Recent Results From **RHIC**

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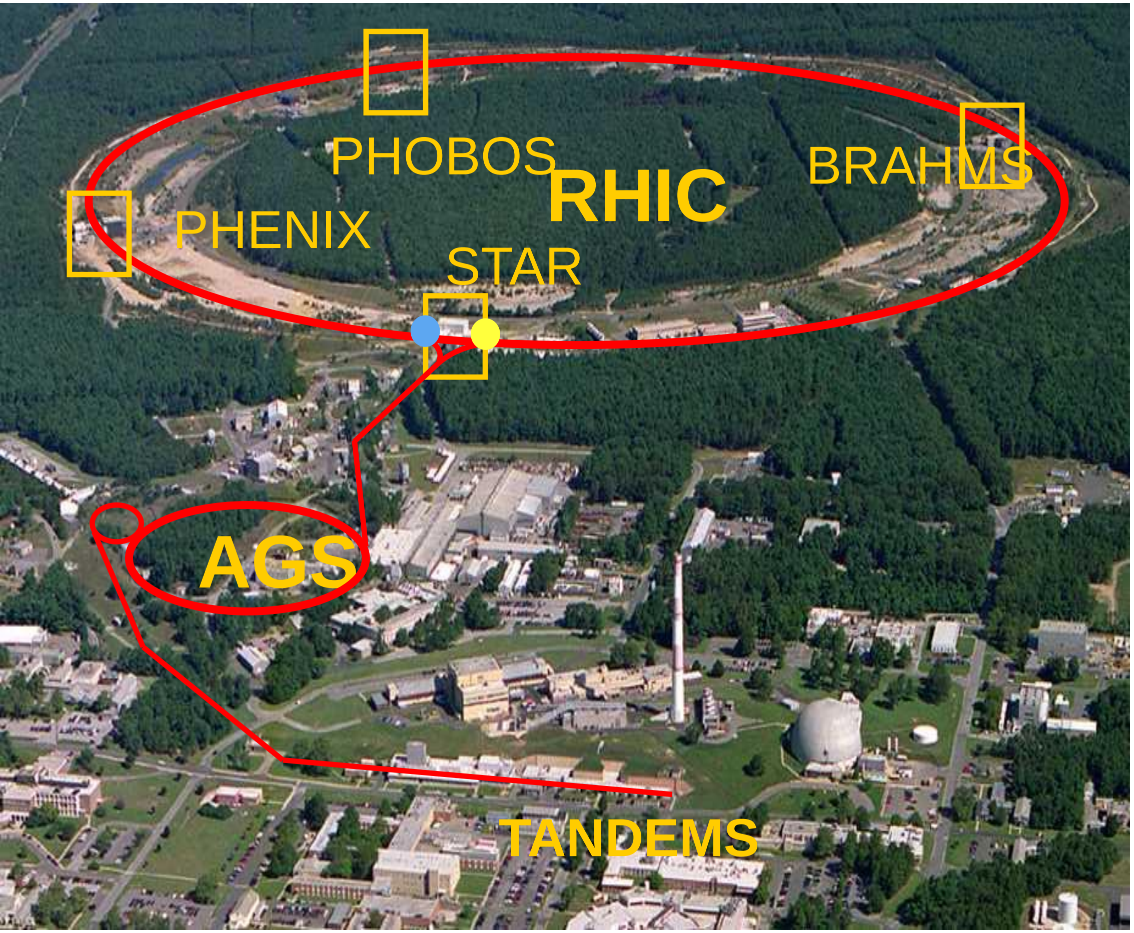
Outline:

- HI program at RHIC
- Data collection and Detector Setups
- Selected recent results
  - Jets, jet-like correlations and medium properties
- Summary and outlook

Relativistic Heavy Ion Collider

- Design goal - studies of phase structure of nuclear matter



- Counter-rotating ion beams

  $p \rightarrow U$

- Maximum center-of-mass energy:

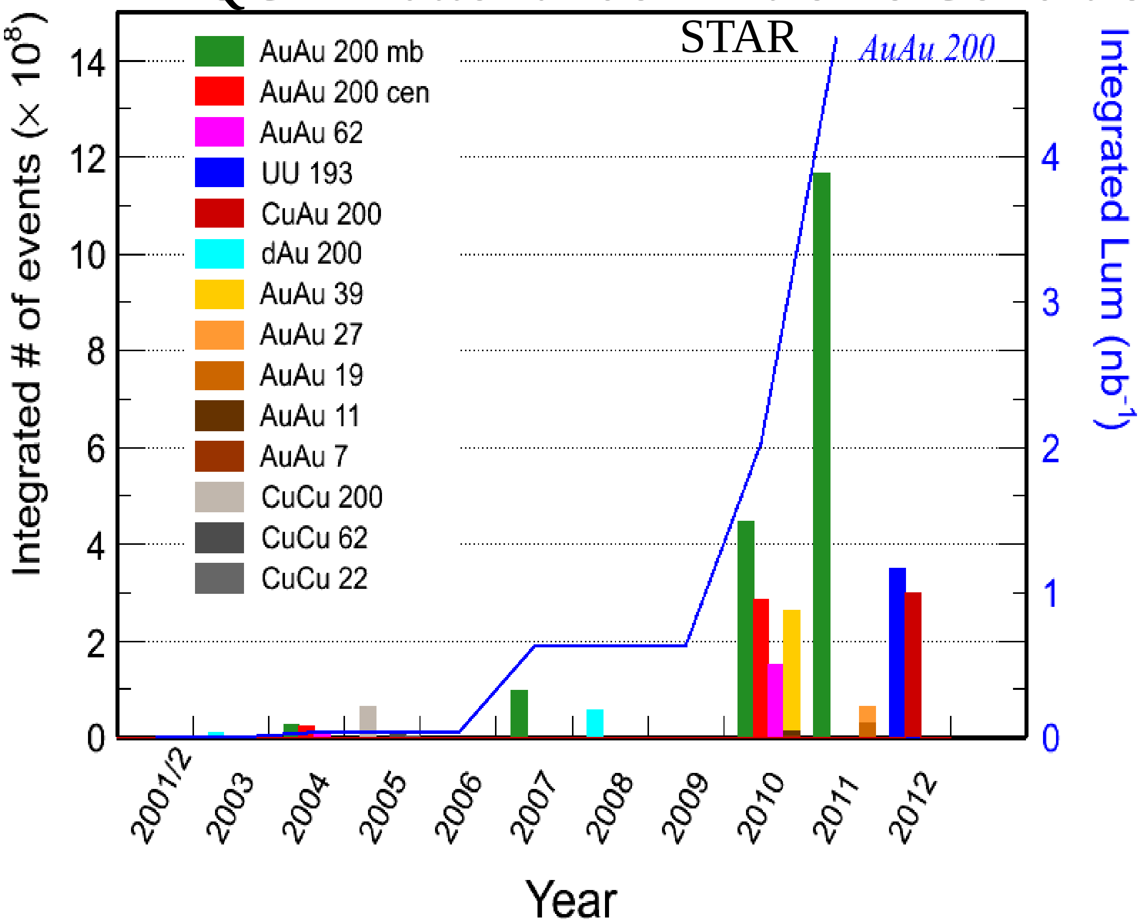
  200 GeV for Au+Au

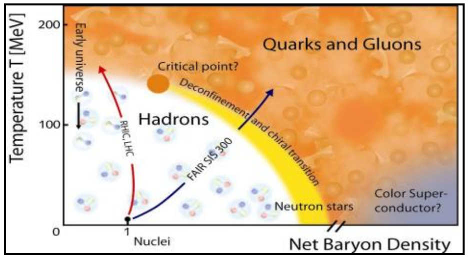
  500 GeV for *pp*

A+A Data Collection

- HI Program:

  QCD matter under Extreme Conditions





- sQGP Studies

  EoS,

  E_{loss} in QCD medium

  ….

