STAR: Characterizing Hot Quark Matter

(Highlighting STAR's Quark Matter 2012 Results)

G. Van Buren
(Brookhaven National Laboratory)
for the STAR Collaboration

Diffraction 2012 Workshop

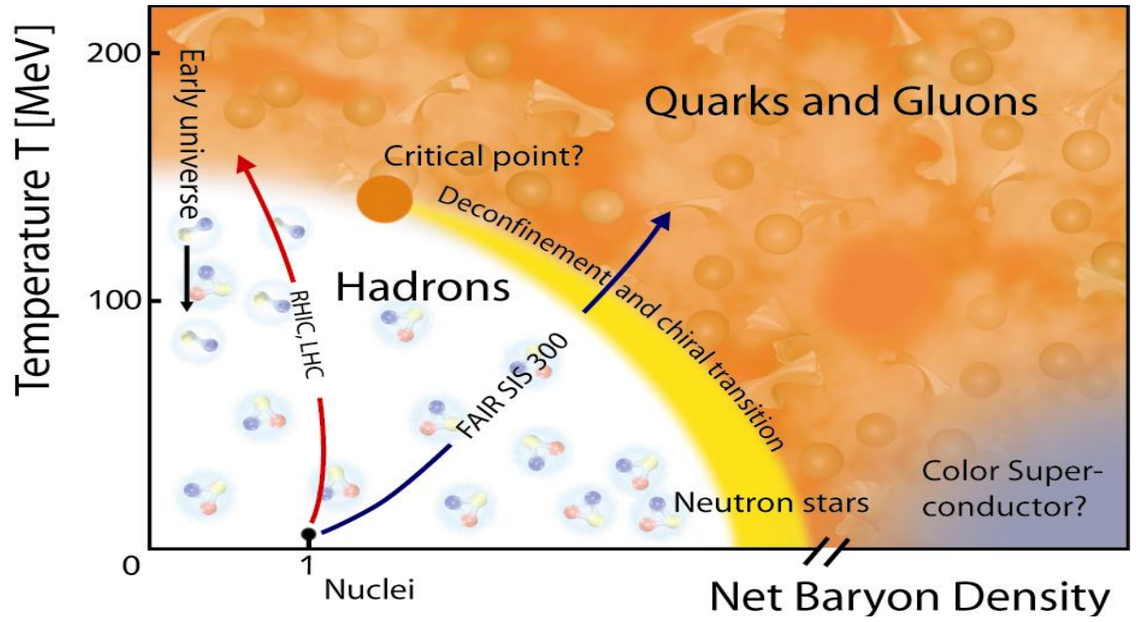
BROOKHAVEN NATIONAL LABORATORY

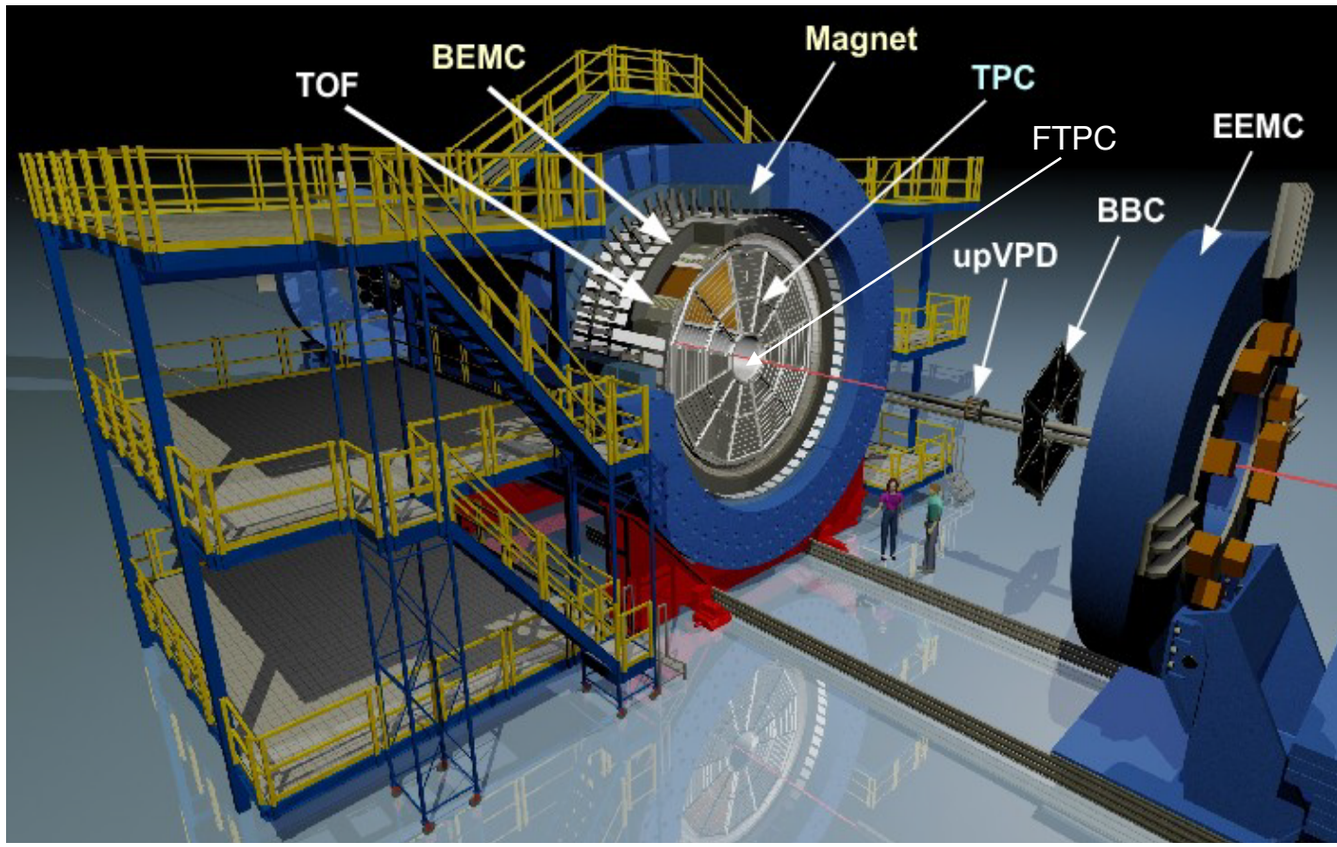
Office of Science
U.S. DEPARTMENT OF ENERGY

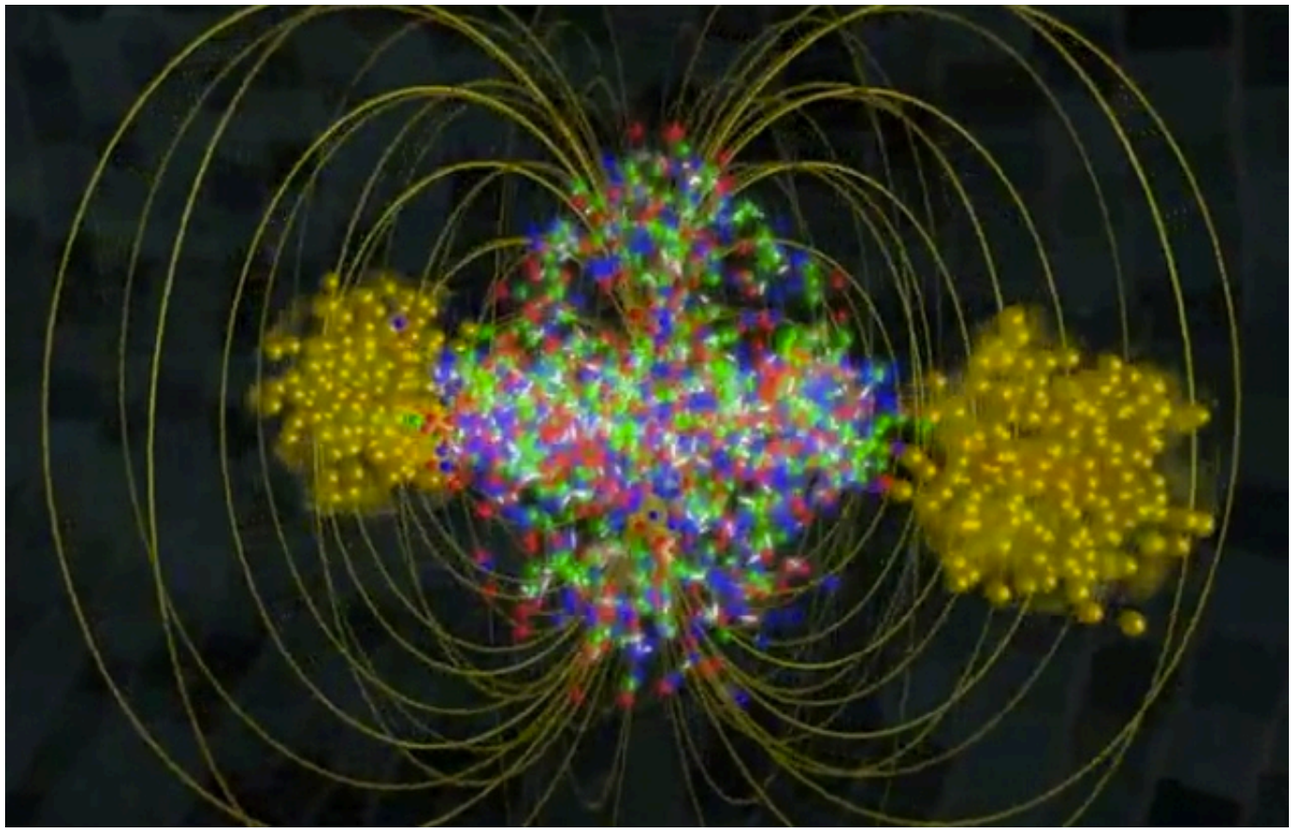
Outline & Intro to STAR

- Exploring hot quark matter
  - Signatures of QGP
  - New observations
- Exploring phase structure
  - Scan along the boundary
  - Search for a critical point

