Centrality-dependent *p*+Pb measurements in ATLAS

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BROOKHAVEN NATIONAL LABORATORY

LPCC LHC Physics Centre at CERN

ATLAS EXPERIMENT

Centrality-dependent *p*+Pb Measurements

1. Total charged particle multiplicity, $dN_{ch}/d\eta$
   - $-2.7 < \eta^{lab} < +2.7$, charged particles with $p_T > 0$
   - ATLAS-CONF-2013-096

~1 μb^{-1}

2. Charged particle nuclear modification factors, R_{pPb}
   - $-2 < y^{*} < +2.5$, 0.1 GeV $< p_T <$ 20 GeV
   - 5.02 TeV pp reference: √s-interpolation of 2.76 and 7 TeV data
   - ATLAS-CONF-2013-107

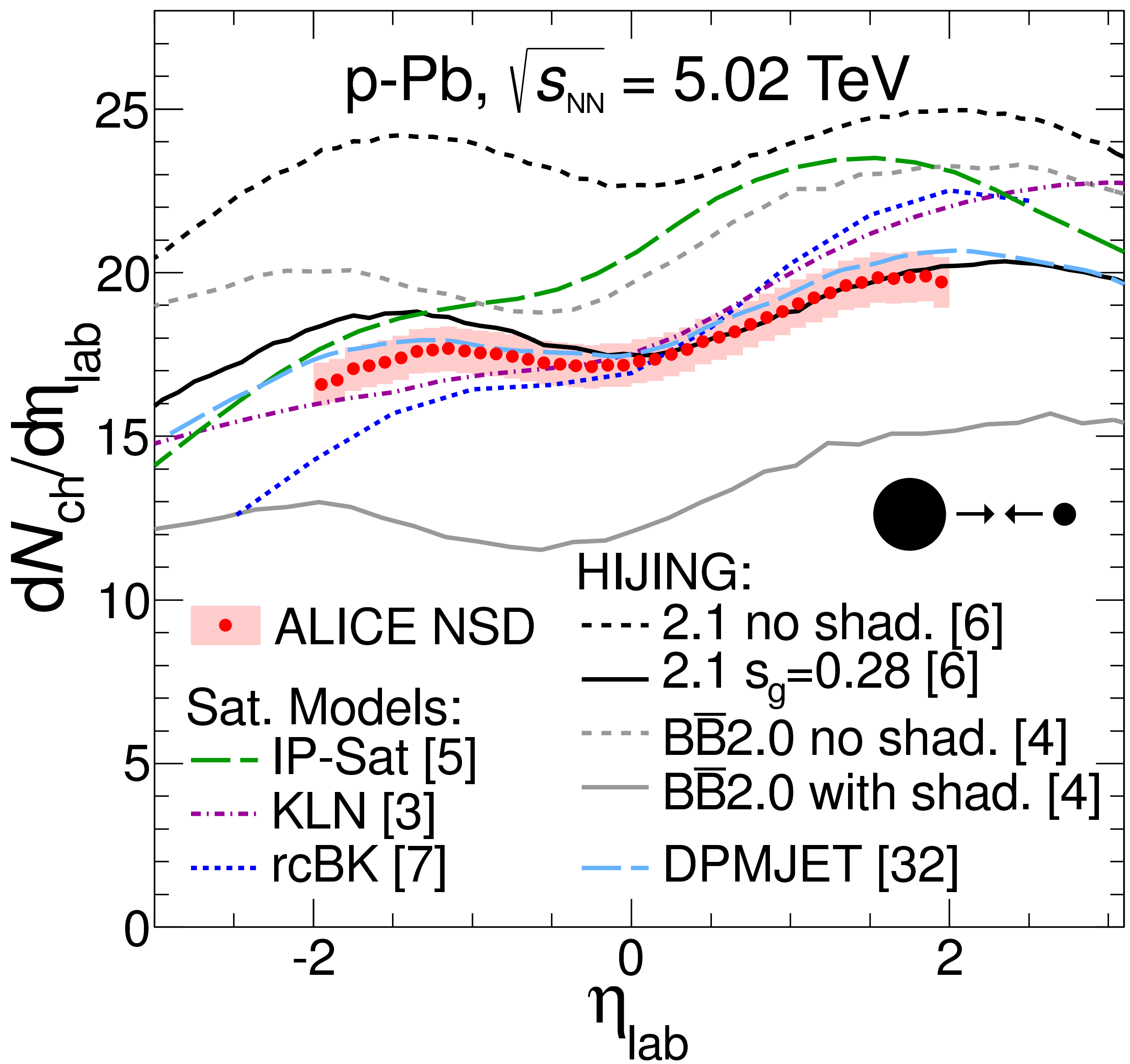
~1 μb^{-1}

3. Jet nuclear modification factors, R_{pPb}^{PYTHIA} and R_{CP}
   - $-4.4 < y^{*} < +0.8$, 25 GeV $< p_T <$ 400 GeV
   - 5.02 TeV pp reference: ATLAS tune of PYTHIA 6.4
   - ATLAS-CONF-2013-105

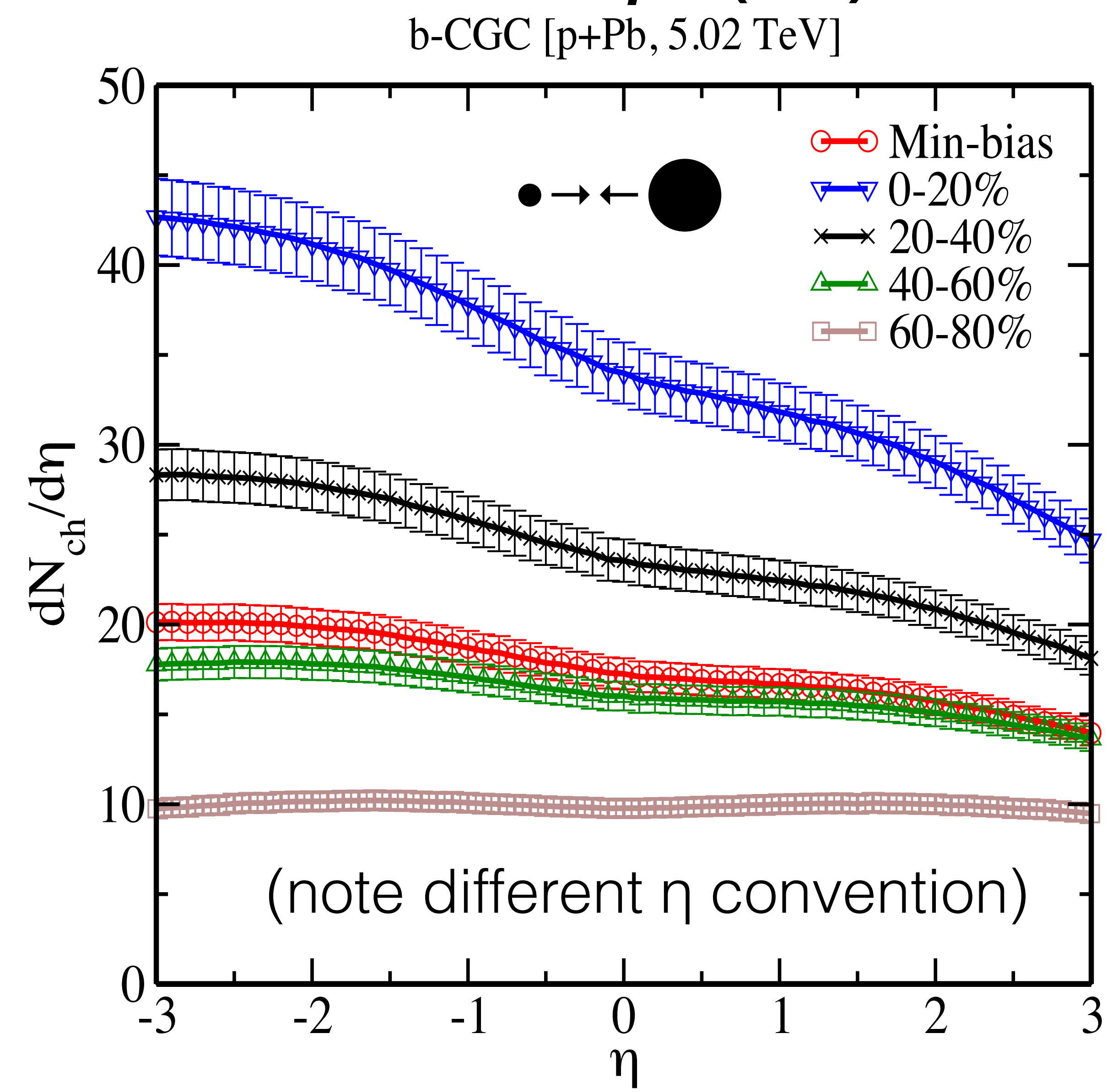
~31 nb^{-1}

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

Soft particle production in $p(d)$+A



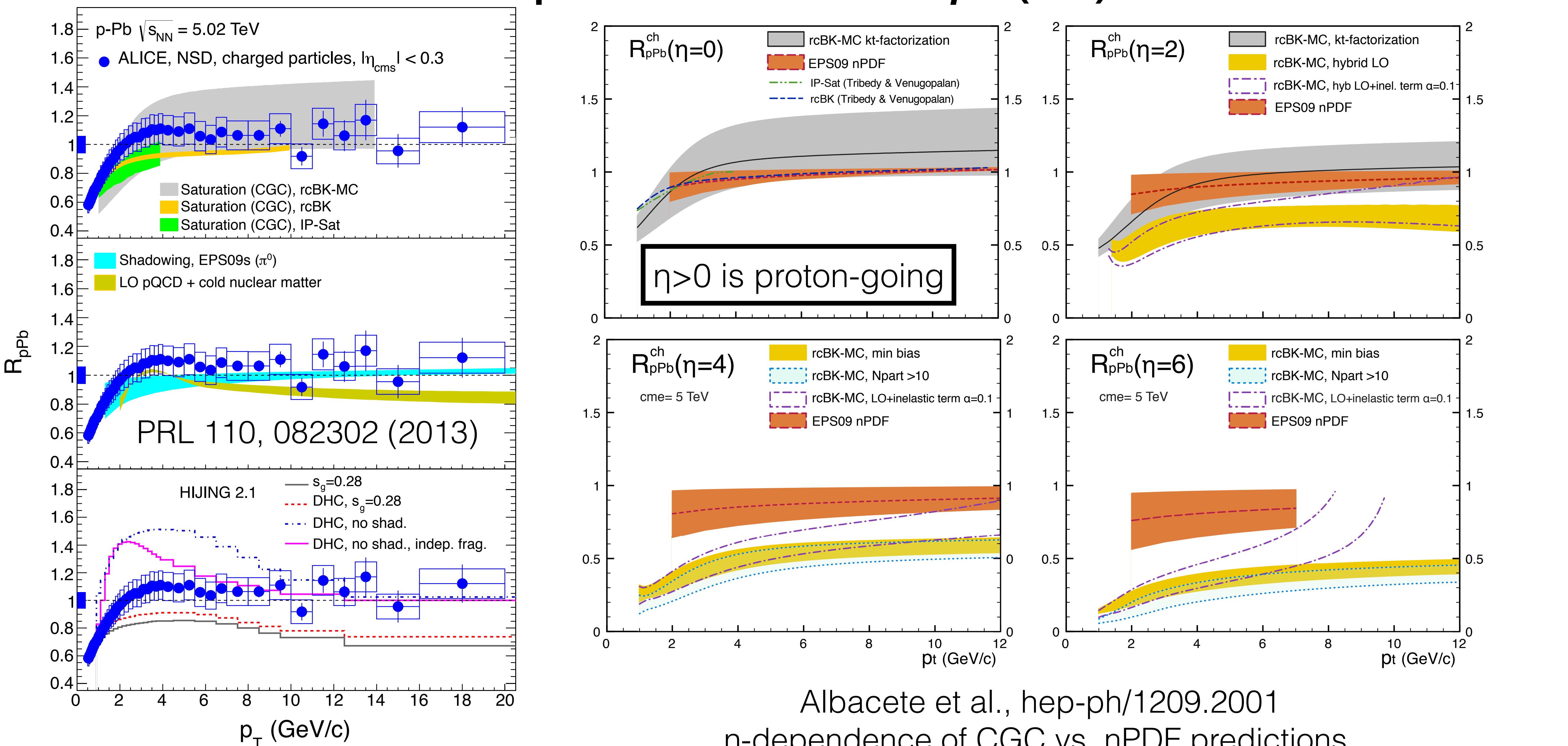
PRL 110, 032301 (2013)



Rezaeian, hep-ph/1210.2385

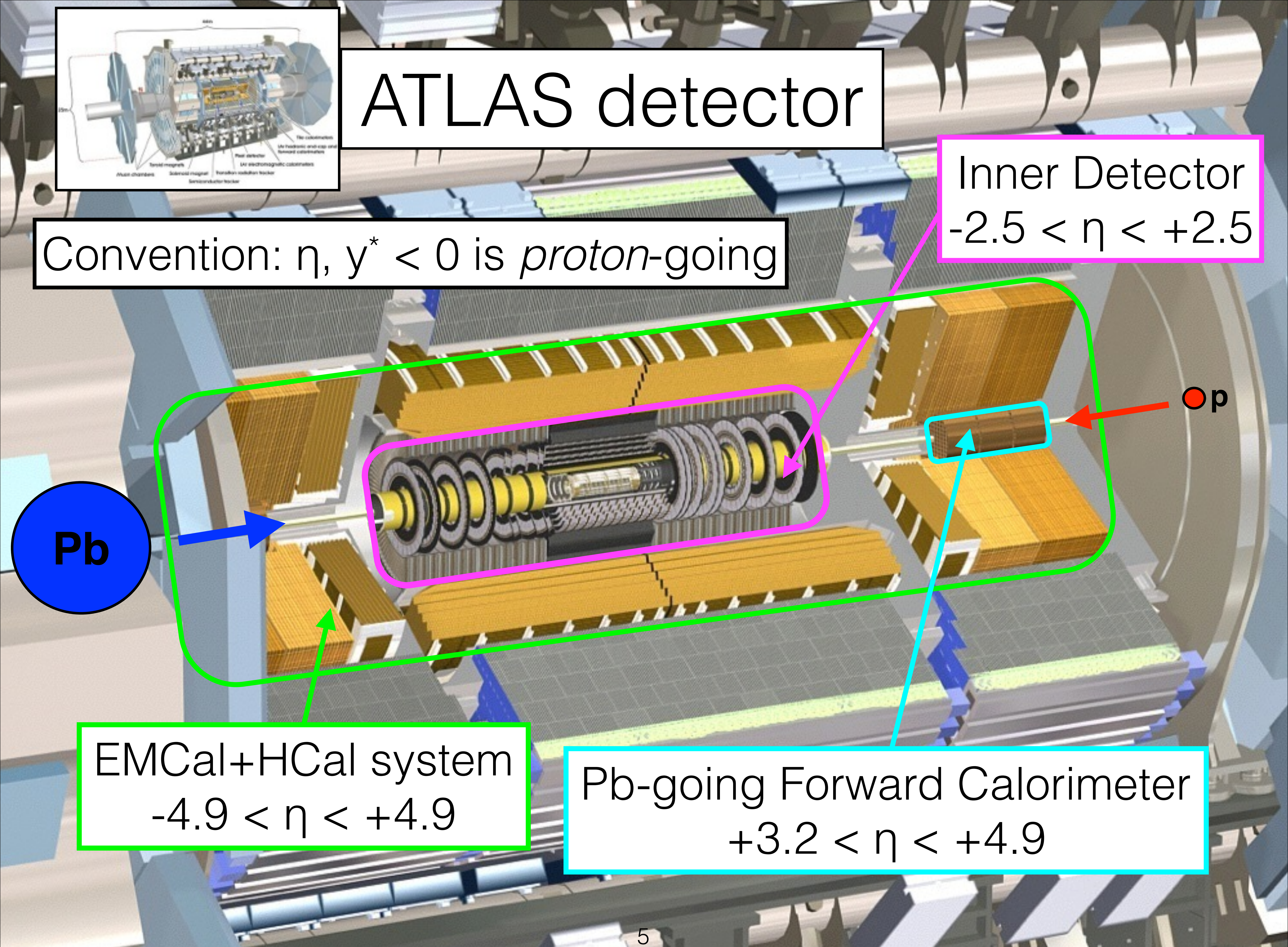
- Total multiplicity: fundamental way to characterize proton-nucleus collisions
  - Sensitive to models of soft particle production and the nuclear wavefunction
  - Centrality-dependent results can provide even more information

