

Electromagnetic processes in ultra-peripheral Pb+Pb collisions with ATLAS

Mateusz Dyndal

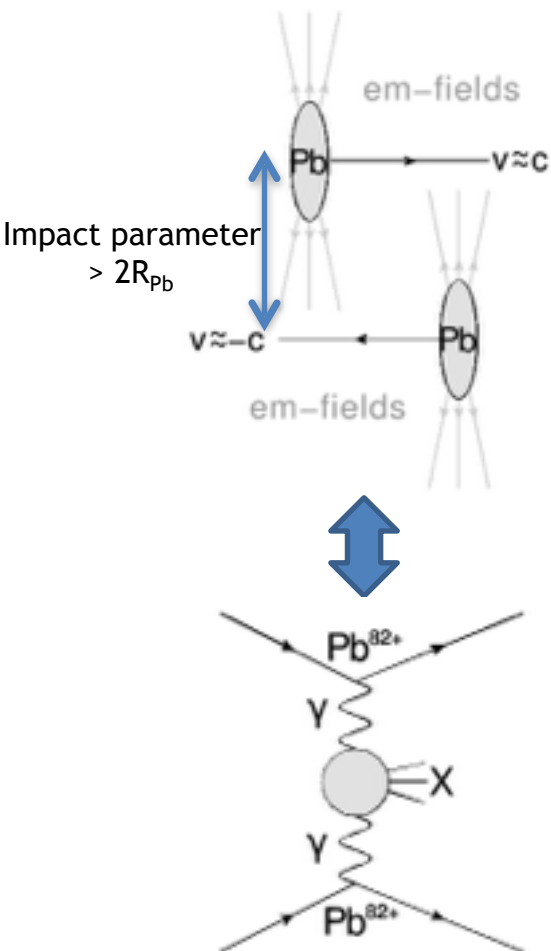
on behalf of the ATLAS Collaboration





- Measurement of high-mass dimuon pairs in ultra-peripheral lead-lead collisions at $\sqrt{s_{NN}} = 5.02$ TeV
[[ATLAS-CONF-2016-025](#)]
- Light-by-light scattering in ultra-peripheral Pb+Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV
[[arxiv:1702.01625](#)]
- Both measurements are based on $L \sim 0.5 \text{ nb}^{-1}$ of data recorded in 2015

Theory: AA ($\gamma\gamma$) \rightarrow AA X scattering



[Fermi, Nuovo Cim. 2 (1925) 143]

[Weizsacker, Z. Phys. 88 (1934) 612]

[Williams, Phys. Rev. 45 (10 1934) 729]

The cross section for **AA ($\gamma\gamma$) \rightarrow AA X** process is calculated using:

(1) Number of equivalent photons (EPA) by integration of relevant EM form factors:

$$n(b, \omega) = \frac{Z^2 \alpha_{em}}{\pi^2 \omega} \left| \int dq_{\perp} q_{\perp}^2 \frac{F(Q^2)}{Q^2} J_1(bq_{\perp}) \right|^2$$

$$Q^2 < 1/R^2 \quad \omega_{\max} \approx \gamma/R$$

(2) EW $\gamma\gamma \rightarrow X$ (elementary) cross section

$$\sigma_{A_1 A_2 (\gamma\gamma) \rightarrow A_1 A_2 X}^{\text{EPA}} = \iint d\omega_1 d\omega_2 n_1(\omega_1) n_2(\omega_2) \sigma_{\gamma\gamma \rightarrow X}(W_{\gamma\gamma})$$

LHC as a photon-photon collider



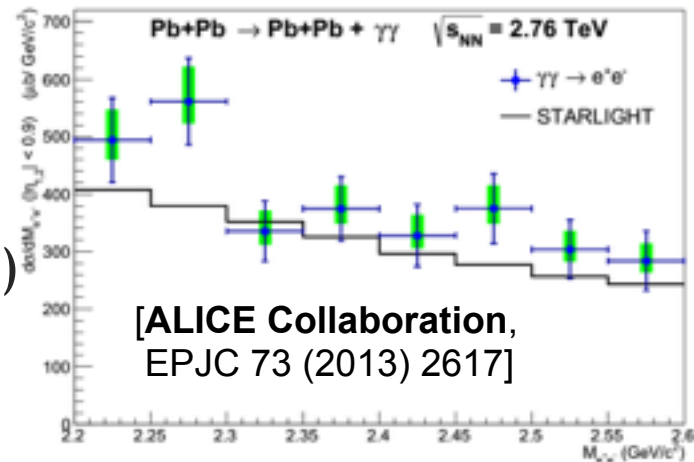
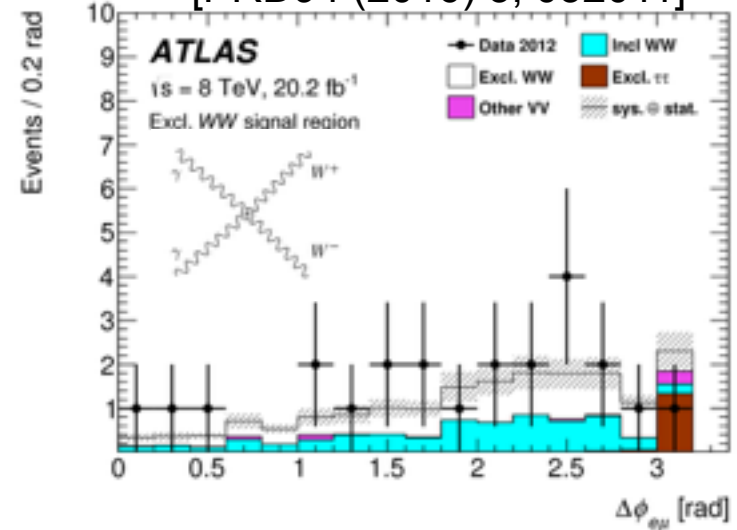
- Many interesting measurements can be done with pp/Pb+Pb beams of quasi-real photons at the LHC [PRD94 (2016) 3, 032011]

