Ultraperipheral collisions of ions at the LHC and nuclear shadowing in photoproduction of vector mesons on nuclei

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Outline:

- Ultraperipheral collisions (UPCs)
- Nuclear shadowing in photoproduction of ρ on nuclei at the LHC
- Summary

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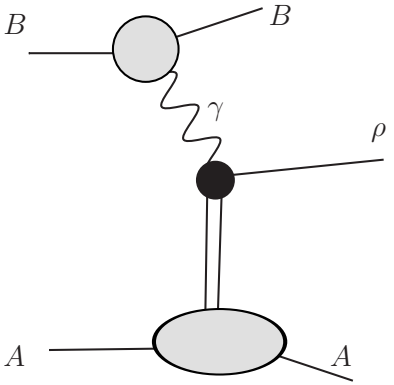
Ultraperipheral collisions (UPCs)

• Ions can interact at large impact parameters b >> R_A+R_B → ultraperipheral collisions (UPCs) → strong interaction suppressed → interaction via quasi-real photons, Fermi (1924), von Weizsäcker; Williams (1934)



- UPCs correspond to empty detector with only two lepton/ pion tracks
- Nuclear coherence by veto on neutron production by Zero Degree Calorimeters and selection of small pt

• Coherent photoproduction of vector mesons in UPCs:

$$\frac{d\sigma_{AB\to AB\rho}(y)}{dy} = N_{\gamma/B}(y)\sigma_{\gamma A\to\rho A}(W) + N_{\gamma/A}(y)\sigma_{\gamma B\to\rho B}(W)$$

Photon flux from QED:
- high intensity ~ Z^2
- high photon energy ~ γ_L

Photoproduction cross section

$y = \ln[W^2/(2\gamma_L m_N M_V)]$

= rapidity of ρ

UPCs@LHC = γp and γA interactions at unprecedentedly large energies, Baltz *et al.*, The Physics of Ultraperipheral Collisions at the LHC, Phys. Rept. 480 (2008) 1

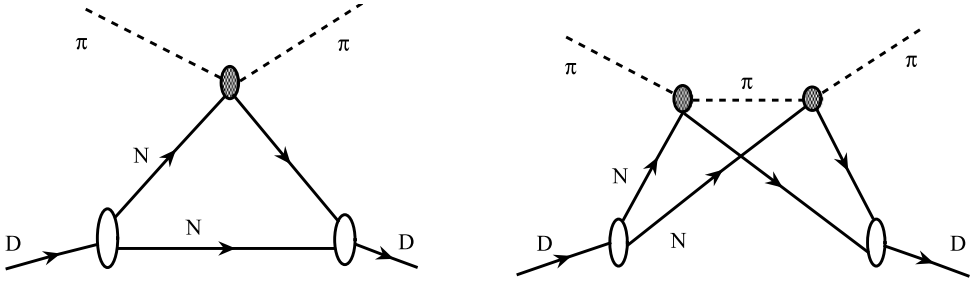
Nuclear shadowing

• Nuclear shadowing (NS) = suppression of cross section on a nucleus compared to sum of cross sections on individual nucleons: $\sigma_A < A\,\sigma_N$.

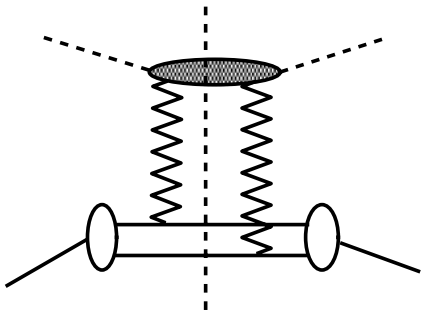
• Observed for various beams (p, π, γ, γ^*, ν) of large energies (> 1 GeV).

