Soft and Hard probes of proton multiple scattering in p+Pb collisions with the ATLAS experiment at the LHC

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on behalf of the ATLAS Collaboration

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DIFFRACTION 2014
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UNIVERSITY OF CAMBRIDGE

ATLAS EXPERIMENT

Motivation

The study of particle production and scaling properties and underlying nature of p+Pb collisions,

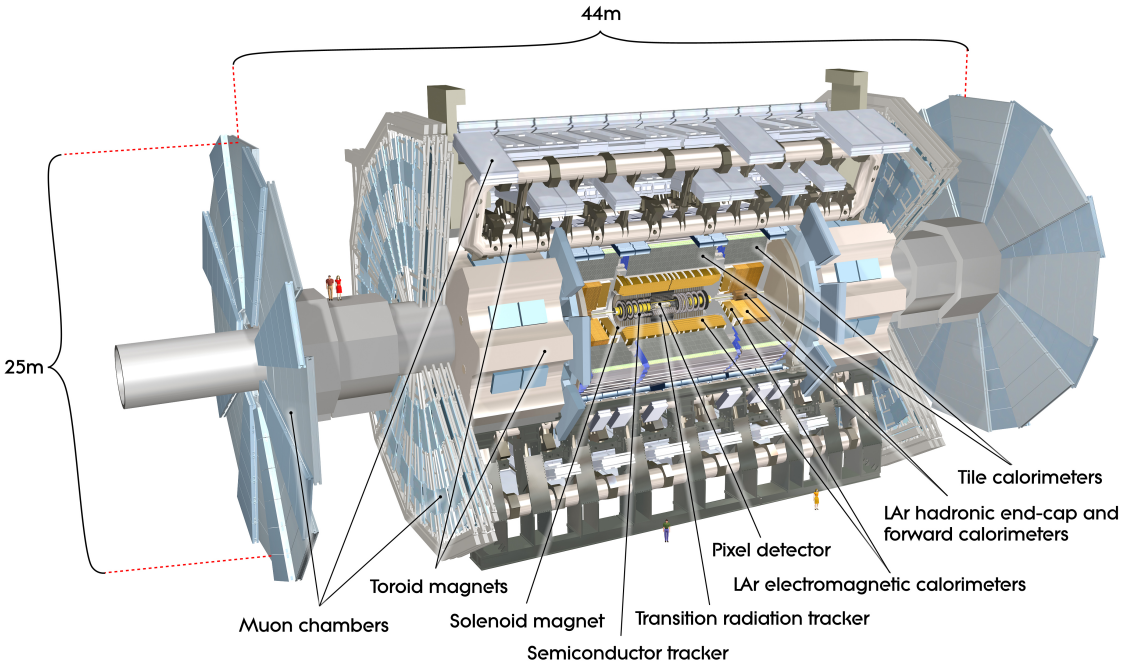
In p+Pb, nucleons are struck multiple times. Simply an incoherent sum of nucleon-nucleon interactions?

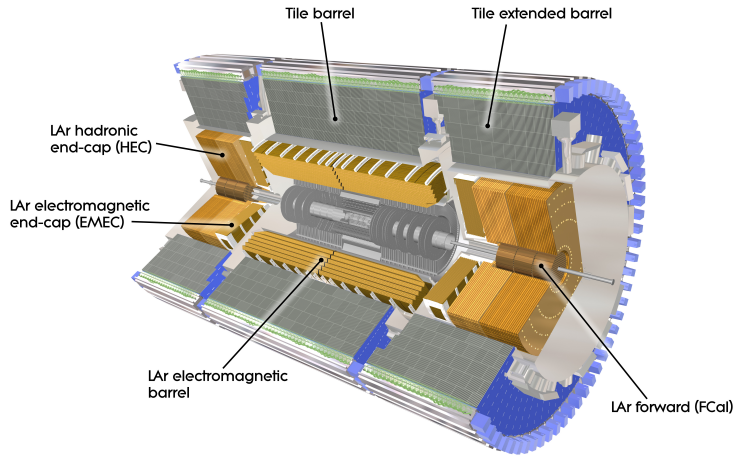
- Hard Probes: Inclusive Jets and Z bosons
- Soft Probes: Charged particle η distributions.

Allow the study initial state nuclear effects.

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HeavyIonsPublicResults

p+Pb data Data: 2012 ($1\mu b^{-1}$) and 2013 ($30\ nb^{-1}$).
p = 4 TeV, Pb = 1.57 TeV/A, $\sqrt{s_{NN}} = 5.02$ TeV and $\Delta y \approx \pm\ 0.47$.



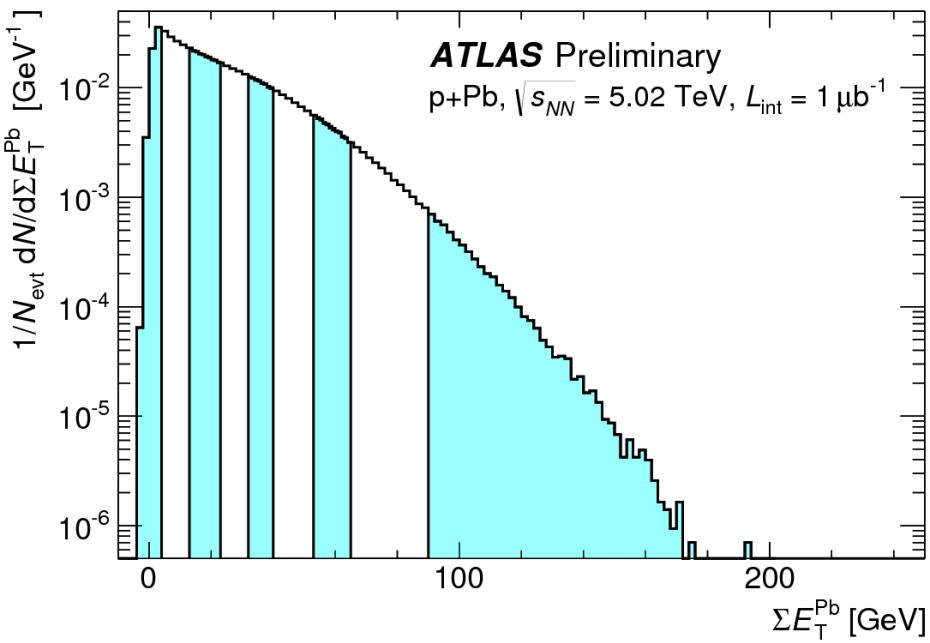


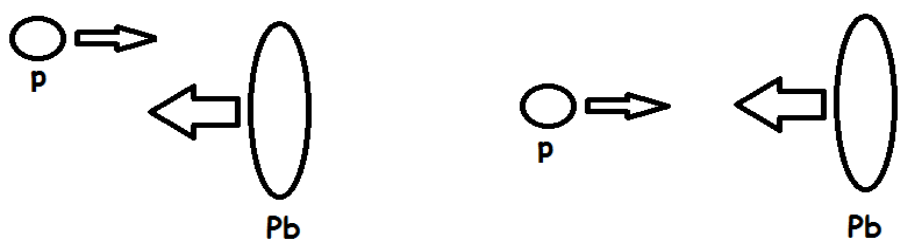
Results presented are based on measurements of:

1. Electrons (ID, MS, CAL)
2. Muons (ID,MS)
3. Charged particles (ID)
4. Jets (ID, CAL)
5. Event activity (FCAL)
6. + trigger system

Experimental Selection of Centrality

Geometry of the p+Pb collision is indirectly constrained by measurements of soft particle production in Pb going direction.
(sensitive to multiple interactions in Pb nucleus).



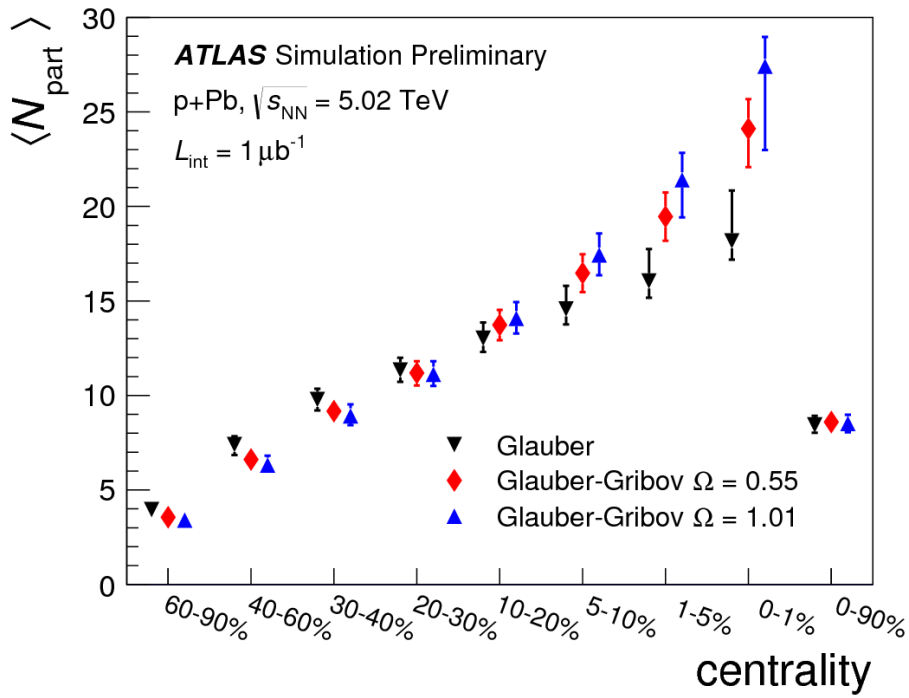


- Centrality characterized by the total E_T deposited in Pb-going Forward Calorimeters.
- Centrality classes defined with percentiles of total E_T: 0-1% (most *central*), 5-10%, 10-20%....60-90% (most *peripheral*).
- Class 90-100% excluded from analysis.

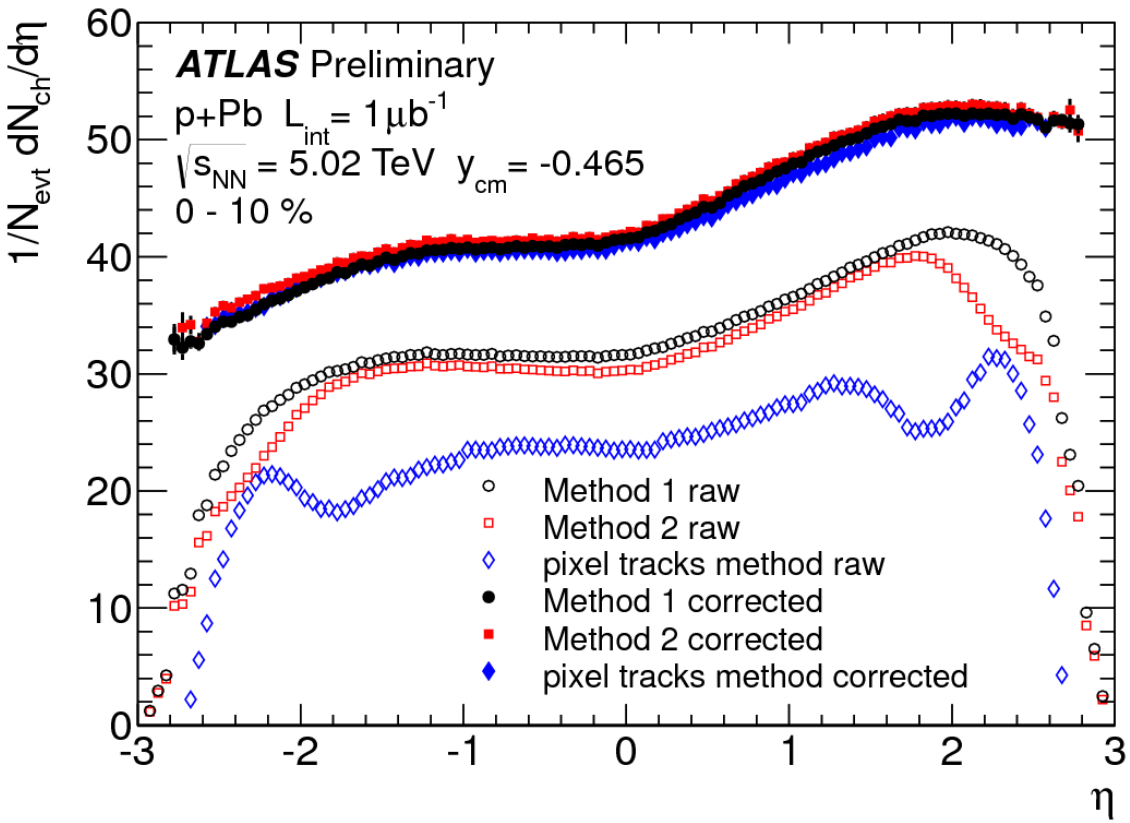
Centrality and Geometry

Estimate the number of nucleons that participate in the p+Pb collision, N_{part}, for each centrality class.

