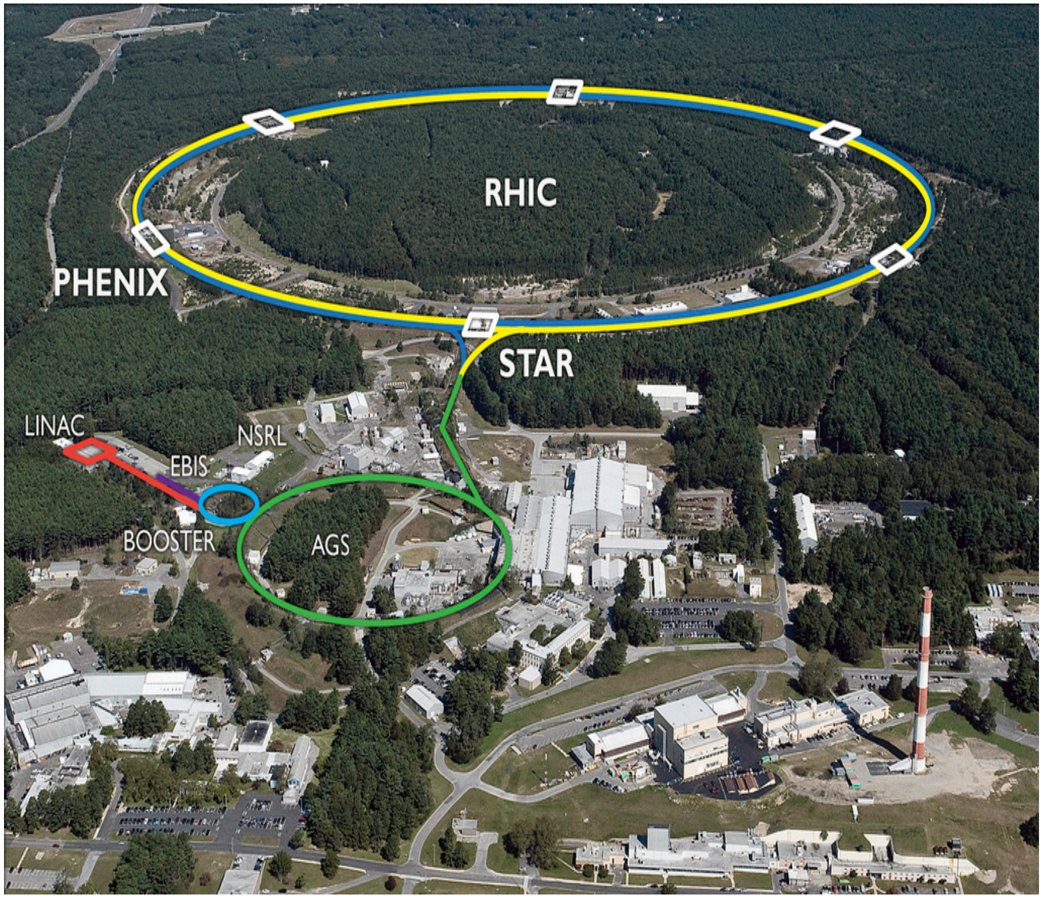
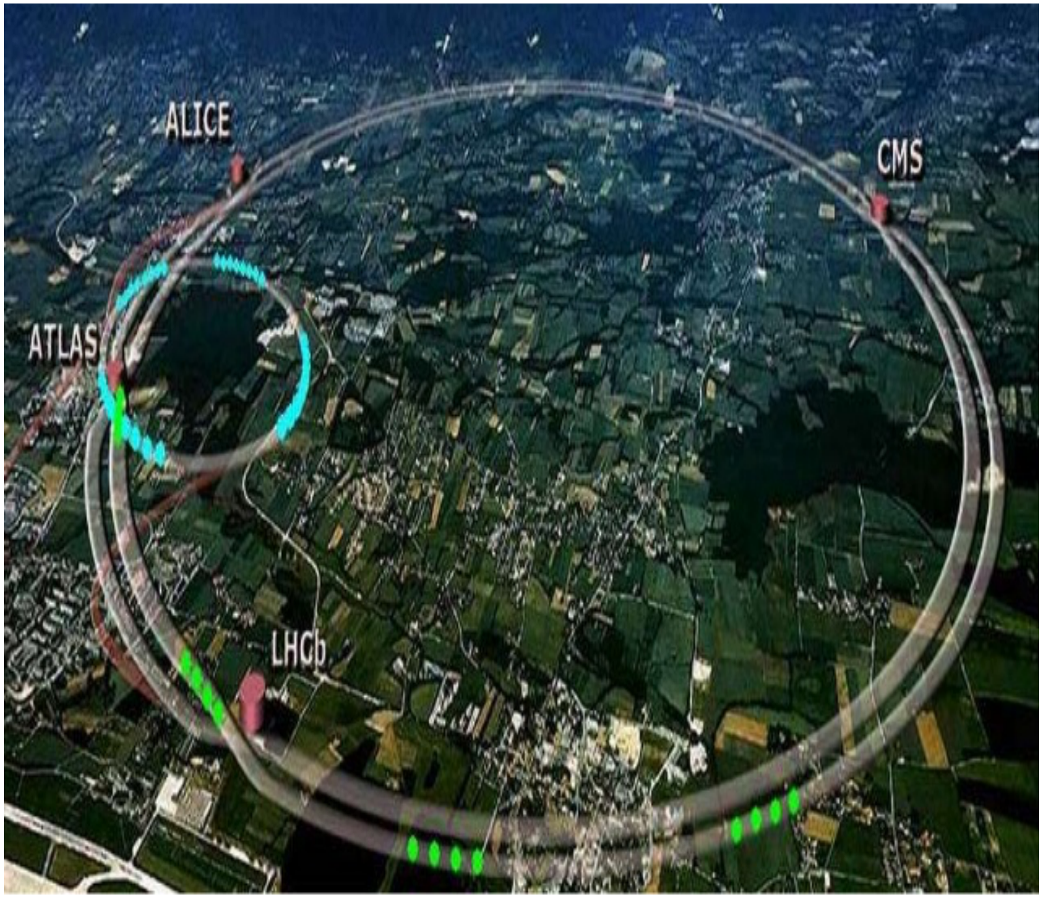
Collectivity in p+Nucleus Collisions

Topics

- Heavy Ion Collisions and QGP
- Small Ridge in pp and pA
- Proton Geometry, Eccentricity and CGC
- Updated Models

