Gamma-gamma scattering

Mariola Kłusek-Gawenda
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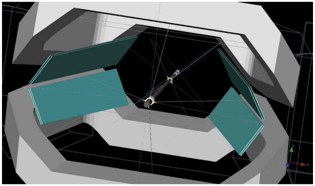

- Equivalent Photon Approximation
- UPC - Light-by-light scattering
- Semicentral collisions

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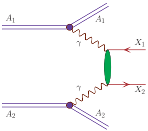
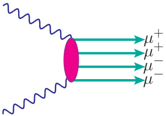
Classification

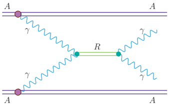
1. Collision energy:
   - low energy processes: $\sqrt{s_{NN}} < 10$ MeV/nucleon;
   - intermediate energies: $\sqrt{s_{NN}} = (10 - 100)$ MeV/nucleon;
   - relativistic energies: $\sqrt{s_{NN}} = (0.1 - 100)$ GeV/nucleon;
   - ultrarelativistic energies: $\sqrt{s_{NN}} > 100$ GeV/nucleon;
2. Centrality (for ^{208}Pb):
   - central collisions: b $\approx$ (0 fm $+\triangle b$);
   - semi-central collisions: b $\approx$ (5 $-$ 10) fm;
   - semi-peripheral collisions: b $\approx$ (10 $-$ 12) fm;
   - peripheral collisions: b $\approx$ (12 fm $-(R_1 + R_2)$);
   - ultraperiperal collisions: b $> (R_1 + R_2)$;

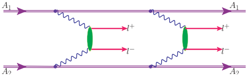
   where $R = R_0 A^{1/3}$.
3. Type of production:

$\gamma\gamma$ fusion





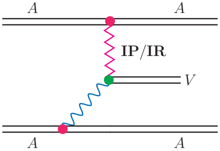


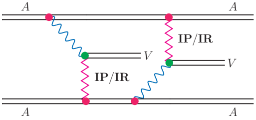


- ✓ $\rho^0\rho^0$, $J/\psi J/\psi$
- ✓ $\pi^+\pi^-$, $\pi^0\pi^0$
- ✓ $c\bar{c}$, $b\bar{b}$
- ✓ e^+e^-, $\mu^+\mu^-$, $\tau^+\tau^-$
- ✓ $\gamma\gamma$

- ✓ $p\bar{p}$
- ✓ $\pi^+\pi^-\pi^+\pi^-$
- ✓ $e^+e^-e^+e^-$
- ✓ $\mu^+\mu^-\mu^+\mu^-$

Photoproduction





- ✓ ρ^0, J/ψ
- ✓ $\rho^0\rho^0$, $J/\psi J/\psi$

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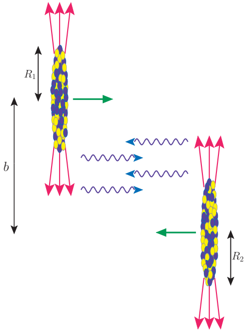
Equivalent Photon Approximation



The strong electromagnetic field is a source of photons that can induce electromagnetic reactions in ion-ion collisions.
Electromagnetism is a long-range force, so electromagnetic interactions occur even at relatively large ion-ion separations.

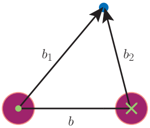
Photon energy: $\omega = \frac{\gamma}{b} \approx \gamma \times 15$ MeV

Virtuality: $Q^2 = \frac{1}{R^2} \approx 0.0008$ GeV^2

$$\sigma_{A_1 A_2 \to A_1 A_2 X_1 X_2} = \int \sigma_{\gamma\gamma \to X_1 X_2}\left(W_{\gamma\gamma}\right) N(\omega_1, \mathbf{b_1})\, N(\omega_2, \mathbf{b_2})\, S^2_{abs}(\mathbf{b})\, \frac{W_{\gamma\gamma}}{2}\, \mathrm{d}W_{\gamma\gamma}\, \mathrm{d}Y_{X_1 X_2}\, \mathrm{d}\bar{b}_x\, \mathrm{d}\bar{b}_y\, \mathrm{d}^2 b$$

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

$$\times \frac{\mathrm{d}\cos\theta}{\mathrm{d}y_{X_1}\, \mathrm{d}y_{X_2}\, \mathrm{d}p_t} \times dy_{X_1}\, dy_{X_2}\, dp_t\, .$$



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Equivalent Photon Flux vs. Form Factor

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

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

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

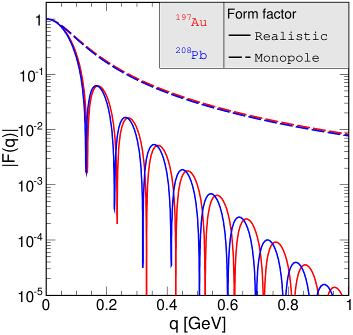
$$N(\omega, b) = \frac{Z^2 \alpha_{em}}{\pi^2 \beta^2} \frac{1}{\omega} \frac{1}{b^2} \times u^2 \left[K_1^2(u) + \frac{1}{\gamma^2} K_0^2(u) \right]$$

