Electroweak Bosons in Heavy Ion Collisions with the ATLAS Detector

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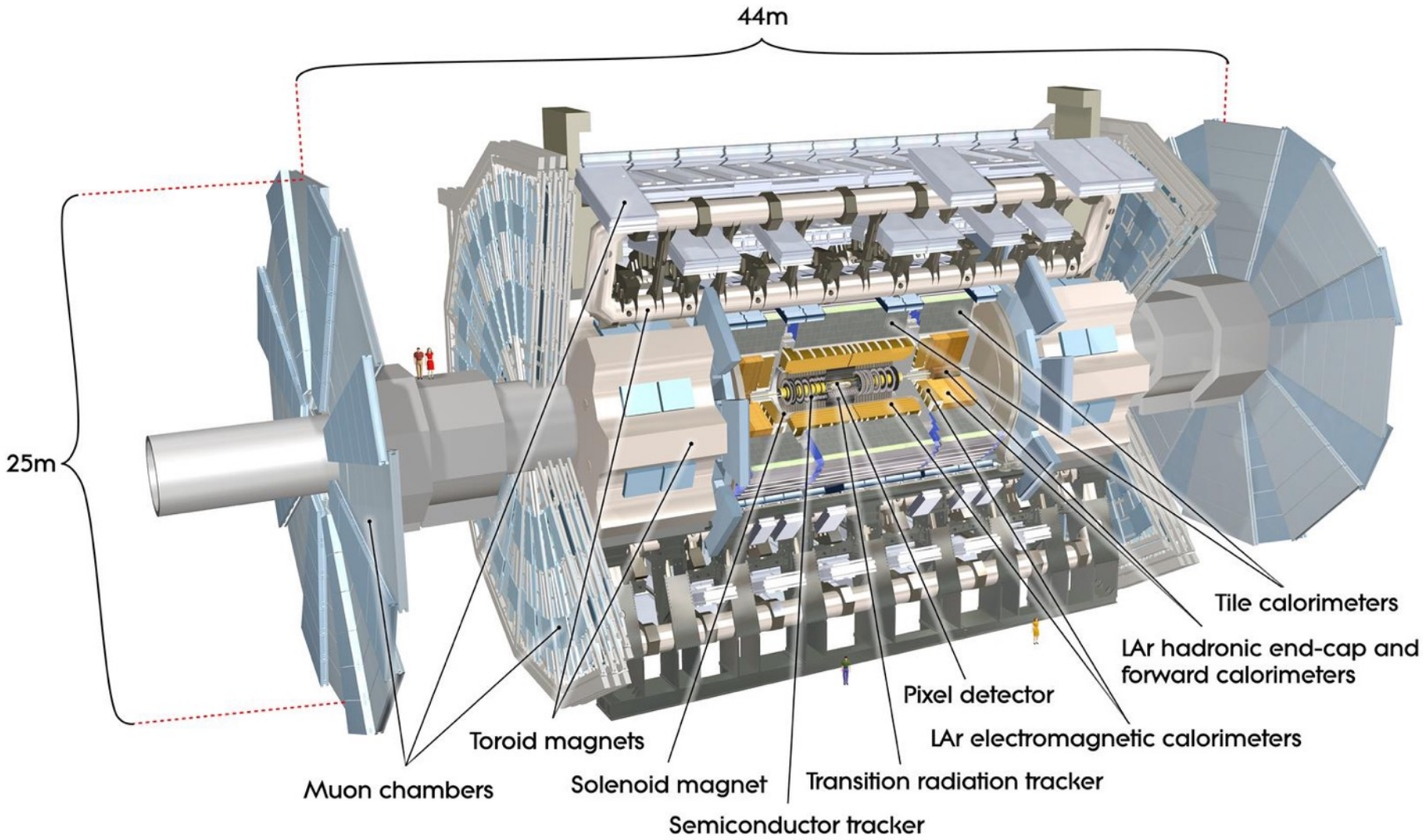
on Behalf of the ATLAS Collaboration

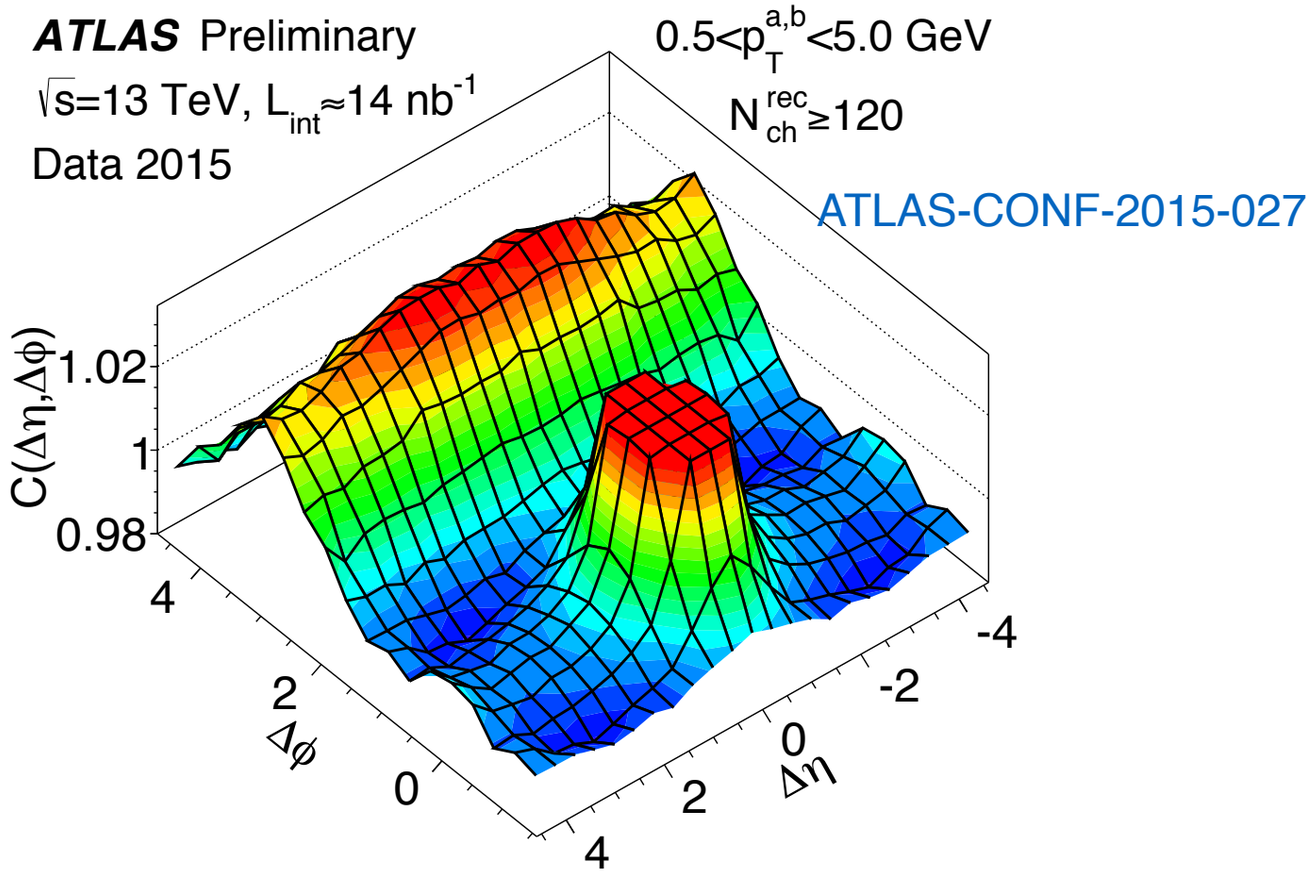
Second Conference on Heavy Ion Collisions in the LHC Era and Beyond
July 2015
Quy Nhon, Vietnam

The ATLAS Detector



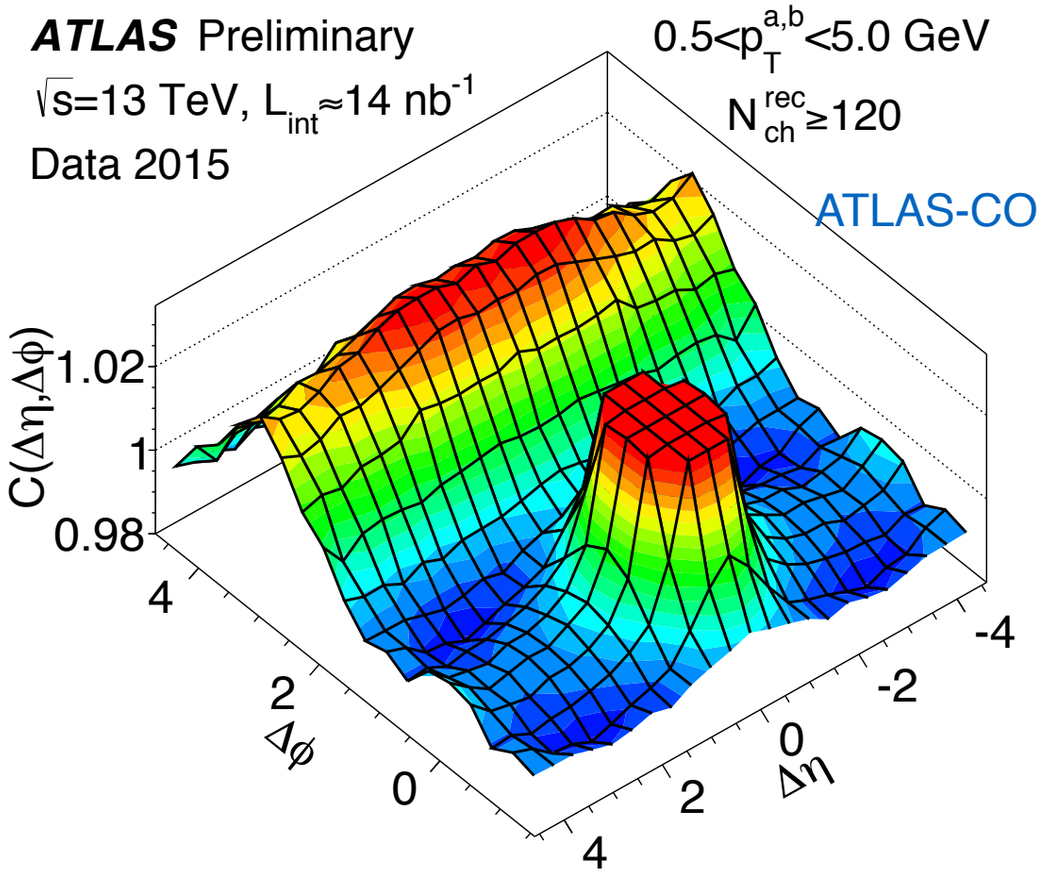
Inner Detector	$\|\eta\| < 2.5$	vertex and track reconstruction
Calorimeter	$\|\eta\| < 3.2$	jet / electron / photo reconstruction
Muon Spectrometer	$\|\eta\| < 2.7$	muon recontruction
Forward Calorimeter (FCal)	$3.2 < \|\eta\| < 4.9$	centrality determination

LHC Run2 Activity — *pp* Ridge



Ridge: enhancement of particle yields at $\Delta\phi$~0 and extend over a long range in $\Delta\eta$.

LHC Run2 Activity — *pp* Ridge



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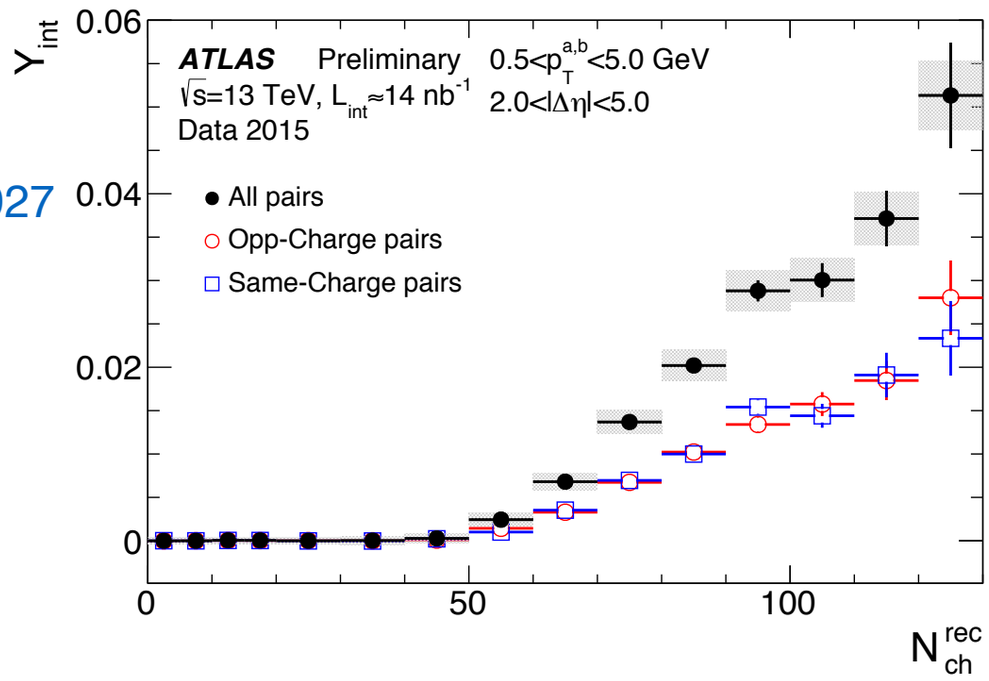
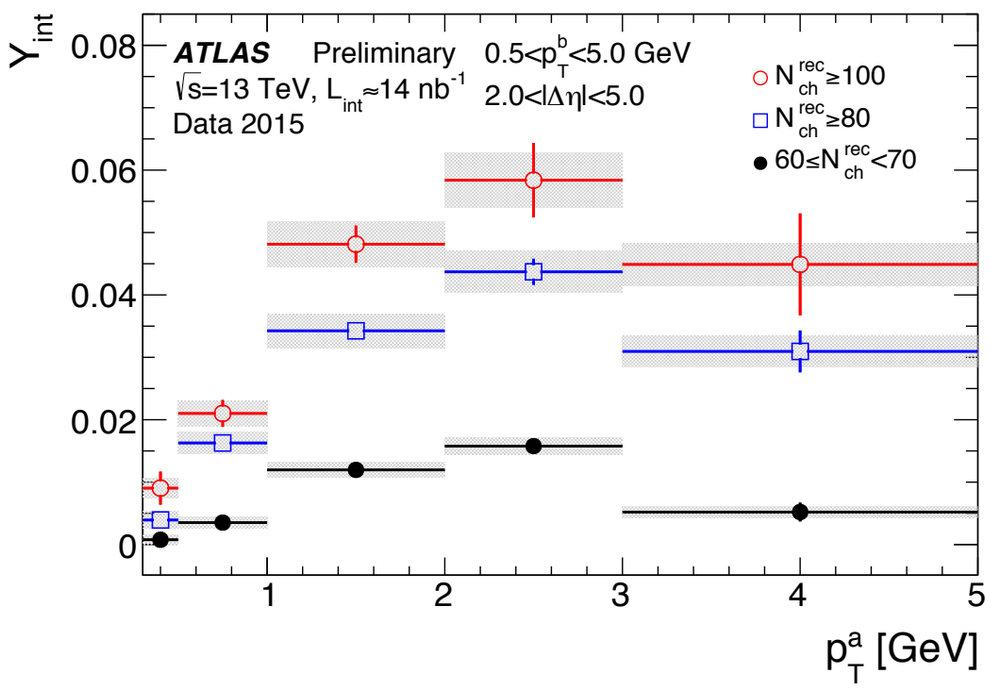




Ridge: enhancement of particle yields at $\Delta\phi$~0 and extend over a long range in $\Delta\eta$.