Hard probes of $p(d)$+A

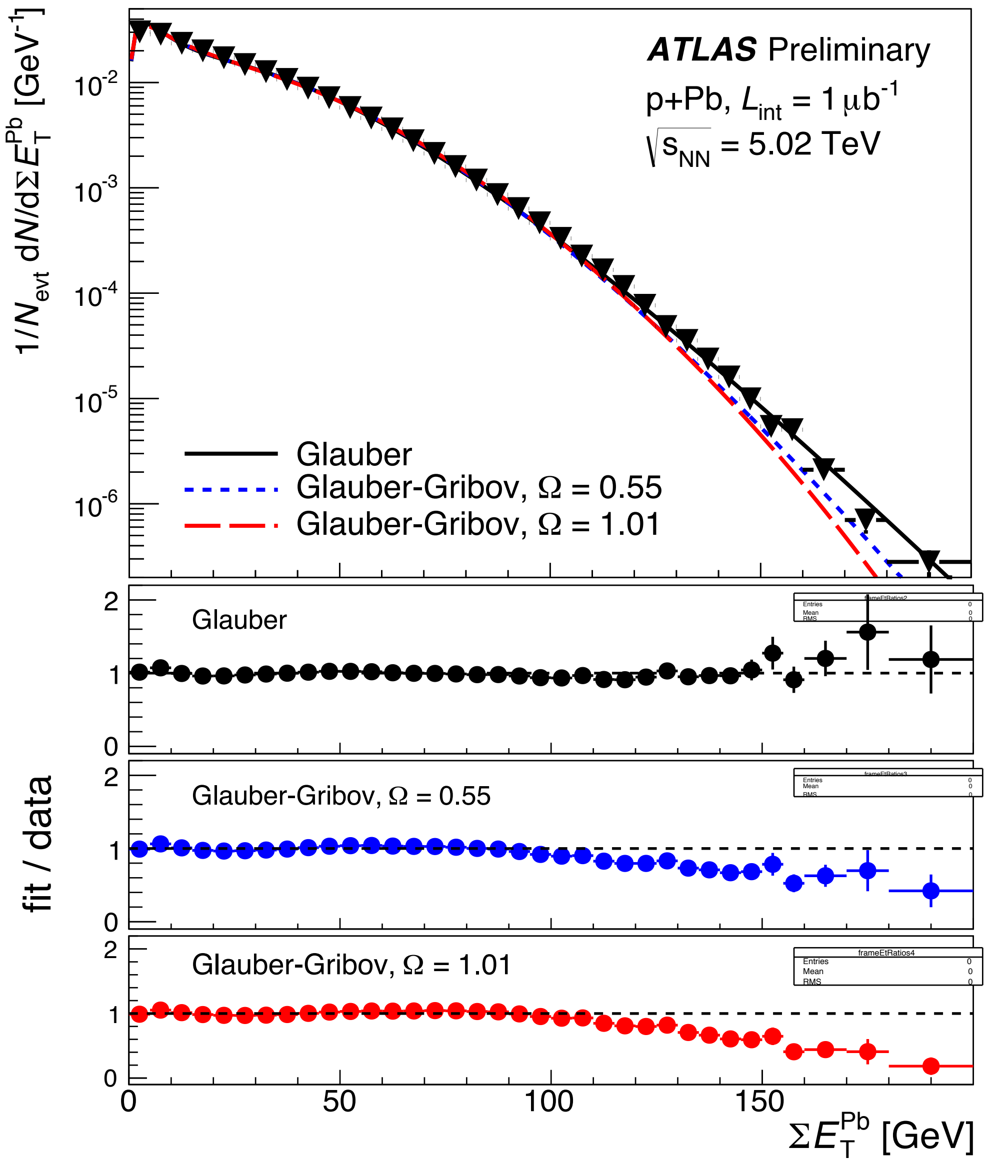


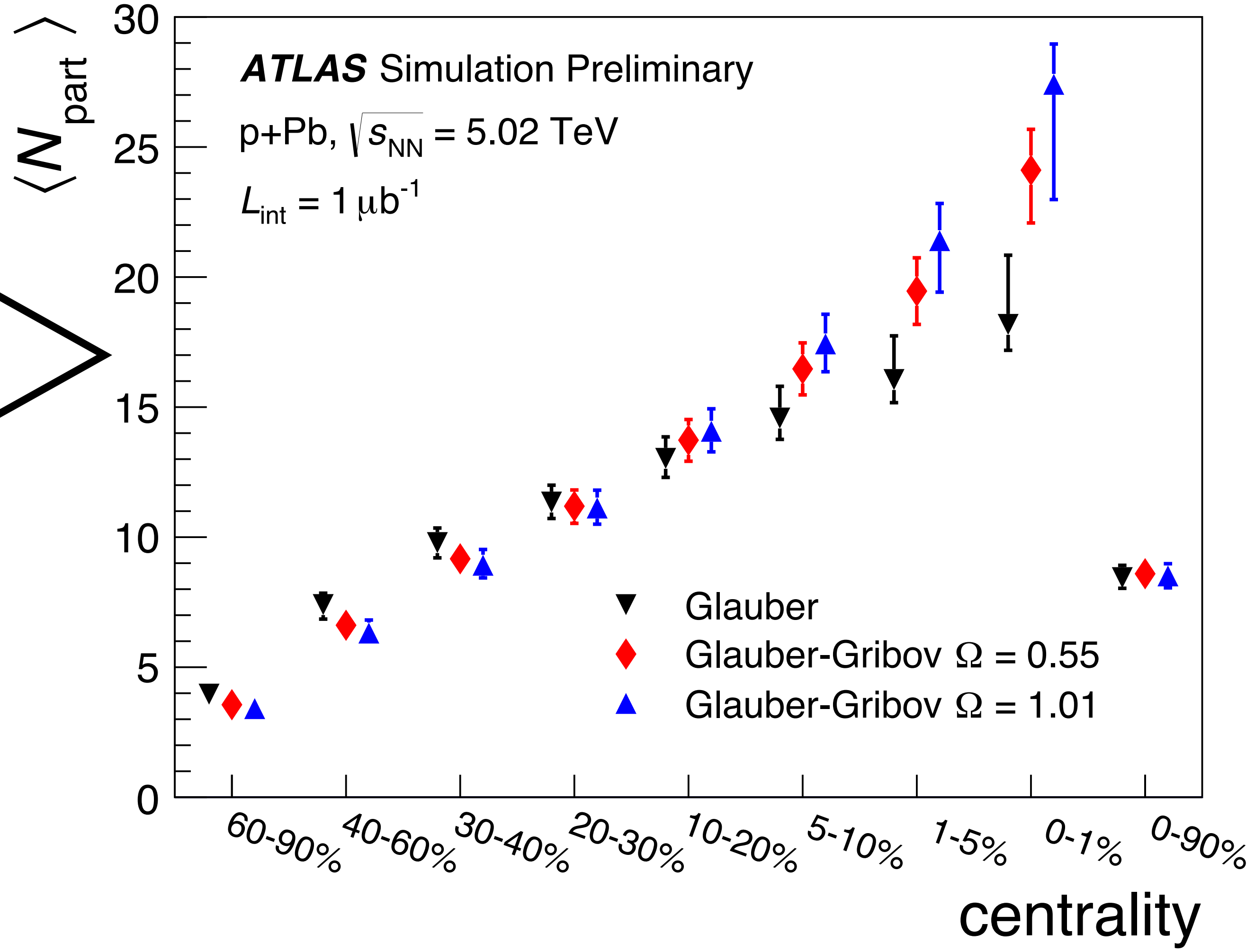
Albacete et al., hep-ph/1209.2001
η-dependence of CGC vs. nPDF predictions

- Hard probes access the partonic content in nuclei
  - Sensitive to initial state energy loss, possible saturation effects, etc.
- Centrality-dependent measurements with a wide kinematic range needed for full picture
  - For example, to probe impact-parameter dependence of the nPDFs


ATLAS detector
Convention: η, y* < 0 is *proton*-going
Inner Detector
-2.5 < η < +2.5
p
Pb
EMCal+HCal system
-4.9 < η < +4.9
Pb-going Forward Calorimeter
+3.2 < η < +4.9

Centrality in *p*+Pb collisions





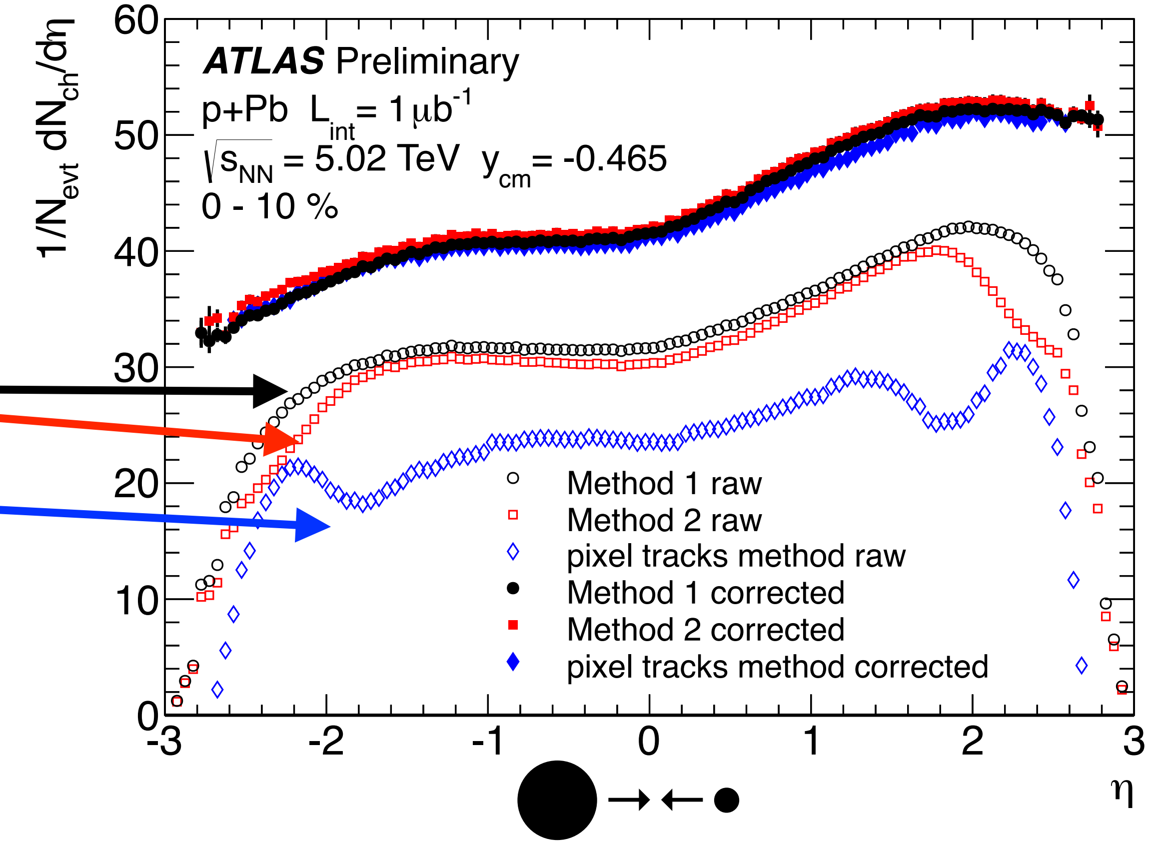
Geometric quantities sensitive to assumptions about the Glauber model

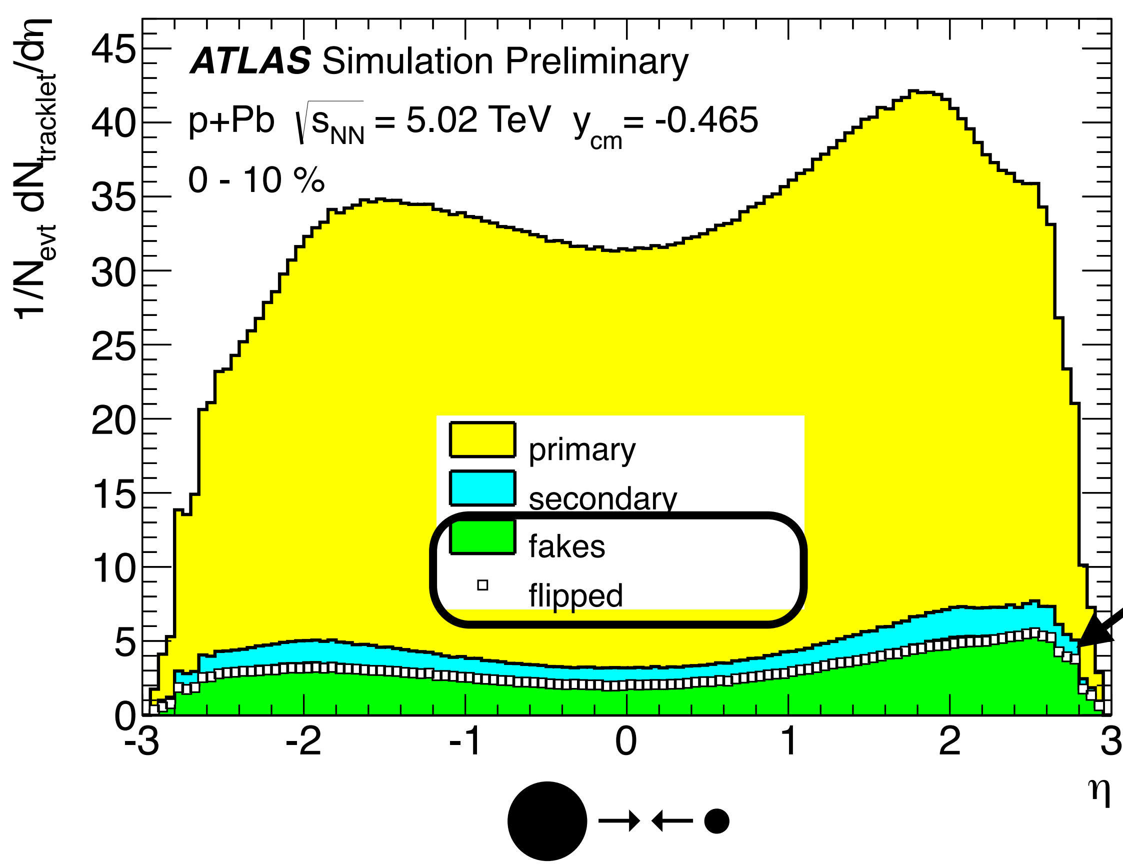
- Centrality determined using ΣE_T in Pb-going FCal, $+3.2 < \eta < +4.9$
  - using the standard Glauber model and two Glauber-Gribov variants as the input $P(N_{part})$ distribution, all three considered "plausible" at this point
  - best fits to the data include non-linear N_{part} dependence & residual diffractive term
- For more detailed discussion, see talk by B. Cole in the morning session

