EDS Blois 2015

Double scattering production of two ρ^0 mesons in UPC

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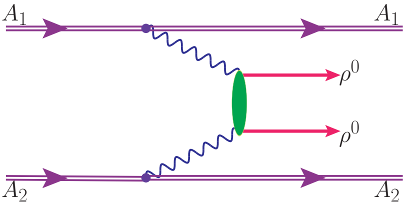
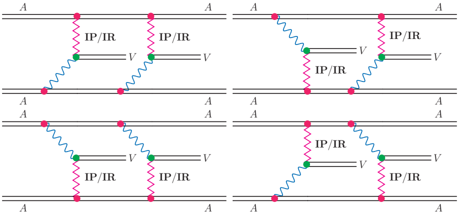
ρ^0 mesons production



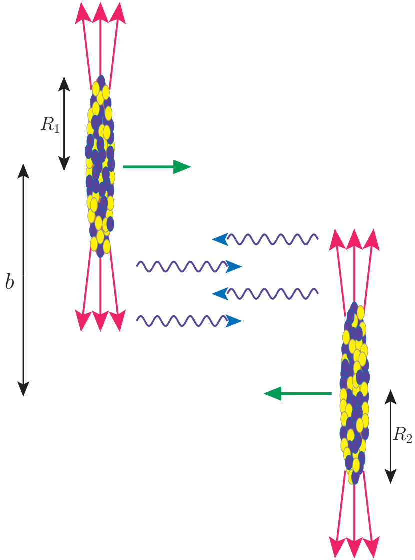
$\Uparrow$ $\gamma\gamma$ fusion

nuclear photoproduction $\Downarrow$



1. Equivalent photon approximation
   - $\gamma\gamma \to \rho^0\rho^0$
     - low-energy bump
     - VDM-Regge
   - form factor
2. ρ^0 production
   - ρ^0 mass smearing
   - STAR & ALICE data
3. $\rho^0\rho^0$ production $\to \pi^+\pi^-\pi^+\pi^-$

Equivalent photon approximation

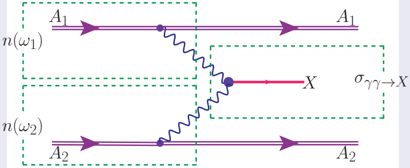


The strong electromagnetic field
is a source of photons
that induce electromagnetic reactions in ion-ion collisions.

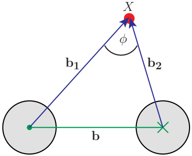
UltraPeriheral Collisions

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

NUCLEAR CROSS SECTION



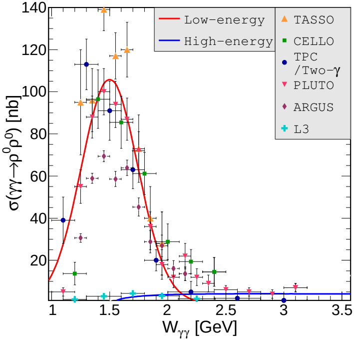
$$n(\omega) = \int_{R_{min}}^{\infty} 2\pi b \mathrm{d}b \, N(\omega, b)$$



$$\begin{aligned}
\sigma_{A_1A_2 \to A_1A_2X} &= \int \mathrm{d}\omega_1 \, \mathrm{d}\omega_2 \, n(\omega_1) n(\omega_2) \sigma_{\gamma\gamma \to X}(\omega_1, \omega_2) \\
&= \ldots \\
&= \int N(\omega_1, \mathbf{b_1}) \, N(\omega_2, \mathbf{b_2}) S^2_{abs}(\mathbf{b}) \\
&\times \sigma_{\gamma\gamma \to X}\left(\sqrt{s_{A_1A_2}}\right) \\
&\times 2\pi b \mathrm{d}b \, \mathrm{d}\overline{b}_x \, \mathrm{d}\overline{b}_y \, \frac{W_{\gamma\gamma}}{2} \mathrm{d}W_{\gamma\gamma} \, \mathrm{d}Y_X
\end{aligned}$$

