

# Highlights from the STAR experiment at RHIC



**Sonia Kabana for the STAR Collaboration**

**SUBATECH and University of Nantes, France**



UNIVERSITÉ DE NANTES

**International Conference on Strangeness in Quark Matter**

**18-24 September 2011, Polish Academy of Arts and Sciences, Cracow, Poland**



**Fryderyk Franciszek Chopin,  
1835**



# Outline

**1 Introduction: physics goals and STAR detector**

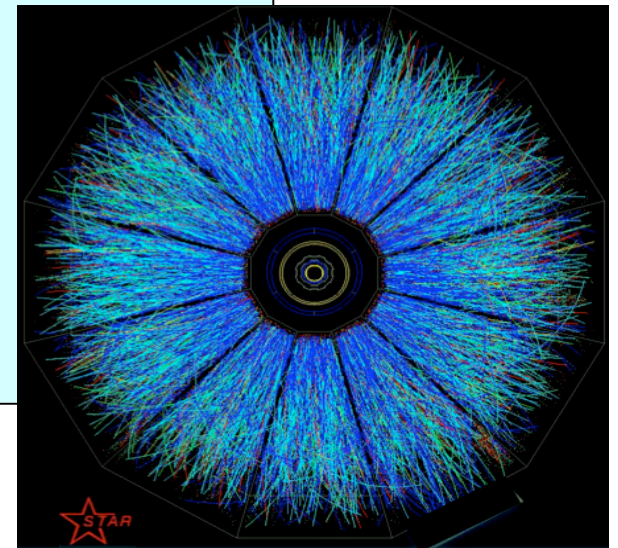
**2 Physics results :**

**A. Charm and beauty**

**B. Antimatter and dileptons**

**C. Beam energy scan**

**3 Conclusions and Outlook**



# STAR talks in SQM2011

## Charm and Beauty:

Non-Photonic Electron and Charged Hadron Azimuthal Correlation in p+p Collisions at  $\sqrt{s_{NN}} = 500$  GeV in STAR

**Wei Li**                      **Session: Flow / Correlations parallel 1 23/Sept Friday 14:40**

J/ $\Psi$  polarization in p+p collisions at  $\sqrt{s_{NN}} = 200$  GeV at STAR

**Barbara Trzeciak**            **Session: Open and Hidden Charm 23/Sep Friday 14:20**

Production of J/ $\Psi$  in min-bias p+p collisions at  $\sqrt{s_{NN}} = 200$  GeV in STAR

**Leszek Kosarzewski**        **Session: Open and Hidden Charm 23/Sep Friday 14:00**

Measurement of J/ $\Psi$  elliptic flow in Au+Au collisions at 200 GeV in STAR experiment

**Hao Qiu**                      **Session: Elliptic Flow 20/Sep Tuesday 17:30**

## Dileptons:

Di-lepton spectrum and elliptic flow in p+p and Au+Au collisions at 200 GeV from STAR

**Bingchu Huang**              **Session: Vector Mesons and Dileptons 23/Sep Friday 14:20**

Leptonic decay of  $\varphi(1020)$  meson measured with the STAR experiment

**Masayuki Wada**              **Session: Various facets of strangeness 20/Sep Tuesday 17:50**



# STAR talks in SQM2011

## Beam Energy scan

Hadron production and freeze-out dynamics with STAR in the RHIC Beam Energy Scan

**Orpheus Mall**

**Session: QCD Phase Diagram 23/Sep Friday 16:50**

QCD phase diagram with  $\varphi$  meson production in relativistic nuclear collisions at RHIC/STAR

**Xiaoping Zhang**

**Session: QCD Phase Diagram 23/Sep Friday 17:50**

Measurements of  $K_s^0$ ,  $\Lambda$  and  $\Xi$  from Au+Au collisions at  $\sqrt{s_{NN}} = 7.7, 11.5$  and  $39$  GeV in STAR

**Xianglei Zhu**

**Session: Various Facets of Strangeness 20/Sep Tuesday 15:20**

Charge Dependence and Scaling Properties of Dynamical K/pi, K/p, and p/pi Fluctuations from the STAR Experiment

**Terence Tarnowski**

**Session: QCD Phase Diagram 23/Sep Friday 18:10**

Energy dependence of elliptic flow of  $\varphi$ -meson in STAR at RHIC

**Md. Nasim**

**Session: Elliptic Flow 20/Sept Tuesday 17:10**

Energy Dependence of Event-by-Event Hadron Ratio Fluctuations from Au+Au Collisions at RHIC

**Jian Tian**

**Session: QCD Phase Diagram 23/Sep Friday 17:30**



# STAR talks in SQM2011

## Beam Energy scan

Directed flow of Identified Particles from the RHIC Beam Energy Scan

**Yadav Pandit**

**Session: Flow/Correlations parallel 2 23/Sep Friday 16:50**

Study of hyperon-hyperon correlations and search for the H-dibaryon with the STAR detector at RHIC

**Neha Shah**

**Session: Anti and Hyper Nuclei 23/Sep Friday 17:10**

Search for the QCD Critical Point with Higher Moments of Net-proton Multiplicity Distributions at RHIC

**Xiaofeng Luo**

**Session: QCD Phase Diagram 23/Sep Friday 17:10**

The elliptic flow  $v_2$  in Au+Au collisions at  $\sqrt{s_{NN}} = 7.7, 11.5$  and 39 GeV at STAR

**Shusu Shi**

**Session: Elliptic Flow 20/Sep Tuesday 16:50**

## Correlations

High-pt triggered dihadron correlations with  $v_n$  background subtraction by STAR

**Fuqiang Wang**

**Session: Flow / Correlations parallel 1 23/Sep Friday 15:20**

Investigating origin of the long range pseudo rapidity correlation in 2D di-hadron measurements from STAR

**Chanaka De Silva**

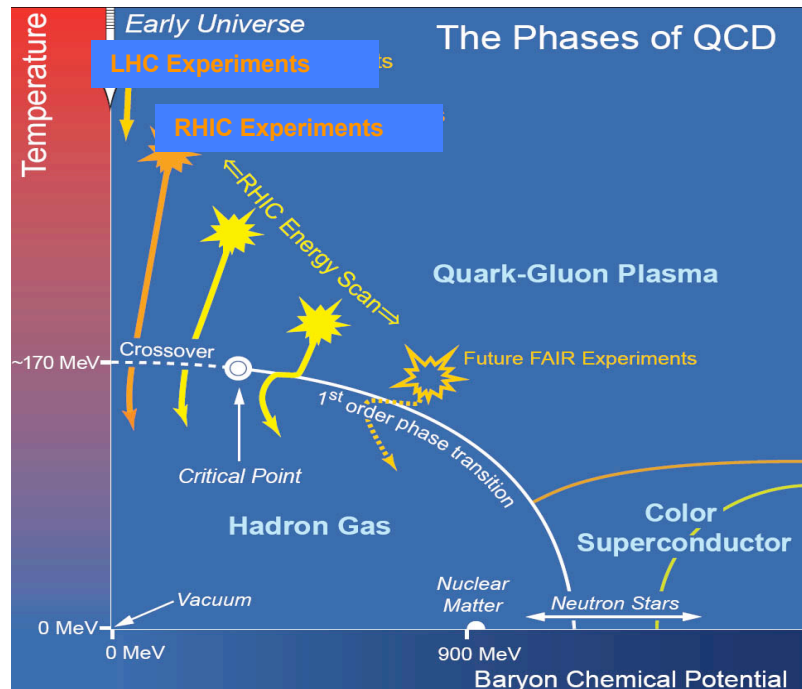
**Session: Flow/Correlations parallel 1 23/Sep Friday 15:40**



# 1 INTRODUCTION: PHYSICS GOALS AND STAR DETECTOR



# Physics goals: Discover the QCD phase diagram



Study QCD matter under extreme conditions of densities and Temperatures and extract its properties

Reproduce a phase transition of the early universe at  $10^{-6}$  sec after the Big Bang, between hadrons and quarks and gluons (Quark-Gluon-Plasma) and map out the QCD phase diagram

QCD on the lattice: cross over at zero net baryon density and  $T_c \sim 160-180$  MeV

RHIC beam energy scan :  $\sqrt{s_{NN}} = 7.7, 11.5, 19.6, 27, 39, (62, 130, 200)$  GeV

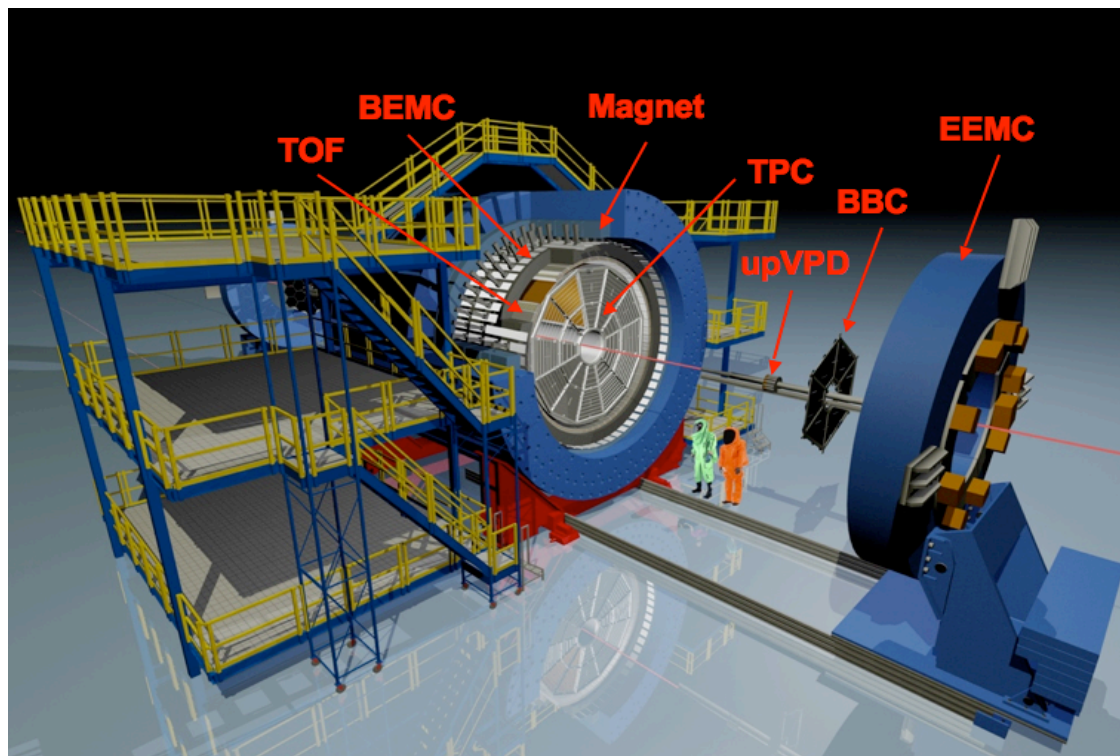
STAR@200 GeV : study the **sQGP** and its properties at **low net baryon density**

STAR energy scan : reveal the **nature of the phase diagram of QCD** :

- **onset** of 1st order phase transition
- **possible critical point**



# The STAR detector at RHIC



Three main detectors :

TPC, TOF, BEMC

Cover midrapidity ( $|\eta| < 1$ )

full azimuth

Allow for **electron and hadron ID** in large acceptance

## The STAR re-naissance :

- \* Barrel Time of Flight: 75% since y2009, 100% since y2010
- \* DAQ1000 since 2009
- \* High Level Trigger (HLT)