- Important pieces
  - RHIC: versatile collider for species, energies, polarization
  - STAR: large mid-rapidity acceptance with calorimetry and tracking with PID in a solenoidal magnetic field

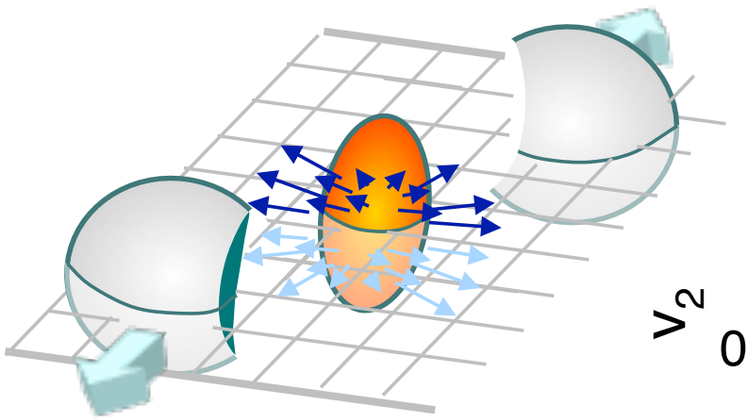






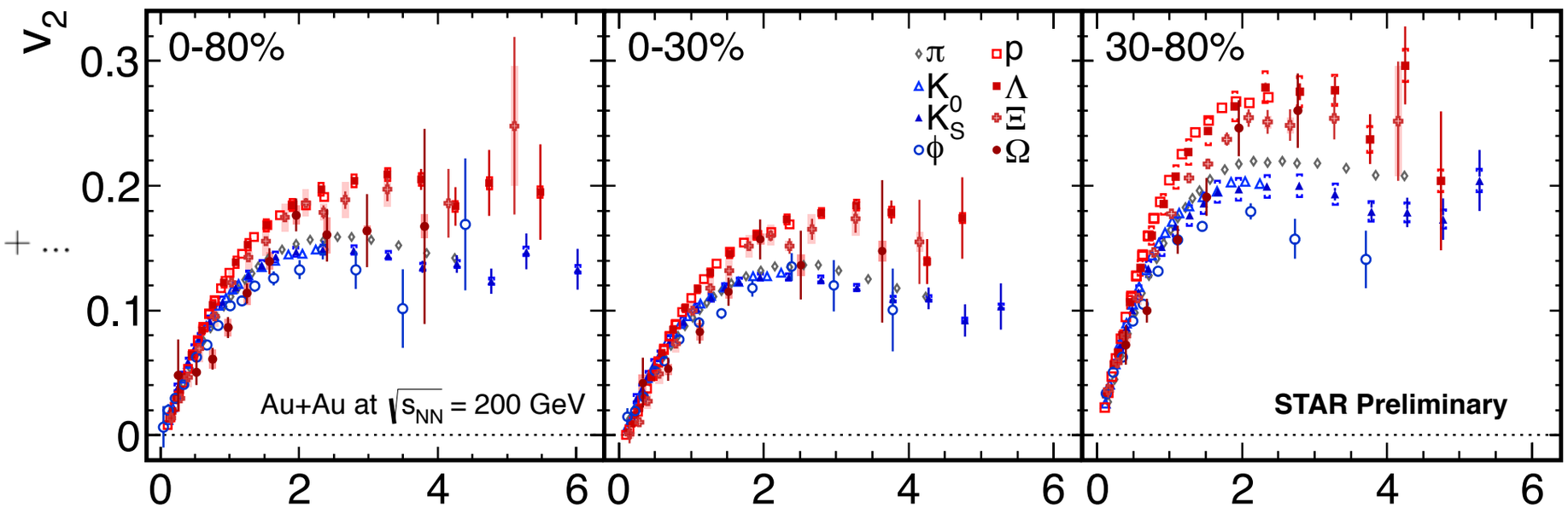
Hot QCD Matter

Partonic Collectivity

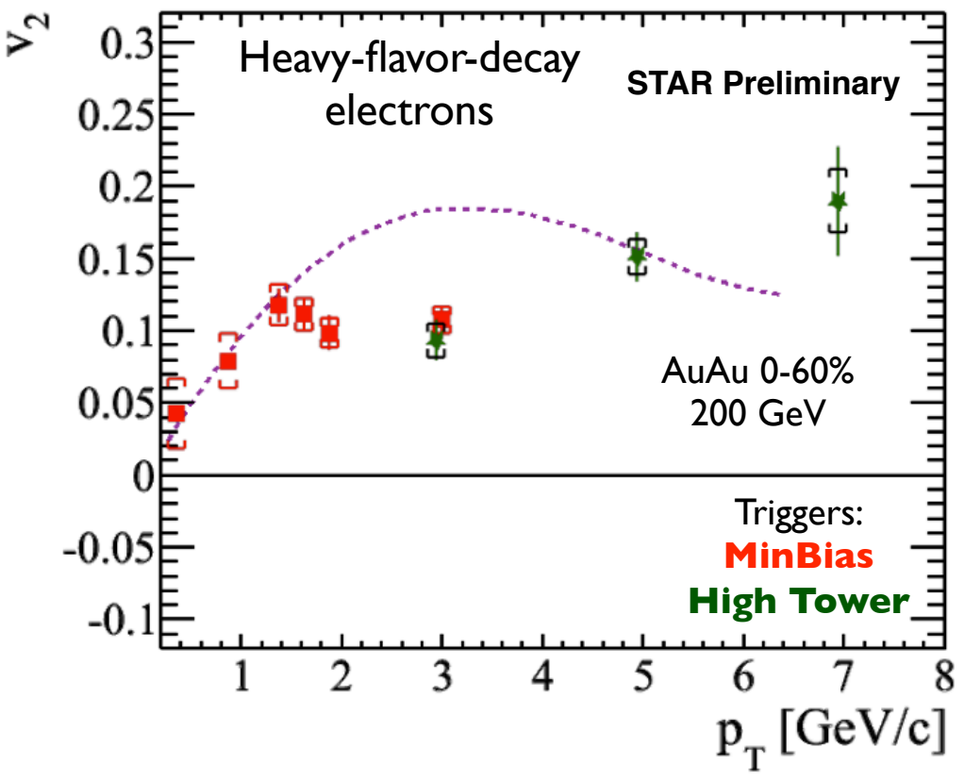


$$\frac{dN}{d\varphi} \propto 1 + 2v_2 \cos[2(\varphi - \psi_R)] + \ldots$$

v_2 = 2nd harmonic coef. from Fourier decomp. of azimuthal momentum distribution



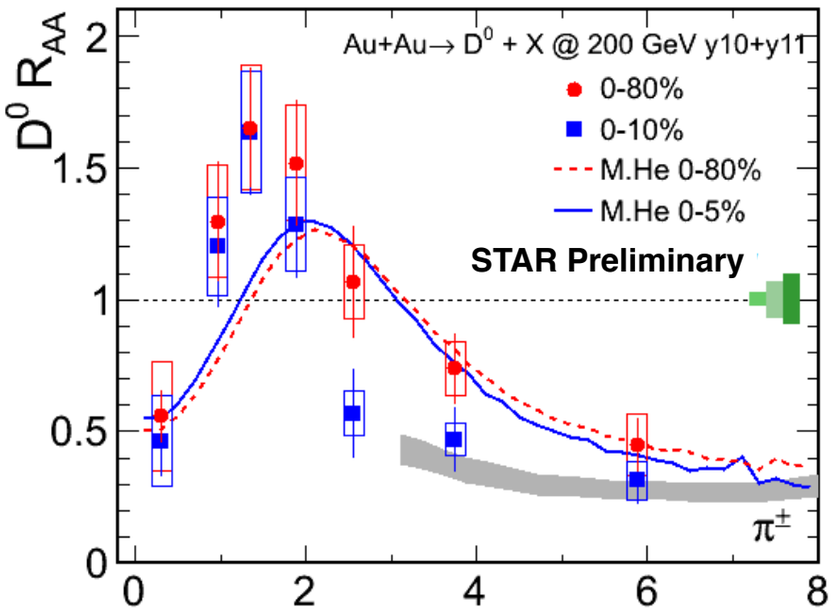
- Central collisions show baryon/meson groupings of v_2
  - ϕ was a key piece: a heavy meson
  - Number-of-constituent-quarks (NCQ) scaling
  - Species independence of scaling at low transverse momenta points to pre-hadronic phenomenon

