Searches for Exotic Particles and Phenomena at RHIC

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Outline

1) RHIC as an Exotic Particle Factory

2) Exotic Di-Hyperons

   ΩΩ

   ΞΞ

   ΛΛ

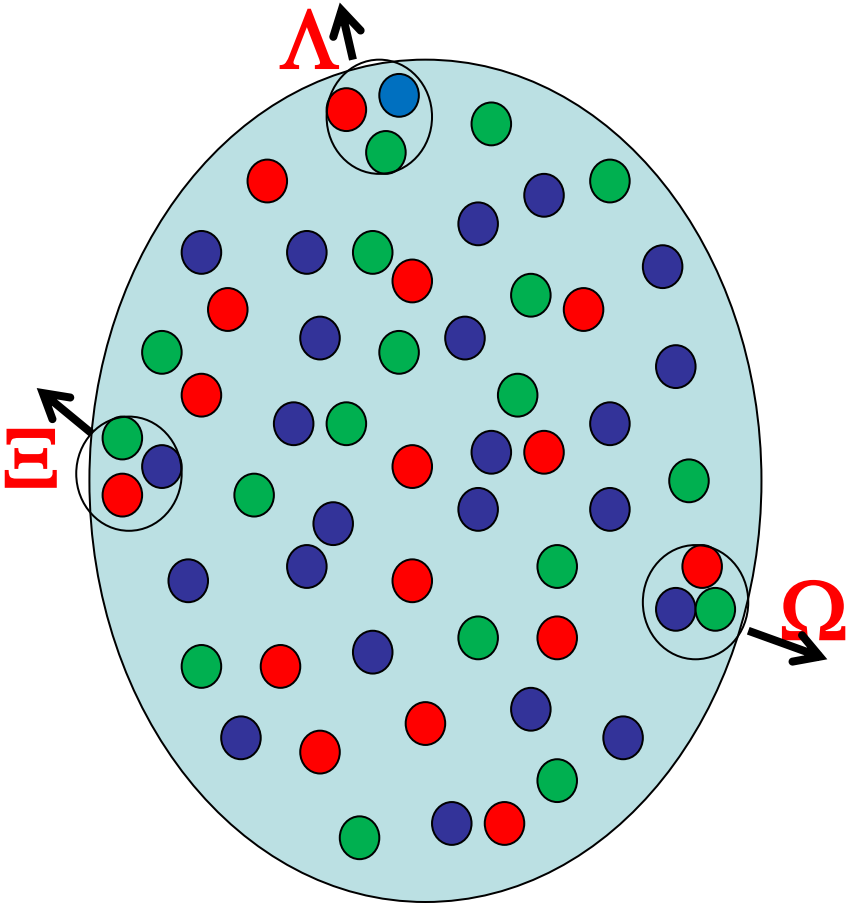
   Hyperon-Hyperon Interactions

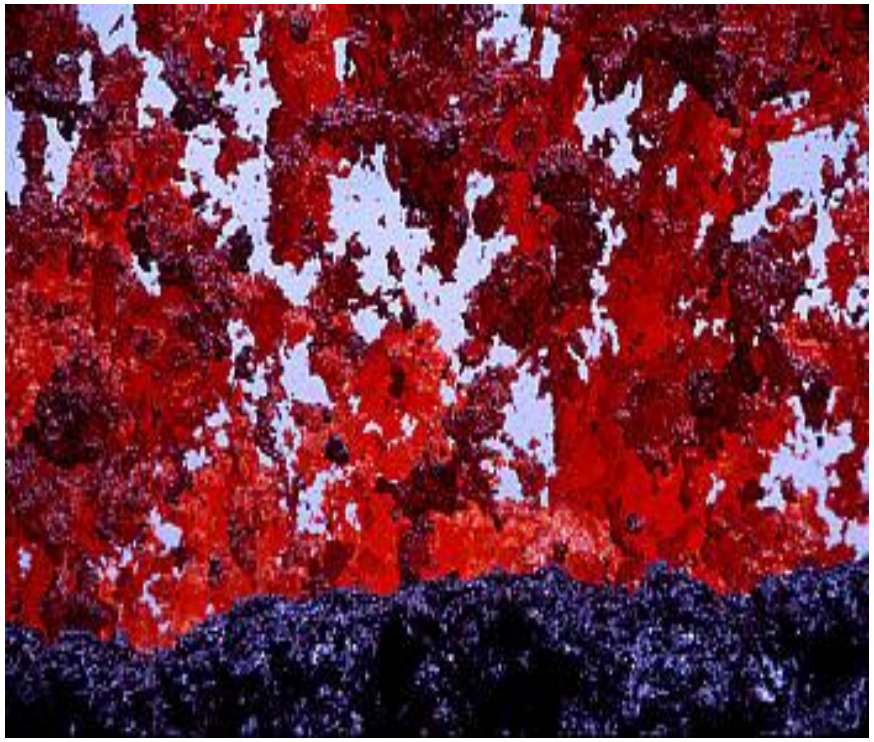
   -- precise determination of Lambda-Lambda
   Lambda-Cascade interactions

   -- is there an H particle? Definitive answer?!

3) QCD topological excitations/Local Parity Violation ?

An Equilibrated Partonic System





Volcanic mediate p_T – Spatter (clumps)

Cluster formation is a common phenomenon for matters at high temperature and density !

Searches for Exotics Beyond 2q and 3q Structure

RHIC – a unique hyperon factory
-- possibly an exotic particle generator

Resonance Particles are difficult in HIC @RHIIC
-- huge combinatorial background !

