Highlights from the STAR experiment at RHIC

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1st International Conference on New Frontiers in Physics (ICFP2012)

10-16 June 2012, Kolymbari, Greece

Outline

1 Introduction: physics goals and STAR detector

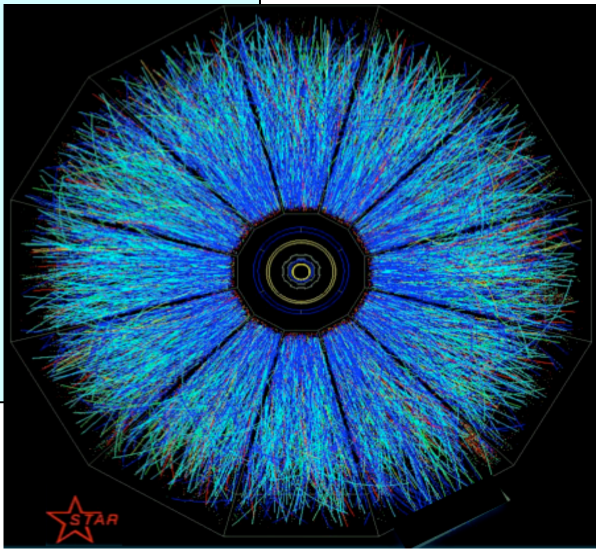
2 Physics results :

A. Charm and beauty

B. Antimatter and dileptons

C. Beam energy scan

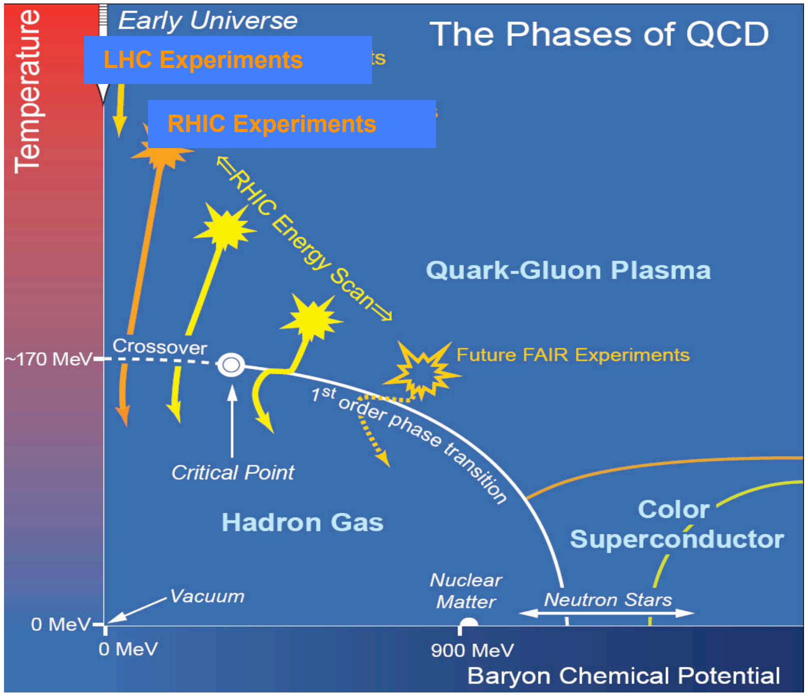
3 Conclusions and Outlook



STAR

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 Tc~160-180 MeV

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

STAR Physics Program : Heavy ions, Nucleon Spin Structure, cold nuclear initial conditions

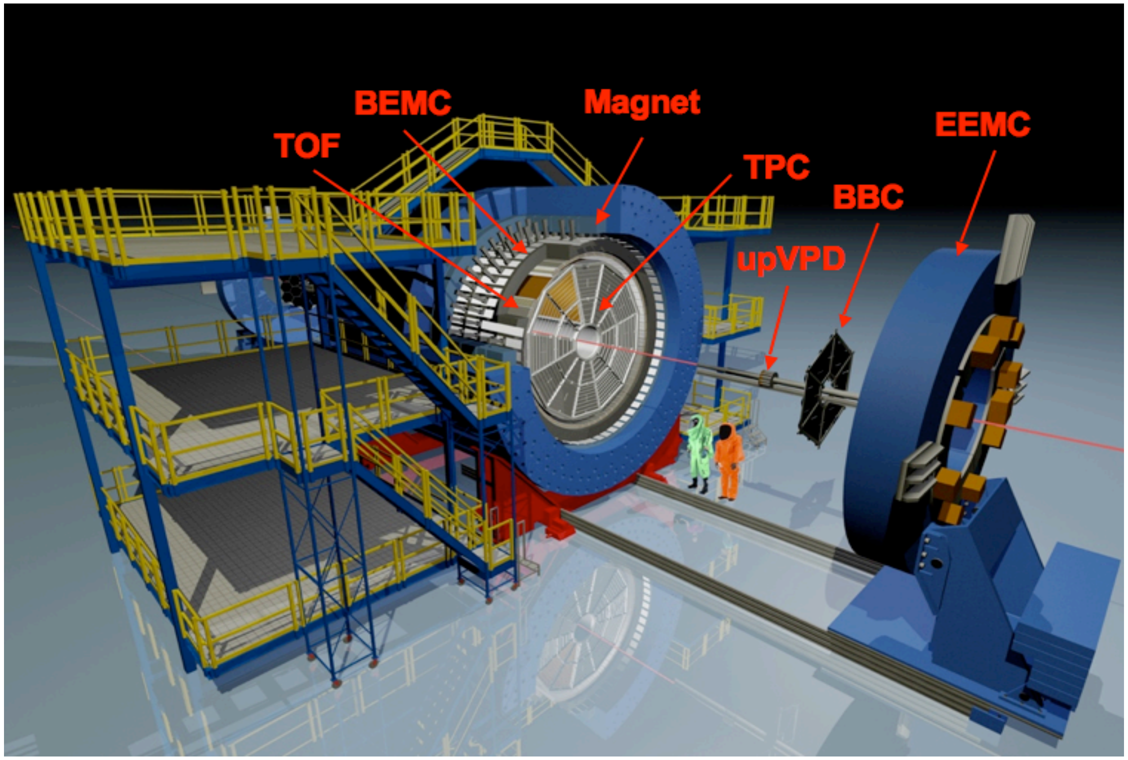
STAR@200 GeV : study the sQGP and its properties at low net baryon density

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 (|η|<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

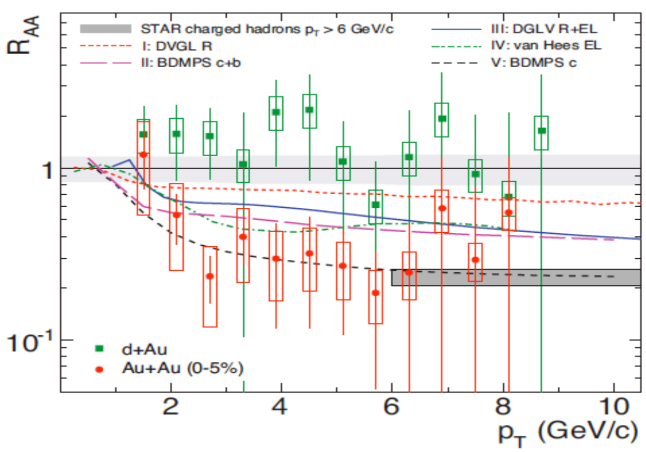
2. PHYSICS RESULTS :
A. CHARM AND BEAUTY

The Heavy Flavour R_{AA} suppression puzzle at RHIC

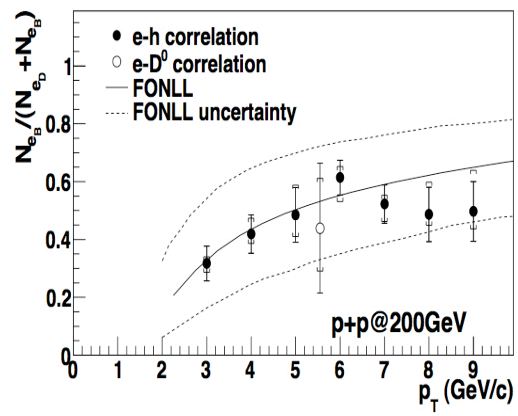
HF Non Photonic Electrons do not follow mass dependence expectations for radiative energy loss

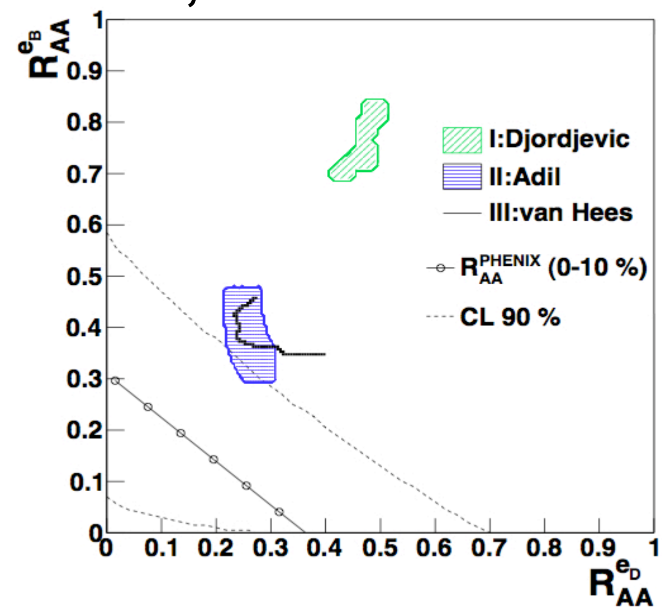
Is beauty also quenched in Au+Au collisions at 200 GeV ?

STAR, PRL 98 (207) 192301, erratum 2011



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





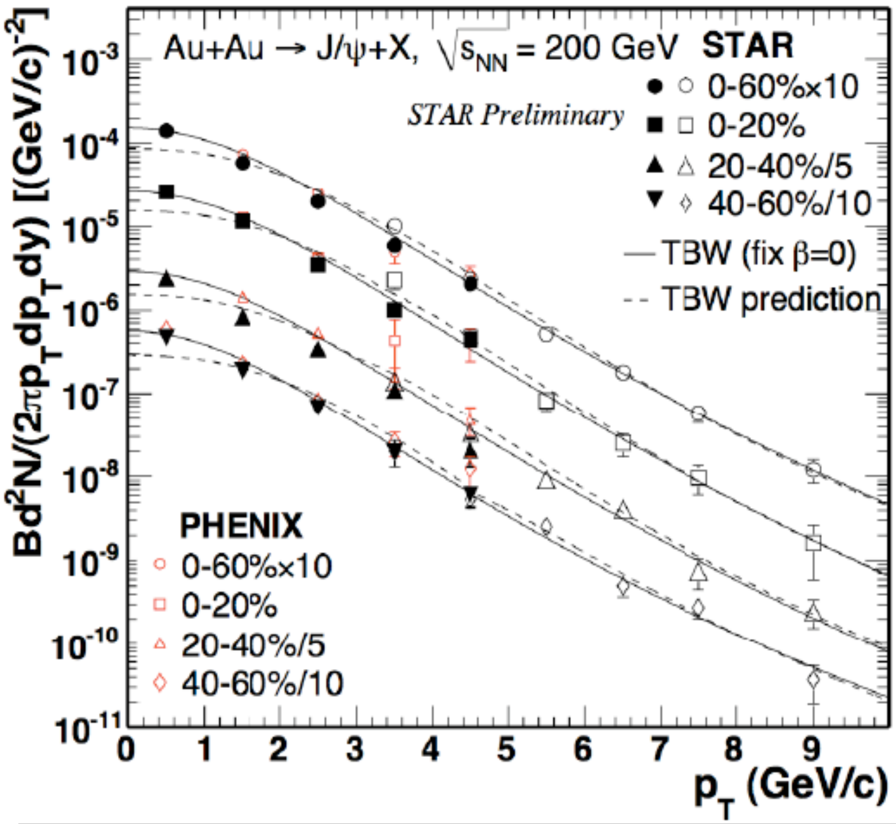
- Contribution of electrons from beauty become ~50% at ~5 GeV p_T in p+p collisions
- $R_{AA}(e_B)$ < 1 even if $R_{AA}(e_D)$=0 -> Beauty and Charm are both suppressed in Au+Au
- Measurements of B and C in Au+Au are crucial

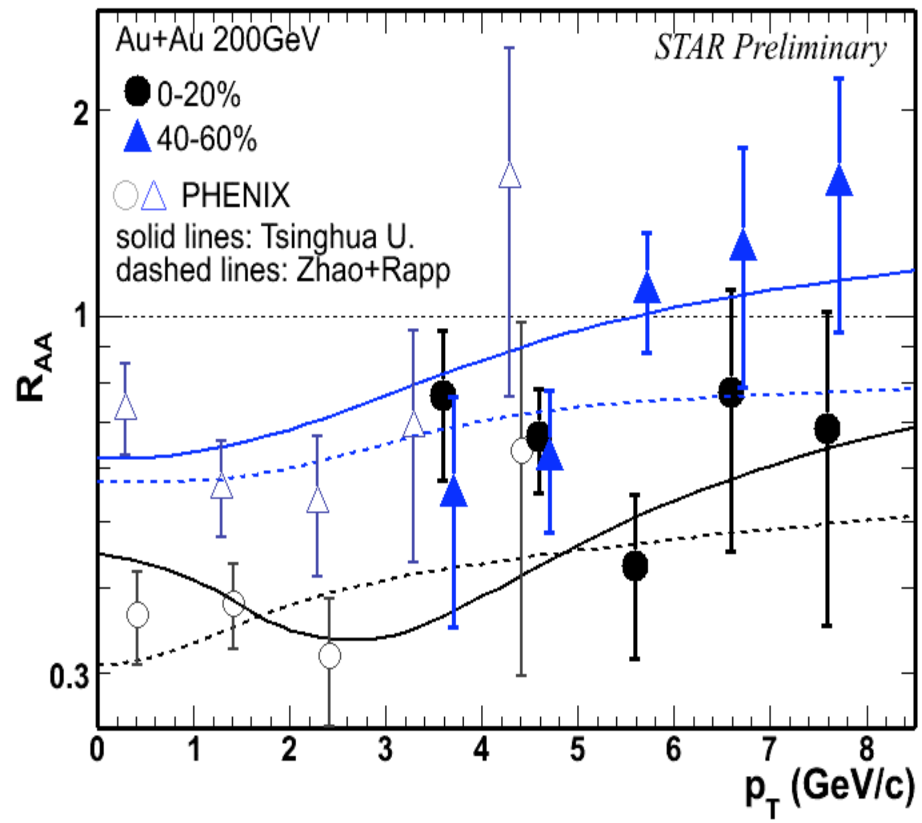
  * Silicon detector upgrade (HFT) of STAR