RHIC and LHC



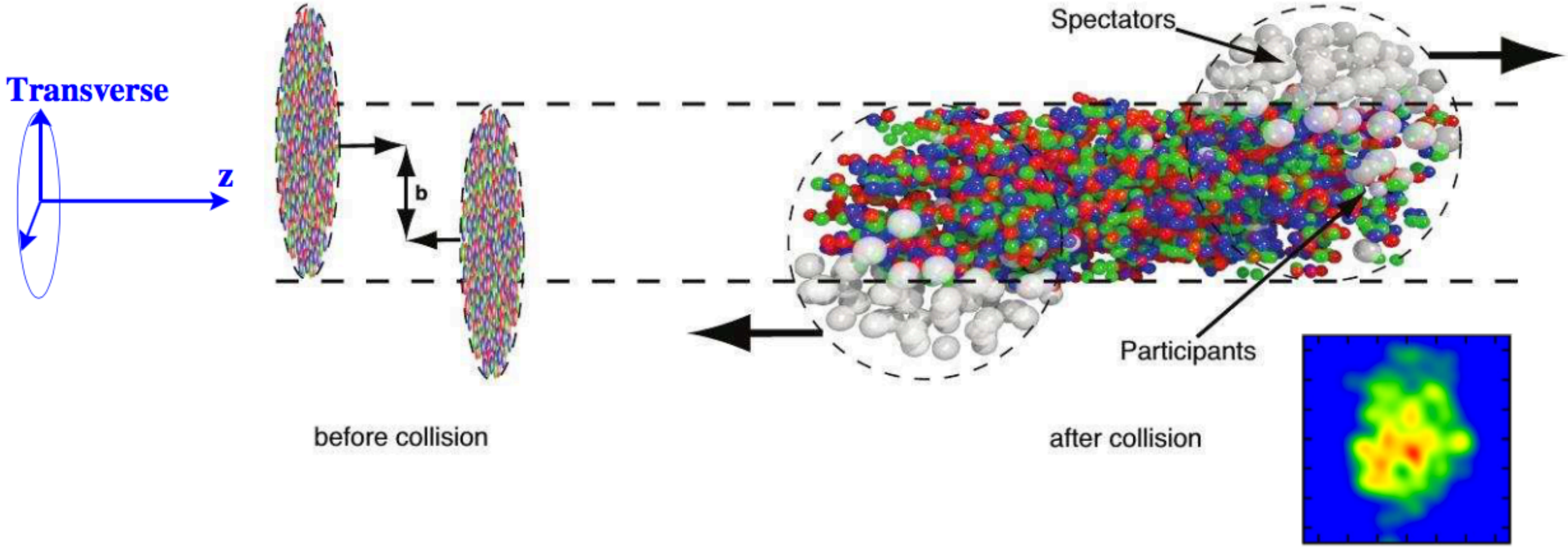


PHENIX

CMS

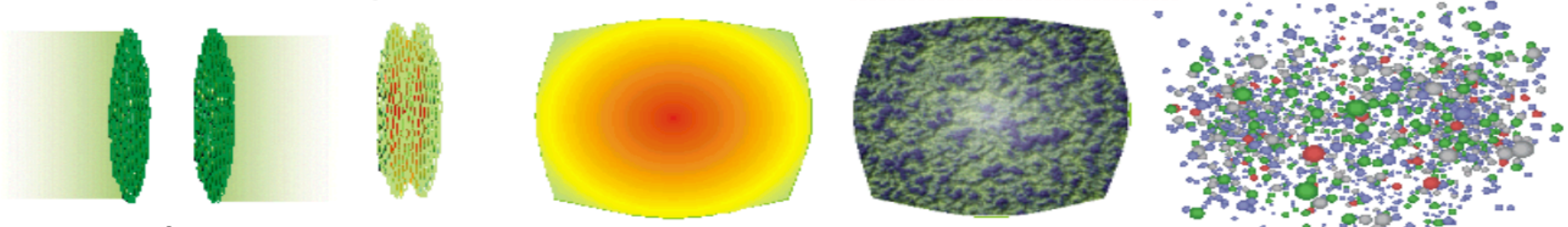
ALICE

AA collisions



Pre-equillibrium

Hadronization



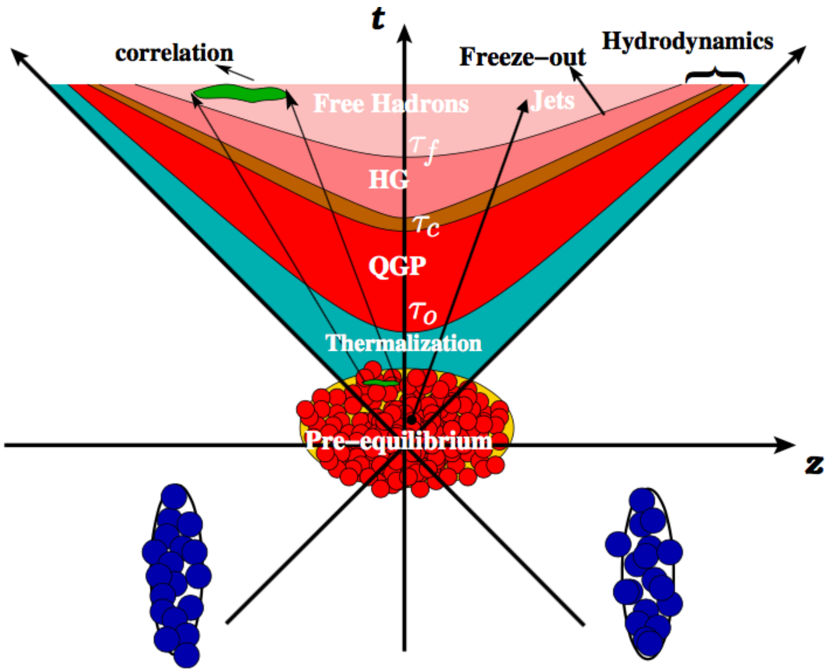
Initial state

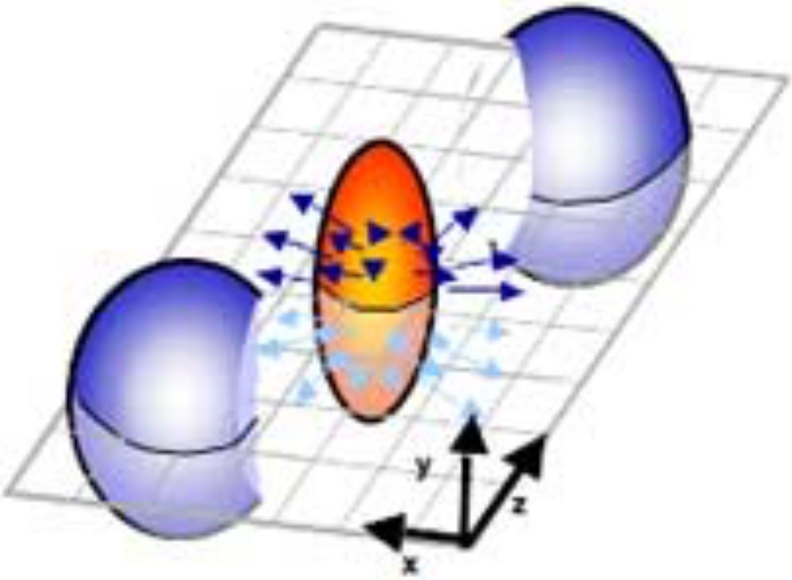
Thermal QGP

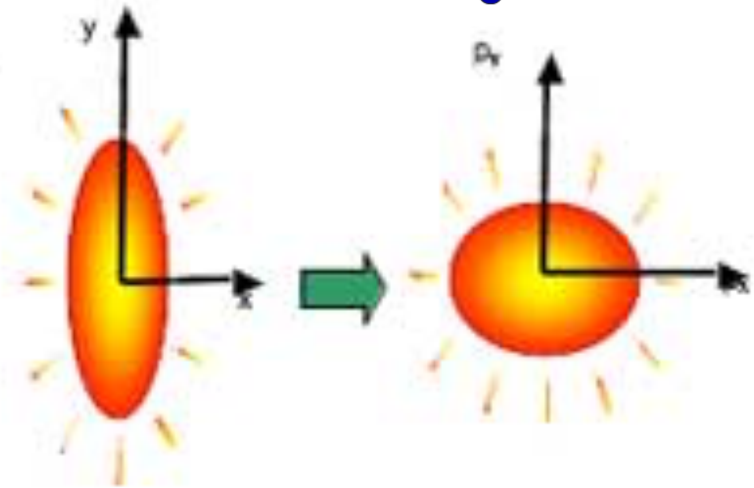
freeze out

Quark Gluon Plasma

- Nuclear Modification Factor
  -compare to low multiplicity pp
- Jet Quenching
- Collective Flow





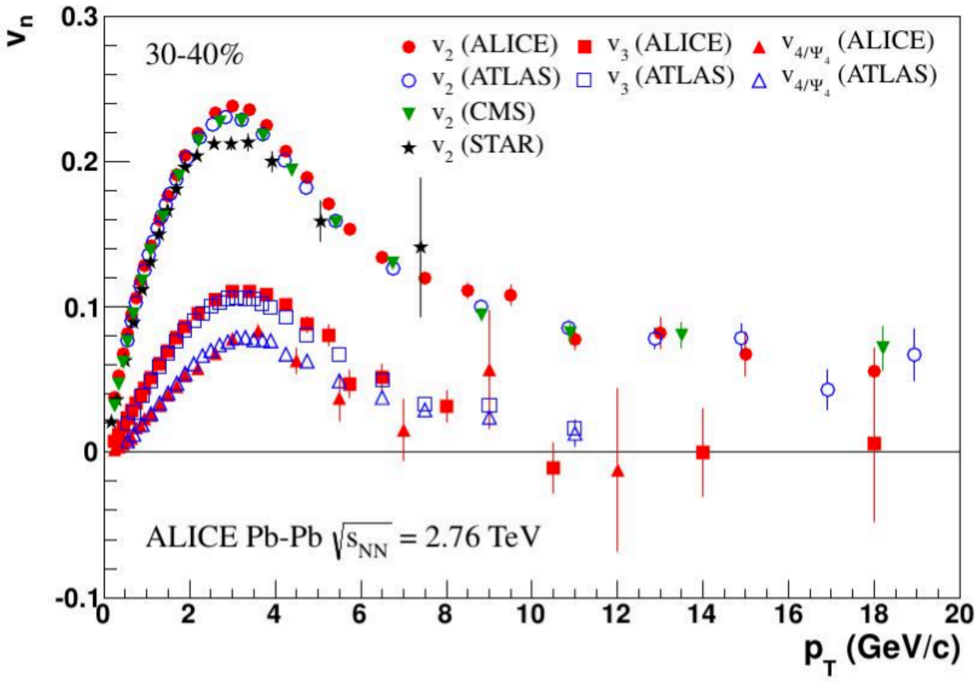


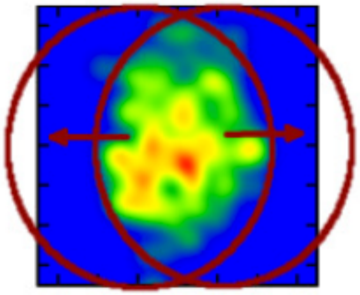
Flow

Anisotropy well described by Hydrodynamics

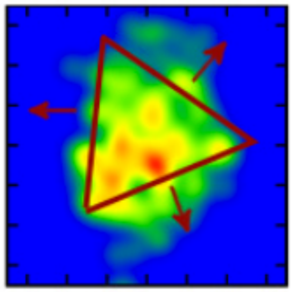
Large number of particles undergoing many interactions.

Describes evolution of the system, **QGP -> QCD**





$\epsilon_2, \psi_2 \Rightarrow v_2$

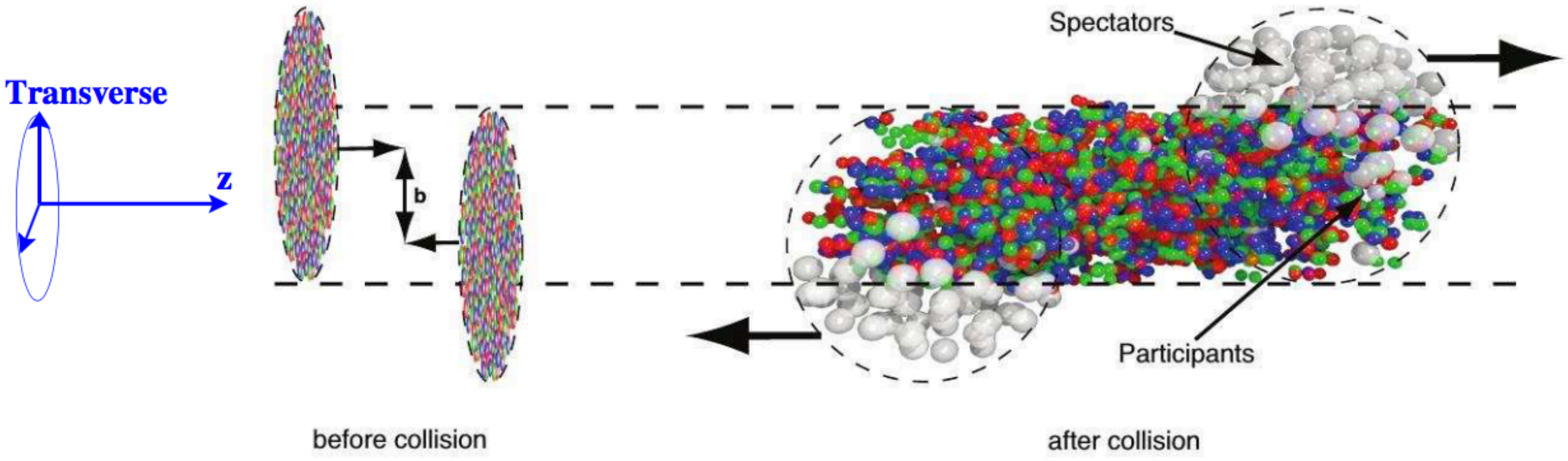


$\epsilon_3, \psi_3 \Rightarrow v_3$

Medium response
to initial geometry

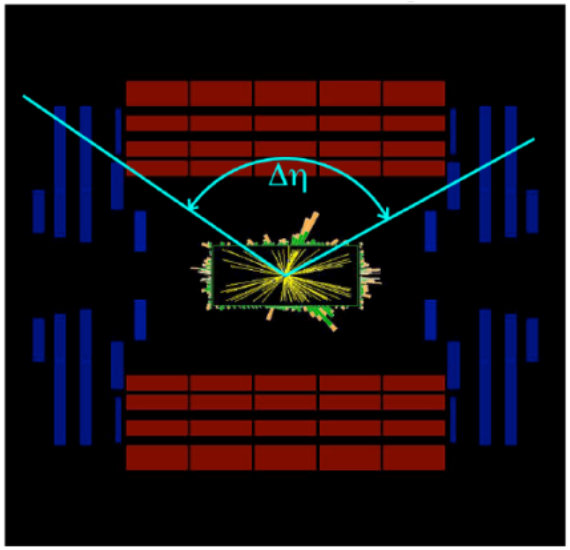
Conditions for Thermalization

- System size >> Mean Free path, **R/λ>>1?**
- How small can a drop of QGP get?
- Can we test this with more peripheral collisions, keeping multiplicity constant?

