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Production of lepton, quark and meson pairs in peripheral ulrarelativistic heavy ion collisions

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In collaboration with M. Kłusek, W. Schäfer

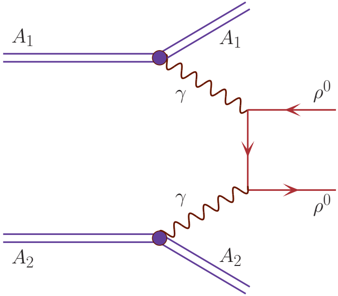
(Ultra)Peripheral Heavy Ion Collisions

1. Usual heavy ion collsions - large multiplicities
   Ultraperipheral heavy ion collisions - smaller multiplicities
2. What do we know about them?
   There are some theoretical predictions
   Experimentally very little is known.
3. The dominant process: coherent photon-photon collisions
   (increased by large charges of nuclei ($Z_1 e$ and $Z_2 e$)
4. Large enhancement (naively: $Z_1^2 Z_2^2$ in the cross section).
5. But nuclei are not point like $\longrightarrow$ charge form factor.
6. One can select final state ! ?
7. Simple final states are interesting.

Contents

1. $AA \longrightarrow A\rho^0\rho^0 A$
2. $AA \longrightarrow A\pi\pi A$
3. $AA \longrightarrow A\mu^+\mu^- A$
4. $AA \longrightarrow AQ\bar{Q}A$
5. Other reactions
6. Conclusions

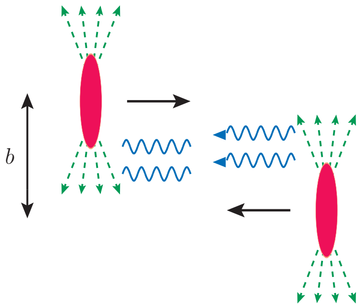
$AA \longrightarrow A\rho^0\rho^0 A$



M. Kłusek, W. Schäfer and A. S., Phys. Lett. **B674** (2009) 92.

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 a source of photons which may interact.

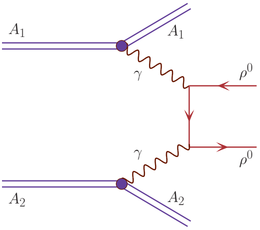
Peripheral collisions:

$b > R_1 + R_2 \cong 14$ fm

The total cross section in EPA

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

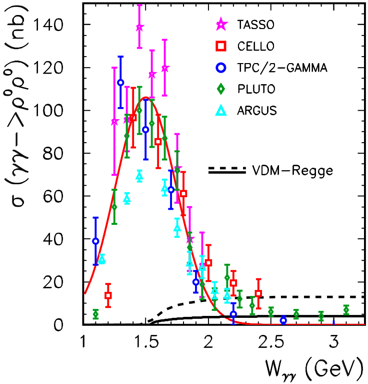
$$= \int \hat{\sigma}\left(\gamma\gamma \longrightarrow \rho^0\rho^0; x_1 x_2 s_{AA}\right) \mathrm{d}n_{\gamma\gamma}\left(x_1, x_2, \mathbf{b}\right)$$



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

The elementary cross section

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



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

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

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

$$\mathcal{M}_{\rho^{0*}\rho^{0*}\to\rho^0\rho^0}(\hat{s},\hat{t};q_1,q_2) = F\left(\hat{t};q_1^2\right)F\left(\hat{t};q_2^2\right)$$
$$\times\hat{s}\left(\eta_P\left(\hat{s},\hat{t}\right)C_P\left(\frac{\hat{s}}{s_0}\right)^{\alpha_P(\hat{t})-1} + \eta_R\left(\hat{s},\hat{t}\right)C_R\left(\frac{\hat{s}}{s_0}\right)^{\alpha_R(\hat{t})-1}\right)$$

- $\eta_P\left(\hat{s},\hat{t}=0\right) \cong i$
- $C_P = 8.56\,mb$
- $\alpha_P\left(\hat{t}\right) = 1.088 + 0.25t$
- $\eta_R\left(\hat{s},\hat{t}=0\right) \cong i-1$
- $C_R = 13.39\,mb$
- $\alpha_R\left(\hat{t}\right) = 0.5 + 0.9t$

$$F(\hat{t};q^2) = \exp\left(\frac{B\hat{t}}{4}\right)\cdot\exp\left(\frac{q^2-m_\rho^2}{2\Lambda^2}\right)$$

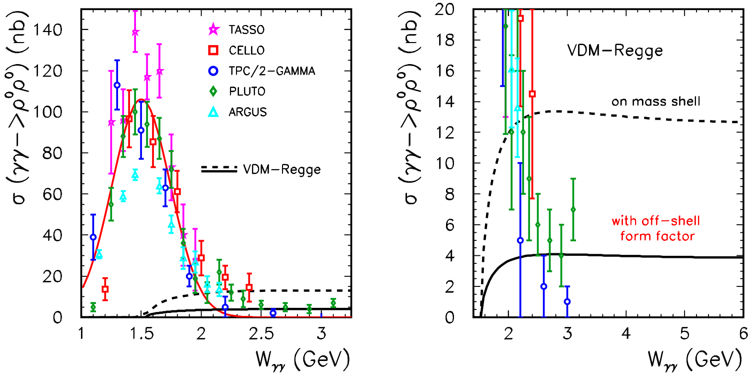
- $B \sim 4\,GeV^{-2}$
- $\Lambda \sim 1\,GeV$

VDM–Regge model

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

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

The elementary cross section



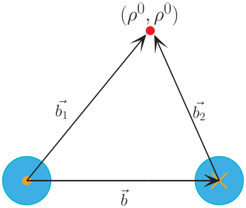
$$\Leftarrow \hat{\sigma}\left(\gamma\gamma \rightarrow \rho^0\rho^0; W_{\gamma\gamma}\right) \Rightarrow$$

