Federal University of Santa Catarina

Exclusive photoproduction of light vector mesons with a holographic wave function model.

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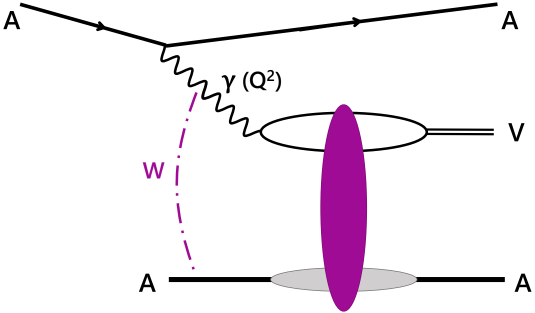
Light vector meson photoproduction in nuclear targets

Coherent production

In the coherent vector meson photoproduction, the nucleus target remains intact.

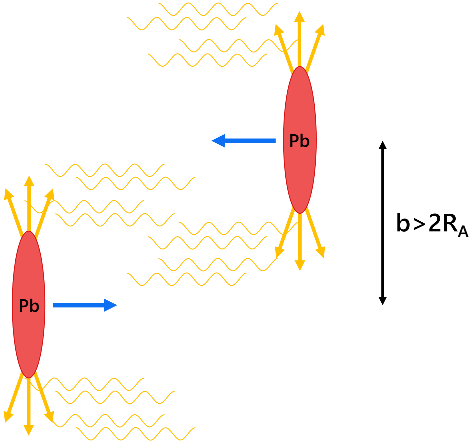


The rapidity differential cross section for the $AA \to AVA$ process can be factorized:

$$\frac{d\sigma^{AA\to AVA}}{dy} = \int d^2b\, \frac{\omega dN_\gamma(\omega, b)}{d\omega} \frac{d\sigma^{\gamma A\to VA}(\omega, b)}{d^2b} + (y \to -y)\,.$$

Photon flux and ultraperipheral collisons

An ultraperipheral collision between two nuclei is defined as the one in which the impact parameter exceeds the sum of the nuclei radius.



Photon flux and ultraperipheral collisons

The photon flux at b emitted by the projectile nucleus, and excluding strong interaction between the colliding ions, is :

$$\omega \frac{dN_\gamma(\omega, b)}{d\omega} = \int d^2 b_\gamma \frac{\omega N_\gamma(\omega, b_\gamma)}{d\omega d^2 b_\gamma} \exp\left(-\sigma_{\rm NN}^{\rm tot} \int d^2 b' T_A(b') T_A(|\vec{b_{AA}} - \vec{b}'|)\right) . \quad (1)$$

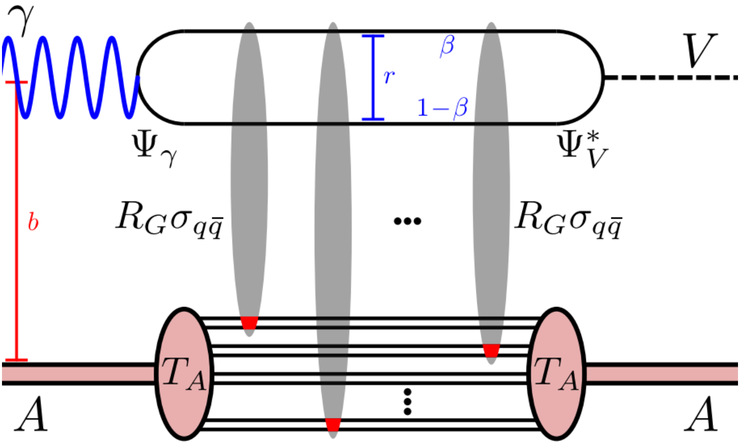
The Weizsäcker-Williams method calculated for a punctual charge is used to calculate the b-dependent photon flux:

$$\frac{\omega d^3 N_\gamma(\omega, b_\gamma)}{d\omega d^2 b_\gamma} = \frac{Z^2 \alpha_{\rm em} \omega^2}{\pi^2 \gamma^2} K_1^2\left(\frac{b_\gamma\, \omega}{\gamma}\right) , \quad (2)$$