▪ pp collisions

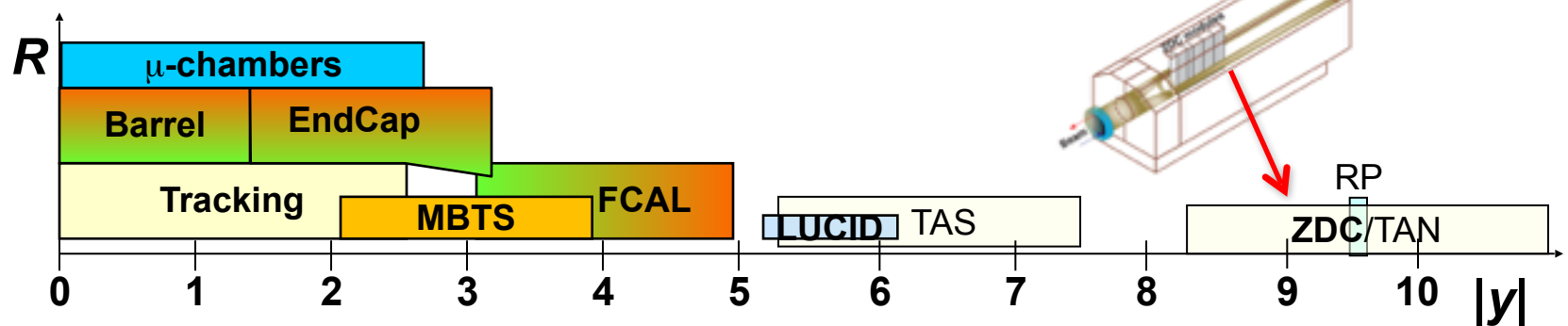
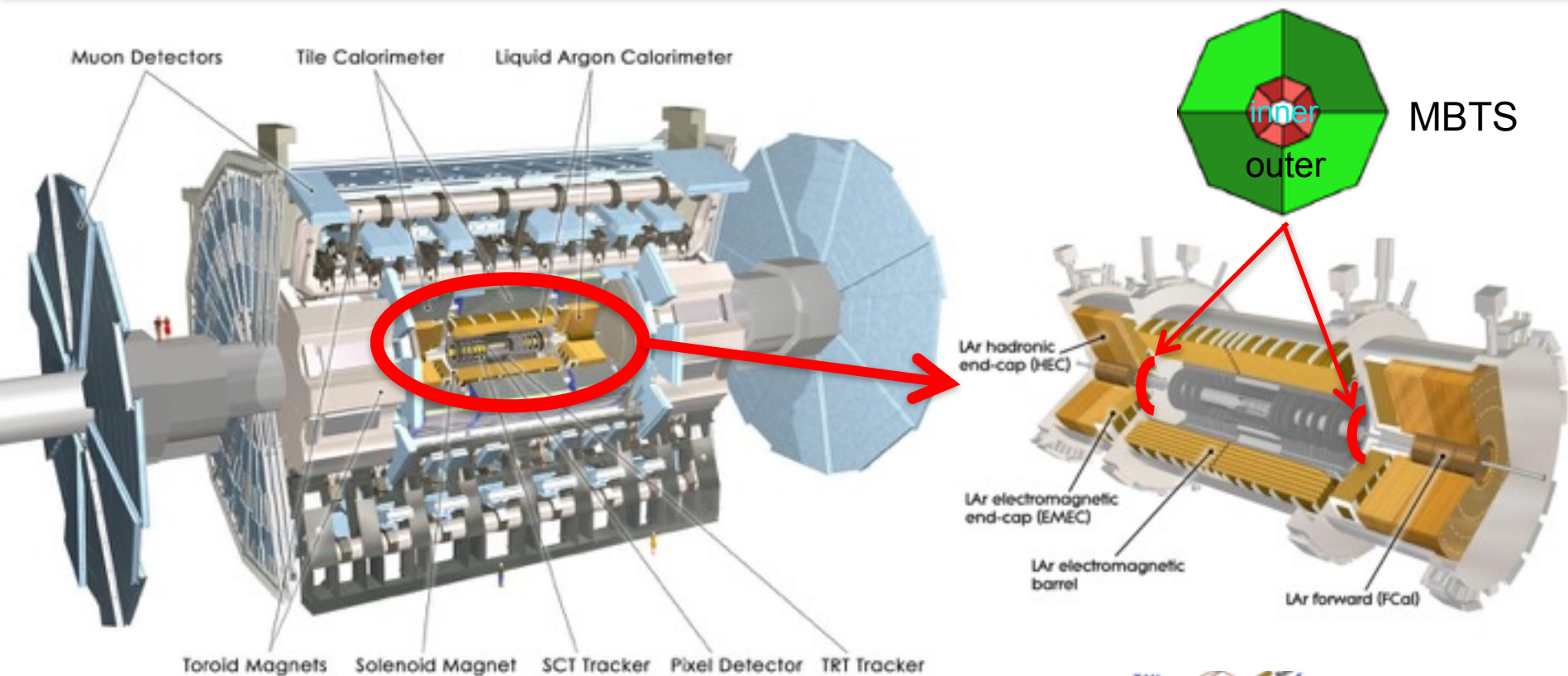
- + harder EPA spectrum ($\omega_{\max} \sim \text{TeV}$)
- large pile-up (multiple interactions per bunch crossing)
- + large datasets available, $O(10 \text{ fb}^{-1})$
- hard to trigger on low- p_T objects

▪ Pb+Pb collisions

- softer EPA spectrum ($\omega_{\max} \sim 100 \text{ GeV}$)
- + AA ($\gamma\gamma$) cross-sections scale as Z^4
- + gluonic cross-sections scale as $\sim A^2$ (lower QCD background expected wrt pp)
- + low pile-up ($<1\%$)
- Short LHC Pb+Pb campaigns (cf. pp)



The ATLAS detector



Measurement of high-mass dimuon pairs



▪ Trigger

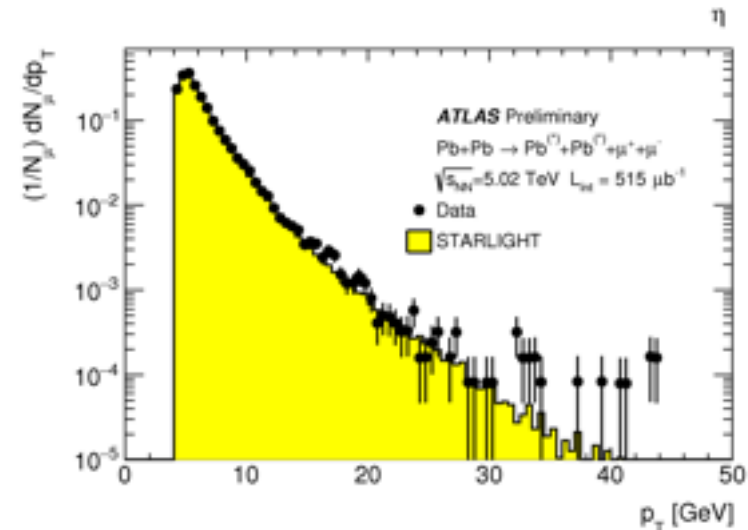
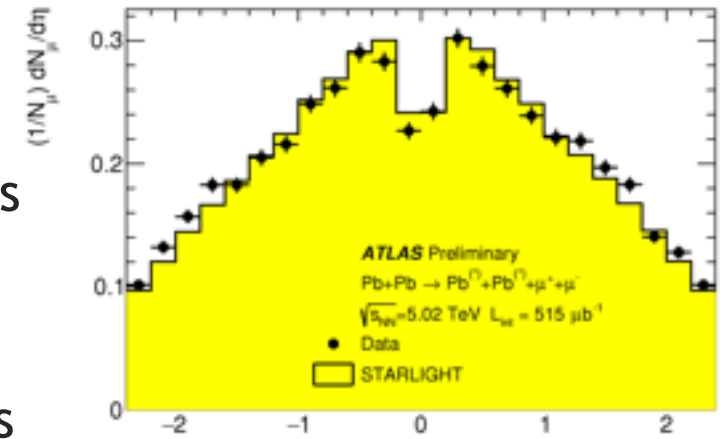
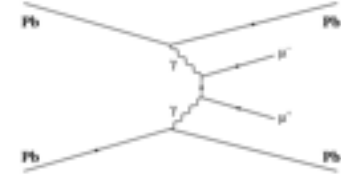
- At least 1 loose muon
- Total E_T in the calorimeter < 50 GeV
- At least one track with 200 MeV
- No more than 1 hit in inner MBTS arrays

