Selected highlights from the STAR experiment at RHIC

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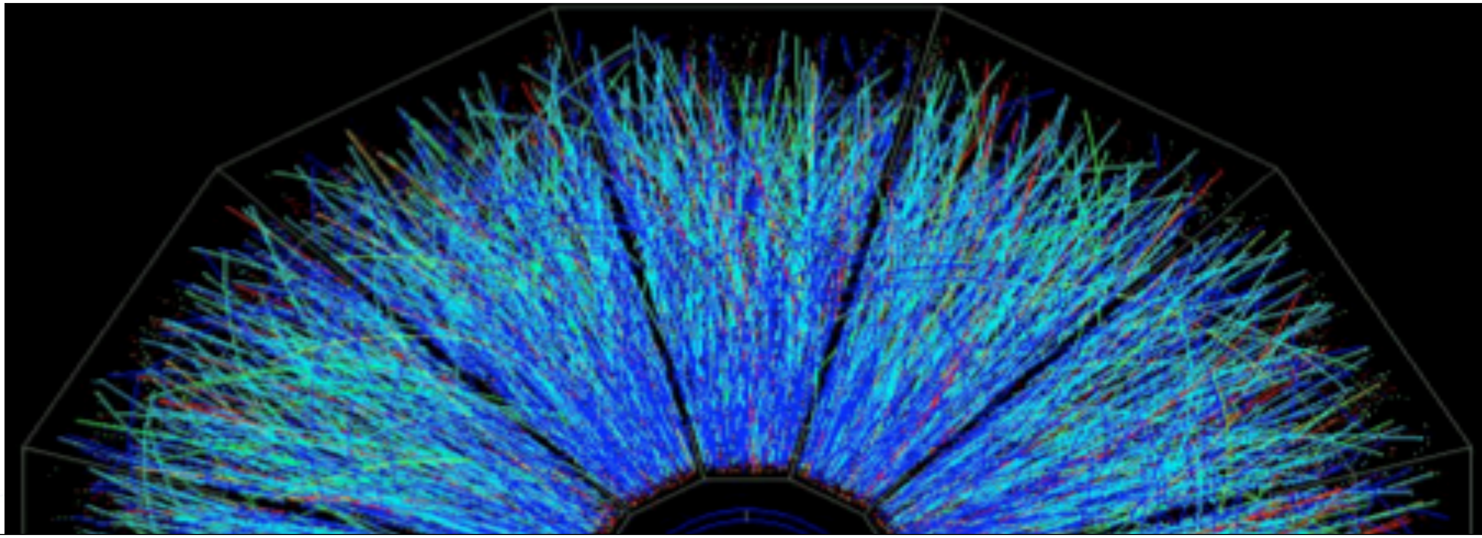


Outline

I Introduction

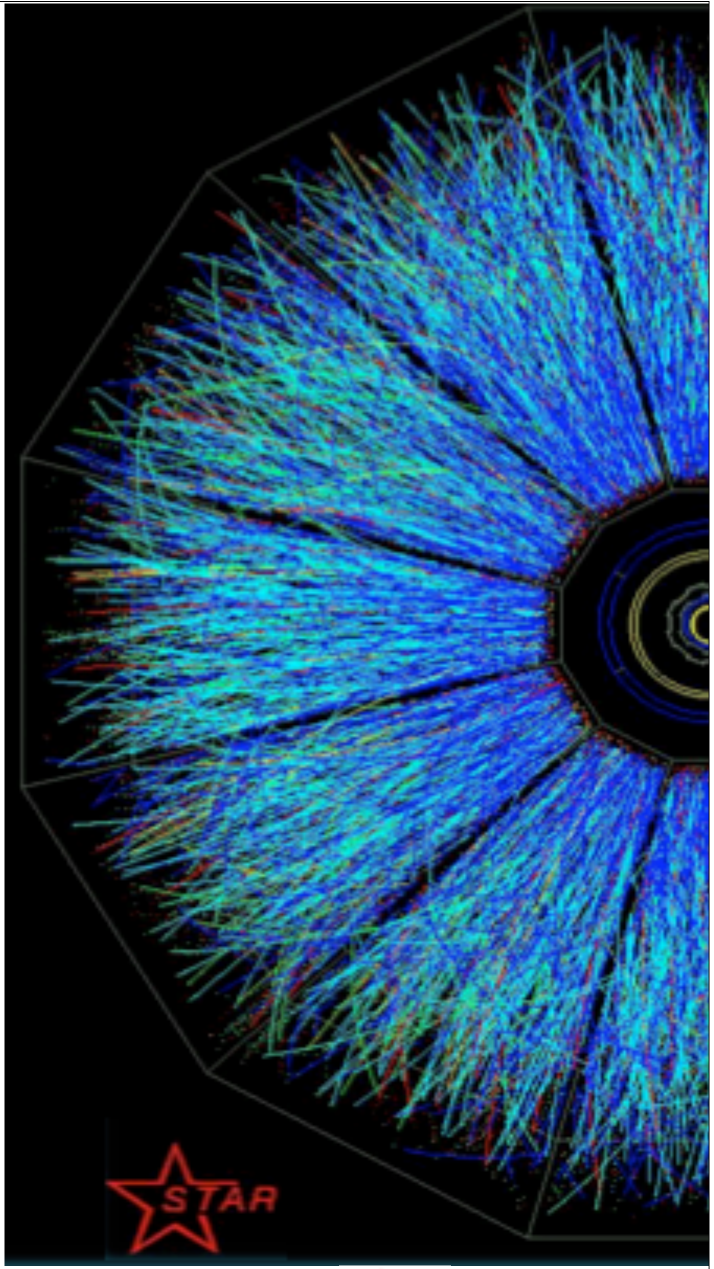
II STAR detector

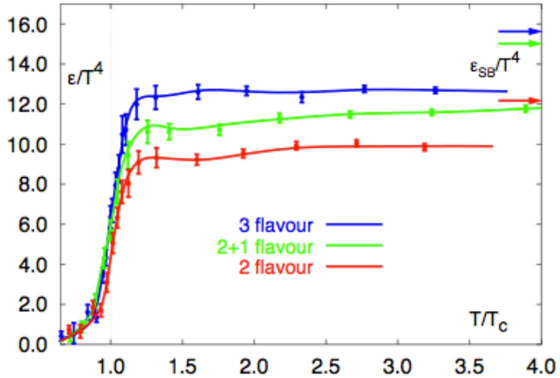
III Selected physics results :

1. Open heavy flavour and jet quenching
2. Hidden heavy flavour
3. Beam Energy Scan

IV Conclusions

V Outlook





I Introduction

Lattice QCD prediction :

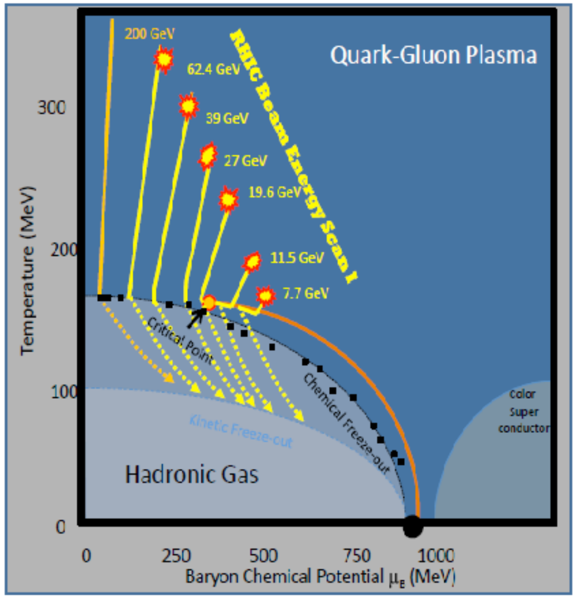
The Hadron <-> Quark Gluon Plasma (QGP) transition

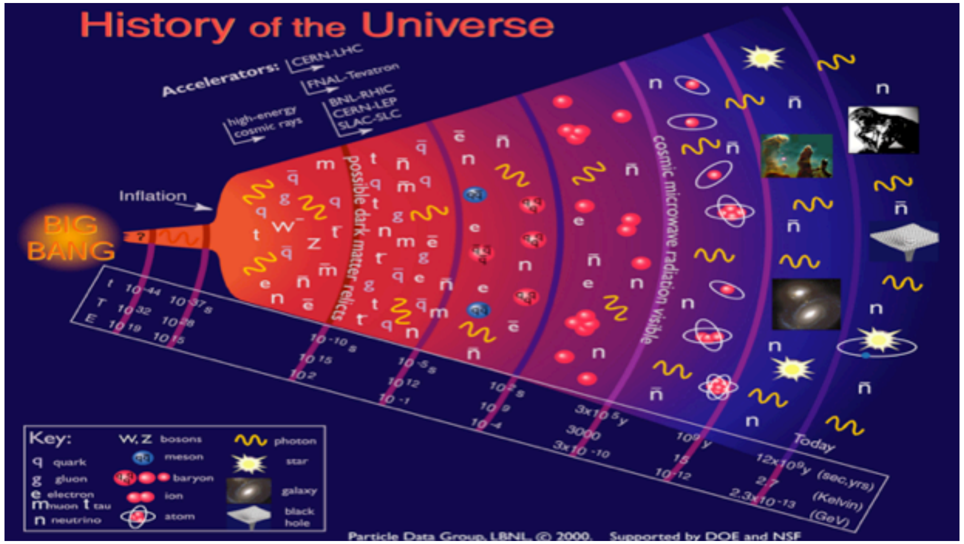
Goal of ultrarelativistic heavy ion physics:

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**

QGP seen from Jura

- A skier (quark?) is confined inside snow patches (hadrons?)

Temperature

- the skier can move further…a new phase develops

..goes up

- a skier (quark?) can move freely over long distances…

..this way

L. Maiani, CERN 2000

Signatures of the Quark Gluon Plasma

A. "Internal" Signatures originating "from the QGP itself" :

Direct photons from QGP → T(QGP)

Strangeness enhancement (Mueller, Rafelski 1981) → K/pi

U,d,s yields for T(freeze out) or pT slopes (Van Hove, H Stoecker et al) → plateau vs energy at Tc → e_init(crit), sqrt(s)("crit")

Multiquark states from QGP (Greiner et al) → 'small QGP-lumps'

Critical fluctuations near the critical point, Tc → K/pi, <pT>, etc

Hadronic mass/width changes (Pisarski 1982) → rho etc

B. "External" Signatures of high pT probes altered by the QGP:

Charmonia suppression (Satz, Matsui 1987) → T(dissociation) of ccbar, bbbar

Jet quenching (J D Bjorken 1982) → medium density

--> Goal is to achieve a combination of many signatures

Historical Milestones of the search for the QCD phase transition

1988-89 AGS BNL and SPS CERN:

Discovery that strangeness is enhanced over pions in Si+Au and Au+Au collisions at sqrt(s)(NN)=1-5 GeV

K/π, Λ/π enhancement in A+A over p+A

2000 CERN press release:

Discovery of a new state of matter in A+A collisions at sqrt(s)(NN)=17, 19 GeV

chi_c, Ψ', J/Ψ suppression,

T(direct γ)~200-300 MeV (model fit),

Strangeness enhancement including Omegas, Xis,

T(chem. fr. out)~170 MeV is located near Tc

2003 BNL press release:

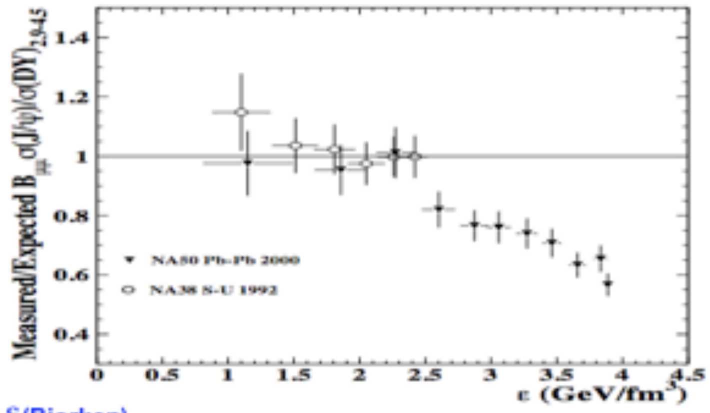
Discovery of jet quenching in Au+Au at √s(NN) = 200 GeV, large elliptic flow

Discovery of a strongly interacting QGP (sQGP)

Applications of Anti de Sitter/Conformal Field Theory duality on sQGP

Marks a new era in QCD studies

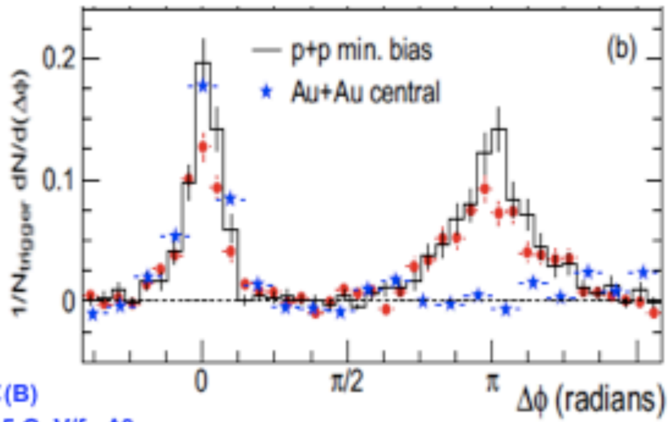
Discovery of J/Psi suppression
NA50 Coll. CERN SPS, 2000



Ɛ(B)= Ɛ(Bjorken)
~3.5 GeV/fm^3

Discovery of jet quenching, RHIC 2003

STAR



Ɛ(B)
~5 GeV/fm^3

Historical milestones

Which are the critical parameters of the phase transition ?:

Several observables where suggestive of an onset of the QCD phase transition at energy lower than top SPS (19 GeV) energy, possibly with ε_c(Bjorken)~1 GeV/fm^3, motivating a low energy scan.

Low energy scan SPS (1999-), RHIC (2009-):

Study onset of transition, search for a possible critical point (as yet inconclusive and ongoing) and map out the QCD phase diagram.

2010: first PbPb collisions at the LHC !

Jet quenching, Quarkonia suppression

ε(B) ~16 GeV/fm^3

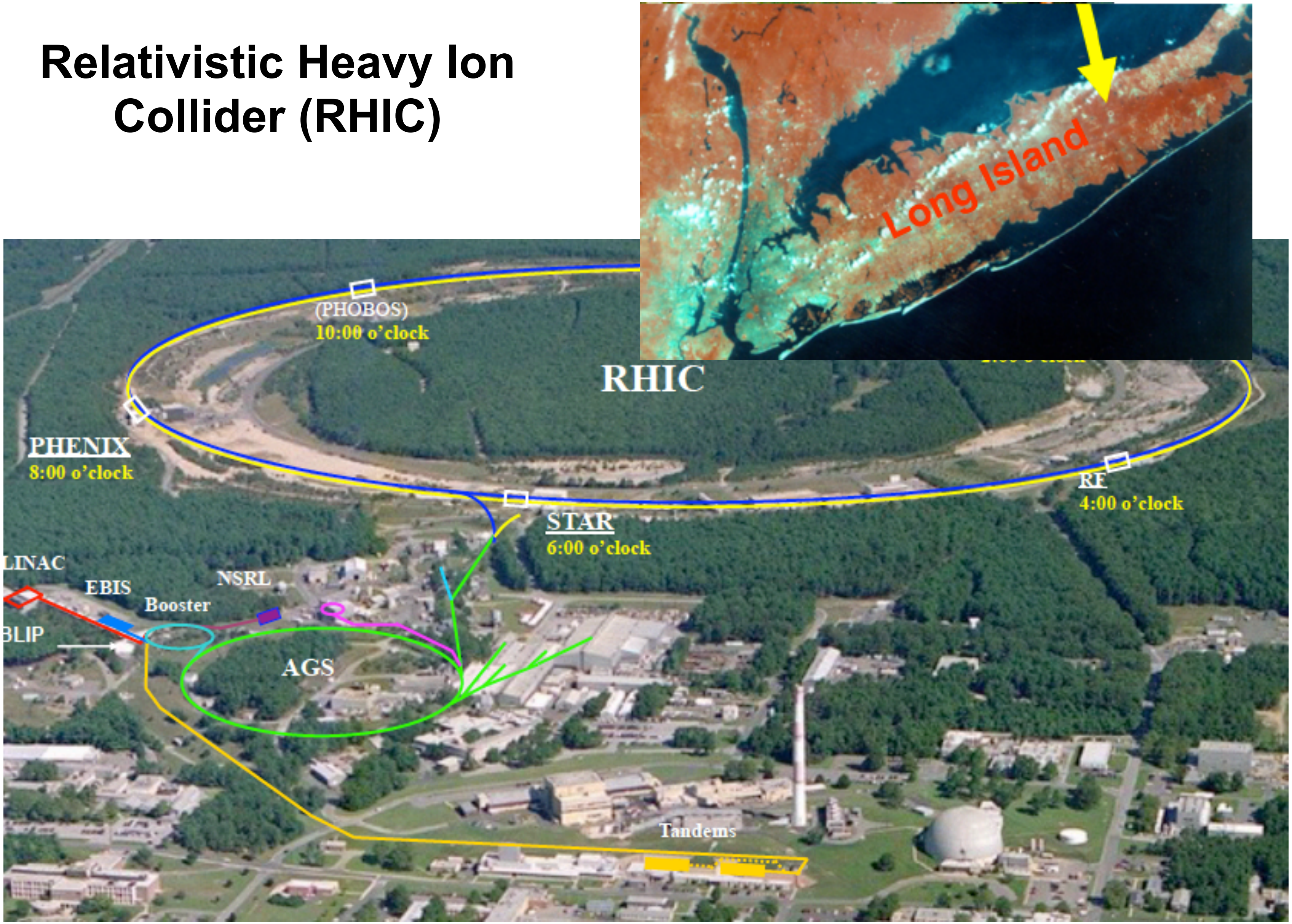
2010/11: RHIC upgrades

highly enhanced identification capabilities due to new detectors

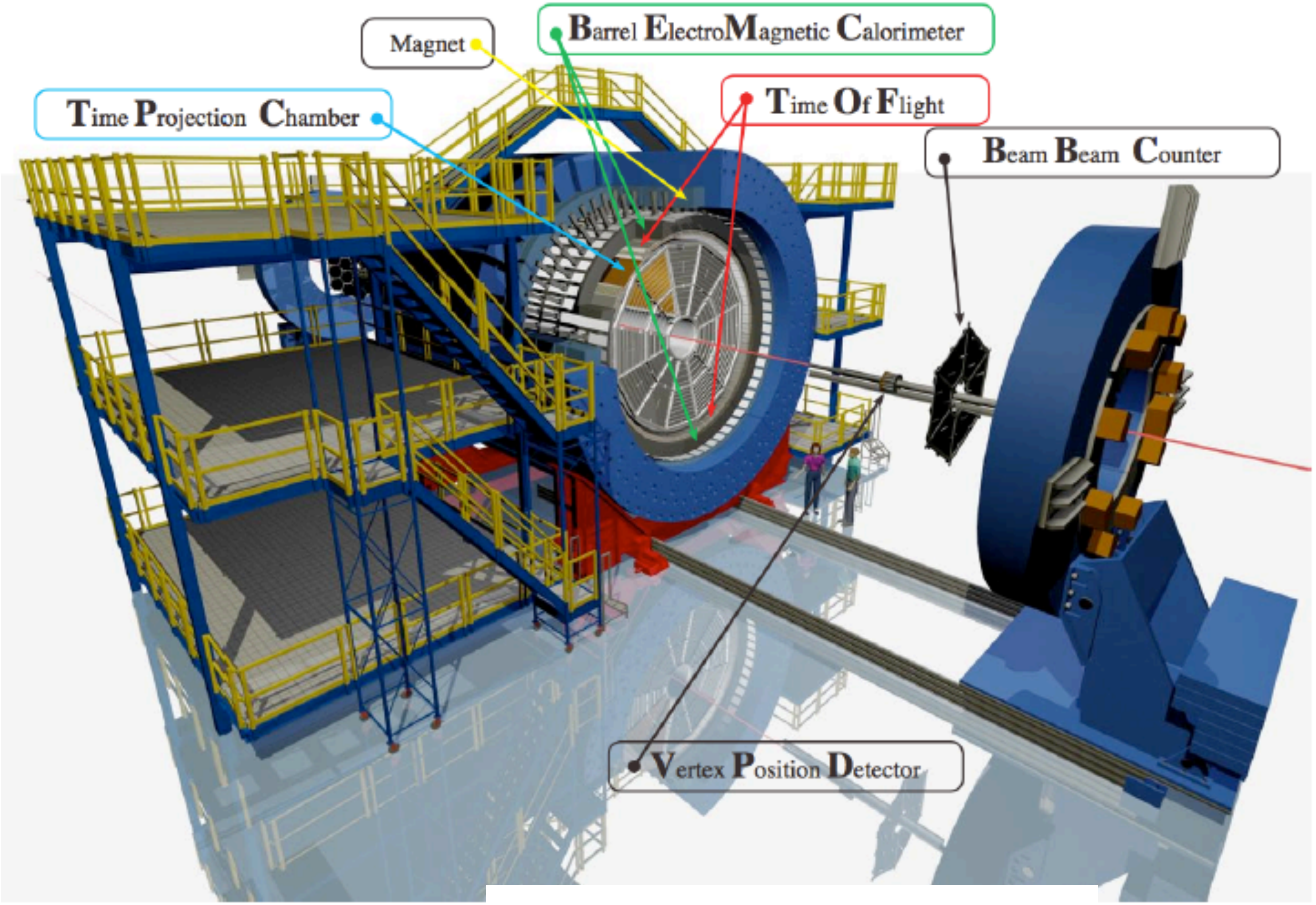
-> since 2009 like a "new RHIC collider and experiments"