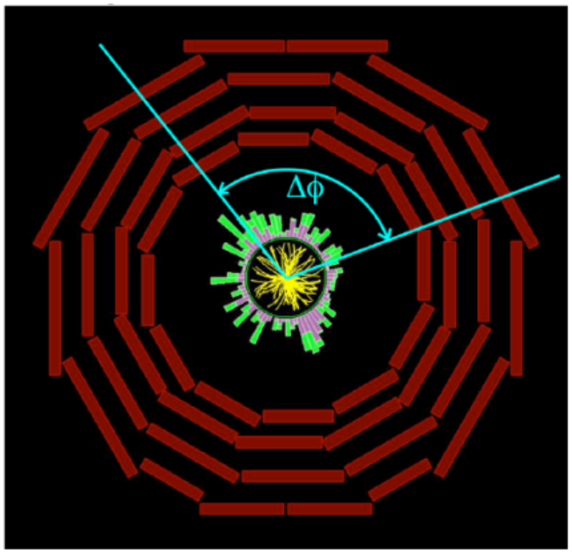


Number of participants ~ Centrality ~ Multiplicity ~ b

Detector angles

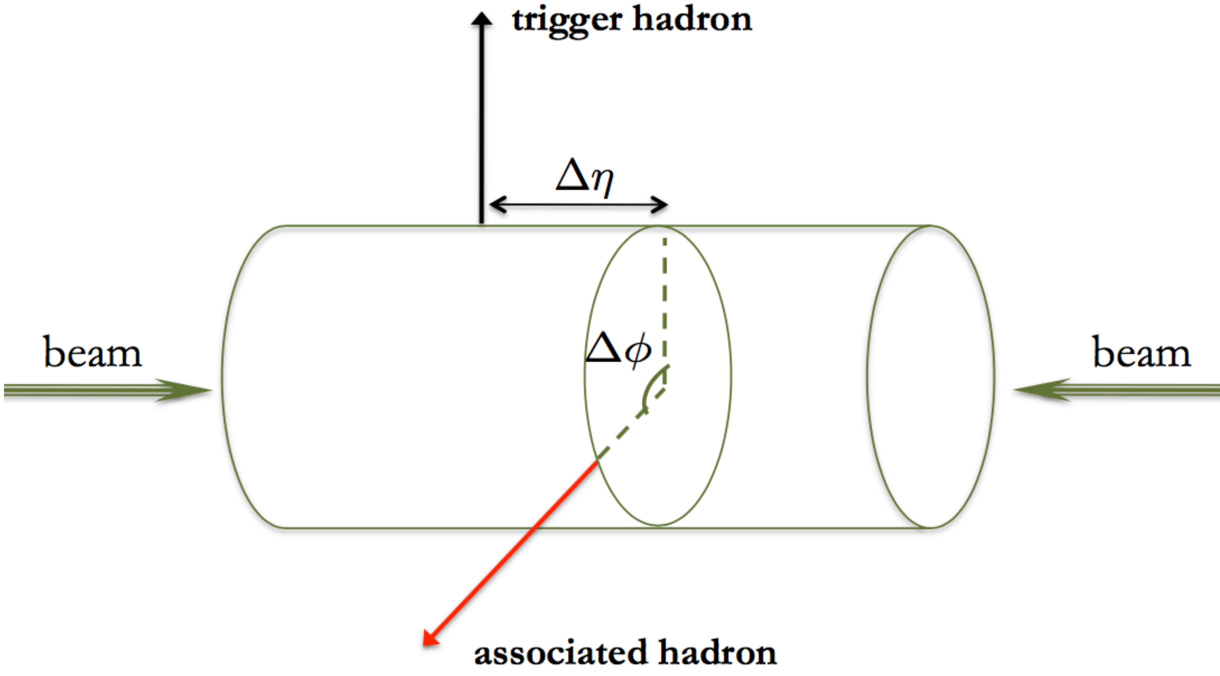


CMS



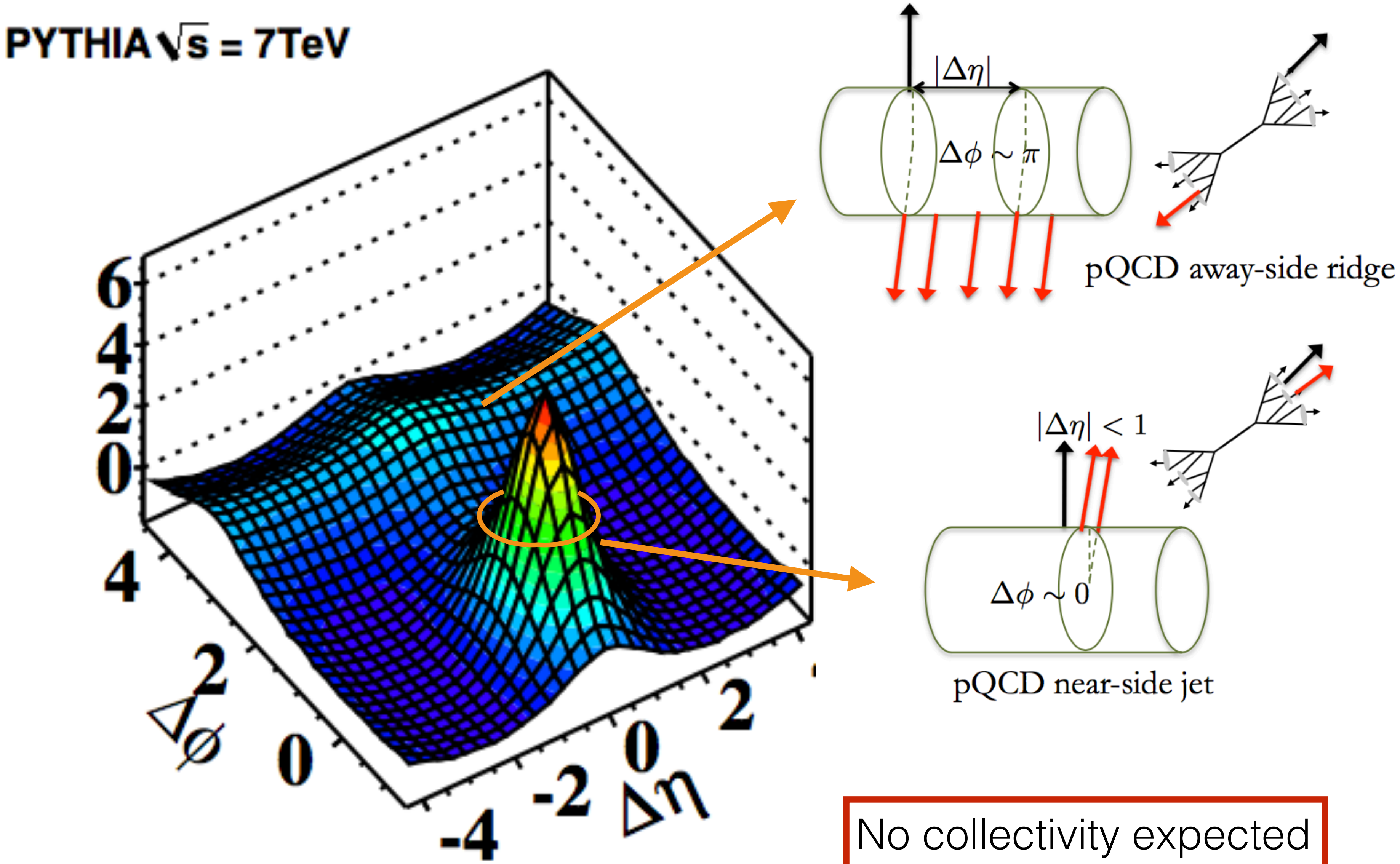
$$\Delta\eta \;\; \Delta\phi$$

Pseudo-rapidity: η
Azimuthal angle: ϕ



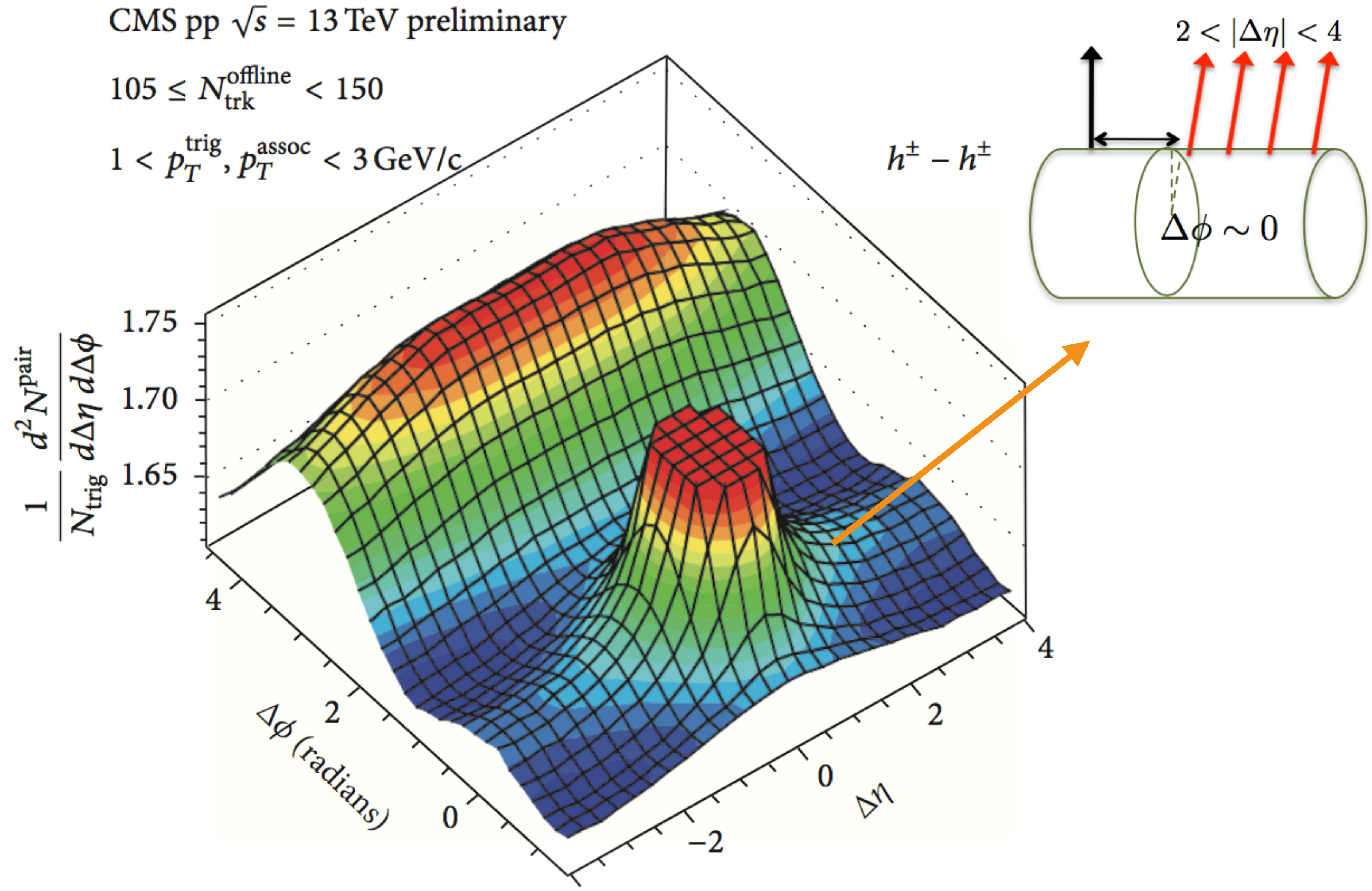
We can quantify the correlation between pairs of particles as a function of angular differences $\Delta\phi$ & $\Delta\eta$