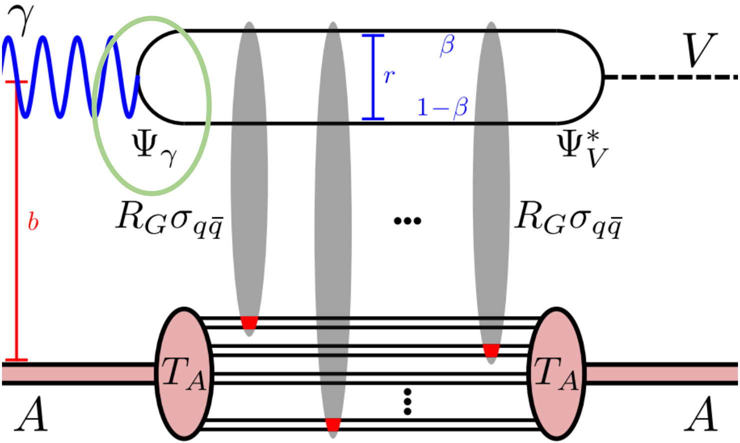
The Woods-Saxon distribution for the lead nuclear density was used in the thickness function

$$T_A(b) = \int_{-\infty}^{+\infty} {\rm d}z\, \rho_A(b, z) . \quad (3)$$

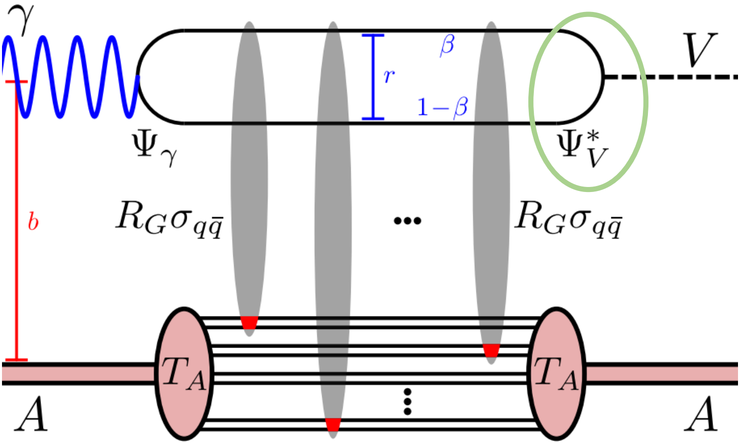
Color dipole approach



Photon wave function



Vector meson wave function



Vector meson wave function
AdS/QCD holographic model

It is considered a semiclassical approximation, which enables the scalar part to be factorized

$$\psi(\beta,\zeta,\varphi) = e^{iL\varphi} X(\beta) \frac{\phi(\zeta)}{\sqrt{2\pi\zeta}} ,$$

with $\zeta^2 = \beta(1-\beta)r^2$.

The hadronic LF wave function is found by solving a relativistic equation, equal to the Schroedinger equation, with the effective confinement potential

$$U(\zeta, J) = \kappa^4\zeta^2 + 2\kappa^2(J-1)$$

$$\left(-\frac{d^2}{d\zeta^2} - \frac{1-4L^2}{4\zeta^2} + U(\zeta)\right)\phi(\zeta) = M^2\phi(\zeta)$$

The solutions, fully relativistic, have the shape of the HO wave functions, while the eigenvalues are given by

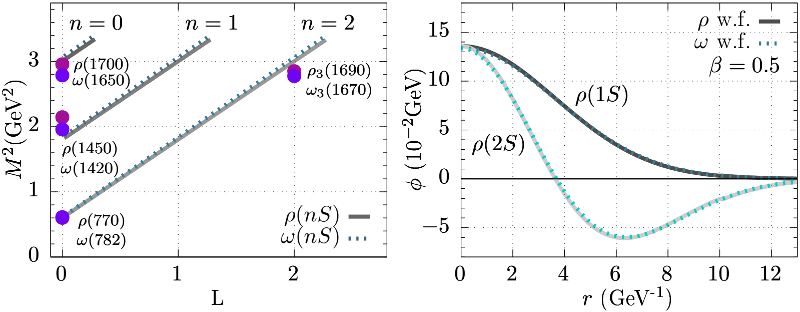
$$M^2 = 4\kappa^2\left(n + \frac{J}{2} + \frac{L}{2}\right) .$$

