Measurements of dilepton production from photon fusion processes in ultraperipheral Pb+Pb collisions with the ATLAS detector

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on behalf of the ATLAS Collaboration

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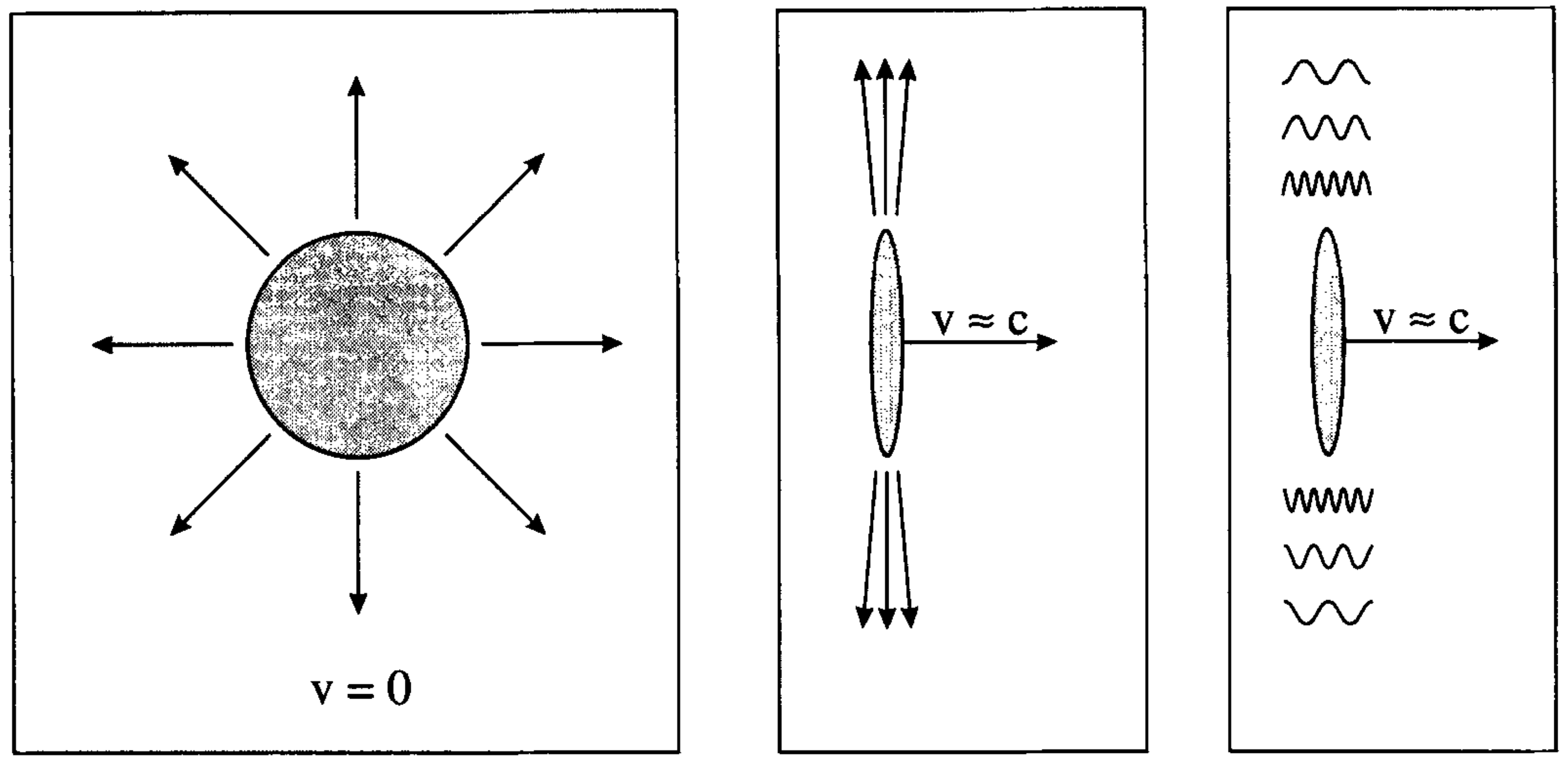
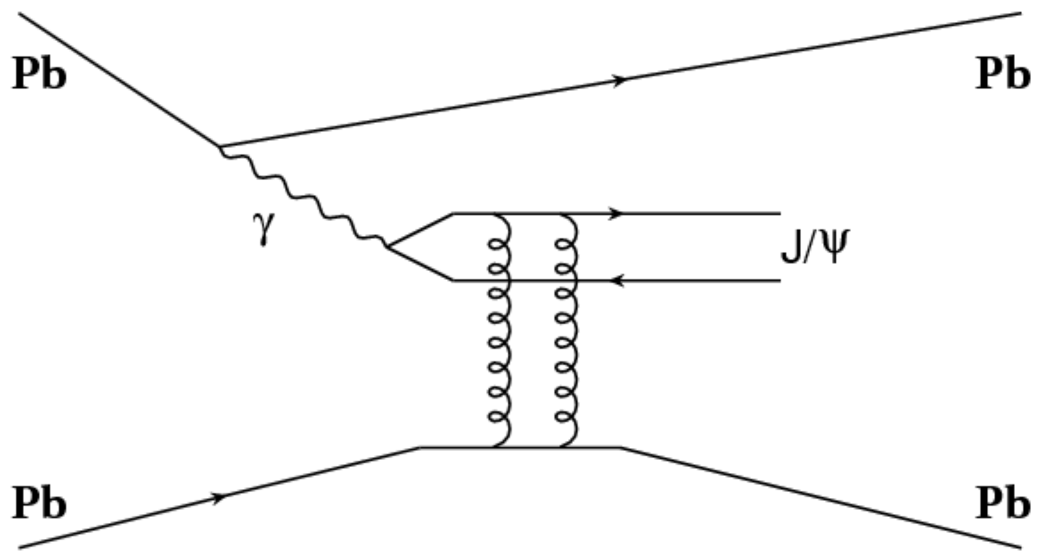
Ultraperipheral collisions at the LHC

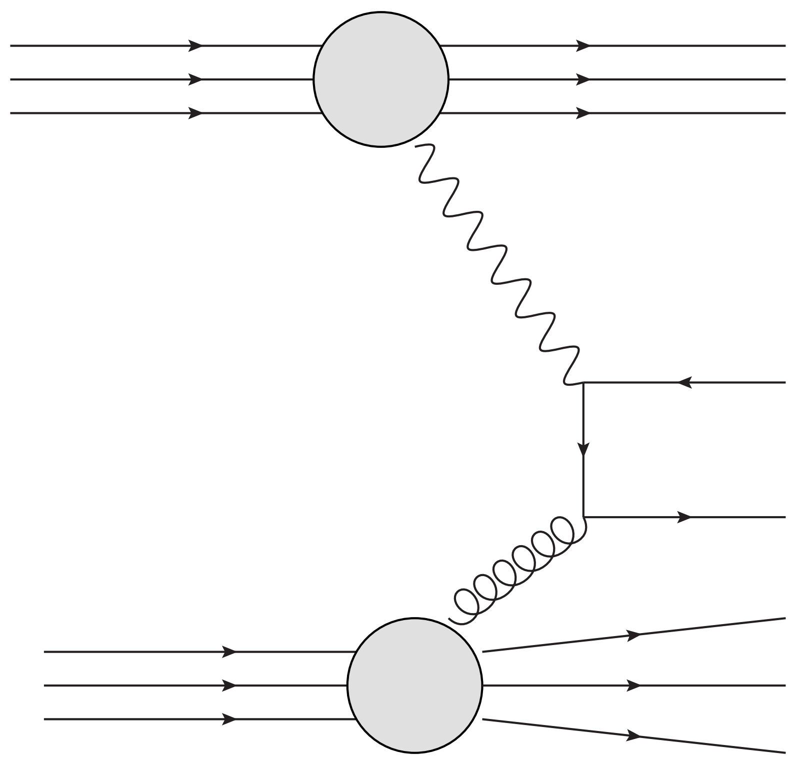
- Boosted nuclei are intense source of quasi-real photons
- **Coherent** photon flux
  - $\mathbf{E_{max} \lesssim \gamma/R \sim 80\ GeV}$ @LHC (**~3 GeV** @RHIC)
  - **Q ~ 1/R ~ 30 MeV** @ LHC/RHIC
  - Each photon flux scales with ~$\mathbf{Z^2}$



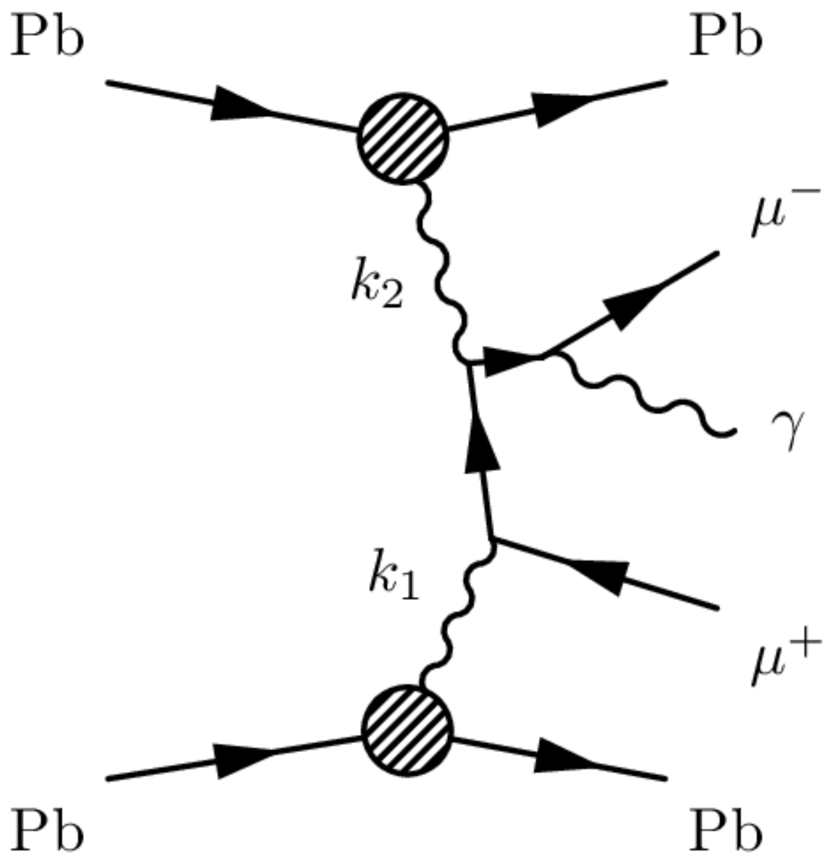
- Various types of interactions possible:



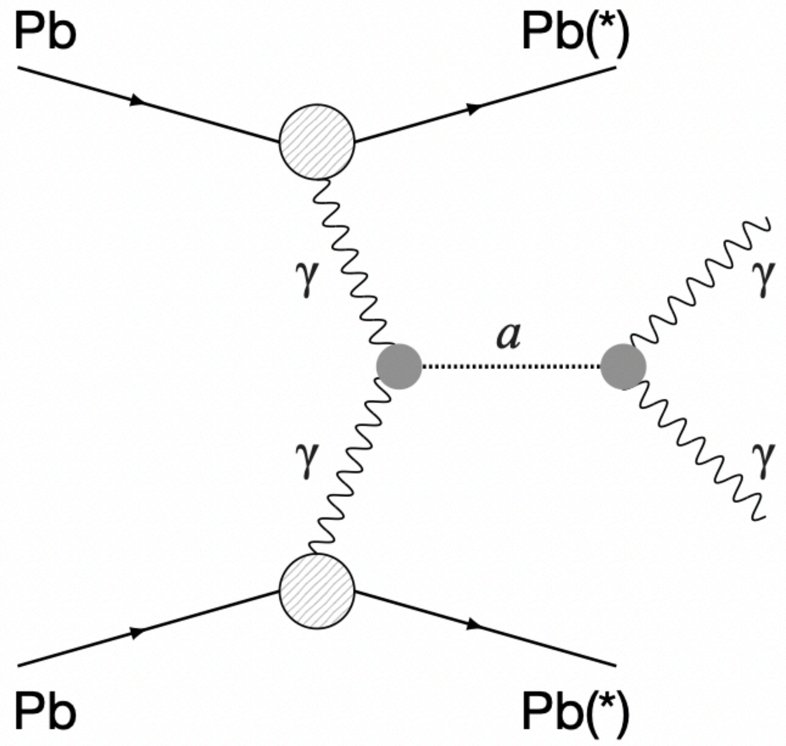
Diffractive Photo-nuclear



(Inelastic) **Photo-nuclear**



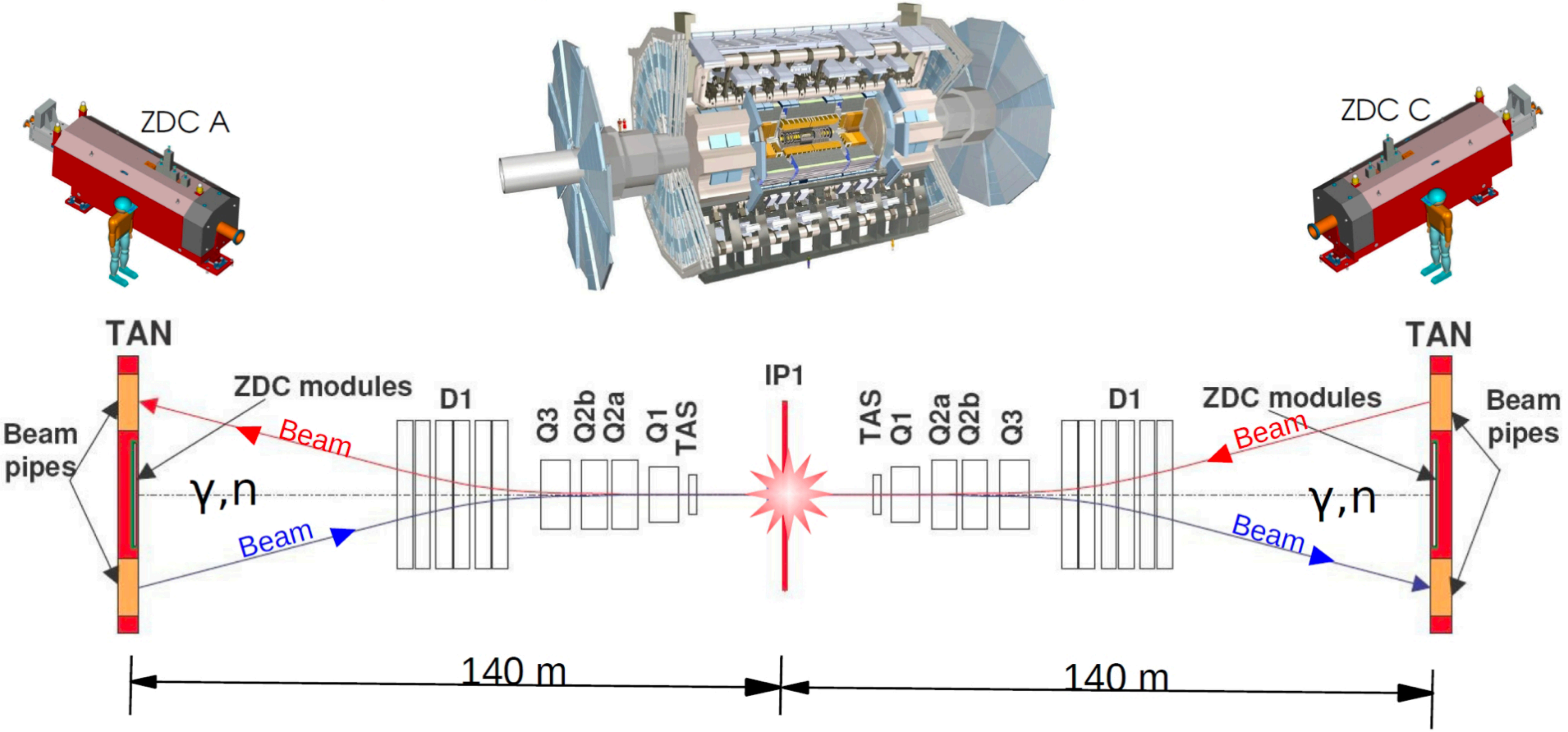
(SM) **Photon-photon**



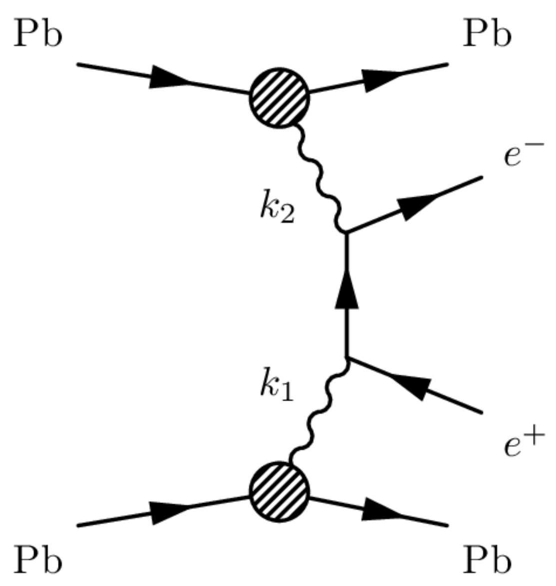
(BSM) **Photon-photon**

Experimental considerations

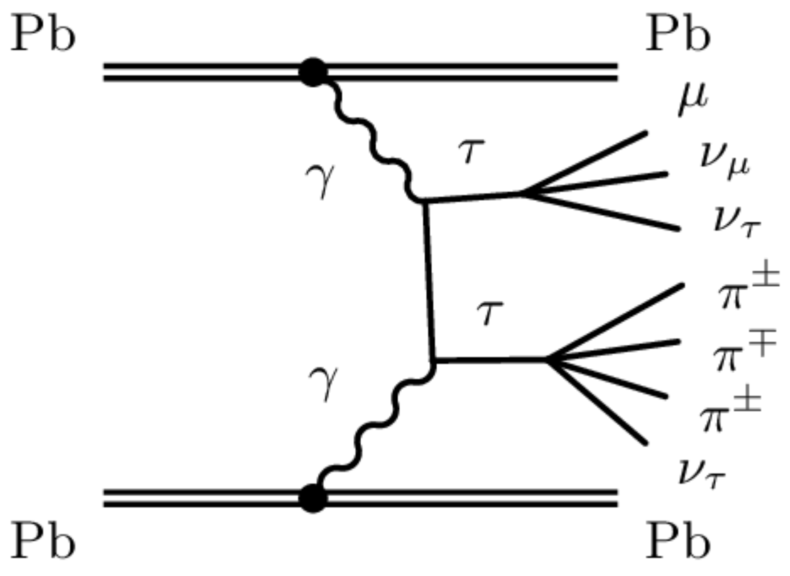
- **Rapidity gaps** & **Exclusive final states** → Veto requirements are essential
- Many sub-detectors available in ATLAS (|eta|<4.9)
- (Absence of) ion dissociation tagged with **Zero Degree Calorimeters (ZDC)**



