STAR Heavy Ion Physics Program and Future Perspective

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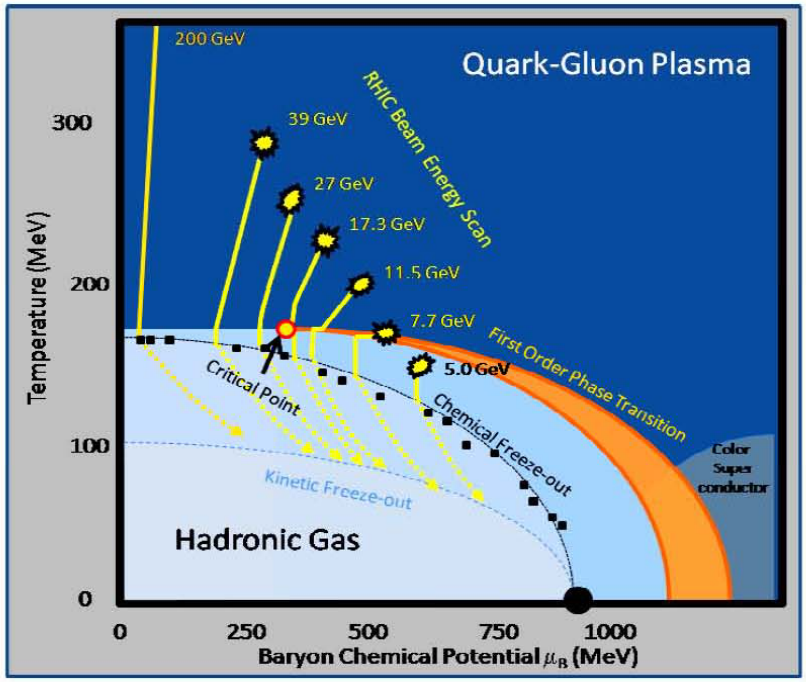
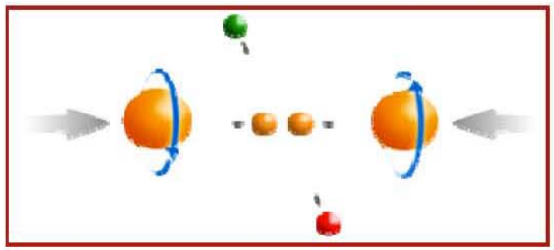
Outstanding Scientific Questions at RHIC

Hot QCD Matter

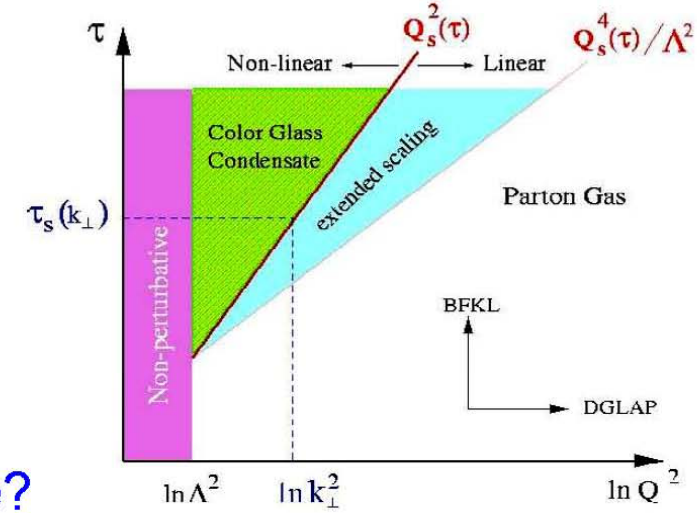


1: Properties of the sQGP
2: Mechanism of energy loss:
weak or strong coupling?
3: Is there a critical point, and if so, where?
4: Novel symmetry properties
5: Exotic particles

Partonic structure



6: Spin structure of the nucleon
7: How to go beyond leading twist and collinear factorization?



8: What are the properties of cold nuclear matter?

Outline

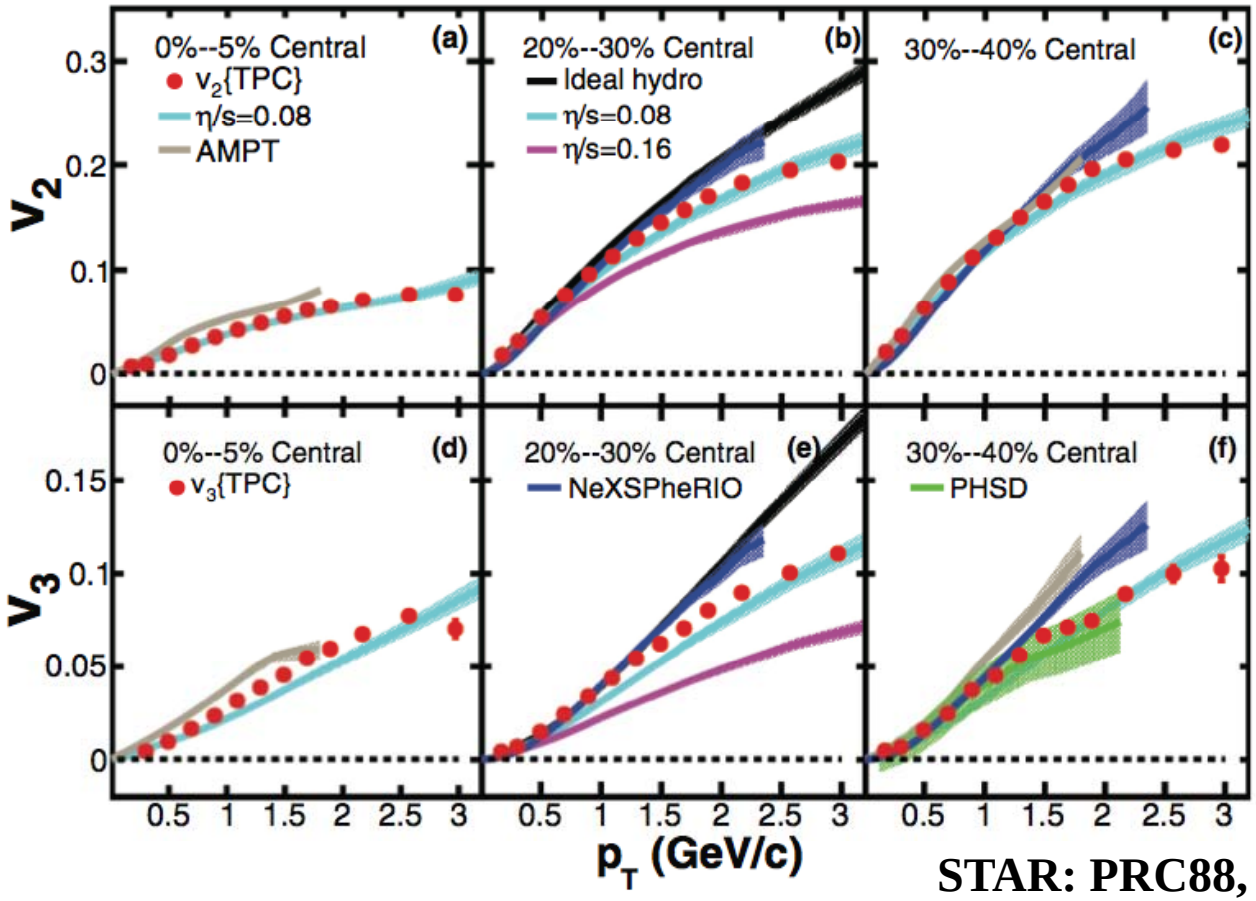
Heavy Quark Probes

RHIC Beam Energy Scan Program Phase I Results

Novel Symmetry and Exotic Searches

Towards Future QCD Studies at RHIC and eRHIC

Initial Conditions Remain a Major Uncertainty

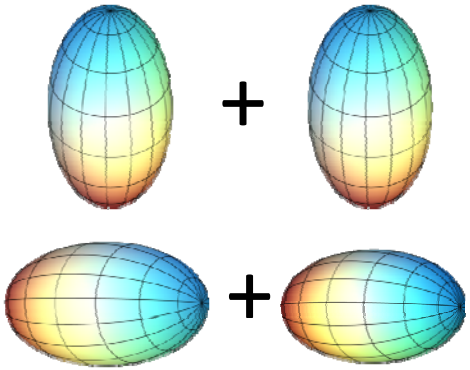


STAR: PRC88, 014904(2013)

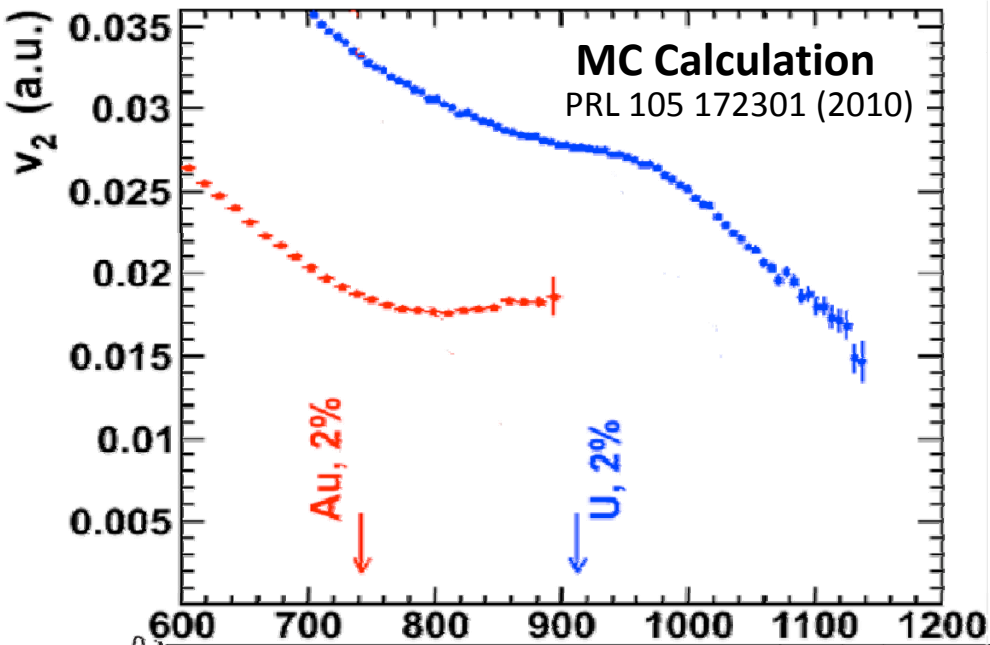
- The initial conditions in the models come from MC-Glauber
- NeXSPheRIO model reproduce the data well for 20-30% and 30-40% at pT < 1 GeV/c
- Both v_2 and v_3 are better described by η/s ~ 0.08

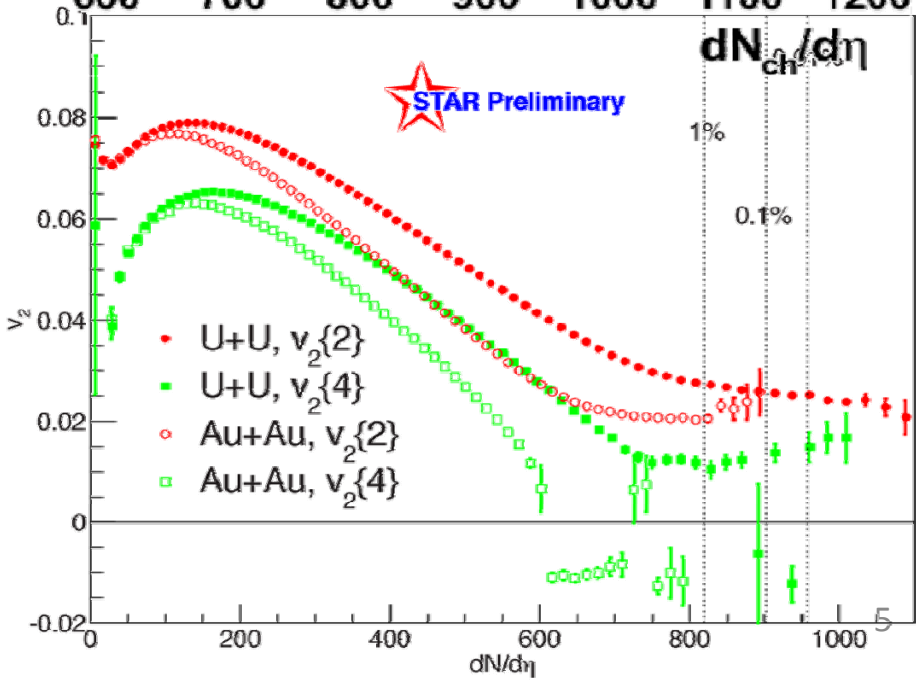
We Do not Truly Understand the Geometry Yet

