

EPS-HEP 2015

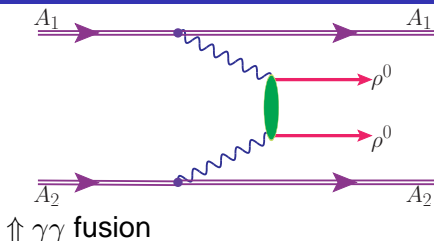
DOUBLE-SCATTERING MECHANISM OF PRODUCTION OF TWO ρ^0 MESONS IN ULTRAPERIPHERAL, ULTRARELATIVISTIC HEAVY ION COLLISIONS

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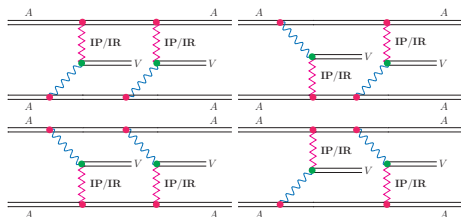
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ρ^0 MESONS PRODUCTION



nuclear photoproduction \downarrow



1 Equivalent photon approximation

- $\gamma\gamma \rightarrow \rho^0\rho^0$
 - low-energy bump
 - VDM-Regge
- form factor

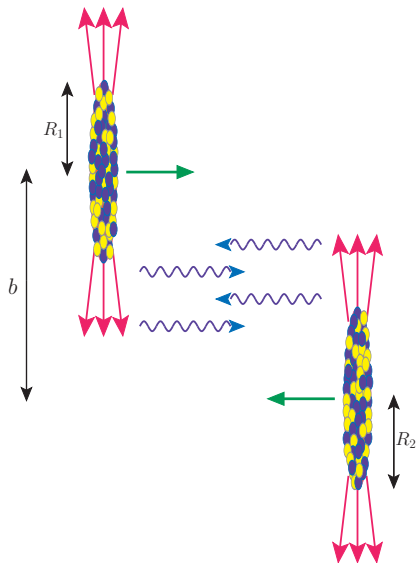
2 ρ^0 production

- ρ^0 mass smearing
- STAR & ALICE data

3 $\rho^0\rho^0$ production

$$\rightarrow \pi^+\pi^-\pi^+\pi^-$$

EQUIVALENT PHOTON APPROXIMATION

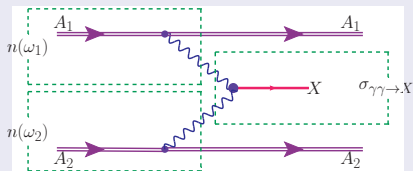


The strong electromagnetic field
is a source of photons
that induce electromagnetic
reactions in ion-ion
collisions.

ULTRAPERIPHERAL COLLISIONS

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

NUCLEAR CROSS SECTION



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

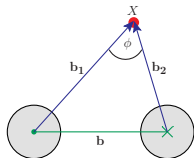
$$\sigma_{A_1 A_2 \rightarrow A_1 A_2 X} = \int d\omega_1 d\omega_2 n(\omega_1) n(\omega_2) \sigma_{\gamma\gamma \rightarrow X}(\omega_1, \omega_2)$$

$$= \dots$$

$$= \int N(\omega_1, \mathbf{b}_1) N(\omega_2, \mathbf{b}_2) S_{abs}^2(\mathbf{b})$$

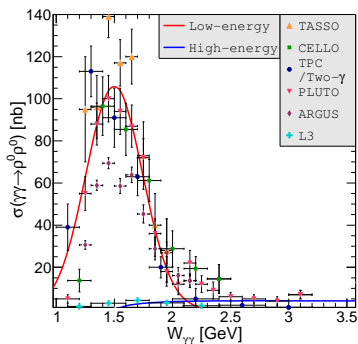
$$\times \sigma_{\gamma\gamma \rightarrow X}(\sqrt{s_{A_1 A_2}})$$

$$\times 2\pi b db d\bar{b}_x d\bar{b}_y \frac{W_{\gamma\gamma}}{2} dW_{\gamma\gamma} dY_X$$