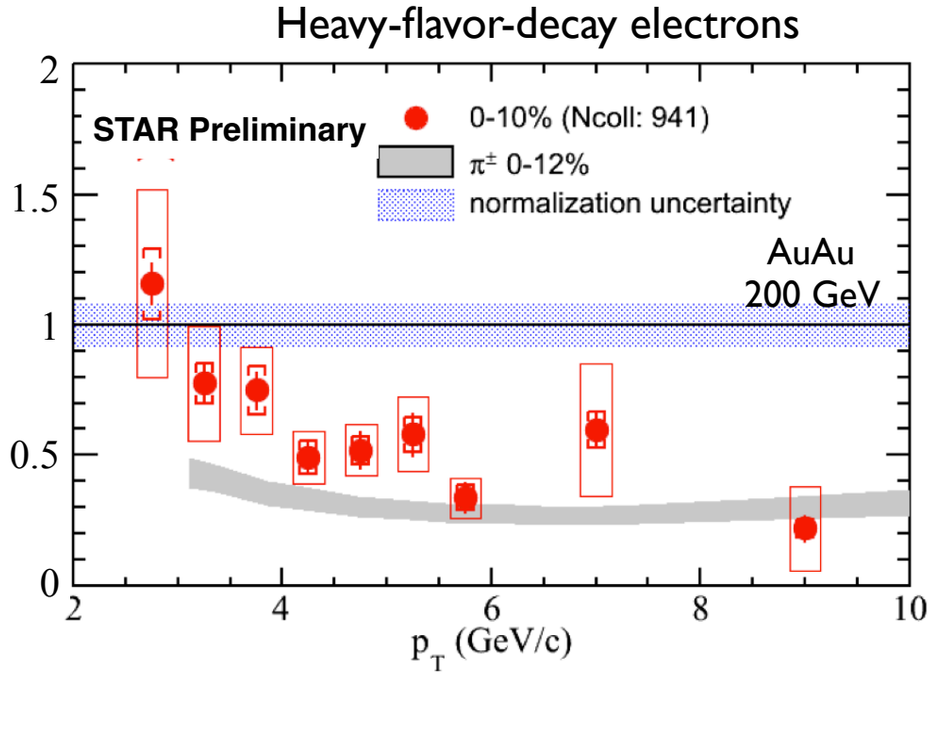


Strongly Interacting Medium

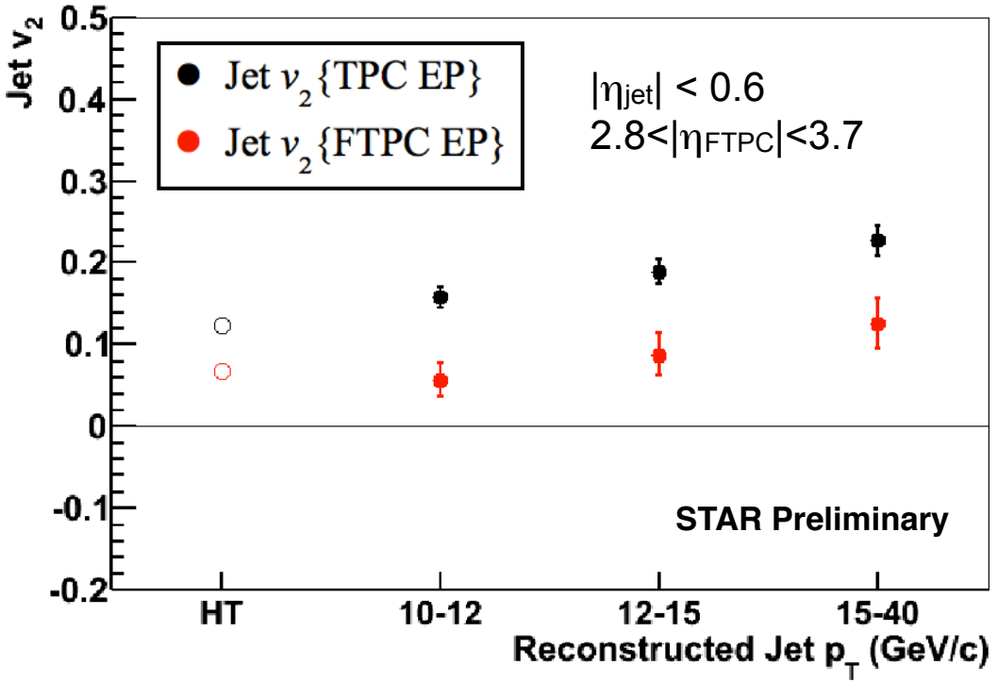
$$R_{AA} = \frac{\sigma_{NN}^{\text{inel}}}{N_{\text{bin}}^{AA}} \frac{d^2N_{AA}/dydp_T}{d^2\sigma_{pp}/dydp_T}$$

R_{AA} = ratio of yields in *AA* relative to *pp*, correcting for number of binary *NN* collisions

