COLUMBIA UNIVERSITY

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# Heavy electroweak boson production in Pb+Pb collisions with ATLAS

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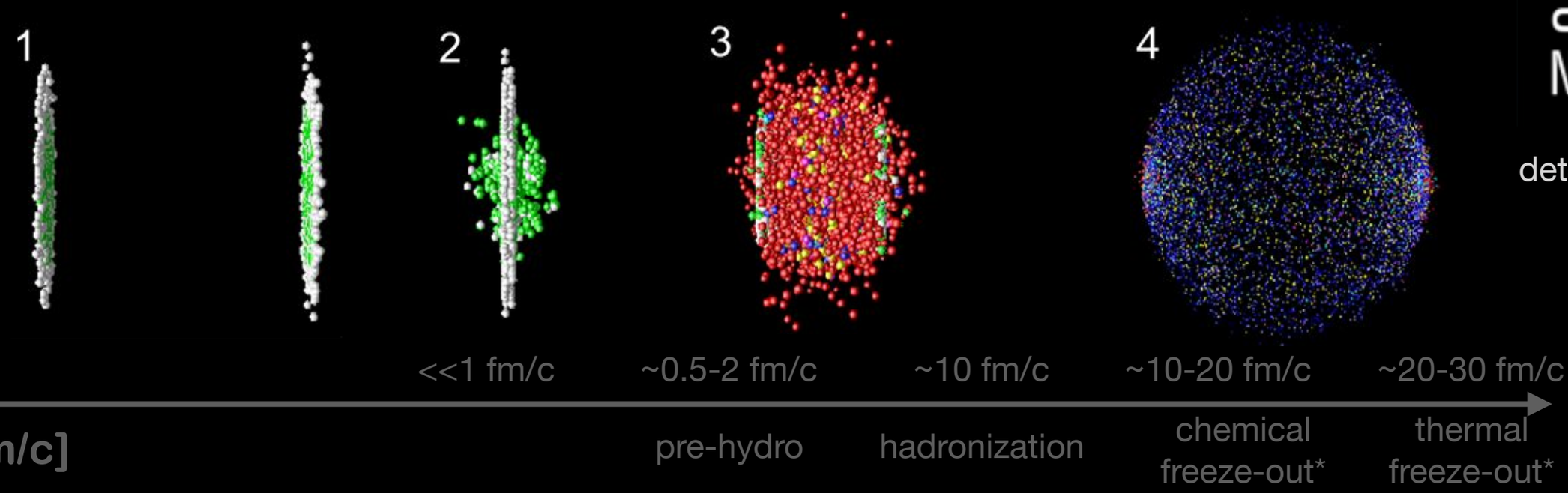
for the ATLAS Collaboration

Weizmann Institute of Science

# Introduction

- heavy EW bosons produced in the hard scattering
- carry information about the initial stage
- do not interact with the QGP

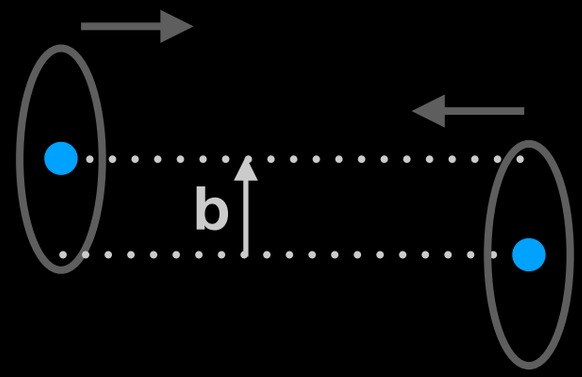



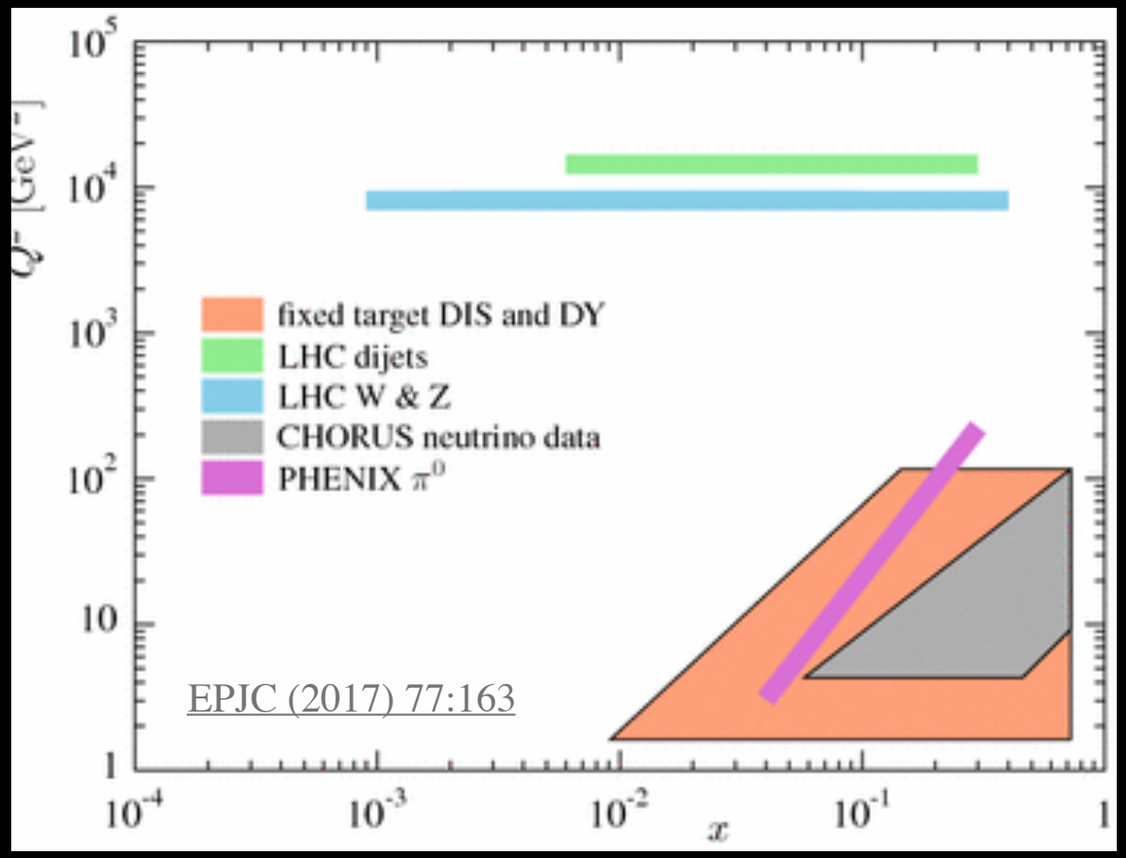

*depends on the hadron species, times quoted for *p* and Λ for 2.76 TeV Pb+Pb

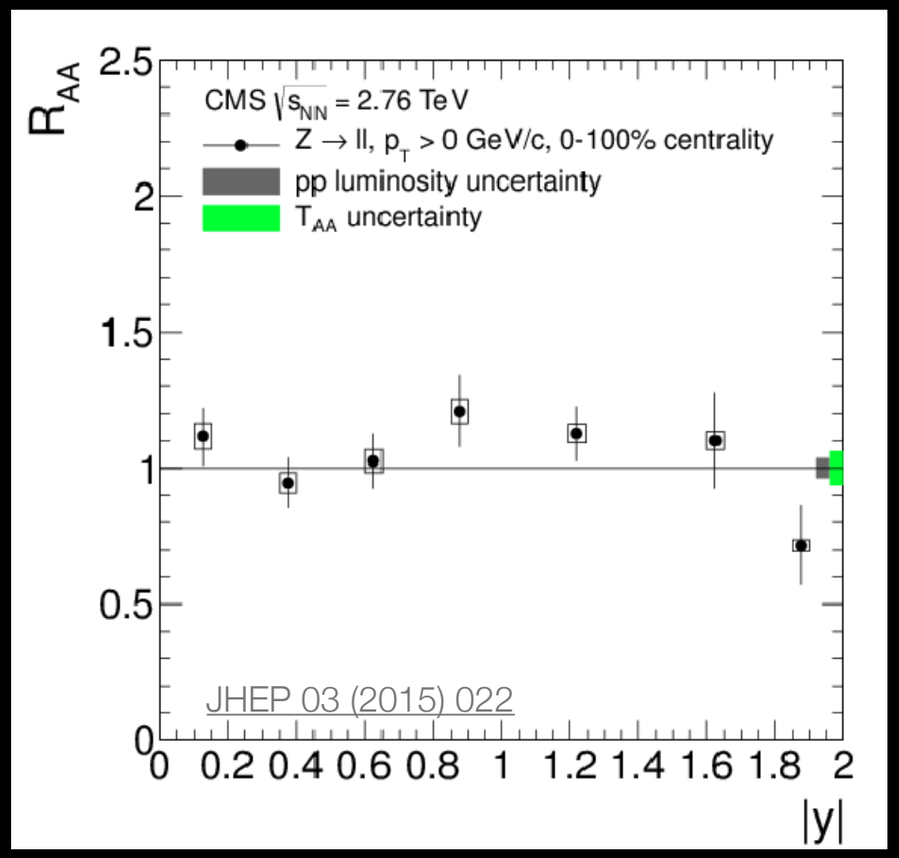
# Physics Questions

- nuclear Parton Distribution Functions (nPDF)
- Glauber model and binary scaling

*nuclear modification:* $$R_{AA}(x) = \frac{N_{inel}^{-1}\ dN/dx}{\langle T_{AA}\rangle\ d\sigma^{pp}/dx}$$



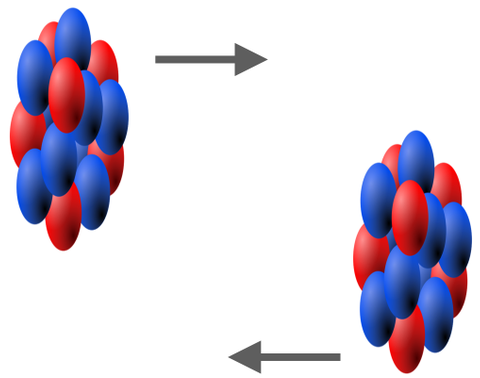



# Results in this talk: $\sqrt{s_{NN}}$=5.02 TeV, Run 2 data

**proton+proton**

**nucleus+nucleus**



25 pb$^{-1}$, 2015

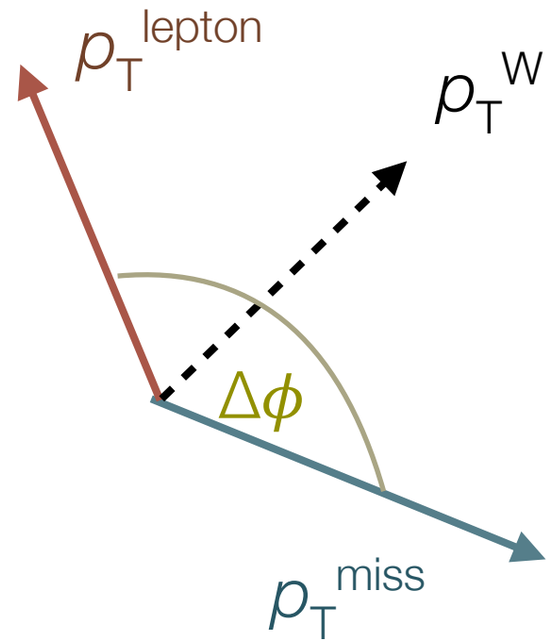
0.49 nb$^{-1}$, 2015

- "W and Z production in 5.02 TeV pp collisions", Eur. Phys. J. C 79, (2019) 128
- "Measurement of W bosons production in Pb+Pb collisions at 5.02 TeV with the ATLAS detector", HION-2018-25 **New!**
- "Z boson production in Pb+Pb collisions at 5.02 TeV measured by the ATLAS detector", ATLAS-CONF-2019-024 **New!**

→ *increase in yield by factor of 5 for Z and 7 for W compared to Run-1*

# *W/Z* boson reconstruction with ATLAS

- single lepton trigger (8/15 GeV for *μ/e* )
- inside precision region of the detector (|η|<2.5)
- high quality reconstruction requirements on the lepton
- minimize hadronic activity around lepton (isolation)
- $p_T^{miss} = -\sum \vec{p}_T^{track}$ : $m_T = \sqrt{2 p_T p_T^{miss}(1-\cos\Delta\phi)}$




| *Z* selection |
| --- |
| opposite charge *e/μ* |
| 66<$m_{\ell\ell}$<116 GeV |

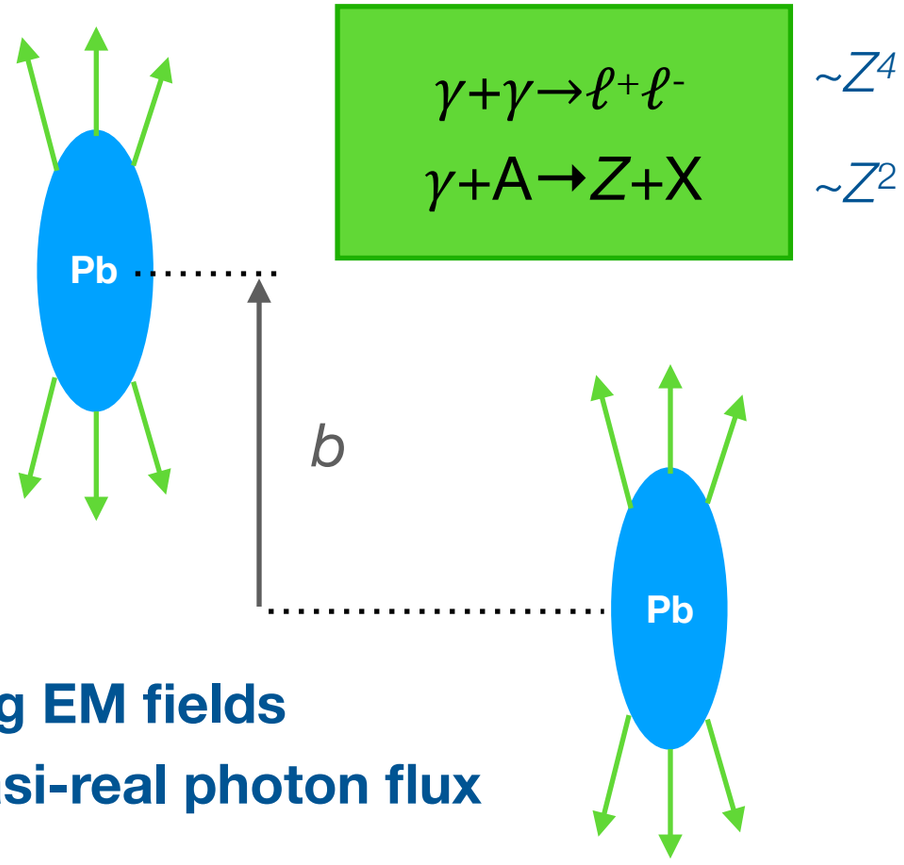
| *W* selection |
| --- |
| $p_T^{miss}$ > 25 GeV |
| $m_T$ > 40 GeV |
| *Z* veto: $m_{\ell\ell}$>66 GeV excluded |

# Background: $Z$ boson

- EW processes: $Z \rightarrow \tau\tau$
- top quark production

simulated
0.1% for e/$\mu$

- **multi-jet:** data-driven estimate of 2%(0.5%) for $e(\mu)$
- **photon-induced:** estimated in peripheral region 50-100% centrality

