LOW-X 2015

VECTOR MESON PHOTOPRODUCTION - FROM CENTRAL TO ULTRAPERIPHERAL HEAVY ION COLLISIONS

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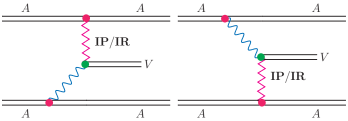
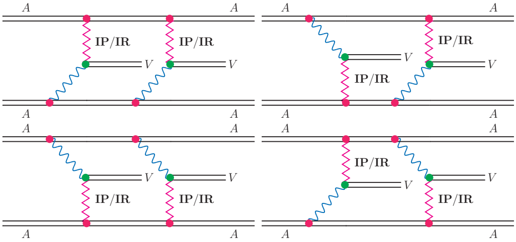
Main goal - Vector mesons production

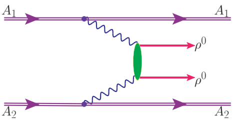
- Single ρ^0 & J/ψ production



- Double-scattering mechanism



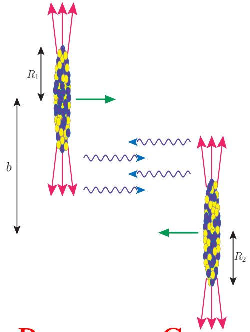
- $\gamma\gamma$ fusion



$\text{Br}(\rho^0\rho^0 \to \pi^+\pi^-\pi^+\pi^-) \simeq 100\%$

STAR, CMS & ALICE data

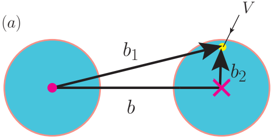
Equivalent Photon Approximation



The strong electromagnetic field is a source of photons that can induce electromagnetic reactions in ion-ion collisions.

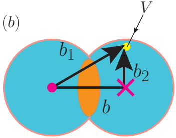
UltraPeripheral Collisions

$$b > R_{min} = R_1 + R_2$$

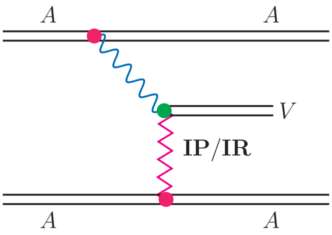


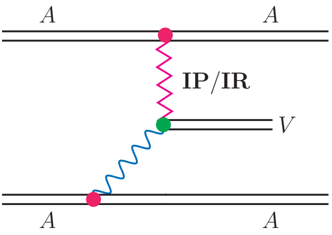
semi-CENTRAL Collisions

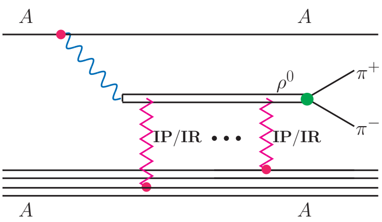
$$b \leq R_{min}$$

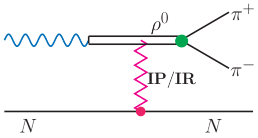


PHOTOPRODUCTION OF VECTOR MESON





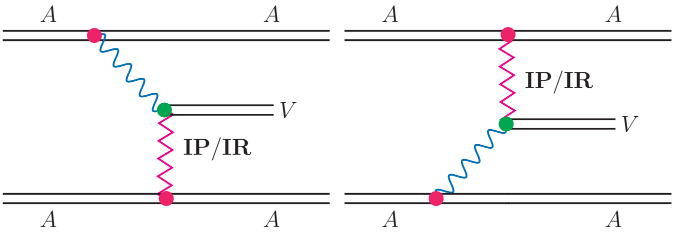




Parameters fixed to describe HERA data

we expect: $\frac{d\sigma(\gamma n \to Vn)}{dt} \approx \frac{d\sigma(\gamma p \to Vp)}{dt}$

