Exclusive Photo-production of J/Ψ and $\Psi(2s)$ as a tool to explore the transition to high and saturated gluon densities at the LHC.

Dr. Martin Hentschinski & Marco Antonio Alcazar Peredo
martin.hentschinski@udlap.mx , marco.alcazarpo@udlap.mx

Department of Actuarial Science, Physics and Mathematics - Universidad de las Américas Puebla
XXXVI Annual Meeting of the Division of Particles and Fields

Our Investigation

- We study the **energy dependence of the cross-section** for exclusive photo-production of vector mesons J/Ψ and its excited state $\Psi(2s)$ with the goal to **find possible signs for the onset of non-linear QCD dynamics**.
- Our study is based on **two dipole models**: the Golec-Biernat, Wuesthoff Model **(GBW)** and the Bartels, Golec-Biernat, Kowalski Model **(BGK)**.
- In both models, **non-linear effects are simulated through exponentiating** of the leading order QCD description, where the BGK model further includes DGLAP evolution into the description.
- Differences between linear and non-linear implementation are on the other hand **enhanced for the ratio of** $\Psi(2s)$ **and** J/Ψ photo-production cross-sections.
- We therefore believe that the **ratio of photo-production cross-sections** can provide a suitable tool to characterize the size of **non-linear QCD effects** at current collider energies.

Figure 1:An ultra-peripherical collision occurring between a hadron and an ultra heavy lead atom where they are exchanging a photon with momentum q and creating a dipole of quarks, resulting into a charmonium bound state. t is the momentum transfer $t = (q - q')$ and W^2 is the squared center-of-mass energy. [1]

Exclusive Photo-production of Vector Mesons

- The **Exclusive photo-production** of vector mesons J/Ψ and $Psi(2s)$ is produced by the interaction between a quasi-real photon and a proton in an ultra-peripheral collision of heavy lead ions which have the characteristic of leaving the nuclei intact after the interaction.
- In Figure [3] we can appreciate, thanks to the CMS Collaboration, the Exclusive Photo-production of a vector meson J/Ψ.

Results

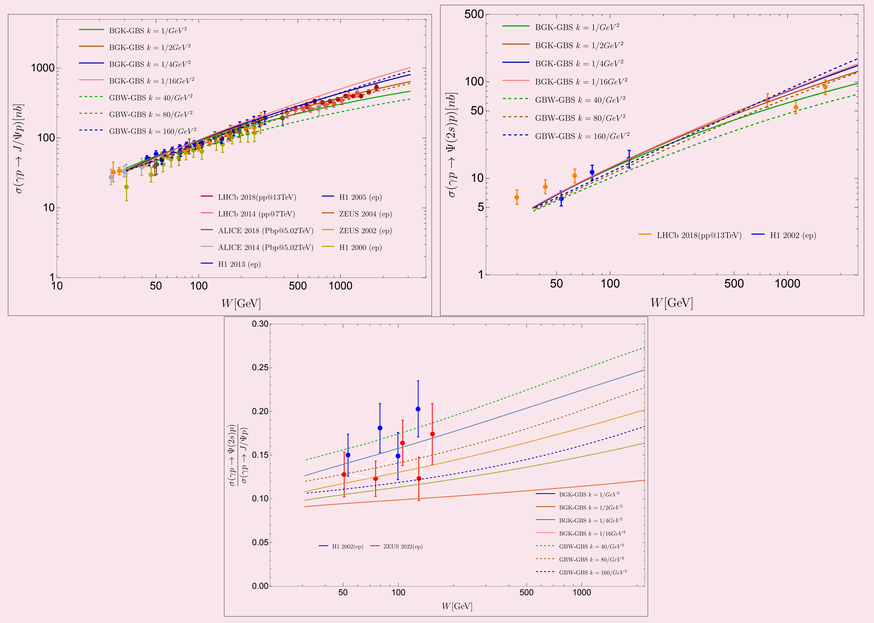

Figure 2:The energy dependence of the J/Ψ, $\Psi(2s)$ and the ratio of $\Psi(2s)$ and J/Ψ for the photo-production cross section process as provided by the GBW and the BGK Model for gluon distribution implementing the GBS fit. [3]

