PHOTON-PHOTON SCATTERING AT THE LHC IN COLLISIONS OF NUCLEI

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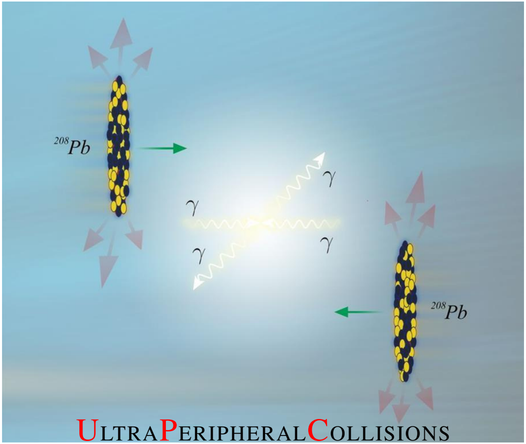
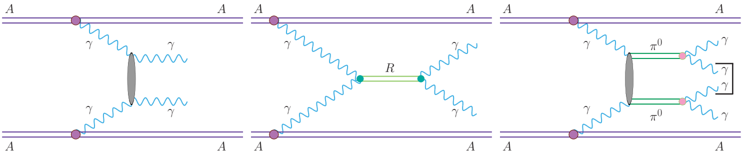
WPCF2018



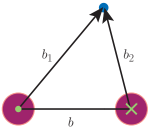
- M. K-G, P. Lebiedowicz, A. Szczurek,
  Light-by-light scattering in ultraperipheral Pb-Pb collisions at energies available at the CERN Large Hadron Collide, Phys. Rev. **C93** (2016) 044907,
- M. K-G, W. Schäfer, A. Szczurek,
  Two-gluon exchange contribution to elastic $\gamma\gamma \to \gamma\gamma$ scattering and production of two-photons in ultraperipheral ultrarelativistic heavy ion and proton-proton collisions, Phys. Lett. **B761** (2016) 399,
- M. K-G, R. McNulty, R. Schicker, A. Szczurek,
  Measurements of light-by-light scattering in UPC of heavy ions at the LHC - smaller diphoton collision energies, in preparation.

Nuclear Cross Section



Continuum **Resonances** **Background**

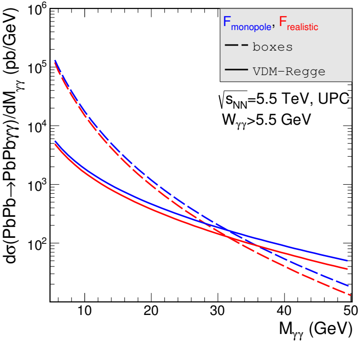
$$
\begin{aligned}
\sigma_{A_1 A_2 \to A_1 A_2 \gamma\gamma} &= \int N(\omega_1, \mathbf{b_1})\, N(\omega_2, \mathbf{b_2})\, S^2_{abs}(\mathbf{b}) \\
&\times \sigma_{\gamma\gamma \to \gamma\gamma}(W_{\gamma\gamma}) \\
&\times \mathrm{d}^2 b\, \mathrm{d}\overline{b}_x\, \mathrm{d}\overline{b}_y\, \frac{W_{\gamma\gamma}}{2} \mathrm{d}W_{\gamma\gamma}\, \mathrm{d}Y_{\gamma\gamma}
\end{aligned}
$$

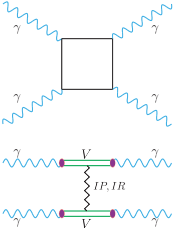


AA→AAγγ - FORM FACTOR

⇨ realistic

⇨ monopole

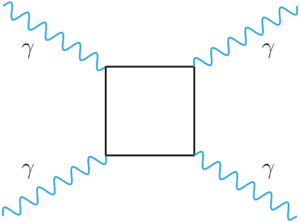


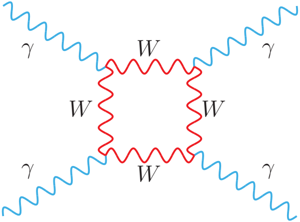


$\frac{\sigma_{monopole}}{\sigma_{realistic}} \nearrow$ for larger values of kinematic variables