2011: Y suppression discovered at RHIC and LHC
2012 : Sequential quarkonia suppression at the LHC
2013: First p+Pb run at LHC

Relativistic Heavy Ion Collider (RHIC)



II STAR: Solenoidal Tracker At RHIC



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

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

III Selected physics results

III.1 Open heavy flavor and jet quenching

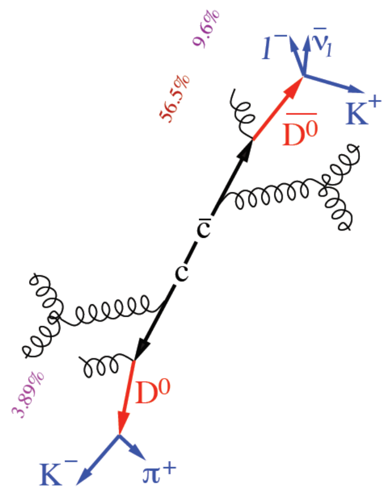
STAR heavy flavor measurements

STAR measures:

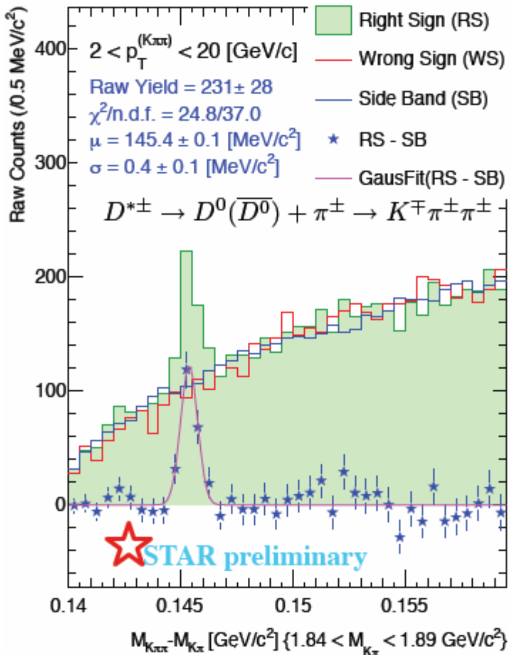
* Charm via direct D meson reconstruction

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

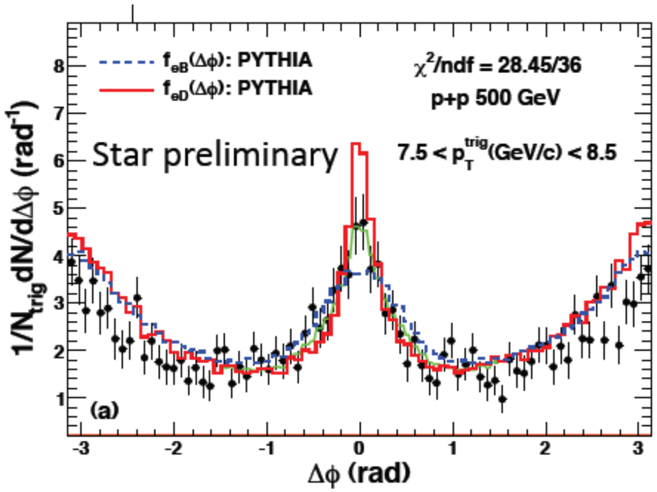
* Quarkonia via reconstruction of their decay to -> e+ e-



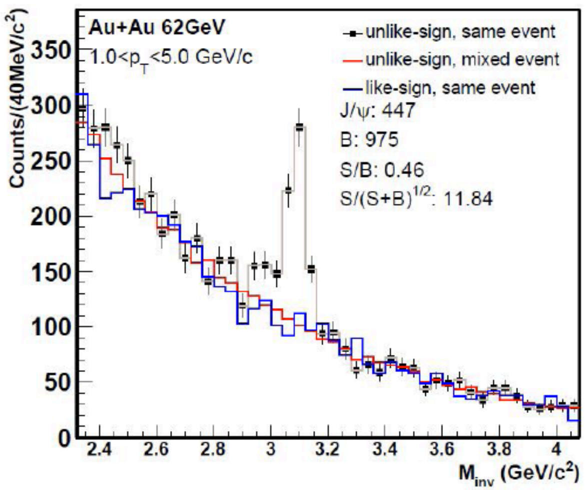
p+p 500 GeV



p+p 500 GeV
e-h correlations

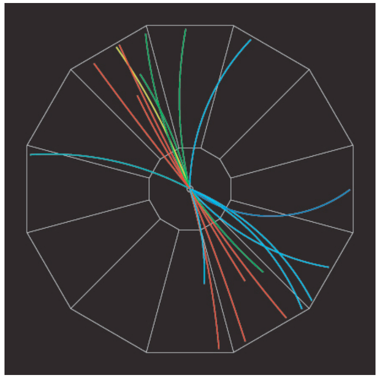


Au+Au 62 GeV

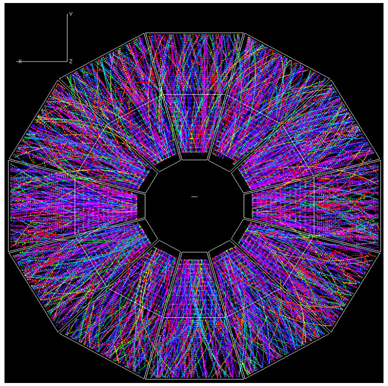


Jet quenching and heavy flavour

p+p Collision



Au+Au Collision

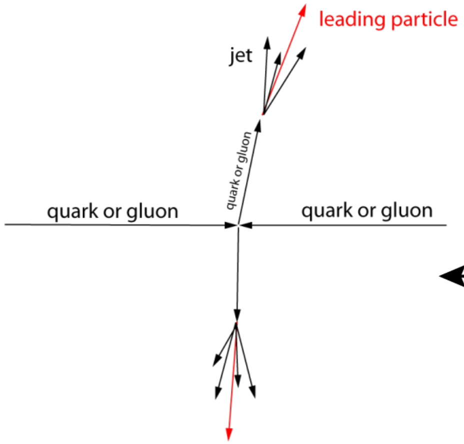


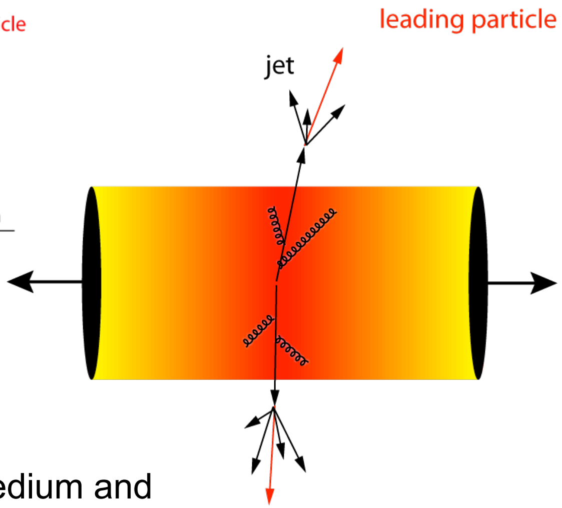
We compare A+A to expectations from p+p, using the “nuclear modification factor” R_{AA} defined as:

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

N coll : Average number of NN collisions in AA collision

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

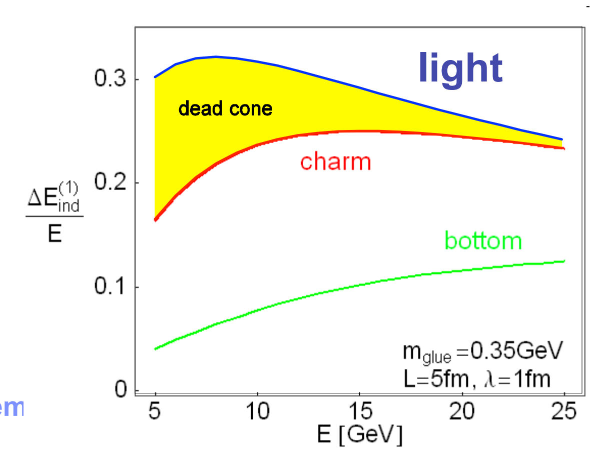




Partons interact with the medium and loose energy through eg gluon radiation

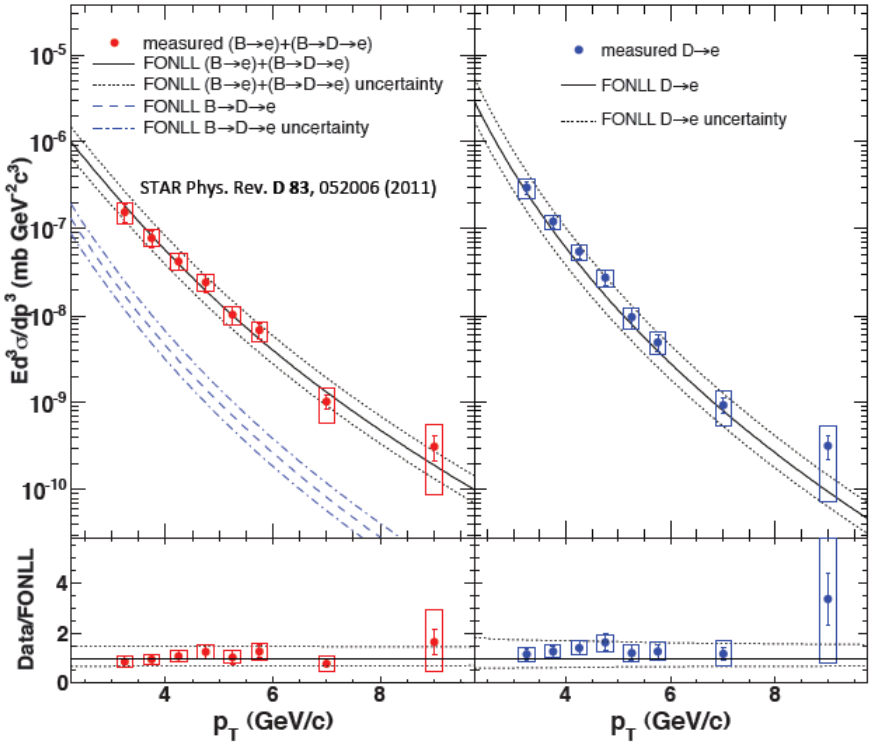
Quarks are expected to exhibit different radiative energy loss depending on their mass (**D.Kharzeev et al. Phys Letter B. 519:1999**)

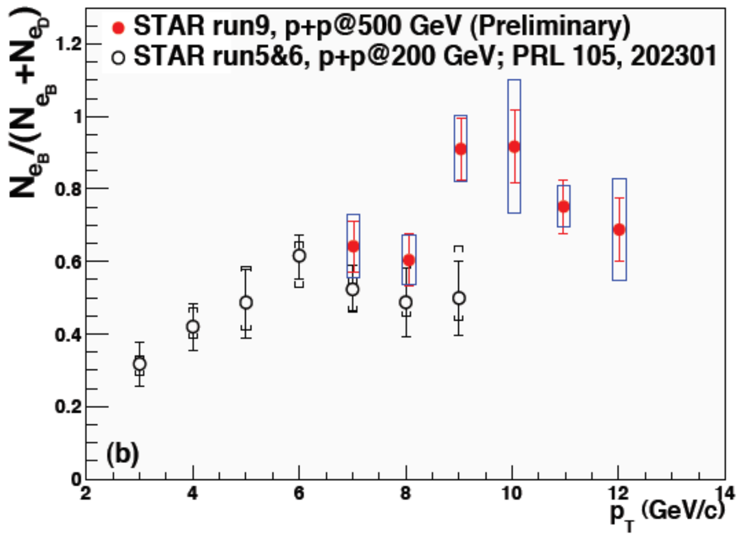
M.Djordjevic PRL 94 (2004)



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

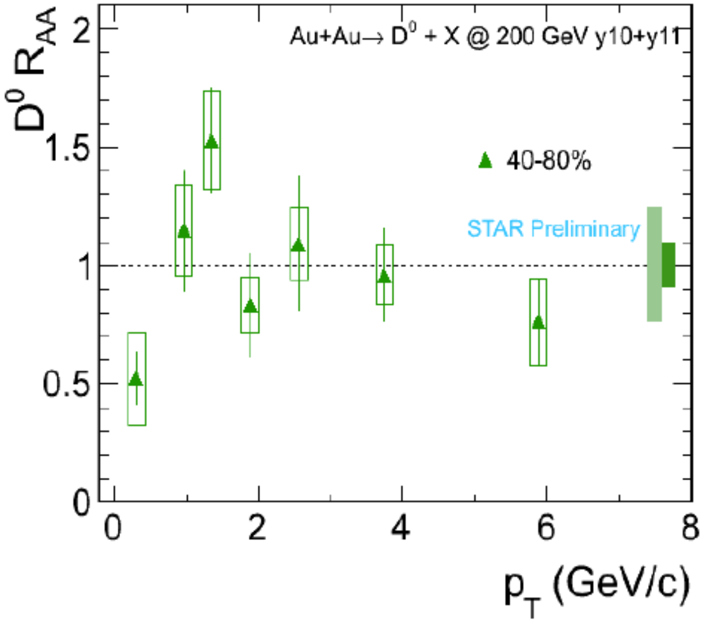
p+p 200 GeV

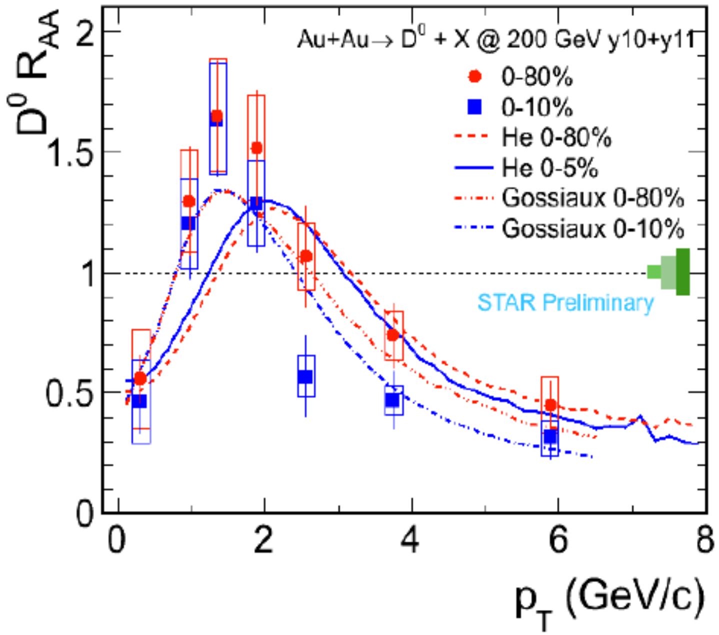


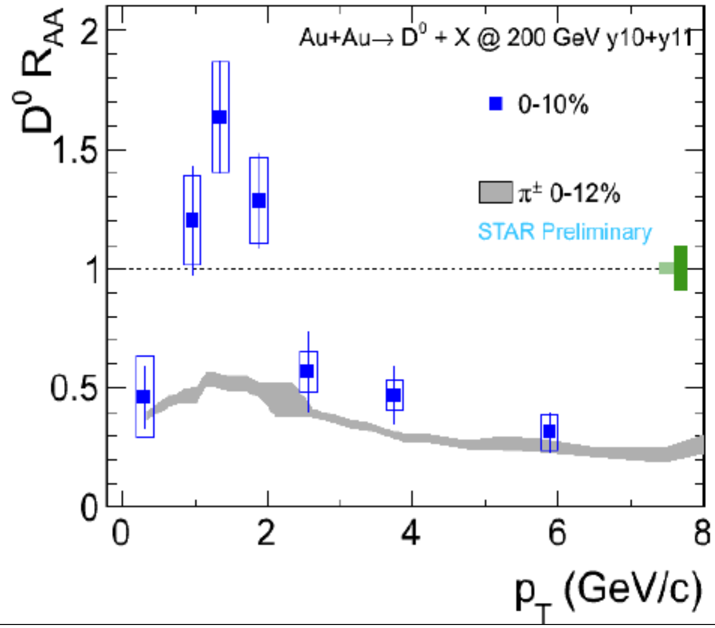


* B and D components to non-photonic electrons have been separately measured and are consistent with FONLL predictions

