Electroweak Bosons in Pb+Pb and p+Pb Collisions

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Hard Probes

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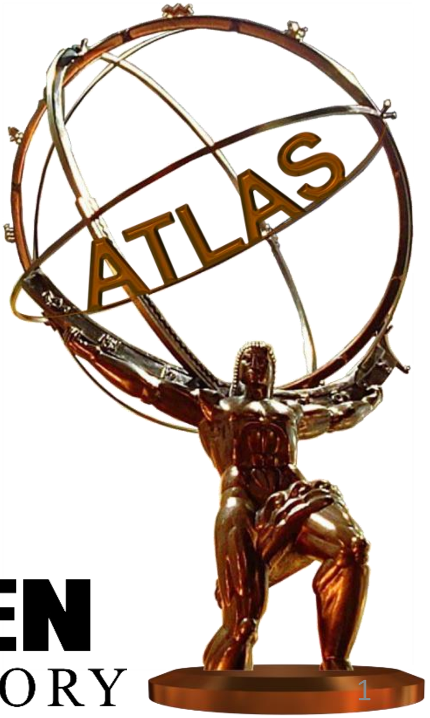


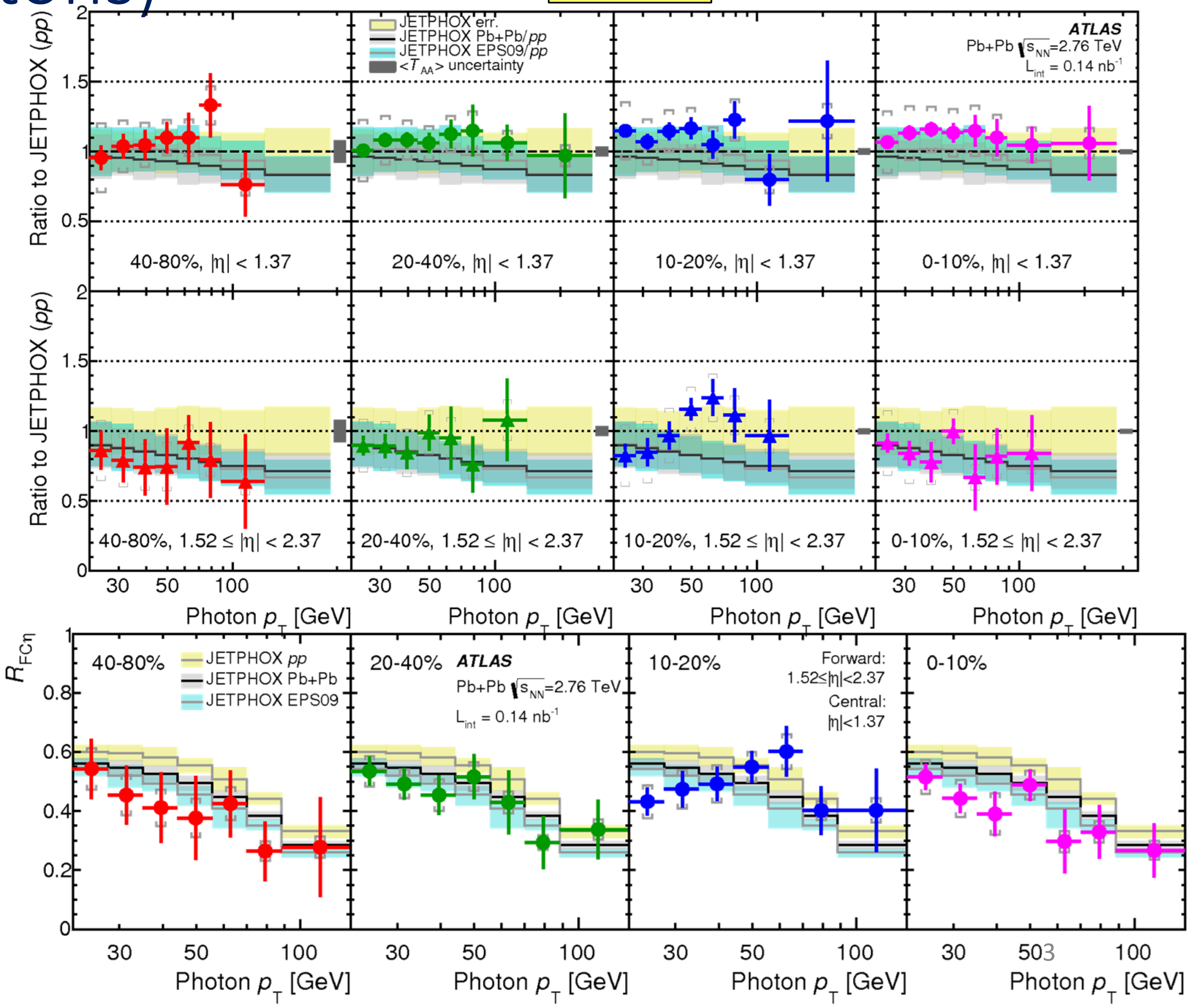
Motivational Questions

- How are free nucleon parton distribution functions (PDFs) modified in heavy nuclear systems (i.e. nuclear effects)?
- Can we confirm our understanding of the collision geometry in Pb+Pb?
- Do we understand the geometry and centrality in a p+Pb system?

What has been observed so far in Pb+Pb (photons)

NEW

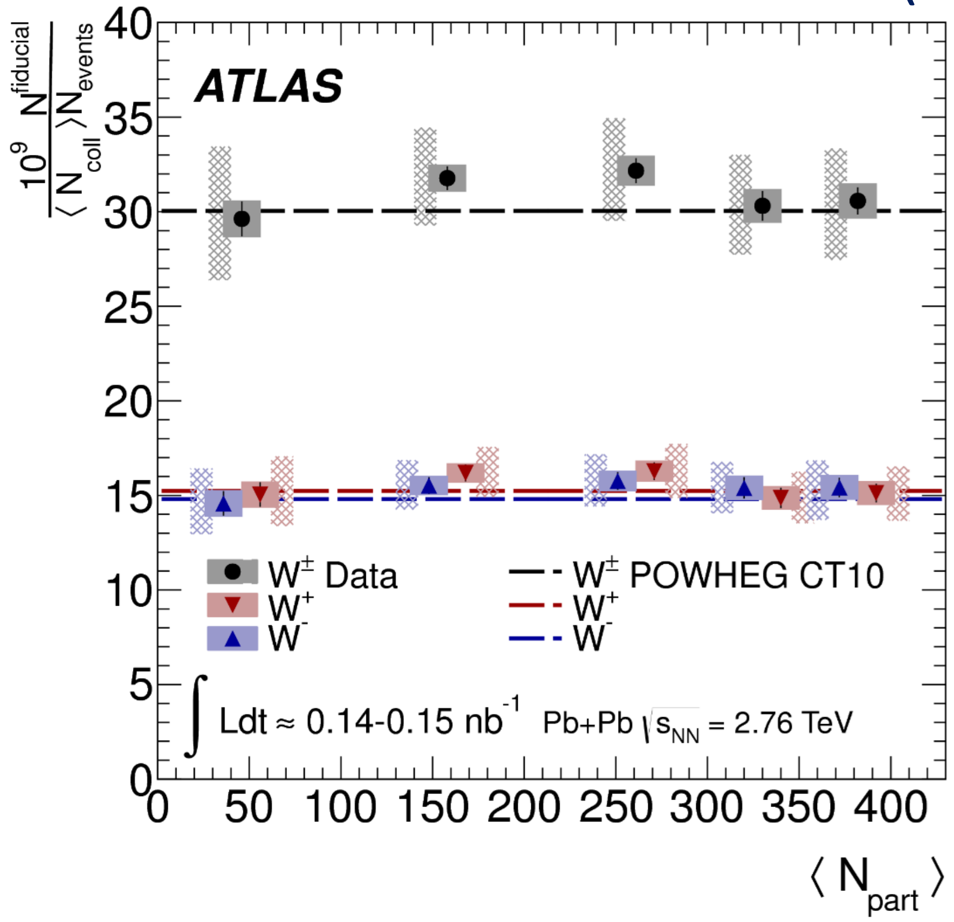
- (*Top*) Ratio of data to NLO pQCD *pp* predictions at central and forward pseudorapidity intervals
    - Pb+Pb predictions with and without nuclear effects also shown
    - cannot exclude models without nuclear effects
- (*Bottom*) Ratio of yields measured at forward (1.52<|η|<2.37) and central (| η|< 1.37) pseudorapidity intervals
    - More sensitive to nuclear effects
    - Again, current precision of the measurement prohibits vetoing the NLO pQCD model without nuclear effects

