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Comment on forward heavy-ion physics in 2021-2022 – focus on flow fluctuations

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Opportunities for Exploring Longitudinal Dynamics in Heavy Ion Collisions at RHIC

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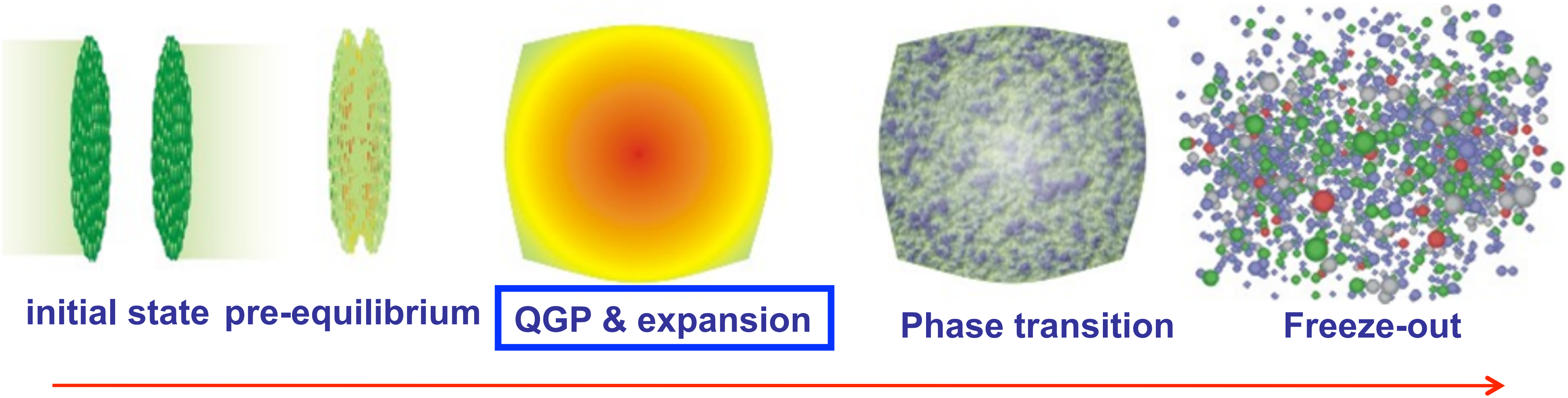
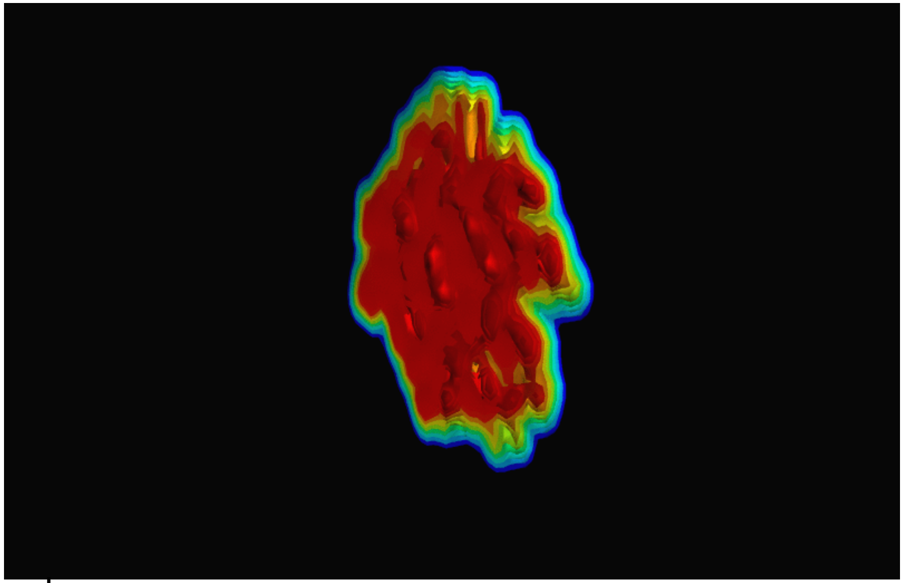
PURPOSE:

The last decades of heavy ion collisions have been marked by significant progress in understanding the transverse structure and dynamics in heavy ion collisions. Spurred by the observations of highly distorted correlation structures in heavy ion collisions the community has developed a detailed picture encapsulated in sophisticated dynamical models to capture these details. These models have led to significant improvements in our understanding of the emergent properties of high density, high temperature QCD, including transport properties. Even with this significant progress however, important open questions remain about the longitudinal structure and dynamics in these collisions: what is the structure of the initial state and how does it evolve with rapidity? Over what rapidity range does coherence in the initial state persist? What mechanism or mechanisms transport baryons toward mid-rapidity? How large are hydrodynamic fluctuations and how far do they spread in rapidity space? While many of the questions are fascinating in their own rights, failure to answer some will make it difficult to draw conclusions about other aspects of Heavy Ion collisions, including the nature of net baryon fluctuations and the extent to which hydrodynamic noise influences the correlation functions used to determine the transport properties of the QGP. For this reason we propose to organize this workshop to discuss opportunities to answer these questions in a physics program that could be conducted during the final phases of RHIC operations.