R_{AA}(J/Ψ) in Au+Au collisions at 200 GeV

STAR, QM2011

Zebo Tang and the STAR Collaboration, J.Phys.G (2011) 124107





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

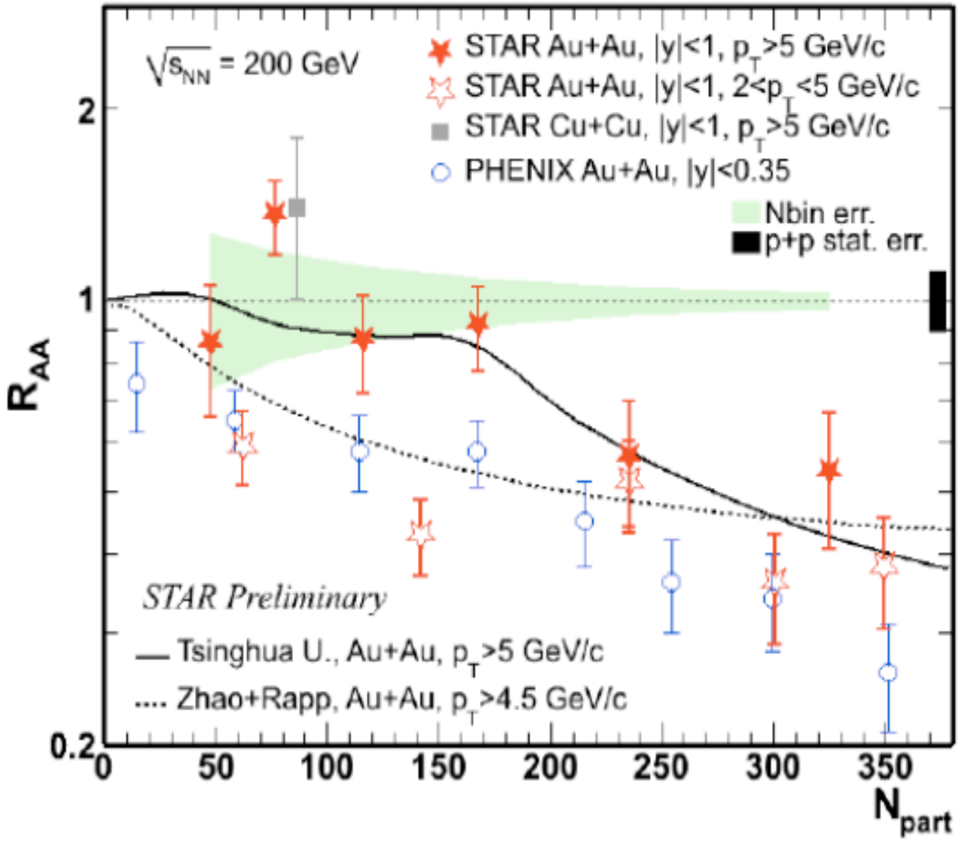
STAR extends the measurement to 10 GeV/c

R_{AA}(J/Ψ) 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

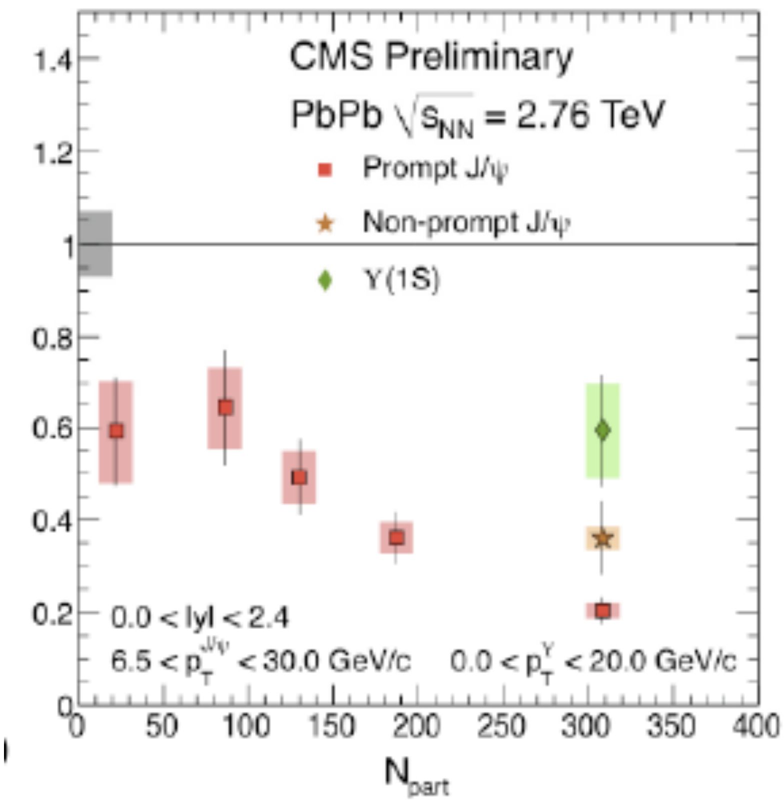
STAR, QM2011

Zebo Tang and the STAR Collaboration, J.Phys.G (2011) 124107



CMS, QM2011

B. Wyslouch and the CMS Collaboration



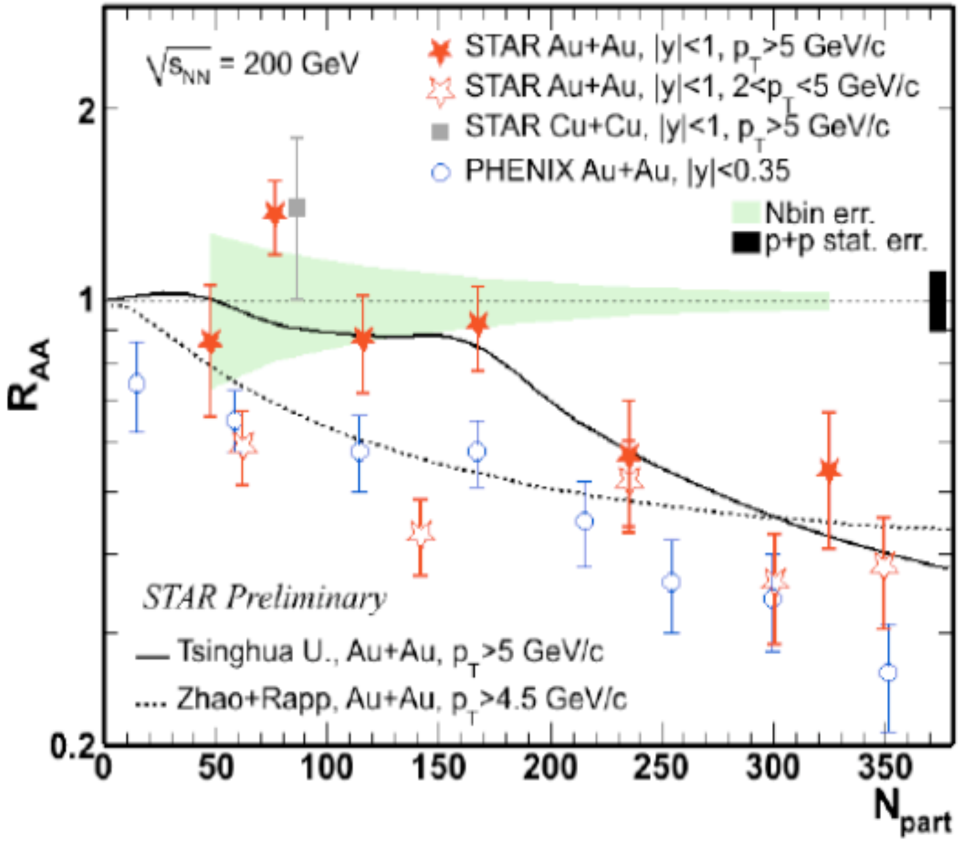
* Suppression in central collisions at high p_T
* Systematically higher at high p_T

• Midrapidity high p_T J/ψ seems to have more suppression at LHC

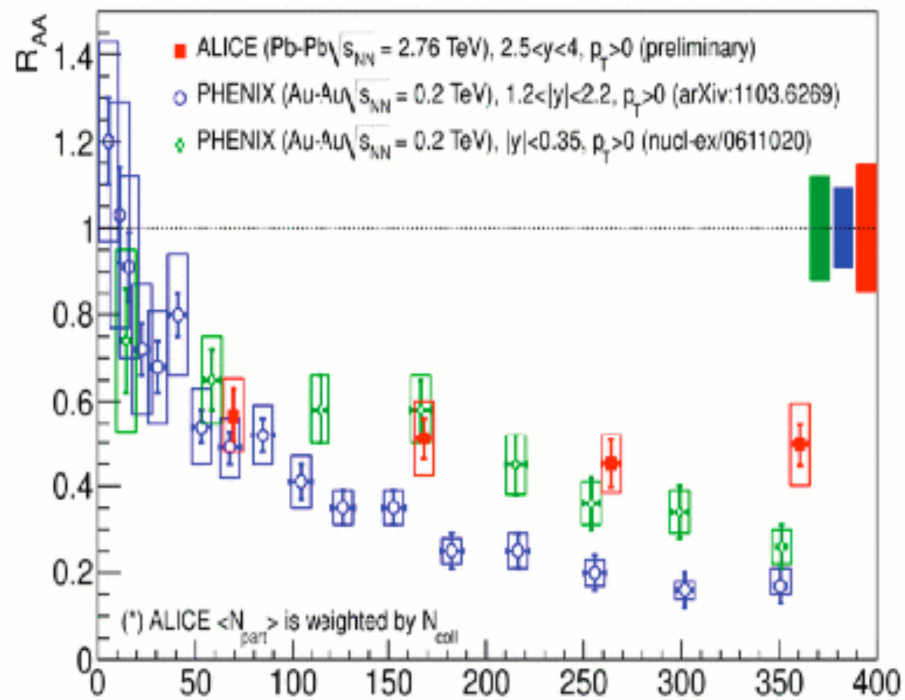
- consistent with larger system size at LHC

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

STAR, QM2011



T.Nayak and the ALICE Collaboration, LP2011



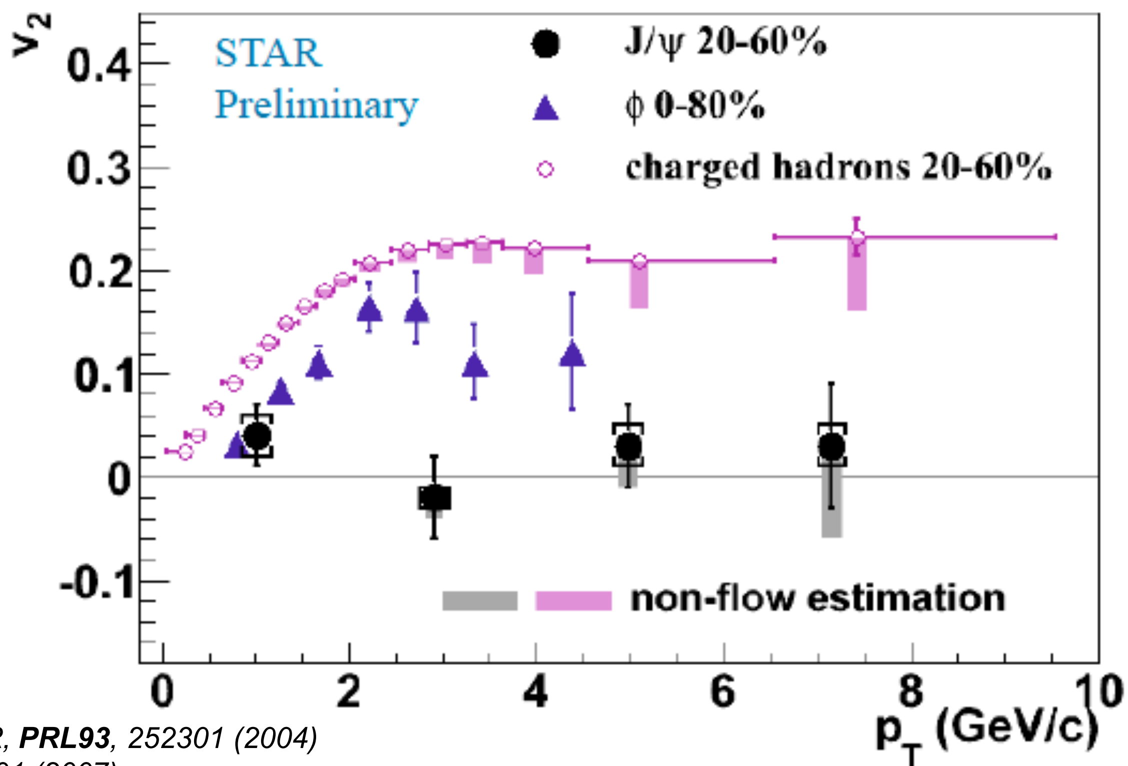
* Suppression in central collisions at high p_T
* Systematically higher at high p_T

- Low p_T J/ψ seem to have less suppression at LHC

  \- Possibly related to J/Psi regeneration at LHC

Does the J/Ψ flow at RHIC ?

Gang Wang and the STAR Collaboration, CPOD2011



*charged hadrons, STAR, **PRL93**, 252301 (2004)*
*ϕ, STAR, **PRL99**, 112301 (2007)*

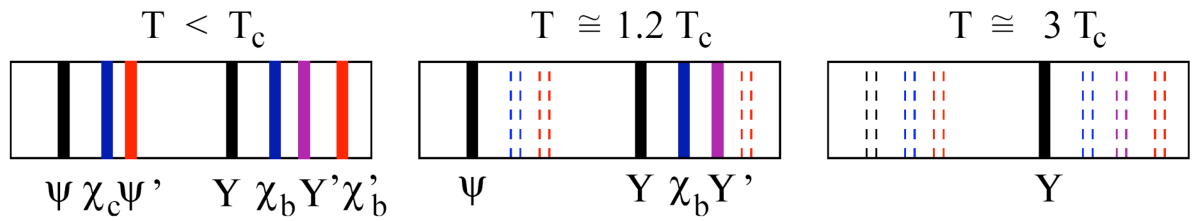
- ***J/ψ* v_2 ~ 0 in the p_T range of 2 to 8 GeV/c in mid-central 20-60%**

➡ **Disfavors coalescence from thermalized charm quarks at RHIC**

Υ suppression in Au+Au @ 200 GeV

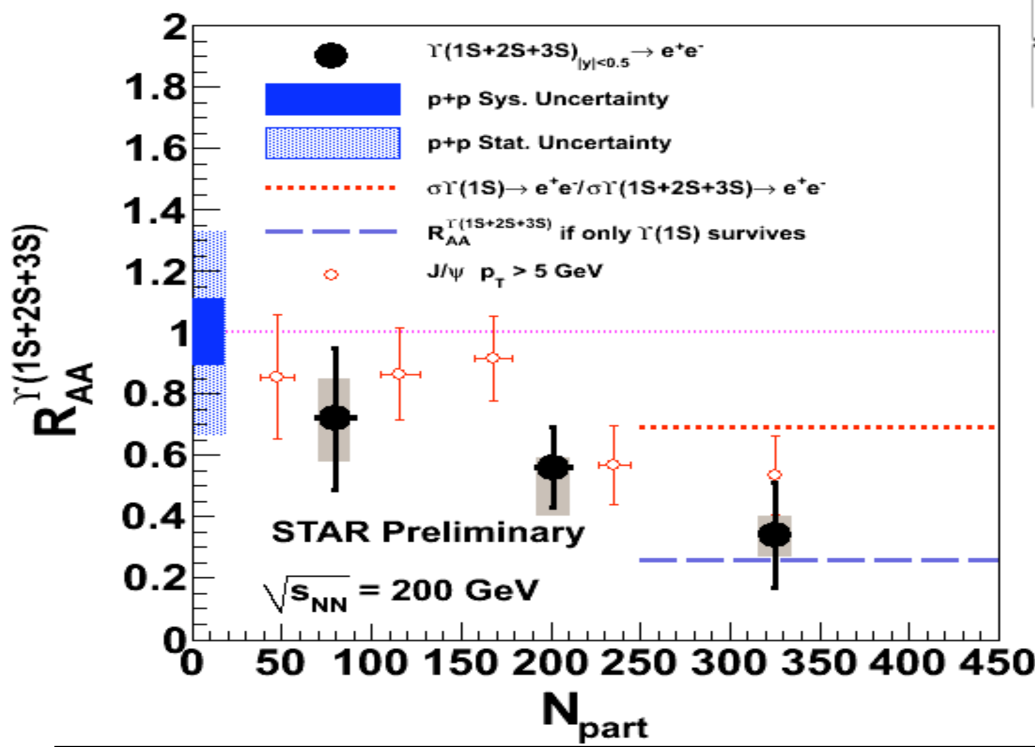
STAR, QM2011

R. Reed et al



state	$J/\psi(1S)$	$\chi_c(1P)$	$\psi'(2S)$	$\Upsilon(1S)$	$\chi_b(1P)$	$\Upsilon(2S)$	$\chi_b(2P)$	$\Upsilon(3S)$
T_d/T_c	2.10	1.16	1.12	> 4.0	1.76	1.60	1.19	1.17

