Beam Energy Scan at RHIC

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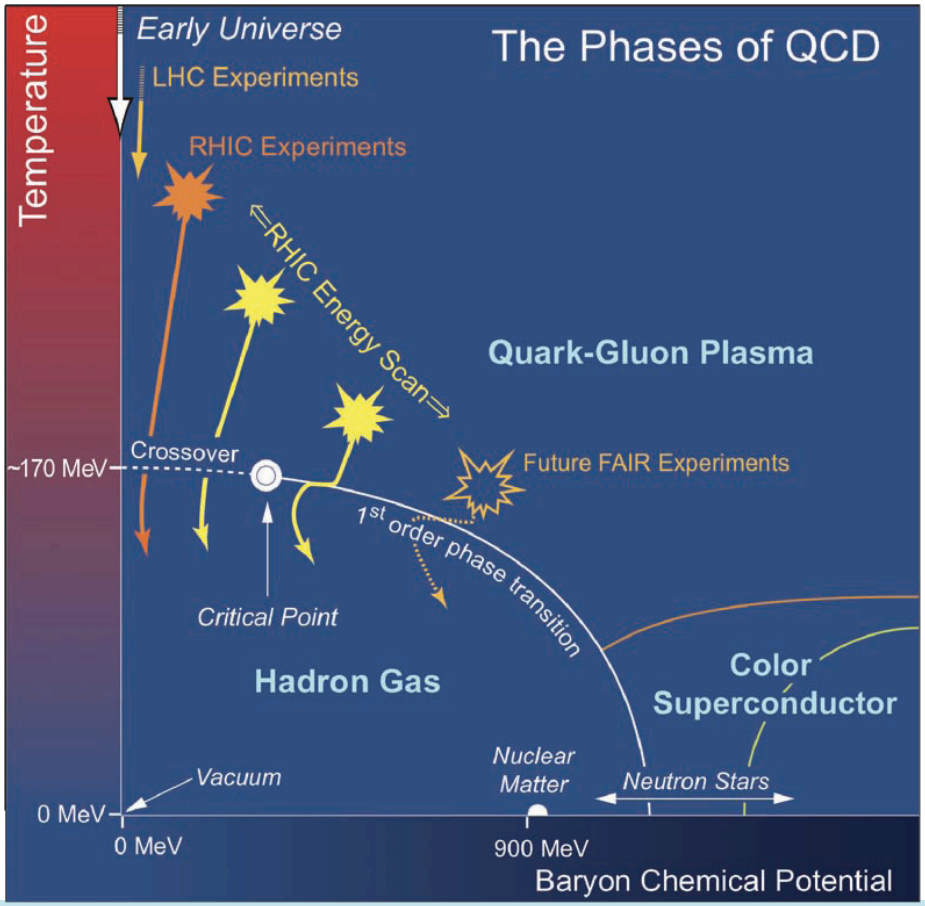
Outline

- ***Goals of Beam Energy Scan Program***
- ***Selected results***
- ***Summary***
- ***Future plans***

EMMI Workshop 'Prospects and Challenges for Future Experiments in Heavy Ion Collisions', GSI, 15th -16th Feb 2013

Goals of BES Program



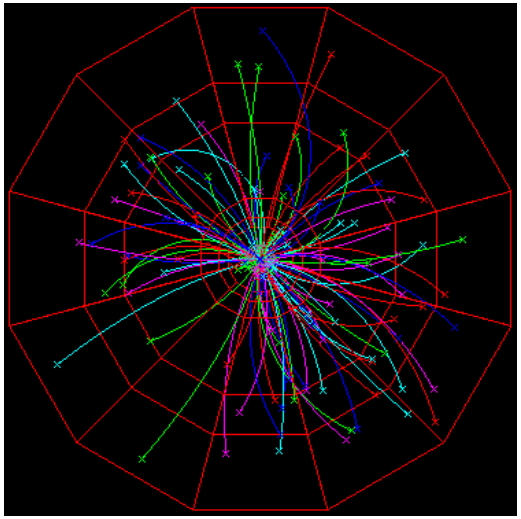
Study the phase structure of QCD Phase diagram

- ***Consolidate the signals of quark-hadron transition observed at top RHIC energies***
- ***Look for signatures of possible 1st order phase transition***
- ***Look for signatures of possible critical point***

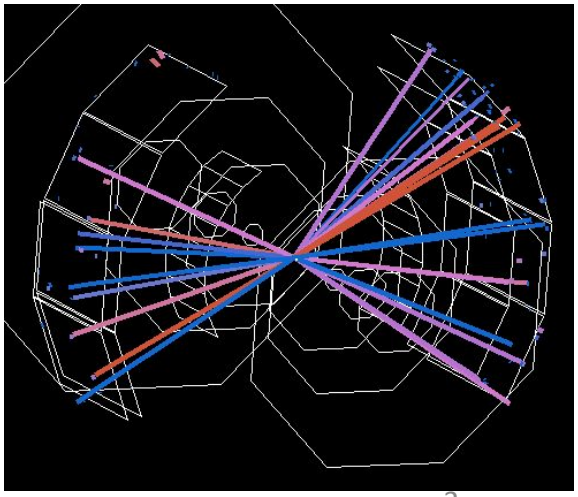
Beam Energy Scan Program

Beam Energy (GeV)	PHENIX	STAR	Year
5.0		✔	2012 (Test Run)
7.7	✔	✔	2010
9.2		✔	2008 (Test Run)
11.5		✔	2010
19.6	✔	✔	2011
27	✔	✔	2011
39	✔	✔	2010
62.4	✔	✔	2010
200	✔	✔	2010

