SINGLE AND DOUBLE SCATTERING PRODUCTION OF FOUR LEPTONS IN LEAD-LEAD UPC

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MPI@LHC'17

FOUR LEPTONS IN PB-PB UPC

EPA

FOUR-LEPTON PRODUCTION

ELECTRONS

MUONS

CONCLUSION

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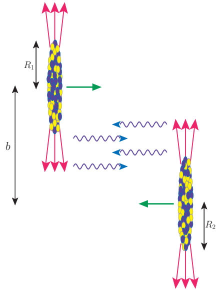
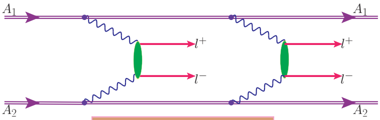


ULTRA PERIPHERAL COLLISIONS

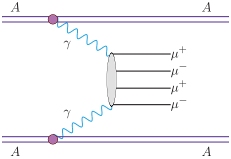
$b > R_{min} = R_1 + R_2$

1. M. K-G, A. Szczurek,
   Double scattering production of two positron–electron pairs in ultraperipheral heavy-ion collisions,
   Phys. Lett. **B763** (2016) 416,
2. A. van Hameren, M. K-G, A. Szczurek,
   From the Single- and double-scattering production of four muons in ultraperipheral PbPb collisions at the Large Hadron Collider,
   Phys. Lett. **B776** (2018) 84,

Double-scattering



Single-scattering



ALICE, ATLAS, CMS, LHCb (^{208}Pb+^{208}Pb @ $\sqrt{s_{NN}} = 2.76, 3.5, 5.02, 5.5$ TeV)

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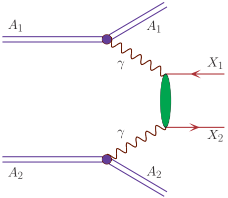
Nuclear Cross Section



$$\sigma_{A_1 A_2 \to A_1 A_2 X_1 X_2} = \dots$$

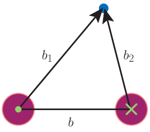
NAIVELY $\Rightarrow \dots$

$$= \int \mathrm{d}\omega_1\, \mathrm{d}\omega_2\, n(\omega_1) n(\omega_2) \times \sigma_{\gamma\gamma \to X_1 X_2}(\omega_1, \omega_2)$$

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

MORE CORRECTLY $\Rightarrow \dots$

$$= \int N(\omega_1, \mathbf{b_1})\, N(\omega_2, \mathbf{b_2}) S^2_{abs}(\mathbf{b}) \times \sigma_{\gamma\gamma \to X_1 X_2}(W_{\gamma\gamma}) \times \mathrm{d}^2 b\, \mathrm{d}\overline{b}_x\, \mathrm{d}\overline{b}_y\, \frac{W_{\gamma\gamma}}{2} \mathrm{d}W_{\gamma\gamma}\, \mathrm{d}Y_{X_1 X_2}$$



Photon flux & Form factor

✗ charge distribution in nucleus

$$N(\omega, b) = \frac{Z^2 \alpha_{em}}{\pi^2 \beta^2} \frac{1}{\omega} \frac{1}{b^2} \times \left| \int \mathrm{d}\chi \, \chi^2 \frac{F\left(\frac{\chi^2+u^2}{b^2}\right)}{\chi^2 + u^2} J_1(\chi) \right|^2$$

$$\beta = \frac{p}{E}, \gamma = \frac{1}{\sqrt{1-\beta^2}}, u = \frac{\omega b}{\gamma \beta}, \chi = k_\perp b$$

- realistic charge distribution

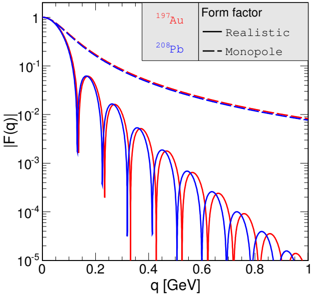
$$F\left(\mathbf{q}^2\right) = \frac{4\pi}{|\mathbf{q}|} \int \rho(r) \sin(|\mathbf{q}| r) \, r \mathrm{d}r$$

- point-like $F\left(\mathbf{q}^2\right) = 1$

$$N(\omega, b) = \frac{Z^2 \alpha_{em}}{\pi^2 \beta^2} \frac{1}{\omega} \frac{1}{b^2} \times u^2 \left[K_1^2(u) + \frac{1}{\gamma^2} K_0^2(u) \right]$$

