Nucleon Structure and Soft QCD from ATLAS

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Outline

- Impact of ATLAS W+jets and Z+jets data on proton Parton Distribution Functions (PDF)
- Single dissociative events in photon-induced dilepton production with forward proton tag
- $gg \rightarrow \gamma\gamma$ production in light-by-light scattering and dissociative reactions in di-muon production in ultraperipheral Pb+Pb collisions
- Inclusive single diffractive dissociation cross-section
- Underlying event in Z boson production
- Conclusions

Impact of ATLAS W+jets and Z+jets data on the QCD analysis of proton PDFs at 8 TeV, arXiv:2101.05095, 20 fb^{-1}

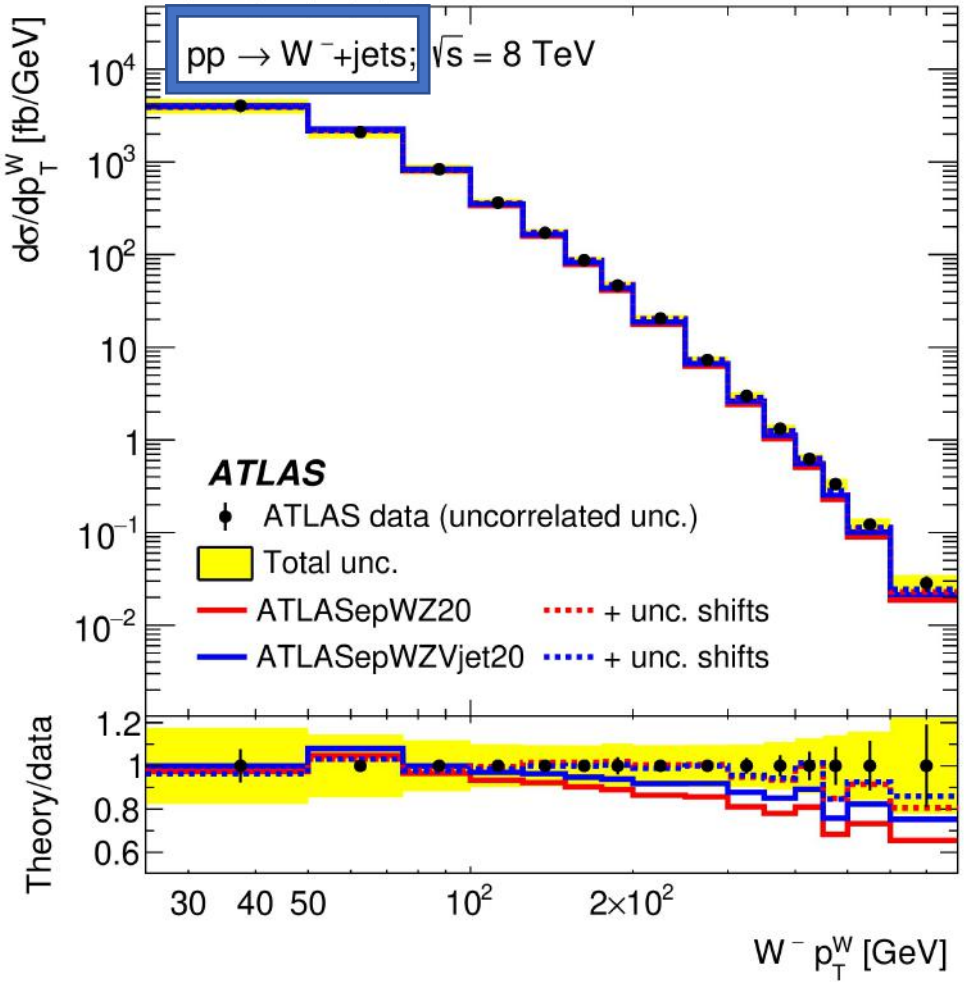
- PDF are needed for
  accurate predictions of both SM and BSM cross-sections at the LHC
- New set of proton PDF, ATLASepWZVjet20,
  at next-to-next-to-leading order in QCD
- Requirement for precise PDF determination:
  - data covering a wide range of negative squared four-momentum transfer (denoted by Q) and
  - Bjorken x, the fraction of the proton's longitudinal momentum carried by the parton initiating the interaction

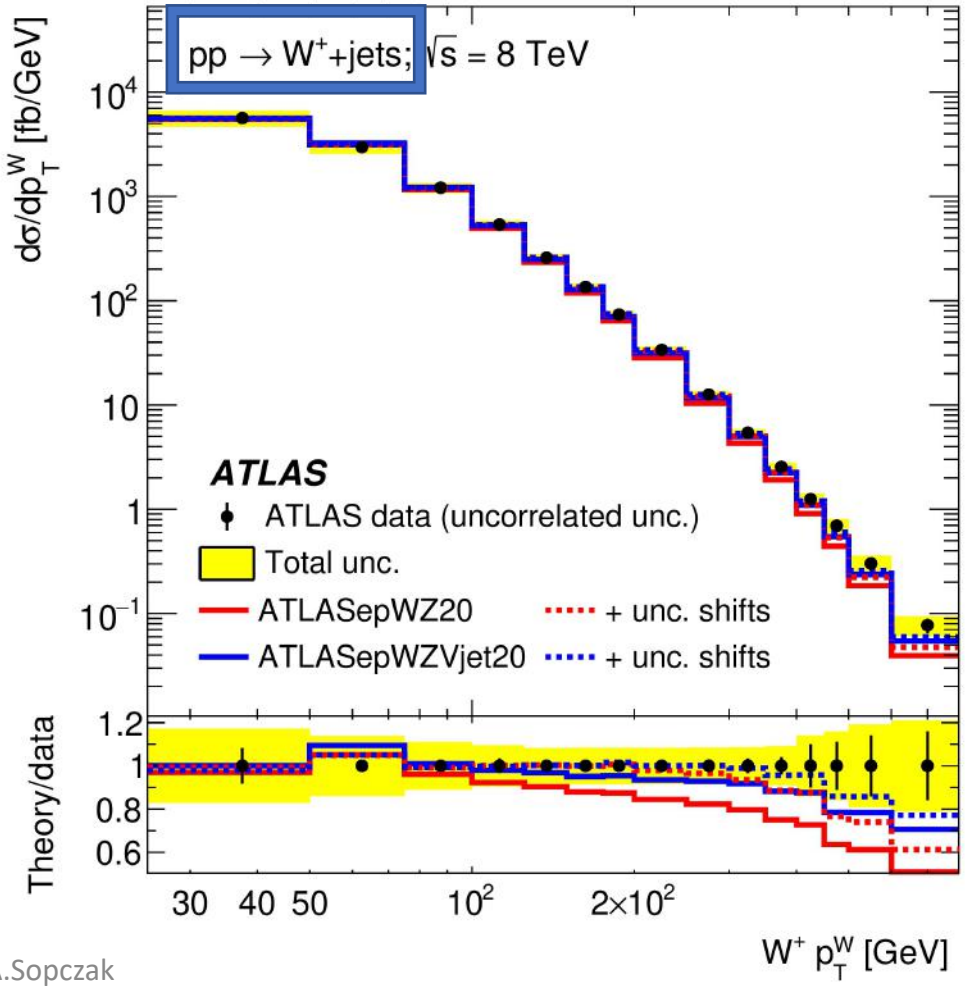
Impact of ATLAS W+jets and Z+jets data on the QCD analysis of proton PDFs at 8 TeV, arXiv:2101.05095, 20 fb^{-1}

- ATLAS W+jets and Z+jets, 8 TeV data, JHEP **05** (2018) 077, EPJ C **79** (2019) 847, in combination with 7 TeV data, Eur. Phys. J. C **77** (2017) 367, and HERA data, Eur. Phys. J. C **75** (2015) 580.
- PDF fit performed at NNLO in perturbative QCD, made possible by recent theoretical developments for vector-boson production in association with jets, PRL **115** (2015) 062002, PRL **117** (2016) 022001, and accounts for correlation of systematic uncertainties between data sets.
- Comparison: ATLASepWZVjet20 PDF set and an equivalent fit performed without the V+jets data PDF set (ATLASepWZ20)

Impact of ATLAS W+jets and Z+jets data on the QCD analysis of proton PDFs at 8 TeV, arXiv:2101.05095, 20 fb^{-1}

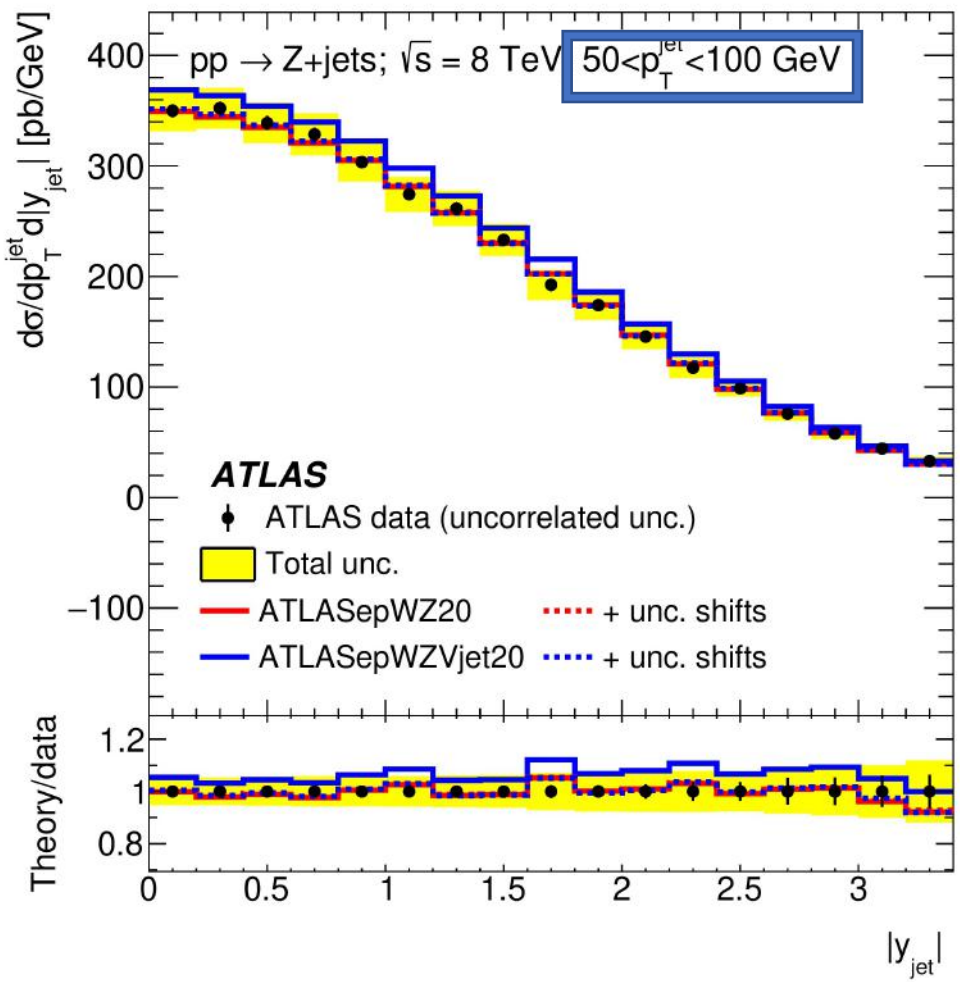
- Differential cross-section measurements: W^-+jets, W^++jets

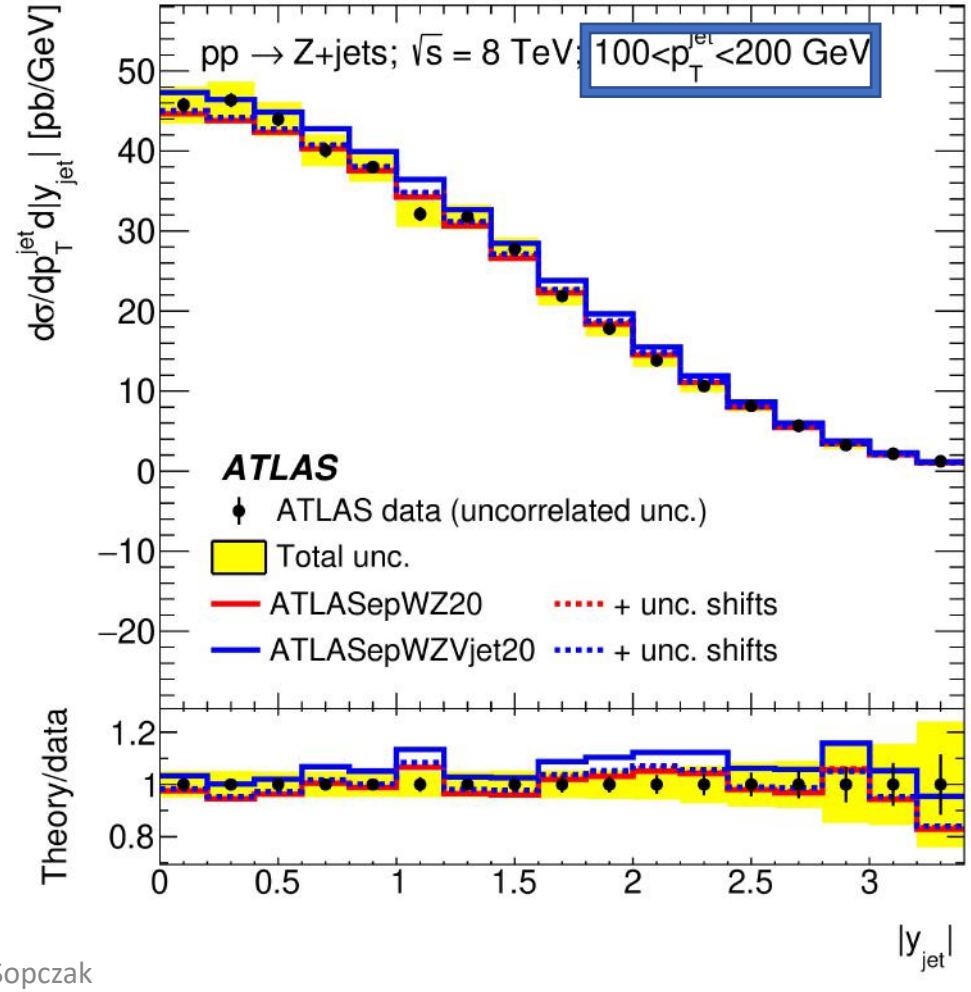




Impact of ATLAS W+jets and Z+jets data on the QCD analysis of proton PDFs at 8 TeV, arXiv:2101.05095, 20 fb^{-1}

