Identifying longitudinal rapidity fluctuations and directed flow measurements

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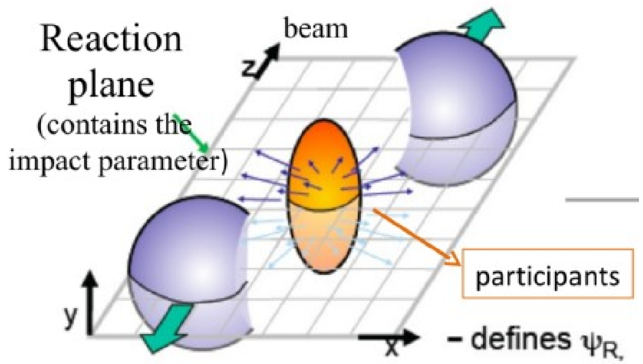
Outline

- EbE fluctuations of initial state and global symmetry
- Longitudinal fluctuations
- Longitudinal rapidity fluctuations with spectators
- Conclusions

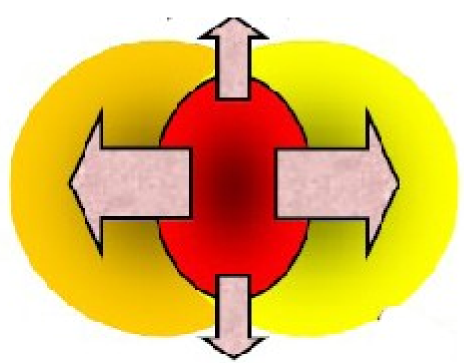
Global symmetry

"True" reaction plane Ψ_R: defined by impact parameter and beam direction



$$E\frac{d^3N}{d^3p}=\frac{1}{2\pi}\frac{d^2N}{p_t dp_t dy}\left(1+\sum_{n=1}^{\infty}2v_n\cos\left(n\left(\varphi-\Psi_r\right)\right)\right)$$

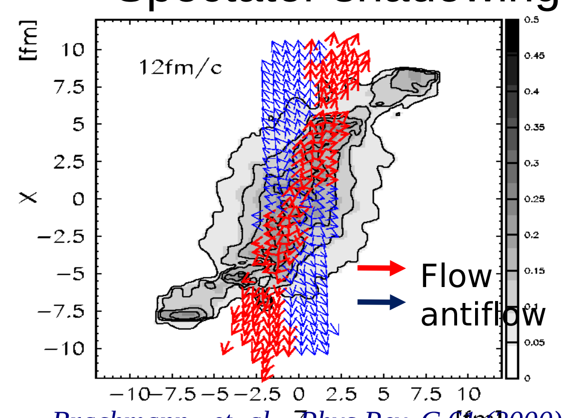
Elliptic flow: pressure gradients



$v_2 \sim \varepsilon$

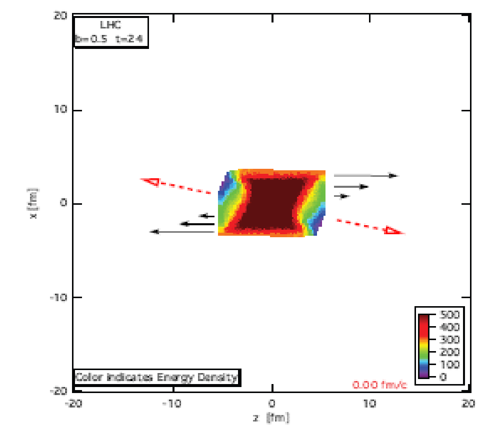
Different mechanisms for directed flow:

Spectator shadowing



Brachmann, et. al. , Phys.Rev. C 61 (2000) 024909.
Bravina et. al., Phys Rev C 61 (2000) 064902

Tilted source



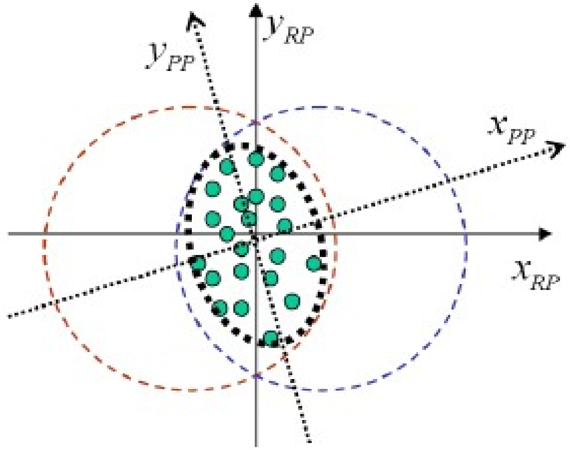
L.P. Csernai, et.al., Phys.Rev.C84:024914,2011

- v_2 evolves w. r. t. reaction plane Ψ_R.
- v_1 evolves w. r. t. reaction plane Ψ_R.

