Photon-photon fusion measurements at ATLAS

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on behalf of the ATLAS Collaboration

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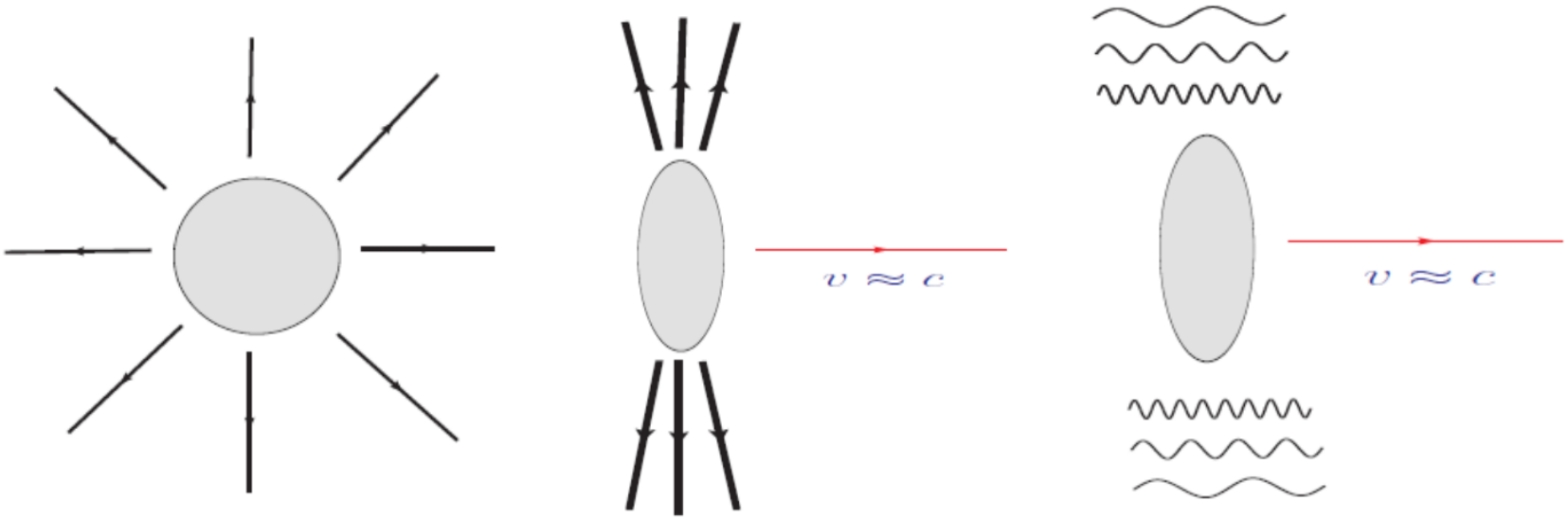
Low-x 2021
September 30, 2021

Two-photon processes



- Accelerated charged particles surrounded by photons
- Equivalent photon approximation
- Two-photon processes can be computed with QED

PbPb:

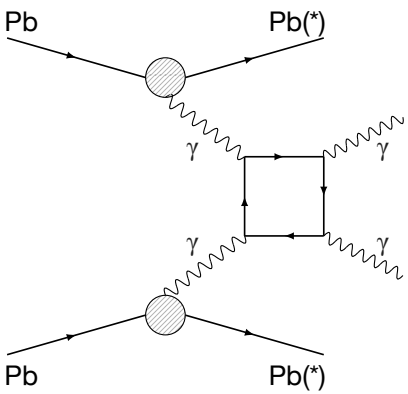
- high charge
- higher photon luminosity (Z^4)
- low pile-up
- clean events

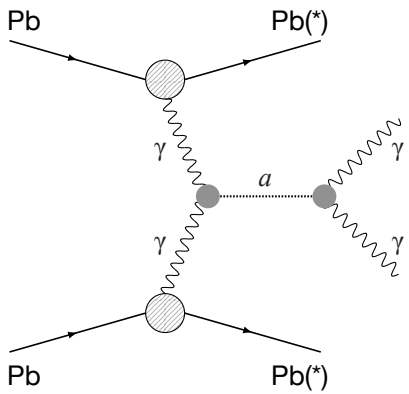
pp:

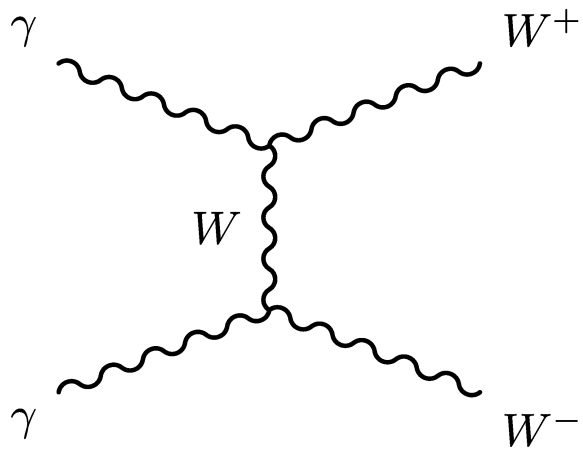
- high luminosity
- higher photon energy
- high pile-up
- busy events

Motivation

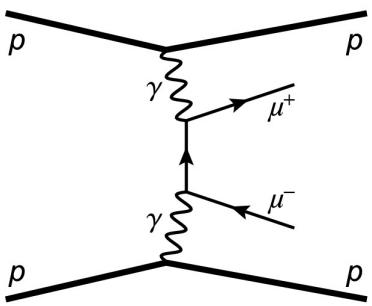
EWK – possible new particles, SM tests



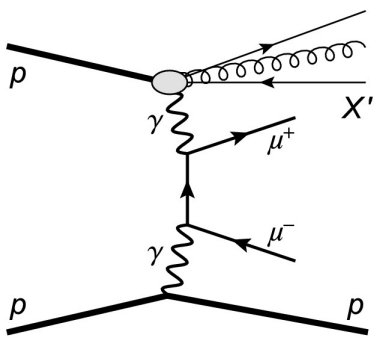




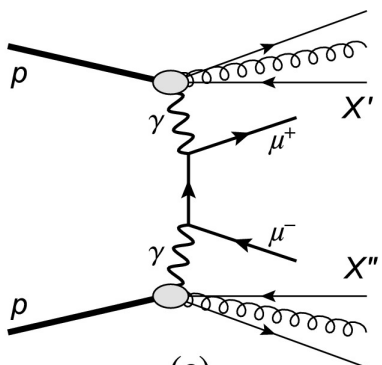
QCD – proton dissociation, additional exchanges



(a)



(b)



