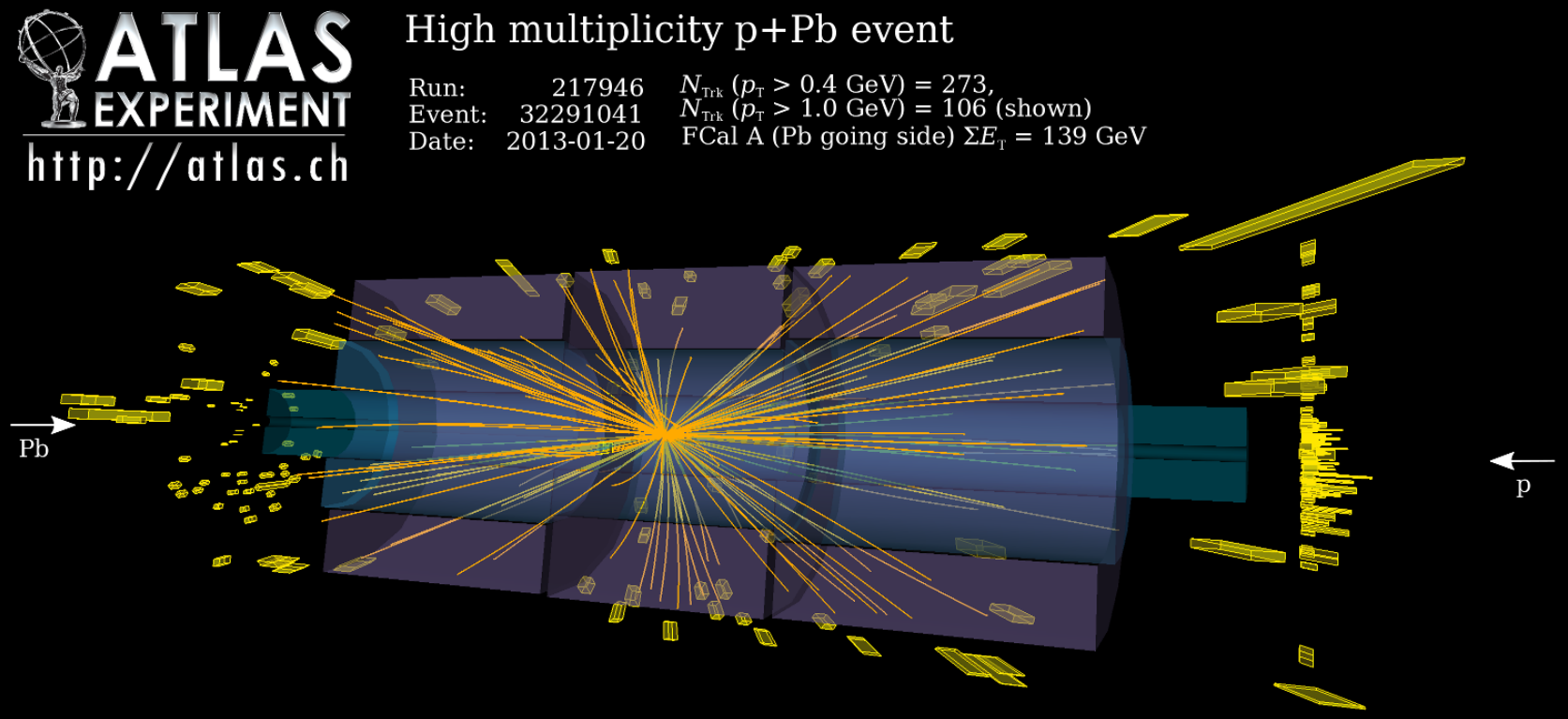
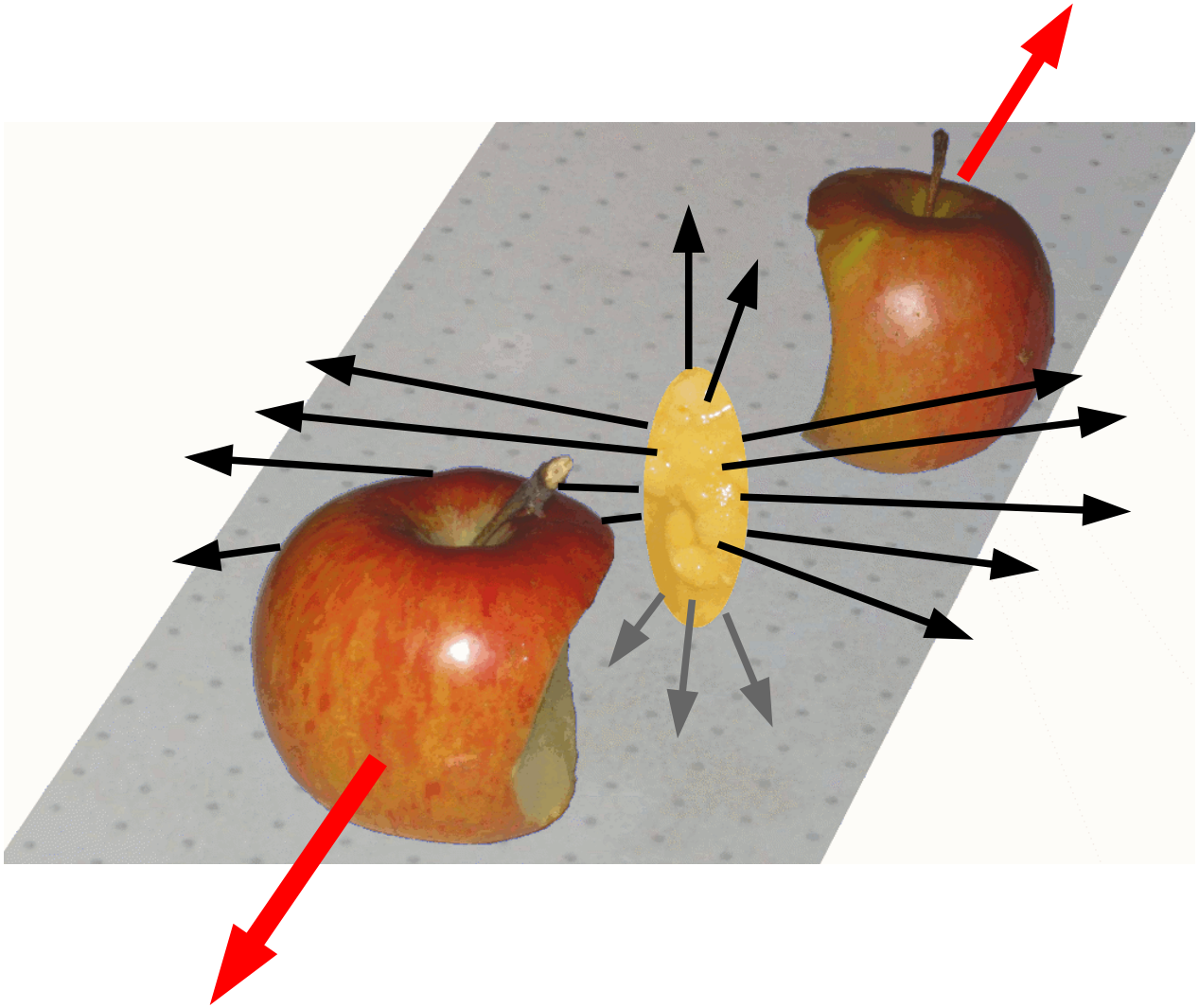
Flow measurements in p+Pb (and their comparison with Pb+Pb) at ATLAS

Krzysztof Woźniak, IFJ PAN, Kraków, Poland
for the ATLAS Collaboration

Rencontres de Moriond 2015, QCD and High Energy Interactions

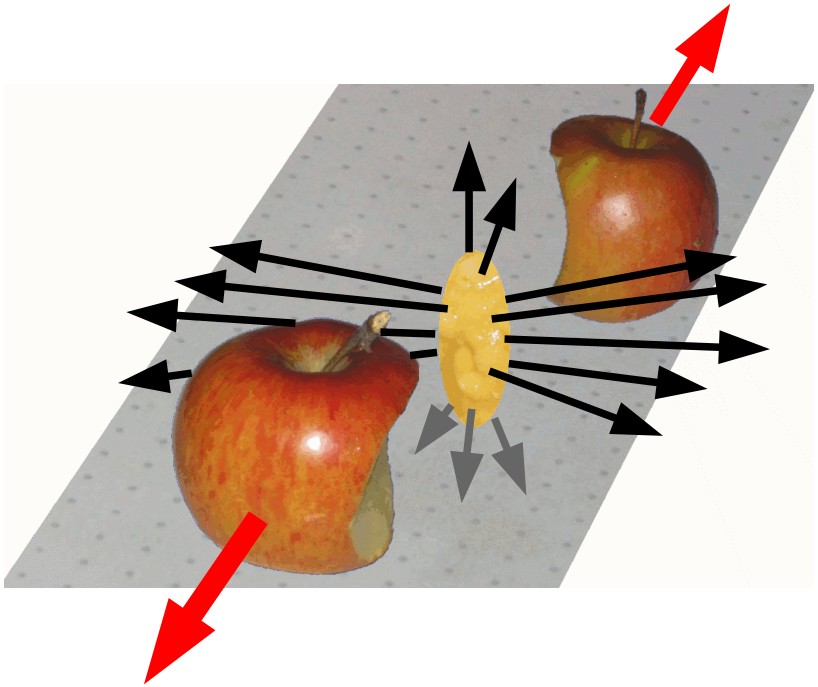


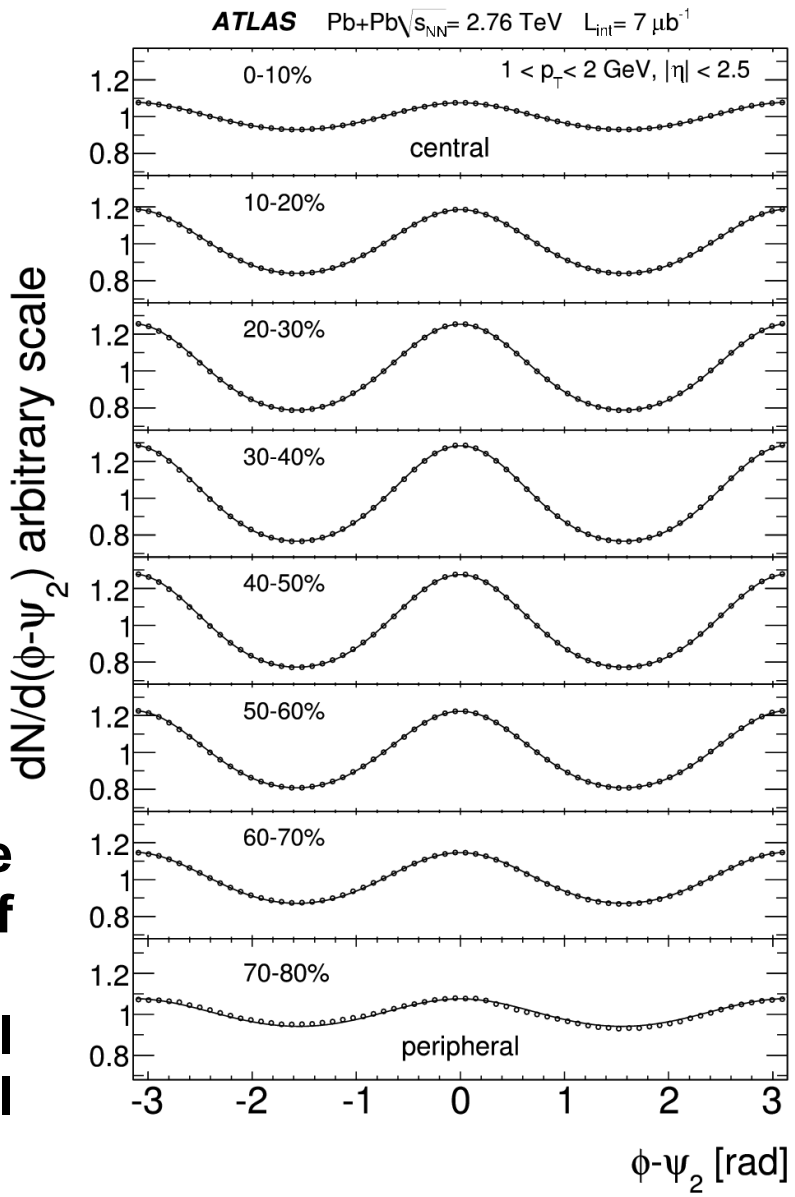
Flow in heavy ion collisions



In the collisions of nuclei Quark-Gluon Plasma (QGP) is created. Preassure gradients result in differences in particle emmision observed as particle flow.

