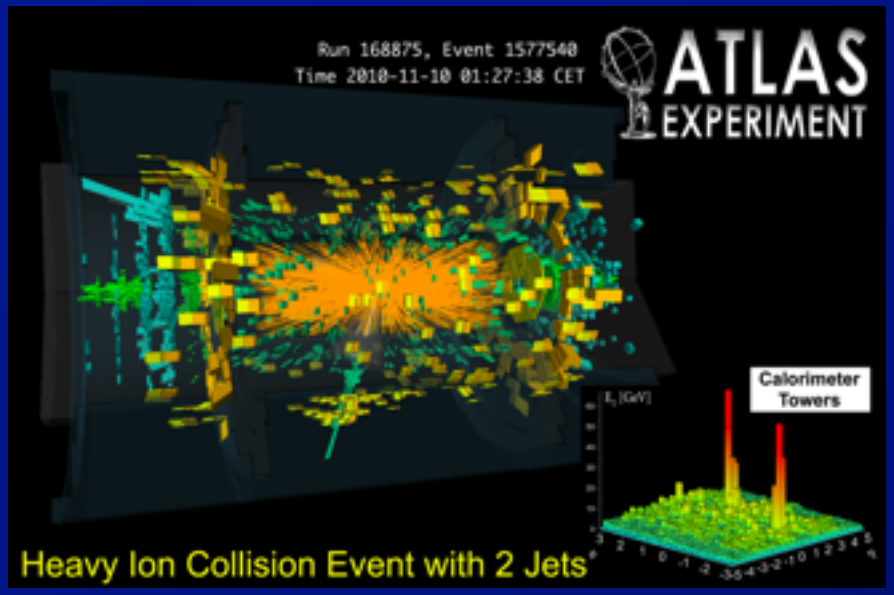
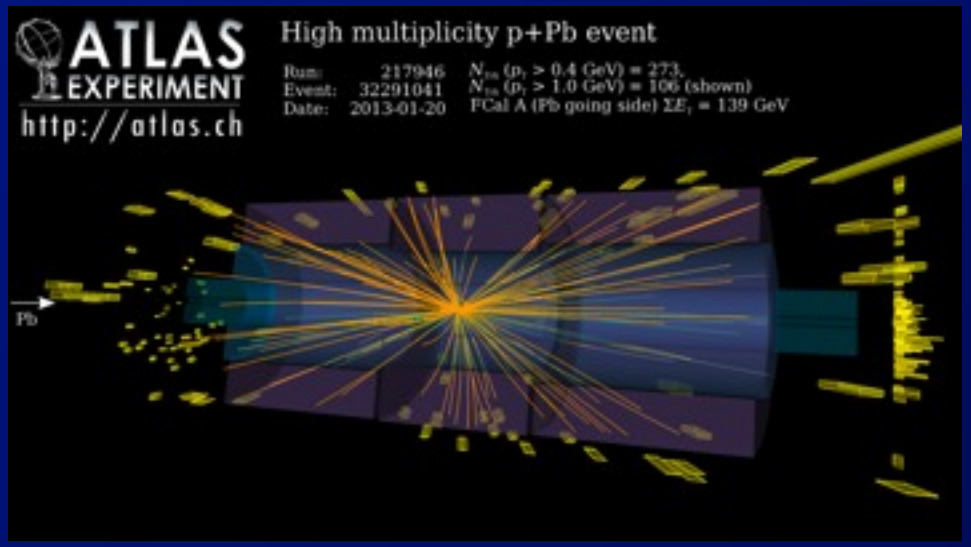
An overview of new results from the ATLAS Heavy Ion Physics Program

Prof. Brian. A Cole
Columbia University

for the ATLAS collaboration





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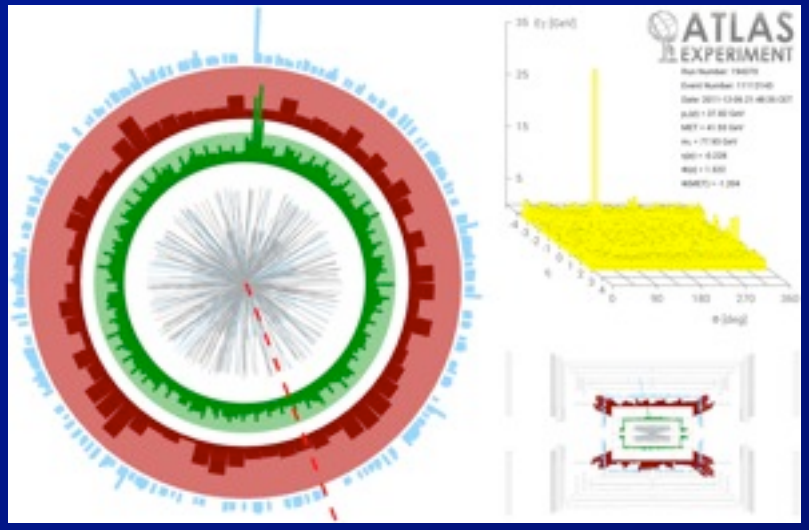
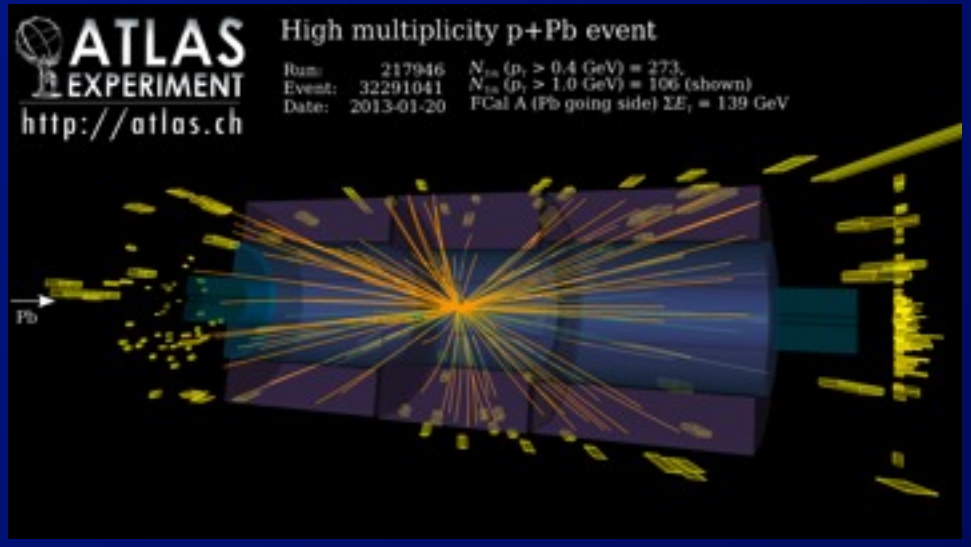
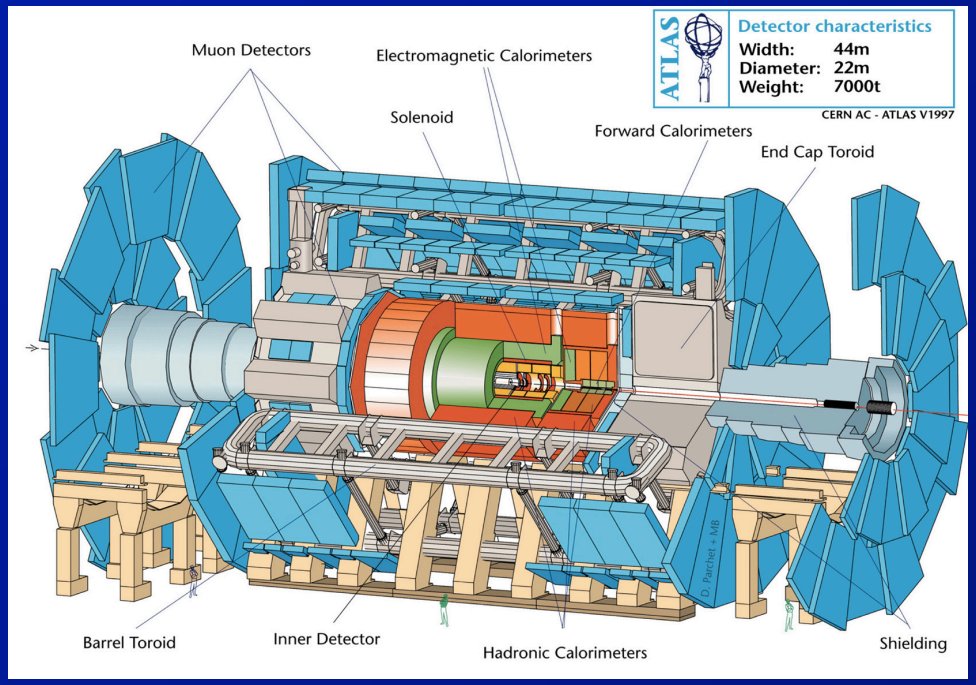
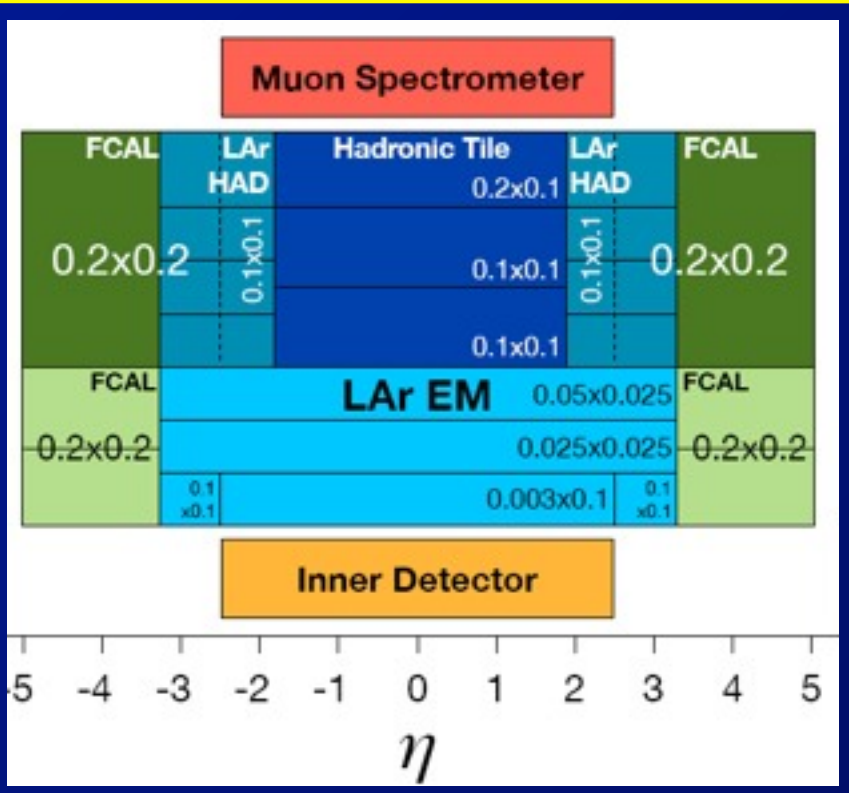
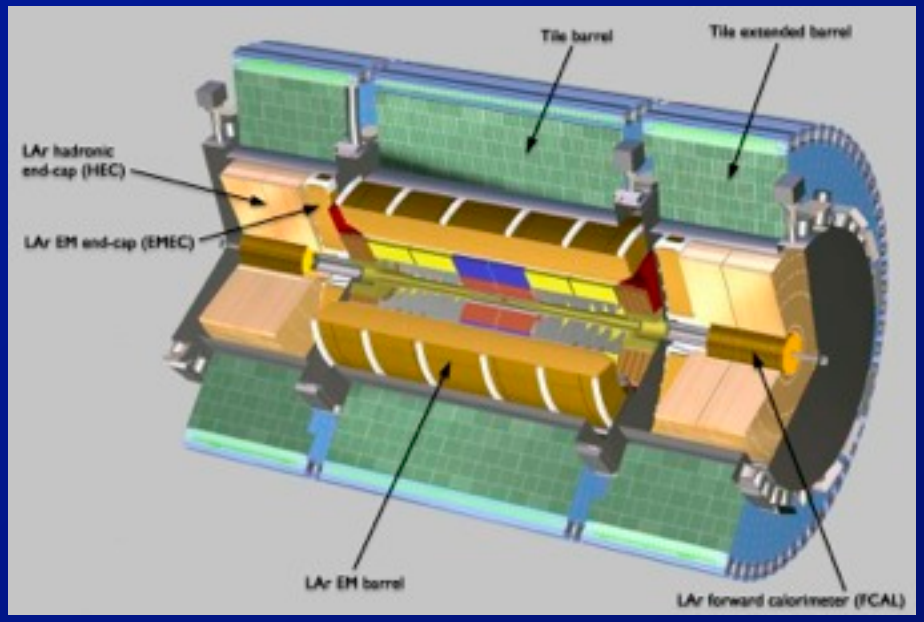


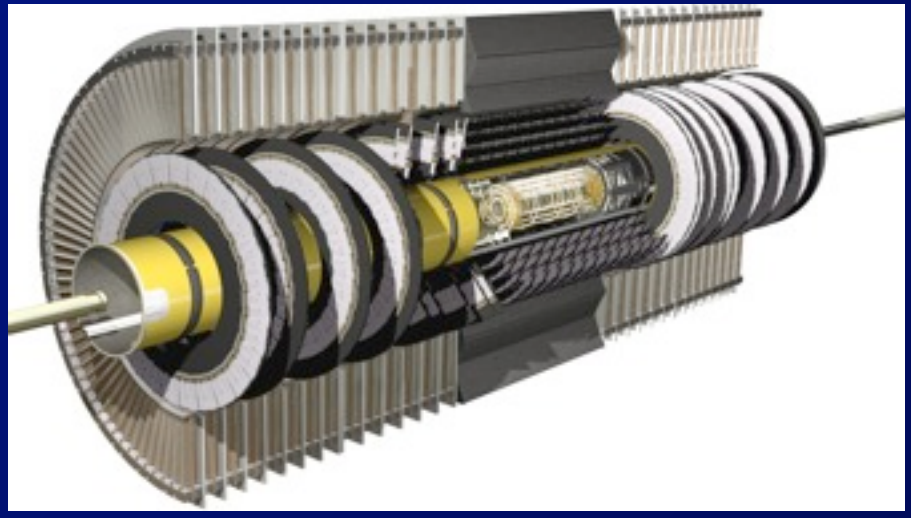


The ATLAS Detector



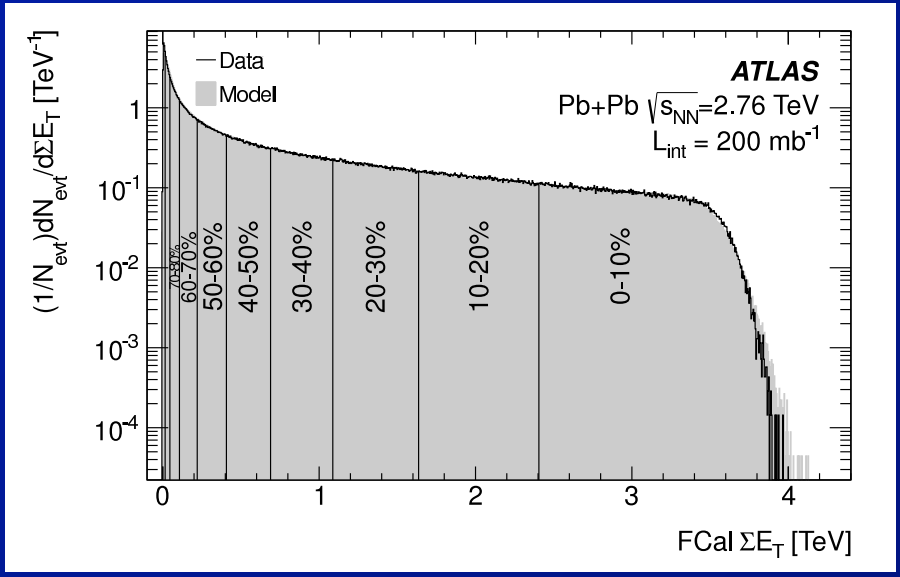




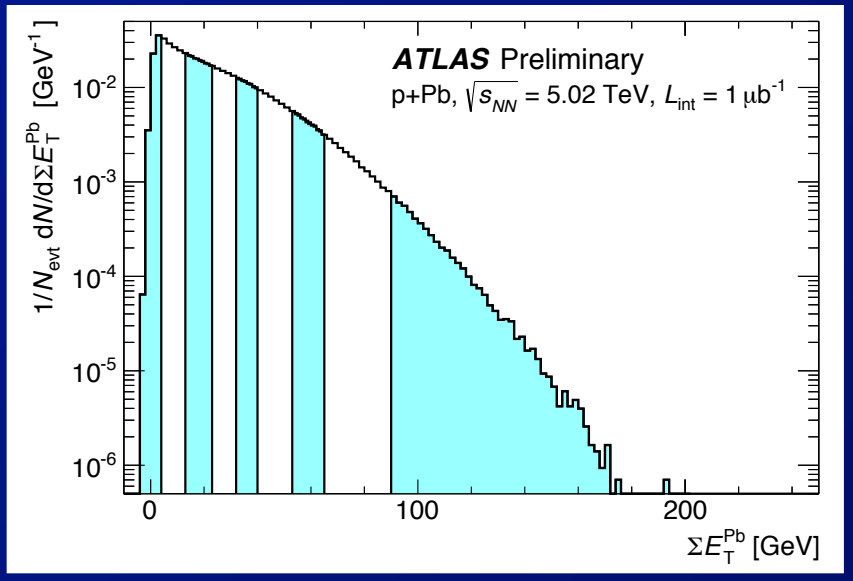


Centrality in Pb+Pb, p+Pb

3.2 < |η| < 4.9

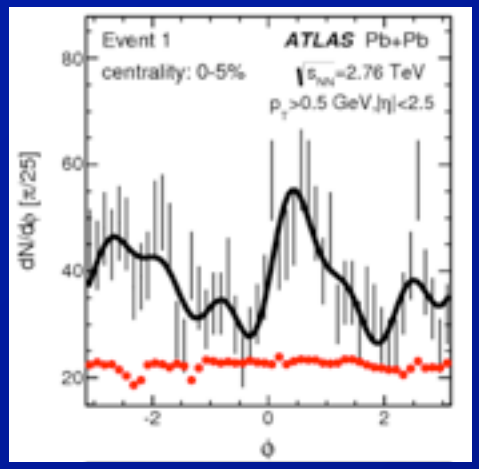


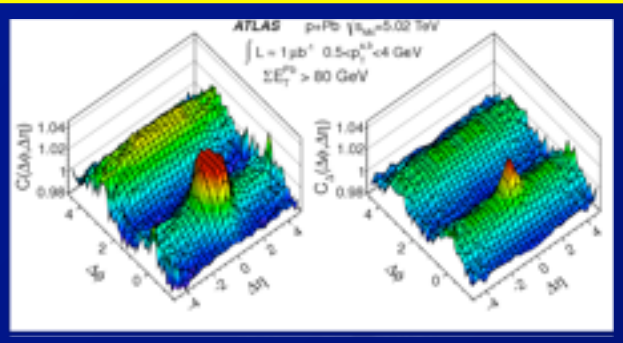
-4.9 < η < -3.2

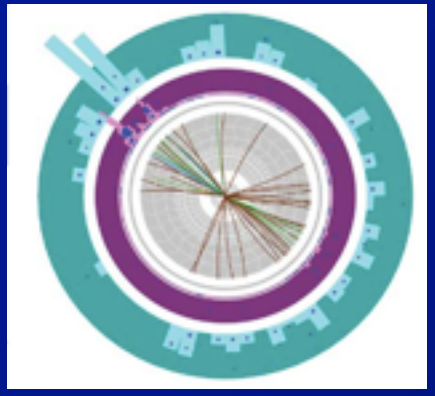


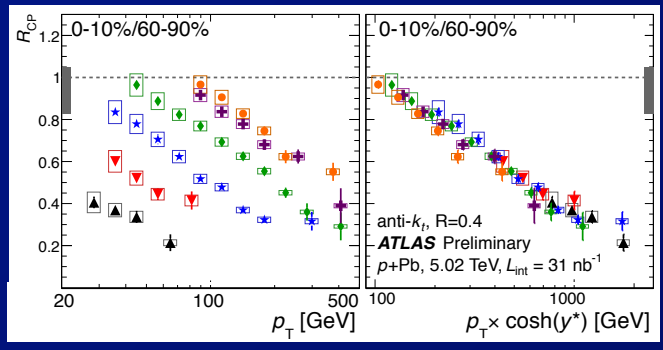
- **Measured using forward calorimeter(s)**
  - In p+Pb, on Pb-going side only
    - ⇒Note: ATLAS p+Pb measurements now use "usual" convention (positive η in proton direction)
- **For Pb+Pb usual Glauber MC for geometry**
- **For p+Pb use both Glauber and Glauber-Gribov color-fluctuation model *a la* Strikman *et al.***

Physics Goals









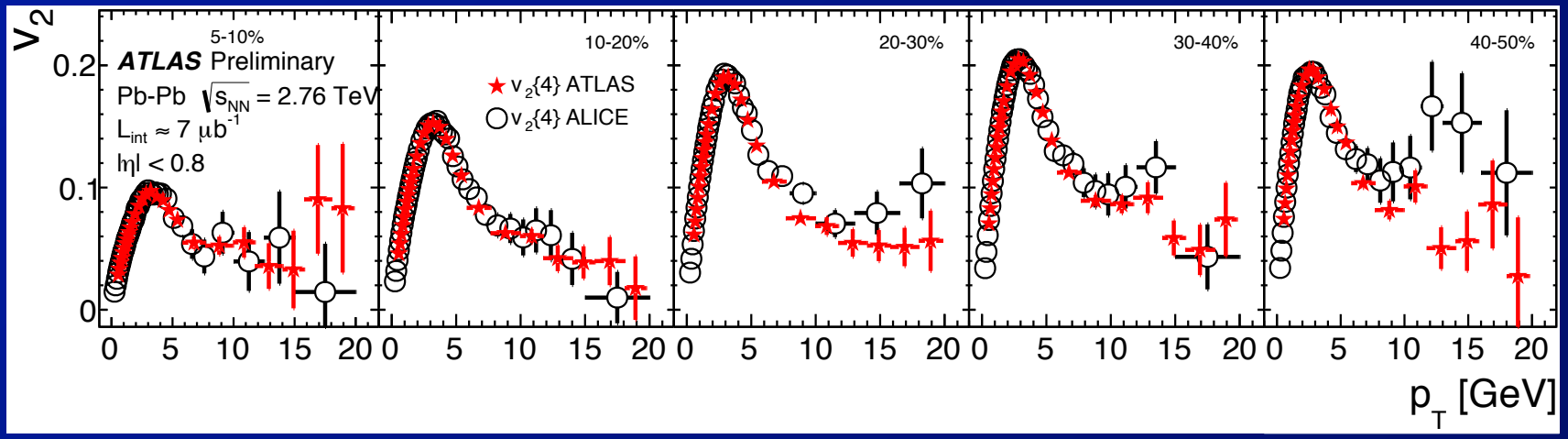
- **Study the strongly coupled quark gluon plasma using both soft and hard probes**
  - Study the collective response of the plasma to (fluctuating) initial conditions (flow).
  - Study modification of energetic parton showers by the plasma (jet quenching)
  - Calibrate both in proton-lead collisions.

⇒Themes: improving precision, exploring new directions

Collective dynamics in Pb+Pb and p+Pb(?) collisions

Pb+Pb v_n via cumulants

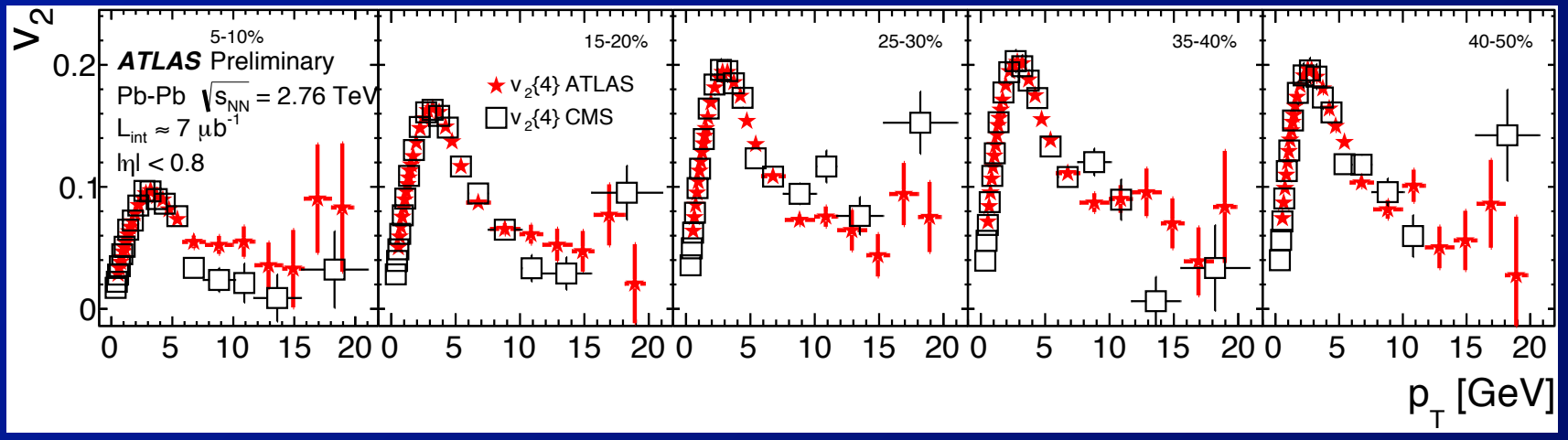
- p_T-differential measurements
  - ⇒Good agreement between three experiments



Pb+Pb v_n via cumulants

- p_T-differential measurements

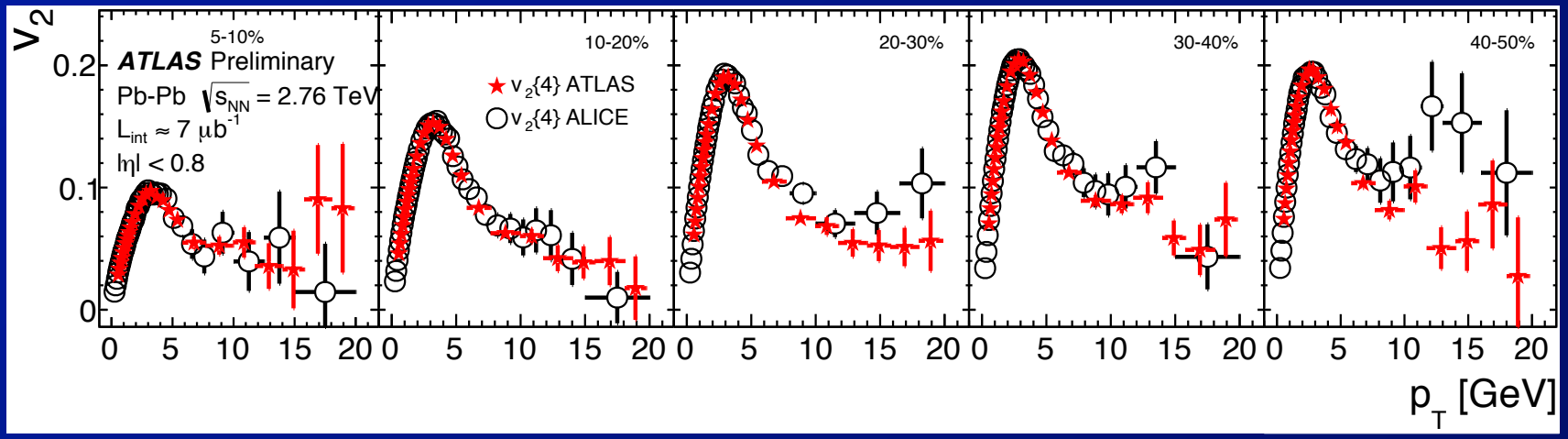
  ⇒Good agreement between three experiments



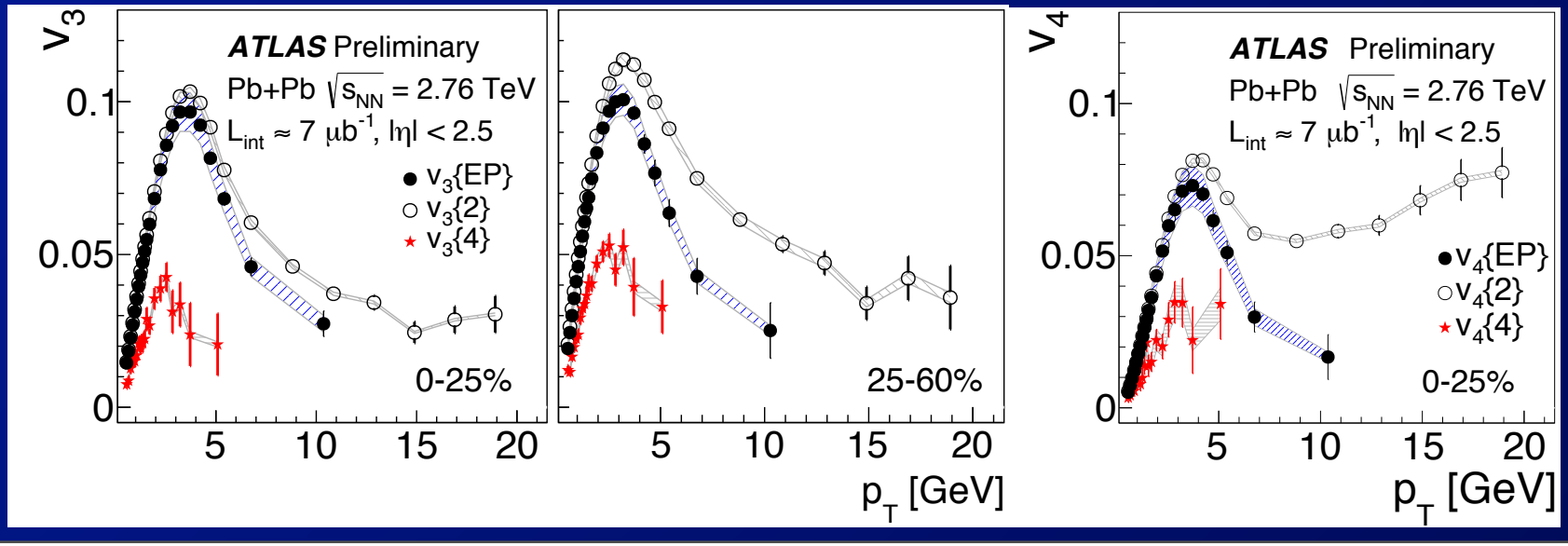
Pb+Pb v_n via cumulants

- p_T-differential measurements

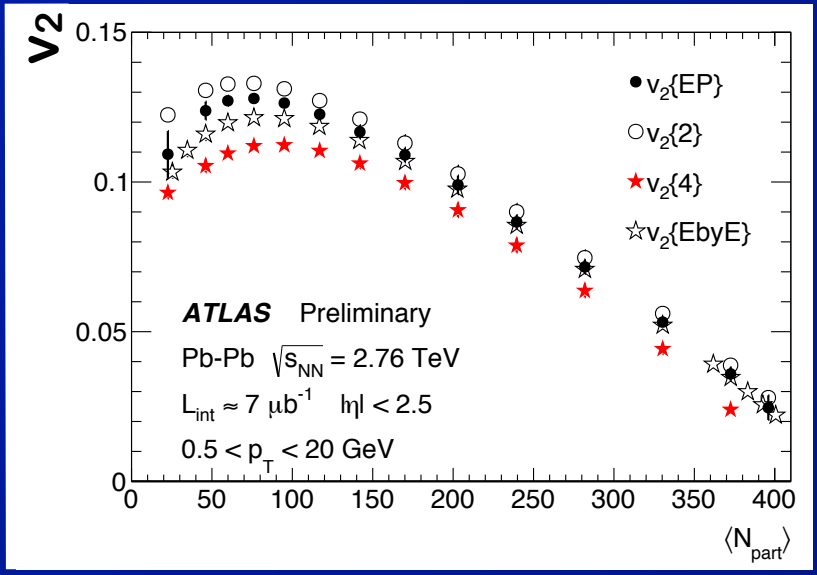
⇒Good agreement between 3 experiments on v_2

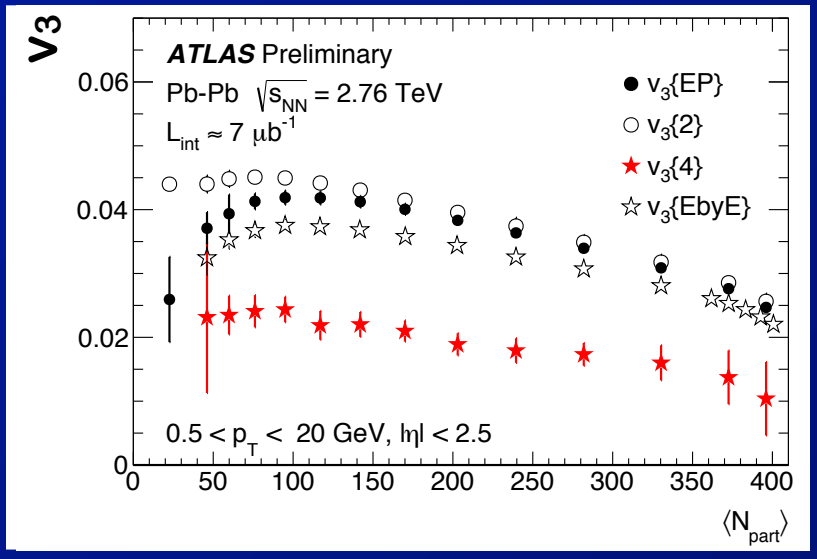


⇒ Significant, smaller $v_3\{4\}$, $v_4\{4\}$



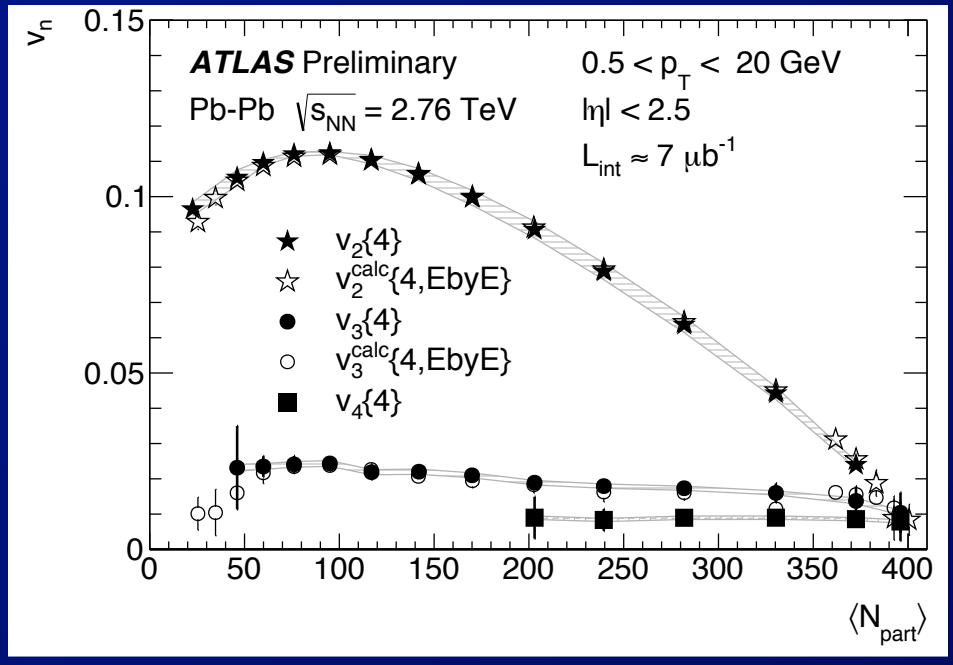
Pb+Pb v_n via cumulants





different methods measure different "v_n"s (fluctuations)

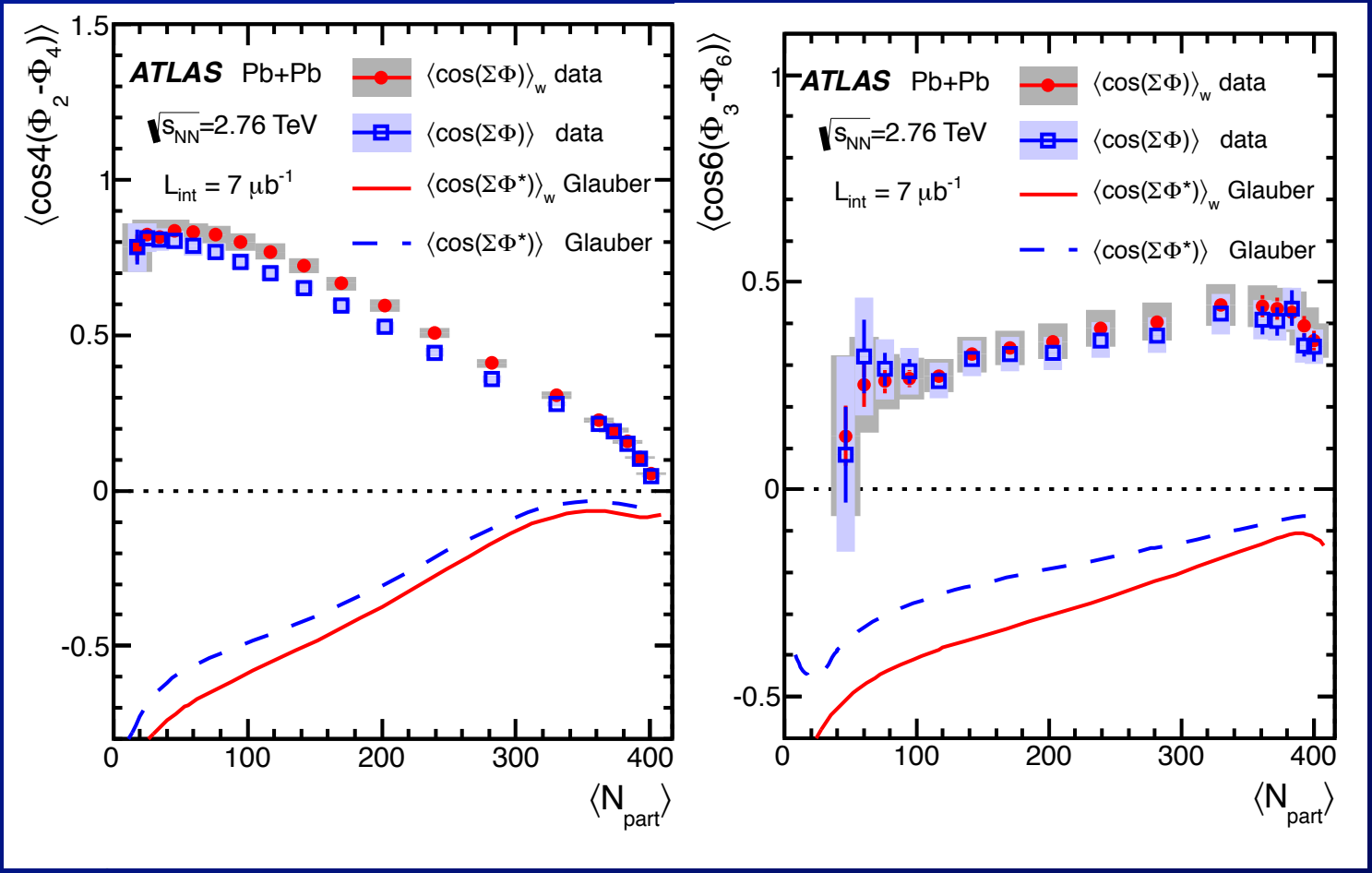
compare cumulant v_n's to event-by-event calculations of same



- Good consistency between cumulant results and published ATLAS event-by-event measurements

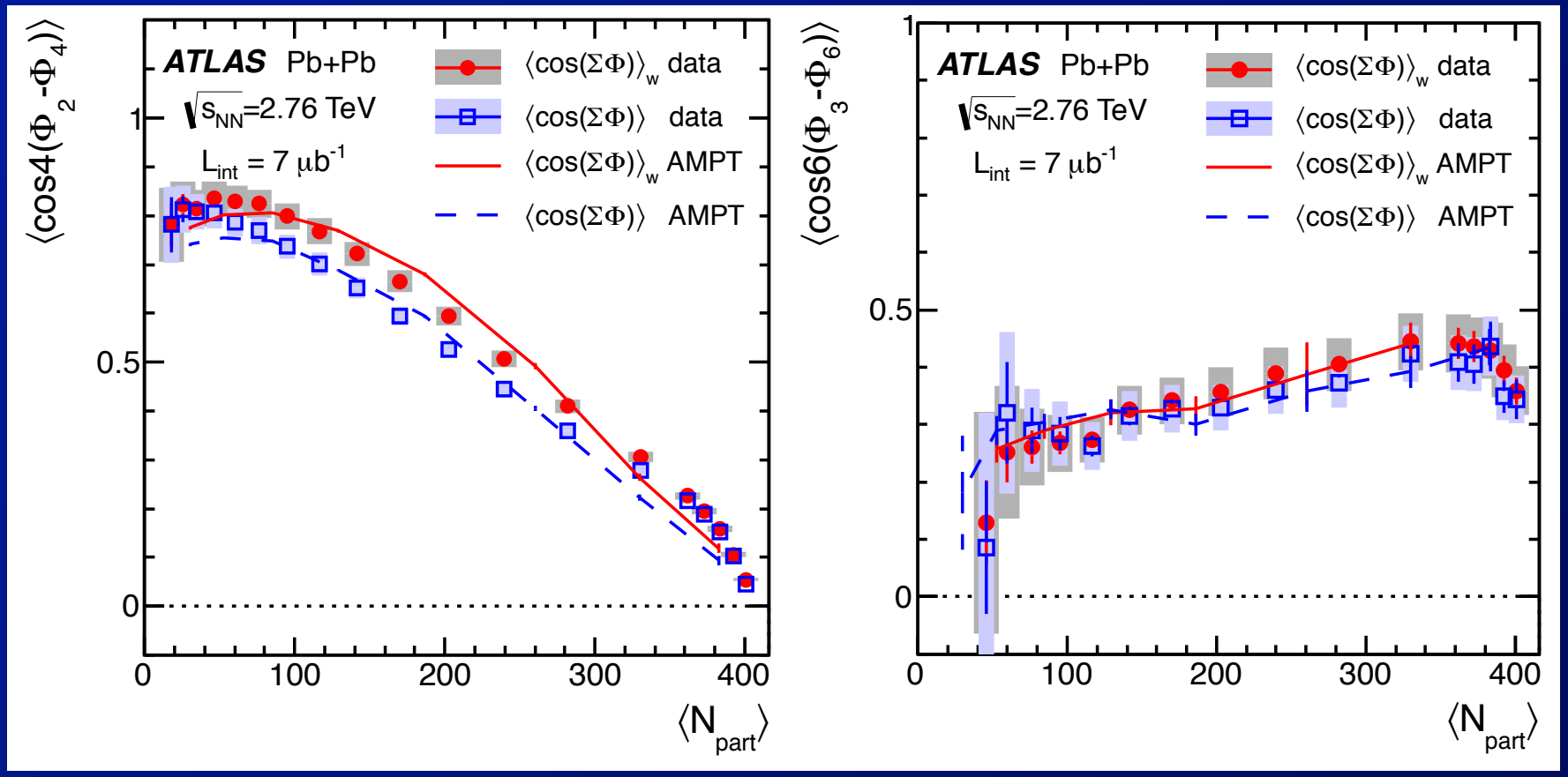
Event plane angle correlations

- Measure event plane angles, Φ_n, event -by-event using ATLAS calorimeter (arXiv:1403.0489)
  - Evaluate $\langle \cos\left(jk\left[\Phi_n - \Phi_m\right]\right)\rangle$
  - Compare to Glauber: poor agreement

