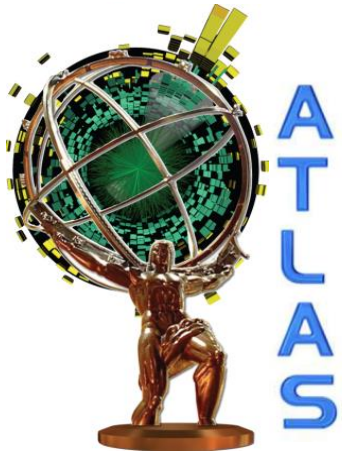
ATLAS measurements of the ridge(s) in p+Pb collisions using two-particle correlations and cumulants



Sooraj Radhakrishnan

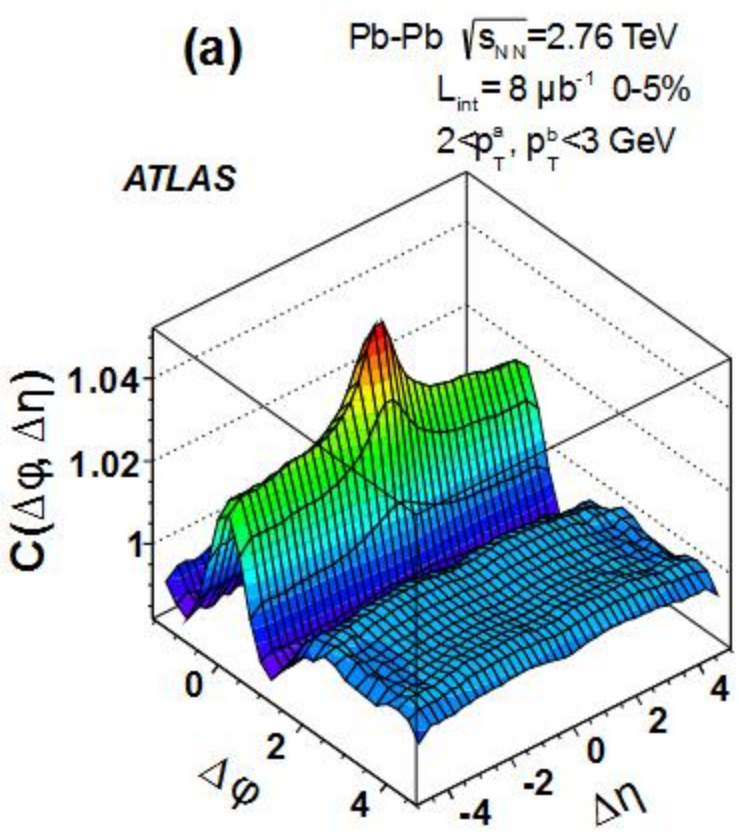
On behalf of the ATLAS collaboration

Phys.Rev.Lett. 110,182302(2013)
and
arXiv:1303.2084

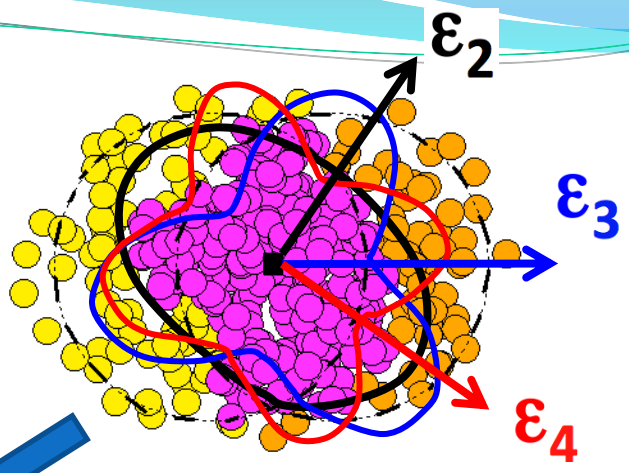
Stony Brook University

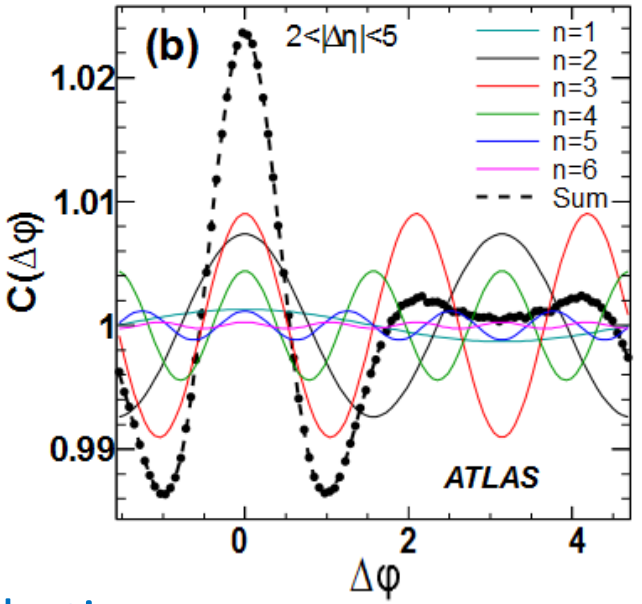
LowX Israel2013 May 30 – June 4

Ridge in Heavy Ion collisions



PhysRevC.86.014907



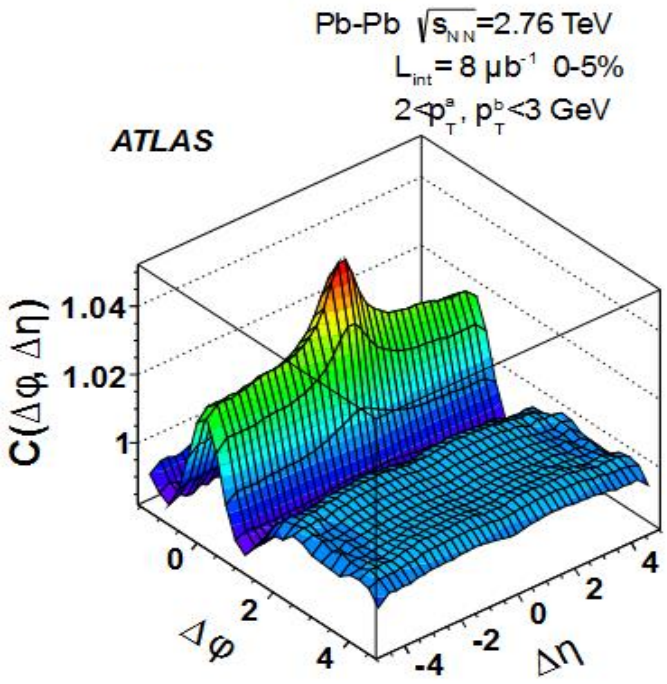


PhysRevC.86.014907

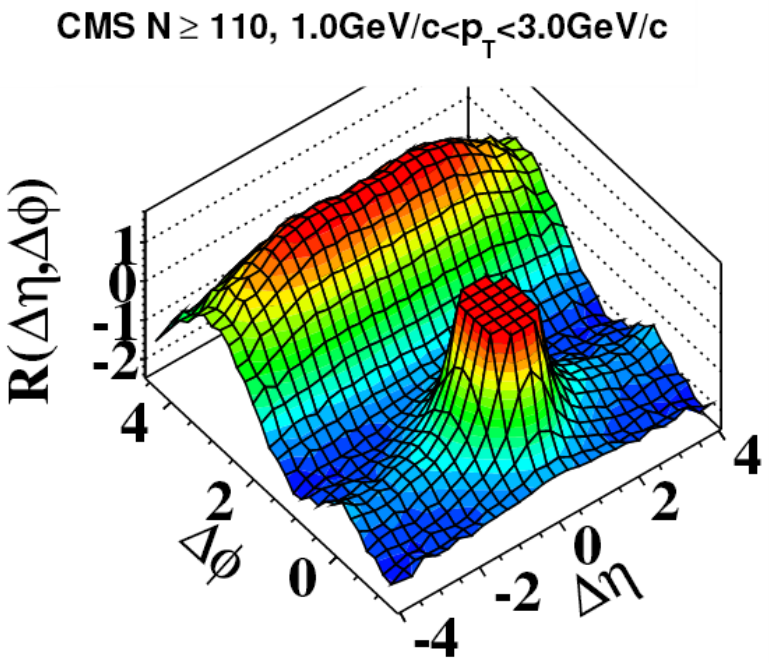
- Long-range structures in Δη seen in pair distributions on the near side (Δϕ ~ 0) and away side (Δϕ ~ π) by RHIC and LHC experiments.
- Well explained by initial shape and density fluctuations followed by hydrodynamic evolution.

Ridge in p+p collisions!

(CMS Collaboration: JHEP09(2010)091)



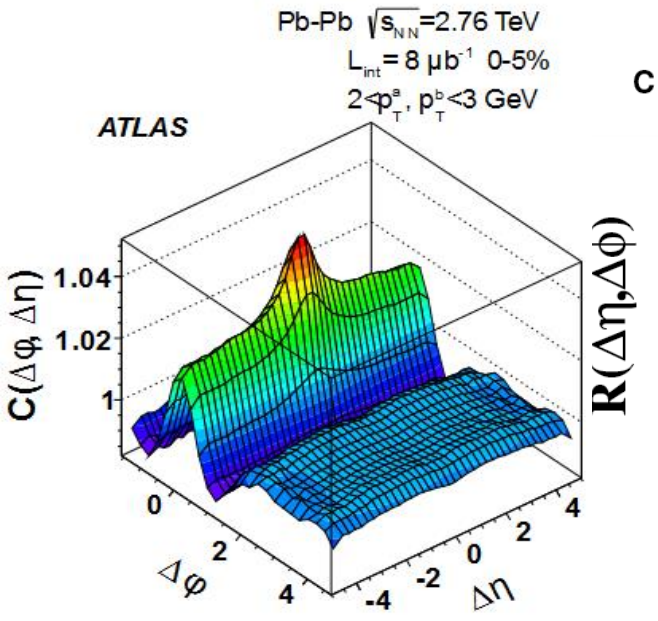
Pb+Pb

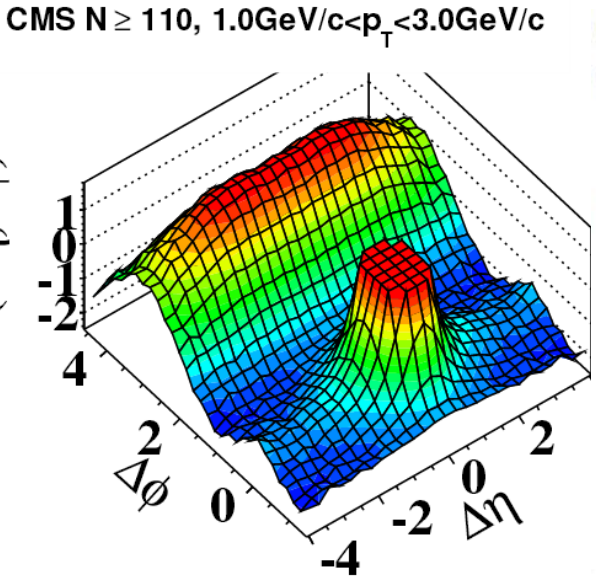


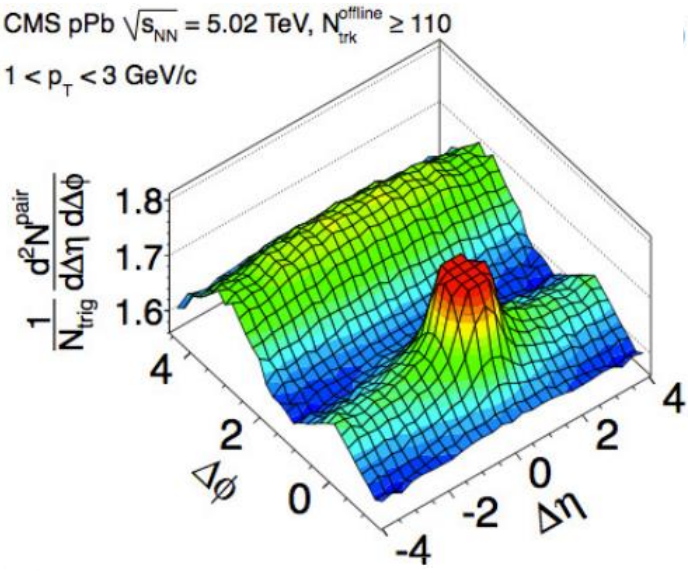
p+p

- A ridge structure extended in pseudorapidity on the near side (Δϕ ~ 0), was observed in high multiplicity p+p collisions by CMS, albeit much smaller in magnitude compared to that in heavy ion collisions,
- Source of these correlations are not well understood.
  - Initial state (CGC) effects?
  - Flow as in heavy ions?

