Stony Brook University

Recent results on the pA 'ridge' @LHC

Sooraj Radhakrishnan

p(d)+A workshop, RHIC-AGS Users Meeting

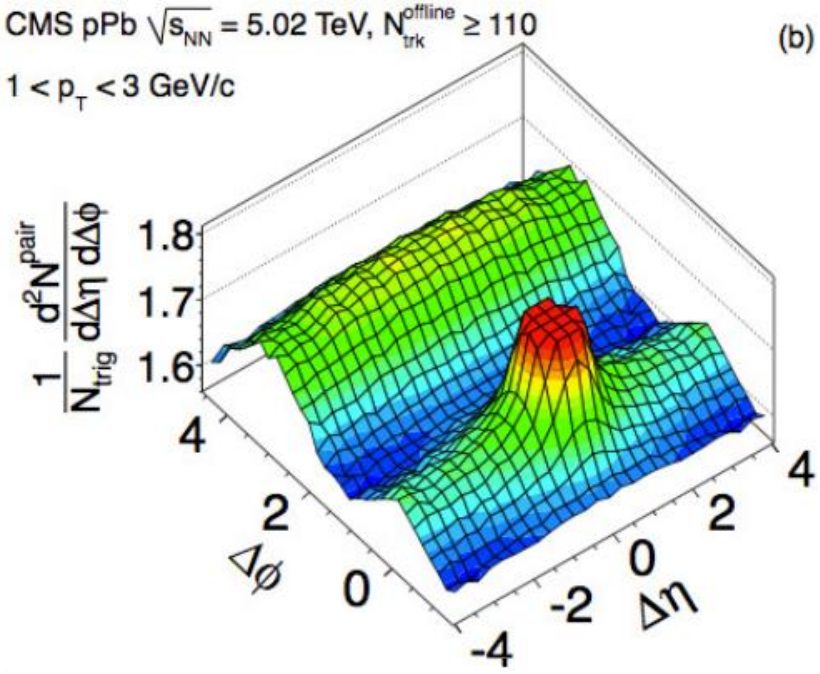
Brookhaven

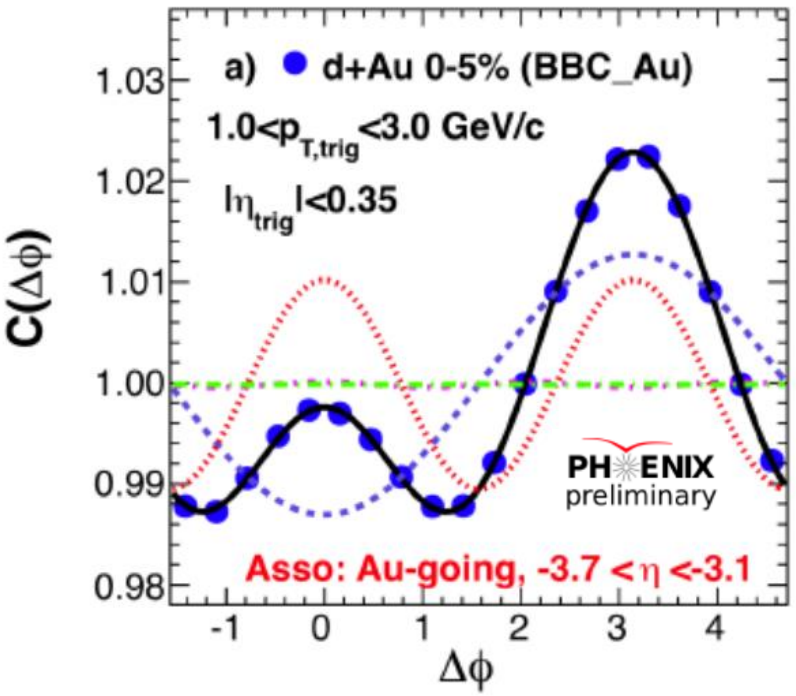
dA and Planning for pA, HE3-A

RHIC & AGS Annual Users' Meeting

Hosted By Brookhaven National Laboratory

Introduction: Ridge in p + Pb collisions



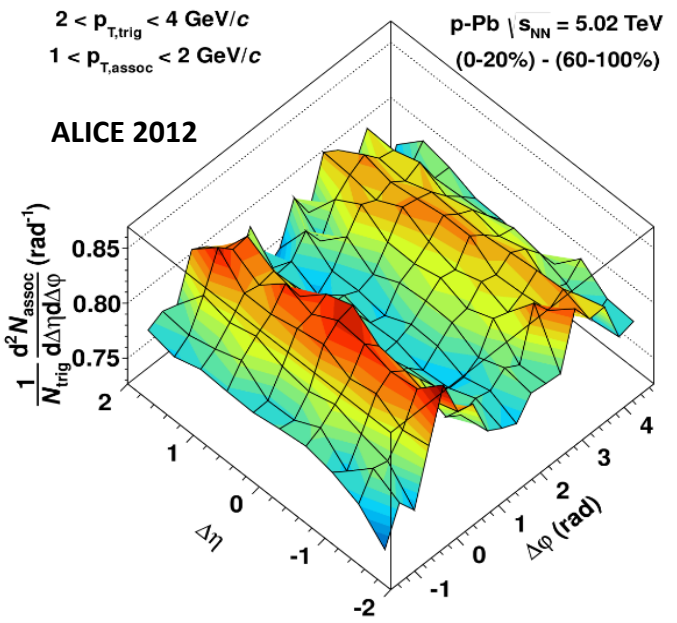


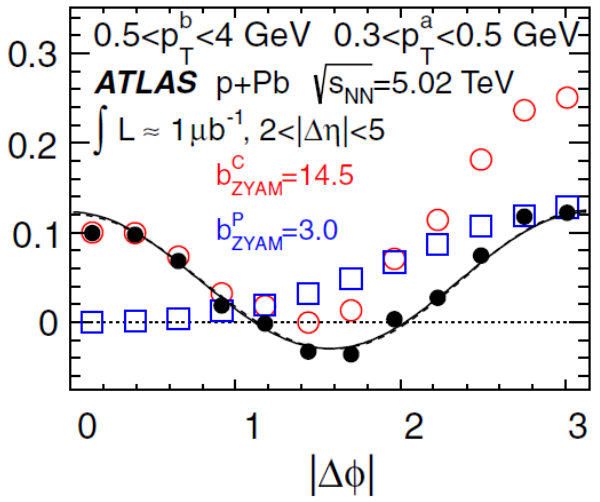
CMS: Phys.Lett.B7198(2013)

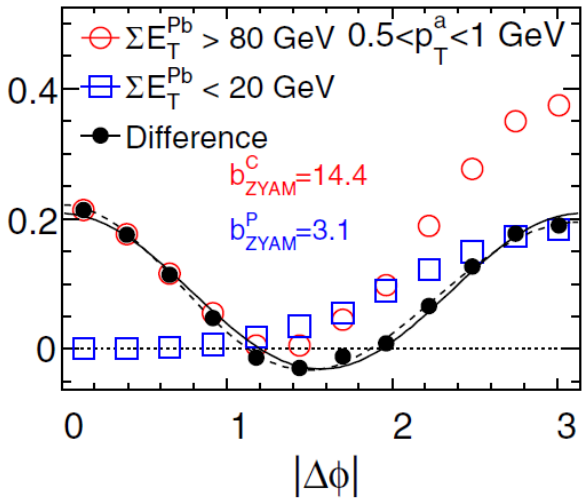
- Long range correlation ("ridge") seen in two particle angular correlations in high multiplicity p+Pb at LHC
- Similar observation in d+Au at RHIC
- Origin and nature of these correlations?
  - Collective behavior? Flow? Driven by initial state correlations?

Introduction: Ridge in p + Pb collisions

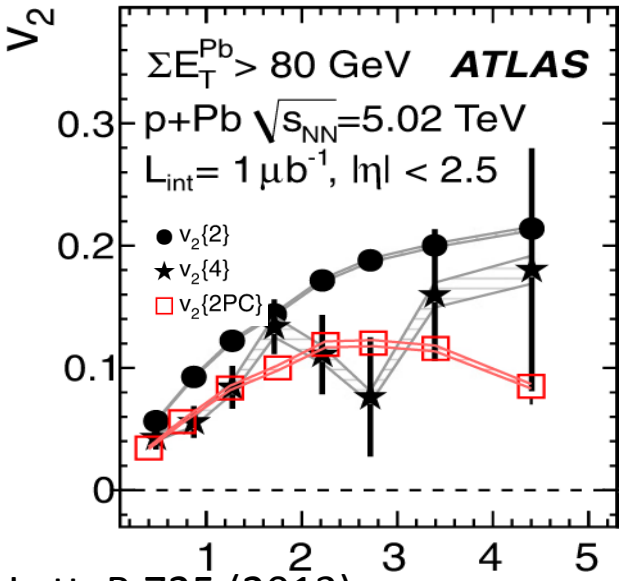
"**Double ridge**" *ALICE*: Phys. Lett. B 719 29 (2013), *ATLAS* : Phys. Rev.Lett. 110 (2013)





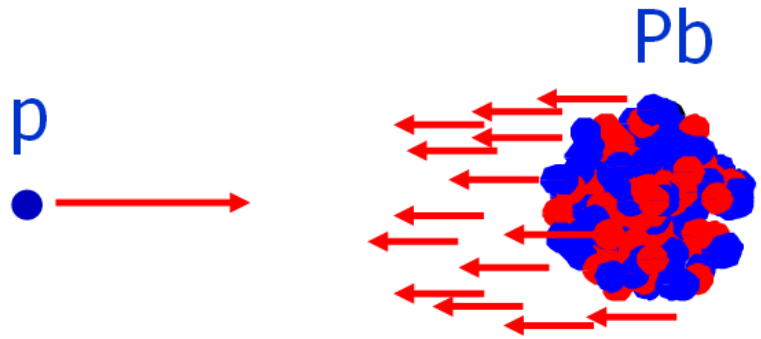


- Peripheral subtraction revealed 'double ridge'
- Extracted v_n shows similar p_T dependence as in Pb+Pb
- Non zero $v_2\{4\}$ was measured.



ATLAS: Phys. Lett. B 725 (2013)

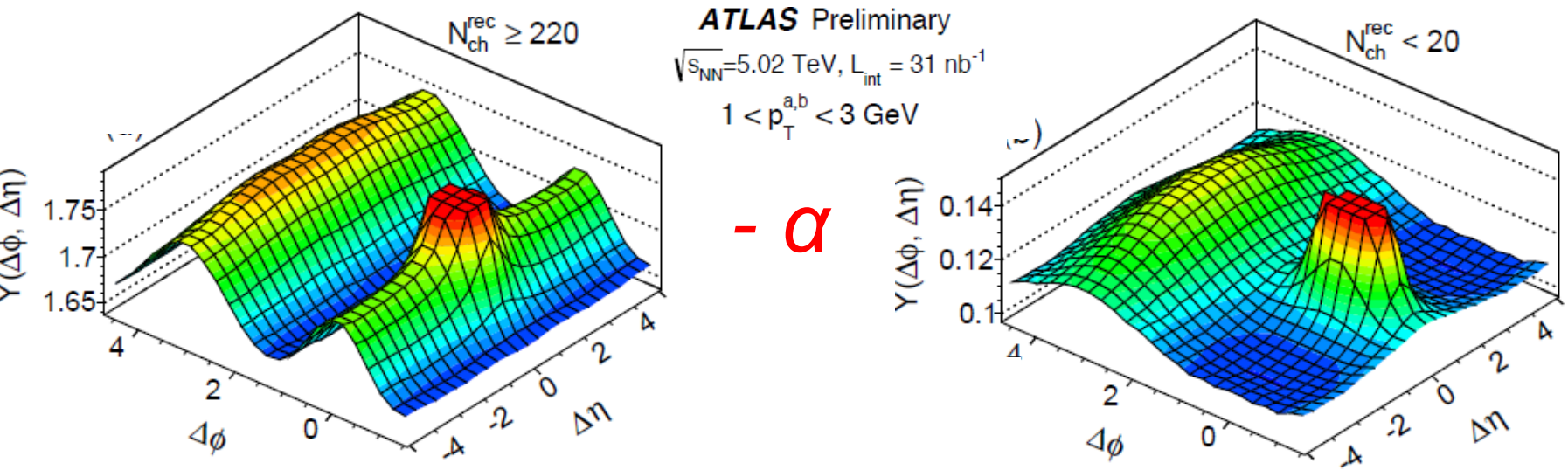
Introduction: Ridge in p + Pb collisions



$\sqrt{s_{NN}} = 5.02$ TeV, Integrated Luminosity ~30 nb^{-1}

- Wealth of new results from the 2013 p+Pb run at LHC
  - Higher p_T
  - higher order cumulants
  - particle species dependence
  - comparisons to peripheral Pb+Pb
  - ……

Recoil subtraction



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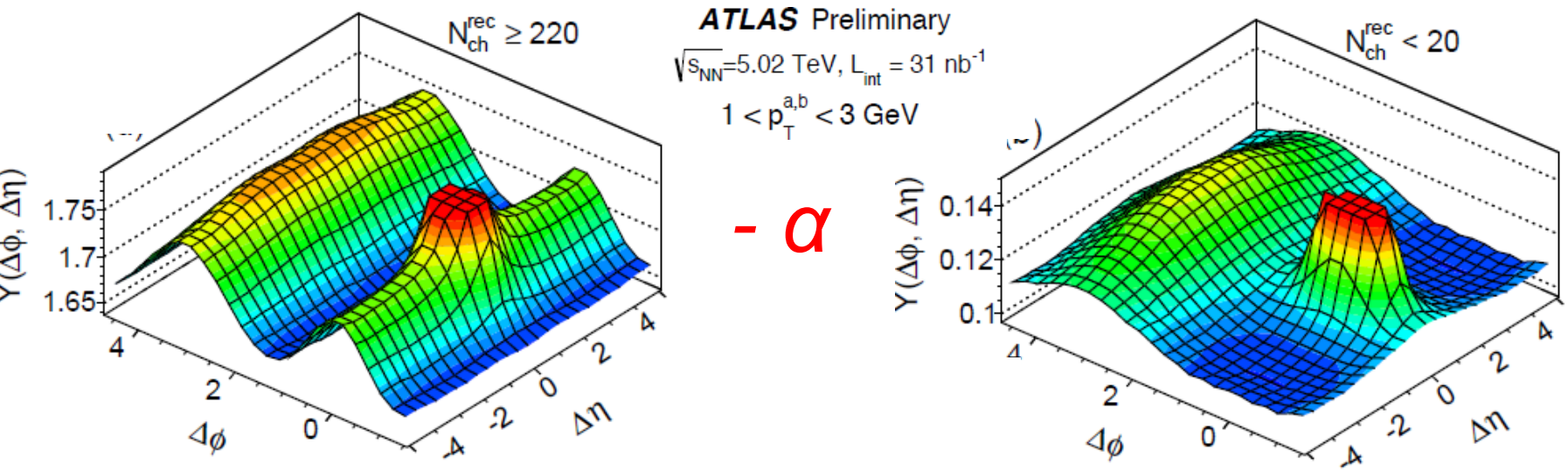
- α to match the near side jet yield between peripheral and central classes.