• Explained by simultaneous interaction of projectile with target nucleons → destructive interference among amplitudes for interaction with 1, 2, …nucleons → nucleons in rear of the nucleus "see" smaller (shadowed) flux: $\sigma_A \sim A^{2/3}$.

elastic intermediate state, Glauber 1955



inelastic intermediate state, Gribov 1969



• NS in photoproduction of light vector mesons ρ, ω, ϕ:
  - dynamics of soft γp and γA interaction at high energies
  - test of VMD model and role of inelastic (Gribov) shadowing

• NS in photoproduction of heavy vector mesons J/ψ, ψ(2S), Υ:
  - mechanism of nuclear shadowing: leading twist vs. HT vs. saturation
  - new constraints on nuclear gluon distribution $g_A(x,\mu^2)$ at small x

Coherent photoproduction of ρ on nuclei

- Measured with fixed targets (SLAC, W < 6 GeV), in Au-Au UPCs at RHIC (W < 12 ГэВ), and Pb-Pb UPCs at the LHC@2.76 TeV (W=46 GeV).

- For W < 10 GeV, explained by the vector meson dominance (VMD) model for $\gamma \rightarrow \rho$ transition and Glauber model for shadowing in ρA scattering:

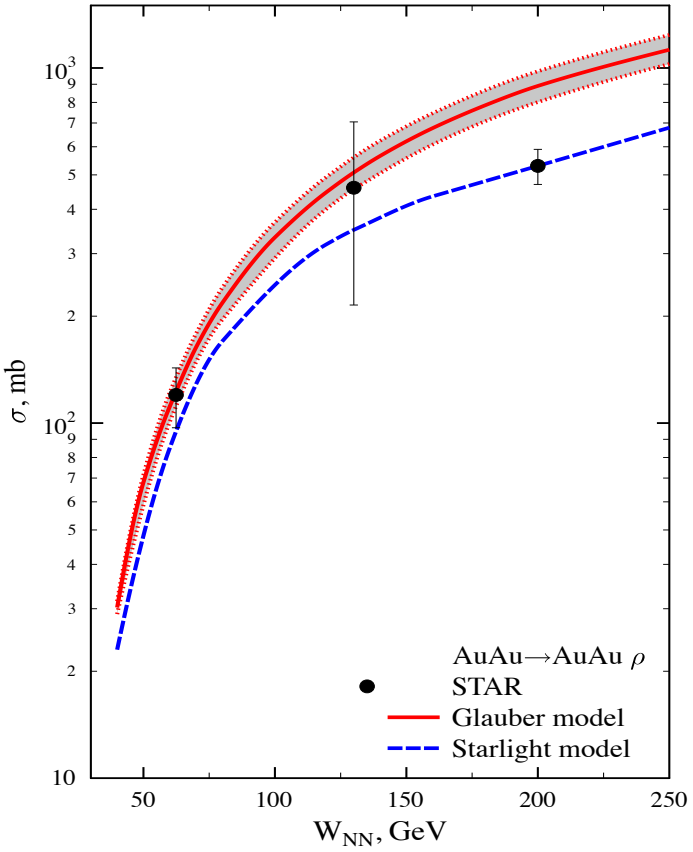
$$\sigma^{\mathrm{VMD}}_{\gamma A \rightarrow \rho A} = \left(\frac{e}{f_\rho}\right)^2 \int d^2b \left|1 - e^{-\frac{1}{2}\sigma_{\rho N} T_A(b)}\right|^2$$

$\sigma_{\rho N}$ from constituent quark model/data:

Optical density:

$$T_A(b) = \int dz \rho_A(b,z)$$

Frankfurt, Strikman, Zhalov, 2002



- …but fails to describe large-W RHIC (STAR), Adler, et al, Phys. Rev. Lett. 89 (2002) 272302; Abelev et al., Phys. Rev. C 77 (2008) 034910; Agakishiev, et al., Phys. Rev. C 85 (2012) 014910 and ALICE data by factor **~1.5**, Adam et al (ALICE), JHEP 1509 (2015) 095

- Dipole models describe data better, but strongly model-dependent, Goncalves, Machado, PRC 84 (2011) 011902

- Best description by STARlight despite approximate treatment of Glauber model, Klein and Nystrand, PRC60 (1999) 014903.