▪ Event selection

- 2 opposite-sign and good-quality muons with $p_T > 4$ GeV, $|\eta| < 2.4$, $m_{\mu\mu} > 10$ GeV
- Reconstructed vertex with no additional tracks
- 12069 dimuon pairs were selected in data

▪ Signal modelling

- Starlight 1.1 (EPA + LO QED)



Measurement of high-mass dimuon pairs

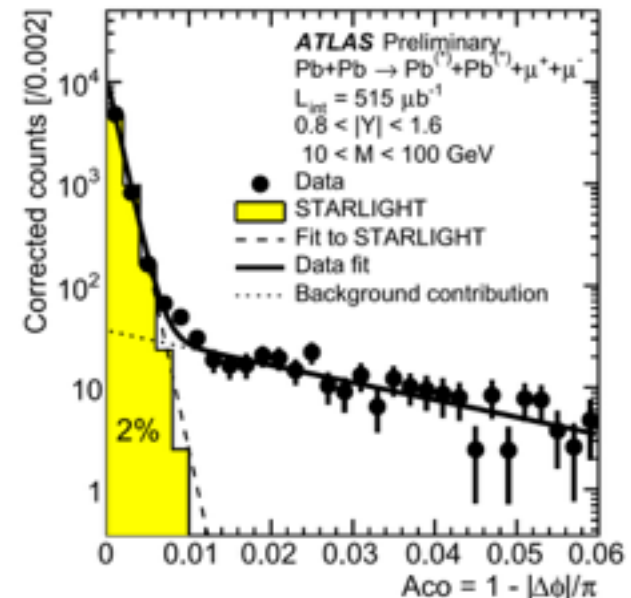
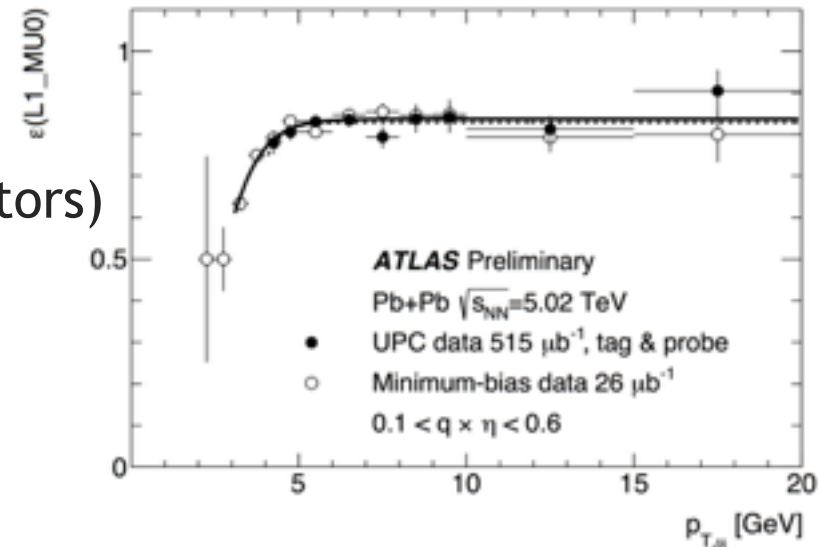


▪ Corrections

- Trigger efficiency (data-driven)
- Muon reco efficiency (MC+scale factors)
- Vertex efficiency (MC)

▪ Acoplanarity distributions

- Most of dimuon pairs are produced back-to-back (as expected)
- Small Aco tail also visible
- Two assumptions are tested:
 - 1) tail is due to background
 - 2) tail is due to HO QED effects (not included in Starlight)
- Average of 1) and 2) is taken as a central value, full difference as a systematic uncertainty



Measurement of high-mass dimuon pairs

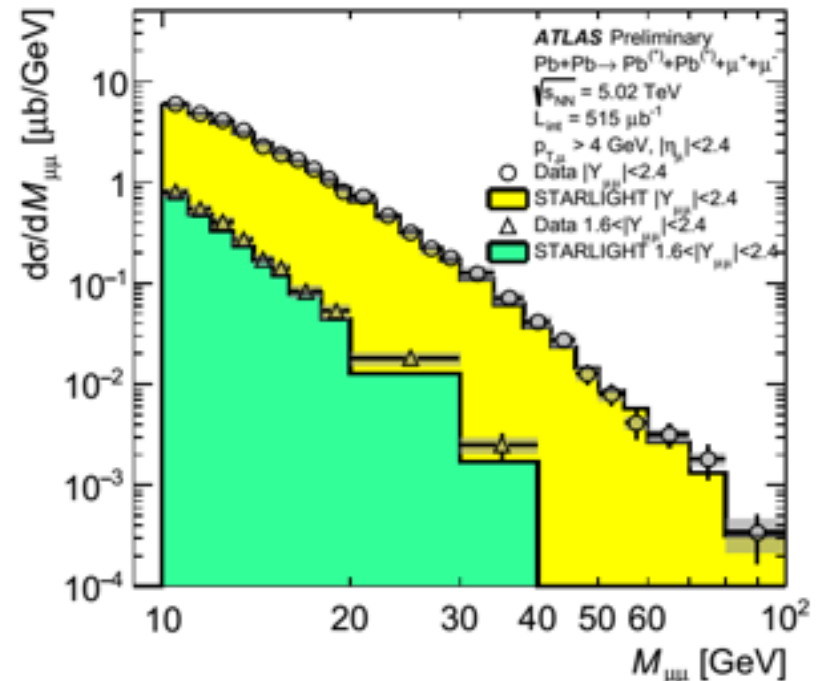
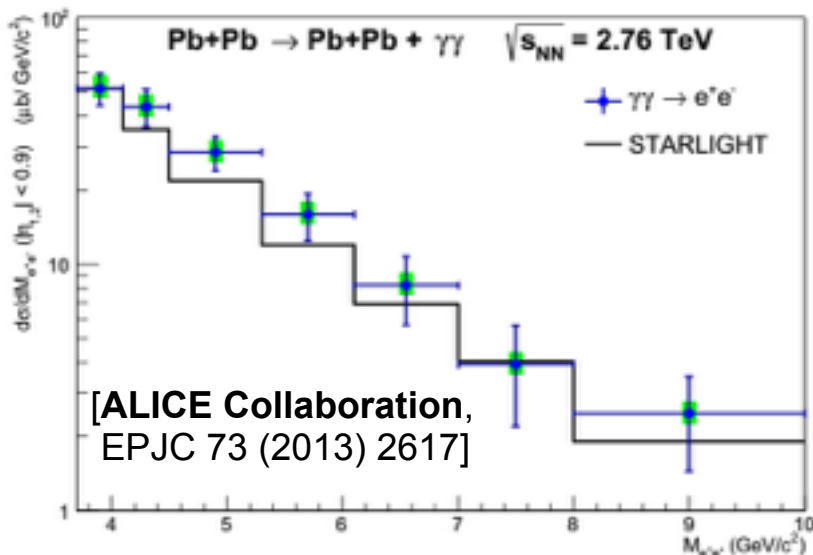