Recoil subtraction



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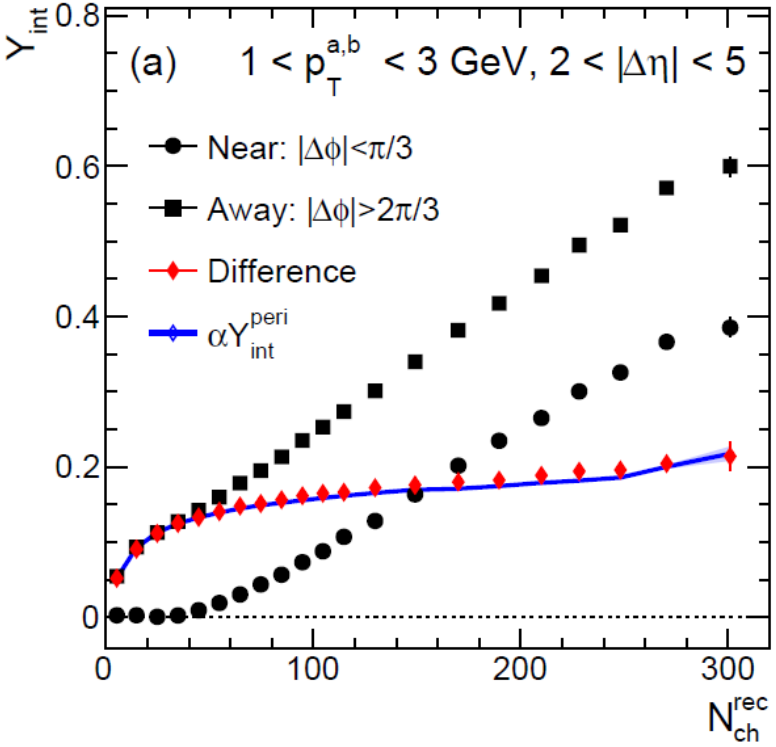
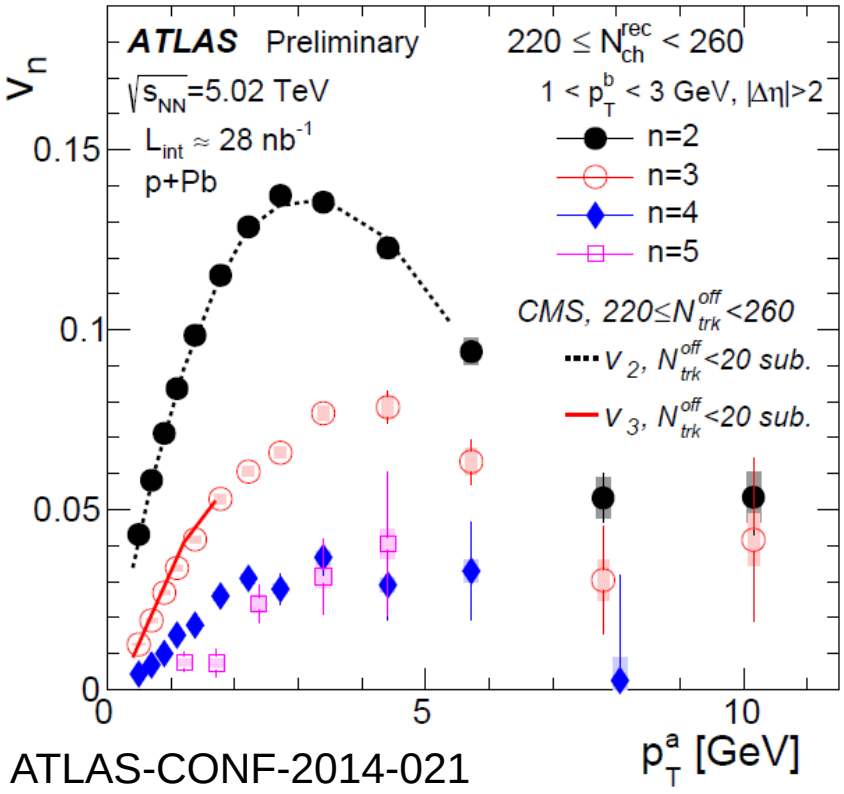


- Motivated by weak dependence of yield difference with multiplicity.
- Estimated recoil yield closely matches the yield difference.
  - holds if either trigger or associated particle in 1-3 GeV
  - Deviations attributed to long-range v_1

v_n to higher p_T



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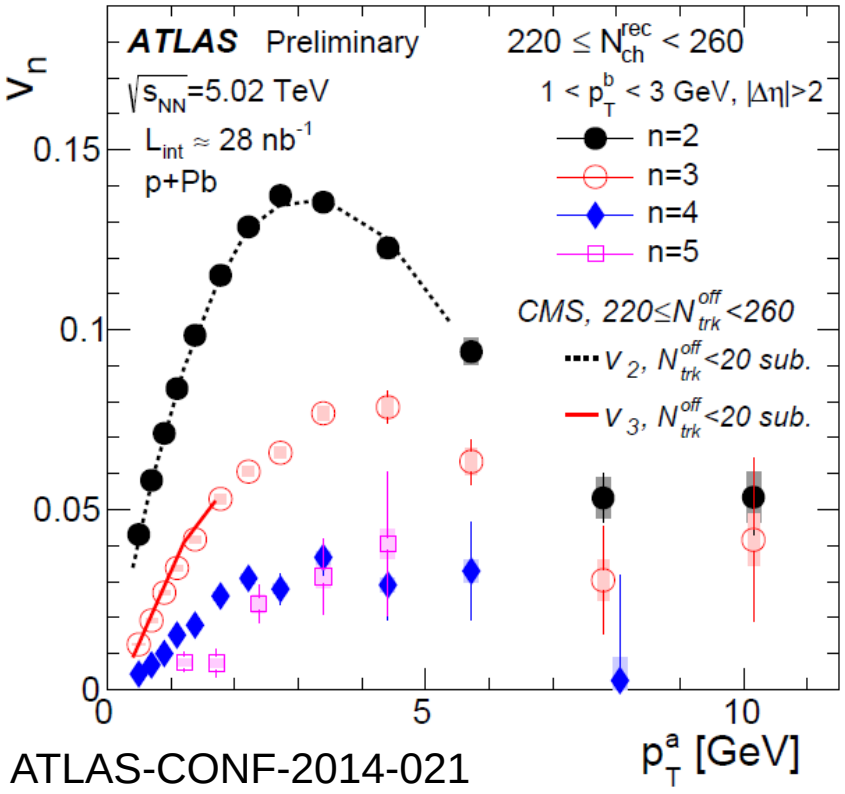
- Rise with p_T at low p_T and then decraese → similar to Pb+Pb
- Non-zero, positive v_n at high p_T
- Magnitude decrease with increasing n
  - Could be expected in flow picture, higher harmonics are damped more
  - Non-zero v_5 in high multiplicity event classes.

v_n to higher p_T



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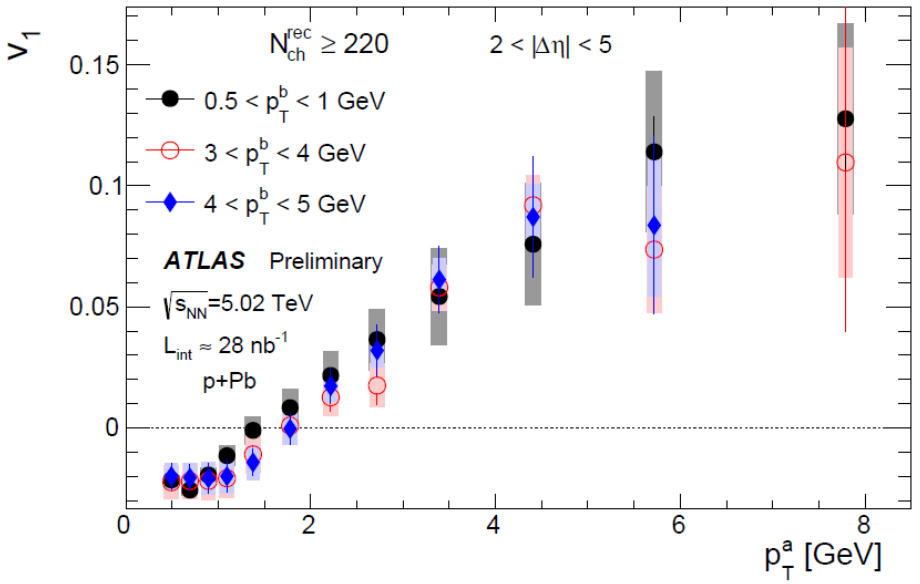

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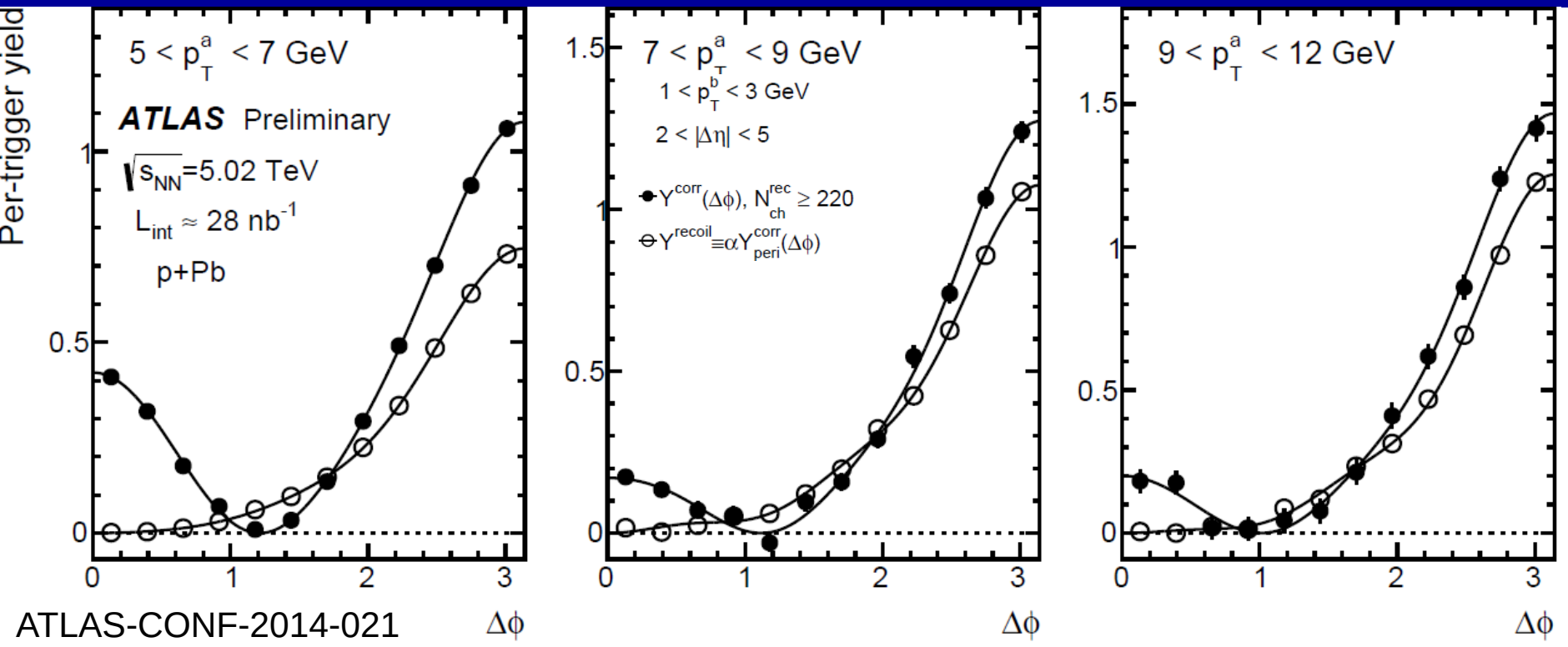
- Non-zero, positive v_n at high p_T
- Magnitude decrease with increasing n
  - Could be expected in flow picture, higher harmonics are damped more
  - Non-zero v_5 in high multiplicity event classes.
- Large v_1 ($\sim v_3$) also observed, which is –ve at low p_T