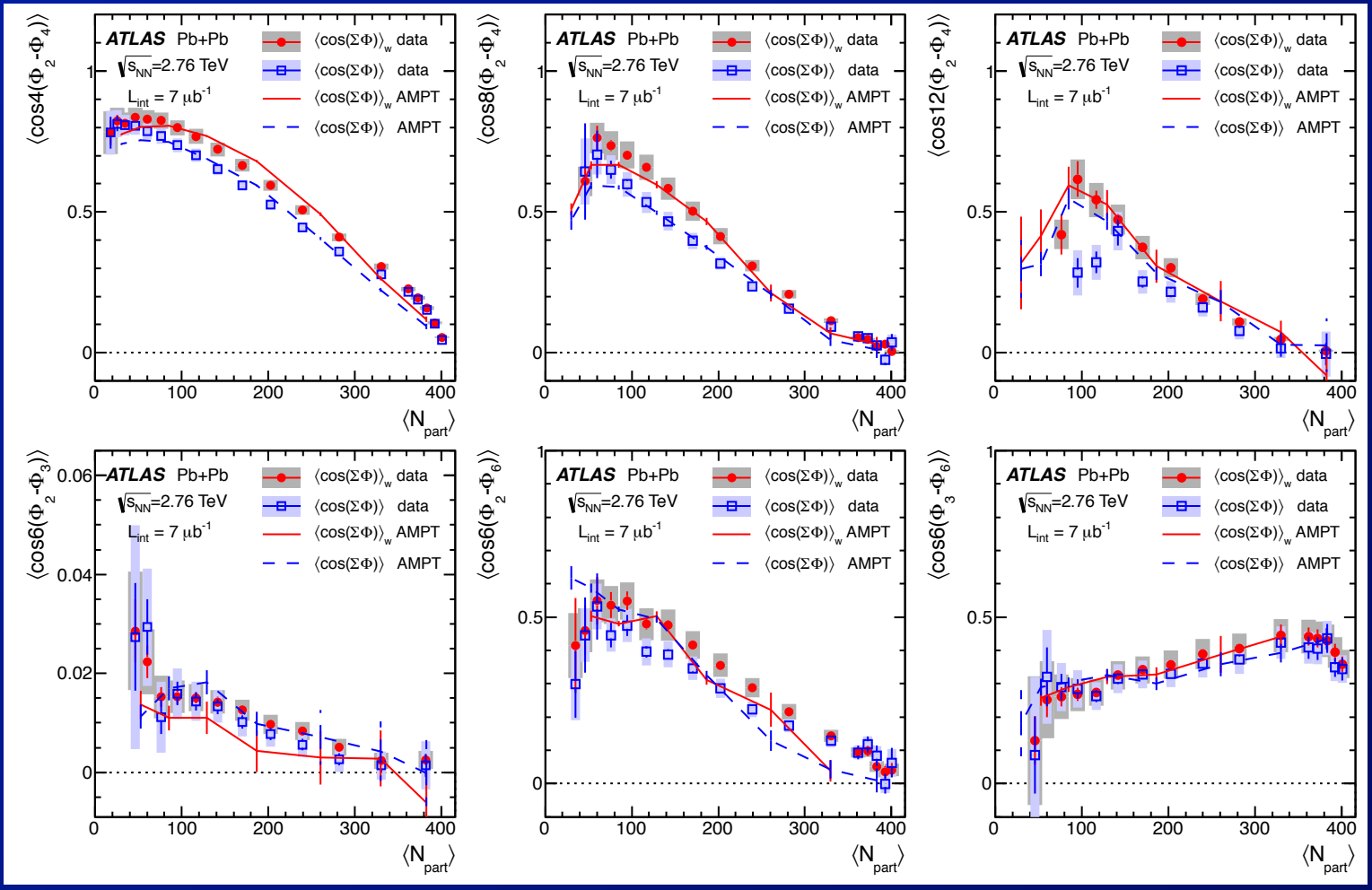


Event plane angle correlations

- Measure event plane angles, Φ_n, event -by-event using ATLAS calorimeter (arXiv:1403.0489)
  - Evaluate $\langle \cos\left(jk\left[\Phi_n - \Phi_m\right]\right)\rangle$
  - Compare to AMPT: good agreement



Event plane angle correlations (3)



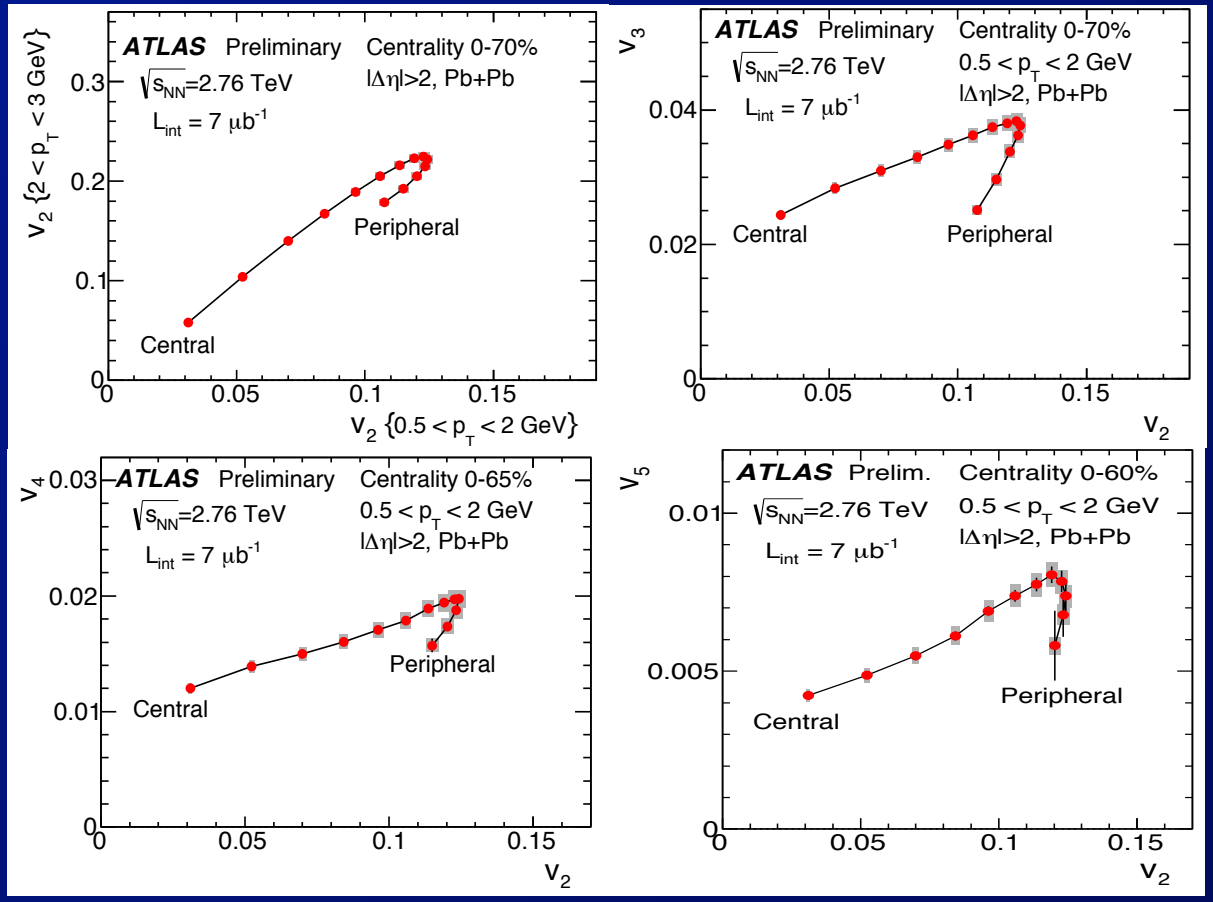
- Results for all 2, 3-plane correlations agree poorly with Glauber, well with AMPT
  - ⇒ Significant non-linear flow contributions to higher order harmonics

v_n correlations

- Study correlations between v_n's using two-particle correlations with $|\Delta\eta| > 2$
  - Plot correlation of (e.g.) v_2 and v_2, v_3, v_4, v_5 values in different 5% centrality bins

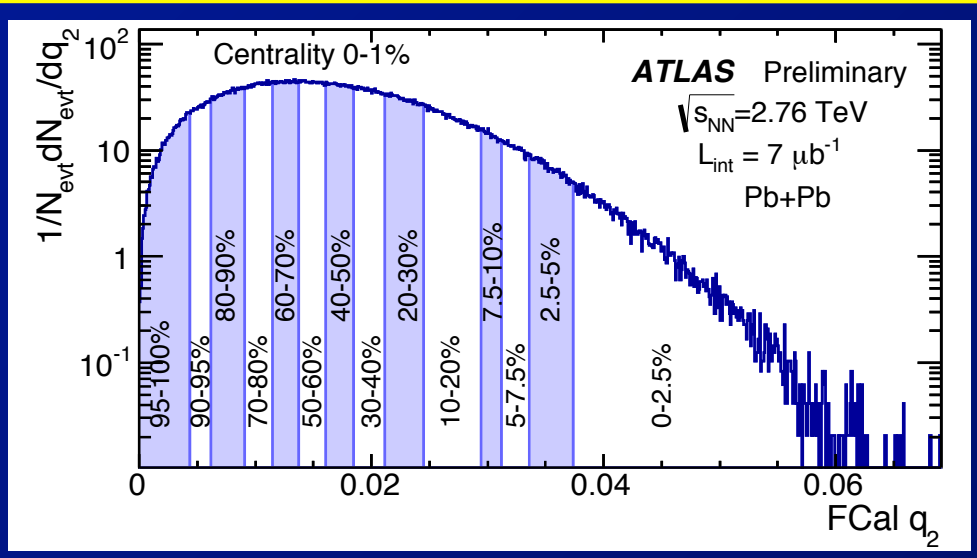
⇒non-monotonic variation

⇒Role of finite viscosity in peripheral collisions?



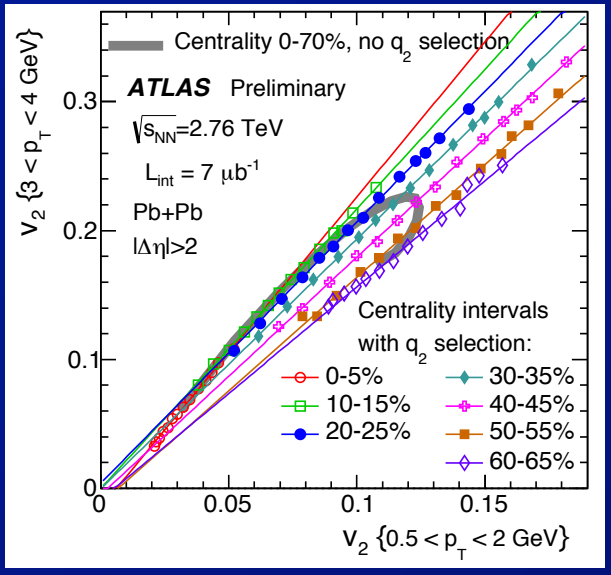
Event v_2-selected results

- Fix initial geometry via centrality, select events according to elliptic flow vector magnitude (q_2)
  - Measured in FCals

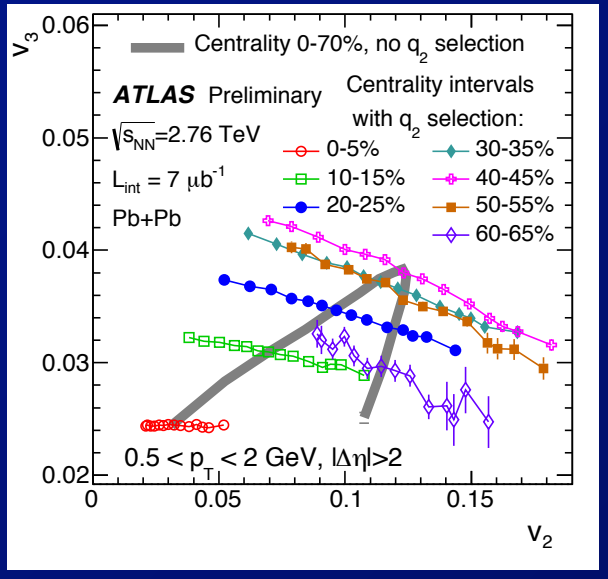


⇒Study two-particle correlations in $|\eta|< 2.5$

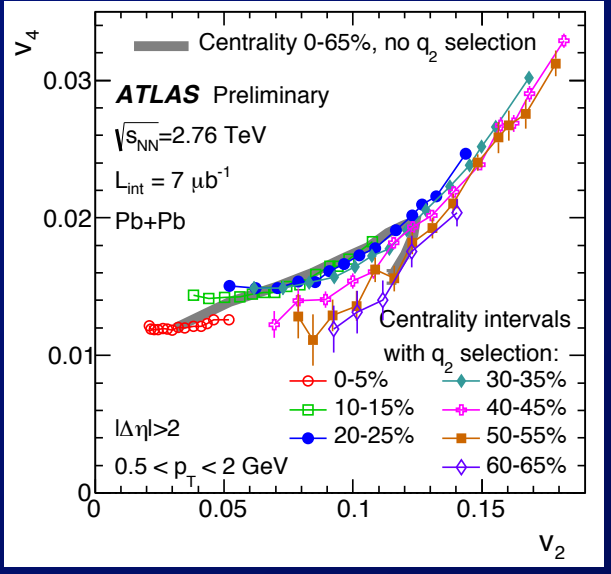
v_2 (higher p_T)



v_3

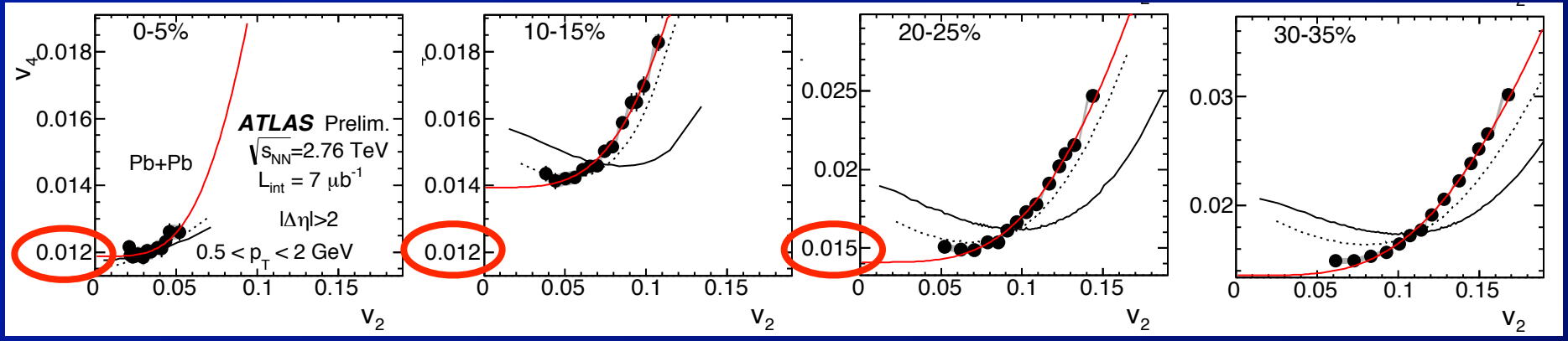


v_4

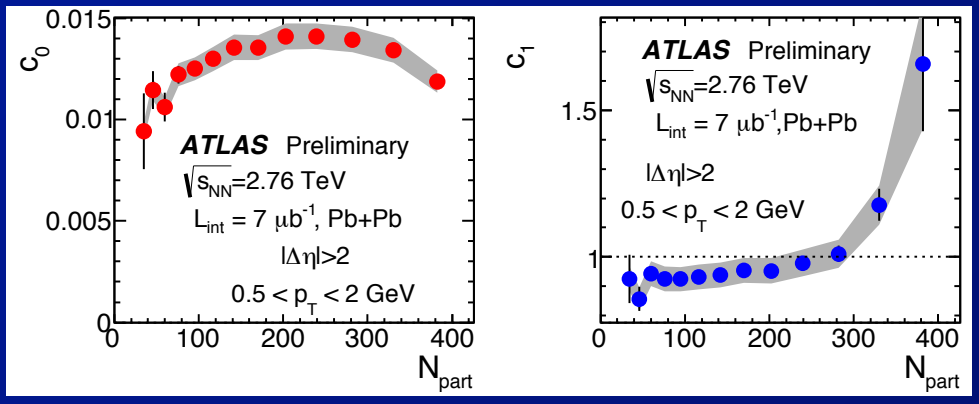


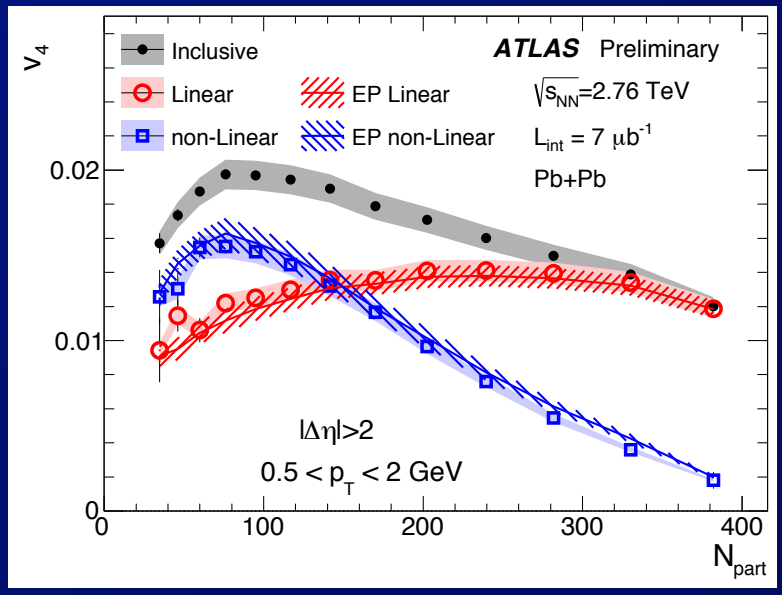
Studying flow non-linearity in v_4

- v_2-v_4 correlations within centrality bins



- Fit to $\sqrt{c_0^2 + (c_1 v_2^2)^2}$ to separate ε_4- ("linear") and v_2- ("non-linear") driven contributions

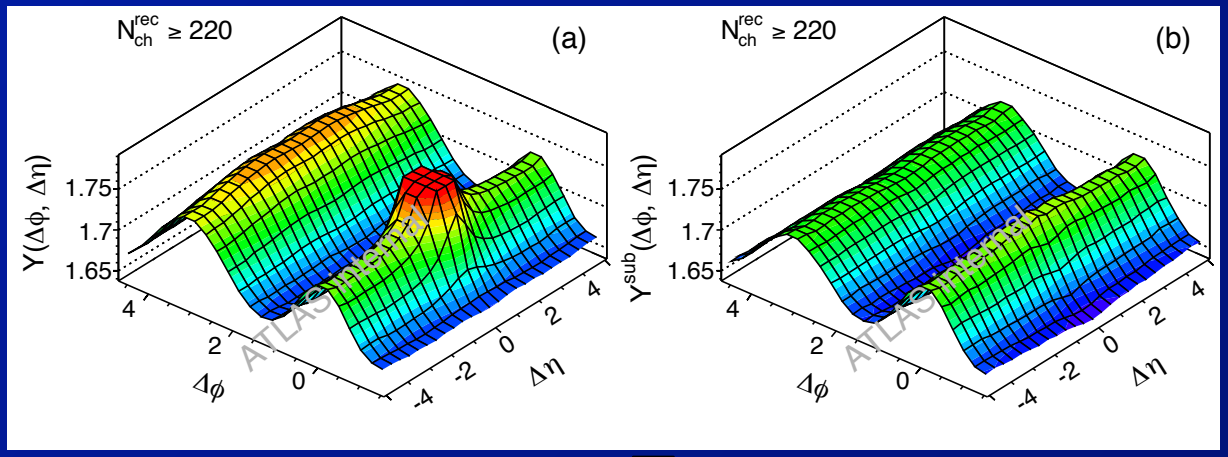


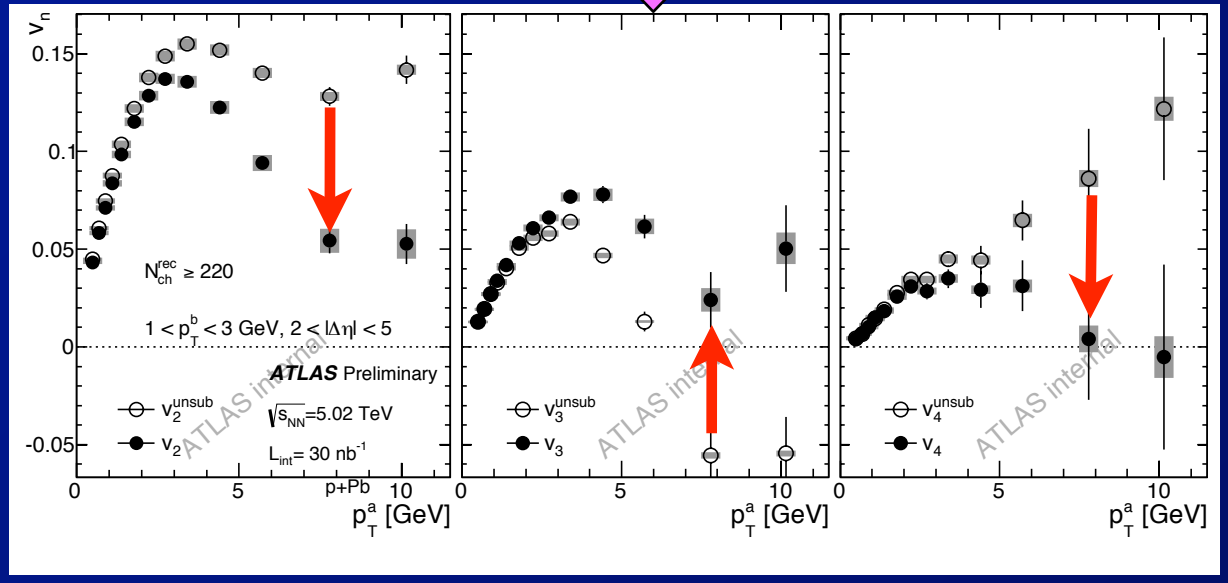


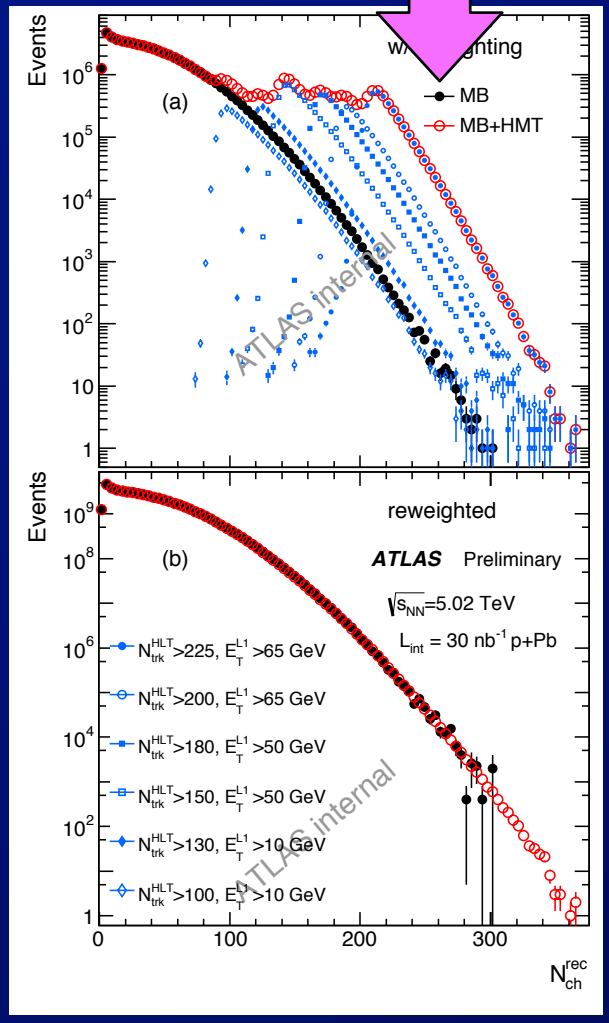
- Plot linear and non-linear components vs centrality

p+Pb v_n: overview

- Use minimum-bias + high-multiplicity trigger data
- Apply "improved" peripheral subtraction



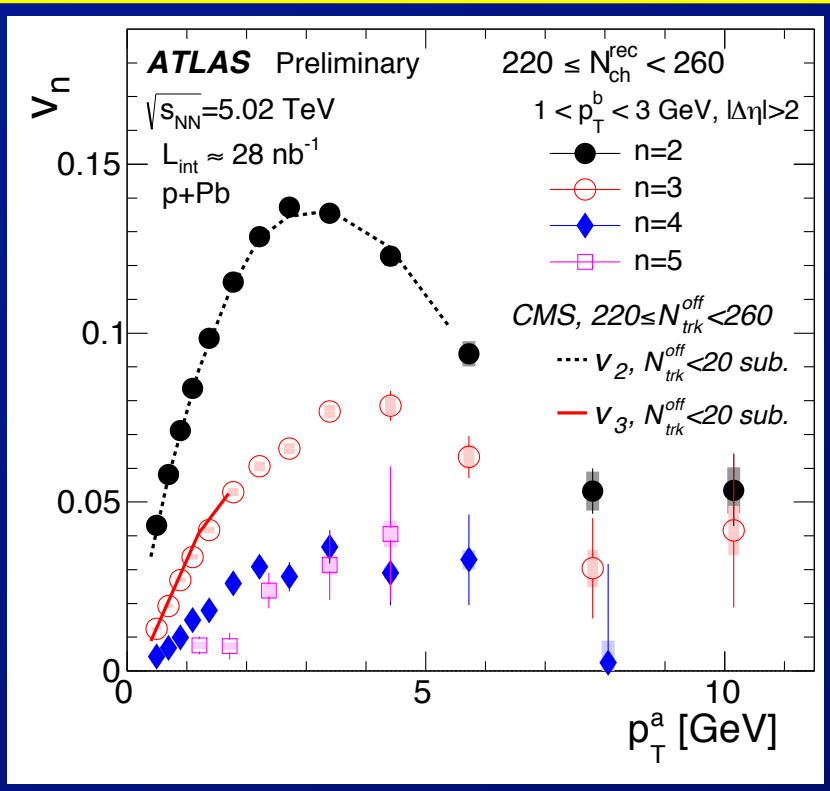




Radhakrishnan: Correlations and fluctuations, 2

p+Pb 2-particle $v_n(p_T)$

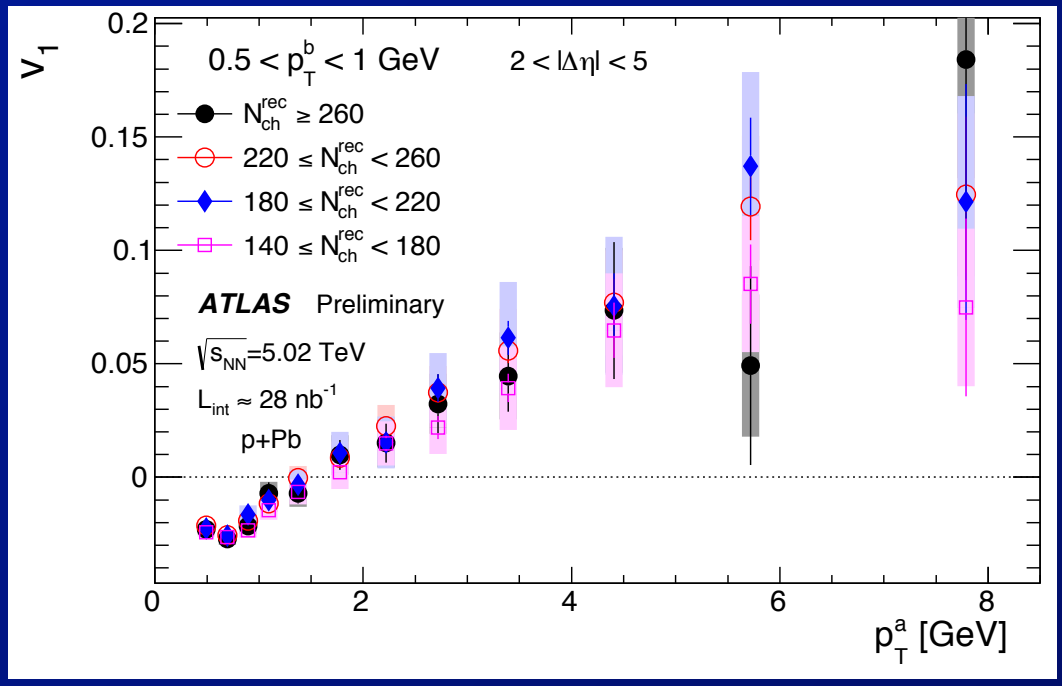
- **Observe:**
  - significant values for n = 2,3,4,5
    - ⇒For n = 2,3 to 10 GeV



p+Pb 2-particle $v_n(p_T)$

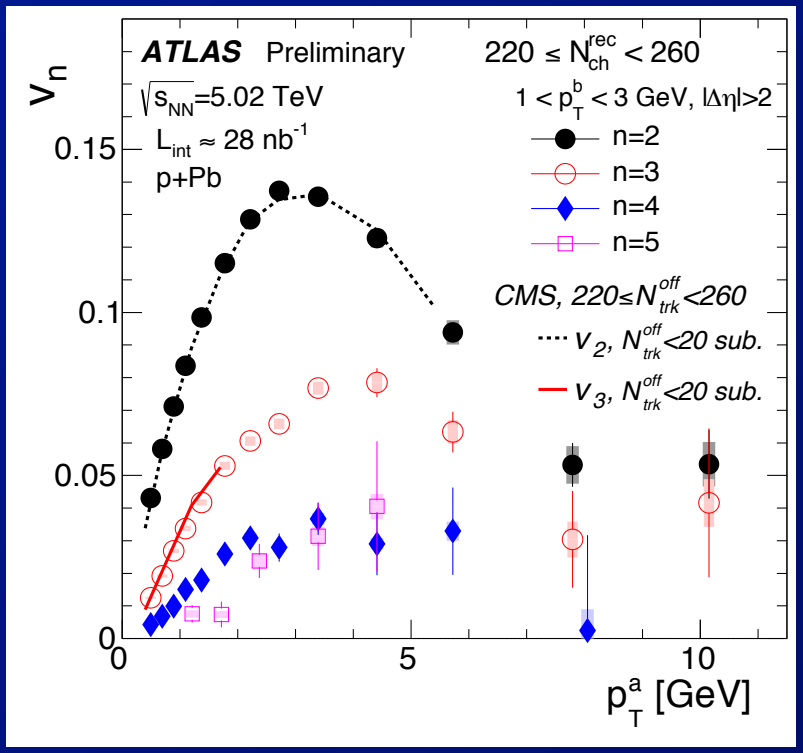
- **Observe:**
  - significant values for n = 1,2,3,4,5

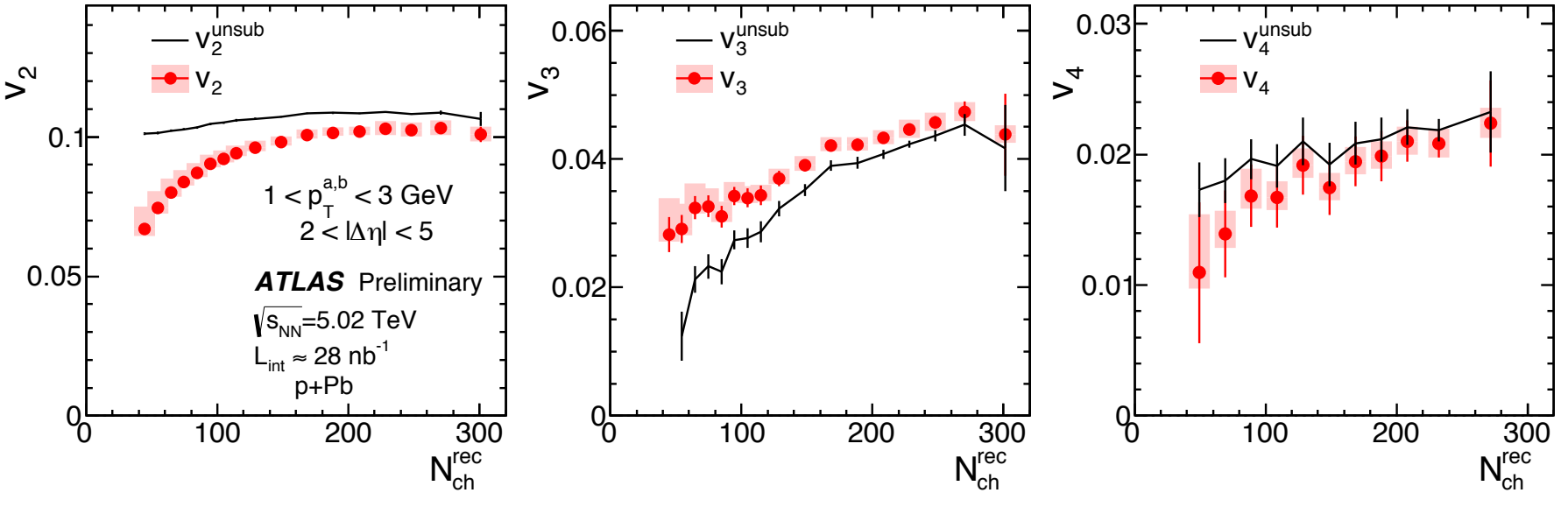
    $\Rightarrow v_1 \sim v_3$



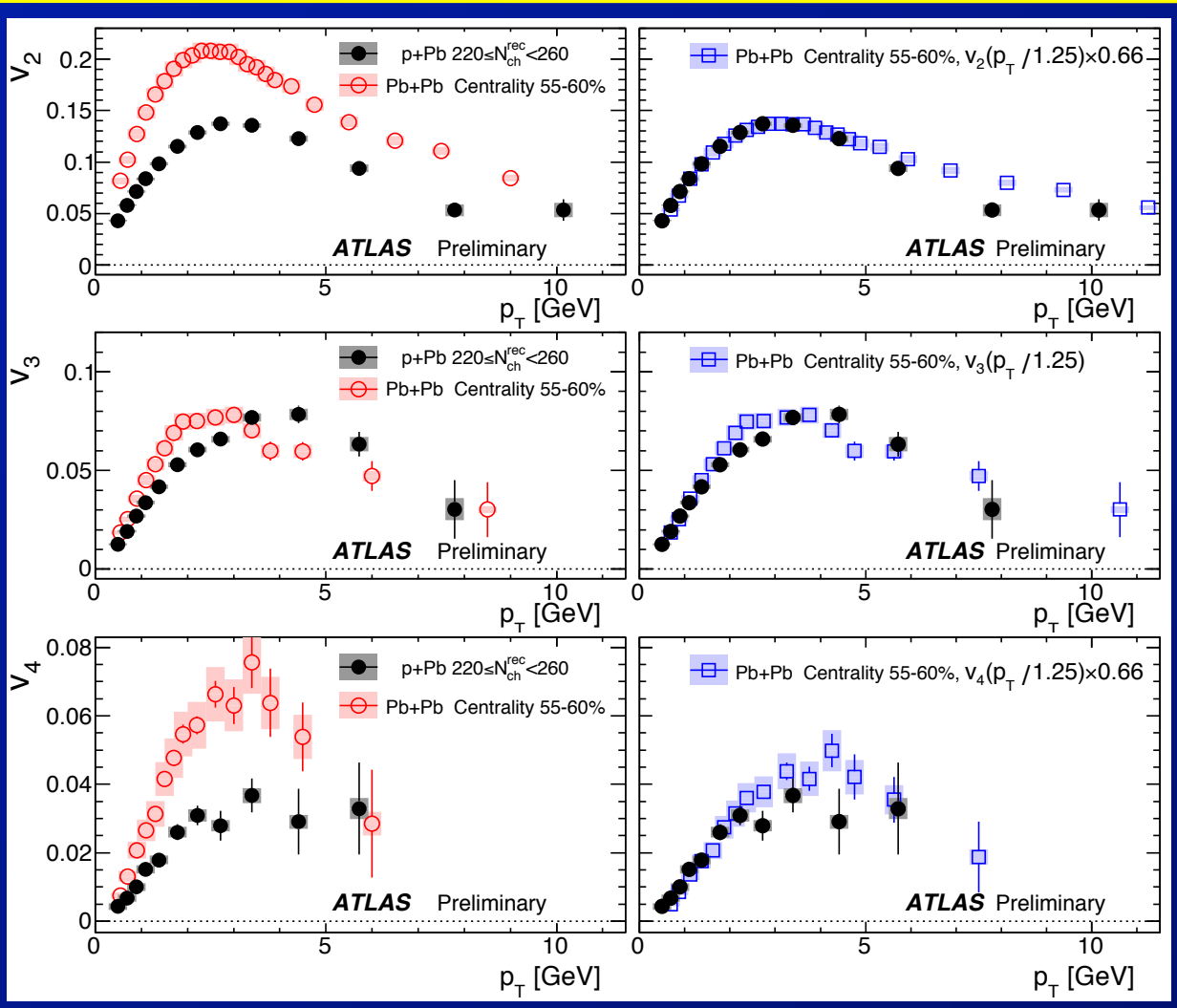
p+Pb 2-particle $v_n(p_T)$

- **Observe:**
  - significant values for n = 1,2,3,4,5
    - ⇒v_2 ~ constant at high multiplicity
    - ⇒v_3 increases over whole multiplicity range





Compare p+Pb, Pb+Pb v_n



Right panels adjust p+Pb p_T scale by 4/5 to account for difference in $\langle p_T \rangle$ (Teany et al)

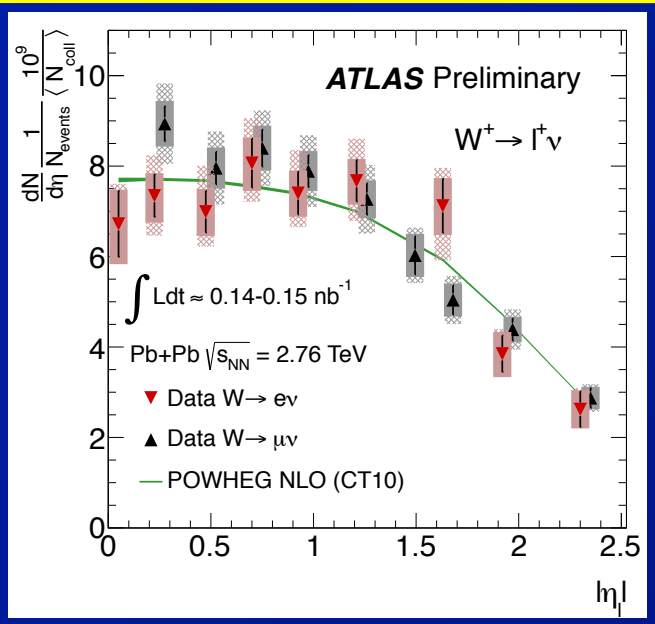
Pb+Pb v_2 and v_4 multiplied by 0.66 to match p+Pb

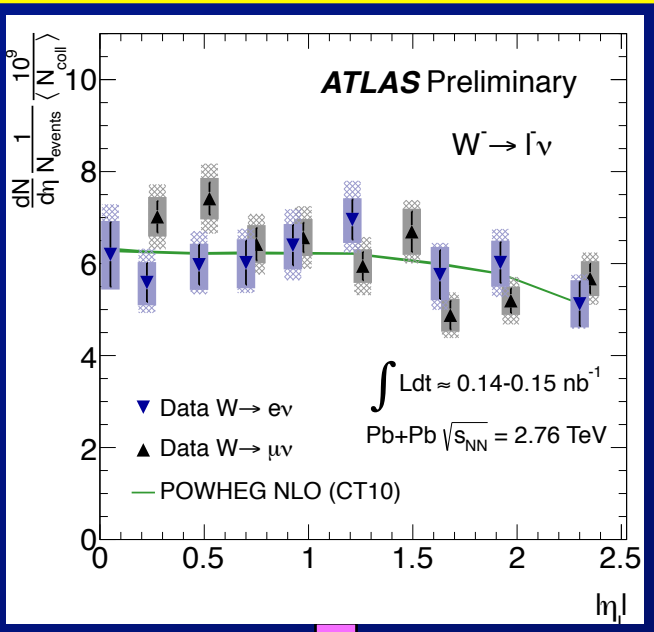
- Compare p+Pb and Pb+Pb

  ⇒Good agreement between p+Pb and Pb+Pb when including p_T and v_2, v_4 rescaling

Hard probes:
electro-weak bosons, jets

$W^{\pm}$ production in Pb+Pb collisions



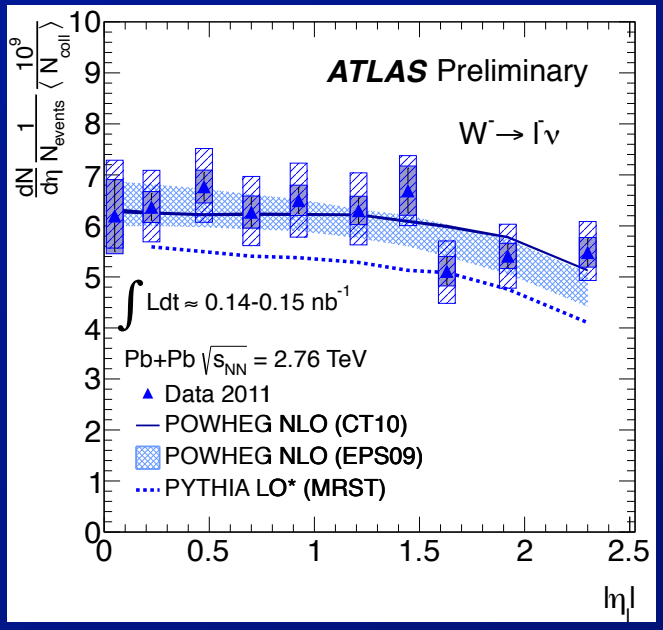


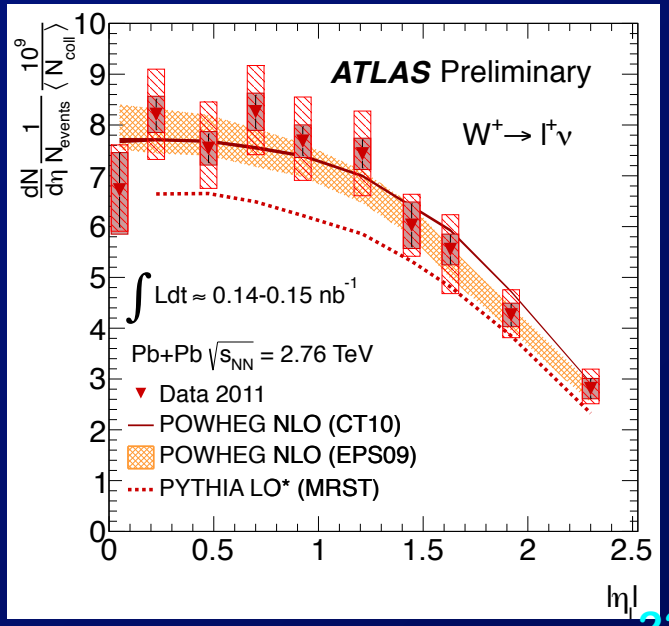
- **Measure**
  - $W \to e^{\pm}\nu$
  - $W \to \mu^{\pm}\nu$
  - \+ charged particle $\not{p}_T$

