

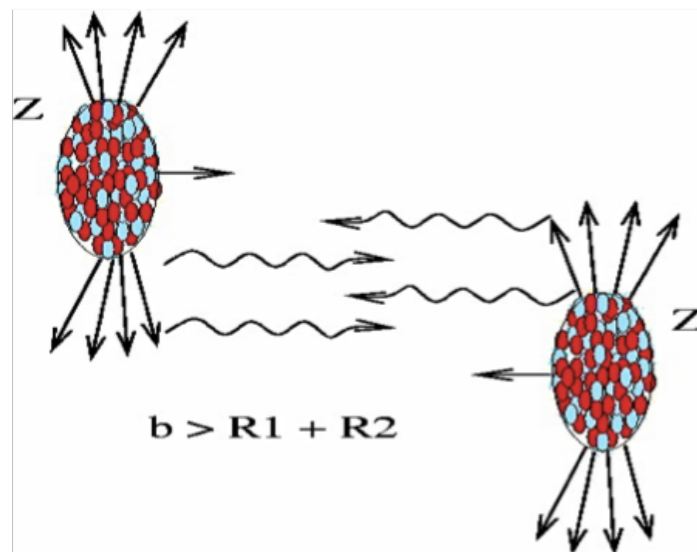


*Dilepton production and BSM physics from
photon fusion processes in UPC and non-UPC
Pb+Pb collisions with the ATLAS detector*

Iwona Grabowska-Bold (AGH UST, Kraków)
for the ATLAS Collaboration

March 28th, 2023



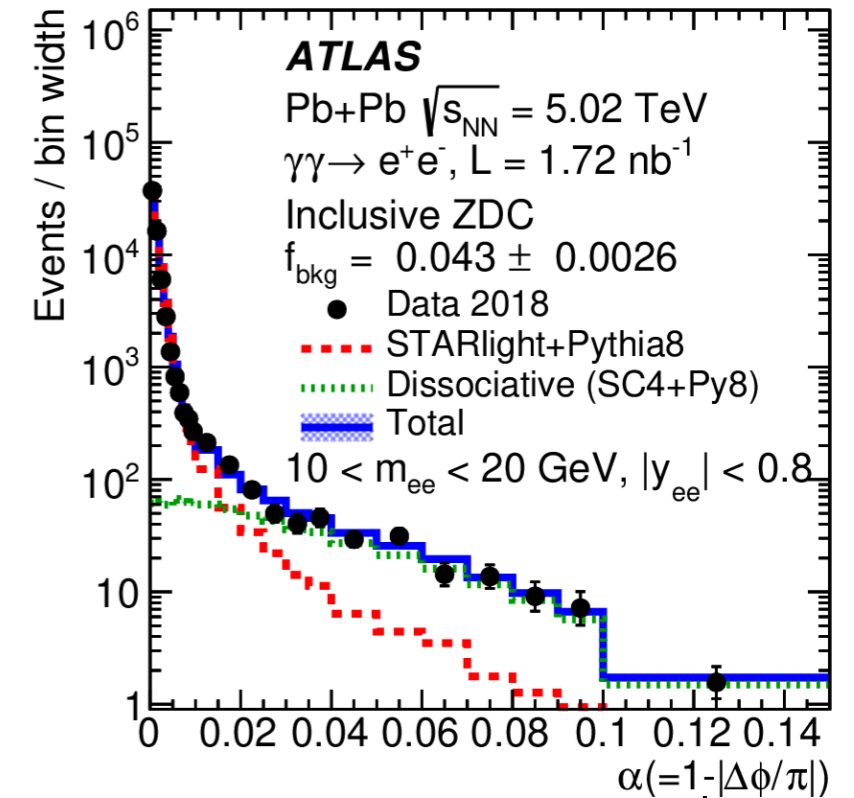


- **Ultra-peripheral collisions (UPC)** of lead-lead (Pb+Pb) have attracted a lot of attention in the heavy-ion community
 - Very clean environment to study **quantum electrodynamics (QED)** and **photon fluxes** within the Equivalent Photon Approximation (EPA) framework
 - $Z^4 (\approx 4.5 \times 10^7)$ **enhancement** of cross sections in Pb+Pb wrt proton-proton (pp) collisions
 - **Zero Degree Calorimeters (ZDC)** offer control over backgrounds and impact-parameter dependence
 - $\gamma\gamma$ collisions prove to be a competitive tool for **searches** for **beyond Standard Model (BSM)** physics
 - **Non-UPC** $\gamma\gamma \rightarrow \mu^+\mu^-$ events seem to be a **new probe** of the QGP
- The following results from 5.02 TeV UPC Pb+Pb collisions from **ATLAS** are discussed:
 - **Final** $\gamma\gamma \rightarrow \mu^+\mu^-$ [[PRC 104 \(2021\) 024906](#)]
 - **Final** $\gamma\gamma \rightarrow e^+e^-$ [[arXiv:2207.12781](#)] accepted for JHEP
 - **Final** $\gamma\gamma \rightarrow \tau^+\tau^-$ [[arXiv:2204.13478](#)] accepted for PRL
 - **Final** non-UPC $\gamma\gamma \rightarrow \mu^+\mu^-$ [[arXiv:2206.12594](#)] accepted for PRC

EXCLUSIVE DIMUONS AND DIELECTRONS

[arXiv:2207.12781]

	$\gamma\gamma \rightarrow \mu^+\mu^-$	$\gamma\gamma \rightarrow e^+e^-$
Data	2015	2018
Int lumi	0.48 nb ⁻¹	1.72 nb ⁻¹
Fiducial	$p_T^\mu > 4 \text{ GeV}$ $ \eta^\mu < 2.4$ $m_{\mu\mu} > 10 \text{ GeV}$ $p_T^{\ell\ell} < 2 \text{ GeV}$	$p_T^e > 2.5 \text{ GeV}$ $ \eta^e < 2.5$ $m_{ee} > 5 \text{ GeV}$
Event candidates	12k	30k

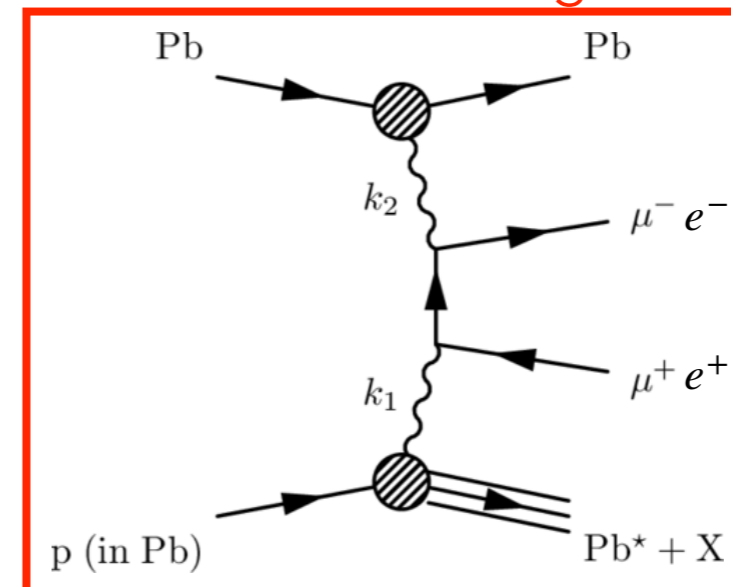
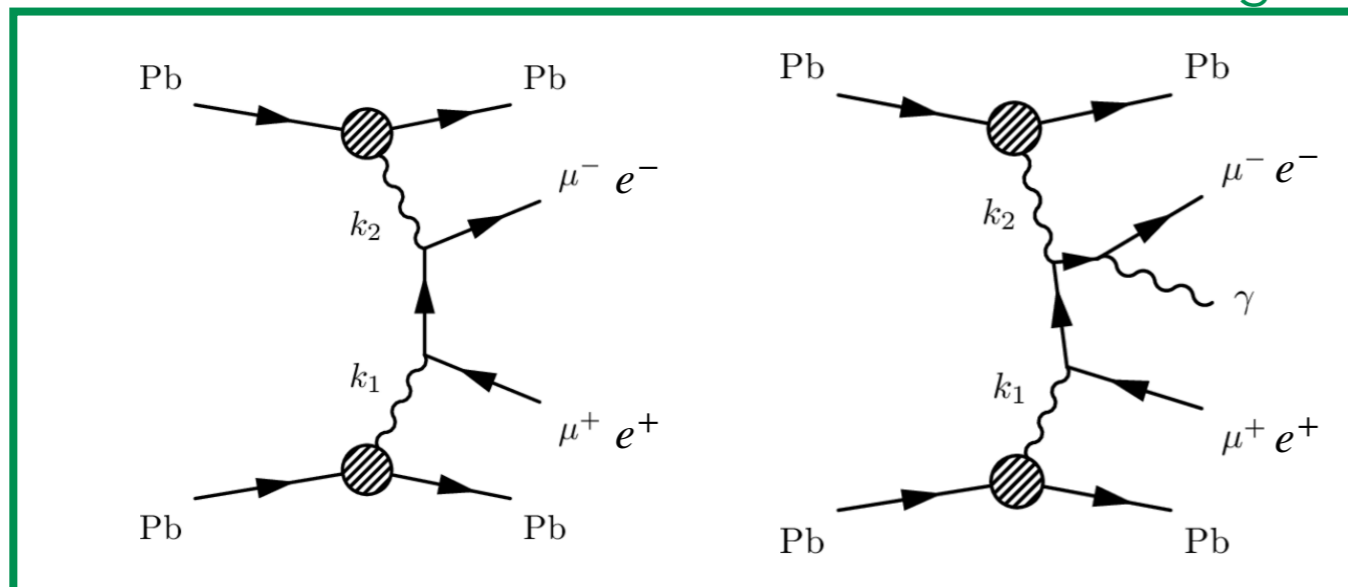


Background Dissociative LPair (3%) Dissociative SuperChic v4.0 (4%)

- Large improvements in experimental techniques with dielectrons
- For instance: more precise evaluation of dissociative background

