Small System Observables

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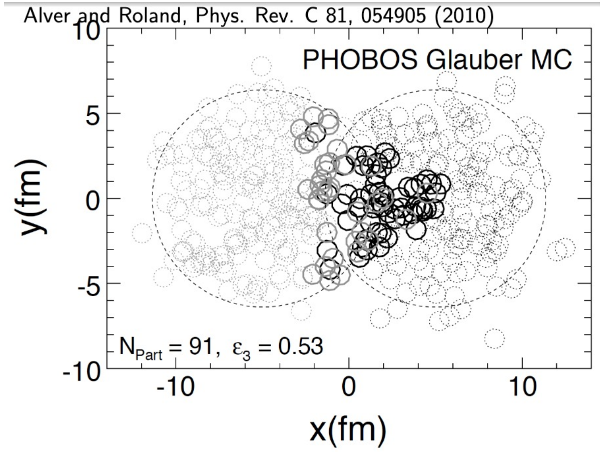
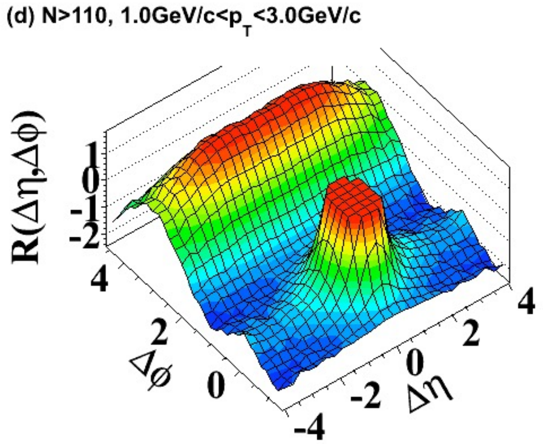
The Distant Past

- Prior to ~2010 it was generally assumed that:
  - AA collisions – Flow = QGP
  - p/dA collisions – No flow (or QGP), baseline measurement to understand CNM
  - pp collisions – No flow (or QGP), baseline measurement to understand AA
- Two key observations radically changed our picture of HI collisions:



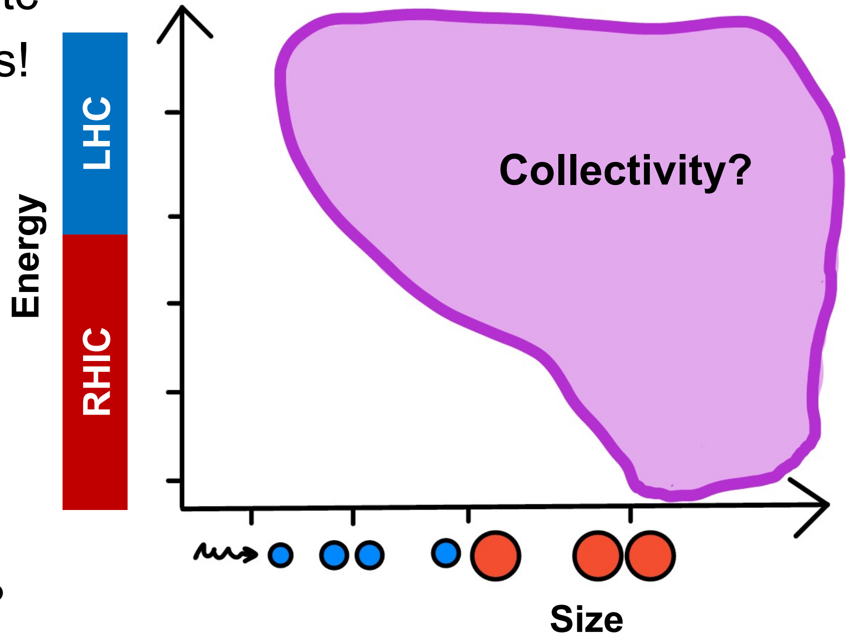
Fluctuations Matter

Flow signatures found in small systms

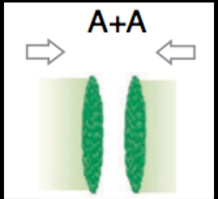


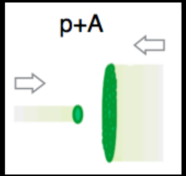
Thoughts

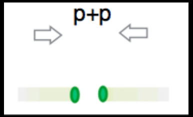
- There are no baselines, only physics (QCD)
  - We should learn from our mistakes!
- We should be careful - correlation doesn't necessarily mean collectivity
  - Phase space considerations, etc
  - Especially key in small systems!
- I should have a third axis – **probe**
  - Collectivity in the HF sector in small systems is quite interesting
- Where does collectivity exist?
- What do our observations and calculations imply about the **underlying physics mechanisms**?