▪ Systematic uncertainties

- Dominated by luminosity uncertainty; total syst. unc. $\sim 10\%$

▪ Results

- Total fiducial cross section: $\sigma_{\text{meas.}} = 32.2 \pm 0.3 \text{ (stat.)} \pm 4.0 \text{ (syst.)} \mu\text{b}$
-> Starlight predictions: $\sigma_{\text{starlight}} = 31.6 \mu\text{b}$
- Both $d\sigma/dm_{\mu\mu}$ and $d\sigma/dy_{\mu\mu}$ are also in agreement with Starlight
- Clear extension of ALICE measurement at 2.76 TeV



Search for light-by-light scattering



▪ Motivation

▪ Light-by-light ($\gamma\gamma \rightarrow \gamma\gamma$) scattering

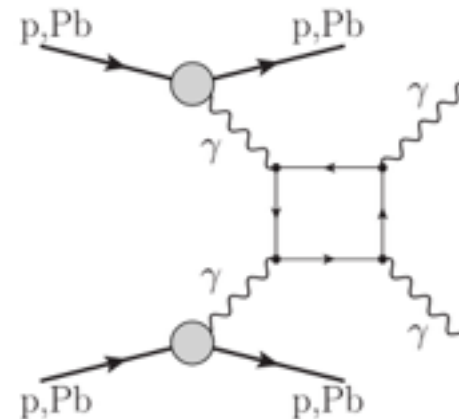
- Tested indirectly in measurements of the anomalous magnetic moment of the electron and muon
- Previous LbyL measurements involve Delbruck scattering and photon splitting process at low-energies

▪ Proposed as a possible channel to study

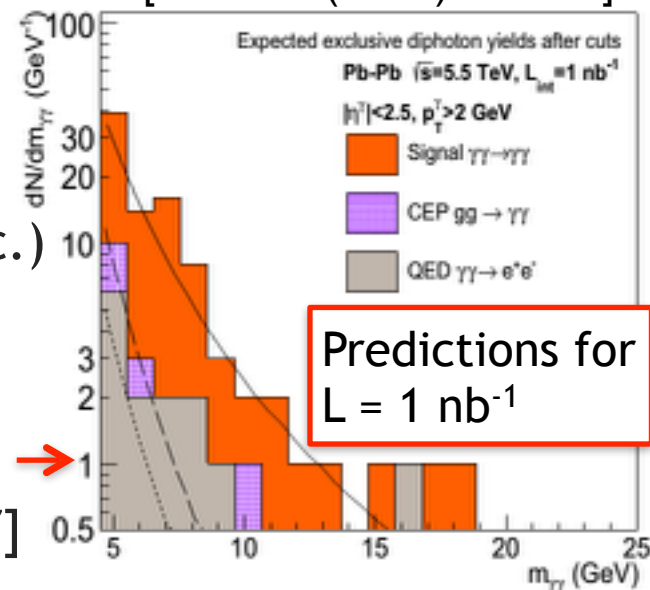
- Anomalous gauge couplings
- Contributions from BSM particles (axions etc.)

▪ Recent studies/predictions for SM rates

- [D. d'Enterria et al. PRL 111 (2013) 080405] →
- [A. Szczurek et al. PRC 93 (2016) 4, 044907]



[PRL 111 (2013) 080405]



Search for light-by-light scattering



▪ Trigger

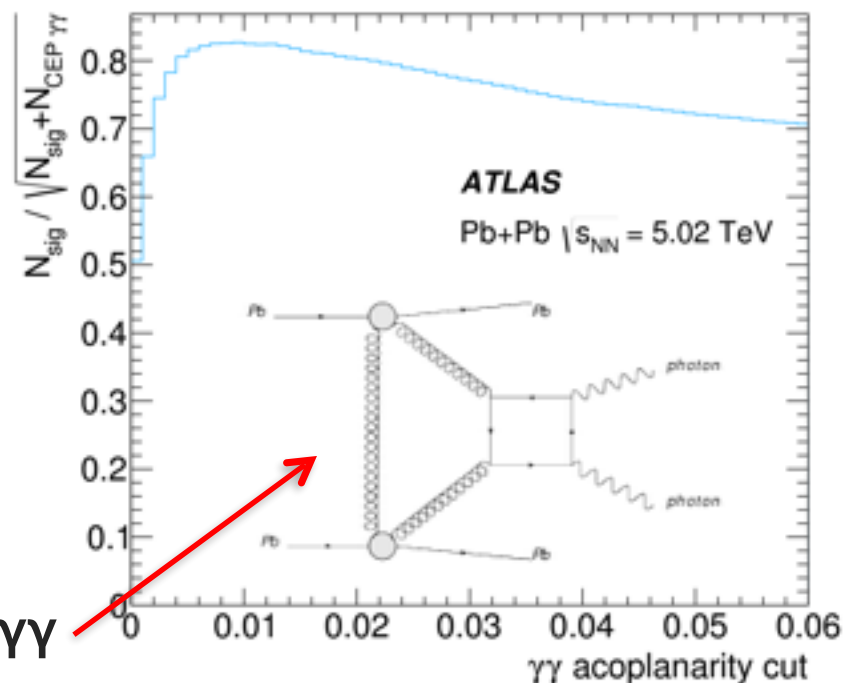
- Total E_T in the calorimeter: 5 - 200 GeV
- No more than 1 hit in inner MBTS arrays
- Between 0-10 hits in the pixel detector

▪ Event selection

- Two photons, $E_T^\gamma > 3$ GeV,
 $|\eta^\gamma| < 2.37$, $m_{\gamma\gamma} > 6$ GeV
- Exclusivity veto: no tracks
- $p_T(\gamma\gamma) < 2$ GeV
- $A_{co} = (1 - \Delta\phi/\pi) < 0.01$

▪ Main background

- Central Exclusive Production $gg \rightarrow \gamma\gamma$
- Misidentified electrons from $\gamma\gamma \rightarrow ee$