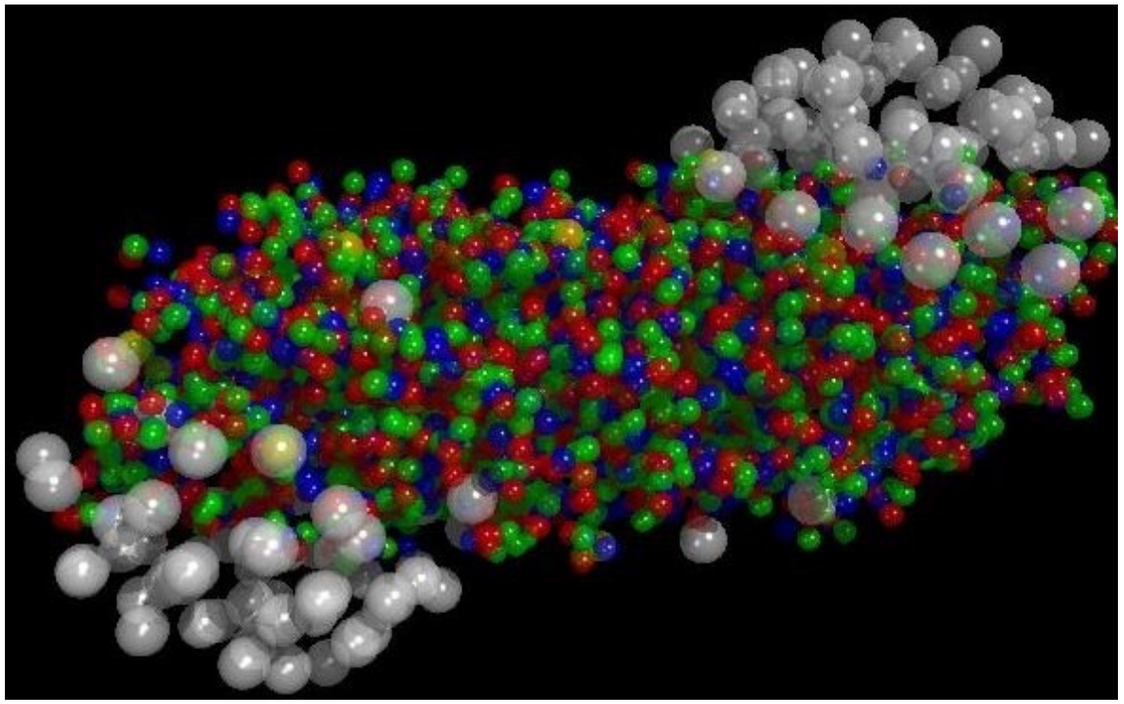
Integrated long range nearside ridge yield :

✦Same contribution from Opp-charge and Same-charge pairs (not from jets and resonances decay).

✦Consistent with CMS 7 TeV pp data.

Physics Motivation

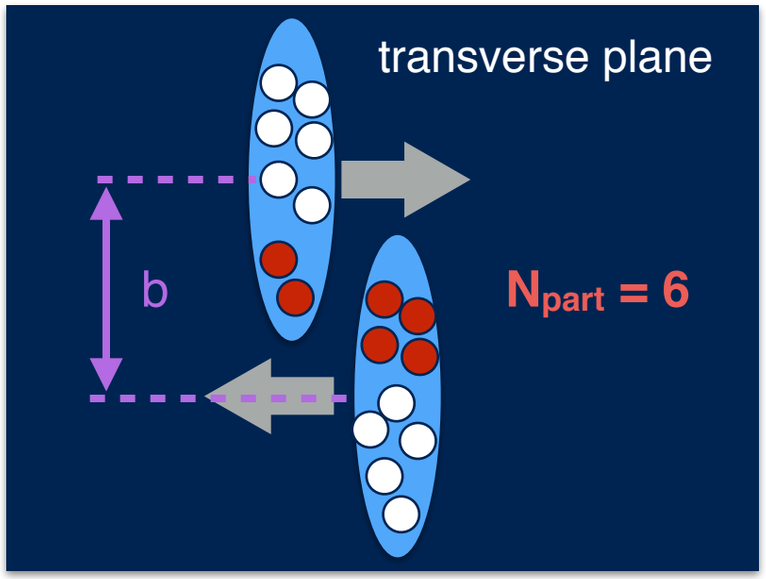
- Electroweak (EW) bosons are produced via hard processes at the early stage of the collisions before quark-gluon plasma (QGP) is formed.
- Sensitive to parton distribution function modification in-medium.
- Sensitive to the overall thickness of the colliding nuclear matter.
- Baseline towards understanding centrality and geometry in the *p*+Pb system.



Potential nuclear effects:

- Gluon saturation
- Gluon shadowing
- Partonic energy loss
- modified parton distributions
- modified fragmentation function

Geometry and Centrality



Number of binary collisions: N_{coll}
Number of participants in the collision: N_{part}

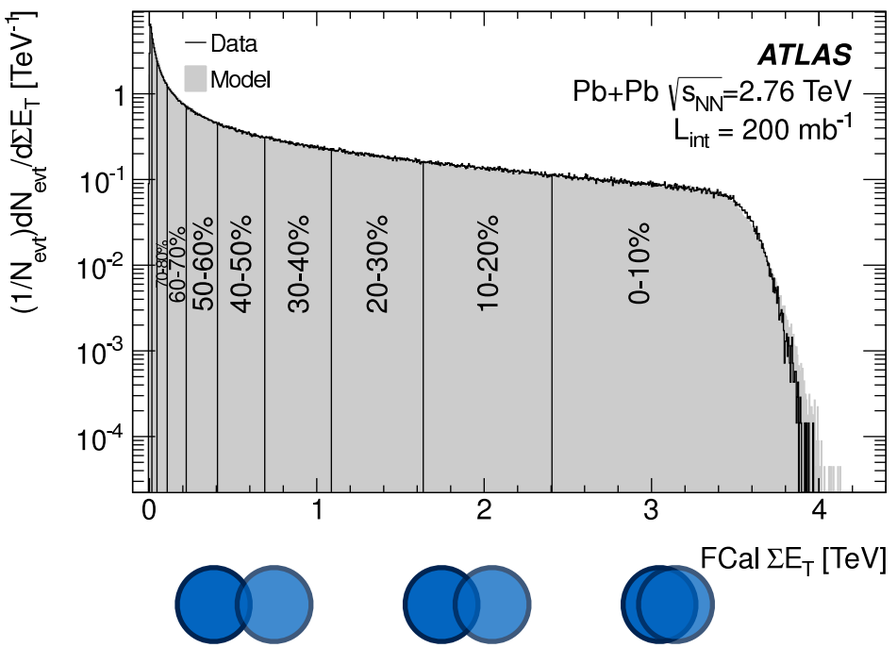
FCal E_T ⇒ Centrality ⇒ N_{coll} and N_{part}

Glauber Model (Pb+Pb and *p*+Pb)

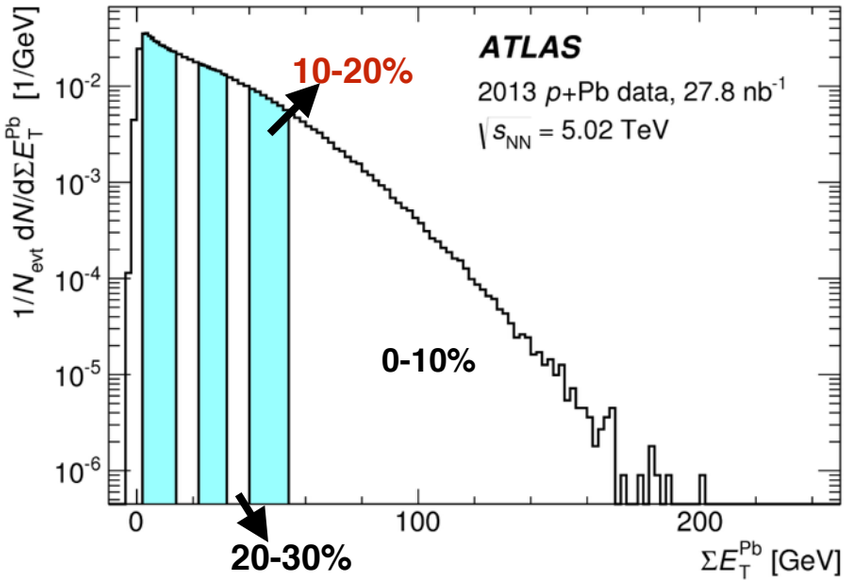
GGCF Model (*p*+Pb)

Partition FCal total E_T distribution into ranges corresponding to fixed percentiles of the total.

Phys. Lett. B707 (2012) 330-348



arXiv:1412.4092



Glauber-Gribov Color Fluctuation (GGCF) model:

- Event-by-event fluctuation
- Magnitude of fluctuations characterized by ω_σ. $\omega_\sigma = 0$ for Glauber model.

FCal total E_T in Pb beam direction

PDF Test: Prompt Photons in PbPb

Prompt photon:

- Direct emission
- Fragmentation contribution

Isolation cut to suppress non-prompt background.

Model with different PDF configurations:

- JETPHOX (pp)
- JETPHOX (pp+pn, correct isospin)
- JETPHOX EPS09 (nuclear effects)

PDF Test: Prompt Photons in PbPb

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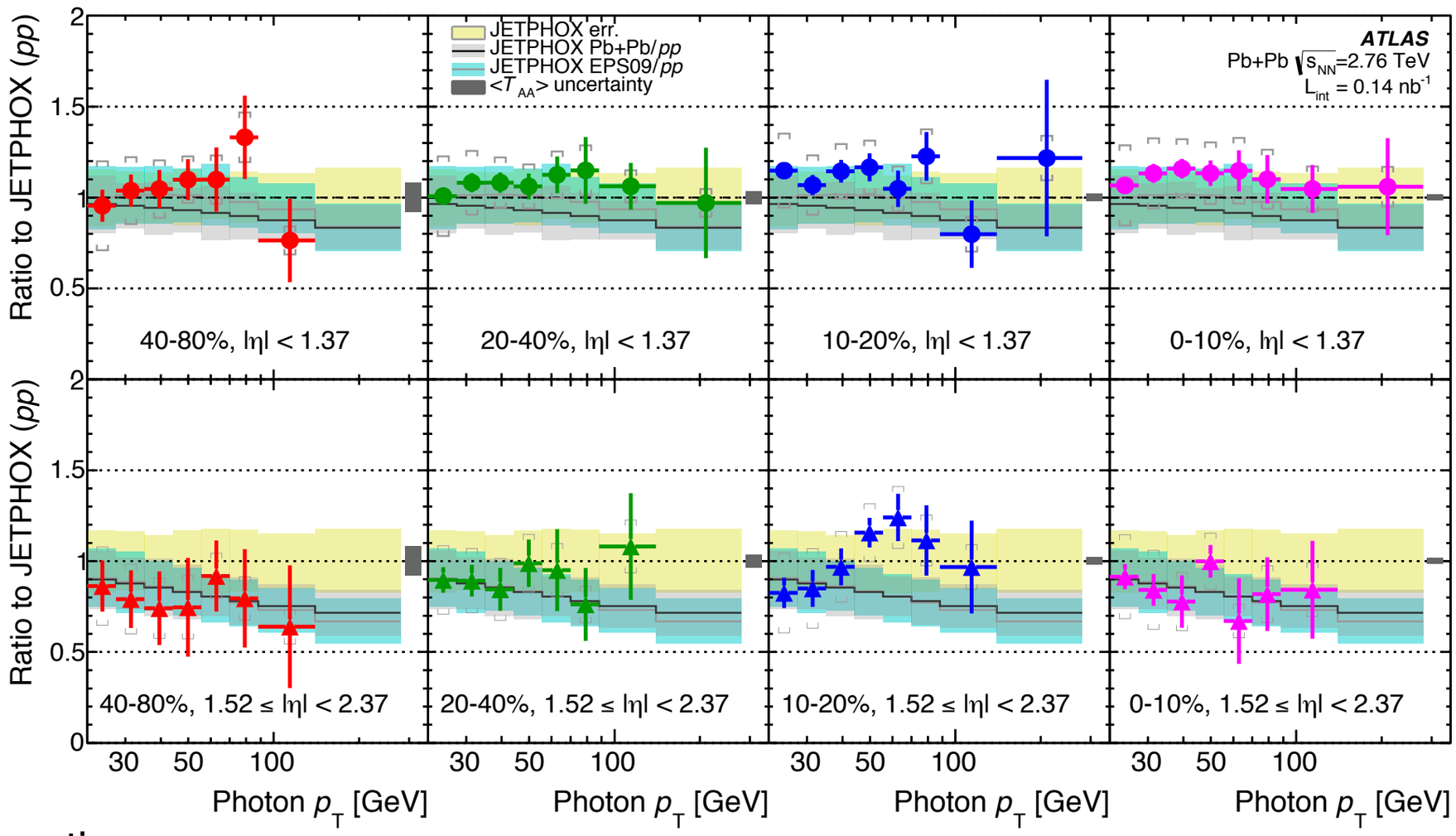
arXiv:1506.08552



Model with different PDF configurations:

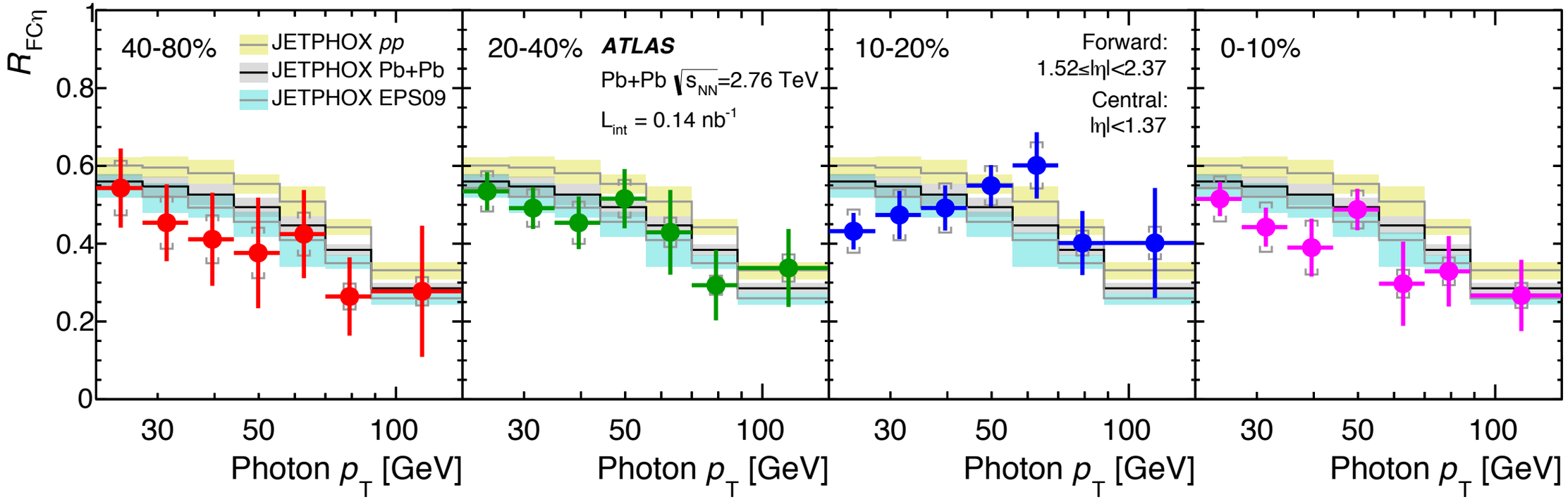
- JETPHOX (pp)
- JETPHOX (pp+pn, correct isospin)
- JETPHOX EPS09 (nuclear effects)

Data/Model to JETPHOX (*pp)* Ratio in 3D

- Visible isospin effects.
- Cannot exclude models w/o nuclear effects.