Adrian Dumitru, Kevin Dusling, Jiangyong Jia, Akihiko Monnai,
Paul Sorensen, and Prithwish Tribedy

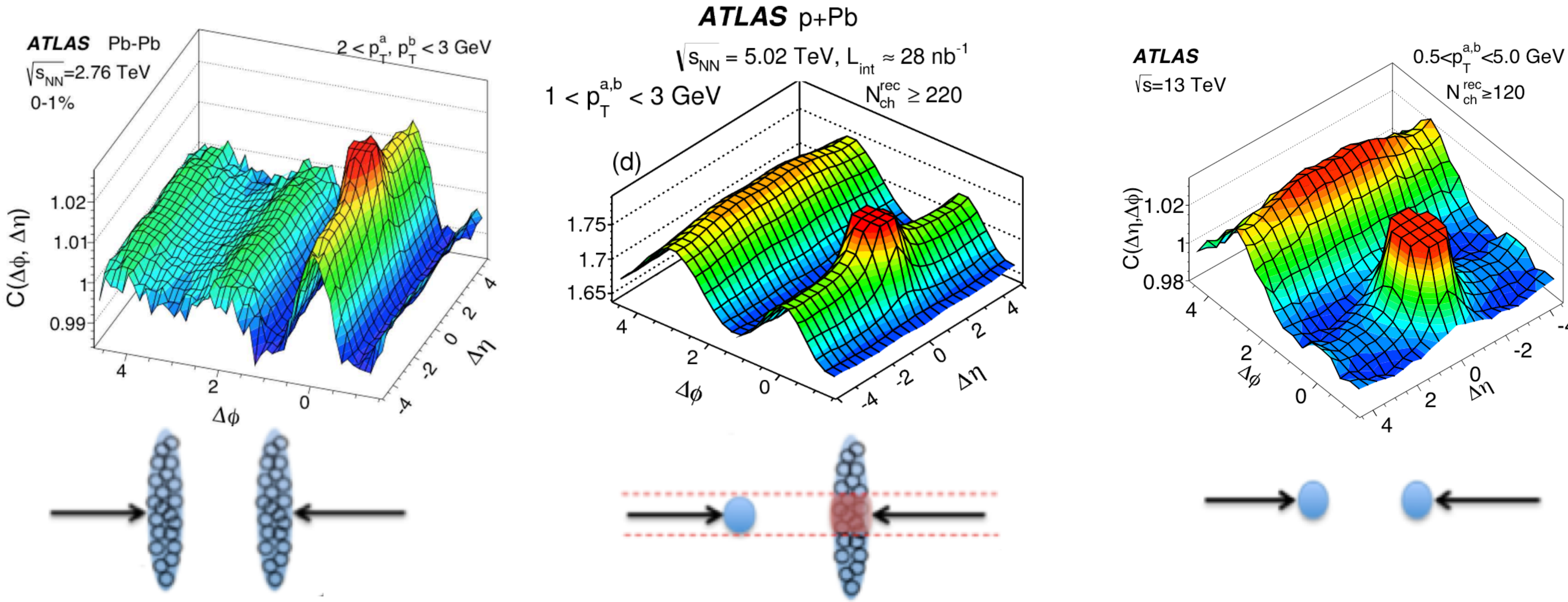
Space-time picture of heavy-ion collisions