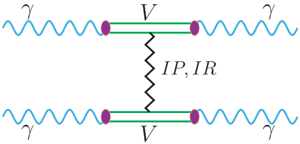
$\gamma - \gamma$ ELASTIC SCATTERING

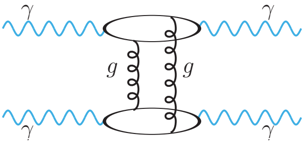
WELL-KNOWN



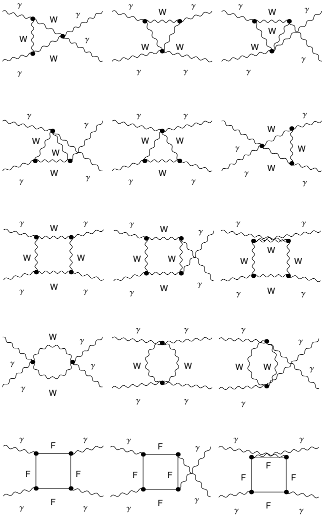


WE ADD



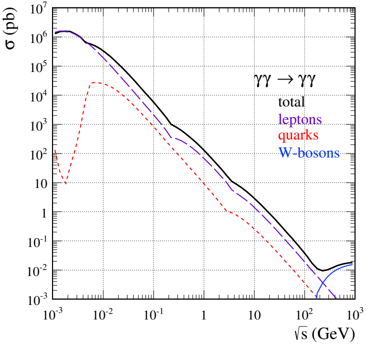


BOXES $\gamma\ \gamma \rightarrow \gamma\ \gamma$



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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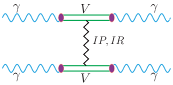
VDM-Regge contribution

ρ, ω, ϕ

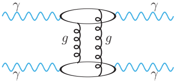
$\Rightarrow$



2-gluon exchange

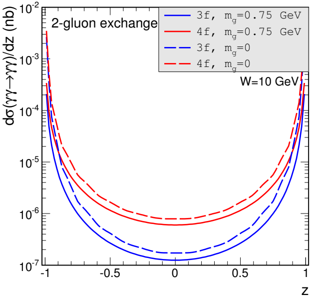
16 diagrams

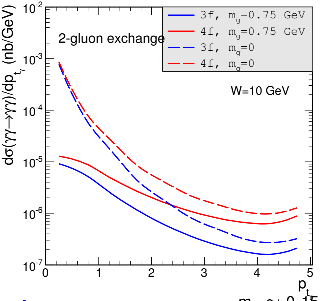
$\Rightarrow$



$z = \cos\theta$; θ - scattering $\sphericalangle$

$p_{t_\gamma} = p \sin\theta$





3f = u ,d, s

4f = u, d, s, c

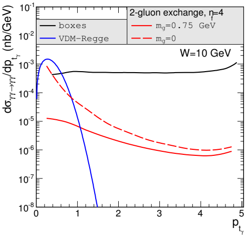
$m_u \simeq 0.15$ GeV
$m_d \simeq 0.15$ GeV
$m_s \simeq 0.30$ GeV
$m_c \simeq 1.50$ GeV

Significant effect of c quark inclusion at $z \approx 0$ (large p_{t_γ}) - interference

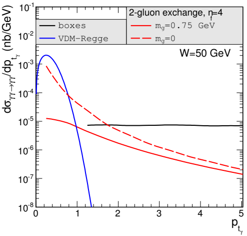
EXPERIMENTAL IDENTIFICATION OF PROCESSES?