Flow in heavy ion collisions - azimuthal angle distribution

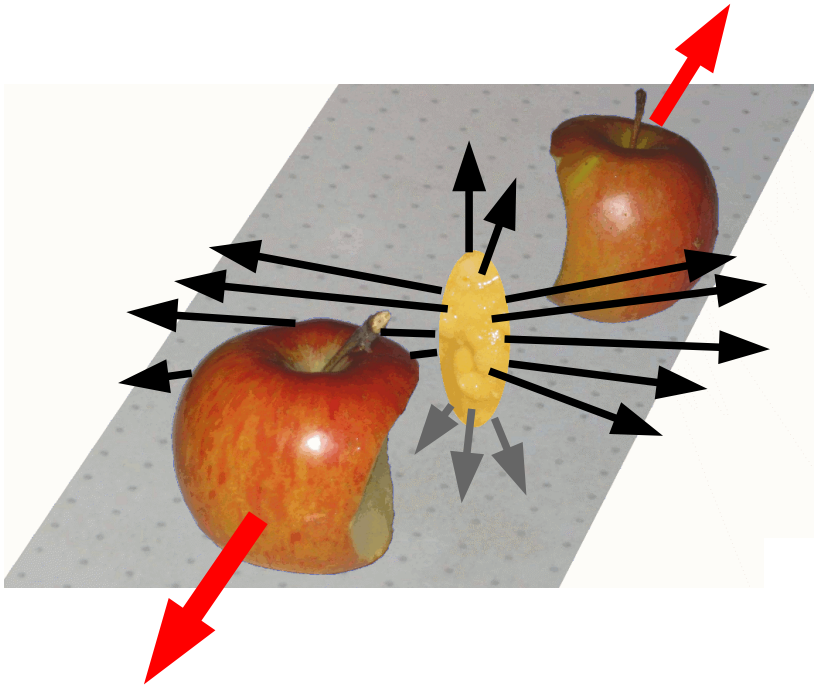




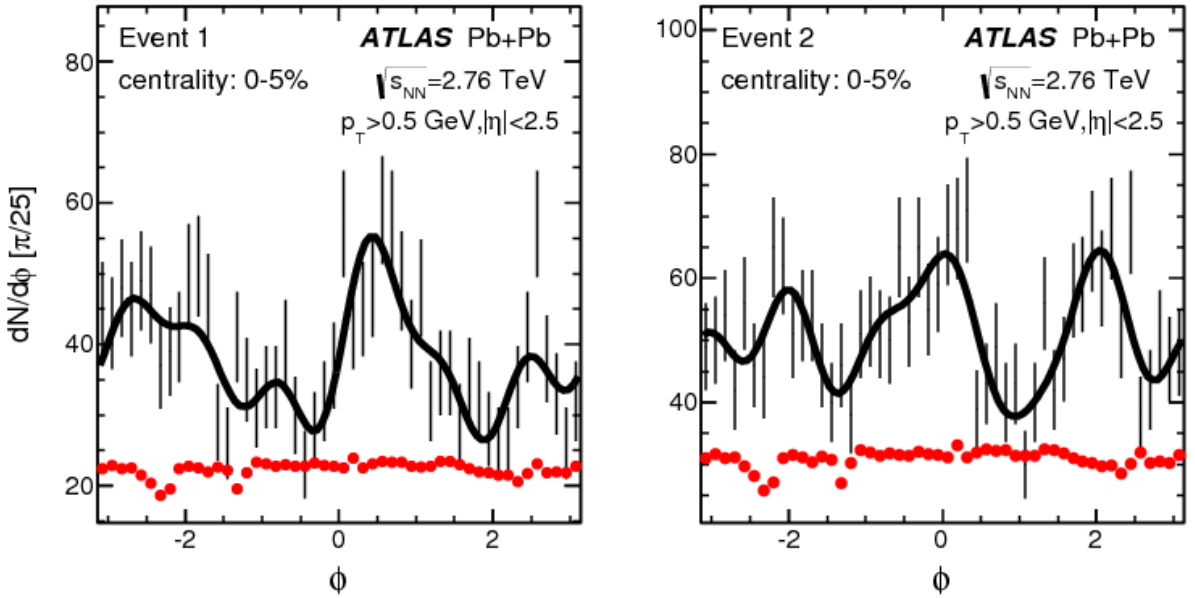
Elongated shape of collision volume leads to sinusoidal modulation of the azimuthal angle distribution.
In Pb+Pb collisions maximal amplitude is reached in mid-central collisions.

ATLAS, Phys. Lett. B707 (2012) 330.

Flow in heavy ion collisions - azimuthal angle distribution

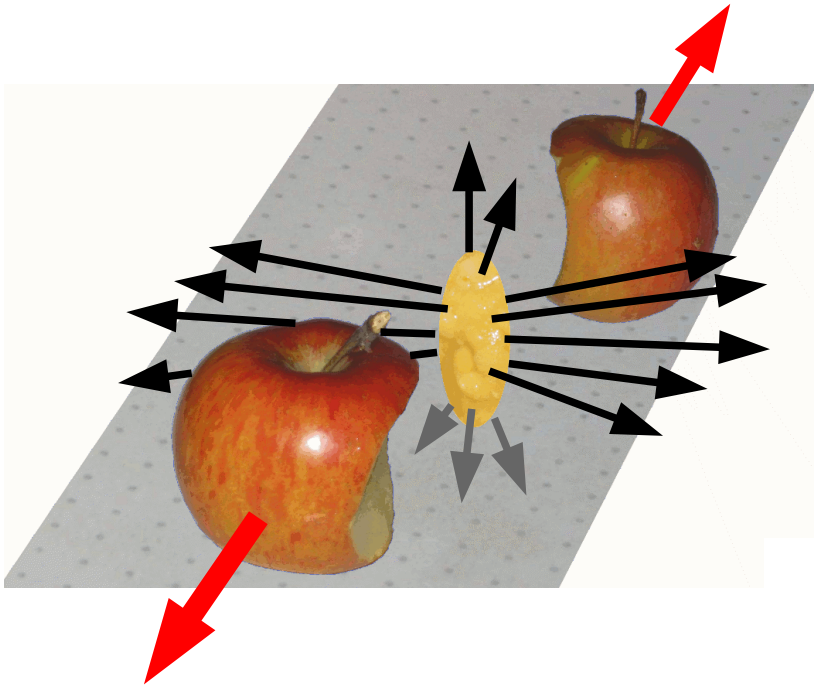


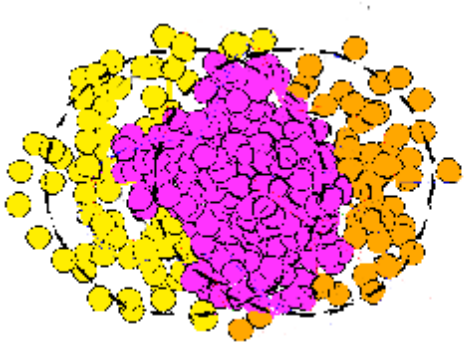
Especially in the most central collisions azimuthal angle distribution deviates from sinusoidal form.



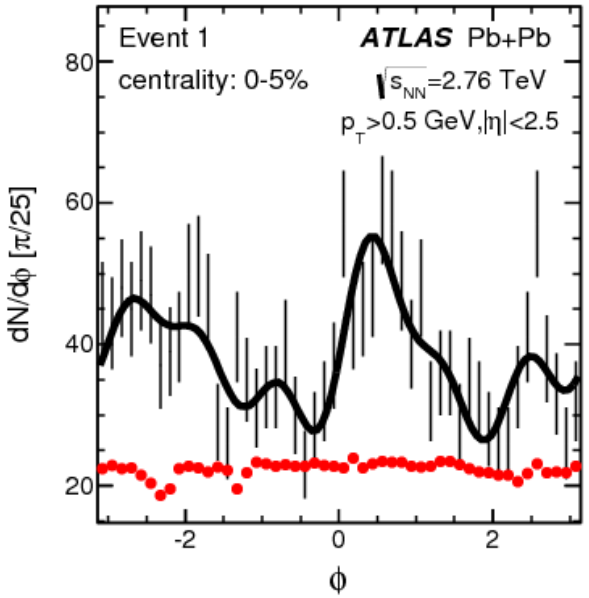
ATLAS, JHEP11 (2012) 183.

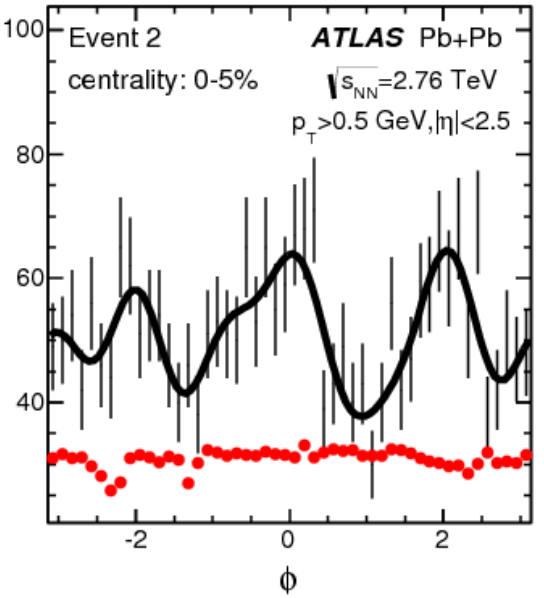
Flow in heavy ion collisions - nuclei overlap fluctuations





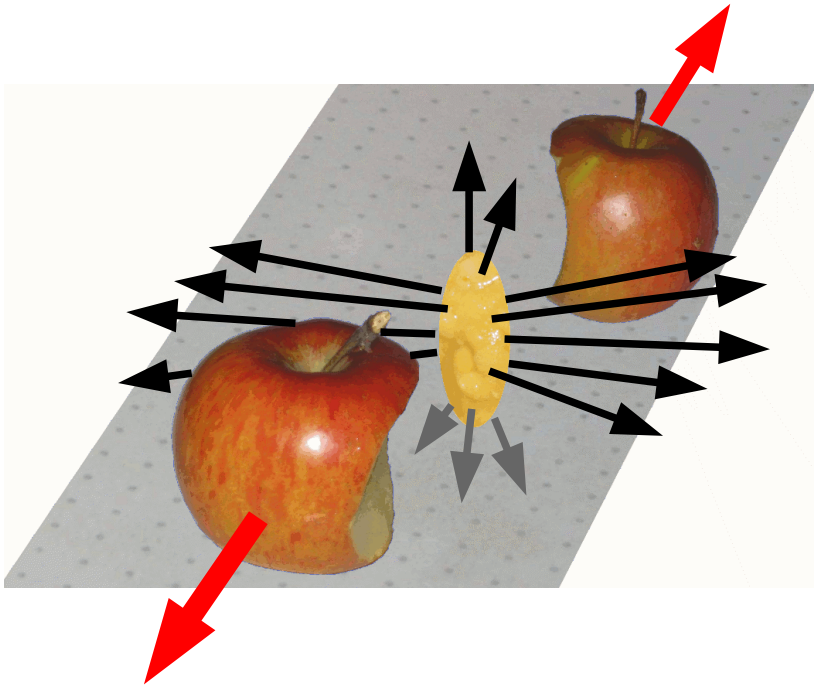
Especially in the most central collisions azimuthal angle distribution deviates from sinusoidal form.
It is connected with the fluctations of the shape of the initial collision volume.

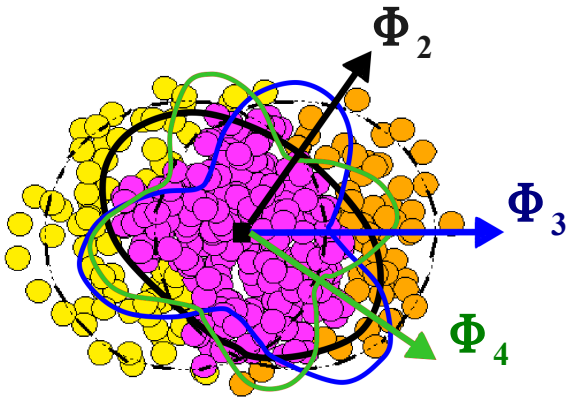




ATLAS, JHEP11 (2012) 183.

Flow in heavy ion collisions - Fourier decomposition





Event plane method

$$\frac{dN}{d\phi} \sim 1+2\sum_{n=1}^{\infty} v_n(p_T,\eta)\cos(n(\phi-\Phi_n))$$

$$v_n = \langle\cos(n(\phi-\Phi_n))\rangle$$

Two-particle correlations method

$$\frac{dN}{d(\phi_a-\phi_b)} \sim 1+2\sum_{n=1}^{\infty} v_{n,n}(p_T^a,p_T^b)\cos(n(\phi_a-\phi_b))$$

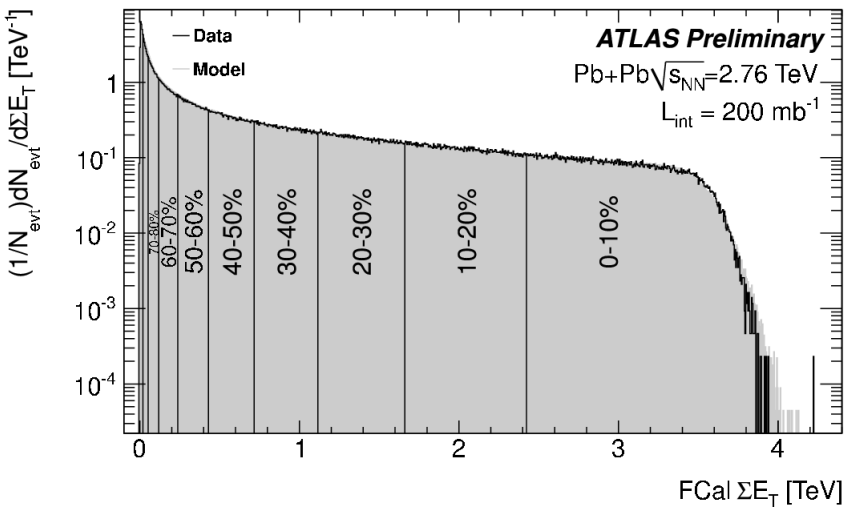
$$v_{n,n} = \langle\cos(n(\phi_a-\phi_b))\rangle$$

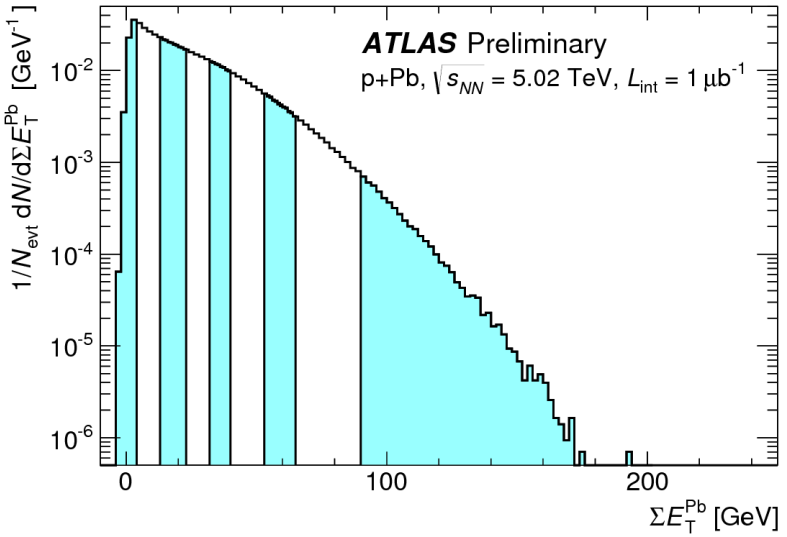
for flow: $v_{n,n}(p_T^a,p_T^b) = v_n(p_T^a)v_n(p_T^b)$

Cumulants from 2k-particle correlations

$$\langle corr_n\{2k\}\rangle = \langle\exp(in(\phi_1+\ldots+\phi_k-\phi_{k+1}+\ldots+\phi_{2k}))\rangle$$