PDF Test: Prompt Photons in PbPb

arXiv:1506.08552

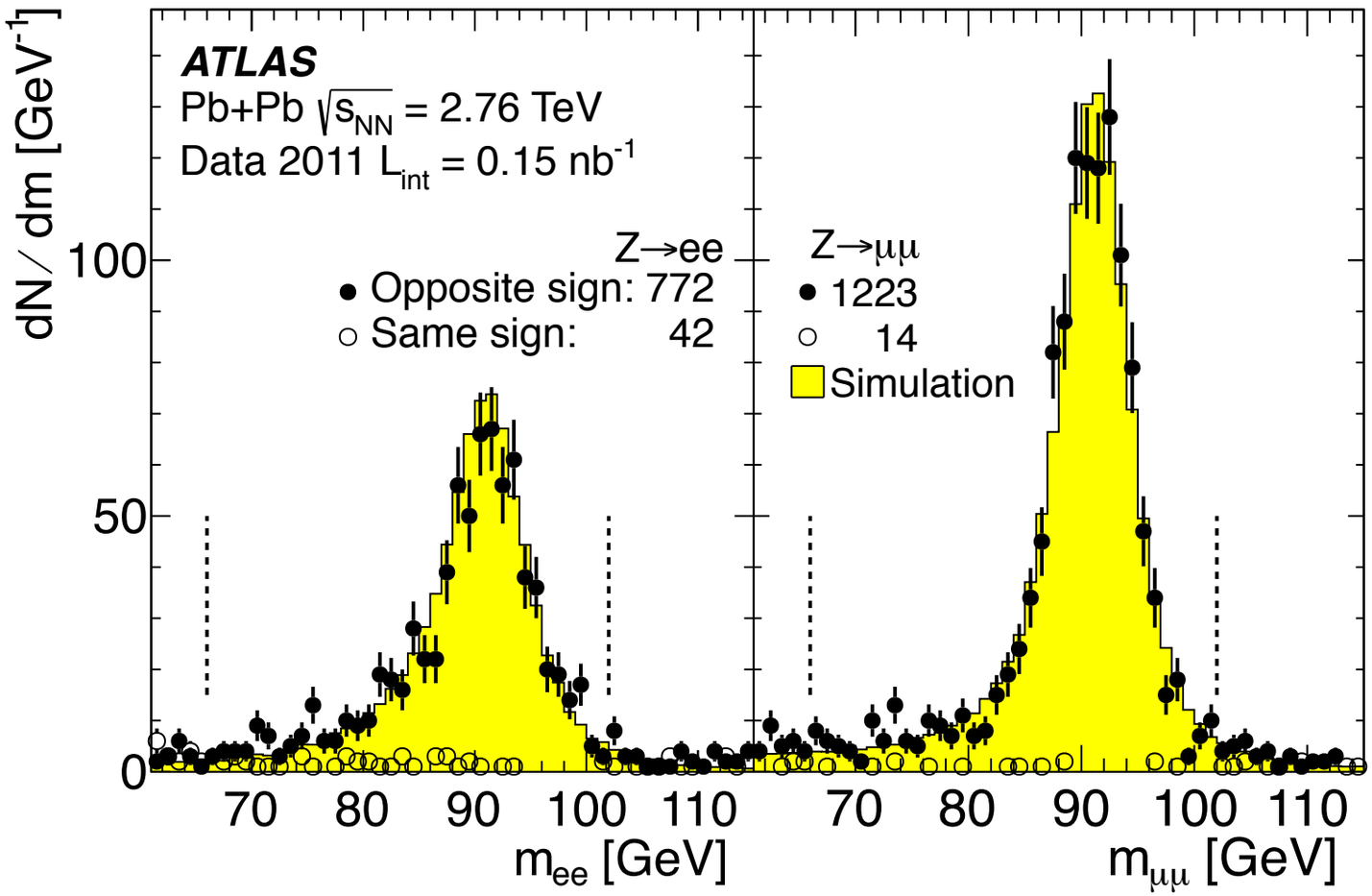


R_{FC}, forward to central photo yield ratio.

- Reduction of both experimental and theoretic uncertainties in this ratio.
- No precision to veto the NLO pQCD model w/o nuclear effects.

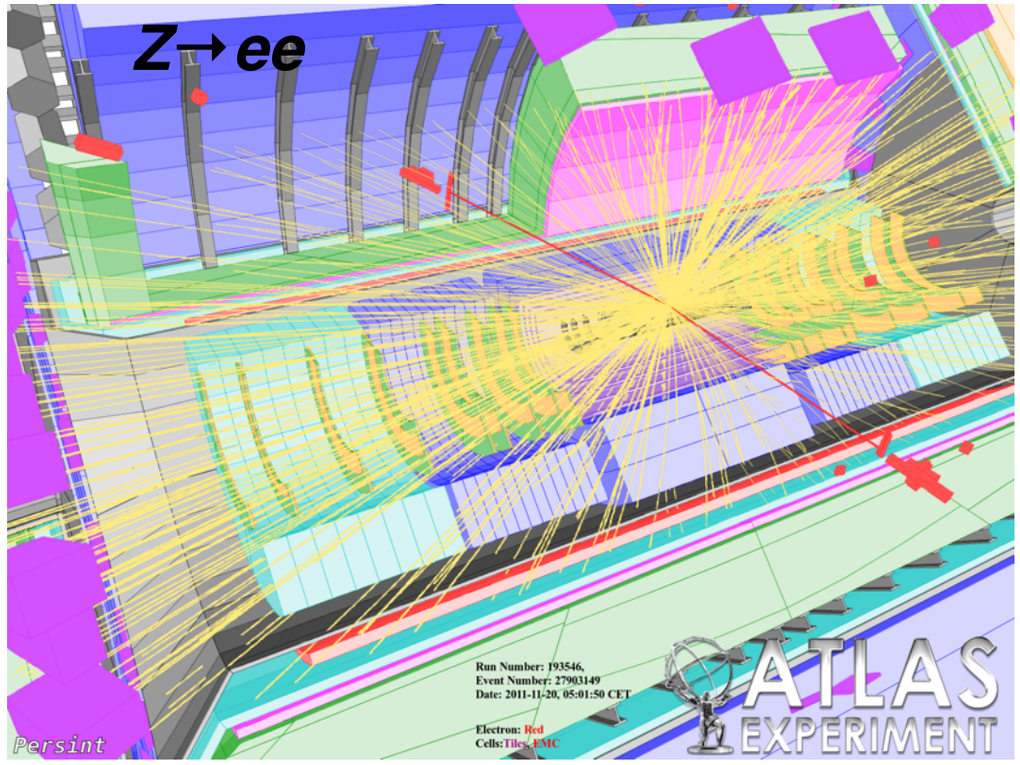
Z Event in Pb+Pb

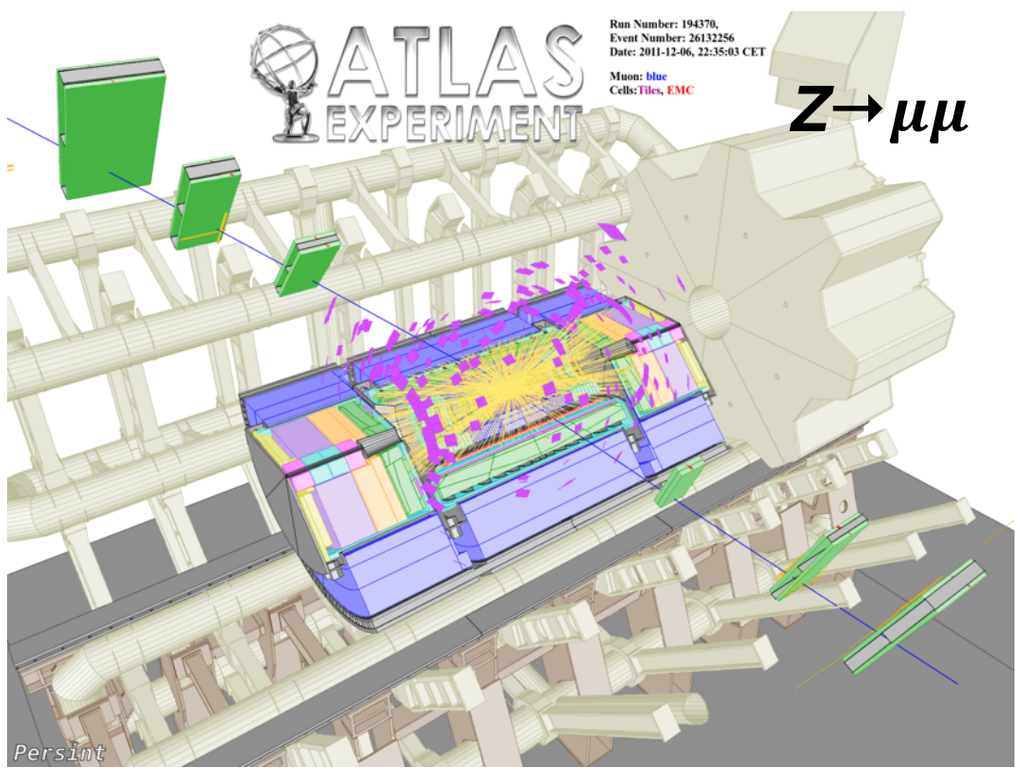
Phys. Rev. Lett. 100, 022301(2013)



Measured via di-muon and di-electron channels and combined.

Z peak well reproduced in simulation.





PDF Test: Z Boson in Pb+Pb

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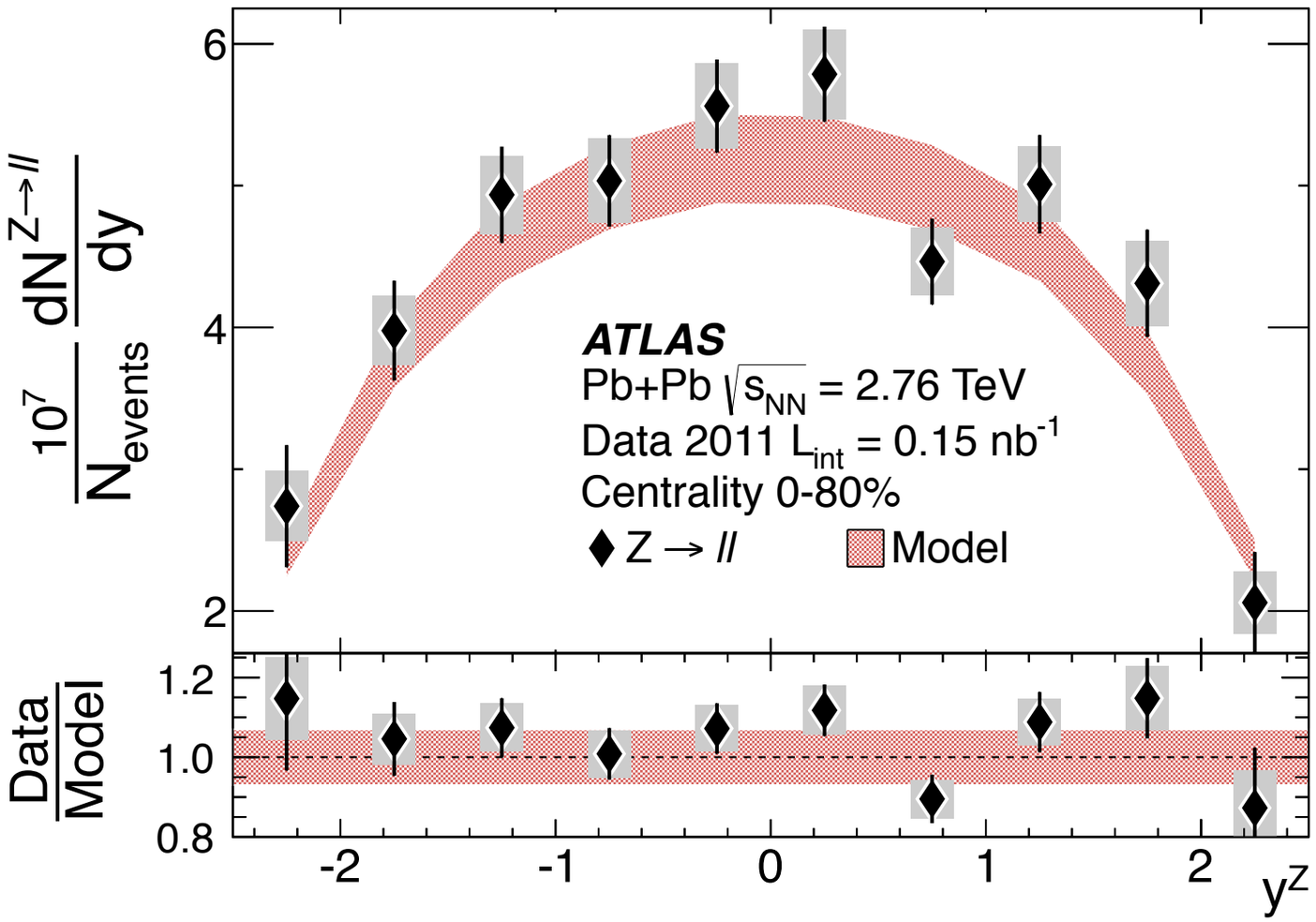


Model:

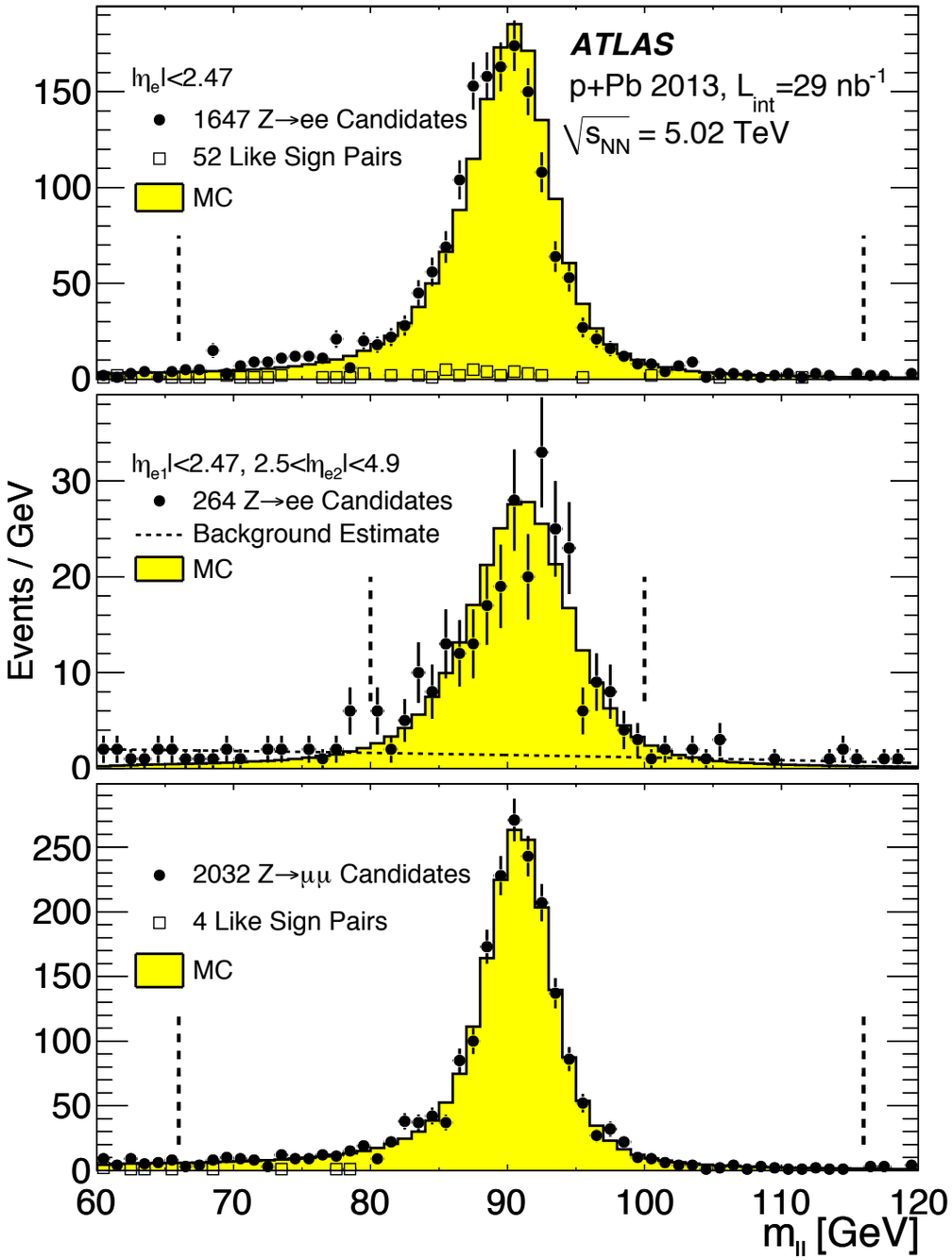
- NNLO calculation scaled by $\langle T_{AA} \rangle$

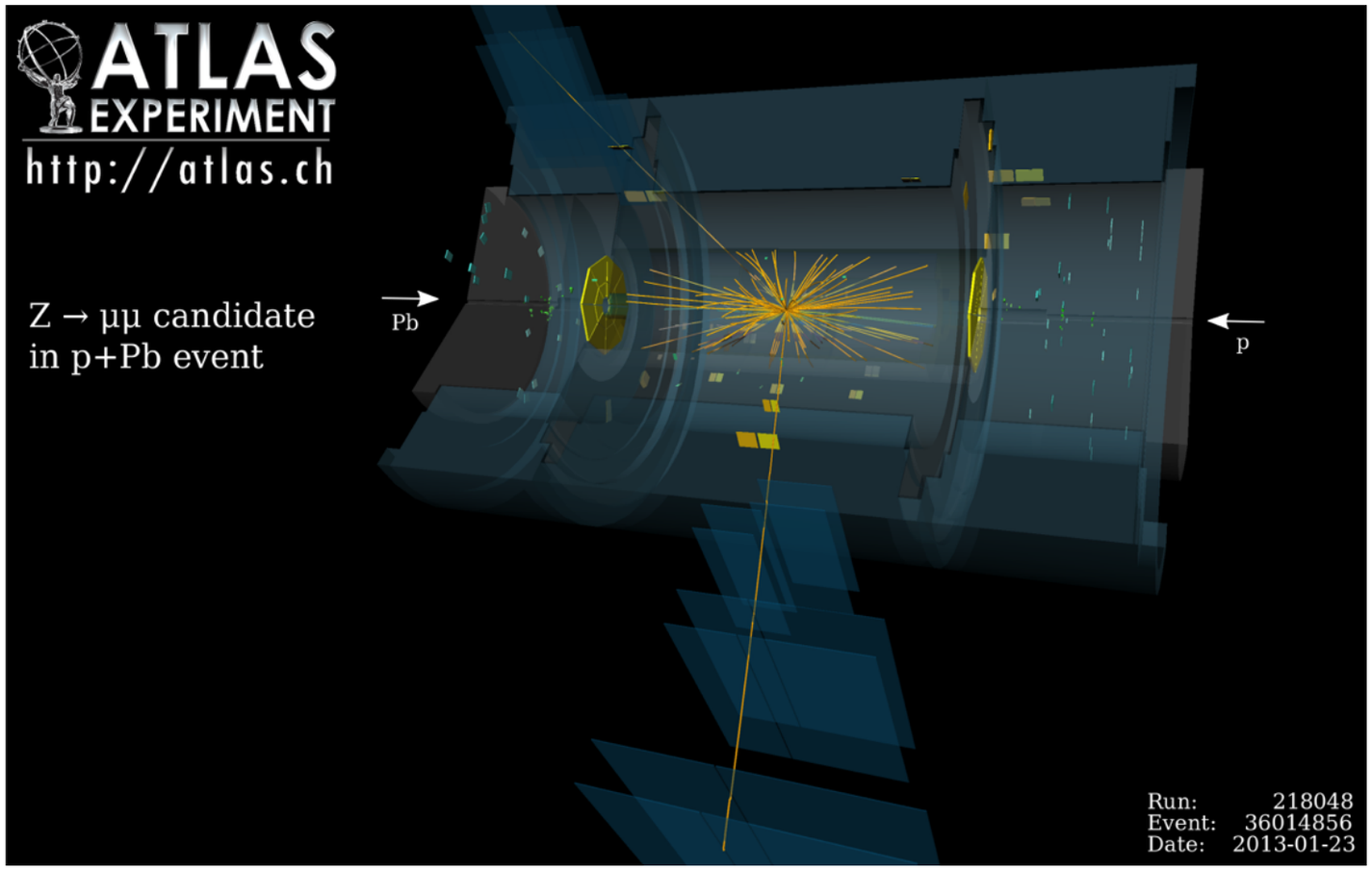
Z per-event yield differential in rapidity:

Cannot reject model without nuclear effects. No centrality dependence of this shape is observed.

Z Event in *p*+Pb

arXiv:1507.06232



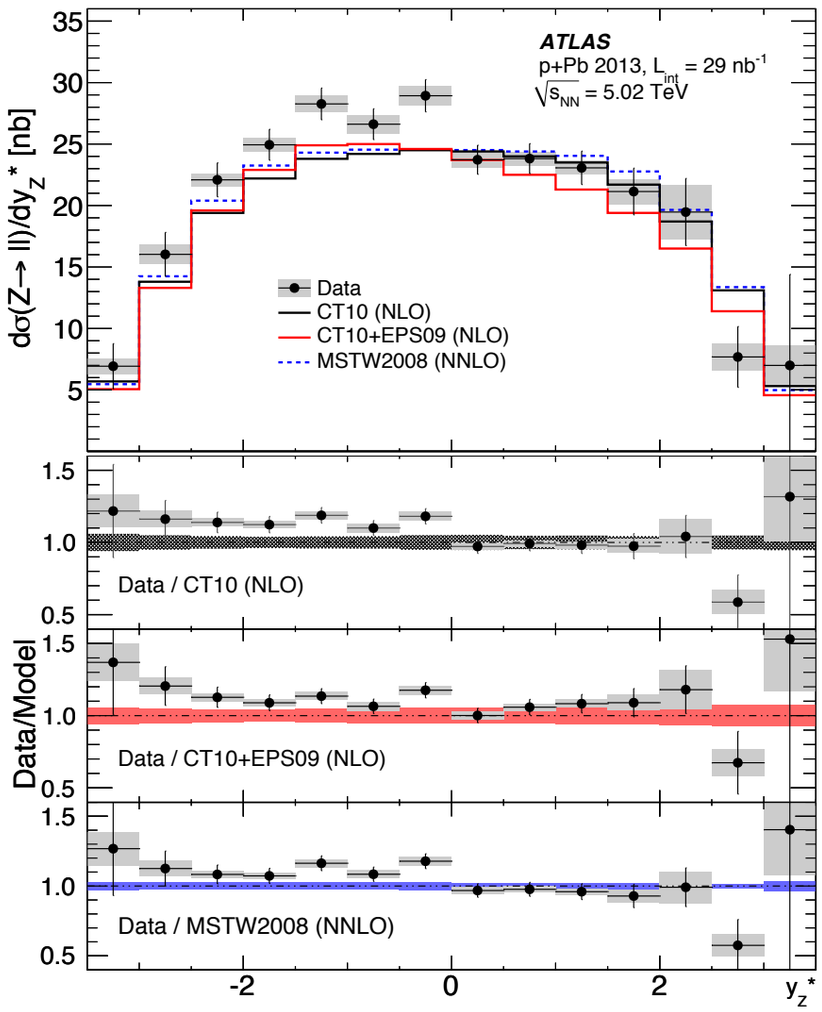


Similar with Pb+Pb analysis. Forward electron used to extend rapidity coverage.

PDF Test: Z Bosons in *p*+Pb

y*: center of mass rapidity being positive in forward (proton beam direction).

arXiv:1507.06232



Models:

- CT10 (NLO)
- MSTW2008 (NLO)
- CT10+EPS09 (NLO)

Z production is enhanced in the backward rapidity y* compared to three models

PDF Test: Z Bosons in *p*+Pb

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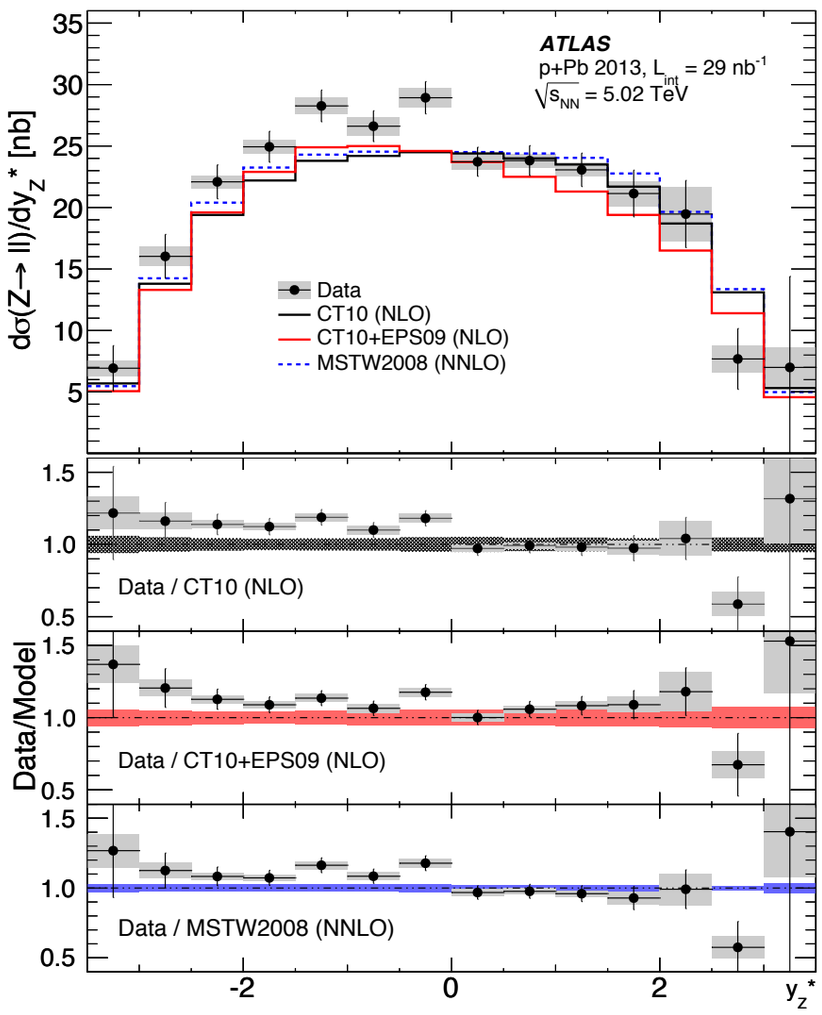
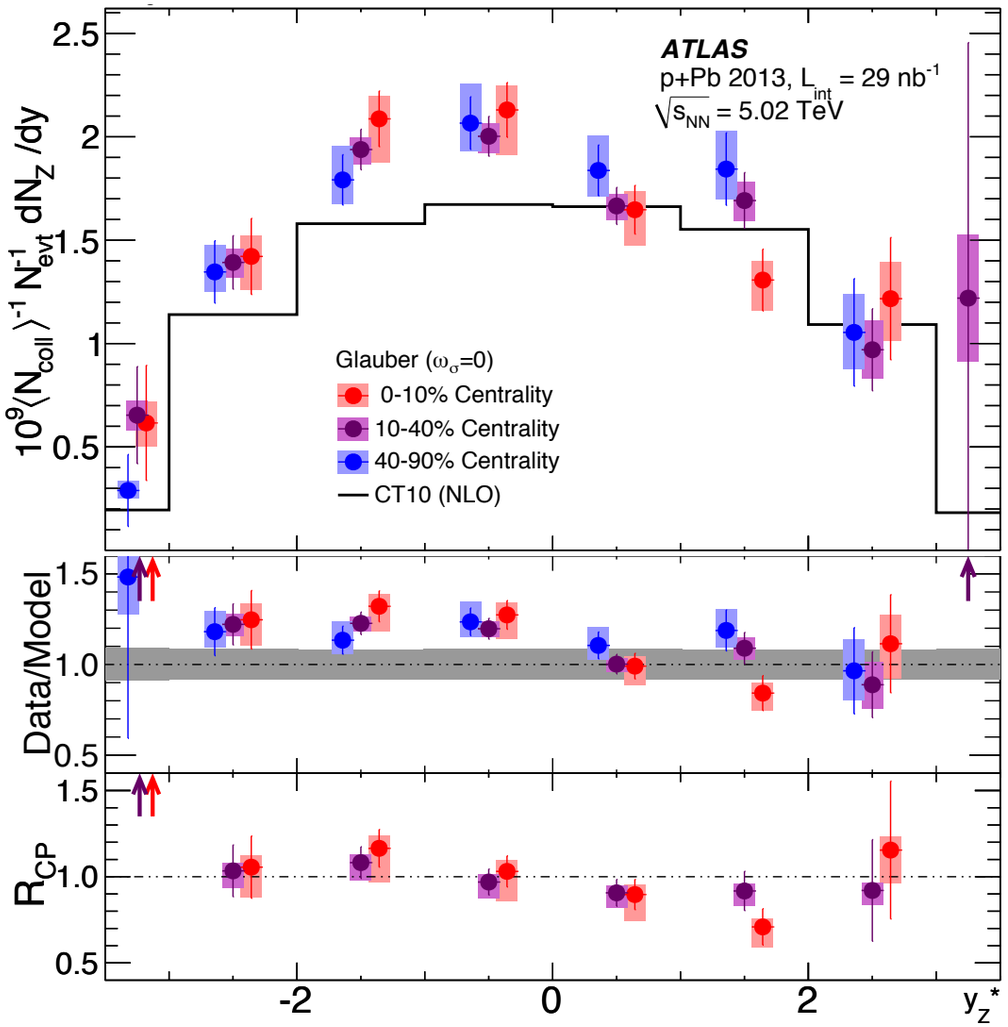