- monopole $F\left(\mathbf{q}^2\right) = \frac{\Lambda^2}{\Lambda^2 + |\mathbf{q}|^2}$

$$\sqrt{\langle r^2 \rangle} = \sqrt{\frac{6}{\Lambda^2}} = 1 \text{ fm } A^{1/3}$$



Four leptons in Pb-Pb UPC
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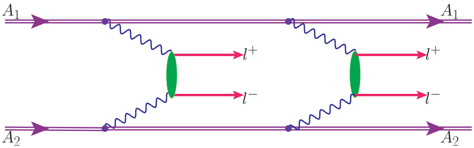
FOUR-LEPTON PRODUCTION



$$P_{AA\xrightarrow{\gamma\gamma}AAl^+l^-}(b; y_{l^+}, y_{l^-}, p_{t,l}) = \int N(\omega_1, \mathbf{b_1})\, N(\omega_2, \mathbf{b_2}) S^2_{abs}(\mathbf{b}) \times \frac{\mathrm{d}\sigma_{\gamma\gamma\to l_1 l_2}(W_{\gamma\gamma})}{\mathrm{d}z}\, \mathrm{d}\bar{b}_x\, \mathrm{d}\bar{b}_y\, \frac{W_{\gamma\gamma}}{2} \mathrm{d}W_{\gamma\gamma}\, \mathrm{d}Y_{l_1 l_2}$$

$$\frac{\mathrm{d}\sigma_{A_1A_2\to A_1A_2 l_1^+ l_2^- l_3^+ l_4^-}}{\mathrm{d}y_{l^+}\mathrm{d}y_{l^-}\mathrm{d}p_{t,l}\mathrm{d}y_{l^+}\mathrm{d}y_{l^-}\mathrm{d}p_{t,l}} = \frac{1}{2}\int \frac{\mathrm{d}P^{I}_{AA\xrightarrow{\gamma\gamma}AAl^+l^-}(b; y_{l^+}, y_{l^-}, p_{t,l})}{\mathrm{d}y_{l^+}\mathrm{d}y_{l^-}\mathrm{d}p_{t,l}} \times \frac{\mathrm{d}P^{II}_{AA\xrightarrow{\gamma\gamma}AAl^+l^-}(b; y_{l^+}, y_{l^-}, p_{t,l})}{\mathrm{d}y_{l^+}\mathrm{d}y_{l^-}\mathrm{d}p_{t,l}}\, \mathrm{d}^2 b$$

$$\sigma_{A_1A_2\to A_1A_2 l^+l^-} = \int \frac{\mathrm{d}P_{AA\xrightarrow{\gamma\gamma}AAl^+l^-}(b; y_{l^+}, y_{l^-}, p_{t,l})}{\mathrm{d}y_{l^+}\mathrm{d}y_{l^-}\mathrm{d}p_{t,l}}\, \mathrm{d}^2 b \times \mathrm{d}y_{l^+}\mathrm{d}y_{l^-}\mathrm{d}p_{t,l}$$

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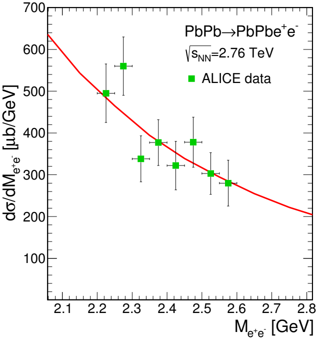
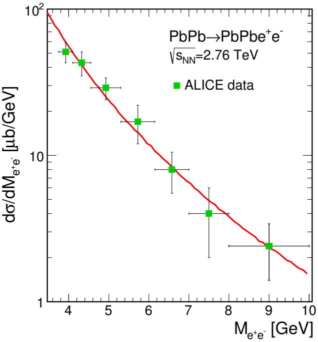
$AA \to AAe^+e^-$ - calculations vs. data

- ALICE Collaboration (Abbas, E. et al.), *Charmonium and e^+e^- pair photoproduction at mid-rapidity in ultra-peripheral Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV*, Eur. Phys. J. **C73** (2013) 2617

2.2 GeV $< M_{ee} <$ 2.6 GeV | $|y_e| < 0.9$ | 3.7 GeV $< M_{ee} <$ 10 GeV





Good description of single pair production $\Rightarrow$ two e^+e^- pair production

