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The role of longitudinal correlations and fluctuations :Exp

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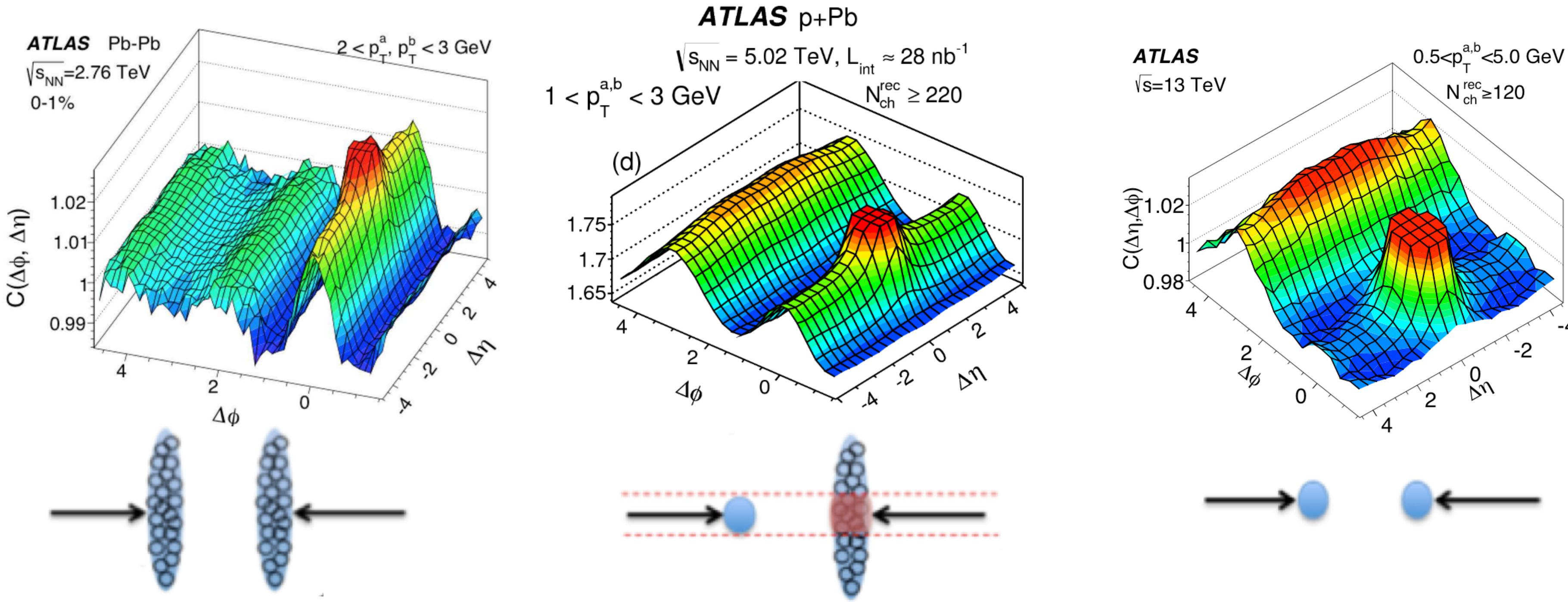
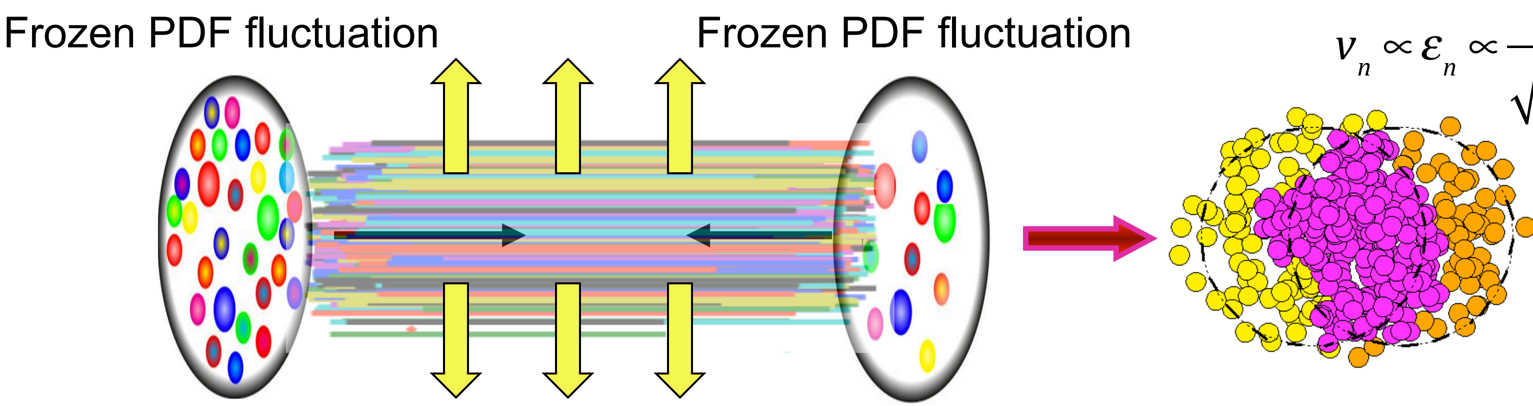
Initial Stages 2016

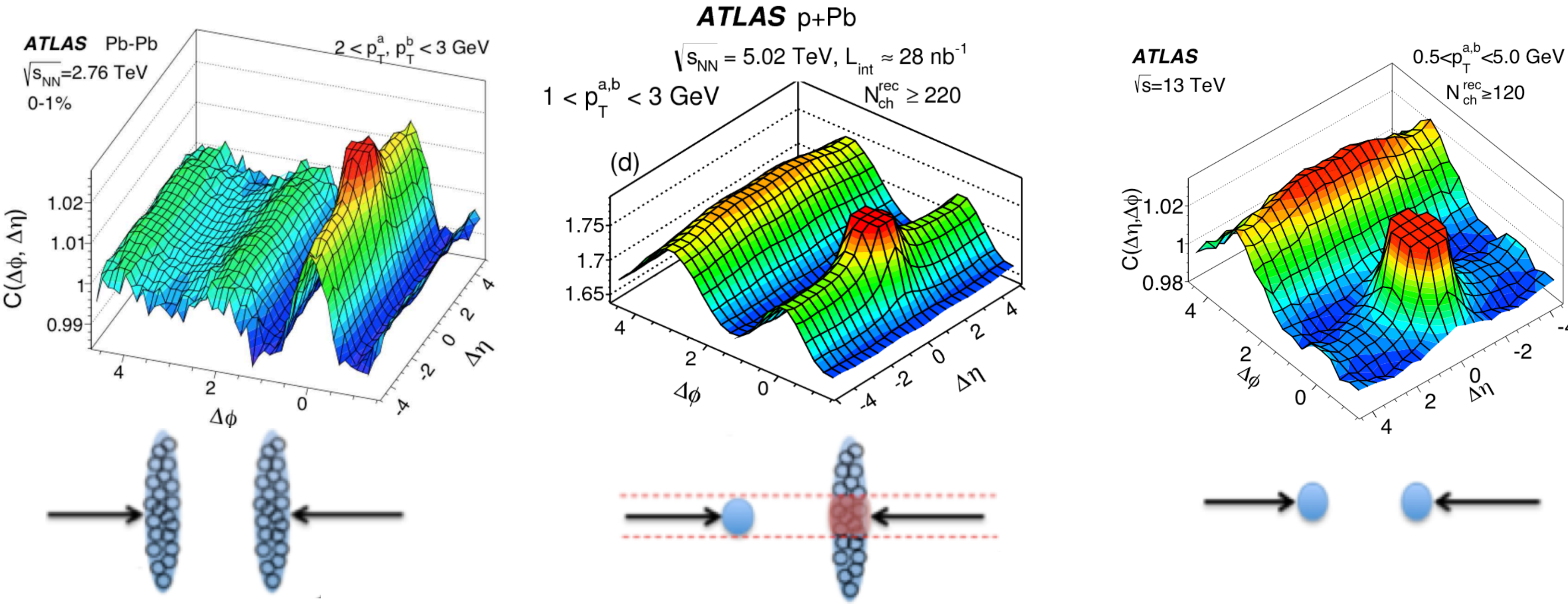


Nature of sources seeding these long-range collective ridges?



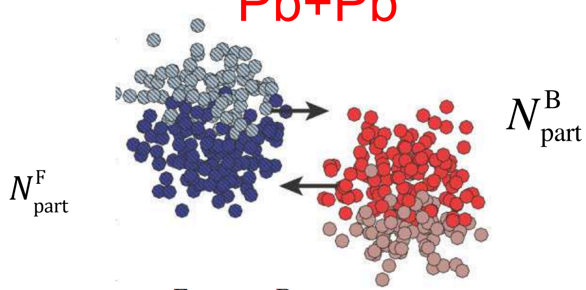
$$v_n \propto \varepsilon_n \propto \frac{1}{\sqrt{n_{sources}}}$$

How many sources, their sizes & transverse distribution?
they transport in rapidity?



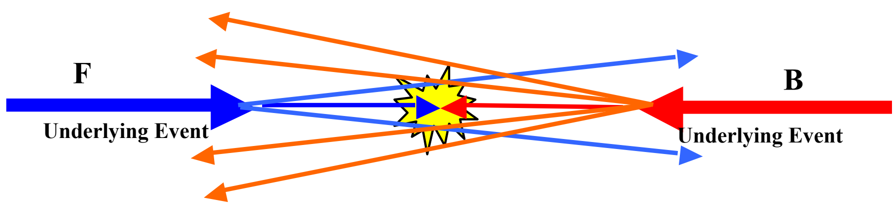
Nature of sources seeding these long-range collective ridges?

Pb+Pb



$$A_{part} = \frac{N^{F}_{part} - N^{B}_{part}}{N^{F}_{part} + N^{B}_{part}}$$

p+p



MPI: $n_f \neq n_b$

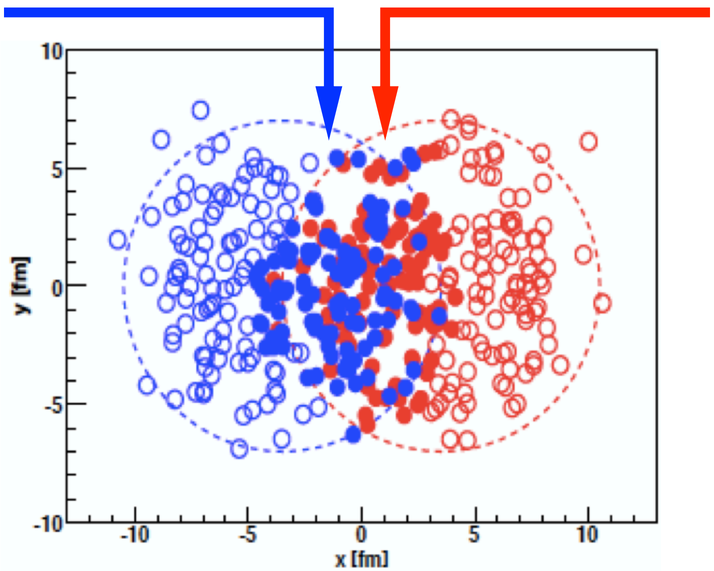
$$A_n = \frac{n_f - n_b}{n_f + n_b}$$

Forward-backward flow/multiplicity correlations provide a handle

Three types of longitudinal correlations

Fluctuation of sources in two nuclei → fluc. of size and transverse-shape

$N^{\mathrm{F}}_{\mathrm{part}}$ $\varepsilon^{\mathrm{F}}_{n} e^{in\Psi^{F}_{n}}$ $N^{\mathrm{B}}_{\mathrm{part}}$ $\varepsilon^{\mathrm{B}}_{n} e^{in\Psi^{B}_{n}}$

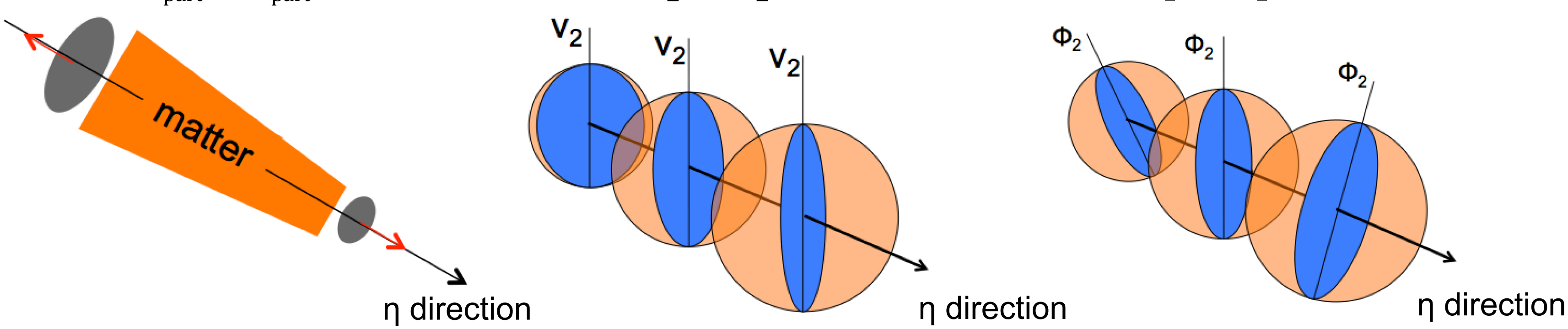


Consequences:

(a) $N^{\mathrm{F}}_{\mathrm{part}} \neq N^{\mathrm{B}}_{\mathrm{part}}$

(b) $\varepsilon^{\mathrm{F}}_{2} \neq \varepsilon^{\mathrm{B}}_{2}$

(c) $\Psi^{\mathrm{F}}_{2} \neq \Psi^{\mathrm{B}}_{2}$



Asymmetry in multiplicity

Asymmetry in flow magnitude

not a de-correlation

Torque/twist of flow plane

Two-particle correlation observables

Most general form in angular space: $C(\eta_1, \eta_2, \Delta\phi)$

$$C(\eta_{1,}\eta_{2,}\Delta\phi) = \underline{C_N(\eta_{1,}\eta_2)}\left[1 + 2\sum_n \underline{V_{n\Delta}(\eta_{1,}\eta_2)}\cos n\Delta\phi\right]$$

FB Multiplicity fluctuation

FB flow fluctuation

$$C_N(\eta_{1,}\eta_2) = \frac{\langle N(\eta_1) N(\eta_2)\rangle}{\langle N(\eta_1)\rangle \langle N(\eta_2)\rangle}$$

ATLAS observable

$$V_{n\Delta}(\eta_{1,}\eta_2) = \langle \mathrm{v}_n(\eta_1)\mathrm{v}_n(\eta_2)\cos n[\Phi_n(\eta_1) - \Phi_n(\eta_2)]\rangle$$

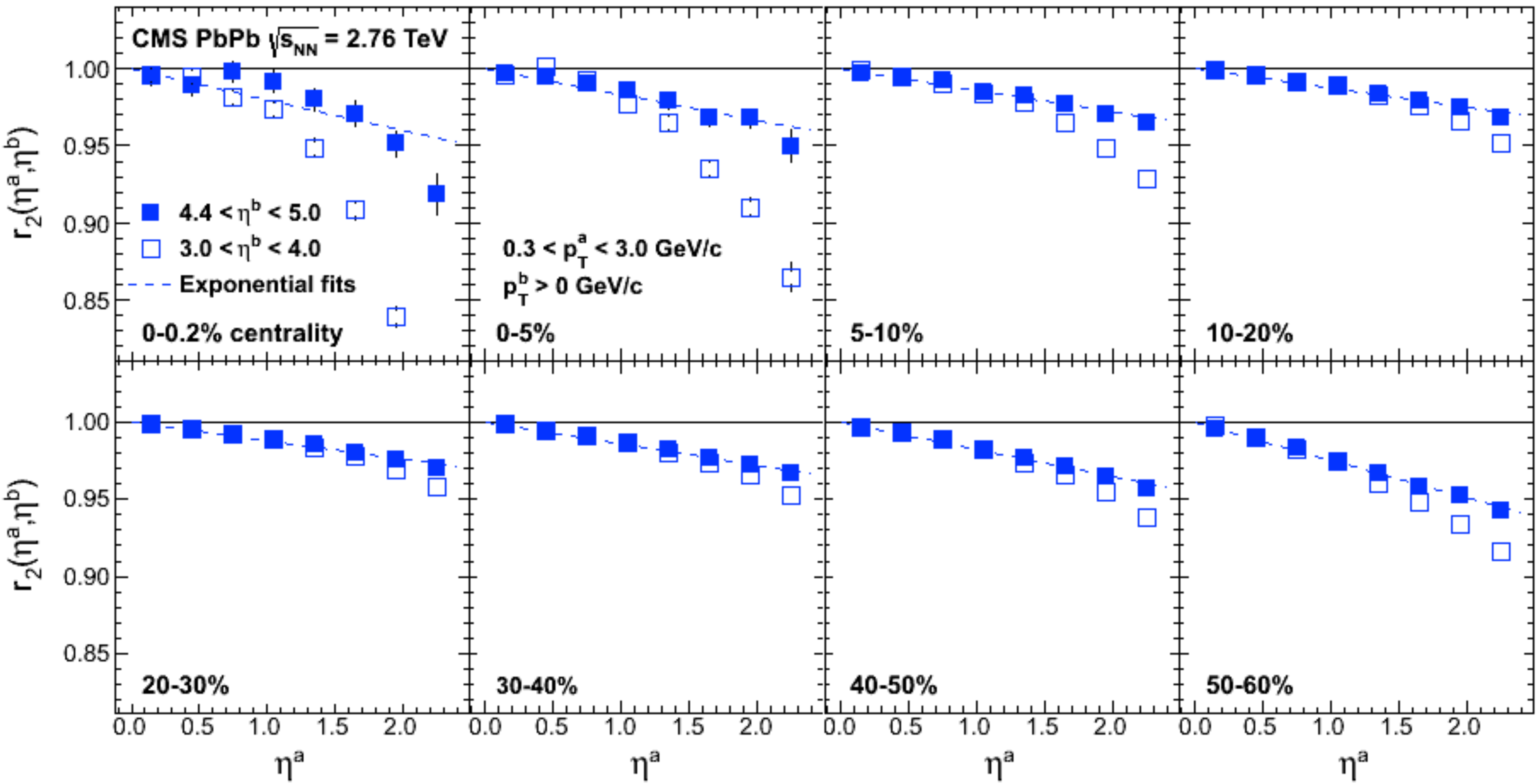
CMS observable: $r(\eta, \eta_{ref}) = \dfrac{V_{n\Delta}(-\eta, \eta_{ref})}{V_{n\Delta}(\eta, \eta_{ref})}$

Driven by N_{part} asymmetry

Driven by twist & asymmetry of ε_n

2^{nd}-order flow in PbPb

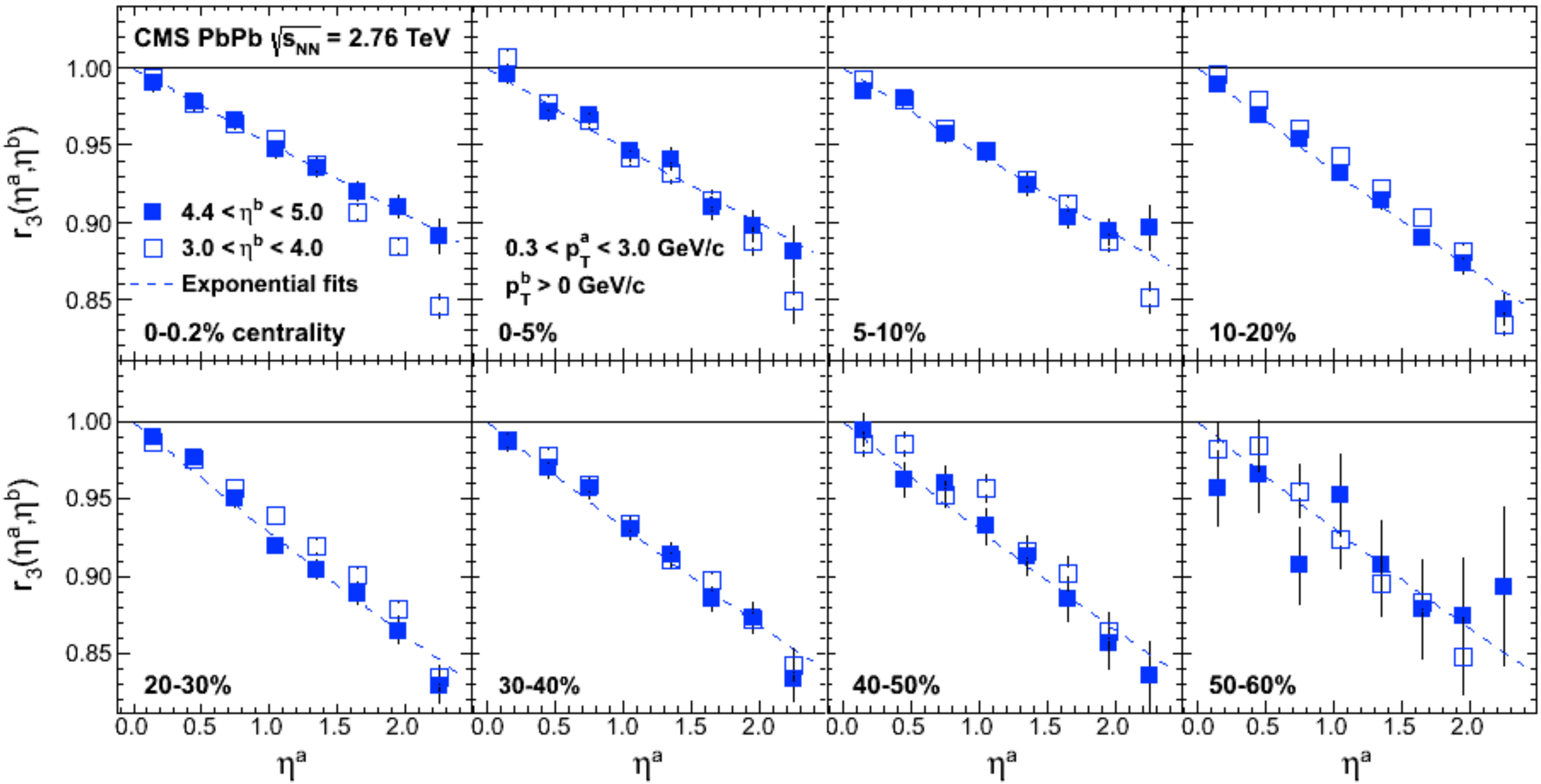
$$r_n(\eta^a,\eta^b) \equiv \frac{V_{n\Delta}(-\eta^a,\eta^b)}{V_{n\Delta}(\eta^a,\eta^b)}$$



- Linear function except in most central collisions
- Slope decreases then increases from central to peripheral

3^{rd}-order flow in PbPb

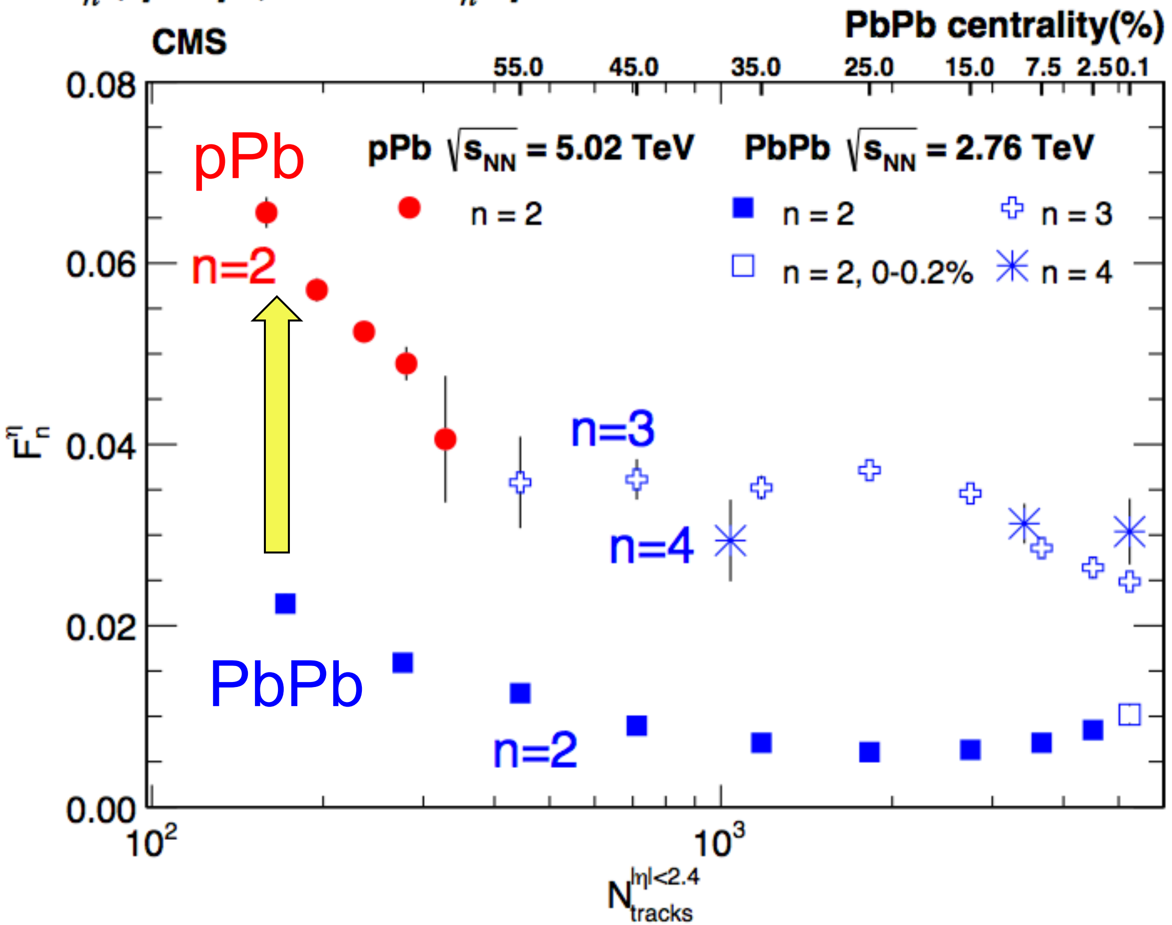
$$r_n(\eta^a,\eta^b) \equiv \frac{V_{n\Delta}(-\eta^a,\eta^b)}{V_{n\Delta}(\eta^a,\eta^b)}$$