- Geometry estimated with semi-classical model. "Glauber" with $\sigma_{NN} = 70 \pm 5$ mb, and
- "Glauber-Gribov" extension with event-by-event fluctuations on σ_{NN} controlled by Ω, estimated from data PLB 633 (2006), PLB 722 (2013) .
- Monte Carlo simulation and fit to measured FCAL E_T used to estimate $\langle N_{part} \rangle$ in each centrality class.

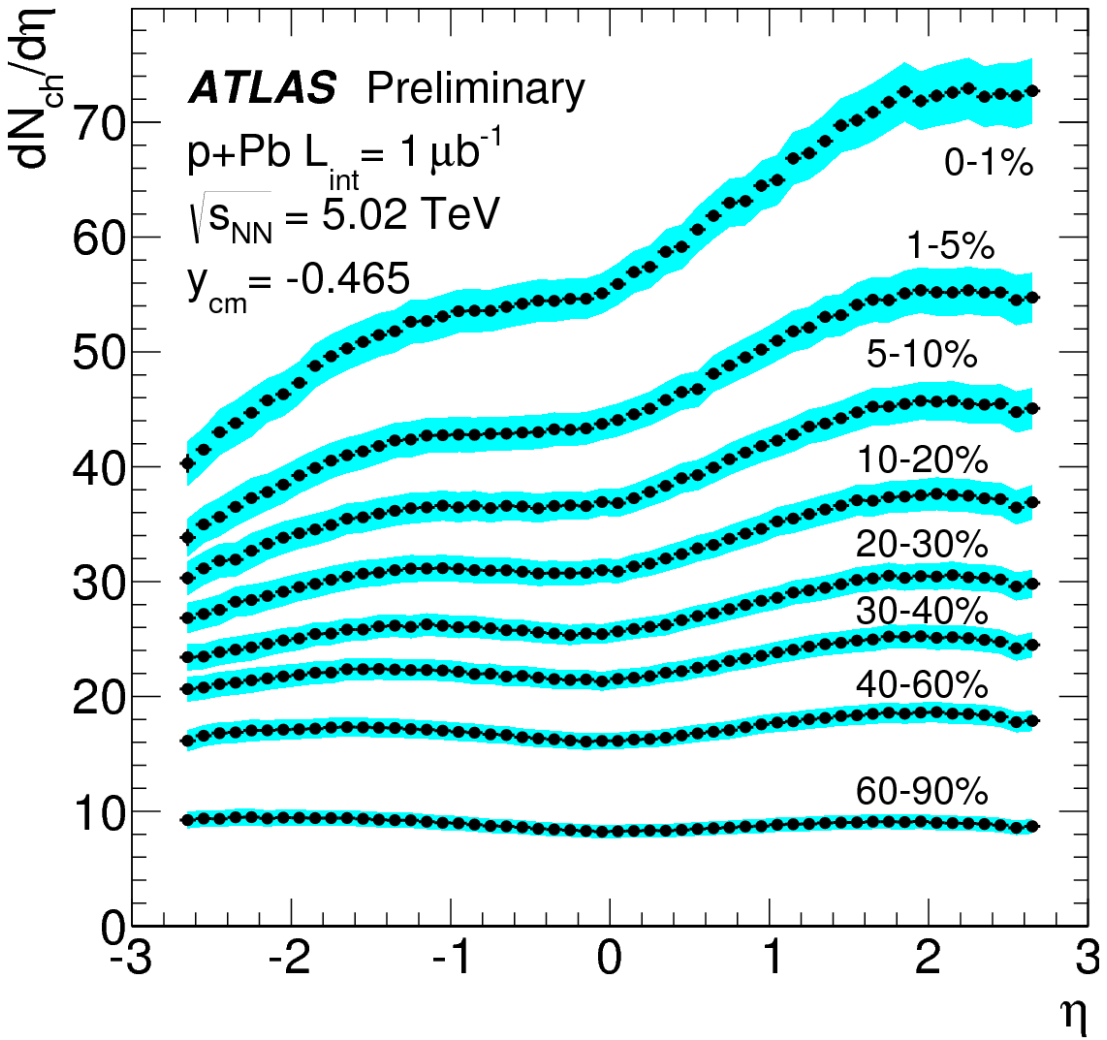


Charged particle reconstruction



- Hits in the first three Pixel detector layers are used.
- Three methods with different systematics and acceptance.
  - Two 2-point tracklet methods. (black and red).
  - 3-point track method (extrapolated to p_T=0). (blue)
- Consistency among methods after corrections. ✓

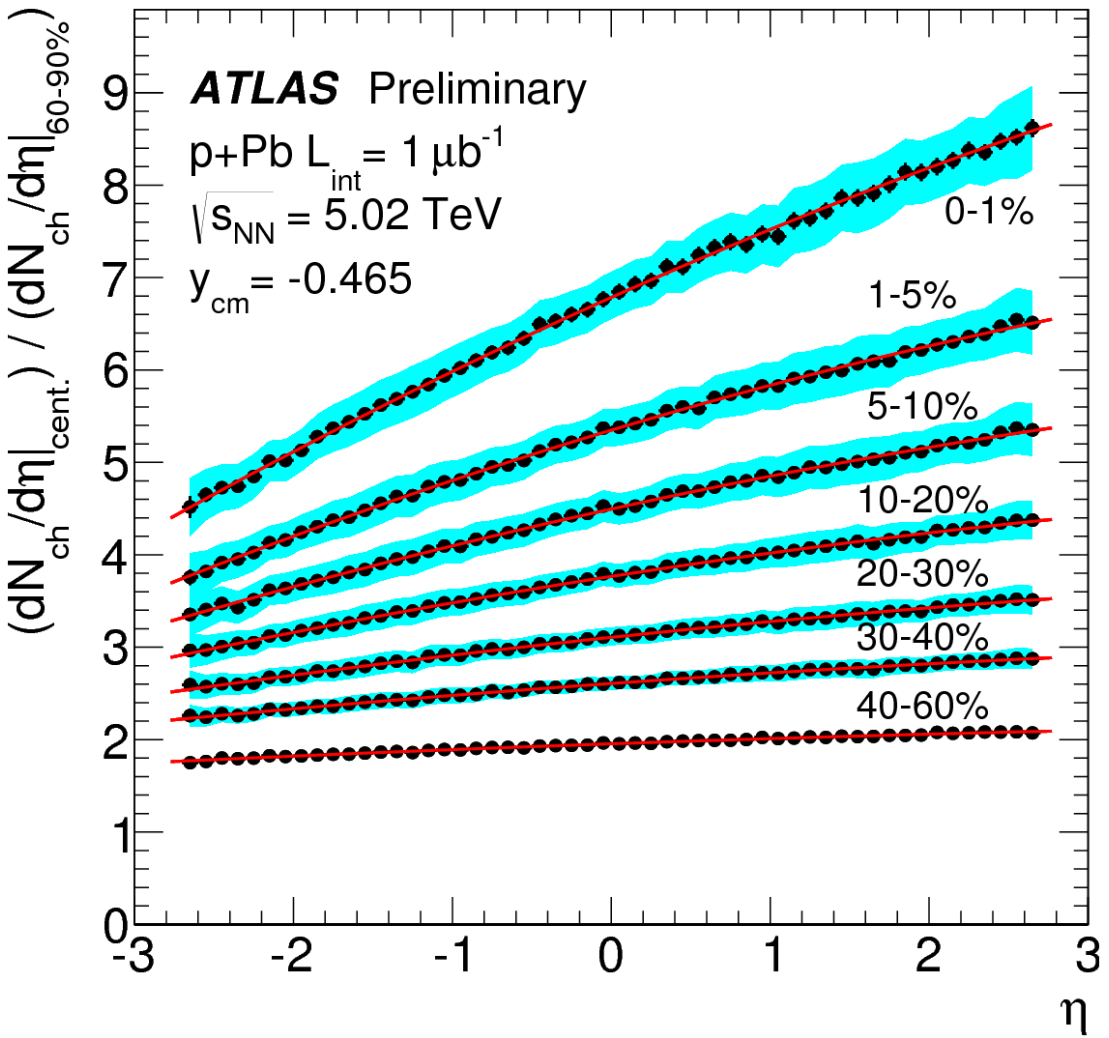
Charged particle multiplicity vs centrality



- $dN_{\mathrm{ch}}/d\eta$ measured for $|\eta| < 2.7$ in eight centrality intervals.
- Visible double peak structure.
- Distribution asymmetry has strong centrality dependence.

$\eta < 0$ is proton-going.

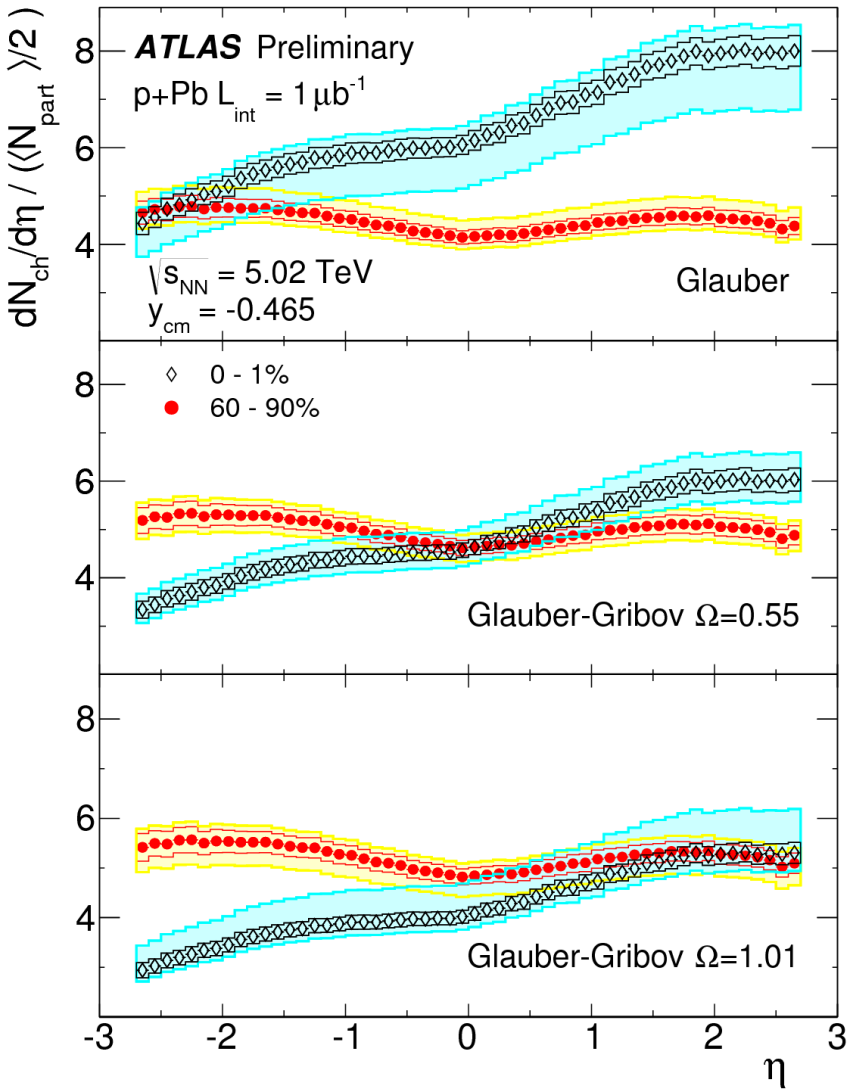
Ratios to the most peripheral distribution



- Divide by the most peripheral (60-90%) events "*pp* like".
- Double peak divides out
- Ratio grows linearly with η. Centrality dependent slope

$\eta < 0$ is proton-going.