Modified vector meson dominance (mVMD) model

- At large beam energies E_γ, the photon can be viewed as superposition of long-lived ($l_c \sim E_\gamma$) fluctuations interacting with hadrons with different cross sections, Gribov, Ioffe, Pomeranchuk 1965; Good, Walker, 1960

- It can be realized by introducing the probability distribution $P(\sigma)$, Blattel et al 1993

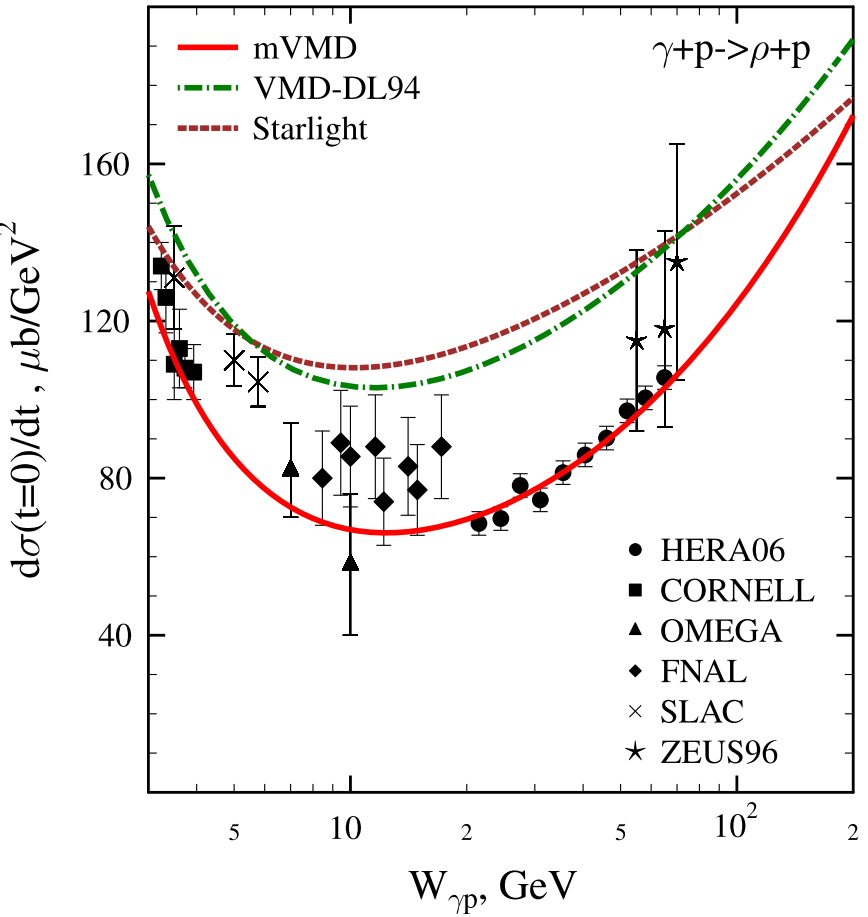
$$\int d\sigma\, P(\sigma) = 1\,,$$

$$\int d\sigma\, P(\sigma)\sigma = \langle\sigma\rangle\,, \quad \rightarrow \text{ from } \quad d\sigma(\gamma p \to \rho p)/dt$$

$$\int d\sigma\, P(\sigma)\sigma^2 = \langle\sigma\rangle^2(1+\omega_\sigma) \quad \rightarrow \text{ from measured } \gamma \text{ diffract. dissociation into large masses, Chapin 1985}$$

- Shape like for pion, Blattel et al, 1993 + small-σ enhancement to take into account smaller size of ρ in $\gamma p \to pp$ than in $\sigma_{\pi N}$ $\rightarrow$

$$P(\sigma) = C\,\frac{1}{1+(\sigma/\sigma_0)^2}\,e^{-(\sigma/\sigma_0-1)^2/\Omega^2}$$