Single vector meson production

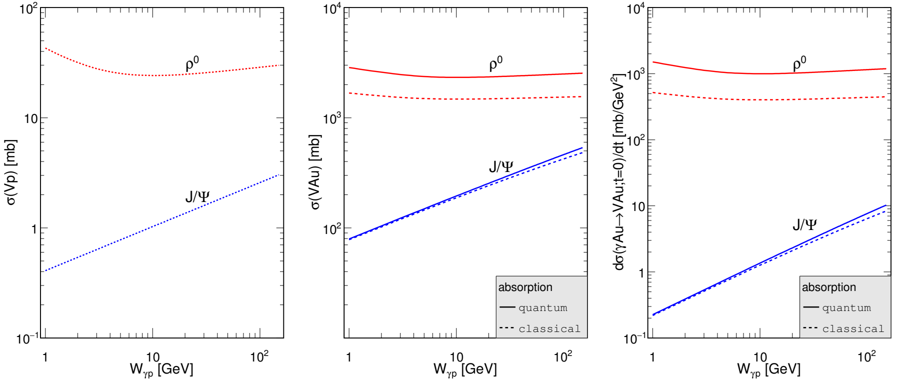


$$\frac{\mathrm{d}\sigma_{A_1 A_2 \to A_1 A_2 V}}{\mathrm{d}^2 b \mathrm{d}y} = \frac{\mathrm{d}P_{\gamma \mathbf{P}}(b,y)}{\mathrm{d}y} + \frac{\mathrm{d}P_{\mathbf{P}\gamma}(b,y)}{\mathrm{d}y} \quad (1)$$

$$\frac{\mathrm{d}P_{1/2}(b,y)}{\mathrm{d}y} = \omega_{1/2} N(\omega_{1/2}, b)\, \sigma_{\gamma A_{2/1} \to V A_{2/1}}(W_{\gamma A_{2/1}}) \quad (2)$$

- point-like $F(q) = 1$
- realistic $F(q) = \frac{4\pi}{q} \int \rho(r) \sin(qr)\, r dr$
- monopole $F(q) = \frac{\Lambda^2}{\Lambda^2 + q^2}$ $\quad \Lambda = \sqrt{\frac{6}{<r^2>}}$

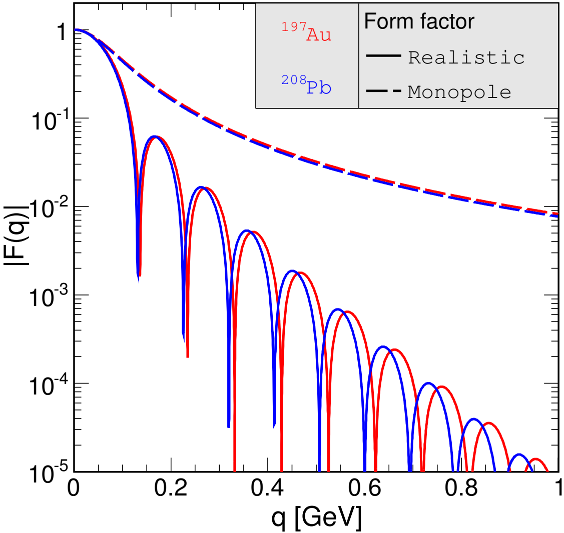
$\frac{d\sigma_{\gamma p\to Vp}(t=0)}{dt}$ ← HERA data



- $\sigma^{CM}_{tot}(VA) = \int d^2\mathbf{r}\,\left(1 - \exp\left(-\sigma_{tot}(Vp)\,T_A(\mathbf{r})\right)\right)$
- $\sigma^{QM}_{tot}(VA) = 2\int d^2\mathbf{r}\,\left(1 - \exp\left(-\frac{1}{2}\sigma_{tot}(Vp)\,T_A(\mathbf{r})\right)\right)$

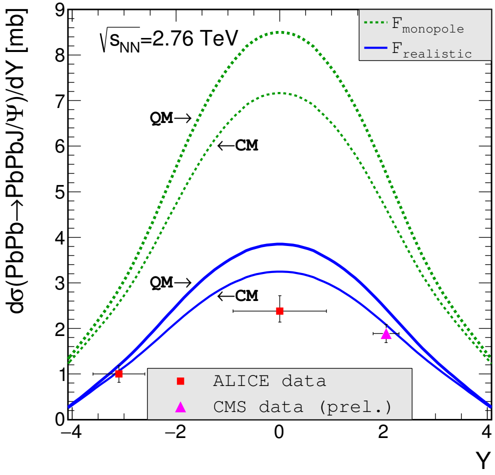
$$\sigma_{\gamma A\to VA}(W_{\gamma A_{2/1}}) = \frac{d\sigma_{\gamma A\to VA}(t=0)}{dt}\int_{-\infty}^{t_{max}} dt\,\left|F_A(t)\right|^2$$