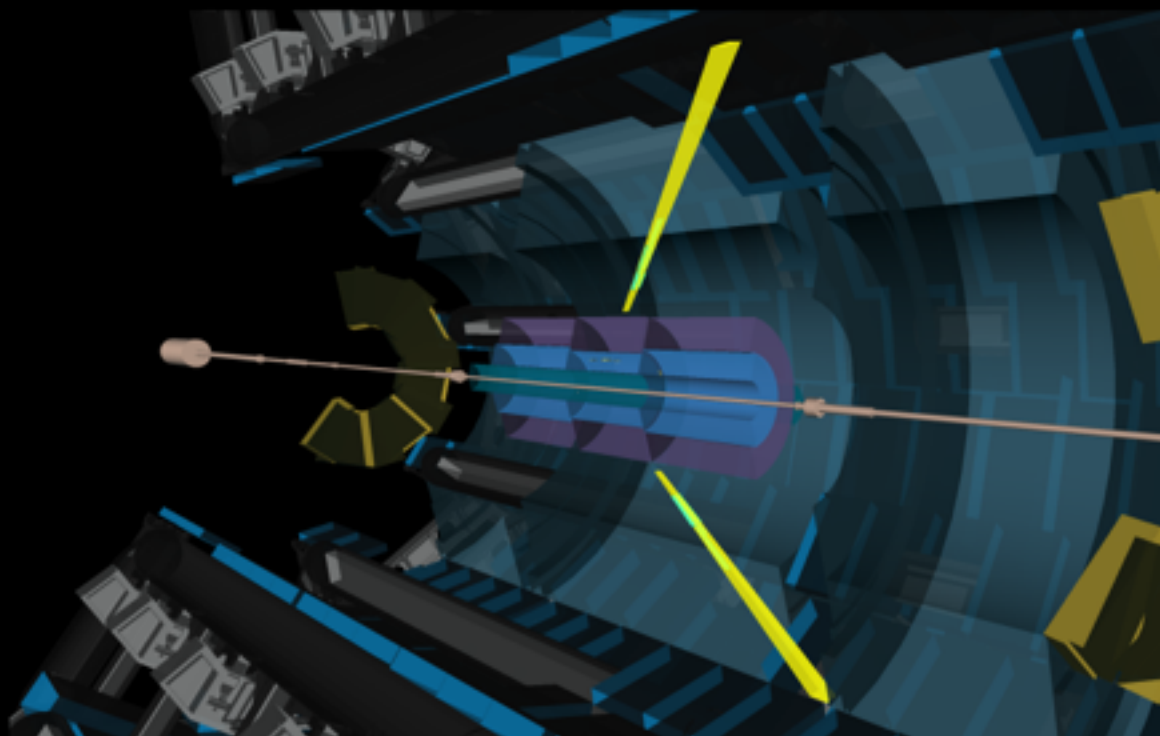
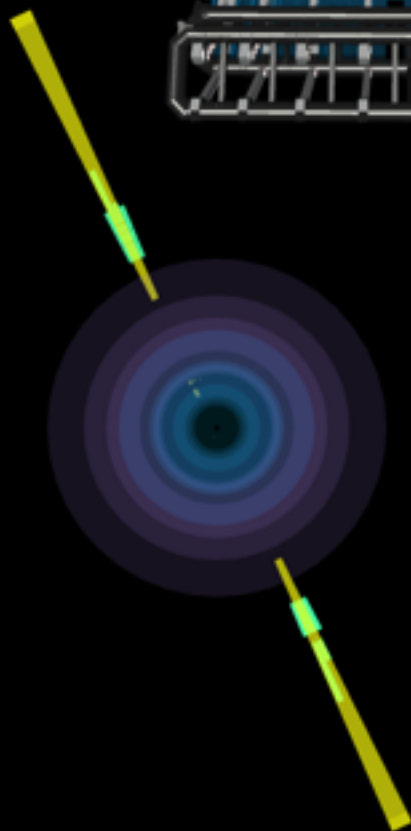
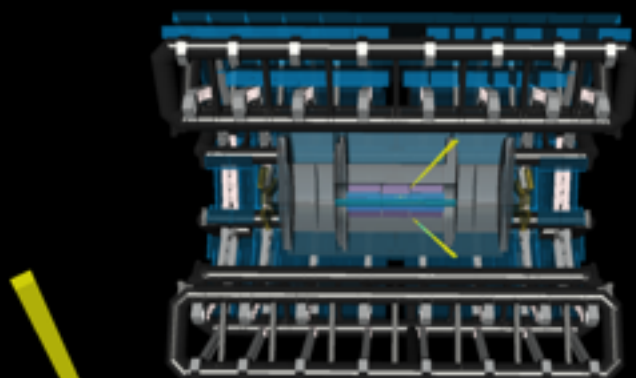
Search for light-by-light scattering



Run: 287931

Event: 461251458

2015-12-13 09:51:07 CEST



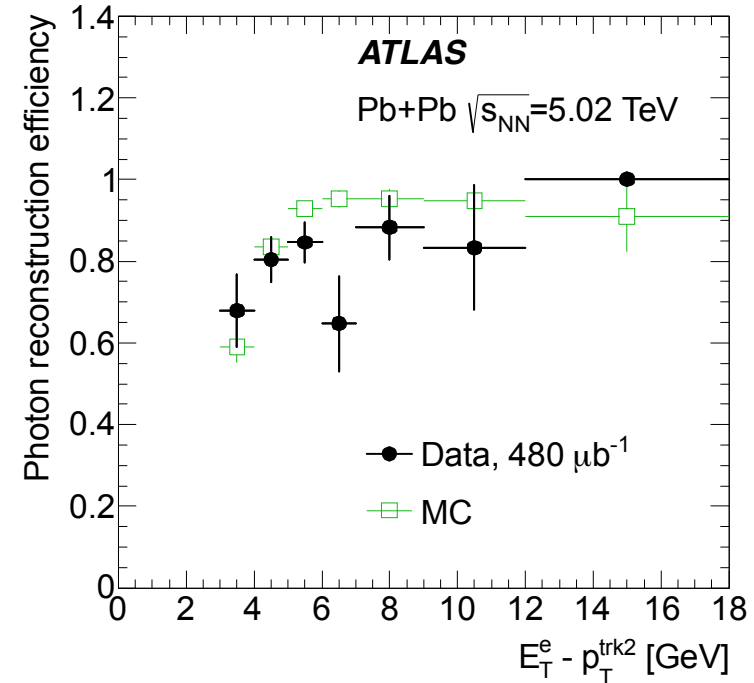
Search for light-by-light scattering



- **Photon performance cross-checks**

- $\gamma\gamma \rightarrow l^+l^-$ events are used for:

- Trigger efficiency studies
- Photon reconstruction/PID efficiency (hard-bremsstrahlung/FSR photons)
- Photon energy scale/resolution (EM dicluster properties from $\gamma\gamma \rightarrow ee$)