Ridge at higher p_T



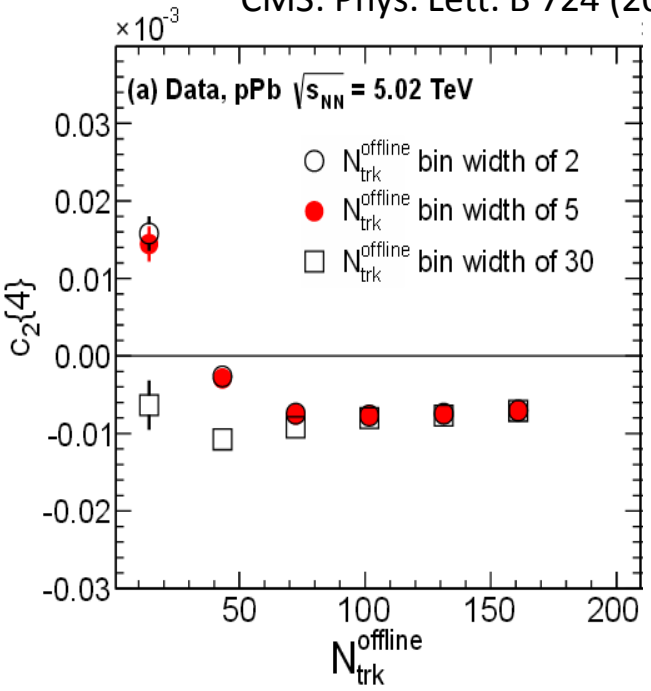
$$Y^{corr}(\Delta\phi) = \frac{\int B(\Delta\phi)d\Delta\phi}{\pi}\left(\frac{S(\Delta\phi)}{B(\Delta\phi)} - b_{ZYAm}\right)$$

- Near-side ridge visible through the entire p_T range studied.
- Yield on away-side also larger than recoil component.
- What is the origin of ridge at $p_T \sim 10\ GeV$? In medium energy loss?
  - How does this affect our understanding of AA ridge at similar p_T?

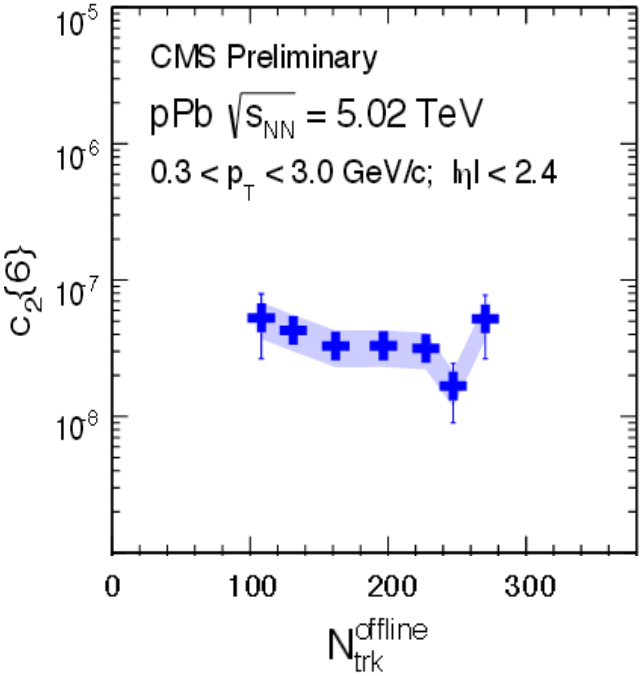
Multiparticle correlations – Collective behavior?

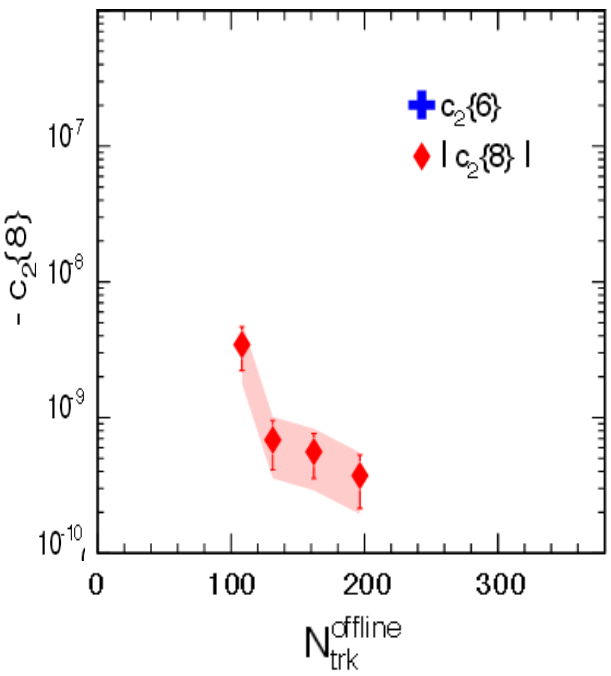
- Are the ridge correlations from a global anisotropy?
- Multiparticle cumulants : n^{th} order cumulant insensitive to 'non-flow' correlations of less than n particles

CMS: Phys. Lett. B 724 (2013)



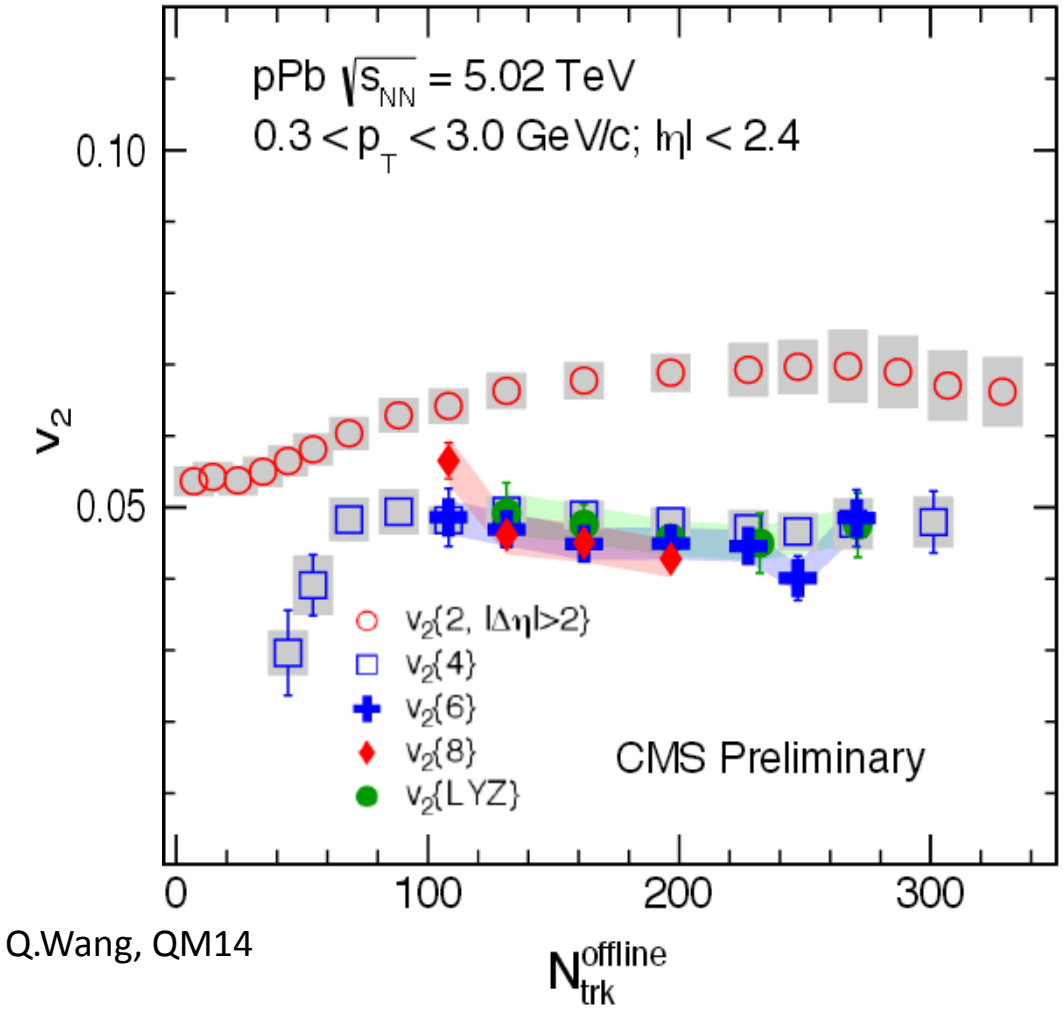
Q.Wang , QM14





$$v_n\{4\} = \sqrt[4]{-c_n\{4\}};\quad v_n\{6\} = \sqrt[6]{\frac{1}{4}c_n\{6\}};\quad v_n\{8\} = \sqrt[8]{-\frac{1}{33}c_n\{8\}}$$

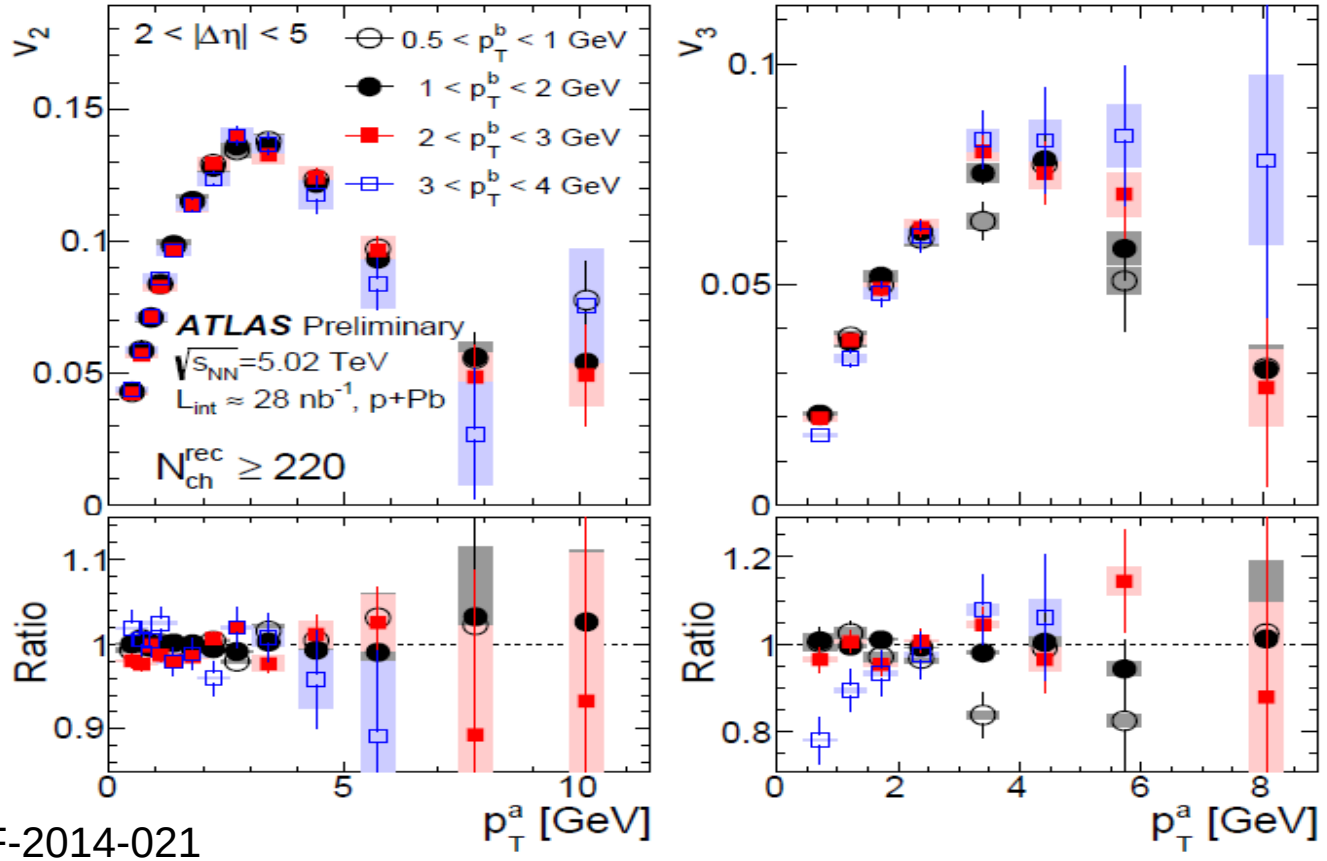
Multiparticle correlations – Collective behavior?