H. Satz, NPA 783 (2007) 249c



- Υ(1S+2S+3S) suppression at central collisions
- First measurement of Υ suppression at RHIC
- R_{AA} at most central point is in agreement with only Y(1S) surviving

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

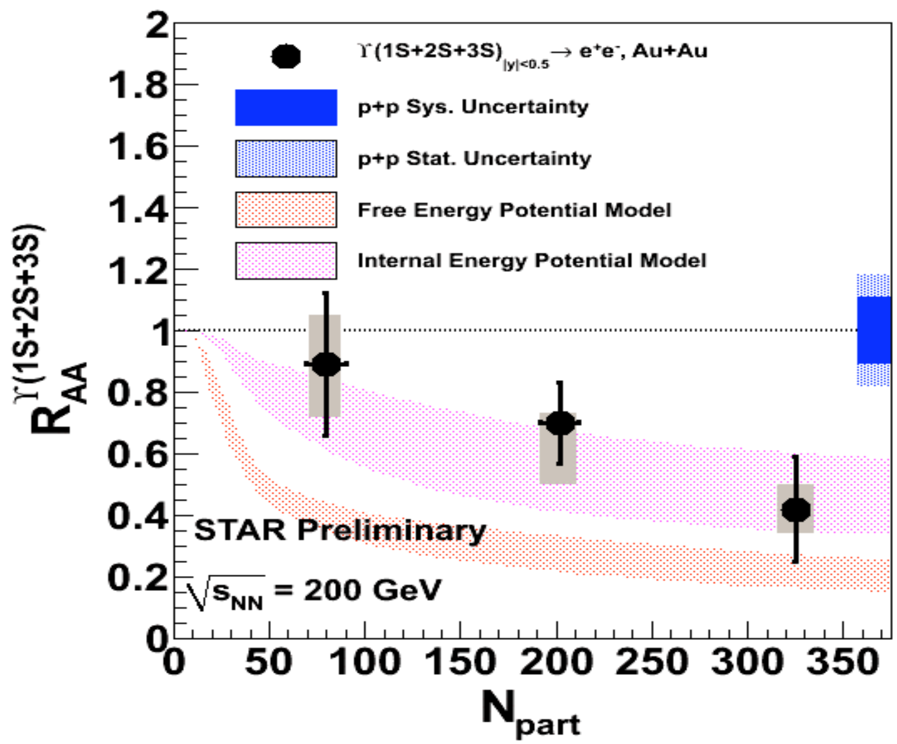
--> Data in agreement with Y(2S+3S)/Y(1S) suppression both at RHIC and LHC

Υ suppression in Au+Au @ 200 GeV

STAR, Hard Probes 2012

Antony Kesich et al

Model: M. Strickland, D. Bazow, arXiv:1112.2761



Models from M. Strickland and D. Bazow, arXiv:1112.2761v4

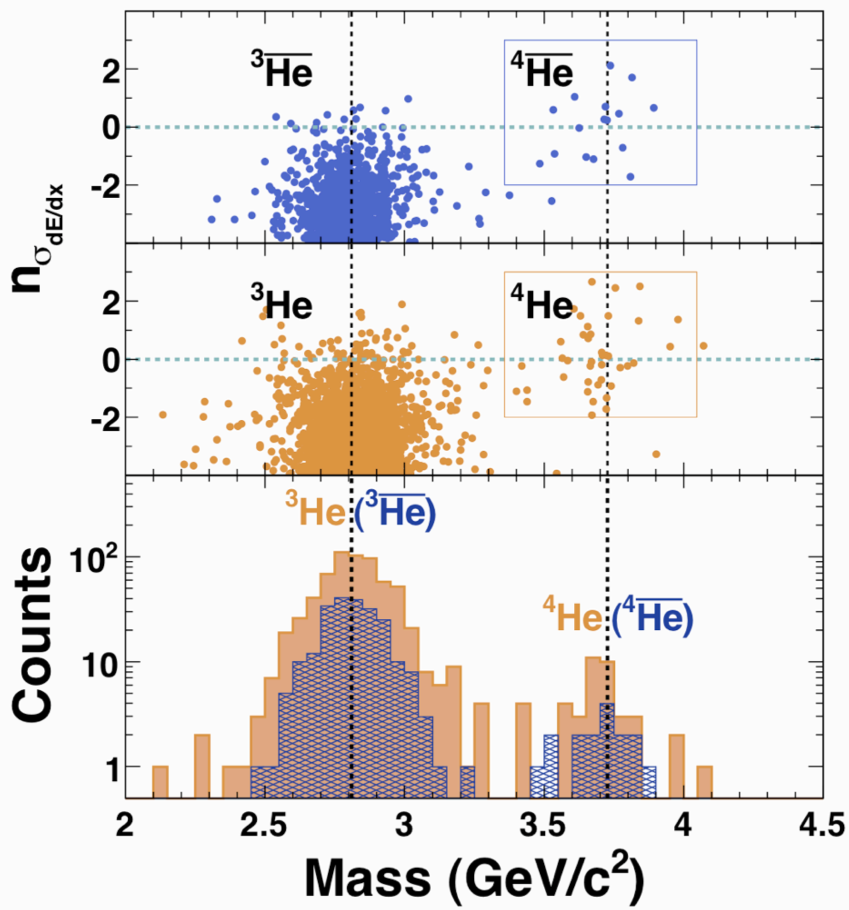
- Model with fireball expansion and quarkonium feed-down
- Results are consistent with 2S and 3S suppression in the model
- The data indicate initial Temperature in the range 428-442 MeV and $1/(4\pi)<\eta/S<3/(4\pi)$

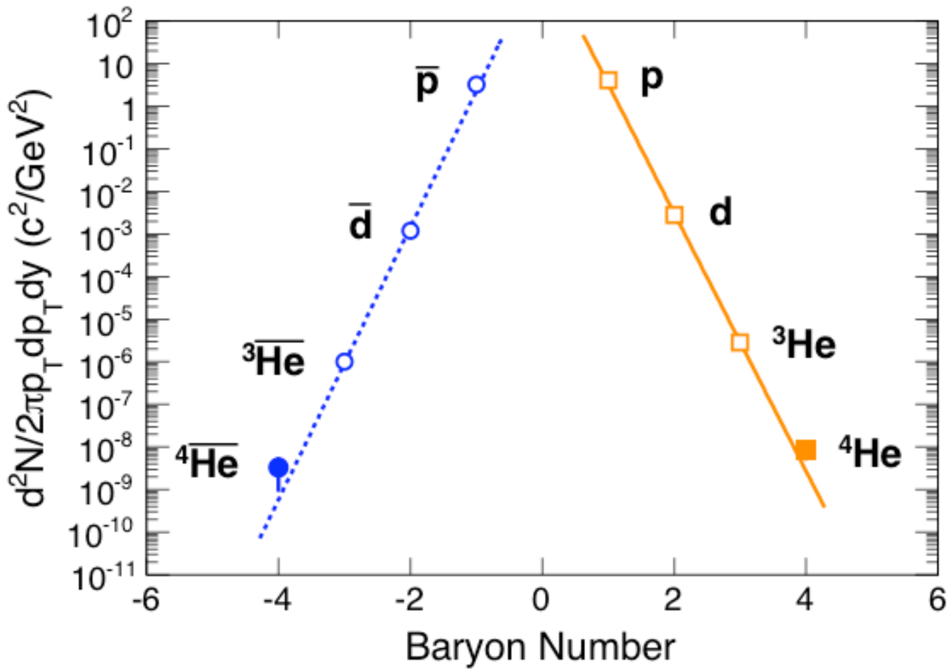
B. ANTIMATTER AND DILEPTONS

First observation of anti-^{4}He

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

The heaviest antimatter nucleus measured





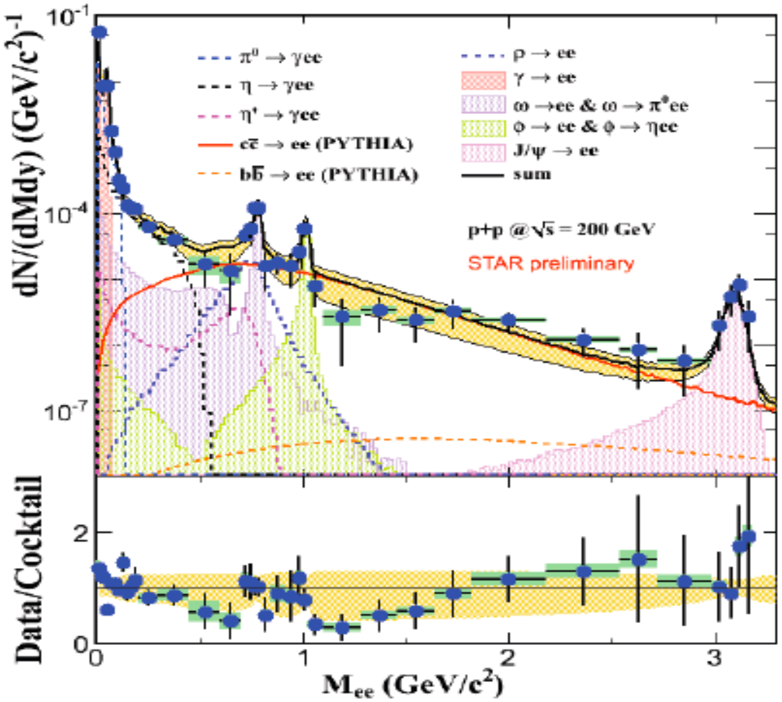
- First measurement ever of 18 anti-^{4}He based on TPC+TOF+HLT
- Consistent with thermal & coalescence model expectation

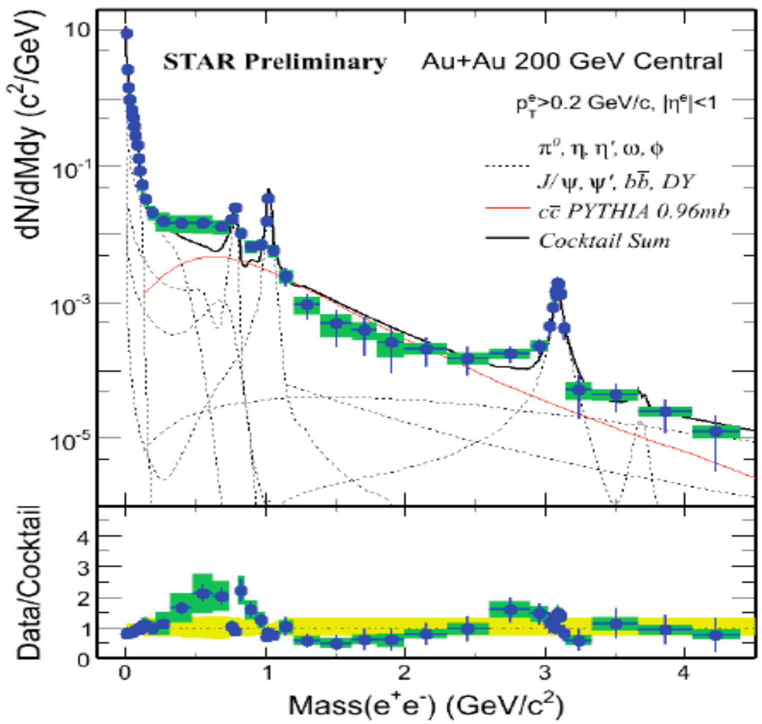
Sets the background for observation of antimatter in space

Dilepton production in p+p and Au+Au collisions

Bingchu Huang and the STAR Collaboration, SQM2011

J. Zhao and the STAR Collaboration, Hard Probes 2012





Cocktail consistent with data in pp collisions

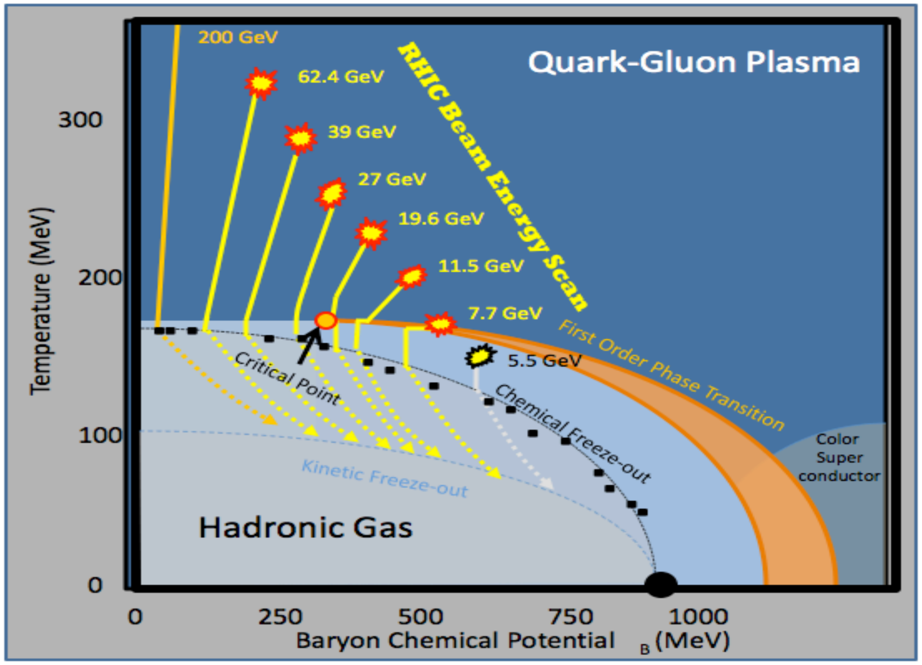
Low mass region (LMR) enhancement in central AuAu (no rho contribution in the cocktail)

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

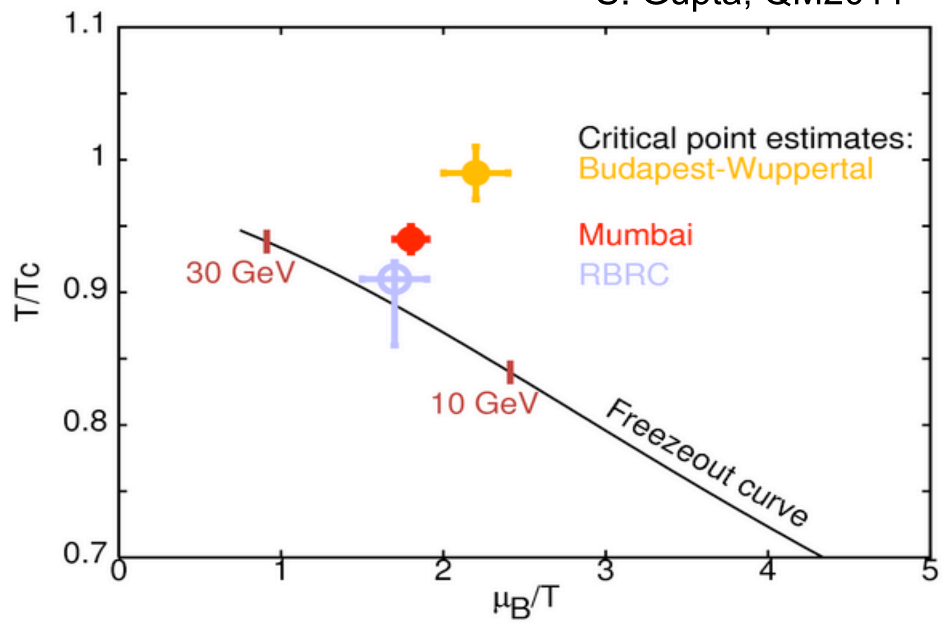
C. BEAM ENERGY SCAN

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:

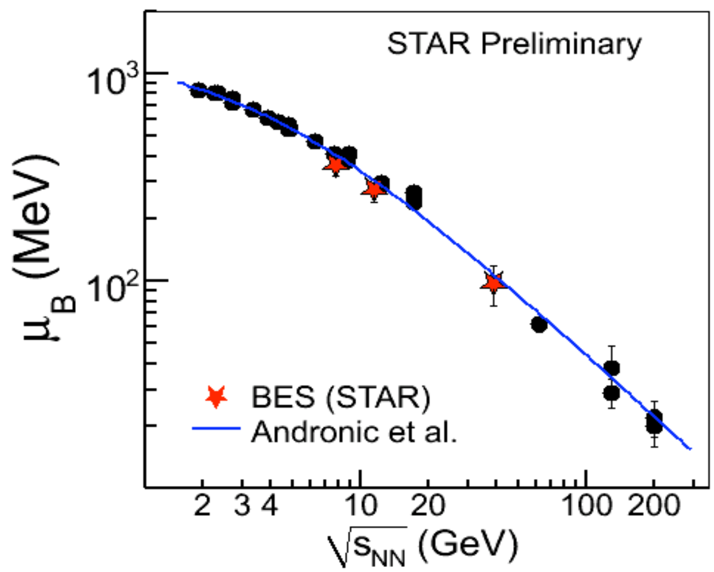
sqrt(s)= 7.7, 11.5, 19.6, 27, 39, (62, 130, 200) GeV

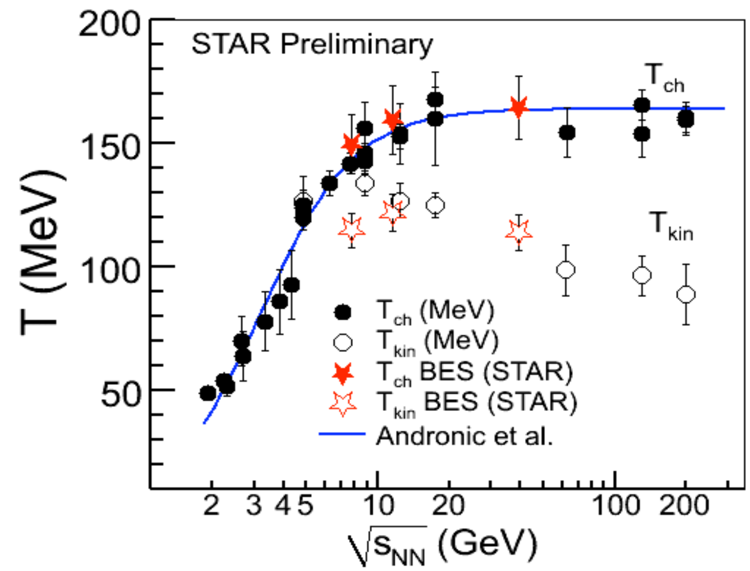
http://drupal.star.bnl.gov/STAR/starnotes/public/sn0493 arXiv:1007.2613

Energy dependence of thermal and chemical freeze out parameters

Orpheus Mall for the STAR Collaboration, SQM2011

STAR, QM2011

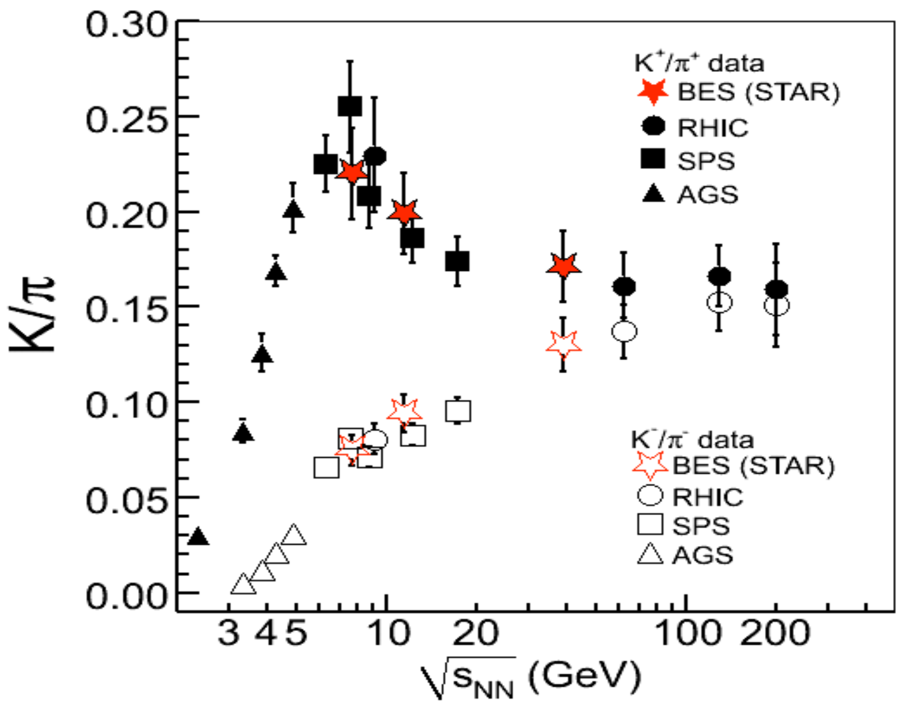


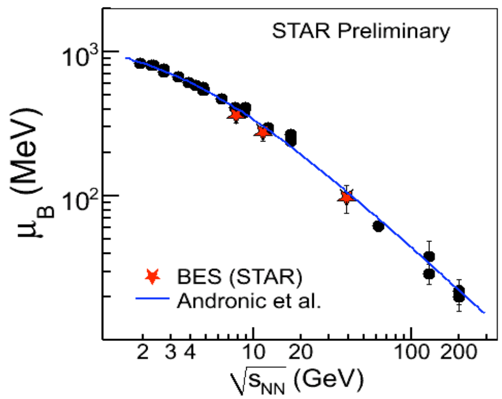


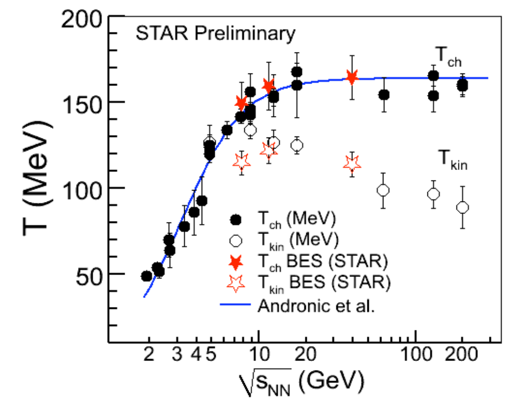
- **Scanning the (T, μ_B) space**
- **Chemical freeze-out temperature is independent of collision centrality and system size at RHIC energies**

What can we learn from the K/π ratio ?

STAR, QM2011



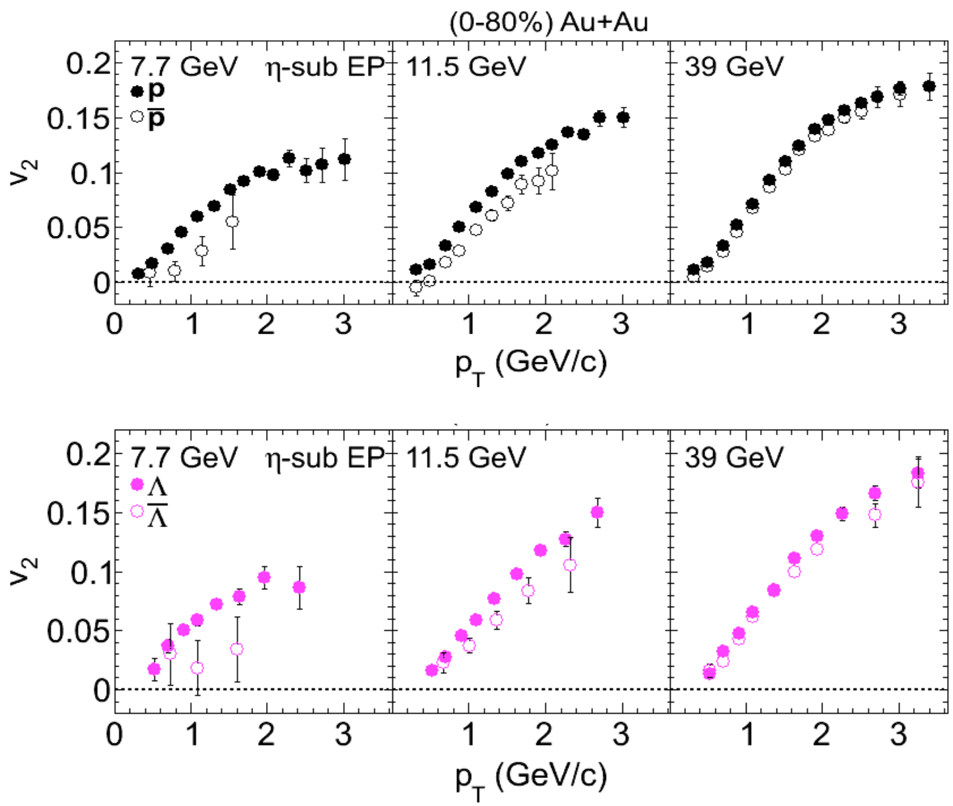


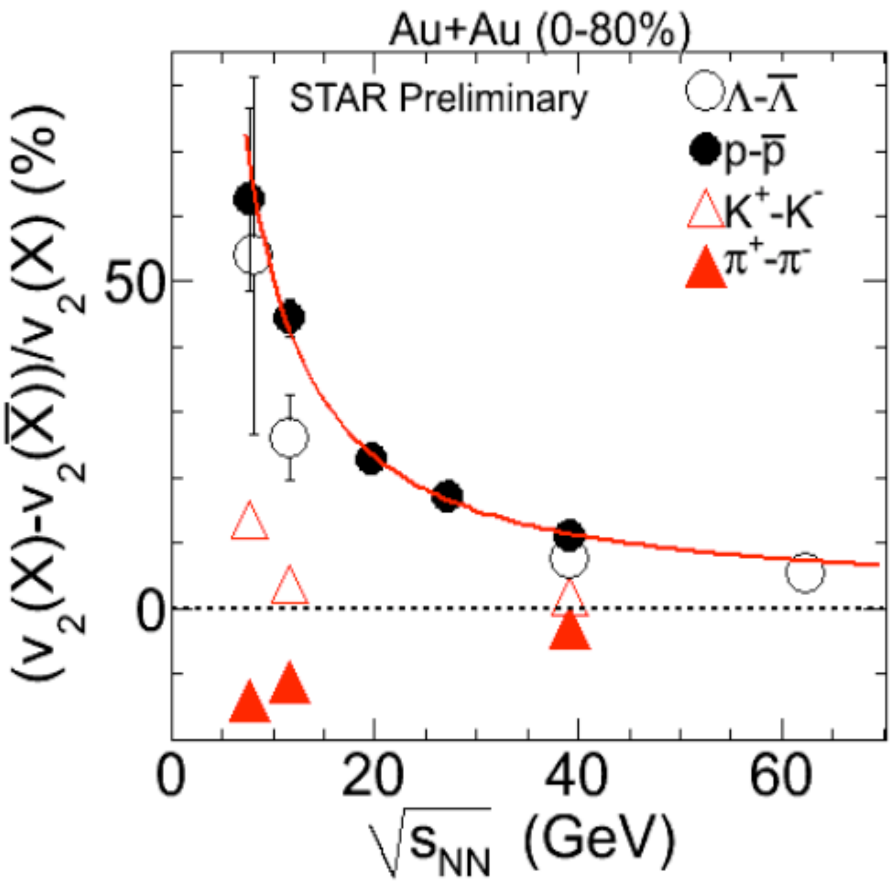


- New STAR data on K/π are in agreement with previous SPS measurements
- Maximum of K^+/π^+ near $\sqrt{s_{NN}}$ = 7-8 GeV not seen in K^-/π^- in A+A
- Can be related to $K^+\Lambda$ associated production and the μ_B and T_{ch} beam energy dependence, for example as described in the thermal model by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

Particle and antiparticle v_2 energy dependence

S. Shi, STAR, CPOD2011



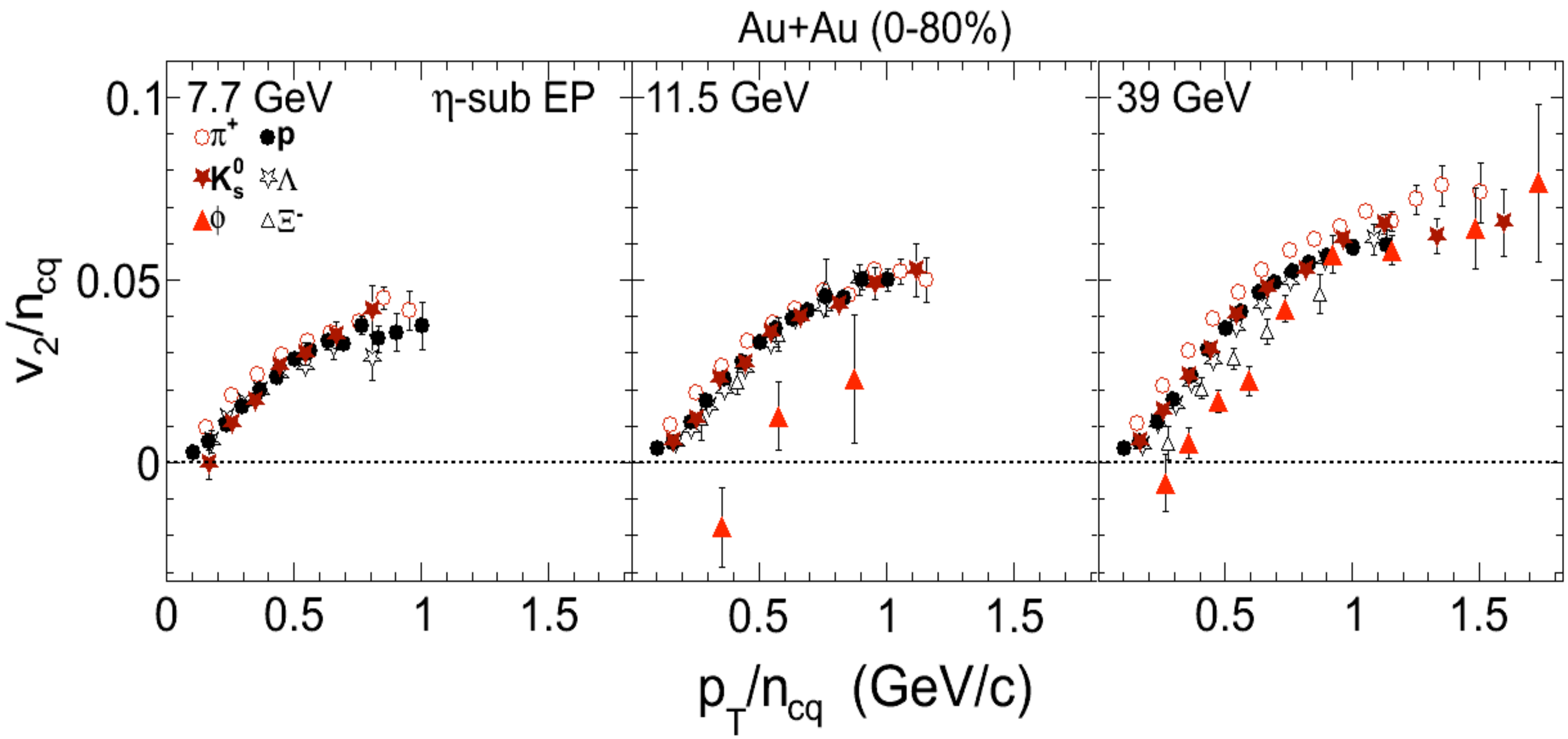


Difference observed between the v_2 of particles and antiparticles below 39 GeV.