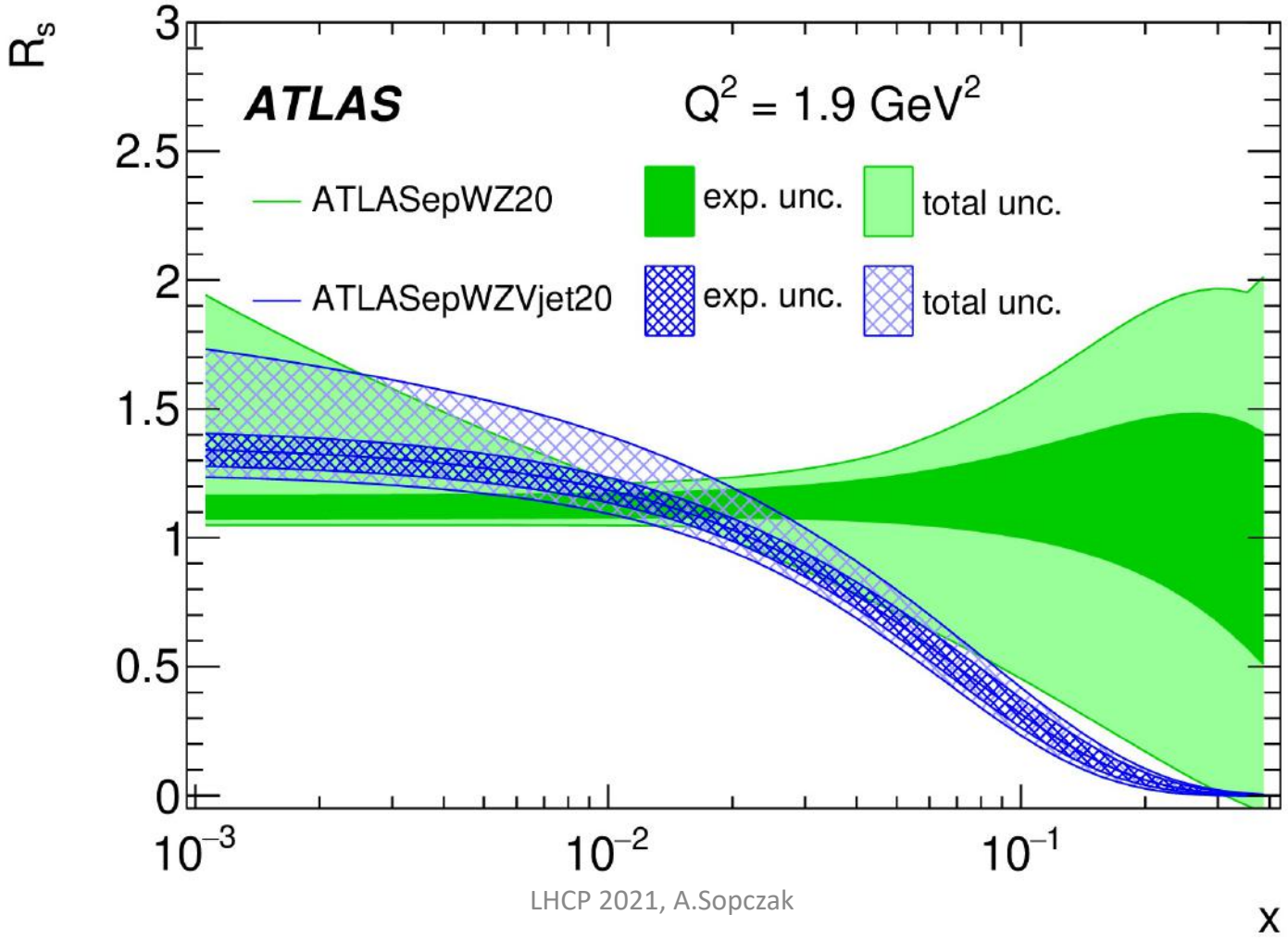
- Differential cross-section measurements: Z+jets





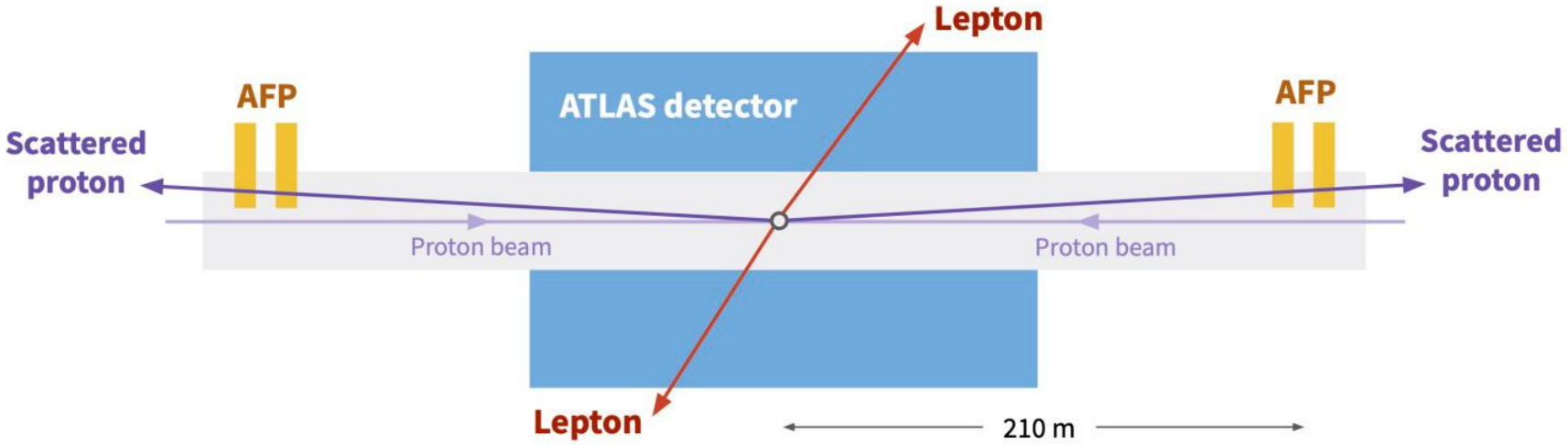
Impact of ATLAS W+jets and Z+jets data on the QCD analysis of proton PDFs at 8 TeV, arXiv:2101.05095, 20 fb^{-1}

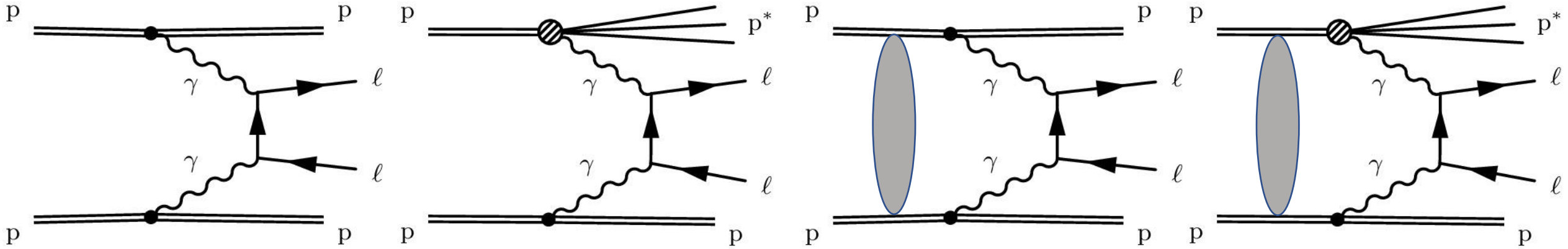
- Important effect of the V+jets data, R_s = (s + sbar)/(ubar + dbar)



Photon-induced dilepton production with forward proton tag at 13 TeV, PRL 125 (2020) 261801, 14.6 fb^{-1}

- Scattered protons detected by ATLAS Forward Proton (AFP) spectrometer
- Light leptons (ee or $\mu\mu$) reconstructed in ATLAS central detector
- Signal: exclusive or single dissociative (soft QCD) and re-scattering

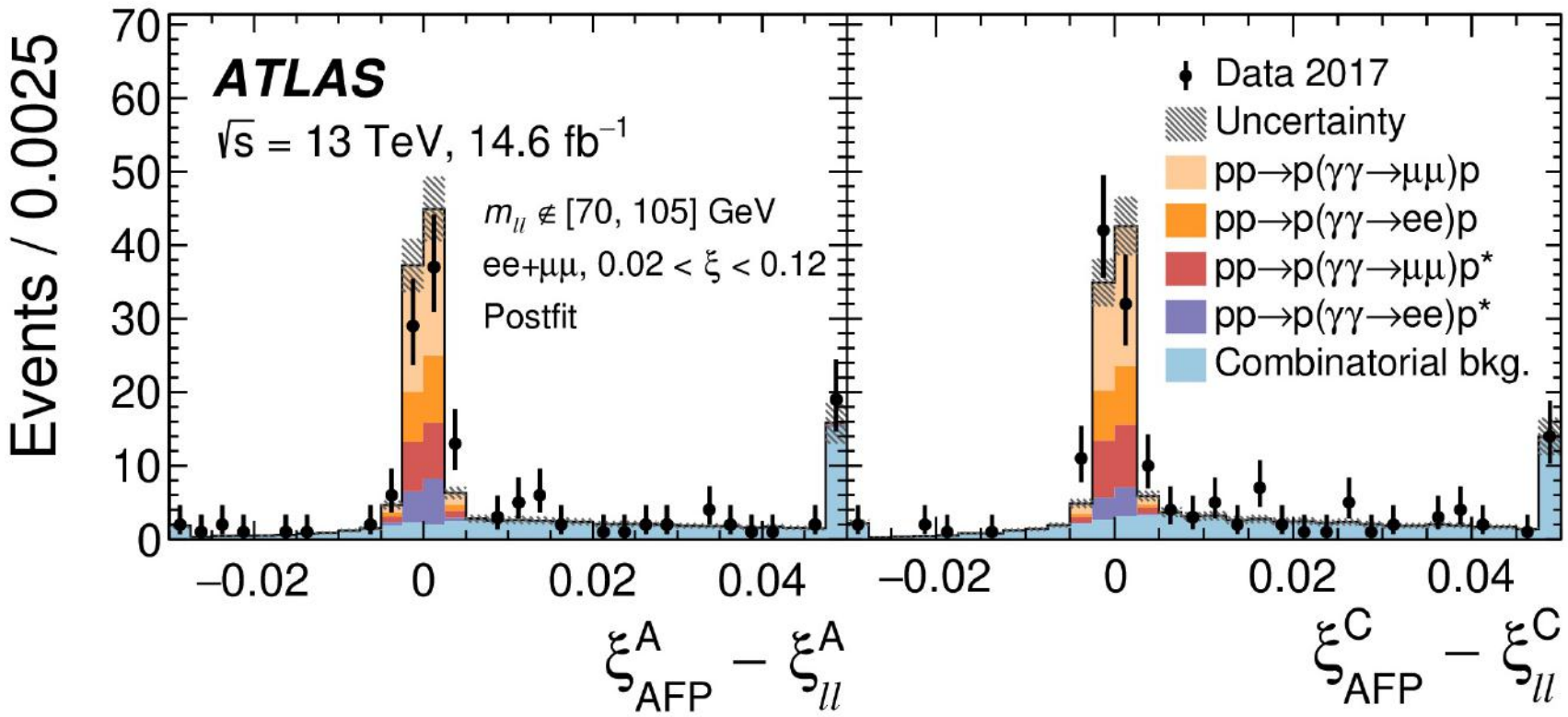




Photon-induced dilepton production with forward proton tag at 13 TeV, PRL 125 (2020) 261801, 14.6 fb^{-1}

