Institute of Nuclear Physics PAN, PL-31-342 Cracow, Poland

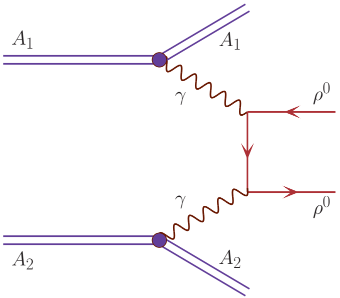
Exclusive production of $\rho^0\rho^0$ pairs in ultrarelativistic heavy ion collisions

Mariola Kłusek–Gawenda

In collaboration with A. Szczurek and W. Schäfer

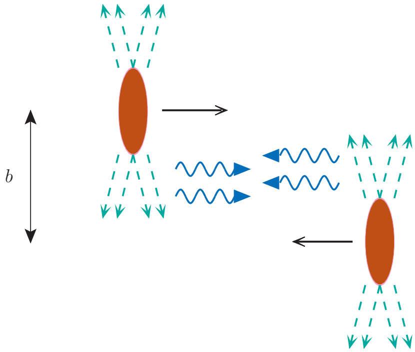
1. $AA \to A\rho^0\rho^0 A$
2. Equivalent photon approximation
   - Elementary cross section
     - Experimental data
     - Vector dominance model (VDM) - Regge
3. Form factor
   - Realistic
   - Monopole
4. Results
5. Conclusions

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



Accelerator	Nuclei	$\sqrt{s_{NN}}$	γ_{cm}
RHIC	Au–Au	200 GeV	107
LHC	Pb–Pb	5.5 TeV	2 932

Equivalent photon approximation (EPA)



The strong electromagnetic field is used as a source of photons to induce electromagnetic reactions.

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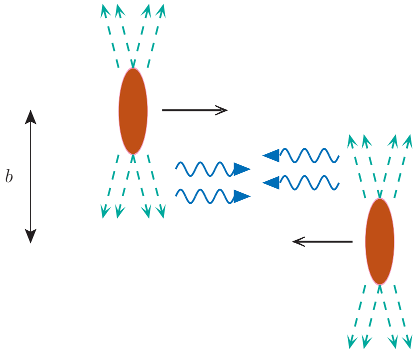

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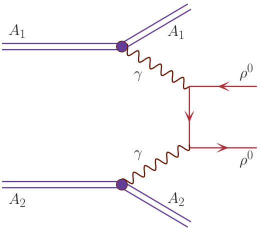
Peripheral collisions:

$b > R_1 + R_2 \cong 14$ fm

The total cross section in EPA

$$\sigma\left(AA \to \rho^0\rho^0 AA; s_{AA}\right)$$
$$= \int \hat{\sigma}\left(\gamma\gamma \to \rho^0\rho^0; x_1 x_2 s_{AA}\right) \mathrm{d}n_{\gamma\gamma}\left(x_1, x_2, \mathbf{b}\right)$$



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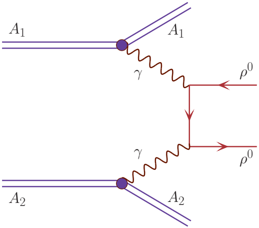
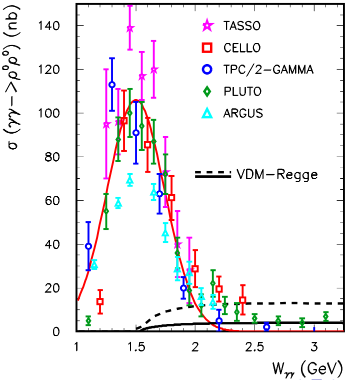


- $x_{1,2} = \frac{\omega_{1,2}}{\gamma M_A}$

The elementary cross section

$$\hat{\sigma}\left(\gamma\gamma \to \rho^0\rho^0; W_{\gamma\gamma}\right)$$



VDM–Regge model $\Rightarrow \hat{\sigma}\left(\gamma\gamma \to \rho^0\rho^0\right)$

$$\mathcal{M}_{\gamma\gamma\to\rho^0\rho^0}(\hat{s},\hat{t};q_1,q_2) = C^2_{\gamma\to\rho^0}\mathcal{M}_{\rho^{0*}\rho^{0*}\to\rho^0\rho^0}(\hat{s},\hat{t};q_1,q_2)$$

