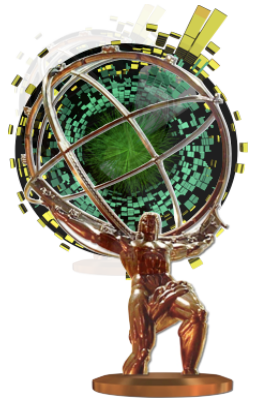
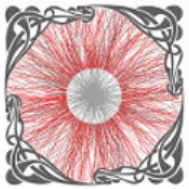




XXIV QUARK MATTER
DARMSTADT 2014

AGH

Measurements of vector boson production in lead-lead and proton-lead collisions with the ATLAS detector

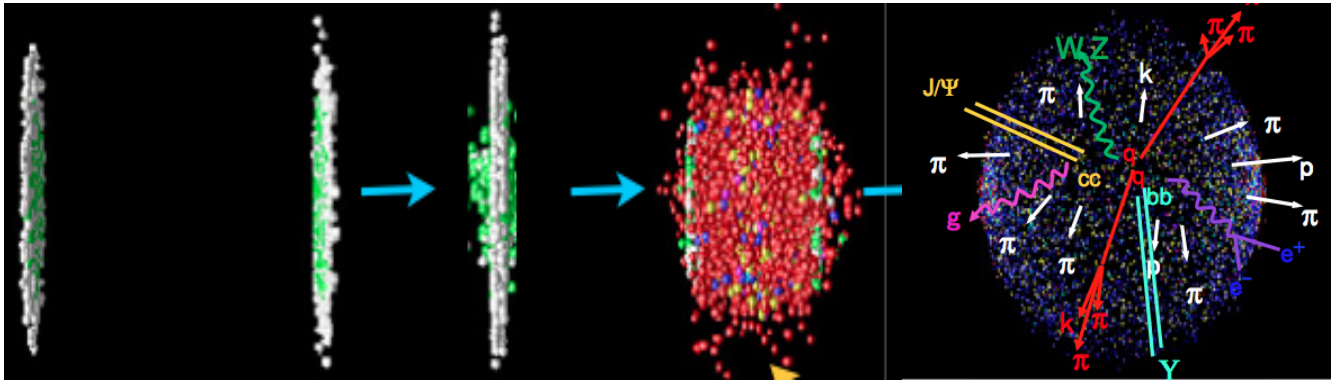
Iwona Grabowska-Bold (AGH-UST)
on behalf of the ATLAS Collaboration
Darmstadt, Germany, May 19th, 2014

Outline

- Introduction
  - Physics motivation
  - ATLAS experiment
- Overview of measurements on vector bosons
  - Photons
    - Inclusive photons in Pb+Pb (ATLAS-CONF-2012-051)
    - γ+jet momentum imbalance in Pb+Pb (ATLAS-CONF-2012-121)
  - Z bosons
    - Z bosons in Pb+Pb (Phys.Rev.Lett 110 (2013) 022301)
    - Z+jet momentum imbalance (ATLAS-CONF-2012-119)
    - Z boson production in p+Pb (ATLAS-CONF-2014-020)
  - W bosons
    - W bosons in Pb+Pb (ATLAS-CONF-2014-023)
- Summary

Old measurements
New measurements

Physics motivation

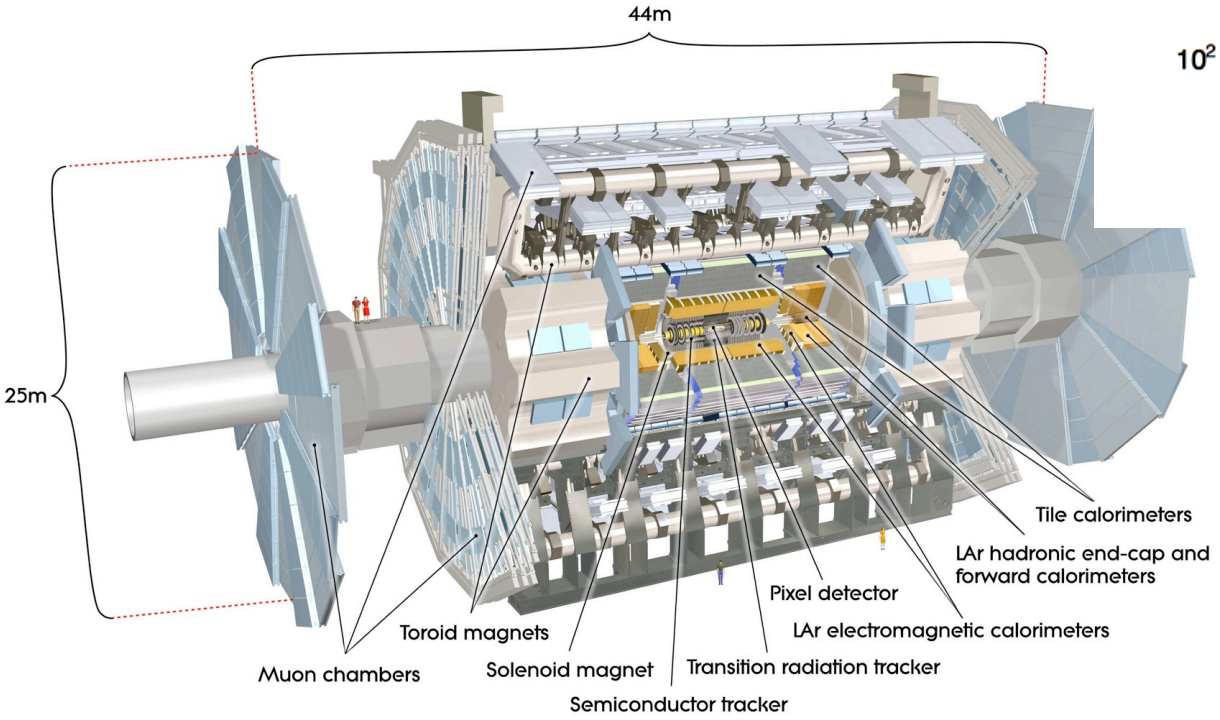


One of the main goals of heavy-ion physics is to study QGP

- *Electroweak (EW) bosons* are produced in hard processes before quark-gluon plasma (QGP) is formed
- They are colorless probes which are supposed not to interact with QGP
  - Leptons which are produced as decay products of weak bosons are colorless as well → QGP is transparent to them
- One can explore *jet quenching* in EW+jet events using EW bosons as calibration tools
- In addition, the EW boson production mechanism (e.g. via qq-bar annihilation) makes them sensitive to *parton distribution functions* (PDFs)
  - Since studies are done in the heavy-ion (HI) environment, one can investigate nuclear modifications to PDFs (nPDFs)
  - Proton-lead collisions are a perfect tool to disentangle initial- from final-state effects

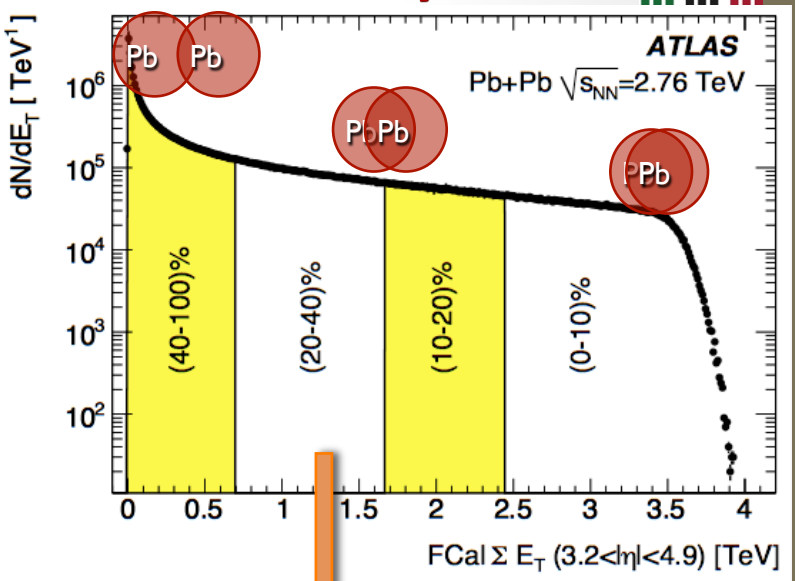
ATLAS detector

Three main components: Inner tracker, electromagnetic (EM) and hadronic (HAD) calorimeters, and muon system