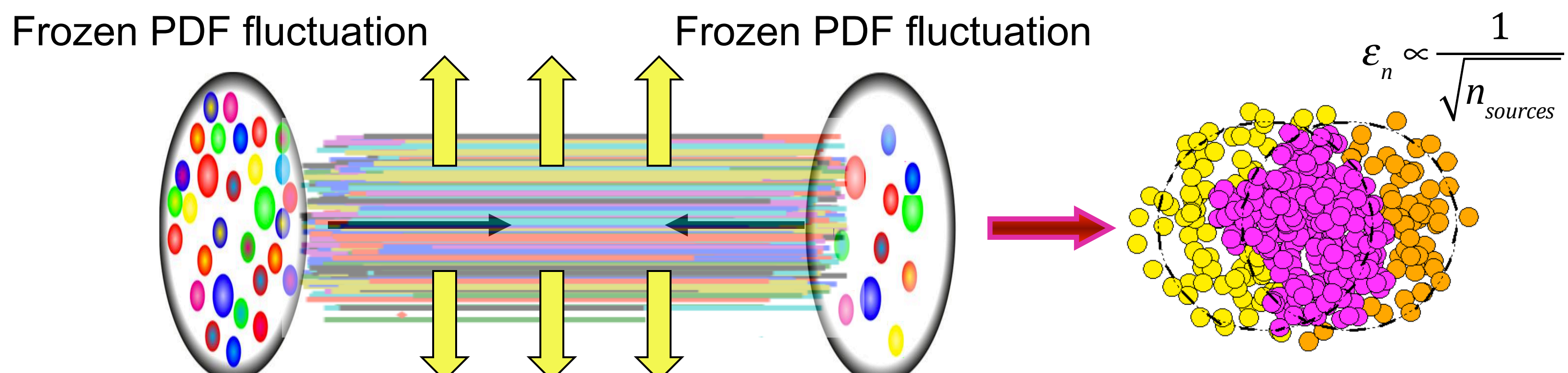


Credit B. Schenke

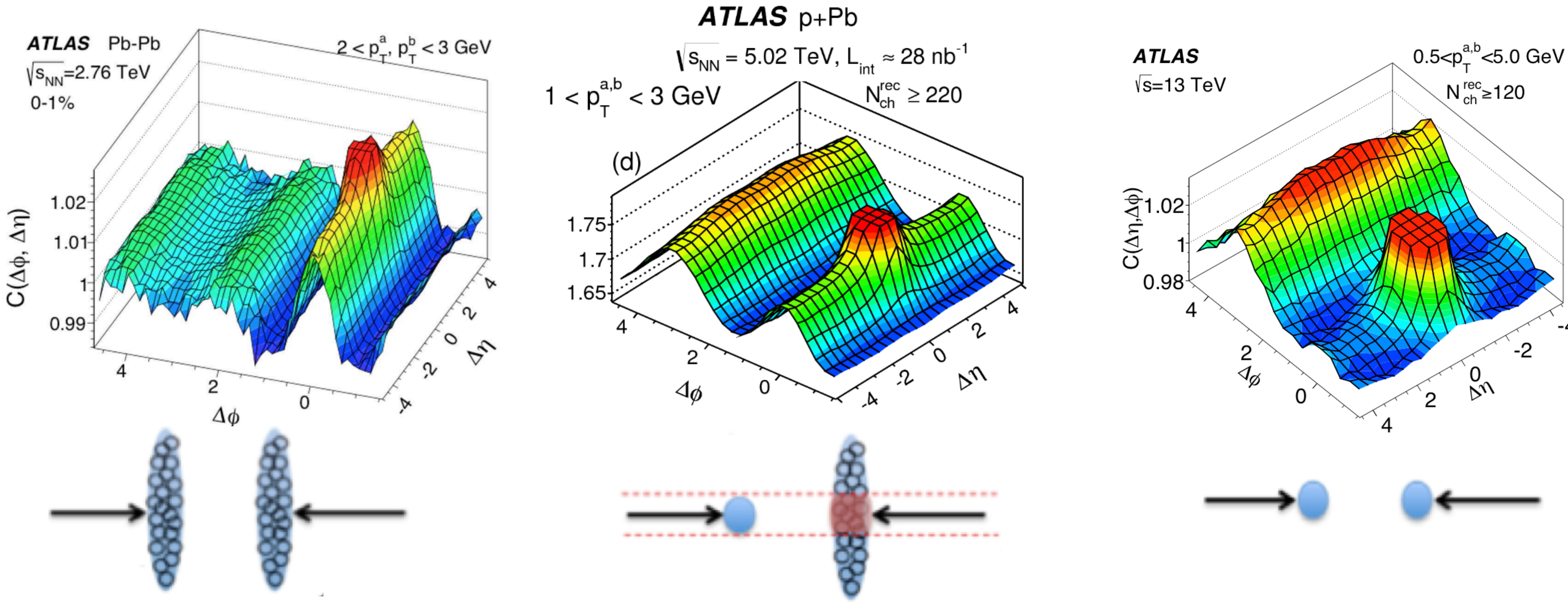
Space-time dynamics ⟺ QGP properties



What sources seed these long-range collective ridges?