Pentaquark candidates to search for

- **-- pK_S**
- **-- pK^+**
- **-- $\Xi^- \pi^-$**
- **-- $\Omega\pi$ or ΩK**

Di-baryons

- **Λ–Λ correlation and/or H particle**
- **[Ξ^0-p]→Λp**
- **[Ω-Ω]**

Hyperon Production Rate

Central Au+Au Collision (0-5%)
dn/dy @ mid-rapidity

$$\Lambda - 16.7 \pm 0.2 \pm 1.1$$

$$\overline{\Lambda} - 12.7 \pm 0.2 \pm 0.9$$

$$\Xi^{-} - 2.17 \pm 0.06 \pm 0.19$$

$$\overline{\Xi}^{+} - 1.83 \pm 0.05 \pm 0.20$$

$$\Omega + \overline{\Omega} - 0.53 \pm 0.04 \pm 0.04$$

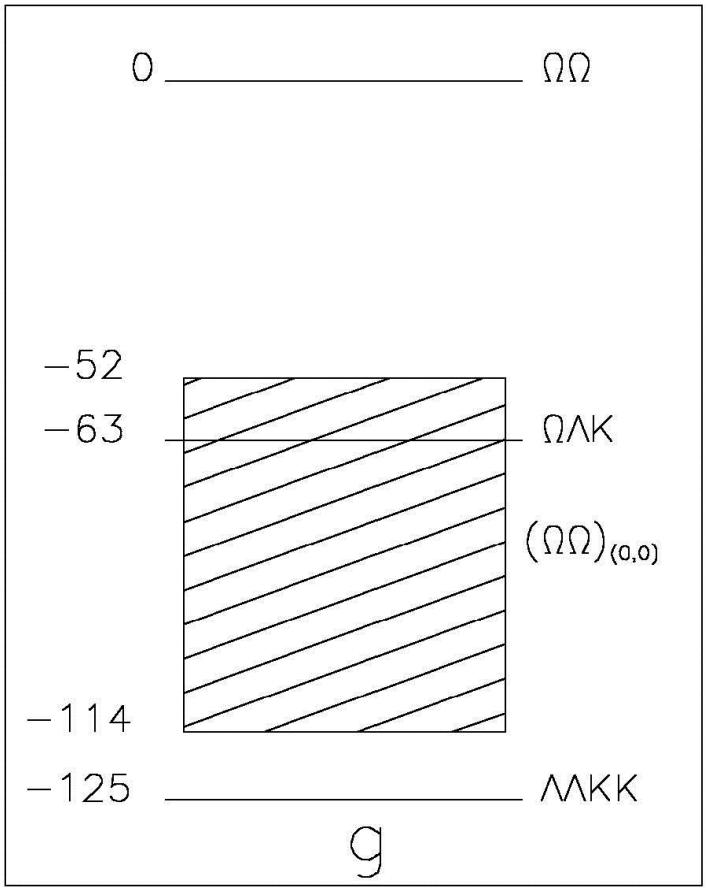
An ΩΩ State ?

Z.Y. Zhang, Y.W. Yu et al

ΩΩ state is the most bound state !

The production venue:
heavy ion collisions

Production rate ?



ΞΞ Bound State

Nucleon-Nucleon	Hyperon-Hyperon
p-p – resonance coulomb repulsive	ΞΞ state
p-n -- bound state deuteron	
n-n – unbound state	

-- Gerald Miller 2004

Physics Information in Correlation Function

Λ–Λ Correlation Function:

both Λs from the primary vertex –

if there is a $\Lambda\Lambda$ resonance state

-- enhanced peak at resonance

and attractive Λ–Λ interactions

if there is a bound state H, then two Λs near threshold can form H

-- depletion of Λ–Λ correlations

(WRT a reference?!)

(if we can measure p-n correlation, the effect of deuteron formation)

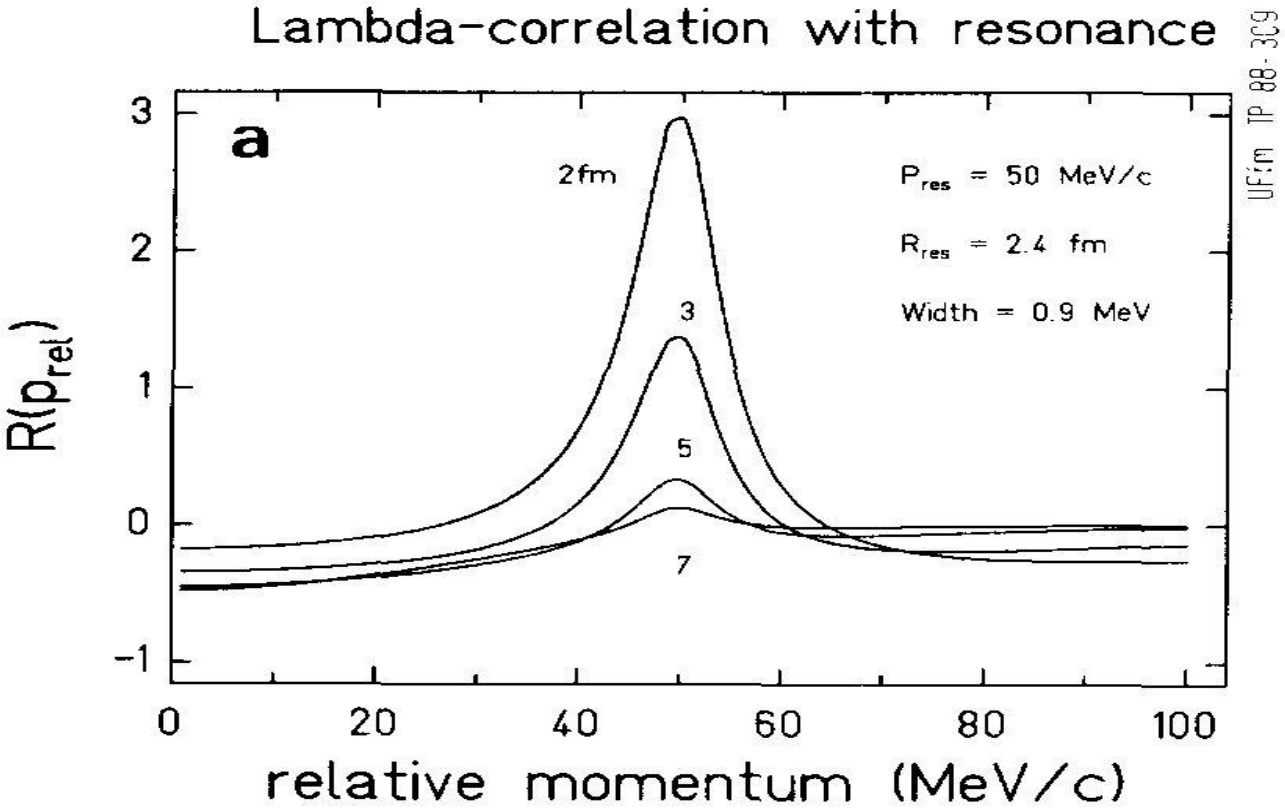
both Λs from secondary vertices –

weak decay product – [Ξ-Λ] state?

H^0 in Λ-Λ Correlations

Influence of possible low energy resonance on Λ-Λ correlations.

Greiner and Muller, Phys Lett B 219 (1989) 199



A wide resonance will be difficult to observe!