Full azimuthal acceptance

Centrality

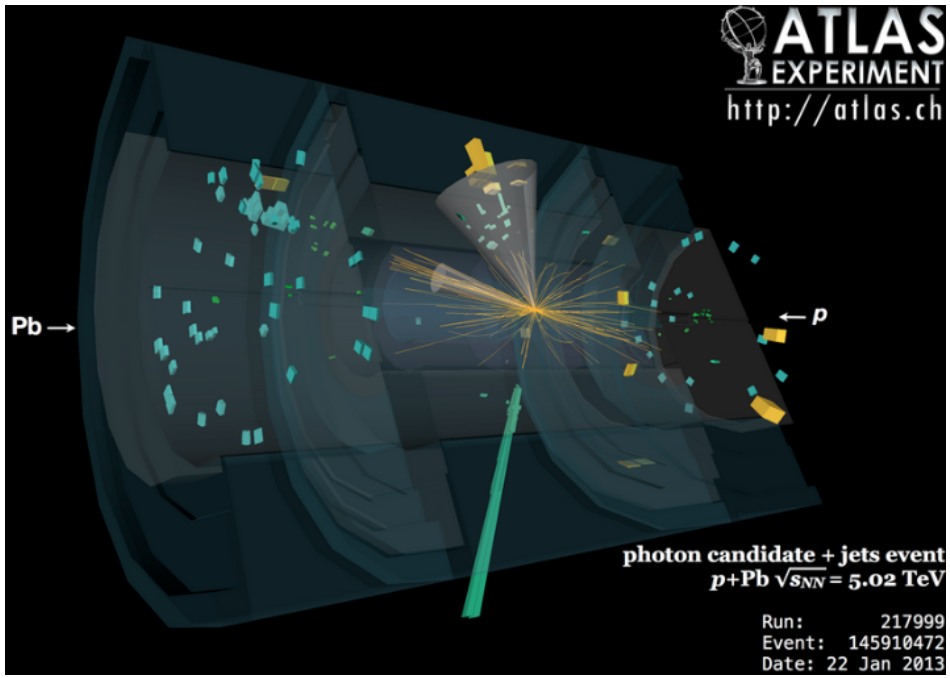


FCal E_T→centrality→$N_{part}N_{coll}$

In Pb+Pb: total FCal E_T
In p+Pb: FCal E_T on Pb-going side

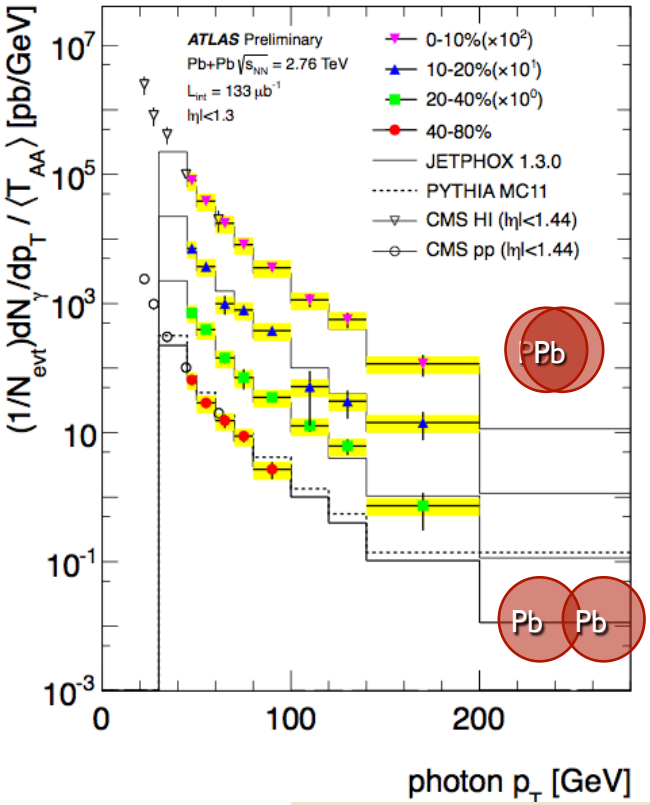
Sub-detectors	|η| coverage
Inner Tracker	<2.5
Muon Spectrometer	< 2.7
EM Calorimeter	<3.2
HAD Calorimeter	<4.9

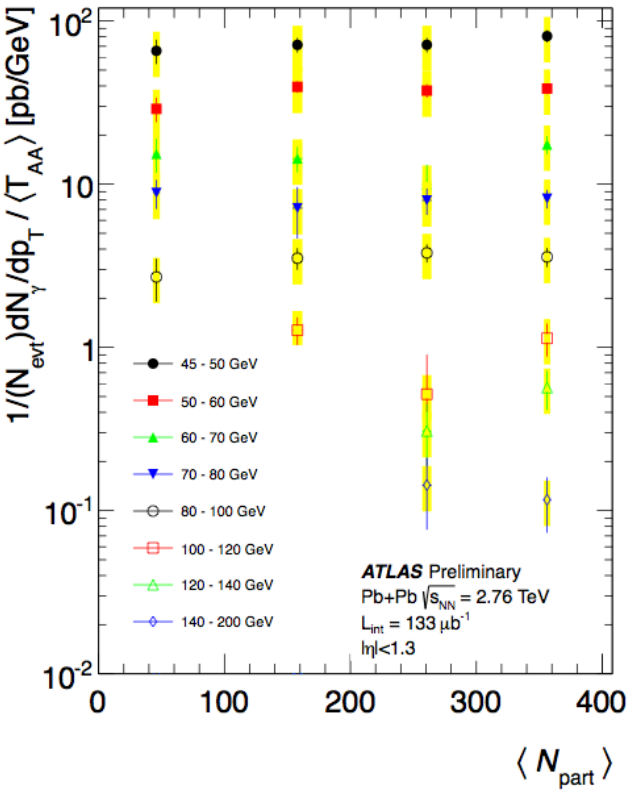
PHOTONS


ATLAS
EXPERIMENT
http://atlas.ch
Pb →
← p
photon candidate + jets event
p+Pb √sNN = 5.02 TeV
Run: 217999
Event: 145910472
Date: 22 Jan 2013

Inclusive direct photons in Pb+Pb

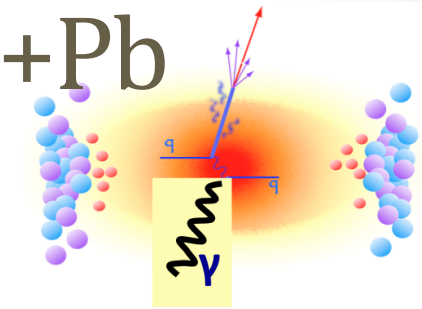
- Photons with $45<p_T<200$ GeV and $|\eta|<1.3$ in ATLAS
- CMS *p+p* and Pb+Pb at 2.76 TeV: Phys. Lett. B **710**, 256 (2012)
  - 10% larger interval in η
  - Isolation condition: $E_T(R_{iso}=0.4)<5$GeV
  - Good agreement with the ATLAS measurement
- PYTHIA and JETPHOX shown for comparisons
- → Update on inclusive photons in Peter Steinberg's talk on Tuesday



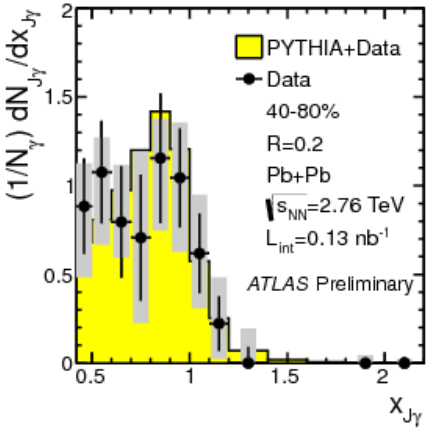


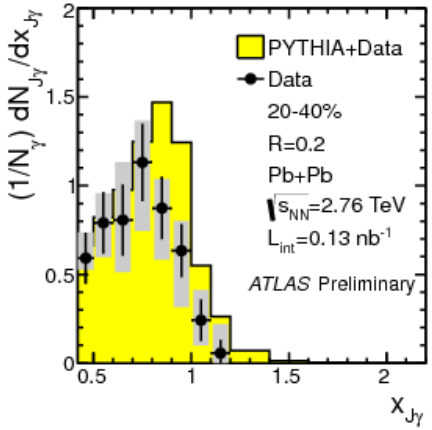
- No centrality dependence in any of the measured p_T intervals
- Photon yields in HI collisions scale linearly with $\langle T_{AA}\rangle$ (nuclear thickness function) or equivalently with $\langle N_{coll}\rangle$ → no interaction with QGP