Form factor

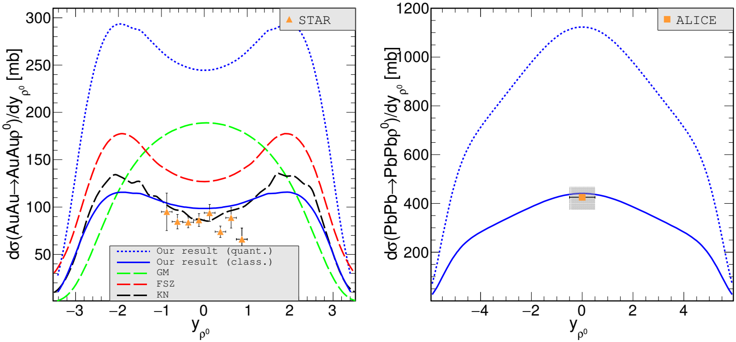


1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
|F(q)|
0
0.2
0.4
0.6
0.8
1
q [GeV]
^{197}Au
^{208}Pb
Form factor
Realistic
Monopole

J/ψ meson production

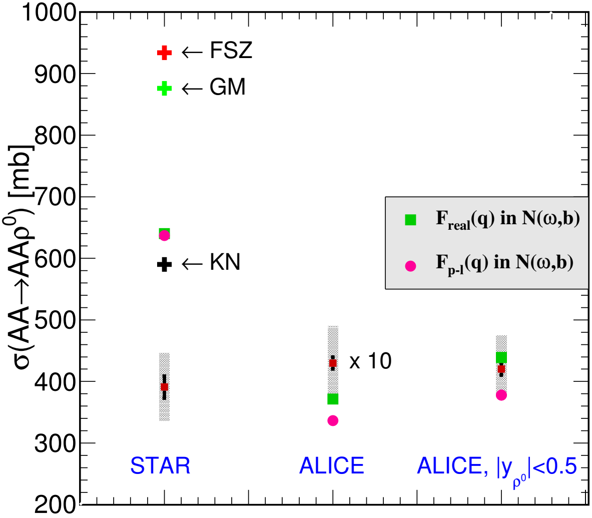


ρ^0 MESON PRODUCTION

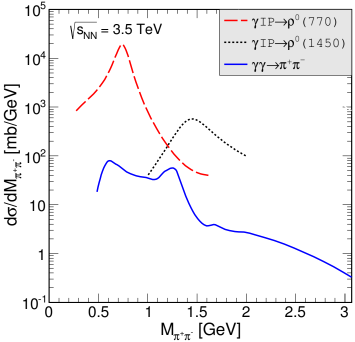


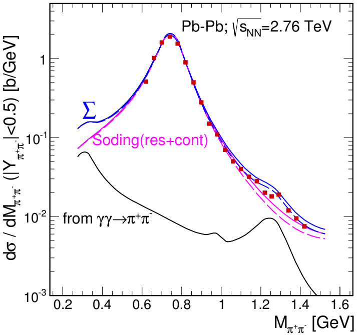
GM - V.P. Gonçalves and M.V.T. Machado, "The QCD pomeron in ultraperipheral heavy ion collisions. IV. Photonuclear production of vector mesons", Eur. Phys. J. **C40** (2005) 519,
FSZ - L. Frankfurt, M. Strikman and M. Zhalov, "Signals for black body limit in coherent ultraperipheral heavy ion collisions", Phys. Lett. **B537** (2002) 51,
KN - S. Klein and J. Nystrand, "Exclusive vector meson production in relativistic heavy ion collisions", Phys. Rev. **C60** (1999) 014903

Single ρ^0 meson production



ρ^0 production vs. Two-pion production





Reference:
M. Kłusek-Gawenda and A. Szczurek,
Phys. Rev. **C87** (2013) 054908
"$\pi^+\pi^-$ and $\pi^0\pi^0$ pair production in photon-photon and in ultraperipheral ultrarelativistic heavy ion collisions",