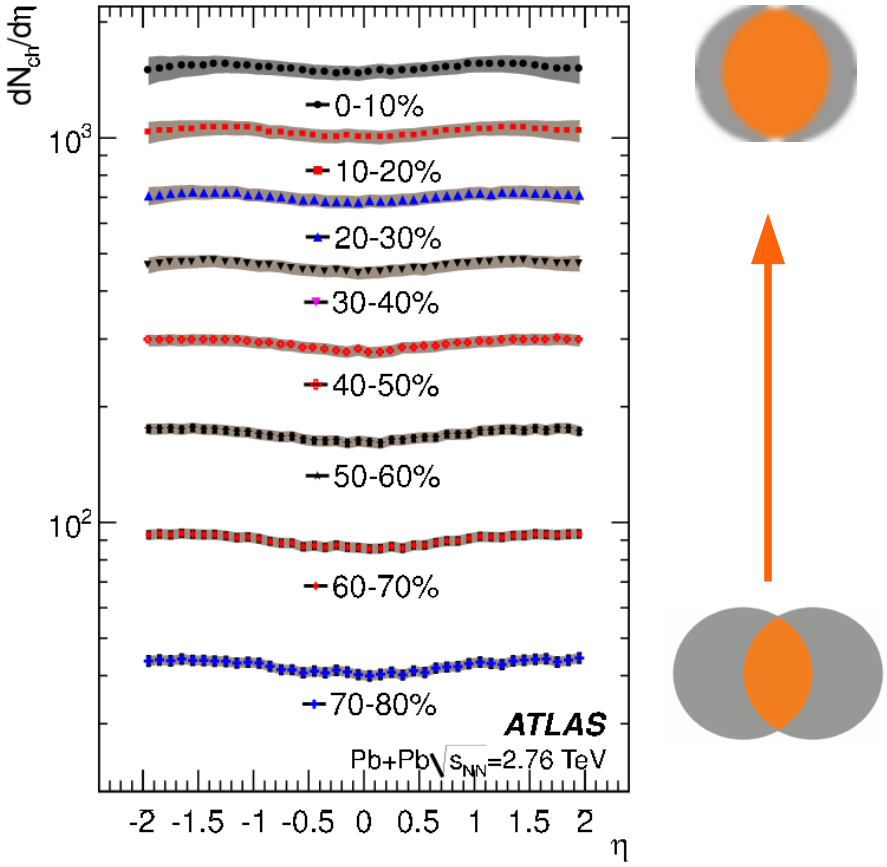
Centrality of Pb+Pb and p+Pb collisions



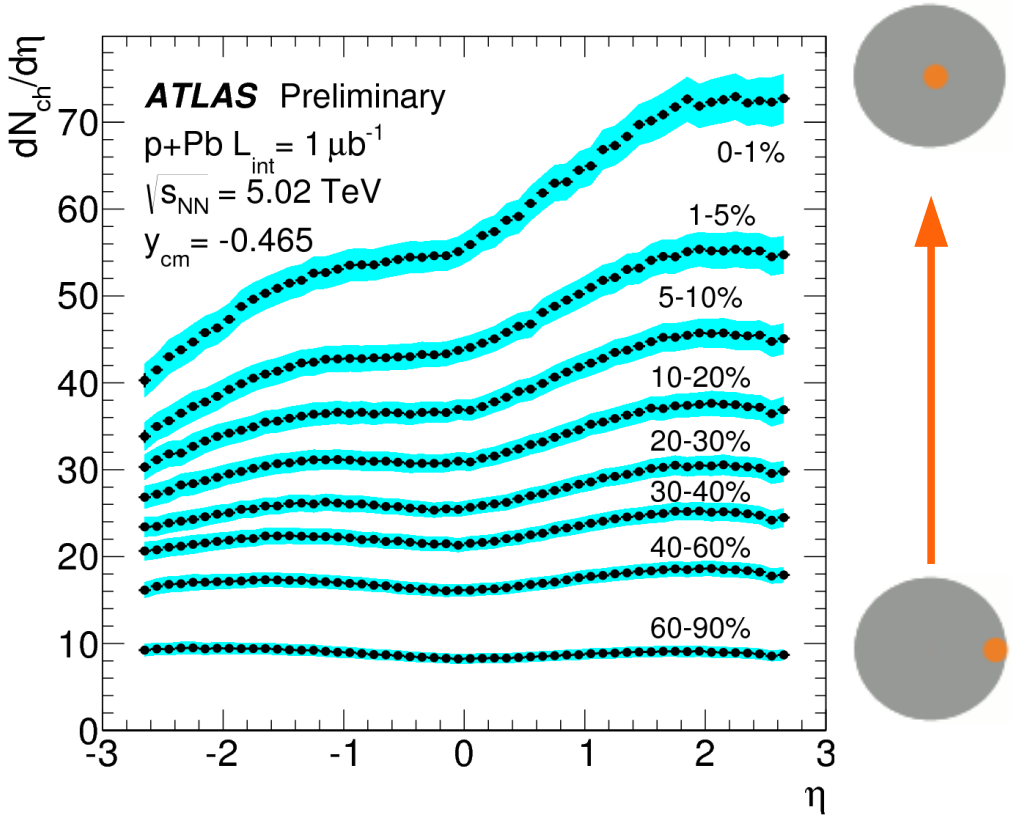


Distribution of the signals registered in the Forward Calorimeter (FCal), in 3.1 < |η| < 4.9 range, is divided into bins with appropriate percentage of events. For p+Pb collisions only the side of Pb nuclei fragmentation is used.
Fraction of the sampled non-Coulomb inelastic cross section after all trigger selection cuts is estimated to be 98% ±2%

Particle density distributions



ATLAS, Phys. Lett. B710 (2012) 363.

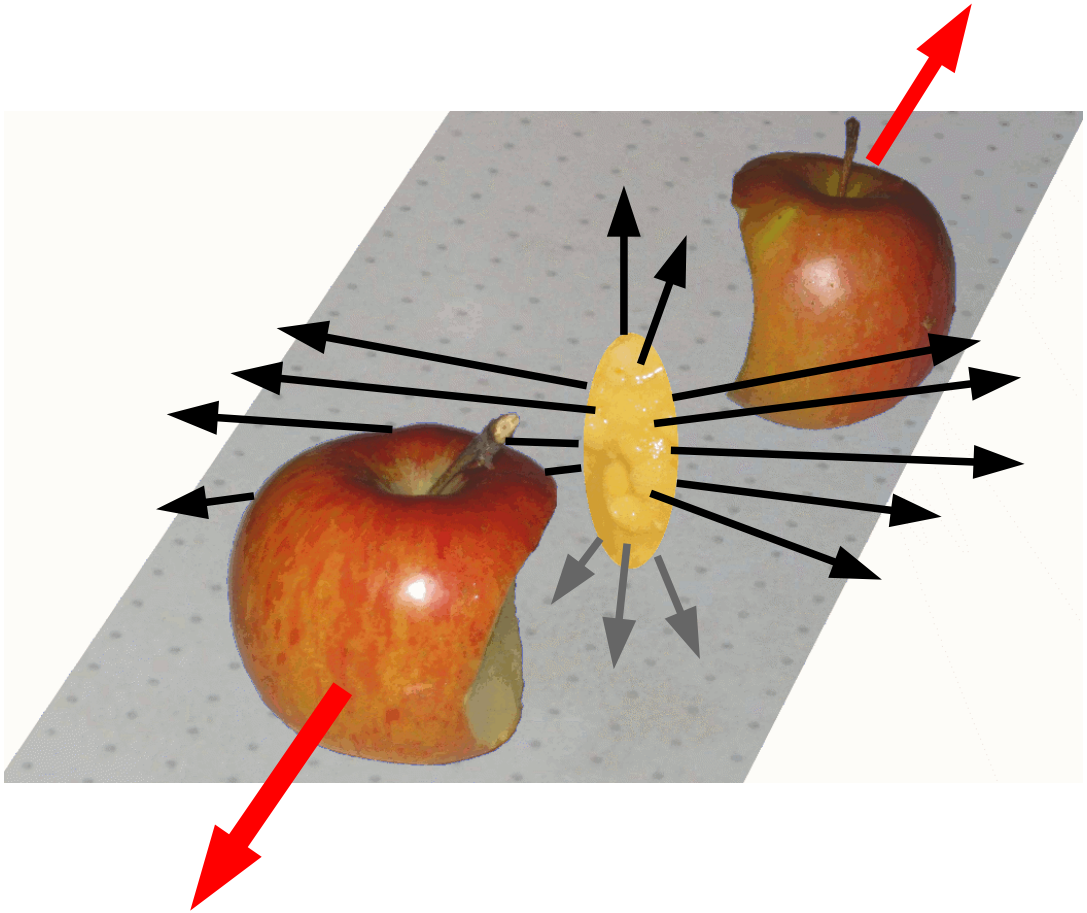


ATLAS-CONF-2013-096.

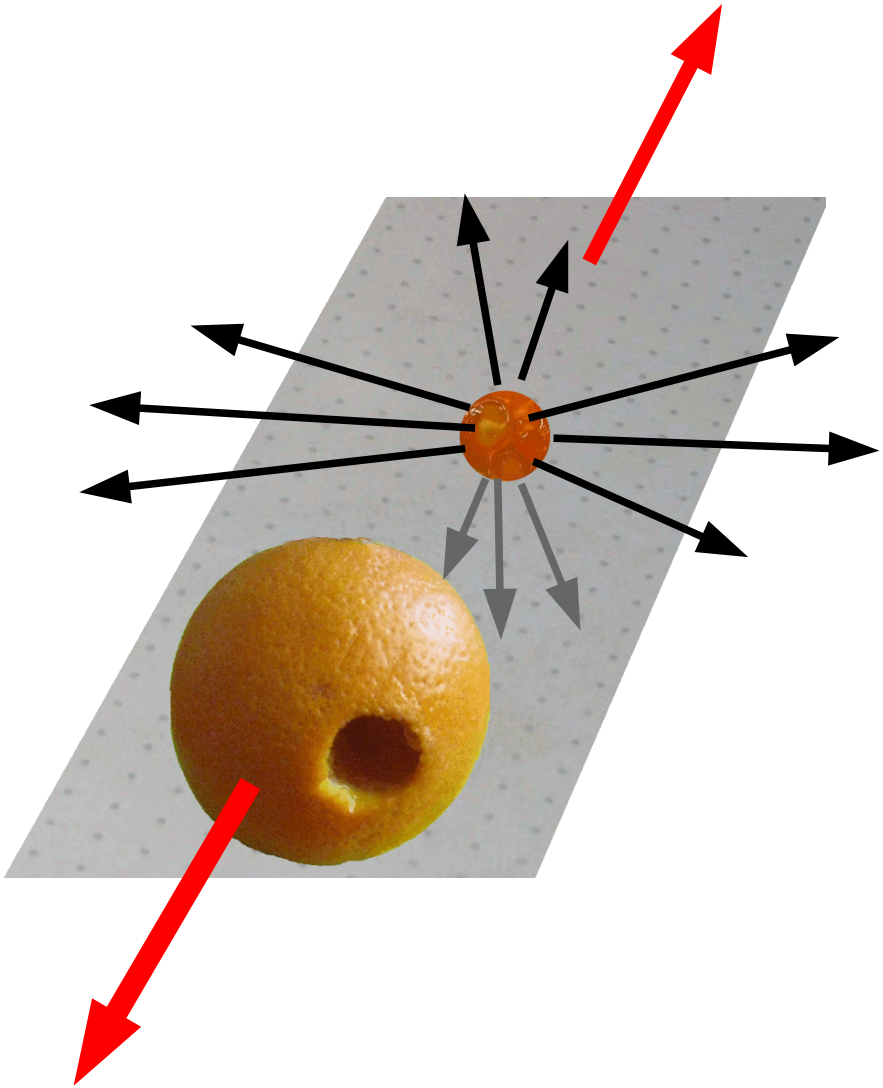
Large difference in the multiplicity.
Asymmetric shape of pseudorapidity distribution in the central p+Pb collisions