Q.Wang, QM14

- $v_2\{4\}, v_2\{6\}, v_2\{8\}$ and also v_2 from LYZ agree within 10%
- Higher order cumulants indeed reflect a global correlation.
  - Collective response leads to global anisotropy, not expected a priori from initial state correlations

v_n factorization



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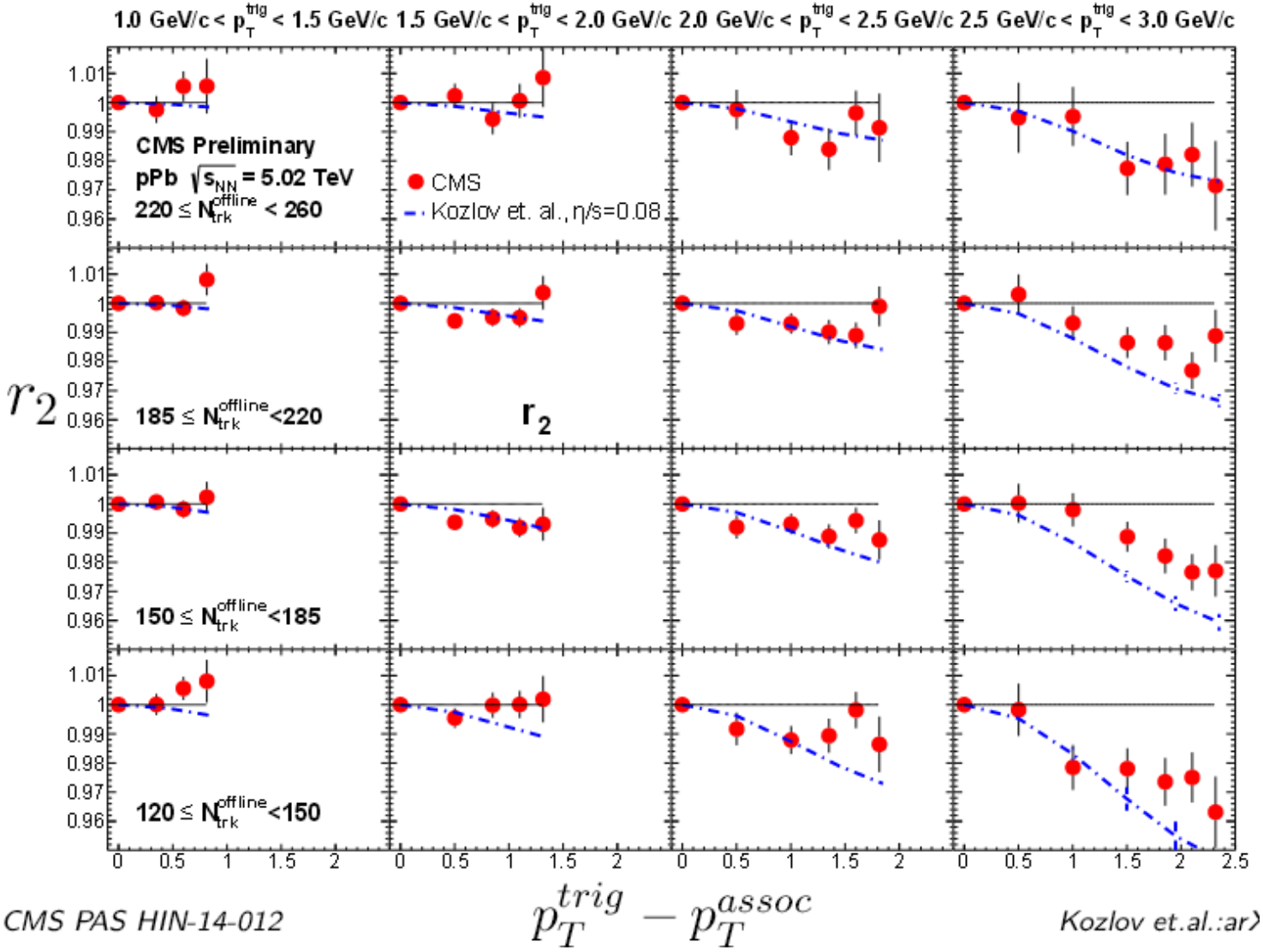
Check factorization assumption: $v_n(p_T{}^a) = \dfrac{v_{n,n}(p_T{}^a, p_T{}^b)}{\sqrt{v_{n,n}(p_T{}^b, p_T{}^b)}}$

- Good factorization seen for v_2 and v_3, particularly at low p_T
  - Factorization holds within 4% for $v_2 < 4$ GeV and for $v_3 < 3$ GeV.
- Also suggests a global anisotropy.

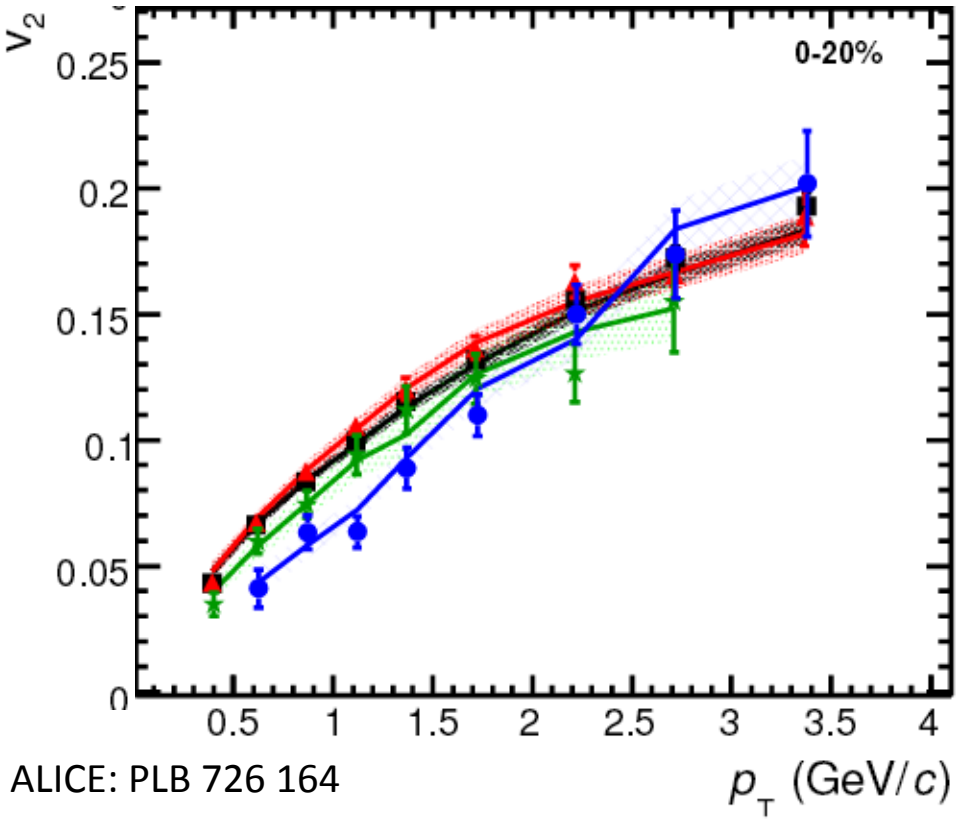
v_n factorization

$$r_n = \frac{V_{n\Delta}(p_{T_1}, p_{T_2})}{\sqrt{V_{n\Delta}(p_{T_1}, p_{T_1}) V_{n\Delta}(p_{T_2}, p_{T_2})}}$$



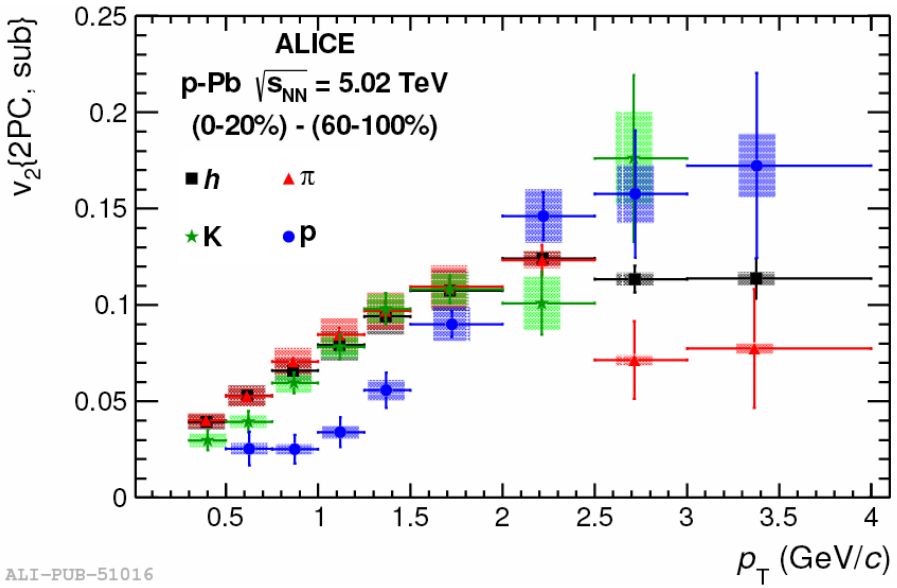
- Factorization holds within 3-4%
- Extend of factorization breaking comparable to that from hydro calculation.

Particle species dependence



ALICE: PLB 726 164

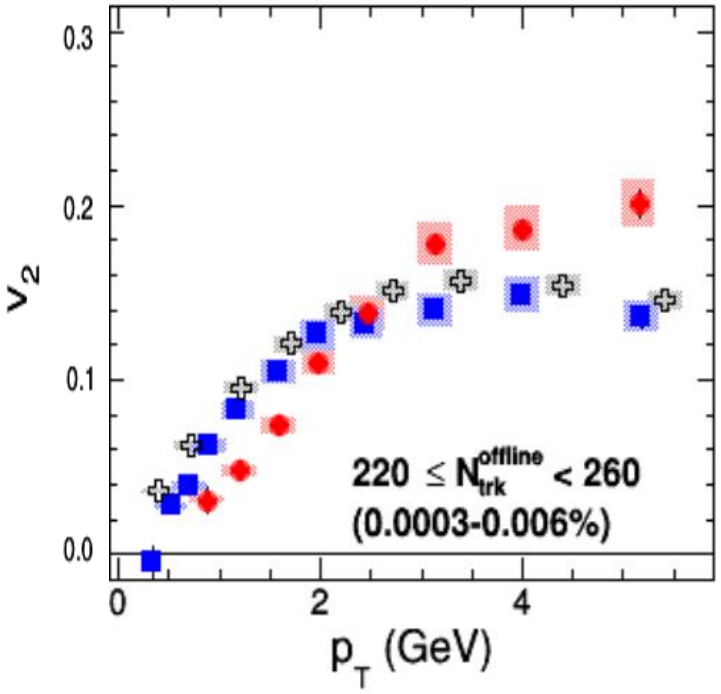
No recoil subtraction

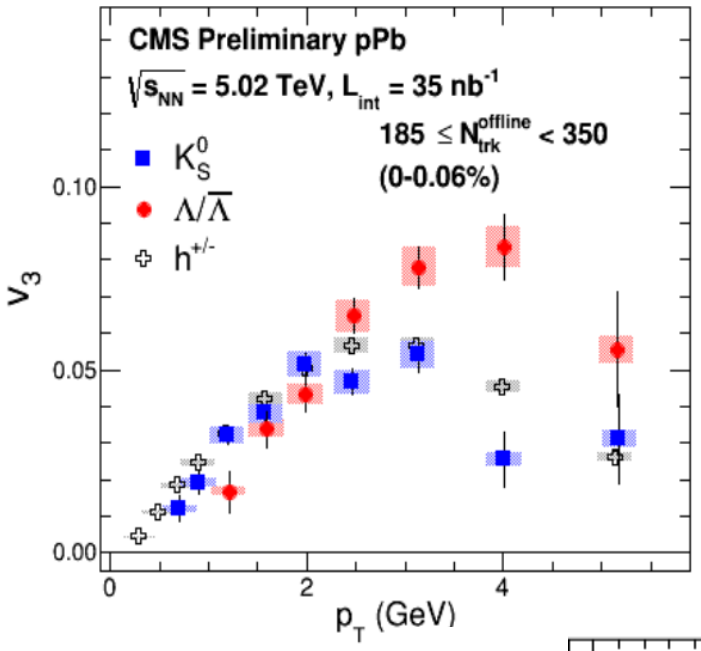


After recoil subtraction

- Mass ordering seen at low p_T
  - heavier particles have lower v_2 at the same p_T
- Can be explained in hydro models