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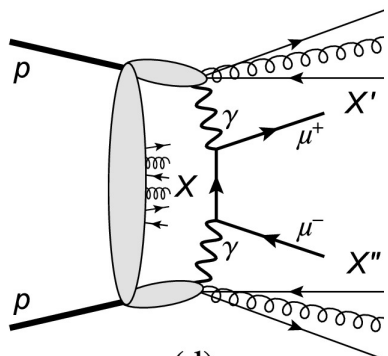
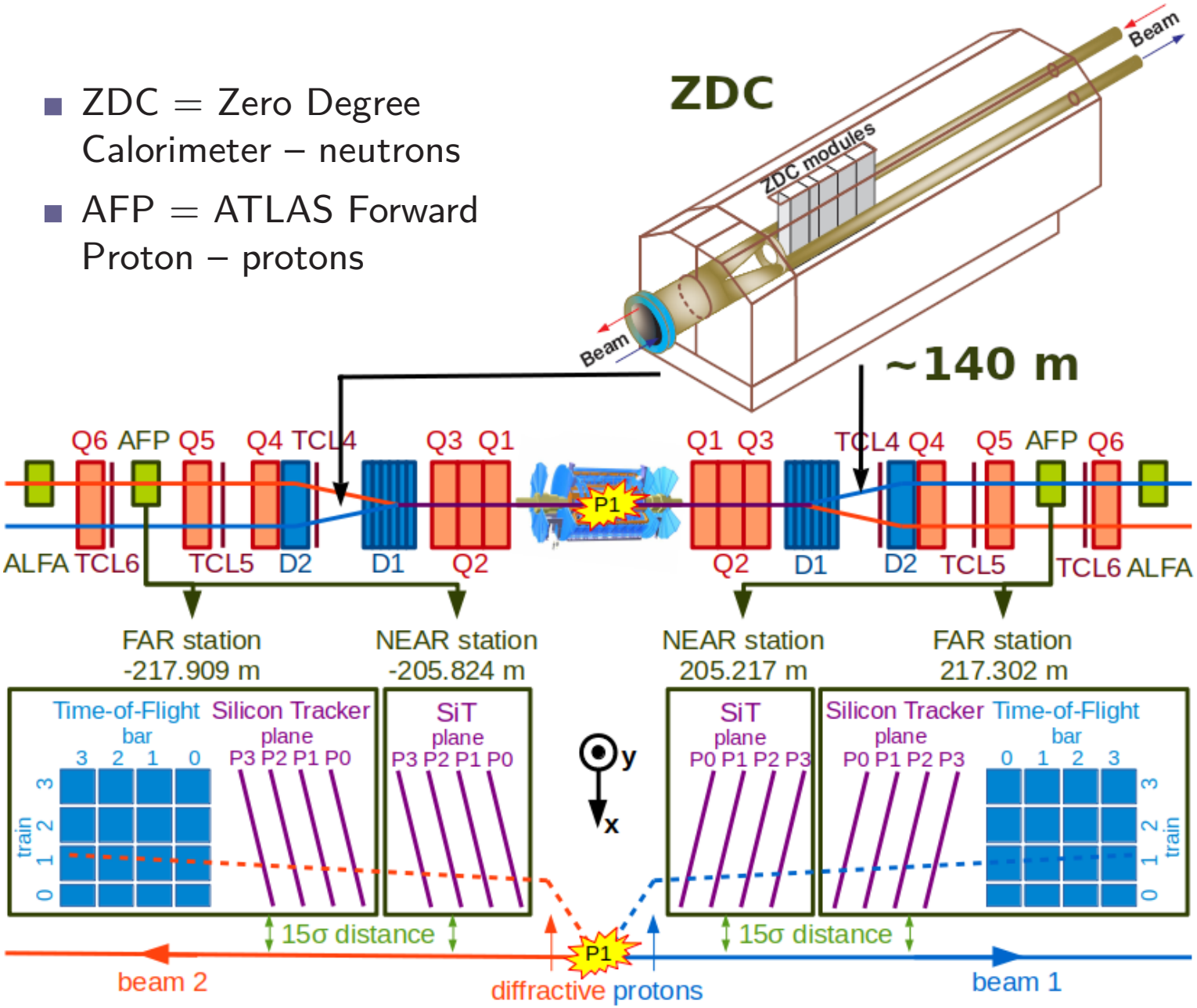


(d)

ATLAS Forward detectors

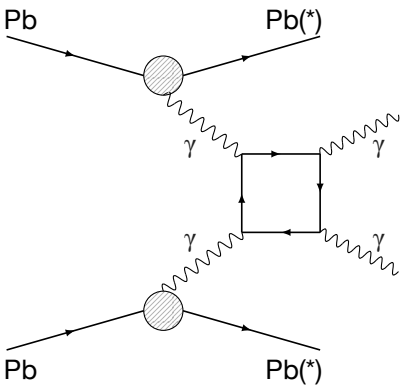
- ZDC = Zero Degree Calorimeter – neutrons
- AFP = ATLAS Forward Proton – protons



$\gamma\gamma \to \gamma\gamma$ in PbPb

Measurement of light-by-light scattering

[JHEP 03 (2021) 243]



Background: $gg \to \gamma\gamma$

Total cross-section:

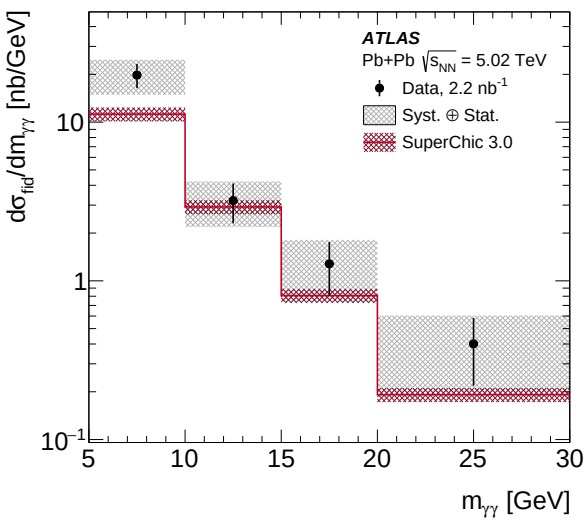
- Measurement:

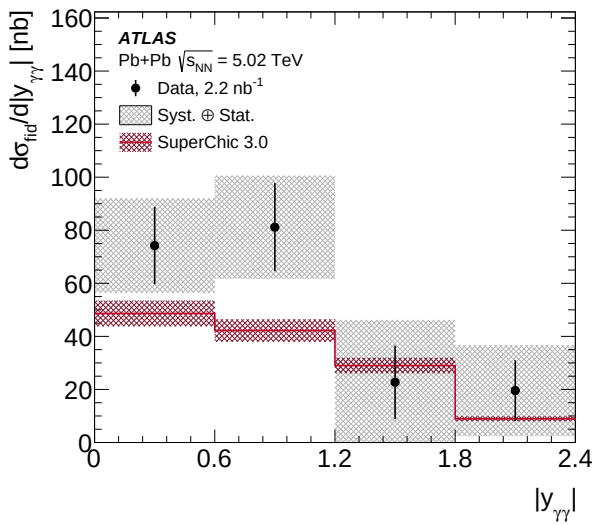
$$\sigma_{fid} = 120 \pm 17\ (stat.) \pm 13\ (syst.) \pm 4\ (lumi.)\ \text{nb}$$

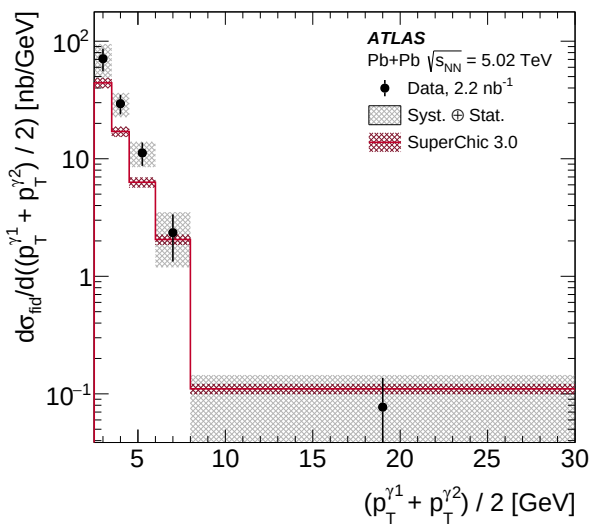
- SuperChic v3.0 prediction: 78 ± 8 nb
- Data to SuperChic ratio: 1.54 ± 0.32

Differential cross-section:

- Uncertainties dominated by statistics
- No significant differences between predictions and data



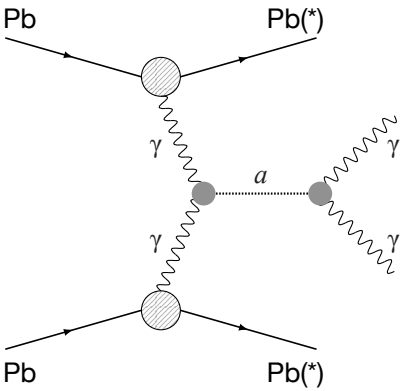


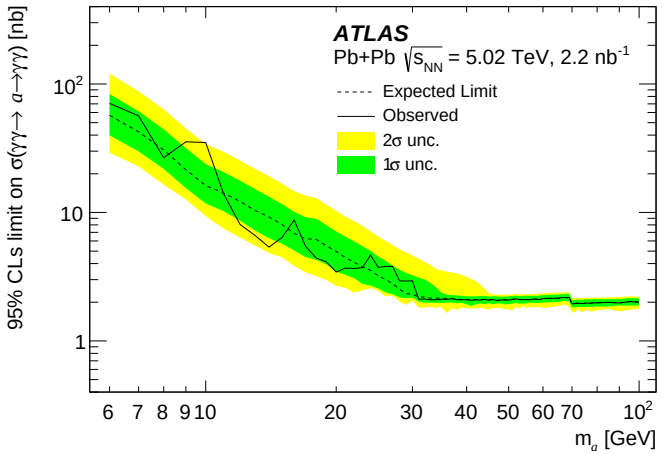


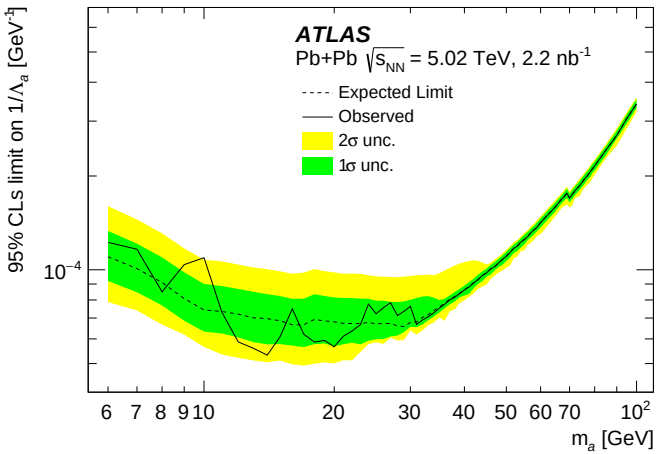
$\gamma\gamma \to \gamma\gamma$ in PbPb

Search for ALP

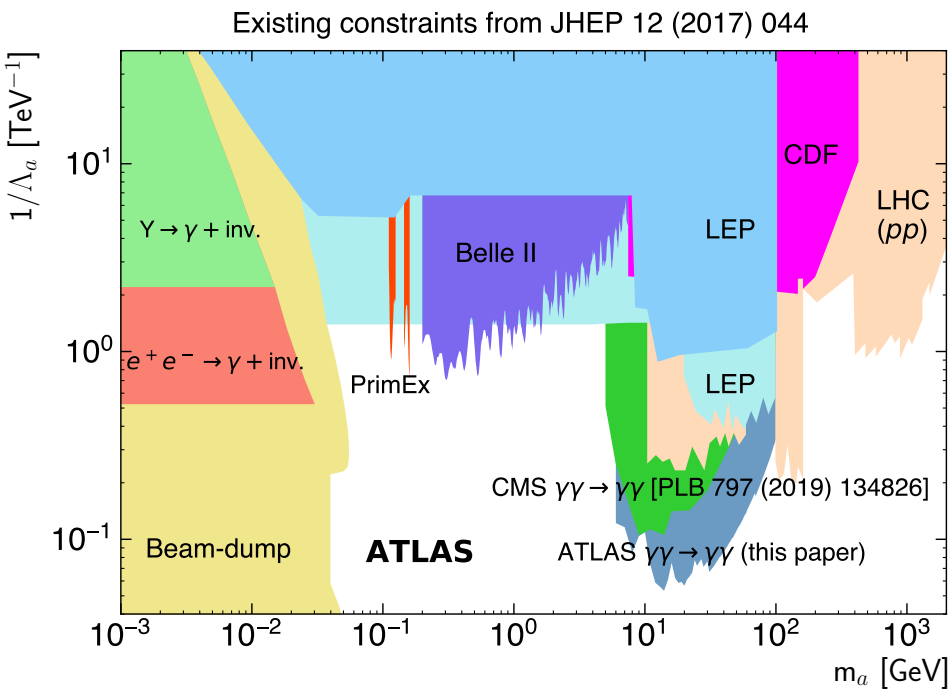
[JHEP 03 (2021) 243]