Geometry of Pb+Pb and p+Pb collisions

Pb+Pb collision

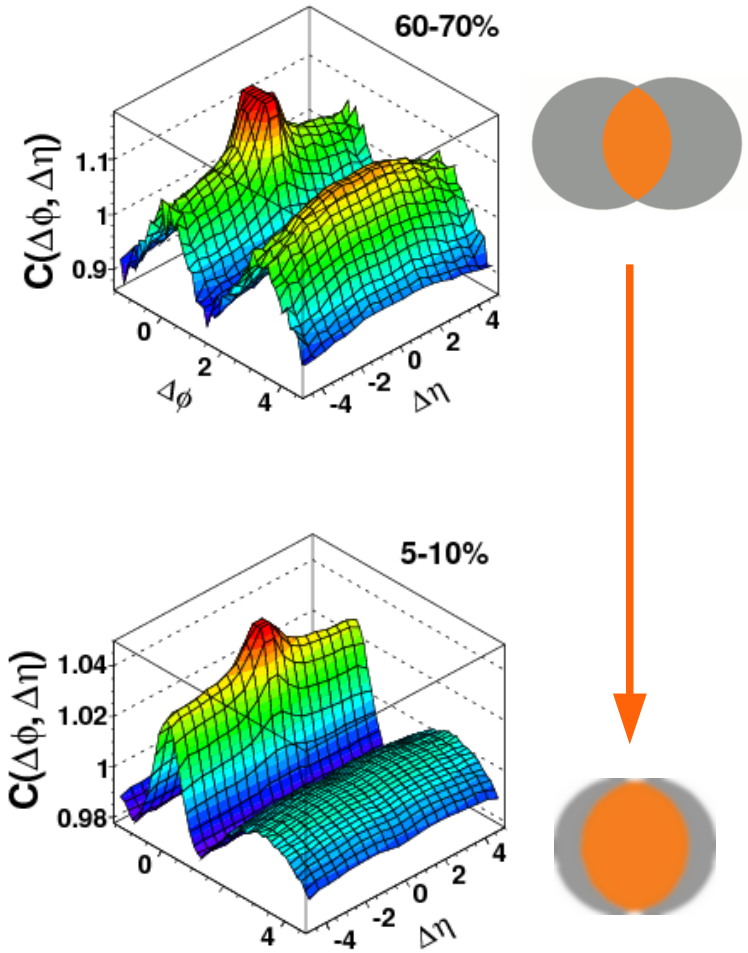


p+Pb collision



Two-particle correlations in Pb+Pb collisions

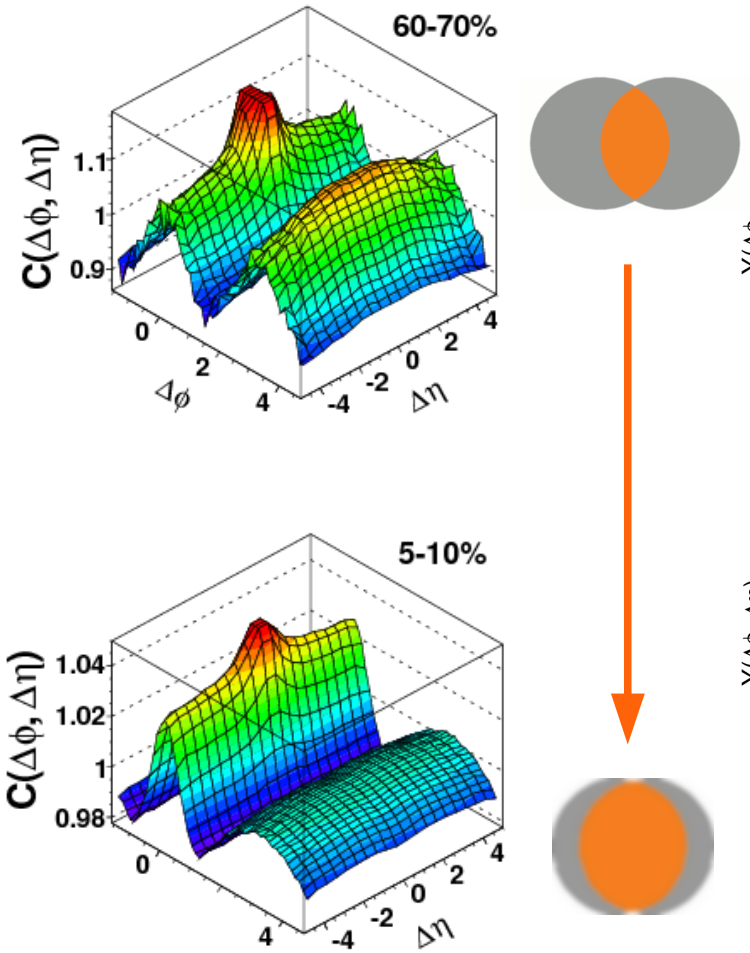
Pb+Pb collisions



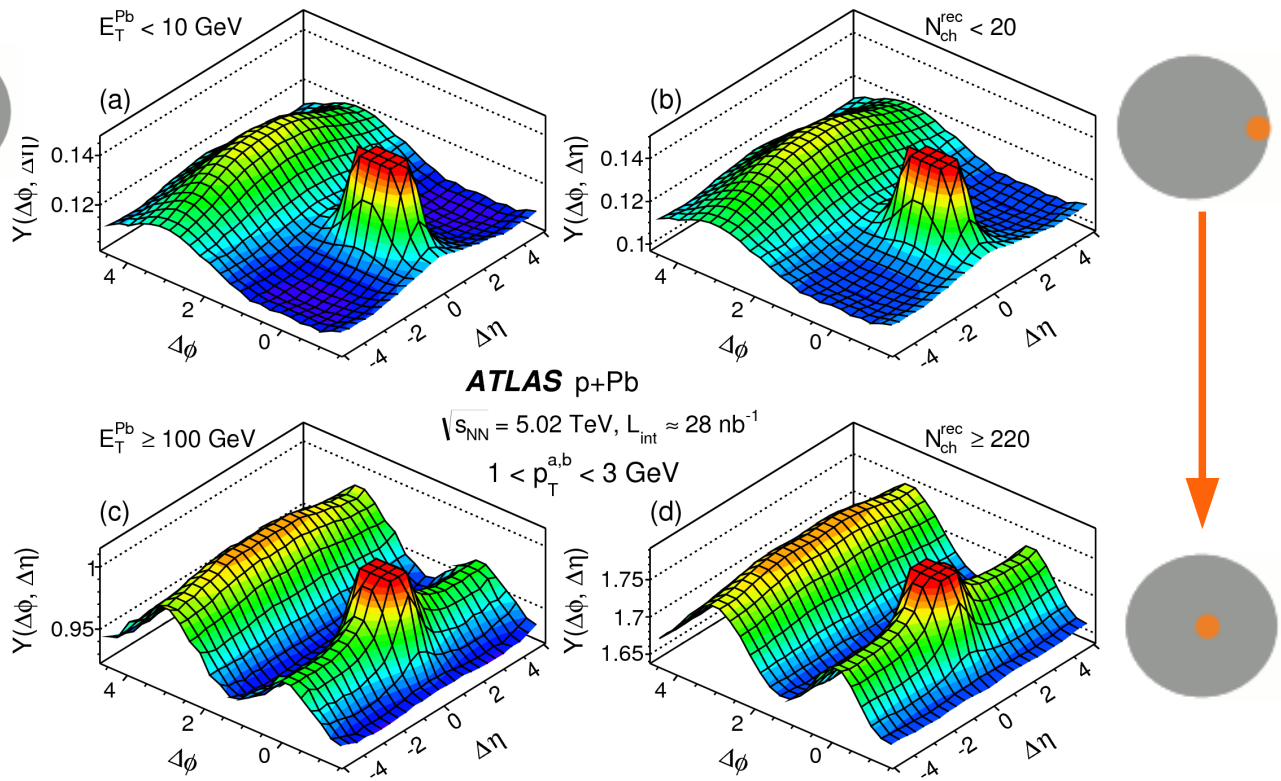
Phys. Rev. C86 (2012) 014709.

Two-particle correlations in p+Pb collisions

Pb+Pb collisions



In the p+Pb events with high multiplicity a long-range correlation similar to flow is observed.



$$Y(\Delta\phi,\Delta\eta)=\frac{\int B(\Delta\phi,\Delta\eta)\,d\Delta\phi\,d\Delta\eta}{\pi\eta_{\Delta}^{max}}\left(\frac{S(\Delta\phi,\Delta\eta)}{B(\Delta\phi,\Delta\eta)}\right)$$

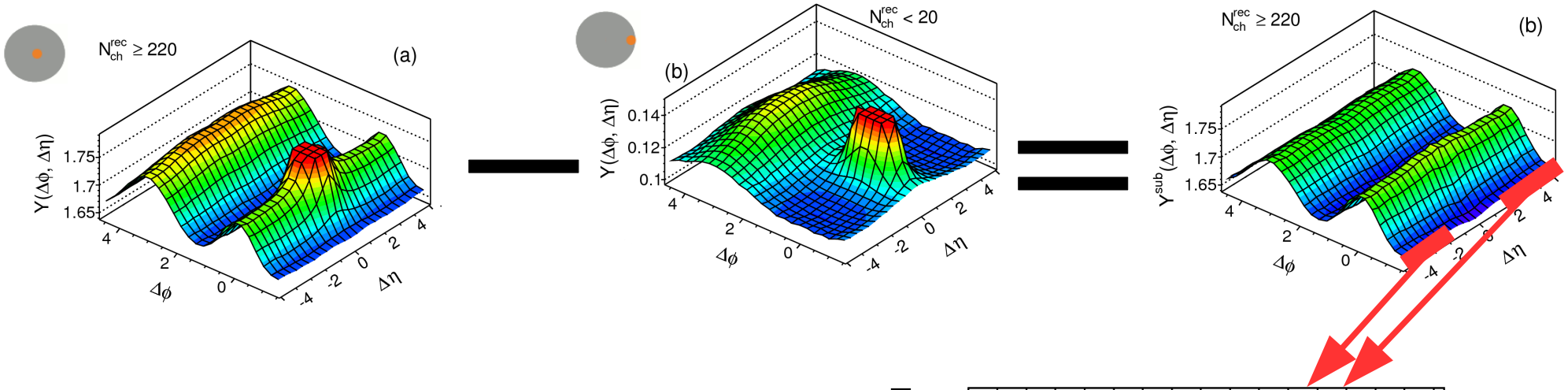
S - signal

B - background mixed events

Phys. Rev. C90 (2014) 044906.

Per trigger yield in p+Pb collisions - recoil subtraction

To study long-range effects without contribution from jets, the yield from peripheral events has to be subtracted:



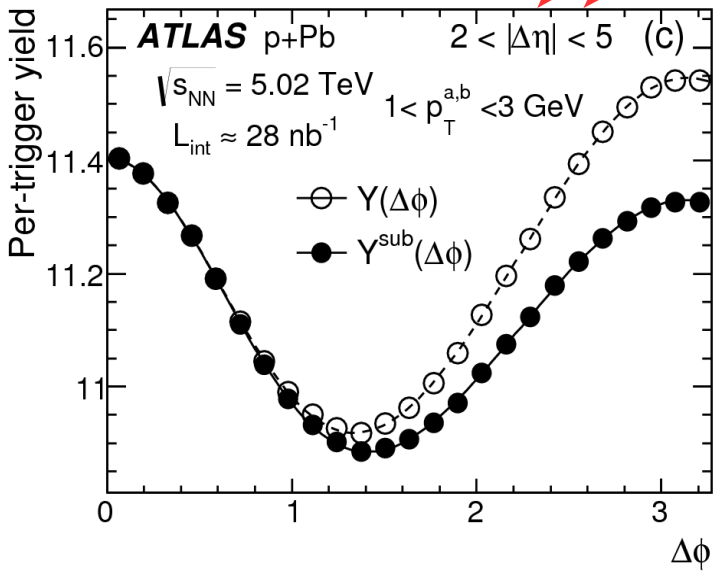
$$Y^{sub}(\Delta\phi,\Delta\eta) = Y(\Delta\phi,\Delta\eta) - \alpha Y^{corr}_{peri}(\Delta\phi,\Delta\eta)$$

$$Y^{corr}(\Delta\phi,\Delta\eta) = \frac{\int B(\Delta\phi,\Delta\eta)\,d\Delta\phi\,d\Delta\eta}{\pi\eta_{\Delta}^{max}}\left(\frac{S(\Delta\phi,\Delta\eta)}{B(\Delta\phi,\Delta\eta)} - b_{ZYAM}\right)$$

Pedestal

$$\alpha = \frac{Y^{N\text{-Peak}}}{Y^{N\text{-Peak}}_{peri}}$$

$$Y^{recoil}(\Delta\phi) = \alpha Y^{corr}_{peri}(\Delta\phi)$$



raw yield

corrected yield

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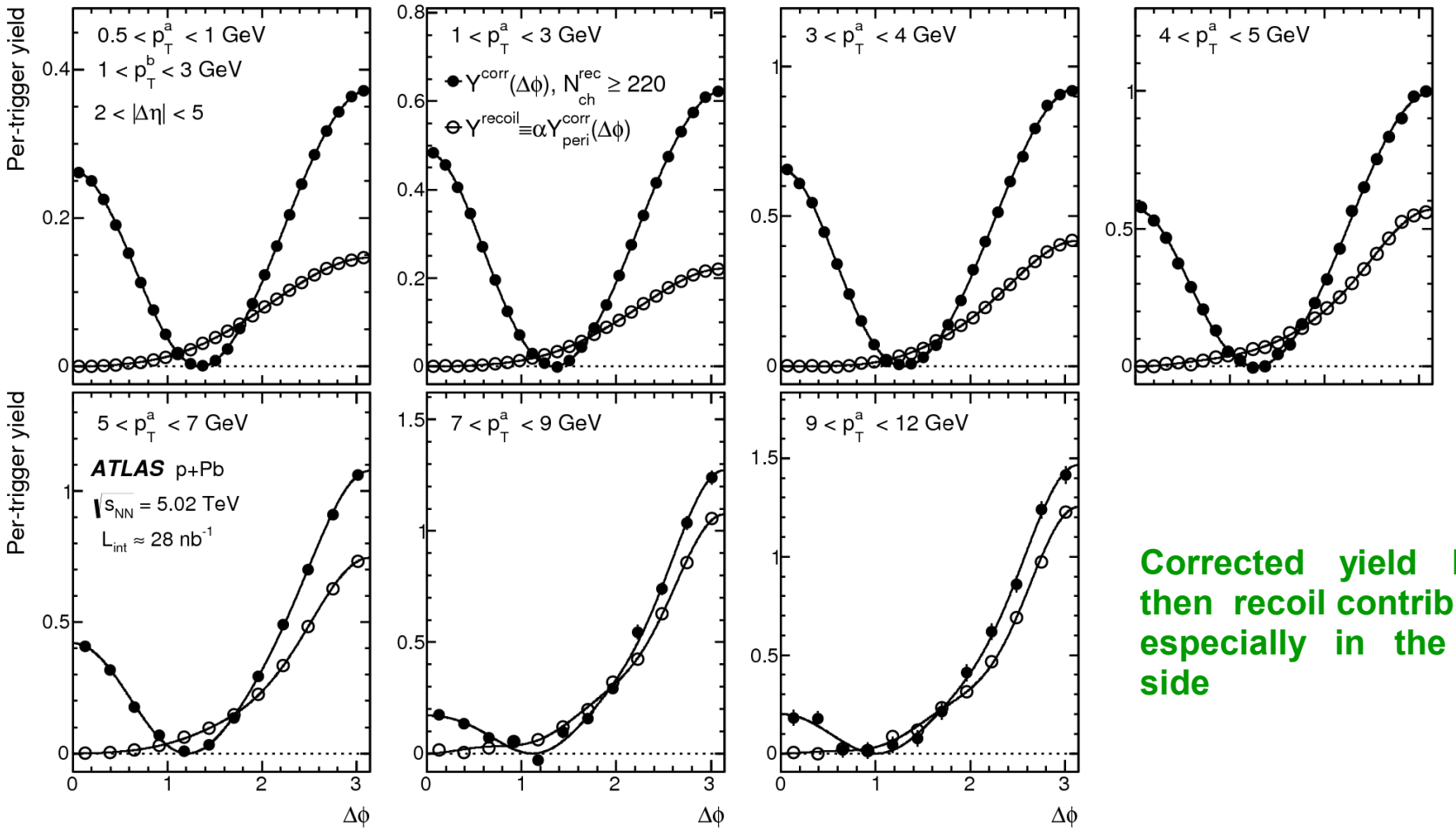
Per trigger yield in p+Pb collisions - corrected and recoil yields