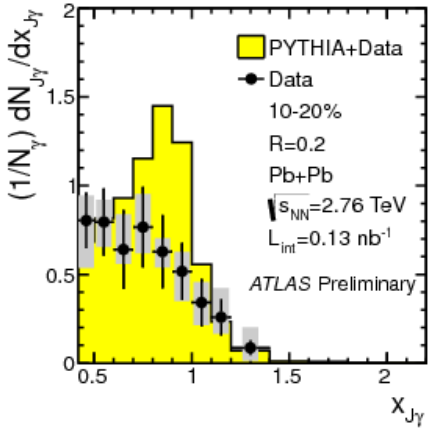
γ+ jet correlations in Pb+Pb

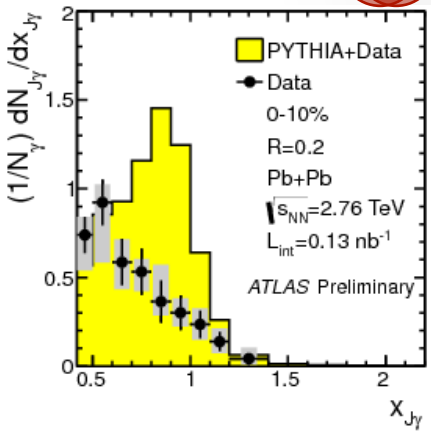


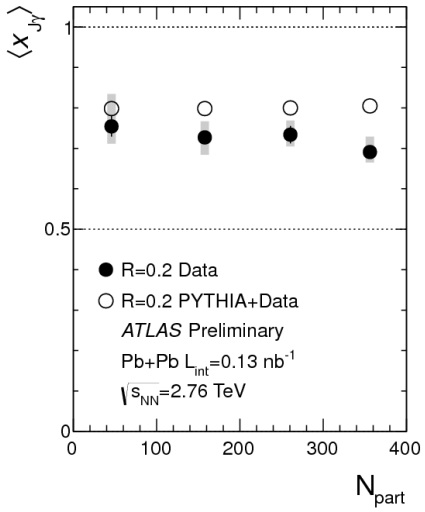
$x_{J\gamma}=p_T^{jet}/p_T^{\gamma}$

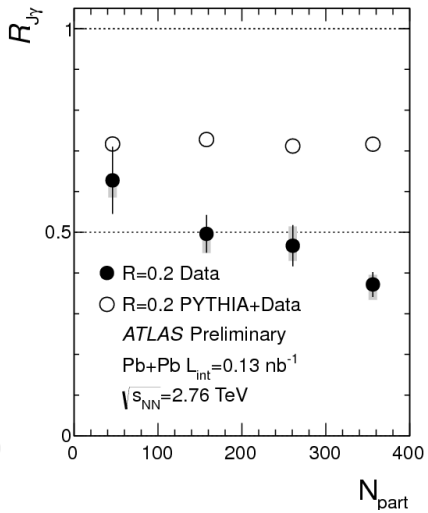












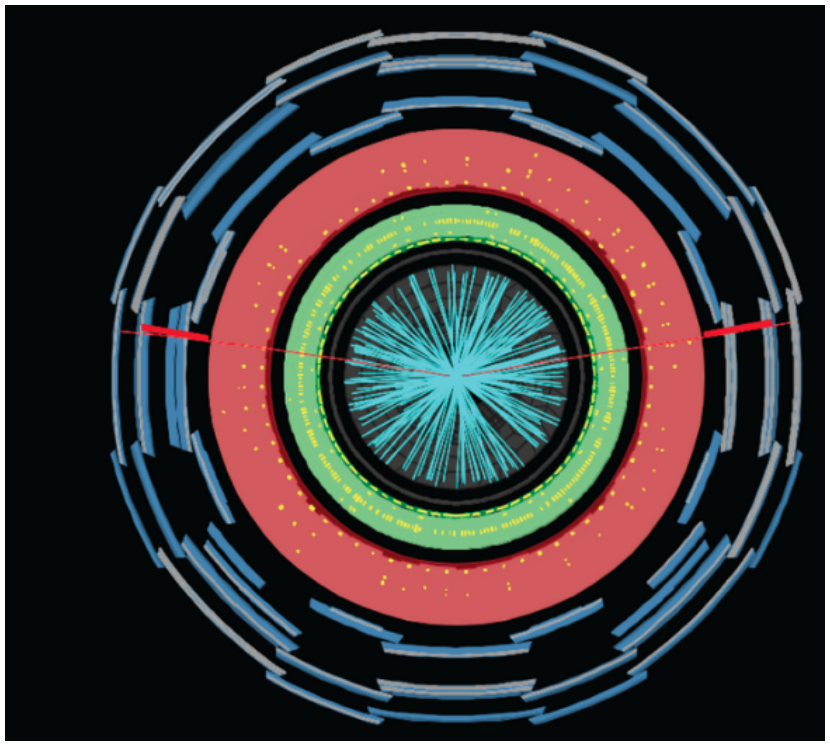
Photons: $60<p_T<90$ GeV and $|\eta|<1.3$
Jets: $p_T>25$ GeV and $|\eta|<2.1$
$|\Delta\varphi|>7\pi/8$

$\langle x_{J\gamma} \rangle$ - mean energy fraction

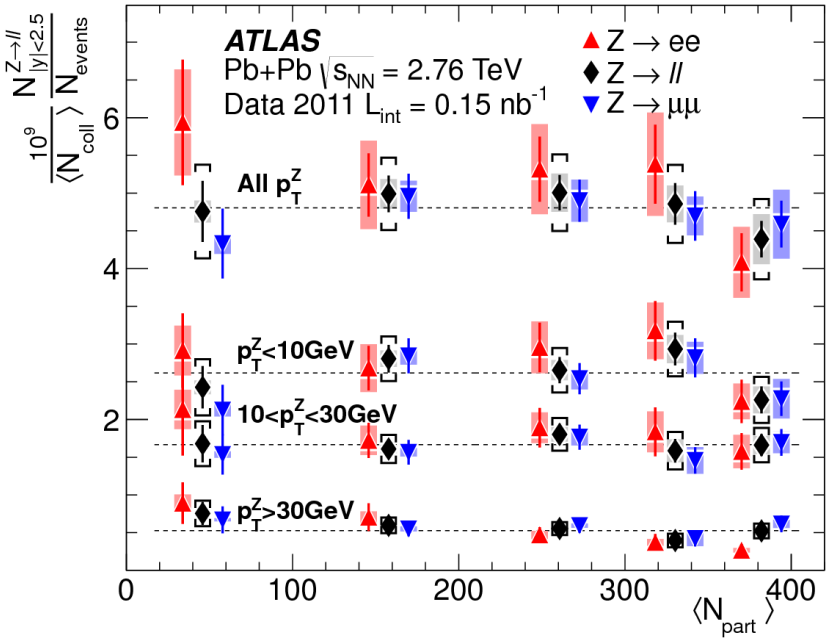
$R_{J\gamma}$ - fraction of jet/gamma pairs to the total number of photons

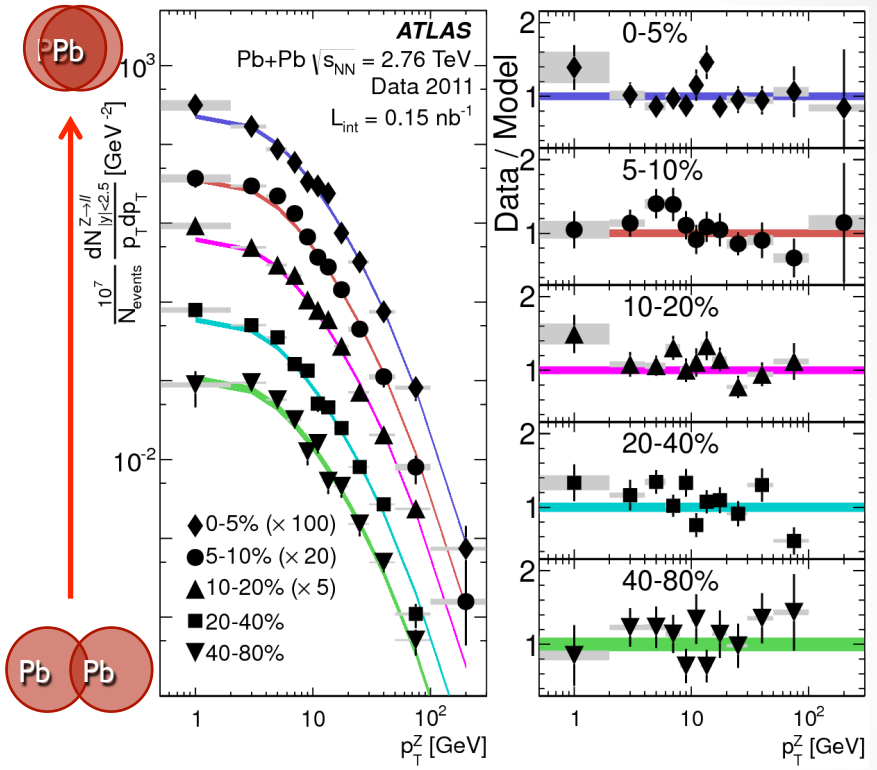
Significant change in $R_{J\gamma}$ in central events, which is inconsistent with the PYTHIA-based model

Z BOSONS



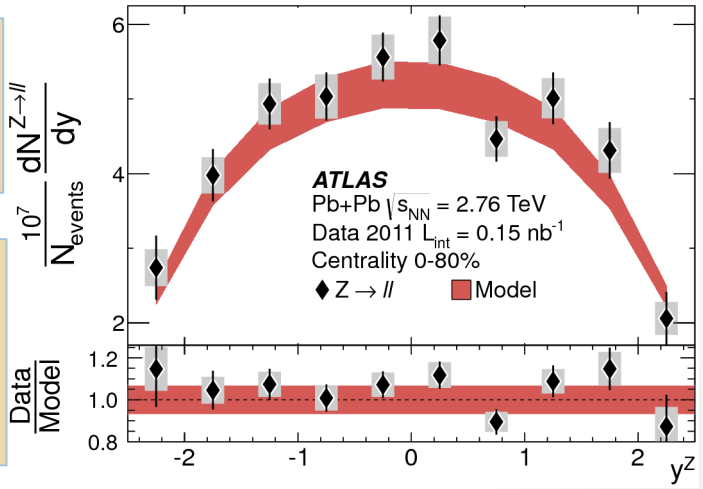
Z boson yields in Pb+Pb



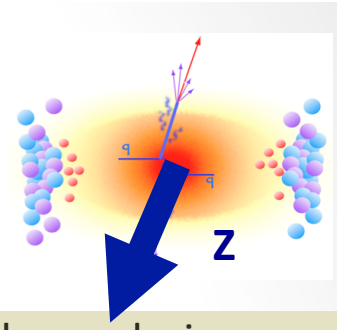


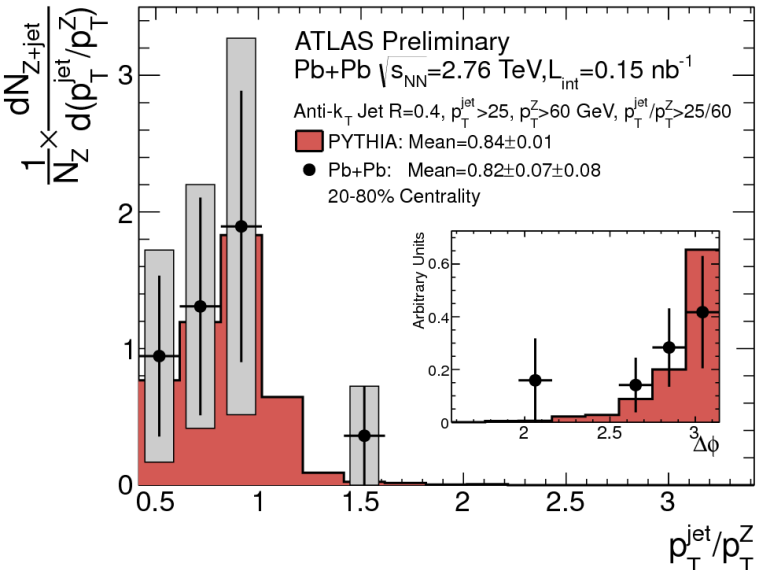
- Electron and muon channels consistent
- Binary collision scaling appears to hold true
  → no interaction with QGP