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

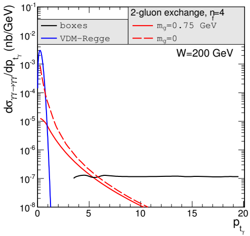
$W = 10$ GeV



$W = 50$ GeV

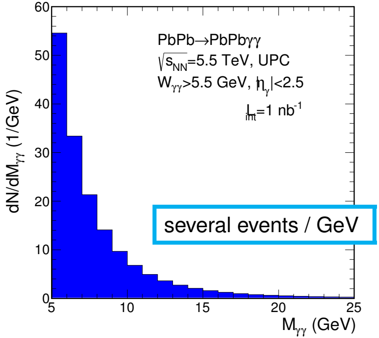


$W = 200$ GeV



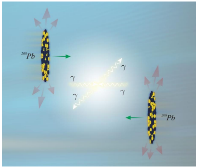
$\gamma - \gamma$ Collider (the International $e^+ e^-$ Linear Collider) ?

number of count



Photon collisions:
Photonic billiards might be the newest game!

www.eurekalert.org/pub_releases/2016-05/thni-pcp051916.php



σ(PbPb→PbPb$\gamma\gamma$) [nb] at LHC ($\sqrt{s_{NN}} = 5.5$ TeV) and 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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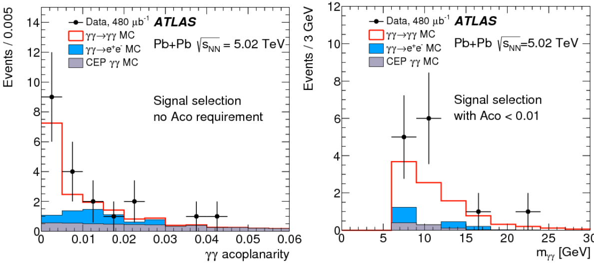
AA→AA$\gamma\gamma$ - THEORETICAL PREDICTIONS VS. EXPERIMENT

- 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



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

- ✔ $\gamma\gamma \to \gamma\gamma$ - using our calculations
- ✔ background:
  - ✔ $\gamma\gamma \to e^+e^-$
  - ✔ $gg \to \gamma\gamma$
  - ✔ $\gamma\gamma \to q\bar{q}$
- ✔ 13 events were observed

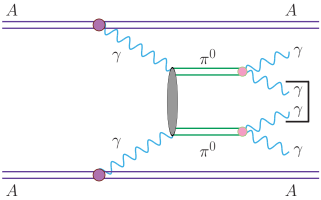
ATLAS ⇒ $\sigma = 70 \pm 20$(stat.)± 17(syst.) nb

from ours model ⇒ $\sigma = 49 \pm 10$ nb

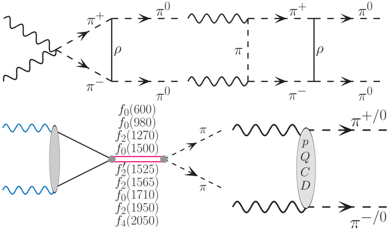
PRL (2013)/(2016) ⇒ $\sigma = 45 \pm 9$ nb

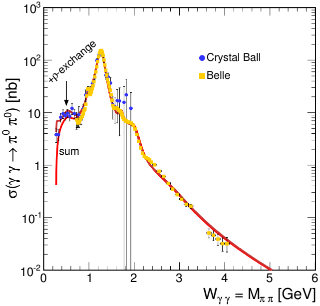
$M_{\gamma\gamma} < 5$ GEV $\Rightarrow \pi^0\pi^0$ BACKGROUND

- M. K-G, A. Szczurek, $\pi^+\pi^-$ and $\pi^0\pi^0$ pair production in photon-photon and in ultraperipheral ultrarelativistic heavy ion collisions, Phys. Rev. **C87** (2013) 054908
  - $W_{\gamma\gamma} \in (2m_\pi - 6)$ GeV
  - total cross section & angular distributions
  - simultaneously for $\gamma\gamma \to \pi^+\pi^-$ & $\pi^0\pi^0$