Per trigger yield integrated over $2 < |\Delta\eta| < 5$ range, in high multiplicity events and several intervals of p_T^a



corrected yield

recoil

Corrected yield larger then recoil contribution, especially in the near side

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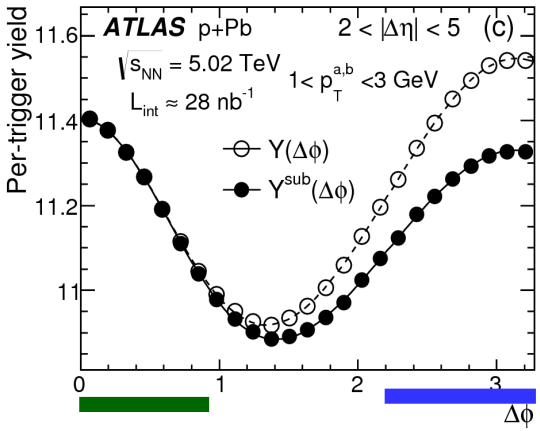
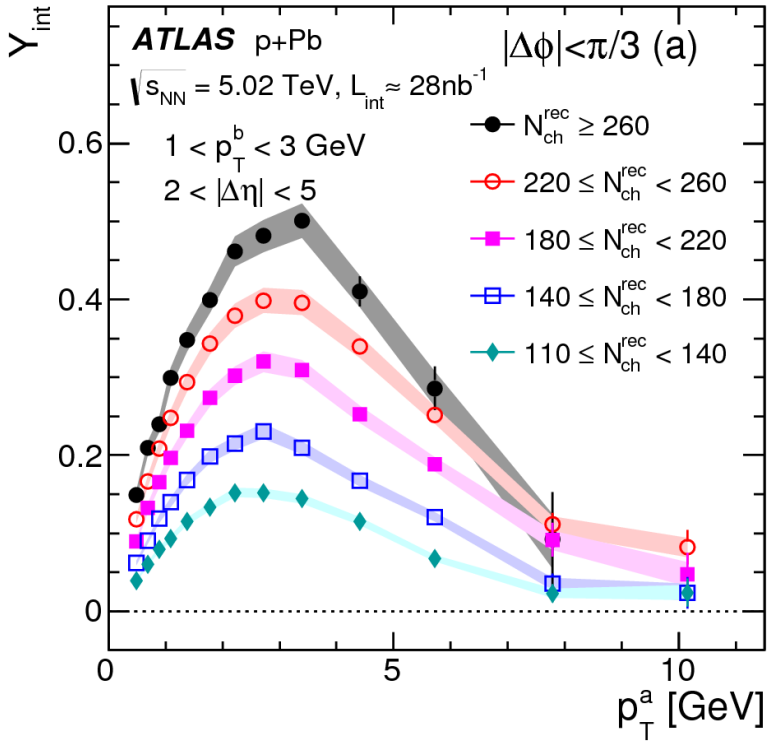
Per trigger yield in p+Pb collisions - dependence on p_T

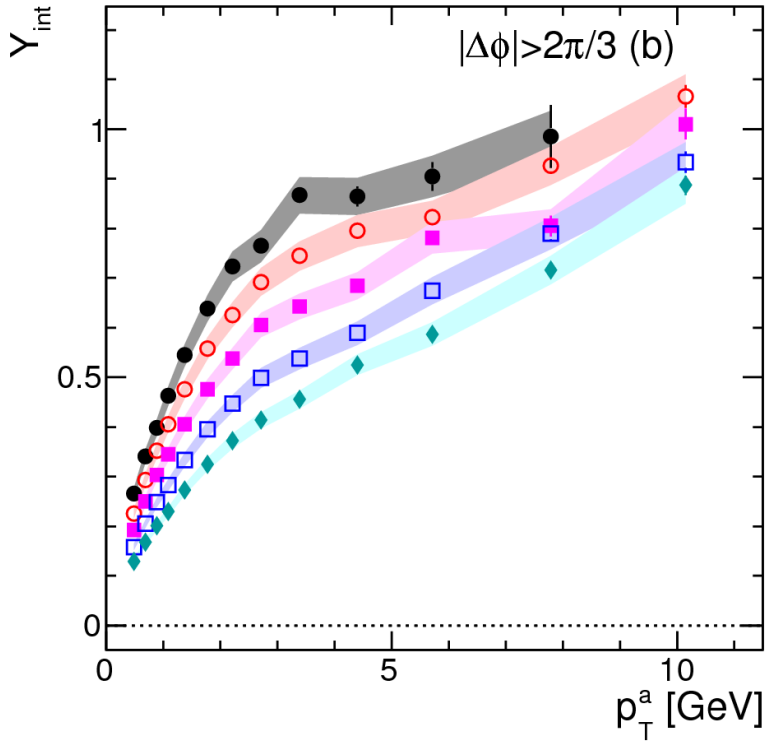


Yield integrated in Δφ ranges: near and away sides for several multiplicity intervals as a function p_T^a

near side

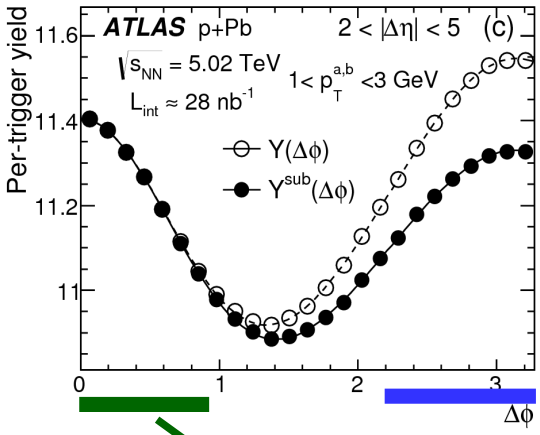


away side



Phys. Rev. C90 (2014) 044906.

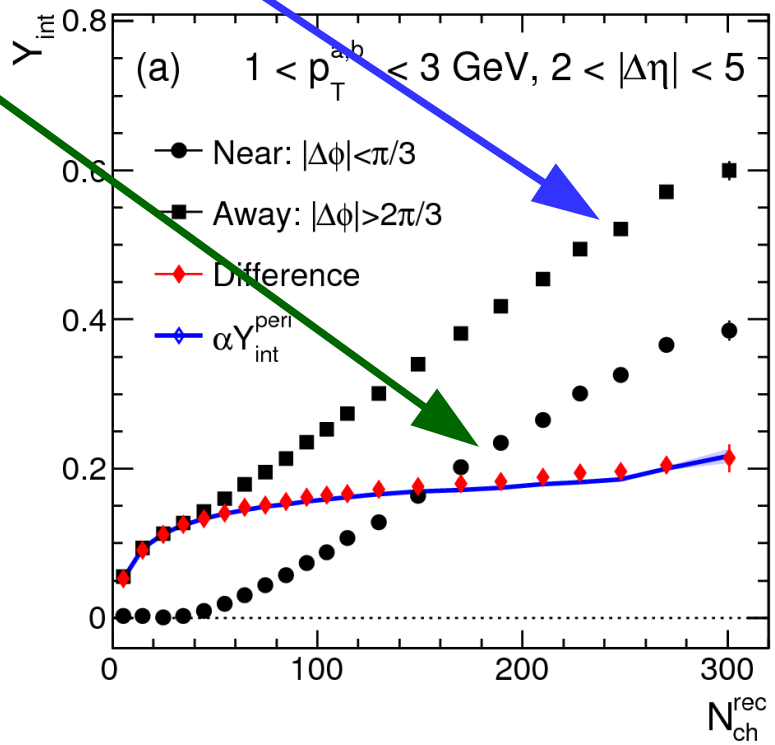
Per trigger yield in p+Pb collisions - dependence on multiplicity

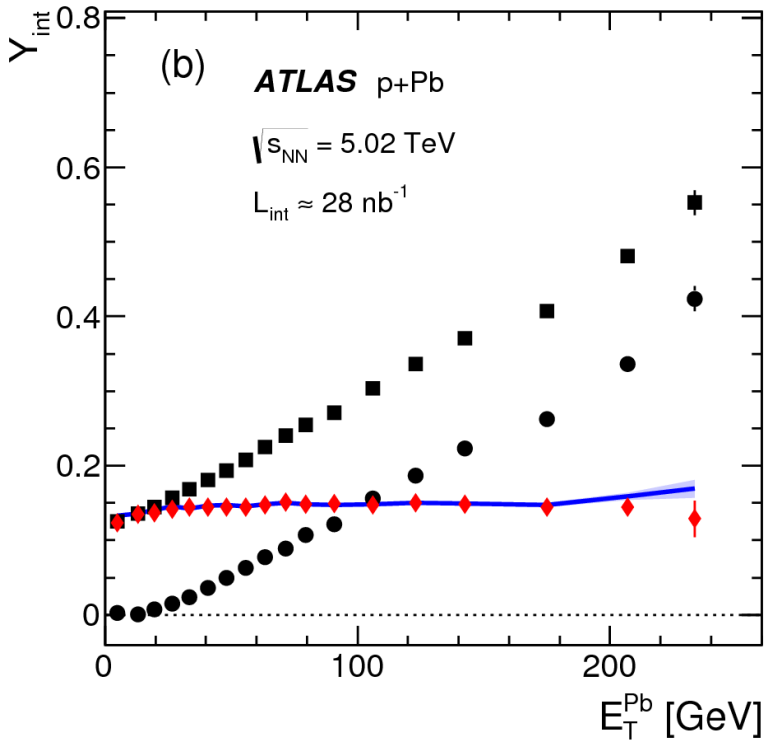


Yield integrated in Δφ ranges: near and away sides for $1 < p_T^{a,b} < 3$ GeV as a function of multiplicity

away side

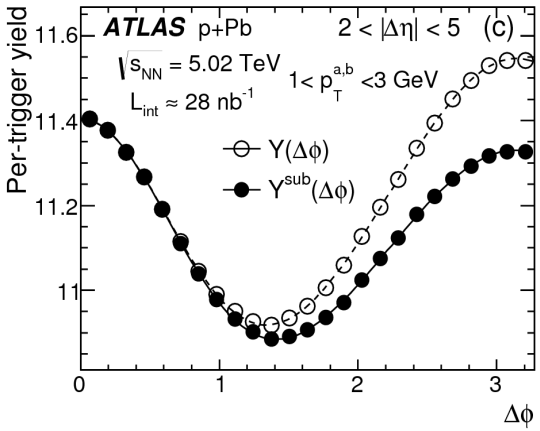
near side





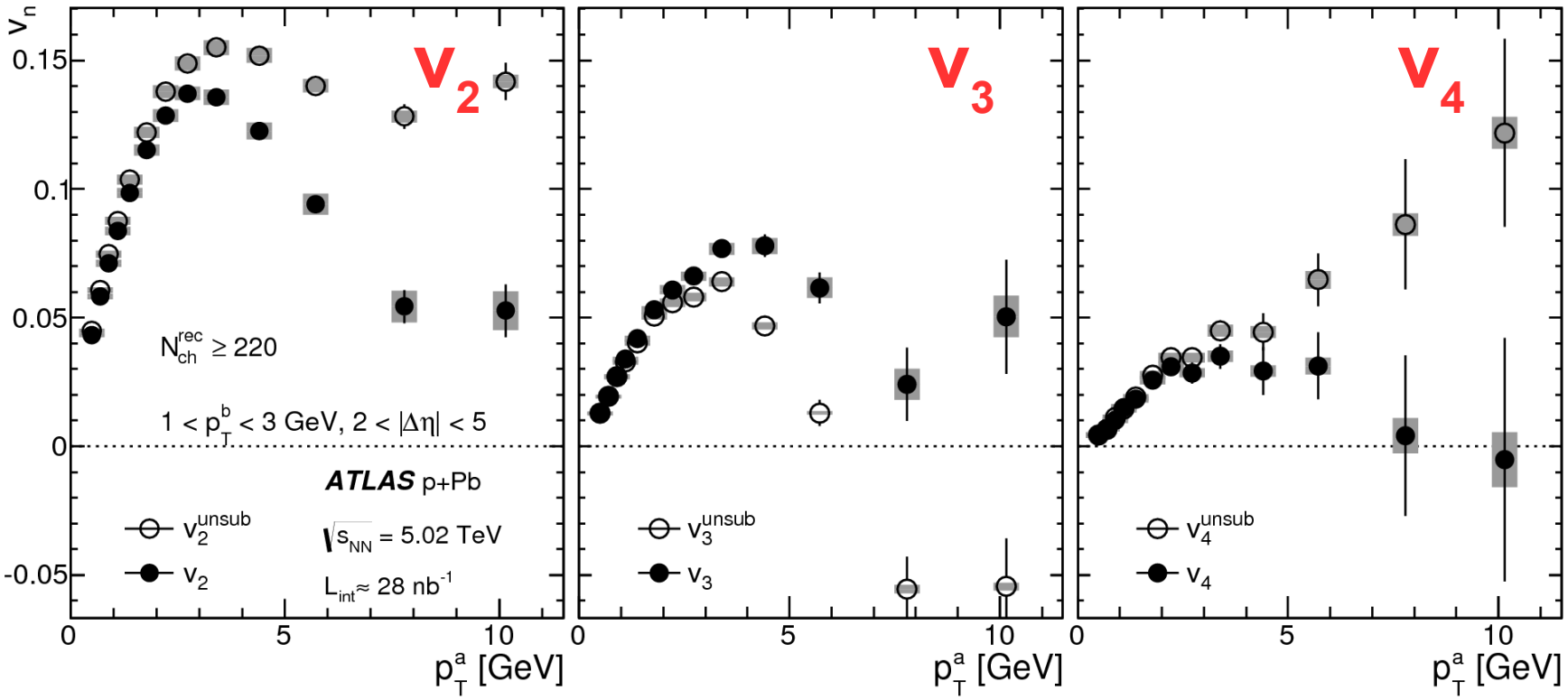
Phys. Rev. C90 (2014) 044906.

Flow in p+Pb collisions



Flow harmonics obtained from correlation function without subtraction (v_n^{unsub}) and after subtraction (v_n).

v_2 and v_4 decrease at large p_T, while v_3 increases in this procedure.