ELEMENTARY CROSS SECTION

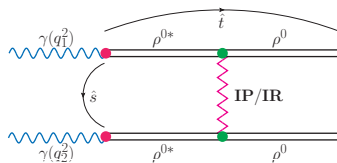
$$\bullet \sigma_{\gamma\gamma \rightarrow \rho^0 \rho^0}^{\text{low-energy}}(W_{\gamma\gamma})$$



$$\bullet \sigma_{\gamma\gamma \rightarrow \rho^0 \rho^0}^{\text{high-energy}} = \int_{\hat{t}_{\min}(\hat{s})}^{\hat{t}_{\max}(\hat{s})} \frac{d\sigma_{\gamma\gamma \rightarrow \rho^0 \rho^0}^{\text{high-energy}}}{d\hat{t}} d\hat{t}$$

$$\frac{d\sigma_{\gamma\gamma \rightarrow \rho^0 \rho^0}^{\text{high-energy}}}{d\hat{t}} = \frac{1}{16\pi\hat{s}^2} \underbrace{\left| \mathcal{M}_{\gamma\gamma \rightarrow \rho^0 \rho^0}(\hat{s}, \hat{t}; q_1, q_2) \right|^2}_{C_{\gamma \rightarrow \rho^0} C_{\gamma \rightarrow \rho^0} \mathcal{M}_{\rho^{0*} \rho^{0*} \rightarrow \rho^0 \rho^0}(\hat{s}, \hat{t}; q_1, q_2)}$$

$$\left(\eta_{\mathbf{P}}(\hat{s}, \hat{t}) C_{\mathbf{P}} \left(\frac{\hat{s}}{s_0} \right)^{\alpha_{\mathbf{P}}(\hat{t})-1} + \eta_{\mathbf{R}}(\hat{s}, \hat{t}) C_{\mathbf{R}} \left(\frac{\hat{s}}{s_0} \right)^{\alpha_{\mathbf{R}}(\hat{t})-1} \right) \times \hat{s} F(\hat{t}; q_1^2 \approx 0) F(\hat{t}; q_2^2 \approx 0)$$

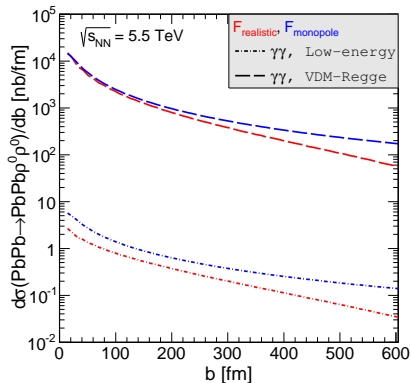
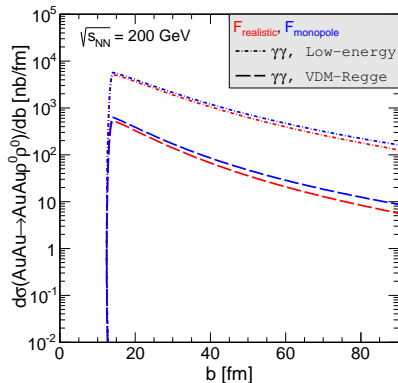


Reference: M. Klusek, W. Schäfer and A. Szczurek "Exclusive production of $\rho^0 \rho^0$ pairs in $\gamma\gamma$ collisions at RHIC", Phys.Lett. **B674** (2009) 92