R_{AA} of D_0 in Au+Au 200 GeV





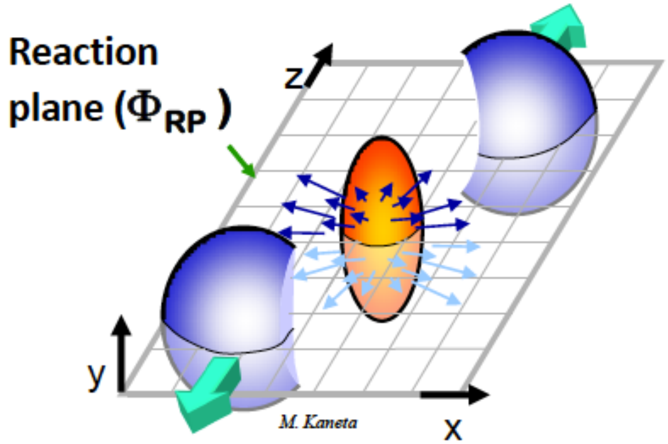


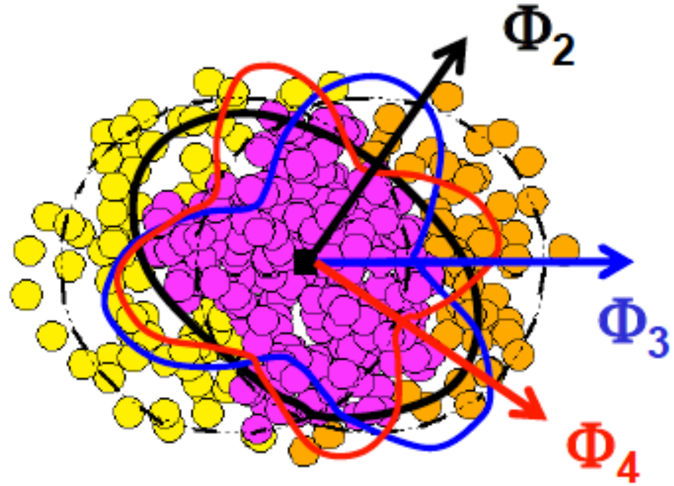
He et al, PRC86 014903, arXiv:1204.4442
PB Gossiaux: arXiv: 1207.5445

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

R_{AA} of D_0 at high p_T:
- unsuppressed for peripheral events
- suppressed for central events
- suppression at high p_T similar to pions

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





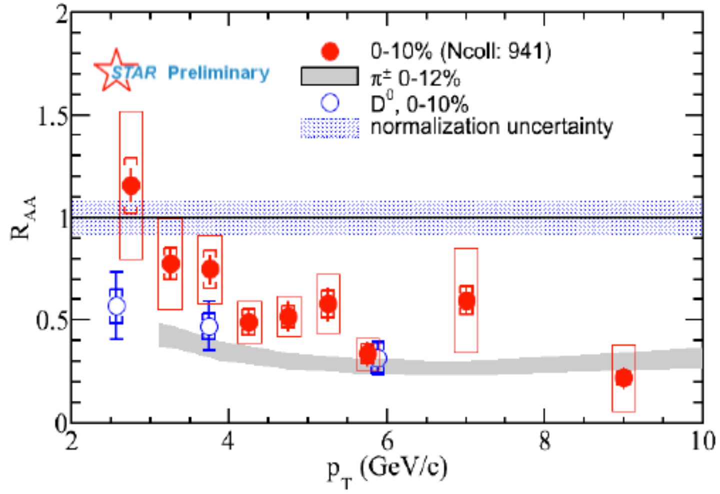
Matter in the overlapp area of two colliding nuclei gets compressed and heated

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

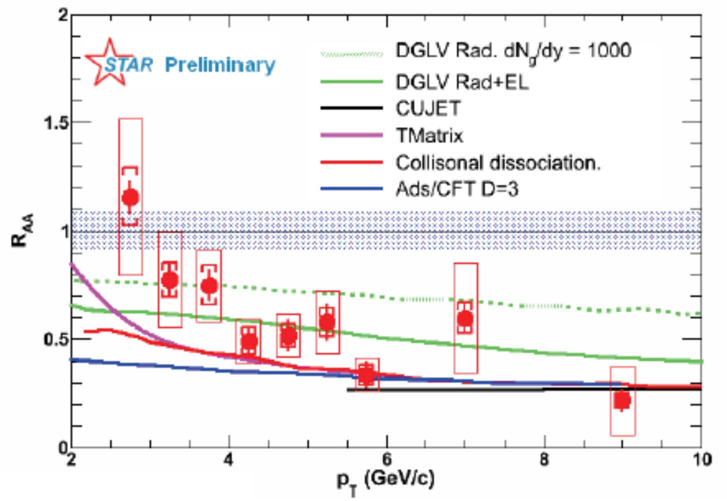
$$v_n = \langle \cos[n(\phi - \Phi_n)] \rangle$$

v : flow coefficients
(v1: directed flow, v2: elliptic flow, ...)

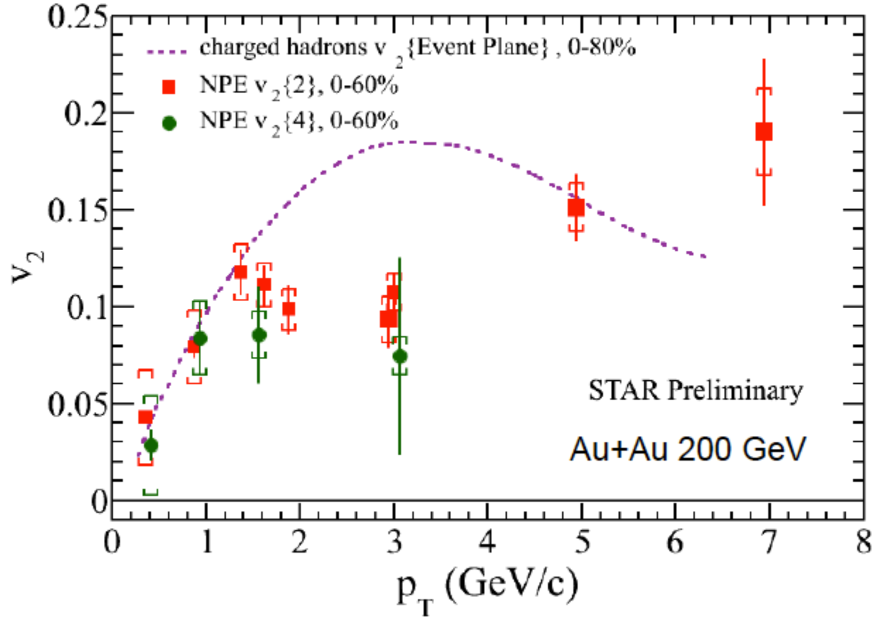
Non-photonic electrons (NPE)



R_{AA} of D_0 and NPE show similar strong suppression in central Au+Au 200 GeV at high p_T



Models with only radiative energy loss do not describe the data

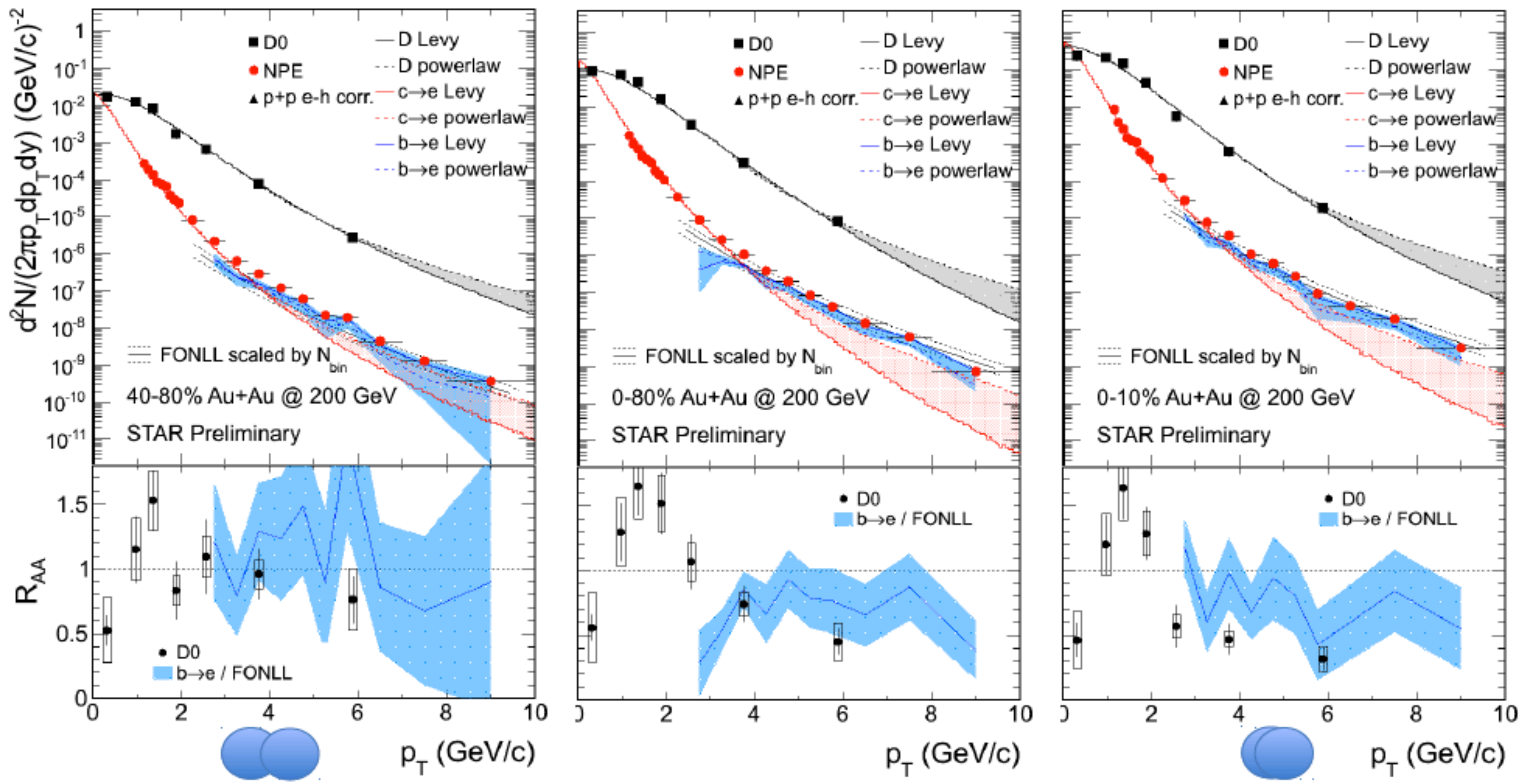


NPE show nonzero v_2

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

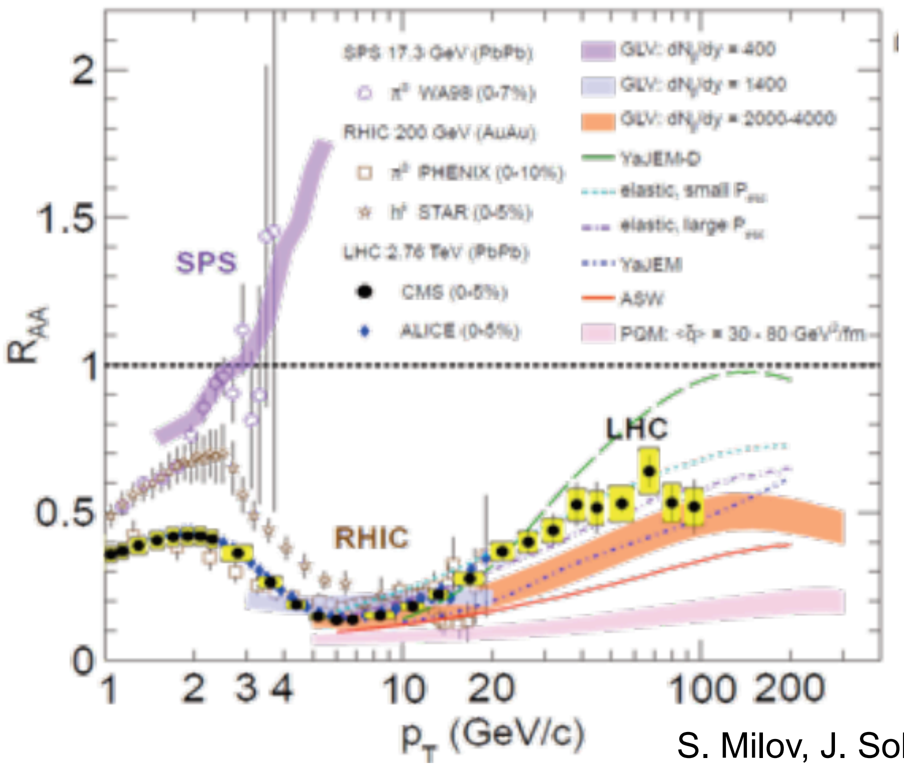
Is beauty less suppressed than charm ?

Yifei Zhang et al (STAR) SQM2013



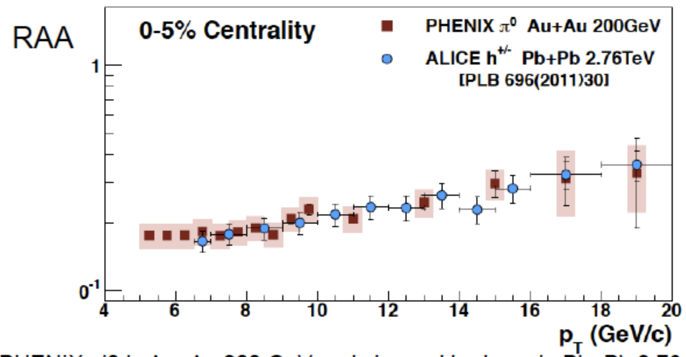
No suppression in peripheral Au+Au collisions
No obviously larger suppression of B compared to D0 in 0-80% and 0-10% Au+Au collisions
(Hint of possible less suppression of B as compared to D in some cases for 0-10%)
New STAR Heavy Flavor Tracker needed

Jet quenching hadrons



S. Milov, J. Solana, QM2012

Sakaguchi, PHENIX, QM2012



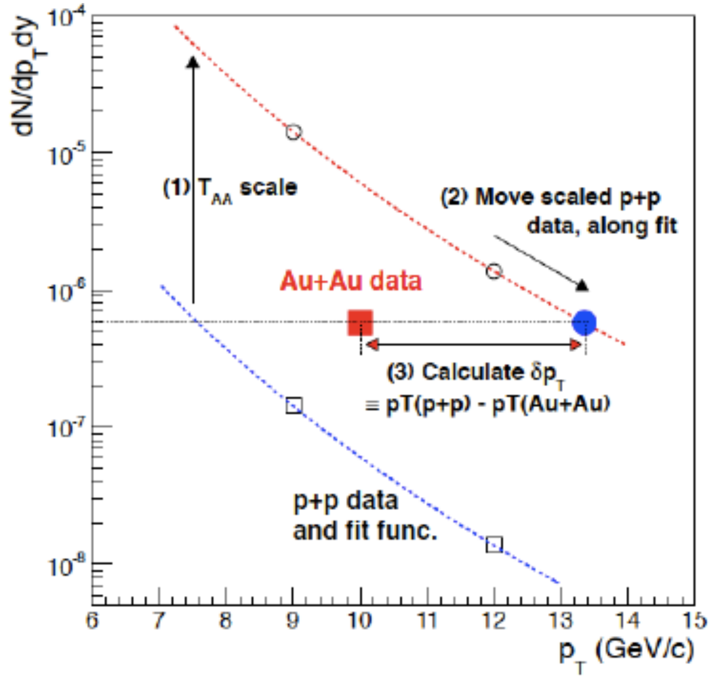
PHENIX pi0 in Au+Au 200 GeV and charged hadrons in Pb+Pb 2.76 TeV 0-5% look very similar

RAA compared to models for energy loss allows for an estimate of gluon density dN/dy(gluon)
Here as an example we get (GLV model):

- **dN/dy(g)=400 for SPS**
- **dN/dy(g)=1400 for RHIC**
- **dN/dy(g)=2000-4000 for LHC**

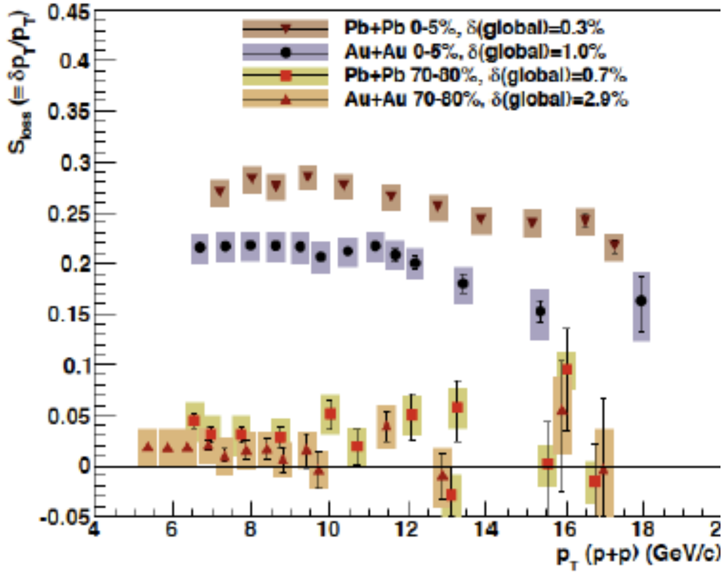
To estimate with confidence dN/dy(g), we should understand the mechanism of jet quenching via studies of its dependence from pT, energy, event plane, path length, centrality, quark mass etc

Fractional momentum loss from PHENIX



Measure fractional momentum loss instead of RAA

arXiv 1208.2254



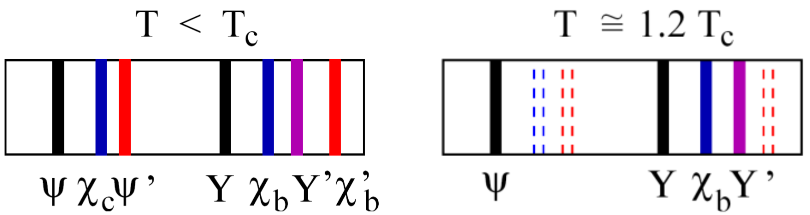
- Different dpT/pt for RHIC and LHC, for same RAA
- dpt/pt is 25% higher for ALICE
- dpt/pt decreases slightly with increasing pt (where rise of RAA occurs)

Fract. momentum loss : dpt(LHC) ~ 1.25 dpt(RHIC)
Charged multiplicity: dN/dy(LHC) ~ 2.2 dN/dy(RHIC)

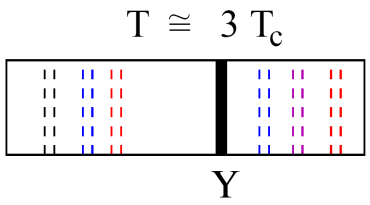
-> Interaction region at LHC less opaque to hard partons than RHIC ?