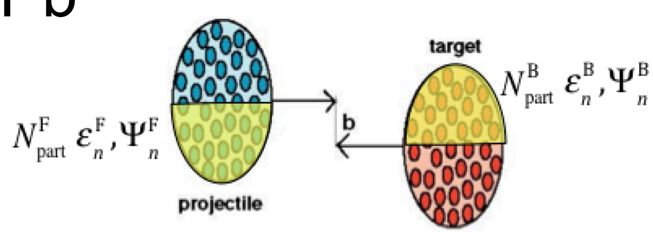


How many such sources, their sizes & transverse distribution?

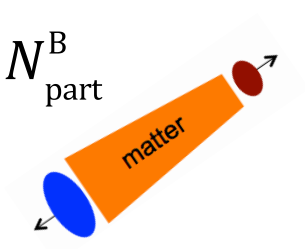


What sources seed these long-range collective ridges?

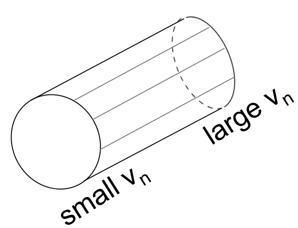
Pb+Pb



$N_{\rm part}^{\rm F} \neq N_{\rm part}^{\rm B}$



$\varepsilon_n^{\rm F} \neq \varepsilon_n^{\rm B}$



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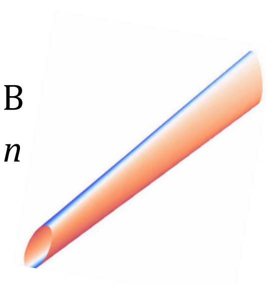

