\left(W_{\gamma h}^2\right)$$

- Result is dependent on the magnitude/energy dependence of the $\gamma h \rightarrow Z^0 h$ cross section, which is currently unknown.

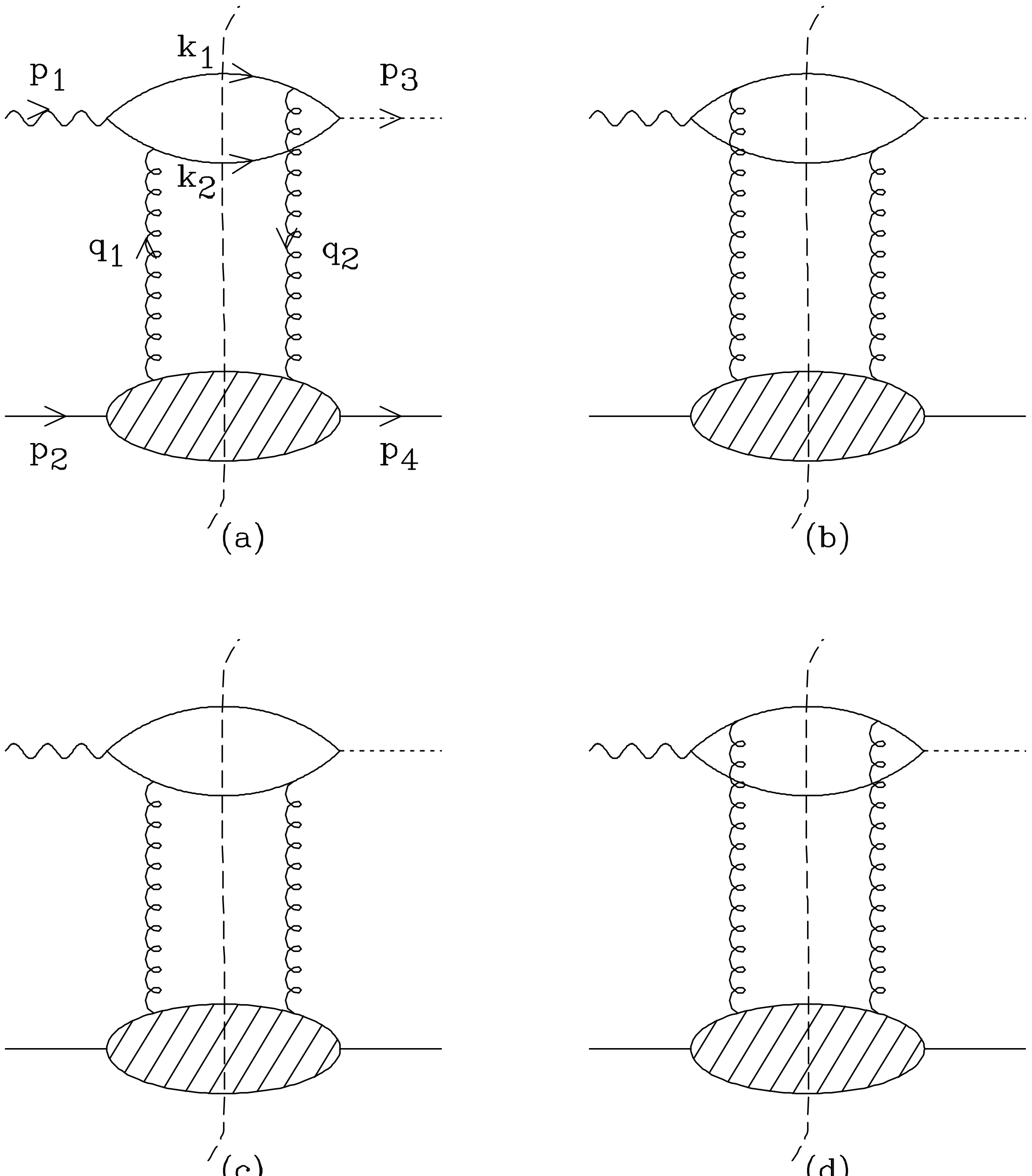
Diffractive Z^0 photoproduction

- We focus on the high energy limit of this process.
- Leading processes are initiated by gluons and we make use of the intuitive color dipole picture.
- The amplitude for production of the exclusive process, $\gamma h \to Z^0 h$, is given by:

$$\mathcal{A}^{\gamma^* h \to Z^0 h} = \int \mathrm{d}^2\vec{r} \int_0^1 \mathrm{d}z \, \Psi^*_{Z^0}(z, r, M_Z) \, \mathcal{A}_{q\bar{q}}(x, r, \Delta) \, \Psi_{\gamma^*}(z, r, Q^2)$$