STAR

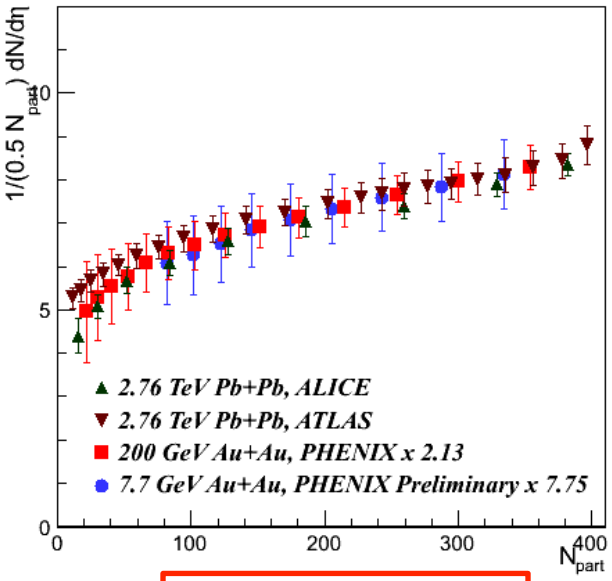


PHENIX

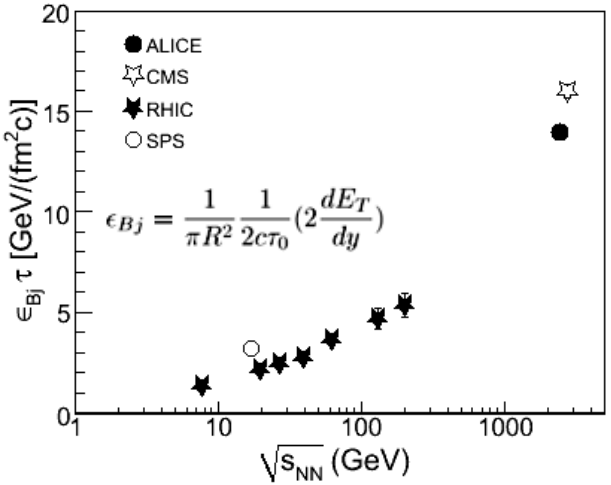


Observations at Freeze-out

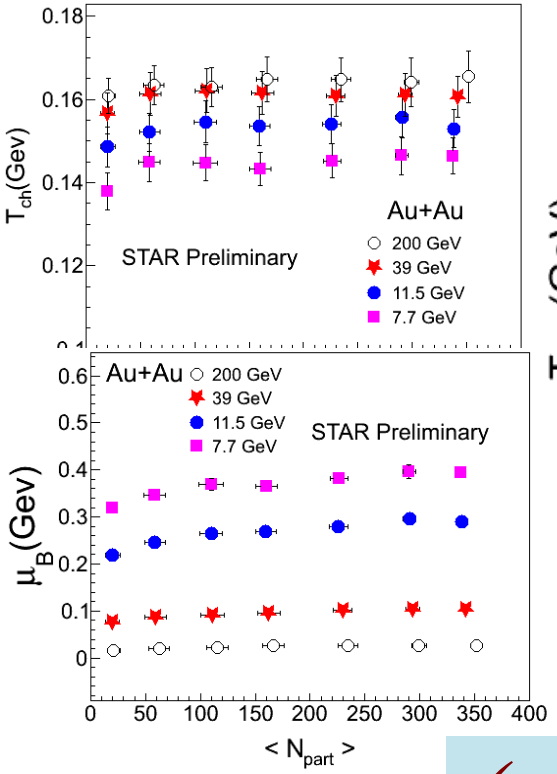
Multiplicity Density

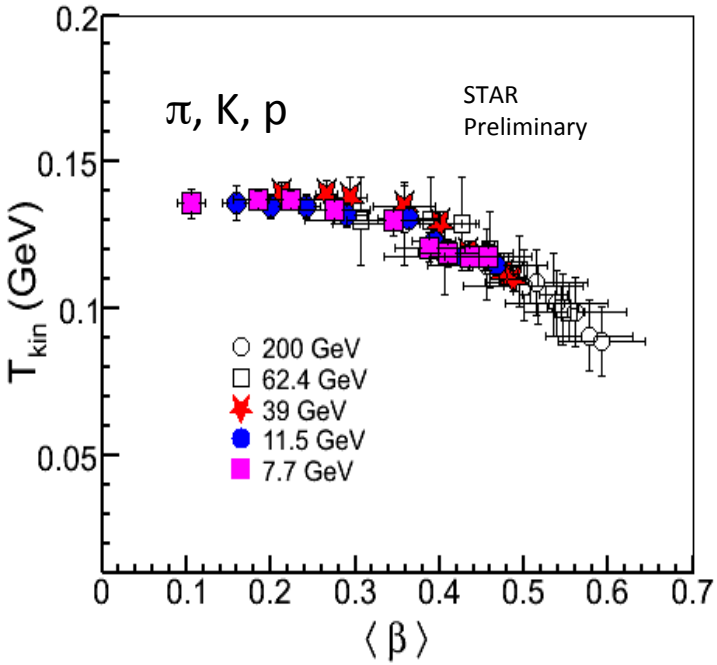


Energy Density



Temperature, Collectivity and Baryon Density



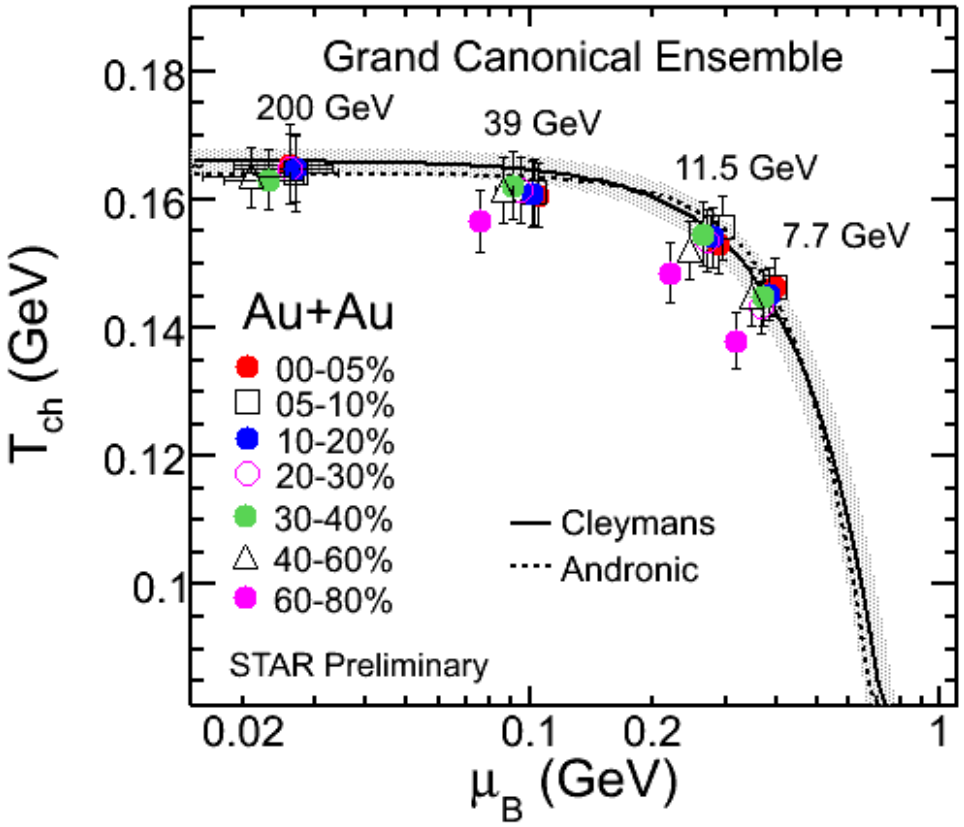


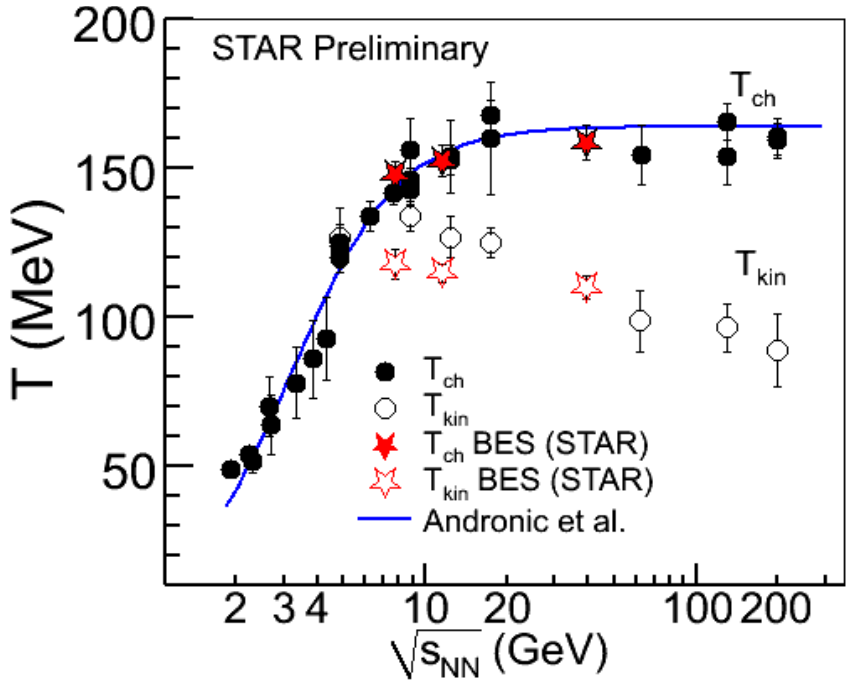
Jeffery T. Mitchell, QM2012

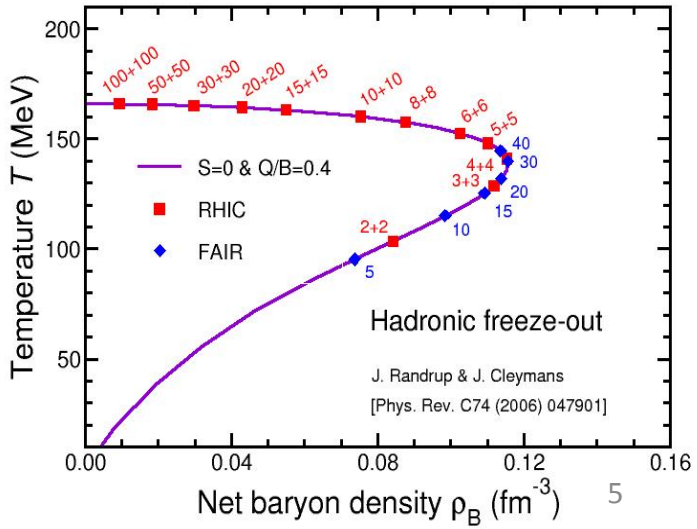
Lokesh Kumar, QM2012
Sabita Das, QM2012

- ✓ $dN_{ch}/d\eta$ and ε_{bj} varies ~ 4
- ✓ T_{ch}: 160 – 140 MeV
- ✓ μ_B: 20 – 400 MeV
- ✓ T_{kin}: 90 – 130 MeV
- ✓ β : 0.6 – 0.08