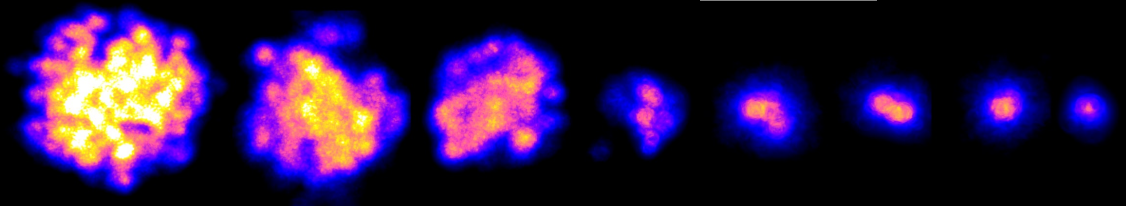


Near side ridge and collectivity across systems



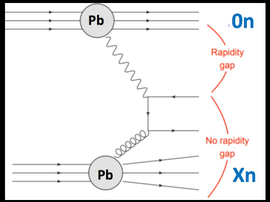






U+U Au+Au Ru+Ru O+O ^{3}He+Au d+Au p+Au p+p

IP-Glasma initial energy density, τ=0.4 fm, single central event, Shen QM19



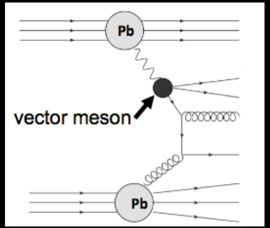
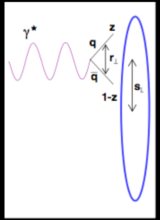
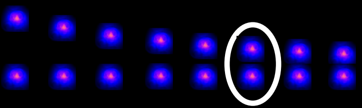