ELEMENTARY CROSS SECTION

- $\sigma^{\mathrm{low-energy}}_{\gamma\gamma\to\rho^0\rho^0}\,(W_{\gamma\gamma})$



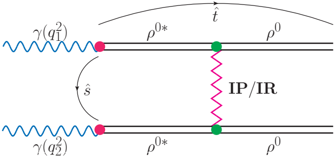
- $\sigma^{\mathrm{high-energy}}_{\gamma\gamma\to\rho^0\rho^0} = \int_{\hat{t}_{min}(\hat{s})}^{\hat{t}_{max}(\hat{s})} \frac{d\sigma^{\mathrm{high-energy}}_{\gamma\gamma\to\rho^0\rho^0}}{d\hat{t}}\,d\hat{t}$

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

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

$$\left(\eta_{\mathbf{P}}\left(\hat{s},\hat{t}\right)C_{\mathbf{P}}\left(\frac{\hat{s}}{s_0}\right)^{\alpha_{\mathbf{P}}(\hat{t})-1} + \eta_{\mathbf{R}}\left(\hat{s},\hat{t}\right)C_{\mathbf{R}}\left(\frac{\hat{s}}{s_0}\right)^{\alpha_{\mathbf{R}}(\hat{t})-1}\right)$$

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

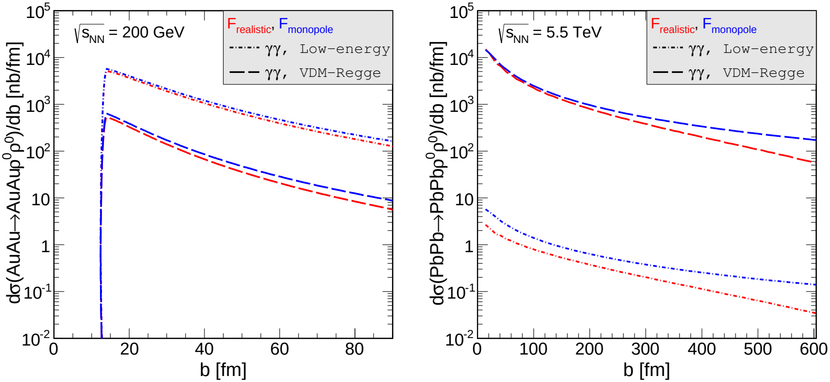


Reference: M. Kłusek, W. Schäfer and A. Szczurek "Exclusive production of $\rho^0\rho^0$ pairs in $\gamma\gamma$ collisions at RHIC", Phys.Lett. **B674** (2009) 92