Also less material inside TPC since 2008





# 2. PHYSICS RESULTS :

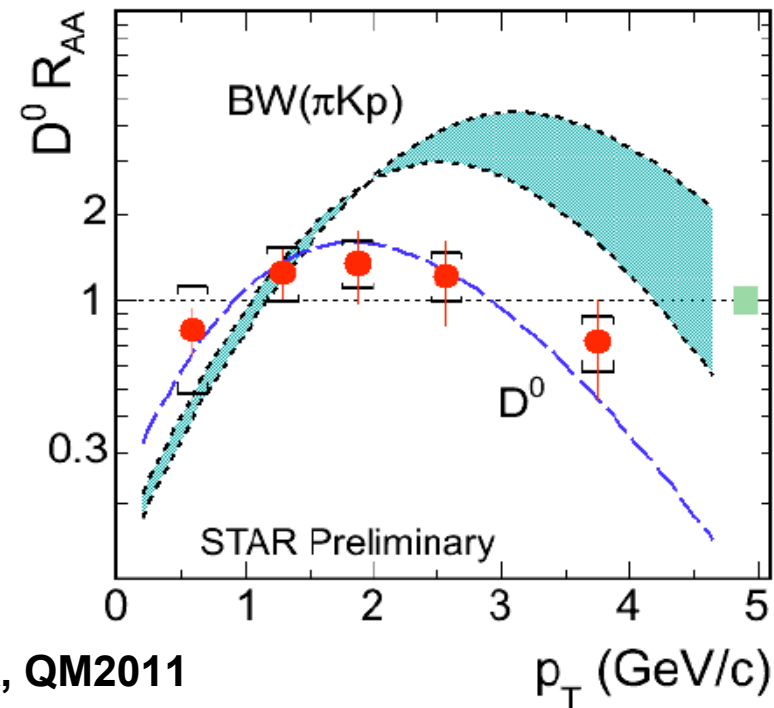
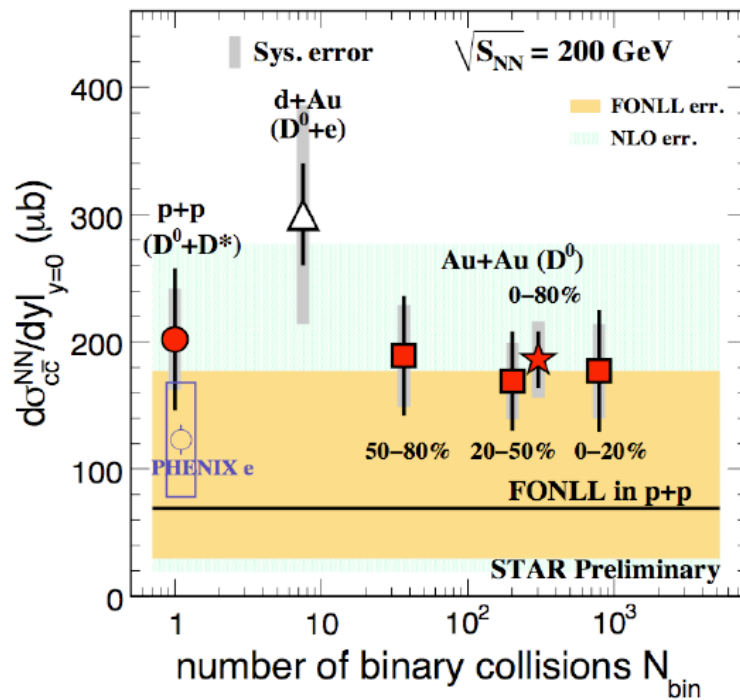
## A. CHARM AND BEAUTY



# Charmed hadrons

Advantage of STAR with respect to other RHIC experiments :

Direct measurement of charm cross section down to low  $p_T$ , through D mesons



STAR, QM2011

- Charm cross section is consistent with upper bound of FONLL calculation in p+p
- Charm cross section follows number of binary collision scaling -> Charm quarks are mostly produced by initial hard scattering

- First measurement of  $D^0 R_{AA}$  at RHIC  
 $R_{AA} \sim 1$  in  $p_T < 3$  GeV/c
- Different from Blast Wave prediction with freezeout parameters of light hadrons ->  $D^0$  freeze out **earlier** than light hadrons

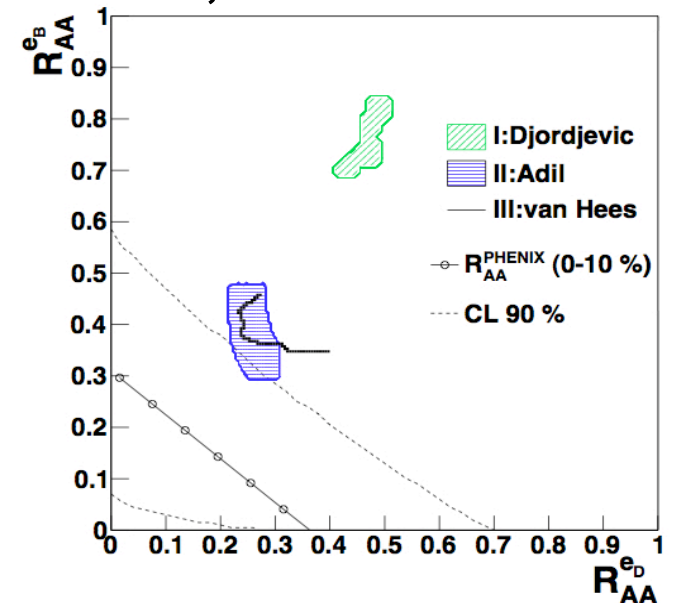
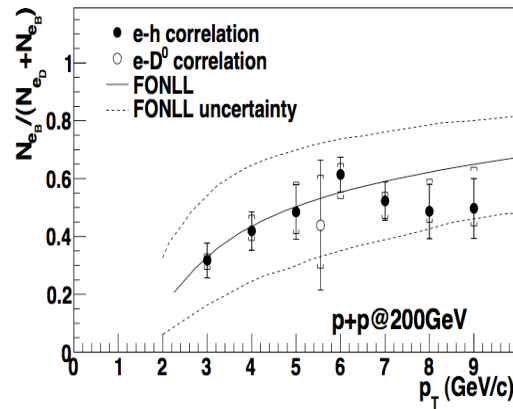
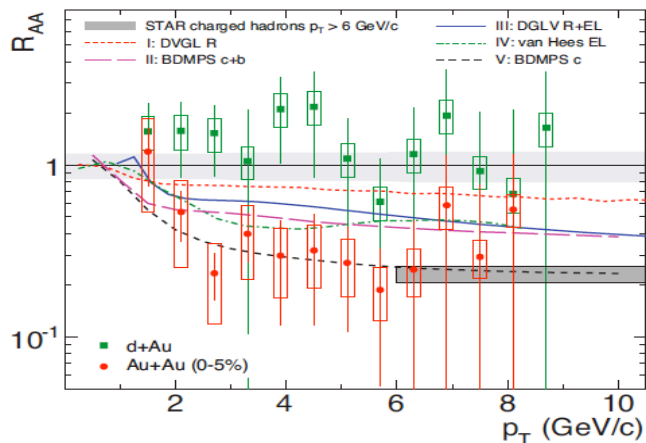


# Towards the resolution of the HF $R_{AA}$ puzzle at RHIC

- HF NPE do not follow mass dependence expectations for rad. energy loss
- Is beauty also quenched in Au+Au collisions at 200 GeV ?

STAR, PRL 98 (207) 192301, erratum 2011

M Aggarwal et al, STAR, PRL 105 202301 2010, arXiv:1007.1200



- Contribution of electrons from beauty become  $\sim 50\%$  at  $\sim 5$  GeV  $p_T$  in p+p collisions
- $R_{AA}(e_B) < 1$  even if  $R_{AA}(e_D)=0$   $\rightarrow$  Beauty and Charm **are both suppressed** in Au+Au
- Measurements of B and C in Au+Au are crucial

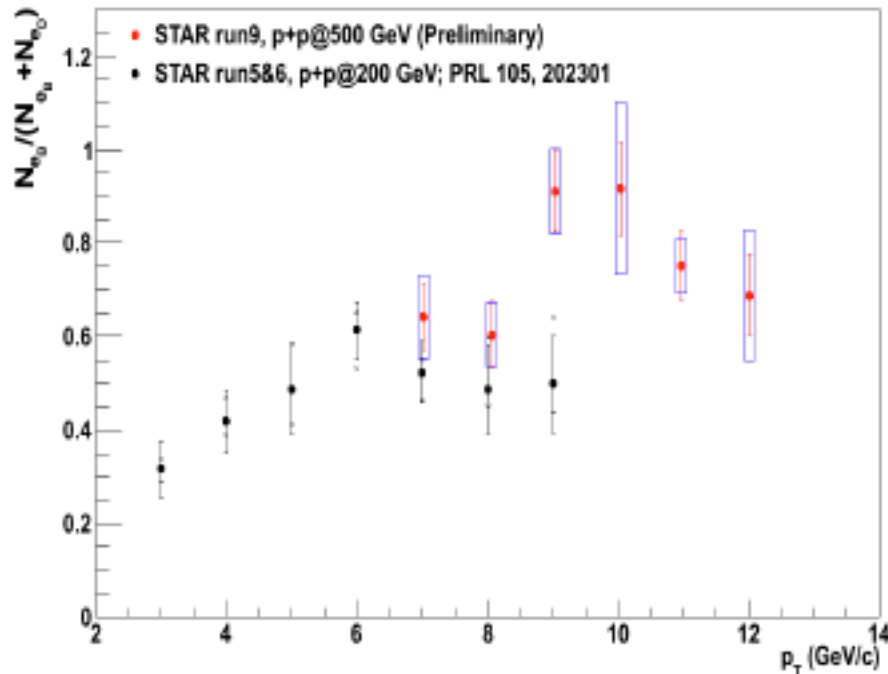
\* Silicon detector upgrade (HFT) of STAR



# Disentangling beauty and charm in p+p at 500 GeV

**STAR talk at this conference :**

**Wei Li      Session: Flow / Correlations parallel 1    23/Sept    Friday 14:40**



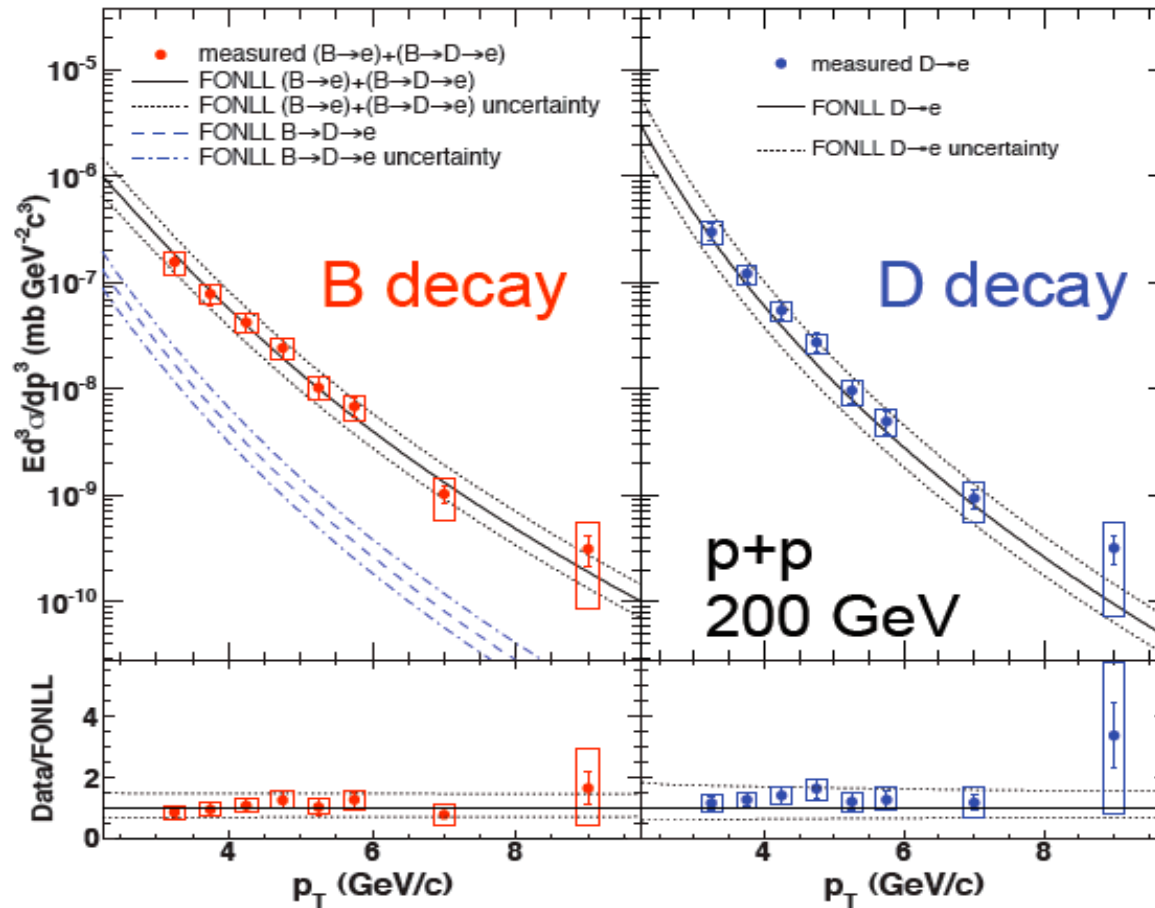
- Using NPE-hadron correlations compared to Pythia 8.1 -> extract Beauty contribution up to  $p_T=12.5$  GeV

- Electrons from Beauty contribute more than 60% to the non-photon electrons above  $p_T$  of 8 GeV in p+p collisions at 500 GeV

- $e_B / (e_B + e_D)$  ratio is energy dependent



# Separate Charm and Beauty Contributions to NPE



STAR, PRD83, 052006 (2011)