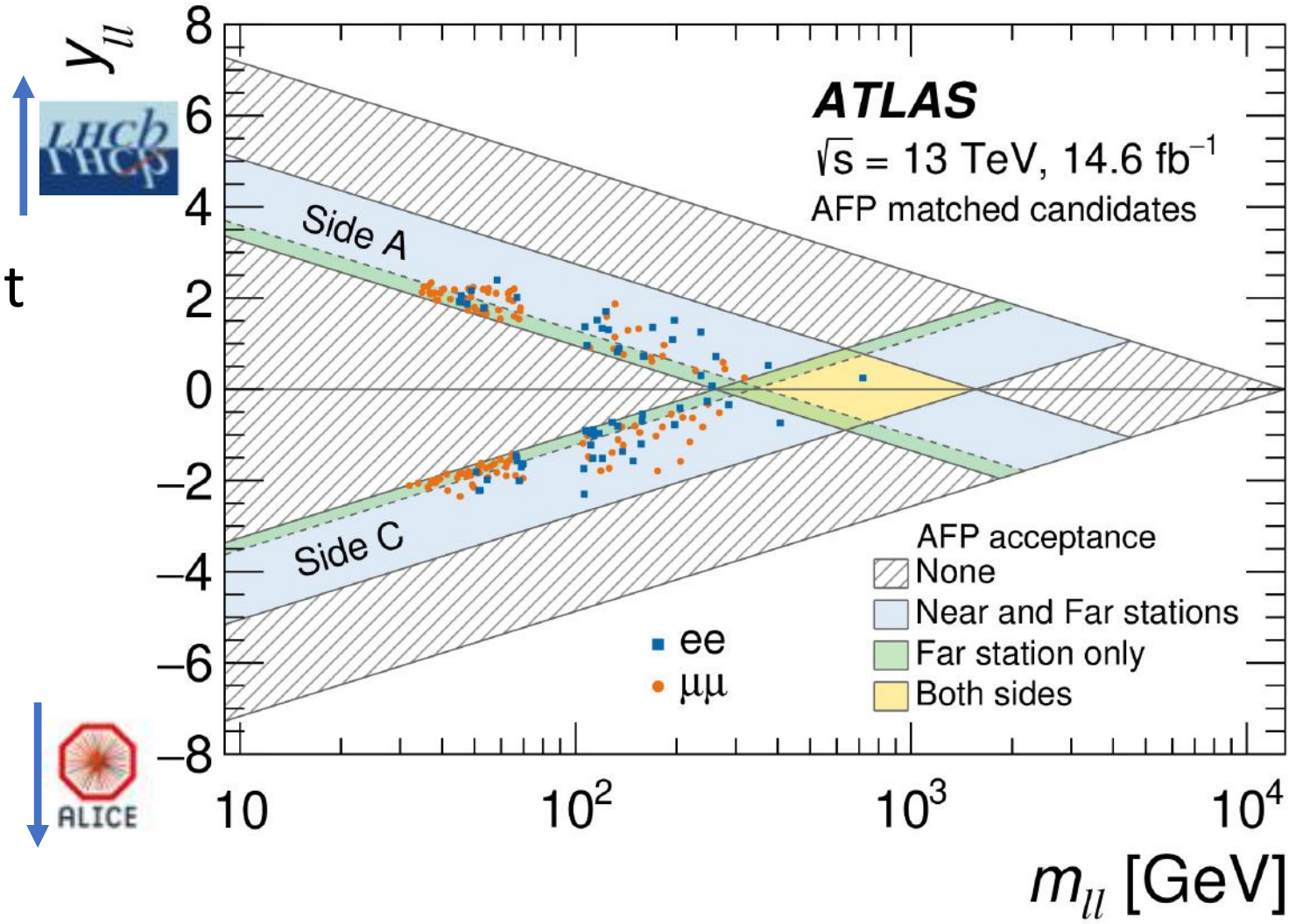
- matching of lepton pair and proton kinematics, ξ_{ll}, ξ_{AFP}
- AFP detection range $0.02 < \xi < 0.12$
- Signal and combinatorial background processes
- p^* dissociated proton

$$\xi_{ll} = (m_{ll}/\sqrt{s})e^{\pm y_{ll}}, \ \xi_{AFP} = 1 - E_p/E_{beam}$$



Photon-induced dilepton production with forward proton tag at 13 TeV, PRL 125 (2020) 261801, 14.6 fb^{-1}

- Data event candidates: dilepton rapidity $y_{\ell\ell}$ versus $m_{\ell\ell}$ plane
- Event selection and kinematic matching $|\xi_{AFP} - \xi_{\ell\ell}| < 0.005$ on at least one side
- Shaded (hatched) areas denote the acceptance (no acceptance) for the AFP stations
- Areas neither shaded nor hatched correspond to $\xi \notin [0, 1]$
- Future double tag events will increase distinction between exclusive/dissociated production



Photon-induced dilepton production with forward proton tag at 13 TeV, PRL 125 (2020) 261801, 14.6 fb^{-1}

- 57 (123) candidates in the e^+e^-+p ($\mu^+\mu^-$+p) final states
- Background-only hypothesis rejected with a significance >5σ in each channel
- Cross-section measurements in the fiducial detector acceptance $\xi \in [0.035; 0.08]$

σ(ee+p) = 11.0 $\pm$2.6 (stat) $\pm$1.2 (syst) $\pm$0.3 (lumi) fb

$\sigma(\mu\mu$+p) = 7.2 $\pm$1.6 (stat) $\pm$0.9 (syst) $\pm$0.2 (lumi) fb

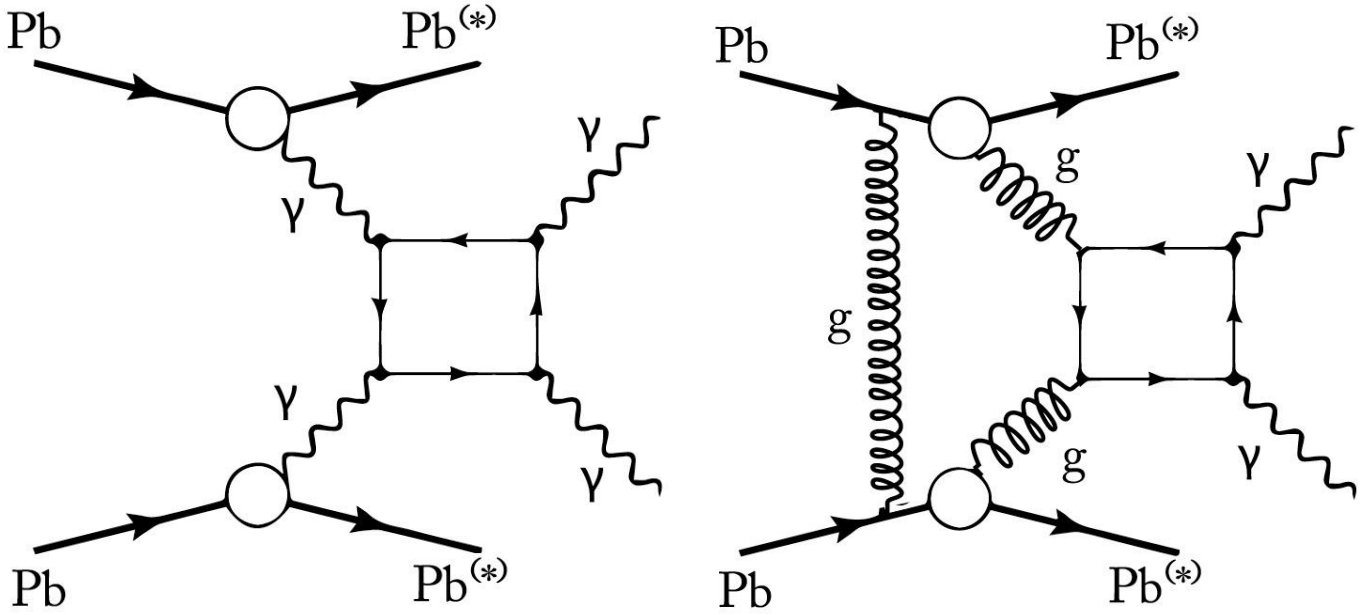
- Comparison with proton soft survival (no additional soft re-scattering) models:

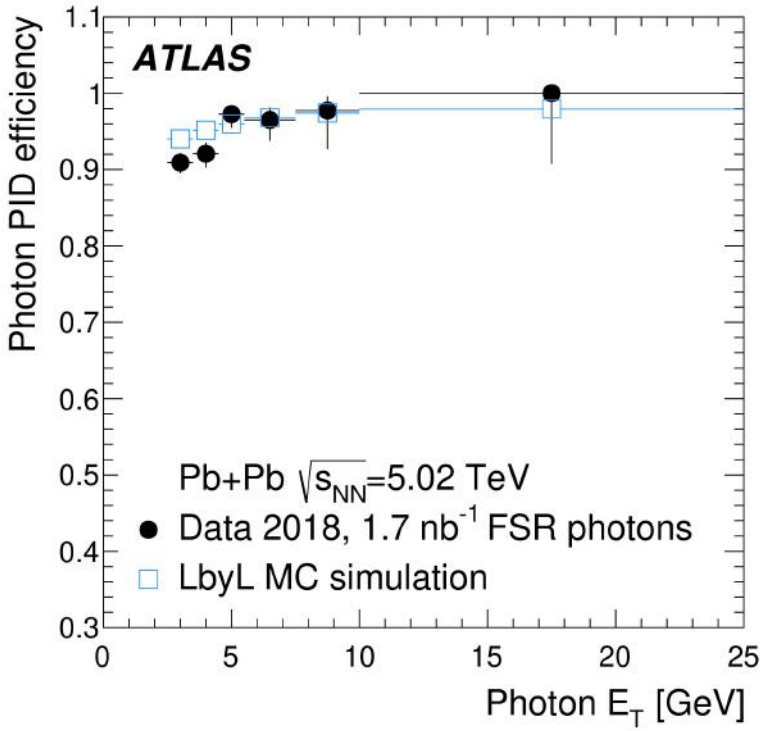
$\sigma_{\text{HERWIG+LPAIR}} \times S_{\text{surv}}$	$\sigma^{\text{fid.}}_{ee+p}$ [fb]	$\sigma^{\text{fid.}}_{\mu\mu+p}$ [fb]
$S_{\text{surv}} = 1$	15.5 ± 1.2	13.5 ± 1.1
S_{surv} using Refs. [31,30]	10.9 ± 0.8	9.4 ± 0.7
SUPERCHIC 4 [94]	12.2 ± 0.9	10.4 ± 0.7
Measurement	11.0 ± 2.9	7.2 ± 1.8

[31] Eur. Phys. J. C 76 (2016) 9
[30] Phys. Lett. B 741 (2015) 66
[94] Eur. Phys. J. C80 (2020) 925

Light-by-light scattering in ultraperipheral Pb+Pb collisions, JHEP 03 (2021) 243, 2.2 nb^{-1}

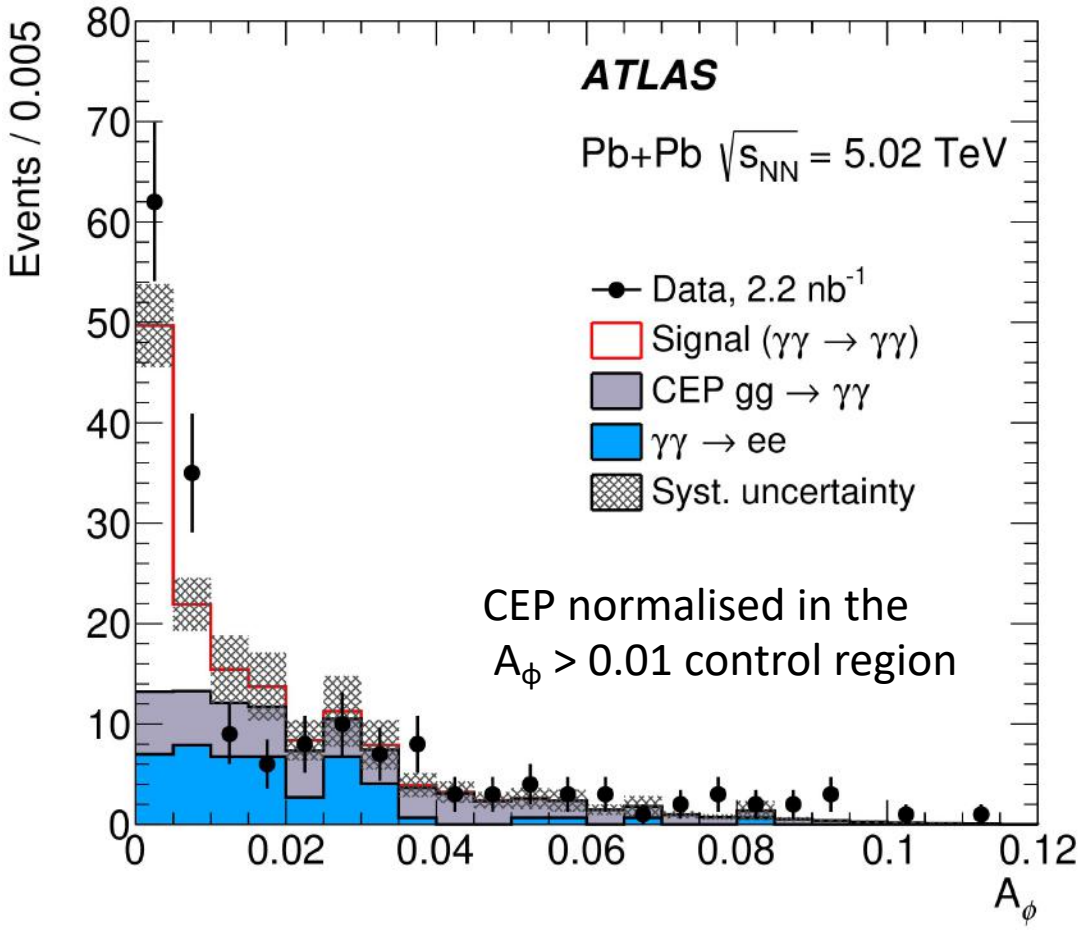
- Signal: Light-by-Light scattering γγ→γγ
- Background: Central Exclusive Production (CEP) gg→γγ
- photon Particle IDentification (PID) efficiency optimized for low E_T