Mass dependent κ

$$\kappa = \frac{M_{V\,(n=0)}}{\sqrt{2}}$$

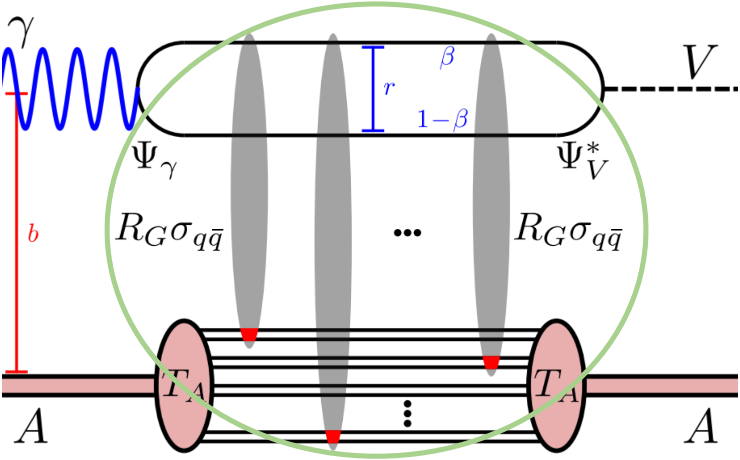
Vector meson wave function
AdS/QCD holographic model

The left panel shows the mass spectroscopy of ρ and ω vector mesons.



The right panel presents the LF wave functions for the ρ vector meson at ground and excited states.

Dipole-nucleus cross section



Glauber–Gribov model

Coherent production

The total cross sections for the $\gamma A \to VA$ process is

$$\frac{d\sigma^{\gamma A \to VA}(\omega, b)}{d^2 b} = \left| \int d\beta d^2 r \, \Psi_V^* \Psi_\gamma(\beta, r) \left(1 - \mathrm{e}^{-\sigma_{q\bar{q}}(x,r) T_A(b)/2}\right) \right|^2$$

The GBW model was used to describe the dipole cross section $\sigma_{q\bar{q}}$.

Corrections

1. Real part

$$\sigma_{q\bar{q}}(x, r) \Rightarrow \sigma_{q\bar{q}}(x, r)\left(1 - i\frac{\pi}{2}\lambda\right)$$

2. Skewness

$$R_g(\lambda) = \frac{2^{2\lambda+3}}{\sqrt{\pi}} \frac{\Gamma(\lambda + 5/2)}{\Gamma(\lambda + 4)}$$

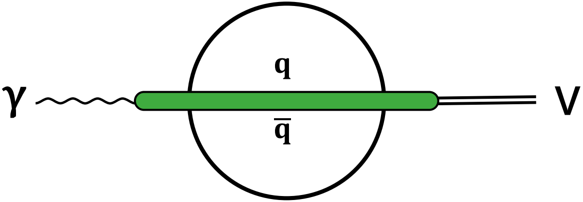
$$\lambda = \frac{\partial \ln \sigma_{q\bar{q}}(x, r)}{\partial \ln (1/x)}$$

Coherence length

At high energies, the $q\bar{q}$ pair lifetime, called coherence length, is defined as

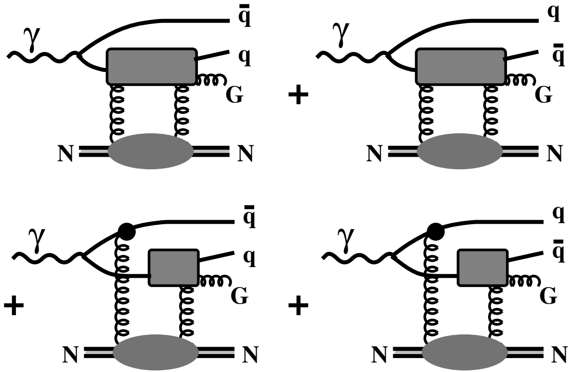
$$l_c = \frac{2\omega'}{M_V^2} \,. \tag{4}$$

The dipole model considers it to be much bigger than the nucleus radius.



Higher states

At high energies, we need to consider that the photon can split into higher states with gluons $|q\bar{q}g\rangle$, $|q\bar{q}gg\rangle$, ...



[Kopeliovich, Schafer and Tarasov, Phys. Rev. D 62 054022, 2000]

This is taken into account in the dipole–proton cross section.

Gluon shadowing

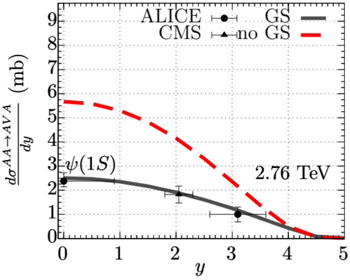
The infinite lifetime approximation fails for higher Fock states
$\hookrightarrow$ reduction of the γA cross section.
$\hookrightarrow$ effect called **gluon shadowing**.