- **Systematic uncertainties**

- Dominated by photon reco/PID efficiency uncertainty

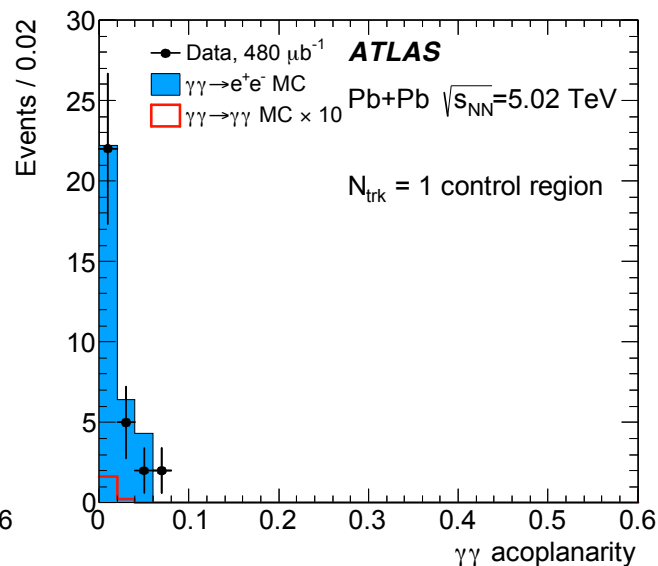
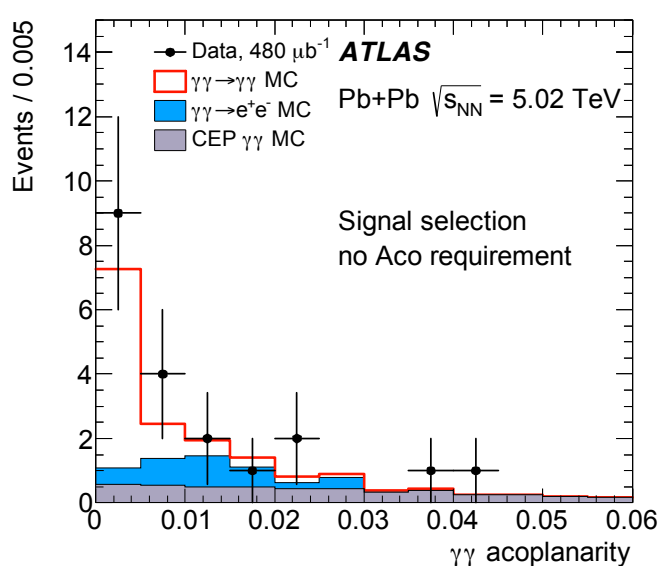
Source of uncertainty	Relative uncertainty
Trigger	5%
Photon reco efficiency	12%
Photon PID efficiency	16%
Photon energy scale	7%
Photon energy resolution	11%
Total	24%

Search for light-by-light scattering



Results

- 13 events observed in data
- 7.3 signal events + 2.6 background events expected



- Significance is estimated using profile likelihood method

Selection	$\gamma\gamma \rightarrow e^+e^-$	CEP $gg \rightarrow \gamma\gamma$	Hadronic fakes	Other fakes	Total background	Signal	Data
Preselection	74	4.7	6	19	104	9.1	105
$N_{\text{trk}} = 0$	4.0	4.5	6	19	33	8.7	39
$p_T^{\gamma\gamma} < 2$ GeV	3.5	4.4	3	1.3	12.2	8.5	21
Aco < 0.01	1.3	0.9	0.3	0.1	2.6	7.3	13
Uncertainty	0.3	0.5	0.3	0.1	0.7	1.5	

Search for light-by-light scattering



Results

- Observed significance: 4.4σ (3.8σ expected)

- Fiducial cross section is estimated in the region:

- $p_T^\gamma > 3 \text{ GeV}$, $|\eta^\gamma| < 2.4$, $m_{\gamma\gamma} > 6 \text{ GeV}$,

- $p_T(\gamma\gamma) < 2 \text{ GeV}$, $A_{\text{co}} < 0.01$

- $\sigma_{\text{meas.}} = 70 \pm 20 \text{ (stat.)} \pm 17 \text{ (syst.) nb}$

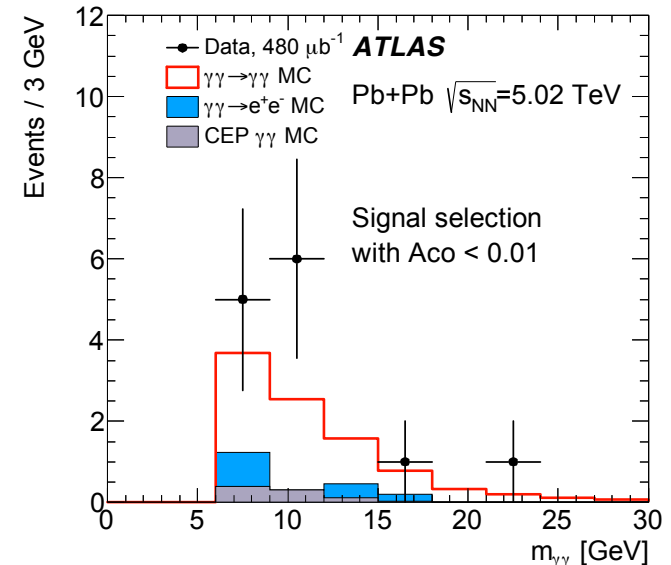
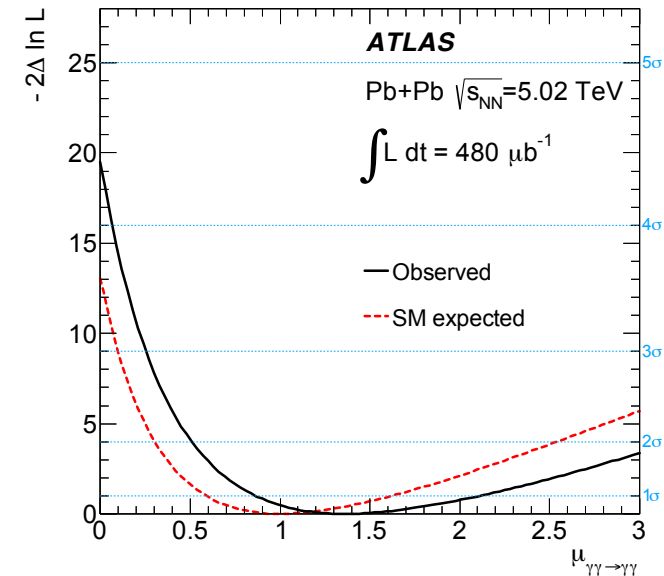
- SM predictions:

- $45 \pm 9 \text{ nb}$

[PRL 111 (2013) 080405]

- $49 \pm 10 \text{ nb}$

[PRC 93 (2016) no.4, 044907]



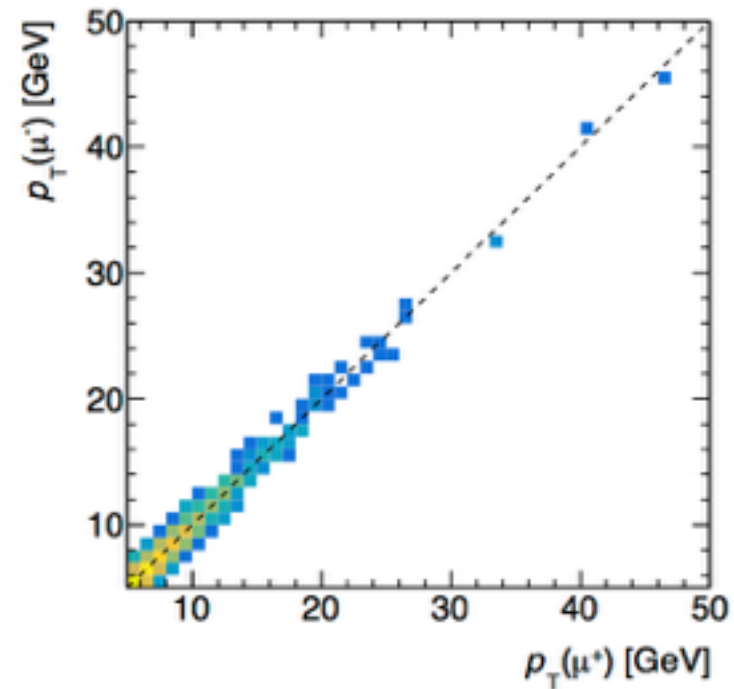
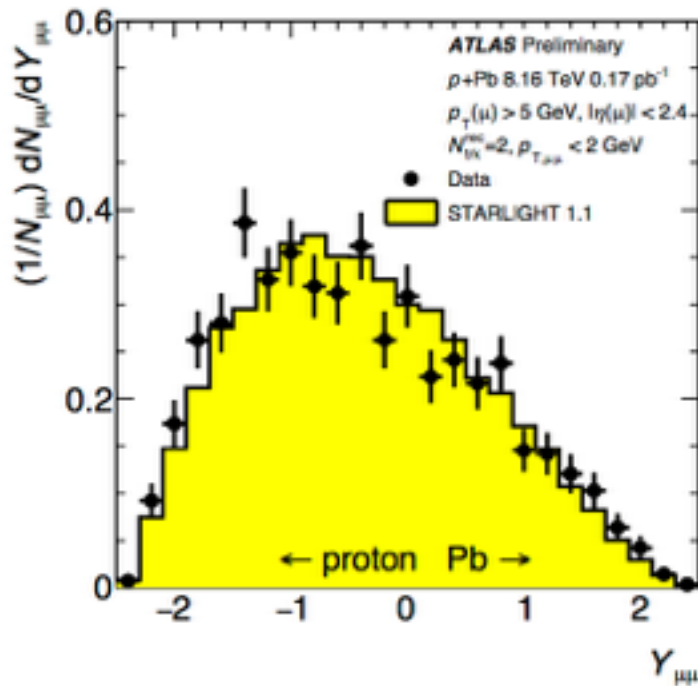