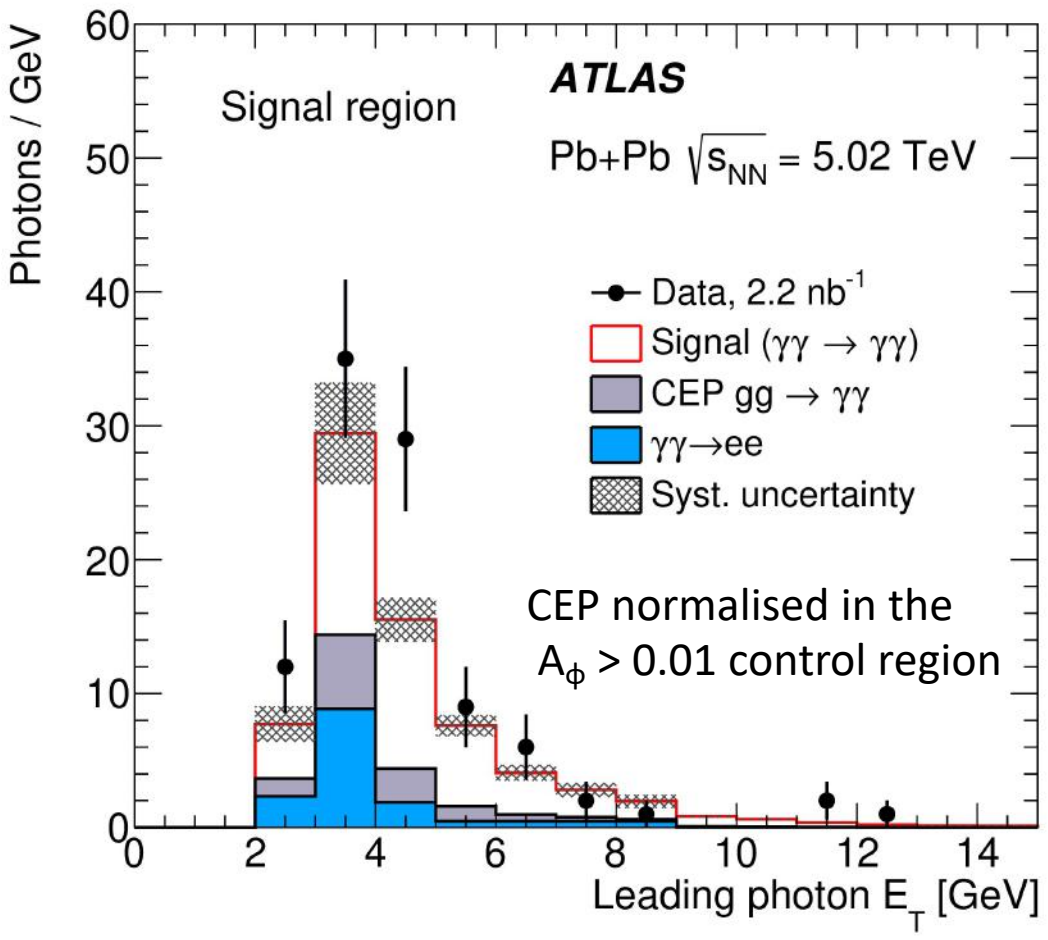


Light-by-light scattering in ultraperipheral Pb+Pb collisions, JHEP 03 (2021) 243, 2.2 nb^{-1}

- Di-photon acoplanarity

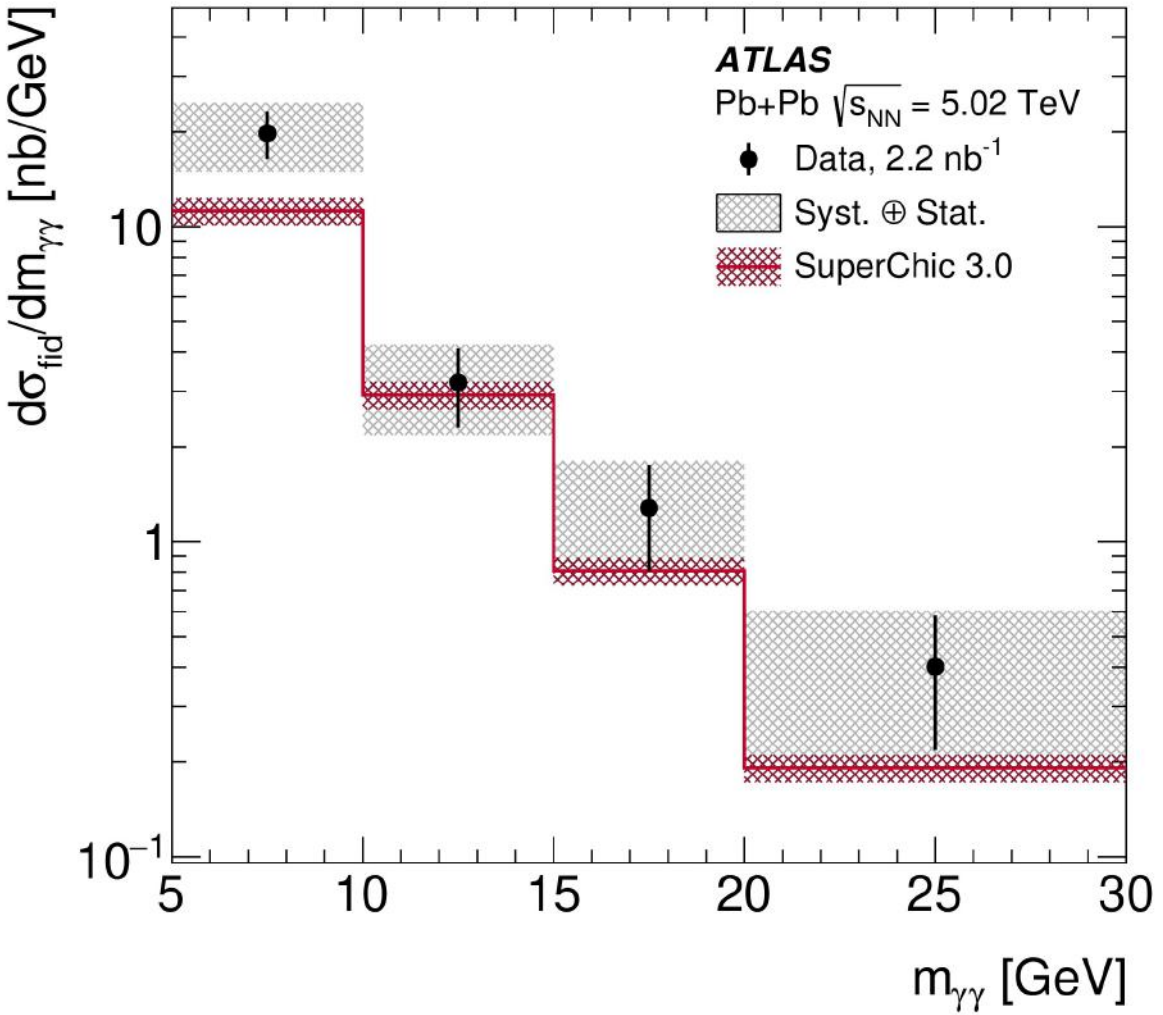


- Leading photon transverse energy



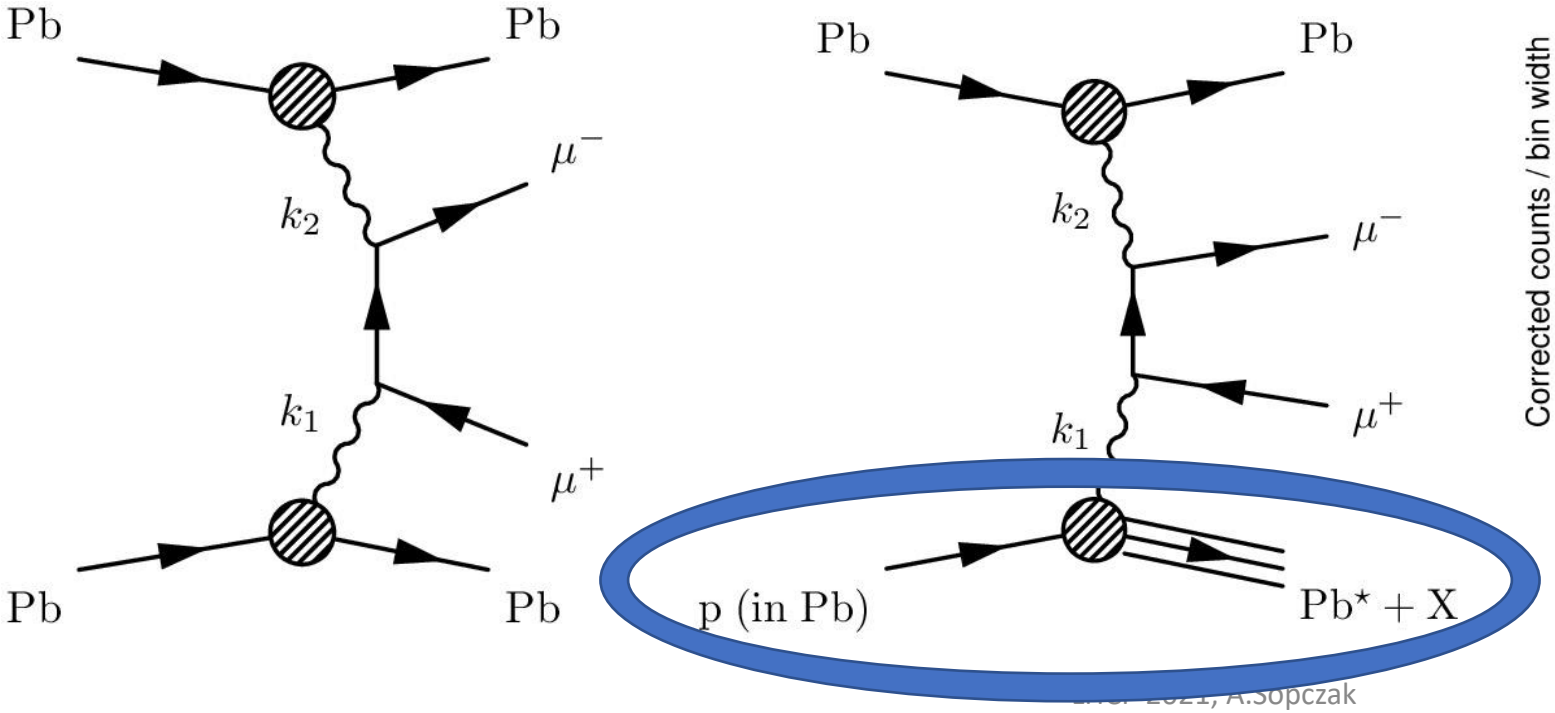
Light-by-light scattering in ultraperipheral Pb+Pb collisions, JHEP 03 (2021) 243, 2.2 nb^{-1}

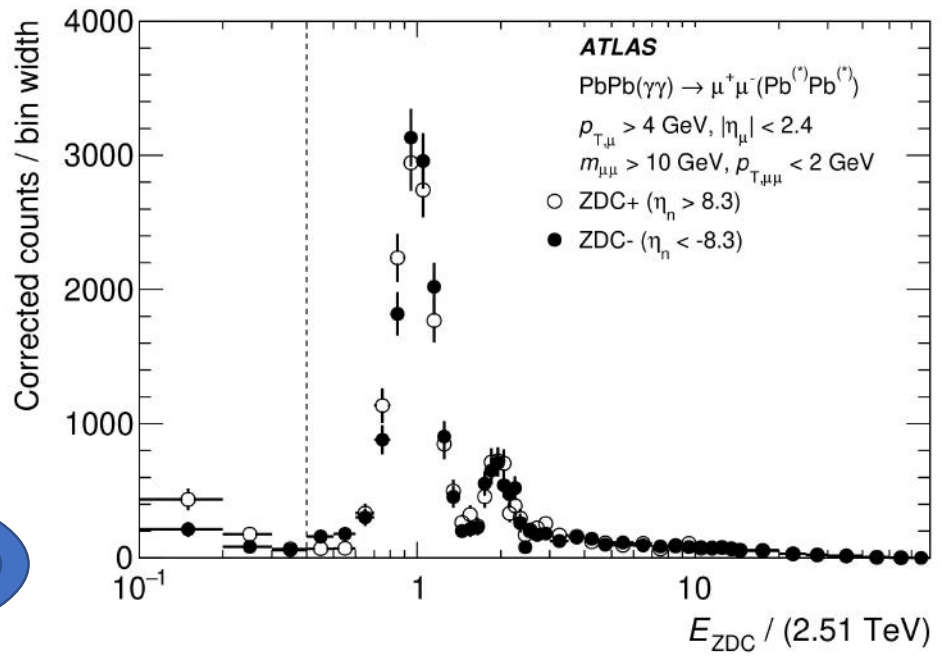
- Differential fiducial cross-sections $\gamma\gamma \rightarrow \gamma\gamma$ production in Pb+Pb collisions at $\sqrt{s_{NN}}$=5.02 TeV
- SuperChic v3.0 SM prediction, fair description of the data within uncertainties (experimental systematic and statistical, and theoretical)
- CEP $gg \rightarrow \gamma\gamma$ uncertainty 11% statistics in CR, negligible experimental uncertainties
- CEP $gg \rightarrow \gamma\gamma$ 21% change with extra gluon interaction, further checks with varying parton distribution functions (pdf)
- CEP $gg \rightarrow \gamma\gamma$ background 12±3 events