I. Charged particle $dN_{ch}/d\eta$

Charged particle reconstruction

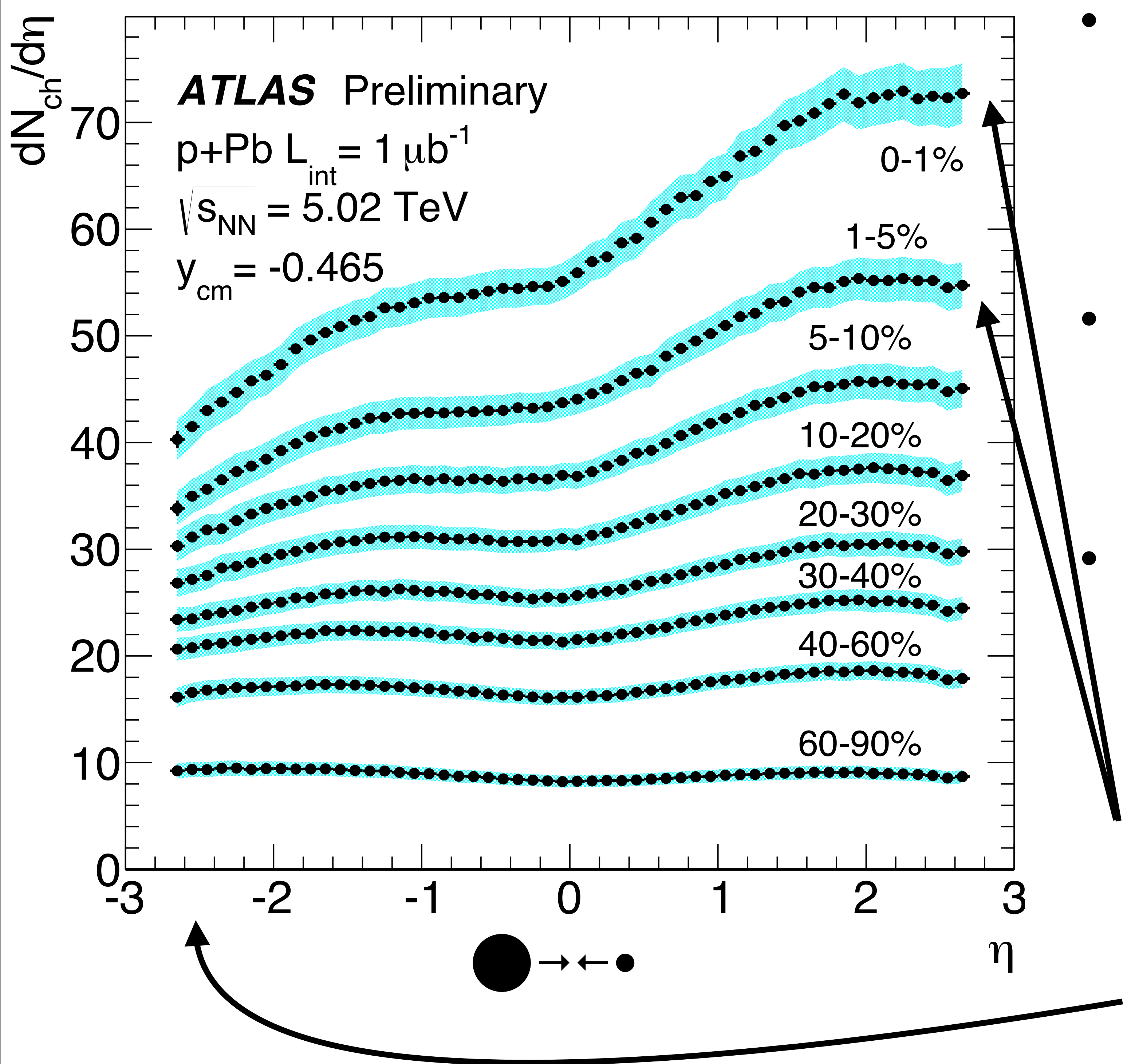
- Hits in the first three Pixel detector layers are used
- Three methods with different systematics:
  - Two 2-point tracklet methods
  - 3-point track method (& extrapolation to $p_T = 0$)
- Consistency in the results after all corrections





- "Fake" tracklets resulting from combinatoric pixel cluster pairs
  - Estimated by 180° flip of pixel clusters in the outer layer
  - Procedure benchmarked in MC
- Fake contribution statistically subtracted

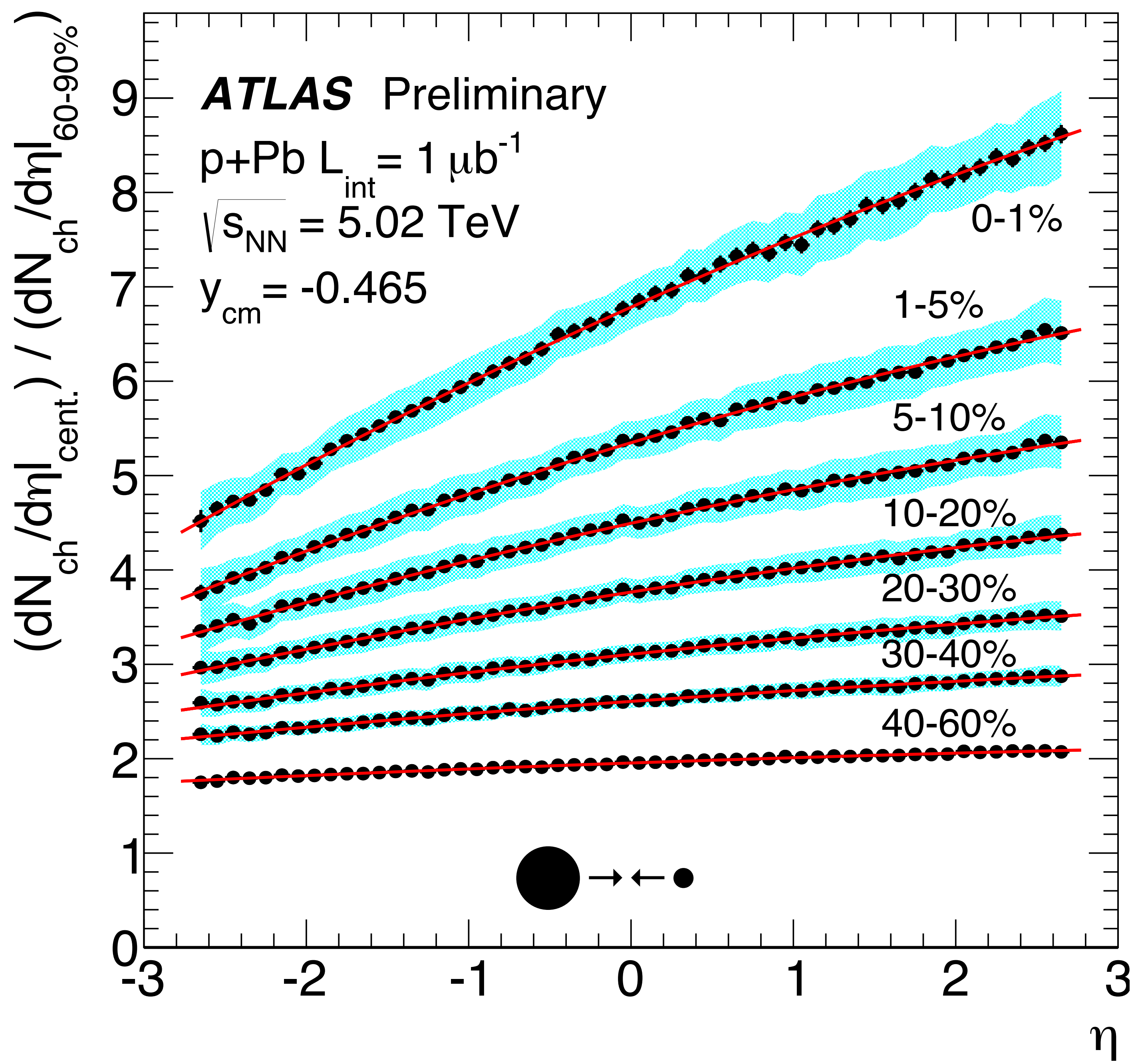
$dN_{ch}/d\eta$ vs. centrality



- 8 centrality bins from 0-1% to 60-90%
    - visible double peak structure
- Distribution becomes more asymmetric in more central events
- Large difference in $dN_{ch}/d\eta$ between adjacent centrality classes
    - especially between 0-1% and 1-5% centralities!
    - centrality dependence even at η = -2.7

$dN_{ch}/d\eta$ central/peripheral ratio

- Divided by $dN_{ch}/d\eta$ in 60-90% centrality
  - (similar to an R_{CP} but without removing any geometric factors — yet)
  - double peak divides out
- Ratio grows linearly with η!
  - with a centrality-dependent slope

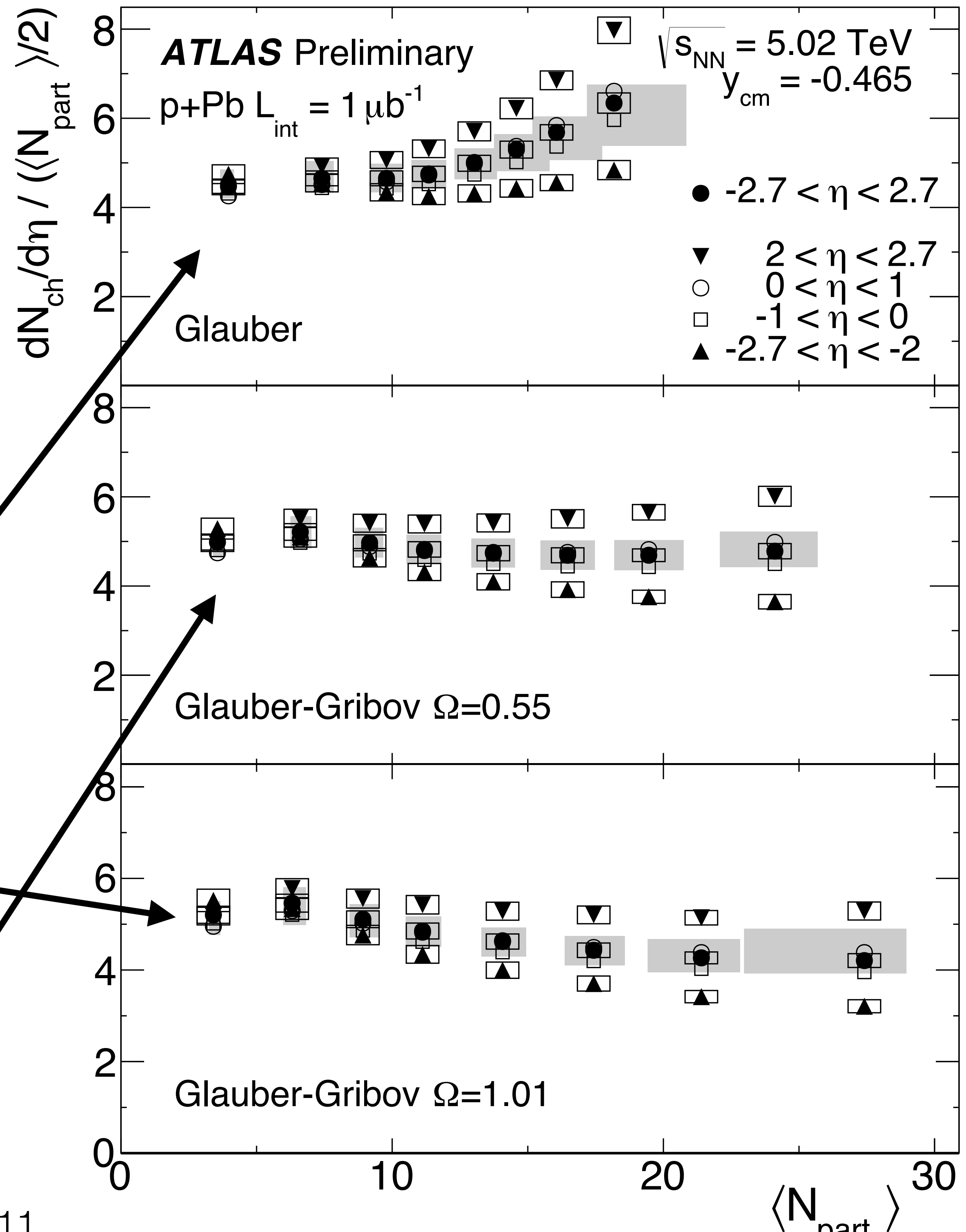


- Note: factor of 2 change in 0-1% bin from η = -2.7 to η = +2.7

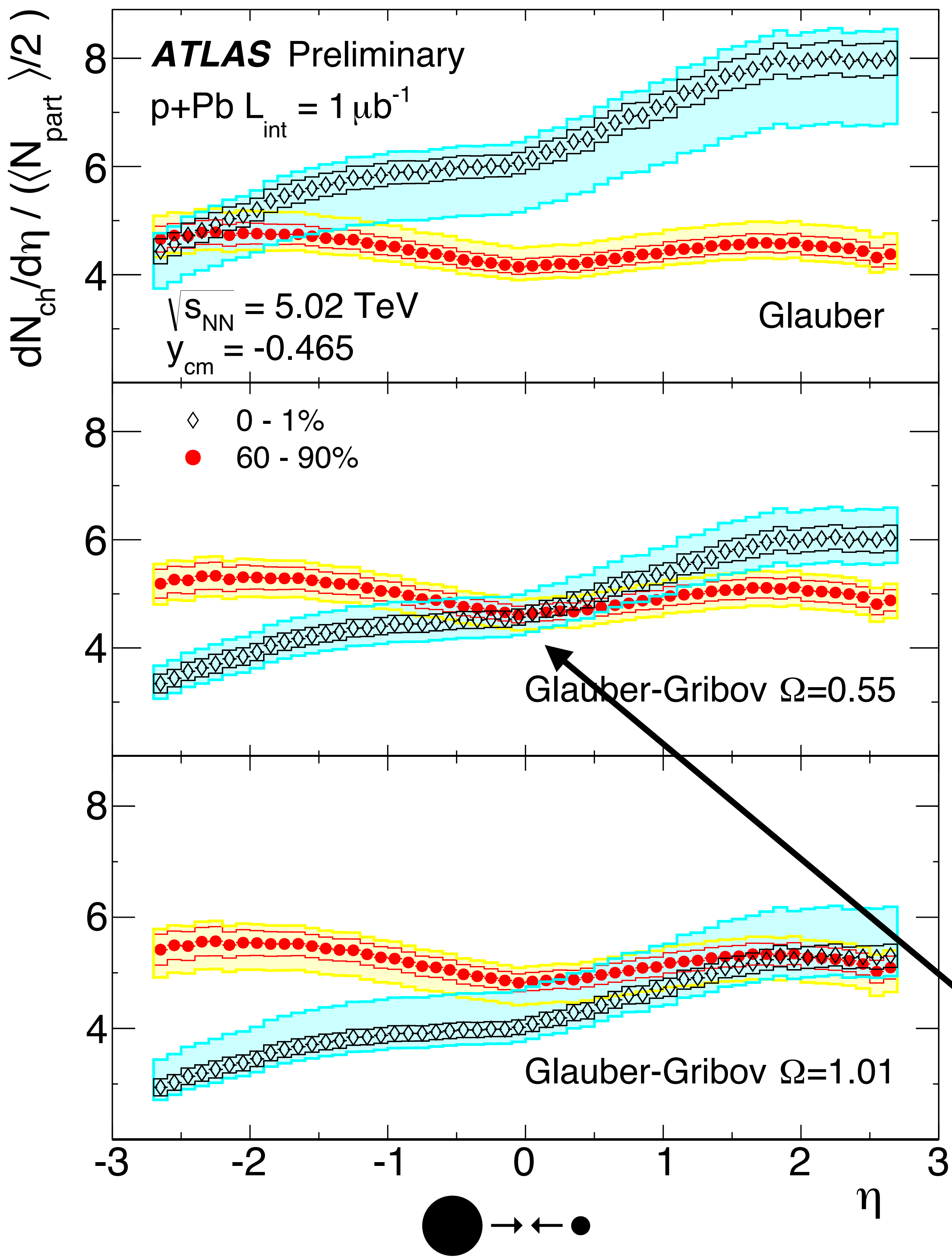
N_{part} scaling of $dN_{ch}/d\eta$

η<0 is proton-going

- What about the multiplicity per participant pair?
  - $(dN_{ch}/d\eta) / (N_{part} / 2)$
  - Normalized by N_{part} according to the three geometric models
  - Shown for 5 η selections
- In the default Glauber, N_{ch} per participant increases at high N_{part}
- In the Glauber-Gribov 1.01, N_{ch} per participant decreases at high N_{part}
- In Glauber-Gribov 0.55, recover *N_{part}-scaling* within systematics