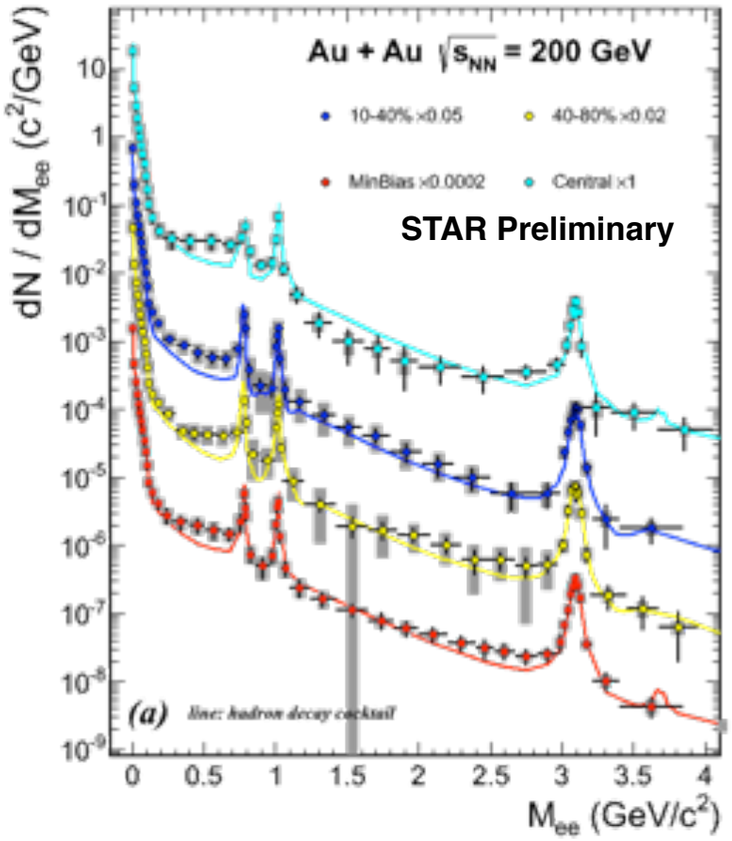


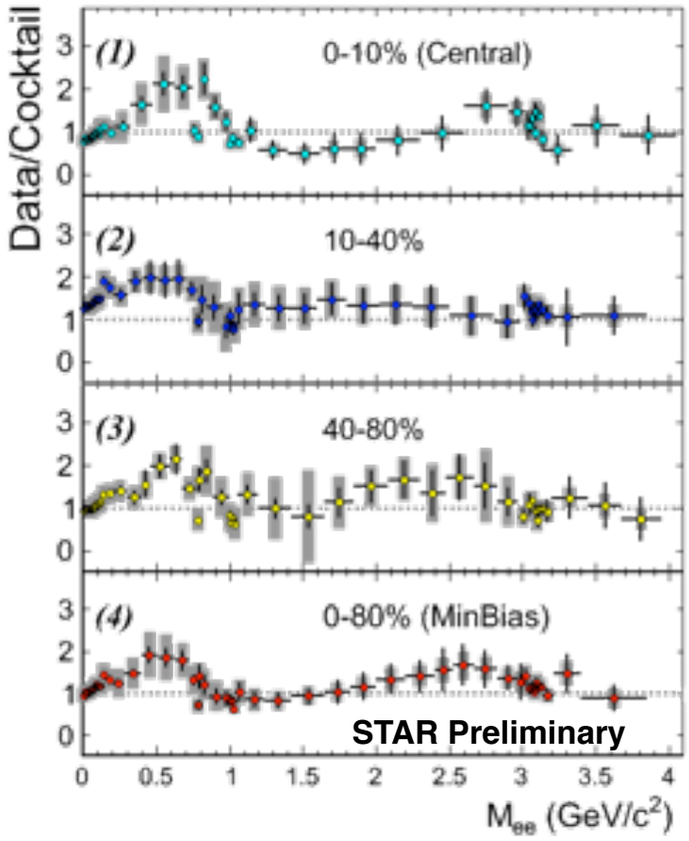


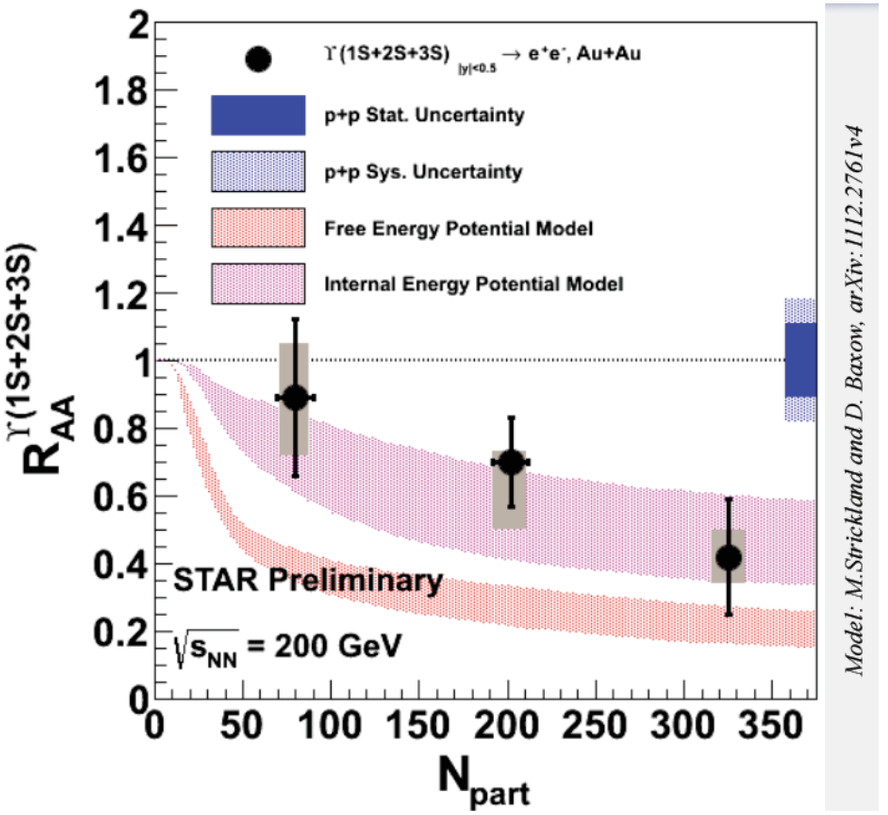
- Suppression of high momentum particles
  - Including heavy flavor
  - Correlation of suppression with reaction plane (i.e. path length)
- Assuming v_2 is hydro flow, together imply minimal shear viscosity (η/s)



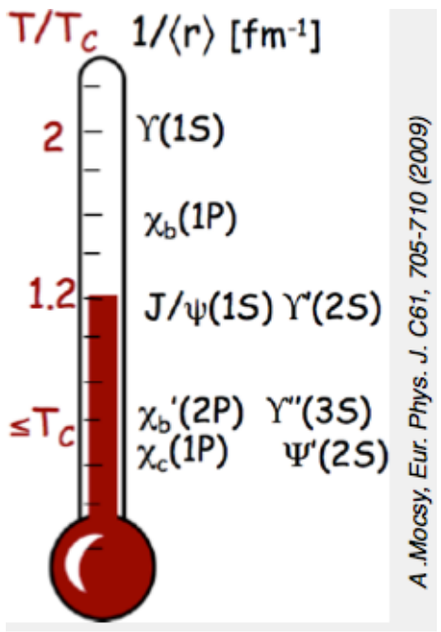
Effects on Resonances



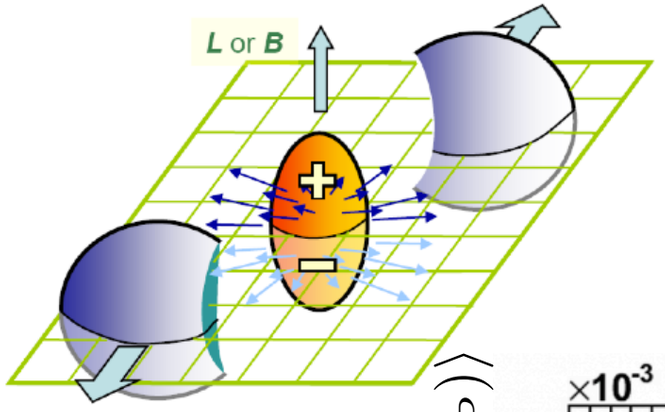


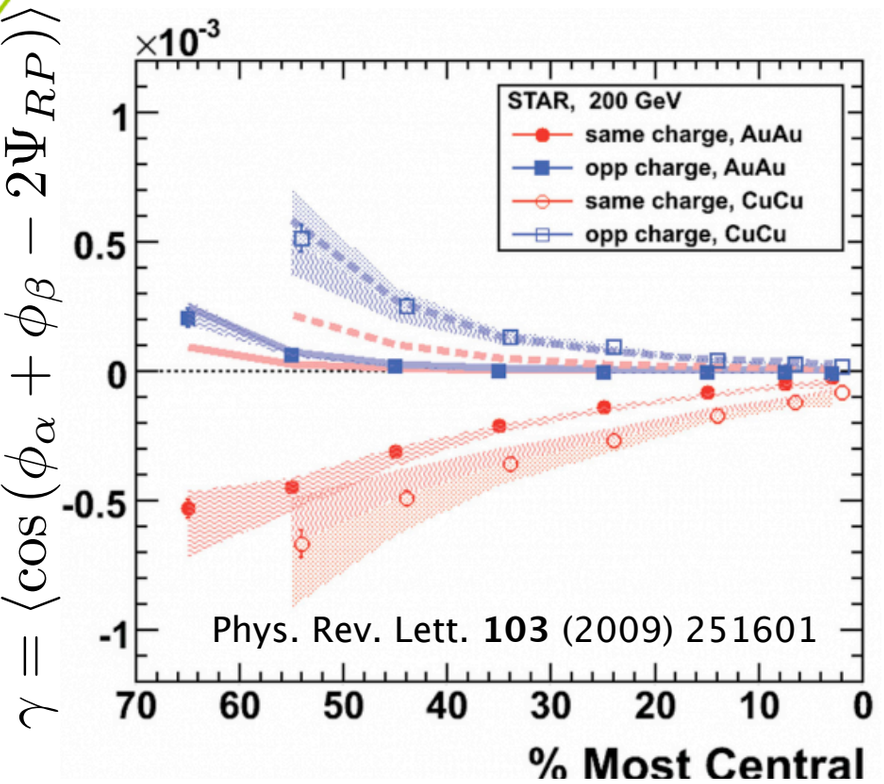


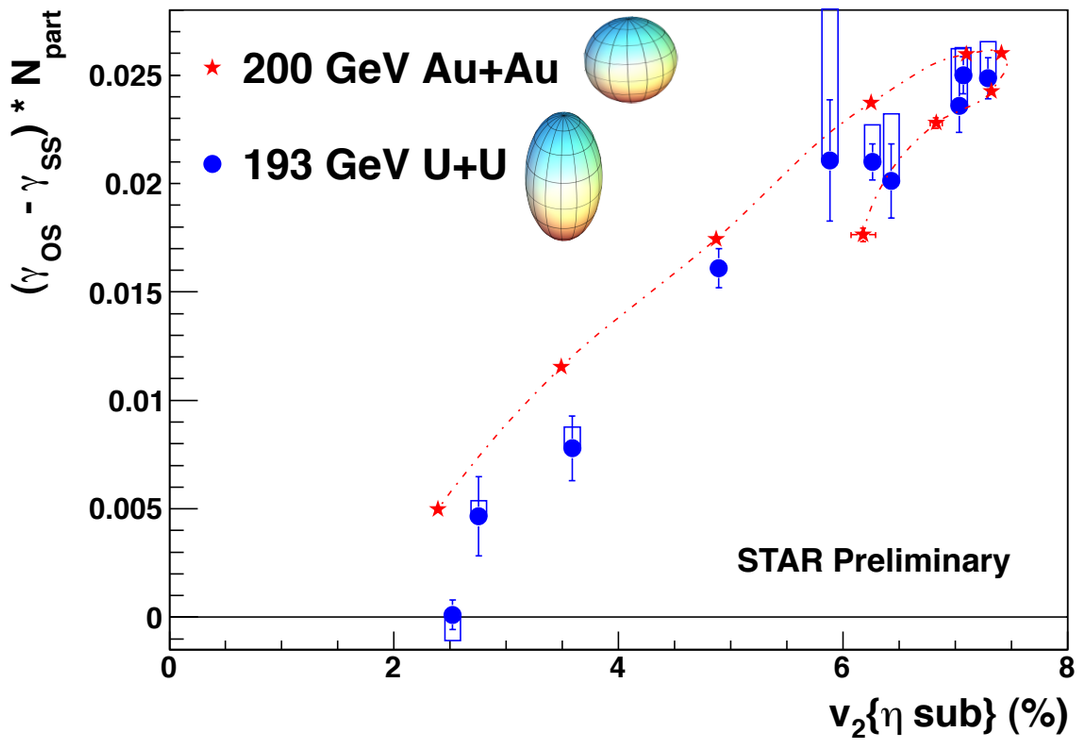
- Di-electron invariant mass spectrum enhanced at low mass compared to cocktail…for all centralities?
  - Consistent with broadening of the rho
- Suppression of Upsilon yields in central AA hints at melting of excited states (model dependent)