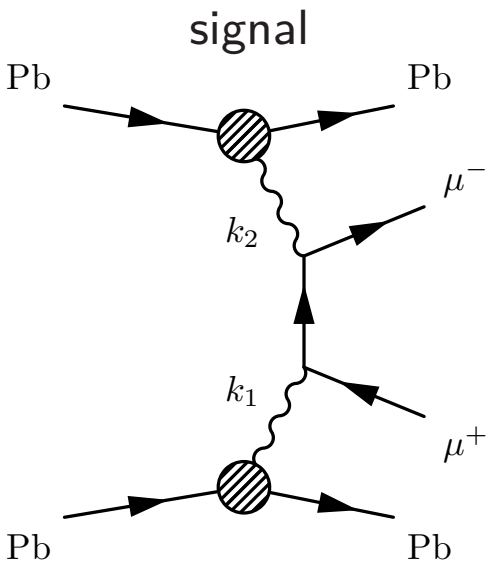


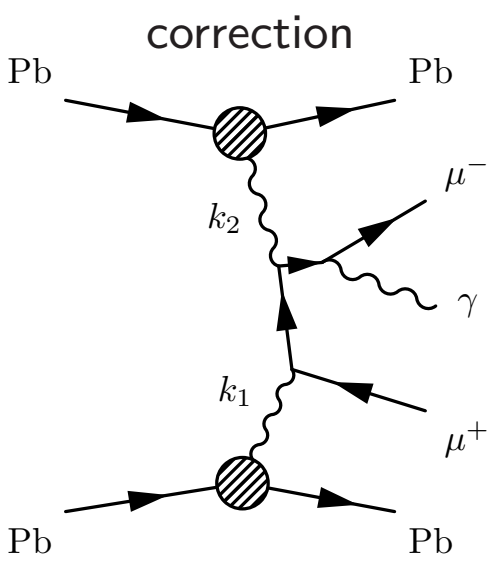


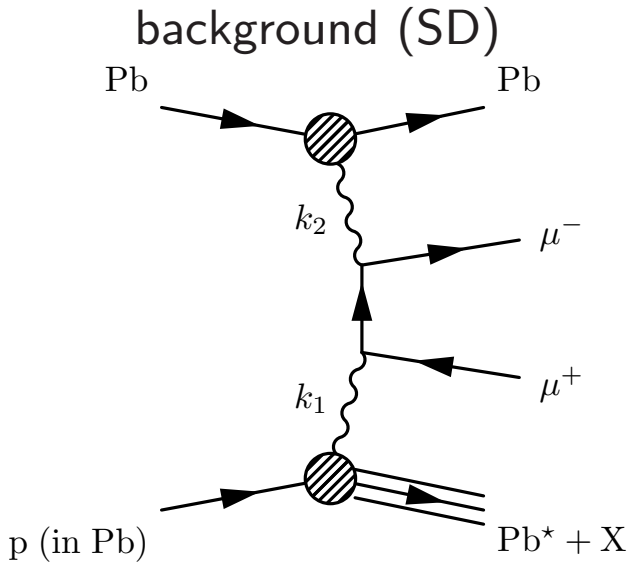


- Background: LbyL, $gg \to \gamma\gamma$
- MC prediction with STARlight v2.0
- ALP mass range: 6 - 100 GeV





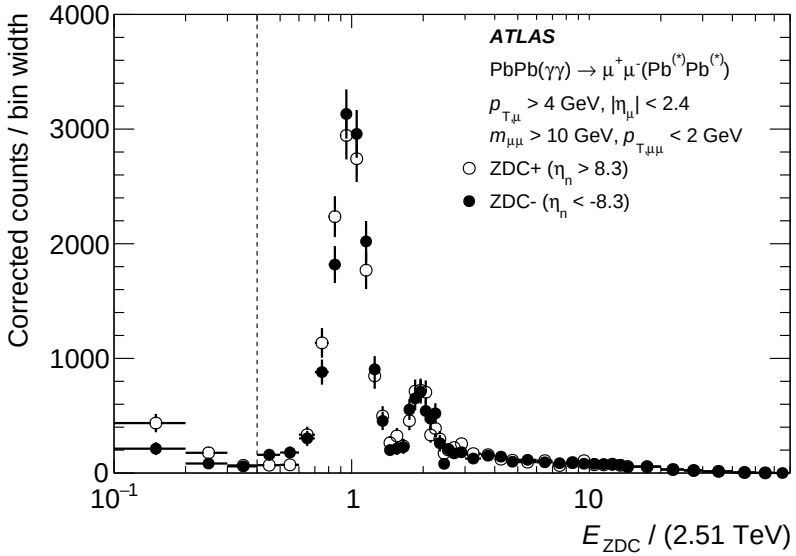




- Exclusive dimuon production
- Main background: single-diffractive dimuon production
- MC predictions with STARlight and Pythia8

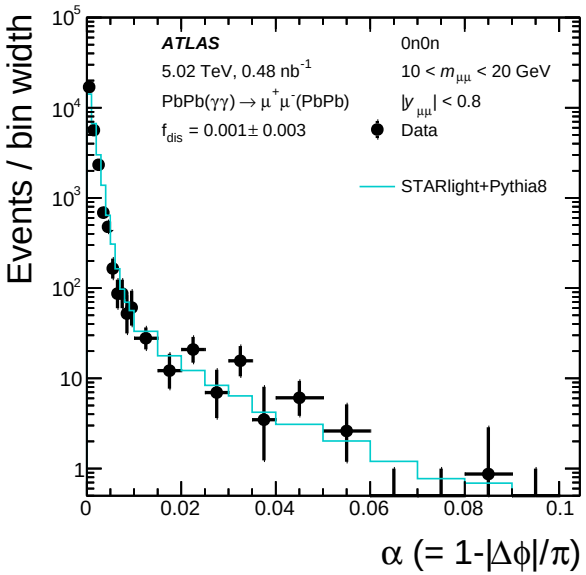
Exclusive $\gamma\gamma \to \mu\mu$ in PbPb [Phys. Rev. C 104, 024906 (2021)]