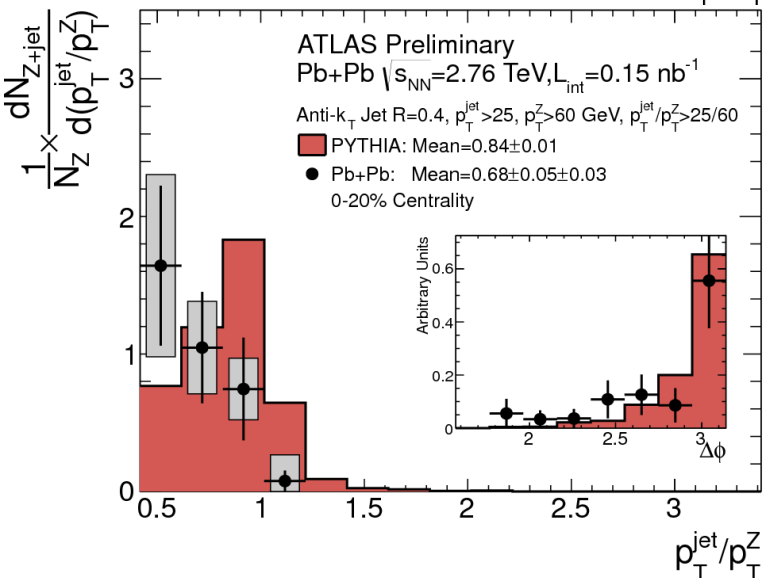
→PYTHIA normalized to the Z→l^+l^- cross section in p+p from NNLO calculations and scaled by <T_{AA}> – agrees well
→No centrality dependence of this shape is observed



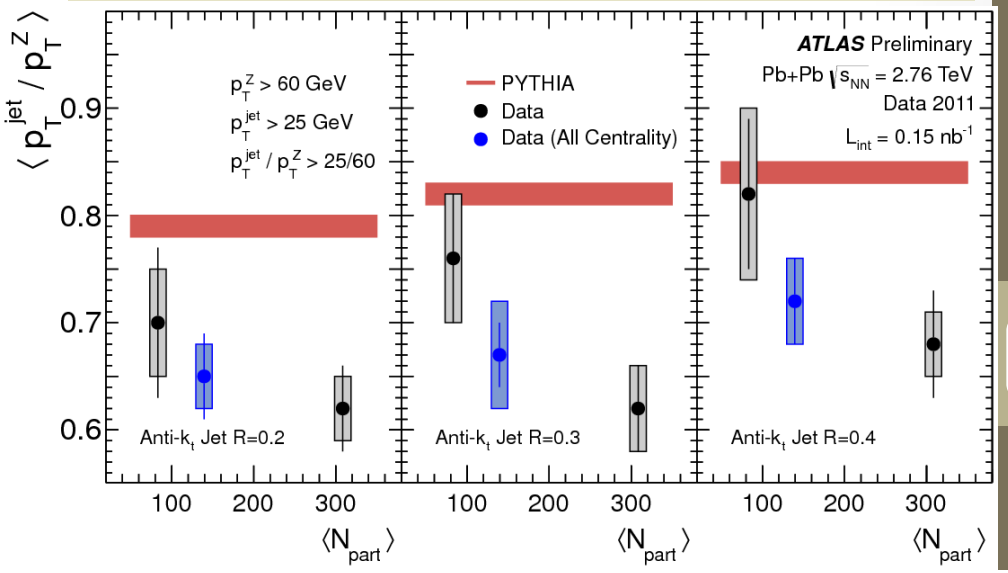
p_T imbalance of Z+jet in Pb+Pb





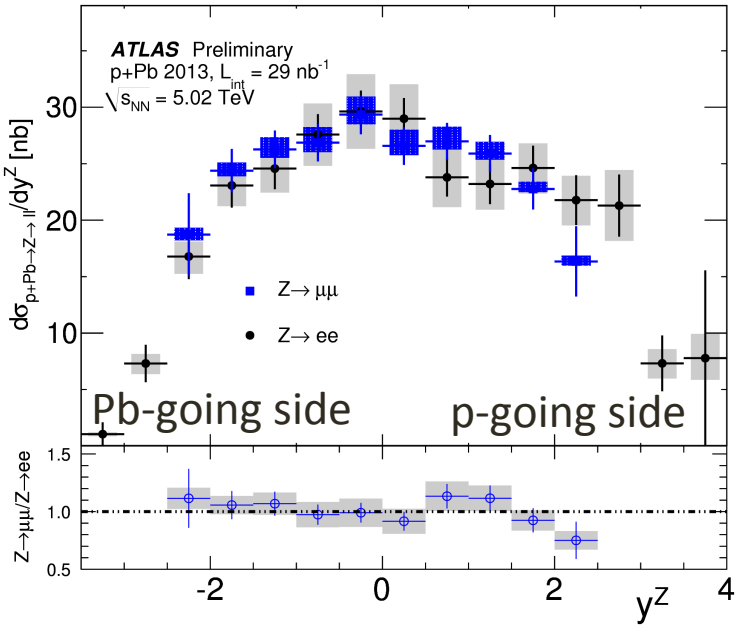


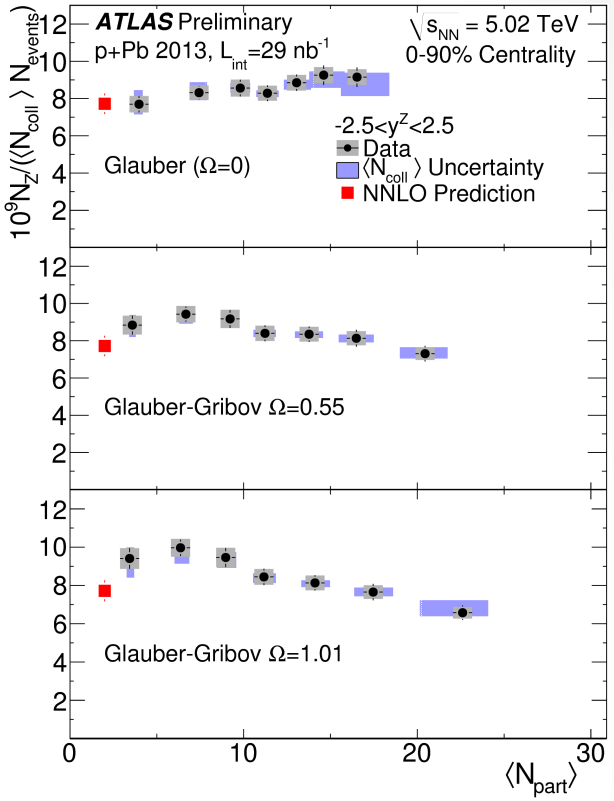
- Only 36 events satisfy the analysis criteria in the entire Pb+Pb data sample
  - Unfolded and efficiency corrected ratio p^{jet}_T/p^Z_T
  - Statistical uncertainty dominates
- Three jet sizes: 0.2, 0.3, 0.4
- Data compared to the PYTHIA-based model which contains no energy loss mechanism – significant deviation from the model
  - Both normalized by a number of Z bosons with p^Z_T>60GeV



Z bosons in p+Pb

- Proton-lead collisions at $\sqrt{s_{NN}}$=5.02 TeV
  - System sensitive to initial-state effects
- Rapidity boost: y*=y-0.465
- Z bosons reconstructed via di-muon and di-electron decays
- Di-muons: $-2.5<y^Z<2.5$, $p_T^{leading}>20$ GeV
- Di-electrons: $-3.5<y^Z<4.0$, $p_T^{leading}>20$ GeV
- Good agreement between channels
- → More details in Zvi Citron's talk





→Z boson production yields per minimum bias event divided by $\langle N_{coll}\rangle=\langle N_{part}\rangle-1$

- Centrality calibrated based on FCal E_T^{Pb}
- Various models explored for collision geometry: standard Glauber (Ω=0), Glauber-Gribov (Ω=0.55, Ω=1.01)