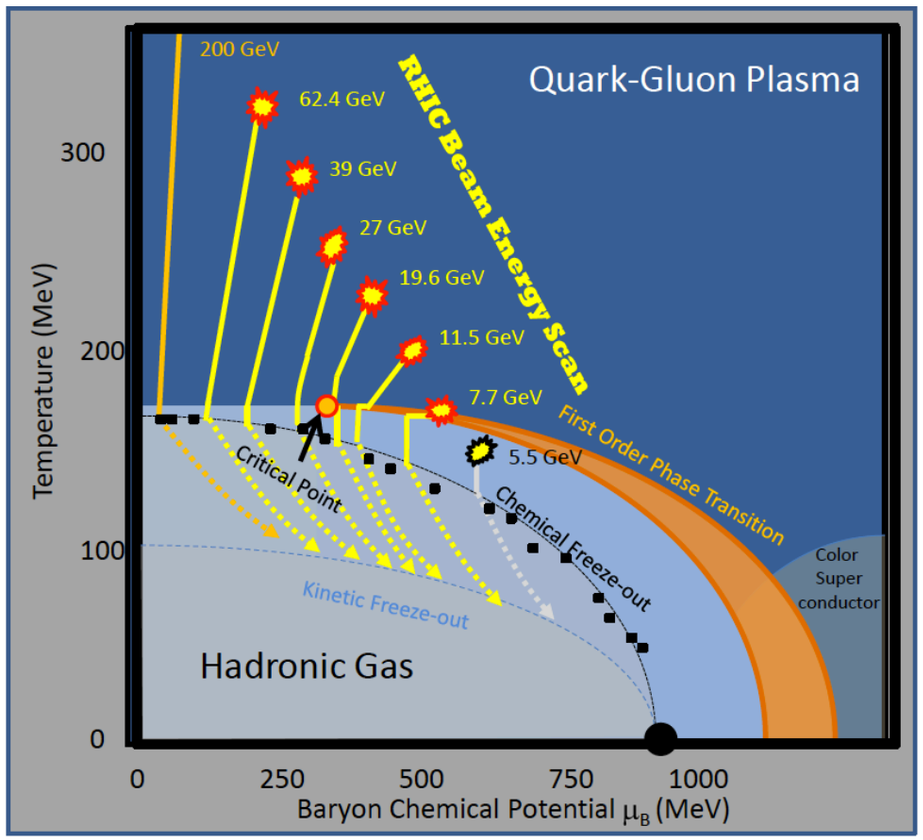
Local Parity Violation?

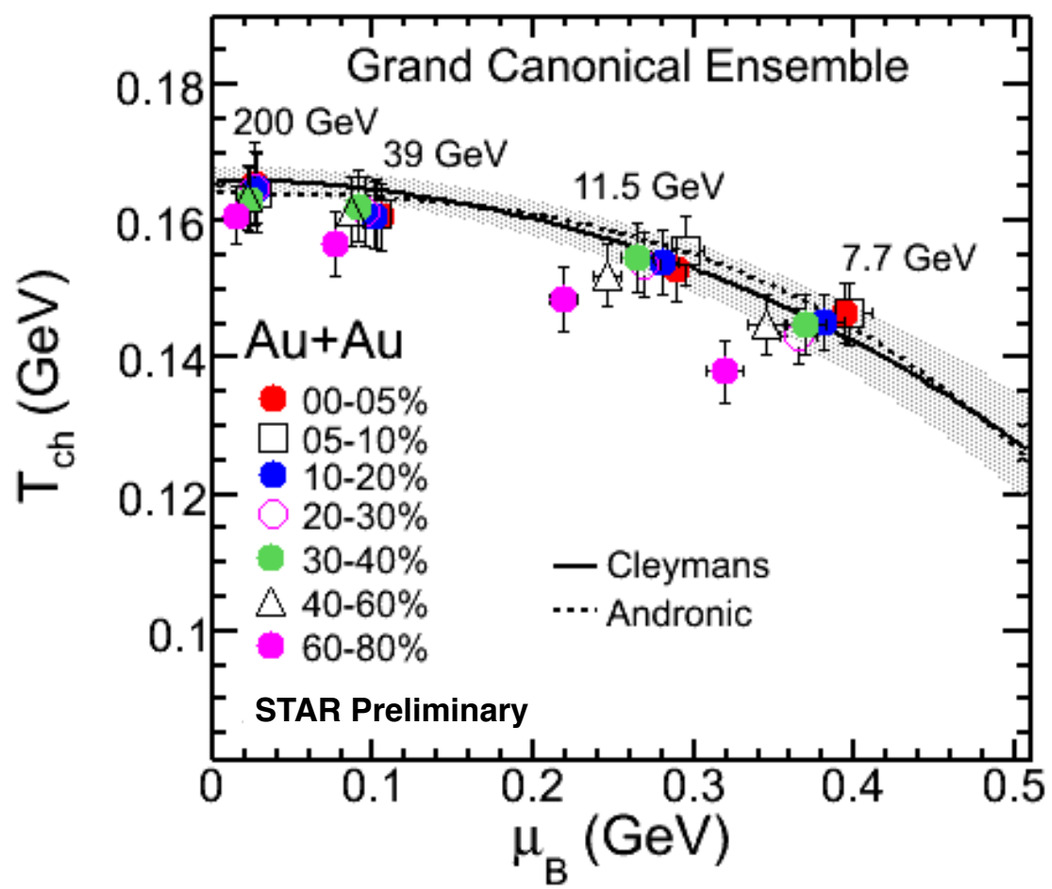






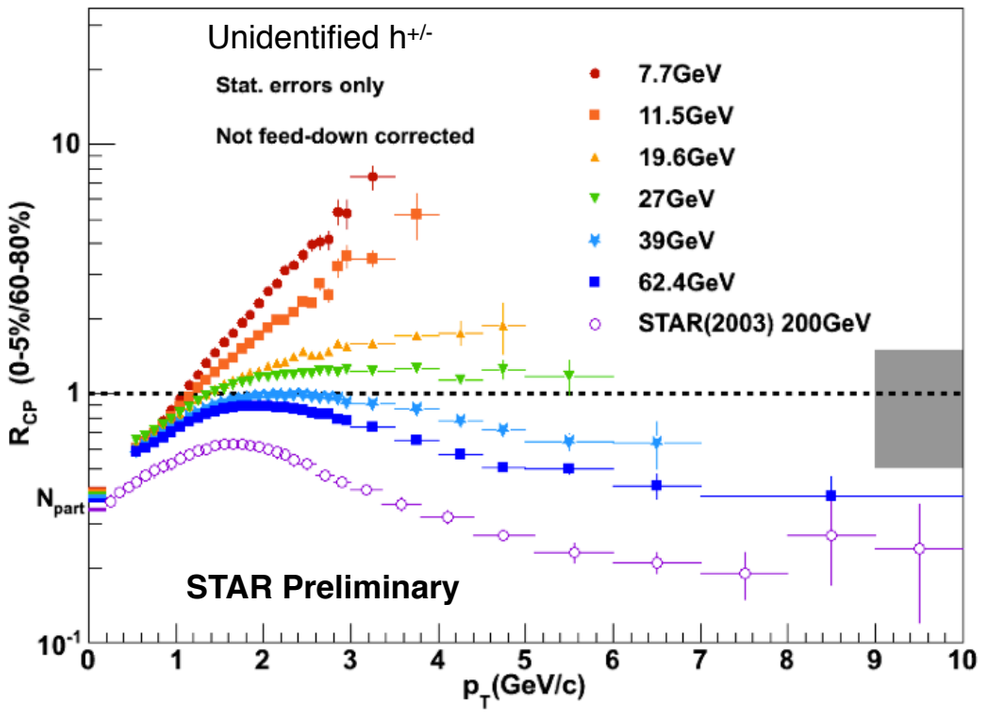
- Possible local parity violation consistency in separation of +/- charges (opposite directions) w.r.t. the reaction plane
- Central (completely overlapping) UU collisions test chiral magnetic effect against charge conservation with v_2
  - Separation consistent with zero, despite non-zero v_2 for 1% central