Importance of ZDC

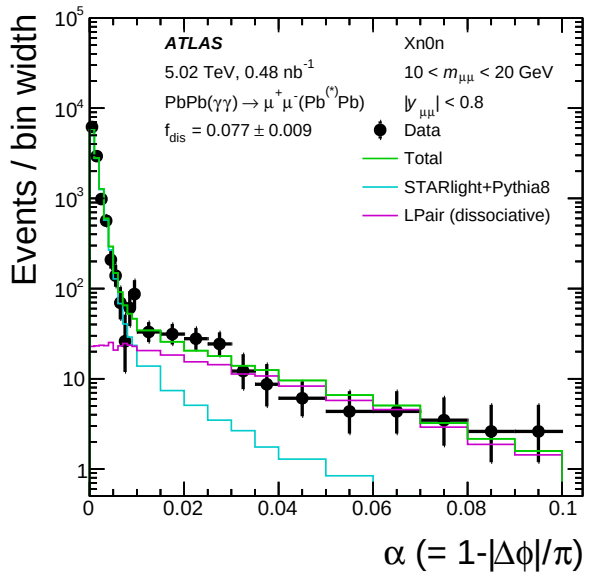


- Dissociative processes induce nuclear breakup – emmission of forward neutrons
- Presence of forward neutrons affects the impact parameter dependence of the two-photon flux
- Clear sepearation of one-neutron peak
- Well described by STARlight+Pythia8 and Lpair

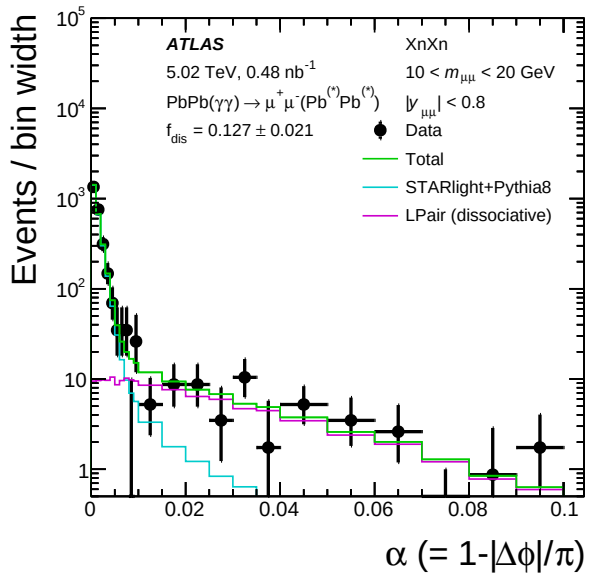
0n0n



Xn0n

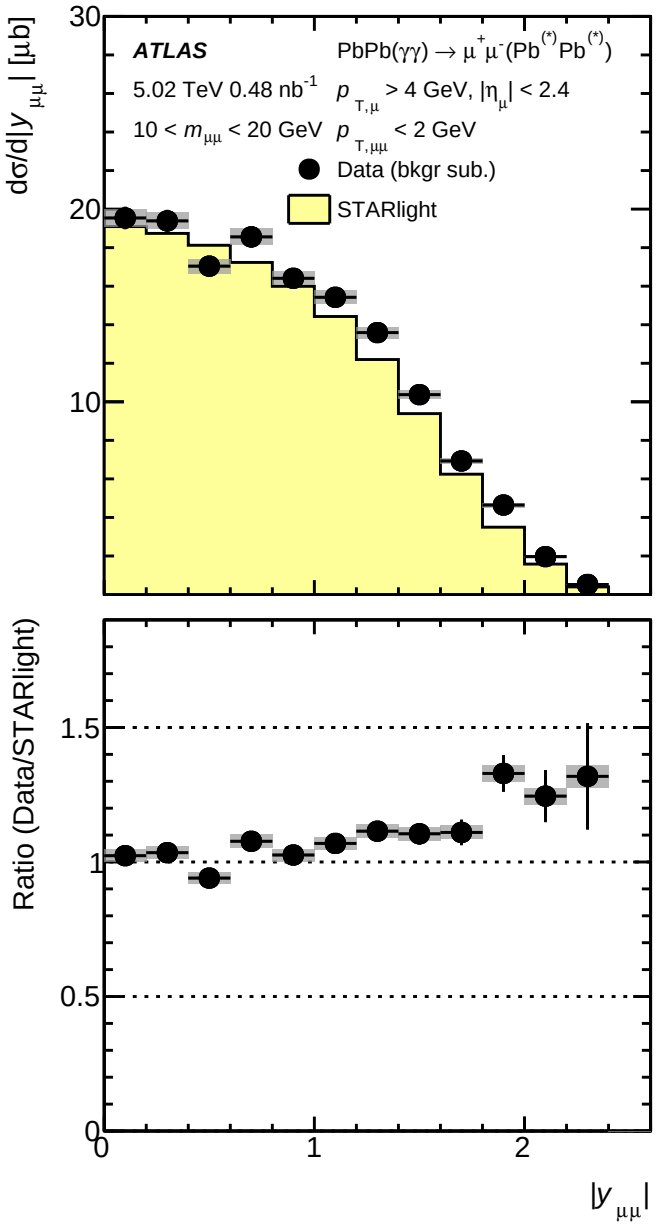


XnXn



Exclusive $\gamma\gamma \to \mu\mu$ in PbPb [Phys. Rev. C 104, 024906 (2021)]

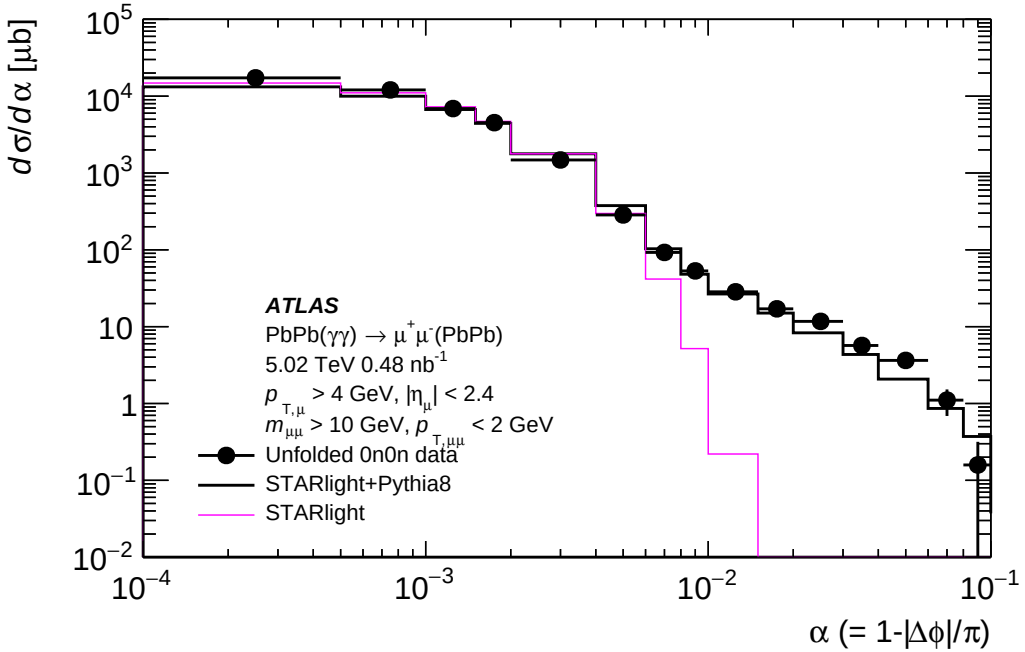
Cross-section measurement



- Total cross-section:
  - Measurement:

$$\sigma_{fid} = 34.1 \pm 0.3\ (stat.) \pm 0.7\ (syst.)\ \mu\text{b}$$

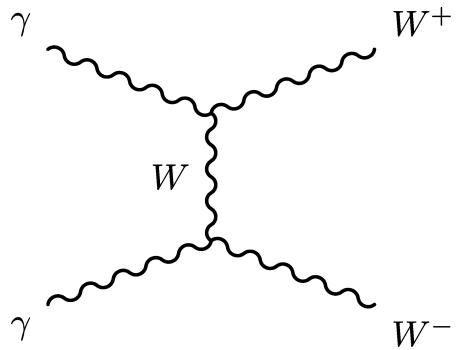
  - STARlight: $32.1\ \mu\text{b}$
  - STARlight + Pythia8: $30.8\ \mu\text{b}$
- Differential cross-section:
  - Generally good agreement with STARlight
  - Noticeable difference for higher $|y_{\mu\mu}|$

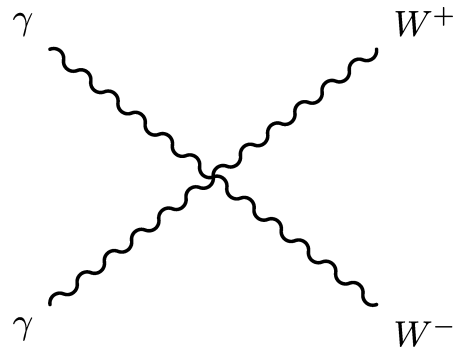


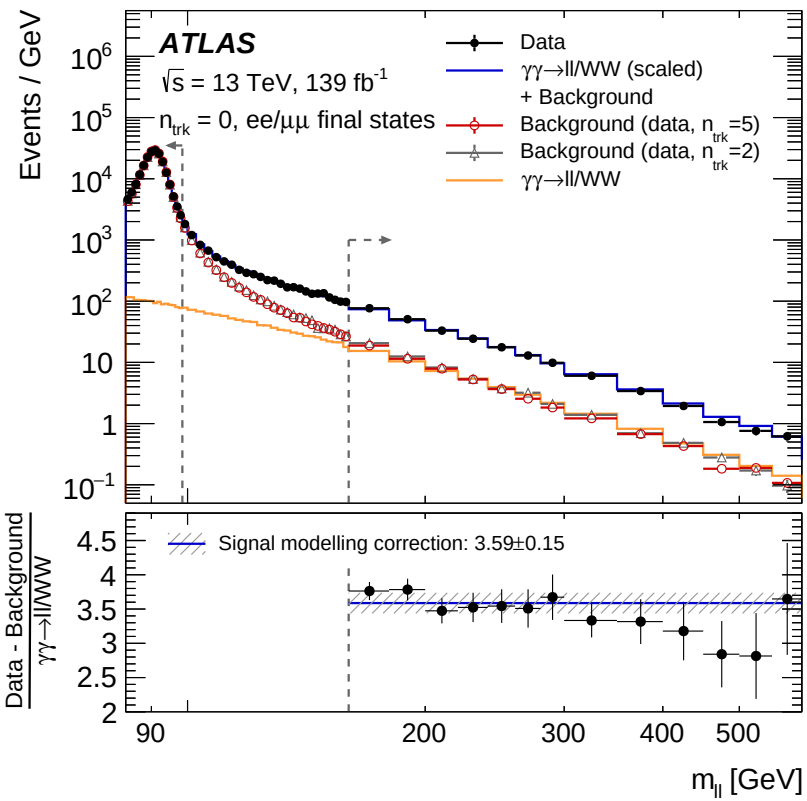
$\gamma\gamma \to WW$ in pp

[PLB 816 (2021) 136180]