v_2(part) - v_2(anti-part) difference is increasing as beam energy is decreasing

Energy Dependence of ϕ v_2

S. Shi, STAR, CPOD2011



- Universal trend for most of particles
- The ϕ meson does not follow the trend of other mesons at 11.5 GeV

  (Mean deviation from pion distribution is 2.6 sigma)
- Hadronic interactions dominant for $\sqrt{(s)} \leq 11.5$ GeV

3. CONCLUSIONS AND OUTLOOK

Conclusions

- **STAR enters a new era of <u>high precision / high statistics measurements</u> thanks to major recent upgrades (TOF, DAQ, HLT).**

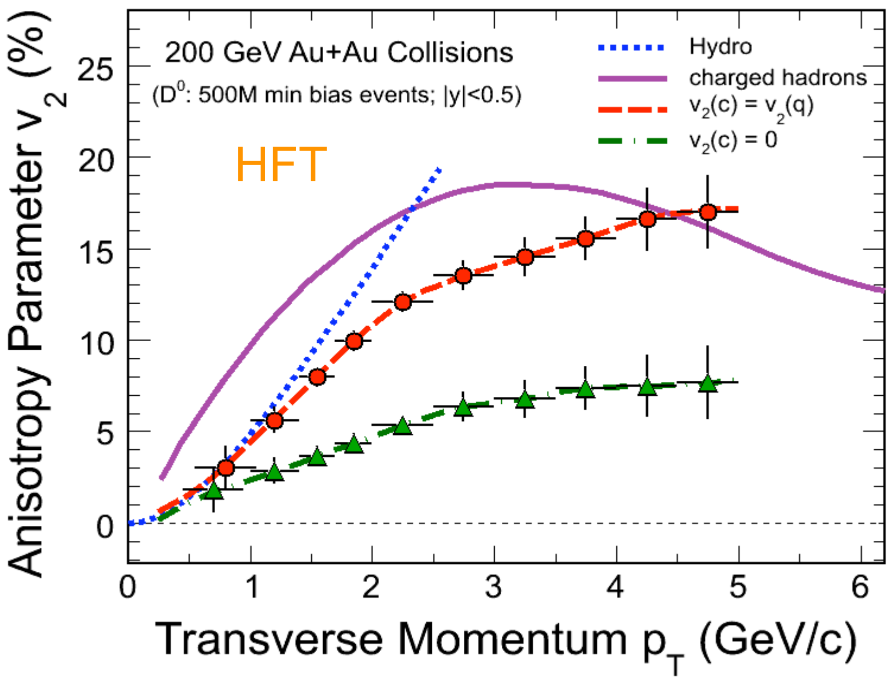
- **At top energy 200 GeV collisions with small μ_B~20 MeV, we study the sQGP properties**

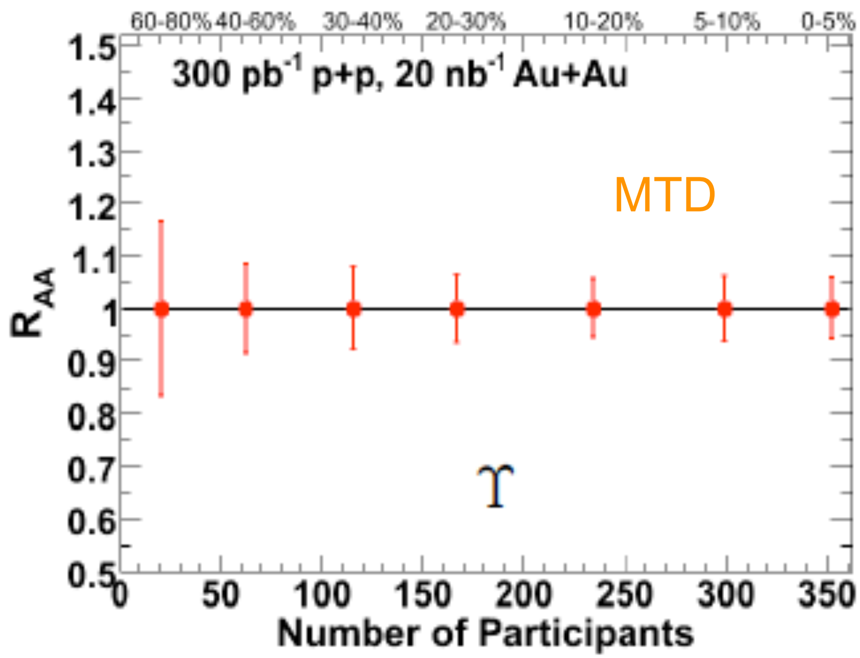
- **At beam energy scan, we explore the QCD phase structure, searching for critical point and phase boundary**

Outlook

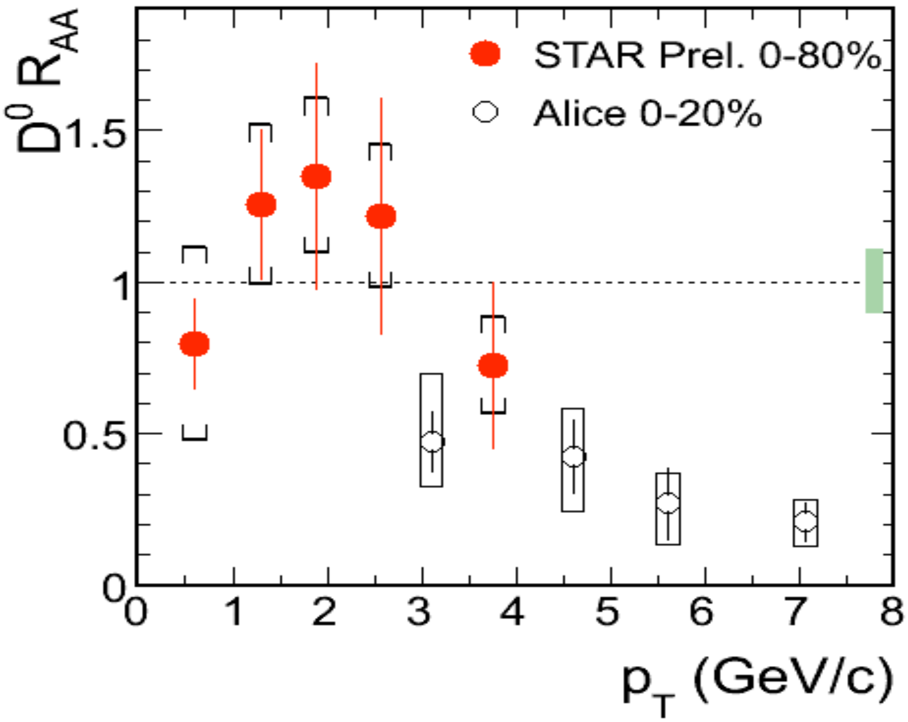
Near future upgrades :

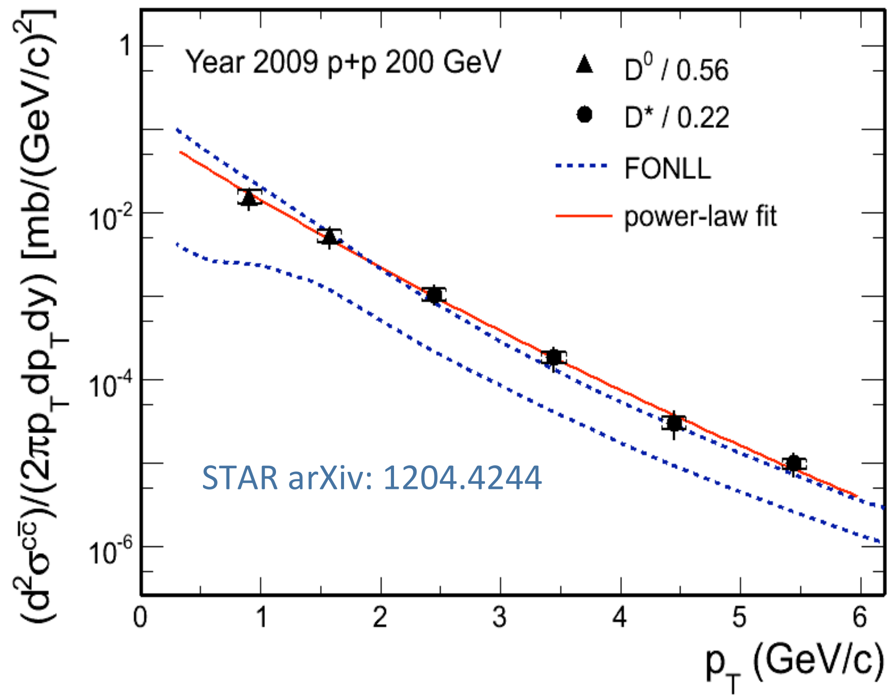
- **Precision measurements of Open Heavy Flavour with a new silicon vertex detector, designed to reach a DCA resolution of ~30 microns : Heavy Flavour Tracker (HFT). Data taking 2014.**
- **Precision measurements of Quarkonia, HF to e-μ, and dimuon pairs, with a new Muon Telescope Detector (MTD) (80%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





Charmed hadrons





STAR, Hard Probes 2012

D Tlusty et al (STAR)

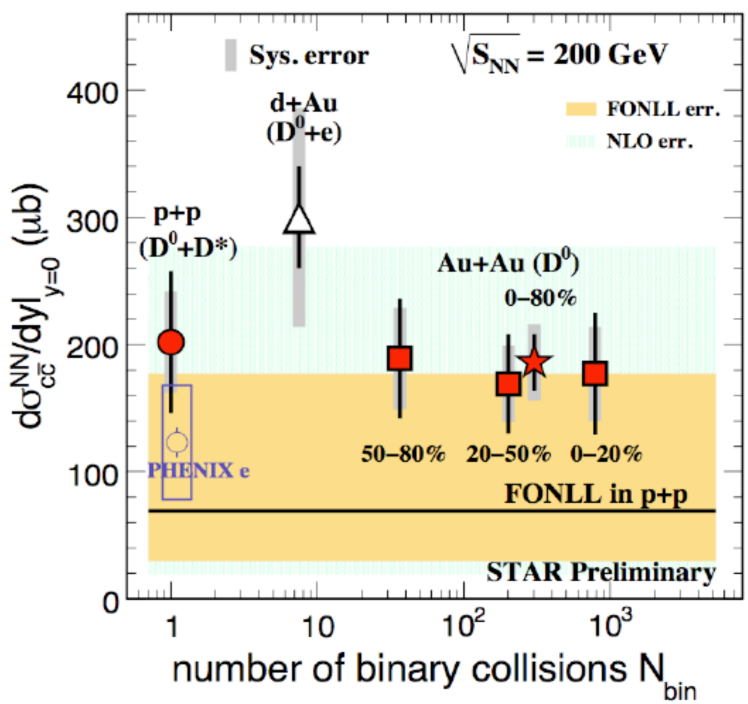
- RAA of D0 in 200 GeV Au+Au collisions 0-80% centrality is consistent with no suppression up to pT < 3 GeV/c. Future: HFT
- ALICE RAA of D0 is suppressed at high pT in 2.76 TeV Pb+Pb collisins 0-20% centrality.

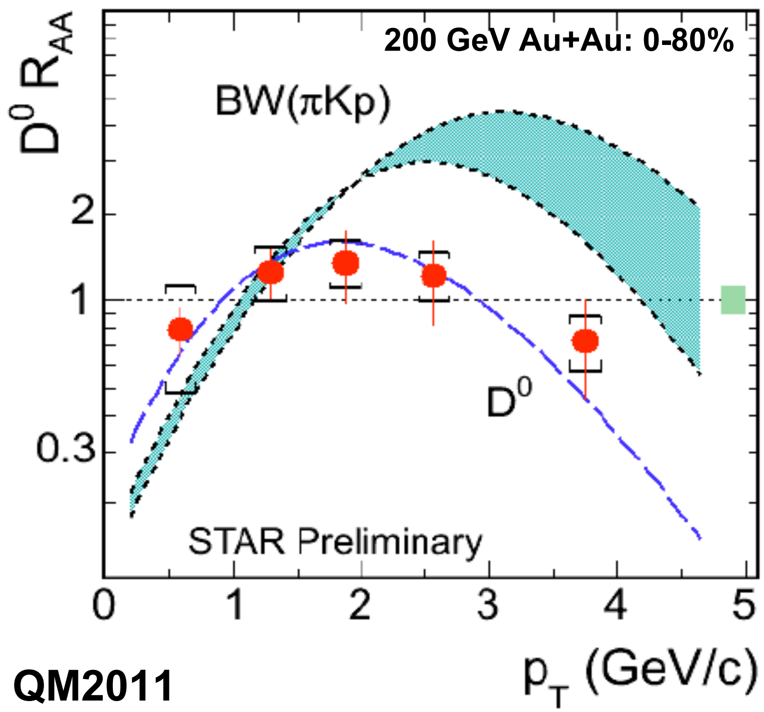
- D0 and D* spectra in p+p collisions at 200 GeV (STAR arXiv:1204.4244)
- Cross section consistent with FONLL upper limit (Fixed-Order Next-to-Leading Logarithm: M. Cacciari, PRL 95 (2005) 122001.)

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

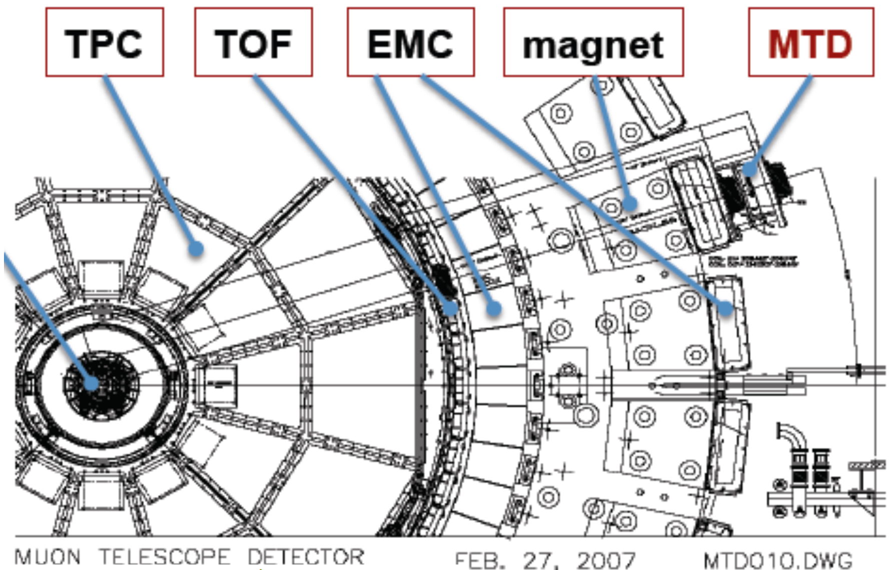
YiFei Zhang, JPG 38, 124142 (2011)

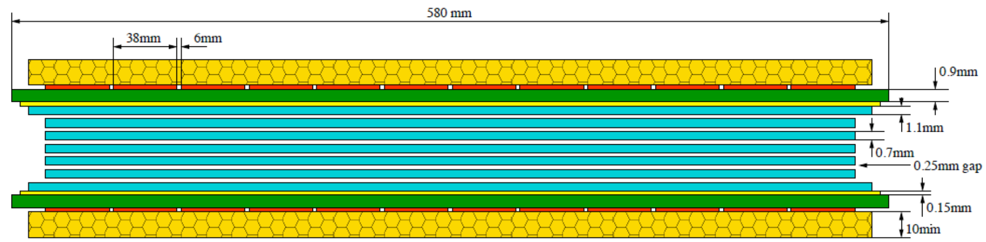
- Charm cross section is consistent with upper bound of FONLL calculation in p+p
- Charm cross section follows number of binary collision scaling -> Charm quarks are mostly produced by initial hard scattering

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

Backup slides

Muon Telescope Detector (MTD)





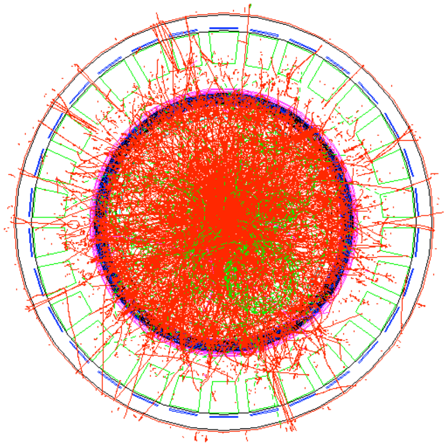
Use the magnet steel as absorber and TPC for tracking.

