Double Parton Scattering in Ultraperipheral Collisions

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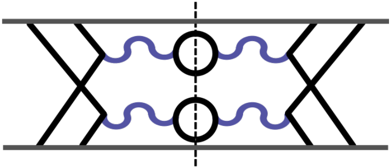
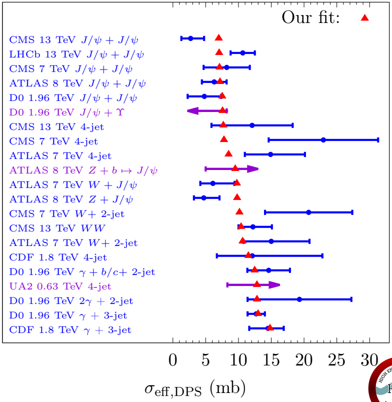
- Two independent interactions in the same collision.

E. Huayra, J. V. C. Lovato and EGdO, JHEP **09**, 177 (2023).





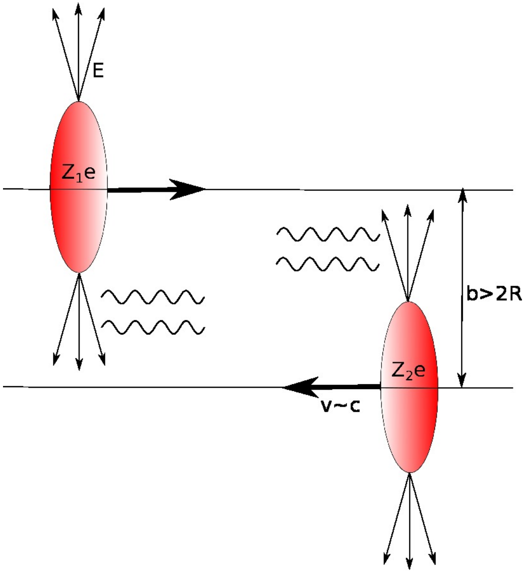
Pocket Formula

$$\sigma^{\text{DPS}}_{A,B} = \frac{m}{2} \frac{\sigma^{\text{SPS}}_A \sigma^{\text{SPS}}_B}{\sigma_{\text{eff}}}$$

$m = 1$ Equal final states;

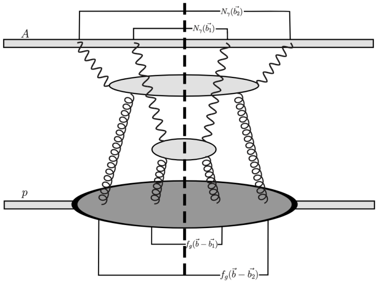
$m = 2$ Different final states.

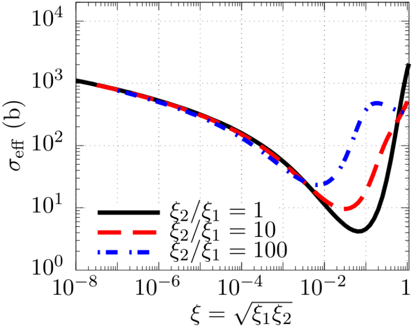
What are ultraperipheral collisions (UPCs)?



- Interactions are between "quasi–real" photons;
- The interaction is predominantly electromagnetic;
- Can we have **double parton scattering**?