U+U Collisions



Prolate





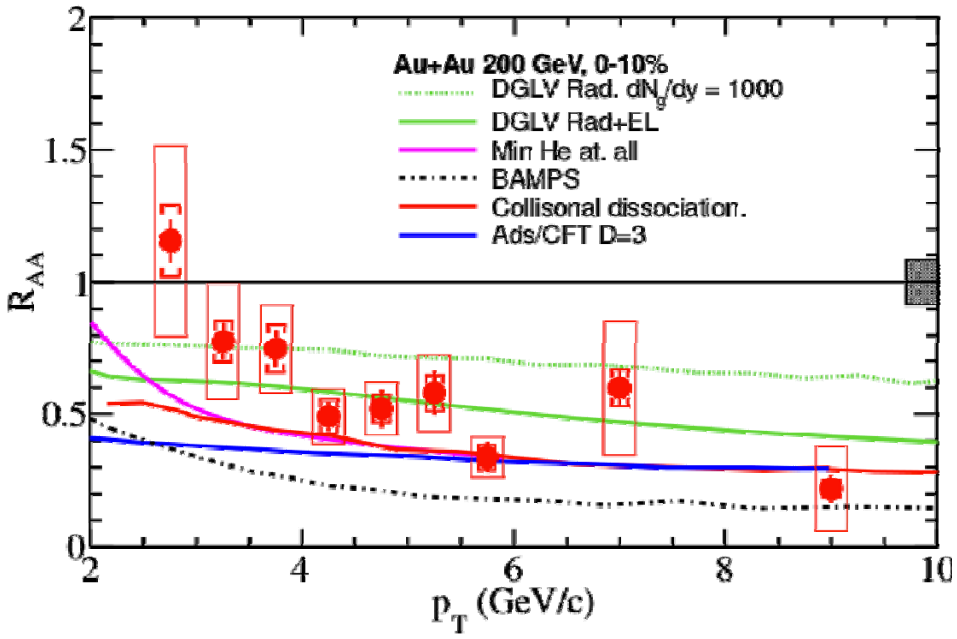
We do not understand detailed features from U+U data based on known collision geometry dependence of v_2 !

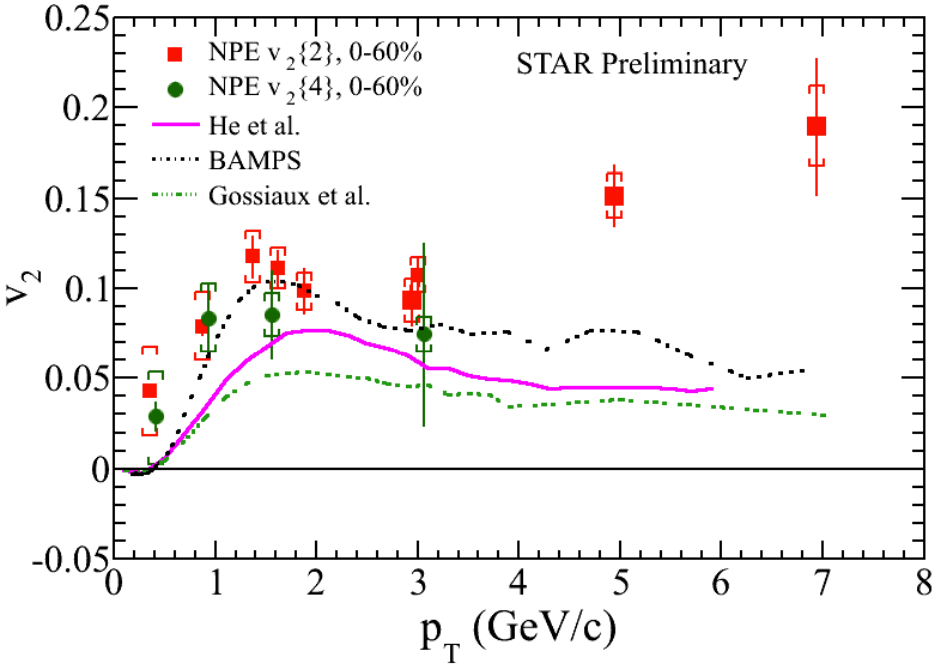
Incomplete understanding of geometrical and dynamical fluctuations !!

Heavy Quark Probe of sQGP properties

NPE – access to high pT region

Simultaneous Measurements of R_{AA} and v_2



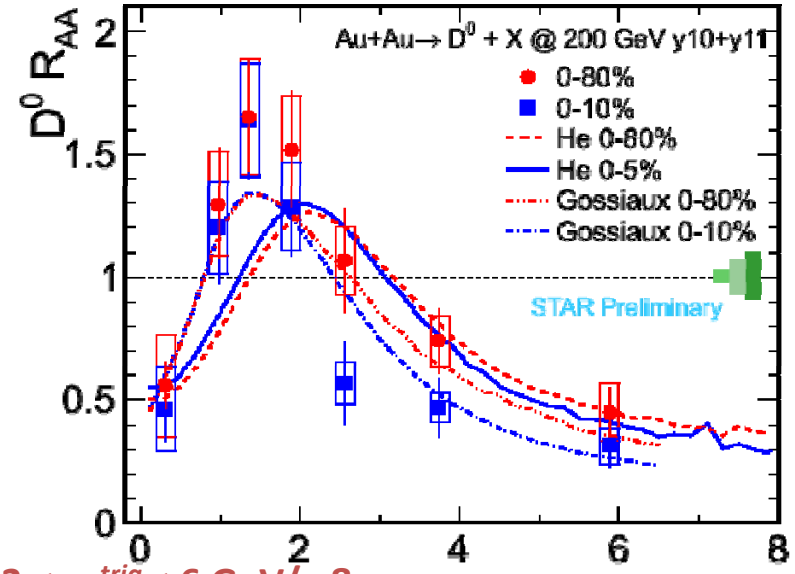


Better p+p reference data

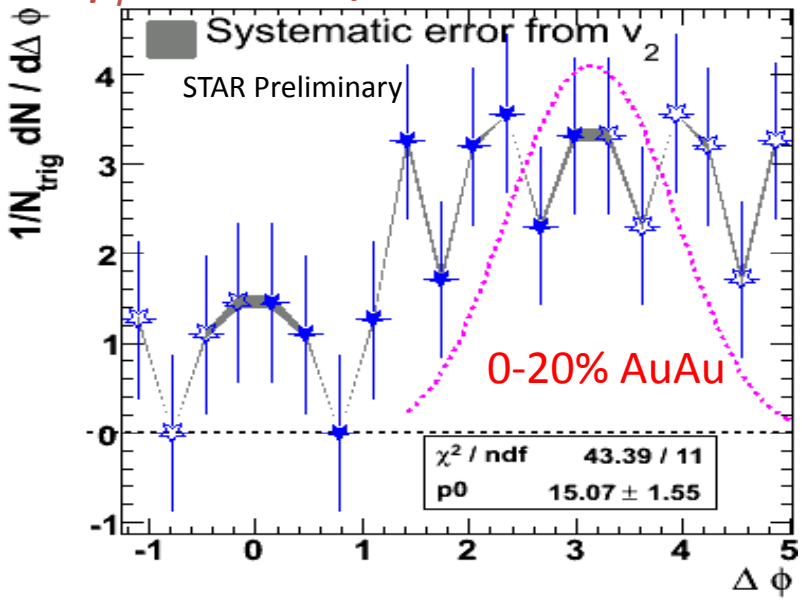
Nature of the measured v_2 value at high pT

Separation of B and D decay electrons !

Heavy Quark Collectivity – Next 2 years !



$3 < p_T^{trig} < 6$ GeV/c &
$0.15 < p_T^{asso} < 0.5$ GeV/c



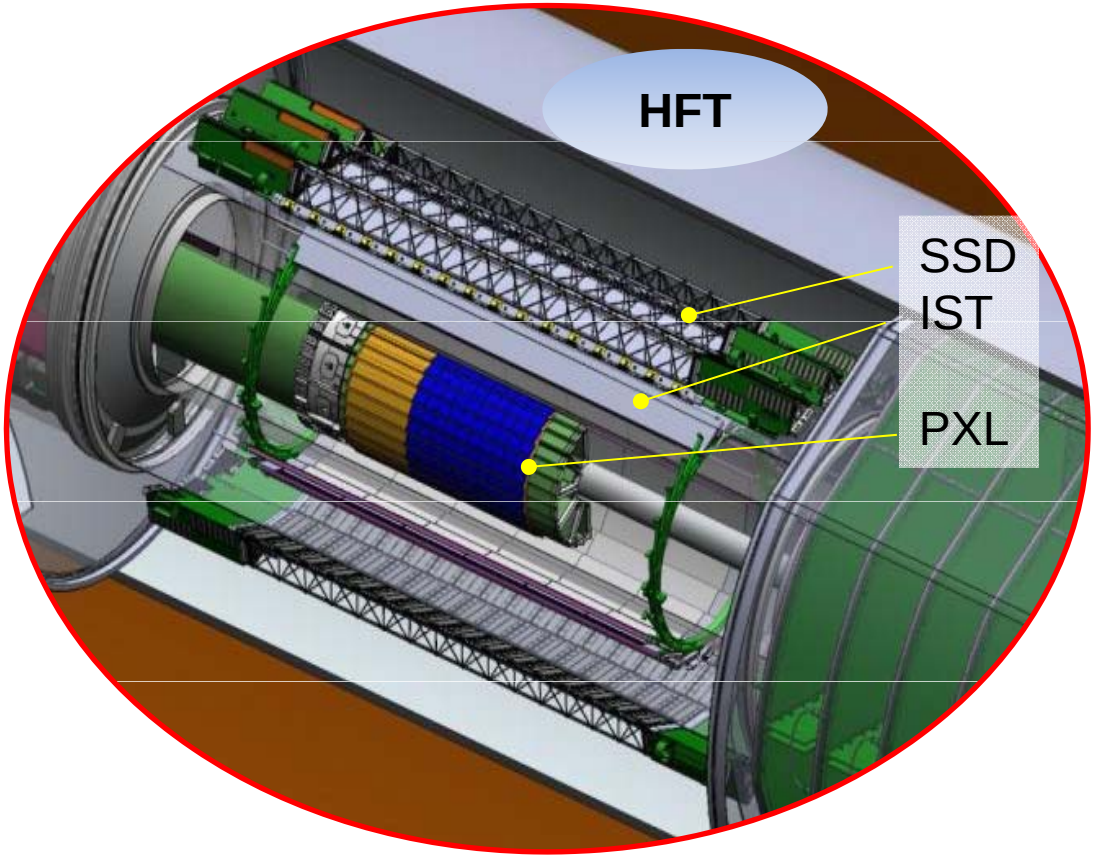
Elliptic Flow v_2 of D at low pT

NPE – Separation of B and D decays in Au+Au collisions

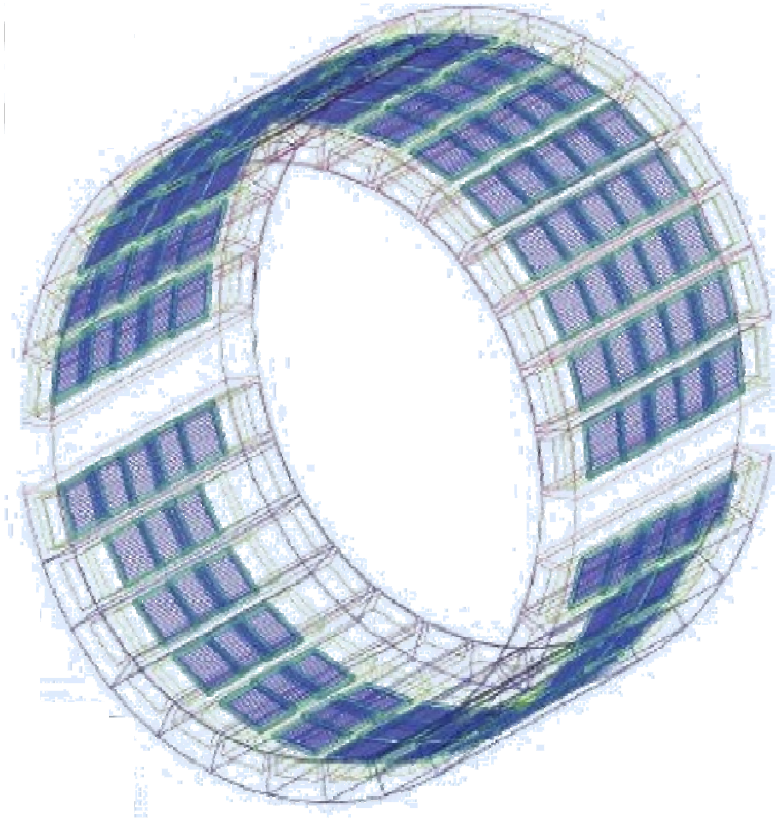
----Needs HFT Upgrade

Heavy Quark Tagged Jet-Medium Interaction and Medium Response !