III.2 Quarkonia

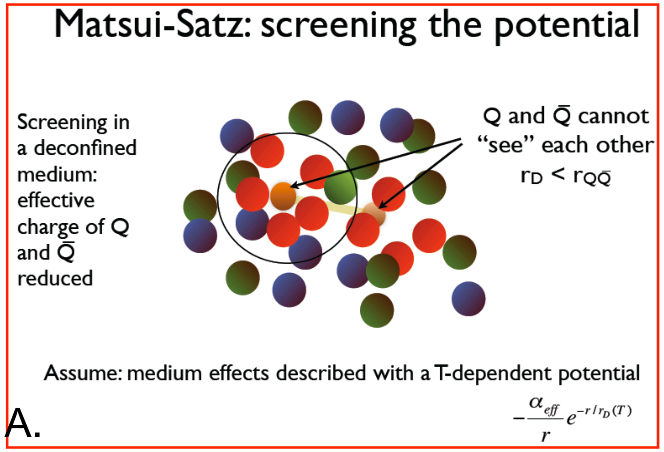
Quarkonia



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

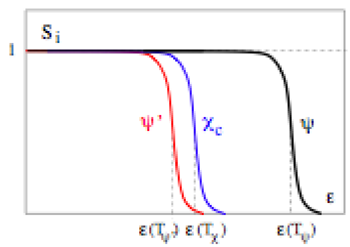


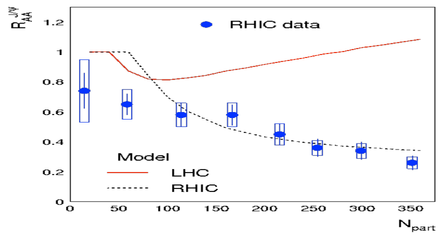
state	$J/\psi(1S)$	$\chi_c(1P)$	$\psi'(2S)$	$\Upsilon(1S)$	$\chi_b(1P)$	$\Upsilon(2S)$	$\chi_b(2P)$	$\Upsilon(3S)$
T_d/T_c	2.10	1.16	1.12	> 4.0	1.76	1.60	1.19	1.17

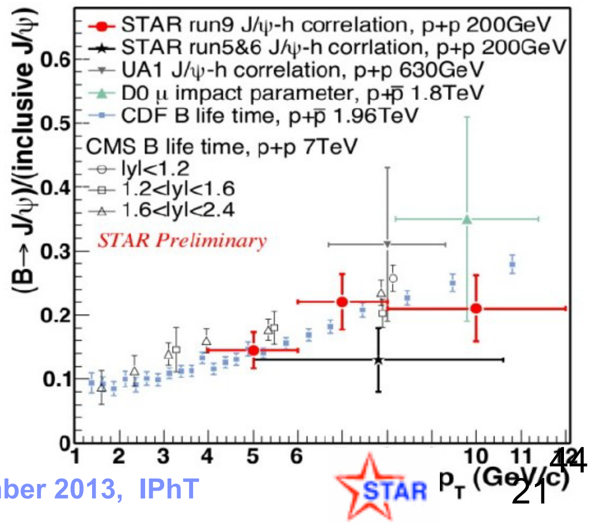


Quarkonia: Thermometer of QGP via their suppression pattern

Many effects play a role like dissociation in QGP, cold matter absorption, recombination/coalescence from c, cbar, feeding, eg B mesons carry 10-25% of charmonia yields (B->J/Psi from J/Psi-h correlation STAR measurement)



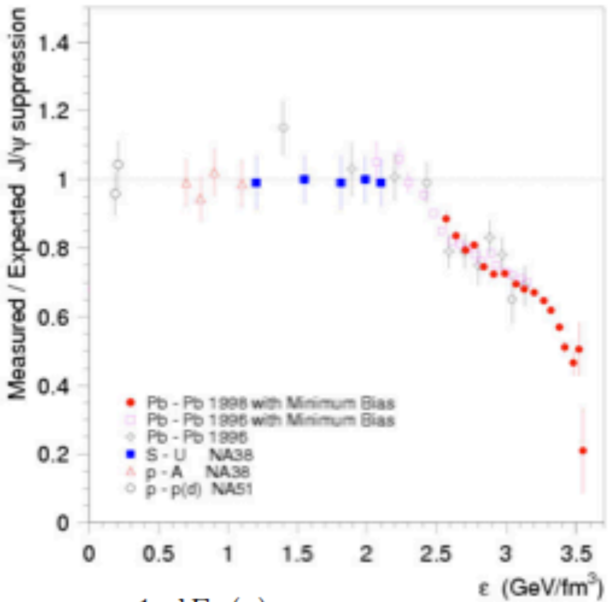




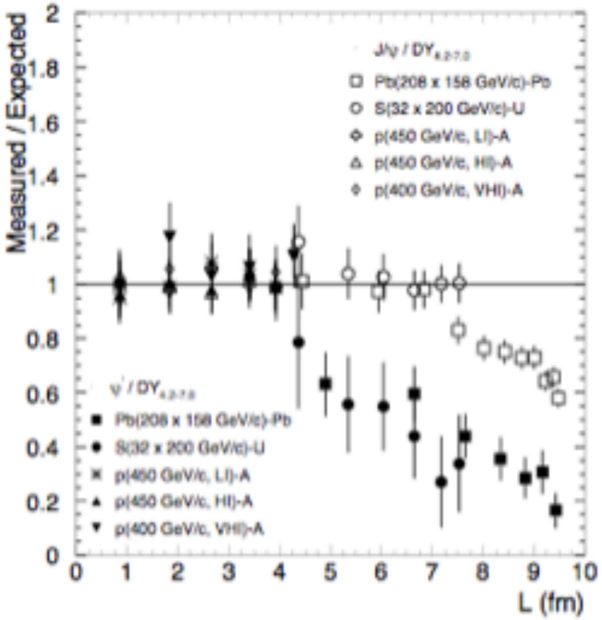
CERN press release 2000

Sequential Psi prime and J/Psi suppression has been observed at CERN SPS Pb+Pb 158 A GeV

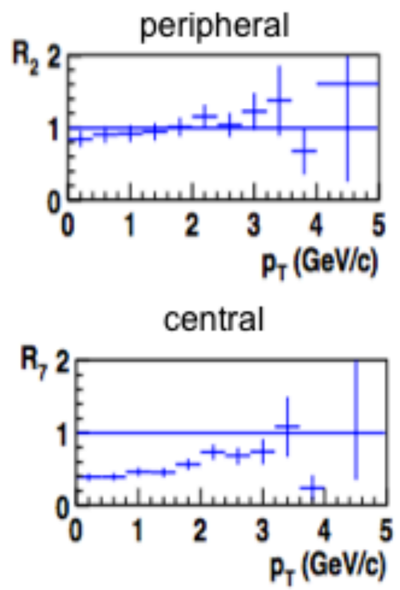
NA50, Phys Lett B 477 (2000) 28



Eur Phys J C 49 (2007) 559



J/Psi/DY n-bin/1st bin



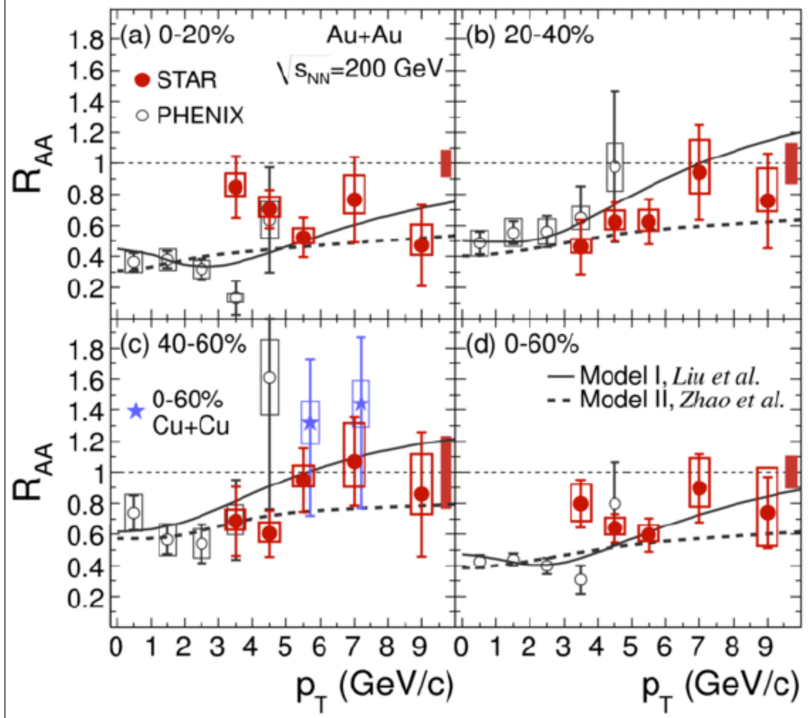
A Kurepin, 18th Nucl Phys Div Conf of EPS, Aug 23-29, 2004

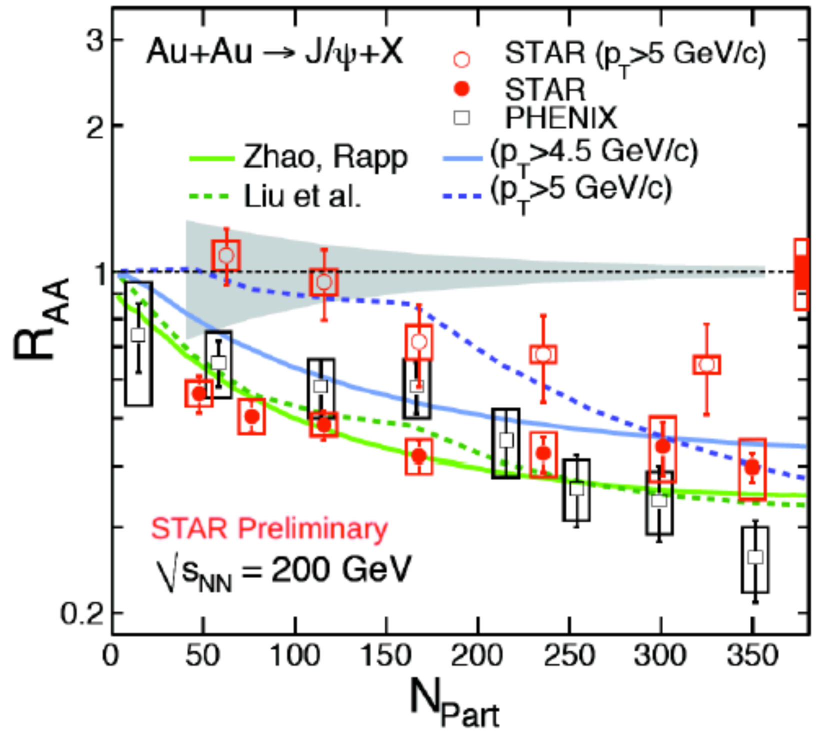
$$\varepsilon_{Bj}(\tau) = \frac{1}{A\tau}\frac{dE_T(\tau)}{dy},$$

- **Psi prime is suppressed from 1.23 GeV/fm^3 on**
- **J/Psi is suppressed from ~2.4 GeV/fm^3 on**
- **J/Psi supression occurs mainly at low pT**

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

PLB 722 (2013) 55

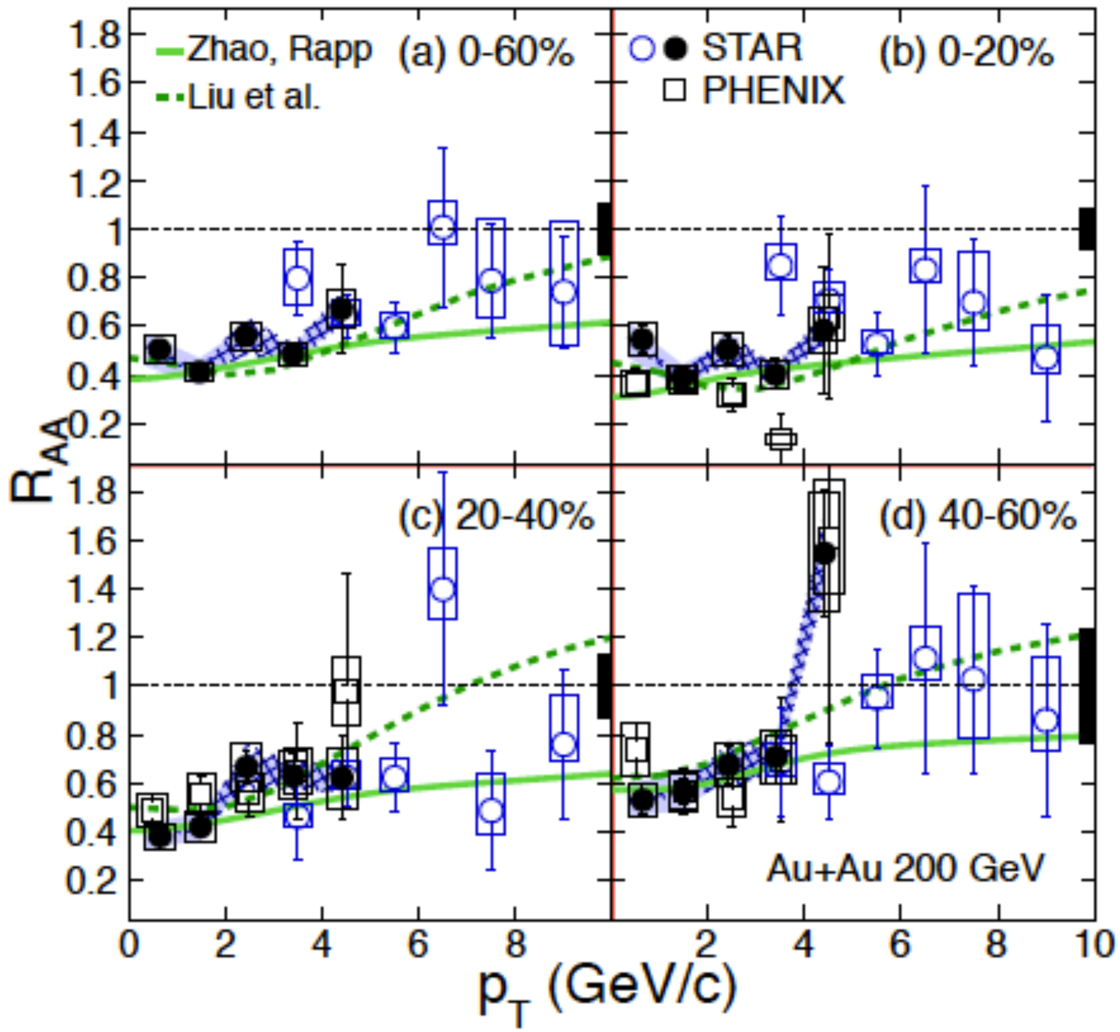




Liu et al, PLB 678 (2009) 72
Zhao et al, PRC 82 (2010) 064905

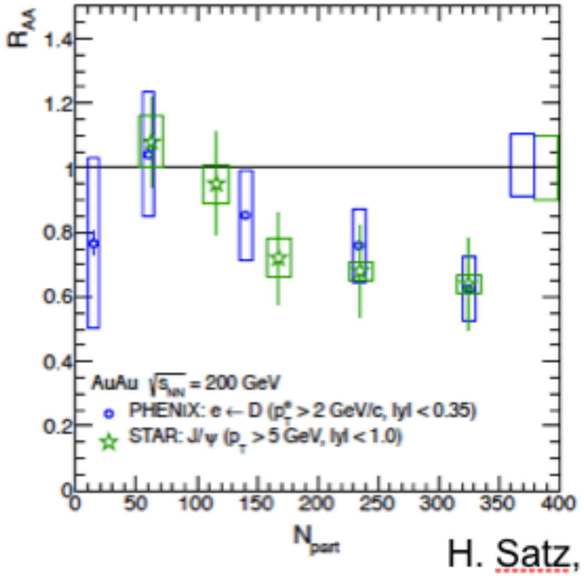
- J/Psi not suppressed at high p_T's in non-central collisions
- J/Psi suppressed at all p_T's for most central events
- R_{AA} of J/Psi is systematically larger for higher p_T

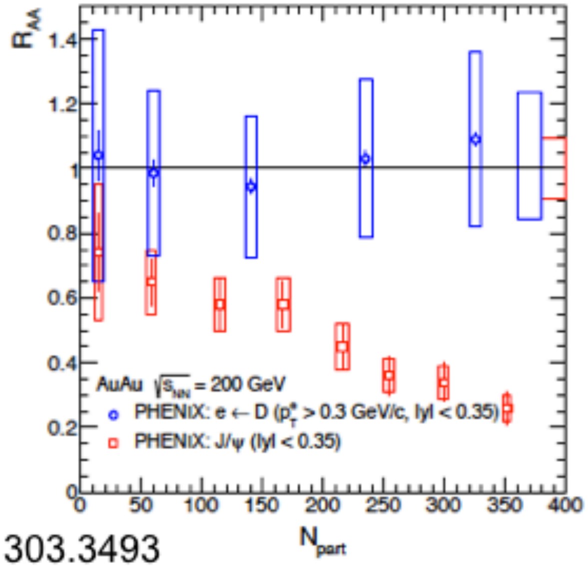
J/Psi at low pT STAR



STAR, arXiv 1310.3563

J/Psi compared to open charm - RHIC



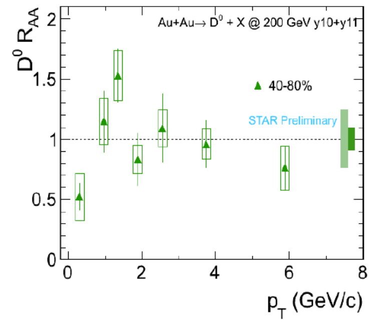


H. Satz, arXiv 1303.3493

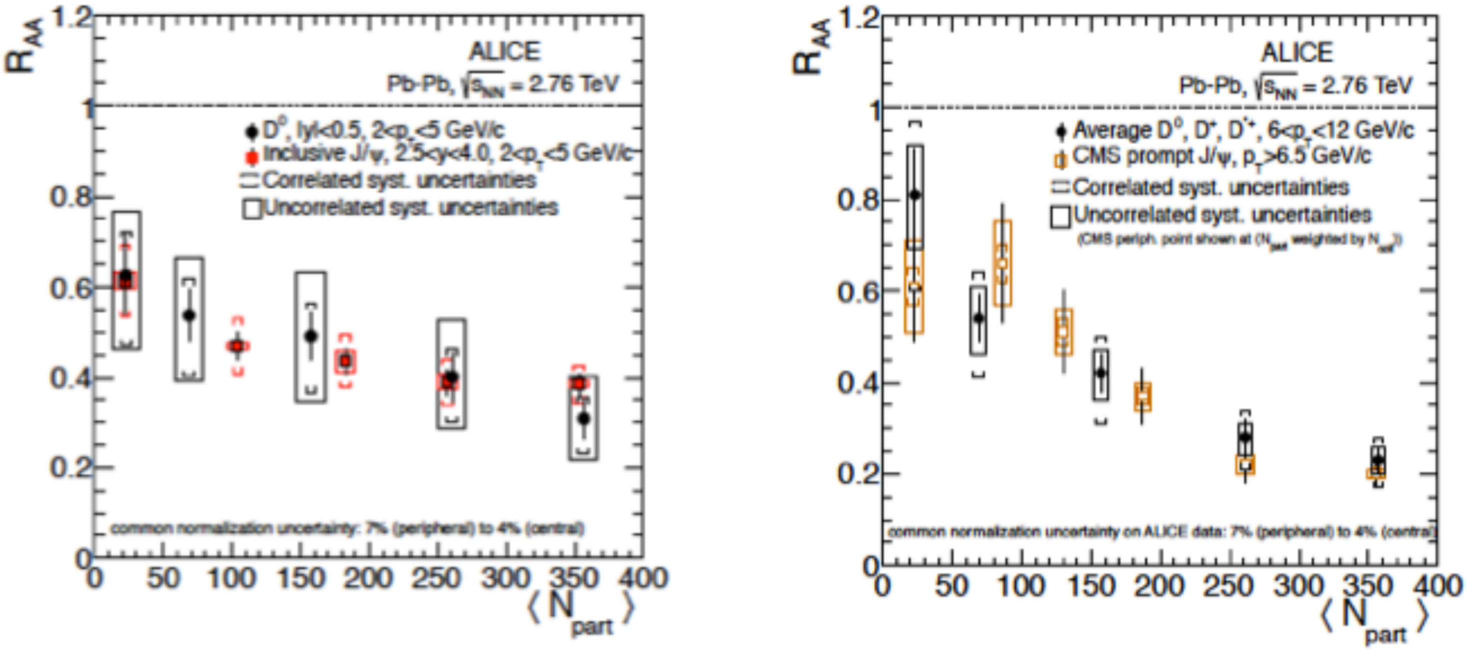
*** J/Psi seems to be neither suppressed nor enhanced with respect to open charm at all centralities at high pT (However pT range is not exactly the same)**

*** J/Psi seems to be significantly suppressed with respect to open charm at low pT in central Au+Au events (same acceptance here)**