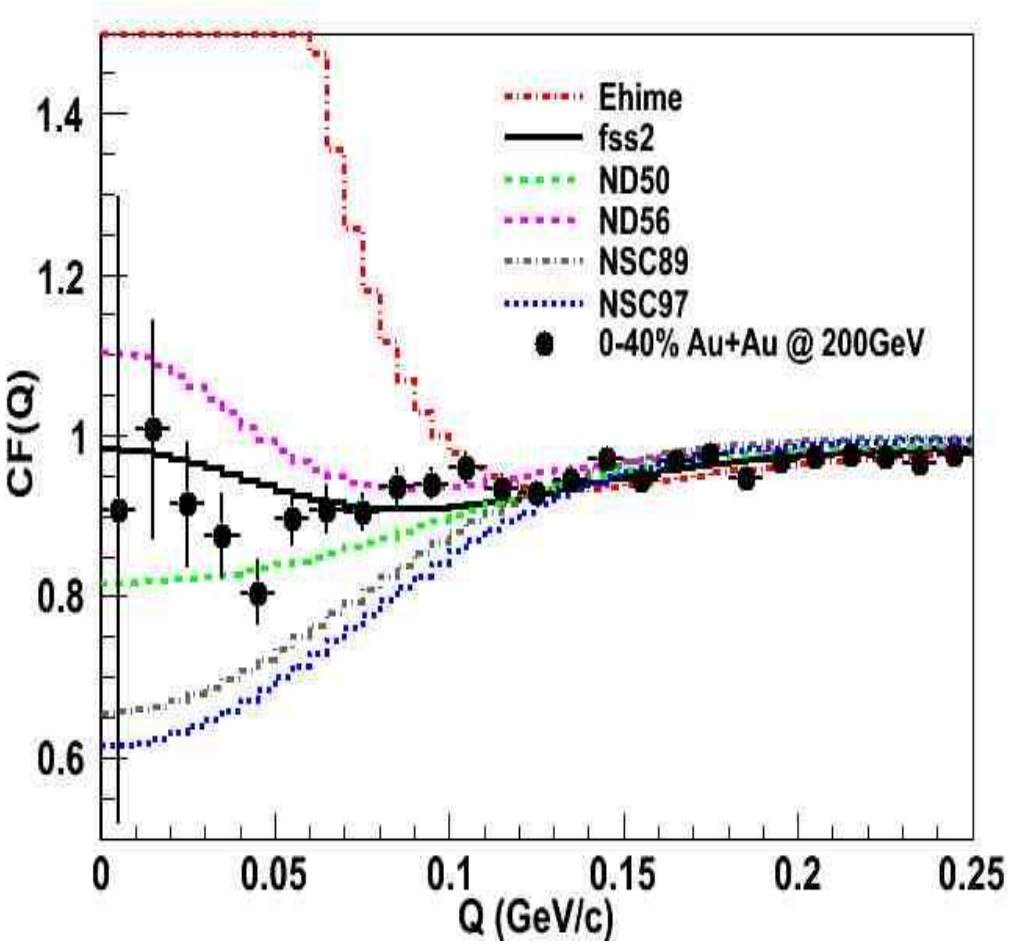
Correlation Function and Direct Decay Searches Complementary

Correlation Function – Depletion of phase space due to bound state formation
-- inclusive, sensitive to total yield

Direct Searches
-- depend on branching ratio

If H(uuddss) is a weakly bound state with a binding energy ~ 10s MeV as predicted by recent Lattice QCD calculations,
$H \rightarrow \Lambda + p + \pi$
branching ratio?

ΛΛ Correlation Function

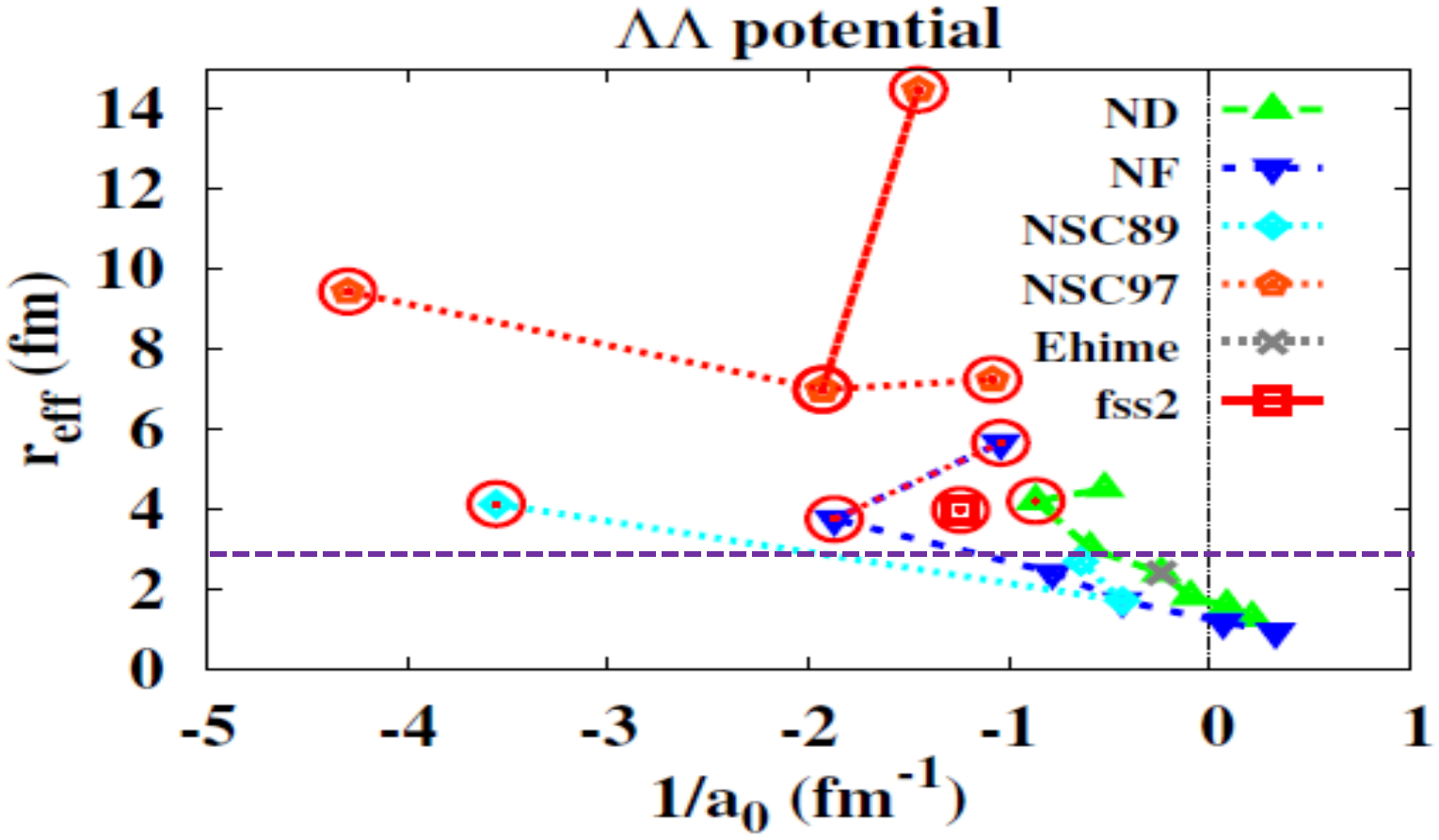


Not very Strong Correlation

- Type of ΛΛ interaction:
  - Meson exchange models: Nijmegen model D, F, Soft Core (89, 97)
  - Quark cluster model interaction: fss2
  - Phenomenological model: Ehime
- ΛΛ interaction → Attractive
- Inclusive ΛΛ correlations: Feed down contributions included in theoretical models.