photo-nuclear

PhP limit of DIS

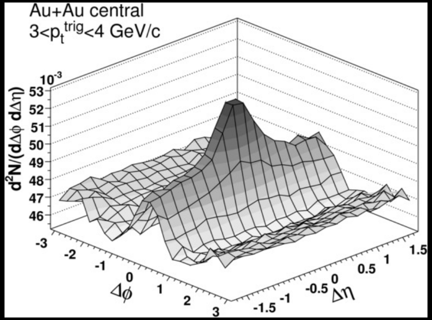


larger Q^2

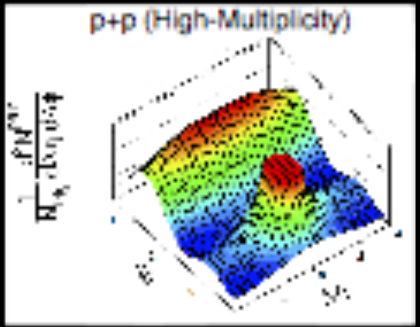


e+p/A

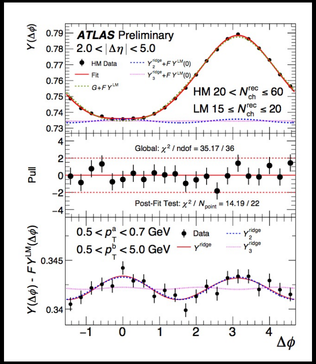
Scan of x-Q^2

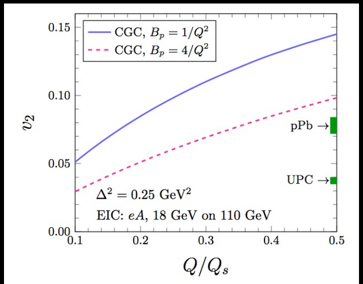


STAR collaboration, Phys. Rev. Lett. 95, 152301
Phys. Rev. C 80 (2009) 64912



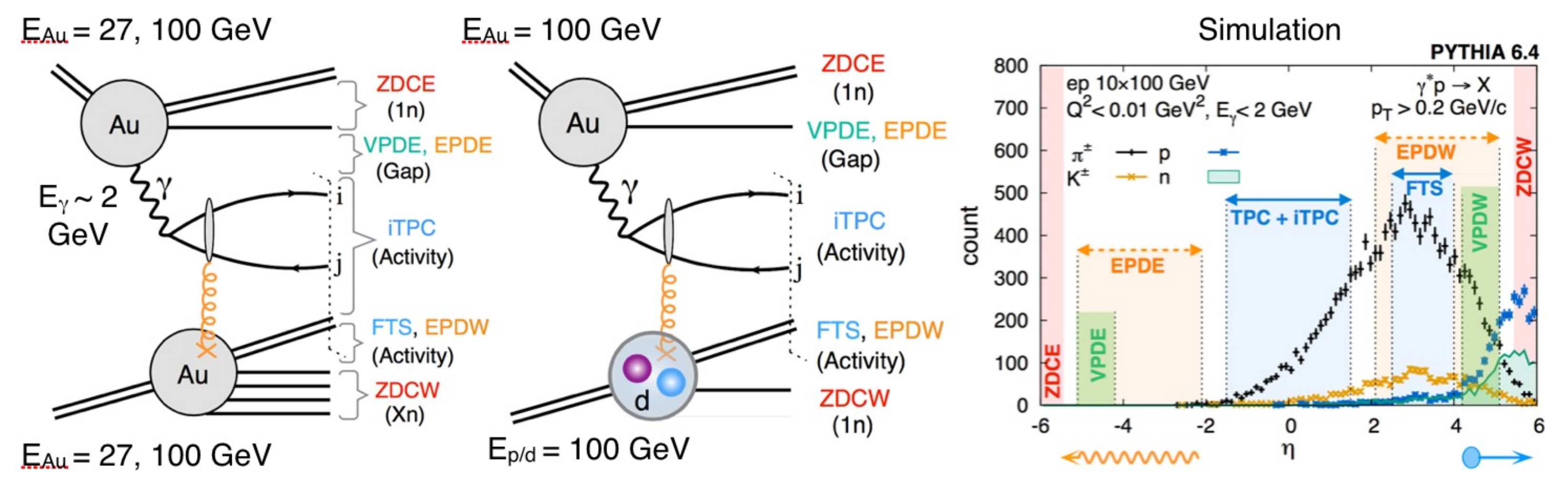
CMS collab., JHEP 1009:091,2010





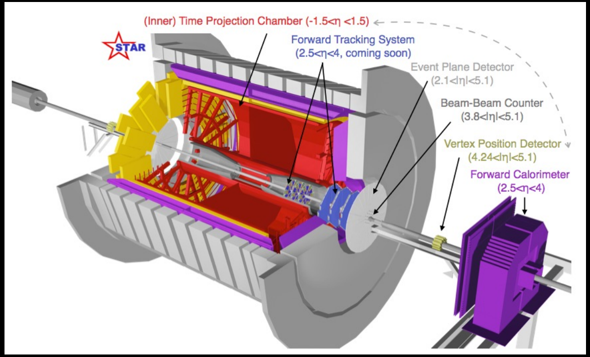
Seidlitz, HP 2020, ATLAS-CONF-2019-022

Opportunities with STAR



Opportunities in UPC with STAR@RHIC:

1. Enhanced pseodorapidity acceptance (iTPC,EPD,FTS/FCS)
2. Anticipated Au+Au 200 GeV run of RHIC (2023, 2025)
3. Data on tape: Au+Au 54 GeV (2017), Au+Au 200 GeV (2019)
4. Opportunistic p+Au or d+Au run at RHIC (2021, 2024)

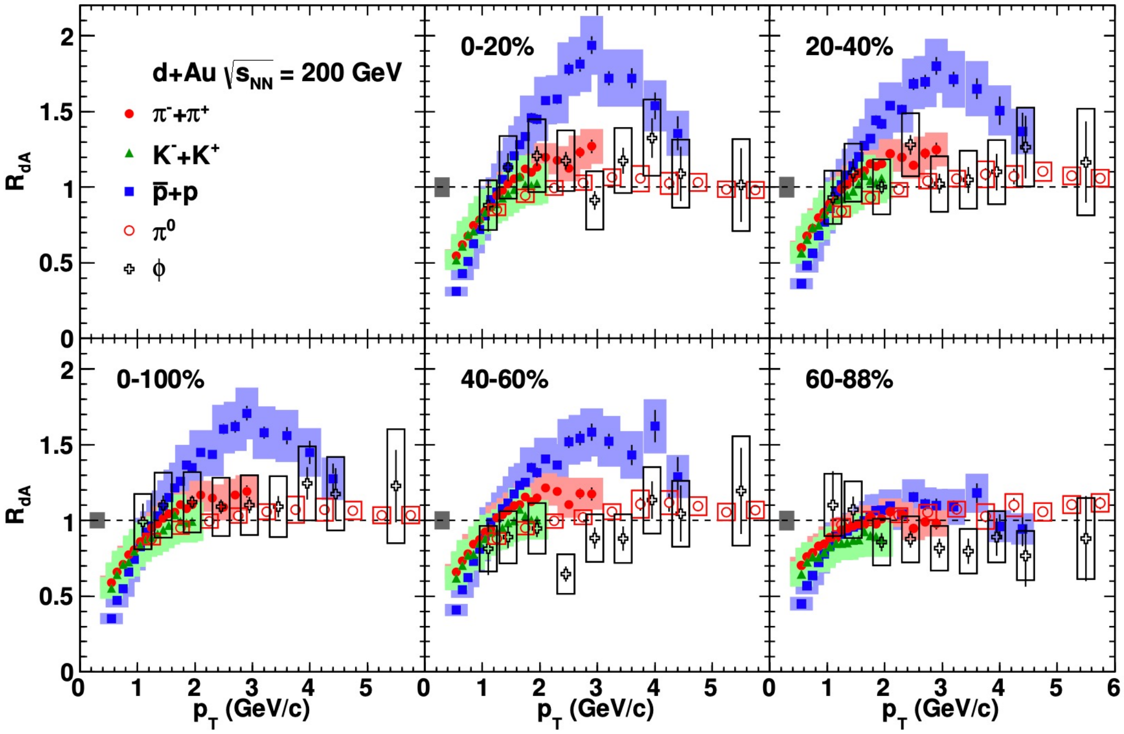


Measurements:

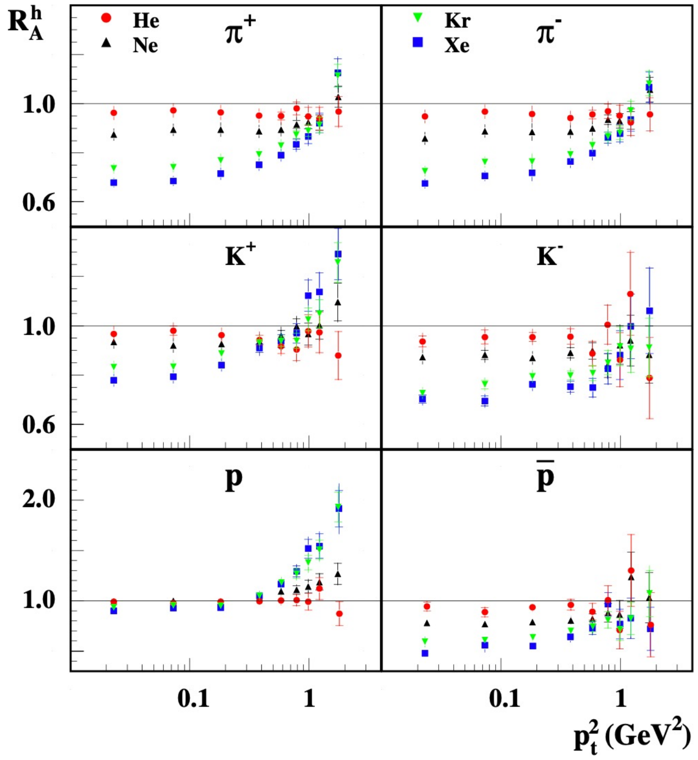
1. Ridge, 2. change of chemistry (pi/k/p yield) & compare to hadronic events

Hadronization is modified in collisions with a nucleus

PHENIX, Phys. Rev. C 88, 024906 (2013)



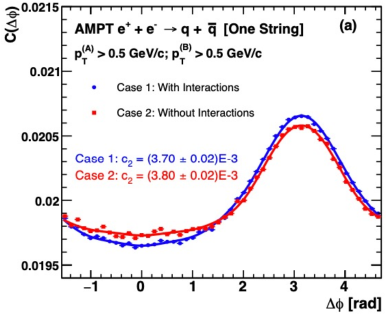
HERMES, Phys. Lett. B 780, 1 (2007)

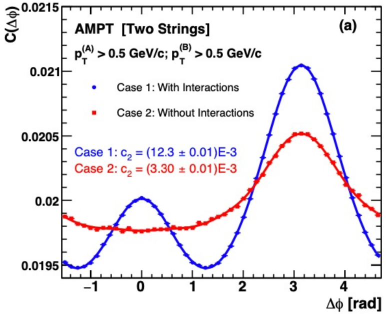


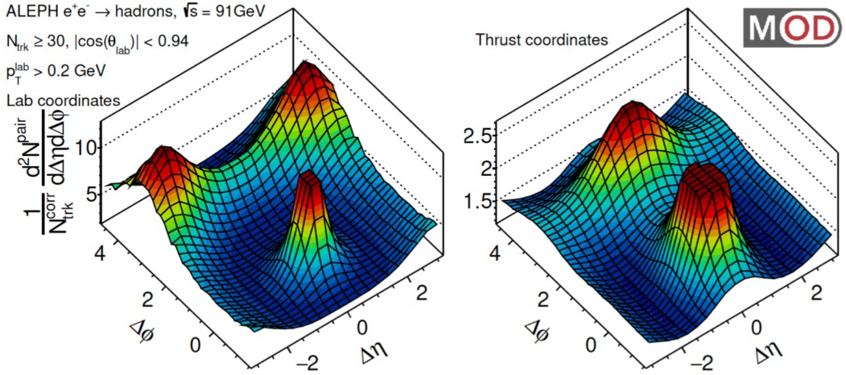
Different hadronization mechanism? Modified fragmentation functions? Etc...

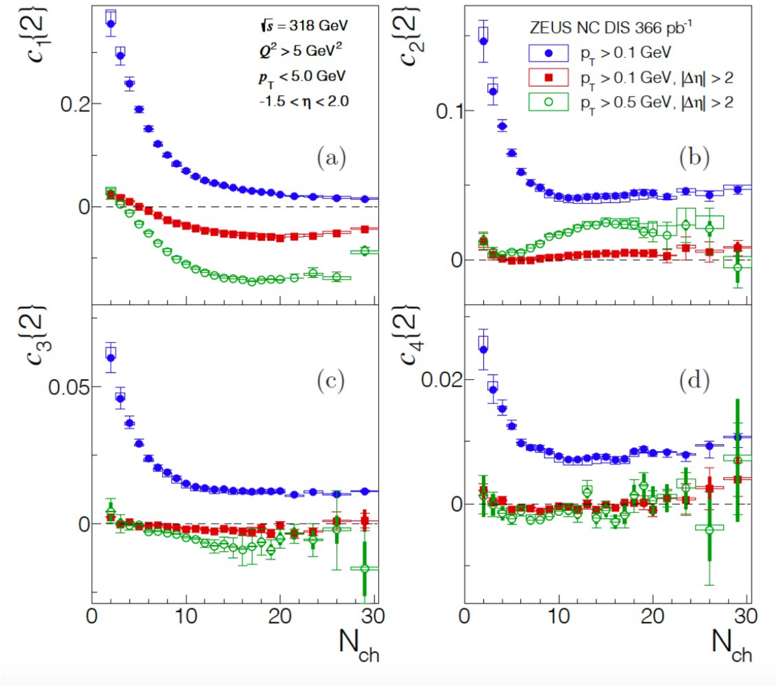
No collectivity in $e^{+}+e^{-}$, $e+p$. What about $e+A$?