Ridge in p+Pb collisions



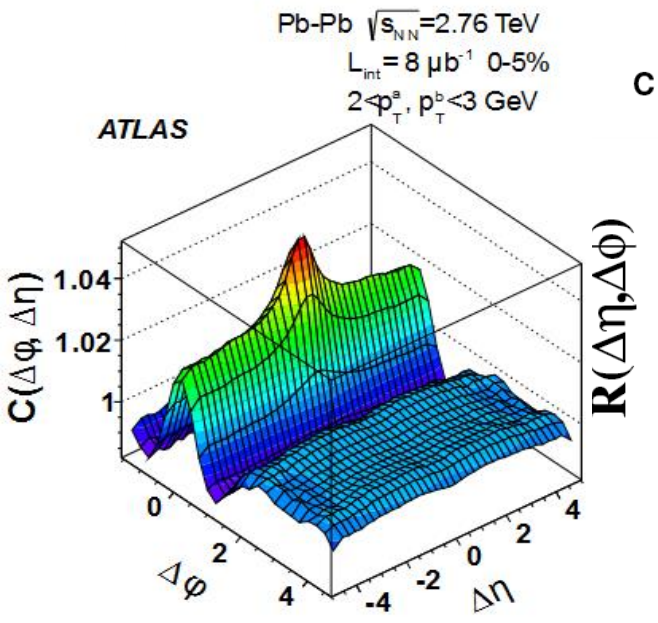


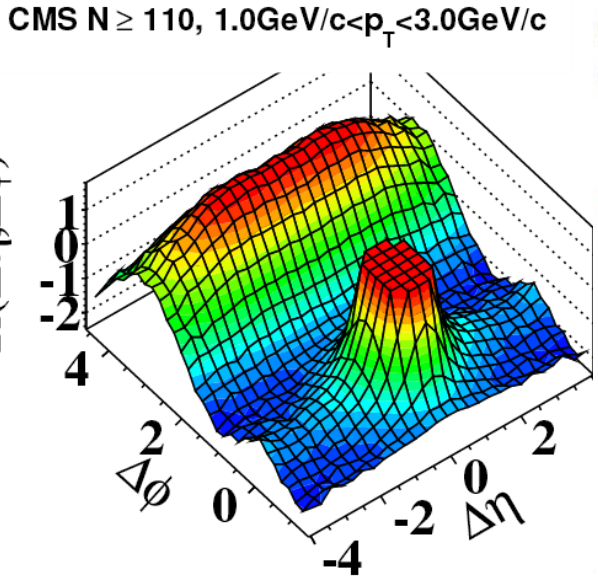


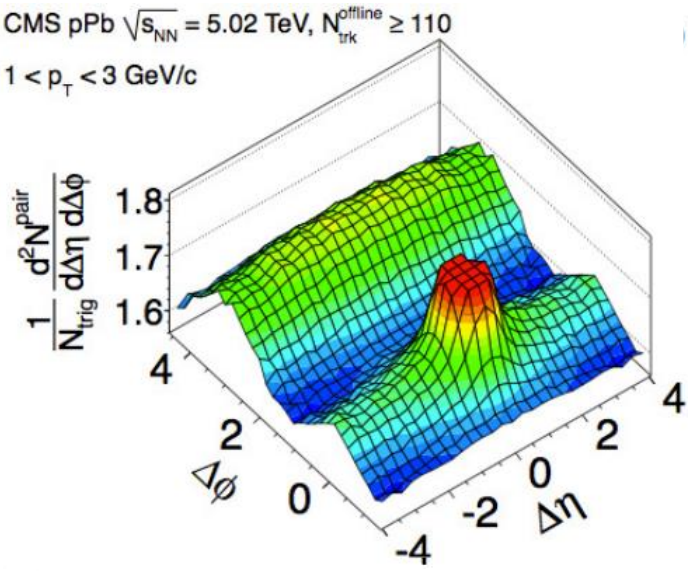
Pb+Pb **p+p** **p+Pb**

- Not surprisingly(!), a similar near side ridge is observed in p+Pb collisions by CMS, ALICE and ATLAS.
- Nature and origin of these ridge correlations?

Ridge in p+Pb collisions



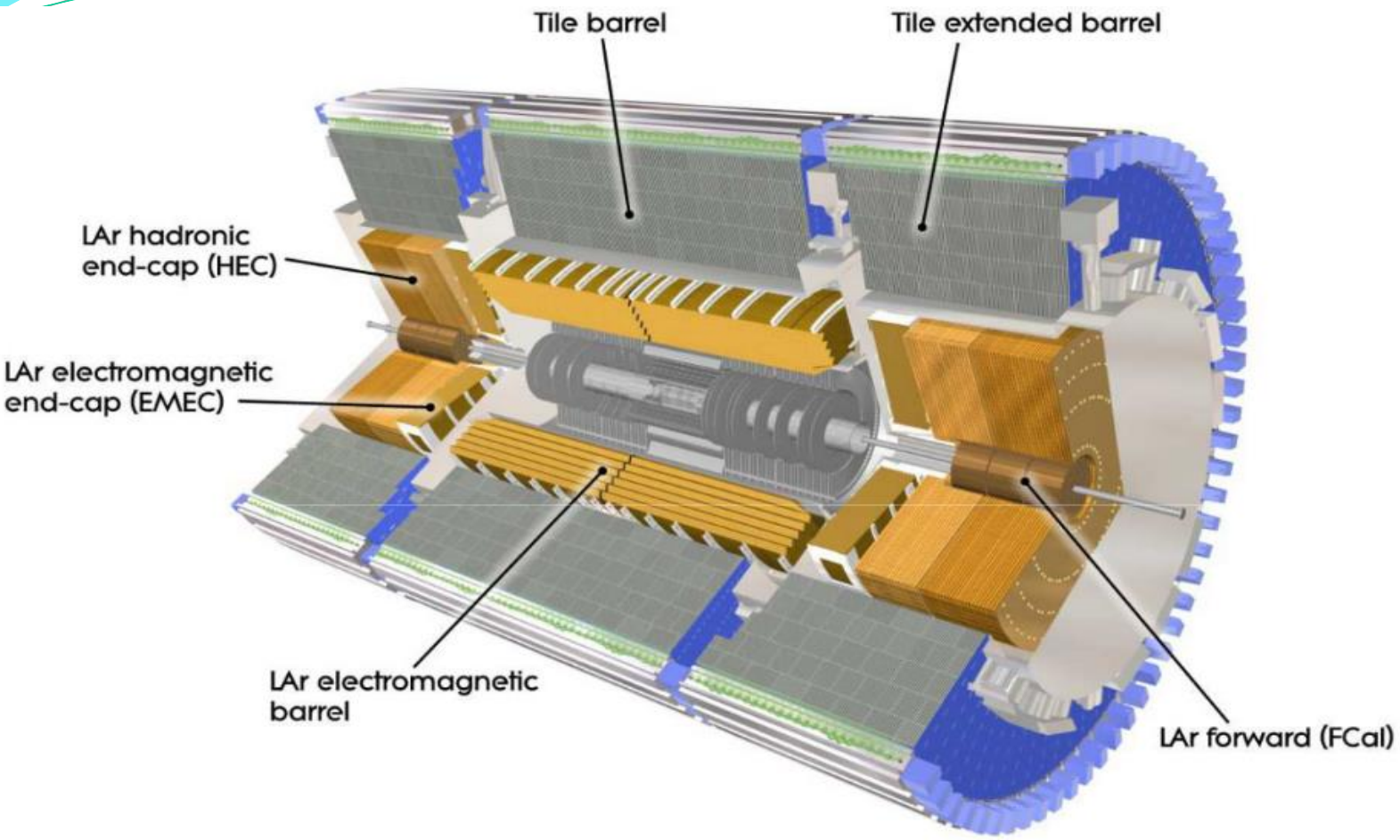




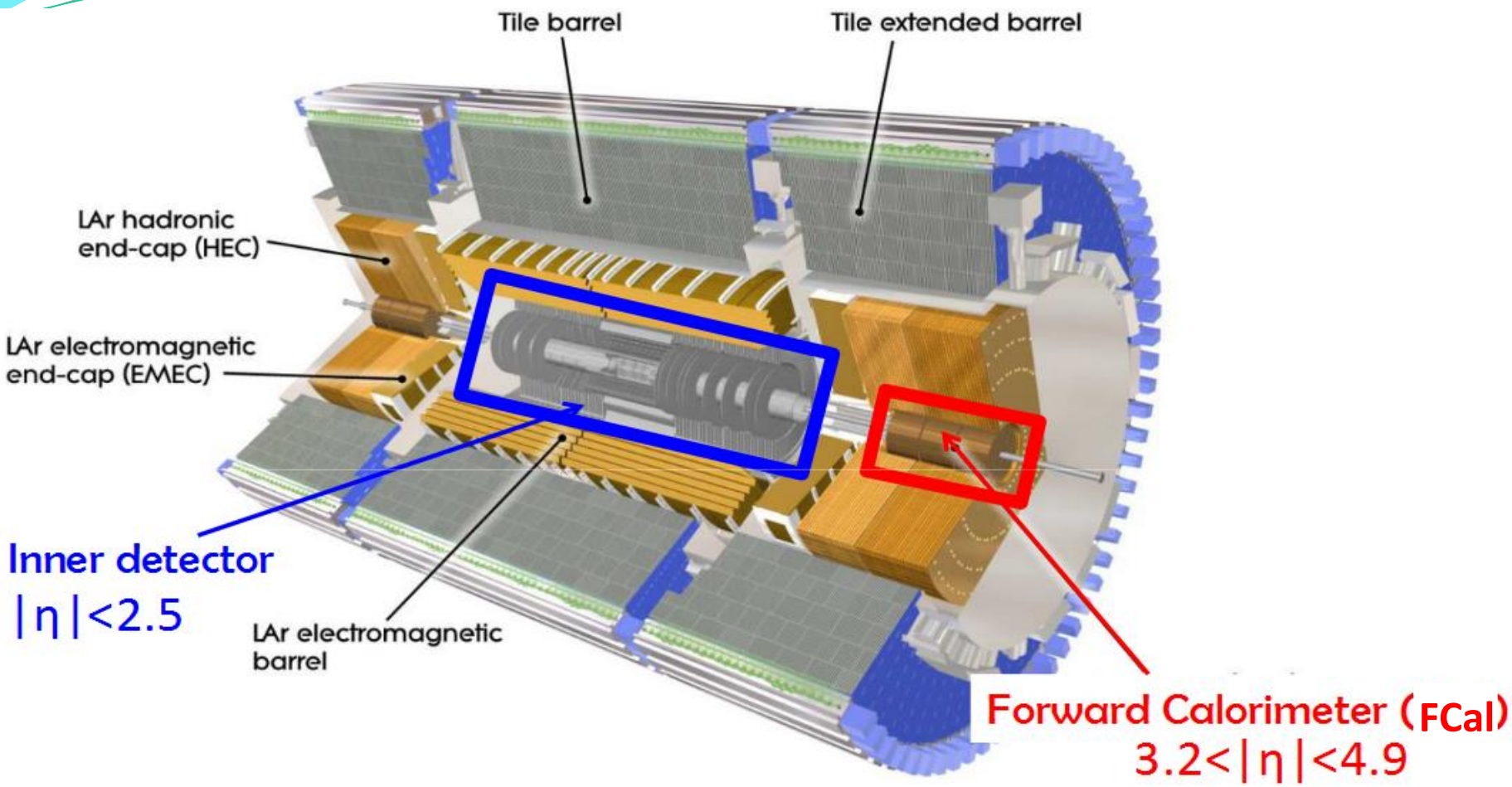
Pb+Pb **p+p** **p+Pb**

- Not surprisingly(!), a similar near side ridge is observed in pPb collisions by CMS, ALICE and ATLAS.
- Is there an away side ridge?
  - If so, how does it look like?
  - p_T, multiplicity and charge dependence?