- Slope ~ independent of centrality

Compared PbPb with pPb

$$r_n(\eta^a,\eta^b)=1-2F_n^\eta\eta^a$$

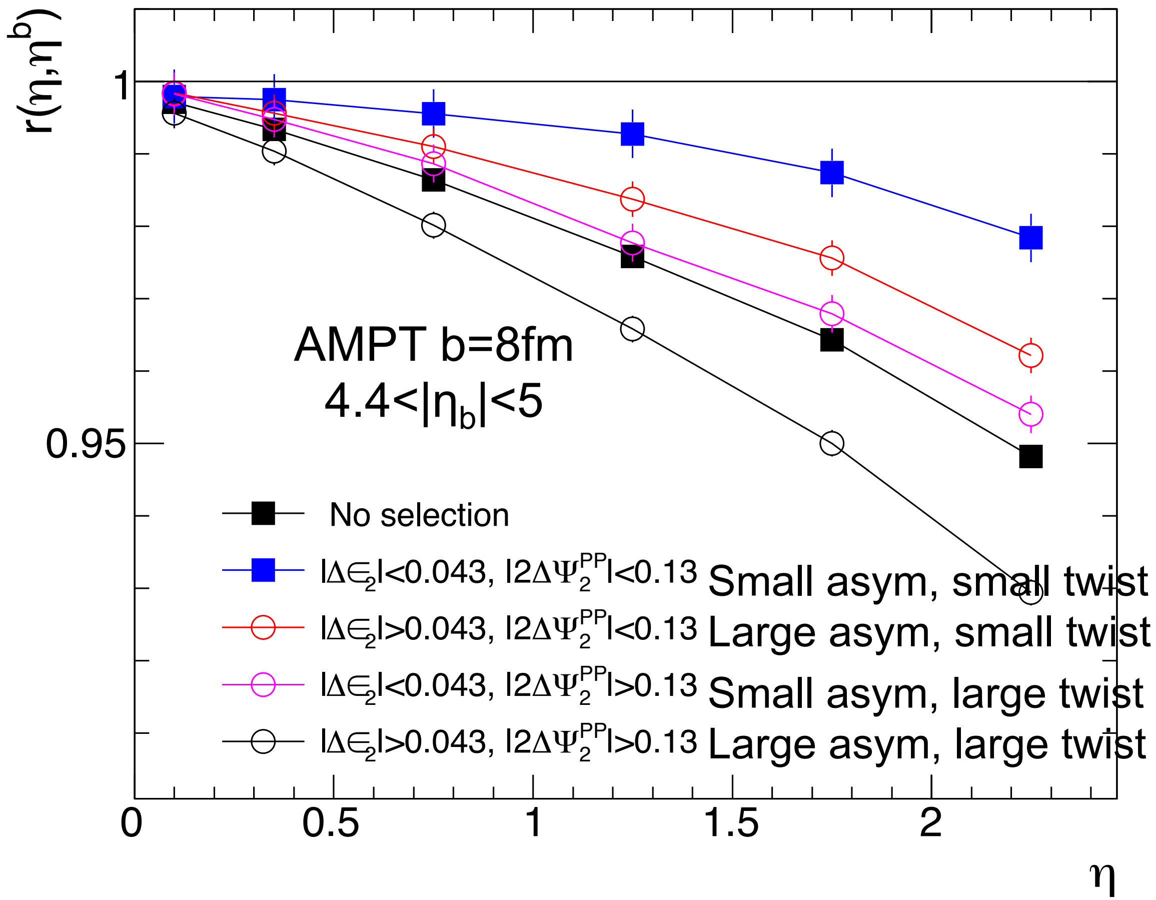


Stronger effect in pPb!   require sub-nucleonic dof.

What about HM pp?

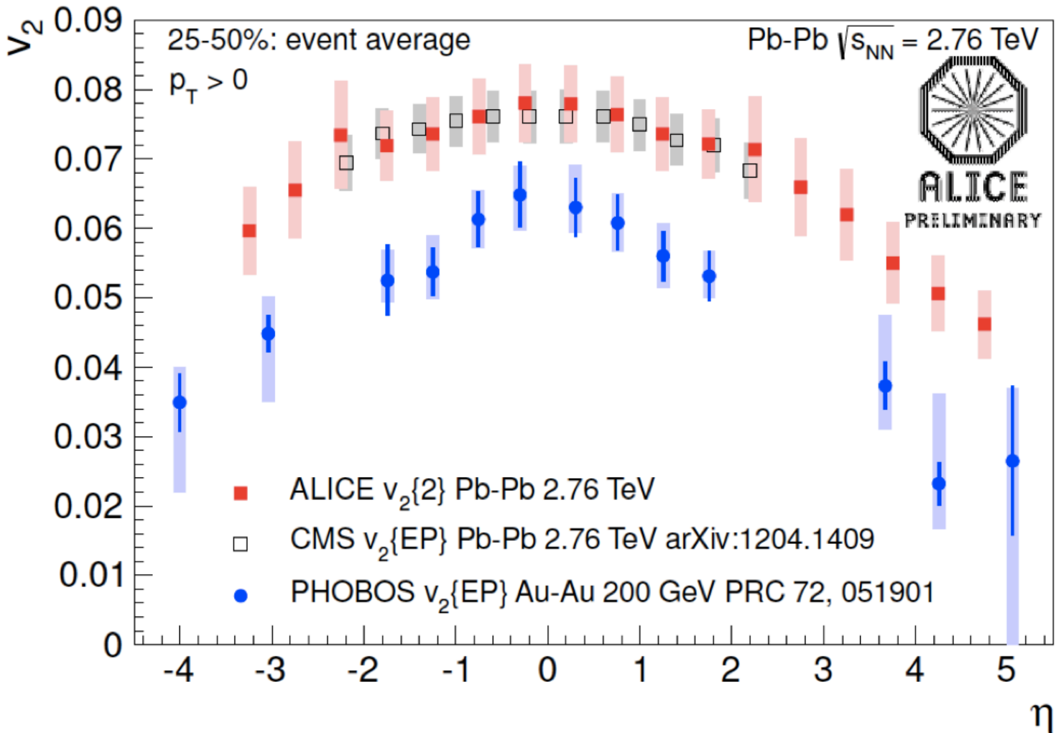
Separate asymmetry and twist contributions

- Select asymmetry and twist based on eccentricity vector in AMPT
  - Cut on asymmetry : $\Delta\varepsilon_2 = \varepsilon_2^F - \varepsilon_2^B$, cut on twist: $\Delta\Psi_2 = \Psi_2^F - \Psi_2^B$



asymmetry contribution > 50% of the twist contribution.

Revisit the $v_n(\eta)$ measurement



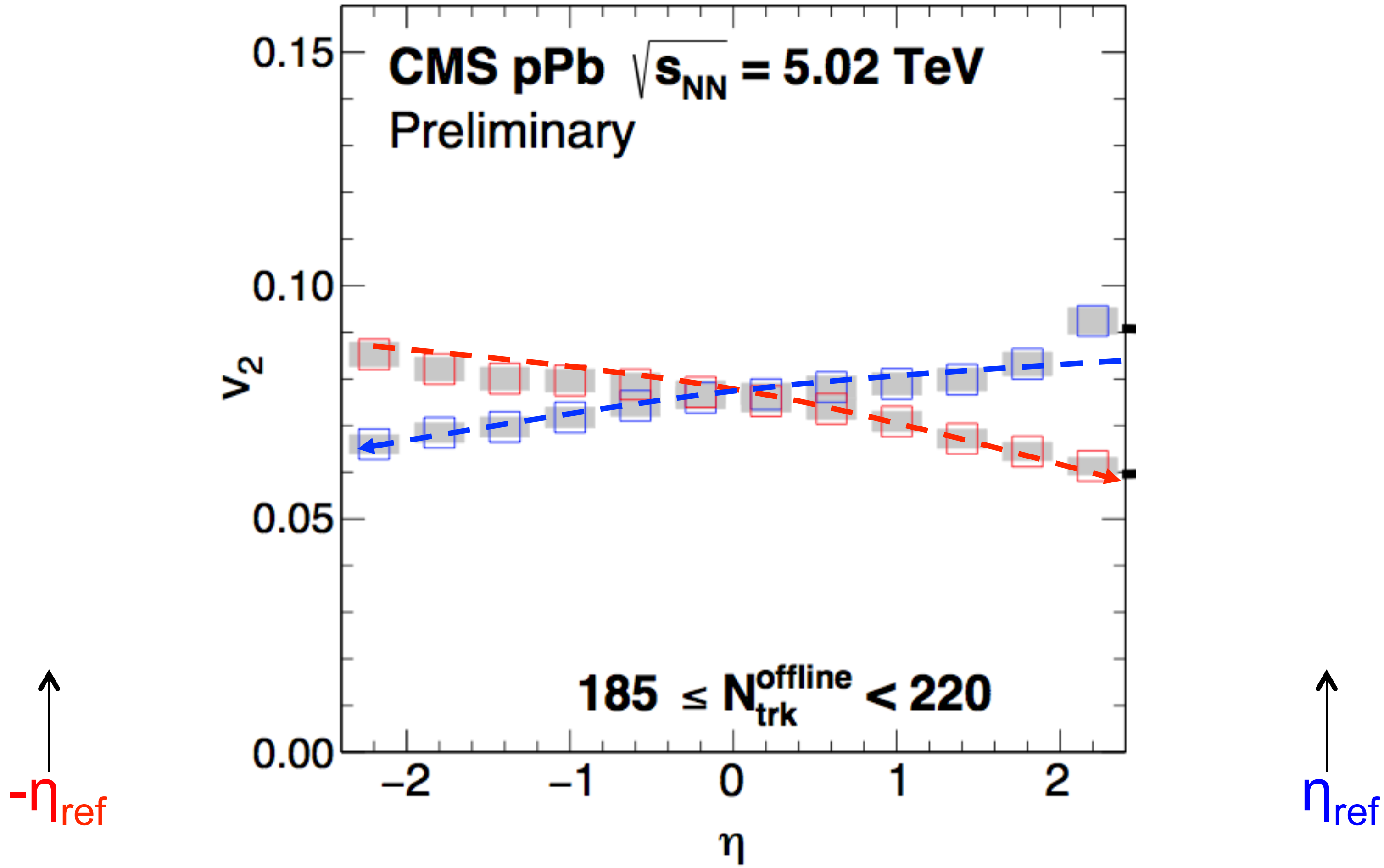
- Relies on 2PC & factorization assumption: $V_{n\Delta}(\eta_1,\eta_2)=v_n(\eta_1)v_n(\eta_2)$.
  - When quoting $v_n(\eta)$, don't forget the reference particle, e.g in SP method:

$$v_n(\eta) \equiv \sqrt{\frac{V_{n\Delta}(\eta,\eta_{ref})}{V_{n\Delta}(\eta_{ref},-\eta_{ref})}}$$

- Distinguish different components of η dependence
  - Intrinsic $v_n(\eta)$
  - Relative fluct. between $v_n(\eta_1)$ and $v_n(\eta_2)$
  - Event-plane decorrelation, $\Psi_n(\eta_1) \neq \Psi_n(\eta_2)$