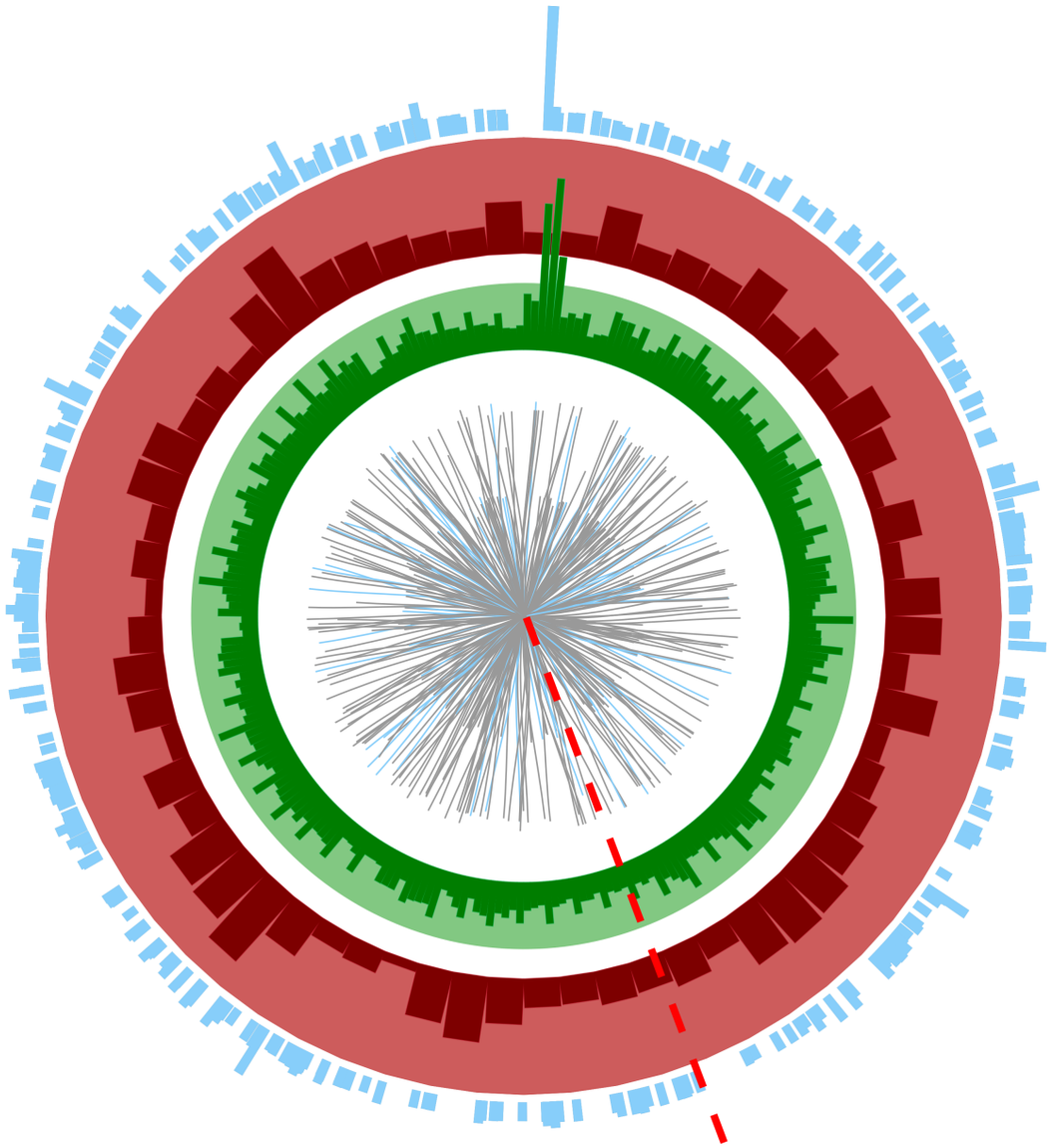


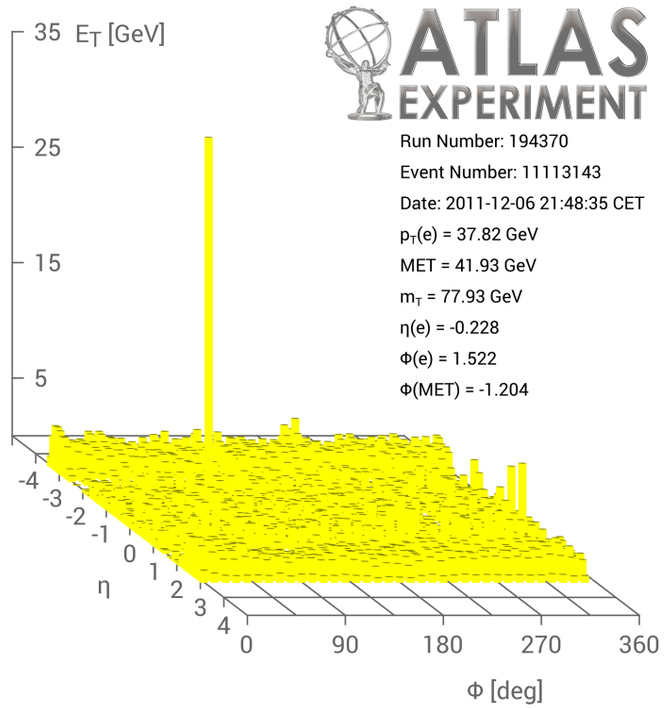
Z production is enhanced in the backward rapidity y* compared to three models

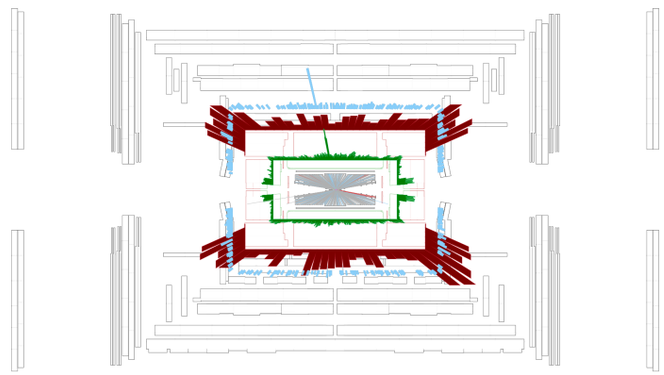
R_{cp}: more central to most peripheral yield ratio.

A slight rapidity dependence of R_{cp} is observed for most central collisions.

W Event in Pb+Pb





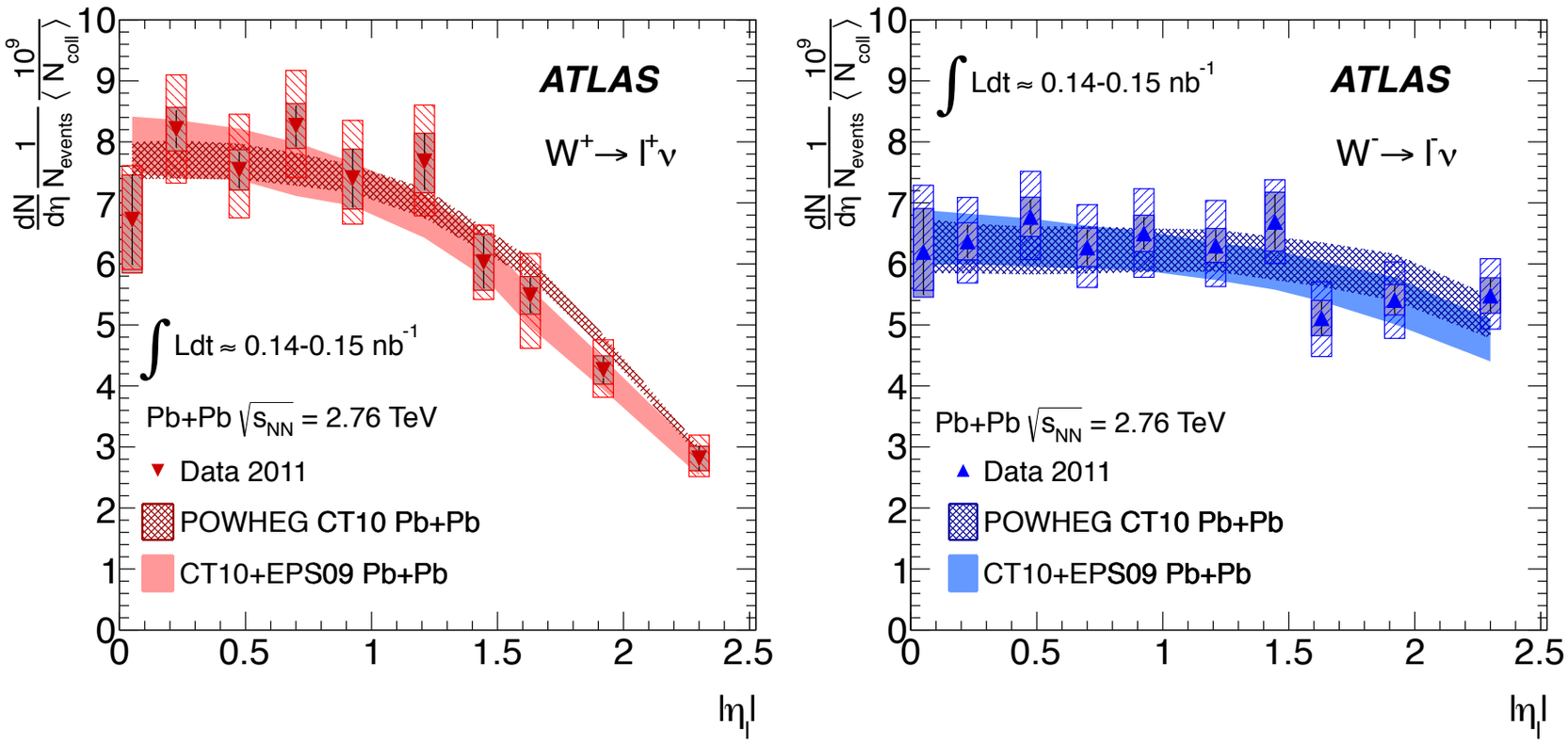


Measured via muon and electron channels and combined.

Momentum imbalance in the transverse plan as a proxy for the true neutrino p_T.

PDF Test: W Bosons in Pb+Pb

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



Models:

- POWHEG CT10
- CT10+EPS09

PDF Test: W Bosons in Pb+Pb

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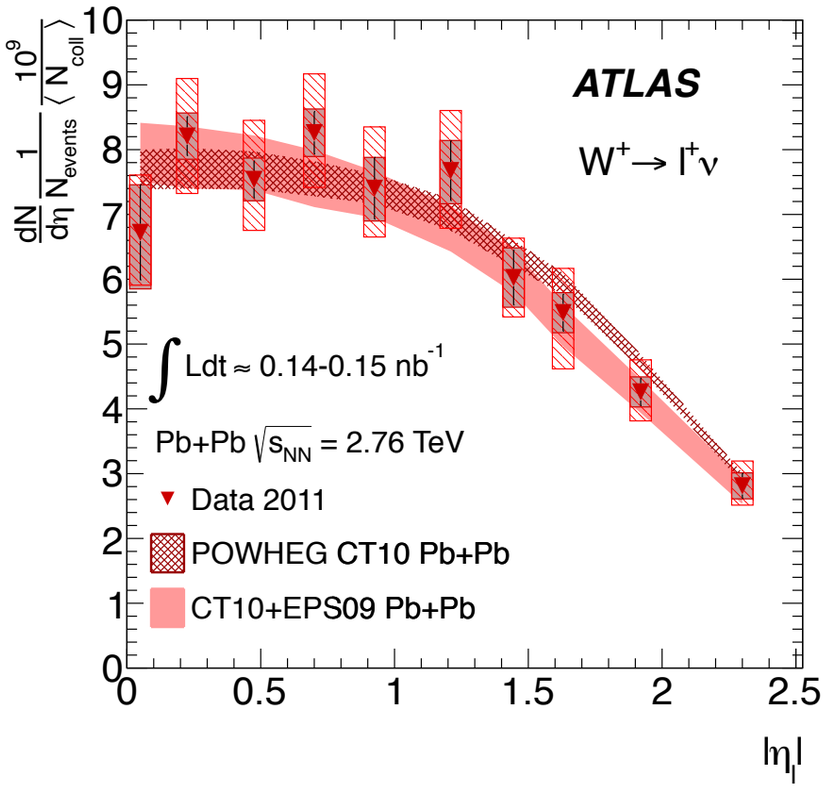
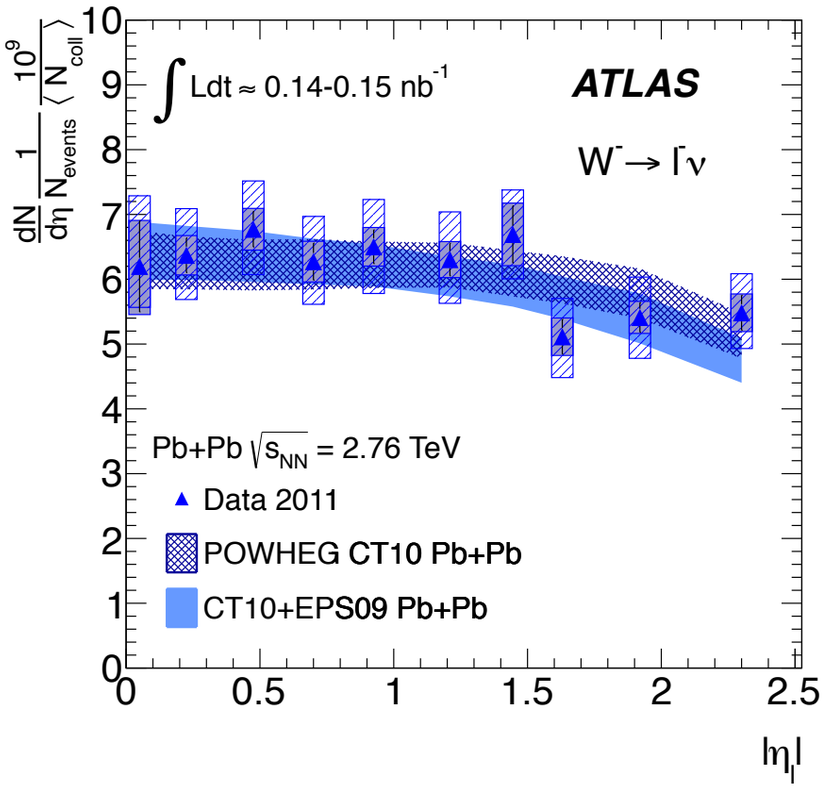
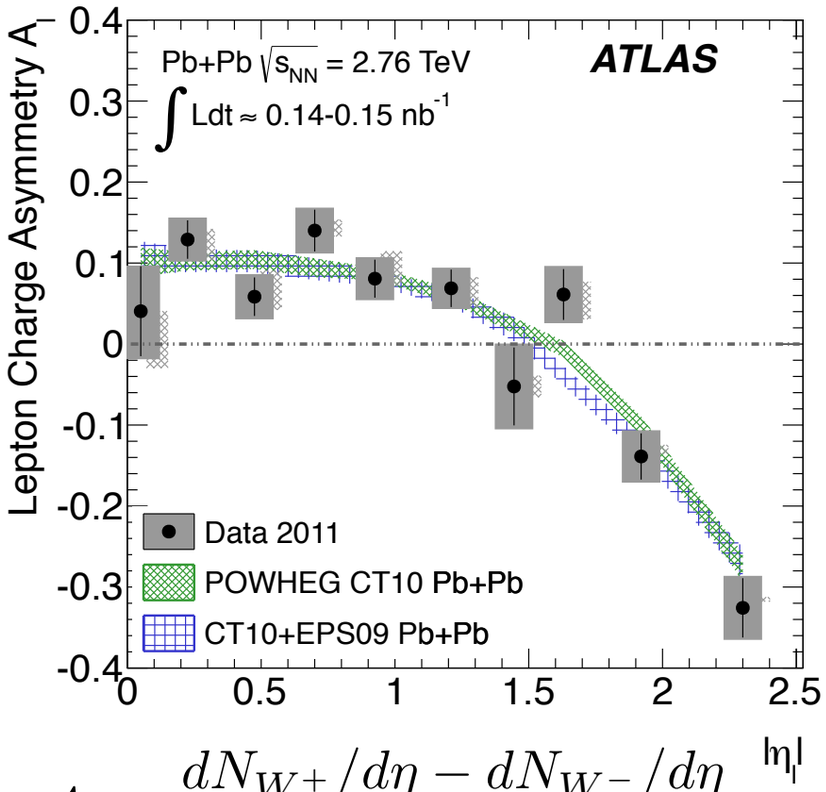