Di-muon production in ultraperipheral Pb+Pb collisions, arXiv:2011.12211, 0.48 nb^{-1}

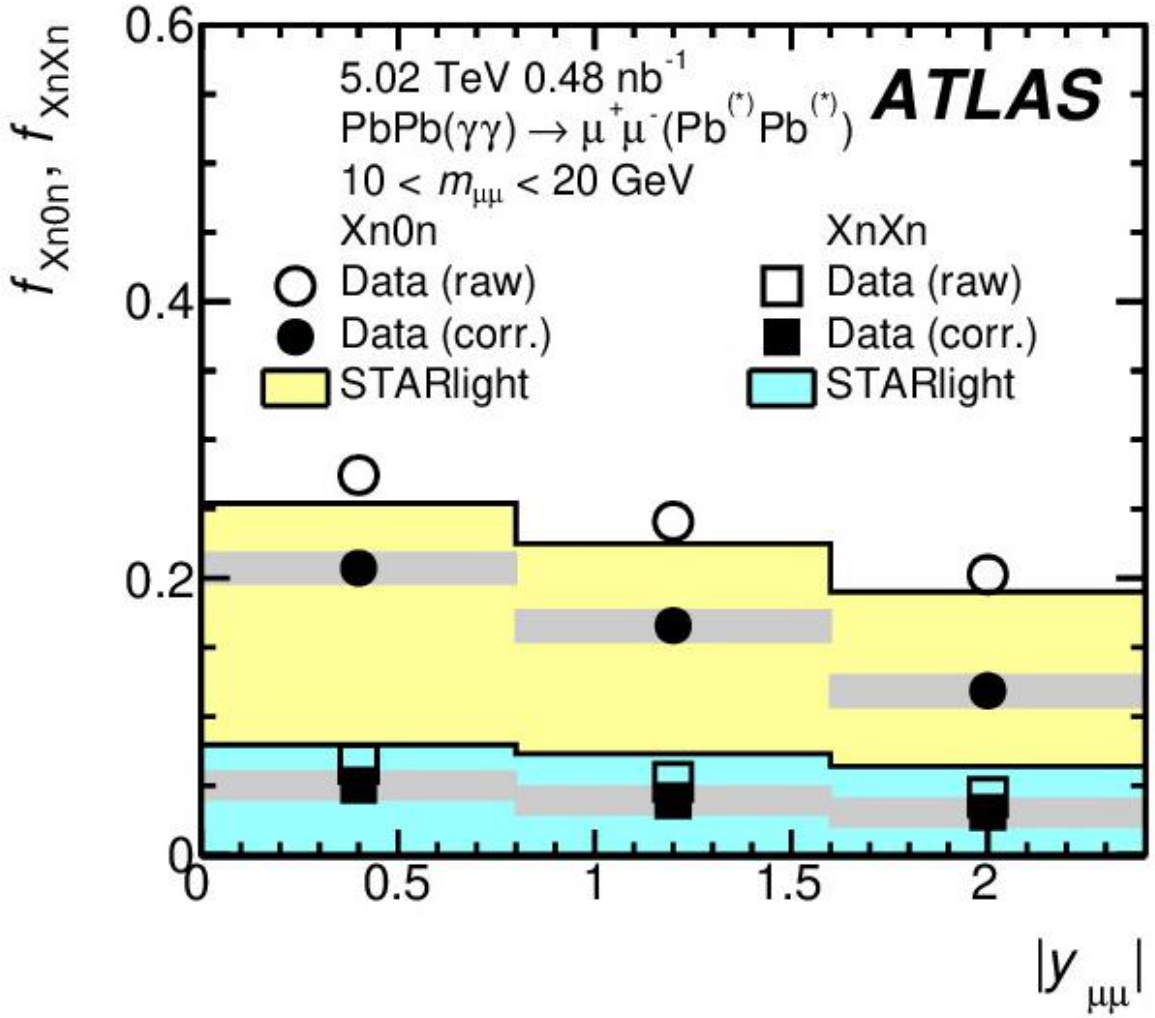
- Signal: PbPb (γγ) → mumu (PbPb)
- Background: dissociative PbPb(γ γ^*) → mumu+X (Pb^*Pb)
- Zero Degree Calorimeter (ZDC) relative energy deposits





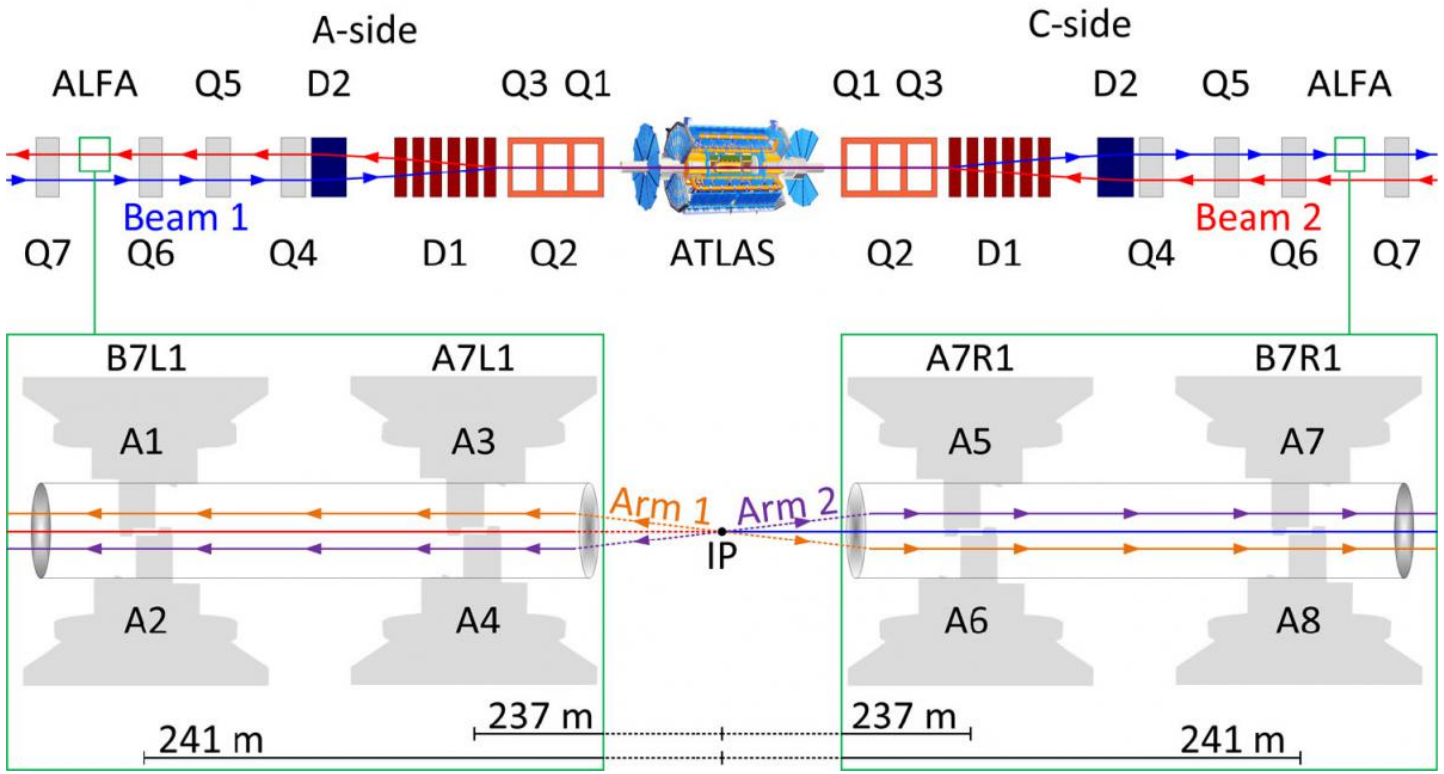
Di-muon production in ultraperipheral Pb+Pb collisions, arXiv:2011.12211, 0.48 nb^{-1}

- Fractions of events with neutron tag on one side (Xn0n) and on both sides (XnXn) as function of rapidity $|y_{\mu\mu}|$
- Good agreement of shape with STARlight prediction, but STARlight generally tends to overestimate the fraction of events with forward neutrons

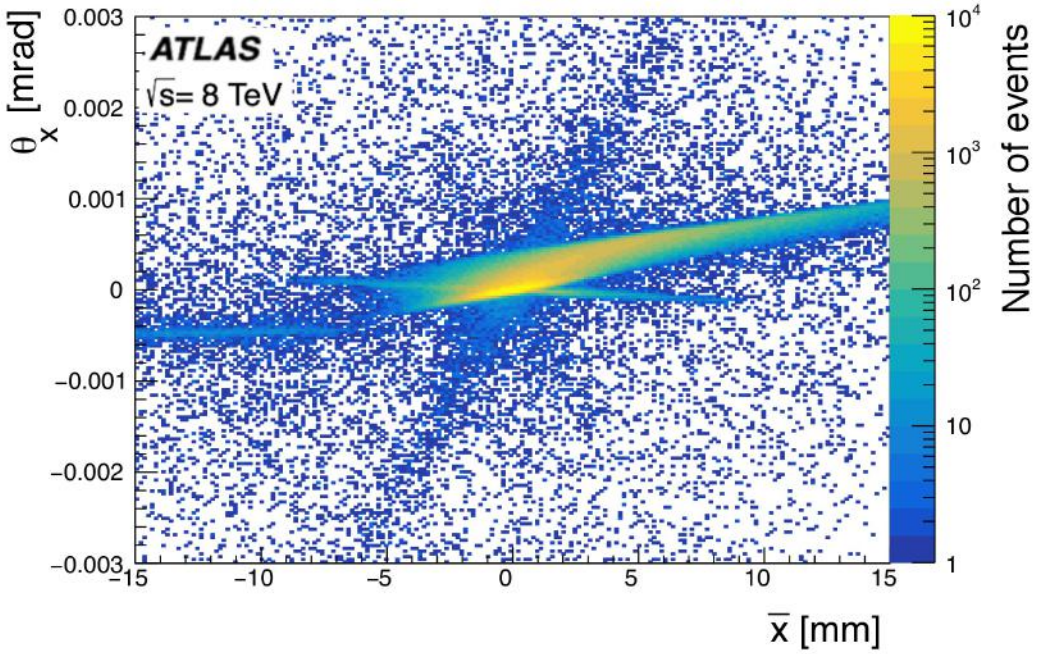


Inclusive single diffractive dissociation cross-section of pp collisions at 8 TeV, JHEP 02 (2020) 042, 24.11 nb^{-1}

- ALFA Roman Pot stations in the outgoing LHC beams
- Data from special run: $\beta^* = 90$ m, L = 1.67 nb^{-1}, $\mu < 0.08$

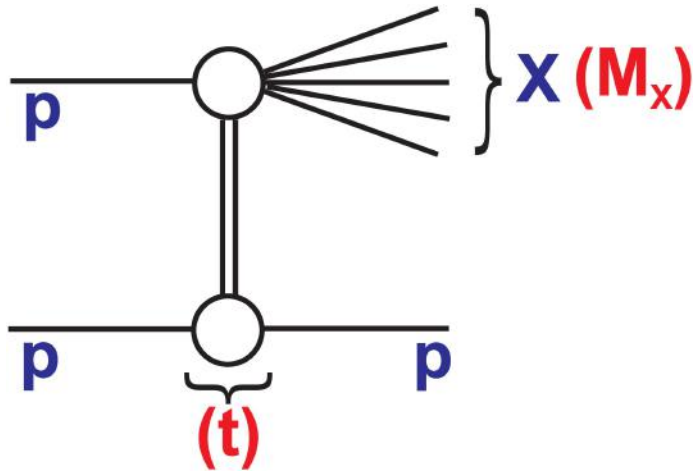


Average scattered proton x position in ALFA versus angle in the x-z plane

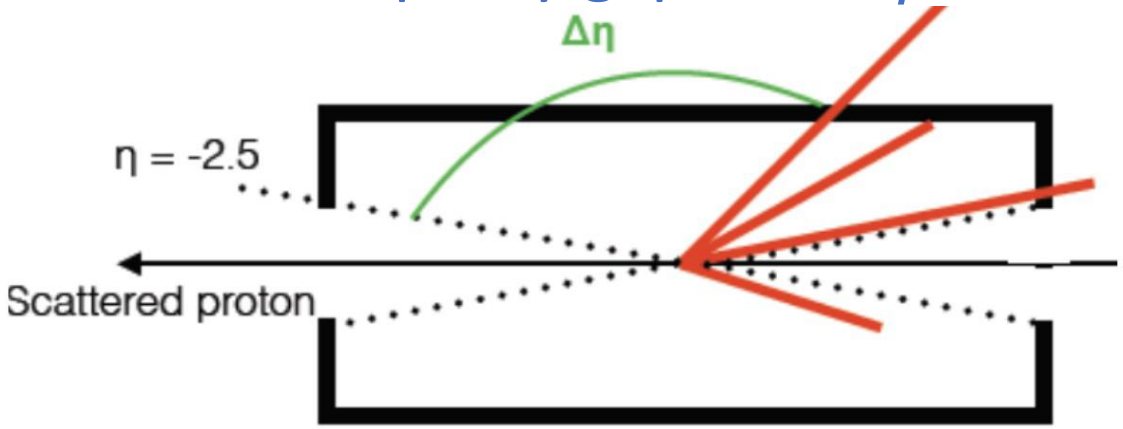


Inclusive single diffractive dissociation cross-section of pp collisions at 8 TeV, JHEP 02 (2020) 042, 24.11 nb^{-1}