BES: Freeze-out Dynamics



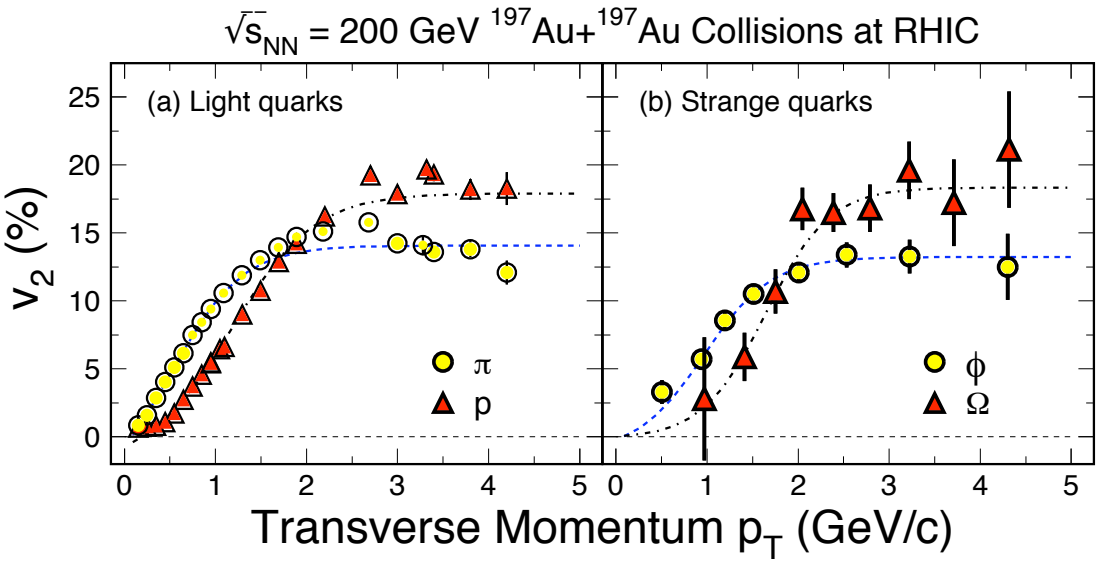


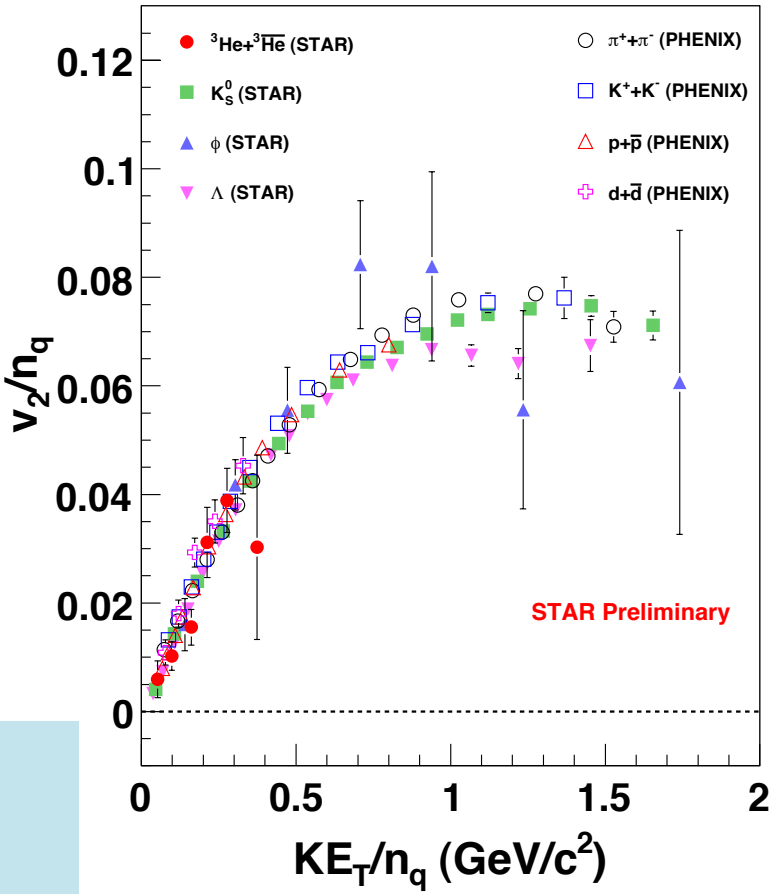


- ✓ ***Temperature dependence of baryon chemical potential***
- ✓ ***Life time between chemical and kinetic freeze-out reduced***
- ✓ ***High net-baryon density matter formed***

Top RHIC Energy: NCQ Scaling

Baryon-Meson Splitting -→ NCQ Scaling





Low p_T : hydrodynamic mass ordering

High p_T: ***number of quarks scaling***

✓ ***Partonic Collectivity***

✓ ***De-confinement in Heavy-Ion collisions***

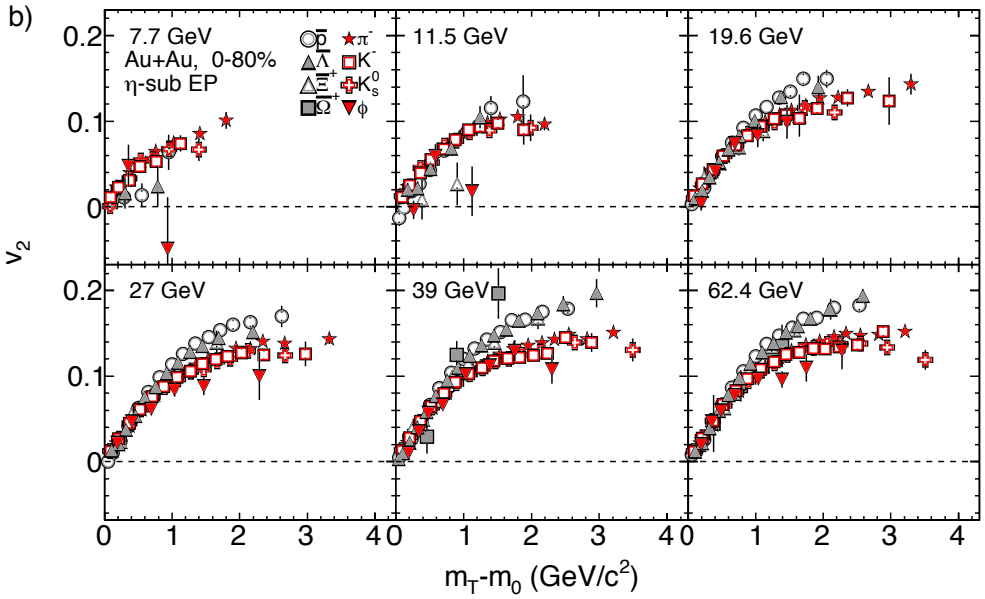
STAR: QM2009, CPOD2011

STAR, PRL **95**, 122301 (2005)

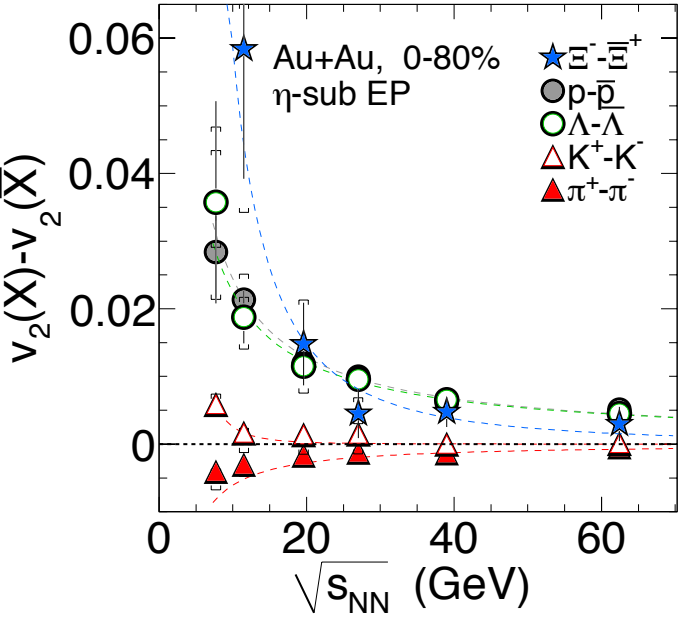
PHENIX, PRL **98**, 162301 (2007)

