WE-HERAEUS PHYSICS SCHOOL 2015

NEW THEORETICAL RESULTS IN UPC

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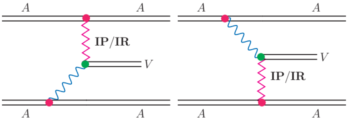
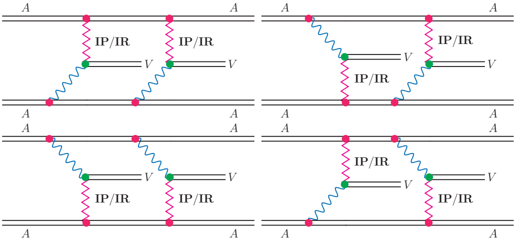
Institute of Nuclear Physics PAS Kraków

Main goal - Vector mesons production

- Single ρ^0 & J/ψ production



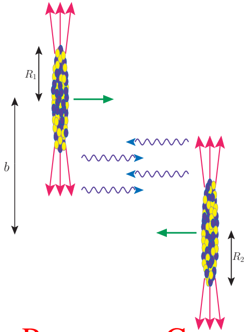
- Double-scattering mechanism



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

STAR, CMS & ALICE data

EQUIVALENT PHOTON APPROXIMATION

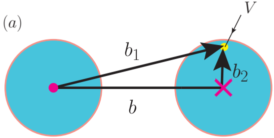


The strong electromagnetic field is a source of photons that can induce electromagnetic reactions in ion-ion collisions.

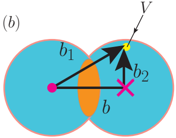
ULTRAPERIHERAL COLLISIONS

SEMI-CENTRAL COLLISIONS

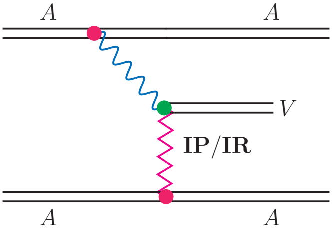
$$b > R_{min} = R_1 + R_2$$

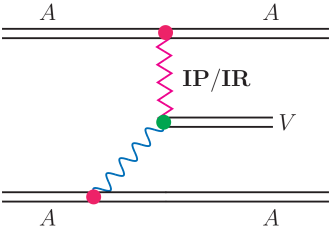


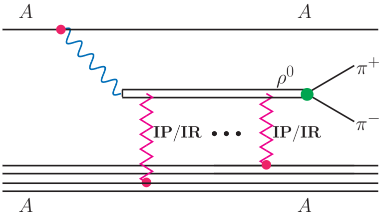
$$b \leq R_{min}$$

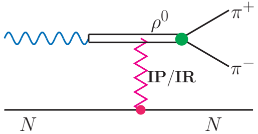


PHOTOPRODUCTION OF VECTOR MESON



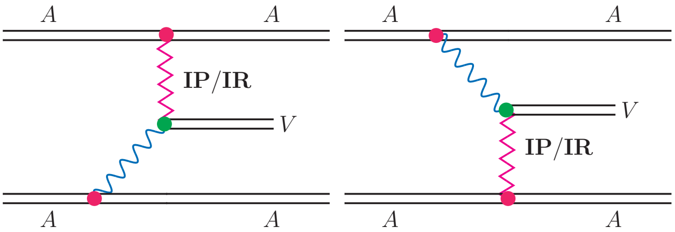






Parameters fixed to describe HERA data
we expect: $\frac{d\sigma(\gamma n \to Vn)}{dt} \approx \frac{d\sigma(\gamma p \to Vp)}{dt}$