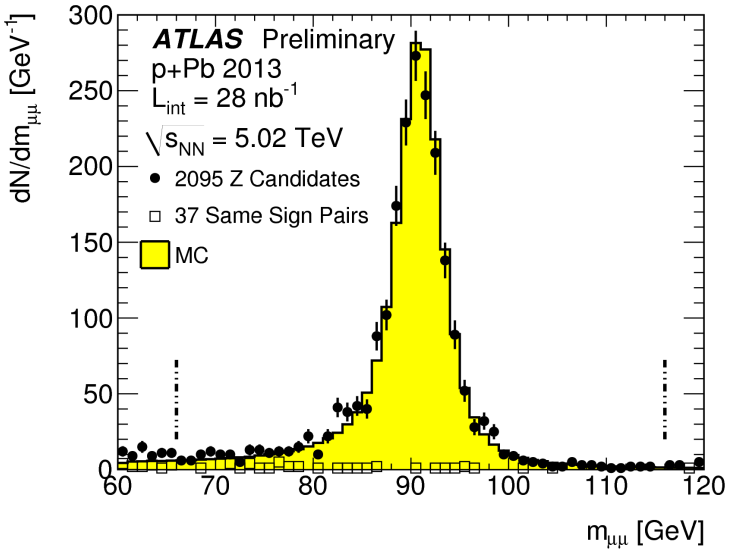
N_{part} scaling

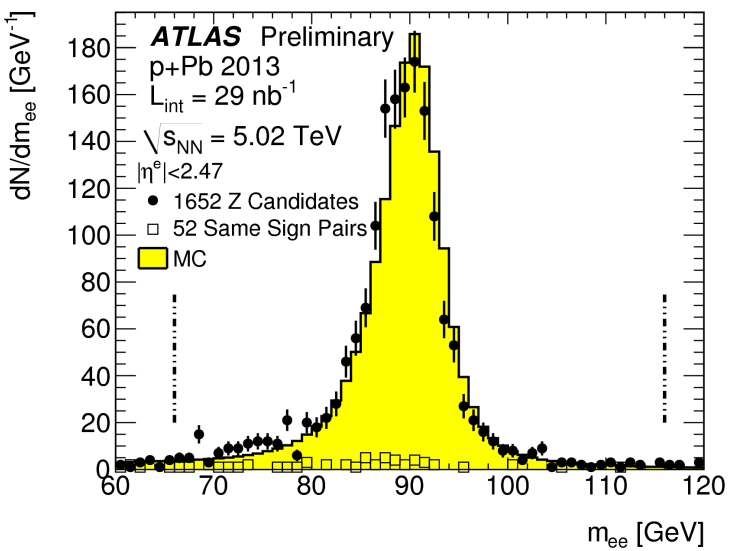


$\eta < 0$ is proton-going.

- Normalized to $\langle N_{part}/2 \rangle$ for 0-1% and 60-90% events.
- Same data but different $\langle N_{part} \rangle$ according to three geometrical models
- Intercept (scaling) occurs at different η for the different models.
- Central events show enhancement at Pb-going side, or suppression at p-going side depending on model.

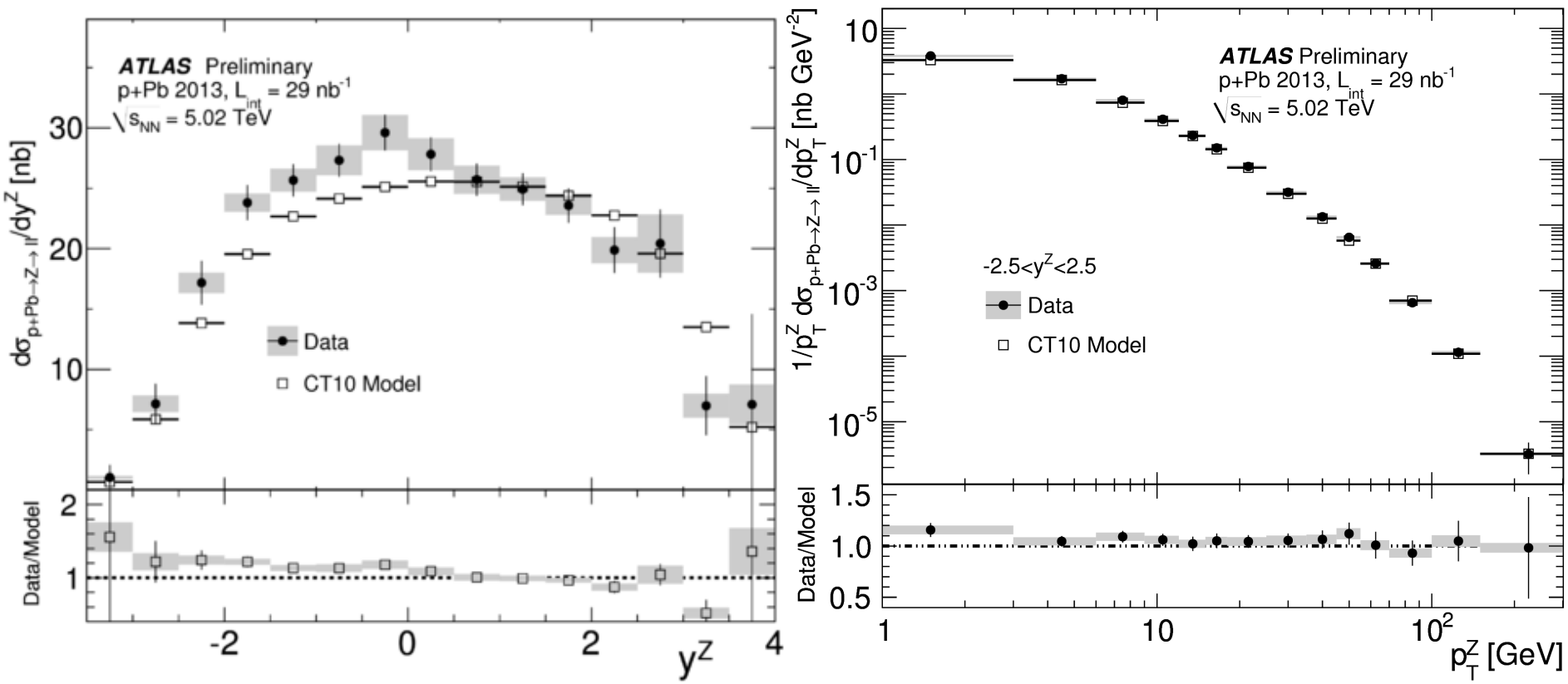
Z boson reconstruction: $Z \to \mu\mu$ and $Z \to ee$





- Dimuon and dielectron channel used. Good agreement; results are combined.
- MC: Powheg CT10, PYTHIA8 showering. Used to correct data. Checked with data-driven methods.
- MC is normalized to total NNLO prediction, used as baseline.

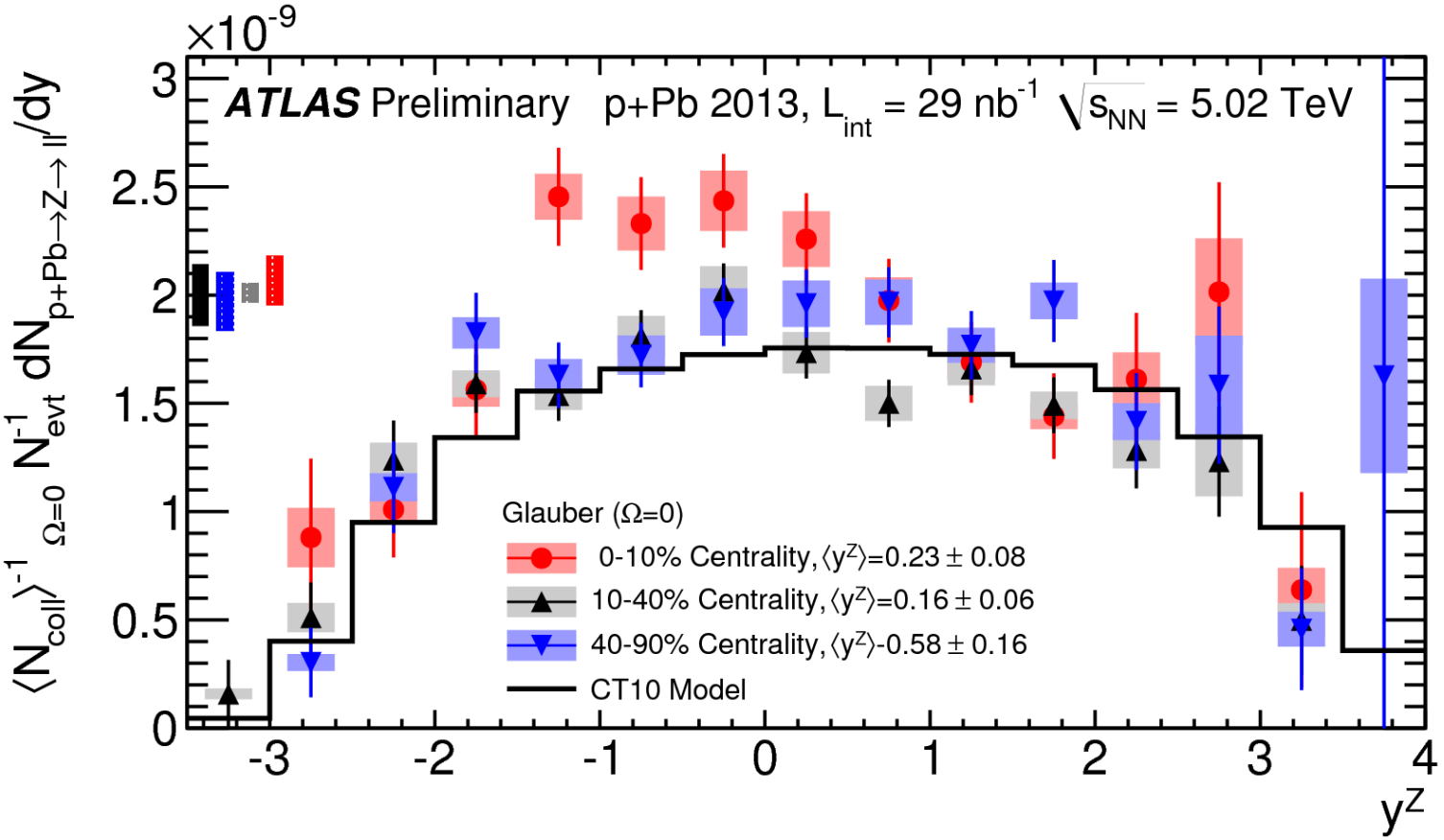
Z boson differential cross-sections



$y > 0$ is proton-going.

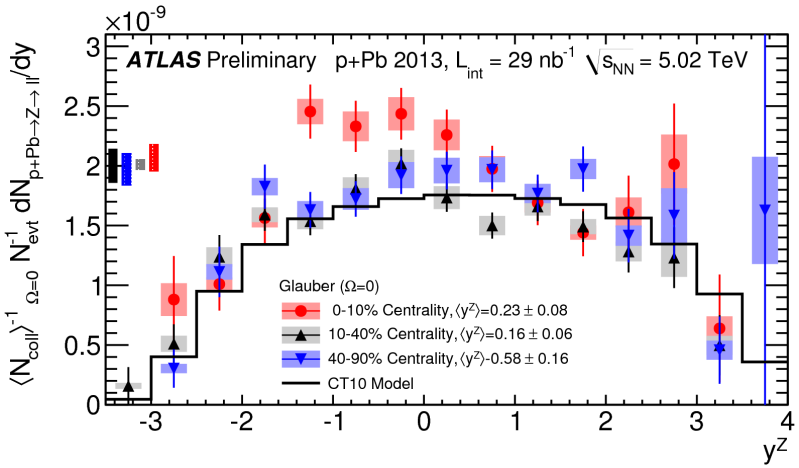
- Significant excess at Pb going side with respect to CT10.