Exclusive Photo-Production Cross-Section

The **dominant imaginary part of the scattering amplitude** can obtained as a convolution of the inclusive dipole cross-section and the functions $\bar{\Sigma}_T^{(1,2)}$ which describe the transition of a transverse polarized photon into a vector meson V: [1]

$$\Im m A_T(W^2, t=0) = \int d^2\mathbf{r}[\sigma_{q\bar{q}}\left(\frac{M_V^2}{W^2}, r\right)\bar{\Sigma}_T^1(r) + \\ + \frac{d}{dr}\sigma_{q\bar{q}}\left(\frac{M_v^2}{W^2}, r\right)\bar{\Sigma}_T^{(2)}(r)$$

where $\sigma_{q\bar{q}}$ give the interaction between gluons, $\mathbf{r}$ is the dipole size and M is the characteristic hard scale for the process.

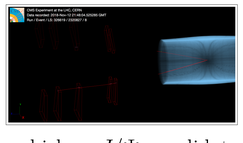

Figure 3:Event in which a J/Ψ candidate is produced in a **ultra-peripheral Pb-Pb collision** and decays into two muons depicted as red lines inside the blue cylinder. [Cauley and Thomas CMS Collaboration, 2018]

Objectives

1. Determinate the photo-production cross-section and compare it with experimental data extracted from HERA and the LHC.

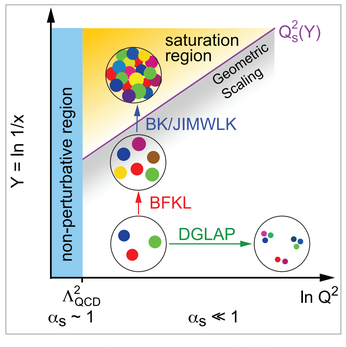

Figure 4:The map of high energy QCD in the (Q^2, $Y = \ln 1/x$) plane. [2]

2. Search for potential signals for the presence of non-linear QCD dynamics

Dipole and Saturation Models

The **Dipole Models** are used to provide an **elegant description of QCD reactions at low-x and low** Q^2 **region.** [3] In our study, we implement and modified two different models: [4]

1. GBW Model
   - Non-Linear Version

$$\sigma_{dip}(x, r^2, k) = \frac{\sigma_0}{k}\left(1 - \exp\left[\frac{-k \cdot r^2 Q_s^2(x)}{4}\right]\right)$$

$$Q_s^2(x) = Q_0^2(\frac{x_0}{x})^\lambda$$

   Is a scale that grows with the energy. (As $x \to 0$)
2. BGK Model
   - Non-Linear Version

$$\sigma_{dip}(x, r^2, k) = \frac{\sigma_0}{k}\left(1 - \exp\left[\frac{-k \cdot \pi^2 r^2 \alpha_s(\mu^2) x g(x, \mu^2)}{3\sigma_0}\right]\right)$$

Conclusions

- Comparing to both HERA and LHC data we find that **differences between linear and non-linear implementations are relatively small** at the level of photo-production cross-sections, in particular if both theoretical and experimental uncertainties are taken into account.
- We also find that the **ratio grows with energy in the presence non-linear effects,** while it remains approximately constant if non-linear effects are absent.
- We introduce **a parameter** k which allows us to vary the strength of non-linear corrections in the dipole models. This parameter does not affect the linear result, but it tells us how **important are the non-linear corrections.**

References

[1] Martin Hentschinski and Emilio Padrón Molina.
Exclusive J/Ψ and $\Psi(2s)$ photo-production as a probe of QCD low x evolution equations.
Phys. Rev. D, 103(7):074008, 2021.

[2] A. Accardi et al.
Electron Ion Collider: The Next QCD Frontier: Understanding the glue that binds us all.
Eur. Phys. J. A, 52(9):268, 2016.

[3] Krzysztof Golec-Biernat and Sebastian Sapeta.
Saturation model of DIS : an update.
JHEP, 03:102, 2018.

[4] Agnieszka Luszczak and Henri Kowalski.
Dipole model analysis of highest precision HERA data, including very low Q^2's.
Phys. Rev. D, 95(1):014030, 2017.

[5] Néstor Armesto and Amir H. Rezaeian.
Exclusive vector meson production at high energies and gluon saturation.
Phys. Rev. D, 90(5):054003, 2014.