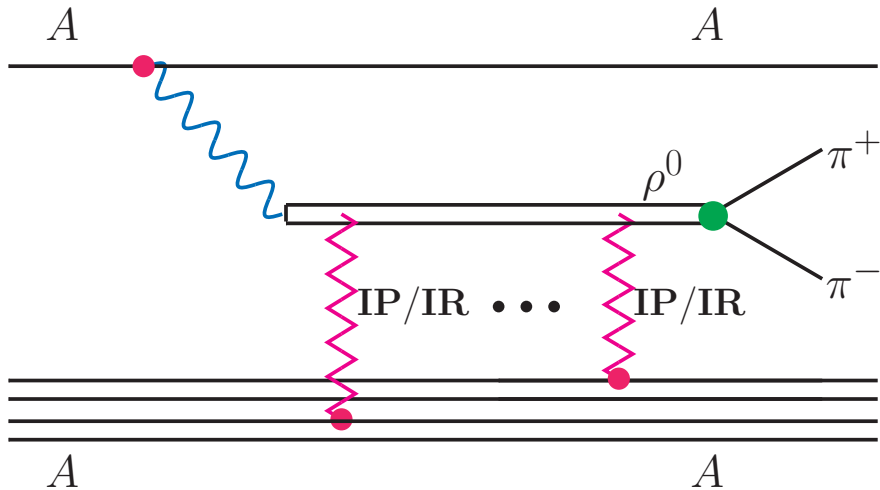
AA \rightarrow AA $\rho^0 \rho^0$ - FORM FACTOR

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

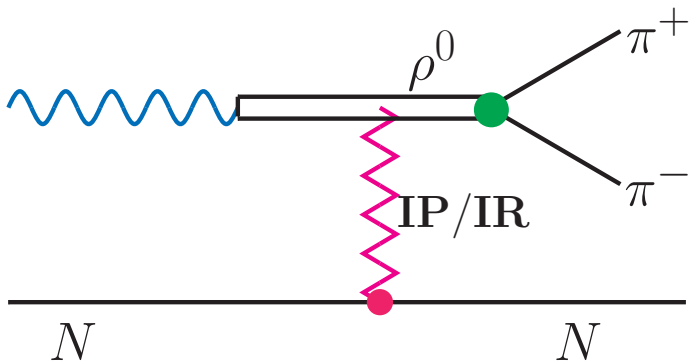
- realistic
- monopole



$$AA \rightarrow AA\rho^0$$



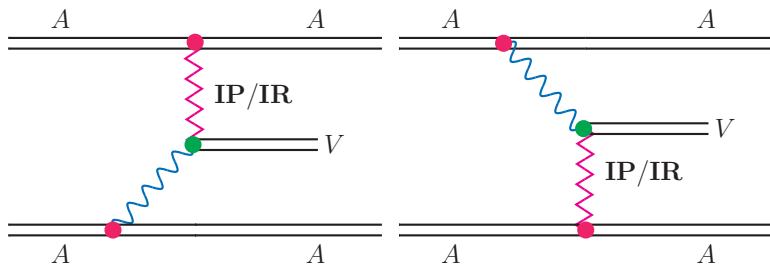
$$\gamma N \rightarrow \rho^0 N$$



$$N = n, p$$

Parameters fixed to describe **HERA data**:

we expect:
$$\frac{d\sigma(\gamma n \rightarrow \rho^0 n)}{dt} \approx \frac{d\sigma(\gamma p \rightarrow \rho^0 n)}{dt}$$

SINGLE ρ^0 MESON PRODUCTION

$$\frac{d\sigma_{A_1 A_2 \rightarrow A_1 A_2 V}}{d^2 b dy} = \frac{dP_{\gamma P}(b, y)}{dy} + \frac{dP_{P\gamma}(b, y)}{dy}$$

$$P_{1/2}(b, y) = \omega_{1/2} \tilde{N}(\omega_{1/2}, b) \sigma_{\gamma A_{2/1} \rightarrow V A_{2/1}}(W_{\gamma A_{2/1}})$$

$$\sigma_{\gamma A \rightarrow \rho^0 A} = \frac{d\sigma_{\gamma A \rightarrow \rho^0 A}(t=0)}{dt} \int_{-\infty}^{t_{\max}} dt \left| F_A(t) \right|^2$$