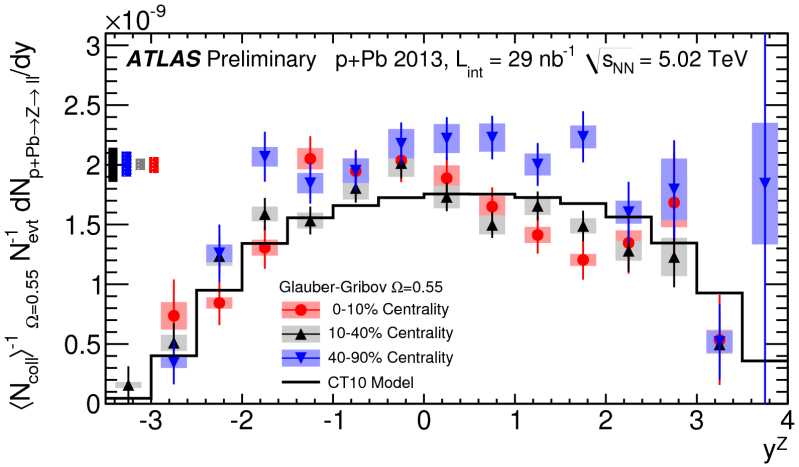
Z boson: N_{coll}-scaled centrality differential yield

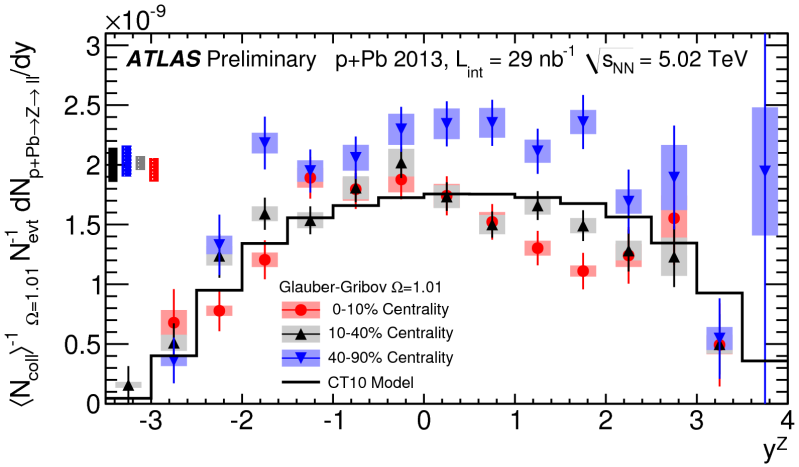


$y > 0$ is proton-going.

- Significant excess at Pb going side only seen at central events. (Standard Glauber...)







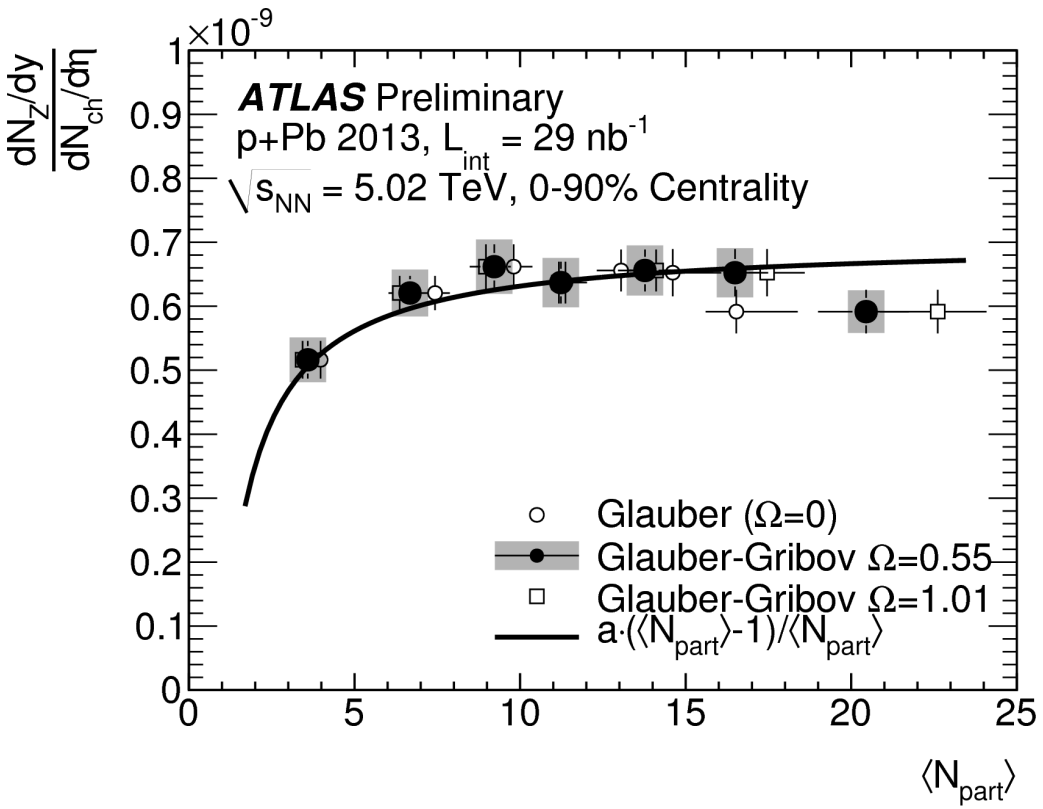
$y > 0$ is proton-going.

- Same data but different N_{coll} according to three geometric models
- Central events show enhancement at Pb going side, or suppression at p going side depending on geometric model.
- Similar trend as in charged particle multiplicity

Ratio: Z bosons / charged particle multiplicity

Expectation

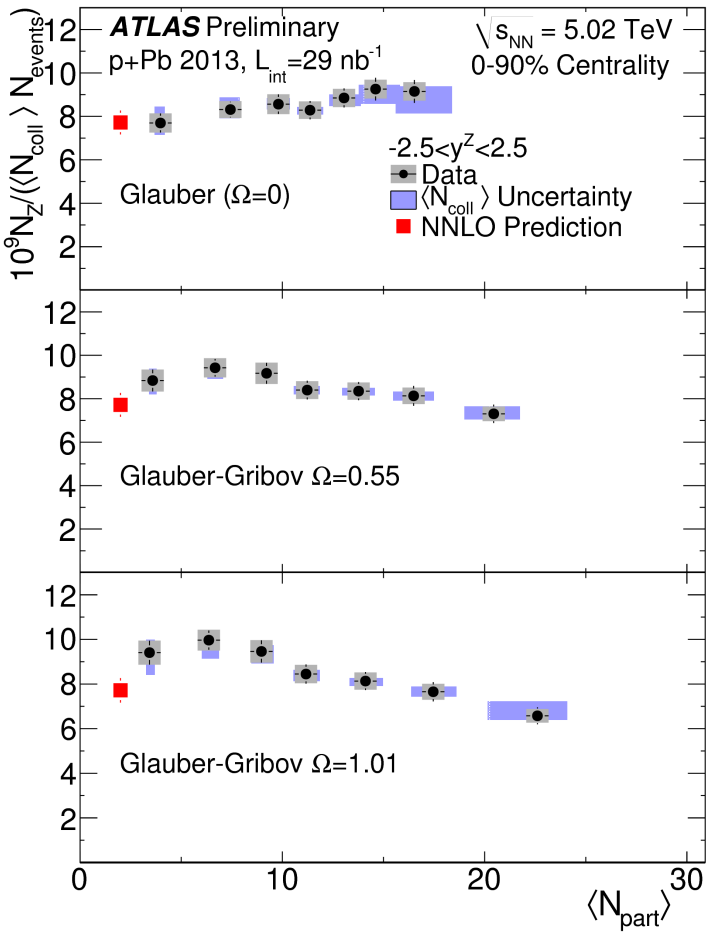
Z bosons $\propto$ number of binary nucleon-nucleon collisions. $\langle N_{\mathrm{coll}} \rangle$
$dN_{\mathrm{ch}}/\eta \propto$ number of participants nucleons $\langle N_{\mathrm{par}} \rangle$



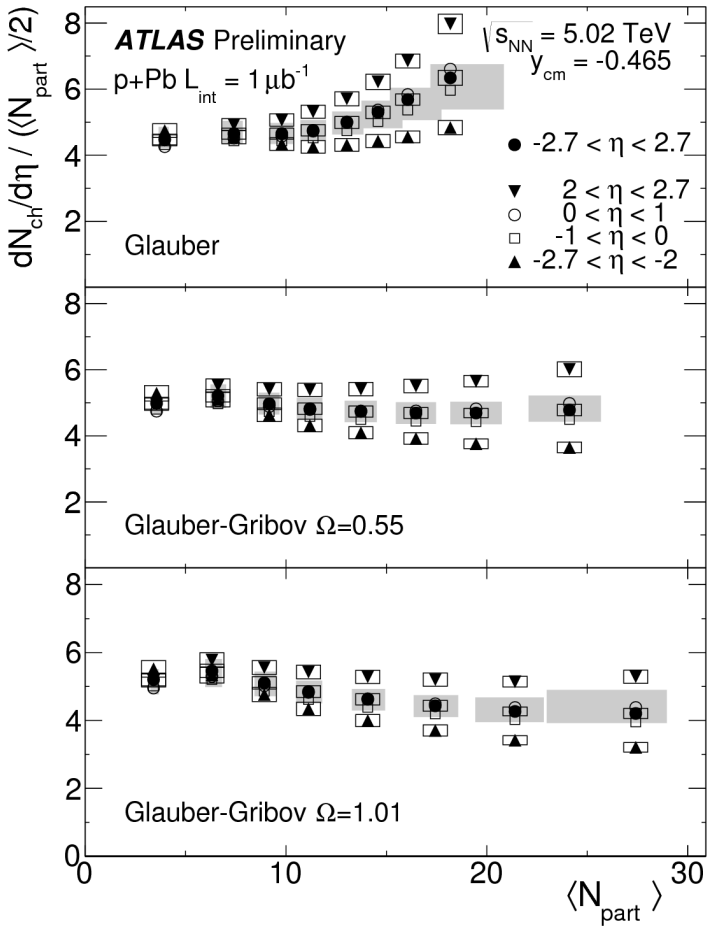
- In p+Pb collisions $\langle N_{\mathrm{coll}} \rangle = \langle N_{\mathrm{par}} \rangle$ -1
- Ratio (model independent) is plotted three times. Glauber model and two extensions.
- Data consistent with expectations

Geometric scaling

Z bosons



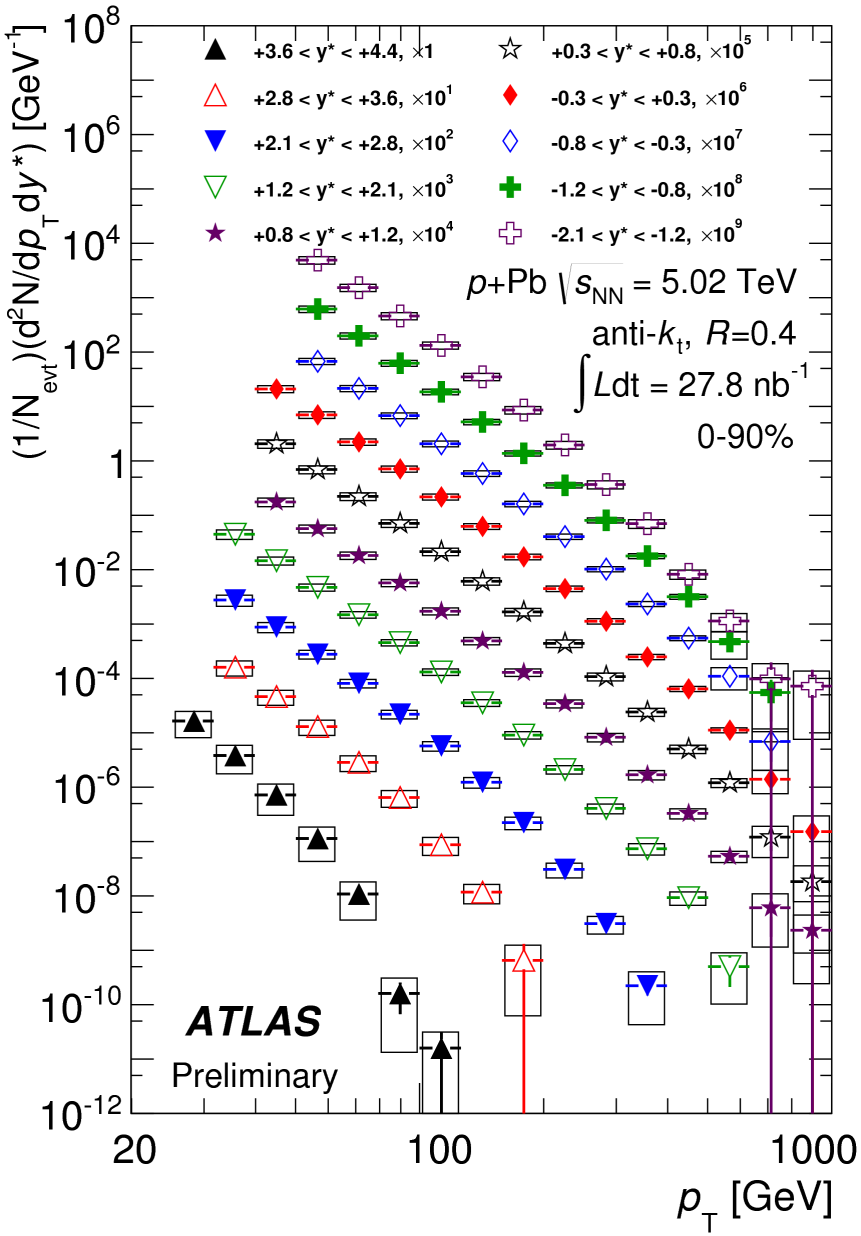
Charged Particles



Scaling behaviour quite sensitive to geometric modelling.
Similar trends in these two different observables.

