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

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# Ultraperipheral collisions at the Line of Physics, University of California, Davis, CA 95616, USA QUASI-RELATION OF Physics, University of California, Davis, CA 95616, USA QUASI-RELATION OF Physics, University of California, Davis, CA 94720, USA QUASI-RELATION OF Physics, University of California, Davis, CA 94720, USA QUASI-RELATION OF Physics, University of California, Davis, CA 94720, USA QUASI-RELATION OF Physics, University of California, Davis, CA 94720, USA QUASI-RELATION OF Physics, University of California, Davis, CA 94720, USA QUASI-RELATION OF Physics, University of California, Davis, CA 94720, USA QUASI-RELATION OF Physics, University of California, Davis, CA 94720, USA QUASI-RELATION OF Physics, University of California, Davis, CA 94720, USA QUASI-RELATION OF Physics, University of California, Davis, CA 94720, USA QUASI-RELATION OF Physics, University of California, Davis, CA 94720, USA QUASI-RELATION OF Physics, University of California, Davis, CA 94720, USA QUASI-RELATION OF Physics, University of California, Davis, CA 94720, USA QUASI-RELATION OF Physics, University of California, Davis, CA 94720, USA QUASI-RELATION OF Physics, University of California, Davis, CA 94720, USA QUASI-RELATION OF Physics, University of California, Davis, CA 94720, USA QUASI-RELATION OF Physics, University of California, Davis, CA 94720, USA QUASI-RELATION OF Physics, University of California, Davis, CA 94720, USA QUASI-RELATION OF Physics, University of California, Davis, CA 94720, USA QUASI-RELATION OF Physics, University of California, Davis, CA 94720, USA QUASI-RELATION OF Physics, University of California, Davis, CA 94720, USA QUASI-RELATION OF Physics, University of California, Davis, CA 94720, USA QUASI-RELATION OF Physics, University of California, USA QUASI-RELATION OF Physics, USA QUASI-RELATION

Boosted nuclei are intense source of quasi-real photons

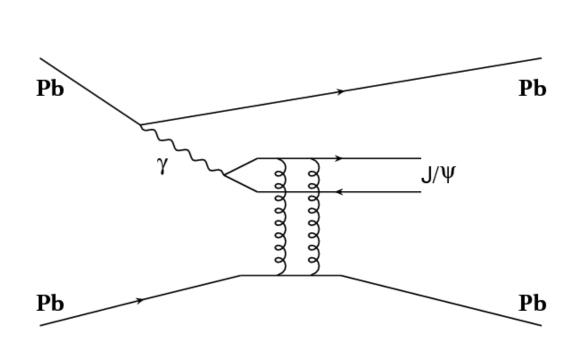
We calculate production rates for several hard processes in ultraperipheral proton-nucleus and nucleus nucleus collisions at the LHC. The resulting high rates demonstrate that some key directions in small x res

proposed for HERA will be actes ible at the LHC through fire ultraperipheral processes. Indeed, these surements can extend the HERA & range by roughly a factor of 10 for similar virtualities. Nonlinear effe

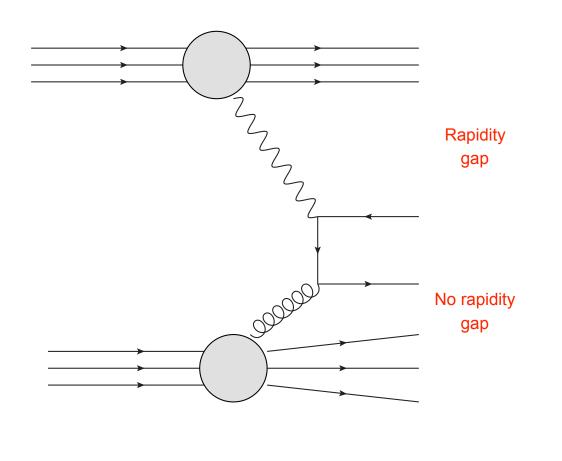
the part of densities will thus be significantly more important in these collisions than at HERA.

- Coherent photon flux
  - $E_{max} \leq \gamma/R \sim 80 \text{ GeV @LHC (~3 GeV @RHIC)}$
  - **Q ~ 1/R ~ 30 MeV** @ LHC/RHIC
  - Each photon flux scales with ~Z2 EMENTS

Various types of interactions possible:



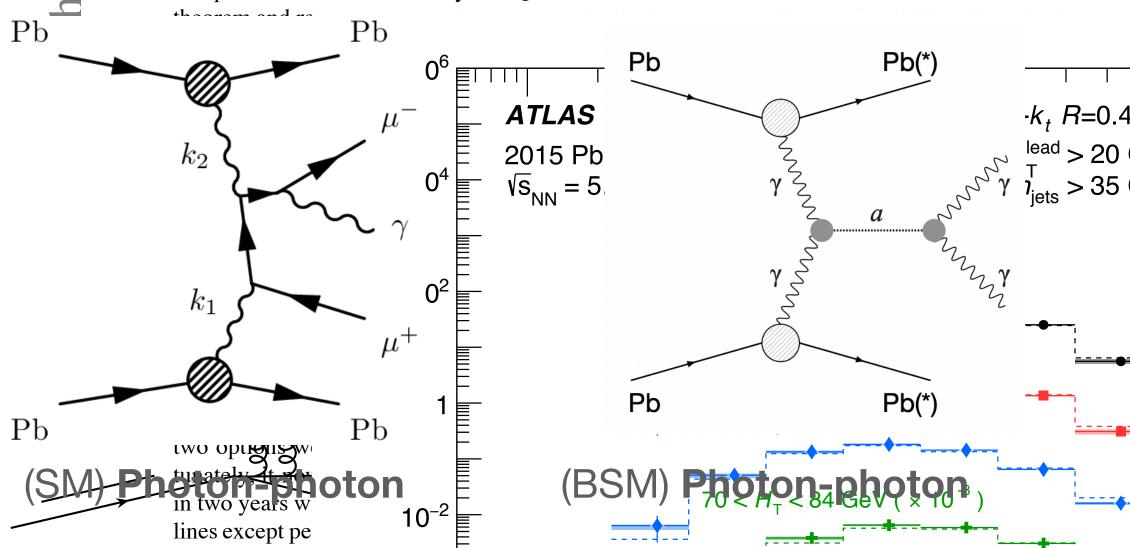
**Diffractive Photo-nuclear** 



(Inelastic) Photo-nuclear

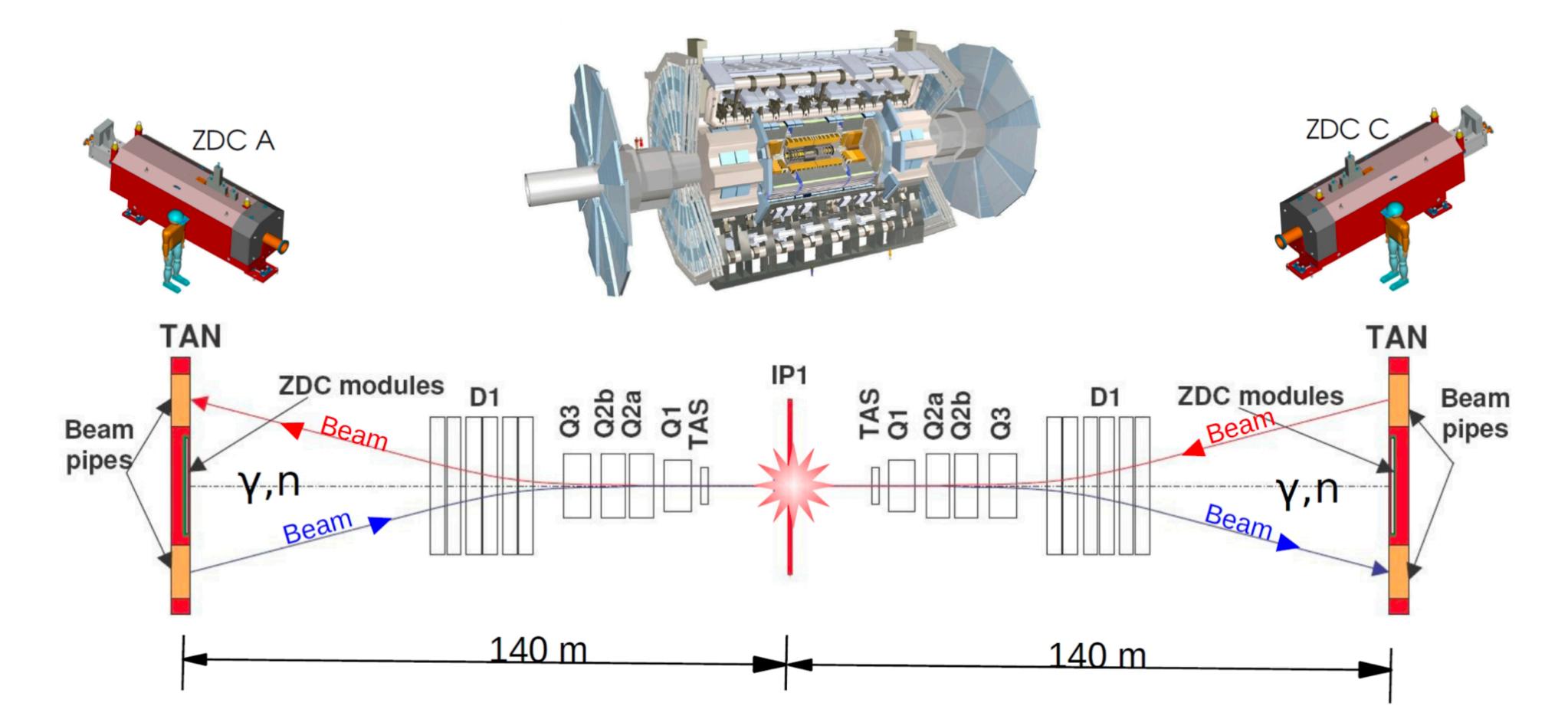
Studies of small x deep inelastic scattering at HERA ubstantially improved our understanding of strong interactions at high energies. Among the key findings of HERA were the direct observation of the rapid growth of the small x structure functions over a wide range of virtualities,  $Q^2$ , and the observation of a significant probability for hard diffraction consistent with approximate scaling and a logarithmic  $Q^2$  dependence ("lead ing twist" dominance). HERA also established a new T substantial rapidity gap An the same directions. class of hard exclusive processes – high  $Q^2$  vector meson production - described by the QCD factorization

continued and extended by studies of ult heavy ion collisions (UPCs) at the LHC. U teractions of two heavy nuclei (or a proto cleus) in which a nucleus emits a quasithat interacts with the other nucleus (or pro collisions have the distinct feature that emitting nucleus either does not break up on a few neutrons through Coulomb exertistic kinematics can be readily identified by t LHC detectors, ATLAS and CMS. In th