SINGLE VECTOR MESON PRODUCTION

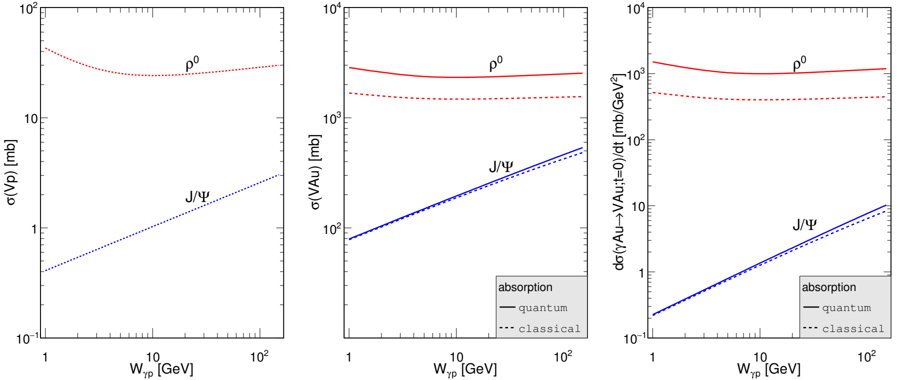


$$\frac{d\sigma_{A_1A_2\to A_1A_2V}}{d^2b\,dy} = \frac{dP_{\gamma\mathbf{P}}(b,y)}{dy} + \frac{dP_{\mathbf{P}\gamma}(b,y)}{dy} \qquad (1)$$

$$\frac{dP_{1/2}(b,y)}{dy} = \omega_{1/2} N(\omega_{1/2}, b)\, \sigma_{\gamma A_{2/1}\to VA_{2/1}}(W_{\gamma A_{2/1}}) \qquad (2)$$

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

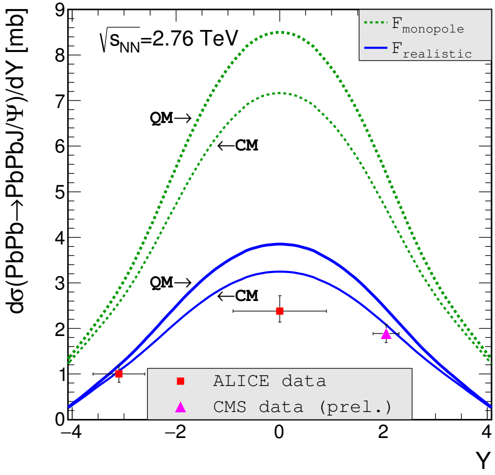
$\frac{d\sigma_{\gamma p \to Vp}(t=0)}{dt}$ ← HERA data



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

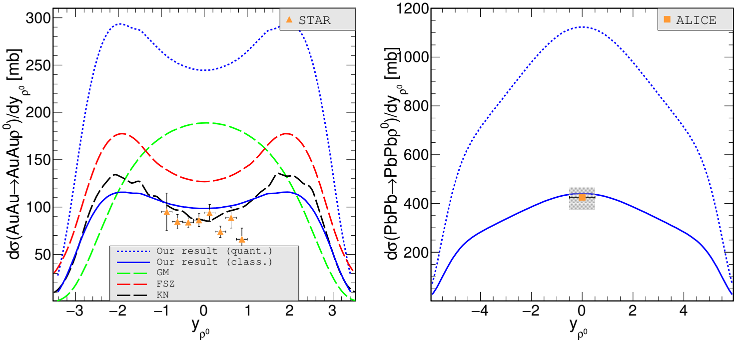
$$\sigma_{\gamma A \to VA}(W_{\gamma A_{2/1}}) = \frac{d\sigma_{\gamma A \to VA}(t=0)}{dt} \int_{-\infty}^{t_{max}} dt \left| F_A(t) \right|^2$$

J/ψ MESON PRODUCTION



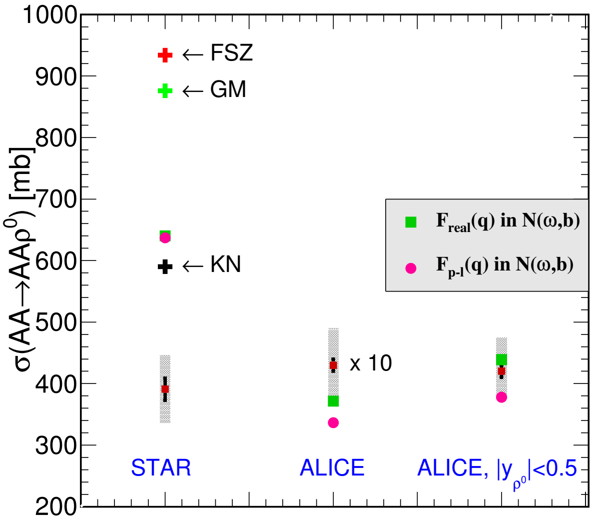
WE-HERAEUS PHYSICS SCHOOL
MARIOLA K-G
INTRODUCTION
EPA
THEORY
PHOTOPRODUCTION OF VECTOR MESONS
SINGLE MESON PRODUCTION
J/ψ MESON PRODUCTION
ρ^0 MESON PRODUCTION
SMEARING OF ρ^0 MASS
DOUBLE-SCATTERING MECHANISM
CONCLUSION