STAR: RAA(D0) shows no suppression for peripheral collisions



J/Psi compared to open charm - LHC

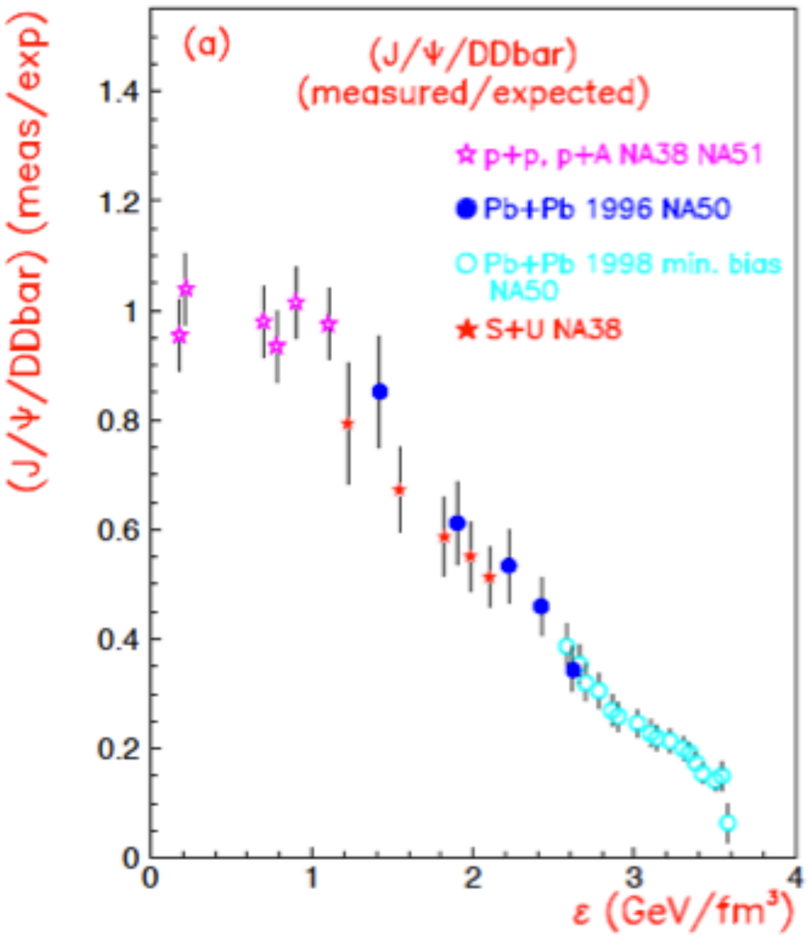


H. Satz, arXiv 1303.3493

J/Psi seems to be neither suppressed nor enhanced with respect to open charm at all centralities, at intermediate (pT=2-5 GeV) and high pT>6.5 GeV

However experiments should compare more precisely within exactly same acceptance (here different y) and at low pT too

J/Psi compared to “open charm” - SPS



S.K., New J. of Physics, Vol. 3, (2001), 16, arXiv 0004138

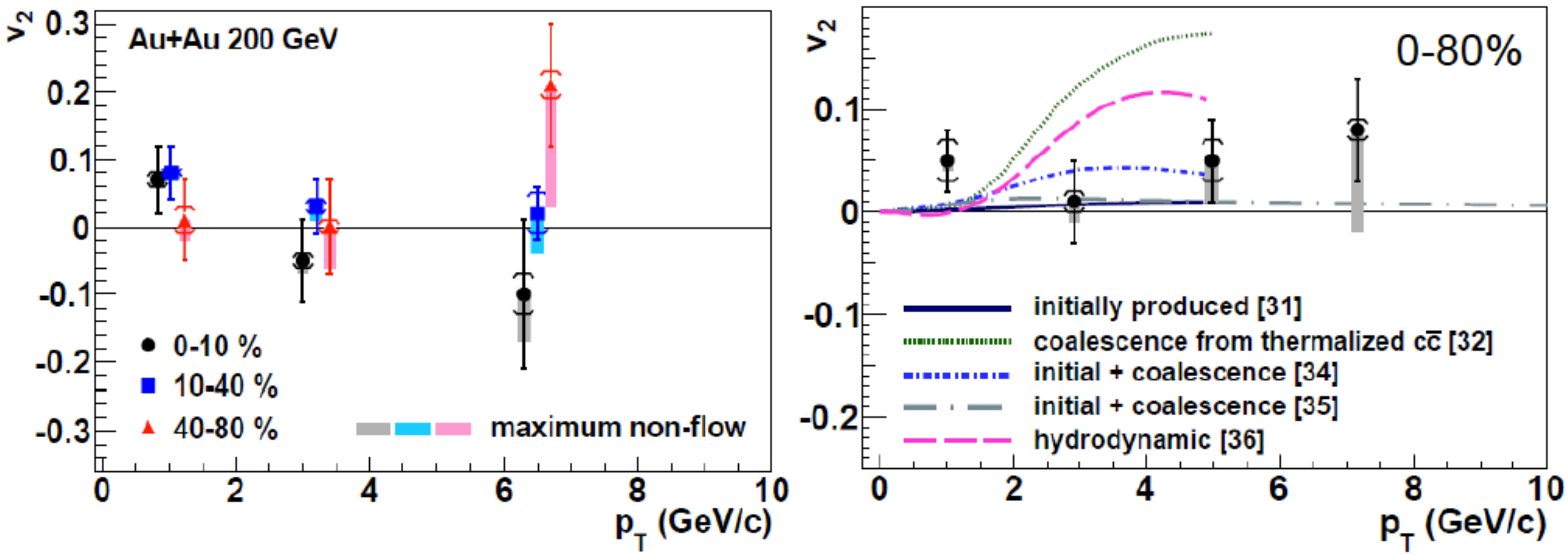
Here the enhancement of dimuons in the intermediate mass(mu+ mu-) region (1.6 -2.5 GeV) is assumed to be due to open charm

Consequences: The J/Psi over the DDbar estimate is suppressed already at 1 GeV/fm^3, namely near the critical energy density for the QGP phase transition

-> open charm and chi_c measurement at SPS energy needed to interpret the SPS data

-> AFTER/CHIC

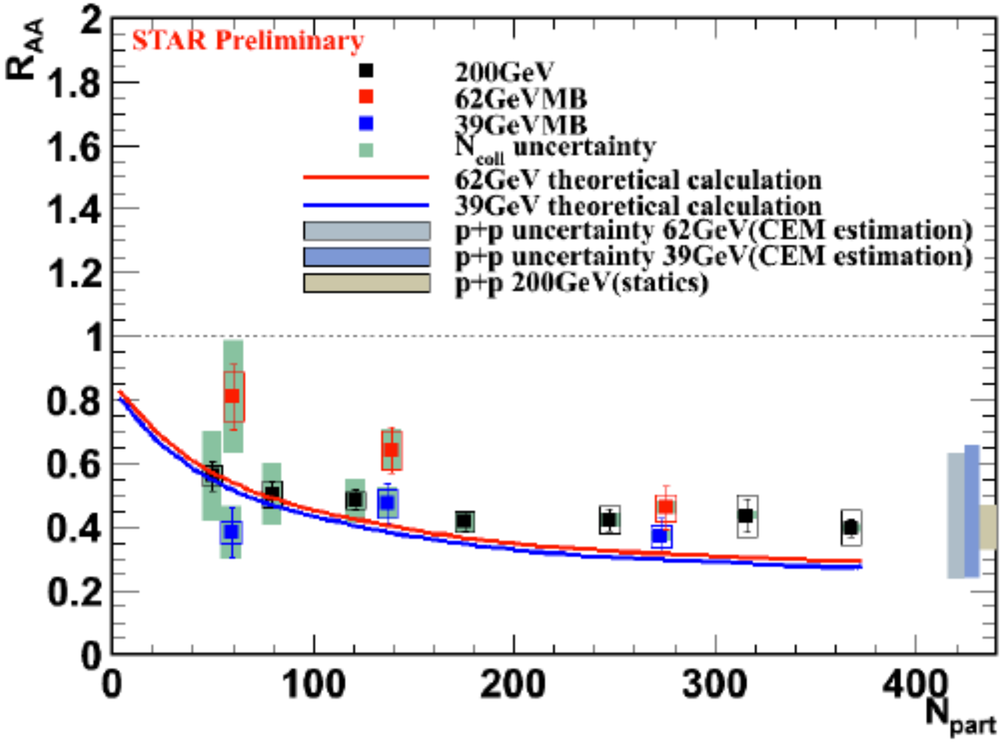
Elliptic flow of J/Psi



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?



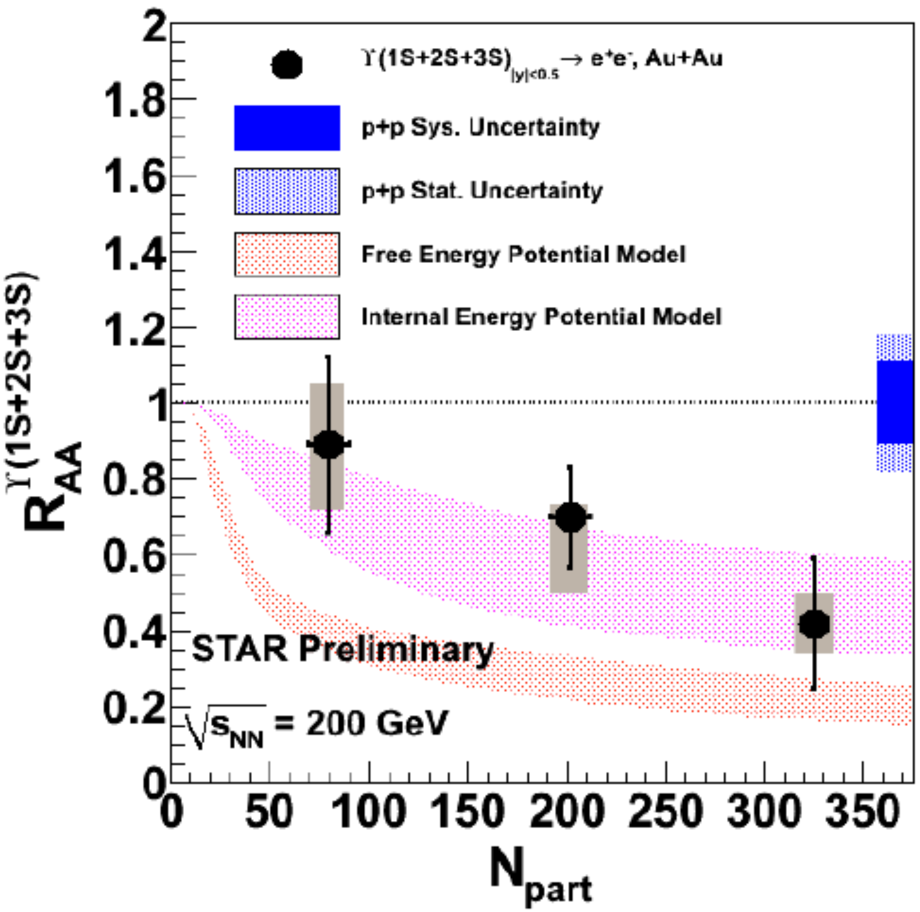
Color Evaporation Model (CEM) estimate for p+p reference used for 39, 62 GeV

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

(SPS J/Psi suppression was at sqrt(s)=17-19 GeV)

Upsilon in Au+Au 200 GeV

Υ suppression was discovered at RHIC (STAR) and LHC (CMS) in 2011



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

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

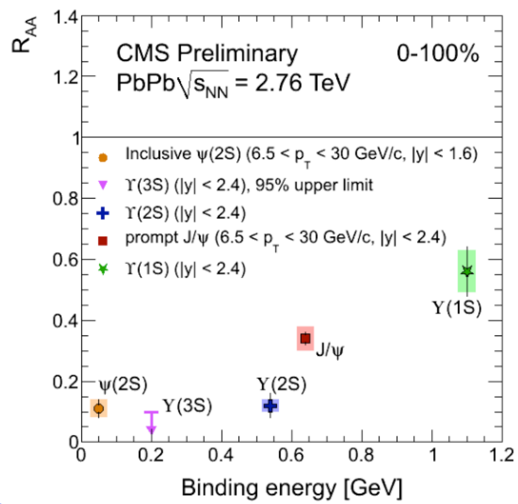
* No suppression in most peripheral collisions

* Exhibits suppression in more central collisions increasing with centrality

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

Model by Strickland et al (PRL 107, 132301, 2011, Nucl. Phys. A879 (2012) 25, arXiv:1112.2761) :

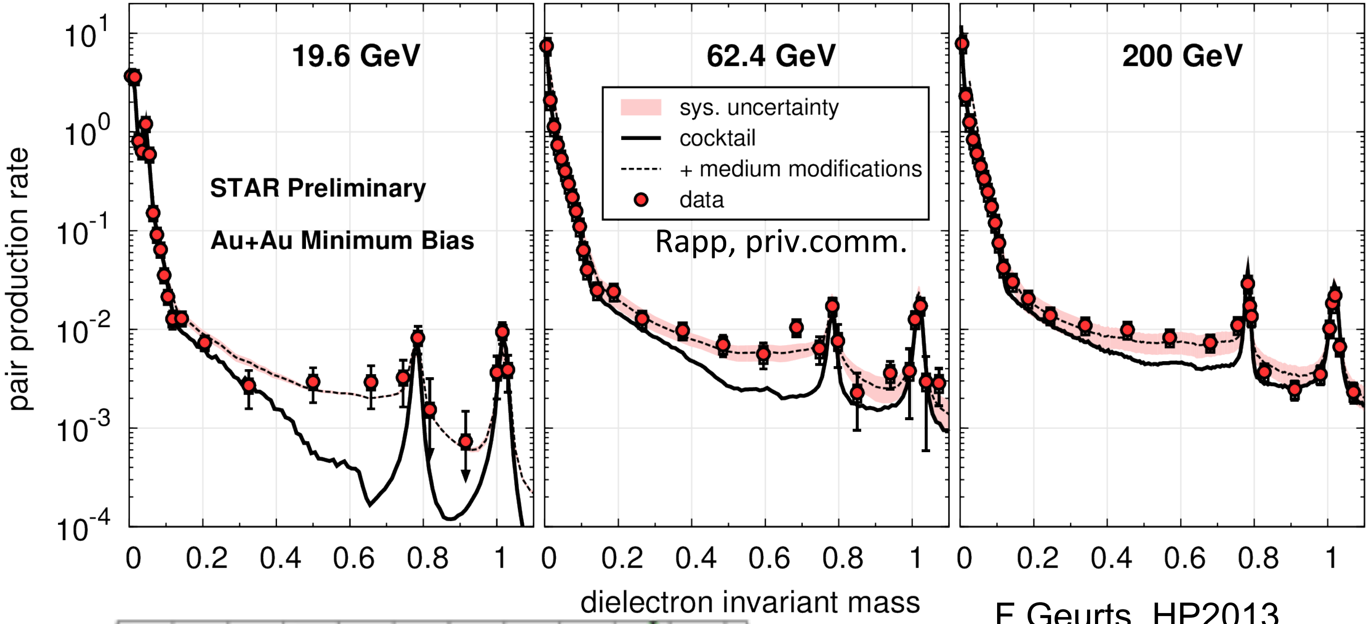
Assumes T_0= 428-442 MeV and $1/4\pi < \eta/S < 3/4\pi$



PRL 109, 222301 (2012)

III.3 Beam Energy Scan

Dielectrons in Beam Energy Scan

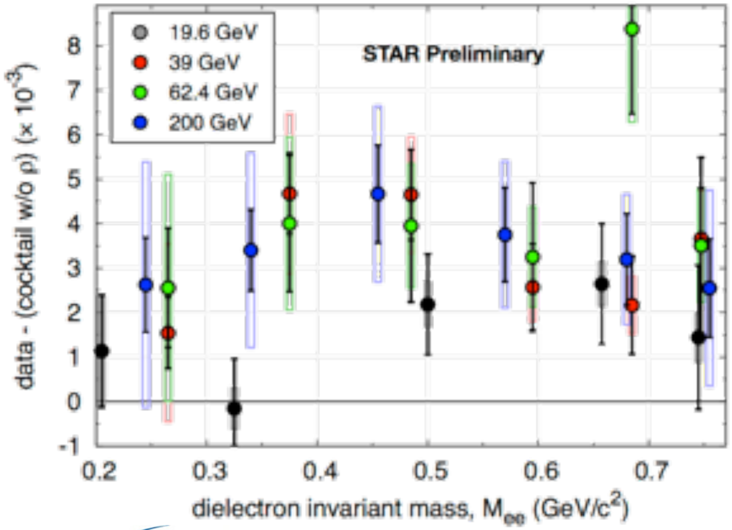


F Geurts, HP2013

Dielectrons < 1 GeV:

* medium modification of vector mesons

* possible link to chiral symmetry restoration

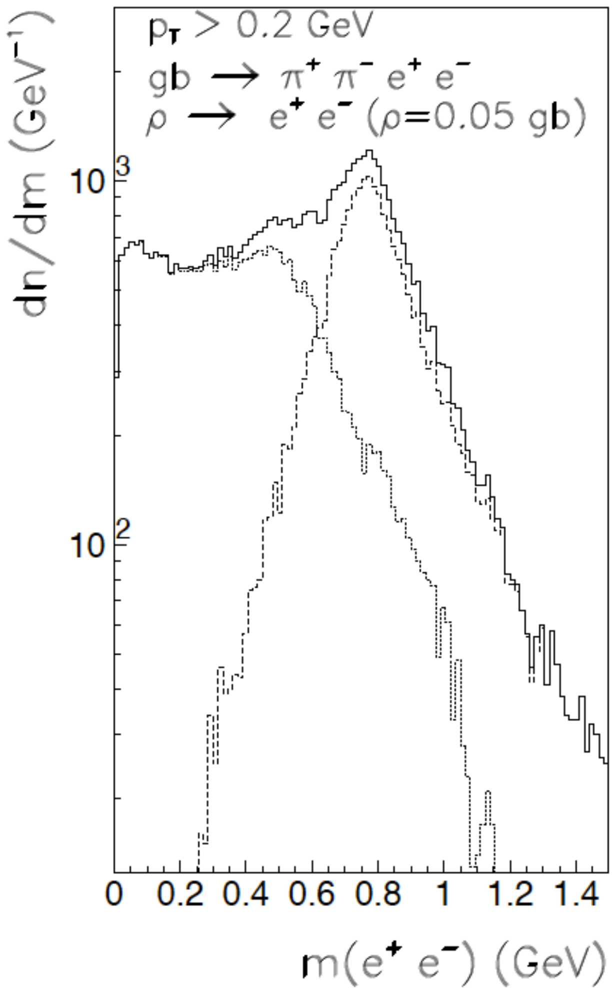


* Low Mass Range (< 1 GeV) excess observed for all energies
* Measurements consistent with models including in-medium ρ broadening

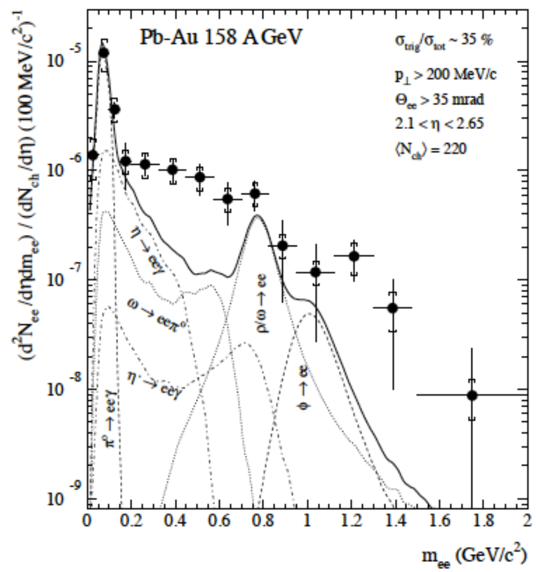
  Model calculations appear to provide robust description from RHIC down to SPS energies