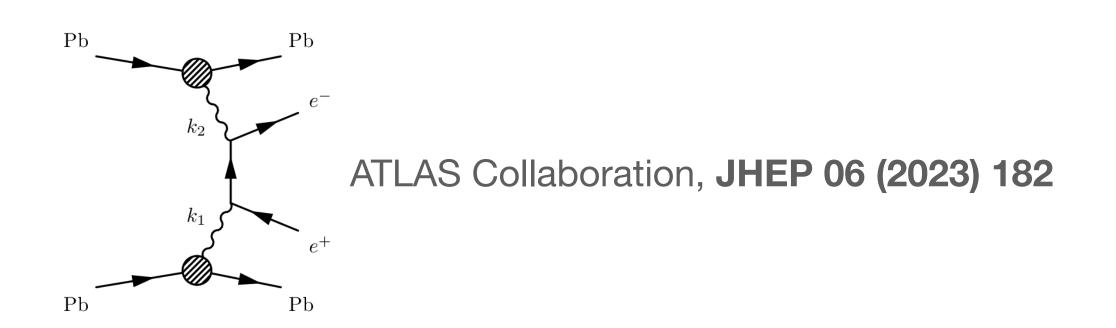


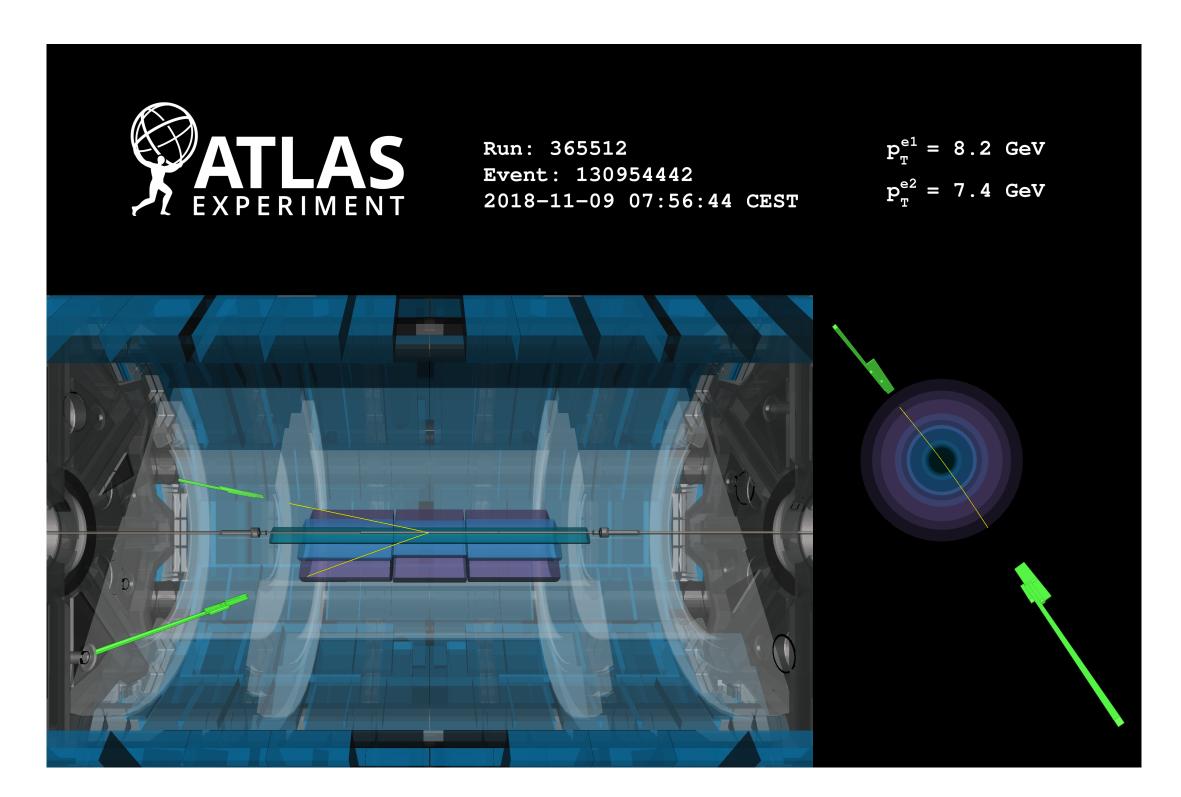
#### Experimental considerations

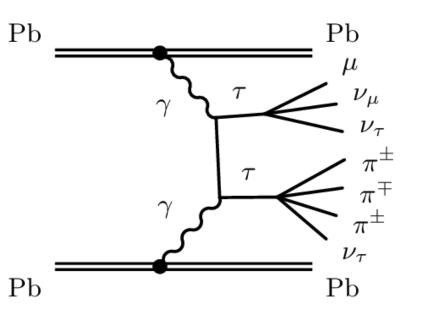
- Rapidity gaps & Exclusive final states → Veto requirements are essential
- Many sub-detectors available in ATLAS (letal<4.9)</li>
- (Absence of) ion dissociation tagged with Zero Degree Calorimeters (ZDC)



#### Outline

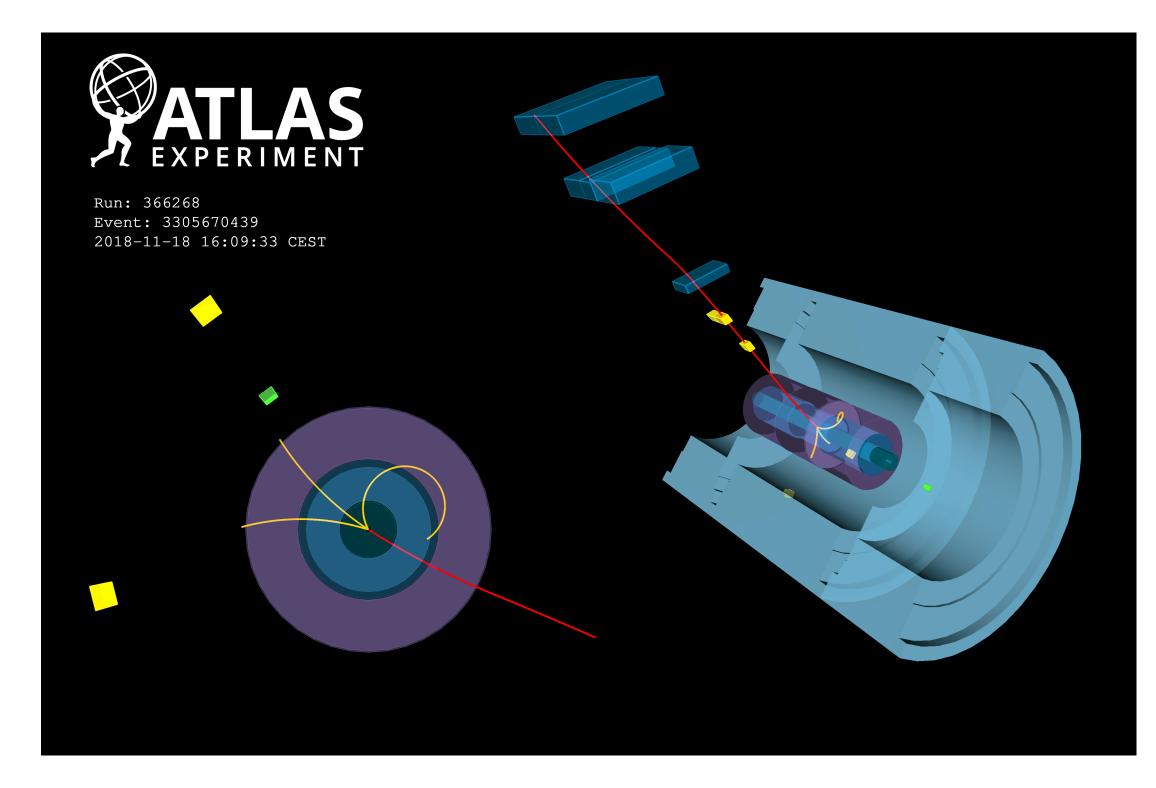






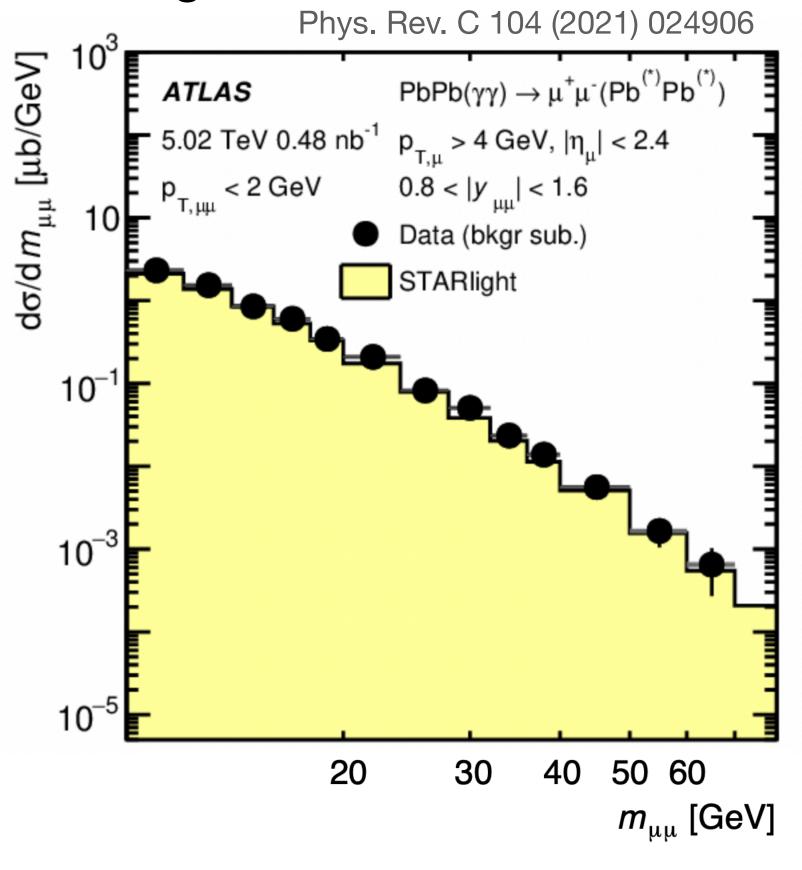
ATLAS Collaboration,

Phys. Rev. Lett. 131 (2023) 15, 151802

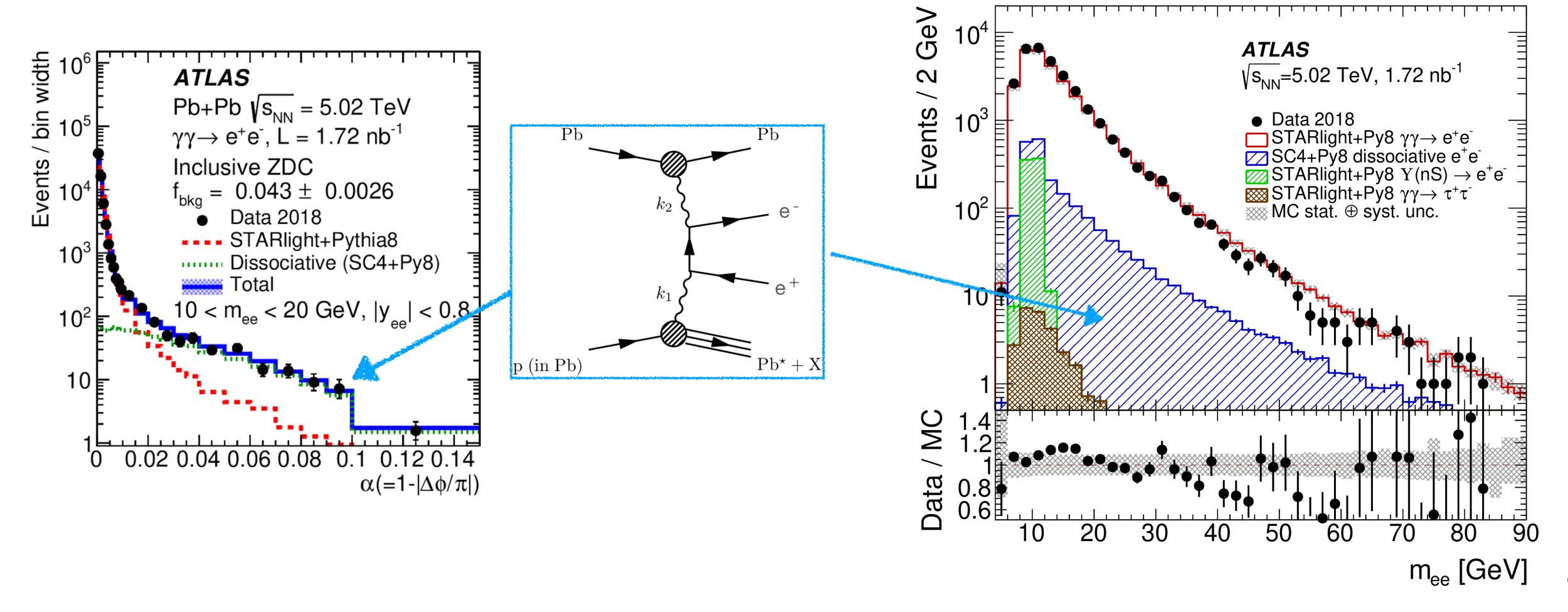


- 'Standard candle' for γγ-fusion processes
  - Good sensitivity for Pb EM formfactors → photon flux modeling
  - Sensitivity to probe higher-order corrections
- New ATLAS measurement (γγ→ee) extends the previous (γγ→μμ) study