Fluctuations and global symmetry

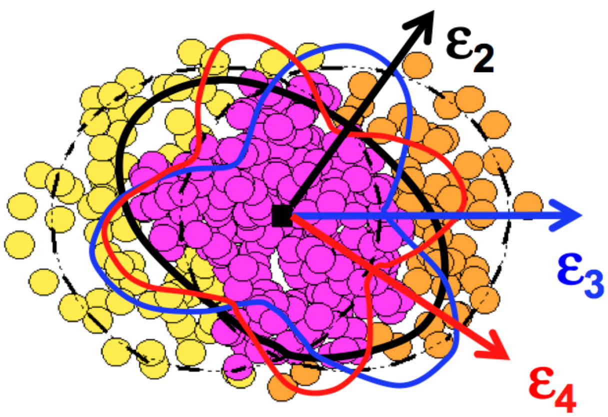
Fluctuations of the participant zone in transverse plane:

M. Luzum, C. Gombeaud, J.-Y. Ollitrault, Phys.Rev.C81:054910,2010.



Due to fluctuations of number of participants, participant plane may differ from reaction plane.

→ Elliptic flow fluctuations.

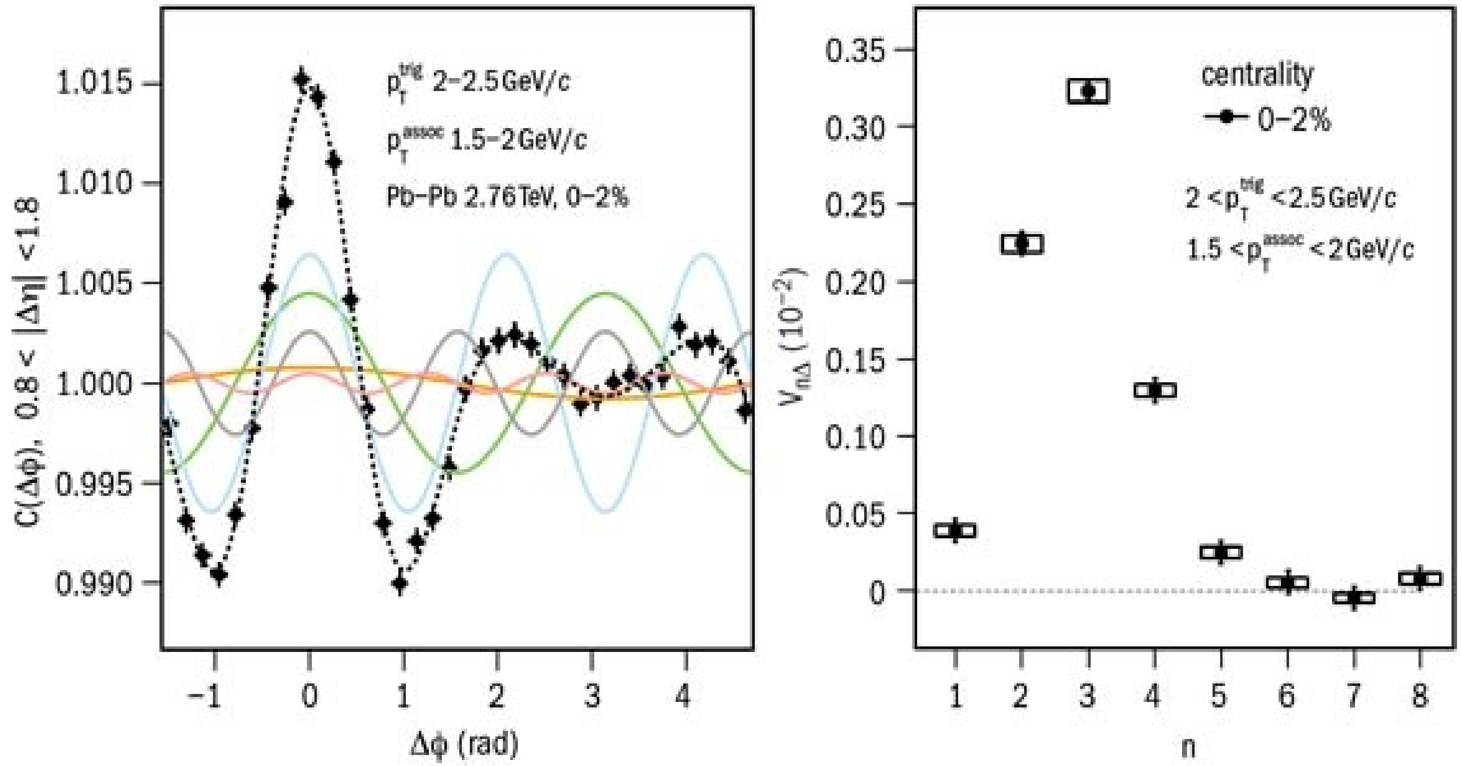


$$E\frac{d^3N}{d^3p} = \frac{1}{\pi}\frac{d^2N}{dp_t^2dy}\left[1 + 2\sum_{n=1}^{\infty} v_n \cos n(\phi - \Psi_n)\right]$$

Higher order flow harmonics, w.r.t its own plane symmetries.

Fluctuations and global symmetry

ALICE: *Phys.Lett.B 708, 249 (2012)*



Flow originating from initial state fluctuations is significant and dominant in central (where from global symmetry no azimuthal asymmetry could occur, all collective v_n = 0) !