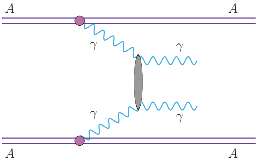
$\gamma\gamma \to \pi^0\pi^0$



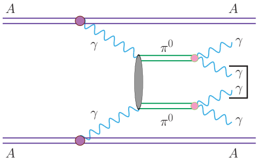


AA→AAγγ for $M_{\gamma\gamma} < 5$ GeV ? NEW

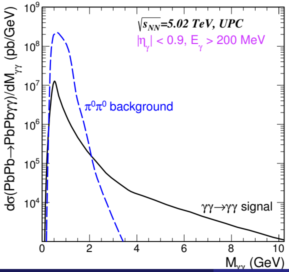
signal

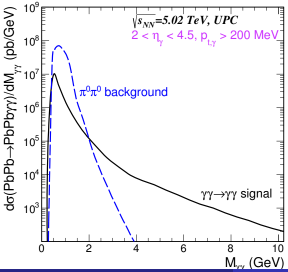


background

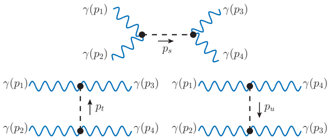


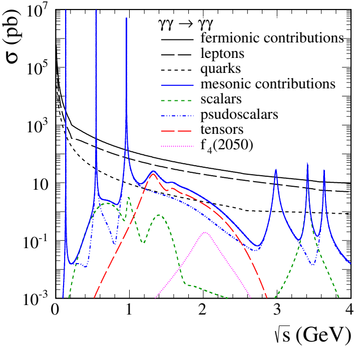
experiment	pseudorapidity range	other condition
ALICE	-0.9 $< \eta_\gamma <$ 0.9	$E_\gamma >$ 200 MeV
LHCb	2.0 $< \eta_\gamma <$ 4.5	$p_{t,\gamma} >$ 200 MeV





$M_{\gamma\gamma} < 5$ GeV ⇒ Meson exchange





$f_0(500)$	π^0	$f_2(1270)$	
$f_0(980)$	η	$a_2(1320)$	
$a_0(980)$	$\eta'(958)$	$f_2'(1525)$	$f_4(2050)$
$f_0(1370)$	$\eta_c(1S)$	$f_2(1565)$	
$\chi_{c0}(1P)$	$\eta_c(2S)$	$a_2(1700)$	

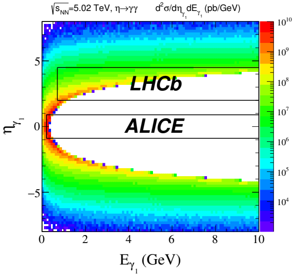
$s-$channel diagrams (leading to peaks at $\sqrt{s} \cong m_M$)

$t-$ and $u-$channels (leading to broad continua)

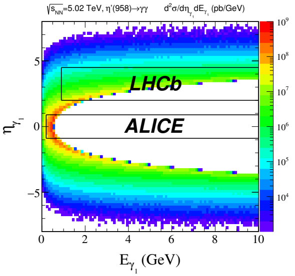
- P. Lebiedowicz, A. Szczurek,
  The role of meson exchanges in light-by-light scattering,
  Phys. Lett. **B772** (2017) 330

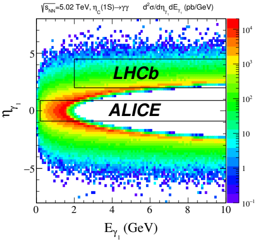
UPC of AA...