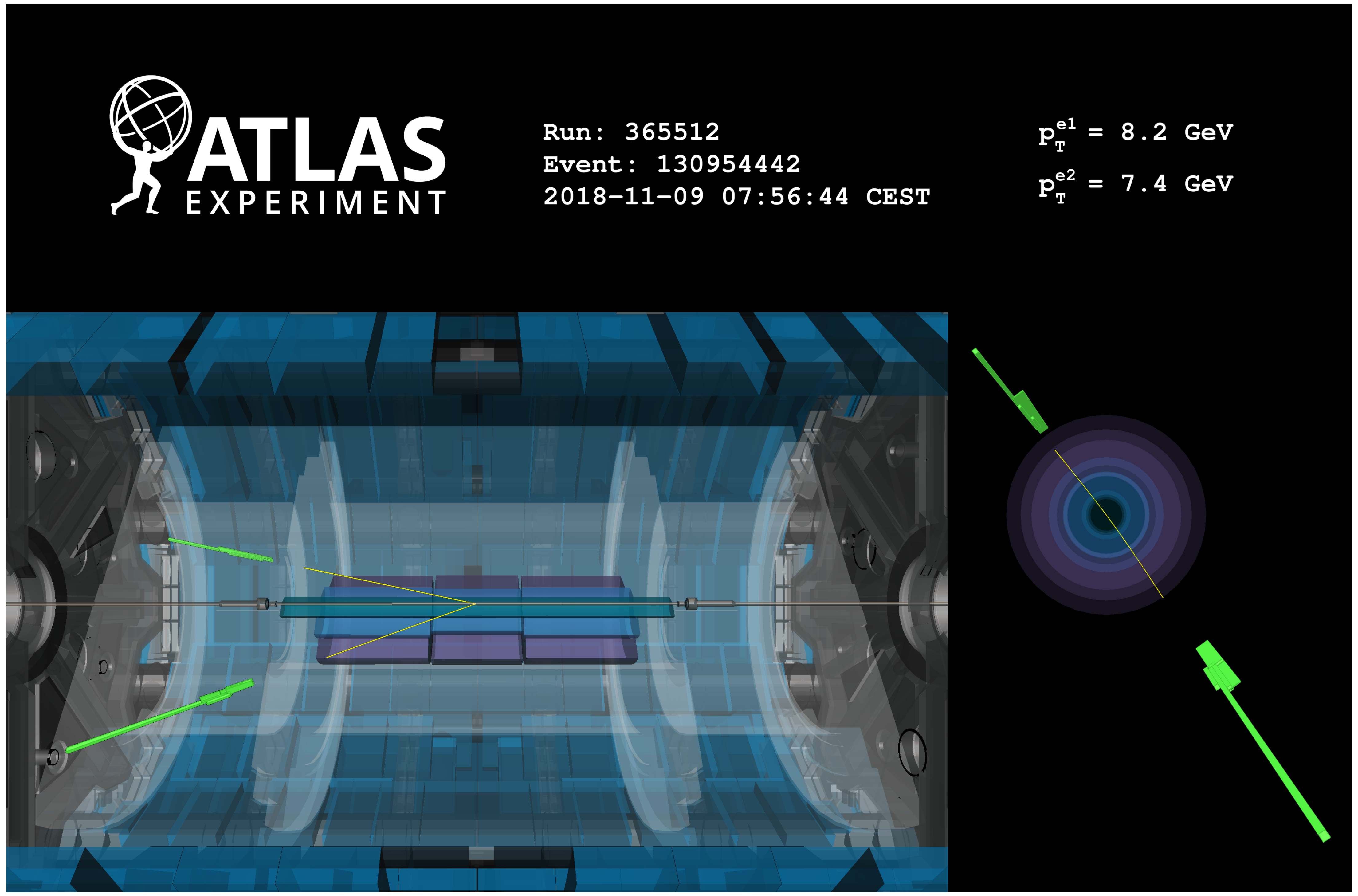
Outline

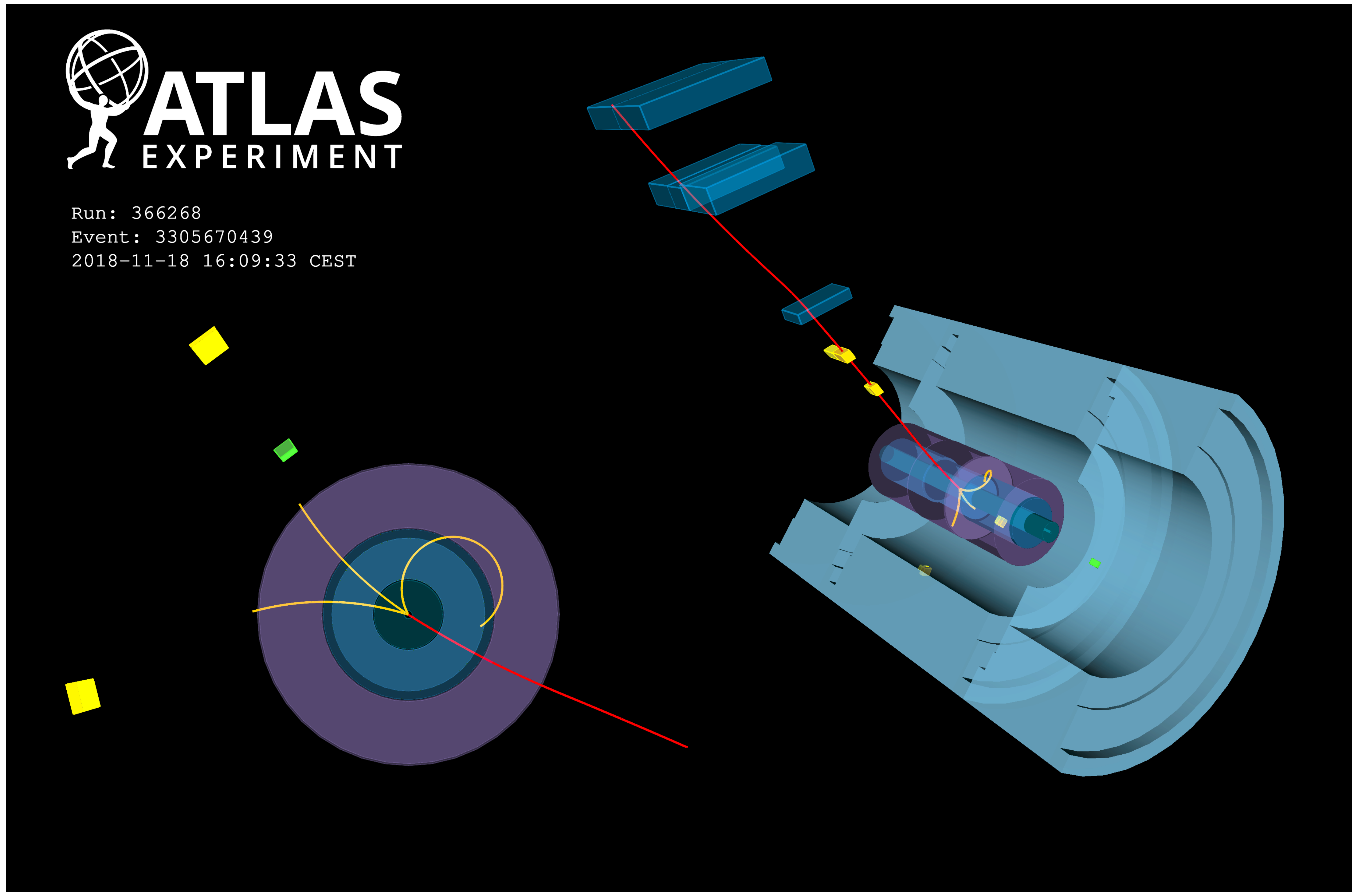


ATLAS Collaboration, **JHEP 06 (2023) 182**



ATLAS Collaboration, **Phys. Rev. Lett. 131 (2023) 15, 151802**

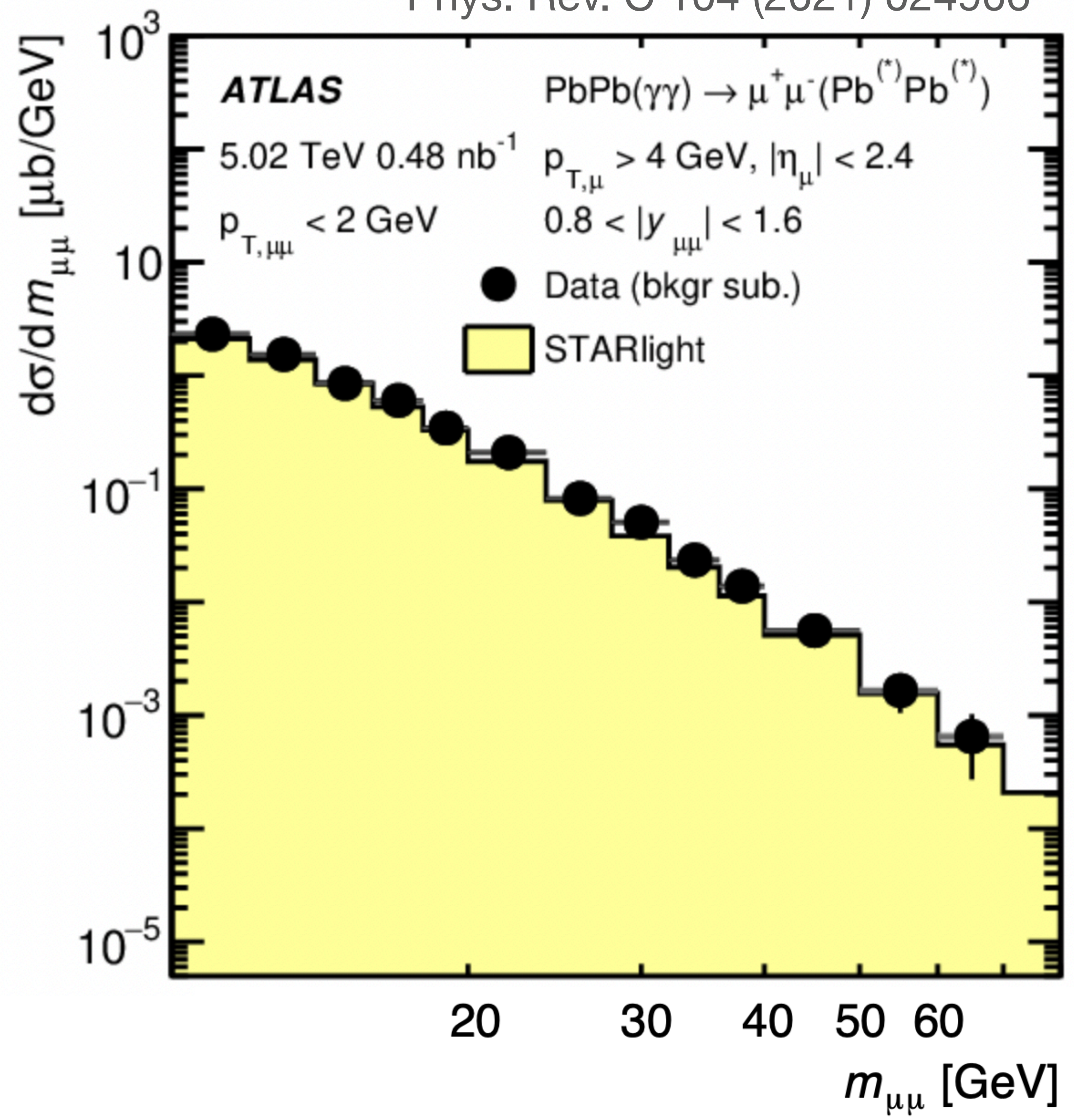




Exclusive dielectron production in Pb+Pb UPC

- ‘Standard candle’ for γγ-fusion processes
  - Good sensitivity for Pb EM formfactors → photon flux modeling
  - Sensitivity to probe higher-order corrections
- New ATLAS measurement (γγ→ee) extends the previous (γγ→μμ) study