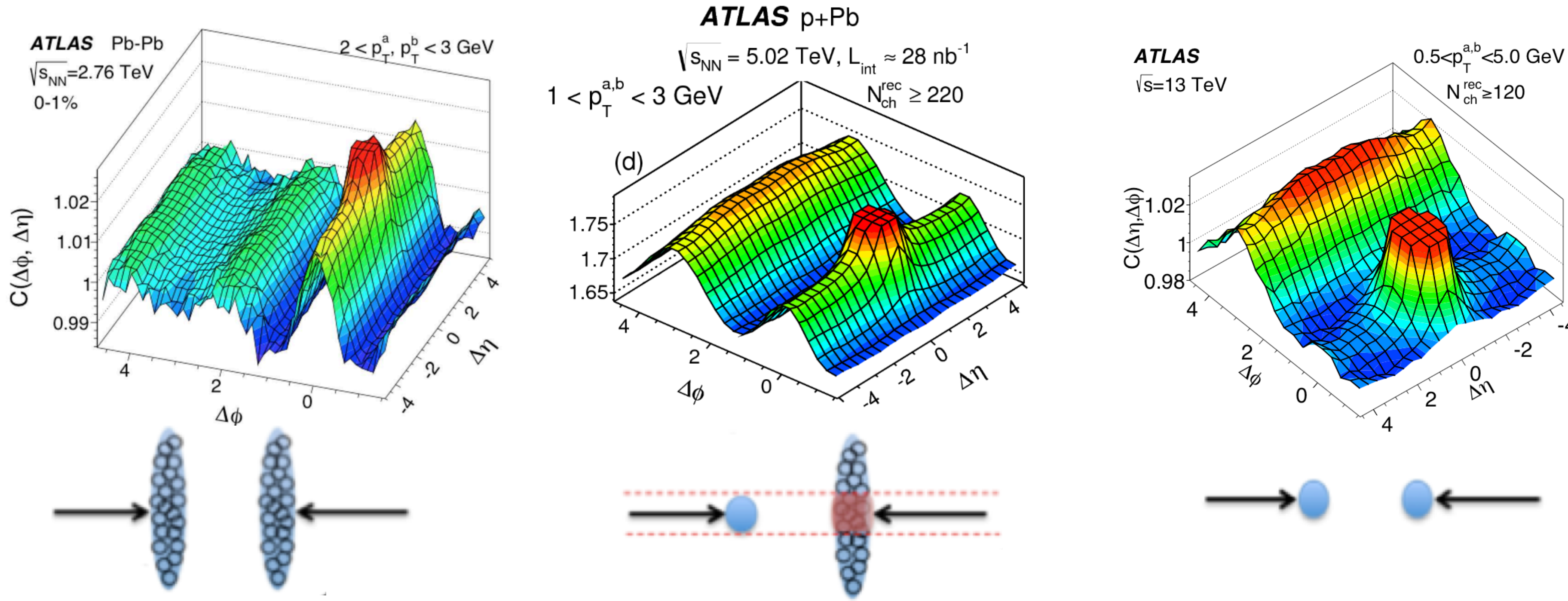

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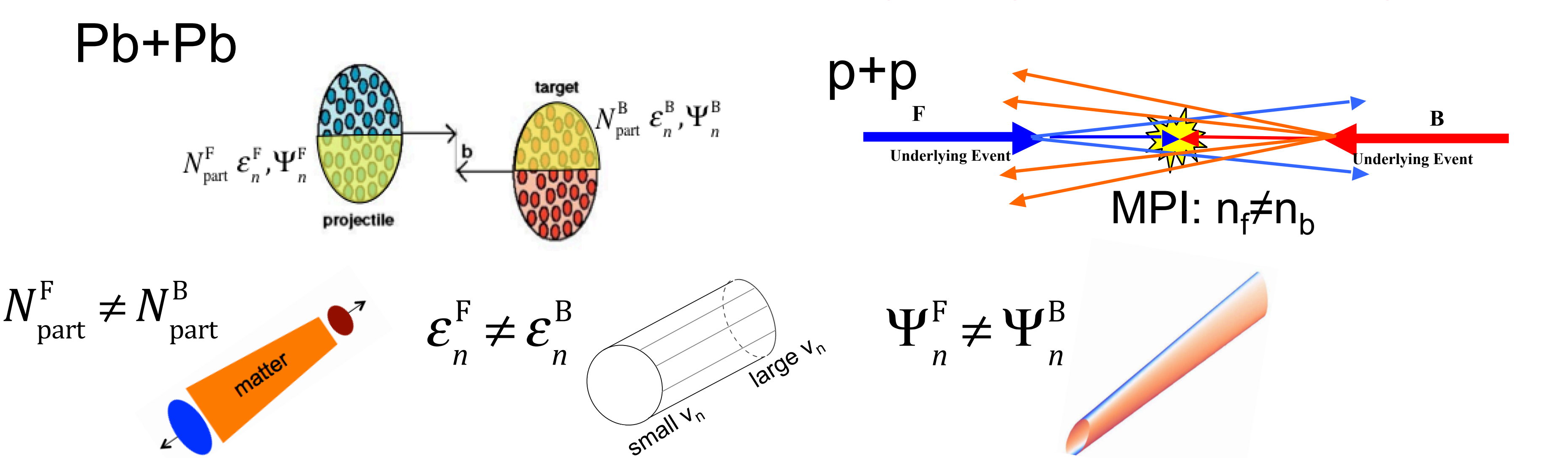
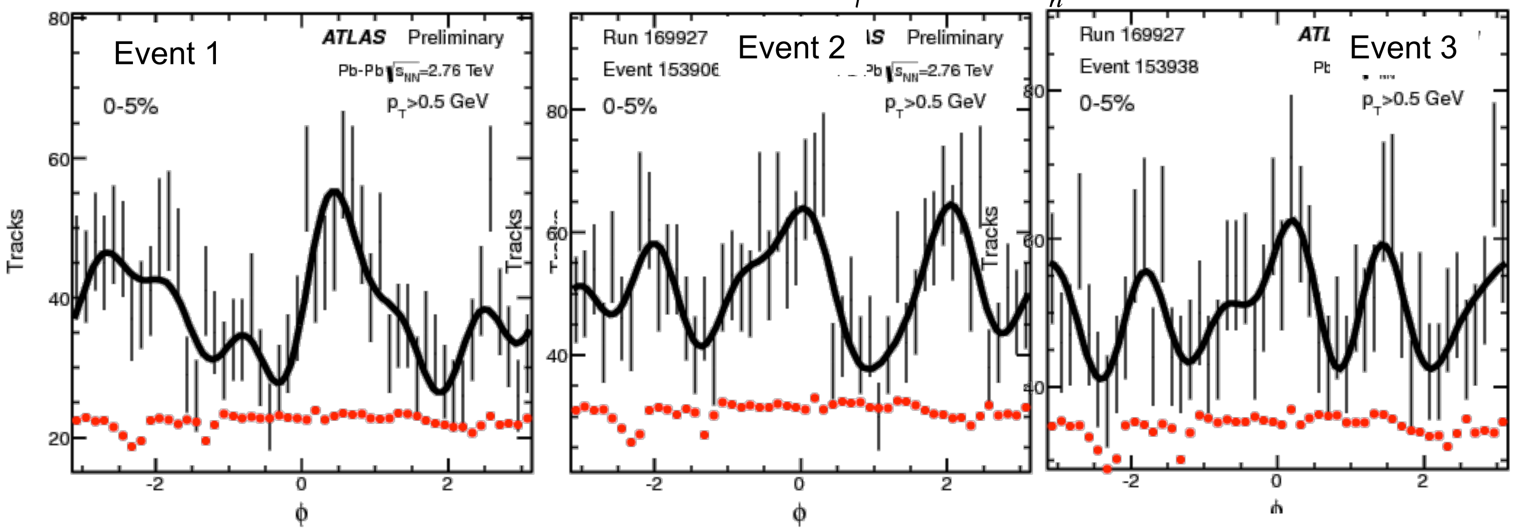