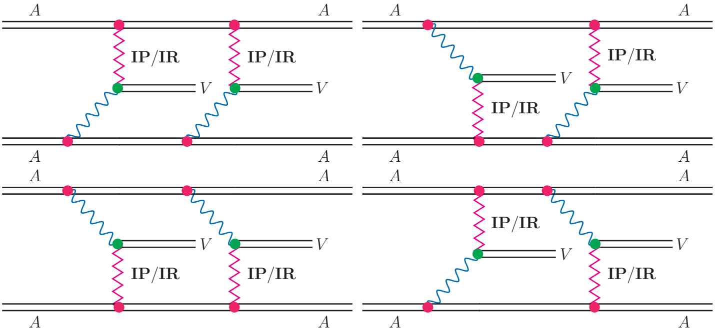
Drell-Söding+$f_2(1270)$

colored solid lines - $\Gamma_{\rho^0} = 150.2$ MeV

colored dashed lines - $\Gamma_{\rho^0} = 140$ MeV

ALICE data arXiv:1503.09177

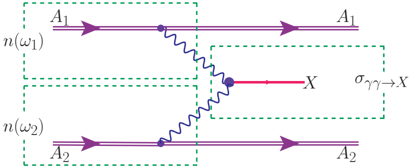
DOUBLE-SCATTERING MECHANISM



$$\frac{d\sigma_{A_1A_2\to A_1A_2\rho^0\rho^0}}{dy_1 dy_2} = \frac{1}{2}\int\left(\frac{dP_{\gamma\mathbf{P}}(b,y_1)}{dy_1} + \frac{dP_{\mathbf{P}\gamma}(b,y_1)}{dy_1}\right) \times \left(\frac{dP_{\gamma\mathbf{P}}(b,y_2)}{dy_2} + \frac{dP_{\mathbf{P}\gamma}(b,y_2)}{dy_2}\right) d^2b$$

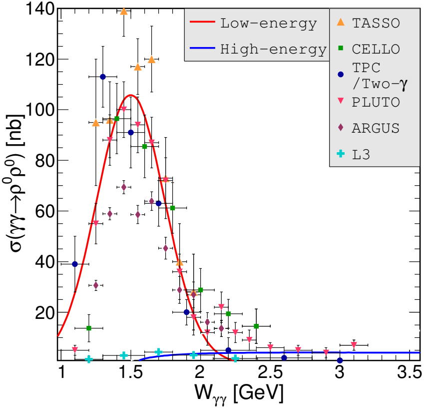
(ρ^0's have negligibly small transverse momenta)

$AA \to AA\rho^0\rho^0$ - $\gamma\gamma$ FUSION

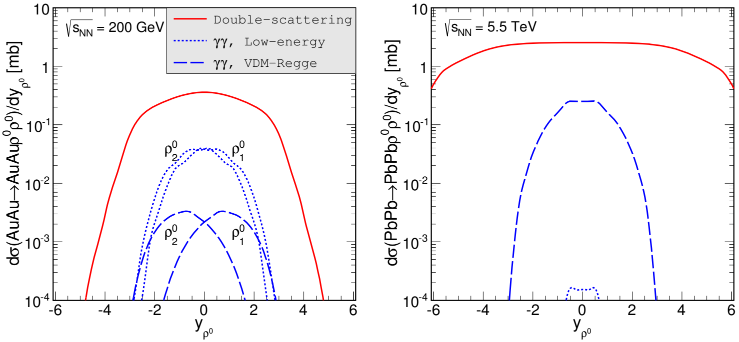


$$n(\omega) = \int_{R_{min}}^{\infty} 2\pi b \mathrm{d}b \, N(\omega, b)$$

Reference:
M. Kłusek, W. Schäfer and A. Szczurek, Phys.Lett. **B674** (2009) 92,
"Exclusive production of $\rho^0\rho^0$ pairs in $\gamma\gamma$ collisions at RHIC"
+ back-up slide