  ⇒ $p_T > 3$ GeV

- **Yields well reproduced by POWHEG**

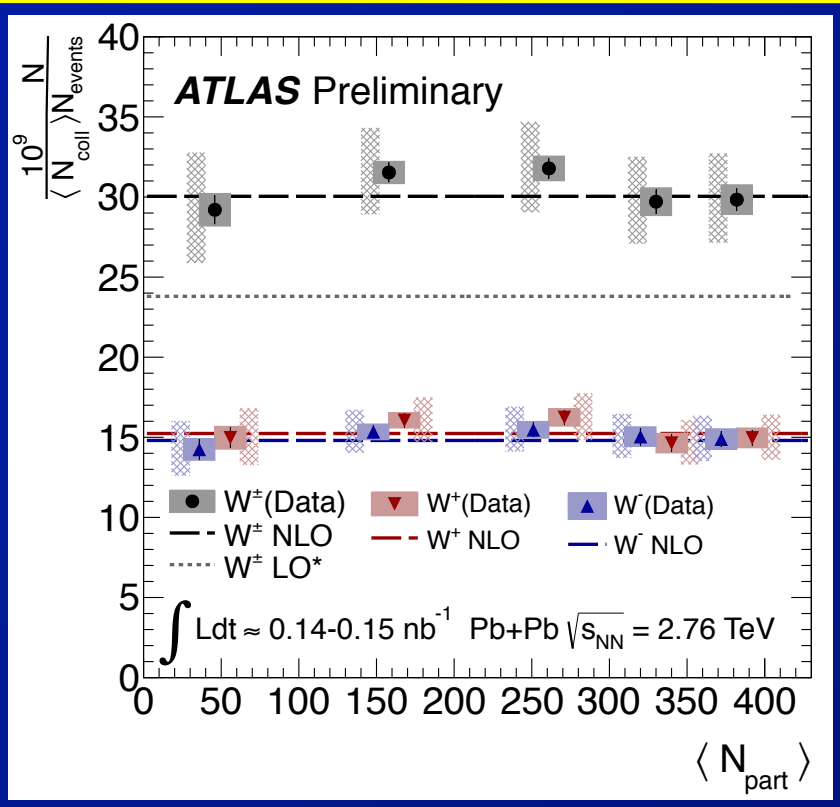
  ⇒ **Data can not (yet) test nPDF effects**

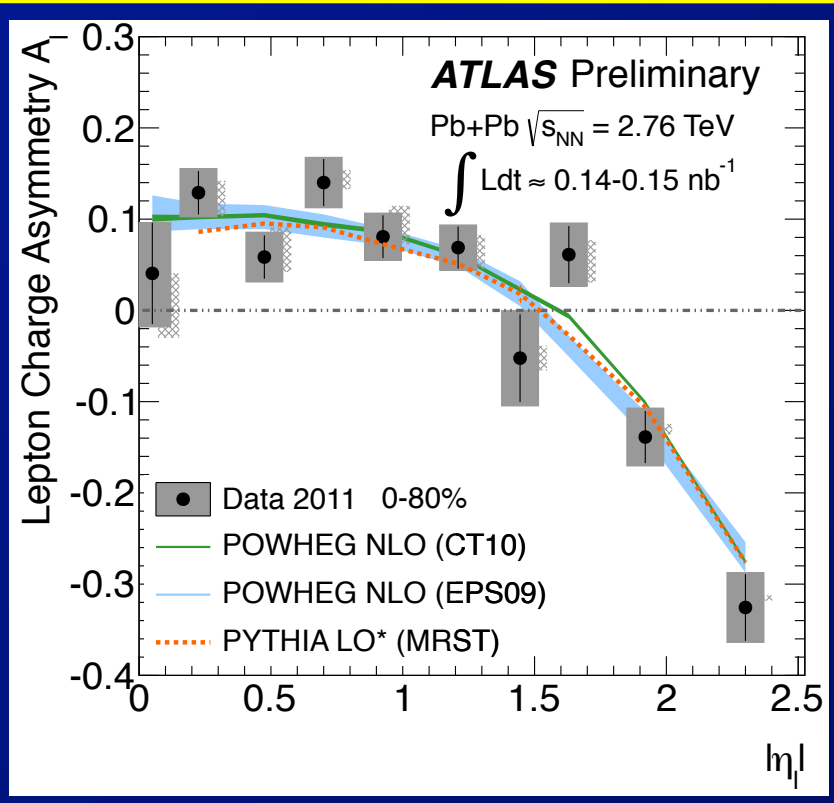




Grabowska-Bold: EM probes: 3

$W^{\pm}$ production in Pb+Pb collisions



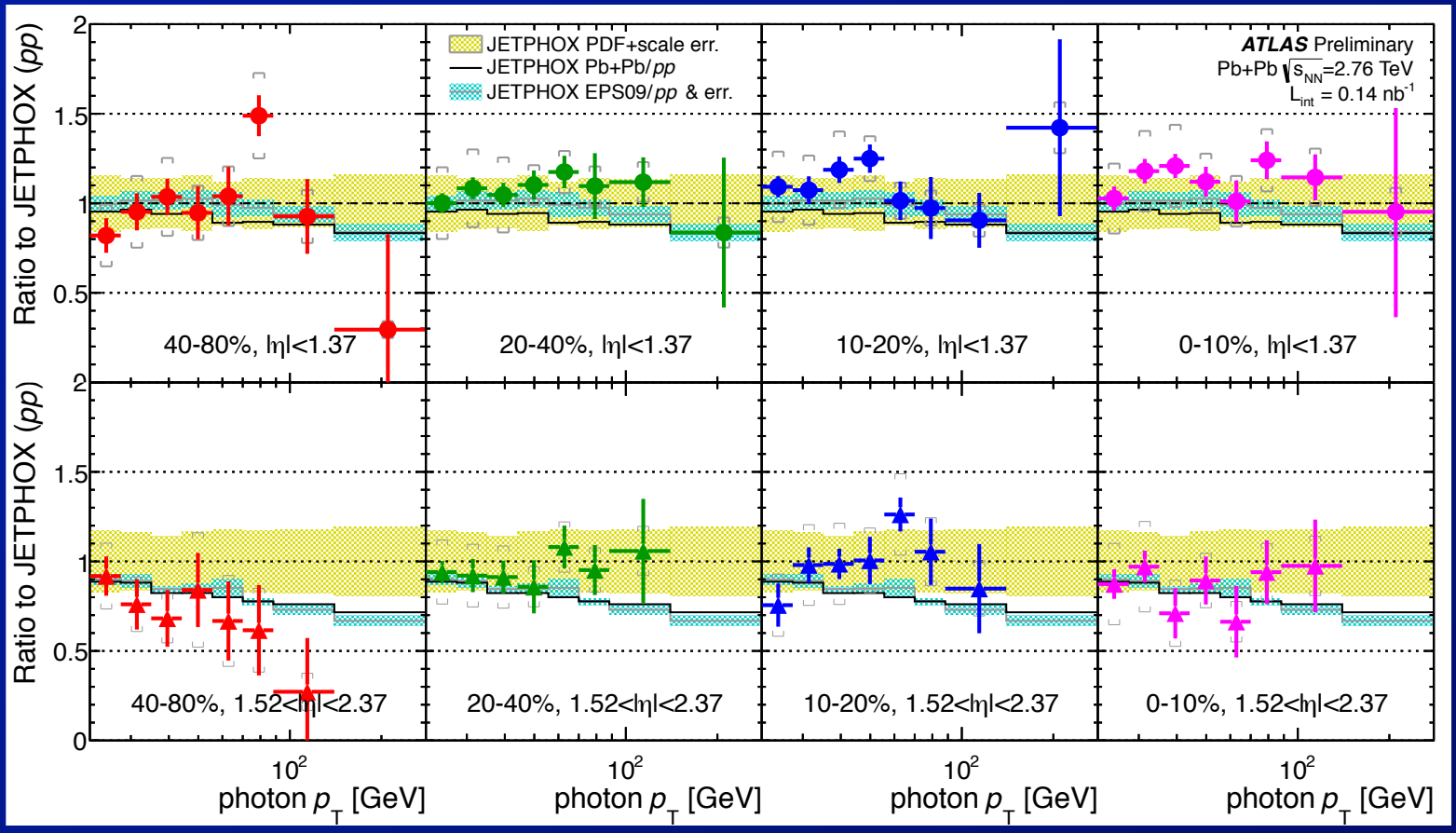


- Evaluate $W^{\pm}$ yield/N_{coll} vs N_{part}
- and W charge asymmetry (inclusive).
  - Yields increase proportional to N_{coll}
  - Charge asymmetry determined by isospin

⇒Additional data to further our understanding of hard scattering in Pb+Pb collisions.

Pb+Pb photon yields

Steinberg: Jets 2



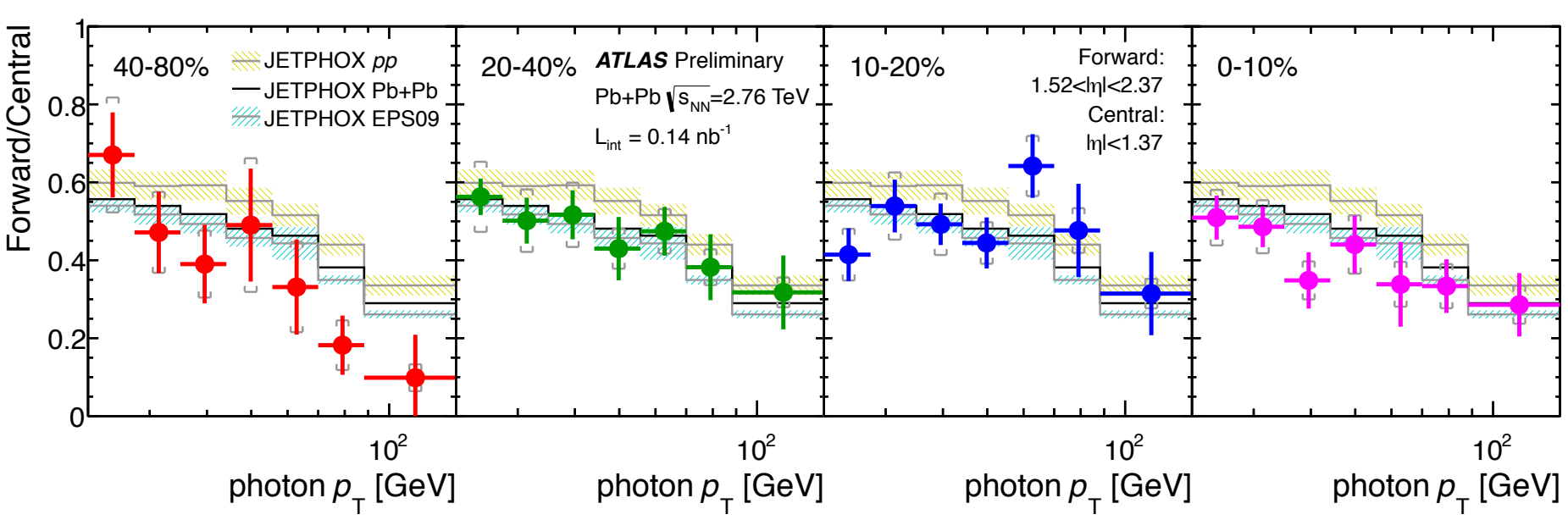
|η|<1.37

1.52<|η|<2.37

- Ratios of isolated, direct photon yields/T_{AA} to NLO pQCD calculation for p-p (JETPHOX1.3)
  - Also shown, JETPHOX for Pb+Pb: iso only, EPS09

⇒Data not yet able to discriminate yet

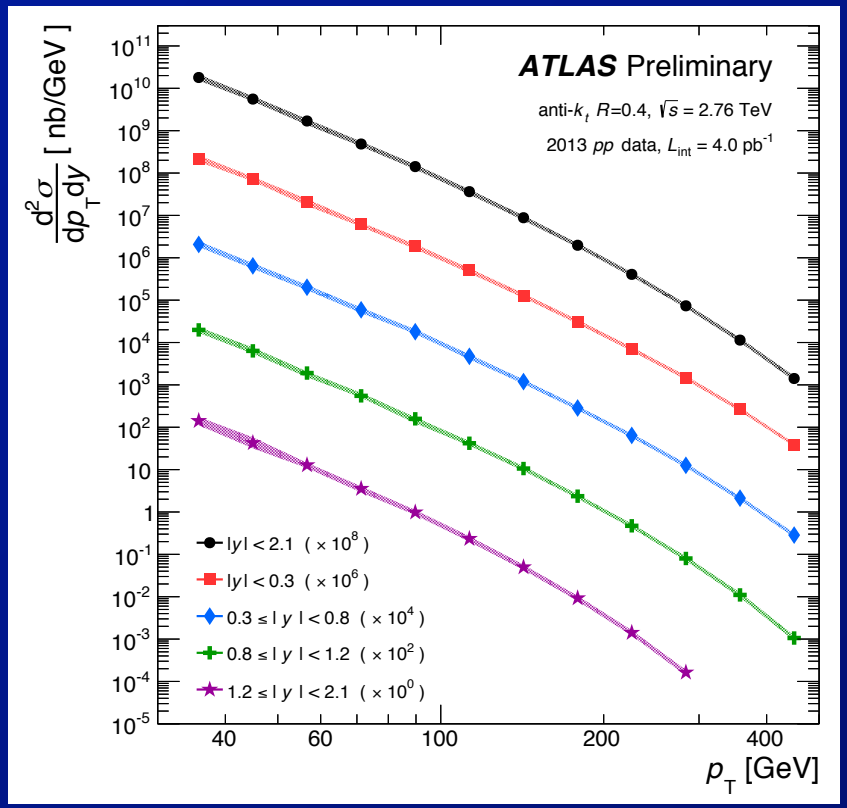
Pb+Pb photon yields

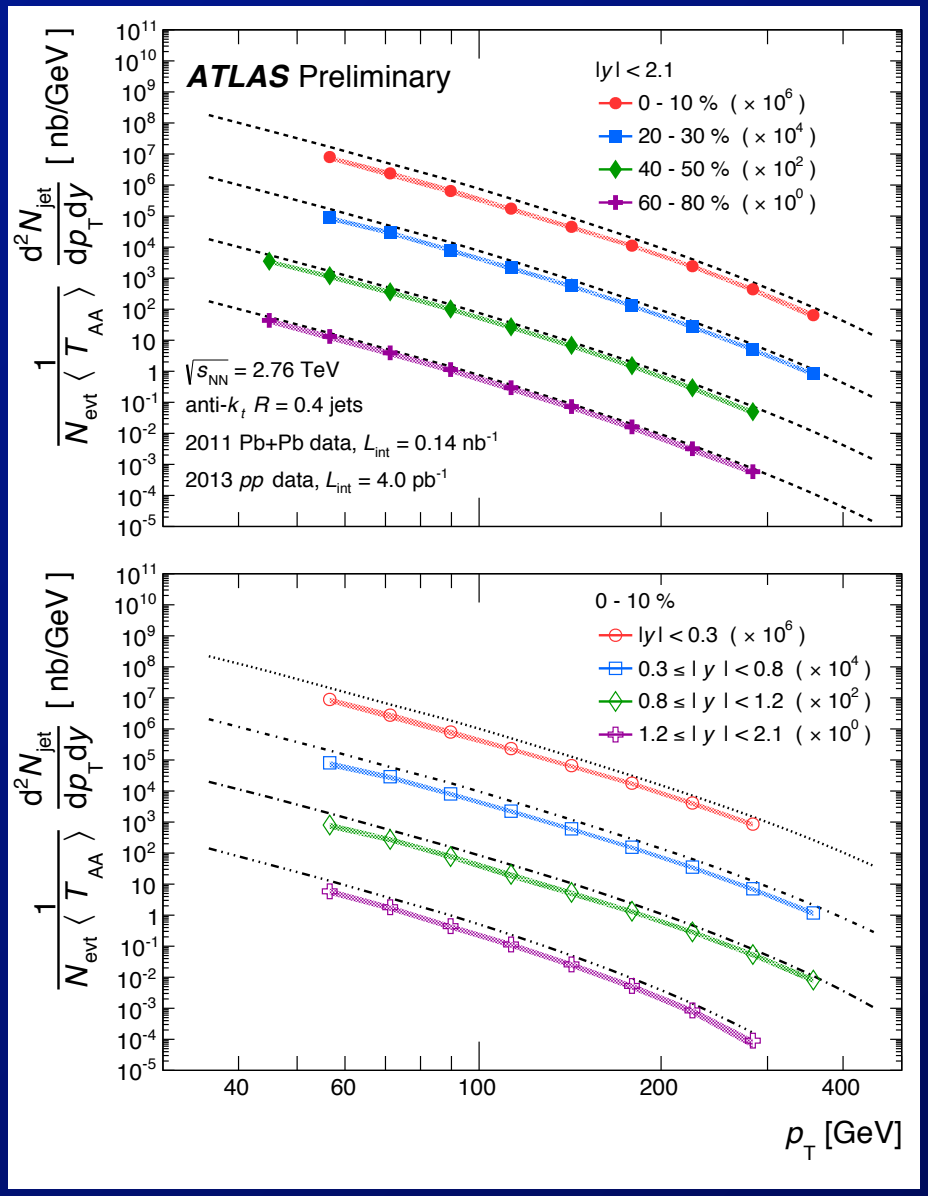


- **Forward (1.52<|η|<2.37) to central (|η|<1.37) yield ratios vs p_T**
  - **More sensitive test of isospin/PDF**
    - **⇒Ratios well described by NLO pQCD**
    - **⇒Need better statistics to probe for isospin, nuclear PDF effects**
      - » **but we're getting close**

Jet spectra: p+p and Pb+Pb

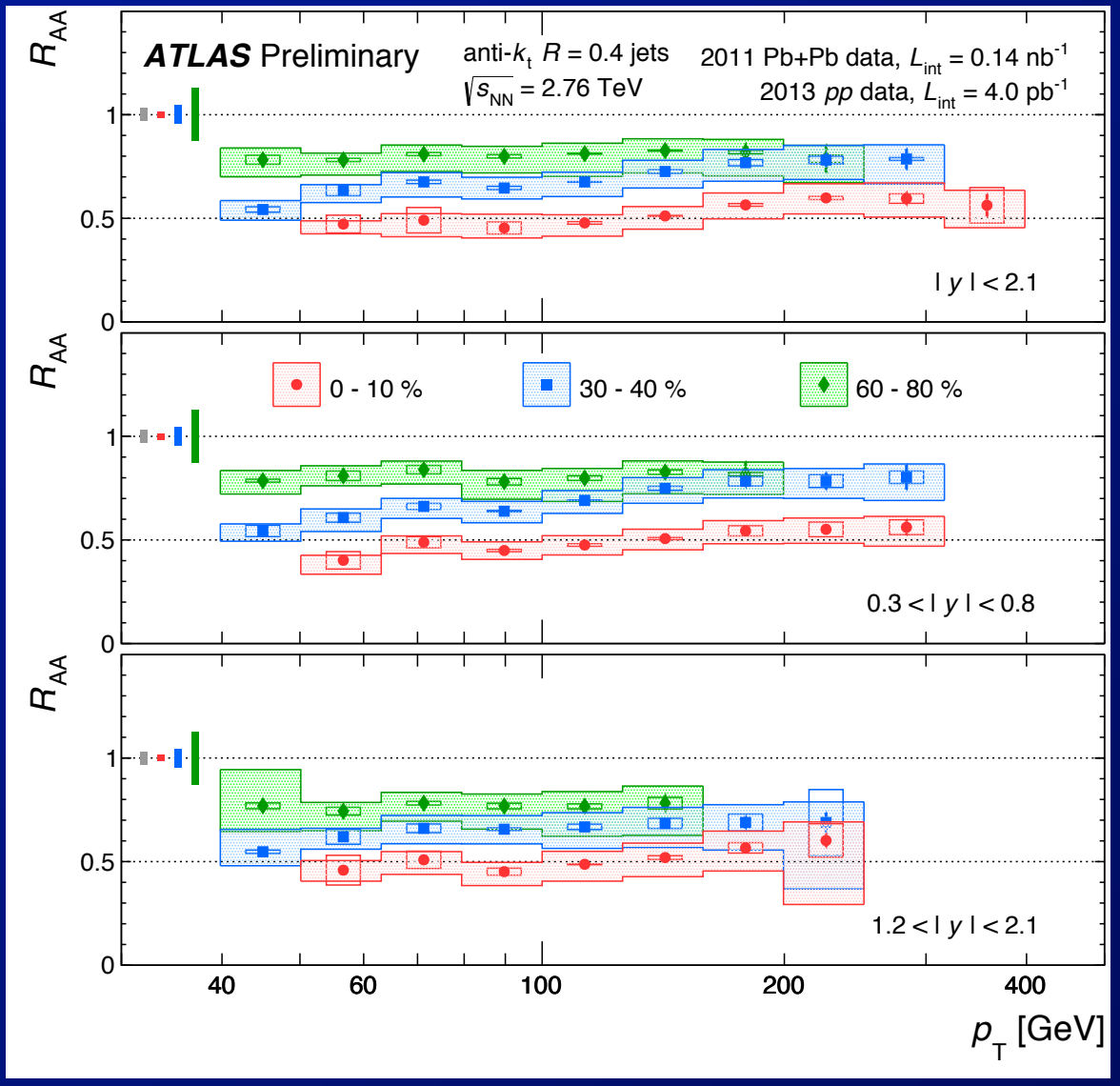
- **Absolutely normalized jet spectra:**
  - 2013 2.76 TeV p+p (left)
    - ⇒ cross-section
  - 2011 Pb+Pb (right)
    - ⇒per-event yields





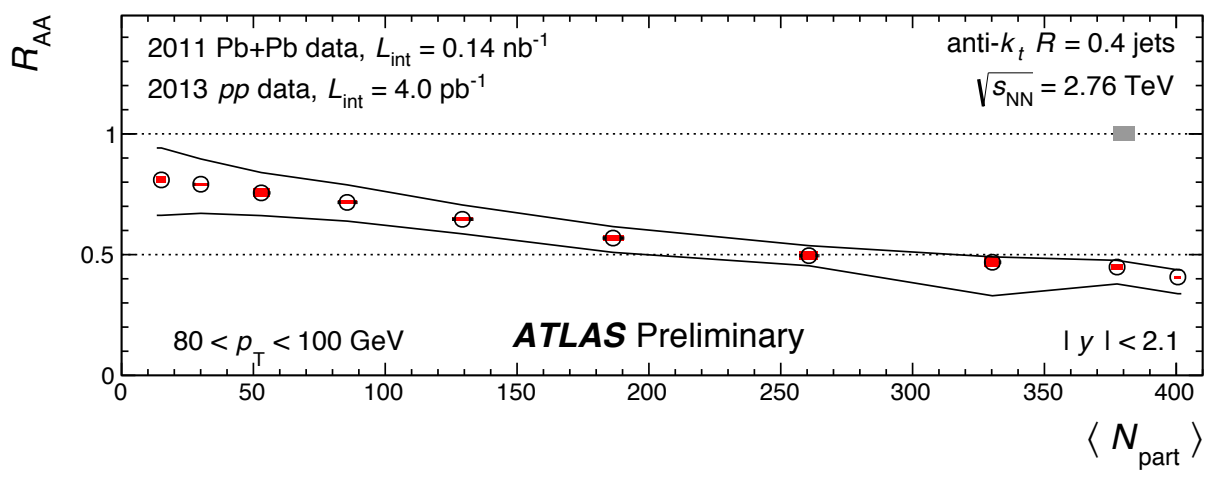
Jet R_{AA}

- R_{AA} vs p_T and y
  - in sub-set of measured centrality bins
    - ⇒Fully unfolded
- Observe
  - Factor of ~ 2 suppression up to jet p_T of 400 GeV
  - Slow increase with increasing jet p_T
    - ⇒May vary with centrality

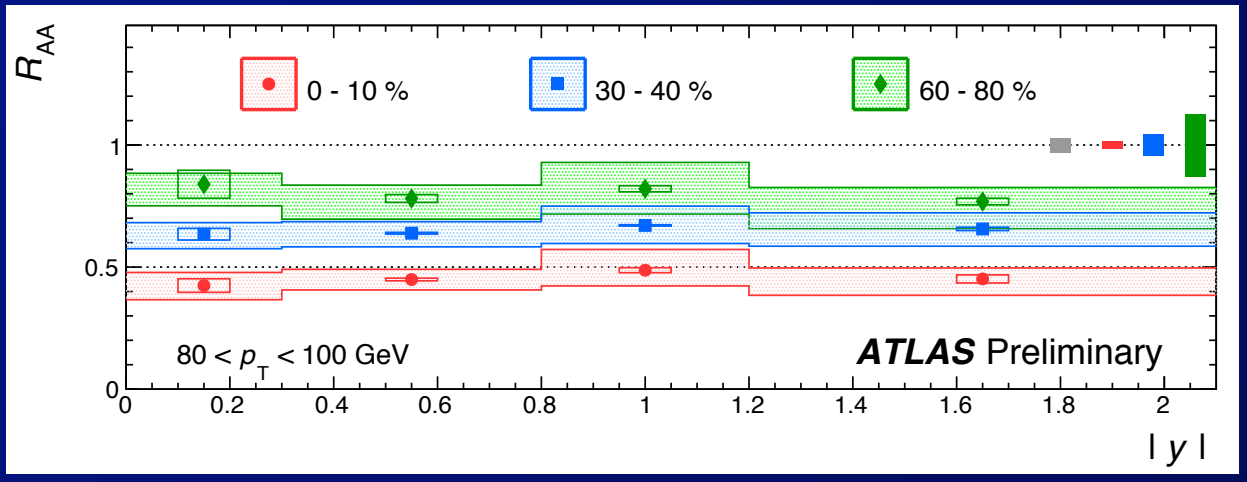


Jet R_{AA}: centrality and y dependence

- R_{AA} monotonically decreases vs N_{part}
  - ⇒0.8 in 60-80%
  - ⇒0.4 in 0-1% at lower jet p_T

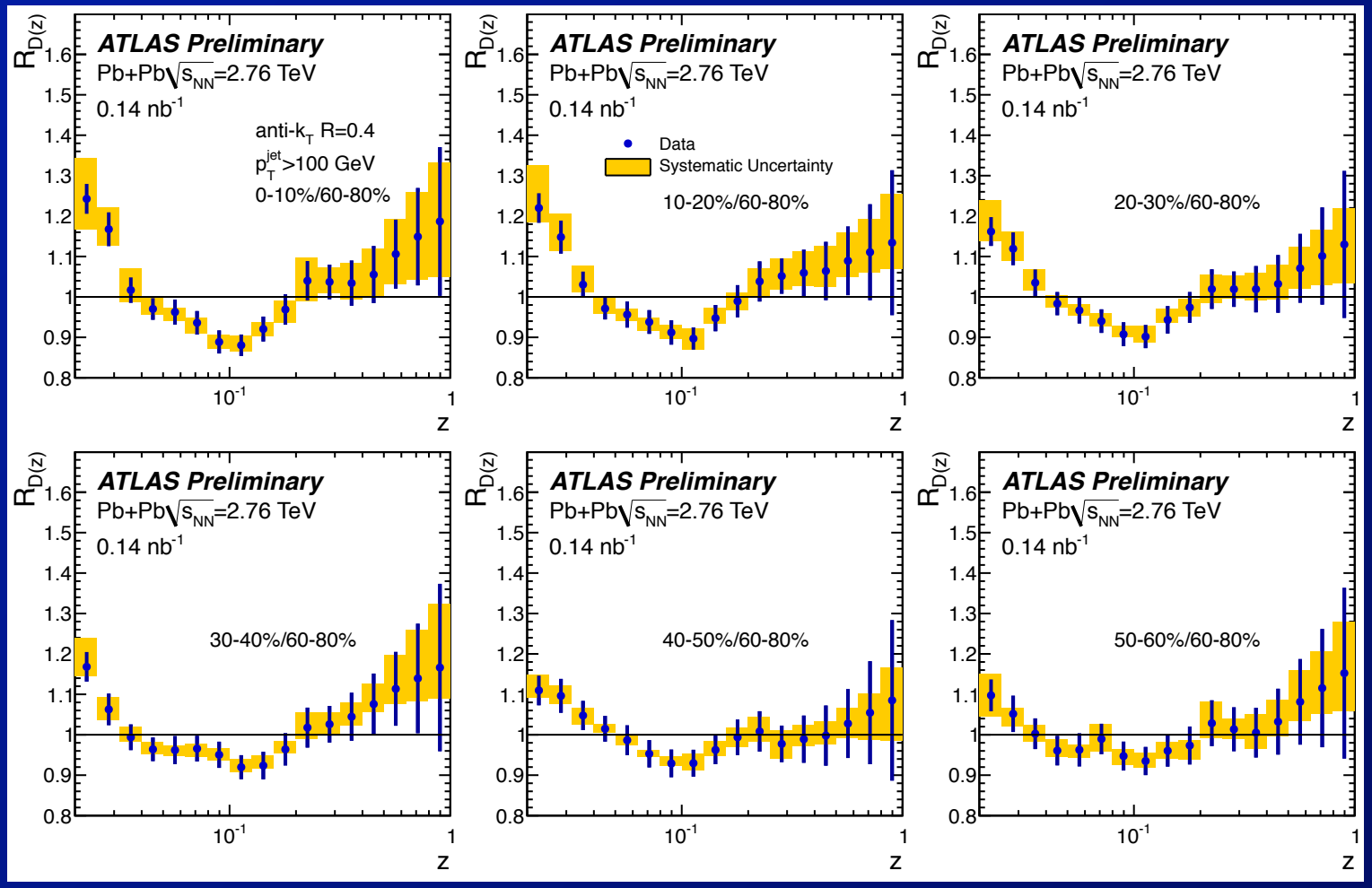


- No significant dependence on rapidity observed
  - – Even though both spectrum shape and q/g fractions vary with y
  - ⇒Test of dE/dx calculations



Pb+Pb modified jet fragmentation

Spousta, Jets 3



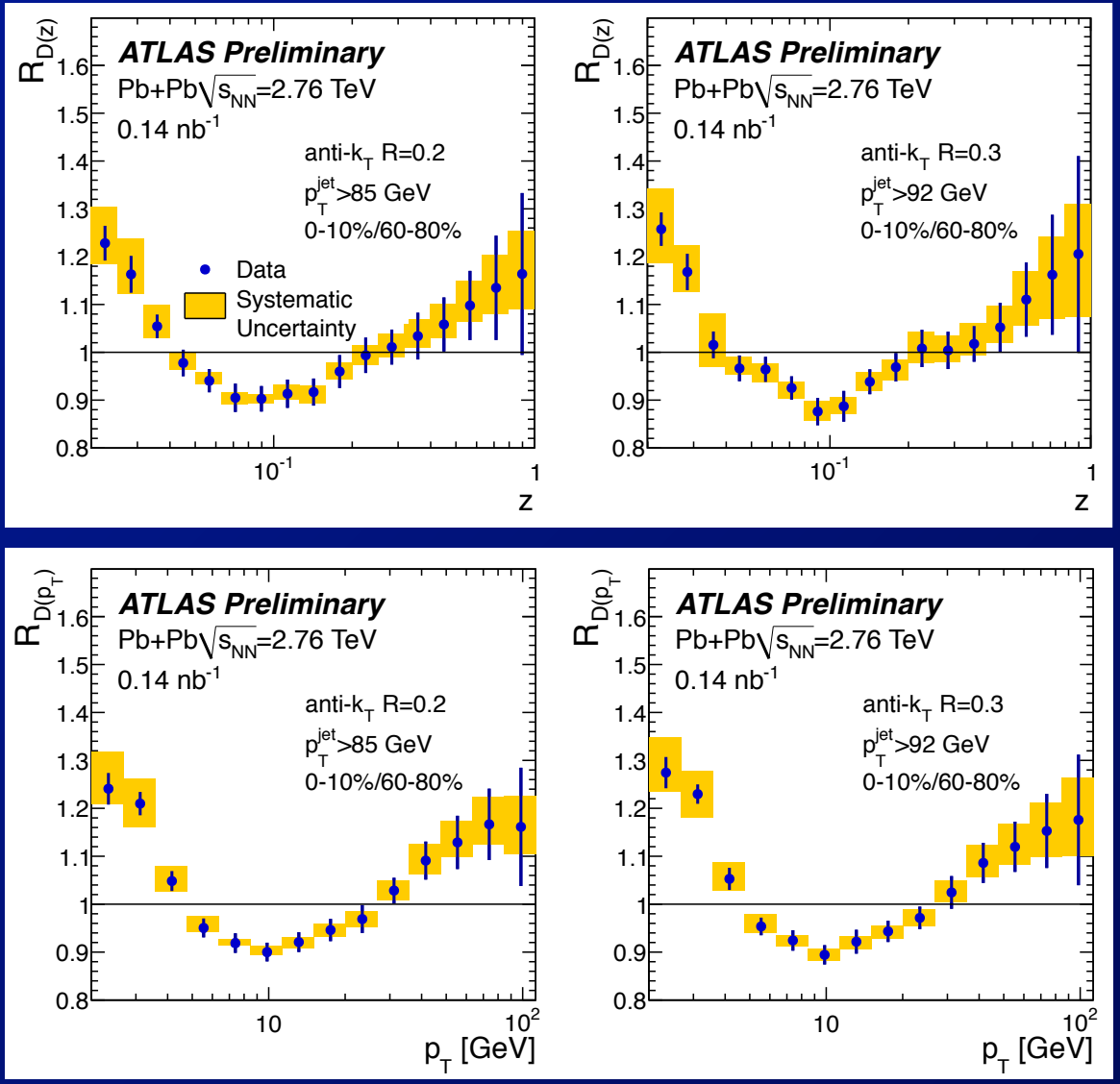
- Ratios of D(z) vs centrality to 60-80% bin
  - In addition to features previously seen

    ⇒ Indication of an enhancement at large z

Pb+Pb modified jet fragmentation (2)

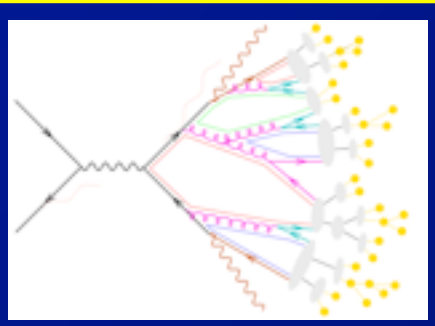
- Enhancement at large z or p_T clearer for:
  - Smaller jet radii
    - ⇒R = 0.2, 0.3
  - fragment pT spectrum, D(p_T)
- Observe
  - ⇒enhancement makes it possible to preserve

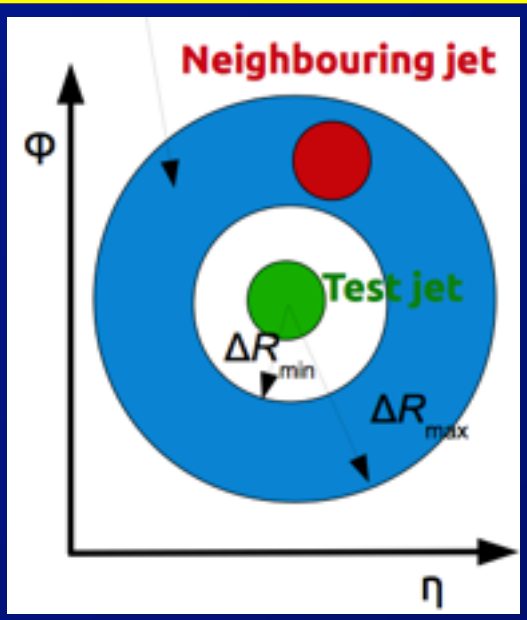
$$\int dz\ zD(z)$$



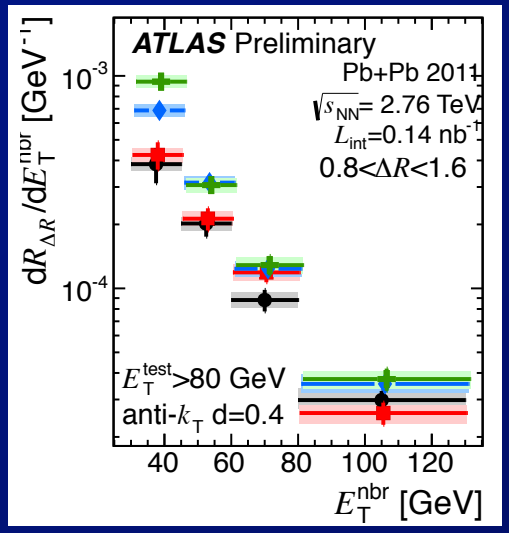
Pb+Pb: correlated nearby jets

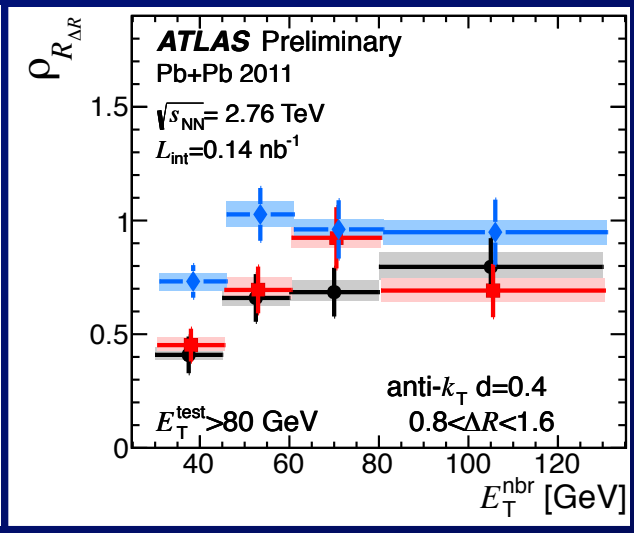
- 1st step in studying internal structure of parton showers
  - Measure nearby jet pairs
    - ⇒Useful probe of relative quenching of correlated jets
- Measure (e.g.) conditional yield of jets associated with "test" jet
  - ⇒Suppressed conditional yield of nearby jets
  - ⇒Interpretation needs theory calculations