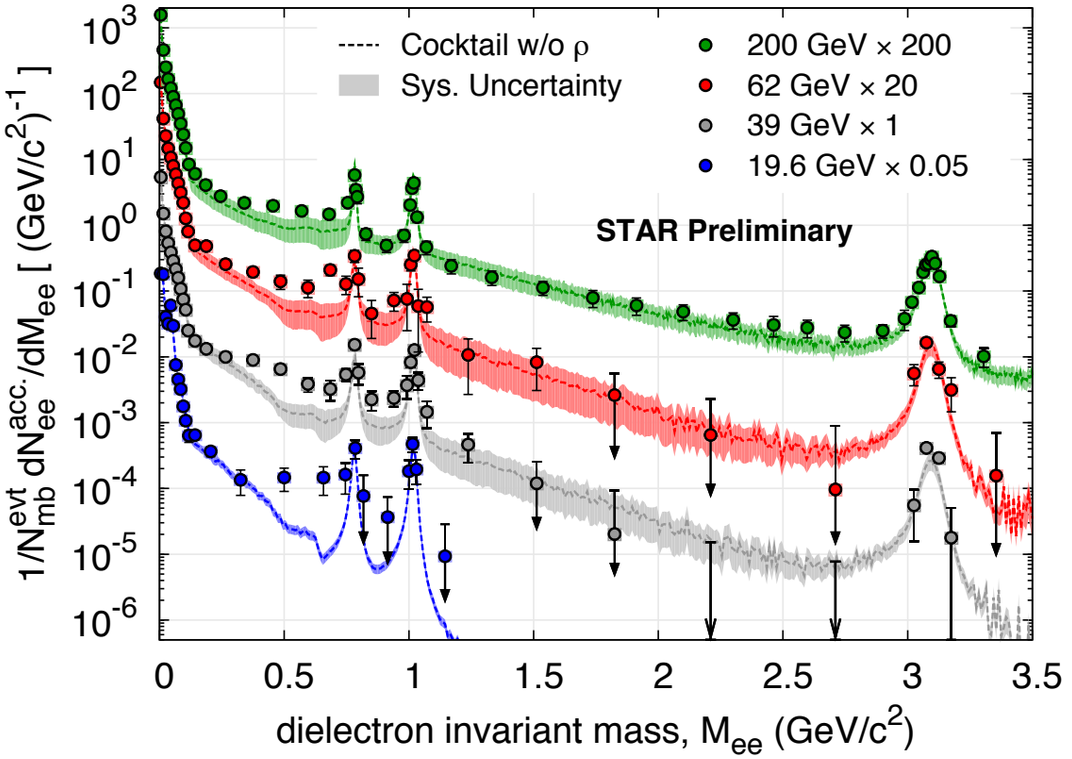




QCD Phase Structure

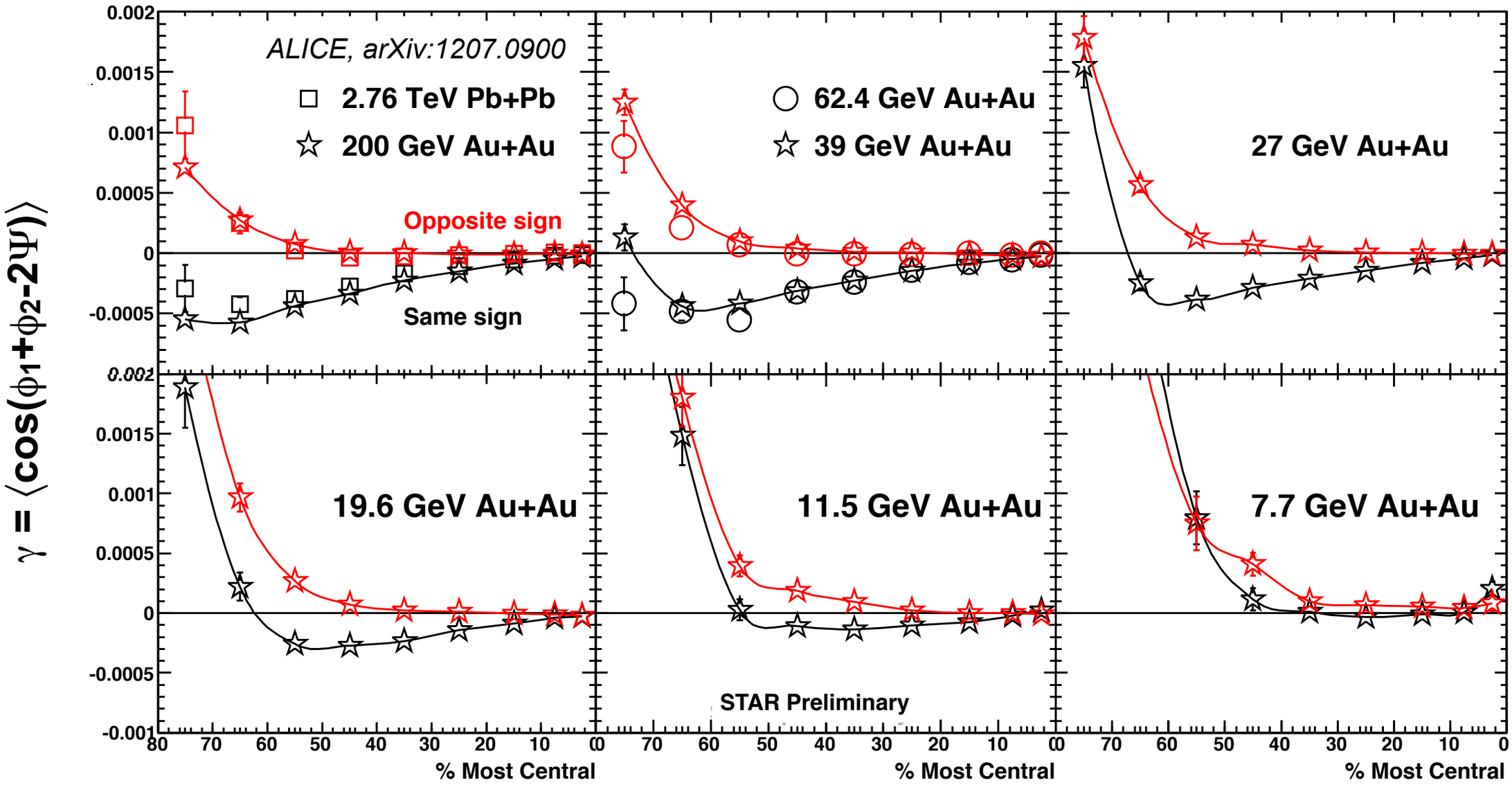
Medium Effects Evolution





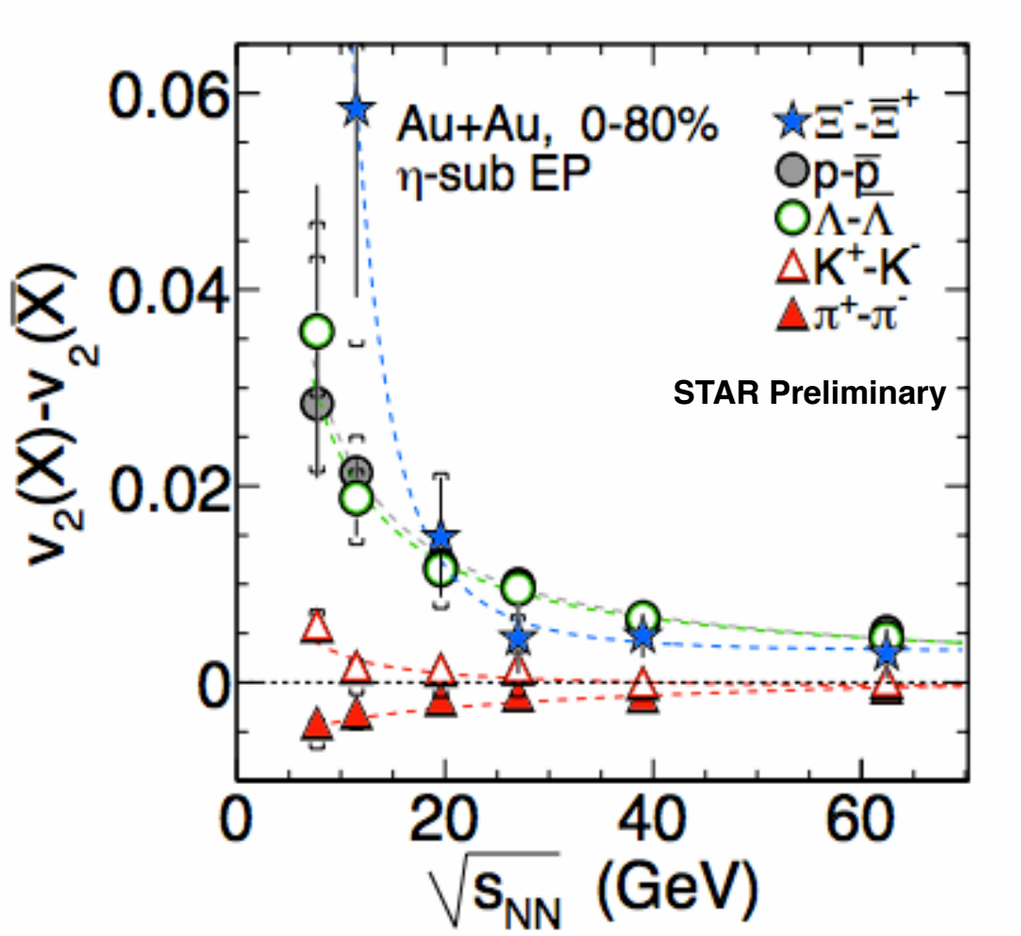
- Smooth high-p_T suppression trend, from "Cronin" enhancement at low collision energies to suppression at high energies
- Di-lepton low-mass enhancement consistent with rho broadening at all energies so far examined (insufficient statistics at low energies)
  - 19.6 GeV results consistent with Ceres at SPS