- $C^2_{\gamma\to\rho^0} = \frac{\alpha^2_{em}}{2.54}$

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$$\mathcal{M}_{\rho^{0*}\rho^{0*}\to\rho^0\rho^0}(\hat{s},\hat{t};q_1,q_2) = F\left(\hat{t};q_1^2\right) F\left(\hat{t};q_2^2\right)$$

$$\times\hat{s}\left(\eta_P\left(\hat{s},\hat{t}\right) C_P\left(\frac{\hat{s}}{s_0}\right)^{\alpha_P\left(\hat{t}\right)-1} + \eta_R\left(\hat{s},\hat{t}\right) C_R\left(\frac{\hat{s}}{s_0}\right)^{\alpha_R\left(\hat{t}\right)-1}\right)$$

- $\eta_P\left(\hat{s},\hat{t}=0\right) \cong i$
- $C_P = 8.56\ mb$
- $\alpha_P\left(\hat{t}\right) = 1.088 + 0.25t$
- $\eta_R\left(\hat{s},\hat{t}=0\right) \cong i-1$
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$$F(\hat{t};q^2) = \exp\left(\frac{B\hat{t}}{4}\right)\cdot\exp\left(\frac{q^2-m_\rho^2}{2\Lambda^2}\right)$$

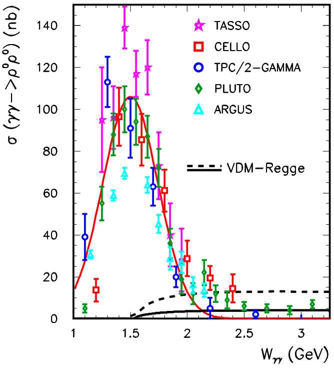
- $B \sim 4GeV^{-2}$
- $\Lambda \sim 1GeV$

VDM–Regge model

$$\frac{d\hat{\sigma}_{\gamma\gamma\to\rho^0\rho^0}}{d\hat{t}} = \frac{1}{16\pi\hat{s}^2}\left|\mathcal{M}_{\gamma\gamma\to\rho^0\rho^0}\right|^2$$

$$\hat{\sigma}_{\gamma\gamma\to\rho^0\rho^0} = \int\limits_{t_{min}(\hat{s})}^{t_{max}(\hat{s})} \frac{d\hat{\sigma}_{\gamma\gamma\to\rho^0\rho^0}}{d\hat{t}}\, d\hat{t}$$

The elementary cross section



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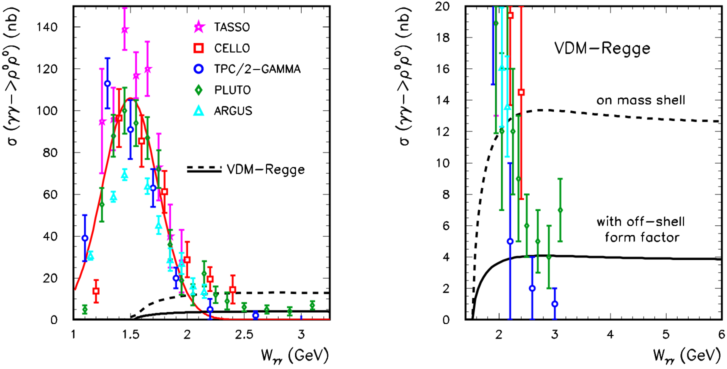