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

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

- realistic

$$F(\mathbf{q}^2) = \frac{4\pi}{|\mathbf{q}|} \int \rho(r) \sin(|\mathbf{q}| r) r dr$$



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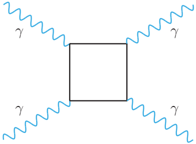
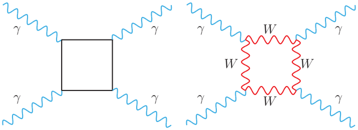
LIGHT-BY-LIGHT SCATTERING

- ❍ Maxwell classical theory
  - ✓ light doesn't interact with each other
- ❍ Quantum theory
  - ✓ interaction of photons through quantum fluctuations



- $\sigma(\gamma\gamma \to \gamma\gamma) \propto \alpha_{em}^4$ → very small
- Photon beams
  - ✗ High-power lasers
    - ➢ K. Homma, K. Matsuura, K. Nakajima, PTEP 2016 (2016) 013C01 *Testing helicity-dependent $\gamma\gamma \to \gamma\gamma$ scattering in the region of MeV*
  - ✔ Ultrarelativistic heavy-ion collision
    - ❍ Cross section $\propto Z^4$
    - ❍ Quasi-real photons

Boxes | **WELL-KNOWN**

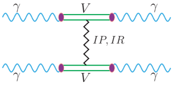


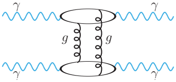
Fermionic boxes (LO QED) | W Box

FormCalc. | LoopTools.

$$\overline{|\mathcal{M}_{\gamma\gamma\to\gamma\gamma}|^2} = \alpha_{em}^4 f(\hat{t}, \hat{u}, \hat{s})$$

VDM-Regge | **WE ADD** | **2-gluon exch.**





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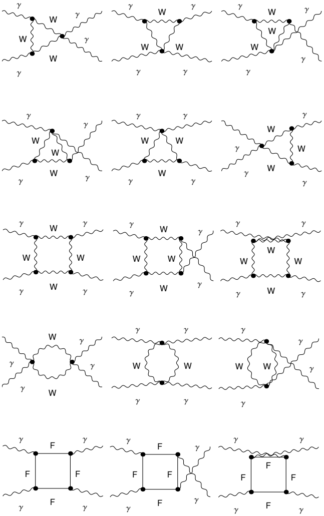
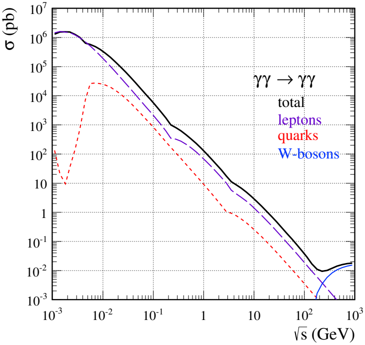
BOXES $\gamma\gamma \to \gamma\gamma$



Fermionic box LO QED - `FormCalc`.

The one-loop W box diagram - `LoopTools`.



We have compared our results with:

- Jikia et al. (1993),
- Bern et al. (2001),
- Bardin et al. (2009).

Bern et al. consider QCD and QED corrections (two-loop Feynman diagrams) to the one-loop fermionic contributions in the ultrarelativistic limit ($\hat{s}, |\hat{t}|, |\hat{u}| \gg m_f^2$). The corrections are quite small numerically.

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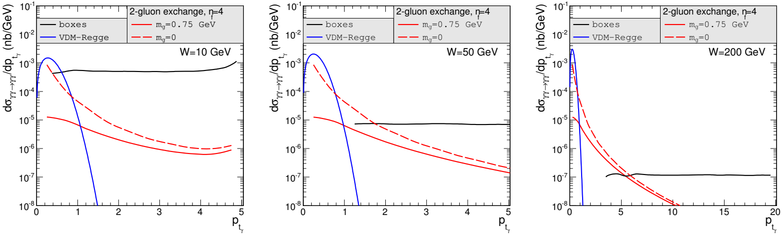
EXPERIMENTAL IDENTIFICATION OF PROCESSES

- ✔ boxes
- ✔ VDM-Regge
- ✔ 2-gluon exchange

W = 10 GeV

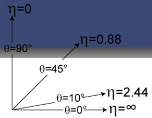
W = 50 GeV

W = 200 GeV



$\gamma - \gamma$ Collider (the International e^+e^- Linear Collider) ?