Status of HFT and MTD Upgrades



Heavy Flavor Tracker

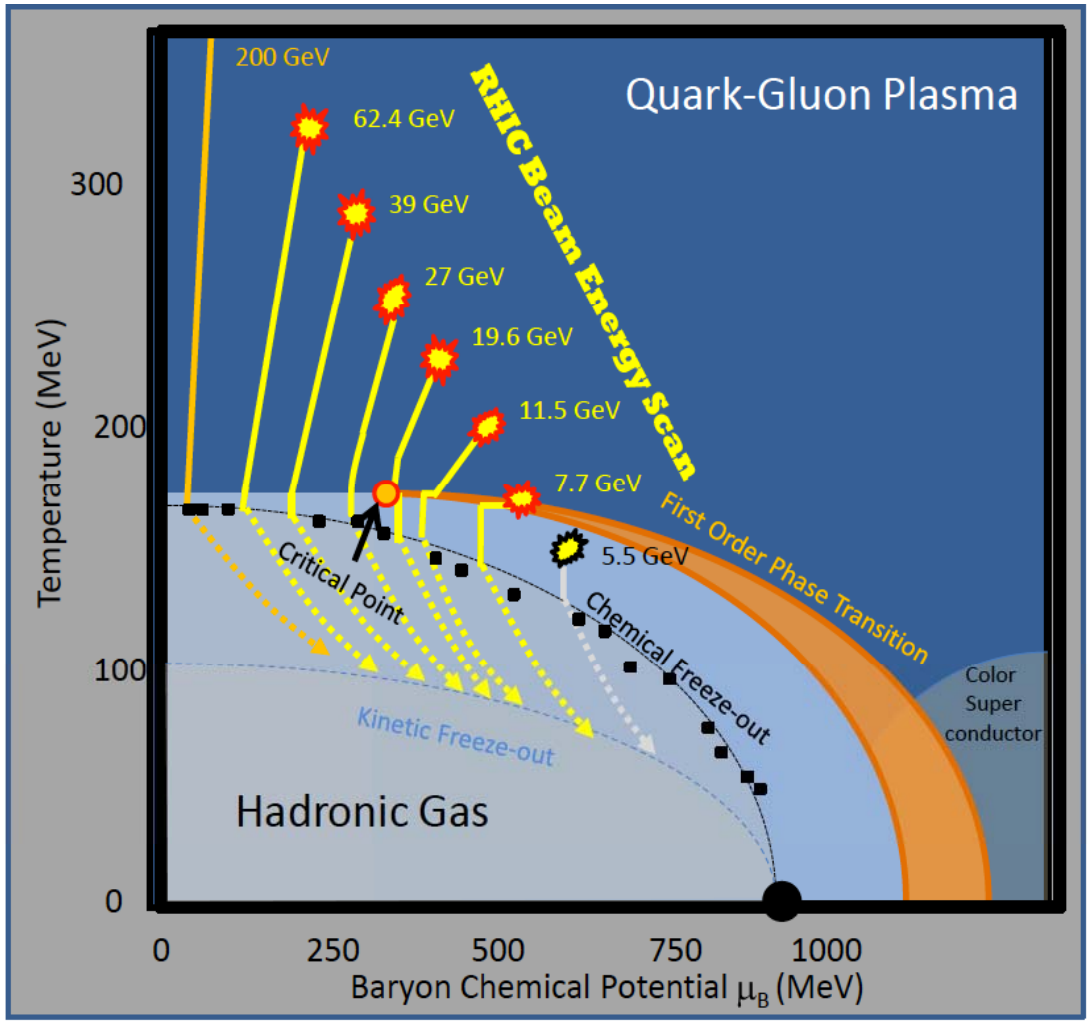


Muon Telescope Detector

Full Detector Commissioning and Physics Running in 2014

Heavy Quark Collectivity, NPE B and D separation, Upsilon

QCD Phase Diagram and RHIC BES-I



Year	En (GeV)	# Event (10^6)
2010	39	130
2010	11.5	12
2010	7.7	5
2011	27	70
2011	19.6	36
2014	15 (?)	

RHIC can deliver low energy beams !
STAR: First glimpse of QCD bulk matter over a broad range of chemical potentials !

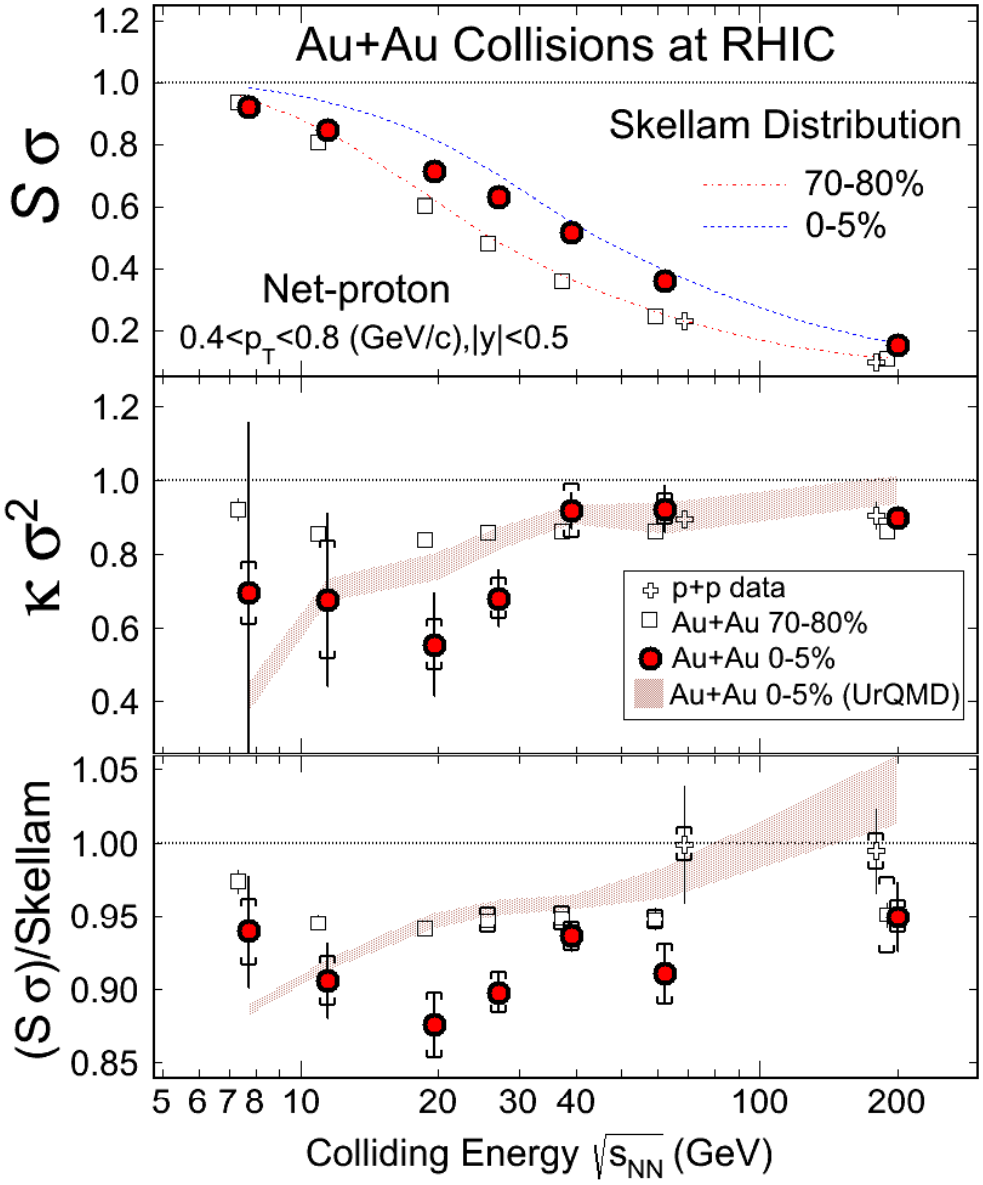
Searches for QCD Critical Point

$$S = \frac{<(\delta N)^3>}{\sigma^3}$$

$$\kappa = \frac{<(\delta N)^4>}{\sigma^4} - 3$$

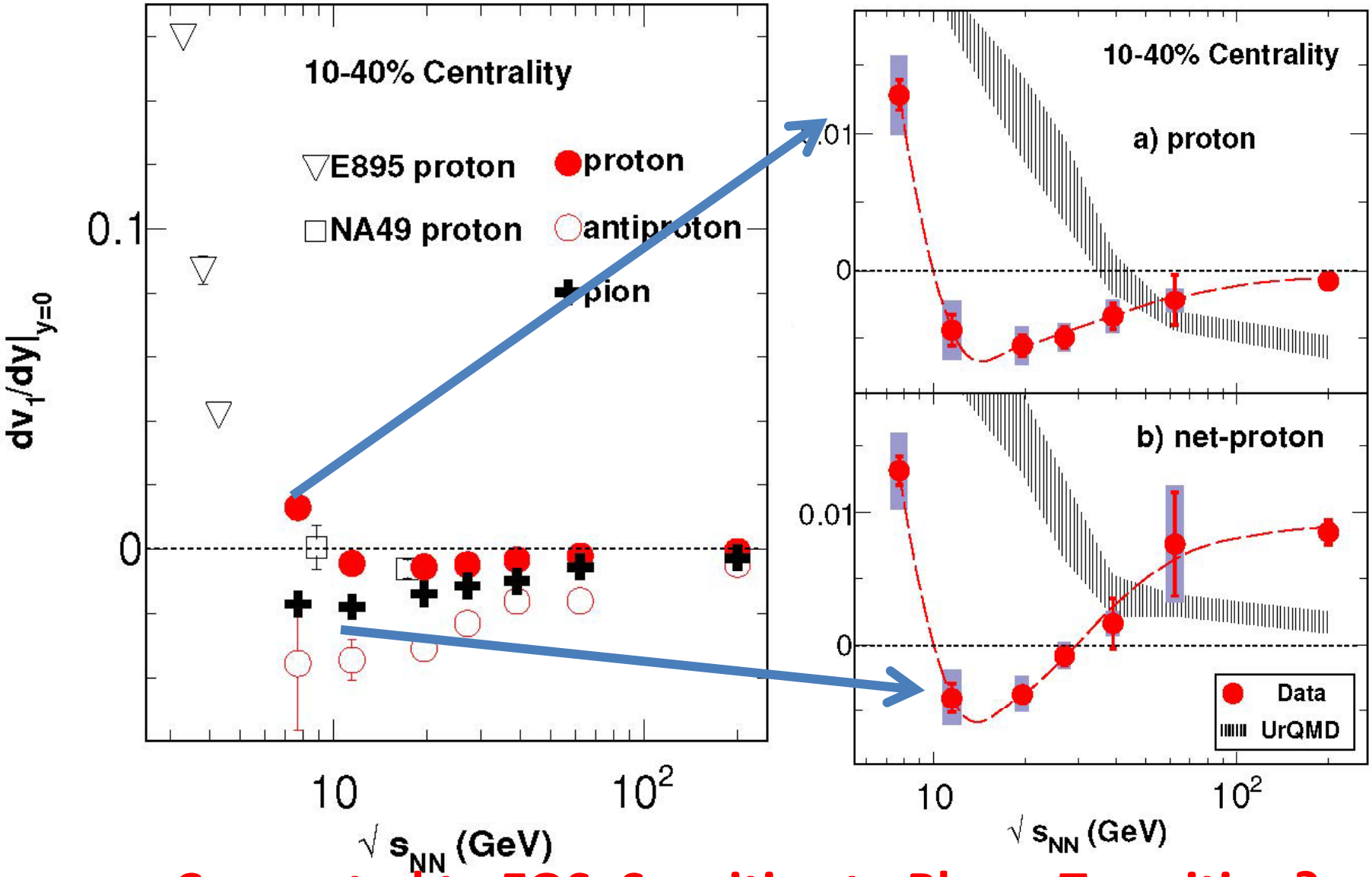
What is the width in sqrt(s) or chemical potential for the QCD critical point ?