nuclear form factor

A SEMI-CLASSICAL MODEL FOR $\gamma A \rightarrow \rho^0 A$ REACTION

$$\sigma_{\gamma A \rightarrow \rho^0 A} = \frac{d\sigma_{\gamma A \rightarrow \rho^0 A}(t=0)}{dt} \int_{-\infty}^{t_{\max}} dt |F_A(t)|^2 \frac{d\sigma_{\gamma A \rightarrow \rho^0 A}(t=0)}{dt} = \frac{\alpha_{em} \sigma_{tot}^2(\rho^0 A)}{4f_{\rho^0}^2}$$

- quasi-Glauber (classical Glauber):

$$\sigma_{tot}(\rho^0 A) = \int d^2\mathbf{r} \left(1 - \exp\left(-\sigma_{tot}(\rho^0 p) T_A(\mathbf{r})\right) \right)$$

- quantum mechanical Glauber:

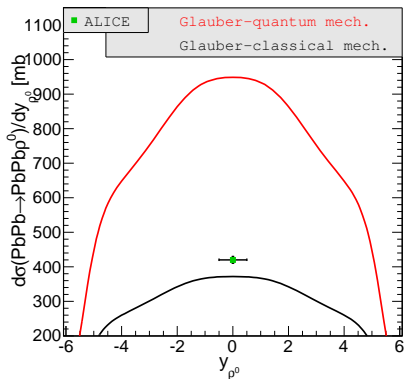
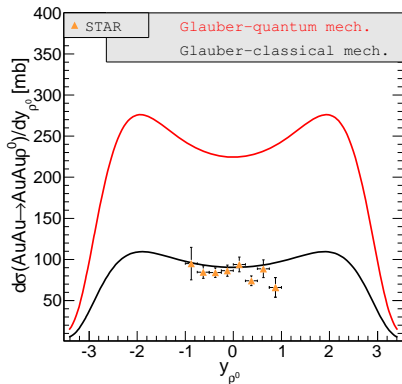
$$\sigma_{tot}^{qm}(\rho^0 A) = 2 \int d^2\mathbf{r} \left(1 - \exp\left(-\frac{1}{2} \sigma_{tot}(\rho^0 p) T_A(\mathbf{r})\right) \right)$$

$$\text{nucleus thickness: } T_A(\mathbf{r}) = \int dz \rho_A \left(\sqrt{|\mathbf{r}|^2 + z^2} \right)$$

$$\sigma_{tot}^2(\rho^0 p) = 16\pi \frac{d\sigma_{\rho^0 p \rightarrow \rho^0 p}(t=0)}{dt} \frac{d\sigma_{\rho^0 p \rightarrow \rho^0 p}(t=0)}{dt} = \frac{f_{\rho^0}^2}{4\pi\alpha_{em}} \frac{d\sigma_{\gamma p \rightarrow \rho^0 p}(t=0)}{dt}$$

$$\text{(VDM)} \frac{d\sigma_{\gamma p \rightarrow \rho^0 p}(t=0)}{dt} = B_{\rho^0} (XW^\epsilon + YW^{-\eta}) \quad \leftarrow \text{HERA data}$$

AA \rightarrow AA ρ^0 VS GLAUBER MODEL



SMEARING OF ρ^0 MASS

$$\frac{d\sigma_{AA \rightarrow AA\rho^0}}{dm dy} = f(m) \frac{d\sigma_{AA \rightarrow AA\rho^0}(y, m)}{dy}$$