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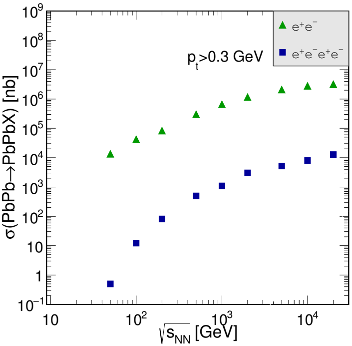
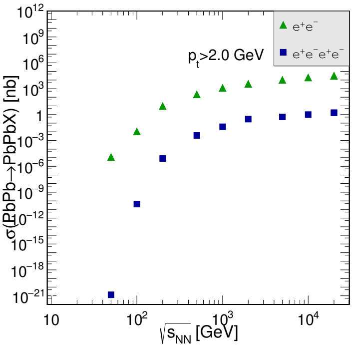
$AA \to AAe^+e^-$ & $AA \to AAe^+e^-e^+e^-$

$p_t > 0.3$ GeV

$p_t > 2.0$ GeV





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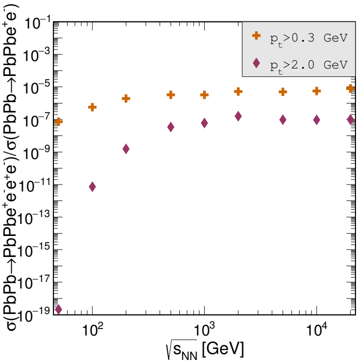
$AA \to AAe^+e^-$ & $AA \to AAe^+e^-e^+e^-$

$$\frac{\sigma_{AA \to AAe^+e^-e^+e^-}}{\sigma_{AA \to AAe^+e^-}}$$



Ratio depends on $\sqrt{s_{NN}}$ and $p_{t,min}$

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$AA \to AAe^+e^-e^+e^-$

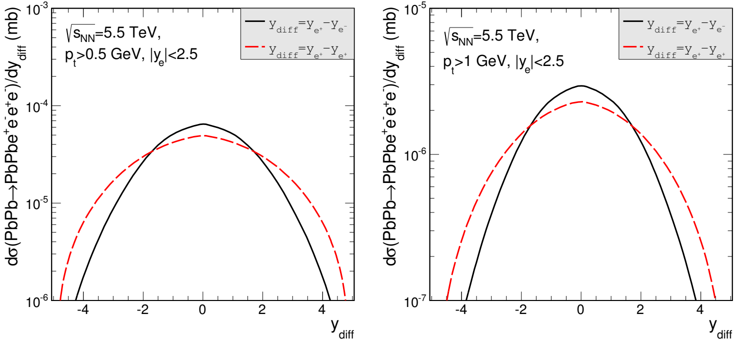
y_{diff}

$p_{t,e} > 0.5$ GeV

$\Rightarrow y_{e^+} - y_{e^-}$

$\Rightarrow y_{e^+} - y_{e^+}$

$p_{t,e} > 1.0$ GeV



Can be measured... $\Longrightarrow$ Firs verification of the DS

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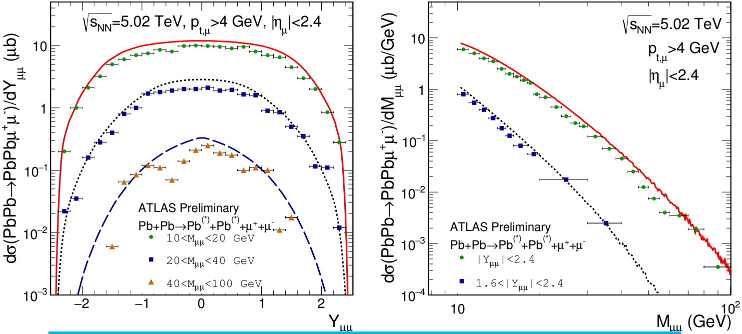
$AA \to AA\mu^+\mu^-$ - CALCULATIONS VS. DATA

➢ ATLAS Collaboration,
Measurement of high-mass dimuon pairs from ultraperipheral lead-lead collisions at $\sqrt{s_{NN}} = 5.02$ TeV with the ATLAS detector at the LHC,
ATLAS-CONF-2016-025

$\frac{d\sigma}{dY_{\mu^+\mu^-}}$ $p_{t,\mu} > 4$ GeV, $|\eta_e| < 0.9$ $\frac{d\sigma}{dM_{\mu^+\mu^-}}$