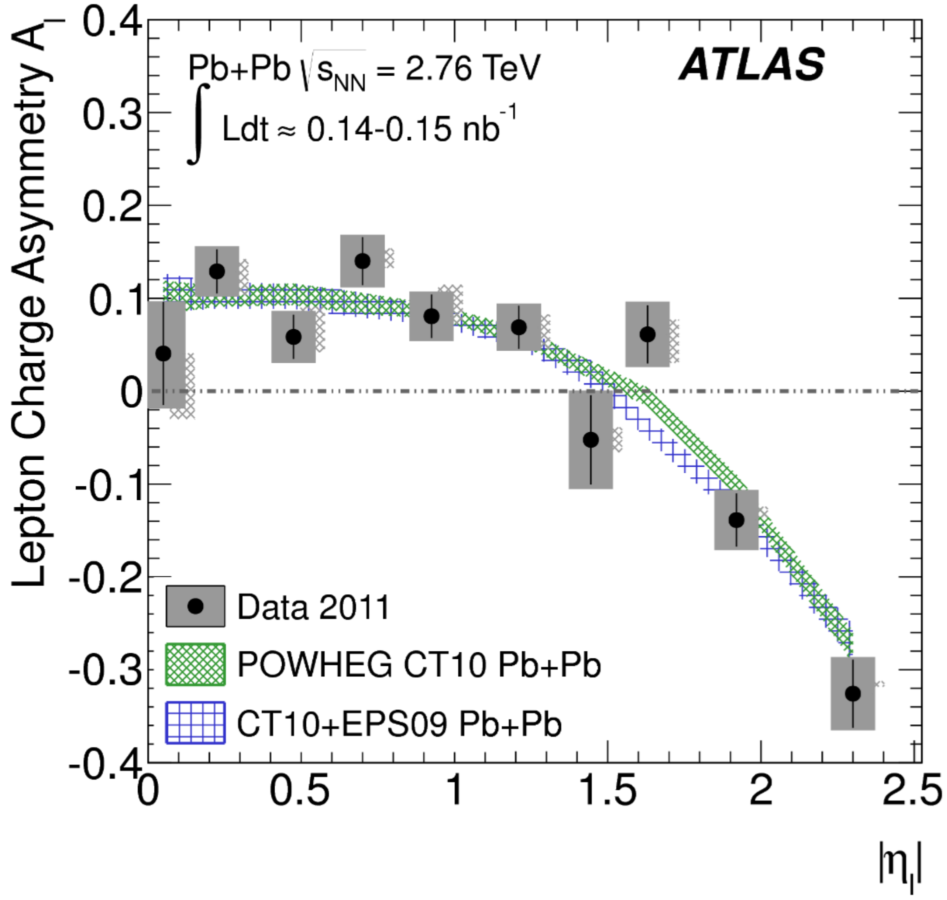


arXiv:1506.08552

What has been observed so far in Pb+Pb (W bosons)

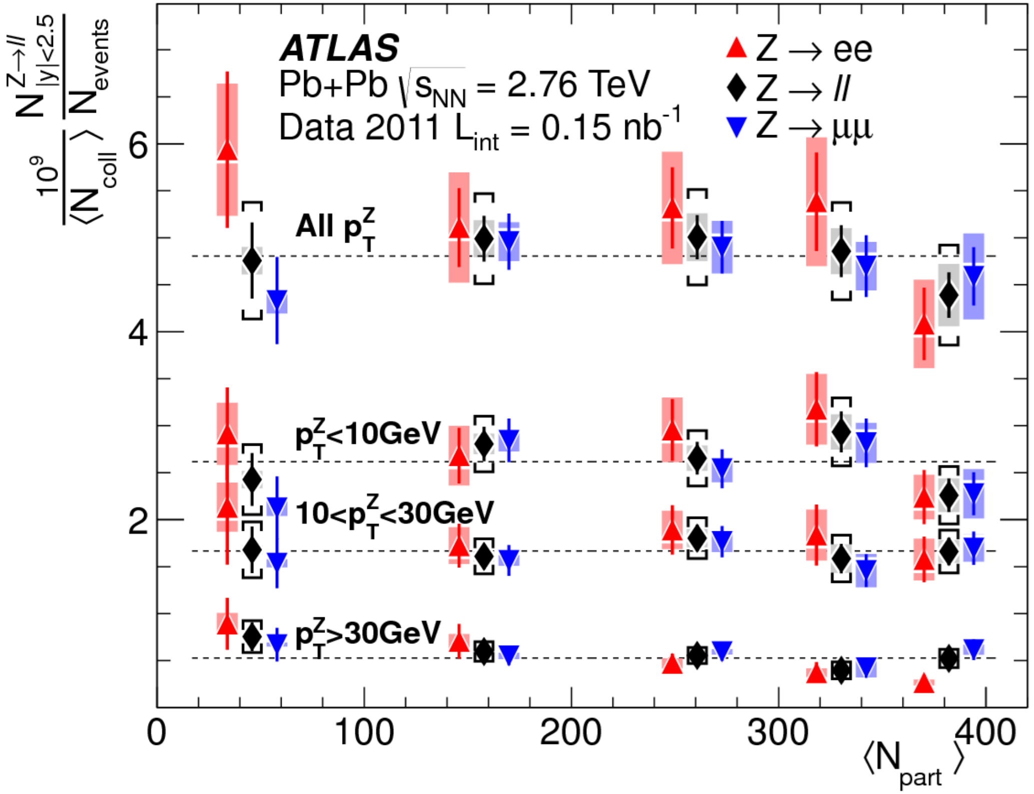
Eur. Phys. J. C (2015) 75:23



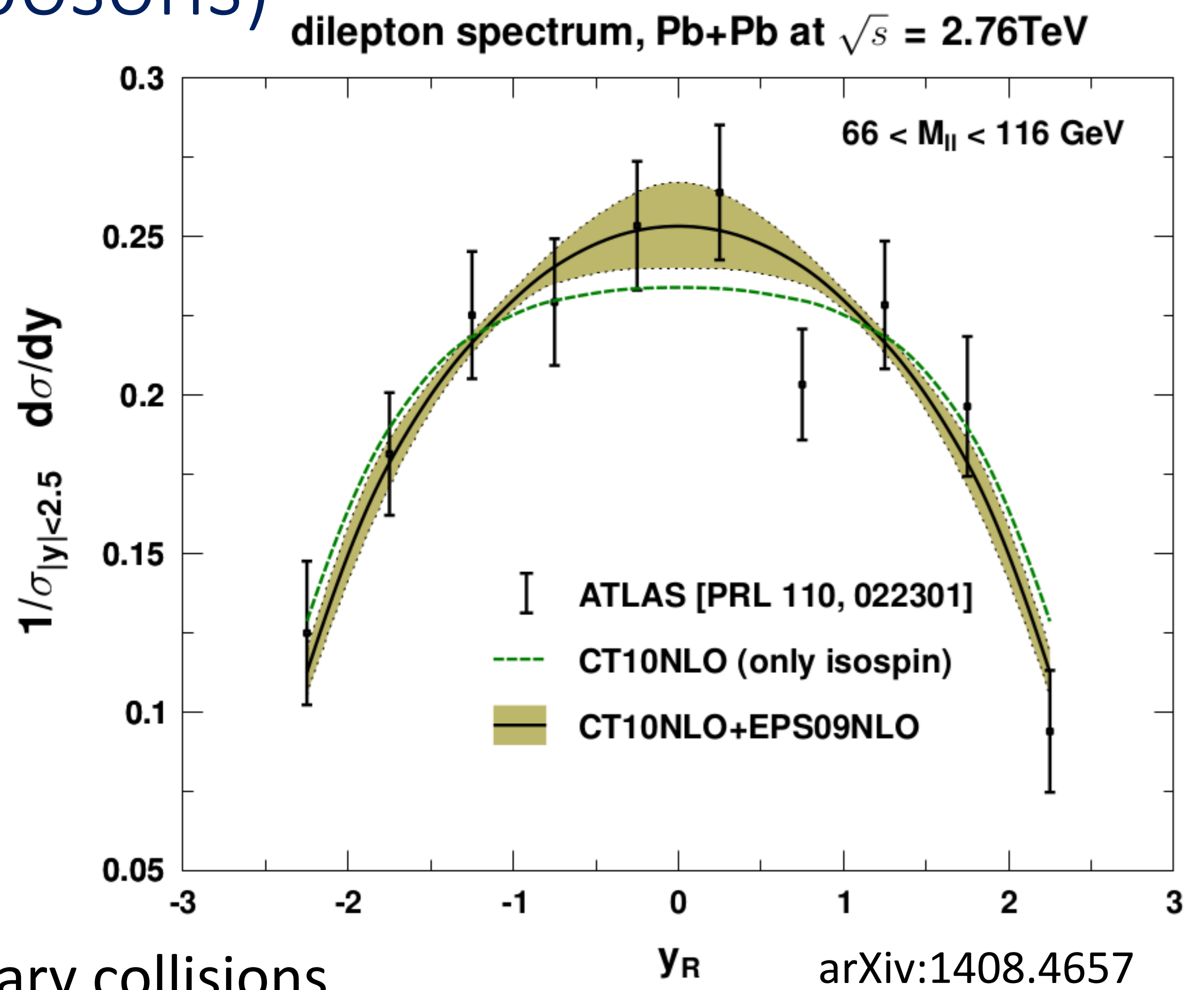


- *W* boson yields scale with number of binary collisions
- Lepton charge asymmetry in pseudorapidity space cannot distinguish between PDFs that incorporate nuclear effects and those that do not

What has been observed so far in Pb+Pb
(Z bosons)



Phys. Rev. C 86, 014907 (2012)