- Beam Energy Scan

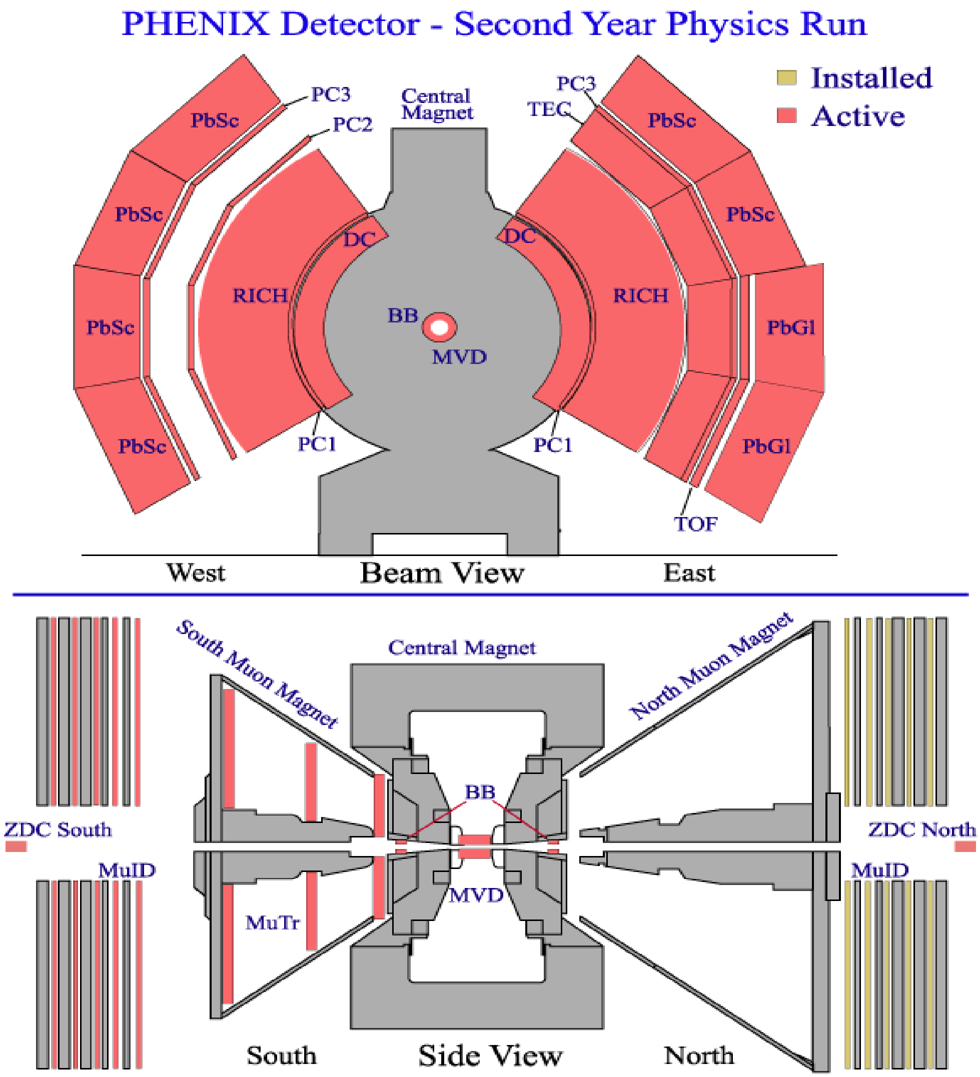
  QCD critical point search,

  Onset of deconfinement,

  Chiral symmetry restoration

  …

PHENIX Detector



Central Arm Detectors

Drift, Pad, Time-Extension Chambers

RICH, EMCal

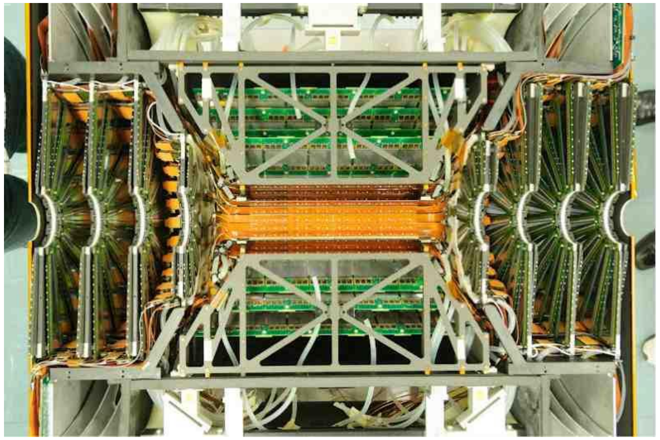
- 2 arms 90º in φ
- 0.7 units of η

Muon Arms Detectors

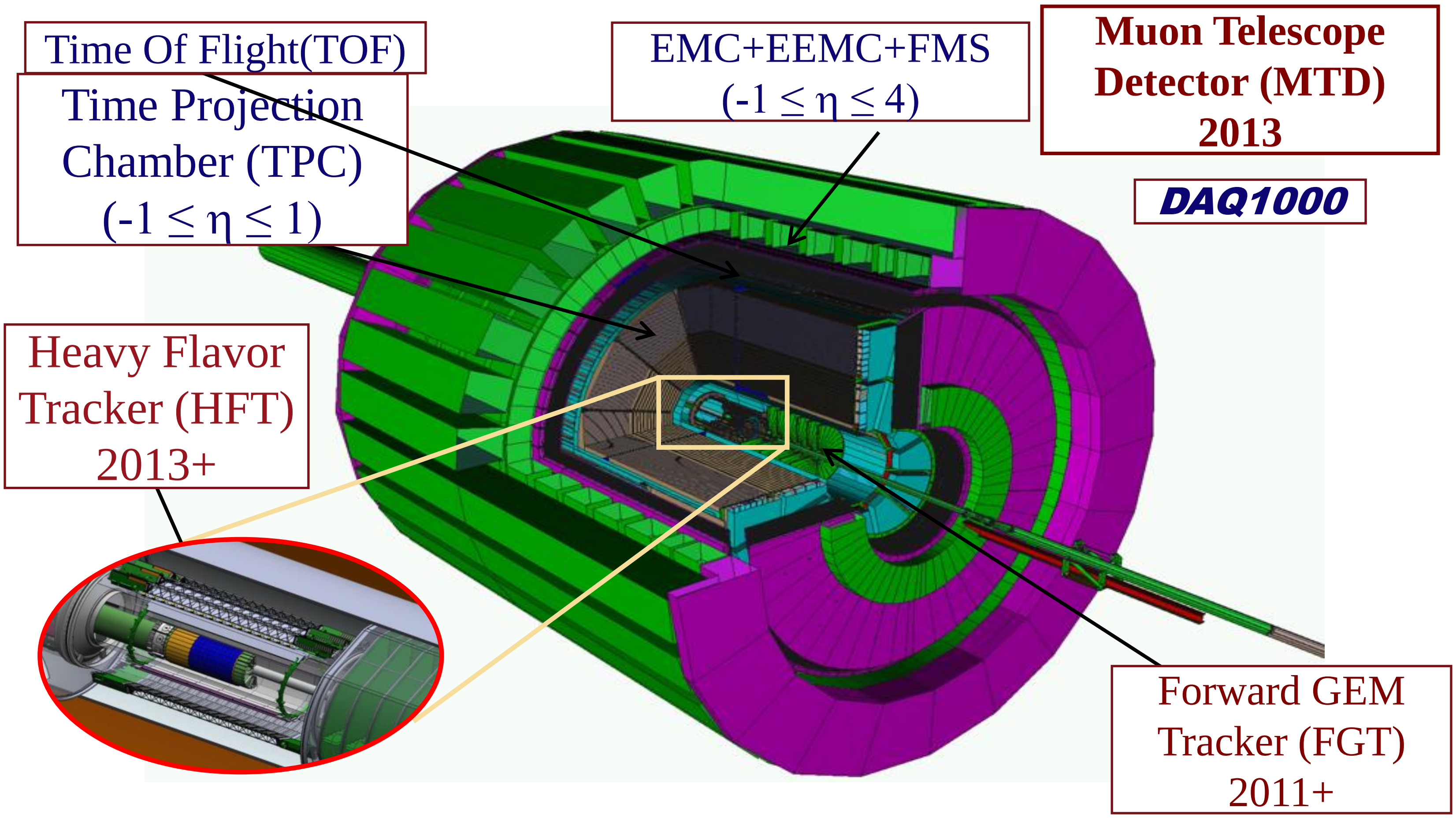
MuTr, MuID, MPC

- $1.2 < |\eta| < 2.2(2.4)$
- $3 < |\eta| < 4$

Upgrade (HF physics): VTX,FVTX