"Overwriting" of single $\mu^+\mu^-$ pair production vs. preliminary data

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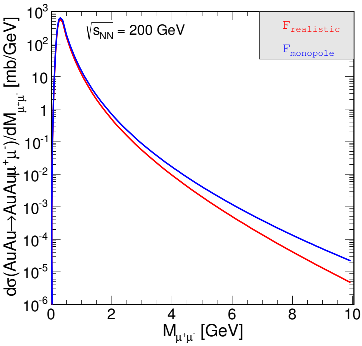
$AA \to AA\mu^+\mu^-$ - FORM FACTOR

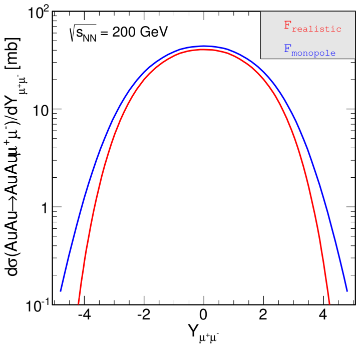
$\Rightarrow$ realistic

$\Rightarrow$ monopole

$M_{\mu^+\mu^-}$

$Y_{\mu^+\mu^-}$

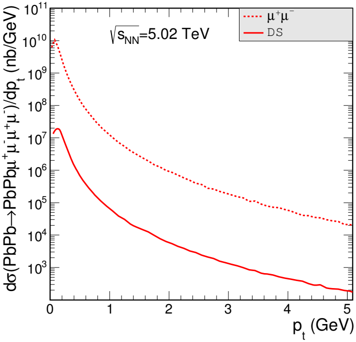




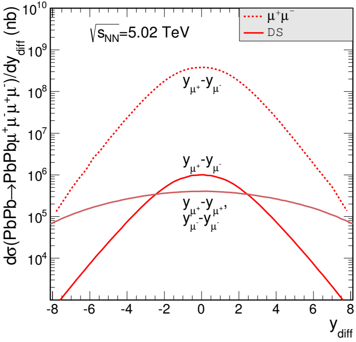
$\frac{\sigma_{monopole}}{\sigma_{realistic}} \nearrow$ for larger values of kinematic variables

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

$p_{t,\mu}$



y_{diff}



Similar like for electron-positron production: $\sigma_{\mu^+\mu^-} \simeq 1000 \times \sigma_{\mu^+\mu^-\mu^+\mu^-}$

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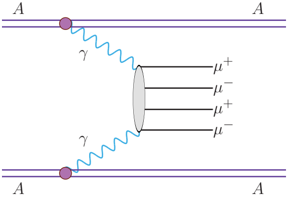
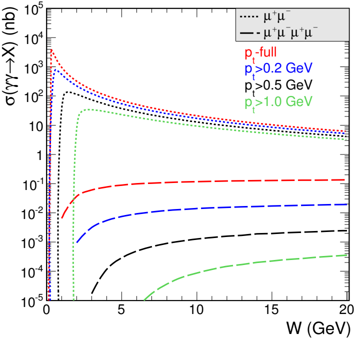
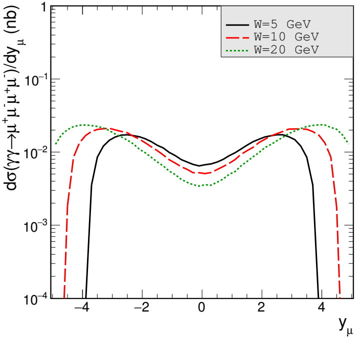
$\gamma\gamma \to \mu^+\mu^-\mu^+\mu^-$ - SINGLE SCATTERING

KATIE- an event generator that is specially designed to deal with initial states that have an explicit transverse momentum dependence, but can also deal with on-shell initial states. KATIE is a parton-level generator for hadron scattering, but requires only a few adjustments to deal with photon scattering.







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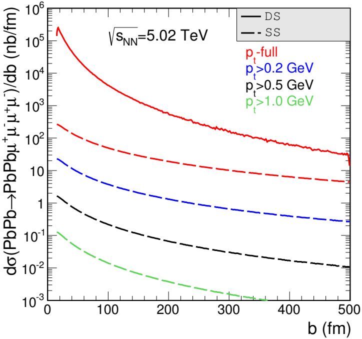
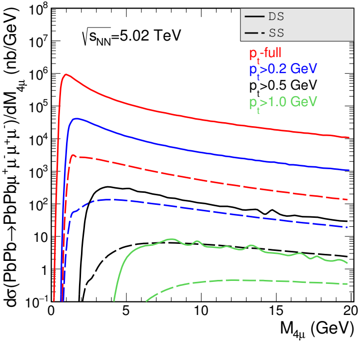
$AA \rightarrow AA\mu^+\mu^-\mu^+\mu^-$