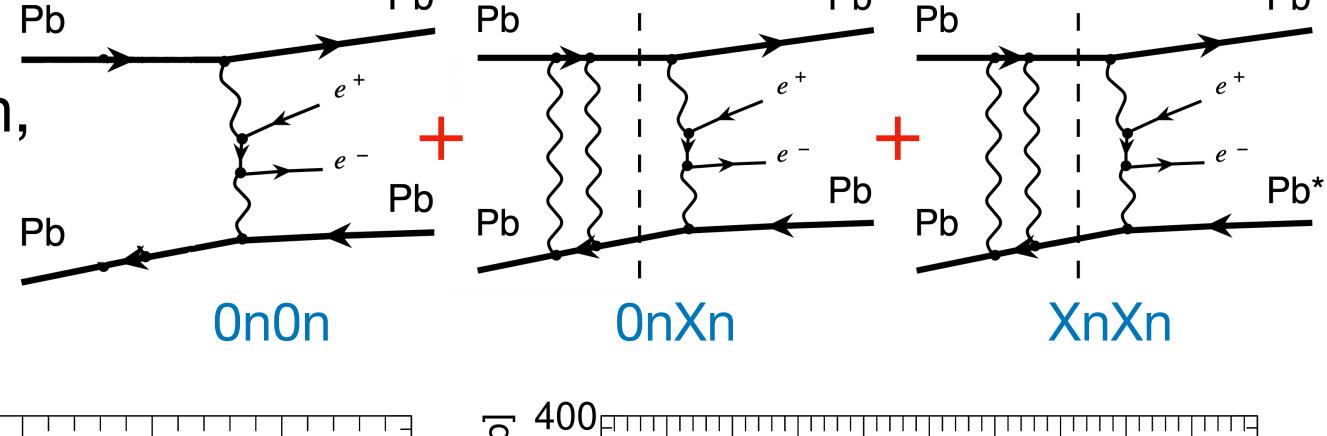
	$\gamma\gamma \rightarrow \mu^{+}\mu^{-}$	$\gamma\gamma \rightarrow e^+e^-$
Data	2015	2018
Int lumi	0.48 nb <sup>-1</sup>	1.72 nb <sup>-1</sup>
Fiducial	$p_{\rm T}^{\mu} > 4  {\rm GeV} \  \eta^{\mu}  < 2.4 \ m_{\mu\mu} > 10  {\rm GeV} \ p_{\rm T}^{\ell\ell} < 2  {\rm GeV} $	$p_{\mathrm{T}}^{e} > 2.5 \text{ GeV}$ $ \eta^{e}  < 2.5$ $m_{ee} > 5 \text{ GeV}$ GeV

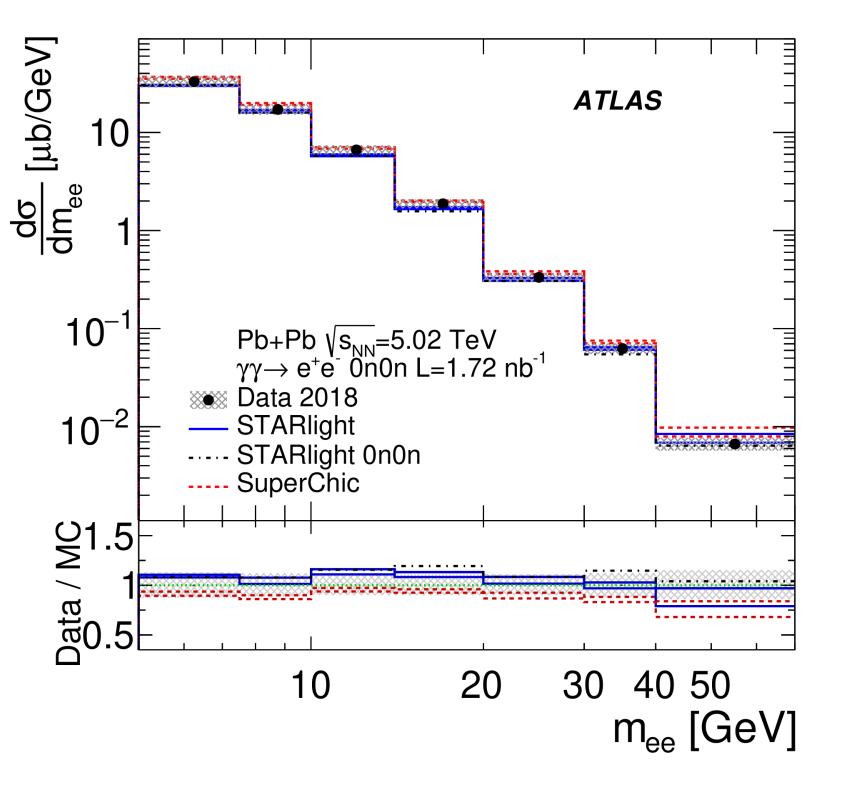


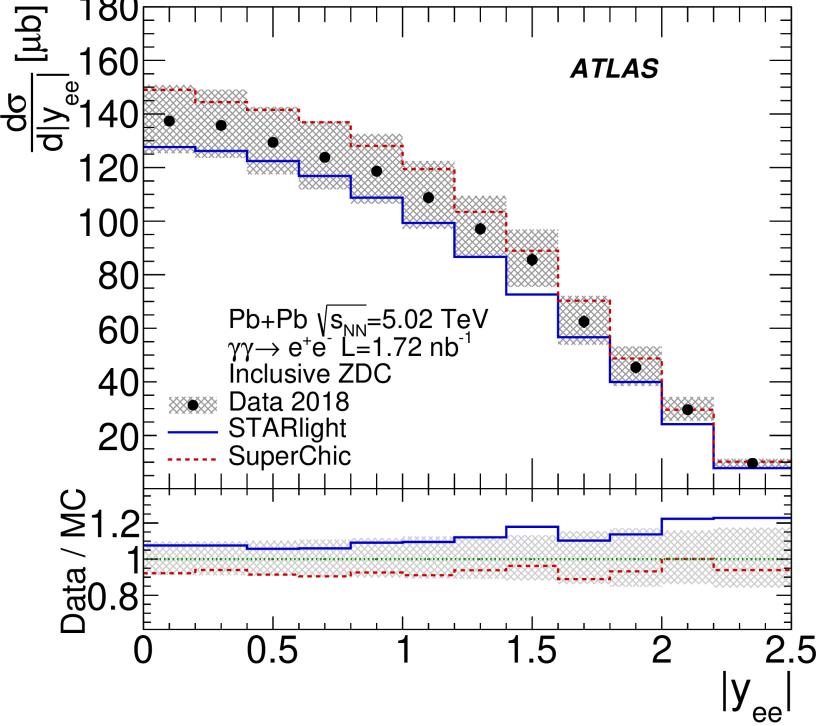
- Background dominated by dissociative production with an off-shell photon
  - Extracted using template fit to dielectron acoplanarity

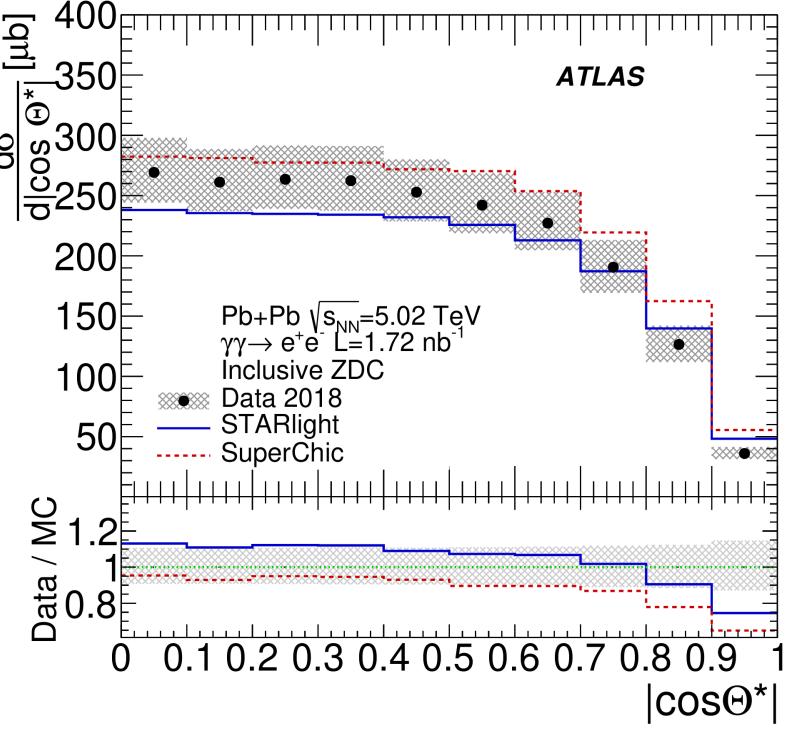


• Results for "inclusive ZDC" selection, i.e. sum of three event classes:

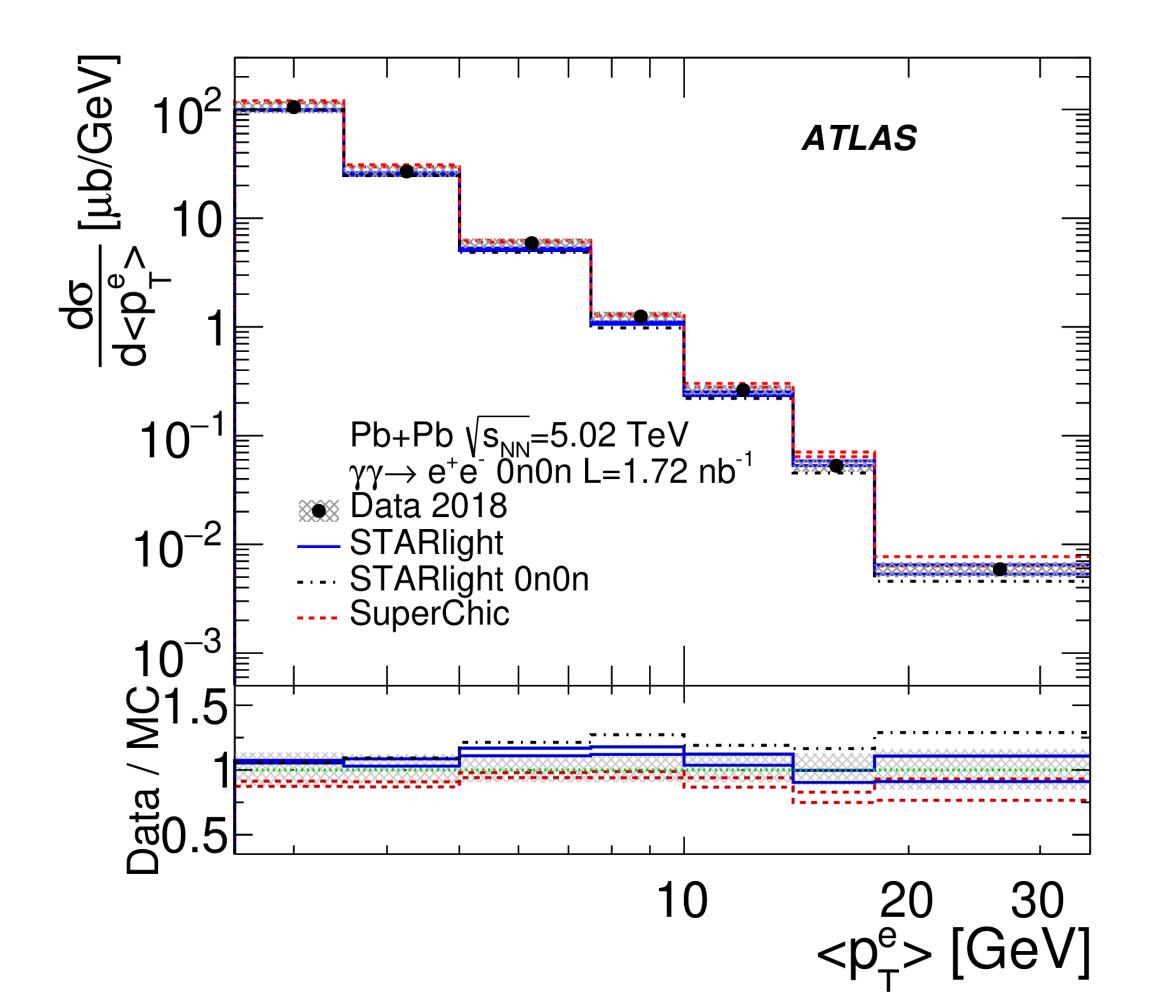


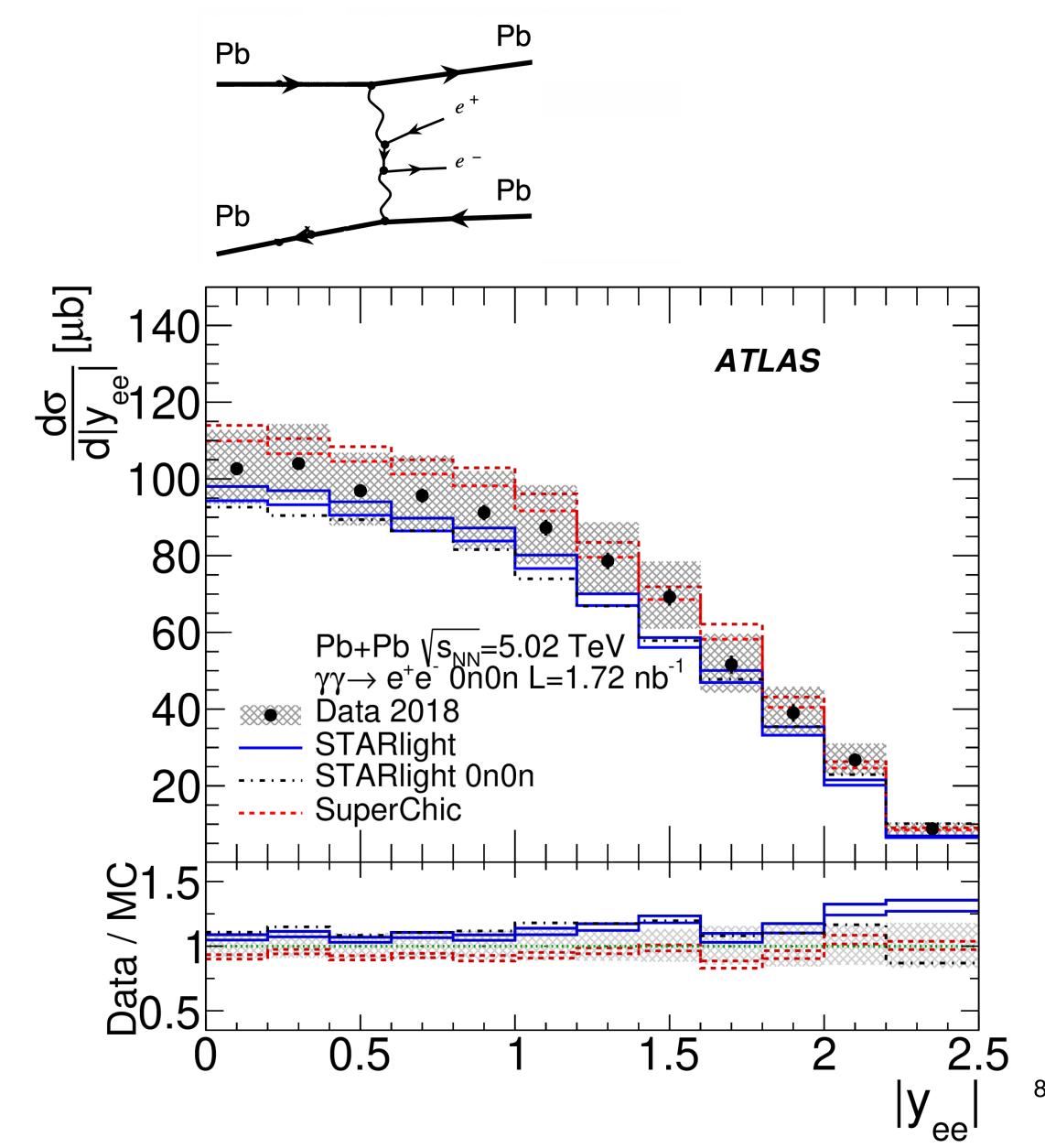






Results for "0n0n" ZDC selection

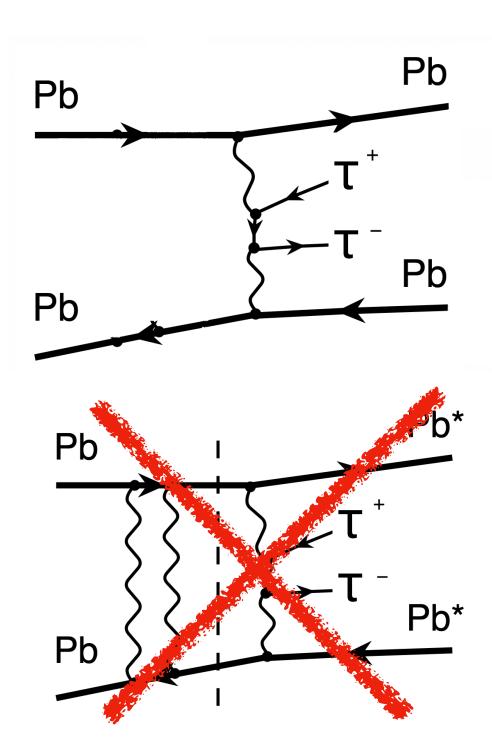




- More challenging experimentally due to low-energy tau decays
- Strategy: exploit semi-leptonic decays with muon
  - μe-SR: muon + electron
  - μ1T-SR: muon + 1 track (soft e/μ/pion)
  - **µ3T-SR**: muon + 3 tracks (3 pions)

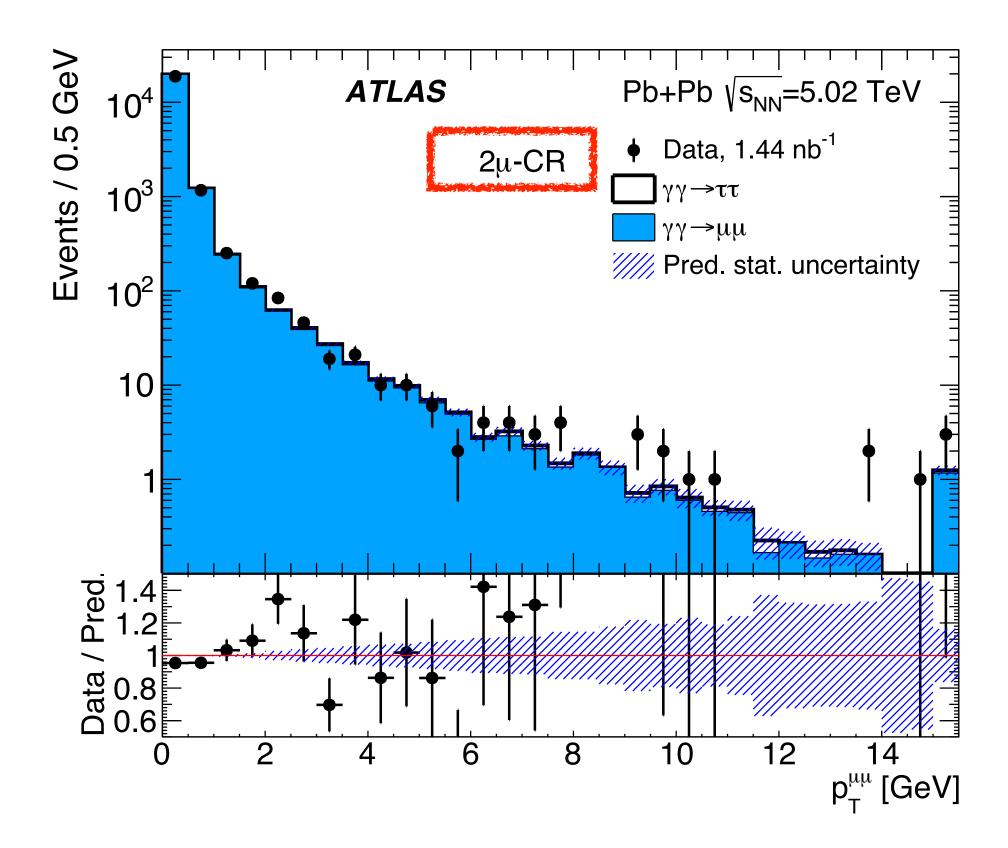
#### • Exclusivity:

- Veto extra tracks
- Veto additional calorimeter clusters (μ1T-SR and μ3T-SR only)
- **OnOn** ZDC selection to further suppress hadronic backgrounds (mainly photonuclear production)