- Single diffractive dissociation (SD), kinematics: squared four-momentum transfer, t, mass, M_X, of the dissociated system X, proton energy loss $\xi = 1 - E_p/E_{beam}$
- Hadron-level cross-sections: σ versus t, ξ, Δη
- Background from non-SD pp collisions
  - Correlated signals in ALFA and the Inner Detector (estimated from MC)
  - Overlay background: coincidences of a signal in ALFA with an uncorrelated signal in the Inner Detector (data-driven estimate, contributes the largest uncertainty)

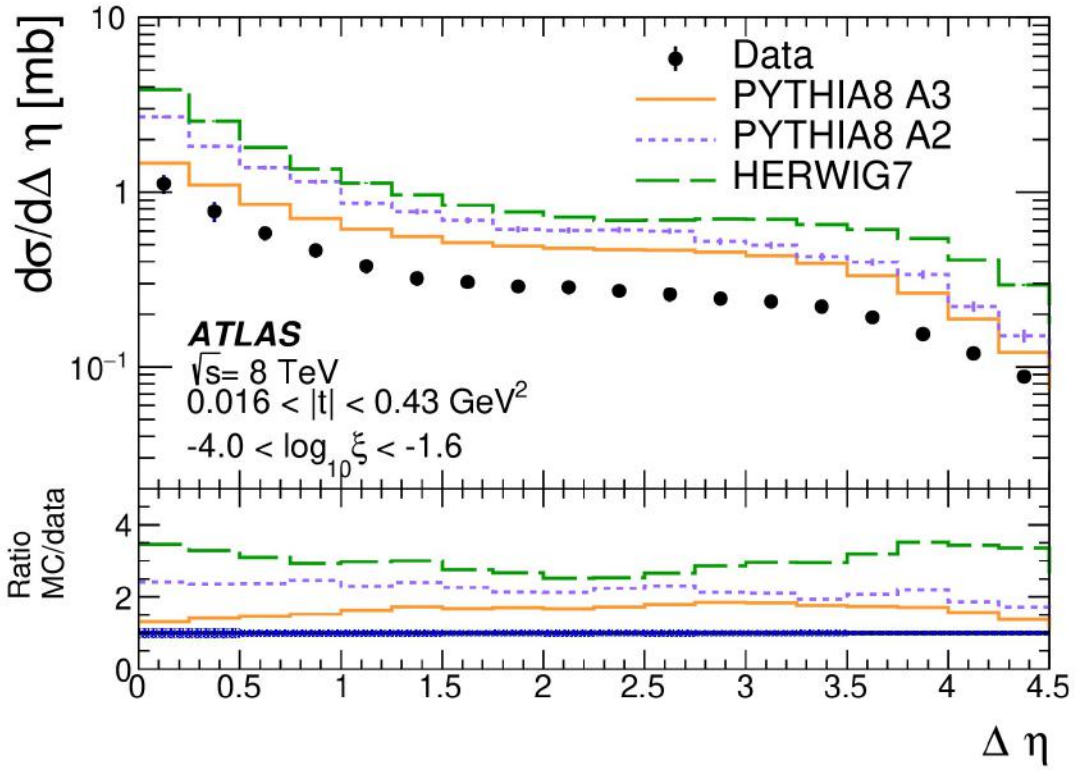


Rapidity gap size $\Delta\eta$



Inclusive single diffractive dissociation cross-section of pp collisions at 8 TeV, JHEP 02 (2020) 042, 24.11 nb^{-1}

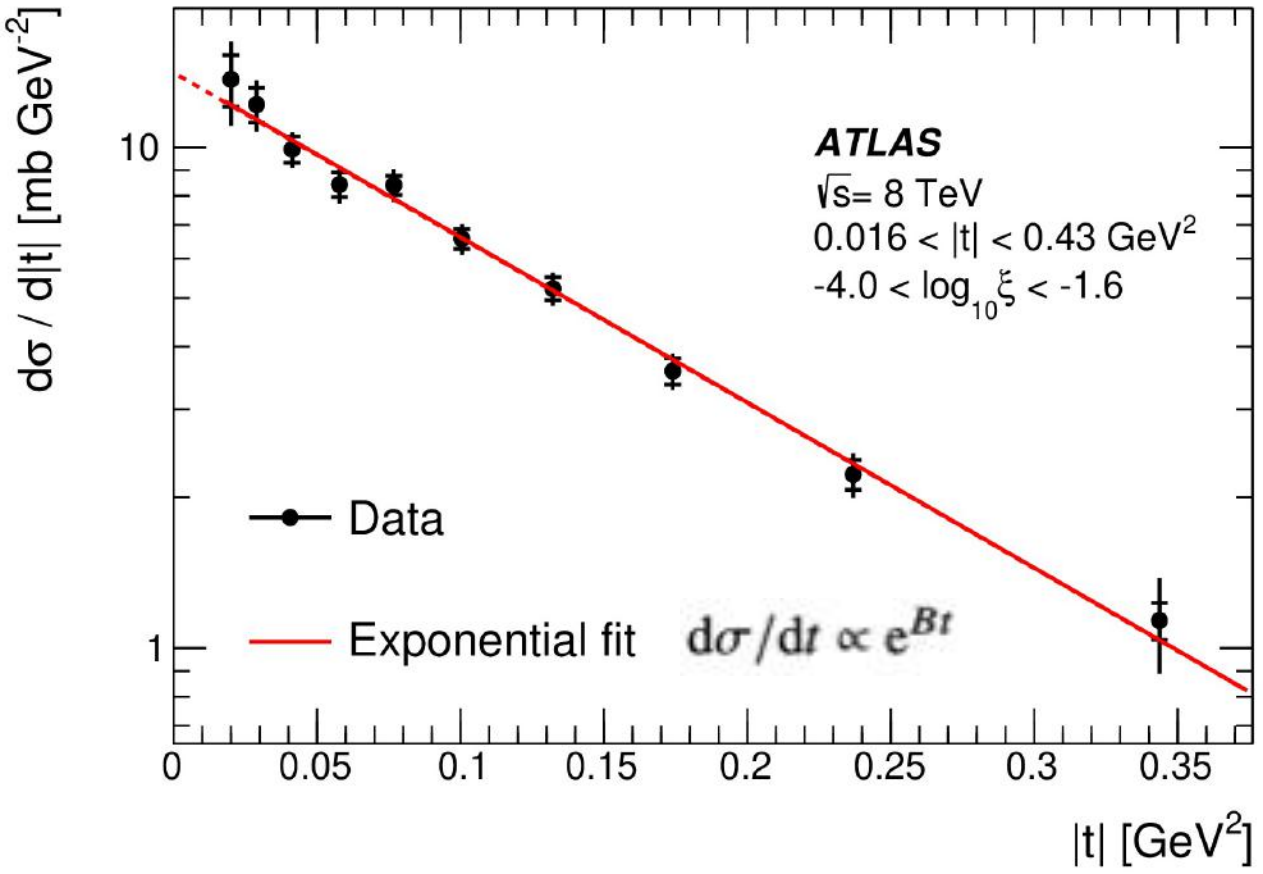
- Hadron-level differential SD cross section as a function of Δη
- Diffractive plateau is visible
- Increase at small rapidity gaps: restricted rapidity region corresponding to the ATLAS tracker acceptance
- Decrease at large rapidity gaps: fiducial range restriction (loss of small-ξ events close to the ξ-edge)
- Generators describe the shape reasonably, but overestimate the cross-section



Distribution	$\sigma_{SD}^{fiducial(\xi,t)}$ [mb]	$\sigma_{SD}^{t\text{-extrap}}$ [mb]
Data	1.59 ± 0.13	1.88 ± 0.15
PYTHIA8 A2 (Schuler–Sjöstrand)	3.69	4.35
PYTHIA8 A3 (Donnachie–Landshoff)	2.52	2.98
HERWIG7	4.96	6.11

Inclusive single diffractive dissociation cross-section of pp collisions at 8 TeV, JHEP 02 (2020) 042, 24.11 nb^{-1}

- Differential cross-section as function of |t|
- Inner error bars stat. uncertainties and outer error bars stat. and syst.
- Generator predictions
  PHYS-PUB-2016-017
  Pythia8 A2: B = 7.82 GeV^{-2}
  Pythia8 A3: B = 7.10 GeV^{-2}
- Measurement
  B=7.65±0.26(stat.)±0.22(syst.) GeV^{-2}
  Systematics dominated by proton overlay backgrounds

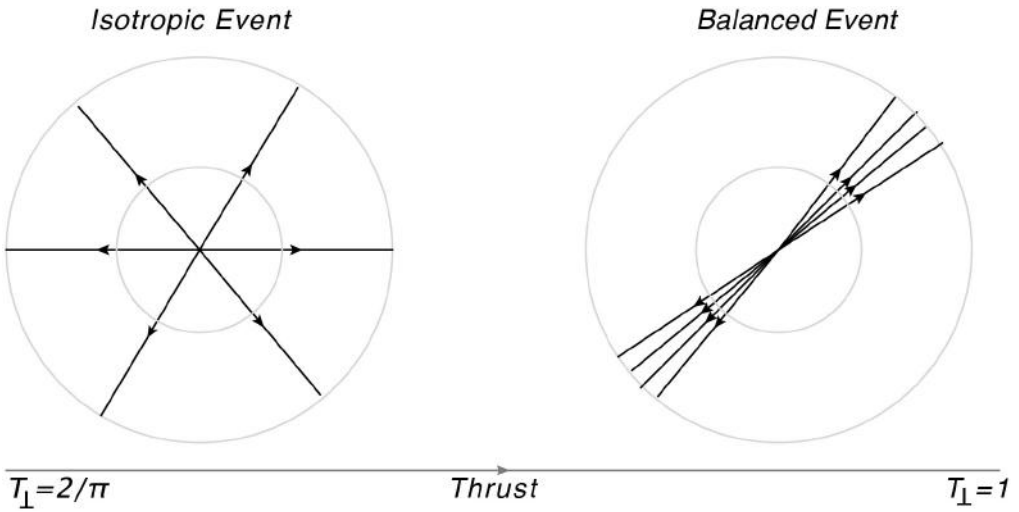


Measurement of Underlying Event in Z Boson Events at 13 TeV, Eur. Phys. J. C 79 (2019) 666. 3.2 fb^{-1}

- Measuring charged-particle distributions sensitive to properties of Underlying Event (UE) in events containing Z boson decaying into a muon pair: $q\bar{q} \rightarrow Z \rightarrow \mu^+\mu^-$
- Transverse thrust describes event topology