ATLAS Detector

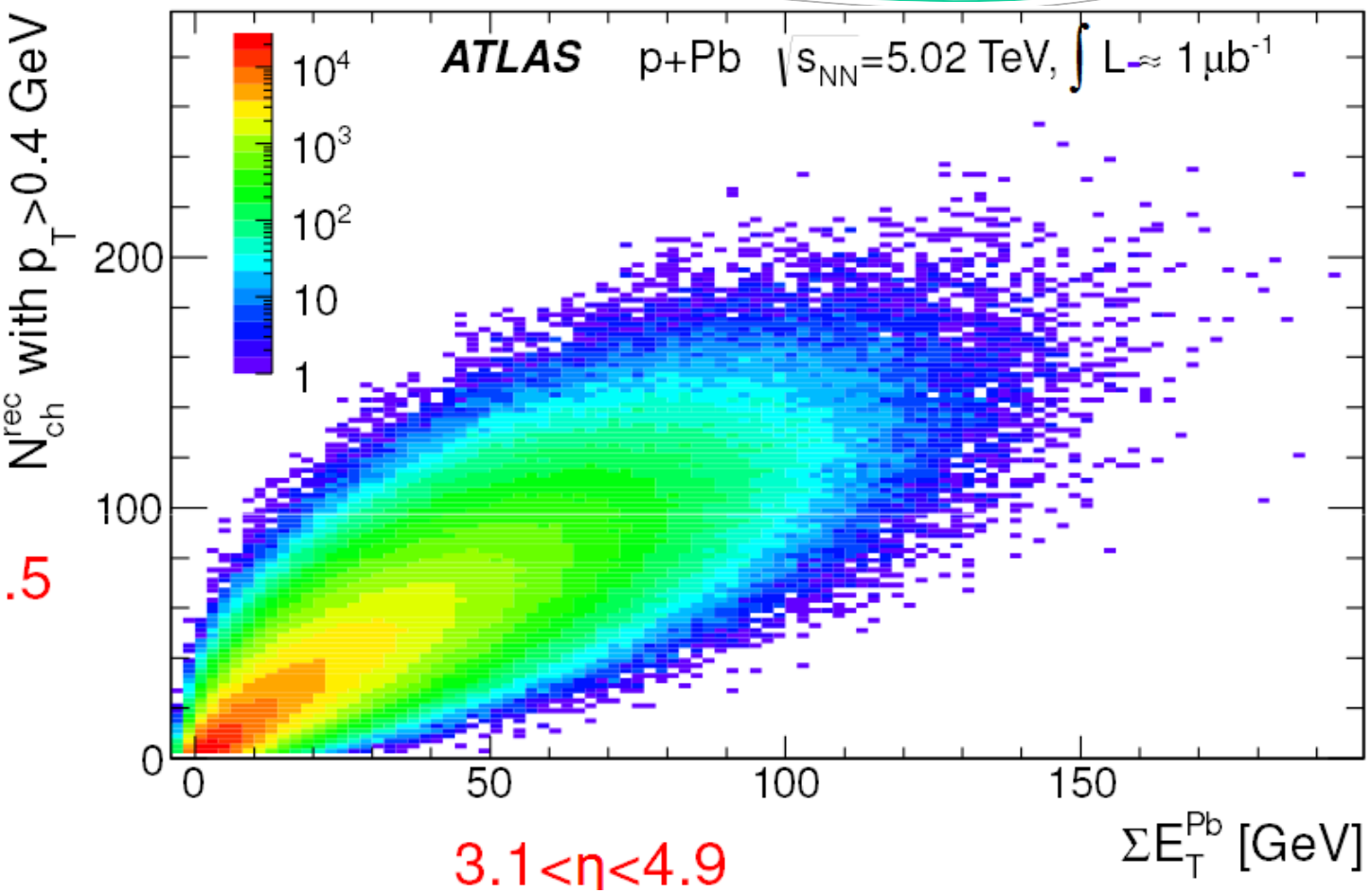


ATLAS Detector



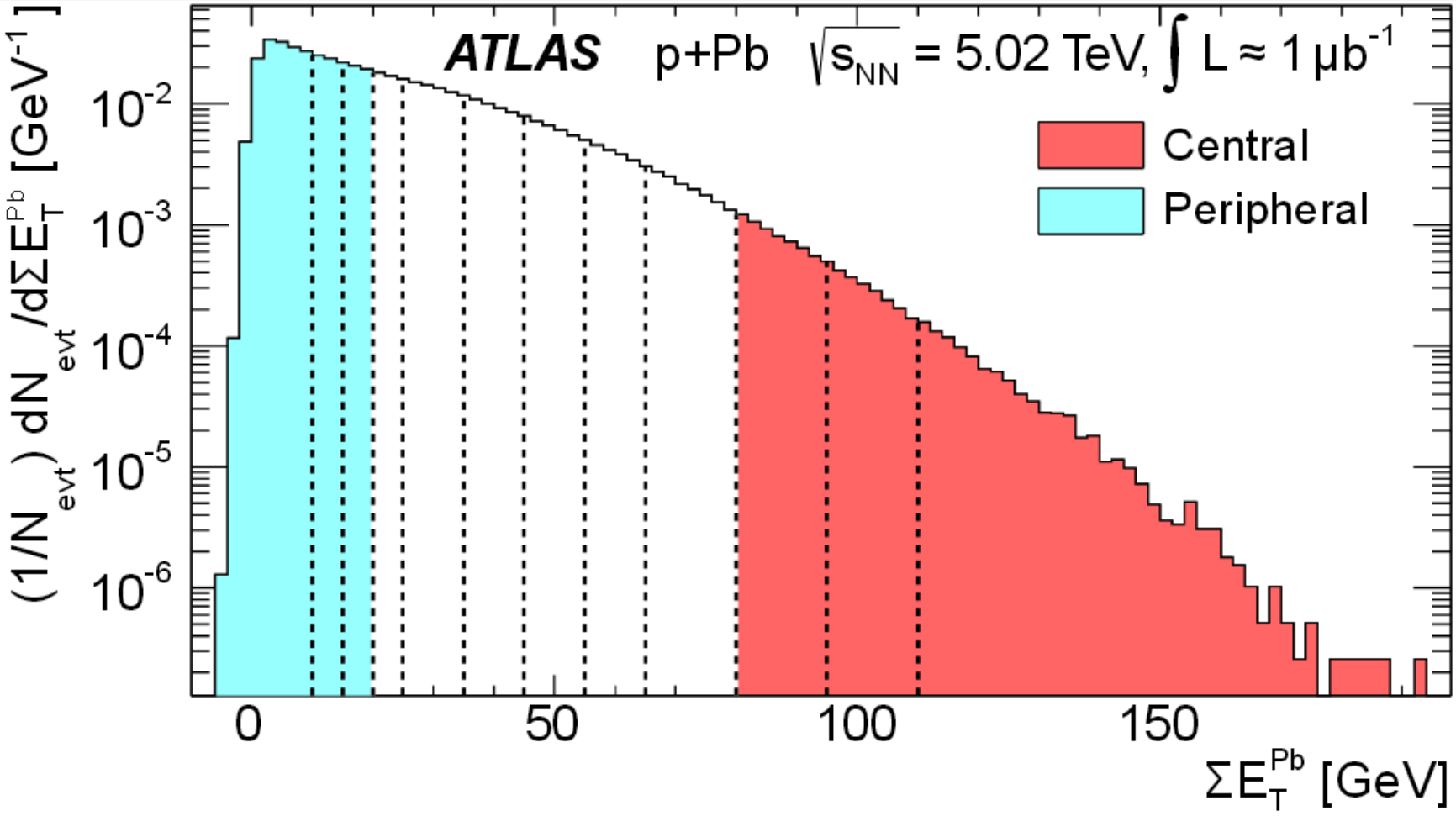
- Inner Detector – Used the reconstructed charged particle tracks in Inner detector for constructing correlations
- Forward Calorimeter(Pb fragmentation side) – Used for determination of 'event activity class'

Event activity classes



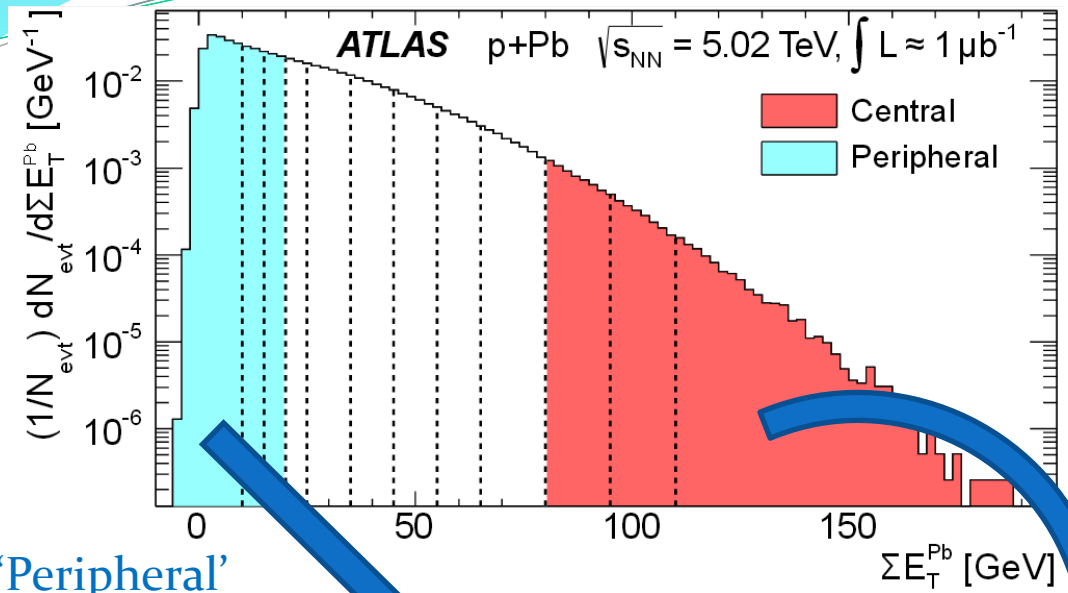
- 'Event activity' is characterized either by the Number of reconstructed tracks with pt> 0.4Gev in the Inner Detector or by the Energy deposited in the Forward Calorimeter in the Pb fragmentation side
- Using Forward Calorimeter energy implies no autocorrelation bias in event activity class definition.

Event activity classes in ΣE_T^{Pb}



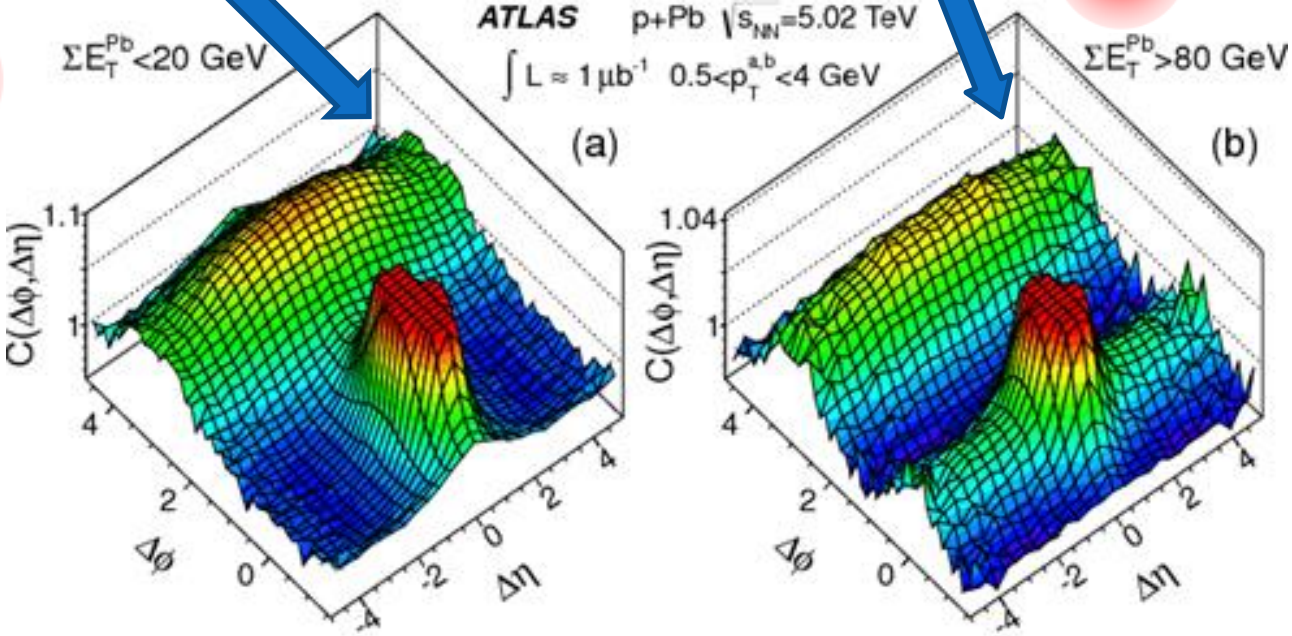
- 12 fine and 4 broad event activity classes in ΣE_T^{Pb} defined for detailed analysis
  - ΣE_T^{Pb}>80 GeV contains top 2% and ΣE_T^{Pb} < 20 GeV contains bottom 52% of all events.

Ridge and event activity



'Peripheral'

'Central'



- The ridge structure is absent in the peripheral event class while its clearly visible in the central event class

Per Trigger Yield (PTY)

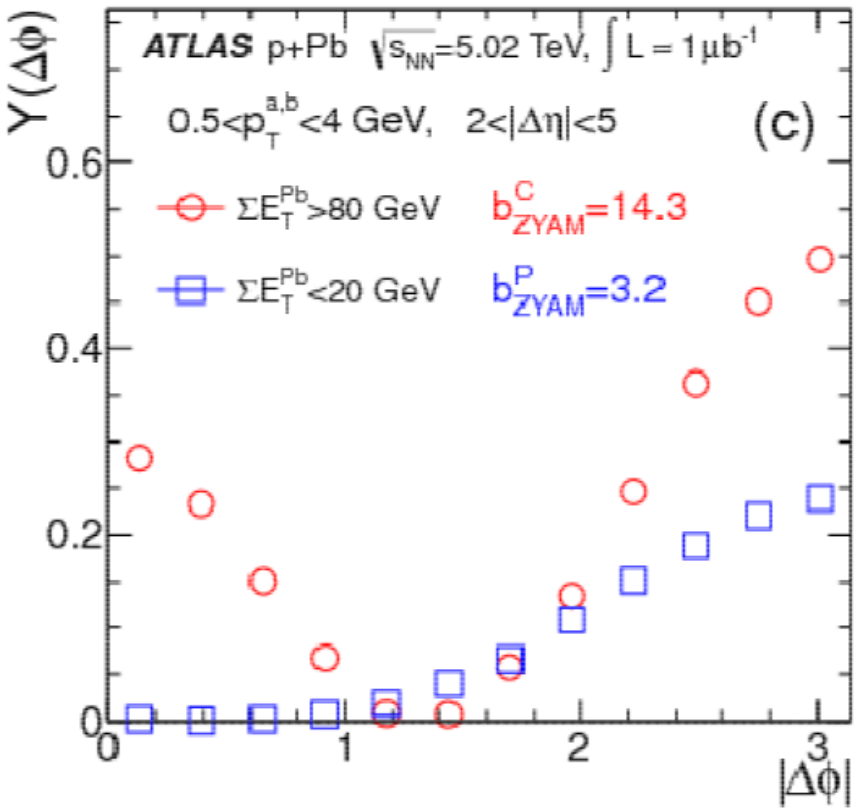
- The correlations in central and peripheral event classes can be compared at the (background subtracted) Per Trigger Yield (Y(Δϕ)) level.