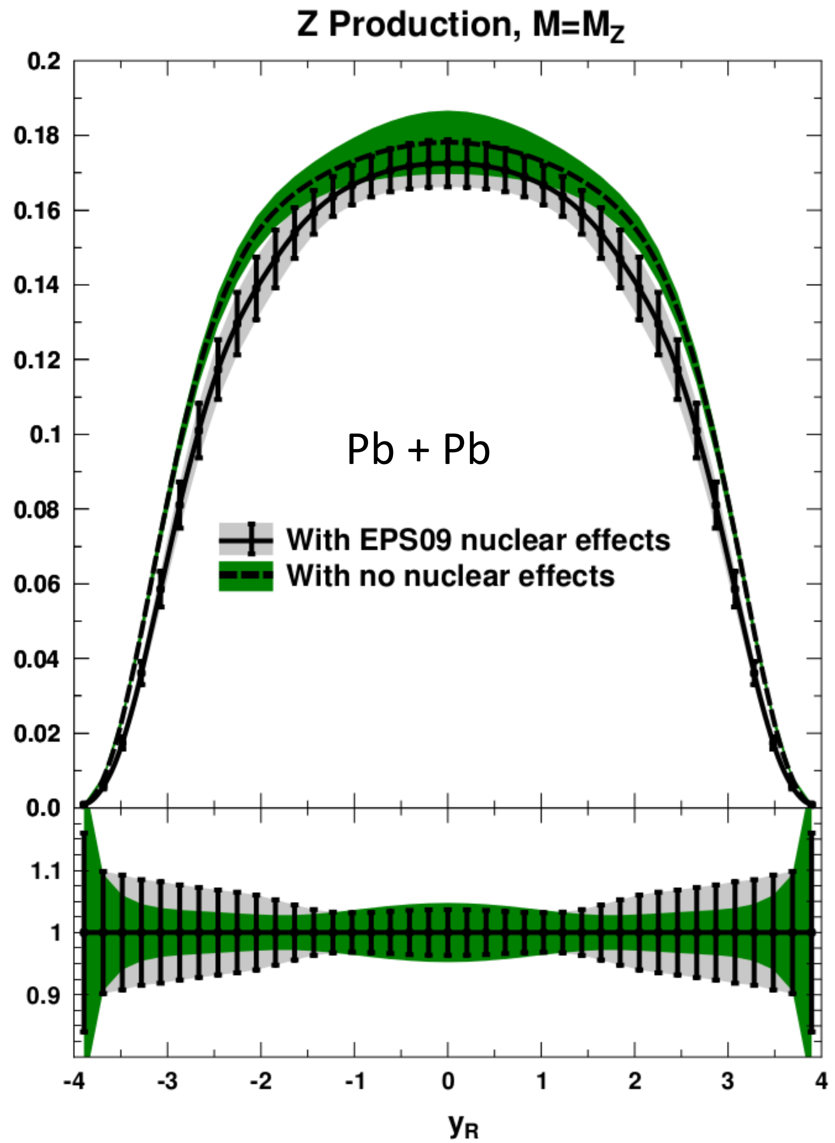


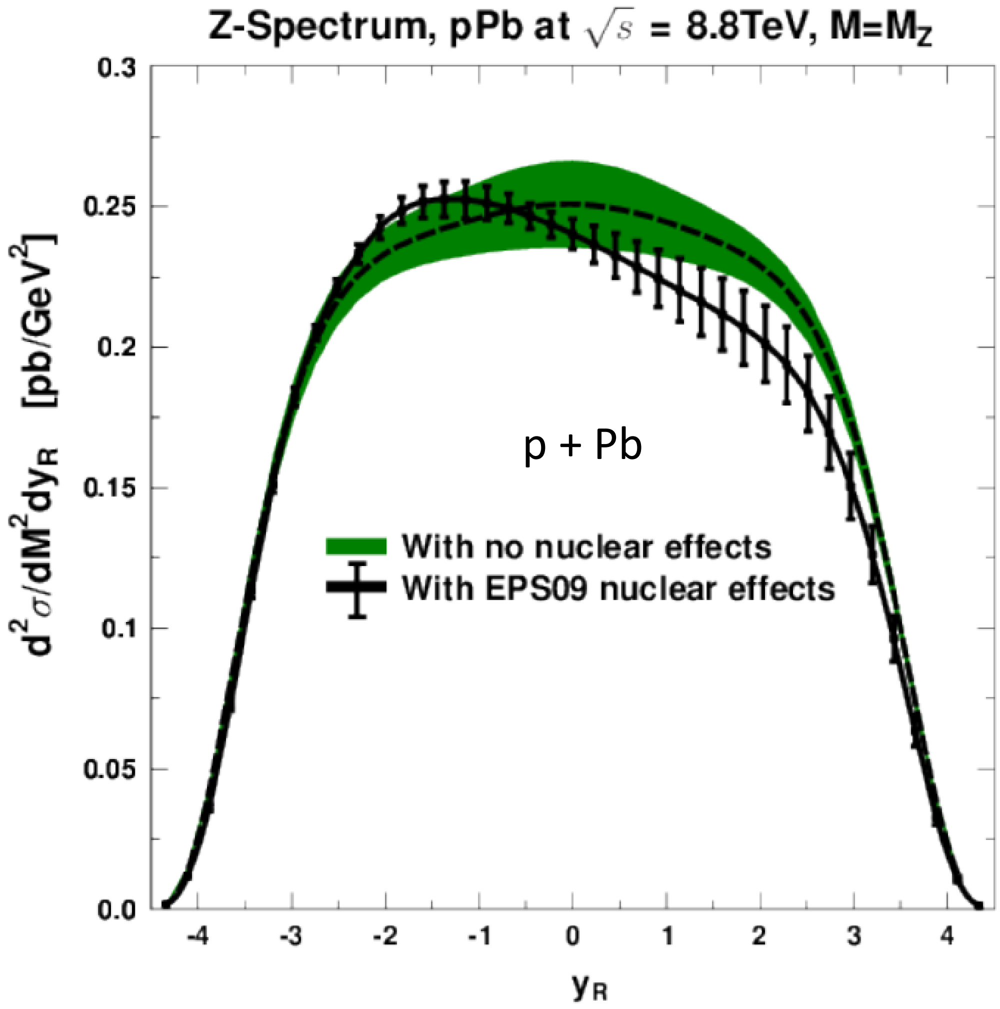
arXiv:1408.4657

- *Z* bosons yields scale with number of binary collisions
- Cannot reject model without nuclear effects (i.e. CT10NLO only isospin)

p+Pb system is more sensitive to nuclear effects

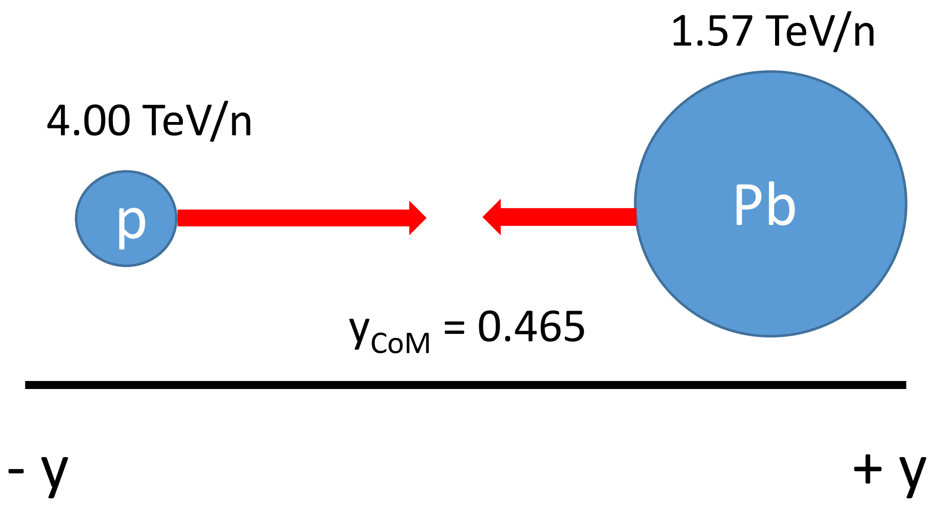
Measuring the Z cross-section provides information on how free nucleon PDFs are modified





arXiv:1010.5392v2

p+Pb system configuration



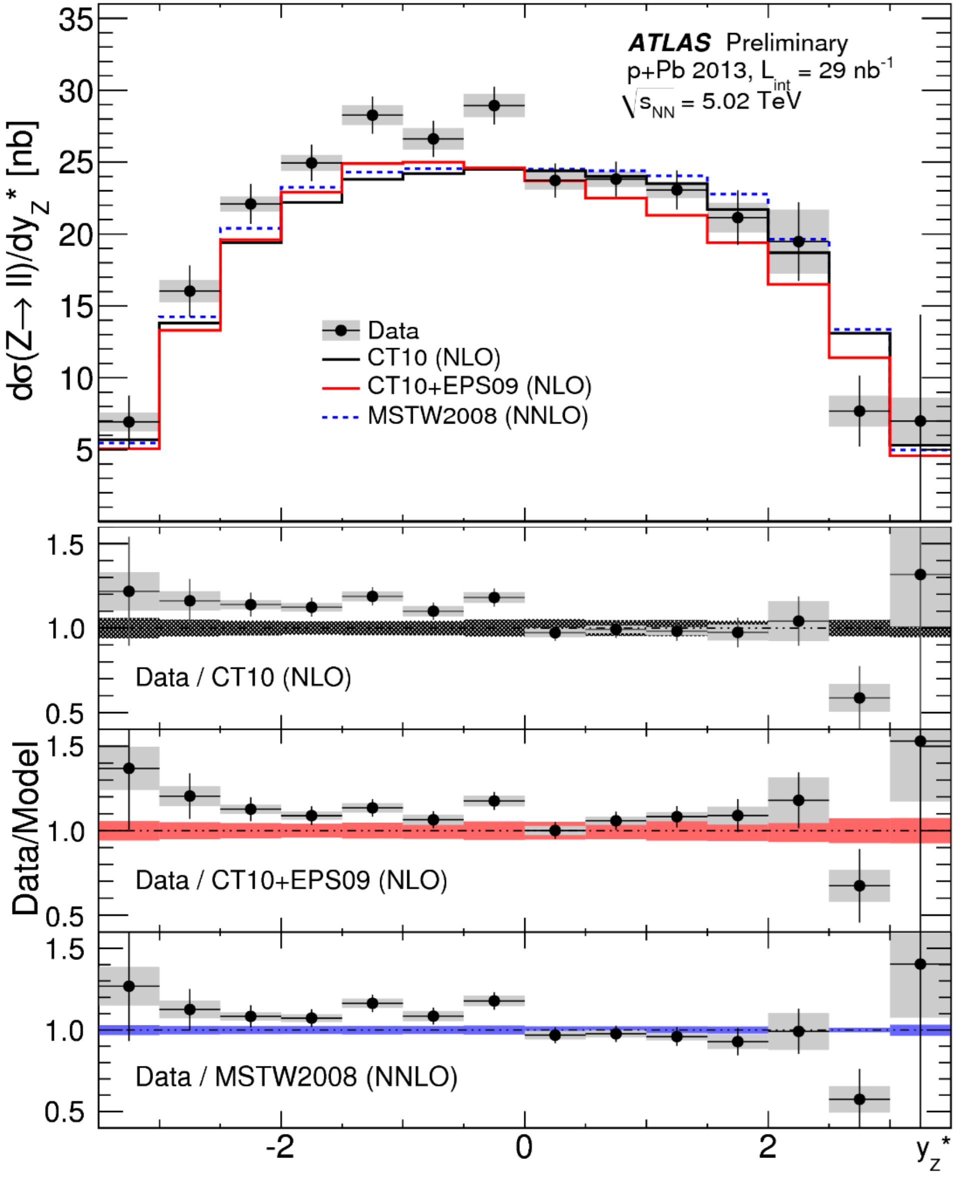
- Center of mass (CoM) shifted by 0.465 units
- Z bosons measured as a function of p_T^Z, CoM rapidity ($y_Z^* = y_Z^{lab} - 0.465$) and mean number of participants (centrality)