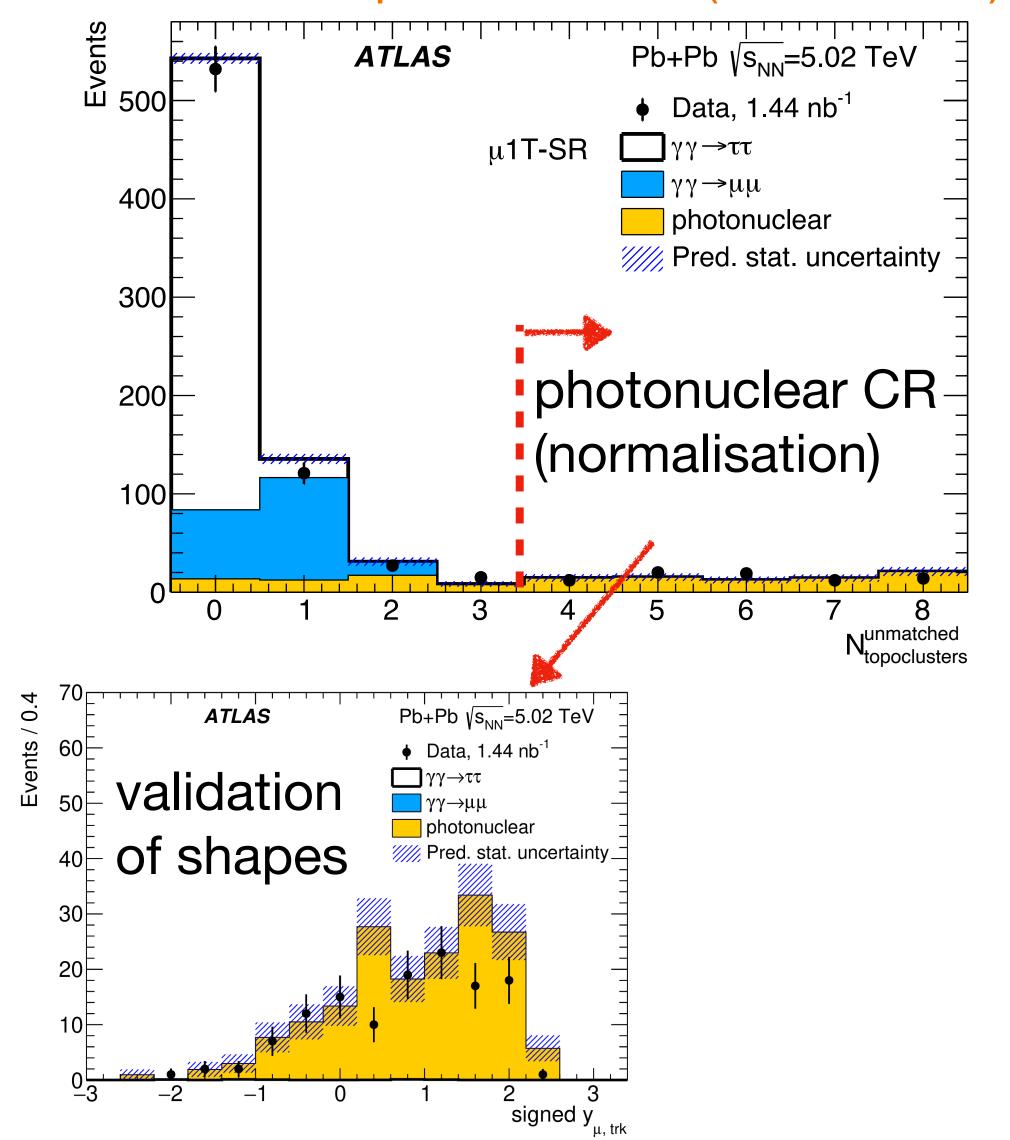


Main backgrounds

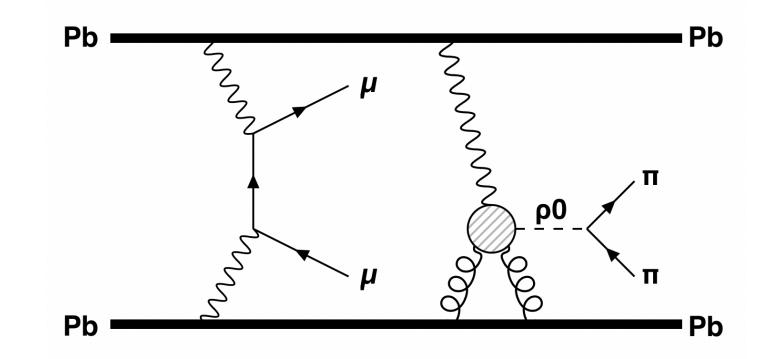


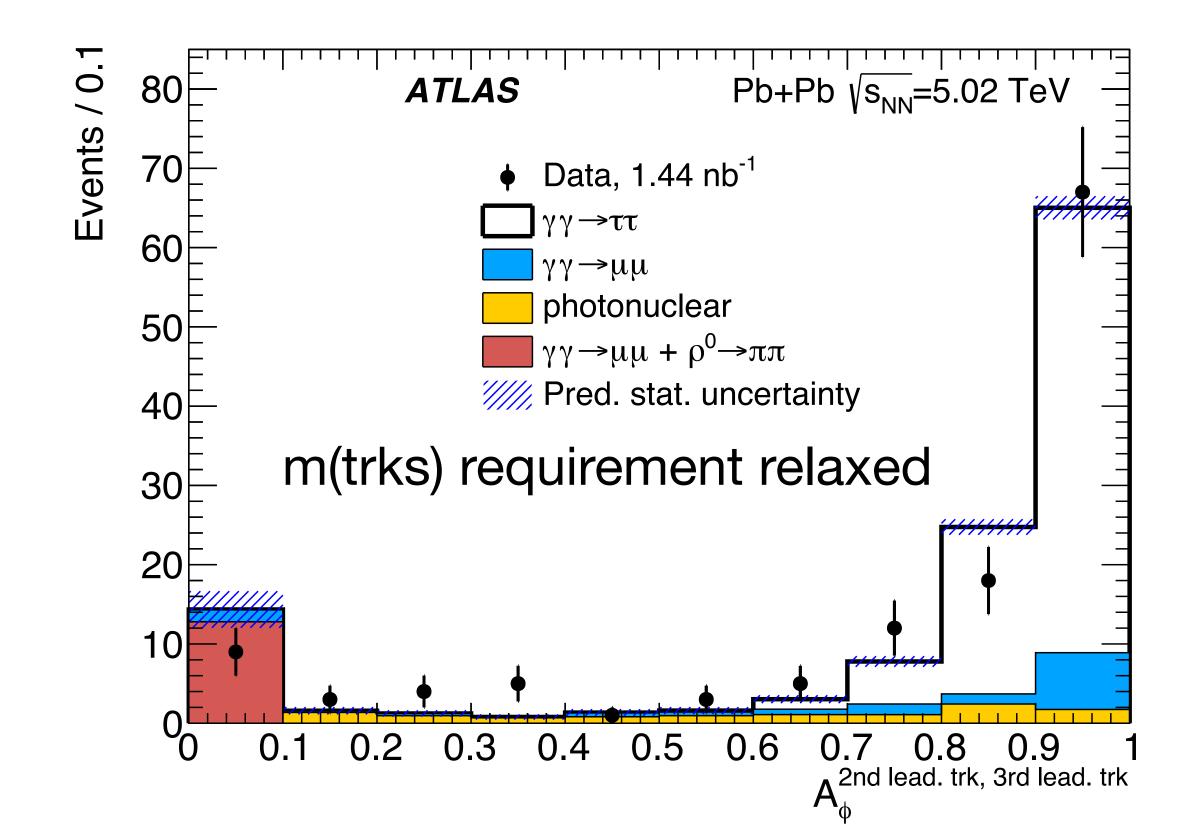


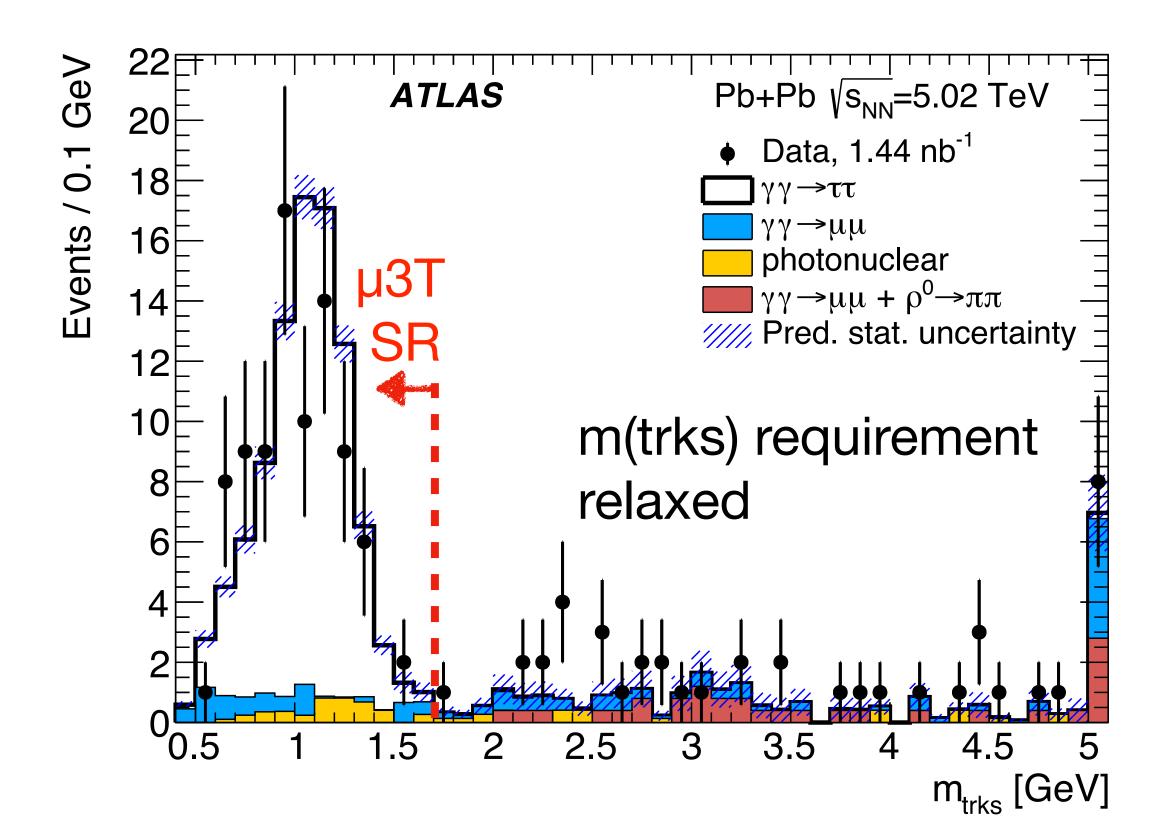
#### Diffractive photonuclear (data-driven)



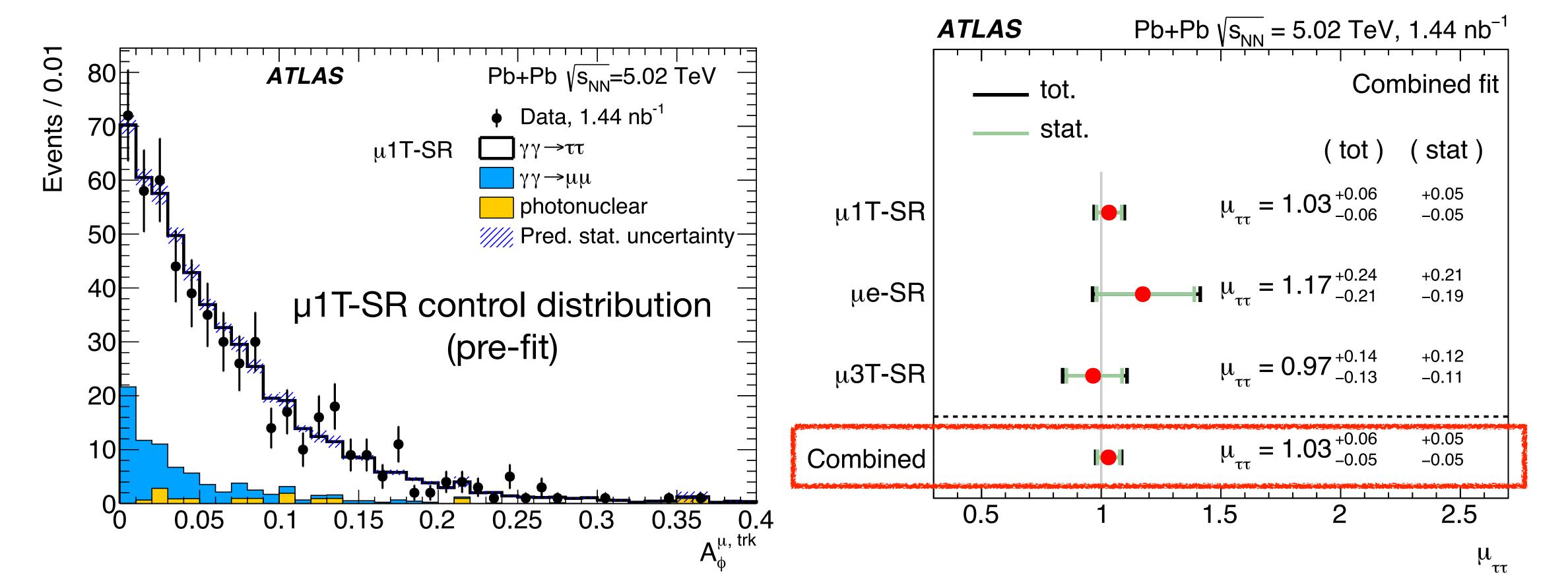
- Other backgrounds
  - Simultaneous γγ→μμ and γPb→ρ0→π+πproduction ('DPS') observed
  - μ3T-SR: Cut on m(trks)<1.7 GeV removes it fully







- 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!