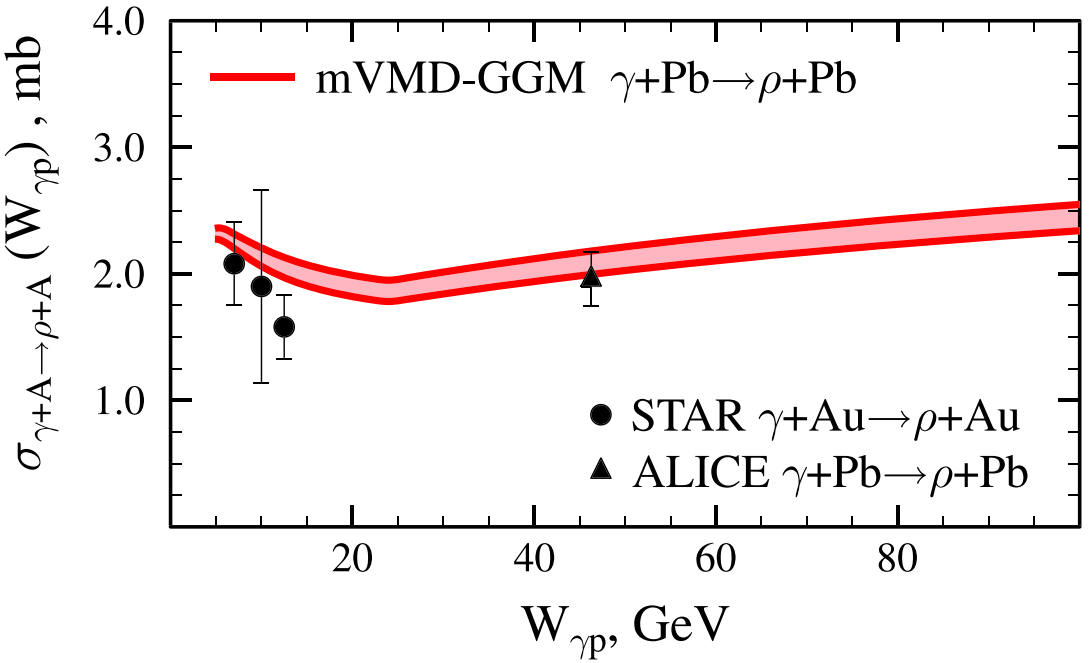
Photoproduction of ρ on Pb in mVMD+Gribov-Glauber model

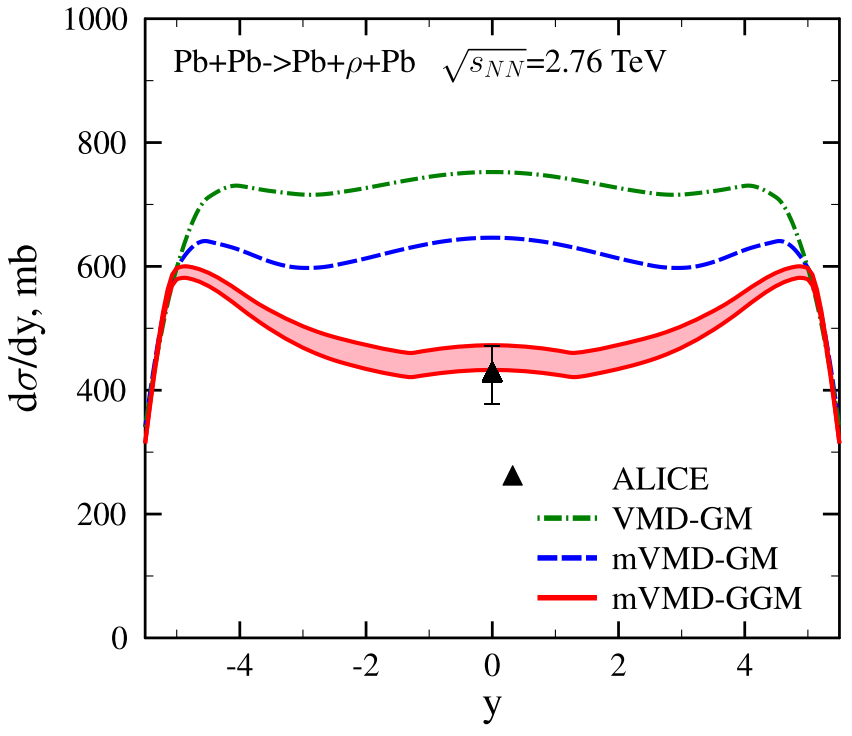
- With cross section fluctuations:

$$\sigma_{\gamma A\to\rho A}^{\text{mVMD-GGM}} = \left(\frac{e}{f_\rho}\right)^2 \int d^2\vec{b} \left| \int d\sigma\, P(\sigma) \left(1 - e^{-\frac{\sigma}{2} T_A(b)}\right) \right|^2$$

- "Two birds with one stone": we describe correctly the elementary $\gamma p \to \rho p$ cross section and include inelastic Gribov shadowing in $\sigma_{\gamma A\to\rho A}$

- $\to$ describe well normalization and W-dependence $\sigma_{\gamma A\to\rho A}$, Frankfurt, Guzey, Strikman, Zhalov, PLB 732 (2016) 51





Predictions for Run 2@LHC: ρ and ϕ mesons

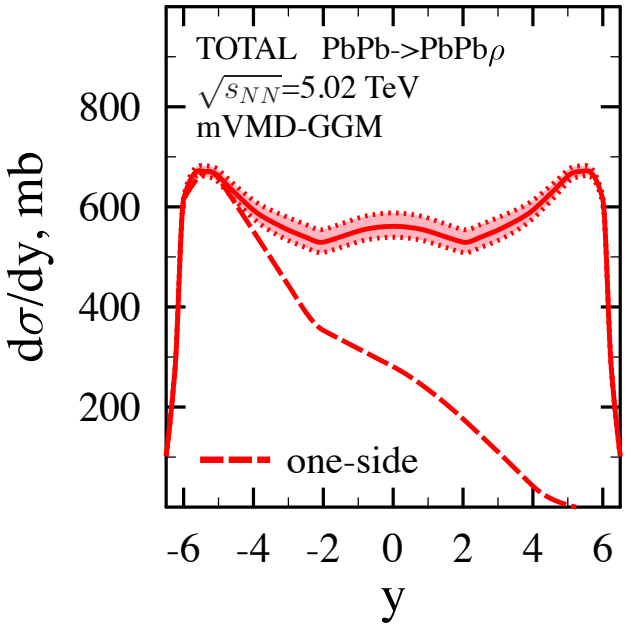
- Combination of mVMD and Gribov-Glauber models:

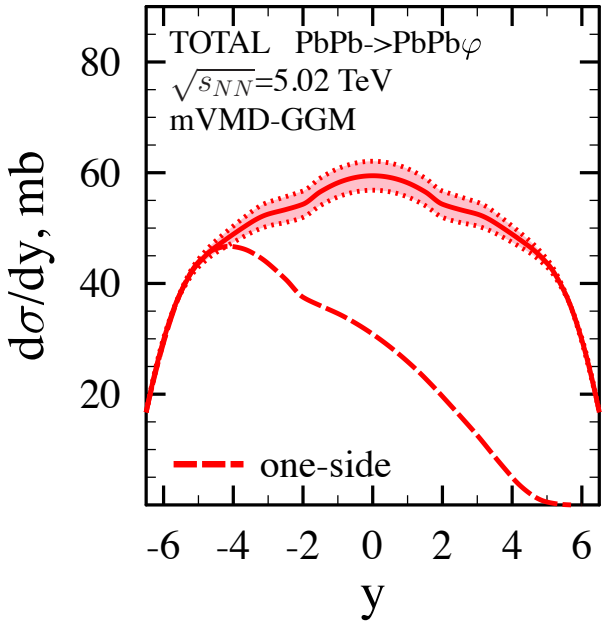
- ρ: P(σ) from data
- ϕ: P(σ) from $\sigma_{\phi N}$ (Donnachie, Landshoff, 1995) + constituent quark $\omega_\sigma^\phi = \frac{\sigma_{NN}}{\sigma_{\phi N}}\omega_\sigma^\phi$