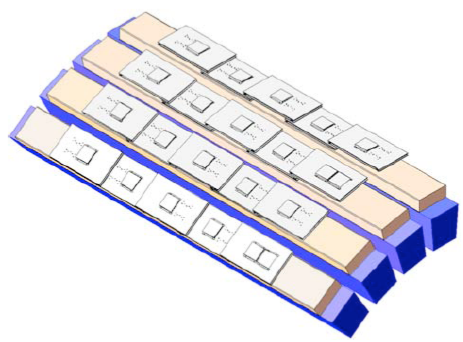
Acceptance: $|\eta|<0.5$ and 45% in azimuth

118 modules, 1416 readout strips, 2832 readout channels

Long-MRPC detector technology,

HPTDC electronics (same as STAR-TOF)

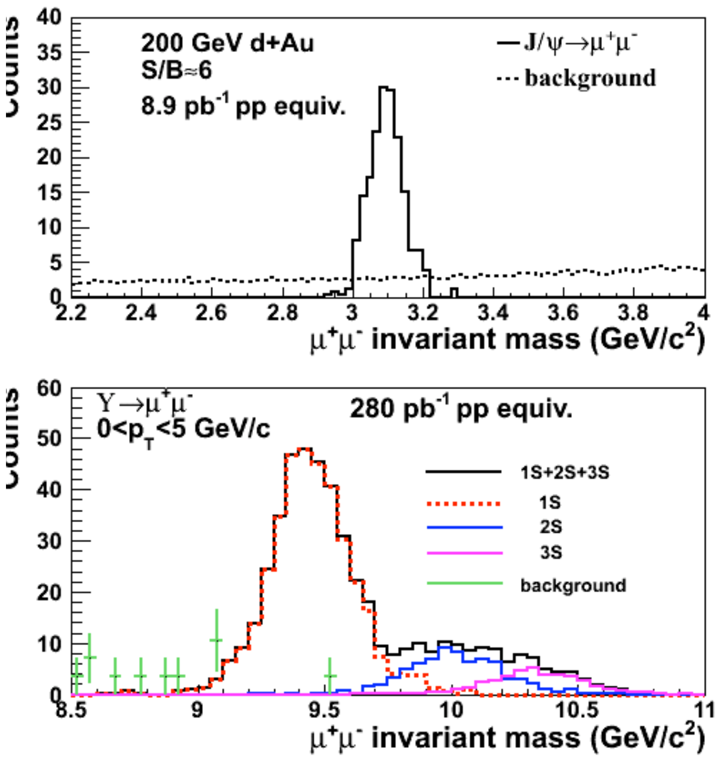




F. Videbaek, (STAR) NN2012

~43% for run 2013 and Complete for run 2014

Quarkonium from MTD

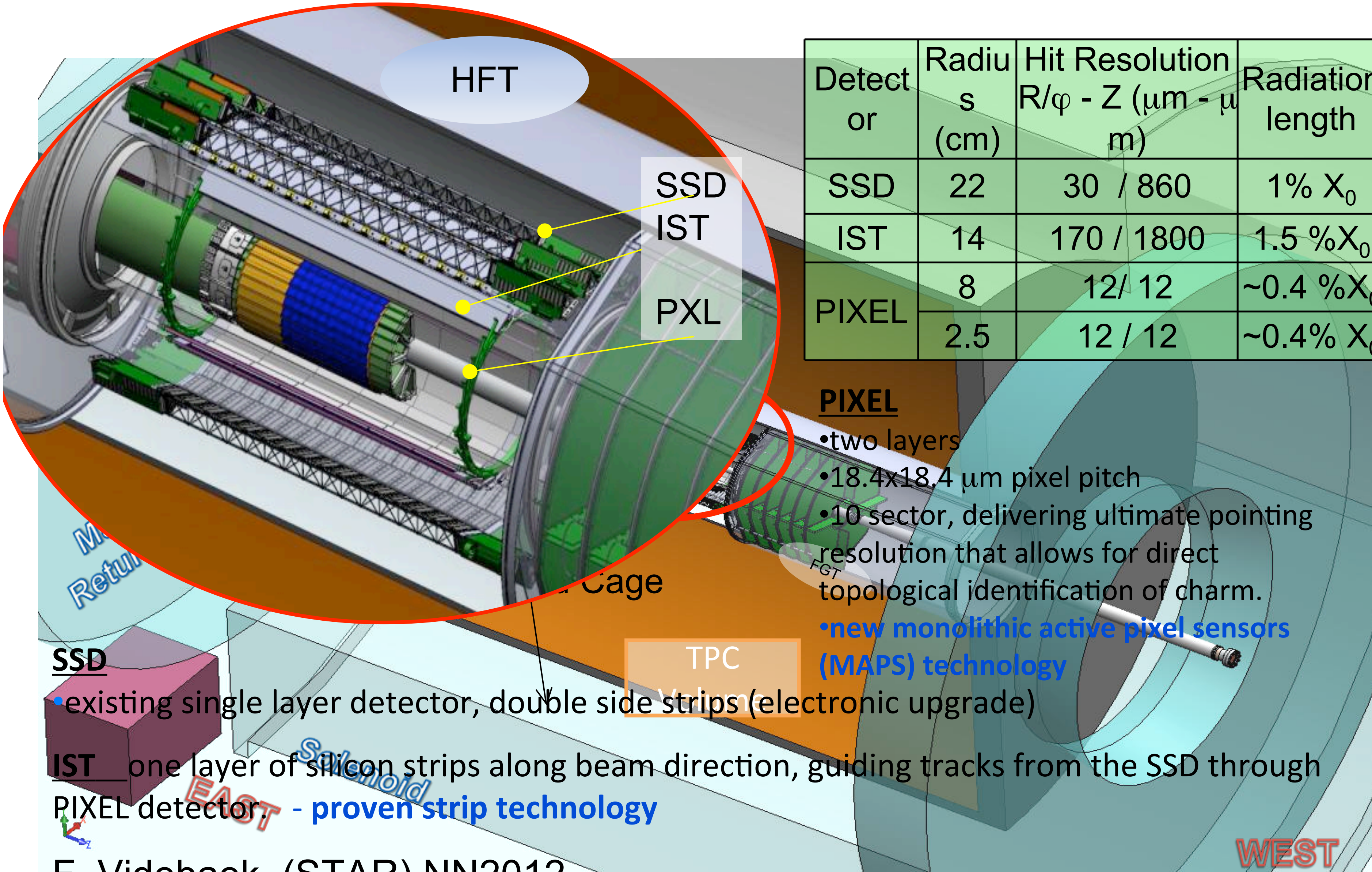


1. J/ψ: S/B=6 in d+Au and S/B=2 in central Au+Au
2. Excellent mass resolution: separate different upsilon states
3. With HFT, study B→J/ψ X; J/ψ→μμ using displaced vertices

Heavy flavor collectivity and color screening, quarkonia production mechanisms:
J/ψ R_{AA} and v_2; upsilon R_{AA} …

Z. Xu, BNL LDRD 07-007; L. Ruan et al., Journal of Physics G: Nucl. Part. Phys. 36 (2009) 095001

Heavy Flavor Tracker (HFT)



Detector	Radius (cm)	Hit Resolution R/φ - Z (μm - μm)	Radiation length
SSD	22	30 / 860	1% X_0
IST	14	170 / 1800	1.5 %X_0
PIXEL	8	12/ 12	~0.4 %X_0
	2.5	12 / 12	~0.4% X_0

PIXEL

- two layers
- 18.4x18.4 μm pixel pitch
- 10 sector, delivering ultimate pointing resolution that allows for direct topological identification of charm.
- **new monolithic active pixel sensors (MAPS) technology**

SSD

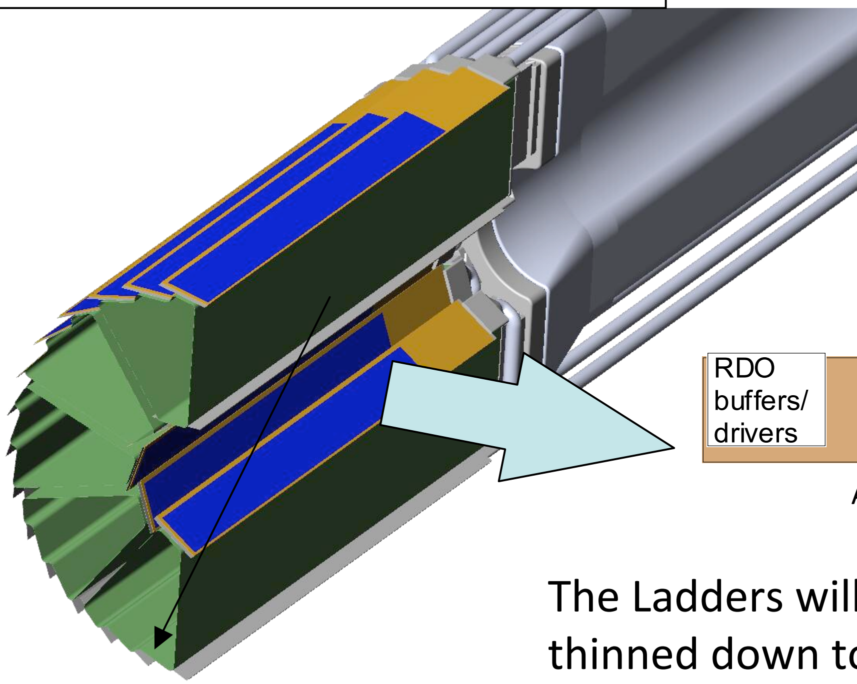
- existing single layer detector, double side strips (electronic upgrade)

IST one layer of silicon strips along beam direction, guiding tracks from the SSD through PIXEL detector. - **proven strip technology**

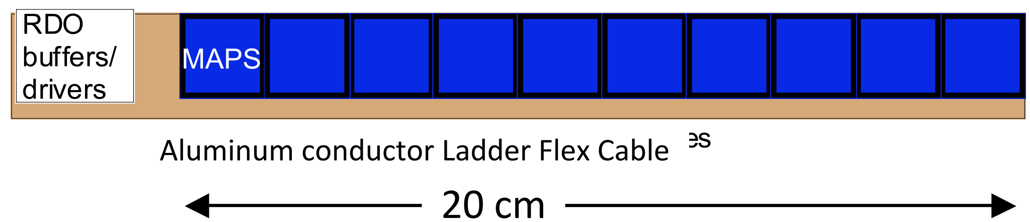
F. Videbaek, (STAR) NN2012

PXL Detector Design

Carbon fibre sector tubes (~ 200µm thick)



Ladder with 10 MAPS sensors (~ 2×2 cm each)



The Ladders will be instrumented with sensors thinned down to 50 micron Si

Novel rapid insertion mechanism allows for dealing effectively with repairs.

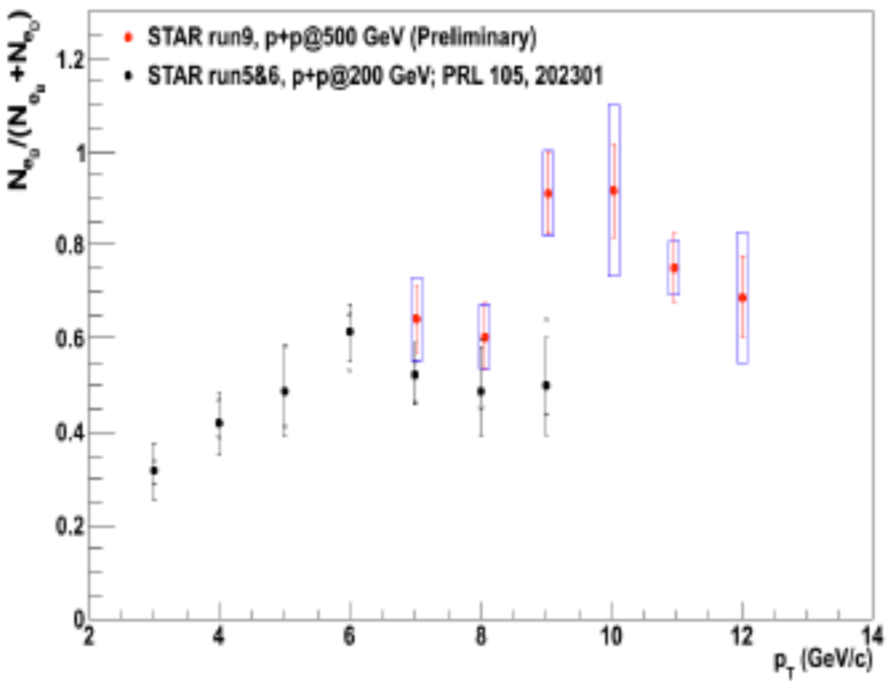
F. Videbaek, (STAR) NN2012

STAR

Disentangling beauty and charm in p+p at 500 GeV

Wenqin Xu and the STAR Collaboration, QM2011

Wei Li and the STAR Collaboration, SQM2011

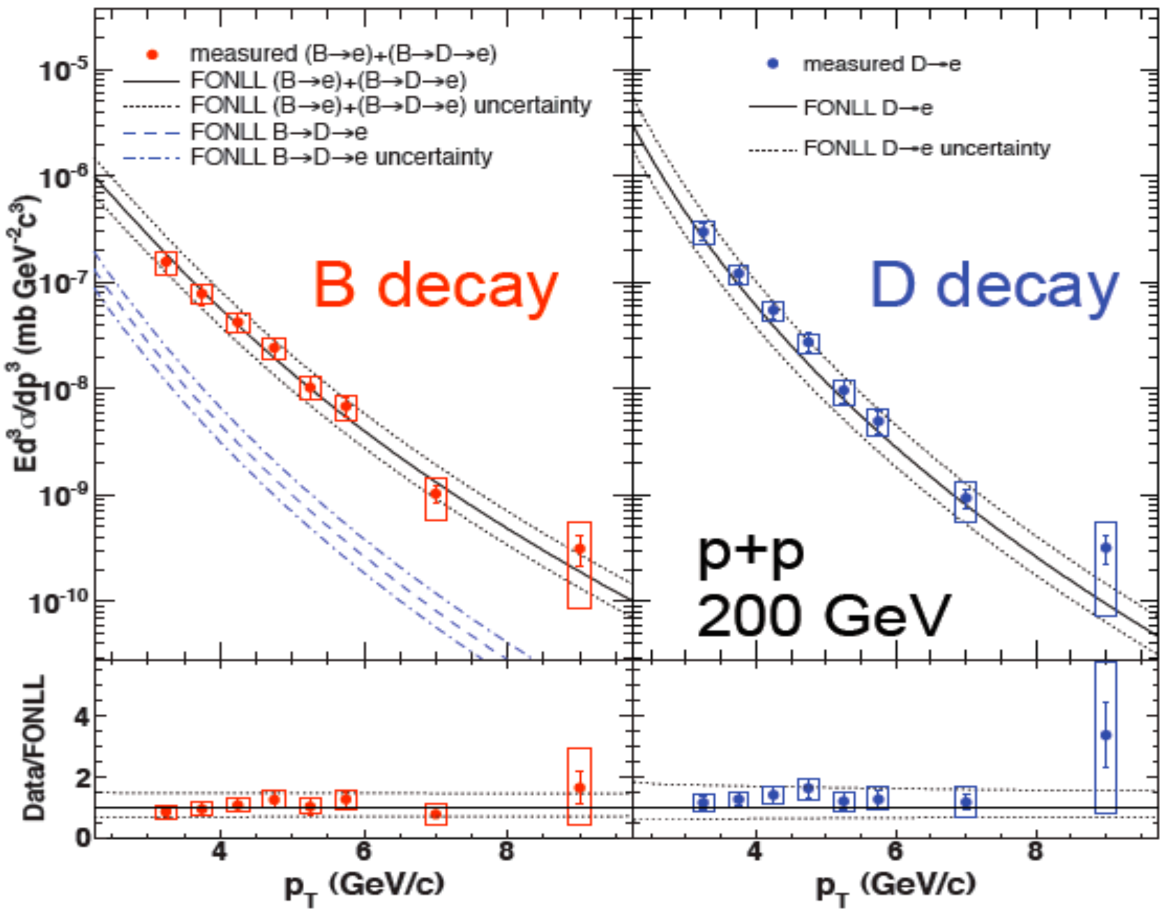


- Using NPE-hadron correlations compared to Pythia 8.1 -> extract Beauty contribution up to p_T=12.5 GeV