$$f(m) = \frac{|\mathcal{A}(m)|^2 N_{orm}}{\int |\mathcal{A}(m)|^2 N_{orm} dm}$$

$$\int N_{orm} |\mathcal{A}(m)|^2 dm = 1$$

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

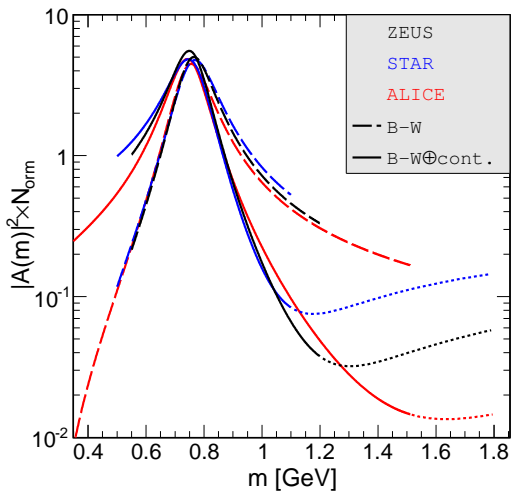
$$\text{running width: } \Gamma_{\rho^0}(m) = \Gamma_{\rho^0} \frac{m_{\rho^0}}{m} \left(\frac{m^2 - 4m_{\pi}^2}{m_{\rho^0}^2 - 4m_{\pi}^2} \right)^{3/2}$$

SMEARING OF ρ^0 MASS

$$A(m) = \mathcal{A}_{B\mathcal{W}} \frac{\sqrt{mm_{\rho^0}\Gamma_{\rho^0}(m)}}{m^2 - m_{\rho^0}^2 + im_{\rho^0}\Gamma_{\rho^0}(m)} + \mathcal{B}_{\pi\pi}$$

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

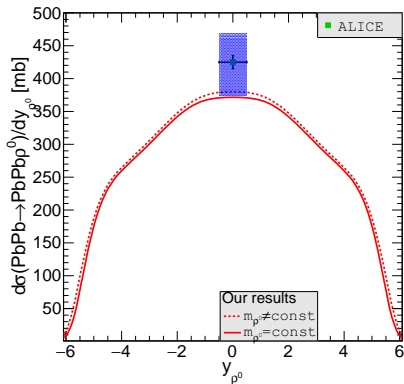
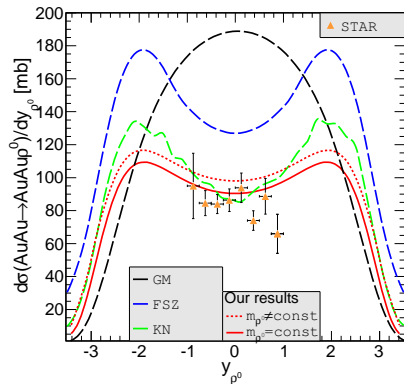
Parameter	ZEUS	STAR	ALICE
m_{ρ^0} [GeV]	0.77 ± 0.002	0.775 ± 0.003	0.761 ± 0.0023
Γ_{ρ^0} [GeV]	0.146 ± 0.003	0.162 ± 0.007	0.1502 ± 5.5
$\left \frac{\mathcal{B}_{\pi\pi}}{\mathcal{A}_{B\mathcal{W}}} \right $ [GeV $^{-1/2}$]	0.669	0.89 ± 0.08	0.5 ± 0.04
m [GeV]	(0.55 – 1.2)	(0.5 – 1.1)	(0.28 – 1.512)

SMEARING OF ρ^0 MASS $3\pi\pi$

Parameter
m_{ρ^0} [GeV]
Γ_{ρ^0} [GeV]
$\left \frac{\mathcal{B}_{\pi\pi}}{\mathcal{A}_{BW}} \right $ [C]
m [GeV]