- $Y(\Delta\Phi) = \frac{N^{pairs}(\Delta\phi)}{N^{trig}} - b_{ZYAM}$

N^{trig} → Number of trigger particles in a given kinematic window.

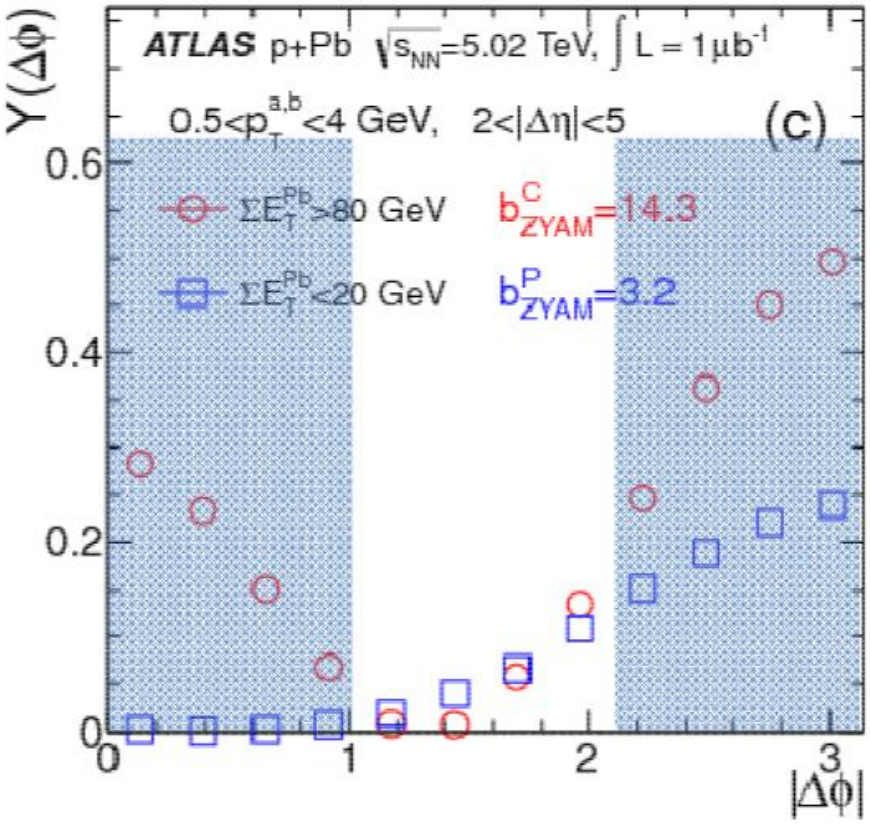
$N^{pairs}(\Delta\phi)$ → Number of pairs in the kinematic window at Δϕ

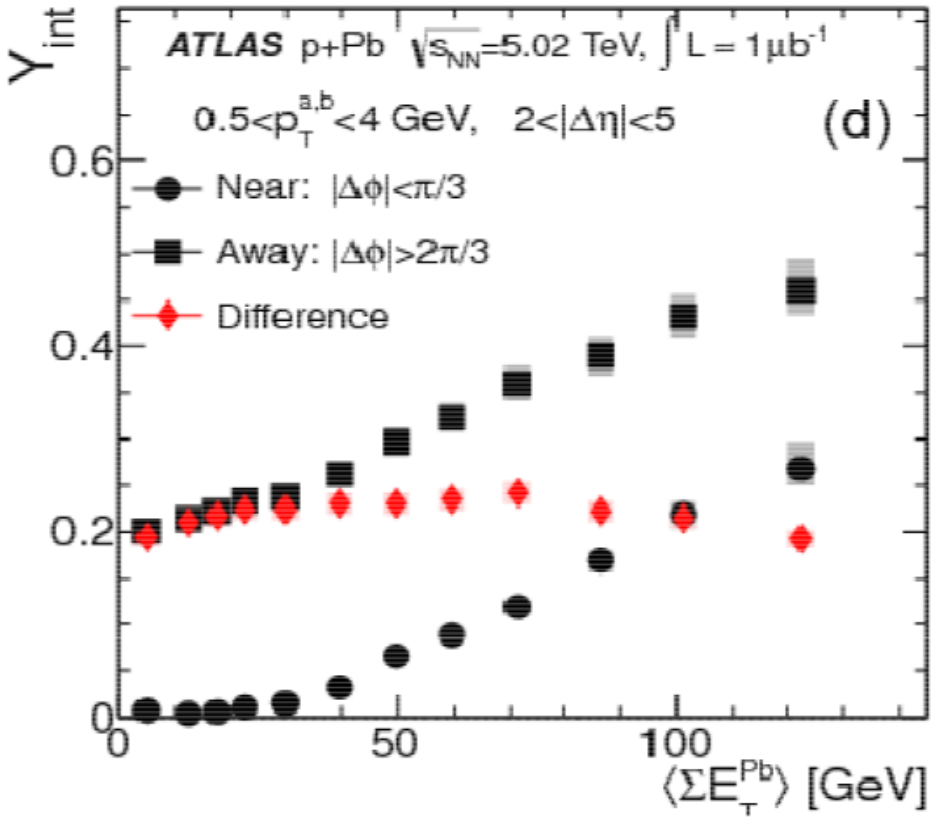
b_{ZYAM} → Combinatorial background from ZYAM



- Peripheral event class shows no near side ridge, but the away side peak from jet fragmentation
- Central event class shows near side ridge and an enhancement on the away side

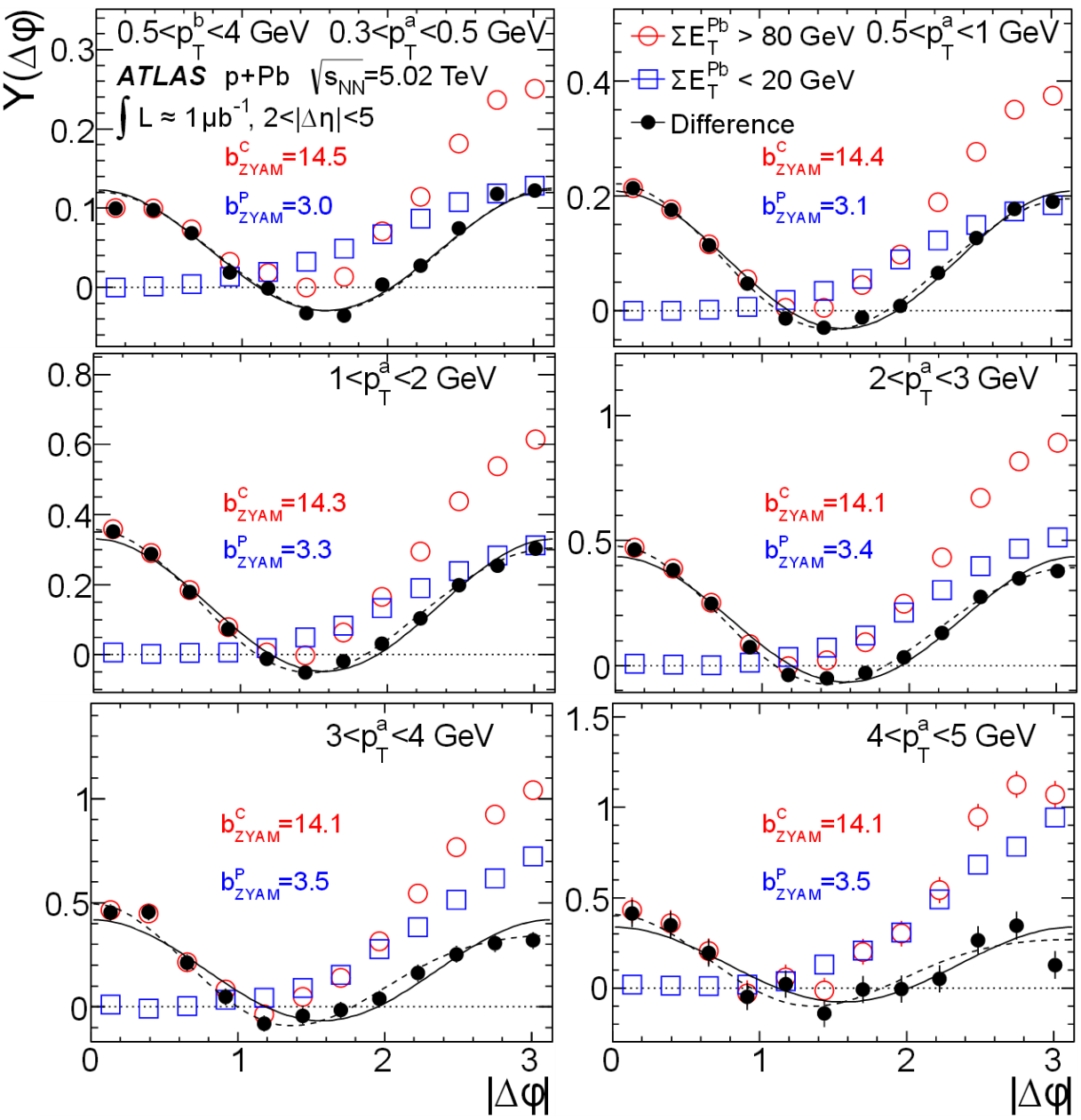
Integrated yield on near side and away side





- Integrated yields (Y_{int}) defined in the windows $0 < |\Delta\phi| < \frac{\pi}{3}$ and $\frac{2\pi}{3} < |\Delta\phi| < \pi$ for near side and away side respectively.
- The yield difference between central and peripheral classes is nearly constant in centrality!