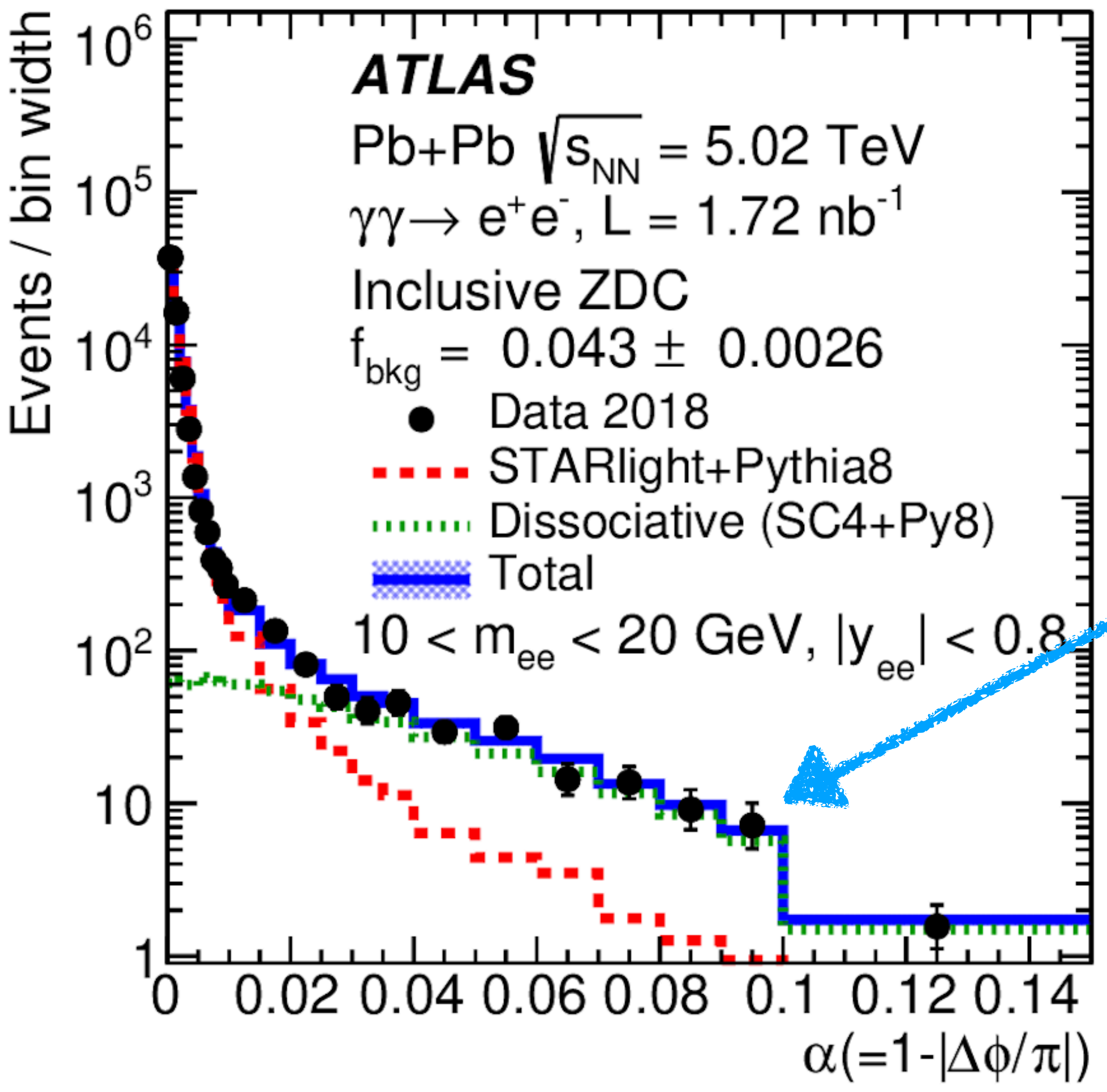
Phys. Rev. C 104 (2021) 024906

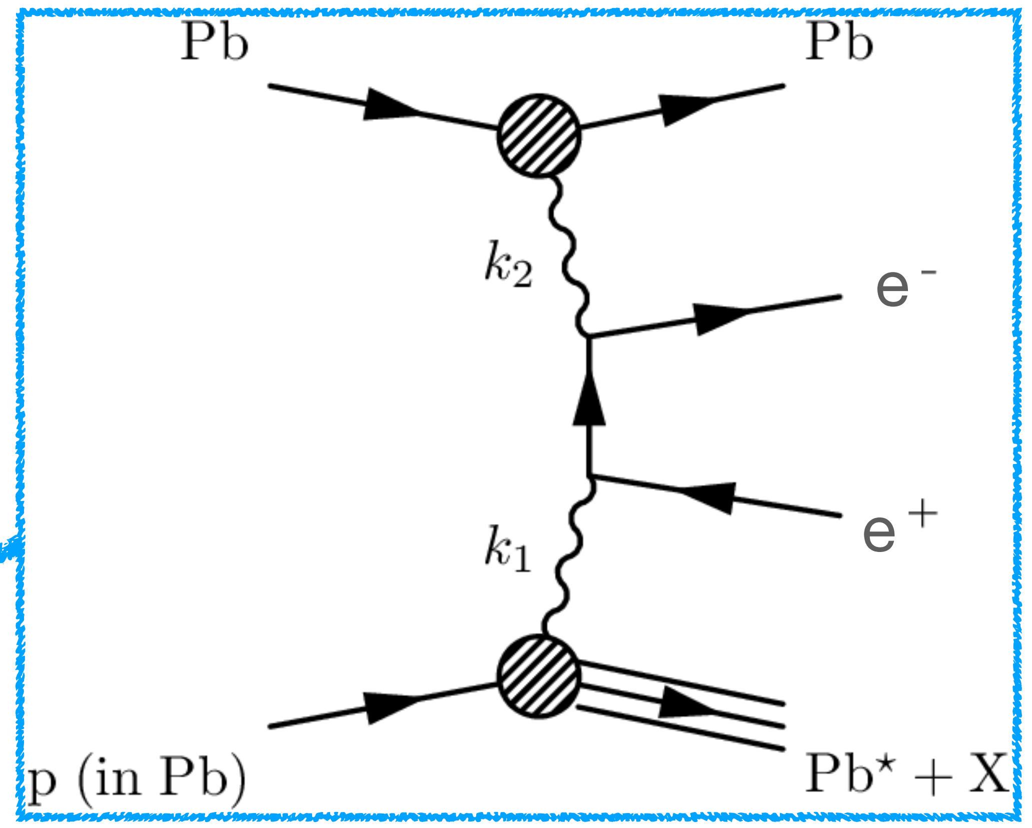


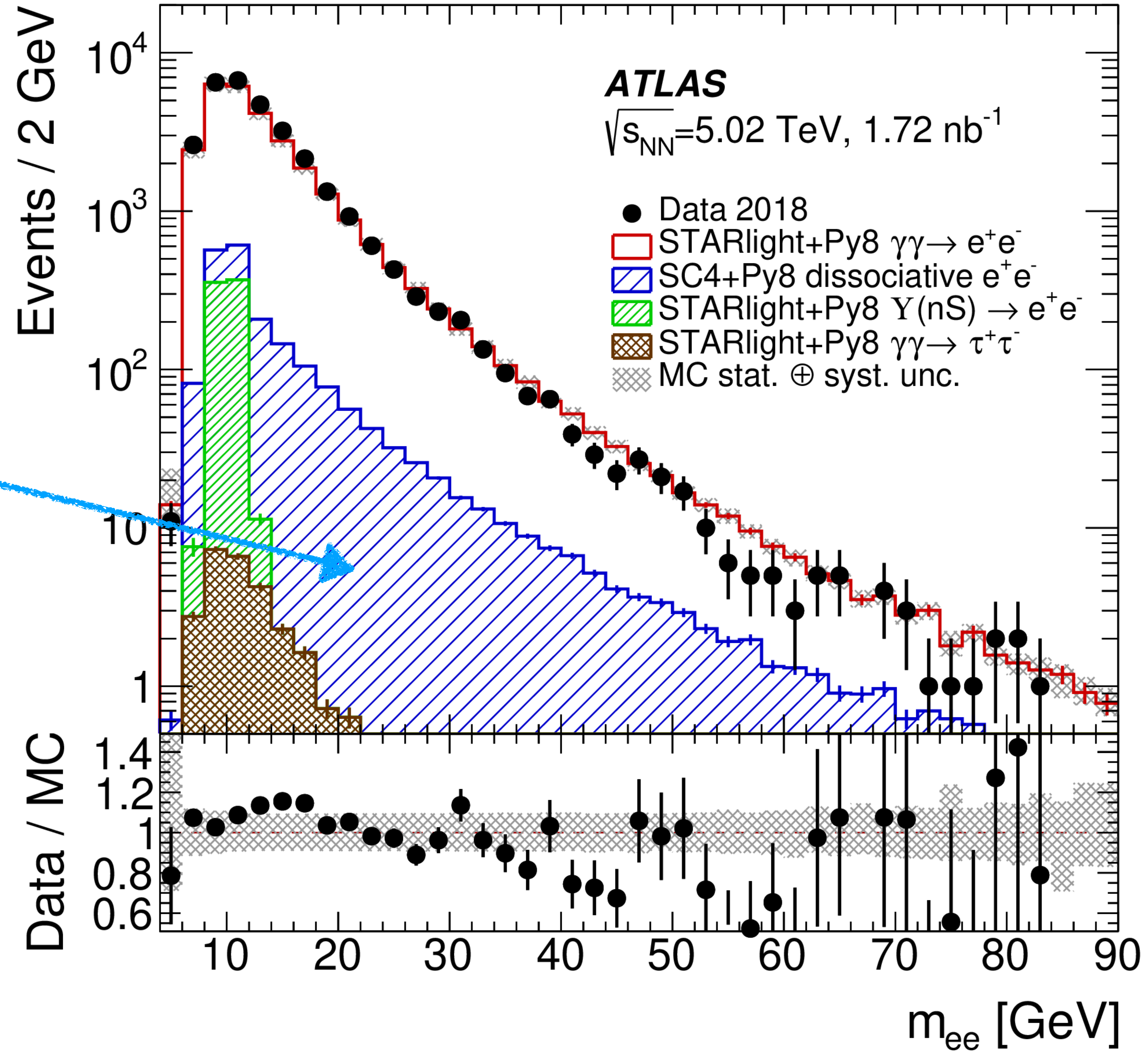
	$\gamma\gamma \to \mu^+\mu^-$	$\gamma\gamma \to e^+e^-$
Data	2015	2018
Int lumi	0.48 nb^{-1}	1.72 nb^{-1}
Fiducial	$p_T^\mu > 4$ GeV $\|\eta^\mu\| < 2.4$ $m_{\mu\mu} > 10$ GeV	$p_T^e > 2.5$ GeV $\|\eta^e\| < 2.5$ $m_{ee} > 5$ GeV
	$p_T^{\ell\ell} < 2$ GeV	

Exclusive dielectron production in Pb+Pb UPC

- Background dominated by dissociative production with an off-shell photon
  - Extracted using template fit to dielectron acoplanarity