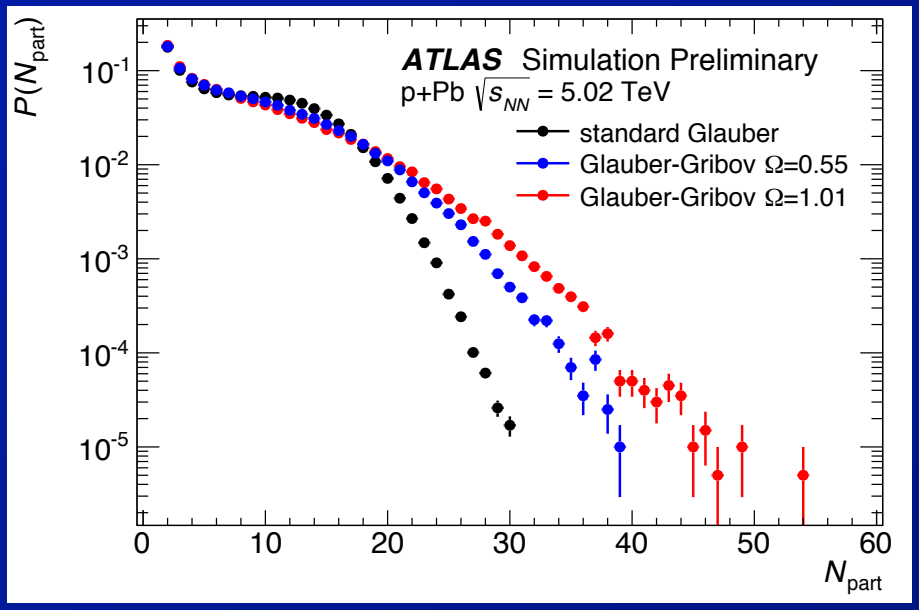
R = 0.4, 0.8 < R < 1.6

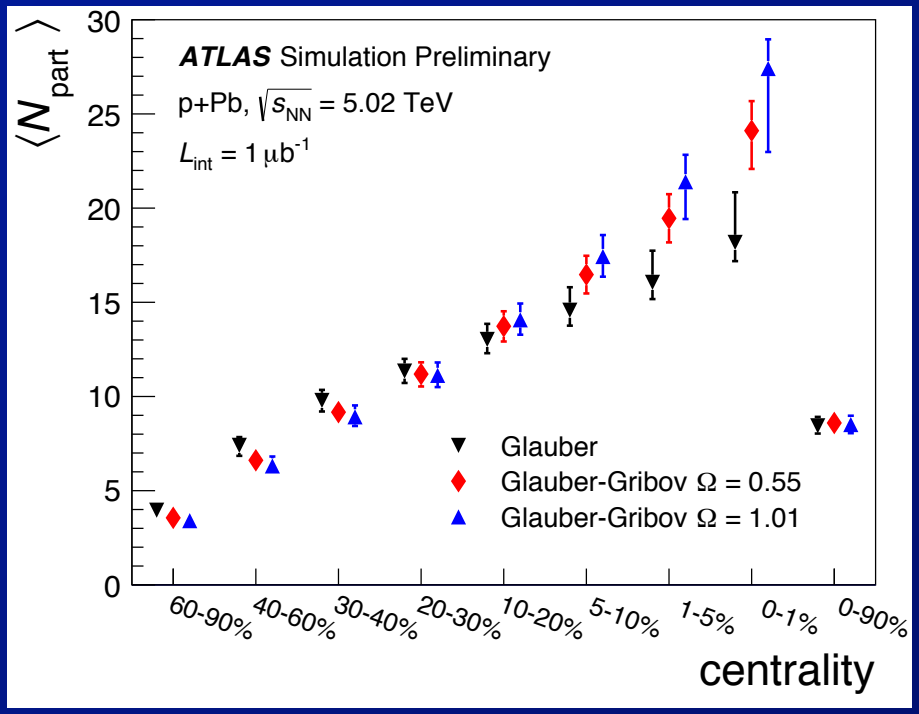


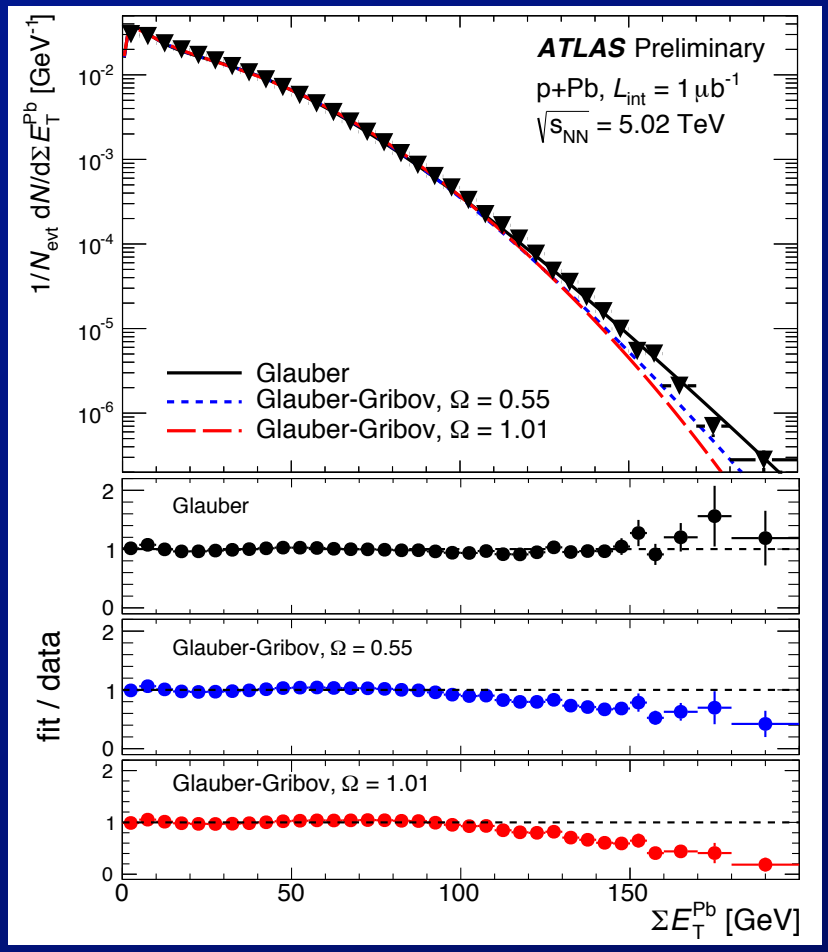


soft and hard particle production in p+Pb collisions

p+Pb Glauber(Gribov) analysis

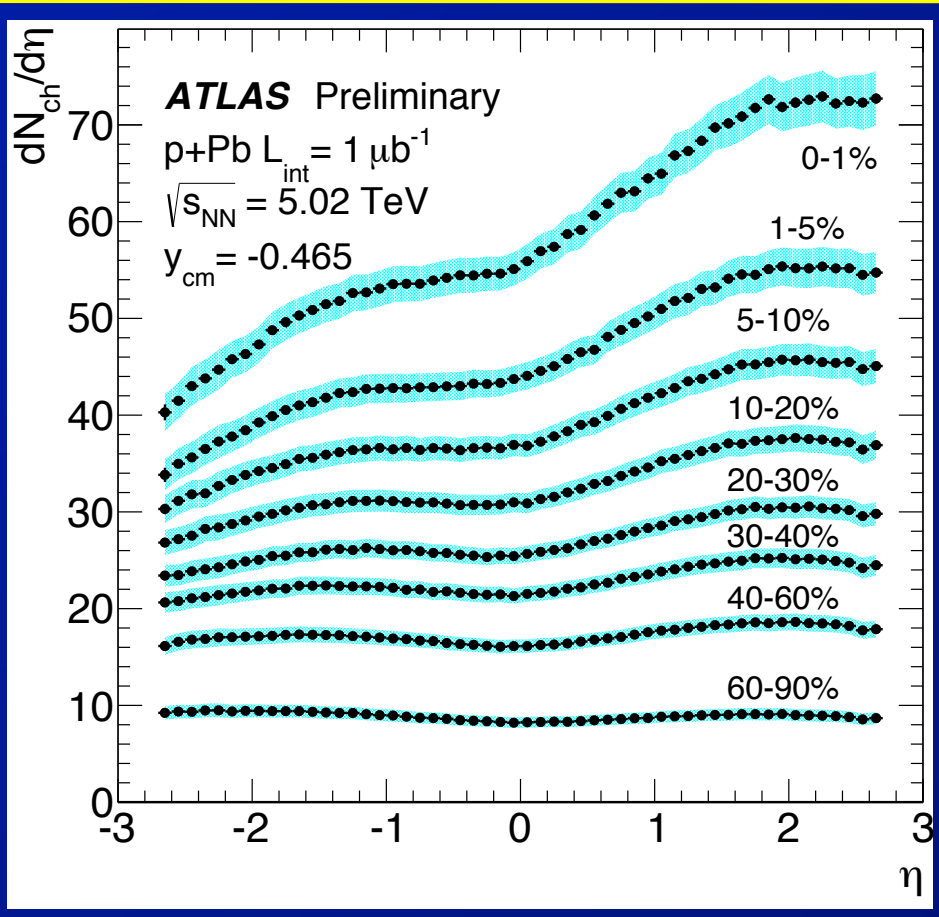


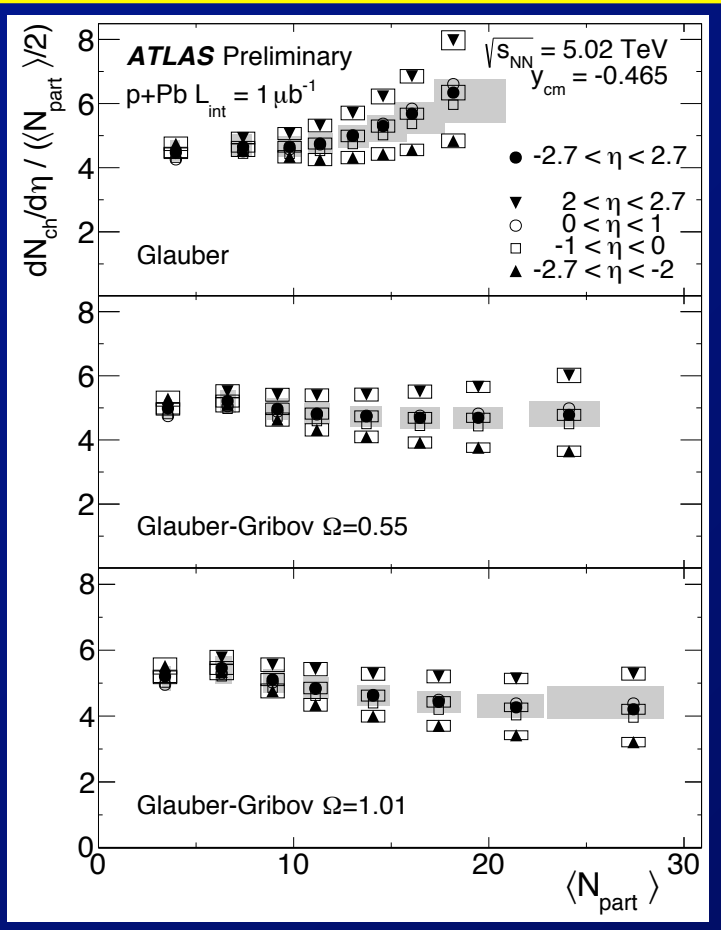




- Evaluating implications of the Strikman *et al* Glauber-Gribov color fluctuations model for p+Pb centrality

p+Pb dN/dη

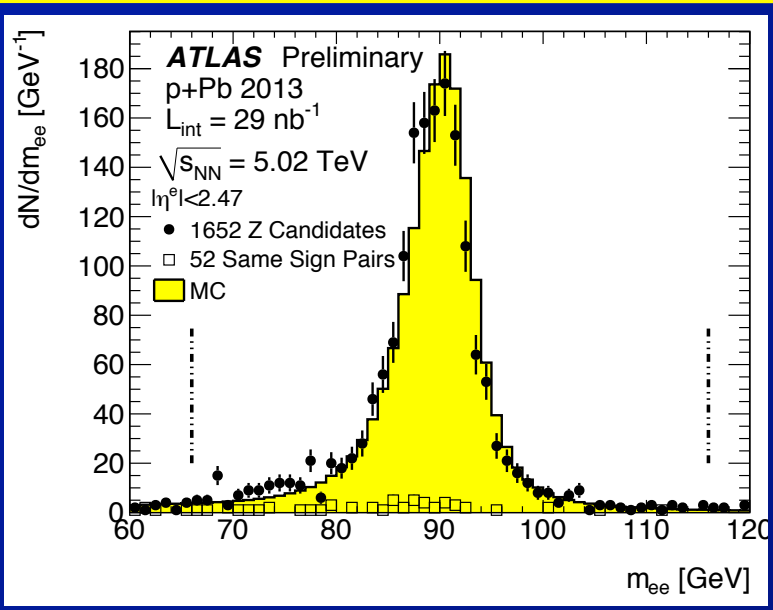




- **Interpretation of the p+Pb multiplicity data depends on choice of geometric model**
  - **Glauber-Gribov CF with $\Omega = 0.55$ ($\omega_\sigma = 0.1$) more "natural" (like wounded-nucleon)**

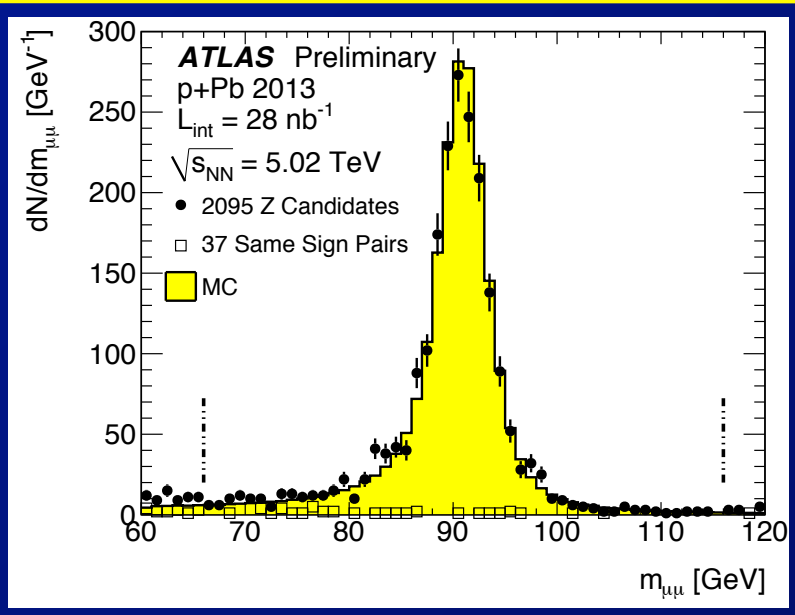
Debbe, Collective dynamics 1

Z production in p+Pb

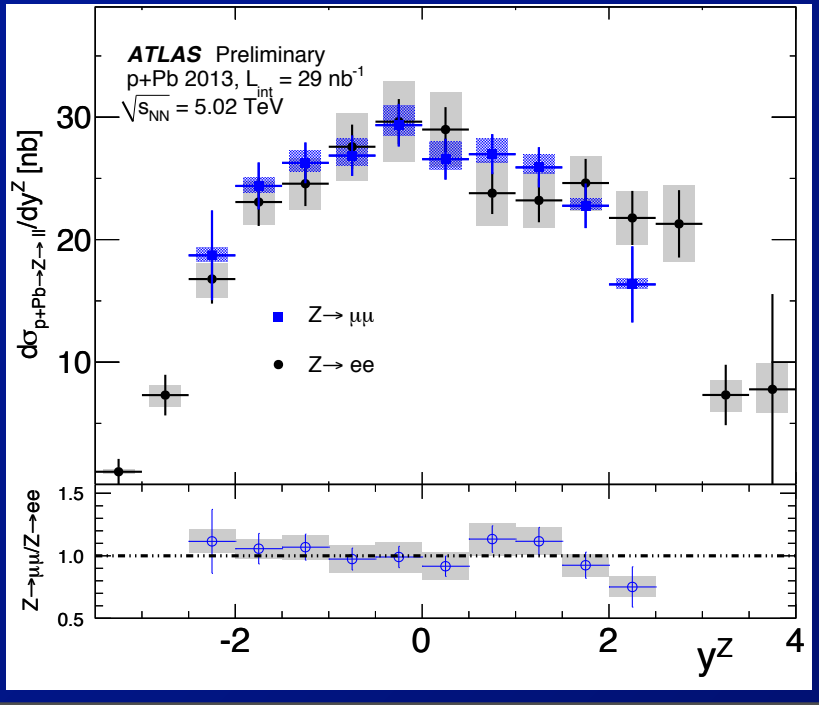


$Z \rightarrow e^+e^-$

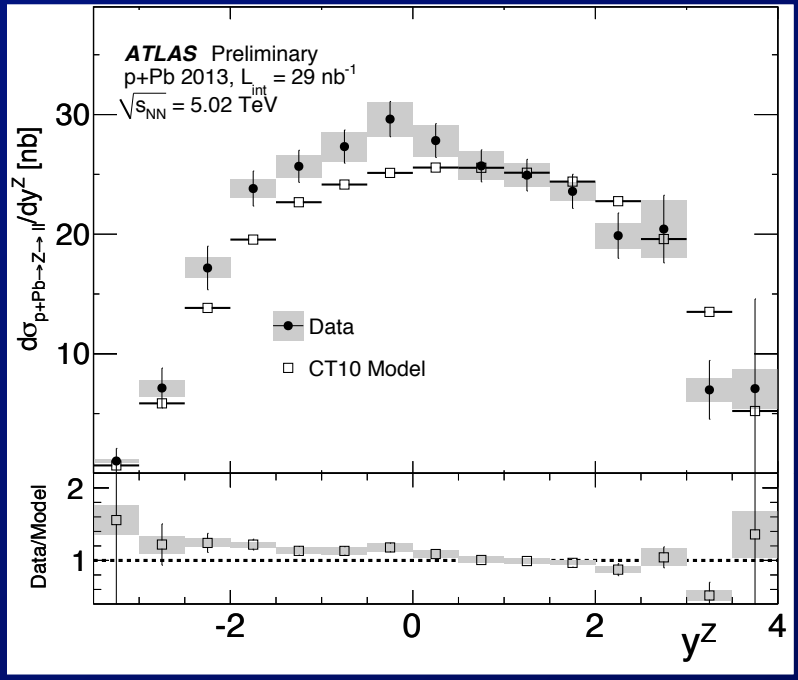
$Z \rightarrow \mu^+\mu^-$



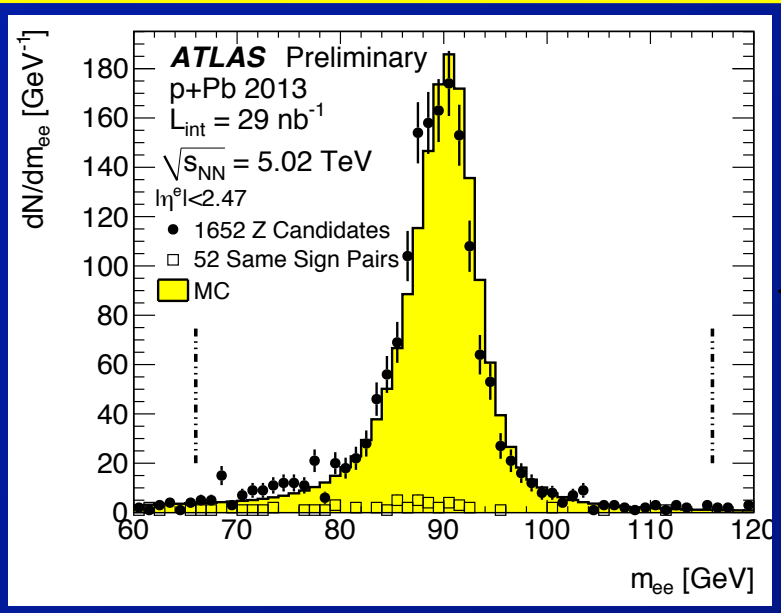
Inclusive cross-sections



Combined cross-section

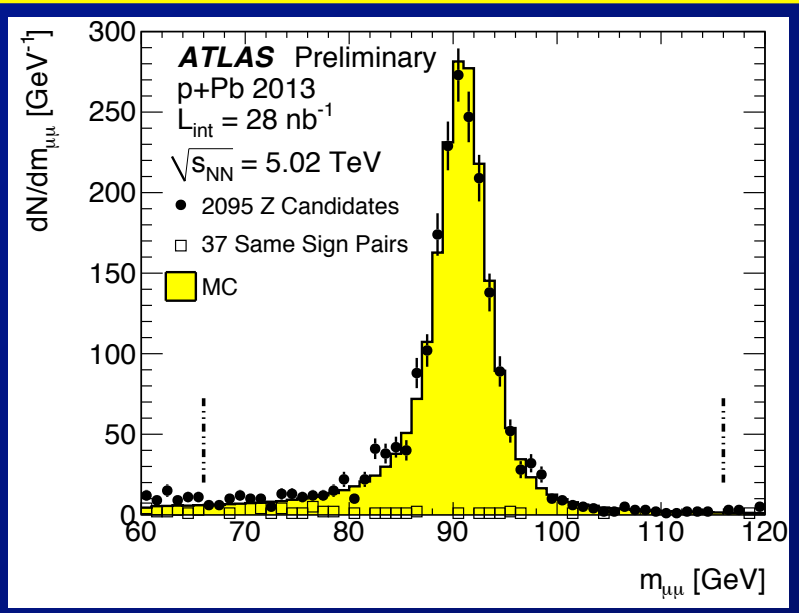


Z production in p+Pb

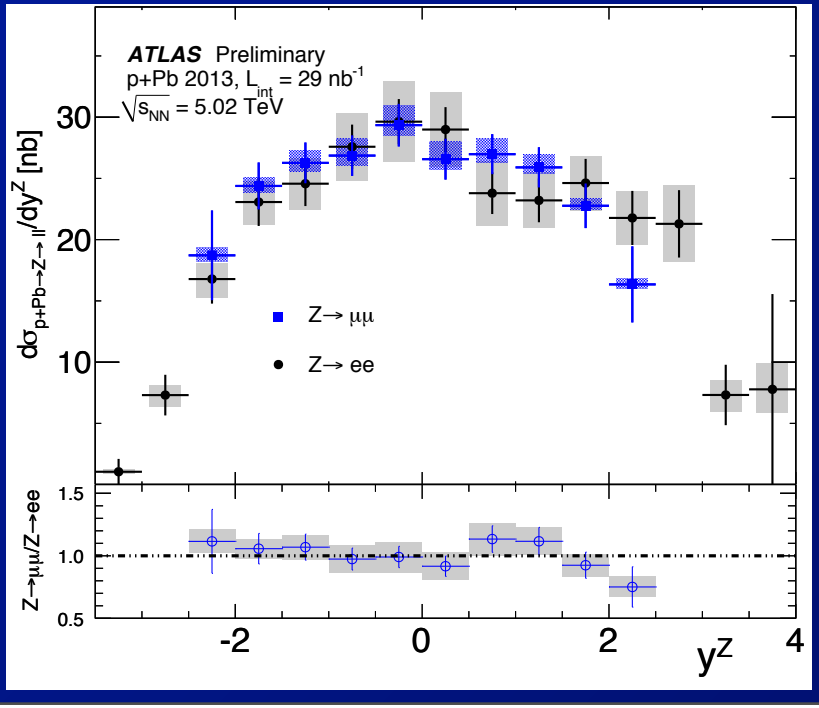


$Z \rightarrow e^+e^-$

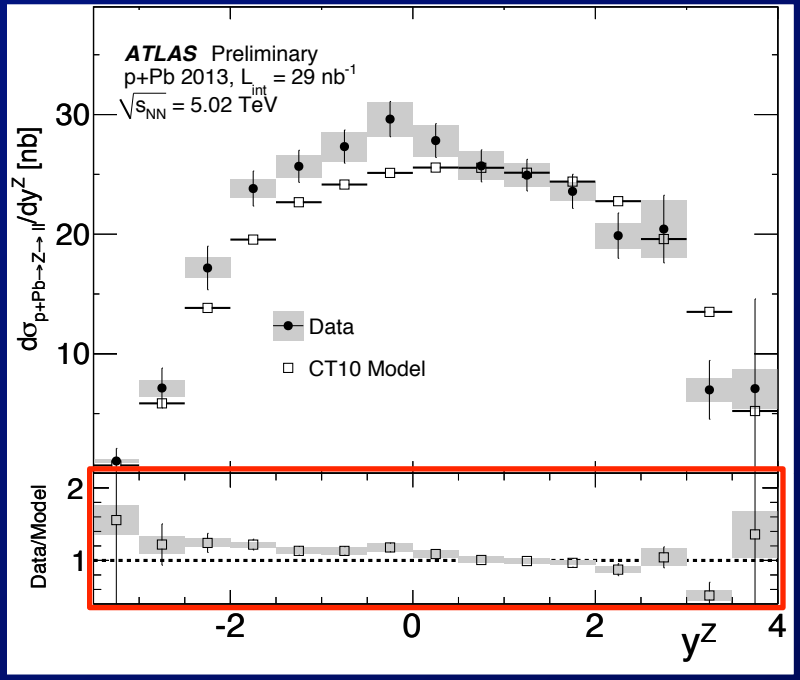
$Z \rightarrow \mu^+\mu^-$



Inclusive cross-sections



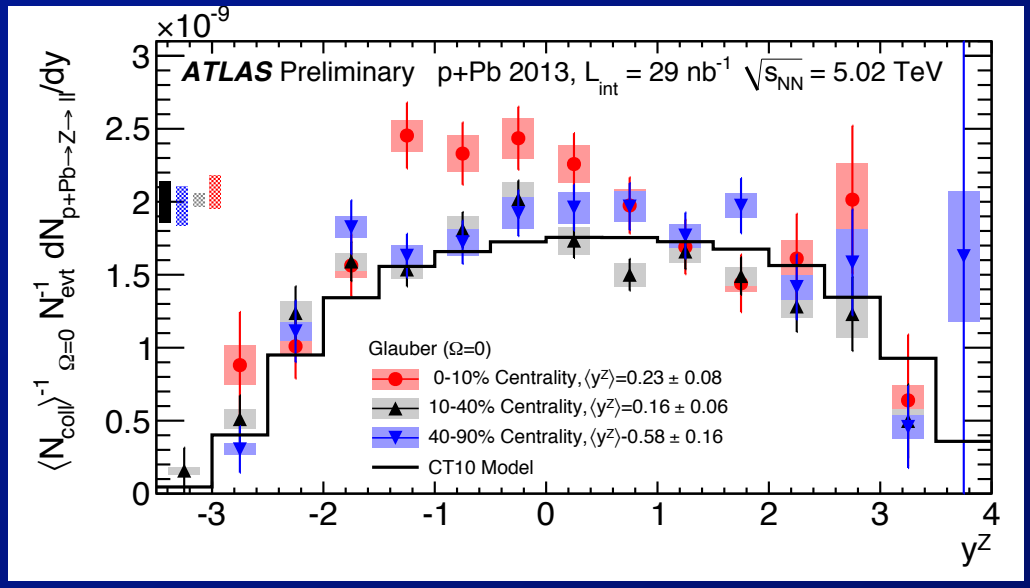
Combined cross-section



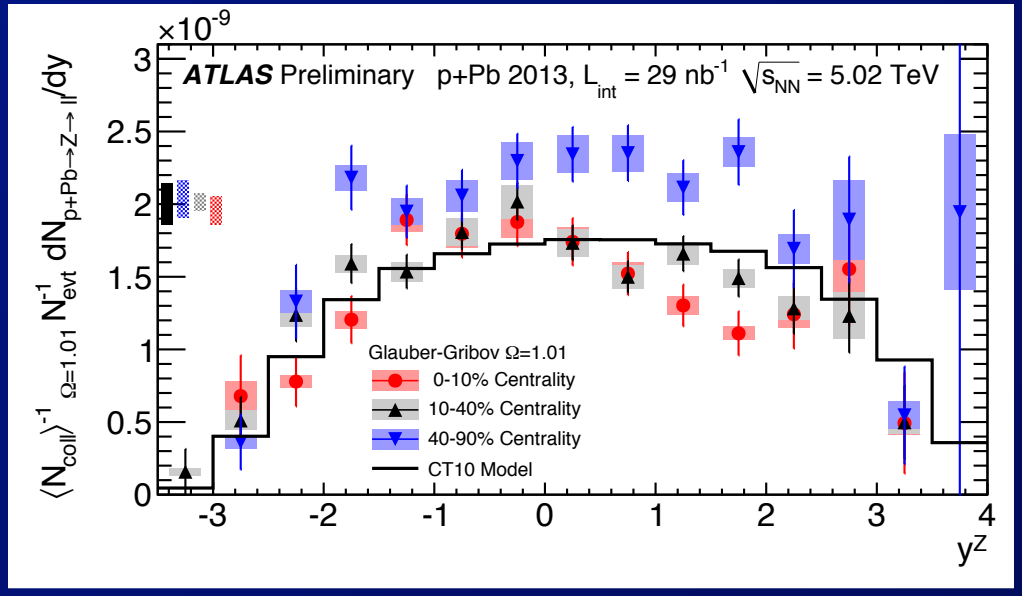
p+Pb Z spectra: centrality dependence

- Plot $1/N_{coll}$ dN/dy in different p+Pb centrality bins
  - Top: Glauber
  - Bottom: Glauber-Gribov CF, $\Omega = 0.55$
    - ⇒Observe centrality dependence
    - ⇒Interpretation depends on the geometric model

Glauber

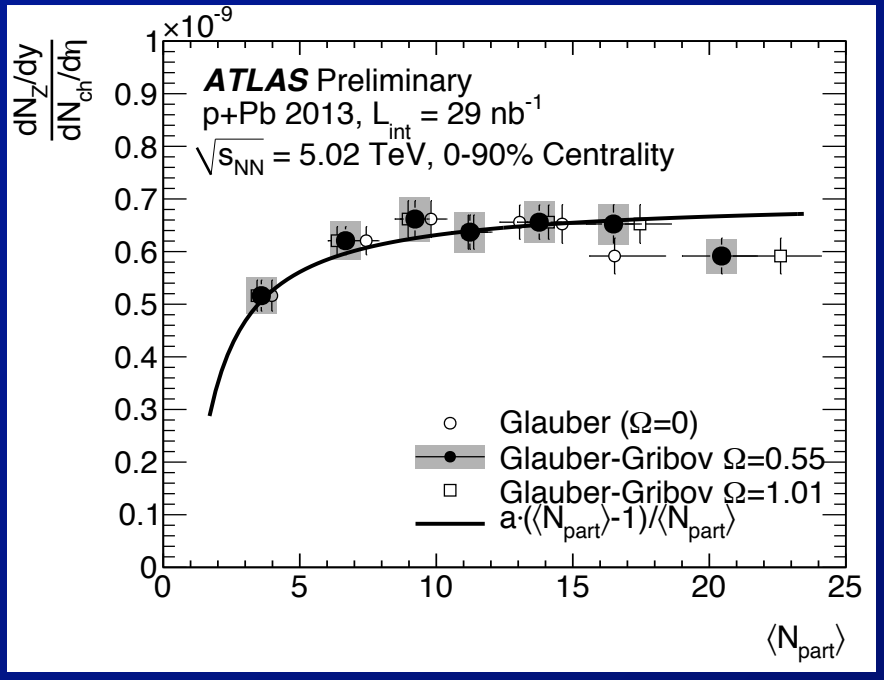


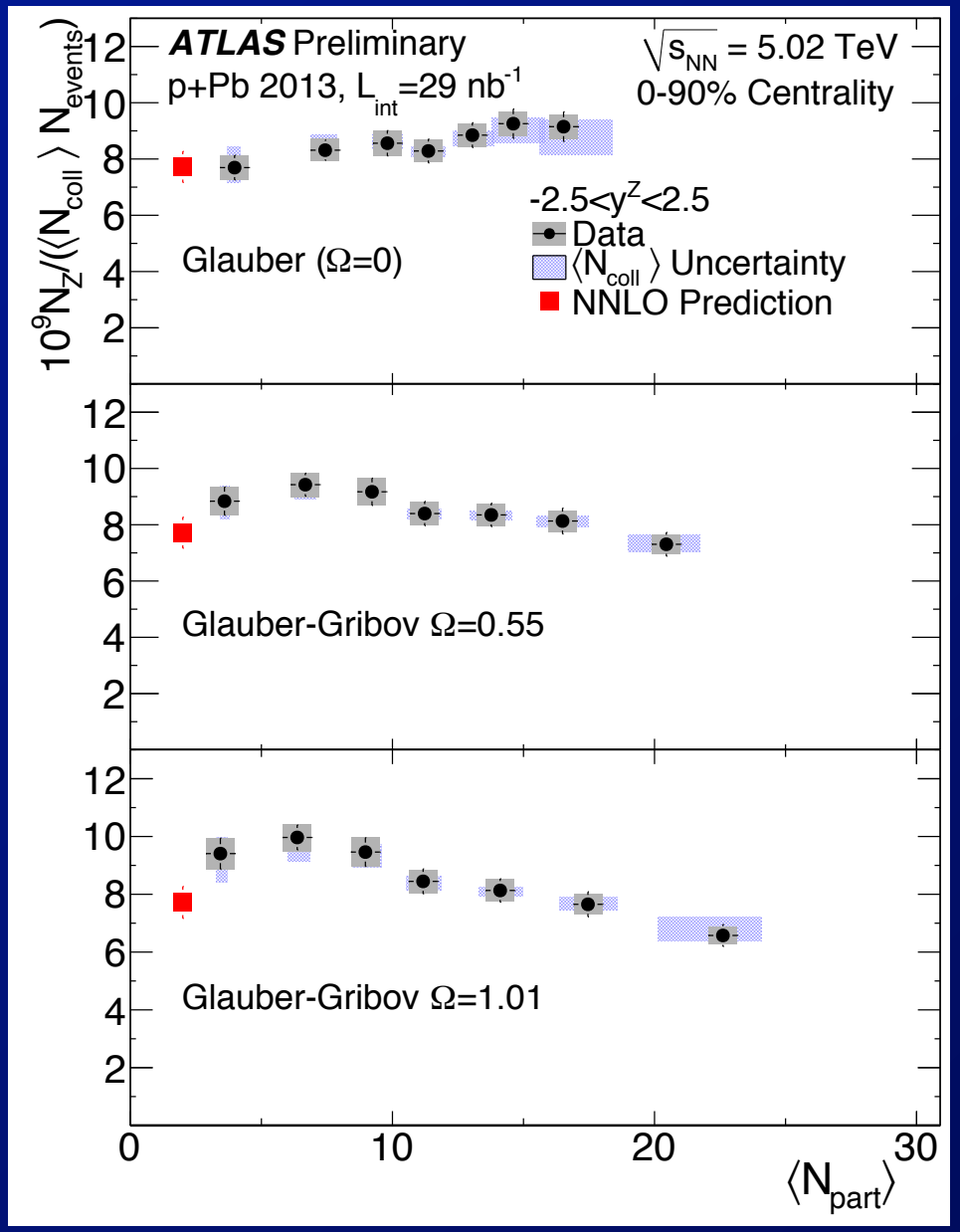
Glauber-Gribov $\Omega = 0.55$



p+Pb Z yields vs centrality

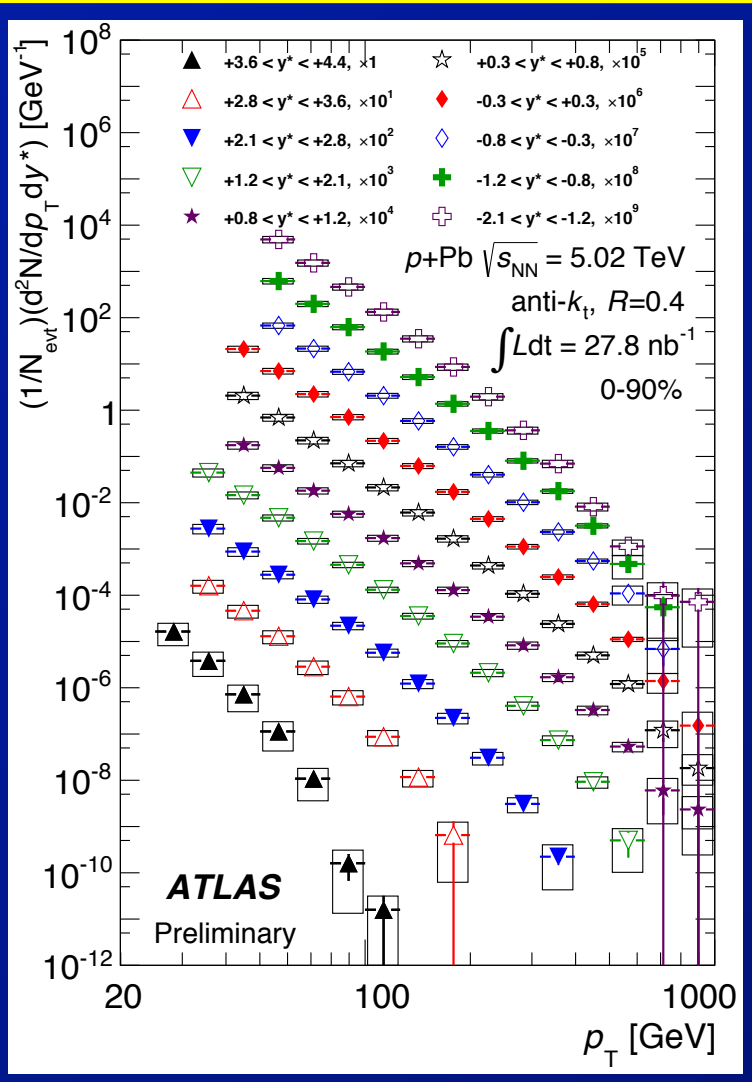
- Evaluate Z yields/N_{coll} vs centrality (N_{part})
  - sensible results for Glauber, GG $\Omega = 0.55$
- Ratio of Z and charged particle yields consistent with $\frac{\langle N_{part}-1\rangle}{\langle N_{part}\rangle}$

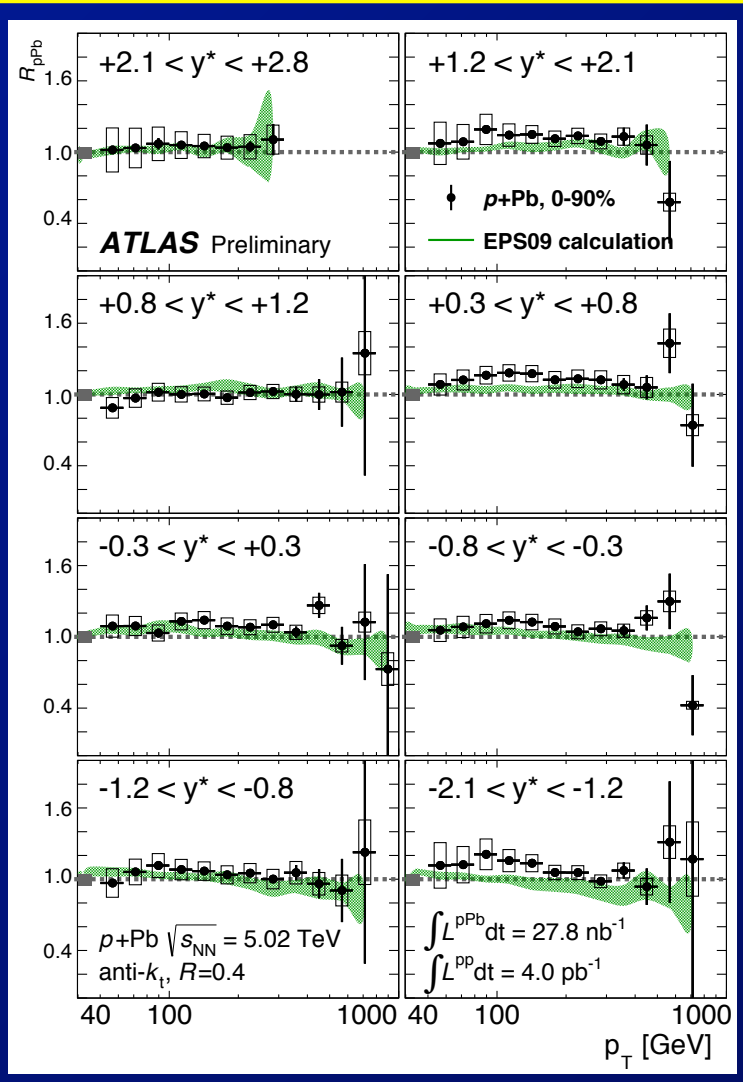




Citron, Heavy flavor: 5

p+Pb Jet production

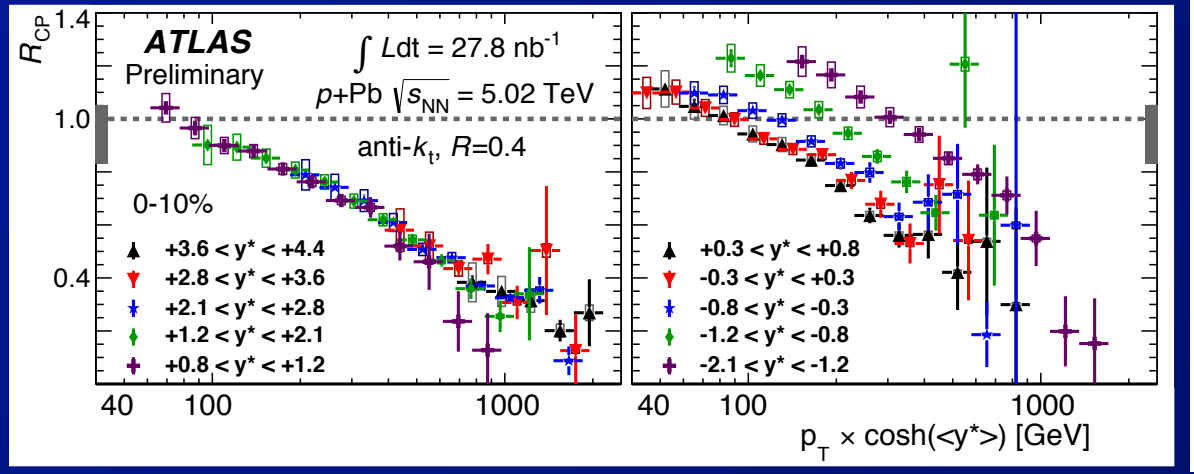


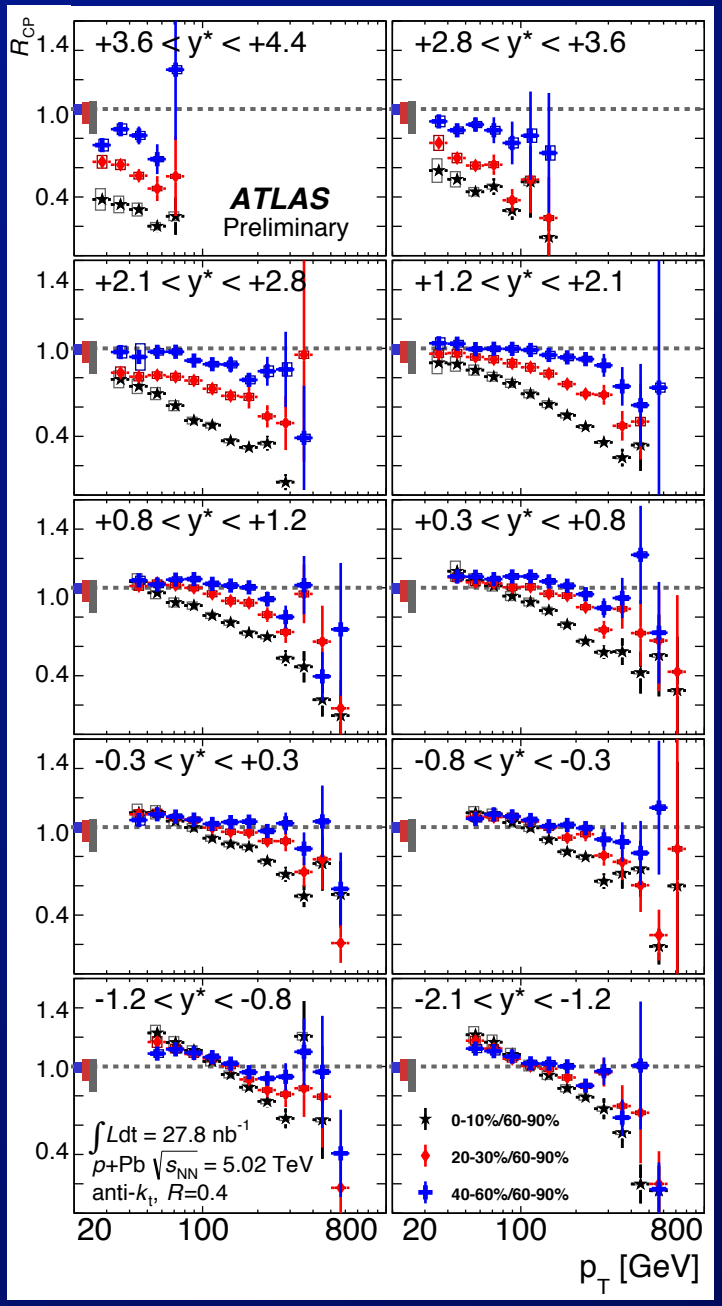


- 0-90% jet yields (left) and jet R_{pPb} (right)
  - ⇒using 2013 p-p reference for R_{pPb}
- R_{pPb} compared to pQCD w/ EPS09 (Armesto)

Jet R_{CP}, R_{pPb}

- As reported at Hard Probes
  - ATLAS observes a strong variation in jet yield with centrality at high p_T or forward rapidities
    - ⇒Scales with $p = p_T \times \cosh(y)$ in forward direction
    - ⇒Depends on x_p ?