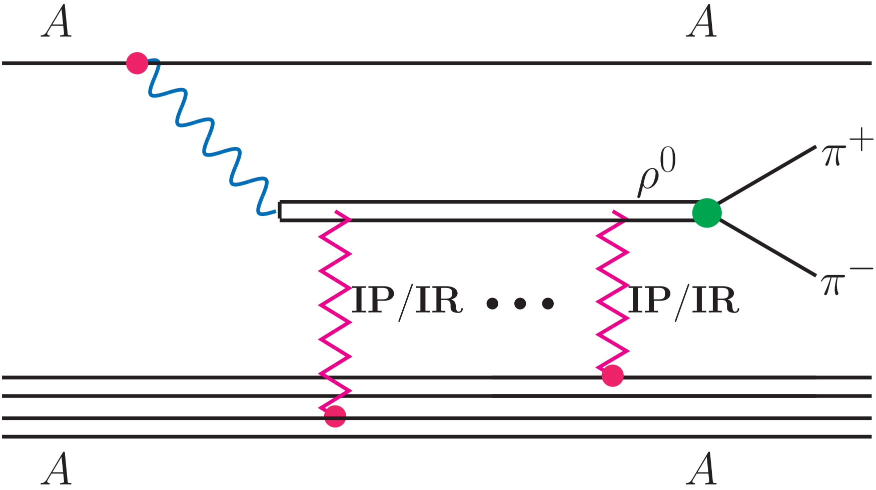
AA→AA$\rho^0\rho^0$ - FORM FACTOR

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

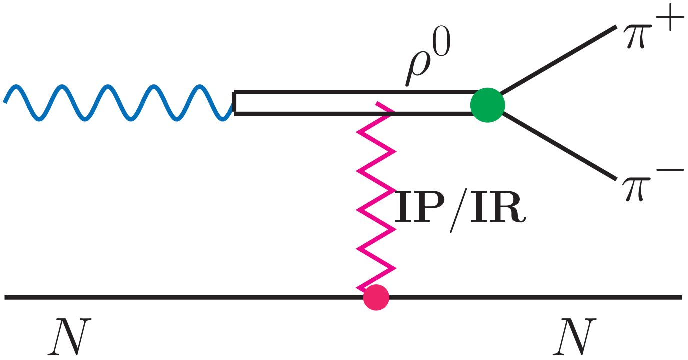
- realistic
- monopole



AA→AAρ^0



$\gamma N \to \rho^0 N$

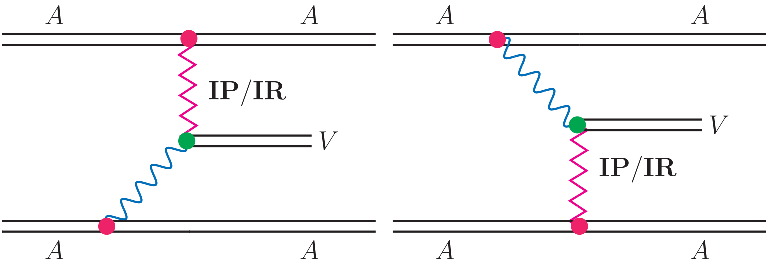


$N = n, p$

Parameters fixed to describe HERA data:

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

SINGLE ρ^0 MESON PRODUCTION



$$\frac{d\sigma_{A_1A_2\to A_1A_2V}}{d^2b\,dy} = \frac{dP_{\gamma\mathbf{P}}(b,y)}{dy} + \frac{dP_{\mathbf{P}\gamma}(b,y)}{dy}$$

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

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

nuclear form factor

A semi-classical model for $\gamma A \to \rho^0 A$ reaction

$$\sigma_{\gamma A\to\rho^0 A} = \frac{d\sigma_{\gamma A\to\rho^0 A}(t=0)}{dt}\int_{-\infty}^{t_{max}} dt\,|F_A(t)|^2 \quad \frac{d\sigma_{\gamma A\to\rho^0 A}(t=0)}{dt} = \frac{\alpha_{em}\sigma^2_{tot}(\rho^0 A)}{4f^2_{\rho^0}}$$

- 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:

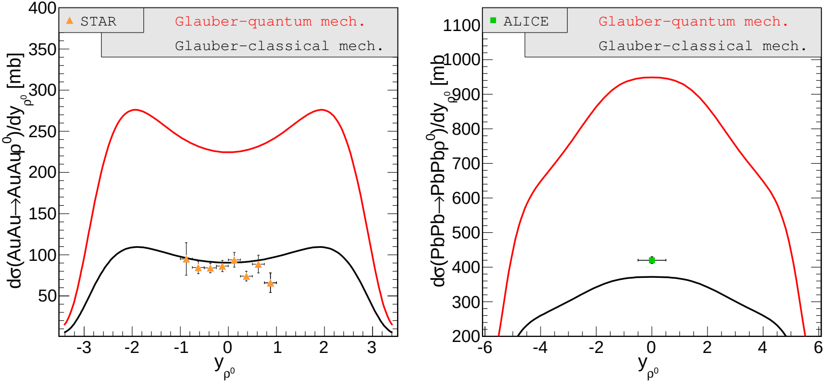
$$\sigma^{qm}_{tot}(\rho^0 A) = 2\int d^2\mathbf{r}\left(1 - \exp\left(-\frac{1}{2}\sigma_{tot}(\rho^0 p)\, T_A(\mathbf{r})\right)\right)$$

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

$$\sigma^2_{tot}(\rho^0 p) = 16\pi\frac{d\sigma_{\rho^0 p\to\rho^0 p}(t=0)}{dt} \quad \frac{d\sigma_{\rho^0 p\to\rho^0 p}(t=0)}{dt} = \frac{f^2_{\rho^0}}{4\pi\alpha_{em}}\frac{d\sigma_{\gamma p\to\rho^0 p}(t=0)}{dt}$$