$$A_l = \frac{dN_{W+}/d\eta - dN_{W-}/d\eta}{dN_{W+}/d\eta + dN_{W-}/d\eta}$$

Models:

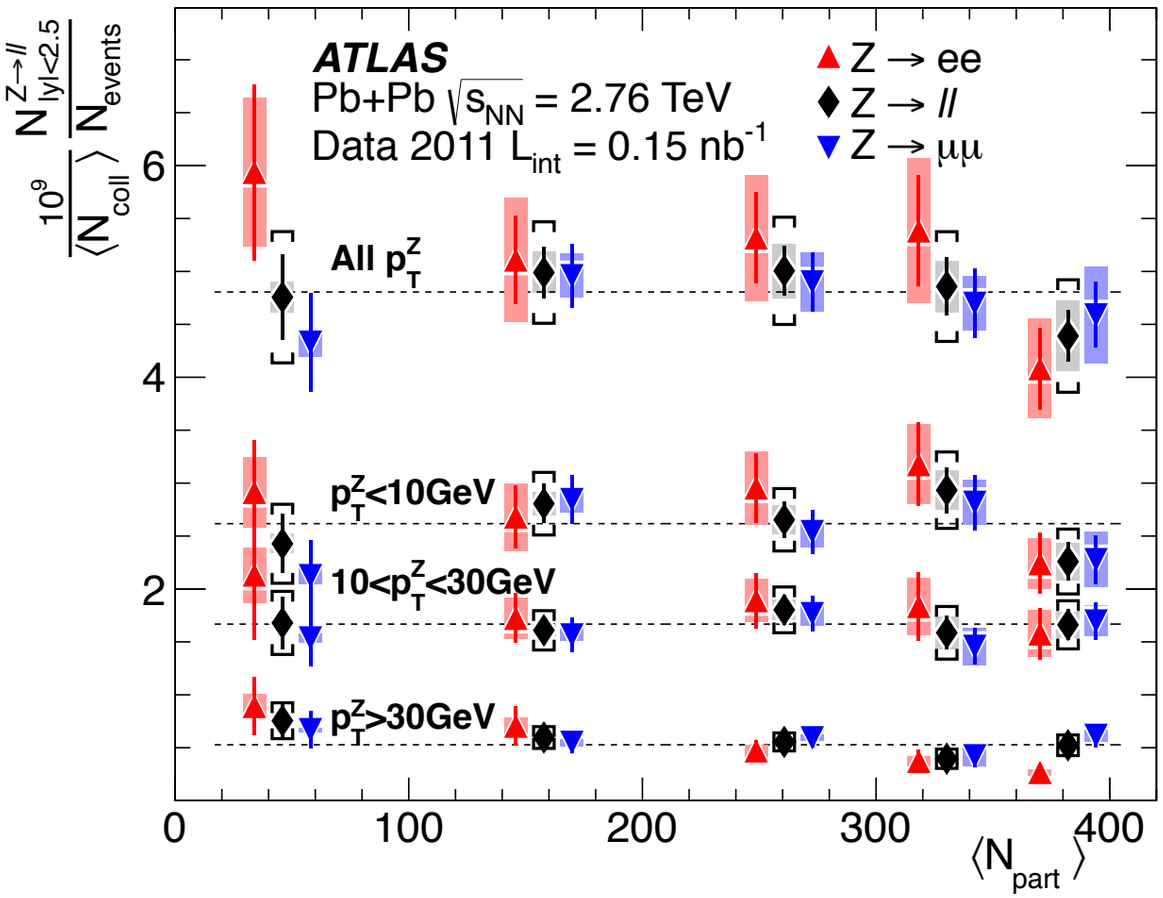
- POWHEG CT10
- CT10+EPS09

W lepton charge asymmetry in pseudorapidity.

- Many correlated systematics cancel out in lepton charge asymmetry.
- Within the experimental precision, cannot distinguish between PDFs that incorporate nuclear effects and those that do not.

Binary Collision Scaling

Phys. Rev. Lett. 100, 022301(2013)



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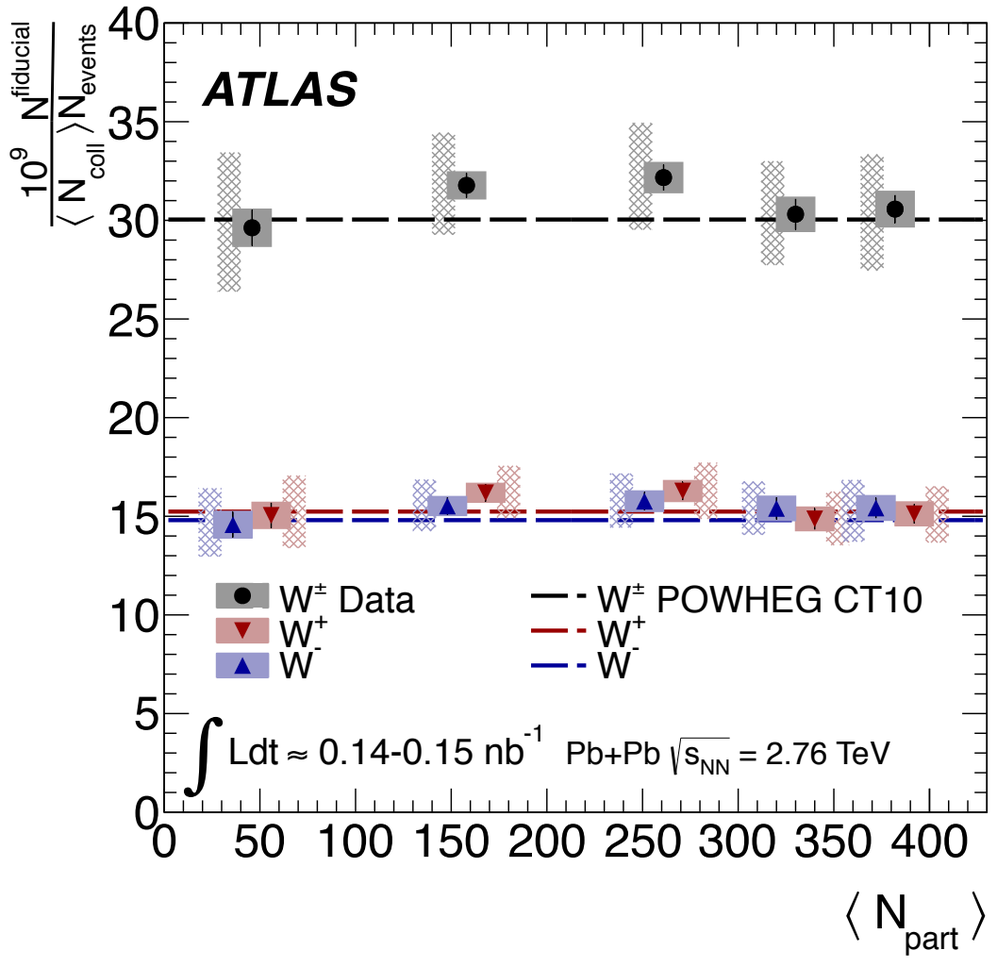


Left) *Z* boson per-event yield divided by $\langle N_{coll}\rangle$ vs. $\langle N_{part}\rangle$

Right) *W* boson per-event yield divided by $\langle N_{coll}\rangle$ vs. $\langle N_{part}\rangle$

- Z and W per-event yield scales with number of binary collisions in Pb+Pb.
- Prompt isolated photons show similarly consistent behavior.

Centrality Bias in *p*+Pb

Origin: Hard scatterings are often correlated with a larger transverse energy of the underlying event.

arXiv:1507.06232

Model calculation:

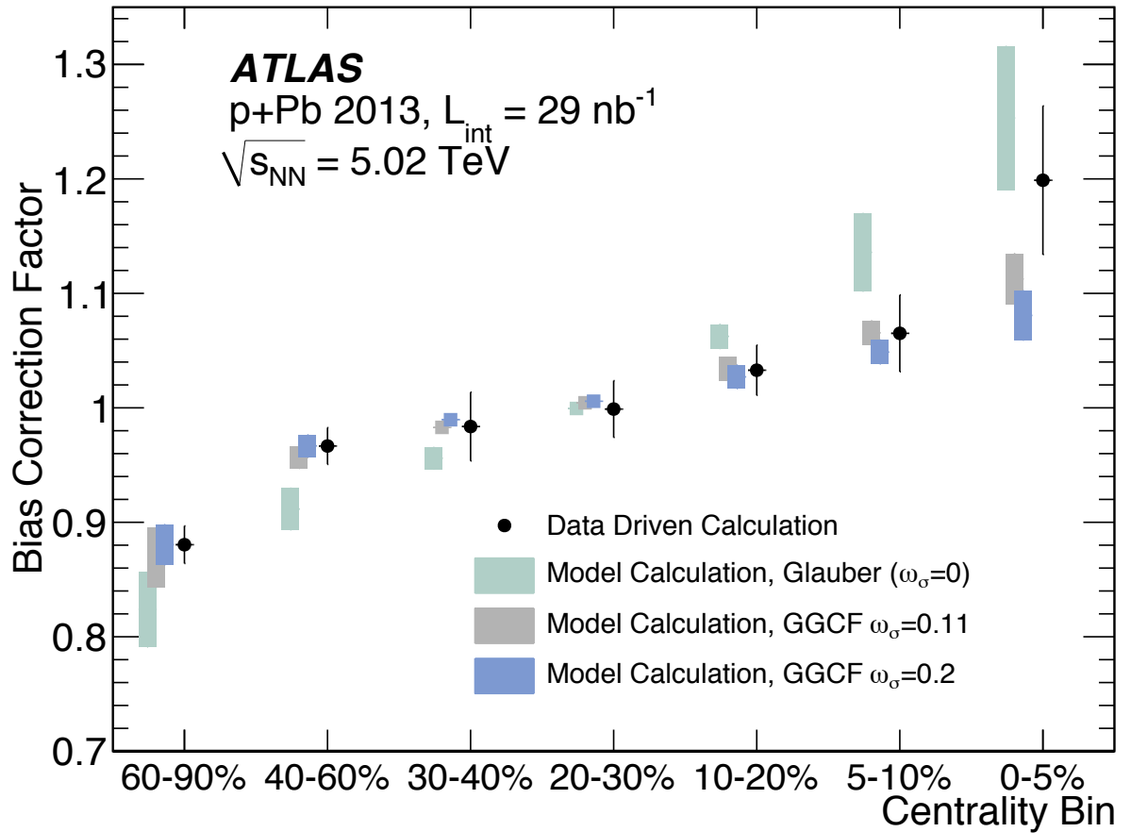
Given correlation between average hard-scattering yield Y_{Ncoll} per p+A collision and total E_T, centrality bias corrections factor (arXiv: 1412.0976) can be calculated from:

$$\rho = \frac{Y_{N_{\rm coll}}(E_{\rm T};\text{correlated})}{Y_{N_{\rm coll}}(\text{uncorrelated})}$$