PTY for different p_T combinations



The recoil subtracted PTY is consistent with a modulation,

$$\Delta Y(\Delta\phi) = a_0 + 2a_1 \cos(2\Delta\phi)$$

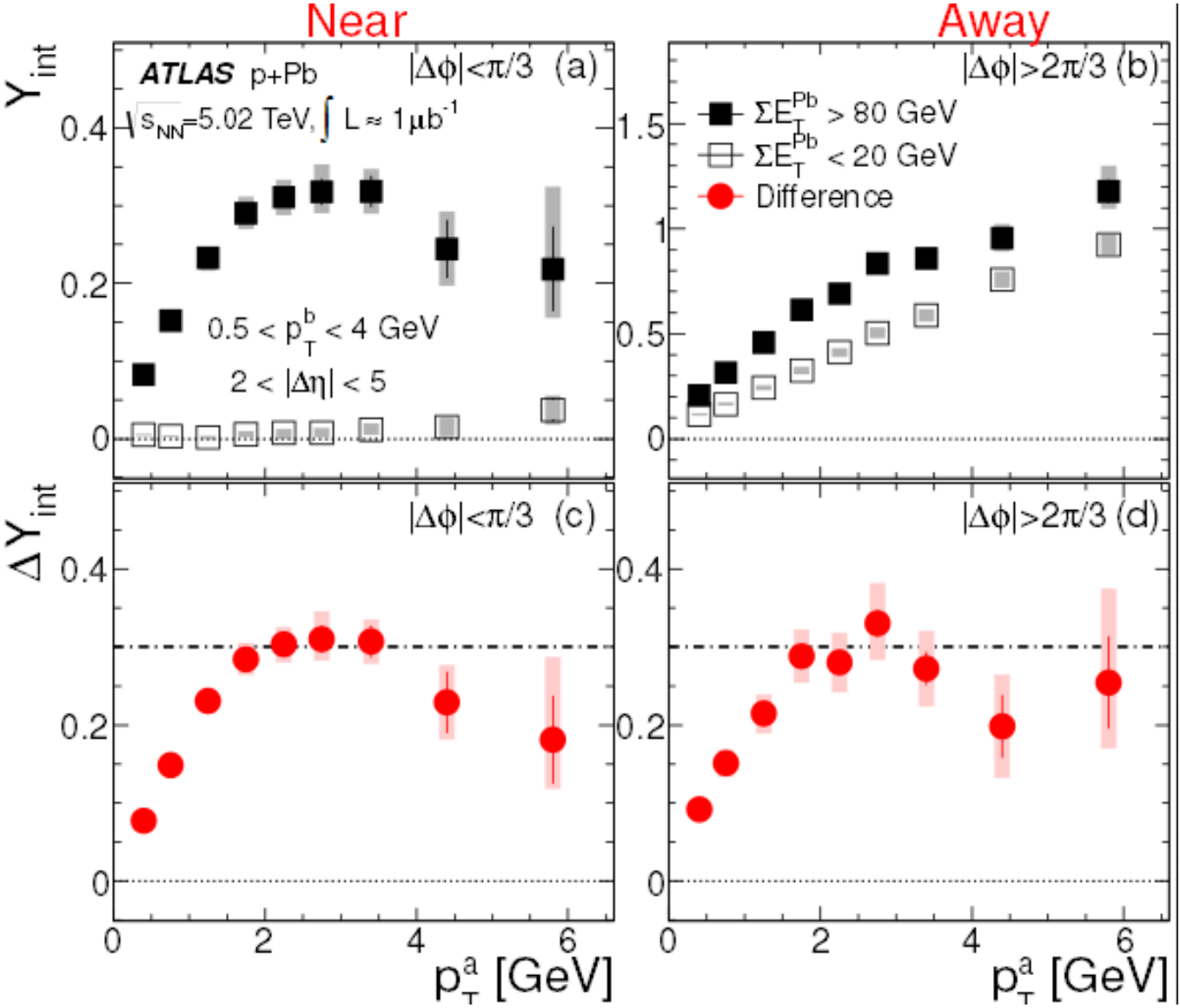
where,

$$a_0 = < \Delta Y(\Delta\phi) >$$

$$a_1 = < \Delta Y(\Delta\phi)\cos(2\Delta\phi) >$$

Similar p_T dependence, near and away side

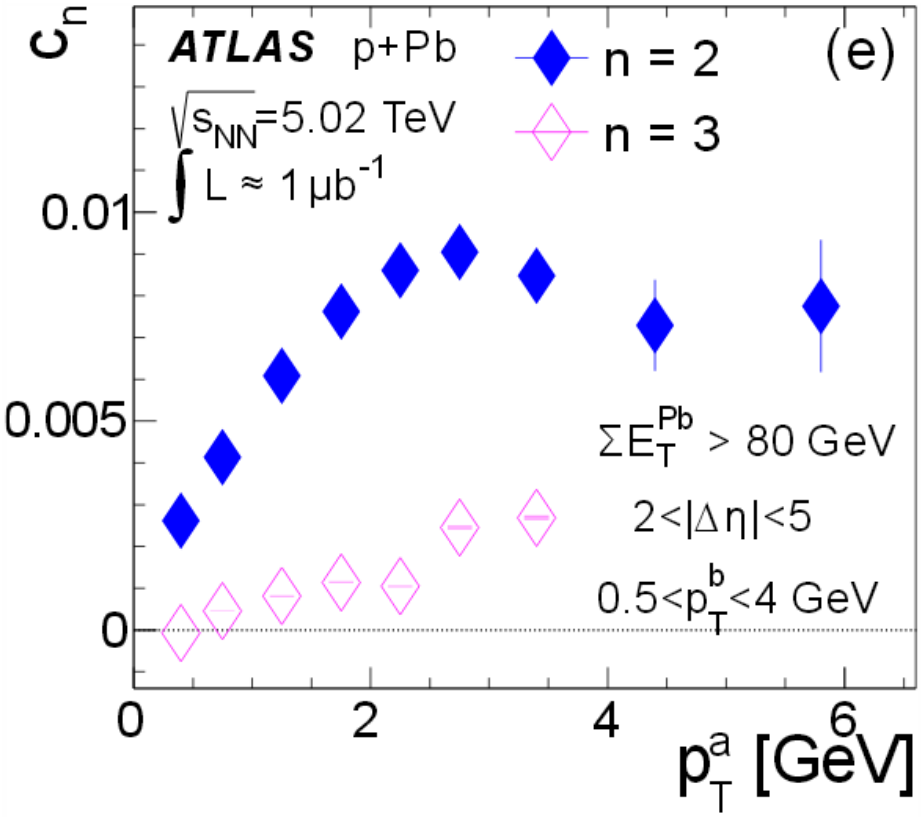
- Recoil subtracted away side has a very similar p_T dependence as near side
- Recoil subtraction doesn't significantly affect near side
- Ridge persists at least up to 6 GeV
- Ridge yield reaches maximum around 3 GeV and then drops



Fourier analysis on recoil subtracted correlation

Extract Fourier coefficients from recoil subtracted correlation function

$$c_n = < C_{R.S}(\Delta\phi)\cos(n\Delta\phi) > ; c_n \leftrightarrow v_{n,n}$$



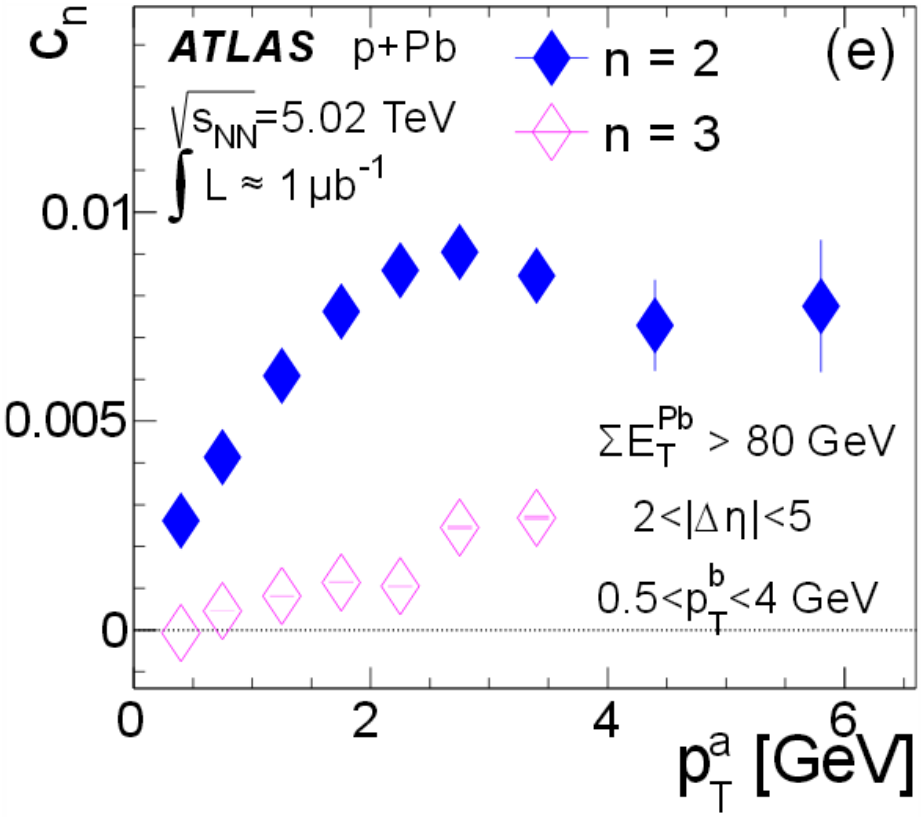
Fourier analysis on recoil subtracted correlation

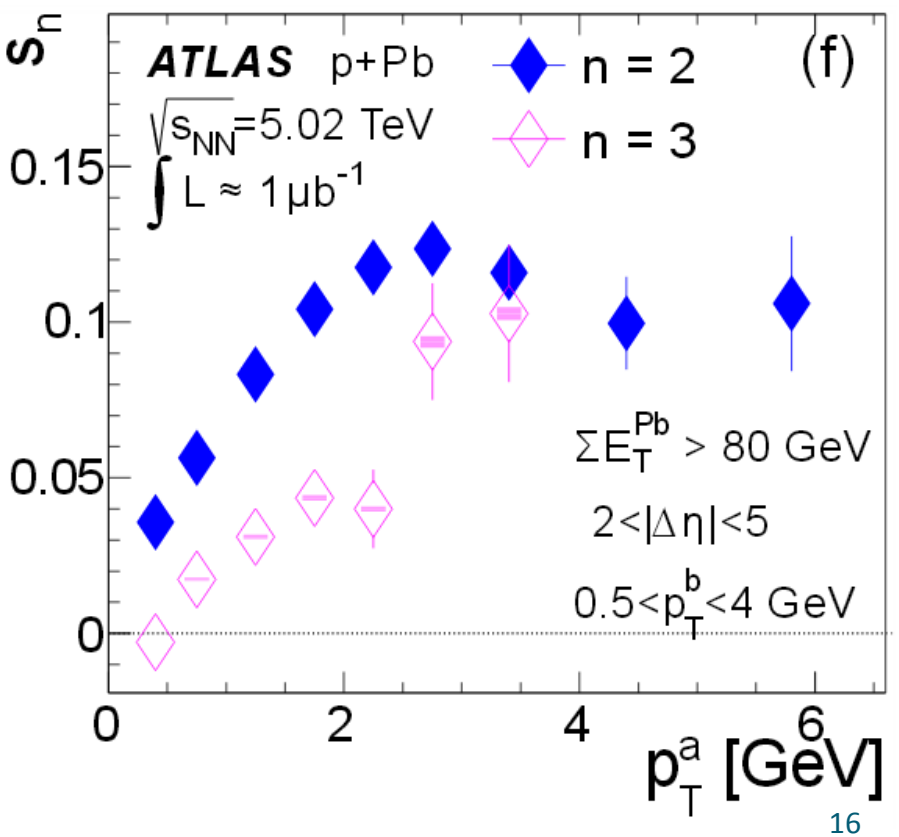
- Extract Fourier coefficients from recoil subtracted correlation function

$$c_n = < C_{R.S}(\Delta\phi)\cos(n\Delta\phi) > ; c_n \leftrightarrow v_{n,n}$$

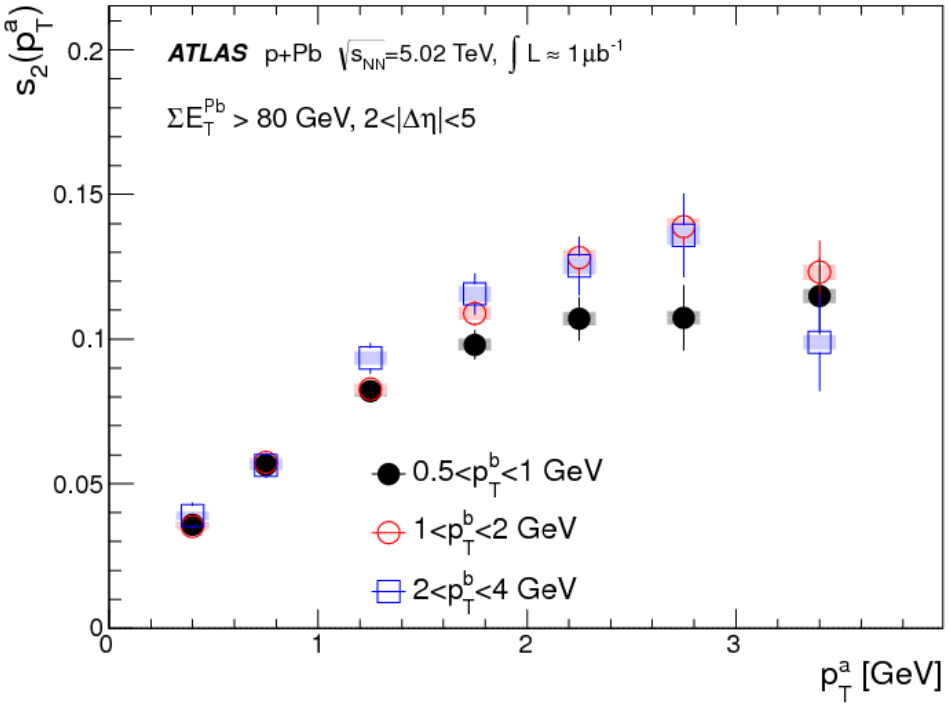
- Factorize as in Heavy Ion 2PCs $c_n(p_T{}^a, p_T{}^b) = s_n(p_T{}^a)\, s_n(p_T{}^b)$