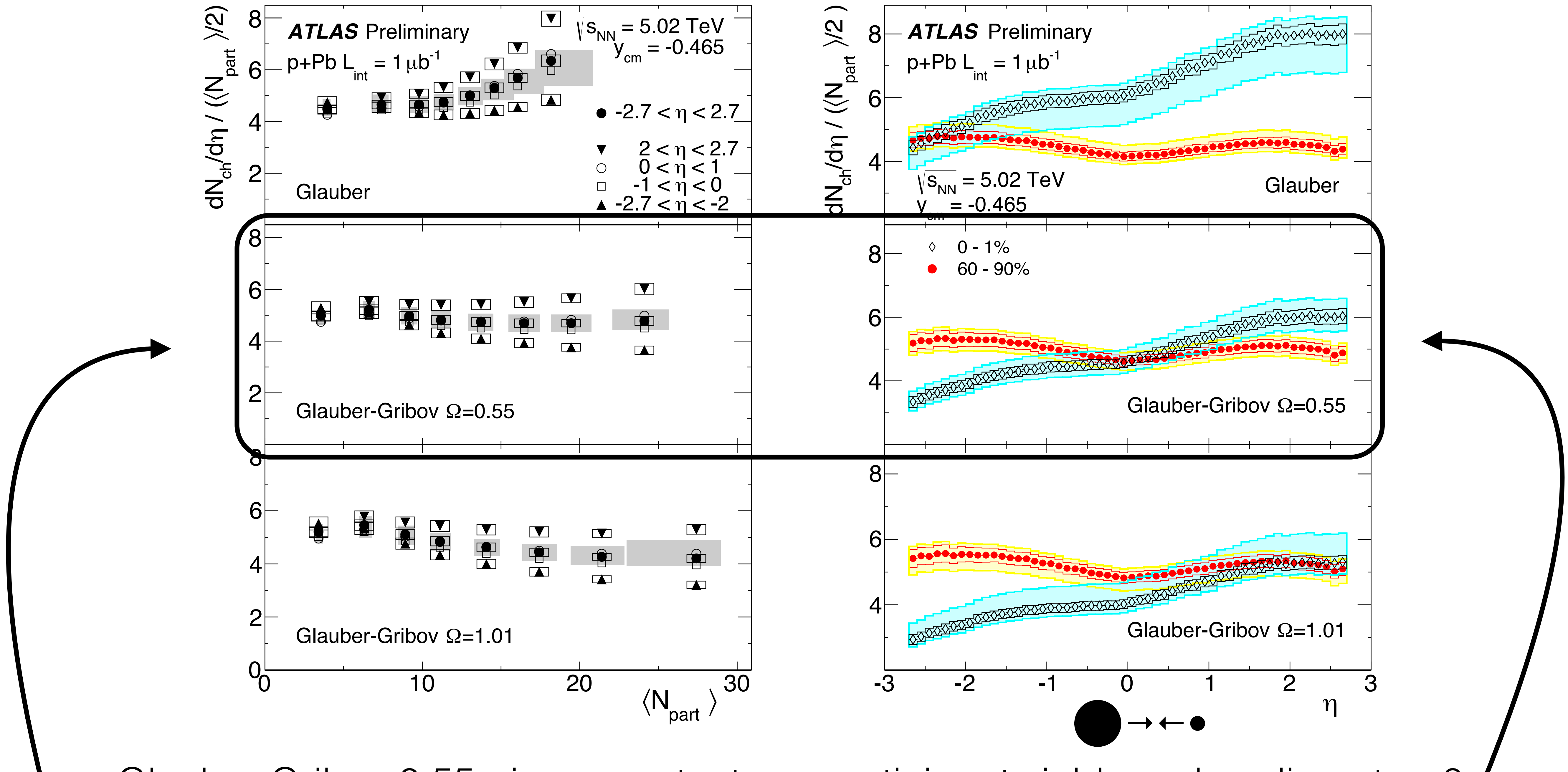


N_{part} scaling … at which η?



- Now, select a few centralities and explore the η-dependence
    - N_{part}-scaled multiplicity for **0-1%** and **60-90%** events
    - same data, just different N_{part}
- For each model, the distributions intersect but at a different η
    - thus, each model has a different "scaling region"
    - For Glauber-Gribov 0.55, this happens right at mid-rapidity

Physics insights from multiplicity?

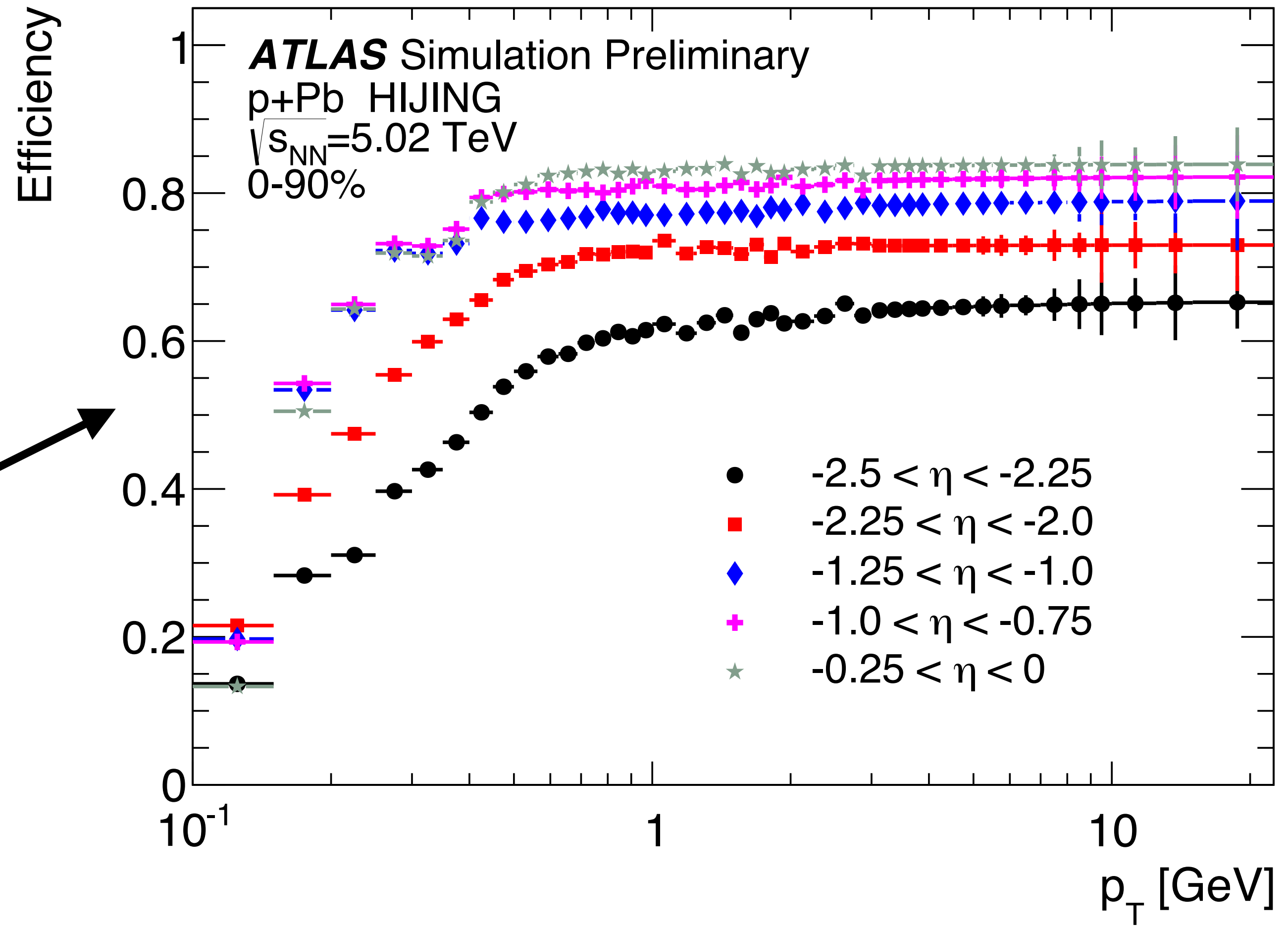


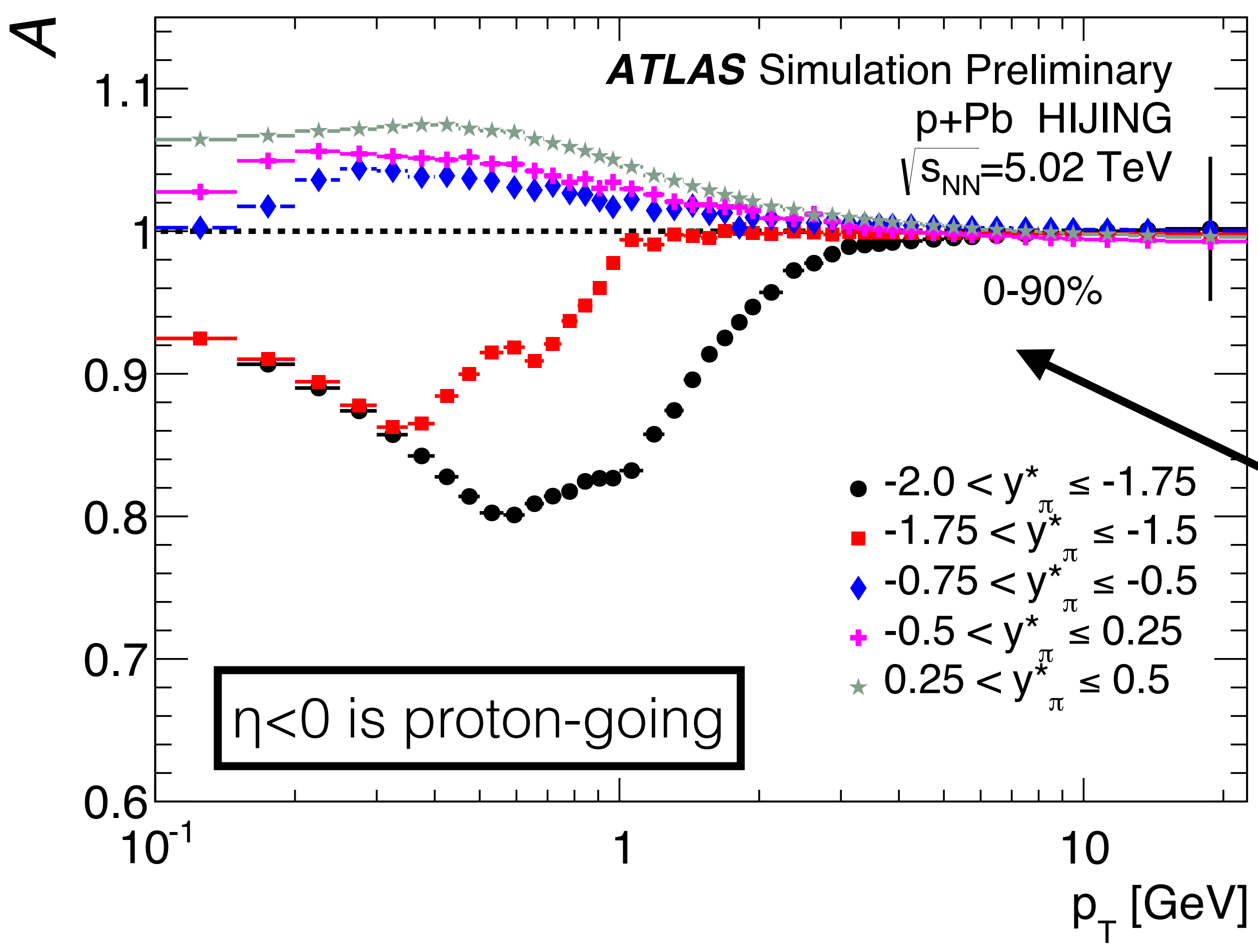
- Glauber-Gribov 0.55 gives constant per-participant yields and scaling at η=0
  - does not necessarily mean Glauber-Gribov is the “right” model
- Rather, emphasizes the sensitivity of the measurement to geometric model

2. Charged particle R_{pPb}

Track reconstruction & corrections

- Charged tracks in the Inner Detector
  - selected according to a set of quality criteria
  - reconstruction & selection efficiency
  - spectra are also corrected for “fake” tracks