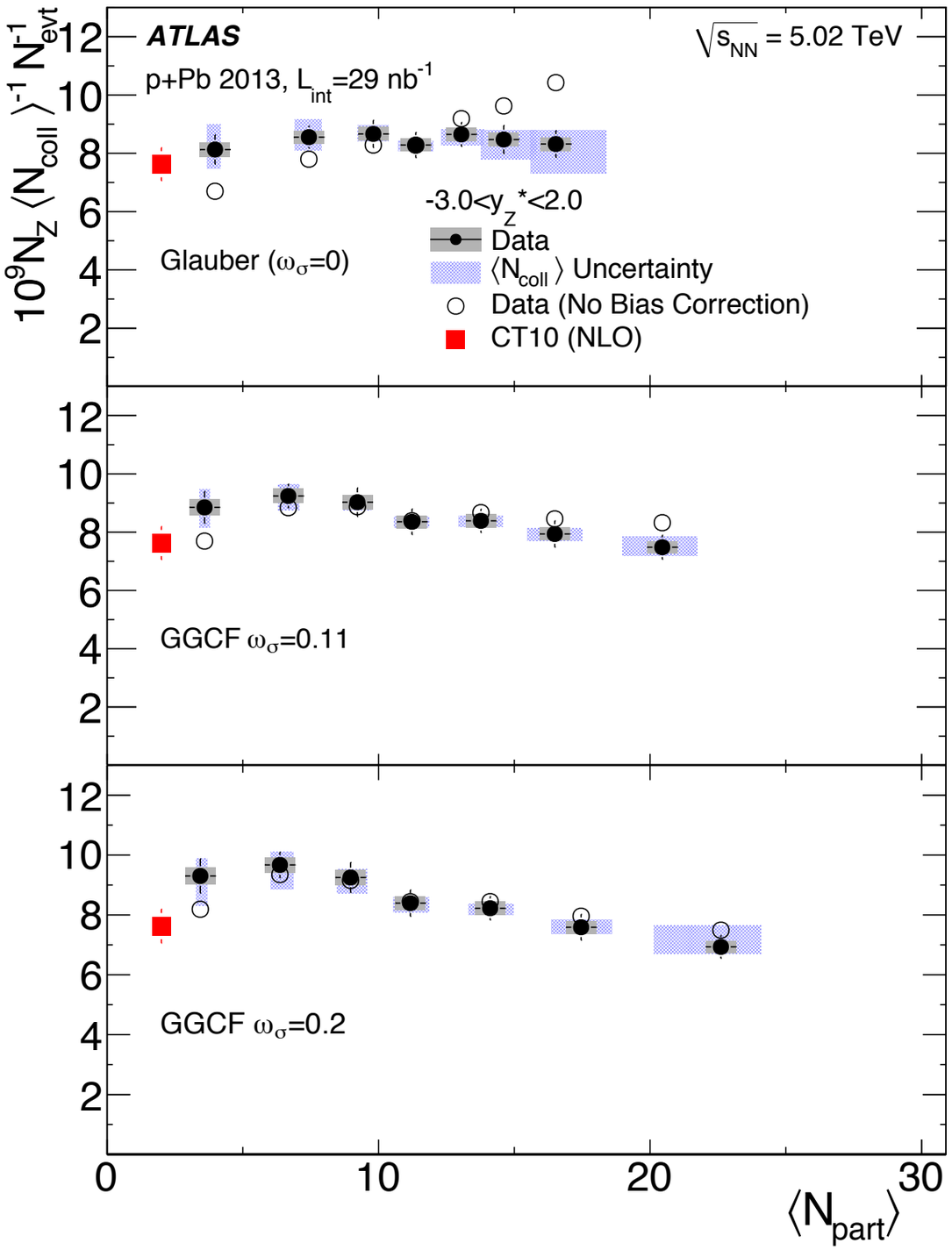
Data-driven calculation:

Subtract “extra” FCal energy from p+Pb event-by-event

Bias correction = ratios of w/o and w/ FCal energy subtraction.



Z Boson Scaling in *p*+Pb



arXiv:1507.06232

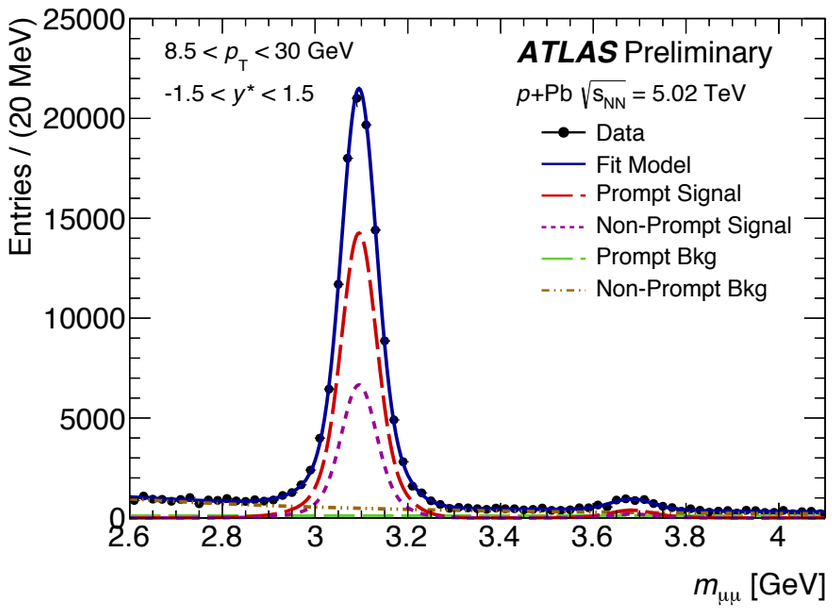
Z boson per-event yield divided by $\langle N_{coll} \rangle$ vs. $\langle N_{part} \rangle$

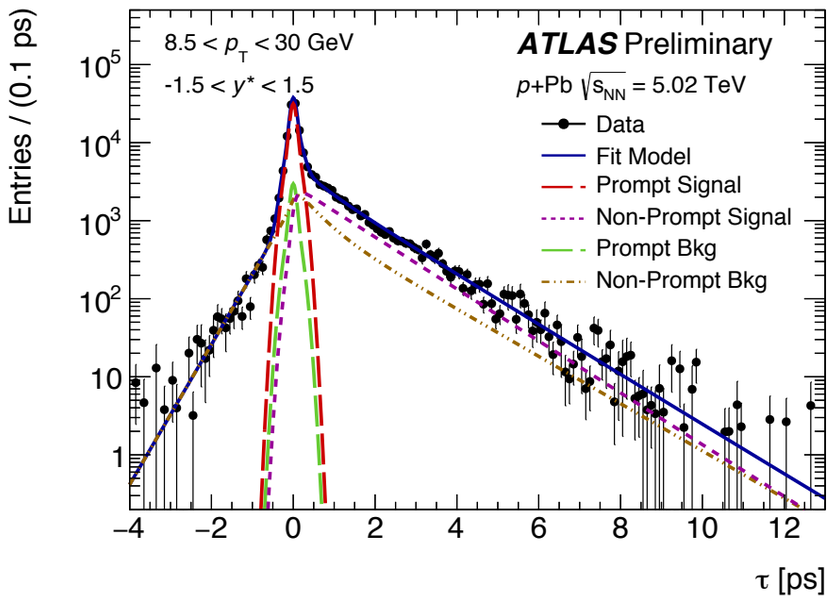
- In the view of models:
  Yields may or may not be centrality dependent, depending on the model employed.

- In the view of binary collision scaling:
  Glauber model appears constant with centrality bias correction applied.

Quarkonia in *p*+Pb

ATLAS-CONF-2015-023





- 2D fit to invariant mass and pseudo-proper lifetime to separate prompt production and decays from B-hadrons.

Quarkonia in *p*+Pb

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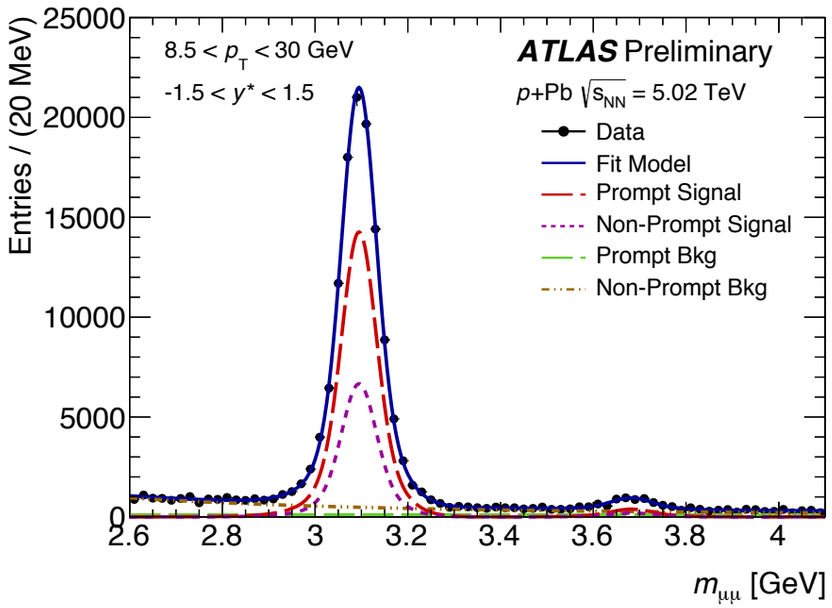
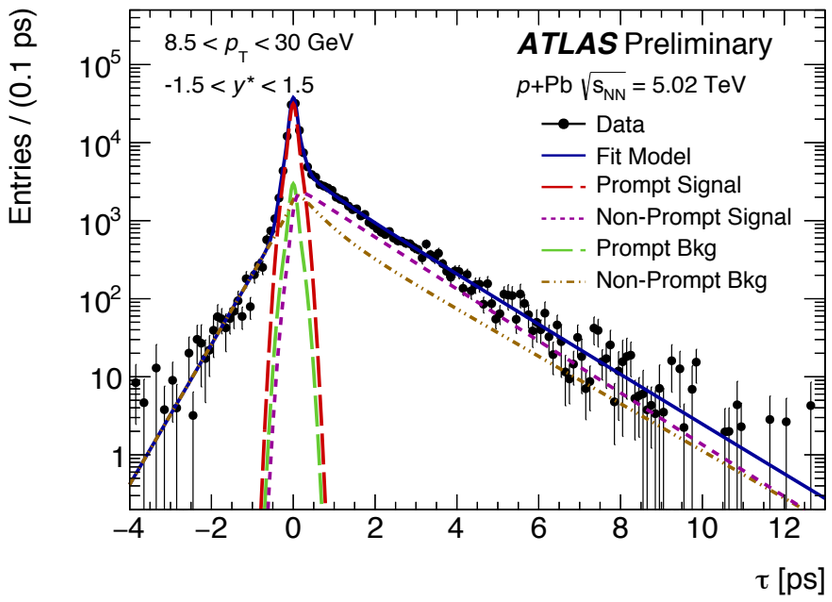
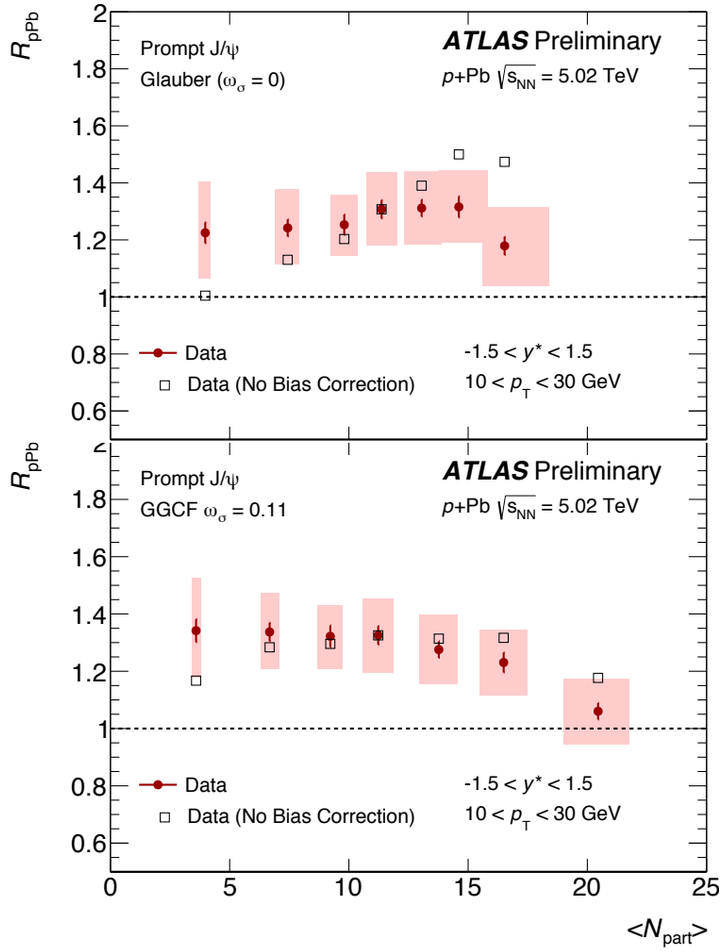
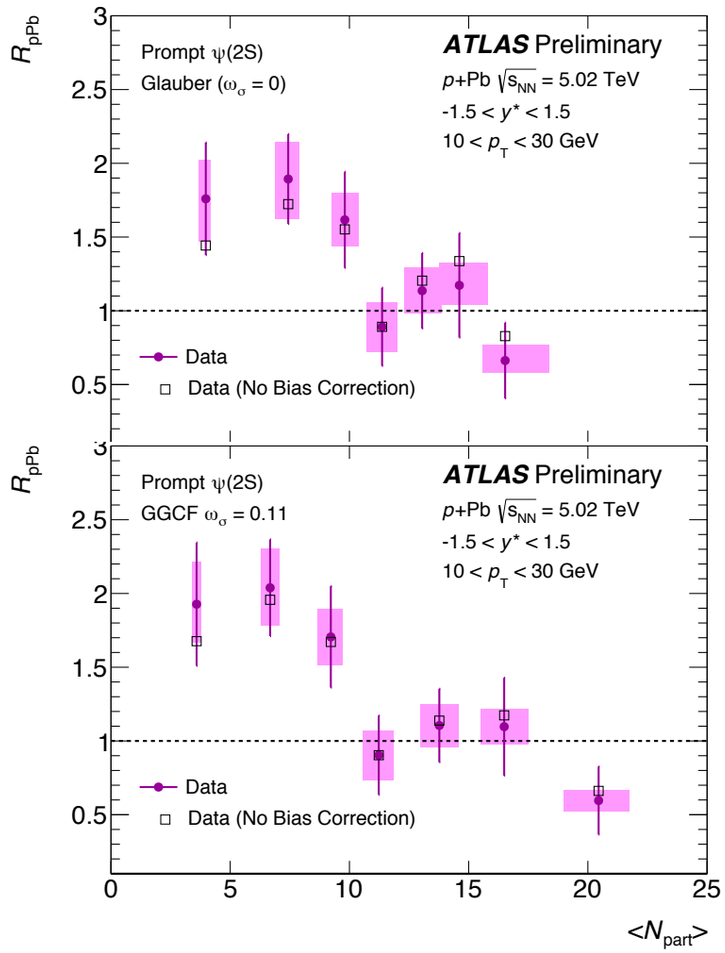




$$R_{\mathrm{pPb}} = \frac{1}{< T_{\mathrm{pPb}} >} \frac{1/N_{\mathrm{evt}}\, d^2N^{cent}_{\mathrm{p+Pb}}/dy^*dp_{\mathrm{T}}}{d^2\sigma_{\mathrm{p+p}}/dy/dp_{\mathrm{T}}}$$

- 2D fit to invariant mass and pseudo-proper lifetime to separate prompt production and decays from B-hadrons.
- pp reference at 5.02 TeV is calculated from interpolating 2.76, 7 and 8 TeV data.
- Centrality dependence of R_{pPb} depends on model employed.





Z boson as a reference for Quarkonia

Use the Z boson production as a reference for the study of centrality dependence of other hard probes.

Model independent way to study centrality dependence of other hard probes.