BES: Break down of NCQ Scaling

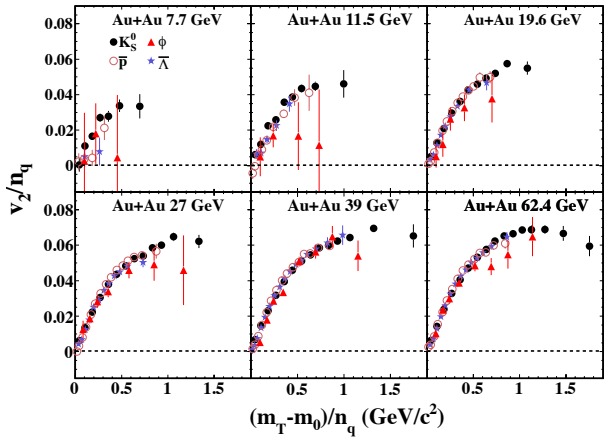
Absence of baryon-meson splitting



V_2(particles) ≠ V_2(anti-particles)



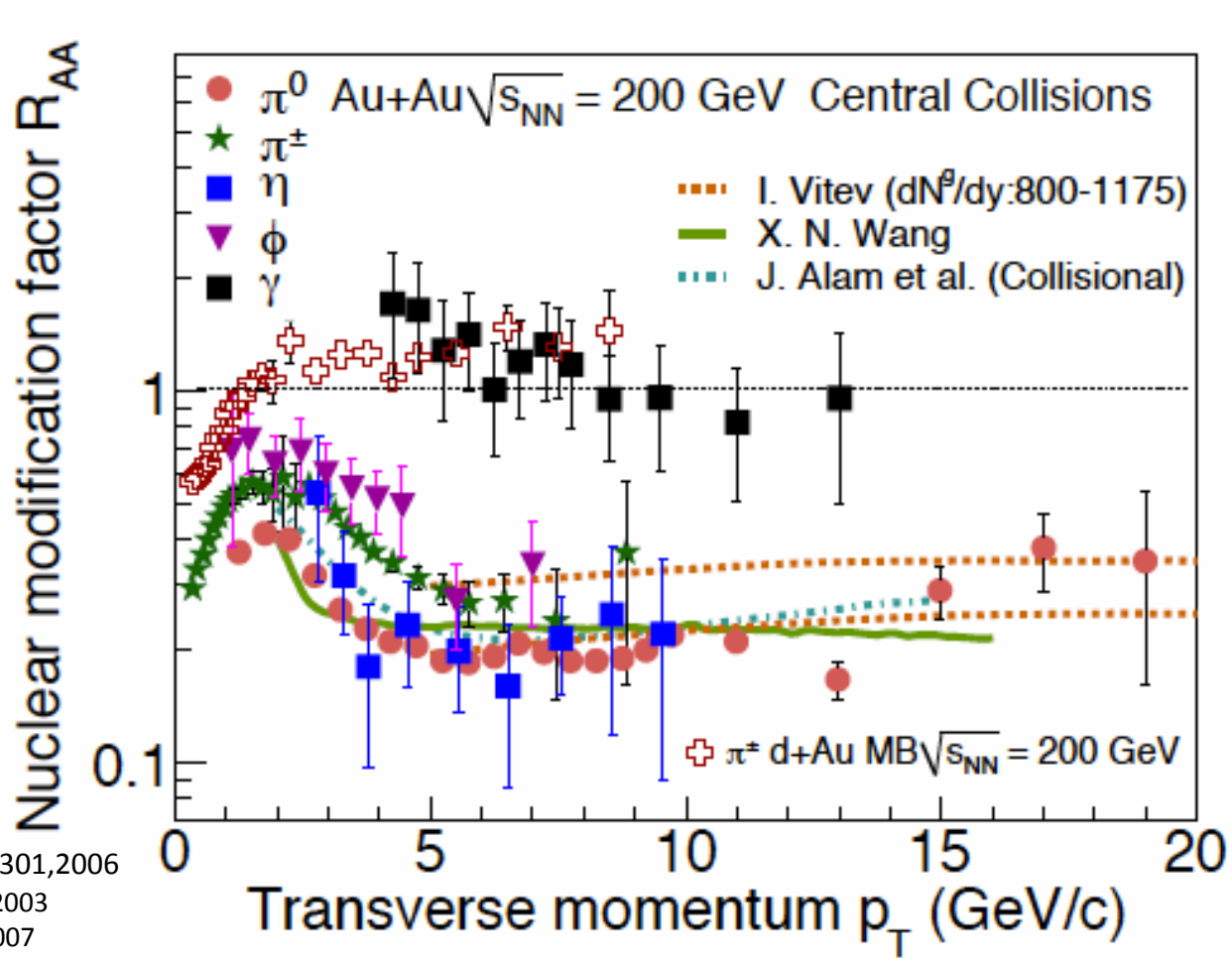
Small azimuthal anisotropy for ϕ-mesons



NCQ scaling as seen for 200 GeV not observed for 11.5 GeV

STAR: 1301.2347 and 1301.2348

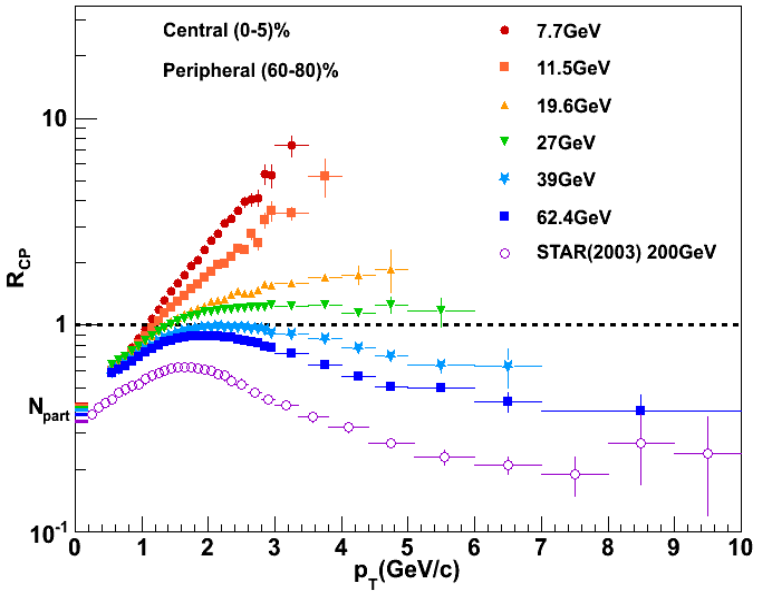
Top RHIC Energy: Suppression in High p_T Hadron Production