Jets in p+Pb

- anti-kt R=0.4 calorimeter jets.
- Underlying Event estimated and subtracted with technique designed for Pb+Pb, checked with *pp*
- Measured in intervals of $y^* = y - \Delta y$, p_T and centrality.



Central to Peripheral Ratio

Null Hyphothesis

p+Pb collisions behave like an incoherent superposition of nucleon-nucleon collisions. That is, there is *geometric scaling*

Observable

$$R_{CP} = \frac{(1/N_{\mathrm{evt}})dN^2/dp_{\mathrm{T}}dy^*}{(1/N_{\mathrm{evt}})dN^2/dp_{\mathrm{T}}dy^*} \times R_{\mathrm{coll}}$$

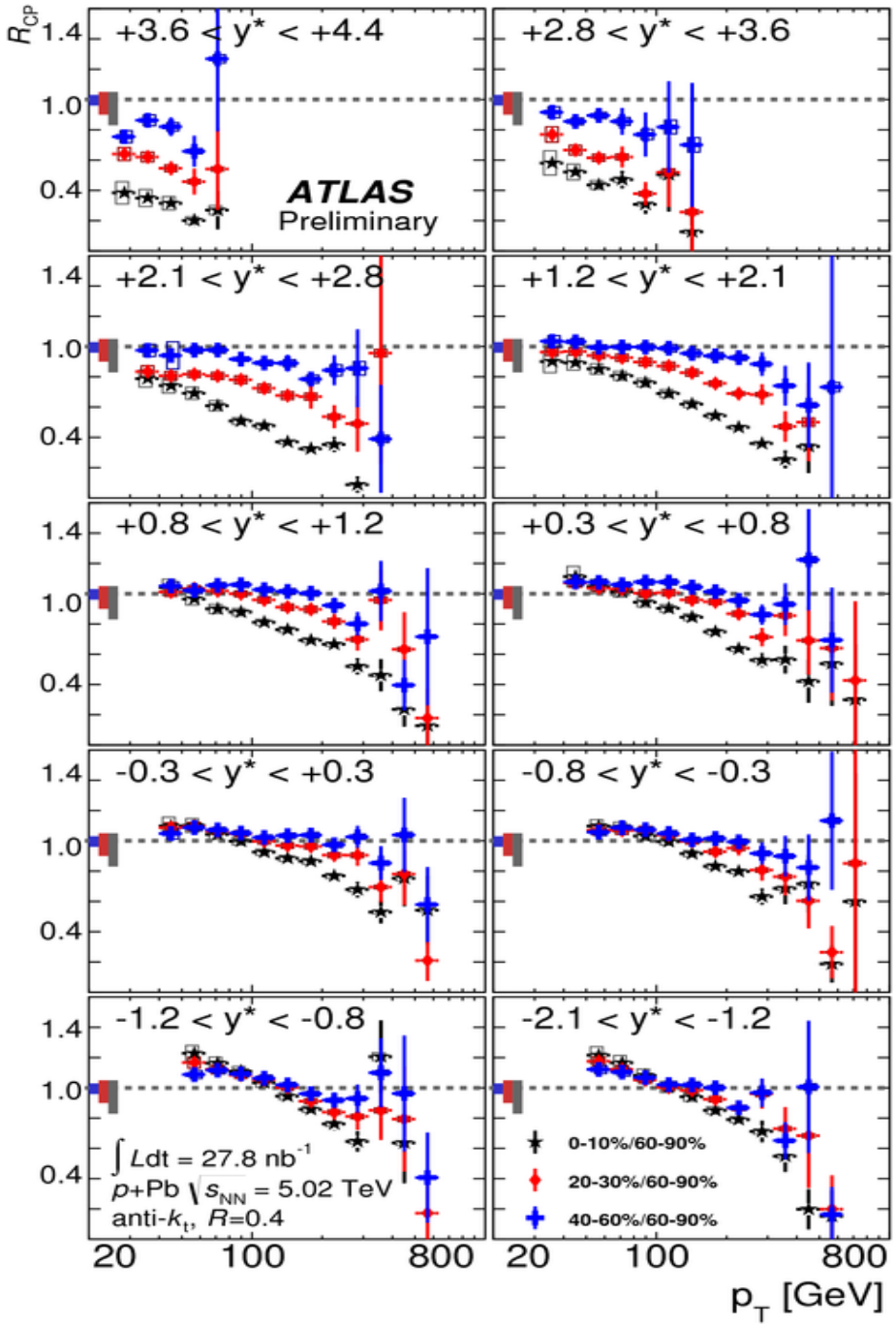
- Per-event yield in Central p+Pb collisions.
- Per-event yield in Peripheral p+Pb collisions.
- Ratio of $\langle N_{coll} \rangle$ at central and peripheral. Glauber model

In the absence of nuclear effects, $R_{CP} \approx 1$.

Jet R_{CP}

$y^* > 0$ is proton-going.

- Larger suppression at large p_T.
- Smooth centrality dependence.
- Suppression more pronounced at large y^*, present even at negative y^*



Nuclear modification factor

Null Hyphothesis

p+Pb collisions behave like an incoherent superposition of nucleon-nucleon collisions. That is, there is *geometric scaling*

Observable

$$R_{\mathrm{pPb}} = \frac{(1/N_{\mathrm{evt}})dN^2/dp_{\mathrm{T}}dy^*}{T_{\mathrm{pA}} \times d\sigma^2/dp_{\mathrm{T}}dy^*}$$

- Per-event yield in p+Pb collisions at $\sqrt{s} = 5.02$ TeV
- Cross-section in pp collisions at $\sqrt{s} = 2.76$ TeV x_T-scaled to $\sqrt{s}$ =5.02 TeV .
- Nuclear thickness function $\propto \langle N_{coll} \rangle$, from Glauber Model.

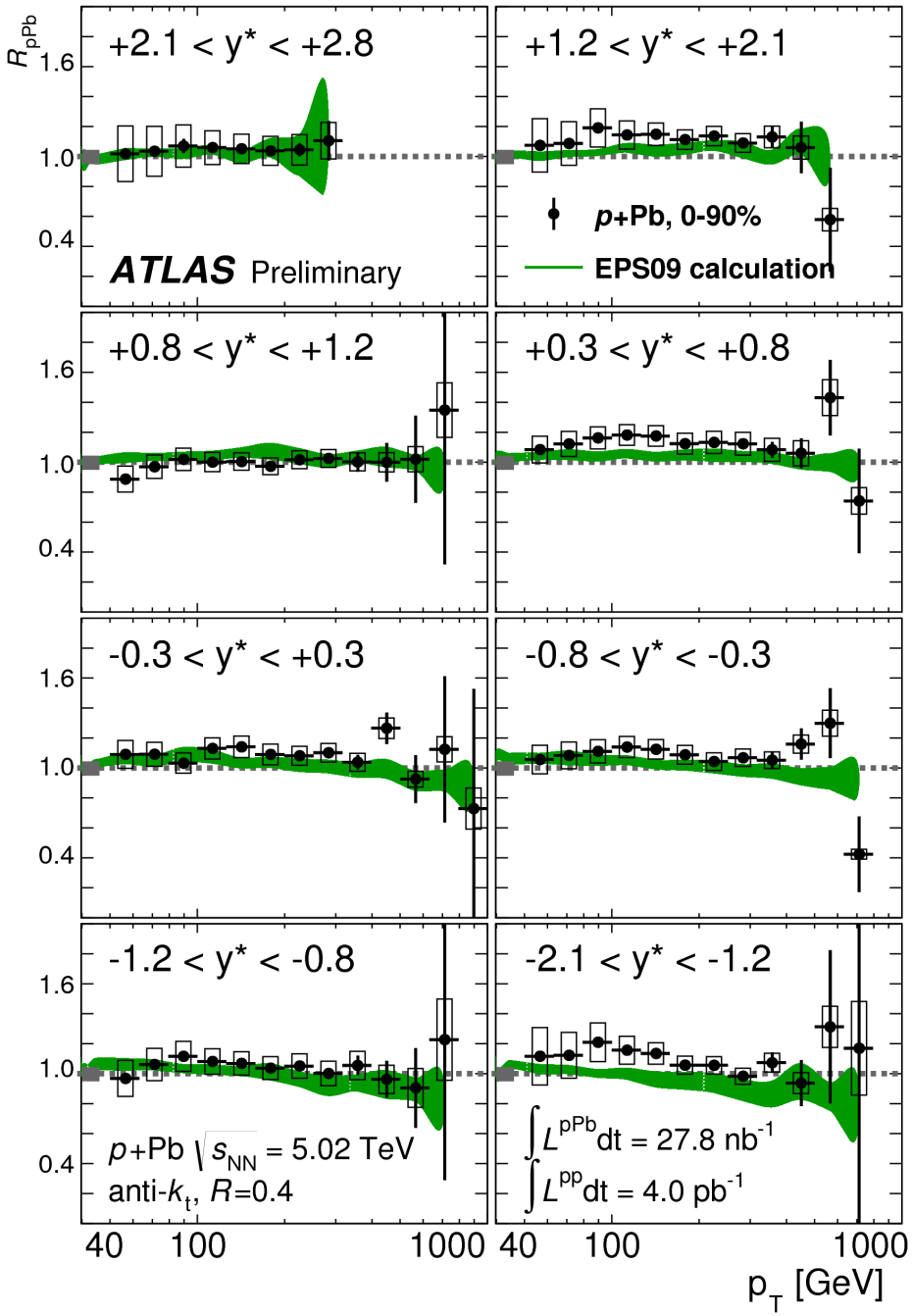
In absence of nuclear effects

$$R_{\mathrm{pPb}} = 1$$

Jet R_{pPb} integrated in centrality.

$y^* > 0$ is proton-going.

- Includes events in 0-90% centrality.
- $\approx$ 5–10% enhancement over geometric scaling.
- Consistent with predictions, nPDF EPS09.