→Z boson production scales with centrality

Z boson cross-sections in p+Pb

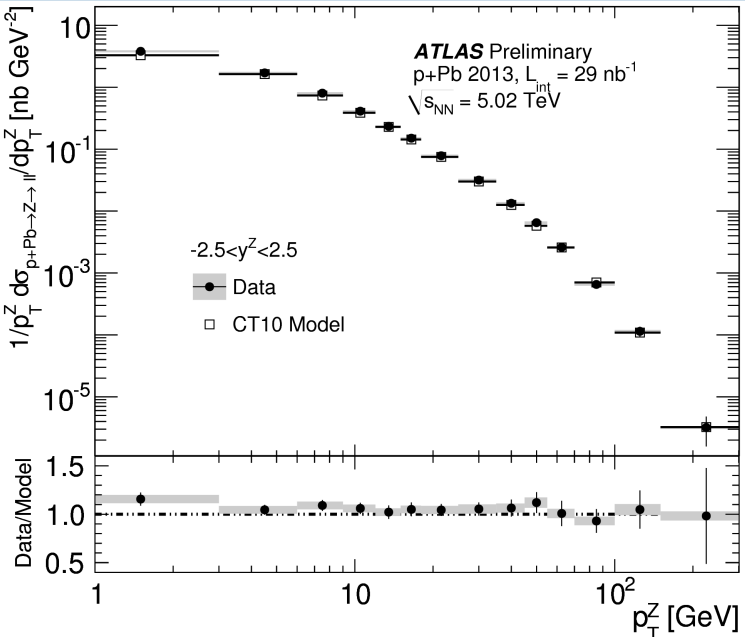
→ Total cross-sections for two channels

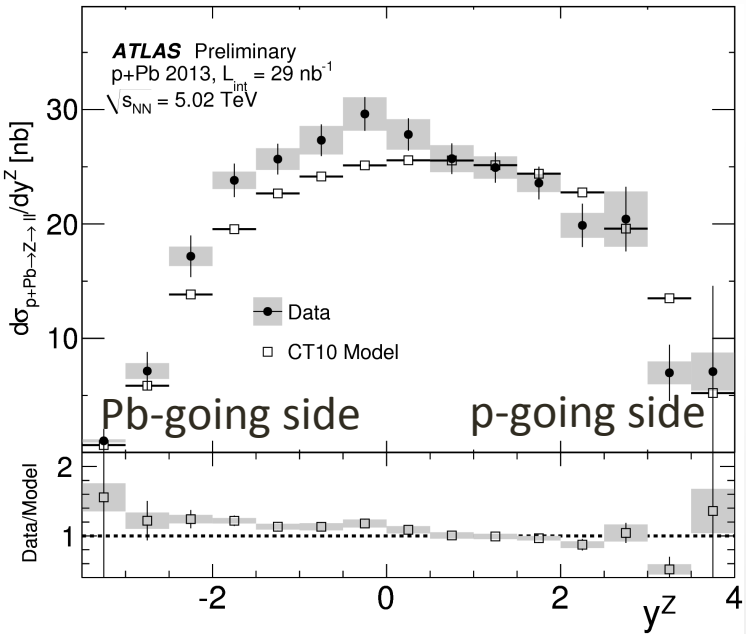
	$\lvert y^Z \rvert < 2.5$	$-3.5 < y^Z < 4.0$
$Z \to \mu^+\mu^-$	$122.1 \pm 3.4 \pm 6.2 \pm 4.2$	N/A
$Z \to e^+e^-$	$122 \pm 3 \pm 13 \pm 4$	$144 \pm 5 \pm 17 \pm 5$
$Z \to \ell^+\ell^-$	$122.7 \pm 2.4 \pm 5.3 \pm 4.2$	$144.1 \pm 4.9 \pm 8.3 \pm 4.9$
Model	114.4	136.8

→ Good agreement

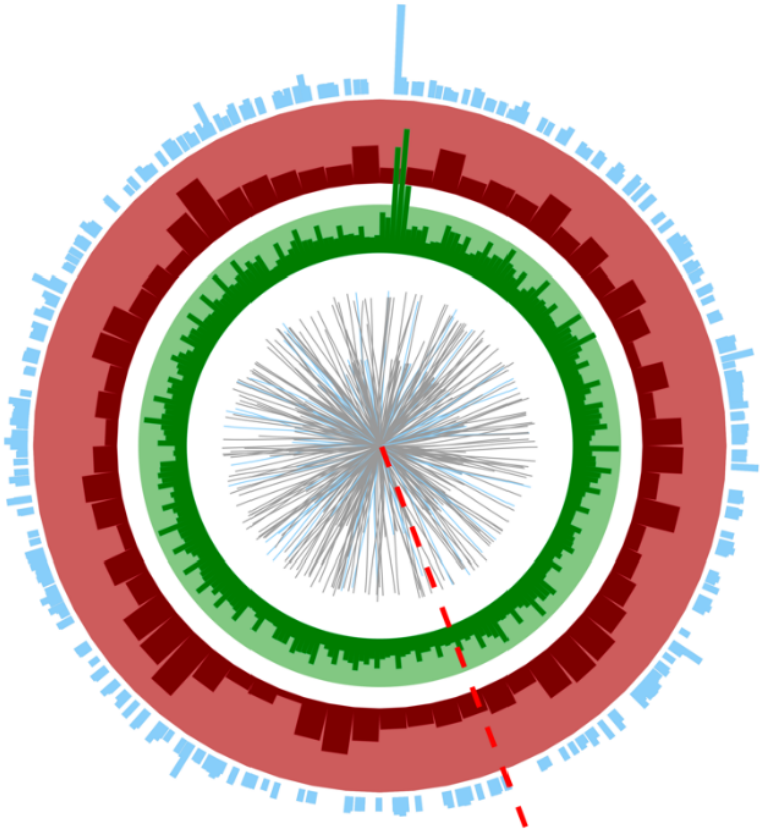
→ Differential cross-sections in p_T^Z and y^Z are compared to NNLO predictions with CT10 PDFs

- → Good shape description by the model in p_T^Z
- → Data reveals excess at negative y^Z (Pb-going side)





W BOSONS

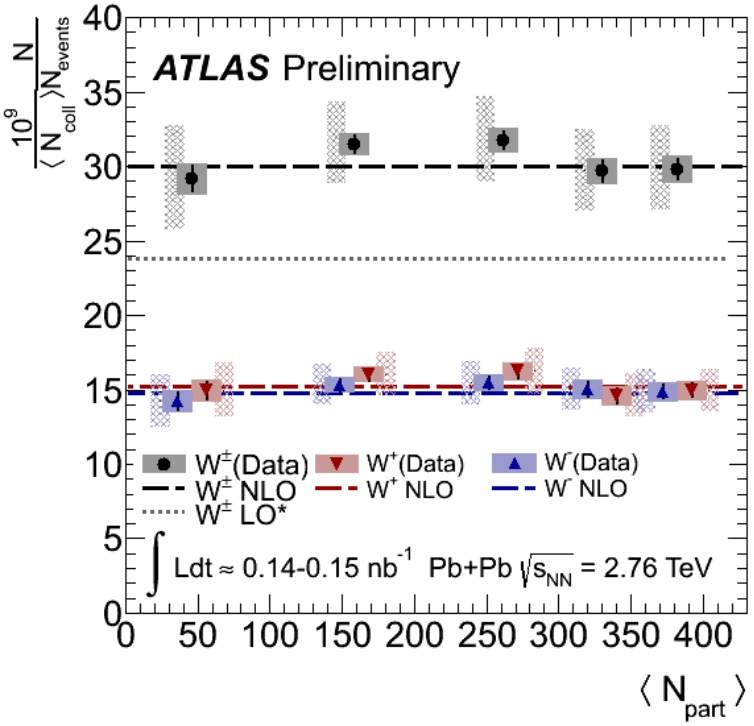


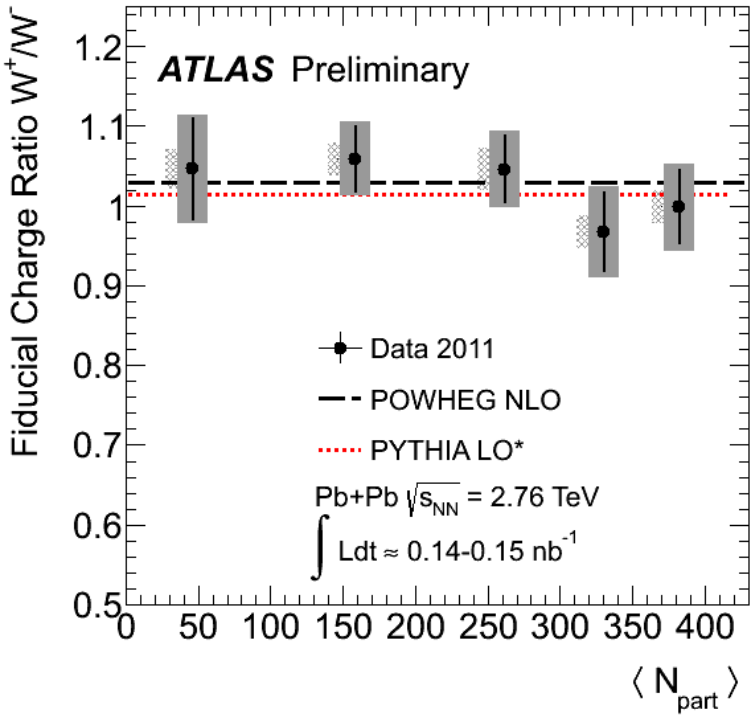
Centrality dependence of W boson production in Pb+Pb

- Measured via muon and electron channels
- Yields extracted in the fiducial volume: p_T^l>25 GeV, p_T^ν>25 GeV, m_T>40 GeV and $|\eta|$<2.5
- Two channels agree, thus they can be combined

→ More details on poster by Rafał Bielski

→Yields are consistent with binary scaling for $W^\pm$, W^+ and W^-
→W^+ and W^- yields are almost identical
→Yields are consistent with NLO predictions, inconsistent with LO*
→Fiducial charge ratio less sensitive to LO*/NLO differences