ALICE

 0.761 ± 0.0023 0.1502 ± 5.5 0.5 ± 0.04 $(0.28 - 1.512)$

SINGLE ρ^0 MESON PRODUCTION

SINGLE ρ^0 MESON PRODUCTION

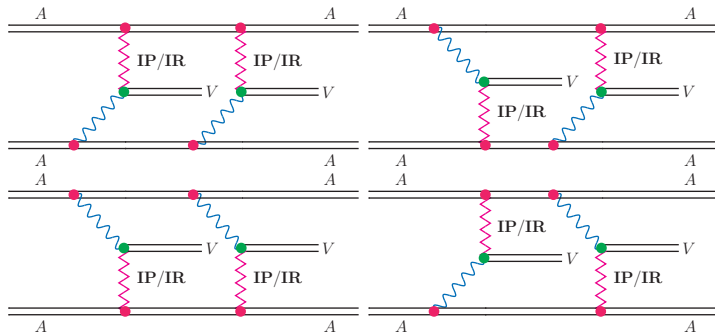
GM	FSZ	KN	Our result		Experimental data
			$m_{\rho^0} = \text{const}$	$m_{\rho^0} \neq \text{const}$	
	$\sqrt{s_{NN}} = 130 \text{ GeV}; \text{ full } y_{\rho^0} $				STAR
	490		359	407	$370 \pm 170 \pm 80$
	$\sqrt{s_{NN}} = 130 \text{ GeV}; y_{\rho^0} < 1$				STAR
	140		130	143	$106 \pm 5 \pm 14$
	$\sqrt{s_{NN}} = 200 \text{ GeV}; \text{ full } y_{\rho^0} $				STAR
876	934	590	590	646	$391 \pm 18 \pm 55$
	$\sqrt{s_{NN}} = 2.76 \text{ TeV}; \text{ full } y_{\rho^0} $				ALICE
			3309	3405	$4200 \pm 100^{+500}_{-600}$
	$\sqrt{s_{NN}} = 2.76 \text{ TeV}; y_{\rho^0} < 0.5$				ALICE
			371	380	$425 \pm 10^{+42}_{-50}$

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,

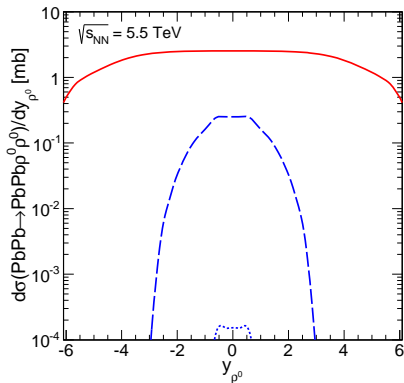
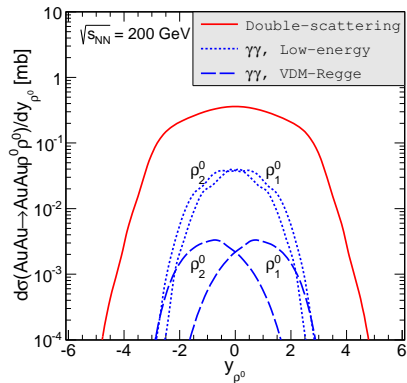
KN - S. Klein and J. Nystrand, "Exclusive vector meson production in relativistic heavy ion collisions", Phys. Rev. **C60** (1999) 014903