Z boson differential cross section: y_Z^*

CERN-PH-EP-2015-146

- Data is asymmetric about the CoM
- Comparison to three models: CT10, CT10EPS09, MSTW2008)
  - Models slightly underestimate data at backward rapidity
  - Ignoring scale, asymmetric behavior is best described by the model that incorporates nuclear effects (i.e. EPS09)

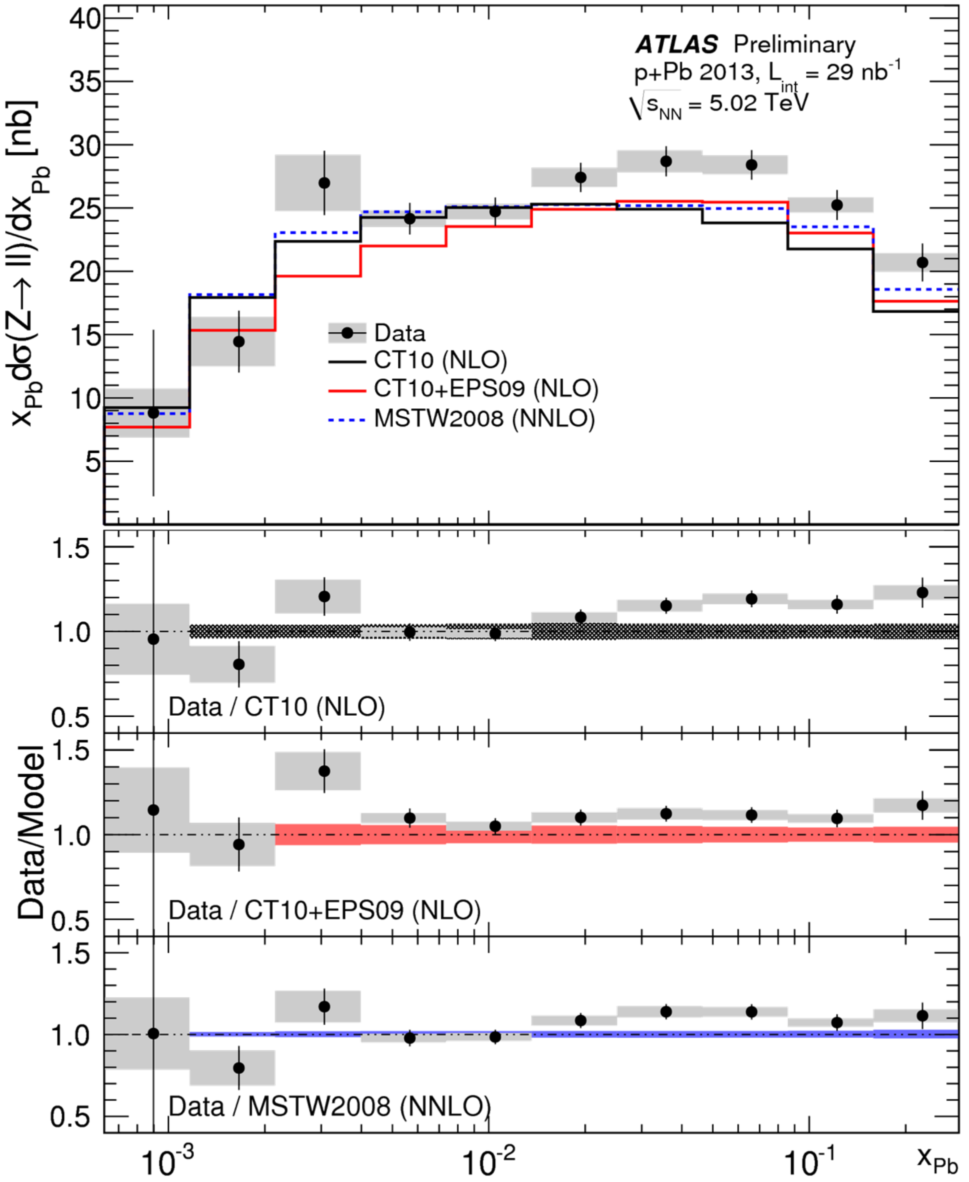
PDF	p-value from χ2 test
CT10+EPS09	0.79
CT10	0.07
MSTW2008	0.01



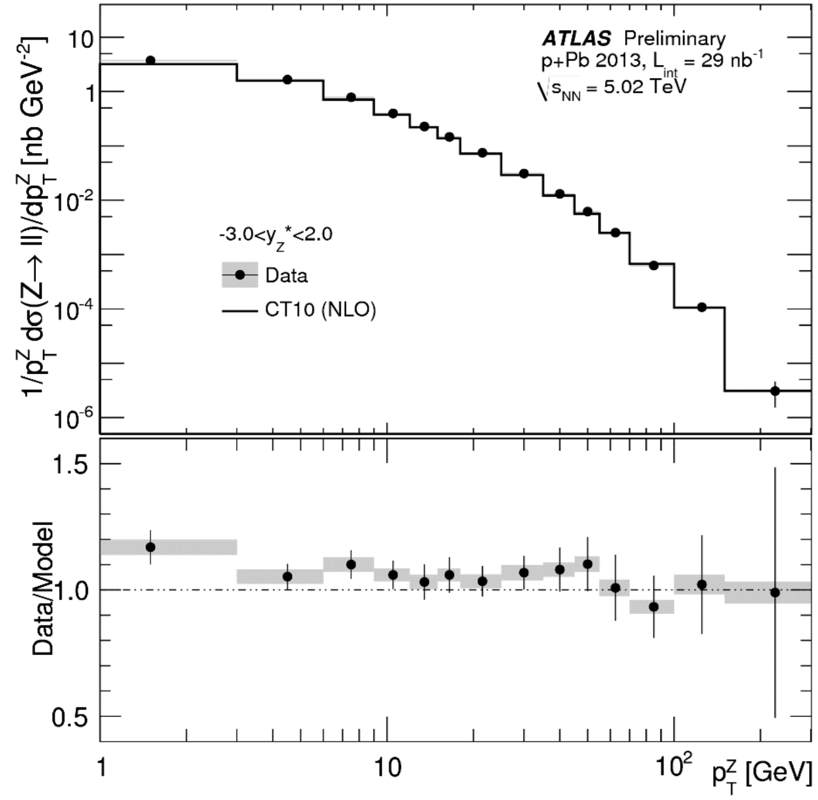
Z boson differential cross section: x_{Pb}

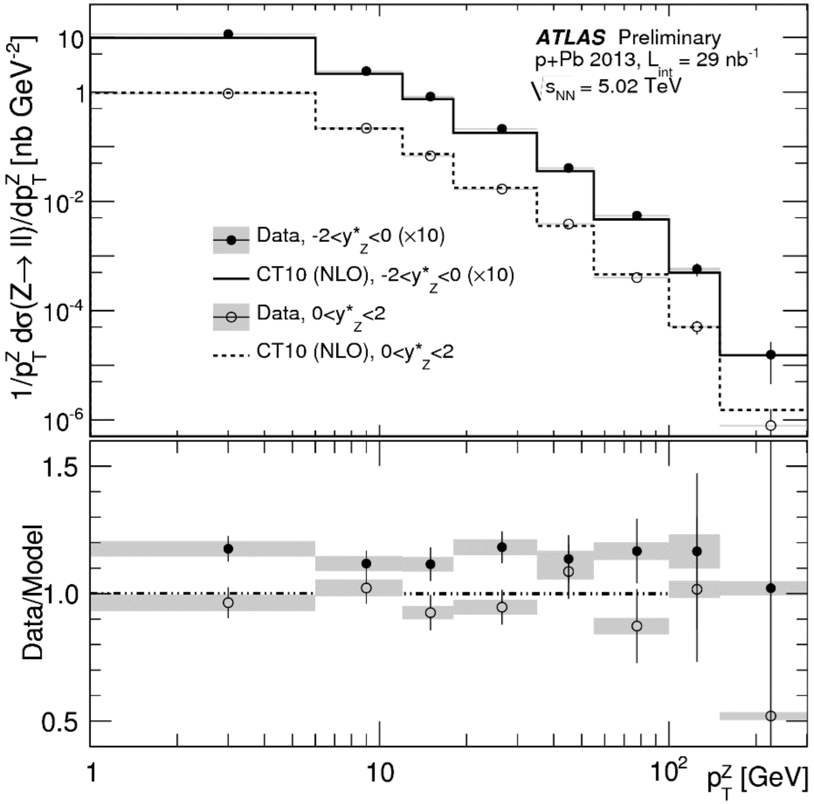
$$x_{Pb} = \frac{M_Z e^{-y_Z^*}}{\sqrt{s_{NN}}}$$