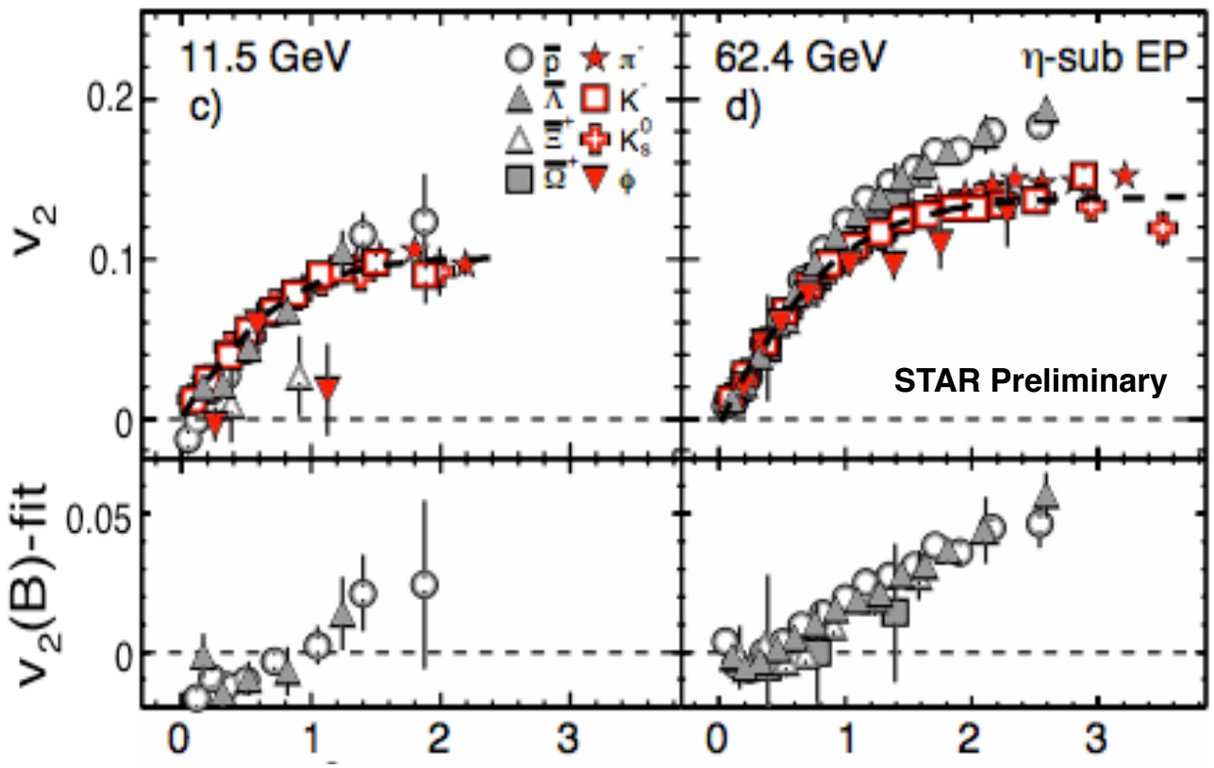
Charge Separation Evolution



- "Turn on" somewhere around 11-19 GeV
  - Possibly observing a threshold for the "Chiral Magnetic Effect"

Breakdown of NCQ Scaling

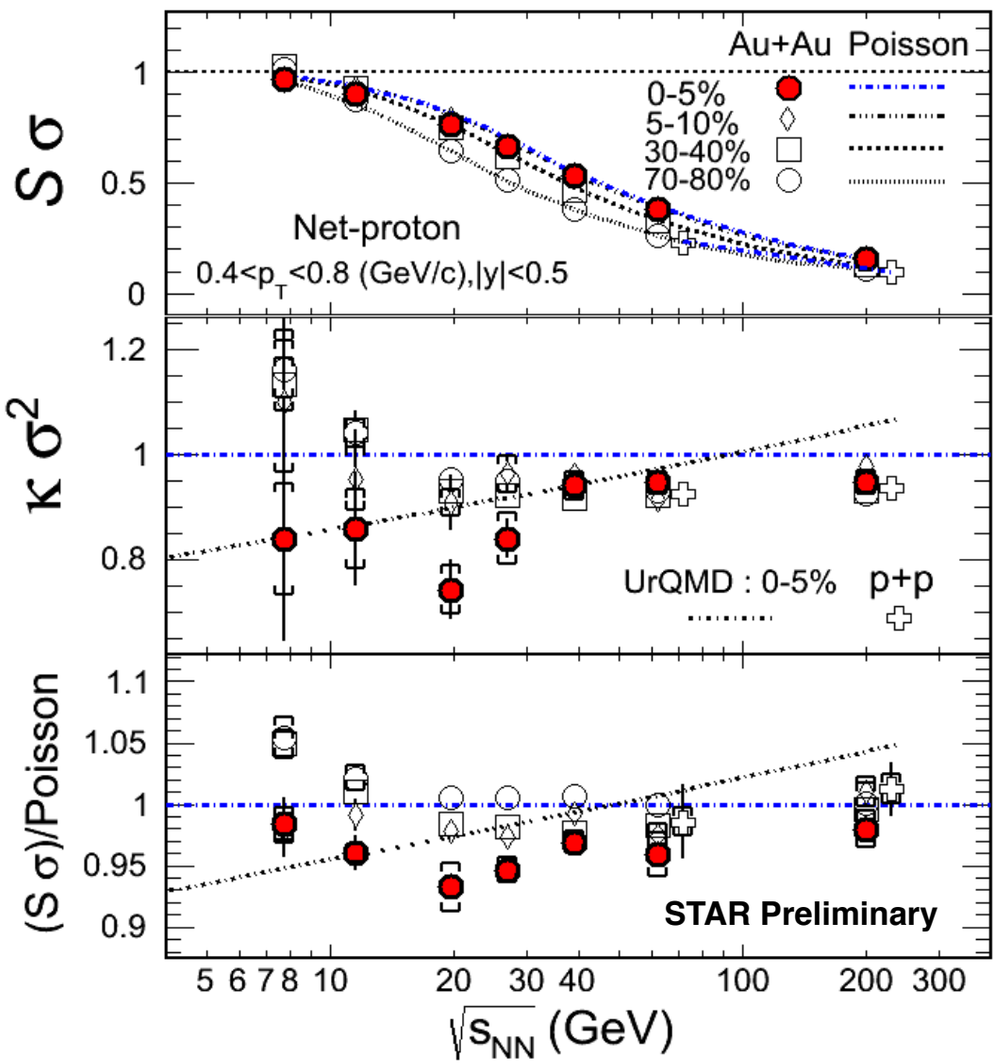




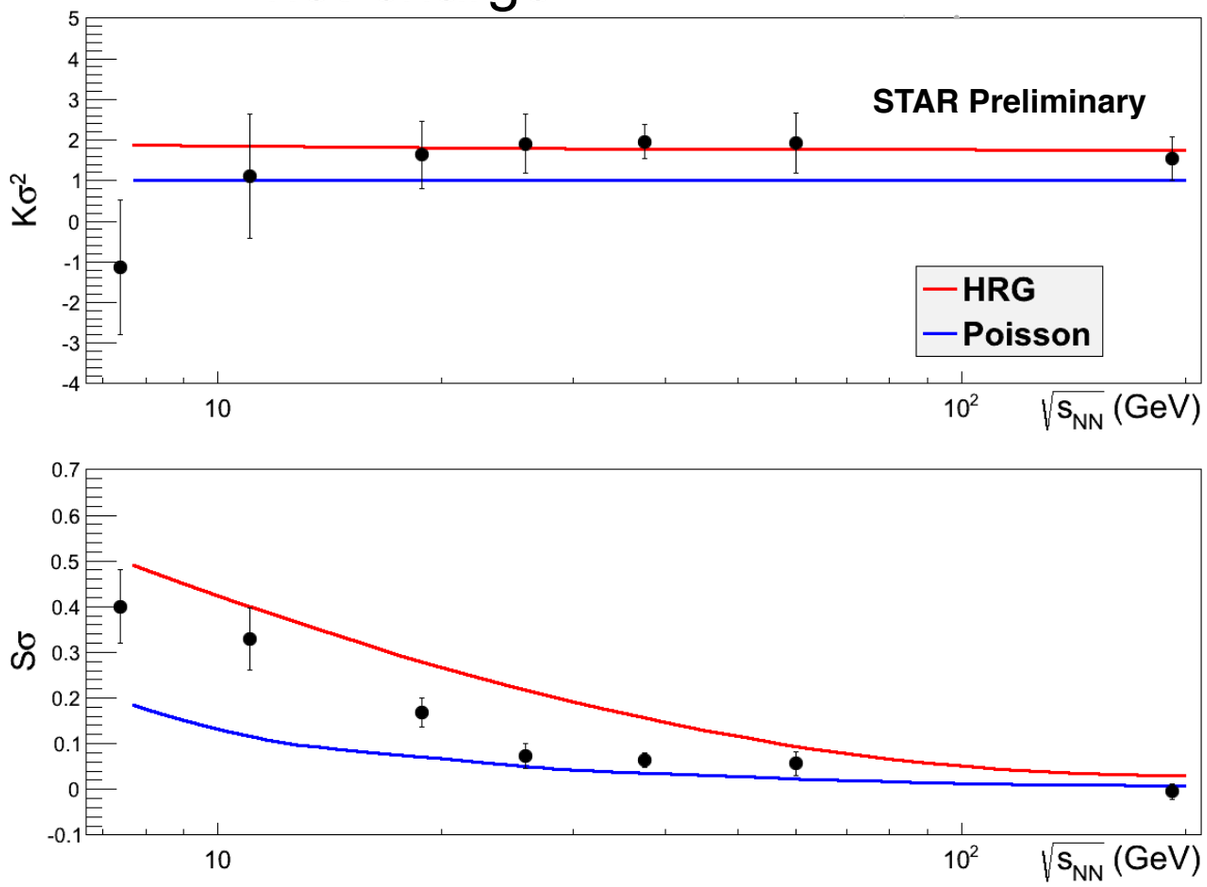
- Separation of v_2 for particles vs. antiparticles grows smoothly with decreasing collision energy
  - Baryon stopping contributions?
- Meson grouping breakdown clear by 11.5 GeV