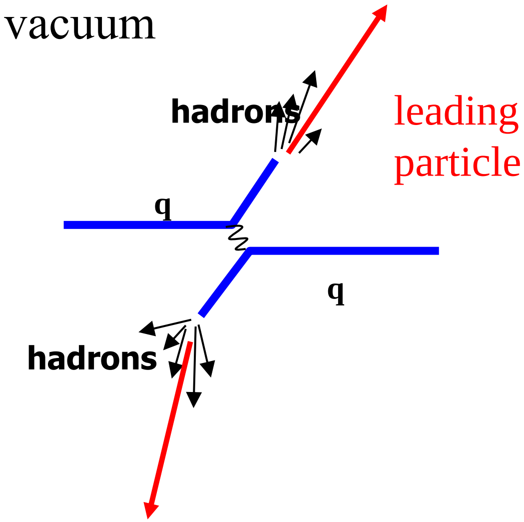
STAR Detector



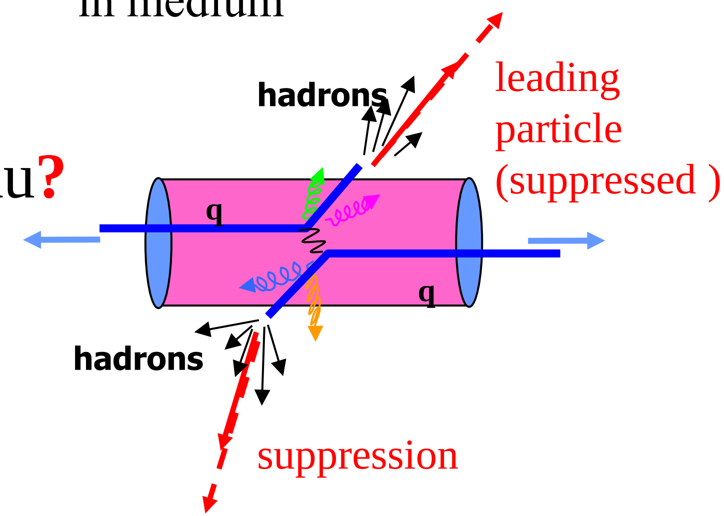
This Talk's Focus

- Angular correlations (with high p_T probes)
  - Early stage (pQCD) probes
  - Interactions of created matter with passing particle
    - Jet quenching
    - Azimuthal anisotropy
  - Long range correlations
- Control over cold matter effects via d+Au?
- **Initial vs. Final state effects?**

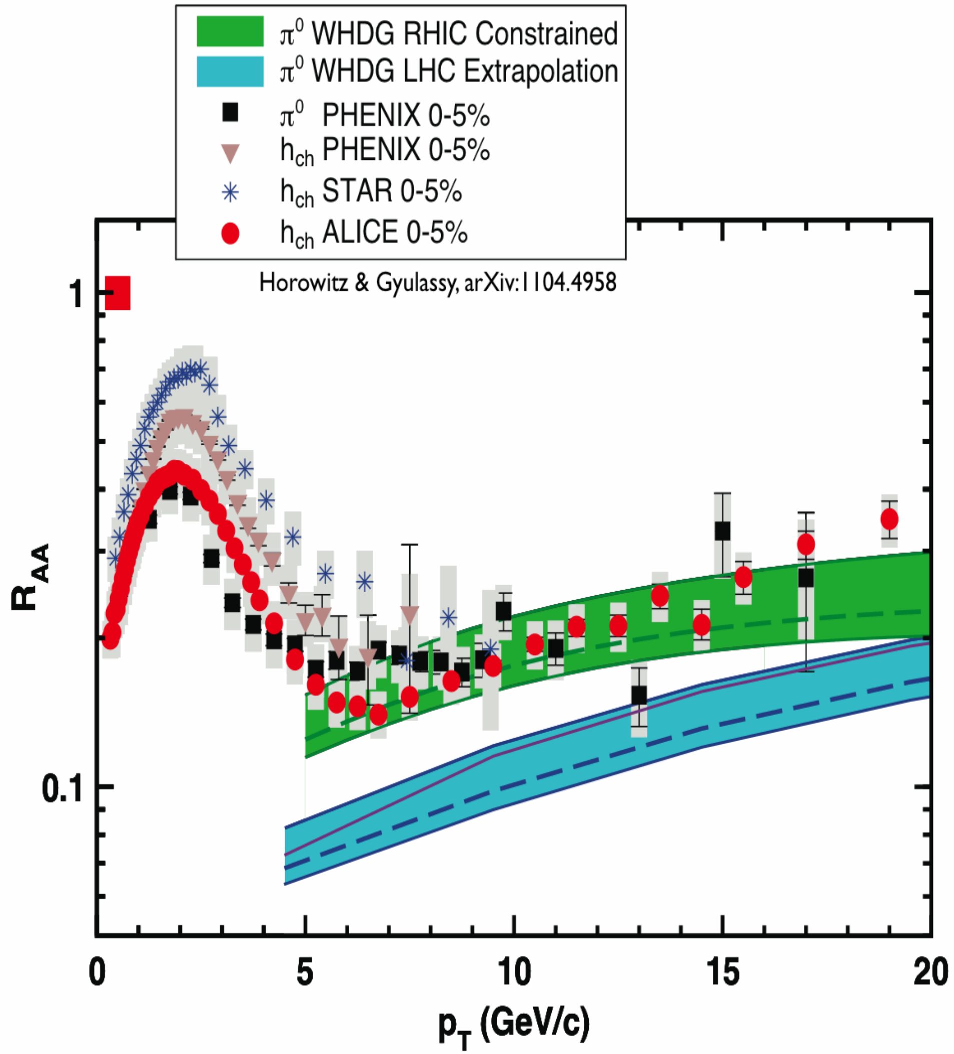
in vacuum



in medium



What are the sQGP signatures?