AMPT: Nagle et al, PRC 97; ALEPH: Badea et al, PRL 123; ZEUS: Abt et al, JHEP 04





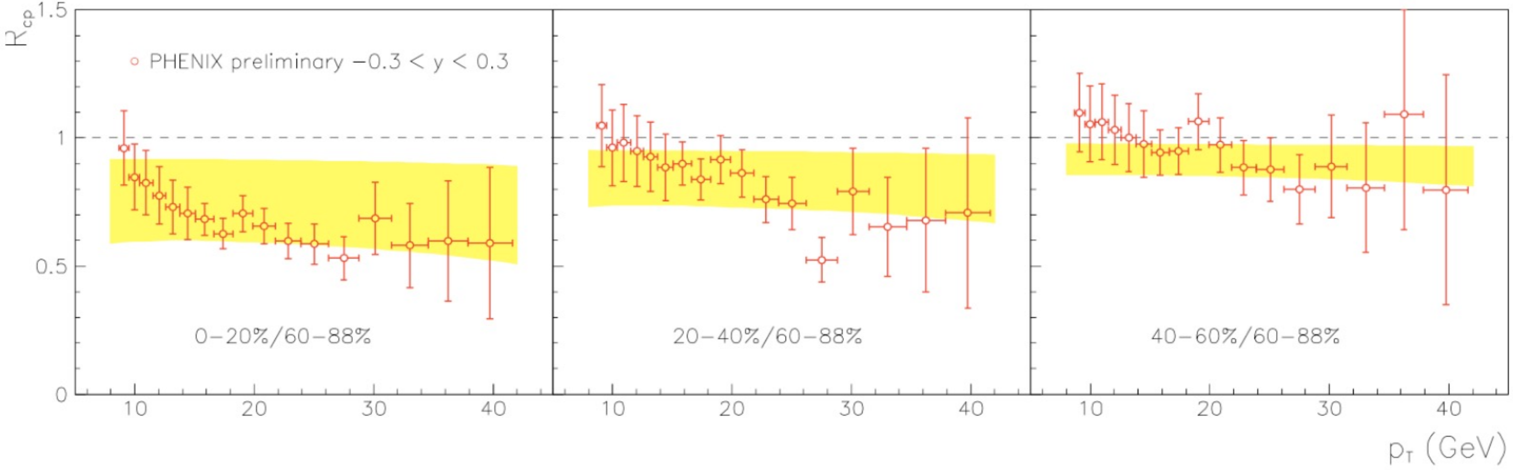




Is the number of color strings the key ingredient for collectivity?

Centrality in pA

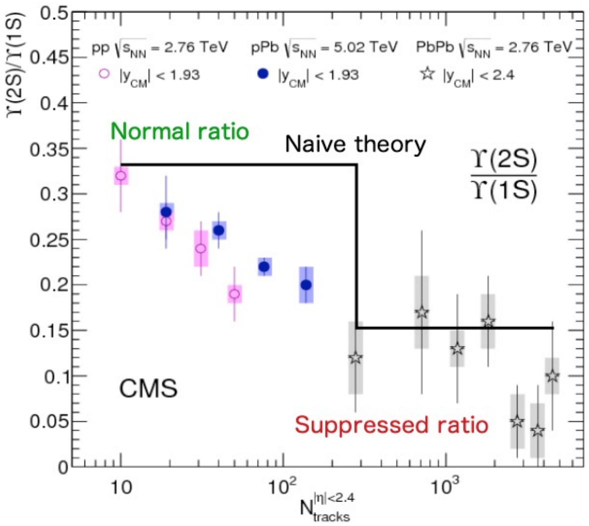
- Centrality definitions and measurements in small systems can be complicated
    - Jets can bias measurements if the η gap between centrality measure and jet measurement are not sufficient

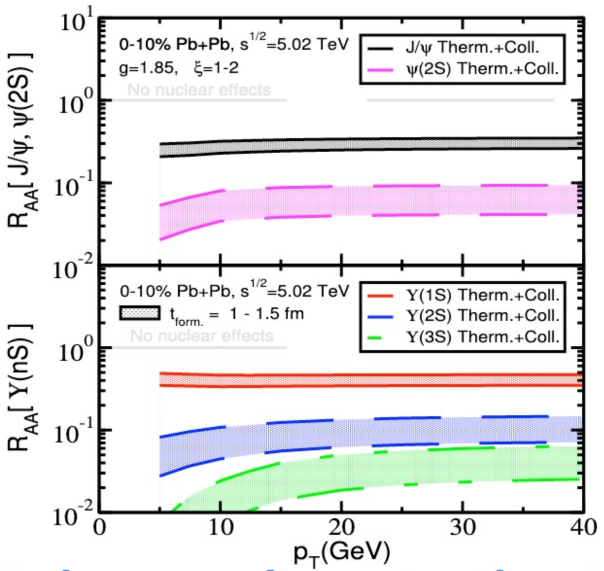


Revisit centrality determination in pA. Jet R_{pA} at large x_F (or x_1) . Energy loss in cold nuclear matter – Connection here is to DY in pA E906 more so than EIC.

Quarkonia as a probe

- Upsilons provide a nice standard candle to probe systems in a scale dependent way with the complication that multiscale jets have
- Separate underlying physics mechanisms via Upsilon and J/ψ





Excited to ground quarkonium states. In AA, but also more importantly pA. Will inform quarkonium physics in eA and also the study of exotics.