Pythia for pp

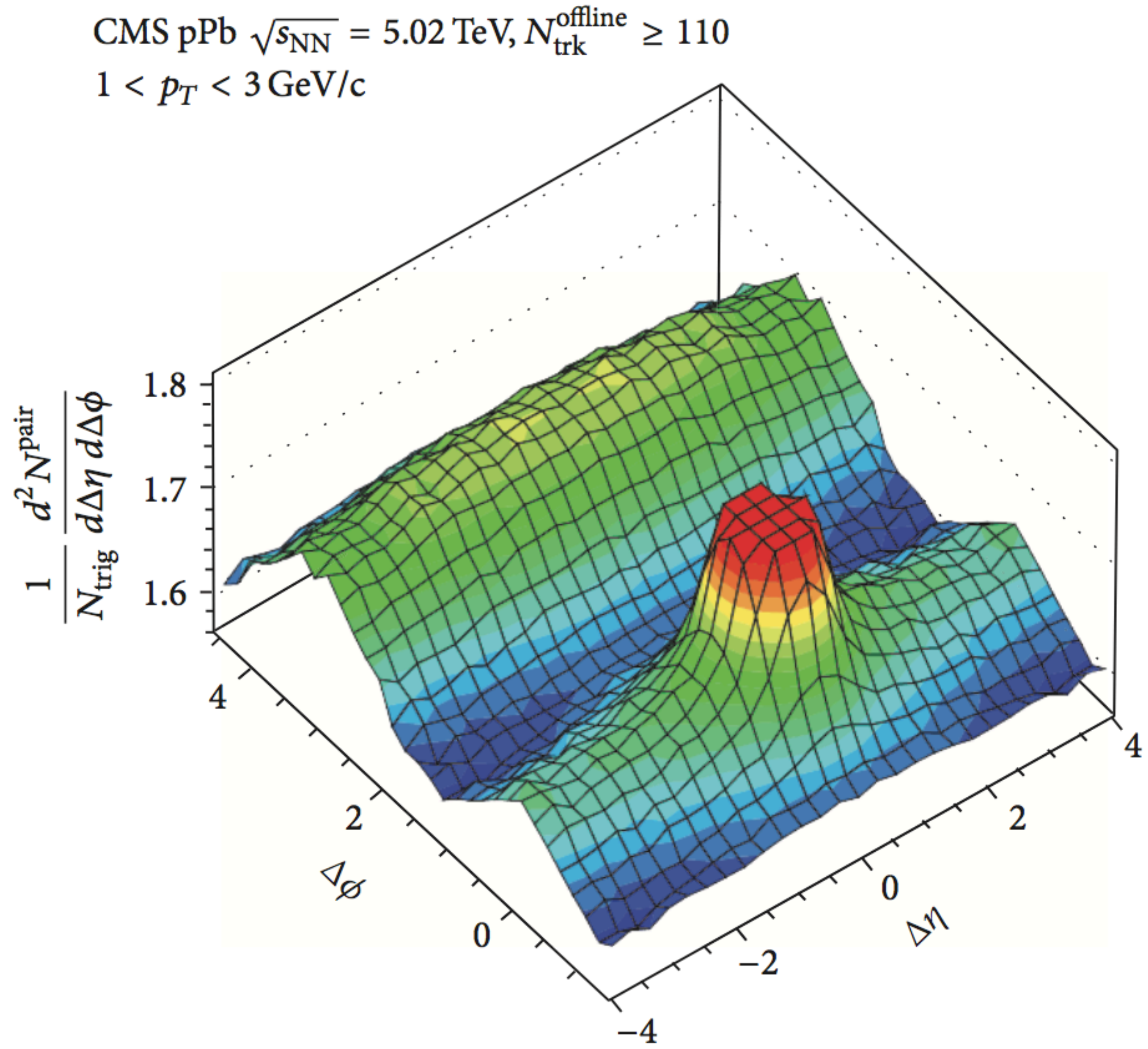


No collectivity expected for small systems

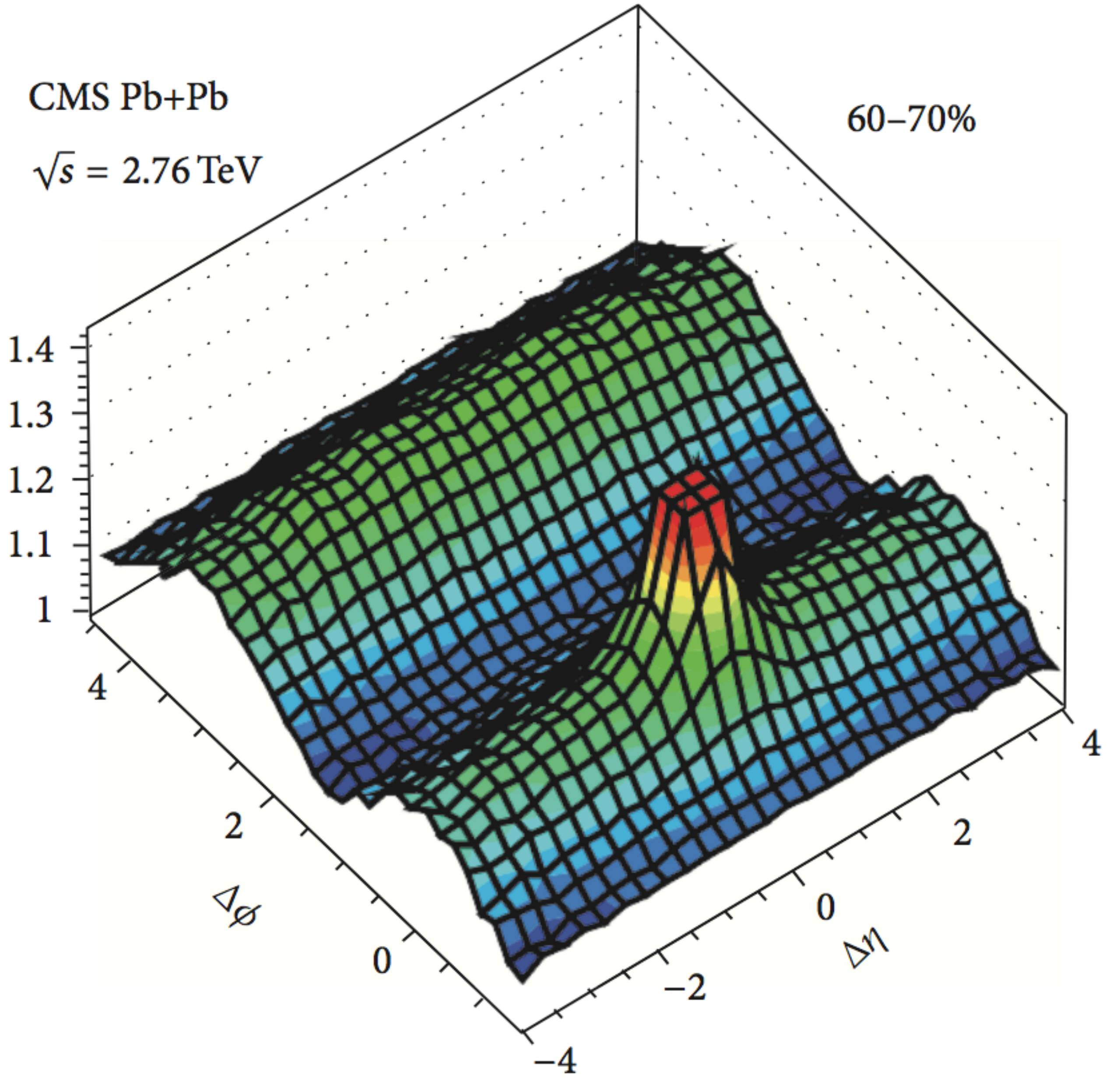
Small Near Side Ridge in pp



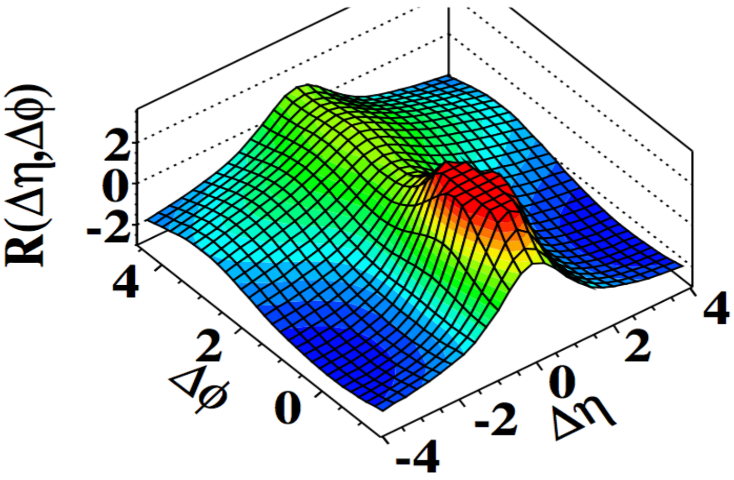
pPb


CMS pPb $\sqrt{s_{NN}}$ = 5.02 TeV, $N_{trk}^{offline} \geq 110$
$1 < p_T < 3$ GeV/c
$\frac{1}{N_{trig}} \frac{d^2 N^{pair}}{d\Delta\eta\, d\Delta\phi}$
1.8
1.7
1.6
4
2
0
$\Delta\phi$
−4
−2
0
2
4
$\Delta\eta$

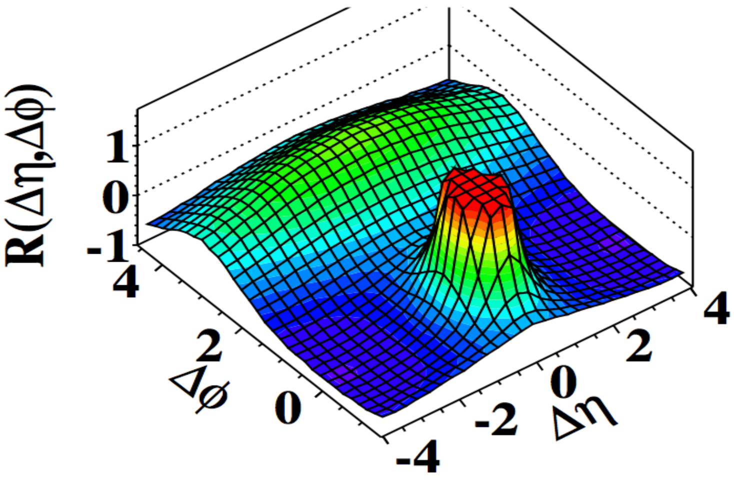
PbPb



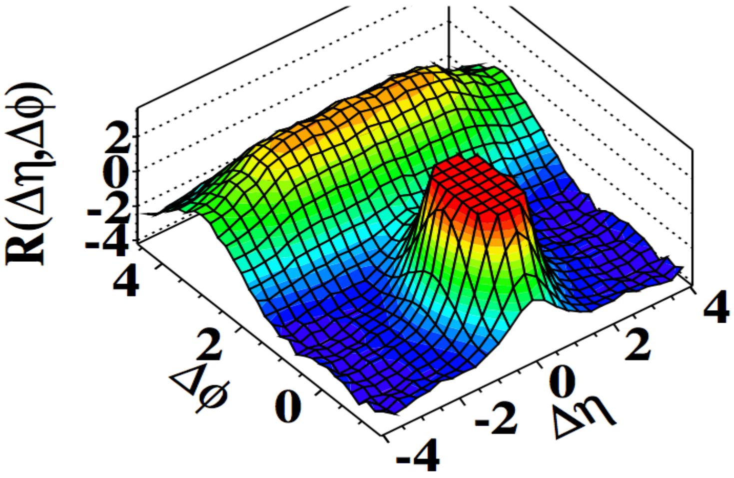
Near Ridge only at High Multiplicity Events