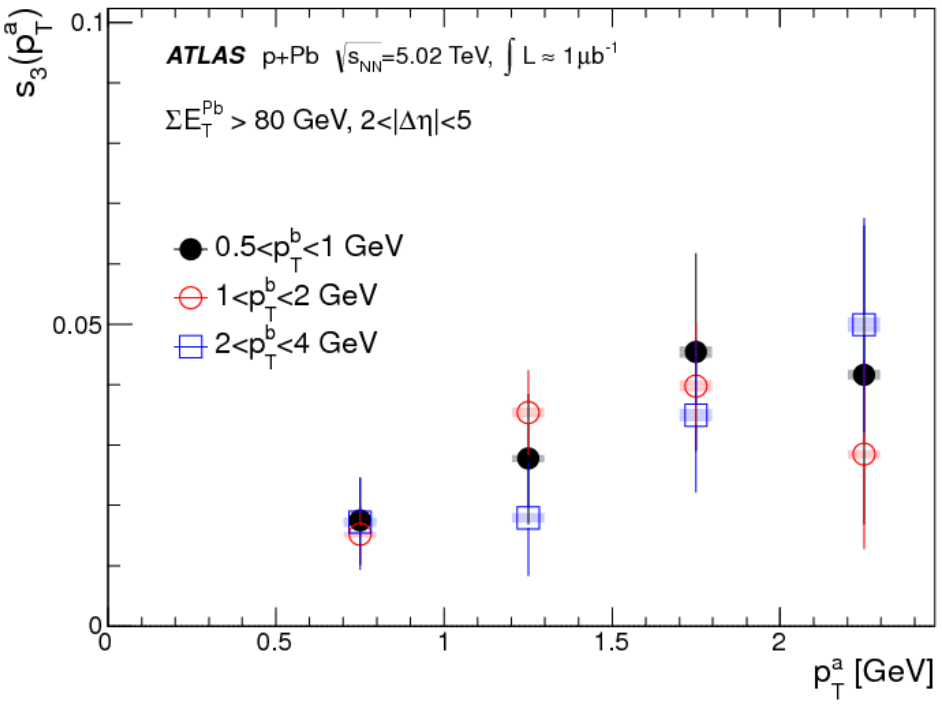
$$s_n(p_T{}^a) = c_n(p_T{}^a, p_T{}^b)/\sqrt{c_n(p_T{}^b, p_T{}^b)}$$





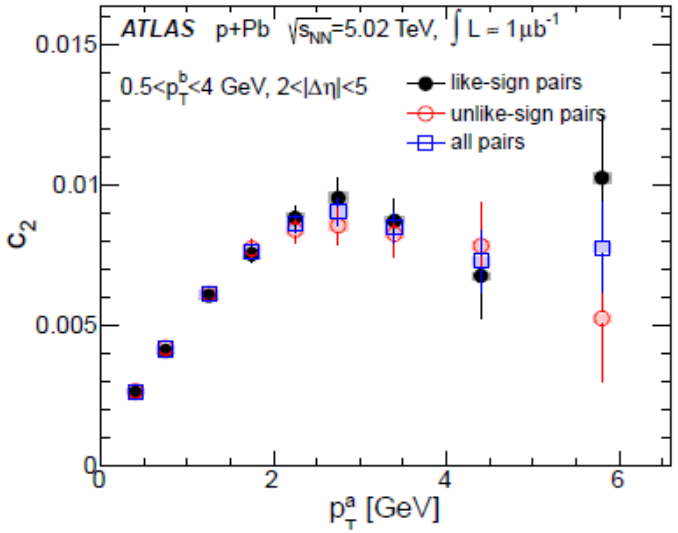
Check factorization of s_n

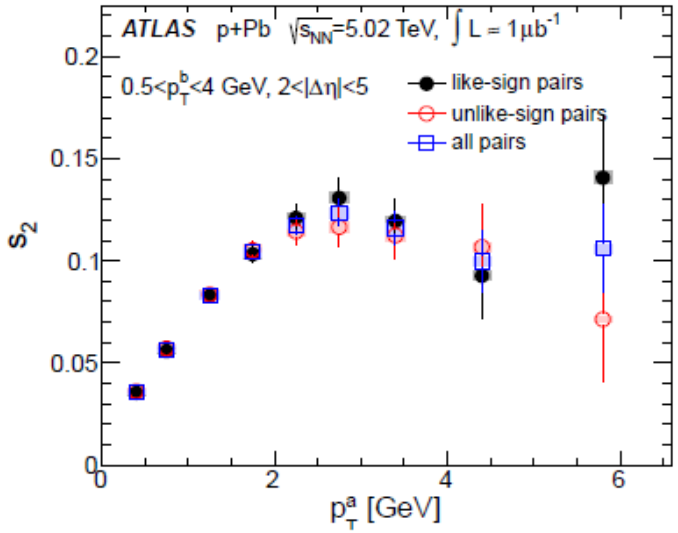


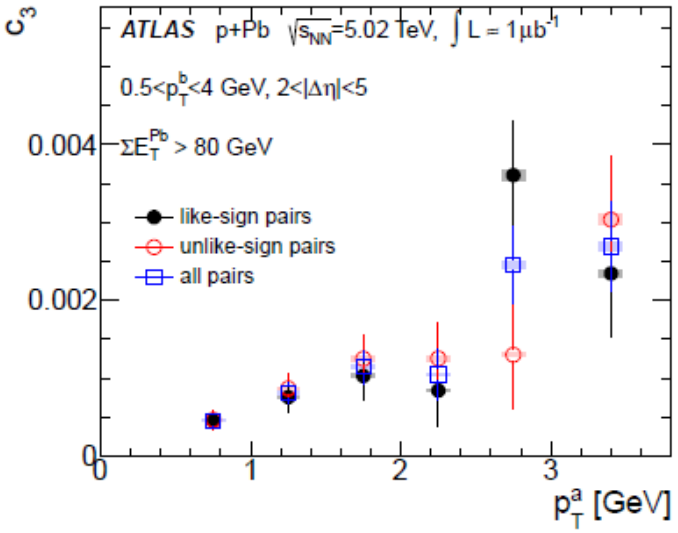


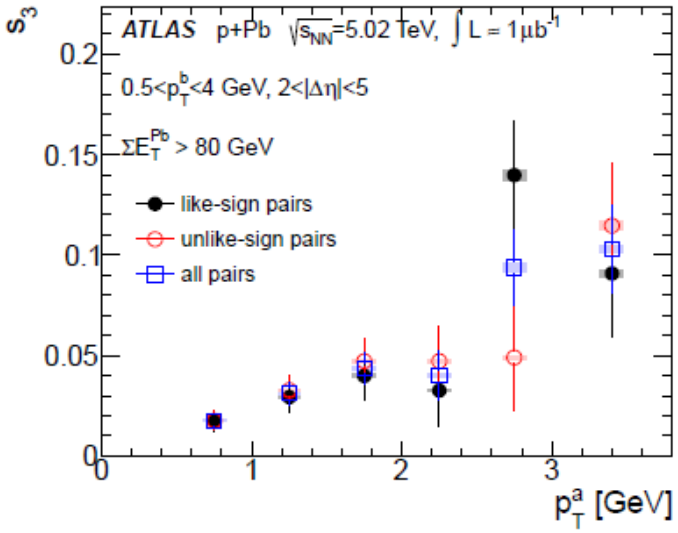
- Use different p_T windows for factorization
- Factorization is valid at 10-20% level for s_2

Charge Dependence



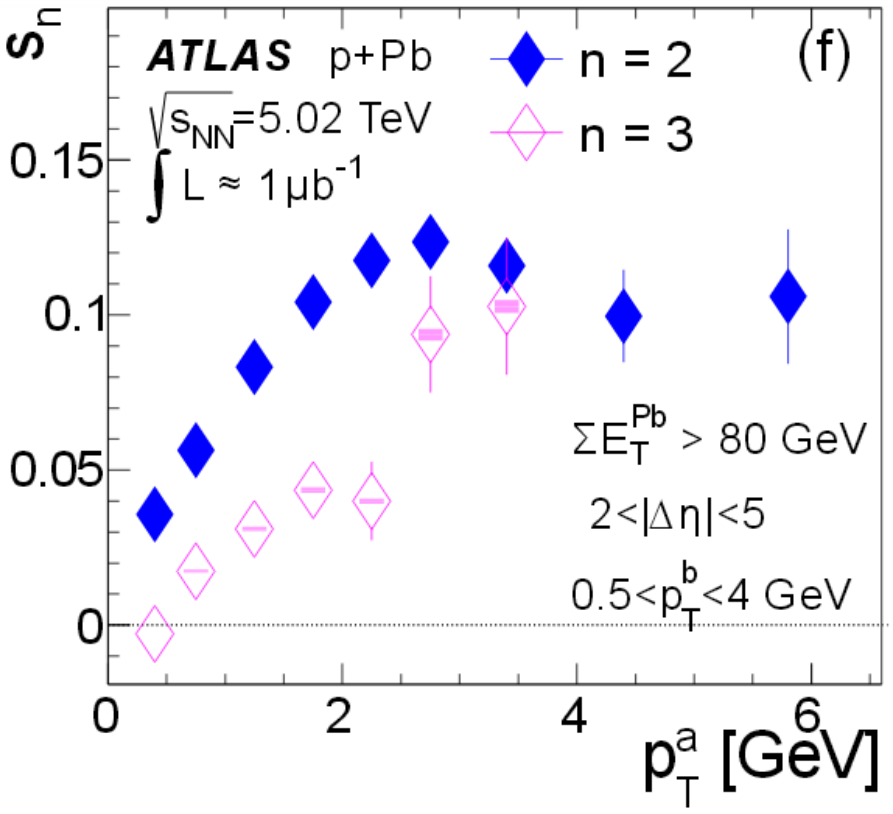


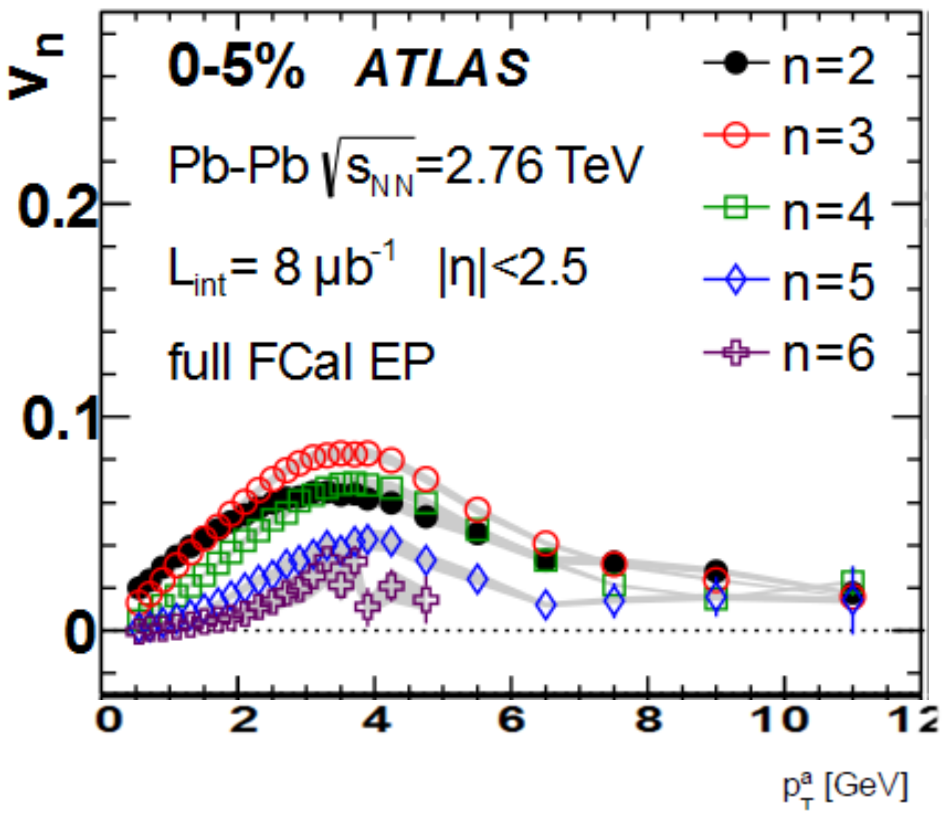




- Results identical for same charged and opposite charged pairs
- Little contribution from jets