Theoretical Model Fit to Data

A. Ohnishi, HHI workshop proceedings 2012



- Scattering length (a_0) is negative
- Current fit from different potential models to data gives indication towards non-existence of bound H-dibaryon
- Large uncertainty in Σ and other hyperon feeddown contributions

Heavy Ion Collisions versus Kaon Beam Facility

Hyperon-hyperon interaction:

kaon beam facility –
difficult to go beyond
- **Λ-Λ**
- **Ξ-N systems**

@RHIC
- **Ξ-Λ**
- **Ξ-Ξ**
- **Ξ-Ω**
- **Ω-Ω systems possible candidates**

- $[\Sigma^+ p] \rightarrow p + p$,
- $[\Xi^0 p] \rightarrow p + \Lambda$,
- $[\Xi^0 \Lambda] \rightarrow p + \Xi^-, \Lambda + \Lambda$
- $[\Xi^0 \ \Xi^-] \rightarrow \Xi^- + \Lambda$,

J. Schaffner-Bielich et al (H-H); G. Miller (Ξ-Ξ); Z.Y. Zhang et al (Ω-Ω)

QCD – Fundamental Corner Stone of the Standard Model

QCD and QCD Vacuum

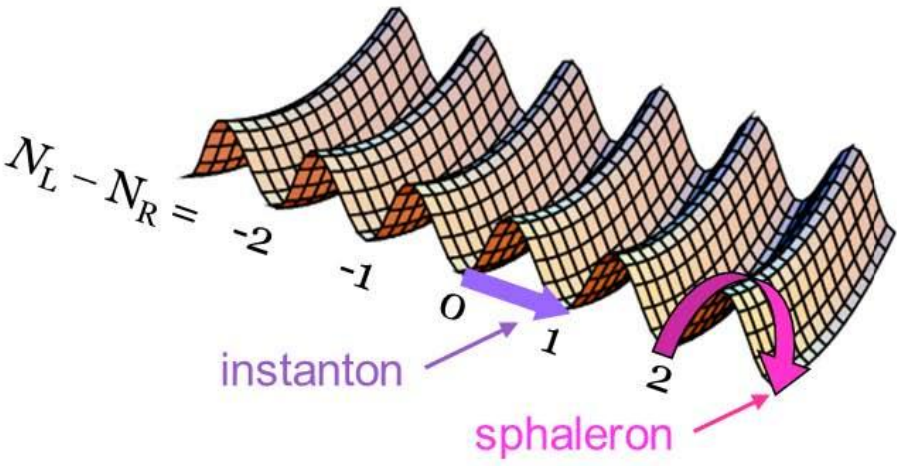
– very rich underlying dynamical structure !!

many intriguing features – (not really exotic)

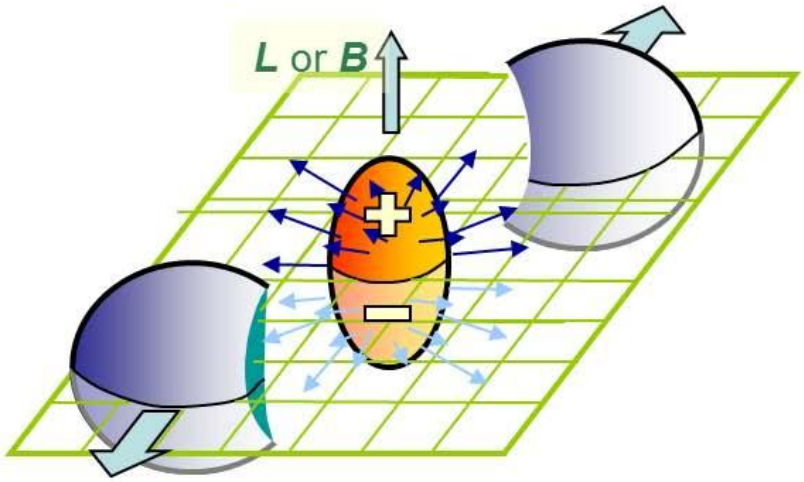
chiral symmetries

topological vacuum excitations

a) Energy of gluon field



b) Chiral magnetic effect ⇒ event EDM



QCD Exotic Dynamic Phenomenon

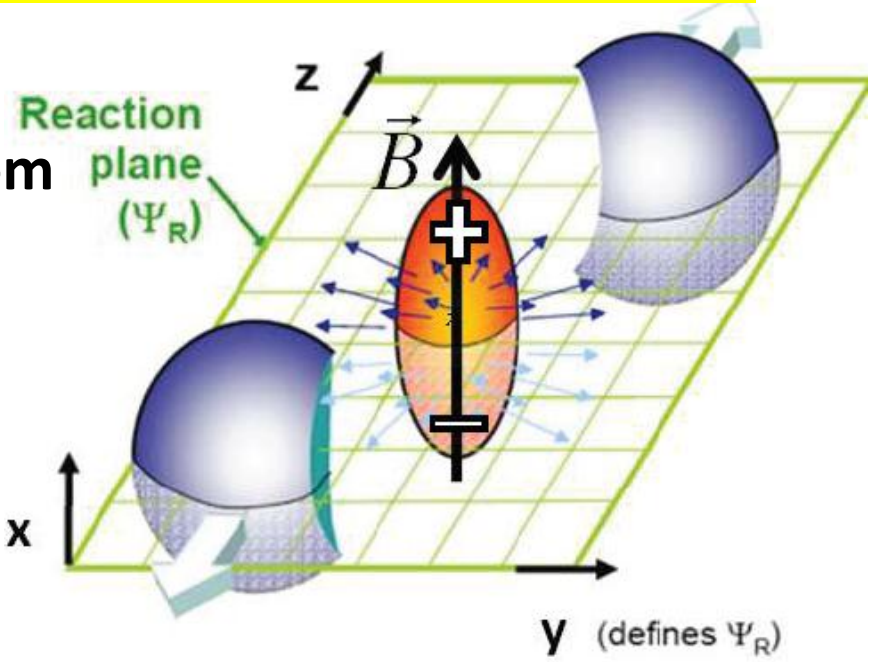
QCD Vacuum Sphaleron excitation coupled to strong magnetic field from spectator protons

-- charge separation across the reaction plane

parity violating in strong interaction

Local Parity Violation

Kharzeev et al NP A803, 227 (2008)



$$\gamma = \left\langle \cos(\phi_\alpha + \phi_\beta - \psi_{RP}) \right\rangle$$

$$= \left[\left\langle v_{1,\alpha} v_{1,\beta} \right\rangle + B_{in} \right] - \left[\left\langle a_\alpha a_\beta \right\rangle + B_{out} \right]$$

Voloshin, PRC70, 057901 (2004)