Double-scattering mechanism vs. $\gamma\gamma$ fusion



Reference:
M. Kłusek-Gawenda and A. Szczurek, Phys. Rev. **C89** (2014) 024912
"Double-scattering mechanism in the exclusive $AA \to AA\rho^0\rho^0$ reaction in ultrarelativistic collisions"

Smearing of ρ^0 mass

Drell-Söding contribution:

$$\mathcal{A}(m) = \mathcal{A_{BW}} \frac{\sqrt{m m_{\rho^0} \Gamma_{\rho^0}(m)}}{m^2 - m_{\rho^0}^2 + i m_{\rho^0} \Gamma_{\rho^0}(m)} + \mathcal{B}_{\pi\pi}$$

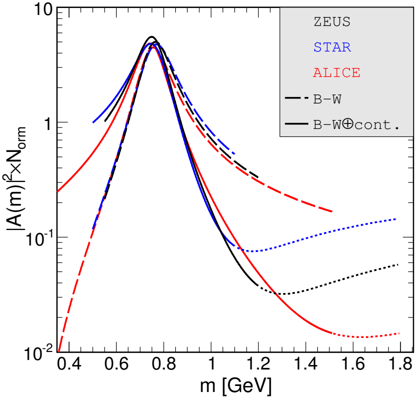
$$\Gamma_{\rho^0}(m) = \Gamma_{\rho^0} \frac{m_{\rho^0}}{m} \left(\frac{m^2 - 4m_\pi^2}{m_{\rho^0}^2 - 4m_\pi^2} \right)^{3/2}$$

Parameter	ZEUS	STAR	ALICE
m_{ρ^0} [GeV]	0.77 ± 0.002	0.775 ± 0.003	0.761 ± 0.0023
Γ_{ρ^0} [GeV]	0.146 ± 0.003	0.162 ± 0.007	0.1502 ± 5.5
$\left\lvert \frac{\mathcal{B}_{\pi\pi}}{\mathcal{A_{BW}}} \right\rvert$ [GeV$^{-1/2}$]	0.669	0.89 ± 0.08	0.5 ± 0.04
m [GeV]	$(0.55 - 1.2)$	$(0.5 - 1.1)$	$(0.28 - 1.512)$

SMEARING OF ρ^0 MASS

Drell-Söding contribution:

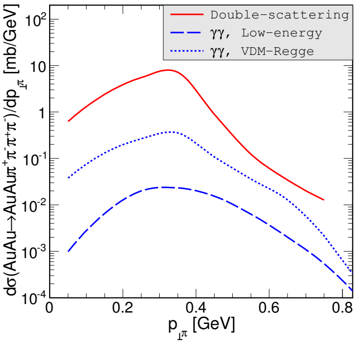
$\mathcal{A}$ … $+ \mathcal{B}_{\pi\pi}$ … $)$ … $3/2$

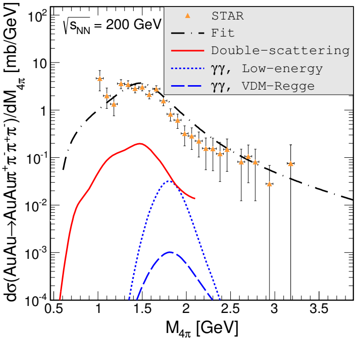


Paramete…		…3 / …7	ALICE
m_{ρ^0} [GeV…		…3	0.761 ± 0.0023
Γ_{ρ^0} [GeV…		…7	0.1502 ± 5.5
$\left\lvert \frac{\mathcal{B}_{\pi\pi}}{\mathcal{A}_{\mathcal{BW}}} \right\rvert$ [G…			0.5 ± 0.04
m [GeV]	$(0.55 - 1.2)$	$(0.5 - 1.1)$	$(0.28 - 1.512)$