(VDM) $\frac{d\sigma_{\gamma p\to\rho^0 p}(t=0)}{dt} = B_{\rho^0}\left(XW^{\epsilon} + YW^{-\eta}\right)$ ← HERA data

$AA \to AA\rho^0$ VS GLAUBER MODEL



Smearing of ρ^0 mass

$$\frac{d\sigma_{AA\to AA\rho_0}}{dm\,dy} = f(m)\frac{d\sigma_{AA\to AA\rho_0}(y,m)}{dy}$$

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

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

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

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

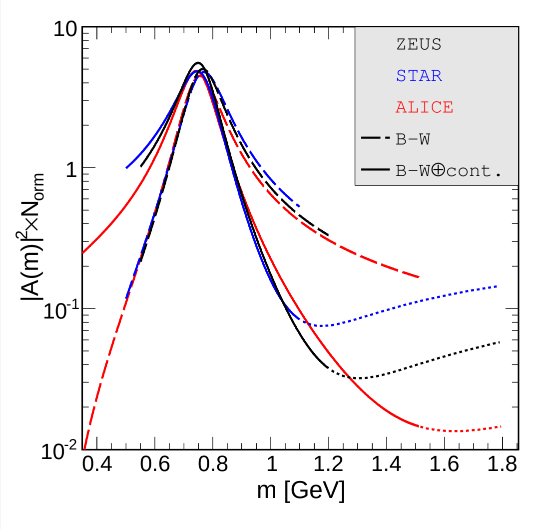
$$\mathcal{A}(m) = \mathcal{A}_{\mathcal{BW}} \frac{\sqrt{m m_{\rho^0} \Gamma_{\rho^0}(m)}}{m^2 - m_{\rho^0}^2 + i m_{\rho^0} \Gamma_{\rho^0}(m)} + \mathcal{B}_{\pi\pi}$$

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

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
$\left\lvert \frac{\mathcal{B}_{\pi\pi}}{\mathcal{A}_{\mathcal{BW}}} \right\rvert$ [GeV$^{-1/2}$]	0.669	0.89 ± 0.08	0.5 ± 0.04
m [GeV]	$(0.55 - 1.2)$	$(0.5 - 1.1)$	$(0.28 - 1.512)$