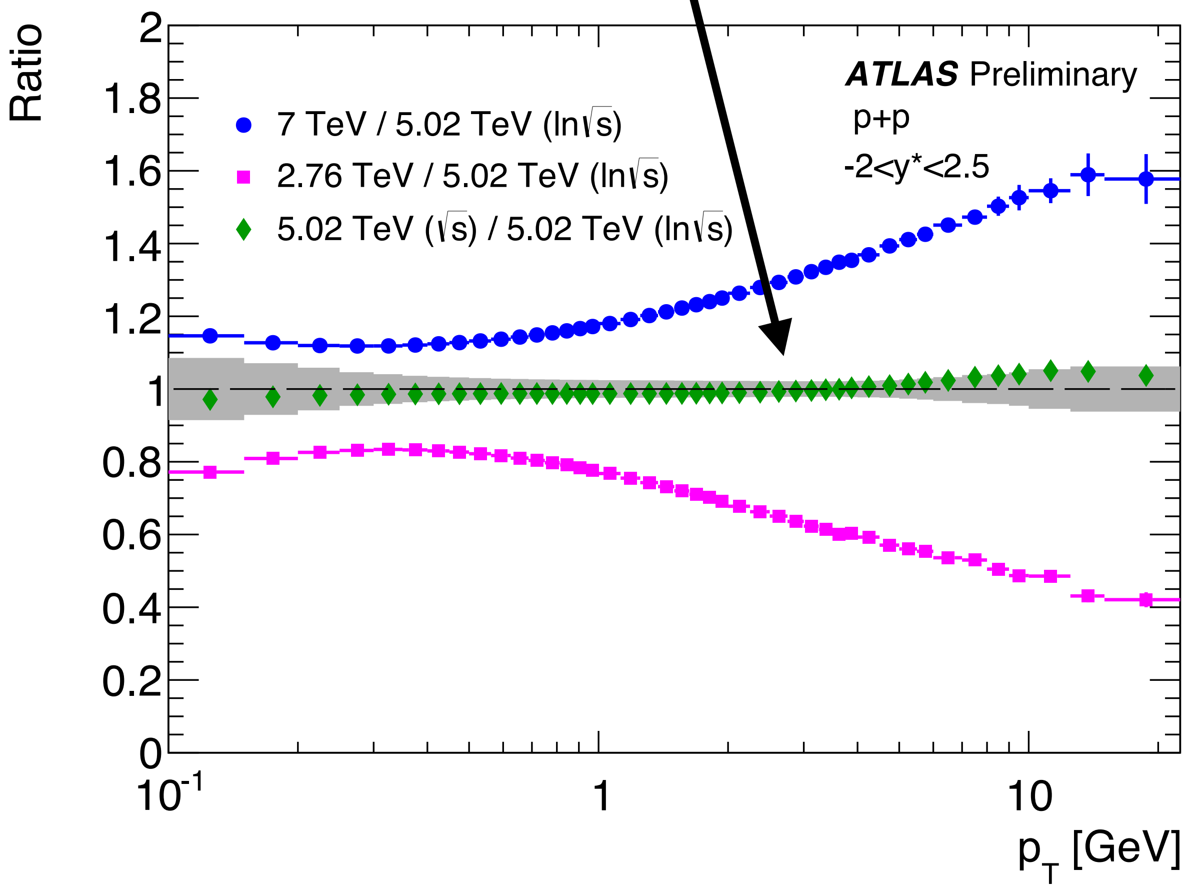


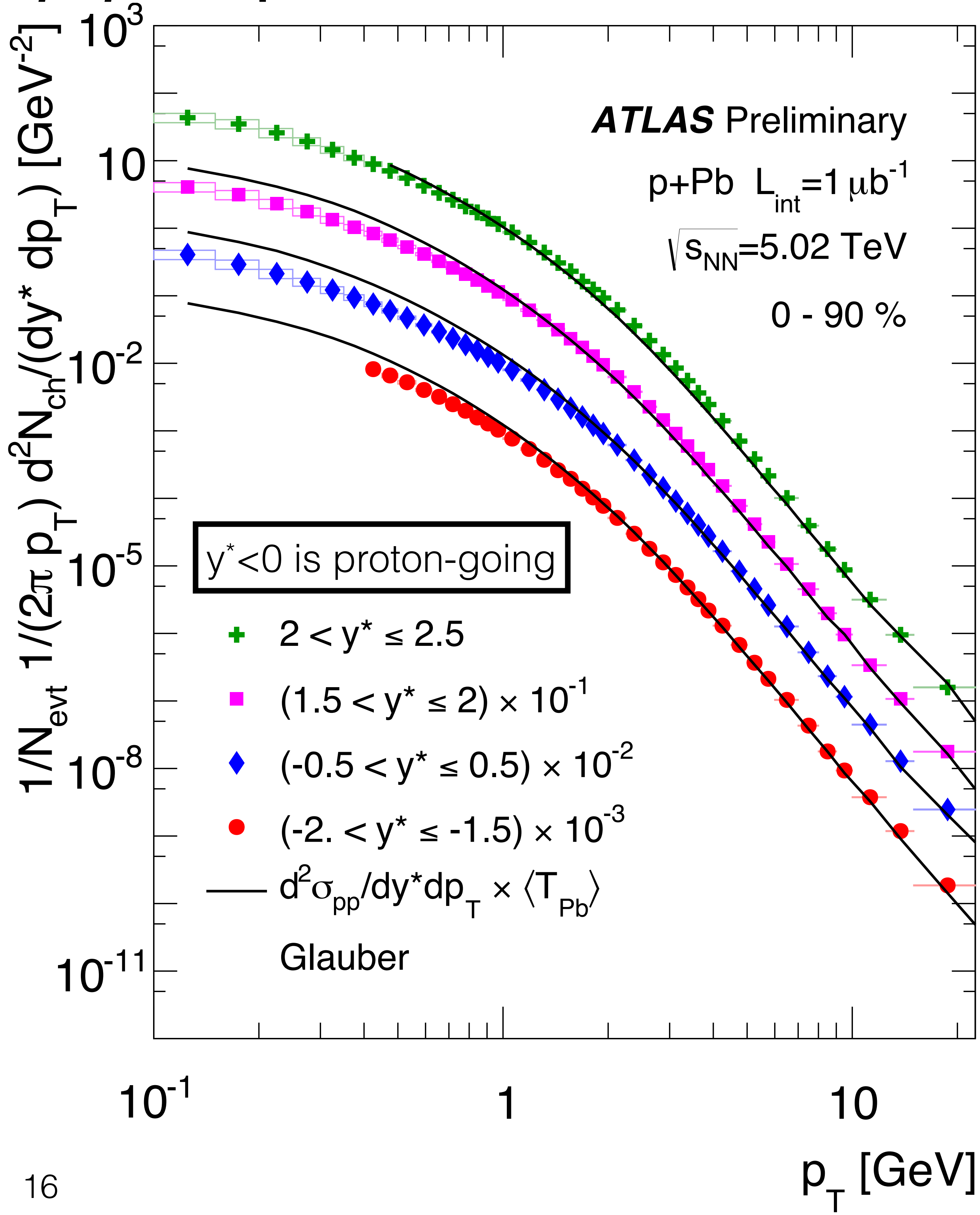


- η-dependent spectra transformed into y^*-dependent spectra
  - with the assumption that all tracks are pions
  - MC-derived factor to correct for this assumption
    - very small above 1 GeV
    - included in systematics

p+Pb and pp spectra

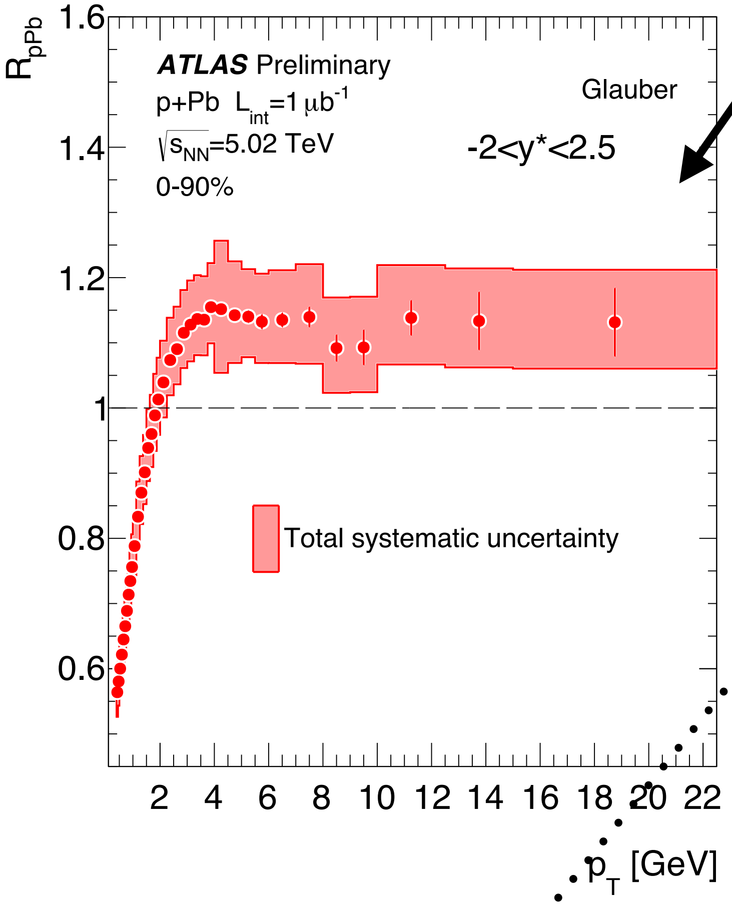
- Fully corrected charged hadron spectra
    - vs. y* (also centrality, not shown)
- pp spectrum generated from √s-interpolated 2.76 TeV and 7 TeV data
    - systematic from assuming √s instead of log(s) interpolation

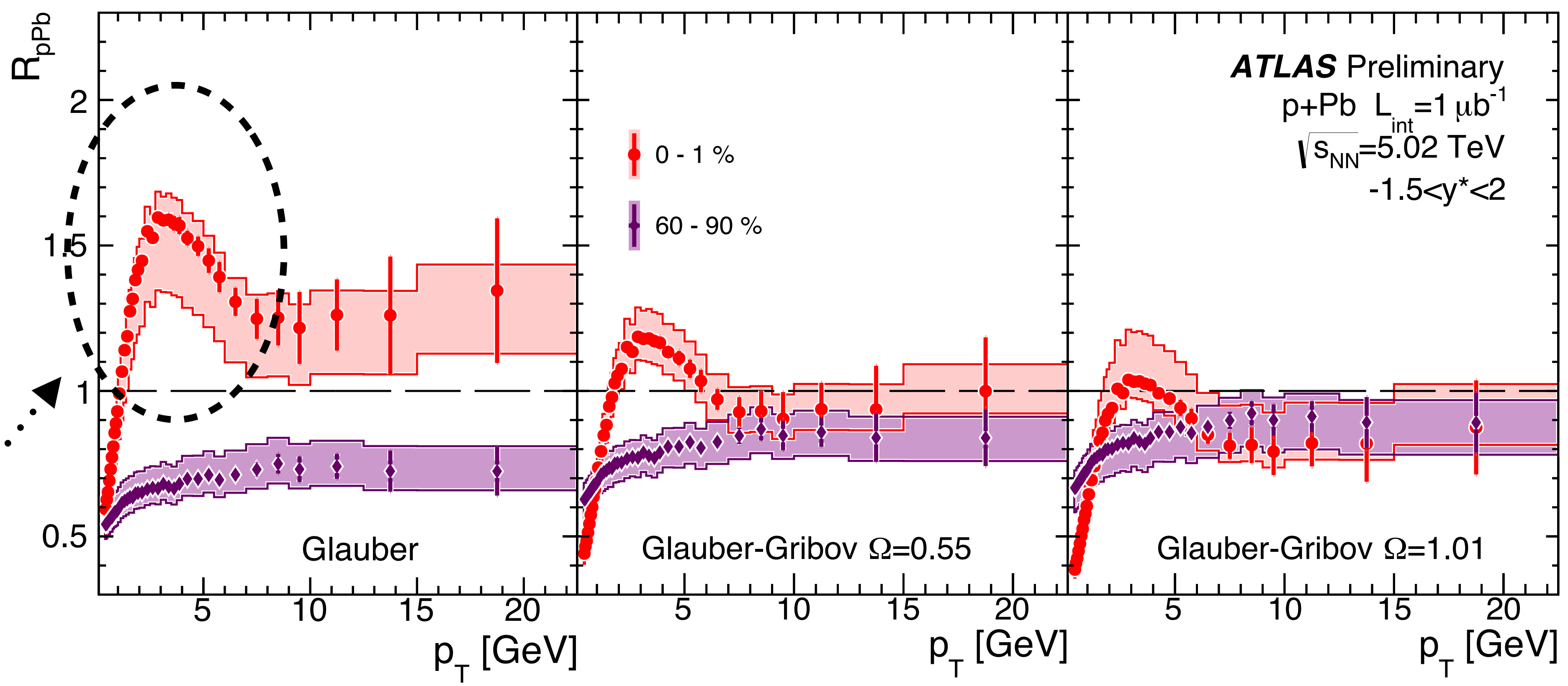




Centrality-dependent R_{pPb}

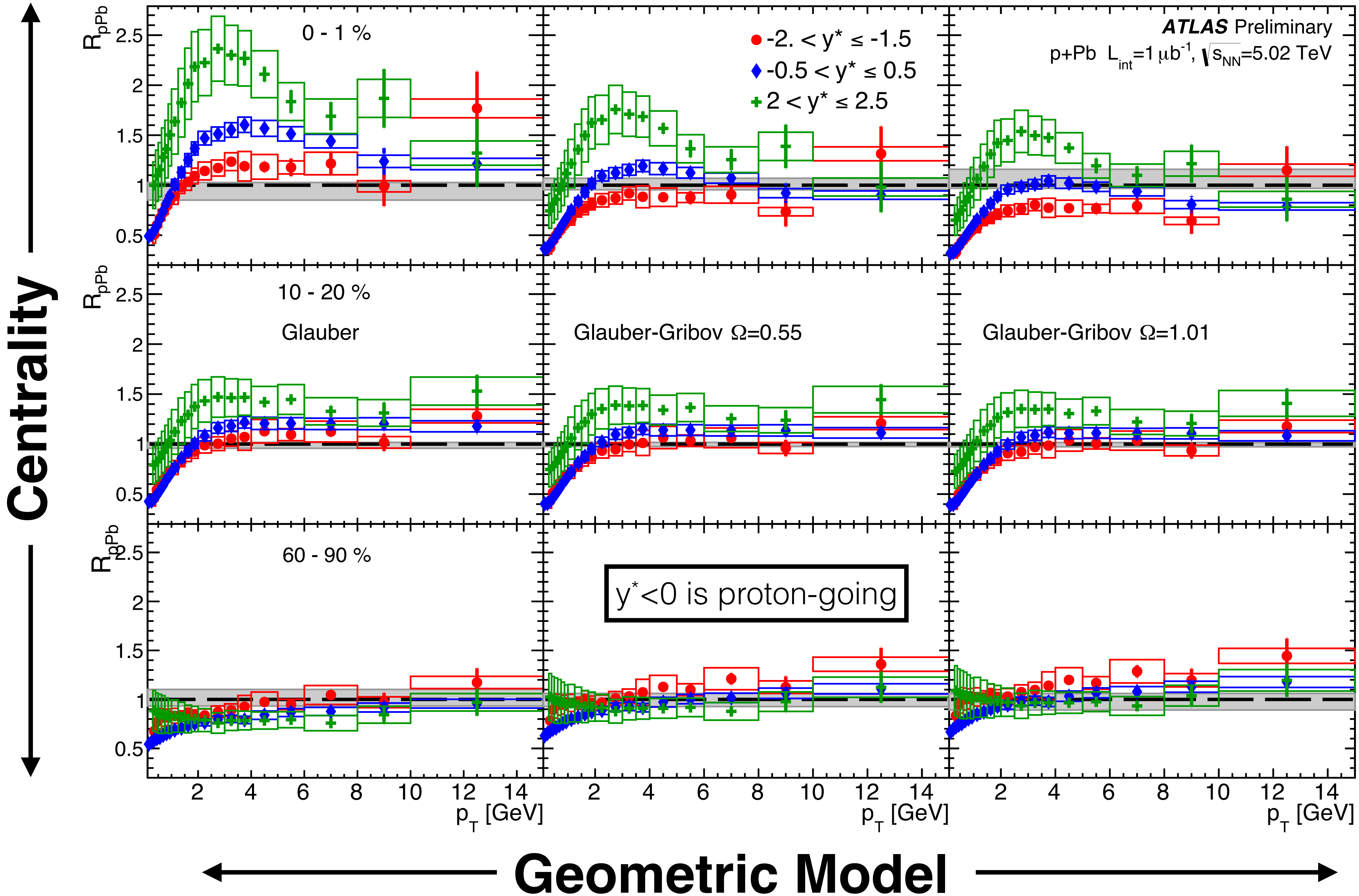
- R_{pPb} for 0-90% p+Pb collisions show a small enhancement
  - almost no interesting features in the p_T dependence
  - same result in all geometric models (Glauber vs. Glauber-Gribov)