Particle species dependence and NCQ scaling

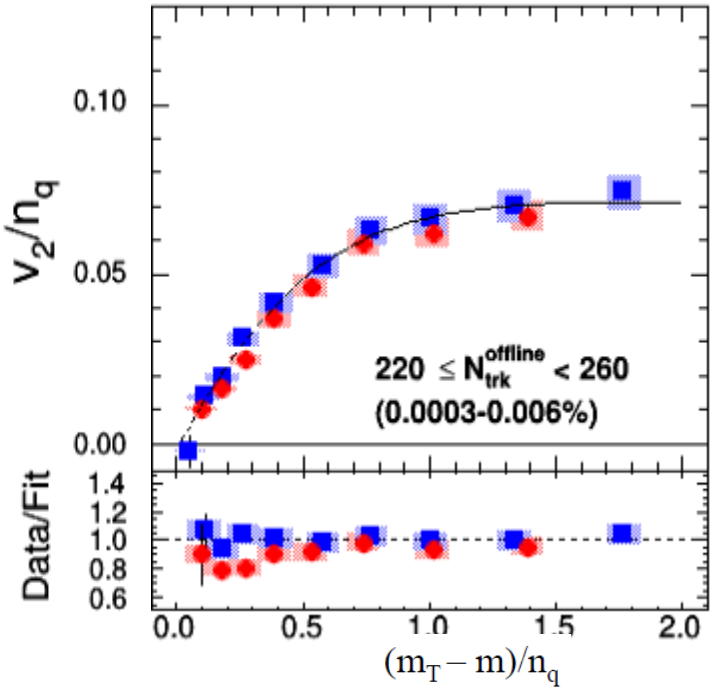




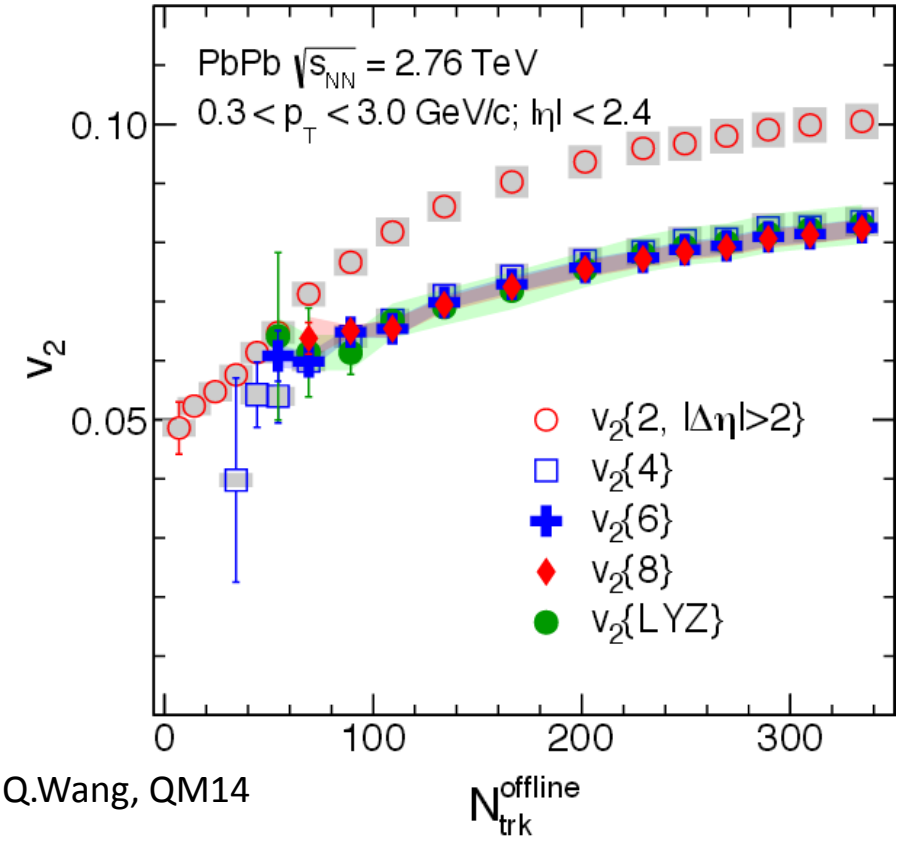
No recoil subtraction

CMS-PAS-HIN-14-002

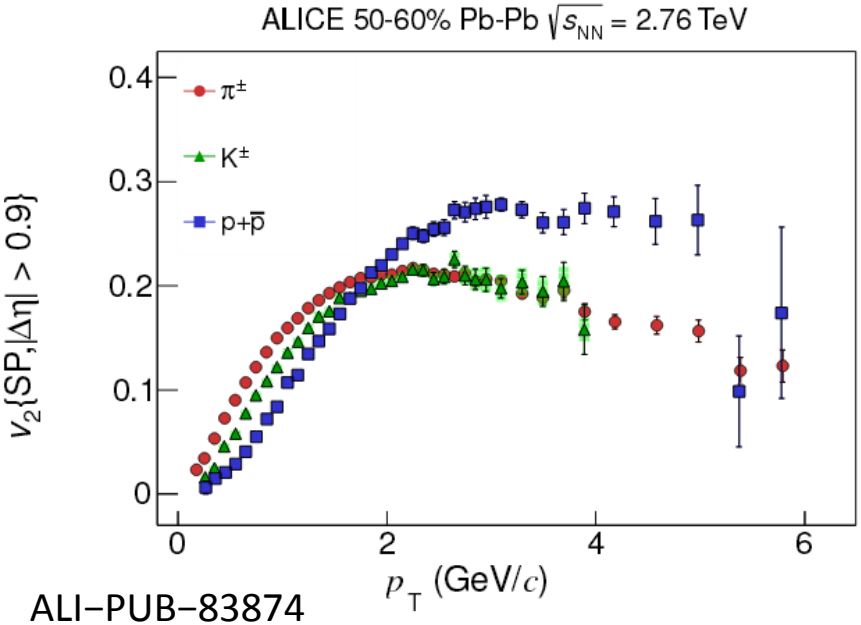
- Mass ordering seen at low p_T and baryon – meson splitting seen at higher p_T for both v_2 and v_3.
- Approximate ncq scaling (breaks at low KE_T)
  - Azimuthal anisotropy developing at partonic stage?



Comparison to peripheral Pb+Pb



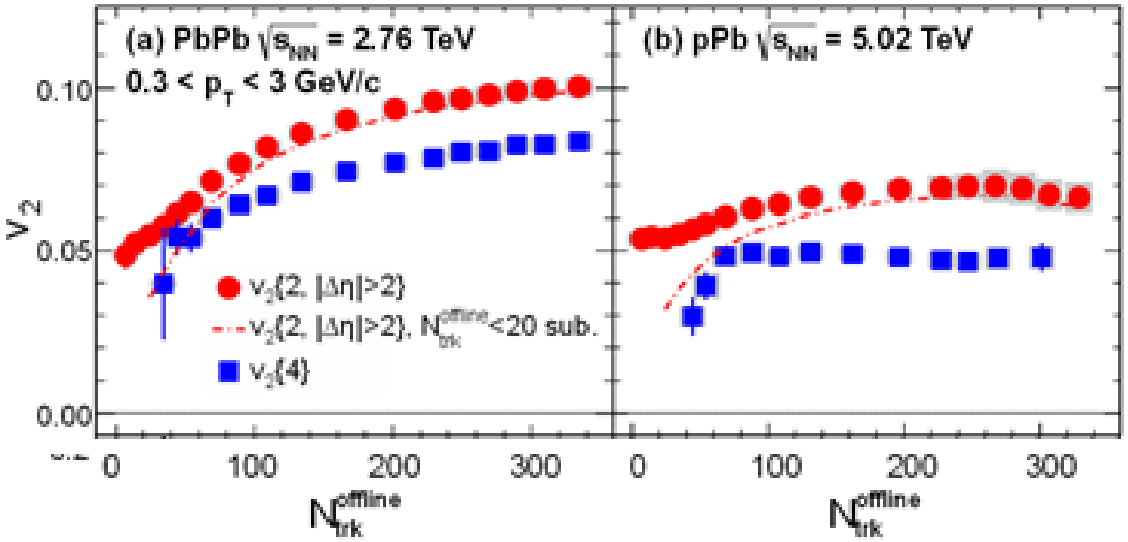
Q.Wang, QM14



ALI–PUB–83874

- v_n from higher order cumulants in peripheral Pb+Pb also reflect a global anisotropy, also the mass ordering and baryon – meson splitting
- How does the v_n from the two systems compare with each other?

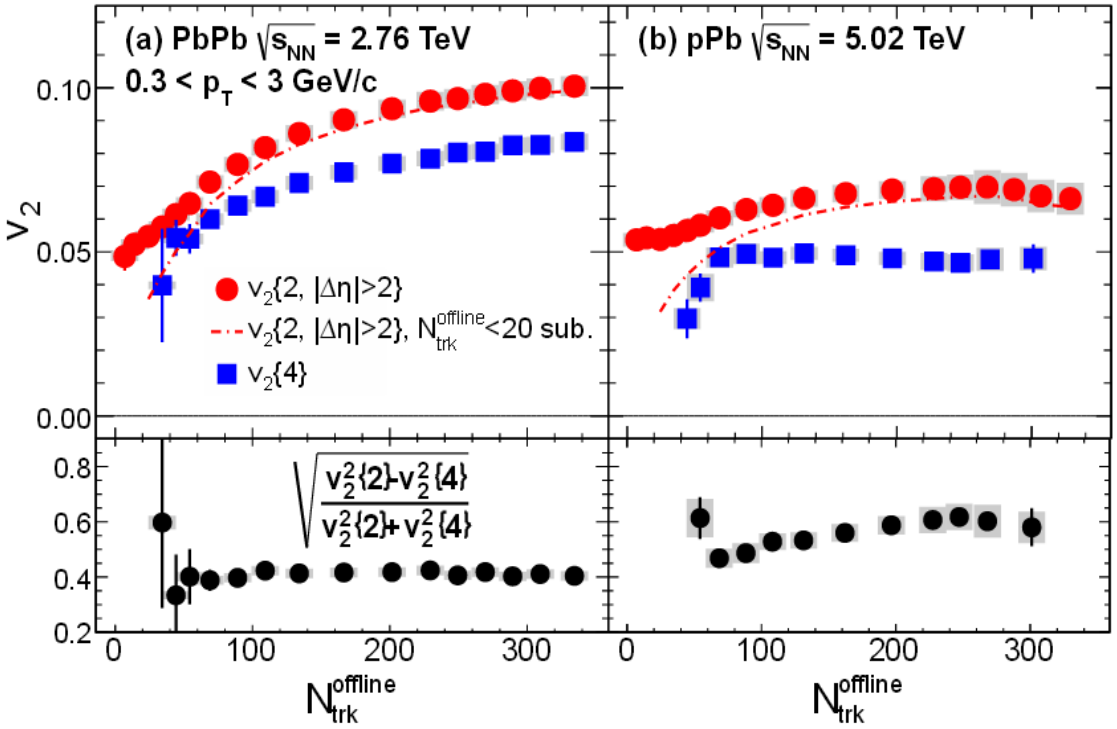
Comparison with peripheral PbPb: fluctuations



CMS: Phys. Lett. B 724 (2013)

- Larger v_2 in Pb+Pb than in p+Pb
  - Pb+Pb gets an elliptic geometry contribution from the overlap.

Comparison with peripheral PbPb: fluctuations



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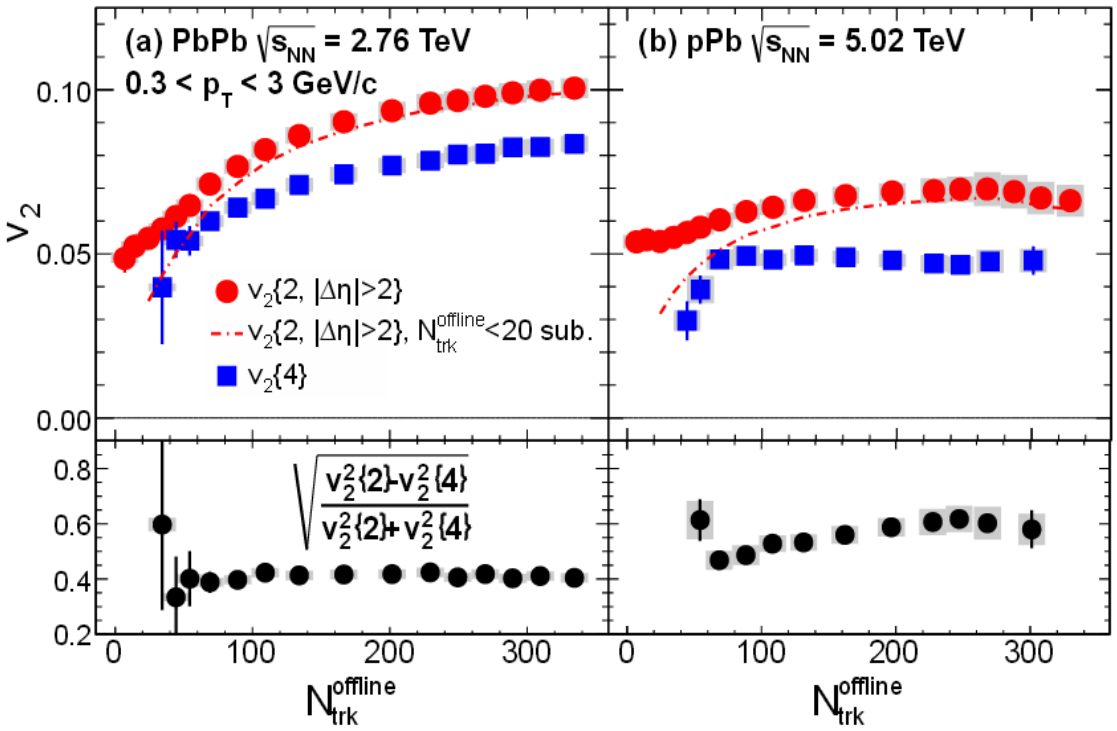
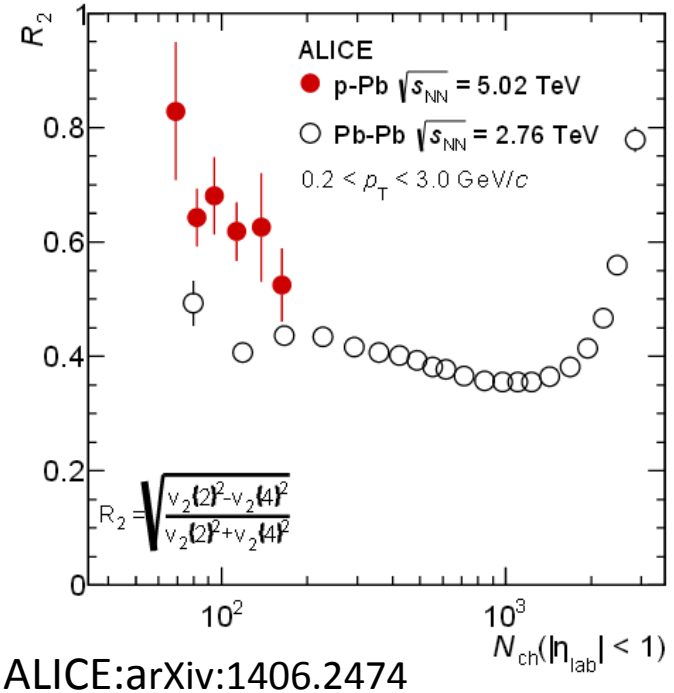
- Larger v_2 in Pb+Pb than in p+Pb
  - Pb+Pb gets an elliptic geometry contribution from the overlap.
- Fluctuations in initial geometry seem to be larger in p+Pb than in Pb+Pb (why?)