What is the most appropriate reference distribution for high moments?



arXiv: 1309.5681

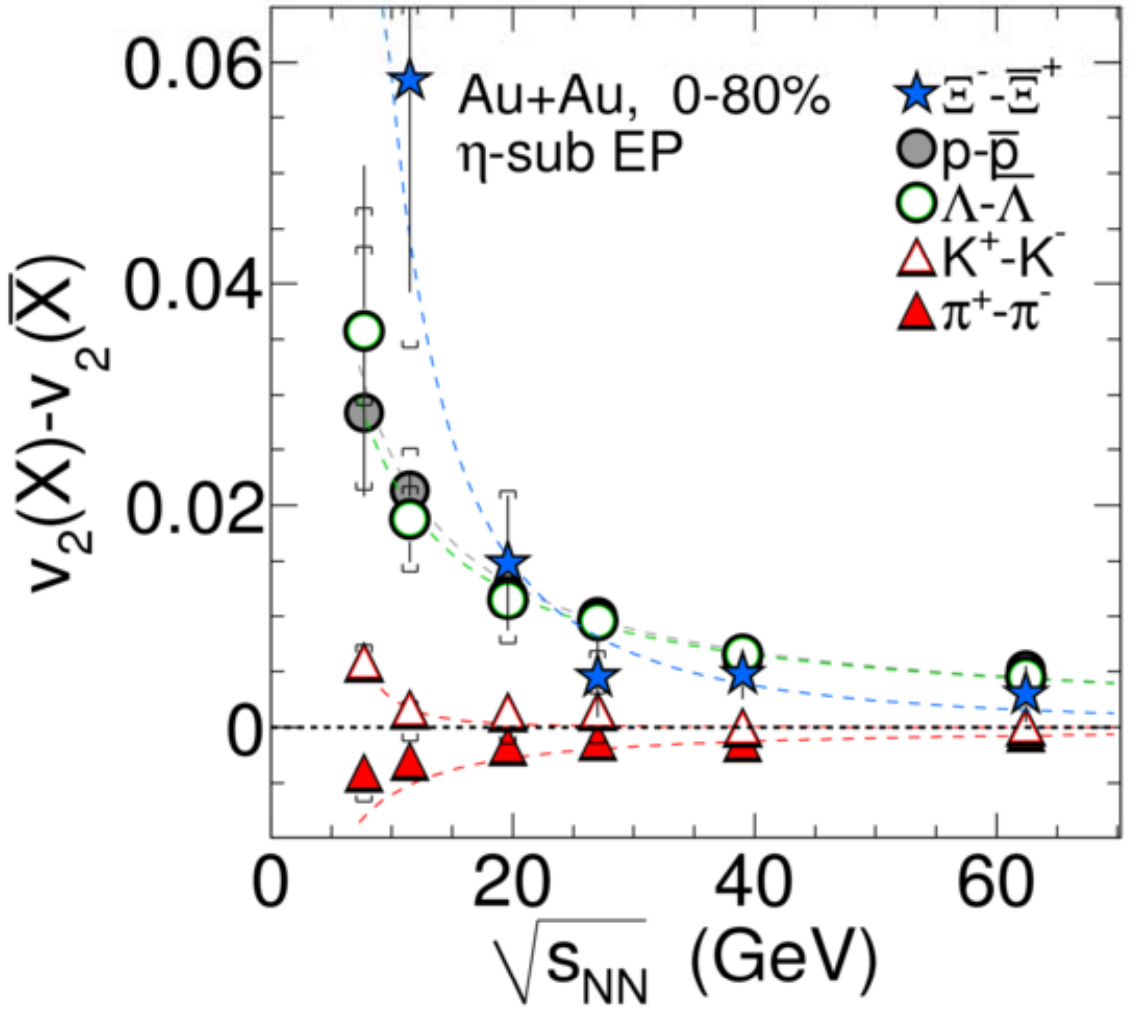
Direct Flow v_1 Slope from BES



Connected to EOS, Sensitive to Phase Transition?

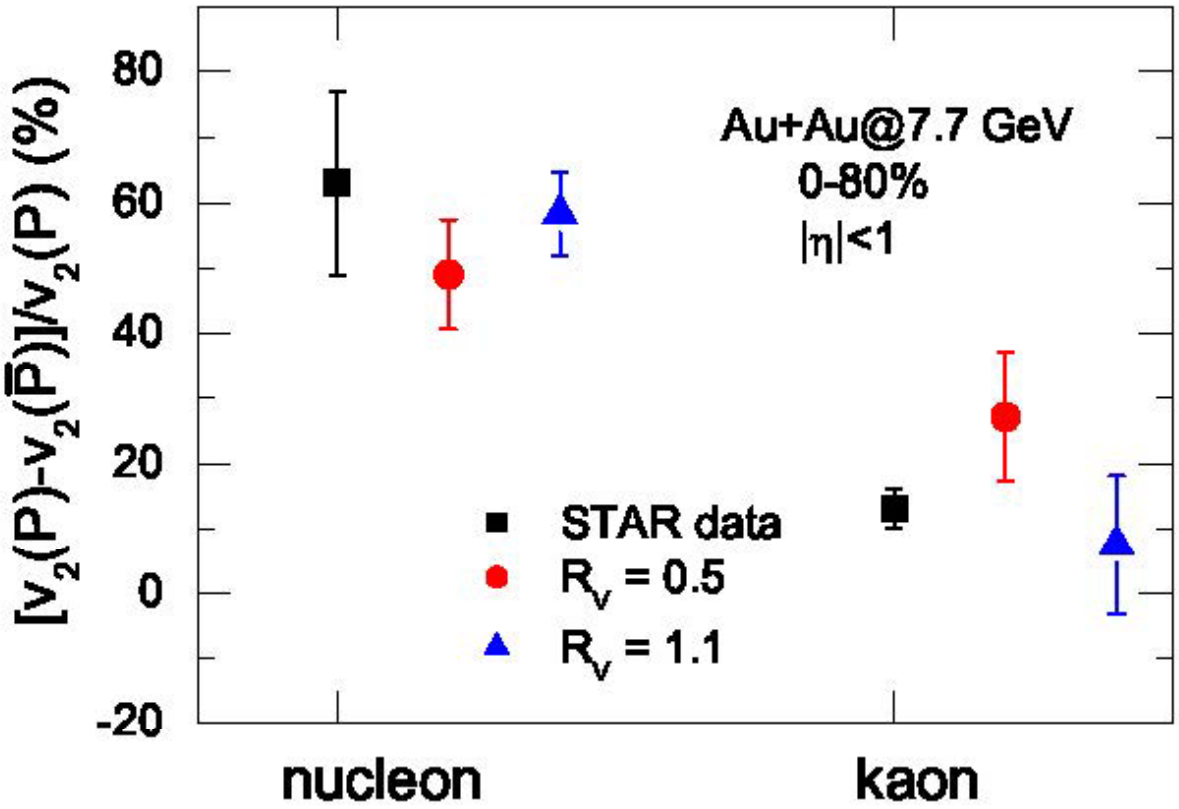
J. Brachmann et al., PRC 61, 024909 (2000)

Systematic v_2 Differences between particle and anti-particles



Mass and Flavor Dependence !!

Implication for large Rv = G_V/G ?



Theoretical models predicted that large R_V →

no critical point or first-order PT in physical region !

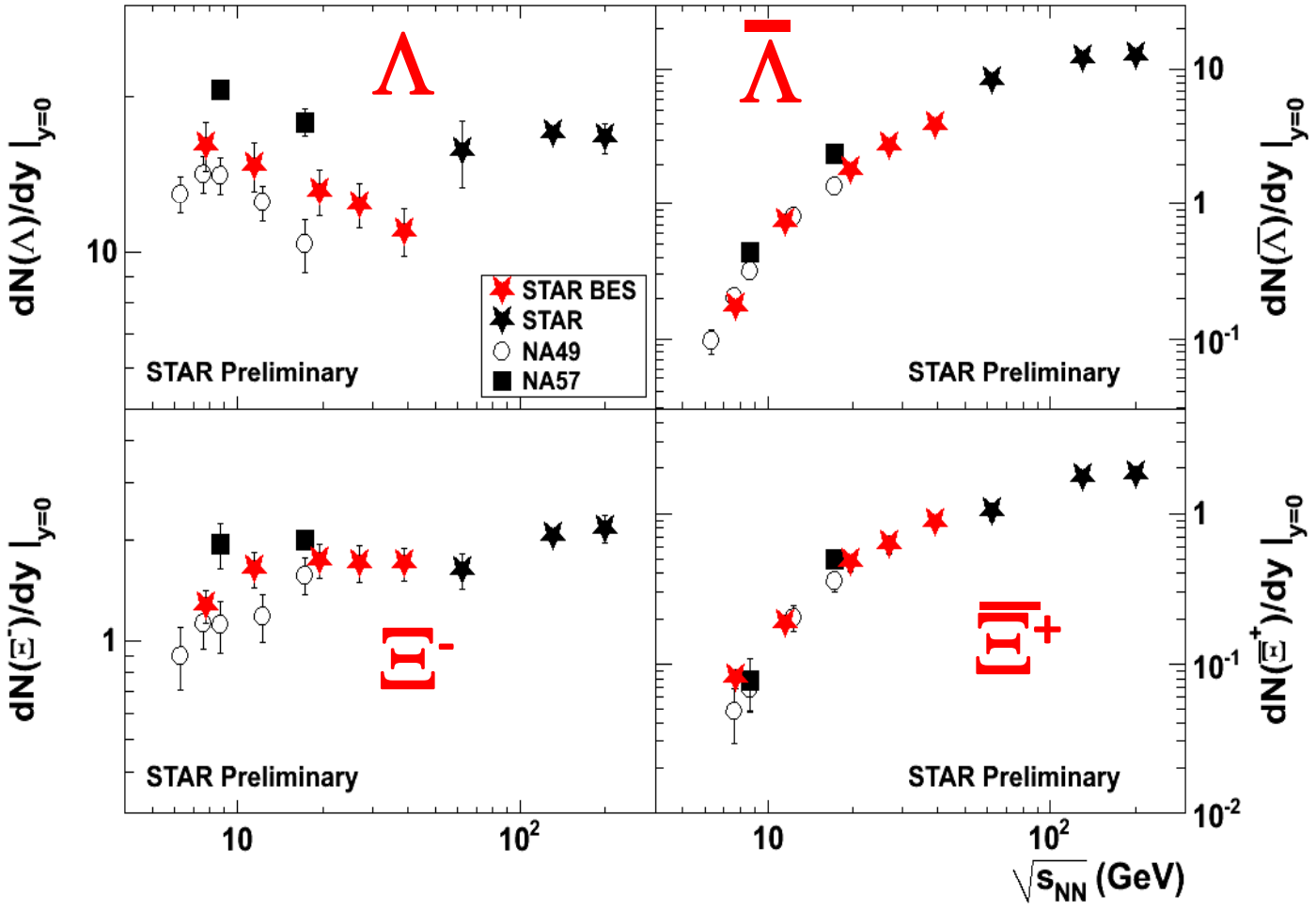
What other measurements to access R_V ?

Jun Xu, Taesoo Song, Che Ming Ko and Feng Li, arXiv 1308.1753

M. Asakawa et al., NP A504, 668 (1989);

N.M. Bratovic, T. Hatsuda and W. Weise, PLB 719 (2013) 131.

Mid-Rapidity Hyperon Yield



Mechanism:
Pair Production
Associated Prod.