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



SMEARING OF ρ^0 MASS

Drell-Söding contribution:

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

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

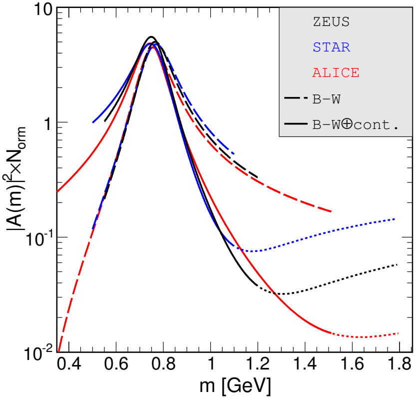
Parameter	ZEUS	STAR	ALICE
m_{ρ^0} [GeV]	0.77 ± 0.002	0.775 ± 0.003	0.761 ± 0.0023
Γ_{ρ^0} [GeV]	0.146 ± 0.003	0.162 ± 0.007	0.1502 ± 5.5
$\left\lvert \frac{\mathcal{B}_{\pi\pi}}{\mathcal{A}_{\mathcal{BW}}} \right\rvert$ [GeV$^{-1/2}$]	0.669	0.89 ± 0.08	0.5 ± 0.04
m [GeV]	$(0.55 - 1.2)$	$(0.5 - 1.1)$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

SMEARING OF ρ^0 MASS

Drell-Söding contribution:

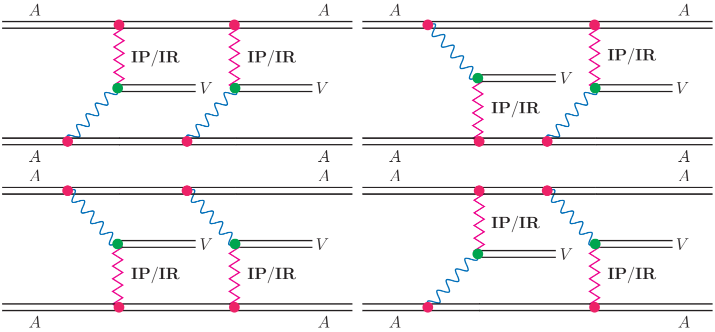
$\mathcal{A}$ … $+ \mathcal{B}_{\pi\pi}$

3/2



Paramete…		…	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]	$(0.55 - 1.2)$	$(0.5 - 1.1)$	$(0.28 - 1.512)$

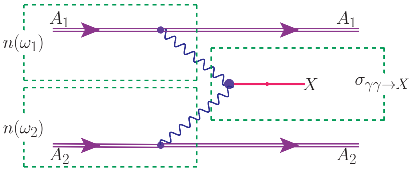
DOUBLE-SCATTERING MECHANISM



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

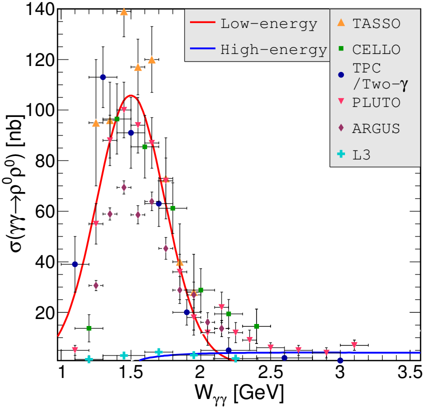
(ρ^0's have negligibly small transverse momenta)