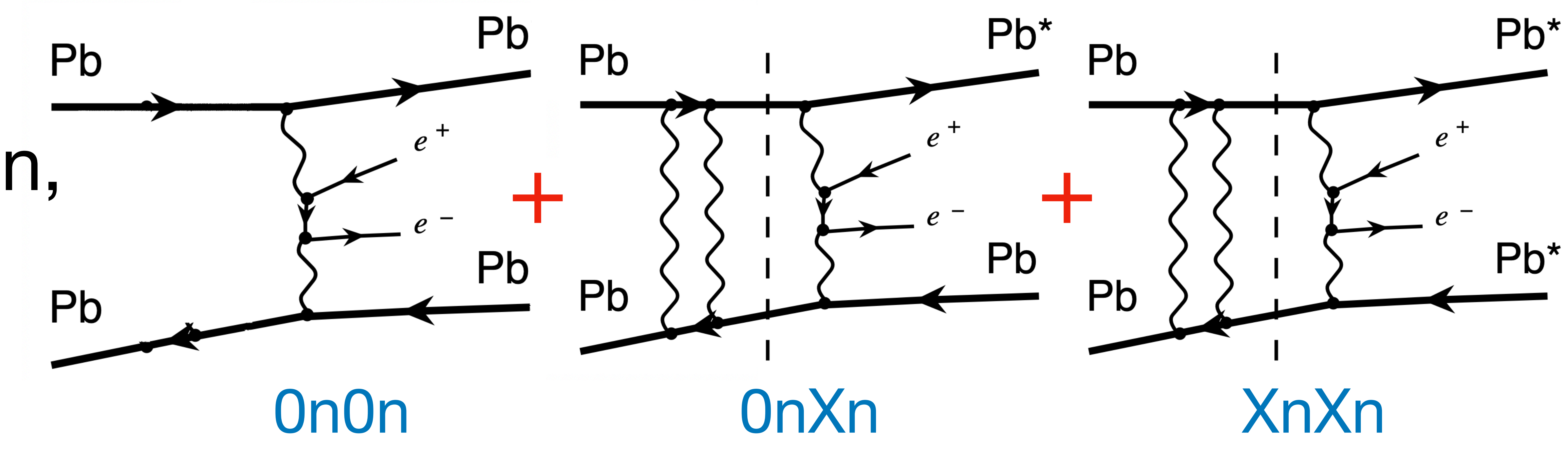


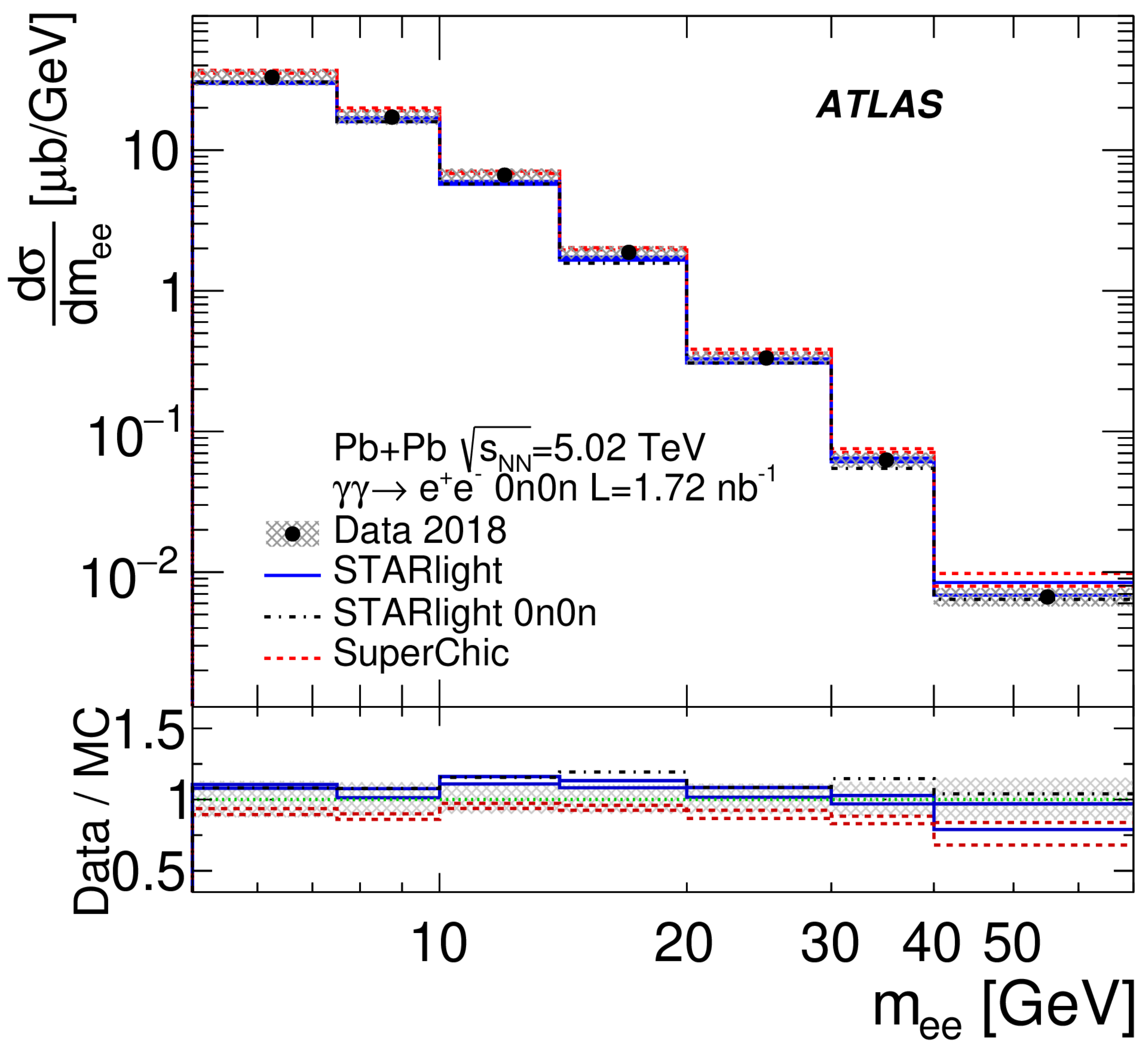


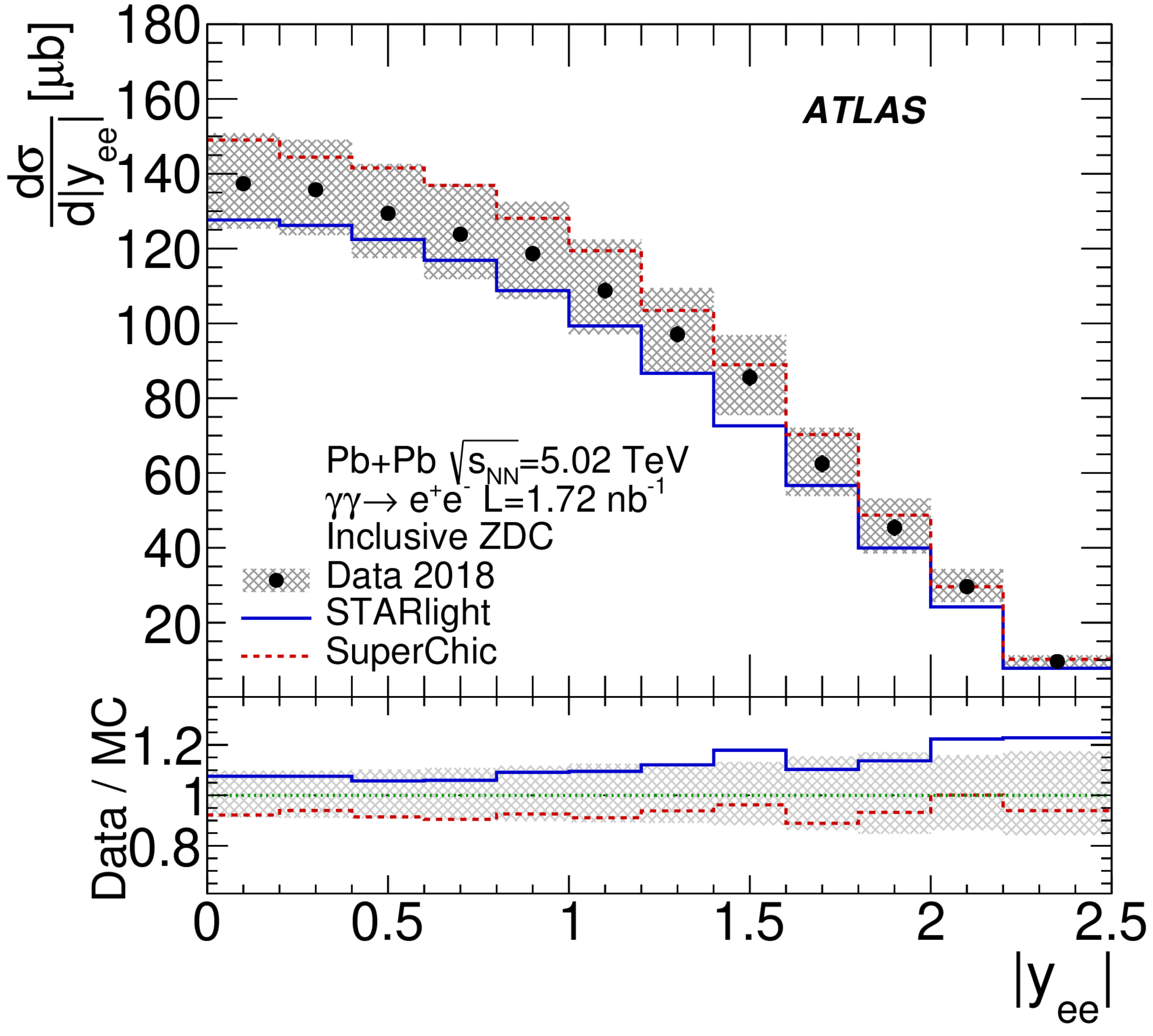


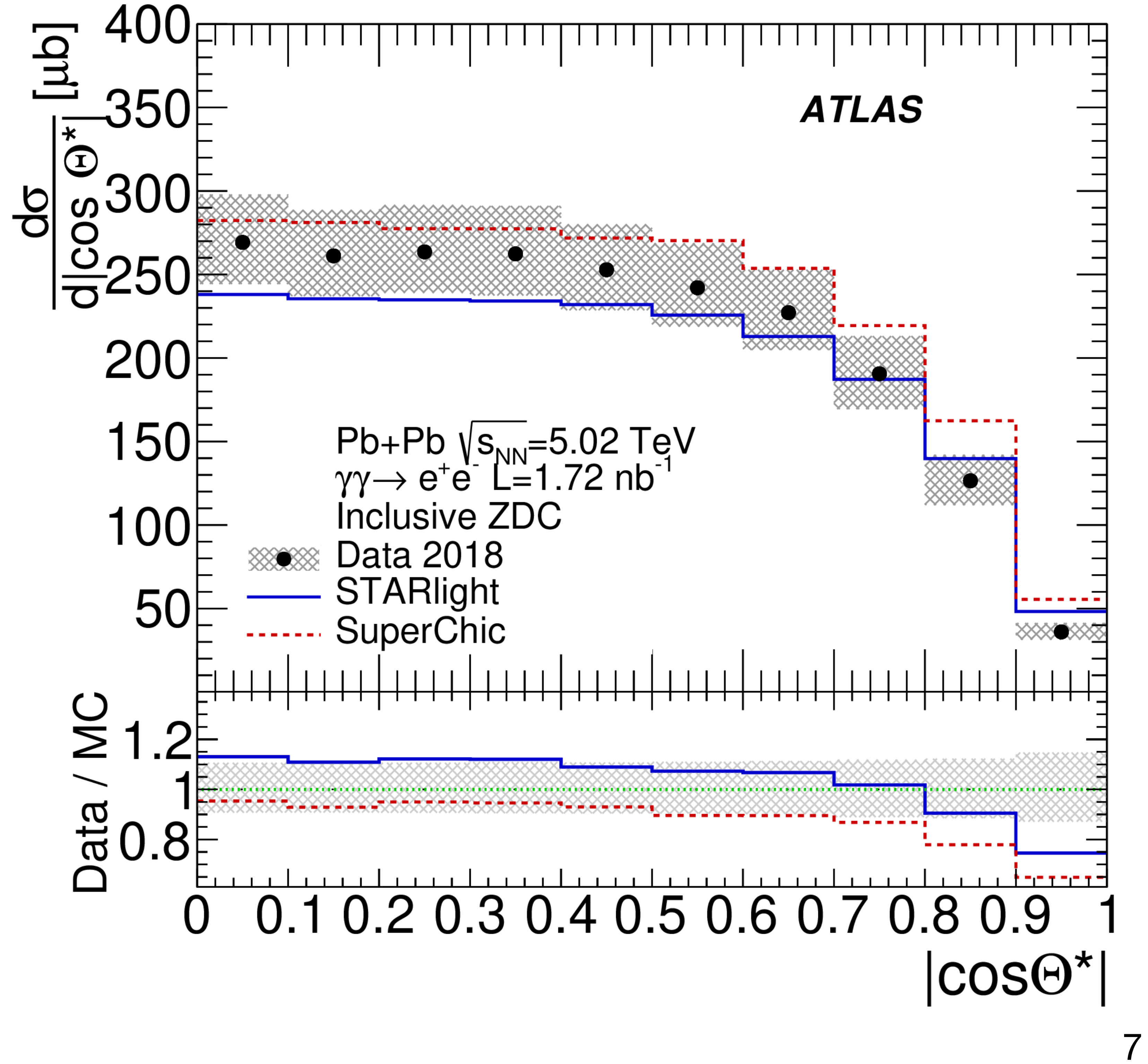
Exclusive dielectron production in Pb+Pb UPC

- Results for “inclusive ZDC” selection, i.e. sum of three event classes:



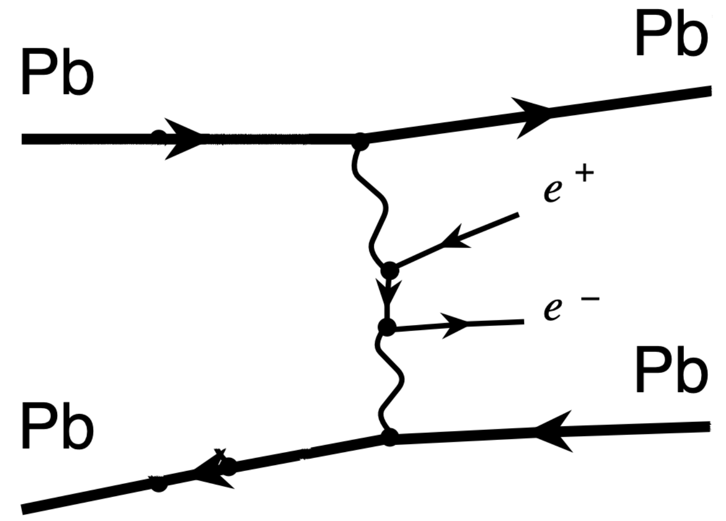


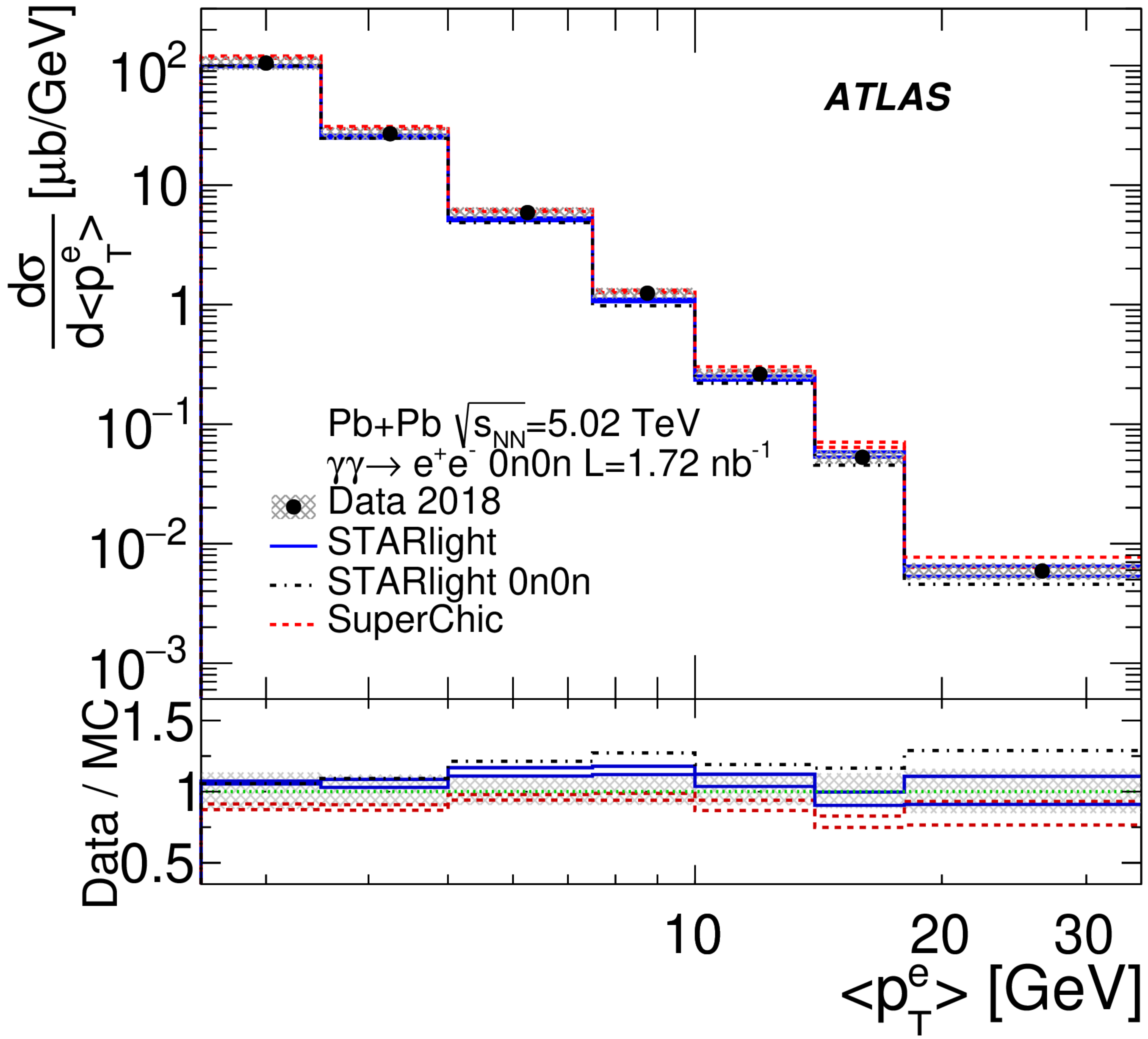


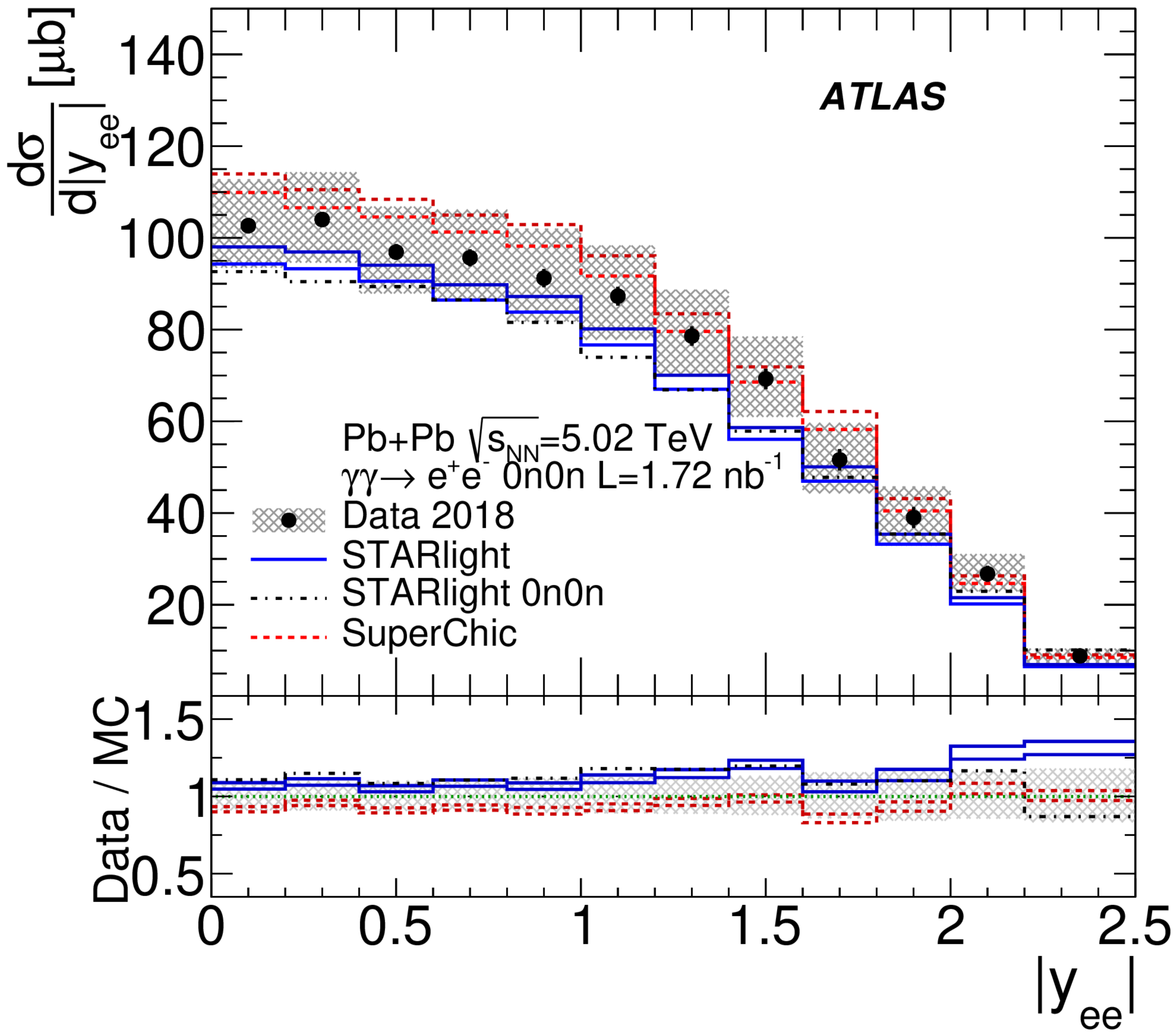


Exclusive dielectron production in Pb+Pb UPC

- Results for “0n0n” ZDC selection

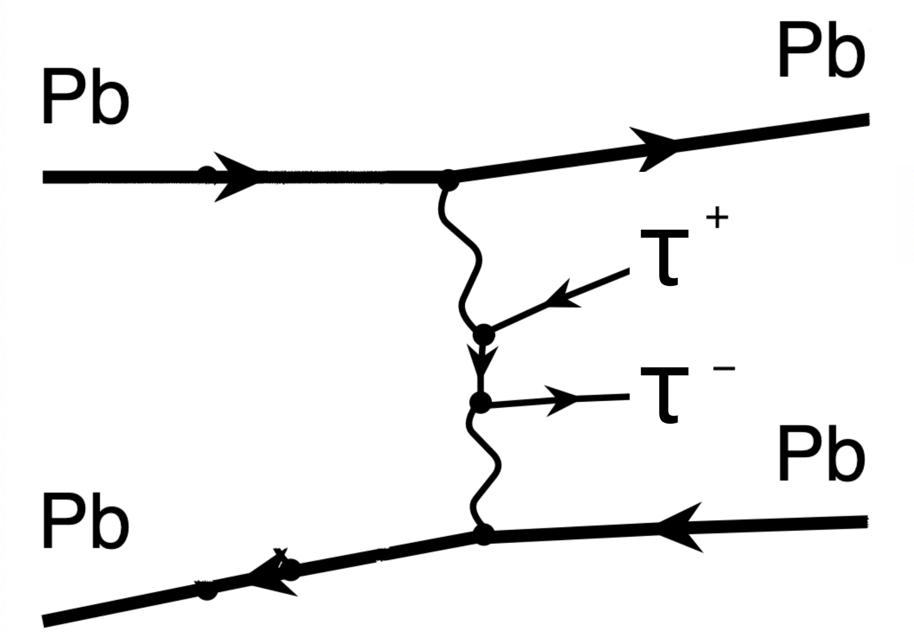




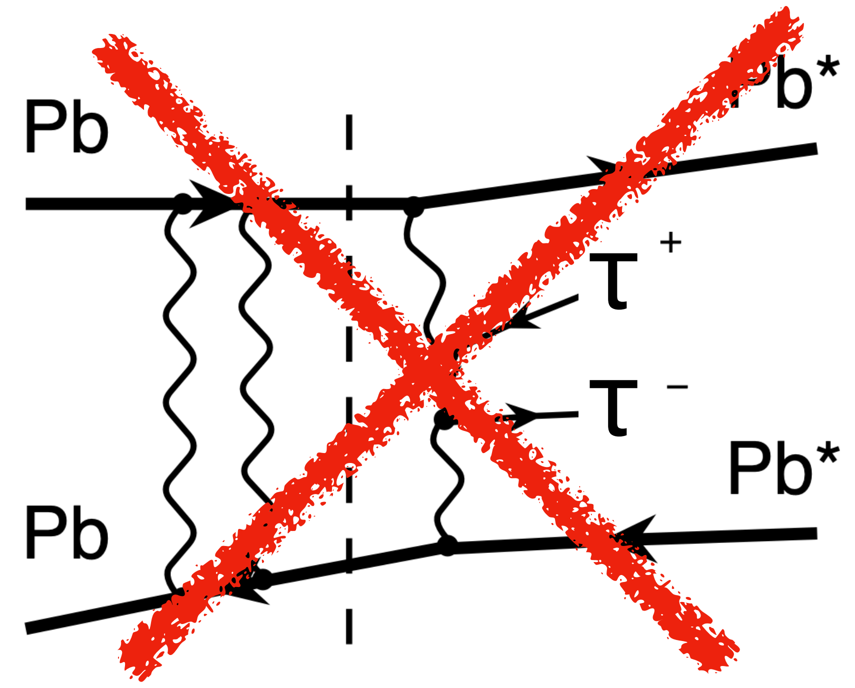


Exclusive tau-pair production in Pb+Pb UPC

- More challenging experimentally due to **low-energy tau decays**
- Strategy: exploit semi-leptonic decays with muon
    - **μe-SR**: muon + electron
    - **μ1T-SR**: muon + 1 track (soft e/μ/pion)
    - **μ3T-SR**: muon + 3 tracks (3 pions)



- **Exclusivity**:
    - Veto extra tracks
    - Veto additional calorimeter clusters (μ1T-SR and μ3T-SR only)