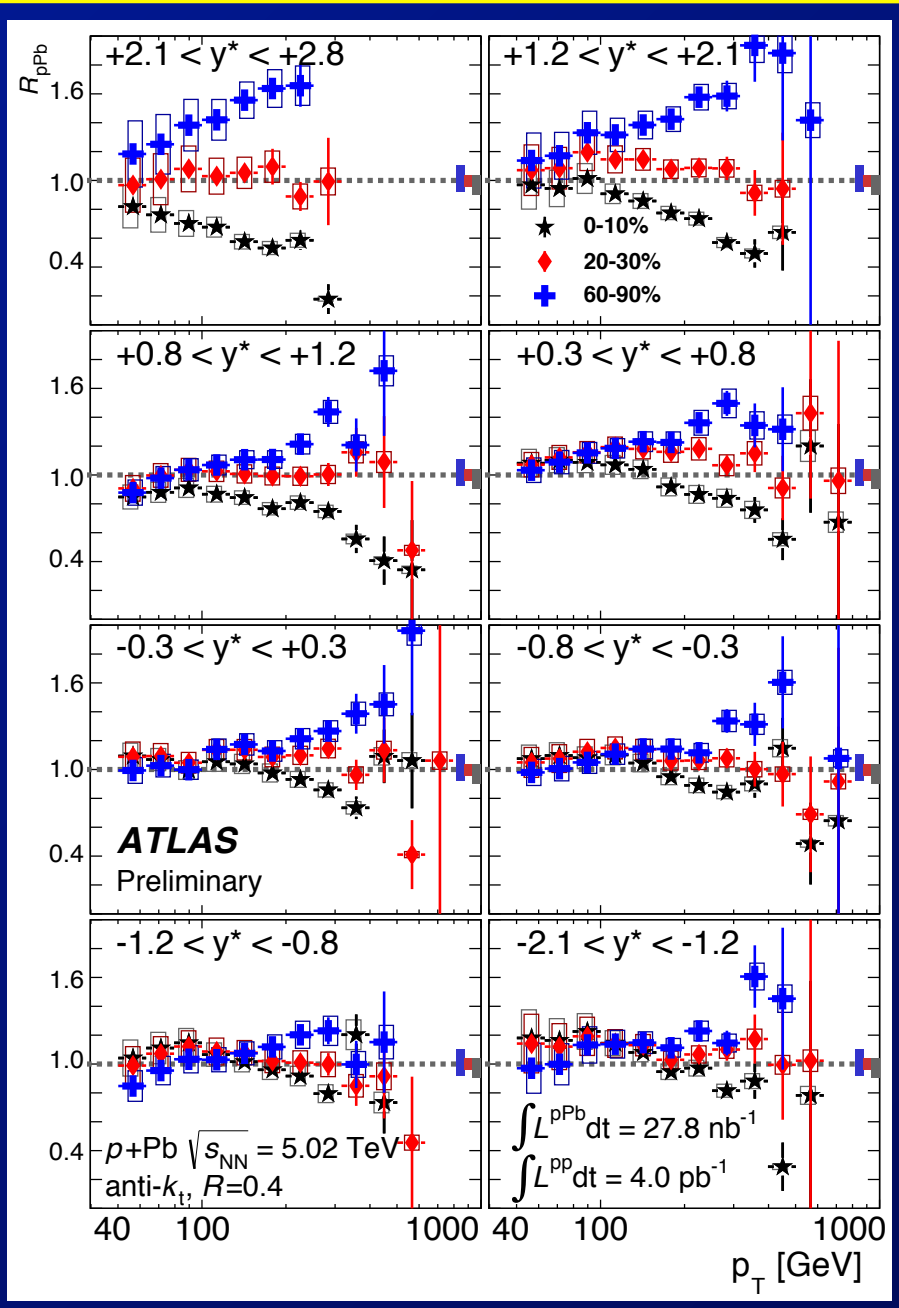


Jet R_{pPb}

- If inclusive R_{pPb} ~ 1 and R_{CP} shows such effects, necessarily
  - peripheral enhancement
  - central suppression

    ⇒Exactly what we observe in the R_{pPb}

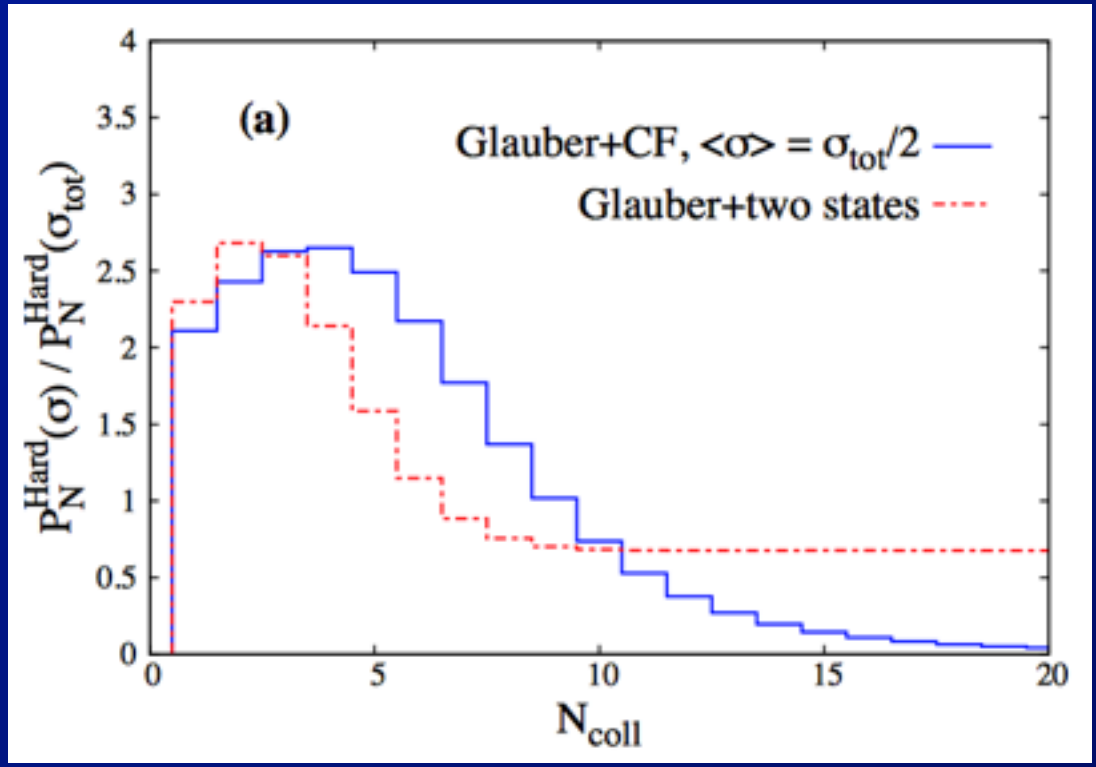
    ⇒?!??
- This was also observed in preliminary PHENIX jet measurement.



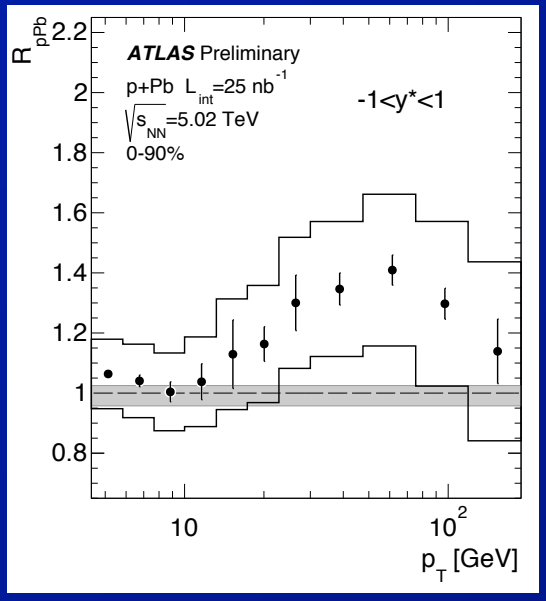
p+Pb jets: geometric explanation?

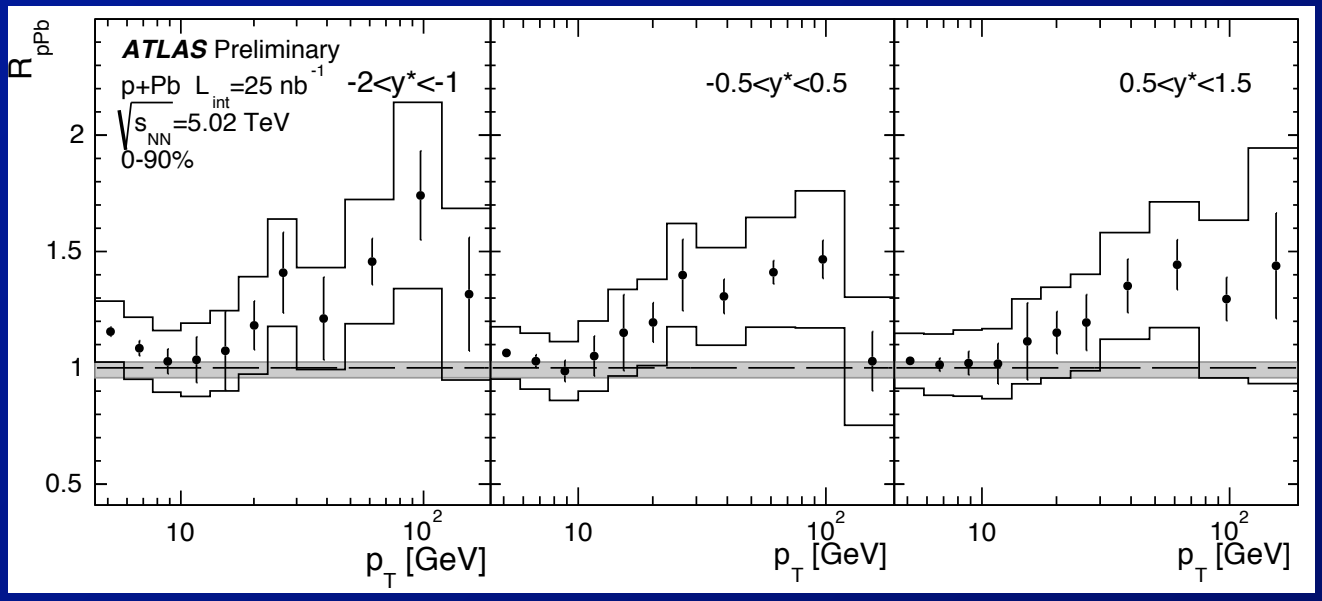
Alvioli, Frankfurt, Strikman arXiv:1402.2868

- Proton spatial configuration (size) depends on x of quark entering hard scattering
  - ⇒protons w/ large(r) *x* partons have a reduced soft cross-section
- Calculation:
  - Reduced cross-section for proton shifts N_{coll} distribution to smaller values
  - ⇒Suggestive, but conditional probabilities are "backwards" compared to data …
  - ⇒Calculation analogous to data underway.



p+Pb charged particle R_{pPb}



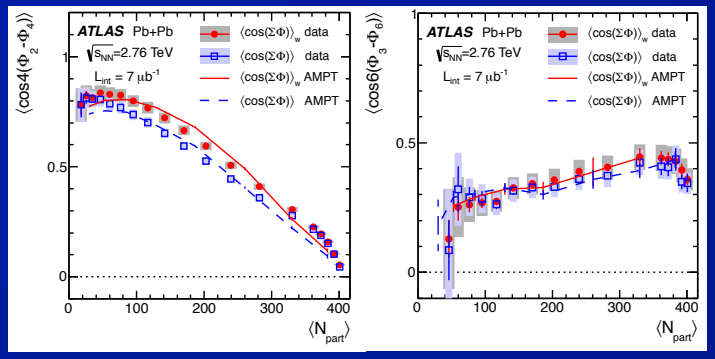


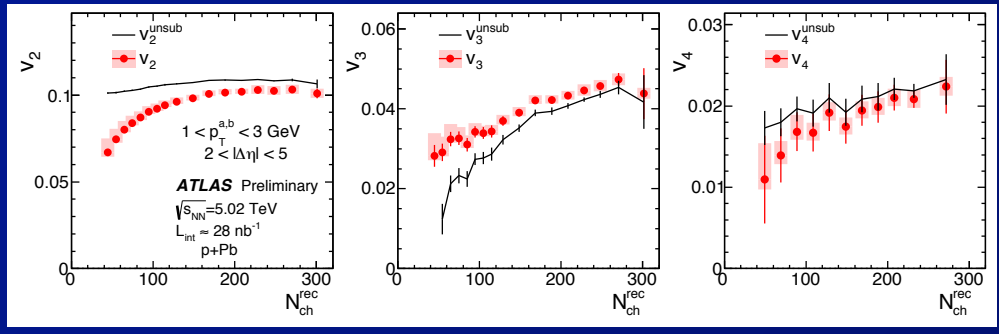
- p-p charged particle cross-section measured at 2.76 TeV, 7 TeV, interpolated to 5.02 TeV
  - Three different interpolation methods tested
- R_{pPb} measured for 0-90% and as a function of centrality, in different y* intervals
  - Results here for 0-90%

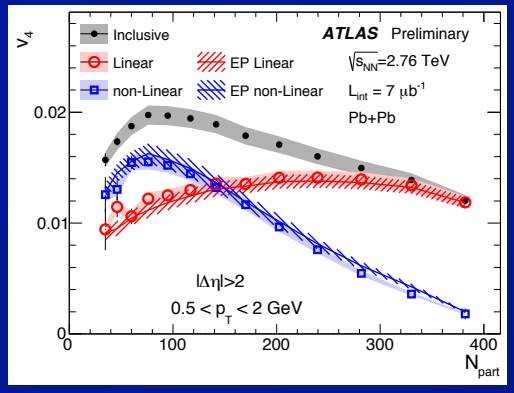
⇒Confirm CMS observation!?

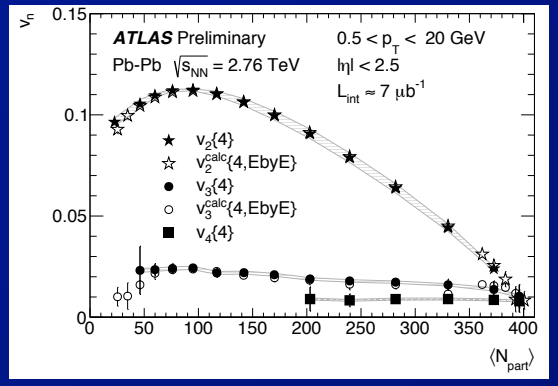
Balek, Jets 2

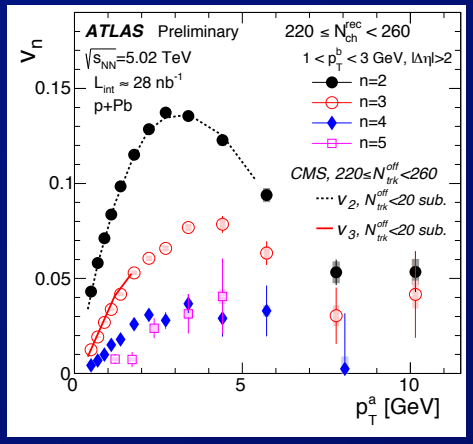
Summary: soft probes





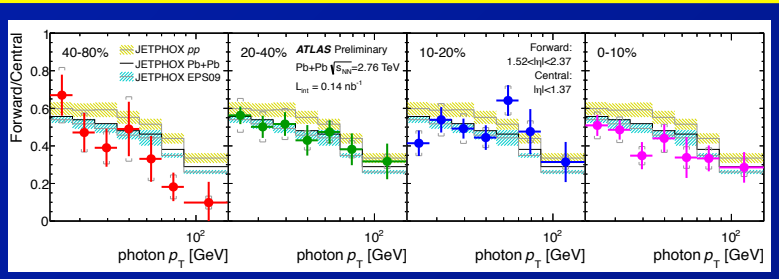


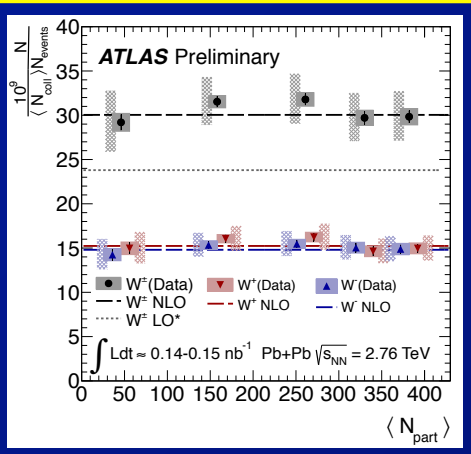


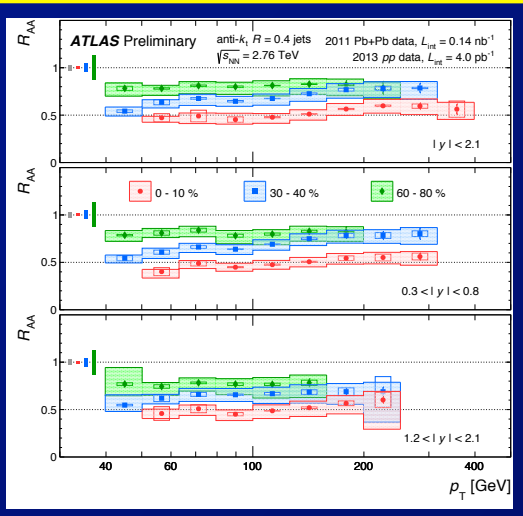


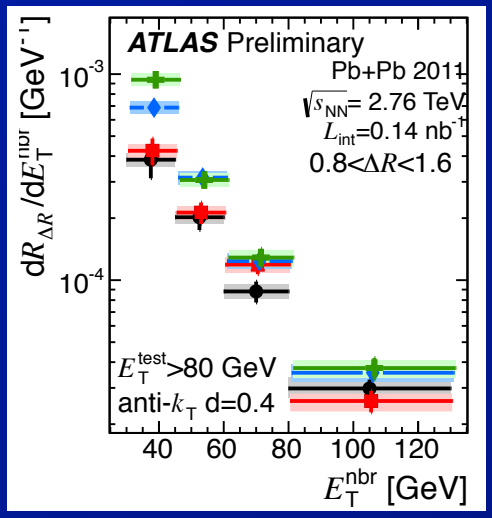
- **Pb+Pb:**
  - ⇒consistency between cumulant and previous event-by-event flow measurements.
  - ⇒Φ_n and v_n correlations show non-linear flow effects
- **p+Pb:**
  - ⇒Measure significant v_1-v_5, out to 10 GeV for v_2, v_3
  - ⇒Same v_2, v_3, v_4 shapes vs p_T for p+Pb, Pb+Pb

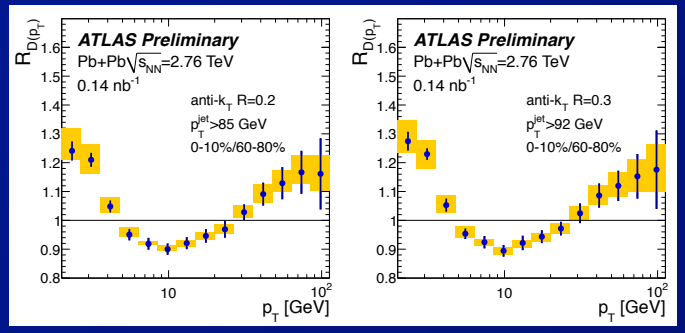
Summary: hard probes

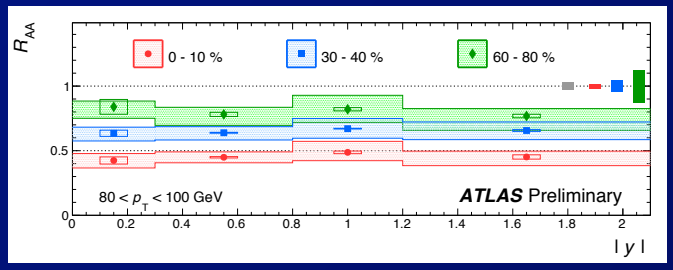






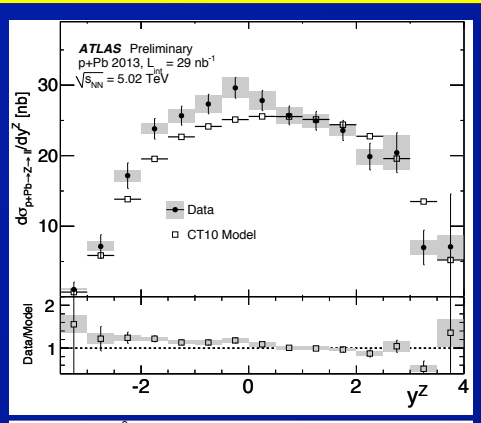


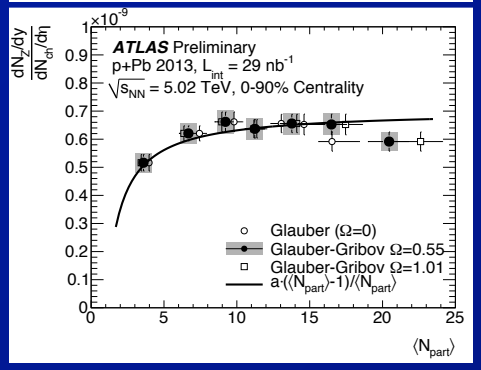


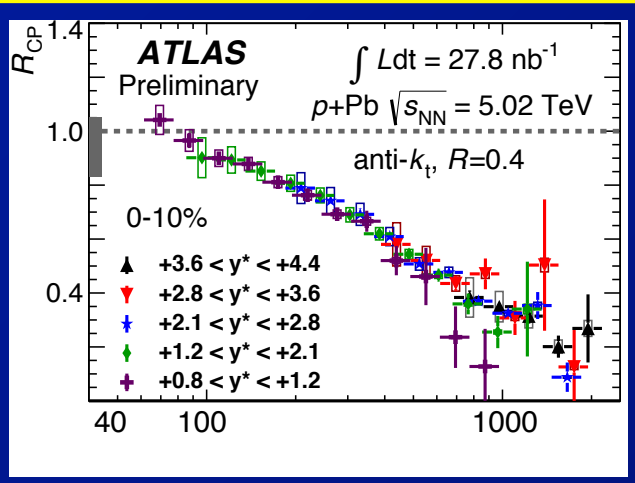


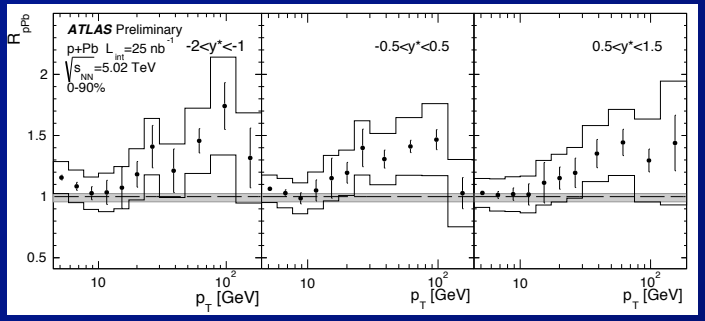
- **New electro-weak boson measurements**
  - ⇒Constraints on hard scattering rates
- **New jet R_{AA} to 400 GeV, vs y, down to 0-1%**
  - ⇒factor of ~ 2 suppression continues to 400 GeV
- **Update jet fragmentation: enhancement @ large z**
- **First look at nearby jets in parton showers**

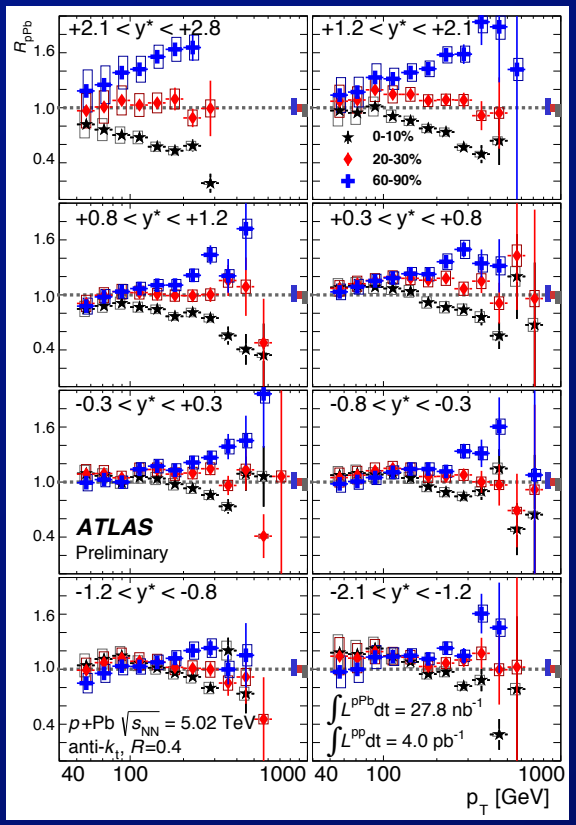
Summary: p+Pb production











- **Z yields and Z/N_{chg} vs centrality make sense**
  - ⇒ starting to see clarity on p+Pb centrality?
- **p+Pb jets show unexpected(?) behavior**
  - ⇒Strikman et al: proton configuration size depends on x
- **ATLAS shows enhanced charged particle R_{pPb} at high p_T**
  - ⇒???

ATLAS conference notes

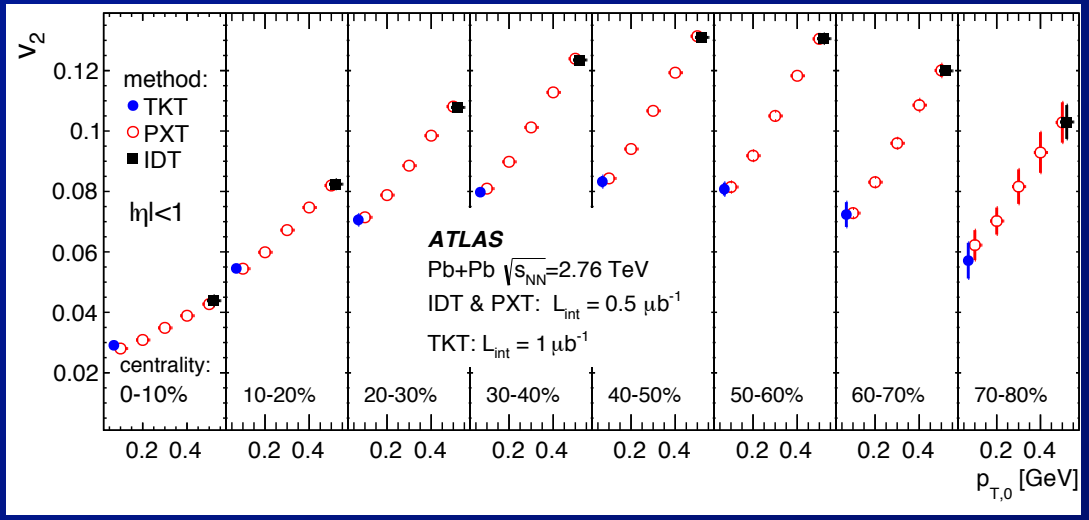
NEW Measurement of the production of neighbouring jets in lead-lead collisions at $\sqrt{s_{NN}}$= 2.76 TeV with the ATLAS detector	ATLAS-CONF-2014-028
NEW Collective flow with higher-order cumulants in lead-lead collisions at $\sqrt{s_{NN}}$=2.76 TeV with the ATLAS detector at the LHC	ATLAS-CONF-2014-027
NEW Centrality, rapidity and pT dependence of isolated prompt photon production in lead-lead collisions at $\sqrt{s_{NN}}$ = 2.76 TeV with the ATLAS detector at the LHC	ATLAS-CONF-2014-026
NEW Measurements of the nuclear modification factor for jets in Pb+Pb collisions at sqrt{NN}=2.76 TeV with the ATLAS detector	ATLAS-CONF-2014-025
NEW Centrality and rapidity dependence of inclusive jet production in $\sqrt{s_{NN}}$=~5.02~TeV proton--lead collisions with the ATLAS detector	ATLAS-CONF-2014-024
NEW Measurement of W boson production and the lepton charge asymmetry in Pb+Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV with the ATLAS detector	ATLAS-CONF-2014-023
NEW Elucidating the event-shape fluctuations via flow correlations and jet tomography studies in 2.76 TeV Pb+Pb collisions using the ATLAS detector	ATLAS-CONF-2014-022
NEW Measurement of the long-range pseudorapidity correlations and associated Fourier harmonics in $\sqrt{s_{NN}}$=5.02 TeV proton-lead collisions with the ATLAS detector	ATLAS-CONF-2014-021
NEW Measurement of the Z-boson production in pPb collisions at $\sqrt{s_{NN}}$=5.02TeV with the ATLAS detector	ATLAS-CONF-2014-020

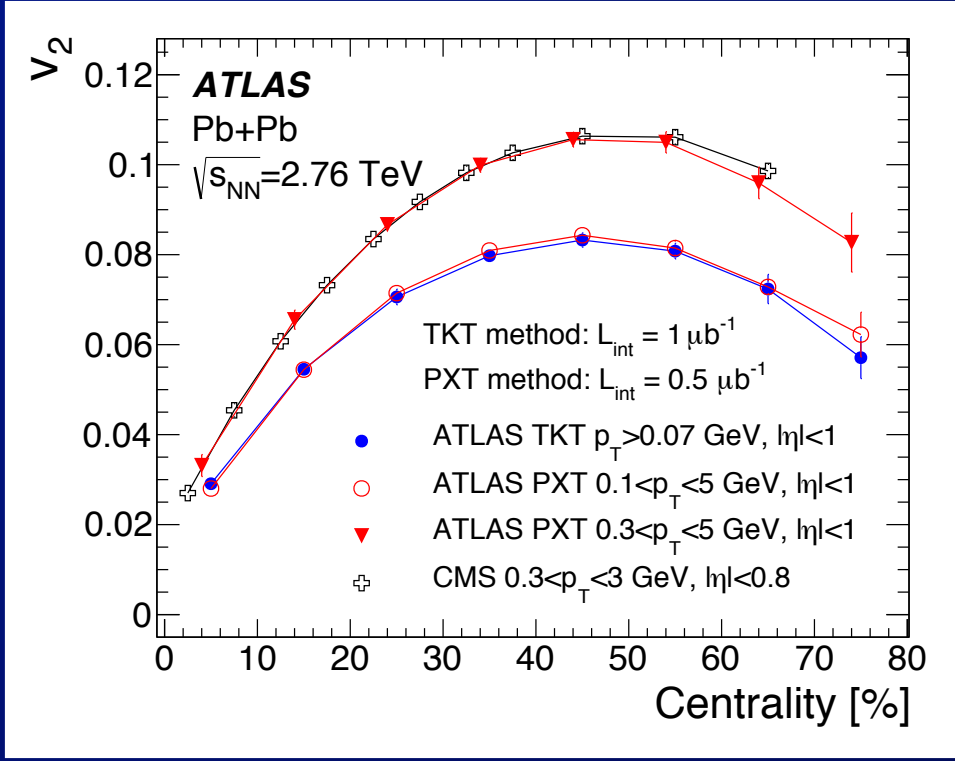
- ATLAS conference notes can be found at
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HeavyIonsPublicResults
- Stay tuned for following publications at
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic

Backup

p_T-Integrated v2

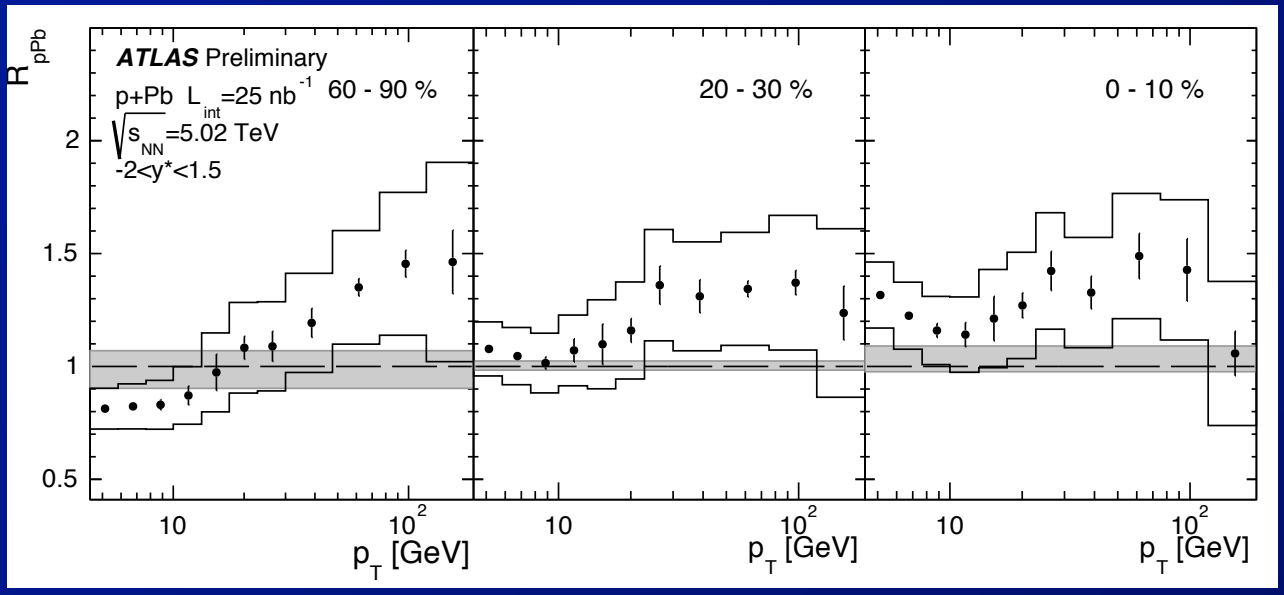
- Use 2-point tracklet and other low-p_T tracking algorithms
  - ⇒Measure v_2 down to 70 MeV
  - ⇒Improved precision on integrated v_2
- Evaluate centrality dependence
  - ⇒Good agreement between 2 methods
  - ⇒Good agreement w/ CMS for p_T > 300 Mev



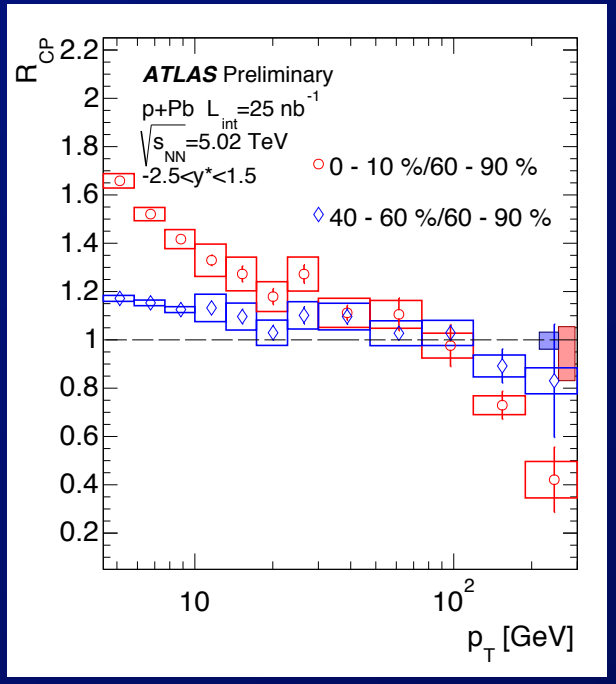


p+Pb charged particle R_{pPb}

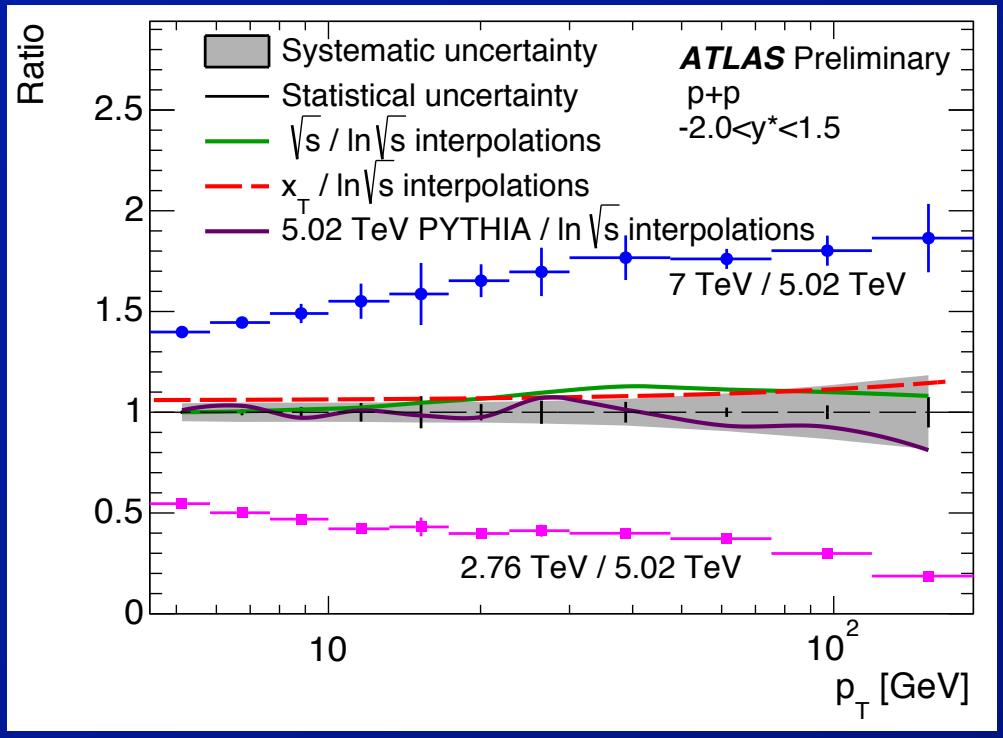
- Enhanced R_{pPb} seen in all centrality bins.

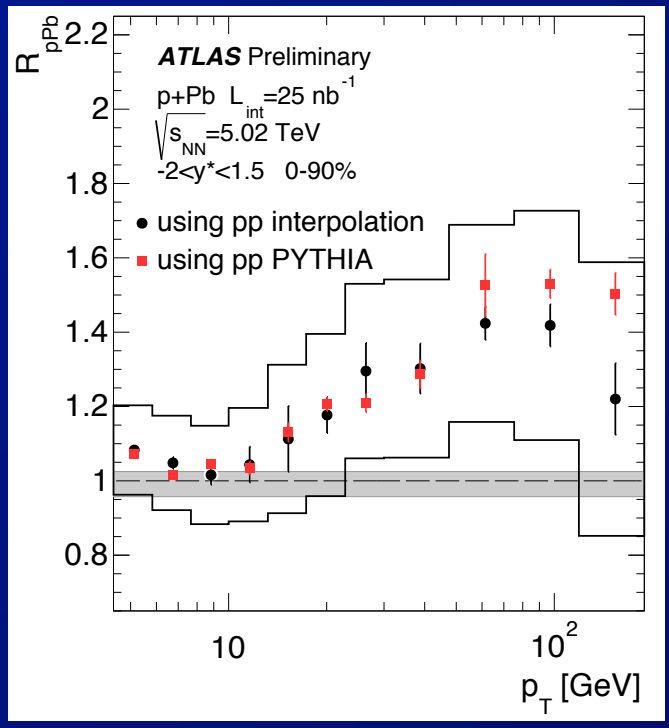


- R_{CP} (integrated over y*) shows similar features as the jet R_{CP}



p+Pb charged particle R_{pPb}



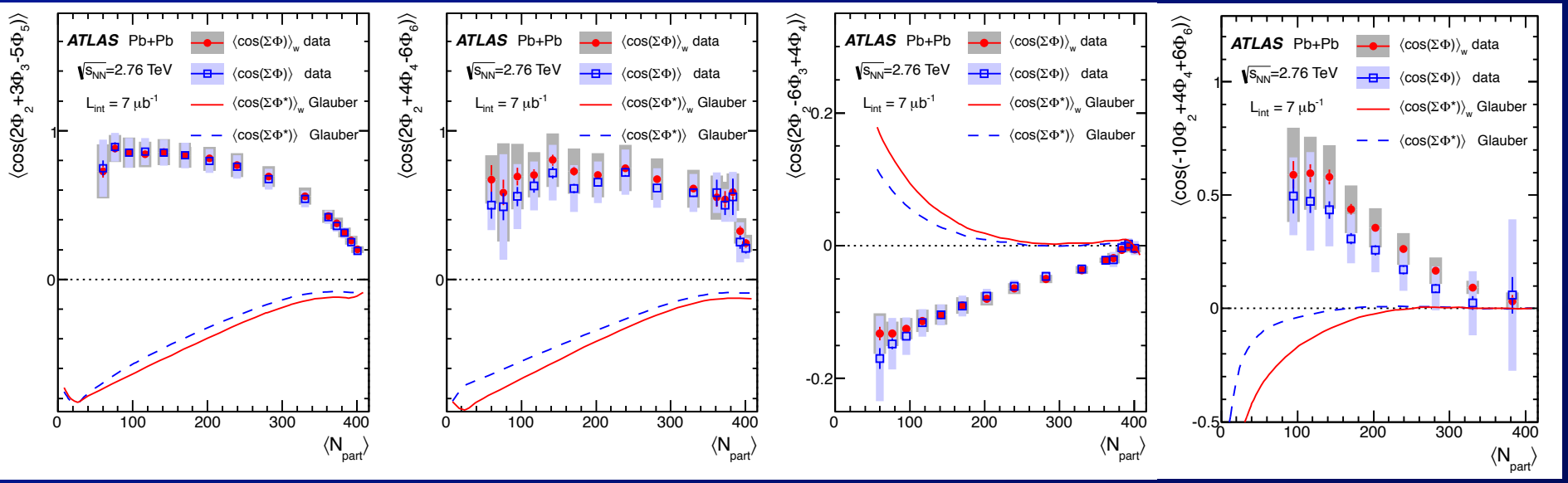


- p-p charged particle cross-section measured at 2.76 TeV, 7 TeV, interpolated to 5.02 TeV
  - Three different interpolation methods tested
- R_{pPb} measured using PYTHIA baseline shows same result obtained with interpolated p-p.