-- quark or hadron level

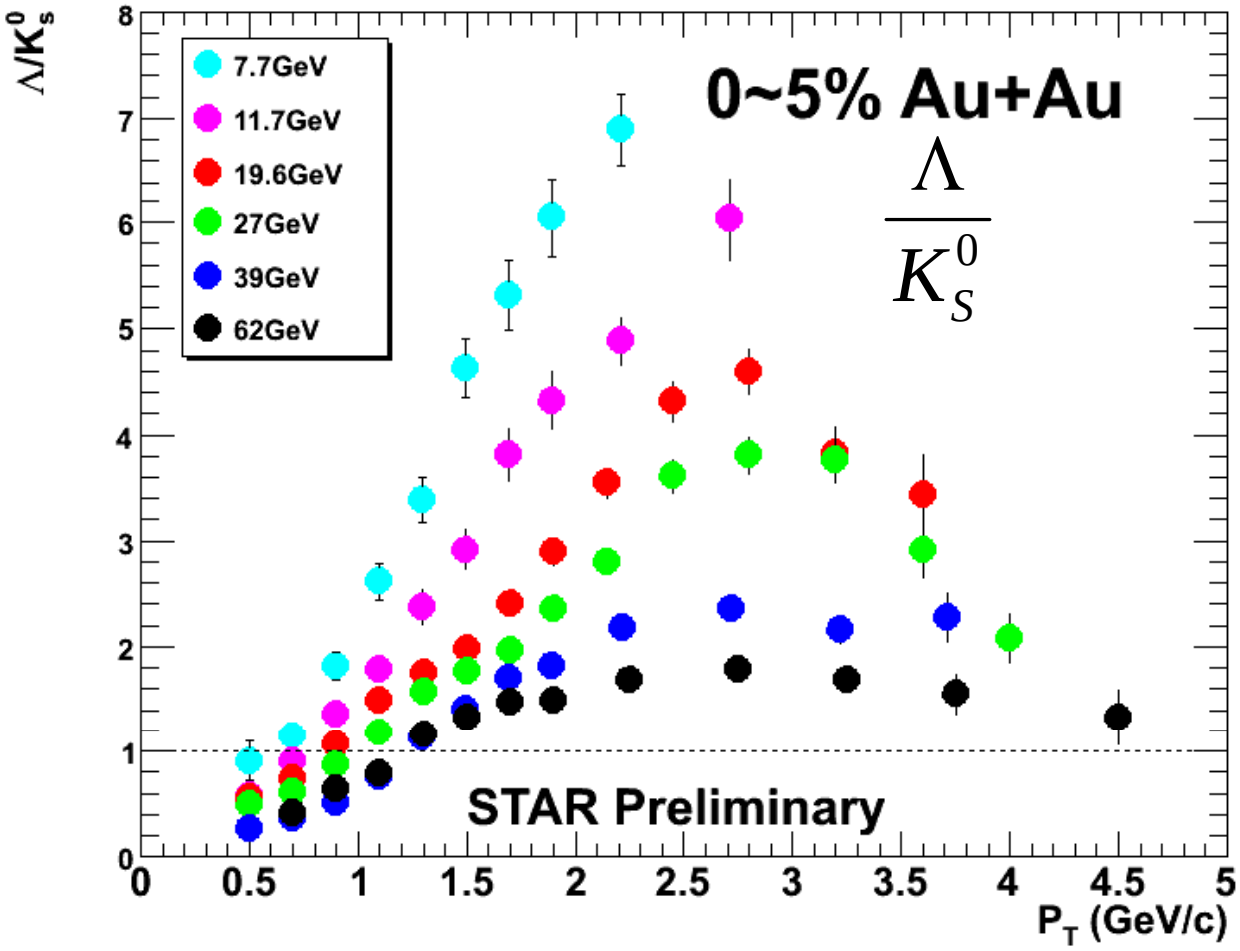
-- difference in hyperon vs. anti-hyperons

-- sensitive to chemical potential

Coalescence and Cluster Formation

Increased Hyperon over Ks ratios

The formation probabilities of baryons and mesons depend on the environment – local parton density



B/m ratios
-- measure of local parton density at hadronization !

Au+Au at 7.7 GeV
-- higher net baryon density !

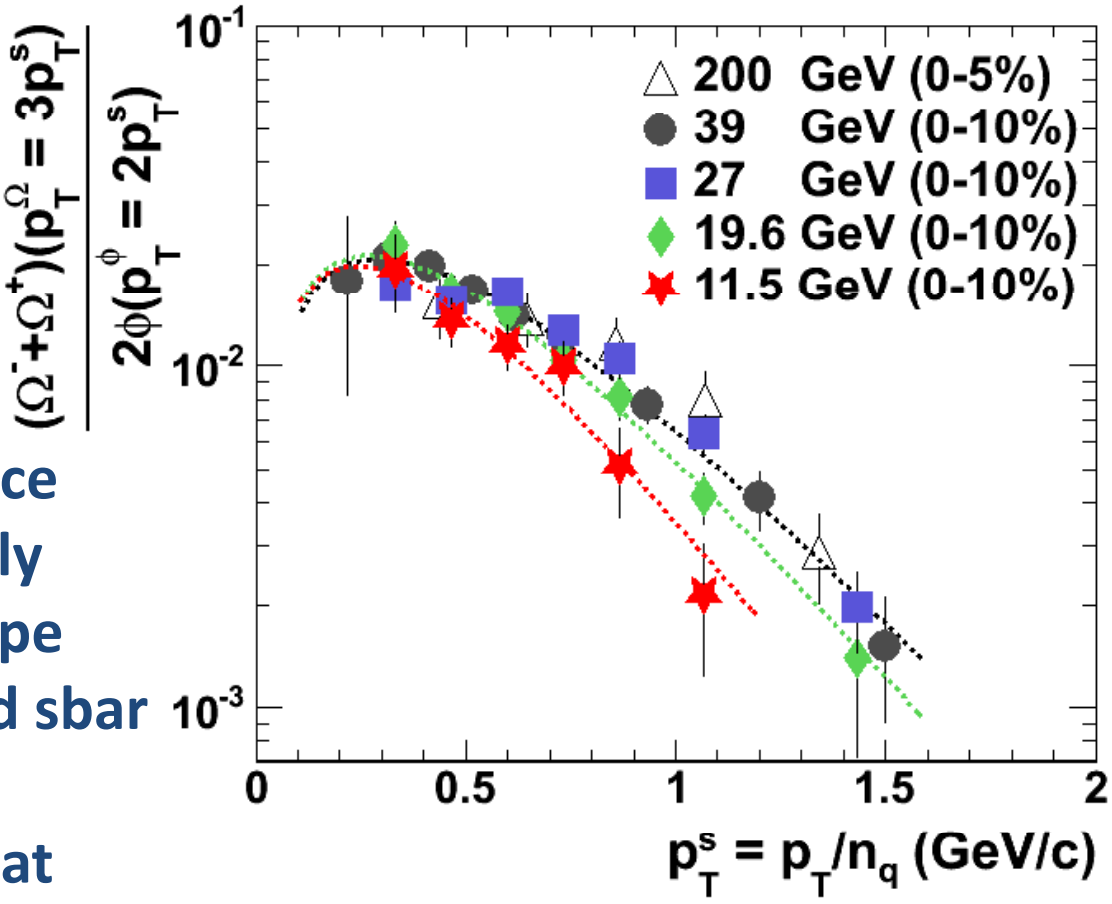
In a broad pT region [1-4] GeV/c, much more hyperons than mesons produced !!
-- Coalescence

Strange quark analysis from Ω and ϕ using Coalescence Framework

Ω(sss) and ϕ(s$\bar{s}$) formed at chemical freezeout from coalescence of 3 s quarks and s-sbar pairs.

Assuming sudden coalescence of s quarks of approximately equal pT and the same shape of pT distributions for s and sbar quarks

The s quark pT distribution at freeze-out ~ $\Omega(3p_T)/\phi(2p_T)$



IS there a difference in partonic dynamics between 11 and 20 GeV?

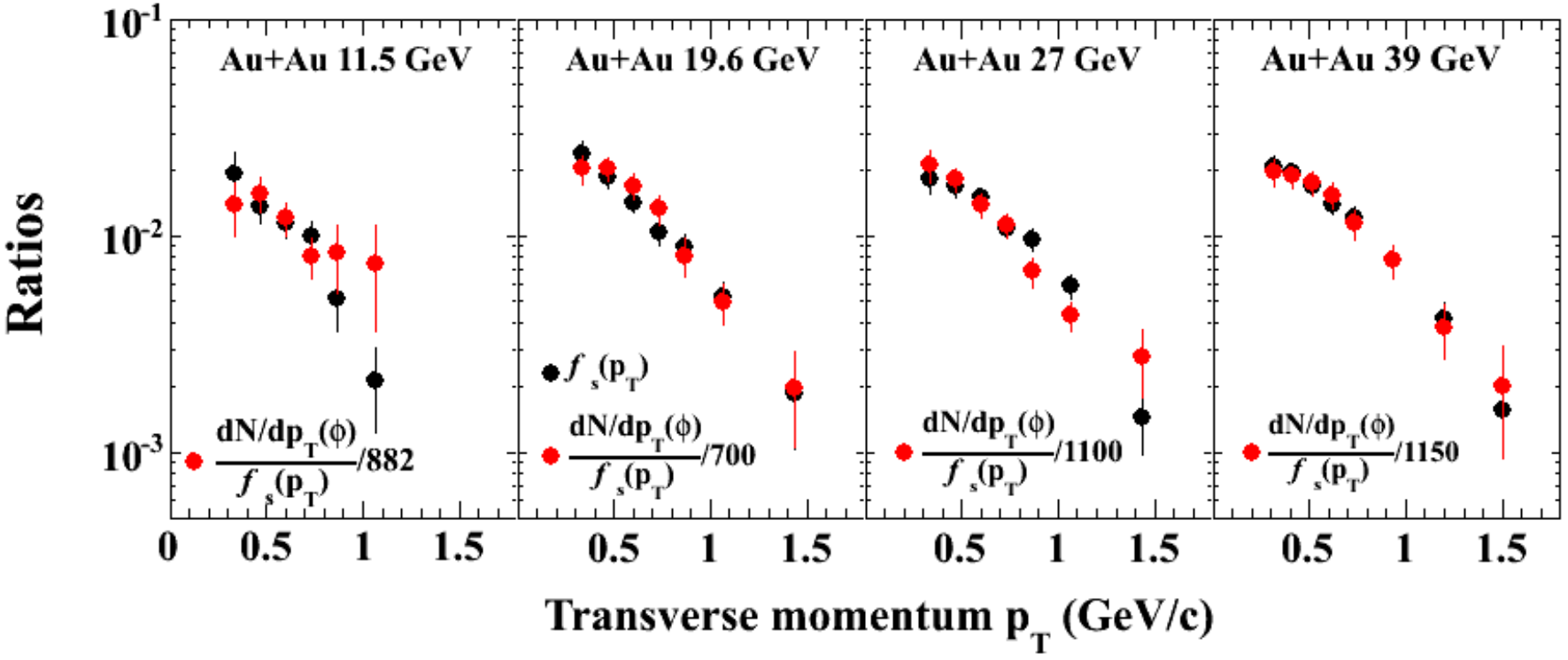
NEED more statistics (BES II) and a 15 GeV run !!

Coalescence Picture !

Independent Empirical Check on Coalescence –

if $s(p_T) \sim \Omega(3p_T)/\phi(2p_T)$, then $\phi(2p_T)/s(p_T)$ is also $s(p_T)$

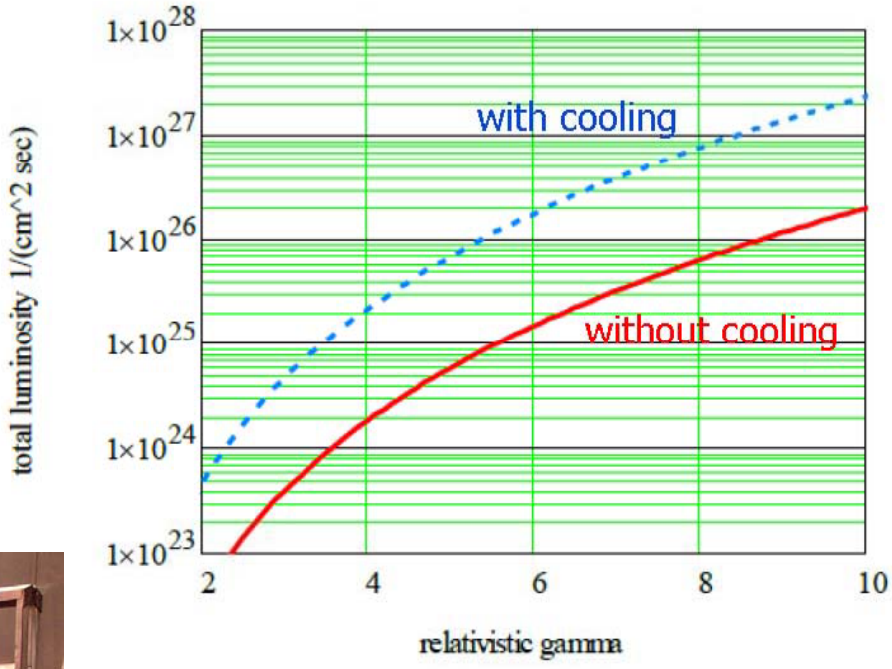
are these functions of similar shape?