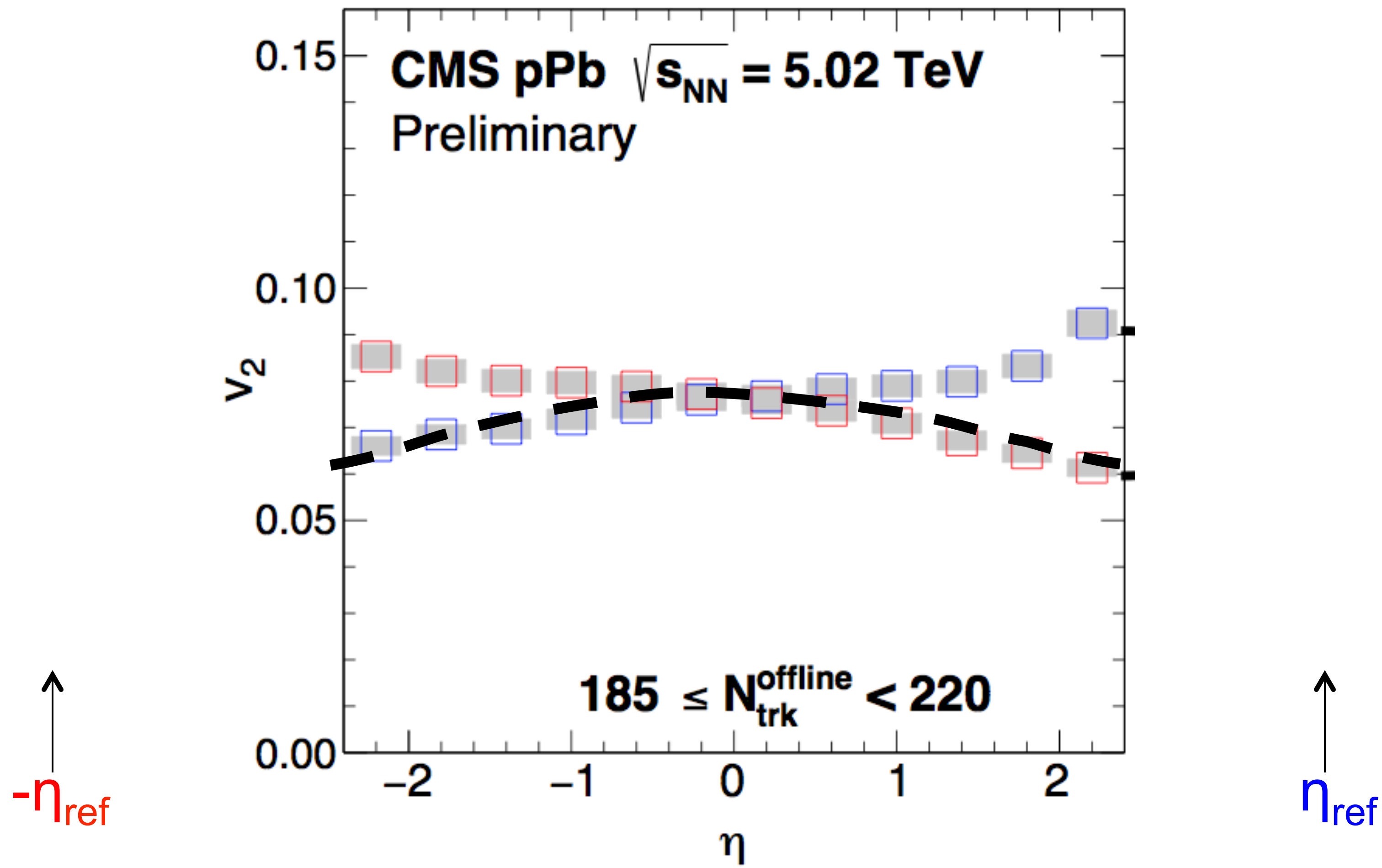
Hydro calc need to include these effects

The fallacy of factorization assumption in η



Observation: v_n always decreases away from reference particle

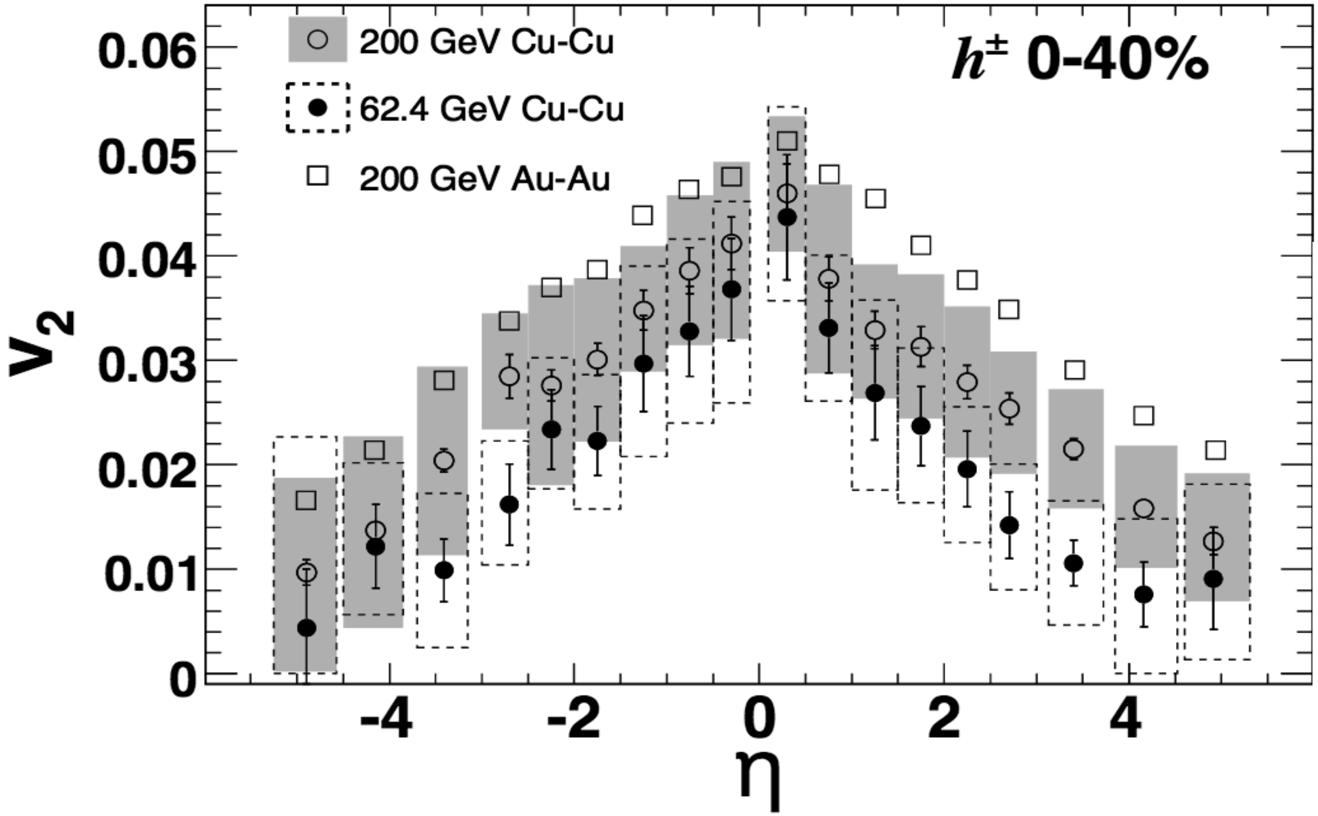
The fallacy of factorization assumption in η

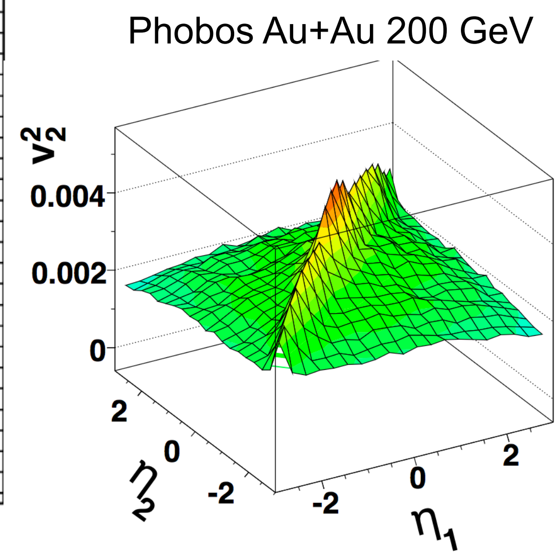


Observation: v_n always decreases away from reference particle

symmetrized result is smaller than truth

Stronger bias at RHIC

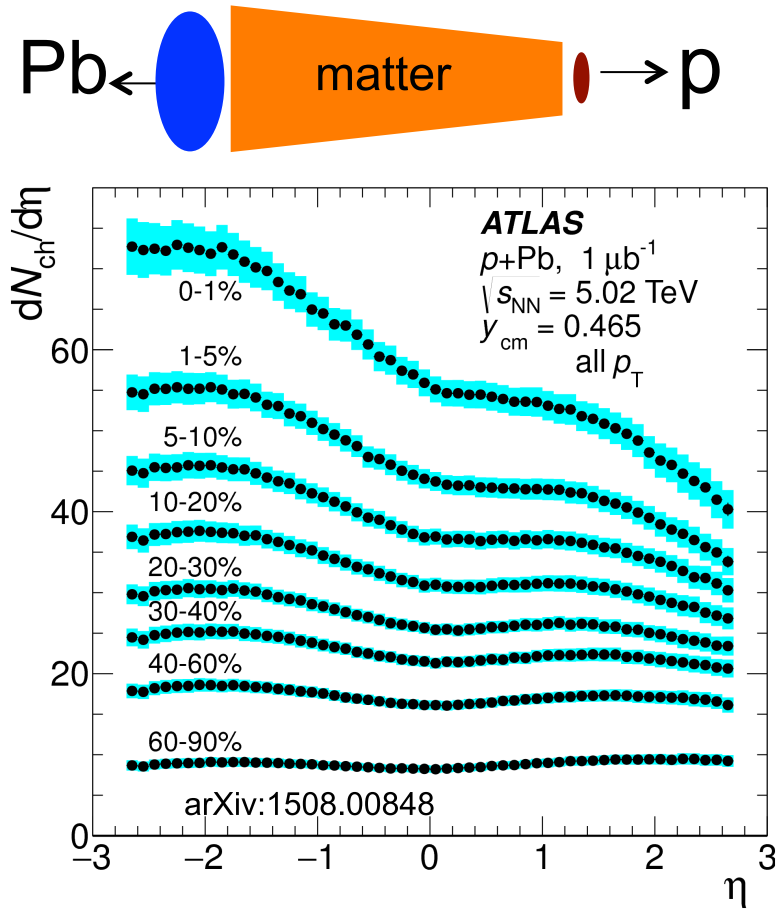




- Measure $V_{n\Delta}(\eta_1,\eta_2)$ instead of only the factorized form!
  - Systematic separation of the short-range and various components of flow.
  - Complete information on collectivity in 3+1D.

0th-order: FB multiplicity asymmetry

- dN/dη shape in pPb reflects asymmetry in num. of F-B sources

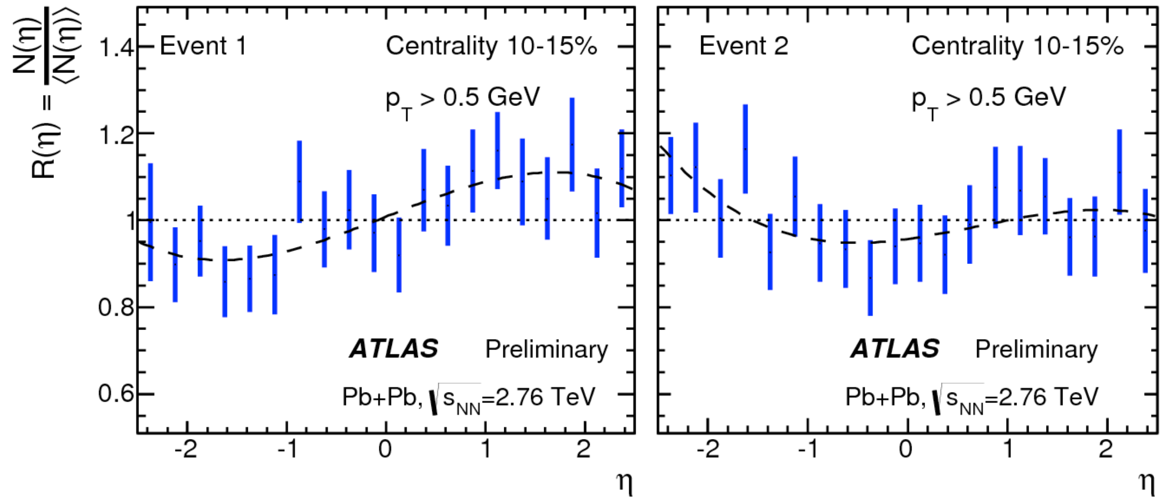


Measure FB asymmetry fluctuation event-by-event?