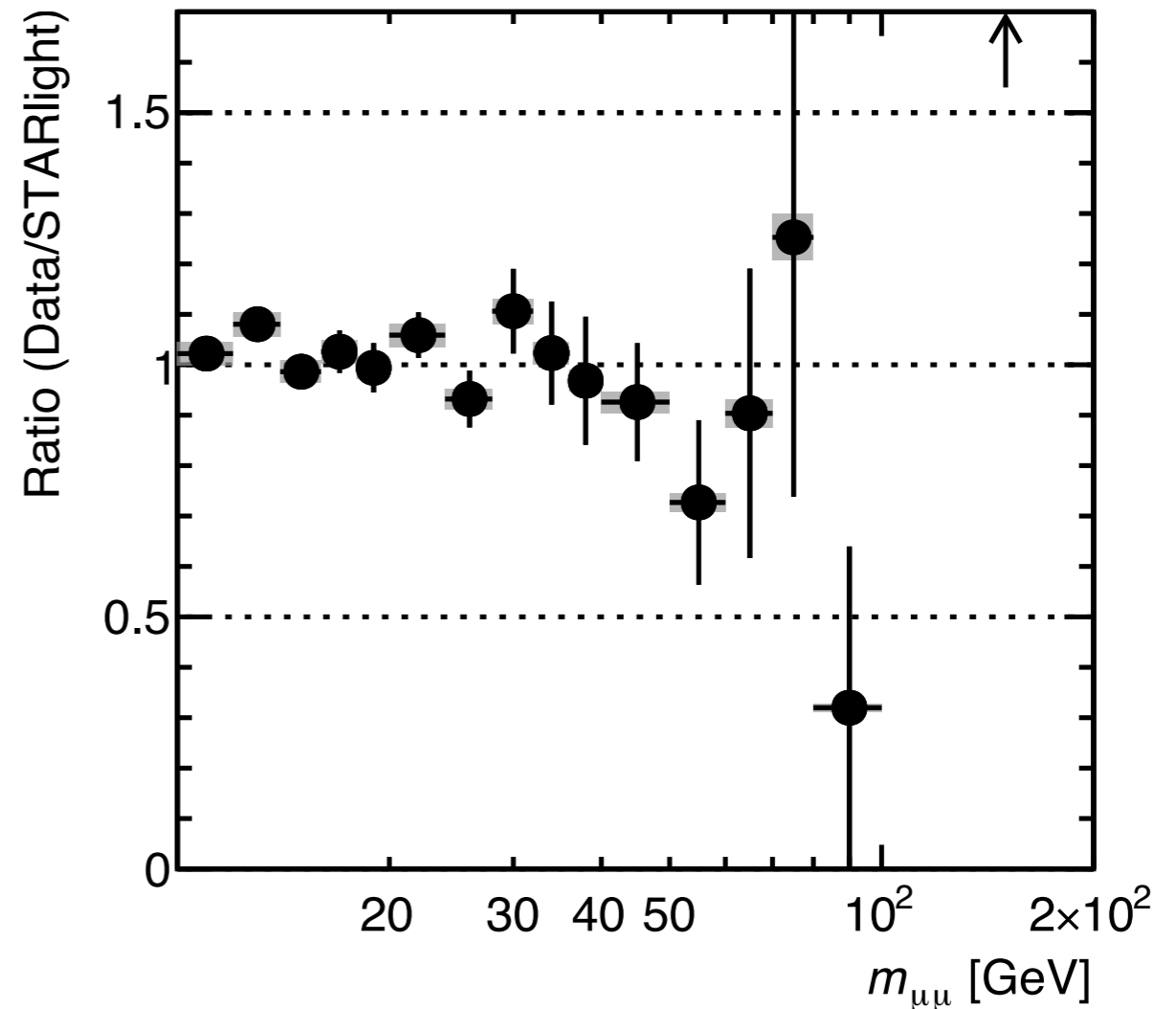
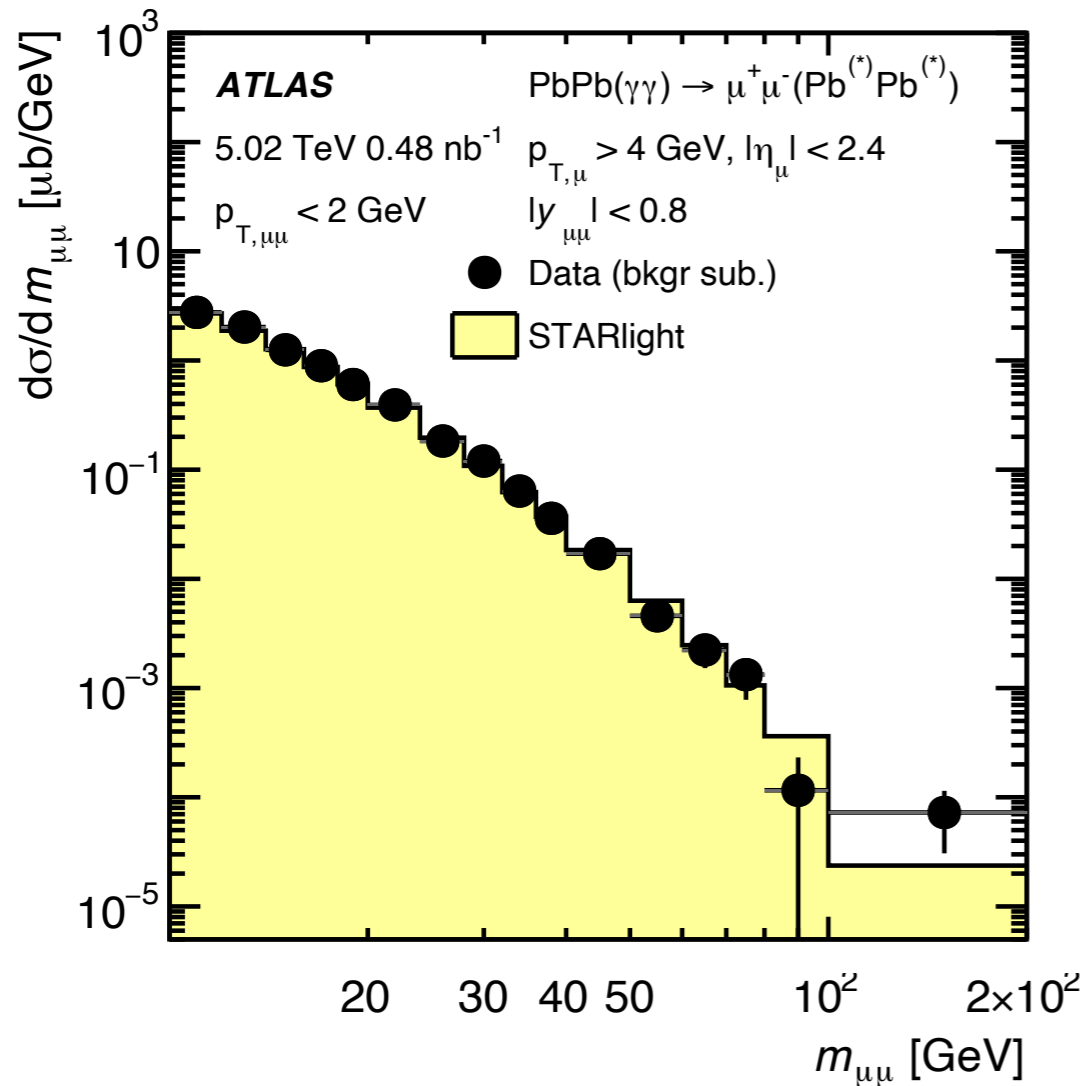
Signal

Background



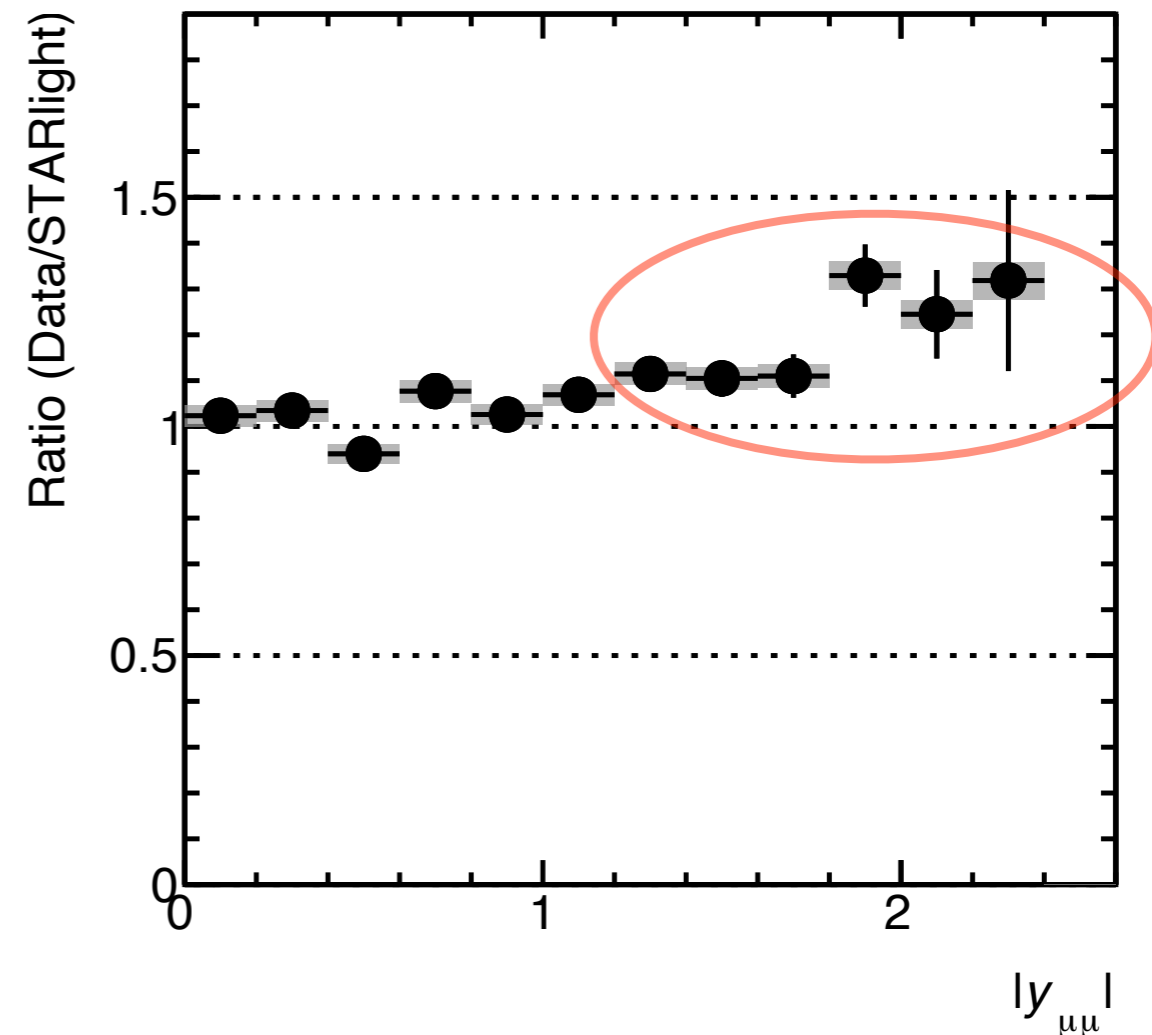
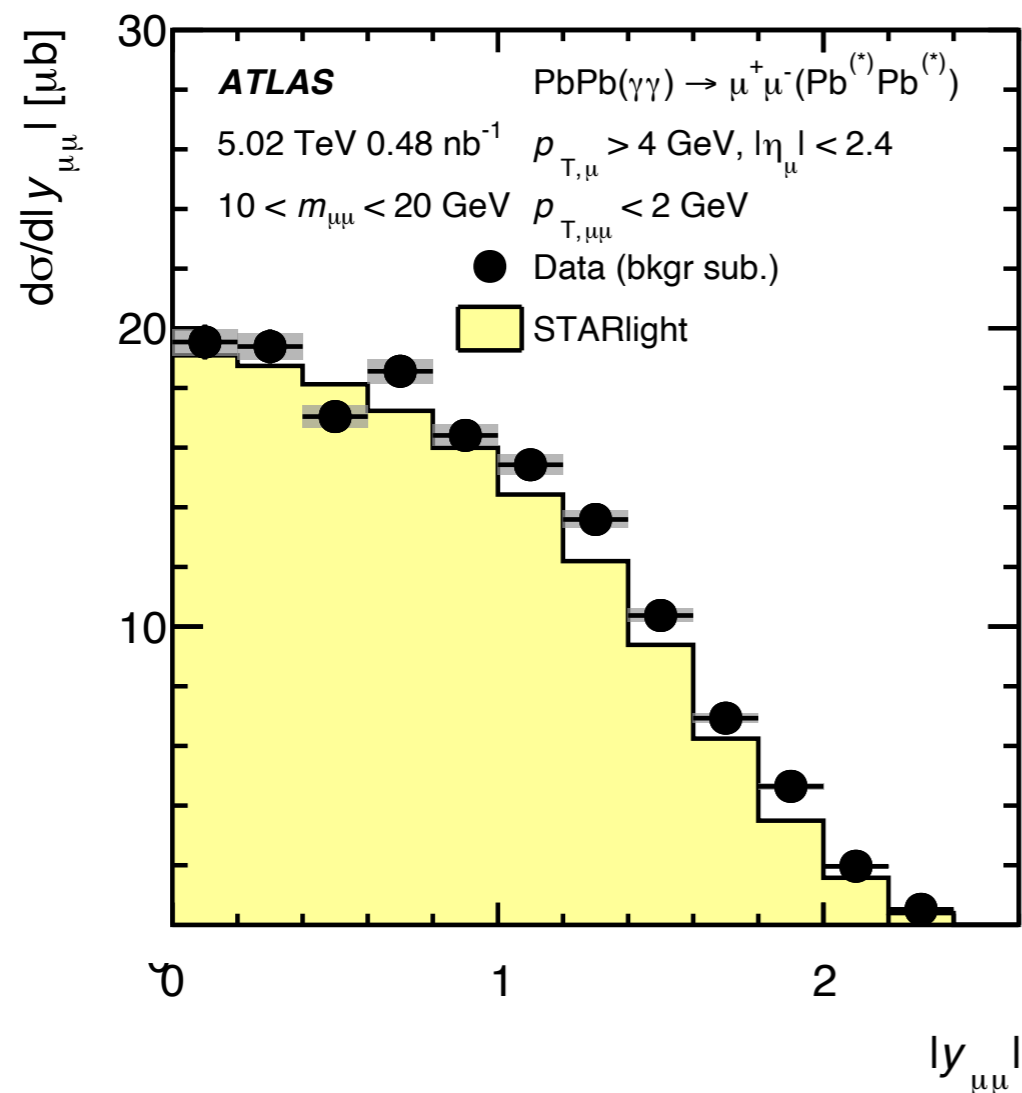
EXCLUSIVE DIMUONS: DIFFERENTIAL CROSS SECTIONS