- Exclusive (QED) processes have been studied in Pb+Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV
- Cross sections of the exclusive $\gamma\gamma \rightarrow \mu^+\mu^-$ production have been measured
 - Consistent with the LO QED calculations from Starlight
- Evidence for SM $\gamma\gamma \rightarrow \gamma\gamma$ production (significance of 4.4σ)
 - Cross section in agreement with QED predictions

Outlook



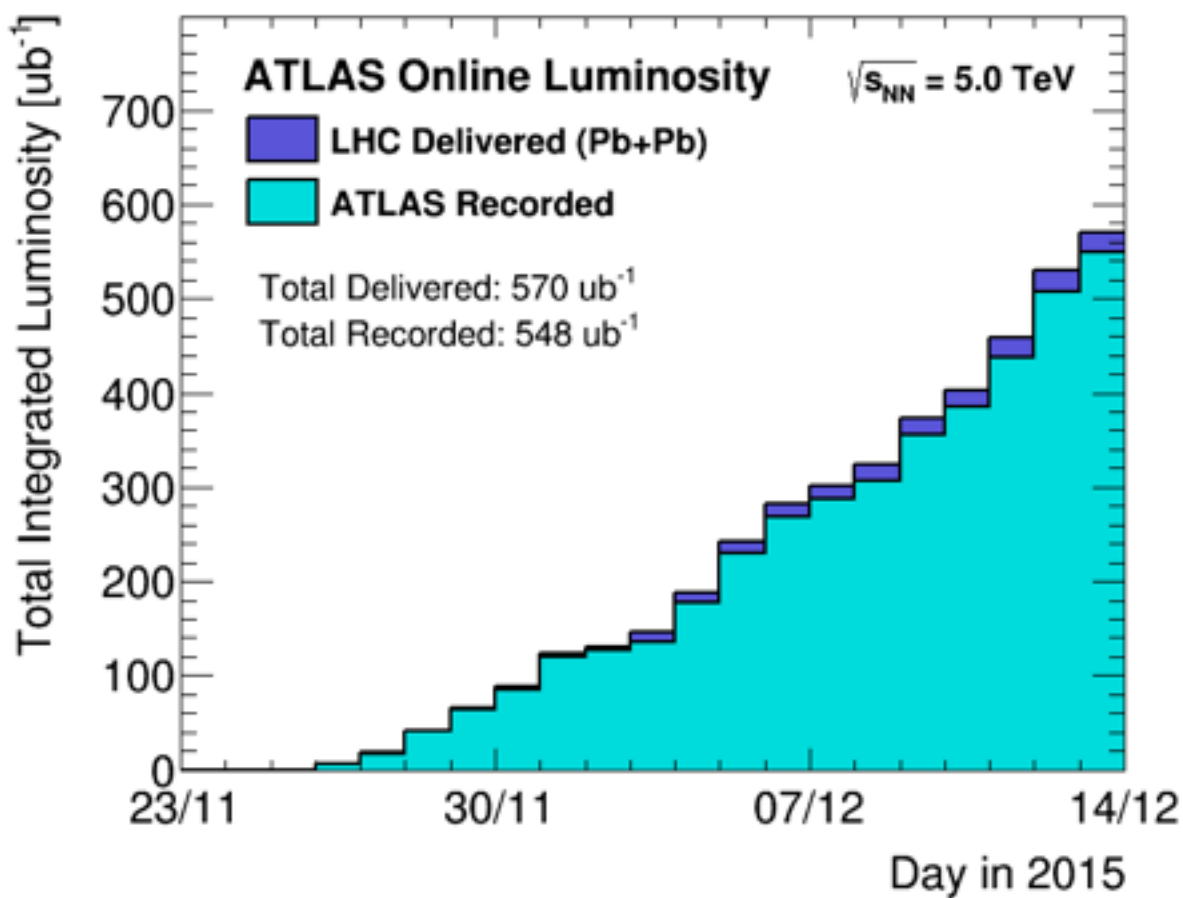
- Further QED measurements can be done with new p+Pb data!