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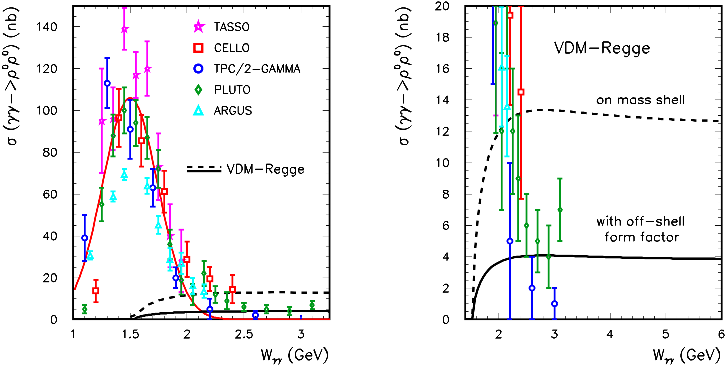

$$\Leftarrow \hat{\sigma}\left(\gamma\gamma \to \rho^0\rho^0; W_{\gamma\gamma}\right) \Rightarrow$$

Low–energy (experimental data) High–energy (VDM-Regge)

The total cross section in EPA

$$\sigma\left(AA \to \rho^0\rho^0 AA; s_{AA}\right)$$
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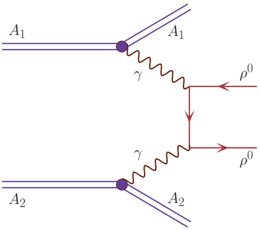
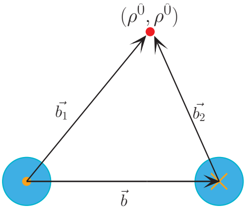


- $x_{1,2} = \frac{\omega_{1,2}}{\gamma M_A}$

Photons flux - continuation of the cross section in EPA

$$\mathrm{d}n_{\gamma\gamma}(x_1, x_2, \mathbf{b}) = \int \frac{1}{\pi}\mathrm{d}^2\mathbf{b}_1 |\mathbf{E}(x_1, \mathbf{b}_1)|^2 \frac{1}{\pi}\mathrm{d}^2\mathbf{b}_2 |\mathbf{E}(x_2, \mathbf{b}_2)|^2$$

$$x \quad S^2_{abs}(\mathbf{b})\delta^{(2)}(\mathbf{b} - \mathbf{b}_1 + \mathbf{b}_2)\frac{\mathrm{d}x_1}{x_1}\frac{\mathrm{d}x_2}{x_2}$$



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- $\mathbf{E}(x, \mathbf{b}) = Z\sqrt{4\pi\alpha_{em}} \int \frac{\mathrm{d}^2\mathbf{q}}{(2\pi^2)} e^{-i\mathbf{bq}} \frac{\mathbf{q}}{\mathbf{q}^2 + x^2 M_A^2} F_{em}\left(\mathbf{q}^2 + x^2 M_A^2\right)$
- $S^2_{abs}(\mathbf{b}) \cong \theta(\mathbf{b} - 2R_A)$

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- $S^2_{abs}(\mathbf{b}) \cong \theta(\mathbf{b} - 2R_A)$
- $\frac{1}{\pi}\int \mathrm{d}^2\mathbf{b}|\mathbf{E}(x, \mathbf{b})|^2 = \int \mathrm{d}^2\mathbf{b} N(\omega, \mathbf{b})$
- $\mathrm{d}\omega_1 \mathrm{d}\omega_2 \to \mathrm{d}W_{\gamma\gamma}\mathrm{d}Y$

The cross section in EPA

Nuclear cross section – EPA

$$\sigma\left(AA \to \rho^0\rho^0 AA; s_{AA}\right) =$$

$$= \int \hat{\sigma}\left(\gamma\gamma \to \rho^0\rho^0; W_{\gamma\gamma}\right)\, \theta\left(|\mathbf{b}_1 - \mathbf{b}_2| - 2R_A\right)$$

$$x \quad N\left(\omega_1, \mathbf{b}_1\right) N\left(\omega_2, \mathbf{b}_1\right) 2\pi b_m \,\mathrm{d}b_m \,\mathrm{d}\overline{b}_x \,\mathrm{d}\overline{b}_y \frac{W_{\gamma\gamma}}{2} \mathrm{d}W_{\gamma\gamma} \mathrm{d}Y$$

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The details of derivation:
Antoni Szczurek, M.K-G
"Exclusive muon-pair productions in ultrarelativistic heavy-ion collisions – realistic nucleus charge form factor and differential distributions"
arXiv:1004.5521