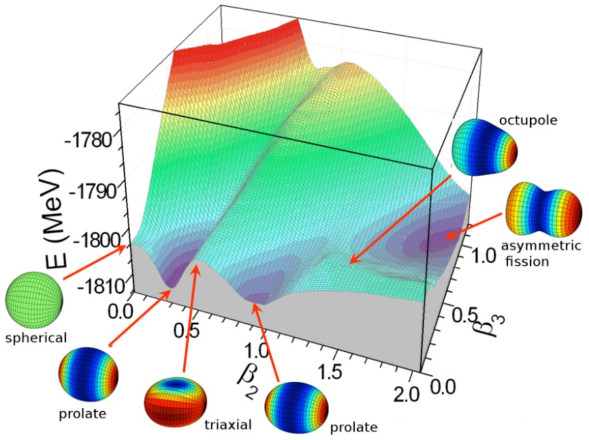
Shape of nuclei

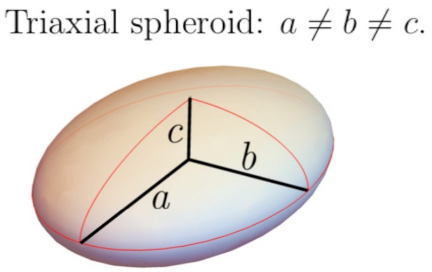
Most ground state stable nuclei are deformed

$$\rho(r,\theta,\phi) = \frac{\rho_0}{1 + e^{(r-R(\theta,\phi)/a}}$$

$$R(\theta,\phi) = R_0\left(1 + \beta_2[\cos\gamma Y_{2,0} + \sin\gamma Y_{2,2}] + \beta_3 Y_{3,0} + \beta_4 Y_{4,0}\right)$$

Shape determined by minimizing the energy





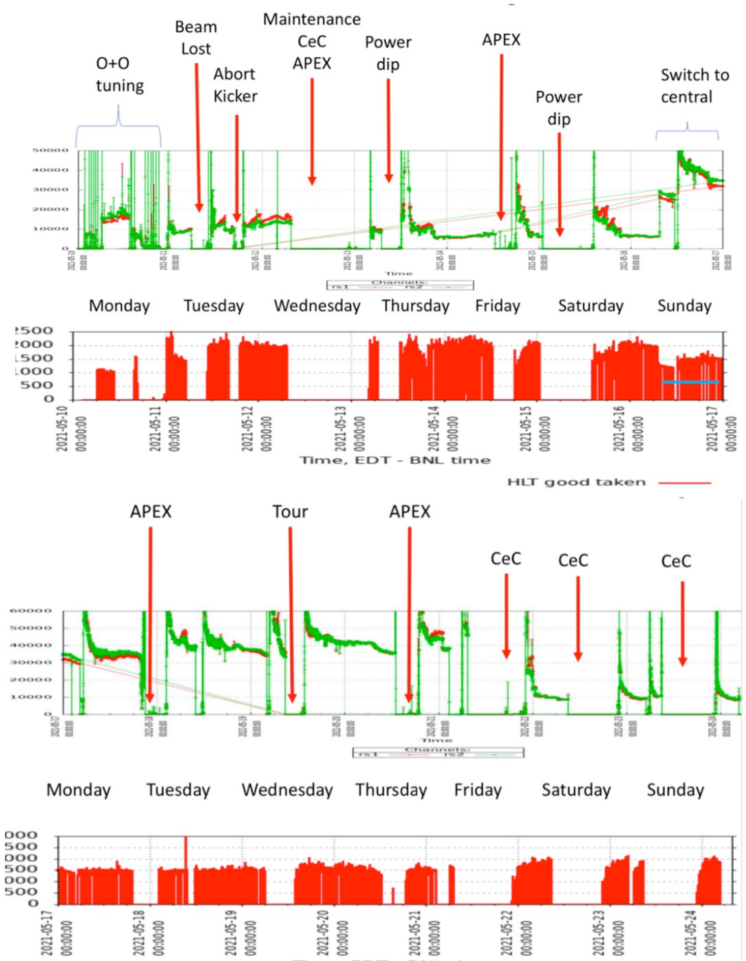
Triaxility controlled by $0 \leq \gamma \leq \pi/3$