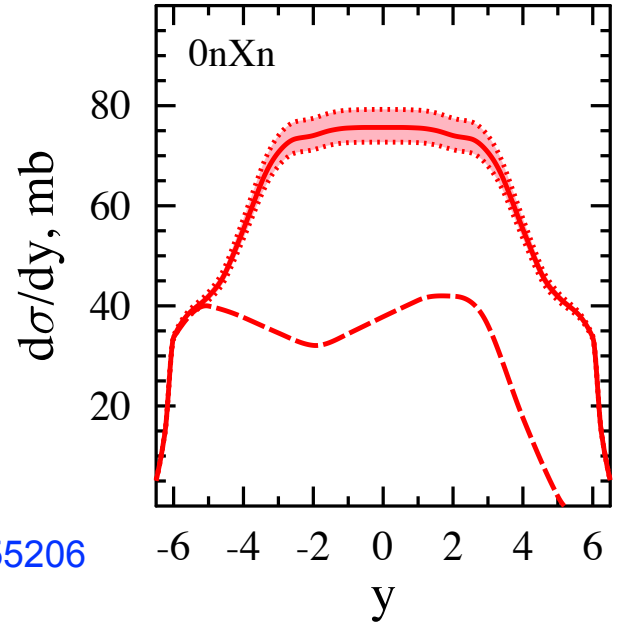
- "Ears" for ρ: effect of Reggeon in $\sigma_{\rho N}$

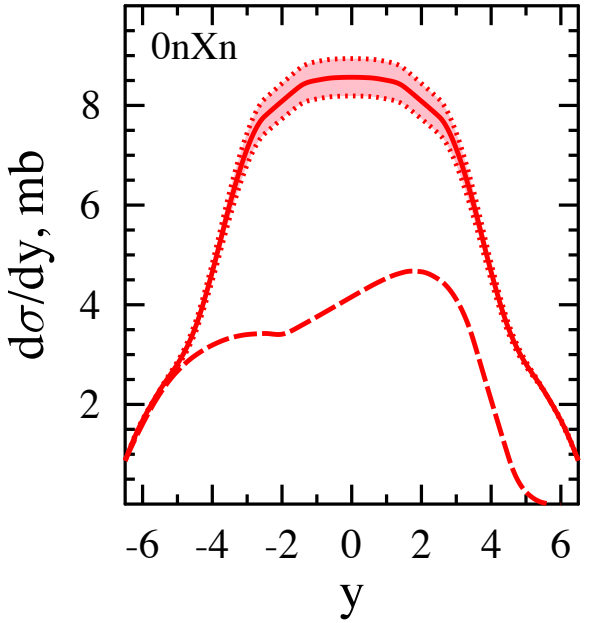
- Change of shape for 0nXn-channel due to large $W_{\gamma p}$ enhancement of photon flux

0nXn-channel: e.m. excitation of either of nuclei with forward emission > 1 neutron in ZDC