[Phys. Rev. C 104 (2021) 024906]



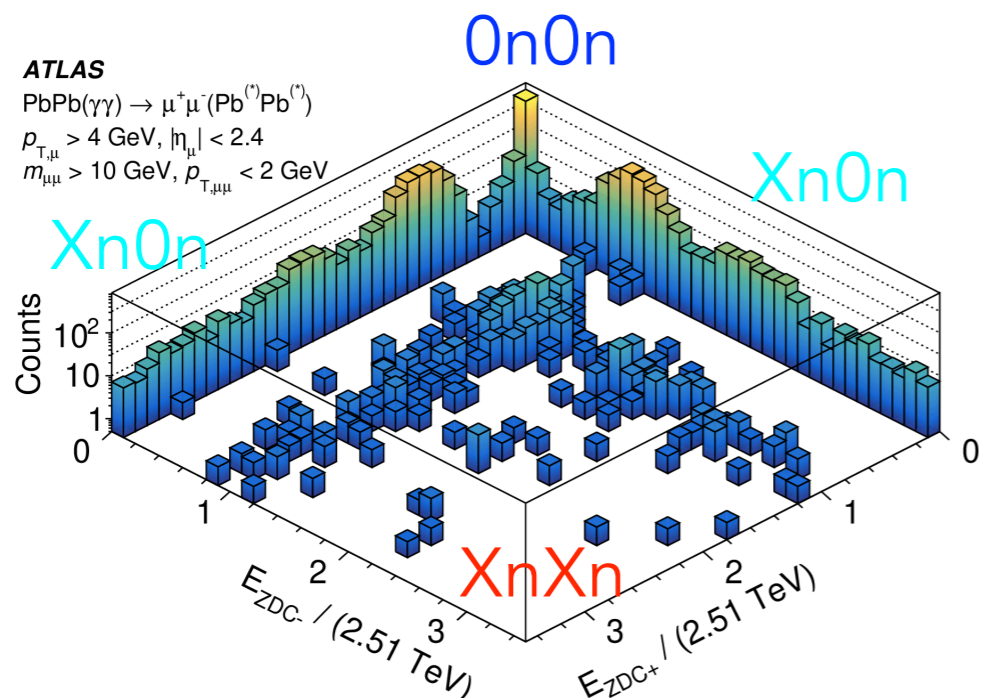
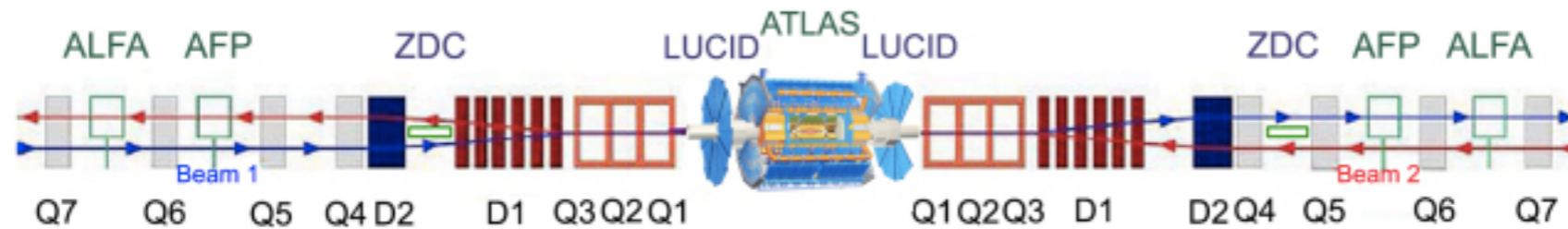
- Differential cross sections studied in $m_{\mu\mu}$, $|y_{\mu\mu}|$, $|\cos \theta^*|$, k_{\min} , k_{\max} , α
- $m_{\mu\mu}$ measured up to 200 GeV
- **Good agreement** with STARlight 2.0

[Phys. Rev. C 104 (2021) 024906]

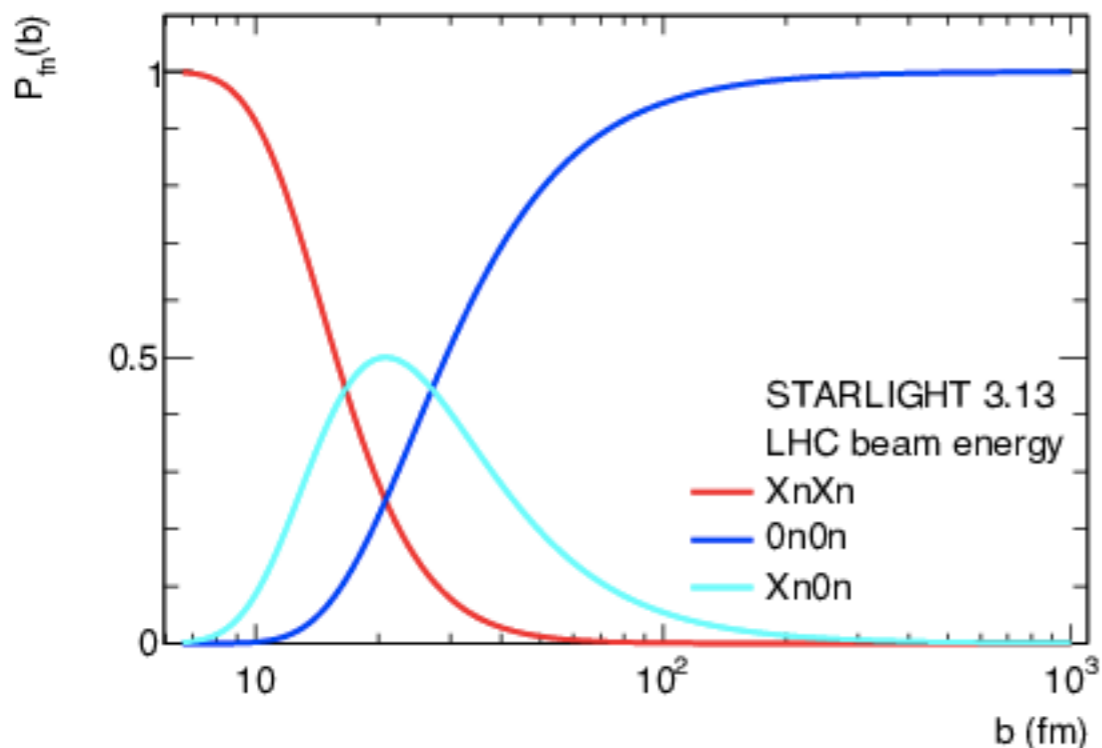


- Differential cross sections studied in $m_{\mu\mu}$, $|y_{\mu\mu}|$, $|\cos \theta^*|$, k_{\min} , k_{\max} , α
- **Good agreement** with STARlight 2.0
- ... but **systematic excess** of the data at higher $|y_{\mu\mu}|$