- Probing large x_{Pb} at backward y_Z^*
- Same conclusions as those observed in y_Z^* distribution, but observed in momentum-fraction space
  - CT10EPS09 best models the overall shape, but scale is slightly high at backward y_Z^* (large x_{Pb})



Z boson differential cross section: p_T^Z

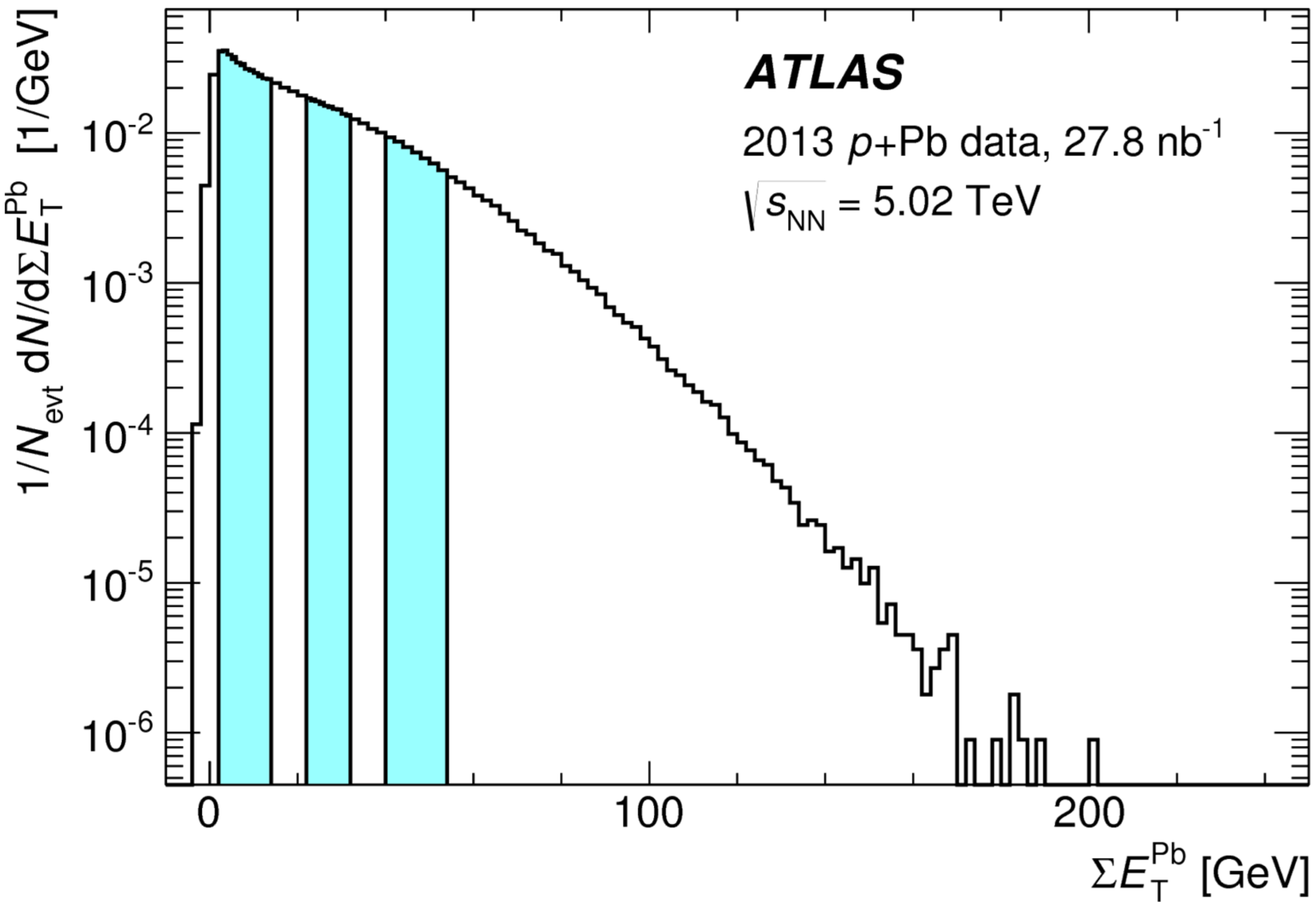




- Shape of the measured differential xsec in p_T^Z space is well represented by CT10 without nuclear effects
  - suggests transverse momenta of Z bosons appear to be insensitive to nuclear modifications
- Shapes of distributions do not change at forward and backward rapidity (only scale does)
- Data is slightly underestimated by the model at backward rapidities

Centrality in p+Pb collisions

- Measure transverse energy $\sum E_T^{Pb}$ deposited in the FCal on the Pb-going side and construct centrality classes
- Use Glauber model to map centrality classes to geometric quantities ($\langle N_{coll}\rangle, \langle N_{part}\rangle, \langle T_{pA}\rangle$)
- Extensions of "standard" Glauber model are also applied to account for event-by-event fluctuations in the nucleon-nucleon xsec
  - Glauber-Gribov Color Fluctuation (GGCF) models
  - Magnitude of fluctuations characterized by ω (or Ω)

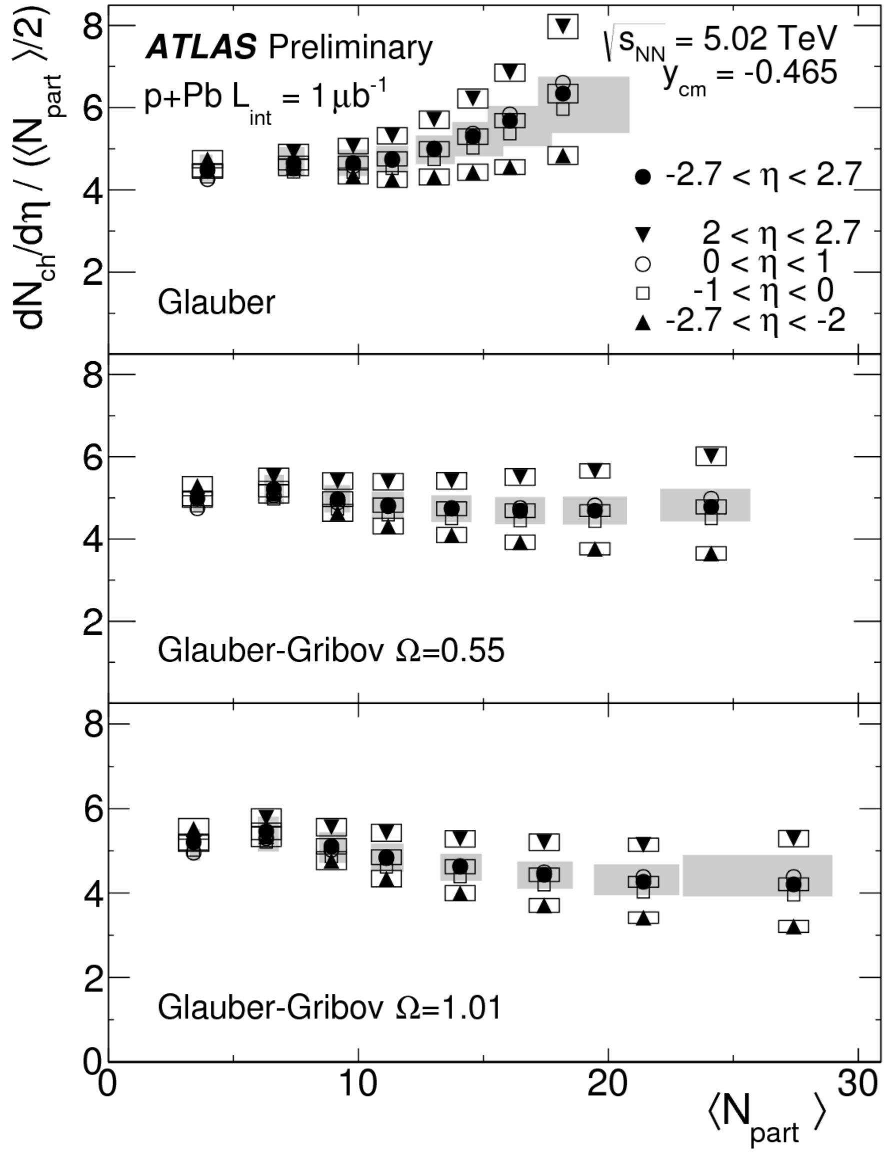


ATLAS-CONF-2013-096

Back to our question: Do we understand the p+Pb collision geometry?