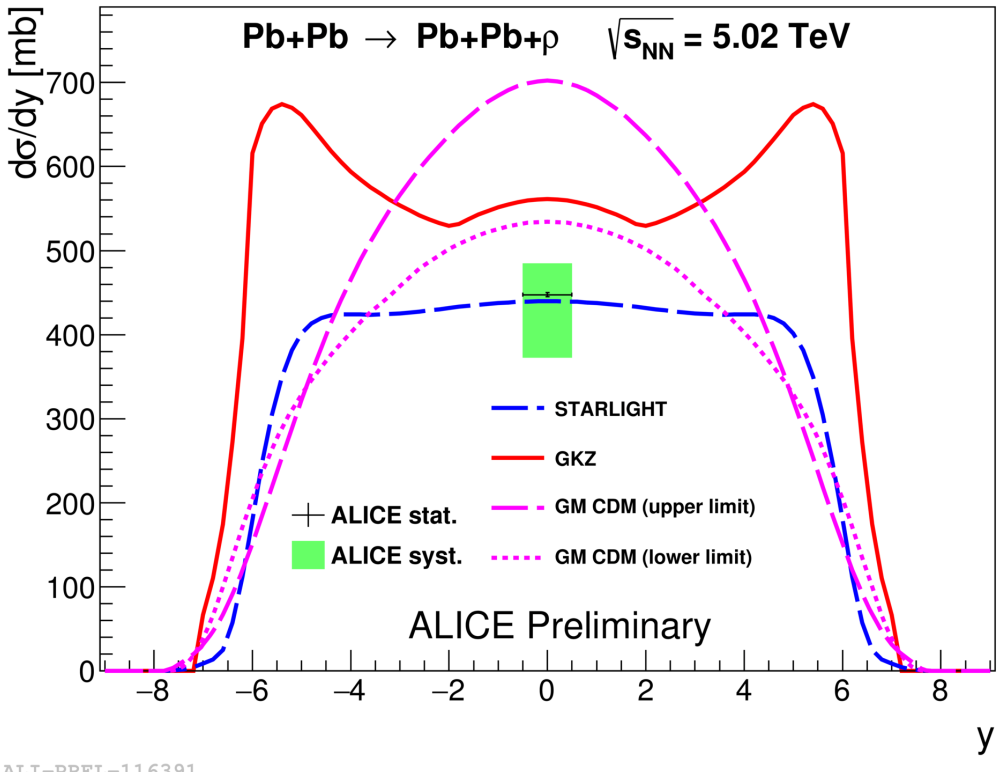
Guzey, Kryshen, Zhalov, PRC 93 (2016) 055206

News from QM2017 on ρ photoproduction on nuclei in Pb-Pb UPCs in Run 2

- Preliminary ALICE result on Pb-Pb UPCs at $\sqrt{s_{NN}}$=5.02 TeV: cross section is almost the same as in Run 1
- Cannot be described by our mVMD-GG approach and color dipole models
- Excellent description by STARlight

- $d\sigma/dy = (448 \pm 2(\text{stat})^{+38}_{-75}(\text{syst}))$ [mb]
- Predictions by **STARLIGHT** [2], Gonçalves and Machado using Color Dipole Model (**CDM**) [3,4] and Guzey, Kryshen Zhalov (**GKZ**) [5] reported
- Result compatible with STARLIGHT model

Different theoretical approaches predicts very different shapes of rapidity dependence.