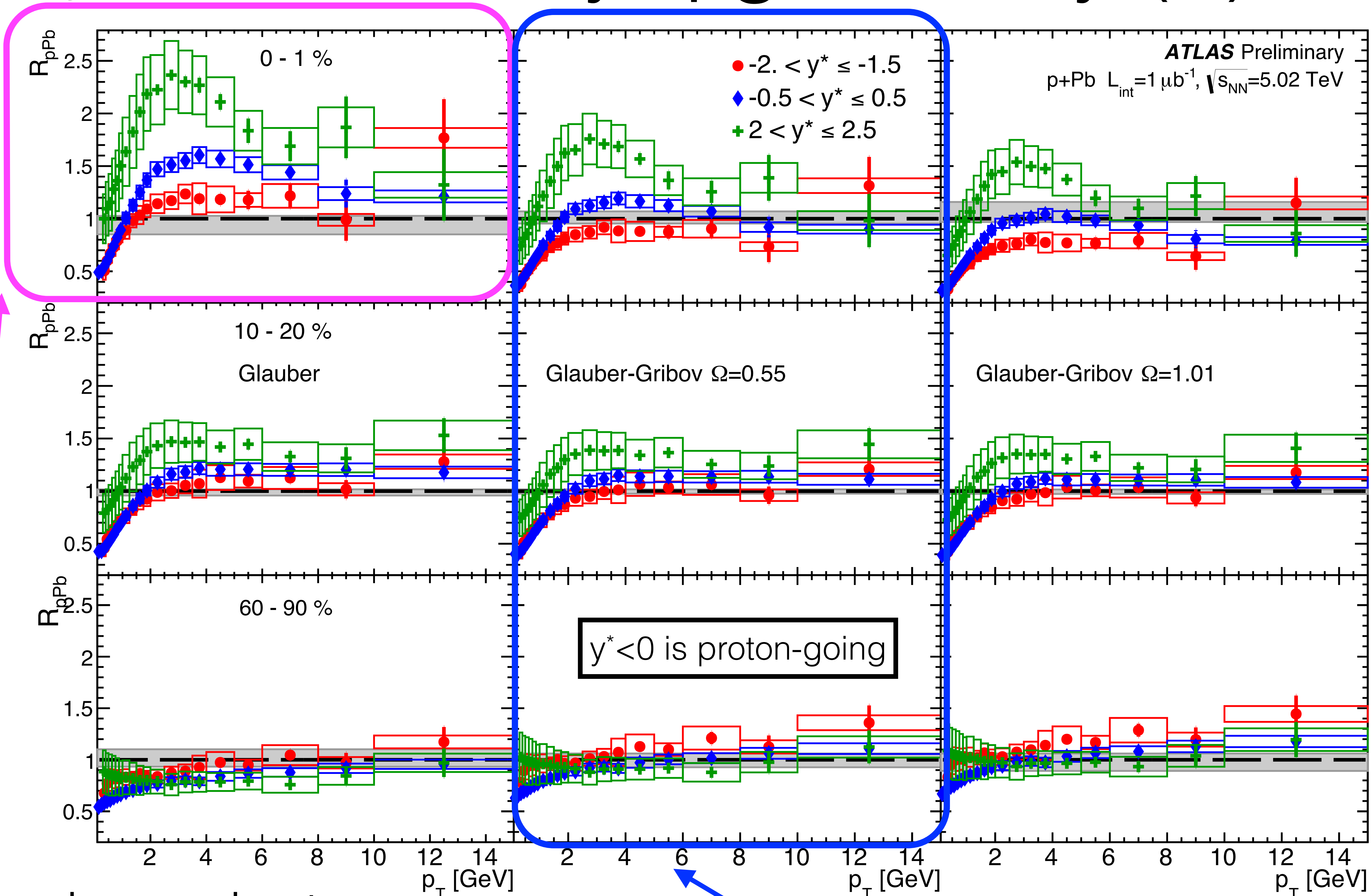


- Substantial split between **0-1%** and **60-90%** R_{pPb}
  - Cronin peak (invisible in the minimum bias) visible in the 0-1%
  - interpretation of high-p_T behavior depends on the geometric model

R_{pPb} vs. centrality/η/geometry (I)



R_{pPb} vs. centrality/η/geometry (II)

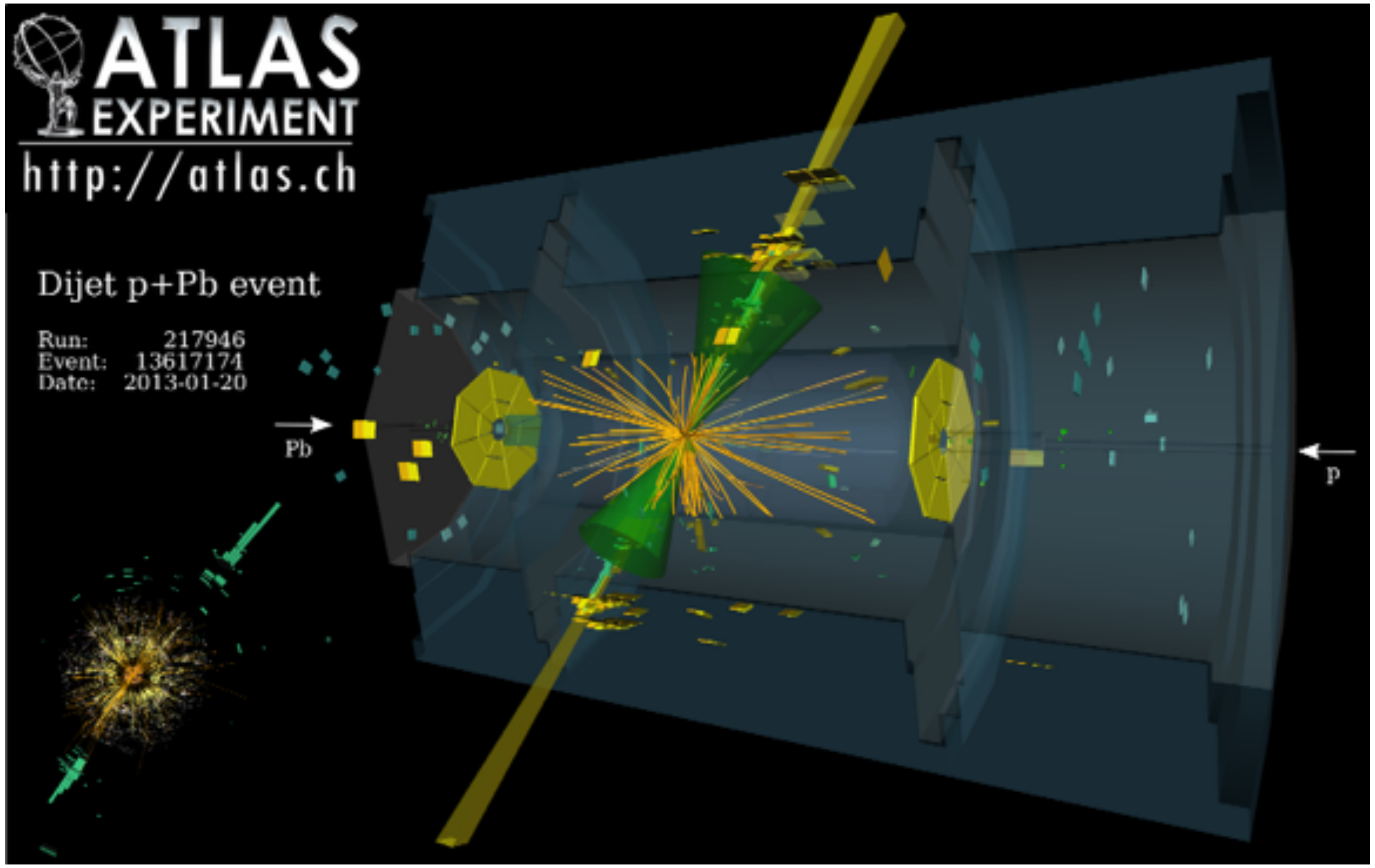


Rapidity-dependent Cronin peak

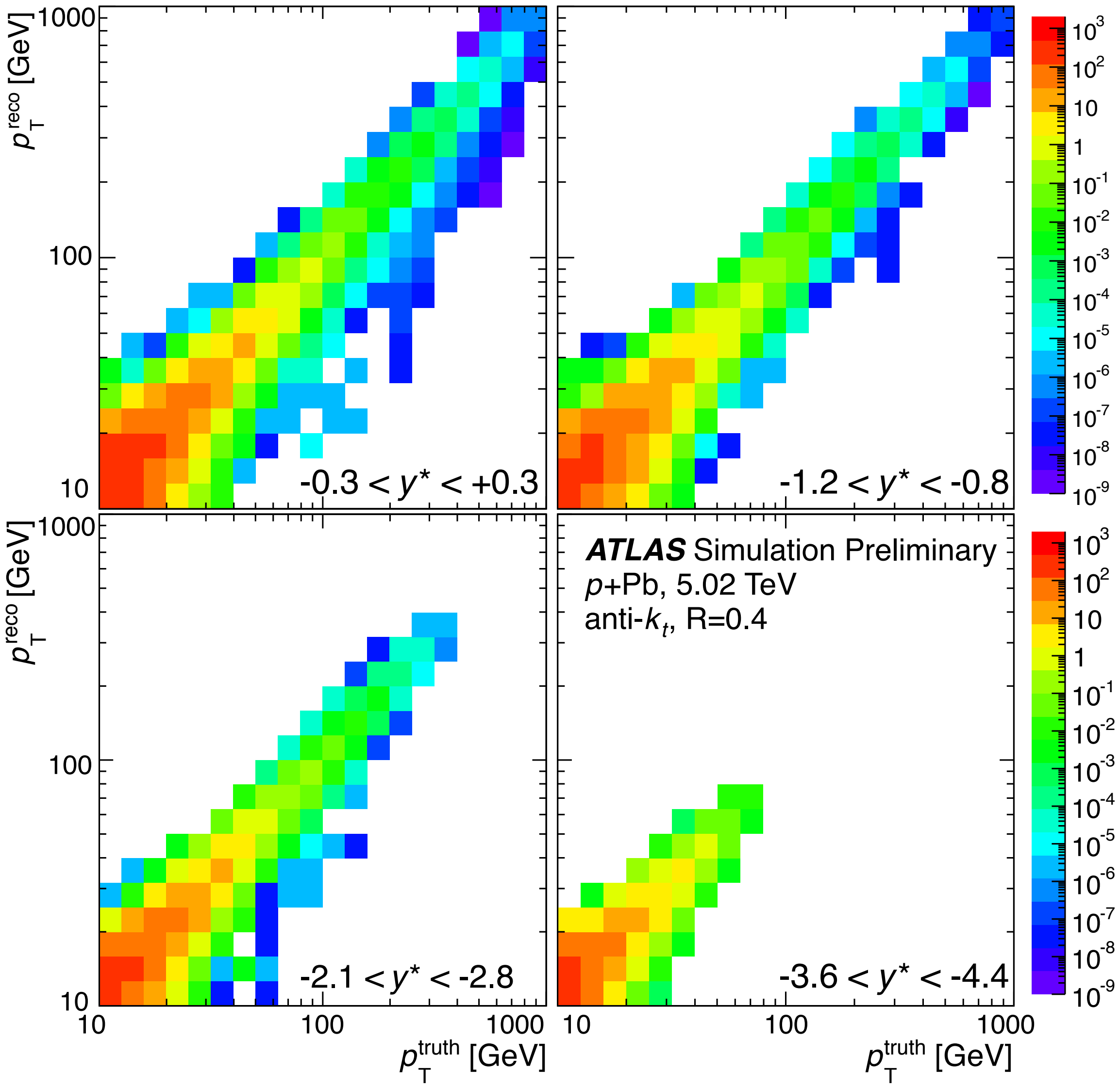
N_{part}-scaling within Glauber-Gribov 0.55