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

Photon flux - continuation of the cross section in EPA

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

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



Photon flux - continuation of the cross section in EPA

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

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

- $\mathbf{E}(x, \mathbf{b}) = Z\sqrt{4\pi\alpha_{em}} \int \frac{\mathrm{d}^2\mathbf{q}}{(2\pi^2)} e^{-i\mathbf{bq}} \frac{\mathbf{q}}{\mathbf{q}^2 + x^2 M_A^2} F_{em}\left(\mathbf{q}^2 + x^2 M_A^2\right)$
- $S^2_{abs}(\mathbf{b}) \cong \theta(\mathbf{b} - 2R_A)$
- $\frac{1}{\pi}\int \mathrm{d}^2\mathbf{b}|\mathbf{E}(x, \mathbf{b})|^2 = \int \mathrm{d}^2\mathbf{b} N(\omega, \mathbf{b})$
- $\mathrm{d}\omega_1 \mathrm{d}\omega_2 \to \mathrm{d}W_{\gamma\gamma}\mathrm{d}Y$

The cross section in b-space EPA

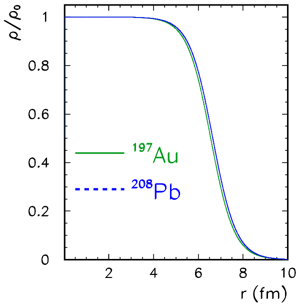
Nuclear cross section – EPA

$$\sigma\left(AA \to \rho^0\rho^0 AA; s_{AA}\right) =$$
$$= \int \hat{\sigma}\left(\gamma\gamma \to \rho^0\rho^0; W_{\gamma\gamma}\right)\,\theta\left(|\mathbf{b}_1 - \mathbf{b}_2| - 2R_A\right)$$
$$x \quad N(\omega_1, \mathbf{b}_1)\, N(\omega_2, \mathbf{b}_1)\, 2\pi b_m\, \mathrm{d}b_m\, \mathrm{d}\overline{b}_x\, \mathrm{d}\overline{b}_y\, \frac{W_{\gamma\gamma}}{2} \mathrm{d}W_{\gamma\gamma}\, \mathrm{d}Y$$

Nucleus charge form factor

REALISTIC F_{em}

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



MONOPOLE F_{em}

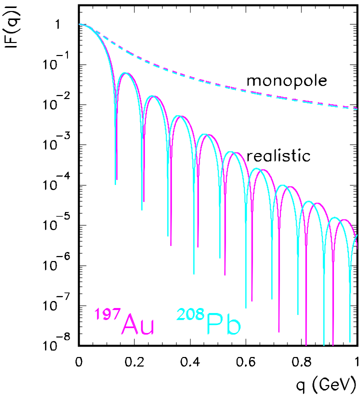
$$F(q^2) = \frac{\Lambda^2}{\Lambda^2 + q^2}$$

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

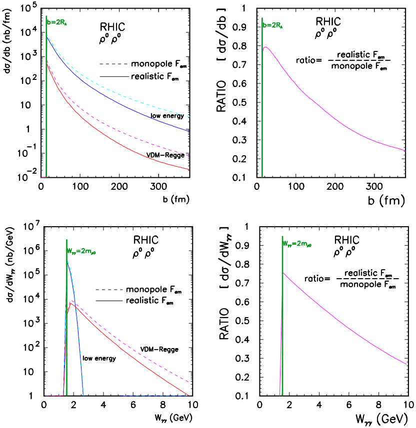
- $^{197}Au \Rightarrow \sqrt{< r^2 >} = 5.3\ fm,\ \Lambda = 0.091\ GeV,$
- $^{208}Pb \Rightarrow \sqrt{< r^2 >} = 5.5\ fm,\ \Lambda = 0.088\ GeV.$

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
0
0.2
0.4
0.6
0.8
1
q (GeV)
monopole
realistic
197Au
208Pb

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



Impact parameter: b.

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

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

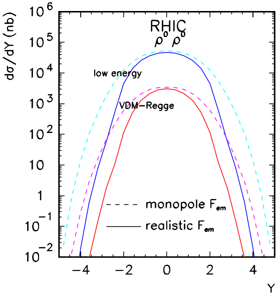
Invariant mass of the $\gamma\gamma$ system: $W_{\gamma\gamma} = M_{\rho^0\rho^0}$.

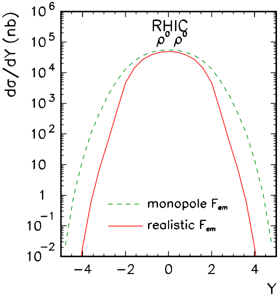
RHIC $\left(Au\ Au \to Au\ \rho^0\rho^0\ Au\right)$

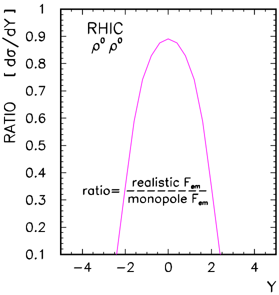
Rapidity of the $\rho^0\rho^0$ pair: $Y = \frac{y_{\rho^0}+y_{\rho^0}}{2}$.

Low–energy+ +VDM-Regge

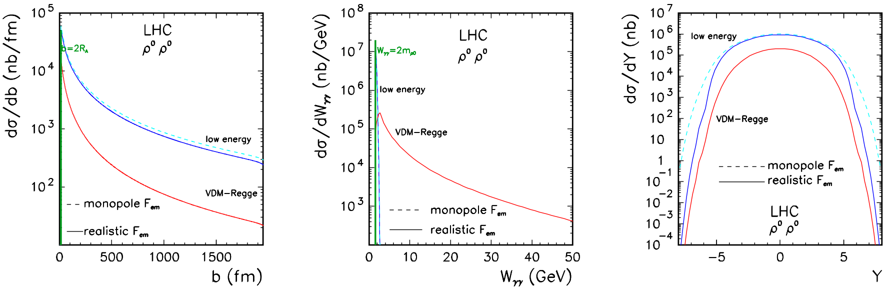
$\text{Ratio} = \frac{d\sigma\left(F_{em}^{REALISTIC}\right)}{d\sigma\left(F_{em}^{MONOPOLE}\right)}$