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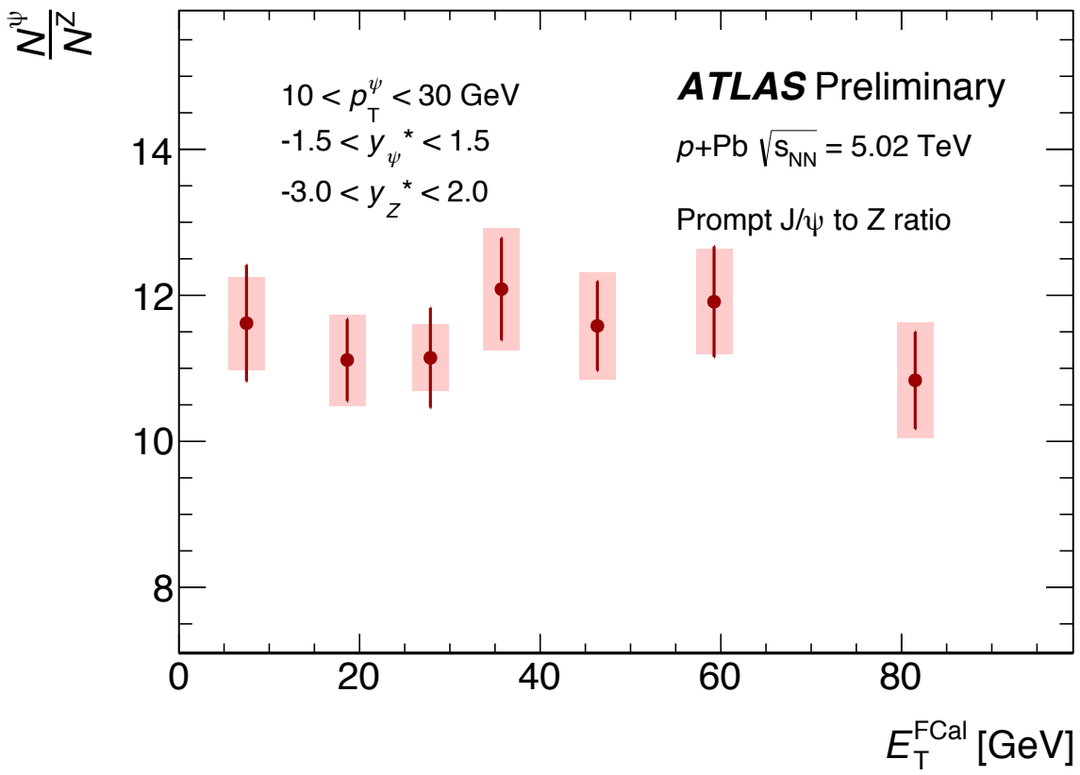
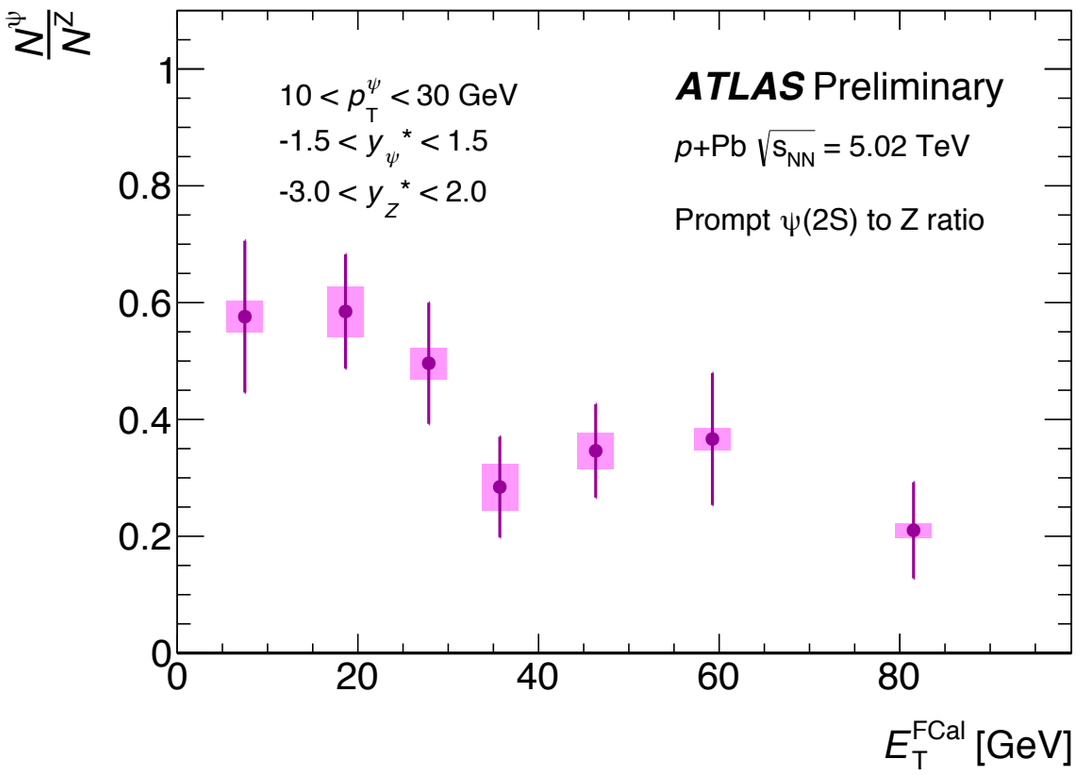




Summary

- Presented highlights of electroweak boson results in Pb+Pb and *Z* boson results in *p*+Pb

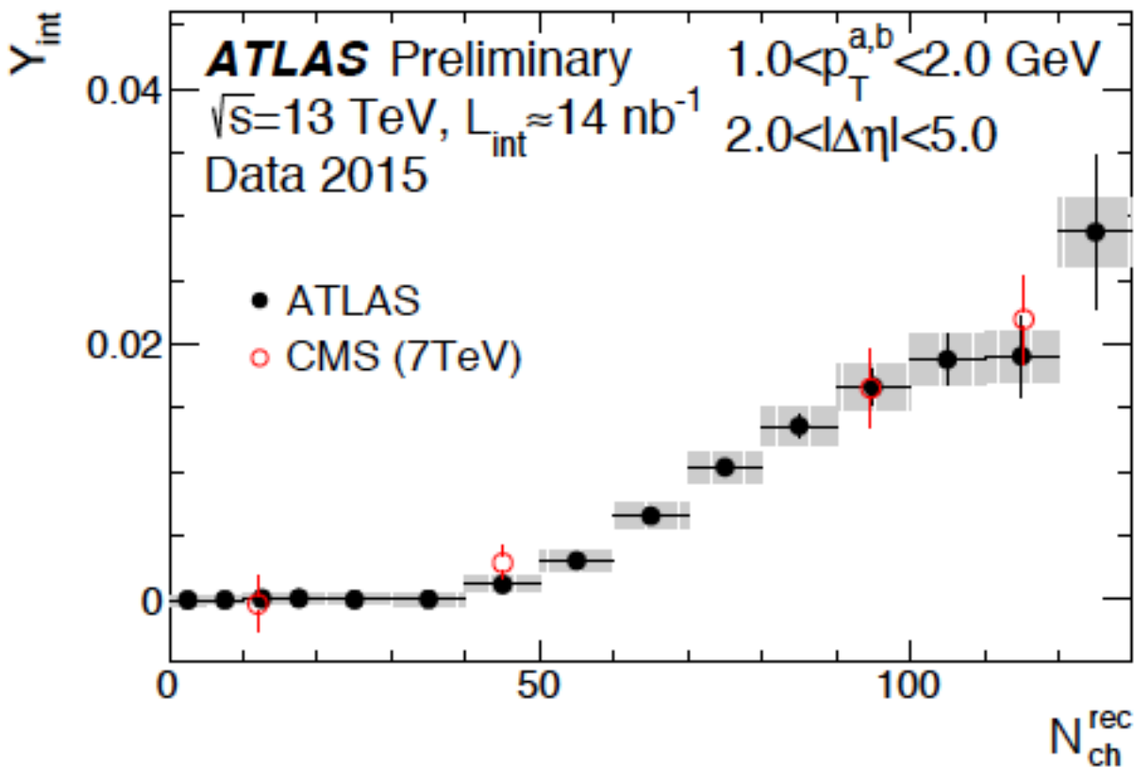
- PDF test in Pb+Pb results are limited by precisions in distinguishing models. In LHC Run 2, with a factor of 10-30 more events, we would be able to make precision measurements.

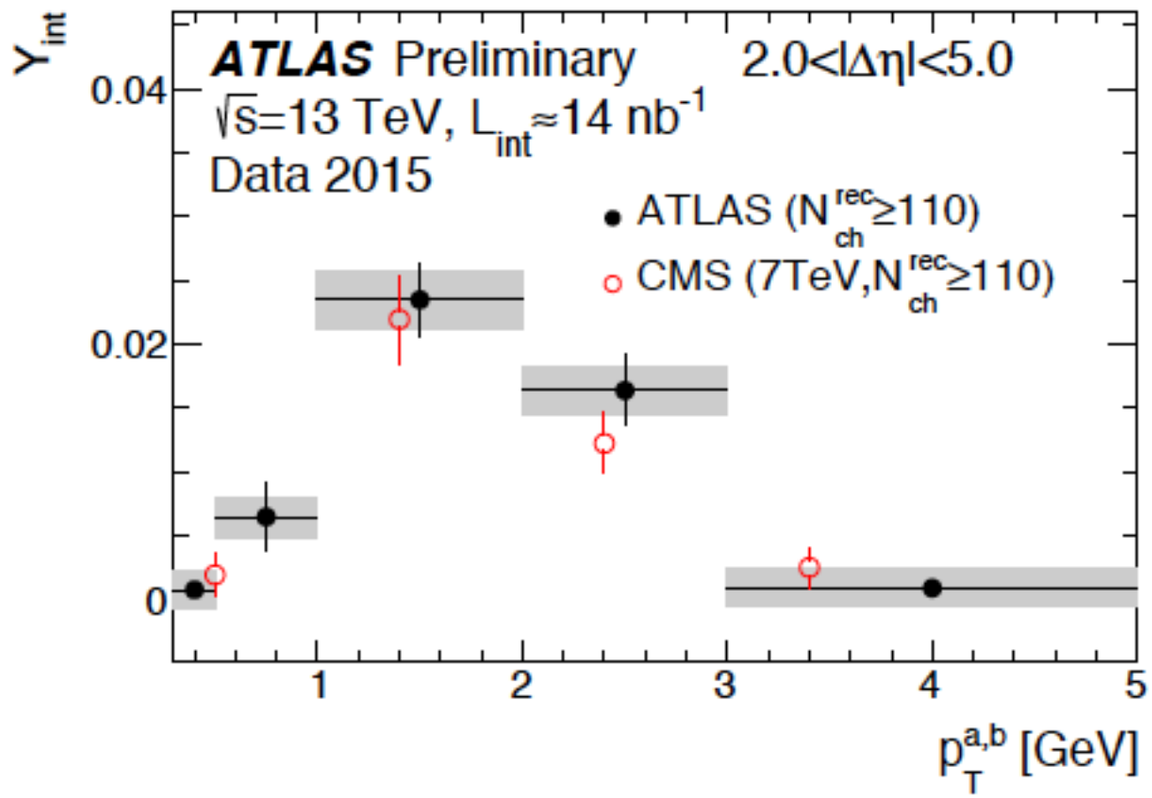
- PDF test in p+Pb by *Z* cross-sections shows slight enhancement in the backward (Pb-side). A weak rapidity dependence of R_{cp} is observed for most central collisions.

- The study of *Z* bosons in *p*+Pb provides insight on centrality bias. The Z boson yield are consistent with binary scaling when the Glauber model with bias corrections is used to determine $\langle N_{coll} \rangle$.

Backup

pp Ridge


Y_int
ATLAS Preliminary
√s=13 TeV, L_int≈14 nb^-1
Data 2015
1.0<p_T^a,b<2.0 GeV
2.0<|Δη|<5.0
ATLAS
CMS (7TeV)
0.04
0.02
0
0
50
100
N_ch^rec

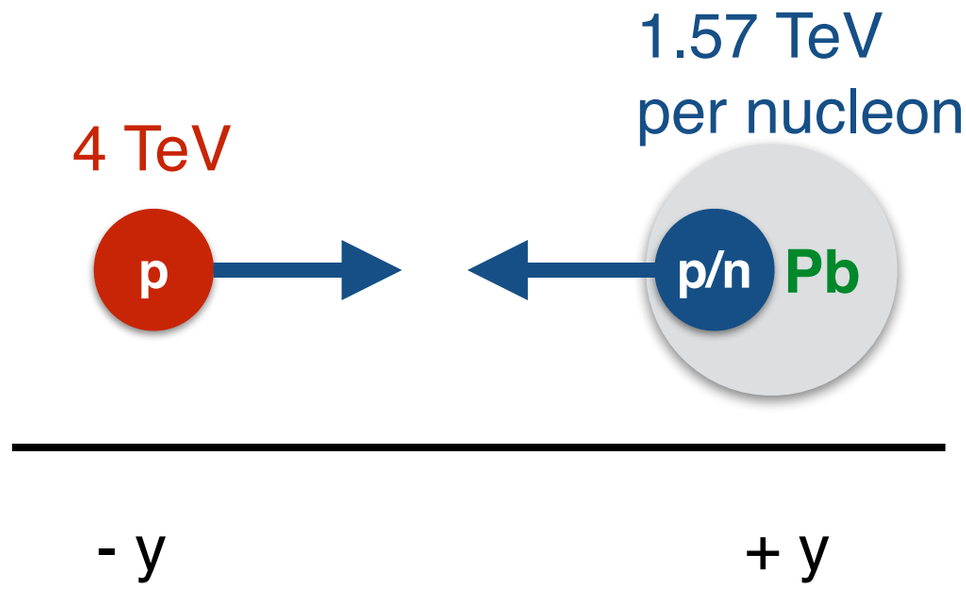

Y_int
ATLAS Preliminary
√s=13 TeV, L_int≈14 nb^-1
Data 2015
2.0<|Δη|<5.0
ATLAS (N_ch^rec≥110)
CMS (7TeV,N_ch^rec≥110)
0.04
0.02
0
1
2
3
4
5
p_T^a,b [GeV]

Configuration of *p*+Pb collision

The proton-nucleon center of mass (CM) frame has a shift of 0.465 in rapidity in the proton beam direction.

y*: CM rapidity being positive in forward (proton beam direction).

p+Pb collision beam configuration



Glauber and GGCF models

To model N_{part} distribution we used:

- standard Glauber with σ_{NN} cross section = 70±5mb
- Glauber-Gribov color fluctuation models, with $< \sigma_{NN} >$= 70±5mb

In GGCF model:

$$P_h(\sigma_{\rm tot}) = \rho \frac{\sigma_{\rm tot}}{\sigma_{\rm tot}+\sigma_0} exp\Big\{ - \frac{(\sigma_{\rm tot}/\sigma_0 - 1)^2)}{\Omega^2} \Big\}$$

- σ_{tot} is considered frozen for each event
- parameter Ω controls the amount of fluctuations (Ω = 5 ω_σ)
- Ω is extracted from experimental data: 0.55 and 1.01