AA→AA$\gamma\gamma$ - FORM FACTOR

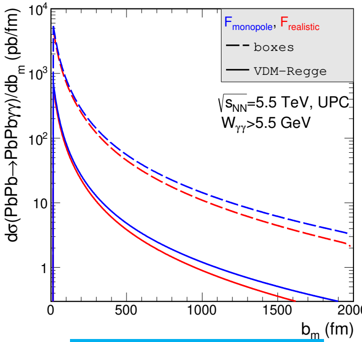


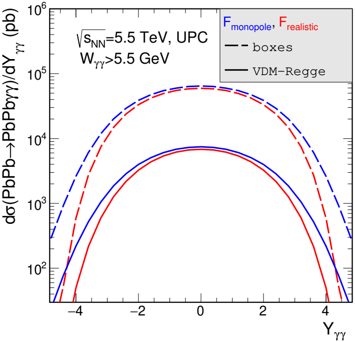
⇨ realistic

⇨ monopole

impact parameter

$$Y_{\gamma\gamma} = \frac{1}{2}\left(y_{\gamma_1} + y_{\gamma_2}\right)$$

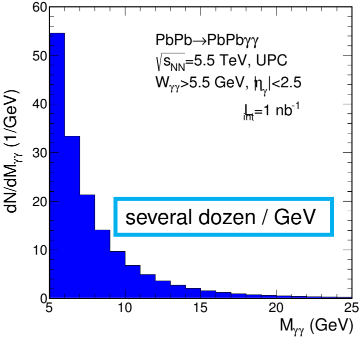




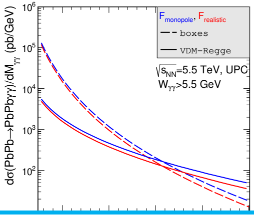
↑ theoretical distribution

$Y_{\gamma\gamma} \neq y_\gamma$

$\frac{\sigma_{monopole}}{\sigma_{realistic}}$ ↗ for larger value of kinematical variables



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



VDM-Regge dominates for $W_{\gamma\gamma} > 30$ GeV

σ(PbPb→PbPb$\gamma\gamma$) [nb] @ LHC ($\sqrt{s_{NN}}$ = 5.5 TeV) & FCC ($\sqrt{s_{NN}}$ = 39 TeV)

	cuts	boxes $F_{realistic}$	boxes $F_{monopole}$	VDM-Regge $F_{realistic}$	VDM-Regge $F_{monopole}$
	$W_{\gamma\gamma} > 5$ GeV	306	349	31	36
	$W_{\gamma\gamma} > 5$ GeV, $p_{t,\gamma} > 2$ GeV	159	182	7E-9	8E-9
L	$E_\gamma > 3$ GeV	16 692	18 400	17	18
	$E_\gamma > 5$ GeV	4 800	5 450	9	611
H	$E_\gamma > 3$ GeV, $\lvert y_\gamma \rvert < 2.5$	183	210	8E-2	9E-2
	$E_\gamma > 5$ GeV, $\lvert y_\gamma \rvert < 2.5$	54	61	4E-4	7E-4
C	$p_{t,\gamma} > 0.9$ GeV, $\lvert y_\gamma \rvert < 0.7$ (ALICE cuts)	107			
	$p_{t,\gamma} > 5.5$ GeV, $\lvert y_\gamma \rvert < 2.5$ (CMS cuts)	10			
F	$W_{\gamma\gamma} > 5$ GeV	6 169		882	
C	$E_\gamma > 3$ GeV	4 696 268		574	
C					

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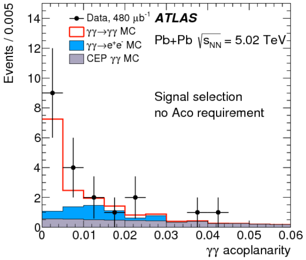
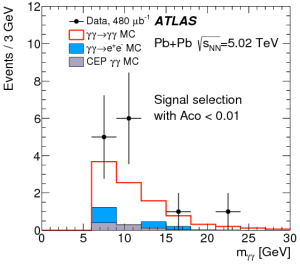
AA→AA$\gamma\gamma$ - ATLAS RESULTS

➢ ATLAS Collaboration (M. Aaboud et al.),
Evidence for light-by-light scattering in heavy-ion collisions with the ATLAS detector at the LHC,
Nature Phys. **13** (2017) 852
Phys. Rev. Lett. **123** (2019) 052001





- ✗ $p_{t_\gamma} > 3$ GeV
- ✗ $|\eta_\gamma| < 2.4$
- ✗ $M_{\gamma\gamma} > 6$ GeV
- ✗ $p_{t_{\gamma\gamma}} < 2$ GeV
- ✗ Aco < 0.01

- ✔ $\gamma\gamma \to \gamma\gamma$ - Our results
- ✔ background:
  - ✔ $\gamma\gamma \to e^+e^-$
  - ✔ $gg \to \gamma\gamma$
  - ✔ $\gamma\gamma \to q\bar{q}$
- ✔ 13 events
  59 events (2019)*

ATLAS ⇒ σ = 70 ± 20(stat.)±17(syst.) nb

(2019)* ⇒ σ = 78 ± 13(stat.)±7(syst.)±3(lumi.) nb

Our result ⇒ σ = 51 ± 0.02 nb

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AA→AA$\gamma\gamma$ - CMS & ATLAS RESULTS - $M_{\gamma\gamma} > 5$ GeV

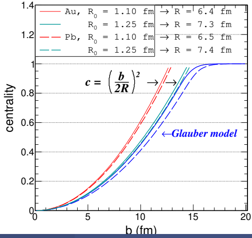
- CMS Coll., Phys. Lett. **B797** (2019) 134826
  - ✗ $E_{t_\gamma} > 2$ GeV
  - ✗ $|\eta_\gamma| < 2.4$
  - ✗ $M_{\gamma\gamma} > 5$ GeV
  - ✗ $p_{t_{\gamma\gamma}} < 1$ GeV
  - ✗ Aco < 0.01
- ATLAS Collaboration, JHEP 03 (2021) 243
  - ✗ $E_{t_\gamma} > 2.5$ GeV
  - ✗ $|\eta_\gamma| < 2.4$
  - ✗ $M_{\gamma\gamma} > 5$ GeV
  - ✗ $p_{t_{\gamma\gamma}} < 1$ GeV
  - ✗ Aco < 0.01