- R_{AA} – the first tool for jet quenching studies

$$R_{AA}(p_T) = \frac{d^2N^{AA}/dp_T d\eta}{T_{AA} d^2\sigma^{NN}/dp_T d\eta}$$

- Colorless probes check N_{coll} scaling: Direct photons

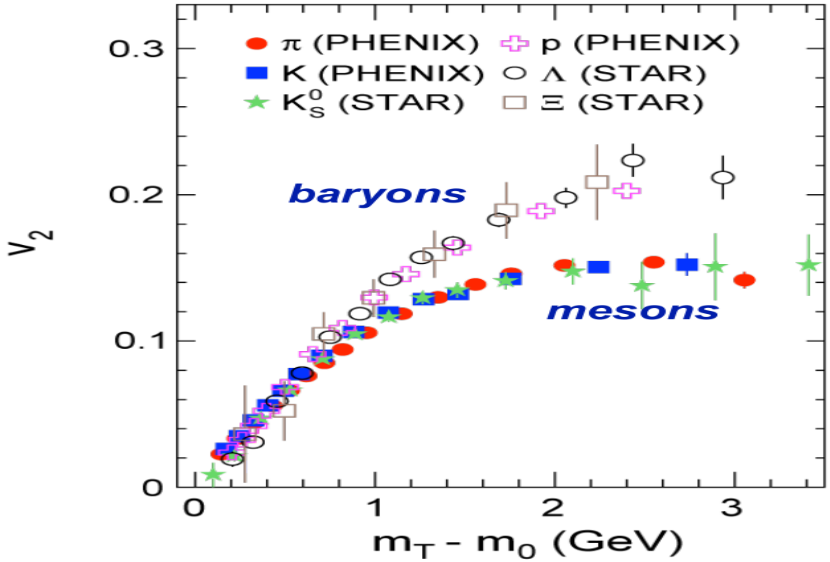
- High p_T hadron suppression:
  - Final state effect in Au+Au collisions
  - Observation extends to all accessible p_T range

- High density opaque medium

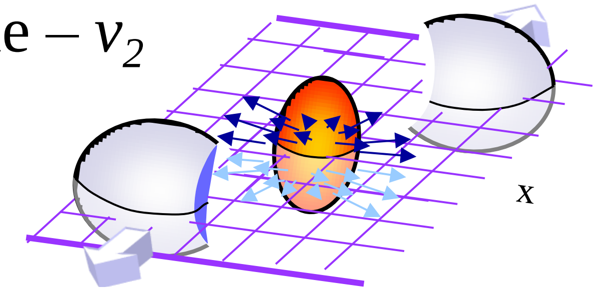
What are the sQGP Signatures?

STAR: PRL 95, 122301 (2005) PHENIX: PRL 98, 162301 (2007)

- Partonic collectivity
- Deconfinement



In multiple measurements, example – v_2



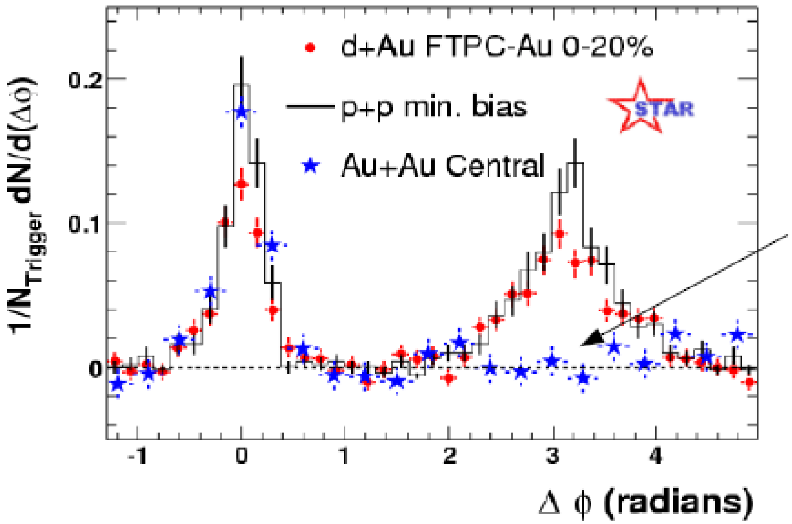
$$\frac{dN}{d\varphi} \propto 1 + 2v_2 \cos[2(\varphi - \psi_R)] + \ldots$$

- Strong anisotropy in the final state, including Ω and ϕ!
- Low p_T - mass ordering, consistency with hydrodynamic calculations
- Higher p_T – NCQ scaling

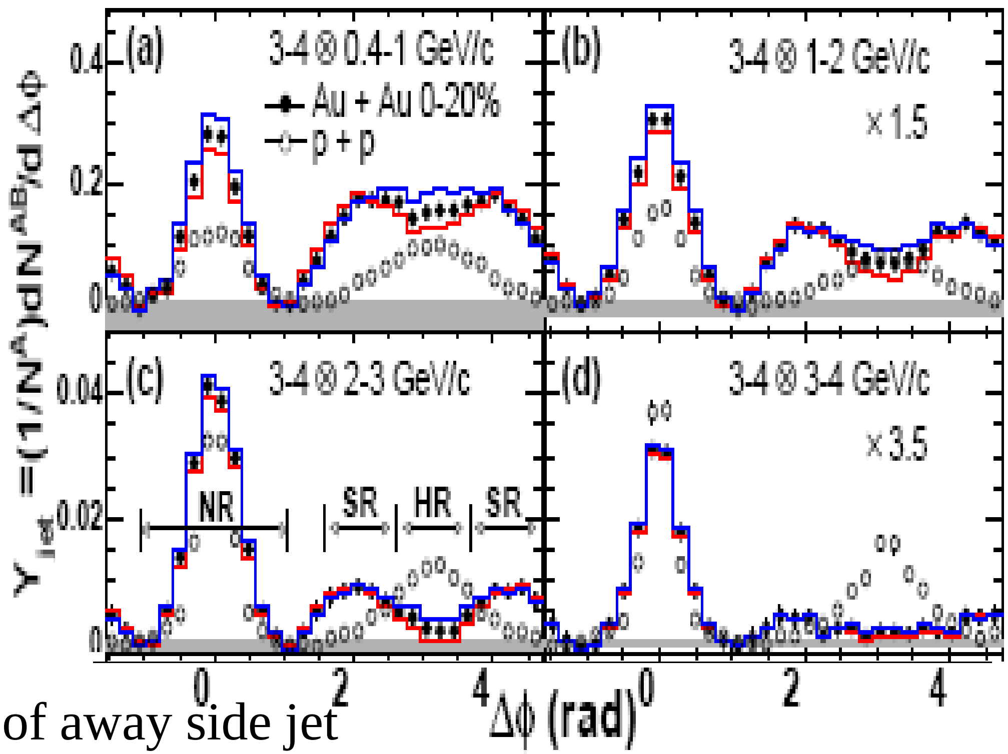
Jet Quenching

trigger: $4 < p_T(\text{trig}) < 6$ GeV
associated: $2 < p_T < p_T(\text{trig})$

STAR:
PRL 90, 082302 (2003)



PHENIX
PRC 78, 014901 (2008)

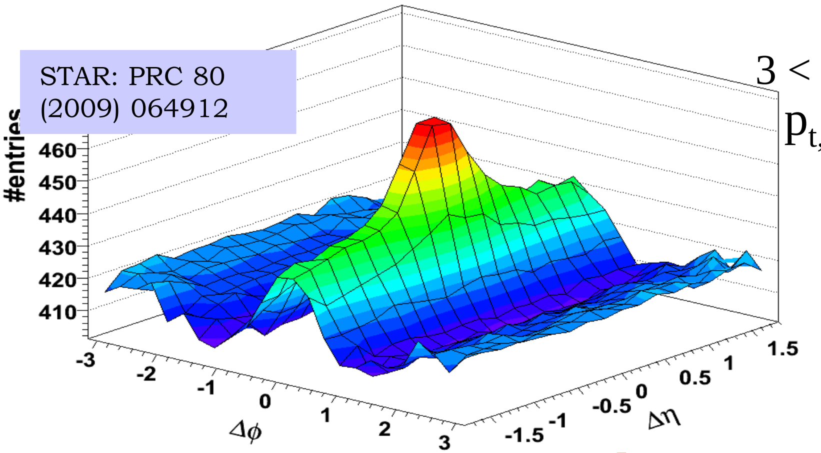


- The discovery plot: disappearance of away side jet
- Associated p_T dependence:
  - Recovering the away side
  - Development of "double-humps" or "shoulders"