Comparison with peripheral PbPb: fluctuations



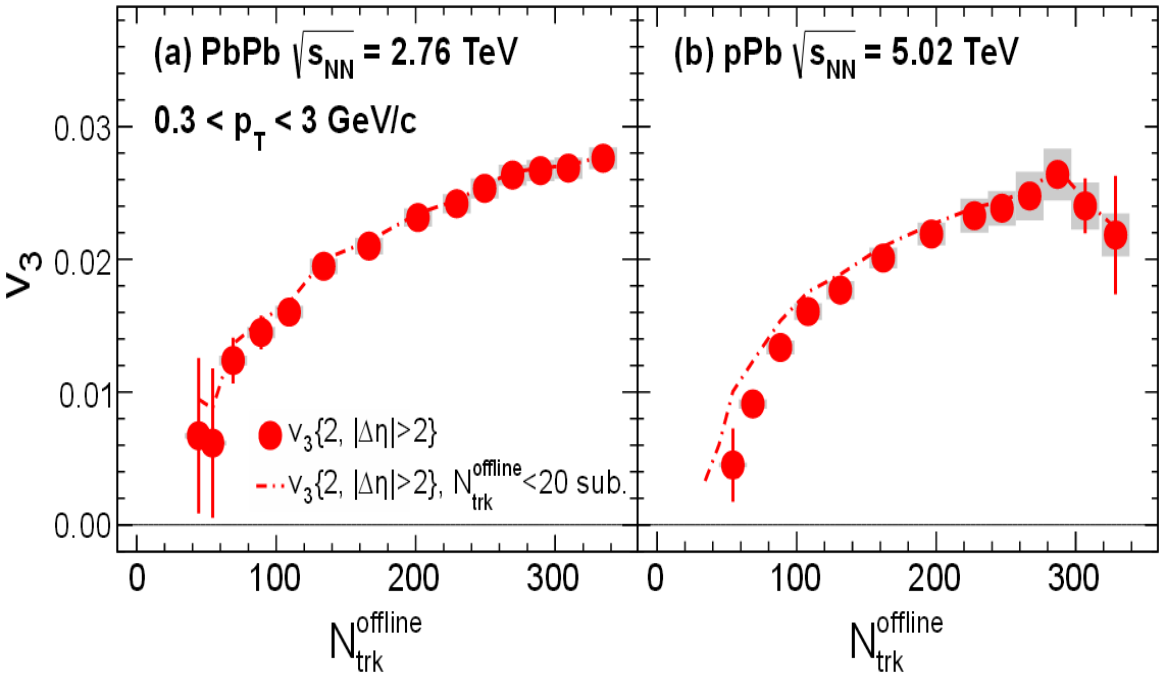


ALICE:arXiv:1406.2474

CMS: Phys. Lett. B 724 (2013)

- Larger v_2 in Pb+Pb than in p+Pb
  - Pb+Pb gets an elliptic geometry contribution from the overlap.
- Fluctuations in initial geometry seem to be larger in p+Pb than in Pb+Pb (why?)

Comparison with peripheral PbPb: third harmonic



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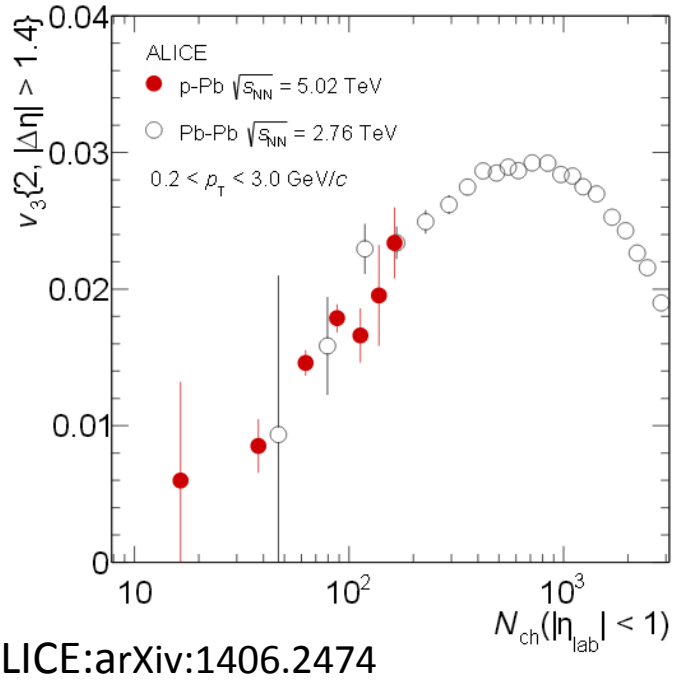
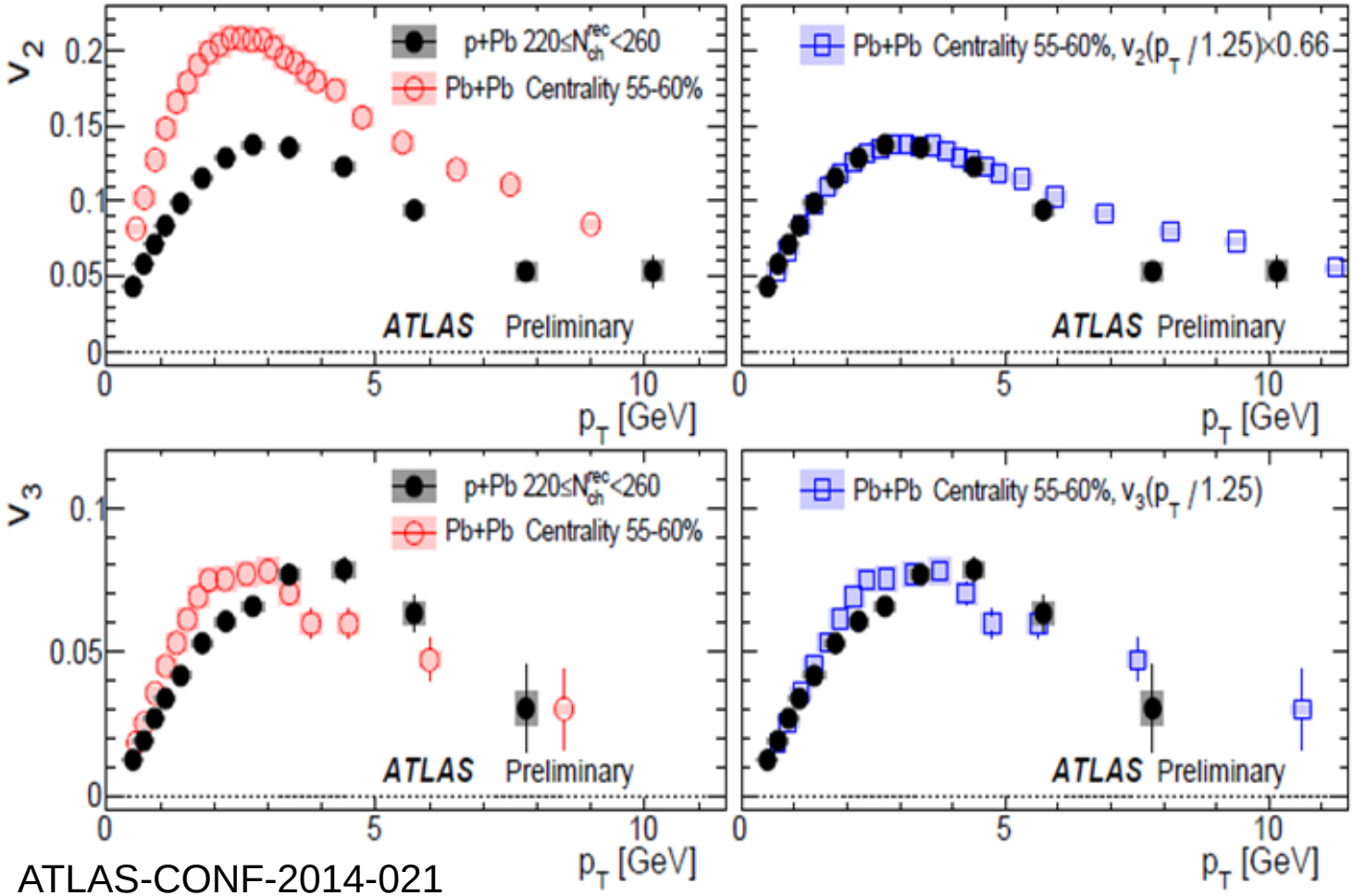


ALICE:arXiv:1406.2474

- Comparable magnitudes for v_3 between the two systems at similar multiplicity.
  - ε_3 is fluctuation driven in both systems.
  - Similar medium response?

v_n scaling between the p+Pb and Pb+Pb systems.



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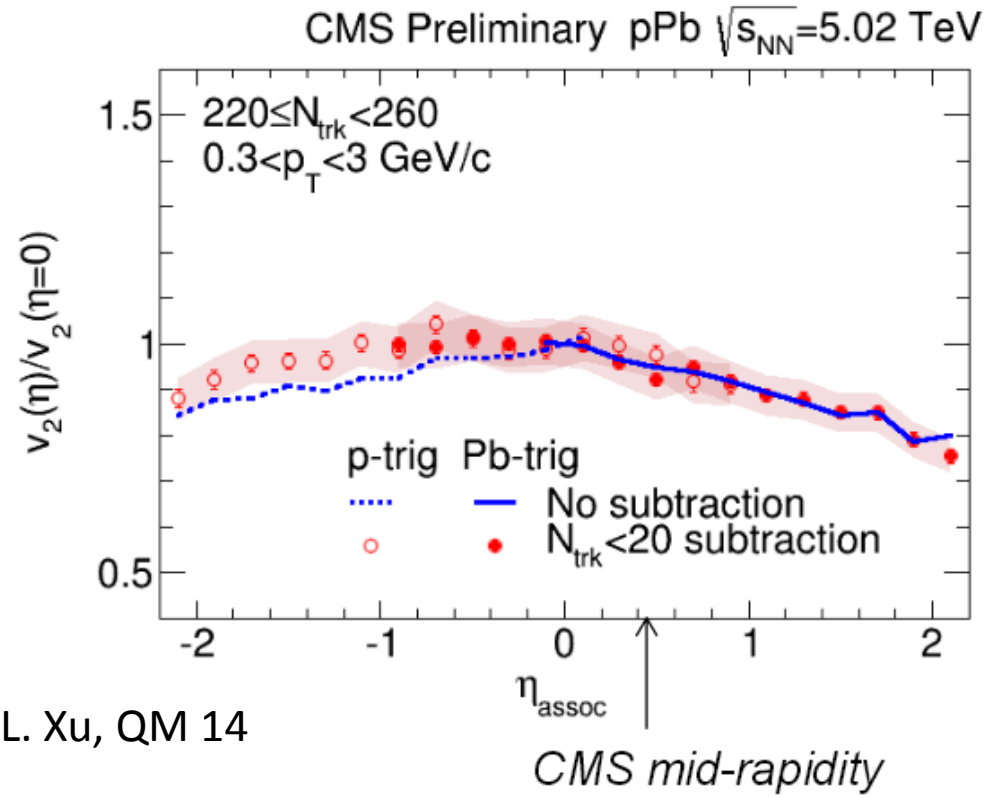
- Pb+Pb values from EP method (>3 units of η gap between tracks and EP)
- Jet contribution is much smaller in Pb+Pb than in p+Pb

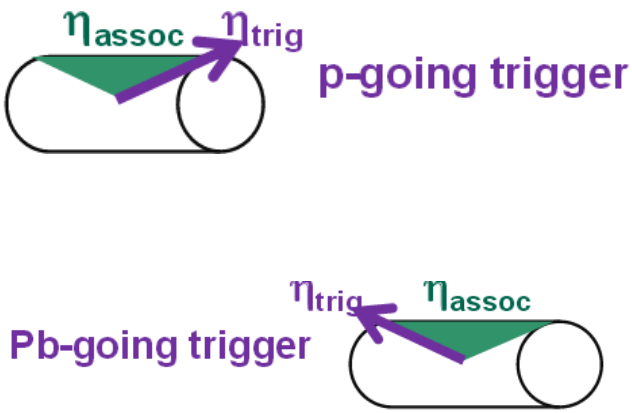
- $v_n(p_T$, p+Pb) may be better compared with $v_n(p_T$, Pb+Pb) (Teaney et.al arXiv:1312.6770)
- After scaling the p_T axis v_n have similar shapes in both systems.
- Support for conformal scaling? And v_n arising from similar collective mechanism in both systems?