Yield Fluctuations

net-protons



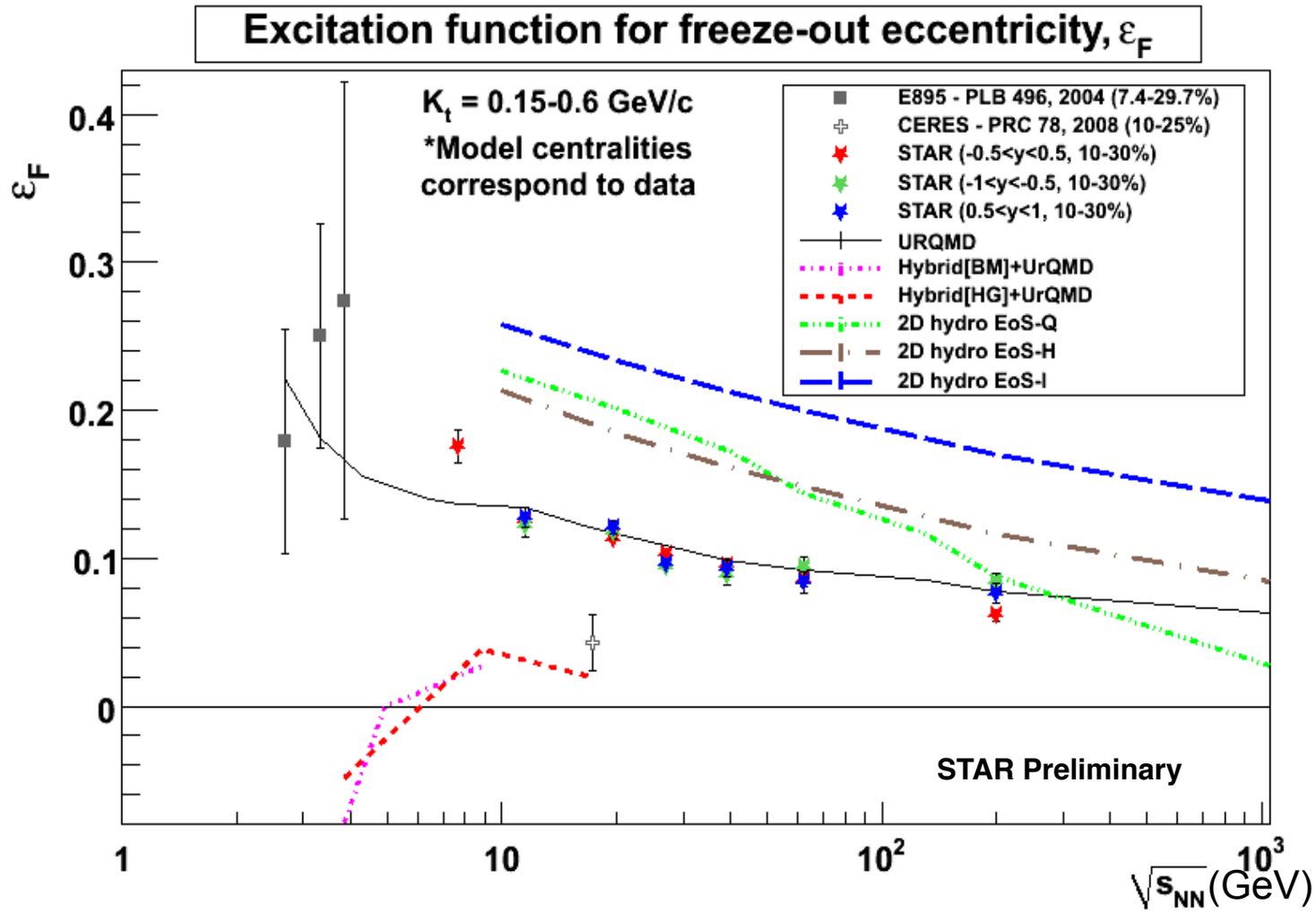
net-charge



$$\sigma^2 = \left\langle (N - \langle N \rangle)^2 \right\rangle, \; S = \left\langle (N - \langle N \rangle)^3 \right\rangle / \sigma^3$$
$$\kappa = \left\langle (N - \langle N \rangle)^4 \right\rangle / \sigma^4 - 3$$

- Expect net yields' moments/cumulants to have sensitivity to fluctuations (as notable deviations) near a critical point
- Existing data does not make a strong case for/against

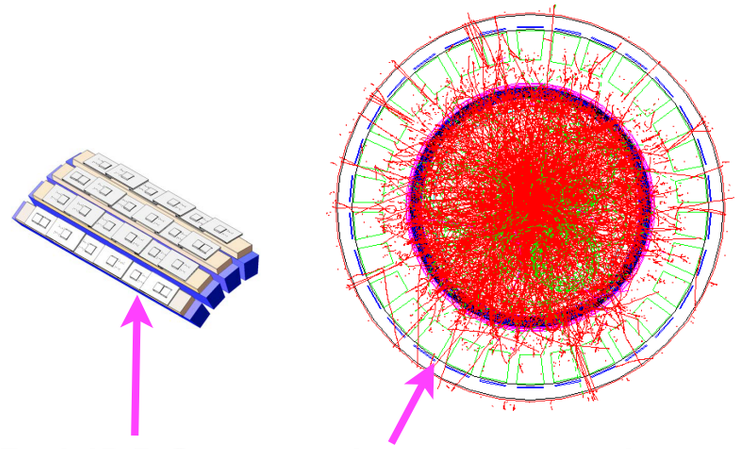
Freeze-out Eccentricity Evolution



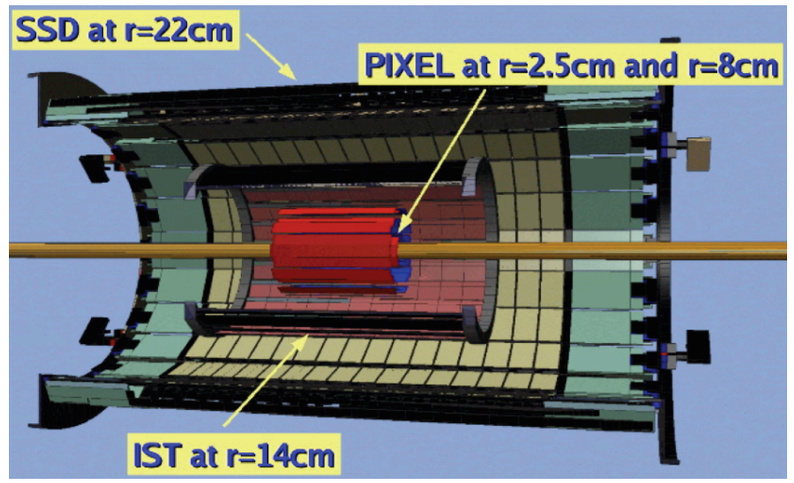
- Expect shape/expansion to see non-monotonic behavior across a 1st order phase transition
- Data from HBT (interferometry) shows no conclusive deviations from hadronic model (URQMD)

Future Directions

- Studies of identified heavy flavor: suppression, anisotropies
  - Detector upgrades to improve identification:
    - Muon Telescope Detector
    - Heavy Flavor Tracker
- More definitive searches for critical point and QGP boundaries
  - Collider upgrade to improve low energy luminosities
  - Possible fixed target for lower energies
- Precision studies of cold nuclear matter

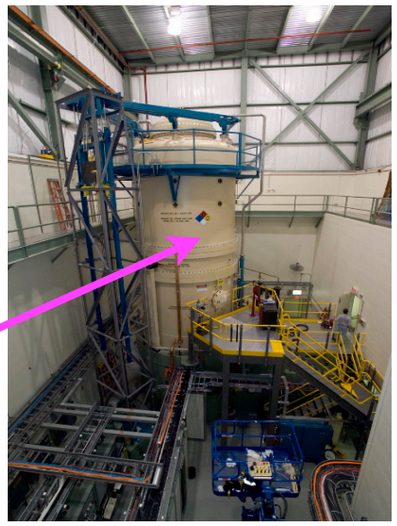


MTD: MRPCs outside magnet yoke, 10% for 2012, final install 2014



HFT silicon inner tracking, prototype for 2013, final install 2014

Re-use of FNAL's e-cooling Pelletron, turn on ~2016



Summary

- High-energy nuclear collisions allow us to determine many characteristics of hot quark matter in the laboratory
  - Case for "sQGP" is getting "stronger": consistent with minimal viscosity, strongly interacting, partonic liquid
    - An abundance of data to test theories quantitatively
  - Observations consistent with local parity violation
  - **Significant improvements in characterization of heavy quark behavior will come with upgrades!**
- Signatures can be dialed in and out via collision energies, centralities
- From the initial scan, not yet definitive on a critical point
  - **Plans for more quantitative studies with Phase II of Beam Energy Scan**
- STAR has been an effective tool for characterizing hot quark matter, and keeps getting better as it grows with ongoing upgrades!