Form factor

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REALISTIC F_{em}

$$F(q) = \int \frac{4\pi}{q}\rho(r)\, sin(qr)\, rdr$$

Form factor

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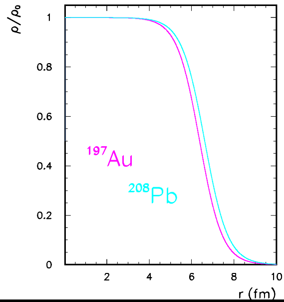

Form factor

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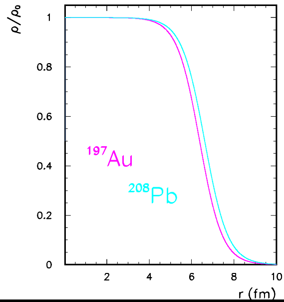
MONOPOLE F_{em}

$$F(q^2) = \frac{\Lambda^2}{\Lambda^2+q^2}$$

$$\Lambda = \sqrt{\frac{6}{<r^2>}}$$



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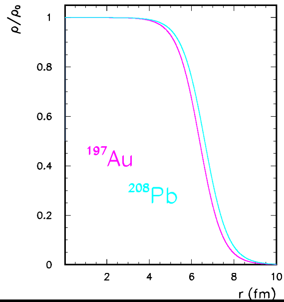

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- $^{197}Au \Rightarrow \sqrt{< r^2 >} = 5.3\ fm,\ \Lambda = 0.091\ GeV,$
- $^{208}Pb \Rightarrow \sqrt{< r^2 >} = 5.5\ fm,\ \Lambda = 0.088\ GeV.$

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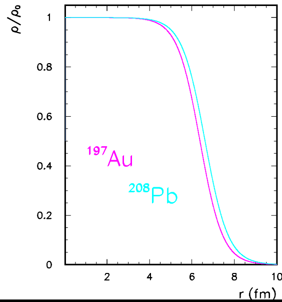

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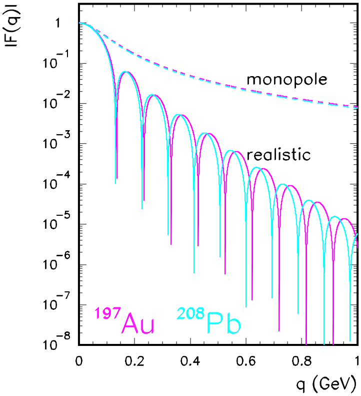
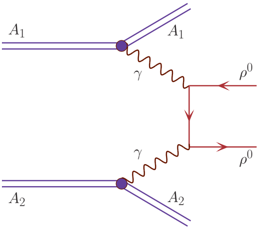
In the literature:
$\Lambda = (0.08 - 0.09)\ GeV$

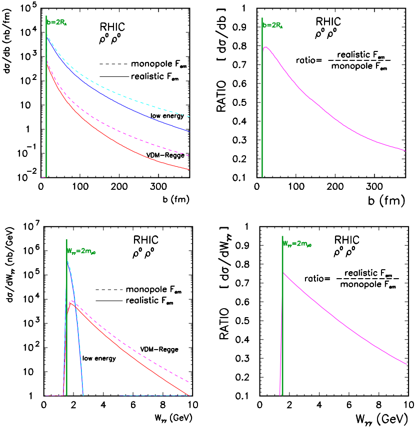
Form factor


|F(q)|
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
monopole
realistic
^{197}Au
^{208}Pb
0
0.2
0.4
0.6
0.8
1
q (GeV)

RESULTS



RHIC $\left(Au\ Au \rightarrow Au\ \rho^0\rho^0\ Au\right)$



Impact parameter: b.