Longitudinal fluctuations

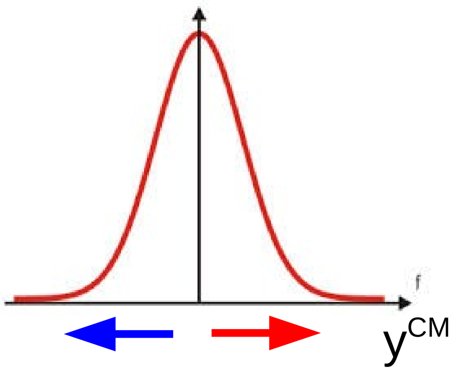
Fluctuations of the participant zone in longitudinal plane:

$\downarrow$

rapidity center of mass fluctuations.

The total 4-momentum of all measured particles: $P = \sum_{i=1}^{M} p_i$

Rapidity center of mass: $$y^{CM} = \frac{1}{2} \ln \frac{E + P_z}{E - P_z}. \qquad \eta^{CM} = \frac{1}{2} \ln \frac{|\vec{P}| + P_z}{|\vec{P}| - P_z}.$$



Method to correct for CM rapidity fluctuations

L. P. Csernai, G. Eyyubova, V.K. Magas, Phys. Rev. C 86, 024912 (2012)

In order to correct for y^{CM} :

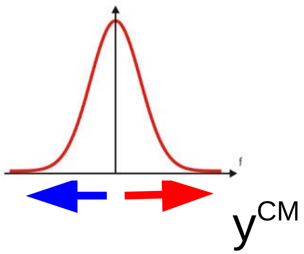
- Determine experimentally EbE the C.M. rapidity.
- Shift each particle rapidity and evaluate flow harmonics.

$$y_i = y_i - y^{CM}; \qquad \eta_i \approx \eta_i - y^{CM}$$

$$v_n(y', p_\perp) = \langle \cos[n(\phi_i - \Psi_{EP})] \rangle$$

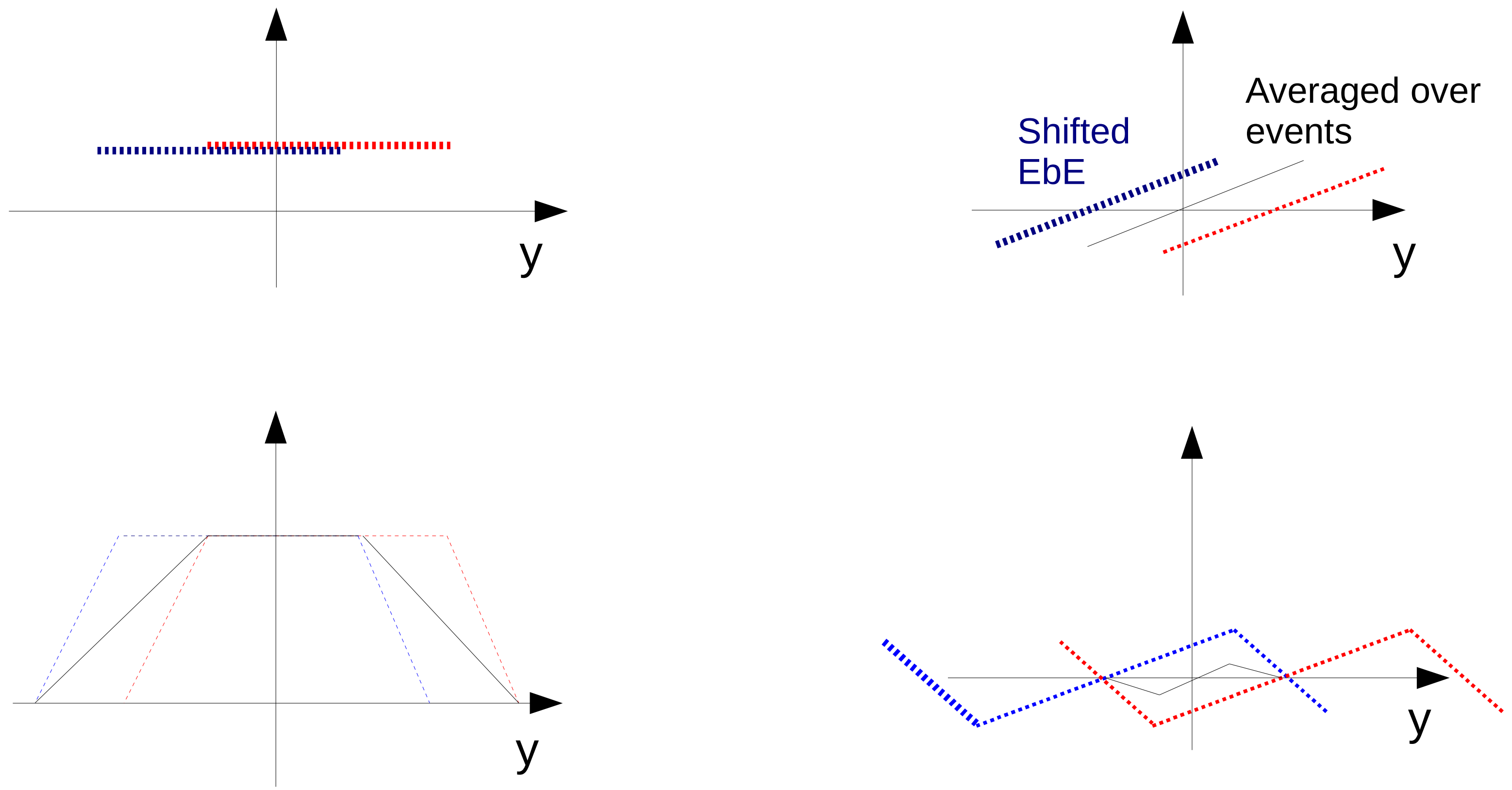
Longitudinal fluctuations and flow

Simple picture



EbE fluctuations of rapidity center of mass are symmetric around zero

$\rightarrow$ for flat or liner $v_n(\eta)$ they averaged out.