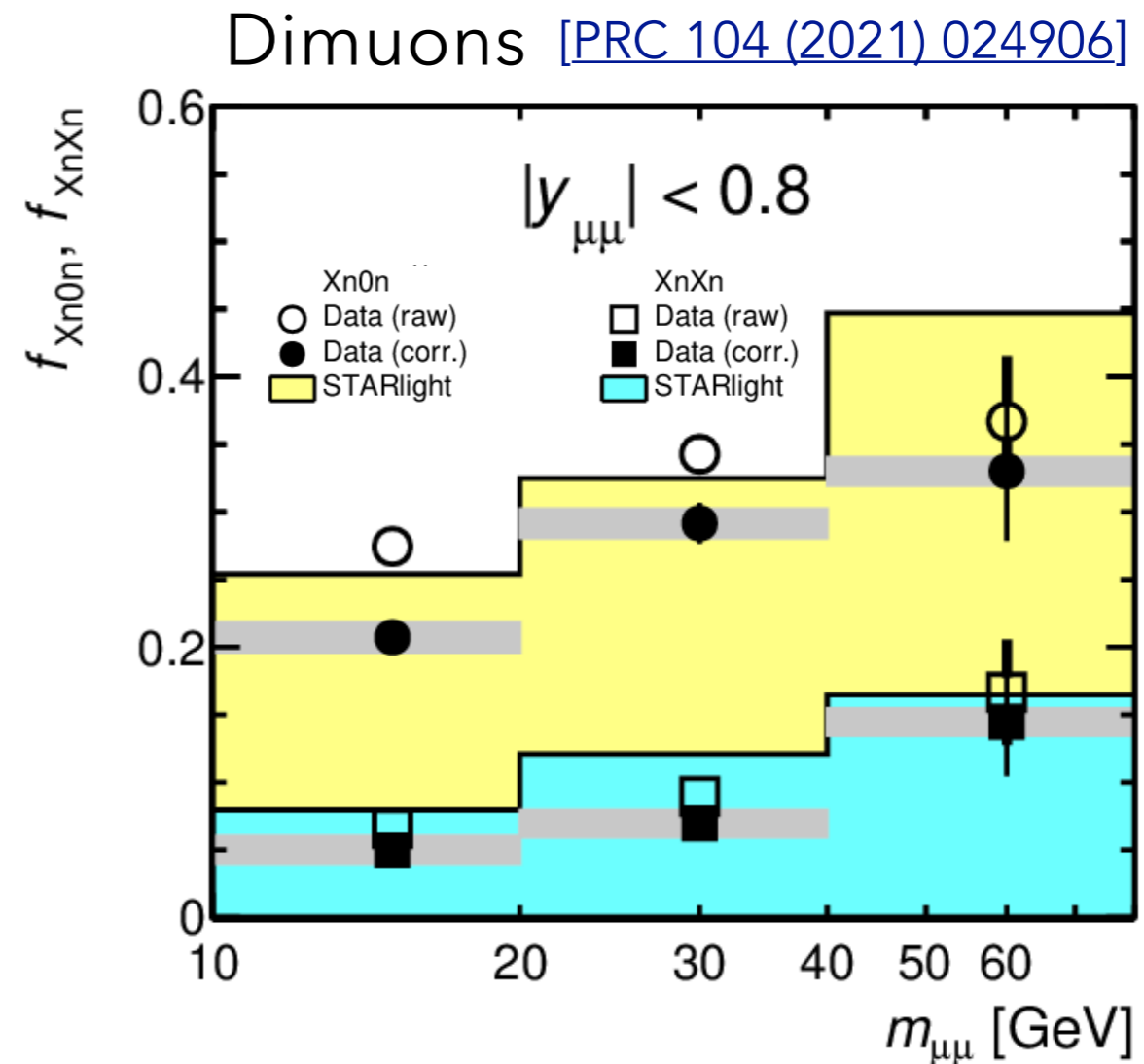
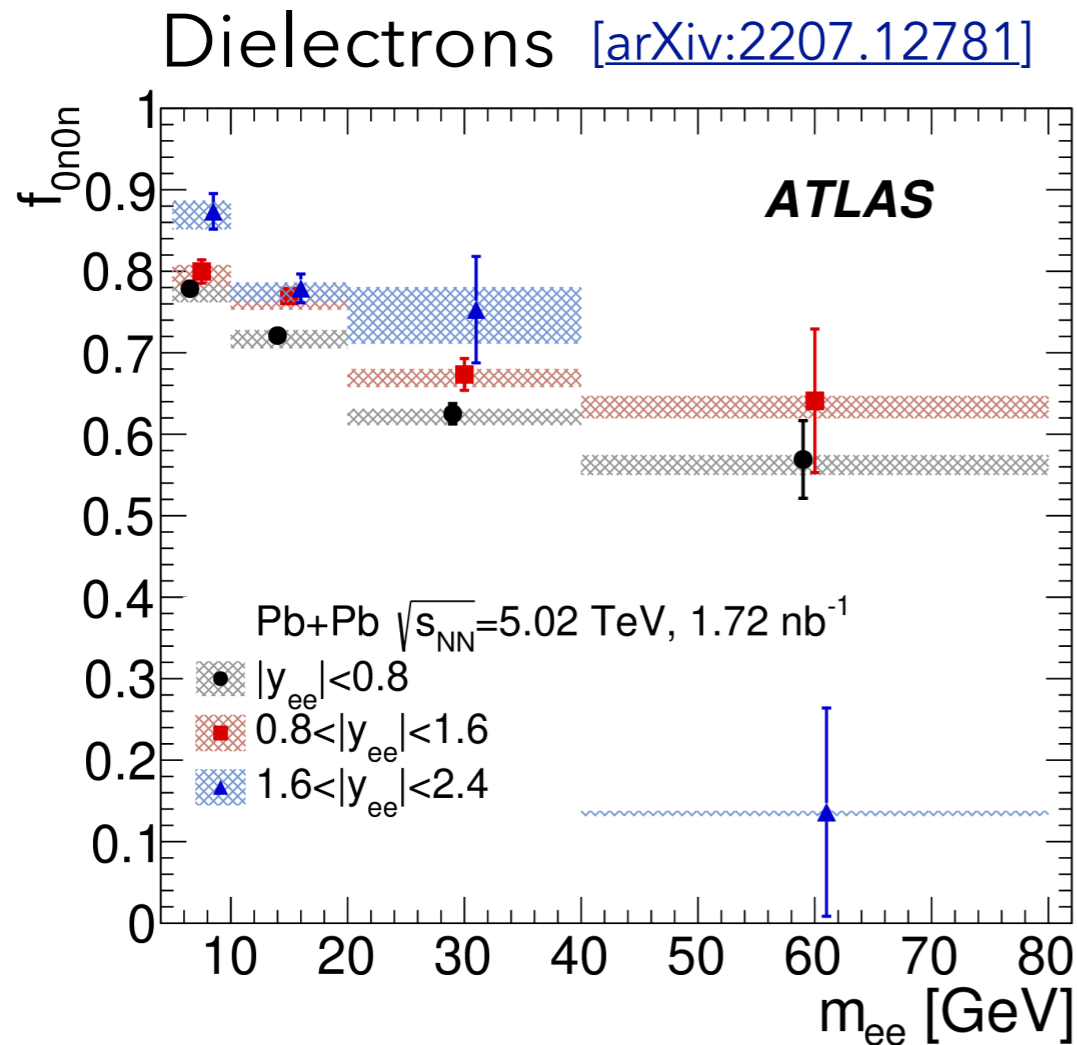
EXCLUSIVE DILEPTONS: ACTIVITY IN ZDC



[[Ann.Rev.Nucl.Part.Sci. 70 \(2020\) 323-354](#)]



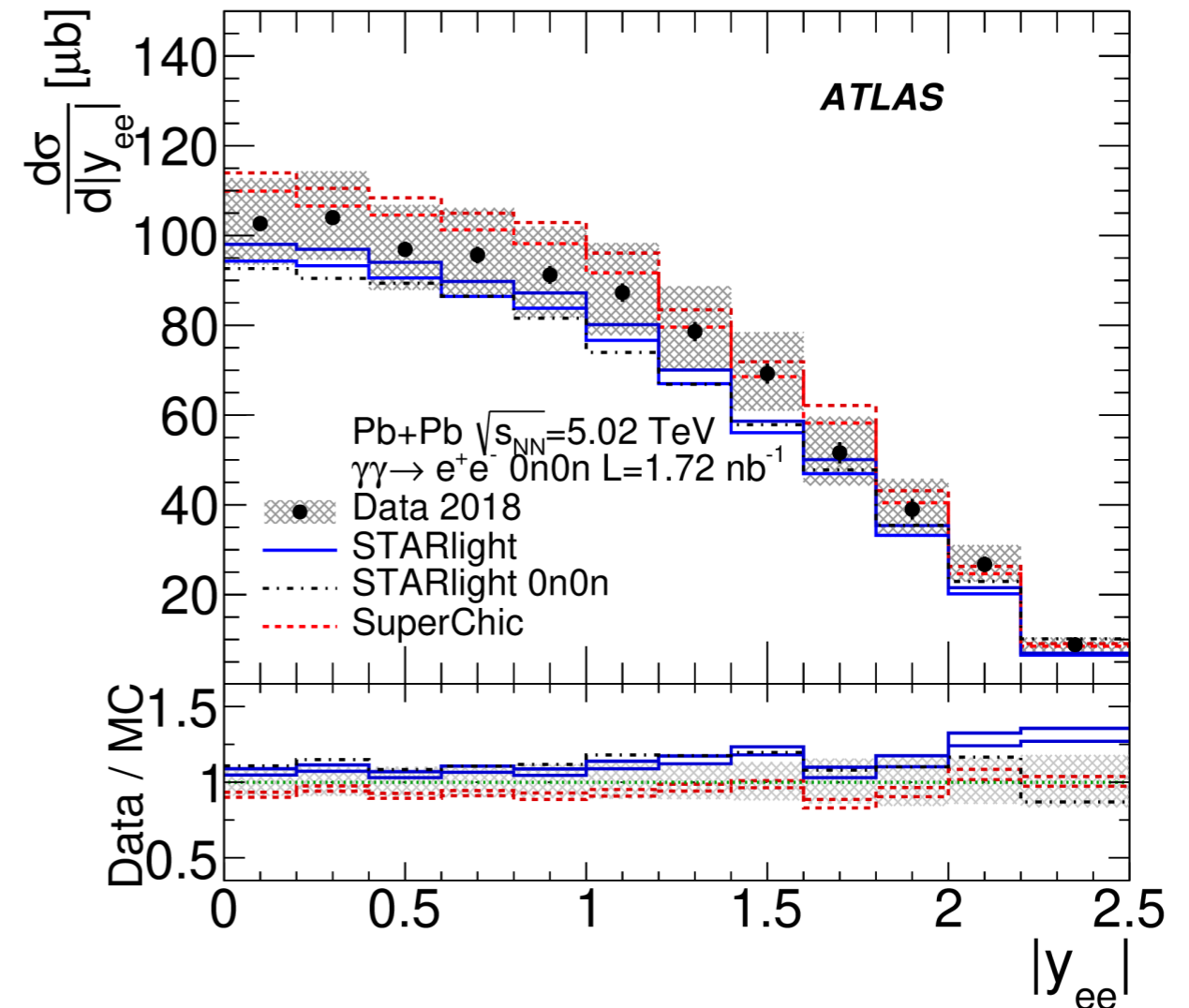
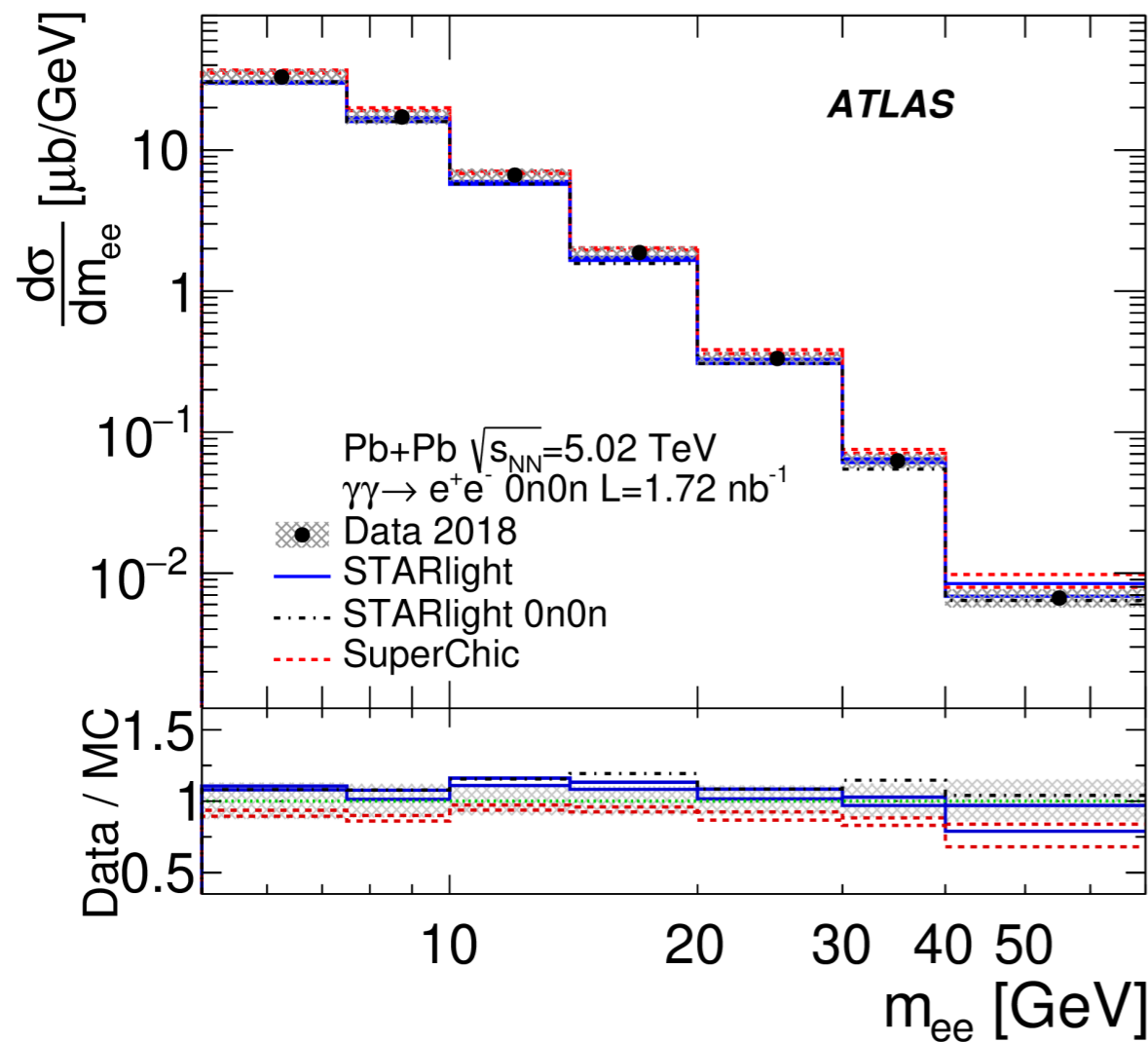
- **ZDC** are 140 m away from the IP ($|\eta| > 8.3$)
 - Detect neutral particles (e.g. neutrons, photons)
- Inclusive sample of $\gamma\gamma \rightarrow \ell^+\ell^-$ is divided into three categories
 - **0n0n**: no activity in neither ZDC arm
 - **Xn0n**: activity in one ZDC arm
 - **XnXn**: activity in both ZDC arms
- Fractions of events falling to each category $f_{0n0n}, f_{Xn0n}, f_{XnXn}$ are measured
 - After subtracting backgrounds and accounting for electromagnetic pileup
- **Each category** probes different **impact parameters** (b)