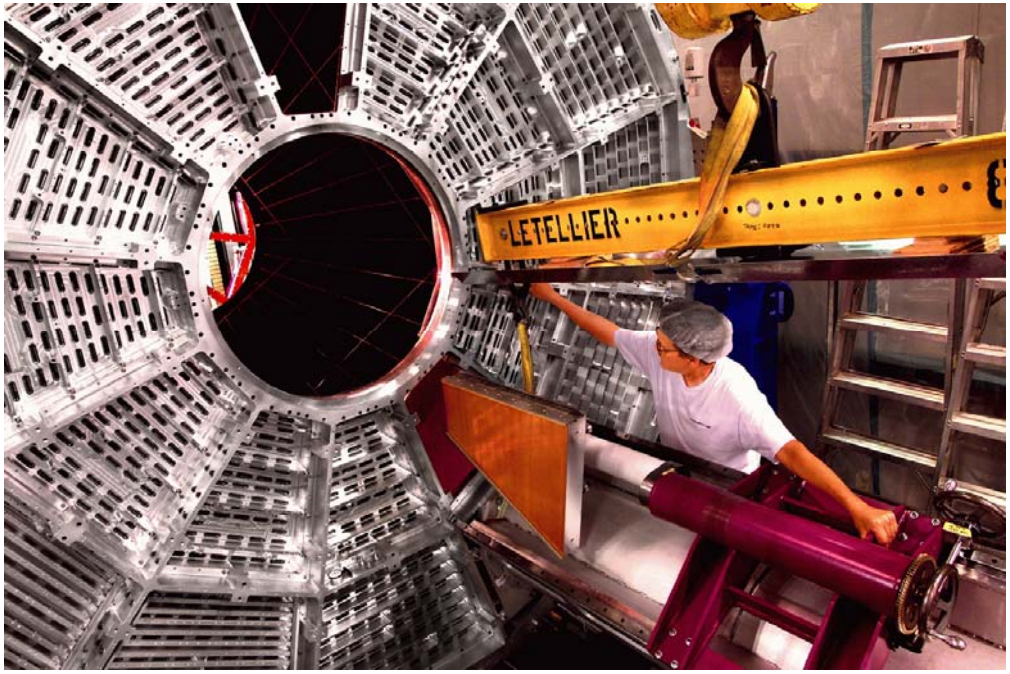


NEED More Data at 11.5 GeV !!

Road to Beam Energy Scan II

1) Need electron cooling to be more efficient !



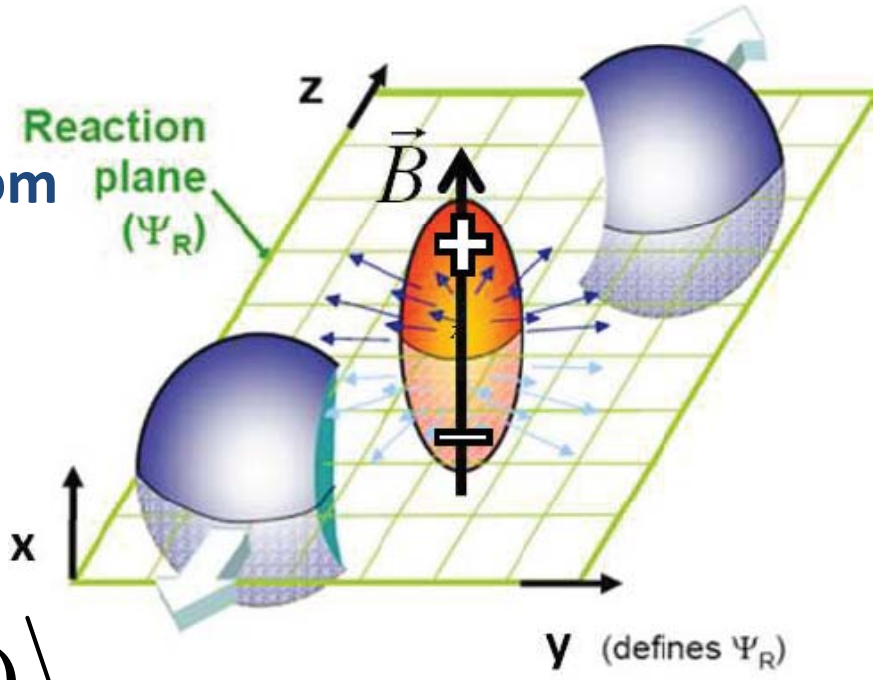


2) STAR TPC Inner Sector readout upgrade
-- enhance tracking and PID in η 1-1.7 region

BES II Starting 2018+

QCD Exotic Phenomena

QCD Vacuum Sphaleron excitation coupled to strong magnetic field from spectator protons
-- charge separation across the reaction plane
parity violating in strong interaction



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

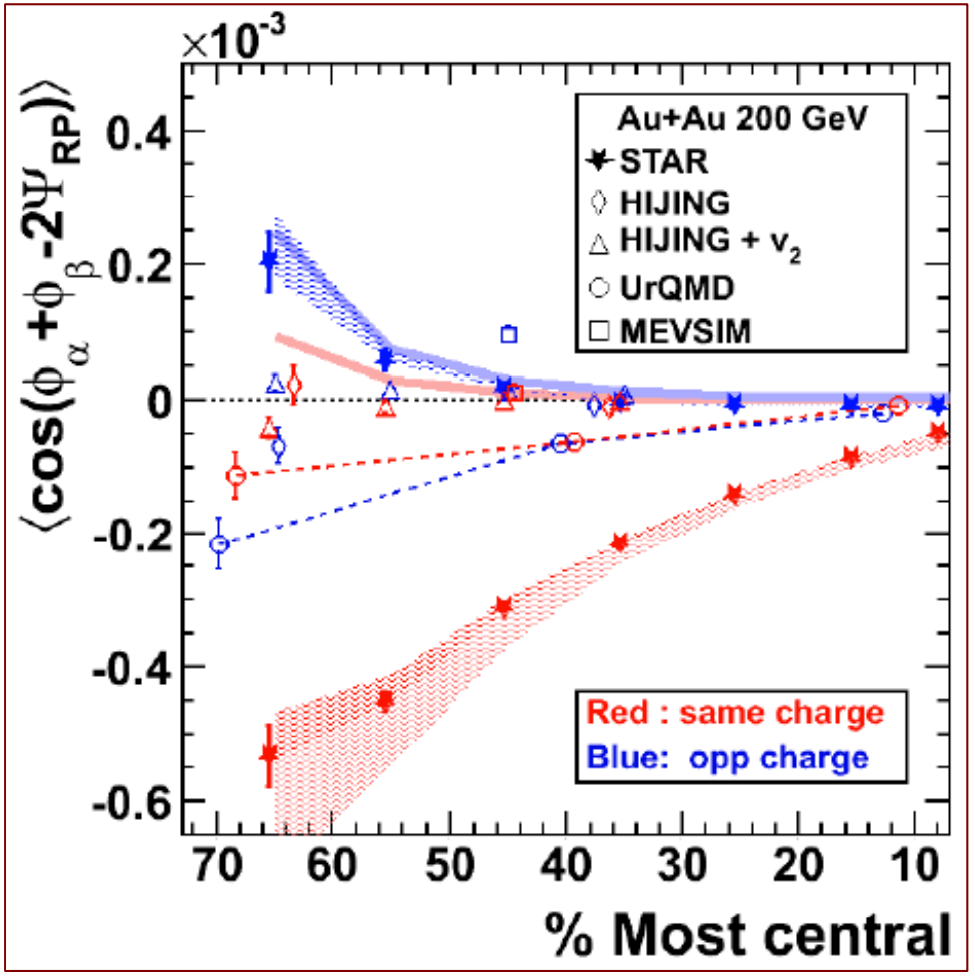
First measurements

B. I. Abelev *et al.* [STAR Collaboration], Phys. Rev. Lett. **103**, 251601 (2009).
B. I. Abelev *et al.* [STAR Collaboration], Phys. Rev. C **81**, 054908 (2010).

Strong charge sign dependent –
Same-Sign (SS)
Opposite-Sign (OS)
correlation – very different feature and magnitude !

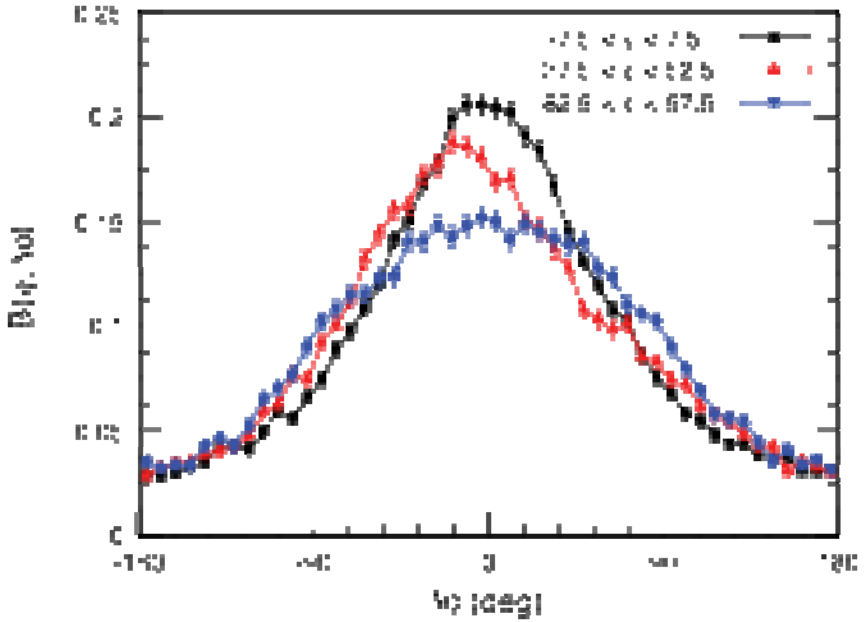
Existing models cannot reproduce the data !

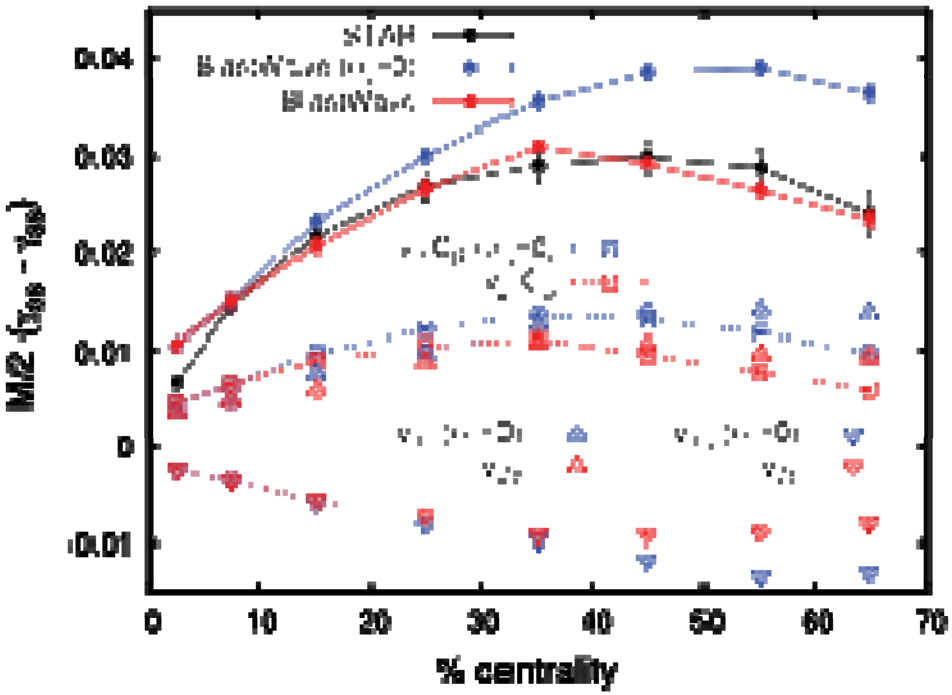
How to separate LPV signal and background?



Conventional Explanation ?