- The quantity $\mathcal{A}_{q\bar{q}}(x, r, \Delta)$ is the elementary amplitude for the scattering of a dipole of size $\vec{r}$ on the hadron, $\vec{\Delta}$ denotes the transverse momentum lost by the outgoing hadron (with $t = -\Delta^2$) and Q^2 is the photon virtuality.
- Extense phenomenology for exclusive processes measured at DESY-HERA (DVCS and vector meson production).

Picture of interaction



Diffractive Z^0 photoproduction

- Within the color dipole approach, the dipole cross section is supposed to be universal.
- Here, the mean dipole size is related to the Z mass, $r \propto 1/m_z$.
- Therefore, interaction is dominated by very small dipole configuration ($r \to 0$).
- In this case, for qualitative estimates the double leading log approximation (DLLA) would be suitable.

$$\sigma_{dip}(x,r) = \mathcal{A}_{q\bar{q}}(x,r,\Delta=0) \propto \frac{\pi^2 r^2}{N_c}\alpha_s(r)\, xg(x, c/r^2)$$

- $xg(x,Q^2)$ is the gluon structure function.

Model for dipole-hadron interaction

- We consider recent model from Marquet-Peschanski-Soyez [PRD76, 034011 (2007)].
- Results are not sensitive to details of model or aspects of saturation physics (due to large scale given by m_Z).
- The elementary dipole-proton amplitude is given by:

$$\mathcal{A}_{q\bar{q}}(x, r, \Delta) = 2\pi R_p^2\, F(\Delta)\, N\left(rQ_{\mathrm{sat},p}(x, |t|), x\right)$$

- The dipole-nucleon scattering amplitude at $t = 0$ is given by:

$$N(x,\, r) = \begin{cases} \mathcal{N}_0 \left(\frac{rQ_{\mathrm{sat}}}{2}\right)^{2\left(\gamma_s + \frac{1}{\kappa\lambda Y}\ln\frac{2}{rQ_{\mathrm{sat}}}\right)}, & \text{for } rQ_{\mathrm{sat}} \leq 2\,, \\ 1 - \mathrm{e}^{-A\ln^2(BrQ_{\mathrm{sat}})}\,, & \text{for } rQ_{\mathrm{sat}} > 2\,, \end{cases}$$

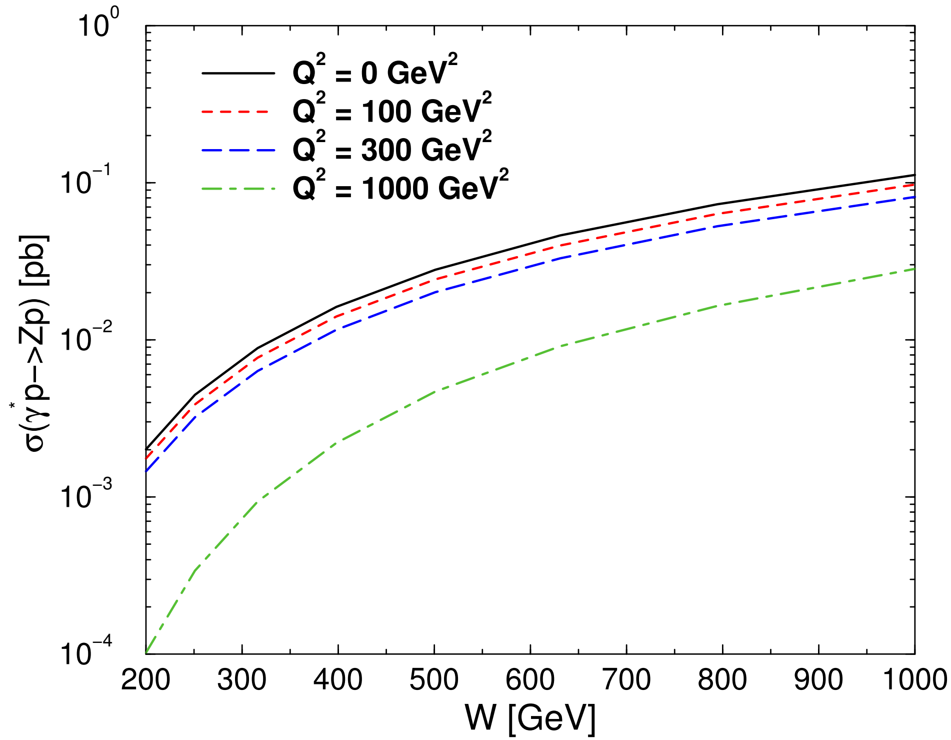
- Here, $Y = \ln(1/x)$ and anomalous dimension $\gamma_s = 0.63$.