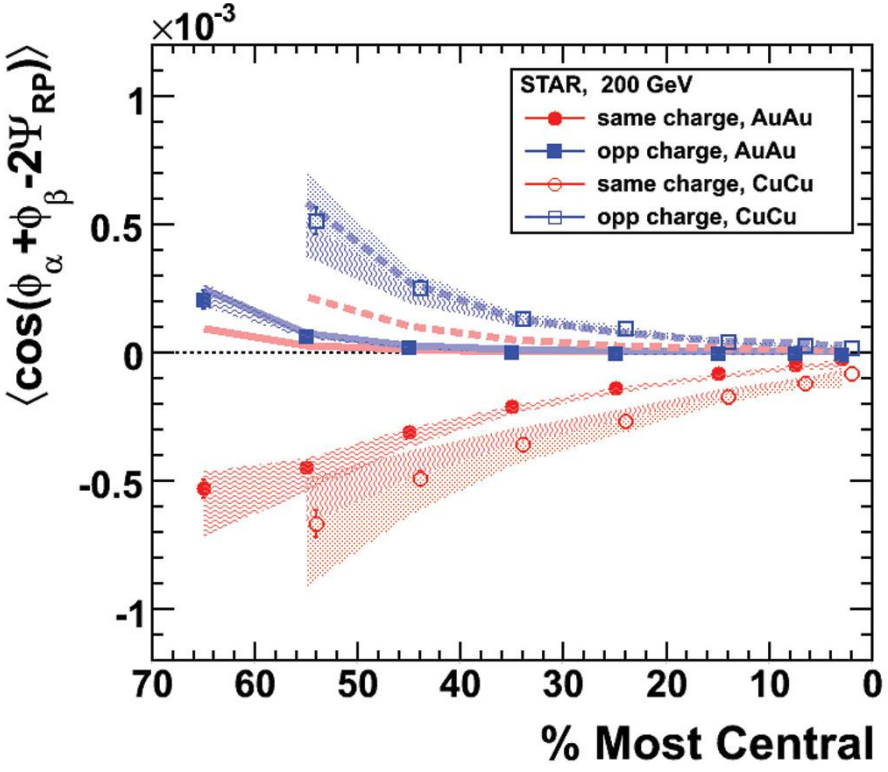
charge dependent – same sign (++,--) and opposite sign(+-, -+) sensitive to charge separation

The Interpretation is not Unique

Empirically, indeed there is RP-dependnt Charge Separation !

STAR Phys. Rev. Lett.103: 251601 (2009)

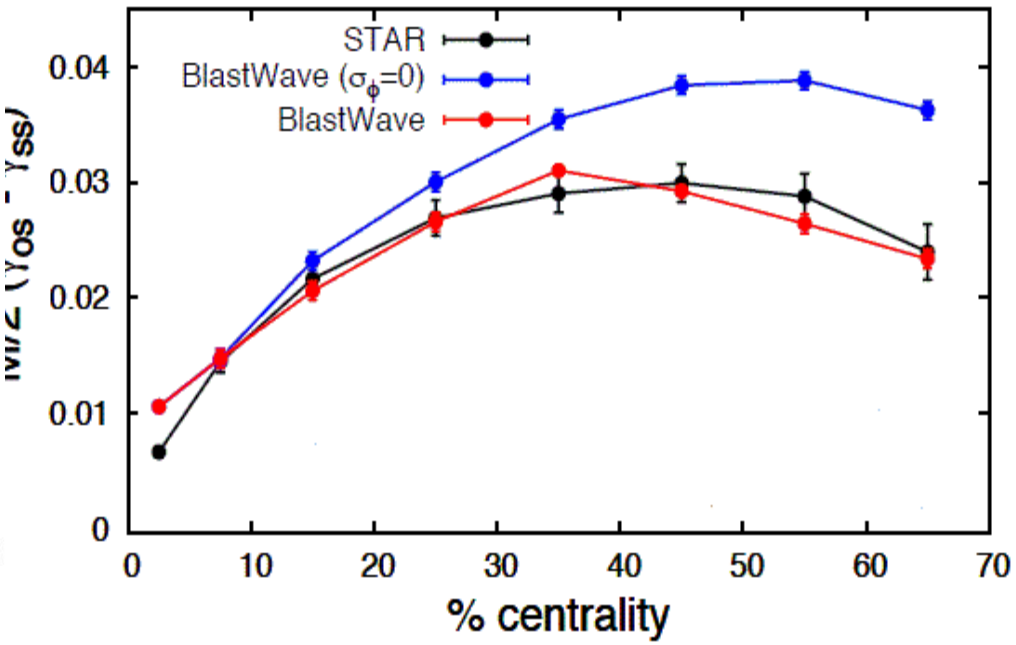
$$\gamma = \left\langle \cos(\phi_\alpha + \phi_\beta - \psi_{RP}) \right\rangle$$
$$= \left[\left\langle v_{1,\alpha} v_{1,\beta} \right\rangle + B_{in} \right] - \left[\left\langle a_\alpha a_\beta \right\rangle + B_{out} \right]$$



Can it be due to a special coupling Between charge balance function and v2 ?