3. Jet R_{pPb}^{PYTHIA} and R_{CP}

Jet selection & corrections



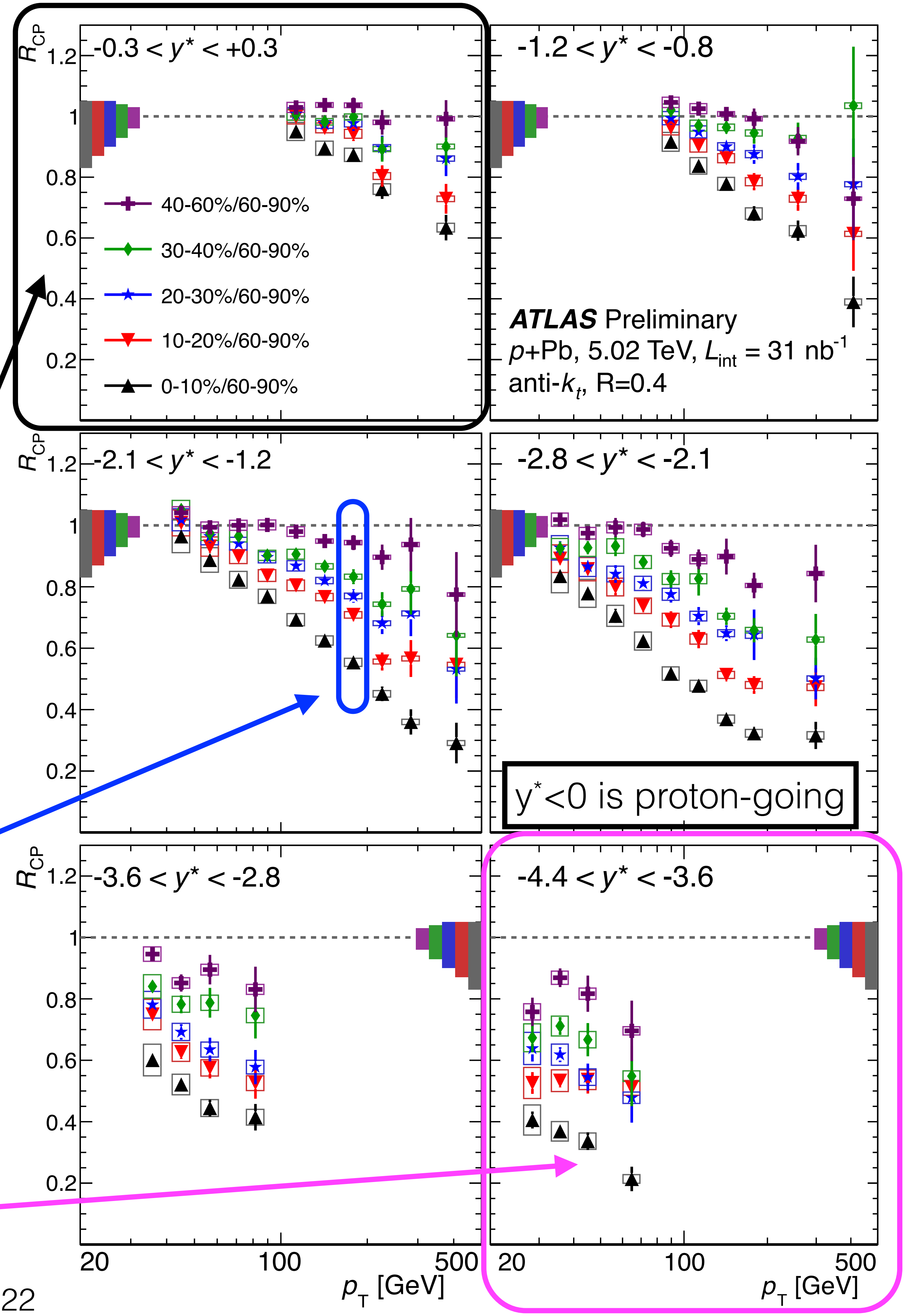
example of *p*+Pb dijet event



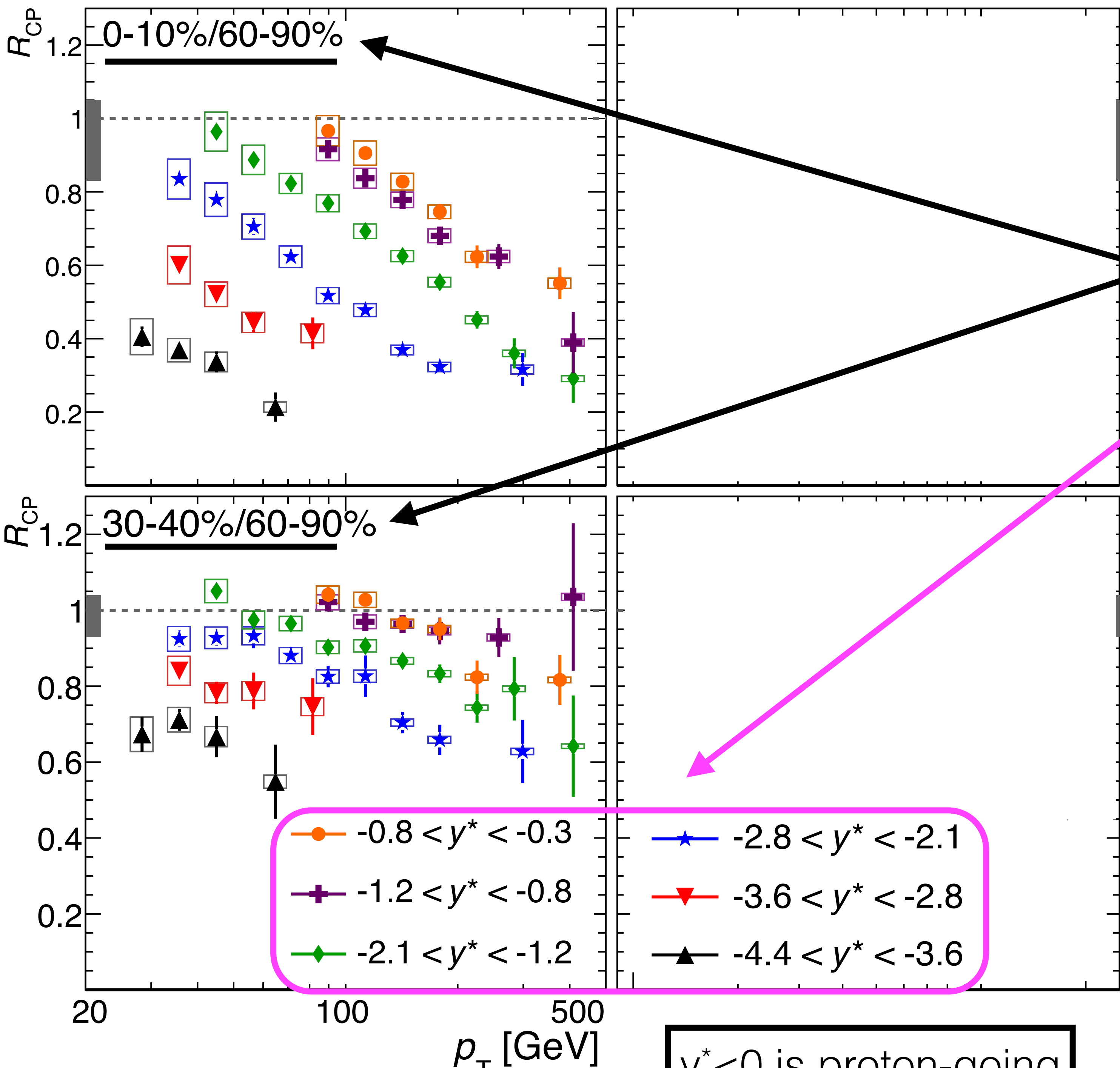
- ATLAS procedure for estimating & subtracting underlying event pedestal
  - developed for Pb+Pb, and successfully benchmarked in *pp*
- Offline jets are selected by the ATLAS High-Level Trigger
- Measured spectra corrected for finite jet energy resolution
  - Jet yields are conservatively reported in a p_T region where the detector response is UE-independent

Jet R_{CP}, at fixed rapidity

- Jet central/peripheral R_{CP}
    - N_{coll}-weighted ratio, with the 60-90% yields in the denominator
    - Each panel at a different y*
- At **mid-rapidity**, R_{CP} is suppressed at high-p_T!
    - suppression increases with p_T
    - suppression is **smooth with centrality**
    - Sequentially stronger suppression at more proton-going rapidities
    - reaching a factor of 5 at **y* = -4**



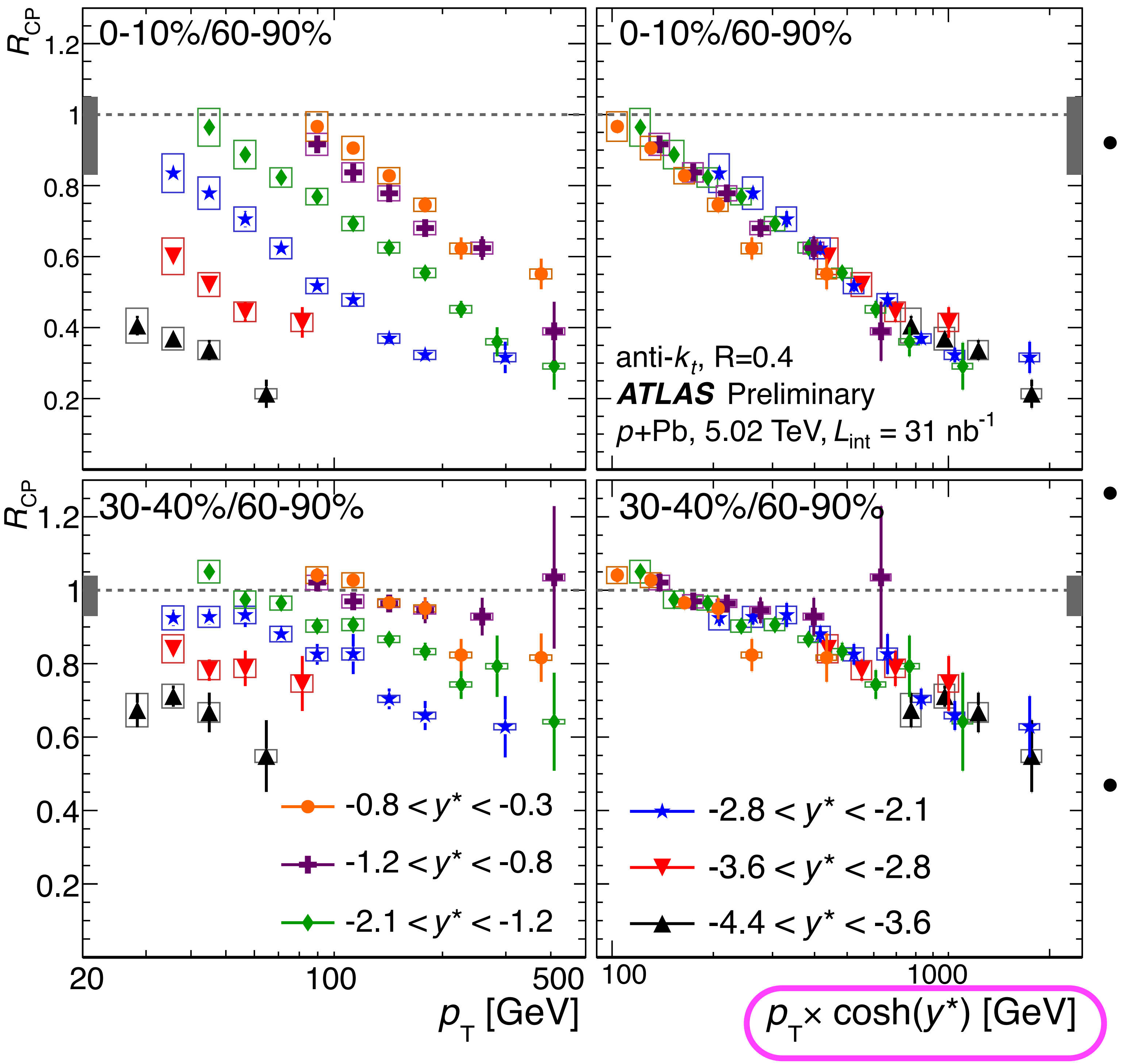
Jet R_{CP}, rapidity dependence (I)



y*<0 is proton-going

- To better investigate the rapidity dependence,
  - **fix the centrality**
  - **plot rapidity selections**
- The R_{CP} is roughly linear in $\log(p_T)$
  - with the same slope at all rapidities
  - but a different intercept
- Is it possible to relate the behavior *at all rapidities* in a simple way?

Jet R_{CP}, rapidity dependence (II)

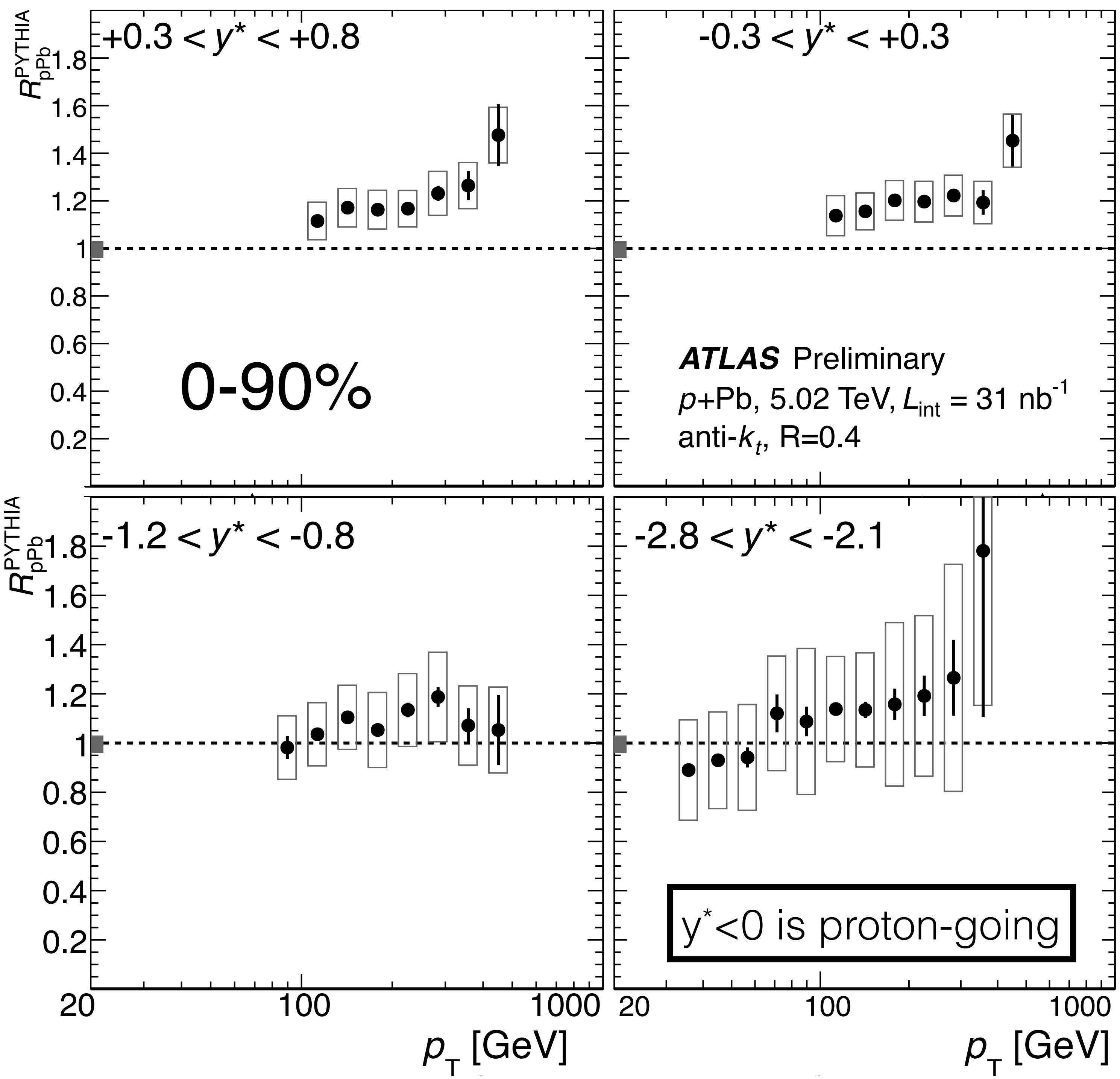


$y^*<0$ is proton-going

- Replot the data at all rapidities,
  - vs. $p = p_T \cosh(y^*)$
  - e.g. **the total jet energy**
- R_{CP} looks the same at all rapidities!
  - $R_{CP}(p_T; y^*) = R_{CP}(p)$
- What is this telling us about the mechanism responsible for the suppression?