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

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

au

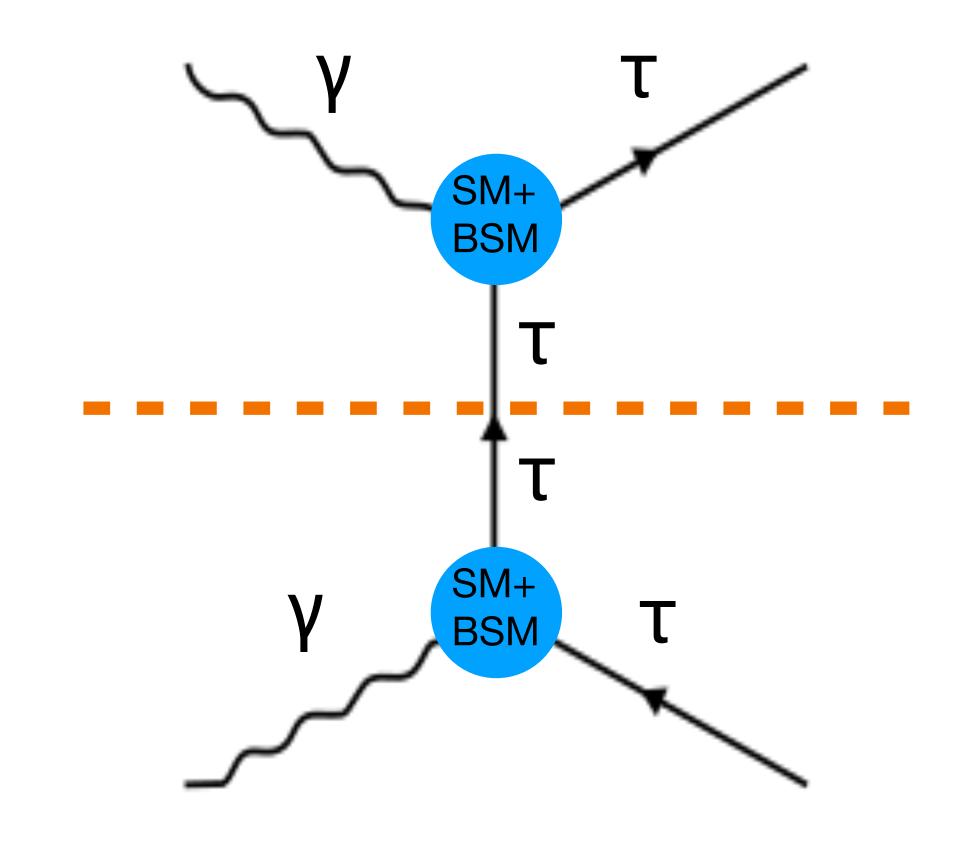
$$J=\frac{1}{2}$$

Mass  $m=1776.86\pm0.12$  MeV  $(m_{\tau^+}-m_{\tau^-})/m_{\rm average}<2.8\times10^{-4},$  CL =90% Mean life  $\tau=(290.3\pm0.5)\times10^{-15}$  s  $c au=87.03~\mu{\rm m}$ 

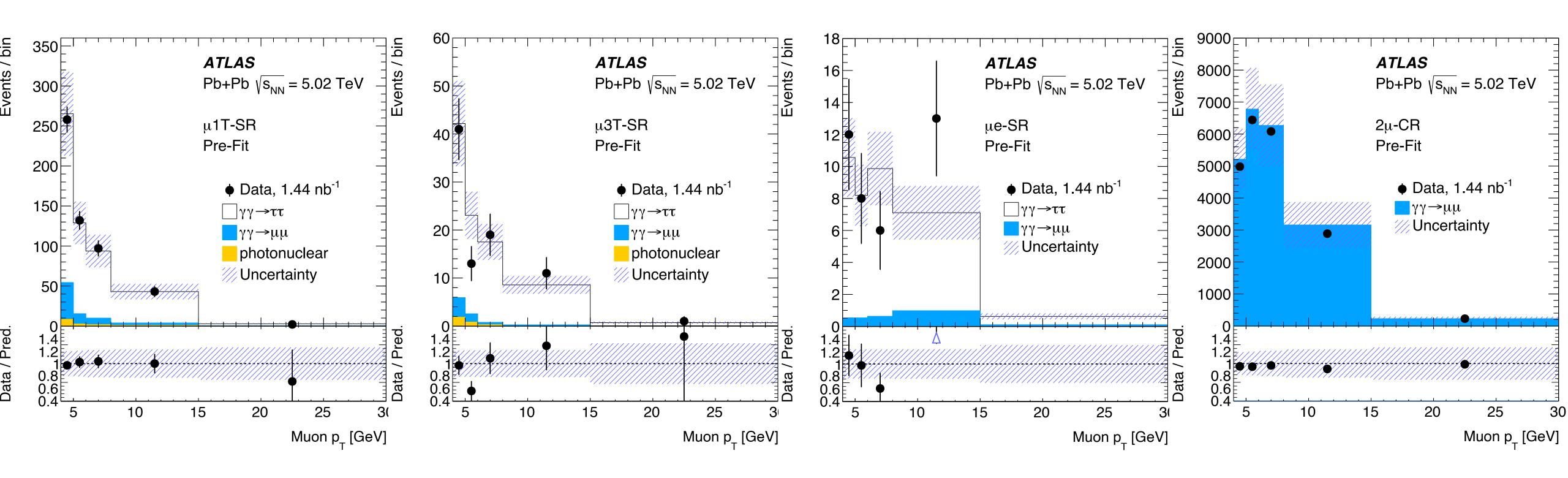
Magnetic moment anomaly >-0.052 and <0.013, CL =95% Re( $d_{\tau}$ ) =-0.220 to  $0.45\times 10^{-16}~e$  cm, CL =95%

 ${
m Im}(d_{ au}) = -0.250 \ {
m to} \ 0.0080 \times 10^{-16} \ e\,{
m cm}, \ {
m CL} = 95\%$ 

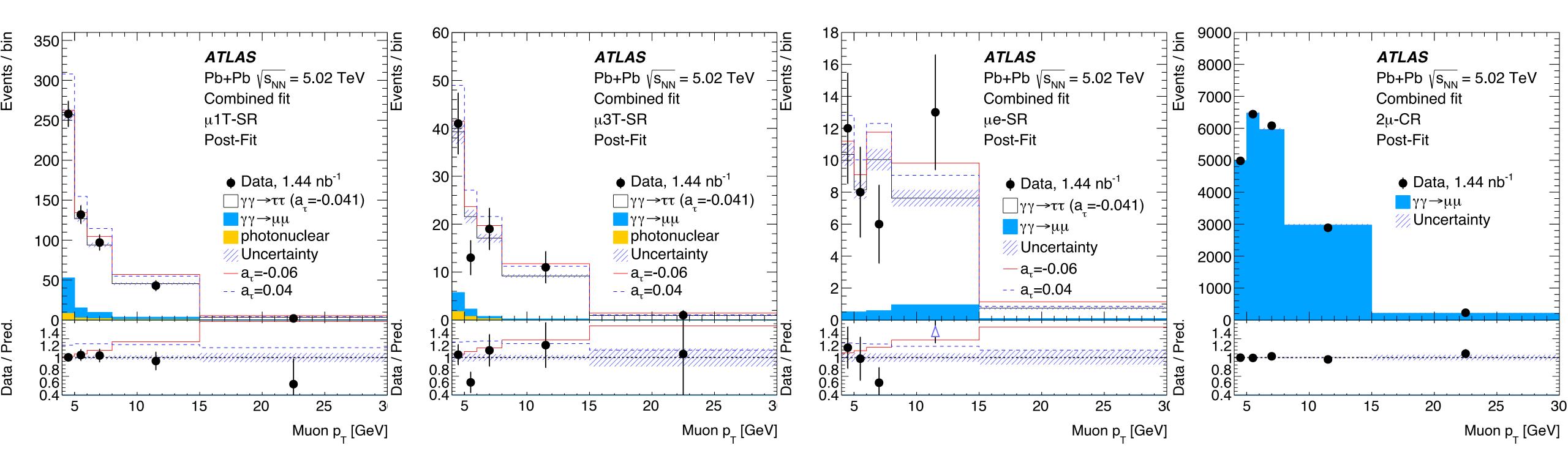
$$a_{\tau}^{\text{SM}} = 0.001\ 177\ 21\ (5)$$



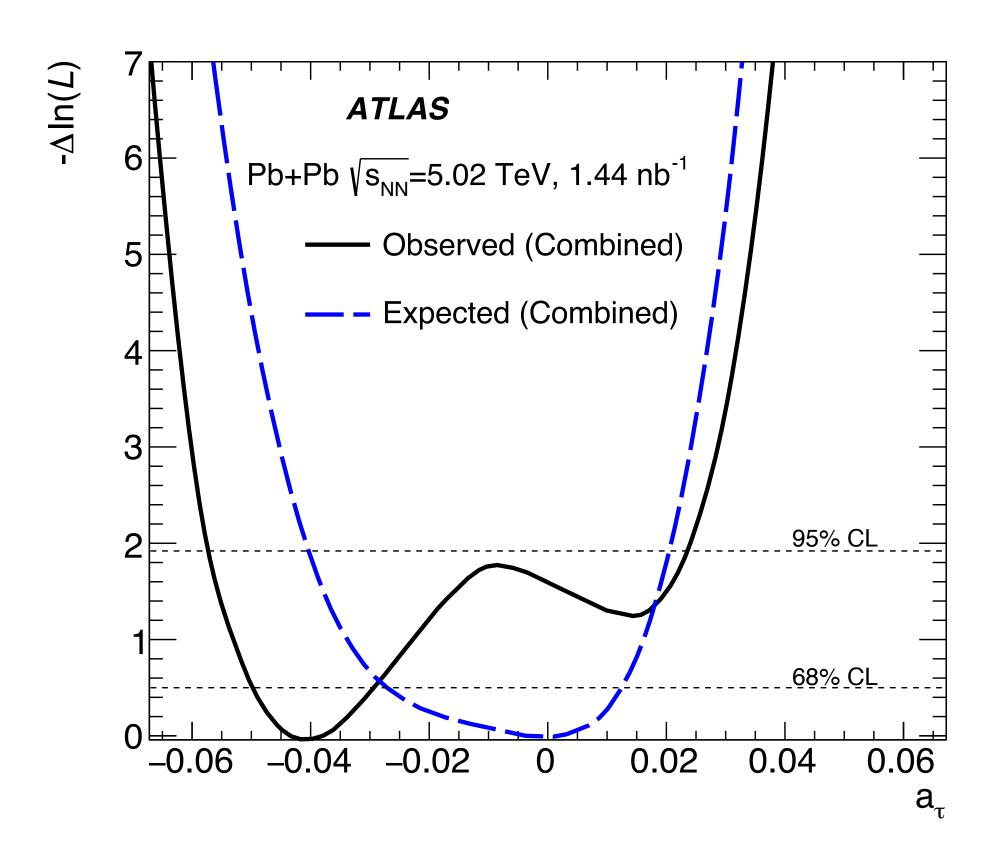
- Measure  $a_{\tau} = (g_{\tau} 2)/2$  with template fit
  - Using pT(μ) distribution in the three SRs and 2μ-CR
  - a<sub>τ</sub> templates: reweighting signal MC [weights from PLB 809 (2020) 135682] + morphing