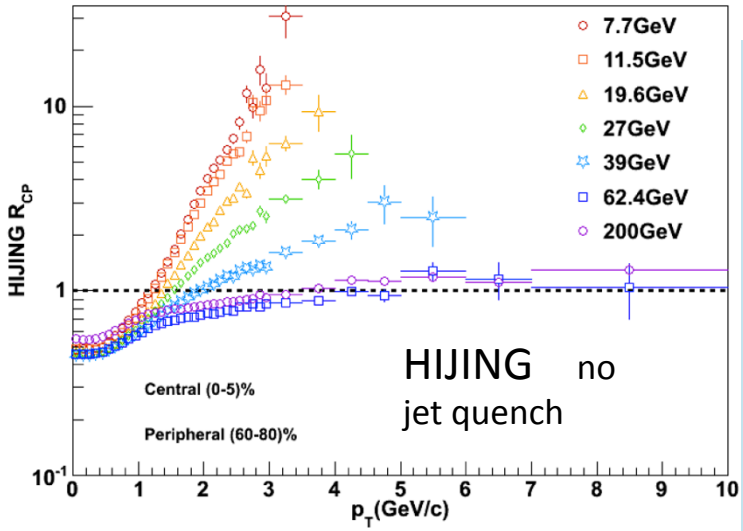


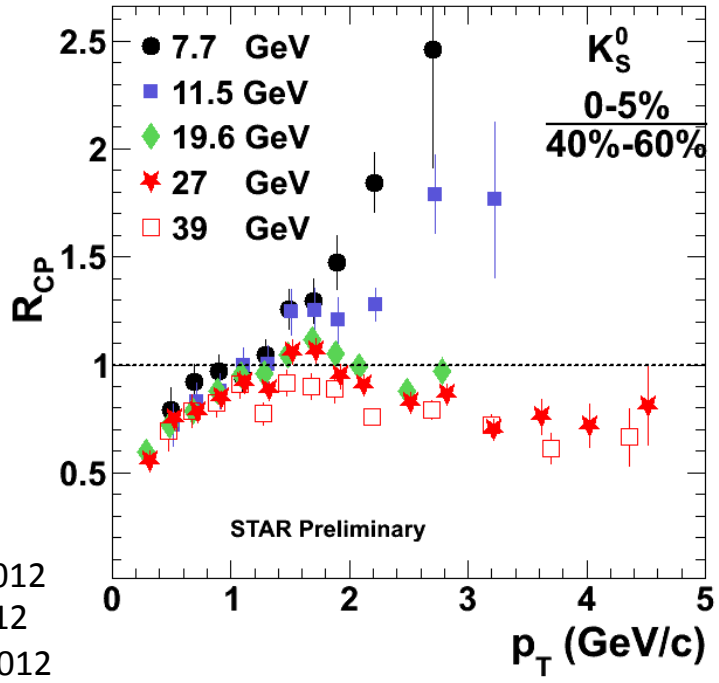
PHENIX : Phys.Rev.Lett.96:202301,2006
STAR : Phys.Rev.Lett.91:072304,2003
Phys.Lett.B655:104-113,2007
New J.Phys.13:065031,2011

Dense medium with color charges – De-confined state

BES: Enhanced High p_T Hadron Production



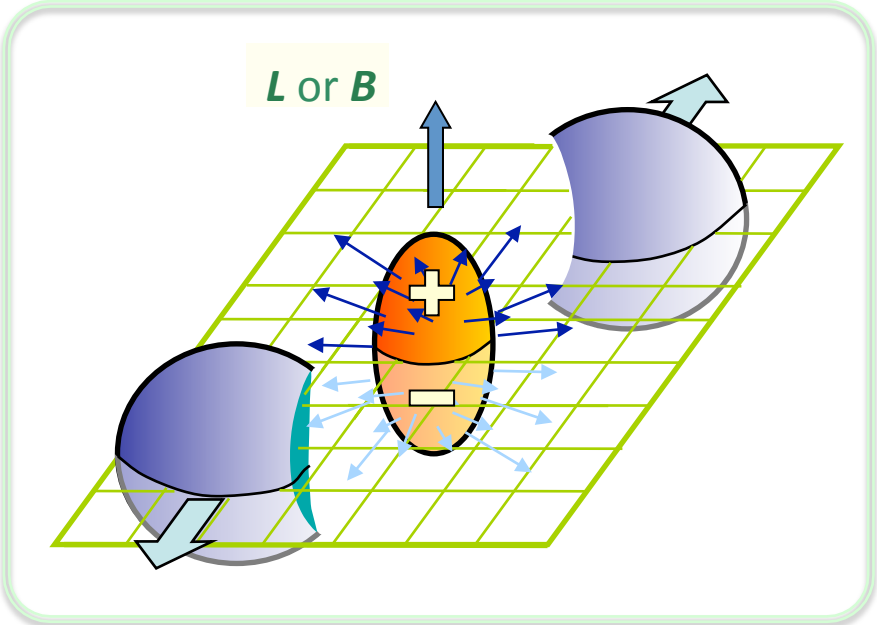




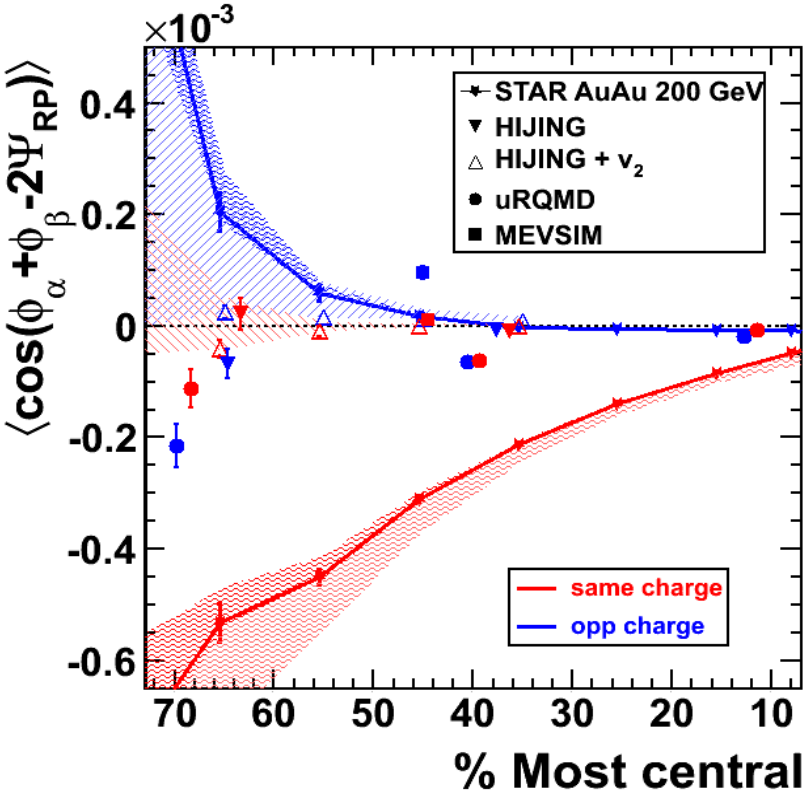
Xiaoping Zhang, QM2012
Lokesh Kumar, QM2012
Stephen Horvat, QM2012

- ✓ ***Enhanced high p_T (> 2 GeV/c) production***
- ✓ ***Lower BES energies qualitatively resembles scenario with no jet quenching as in HIJING***