Event plane angle correlations (2)

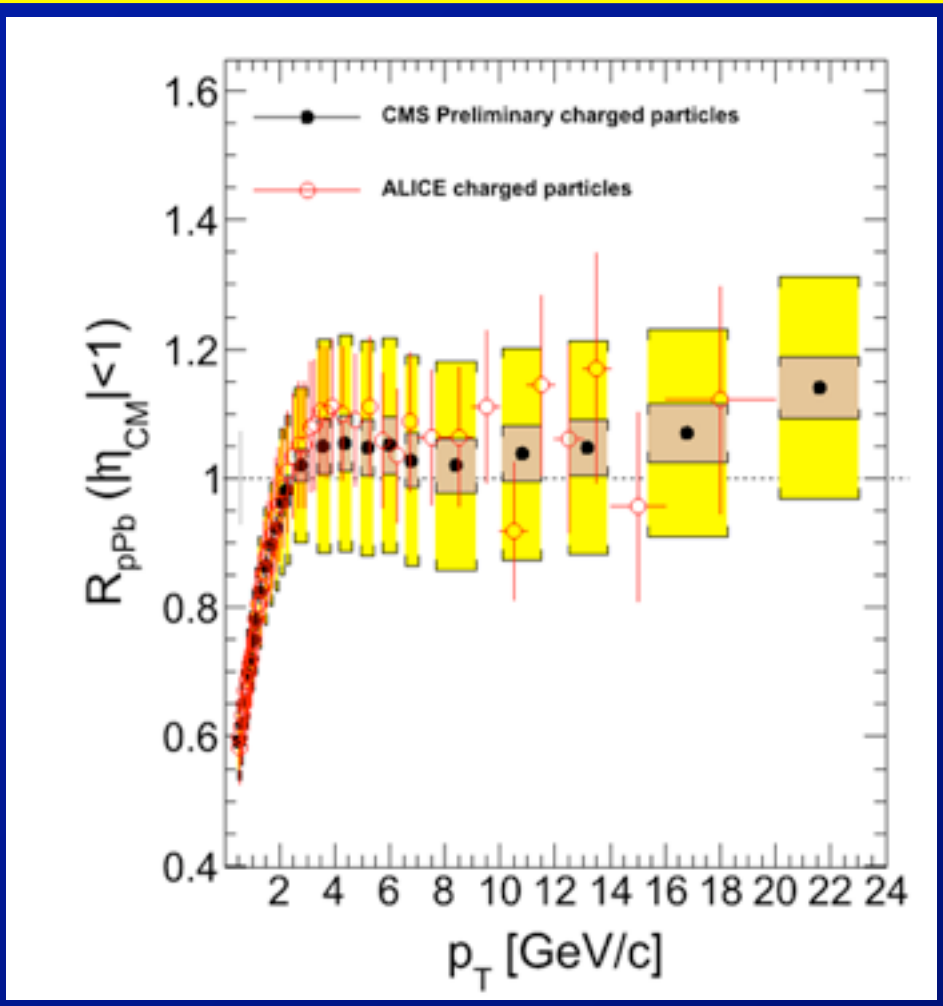
- **Also measure multi-plane correlations**
  - Generally $\langle \cos\left(c_1\Phi_1 + 2c_2\Phi_2 + \ldots + lc_l\Phi_l\right)\rangle$
    $\Rightarrow$ with $c_1 + 2c_2 + \ldots + lc_l = 0$
  - In particular, 34-plane correlations
    $\Rightarrow$ $\langle \cos\left(c_1\Phi_1 + 2c_2\Phi_2 - (c_1 + 2c_2)\Phi_3\right)\rangle$
  - Also poor agreement with Glauber

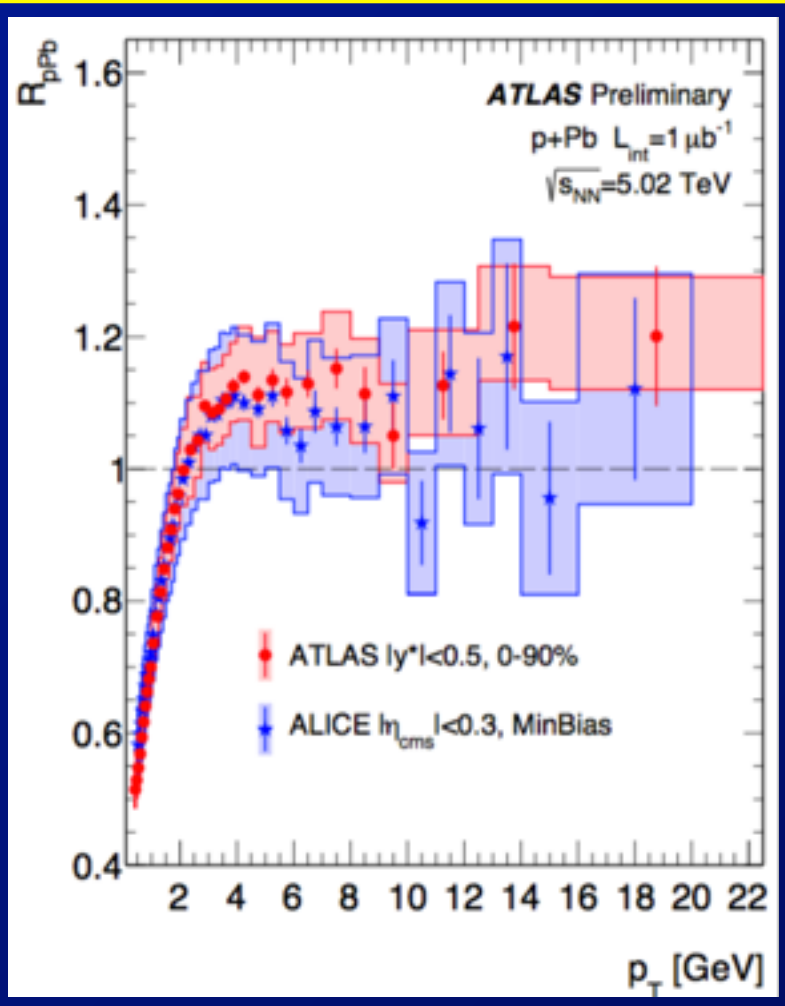
$\langle \cos\left(2\Phi_2 + 4\Phi_4 - 6\phi_6\right)\rangle$ $\langle \cos\left(-10\Phi_2 + 4\Phi_4 + 6\phi_6\right)\rangle$



$\langle \cos\left(2\Phi_2 + 3\Phi_3 - 5\phi_5\right)\rangle$ $\langle \cos\left(2\Phi_2 - 6\Phi_3 + 4\phi_4\right)\rangle$

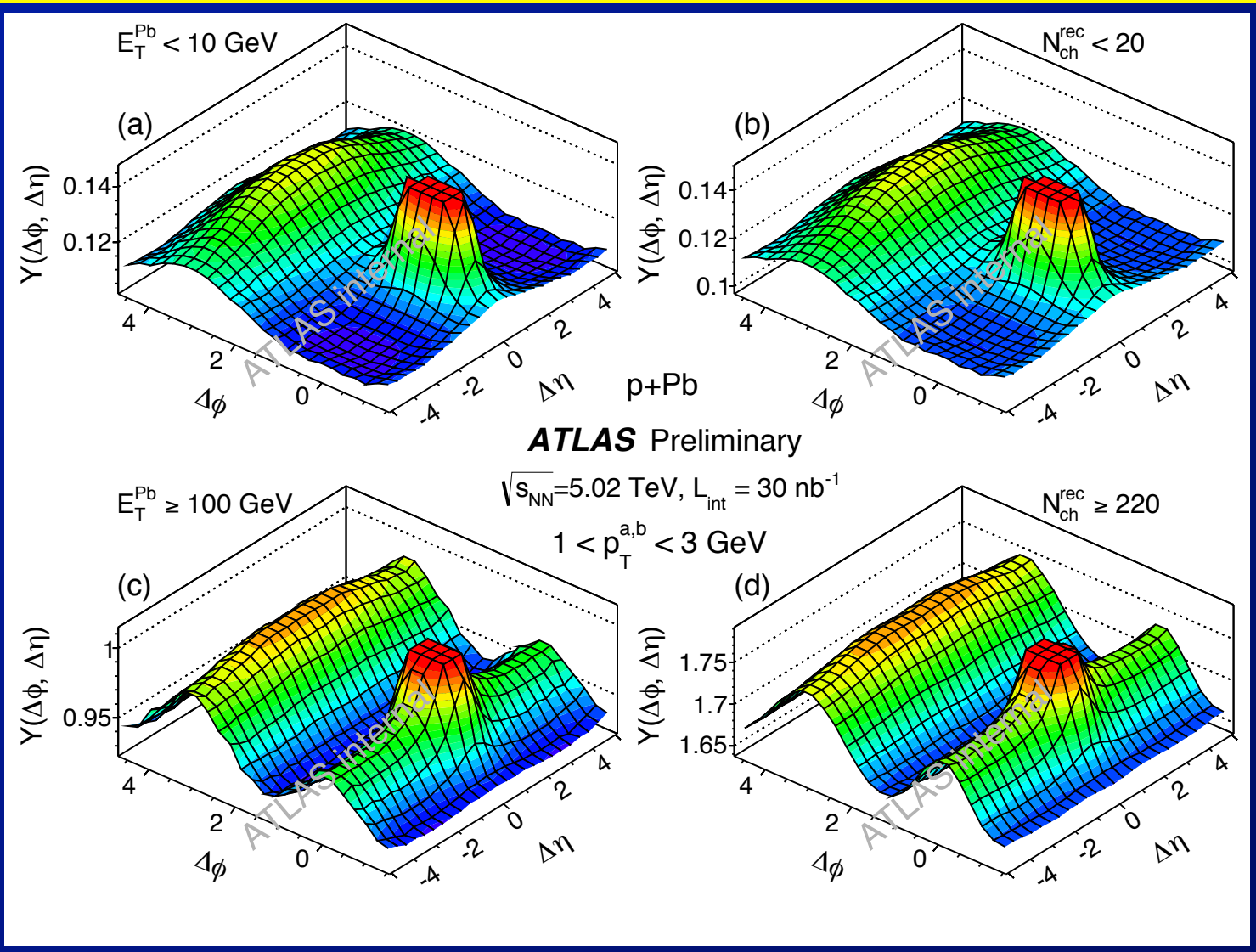
Charged particle R_{pPb}





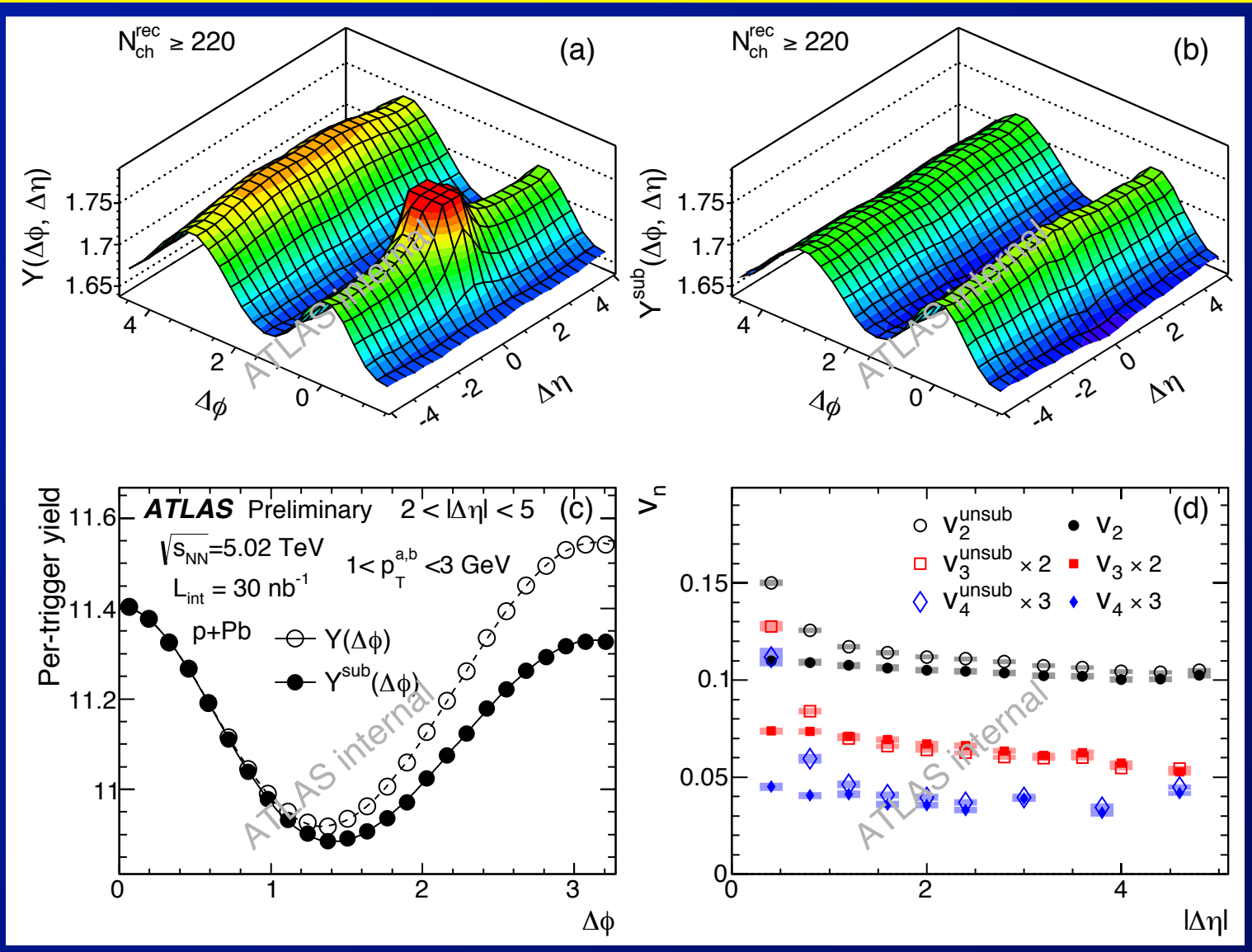
- Good agreement on (almost) minimum-bias charged particle RpPb
  - ⇒Beware differences in event selection

p+Pb 2-particle correlations



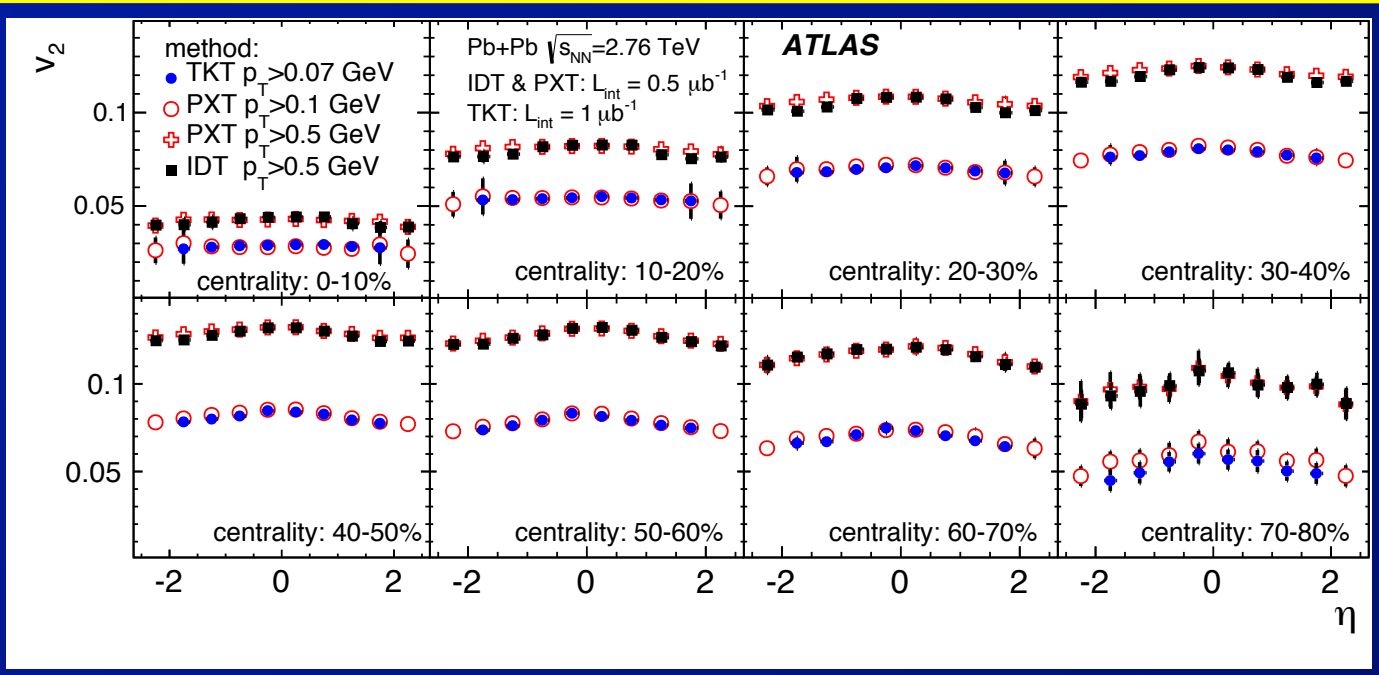
- Good statistical precision on development of the ridge(s) out to high event multiplicities

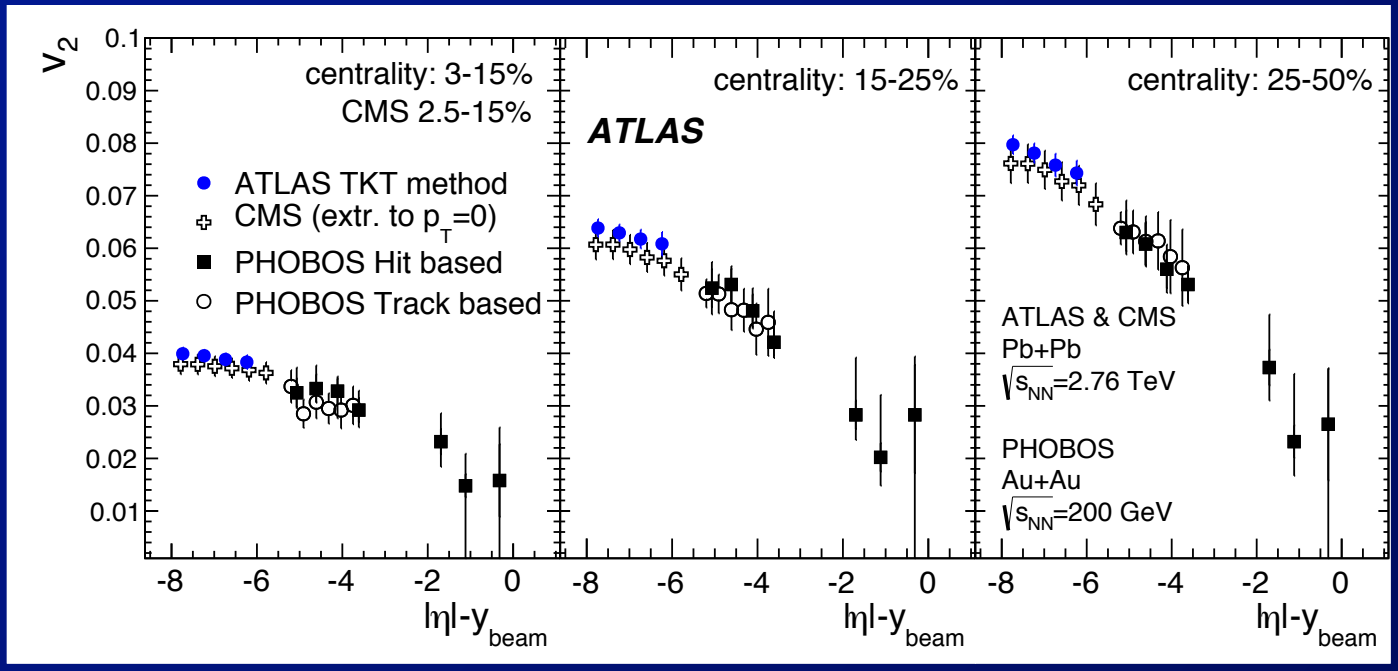
Peripheral subtraction



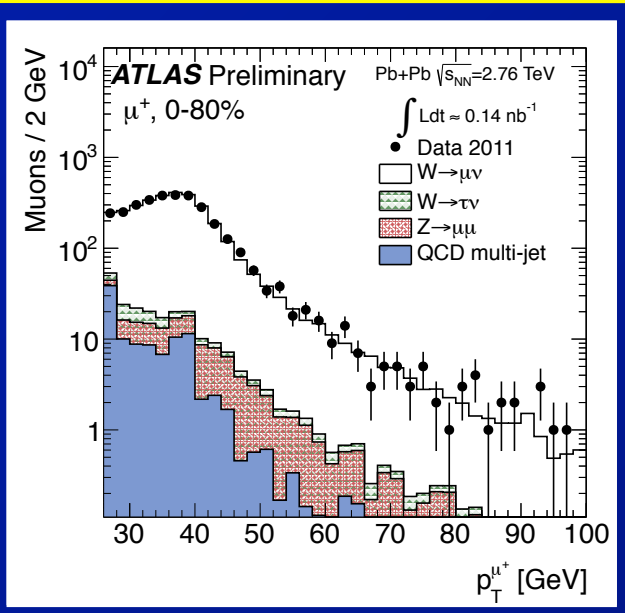
- Apply peripheral subtraction to remove recoil contribution

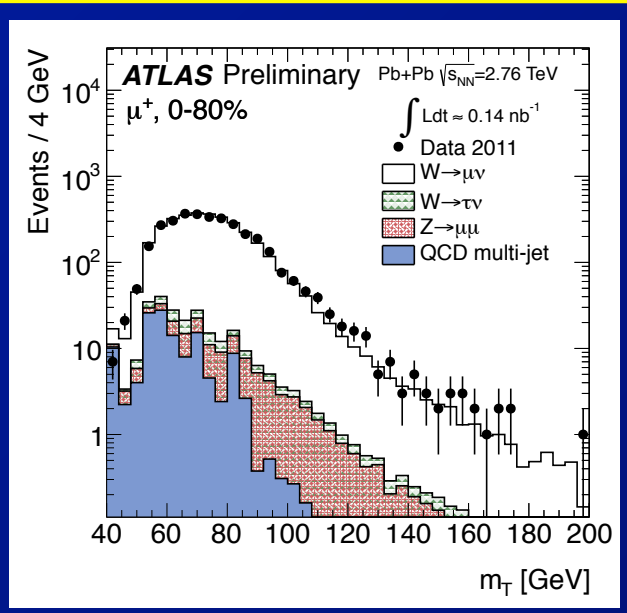
Integrate v_2 vs η

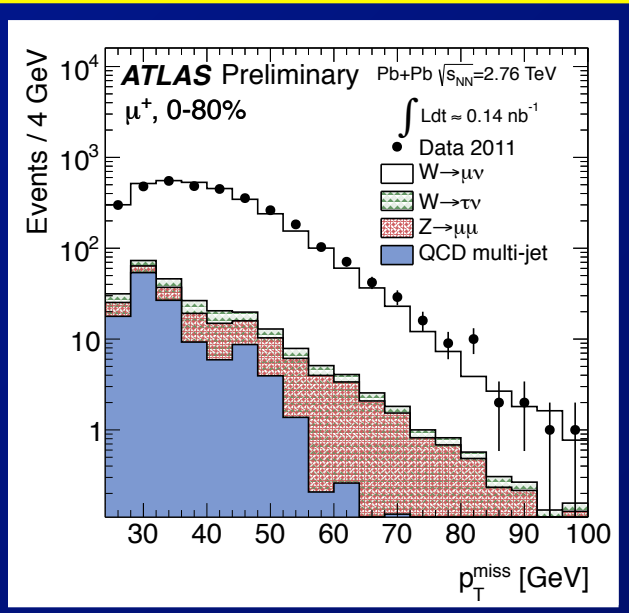


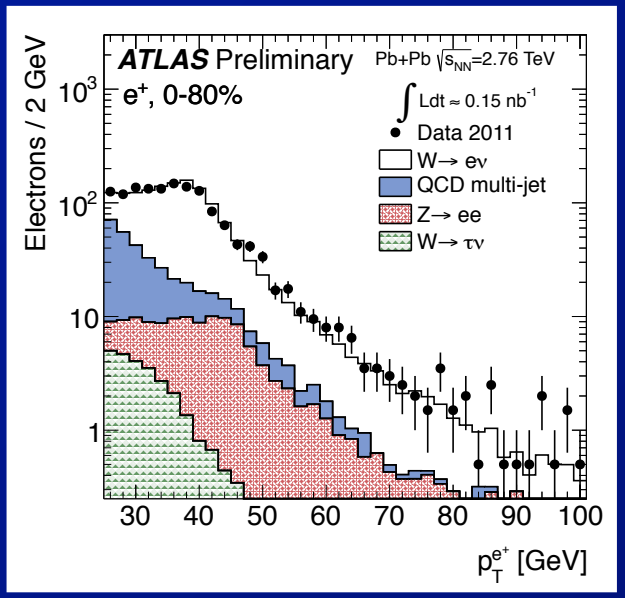


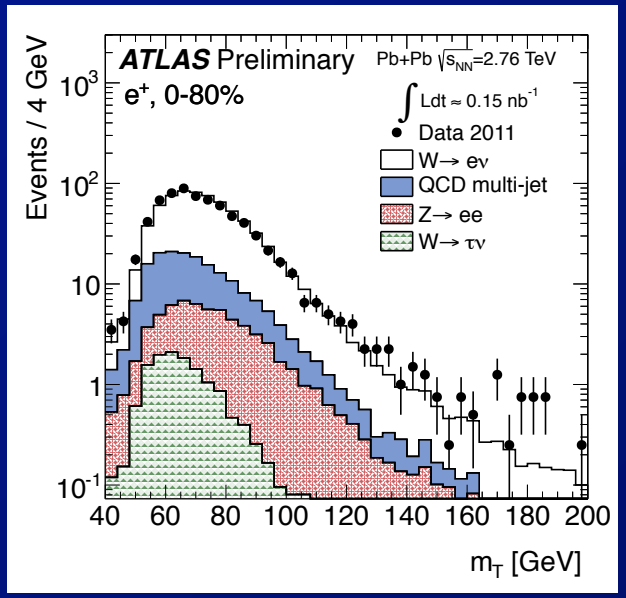
Pb+Pb W: control distributions

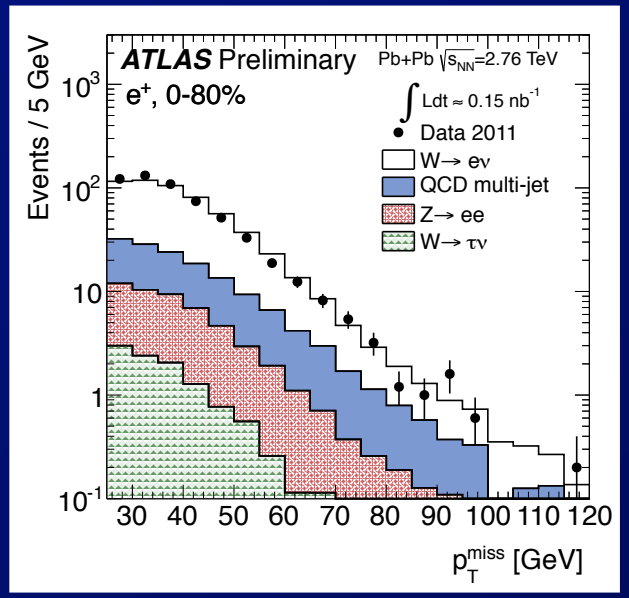




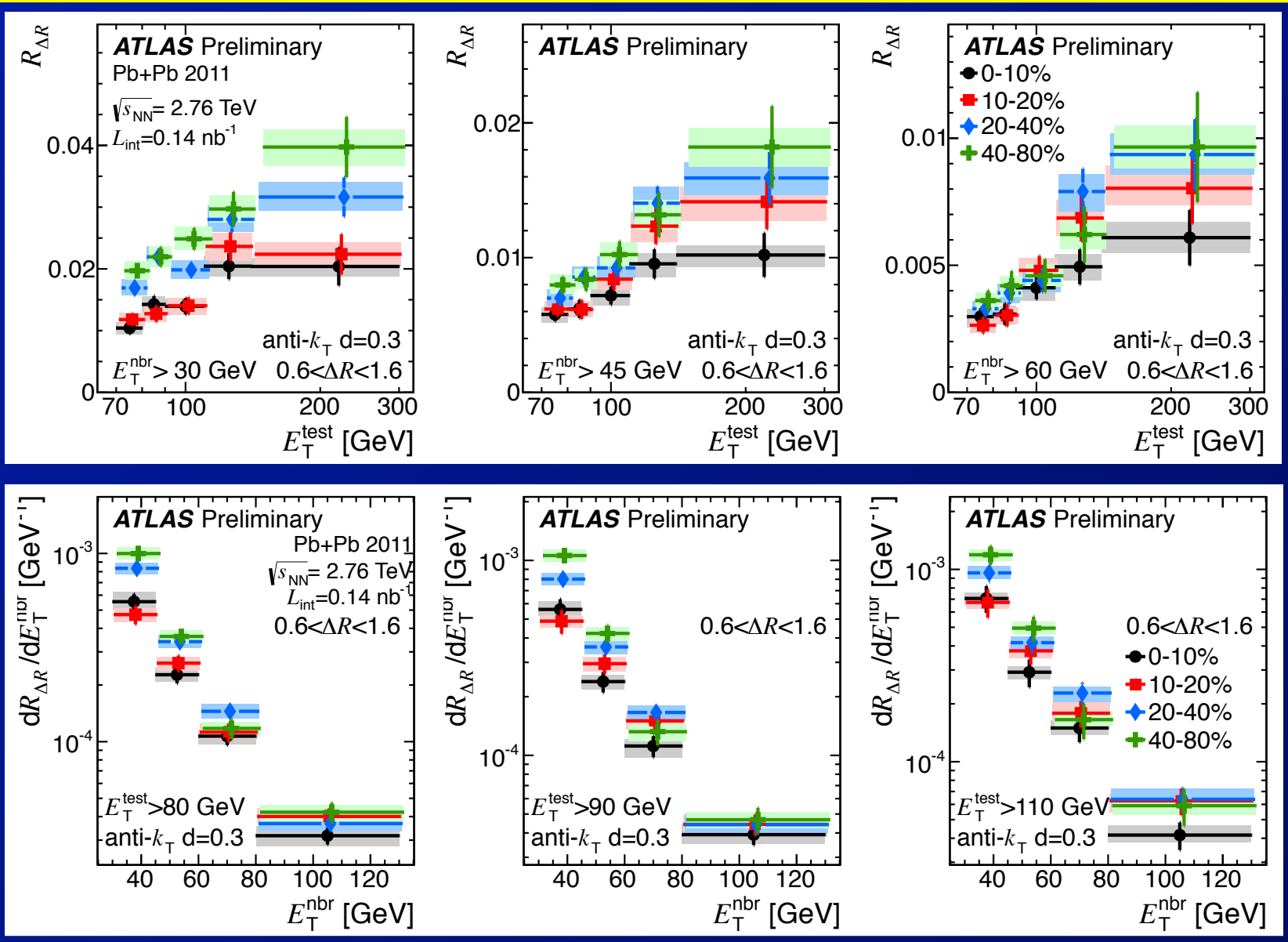




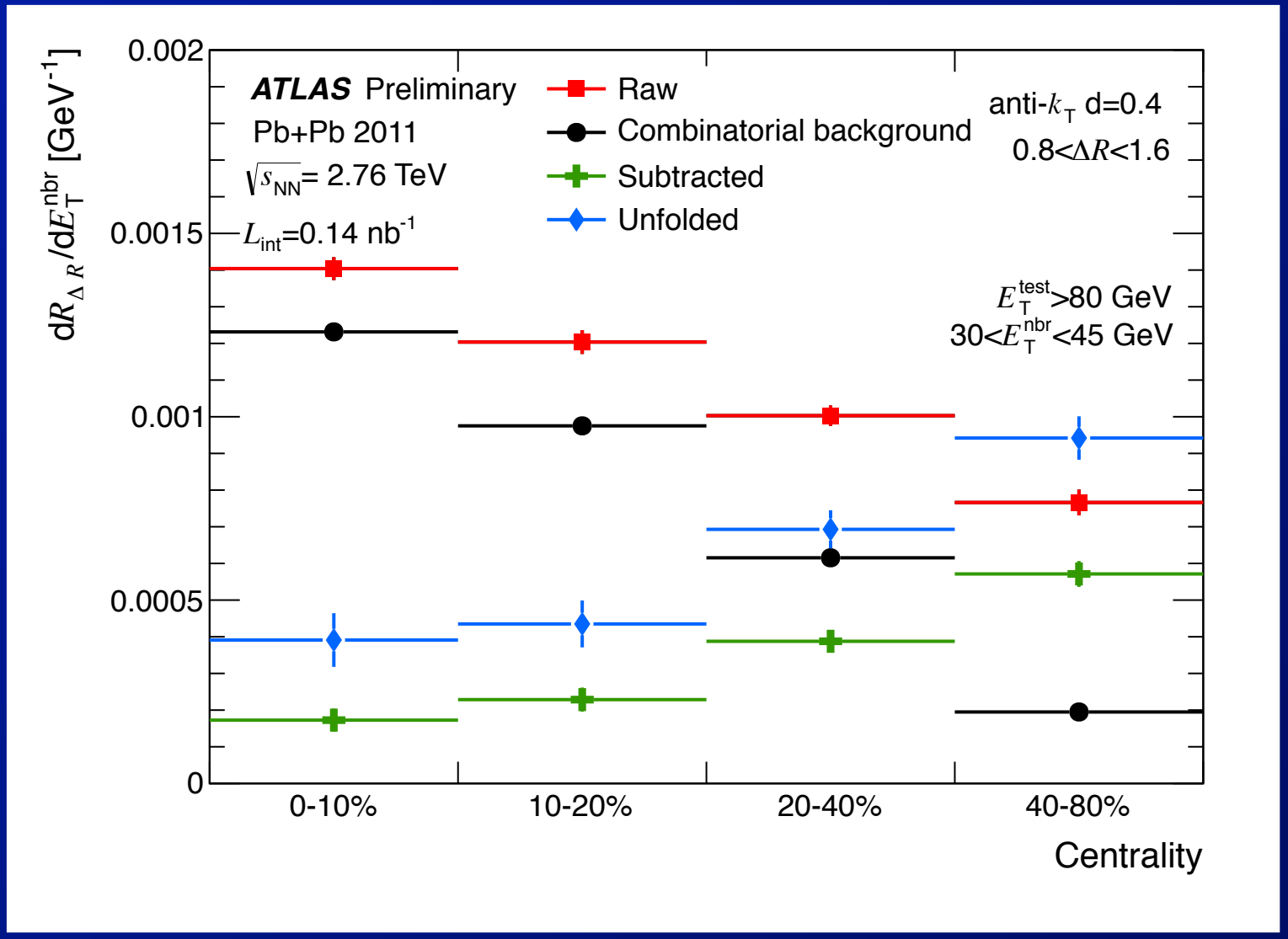




Pb+Pb nearby jets: R = 0.3

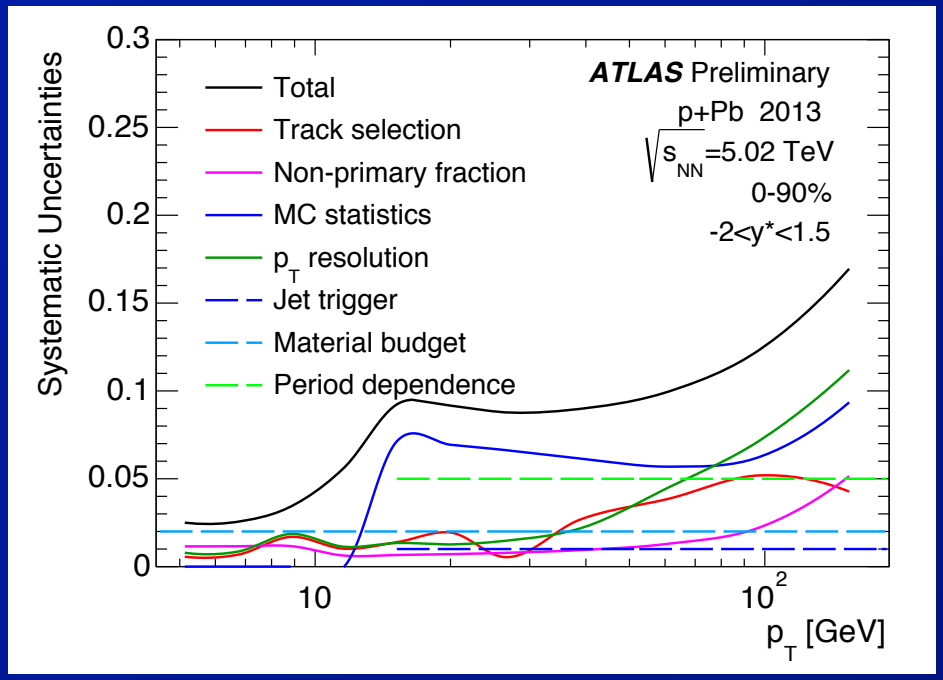


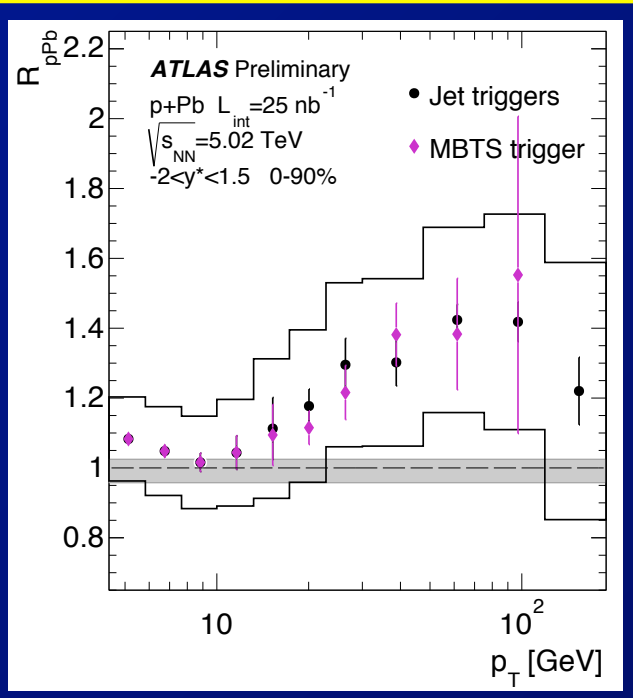
Pb+Pb nearby jets: analysis

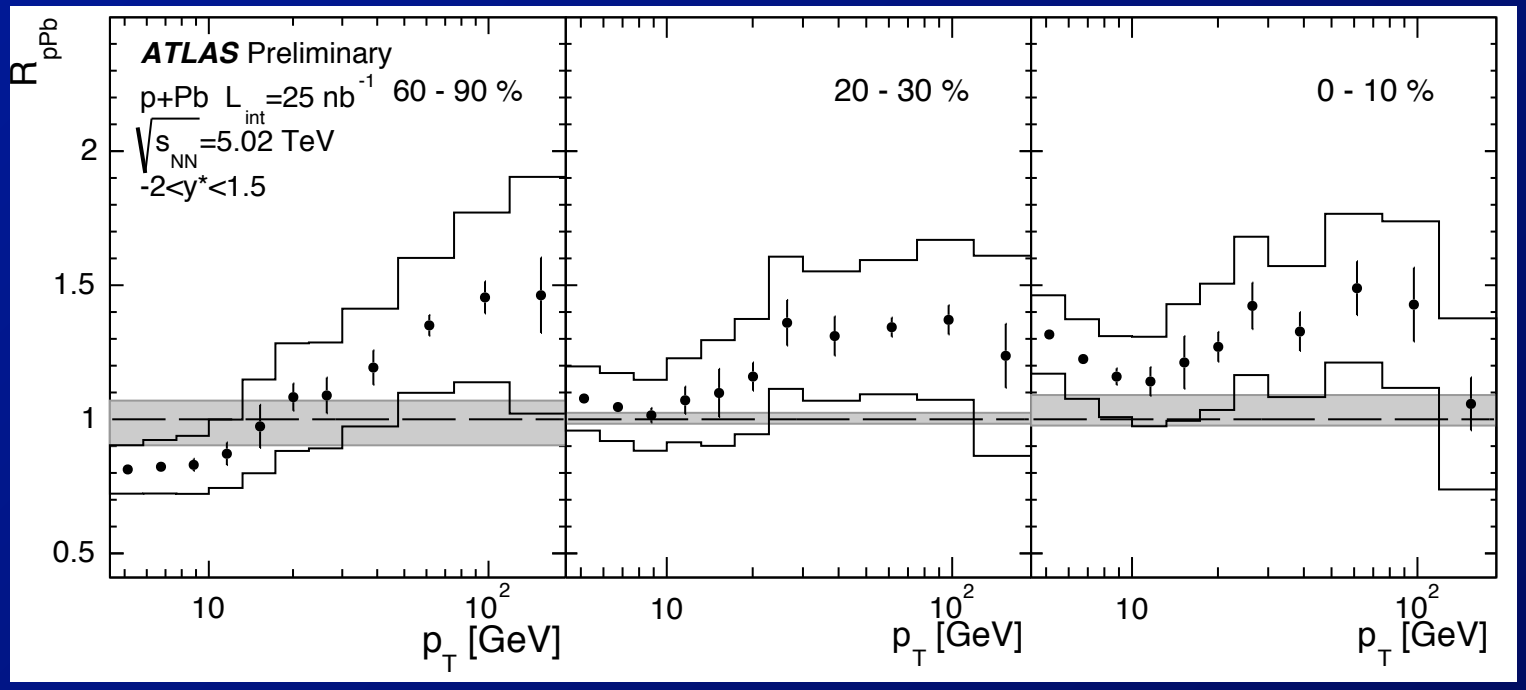


- **Result for the differential neighboring jet yield at various stages of the analysis (lowest p_T)**

Charged R_{pPb}





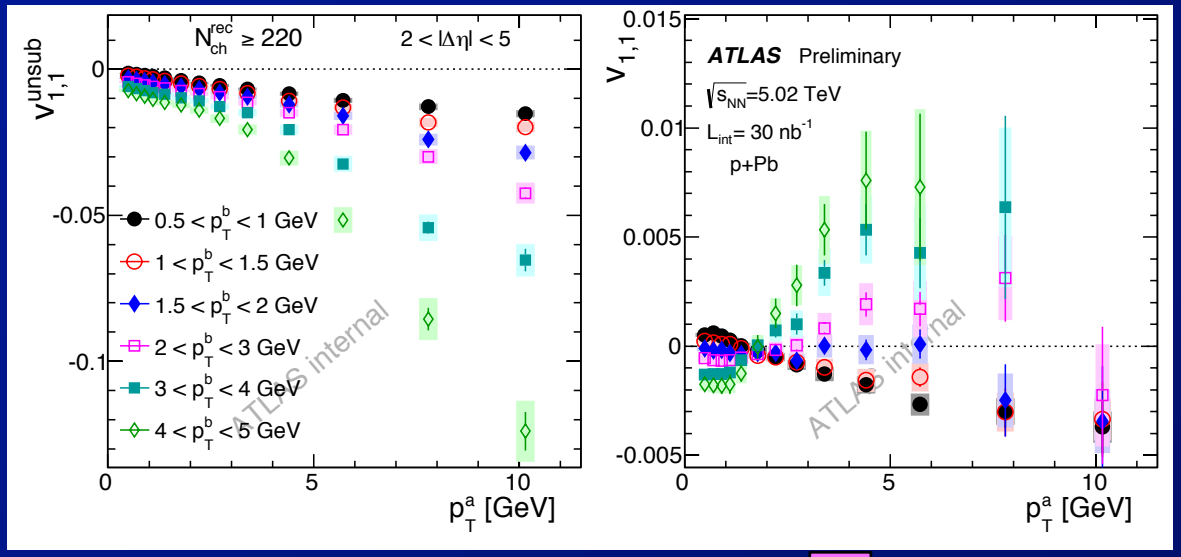


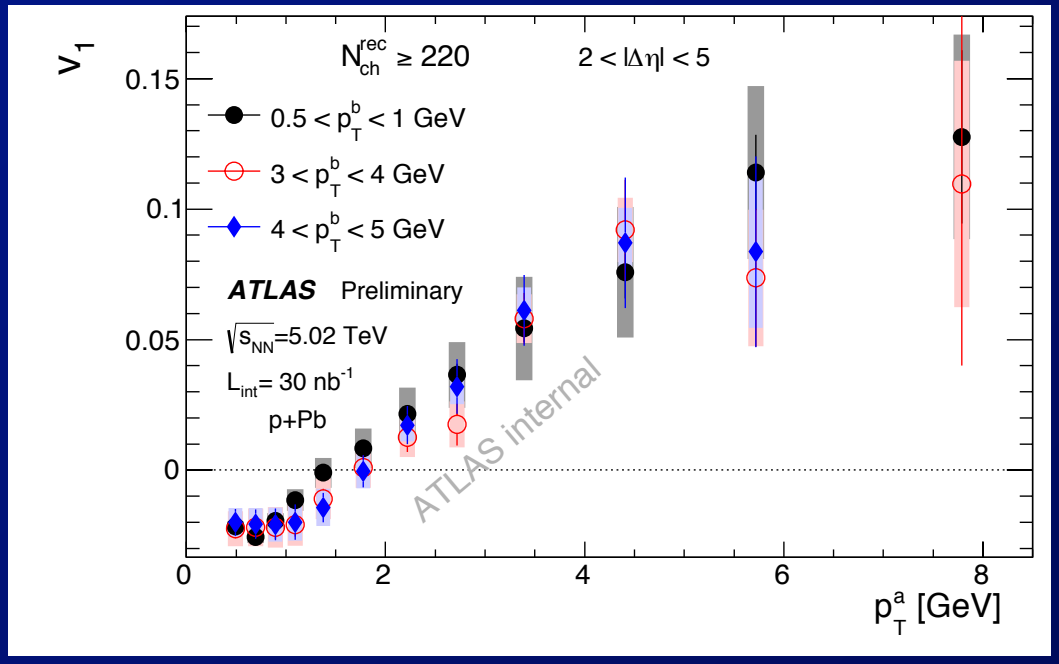
p+Pb v1

- Observe non-zero v_{11} in p+Pb collisions
  - Similar to Pb+Pb, changes sign with increasing p_T
  - Extract v_1 using same procedure applied to Pb+Pb

⇒Observe that v_1 factorizes

⇒Evolution from negative v_1 below ~ 2 GeV to positive above

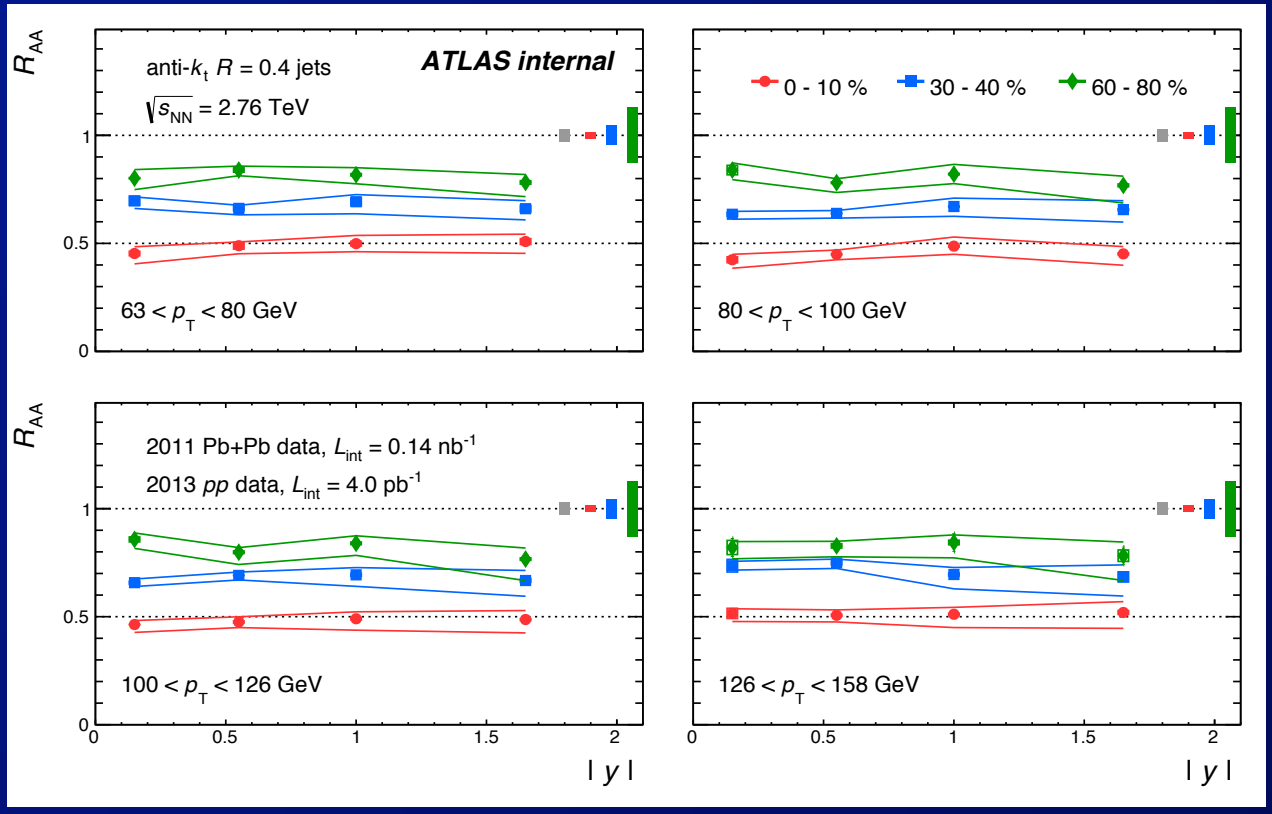




Jet R_{AA}: Rapidity dependence

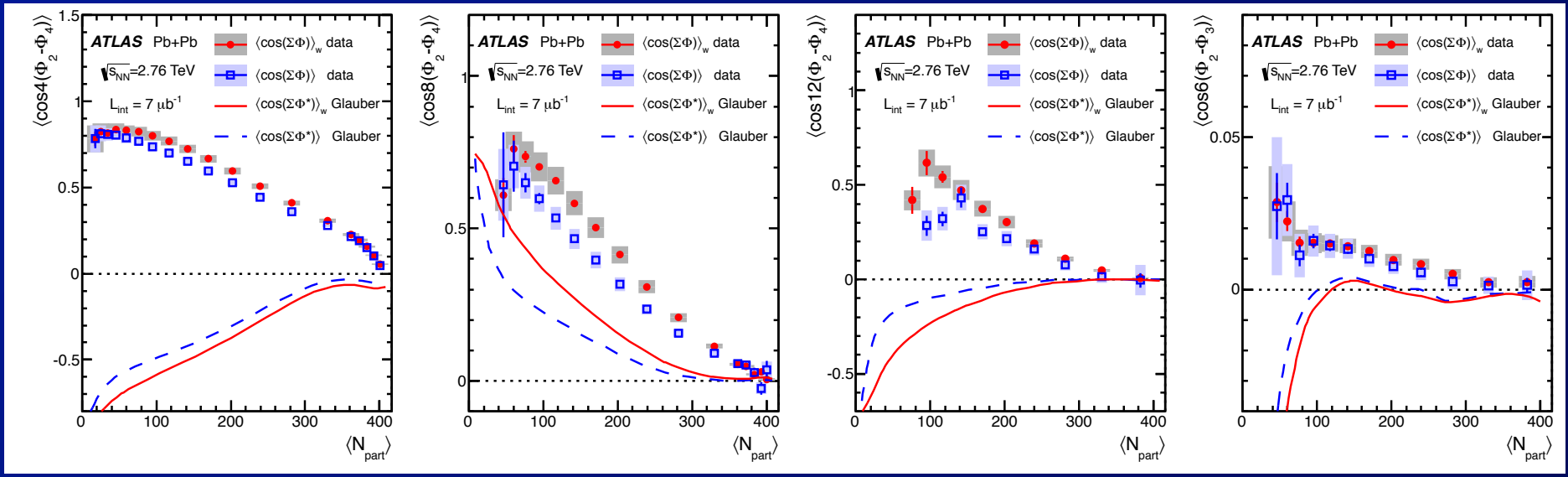
- Why should we expect a y dependence?
  - y dependence of primordial parton spectrum:
    - ⇒jet spectrum steeper with increasing y
  - variation of quark/gluon ratio
    - ⇒q/g increases with increasing y

- Observe no systematic variation with y
  - ⇒Theory?