Experiment		Theory		
		Nuclear radius: $R = R_0 A^{\frac{1}{3}}$		Glauber model
Collaboration	σ nb	$\sigma(b = 13\text{fm})$	$\sigma(b = 14.8\text{fm})$	$\sigma(b = 20\text{fm})$
ATLAS (2018 data)	78 ± 13(stat.)± 7(syst.)	52	50	45
ATLAS (2015+2018)	120 ± 17(stat.)± 13(syst.)	82	80	71
CMS (2015)	120 ± 46(stat.)± 28(syst.)	105	103	92

UPC $\rightarrow b_{min} > 2\times$ R

SO FAR IT WAS 14 FM

centrality [%]	100
nucleus and radius	b (fm)
Pb, $R = 6.5$ fm	13.0
Pb, $R = 7.4$ fm	14.8
Pb Pb, Glauber	20.0



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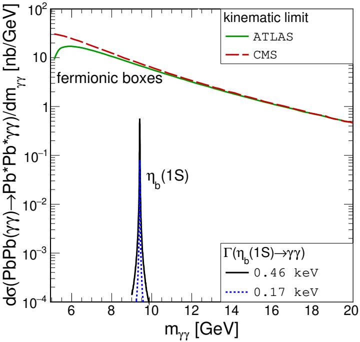
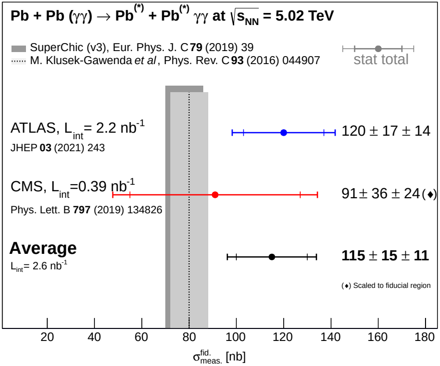
2022 RESULTS





This result paves the way for combining existing or forthcoming measurements using LHC heavy-ion collisions and provides, within the studied phase space region, an additional experimental input to the comparison with state-of-the-art predictions from quantum electrodynamics.

- The European Union's Horizon 2020 research and innovation program under the STRONG-2020, G. K. Krintiras, I. Grabowska-Bołd, M. Kłusek-Gawenda and É. Chapon R. Chudasama and R. Granier de Cassagnac, *arXiv:2204.02845 [hep-ph]*; Light-by-light scattering cross-section measurements at LHC

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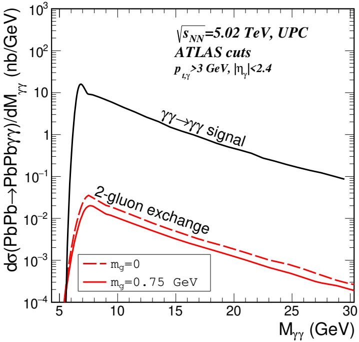
HIGHER ORDER PROCESSES..?

$\gamma\gamma$ invariant mass

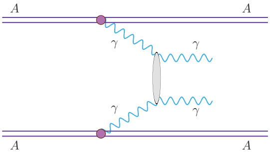


Coherent sum of both processes...?

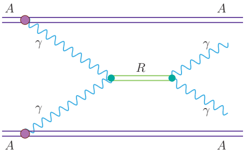
Pionic boxes...?

AA→AA$\gamma\gamma$ FOR $M_{\gamma\gamma} < 5$ GEV ?

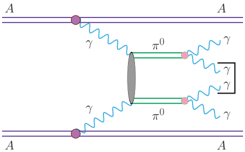
CONTINUUM

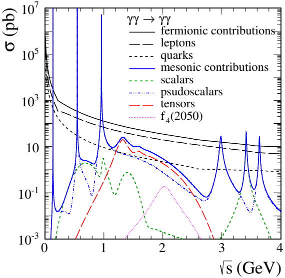


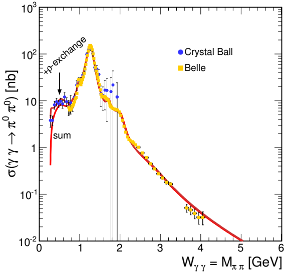
RESONANCES



BACKGROUND







- P. Lebiedowicz, A. Szczurek, *Phys. Lett.* ***B772*** *(2017) 330*, The role of meson exchanges in light-by-light scattering
- M. K-G, 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

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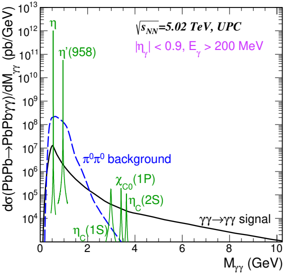
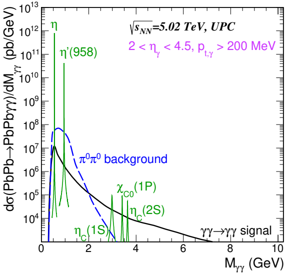
UPC OF AA...