Top RHIC Energy: Charge Correlations



STAR:PRL 103 (2009) 251601;
STAR: 0909.1717

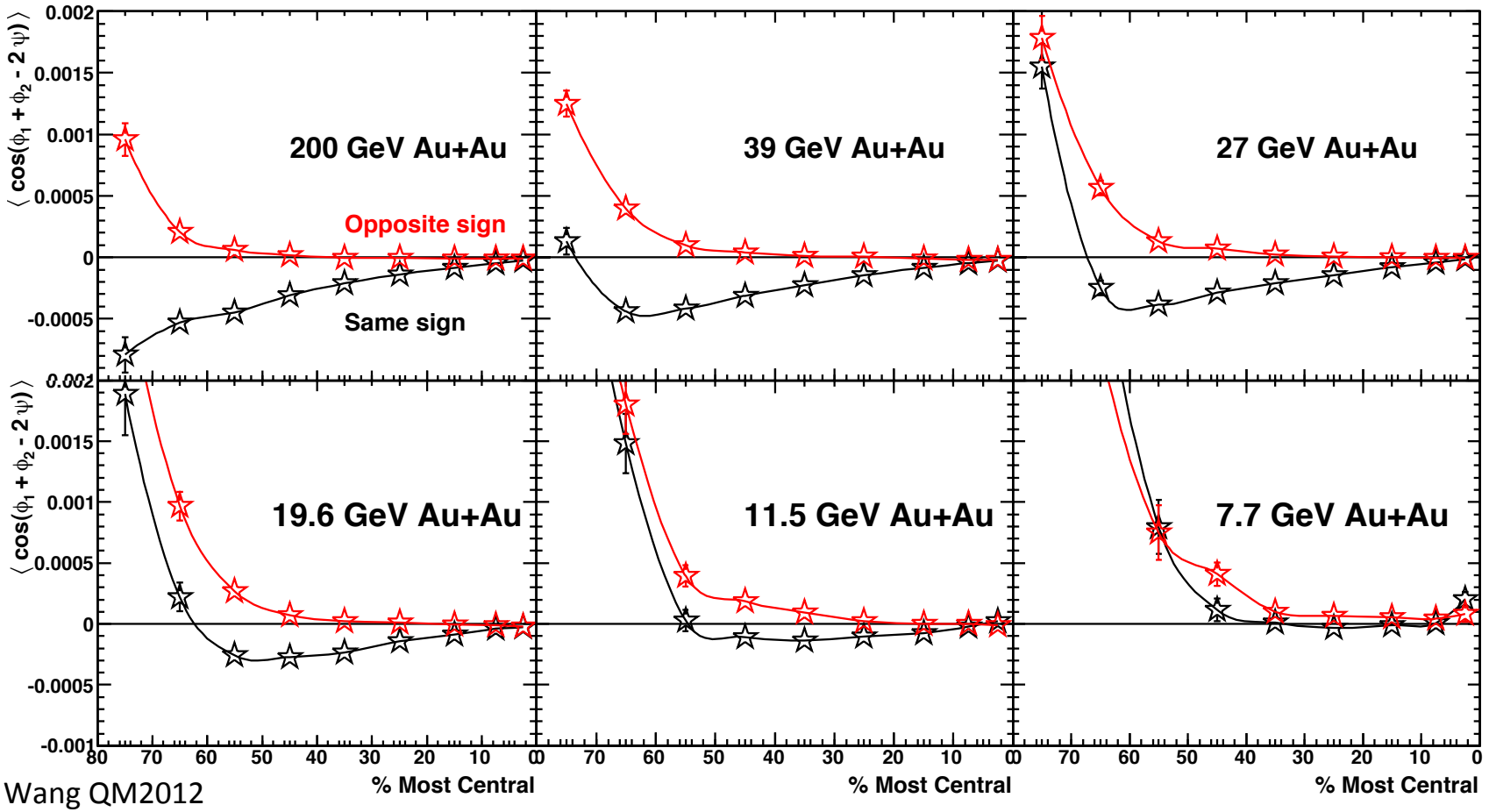


The separation between the same-charge and opposite-charge correlations

- ✓ ***Strong external EM field***
- ✓ ***De-confinement and Chiral symmetry restoration***

BES: Reduced Dynamical Correlations

Splitting of same charge sign and opposite charge sign correlations with respect to event plane