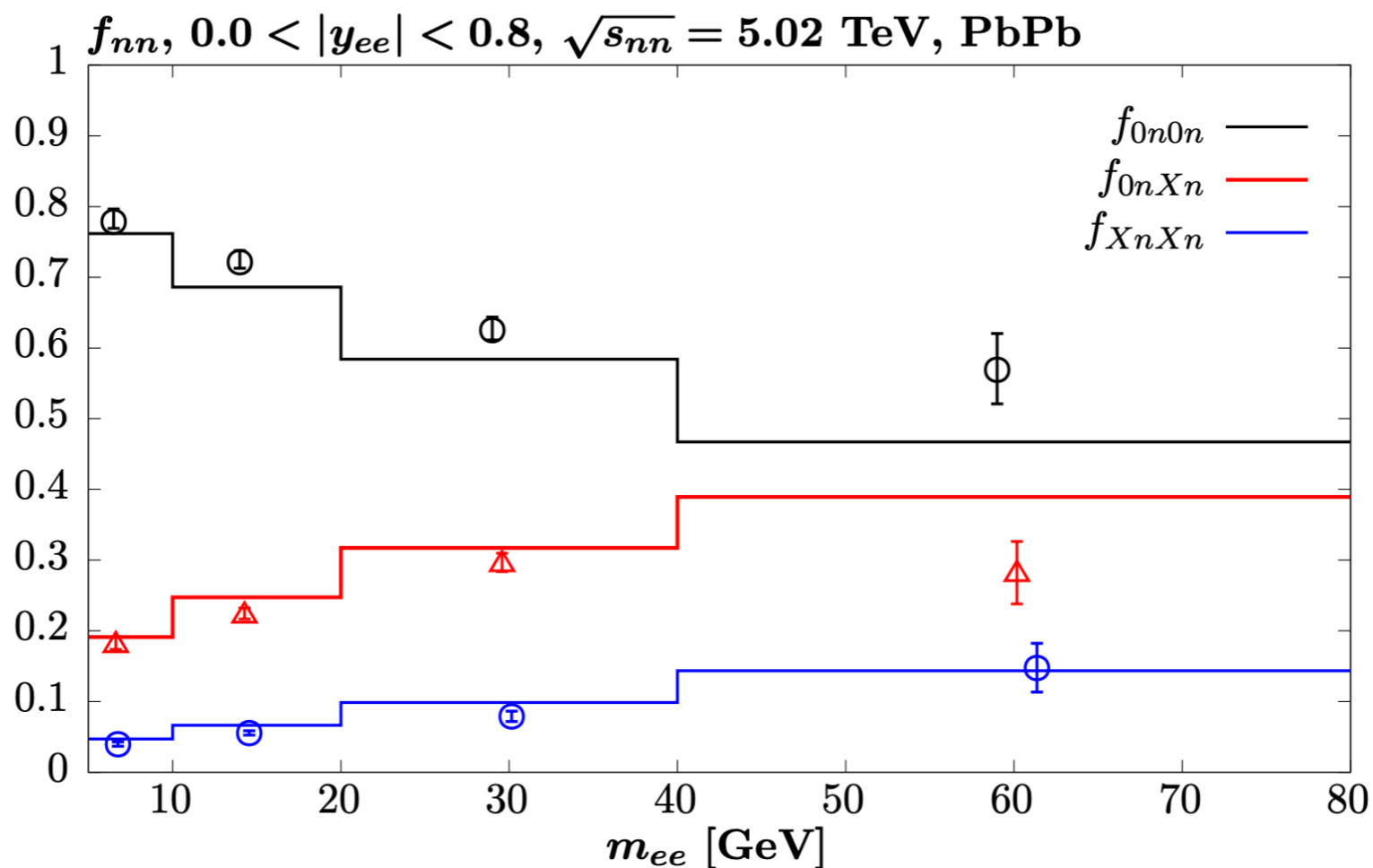
- **Corrected fractions** of events in the **0n0n** (dielectrons) and **Xn0n/XnXn** (dimuons) categories as a function of $m_{\ell\ell}$ in three $|y_{\ell\ell}|$ intervals
 - f_{0n0n} (f_{Xn0n}/f_{XnXn}) **decreases** (increases) with $m_{\ell\ell}$ and increases (decrease) with $|y_{\ell\ell}|$
 - Results consistent between dielectron and dimuon channels
 - **STARlight** qualitatively describes the impact-parameter dependence of the fluxes, but some systematic differences

EXCLUSIVE DIELECTRONS: 0N0N CROSS SECTIONS

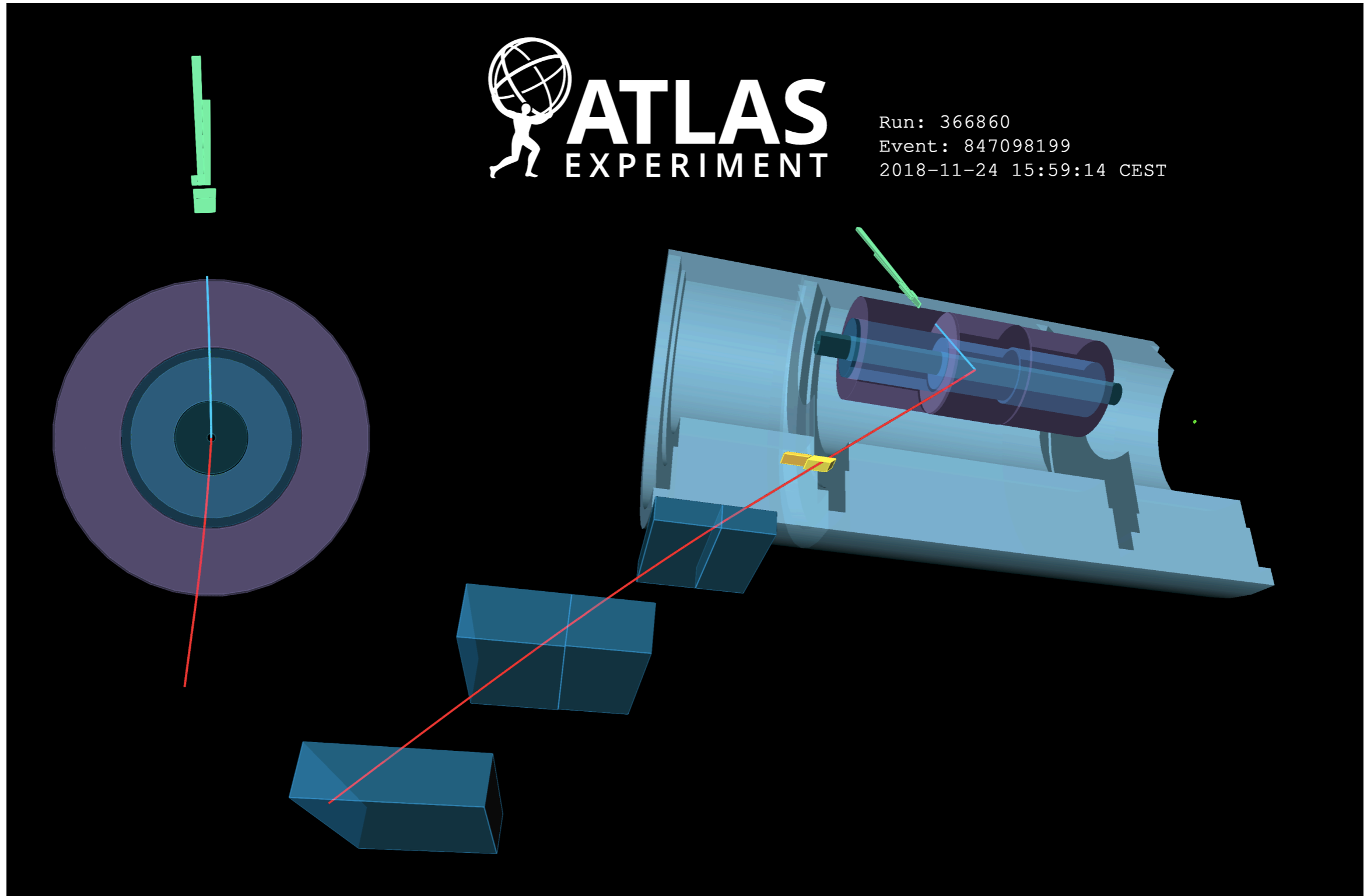
[arXiv:2207.12781]



- Differential cross sections measured in m_{ee} , $|y_{ee}|$, $\langle p_T^e \rangle$ and $|\cos \theta^*|$ in the **0n0n category**
 - **STARlight 0n0n** provides predictions for **neutron production** (black dotted line)
 - **SuperChic 3.05** doesn't implement ZDC selections
 - Use **measured 0n0n fractions with uncertainties** to correct both STARlight and SuperChic predictions
- General conclusions similar to the inclusive ZDC case
 - **STARlight 2.4 (SuperChic 3.05)** systematically lower (higher) than data
 - SuperChic does a better job in the description of shapes