Pseudorapidity dependence.

$v_2(\eta)/\ v_2(0)$:

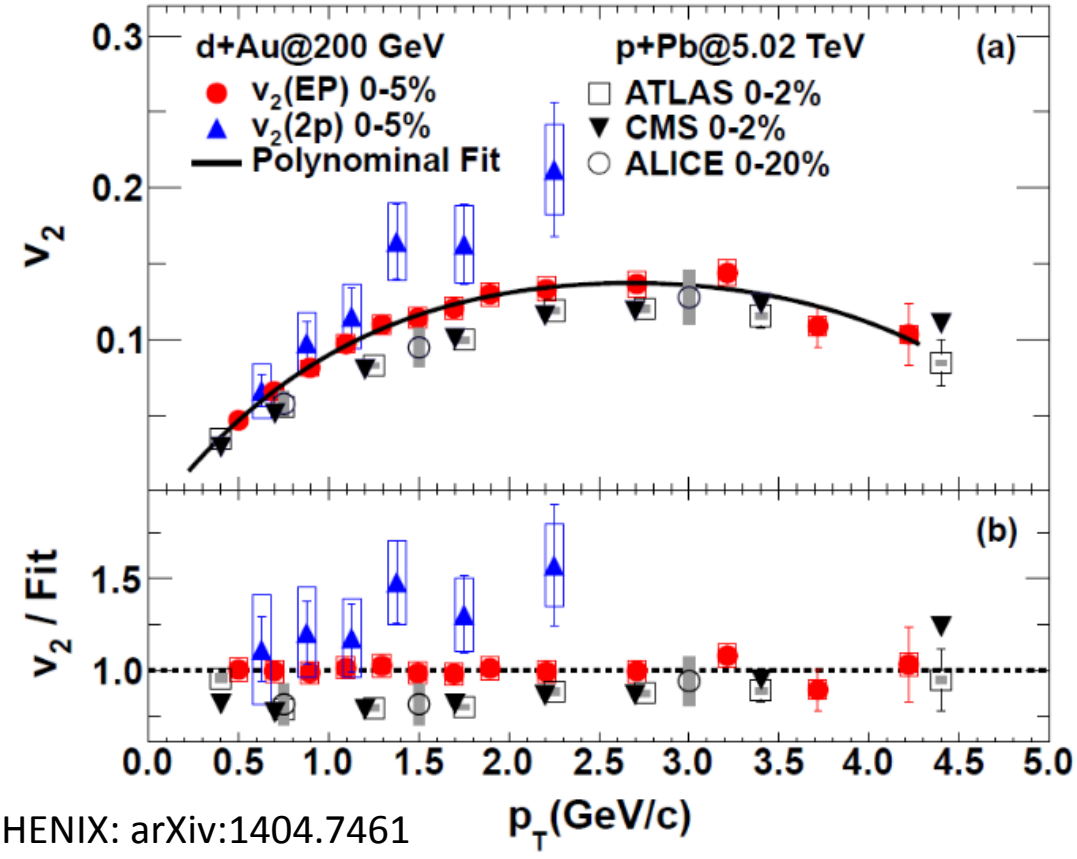


L. Xu, QM 14

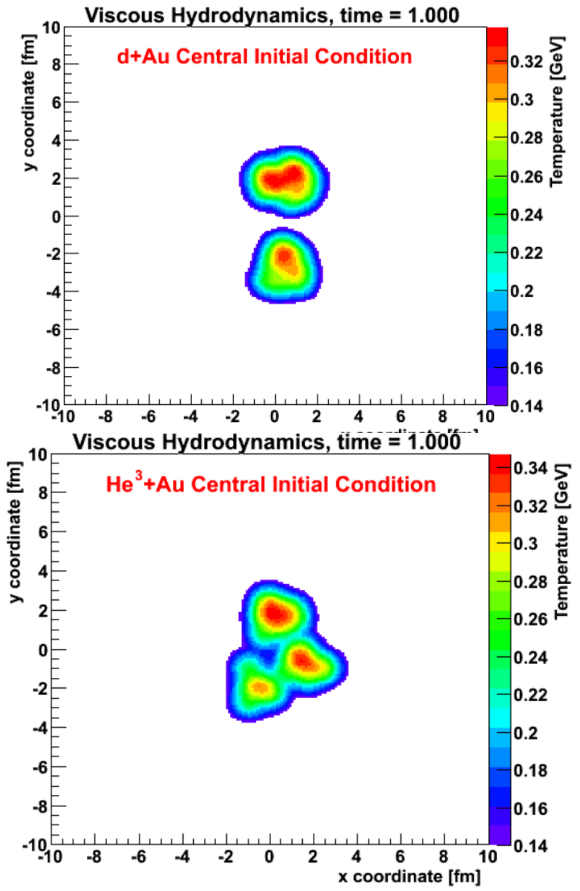


- Small asymmetry between Pb-going and p-going sides
  - Result of multiplicity difference? Difference in initial conditions?
- Does the ridge of p-going side qualitatively differ from that on the Pb-going side in any aspects?

pA and dA ridge



PHENIX: arXiv:1404.7461



P. Romatschke et al: 1312.4565

- v_2 in d+Au at RHIC slightly larger than v_2 in p+Pb at LHC
  - Caution: Is EP method without biases? We don't fully understand the η dependence.
- Would be interesting to see if the geometric picture holds in He^3 + Au collisions

Summary

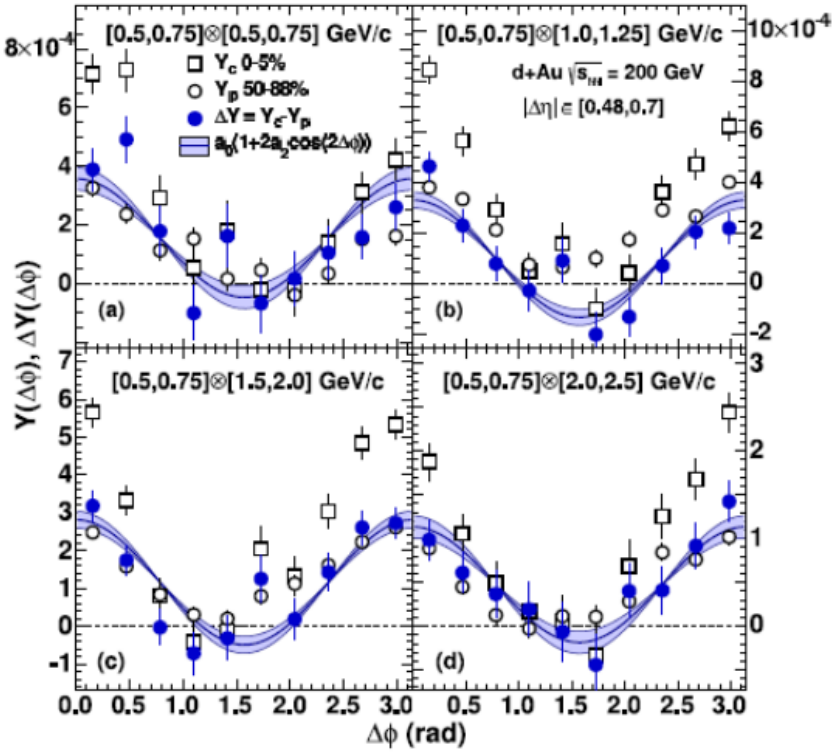
- Non zero ridge yield and v_n measured up to p_T ~ 10 GeV
  - Origin of these correlations?
  - Non-zero first order harmonic also observed in p+Pb

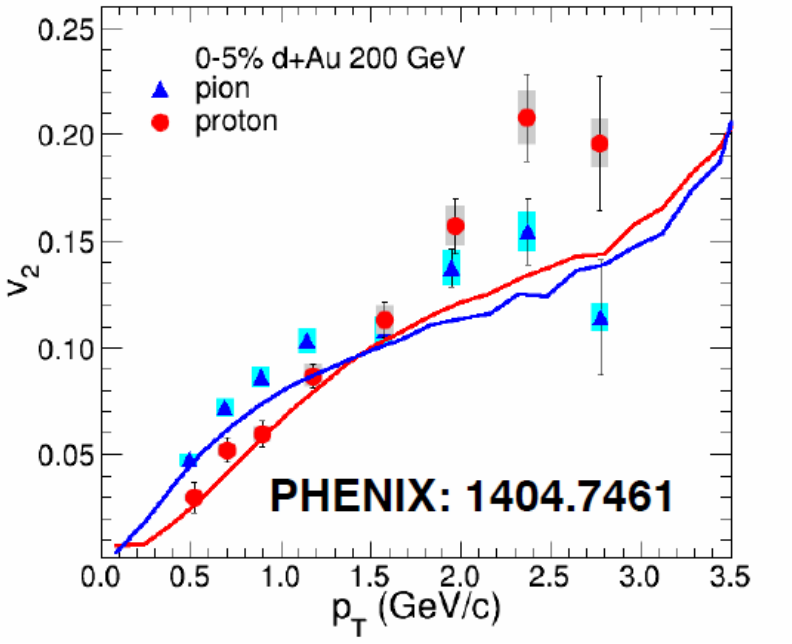
- v_n from multiparticle cumulants consistent with a global anisotropy
  - Strong support for ridge originating from medium response.
  - Good factorization of two particle $v_{n,n}$. Extent of factorization consistent with hydro prediction.

- Comparisons with peripheral Pb+Pb
  - Larger v_2 fluctuations in p+Pb than in Pb+Pb
  - Larger v_2 and v_4 in Pb+Pb, but comparable v_3
  - v_2 after scaling of the p_T axis to account for change in mean p_T differ only by a scale factor between the two systems.