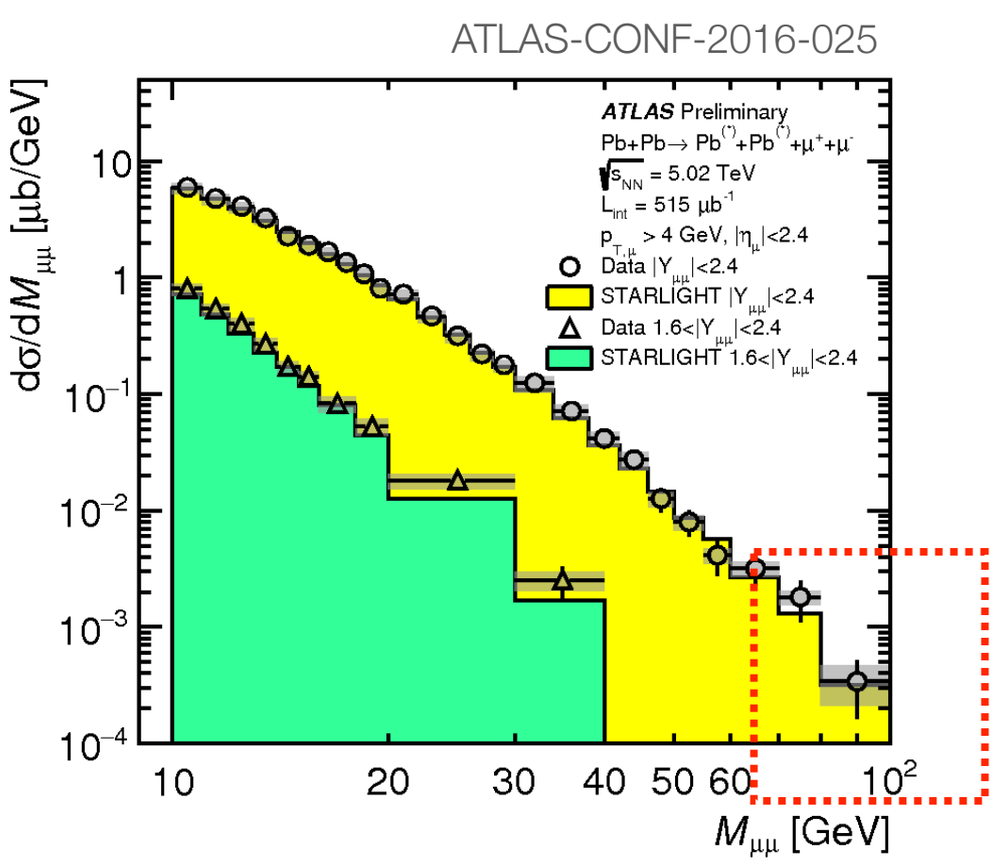



$\gamma+\gamma \rightarrow \ell^+\ell^-$ $\sim Z^4$

$\gamma+A \rightarrow Z+X$ $\sim Z^2$

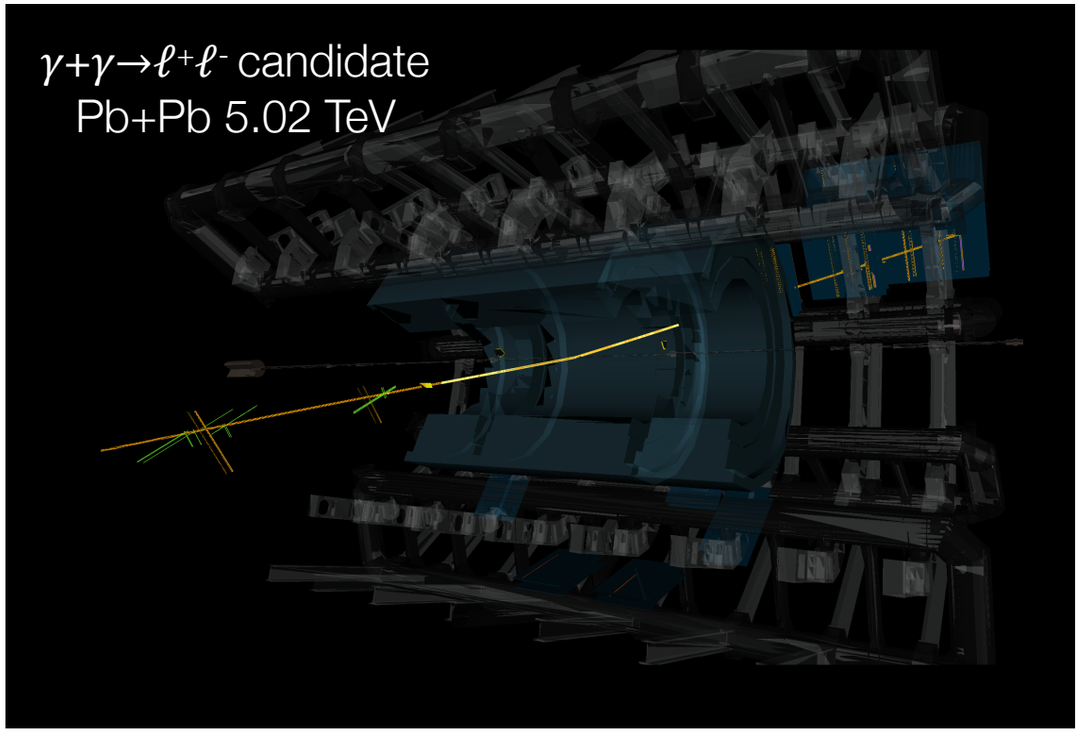
**strong EM fields**

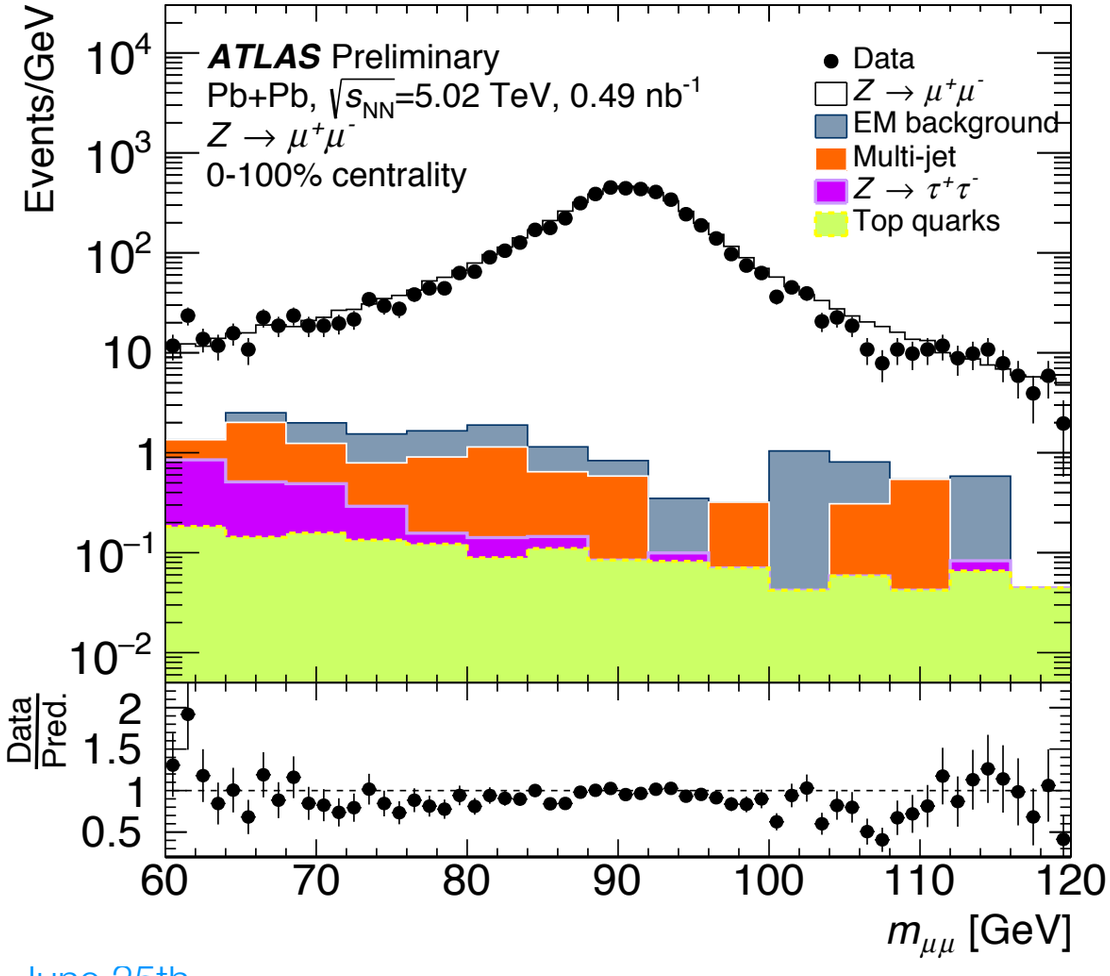
**≈ quasi-real photon flux**



# Background: *Z* boson

- **photon-induced:** isolated in ultra-peripheral region 80-100% centrality
  - large rapidity gap in the event used for background removal
  - requiring coincidence in ZDC signal for 50-100% centrality interval
  - residual background estimated at the level of 0.5%



# Background: *W* boson

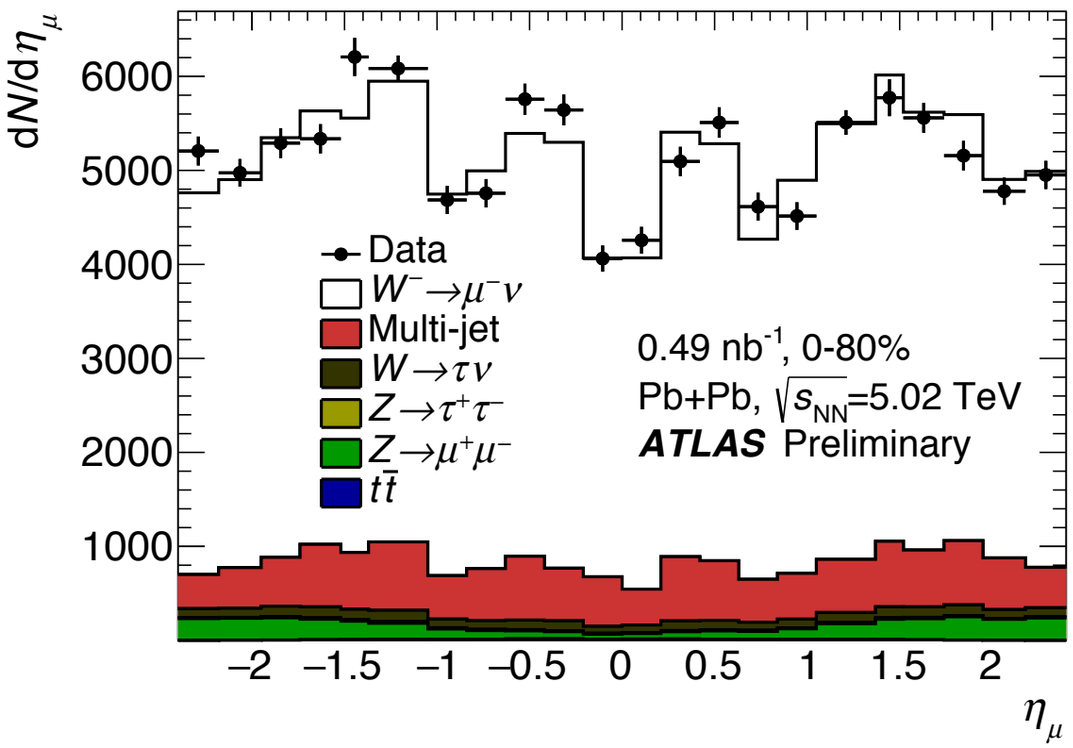
- EW processes: $W\to\tau\nu$, $Z\to\ell\ell$, $Z\to\tau\tau$
- top quark production

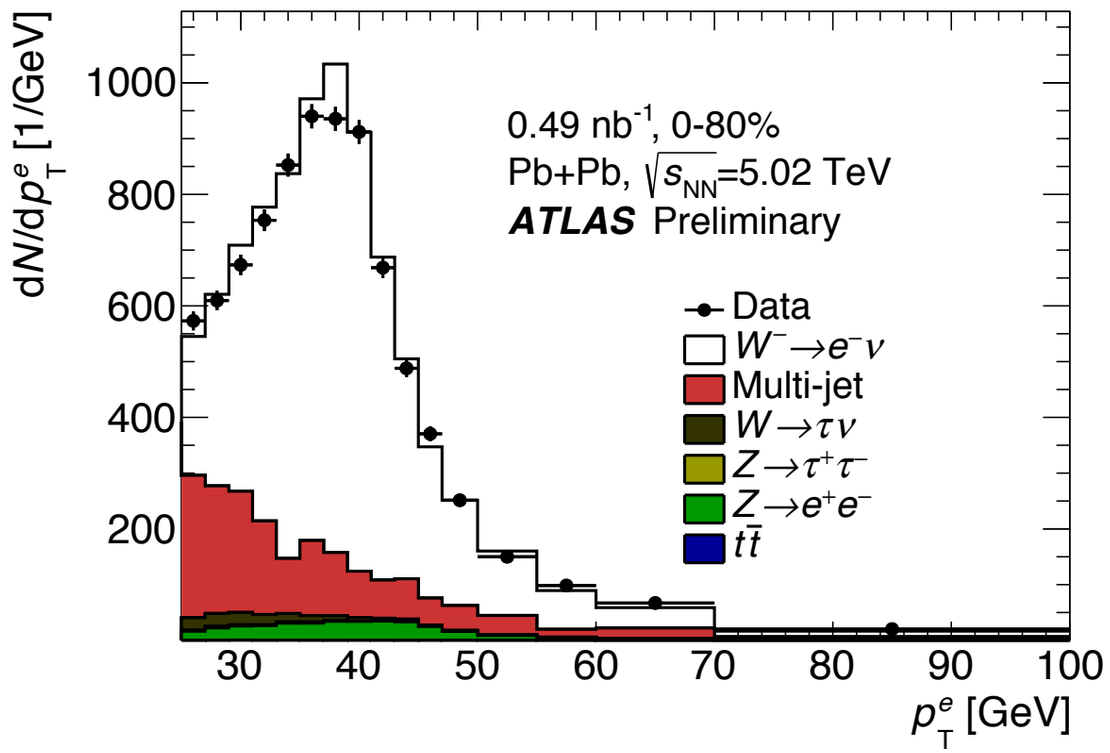
simulated
8% (5%) for e($\mu$)

- **multi-jet**: semileptonic decays of HF hadrons, in-flight decays of kaons and pions, photon conversions or misidentified hadrons

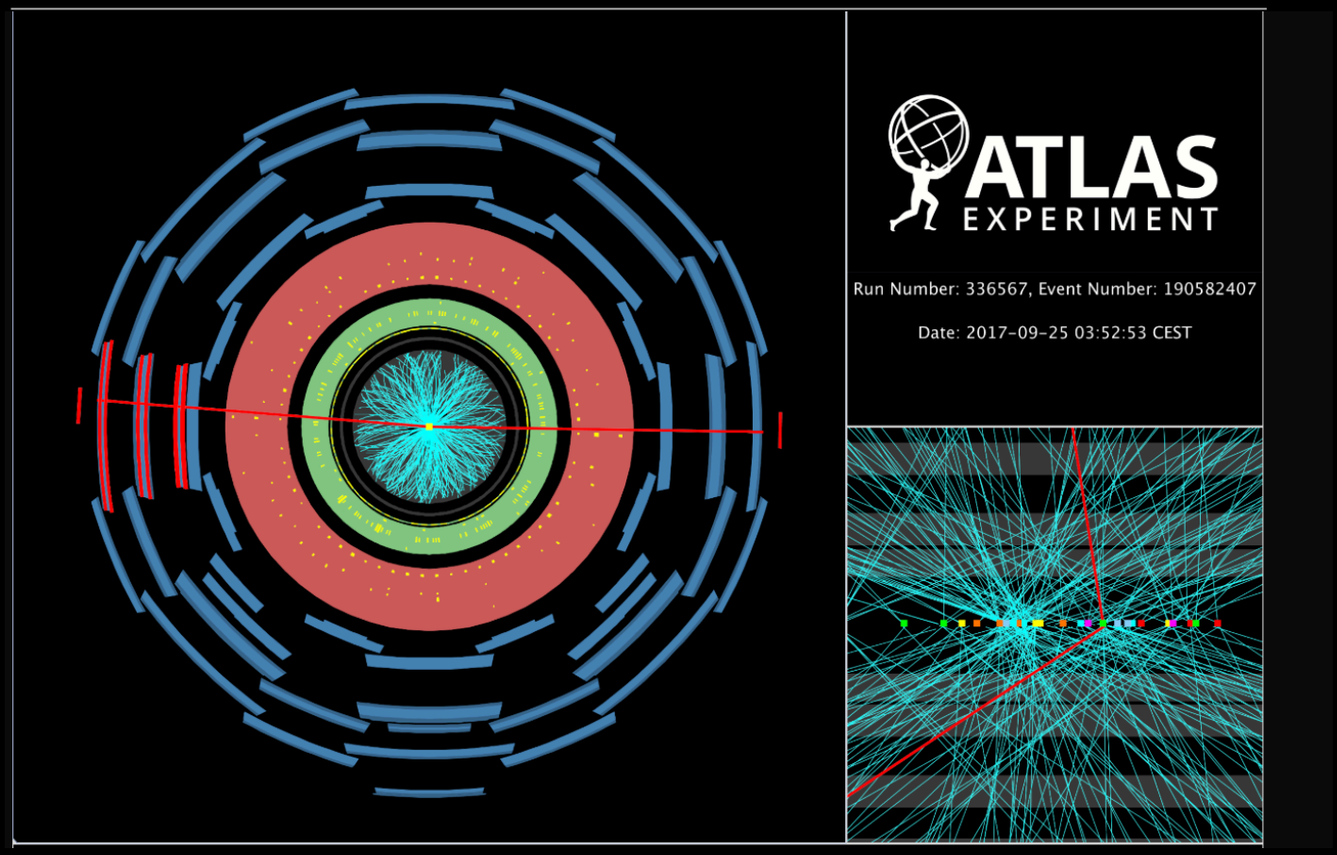
template-fits
20% (12%) for e($\mu$)

- **photon-induced:** suppressed by requiring ZDC coincidence in 50-80%



# proton-proton reference results



# Fiducial cross sections

- fiducial cross sections:

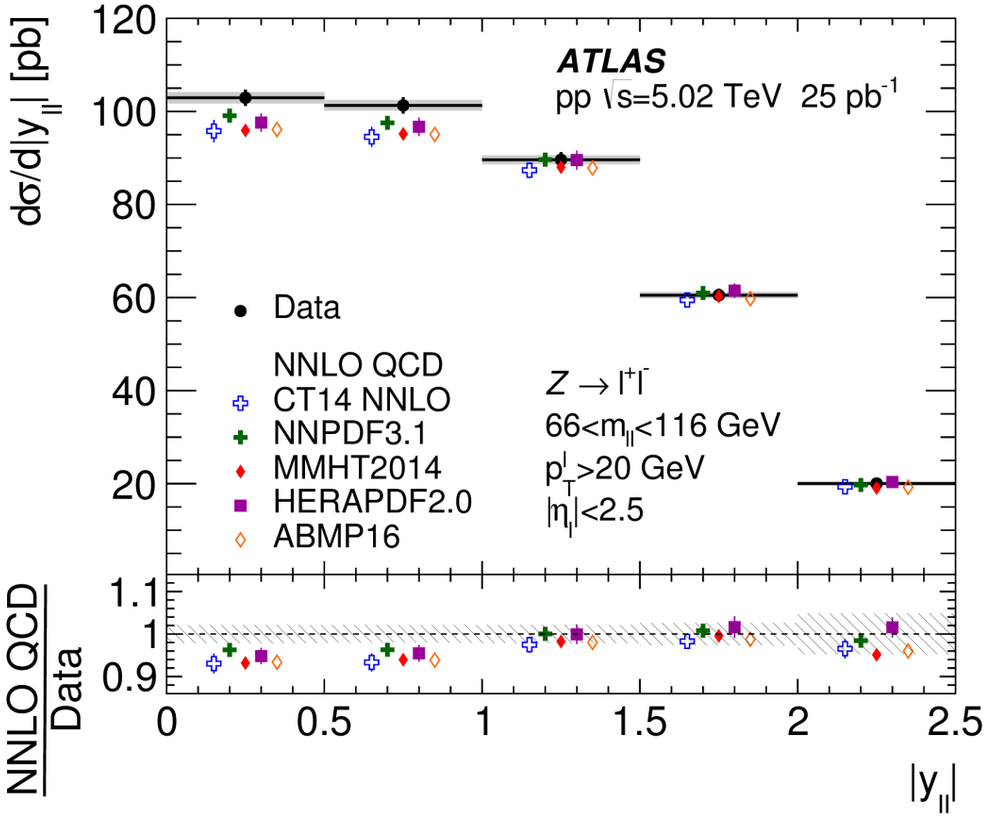
  $W^+$: 2266 ± 9 (stat) ± 29 (syst) ± 43 (lumi) pb