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

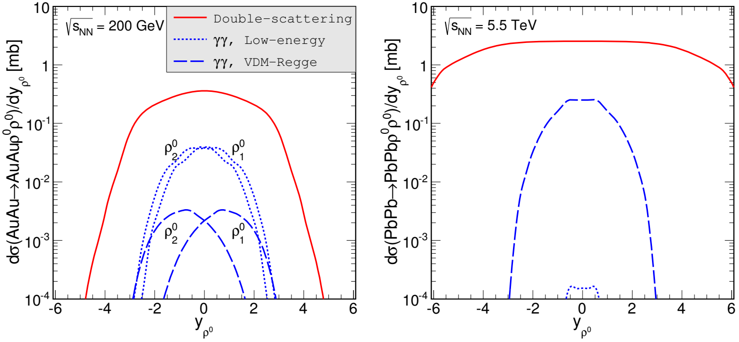


$$n(\omega) = \int_{R_{min}}^{\infty} 2\pi b \mathrm{d}b\, N(\omega, b)$$

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



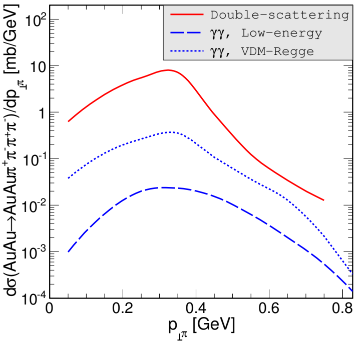
DOUBLE-SCATTERING MECHANISM VS $\gamma\gamma$ FUSION

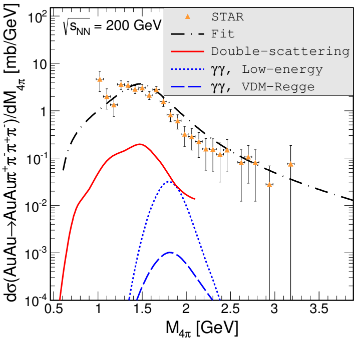


Reference:
M. Kłusek-Gawenda and A. Szczurek, Phys. Rev. **C89** (2014) 024912
"Double-scattering mechanism in the exclusive $AA \to AA\rho^0\rho^0$ reaction in ultrarelativistic collisions",

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

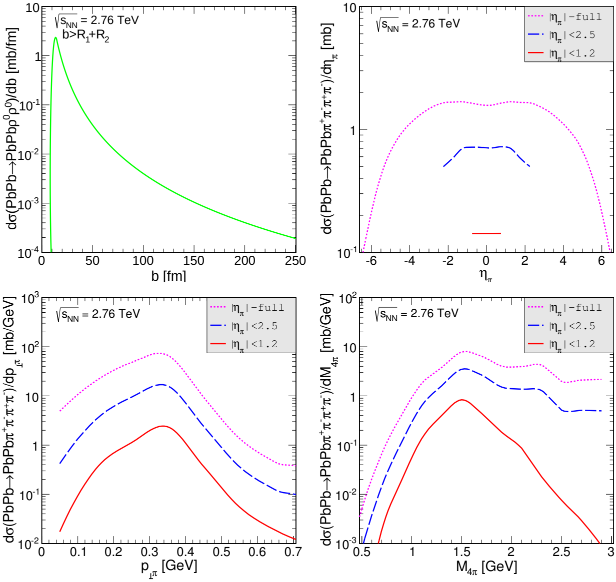
$|\eta_\pi| < 1$



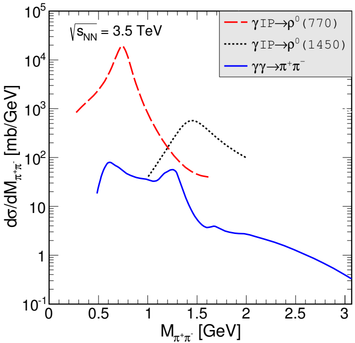


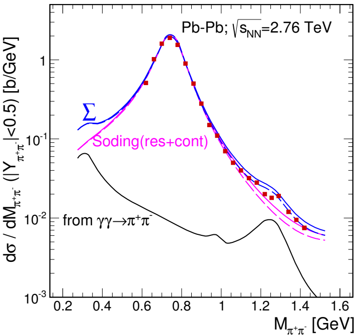
missing mechanisms: $AA \to AA\rho^0(1450) \to 4\pi$ / $AA \to AA\rho^0(1700) \to 4\pi$?

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



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

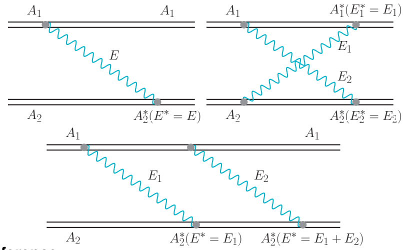
Conclusions

- Impact parameter space approach
- Good description of
  - STAR and ALICE data for $\rho^0(770)$ production
  - CMS and ALICE data for J/ψ production
- Smearing of ρ^0 meson
- Comparison of four-pion production via $\rho^0\rho^0$ production
  - $\gamma\gamma$ fusion
  - nuclear double-photoproduction (very large)