impact parameter

$W_{\gamma\gamma} = M_{4\mu}$





↑ purely theoretical distribution

↑ DS dominates

It is difficult to isolate range of SS domination

*DS - double-scattering mechanism
*SS - a NEW single-scattering mechanism

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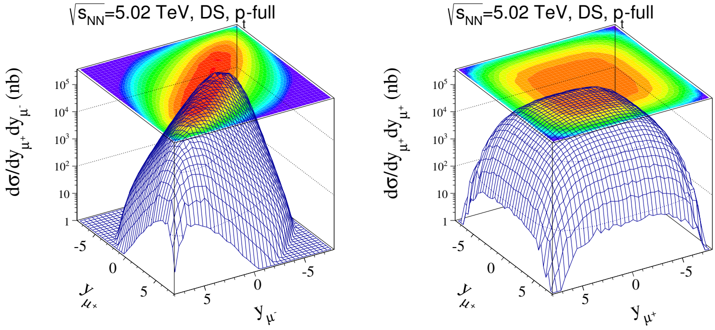
$AA \to AA\mu^+\mu^-\mu^+\mu^-$

y_{μ^+}, y_{μ^-} $\qquad$ $y_{\mu^\pm}, y_{\mu^\pm}$



$p_{t,\mu^+} \simeq p_{t,\mu^-}$ $\Rightarrow$ construction of similar distributions by ALICE or CMS?

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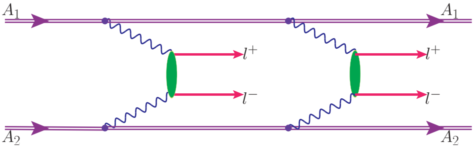

The number of counts for L_{int} = 1 nb^{-1}

(4μ), $\sqrt{s_{NN}} = 5.02$ TeV	
experimental cuts	N
$\lvert y_i \rvert < 2.5$, $p_t > 0.5$ GeV	815
$\lvert y_i \rvert < 2.5$, $p_t > 1.0$ GeV	53
$\lvert y_i \rvert < 0.9$, $p_t > 0.5$ GeV	31
$\lvert y_i \rvert < 0.9$, $p_t > 1.0$ GeV	2
$\lvert y_i \rvert < 2.4$, $p_t > 4.0$ GeV	$\ll 1$

$(4e)$, $\sqrt{s_{NN}} = 5.5$ TeV	
experimental cuts	N
$\lvert y_i \rvert < 2.5$, $p_t > 0.5$ GeV	235
$\lvert y_i \rvert < 2.5$, $p_t > 1.0$ GeV	10
$\lvert y_i \rvert < 1.0$, $p_t > 0.2$ GeV	649
$\lvert y_i \rvert < 1.0$, $p_t > 1.0$ GeV	1

CMS and ALICE $\Rightarrow p_{t,\text{cut}} = 1$ GeV

ALICE $\Rightarrow p_{t,\text{cut}} = 0.2$ GeV

ATLAS $\Rightarrow p_{t,\text{cut}} = 4$ GeV

Potential background

$\downarrow \sqrt{s_{NN}} = 5.5$ TeV, $|y| < 4.9$

Reaction	$p_{t,min}$ = 0.3 GeV	$p_{t,min}$ = 0.5 GeV
$PbPb \to PbPb\pi^+\pi^-\pi^+\pi^-$	2.954 mb	8.862 μb
$PbPb \to PbPbe^+e^-e^+e^-$	7.447 μb	0.704 μb

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CONCLUSION

- EPA in the impact parameter space
- Realistic charge distribution
- Description of the
  - ALICE data for Pb Pb $\to$ Pb Pb e^+e^- and
  - ATLAS data for Pb Pb $\to$ Pb Pb $\mu^+\mu^-$
- Pb Pb $\to$ Pb Pb $\mu^+\mu^-\mu^+\mu^-$ $\Rightarrow \sigma_{SS}^{NEW} < \sigma_{DS}$
- Difficult to isolate a region where SS dominates
- $\sigma_{PbPb \to PbPb l^+ l^-} \cong 1000 \times \sigma_{PbPb \to PbPb l^+ l^- l^+ l^-}$
- The cross sections for four-lepton production strongly depend on the $p_{t,min}$ and y_l
- Triple scattering production $\to$ smaller cross section

Thank you

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