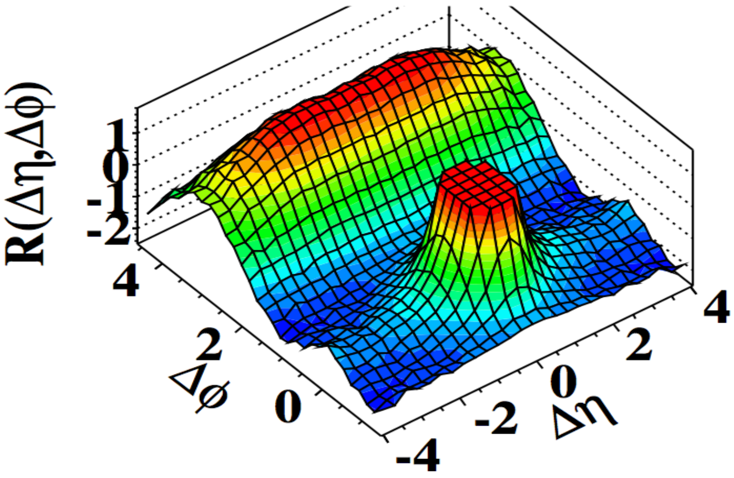
(a) CMS MinBias, p_T>0.1GeV/c



(b) CMS MinBias, 1.0GeV/c<p_T<3.0GeV/c



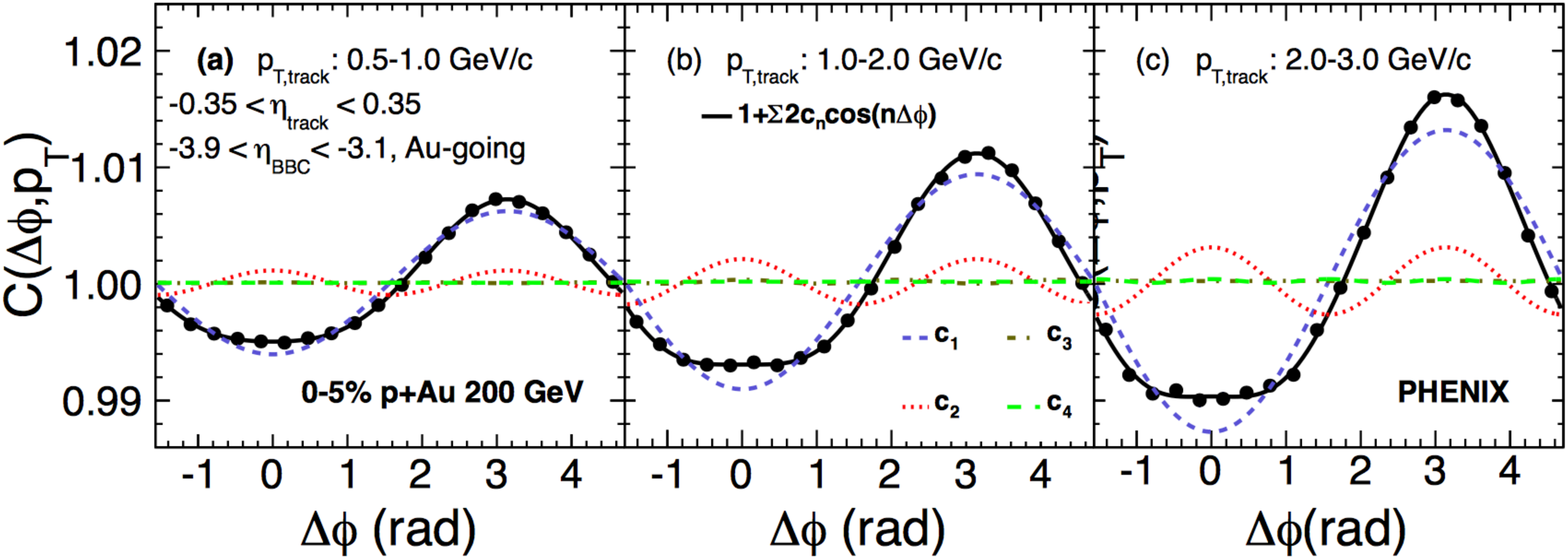
(c) CMS N ≥ 110, p_T>0.1GeV/c



(d) CMS N ≥ 110, 1.0GeV/c<p_T<3.0GeV/c

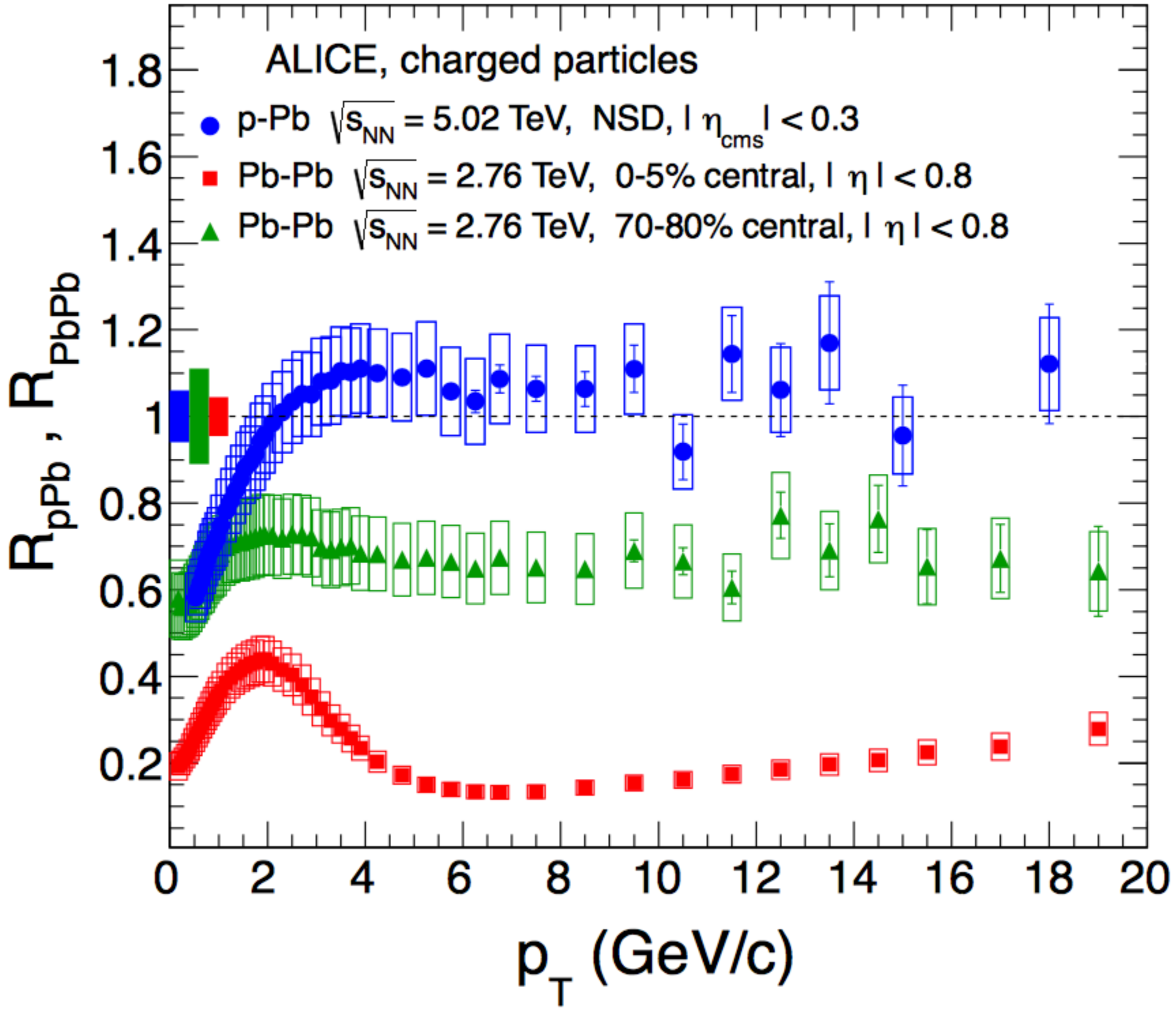
PHENIX at RHIC

Long-range angular correlations $C(\Delta\phi, p_T)$



Fit correlation plot to 4-term Fourier series

Particle Suppression

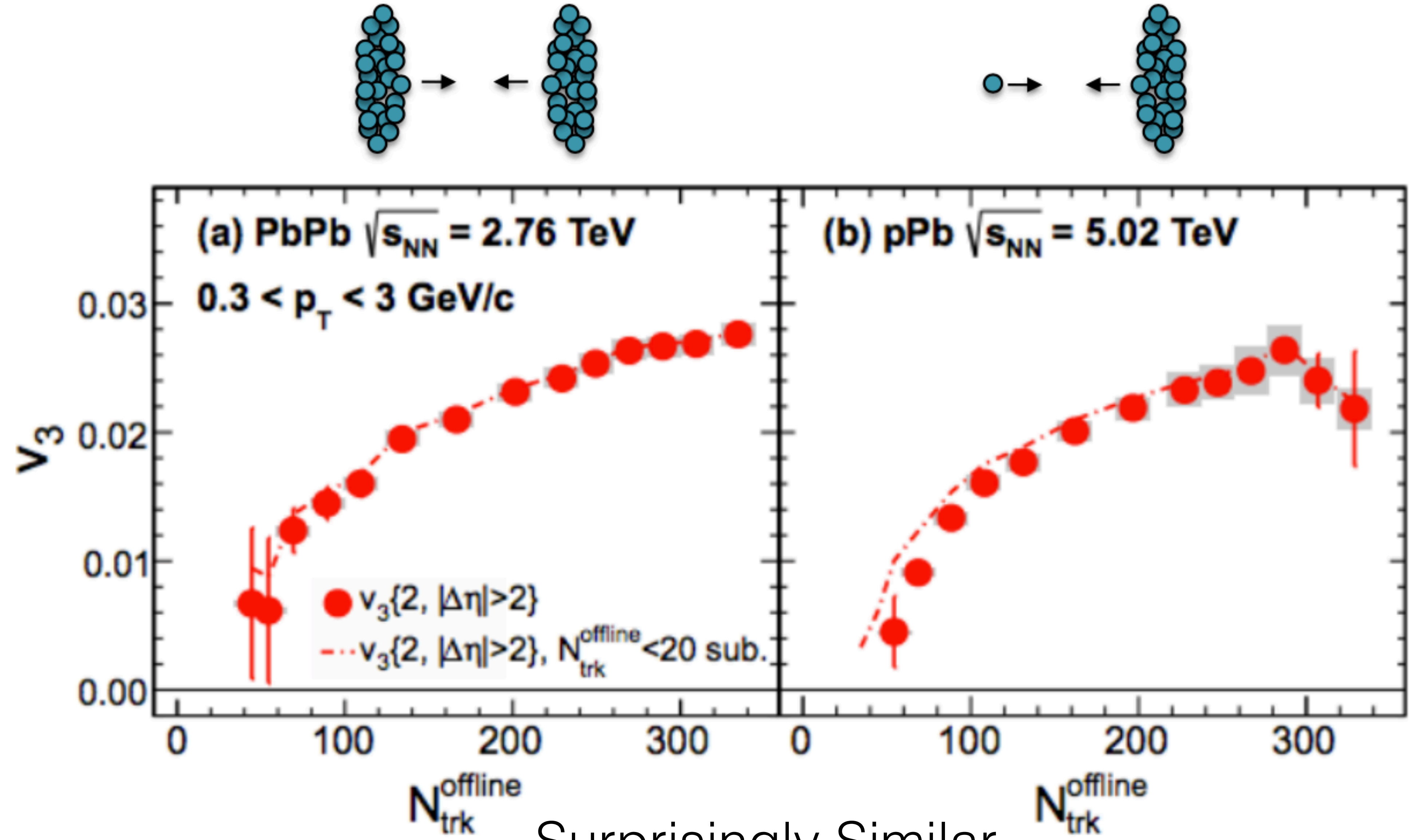


- Jet Quenching
- R_{AA} for charged hadrons vs P_T
- No Isolated high multiplicity pA

"We have argued that the high $p_\perp$ regime in pPb collisions at the LHC is practically free from final state interactions. This allows to do precision physics of other nuclear effects, such as the impact of nuclear parton distribution functions"
nuclphysa.2014.04.023

Demonstrating "that the strong suppression observed in central Pb–Pb collisions at the LHC is not due to an initial-state effect, but rather a fingerprint of the hot matter created in collisions of heavy ions"
PhysRevLett.110.082302

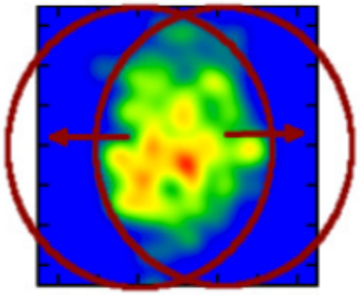
Comparison of v3 in AA and pA



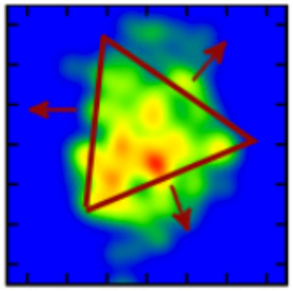
Surprisingly Similar

V_3 and initial state

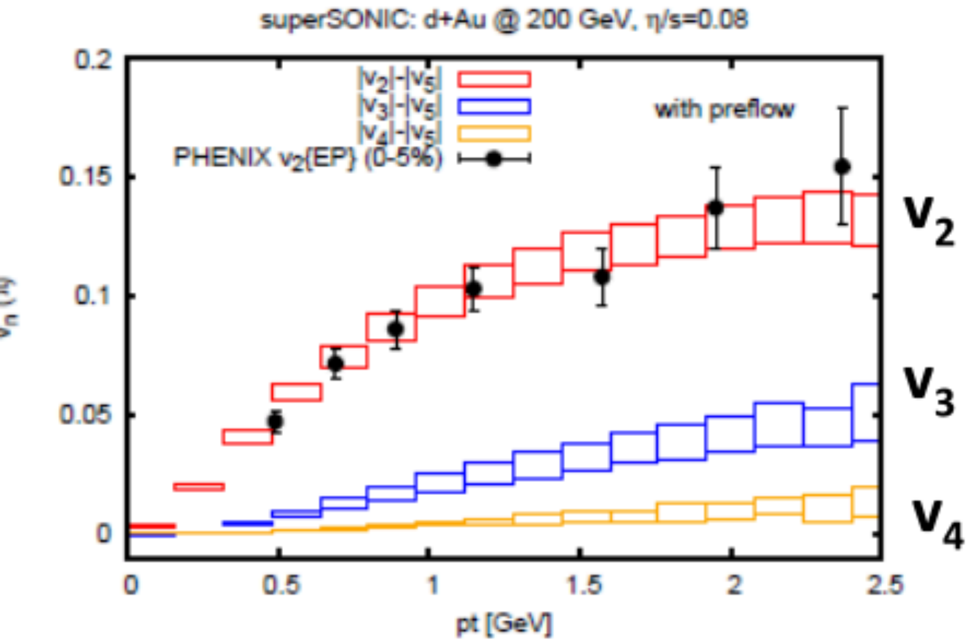
- What is the contribution of initial state geometry to flow?
- V_3 largely affected by pre-equilibrium flow
- More clear in systems with weaker final state interactions