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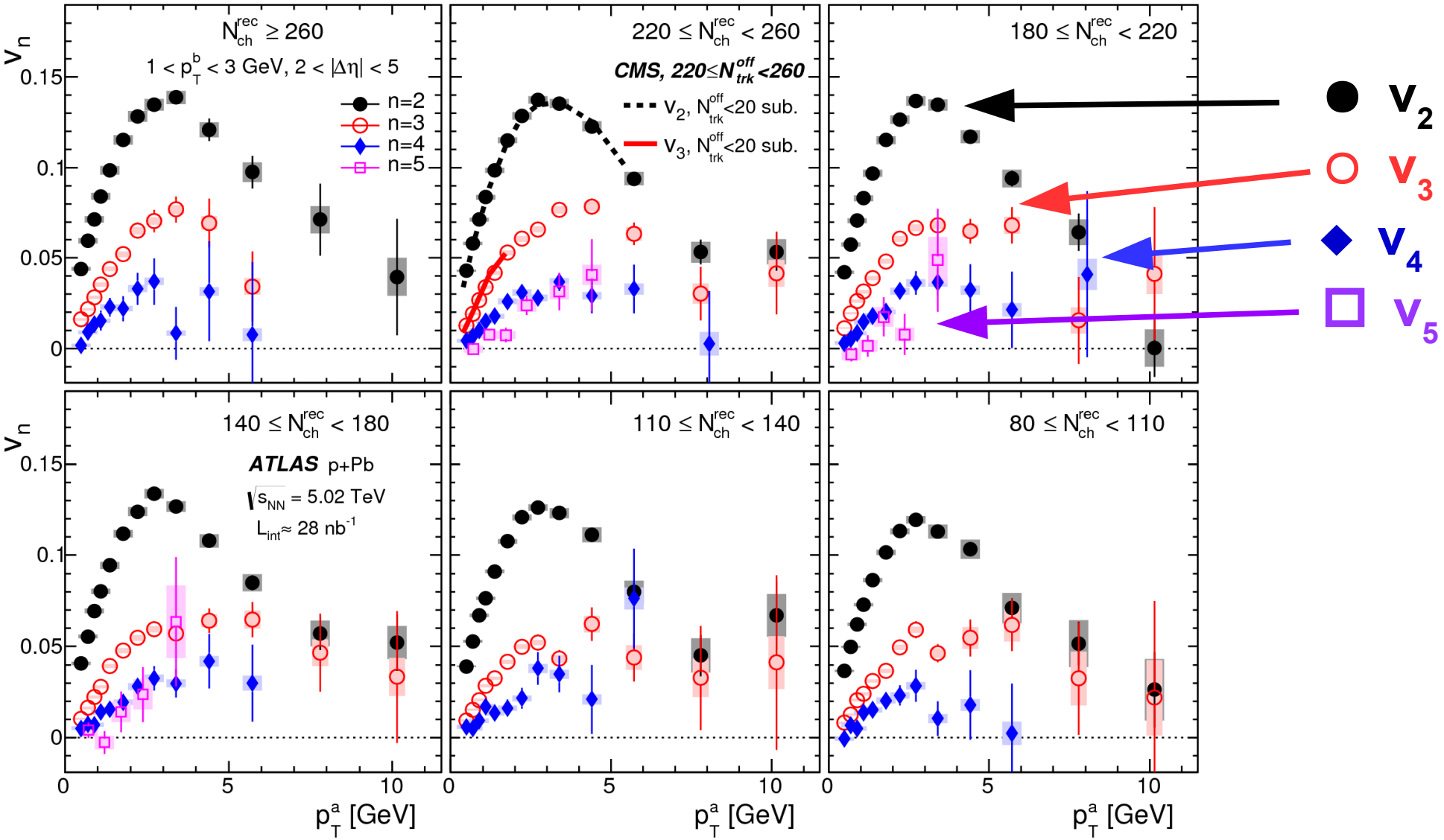
Flow in p+Pb collisions

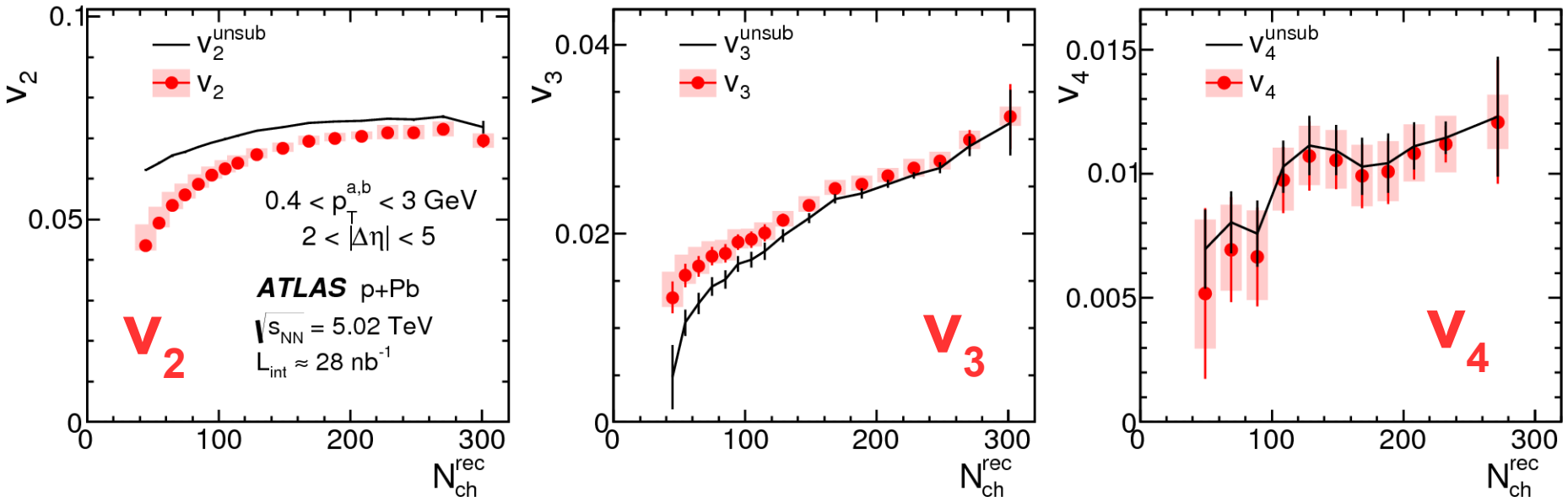
Flow harmonics for different multiplicity ranges, $v_2 > v_3 > v_4$



Phys. Rev. C90 (2014) 044906.

Flow in p+Pb collisions

Flow harmonics as a function of multiplicity

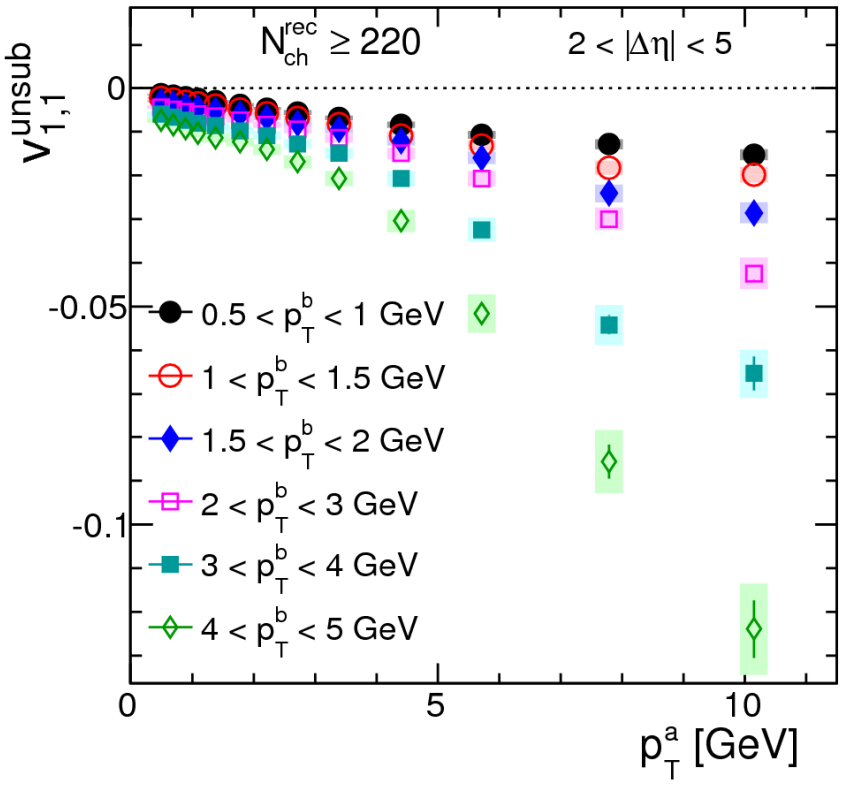


Monotonic increase of flow harmonics with event multiplicity

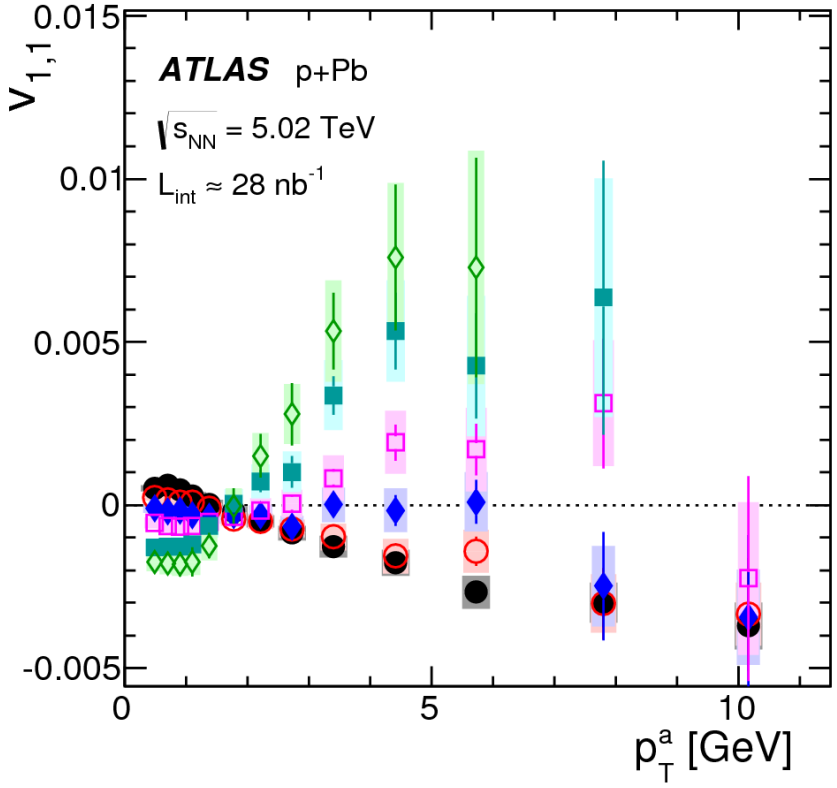
Phys. Rev. C90 (2014) 044906.

Flow in p+Pb collisions - directed flow $v_{1,1}$

$v_{1,1}$ **before** subtracion of recoil contribution



$v_{1,1}$ **after** subtracion of recoil contribution



Calculation of v_1:

$$v_1(p_T^a) = \frac{v_{1,1}(p_T^a, p_T^b)}{v_1(p_T^b)}$$

$$v_1(p_T^b) = sign(p_T^b - p_T^0)\sqrt{v_{1,1}(p_T^a, p_T^b)}$$

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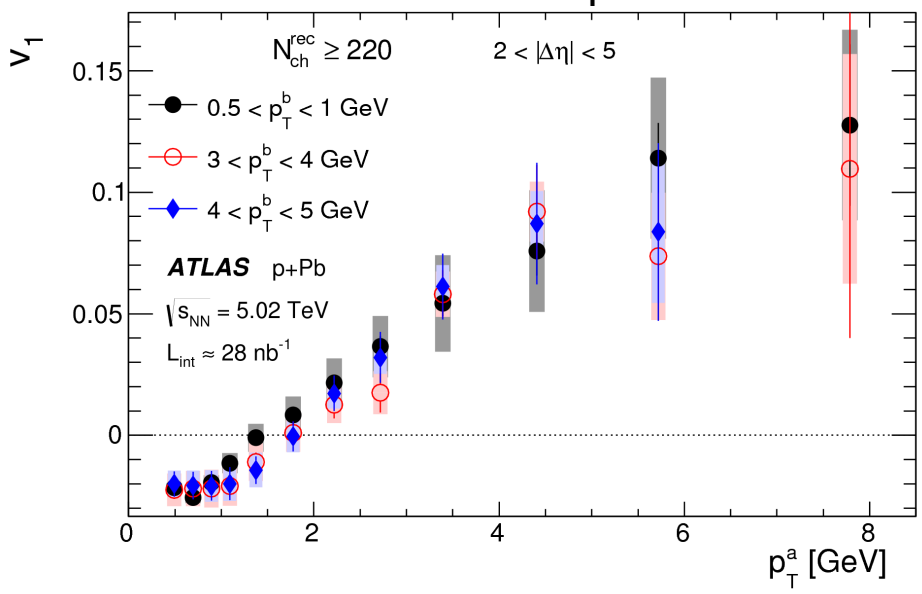
Flow in p+Pb collisions - directed flow v_1

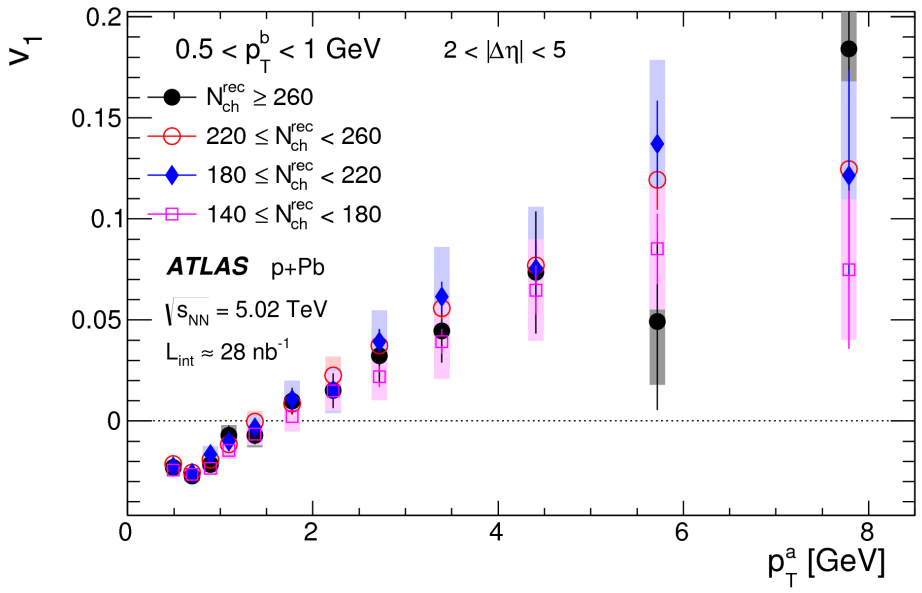
$$v_1(p_T^a) = \frac{v_{1,1}(p_T^a, p_T^b)}{v_1(p_T^b)}$$

$$v_1(p_T^b) = sign(p_T^b - p_T^0)\sqrt{v_{1,1}(p_T^a, p_T^b)}$$

Dependence on p_T^b range



Dependence on multiplicity



Values of v_1 are very similar in different bins of p_T^b and in multiplicity bins starting from 140

Phys. Rev. C90 (2014) 044906.