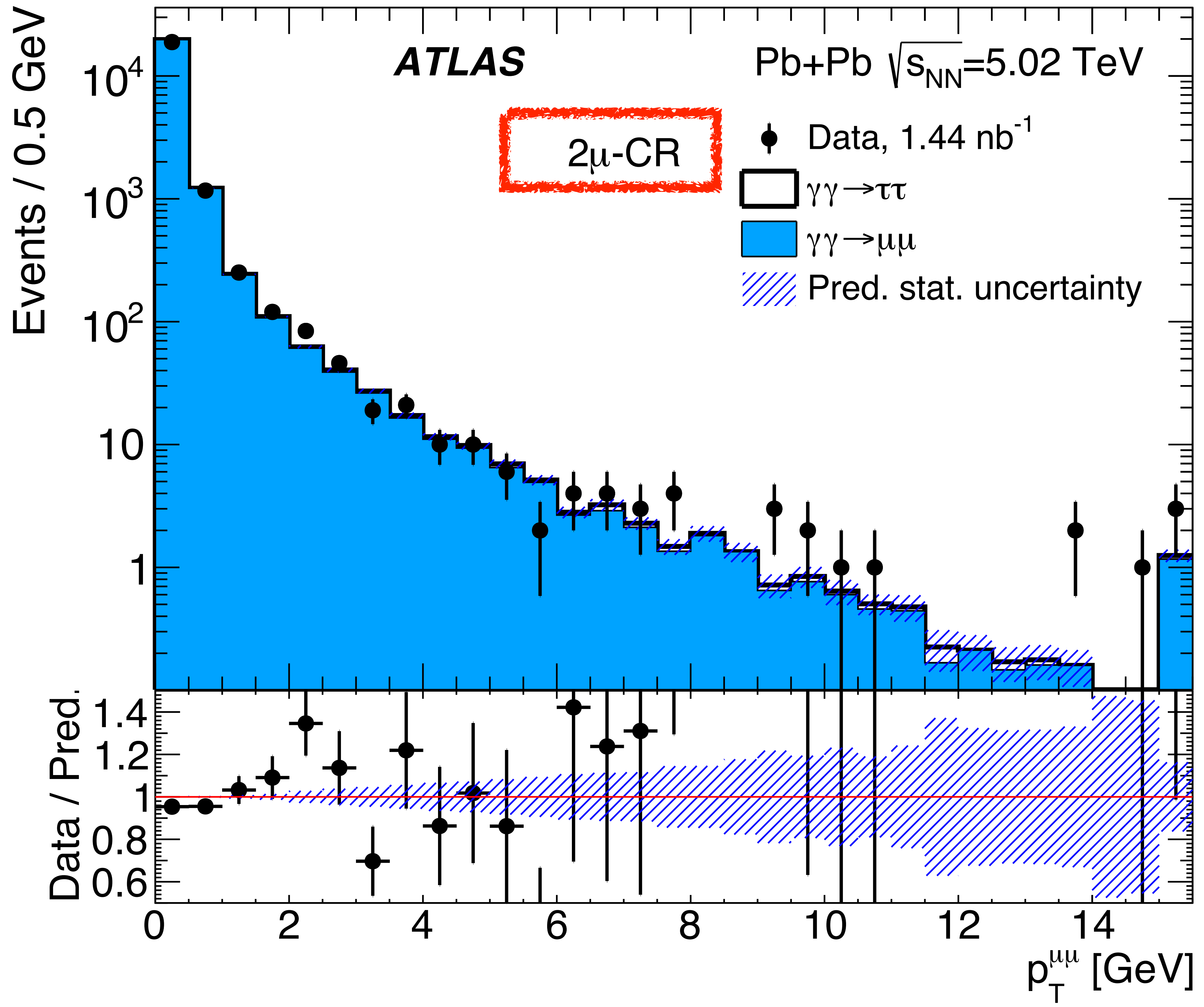


- **0n0n** ZDC selection to further suppress hadronic backgrounds (mainly photonuclear production)

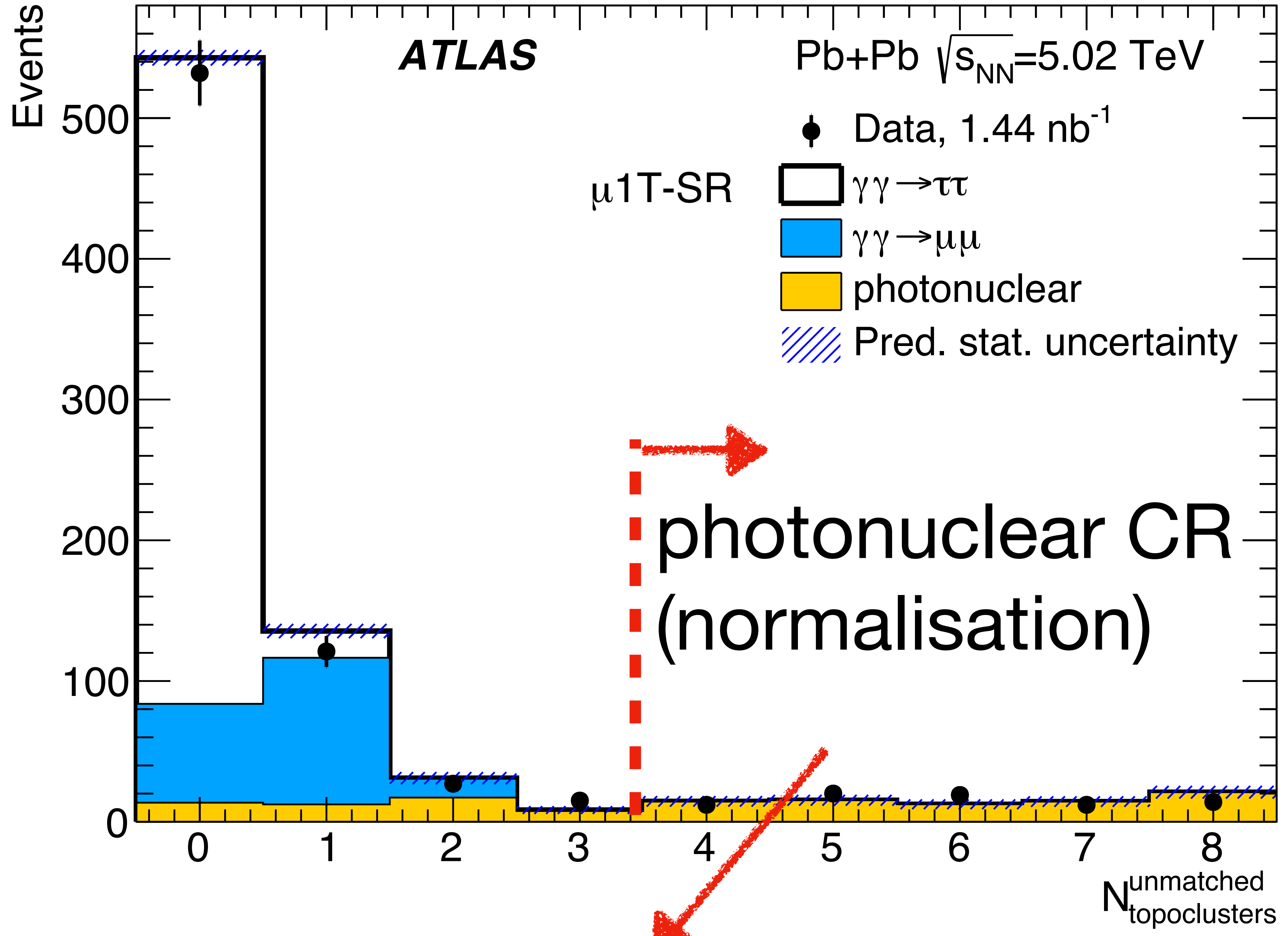
Exclusive tau-pair production in Pb+Pb UPC

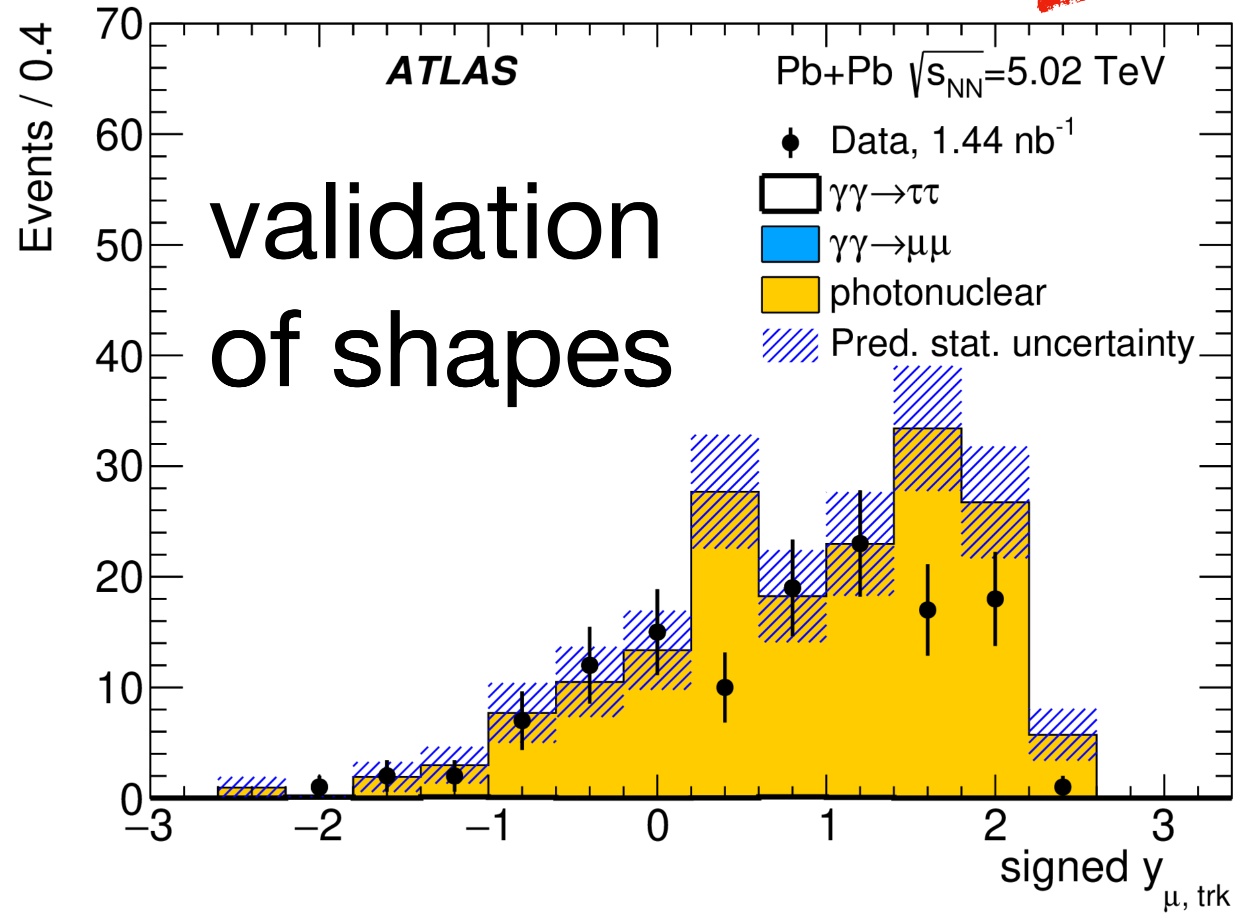
- **Main backgrounds**

γγ → μμγ (MC-based)



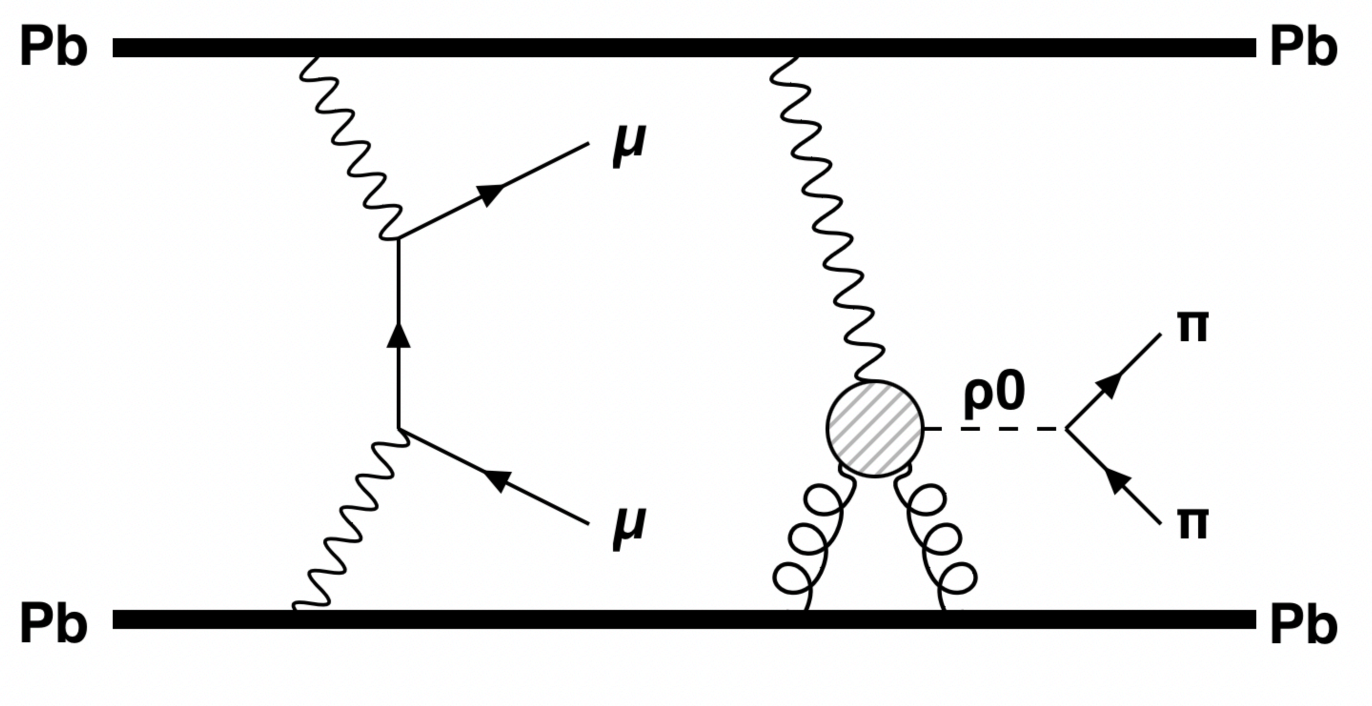
Diffractive photonuclear (data-driven)