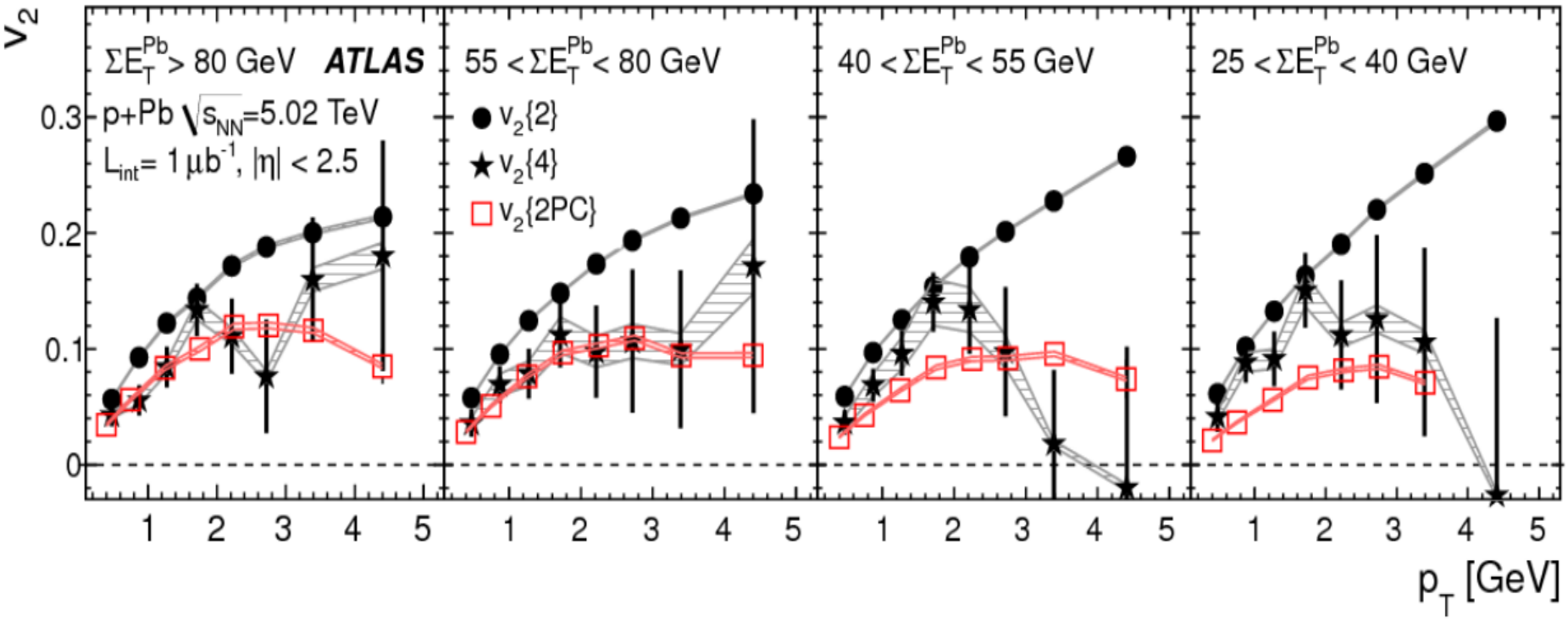
Comparison with Heavy Ions





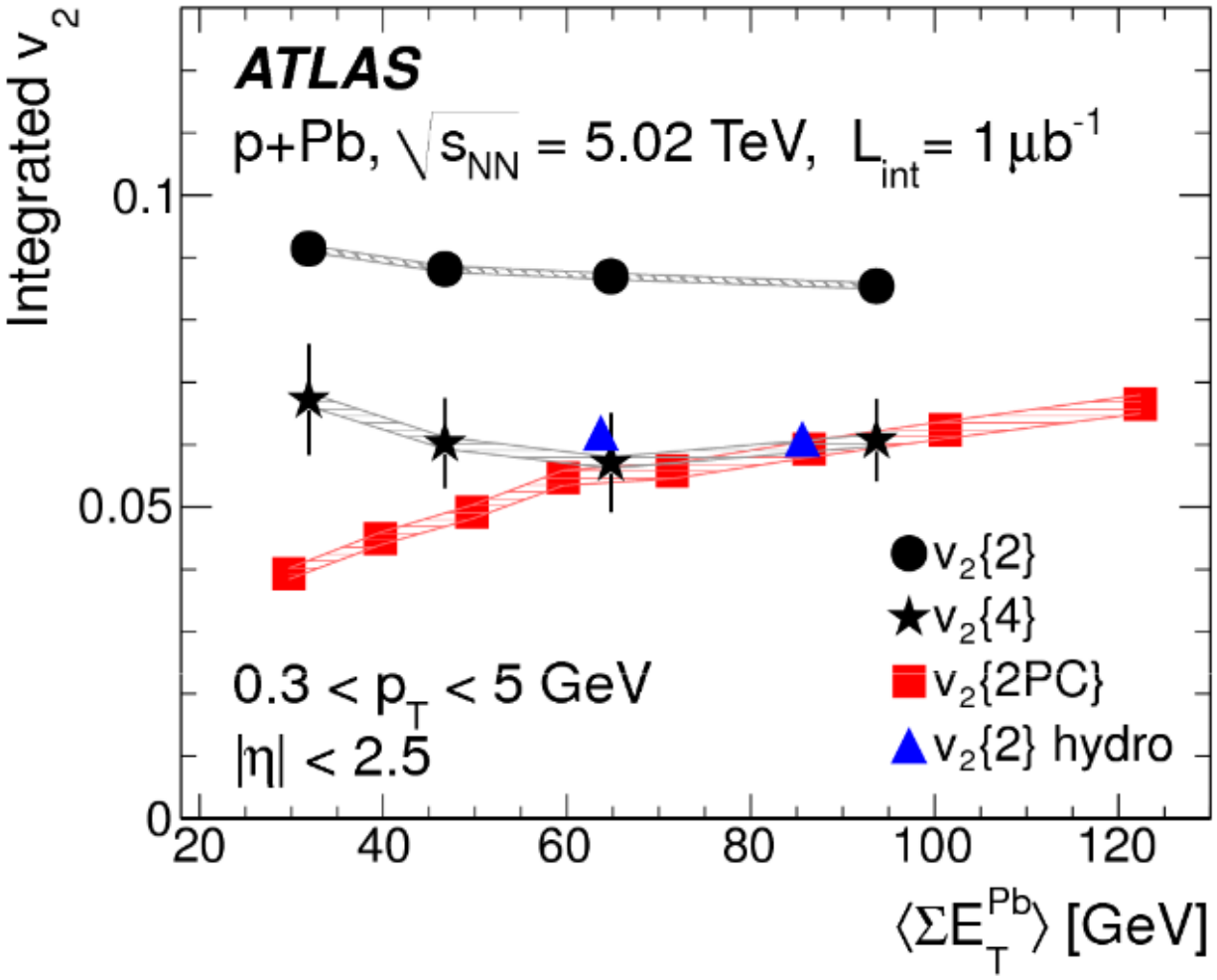
- Similar p_T dependence for second order harmonics
  - Agreement with hydro?
- Relative magnitudes of second and third harmonics different
  - Effect of larger viscosity?

Results from 4 particle and 2 particle cumulants



- Four particle cumulants suppress short range two particle correlations
- $v_2\{4\}$ values have similar p_T and centrality dependence as the recoil subtracted 2PC values
  - Some deviations at lower centrality

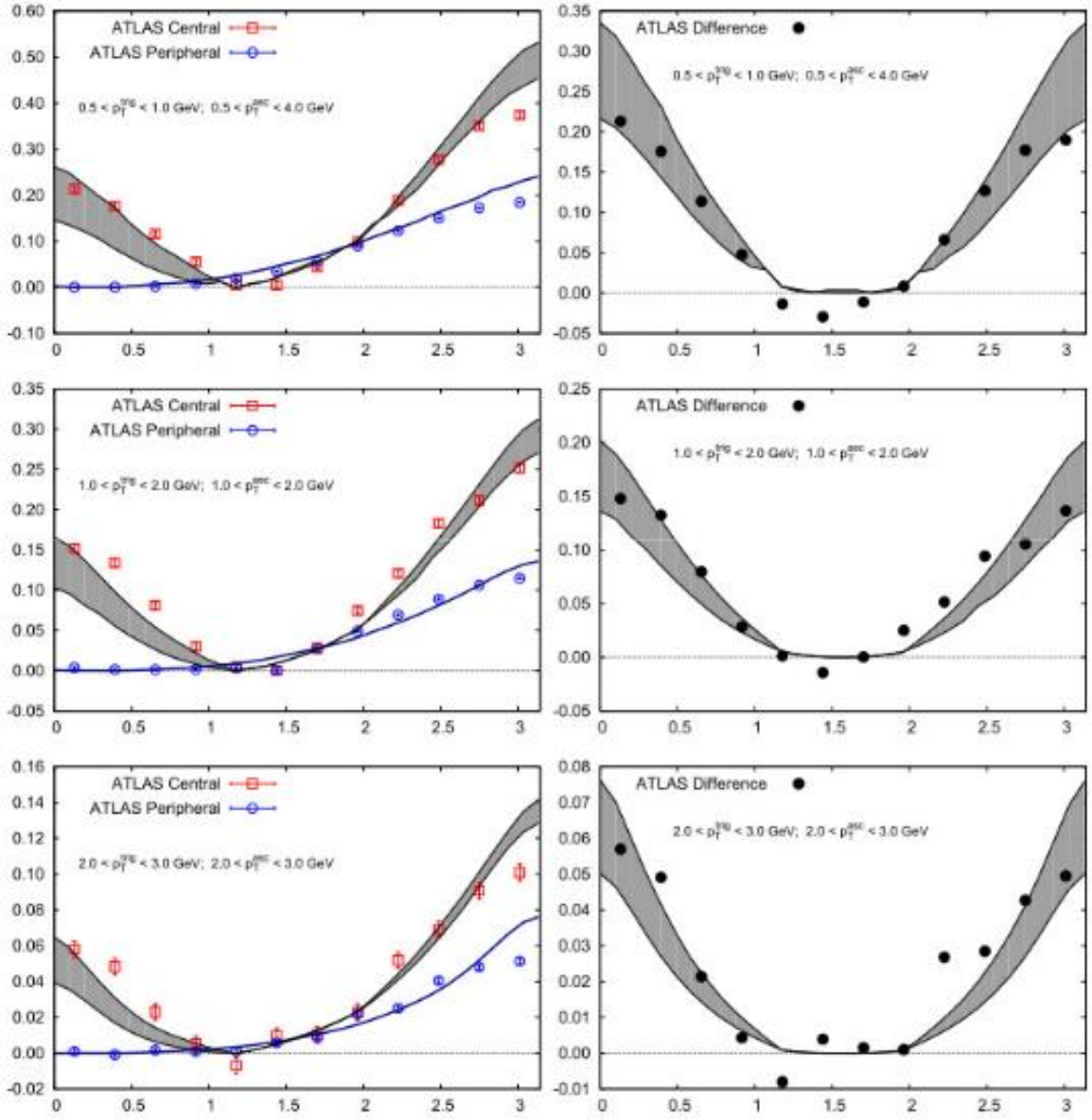
Comparison with Hydro



Hydro calculations: P. Bozek and W. Broniowski, Phys. Lett. B 718 (2013) 1557

- Hydro calculations consistent with $v_2(2PC)$ and $v_2\{4\}$

Comparison to CGC



- Ridge can also result from initial state effects (eg: Color Glass Condensate (C.G.C) effects)
- Ridge yield and p_T dependence well described by CGC calculations as well

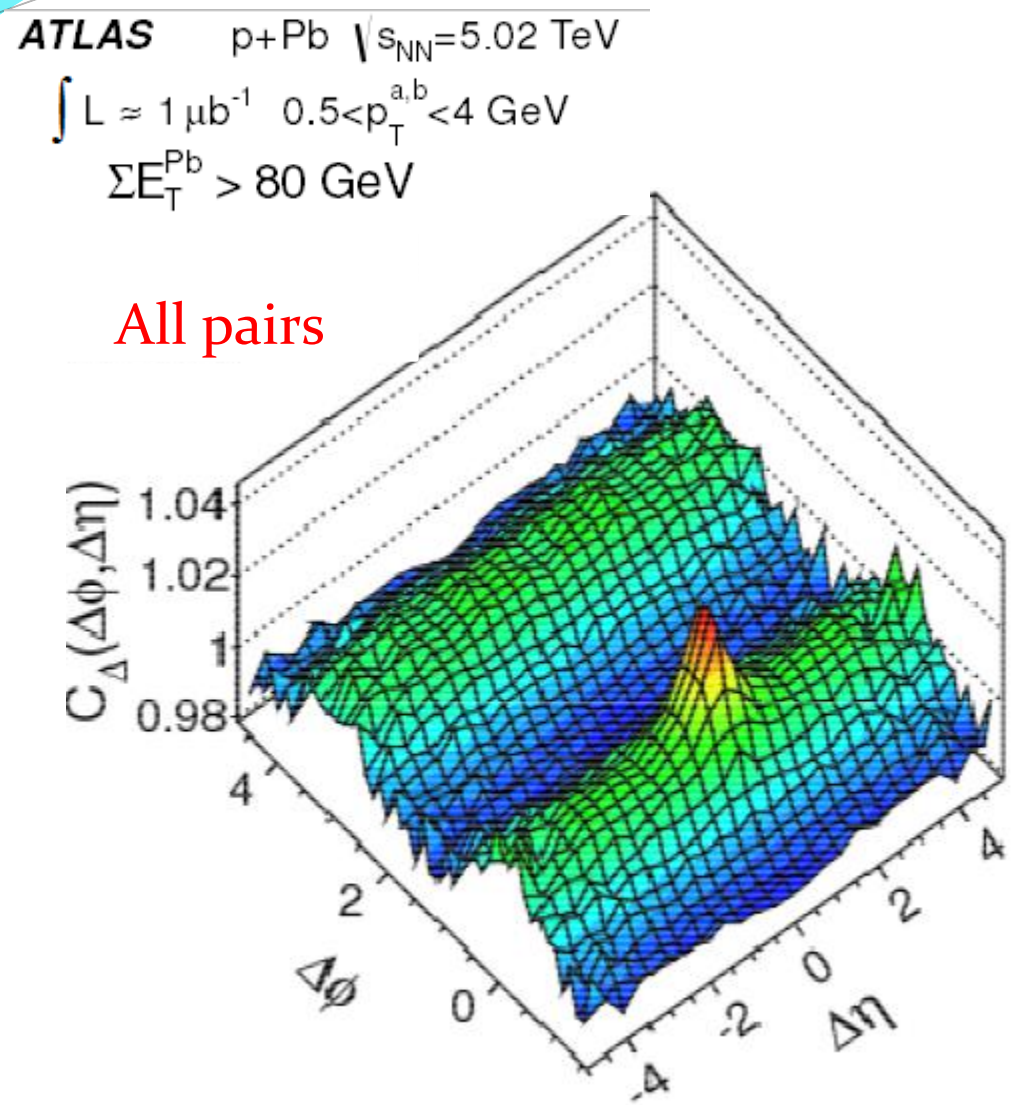
Kevin Dusling, Raju Venugopalan (arXiv 1302.7018)