$\pi^+\pi^-\pi^+\pi^-$ PRODUCTION @ RHIC

$|\eta_\pi| < 1$

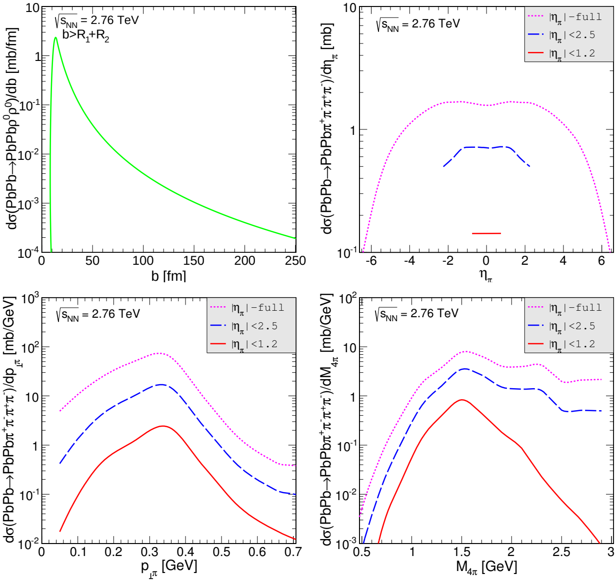




missing mechanisms:

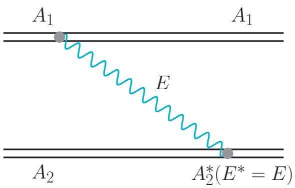
$AA \to AA\rho^0(1450) \to 4\pi$
$AA \to AA\rho^0(1700) \to 4\pi$ **?**

$\pi^+\pi^-\pi^+\pi^-$ production @ LHC

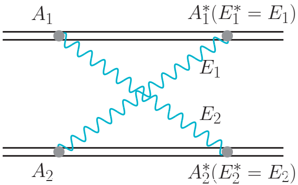


ELECTROMAGNETIC EXCITATION IN UPC

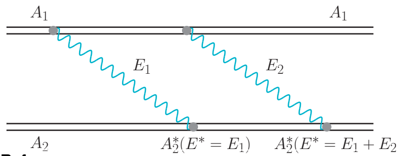
Single excitation



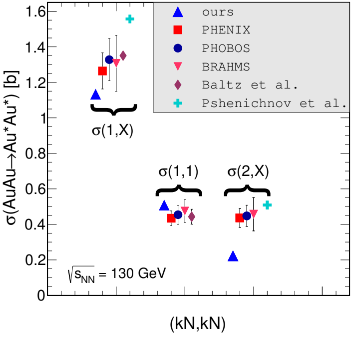
Mutual excitation



Double excitation

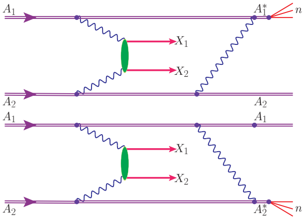


Reference:
M. Kłusek-Gawenda, M. Ciemała, W. Schäfer and A. Szczurek, Phys. Rev. **C89** (2014) 054907, ”Electromagnetic excitation of nuclei and neutron evaporation in ultrarelativistic ultraperipheral heavy ion collisions”

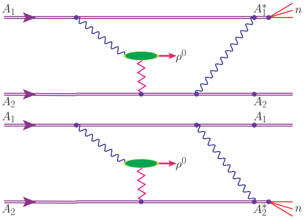


VECTOR MESON PRODUCTION WITH NUCLEAR EXCITATION

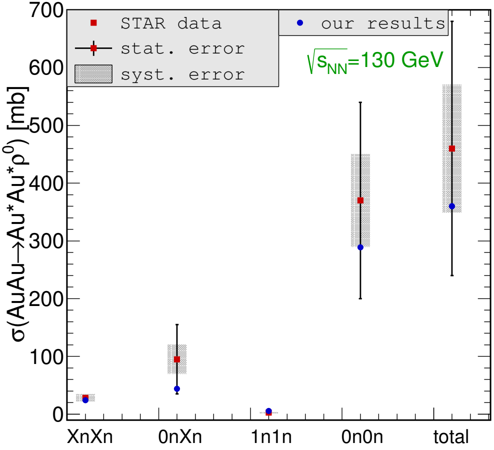
$$AA \to AA^*(kn)X_1X_2$$



$$AA \to AA^*(kn)\rho^0$$



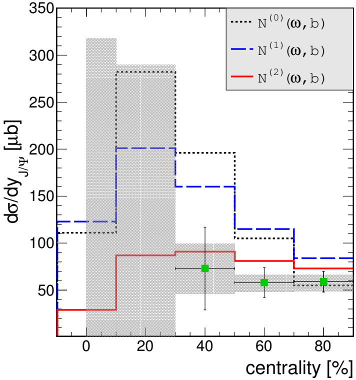
ρ^0 production in heavy ion UPC with nuclear excitation