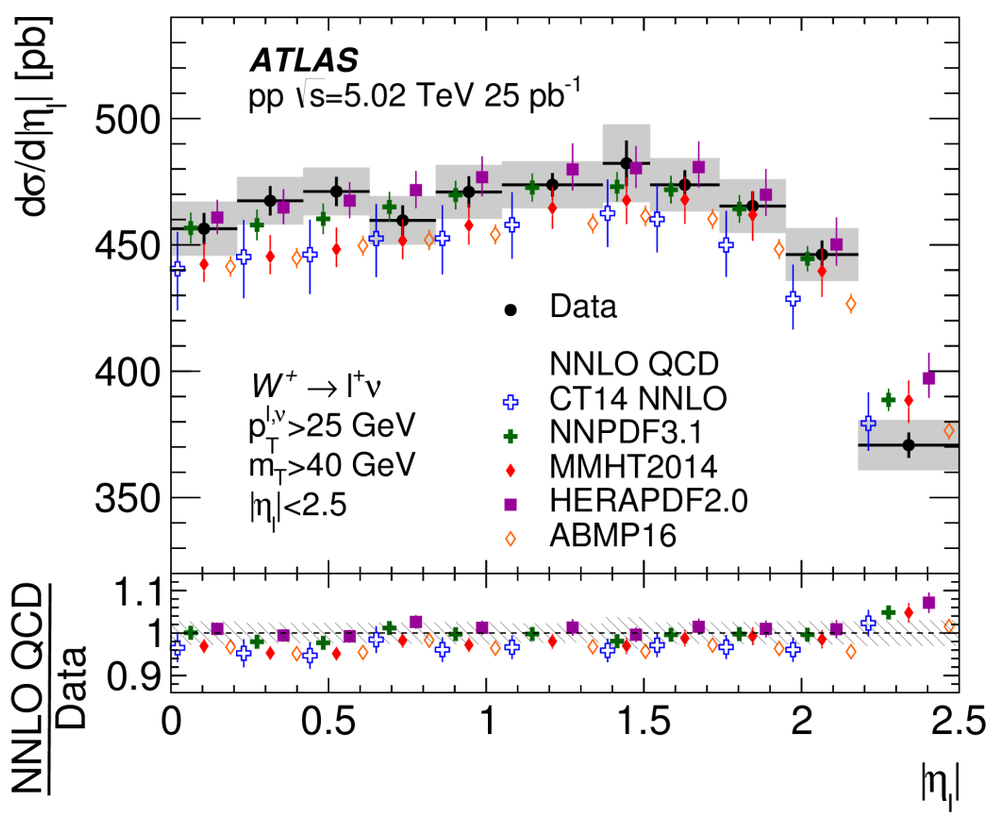
  $W^-$: 1401 ± 7 (stat) ± 18 (syst) ± 27 (lumi) pb

  $Z$: 374.5 ± 3.4 (stat) ± 3.6 (syst) ± 7.0 (lumi) pb

in agreement with NNLO pQCD

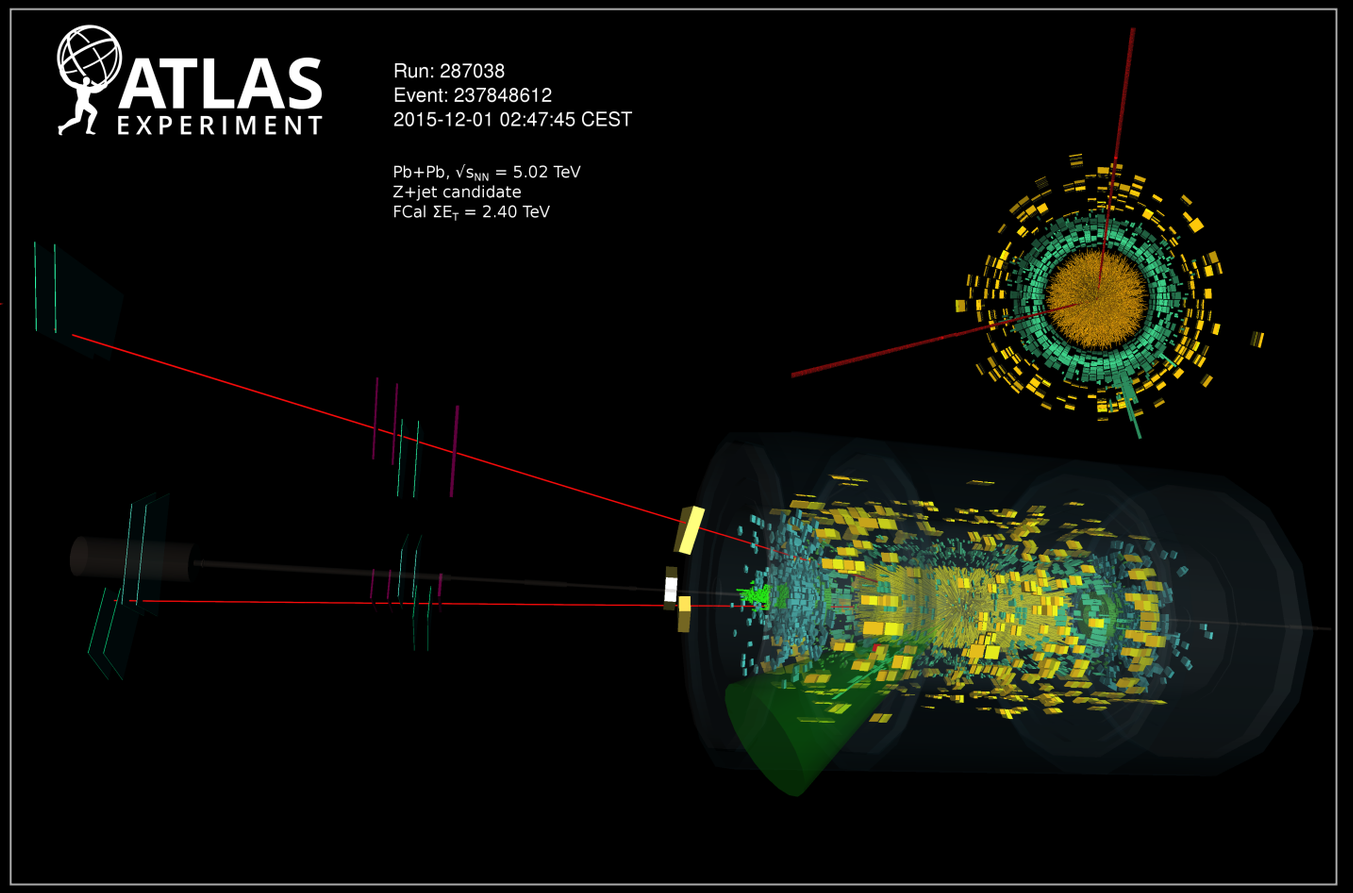
1.2-1.7% measurement precision



# lead-lead results

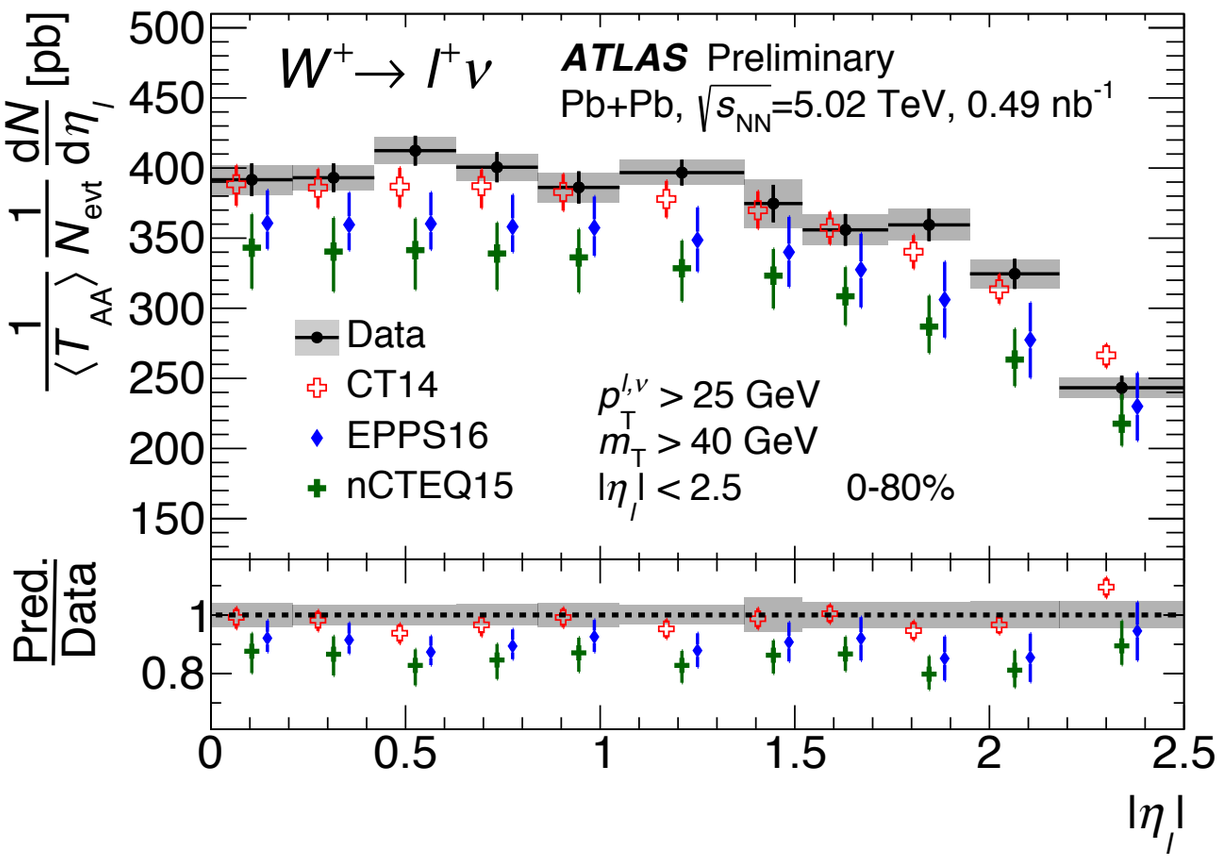
New!



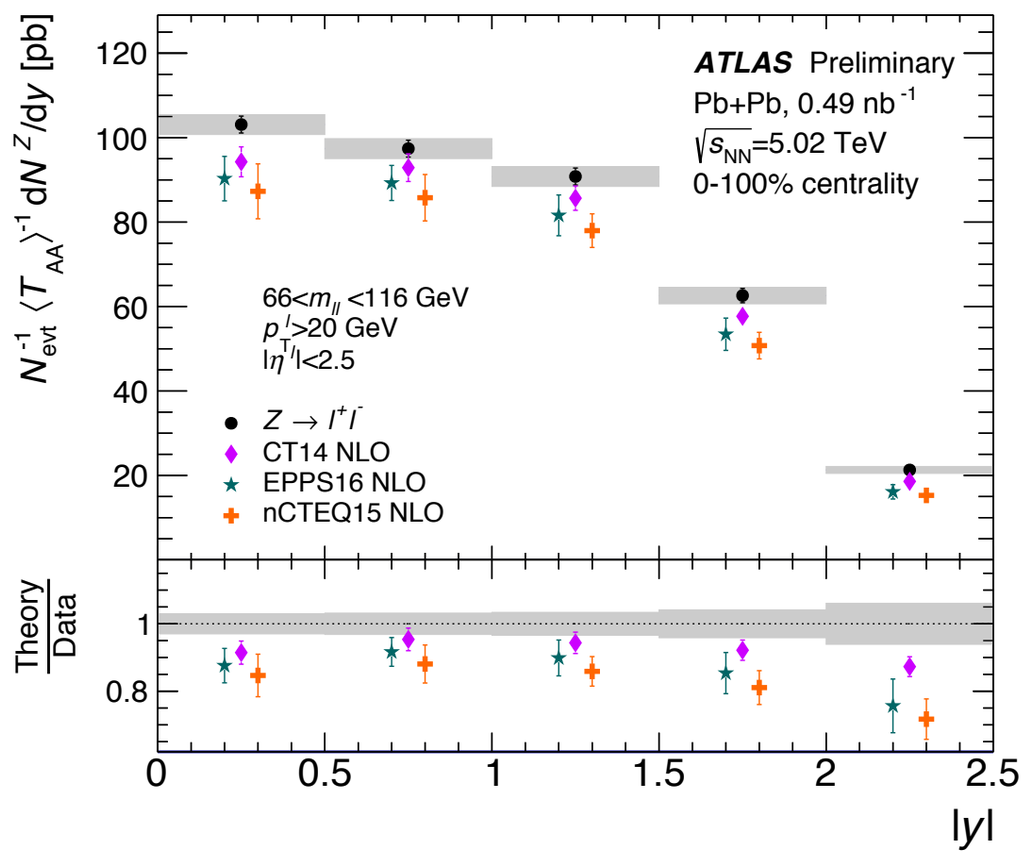
# *W* and *Z* yields versus nPDF predictions

- best agreement observed with free proton PDF (CT14) + isospin
- nPDF underestimate the yields at the level of 1-3$\sigma$
- results consistent between *W* and *Z* measurements

Normalised yield versus $|\eta|$



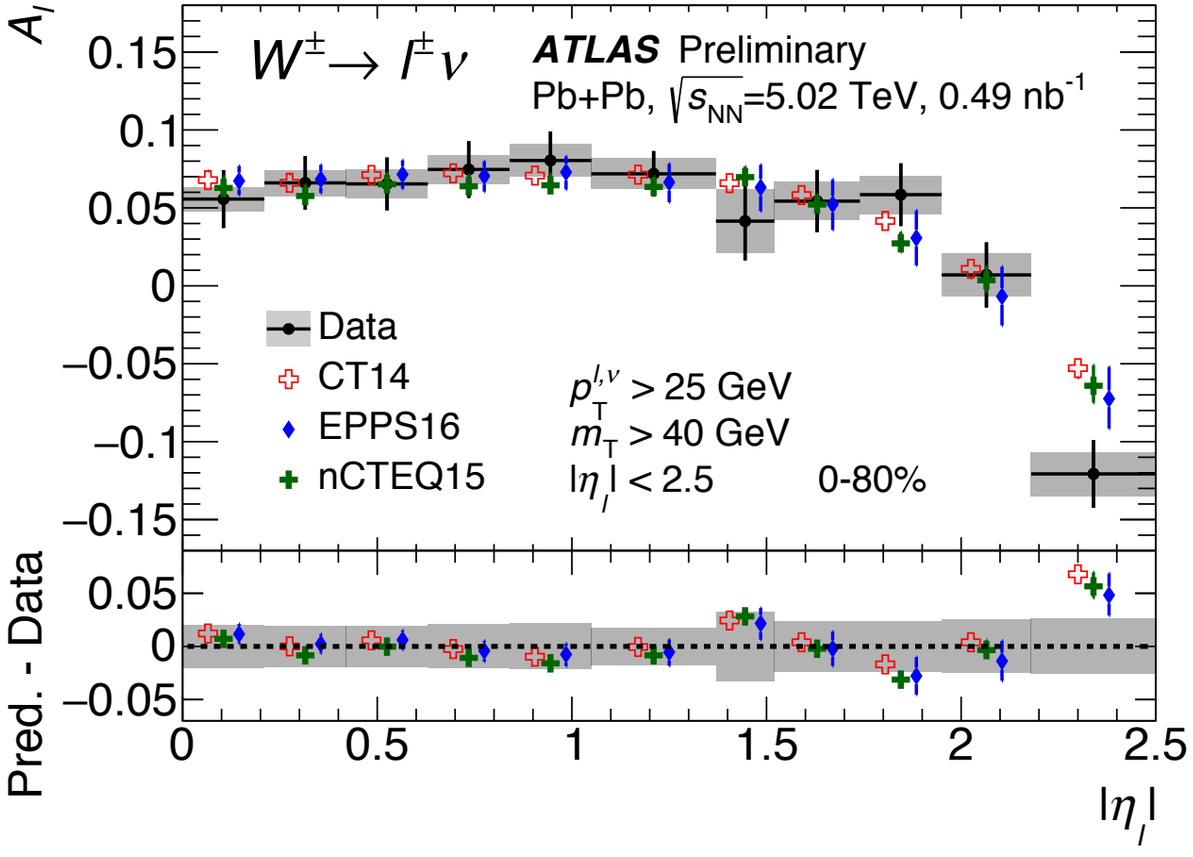

Normalised yield versus $|y|$



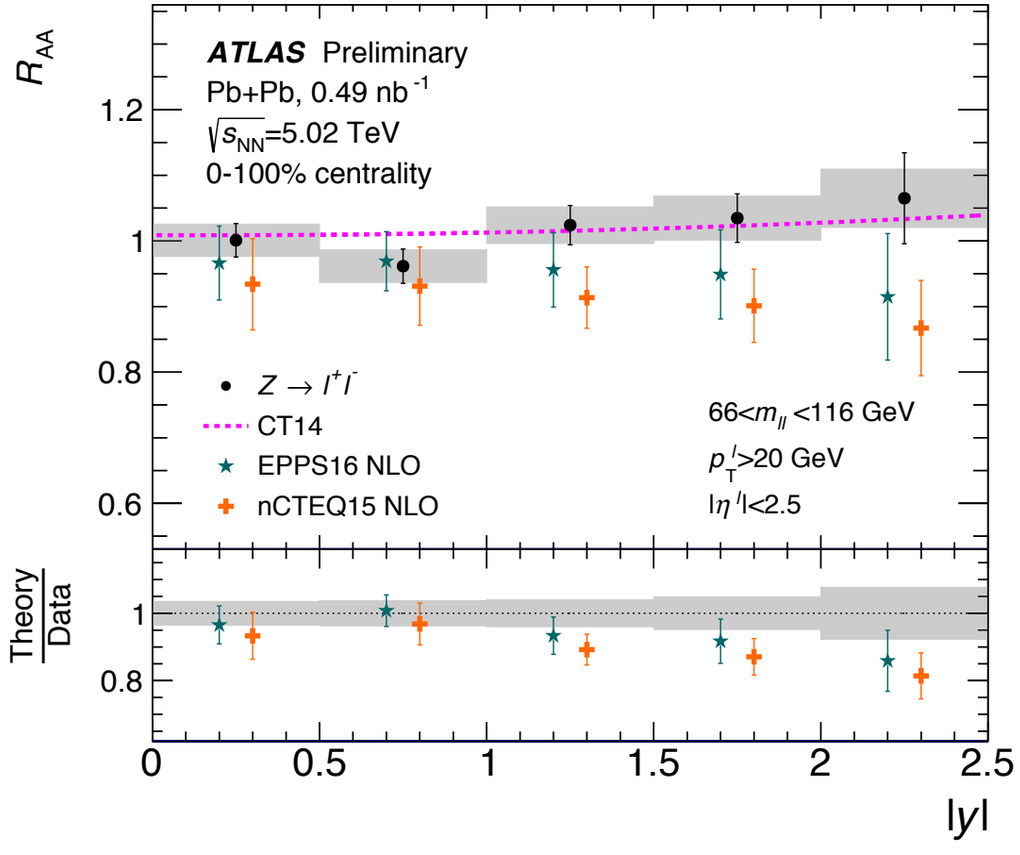
# Results versus nPDF NLO predictions

- no difference between free PDF and nPDF for lepton charge asymmetry
- *Z* boson $R_{AA}$(y): best agreement observed with free proton PDF (CT14) + isospin