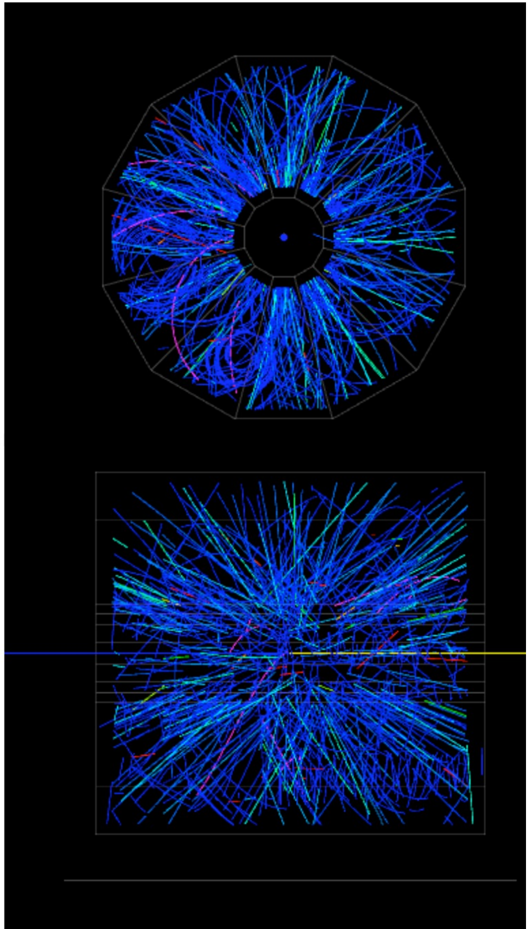
Prolate: a=b<c→β_2, γ=0

Oblate: a<b=c →β_2, γ=π/3

Main tool: transition rates B(En) among low lying states

200 GeV O+O

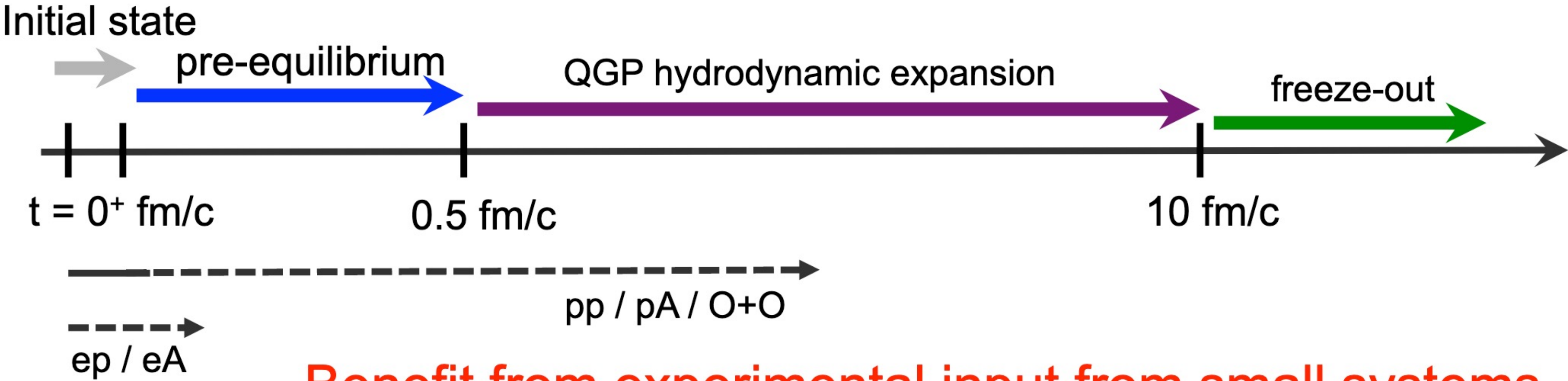




OO Running at STAR will allow a more differential look at the **size** AND **geometry** dependence!

System Evolution

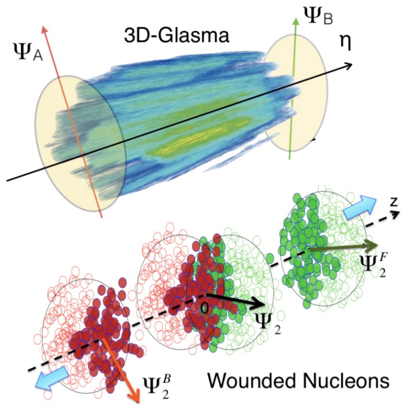
- System size / collision energy changes influence from initial state/pre-equilibrium/QGP phase
    - Disentangle final state from initial state physics



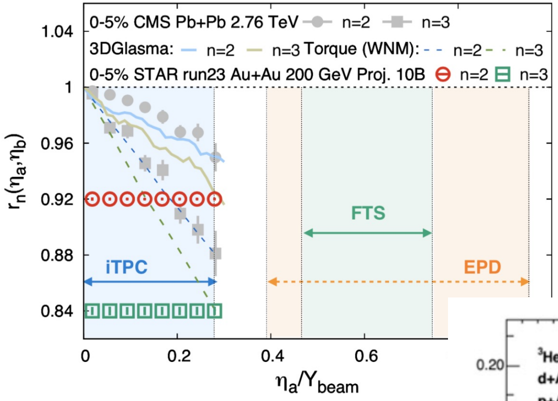
Benefit from experimental input from small systems

Longitudinal structure and dynamics

3D partonic structure in A+A
Accessible via rapidity correlations



what about p+p, and
proton structure in 3D?



