Selected highlights from the STAR experiment at RHIC

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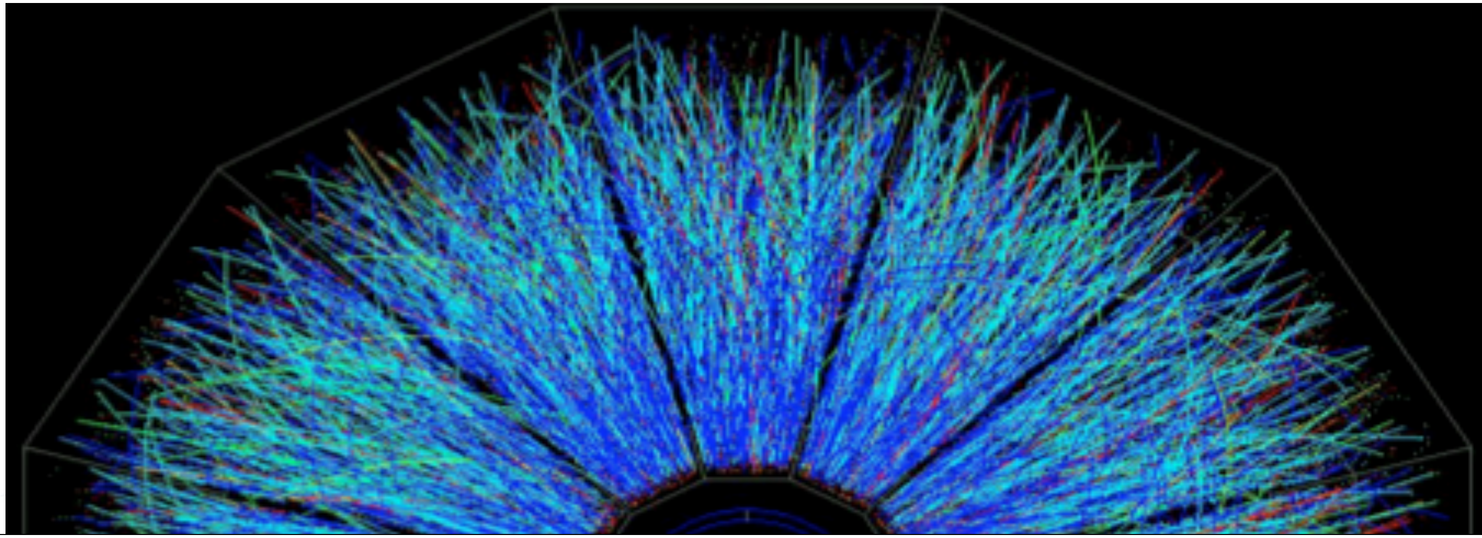
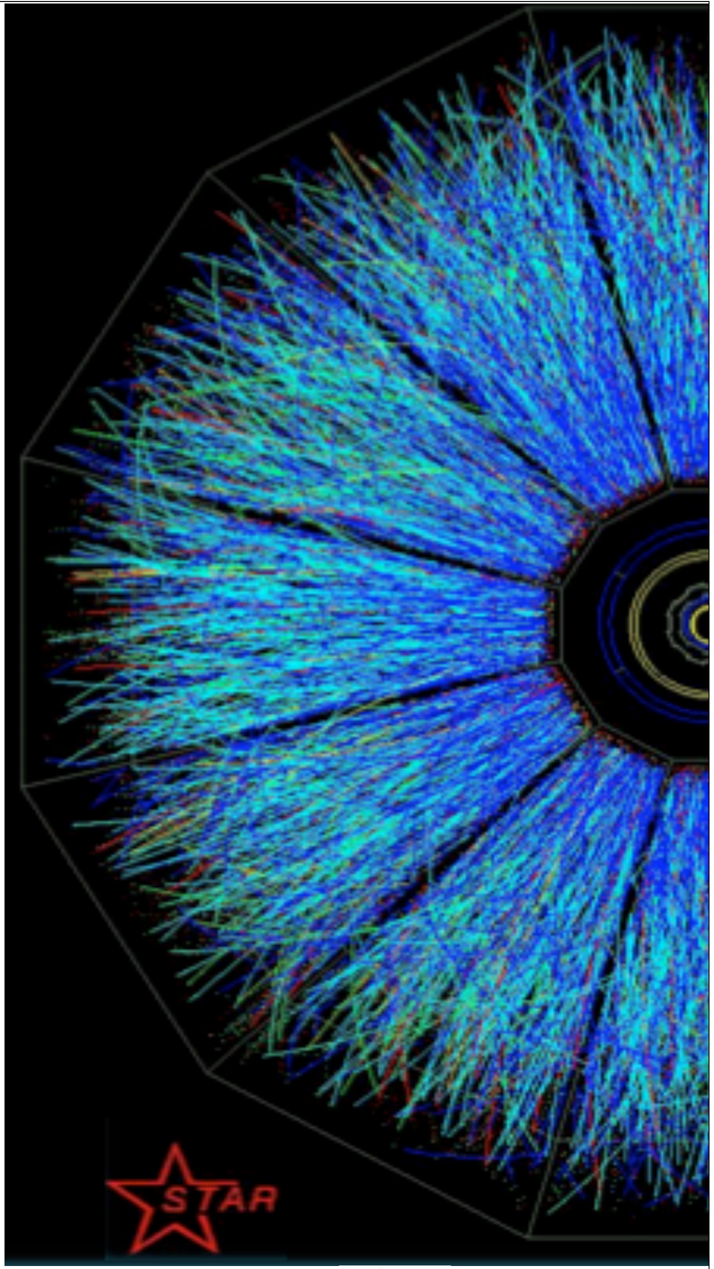
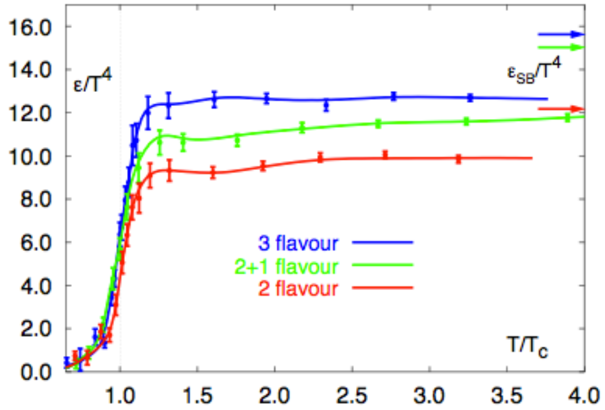


Outline



I Introduction



Lattice QCD prediction :

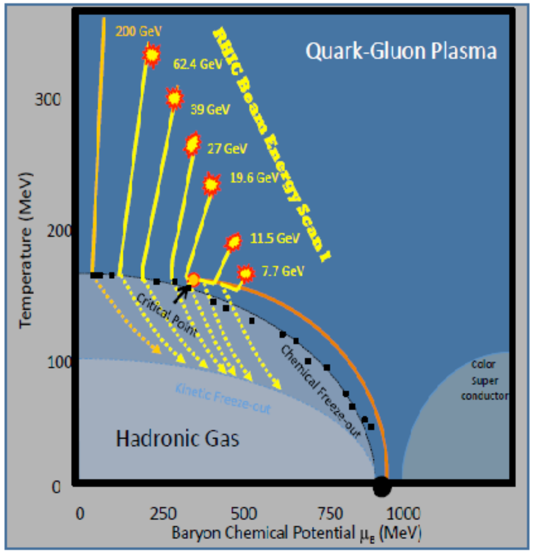
The Hadron <-> Quark Gluon Plasma (QGP) transition

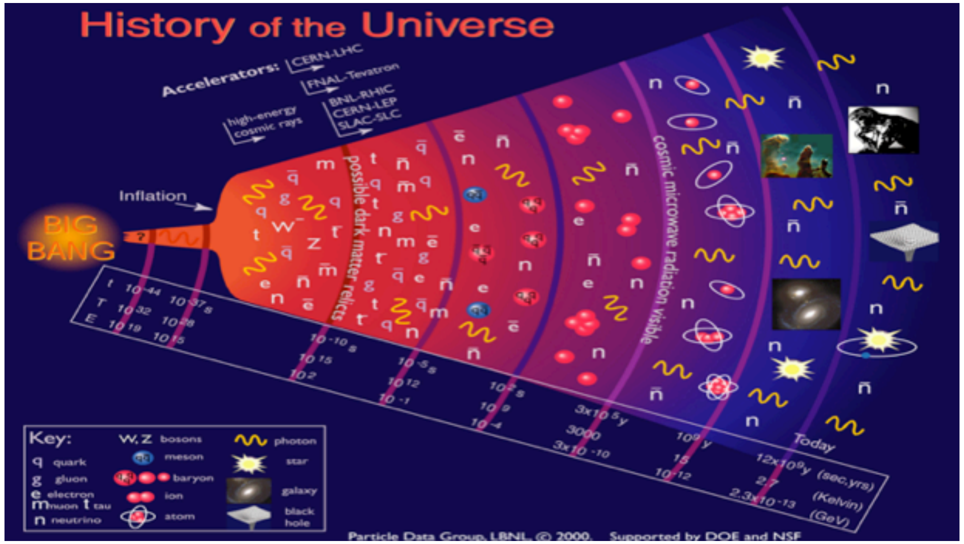
Goal of ultrarelativistic heavy ion physics:

Study QCD matter under extreme conditions of densities and Temperatures

Map out the QCD phase diagram and measure QGP characteristics

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)