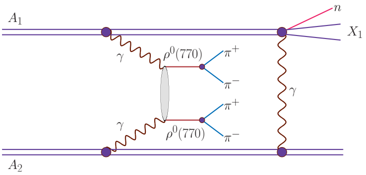


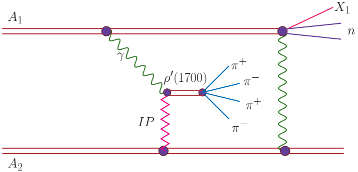


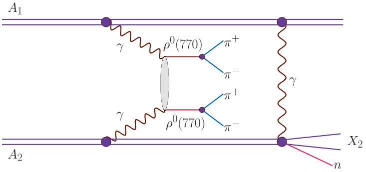
LHC $\left(Pb\ Pb \to Pb\ \rho^0\rho^0\ Pb\right)$

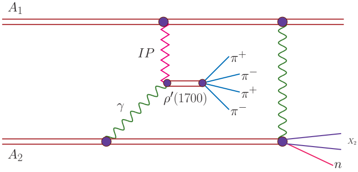


$AA \longrightarrow A^* A^* \pi^+ \pi^- \pi^+ \pi^-$

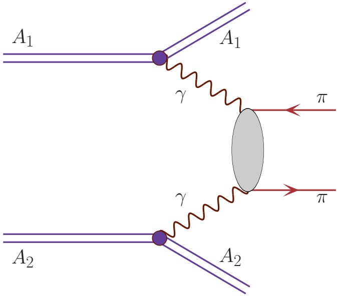








$PbPb \to PbPb\pi\pi$ at large invariant masses



Accelerator LHC:

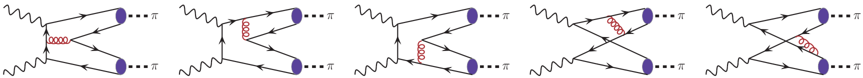
- $\sqrt{s_{NN}} = 3.5$ TeV
- $\gamma_{cm} = 2\,932$ GeV

Kłusek-Gawenda,Szczurek, Phys. Lett. **B700** (2011) 114004.

Elementary cross section for $\gamma\gamma \to \pi\pi$

The $\gamma\gamma \to (q\bar{q})(q\bar{q}) \to \pi\pi$ amplitude in the LO pQCD

$$\mathcal{M}(\lambda_1,\lambda_2) = \int_0^1 dx \int_0^1 dy\, \phi_\pi\left(x,\mu_x^2\right) T_H^{\lambda_1\lambda_2}\left(x,y,\mu^2\right) \phi_\pi\left(y,\mu_y^2\right) \times F_{reg}^{pQCD}(t,u)$$



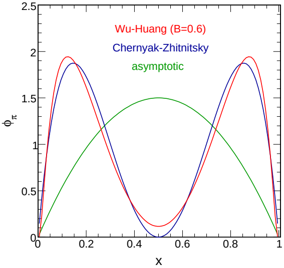
- $\mu_x = min\,(x, 1-x)\sqrt{s(1-z^2)}$,
- $z = \cos\theta$,
- $F_{reg}^{pQCD}(t,u) = \left[1 - \exp\left(\frac{t-t_m}{\Lambda_{reg}^2}\right)\right]\left[1 - \exp\left(\frac{u-u_m}{\Lambda_{reg}^2}\right)\right]$

The quark distribution amplitude of the pion

$$\phi_\pi\left(x,\mu_0^2\right)_{\mathbf{WH}} = \frac{\sqrt{3}A\,m_q\beta}{2\sqrt{2}\pi^{3/2}f_\pi}\sqrt{x\left(1-x\right)}\left(1+B\times C_2^{3/2}\left(2x-1\right)\right)$$
$$\times \left(\mathrm{Erf}\left[\sqrt{\frac{m_q^2+\mu_0^2}{8\beta^2x\left(1-x\right)}}\right]-\mathrm{Erf}\left[\sqrt{\frac{m_q^2}{8\beta^2x\left(1-x\right)}}\right]\right)$$

- B $= 0.6$
- m$_q$ $= 0.3$ GeV
- A $= 16.62$ GeV^{-1}
- $\beta = 0.745$ GeV

$$\phi_\pi(x)_{\mathbf{CZ}} = 30x(1-x)(2x-1)^2$$
$$\phi_\pi(x)_{\mathbf{as}} = 6x(1-x)$$

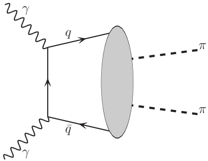


from amplitude to cross section

high energy normalization

$$\sigma\left(\gamma\gamma \rightarrow \pi\pi\right) = \int \frac{2\pi}{4 \cdot 64\pi^2 W^2} \frac{p}{q} \sum_{\lambda_1,\lambda_2} \left|\mathcal{M}\left(\lambda_1, \lambda_2\right)\right|^2 dz$$

Hand-bag model, Diehl-Kroll-Vogt



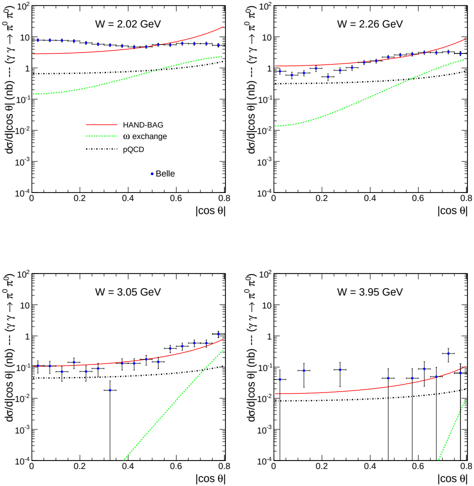
Hand-bag model:

$$\sigma\left(\gamma\gamma \to \pi^+\pi^-\right) = \frac{4\pi\alpha_{em}^2}{s}\left(\frac{\cos\theta_0}{\sin^2\theta_0} + \frac{1}{2}\ln\frac{1+\cos\theta_0}{1-\cos\theta_0}\right)\left|R_{\pi\pi}(s)\right|^2$$