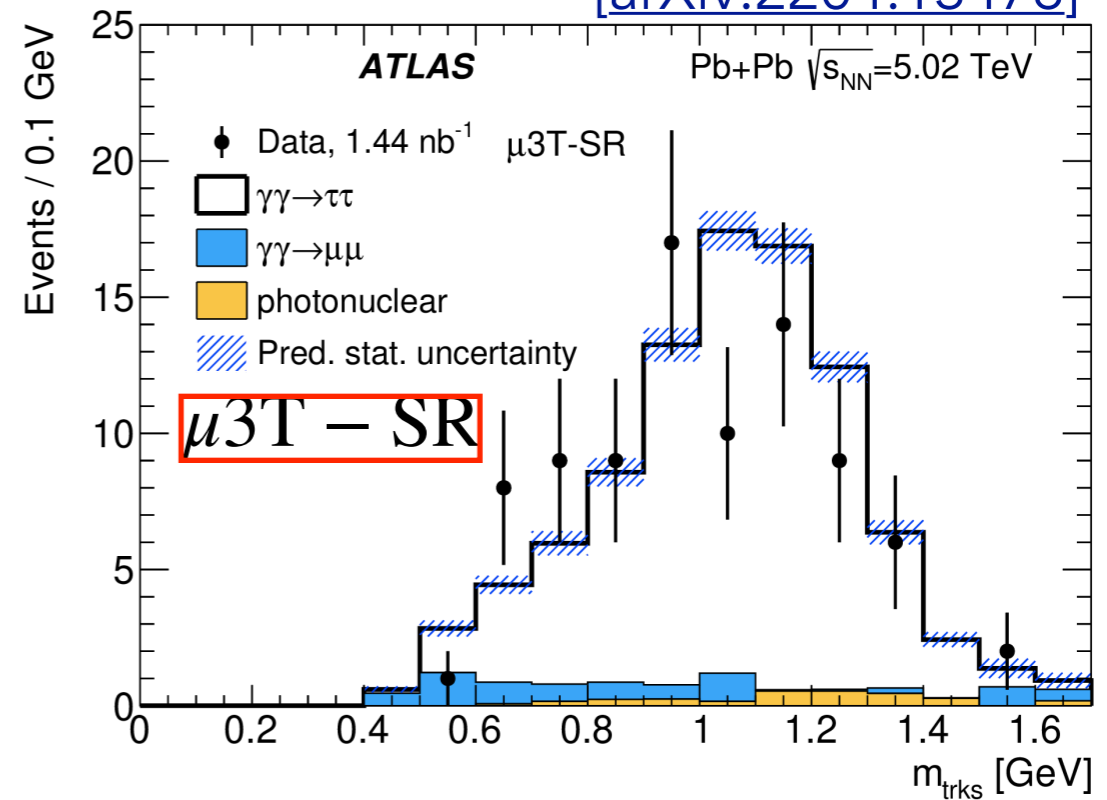
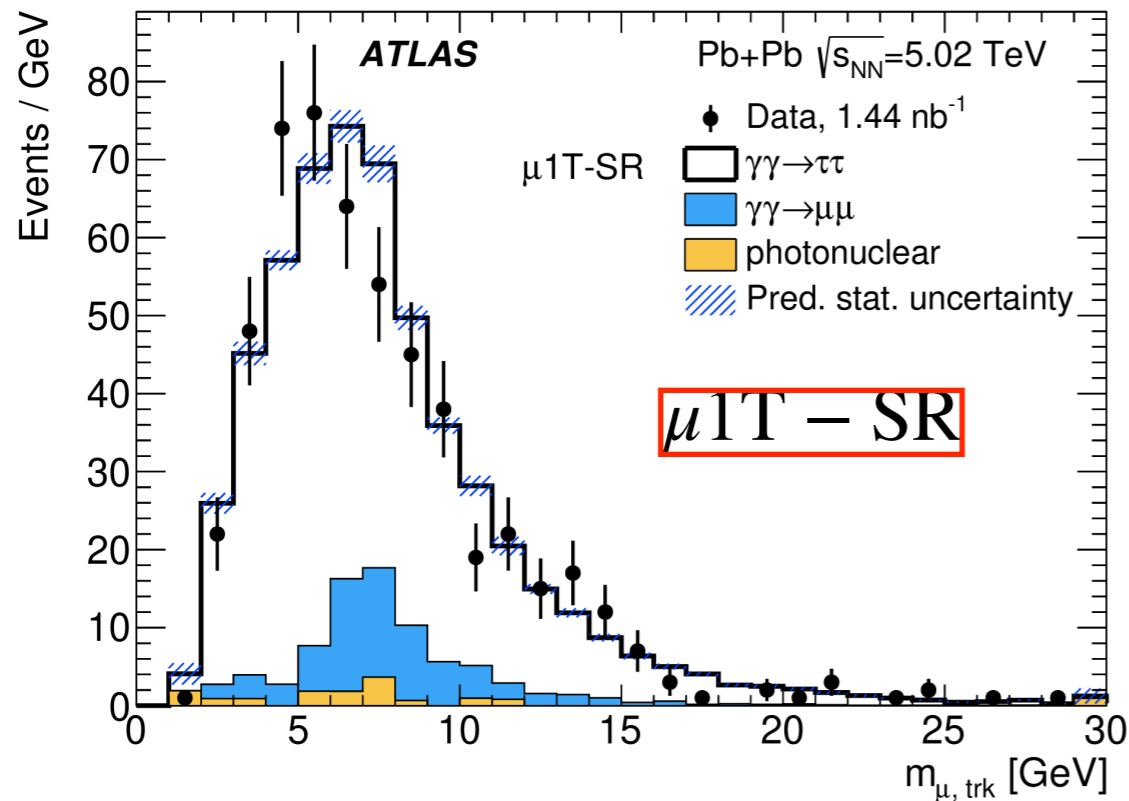
- Recent developments in **SuperChic v4.2** bring modeling of ion excitation/de-excitation and emission of neutrons in the forward direction
 - See L.H. Harland-Lang [arXiv:2303.04826](https://arxiv.org/abs/2303.04826) for more details
- **Good description** of dielectron/dimuon data from ATLAS



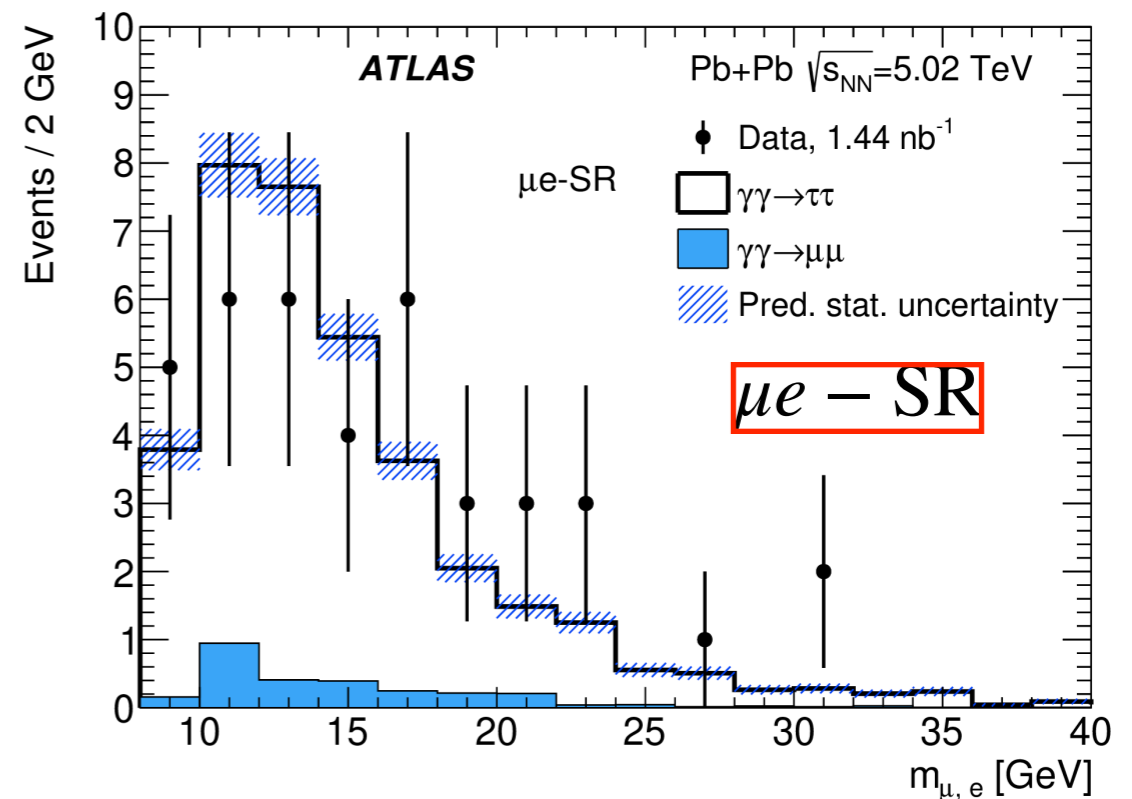
- Event candidate for $\gamma\gamma \rightarrow \tau^+\tau^- \rightarrow e^+\nu_e\nu_\tau\mu^-\nu_\mu\nu_\tau$