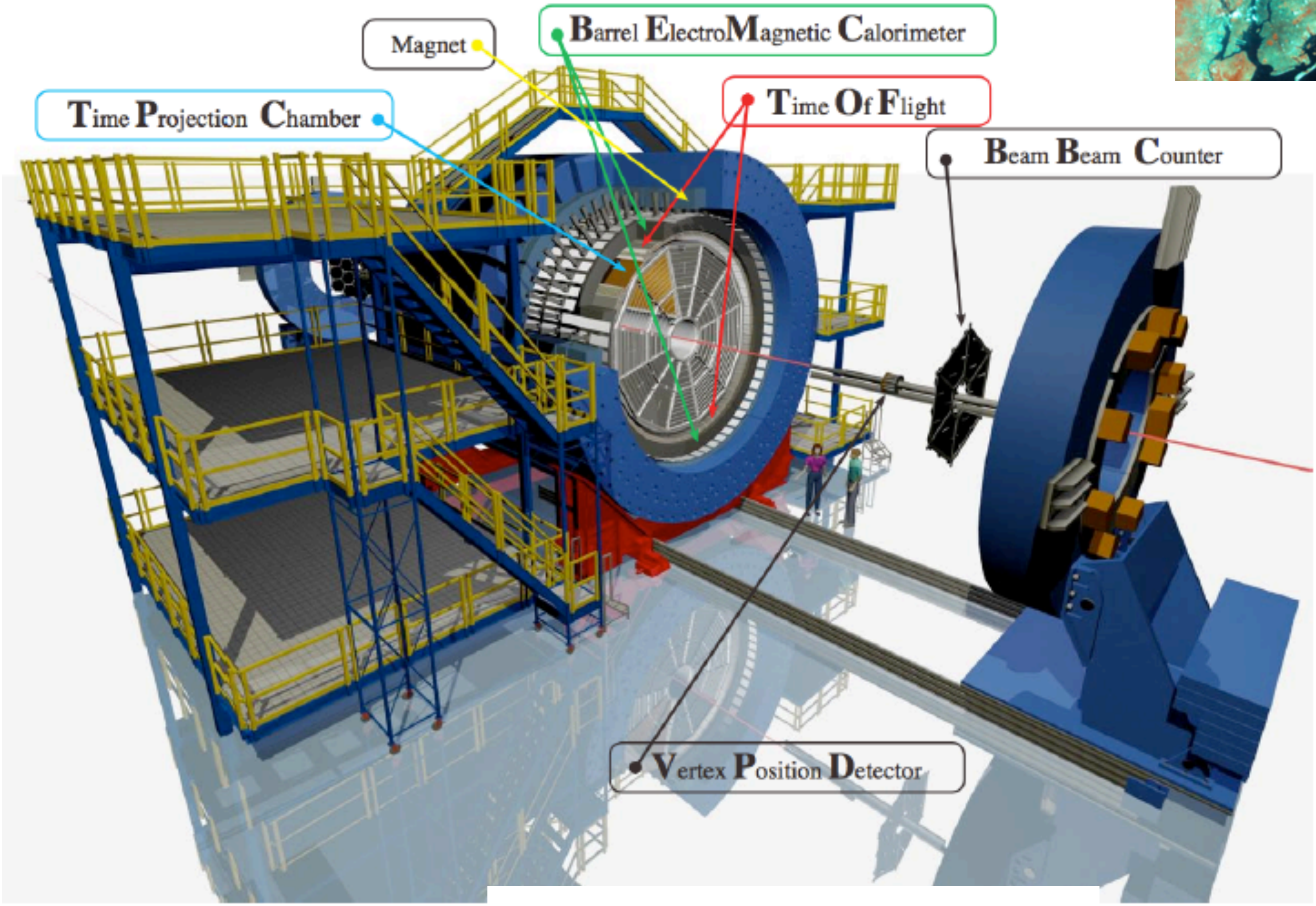




Beam Energy Scan at RHIC:

* **Search for onset of QGP signatures**
* **Search for signals of the phase boundary**
* **Search for the QCD critical point**

II STAR: Solenoidal Tracker At RHIC



Particle identification mainly via
- de/dx in the TPC
- topological decay reconstruction in TPC for strange particles and D mesons
- TOF
- Barrel EMCal (used also as fast online trigger)

$$-1 < \eta < 1, 0 < \phi < 2\pi$$

III Selected physics results

III.1 Open heavy flavor

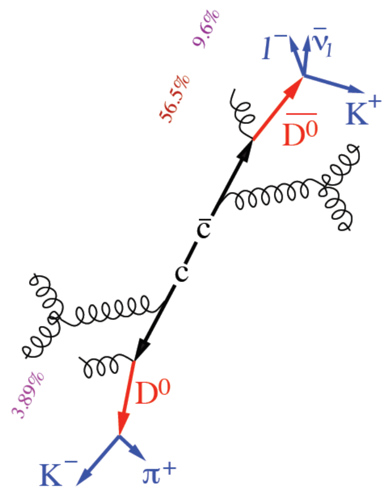
STAR heavy flavor measurements

STAR measures:

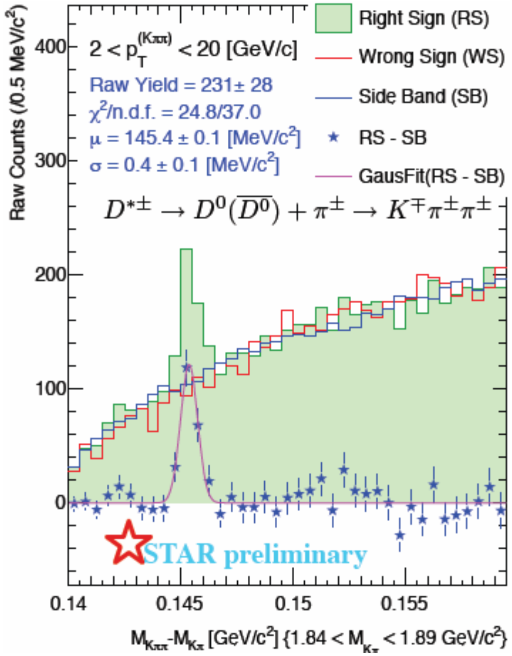
* Charm via direct D meson reconstruction

* Open charm and beauty via electrons from semileptonic decay of charmed hadrons, and e-h and e-D correlations

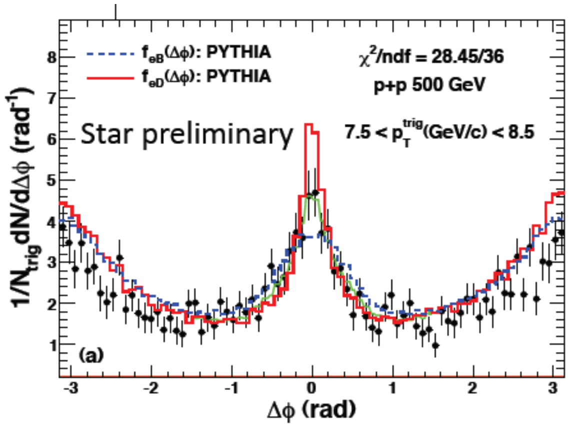
* Quarkonia via reconstruction of their decay to -> e+ e-



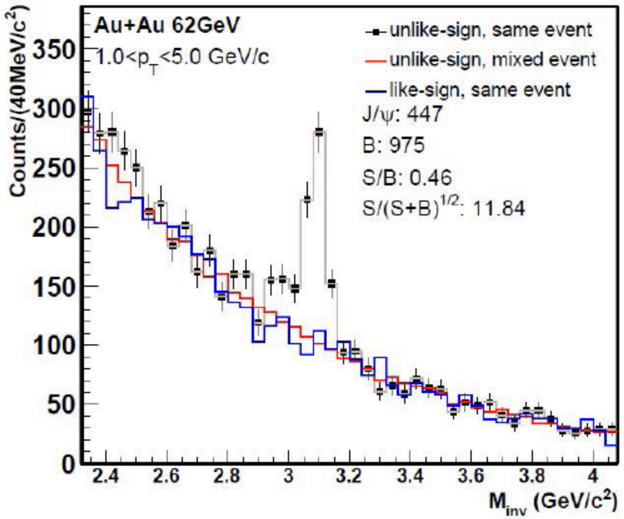
p+p 500 GeV



p+p 500 GeV
e-h correlations

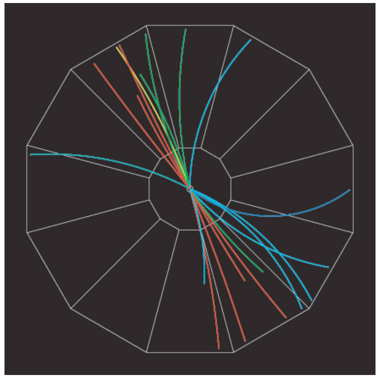


Au+Au 62 GeV

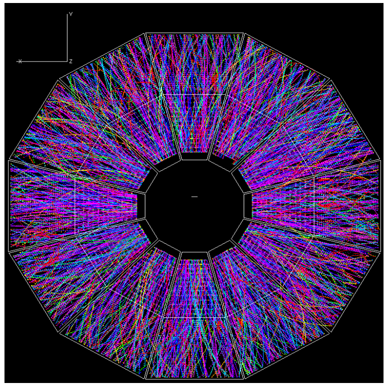


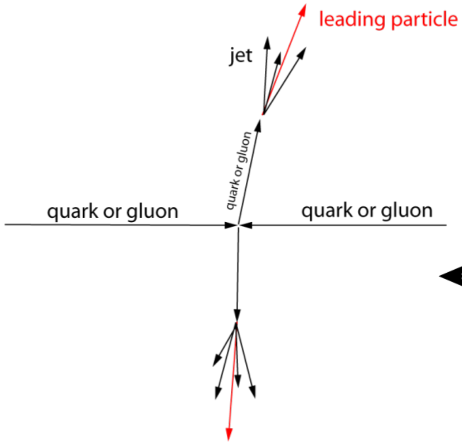
Jet quenching and heavy flavour

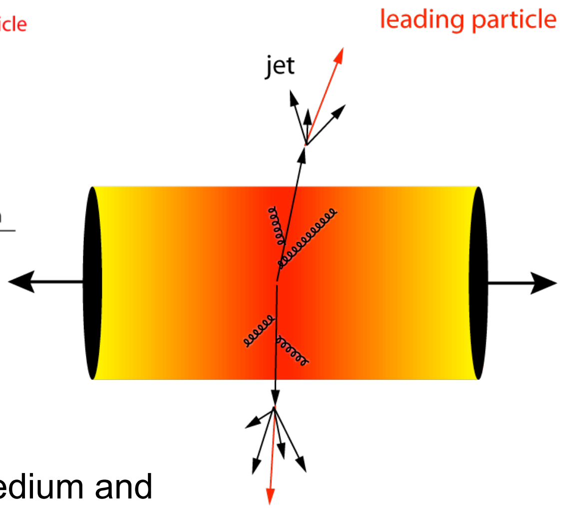
p+p Collision



Au+Au Collision







Partons interact with the medium and loose energy through eg gluon radiation

We compare A+A to expectations from p+p, using the "nuclear modification factor" R_{AA} defined as:

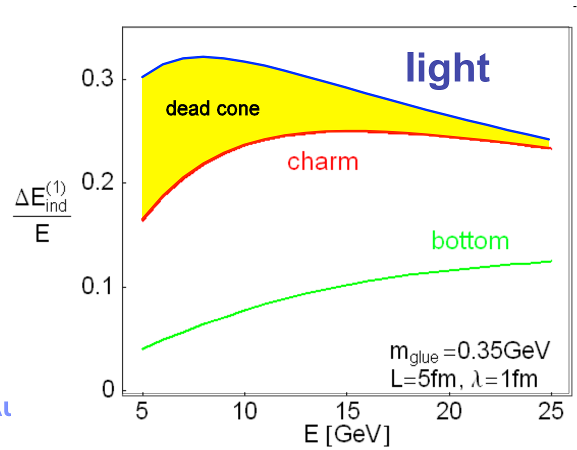
$$R_{AA}(p_T) = \frac{Yield(A+A)}{Yield(p+p) \times \langle N_{coll} \rangle}$$

N coll : Average number of NN collisions in AA collision

Suppression of jets in AuAu: $R_{AA} < 1$

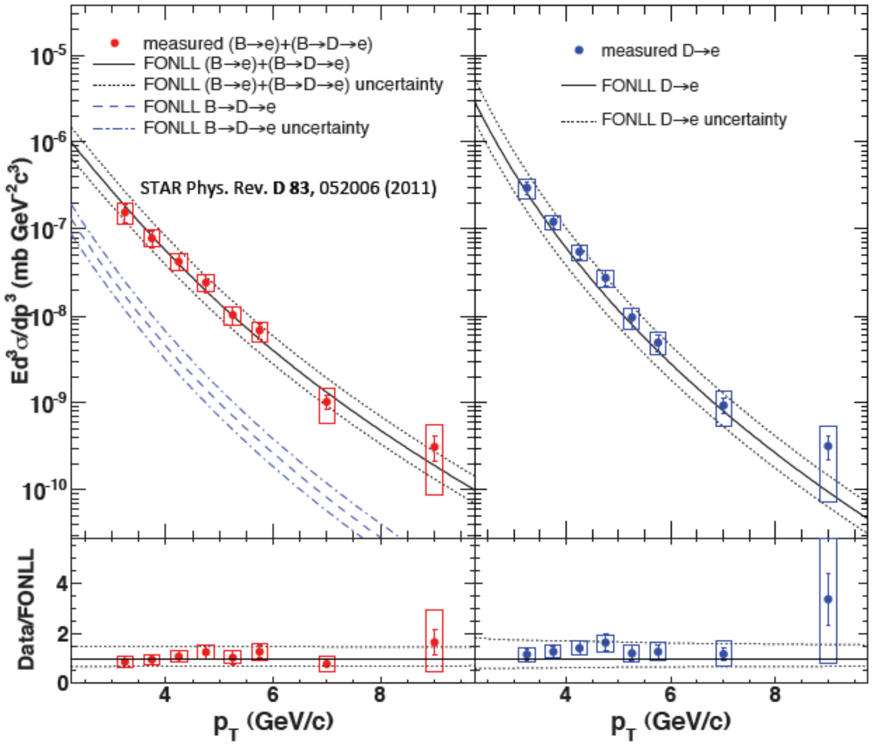
Quarks are expected to exhibit different radiative energy loss depending on their mass (**D.Kharzeev et al. Phys Letter B. 519:1999**)

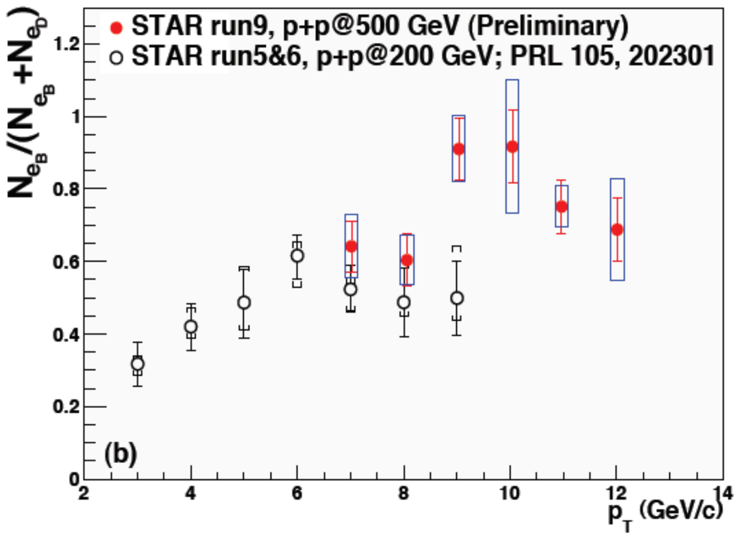
M.Djordjevic PRL 94 (2004)



B and D separation in p+p 200 and 500 GeV

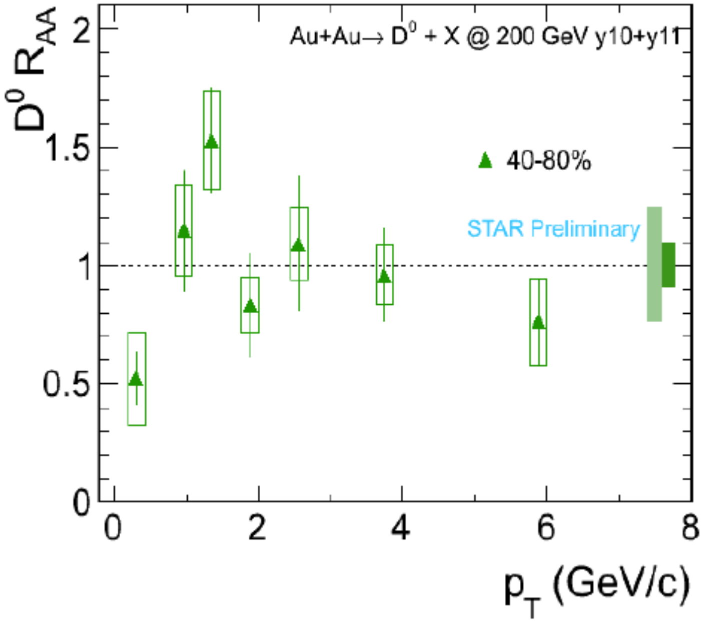
p+p 200 GeV

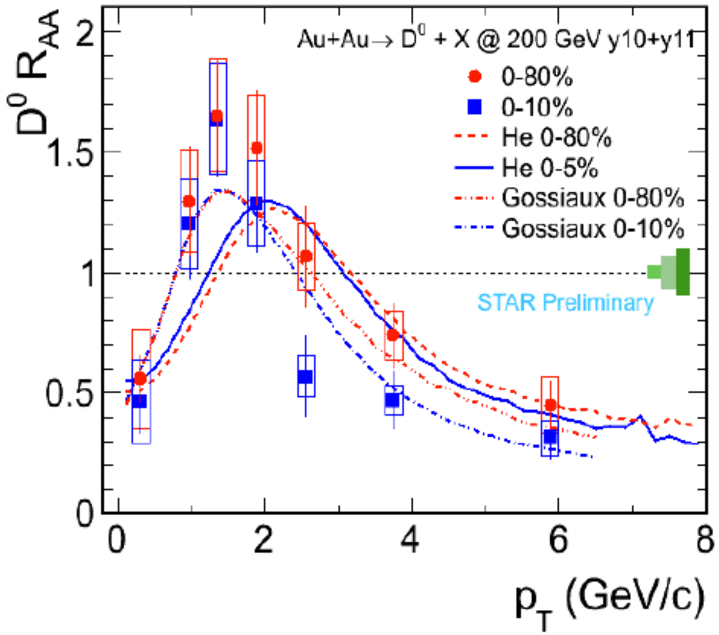


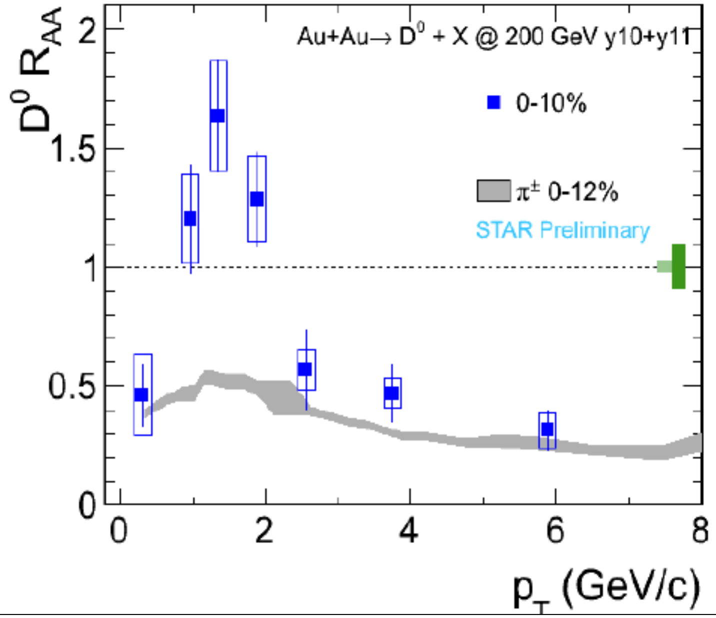


* B and D components to non-photonic electrons have been separately measured and are consistent with FONLL predictions