The effect of fluctuations on flow depends on:

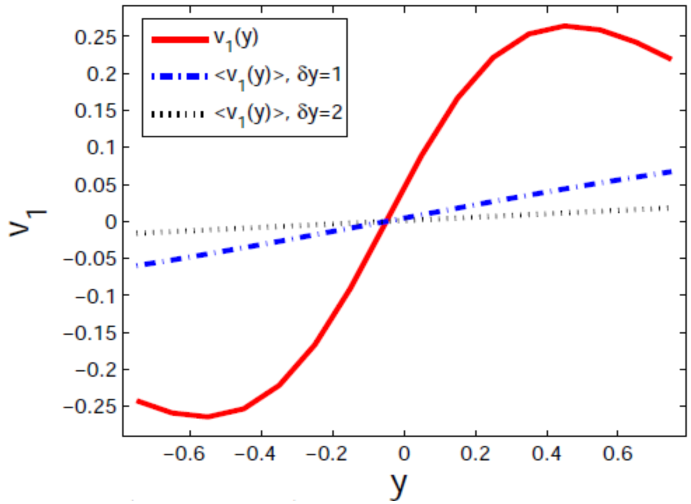
- Width of y^{CM} fluctuations
- Shape of $v_n(\eta)$ dependence

Experimental observables

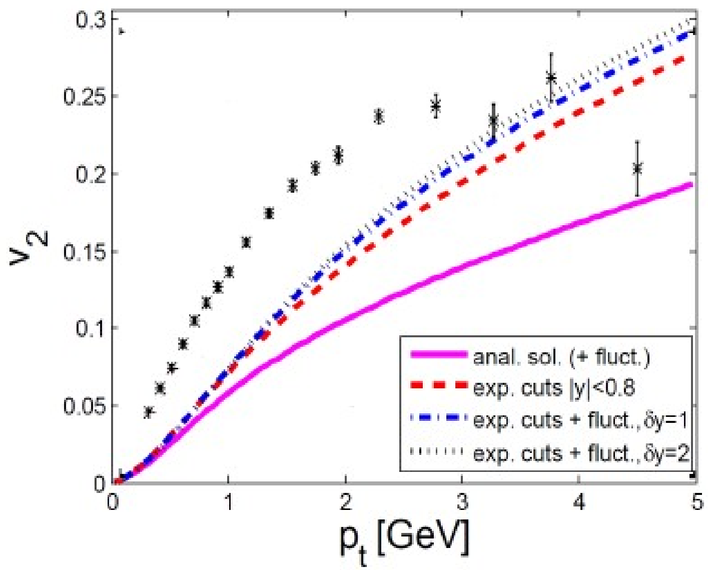
More realistic examples

Directed flow

L.P. Csernai, et.al., Phys.Rev.C84:024914,2011

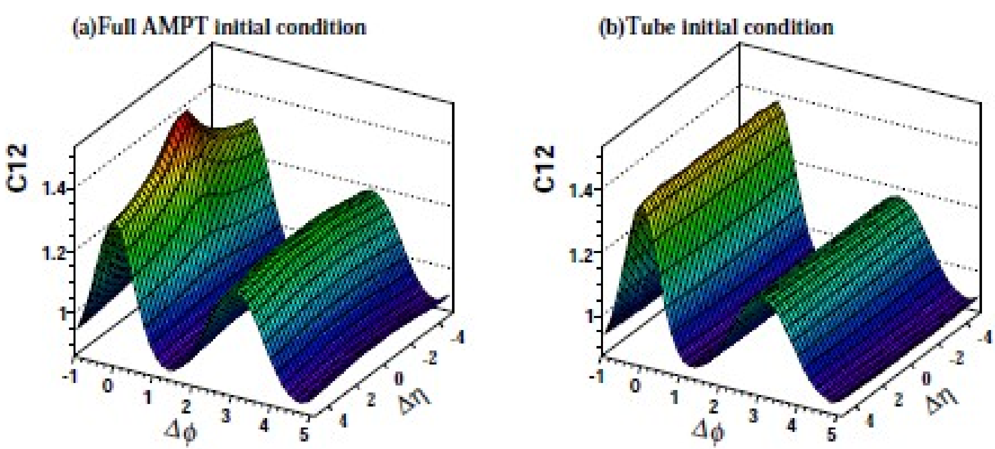


Elliptic flow



Dihadron correlation

L.G. Pang, Q. Wang, X.N. Wang, Phys. Rev. C 86,024911 (2012).