Forward-backward multiplicity/flow correlations provide a handle

Event-by-event distributions

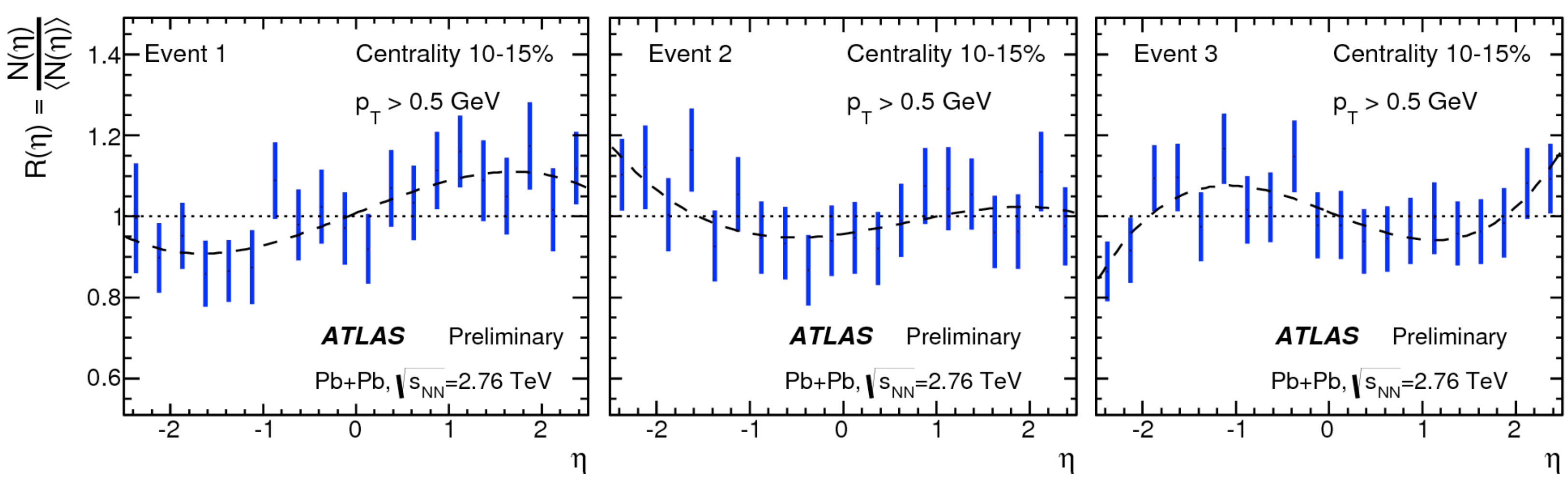
Transverse multiplicity fluctuations

$$\frac{dN}{d\phi} \propto 1 + 2\sum_n v_n \cos n(\phi - \Phi_n)$$



Longitudinal multiplicity fluctuations

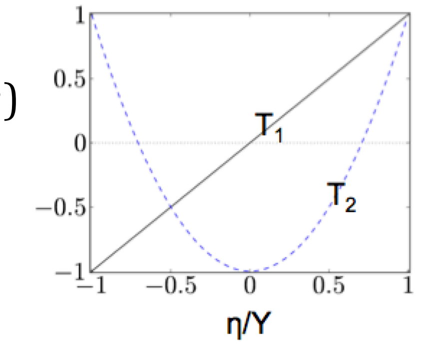
$$\frac{N(\eta)}{\langle N(\eta)\rangle} = 1 + \sum_n a_n T_n(\eta)$$



Longitudinal event-by-event fluctuations

- Longitudinal shape fluctuations quantify via Legendre expansion

$$\frac{N(\eta)}{\langle N(\eta)\rangle}=1+\sum_n a_n T_n(\eta) \qquad \frac{v_n(\eta)}{\langle v_n(\eta)\rangle}=1+\sum_n b_n T_n(\eta) \qquad \Phi_n(\eta)=\Phi_n(0)+\sum_n c_n T_n(\eta)$$