Dielectron modification and glueball enhancement

S.K., P. Minkowski, Phys. Lett. B 472 (2000) 155



NA45, Phys. Lett. B422 (1998) 405

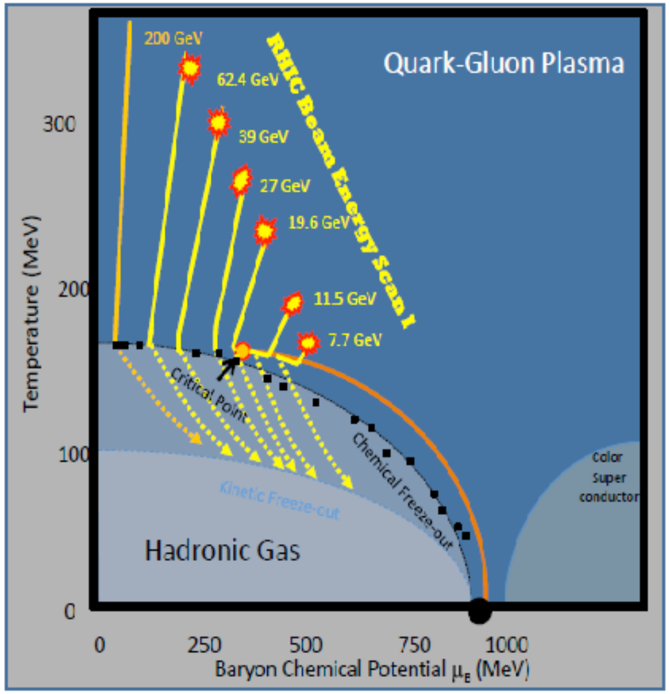


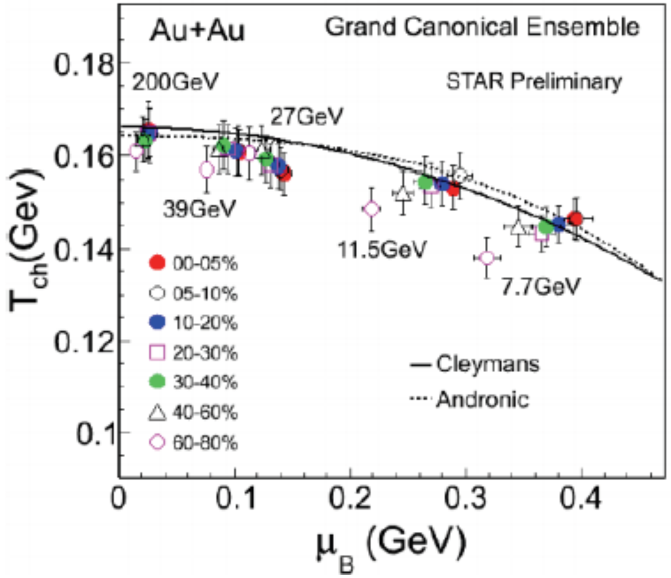
* An enhanced assumed glueball 0++ production in QGP via e.g. gb(0++) -> e+e-pi+pi- causes a modification of dielectrons in the Low Mass Range

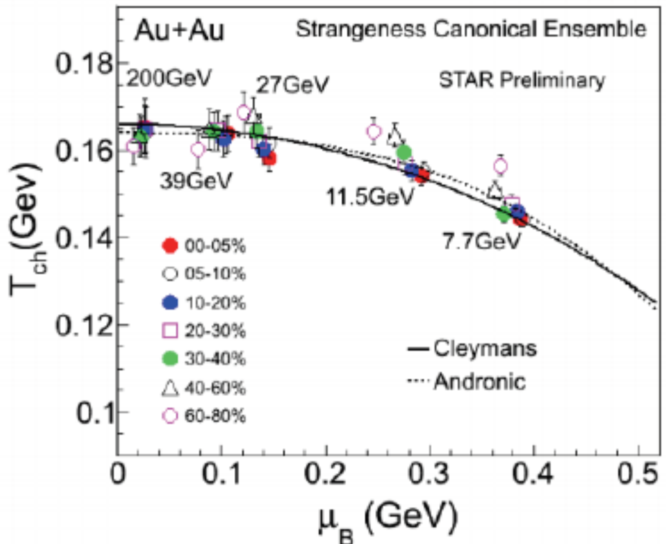
* Glueball enhancement as QGP signature

* STAR future glueball search planned

Chemical freeze out temperature vs baryochemical potential





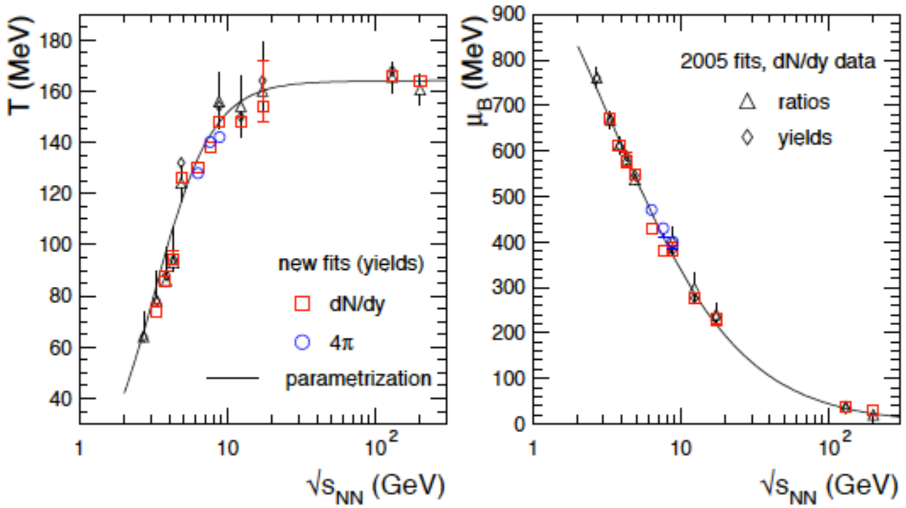


Model used for particle ratio fits: THERMUS by J Cleymans et al

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

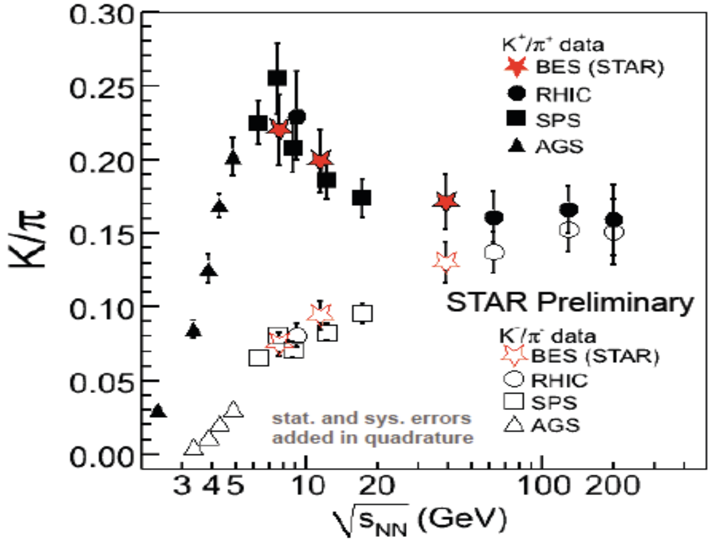
What can we learn from thermal model fits?

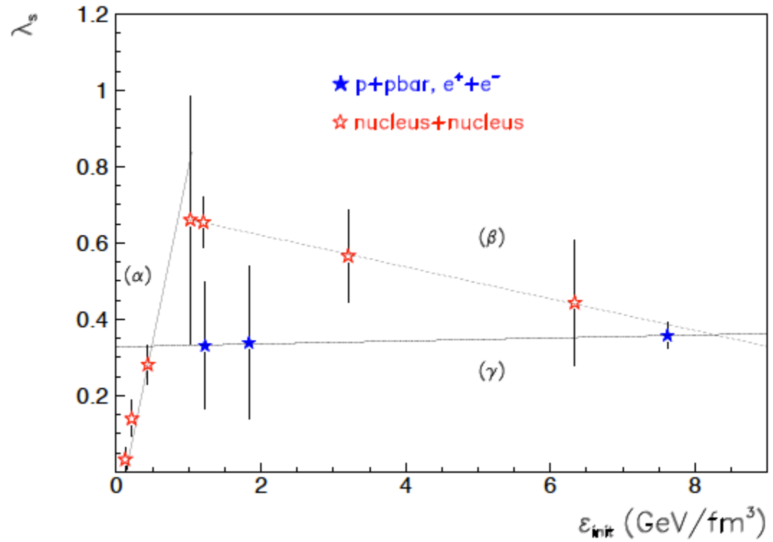
A Andronic et al, arXiv 0911.4806



Chemical freeze out temperature at high energy is similar to Tcrit

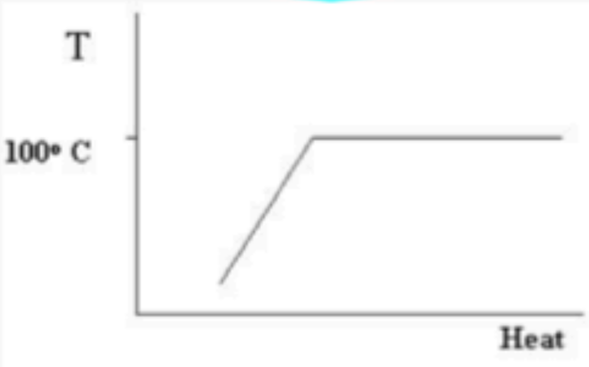
S.K. Eur. Phys.J.C21(2001) 545

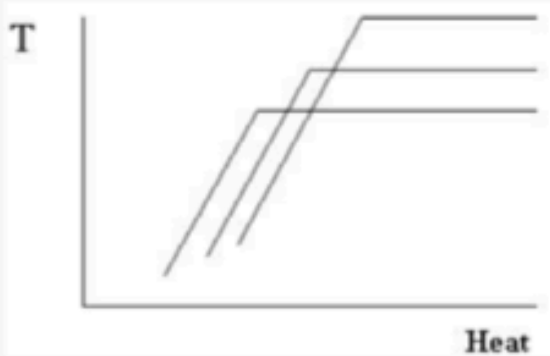




Gedanken experiment to identify the water steam phase transition:

We heat a box with water more and more and measure its temperature T. We can only measure the T of the water (Had. Gas) and not of the steam (QGP). We plot T versus heat. T will rise until we heat enough to reach T=100° C. From then on, it will remain the same, namely T_{lim} ~< 100° C. Each time steam is present, we have to wait until it is again water, to measure its T. (E.g. R.Hagedorn (1965), H. Stocker et al (1981) etc.)





Now we repeat the experiment adding each time salt to the water. The T versus heat curve will not be as before, and we can not find the T_{lim}= 100° C.

S. Kabana, J. Phys. G27 (2001) 497

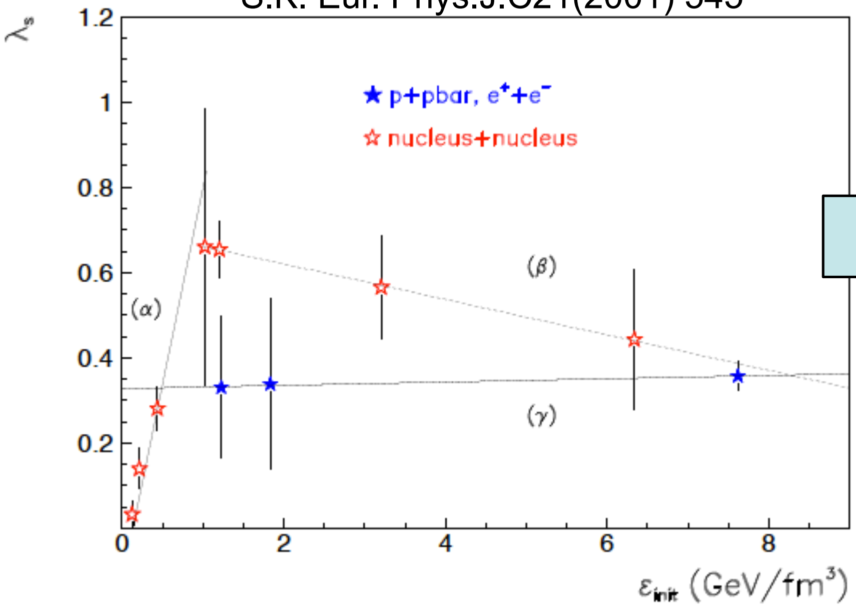
S.K., P. Minkowski, New J Phys 3 (2001) 4

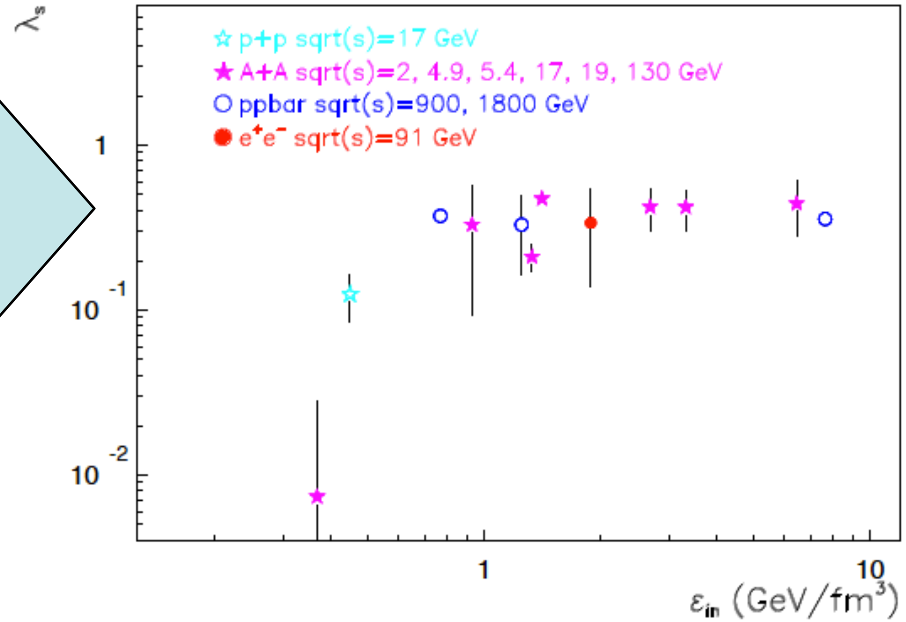
The baryochemical potential is like salt for hadronic systems.

Therefore, in order to measure a unique curve of T at freeze-out as a function of ε(init) in hadronic particle systems, one has to use the same conditions, with the same μB, the simplest one beeing μB=0.

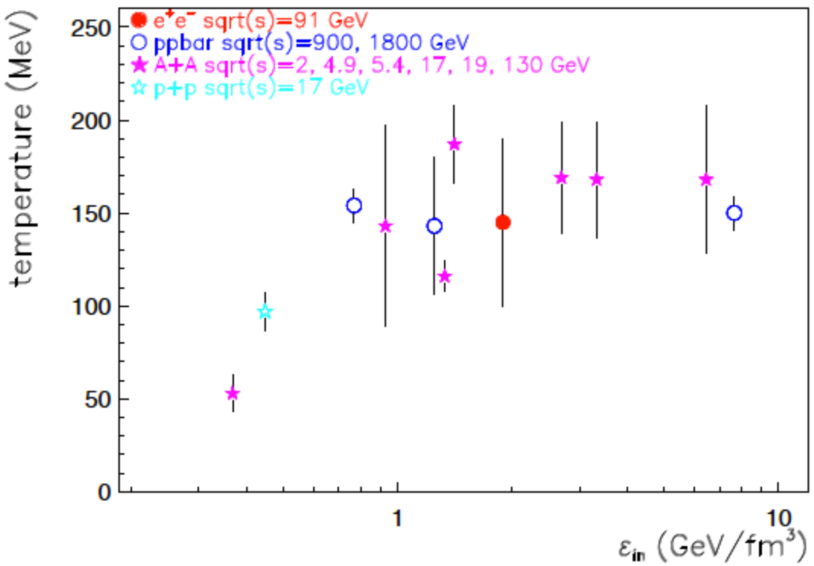
Universality of strangeness enhancement at μ_B =0

S.K. Eur. Phys.J.C21(2001) 545





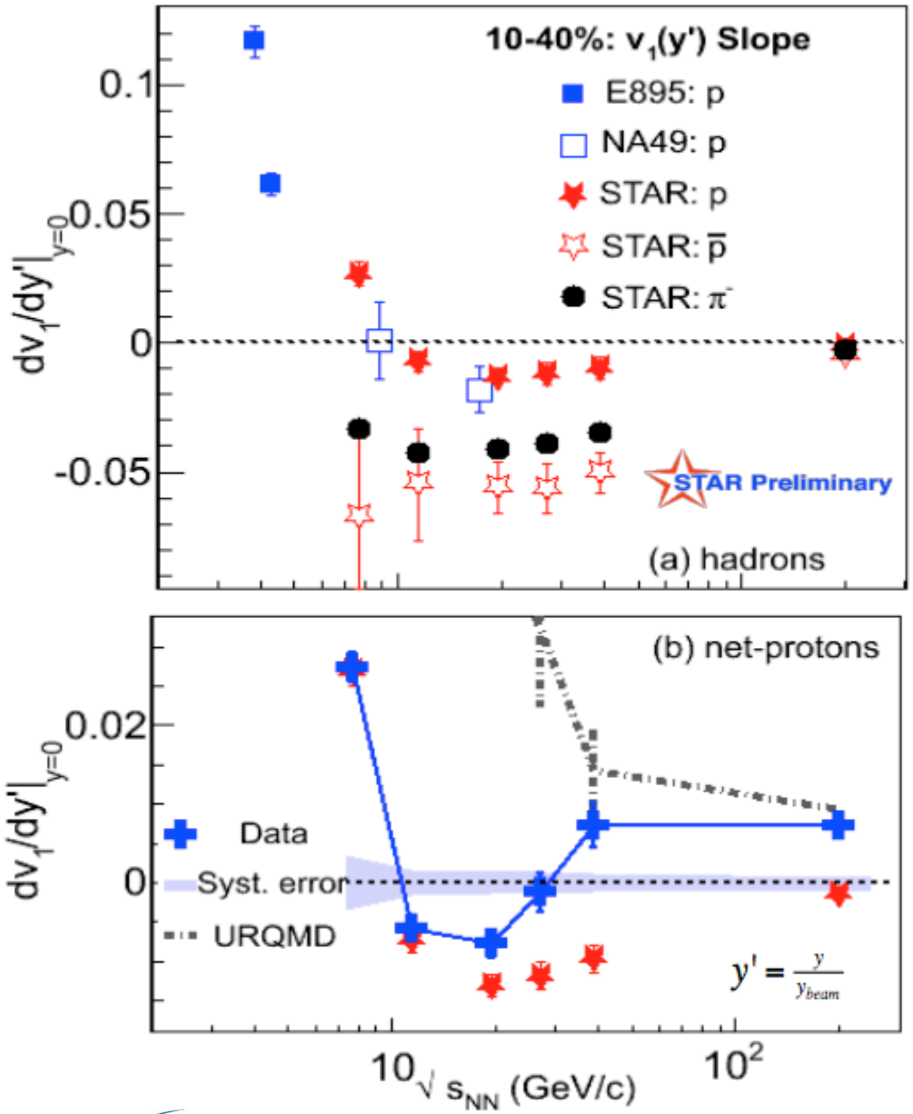
S.K., P. Minkowski, New J. Phys 3 (2001) 4