Asymmetry versus $|\eta|$

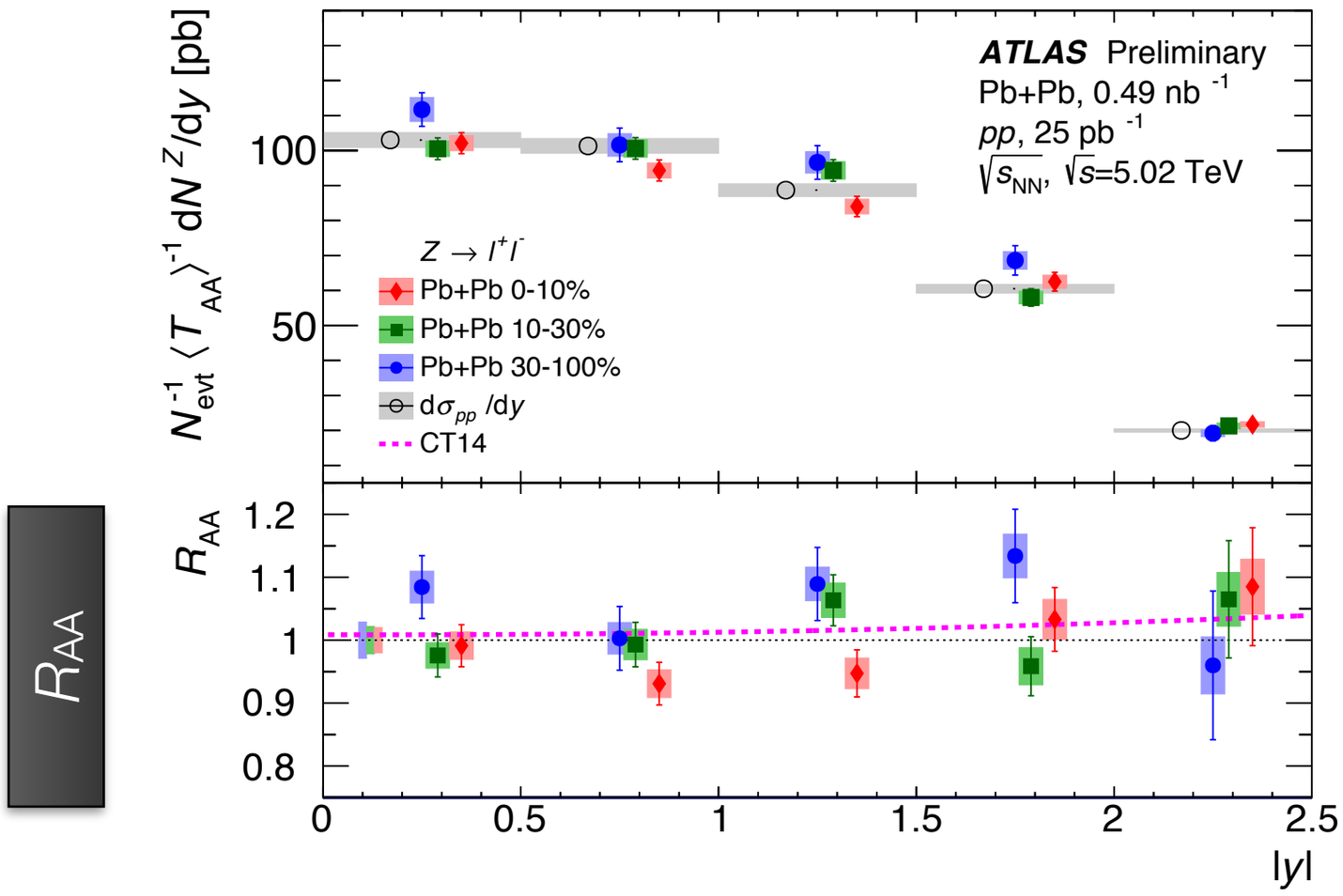



$R_{AA}$ versus $|y|$



# Rapidity distributions in centrality

Normalised yield versus $|\eta|$




**0-10%**

**10-30%**

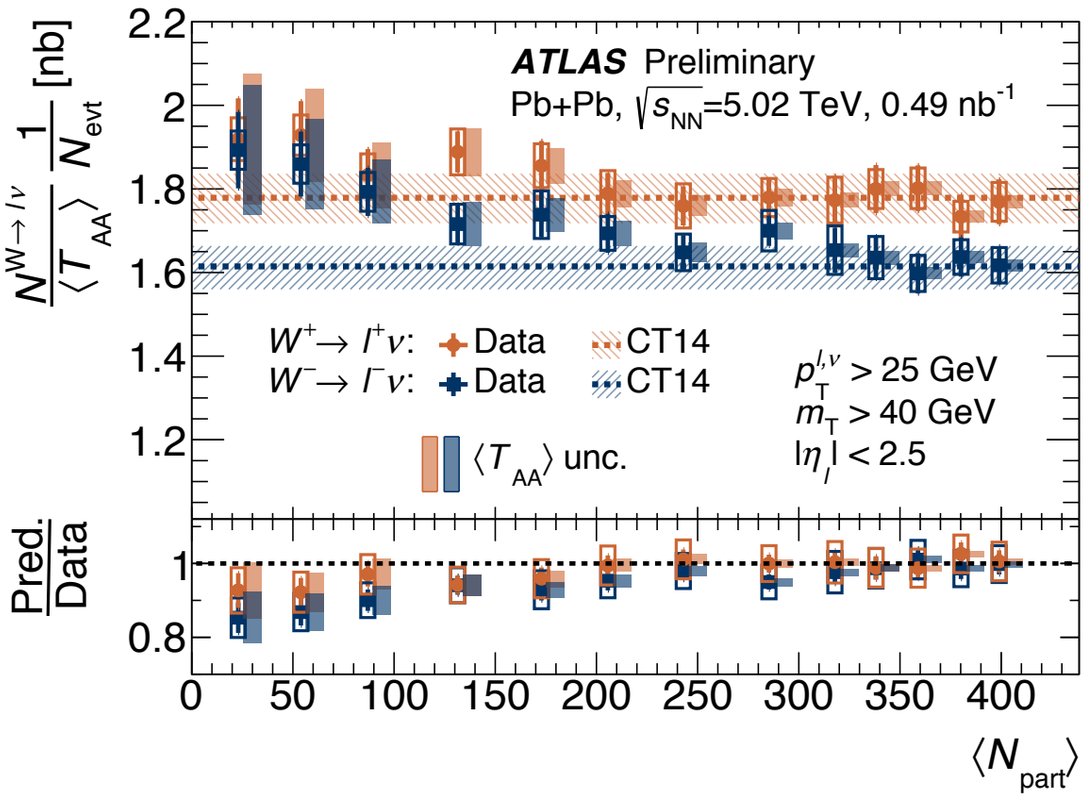
**30-100%**

- no significant difference in rapidity distribution between different centrality classes

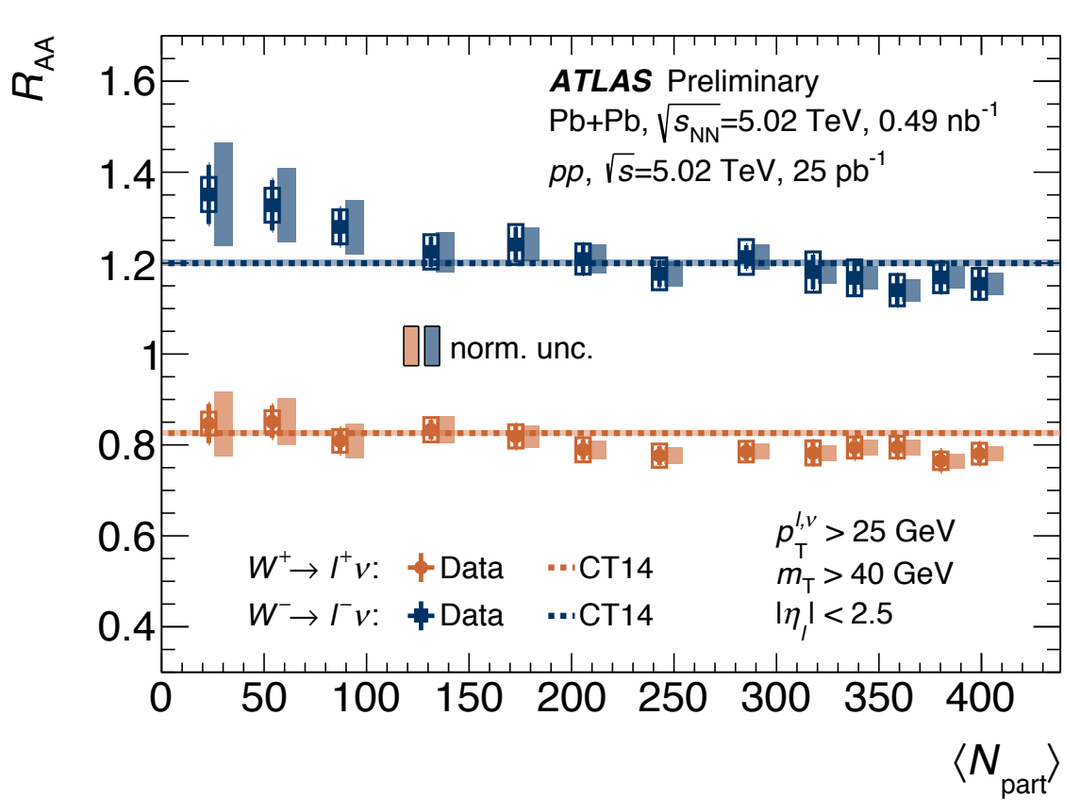
# Binary scaling: *W* boson

- yields show good agreement with predictions for $N_{part}$>200
  - excess in peripheral 50-80% at the level of 1.7 (0.9)$\sigma$ for $W^-$ ($W^+$)
- $R_{AA}$ deviates from unity due to isospin effect
  - agrees with predictions up to 1.2 (0.4)$\sigma$ in peripheral and 1.1 (1.8)$\sigma$ in central for $W^-$ ($W^+$)

Normalised yield versus <$N_{part}$>



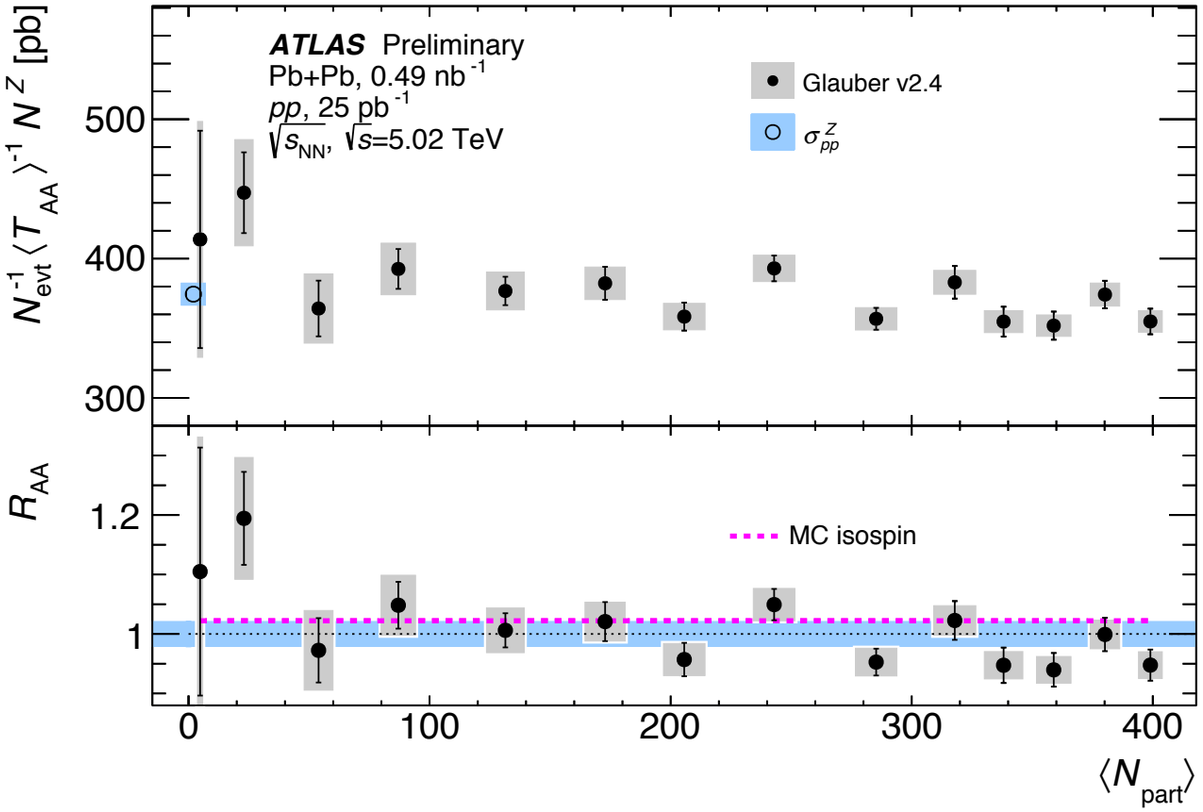

$R_{AA}$ versus <$N_{part}$>



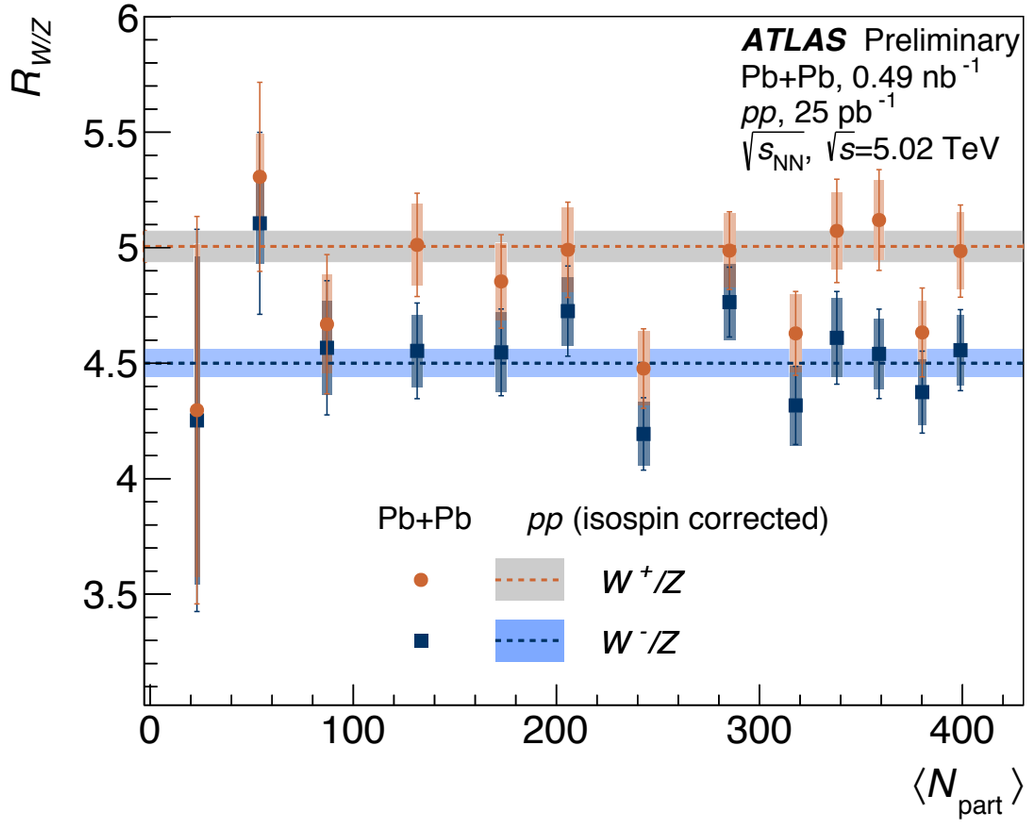
# Binary scaling: *Z* boson

- consistent with predictions within one standard deviation
- *W/Z* ratio constant over centrality and consistent with *pp* 5.02 TeV measurement

Normalised yield versus $\langle N_{part} \rangle$




*W/Z* ratio versus $\langle N_{part} \rangle$

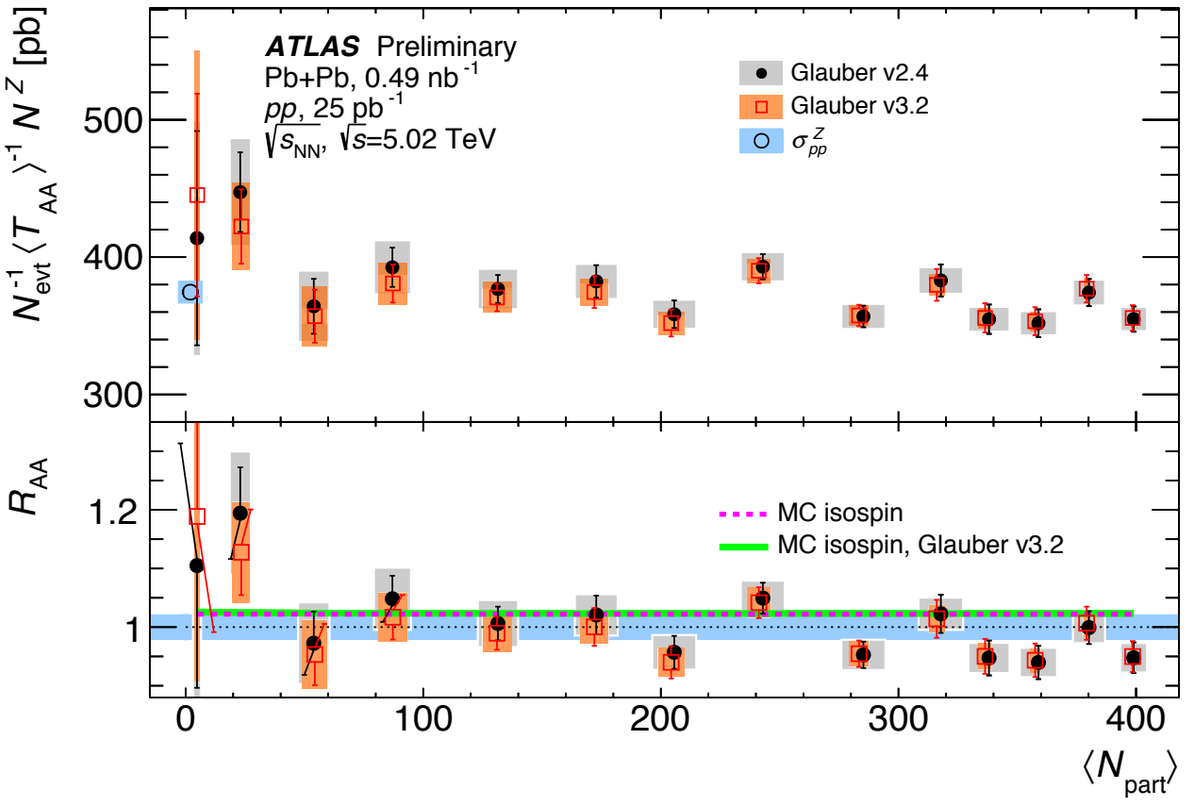


# Binary scaling: Glauber MC comparison

- calculated with Glauber MC v2.4 and v3.2 (includes also the neutron skin effect)
- slope for $Z$ inspected by linear fits: $R_{AA}$ decrease with $N_{part}$ 10%±7% for Glauber v2.4 and 5%±6% for Glauber v3.2
- two versions consistent within measurement uncertainties for $Z$ and $W$