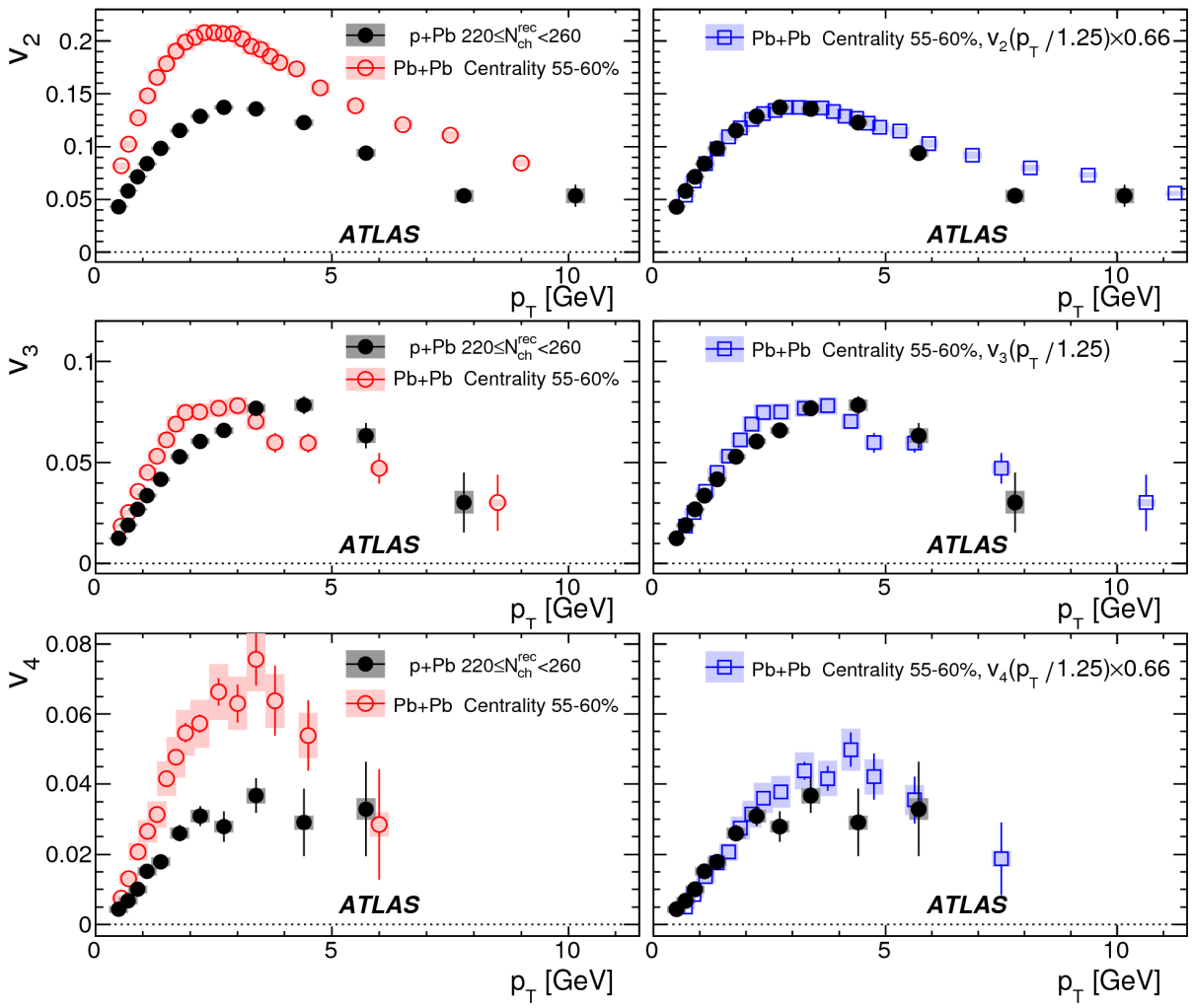
Flow in p+Pb collisions - comparison with Pb+Pb collisions

Comparison of $v_n(p_T)$ in p+Pb and Pb+Pb collisions, n=2-4

Rescaling of Pb+Pb harmonics:

- change of p_T by a factor K=1.25 (to account for different values of $<p_T>$)
- modification of the absolute magnitude of v_2 and v_4 by a common empirical factor 0.66

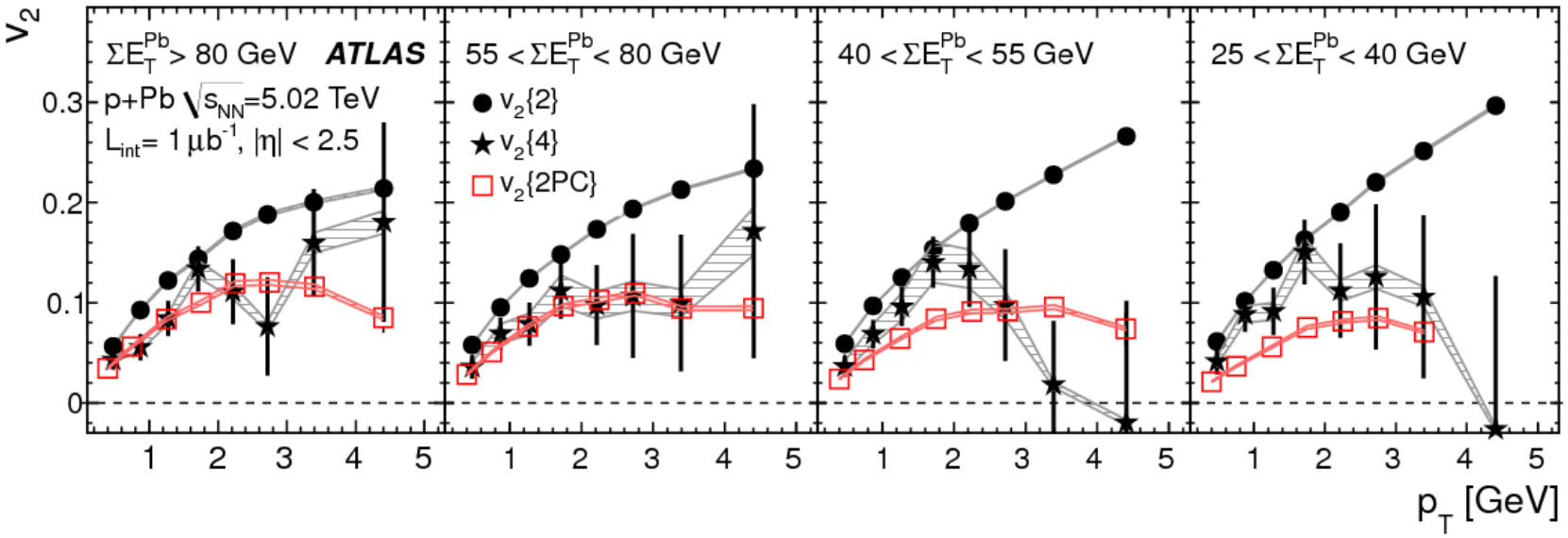
Similar shape of $v_n(p_T)$ is obtained



Phys. Rev. C90 (2014) 044906.

Flow in p+Pb collisions - cumulants method

Elliptic flow obtained from two-particle, $v_2\{2\}$, and four-particle, $v_2\{4\}$ cumulants compared with v_2 values from two-particle correlations, $v_2\{2PC\}$.



$v_2\{2\} > v_2\{4\}$, as in $v_2\{4\}$ contributions from two-particle correlations are canceled.

Phys. Lett. B 725 (2013) 60.

Summary

Two particle correlation in p+Pb collisions studied by ATLAS

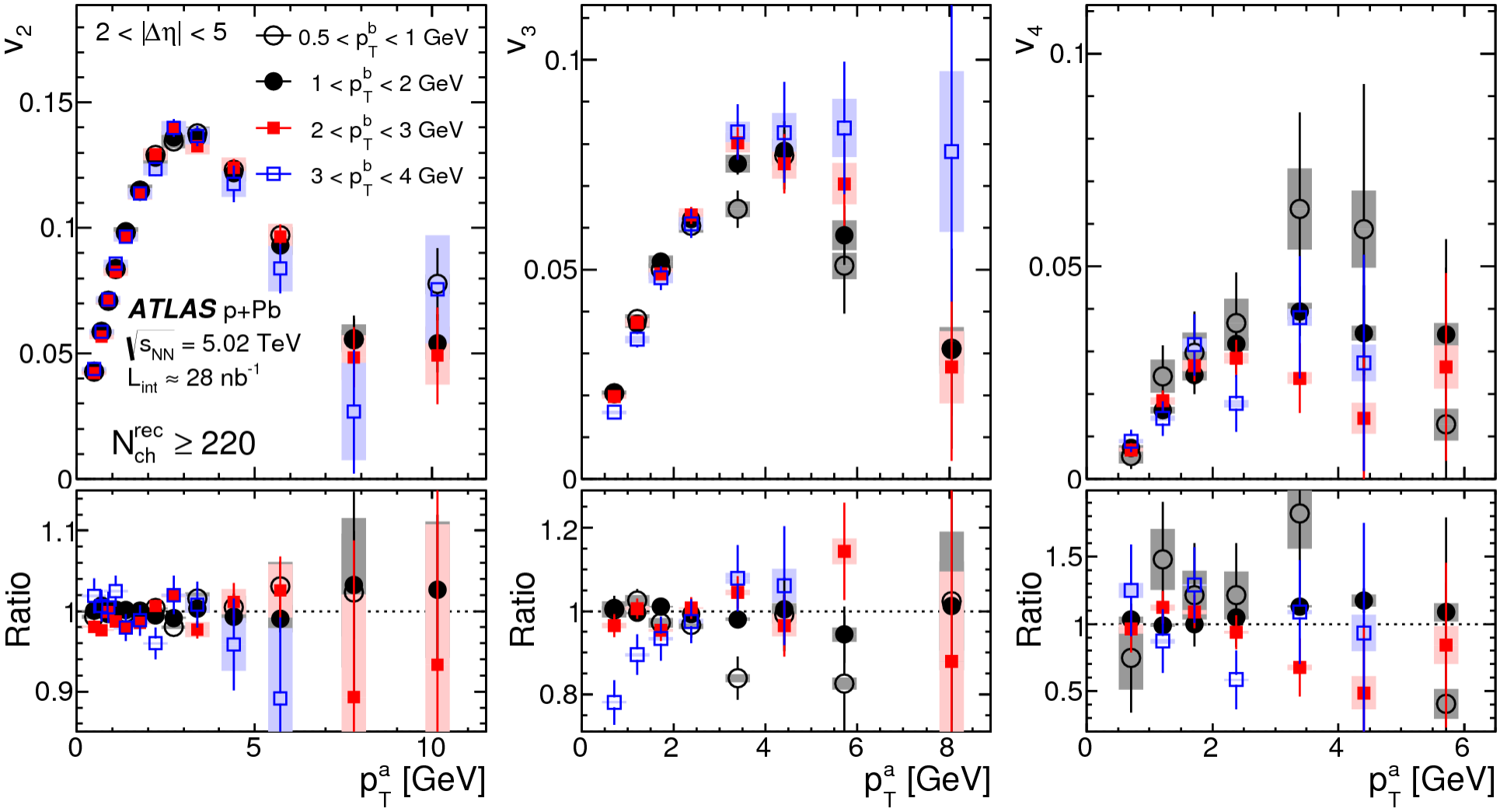
- in p+Pb events with high multiplicity correlations similar to flow seen in Pb+Pb collisions are observed
- in order to remove contributions from jets the yield from peripheral collisions has to be subtracted

Properties of flow phenomena in p+Pb collisions

- the magnitude of v_n decreases with n, for n=2-5
- v_n values, for n=2-5, increase with p_T up to 3-4 GeV and then decrease
- v_2 saturates at large multiplicity, while v_3 increases linearly
- v_1 changes sign at p_T 1.5-2.0 GeV and increases linearly
- the shape of v_n (p_T), for n=2-4, is very similar in p+Pb and peripheral Pb+Pb collisions, when a rescaling of p_T is first applied
- the elliptic flow has the same dependence on the number of particles used in cumulants method: $v_2\{2\} > v_2\{4\}$, both in p+Pb and Pb+Pb collisions, indicating sizable contribution from non-flow correlations to $v_2\{2\}$

Flow in p+Pb collisions

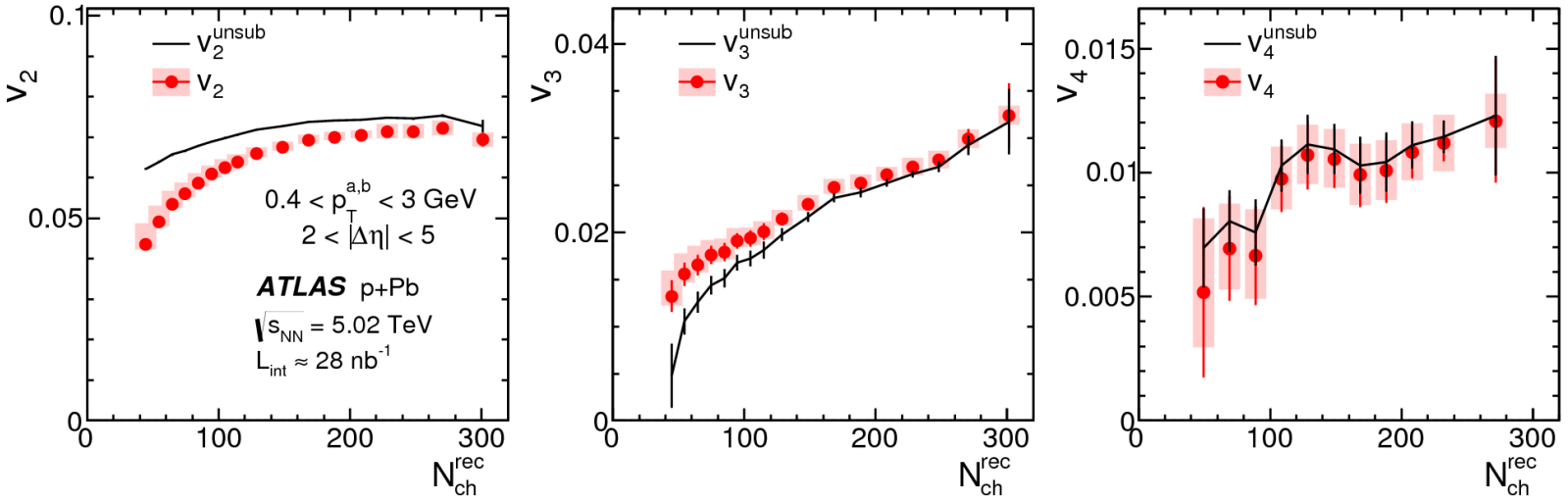
Flow harmonics for different ranges of p_T^b - very small differences