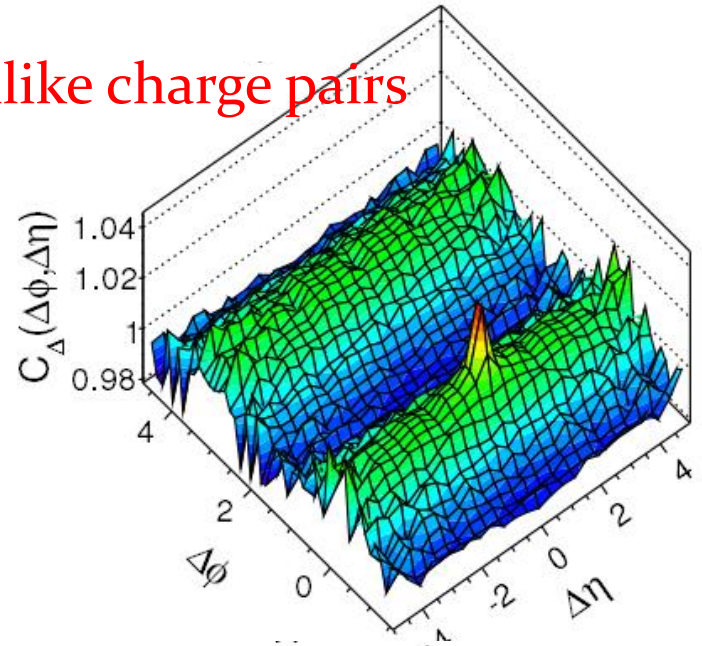
Summary

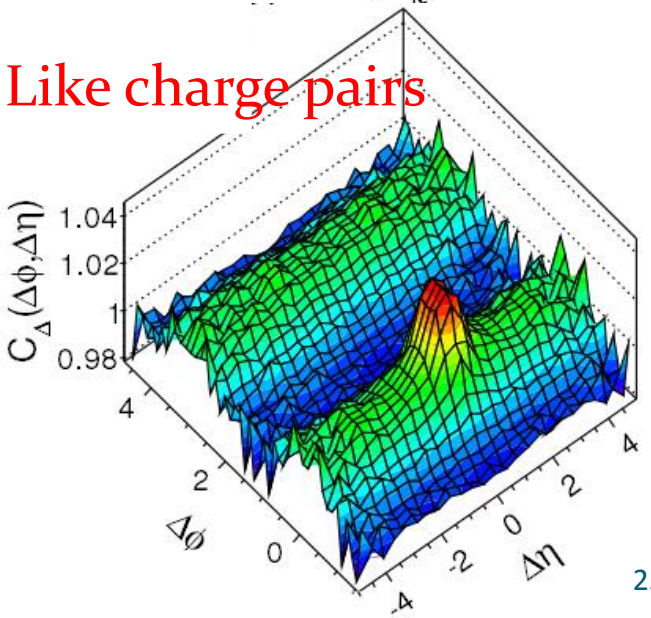
- Long Range azimuthal correlations (ridge) observed by ATLAS in p+Pb collisions
- Symmetric near side and away side ridge(s)
  - Similar p_T and centrality dependence
- Ridge yield and Fourier coefficients have similar p_T dependence as in heavy ion collisions
- Cumulant analysis shows similar p_T and centrality dependence for $v_2\{4\}$
- Agreement with Hydro calculations, Ridge yield and p_T dependence reproduced by CGC calculations as well.

BACK UP

Recoil subtracted correlation



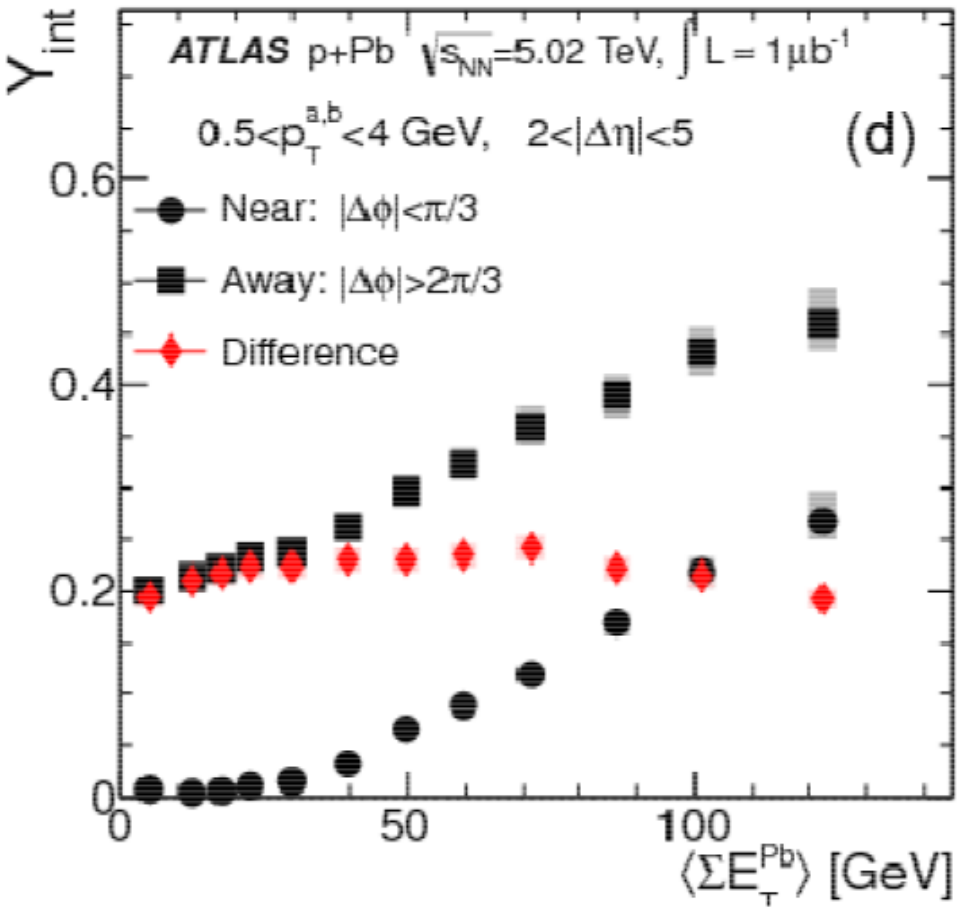


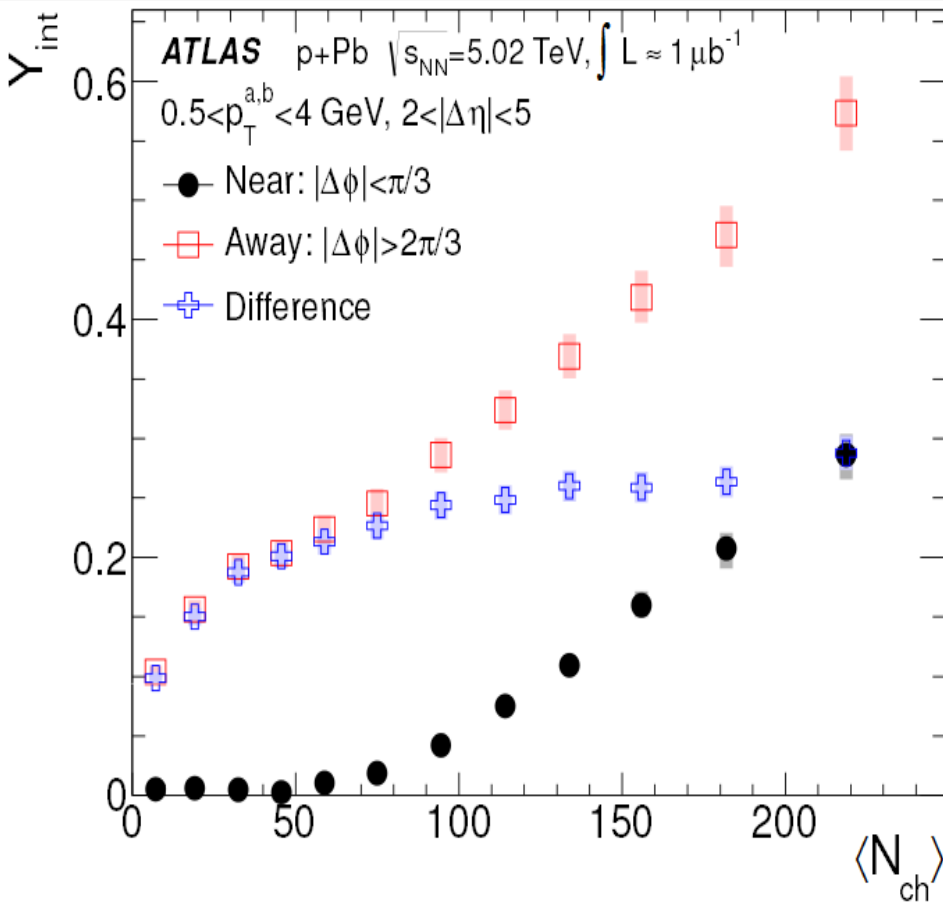


Mean N_{ch} in event activity classes

$\Sigma E_{\mathrm{T}}^{\mathrm{Pb}}$ range [GeV]	> 110	95-110	80-95	65-80	55-65	45-55	35-45	25-35
Percentage [%]	0.21	0.45	1.24	3.11	3.99	6.37	9.71	13.80
$\langle \Sigma E_{\mathrm{T}}^{\mathrm{Pb}} \rangle$ [GeV]	122.4	101.2	86.4	71.4	59.6	49.7	39.7	29.7
$\langle N_{\mathrm{ch}} \rangle$	183.1±8.2	159.9±7.2	141.3±6.4	122.5±5.5	107.2±4.8	93.3±4.2	78.8±3.6	63.3±2.9
$\sigma_{N_{\mathrm{ch}}}$	37.0±2.1	33.1±1.9	31.5±1.8	29.6±1.7	27.6±1.6	25.9±1.5	24.1±1.4	21.8±1.2
$\Sigma E_{\mathrm{T}}^{\mathrm{Pb}}$ range [GeV]	20-25	15-20	10-15	< 10	> 80	55-80	25-55	< 20
Percentage [%]	8.67	10.11	11.98	30.36	1.90	13.47	29.88	52.45
$\langle \Sigma E_{\mathrm{T}}^{\mathrm{Pb}} \rangle$ [GeV]	22.4	17.4	12.4	4.9	94.4	64.8	37.3	9.0
$\langle N_{\mathrm{ch}} \rangle$	51.0±2.3	41.8±1.9	31.7±1.5	15.9±0.7	150.3±6.8	113.9±5.1	74.7±3.4	24.5±1.1
$\sigma_{N_{\mathrm{ch}}}$	19.6±1.1	17.9±1.0	15.7±0.9	11.8±0.7	35.2±2.0	29.4±1.7	26.1±1.5	17.5±1.0

Autocorrelation bias in N_{ch} based selection

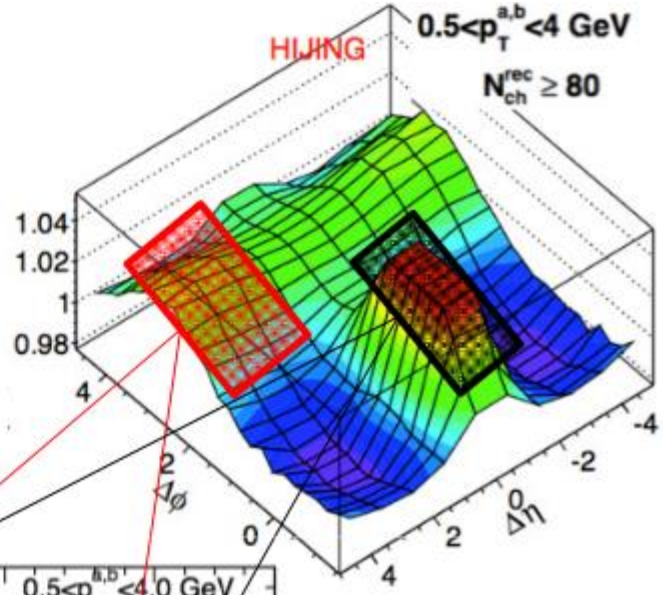




- Away Side Yield shows a sharp drop for events required to have low $<N_{ch}>$: natural consequence of autocorrelations between $<N_{ch}>$ and production of correlated pairs.

N_{ch} bias with Hijing

- Hijing has no ridge, mostly short range correlations.



Clear bias effects in N_{ch} based selections