$R_{AA}$

Normalised yield versus $\langle N_{part} \rangle$

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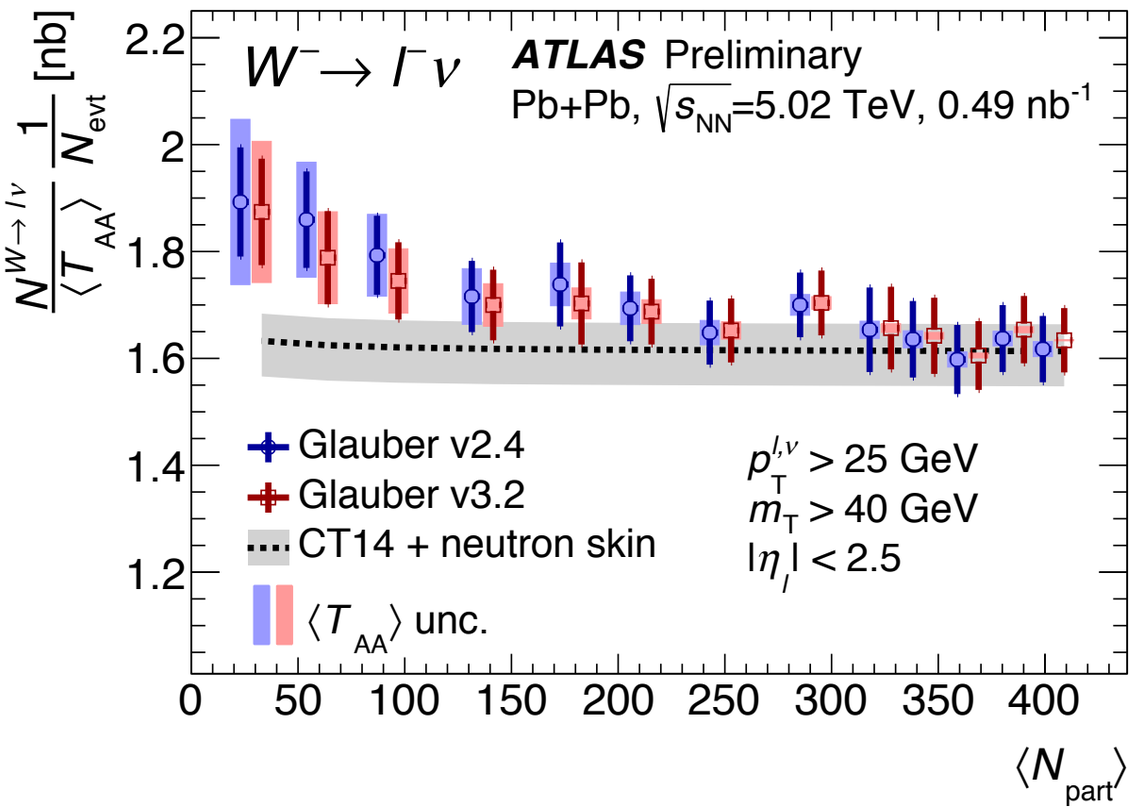
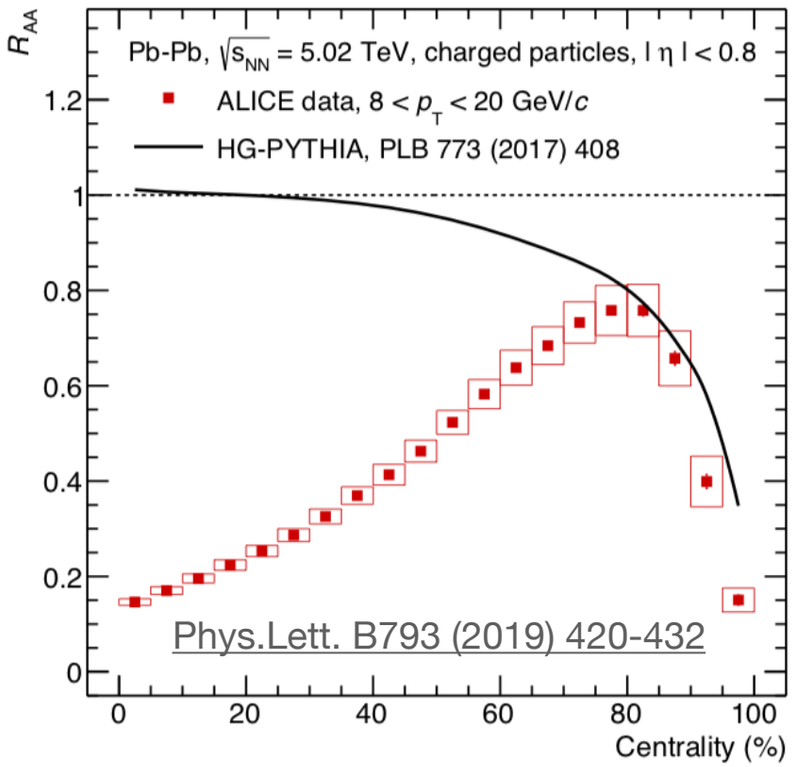


# Comparison with HG-Pythia predictions

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- agrees qualitatively with ALICE charged hadron $R_{AA}$ suppression

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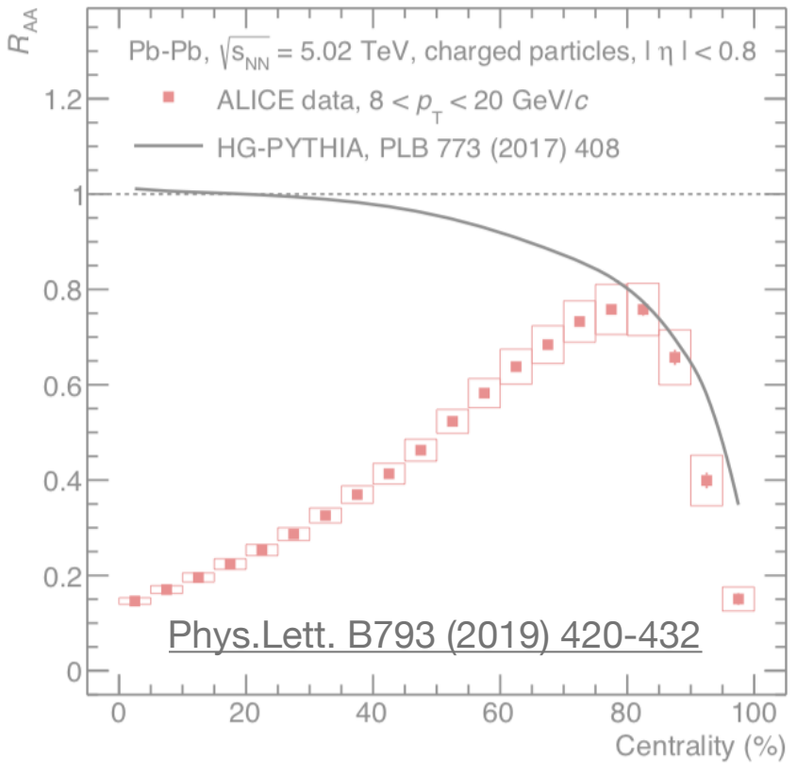


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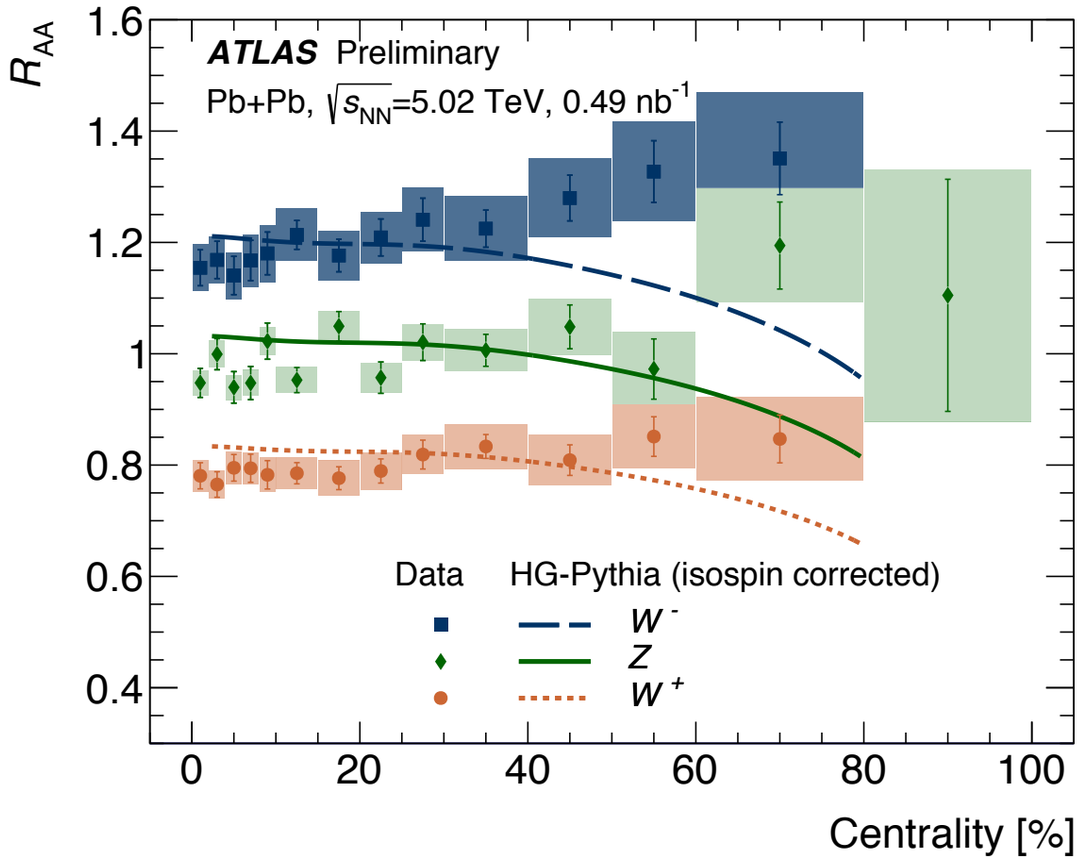


- compared for 0-80% centrality (small smearing) and scaled with the isospin factor
- opposite trend measured for *W* and *Z* bosons in ATLAS

# Summary

- new results presented for *W* and *Z* boson measurements in 2015 Pb+Pb data
- *Z* boson measurement extended to 100% centrality

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**Glauber model**

- $R_{AA}$ in centrality overall constant with unity for *W* and *Z* within 1$\sigma$
- indication of peripheral excess in measured yields at the level of 1-2$\sigma$ for *W*
- no apparent suppression predicted by HG-Pythia observed in peripheral events

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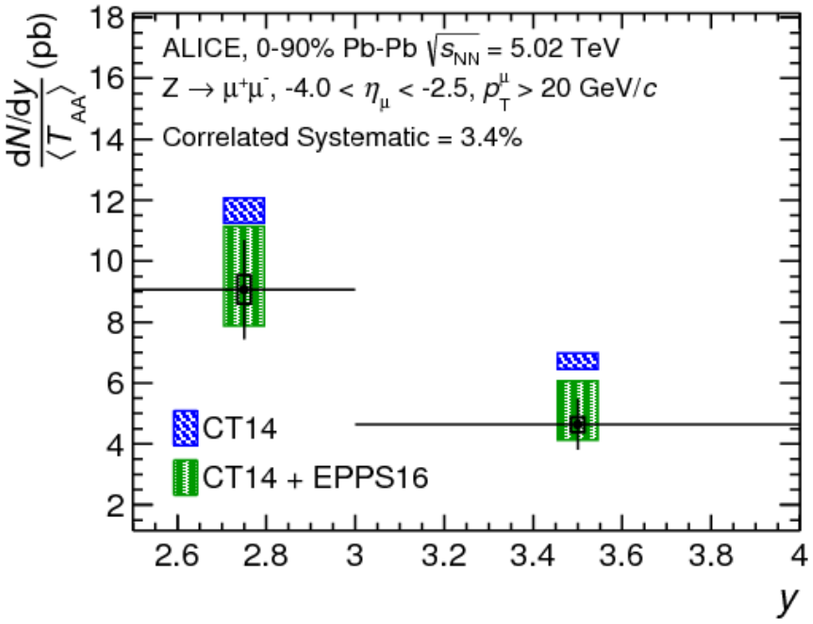
*Thank you!*

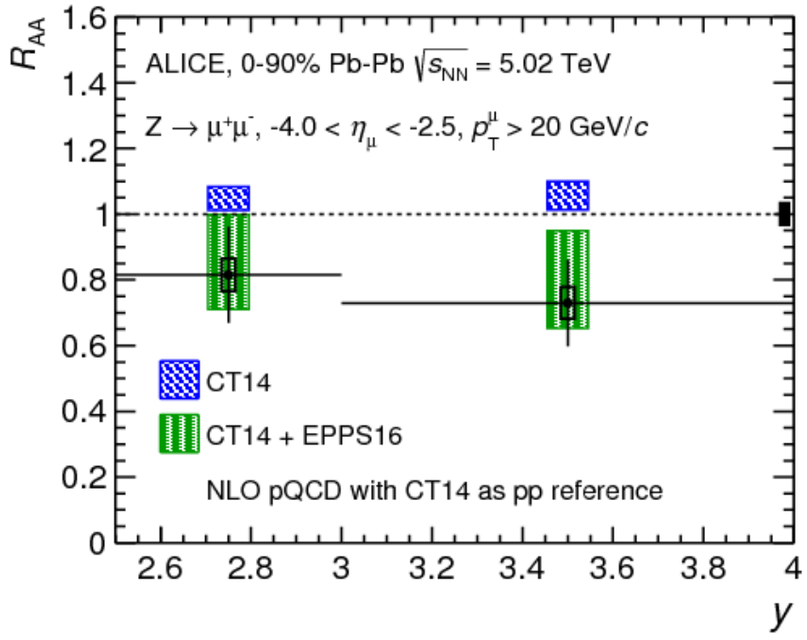
# Backup

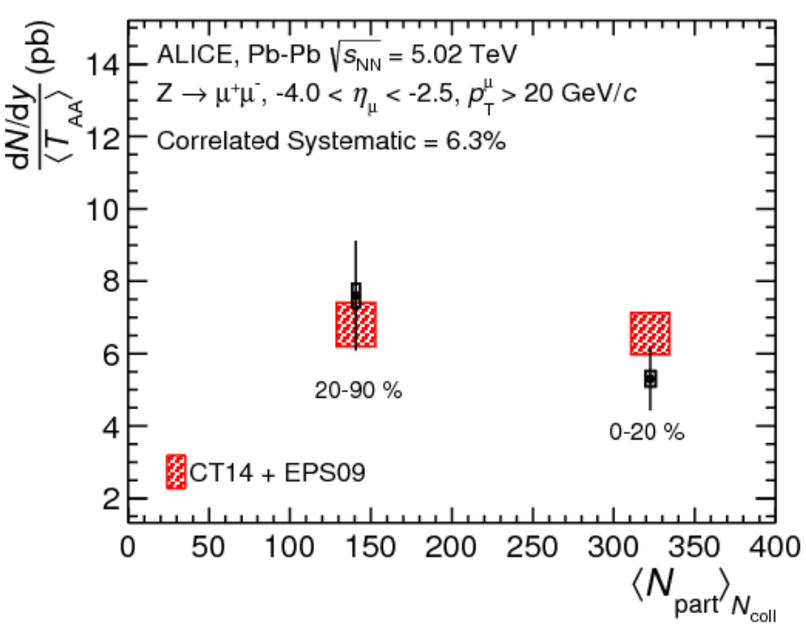
# Comparison with other experiments

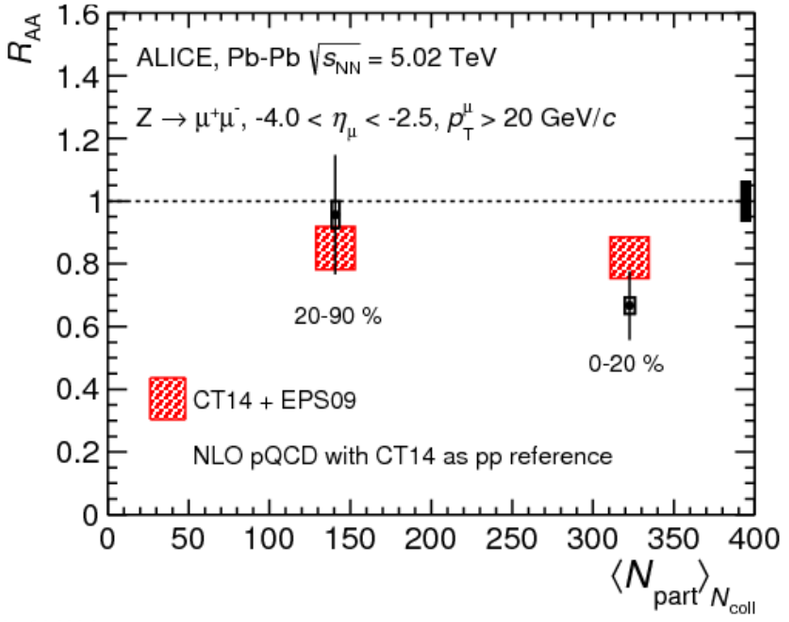
- ALICE at large rapidities consistent with CT14+EPPS16

Phys.Lett. B780 (2018)