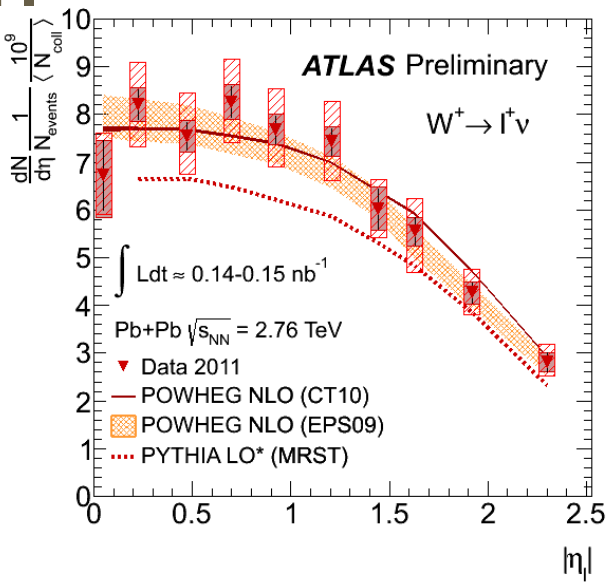


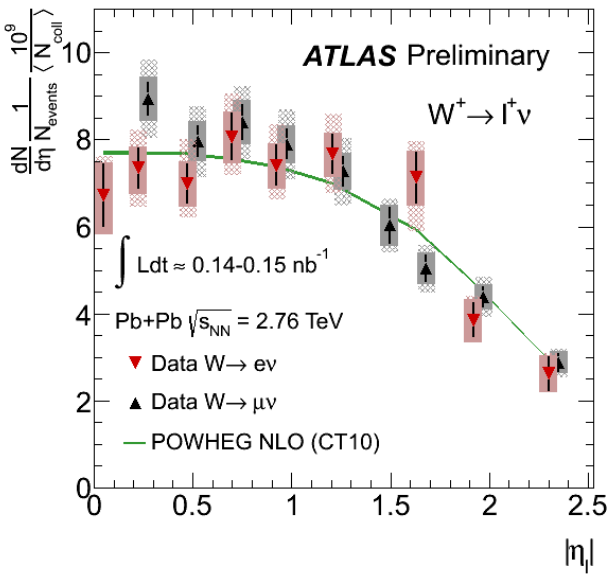


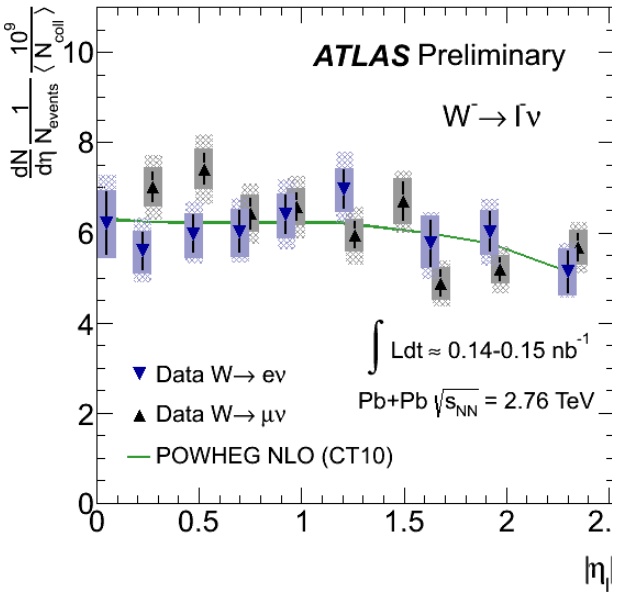
Differential yields in |η|

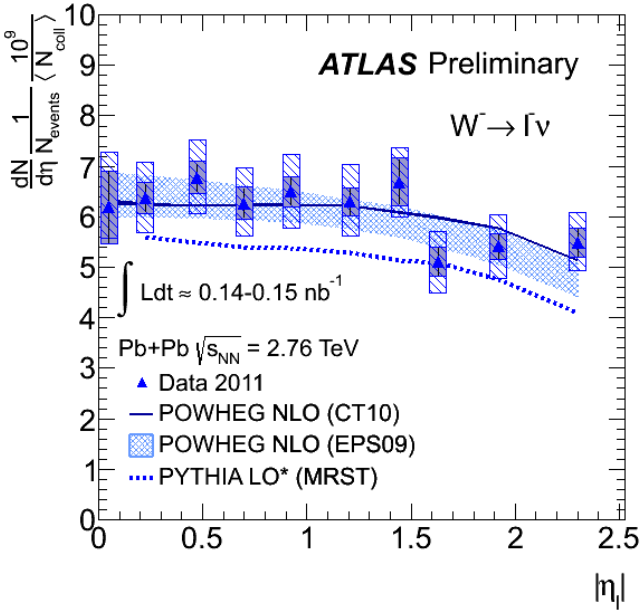
- Differential yields measured in the fiducial volume for W^+ and W^-

→Yields are consistent between muons and electrons
→They can be combined
→Differences in shapes of W^+ and W^- are due to isospin effect and spin conservation
→NLO pQCD describes data well while LO* is underestimated
→No sensitivity of the measurement to nuclear modifications







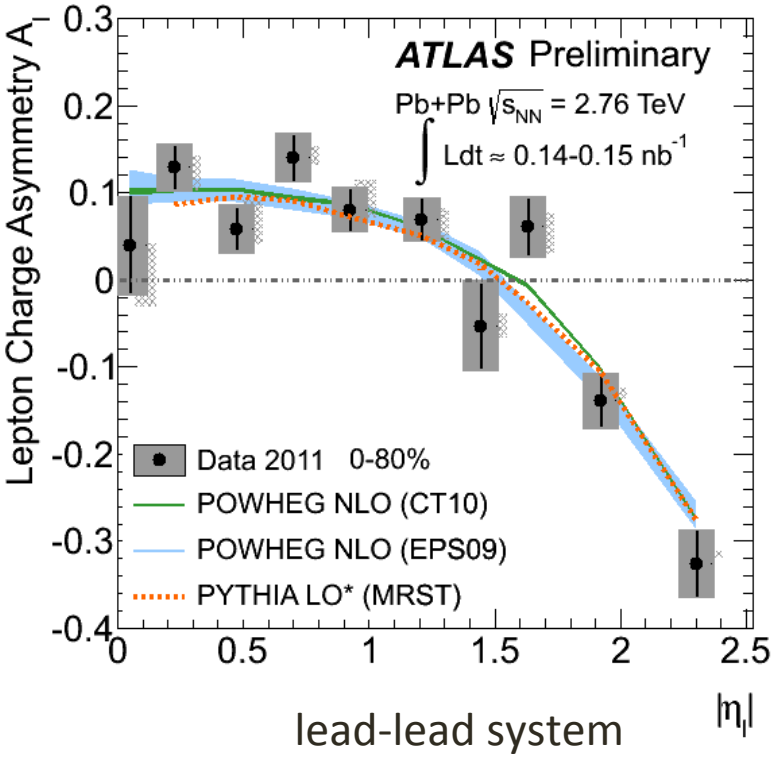


Lepton charge asymmetry

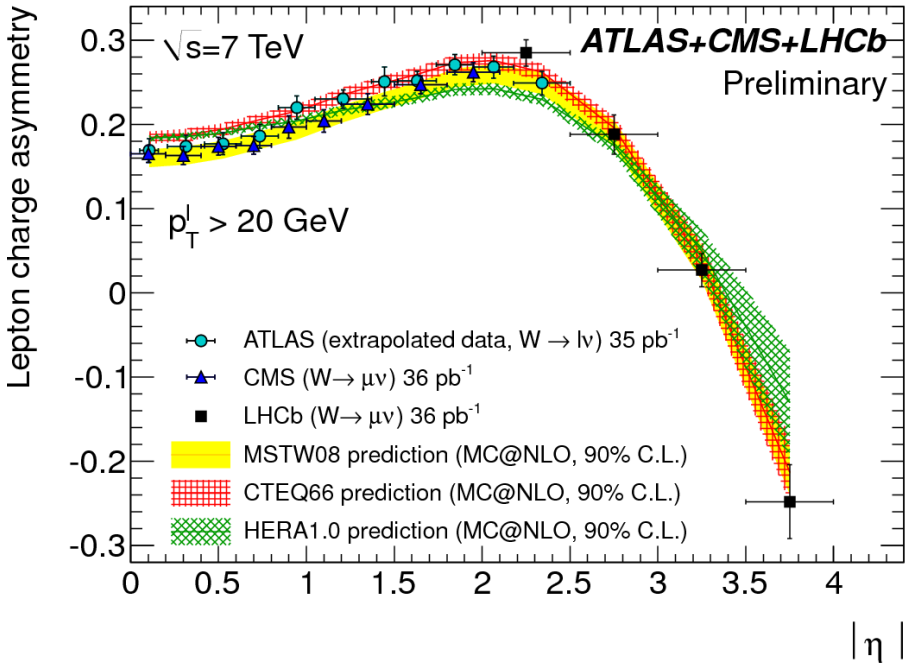
$$A_\ell = \frac{dN_{W^+\to\ell^+\nu}/d\eta_\ell - dN_{W^-\to\ell^-\bar{\nu}}/d\eta_\ell}{dN_{W^+\to\ell^+\nu}/d\eta_\ell + dN_{W^-\to\ell^-\bar{\nu}}/d\eta_\ell}$$

- Many correlated systematics cancel out in the ratio
- Observable which is sensitive to initial-state content + spin conservation

→Clear difference between A_l in Pb+Pb and p+p systems
→Each theoretical prediction describes data well
→Nuclear modifications remain unclear within the experimental precision