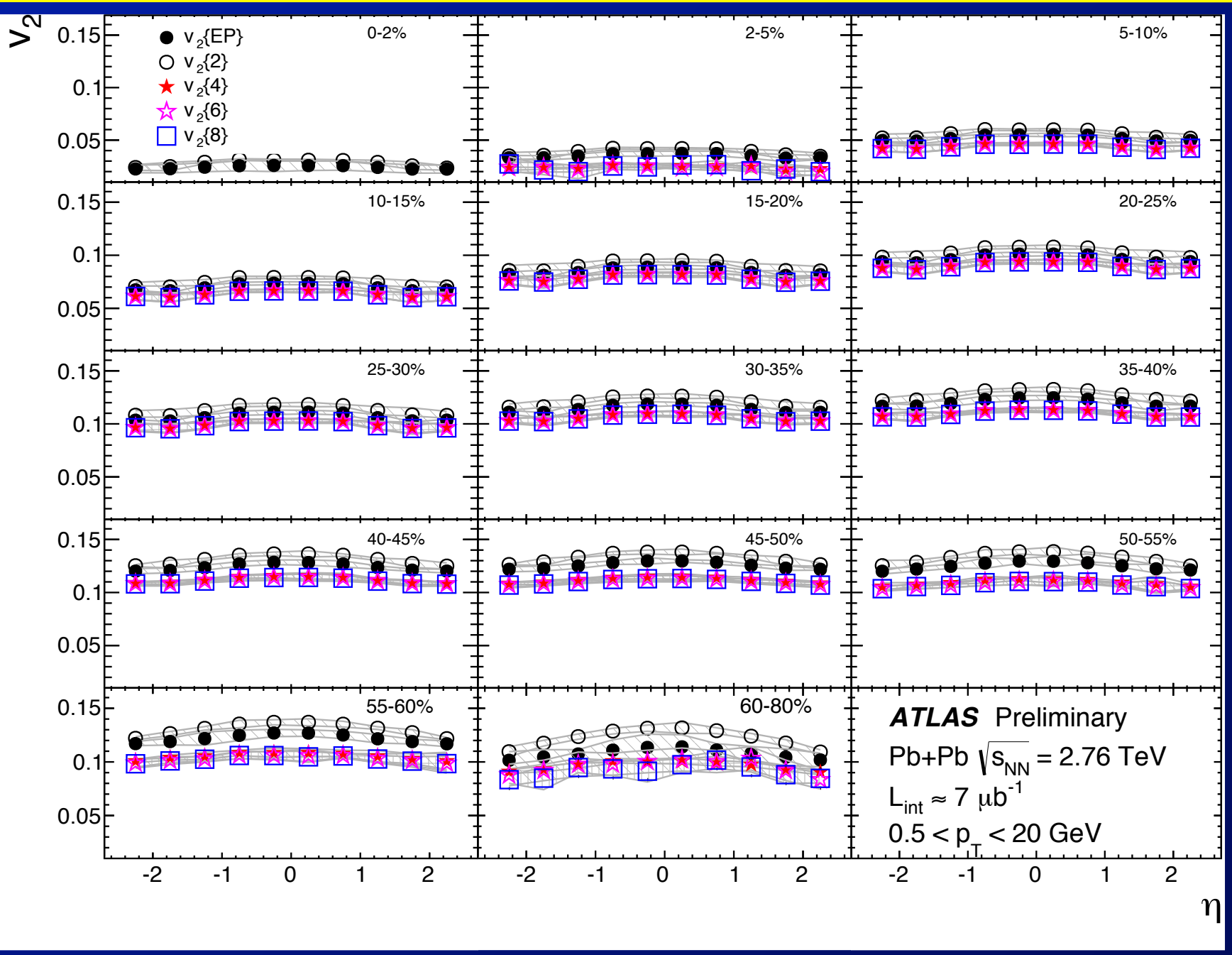
Event plane angle correlations

- Measure event plane angles, Φ_n, event -by-event using ATLAS calorimeter (arXiv:1403.0489)
  - Evaluate $\langle \cos\left(jk\left[\Phi_n - \Phi_m\right]\right)\rangle$
    - ⇒corrected for event plane resolution.
    - ⇒In 5% bins of centrality + 1% bins over 0-5%
  - Compare to Glauber only (here)
    - ⇒Poor agreement

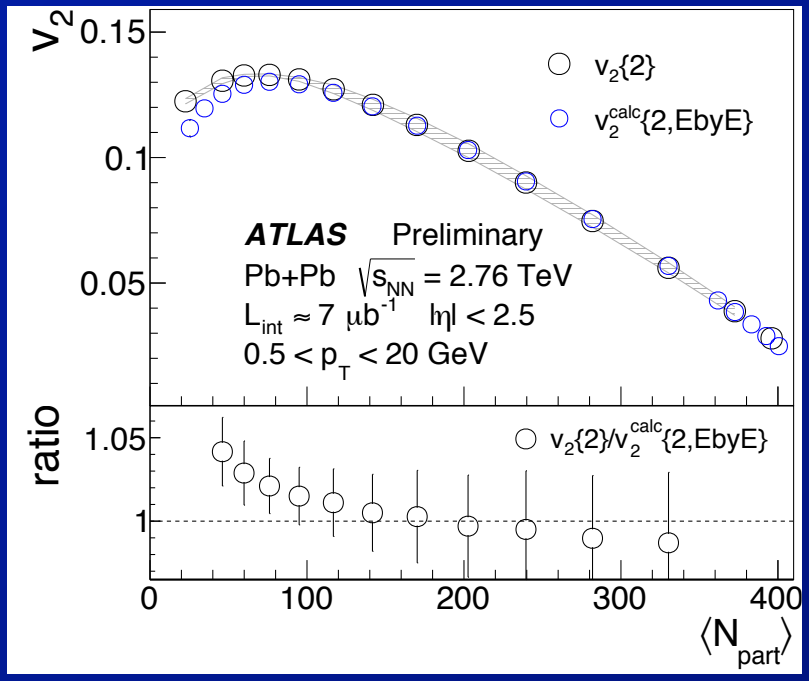


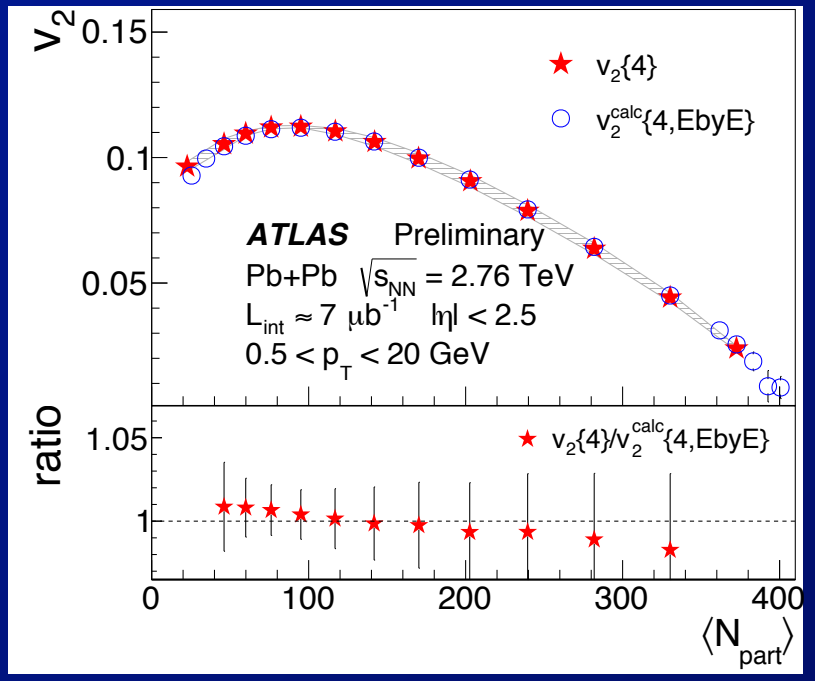
$\langle \cos\left(4\left[\Phi_2 - \Phi_4\right]\right)\rangle$ $\langle \cos\left(8\left[\Phi_2 - \Phi_4\right]\right)\rangle$ $\langle \cos\left(12\left[\Phi_2 - \Phi_4\right]\right)\rangle$ $\langle \cos\left(6\left[\Phi_2 - \Phi_3\right]\right)\rangle$

Cumulant v_2 vs η

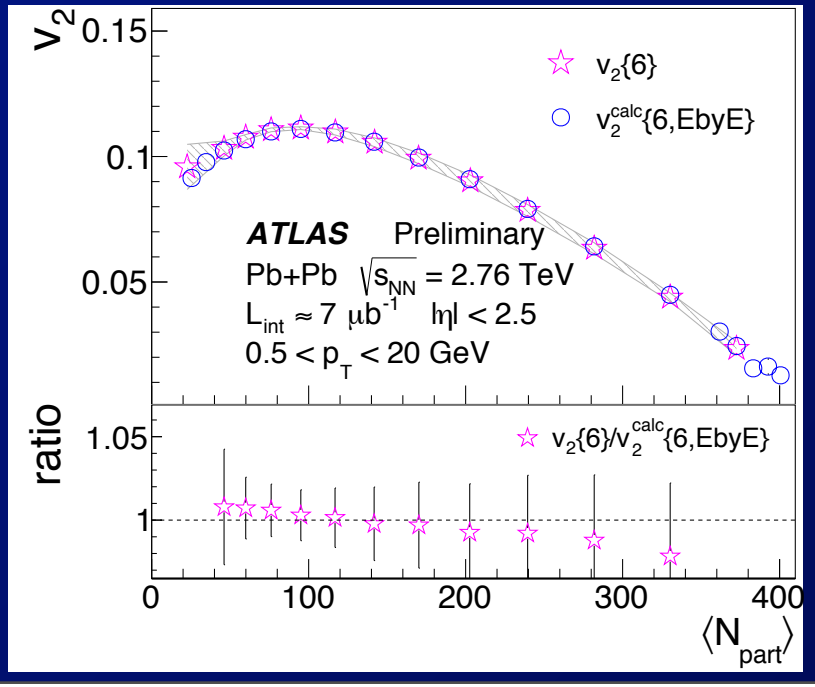


Cumulant, E-by-E v_2

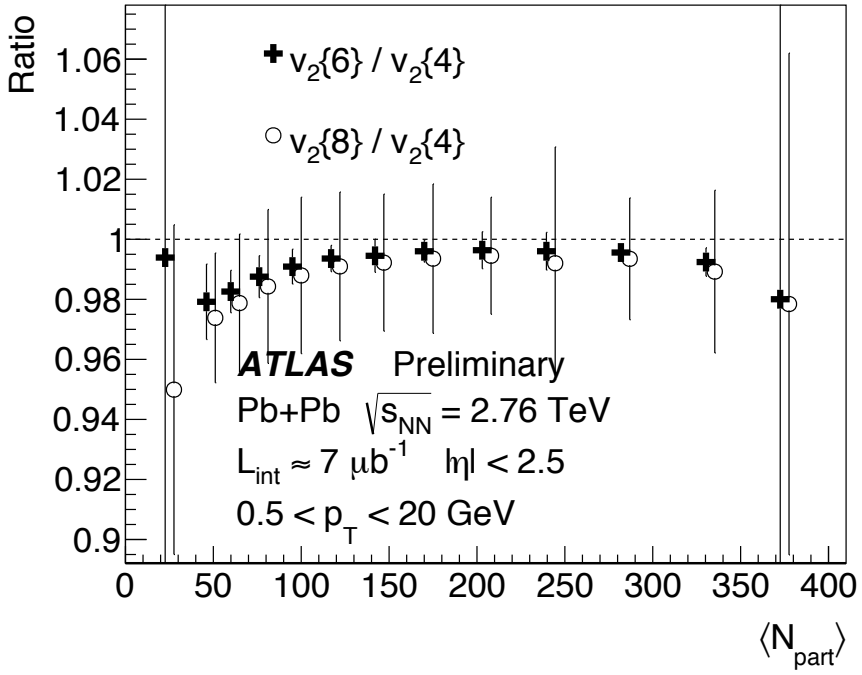


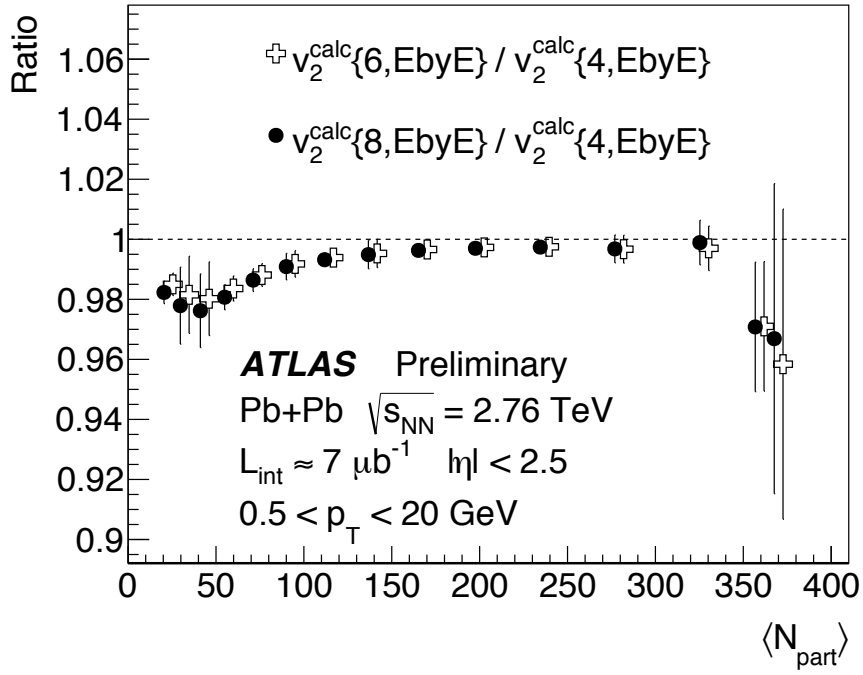


- Comparison of 2, 4, 6-particle cumulant v_n values to those calculate using e-by-e measurements



Cumulant, E-by-E v_2 (2)



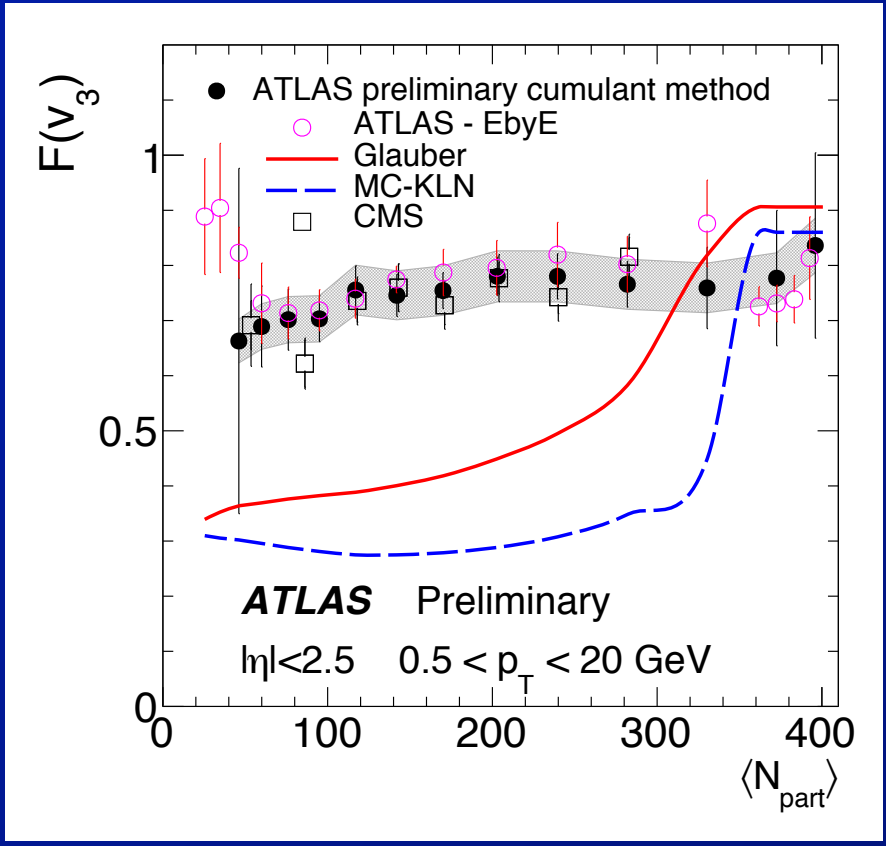


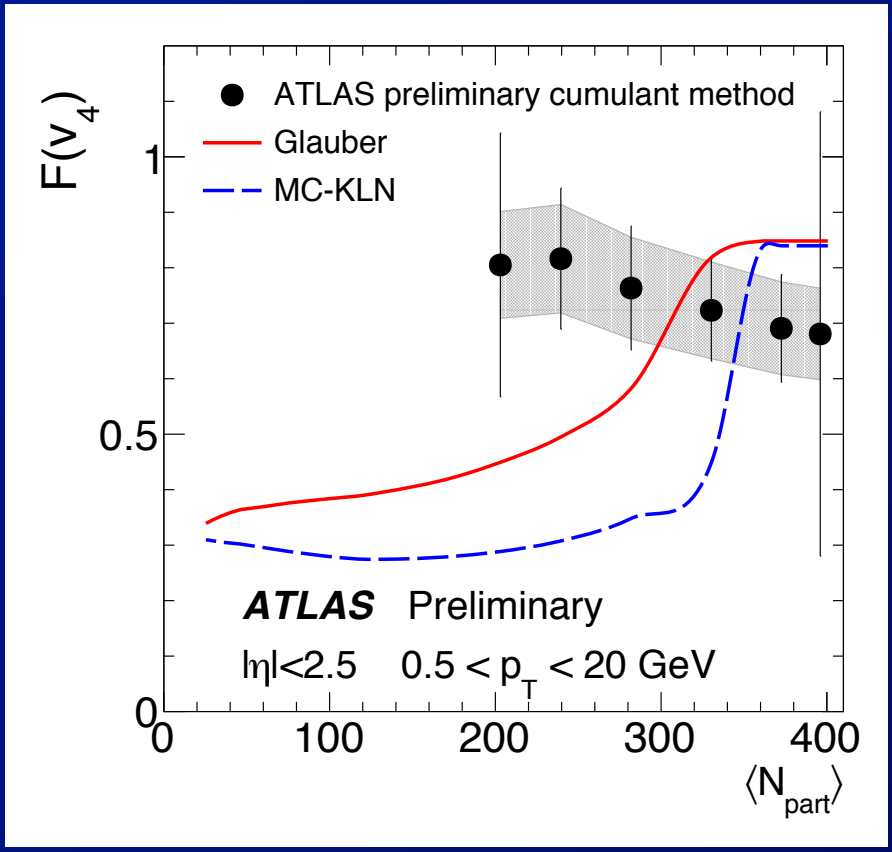
- **Comparison between $v_2\{4\}$, $v_2\{6\}$, $v_2\{8\}$**
  - Left: cumulants
  - Right: event-by-event

  ⇒Good agreement

  ⇒Probe of flow fluctuations

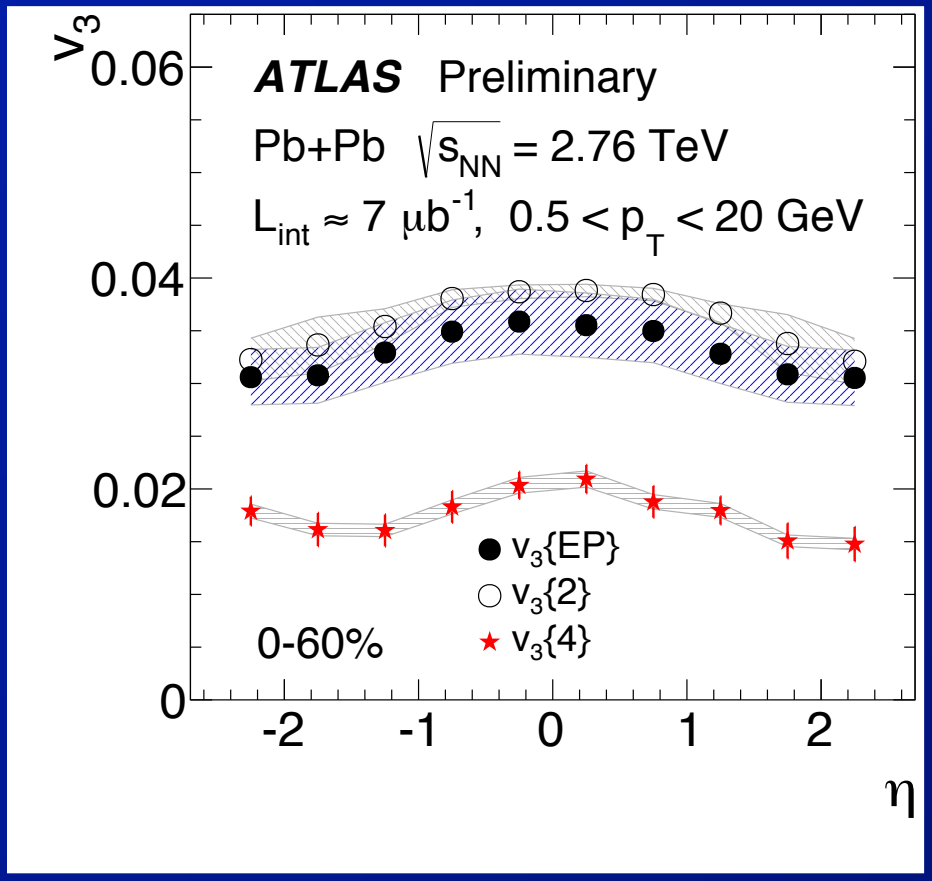
Cumulant, v_3, v_4 fluctuations

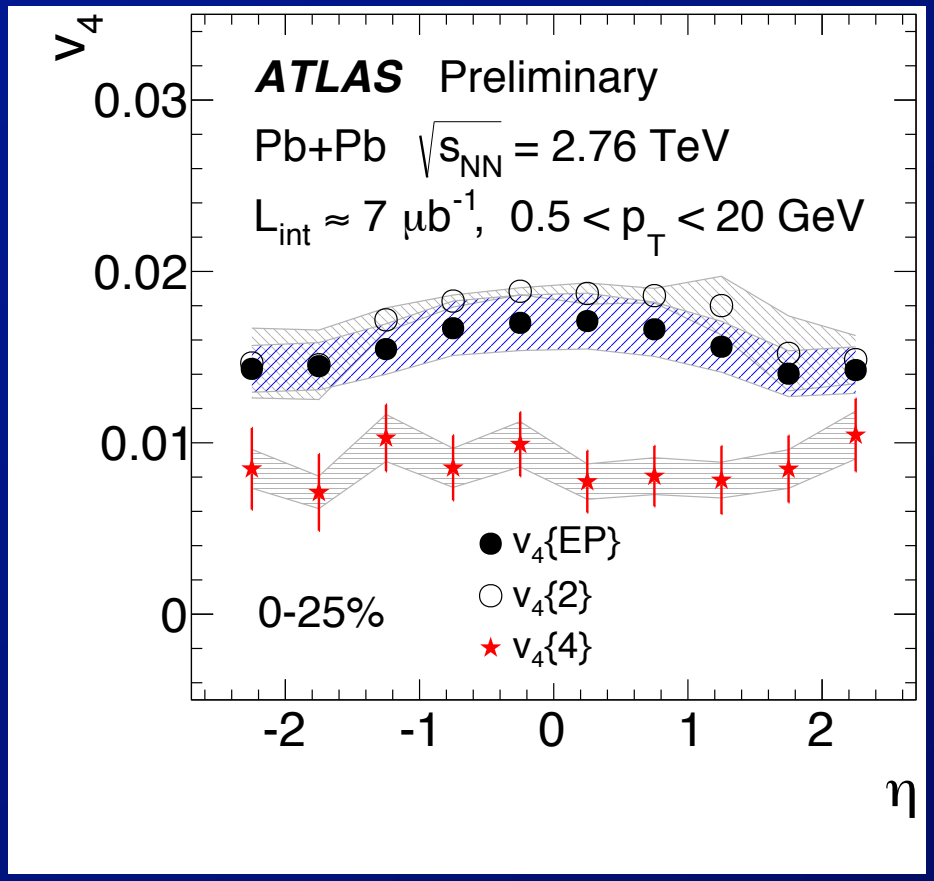




- v_3 and v_4 fluctuations agree well with the event-by-event results
  - ⇒Not described by Glauber or MC-KLN

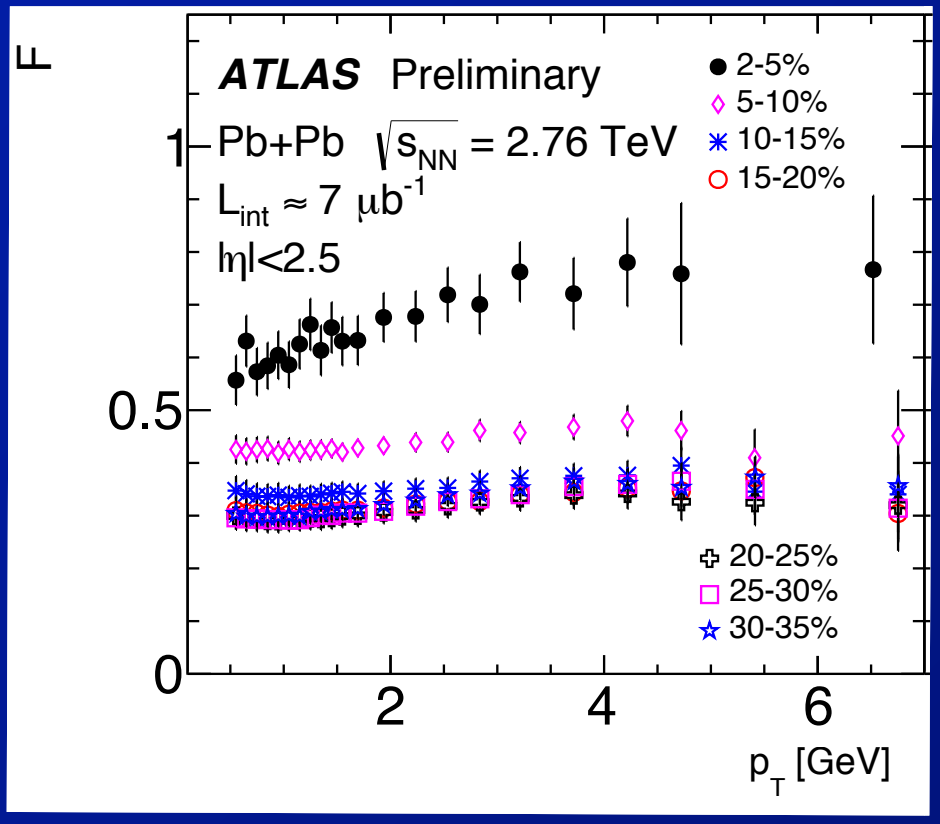
Cumulant v_3, v_4 vs η

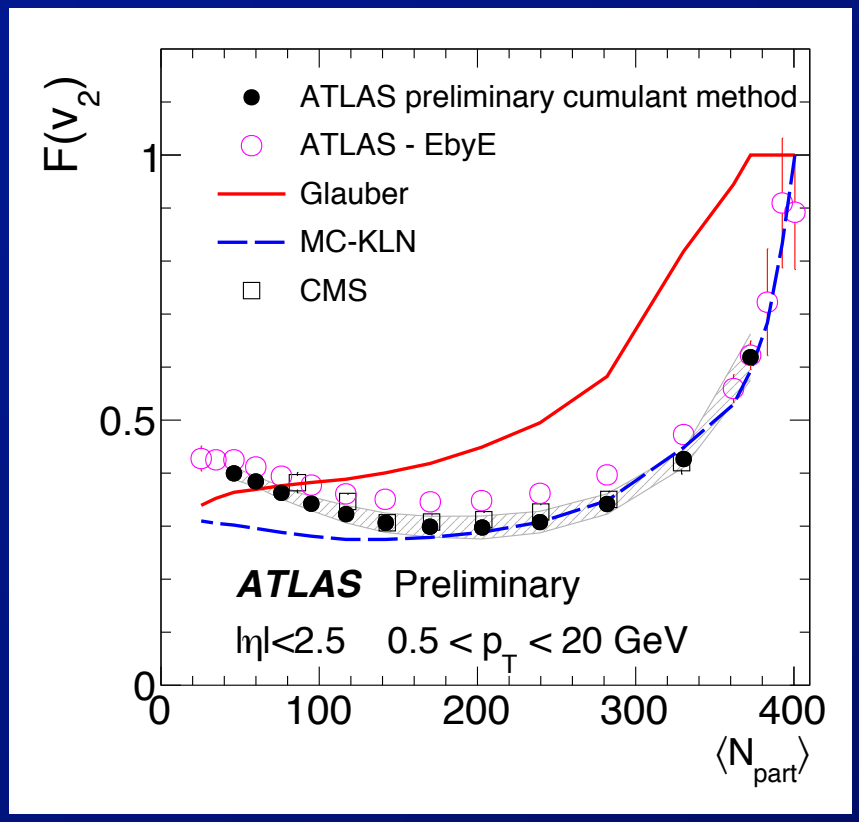




- η dependence of v3, v4 averaged over large centrality interval
  - OK, because weak dependence on centrality

Cumulant, v_2 fluctuations

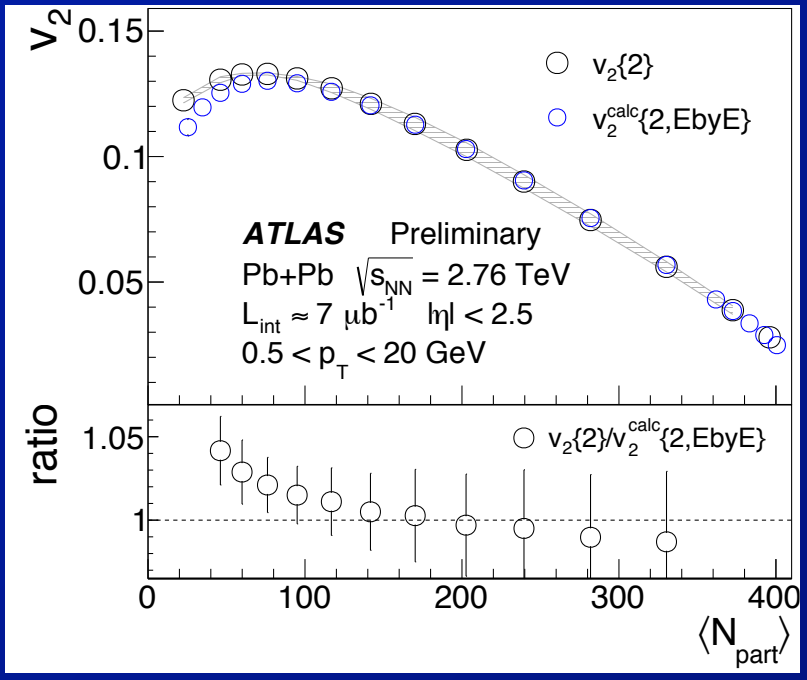


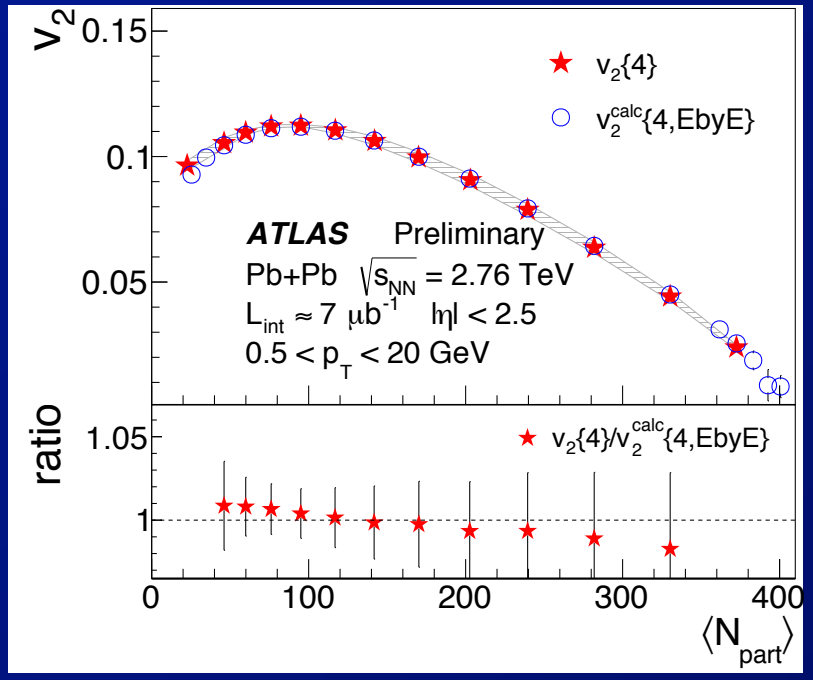


- Evaluate flow fluctuations using the cumulant and (previous) event plane "v_2"

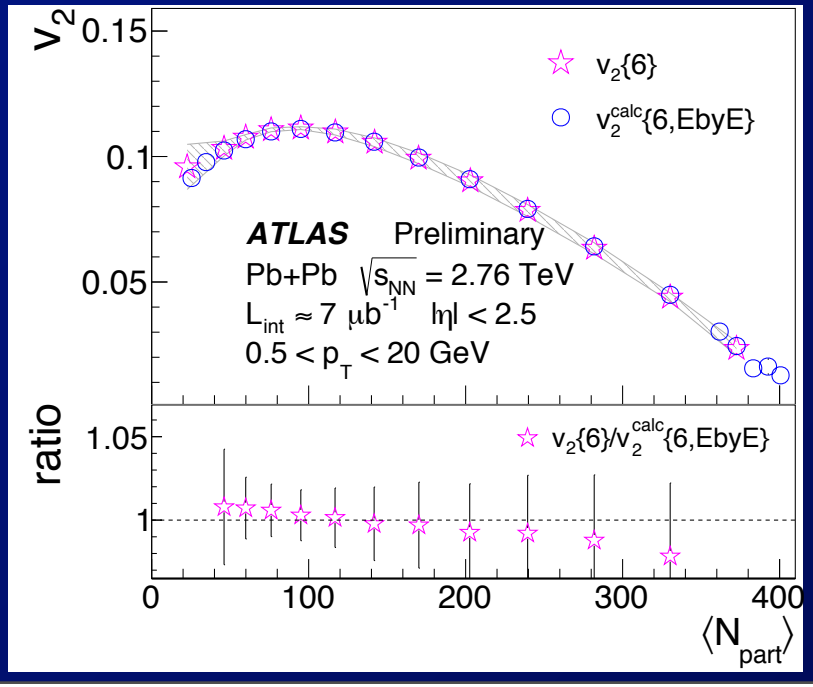
$$F = \sqrt{\frac{v_2\{EP\}^2 - v_2\{4\}^2}{v_2\{EP\}^2 + v_2\{4\}^2}}$$