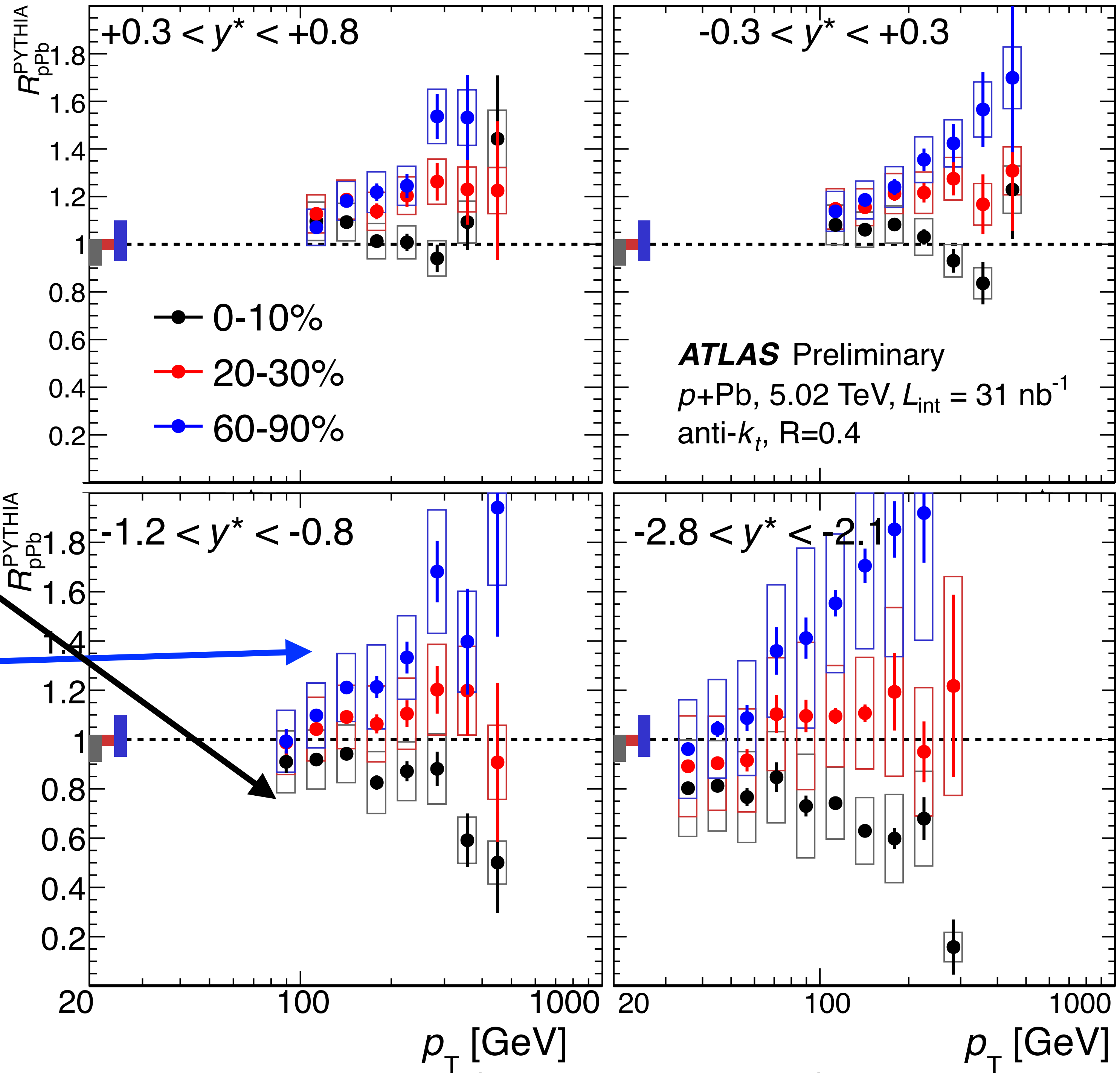
Jet R_{pPb}^{PYTHIA}, minimum bias

- Jet R_{pPb}^{PYTHIA}
  - for 0-90% *p*+Pb events
  - made with a PYTHIA reference
- Data at all rapidities consistent with a small (10%) enhancement
  - but no strong p_T, and rapidity-dependent modification
- How can this be reconciled with the R_{CP}?



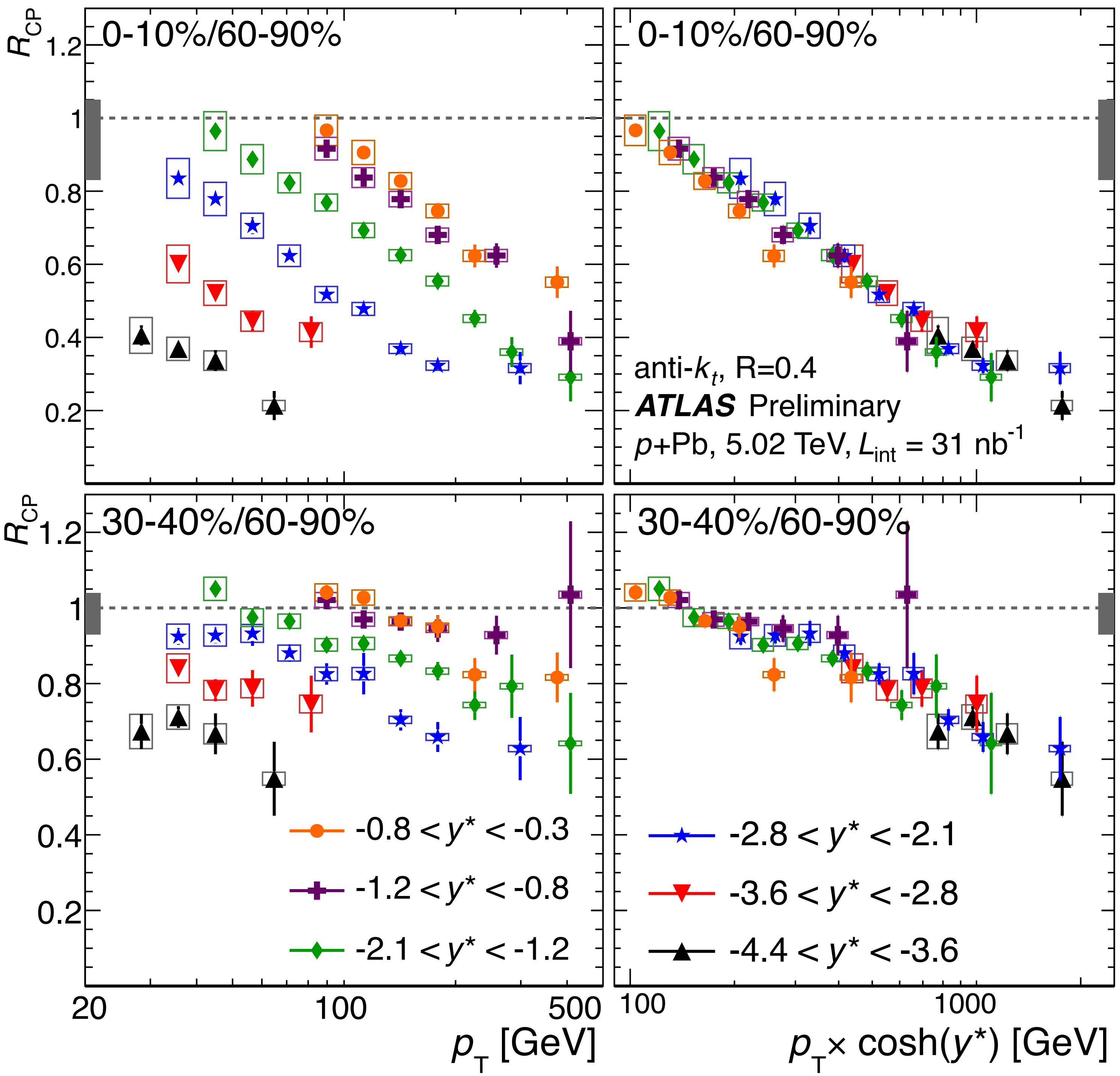
Jet R_{pPb}^{PYTHIA}, centrality dependence

- Jet R_{pPb}^{PYTHIA}
  - for **0-10%**, **20-30%** and **60-90%** *p*+Pb events
  - made with a PYTHIA reference
- Suppression in **central** events
- Enhancement in **peripheral** events
  - similar pattern at all y^*
- The combination of the two results in a suppressed R_{CP}



y*<0 is proton-going

A word on centrality "bias"



y*<0 is proton-going

- Much discussion of how the centrality variable may be affected by the presence of a hard process
  - e.g. instead of just geometry
  - not (quite) the scope of this talk
- Any explanation of the data as a "centrality bias" must:
  - explain the strong and surprising rapidity dependence
    - y* = -4 bin is 7 units of rapidity away from the Pb-going FCal!
  - explain the p_T dependence
  - explain the *sign* of the effect
    - all studies suggest we may be *overestimating* the yields in central collisions, if anything

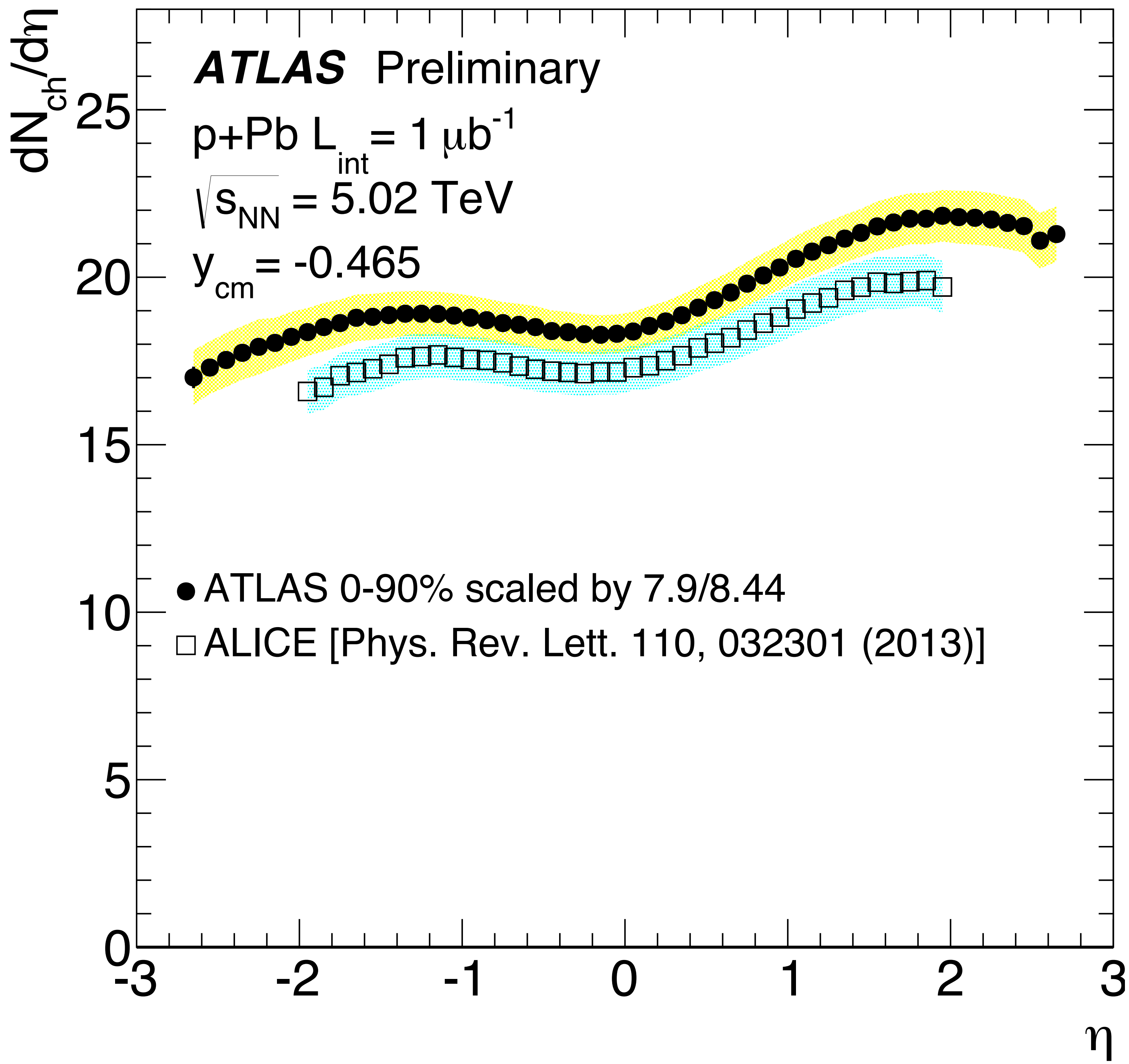
Conclusion

- Summary of centrality-dependent *p*+Pb measurements by ATLAS

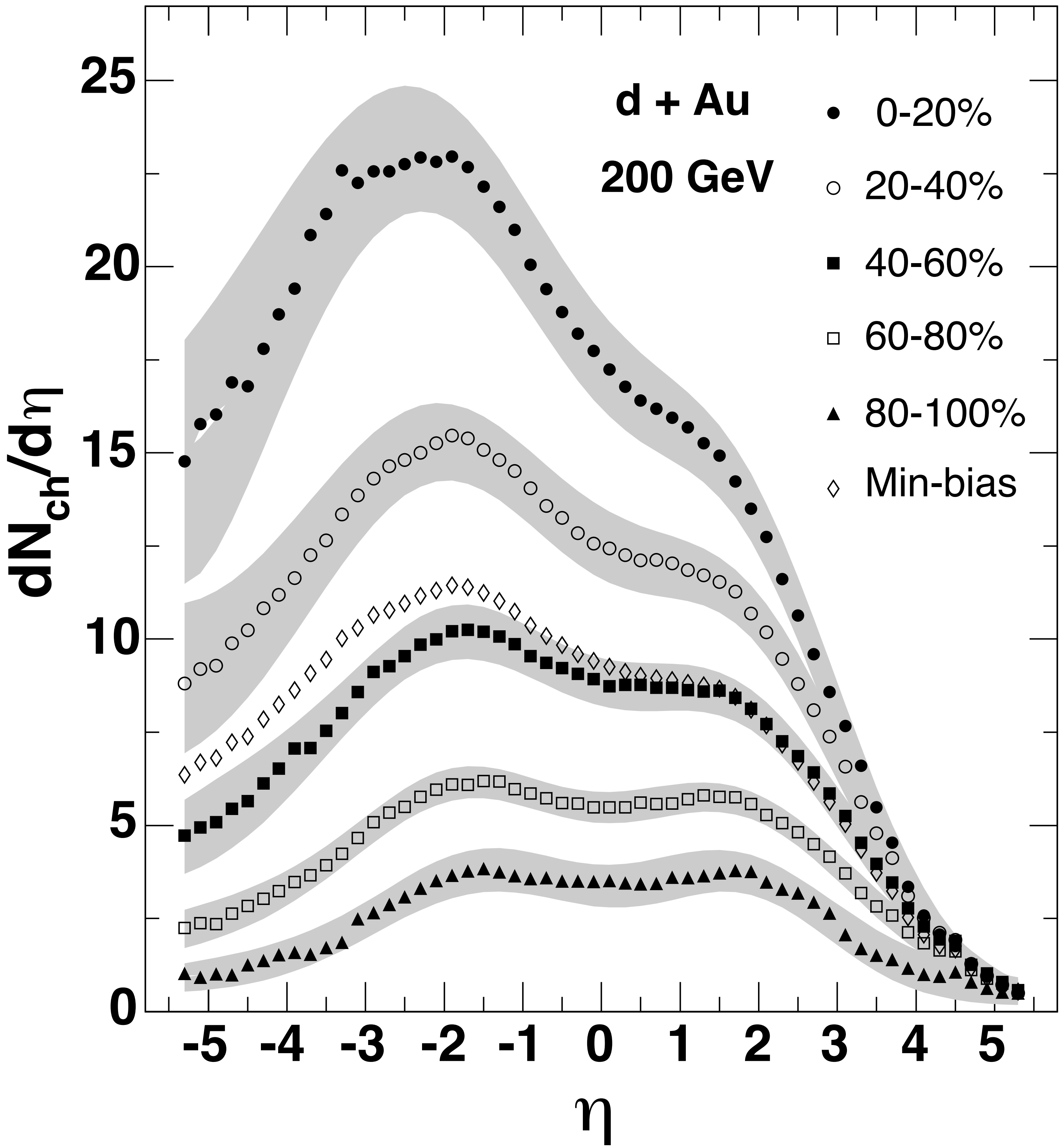
1. Total charged particle multiplicity
   - selecting on centrality changes the shape of $dN_{ch}/d\eta$
   - considering fluctuations in σ_{NN} has implications for observed N_{part}-scaling
2. Charged particle nuclear modification factor
   - non-trivial rapidity & centrality dependence, including a Cronin peak
3. Jet nuclear modification factors
   - jet yields are strongly modified in a p_T- and rapidity-dependent way
   - trends at all rapidities are consistent with a function of the total jet energy
   - enhancement in peripheral collisions and suppression in central ones

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

Backup: ATLAS vs. ALICE multiplicity



Backup: PHOBOS multiplicity vs. centrality



Backup: ATLAS vs. ALICE R_{pPb}