EXCLUSIVE DITAU: CONTROL PLOTS

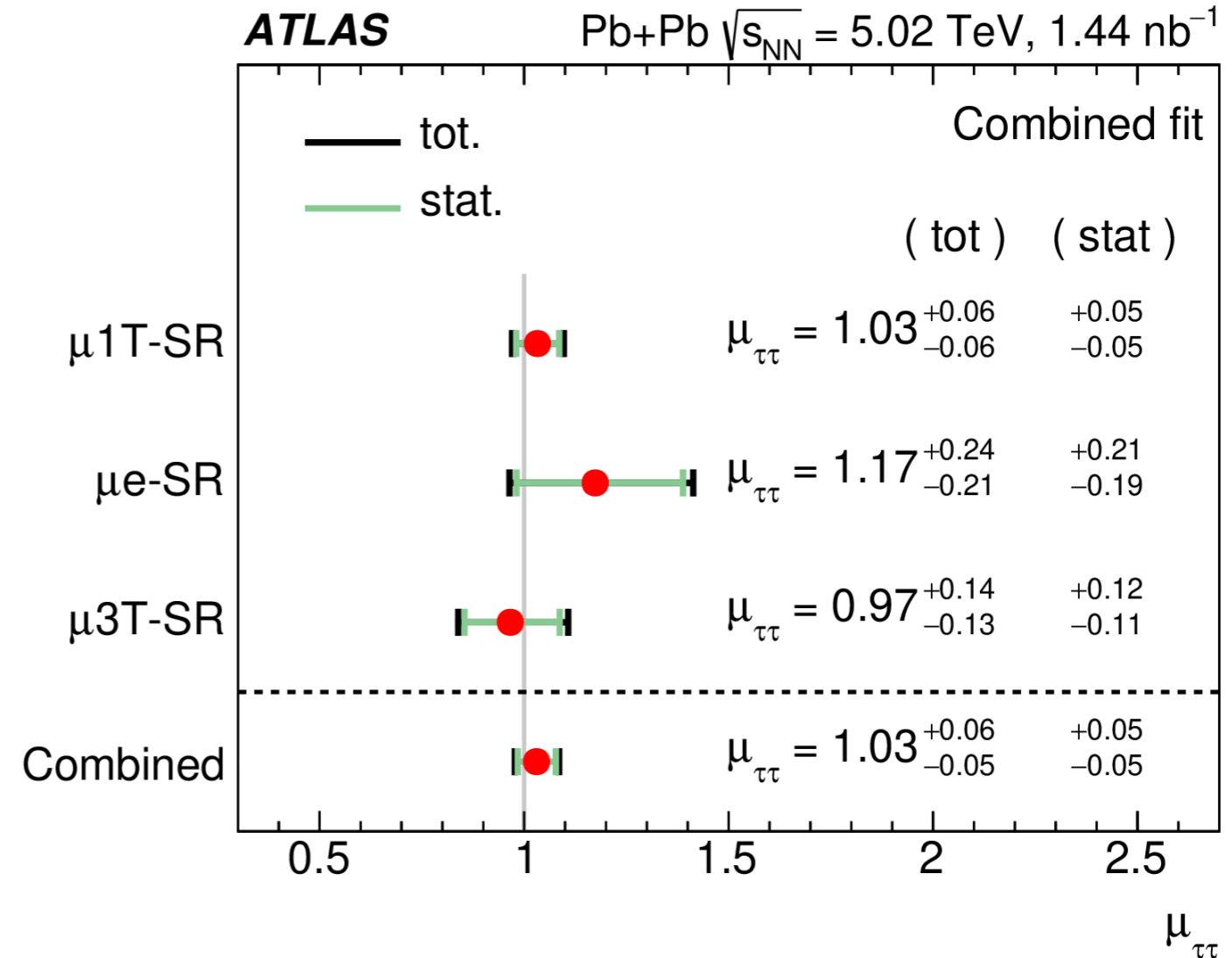
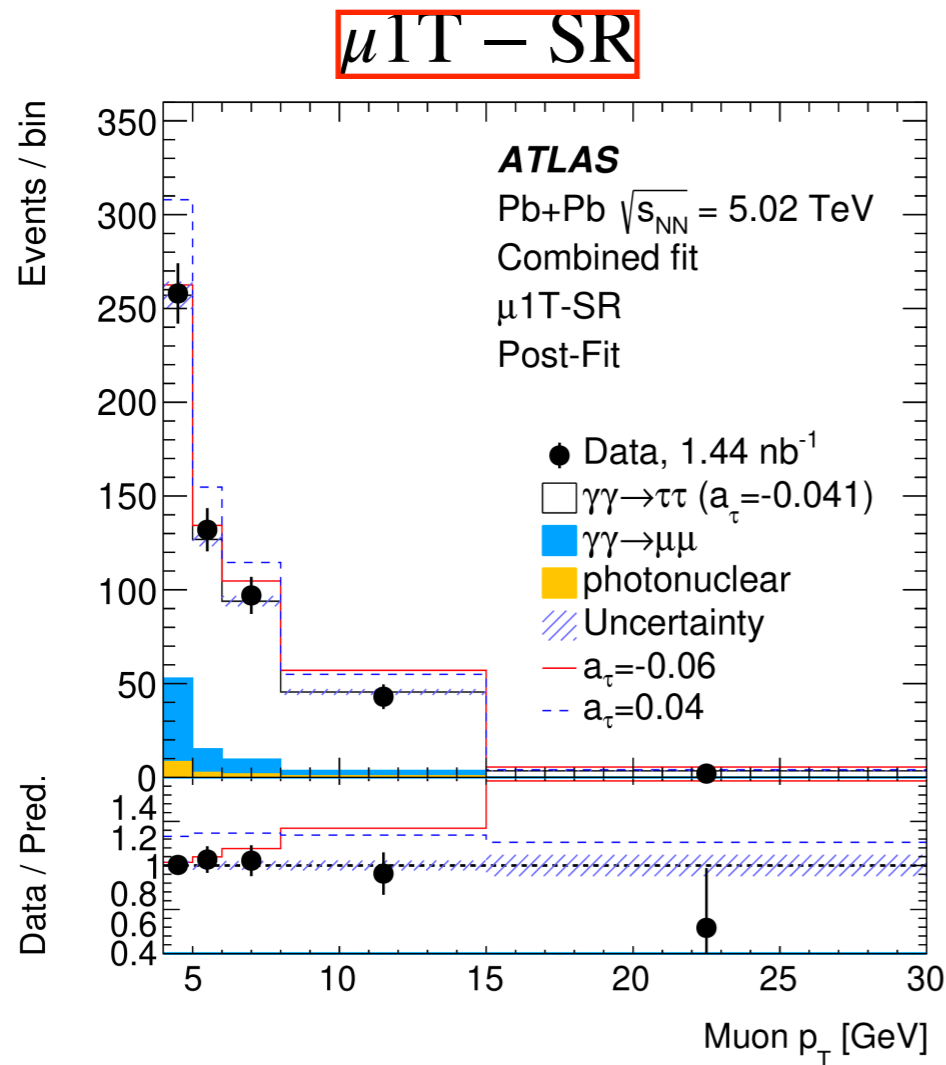
[arXiv:2204.13478]



- $\gamma\gamma \rightarrow \tau^+\tau^-$ measured in **three channels**:
 - $\mu 1T-SR$: muon + 1 track (e/ μ /hadron)
 - $\mu 3T-SR$: muon + 3 tracks (3 hadrons)
 - $\mu e-SR$: muon + electron
- Main backgrounds:
 - $\gamma\gamma \rightarrow \mu^+\mu^-(\gamma)$ and photonuclear
 - In general little background contributions in all three SR (15%)
- **Good agreement** of SM predictions with data

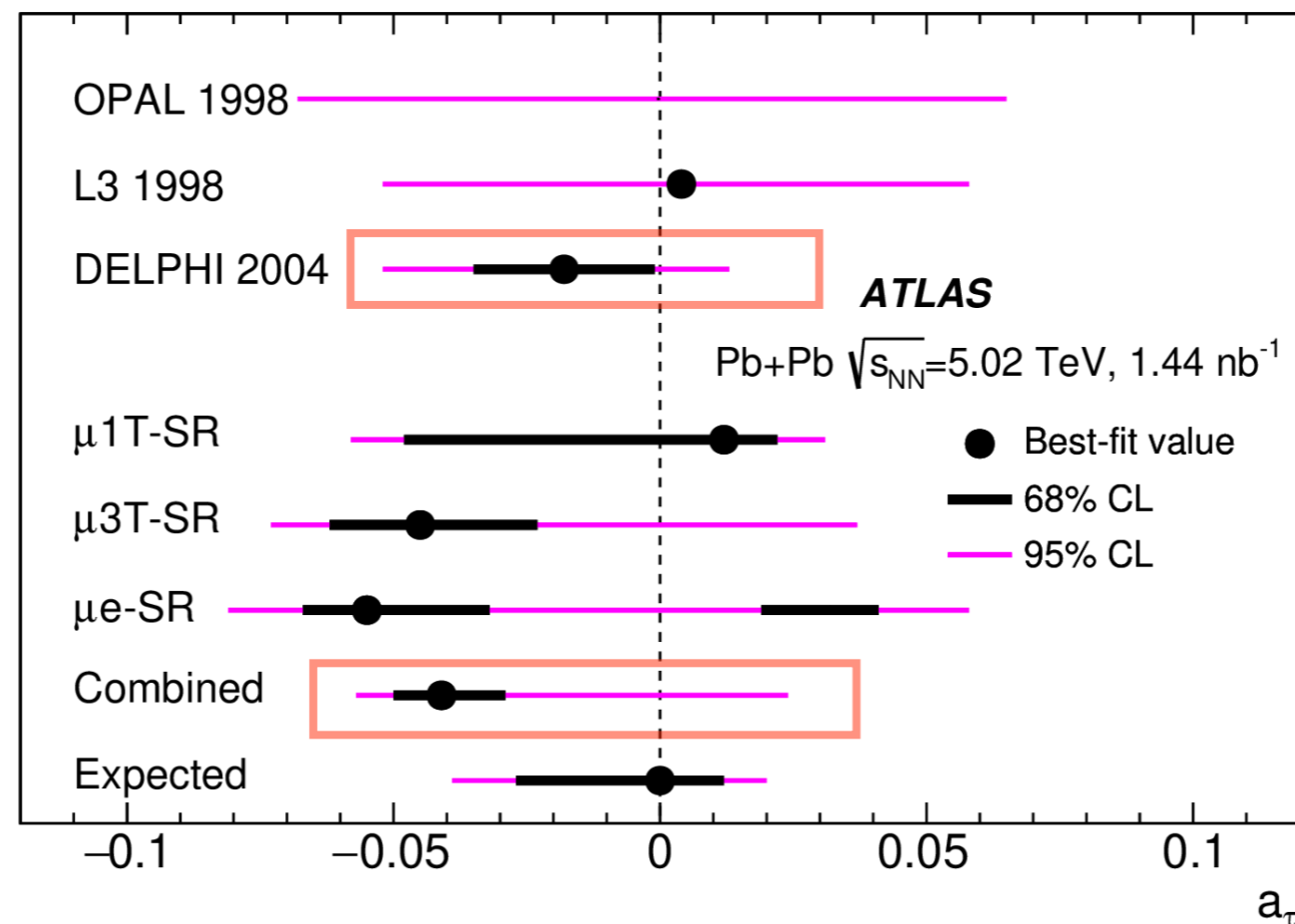


[arXiv:2204.13478]



- **Signal strength** $\mu_{\tau\tau} = N_{\gamma\gamma \rightarrow \tau\tau}^{\text{meas}} / N_{\gamma\gamma \rightarrow \tau\tau}^{\text{SM,pred}}$ measured using a profile-likelihood fit to the p_T^μ **distribution** in the three SRs and 2μ -CR
- Result of $\mu_{\tau\tau}$ for each SR assuming a_τ anomalous magnetic moment from SM are **compatible with unity**

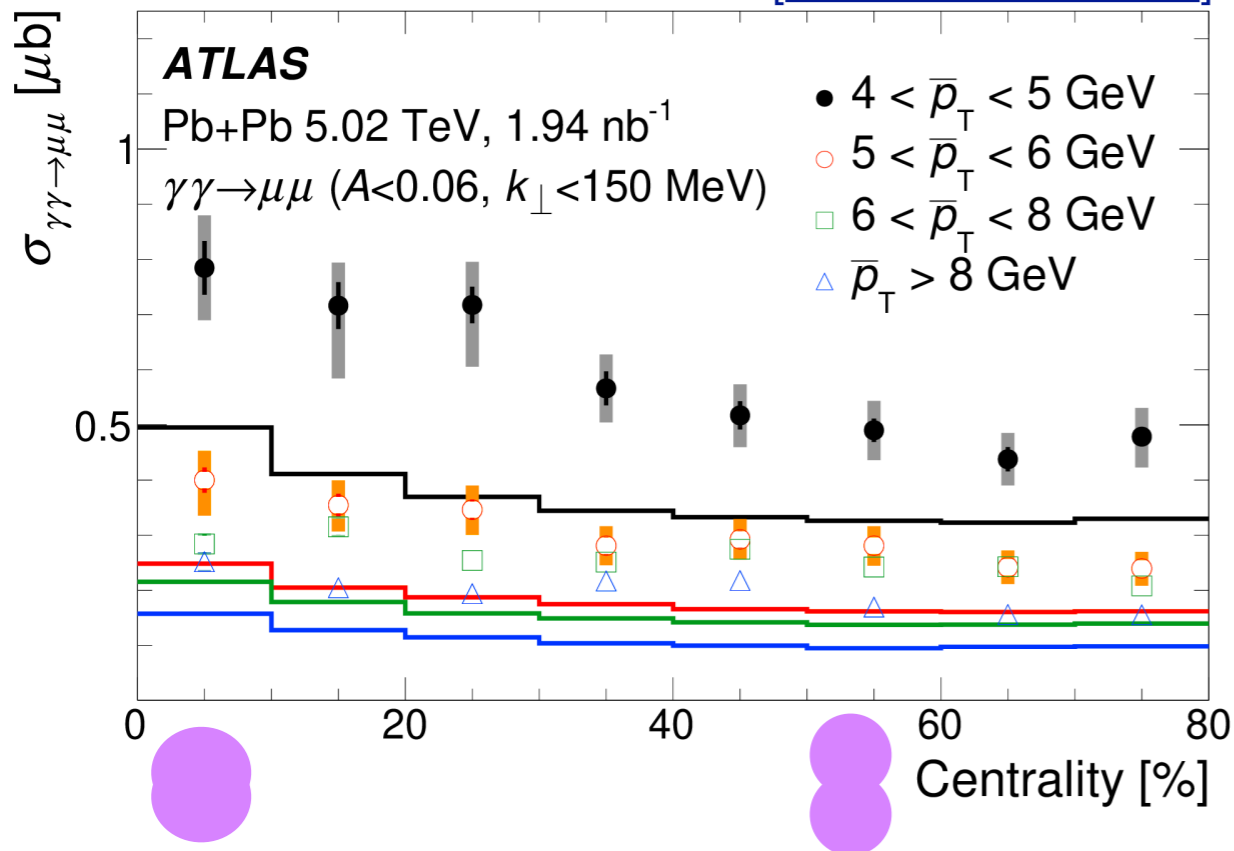
[arXiv:2204.13478]