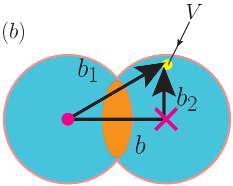


(very preliminary)

PbPb→PbPbJ/Ψ

- $N^{(0)}(\omega,b) = \frac{Z^2\alpha_{em}}{\pi^2}\left|\int u^2 J_1(u)\,\frac{F\left(\frac{\left(\frac{\omega b}{\gamma}\right)^2+u^2}{b^2}\right)}{\left(\frac{\omega b}{\gamma}\right)^2+u^2}\right|^2,$
- $N^{(1)}(\omega,b) = \int N^{(0)}(\omega,b_1)\,\frac{\theta(R_A-\mathbf{b_2})}{\pi R_A^2}\,\mathrm{d}^2 b_1\;,$
- $N^{(2)}(\omega,b) = \int N^{(0)}(\omega,b_1)\,\frac{\theta(R_A-\mathbf{b_2})\times\theta(\mathbf{b_1}-R_A)}{\pi R_A^2}\,\mathrm{d}^2 b_1\;.$





ALICE data:
talk given by Laura Massacrier at EDS Blois workshop, 29th June - 4th July 2015, Borgo, Corsica, France

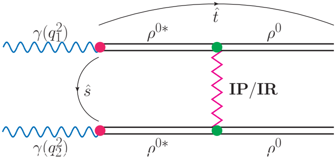
CONCLUSIONS

1. Impact parameter space approach
2. Realistic form factor
3. **UPC:** Good description of
   - STAR and ALICE data for $\rho^0(770)$ production
   - CMS and ALICE data for J/ψ production
4. **More central:** Good description of
   - ALICE data for J/ψ production
5. Smearing of ρ^0 meson
6. Comparison of four-pion production via $\rho^0\rho^0$ production with STAR data
   - $\gamma\gamma$ fusion
   - nuclear double-photoproduction (very large)
7. Coherent ρ^0 production in Au-Au UPC with electromagnetic dissociation of heavy ions at RHIC

Back-up slides

Elementary cross section $\gamma\gamma \to \rho^0\rho^0$

$$\sigma^{\text{high-energy}}_{\gamma\gamma\to\rho^0\rho^0} = \int_{\hat{t}_{min}(\hat{s})}^{\hat{t}_{max}(\hat{s})} \frac{d\sigma^{\text{high-energy}}_{\gamma\gamma\to\rho^0\rho^0}}{d\hat{t}} d\hat{t} \tag{3}$$



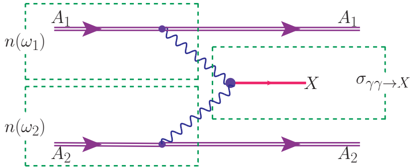
$$\frac{d\sigma^{\text{high-energy}}_{\gamma\gamma\to\rho^0\rho^0}}{d\hat{t}} = \frac{1}{16\pi\hat{s}} \left| \mathcal{M}_{\gamma\gamma\to\rho^0\rho^0}\left(\hat{s},\hat{t};q_1,q_2\right)\right|^2 \tag{4}$$

$$\mathcal{M}_{\gamma\gamma\to\rho^0\rho^0}\left(\hat{s},\hat{t};q_1,q_2\right) = C_{\gamma\to\rho^0} C_{\gamma\to\rho^0} \mathcal{M}_{\rho^{0*}\rho^{0*}\to\rho^0\rho^0}\left(\hat{s},\hat{t};q_1,q_2\right) \tag{5}$$

$$\mathcal{M}_{\rho^{0*}\rho^{0*}\to\rho^0\rho^0}\left(\hat{s},\hat{t};q_1,q_2\right) = \left(\eta_{\mathbf{P}}\left(\hat{s},\hat{t}\right) C_{\mathbf{P}} \left(\frac{\hat{s}}{s_0}\right)^{\alpha_{\mathbf{P}}\left(\hat{t}\right)-1} + \eta_{\mathbf{R}}\left(\hat{s},\hat{t}\right) C_{\mathbf{R}} \left(\frac{\hat{s}}{s_0}\right)^{\alpha_{\mathbf{R}}\left(\hat{t}\right)-1}\right)$$