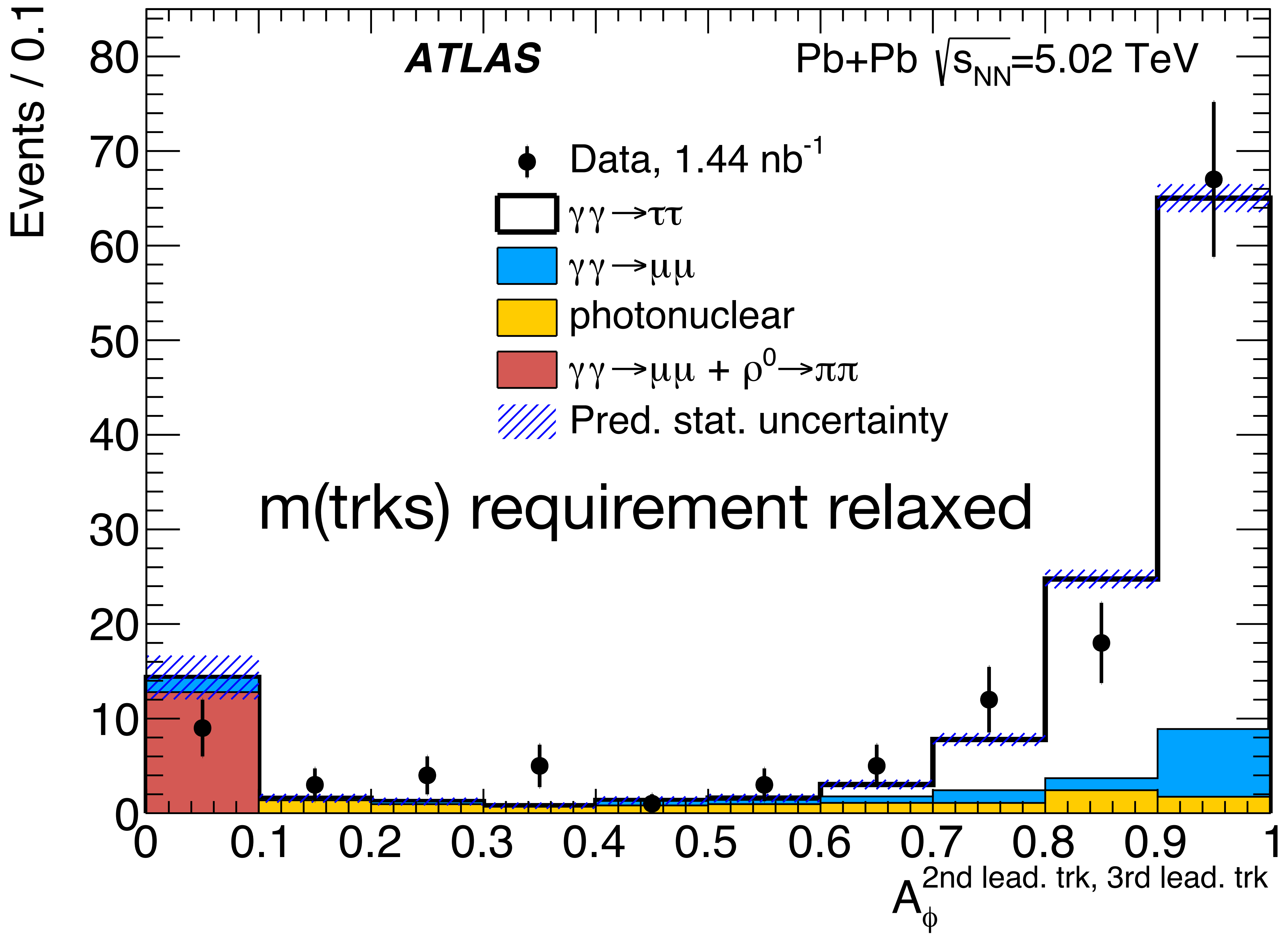


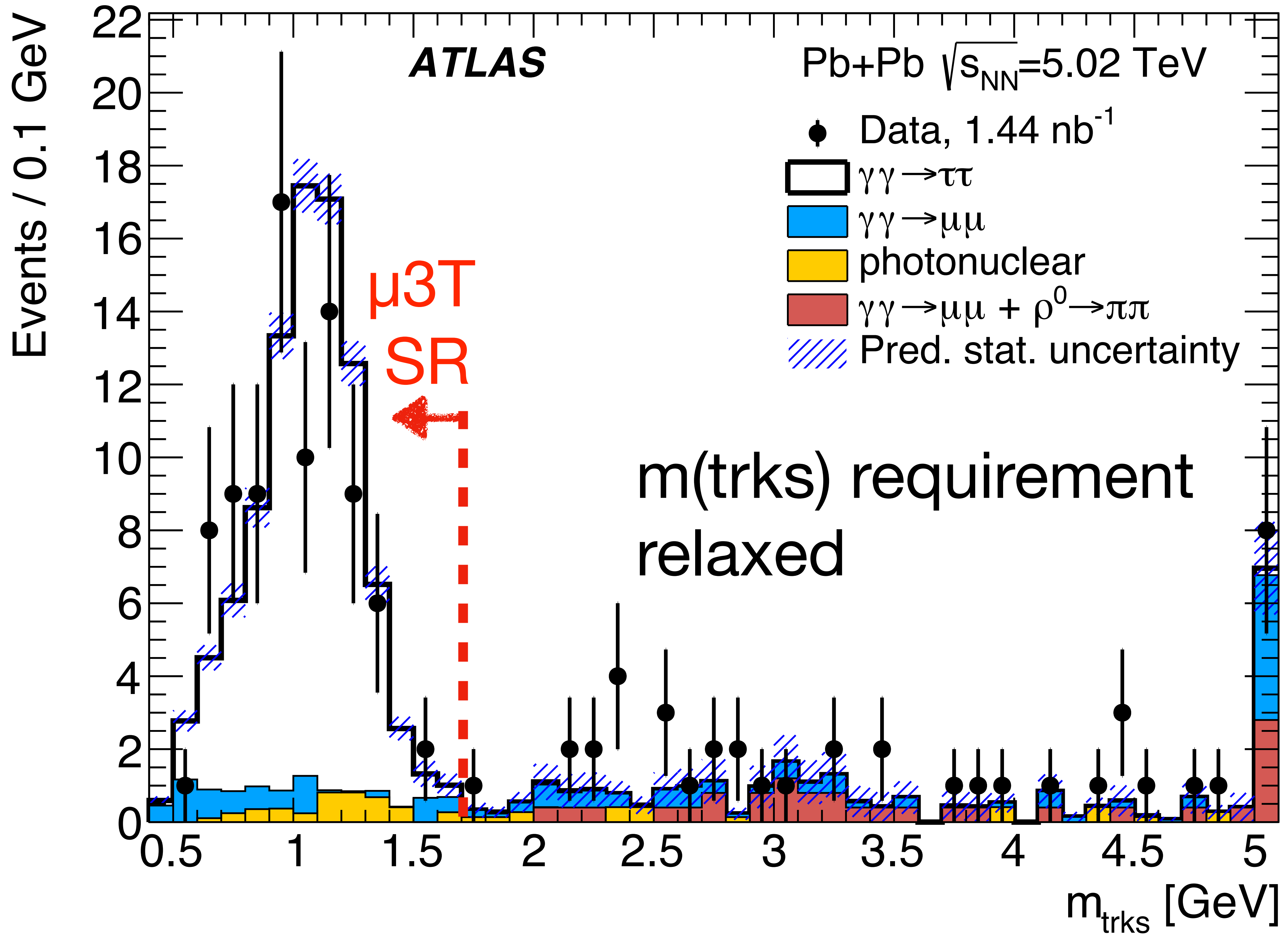


Exclusive tau-pair production in Pb+Pb UPC

- Other backgrounds
  - Simultaneous **γγ→μμ and γPb→ρ0→π+π-** production (‘DPS’) observed
  - μ3T-SR: Cut on m(trks)<1.7 GeV removes it fully

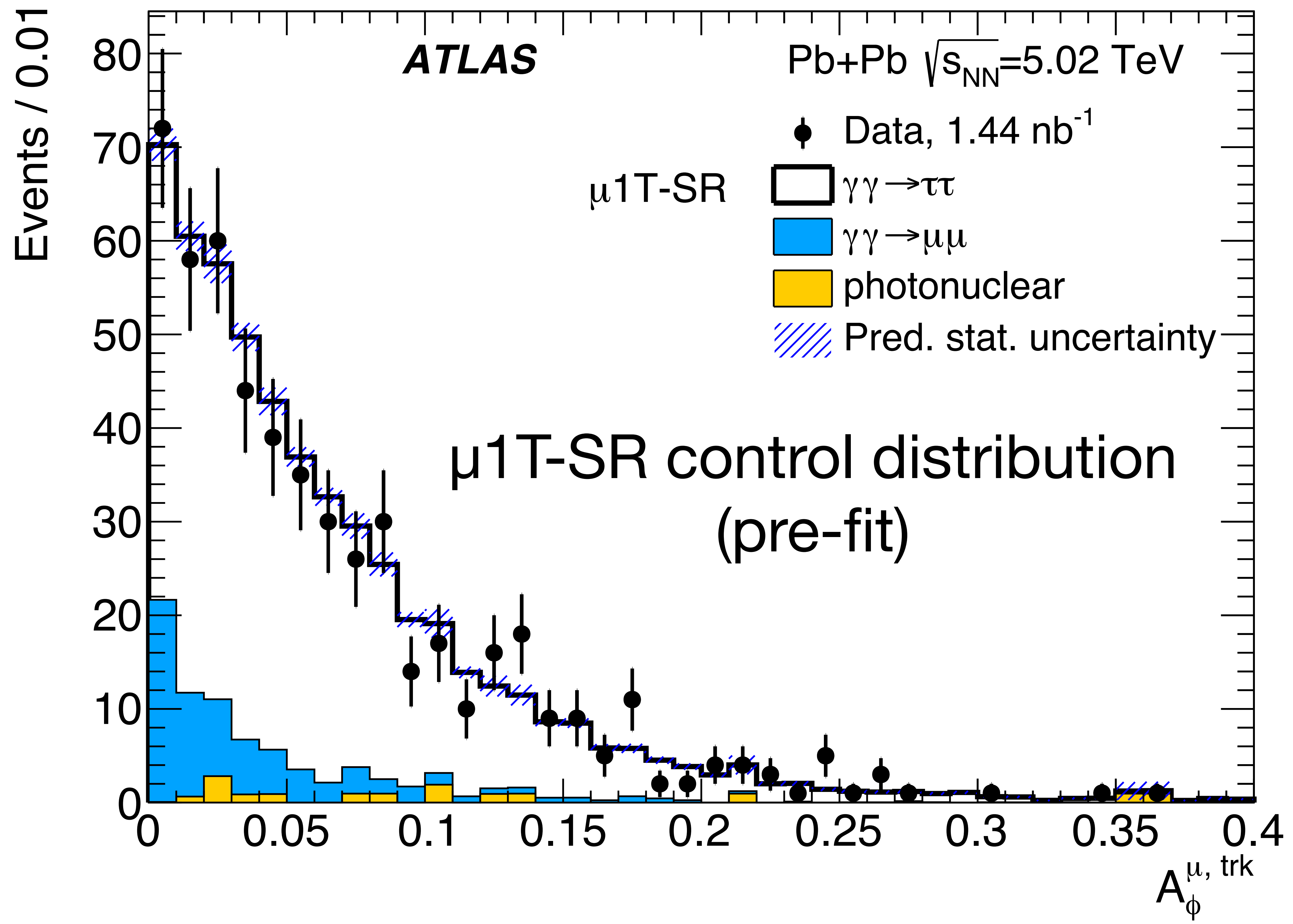


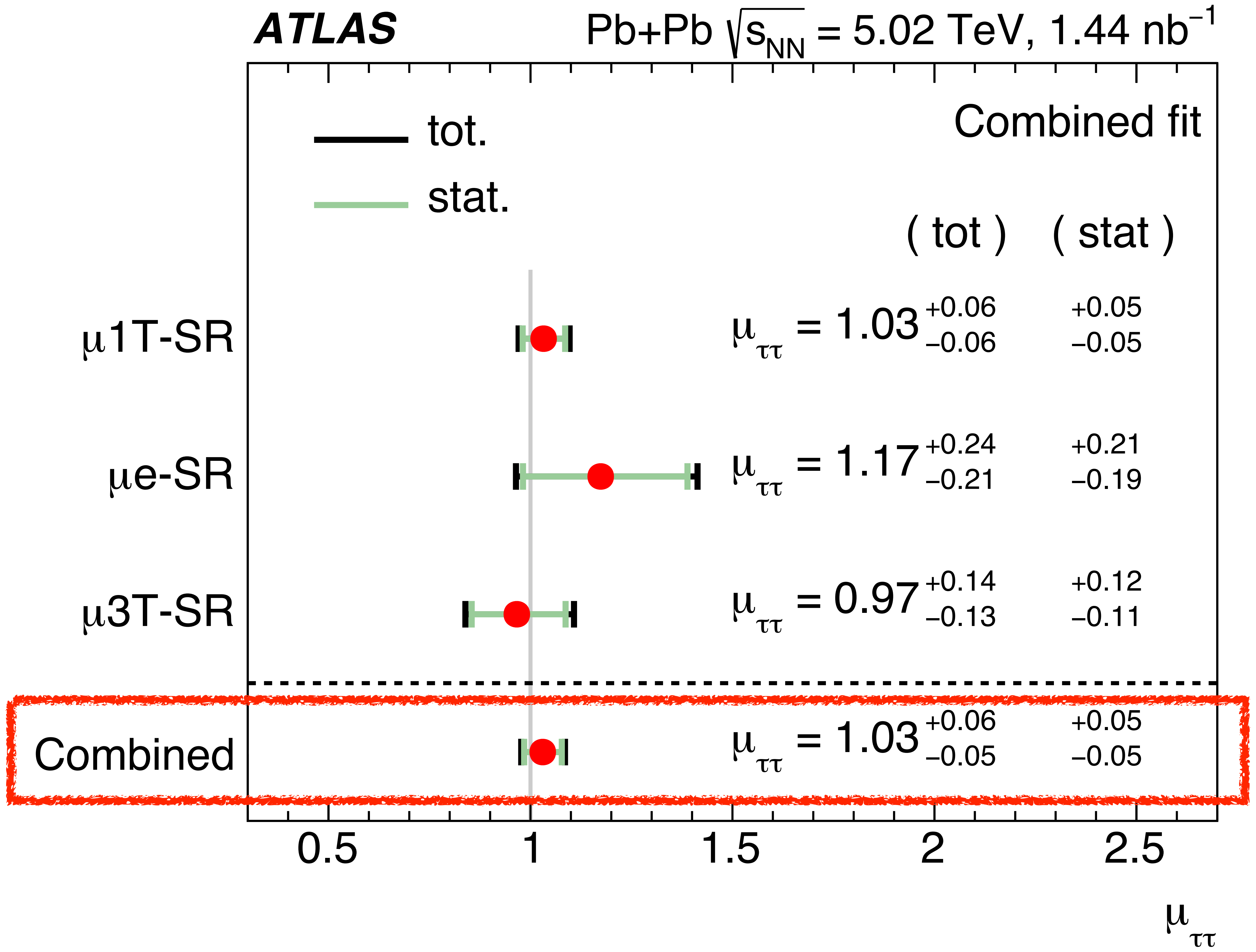




Exclusive tau-pair production in Pb+Pb UPC

- Signal strength extraction
  - Simultaneous fit to μ1T-SR, μ3T-SR, μe-SR and 2μ-CR
  - Many systematics **correlated** between SRs and 2μ-CR → get reduced!





Exclusive tau-pair production in Pb+Pb UPC

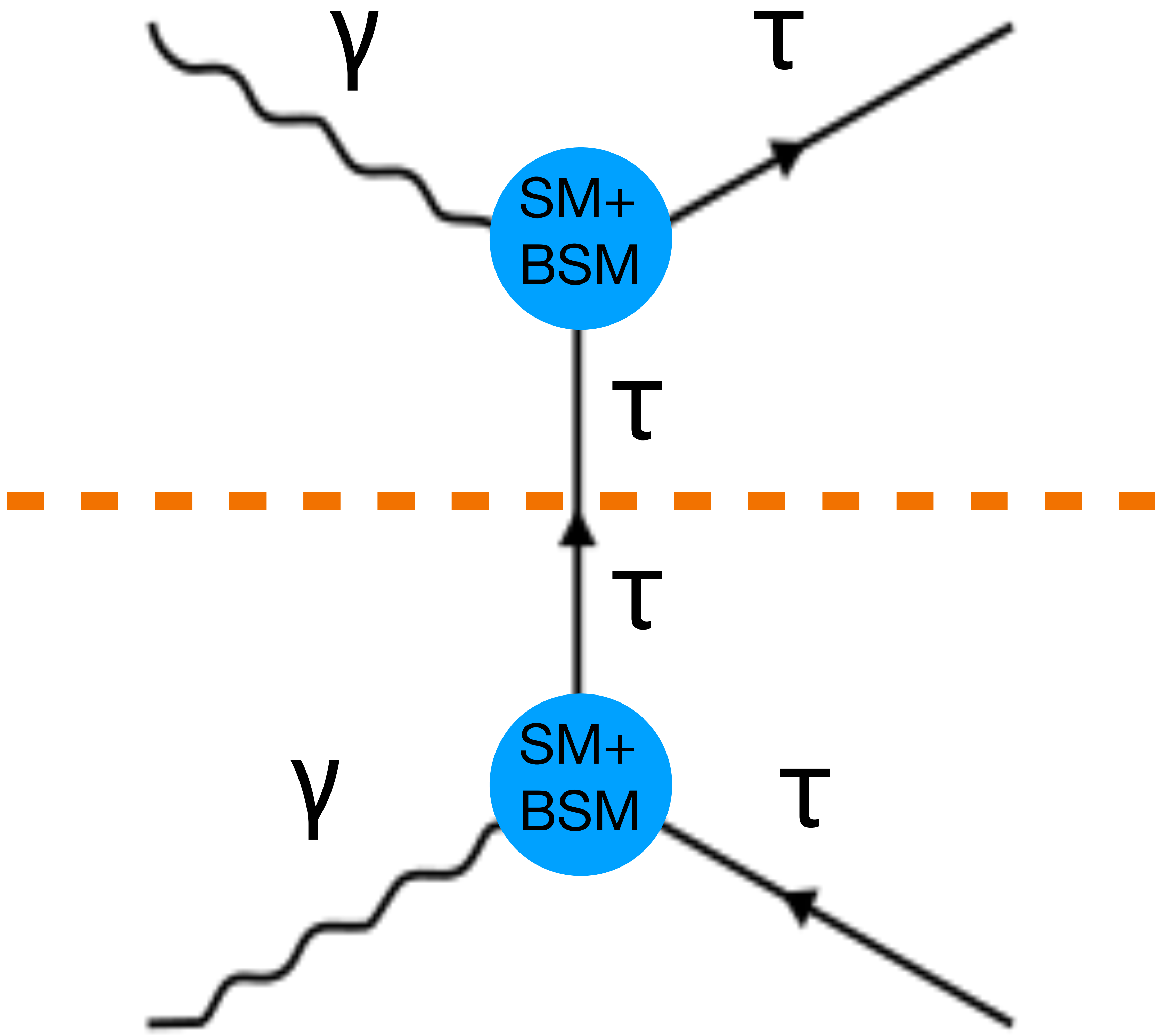
- **a_{tau} = (g_{tau}-2)/2** poorly constrained experimentally; can be sensitive to BSM

R.L. Workman et al. (Particle Data Group), Prog. Theor. Exp. Phys. 2022, 083C01 (2022)

τ $J = \frac{1}{2}$

Mass $m = 1776.86 \pm 0.12$ MeV
$(m_{\tau^+} - m_{\tau^-})/m_{\text{average}} < 2.8 \times 10^{-4}$, CL = 90%
Mean life $\tau = (290.3 \pm 0.5) \times 10^{-15}$ s
$c\tau = 87.03\ \mu$m
Magnetic moment anomaly > -0.052 and < 0.013, CL = 95%
$\text{Re}(d_\tau) = -0.220$ to 0.45×10^{-16} e cm, CL = 95%
$\text{Im}(d_\tau) = -0.250$ to 0.0080×10^{-16} e cm, CL = 95%

$$a_\tau^{\text{SM}} = 0.001\,177\,21\ (5)$$



Exclusive tau-pair production in Pb+Pb UPC

- Measure **$a_\tau = (g_\tau - 2)/2$** with template fit
  - Using pT(μ) distribution in the three SRs and 2μ-CR
  - a_τ templates: reweighting signal MC [weights from PLB 809 (2020) 135682] + morphing