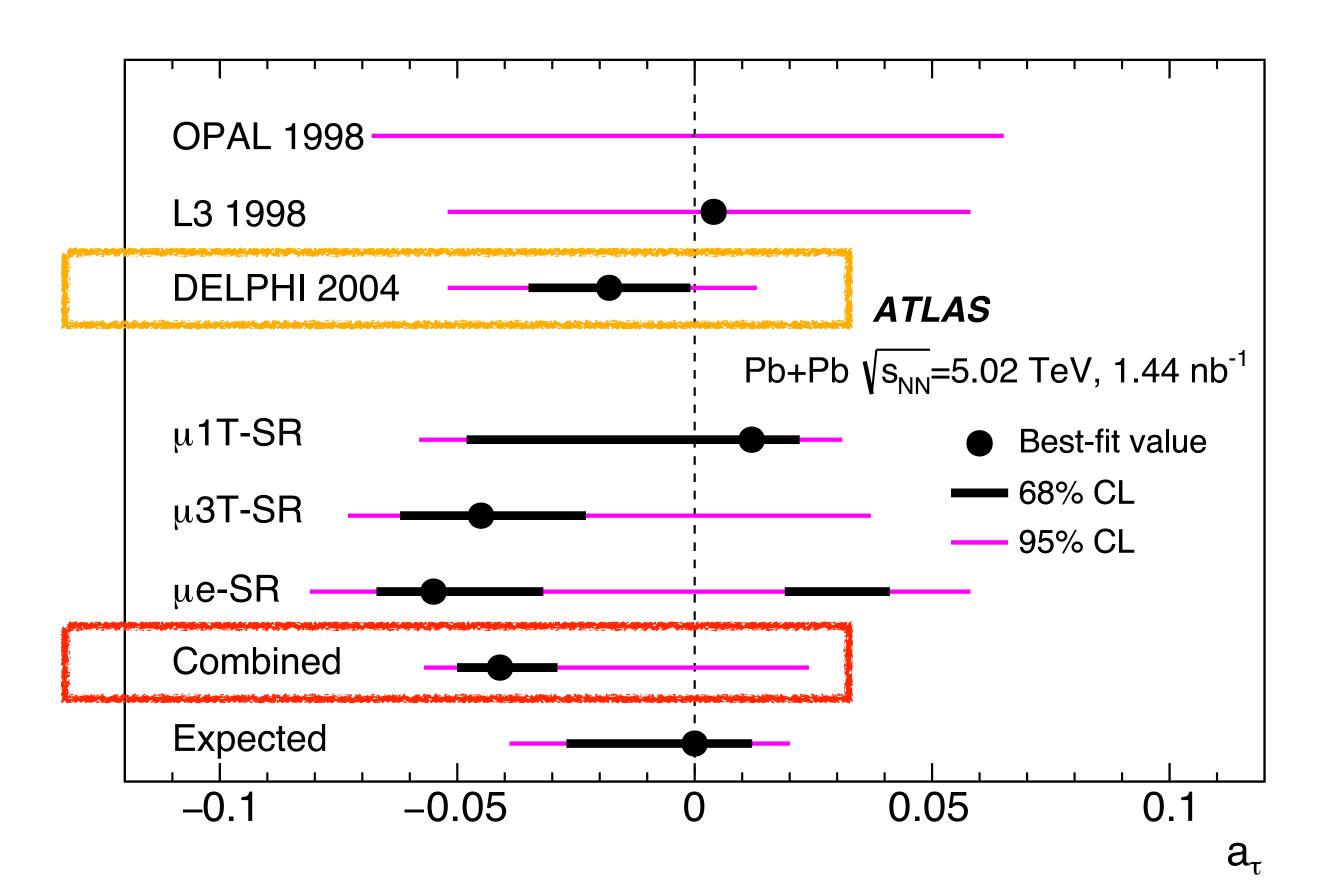


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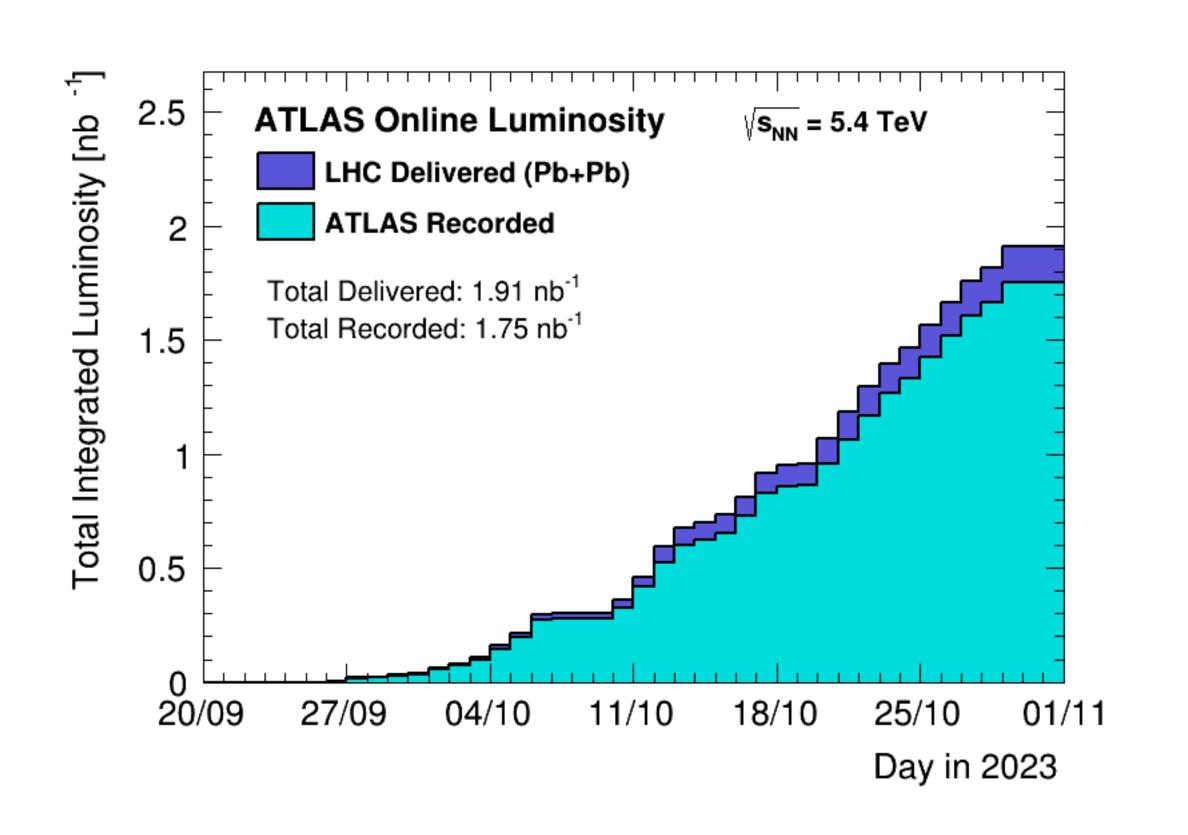
• Constraints on a<sub>τ</sub> similar to those observed at LEP

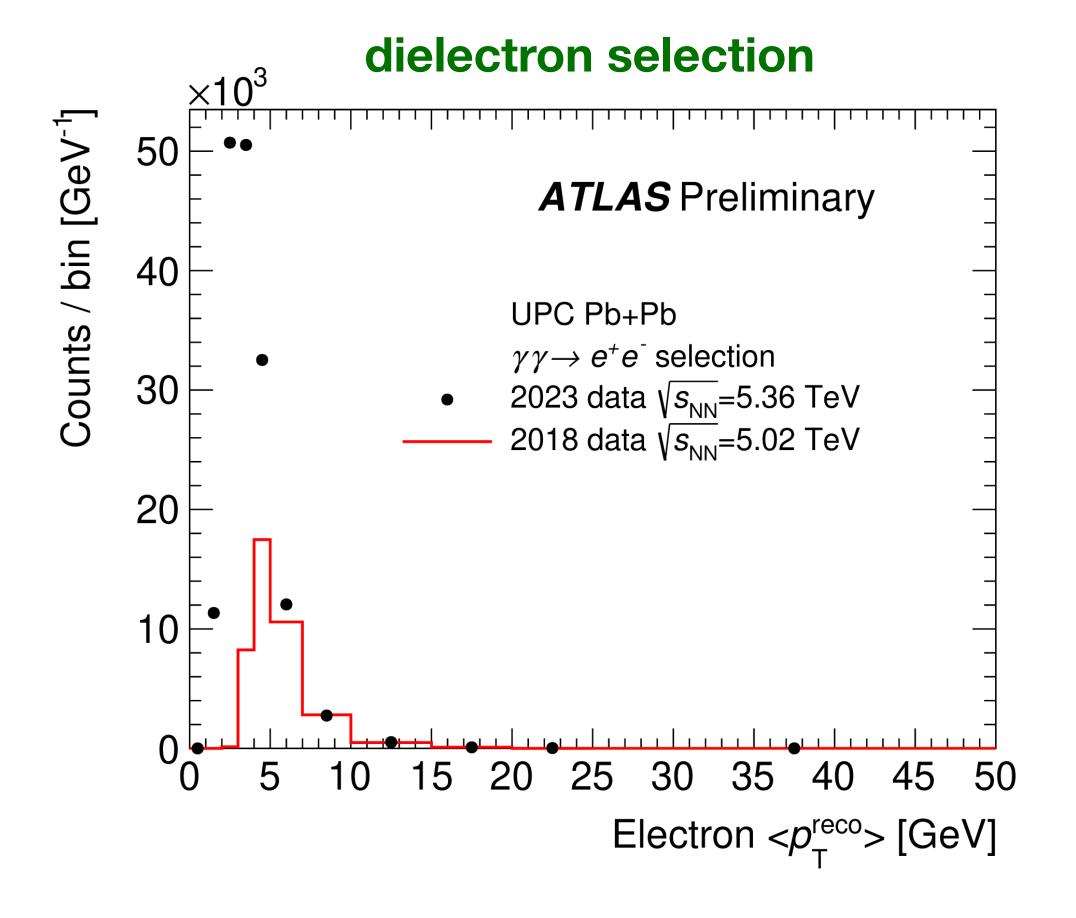




#### Future ATLAS UPC measurements with leptons

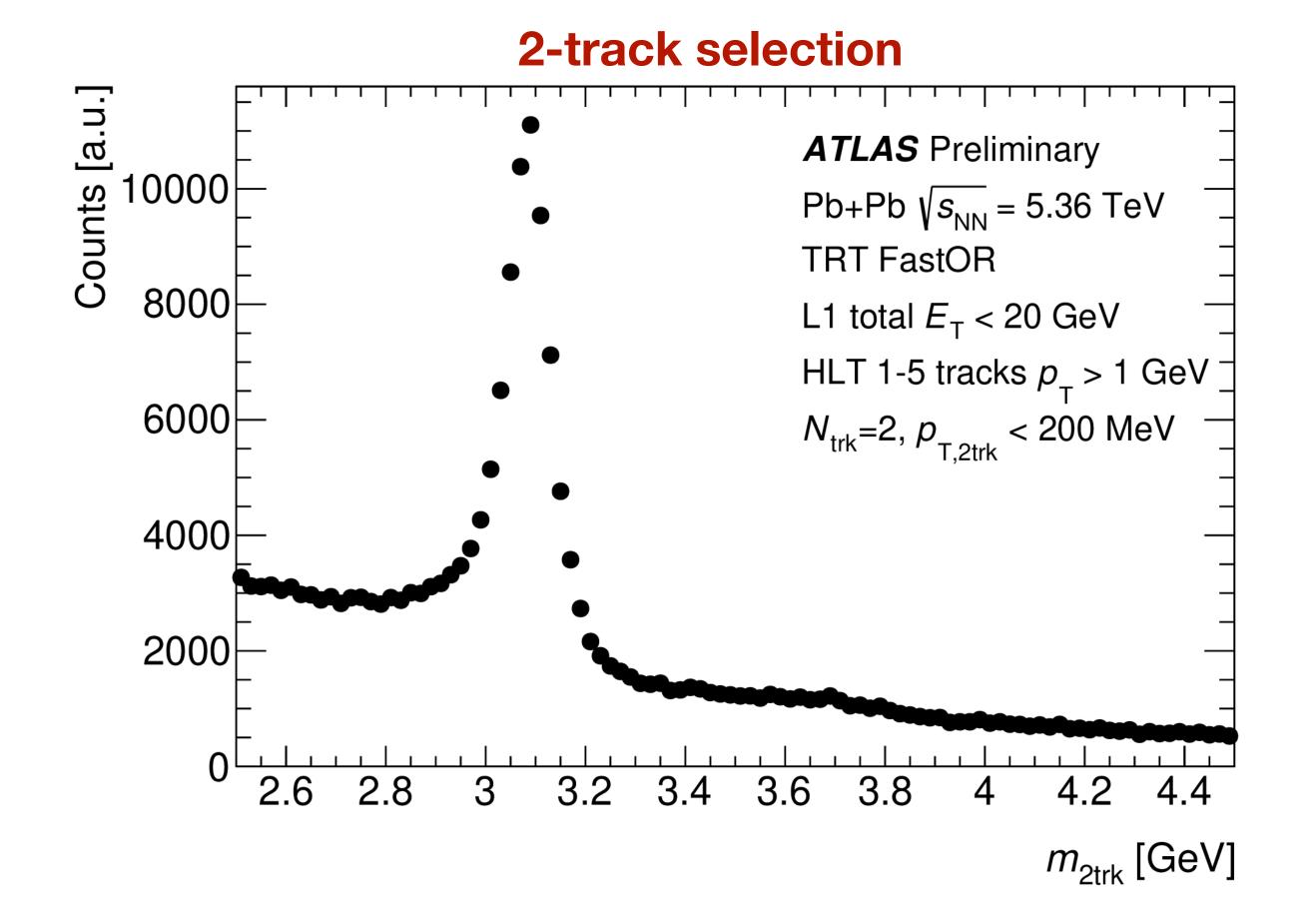
- ~1.7/nb of 5.36 TeV data recorded in 2023 by ATLAS
- Thanks to the **offline (egamma)** and ATLAS TRT "Fast-OR" L1 trigger improvements, we can reach much lower lepton transverse momenta in Run3!