RAA of D0 in Au+Au 200 GeV





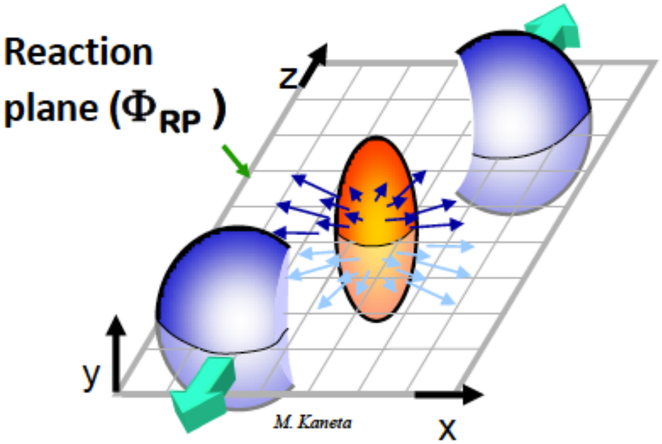


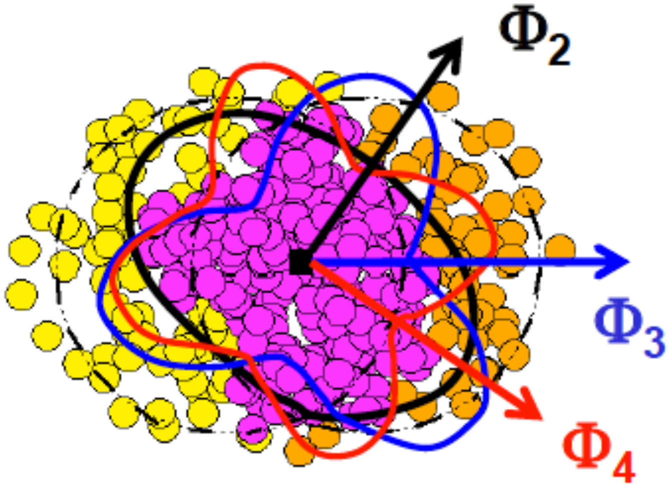
He et al, PRC86 014903, arXiv:1204.4442
PB Gossiaux: arXiv: 1207.5445

Models: bump may be due to radial flow of thermalized light quark which coalesces with charm

RAA of D0 at high pT:
- unsuppressed for peripheral events
- suppressed for central events
- suppression at high pT similar to pions

Flow coefficients vn, n=1,2,3..



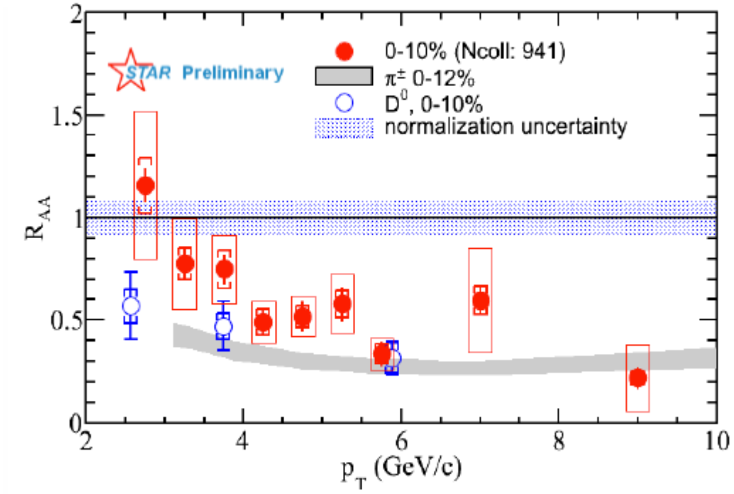


$$\frac{dN}{d\phi} \propto 1 + 2\sum_{n=1}^{\infty} v_n \cos[n(\phi - \Phi_n)]$$

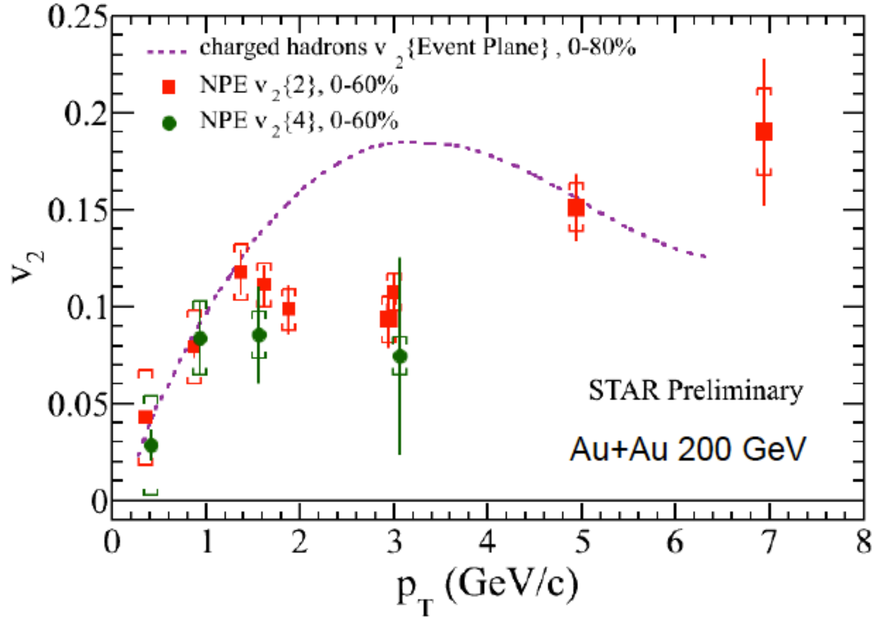
$$v_n = \langle \cos[n(\phi - \Phi_n)] \rangle$$

* Initial shape of the interaction region (v2 - elliptic flow)

Non-photonic electrons (NPE)

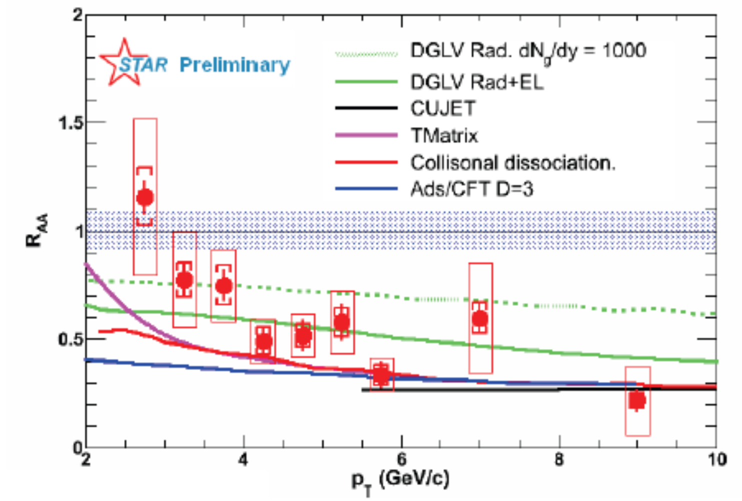


R_{AA} of D0 and NPE show similar strong suppression in central Au+Au 200 GeV at high p_T



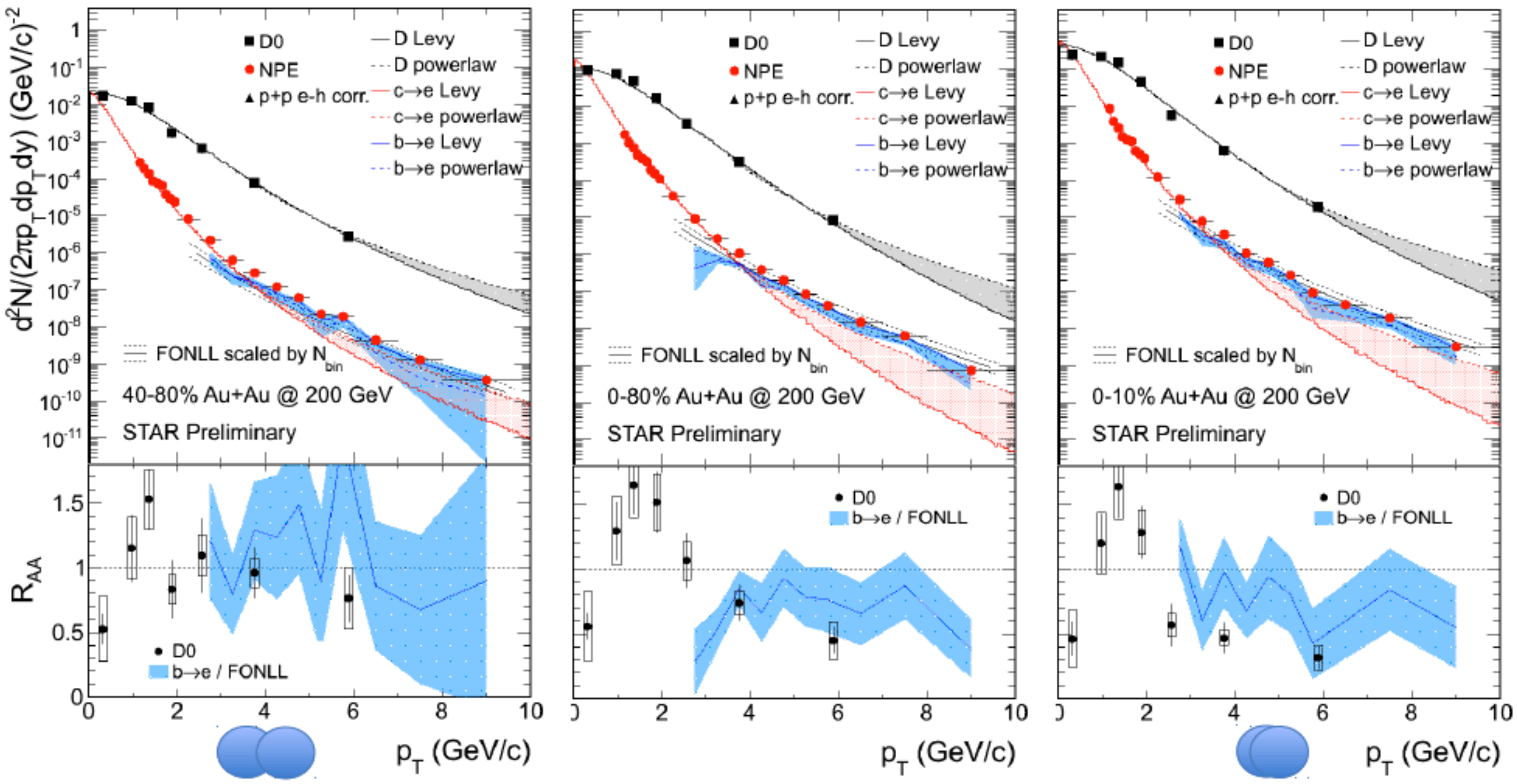
NPE show nonzero v_2

Increase of v_2 at high p_T's may be due to jet-like correlation and/or path length dependence