$$T_\perp = \frac{\sum_i | p_{T,i} \cdot \hat{n} |}{\sum_i | p_{T,i} |}$$

$\hat{n}$ is the unit vector maximizing the thrust

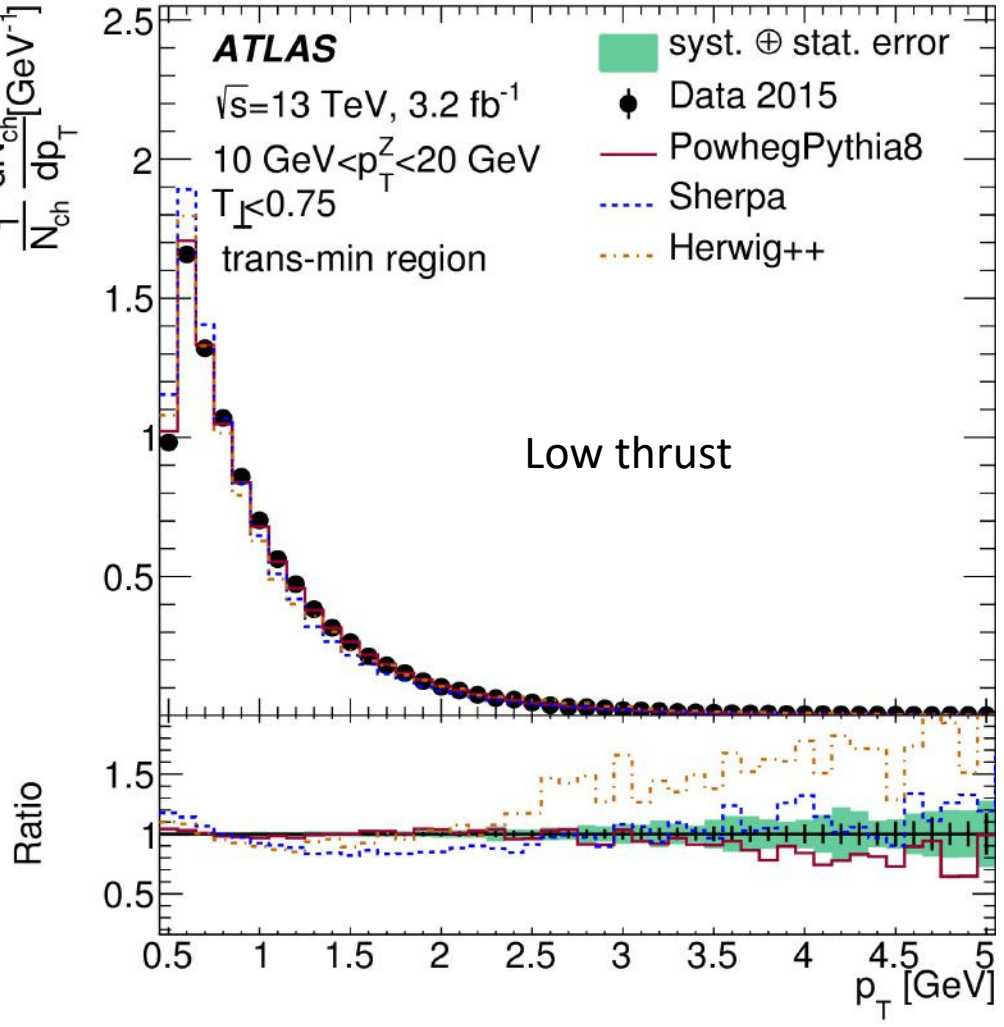


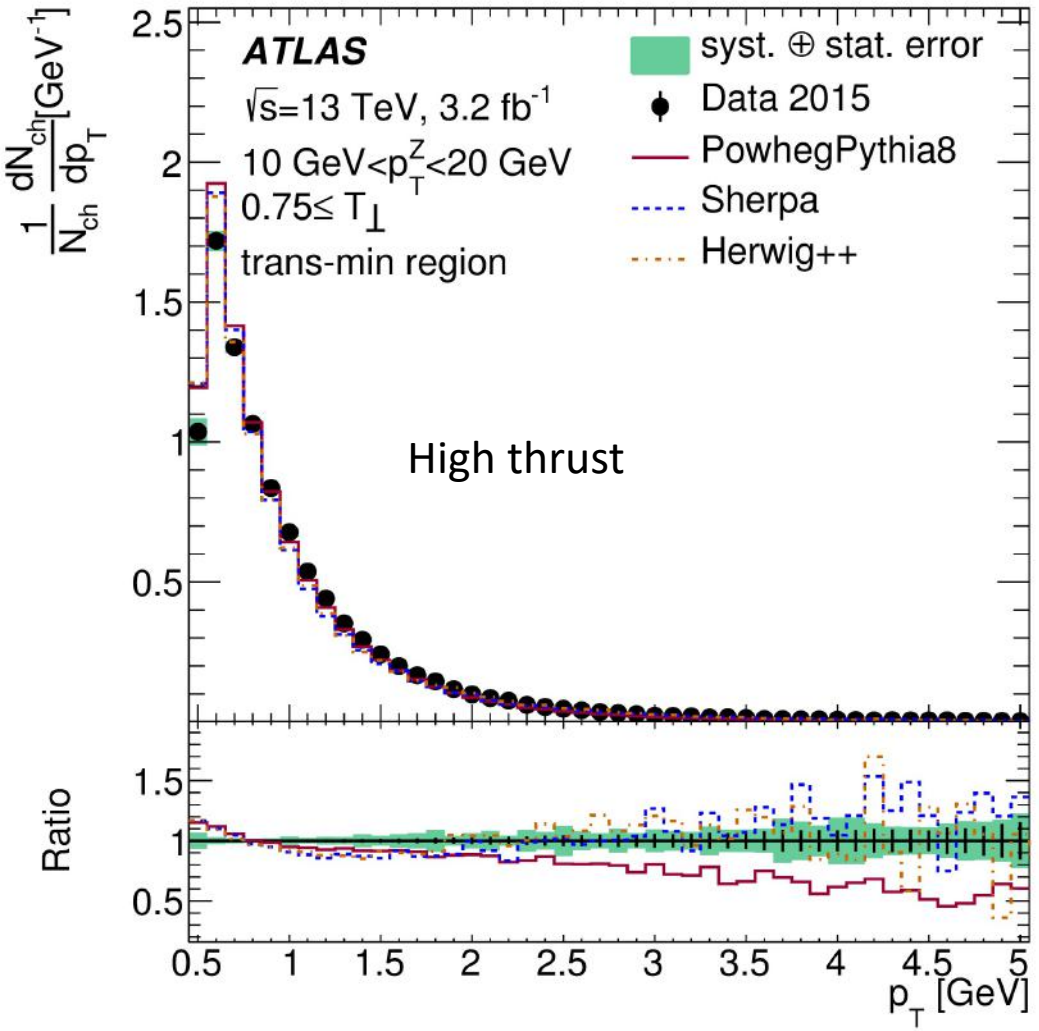
Events with lower thrust more sensitive to Multiple Parton Interactions (MPI)

- Background:
  $Z \rightarrow \tau\tau$, $Z \rightarrow tt$, $WW \rightarrow \mu\nu\mu\nu$ (MC 0.7%)
- Two transverse regions differentiated by the scalar sum of the transverse momentum of the charged-particle: trans-max and trans-min
- Trans-min region is highly sensitive to UE

Measurement of Underlying Event in Z Boson Events at 13 TeV, Eur. Phys. J. C 79 (2019) 666. 3.2 fb^{-1}

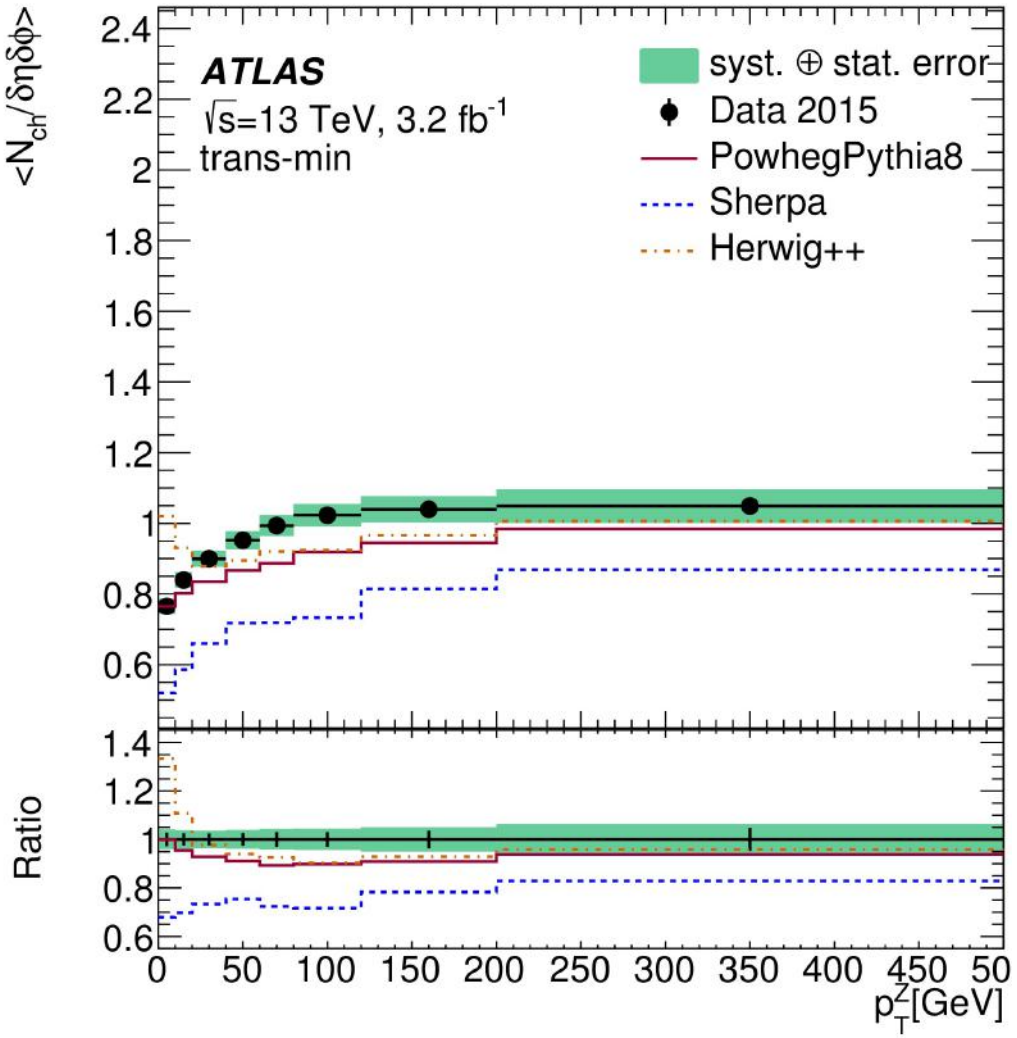
- Powheg-Pythia8 good agreement at low thrust
- Herwig++ good agreement at high thrust
- Sherpa overall good agreement



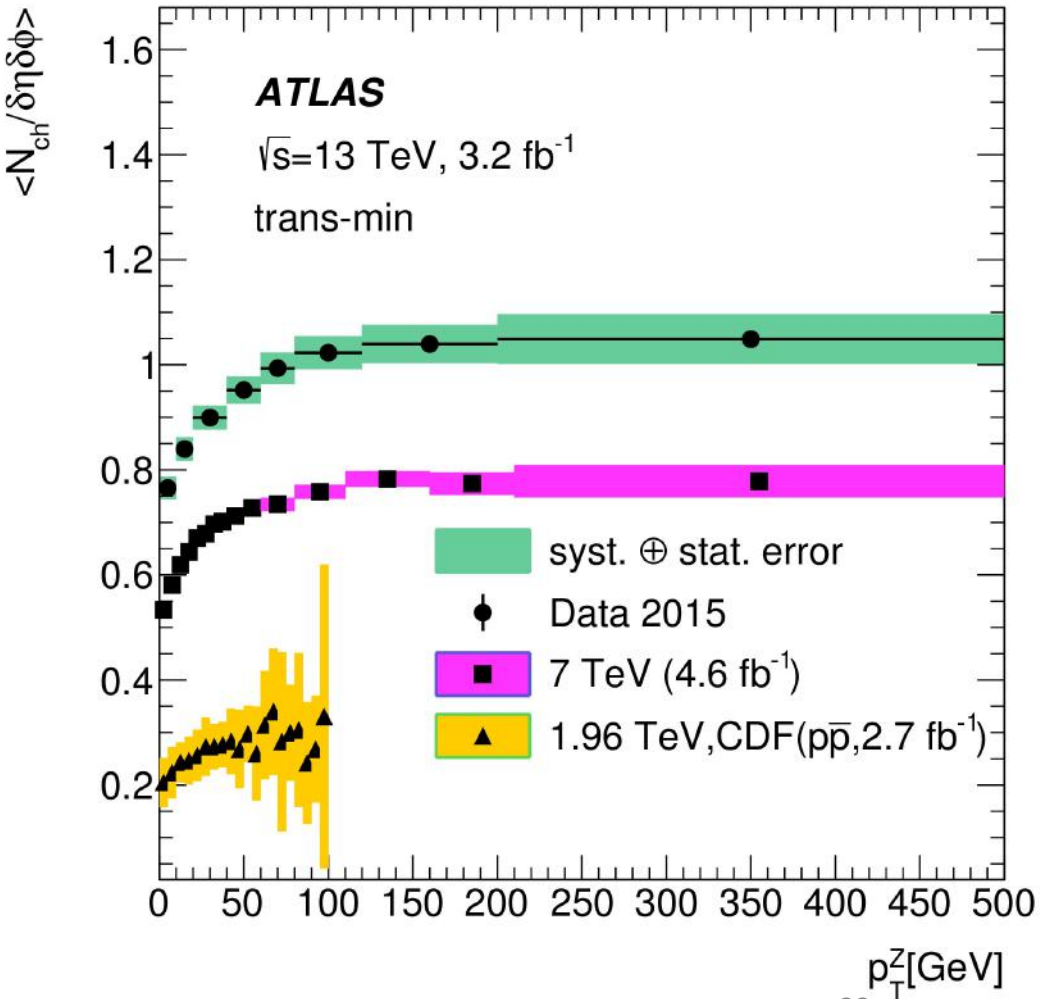


Measurement of Underlying Event in Z Boson Events at 13 TeV, Eur. Phys. J. C 79 (2019) 666. 3.2 fb^{-1}

- Charge multiplicity versus $p_{\mathrm{T}}^{\mathrm{Z}}$
- Significant deviations in tested generators
- UE activity increases with $p_{\mathrm{T}}^{\mathrm{Z}}$ and √s



Compared to previous measurements



Conclusions

Zoom id 8913451401

- ATLAS W+jets and Z+jets data improve QCD proton PDFs
- Single dissociative (soft QCD) and re-scattering probed in photon-induced dilepton production with forward proton tag
- Comparison with predictions of $gg \to \gamma\gamma$ production and dissociative reactions in light-by-light scattering and di-muon production in ultraperipheral Pb+Pb collisions
- Inclusive single diffractive dissociation cross-section and comparison with event generator predictions
- Underlying event measured in Z boson production and compared with event generator predictions

- Future: precision increase with analysis of larger/new data sets
- Much potential for collaboration with phenomenologists

References

pdf from W+jets and Z+jets data

- https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/STDM-2019-18/

AFP

- https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/STDM-2018-16/

Pb+Pb

- https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/HION-2019-08/
- https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/HION-2016-02/