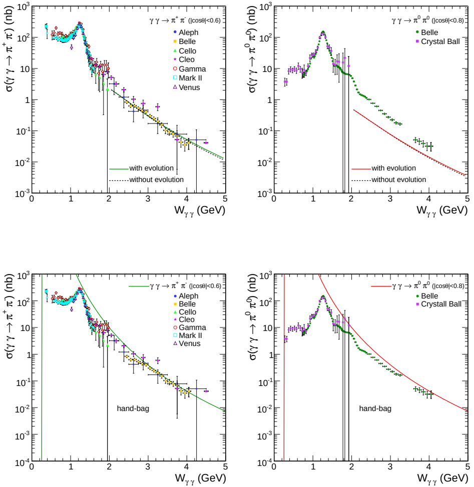
$$R_{\pi\pi}(s) = \frac{5}{9s}a_u\left(\frac{s_0}{s}\right)^{n_u} + \frac{1}{9s}a_s\left(\frac{s_0}{s}\right)^{n_s}$$

- $s_0 = 9$ GeV^2
- $a_u = 1.375$ GeV^2
- $n_u = 0.4175$
- $a_s = 0.5025$ GeV^2
- $n_s = 1.195$

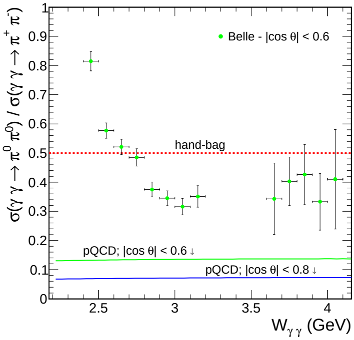
$\frac{d\sigma(\gamma\gamma\to\pi^0\pi^0)}{dz} \Longrightarrow$ pQCD vs hand-bag vs ω exchange



$\sigma(\gamma\gamma \to \pi^+\pi^-)$, $\sigma(\gamma\gamma \to \pi^0\pi^0) \Longrightarrow$ pQCD vs hand-bag

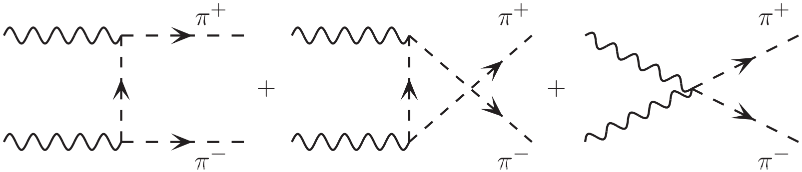


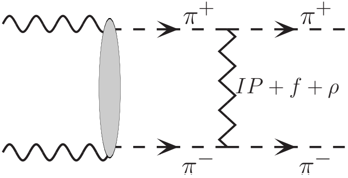
$\sigma(\gamma\gamma \longrightarrow \pi^0\pi^0)\ /\ \sigma(\gamma\gamma \longrightarrow \pi^+\pi^-) \Longrightarrow$ pQCD vs hand-bag



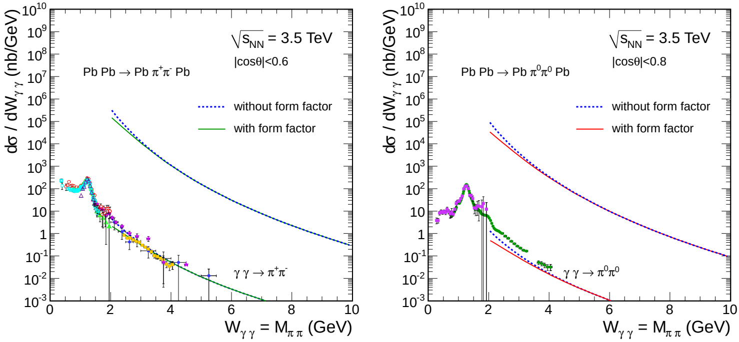
Other mechanisms?

Pion exchange and high-energy pion-pion rescattering

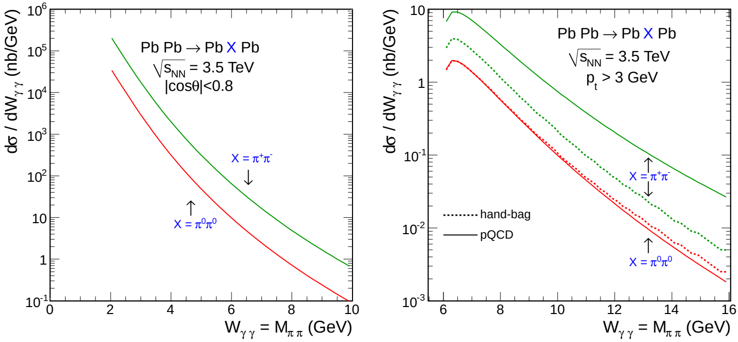




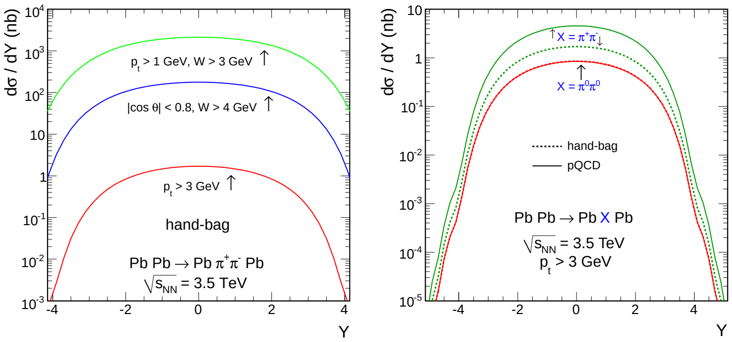
$AA \longrightarrow A\pi\pi A$, results



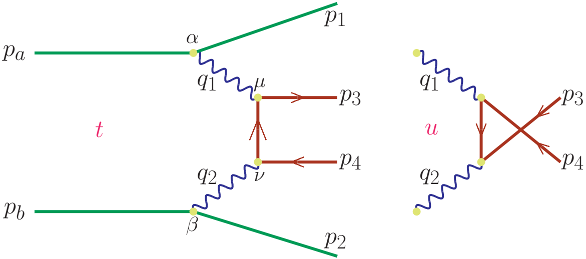
$AA \to A\pi\pi A$, results



$AA \to A\pi\pi A$, results



$AA \to A\mu^+\mu^- A$



Mariola Kłusek-Gawenda and A.S.
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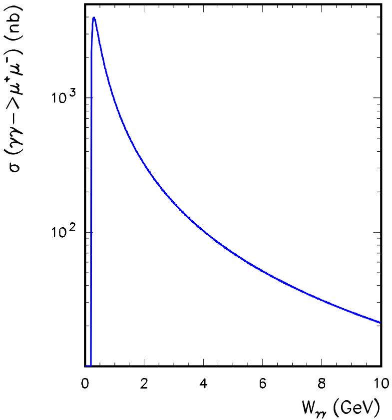
$AA \longrightarrow A\mu^+\mu^- A$