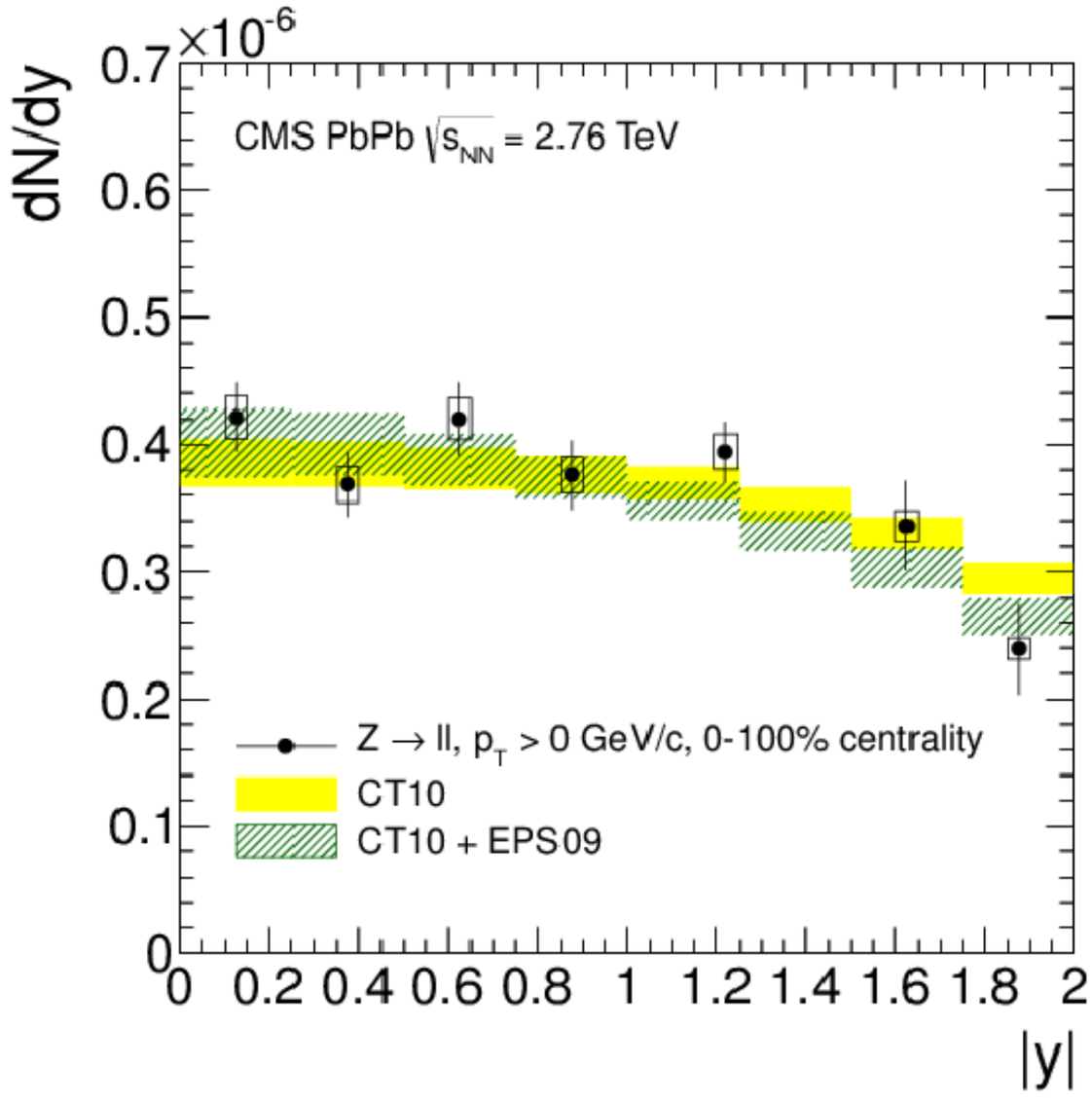



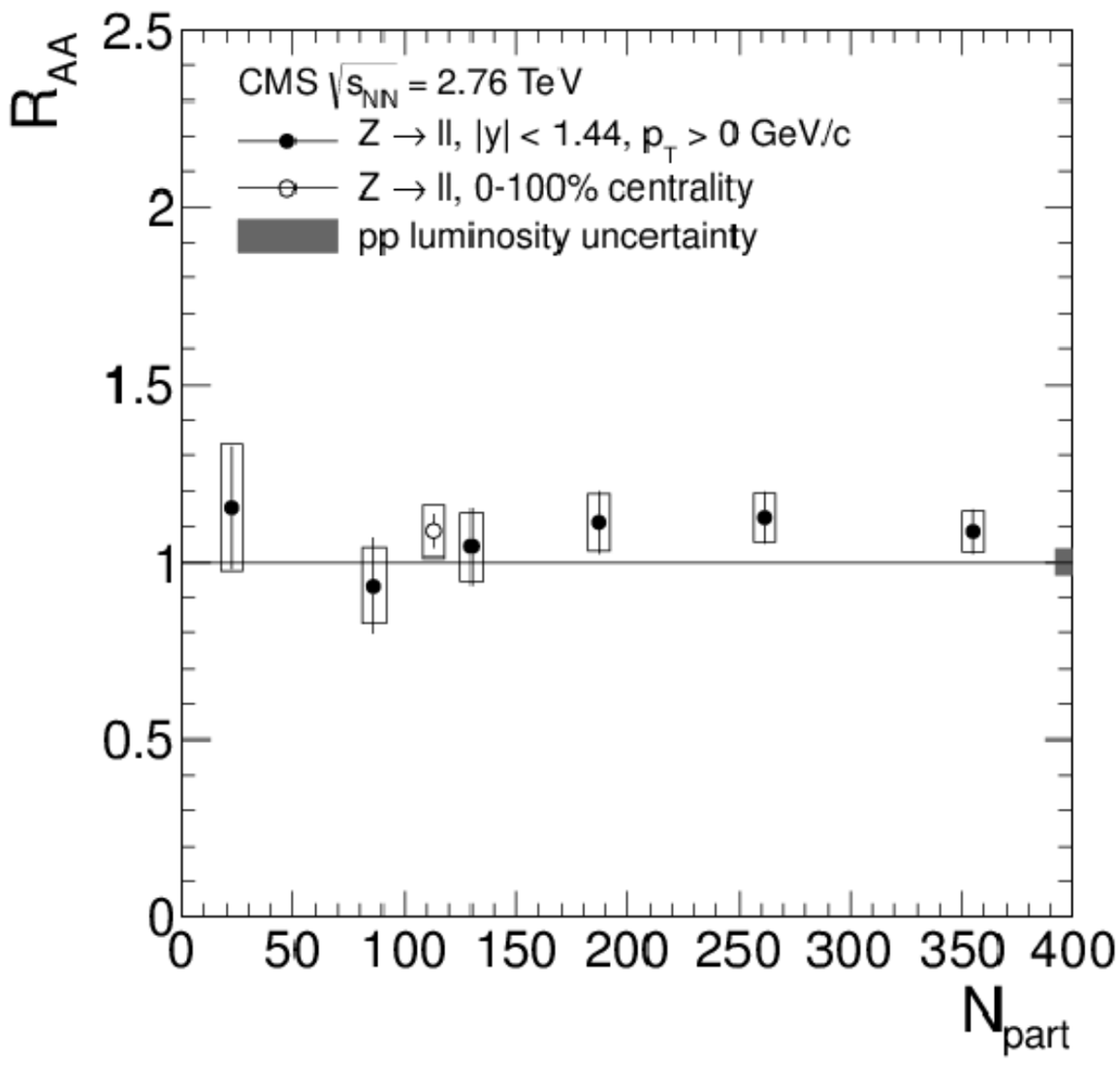



# Comparison with other experiments

- CMS Run-1 data result: no significant nuclear modification observed

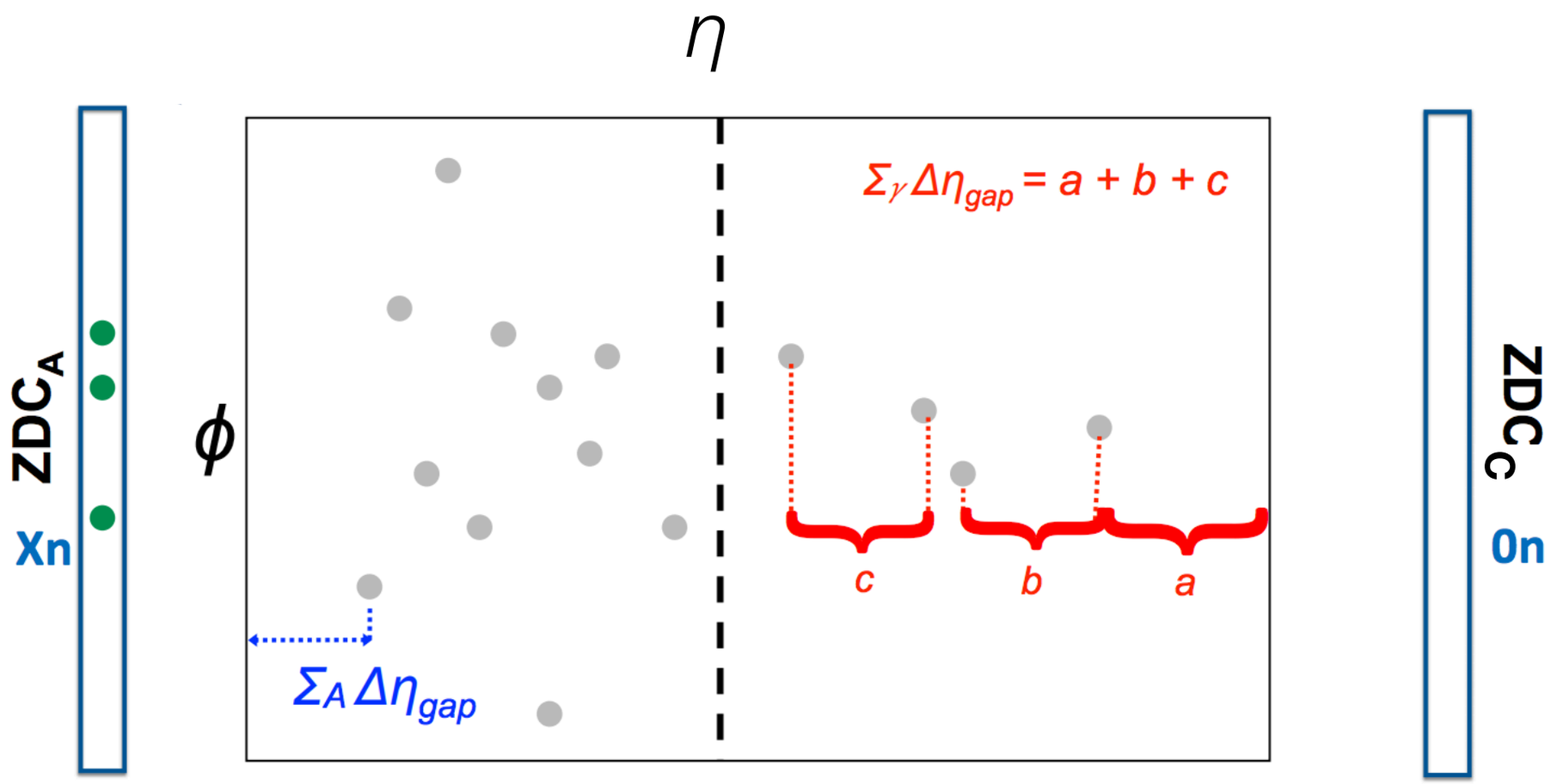
J. High Energy Phys. 03 (2015) 022



# UPC background treatment for the *Z* measurement

- rapidity gap calculation rejecting the EM background in 50-100% centrality
- requiring $\Sigma\Delta\eta^{gap}<2.5$ and the ZDC coincidence signal (34 events excluded)

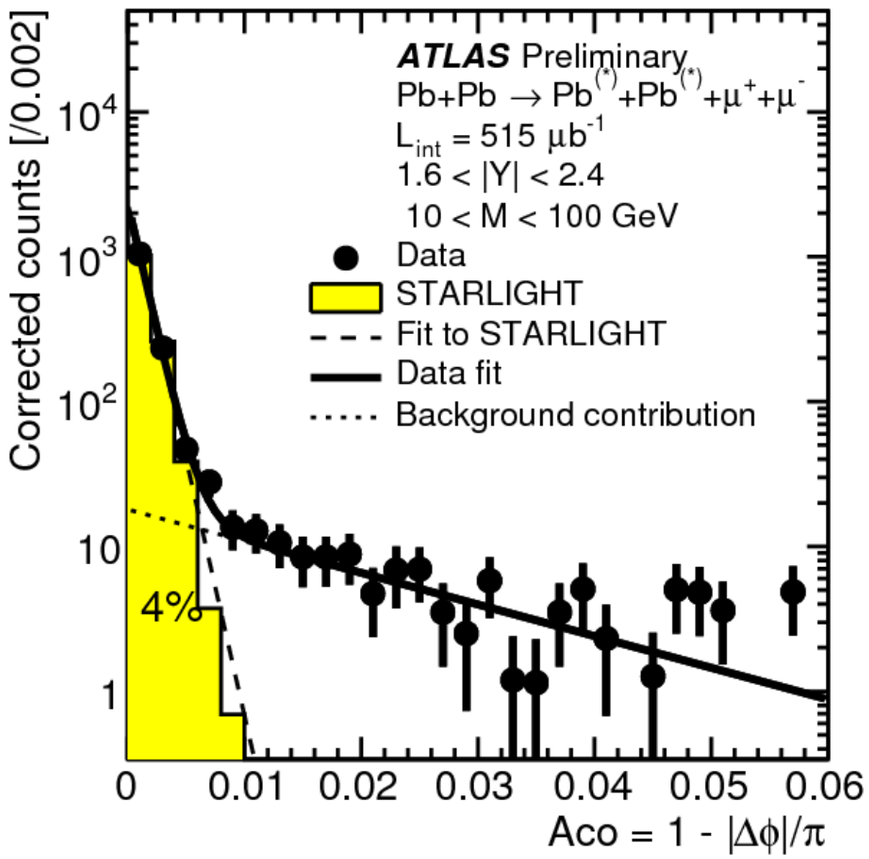



Blair Daniel Seidlitz, Wednesday 3 pm

# UPC background treatment for the *Z* measurement

- no gap if a photon-induced event is on top of hadronic production
- using acoplanarity to quantify background lepton correlations: Aco=1-$|\Delta\phi|/\pi$

ATLAS-CONF-2016-025

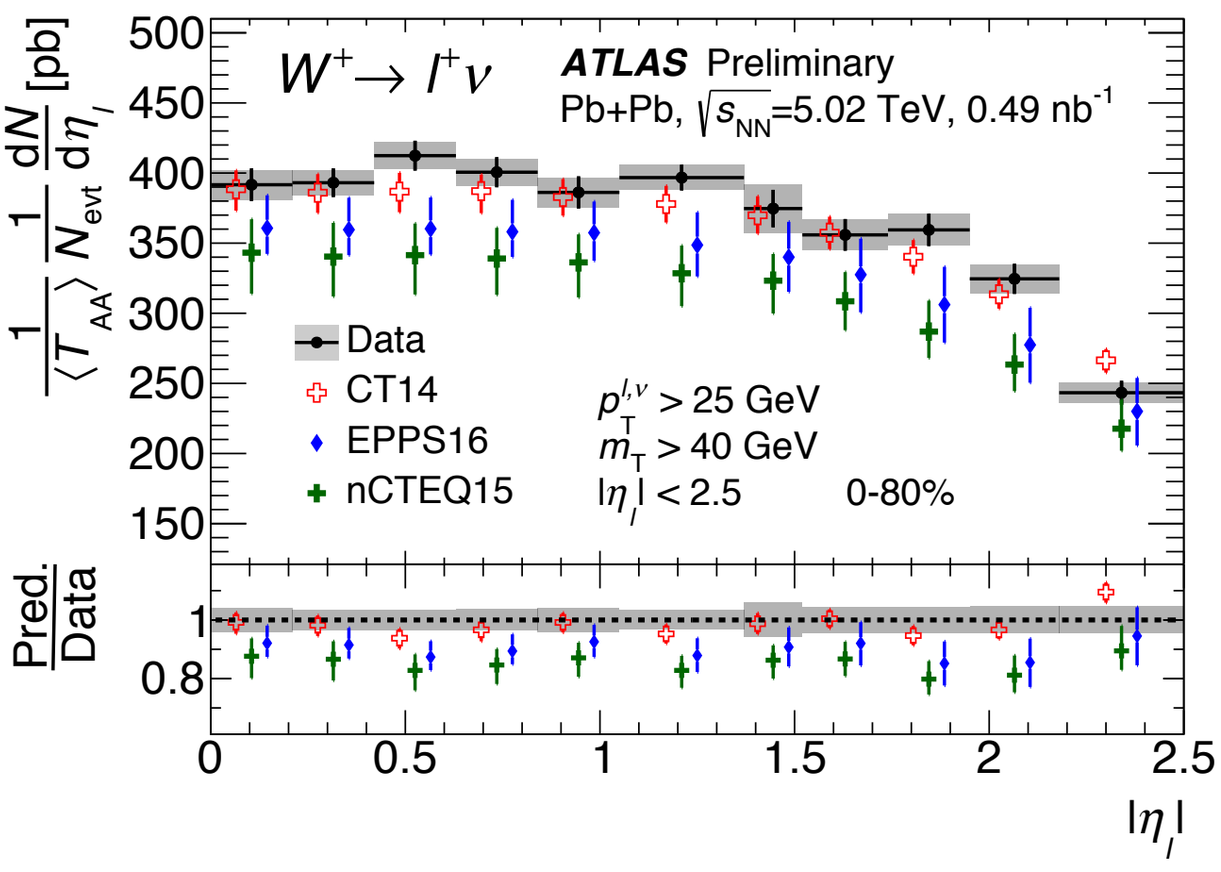


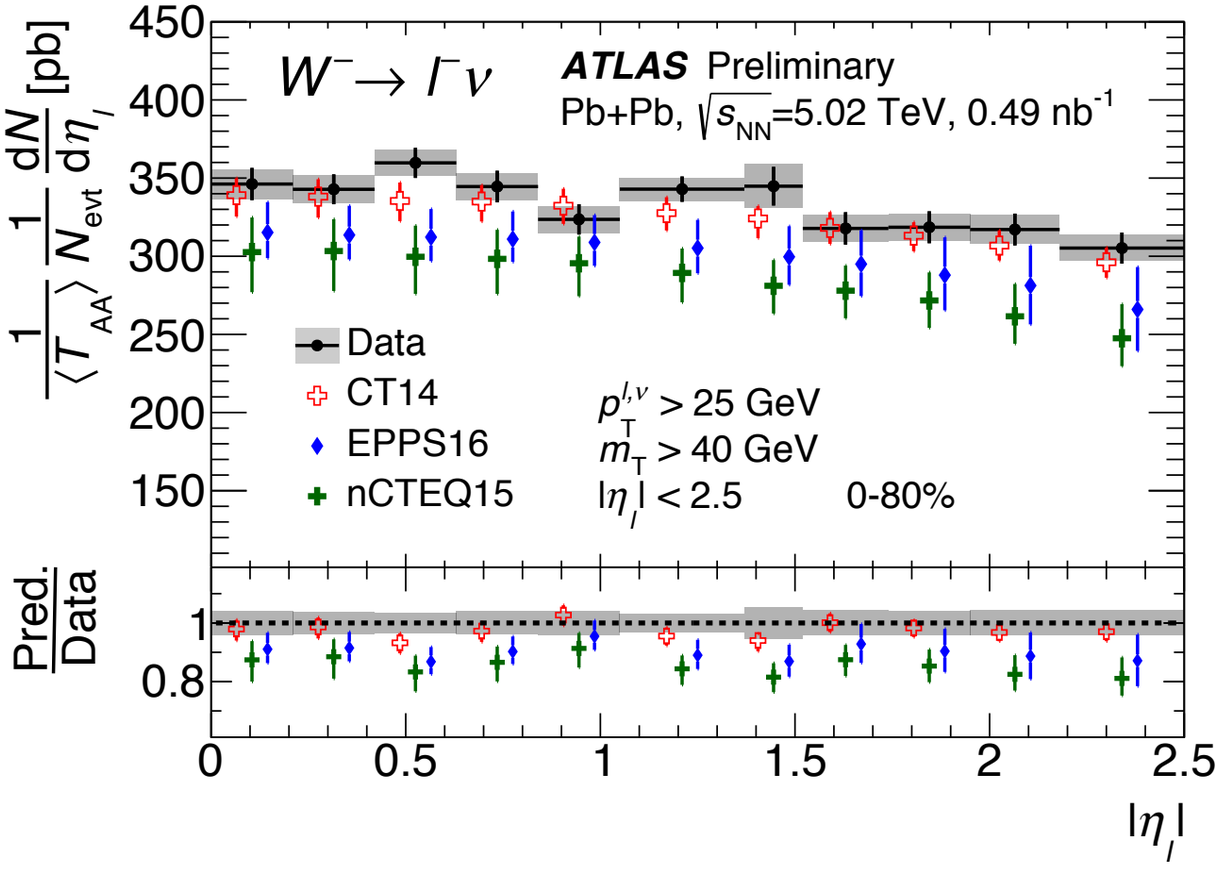

- hadronic *Z* production yields 13.3±0.4% for Aco<0.01
- in the rejected background sample ($\Sigma\Delta\eta^{gap}$>2.5) 76.5% have Aco<0.01
- estimate additional photon-induced background by comparing total yield to number of candidates with Aco<0.01 per centrality bin
- remaining background: 18±8 out of 258 in 50-60%, 15±5 out of 182 in 60-80% and 7±3 out of 28 in 80-100%