ALFA

- https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/STDM-2018-01/

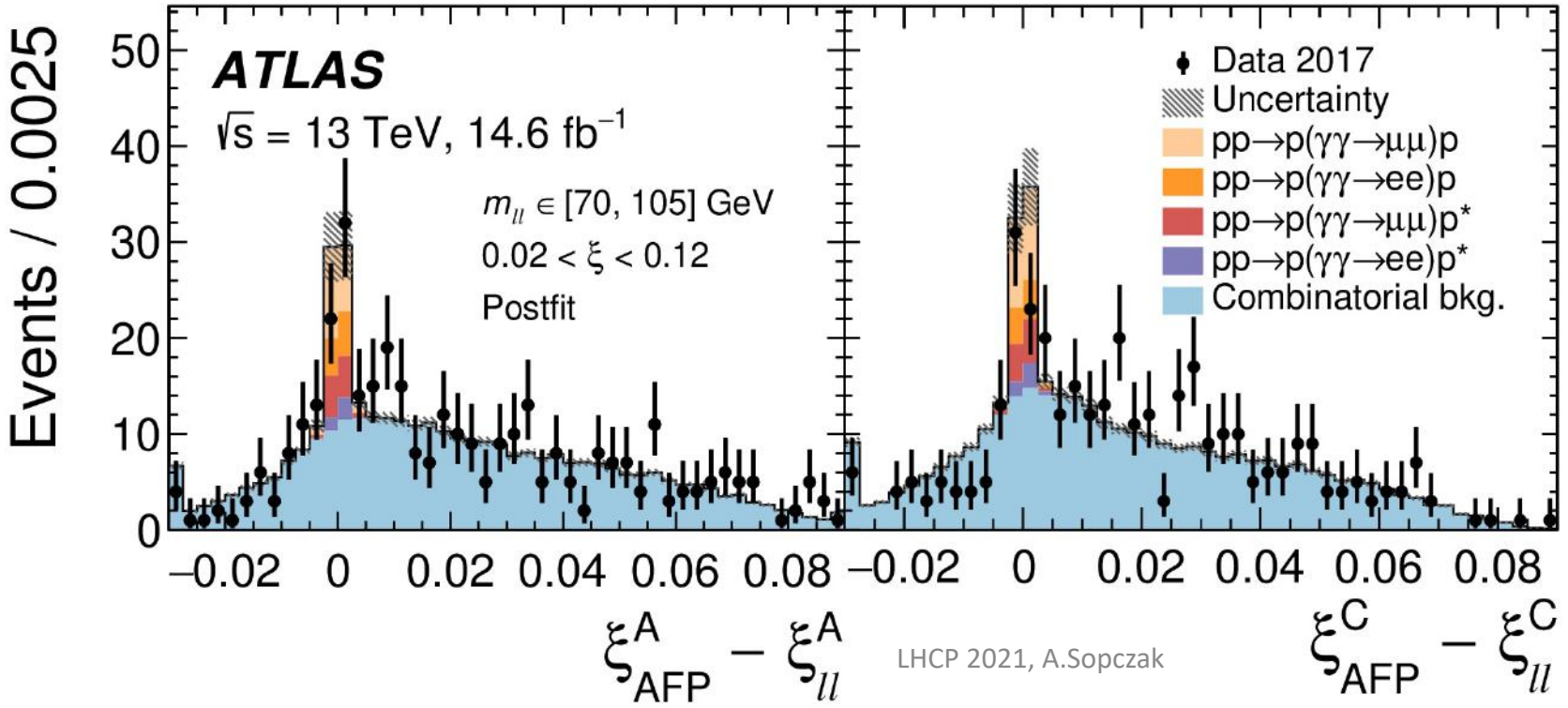
Underlying event

- https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/STDM-2017-28/

Extra

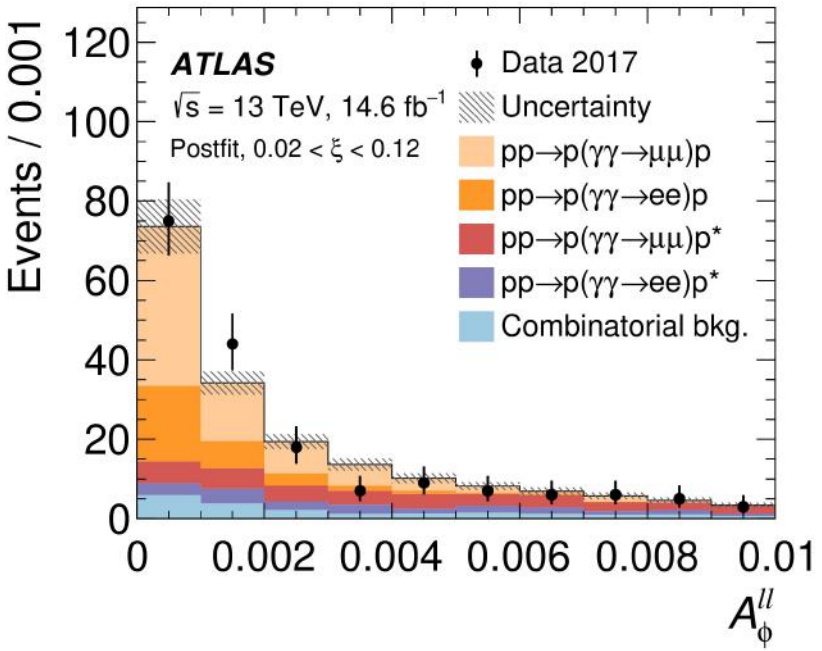
Photon-induced dilepton production with forward proton tag at 13 TeV, PRL 125 (2020) 261801, 14.6 fb^{-1}

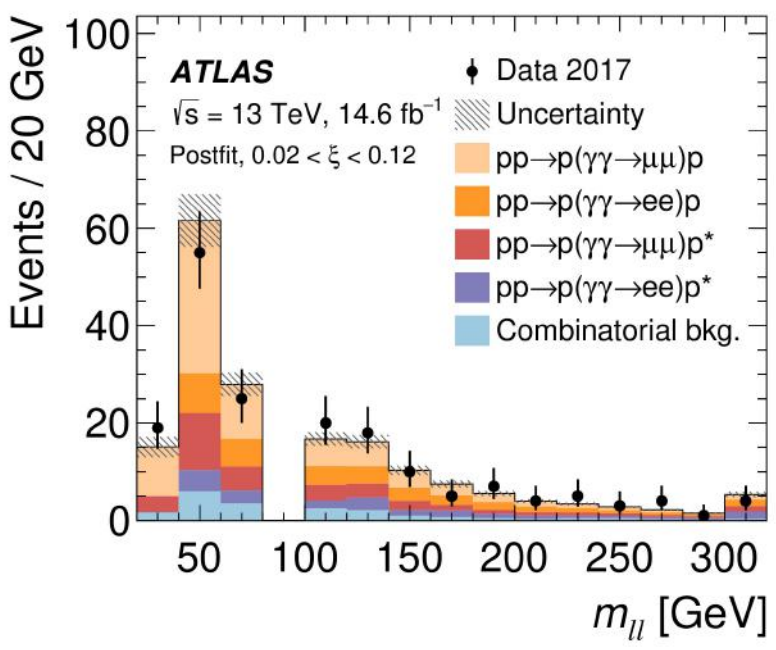
- Distributions of ξ_{AFP} - $\xi_{\ell\ell}$ in the 70 < $m_{\ell\ell}$ <105 GeV
- The simulated signals are normalized to Herwig and Lpair predictions, with soft-survival effects being included by applying an $m_{\ell\ell}$-dependent reweighting from Ref. [31] and Lpair additionally scaled down by 15% [30].

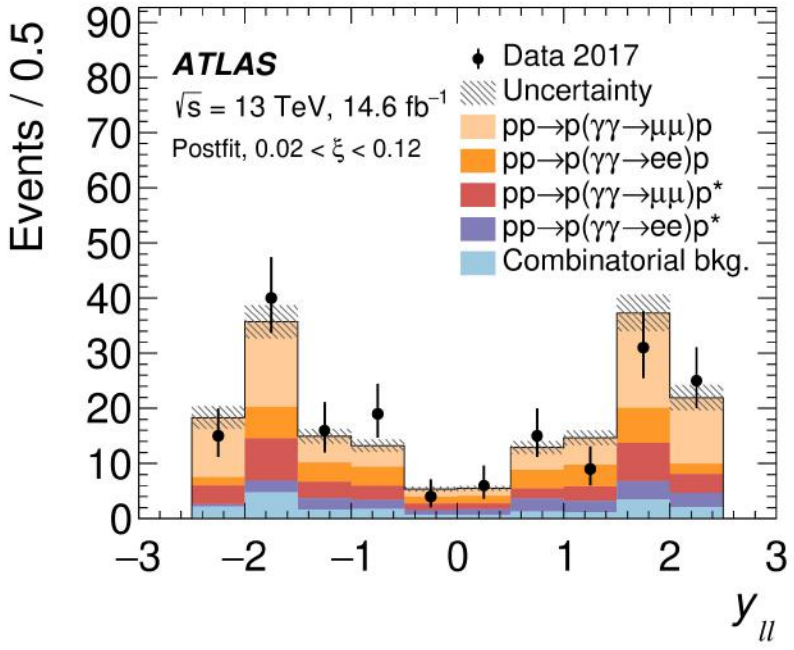


Photon-induced dilepton production with forward proton tag at 13 TeV, PRL 125 (2020) 261801, 14.6 fb^{-1}

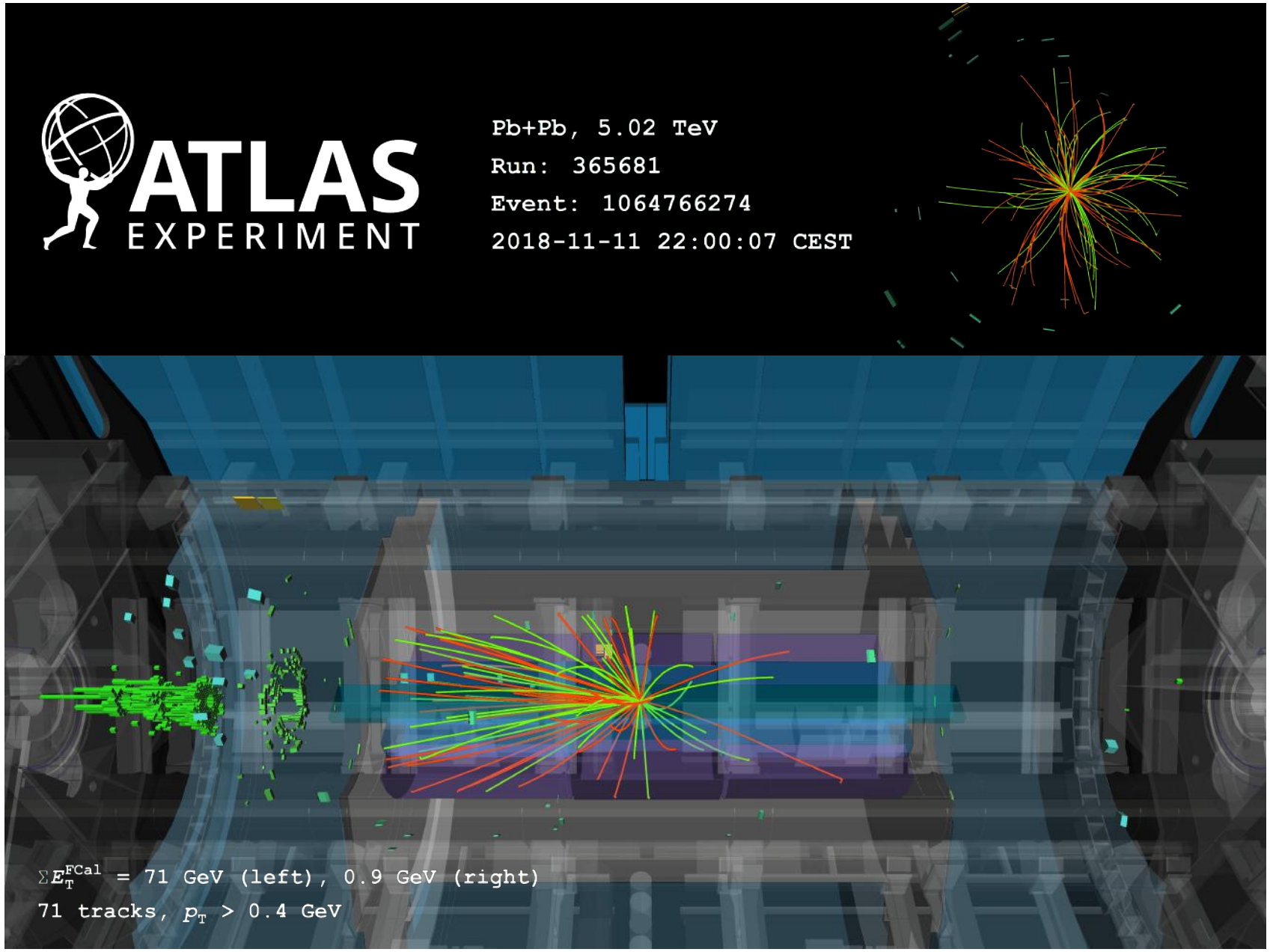
- Dilepton acoplanarity $A_\phi^{\ell\ell}$ (left), invariant mass $m_{\ell\ell}$ (center), rapidity $y_{\ell\ell}$ (right)
- $\xi_{\ell\ell}$, ξ_{AFP} in [0.02, 0.12] and $|\xi_{AFP} - \xi_{\ell\ell}|<0.005$ for at least one AFP side.
- Events with $70 < m_{\ell\ell} < 105$ GeV are vetoed.







2018 heavy ion collision event (365681,1064766274): an ultra-peripheral photo-nuclear collision. 30-11-2018



ATLAS-EVENTDISPLAY-2018-008