Overview





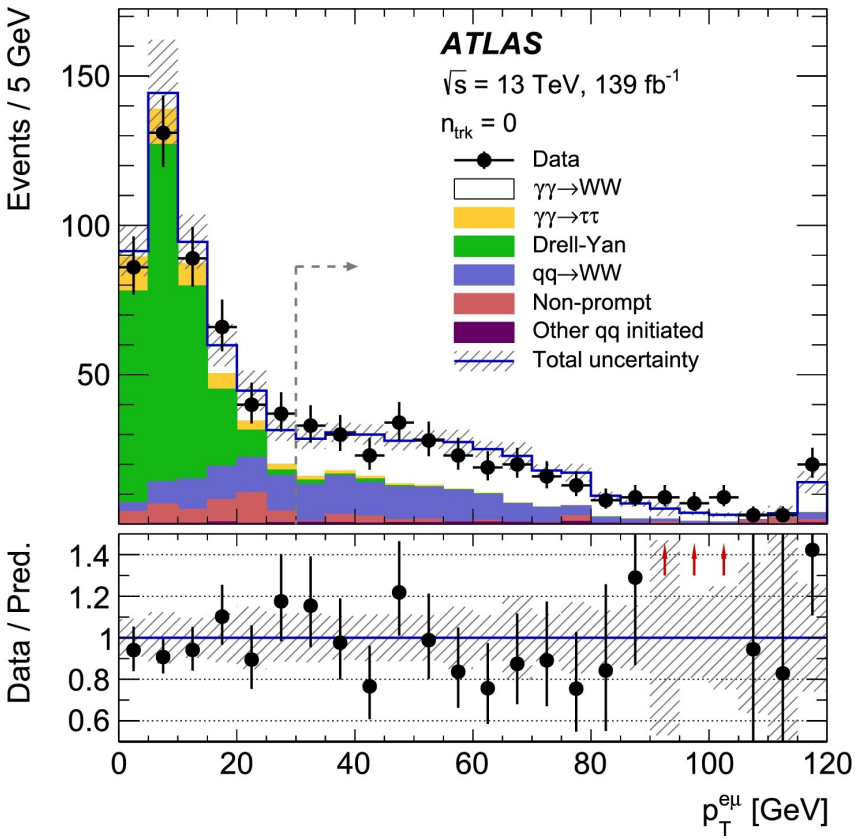


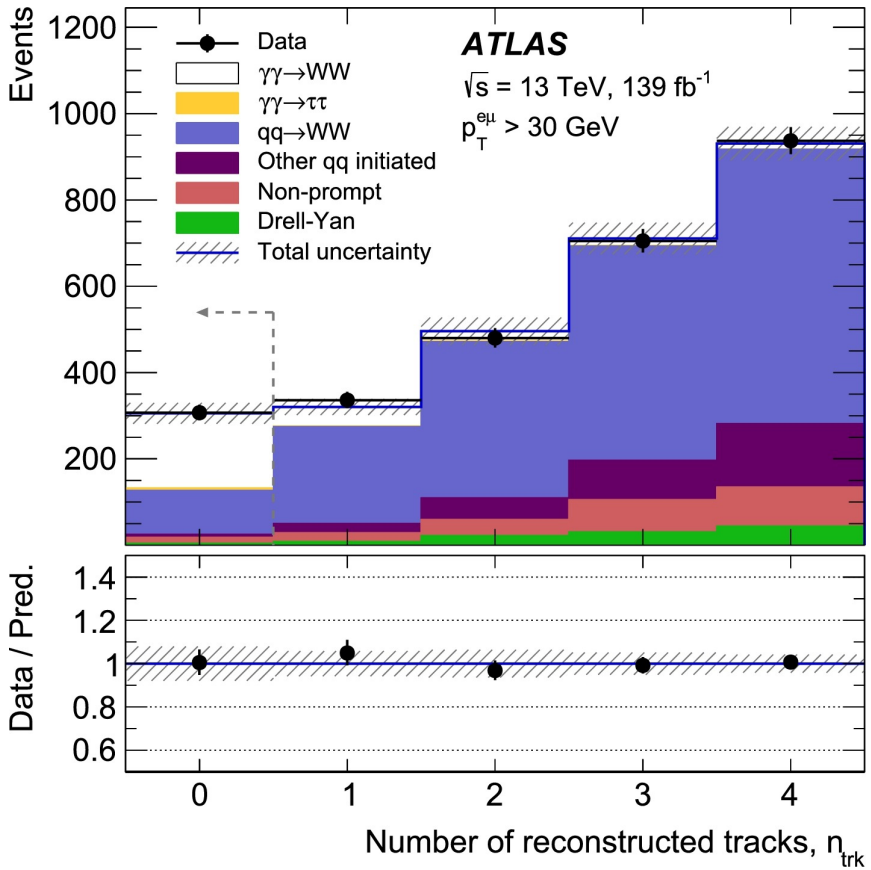
- Measured final state: $WW \to e^{\pm}\nu\mu^{\mp}\nu$
- Protons either intact or dissociated
- Background: $qq \to WW$, $gg \to WW$, $\gamma\gamma \to \tau\tau$, Drell-Yan
- Modelling with Sherpa, Powheg+Pythia8/Herwig7:
  - pile-up, underlying event
  - signal – correction as ratio of $\gamma\gamma \to ll/WW$ with exclusivity requirement to simulated elastic process only

$\gamma\gamma \to WW$ in pp

Cross-section measurement

[PLB 816 (2021) 136180]

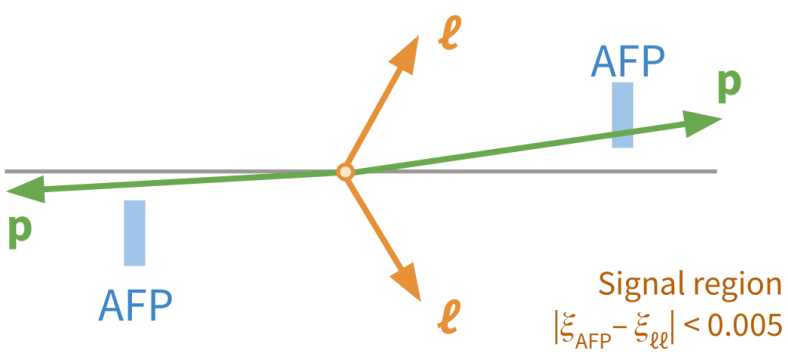




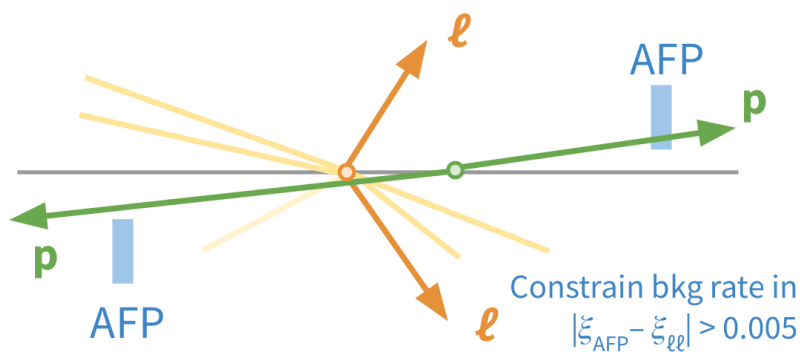
- Measurement: $\sigma_{fid} = 3.13 \pm 0.31\ (stat.) \pm 0.28\ (syst.)$ fb
- Herwig7 elastic rescaled: $\sigma = 2.34 \pm 0.27$ fb
- MG5_aMC@NLO+Pythia8: $\sigma = 4.3 \pm 1.1$ fb – no rescattering effects
- MG5_aMC@NLO+Pythia8 $\times$ **0.65**: $\sigma = 2.8 \pm 0.8$ fb — PLB 741 (2015) 66–70
- MG5_aMC@NLO+Pythia8 $\times$ **0.82**: $\sigma = 3.5 \pm 1.0$ fb — arXiv:1508.02718
- Observed significance: 8.4σ

- Previous measurement without proton tag [Phys. Lett. B 777 (2018) 303]
- Measured process: $pp \to p(\gamma\gamma \to l\bar{l})p^*$
- Significant uncertainties with modelling QCD interactions between scattered protons in $\gamma\gamma$ processes $\to$ cross-section supression
- Poorly constrained especially at high $\gamma\gamma$ invariant masses
- Direct proton measurement - additional supression of background processes and events involving proton dissociation

Signal:



Background:



- ξ – fraction of proton energy carried by the photon
- ξ from proton measurement:

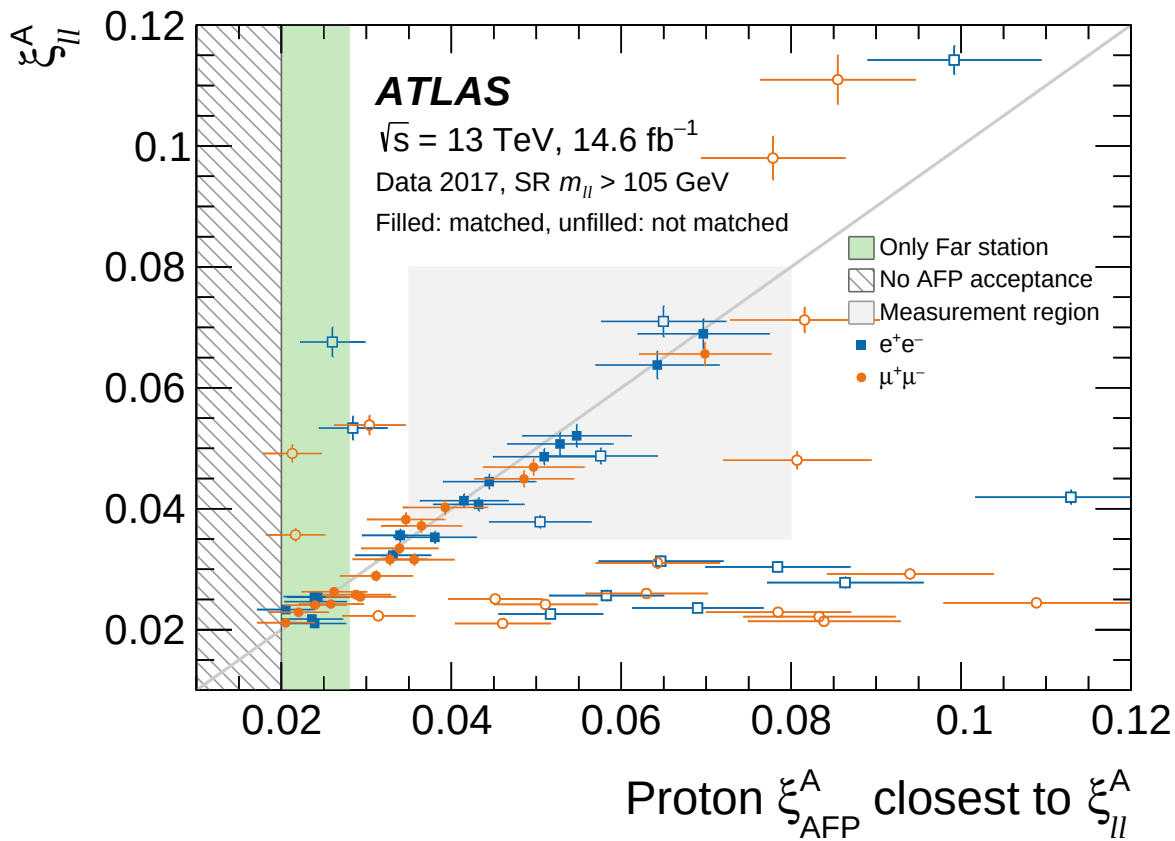
$$\xi_{AFP} = 1 - \frac{E_{proton}}{E_{beam}}$$

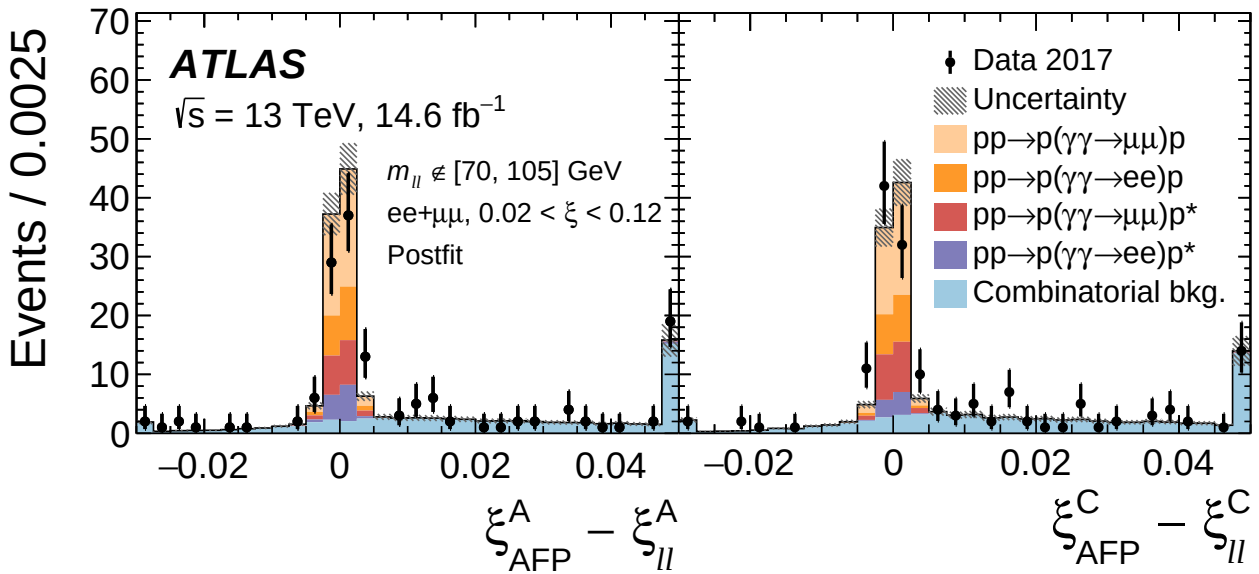
- ξ from $l\bar{l}$ system:

$$\xi_{ll}^{\pm} = \frac{M_{l\bar{l}}}{\sqrt{s}} \cdot e^{\pm y_{l\bar{l}}}$$

- Matching criteria:

$$|\xi_{AFP} - \xi_{ll}| < 0.005$$





	σ^{ee+p}_{fid} [fb]	$\sigma^{\mu\mu+p}_{fid}$ [fb]
Measurement	$\mathbf{11.0 \pm 2.9}$	$\mathbf{7.2 \pm 1.8}$
SuperChic4 predicitons		
Exclusive + single-dissociative	$\mathbf{12.2 \pm 0.9}$	$\mathbf{10.4 \pm 0.7}$
Exclusive	8.6 ± 0.6	7.3 ± 0.5
Single-dissociative	3.6 ± 0.6	3.1 ± 0.5

- First cross-section measurement with AFP tag

Summary

- Photon-photon interactions present in hadron-hadron collisions
- Interesting from both points of view: EWT and QCD
- ATLAS measurements in PbPb and pp collisions outlined
- Importance of forward detectors:
  - ZDC – forward neutrons
  - AFP – forward protons