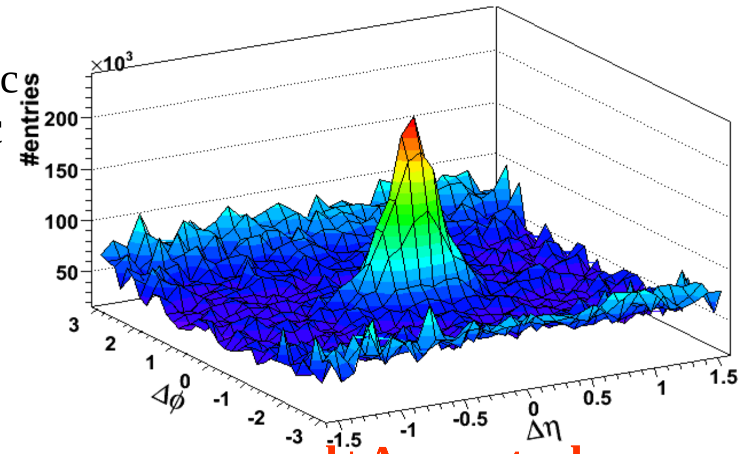
Correlations in 2D – The Ridge

STAR: PRC 80 (2009) 064912

$3 < p_{T,trigger} < 4$ GeV/c
$p_{t,assoc.} > 2$ GeV/c



Au+Au central



d+Au central

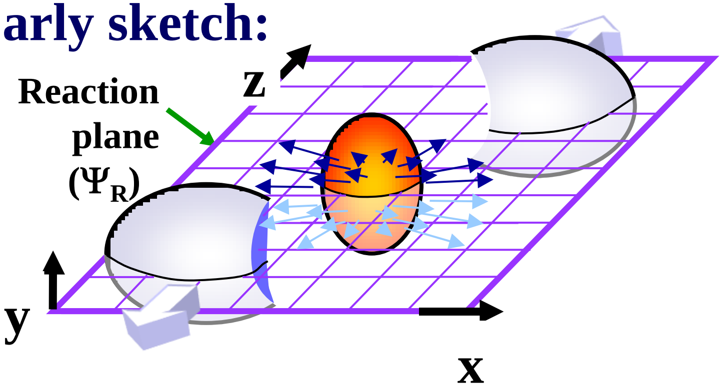
From not-so-recent results:

- Ridge correlated with jet direction
- Approximately independent of Δη and trigger p_T
- Extends to acceptance boundary and to the highest trigger p_T measured
- Production mechanisms for jet and ridge differ

Until recent, the ridge open question:
manifestation of the jet quenching or coincidental nuisance?

Azimuthal Anisotropy

Early sketch:

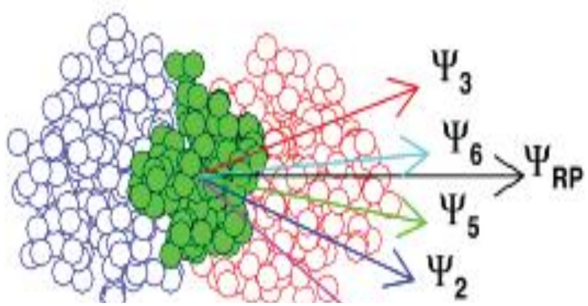


$$\frac{d^3N}{p_T dp_T d\eta d\phi} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T d\eta}\left(1+\sum_{k=1}^{\infty} 2v_{n=km}(p_T,\eta)\cos\left[n(\phi-\Psi_m)\right]\right)$$

Motivation for "v_n fit":

- Cross-talk between data and theory - transport model predictions

Glauber-based picture:



$$\Psi_m^{pp} = \frac{1}{m}\tan^{-1}\left\{\frac{\sum_{i=1}^{N_{part}} r_i^m \sin(m\phi_i)}{\sum_{i=1}^{N_{part}} r_i^m \cos(m\phi_i)}\right\} - \frac{\pi}{m}$$

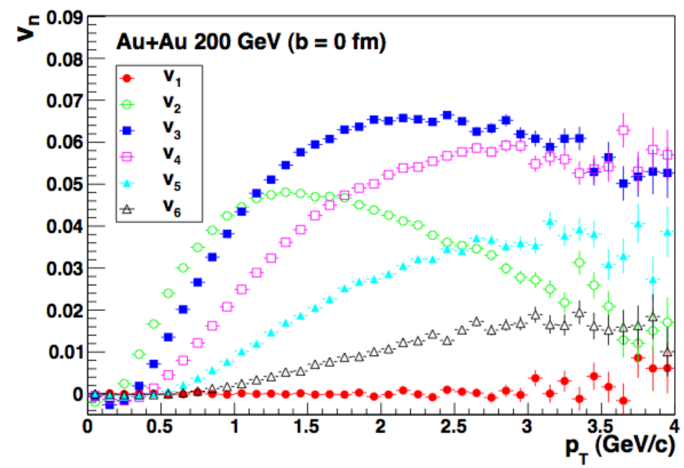
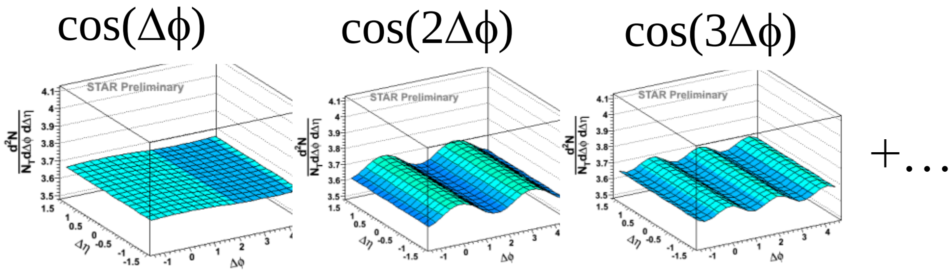


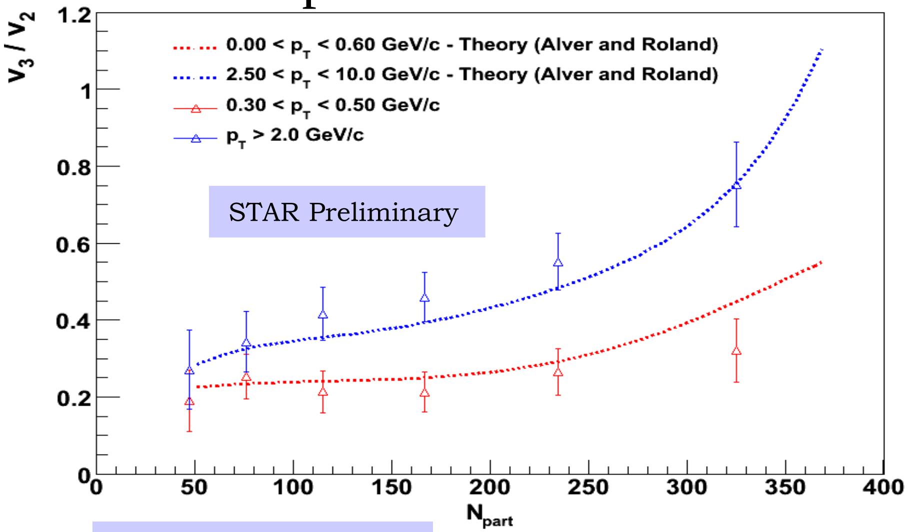
FIG. 2: (Color online) Azimuthal anisotropies of hadron spectra $v_n(p_T)$ ($n = 1 - 6$) in central ($b = 0$) $Au + Au$ collisions at $\sqrt{s} = 200$ GeV from AMPT model calculation.