Cumulant, e-by-e v_2

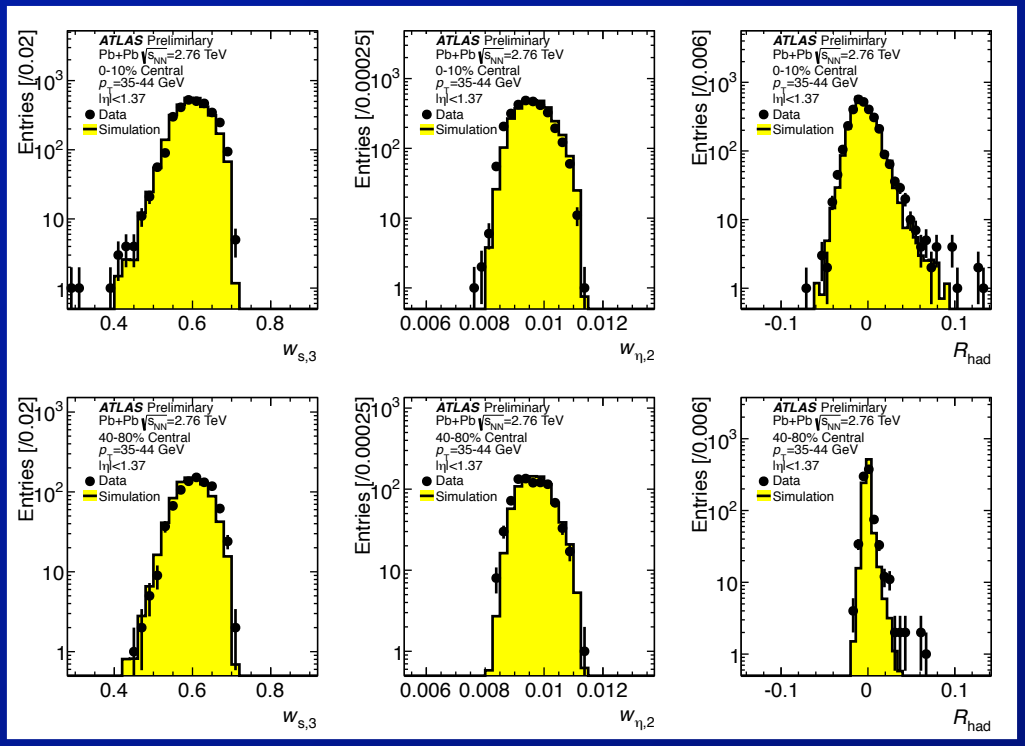


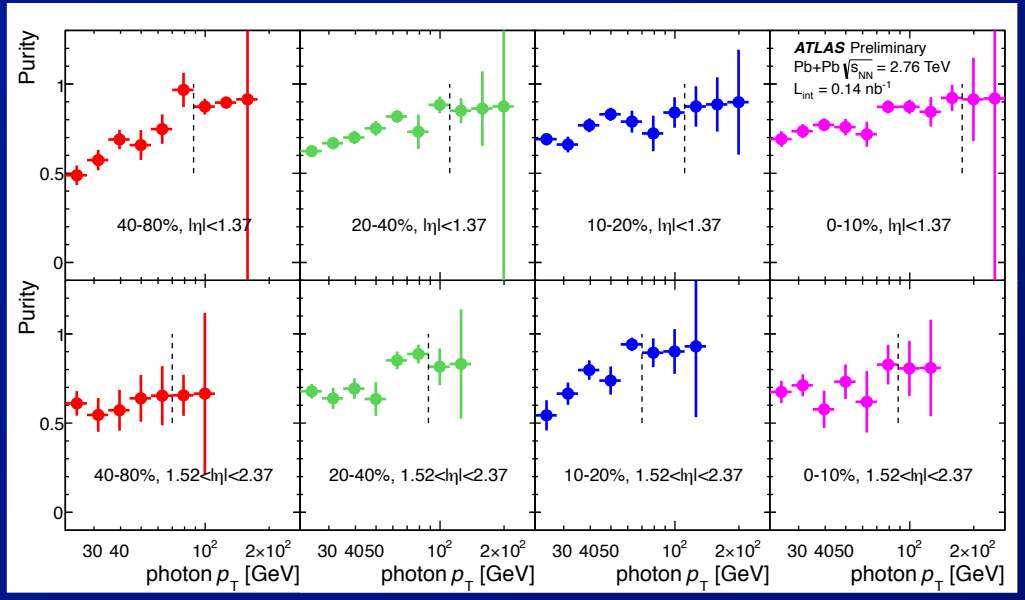


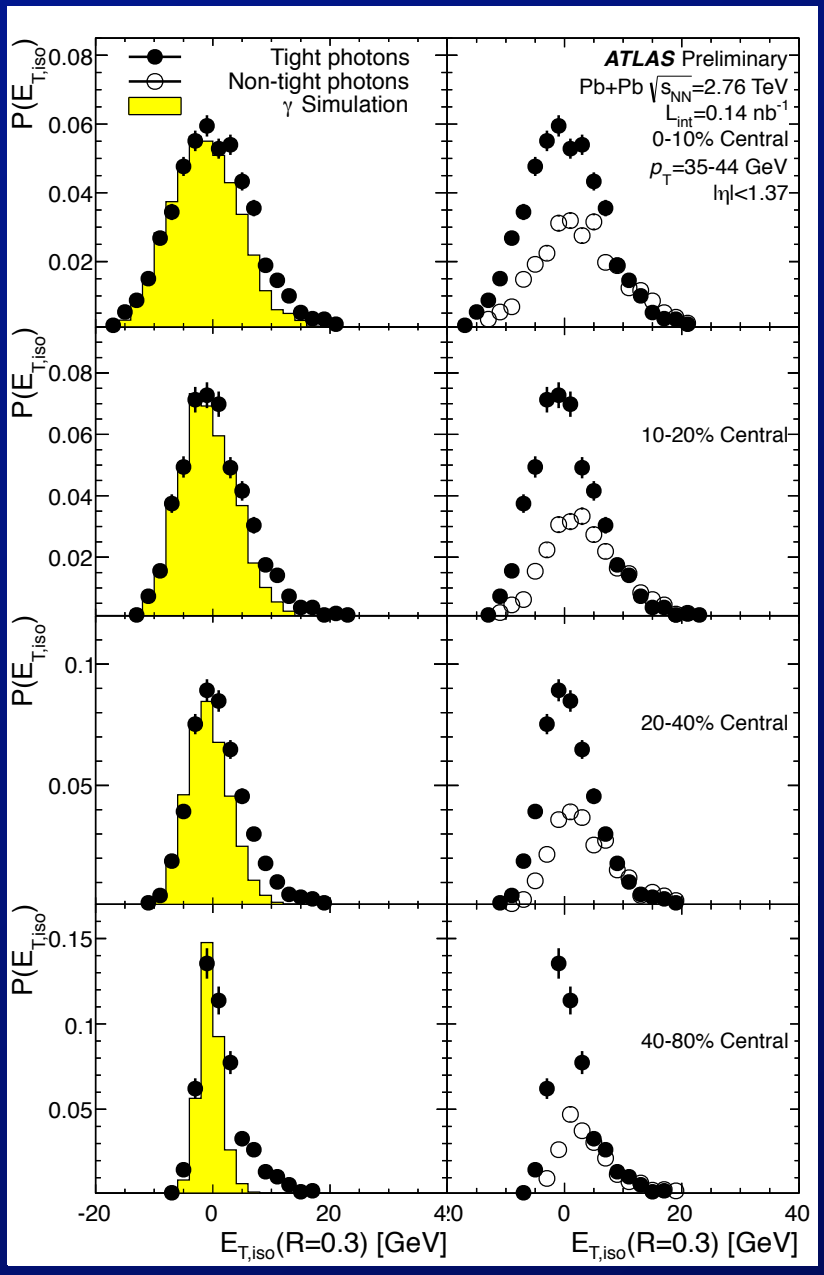
- Comparison of 2, 4, 6-particle cumulant v_n values to those calculate using e-by-e measurements



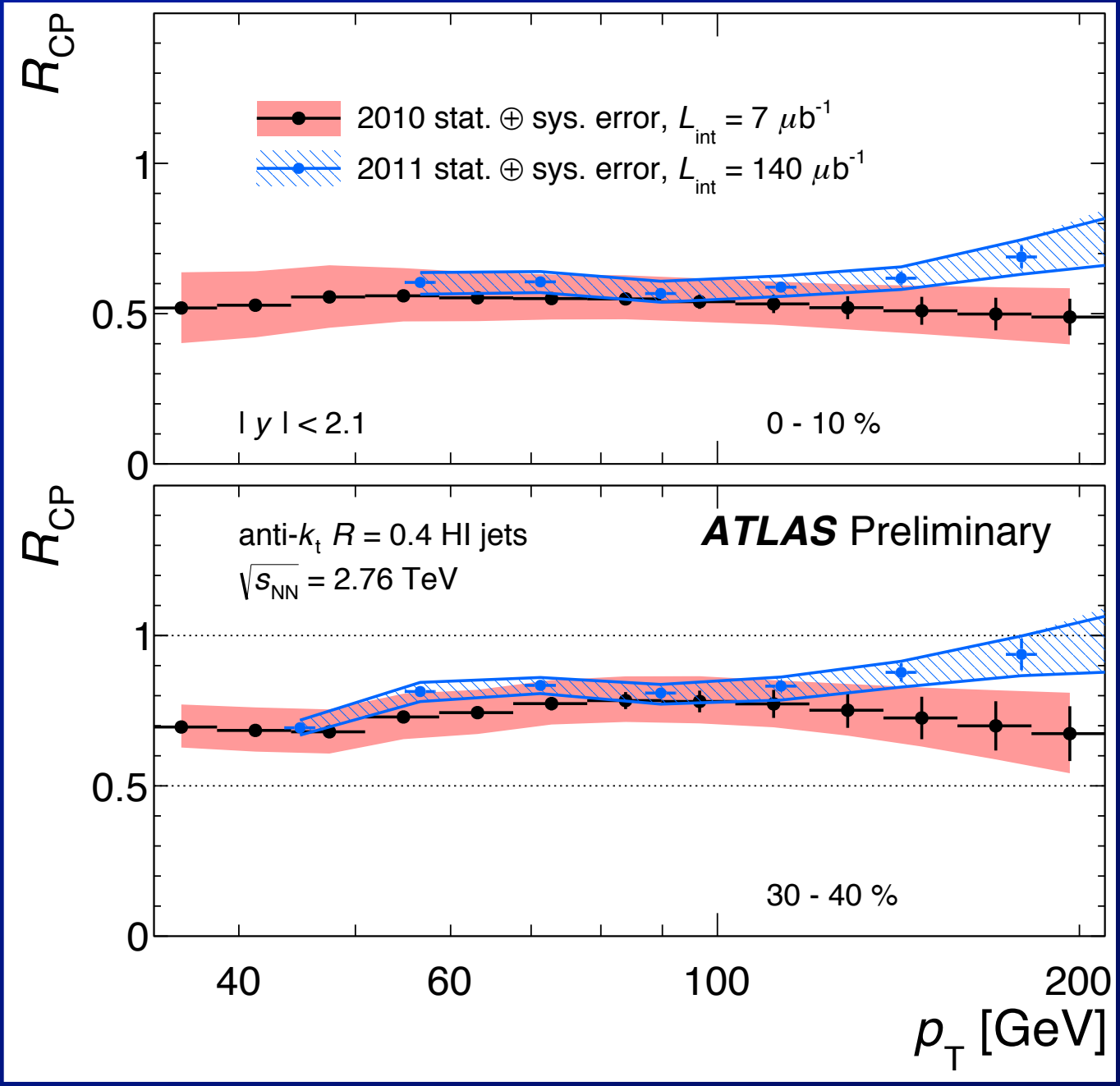
Pb+Pb photons, ID, purity



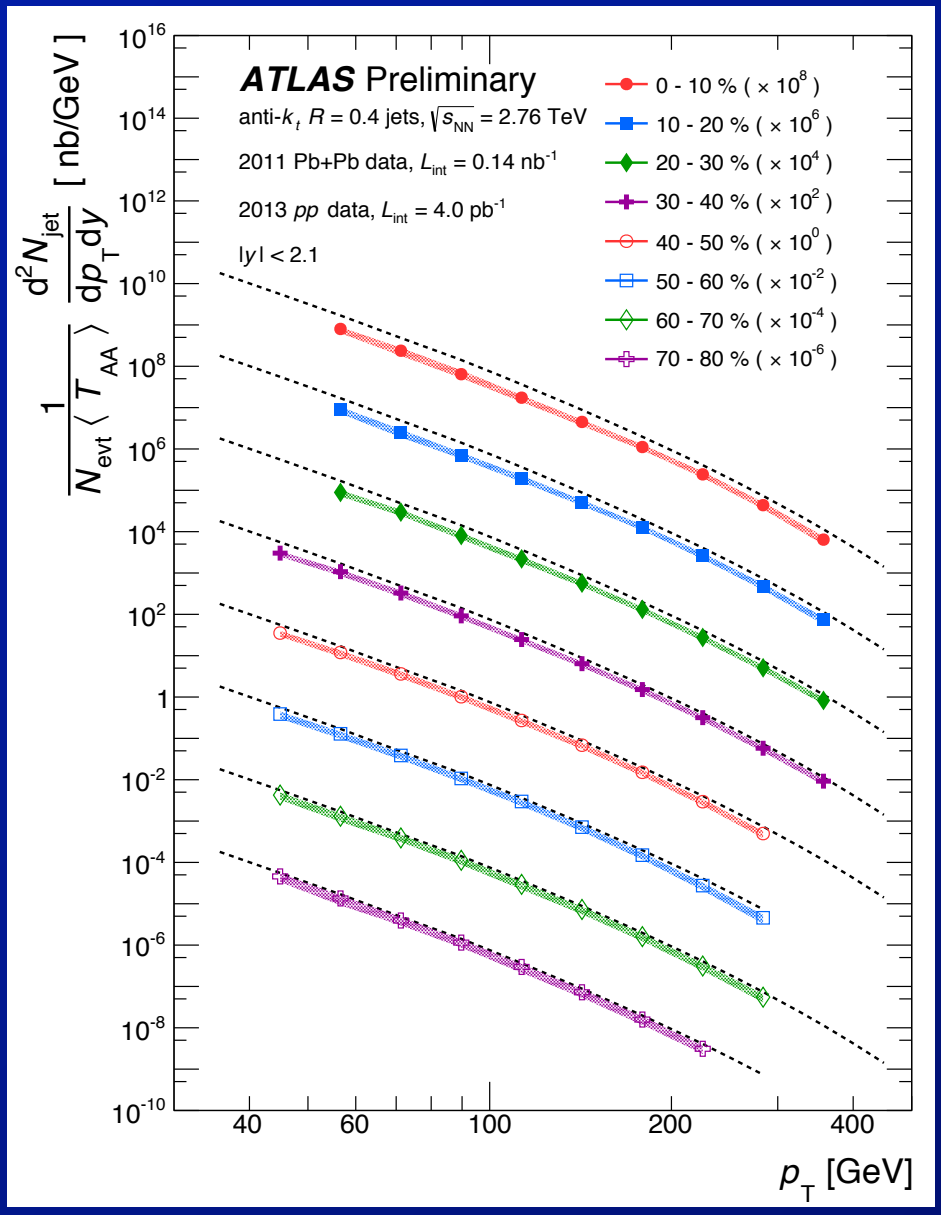


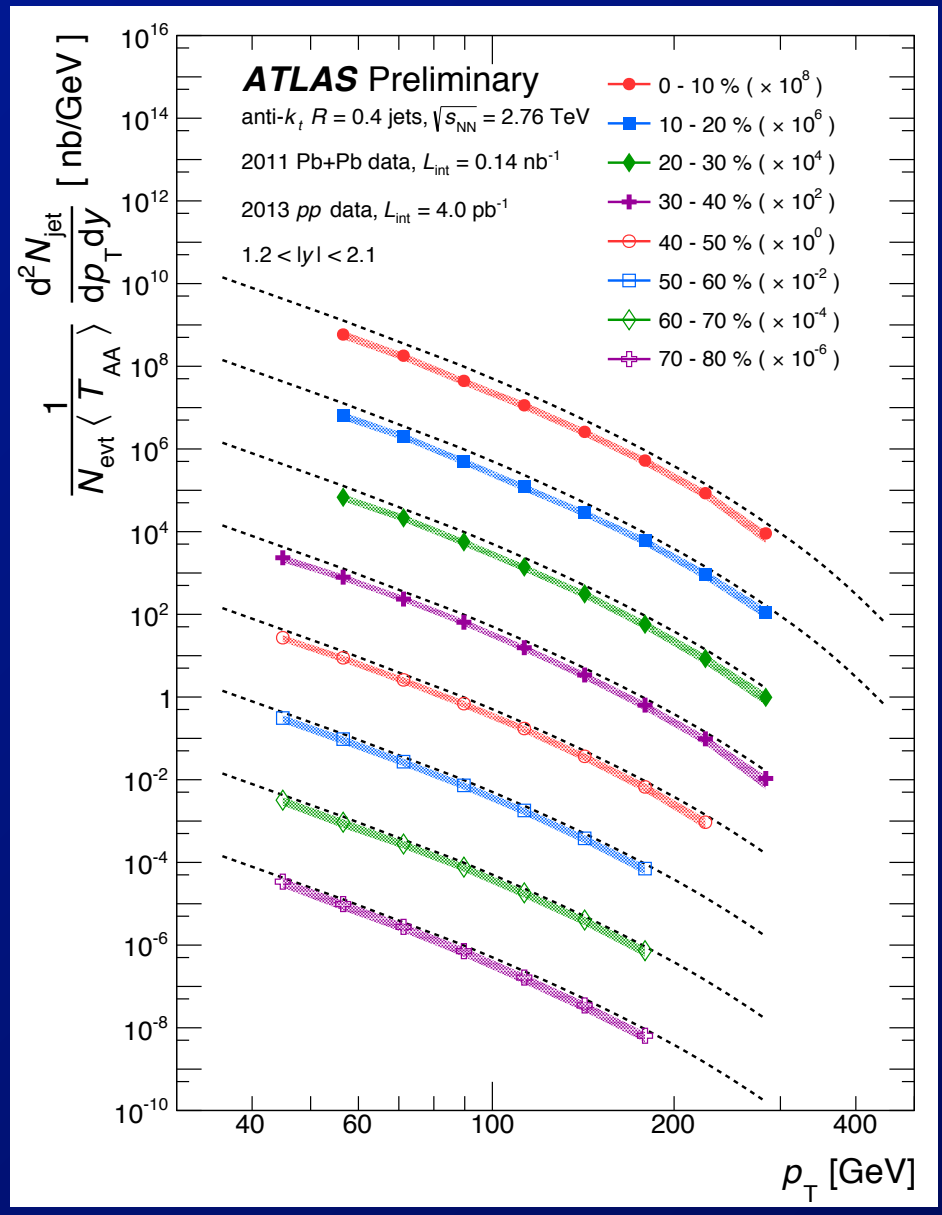


Jet R_{CP} comparison

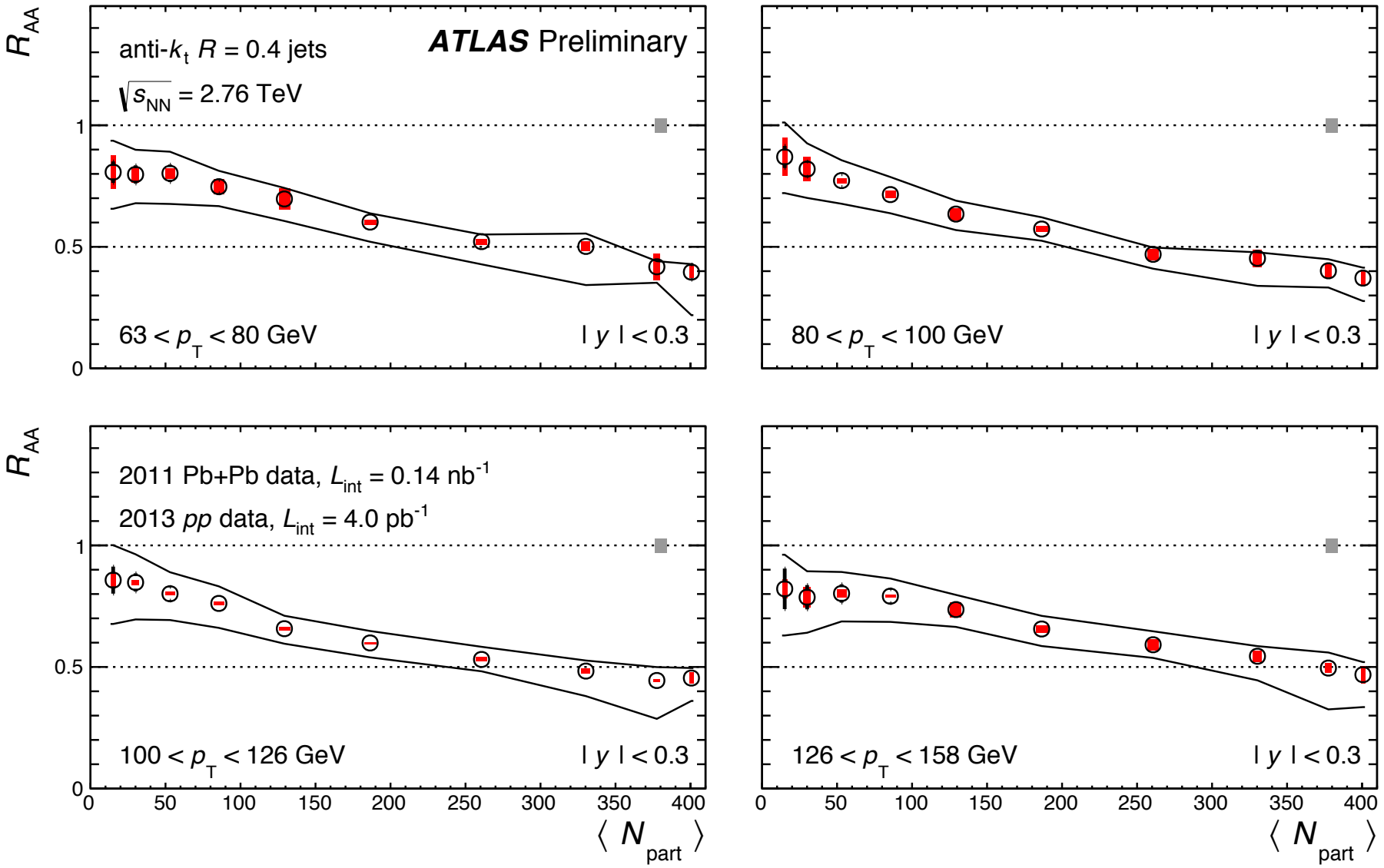


Pb+Pb Jet spectra

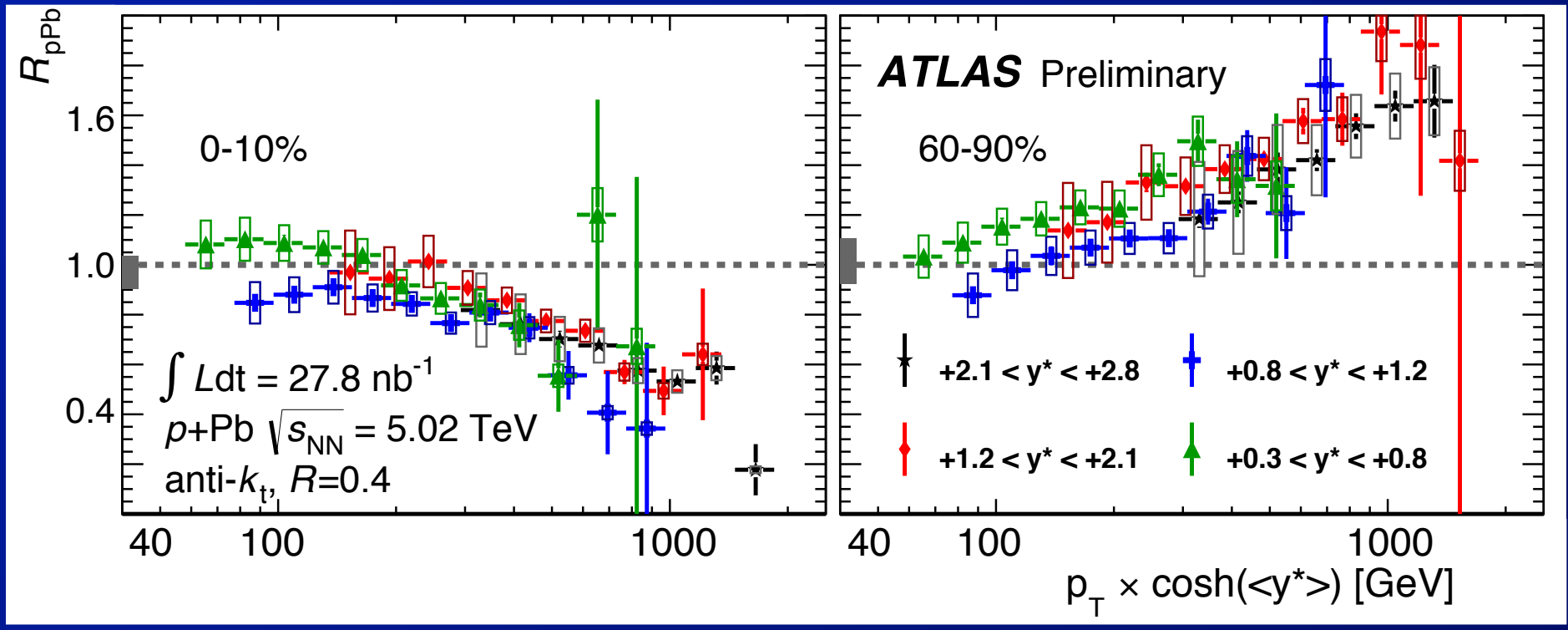




Pb+Pb jet R_{AA} vs N_{part}



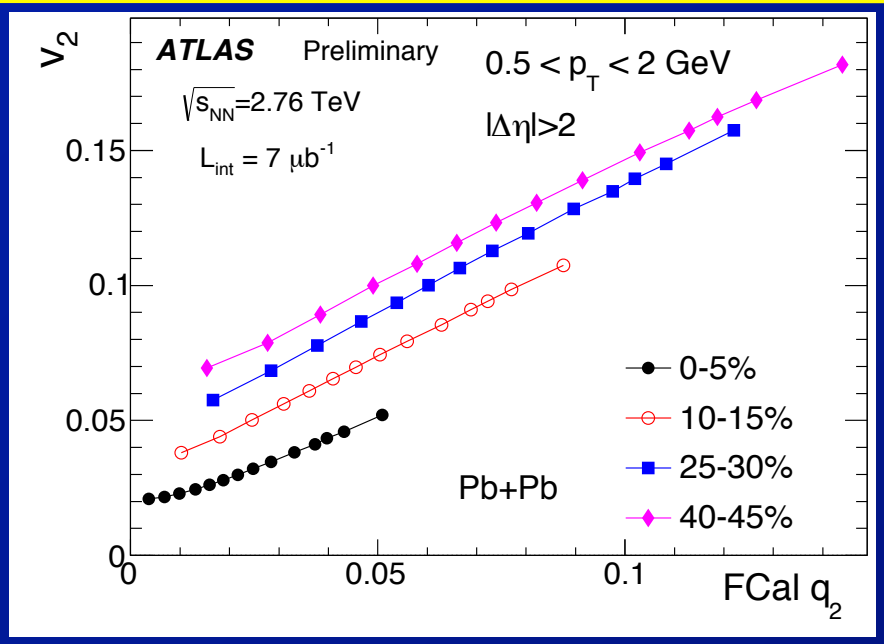
p+Pb R_{pPb} scaling

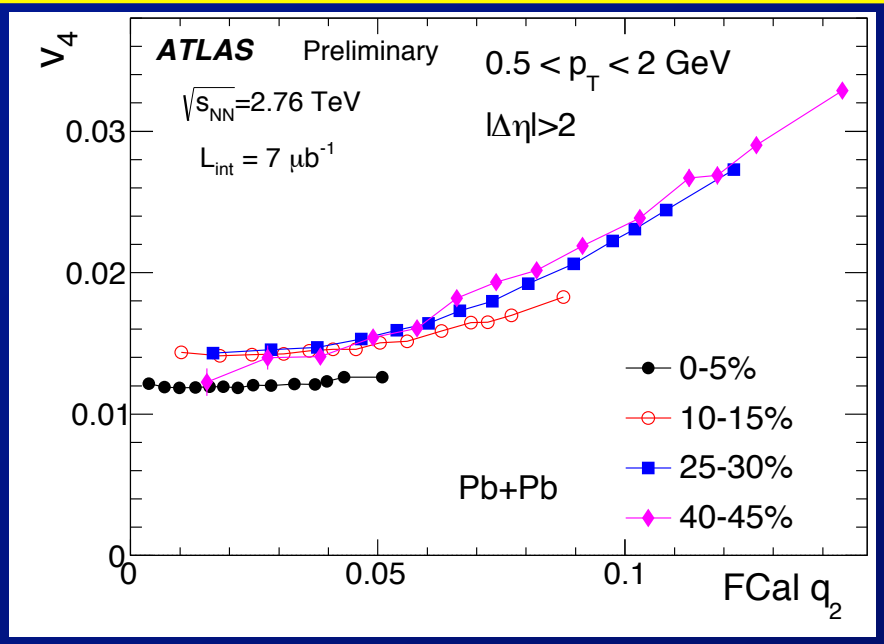


- scaling with p_T cosh(y) less clean in R_{pPb}
  - Errors larger, p-p interpolation, p+Pb y shift, …

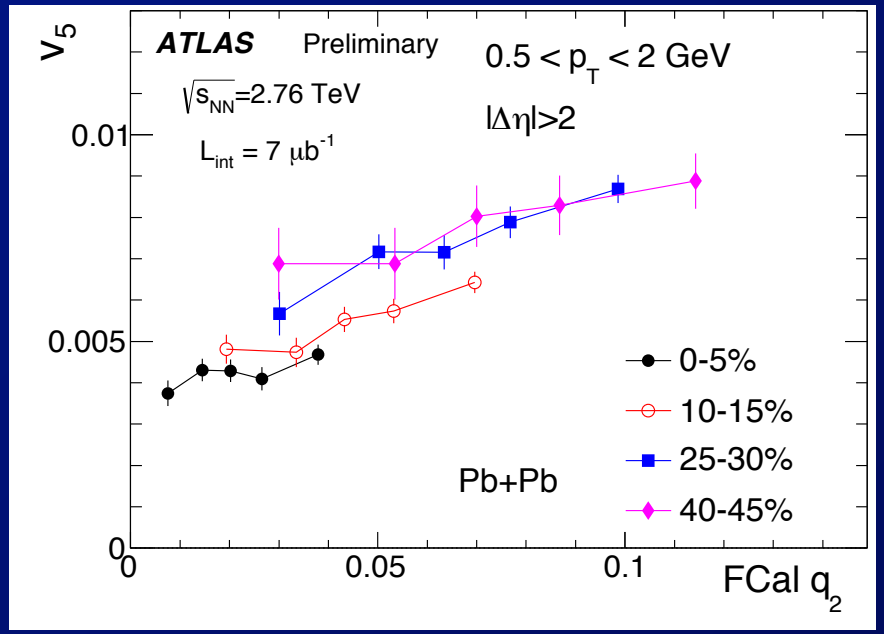
    ⇒but still present for both peripheral and central collisions

Pb-Pb v_n correlations

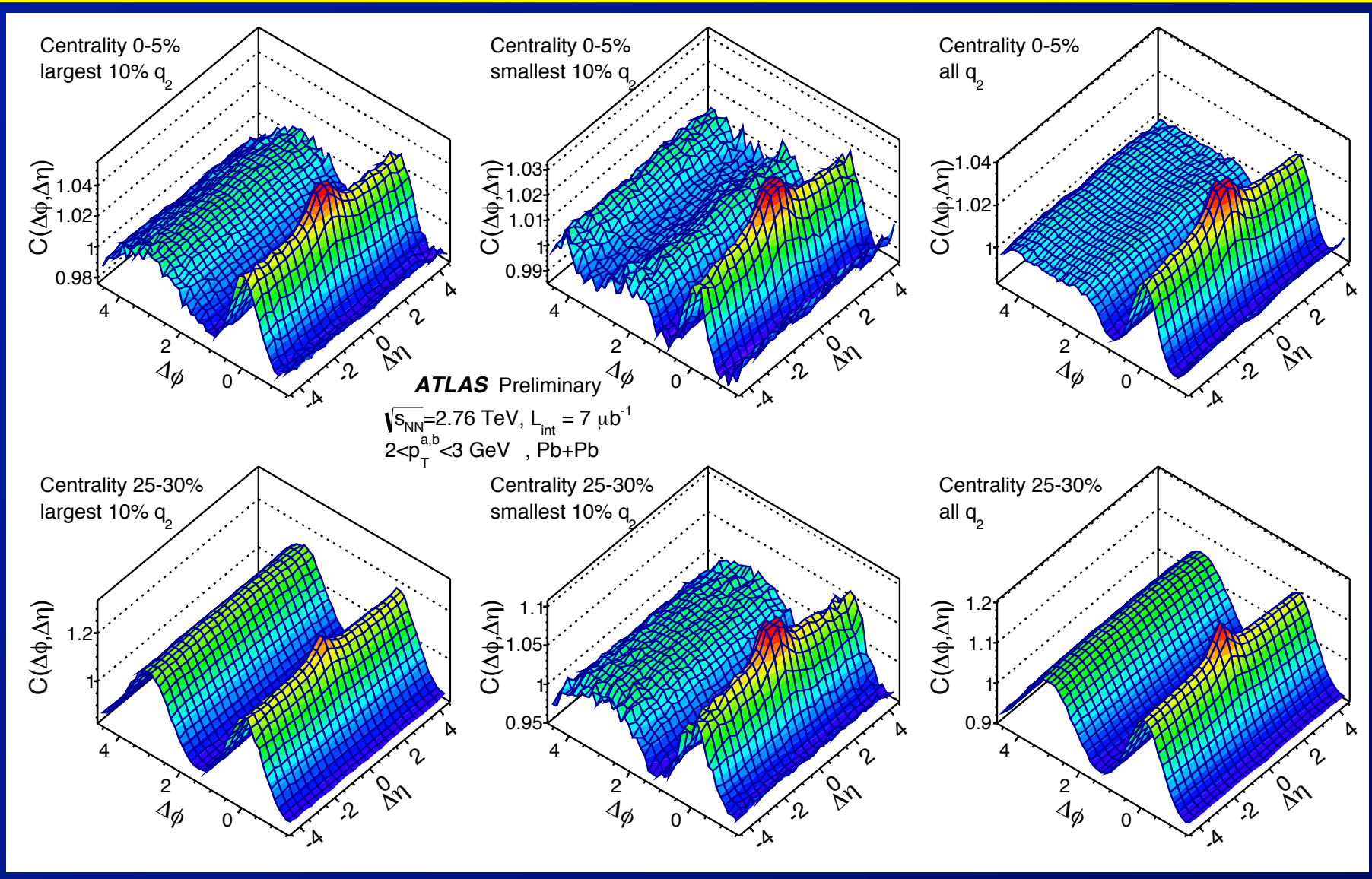




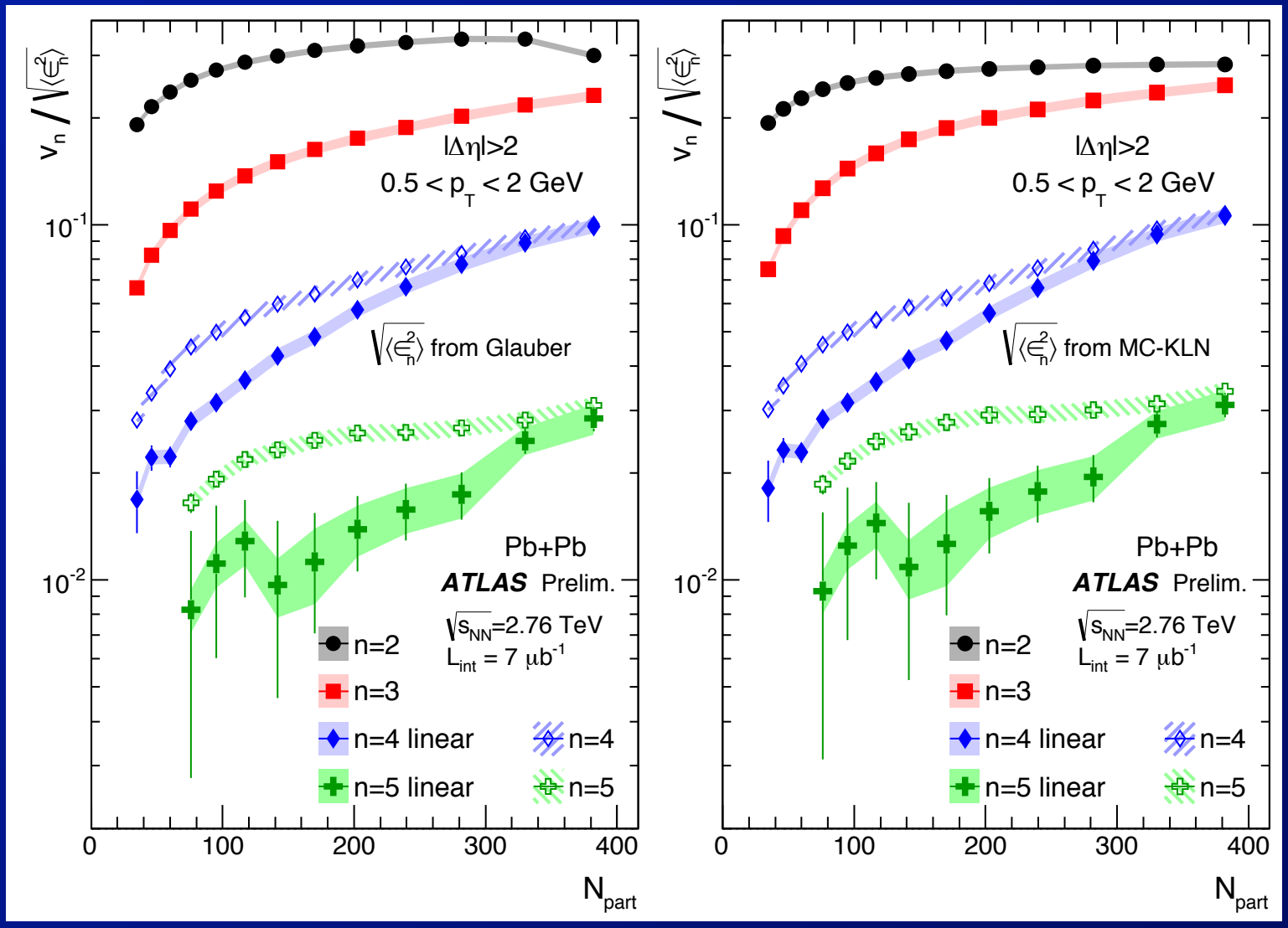
- v_n vs q_2 for v_3, v_4, v_5 in different centrality bins



Pb+Pb q_2-selected 2-particle correlations

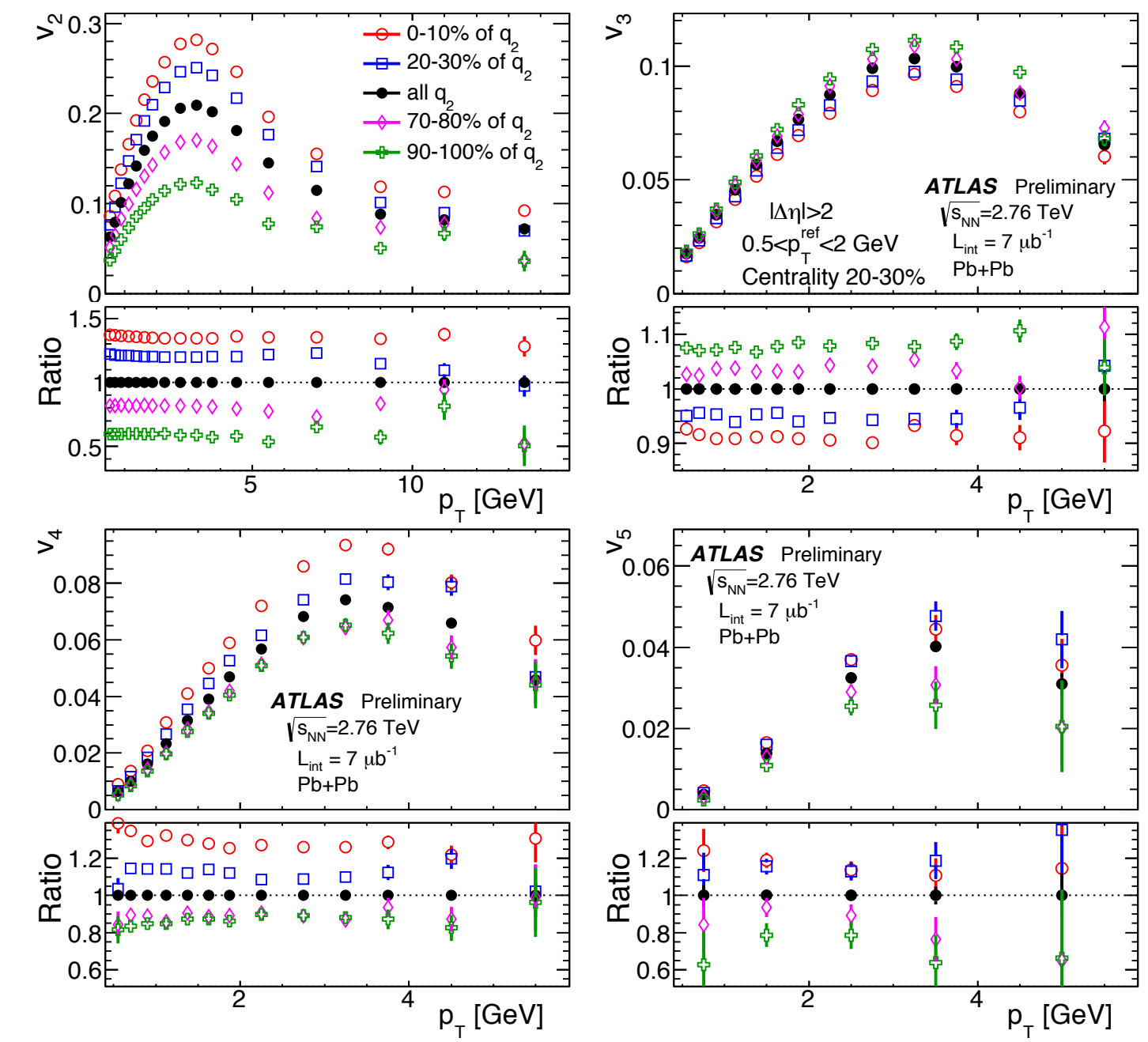


Pb+Pb vn scaling, decomposition

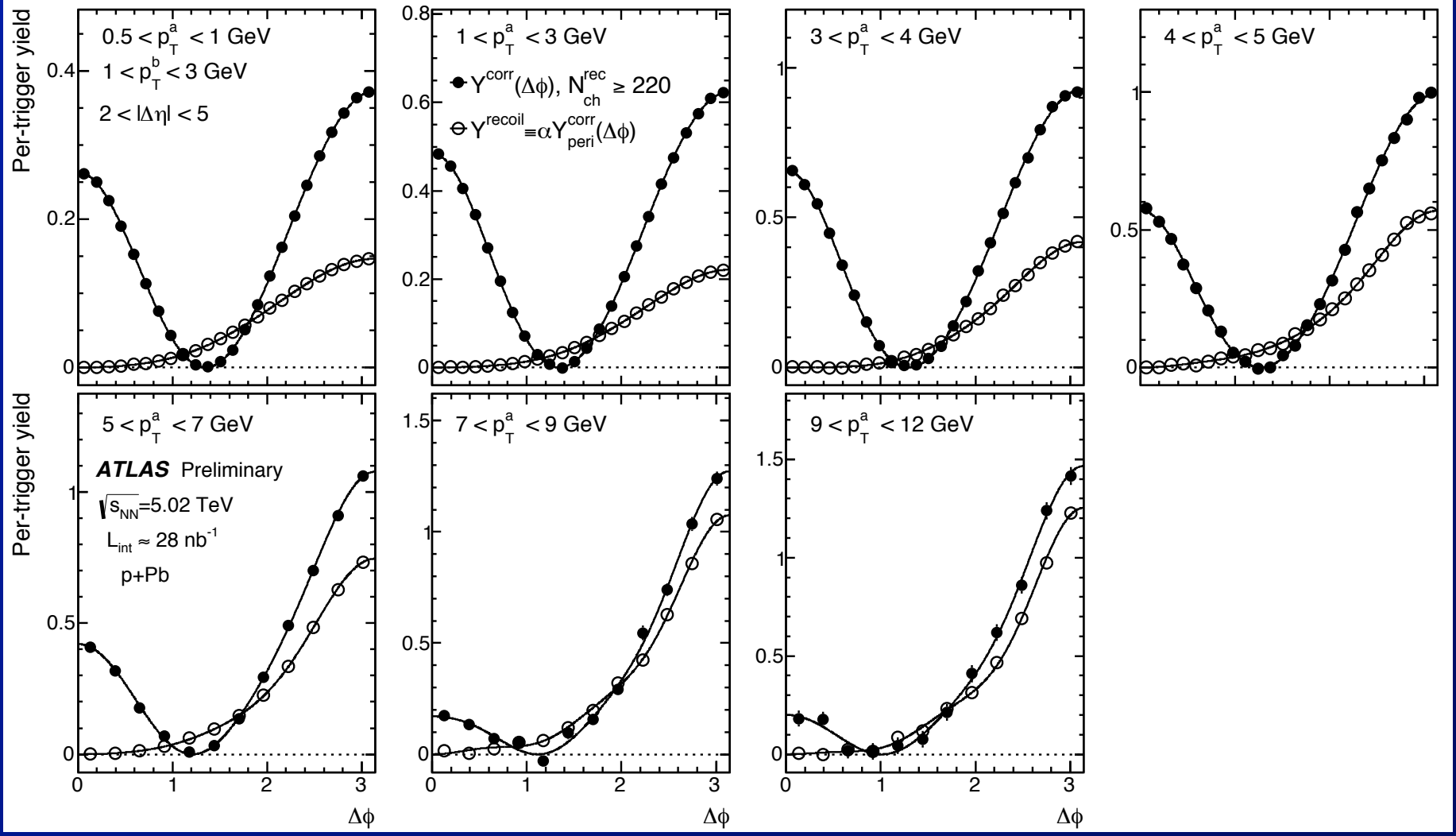


- Evaluation of v_n scaling, with and without the non-linear flow contribution

Pb+Pb q_2-selected $v_n(pT)$



p+Pb 2-particle Δφ vs p_T



- Clearly see the symmetric ridges even for p_T > 9 GeV!

Peripheral subtraction

- Scale up the peripheral conditional yield to match more central bin in the jet peak