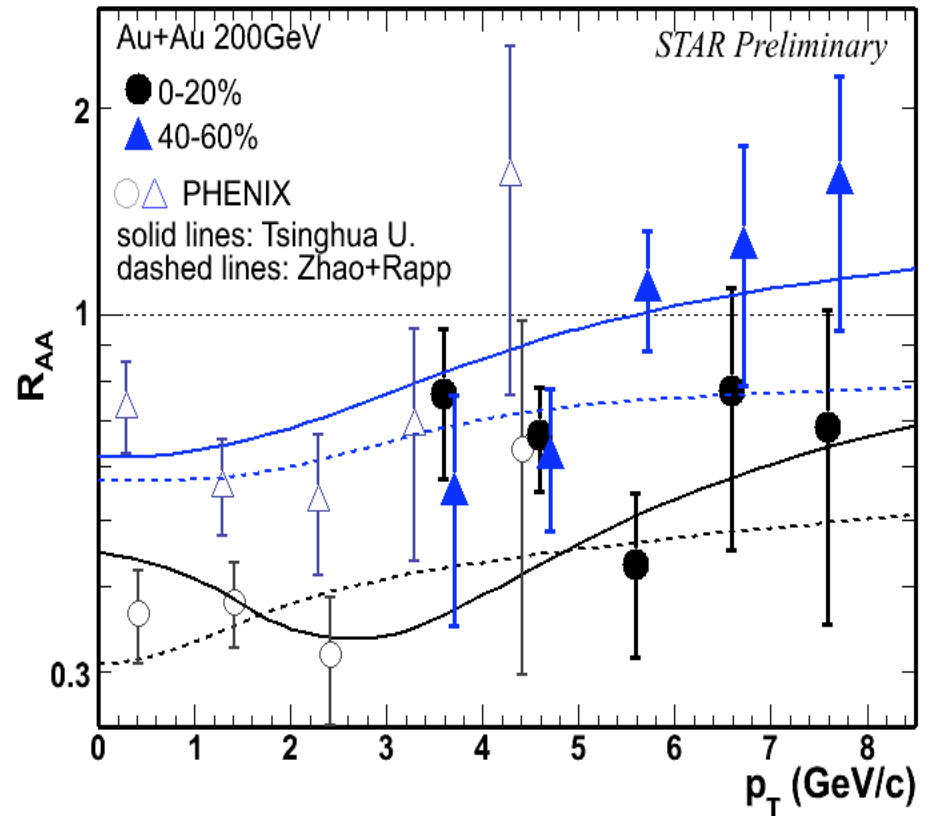
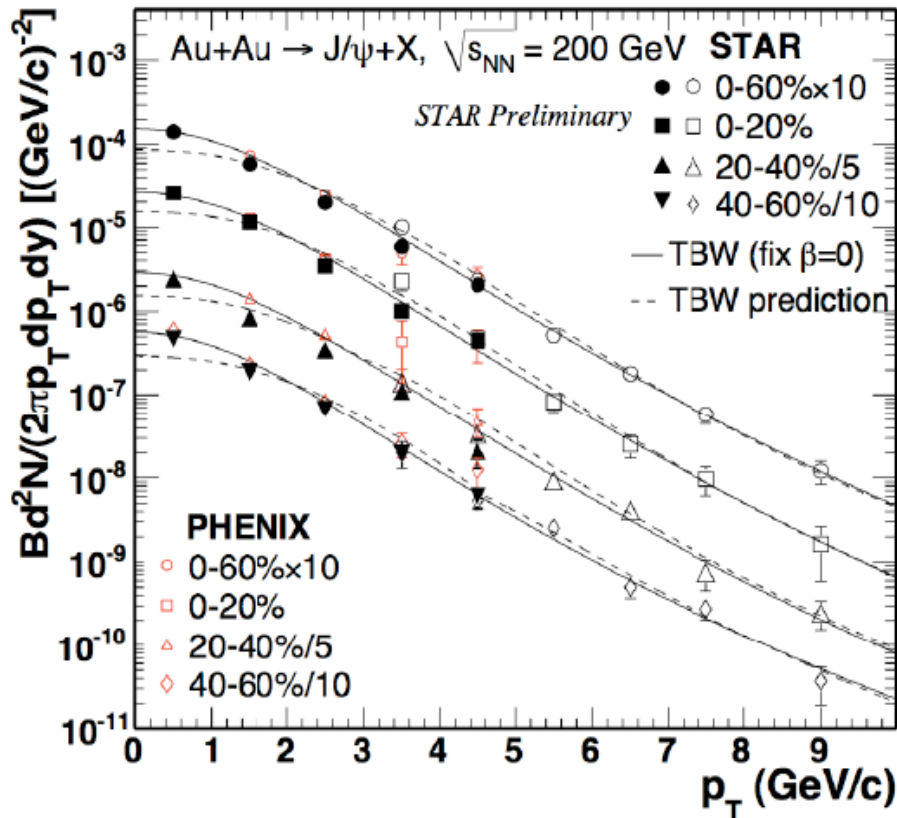
FONLL, M Cacciari et al, PRL95,  
122001 (2005)

Measurement of Beauty- $\rightarrow$ NPE cross section in p+p 200 GeV  
Beauty and charm consistent with FONLL in p+p 200 GeV



# $R_{AA}(J/\Psi)$ in Au+Au collisions at 200 GeV

STAR, QM2011



STAR and PHENIX data agree with each other in the overlap region

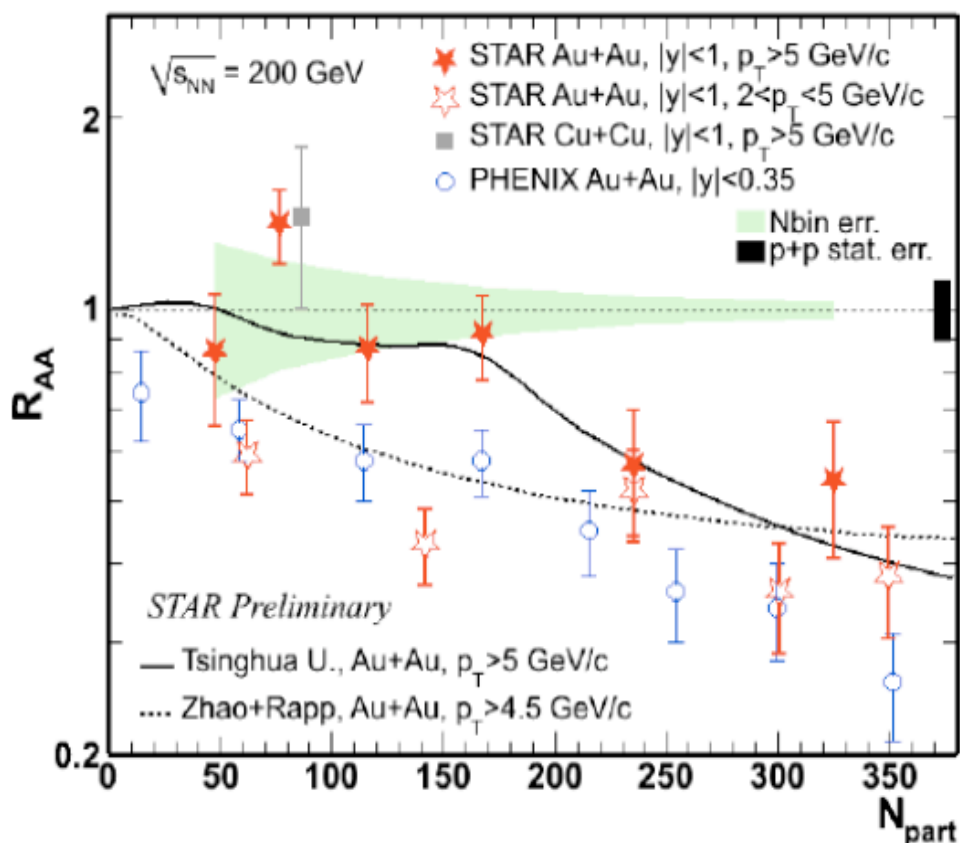
STAR extends the measurement to 10 GeV/c

$R_{AA}(J/\Psi)$  from STAR: suppressed in most central Au+Au at  $p_T$  3.5-8 GeV

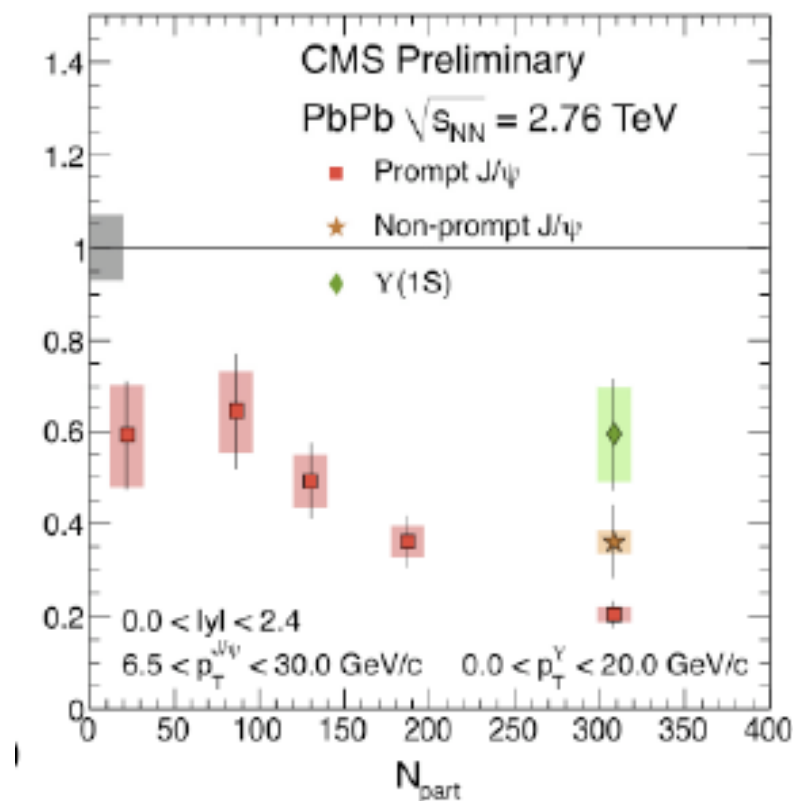


# $p_T$ , $N_{part}$ and energy dependence of $R_{AA}(J/\Psi)$ in Au+Au

STAR, QM2011, EPS-HEP 2011



CMS highlight QM2011



- \* Suppression in central collisions at high  $p_T$
- \* Systematically higher at high  $p_T$

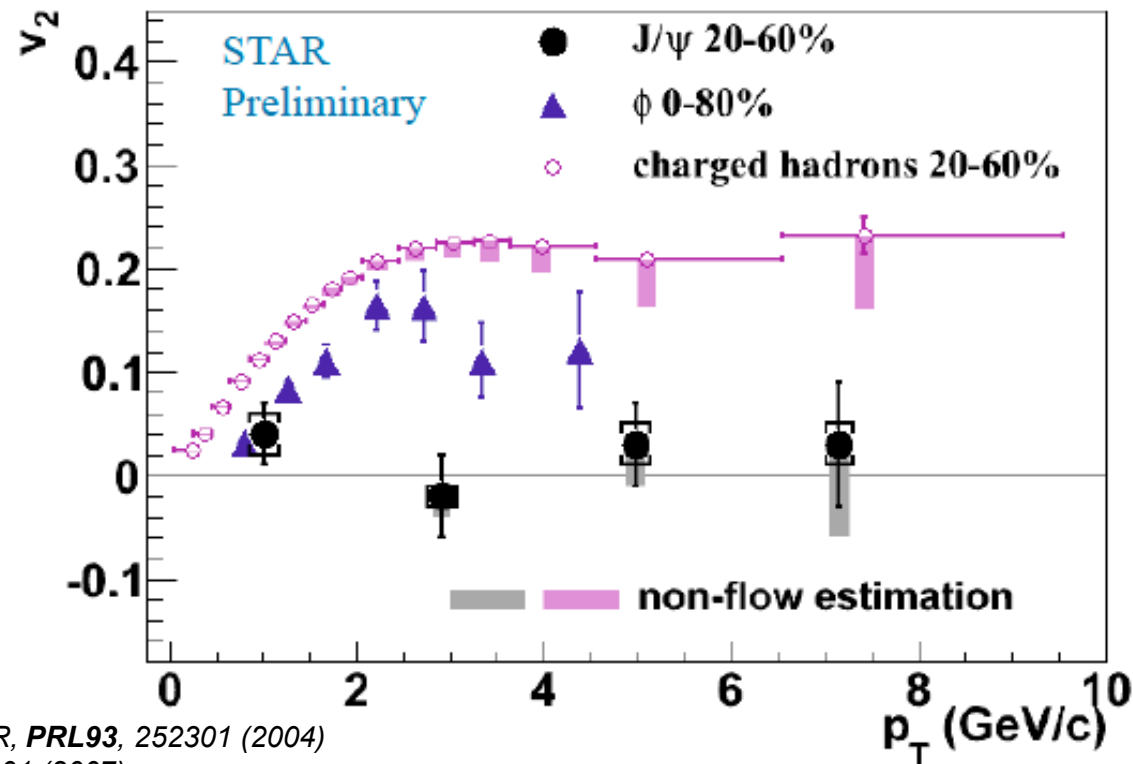
- Midrapidity high  $p_T$   $J/\psi$  seems to have more suppression at LHC
- consistent with larger system size at LHC