- Charged-particle yields (normalized by $\langle N_{part} \rangle$)
  - depending on the model employed, yields may or may not be centrality independent

ATLAS-CONF-2013-096

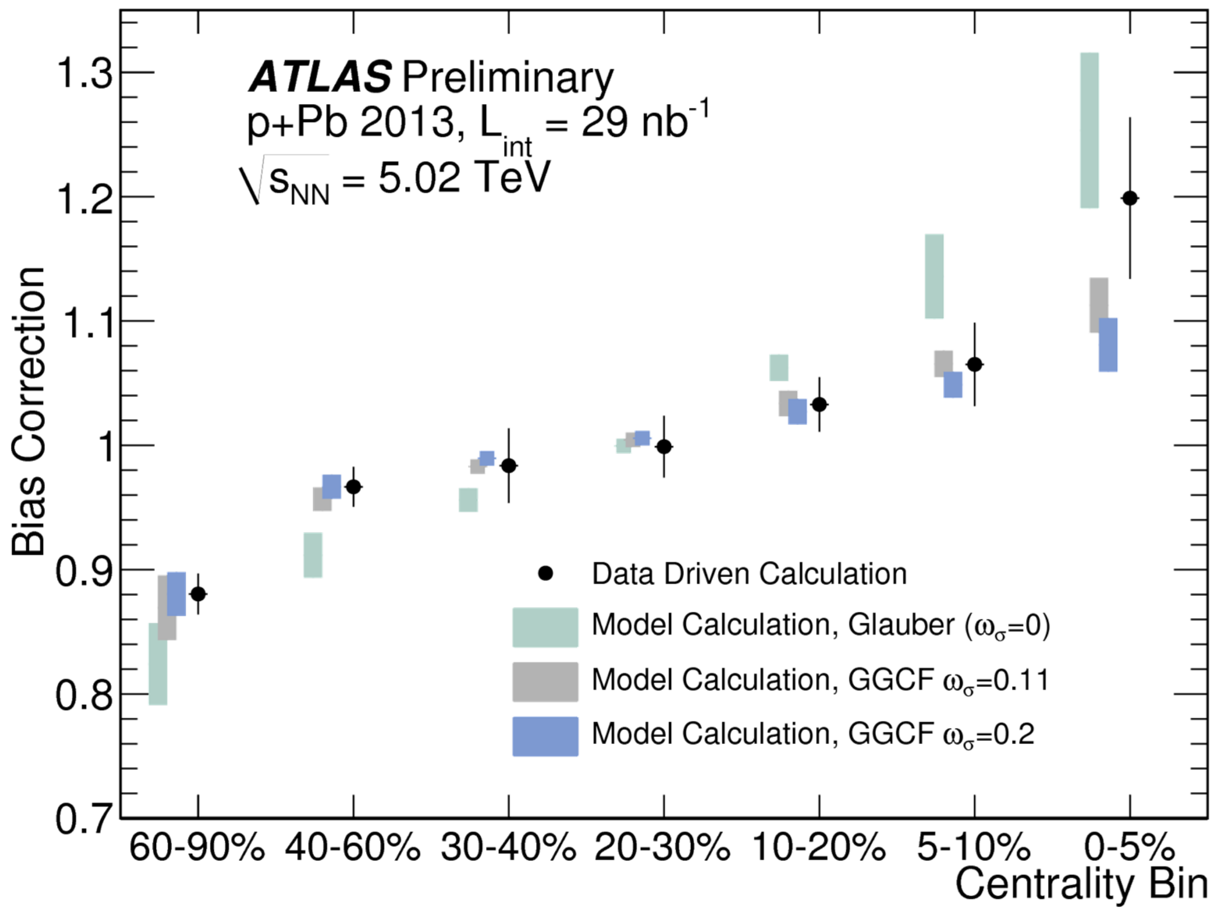


Before we get to *Z* bosons: Centrality Bias

- Hard scattering processes are accompanied by a larger magnitude of transverse energy or charged particle multiplicity in the UE with respect to events without a hard process
- Given average hard-scattering yield Y_{Ncoll} (e.g. high-p_T jets) per p+A collision for fixed N_{coll} and correlation with total E_T, centrality bias (arXiv: 1412.0976) calculated from:

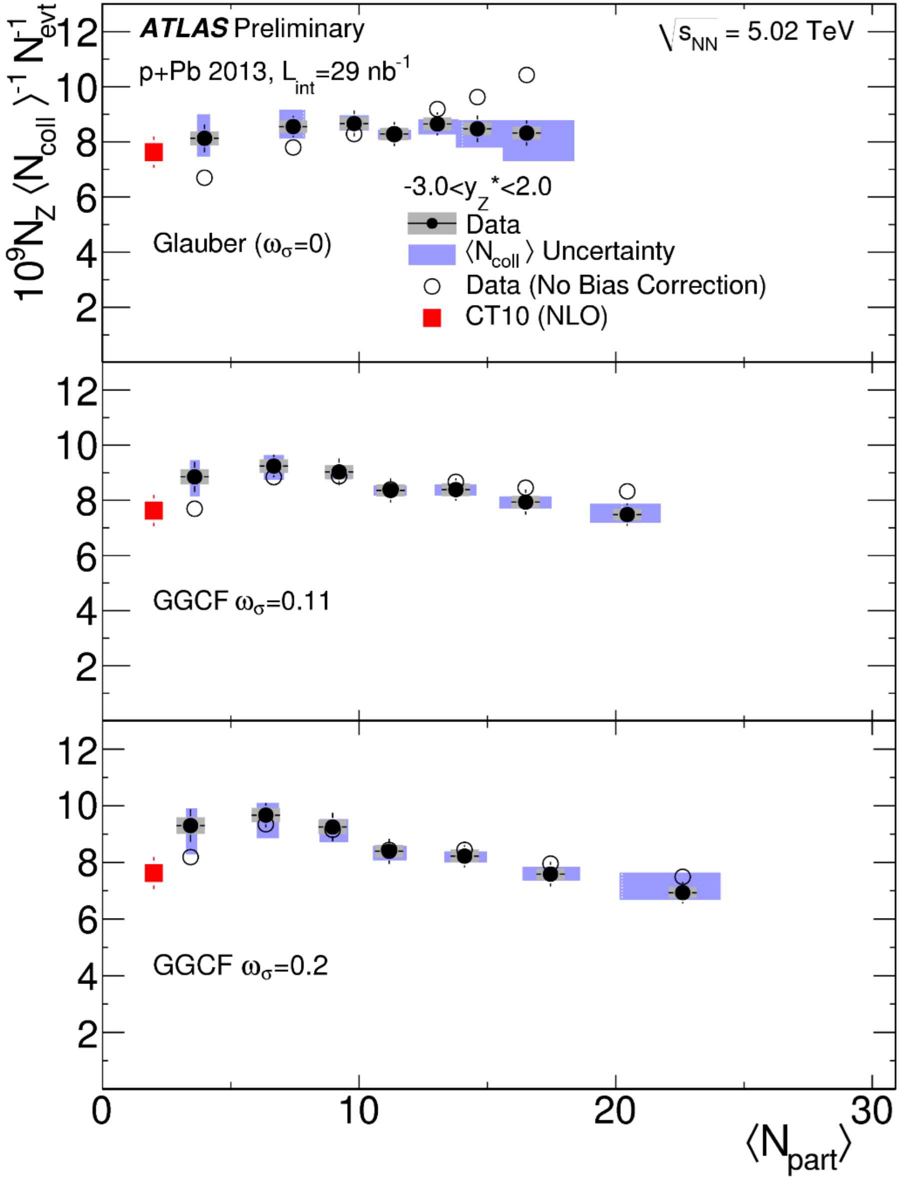
$$\rho = \frac{f(Y_{Ncoll}(E_T; correlated))}{f(Y_{Ncoll}(uncorrelated))}$$

- data-driven cross check using *pp* events with *Z* bosons and interpolating between energies
  - "Extra" FCal energy in these events subtracted event-by-event in p+Pb
  - ratios with and without subtraction = bias factor



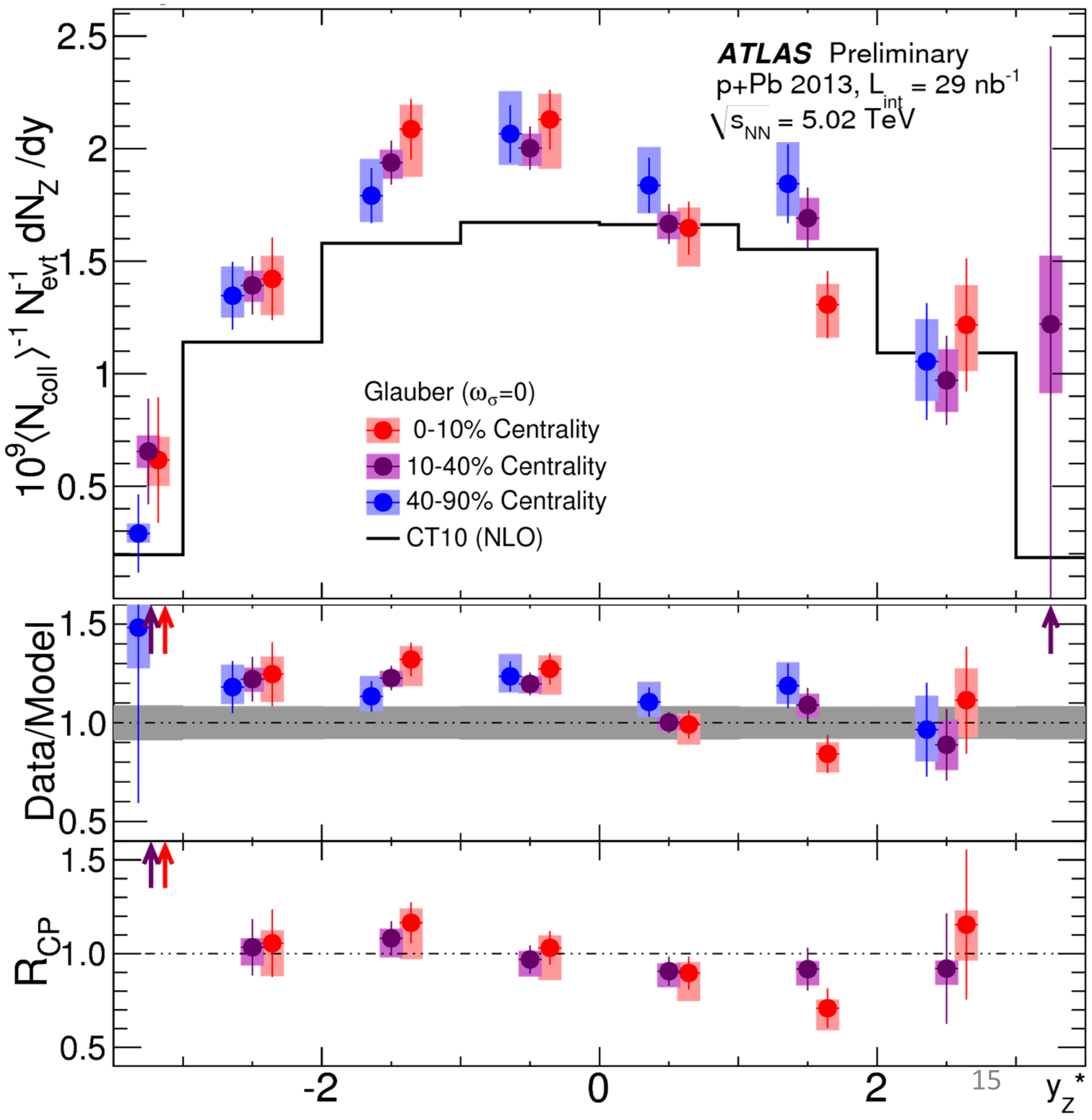
Z boson yields in centrality classes

- Yields normalized by $\langle N_{coll} \rangle$ (binary scaling)
- With centrality bias correction, yields appear constant using standard Glauber, less so using GGCF models
- Without application of centrality bias correction, *Z* boson yields show similar behavior to that observed for charged particles