Pre-fit

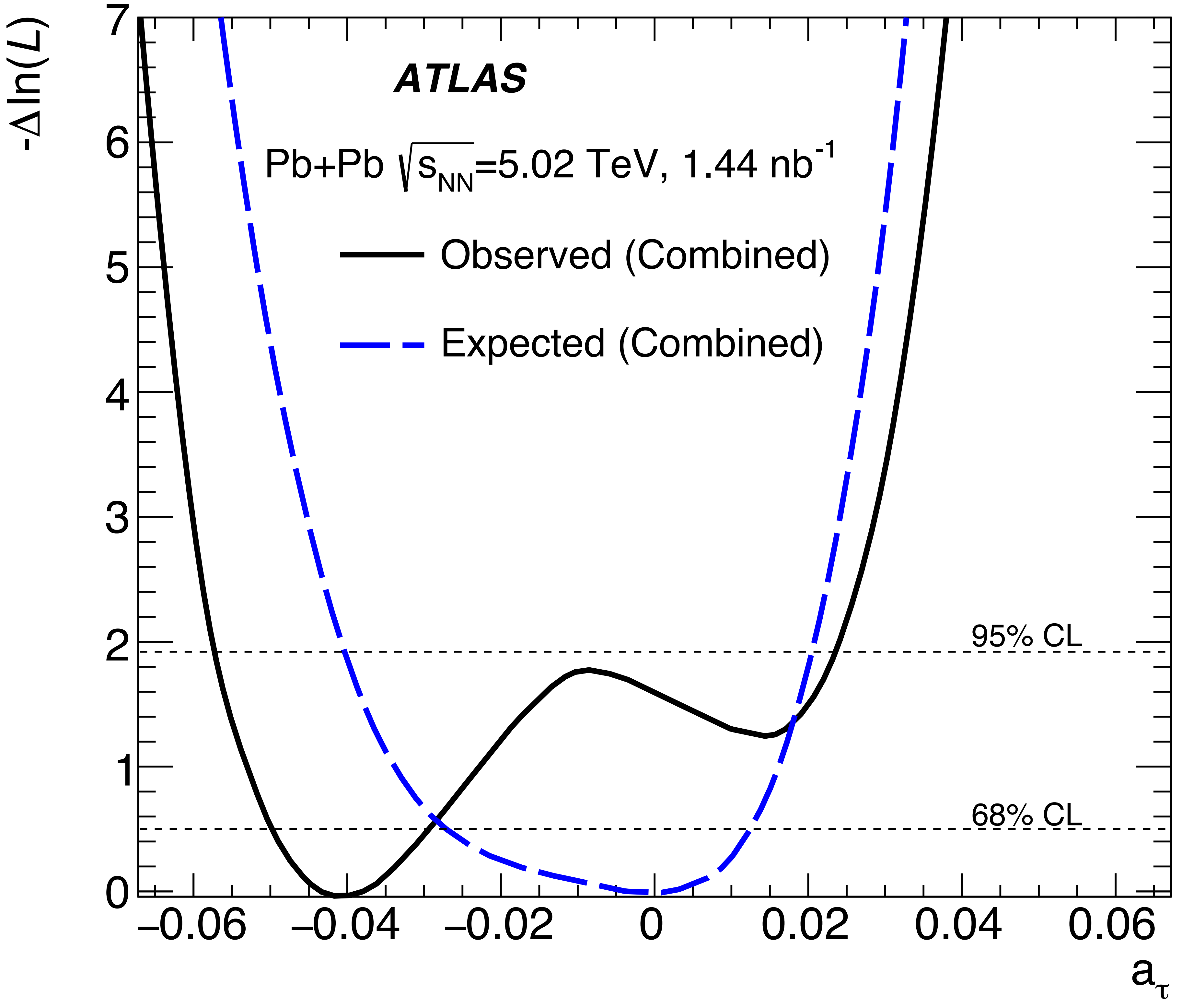
Exclusive tau-pair production in Pb+Pb UPC

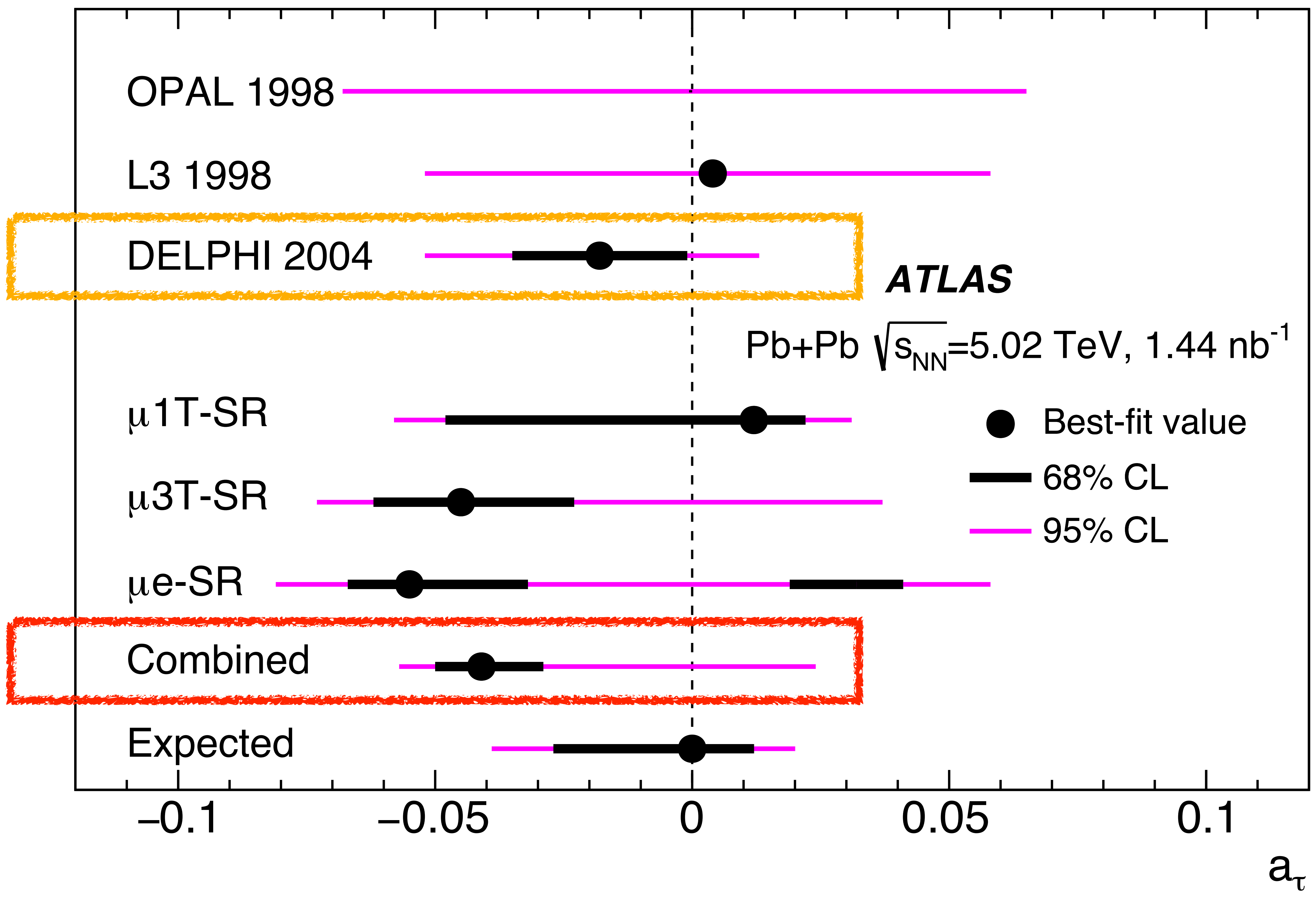
- Measure $\mathbf{a_\tau = (g_\tau - 2)/2}$ with template fit
  - Using pT(μ) distribution in the three SRs and 2μ-CR
  - a_τ templates: reweighting signal MC [weights from PLB 809 (2020) 135682] + morphing

Post-fit

Exclusive tau-pair production in Pb+Pb UPC

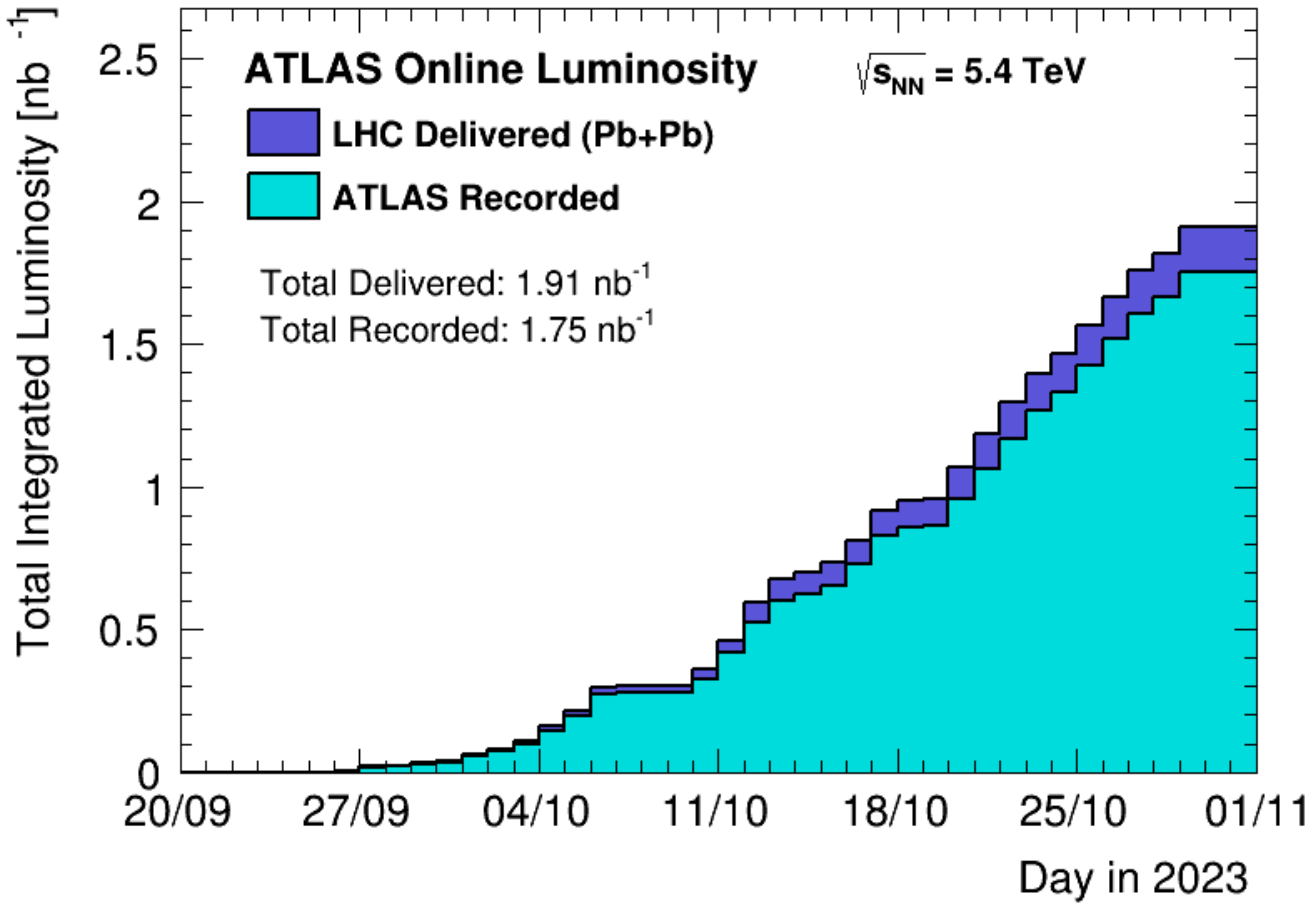
- Constraints on a_τ similar to those observed at LEP



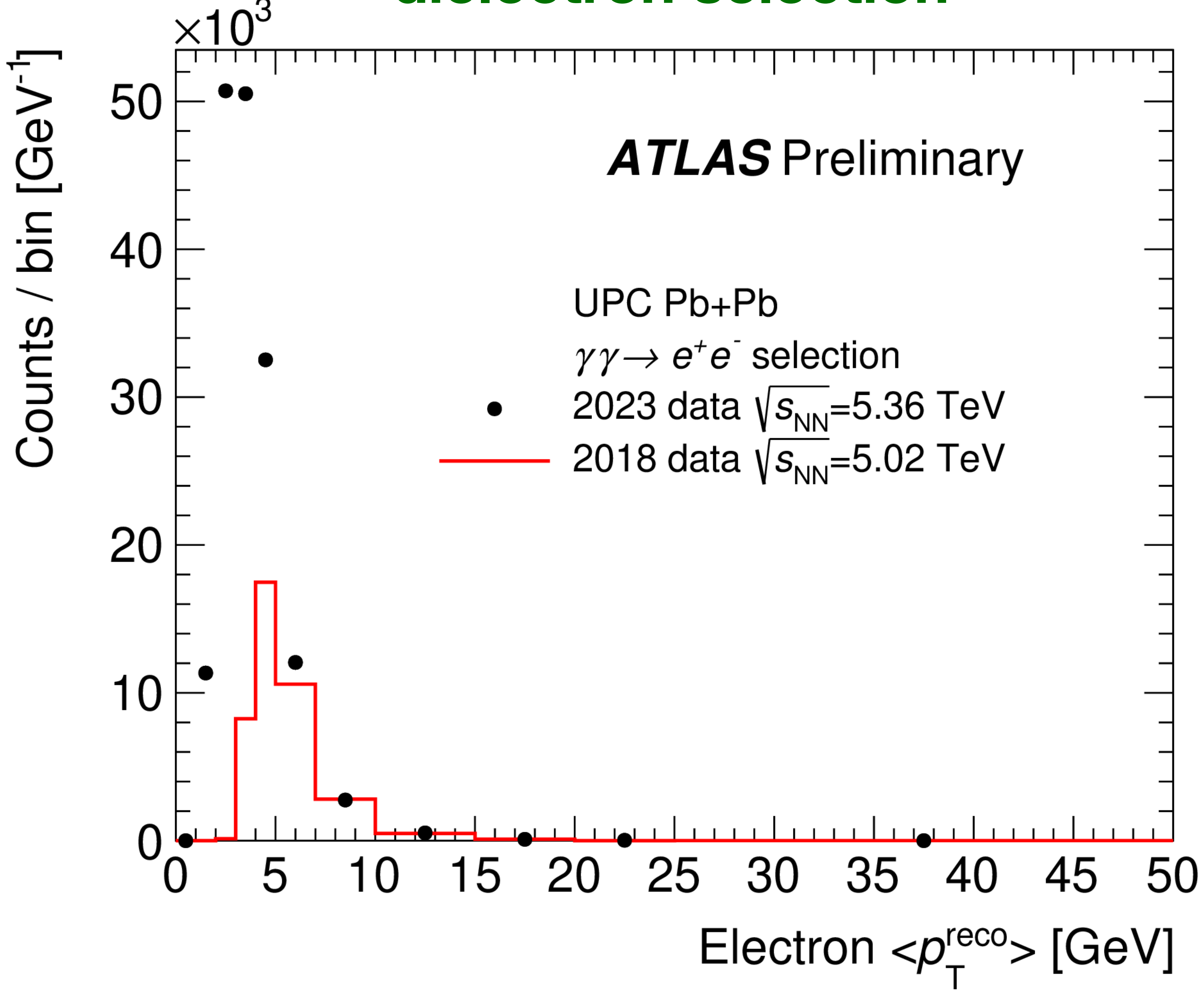


Future ATLAS UPC measurements with leptons

- ~1.7/nb of 5.36 TeV data recorded in 2023 by ATLAS
- Thanks to the **offline (egamma)** and ATLAS TRT “Fast-OR” L1 trigger improvements, we can reach much lower lepton transverse momenta in Run3!