At zero baryochemical potential λ_s follows the temperature

Onset of temperature saturation near
ϵ(init, Bjorken)~1 GeV/fm^3
-> onset is near sqrt(s)(NN) ~ 8-10 GeV

Directed flow of protons



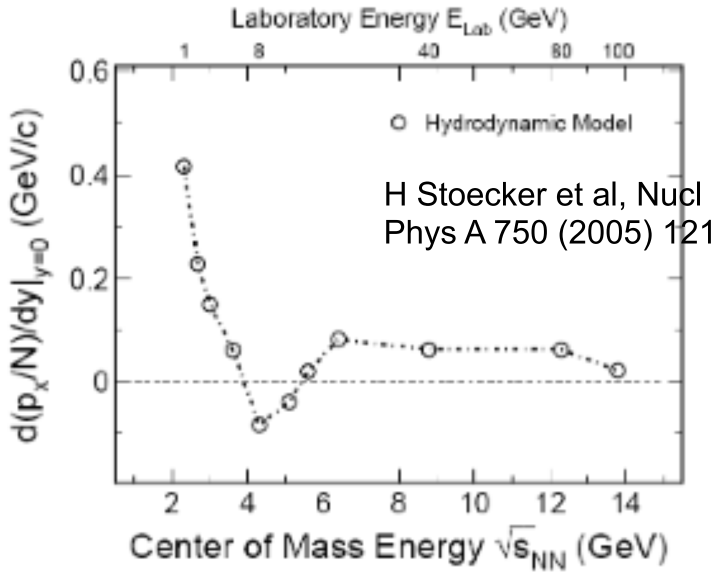
* Directed flow slope is sensitive to a 1st order transition

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

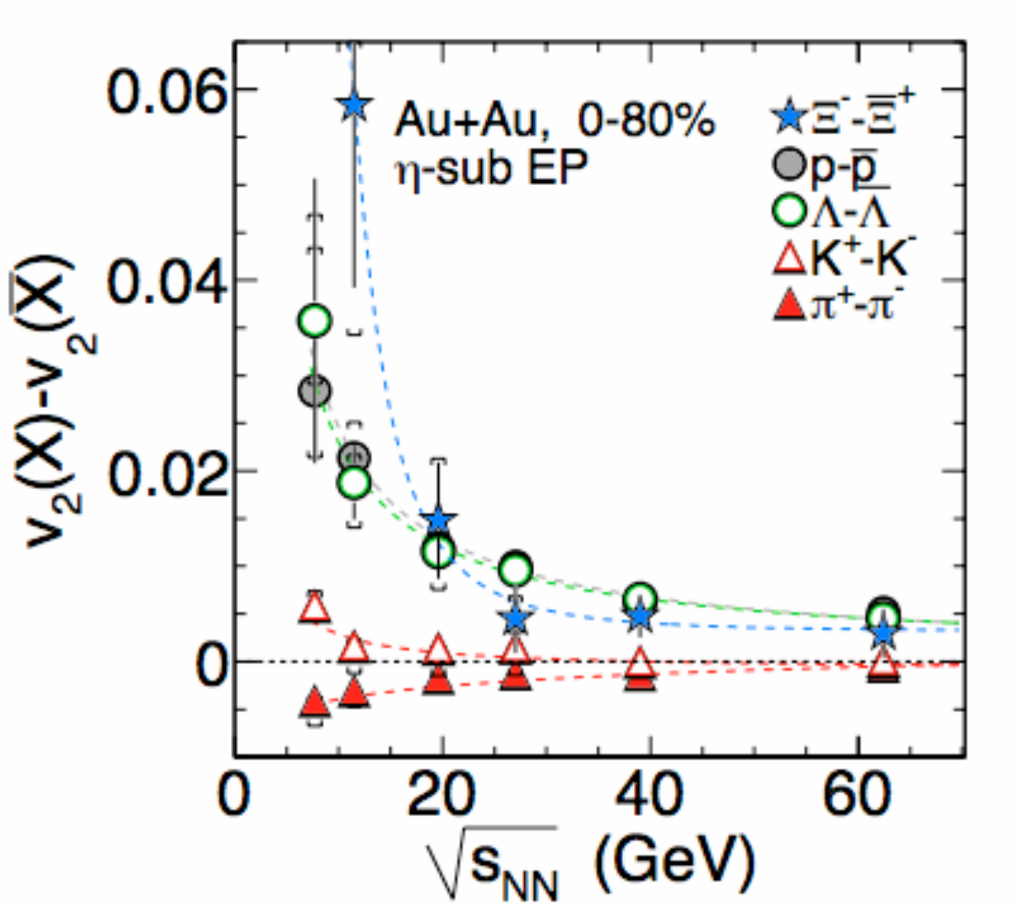
Pions and antiprotons have always negative v1 slopes.

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

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



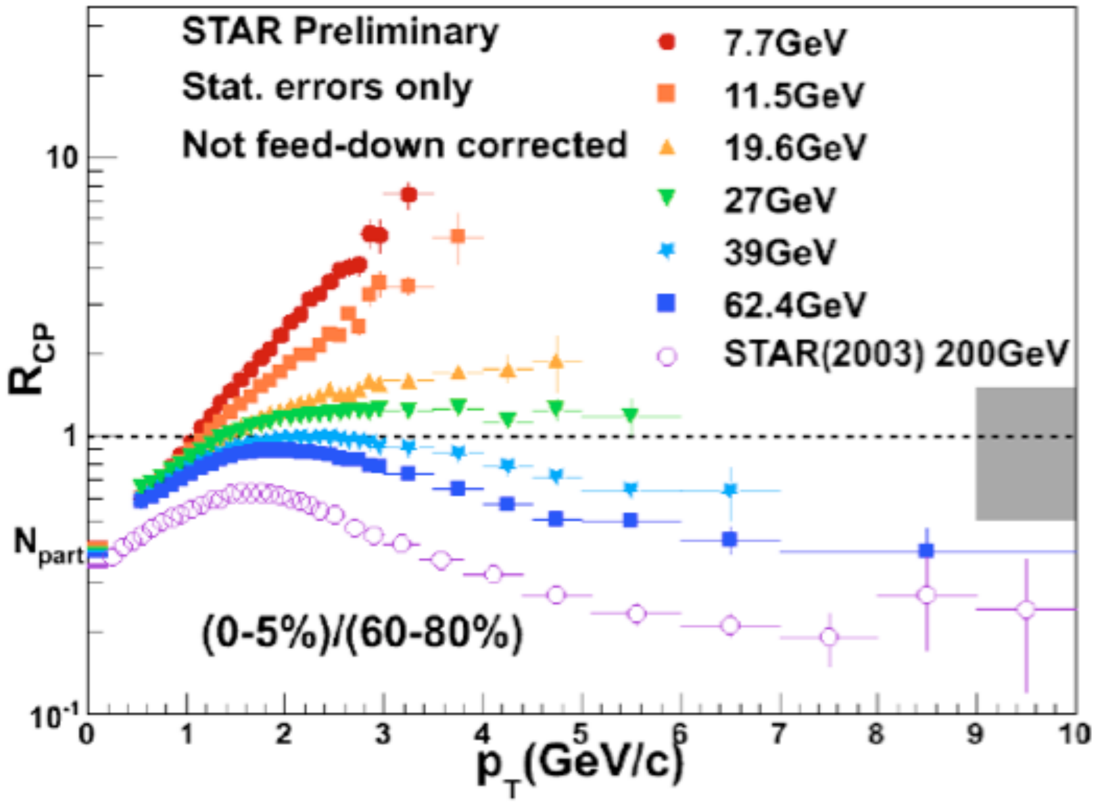
Elliptic flow energy dependence



* 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 at high pT sets in from √s=39 GeV on

IV Conclusions

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

Open Heavy Flavor and jet quenching:
- "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
- fract. pT loss at RHIC < at LHC

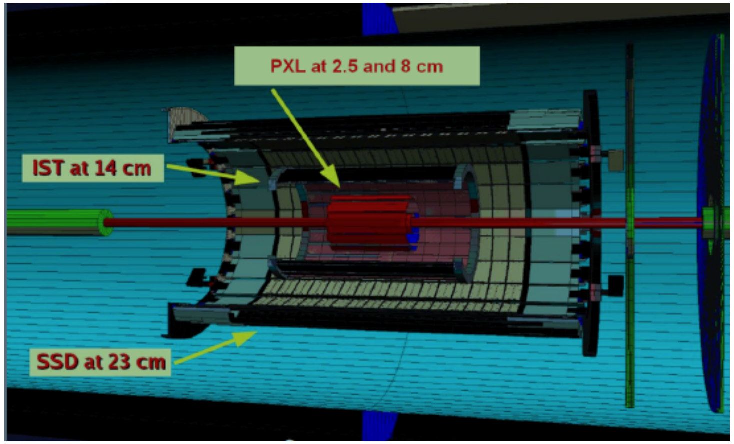
Quarkonia suppression:
- J/Psi suppression and elliptic flow
- Upsilon suppression in central Au+Au collisions 200 GeV, consistent with suppression of Y(2S+3S)

Beam Energy Scan:
- Dissapearance of key QGP signatures at low energies

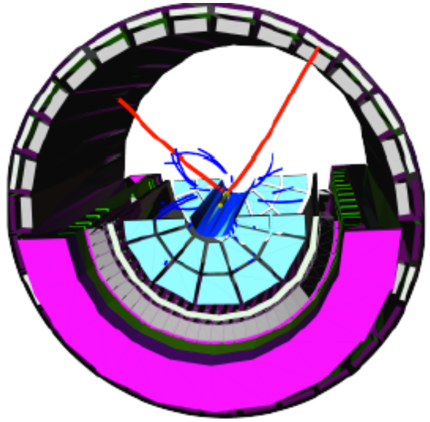
V Outlook

Short term STAR upgrades

Heavy Flavor Tracker

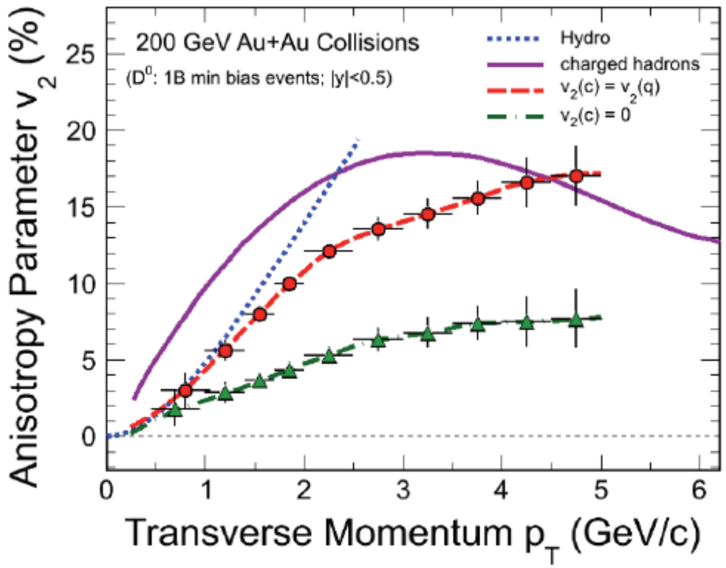


Muon Telescope Detector



Expectations for 2014 run with HFT

J/Psi event in p+p 500 GeV



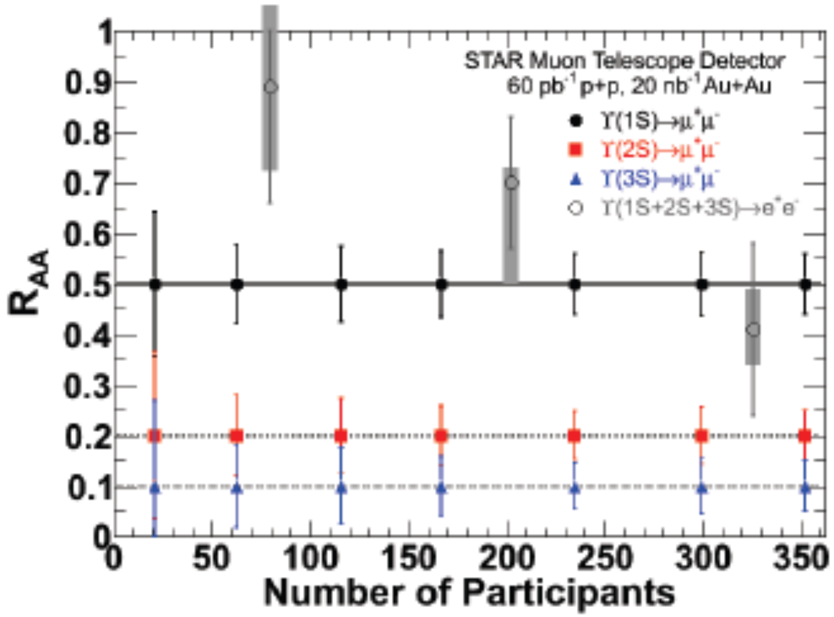
* HFT pixel prototype with 3 sectors took first data in 2013.

* MTD 63% installed and took data in 2013. Long Multi-gap Resistive Plate Chamber (MRPC) technique.

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

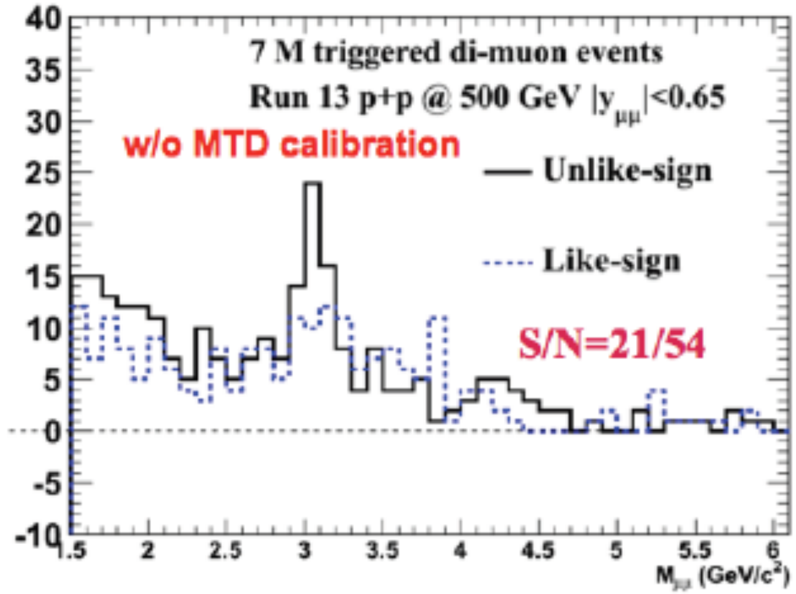
Muon Telescope Detector

Simulation



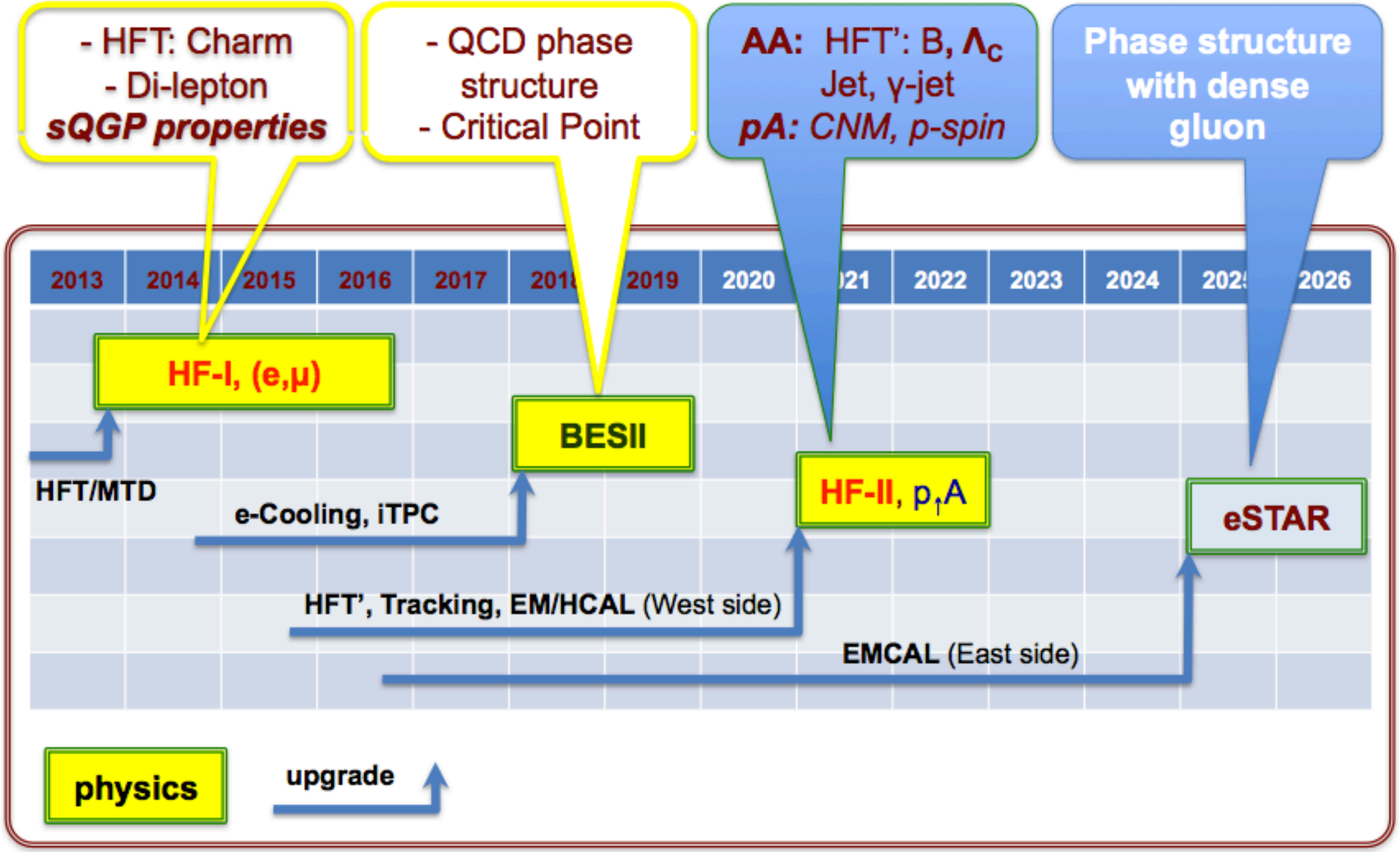
Expected errors of RAA from Muon Telescope Detector (simulation)