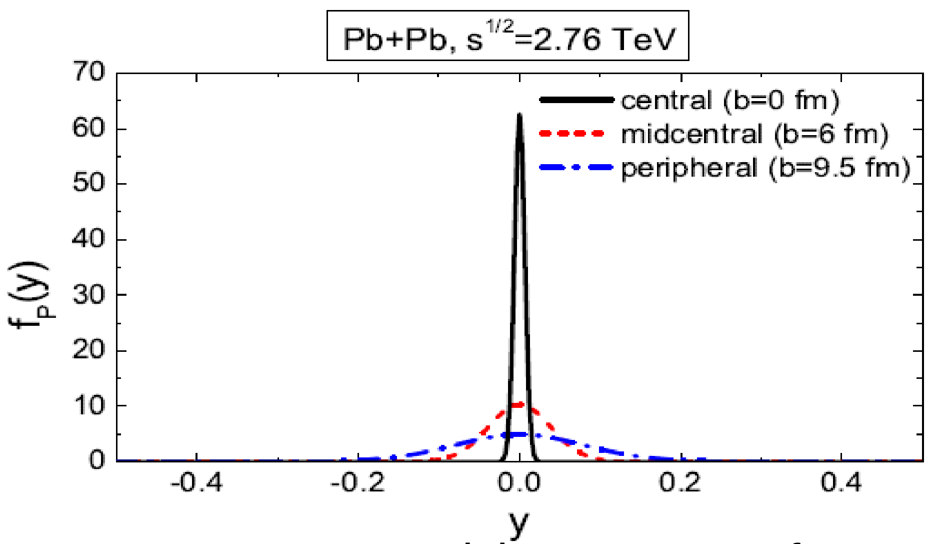


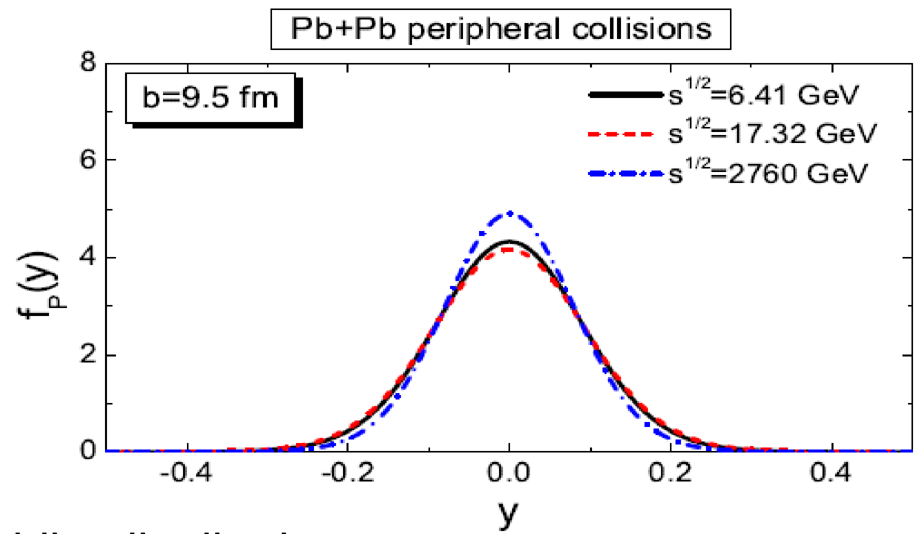
Near-side peak with fluctuations in longitudinal direction.

Longitudinal fluctuations are relevant for many experimental observables.