Momentum-space calculation

$$\sigma = \int \frac{1}{2s}\overline{|\mathcal{M}|^2}\,(2\pi)^4\,\delta^4\,(p_a + p_b - p_1 - p_2 - p_3 - p_4) \times \frac{d^3p_1}{(2\pi)^3\,2E_1}\frac{d^3p_2}{(2\pi)^3\,2E_2}\frac{d^3p_3}{(2\pi)^3\,2E_3}\frac{d^3p_4}{(2\pi)^3\,2E_4}\,. \quad (1)$$

$$\frac{d^3p_i}{E_i} = dy_i\,d^2p_{it} = dy_i p_{it} dp_{it} d\phi_i\,. \quad (2)$$

$$\sigma = \int \frac{1}{2s}\overline{|\mathcal{M}|^2}\delta^4\,(p_a + p_b - p_1 - p_2 - p_3 - p_4)\,\frac{1}{(2\pi)^8}\frac{1}{2^4} \times (dy_1 p_{1t} dp_{1t} d\phi_1)\,(dy_2 p_{2t} dp_{2t} d\phi_2)\,(dy_3 d^2p_{3t})\,(dy_4 d^2p_{4t}) \quad (3)$$

$$\mathbf{p}_m = \mathbf{p}_{3t} - \mathbf{p}_{4t} \quad (4)$$

Momentum-space calculation

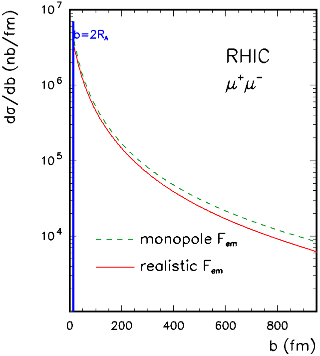
The helicity dependent amplitude of the process can be written as

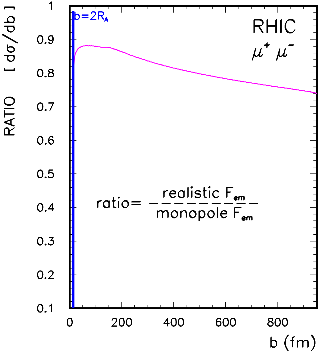
$$\mathcal{M}_{\lambda_3,\lambda_4}(t) = e\,F(q_1)\,(p_a+p_1)^{\alpha}\,\frac{-i\,g_{\alpha\mu}}{q_1^2+i\varepsilon}\,\bar{u}(p_3,\,\lambda_3)\;i\,\gamma^{\mu}\,\frac{i\,[(\not{p}_3-\not{q}_1)+m_{\mu}]}{(q_1-p_3)^2-m_{\mu}^2}$$
$$\times\; i\,\gamma^{\nu}\,v(p_4,\,\lambda_4)\,\frac{-i\,g_{\nu\beta}}{q_2^2+i\varepsilon}\,(p_b+p_2)^{\beta}\;e\,F(q_2)\,, \tag{5}$$

$$\mathcal{M}_{\lambda_3,\lambda_4}(u) = e\,F(q_1)\,(p_a+p_1)^{\alpha}\,\frac{-i\,g_{\alpha\mu}}{q_1^2+i\varepsilon}\,\bar{u}(p_3,\,\lambda_3)\;i\,\gamma^{\nu}\,\frac{i\,[(\not{p}_3-\not{q}_2)+m_{\mu}]}{(q_2-p_3)^2-m_{\mu}^2}$$
$$\times\; i\,\gamma^{\mu}\,v(p_4,\,\lambda_4)\,\frac{-i\,g_{\nu\beta}}{q_2^2+i\varepsilon}\,(p_b+p_2)^{\beta}\;e\,F(q_2)\,. \tag{6}$$

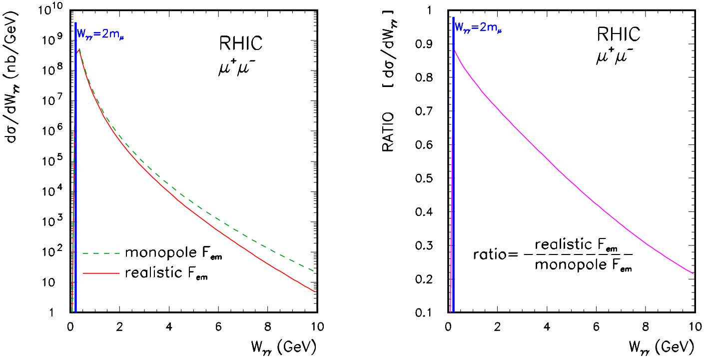
Finally, one has to calculate the 8-dimensional integral numerically.

Impact parameter dependence (EPA)