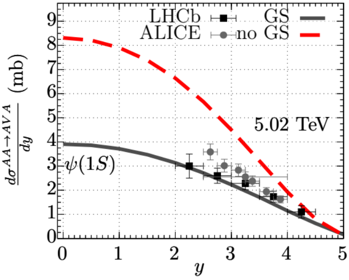
It is possible to rescale the dipole cross section by the factor R_G

$$\sigma_{q\bar{q}}(r,x) \to \sigma_{q\bar{q}}(r,x) R_G(x,\mu^2)\,.$$

Gluon shadowing for heavy vector mesons

In the heavy vector meson case it is calculated with EPPS16 and a factorization scale $\mu = M_V/2$.
[Henkels, E.G.O., Pasechnik, Trebien, Phys. Rev. D 102, 014024 (2020)].



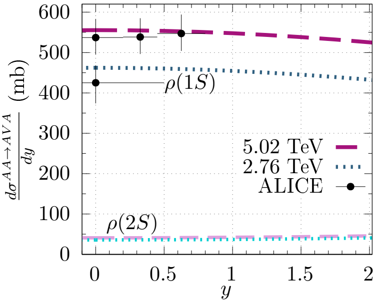


The evolution does not reach the light vector meson scale.

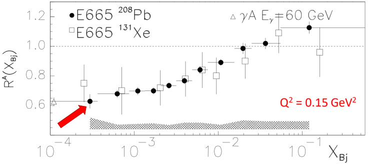
We do not have gluon shadowing for smaller scales
$\hookrightarrow$ This is a **PROBLEM**.

Gluon shadowing extraction

ρ vector meson



F_2 data



[Data taken from the Fermilab E665 Collaboration,

Z.Phys.C 67 (1995) 403-410]

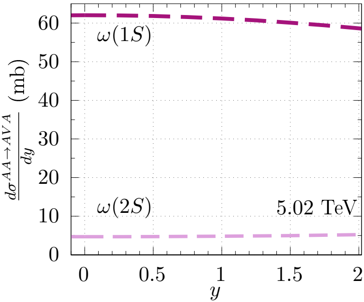
$$\frac{F_2^A}{AF_2^p} = 0.537$$

The available data led to an optimal value for the gluon shadowing

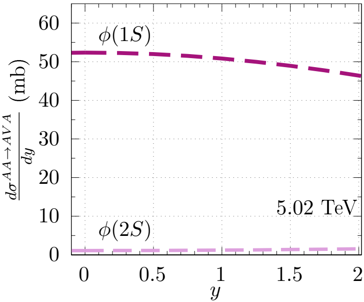
$$R_G = 0.85$$

Coherent photoproduction predictions

ω vector meson



ϕ vector meson

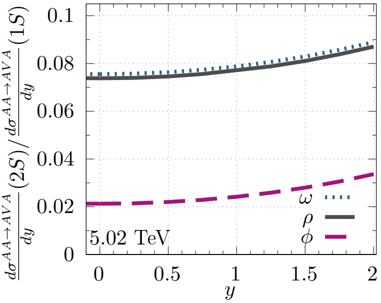


We used the same $R_G = 0.85$ factor to make predictions for other light vector mesons.

Measurements can bring information about the R_G scale dependence.

$2S$ to $1S$ ratio predictions

ρ, ω, and ϕ vector mesons



Predictions for the ratio between the excited state cross section and its corresponding ground state cross section.

This can be a tool for finding the best dipole cross section model.

Conclusion

Conclusion

- **Light vector meson** photoproduction: **small hard scales Q^2**.

- The **Glauber-Gribov** approach is used for nuclear targets.
- The inclusion of **gluon shadowing** R_g is necessary.
- By fitting **$\rho(1S)$ UPC ALICE** and **F_2** data, we effectively obtain: **$R_g = 0.85$**.
- We make **predictions**: $\rho(2S)$, $\omega(1S, 2S)$, and $\phi(1S, 2S)$.
- The **ratio** between excited and ground state cross sections depend on **vector meson wavefunctions** and probe the **dipole cross section**.

See more:

Poster 'Photoproduction of light meson using holographic models' - Haimon Trebien

Acknowledgments

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Thank you!