η

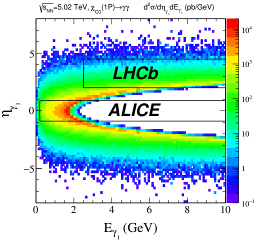


$\eta'(958)$

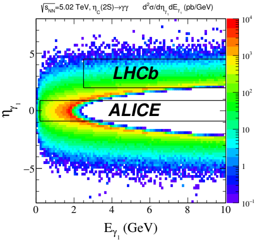




$\eta_c(1S)$



$\chi_{c0}(1P)$



$\eta_c(2S)$

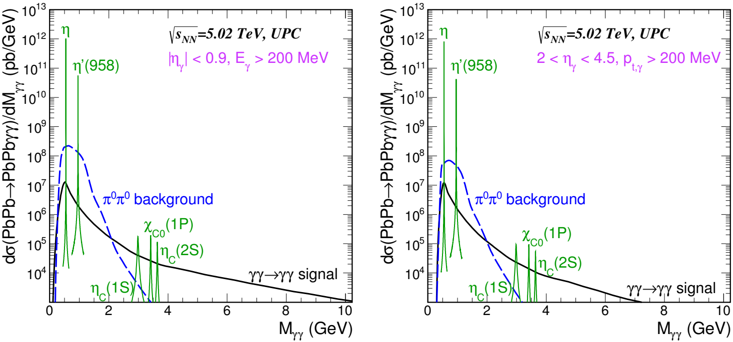
Meson exchange at UPC

$$\mathcal{M}_{\gamma\gamma\to R\to\gamma\gamma}(\lambda_1,\lambda_2) = \frac{\sqrt{64\pi^2 W_{\gamma\gamma}^2 \Gamma_R^2 Br^2(R\to\gamma\gamma)}}{\hat{s} - m_R^2 - i m_R \Gamma_R} \times \frac{1}{\sqrt{2\pi}}\,\delta_{\lambda_1-\lambda_2}$$

ALICE cuts

- ✔ boxes
- ✔ bkg
- ✔ mesons

LHCb cuts



RESONANSE CONTRIBUTION & EXPERIMENTAL RESOLUTION

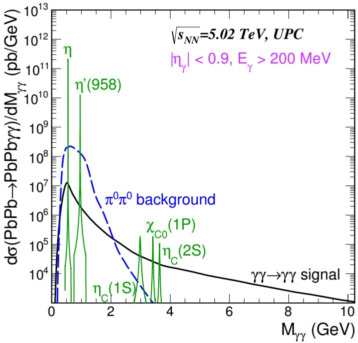
ENERGY RESOLUTION

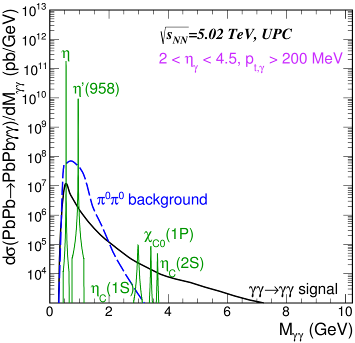
$$\frac{\sigma_{E_\gamma}}{E_\gamma} = 1\%$$

$$\frac{\sigma_{E_\gamma}}{E_\gamma} = \frac{0.085}{\sqrt{E_\gamma}} + \frac{0.003}{E_\gamma} + 0.008$$

ALICE cuts

LHCb cuts





Energy resolution modifies resonant signals

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RESONANSE CONTRIBUTION & EXPERIMENTAL RESOLUTION

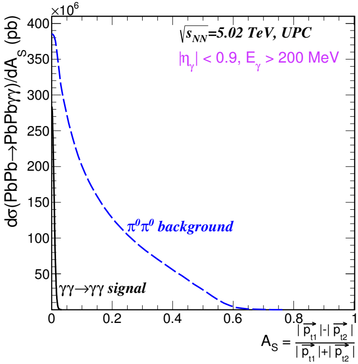
SCALAR ASYMMETRY

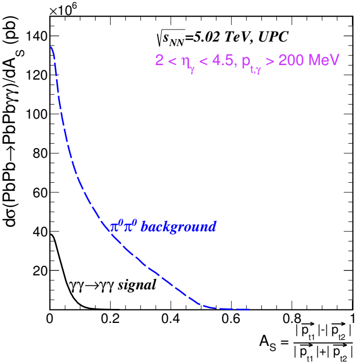
$$A_S = \frac{p_{1,t} - p_{2,t}}{p_{1,t} + p_{2,t}}$$

$$p_{1,t} = p_t + \left(\frac{p_t}{E_1}\right)\delta E_1$$

$$p_{2,t} = p_t + \left(\frac{p_t}{E_2}\right)\delta E_2$$

ALICE cuts | **LHCb cuts**



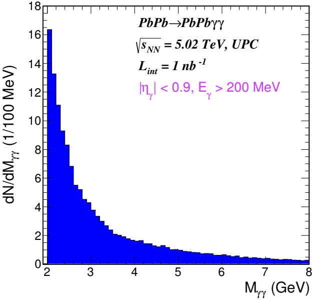


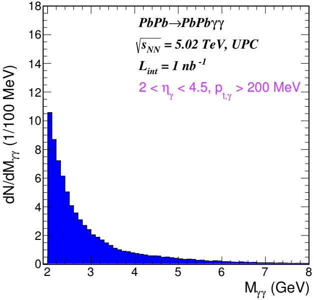
Difficult to separate a region where the $\gamma\gamma \to \gamma\gamma$ signal wins