Leading component is a_1, b_1, or c_1

- Observables (examples):

$$V_{n\Delta}(\eta_a,\eta_b)=\left\langle v_n(\eta_a)v_n(\eta_b)\cos n\left[\Phi_n(\eta_a)-\Phi_n(\eta_b)\right]\right\rangle$$

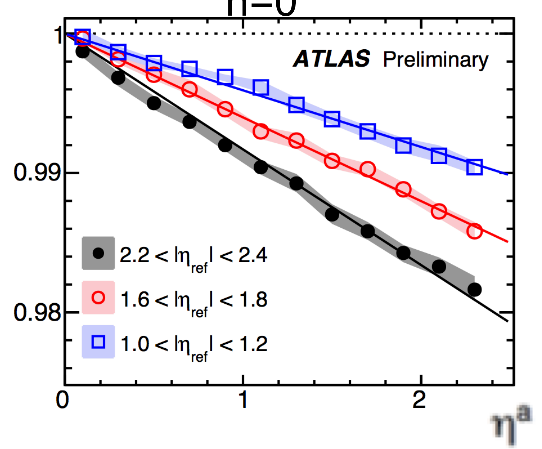
FB multiplicity asymmetry between $-\eta_a$ and η_a:

$$r_0(\eta_a,\eta_b)=\frac{\langle N(-\eta_a)N(\eta_b)\rangle}{\langle N(\eta_a)N(\eta_b)\rangle}$$

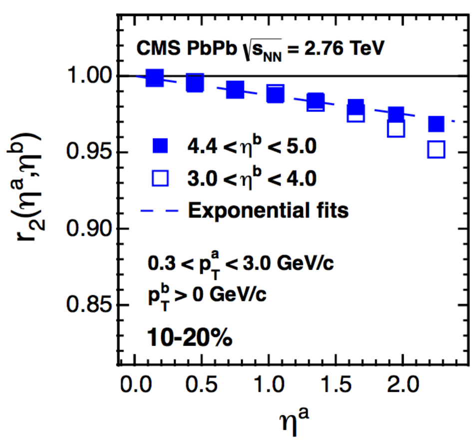
Twist & asymmetry between $-\eta_a$ and η_a:

$$r_n(\eta_a,\eta_b)=\frac{V_{n\Delta}(-\eta_a,\eta_b)}{V_{n\Delta}(\eta_a,\eta_b)}$$

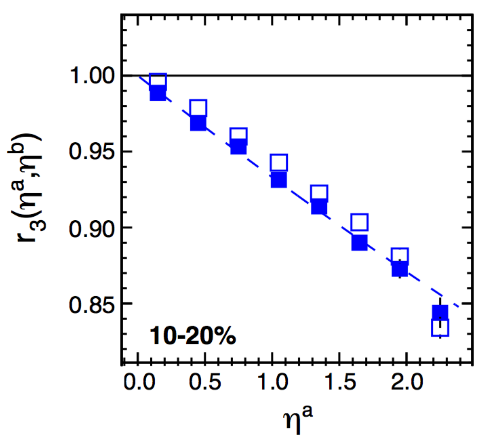
n=0



n=2

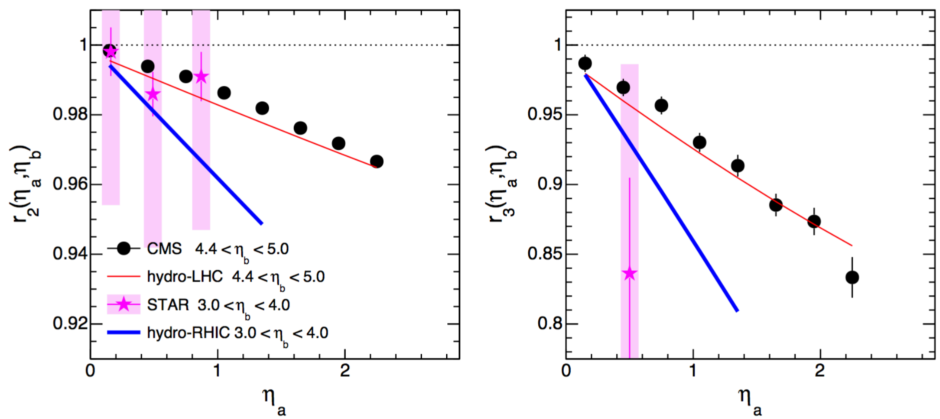


n=3

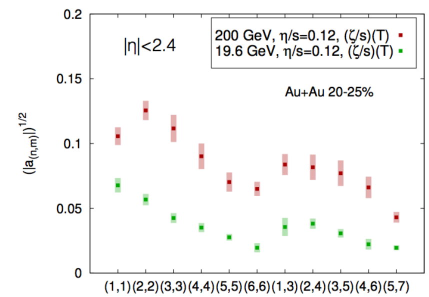


Why at RHIC?