# *W* yields versus nPDF predictions

- best agreement observed with free proton PDF (CT14) + isospin
- nPDF underestimate the yields at the level of 10-20%

Normalised yield versus $|\eta|$

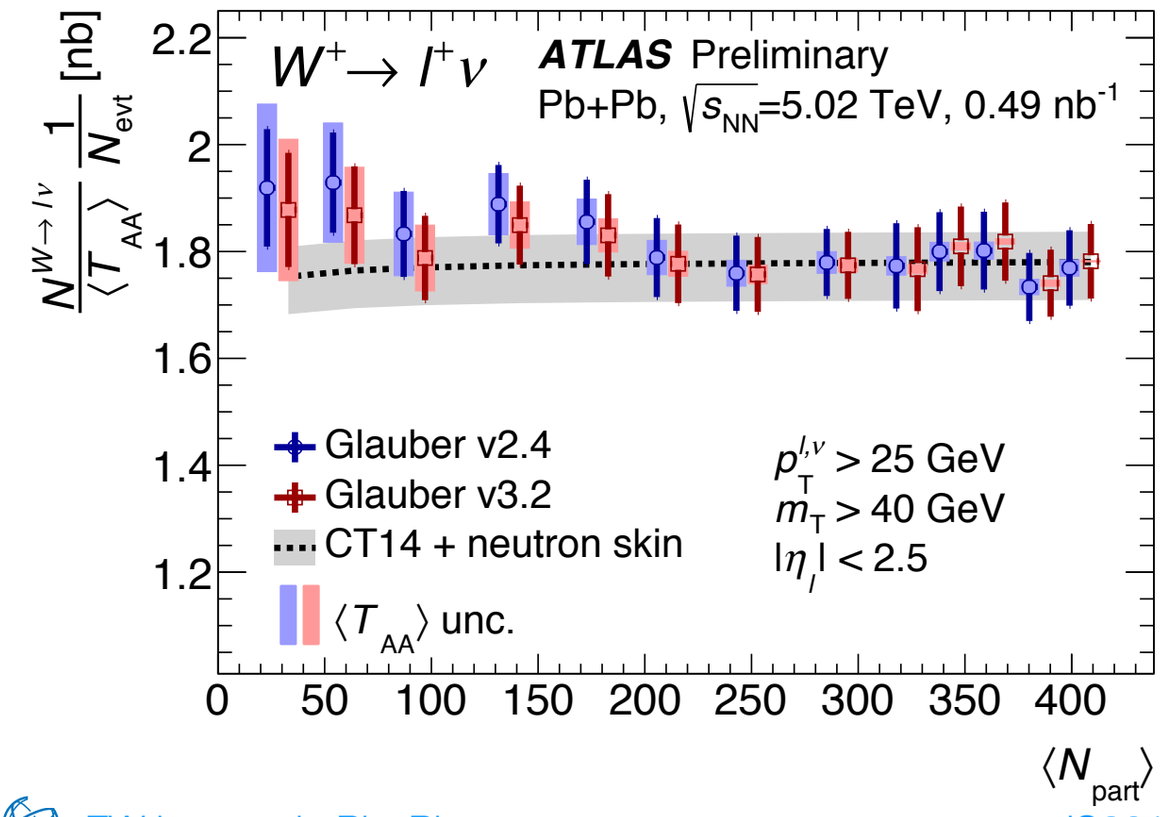


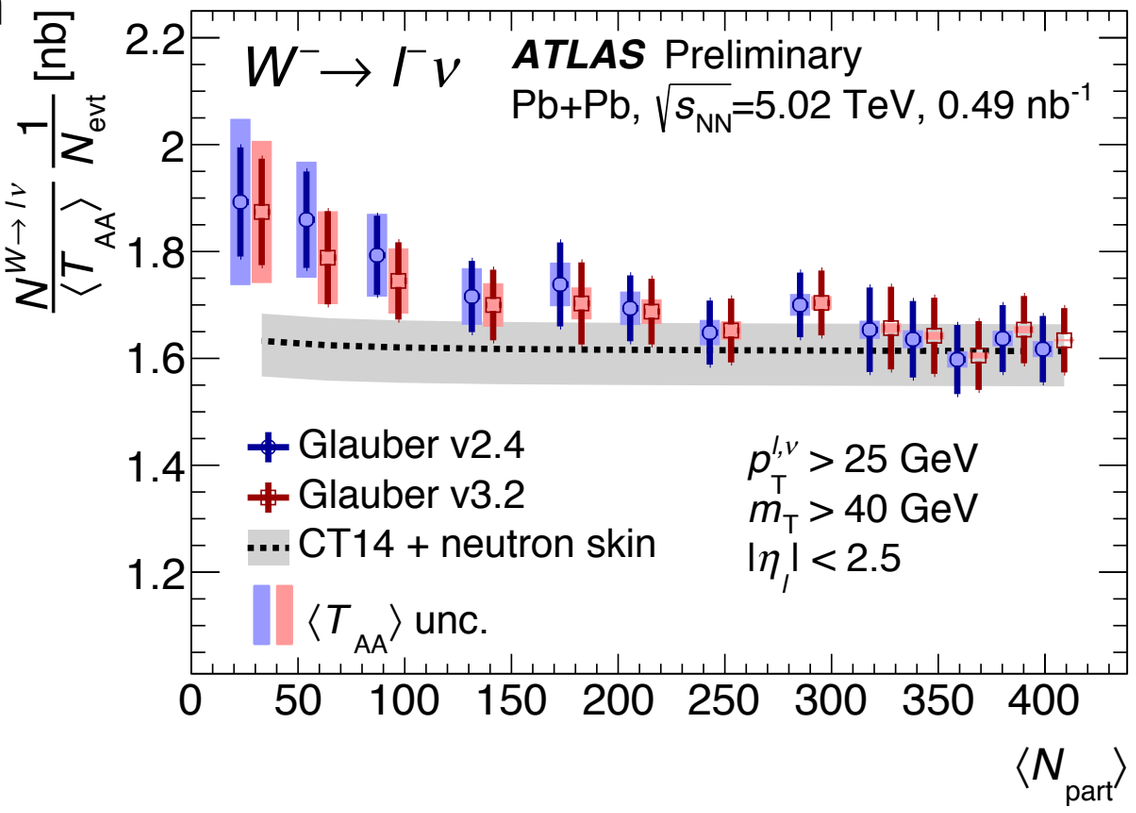
# Binary scaling: Glauber MC comparison for W

- calculated with Glauber MC v2.4 and v3.2 (includes also the neutron skin effect)
- neutron skin effect largest in the most peripheral bin, where the predictions differ by –1.4% (+1%) for $W^+$ ($W^-$) bosons relative to predictions calculated using a constant proton-to-neutron ratio.

Normalised yield versus $\langle N_{part} \rangle$

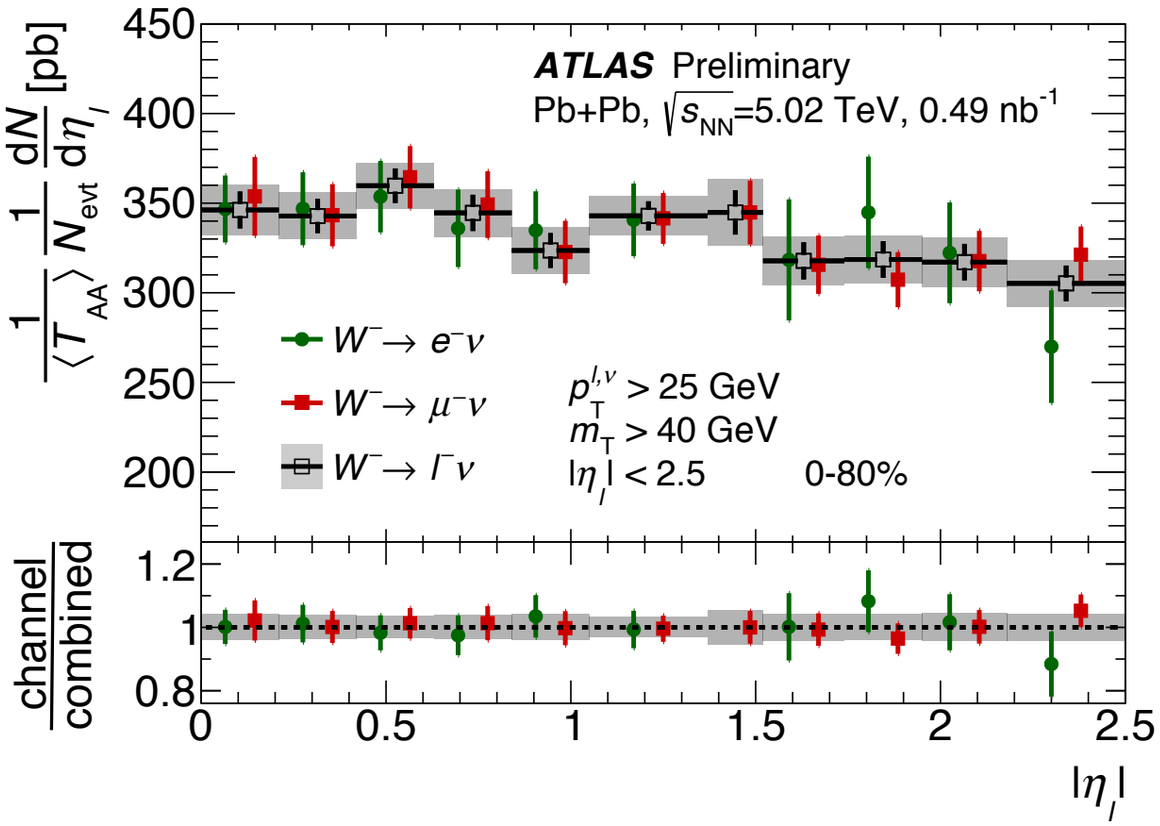


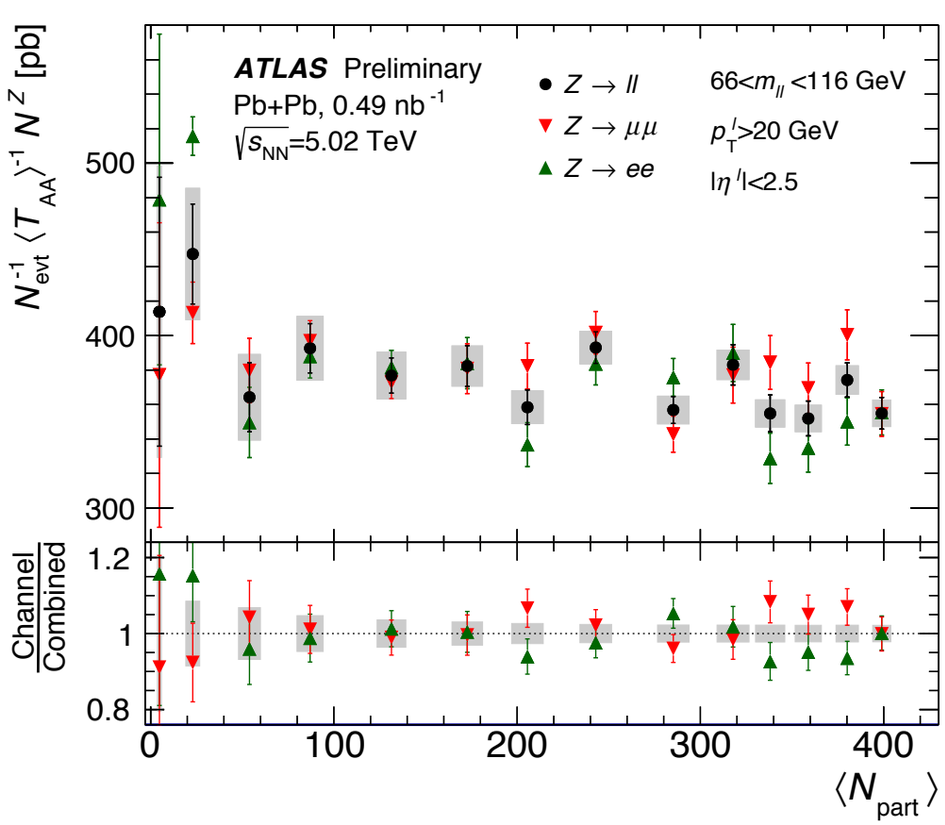

en



# Channel combination

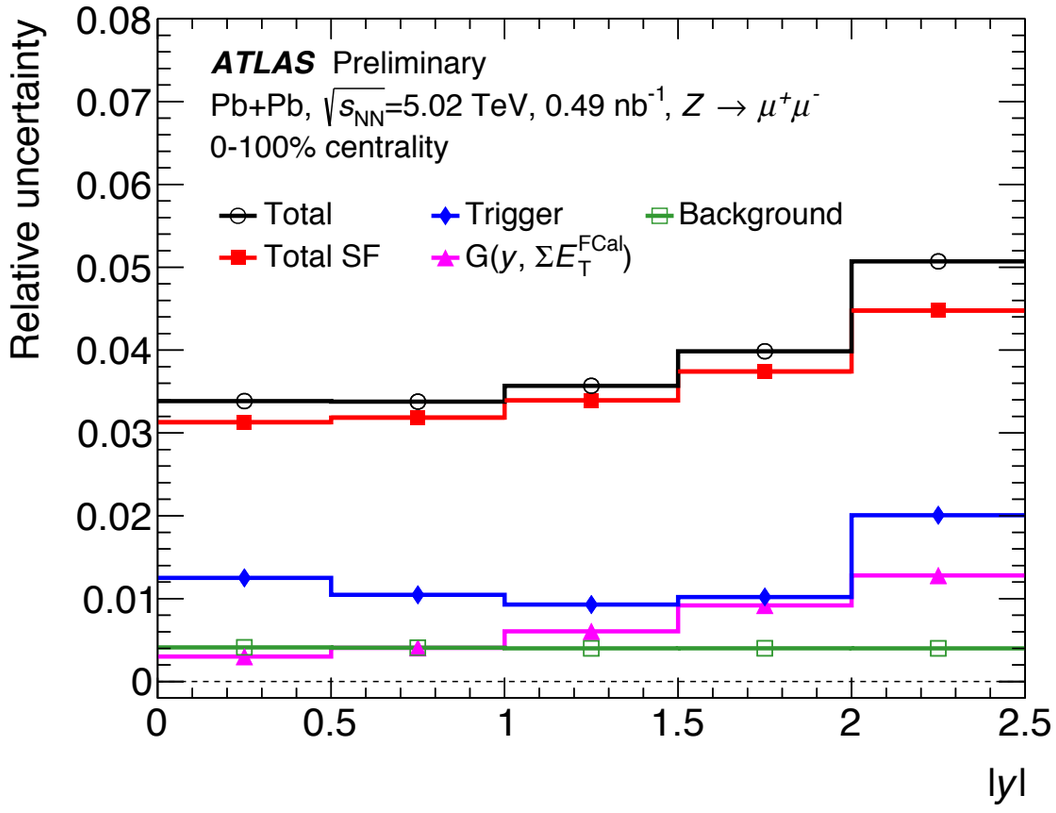
- using Best Linear Unbiased Estimate method (BLUE)
- taking into account correlations across channels and measurement bins
- channels consistent in lepton pseudorapidity (dilepton rapidity) and event centrality