Long Range Correlation – Fourier Fits

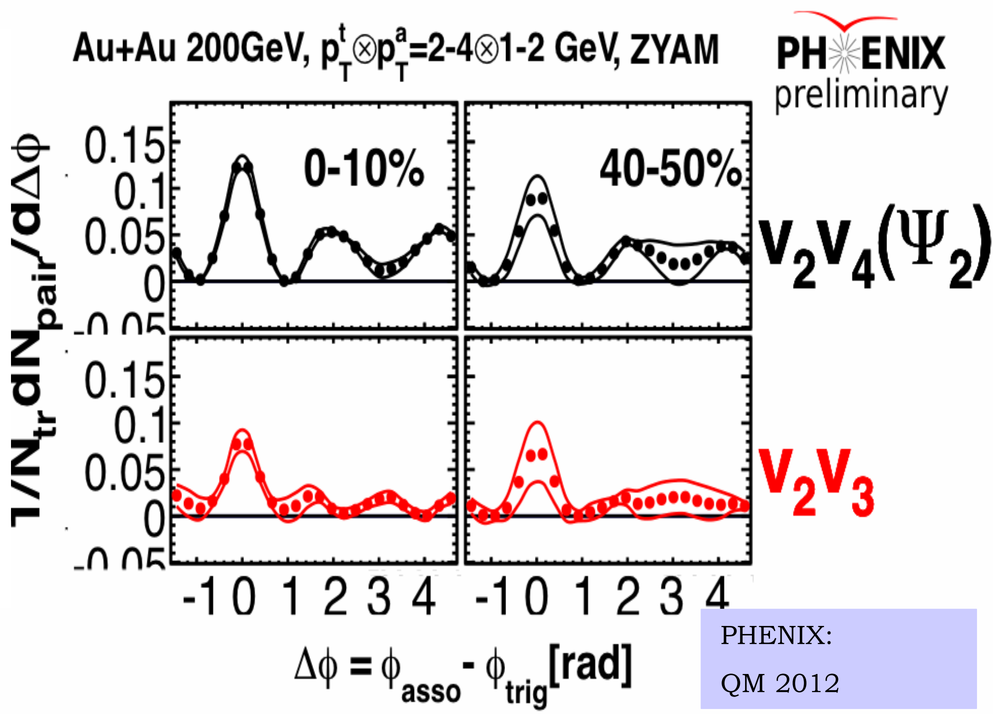


- Long range correlations near- and away from the trigger could be simultaneously described via higher order v_n terms

- Comparison with flow:



Alver and Roland,
PRC 81, 054905 (2010)



PHENIX:
QM 2012

All in Hydro?

200 GeV Au+Au collisions

Excellent agreement for PHENIX and STAR:

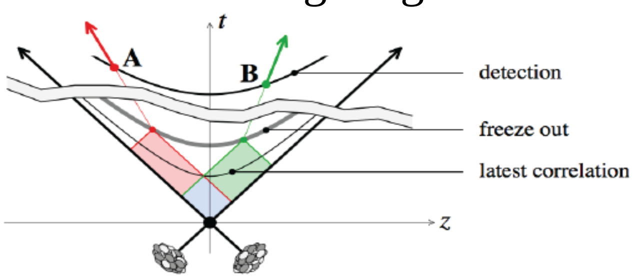
- $v_3 \sim v_2$ in central events
- v_3 and higher harmonics ~ centrality independent → origin in fluctuations

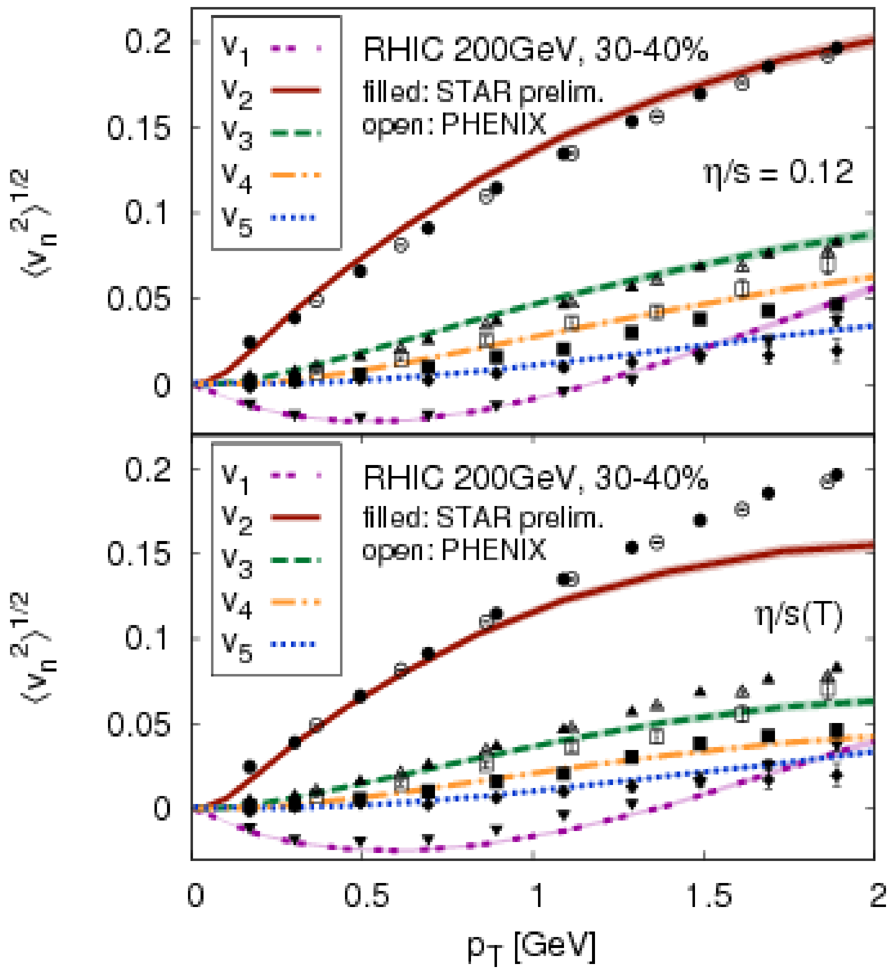
Centrality and p_T dependences of v_n well reproduced by hydro calculations

Precision measurements constrain η/s

What's the catch?

- Unresolved issue of fast thermalization
- Long range correlations probe ~10^{-24}s

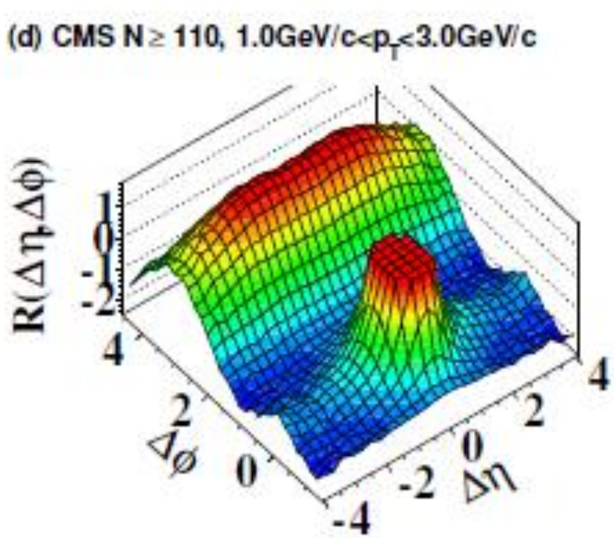




PRL 110, 012302 (2013)

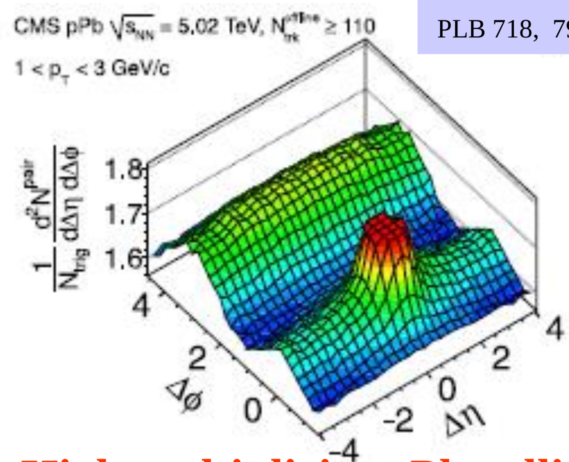
Hot Topic: dA (pA) Collisions

- Renewed attention to the "reference"
  - Understanding cold nuclear effects
  - Understanding initial state in HI collisions