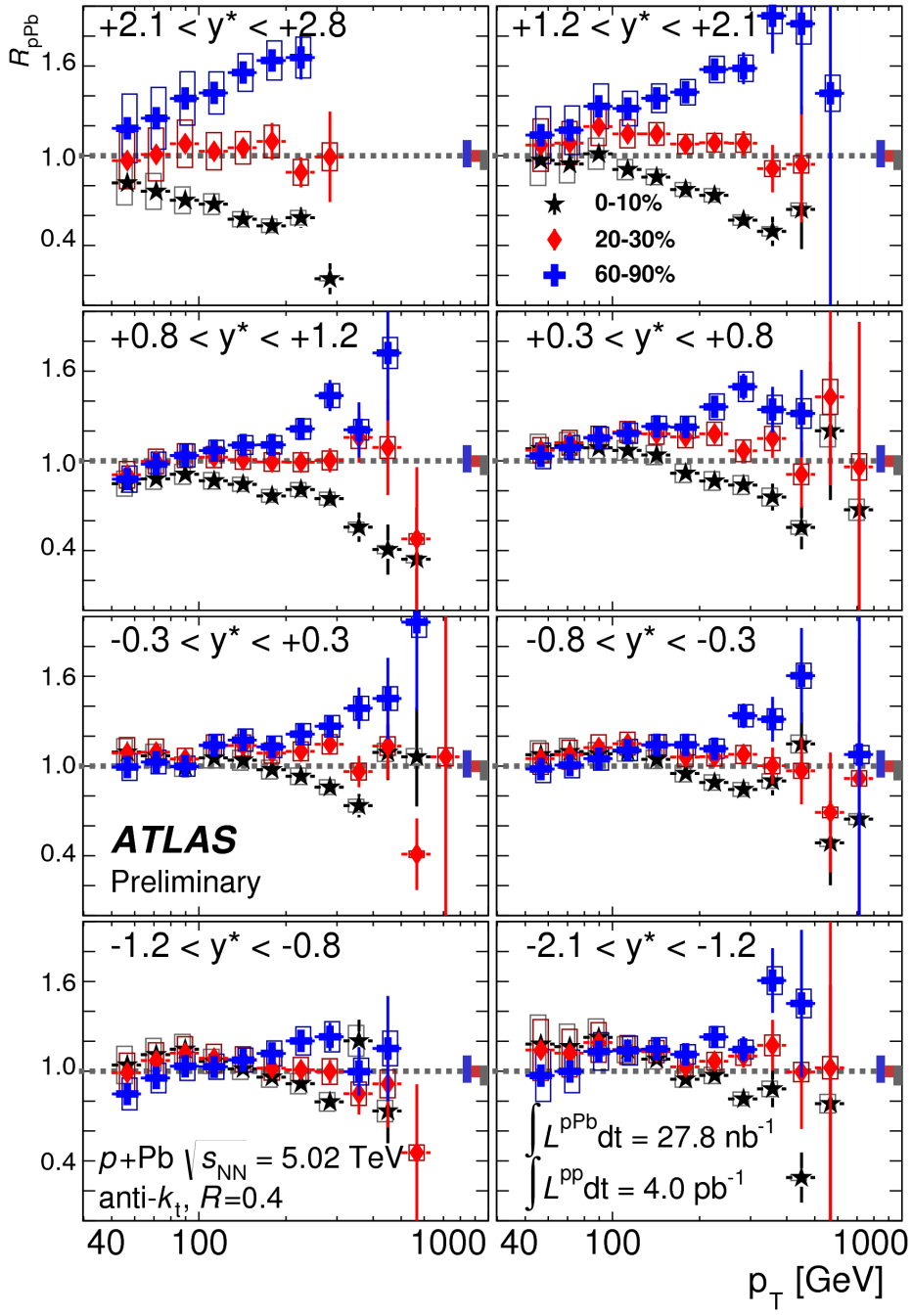


Jet R_{pPb} vs centrality.

$y^* > 0$ is proton-going.

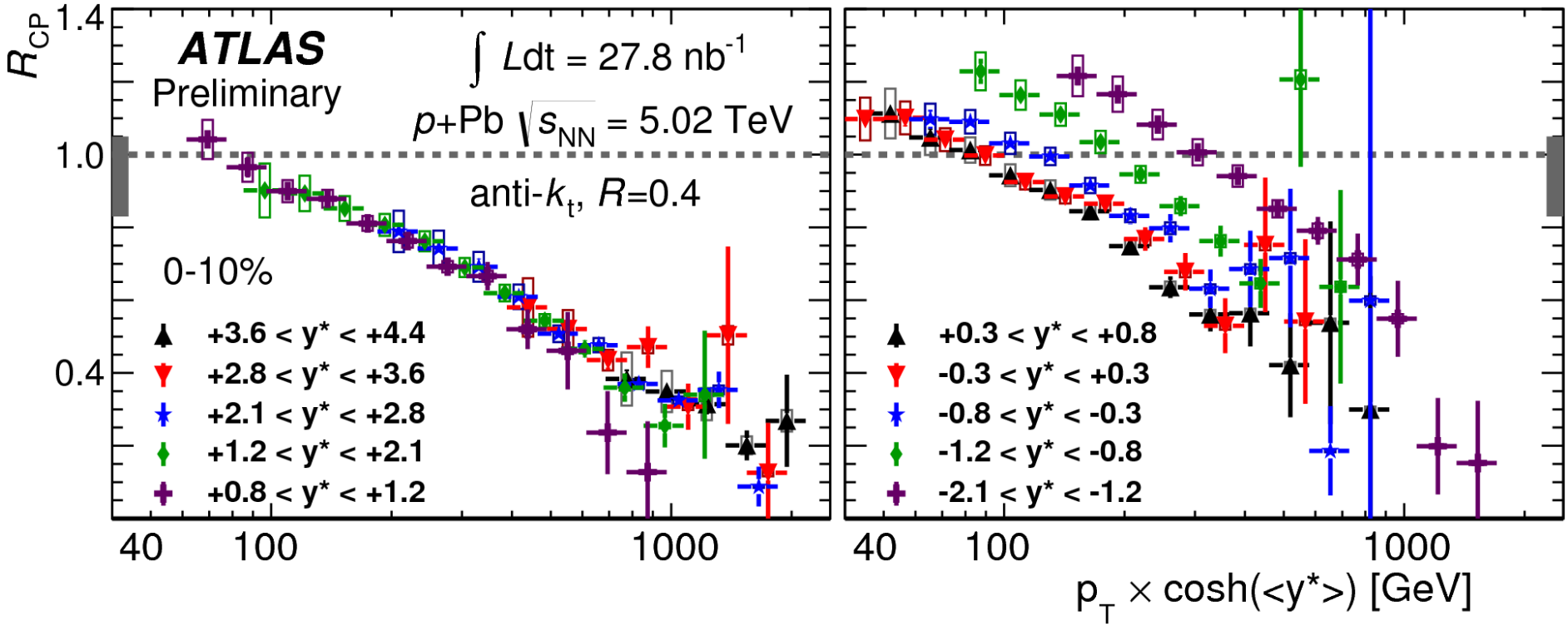
0-10% centrality. Suppressed.
60-90% centrality Enhanced!

- Larger modifications at large p_T and forward y^*
- Geometric scaling at low p_T and backward y^*



R_{CP} vs p

If the data is presented vs $p = p_T \cosh(y^*)$ (total jet energy)

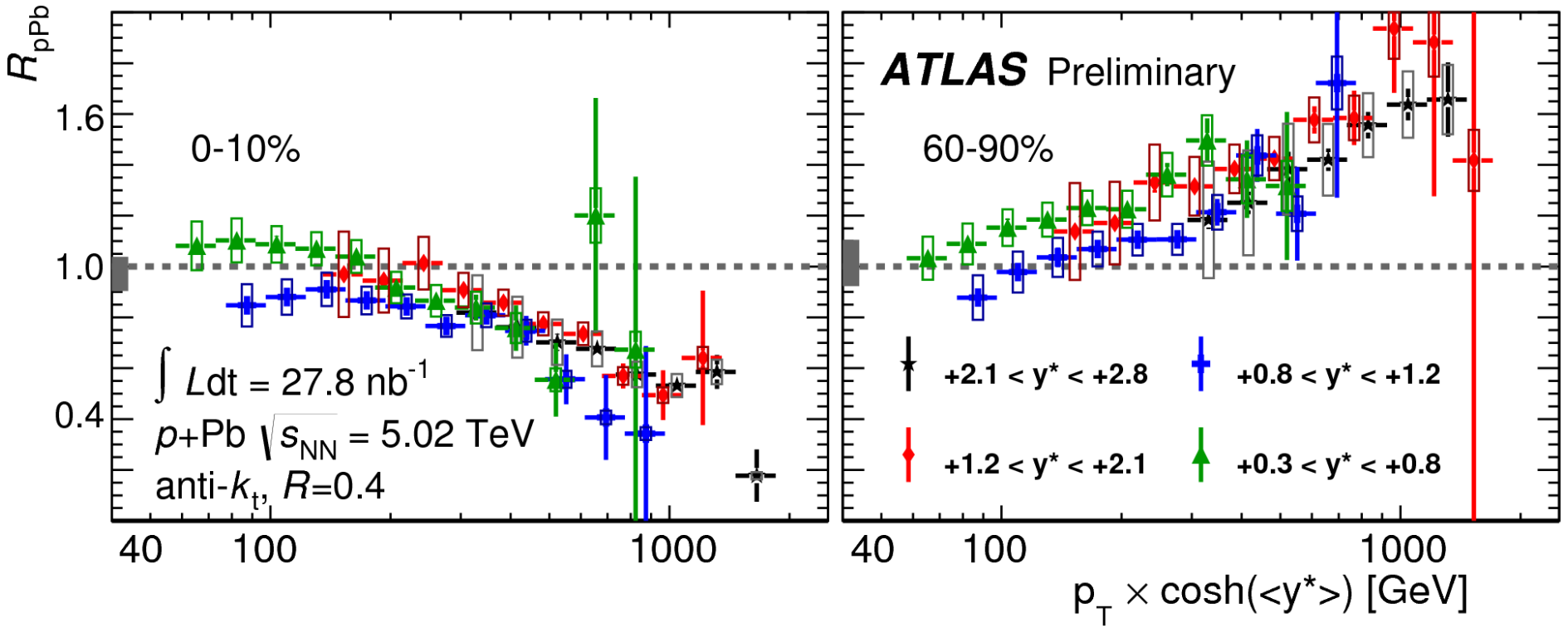


$y^* > 0$ is proton-going.

- Data at forward y^* follow same trend.
- Implications for underlying suppression mechanism?

R_{pPb} vs p in central and peripheral events.

If the data is presented vs $p = p_T \cosh(y^*)$ (total jet energy)

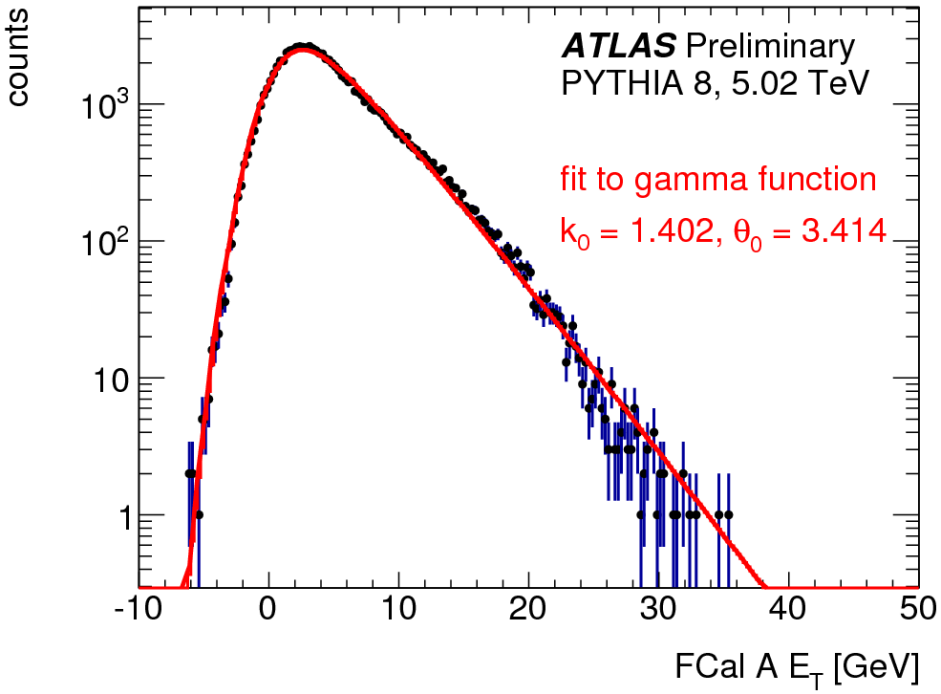


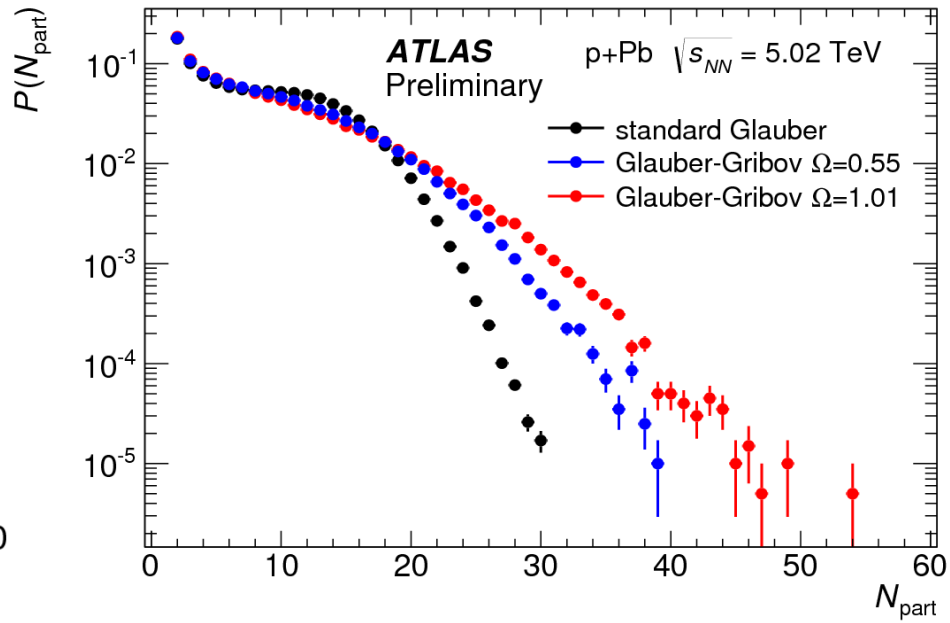
- Jet energy scaling less perfect, but present in both central and peripheral events.