Pseudorapidity correlation function

Single particle distribution

$$R_S(\eta) \equiv \frac{N(\eta)}{\langle N(\eta) \rangle}$$



$$C = \frac{\langle N(\eta_1) N(\eta_2) \rangle}{\langle N(\eta_1) \rangle \langle N(\eta_2) \rangle} = \langle R_S(\eta_1) R_S(\eta_2) \rangle_{events}$$

Mixed events

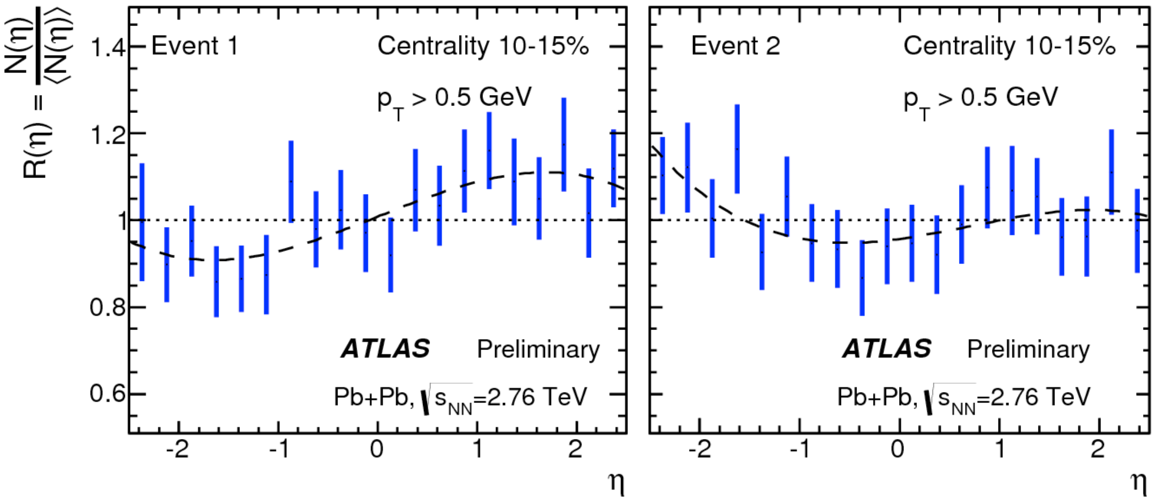
Disentangles statistical fluctuation from dynamical fluctuation

Can also do multi-particle correlations: Bzdak, Bozek, Broniowski 1509.02967, 1509.04124

Leading-order contribution

Single particle distribution

$$R_S(\eta) \equiv \frac{N(\eta)}{\langle N(\eta) \rangle} \approx 1 + a_1 \eta$$

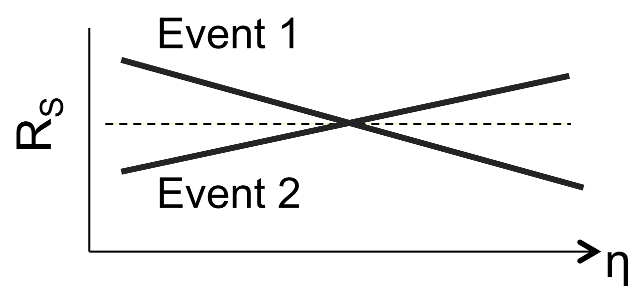


$$C = \frac{\langle N(\eta_1) N(\eta_2) \rangle}{\langle N(\eta_1) \rangle \langle N(\eta_2) \rangle} = \langle R_S(\eta_1) R_S(\eta_2) \rangle_{events}$$

$$\approx 1 + \langle a_1 \eta_1 a_1 \eta_2 \rangle$$

$$= 1 + \langle a_1^2 \rangle \eta_1 \eta_2$$

Mixed events



Disentangles statistical fluctuation from dynamical fluctuation

Can also do multi-particle correlations: Bzdak, Bozek, Broniowski 1509.02967, 1509.04124

Properties of multiplicity correlation

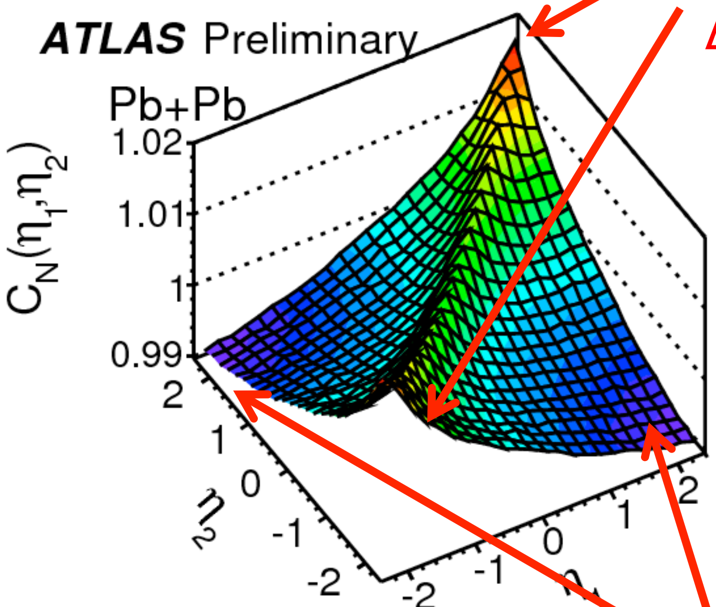
$$C_N = 1 + \delta_{SRC} + \delta_{LRC}$$

$p_T > 0.2$ GeV

$100 \le N_{ch}^{rec} < 120$

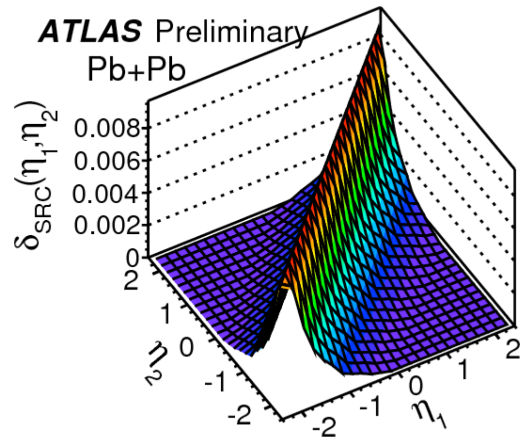
Short-range correlation δ_{SRC}

$\Delta\eta = \eta_1 - \eta_2 \sim 0$



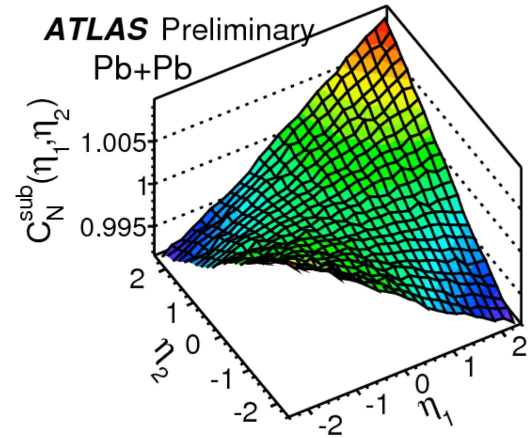
Long range correlation δ_{LRC}

=



$$\Delta_{SRC} = \frac{\int \delta_{SRC}(\eta_1,\eta_2)d\eta_1 d\eta_2}{4Y^2}$$

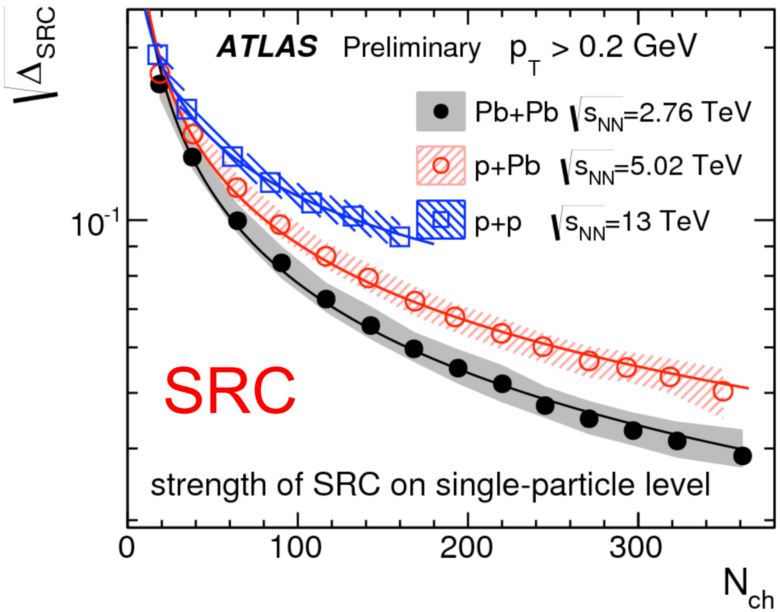
=

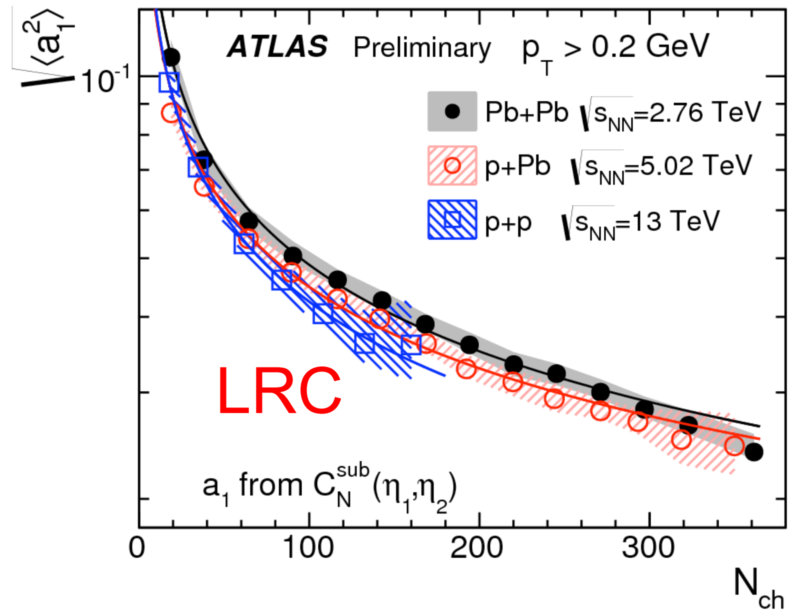


See Mingliang Zhou's talk

Consistent with $\approx 1 + \langle a_1^2 \rangle \eta_1 \eta_2$

Dependence on N_{ch} and collision systems





SRC controlled by num. of sources

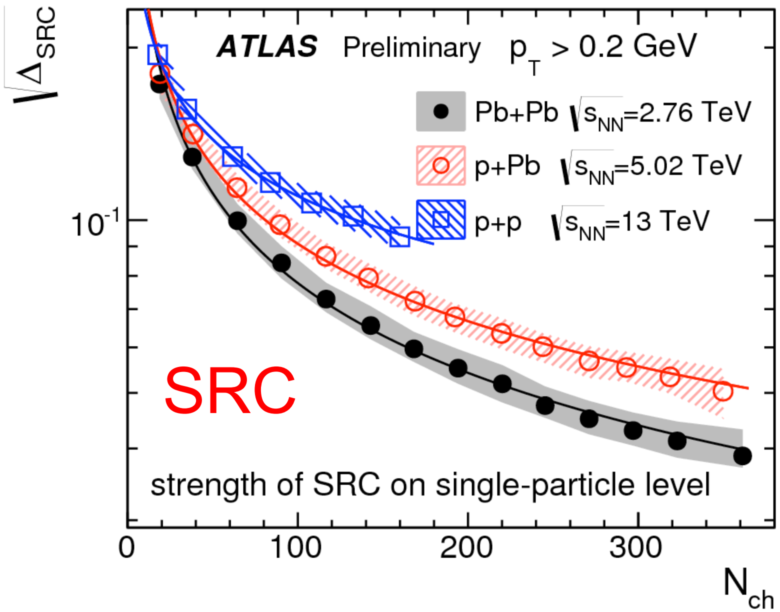
$$n = n_f + n_b \propto N_{\mathrm{ch}}$$

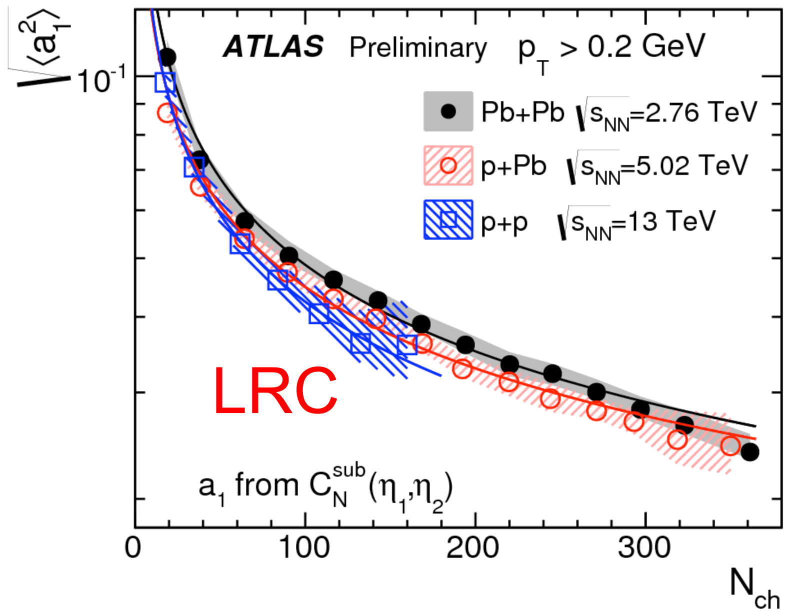
LRC controlled by FB asymmetry of sources

$$A_n = \frac{n_f - n_b}{n_f + n_b}, \qquad \langle a_1^2 \rangle \propto \langle A_n^2 \rangle$$

Expect 1/√N for independent-source emission

Dependence on N_{ch} and collision systems





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LRC controlled by FB asymmetry of sources

$$A_n = \frac{n_f - n_b}{n_f + n_b} \qquad \langle a_1^2 \rangle \propto \langle A_n^2 \rangle$$