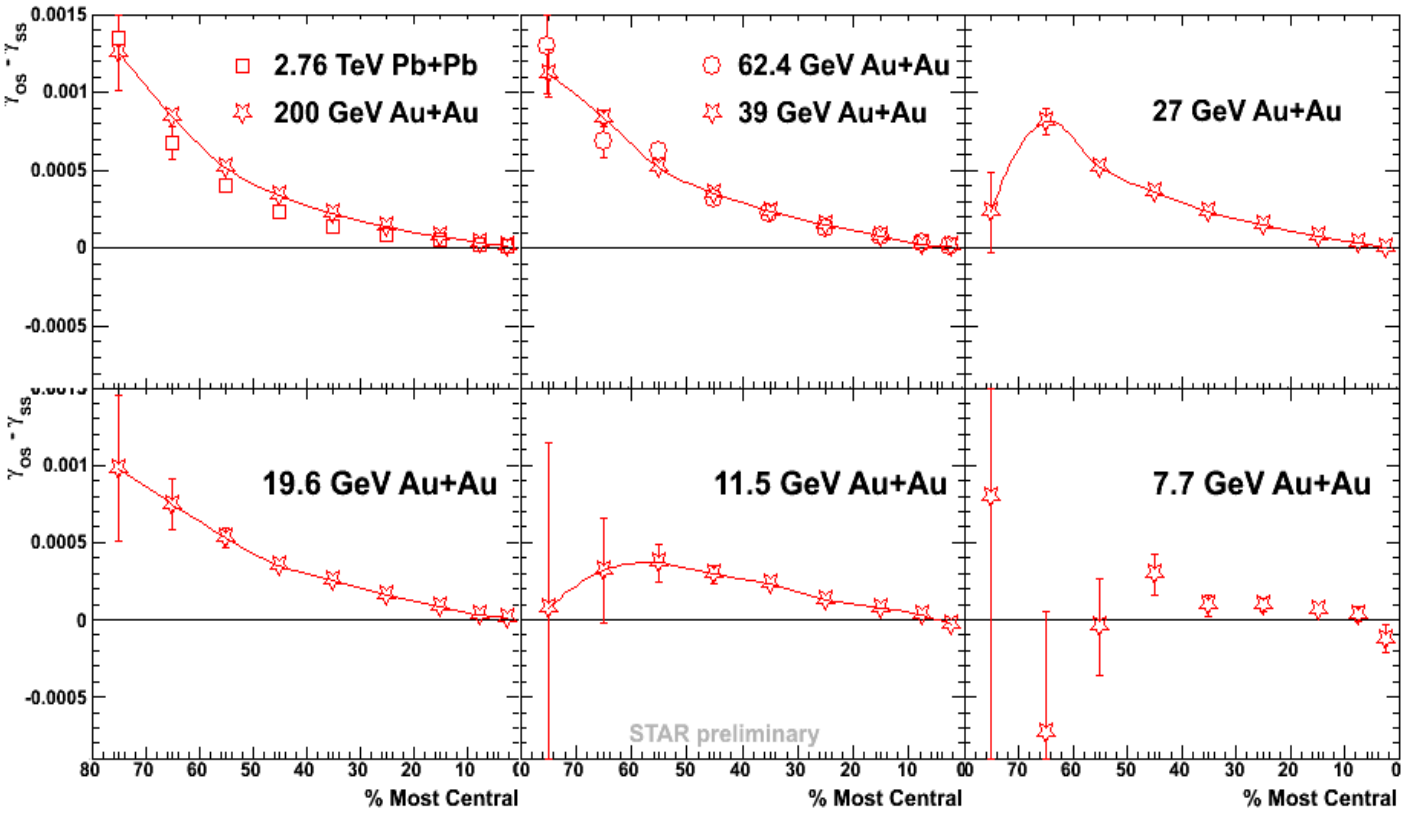
Phys.Rev.C83:014913,2011

(γ_{os}-γ_{ss}) Scaled by Npart



Beam Energy Scan Data

The disappearance of (γ_{OS}-γ_{SS}) at 7.7 GeV



Why? -- no QGP formation at 7.7 GeV?