- ✔ boxes
- ✔ bkg
- ✔ mesons

ALICE cuts



LHCb cuts



Total nuclear cross section [nb]

Energy	$W_{\gamma\gamma}$ = (0 − 2) GeV		$W_{\gamma\gamma} > 2$ GeV	
Fiducial region	ALICE	LHCb	ALICE	LHCb
Boxes	4 890	3 818	146	79
$\pi^0\pi^0$ bkg	135 300	40 866	46	24
η	722 573	568 499		
$\eta'(958)$	54 241	40 482		
$\eta_c(1S)$			9	5
$\chi_{c0}(1P)$			4	2
$\eta_c(2S)$			2	1

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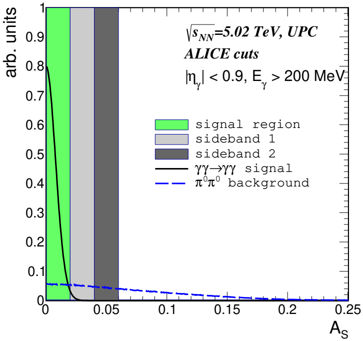
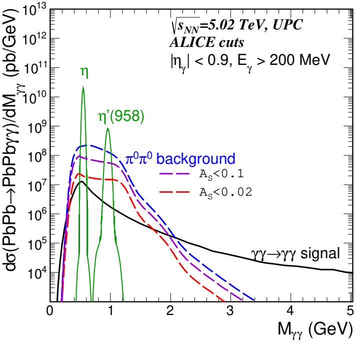
EXPERIMENTAL RESOLUTION & SCALAR ASYMMETRY & "UNWANTED" BKG

$$A_S = \left| \frac{|\vec{p}_T(1)| - |\vec{p}_T(2)|}{|\vec{p}_T(1)| + |\vec{p}_T(2)|} \right|$$

A_S



$M_{\gamma\gamma}$



80% of the signal events at $A_S < 0.02$

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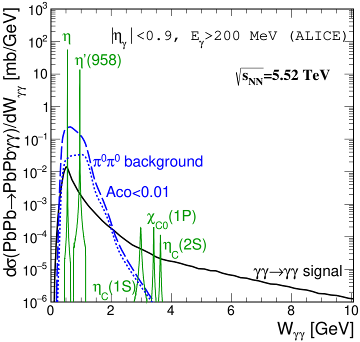
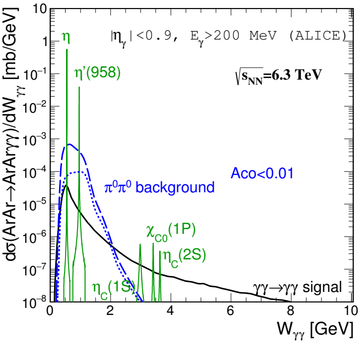
AA→AA$\gamma\gamma$ @ MIDRAPIDITY

$^{208}Pb^{82+} + ^{208}Pb^{82+}$

$^{40}Ar^{18+} + ^{40}Ar^{18+}$





$$\sigma_{tot} \propto (Z_{Pb}/Z_{Ar})^4 \approx 430$$

$$\sqrt{s_{NN}} = \sqrt{\frac{Z_1 Z_2}{A_1 A_2}} \sqrt{s_{pp}}$$

Run 5: $L_{\mathrm{int}}^{\mathrm{Ar-Ar}}$ = (3 – 8.8) pb → 1460–4280 signal events ($W_{\gamma\gamma} > 2$ GeV)

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AA→AA$\gamma\gamma$ @ FORWARD REGION ?

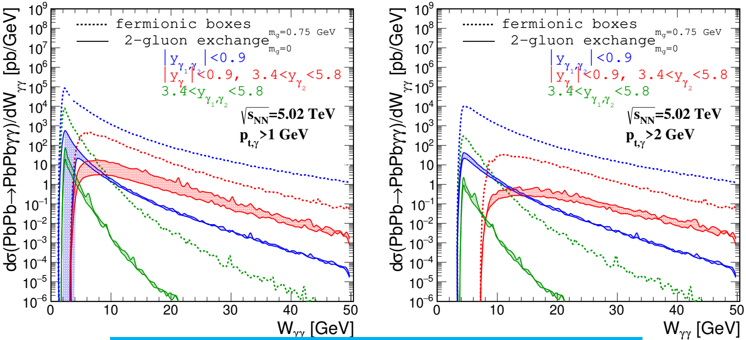
✓ ALICE Collaboration,
Letter of Intent: A Forward Calorimeter (FoCal) in the ALICE experiment,
CERN-LHCC-2020-009

FOCAL $\rightarrow 3.4 < \eta < 5.8$

The forward electromagnetic and hadronic calorimeter is an upgrade to the ALICE experiment, to be installed during LS3 for data-taking in 2027–2029 at the LHC.