lead-lead system



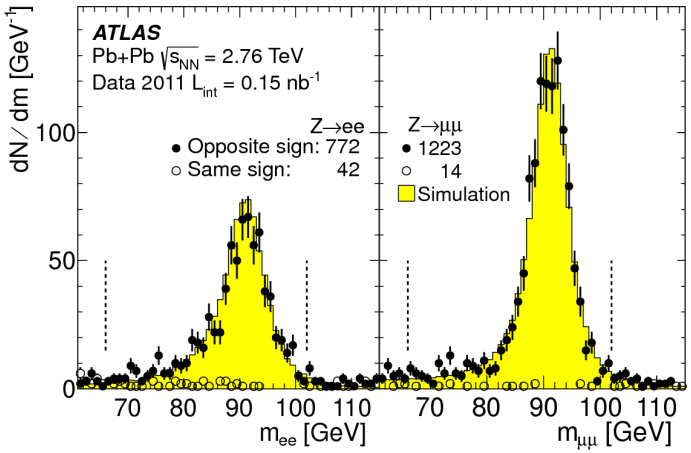
proton-proton system

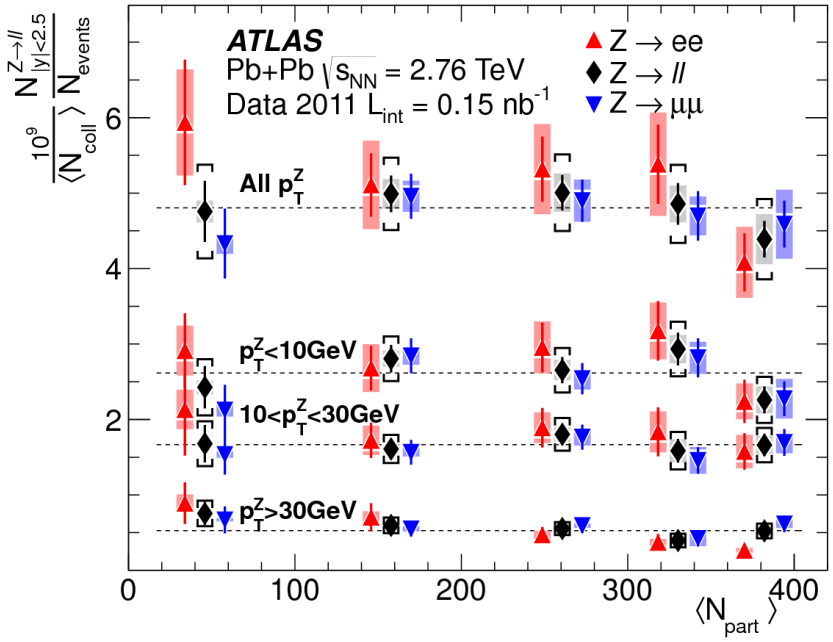
Summary

- ATLAS experiment has a variety of measurements with vector boson production in heavy-ion collisions based on Run 1 data
  - Direct isolated photons inclusive and in association with jets
  - Z bosons inclusive and in association with jets
  - W bosons inclusive
  - → Weak bosons have been measured via leptonic decay modes
  - → Both lead-lead and proton-lead systems explored
- → Linear scaling of EW boson production yields with centrality ($<N_{part}>$) has been established
  - → Followed by no suppression of leptonic decay products in the QGP
- → NLO/NNLO pQCD predictions describe data very well both in shape and normalization
  - → Some departure from the predictions in the proton-lead system
- → Sensitivity to the isospin effect and nPDFs has been tested
  - → W boson yields in $|\eta|$ can be only described taking into account the isospin effect
  - → No much sensitivity to nuclear modifications to PDFs within the current experimental precision

Back-up slides

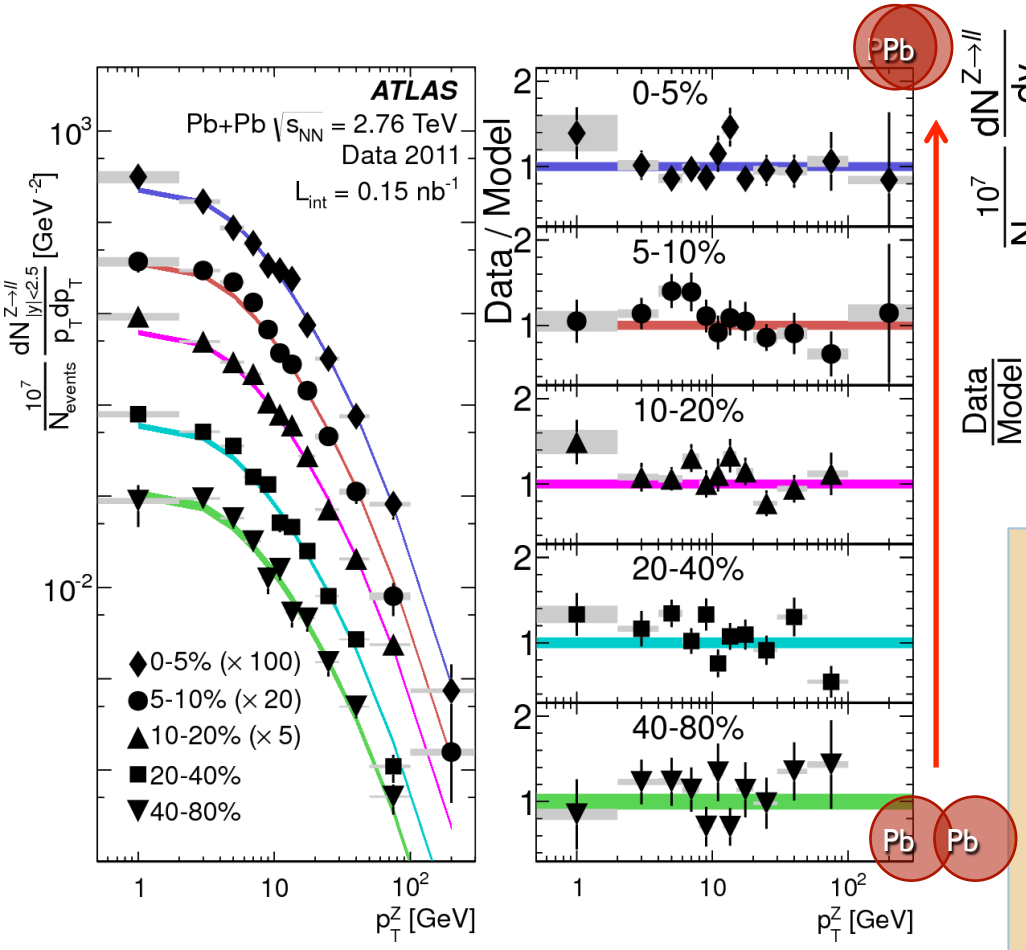
Z yield centrality dependence in Pb+Pb

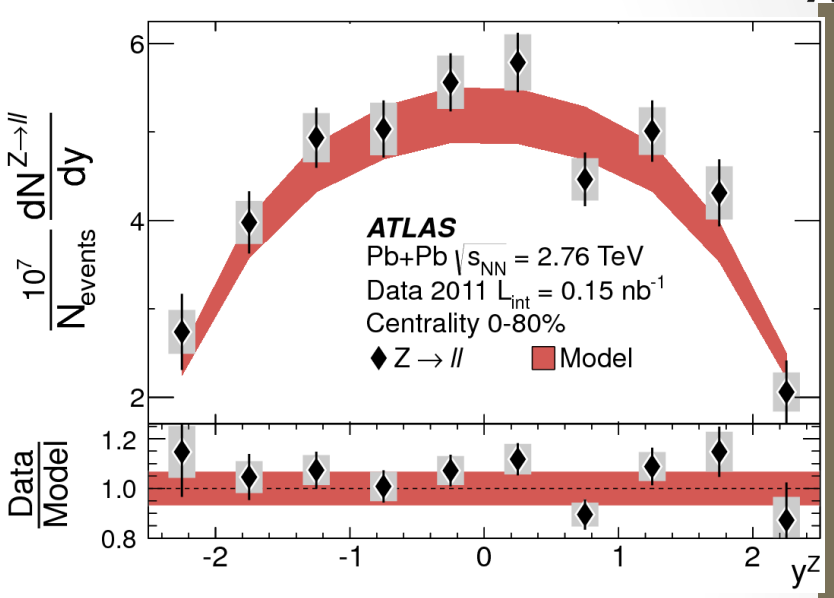




- Clean measurement: very high purity 95% for electrons and 99% for muons
- Corrected Z boson yield scaled by $\langle N_{coll}\rangle$
- Electron and muon channels consistent
- Bars: stat uncertainty, boxes: syst uncertainty, brackets: combined, including $\langle N_{coll}\rangle$
- Dashed lines are constant fits to combined yields
- Binary collision scaling appears to hold true → no interaction with QGP

p_T and η distributions of Z's in Pb+Pb





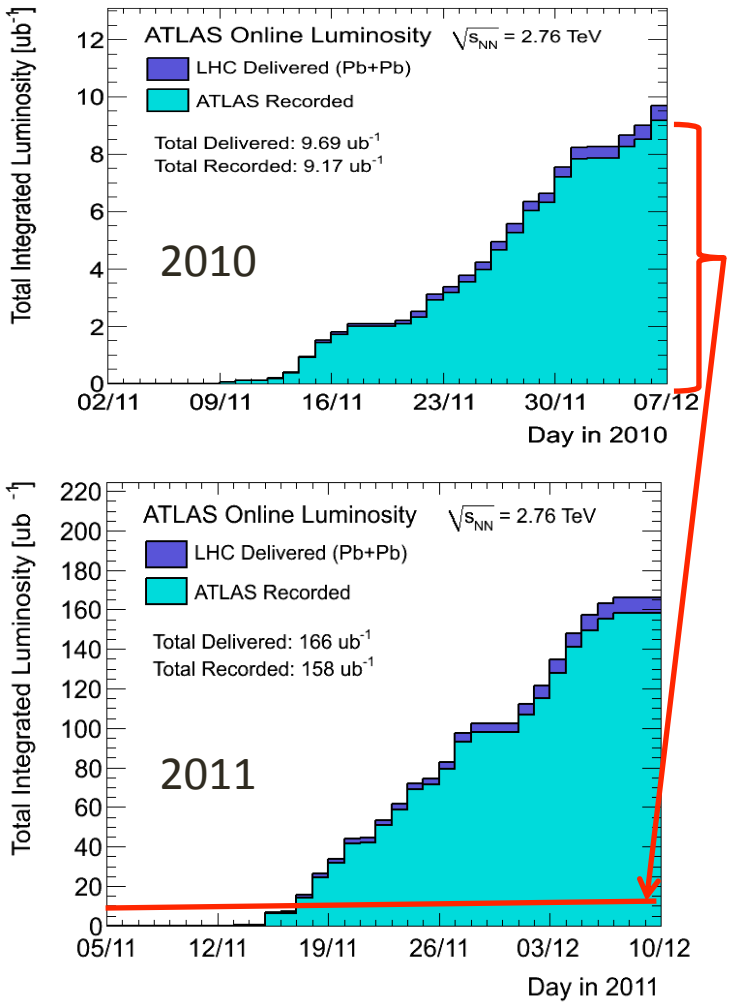
→Each decay channel corrected and background subtracted, then channels combined