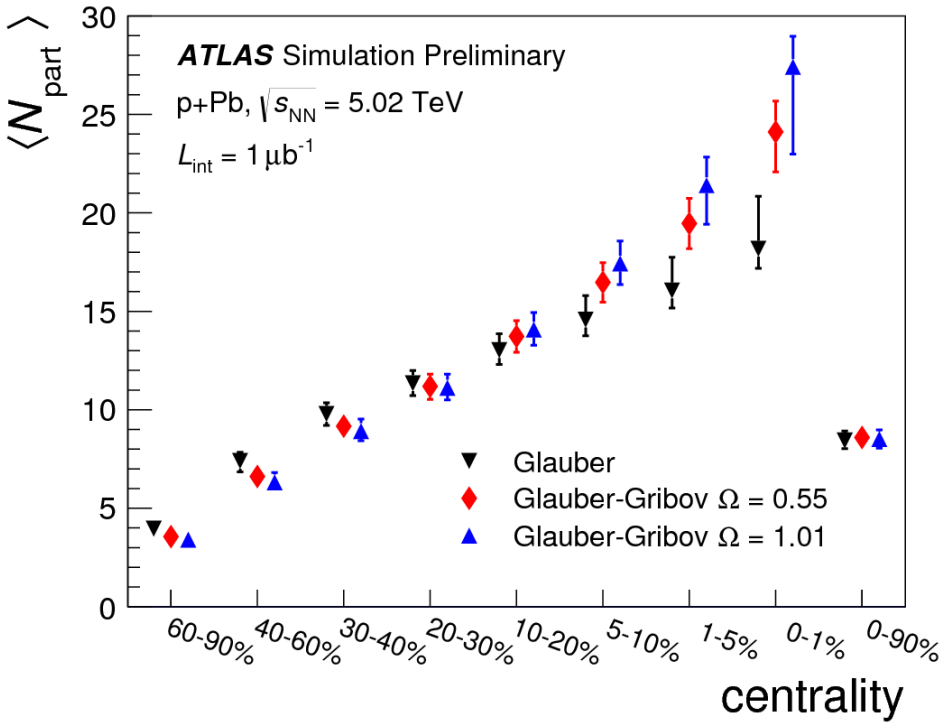
Conclusions

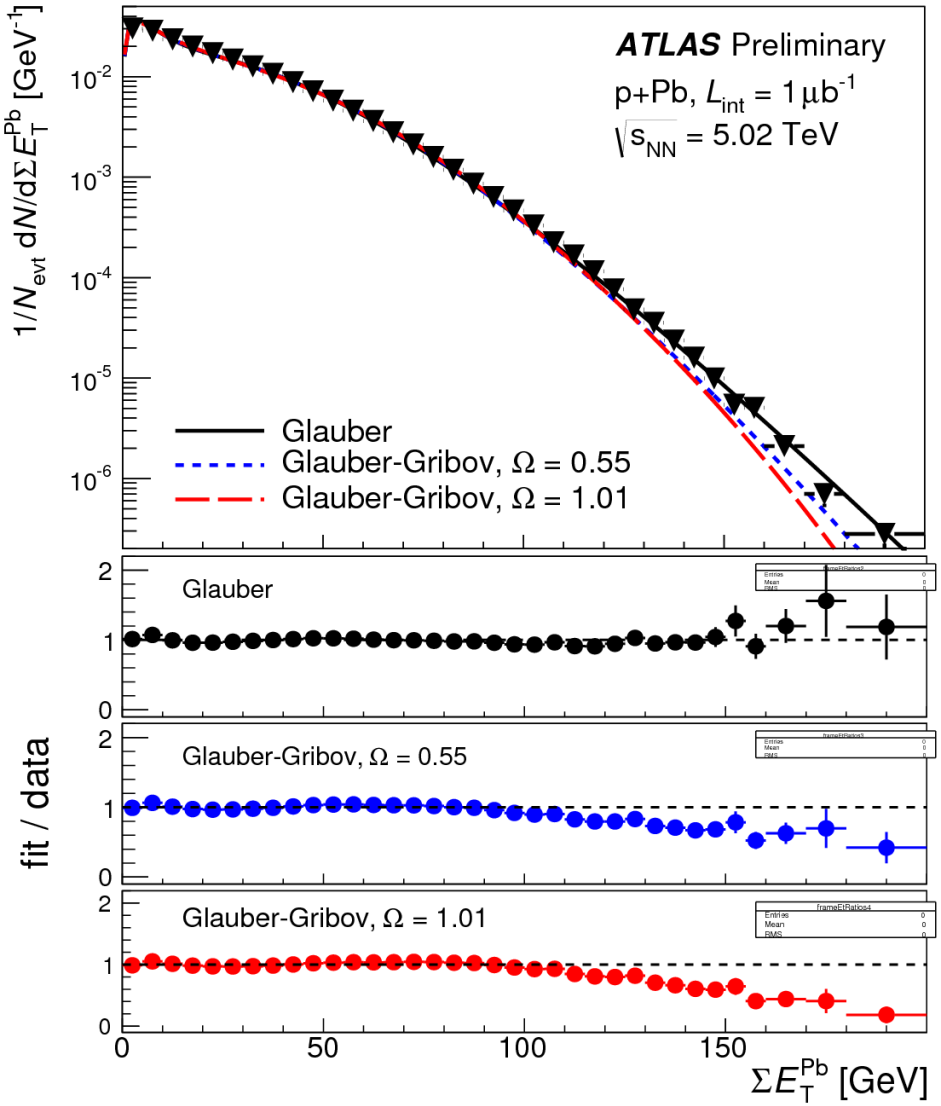
- $dN/d\eta$ shows strong centrality dependent asymmetry.
  - Almost linear η dependence when scaled by peripheral (proxy to pp).
- Z rapidity cross-sections show significant asymmetry.
  - Centrality dependent.
- Scaled Z bosons and $dN/d\eta$ show similar N_{part} dependence.
  - Behaviour dependent on geometric model.
  - Show the importance of considering fluctuations in σ_{NN}
- Jet rates mildly enhanced in 0-90% centrality.
  - Consistent with nPDFs expectations
- Strong centrality dependence effects in jets yields.
  - At high p_T, suppression for central events and enhancement for peripheral events.

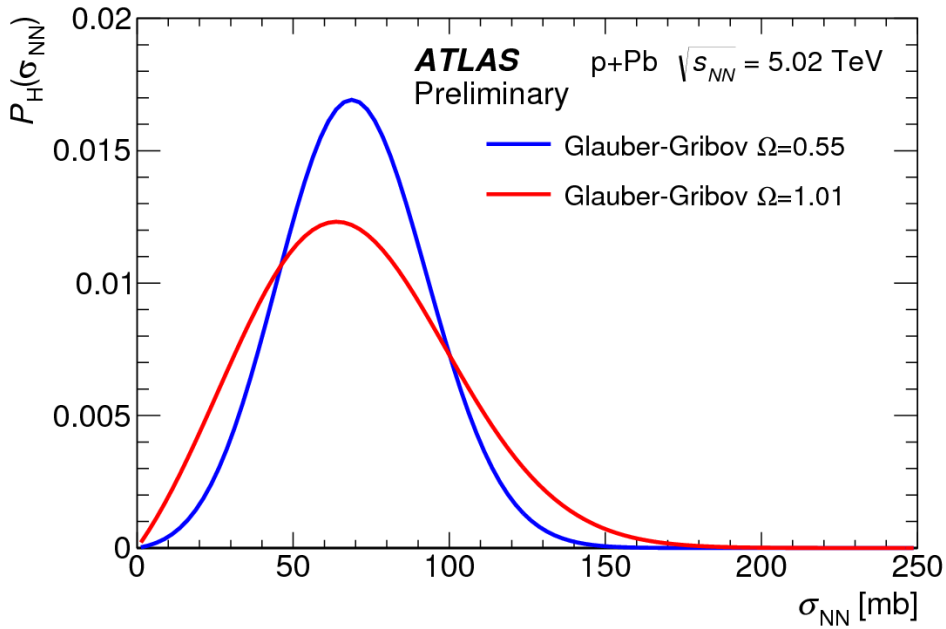
Stay tuned for more p+Pb results: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HeavyIonsPublicResults

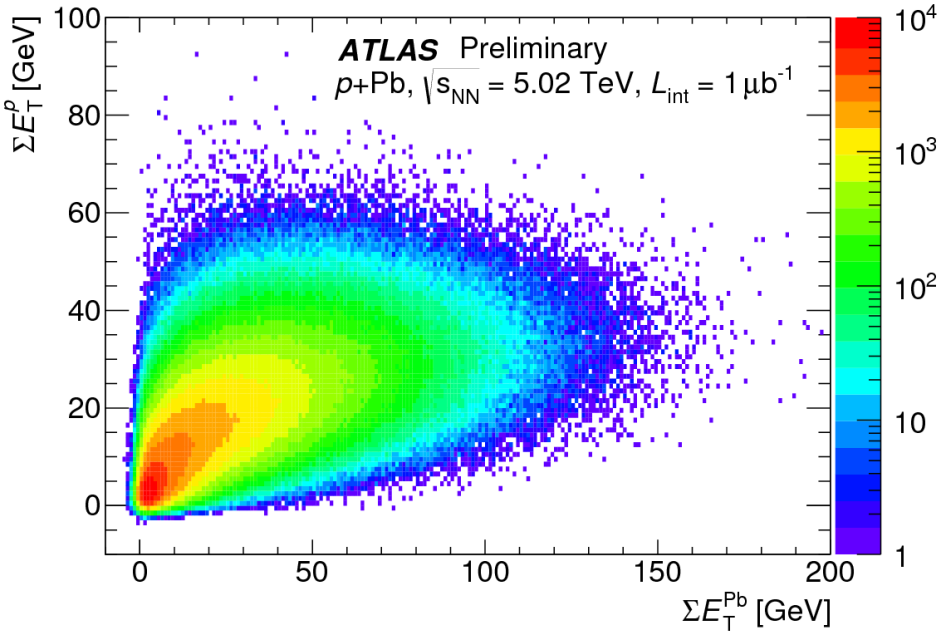

counts
ATLAS Preliminary
PYTHIA 8, 5.02 TeV
fit to gamma function
k_0 = 1.402, θ_0 = 3.414
FCal A E_T [GeV]

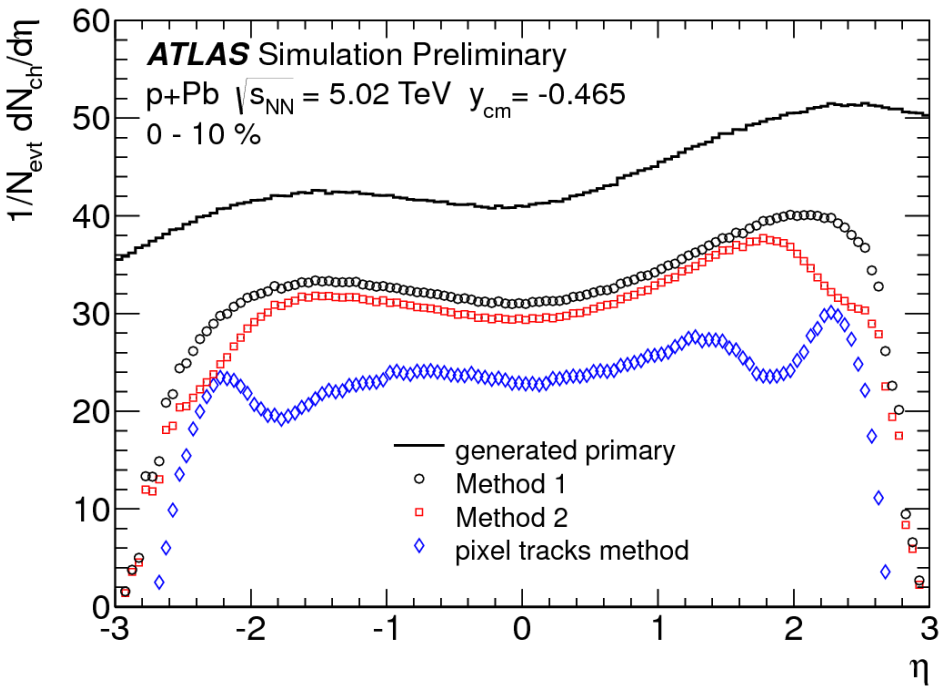

$P(N_{part})$
ATLAS
Preliminary
p+Pb $\sqrt{s_{NN}}$ = 5.02 TeV
standard Glauber
Glauber-Gribov Ω=0.55
Glauber-Gribov Ω=1.01
N_{part}