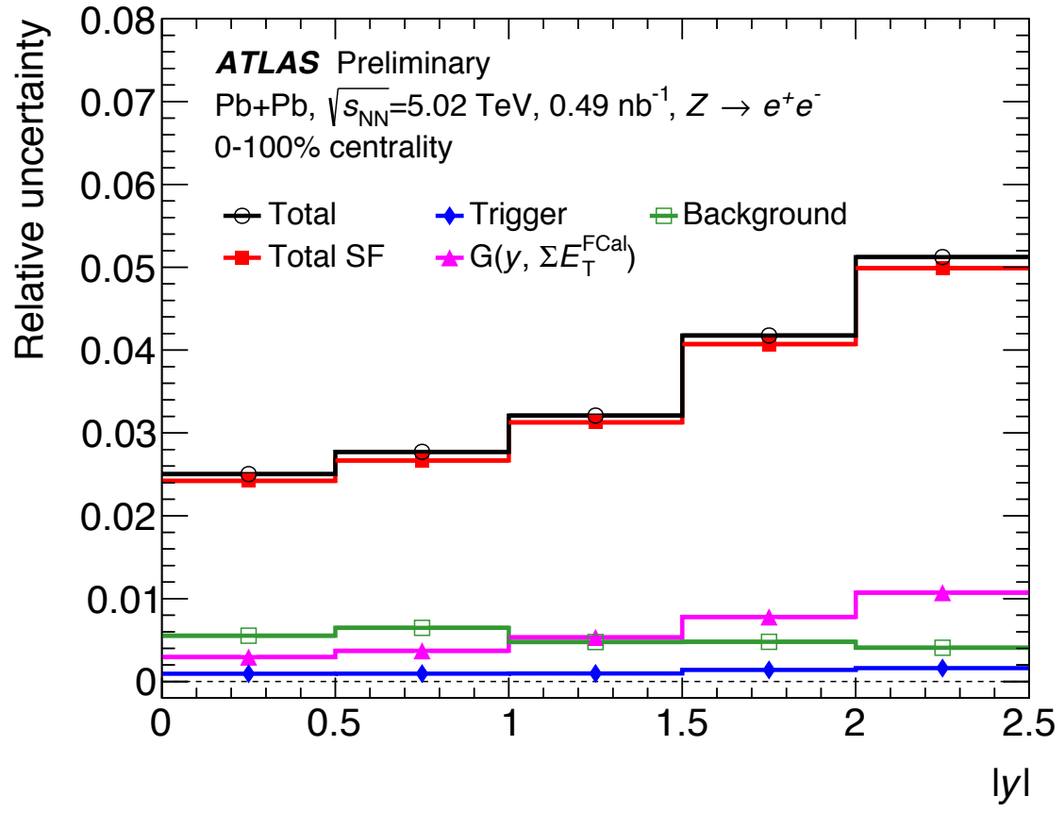


# Systematic uncertainties: *Z* boson

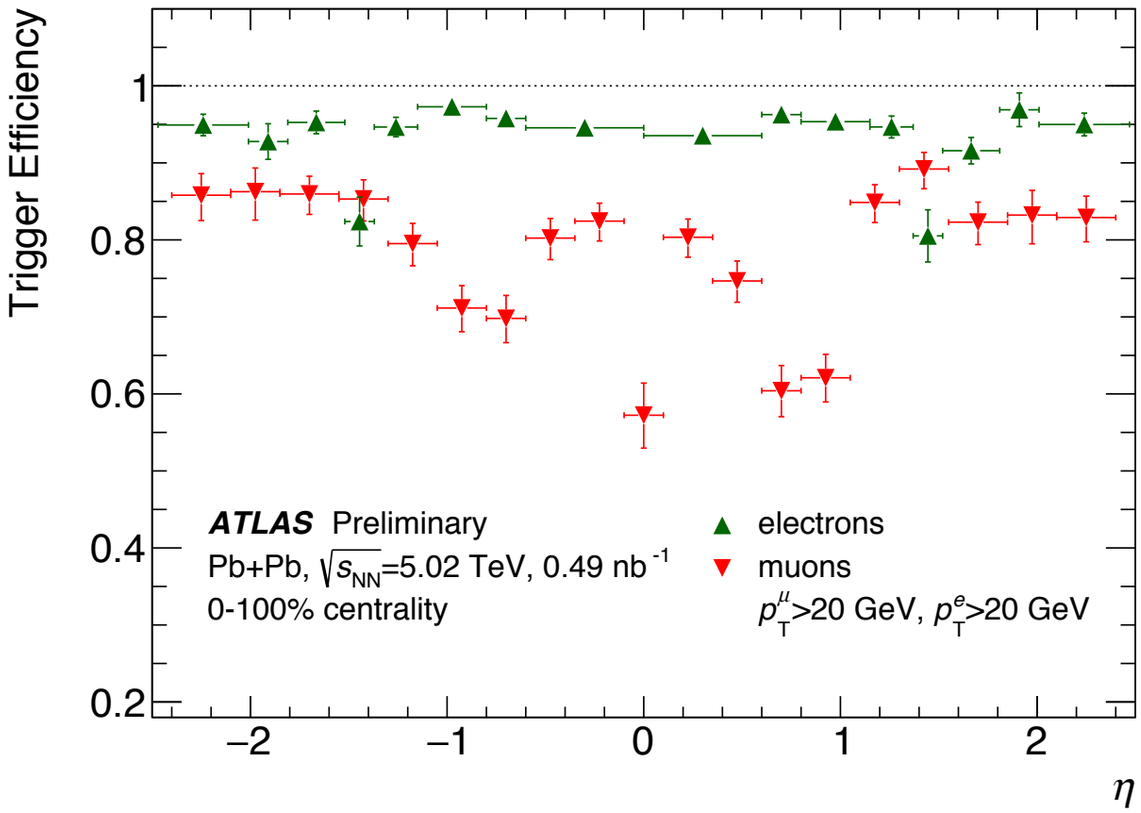
- leading contribution from the lepton performance correction
- constant contribution in centrality

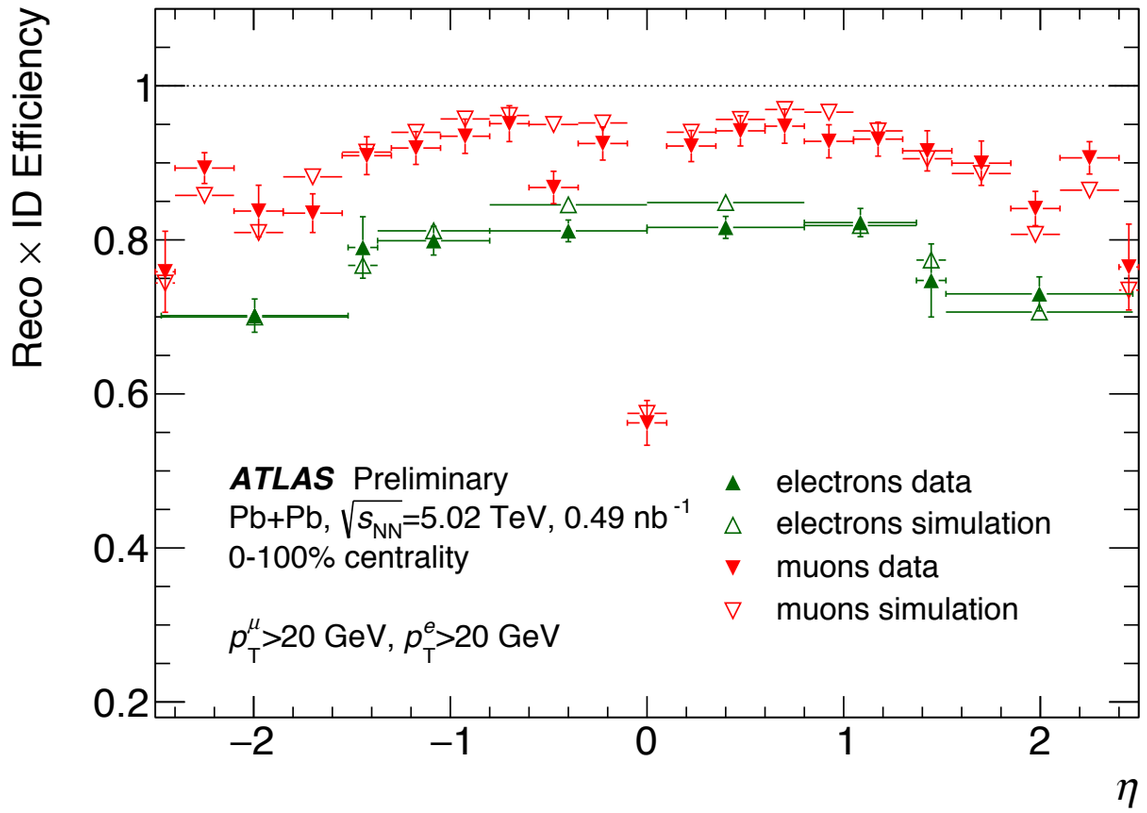


# Lepton reconstruction performance: *Z* boson

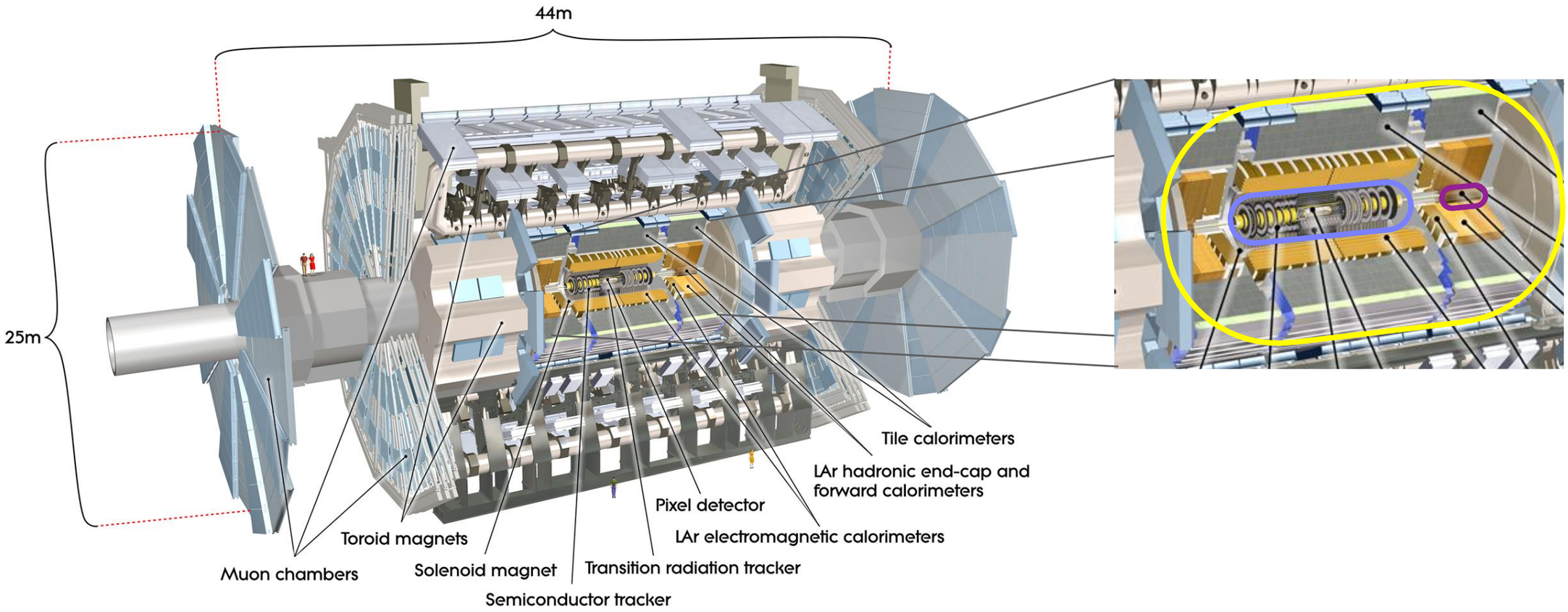
- plots show lepton trigger efficiency (left) and reconstruction x identification efficiency (right)



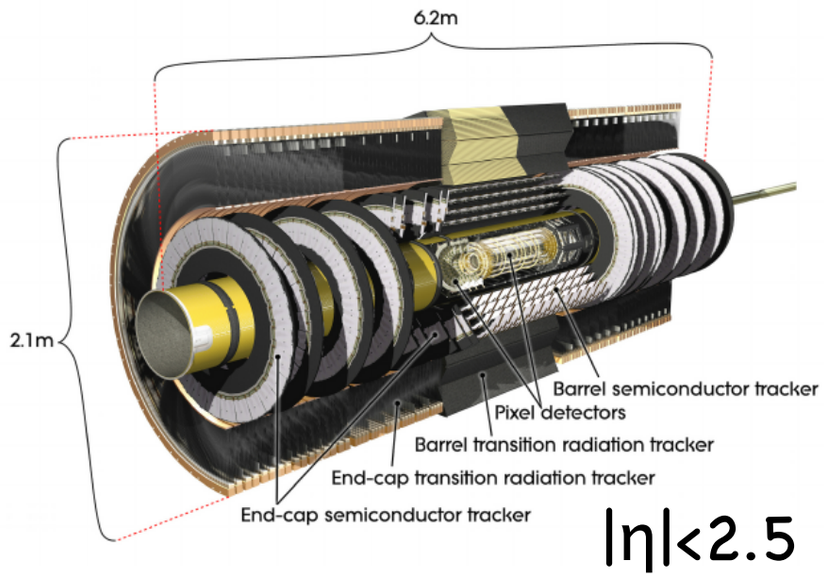
# *W/Z* boson reconstruction with ATLAS

- decay channels: $Z \to ee$, $Z \to \mu\mu$, $W \to e\nu$, $W \to \mu\nu$
- inner detector ($|\eta|<2.5$) - tracking electrons and muons, $p_T^{miss}$ for $\nu$ kinematics
- EM calorimeter ($|\eta|<3.2$) - electron ID and energy
  FCAL ($3.2<|\eta|<4.9$) - centrality mapping
- muon spectrometer ($|\eta|<2.8$) - muon ID and kinematics



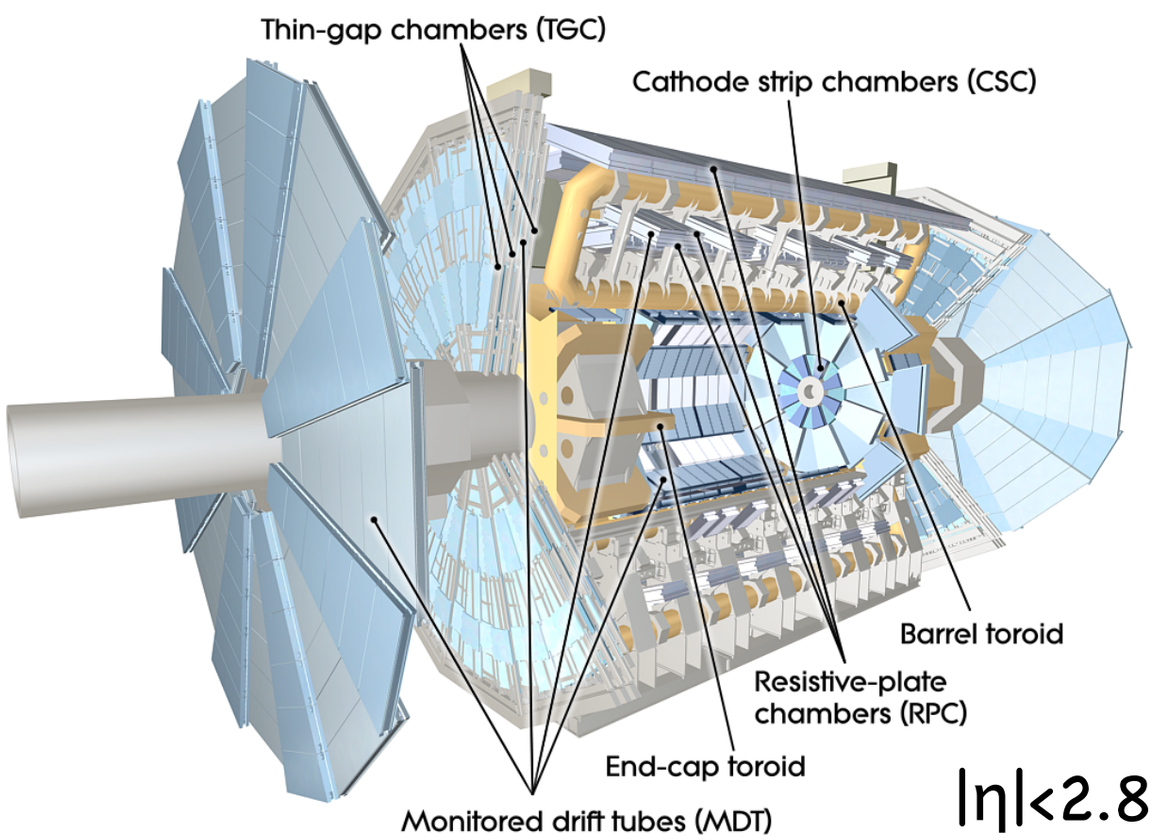
# ATLAS detector

- inner detector for tracking and momentum measurement
- EM calorimeter: electrons and photons
  FCAL for centrality mapping
- muon spectrometer

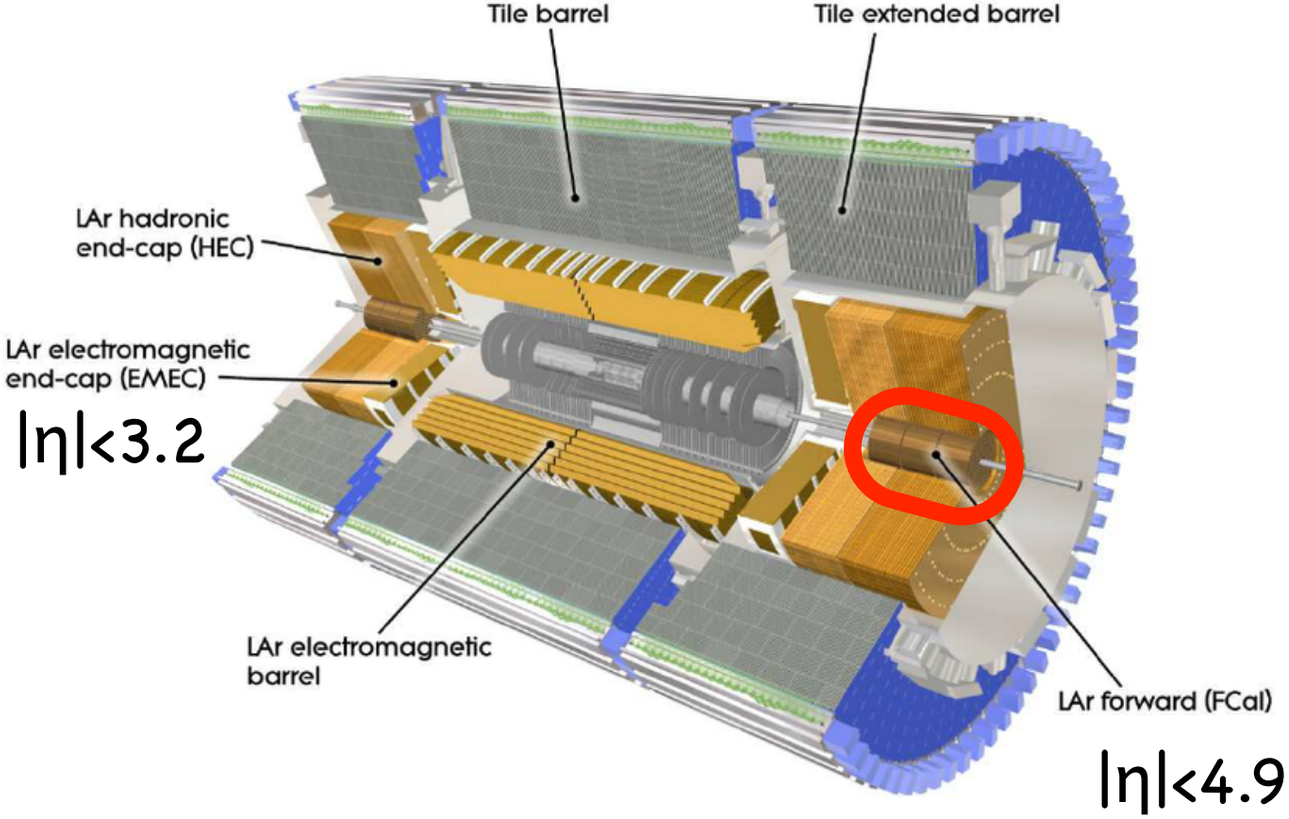



|η|<2.5

|η|<1.4




|η|<2.8




|η|<3.2

|η|<4.9

# Measurement corrections: *W* and *Z* boson

- *W* boson
  - bin-by-bin unfolding in pseudorapidity and centrality
  - correction varied for systematics
  - $N_W = \frac{N_W^{\text{obs}} - N_W^{\text{bkg}}}{C_W}$ , $C_W = \frac{N_W^{pass}(\eta, \text{centrality})}{N_W^{gen}(\eta, \text{centrality})}$

- *Z* boson
  - bin-by-bin unfolding in pseudorapidity, momentum and centrality
  - correction varied for systematics
  - $N_Z = \frac{N_Z^{\text{obs}} - N_Z^{\text{bkg}}}{C_Z \times \varepsilon_{\text{trig}}}$ , $C_Z = \frac{N_Z^{pass}}{N_Z^{gen}} = \text{F}(p_{\text{T}}, y) \times \text{G}(y, \text{centrality})$