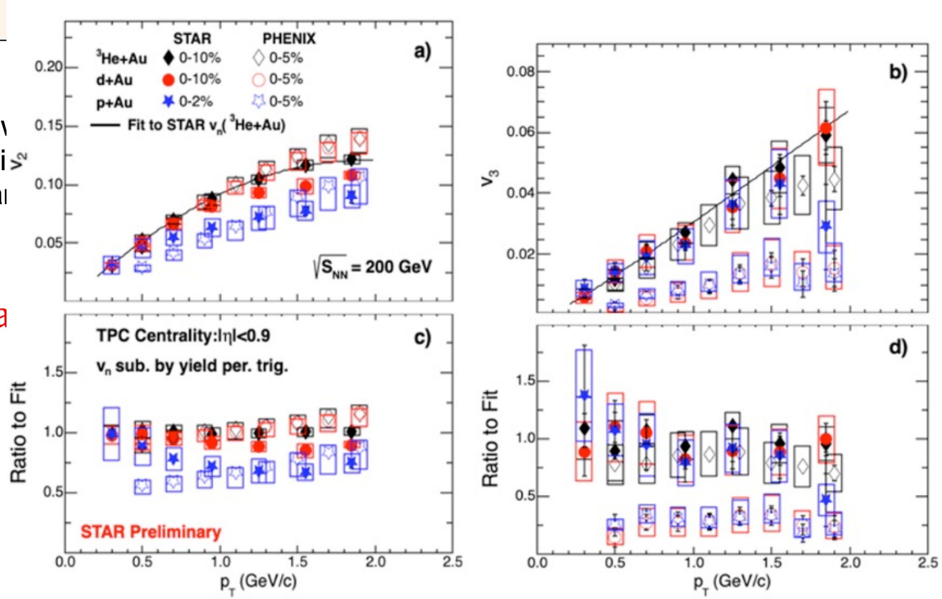
Extended coverage of STAR w
enable precision on the rapidi
structure of IS in both small a
large systems

Multiple particle correlations and explore new observa

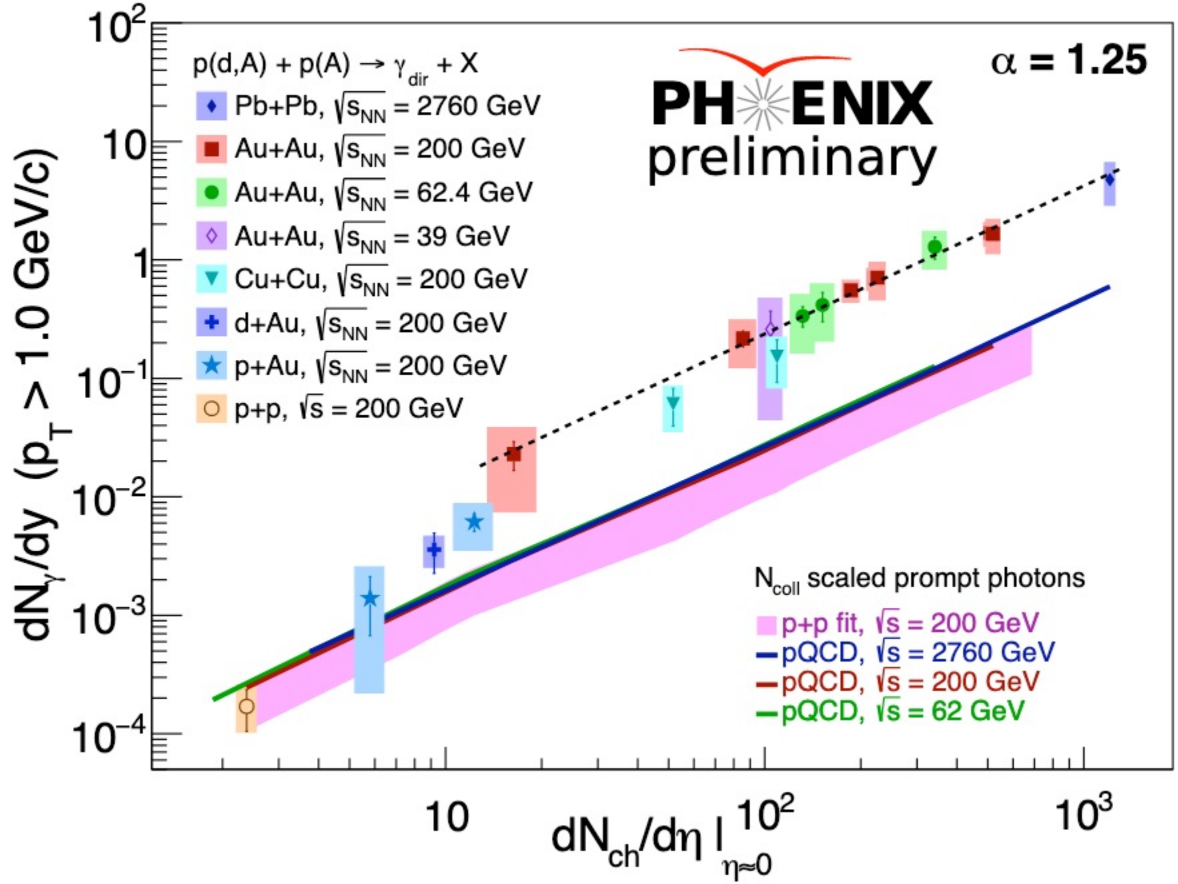
PHENIX/STAR v3 discrepancy

Differences in STAR/PHENIX geometry with the effect of longitudinal structure (and fluctuations!) could explain this discrepancy

- Exploit differences to understand the physics!



Photon yields



We see a transition away from a pure pQCD prediction of the prompt photon yield at ~ dN_{ch}/dh ~ 10!

- High energy pp?
- Excess photon yield vs signals of collectivity?

Conclusions/Future

- Collectivity exists from pp → AA
    - What process(es) create this collectivity?
        - Final state?
        - Geometry?
        - Initial state?
- Jet/HF probes allow a scan of the size structure within the small systems
- Geometry/Fluctuations play a large role and should be used to differentiate different processes