$p_{t,\gamma} > 1$ GeV

$p_{t,\gamma} > 2$ GeV



Boxes & 2-gluon exchange (with effective gluon mass)

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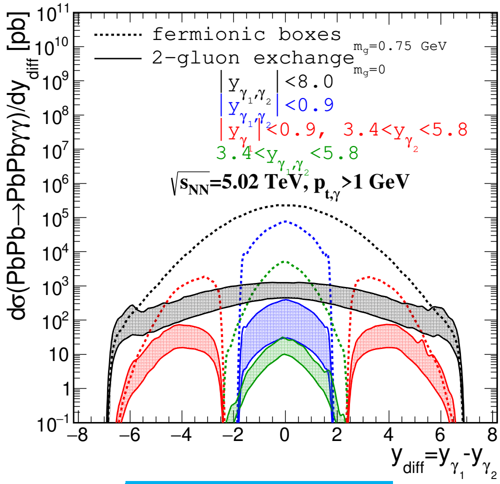
AA→AA$\gamma\gamma$ @ FORWARD REGION ?

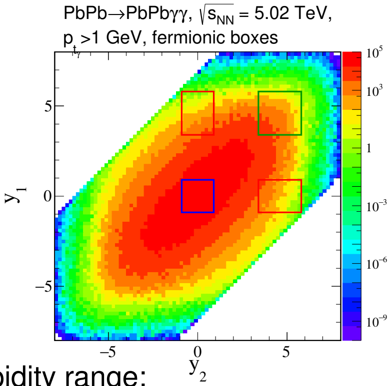
$y_{\gamma_1} - y_{\gamma_2}$



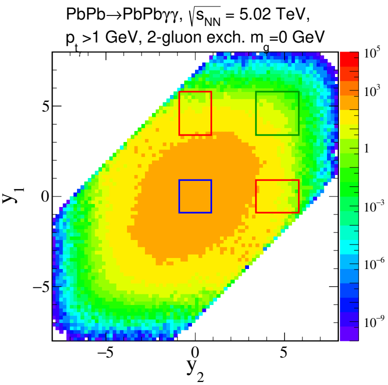
A smaller $p_{t,\gamma}$ is desirable

AA→AA$\gamma\gamma$ @ FORWARD REGION ?

fermionic boxes



2-gluon exchange



Rapidity range:

- $|y_{\gamma_{1,2}}| < 0.9$
- $y_{\gamma_1} < 0.9$, $3.4 < y_{\gamma_2} < 5.8$
- $3.4 < y_{\gamma_{1,2}} < 5.8$

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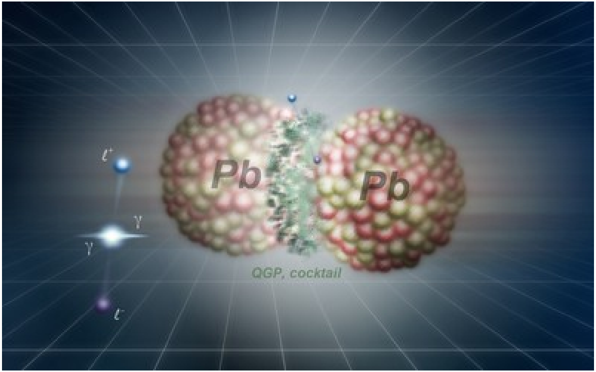
SEMICENTRAL HEAVY-ION COLLISIONS



- From ultraperipheral to semicentral collisions → dilepton sources
  - $\gamma\gamma$ fusion mechanism
- Invariant mass
  - SPS (NA60 data)
  - RHIC (STAR data)
  - LHC (ALICE data)
- Low-P_T dilepton spectra
  - RHIC (STAR data)
  - LHC (ALICE data)
- Acoplanarity
  - LHC (ATLAS data)

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DIELECTRON INVARIANT-MASS SPECTRA - RHIC

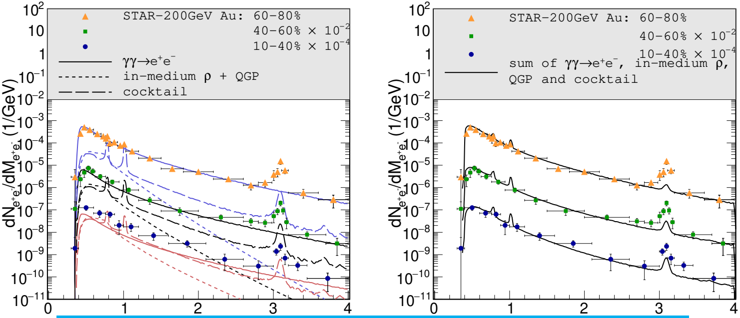
$p_t > 0.2$ GeV,

$|\eta_e| < 1$

$|y_{e^+e^-}| < 1$

- ✔ $\gamma\gamma$-fusion
- ✔ thermal radiation
- ✔ hadronic cocktail

3 centrality classes



The coherent emission dominates for the two peripheral samples

and is comparable to the cocktail and thermal radiation yields in semi-central collisions.