E. Huayra, EGdO and R. Pasechnik, Eur. Phys. J. C **79**, 880 (2019).

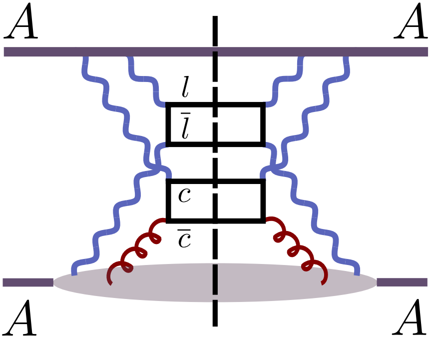


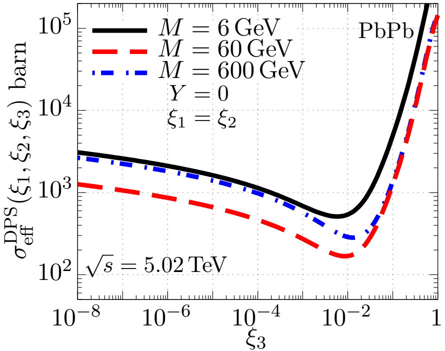


- We see a **dependence on the photon momentum fraction** ξ.
- For small ξ, photons are spread out and they are not found together.
- For large ξ, photons are closer to the nucleus and UPC does not happen.

$c\bar{c}l\bar{l}$ DPS production: $3\gamma + 1g$ **in the initial state**

E. Huayra, EGdO, R. Pasechnik and B. O. Stahlhöfer., Phys. Rev. D **104**, (2021).





- Probes the gluons and the photons inside the nucleus.

J/Ψ and $\mu\mu$ production measurement

ALICE SPS measurements:

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

ALICE

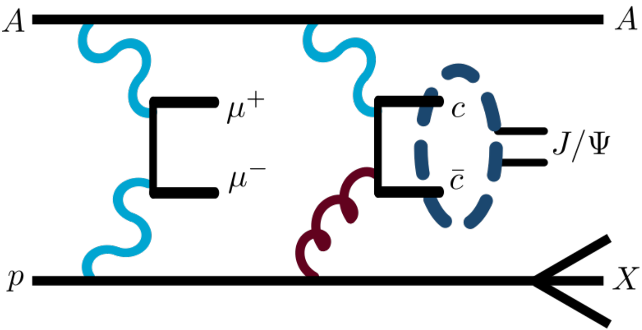
CERN-EP-2023-059
29 March 2023

Exclusive and dissociative J/ψ photoproduction, and exclusive dimuon production, in p–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 8.16 TeV

ALICE Collaboration*

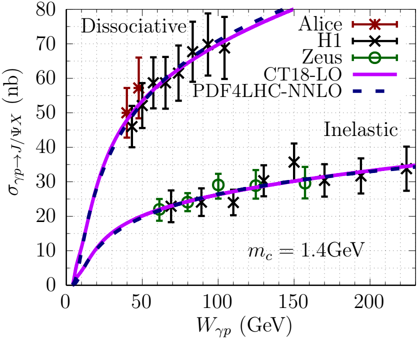
- This detection is characterized by a large rapidity gap.
- What are the partons involved?

The goal: DPS with proton dissociation



- $3\gamma + 1g$ in the initial state;
- Probes the photon distribution of the proton;
- Keeps the large rapidity gap.

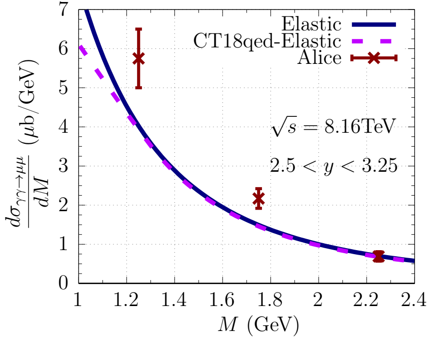
J/ψ production in color evaporation model



Dissociative parameters fit

$F_\psi = 0.084 \quad \mu_F = 1.89$

Dimuon production



Dimuon + J/Ψ cross section via DPS in Ap UPCs

Differential cross section

$$\frac{d\sigma_{Ap\to A\mu\mu J/\Psi X}}{dY_{\mu\mu}dM^2_{\mu\mu}dY_{J/\psi}dM^2_{J/\psi}} = \int d^2\vec{b}\,\Theta(b-R_A-R_p)\int d^2\vec{b}_{\gamma_1}\int d^2\vec{b}_{\gamma_3}$$

$$\times\,\frac{\xi_1\xi_2}{M^2_{\mu\mu}}\Theta(b_{\gamma_1}-R_A)N_{\gamma_1}(\xi_1,\vec{b}_{\gamma_1})N_{\gamma_2}(\xi_2,\vec{b}_{\gamma_2}=\vec{b}_{\gamma_1}-\vec{b})\,\hat{\sigma}_{\gamma_1\gamma_2\to\mu\mu}$$