Number of counts for $M_{\gamma\gamma} > 2$ GeV

ALICE cuts

LHCb cuts



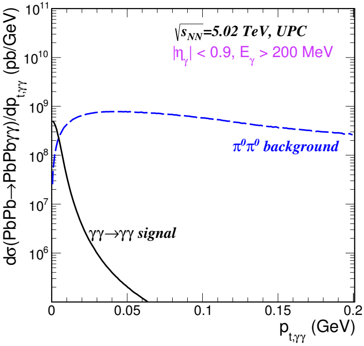


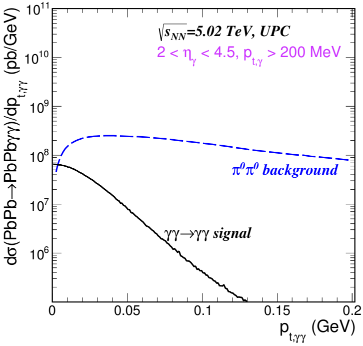
Energy	$W_{\gamma\gamma} = (0-2)$ GeV		$W_{\gamma\gamma} > 2$ GeV	
Fiducial region	ALICE	LHCb	ALICE	LHCb
boxes	4 890	3 818	146	79
$\pi^0\pi^0$ background	135 300	40 866	46	24
η	722 573	568 499		
$\eta'(958)$	54 241	40 482		
$\eta_c(1S)$			9	5
$\chi_{c0}(1P)$			4	2
$\eta_c(2S)$			2	1

RESONANSE CONTRIBUTION & EXPERIMENTAL RESOLUTION

$$p_{t,\gamma\gamma} = (|\vec{p_{t1}} + \vec{p_{t2}}|)$$

ALICE cuts | **LHCb cuts**





Very limited region where the signal overestimates the background

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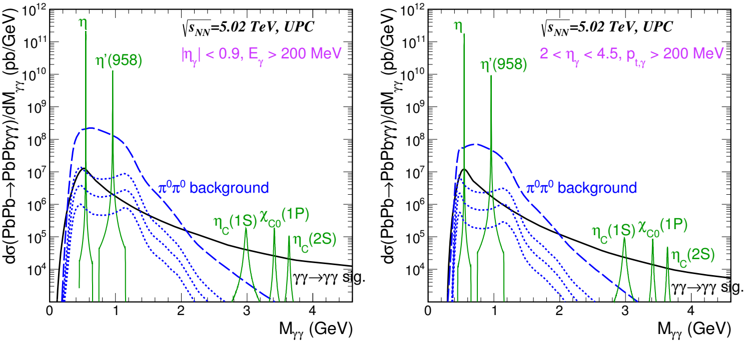
AA→AA$\gamma\gamma$ FOR $M_{\gamma\gamma} < 2$ GEV ?

ALICE cuts

LHCb cuts



$p_{t,\gamma\gamma} <$ 0.005 GeV
0.010 GeV
0.020 GeV

The cuts on $p_{t,\gamma\gamma}$ seems the most efficient to reduce the background

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Conclusion

- EPA in the impact parameter space
- Realistic charge distribution
- Description of the ATLAS data for Pb Pb $\to$ Pb Pb $\gamma\gamma$
- Light-by-light scattering in UPC for $M_{\gamma\gamma} < 5$ GeV - **new project**
  1. signal
  2. background
  3. $\gamma\gamma \to \eta/\eta' \to \gamma\gamma$ resonance scattering can be measured with good statistic
- Sizeable counting rates for realistic luminosity
- Experimental energy resolution (ALICE & LHCb)

$W_{\gamma\gamma} < 2$ GeV: cut on $p_{t,\gamma\gamma} = (|\vec{p_{t1}} + \vec{p_{t2}}|)$ - optimal solution
$W_{\gamma\gamma} > 2$ GeV: to test the Standard Model

Thank you