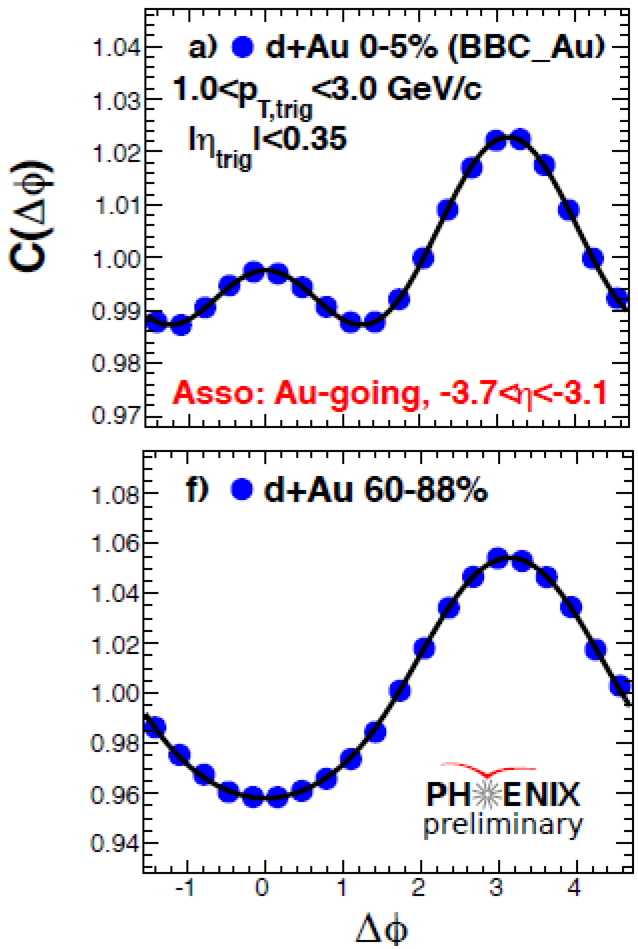
High multiplicity pp collisions

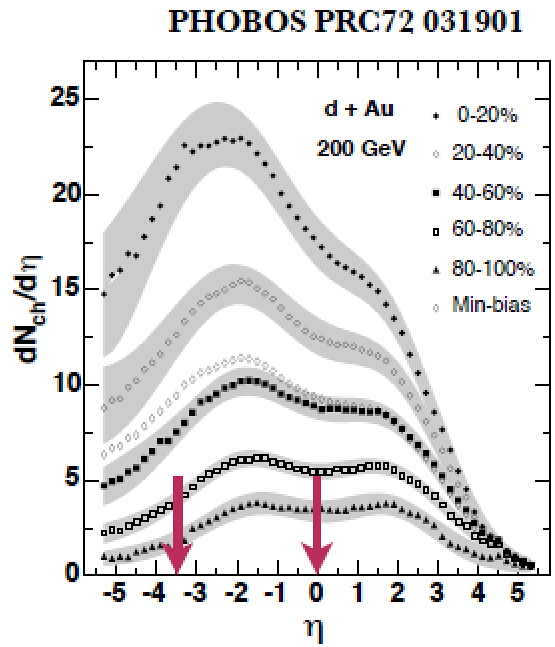
CMS
PLB 718, 795 (2013)



High multiplicity pPb collisions

PHENIX: d+Au Correlations

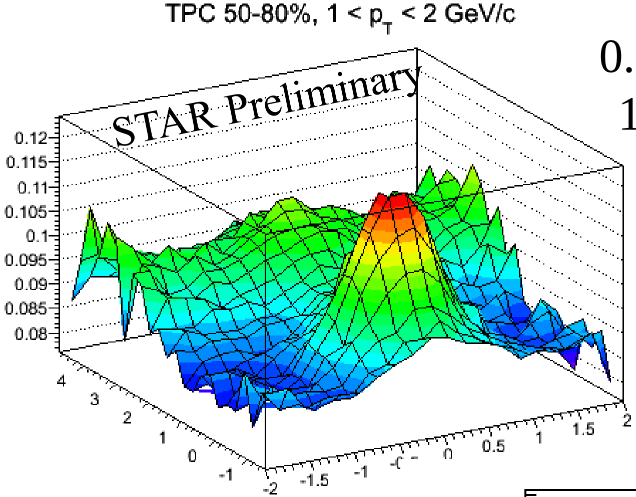




A. Sickles
MIT pA Workshop

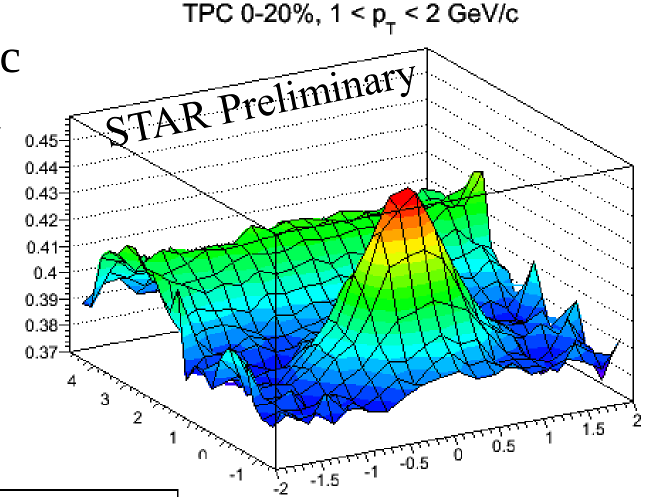
Ridge in high multiplicity d+Au collisions!