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EPA in the impact parameter space - the pair transverse momentum $P_T^{\ell^+\ell^-}$ is neglected

$$\sigma_{A_1 A_2 \to A_1 A_2 \ell^+\ell^-} = \int N(\omega_1, \mathbf{b_1}) N(\omega_2, \mathbf{b_2}) \delta^{(2)}(\mathbf{b} - \mathbf{b}_1 - \mathbf{b}_2) \int d^2\mathbf{b}_1 d^2\mathbf{b}_2 d^2\mathbf{b}\, dy_{\ell^+} dy_{\ell^-} dp_{t,\ell}^2 \frac{d\sigma(\gamma\gamma \to \ell^+\ell^-; \hat{s})}{d(-\hat{t})}$$

➪ ***k_t*-factorization**

$$\frac{dN_{ll}}{d^2\mathbf{P}_T^{\ell^+\ell^-}} = \int \frac{d\omega_1}{\omega_1} \frac{d\omega_2}{\omega_2} d^2\boldsymbol{q}_{1t} d^2\boldsymbol{q}_{2t} \frac{dN(\omega_1, q_{1t}^2)}{d^2\boldsymbol{q}_{1t}} \frac{dN(\omega_2, q_{2t}^2)}{d^2\boldsymbol{q}_{2t}} \delta^{(2)}(\boldsymbol{q}_{1t} + \boldsymbol{q}_{2t} - \mathbf{P}_T^{\ell^+\ell^-}) \hat{\sigma}(\gamma\gamma \to \ell^+\ell^-)\Big|_{\text{cuts}},$$

➪ **Exact calculation**

$$\frac{d\sigma[\mathcal{C}]}{d^2\mathbf{P}_T^{\ell^+\ell^-}} = \int \frac{d^2\boldsymbol{Q}}{2\pi} w(Q; b_{\max}, b_{\min}) \int \frac{d^2\boldsymbol{q}_1}{\pi} \frac{d^2\boldsymbol{q}_2}{\pi} \delta^{(2)}(\mathbf{P}_T^{\ell^+\ell^-} - \mathbf{q}_1 - \boldsymbol{q}_2) \int \frac{d\omega_1}{\omega_1} \frac{d\omega_2}{\omega_2}$$
$$\times \quad E_i\left(\omega_1, \boldsymbol{q}_1 + \frac{\boldsymbol{Q}}{2}\right) E_j^*\left(\omega_1, \boldsymbol{q}_1 - \frac{\boldsymbol{Q}}{2}\right) E_k\left(\omega_2, \boldsymbol{q}_2 - \frac{\boldsymbol{Q}}{2}\right) E_l^*\left(\omega_2, \boldsymbol{q}_2 + \frac{\boldsymbol{Q}}{2}\right) \frac{1}{2\hat{s}} \sum_{\lambda\bar{\lambda}} M_{ik}^{\lambda\bar{\lambda}} M_{jl}^{\lambda\bar{\lambda}\dagger}\, d\Phi(\ell^+\ell^-).$$

The factorization formula is written in terms of the Wigner function:

$$N_{ij}(\omega, \mathbf{b}, \mathbf{q}) = \int \frac{d^2\mathbf{Q}}{(2\pi)^2} \exp[-i\mathbf{b}\mathbf{Q}]\, E_i\left(\omega, \mathbf{q} + \frac{\mathbf{Q}}{2}\right) E_j^*\left(\omega, \mathbf{q} - \frac{\mathbf{Q}}{2}\right) = \int d^2\mathbf{s}\, \exp[i\mathbf{q}\mathbf{s}]\, E_i\left(\omega, \mathbf{b} + \frac{\mathbf{s}}{2}\right) E_j^*\left(\omega, \mathbf{b} - \frac{bs}{2}\right),$$

$$N(\omega, \mathbf{q}) = \delta_{ij} \int d^2\mathbf{b}\, N_{ij}(\omega, \mathbf{b}, \mathbf{q}) = \delta_{ij} E_i(\omega, \mathbf{q}) E_j^*(\omega, \mathbf{q}) = \Big|\boldsymbol{E}(\omega, \mathbf{q})\Big|^2,$$

$$N(\omega, \mathbf{b}) = \delta_{ij} \int \frac{d^2\boldsymbol{q}}{(2\pi)^2} N_{ij}(\omega, \mathbf{b}, \mathbf{q}) = \delta_{ij} E_i(\omega, \mathbf{b}) E_j^*(\omega, \mathbf{b}) = \Big|\mathbf{E}(\omega, \mathbf{b})\Big|^2.$$

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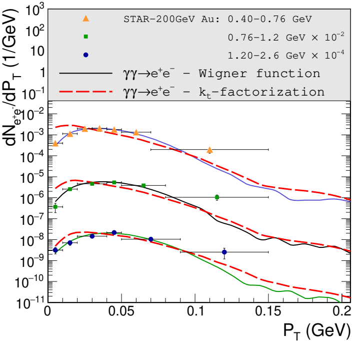
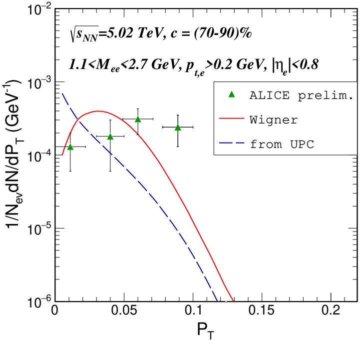
PAIR TRANSVERSE MOMENTUM - RHIC & LHC