→PYTHIA normalized to the Z→l^+l^- cross section in p+p from NNLO calculations and scaled by <T_{AA}> – agrees well

→Incorporating p+n and n+n collisions would increase the cross section by 3%

→No centrality dependence of this shape is observed

Heavy Ions in ATLAS



Heavy-ion runs at $\sqrt{s_{NN}} = 2.76TeV$

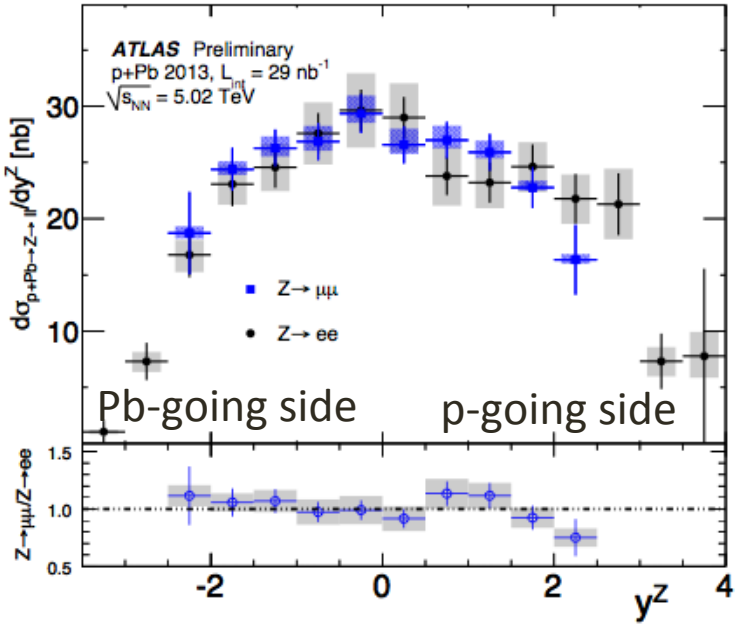
- Data recording efficiency > 95%
- Fraction of data passing data-quality criteria > 99%

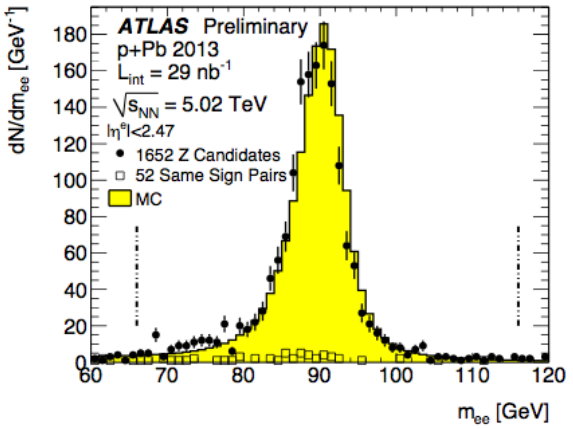
◆ In 2010 ATLAS recorded 9.2 μb^{-1} of Pb+Pb data
  - With 1μb^{-1} magnetic field-off data
  - Minimum bias triggers only
  - Pile-up negligible

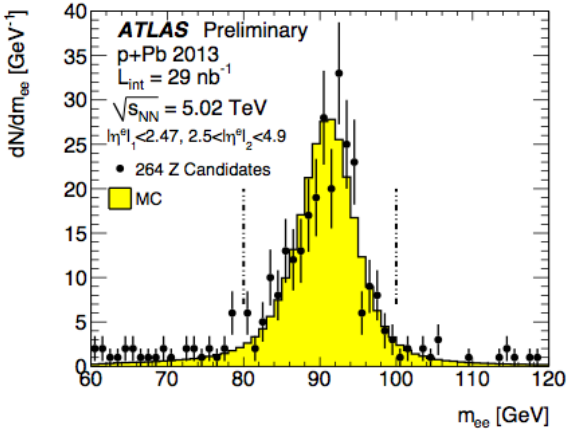
◆ In 2011 ATLAS recorded 158 μb^{-1} of Pb+Pb data
  - Various High Level Triggers used
  - $N_{event}=(1.03\pm0.02)\times10^9$ events probed
  - Pile-up = 0.05%

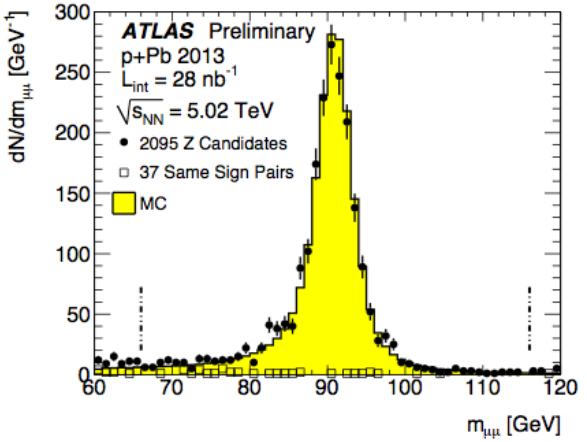
Z bosons in p+Pb

- Proton-lead collisions at $\sqrt{s_{NN}}$=5.02 TeV
  - System sensitive to initial-state effects
- Rapidity boost: y*=y-0.465
- Z bosons reconstructed via di-muon and di-electron decays
- Di-muons: $-2.5<y^{Z}<2.5$, $p_T^{leading}>20$ GeV
- Di-electrons: $-3.5<y^{Z}<4.0$, $p_T^{leading}>20$ GeV
- Good agreement between channels
- → More details in Zvi Citron's talk







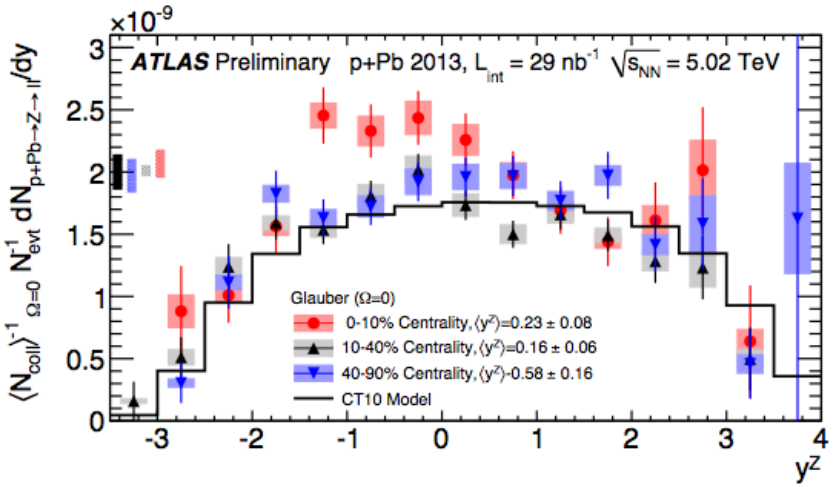


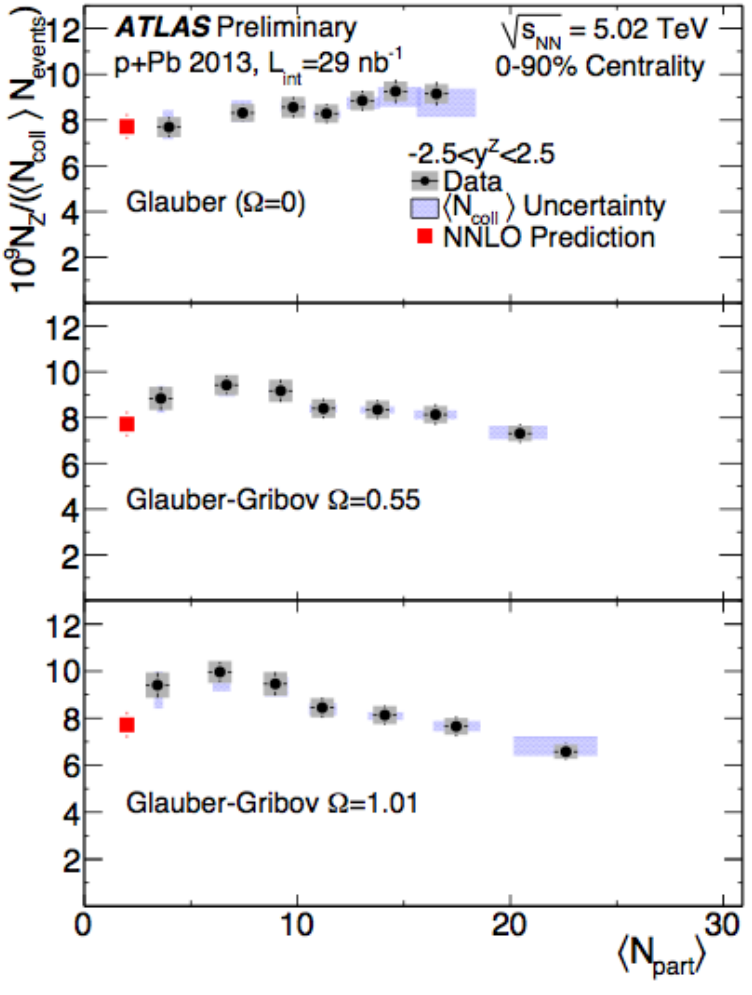
Z boson centrality dependence in p+Pb

→Z boson production yields per minimum bias event divided by $\langle N_{coll}\rangle=\langle N_{part}\rangle-1$

- Centrality calibrated based on FCal E_T^{Pb}
- Various models explored for collision geometry: standard Glauber (Ω=0), Glauber-Gribov (Ω=0.55, Ω=1.01)

→Z boson production scales with centrality
→Similar behavior to charged particle yields
→Excess of Z boson production for 0-10% bin





Z boson centrality dependence in p+Pb