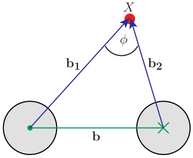
$$\times \hat{s} F\left(\hat{t};q_1^2\approx 0\right) F\left(\hat{t};q_2^2\approx 0\right) \tag{6}$$

Nuclear cross section



$$n(\omega) = \int_{R_{min}}^{\infty} 2\pi b \mathrm{d}b \, N(\omega, b) \qquad (7)$$

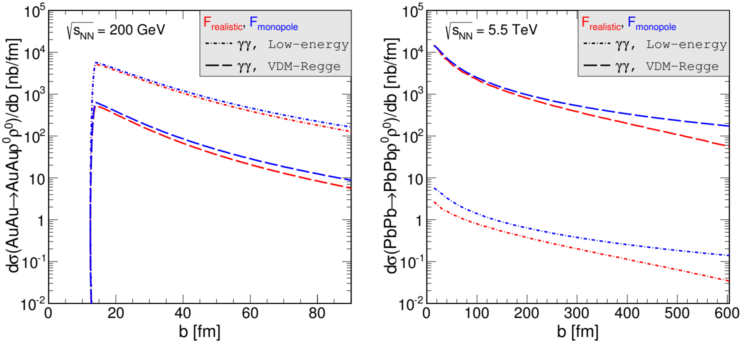
$$\begin{aligned} \sigma_{A_1 A_2 \to A_1 A_2 X} &= \int \mathrm{d}\omega_1 \, \mathrm{d}\omega_2 \, n(\omega_1) n(\omega_2) \sigma_{\gamma\gamma\to X}(\omega_1, \omega_2) \\ &= \ldots \\ &= \int N(\omega_1, \mathbf{b_1}) \, N(\omega_2, \mathbf{b_2}) S^2_{abs}(\mathbf{b}) \\ &\times \; \sigma_{\gamma\gamma\to X}\left(\sqrt{s_{A_1 A_2}}\right) \\ &\times \; 2\pi b \mathrm{d}b \, \mathrm{d}\overline{b}_x \, \mathrm{d}\overline{b}_y \, \frac{W_{\gamma\gamma}}{2} \mathrm{d}W_{\gamma\gamma} \, \mathrm{d}Y_X \qquad (8) \end{aligned}$$



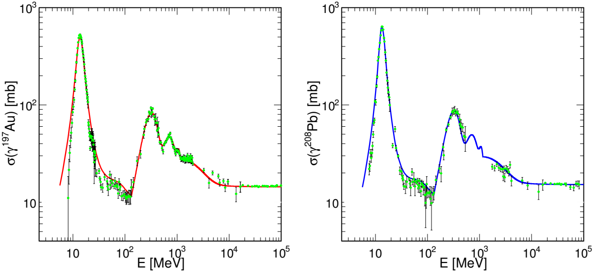
AA→AA$\rho^0\rho^0$ - form factor

$N(\omega_{1/2}, \mathbf{b}_{1/2})$ depends on the form factor

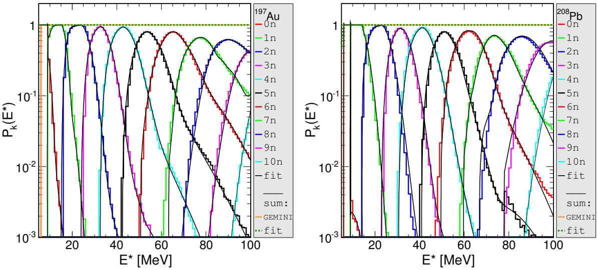
- realistic
- monopole



Photoabsorption $\sigma(\gamma A \to A) \downarrow$



Probability of neutron multiplicity ↓



Excitation function $\gamma^{A}X \rightarrow kn^{A-1}X \downarrow$