Blast Wave Parameterization = Charge Correlation + Radial + Elliptic Flow

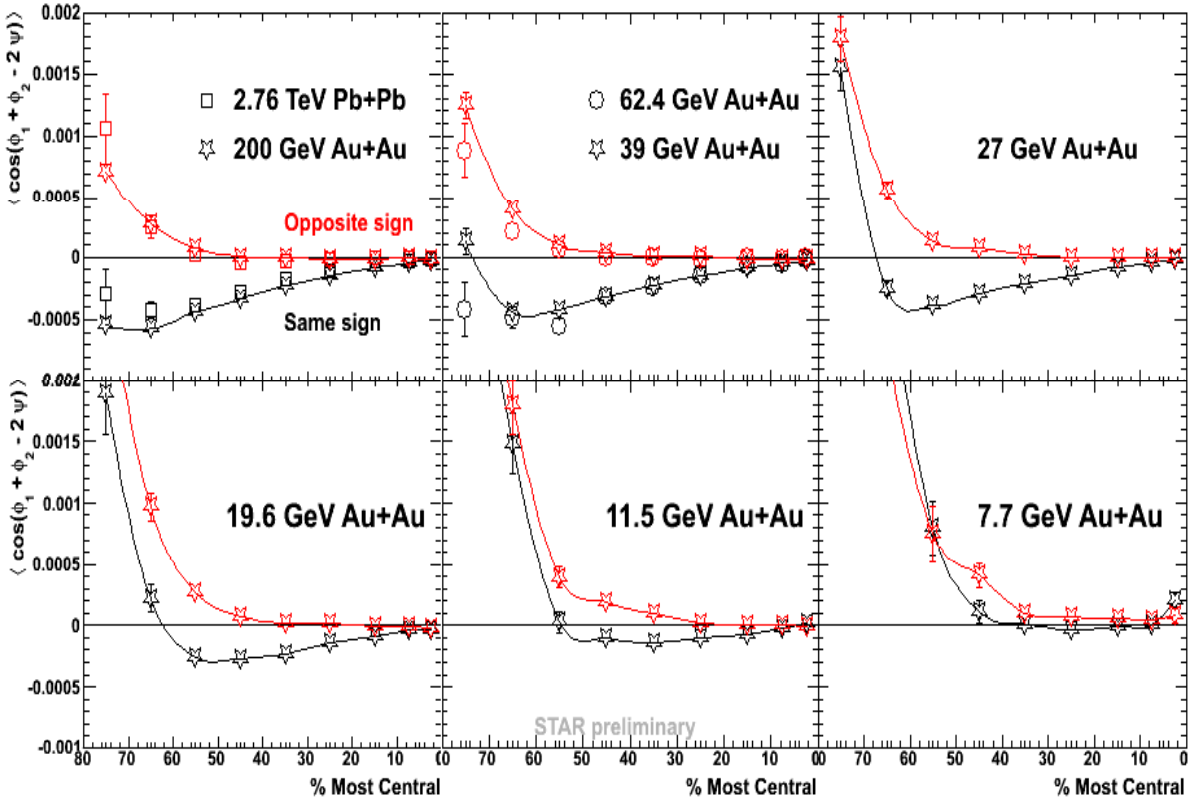




- With some “adjustments” can describe the data (diff “opp” - “same”).
- Note that the correlator is inversely proportional to multiplicity

Schlichting and Pratt, PRC83 014913 (2011)

Recent STAR Results on the Charge Separation Measurement



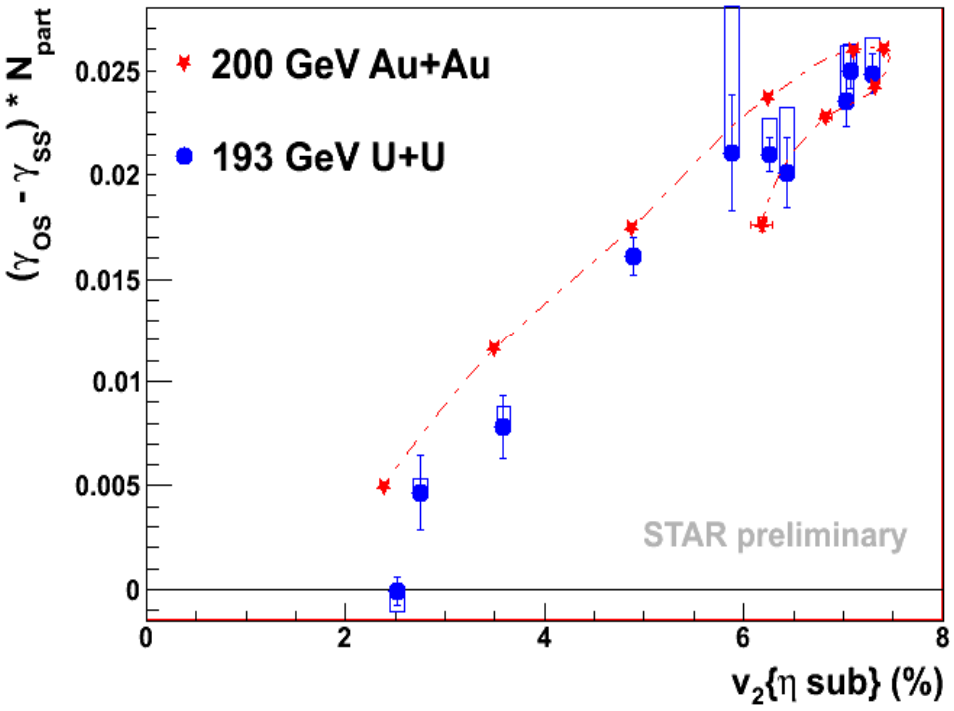
Charge separation

-- disappears at low energy where QGP presumably cannot be formed and/or cannot live long enough!

No QGP → No Local Parity Violation !

Is this the unique explanation ?

Recent STAR Results on the Charge Separation Measurement



Charge separation
-- disappears in very central collisions when magnetic field approaches zero, but elliptic flow is finite !

Background has to be coupled to v_2 –
no reason for background to disappear when v_2 is finite !

Measured correlator unlikely be entirely due to background !

Intriguing, yet inconclusive !

Experimental measurements

-- consistent with some aspects of expectations from chiral magnetic effect and chiral magnetic wave

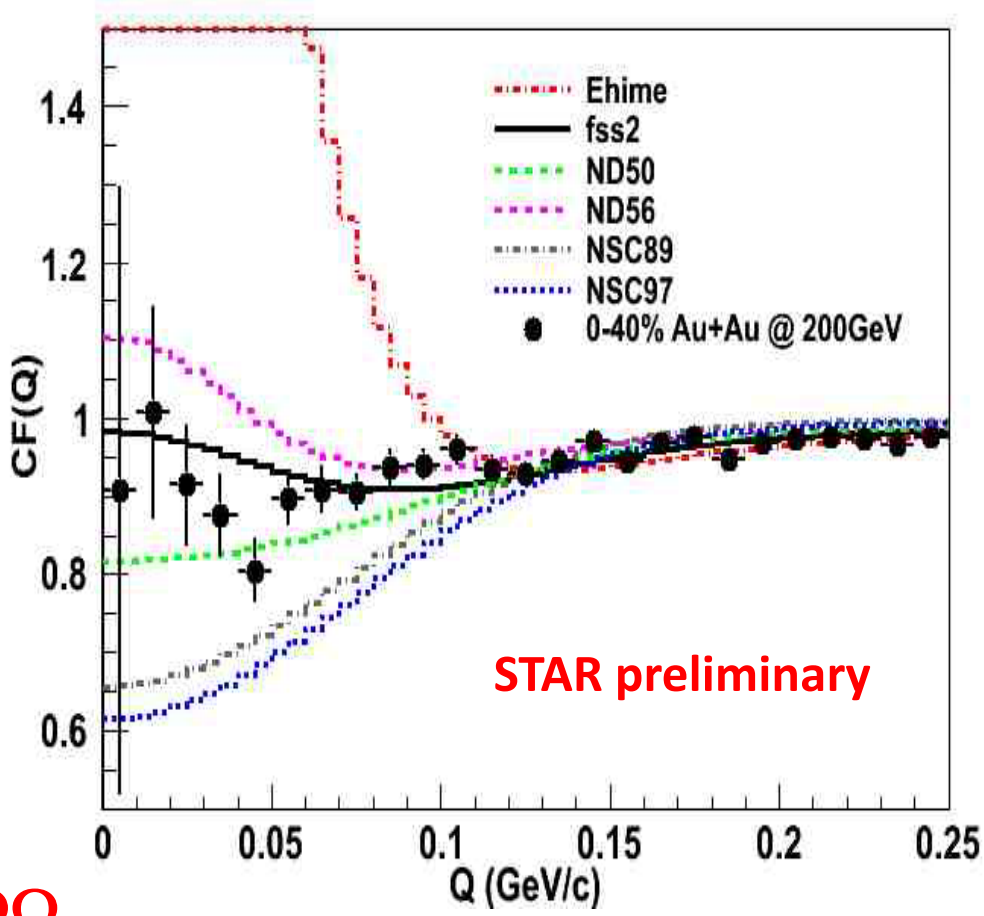
-- But we do not know for sure the magnitude of the background

-- we are not sure of the nature of background for CMW

We need more ideas and explorations !

Searches for Exotic Particles

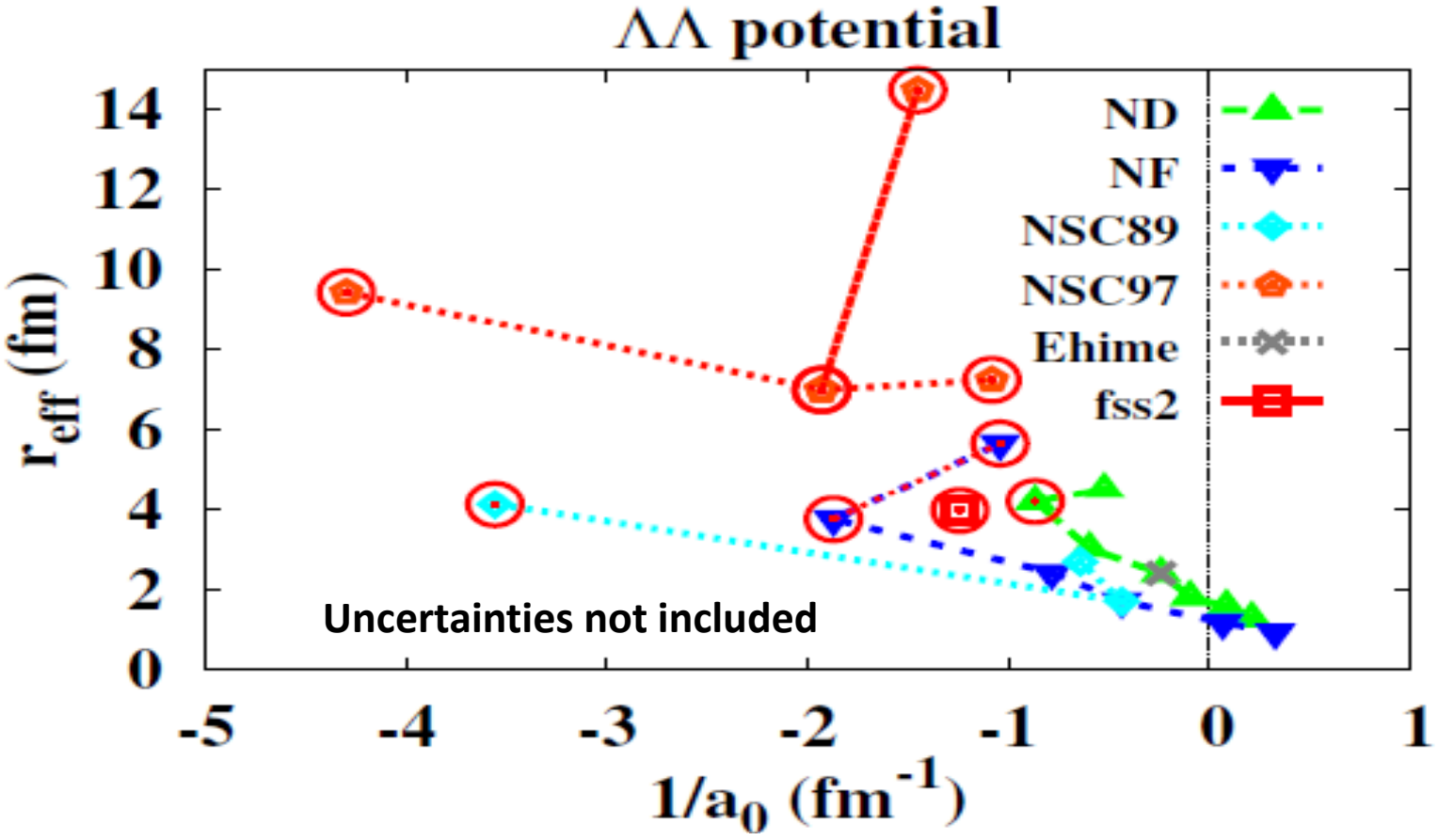
Λ-Λ Correlation
-- sensitive to ΛΛ interaction
H (uuddss) bound state
-- depletion of ΛΛ pairs



Theoretical models fit to
STAR preliminary data:
ΛΛ – attractive interaction
no bound state !

Other di-hyperons ? ΞΞ or ΩΩ
Other exotic particles?