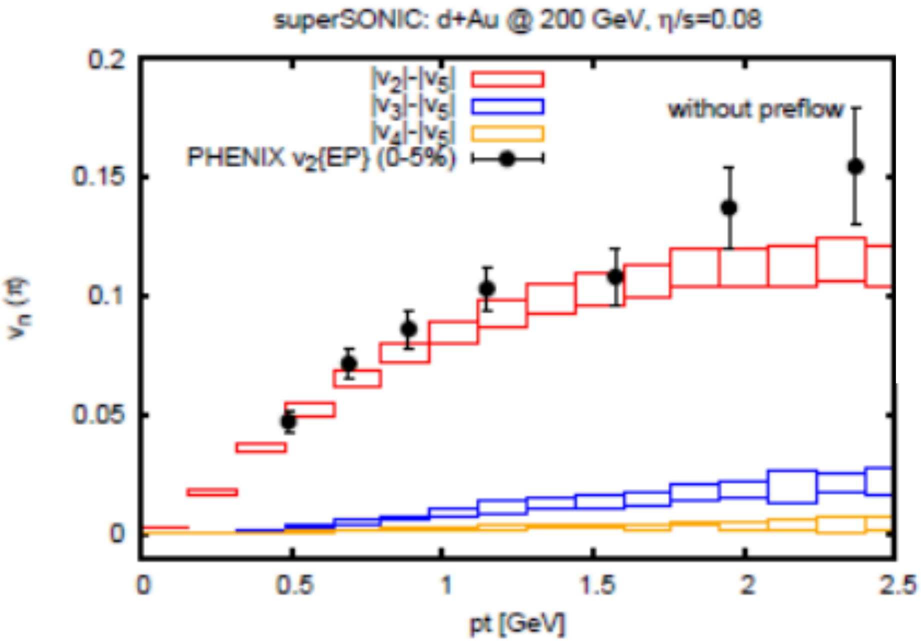
$\epsilon_2, \psi_2 \Rightarrow v_2$



$\epsilon_3, \psi_3 \Rightarrow v_3$



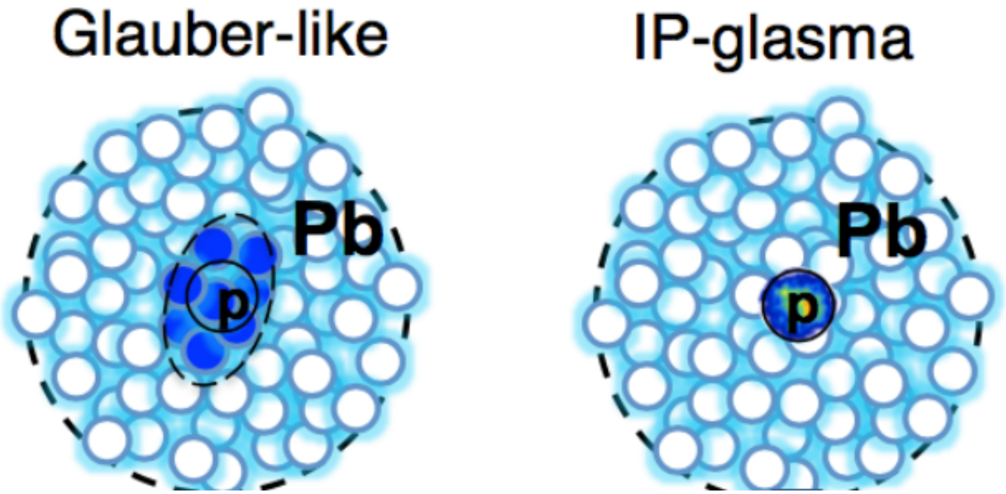
Hydro with pre-equ. flow

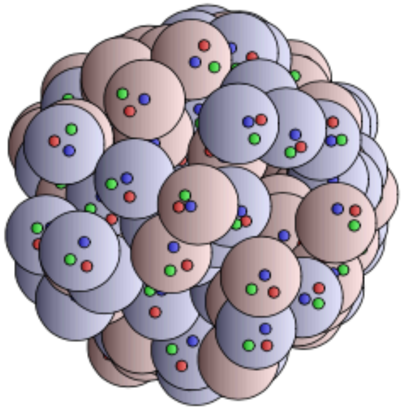


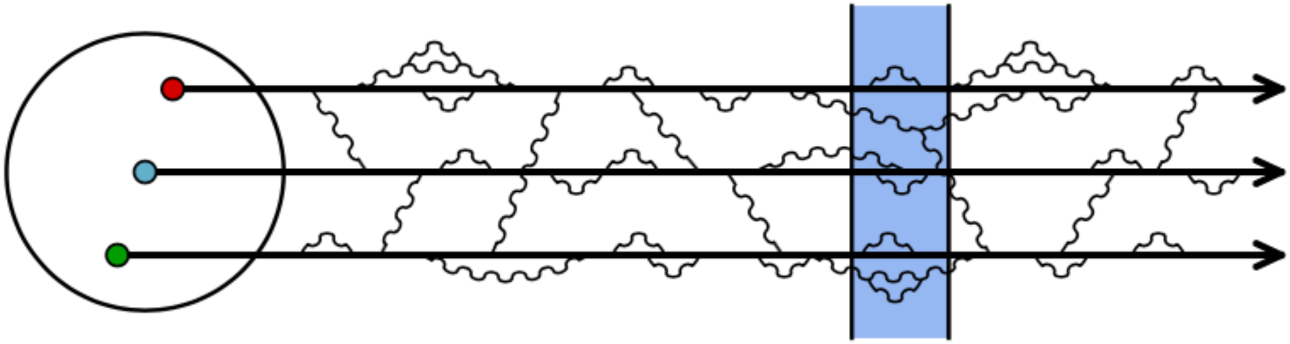
Hydro w/o pre-equ. flow

Geometry of the proton

- Eccentric or Normal?
- Gluon Saturation
 -Colored Glass Condensate
- Different Initial Geometry - different final state particle emission







Parton Content of nucleon at low energy

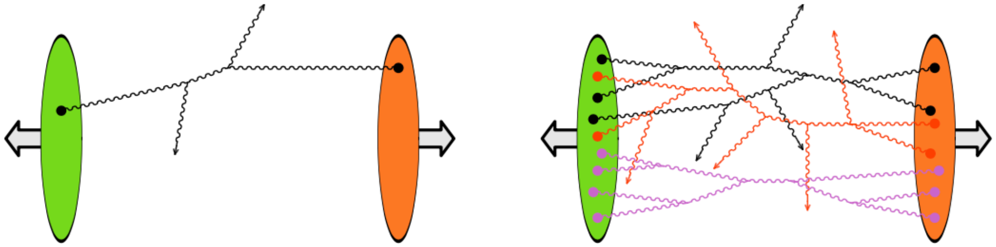
Credit:FRANCOIS GELIS

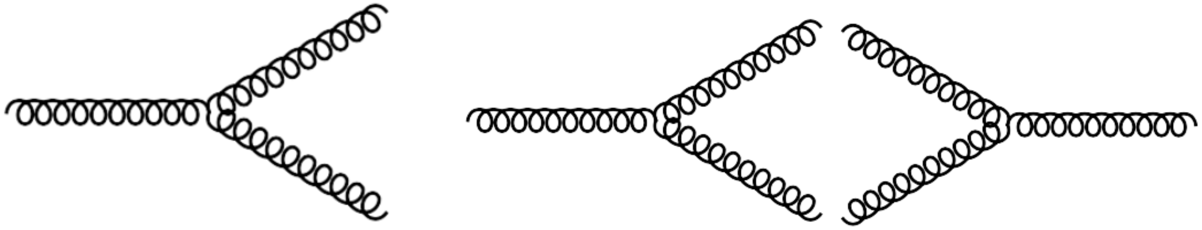
Gluon Saturation

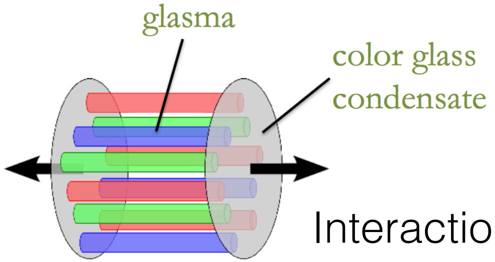
- QCD calculations for collisions
  -quark and gluon content of the hadrons that are being collided

- Relativistic Effects
  - Lorentz Contraction - Geometry Change
  - Time Dilation - lifetimes of fluctuations
  - **# gluons seen in a reaction increases with the Energy**