Models with only radiative energy loss do not describe the data

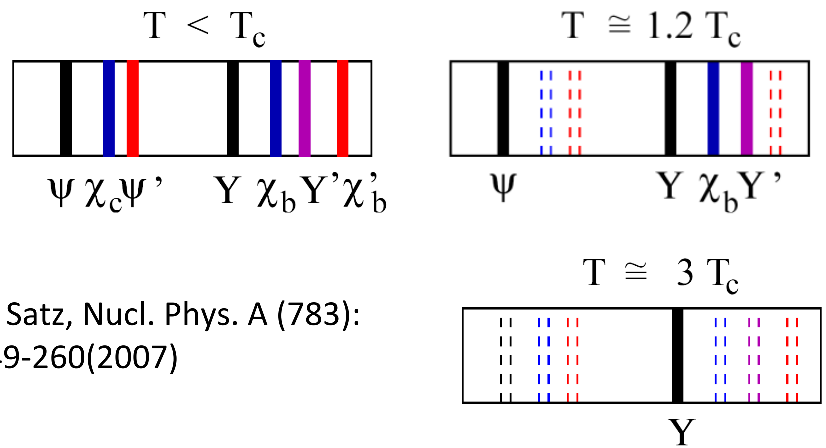
Is B less suppressed than charm ?



Hint of possible less suppression of B as compared to D in some cases
New STAR Heavy Flavor Tracker needed

III.2 Quarkonia

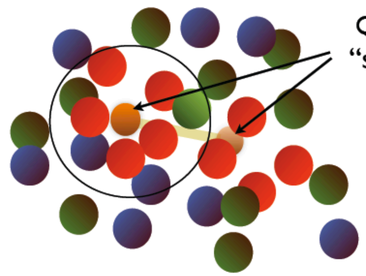
Quarkonia



H. Satz, Nucl. Phys. A (783): 249-260(2007)

Matsui-Satz: screening the potential

Screening in a deconfined medium: effective charge of Q and $\bar{Q}$ reduced



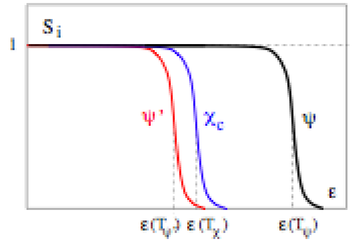
Q and $\bar{Q}$ cannot "see" each other
$r_D < r_{Q\bar{Q}}$

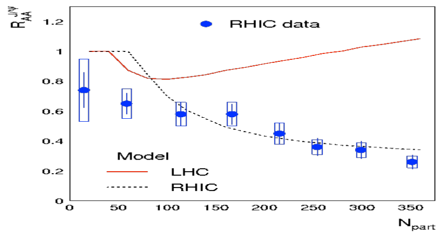
Assume: medium effects described with a T-dependent potential

$$-\frac{\alpha_{eff}}{r} e^{-r/r_D(T)}$$

A. Mocsy

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



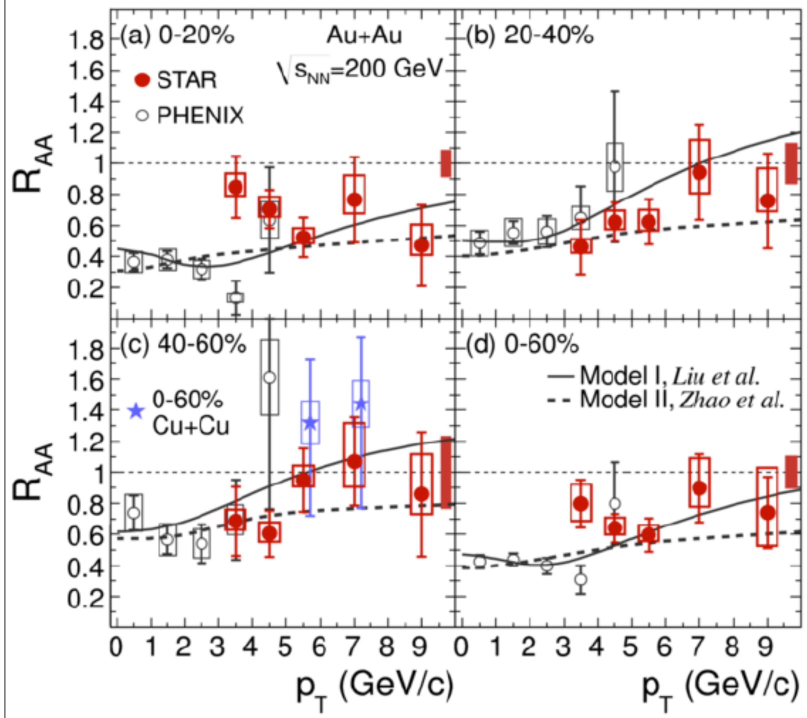


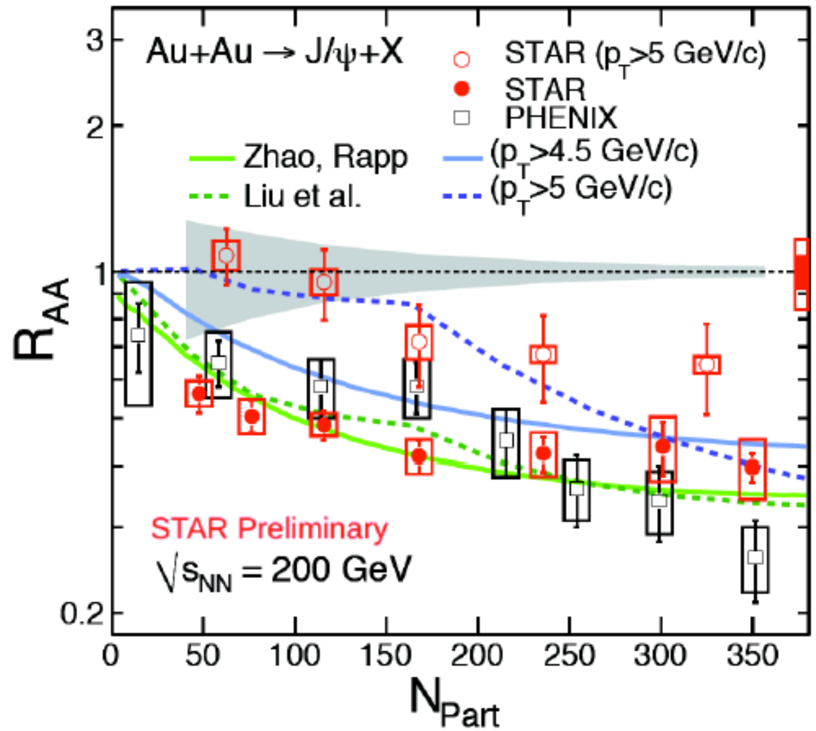
Quarkonia: Thermometer of QGP via their suppression pattern

Many effects play a role like dissociation in QGP, cold matter absorbtion, recombination/coalescence from c, cbar, feeding

p_T dependence of J/Psi suppression in Au+Au, Cu+Cu 200 GeV

PLB 722 (2013) 55

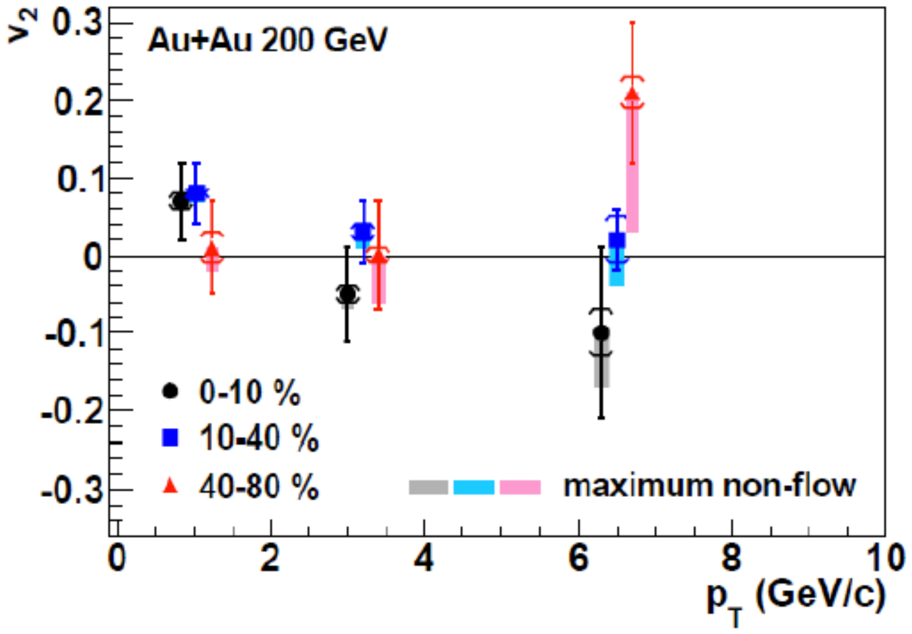


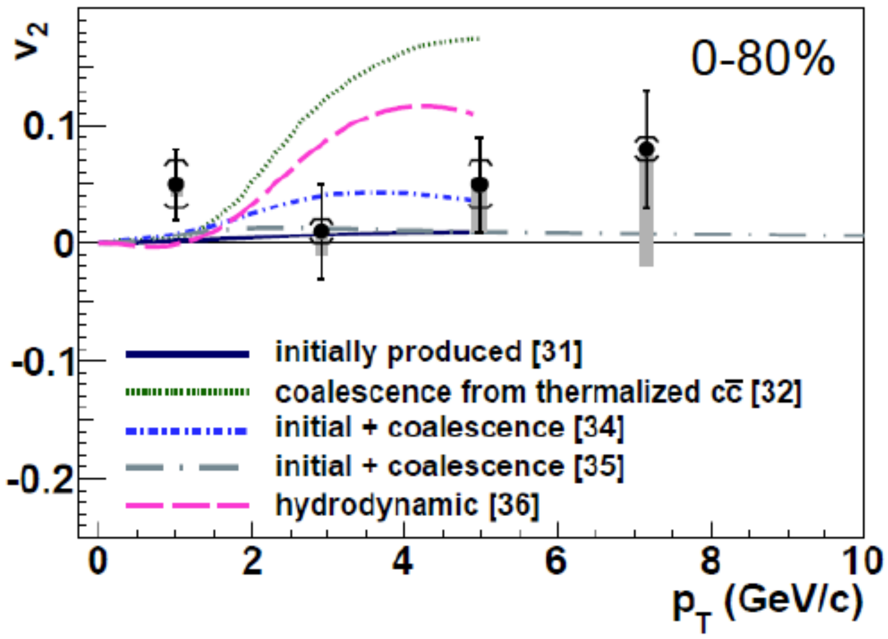


Liu et al, PLB 678 (2009) 72
Zhao et al, PRC 82 (2010) 064905

- J/Psi not suppressed at high p_T's in non-central collisions
- J/Psi suppressed at all p_T's for most central events
- R_{AA} of J/Psi is systematically larger for higher p_T