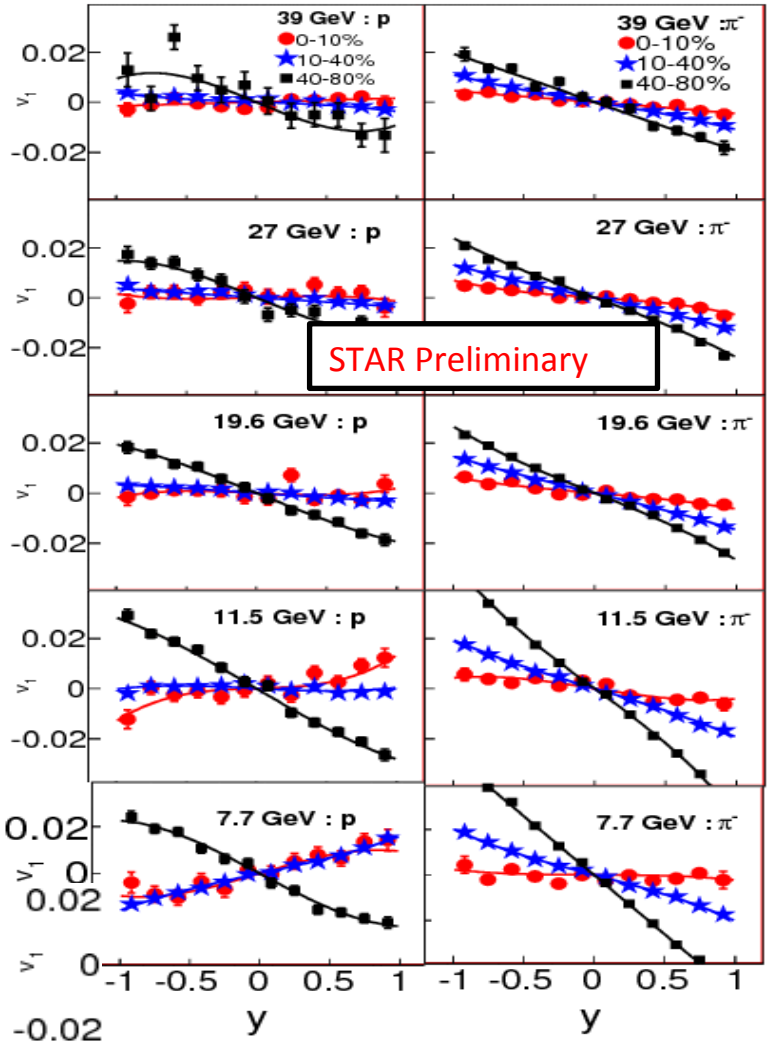


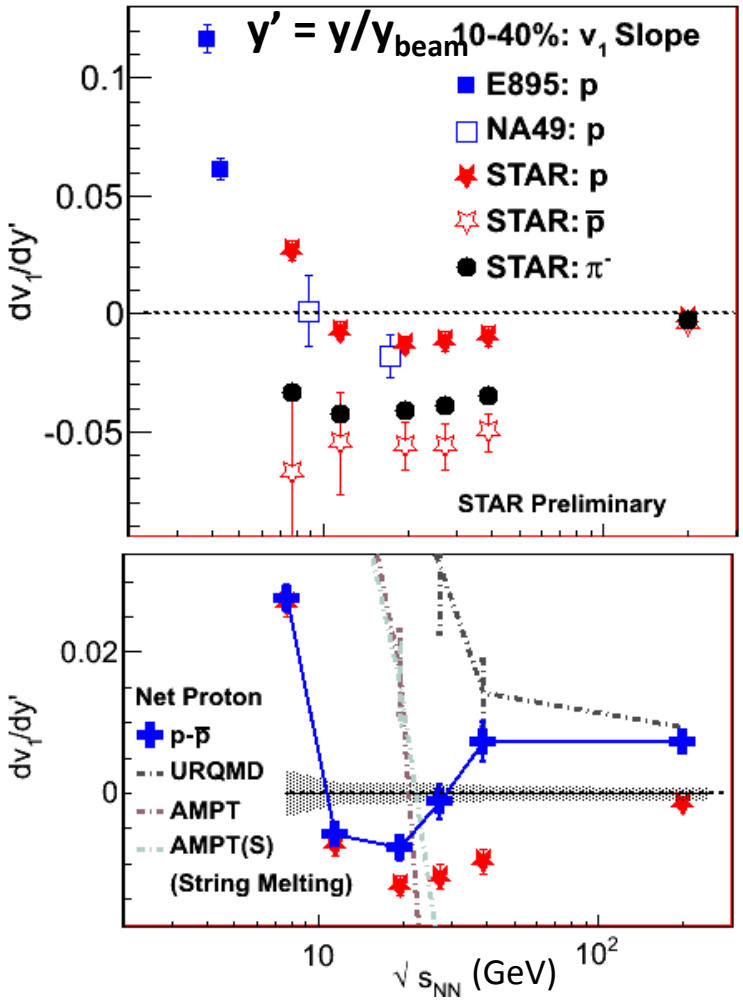
Gang Wang QM2012

Charge correlation splitting vanishes for 11.5 GeV

Equation of State

Yadav Pandit, QM2012



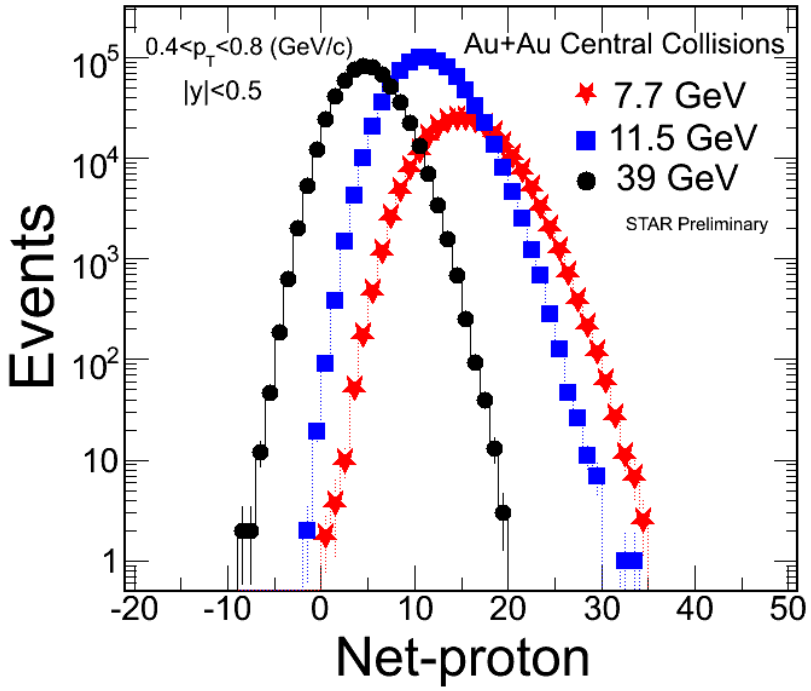


Slope for protons changes positive to negative between 7.7 and 11.5 GeV

Non-monotonic net-proton v_1 slope, qualitatively like hydro "collapse" prediction.

Search for QCD Critical Point

Observable



Sensitivity

Various moments: Correlation length:

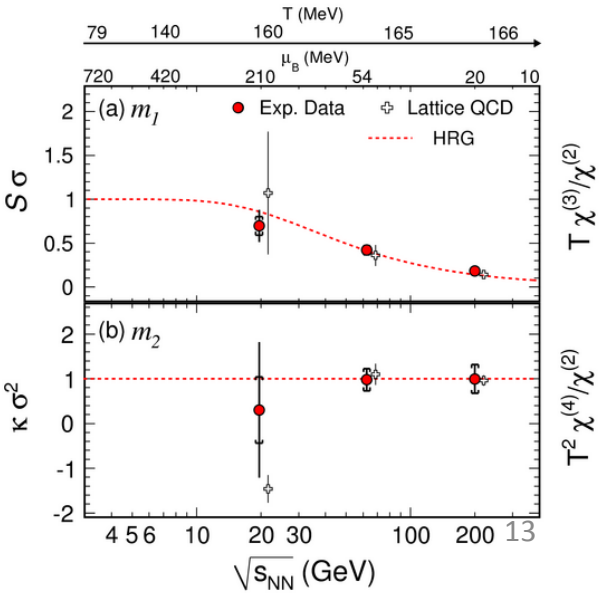
Sigma: $\sigma = \sqrt{< (N - < N >)^2 >}$ $\sim \xi^2$

Skewness: $s = \frac{< (N - < N >)^3 >}{\sigma^3}$ $\sim \xi^{4.5}$

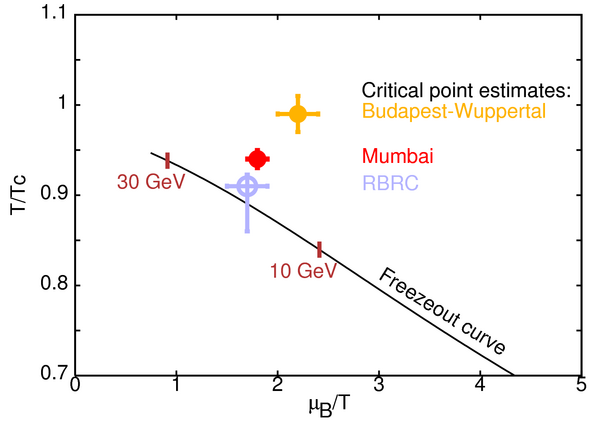
Kurtosis: $\kappa = \frac{< (N - < N >)^4 >}{\sigma^4} - 3$ $\sim \xi^7$

Connection to QCD

Science, 332, 1525 (2011)

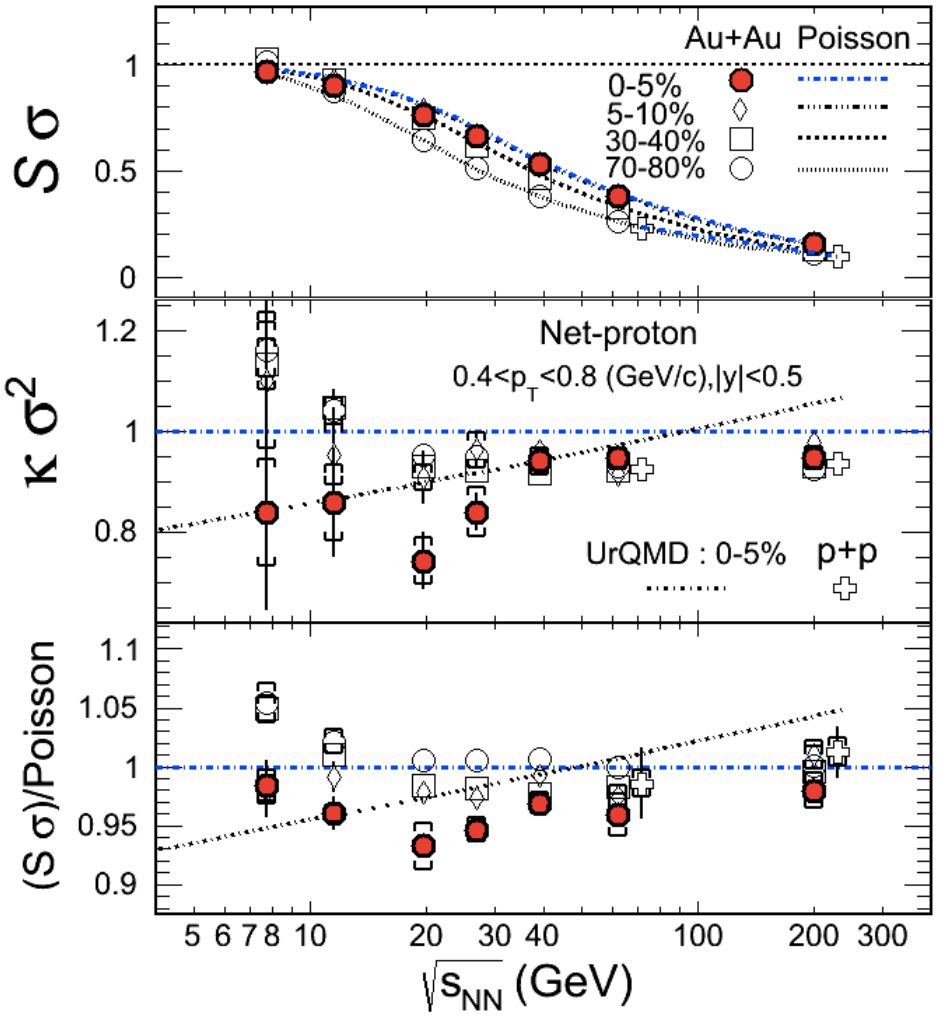


Theory status



Any information on the Critical Point is a major contribution to the QCD phase diagram

BES: Search for QCD Critical Point



STAR net-proton results:

- ✓ ***Data show deviations below Skellam expectation in the 0-5% most central collisions for $\kappa\sigma^2$ and $S\sigma$ at all energies. Larger deviation at $\sqrt{s_{NN}}$ ~ 20GeV***
- ✓ ***UrQMD model show monotonic behavior***
- ✓ ***Higher statistics needed for collisions at $\sqrt{s_{NN}}$ < 20 GeV***

Xiaofeng Luo, QM2012
Physical Review Letters 105 (2010) 022302

Summary

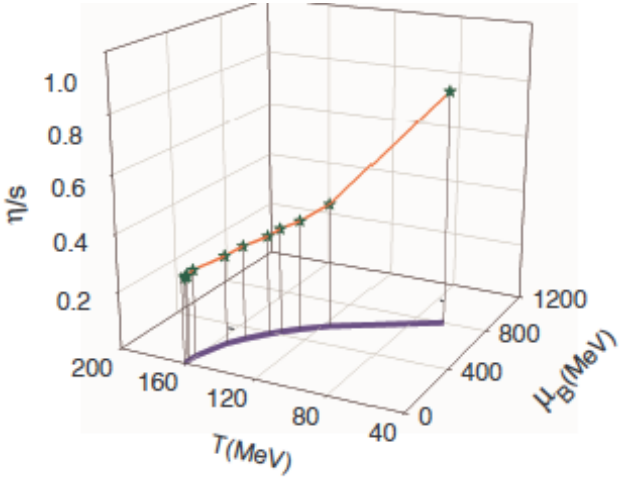
BES program allows for exploring the most interesting part of the QCD phase diagram.