- At Low **x**, valence quarks become negligible





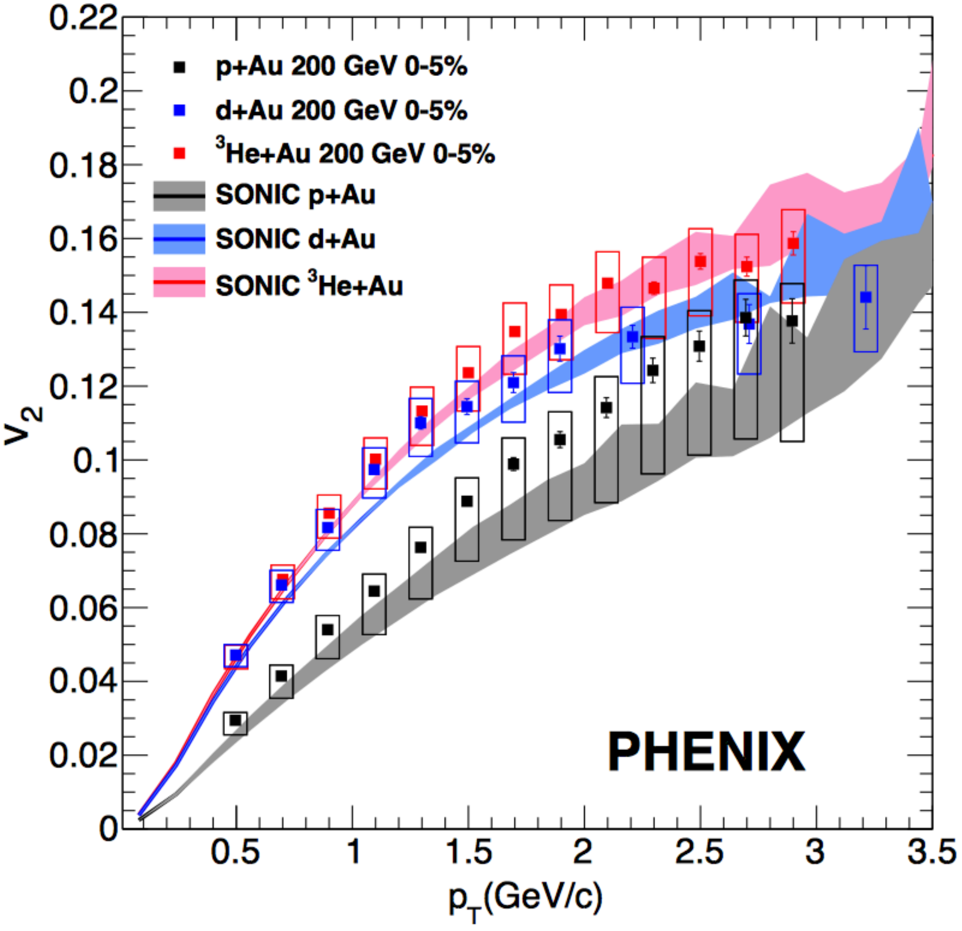


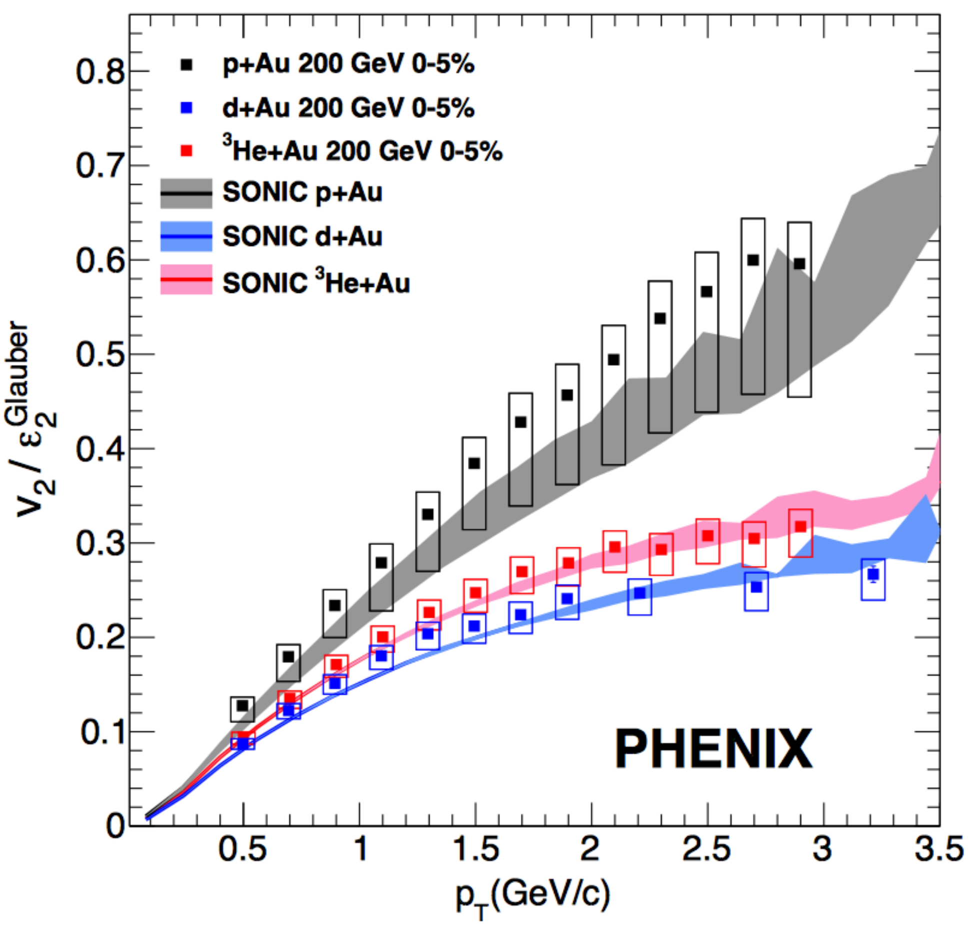
Interaction between Gluons

$$x \equiv p_z/\sqrt{s}$$

Credit:FRANCOIS GELIS

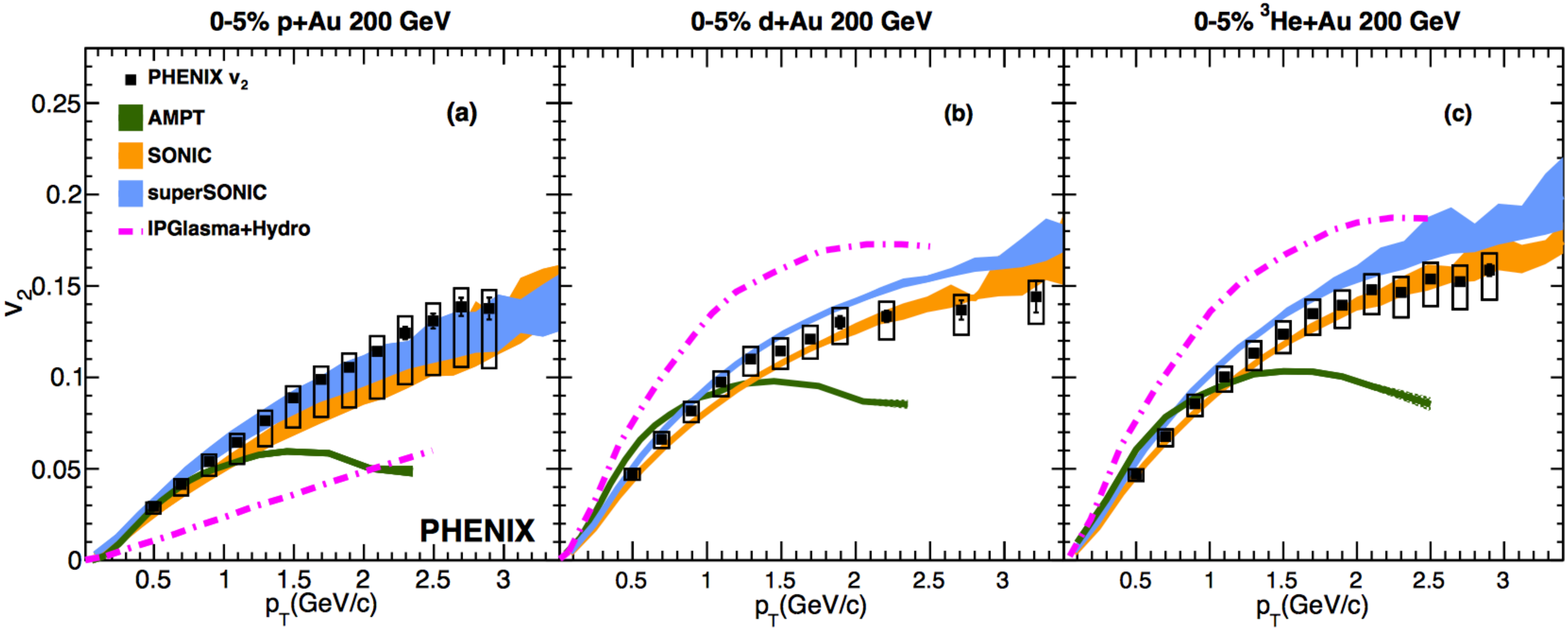
Updated Models vs Data





2016 PHENIX Data

Updated Models vs Data



IP-Glasma initial conditions followed by viscous hydrodynamics worked for AA, overestimates for pA, assumes low eccentricity

superSONIC incorporates Glasma, hydrodynamics expansion, and pre-equilibrium dynamics

Summary

High Multiplicity pA has striking similarities to AA

-Not necessarily QGP

-If flow results are ambiguous in pA, how does that affect our understanding of AA?

Hydro Dynamics isn't the only relevant physics

-Eccentricity and Glauber Model

-Gluon Saturation and CGC

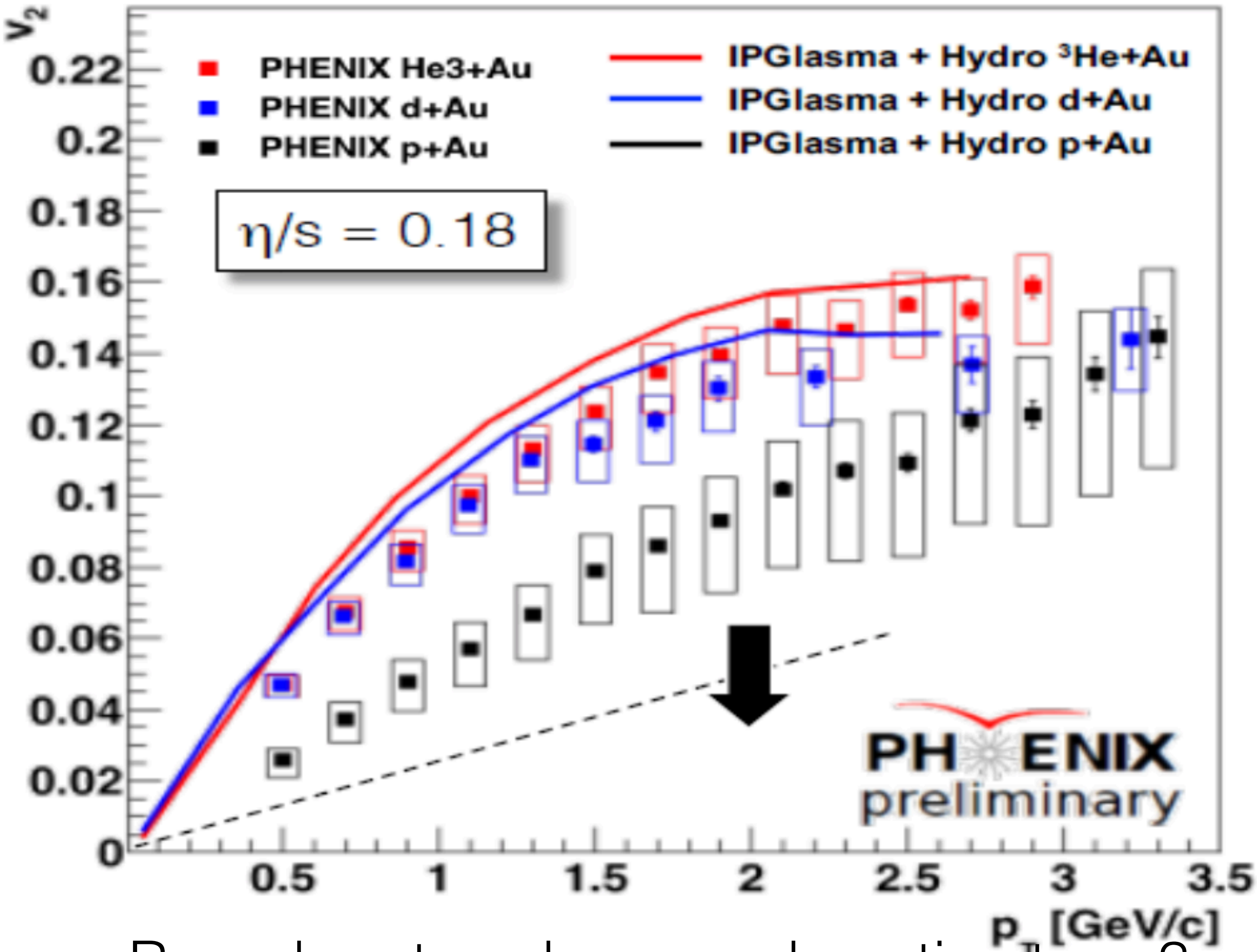
Anisotropy indicates initial geometry is more important that previous thought in pA