$p_t > 0.2$ GeV,
$|\eta_e| < 1$
c=(60-80)%
$|y_{ee}| < 1$

- - - - - - PLB**790** (2019) 339
vs.
—— PLB**814** (2021) 136114

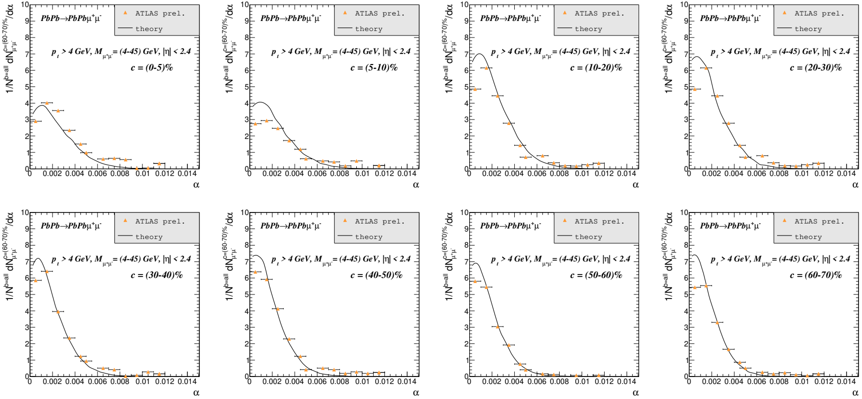
$p_t > 0.2$ GeV,
$|\eta_e| < 0.8$
c=(70-90)%
$M_{e^+e^-}$ =(1.1-2.7) GeV





Small correction to the STAR description & much better situation for LHC

ACOPLANARITY - ATLAS DATA



A successful description of ATLAS data by $\gamma\gamma$-fusion alone

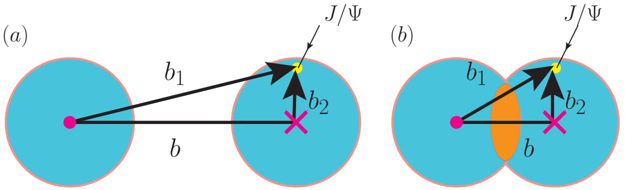
A correct normalization and shape of the distributions

$p_t > 4$ GeV,

$M_{\mu^+\mu^-}$ =(4-45) GeV,

$|\eta_\mu| < 2.4$

CHARMONIUM PHOTOPRODUCTION

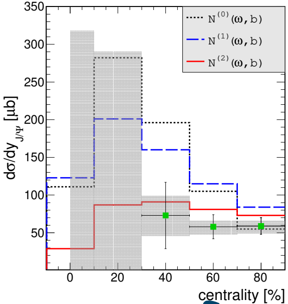


The inclusion of the absorption effect by modifying effective photon fluxes in the impact parameter space.

$$N^{(1)}(\omega_1, b) = \int N(\omega_1, b_1) \frac{\theta(R_A - (|\mathbf{b}_1 - \mathbf{b}|))}{\pi R_A^2} \mathrm{d}^2 b_1$$

$$N^{(2)}(\omega_1, b) = \int N(\omega_1, b_1) \frac{\theta(R_A - (|\mathbf{b}_1 - \mathbf{b}|))(b_1 - R_A)}{\pi R_A^2} \mathrm{d}^2 b_1$$

A successful description of ALICE data



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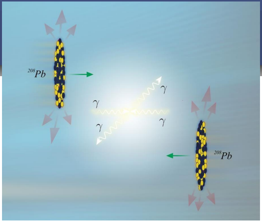
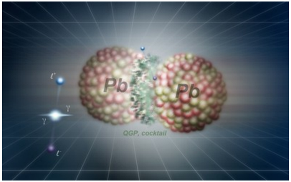
Conclusion

- EPA in the impact parameter space
- Ultraperipheral & semicentral heavy-ion collisions
- Fourier transform of the charge distribution
- Multidimensional integrals $\rightarrow$ differential cross section
- Description of experimental data for UPC and semicentral events
  - STAR - e^+e^-, $\pi^+\pi^-\pi^+\pi^-$
  - ATLAS - $\gamma\gamma$, $\mu^+\mu^-$
  - ALICE - e^+e^-, J/ψ
  - CMS - $\gamma\gamma$
- Predictions focused on experimental acceptance
  - $\mu^+\mu^-\mu^+\mu^-$ - single & double scattering
  - $e^+e^-e^+e^-$ - double scattering
  - $p\bar{p}$
  - $\pi^+\pi^-$ & $\pi^0\pi^0$
  - $\gamma\gamma$ for $M_{\gamma\gamma} < 5$ GeV
- Study of a_τ in UPC
- Collaboration - theoreticians and experimenters
- Future - low p_t

Thank you



Photon collisions: Photonic billiards might be the newest game!, EurekAlert!
Ultraperipheral collisions of lead nuclei at the LHC accelerator can lead to elastic collisions of photons with photons.



Creation without contact in the collisions of lead and gold nuclei, EurekAlert!
Semicentral or central collisions of lead nuclei in the LHC produce QGP and a cocktail with contributions of other particles. Simultaneously, clouds of photons surrounding the nuclei collide, resulting in the creation of $\ell^+\ell^-$ pairs within the plasma and cocktail, and in the space around the nuclei.

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