# Does the $J/\psi$ flow ?

STAR talk in this conference:

Qiu Hao Session: Elliptic Flow 20/Sep Tuesday 17:30



charged hadrons, STAR, *PRL*93, 252301 (2004)

$\phi$ , STAR, *PRL*99, 112301 (2007)

- $J/\psi$   $v_2 \sim 0$  in the  $p_T$  range of 2 to 8 GeV/c in mid-central 20-60%
- ➔ Disfavors coalescence from thermalized charm quarks at RHIC



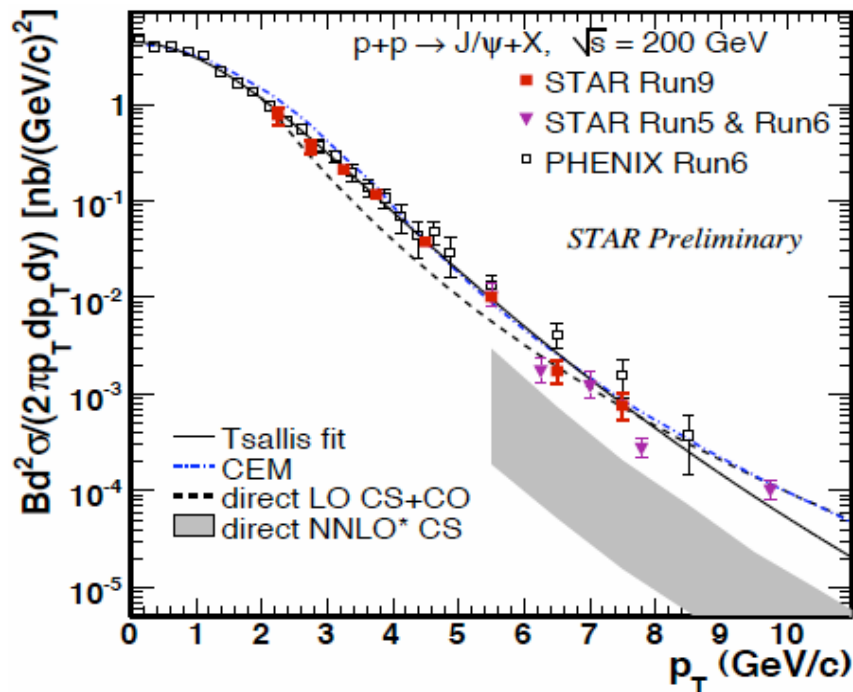


# Models compared to cross section of $J/\psi$ in p+p 200 GeV

STAR talk at this conference:

Leszek Kosarzewski Session: Open and Hidden Charm 23/Sep Friday 14:00

STAR, QM2011



Results consistent with Phenix

Extend to  $p_T \sim 10 \text{ GeV}/c$

Color Singlet Model: direct NNLO\* misses the high- $p_T$  part

LO CS+CO : leave no room for feeddown at high  $p_T$

CEM can reasonably explain the spectra

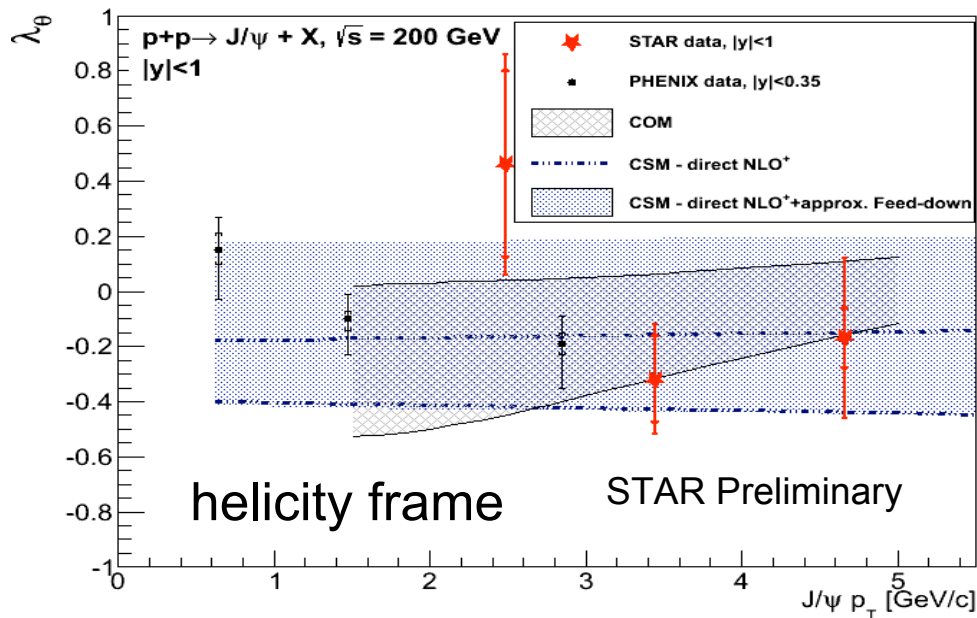


# J/ $\psi$ polarization in p+p at 200 GeV

**STAR talk at this conference:**

**Barbara Trzeciak    Session: Open and Hidden Charm    23/Sep  
Friday 14:20**

*PHENIX: Phys. Rev. D 82, 012001 (2010)*  
*COM: Phys. Rev. D 81, 014020 (2010)*  
*CSM NLO<sup>+</sup>: Phys. Lett. B, 695, 149 (2011)*



**Color Octet Model (NRQCD) : transverse polarization at higher  $p_T$**

**NLO Color Singlet Model: longitudinal polarization at low and mid  $p_T$**

**Color Evaporation Model: has no prediction power regarding polarization**

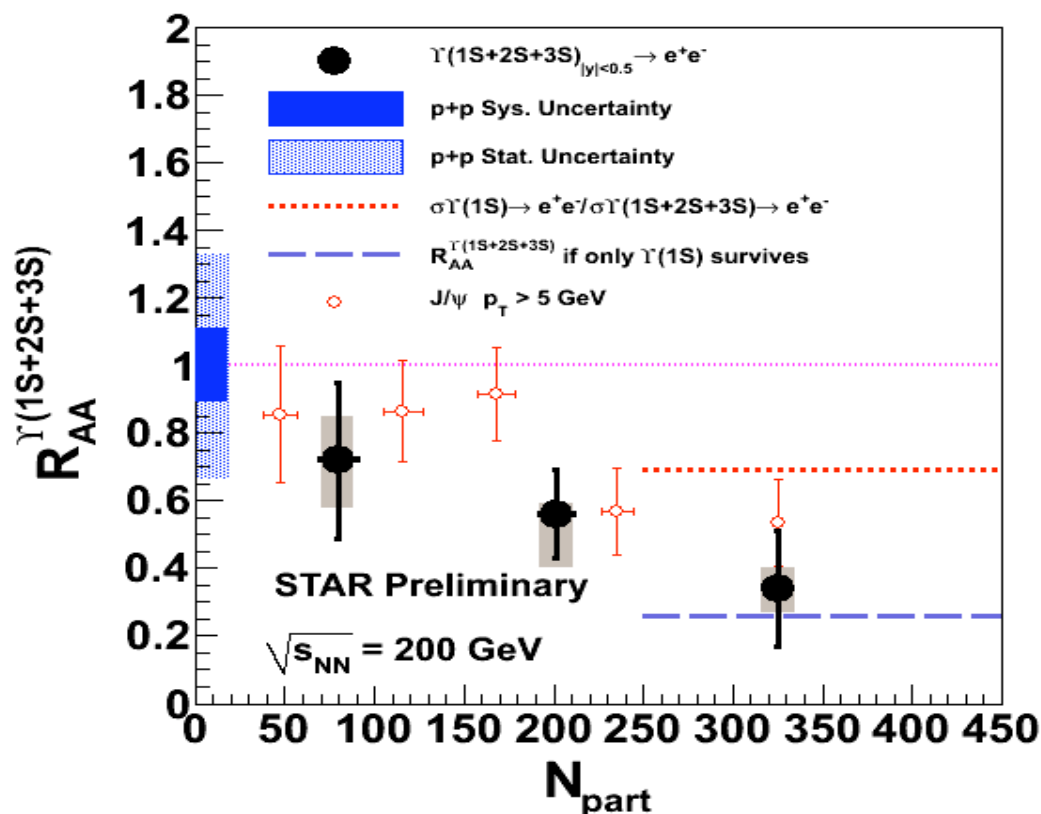
**Results consistent with both COM and CSM models, and consistent with no polarization within uncertainties**



# Y suppression in Au+Au @ 200 GeV

STAR, QM2011

state	J/ψ(1S)	χ <sub>c</sub> (1P)	ψ'(2S)	Υ(1S)	χ <sub>b</sub> (1P)	Υ(2S)	χ <sub>b</sub> (2P)	Υ(3S)
T <sub>d</sub> /T <sub>c</sub>	2.10	1.16	1.12	> 4.0	1.76	1.60	1.19	1.17



H. Satz, NPA 783 (2007) 249c

- $\Upsilon(1S+2S+3S)$  suppression at central collisions
- First measurement of  $\Upsilon$  suppression at RHIC
- $R_{AA}$  at most central point is in agreement with only  $\Upsilon(1S)$  surviving
- Statistical uncertainty will be improved by factors 2 to 3 for Au+Au 2011 and p+p 2009 respectively

Energy dependence of Y suppression: Pb+Pb at the LHC :  $Y(2S+3S)/Y(1S)$  suppression directly observed (CMS, QM2011, PRL107:052302,2011)

--> Data in agreement with  $Y(2S+3S)/Y(1S)$  suppression both at RHIC and LHC



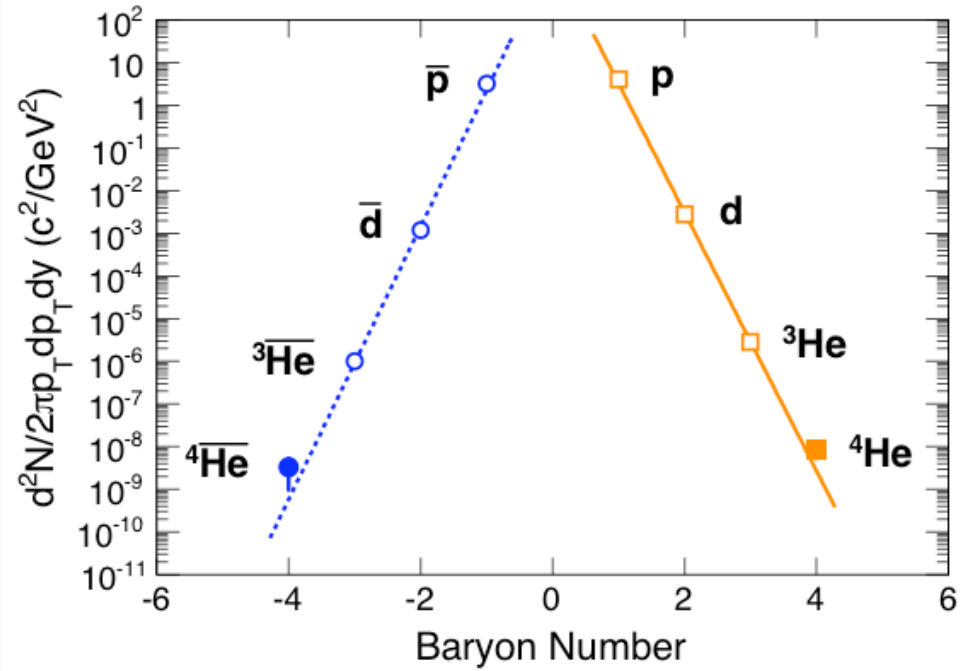
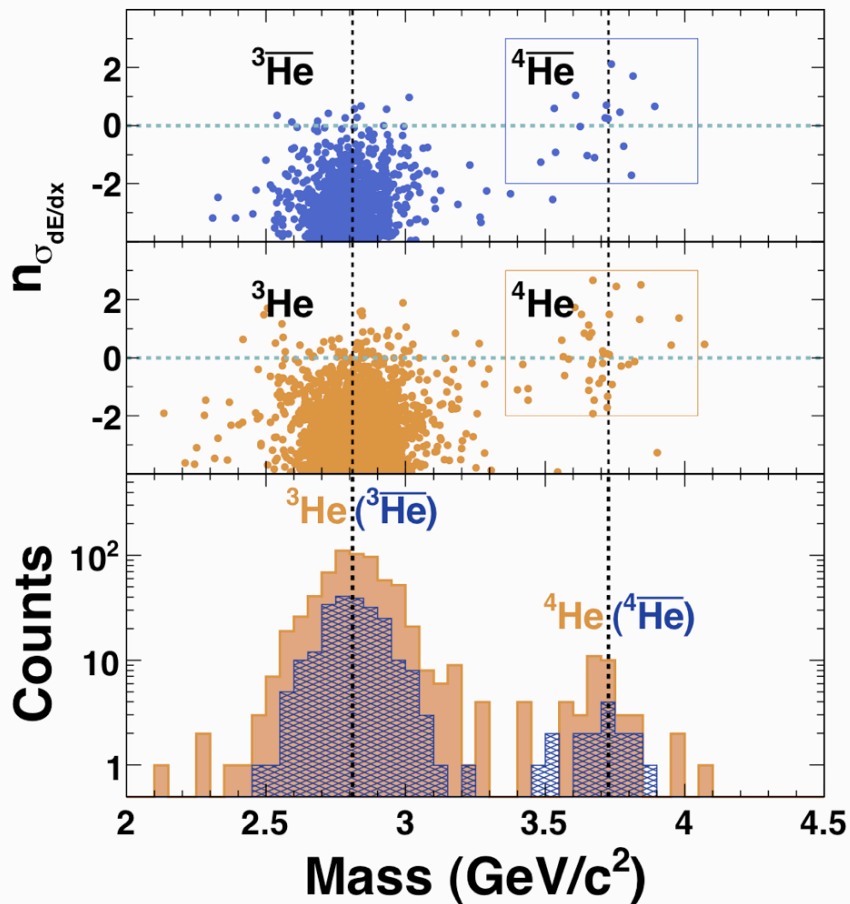
# B. ANTIMATTER AND DILEPTONS