- Electrons from Beauty contribute more than 60% to the non-photonic 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)

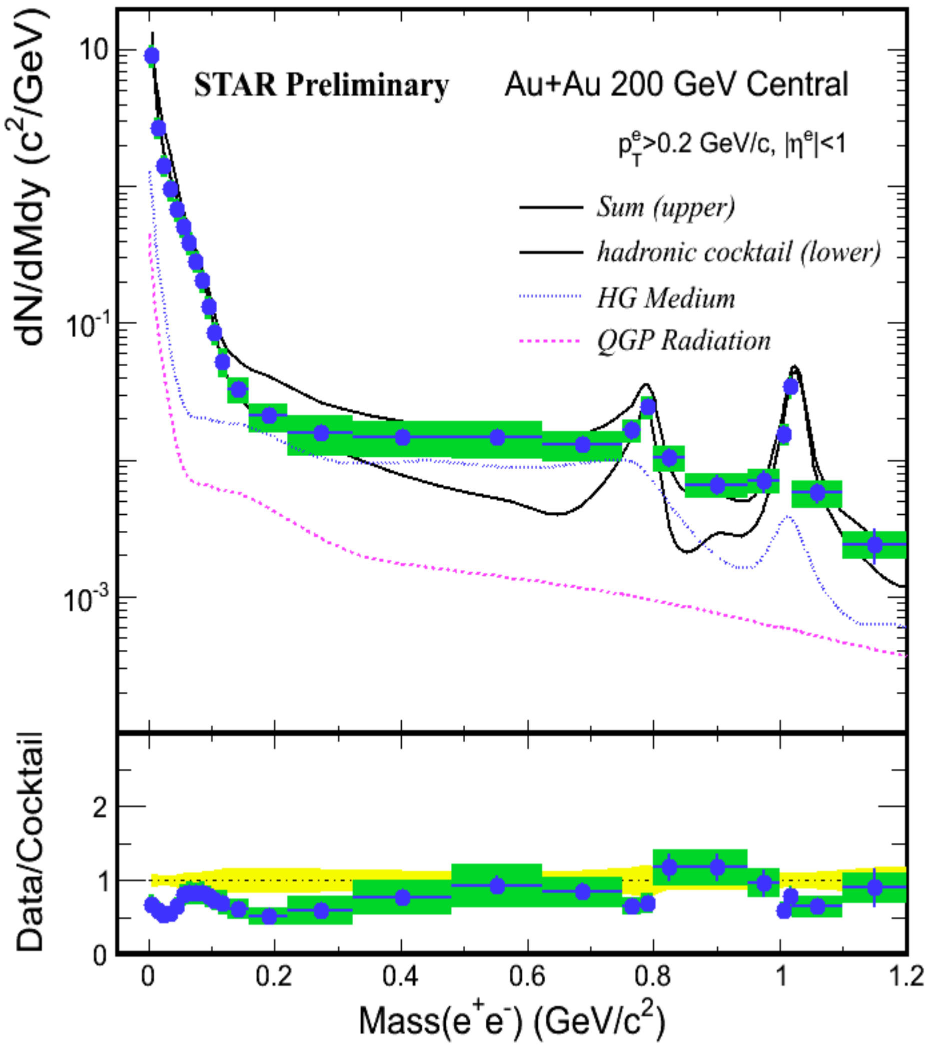
FONLL, M Cacciari et al, PRL95, 122001 (2005)

Measurement of Beauty->NPE cross section in p+p 200 GeV

Beauty and charm consistent with FONLL in p+p 200 GeV

Dilepton production in p+p and Au+Au collisions

J. Zhao and the STAR Collaboration,
Hard Probes 2012



R. Rapp, J. Wambach, Adv. Nucl. Phys. 25, 1, (2000)

Blue dotted: Hadronic gas medium modification

Pink dotted: QGP radiation

Solid lines:

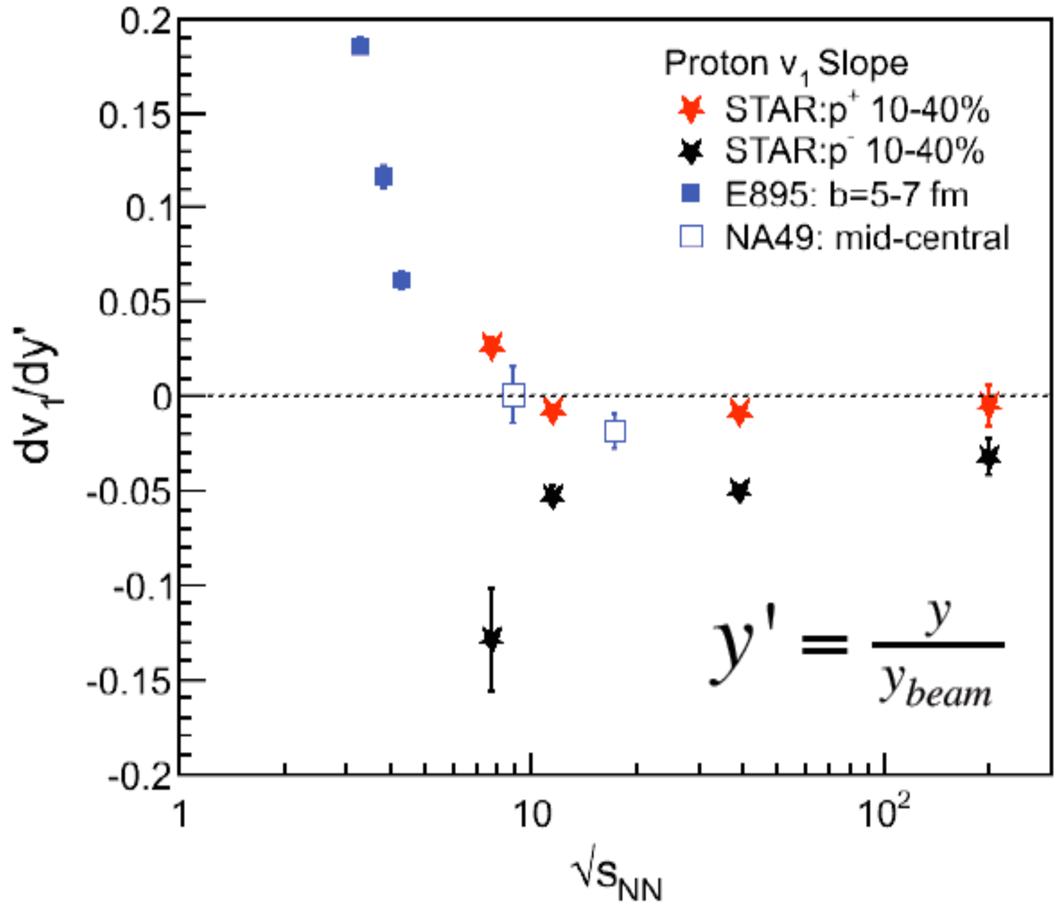
upper: cocktail+HG+QGP

lower :hadronic cocktail

Low mass region (LMR) enhancement in central AuAu is in agreement with models with vector meson in-medium modification

Energy dependence of proton directed flow

Y. Padit, STAR, SQM2011



The slope of the y-dependence of the v1 of the proton

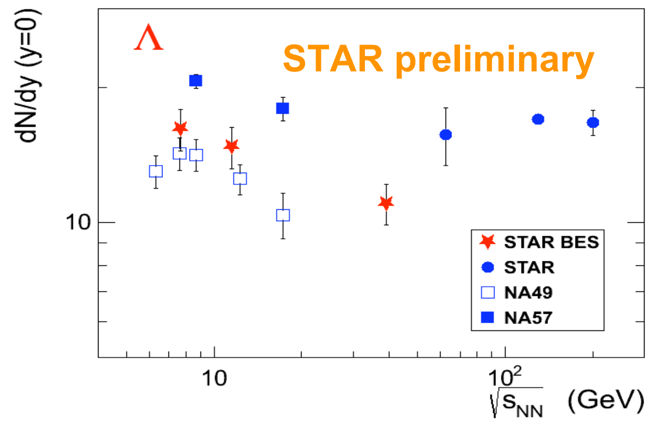
- decreases with increasing energy,

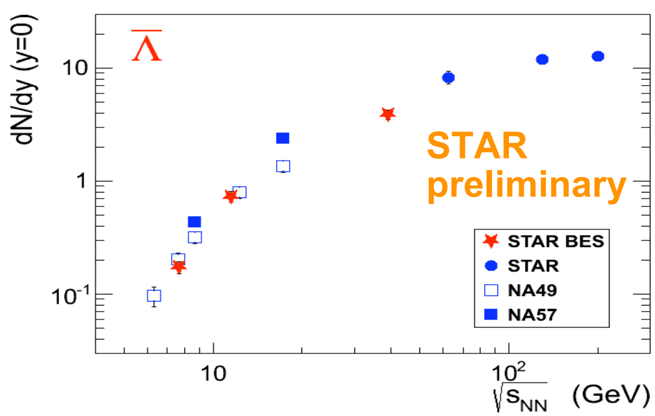
-- changes sign to negative between 7.7 and 11.5 GeV and

- then remains close to zero up to 200 GeV

K^0_s, Λ and Ξ measurements in Au+Au at $\sqrt{s_{NN}}$ = 7.7, 11.5 and 39 GeV

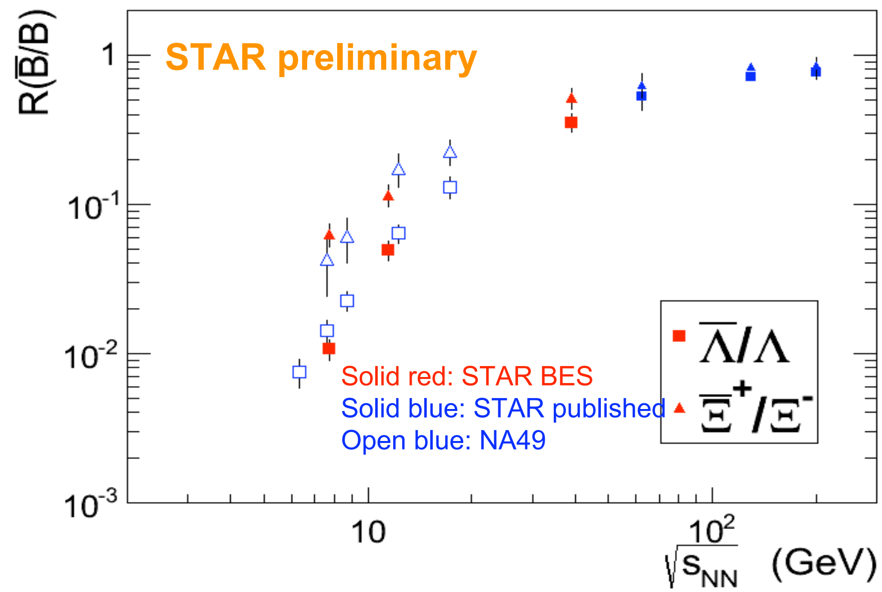
Xianglei Zhu for the STAR Collaboration, SQM2011





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

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

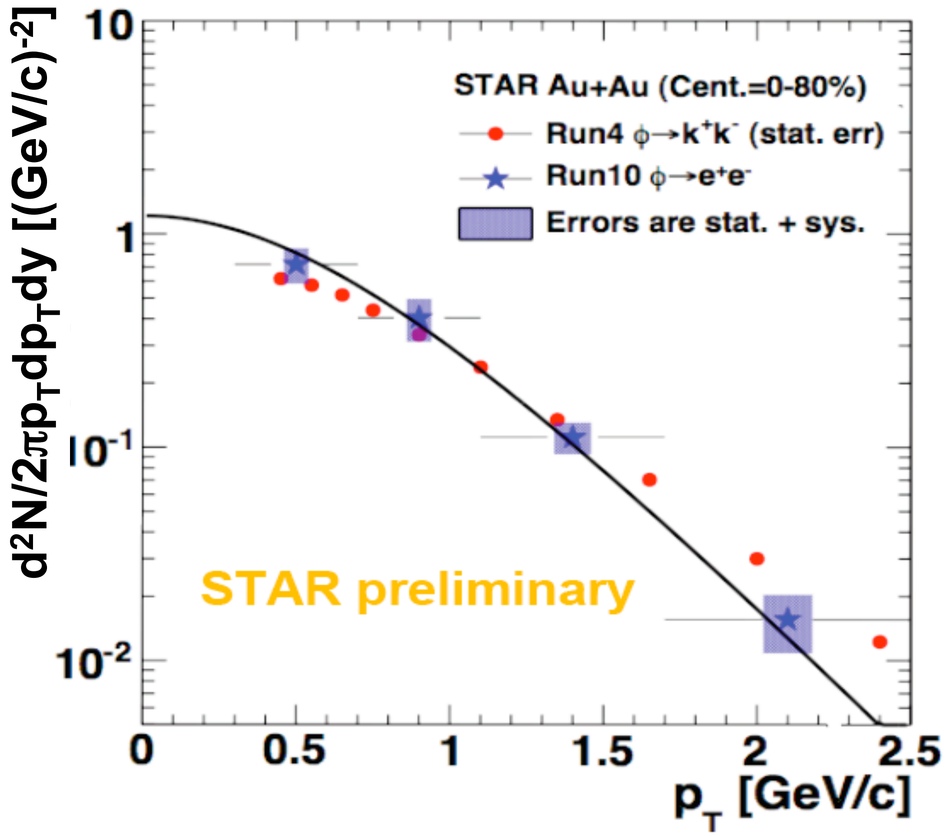


STAR data agree with the NA49 data, with smaller errors

Are the hadronic and leptonic decay of φ consistent ?