Backup



2015 Pb+Pb dataset



LbyL: Object definition

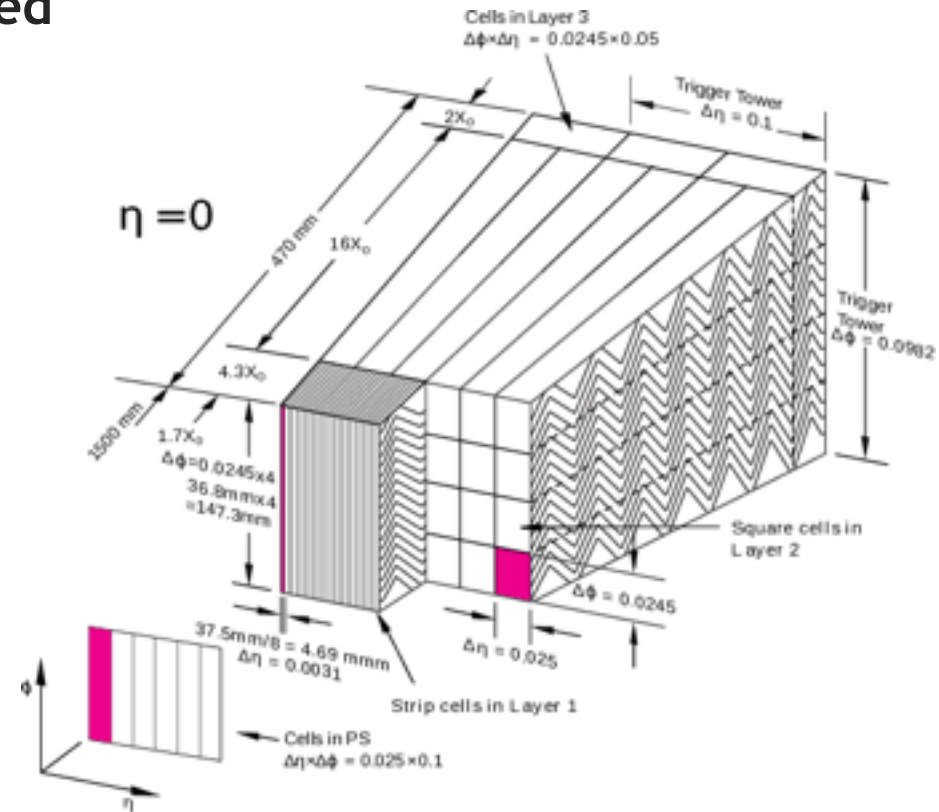


- $\gamma\gamma \rightarrow \gamma\gamma$ cross section decreases very rapidly with $m_{\gamma\gamma}$ and/or E_T
 - Low- E_T photons need to be used

▪ Photons

- $E_T > 3 \text{ GeV}$, $|\eta| < 2.37$,
photon PID based on three
shower-shape variables is used:

E_{ratio}	Ratio of the energy difference associated with the largest and second largest energy deposits to the sum of these energies in the first layer of EM calo
f_1	Fraction of energy reconstructed in the first layer with respect to the total energy of the cluster
W_{eta2}	Lateral width of the shower in the middle layer

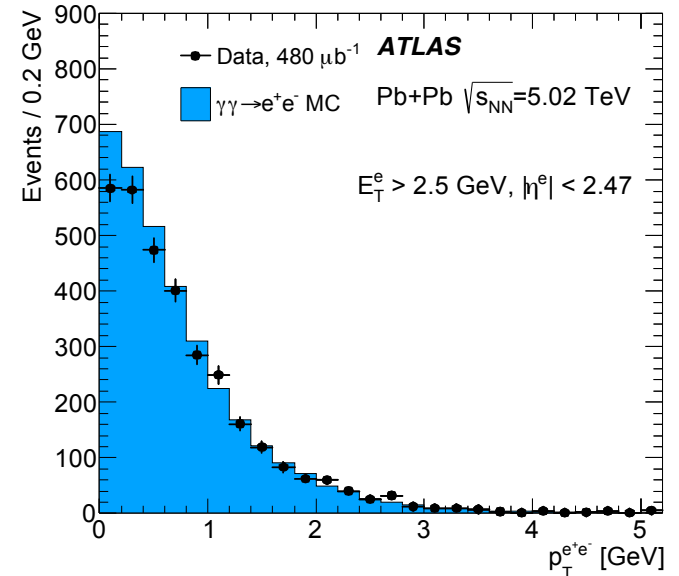
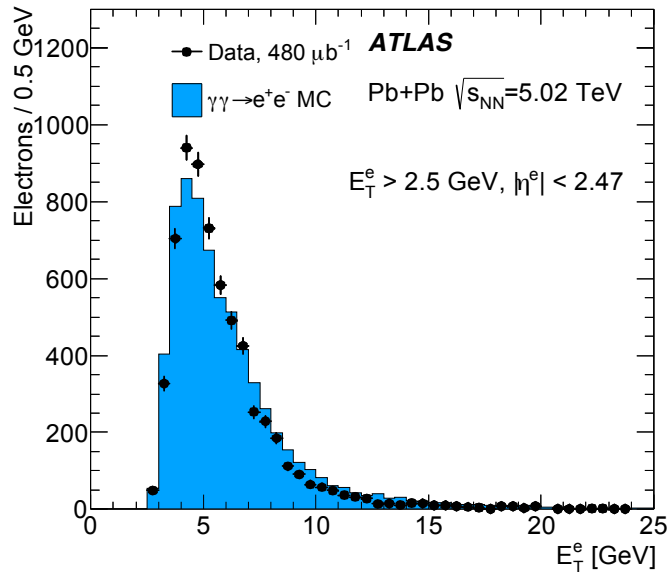


- Charged-particle tracks (vetoed help to reduce background)
 - $p_T > 100 \text{ MeV}$, $|\eta| < 2.5$

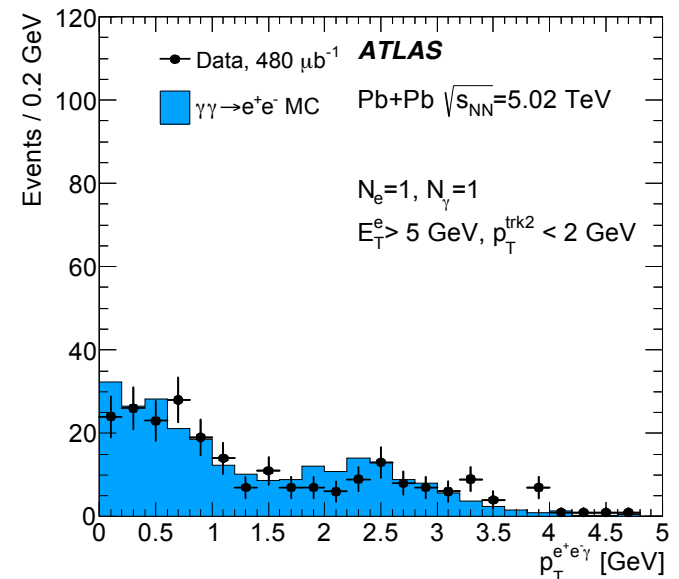
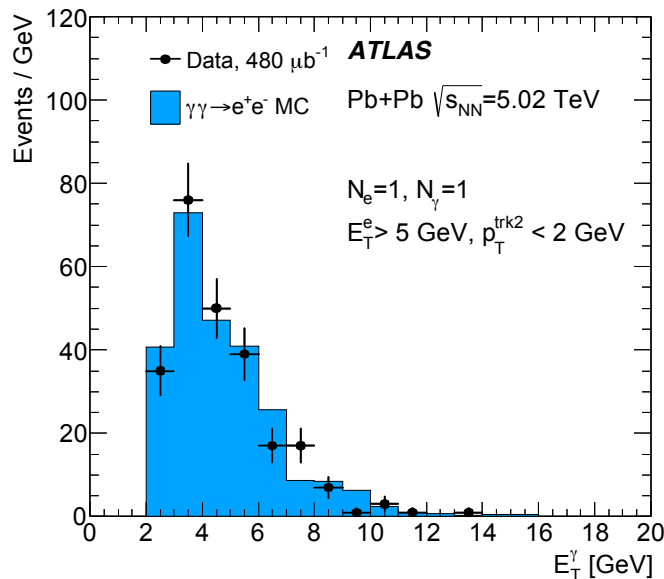
LbyL: Dielectron cross-checks



$\gamma\gamma \rightarrow ee$
selection:



$\gamma\gamma \rightarrow ee\gamma$
(hard-
bremstrahlung)
selection:



LbyL: Expected sensitivity for axion searches



- Example: expected sensitivity for axion searches

[arXiv:1607.06083](https://arxiv.org/abs/1607.06083)