# First observation of anti-<sup>4</sup>He

*Nature* 473, 353-356, (19 May 2011) doi:10.1038/nature10079, **STAR Collaboration**

## The heaviest antimatter nucleus measured



- First measurement ever of 18 anti-<sup>4</sup>He based on TPC+TOF+HLT
- Consistent with thermal & coalescence model expectation

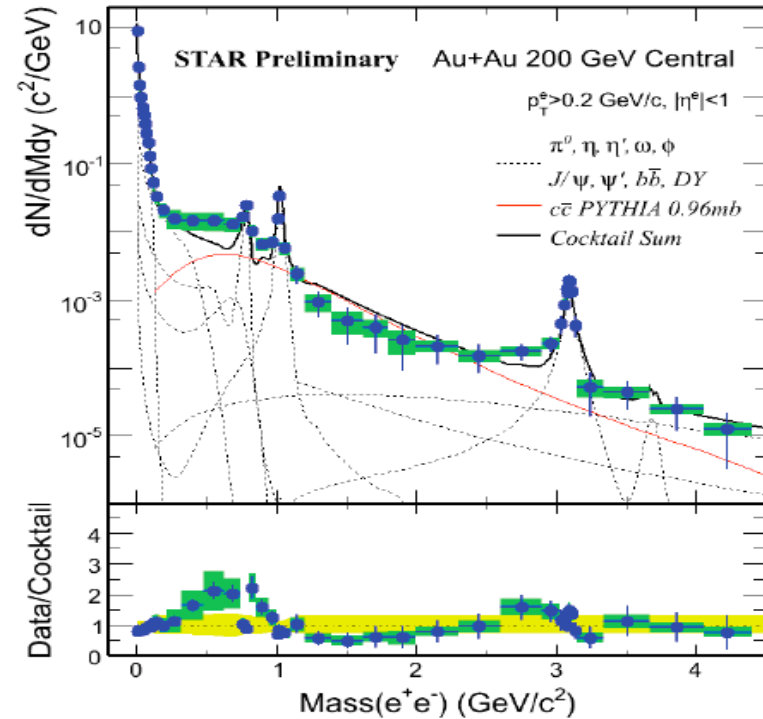
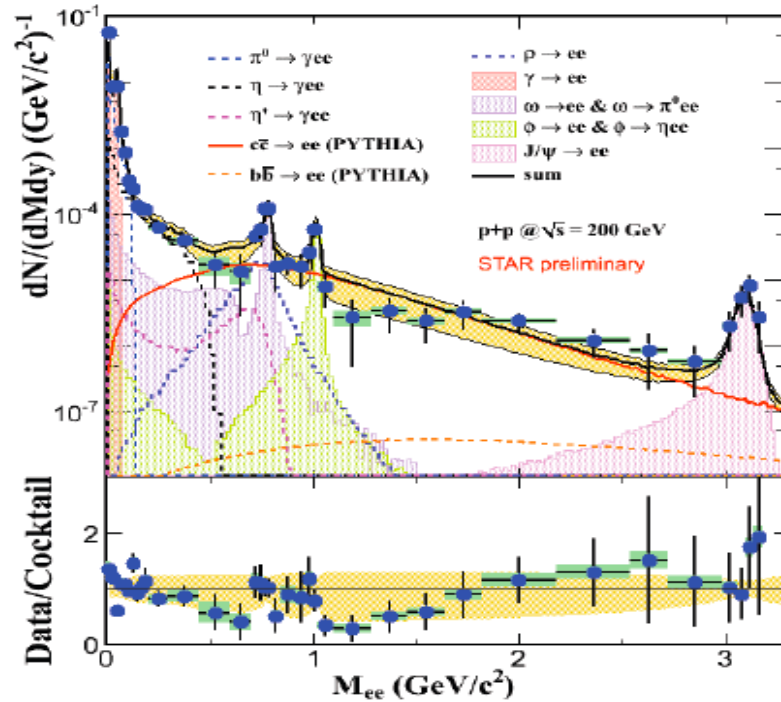
Sets the background for observation of antimatter in space



# Dilepton production in p+p and Au+Au collisions

STAR talk in this conference:

Bingchu Huang Session: Vector Mesons and Dileptons 23/Sep Friday 14:20



Cocktail consistent with data in pp collisions

Low mass region (LMR) enhancement in central AuAu (no rho contribution in the cocktail)

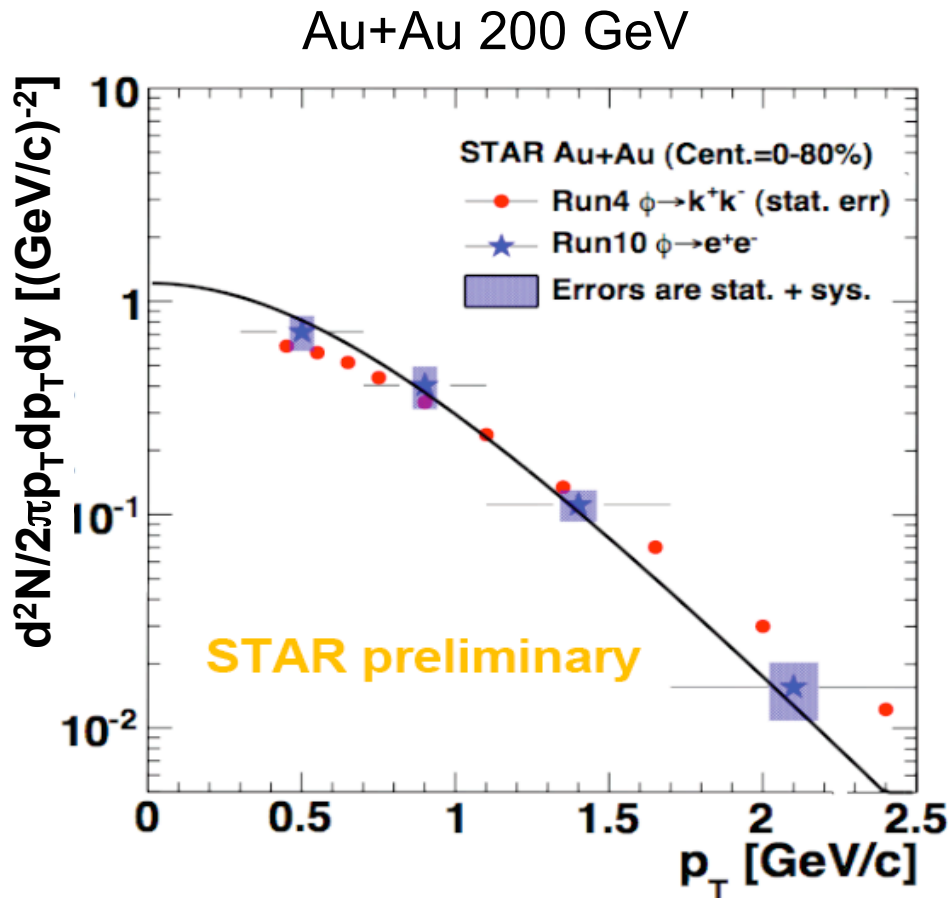
Knowledge on the charm contribution in the IMR is critical to search for the thermal radiation.



# Are the hadronic and leptonic decay of $\phi$ consistent ?

**STAR talk at this conference:**

**Masayuki Wada      Session: Various facets of strangeness    20/Sep Tuesday 17:50**



Hadronic and leptonic decay channel of  $\phi$  in Au+Au collisions at 200 GeV with 0-80% centrality are consistent within errors.