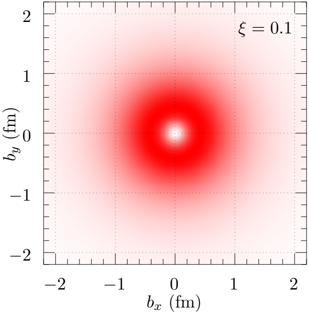
$$\times\,\frac{\xi_3 x}{M^2_{J/\psi}}\Theta(b_{\gamma_3}-R_A)N_{\gamma_3}(\xi_3,\vec{b}_{\gamma_3})G_g(x,\vec{b}_g=\vec{b}_{\gamma_3}-\vec{b})\,F_\psi\hat{\sigma}_{\gamma_3 g\to c\bar{c}}.$$

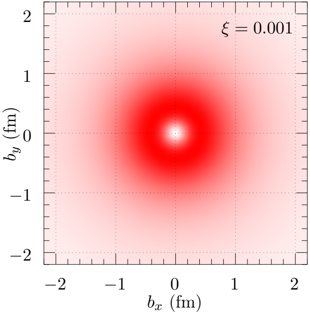
Gluon distribution

$$G_g(x,\vec{b}) = g(x)f_g(\vec{b}),\quad \int d^2\vec{b}f_g(\vec{b}) = 1\,,$$

$$f_g(\vec{b}) = \frac{\Lambda^2}{2\pi}\frac{\Lambda b}{2}K_1(\Lambda b),\quad \Lambda\approx 1.5\,\mathrm{GeV}.$$

$$\frac{d^3N(\xi,\vec{b})}{d\xi d^2\vec{b}} = \frac{\alpha}{\pi^2\xi}\left|\int dq_t \left[\frac{q_t^2}{q_t^2+\xi^2 m_p^2}\left(\frac{q_t^2(1-\xi)}{q_t^2+\xi^2 m_p^2}F_E(Q^2)+\frac{\xi^2}{2}F_M(Q^2)\right)\right]^{1/2} J_1(bq_t)\right|^2 .$$





- Dipole electric $F_E(Q^2)$ and magnetic $F_M(Q^2)$ proton form factors: $\mu_p = 2.79$.

$$F_E(Q^2) = \frac{4m_p^2 G_E^2(Q^2) + Q^2 G_M^2(Q^2)}{4m_p^2 + Q^2},$$

$$F_M(Q^2) = G_M^2(Q^2),$$

$$G_E = G_M/\mu_p = G_D(Q^2),$$

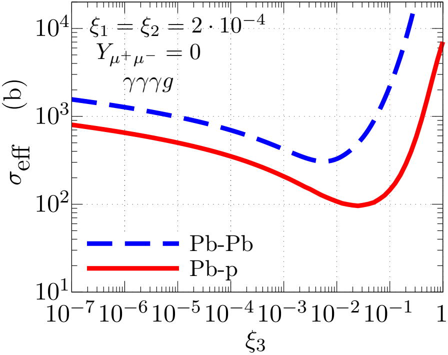
$$G_D(Q^2) \equiv (1 + Q^2/0.71)^{-2}.$$

Overlap function of nucleus and proton photons

$$T_{\gamma_1\gamma_2}(\xi_1,\xi_2,\vec{b}) = \int d^2\vec{b}_{\gamma_1}\,\frac{\Theta(b_{\gamma_1}-R_A)N_{\gamma_1}(\xi_1,\vec{b}_{\gamma_1})N_{\gamma_2}(\xi_2,\vec{b}_{\gamma_1}-\vec{b})}{\overline{N}_{\gamma_1}(\xi_1)\,\overline{N}_{\gamma_2}(\xi_2)}$$