  with STAR data

CONCLUSIONS

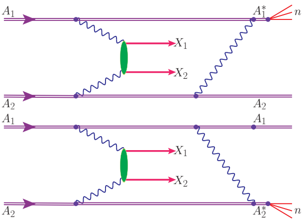
- Multiple Coulomb excitations



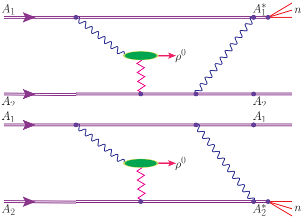
Reference:
M. Kłusek-Gawenda, M. Ciemała, W. Schäfer and A. Szczurek, Phys. Rev. **C89** (2014) 054907,
"Electromagnetic excitation of nuclei and neutron evaporation in ultrarelativistic ultraperipheral heavy ion collisions"

associated with $\rho^0\rho^0$ or ρ^0 production may cause additional excitation of one or both nuclei to the giant resonance region

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

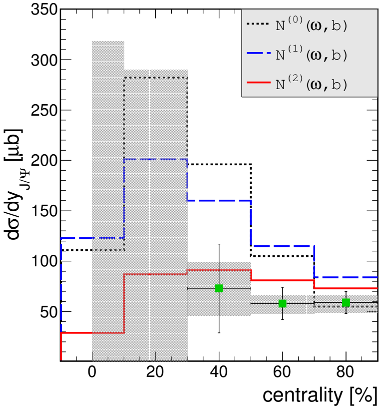


$$AA \to AA^*(kn)\rho^0$$



CONCLUSIONS

- not only UPC $\rightsquigarrow$ PbPb→PbPbJ/Ψ



More details:

Antoni's Sz. talk

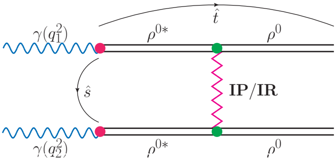
(Friday, 21 Aug)

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

Back-up slides

ELEMENTARY CROSS SECTION $\gamma\gamma \to \rho^0\rho^0$

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



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

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

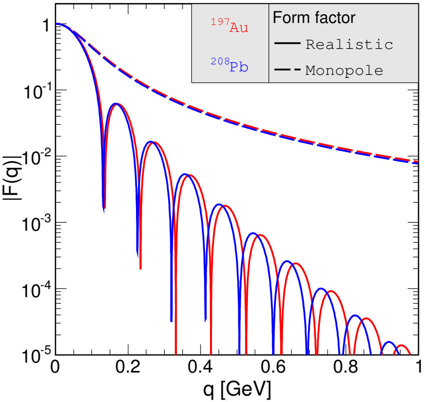
$$\mathcal{M}_{\rho^{0*}\rho^{0*}\to\rho^0\rho^0}\left(\hat{s},\hat{t};q_1,q_2\right) = \left(\eta_{\mathbf{P}}\left(\hat{s},\hat{t}\right) C_{\mathbf{P}} \left(\frac{\hat{s}}{s_0}\right)^{\alpha_{\mathbf{P}}\left(\hat{t}\right)-1} + \eta_{\mathbf{R}}\left(\hat{s},\hat{t}\right) C_{\mathbf{R}} \left(\frac{\hat{s}}{s_0}\right)^{\alpha_{\mathbf{R}}\left(\hat{t}\ri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

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

FORM FACTOR

REALISTIC F_{em}

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



MONOPOLE F_{em}

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

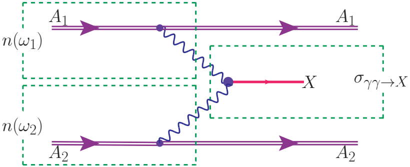
$$\Lambda = \sqrt{\frac{6}{<r^2>}}$$

- $^{197}Au \Rightarrow \sqrt{< r^2 >} = 5.3$ fm, $\Lambda = 91$ MeV,
- $^{208}Pb \Rightarrow \sqrt{< r^2 >} = 5.5$ fm, $\Lambda = 88$ MeV.