# C. BEAM ENERGY SCAN

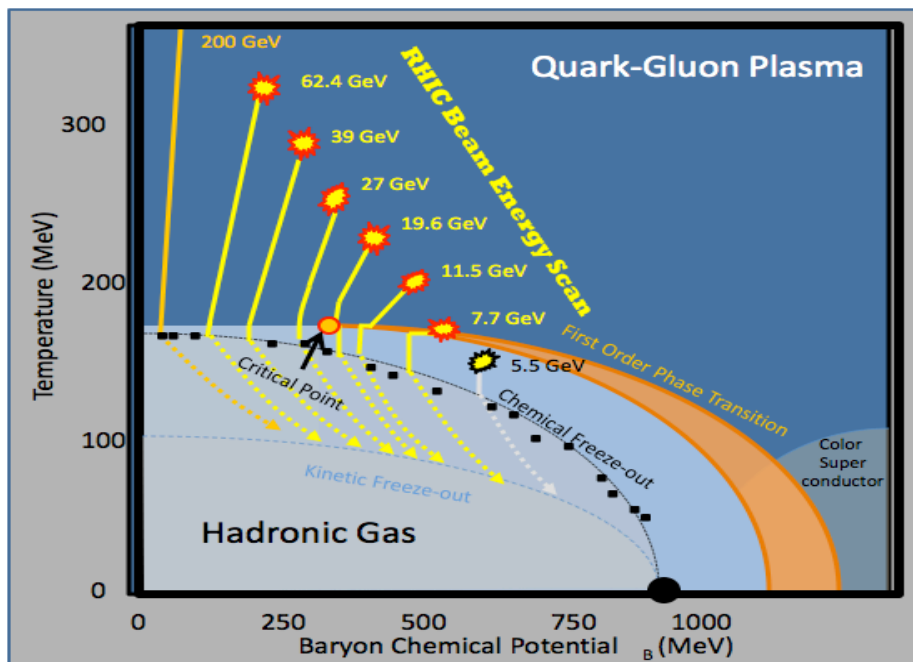




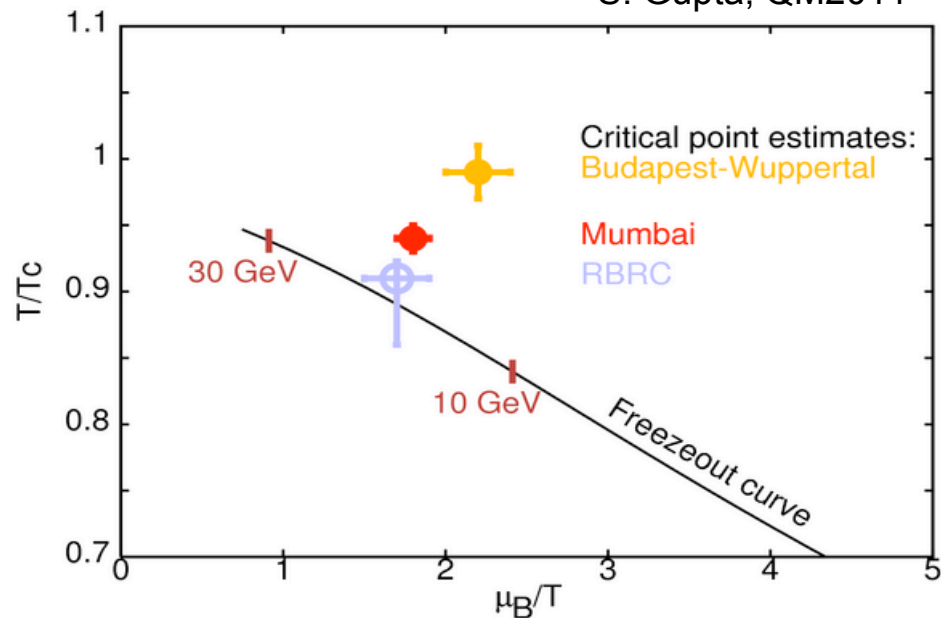
# Beam Energy Scan at RHIC

Goal: Map out the QCD phase diagram searching for

- \* the onset of phase boundary
- \* a possible critical point



S. Gupta, QM2011



**RHIC beam energy scan with Au+Au:**

**sqrt(s) = 7.7, 11.5, 19.6, 27, 39, (62, 130, 200) GeV**

<http://drupal.star.bnl.gov/STAR/starnotes/public/sn0493>

arXiv:1007.2613

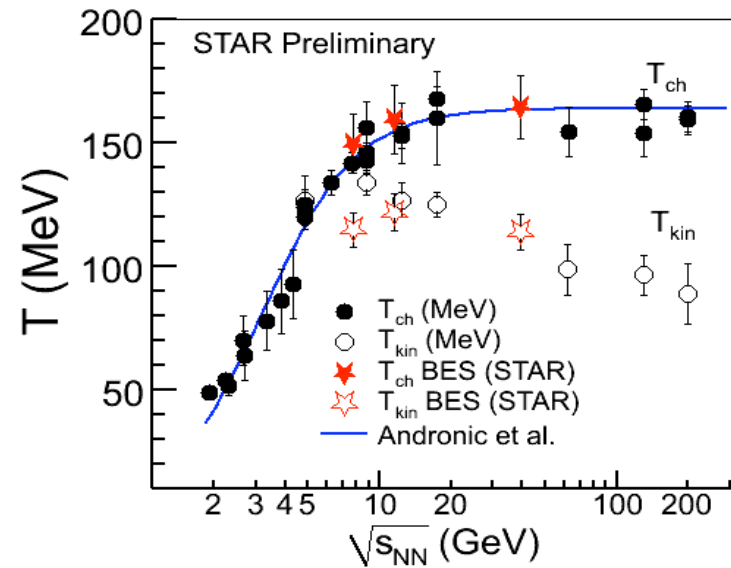
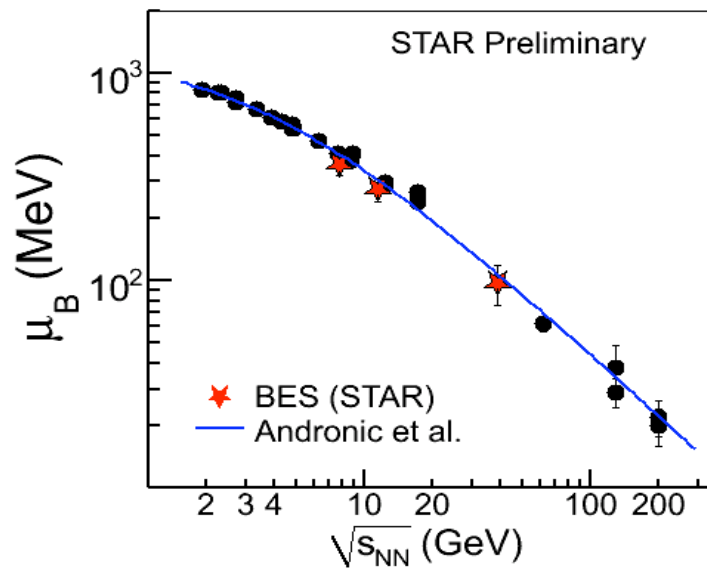


# Energy dependence of thermal and chemical freeze out parameters

**STAR talk at this conference:**

**Orpheus Mall      Session: QCD Phase Diagram 23/Sep Friday 16:50**

STAR, QM2011



- Scanning the  $(T, \mu_B)$  space
- Chemical freeze-out temperature is independent of collision centrality and system size at RHIC energies

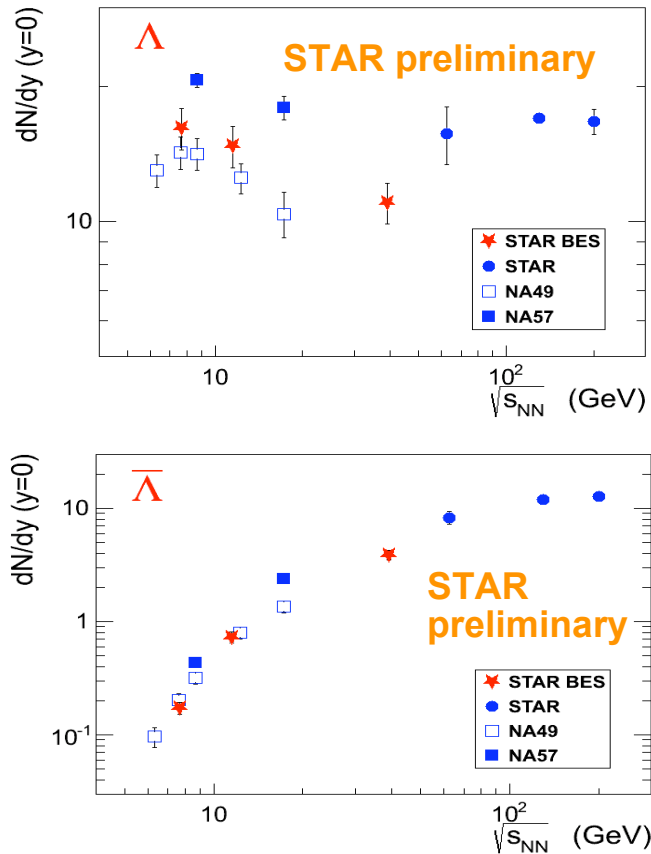


# K<sup>0</sup><sub>s</sub>, $\Lambda$ and $\Xi$ measurements in Au+Au at $\sqrt{s_{NN}} = 7.7, 11.5$ and 39 GeV

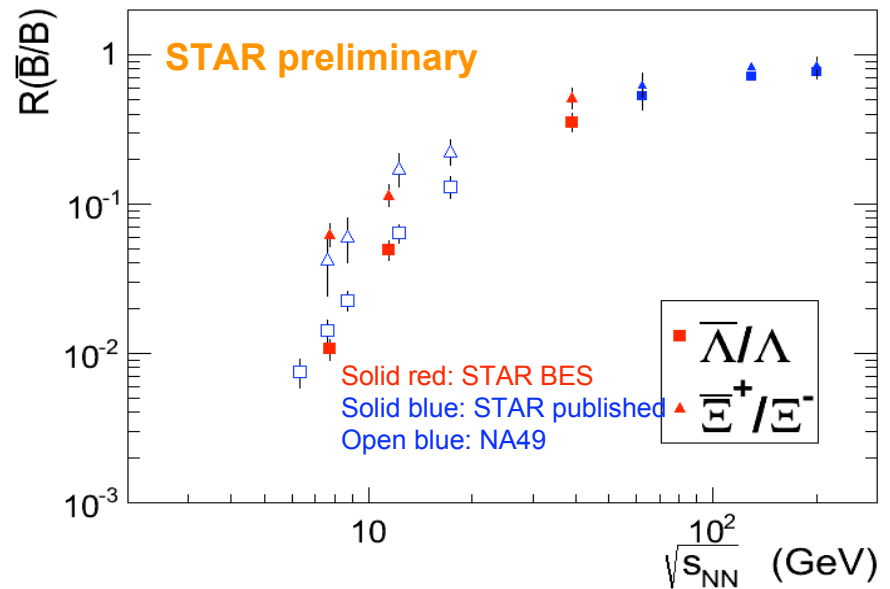
**STAR talk in this conference:**

**Xianglei Zhu**

**Session: Various Facets of Strangeness 20/Sep Tuesday 15:20**



NA49, PRC78,034918.  
NA57, PLB595,68; JPG32, 427  
STAR, PRL86,89,92,98; PRC83



NA57, NA49 yields are scaled by the corresponding number of wounded nucleons:  $dN/dy/Nw * Npart(STAR)$

STAR data agree with the NA49 data, with smaller errors

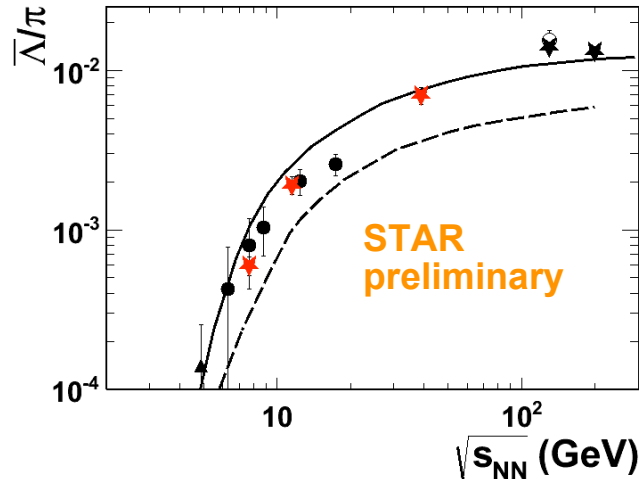
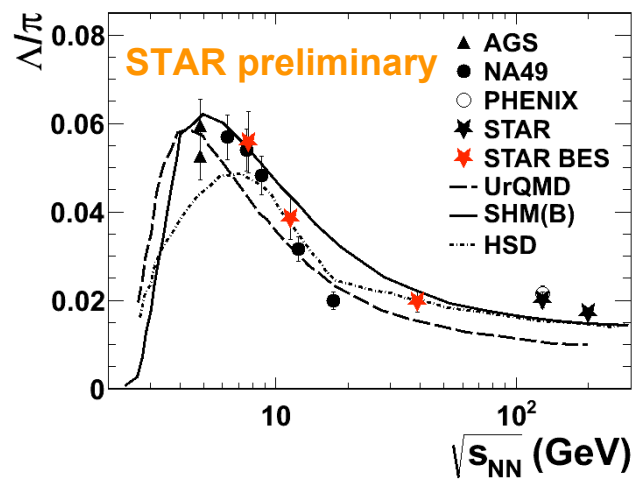


# Energy dependence of strange baryon to $\pi$ ratios

**STAR talk in this conference:**

**Xianglei Zhu**

**Session: Various Facets of Strangeness 20/Sep Tuesday 15:20**



SHM(B):

A. Andronic et.al.

UrQMD:

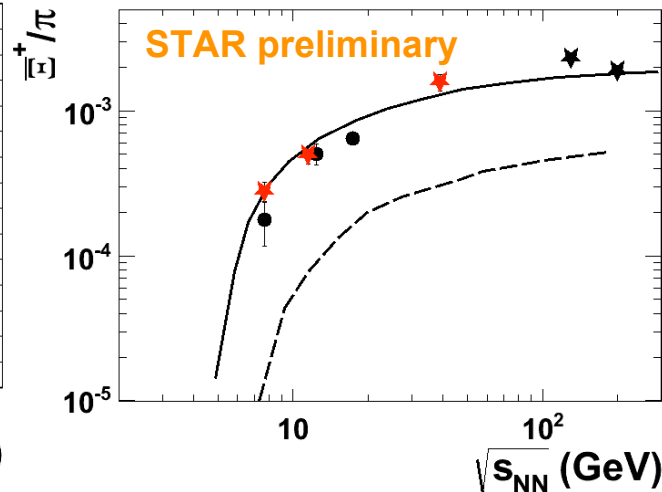
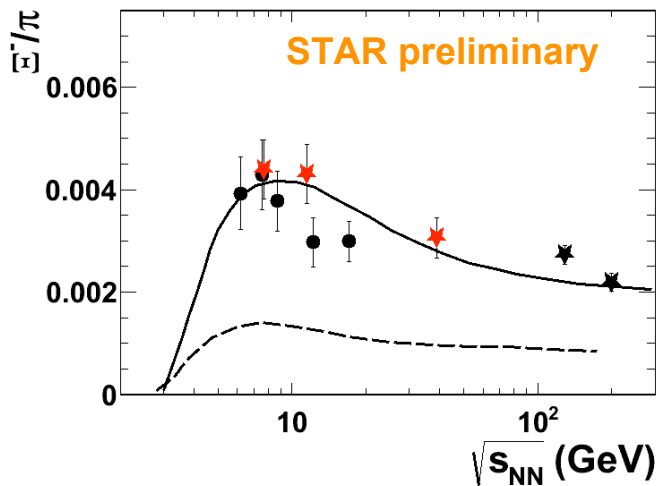
M. Bleicher et.al.

Hadron String Dynamics

(HSD) : E.Bratkovskaya

et.al; W. Cassing and E.