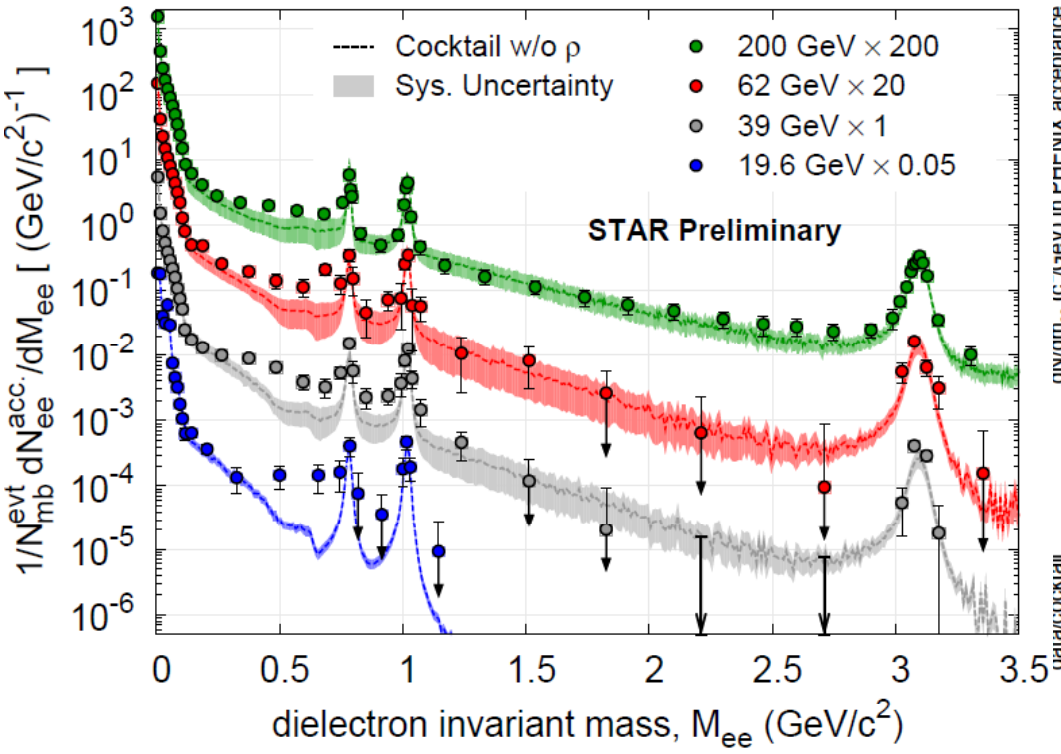
Λ-Λ Correlation Function

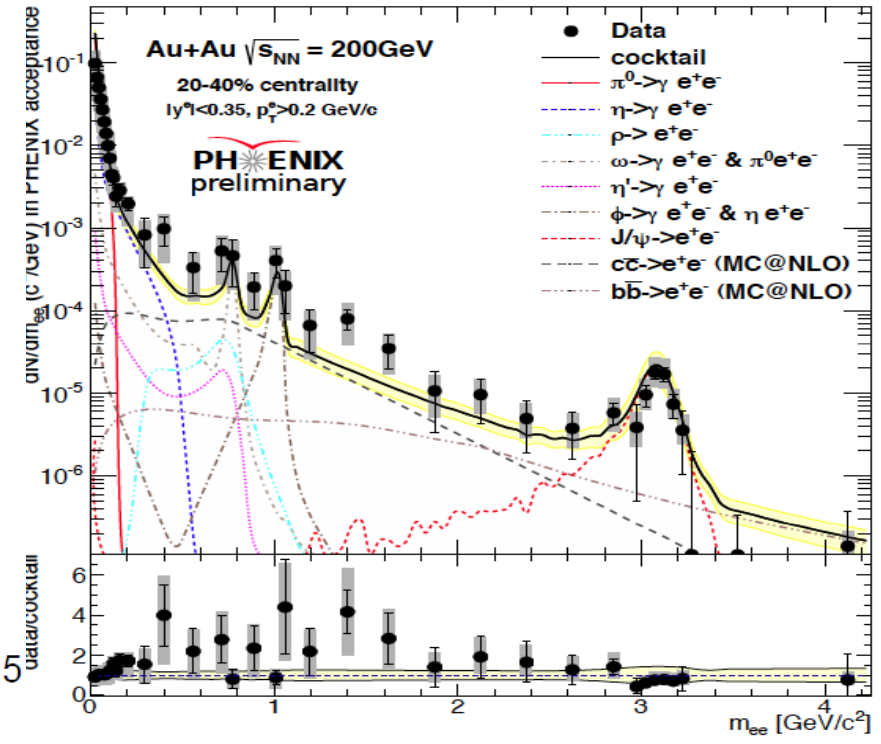


A. Ohnishi, HHI workshop proceedings 2012

- Scattering length (a_0) is negative in most fits
- Current fit from different potential models to data gives indication towards non-existence of bound H-dibaryon

Chiral Symmetry and Di-electrons





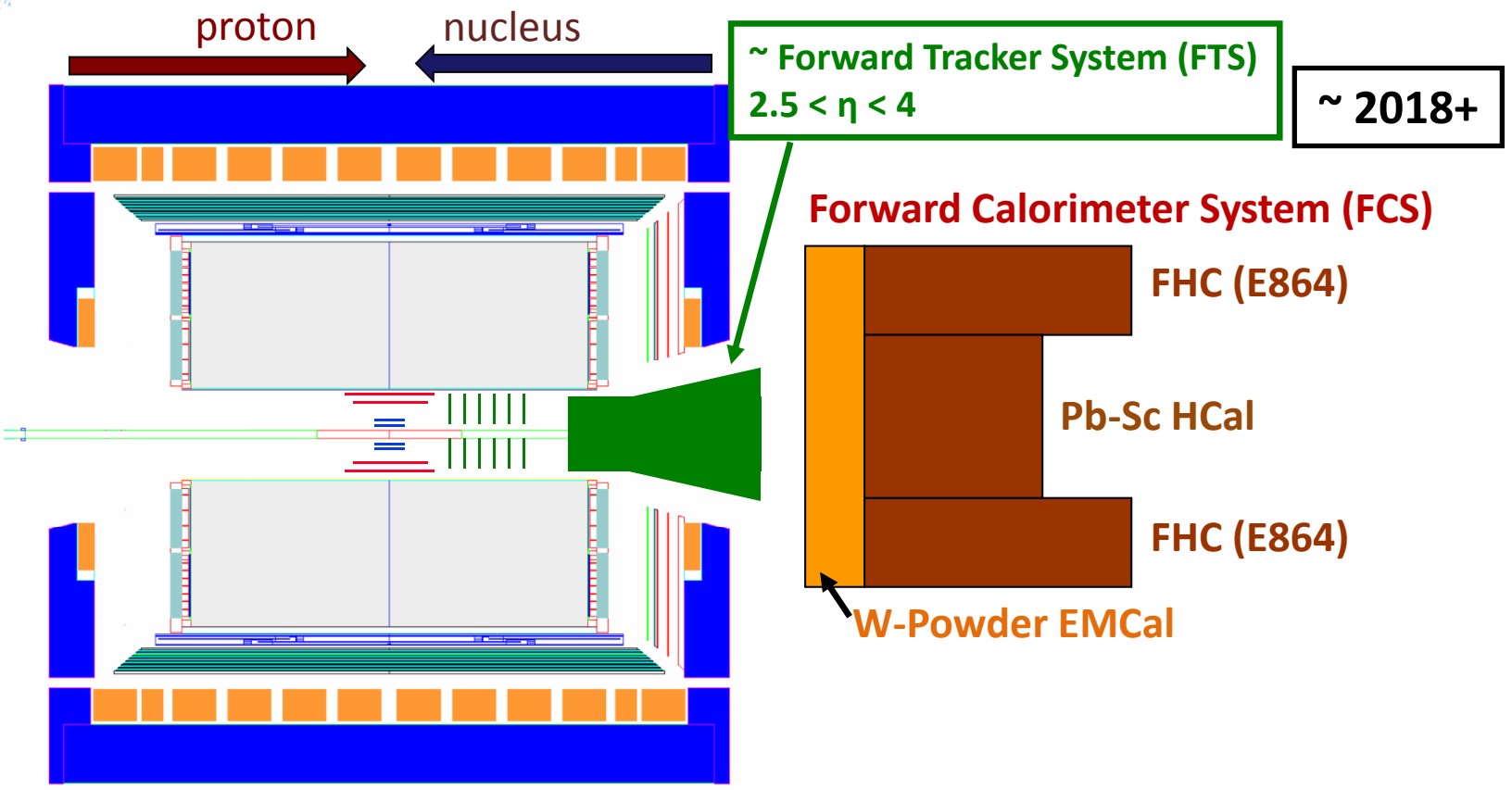
Low mass region (<1.0 GeV) – vector meson properties in the QCD medium

Intermediate mass region (1-3 GeV) – QGP radiation and heavy quark decays (depends on heavy quark evolution in the QCD medium)

Very difficulty experimental measurements!

lessons from SPS – need 5-10 years to understand the signal and background!

STAR Forward Upgrades: QCD at X and x

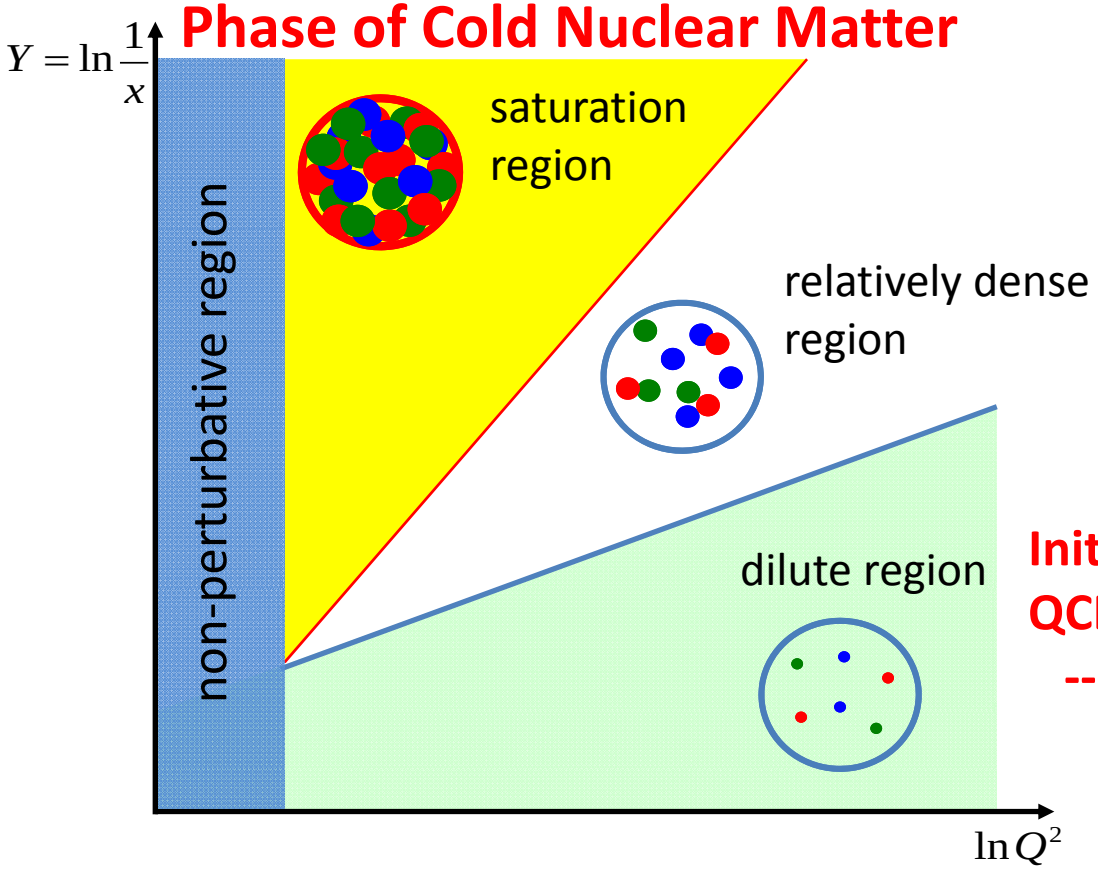


- **Forward instrumentation optimized for pp/pA and AA**
  - **Charged-particle tracking**
  - ***e/h* and γ/π^0 discrimination**
  - **Jet reconstruction**

Gluon Saturation in Nuclei

pA dynamics in the forward proton semi-sphere sensitive to details of the gluons in the nuclei

Phase of Cold Nuclear Matter



Forward direction kinematics favors parton scatterings of large x partons from p off small x partons from A !

Initial conditions for AA
QCD in high density non-linear regime
-- Color Glass Condensate

The quantum nature of the partons must manifest through saturations ! At what Q_S and x scales and to what extent?

RHIC – a Dedicated QCD Facility

QCD – Fundamental Corner Stone of the Standard Model !!

-Dynamics of QCD in bulk matter, vacuum structure and hadrons?

Condensed Matter Physics with Underlying QCD Interactions !

We are beyond the QGP discovery phase already !

LHC -- Energy/Temperature Frontier

RHIC – New Horizons in QCD Phase Structure, Vacuum Excitation, Initial State Color Charge Dynamics, Hadron Structure and Exotics

The Best of STAR is yet to Come

Heavy Flavor Physics – HFT/MTD: 2014-16

QCD Phase Diagram – BES Phase II: 2018-19

Spin, CNM Color Dynamics and AA – Towards eRHIC

eSTAR – STAR in the eRHIC Era