DOUBLE-SCATTERING MECHANISM

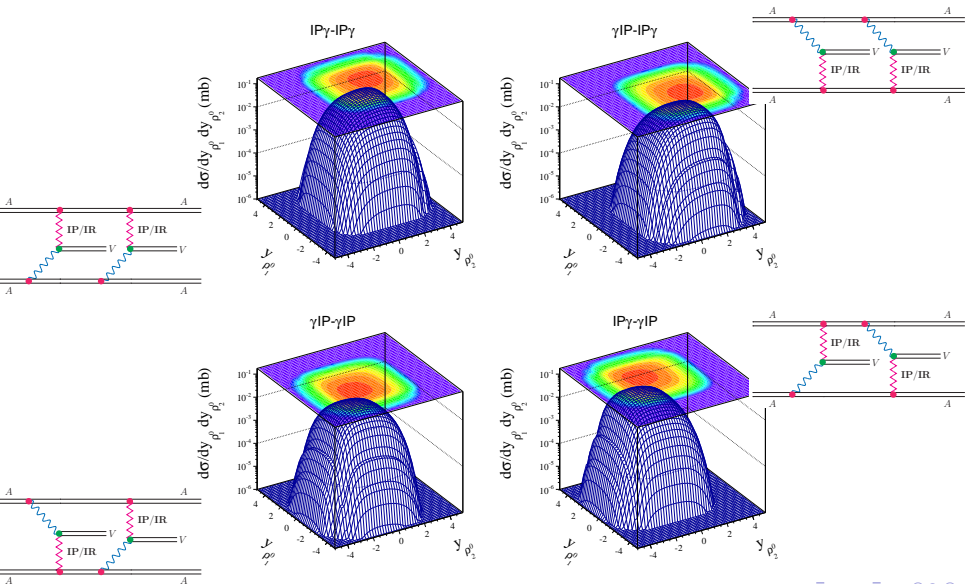


$$\frac{d\sigma_{A_1 A_2 \rightarrow A_1 A_2 \rho^0 \rho^0}}{dy_1 dy_2} = \frac{1}{2} \int \left(\frac{dP_{\gamma \mathbf{P}}(b, y_1)}{dy_1} + \frac{dP_{\mathbf{P} \gamma}(b, y_1)}{dy_1} \right) \times \left(\frac{dP_{\gamma \mathbf{P}}(b, y_2)}{dy_2} + \frac{dP_{\mathbf{P} \gamma}(b, y_2)}{dy_2} \right) d^2 b$$

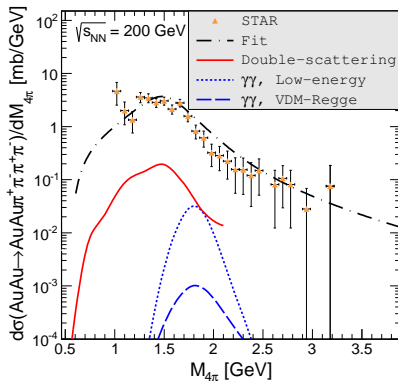
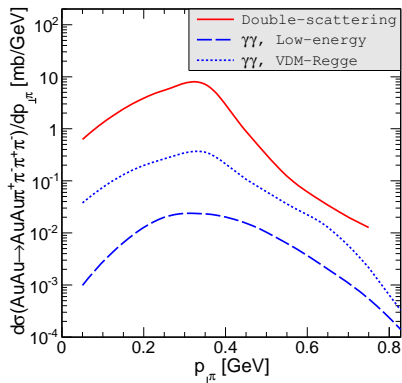
(ρ^0 's have negligibly small transverse momenta)

DOUBLE-SCATTERING MECHANISM VS $\gamma\gamma$ FUSION

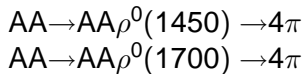
DOUBLE-SCATTERING MECHANISM



DOUBLE-SCATTERING MECHANISM AT RHIC

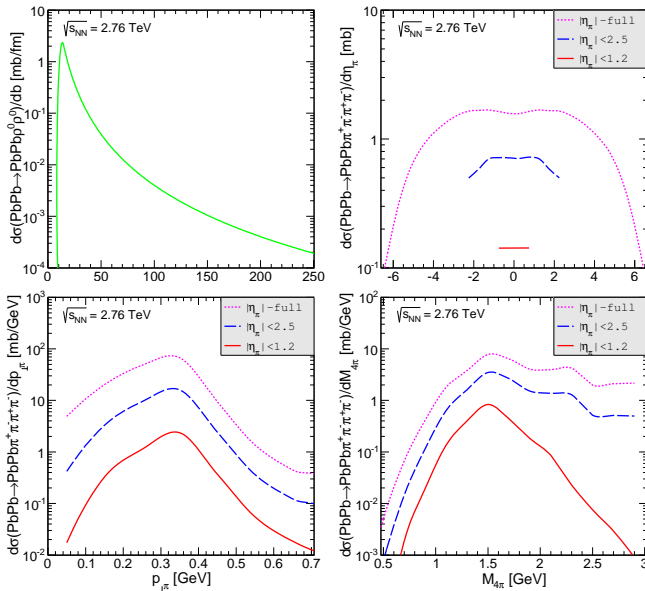


missing mechanisms:



?