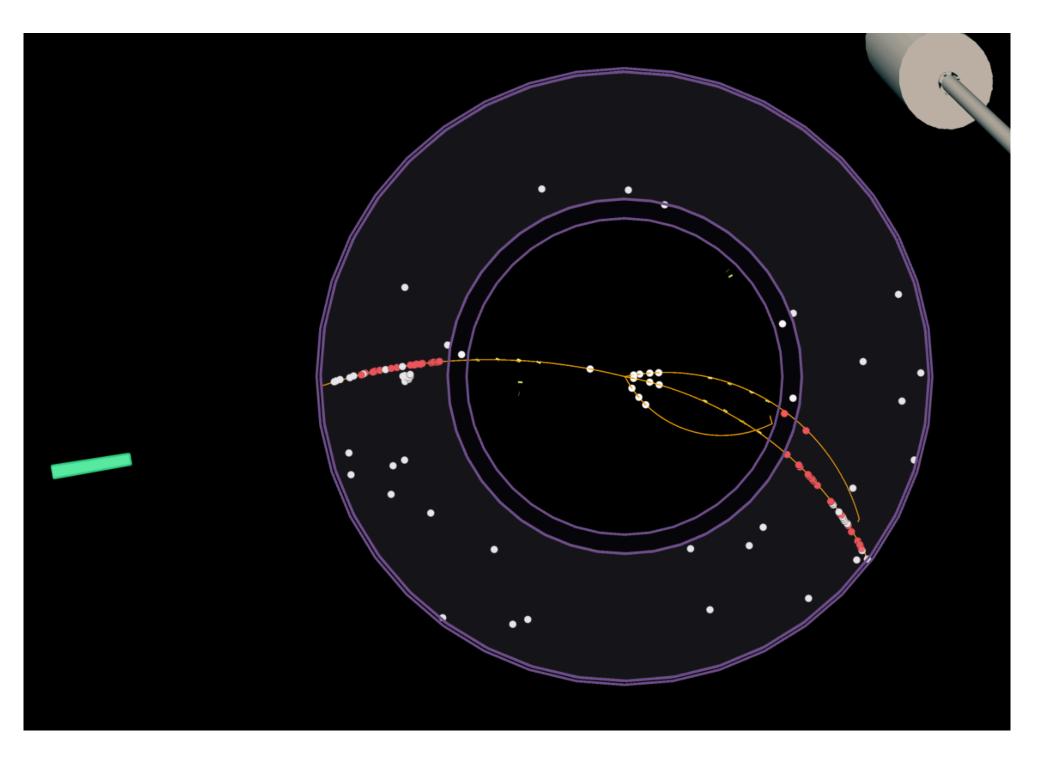


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 $\gamma\gamma \rightarrow \tau \tau \rightarrow e \pi\pi\pi candidate$ 



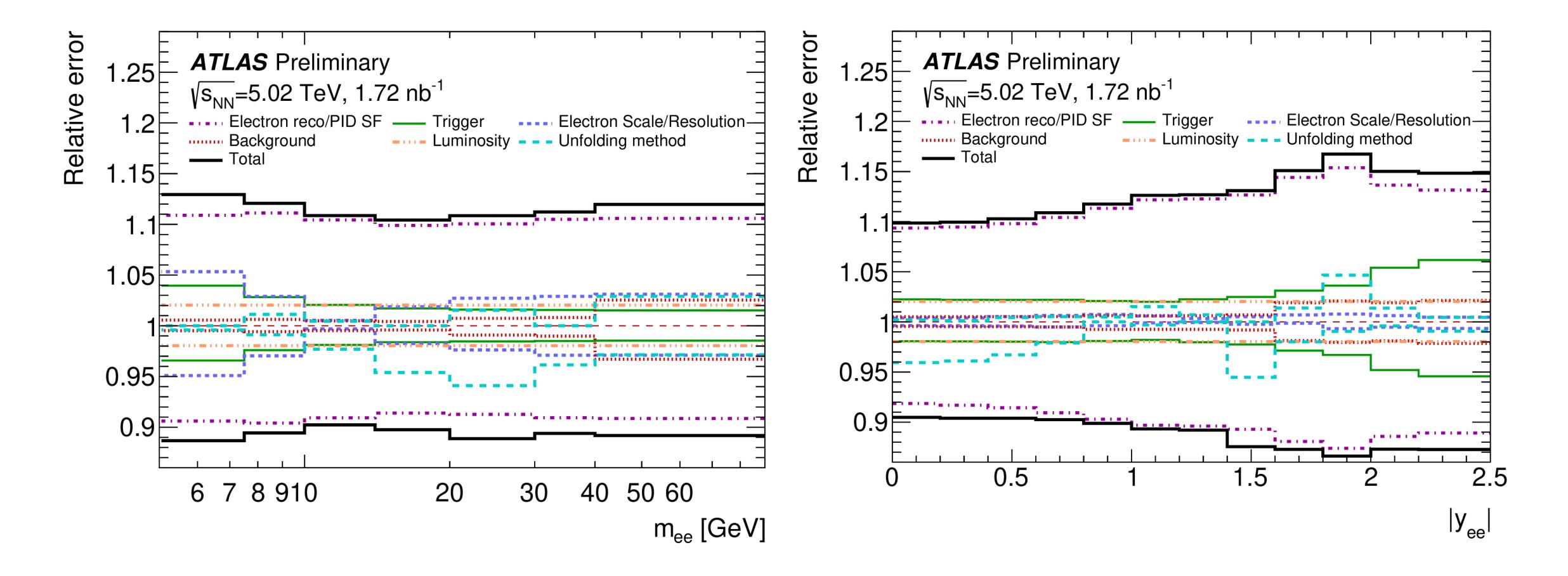
# Summary

- 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.)

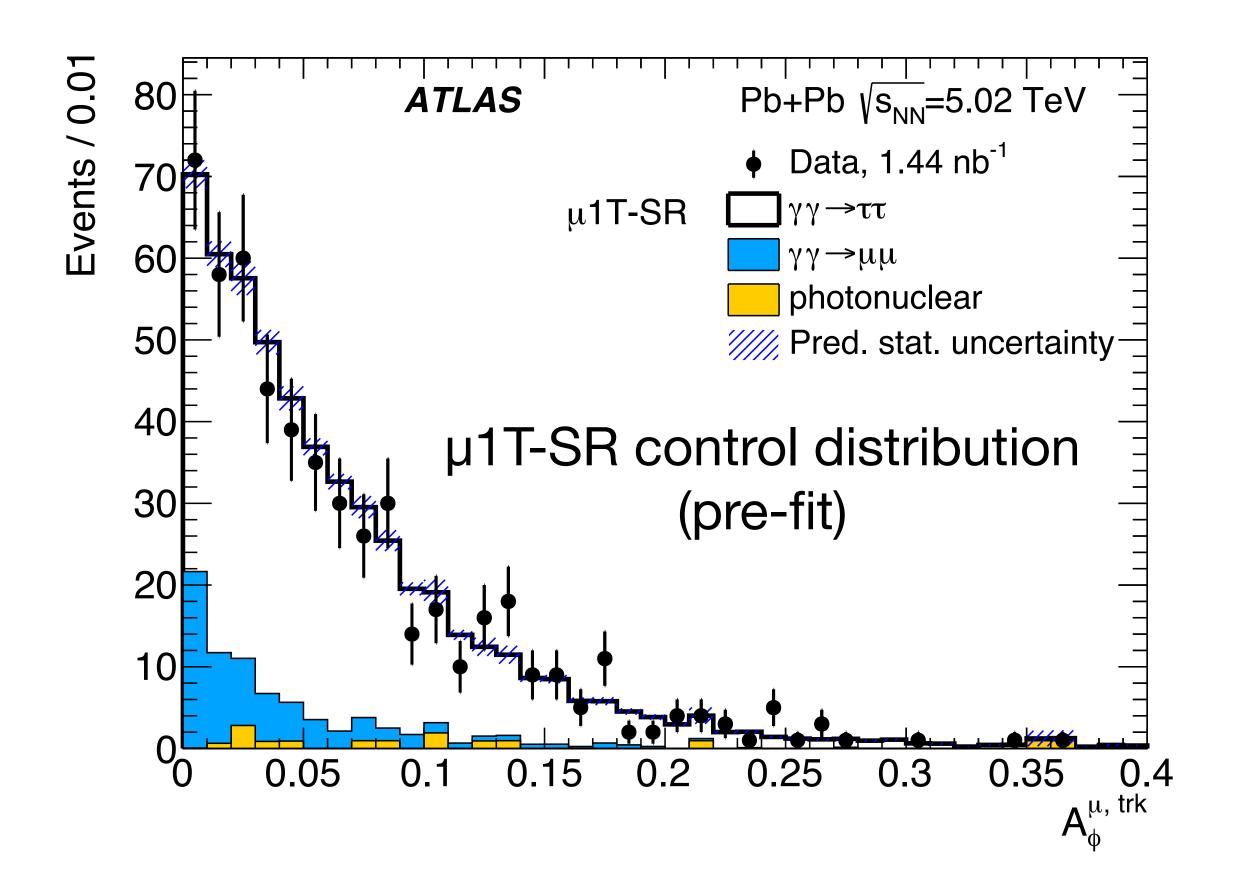
<sup>\*</sup> Research project partly supported by program "Excellence initiative – research university" for the AGH University of Krakow

# Backup

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



- 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!



#### Post-fit impact

Uncertainty	Impact on $\mu_{\tau\tau}$ [%]
muon Level-1 trigger (sys)	1.0
au 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. ( $\mu 1T$ -SR)	0.5
Total systematic	2.6

#### at parameterisation

 Elementary γγ→τ τ cross section has explicit dependence on photon-τ vertex function:

$$i\Gamma_{\mu}^{(\gamma\ell\ell)}(p',p) = -ie \left[ \gamma_{\mu} F_{1}(q^{2}) + \frac{i}{2m_{\ell}} \sigma_{\mu\nu} \underline{q^{\nu}} F_{2}(q^{2}) + \frac{1}{2m_{\ell}} \gamma^{5} \sigma_{\mu\nu} \underline{q^{\nu}} F_{3}(q^{2}) \right]$$

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