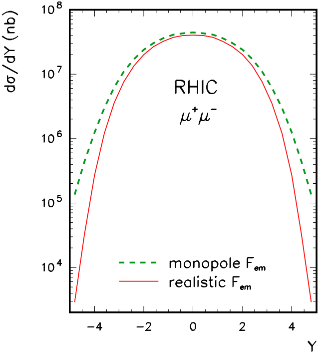


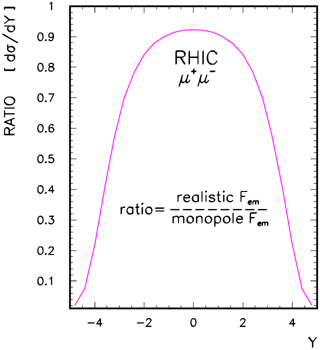


Invariant mass distribution of $\mu^+\mu^-$

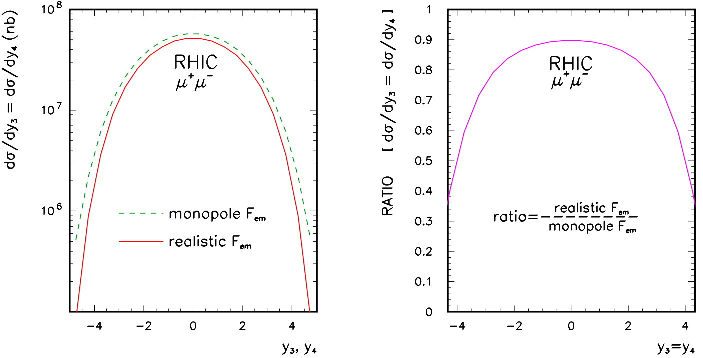


Pair rapidity distribution

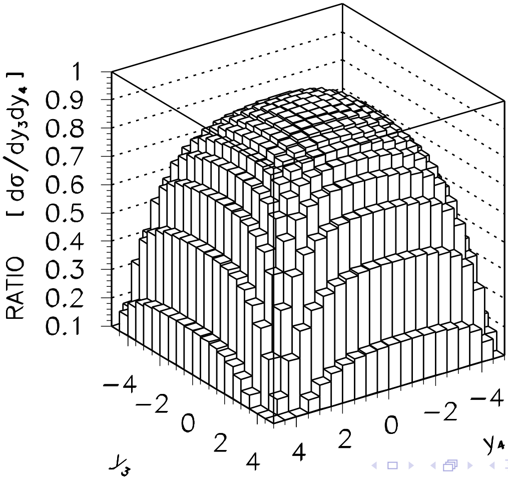




Rapidity distribution of muons



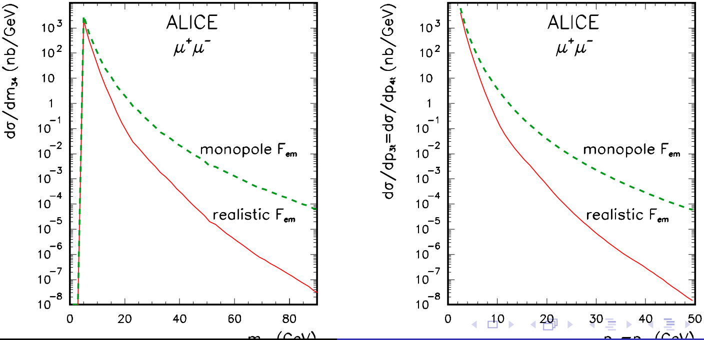
Distribution in $y_{\mu^+}y_{\mu^-}$



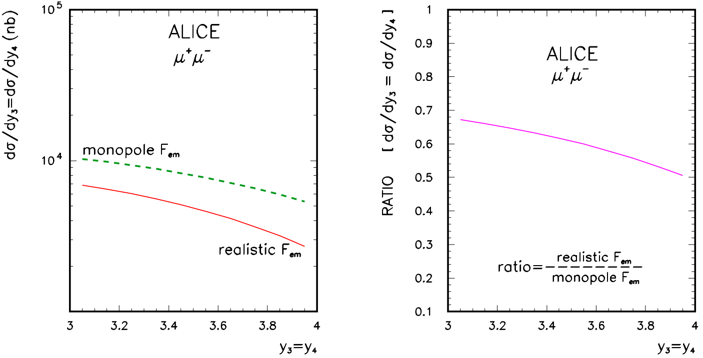
Predictions for ALICE

ALICE

- $p_{3\,t},\ p_{4\,t} \geq 2\ GeV$
- $(y_3,\ y_4) = (3, 4)$



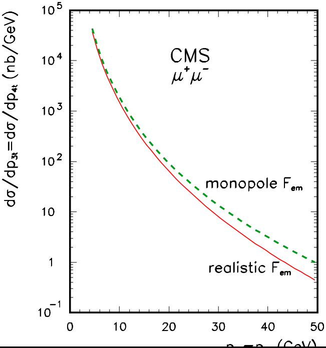
Predictions for ALICE

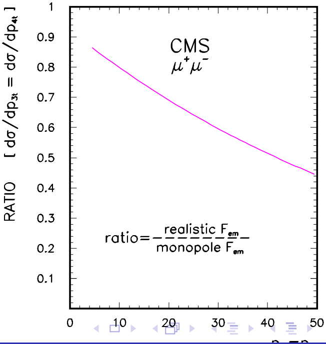


Predictions for CMS

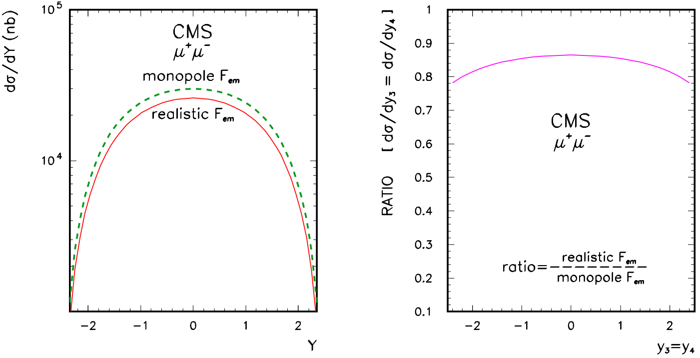
CMS

- $p_{3\,t},\ p_{4\,t} > 4\ GeV$
- $|y_3,\ y_4| < 2.5$



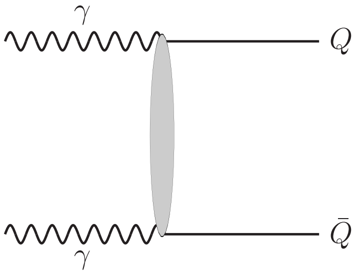


Predictions for CMS



$AA \to AQ\bar{Q}A$

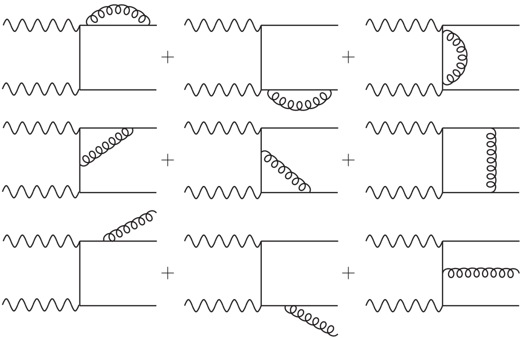
The mechanism analogous to dilepton production



In fact two diagrams (t and u channel quark exchanges) in the Born approximation
M. Kłusek-Gawenda, A.S., M. Machado and V. Serbo, arXiv:1011.1191, Phys. Rev. **C83** (2011) 024903.