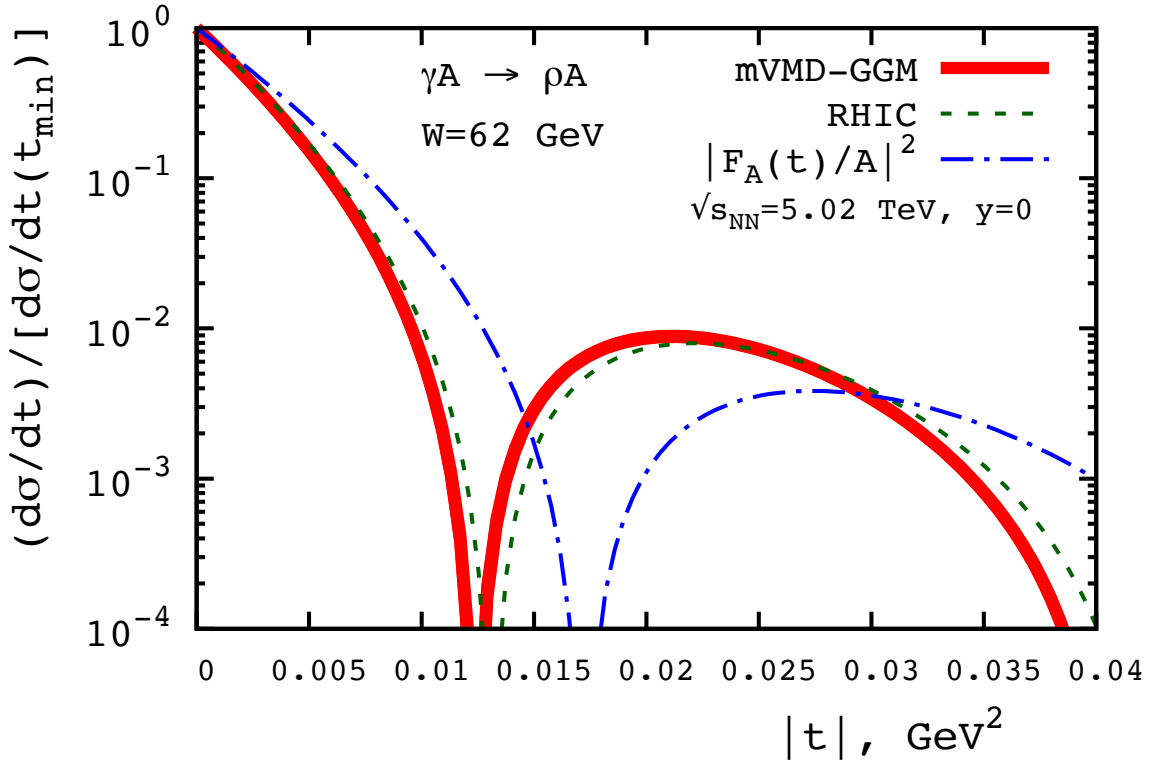


D. Horak (ALICE), poster at conference “Quark Matter 2017”, Feb 6-11, 2017

Nuclear shadowing effects t-dependence

- Nuclear shadowing does not only suppress $\gamma A \to \rho A$ cross section, but also shifts its t-dependence towards smaller |t| by ~14%, Guzey, Strikman, Zhalov, PRC 95 (2017) 055208

$$\frac{d\sigma^{\mathrm{mVMD-GGM}}_{\gamma A\to\rho A}(W_{\gamma p})}{dt} = \left(\frac{e}{f_\rho}\right)^2 \frac{1}{4\pi}\left|\int d^2\vec{b}\, e^{i\vec{q}_\perp \vec{b}} \int d\sigma P(\sigma)\left(1 - e^{-\frac{1}{2}(1-i\eta)\sigma T_A(b)}\right)\right|^2$$



- This trend does not seem to be supported by STAR result at $\sqrt{s_{NN}}$=200 GeV, arXiv: 1702.07705

Summary

• Coherent photoproduction of vector mesons on nuclei in UPCs@LHC allows one to study nuclear shadowing in soft and hard processes at unprecedentedly high energies.

• Photoproduction of ρ, ω, ϕ on nuclei tests the roles of hadronic fluctuations of the photon and inelastic nuclear shadowing.

• Inelastic (Gribov) nuclear shadowing is essential in describing the data on photoproduction of ρ on nuclei at W > 10 GeV.

• Preliminary ALICE Run 2 data on ρ photoproduction on nuclei shows unexpectedly large suppression → challenge for theory.

• For up-to-date info on physics of UPCs, see talks at recent workshop: INT workshop "Probing QCD in Photon-Nucleus Interactions at RHIC and LHC: the Path to EIC", Feb 13-17, 2017: http://www.int.washington.edu/talks/WorkShops/int_17_65W/