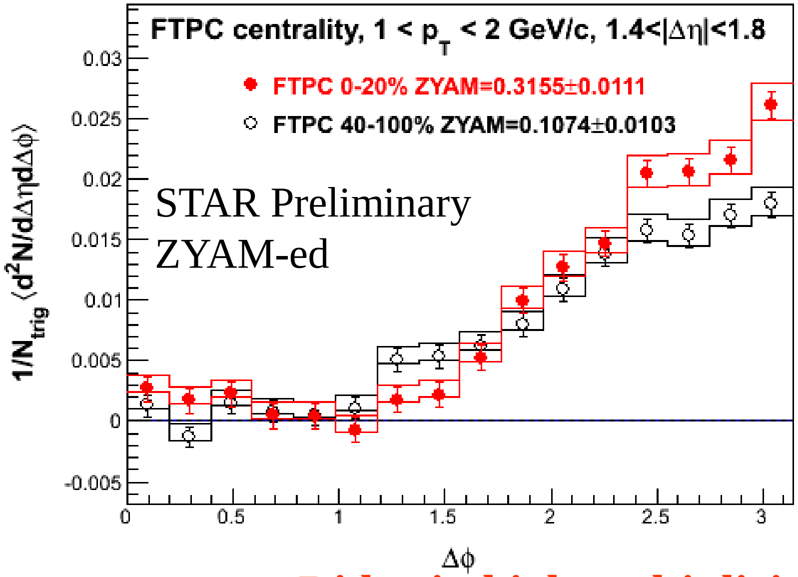
STAR: d+Au Correlations



$0.15 < p_T^{trig} < 3$ GeV/c
$1 < p_T^{assoc} < 2$ GeV/c

TPC mult.
|η|<1
as centrality



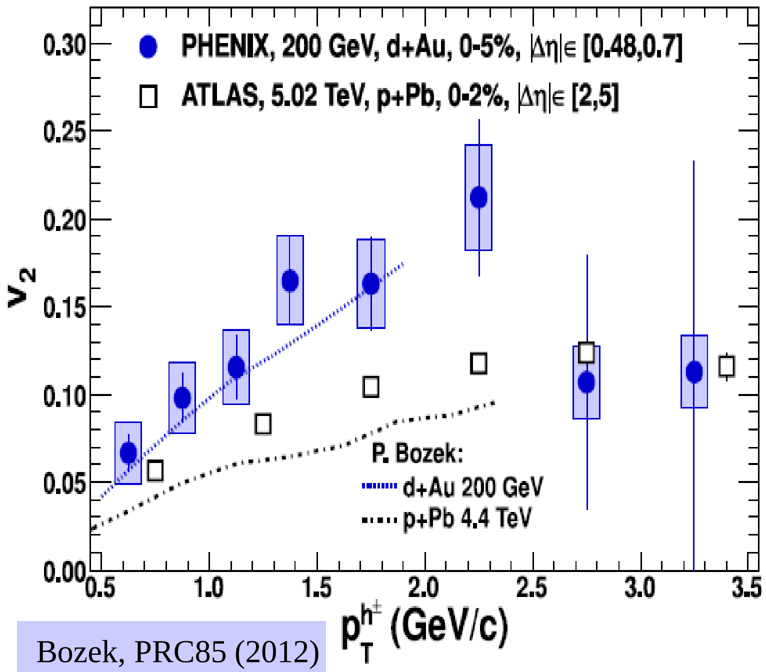


F. Wang
RBRC Workshop

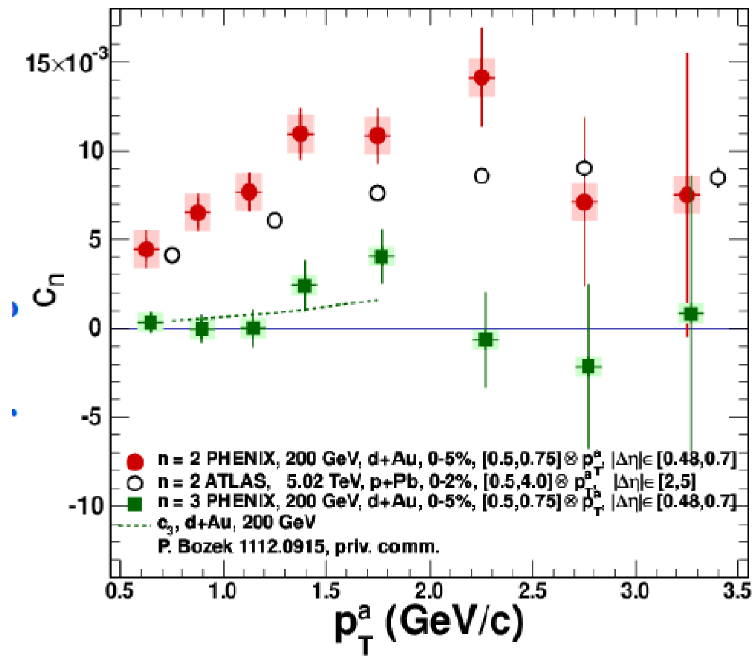
Ridge in high multiplicity d+Au collisions?

What is Ridge in d+Au?

PHENIX, arXiv:1303.1794



Bozek, PRC85 (2012)

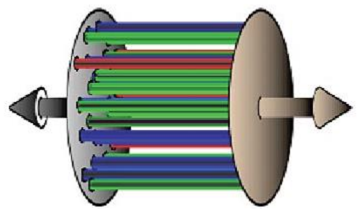


- d+Au ridge consistent with hydro predictions?
- v_2/v_3 depend strongly on initial state

Initial vs. Final State Effects

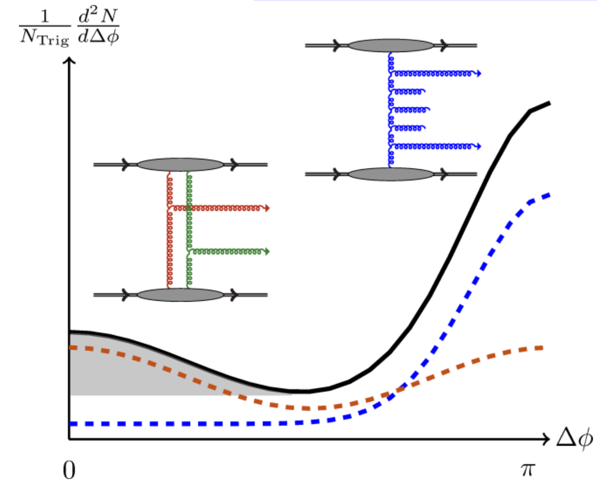
- Are we back to the drawing board?
- **CGC/Glasma:**

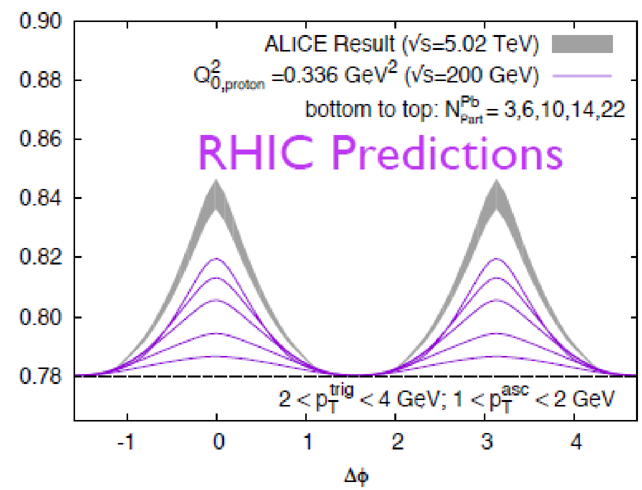
  Weak coupling, high intensity color fields



  - Long-range correlations – induced by color fluctuations
  - High multiplicity events probe rare gluon configurations

Dusling and Venugopalan, arXiv:1302.7018

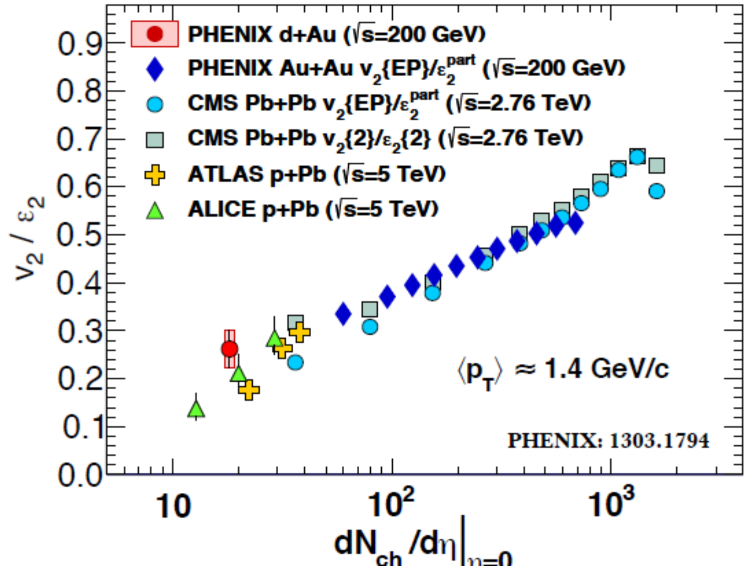




- Describes multiplicity in pA, dA, AA
- Describes v_n for different AA centralities at RHIC and LHC
- A factor of 2 below data on v_n in pPb(?)

Summary

- PHENIX and STAR Au+Au results:
  - Quantitative studies of jet quenching
  - Relevance of partonic DoF
  - Higher order anisotropies from initial state fluctuations



Common trend for different systems?

- Ridge correlations in d+Au

  (needs resolution between the experiments)

- Systematic measurements of v_2/v_3 p_T, energy and centrality dependence should address the relevance of initial and/or final state effects