DOUBLE-SCATTERING MECHANISM AT LHC



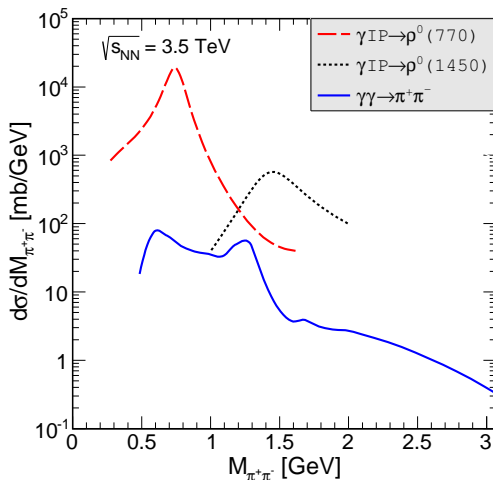
COMPARISON OF THE MECHANISMS

Energy	mechanism	σ_{tot} [mb]
RHIC ($\sqrt{s_{NN}} = 200$ GeV)	double-scattering	1.6
— —	$\rho^0\rho^0$ in $\gamma\gamma$ fusion	0.1
— —	$\pi^+\pi^-\pi^+\pi^-$ in $\gamma\gamma$ fusion	0.1

Reference: M. Kłusek-Gawenda and A. Szczurek "Double-scattering mechanism in the exclusive $AA \rightarrow AA\rho^0\rho^0$ reaction in ultrarelativistic collisions",

Phys. Rev. **C89** (2014) 024912

TWO-PION PRODUCTION



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

TWO-PION PRODUCTION

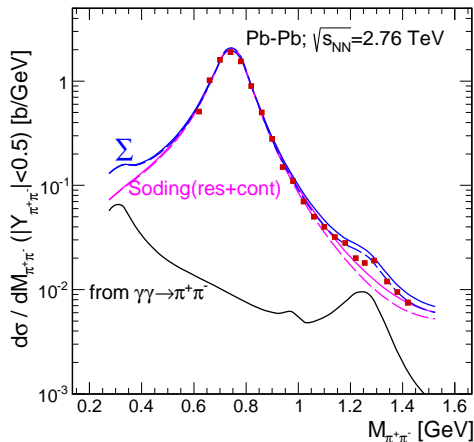
- Impact parameter space approach
- Smearing of ρ^0 meson
- Good description of STAR and ALICE data for single- ρ^0 (770) production

Drell-Söding+ $f_2(1270)$

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

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

ALICE data arXiv:1503.09177



CONCLUSIONS

- Comparison of four-pion production via $\rho^0\rho^0$ production
 - $\gamma\gamma$ fusion
 - nuclear double-photoproduction (**very large**)
 with STAR data
 - Missing contributions (?)
 - $\rho^0(1450)$
 - $\rho^0(1700)$
 - Multiple Coulomb excitations associated with $\rho^0\rho^0$ production may cause additional excitation of one or both nuclei to the giant resonance region (**can be calculated**)
- Reference:** M. Kłusek-Gawenda, M. Ciemala, W. Schäfer and A. Szczurek
 "Electromagnetic excitation of nuclei and neutron evaporation in ultrarelativistic ultraperipheral heavy ion collisions"
 Phys. Rev. **C89** (2014) 054907

Thank You

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Thank You