Masayuki Wada and the STAR Collaboration, SQM2011

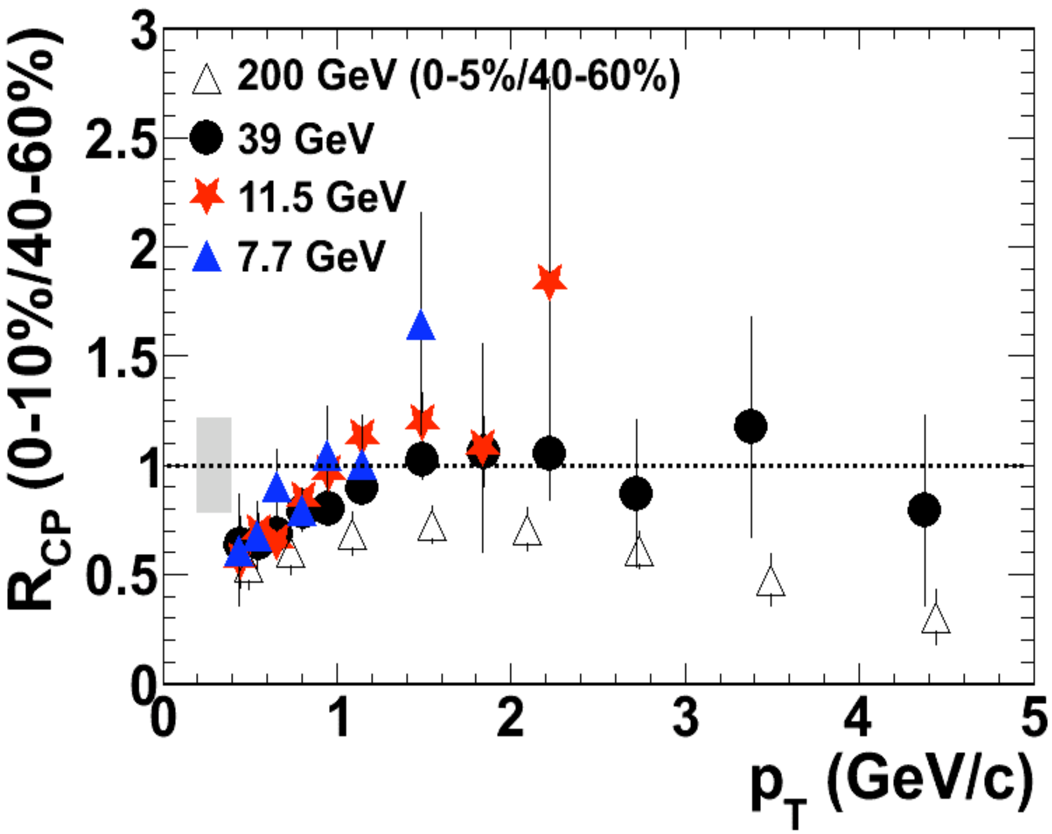
Au+Au 200 GeV



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

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

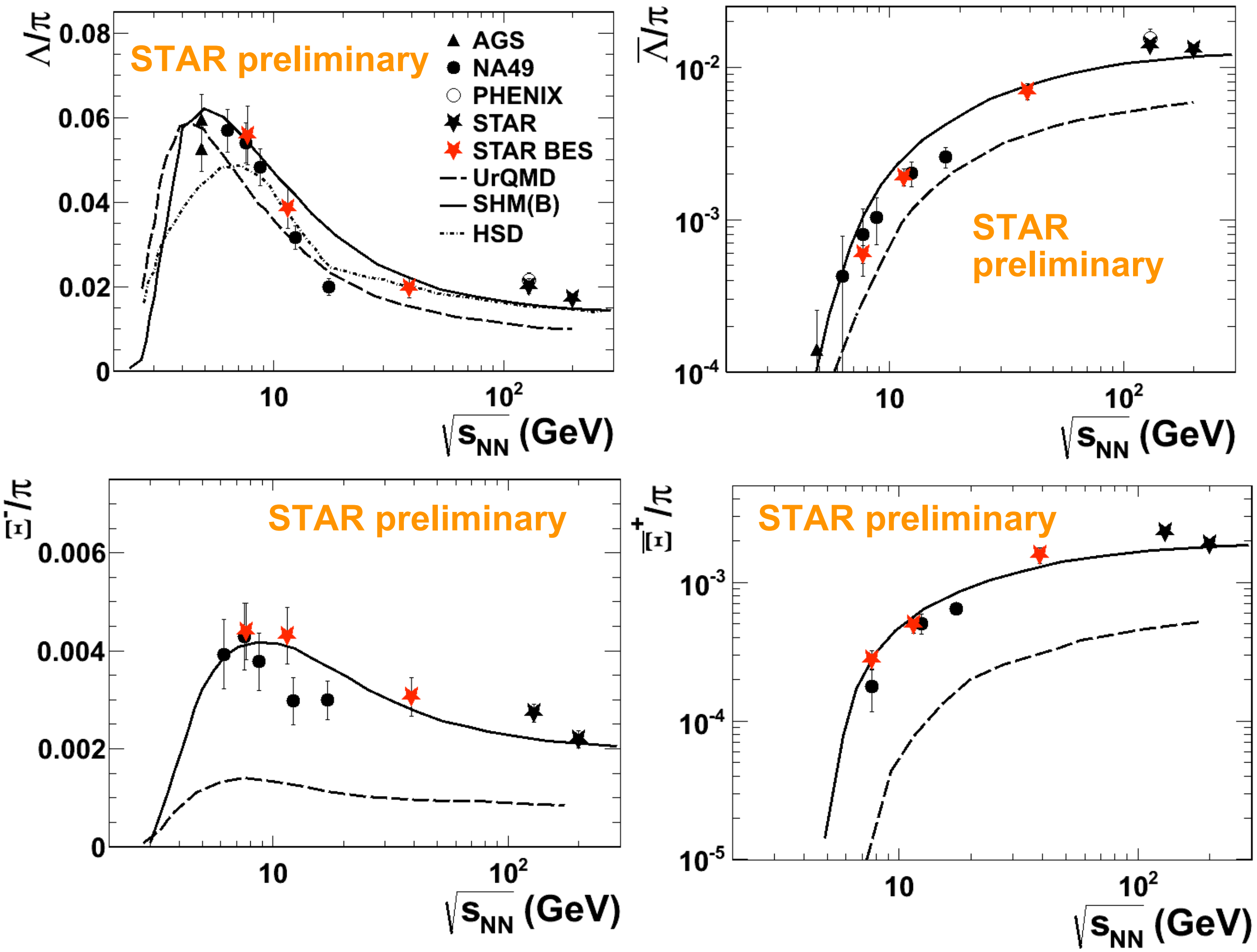
Xiaoping Zhang, STAR, SQM2011



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

Energy dependence of strange baryon to π ratios

Xianglei Zhu, STAR, SQM2011

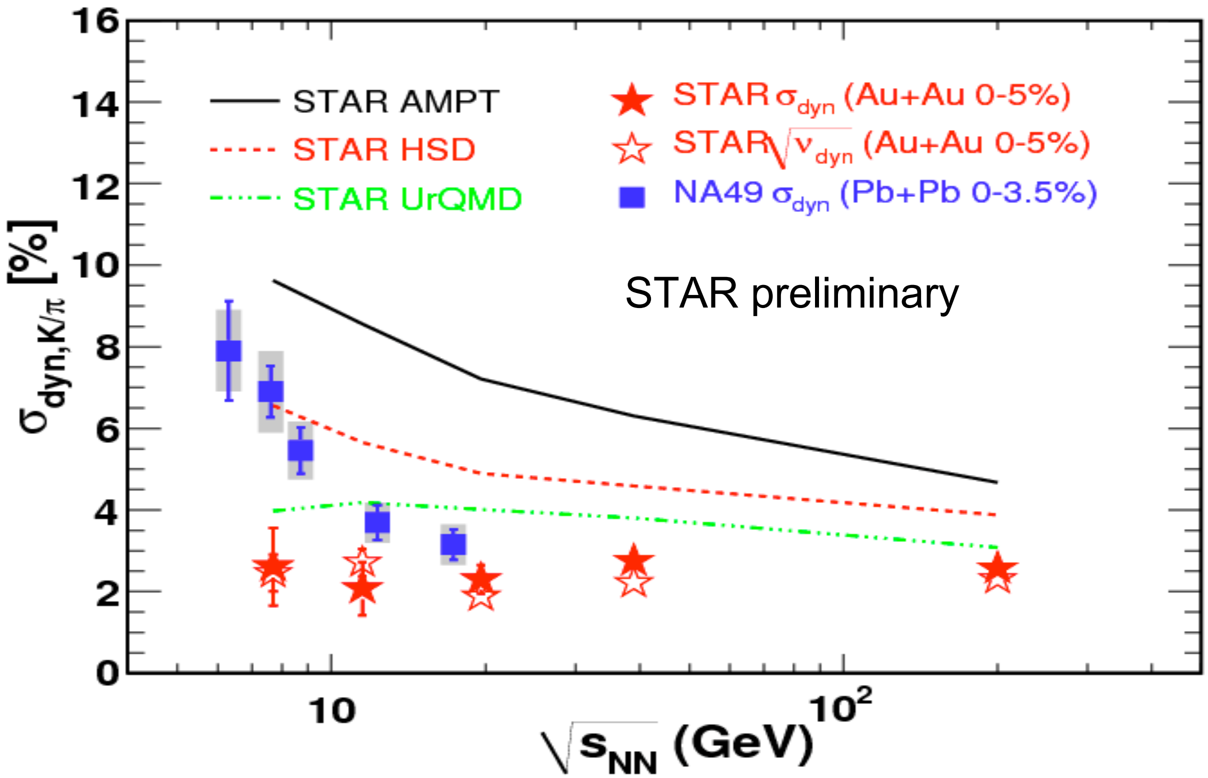


SHM(B):
A. Andronic et.al.
UrQMD:
M. Bleicher et.al.
Hadron String Dynamics (HSD) : E.Bratkovskaya et.al; W. Cassing and E. Bratkovskaya,

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

Search for fluctuations of particle ratios in BES

STAR SQM2011
Jian Tian , Terence Tarnowski



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

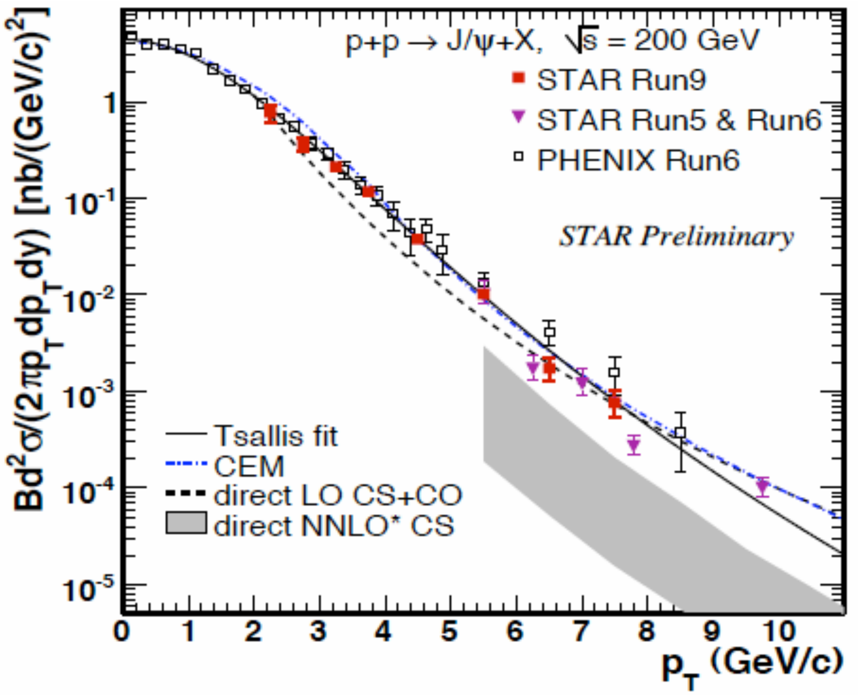
NA49,

PRC79 (2009) 044910

- STAR results using ν_{dyn} and σ_{dyn} agree!
- K/π fluctuations in Au + Au 0-5% collisions show relatively small energy dependence in the measured energy region.

Models compared to cross section of J/ψ in p+p 200 GeV

STAR, QM2011



Results consistent with Phenix

Extend to p_T ~ 10 GeV/c

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

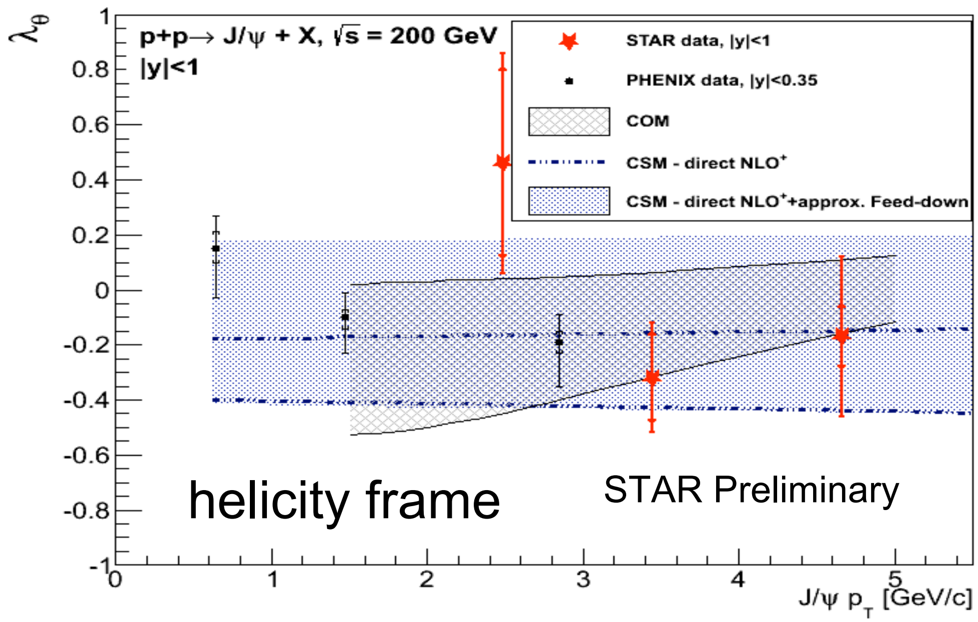
LO CS+CO : leave no room for feeddown at high p_T

CEM can reasonably explain the spectra

J/ψ polarization in p+p at 200 GeV

B. Trzeciak and the STAR Collaboration, SQM2011

PHENIX: Phys. Rev. D 82, 012001 (2010)
COM: Phys. Rev. D 81, 014020 (2010)
CSM NLO⁺: 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

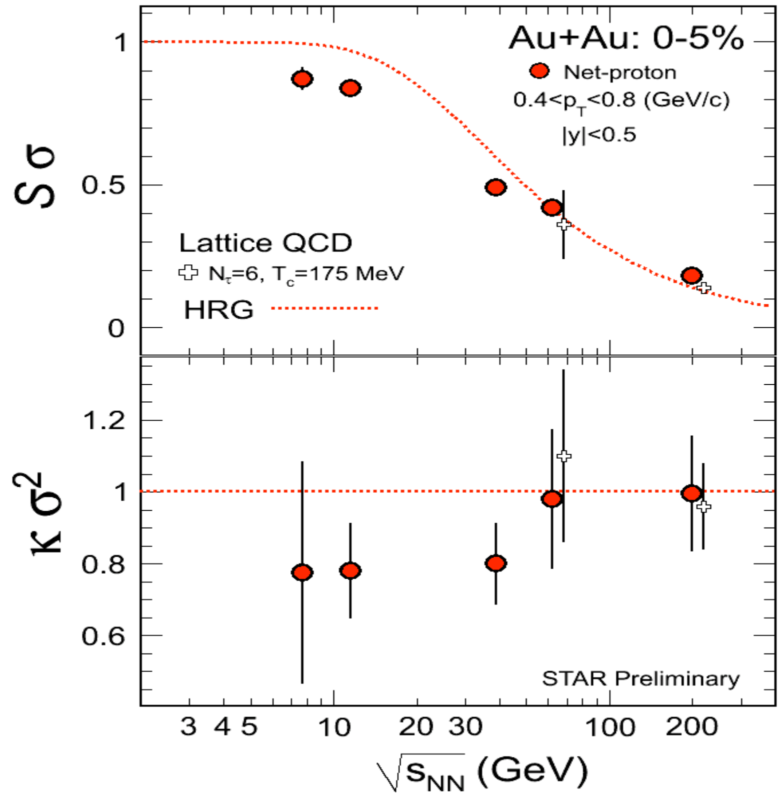
Results consistent with both COM and CSM models, and consistent with no polarization within uncertainties

Net-proton high moments products

X. Luo, STAR, SQM2011

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

S Gupta et al Science 332, 1525 (2011)



σ = standard deviation
S = skewness
κ = 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