- ✓ Breakdown of NCQ scaling (as observed at top RHIC energy)
- ✓ No suppression of high p_T hadrons observed
- ✓ Substantial reduction of charge correlations
- ✓ Hints of non-monotonic behavior of proton v_1 versus rapidity
- ✓ Deviations from simple Poisson expectation for observables related to CP search

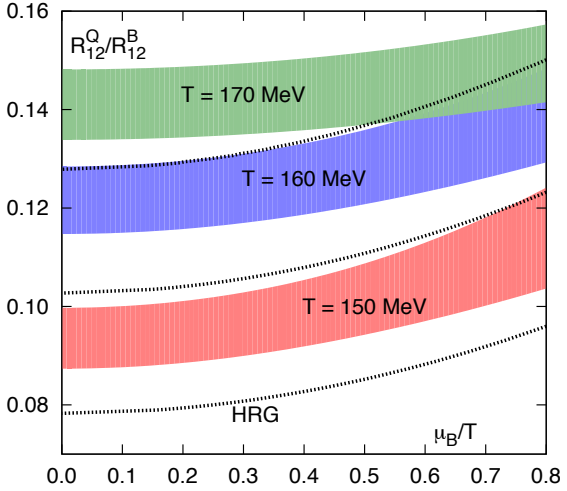
Signatures of partonic interactions for beam energies > 27 GeV
Dominance of hadronic interactions for beam energies ~ 11.5 GeV

Other potential information from BES data

Transport properties of QCD matter at varying baryon density



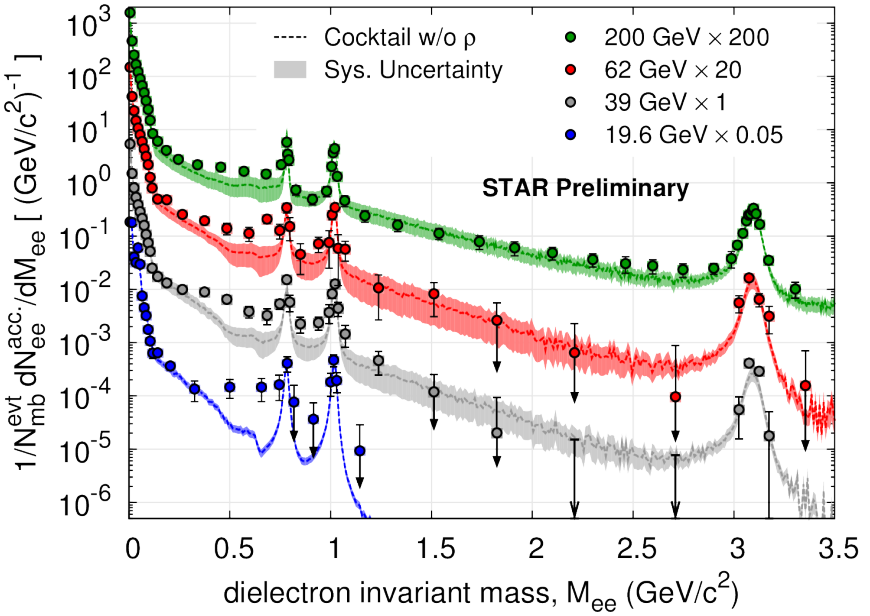
Phys. Rev. C 77 (2008) 024911



Phys. Rev. Lett. 109 (2012) 192302

QCD based ways to extract freeze-out properties and variation of susceptibilities with T & μ_B

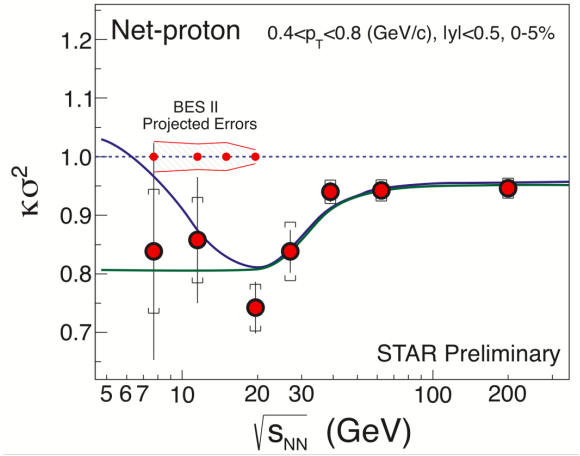
Medium effects through dileptons

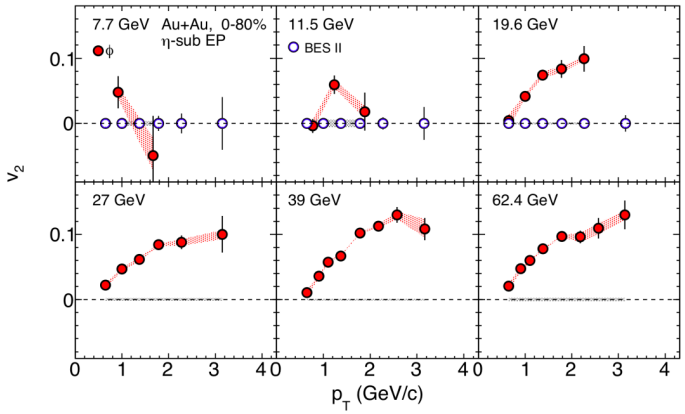


Thermodynamics of QCD matter

Outlook: BES Phase - II

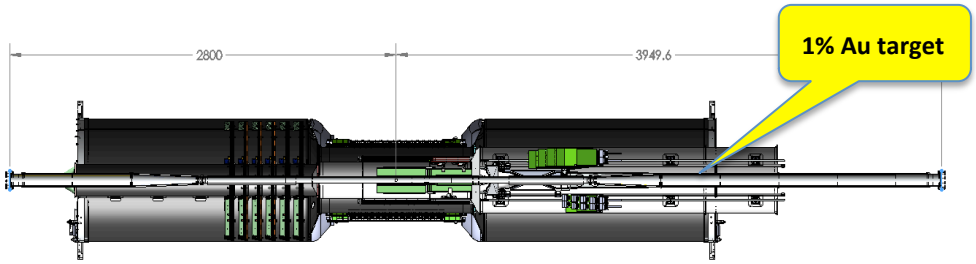
Increase in event statistics





Higher statistics data at lower beam energies + 15 GeV

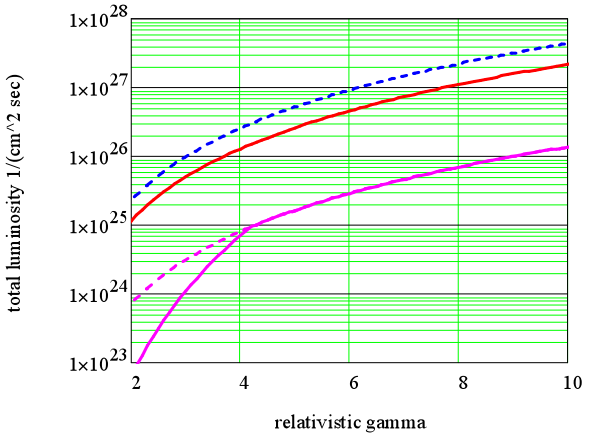
Extending the μ_B reach



μ_B reach can be extended to ~ 750 MeV

A. Fedotov, W. Fischer, private discussions, 2012.

STAR BUR - 2013



Exploring QCD Phase Structure