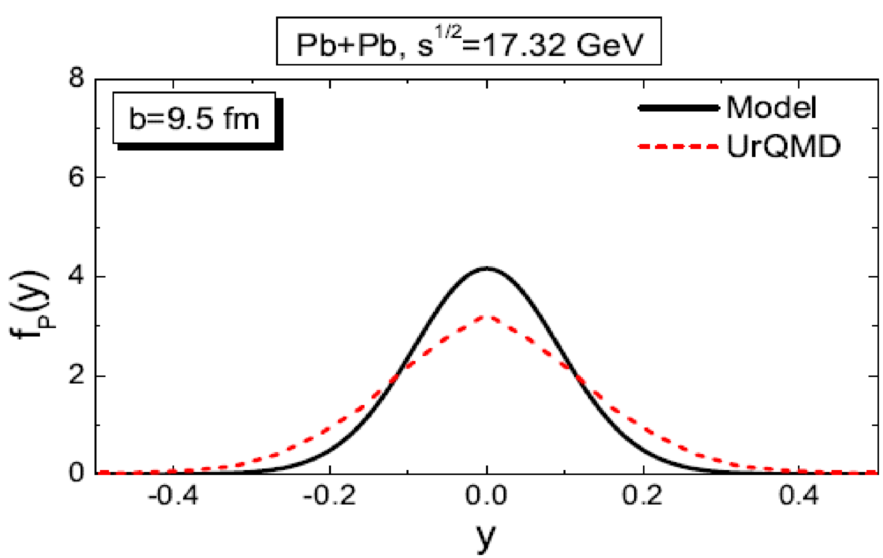
Longitudinal fluctuations

Model: *V.Vovchenko, D.Anchishkin, L.P.Csernai,, Phys.Rev. C88 (2013) 1, 014901*





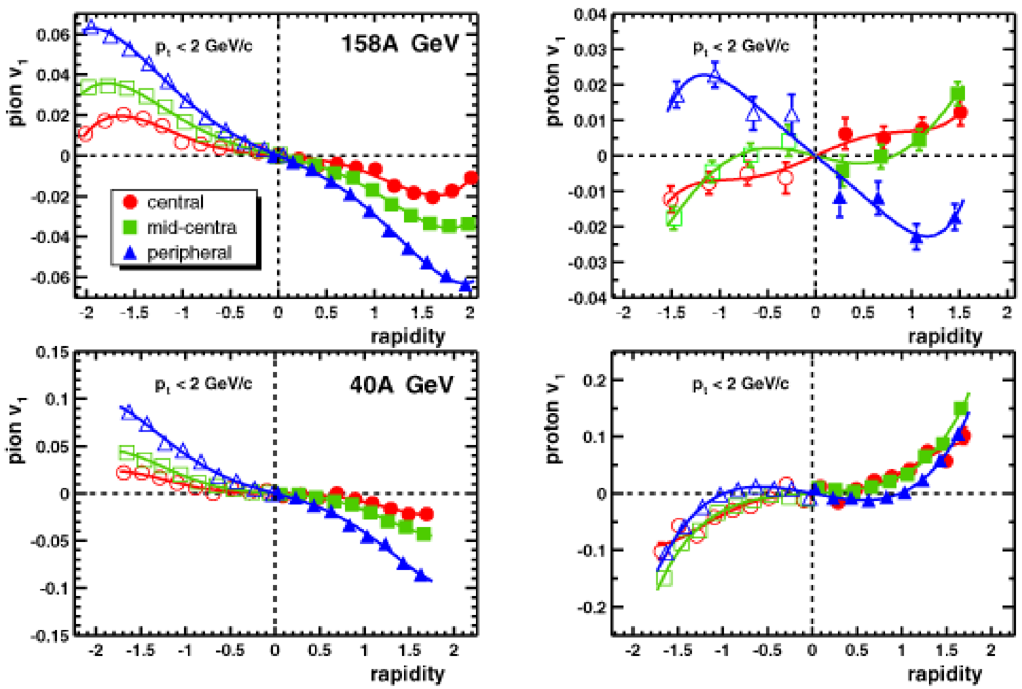
Participant center of mass rapidity distribution.



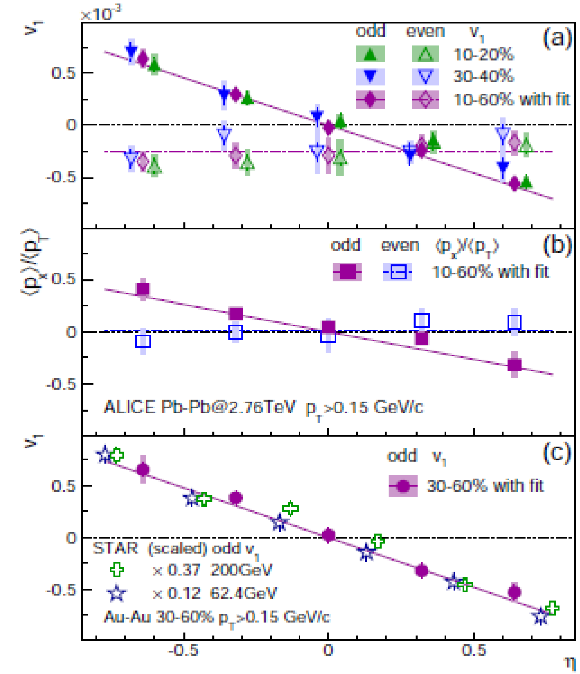
Fluctuations grows for more peripheral collisions.