In the literature:

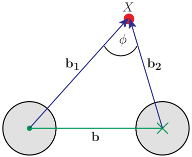
$\Lambda = (80 - 90)$ GeV

NUCLEAR CROSS SECTION



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

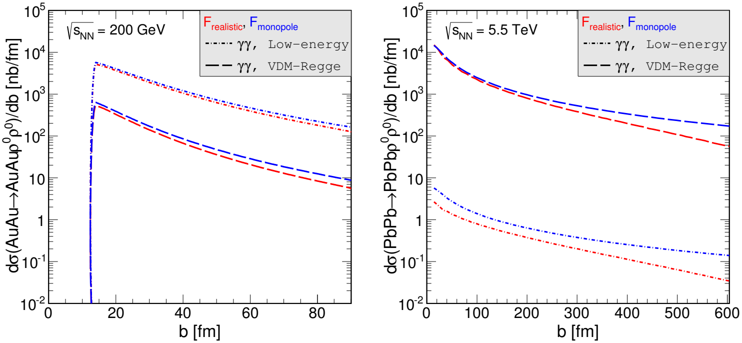
$$\begin{aligned} \sigma_{A_1A_2\to A_1A_2X} &= \int \mathrm{d}\omega_1 \, \mathrm{d}\omega_2 \, n(\omega_1) n(\omega_2) \sigma_{\gamma\gamma\to X}(\omega_1, \omega_2) \\ &= \ldots \\ &= \int N(\omega_1, \mathbf{b_1}) \, N(\omega_2, \mathbf{b_2}) S^2_{abs}(\mathbf{b}) \\ &\times \sigma_{\gamma\gamma\to X}\left(\sqrt{s_{A_1A_2}}\right) \\ &\times 2\pi b \mathrm{d}b \, \mathrm{d}\overline{b}_x \, \mathrm{d}\overline{b}_y \, \frac{W_{\gamma\gamma}}{2} \mathrm{d}W_{\gamma\gamma} \, \mathrm{d}Y_X \quad (8) \end{aligned}$$



AA→AA$\rho^0\rho^0$ - form factor

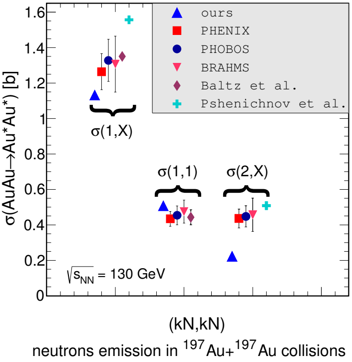
$N\left(\omega_{1/2}, \mathbf{b}_{1/2}\right)$ depends on the form factor

- realistic
- monopole



Mutual electromagnetic dissociation

$$\sigma_{tot}\left(A_1 A_2 \to A_1^* A_2^*\right) = \int d^2\mathbf{b}\, P_{surv}(\mathbf{b}) P_{A_2}^{exc}(\mathbf{b}) P_{A_1}^{exc}(\mathbf{b})$$

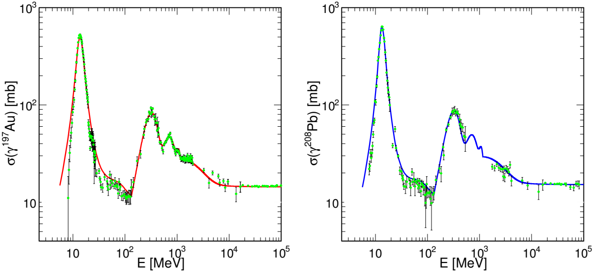


$$P_{surv}(\mathbf{b}) \approx \theta(|\mathbf{b}| - (R_1 - R_2))$$

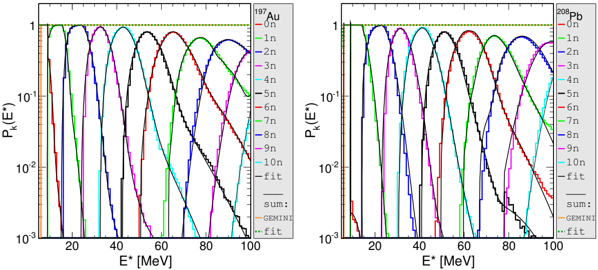
$$P_{A_2}^{exc}(\mathbf{b}) \approx \bar{n}_{A_2}(\mathbf{b}) \exp\left[-\bar{n}_{A_2}(\mathbf{b})\right]$$

$$\bar{n}_{A_2}(\mathbf{b}) = \int_{E_{min}}^{\infty} dE\, N_{A_1}(E, \mathbf{b})\, \sigma_{tot}(\gamma A_2; E)$$

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



Probability of neutron multiplicity ↓



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