Expect 1/√N for independent-source emission

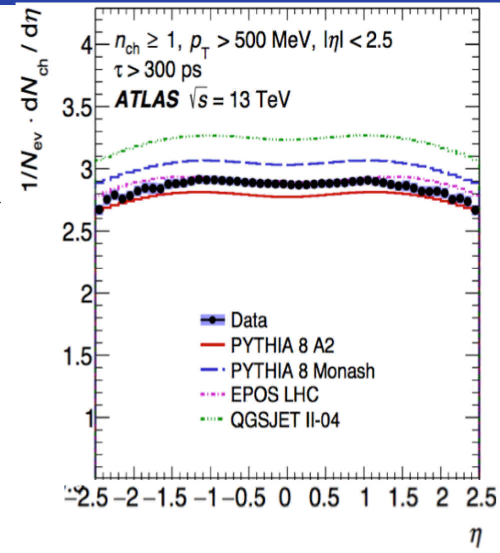
- Fit with $c/N_{\rm ch}^{\alpha}$

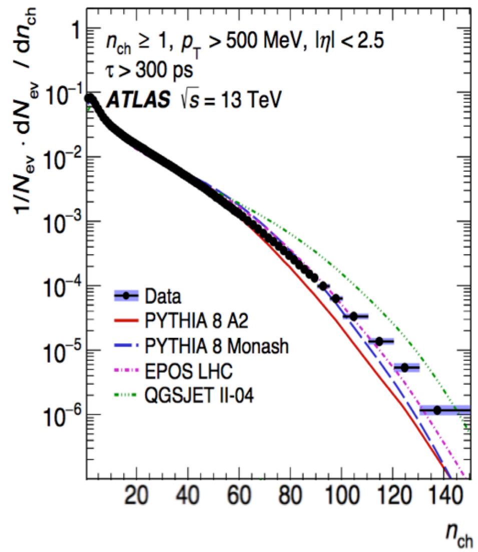
	Pb+Pb	*p*+Pb	*pp*
α for $\sqrt{\Delta_{\rm SRC}}$	0.505 ± 0.011	0.450 ± 0.010	0.365 ± 0.014
α for $\sqrt{\langle a_1^2 \rangle}$	0.454 ± 0.011	0.433 ± 0.014	0.465 ± 0.018

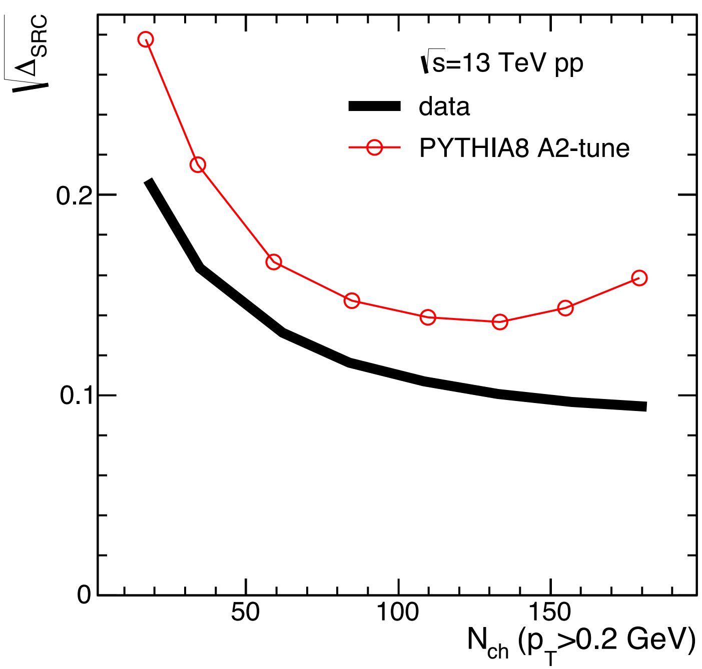
- SRC: more pair/source for smaller system
- LRC: 1/√N behavior independent of collision system

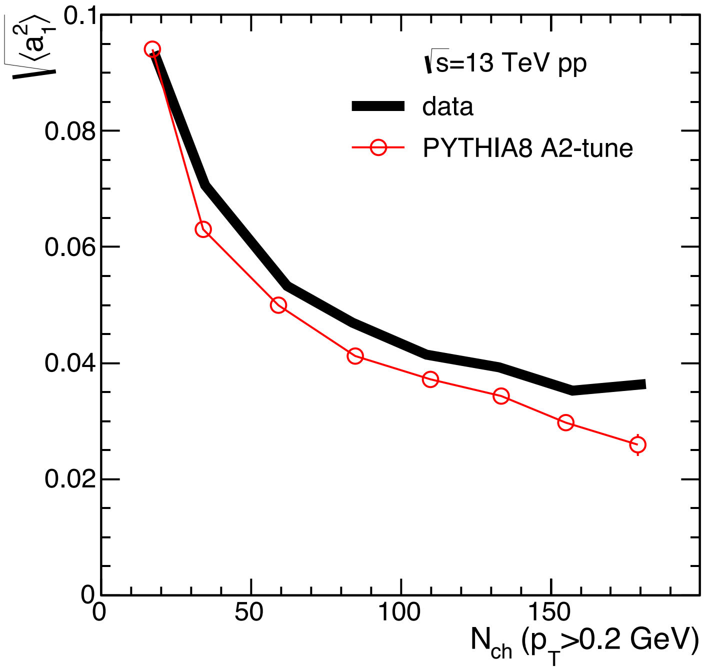
Compare with PYTHIA8 and EPOS-LHC

- Tuned to dN/dη and N_{ch} distribution via MPI
- Models:
  - Over-estimate the SRC
  - Under-estimate the LRC



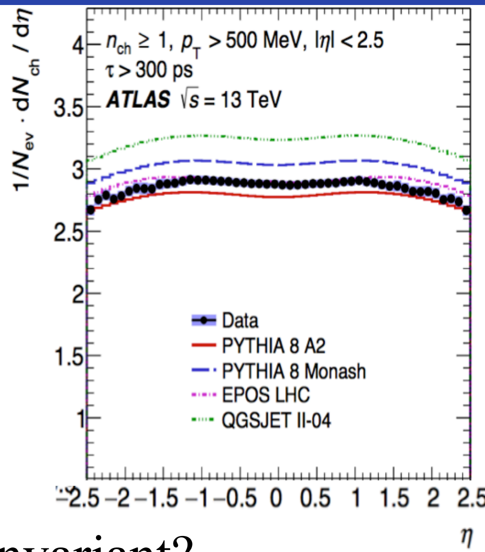


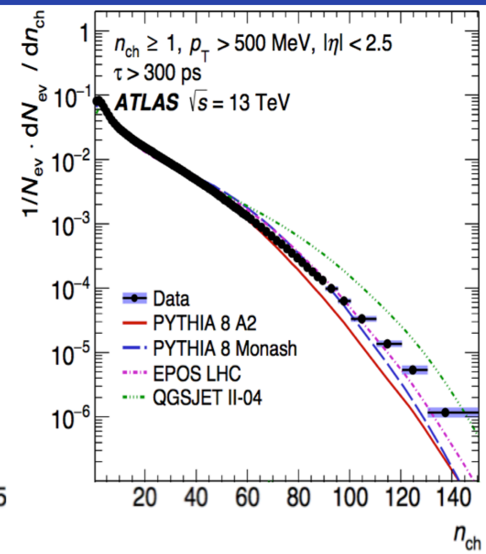




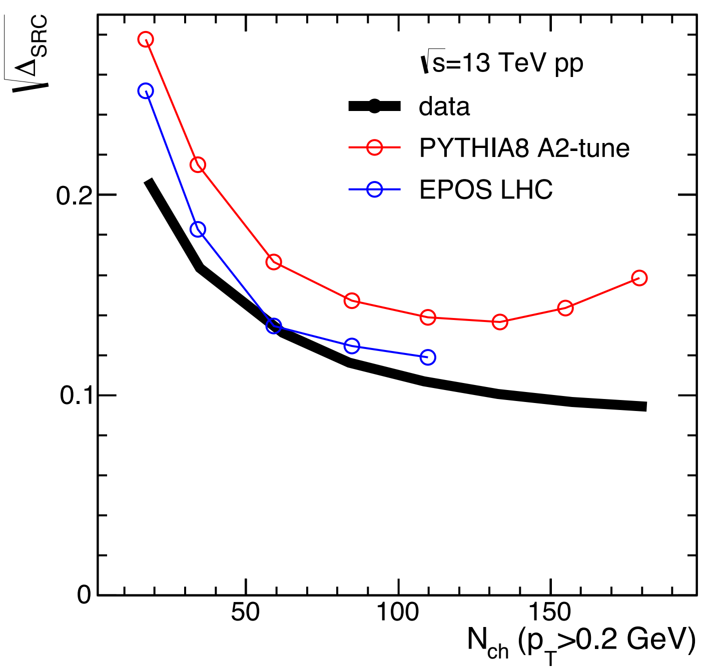
Compare with PYTHIA8 and EPOS-LHC

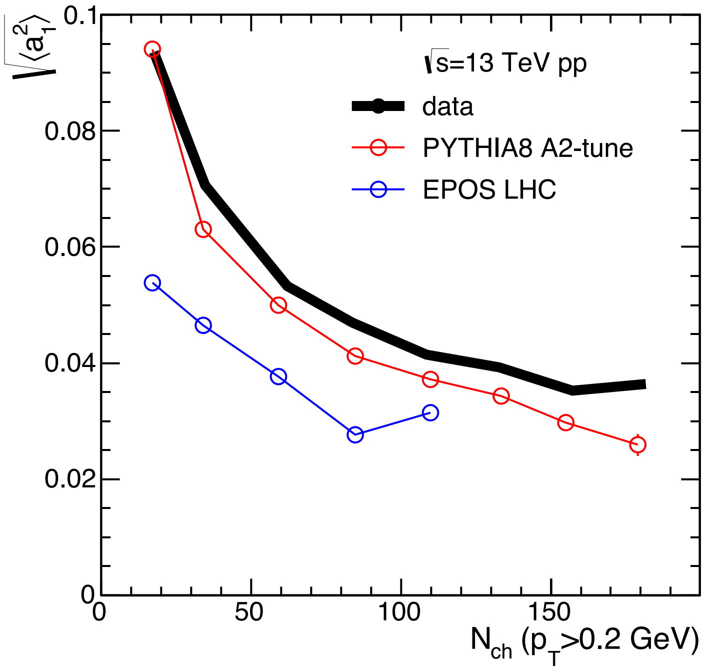
- Tuned to dN/dη and N_{ch} distribution via MPI



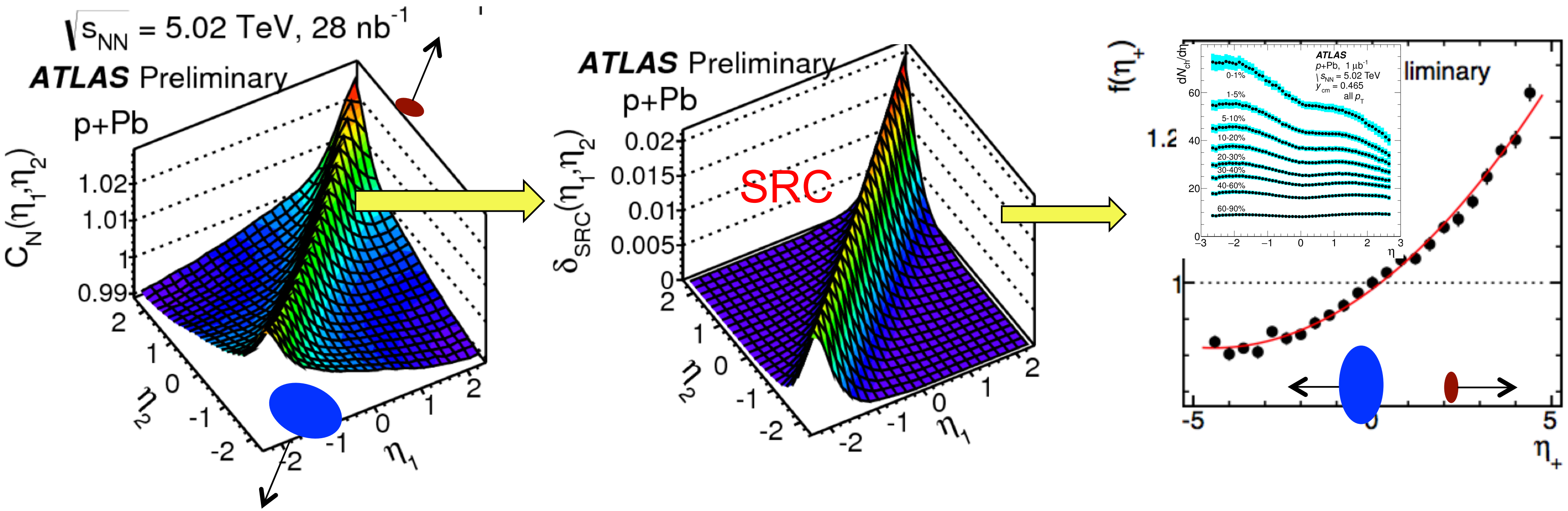


- Models:
  - Over-estimate the SRC
  - Under-estimate the LRC
  - LRC in EPOS is very small, boost invariant?