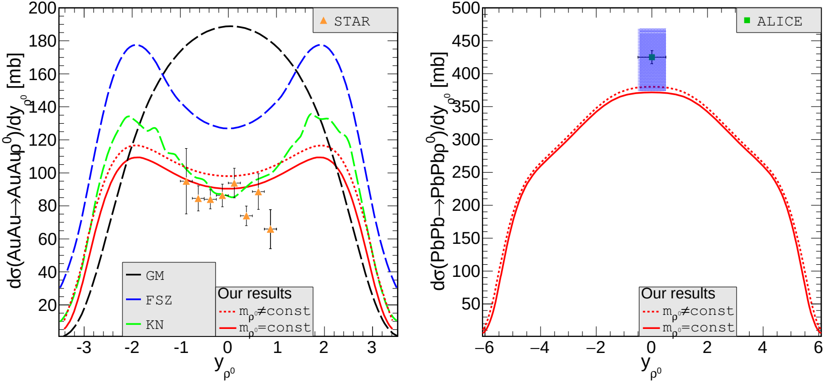
SMEARING OF ρ^0 MASS

$\mathcal{B}_{\pi\pi}$



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

Single ρ^0 meson production

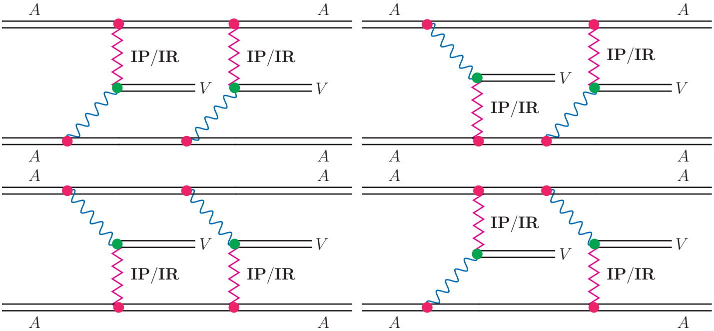


SINGLE ρ^0 MESON PRODUCTION

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

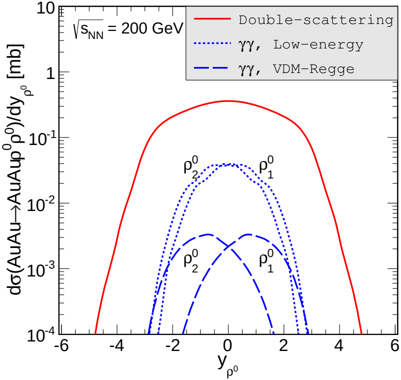
DOUBLE-SCATTERING MECHANISM

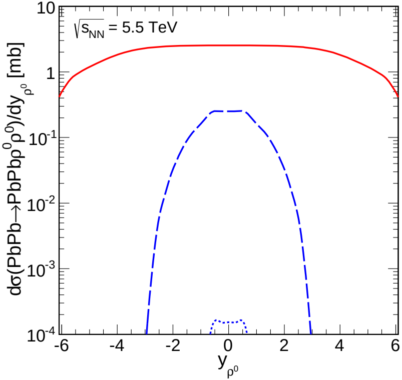


$$\frac{d\sigma_{A_1A_2\to A_1A_2\rho^0\rho^0}}{dy_1 dy_2} = \frac{1}{2}\int\left(\frac{dP_{\gamma\mathbf{P}}(b,y_1)}{dy_1} + \frac{dP_{\mathbf{P}\gamma}(b,y_1)}{dy_1}\right) \times \left(\frac{dP_{\gamma\mathbf{P}}(b,y_2)}{dy_2} + \frac{dP_{\mathbf{P}\gamma}(b,y_2)}{dy_2}\right) d^2b$$

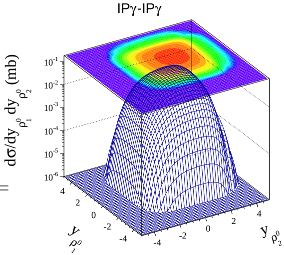
(ρ^0's have negligibly small transverse momenta)

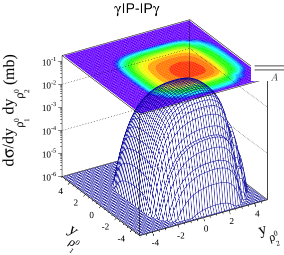
DOUBLE-SCATTERING MECHANISM VS $\gamma\gamma$ FUSION