Centrality dependence of y_Z^*

- Investigate the spatial dependence of nuclear PDFs
- Compare yields in each rapidity interval in more central events to yields in most peripheral events R_{CP}
- Observe a slight rapidity dependence in the R_{CP} in most central events
  - 0-10% class has a slope of -0.11±0.04
  - 10-40% has slope of -0.05±0.03

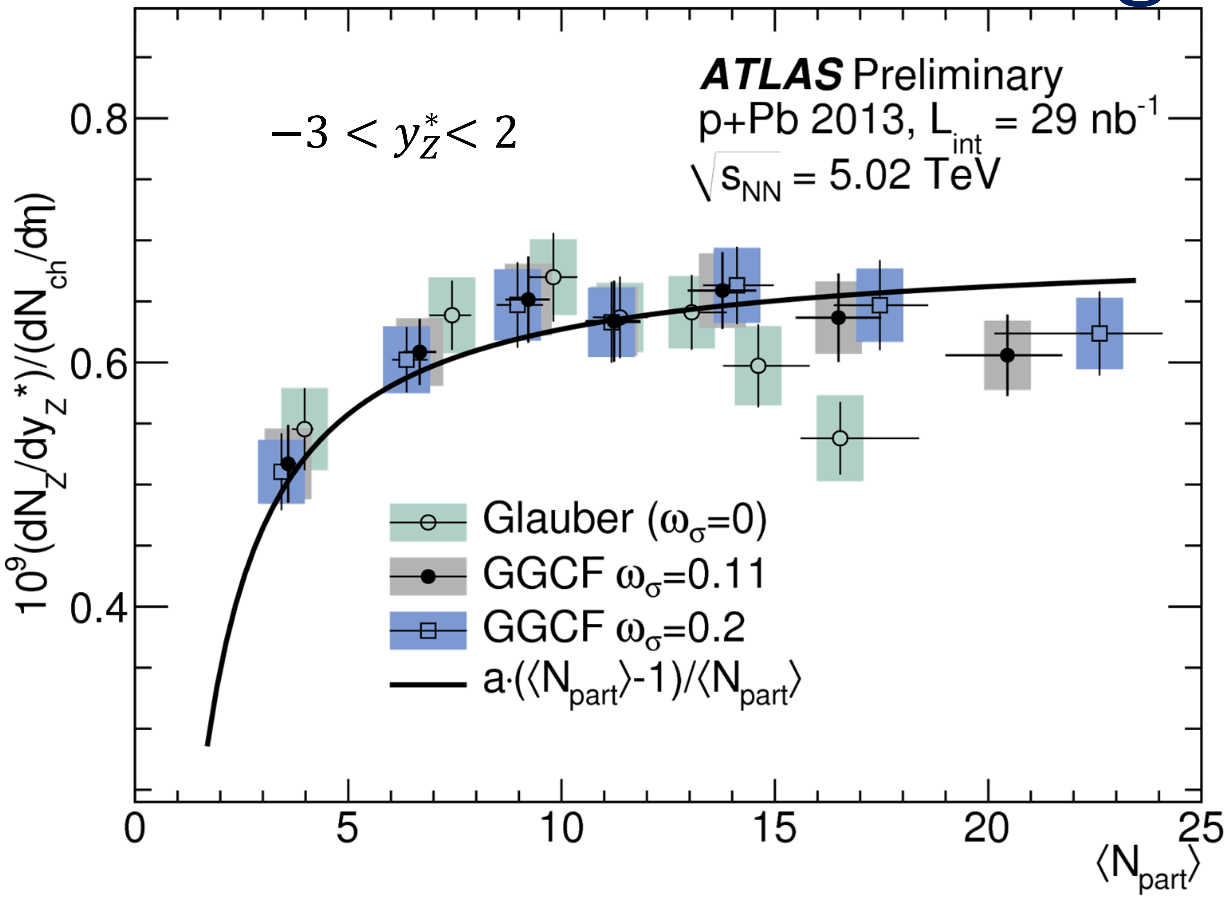


Summary and Outlook

- Presented highlights of past electroweak boson results in Pb+Pb and *Z* boson results in p+Pb
- *Z* cross section presented in p_T^Z, y_Z^* and x_{Pb} space
  - Measured cross section slightly higher than model predictions
  - The rapidity distribution is best described by model that incorporates nuclear effects (EPS09)
- Hints of spatially-dependent nuclear PDFs in centrality-selected y_Z^* distributions
- Showed that *Z* boson yields in different centrality classes may be used to differentiate between various models that describe the p+Pb collision geometry (standard Glauber, GGCF)
  - *A priori* expectation of electroweak binary scaling in p+Pb favors standard Glauber more than GGCF models as valid description of collision geometry
  - But can we do better? Centrality bias corrections and extent of GGCF fluctuations still unclear