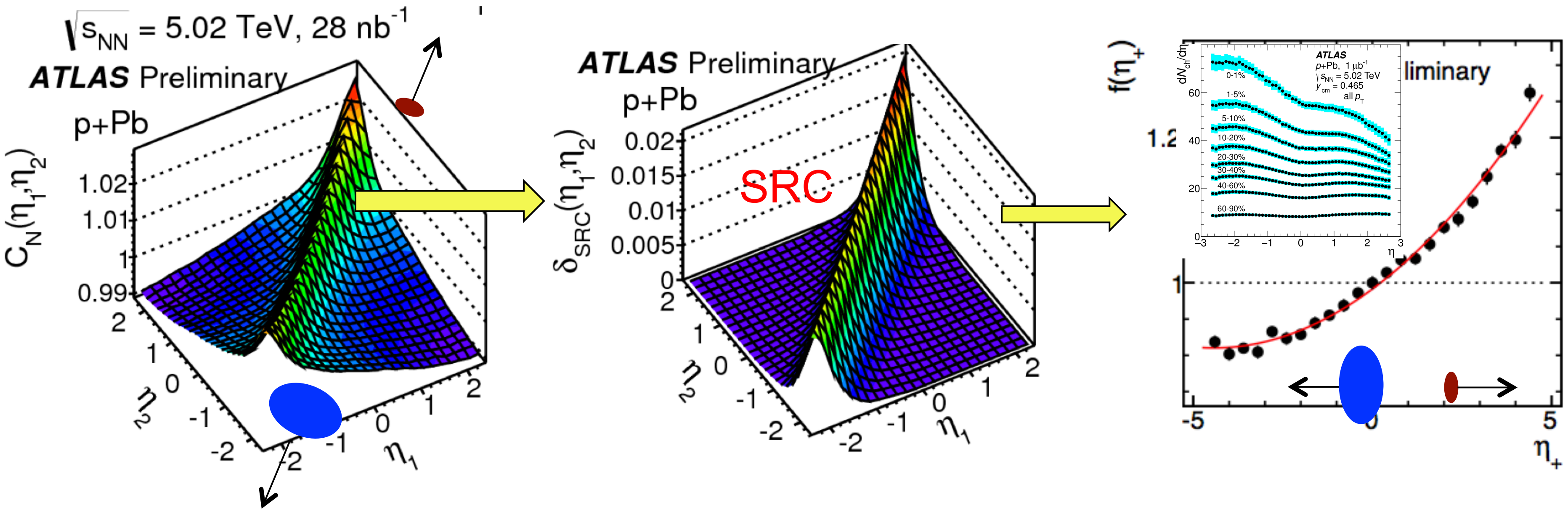


SRC and dN/dη



Asymmetry entirely due to SRC→larger on proton-going side!

SRC and dN/dη



Asymmetry entirely due to SRC→larger on proton-going side!

Assume n_s sources at η, each source produce m particles,

SRC at given η scale as $\approx \frac{n_s m^2}{(n_s m)^2} = \frac{1}{n_s} \propto 1/\frac{dN}{d\eta}$

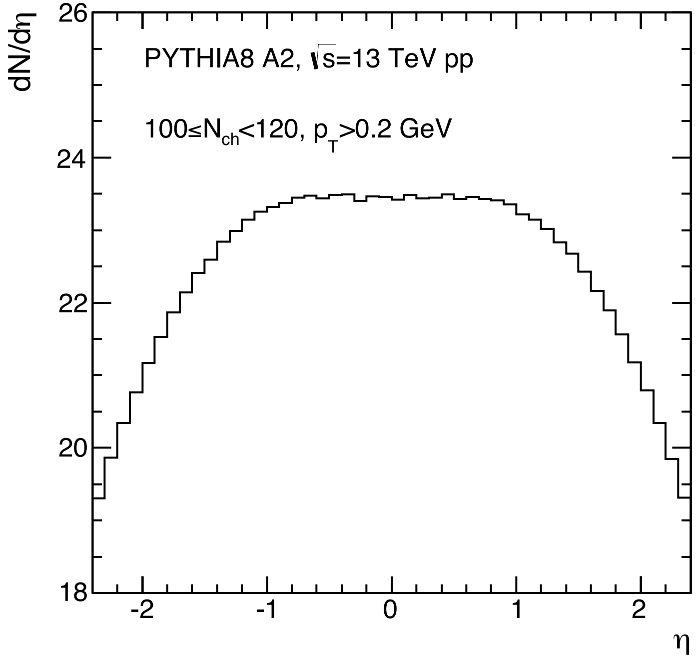
Can use SRC to infer dN/dη shape!

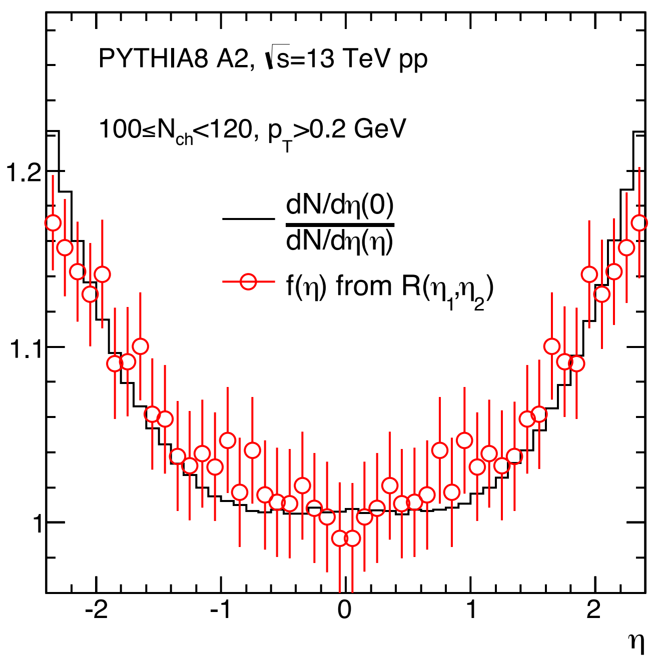
Verify the idea with PYTHIA

- Calculate the f(η) from CF and compare to actual dN/dη(0)/dN/dη(η)

  →Reproducing the dN/dη shape

  →Can use 2PC method to measure dN/dη-shape, small experimental systematics, albeit with assumption that cluster size independent of η.





Summary

- Longitudinal correlations provide info on non-boost-invariant initial conditions & rapidity transports in pp, pA and AA collisions

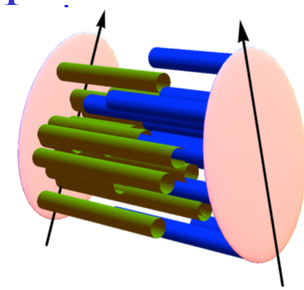
- Longitudinal flow correlations
  - Consistent with rapidity-dependent mixing of initial condition controlled by projectile and target sources.
  - Important to separate different components of flow
  - They need to be properly included in all 3+1D ebye hydro models

- Longitudinal multiplicity correlations
  - Long-range correlations scale as $c/\sqrt{N_{ch}}$ in dependent of collision system
  - Information on the particle production sources?

See Mingliang's talk for more experimental details

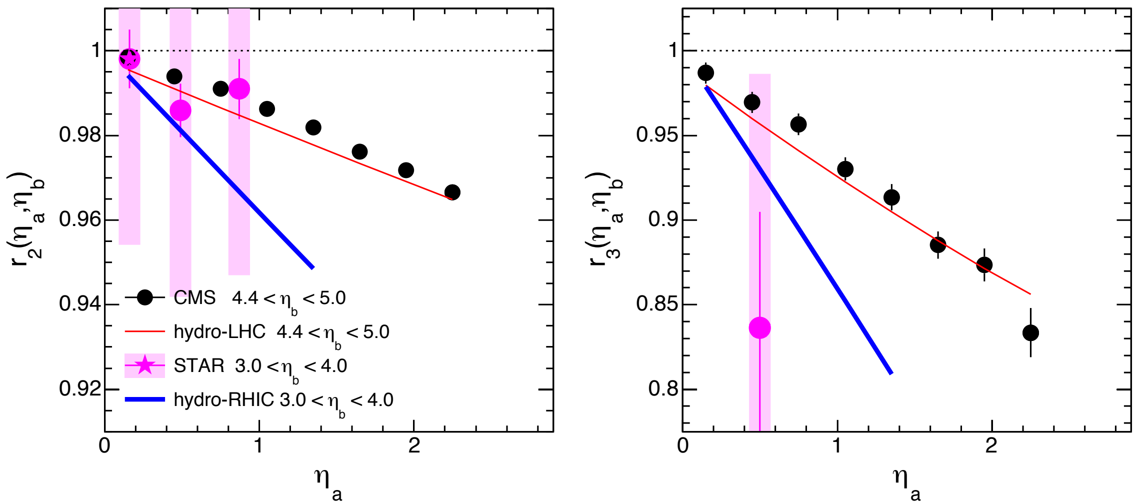
Outlook I

- Measure $V_{n\Delta}(\eta_1,\eta_2)=\langle \mathrm{v}_n(\eta_1)\mathrm{v}_n(\eta_2)\cos n[\Phi_n(\eta_1)-\Phi_n(\eta_2)]\rangle$ in "full" η space
  - Carry the same measurement in HM pp, pPb
  - Systematic separation of SRC and components of flow.
  - Clarify the longitudinal structures of the initial condition.

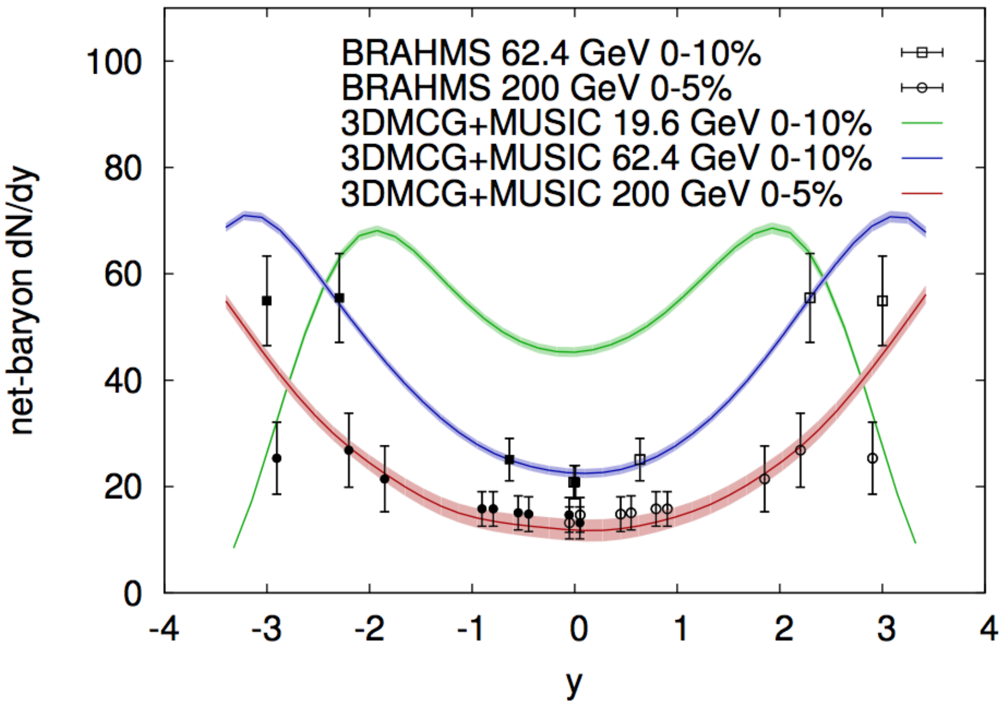


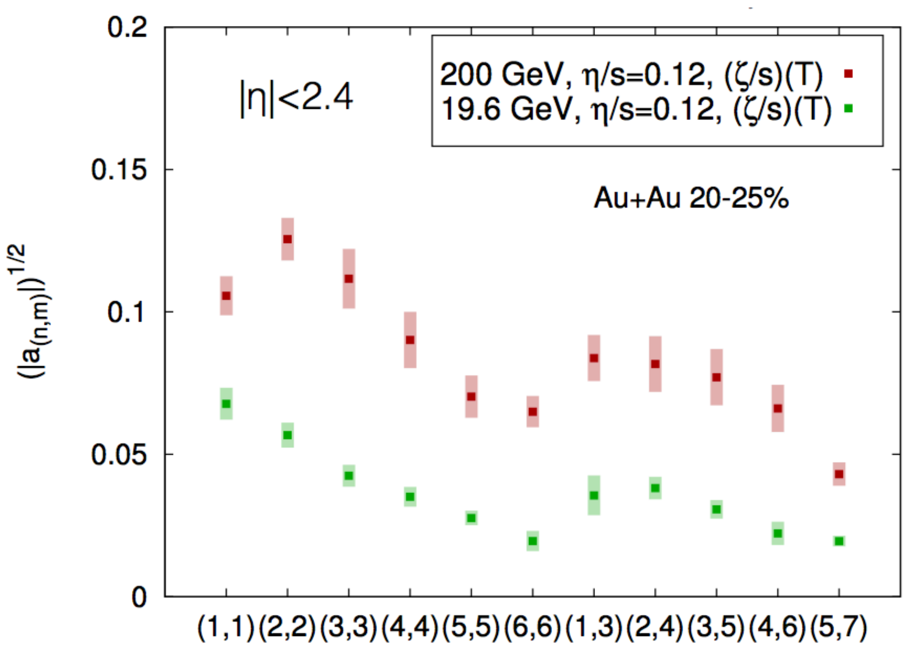
Bozek et.al., arXiv:1011.3354

- Multiplicity correlation $C(\eta_1,\eta_2)$ via identified particles
  - probe transport of conserved quantities in η: charge, net baryon, strangeness..
  - Others, e.g. $\langle p_T\rangle(\eta_1)$, $\langle p_T\rangle(\eta_2)$ correlations   nucl-th/0606061,1106.4334
- Perform similar measurements at RHIC   L.G.Pang, et.al EPJA52 (2016) 97
  - FB asymmetry & decorrelation should be larger due to compressed η profile.
  - √s dependence of number of sources, their η-length and length fluctuations.