- **Tau anomalous magnetic moment** $a_\tau = \frac{g-2}{2}$ with a profile-likelihood fit to the p_T^μ distribution has been extracted
 - **HI collisions at the LHC** contribute to the hot topic of lepton $g-2$ measurements
 - Templates for different a_τ built by reweighting signal MC using weights from [\[PLB 809 \(2020\) 135682\]](#)
- **Constraints on a_τ similar** in precision to those observed by **DELPHI at LEP**
- Dedicated talk on BSM physics from ATLAS by **Agnieszka Ogrodnik**, Tuesday at 16:50

NON-UPC DIMUONS: CROSS SECTIONS

[arXiv:2206.12594]

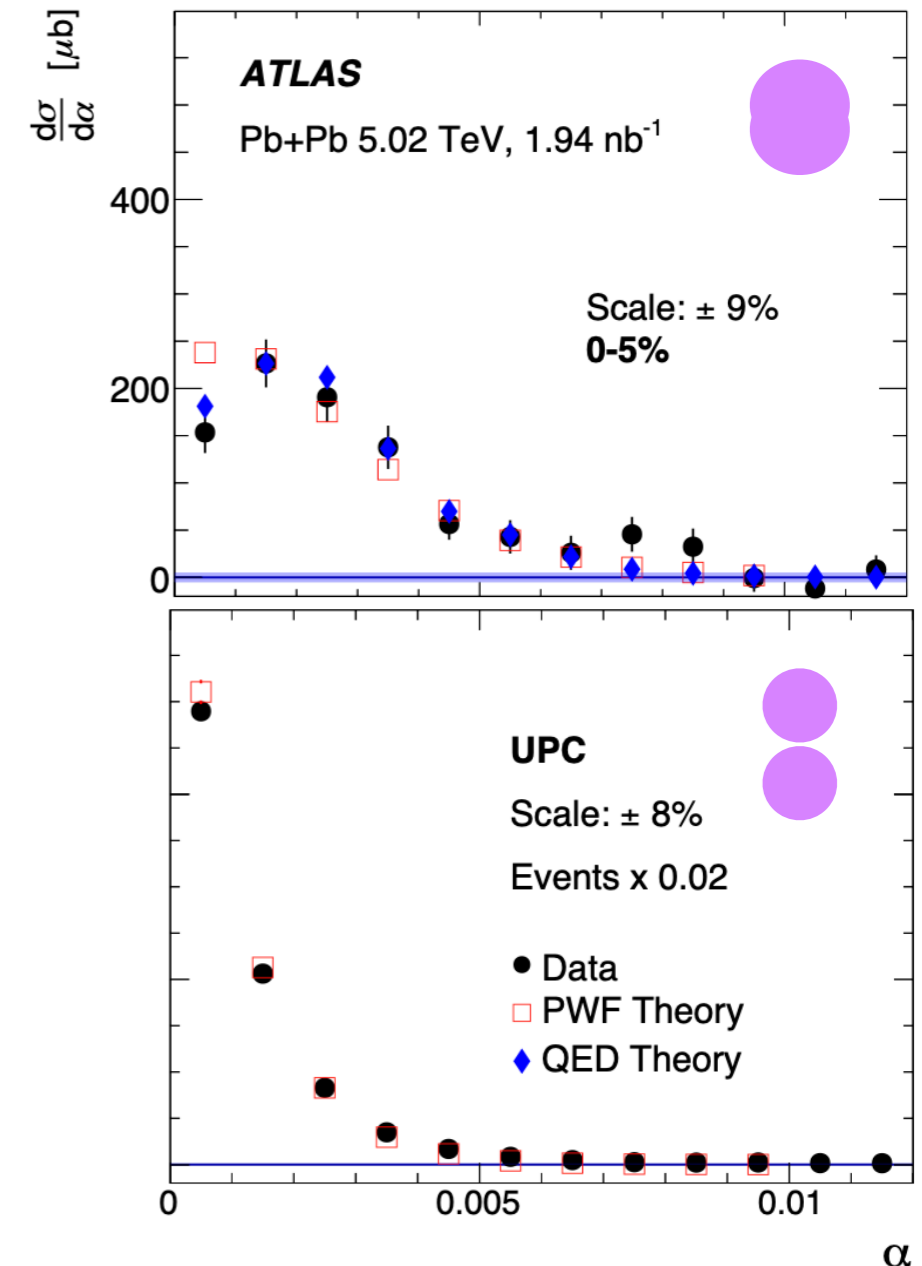


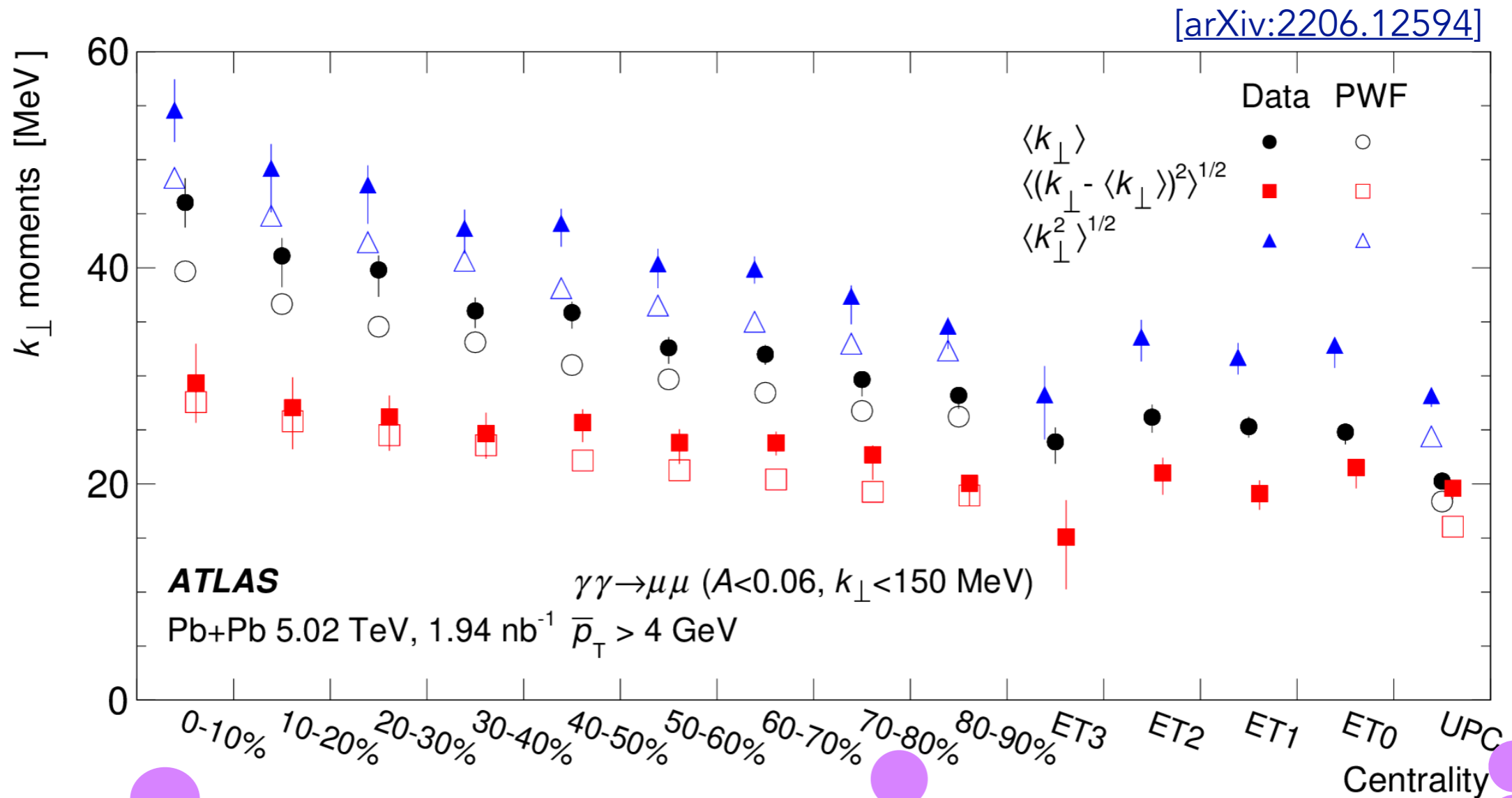
Acoplanarity: $\alpha = 1 - \frac{|\phi_1^\mu - \phi_2^\mu|}{\pi}$

Asymmetry: $A = \frac{|p_{T1}^\mu - p_{T2}^\mu|}{p_{T1}^\mu + p_{T2}^\mu}$

Transverse momentum scale:
 $k_{\perp} = \frac{1}{2}(p_{T1}^\mu + p_{T2}^\mu)(\pi - |\phi_1^\mu - \phi_2^\mu|) = \pi\alpha\bar{p}_T$

- $\gamma\gamma \rightarrow \mu^+\mu^-$ studied in non-UPC events
 - Cross section measured as a function of **centrality**
 - **STARlight predictions** (solid lines) describe the shape but underestimate the normalisation, likely due to the truncation of photon fluxes for $b < R_A$
- Centrality-dependent **broadening** of α and k_{\perp} is confirmed
 - Described by **QED** [PLB 800 (2020) 135089] and **PWF** [PRD 102 (2020) 094013] calculations
- Also the **depletion** of yields at small α and k_{\perp} is found to develop with centrality
 - **PWF** does not reproduce the first point





- Significant increase in the **mean** and **RMS** values is observed as one goes from UPC to higher centralities
- **Standard deviation** shows a much slower increase
- **PWF** predictions reproduce many of the trends, but the mean and RMS values systematically lie below the data
- Predicted trends associated with effects of **magnetic fields** on the dimuons are not observed

- ATLAS provides **precision results** on $\gamma\gamma \rightarrow \ell^+\ell^-$ with $\ell = e, \mu, \tau$ from UPC Pb+Pb collisions recorded in Run 2
 - **Measured cross sections** reveal systematic differences with **STARlight** and **SuperChic** calculations
 - Perhaps suggesting recent discussions on higher order Coulomb effects [[JHEP 2021 \(2021\) 83](#)]
 - **ZDC** provides constraints for **background** and **impact-parameter dependence**
 - Establish a **reference** for **non-UPC** studies
- ATLAS established **observation** of exclusive **ditau** production in UPC Pb+Pb collisions at the LHC with above 5σ **significance**
 - Data is used to **constrain** a_τ at the LHC with a **precision comparable** to the best limit from **DELPHI**
- $\gamma\gamma \rightarrow \mu^+\mu^-$ process is used to probe **non-UPC collisions** with high precision
 - **Broadening** of acoplanarity and transverse momentum scale distributions with centrality confirmed
 - Also significant **depletion** at close-to-zero α and k_\perp values with centrality is established
 - **Initial-state calculations** quantitatively describe many features
 - Effects of **magnetic fields** on the dimuons are not observed
- Run 3 is in progress, new Pb+Pb data taking at $\sqrt{s_{\text{NN}}} = 5.36$ TeV in fall of 2023
 - Expect to **double integrated luminosity** at the end of 2023, a factor of **3.5** more data after Run 3
- All results from ATLAS available at <https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HeavyIonsPublicResults>

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