EXTRA SLIDES

Slope parameter

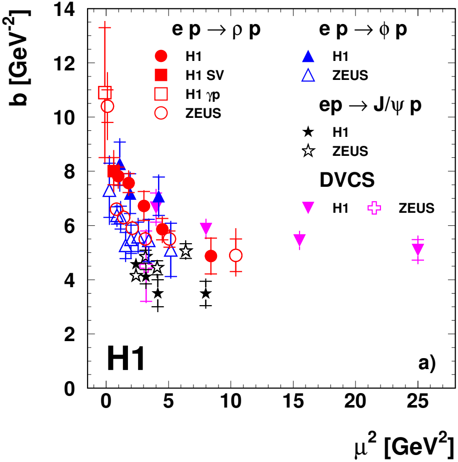
The slope parameter for heavy vector mesons takes the form:

$$B\left(W, Q^2\right) \approx B_0 + 4\alpha'(0)\ln\left(\frac{W}{W_0}\right) - B_1 \ln\left(\frac{Q^2 + M_V^2}{M_{J/\Psi}^2}\right), \tag{5}$$

while the one for light vector mesons is given by:

$$B = N\left[14.0\left(\frac{1\mathrm{GeV}^2}{Q^2 + M_V^2}\right)^{0.2} + 1\right], \tag{6}$$

Slope parameter



Color dipole parametrizations
without impact parameter dependence

1. GBW

   It has the form:

$$\sigma_{q\bar{q}}(x,r) = \sigma_0 \left(1 - e^{-\frac{r^2 Q_s^2(x)}{4}}\right), \tag{7}$$

   with saturation scale defined as $Q_s^2(x) = Q_0^2 \left(\frac{x_0}{x}\right)^{\lambda}$.

2. KST

   It includes corrections for small $\hat{s} \equiv W^2$.

$$\sigma_{\bar{q}q}(r,\hat{s}) = \sigma_0(\hat{s}) \left[1 - e^{-r^2/R_0^2(\hat{s})}\right]. \tag{8}$$

   In this case, the $\hat{s}$- dependence appears in $\sigma_0(\hat{s})$ and $R_0(\hat{s})$, which are given by

$$R_0(\hat{s}) = 0.88\text{fm}\,(s_0/\hat{s})^{0.14}, \quad \sigma_0(\hat{s}) = \sigma_{\text{tot}}^{\pi p}(\hat{s}) \left(1 + \frac{3R_0^2(\hat{s})}{8\left\langle r_{\text{ch}}^2\right\rangle_\pi}\right). \tag{9}$$

Color dipole parametrizations
with impact parameter dependence

3. bSat

   The partial dipole amplitude is

$$N(x, \boldsymbol{r}, \boldsymbol{b}) = 1 - \exp\left(-\frac{\pi^2}{2N_c} r^2 \alpha_s(\mu^2) x g(x, \mu^2) T(b)\right) \tag{10}$$

   with the following scale dependence $\mu^2 = 4/r^2 + \mu_0^2$.

4. BK

   The BK evolution equation is given by

$$\frac{\partial N(r, b, Y)}{\partial Y} = \int d\boldsymbol{r_1} K\left(r, r_1, r_2\right)\left(N\left(r_1, b_1, Y\right) + N\left(r_2, b_2 Y\right) - N(r, b, Y)\right.$$
$$\left. - N\left(r_1, b_1, Y\right) N\left(r_2, b_2, Y\right)\right) . \tag{11}$$

   Gluon recombination effects are taken into account in the non-linear term

Color dipole parametrizations

5. bCGC

It is the interpolation of solutions for the BFKL and the BK :

$$N(x,\mathbf{r},\mathbf{b}) = \begin{cases} N_0\left(\frac{r\,Q_s}{2}\right)^{2[\gamma_s+(1/(\eta\Lambda Y))\ln(2/rQ_s)]} & rQ_s \le 2 \\ 1-e^{-\mathcal{A}\ln^2(\mathcal{B}\,r\,Q_s)} & rQ_s > 2 \end{cases}. \qquad (12)$$

The b-dependence is introduced in the saturation scale

$$Q_s \equiv Q_s(x,b) = \left(\frac{x_0}{x}\right)^{\Lambda/2}\left[\exp\left(-\frac{b^2}{2B_{\mathrm{CGC}}}\right)\right]^{1/(2\gamma_s)}. \qquad (13)$$