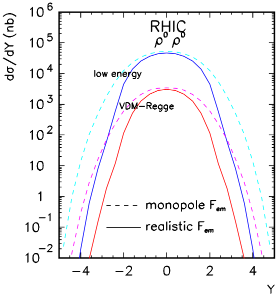
$$\sigma\left(F_{em}\right) = \sigma_{l-e} + \sigma_{VDM-R}$$

$$RATIO = \frac{d\sigma\left(F_{em}^{REALISTIC}\right)}{d\sigma\left(F_{em}^{MONOPOLE}\right)}$$

Invariant mass of the $\gamma\gamma$ system: $W_{\gamma\gamma} = M_{\rho^0\rho^0}$.

RHIC $(Au\ Au \to Au\ \rho^0\rho^0\ Au)$

Rapidity of the $\rho^0\rho^0$ pair: $Y = \frac{y_{\rho^0} + y_{\rho^0}}{2}$.



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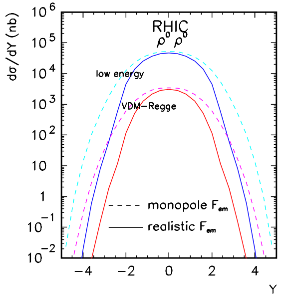
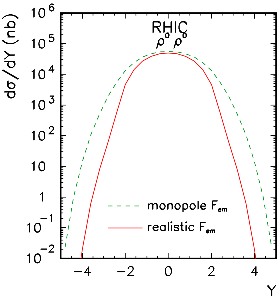
Low–energy+ +VDM-Regge





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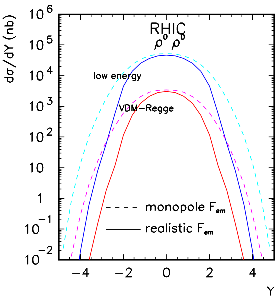

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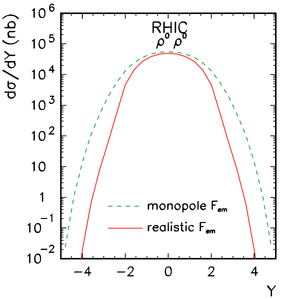
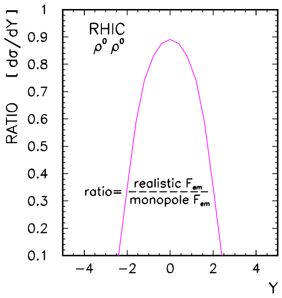
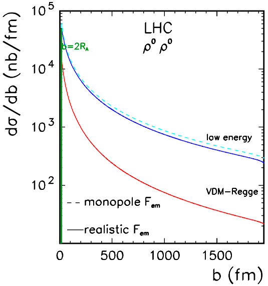


$$\text{Ratio} = \frac{d\sigma(F_{em}^{REALISTIC})}{d\sigma(F_{em}^{MONOPOLE})}$$



LHC $\left(Pb\ Pb \rightarrow Pb\ \rho^0\rho^0\ Pb\right)$



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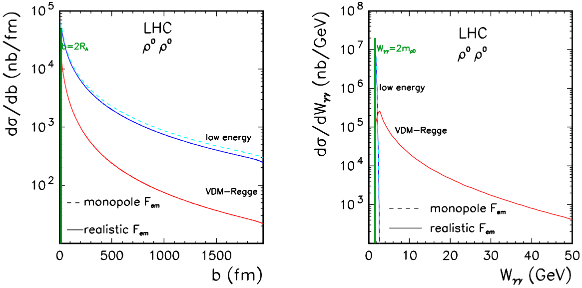

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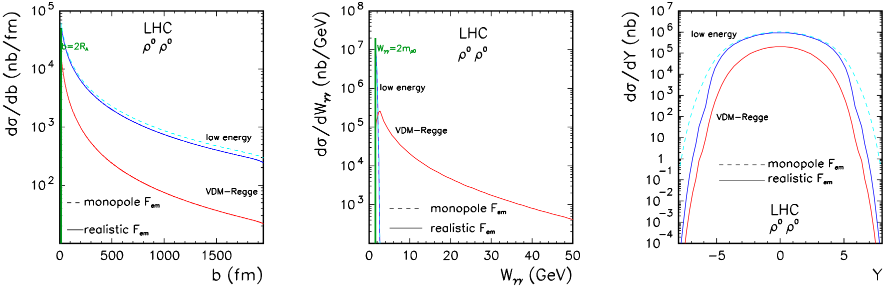
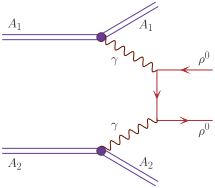