EbyE baryon transport via FB net-proton correlation



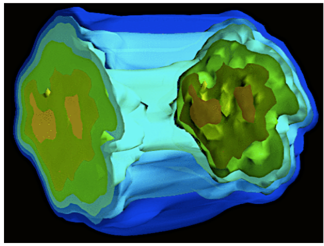


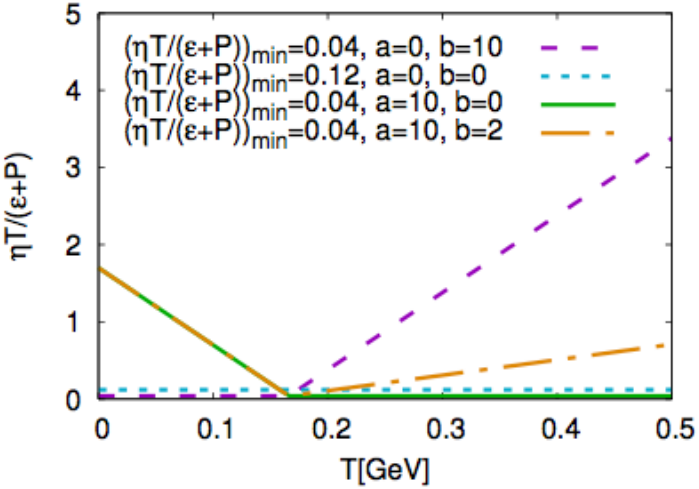
B. Schenke QM2015

Very important in the context of BES-II at RHIC

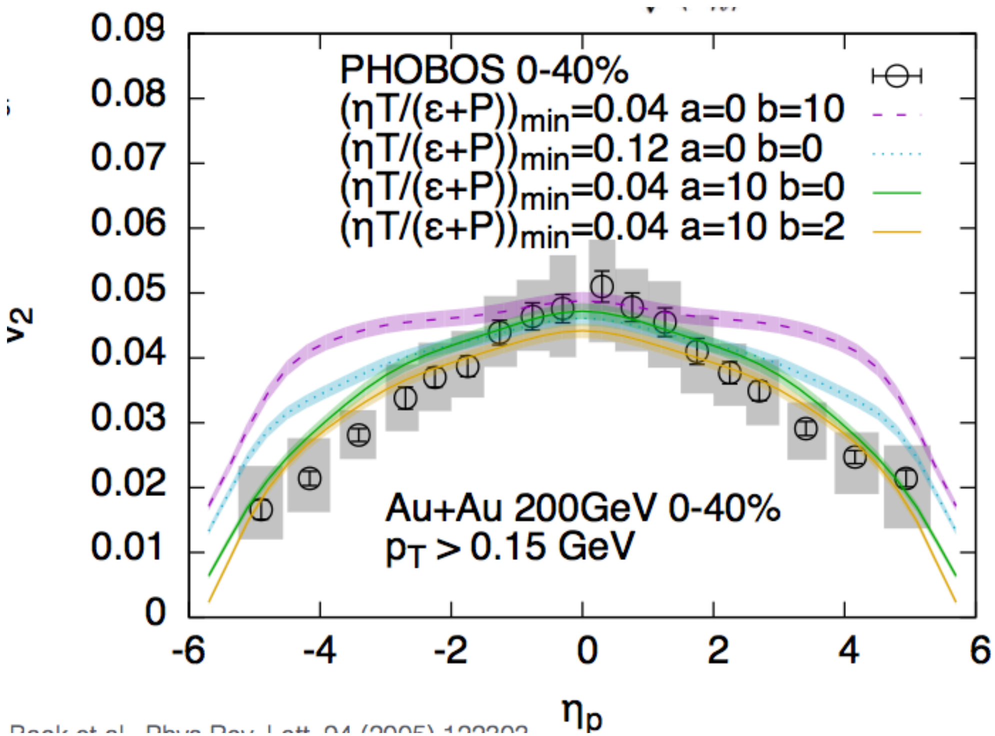
Outlook II

- Differential information on spectra and flow in forward η
  - Map the EbyE fluc & improve full EbyE 3+1D hydrodynamics.
  - Longitudinal pressure, isotropization, hydrodynamic noise….





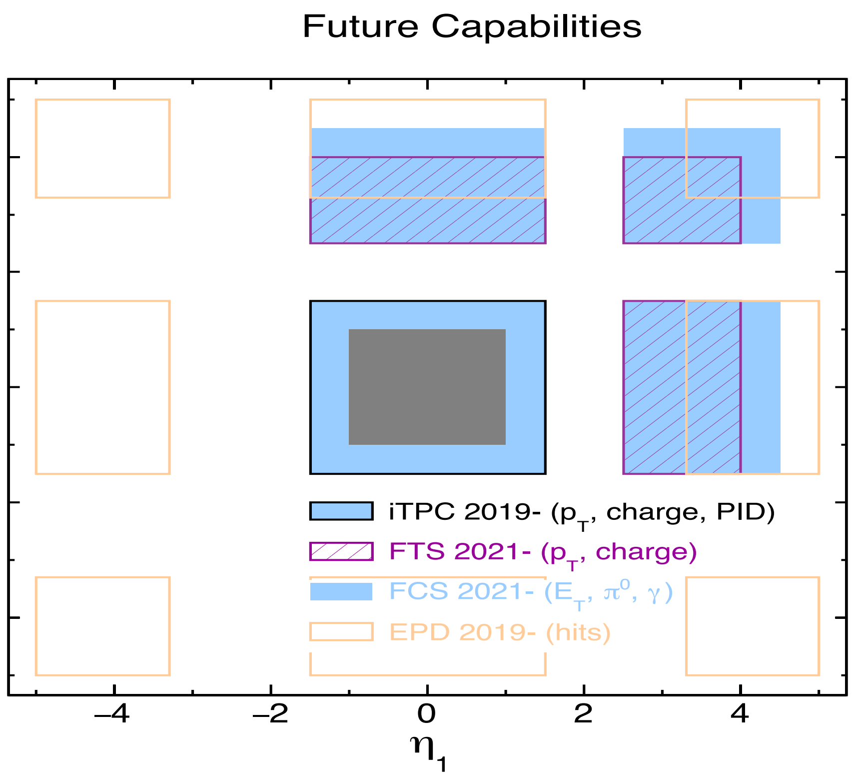
Denicol, Monnai, Schenke 1512.01538

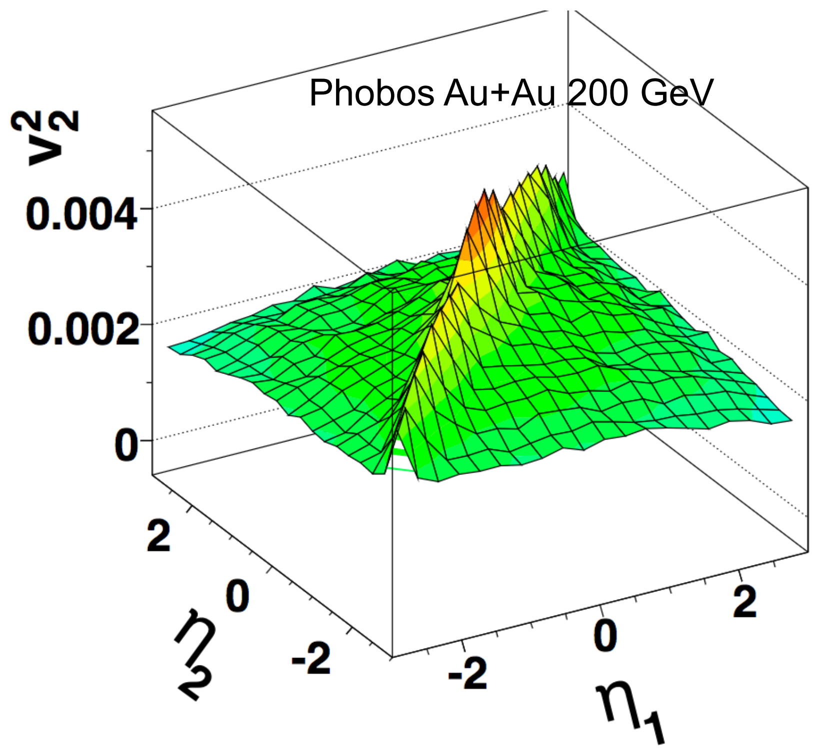


forward high-μ at large √s ≠ mid-rapidity high-μ at small √s

Outlook III

- LHC: LS2 upgrade extend tracking from |η|<2.5 to 4 @ATLAS/CMS
- RHIC: possible STAR forward upgrade, iTPC+FTS+FCS & sPHENIX?

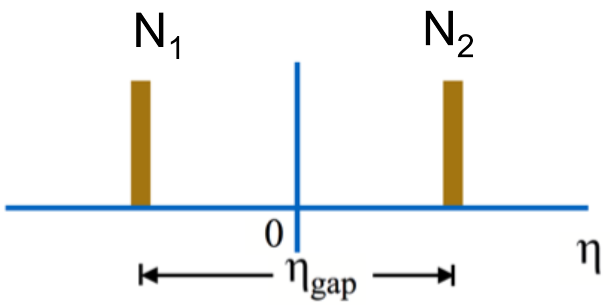




What level of precision we need for the longitudinal dynamics in comparison to the transverse dynamics?

Backup

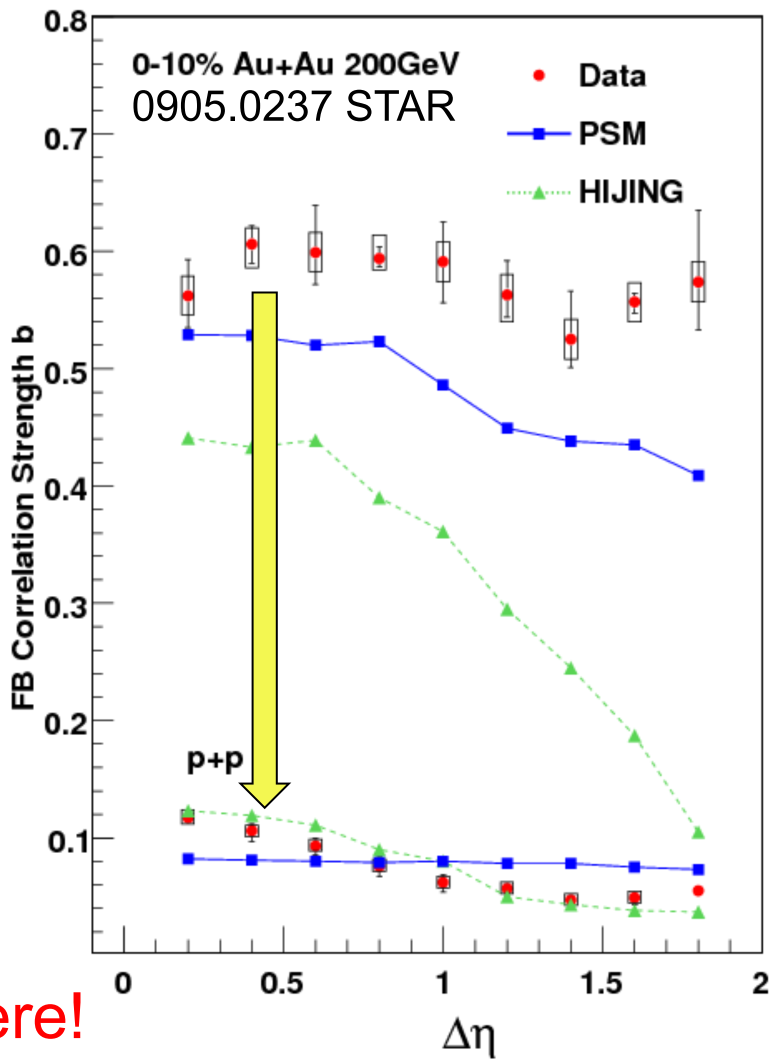
Traditional observable



$$b = \frac{\langle N_1 N_2 \rangle - \langle N_1 \rangle \langle N_2 \rangle}{\sigma_{N_1} \sigma_{N_2}}$$

$$\approx \left(C(\eta_1, \eta_2) - 1 \right) \frac{1}{\sqrt{\langle N_2 \rangle} \sqrt{\langle N_2 \rangle}}$$

Undesirable, e.g. value of b reduces by factor of two if one uses only half of the particles in each rapidity, although physics clearly should remain the same.



Statistical artifacts everywhere!