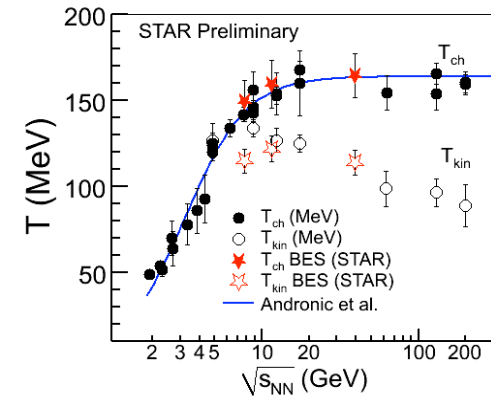
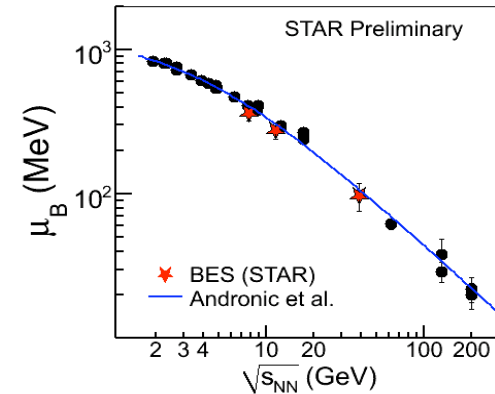
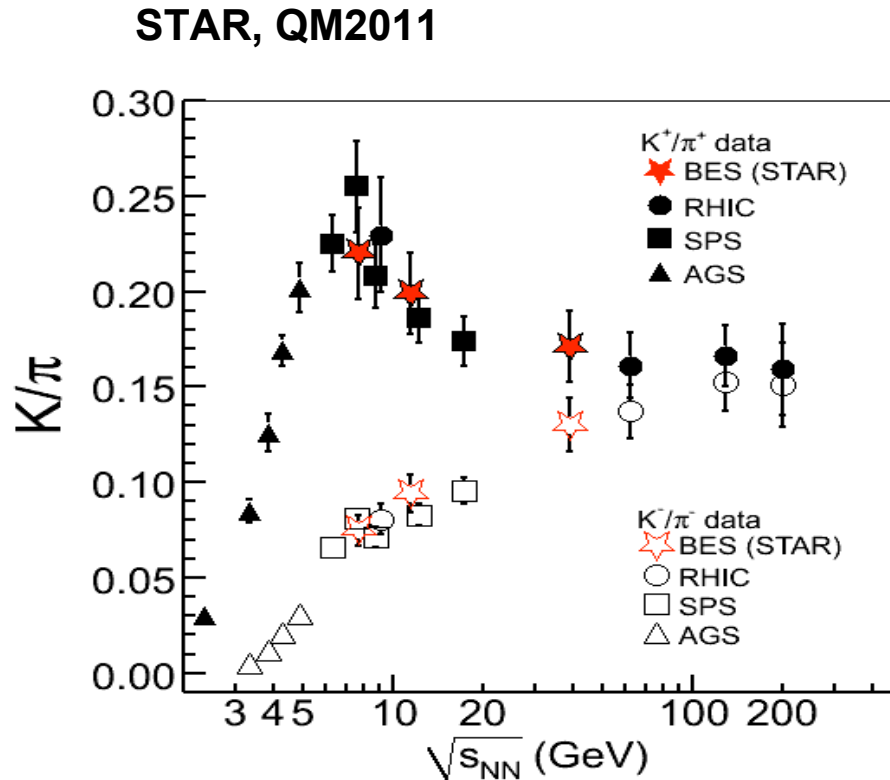
Bratkovskaya,



**STAR data agree well with the statistical hadronization model (SHM(B))**



# What can we learn from the $K/\pi$ ratio ?



- **New STAR data on  $K/\pi$**  are in agreement with previous SPS measurements
- **Maximum of  $K^+/\pi^+$  near  $\sqrt{s_{NN}} = 7-8$  GeV not seen in  $K^-/\pi^-$  in A+A**
- Can be related to  **$K^+\Lambda$**  associated production and the  **$\mu_B$  and  $T_{ch}$  beam energy dependence**, for example as described in the thermal model by A. Andronic et al.

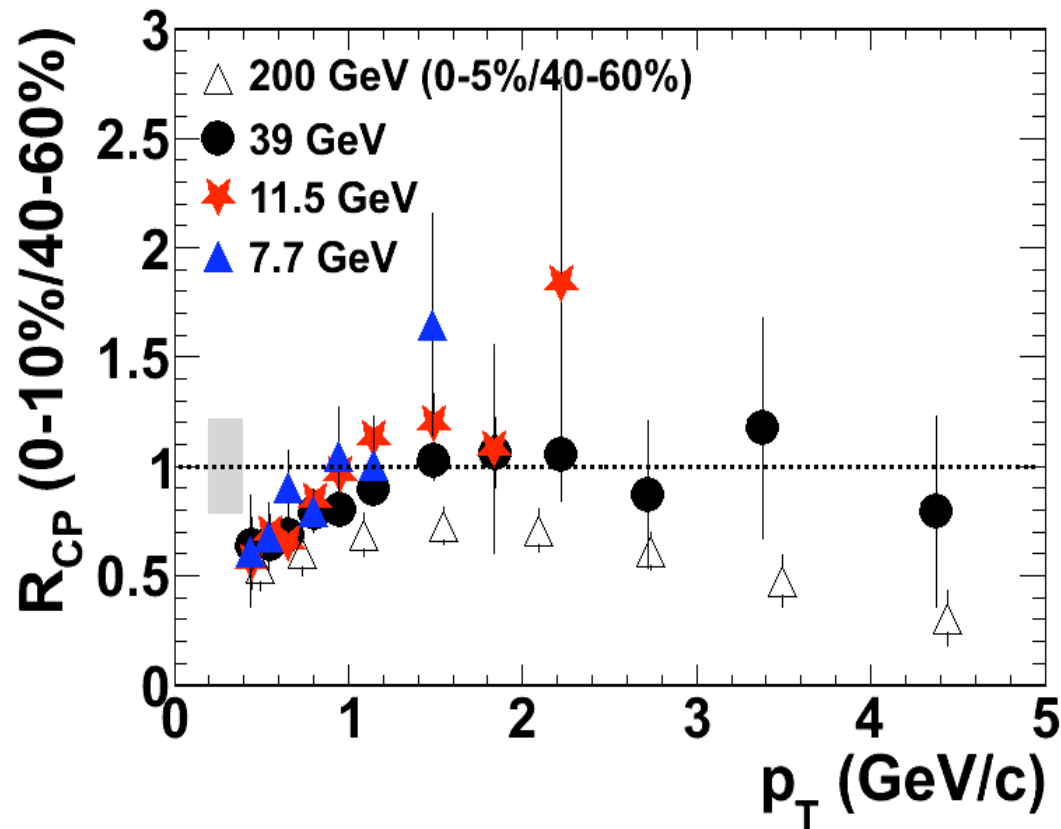
# Energy dependence of $R_{CP}(\phi)$

**STAR talk at this conference:**

**Xiaoping Zhang**

**Session: QCD Phase Diagram**

**23/Sep Friday 17:50**



**No suppression of  $R_{CP}(\phi)$  above  $p_T = 1$  GeV in central Au+Au at 39 GeV**



# Energy Dependence of $\phi$ $v_2$

**STAR talks in this conference:**

**Md. Nasim**

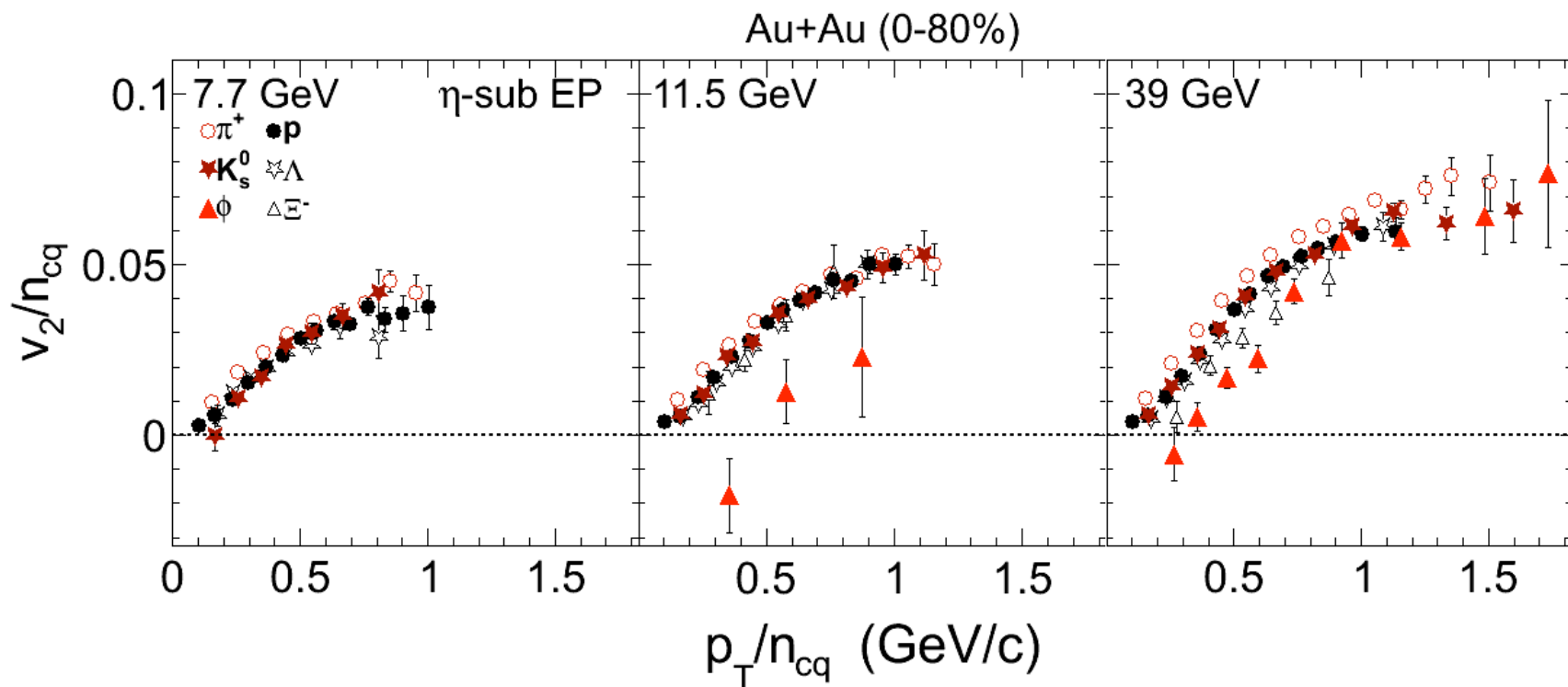
**Xiaoping Zhang**

**Shusu Shi**

**Session: Elliptic Flow 20/Sept Tuesday 17:10**

**Session: QCD Phase Diagram 23/Sep Friday 17:50**

**Session: Elliptic Flow 20/Sep Tuesday 16:50**



**The  $\phi$  meson does not follow the trend of other mesons at 11.5 GeV**



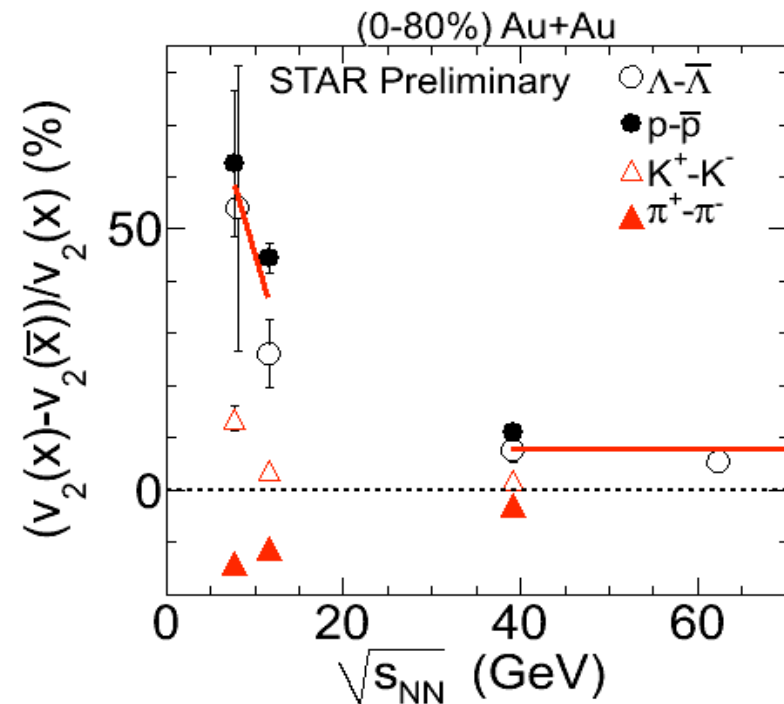
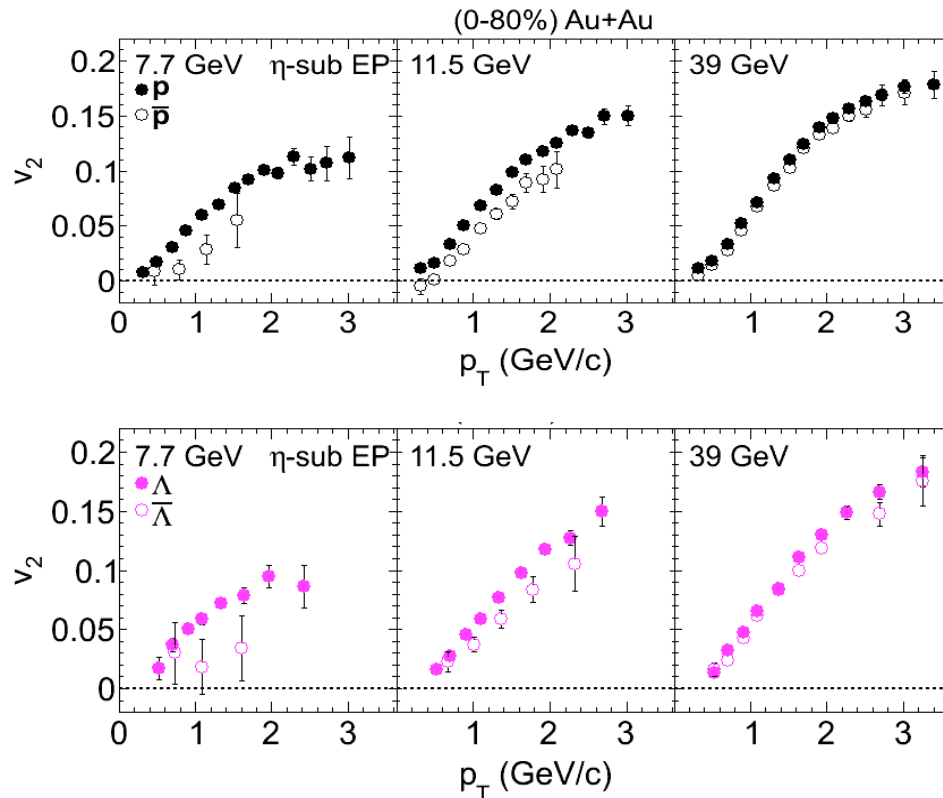
# Particle and antiparticle $v_2$ energy dependence