Elliptic flow of J/Psi

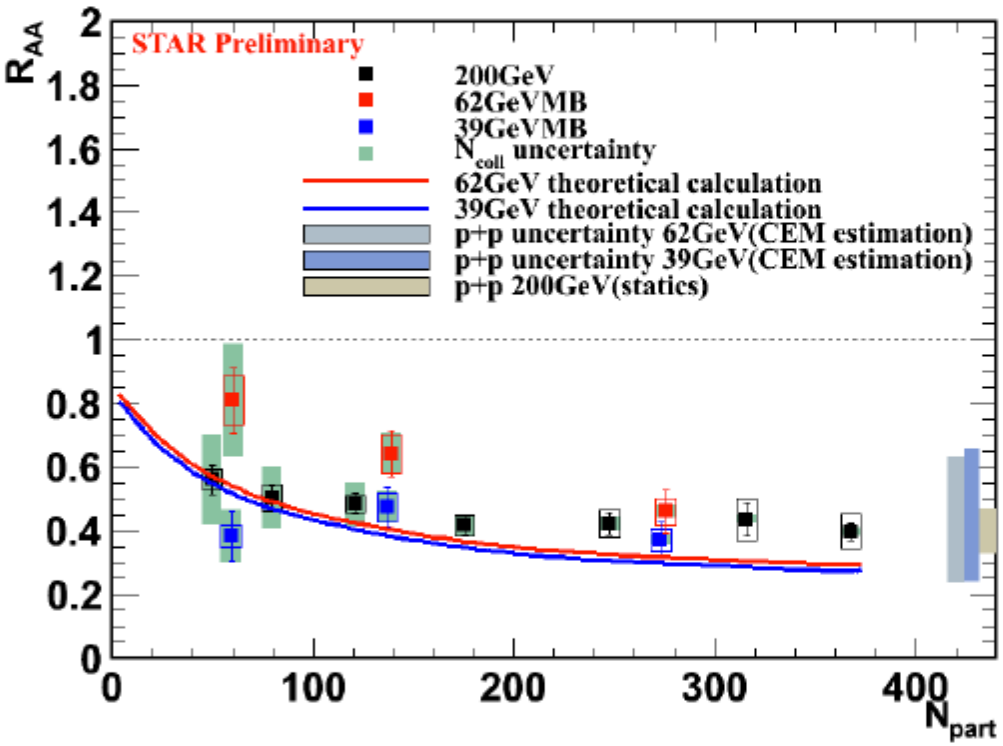




STAR Coll., Phys. Rev. Lett. 111, 052301 (2013)
ArXiv: 1212.3304

J/Psi v_2 consistent with zero for p_T > 2 GeV -> Suggests that J/Psi does not originate dominantly from thermalized c and cbar quark coalescence (assuming c and cbar exhibit elliptic flow)

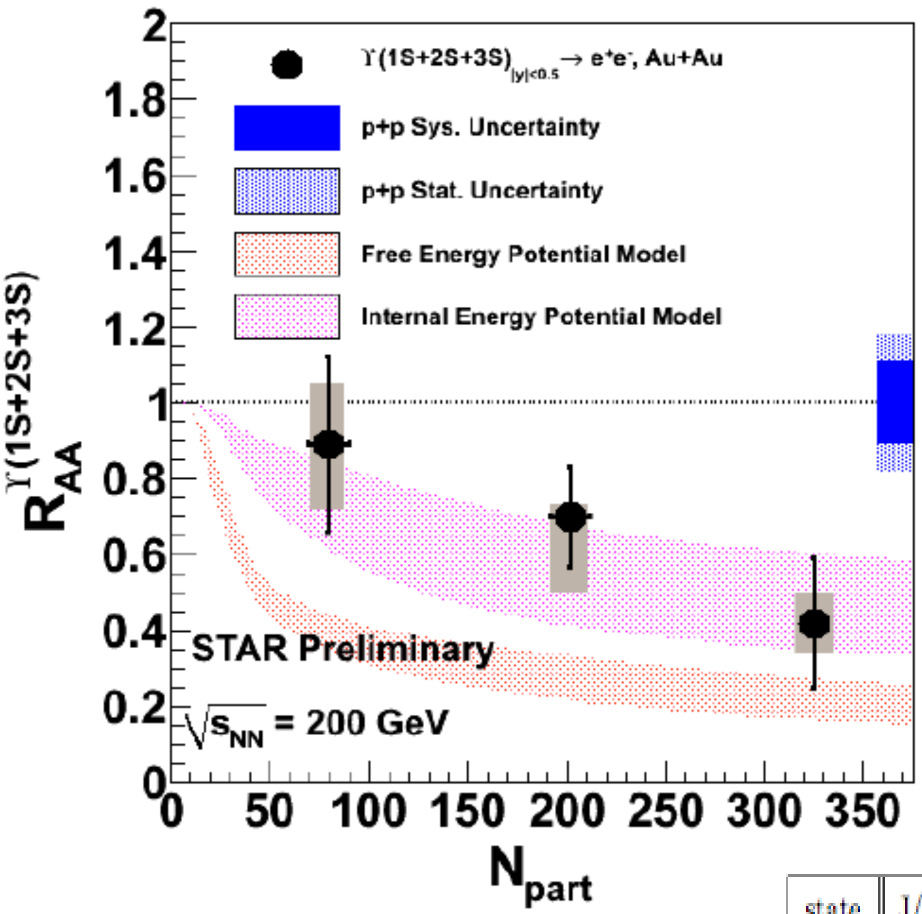
At which energy does J/Psi suppression turn off?



Color Evaporation Model (CEM) estimate for p+p reference used for 39, 62 GeV

R_{AA} of J/Psi is suppressed in similar way at 39, 62 and 200 GeV

Upsilon in Au+Au 200 GeV



Y(1S+2S+3S) in Au+Au collisions at 200 GeV :

* No suppression in most peripheral collisions

* Exhibits suppression in more central collisions increasing with centrality

* The suppression observed is consistent with model assuming Y(2S) and Y(3S) suppression

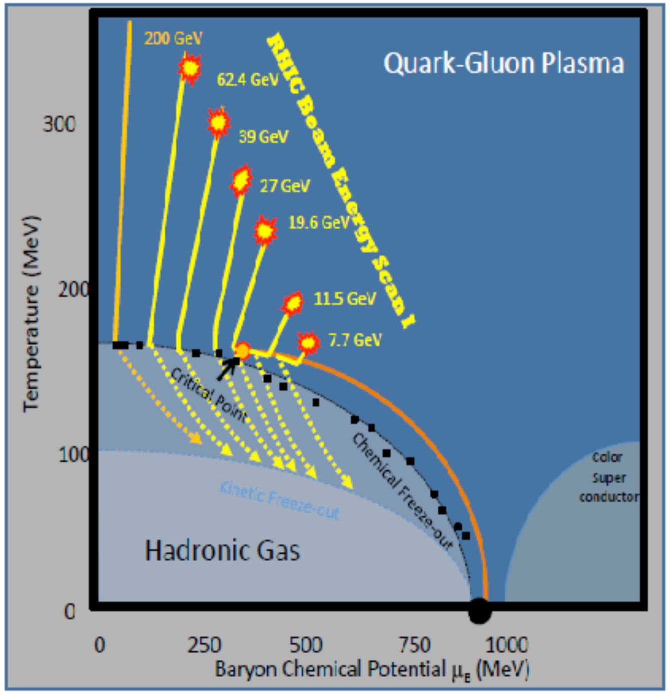
Model by Strickland et al (PRL 107, 132301, 2011) :

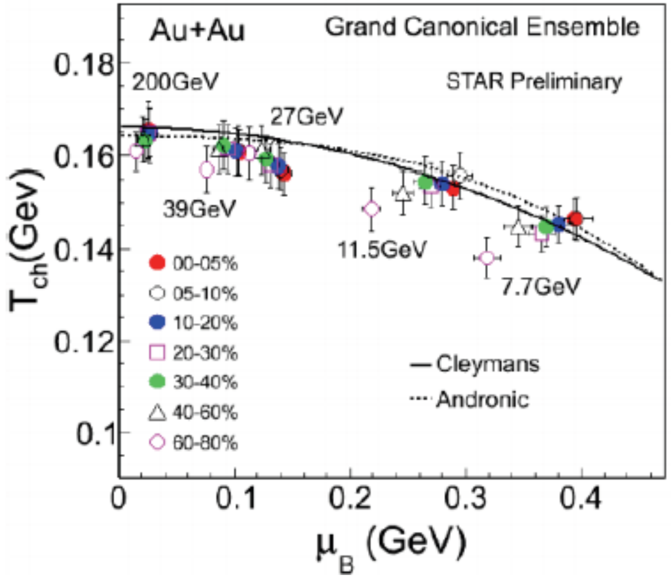
Assumes T_0= 428-442 MeV and $1/4\pi < \eta/S < 3/4\pi$