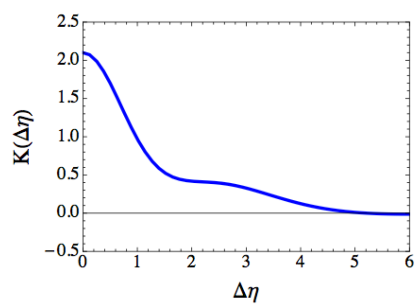
- Input for tuning 3+1D hydro model w/o boost invariance
  - Improve our extraction of η/s
    - See PRC86, 024911 (2012)
  - Effects much larger at smaller √s



- Other opportunities
  - Baryon transport mechanism via FB net proton fluctuations
    - Interesting higher-order shape components!



  - Longitudinal pressure, isotropization?
  - Propagation of hydrodynamic noise.
    - 1112.6405
  - $p(v_n, v_m, \ldots, \Phi_n, \Phi_m, \ldots)$ at different η



Bzdak, Teaney 1210.1965,
J.Jia et.al. 1506.03496
Bzdak, Bozek, Broniowsk i1509.02967,1509.04124
Akihiko, Schenke 1509.04103

Detector requirement for e-by-e measurement

- RHIC has measured <N(η)> and $\langle v_n^2 \rangle$ (Phobos, Brahms,…)

- Need measure event-by-event longitudinal property, require
  - large η and full ϕ
  - Some p_T or PID →is longitudinal response universal?

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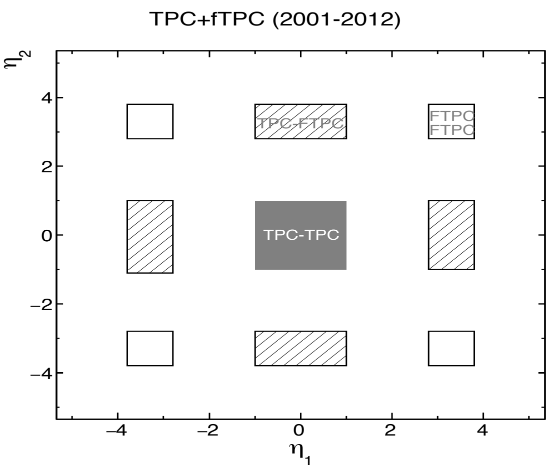
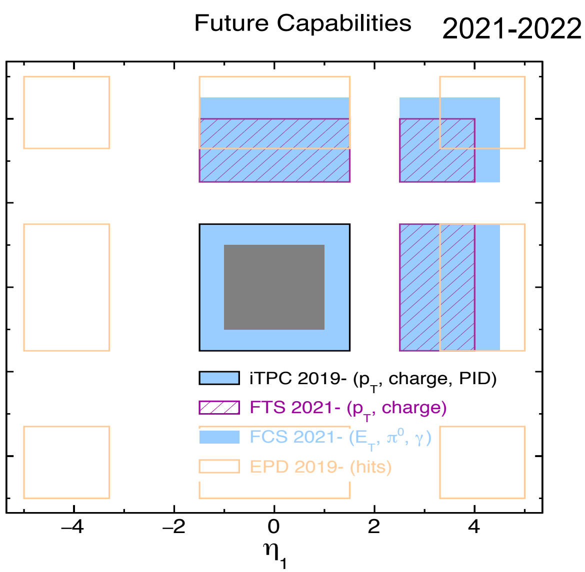
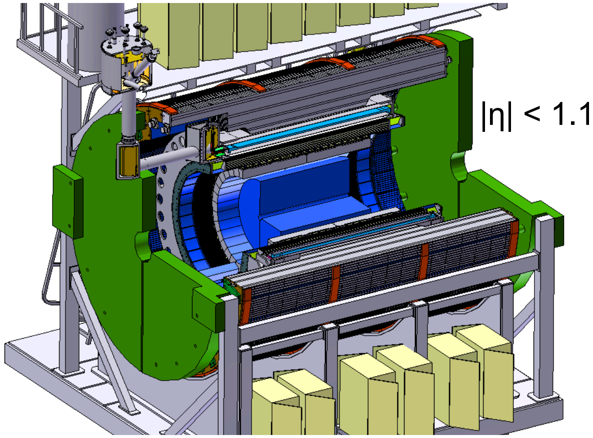




sPHENIX



Possible to add forward detectors?

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