dielectron selection



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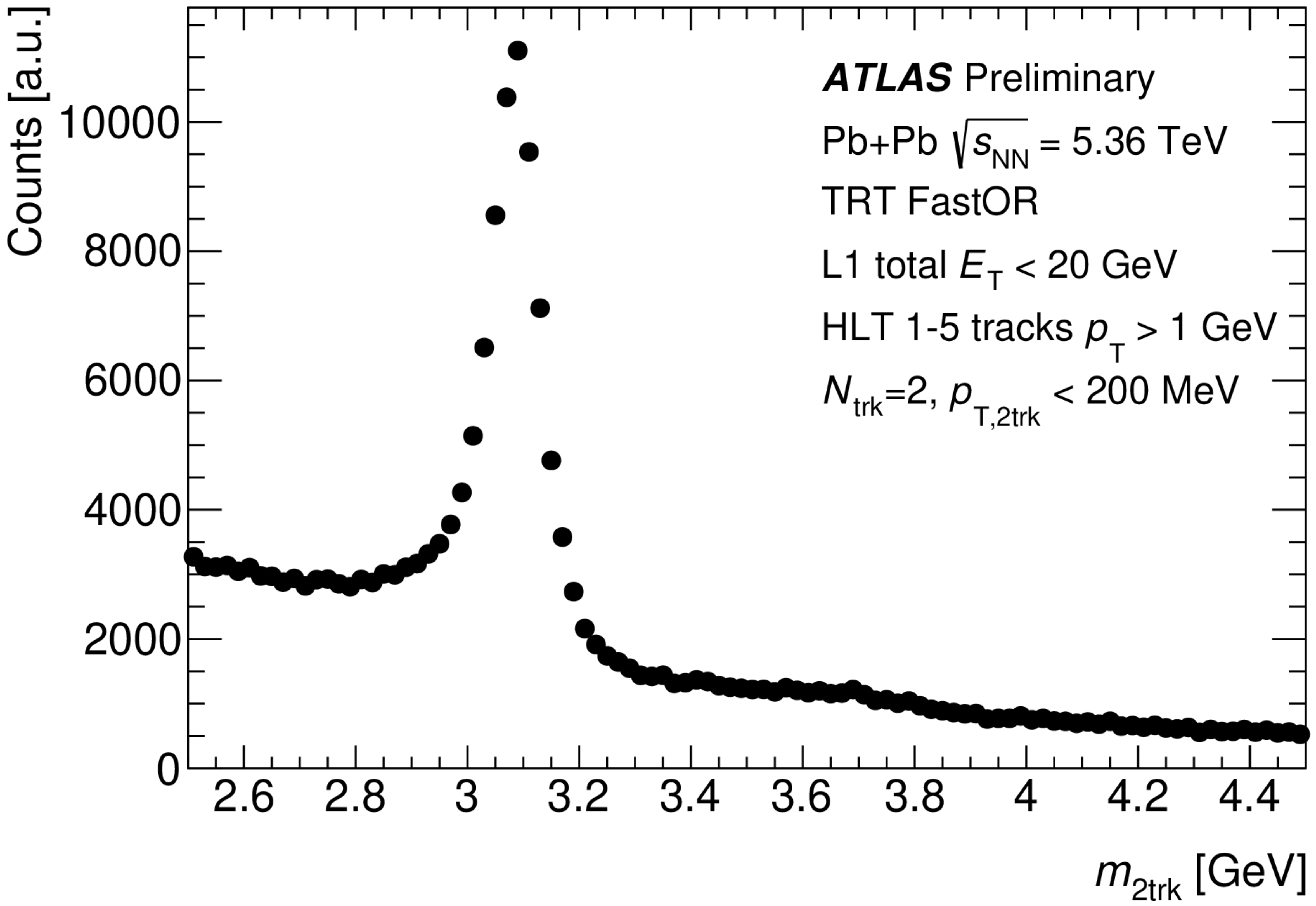
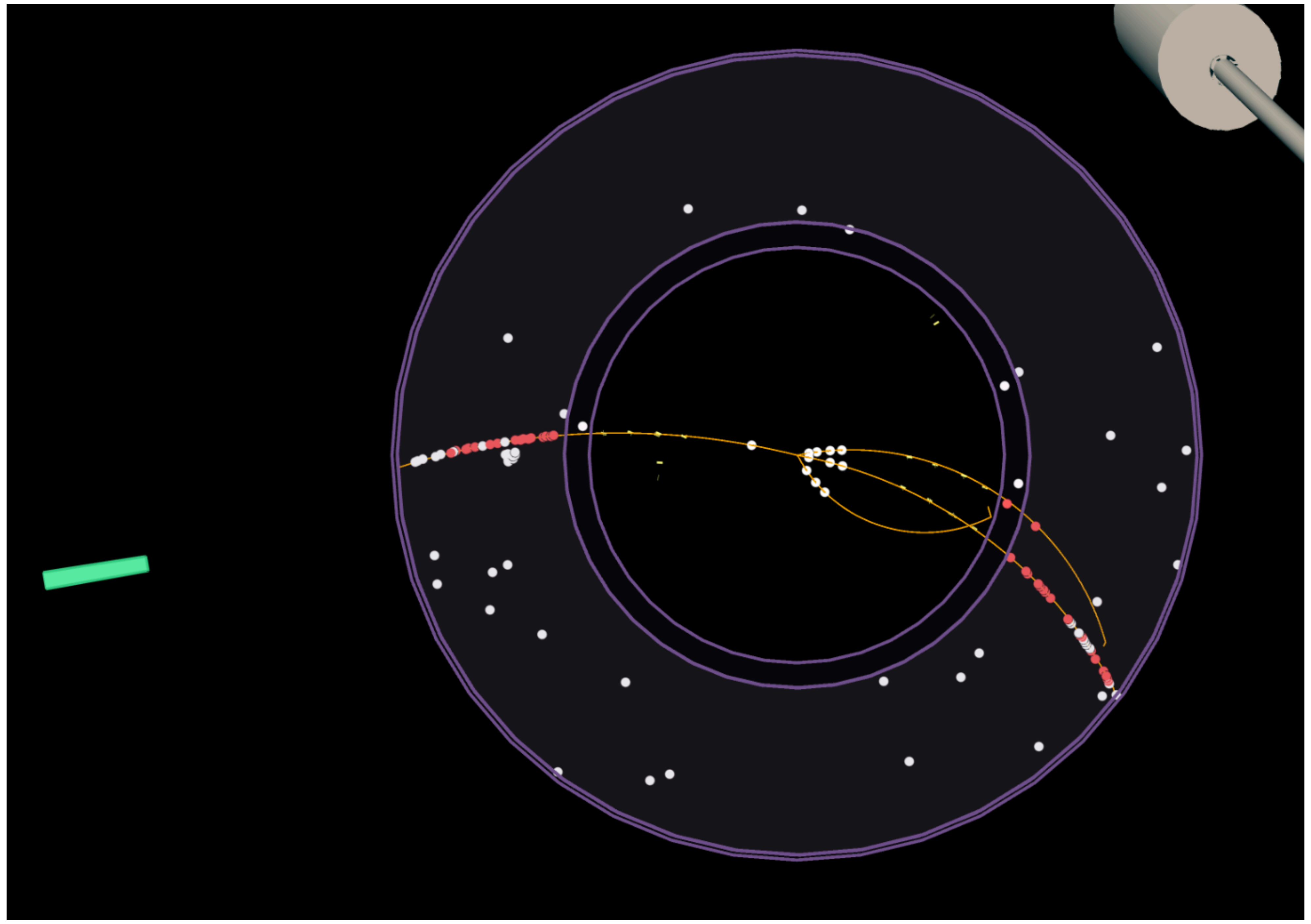
2-track selection



γγ→ τ τ → e πππ candidate



Summary

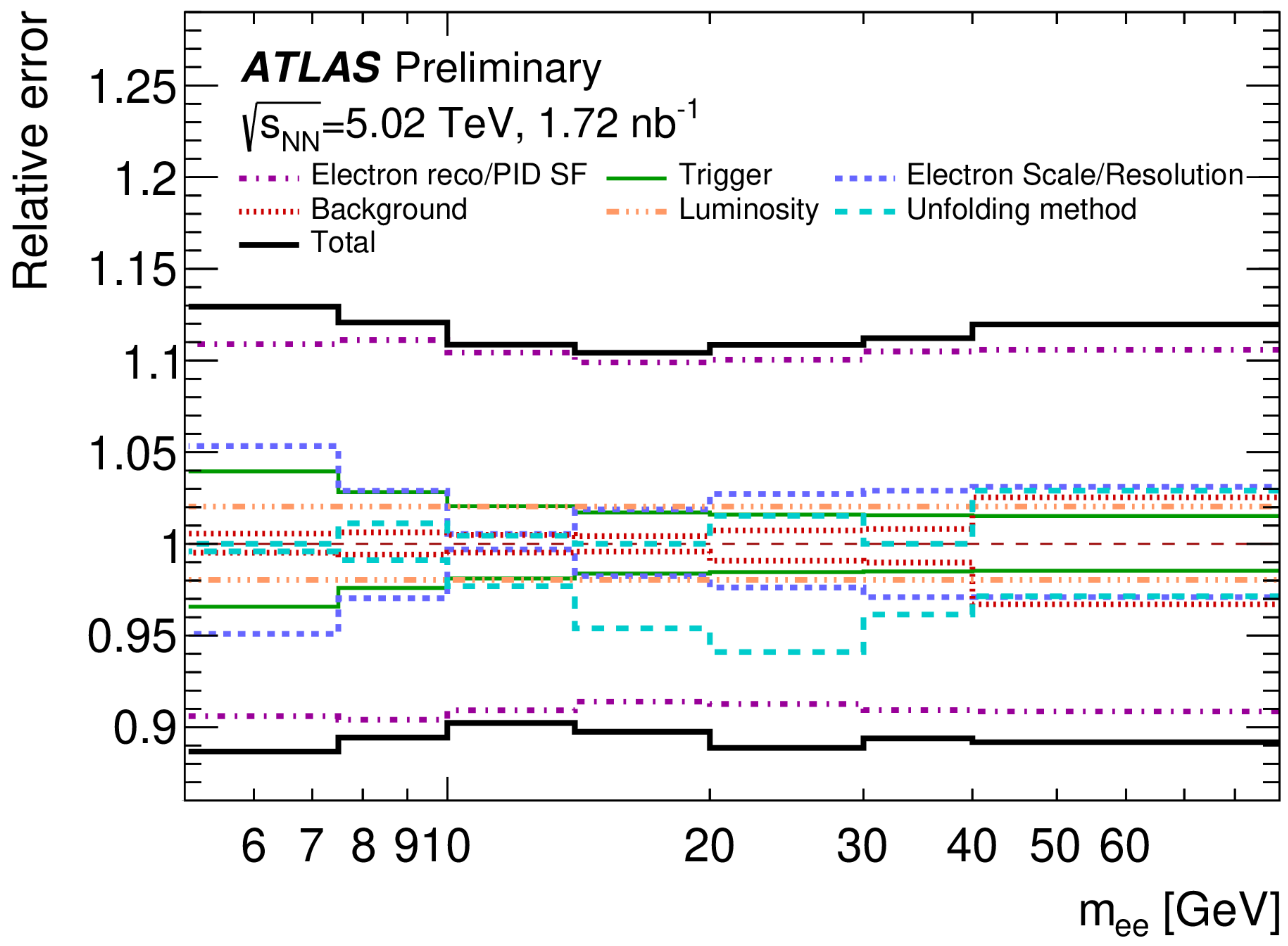
- Rich physics programme of HI UPC at the LHC with ATLAS
- HI UPC (γγ) collisions are excellent QED (and BSM) laboratories
- LHC Run 3 data provides new opportunities (with L1 track-sensitive trigger, offline improvements etc.)

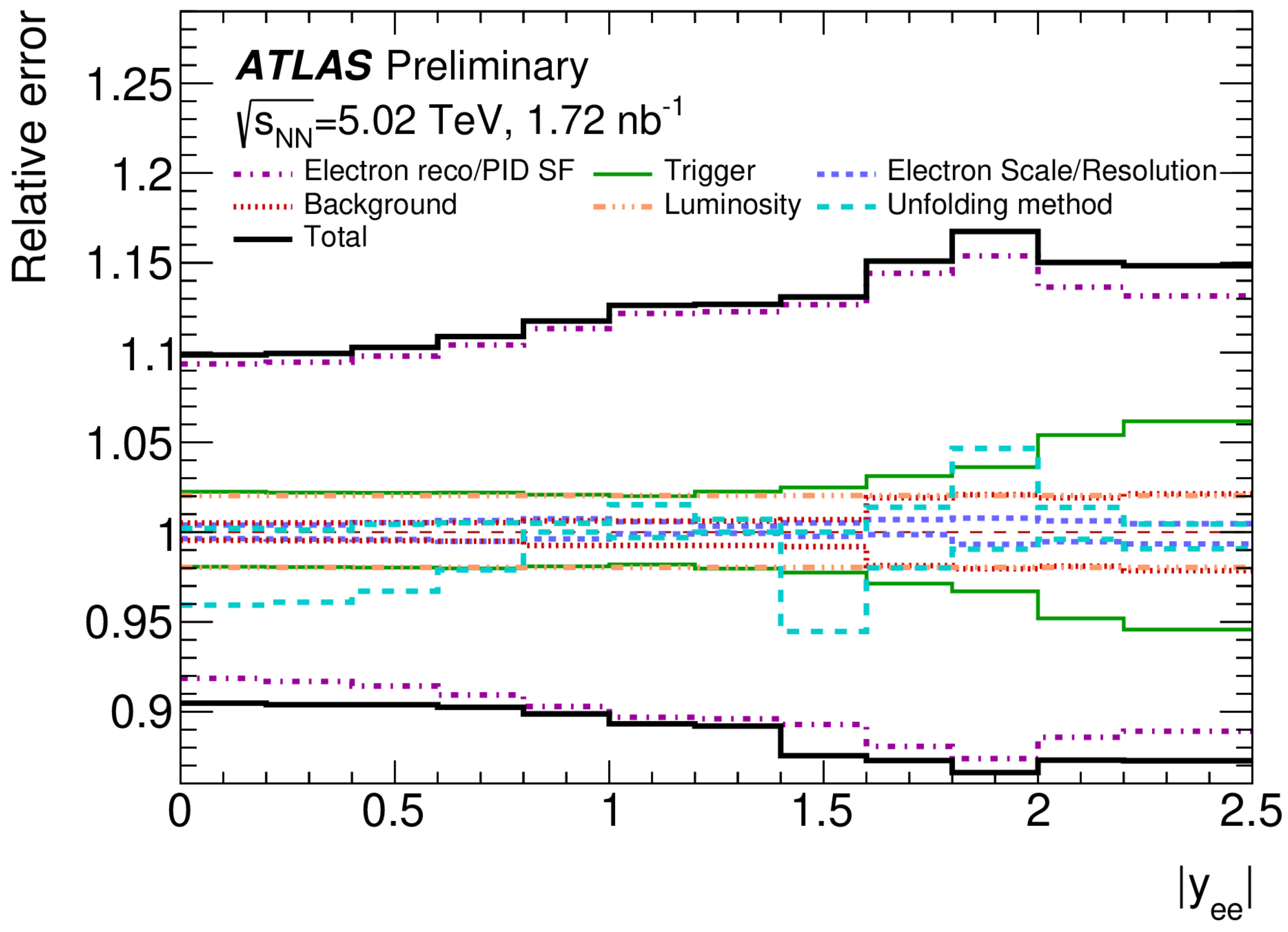
* Research project partly supported by program „Excellence initiative – research university" for the AGH University of Krakow

Backup

Exclusive dielectron production in Pb+Pb UPC

- Systematic uncertainties
  - Dominated by the knowledge of electron reco+identification efficiency





Exclusive tau-pair production in Pb+Pb UPC

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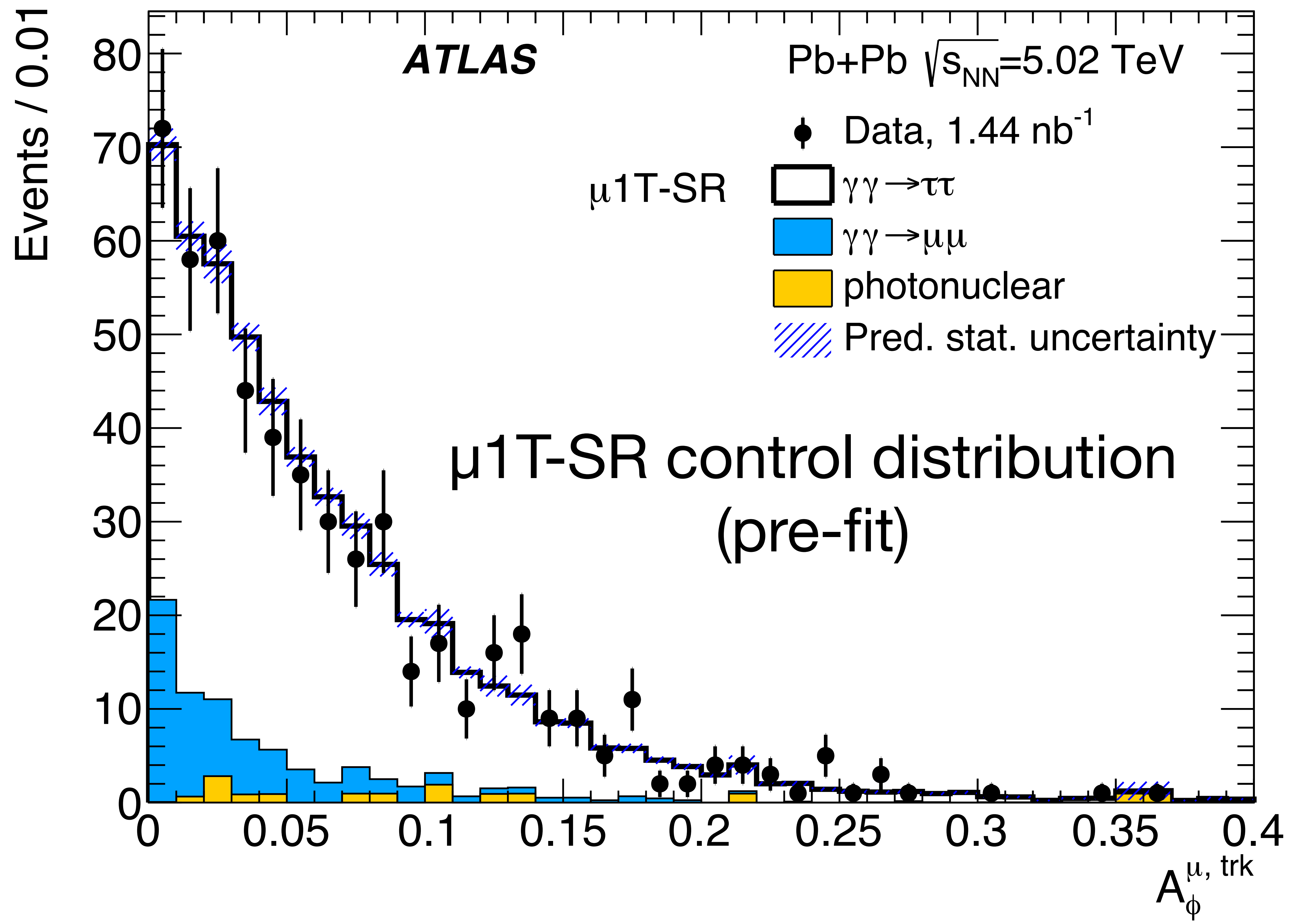

Post-fit impact

Uncertainty	Impact on $\mu_{\tau\tau}$ [%]
muon Level-1 trigger (sys)	1.0
τ decay modeling	1.0
tracking eff. (overall ID material)	0.9
muon Level-1 trigger (stat)	0.7
topocluster reco. eff.	0.6
muon reco. eff. (stat)	0.6
tracking eff. (PP0 material)	0.6
topocluster energy calib.	0.5
muon reco. eff. (sys)	0.5
photonuclear template var. (μ1T-SR)	0.5
Total systematic	2.6

a_τ parameterisation

- Elementary $\gamma\gamma \rightarrow \tau\tau$ cross section has explicit dependence on photon-τ vertex function:

$$i\Gamma_\mu^{(\gamma\ell\ell)}(p',p) = -ie\left[\gamma_\mu F_1(q^2) + \frac{i}{2m_\ell}\sigma_{\mu\nu}q^\nu F_2(q^2) + \frac{1}{2m_\ell}\gamma^5\sigma_{\mu\nu}q^\nu F_3(q^2)\right]$$

$=a_\tau\ (q^2=0)$ $\qquad$ $=d_\tau{*}2m_\tau/e\ (q^2=0)$