**STAR talk in this conference:**

**Shusu Shi**

**Session: Elliptic Flow**

**20/Sep Tuesday 16:50**



**Difference observed between the  $v_2$  of particles and antiparticles at 7.7, 11.5 GeV.**  
 **$v_2(\text{part}) - v_2(\text{anti-part})$  difference is increasing as beam energy is decreasing**



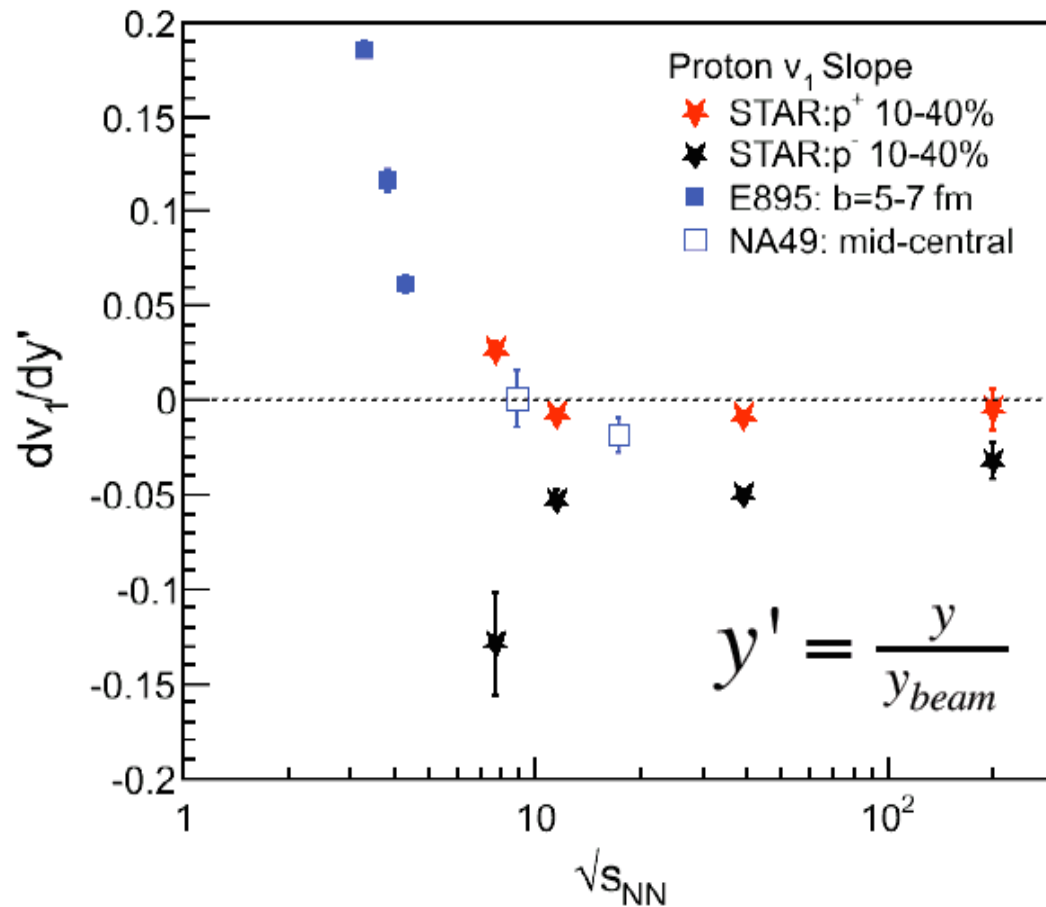


# Energy dependence of proton directed flow

**STAR talk at this conference:**

Yadav Pandit

Session: Flow/Correlations parallel 2 23/Sep Friday 16:50



The slope of the  $y$ -dependence of the  $v_1$  of the proton

- decreases with increasing energy,

-- changes sign to negative between 7.7 and 11.5 GeV and

- then remains close to zero up to 200 GeV



# Net-proton high moments products

**STAR talk at this conference:**

**Xiaofeng Luo**

**Session: QCD Phase Diagram**

**23/Sep Friday 17:10**

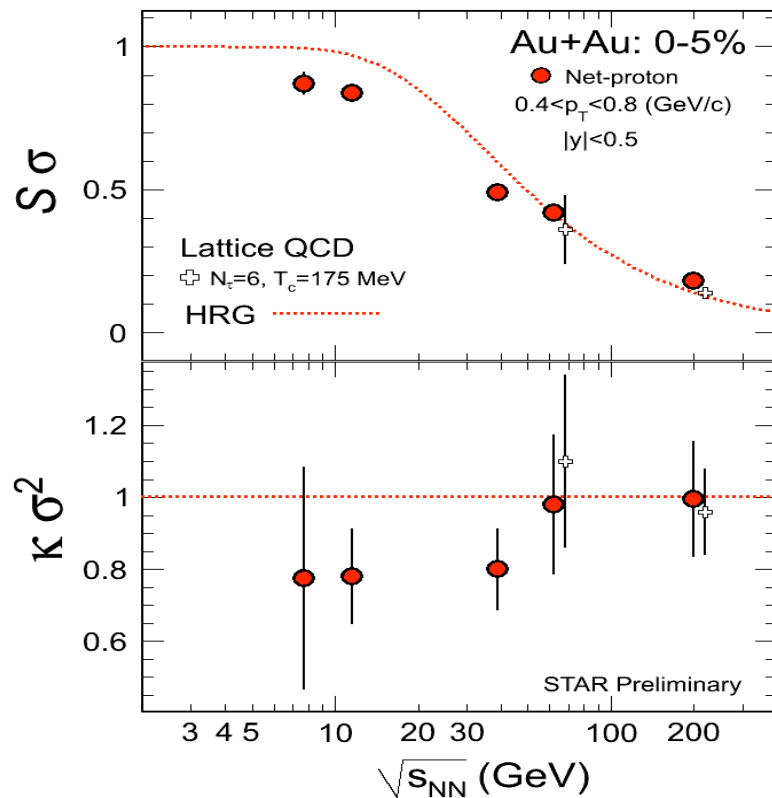
F Karsch, K Redlich, PLB 695, 136, 2011

S Gupta et al Science 332, 1525 (2011)

$\sigma$  = standard deviation

$S$  = skewness

$\kappa$  = kurtosis



$$S\sigma = \chi_B^{(3)} / \chi_B^{(2)}$$

$$\kappa\sigma^2 = \chi_B^{(4)} / \chi_B^{(2)}$$

Consistent with Hadron Resonance Gas (HRG) and lattice at high energy

Deviations from HRG below 39 GeV

Analysis of 19.6 and 27 GeV data is ongoing



# Search for fluctuations of particle ratios in BES

**STAR talks at this conference:**

**Jian Tian**

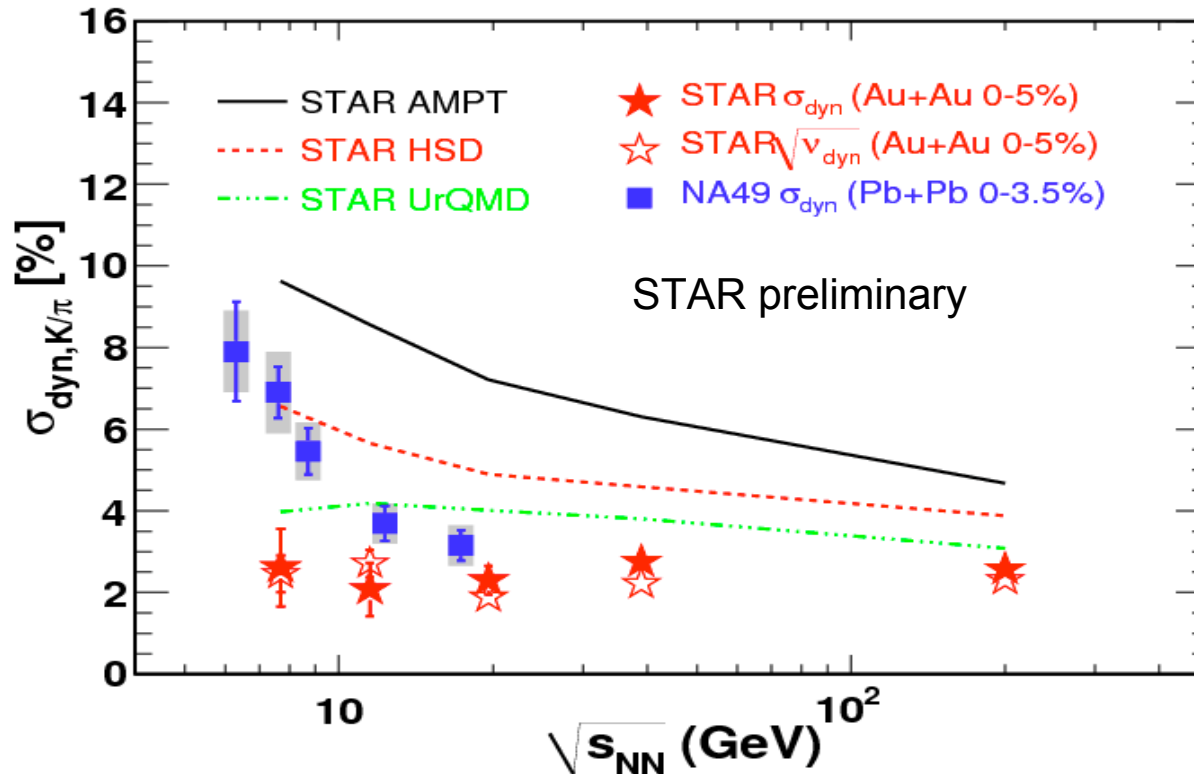
**Session: QCD Phase Diagram**

**23/Sep Friday 17:30**

**Terence Tarnowski**

**Session: QCD Phase Diagram**

**23/Sep Friday 18:10**



$$\sigma_{dyn}^2 \approx V_{dyn}$$

NA49,  
PRC79 (2009) 044910

- STAR results using  $v_{dyn}$  and  $\sigma_{dyn}$  agree!
- $K/\pi$  fluctuations in Au + Au 0-5% collisions show relatively small energy dependence in the measured energy region.



# 3. CONCLUSIONS AND OUTLOOK



# Conclusions

- STAR enters a new era of high precision / high statistics measurements thanks to major recent upgrades (TOF, DAQ, HLT).
- At top energy 200 GeV collisions with small  $\mu_B \sim 20$  MeV, we study the sQGP properties !
- At beam energy scan, we explore the QCD phase structure, searching for critical point and phase boundary !



# Outlook

## Near future upgrades :

- Precision measurements of Open Heavy Flavour with a new silicon vertex detector, designed to reach a DCA resolution of  $\sim 30$  microns : **Heavy Flavour Tracker (HFT)**. Data taking 2014.
- Precision measurements of Quarkonia, HF to  $e-\mu$ , and dimuon pairs, with a new **Muon Telescope Detector (MTD)** (80% ready in 2014).