References

<See BibTex>

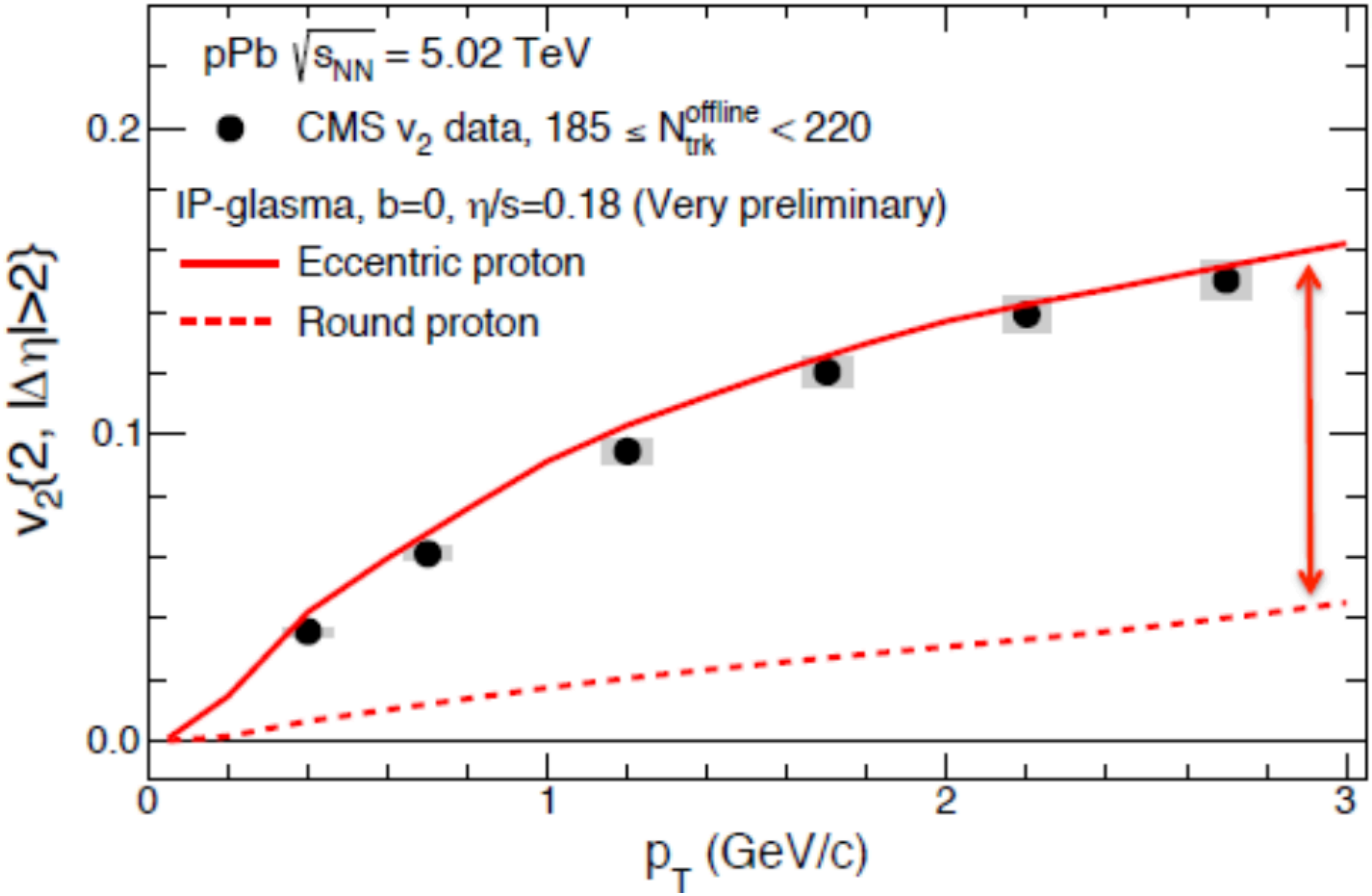
Backups

Importance of Proton Shape

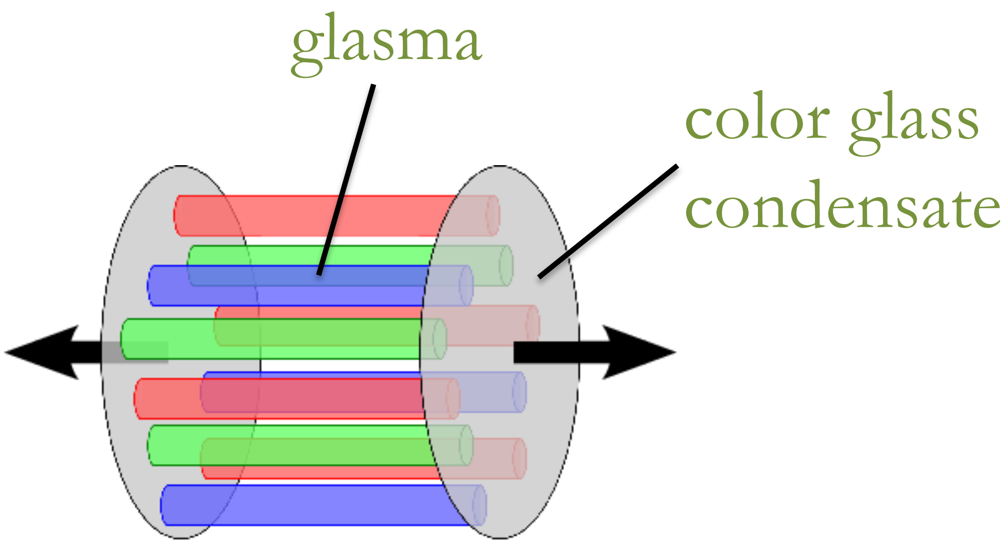


Round proton shape underestimates v3

Glasma, Flow, and Proton Shape



Better match with eccentric proton shape



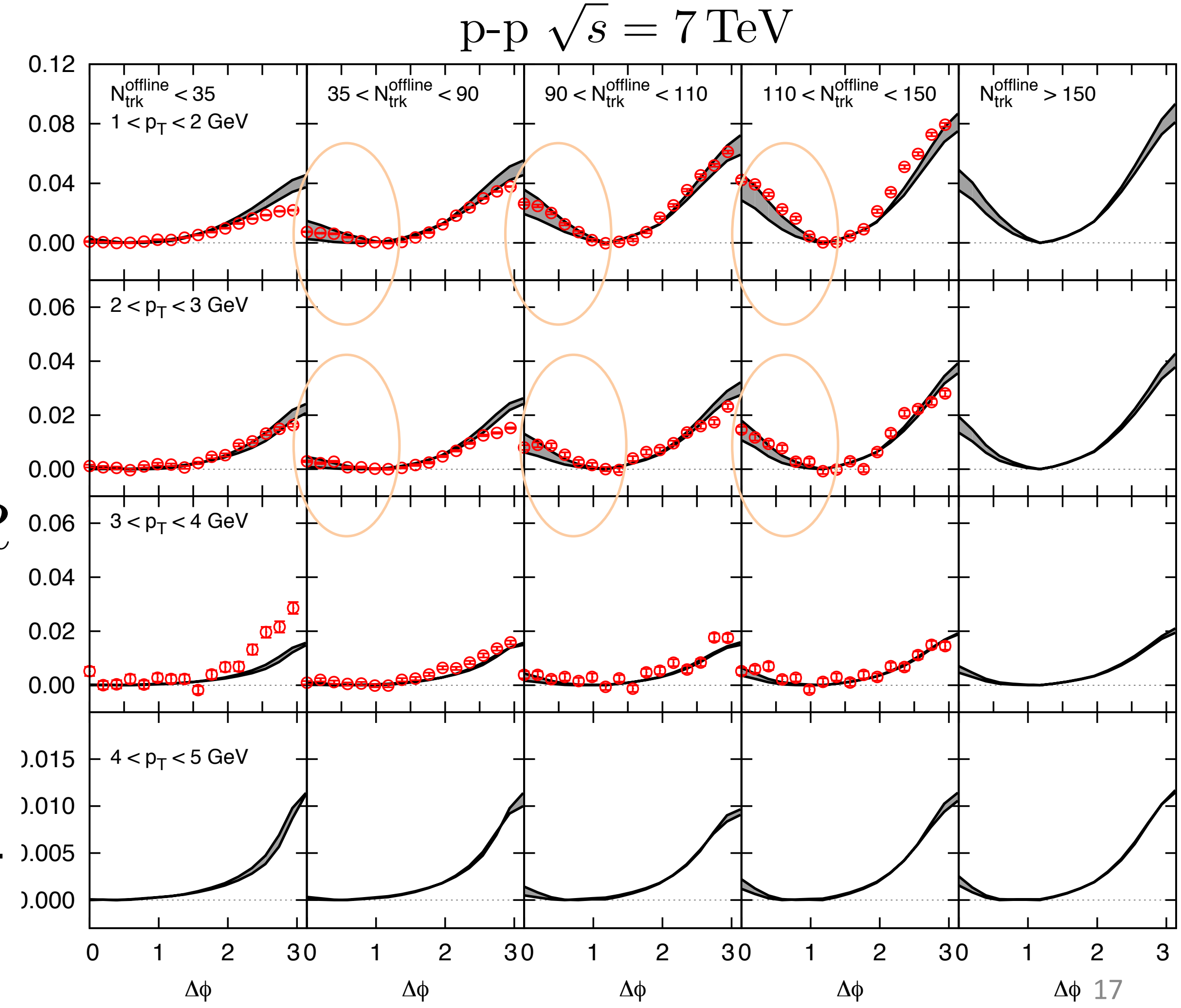
Glasma ('glassy plasma'): Classical, strong chromo-electric and –magnetic color flux tubes between the target and projectile.

They are created by the target and projectile which are highly populated by gluons at small-x ('color glass condensate').

16

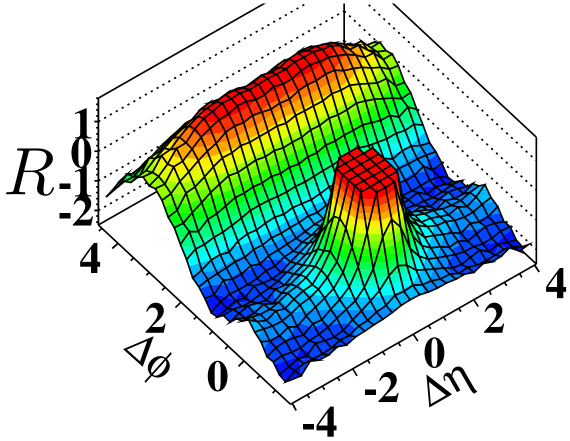
Experiment vs. Glasma

- Glasma diagrams (flux tubes) with gluon saturation reproduce the ridge and explains the systematics of the p-p and p-Pb data well.



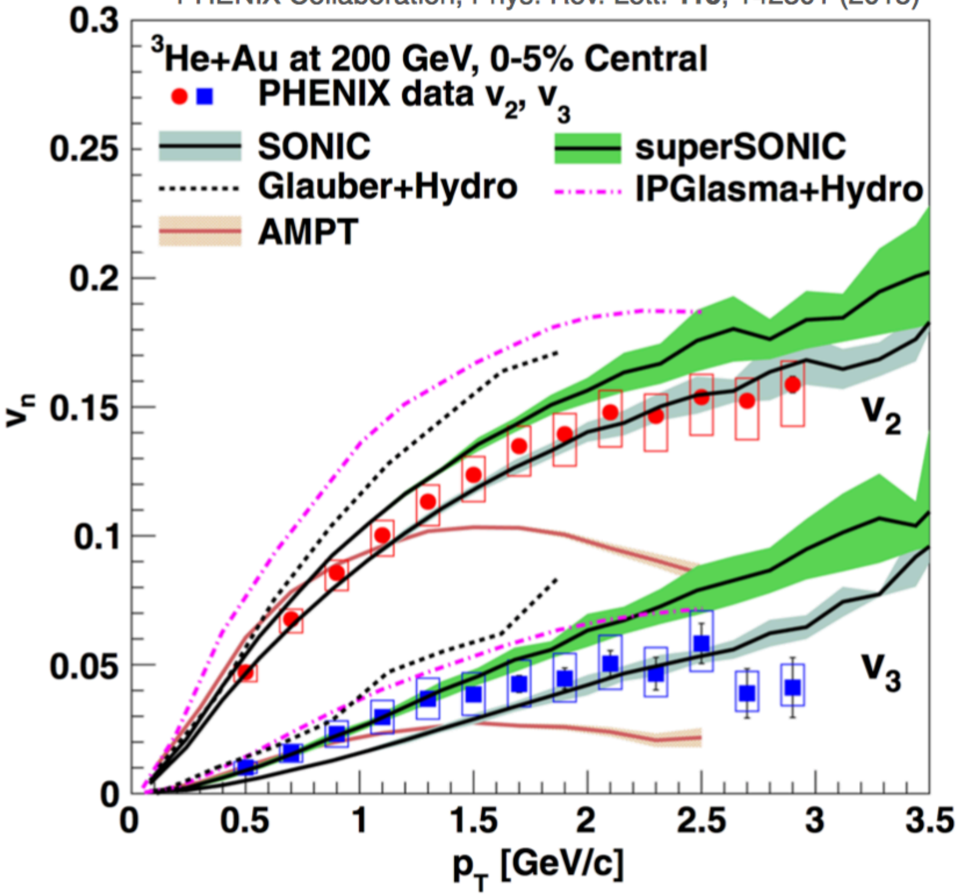
gray band: data

red circles: glasma model



Can't find source on data

glasma models and real data



PHENIX Collaboration, Phys. Rev. Lett. **115**, 142301 (2015)

^{3}He-Au at 200GeV PHENIX