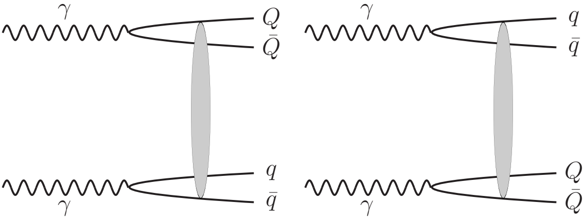
Other mechanisms, QCD corrections

In reality not quarks but mesons could be measured.
D or B mesons are associated with a few pions/kaons.
Therefore other mechanisms leading to similar final state have to be included.



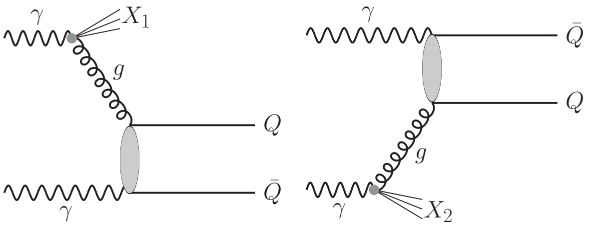
Four-quark component

Two heavy quark/antiquark, two light quark/antiquark



Single-resolved mechanisms

One photon fluctuates to a partonic state with parton distributions.



Elementary cross sections

LO (Born) term:

$$\sigma^{direct}_{\gamma\gamma\to Q\bar{Q}}(W_{\gamma\gamma}) = N_c e_Q^4 \frac{4\pi\alpha_{em}^2}{W_{\gamma\gamma}^2}$$
$$\times \left\{ 2\ln\left[\frac{W_{\gamma\gamma}}{2m_Q}(1+v)\right]\left(1+\frac{4m_Q^2 W_{\gamma\gamma}^2 - 8m_Q^4}{W_{\gamma\gamma}^4}\right) - \left(1+\frac{4m_Q^2 W_{\gamma\gamma}^2}{W_{\gamma\gamma}^4}\right)\right.$$

NLO corrections:

$$\sigma^{QCD}_{\gamma\gamma\to Q\bar{Q}(g)}(W_{\gamma\gamma}) = N_c e_Q^4 \frac{2\pi\alpha_{em}^2}{W_{\gamma\gamma}^2} C_F \frac{\alpha_s}{\pi} f^{(1)}. \qquad (8)$$

function f was calculated by: Kniehl-Kotikov-Merebashvili-Veretin, 2009

Elementary cross sections, 4-quark component

Four-quark component in the dipole-dipole scattering approach based on a saturation approach (Kwieciński-Motyka) with extrapolation down to the threshold (Szczurek)

$$\sigma^{4q}_{\gamma\gamma\to Q\bar{Q}}(W_{\gamma\gamma}) = \sum_{f_2\neq Q} \int \left|\Phi^{Q\bar{Q}}(\rho_1, z_1)\right|^2 \left|\Phi^{f_2\bar{f}_2}(\rho_2, z_2)\right|^2 \sigma_{dd}(\rho_1, \rho_2, x_{Qf}) d^2\rho$$
$$+ \sum_{f_1\neq Q} \int \left|\Phi^{f_1\bar{f}_1}(\rho_1, z_1)\right|^2 \left|\Phi^{Q\bar{Q}}(\rho_2, z_2)\right|^2 \sigma_{dd}(\rho_1, \rho_2, x_{fQ}) d^2\rho$$

where $\Phi^{Q\bar{Q}}(\rho, z)$ are the quark – antiquark wave functions of the photons in the mixed representation and σ_{dd} is the dipole–dipole cross section.

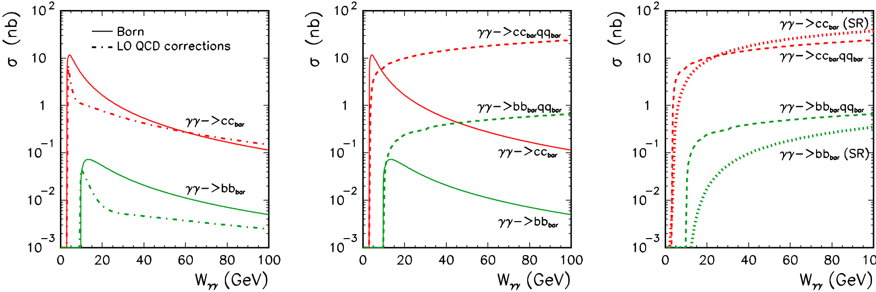
Elementary cross sections

single resolved component

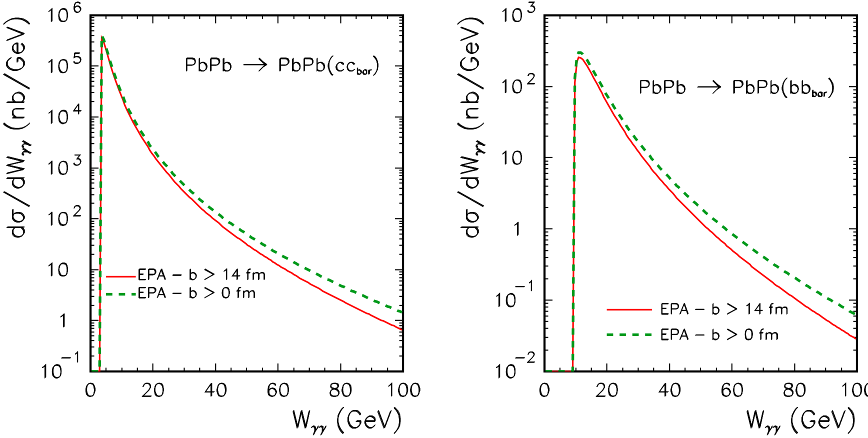
$$\sigma_{1-res}(s) = \int dx_1 \left[g_1 \left(x_1, \mu^2\right) \hat{\sigma}_{g\gamma \to Q\bar{Q}} \left(\hat{s} = x_1 s\right)\right] + \int dx_2 \left[g_2 \left(x_2, \mu^2\right) \hat{\sigma}_{\gamma g \to Q\bar{Q}} \left(\hat{s} = x_2 s\right)\right], \quad (10)$$

where g_1 and g_2 are gluon distributions in photon 1 or photon 2 and $\hat{\sigma}_{q\gamma \to Q\bar{Q}}$ and $\hat{\sigma}_{\gamma g \to Q\bar{Q}}$ are elementary cross sections. In our evaluation we take the GVR1992 gluon distributions in photon.