Dipole-hadron interaction

- Saturation scale at $t = 0$ is given by $Q^2_{\mathrm{sat},p}(x) = Q^2_0\, x^{-\lambda}$.
- The t dependence of Q_s is parameterized as $Q^2_{\mathrm{sat},p}(x, |t|) = Q^2_0(1 + c|t|)\, x^{-\lambda}$, in order to interpolate smoothly between the small and intermediate t regions.
- The form factor $F(\Delta) = \exp(-B|t|)$ catches the t-dependence of the proton vertex (factorized).

Results: $\gamma^* p \to Z^0 p$

- The total cross section (integrated over $|t| \leq 1$) as a function of energy for some photon virtualities.
- For behavior near threshold, we multiplied the total cross section by a factor $(1 - \bar{x})^5$, where $\bar{x} = (M_{Z^0} + m_p)^2 / W^2$.
- $\sigma_{tot}(W >> m_Z, Q = 0) \approx [2.10^{-4} fb] \times \left(\frac{W}{\text{GeV}}\right)^{1.9}$.



Brief comparison to previous approches

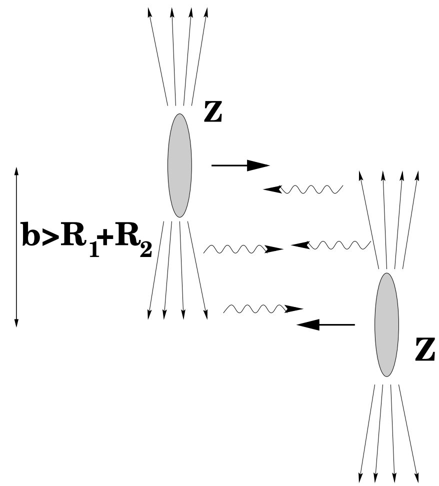
- Work of Bartels-Loewe [ZPC12, 263 (1982)], considering non-forward QCD planar ladder diagrams.
- Direct comparison is a hard task. It is found a cross section $\sigma \approx 10^{-37}$ cm^2 after including branching ratio for the μ-decay. This gives $\sigma_{BL} \approx 0.01$ pb at $\sqrt{s} = 300$ GeV, consistent with ours results.
- J. Pumplin (1996), used two-gluon exchange model of the Pomeron to compute the Z^0 photoproduction. The integrated cross section (energy independent) is $\sigma_{\rm Pumplin}(\gamma p \to Z^0 p) \simeq 0.025$ pb.
- Qualitatively, we have:

$$\mathcal{A}^{\gamma h \to Z^0 h}(x, |t| = 0) \propto \sqrt{2\kappa\lambda Y}\left(\frac{1}{x}\right)^{\frac{\gamma_s^2 \kappa\lambda}{2}}, \qquad \sigma_{tot} \propto \left(\frac{W}{m_Z}\right)^{\gamma_s \kappa\lambda}$$

COnsidering the nuclear case

- We can use the forward scattering amplitude scaling with the number of nucleons, A, squared.
- For the photonuclear reaction, $\gamma A \to Z^0 A$, we will rely on the geometric scaling property of the saturation models within the color dipole approach.
- We replaced $R_p \to R_A$ and $Q^2_{\mathrm{sat},p} \to (A\,\pi R_p^2/\pi R_A^2)^{\epsilon}\,Q^2_{\mathrm{sat},p}$ ($\epsilon = 1.27$) in the proton case. Nuclear form factor.
- For $W \gg M_Z$, one obtains the estimations $\sigma_{tot}(\gamma Pb \to Z^0 Pb) \approx 1\,fb\,(W/\mathrm{GeV})^{1.8}$ and $\sigma_{tot}(\gamma Ca \to Z^0 Ca) \approx 7 \cdot 10^{-2}\,fb\,(W/\mathrm{GeV})^{1.9}$.
- For the nuclear dependence, we get qualitatively, $\sigma(\gamma A \to Z^0 A) \propto [\pi R_A^2 Q^2_{\mathrm{sat},A}]^2/B \approx A^{\frac{2}{3}(1+\epsilon)}\,W^{4\lambda}$, where $B \propto R_A^2$ is the t-slope for the nuclear scattering.