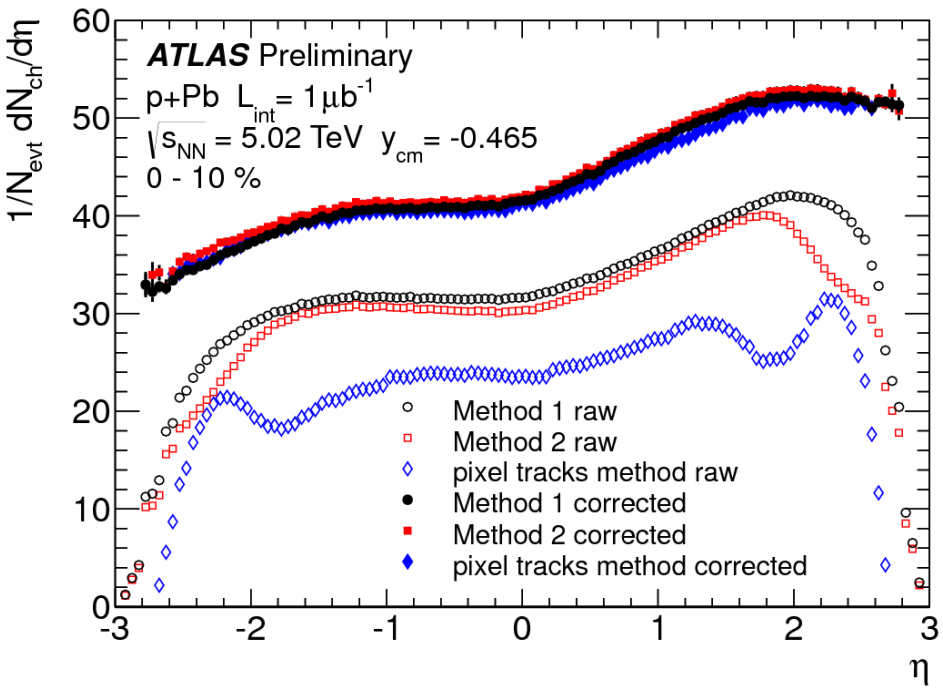

ATLAS Simulation Preliminary
p+Pb, √sNN = 5.02 TeV
Lint = 1 μb-1
Glauber
Glauber-Gribov Ω = 0.55
Glauber-Gribov Ω = 1.01
⟨Npart⟩
centrality
60-90%
40-60%
30-40%
20-30%
10-20%
5-10%
1-5%
0-1%
0-90%

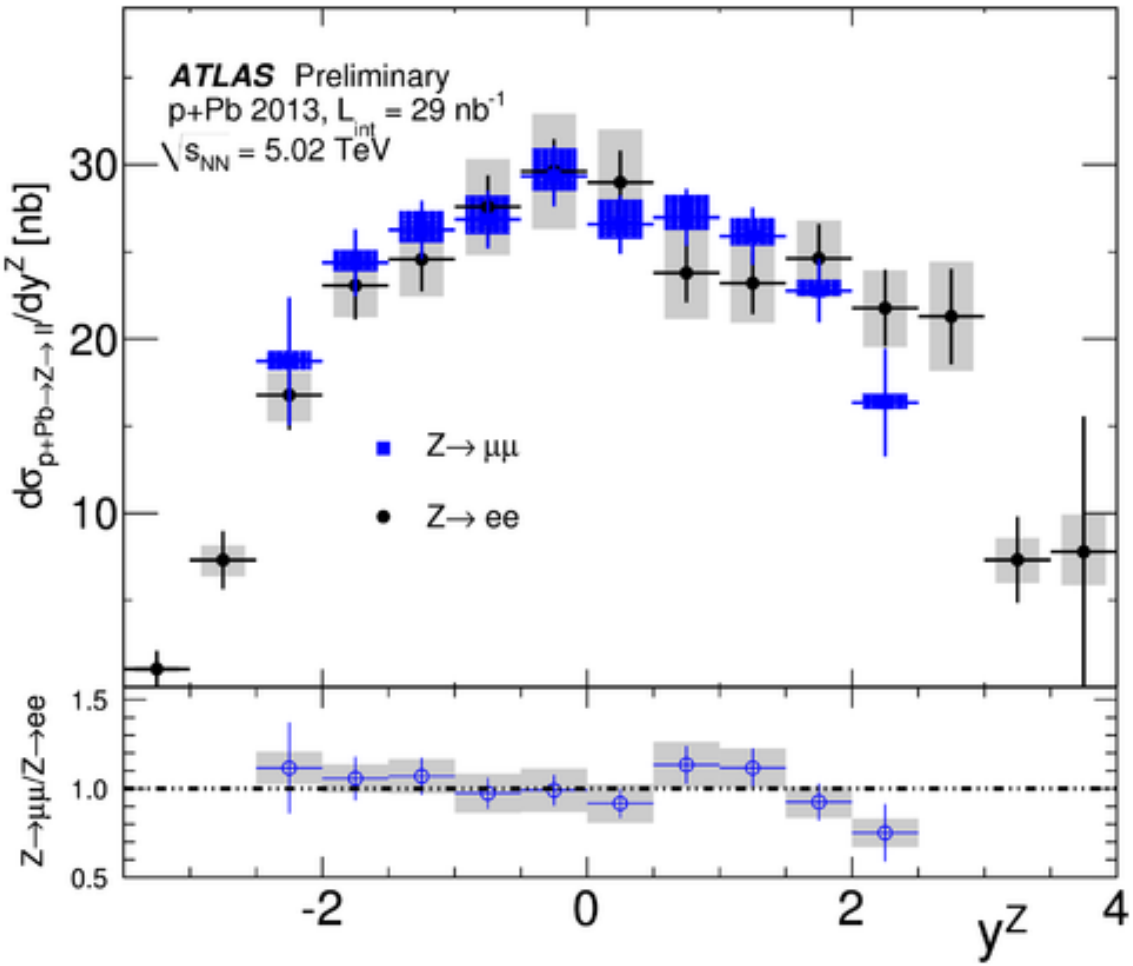

ATLAS Preliminary
p+Pb, Lint = 1 μb-1
√sNN = 5.02 TeV
1/Nevt dN/dΣE_T^Pb [GeV-1]
Glauber
Glauber-Gribov, Ω = 0.55
Glauber-Gribov, Ω = 1.01
fit / data
ΣE_T^Pb [GeV]

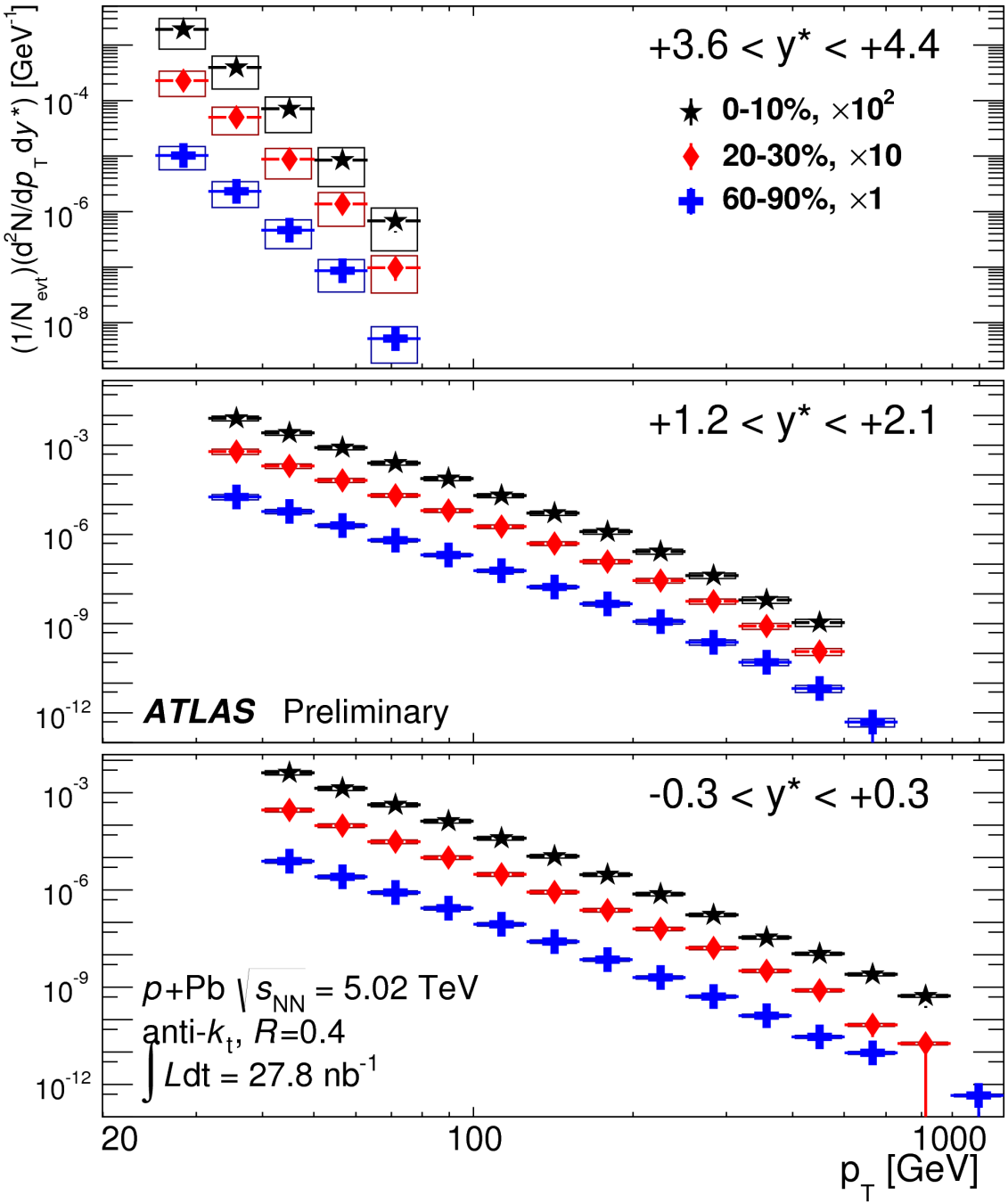

ATLAS
Preliminary
p+Pb $\sqrt{s_{NN}}$ = 5.02 TeV
Glauber-Gribov Ω=0.55
Glauber-Gribov Ω=1.01
$P_H(\sigma_{NN})$
σ_{NN} [mb]
0.02
0.015
0.01
0.005
0
0
50
100
150
200
250


ATLAS Preliminary
p+Pb, √sNN = 5.02 TeV, Lint = 1 μb-1
ΣETPb [GeV]
ΣETp [GeV]
0
50
100
150
200
0
20
40
60
80
100
1
10
10²
10³
10⁴


ATLAS Simulation Preliminary
p+Pb √sNN = 5.02 TeV ycm = -0.465
0 - 10 %
generated primary
Method 1
Method 2
pixel tracks method
1/Nevt dNch/dη
η


ATLAS Preliminary
p+Pb Lint = 1μb-1
√sNN = 5.02 TeV ycm = -0.465
0 - 10 %
Method 1 raw
Method 2 raw
pixel tracks method raw
Method 1 corrected
Method 2 corrected
pixel tracks method corrected
1/Nevt dNch/dη
η


ATLAS Preliminary
p+Pb 2013, L_int = 29 nb^-1
√s_NN = 5.02 TeV
Z→ μμ
Z→ ee
dσ_p+Pb→Z→ ll/dy^Z [nb]
Z→μμ/Z→ee
y^Z


+3.6 < y* < +4.4
0-10%, ×10^2
20-30%, ×10
60-90%, ×1
+1.2 < y* < +2.1
ATLAS Preliminary
-0.3 < y* < +0.3
p+Pb √s_NN = 5.02 TeV
anti-k_t, R=0.4
∫ Ldt = 27.8 nb^-1
(1/N_evt)(d^2N/dp_T dy*) [GeV^-1]
p_T [GeV]
20
100
1000