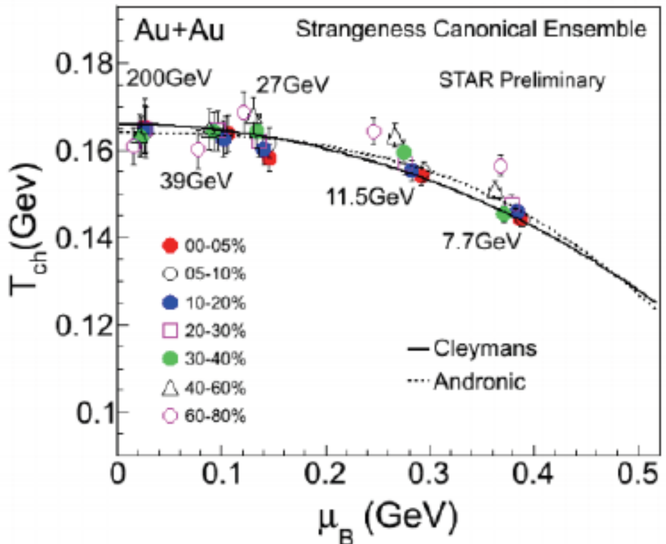
state	$J/\psi(1S)$	$\chi_c(1P)$	$\psi'(2S)$	$\Upsilon(1S)$	$\chi_b(1P)$	$\Upsilon(2S)$	$\chi_b(2P)$	$\Upsilon(3S)$
T_d/T_c	2.10	1.16	1.12	> 4.0	1.76	1.60	1.19	1.17

III.3 Beam Energy Scan

Chemical freeze out temperature vs baryochemical potential



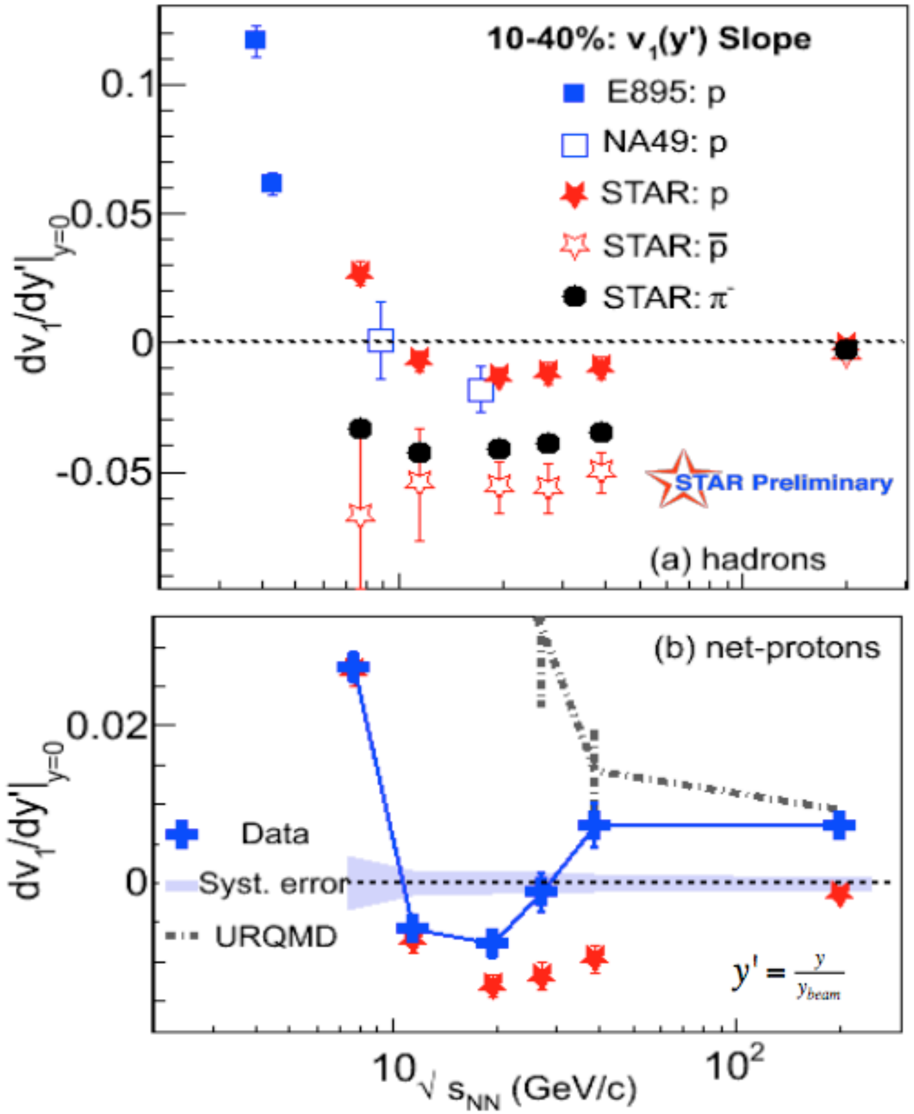




Model used for particle ratio fits: THERMUS by J Cleymans et al

Grand canonical ensemble and strangeness canonical ensemble fits to particle ratios give consistent results for mid-central and central Au+Au collisions and disagree for peripheral collisions

Directed flow of protons



Directed flow slope is sensitive to a 1st order transition

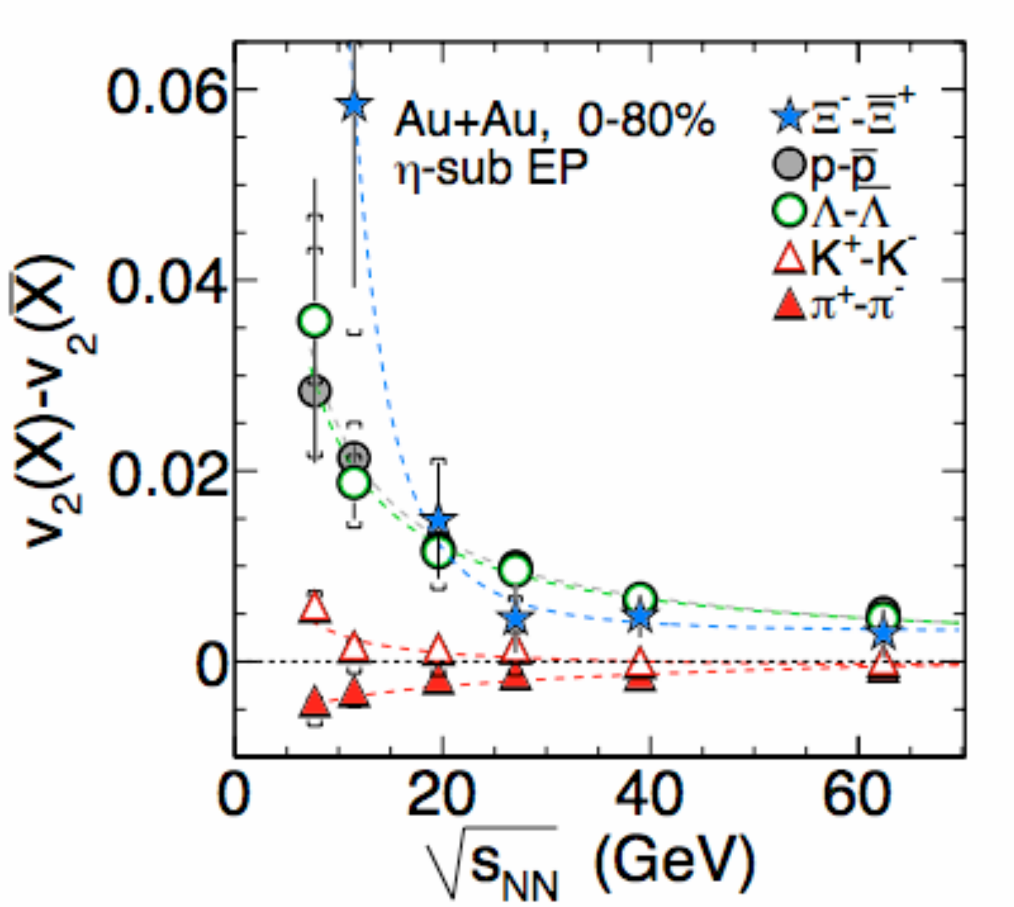
STAR: v_1 slope changes sign from positive to negative between 7.7 and 11.5 GeV

Pions and antiprotons have always negative v1 slopes.

Net-proton v_1 slope shows a minimum around 11.5-19.6 GeV

UrQMD model (model without phase transition) cannot explain the data

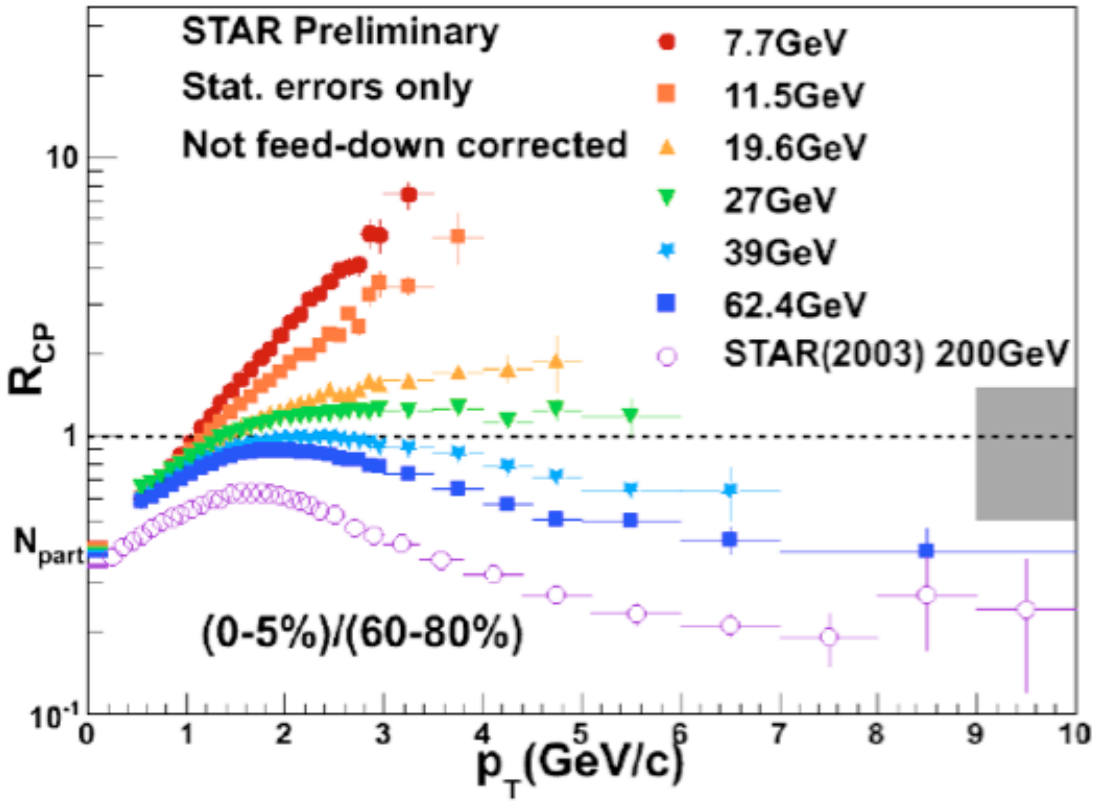
Elliptic flow energy dependence



* Difference between baryon and antibaryon elliptic flow coefficient v_2 is getting larger in lower energies

PRL 110 (2013) 142301
PRC 88 (2013) 014902

At which energy does jet quenching switch off?