Photoproduction in pp or AA collisions



- Exclusive Z^0 photoproduction in pp and AA collisions:

$$\sigma(pp \to Z^0\, pp) = n_p(\omega) \otimes \sigma(\gamma p \to Z^0 p)$$
$$\sigma(AA \to Z^0\, AA) = n_A(\omega) \otimes \sigma(\gamma A \to Z^0 A)$$

- Since photon emission is coherent over the entire nucleus and the photon is colorless we expect that the events to be characterized by two rapidity gaps.

Z^0 protoproduction in pp collisions

- We quote the results for the $p\bar{p}$ Tevatron energy: for total rapidity one has 1.3 fb and 0.7 fb for rapidity $|y| \leq 1$.
- At Tevatron, it implies that the corresponding events rates/second is 2.6×10^{-7} s^{-1}.

LHC	σ_{tot} [rate/second]	$\sigma_{tot}(|y| < 1)$
pp ($\mathcal{L} = 10^7$ mb^{-1}s^{-1})	69 fb [6.8×10^{-4} s^{-1}]	12 fb

- Results indicate that the experimental analyzes of this process is not quite promissing even at the LHC.
- In contrast to central pp, the Z^0 photoproduction occurs in an environment where hadronic background is reduced.
- However, a more detailed discussion about the identification of the outgoing Z^0 and its main backgrounds is necessary.

Z^0 protoproduction in AA collisions

LHC	σ_{tot} [rate/second]	$\sigma(\|y\| < 1)$
PbPb ($\mathcal{L} = 0.42$ mb^{-1}s^{-1})	1.8 nb (0.8×10^{-6} s^{-1})	1.5 nb
CaCa ($\mathcal{L} = 43$ mb^{-1}s^{-1})	63 pb (2.7×10^{-6} s^{-1})	48 pb

- Event rates are very low for UPCs at the LHC.
- Event rate is smaller than the corresponding pp mode.
- Situation is similar for light nuclei.

Comparison to central collisions

LHC	inclusive central	photoproduction
pp ($\sqrt{s} = 14$ TeV)	15–36 nb	0.07 pb
PbPb ($\sqrt{s} = 5.5$ TeV)	471–685 μb	1.8 nb

- For the pp case, the cross section is a factor 10^4 lower than in central collisions.
- Similar trend occurs for the PbPb mode.
- Central production, Ref.: R. Vogt, PRC64, 044901 (2001).
- Comparison should be done with Z^0 production in DPE (two rapididy gap).
- Single diffractive Z^0 production is 1-2% inclusive production.

Main backgrounds

- Two rapidity gaps can also be generated in hadron-hadron interactions via the WW fusion, but in this case it are accompanied by two forward jets which can be used to discriminate between the two processes.
- Processes mediated by a photon implies a distinct transverse momentum distribution, which can be used to separate the diffractive photoproduction.
- Another background process is the production of e^+e^--pairs.
- Due to their small mass, they are produced copiously, predominantly at low invariant mass and energies and in the forward and backward direction.
- In contrast, in the leptonic Z^0 decays, the pair have an invariant mass equal to Z^0 mass and hence very large individual transverse momenta.

Summary

- We study the exclusive Z^0 photoproduction in electromagnetic interactions in pp and AA collisions, which is characterized by clean environment where the Z^0 boson produced is separated of the outgoing hadrons by rapidity gaps.
- We consider the color dipole approach and estimate the total cross section for the exclusive process $\gamma^* h \to Z^0 h$ ($h = p, A$).
- They are input for the process $p\,p \to p\,Z^0\,p$ and production in UPCs, $A\,A \to A\,Z^0\,A$.
- Experimental analyzes could use leptonic Z^0 decay mode in electromagnetic interactions in pp and AA colisions at the LHC.
- The results show that the feasibility is not promising.