Directed flow in experiment

NA49: *Phys.Rev. C68 034903 (2003)*

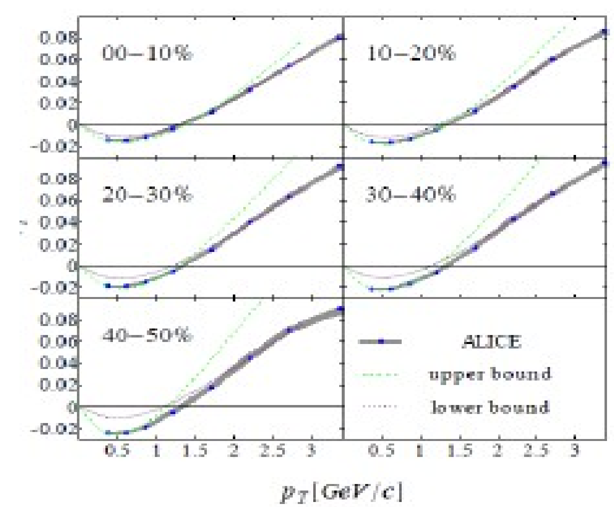


ALICE*: Phys.Rev. Lett. 11, 232302 (2013)*



E. Retinskaya, M. Luzum, J. -Y. Ollitrault, Phys. Rev. Lett. 108, 252302 (2012),

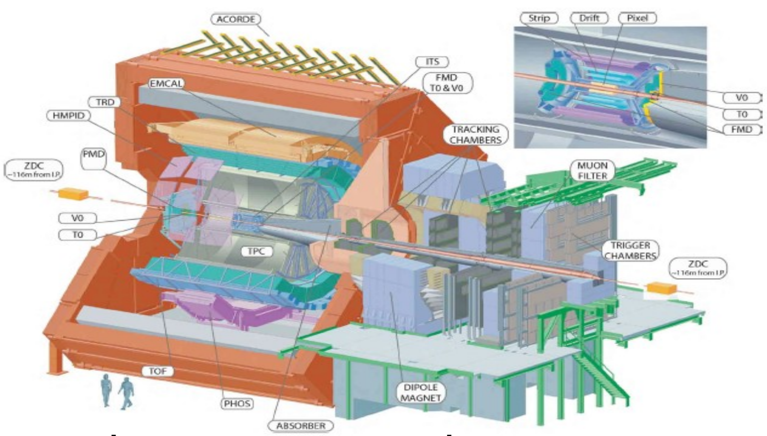
- At LHC v_1 at midrapidity can be approximated with a linear function.
- So far measurements didn't account for longitudinal fluctuations.
- So called rapidity-even v_1 (due to transverse initial state fluctuations) was identified in experiment.



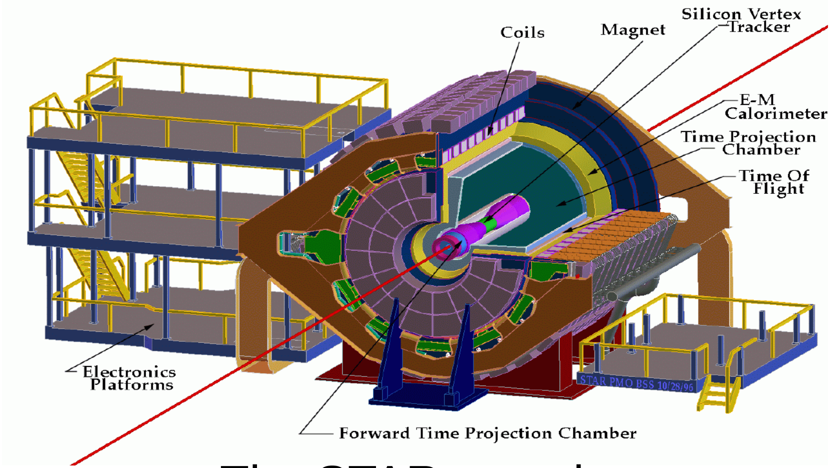
Method to correct for CM rapidity fluctuations

The rapidity acceptance of inner tracker in experiment is constrained.

e.g for ALICE: $|\eta| < \eta_{\rm lim} = 0.8$,
For STAR: $|\eta| < \eta_{\rm lim} = 1$, and so: $|\eta_{\rm C.M.}| << \eta_{\rm lim}$



The ALICE experiment.

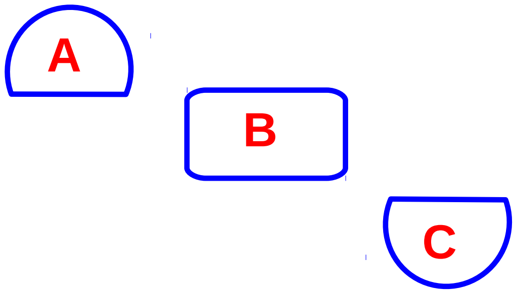


The STAR experiment.

Participant rapidity could be obtained from spectators rapidity.

Method to correct for CM rapidity fluctuations

Participant rapidity from spectators.



The energy and momentum conservation:

$$E_B = E_{Tot} - E_A - E_C \ ,$$

$$P_{zB} = -(P_{zA} + P_{zC})$$

$$\approx -(M_A sinh(y_0) + M_C sinh(-y_0)) \approx -(E_A - E_C)$$

y_0 – beam rapidity, Ma, Mc – mass of target and projectile spectators.

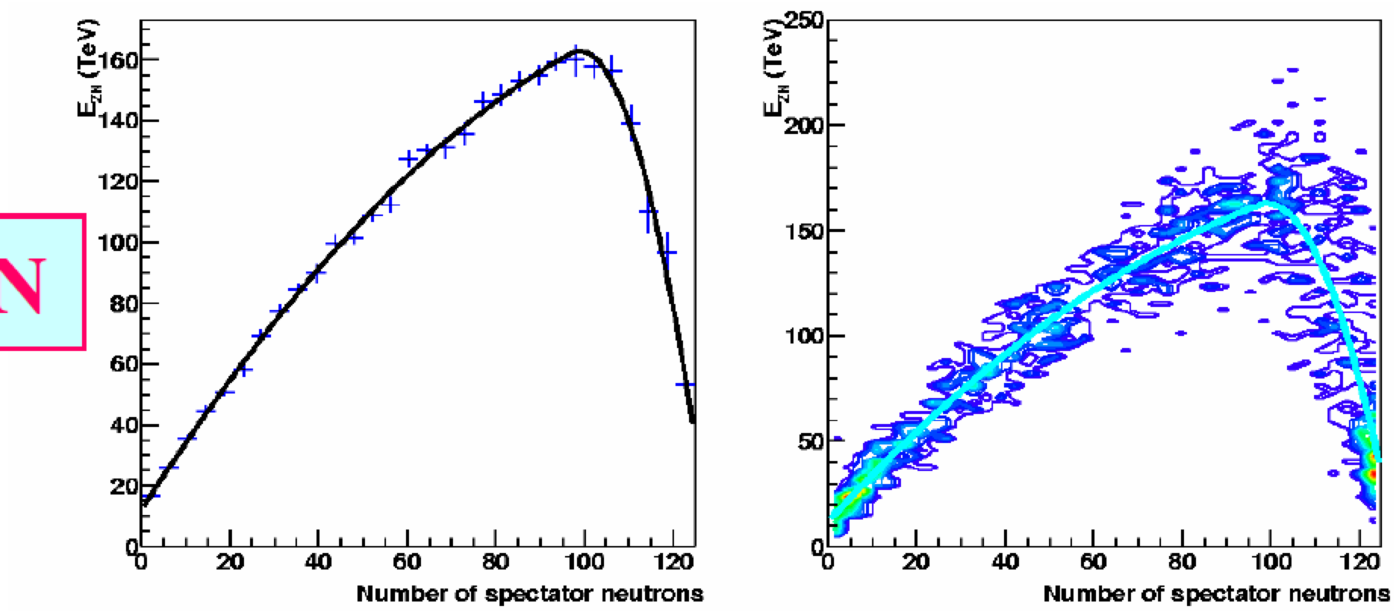
$$y_B^{CM} = \mathrm{artanh}\left(\frac{-(E_A - E_C)}{E_{Tot} - E_A - E_C}\right)$$