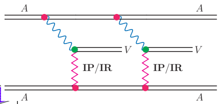


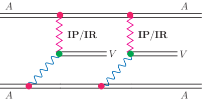


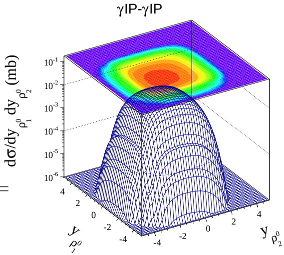
DOUBLE-SCATTERING MECHANISM

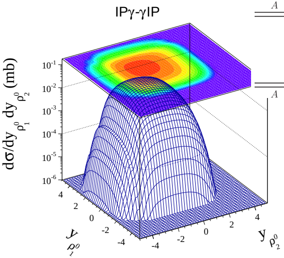


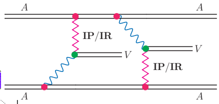


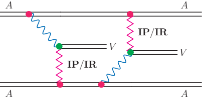






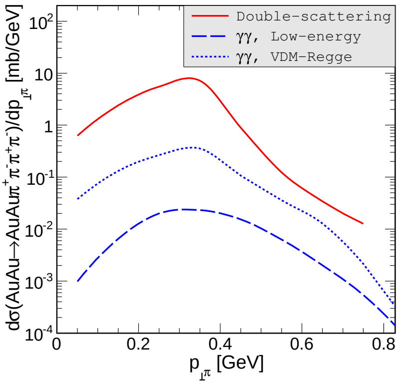


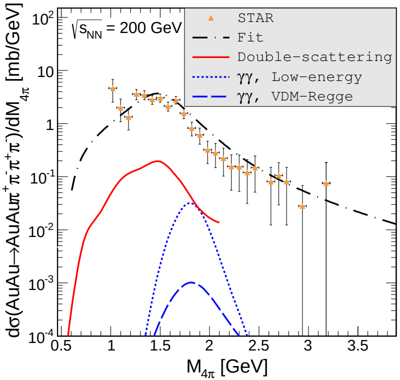




DOUBLE-SCATTERING MECHANISM AT RHIC

$|\eta_\pi| < 1$





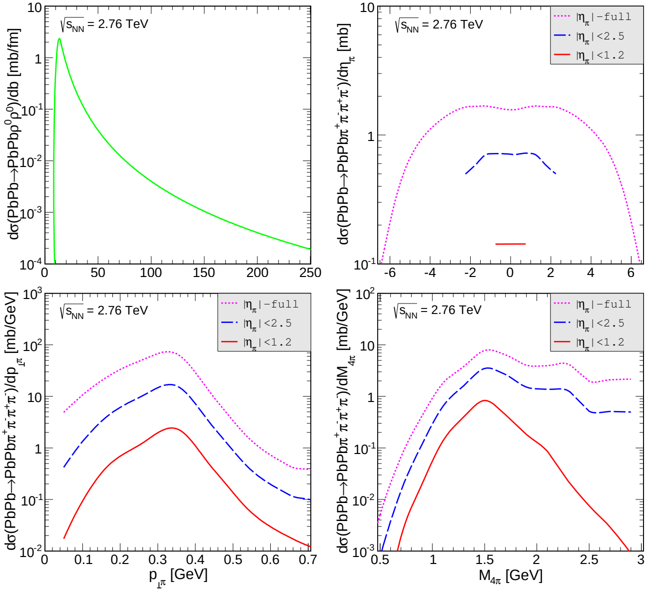
missing mechanisms:

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

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

?

DOUBLE-SCATTERING MECHANISM AT LHC

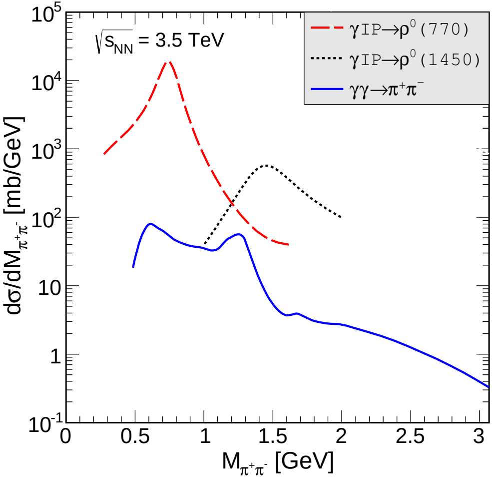


COMPARISON OF THE MECHANISMS

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 $AA \to AA\rho^0\rho^0$ 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

Conclusions

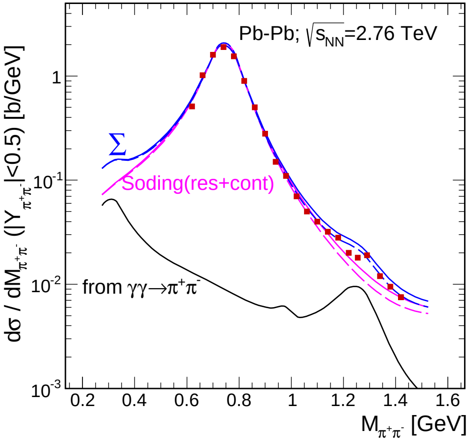
- Impact parameter space approach
- Smearing of ρ^0 meson
- Good description of STAR and ALICE data for single-$\rho^0(770)$ production

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



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. Ciemała, 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