Ingredients in Scott Pratt's model –

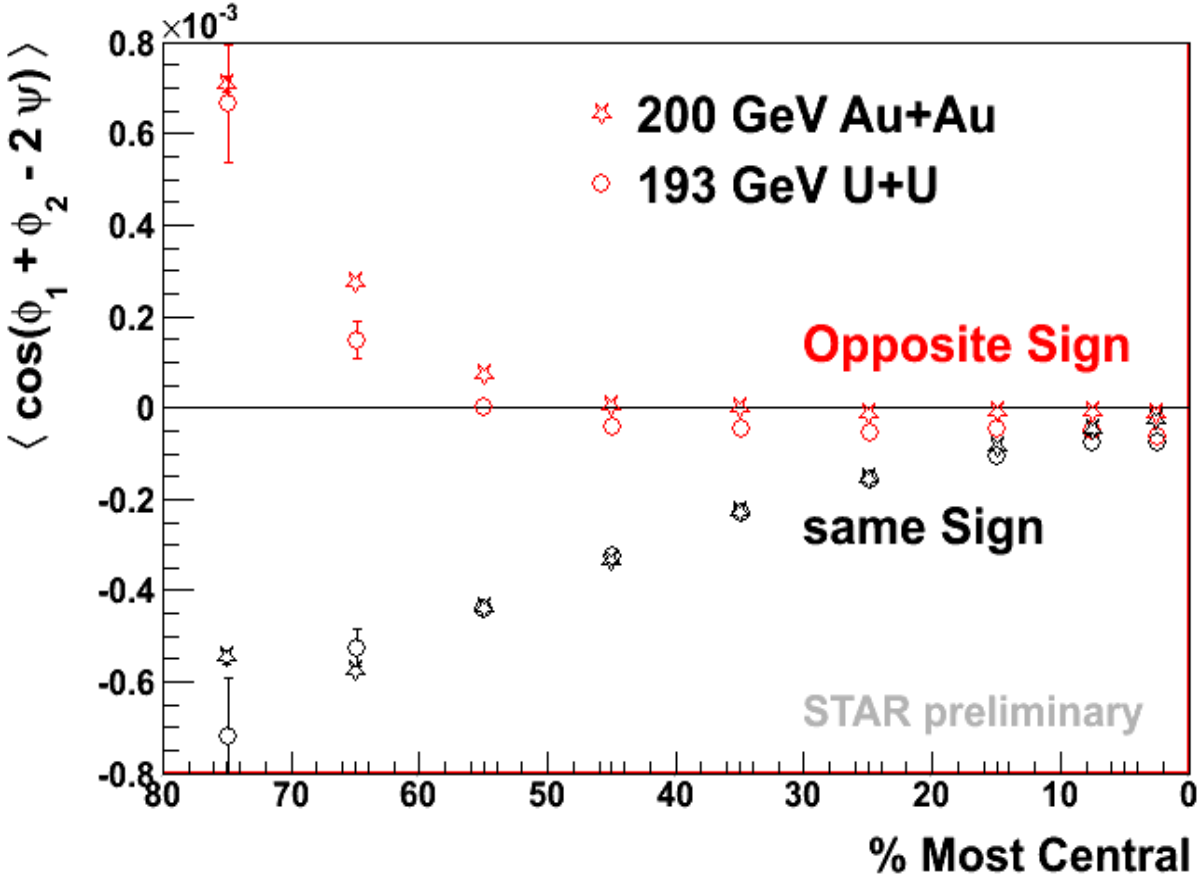
charge balance function and

v2 induced RP dependence on balance function

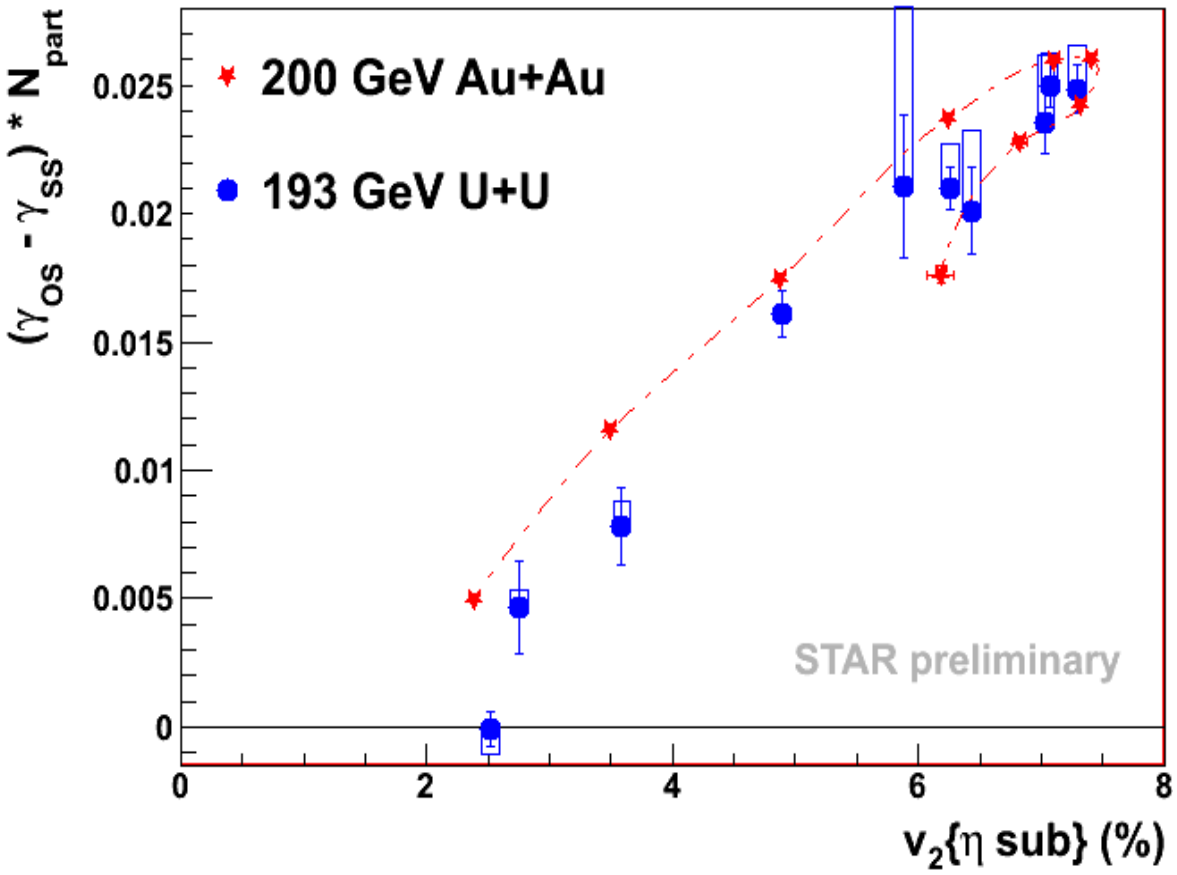
U+U Collisions at RHIC 2012

Uranium – large deformation

Variation on v2 induced background level

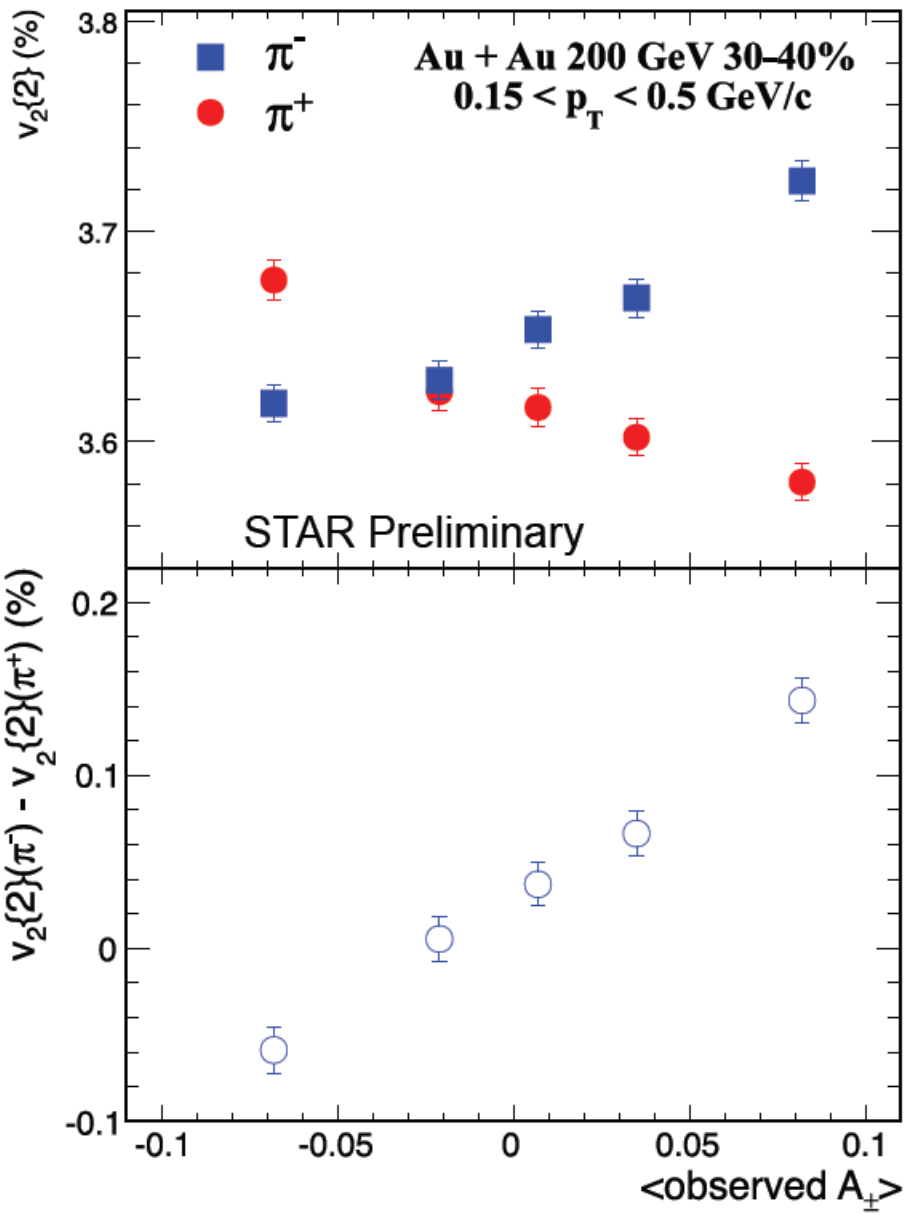


$(\gamma_{OS}-\gamma_{SS})$ Disappears Faster Than v_2



Elliptic flow v_2 induced background (cluster model or blastwave or balance function or momentum/charge conservation) ALONE does not constitute the entire observed $(\gamma_{OS}-\gamma_{SS})$ signal !!

Chiral Magnetic Wave induced Quadrupole Moment ?