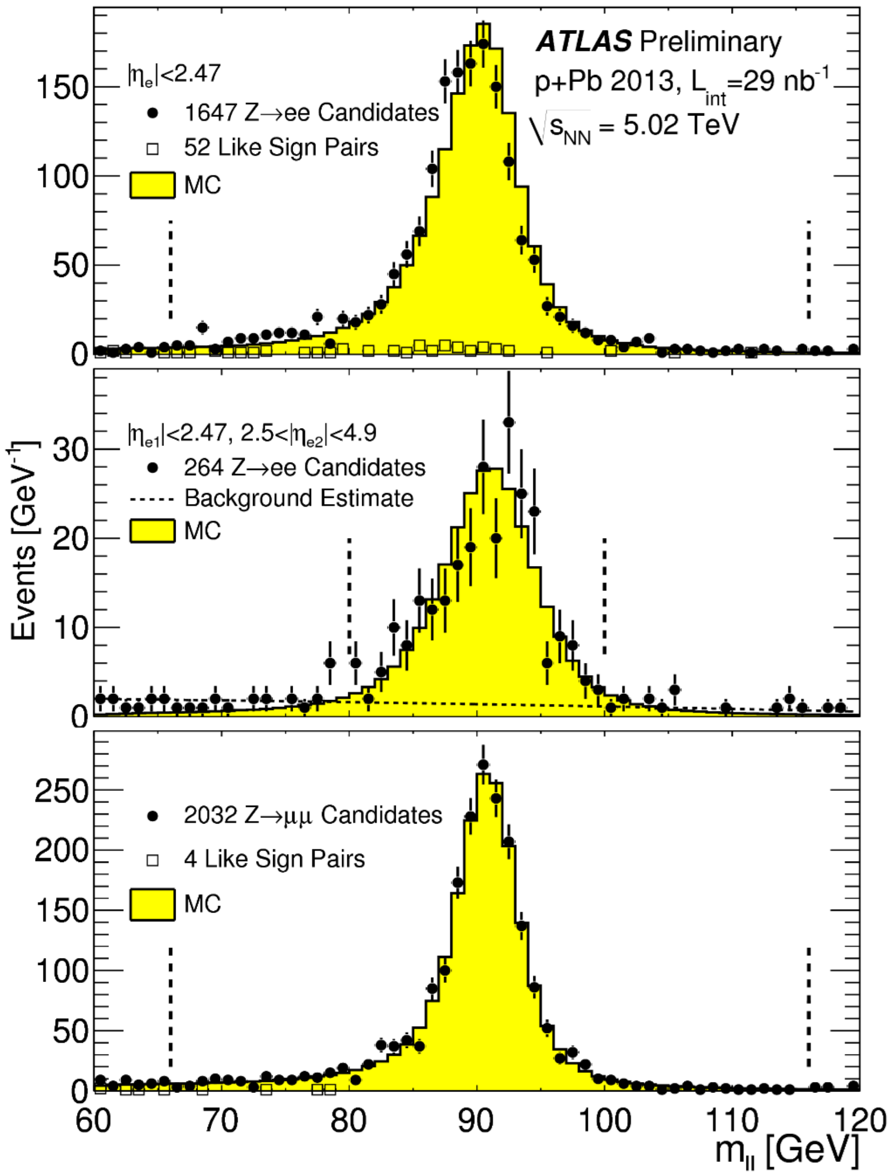
Backup

Comparison of Z bosons with charged particles

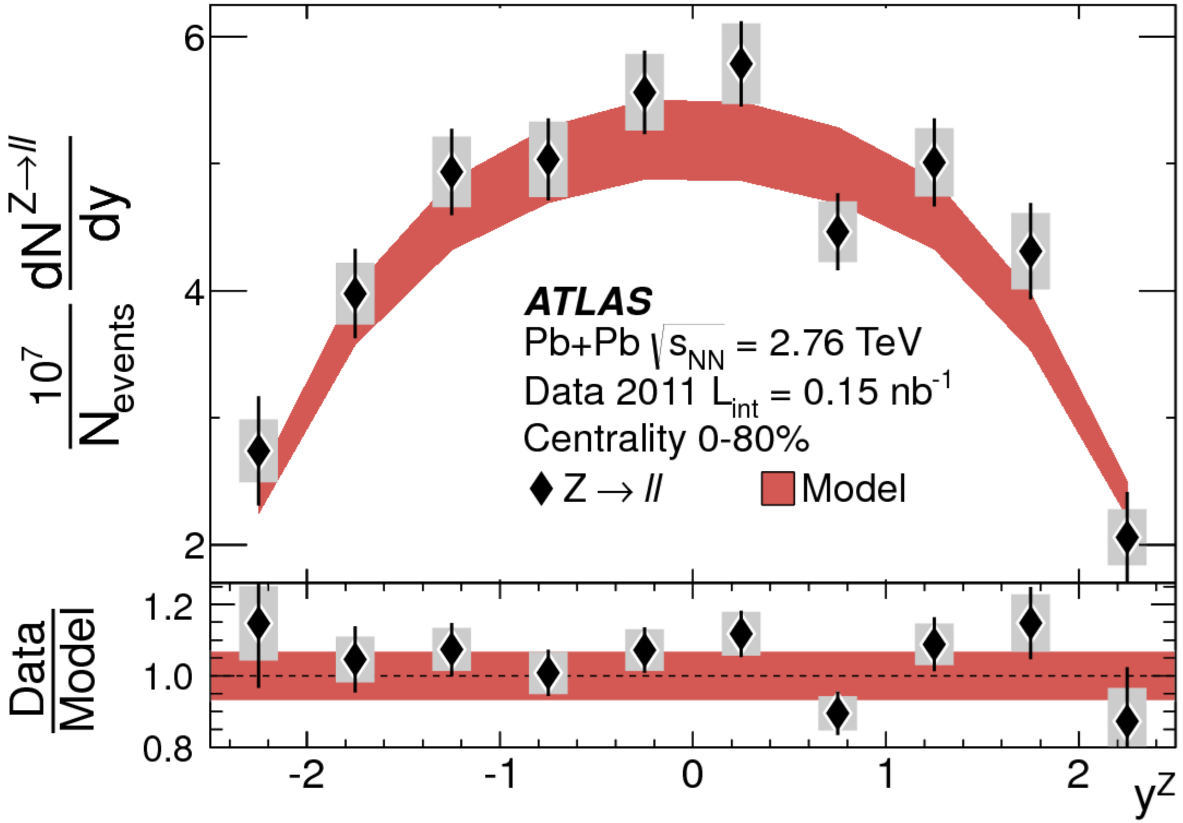


- If scaling behavior is the same for Z bosons and charged particles, yield ratio would follow a $\cdot \langle N_{coll}\rangle / \langle N_{part}\rangle$
- Without centrality bias correction, ratio is similar this expectation
- With centrality bias correction, within standard Glauber, observe deviation in most central events
- Standard Glauber is most correct geometric description, or can we find a more accurate description within the GGCF framework by using Z bosons to constrain ω and the centrality bias?

Dilepton Invariant Mass

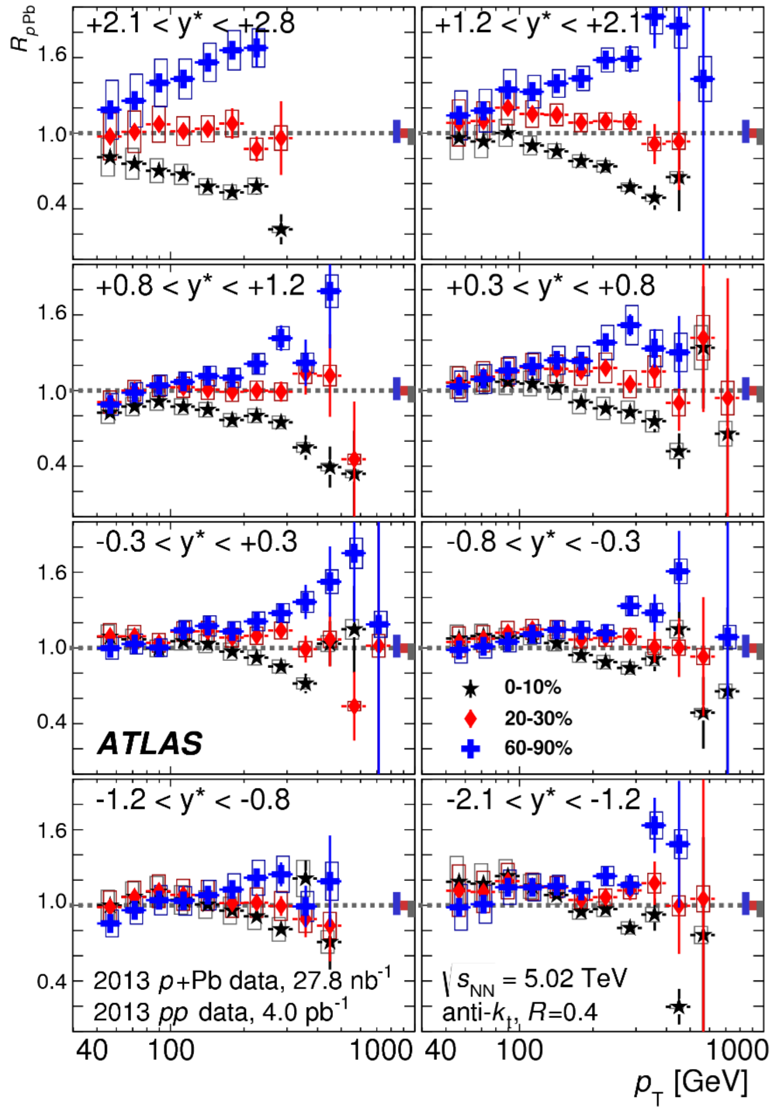


What has been observed so far in Pb+Pb
(Z bosons)

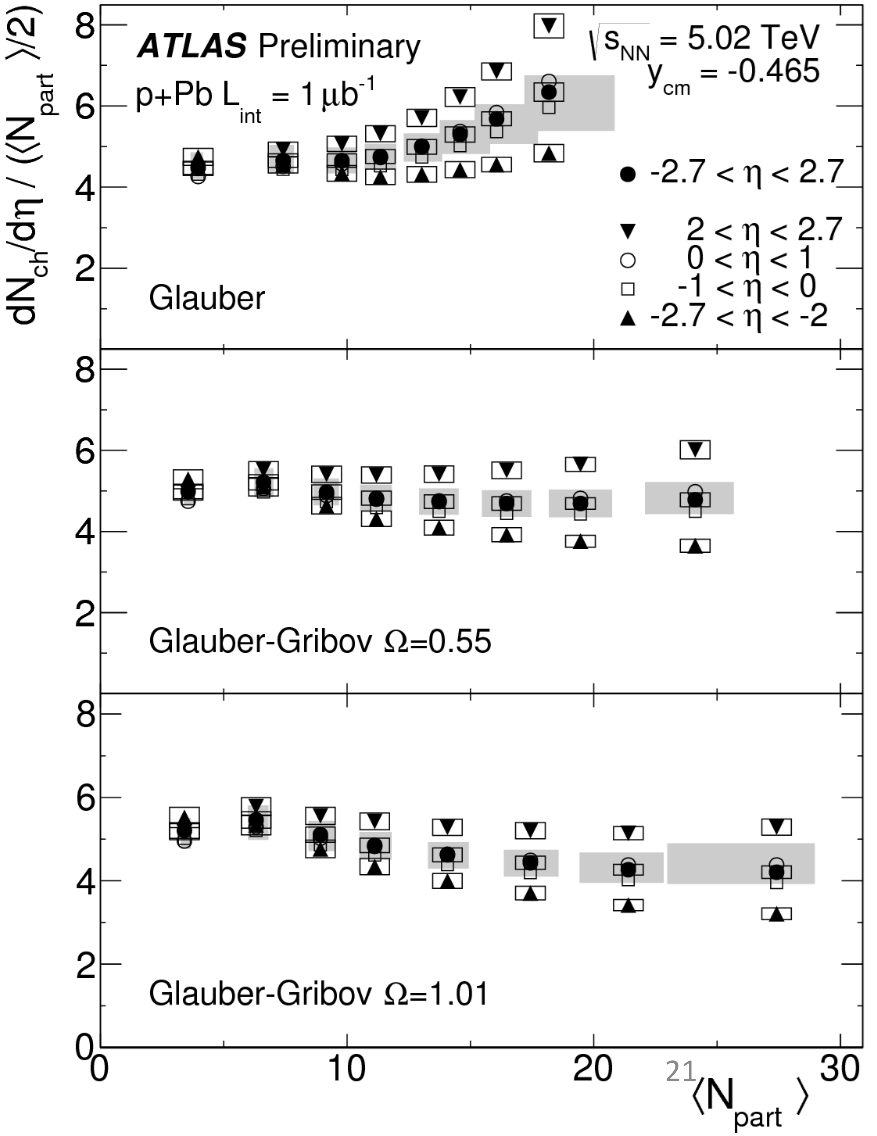


- Rapidity distribution is consistent with NLO predictions without nuclear modifications to PDF

Back to our question: Do we understand the p+Pb collision geometry?



- (Left) Jet nuclear modification factor (R_{pPb})
  - enhancement in peripheral collisions, suppression in central events
- (Right) Charged-particle yields (normalized by $\langle N_{part} \rangle$)
  - depending on the model employed, yields may or may not be centrality independent



What has been observed so far in Pb+Pb (photons)