$E_{A,}$ E_C are measured in Zero Degree Calorimeter.

Experimental method for CM rapidity with ZDC

ZDC: spectator nucleon loss.

ZN



Conf. "Physics at LHC", Vienna, 13-17 July 2004, M. Monteno, ALICE Coll.

Correlation between the rec. energy in the ALICE neutron ZDCs and spectator nucleons, simulated with HIJING.

- Iincomplete fragmentation $\rightarrow$ charged fragments do not reach ZDC, important for peripheral events.

- Correlations are not monotonic.

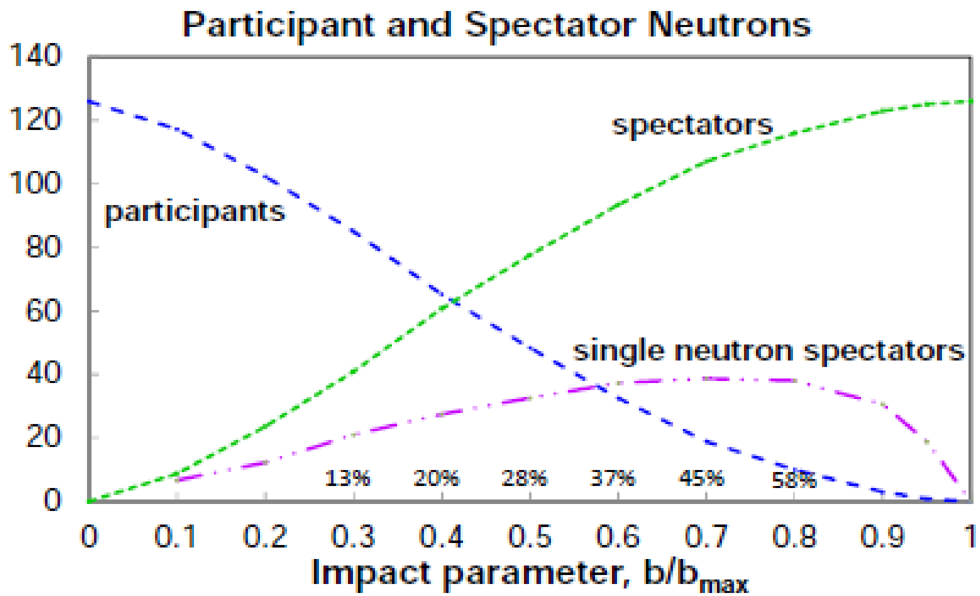
Experimental method for CM rapidity with ZDC

The correction procedure:

We estimate fluctuations for neutrons only. The neutron distribution is assumed to be homogeneous.

1. Calculate the mean energy deposit in each neutron ZDC, $<E^{sn}>$, versus centrality in data.

2. For each centrality (impact parameter) calculate the fraction R(b) of $<E^{sn}>$ to the total spectator neutron energy, given by the model.



Relation between impact parameter and centralities based on Fluid Dynamic model.

Single neutron spectators are based on nuclear multi fragmentation studies → in experiment should be taken from data

L.P. Csernai, V.K. Magas, H. Stocker, D.D. Strottman, Phys. Rev. C 84,02914 (2001)

Experimental method for CM rapidity with ZDC

The correction procedure:

3. EbE energy in each ZDC is corrected:

$$E_A(b) = (A/N)E_A^{sn}R(b)$$
$$E_C(b) = (A/N)E_C^{sn}R(b) ,$$

where A/N is a mass to charge ratio (=208/126 in Pb), accounts for singular proton spectators.

4. Calculate y^{CM} with corrected E_A, E_C.

Additional shift may be needed due to asymmetry in ZDC calibration.

The correction increases with impact parameter → the possibility for larger systematic errors also increases.

Conclusions

- Longitudinal fluctuations are essential for various rapidity dependent observables, and should be taken into account.

- A method for calculating y^{CM} via spectators with the help of Zero Degree Calorimeter is proposed. A correction procedure for incomplete fragmentations effect, which can be applied in experiment, is elaborated.

- Global collective flow can be separated from flow originated from random initial state longitudinal fluctuation by shifting EbE the system to the participant CM rapidity.