BACK UP

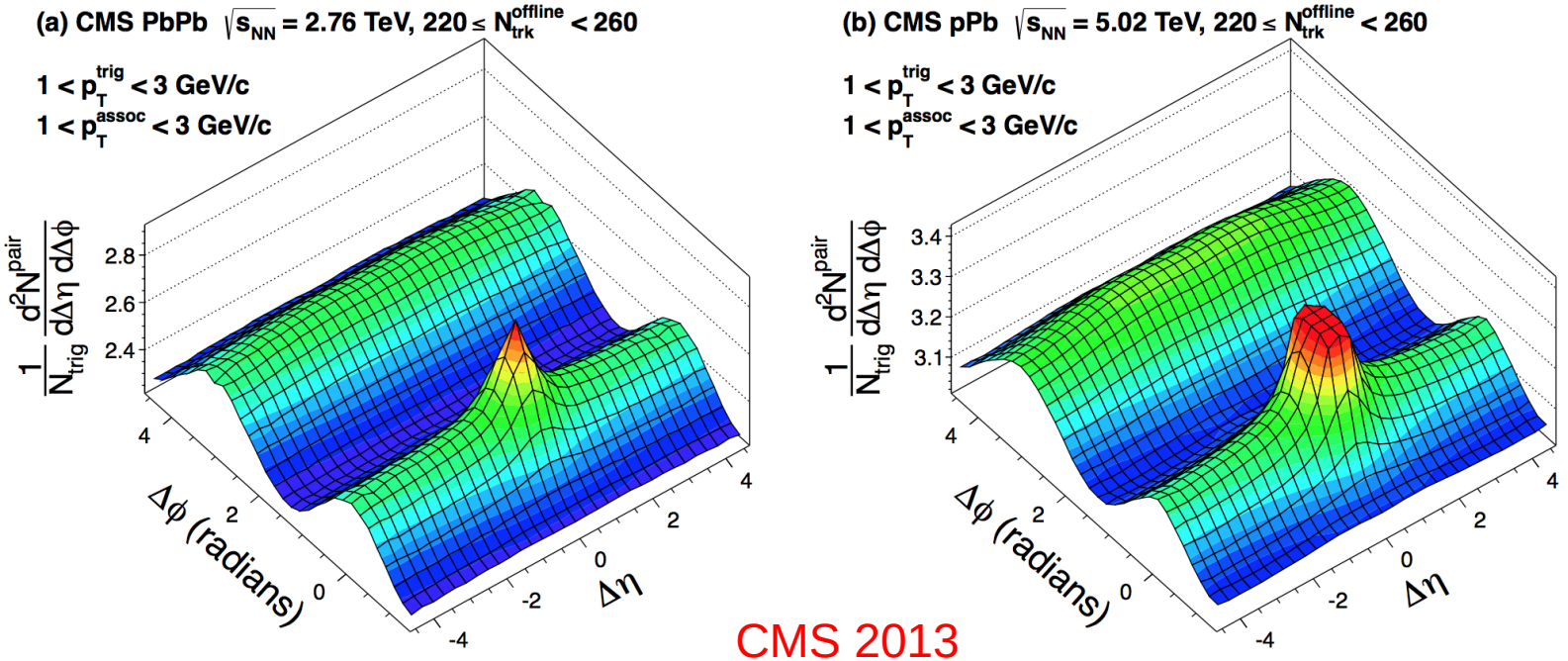
pA and dA ridge





- Qualitatively similar ridge in d+AU at RHIC
  - ‘double ridge’, mass ordering,

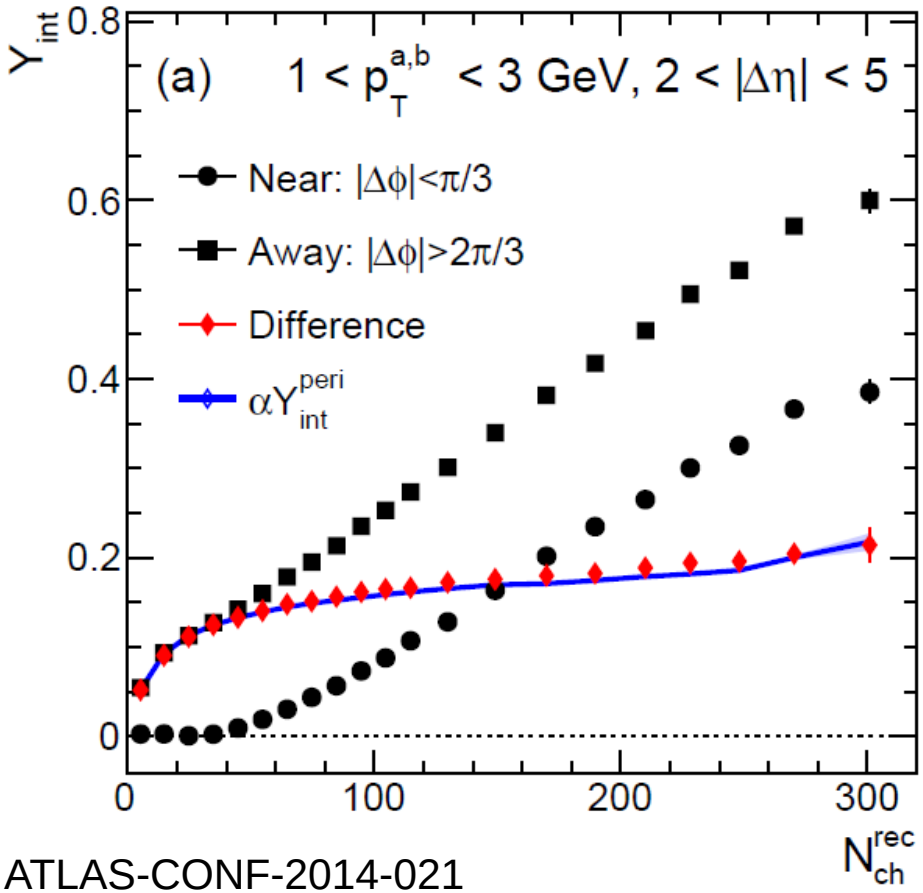
Compare to ridge in peripheral Pb+Pb collisions

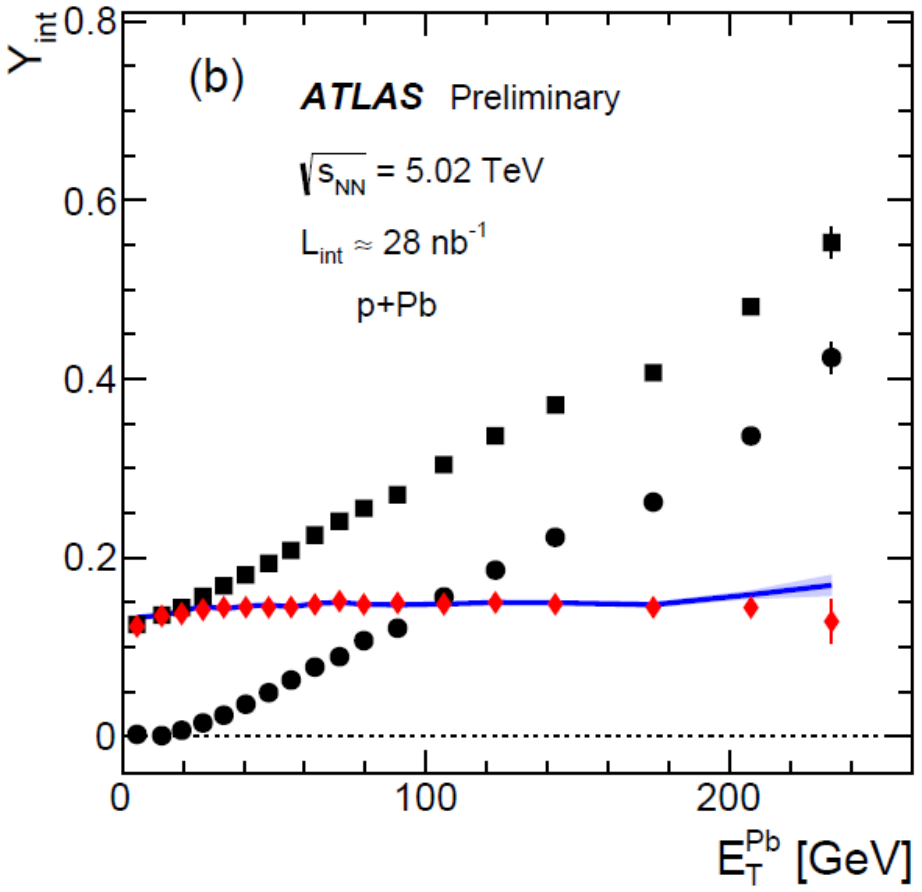


CMS 2013

- Larger jet contribution in similar muliplicity selected p+Pb collisions.

Near side – Away side





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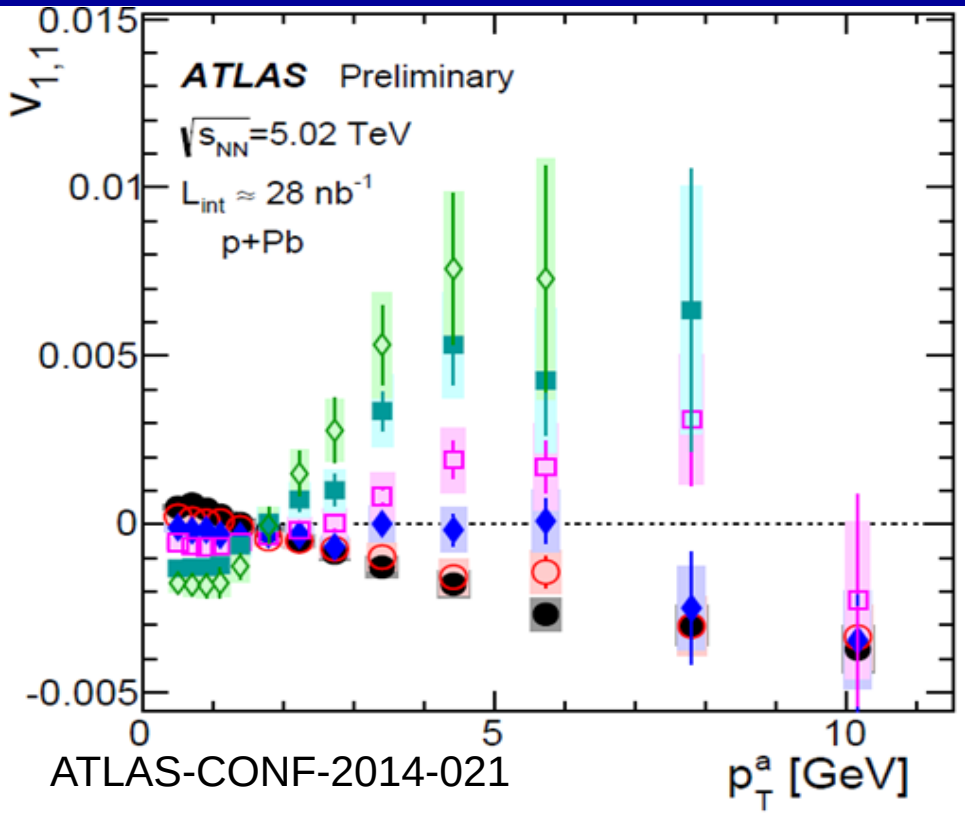
- Away side yield in ${E_T}^{Pb}$ < 10 GeV is ~ 2x that in ${N_{ch}}^{rec}$ < 20

Dipolar flow in p-Pb and Pb+Pb



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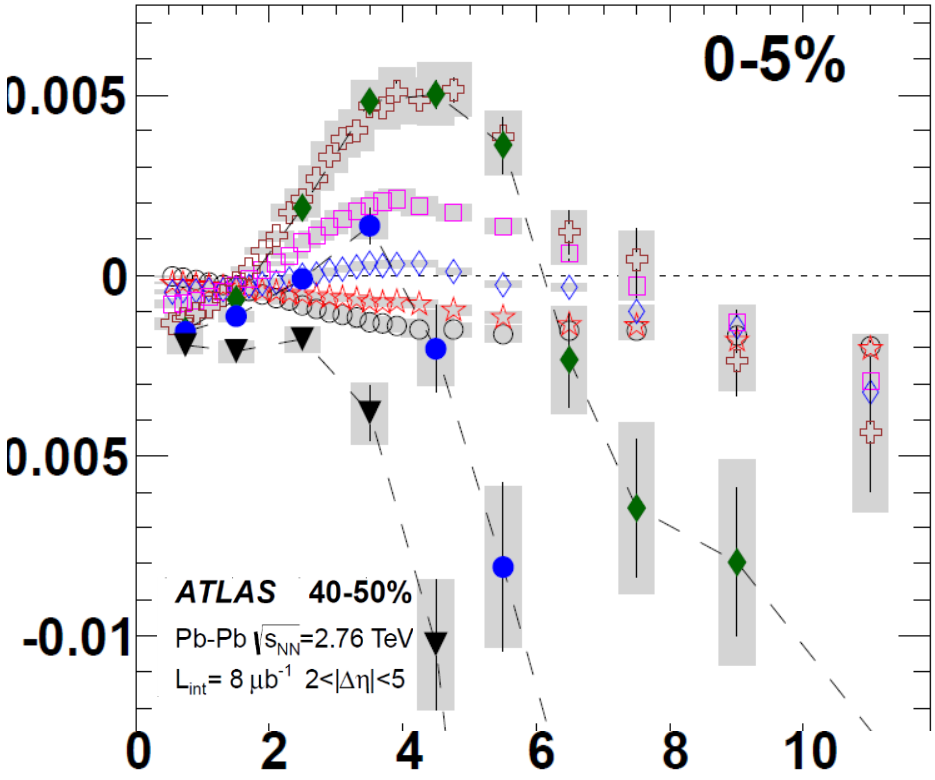
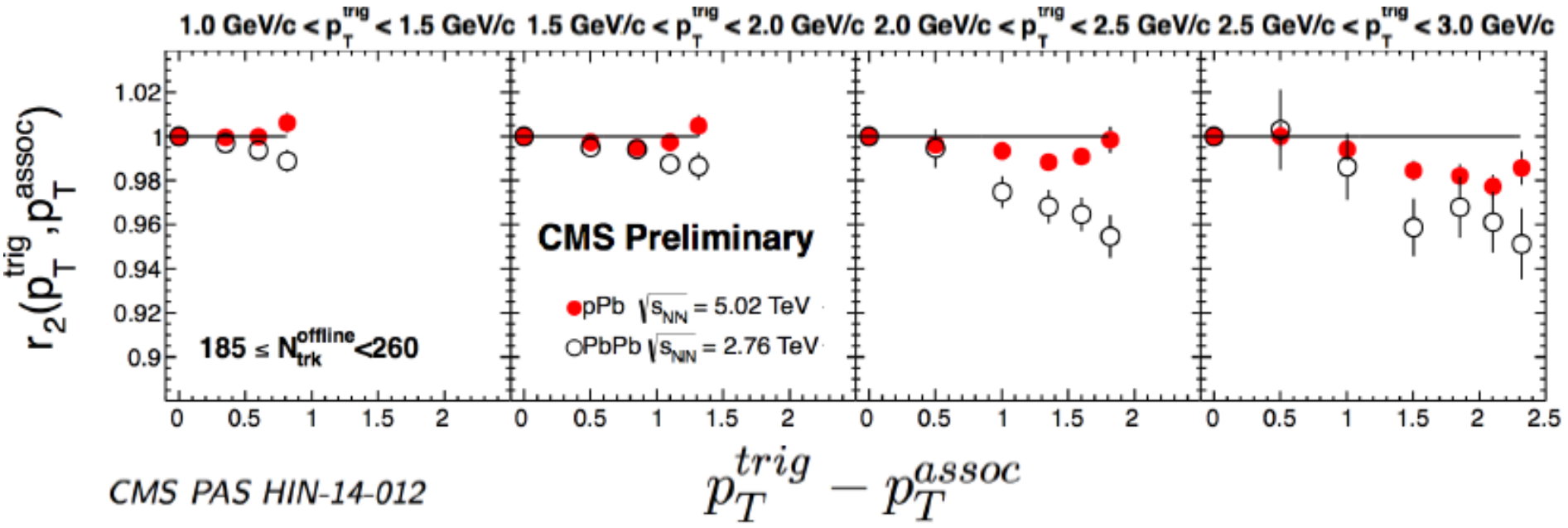


0.5< p_T^a <1 GeV 1< p_T^a <1.5 GeV 1.5< p_T^a <2 GeV 2< p_T^a <3 GeV

3< p_T^a <4 GeV 4< p_T^a <6 GeV 6< p_T^a <8 GeV 8< p_T^a <20 GeV

- $v_{1,1}(p_T{}^a, p_T{}^b)$ in peripheral and central event classes from Pb+Pb collisions.
- In central event class the non flow contributions are suppressed.

Factorization in peripheral Pb+Pb



- Slightly larger breaking of factorization in peripheral Pb+Pb, but still within a few percent.