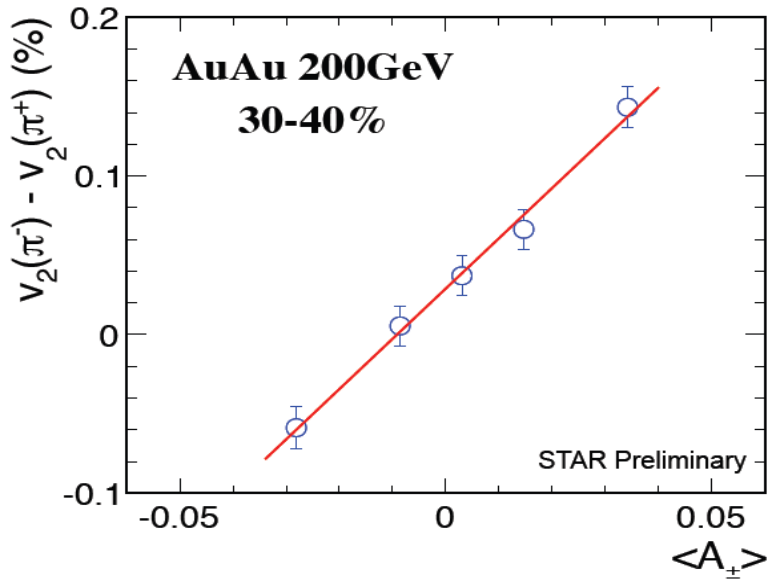


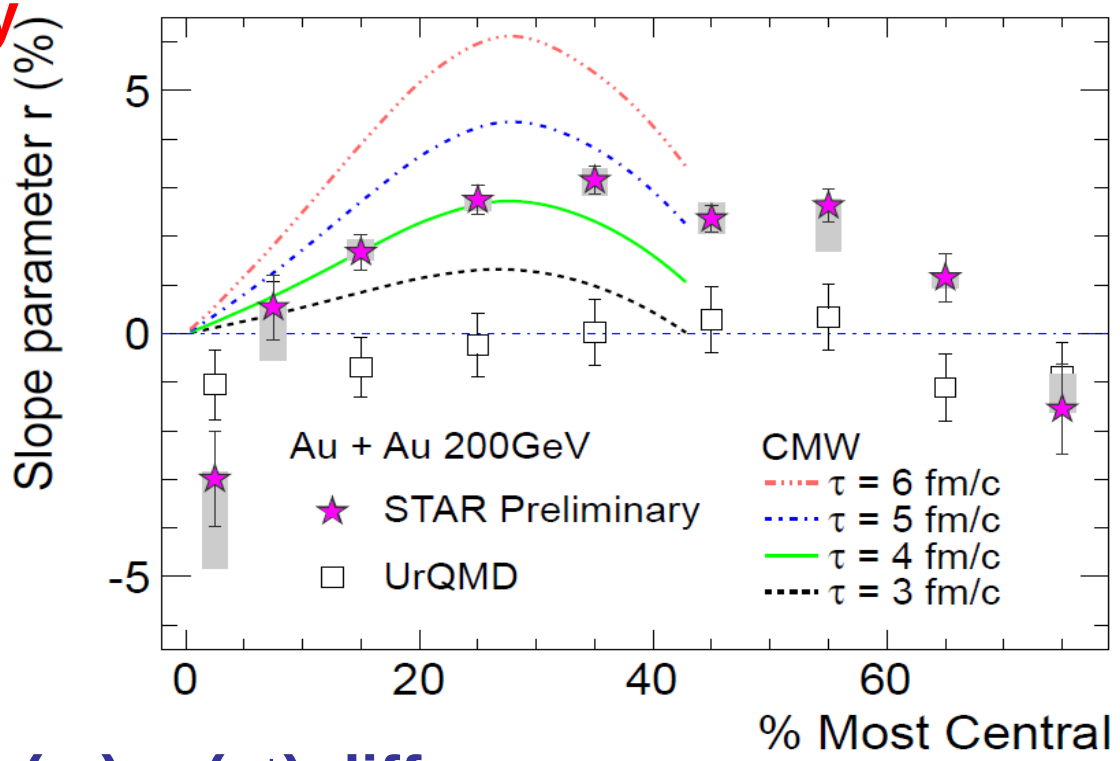
- v_2 was measured with the Q-cumulant method.
- Clear $A_\pm$ dependency
- $v_2(A_\pm)$ slopes for $\pi^\pm$:
  - opposite sign
  - similar magnitude
- v_2 difference vs $A^\pm$ may have a non-zero intercept: other physics?

$$v_2^{\pm} = v_2 \mp \left(\frac{q_e}{\rho_e}\right) A_{\pm}$$

Electric Quadrupole Moment?

STAR QM12 Preliminary





Empirically there is a $v_2(\pi^-)$-$v_2(\pi^+)$ difference
- **depending on the charge asymmetry !**
- **alternative explanations ?**
- **what does it mean to have an electric quadrupole moment for an exploding system ?**

Y. Burnier, D. E. Kharzeev, J. Liao and H-U Yee (2012).

Towards a Definitive Answer?

All theoretical models for LPV are wrong
or only partially correct !

Experimental Knobs –
-- turn off QGP and/or change magnetic field
-- vary the magnitude of the elliptic flow v2

The measured (γ_{os}-γ_{ss}) likely has contributions from possibly LPV signal and background correlations !
How to decompose the signal and background ?

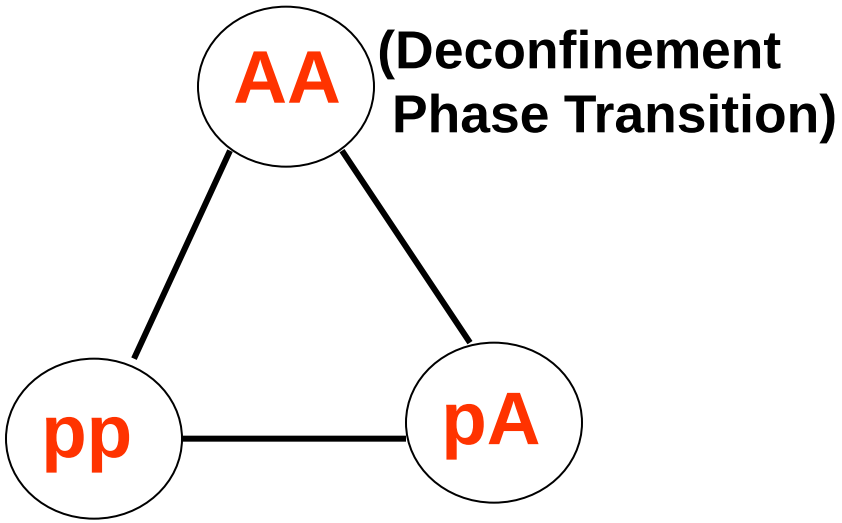
Need new ideas and experimental approaches !

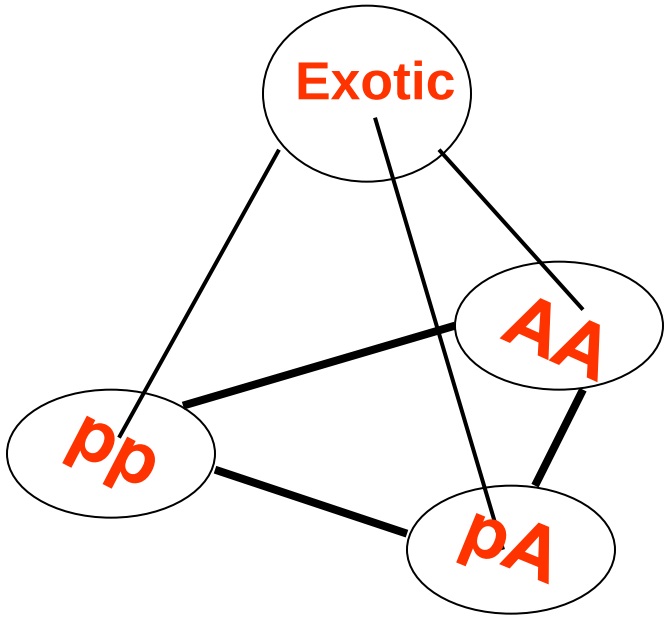
QCD Beyond and Exotics

QCD -- the fundamental corner stone of the Standard Model

RHIC provides a futile ground for exploration of QCD

A New Dimension to RHIC Physics –
Dedicated QCD Machine & Beyond





(spin) **(CGC,EMC)**