Overlap function of nucleus photon and proton gluon

$$T_{\gamma_3 g}(\xi_3,\vec{b}) = \int d^2\vec{b}_{\gamma_3}\,\frac{\Theta(b_{\gamma_3}-R_A)\,N_{\gamma_3}(\xi_3,\vec{b}_{\gamma_3})f_g(\vec{b}_{\gamma_3}-\vec{b})}{\overline{N}_{\gamma_3}(\xi_3)}\,.$$



Effective cross section:

$$\sigma_{\rm eff}^{Ap}(\xi_1,\xi_2,\xi_3)^{-1} = \int d^2\vec{b}\,T_{\gamma_1\gamma_2}(\xi_1,\xi_2,\vec{b})\,T_{\gamma_3 g}(\xi_3,\vec{b})\Theta(b-R_A-R_p)$$

Pocket Formula

The DPS cross sections fatorizes: we have collinear cross sections:

$$\frac{d\Sigma_{\mu\mu}}{dY_{\mu\mu}dM^2_{\mu\mu}} = \frac{\xi_1\xi_2}{M^2_{\mu\mu}}\overline{N}_{\gamma_1}(\xi_1)\overline{N}_{\gamma_2}(\xi_2)\hat{\sigma}_{\gamma_1\gamma_2\to\mu^+\mu^-}.$$

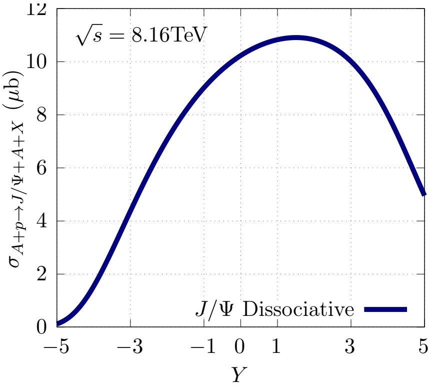
$$\frac{d\Sigma_{J/\psi}}{dY_{J/\psi}dM^2_{J/\psi}} = \frac{\xi_3 x}{M^2_{J/\psi}}\overline{N}_{\gamma_3}(\xi_3)g(x)F_{\psi}\hat{\sigma}_{\gamma_3 g\to c\bar{c}},$$

Pocket Formula

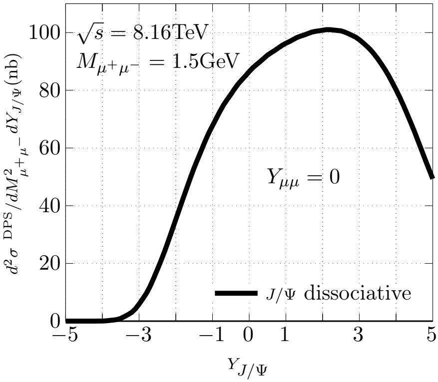
$$\frac{d^2\sigma_{Ap\to A\mu\mu J/\Psi X}}{dY_{\mu\mu}dM^2_{\mu\mu}dY_{J/\psi}dM^2_{J/\psi}} = \frac{1}{\sigma^{Ap}_{\text{eff}}(\xi_1,\xi_2,\xi_3)}\frac{d\Sigma_{\mu\mu}}{dY_{\mu\mu}dM^2_{\mu\mu}}\frac{d\Sigma_{J/\psi}}{dY_{J/\psi}dM^2_{J/\psi}}$$

Results on $Y_{J/\psi}$ distributions

SPS cross section



DPS cross section



- SPS and DPS have different $Y_{J/\psi}$ distributions as the result of the $Y_{J/\psi}$ dependence of the effective cross section.

Conclusions

- We have calculated for the first time two effective cross sections in AA UPC collisions: two gluons or one gluon and one photon in the target.
- Also, we have calculated for the first time the same effective cross sections in the case of proton targets.
- Using selected final states, we have found **mensurable** DPS cross sections for the LHC and FCC;
- We have assumed no correlations of target partons. There may be some.
- Our results stand as **motivation** to future measurements of **DPS in UPCs**.

Acknowledgments

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