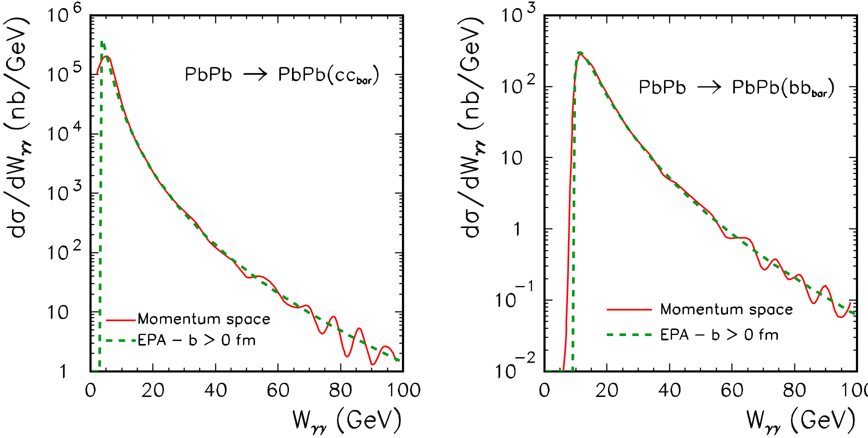
Elementary cross sections, results



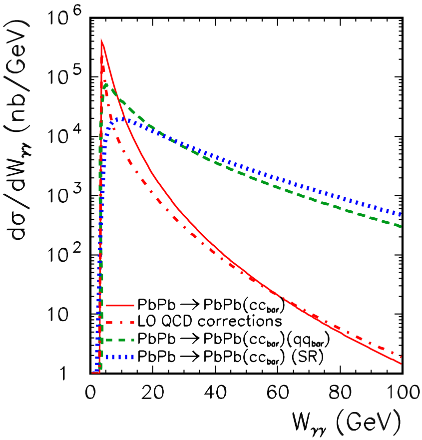
$W_{\gamma\gamma}$-dependence of the nuclear cross section

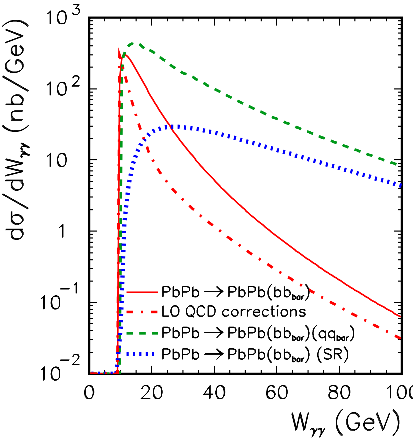


$W_{\gamma\gamma}$-dependence, EPA vs exact



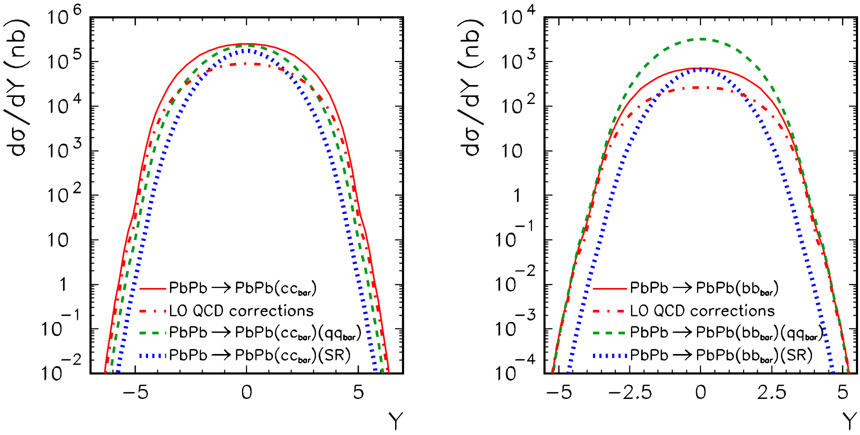
$W_{\gamma\gamma}$-dependence, components





Rapidity distribution

Rapidity of the whole system



Total cross sections

Tablica: Partial contributions of different mechanisms.

	σ_{tot}	Born	QCD-corrections	4-quark	Single-resolved
$c\bar{c}$	2.47 mb	42.5 %	14.6 %	27.1 %	15.8 %
$b\bar{b}$	10.83 μb	18.9 %	7.7 %	64.5 %	8.9 %

Other processes

1. $AA \to A\pi^+\pi^- A$ at low $M_{\pi\pi}$
   $AA \to A\pi^0\pi^0 A$ at low $M_{\pi\pi}$
   Easy for a measurement (ALICE)
2. $AA \to AD^+D^- A$
   $AA \to AD^0\bar{D}^0 A$
   Testing pQCD and distribution amplitudes
   Luszczak-Szczurek, Phys. Lett. **B700** (2011) 116.
3. $AA \to AW^+W^- A$
   Anomalous triple and quartic boson couplings? Not possible
4. $AA \to AJ/\Psi J/\Psi A$
   Testing heavy-quark approaches.

General summary

1. Sizeable cross sections for different processes.
2. Cross sections smaller than in the literature
   Realistic charge distribution, absorptive geometrical effects
3. The role of competitive diffractive processes leading to the same final state has to be explored
   Strikman, Gay Ducati, Machado
4. Experimental feasibility of several processes should be studied.
5. Potential for this type of studies should be better explored.