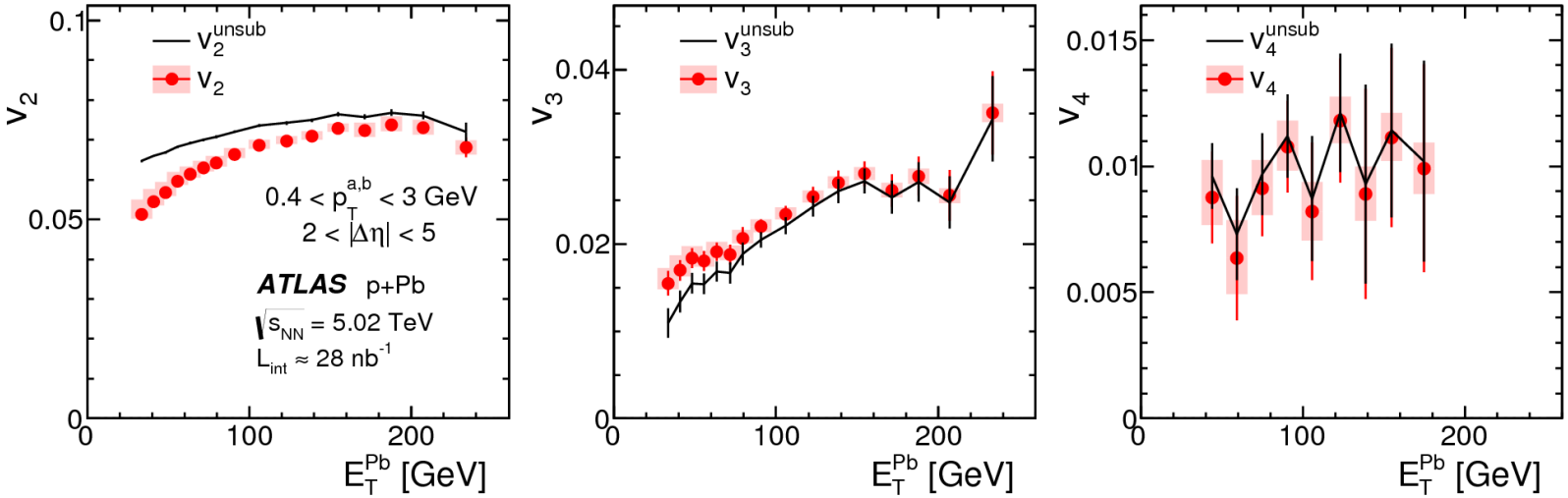
Phys. Rev. C90 (2014) 044906.

Flow in p+Pb collisions

Flow harmonics as a function of multiplicity



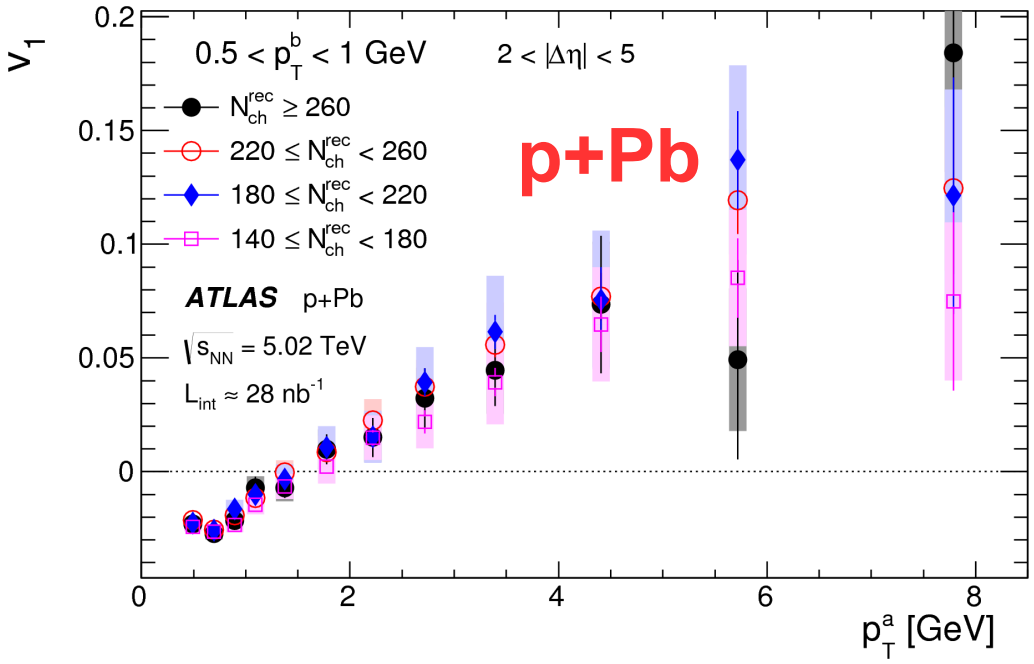
Flow harmonics as a function of the signal in FCal detector



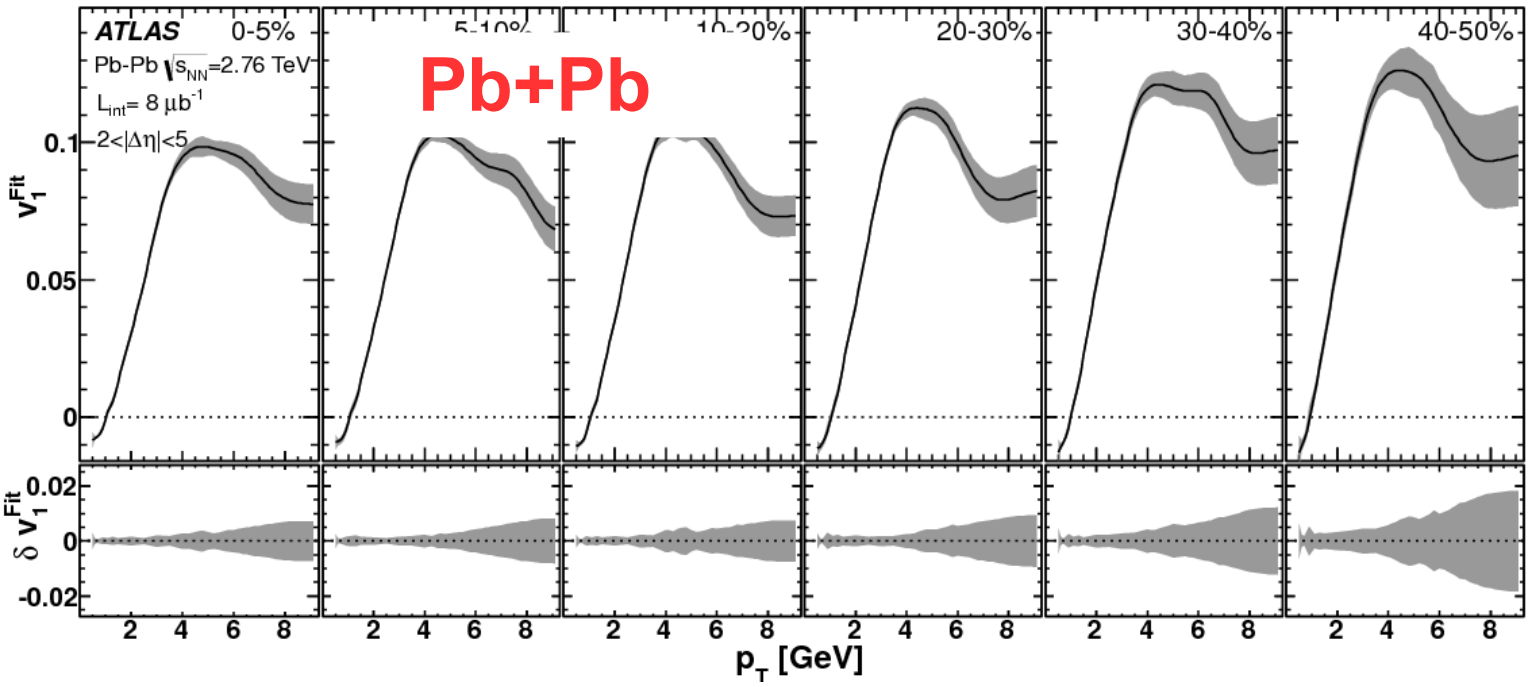
Monotonic increase of flow harmonics with event multiplicity

Phys. Rev. C90 (2014) 044906.

Flow in p+Pb collisions - directed flow v_1



Phys. Rev. C90 (2014) 044906.

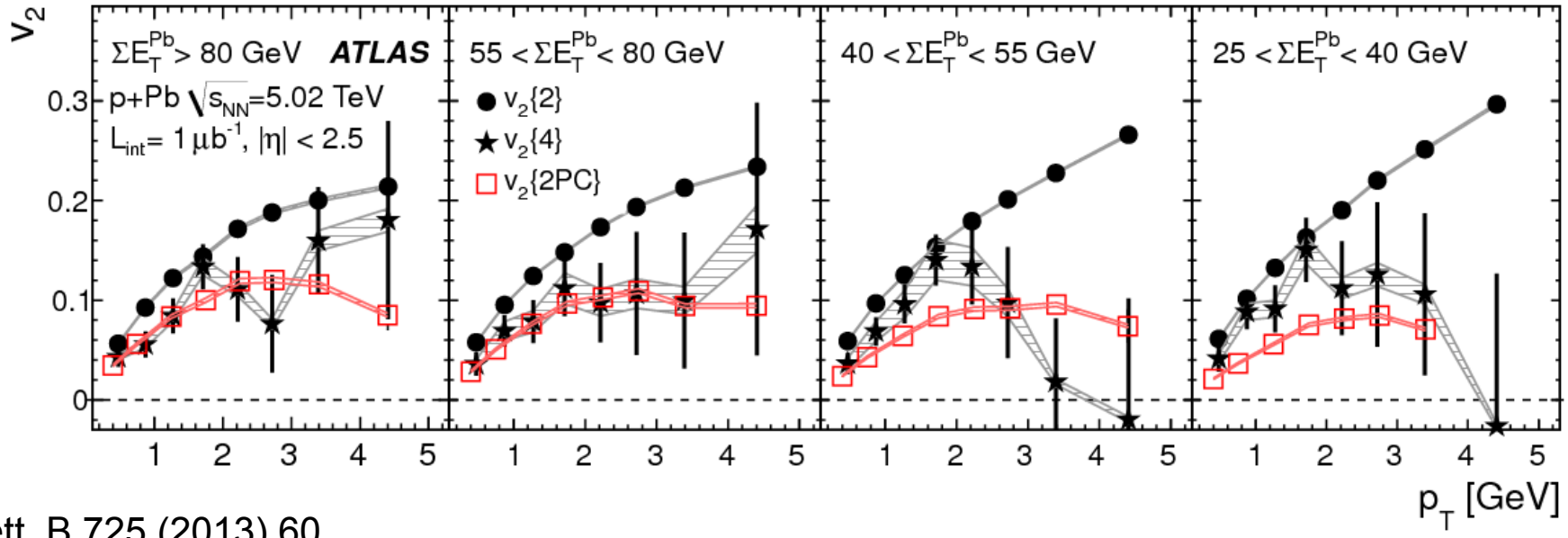


Phys. Rev. C86 (2012) 014709.

Flow in p+Pb collisions - cumulants method

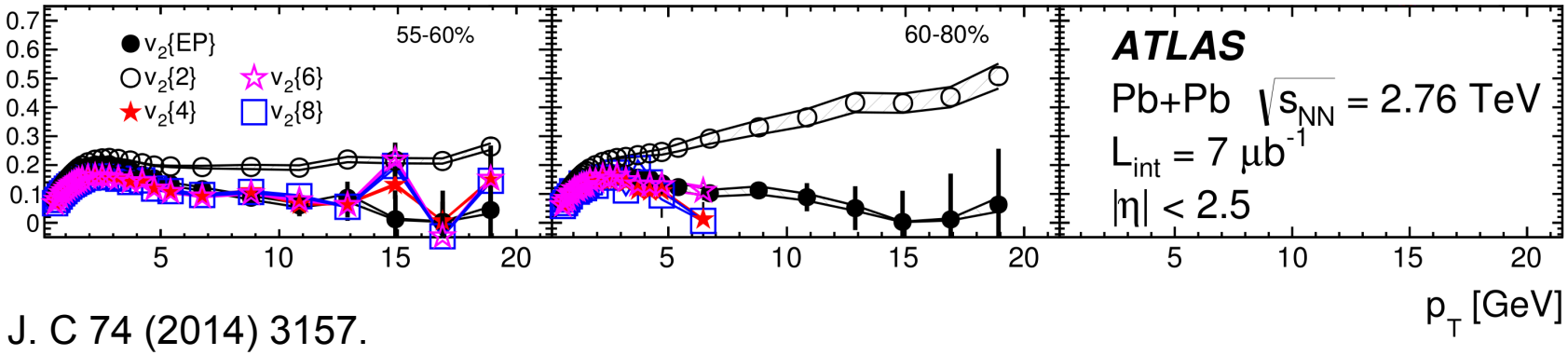
Elliptic flow obtained from two-particle, $v_2\{2\}$, and four-particle, $v_2\{4\}$ cumulants compared with v_2 values from two-particle correlations, $v_2\{2PC\}$.

p+Pb



Phys. Lett. B 725 (2013) 60.

Pb+Pb



Eur. Phys. J. C 74 (2014) 3157.

values of $v_2\{2\}$ and $v_2\{4\}$ measured in p+Pb collisions are comparable with results for semi-peripheral Pb+Pb collisions