R_{CP} suppression measured from $\sqrt{s}$=39 GeV on

IV Conclusions

- Several sQGP signatures observed in central Au+Au collisions at high energy:

Open Heavy Flavor:

- "Jet quenching" of D mesons and of electrons from charm and beauty quarks in Au+Au 200 GeV
- Elliptic flow of electrons from open charm and beauty in Au+Au 200 GeV further constrain models

Quarkonia suppression:

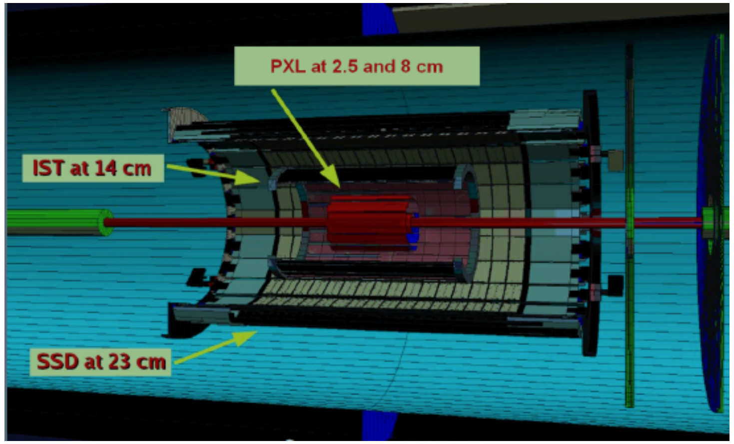
- J/Psi suppression and elliptic flow
- Upsilon suppression in central Au+Au collisions 200 GeV, consistent with suppression of Y(2S+3S)

Beam Energy Scan:

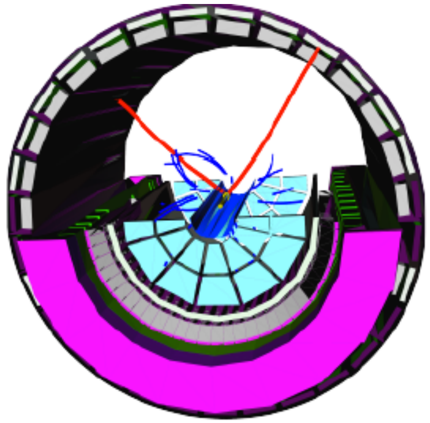
- Dissapearance of key QGP signatures at low energies

V Outlook
Short term STAR upgrades

Heavy Flavor Tracker

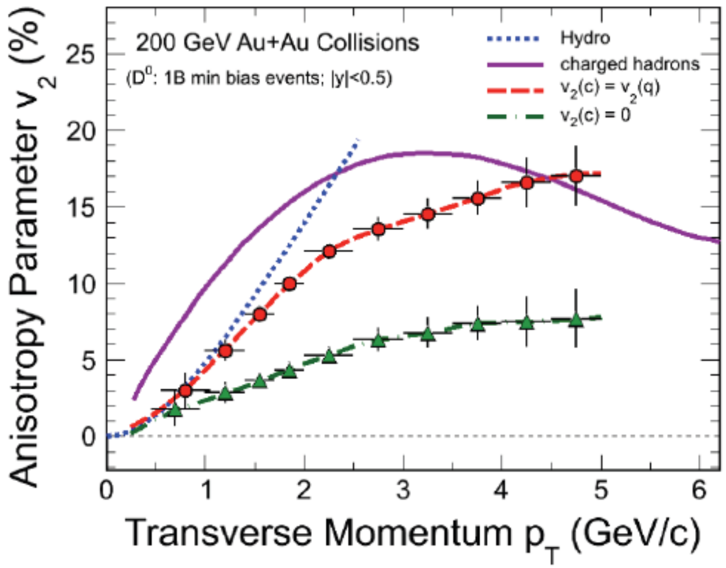


Muon Telescope Detector



Expectations for 2014 run with HFT

J/Psi event in p+p 500 GeV



* HFT pixel prototype with 3 sectors took first data in 2013

* MTD 63% installed and took data in 2013

* Outlook: 2014 full HFT and MTD for Au+Au 200 GeV run

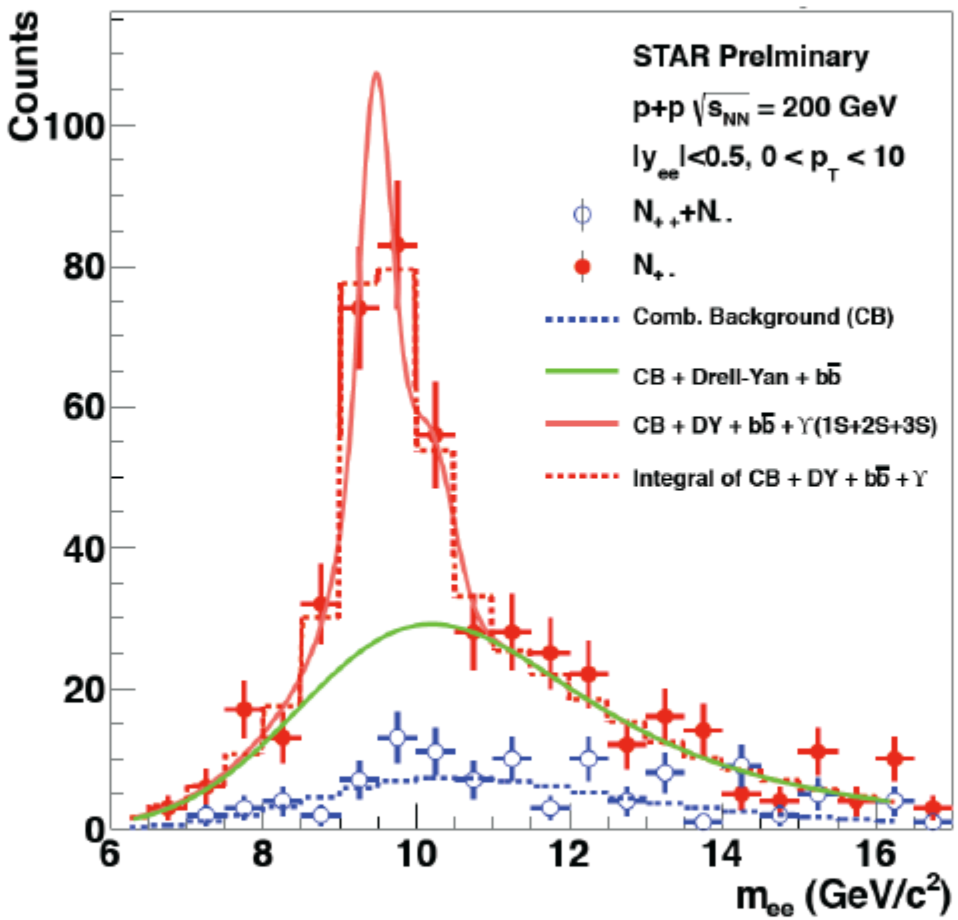
Outlook
BES-II program (>2017)

BES-II:
* Fine energy scan of region $\sqrt{s}$ <~ 20 GeV
* Increased luminosity ~ 3-10 times
* STAR upgrade to extend mid-rapidity coverage

Fixed Target proposal:
* Energy scan of region down to $\sqrt{s}$ ~ 3 GeV
* Annular 1% Au target inside STAR beam pipe, and 2 m away from the interaction point center
* Data taking at beginning of each fill in collider mode

Thank you very much for your attention

Upsilon



STAR Prelminary
p+p $\sqrt{s_{NN}}$ = 200 GeV
$|y_{ee}|$<0.5, 0 < p_T < 10
$N_{++}+N_{--}$
N_{+-}
Comb. Background (CB)
CB + Drell-Yan + $b\bar{b}$
CB + DY + $b\bar{b}$ + ϒ(1S+2S+3S)
Integral of CB + DY + $b\bar{b}$ + ϒ
Counts
0
20
40
60
80
100
6
8
10
12
14
16
m_{ee} (GeV/c^2)

Table 2. Estimates of the isotropic and anisotropic dissociation scales for the J/ψ, χ_{c1}, $\Upsilon(1s)$, $\Upsilon(2s)$, $\Upsilon(3s)$, χ_{b1}, and χ_{b2}. Estimates are taken from Refs. [129, 130].

State	Isotropic QGP (ξ=0)	Anisotropic QGP (ξ=1)
J/ψ	307 MeV	374 MeV
χ_{c1}	$<$ 192 MeV	210 MeV
$\Upsilon(1s)$	593 MeV	735 MeV
$\Upsilon(2s)$	228 MeV	290 MeV
$\Upsilon(3s)$	$<$ 192 MeV	$<$ 192 MeV
χ_{b1}	265 MeV	351 MeV
χ_{b2}	$<$ 192 MeV	213 MeV

M Strickland et al 1302.2180