Conclusions

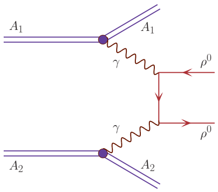


$$\gamma\gamma \to \rho^0\rho^0$$

1. low-$\gamma\gamma$-energy – **parametrized**
2. high-$\gamma\gamma$-energy – **VDM-Regge model** turned out to be consistent with the highest-energy data points from e^+e^- collisions.

first realistic estimate

Conclusions



	$\sigma_{low-energy}$ (mb)	
Form factor	RHIC	LHC
realistic	0.12	5.2
monopole	0.16	5.9
difference	25 %	11 %

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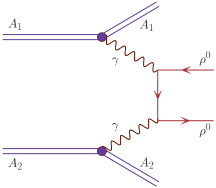

$$\gamma\gamma \to \rho^0\rho^0$$

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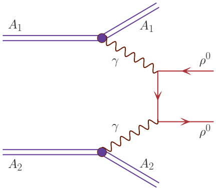
first realistic estimate

Big effects of charge distribution in nuclei for:

- the smaller energy in the center of mass system

Conclusions



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

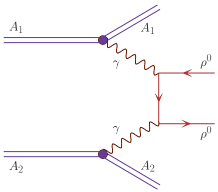
1. low-$\gamma\gamma$-energy – **parametrized**
2. high-$\gamma\gamma$-energy – **VDM-Regge model**

first realistic estimate

Big effects of charge distribution in nuclei for:

- the smaller energy in the center of mass system
- the larger rapidities
- the larger invariant mass of $\gamma - \gamma$ system

Conclusions



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

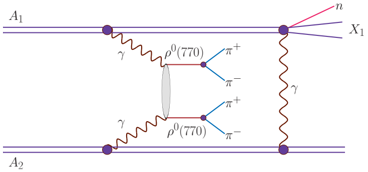
1. low-$\gamma\gamma$-energy – **parametrized**
2. high-$\gamma\gamma$-energy – **VDM-Regge model**

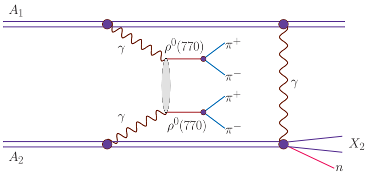
first realistic estimate

Big effects of charge distribution in nuclei for:

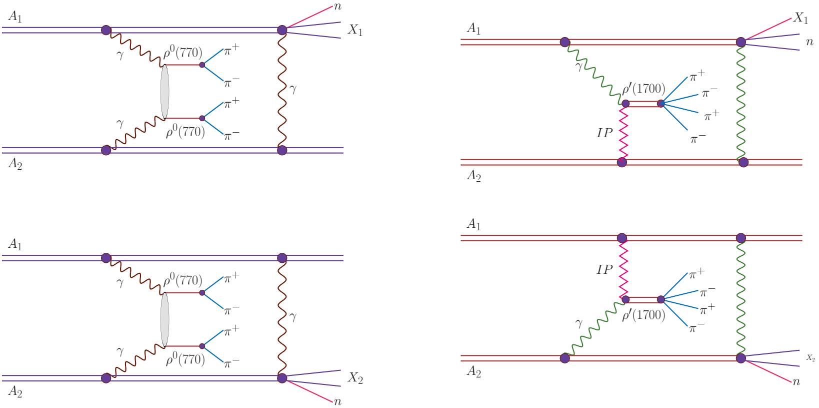
- the smaller energy in the center of mass system
- the larger rapidities
- the larger invariant mass of $\gamma - \gamma$ system
- the heavier mass the bigger effect

$AA \to A^* A^* \pi^+ \pi^- \pi^+ \pi^-$





$AA \to A^* A^* \pi^+ \pi^- \pi^+ \pi^-$



THANK YOU FOR ATTENTION.