STAR data, run 2013
First J/Psi peak with MTD



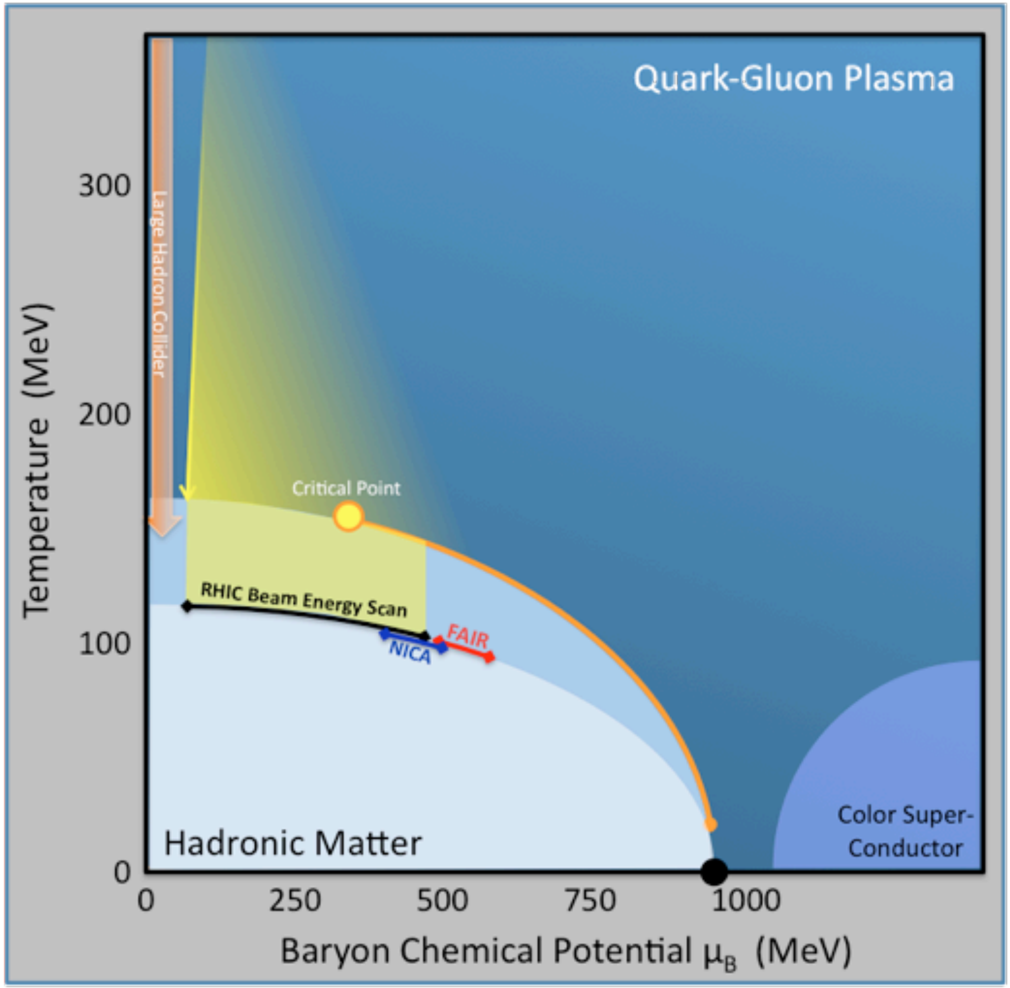
Q. Hao, STAR, SQM2013

STAR upgrade plan



N. Xu, RANP2013

Low energy scans



B Mueller, NSAC 2013

FAIR (online 2019): fixed target mode up to sqrt(s)=4.7 GeV (Later: 2.7-8.3 GeV).
Energy below region of interest ?
Fixed target mode challenging -> because acceptance changes with sqrt(s).
CBM: uniform phase space when measuring excitation functions.

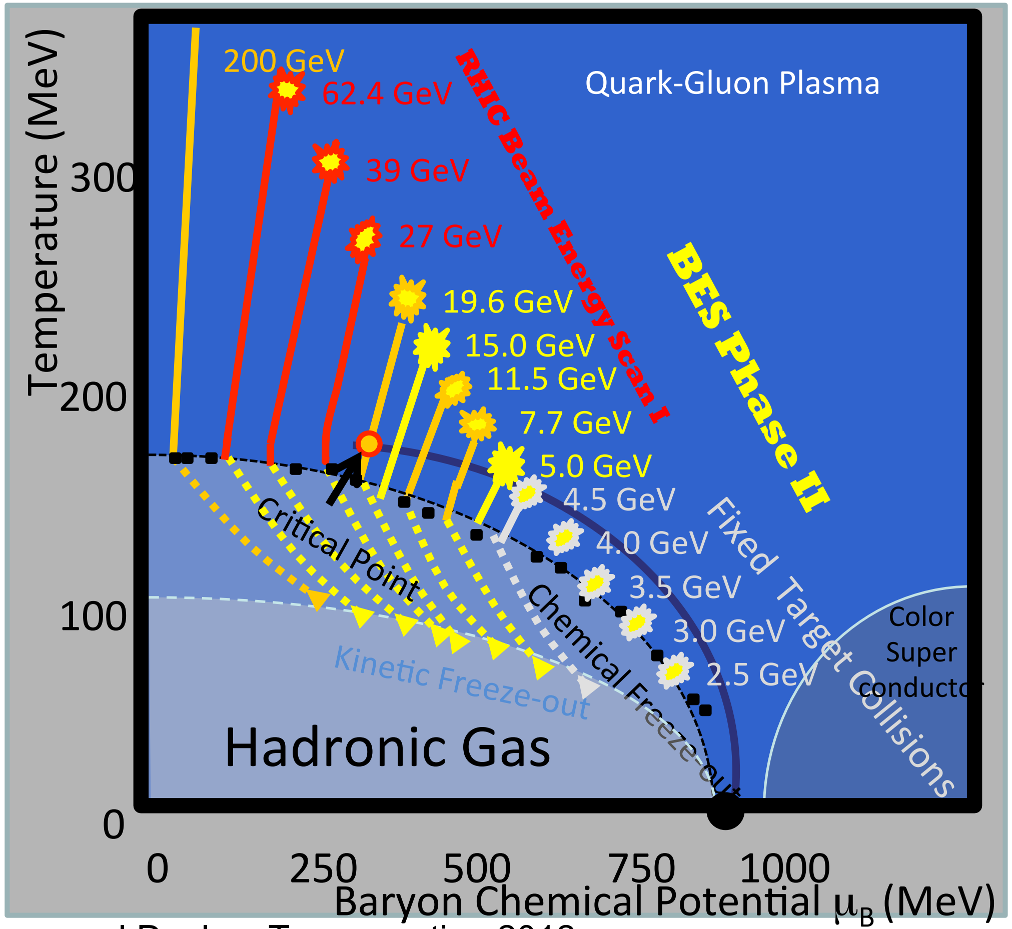
NICA: Au+Au at sqrt(s)(NN)=4-11 GeV in collider mode

RHIC BES: spans largest range of mu_B

CERN SPS: NA61/SHINE sqrt(s)(NN)=6.4-17.4 GeV

New proposal at SPS: CHIC
χ_c suppression and the understanding of charmonia suppression

Phase II of Beam Energy Scan at RHIC (2018-)



J Dunlop, Town meeting 2012

The power of RHIC:

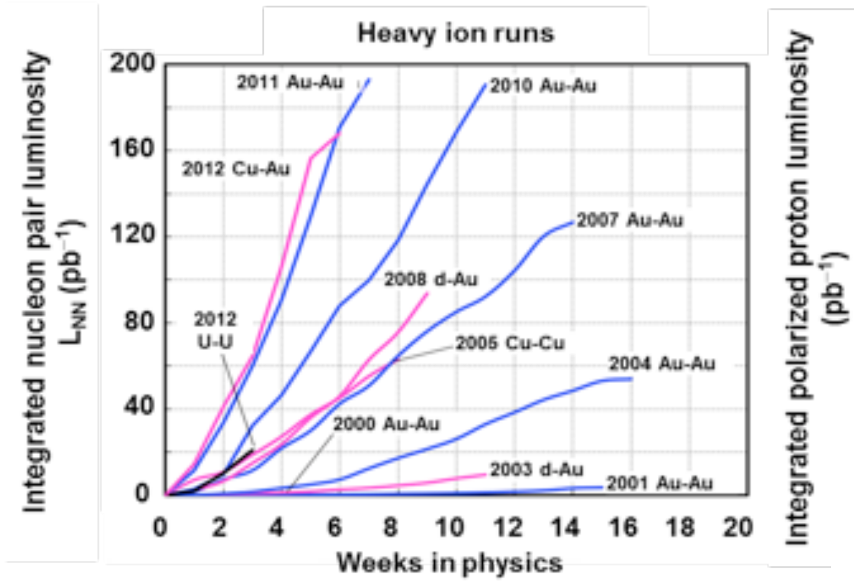
Scan the region below $\sqrt{s}$=20 GeV

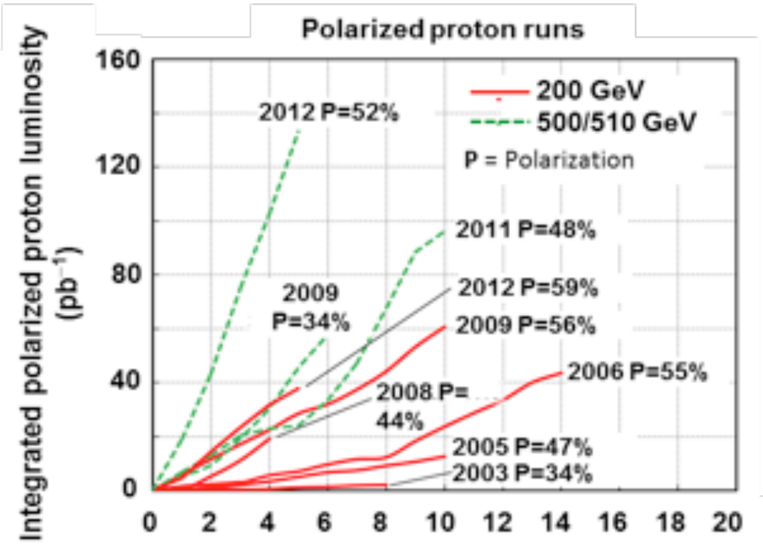
Supplemented by fixed target program in STAR to reach lower $\sqrt{s}$ down to $\sqrt{s}$ ~ 3 GeV

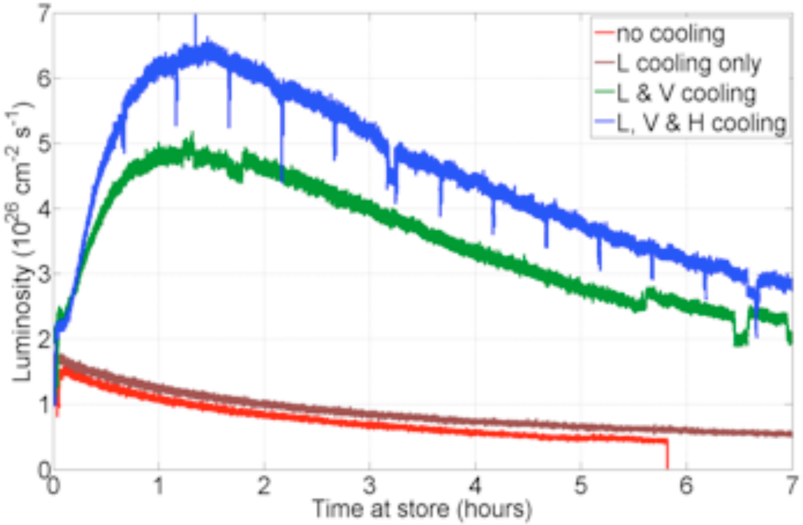
STAR BES II with up to 10 times more luminosity and detector upgrades (+iTPC) will be able to study with precision a large region of the QCD phase diagram

Thank you very much for your attention

RHIC 2010-2013



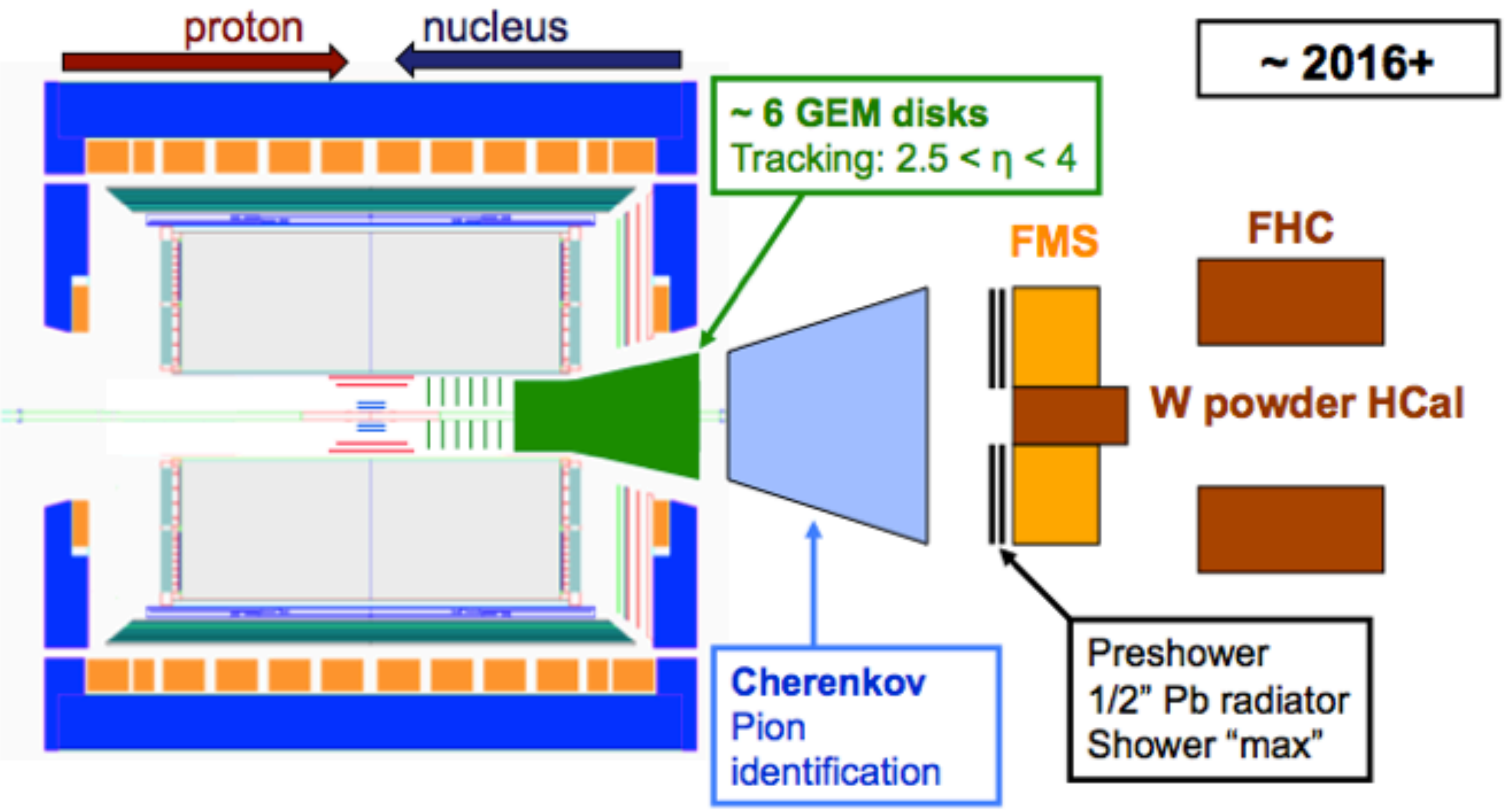




RHIC breakthrough in stochastic cooling: now ~18 times the original design HI luminosity

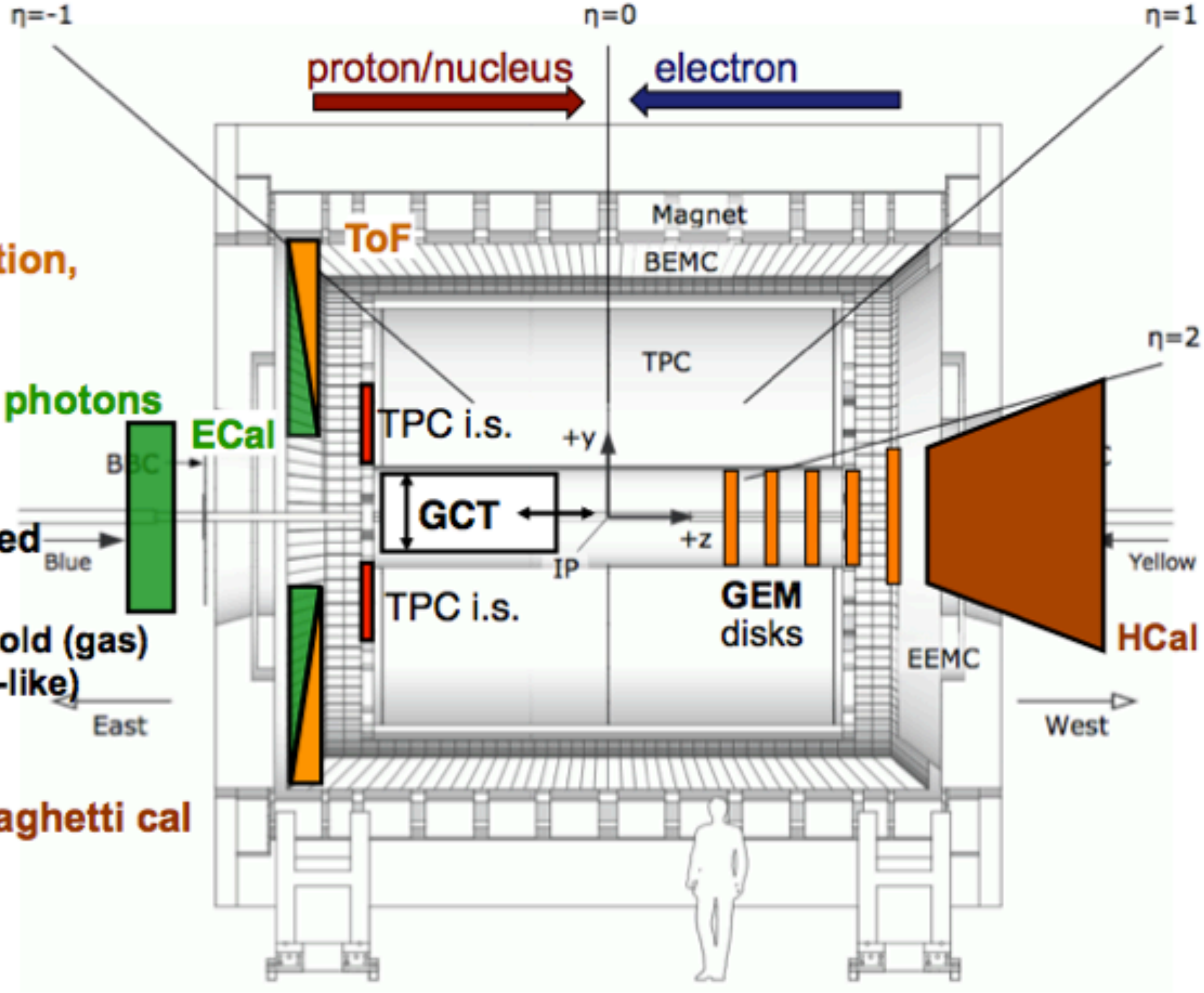
New Electron Beam Ion Source (EBIS) upgrade used in 2012 for U beams

STAR Forward Upgrade (West)



- Forward instrumentation optimized for **p+A** and **transverse spin** physics
  - Charged-particle tracking
  - *e*/*h* and γ/π^0 discrimination
  - Pion identification

Evolving from ***STAR*** into ***eSTAR***



ToF: π , *K* identification,
t_0, electron

ECal: electrons and photons

GCT: a compact tracker with enhanced electron capability

Combine high-threshold (gas) Cherenkov with TPC(-like) tracking

HCal: W powder, spaghetti cal

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

Upsilon

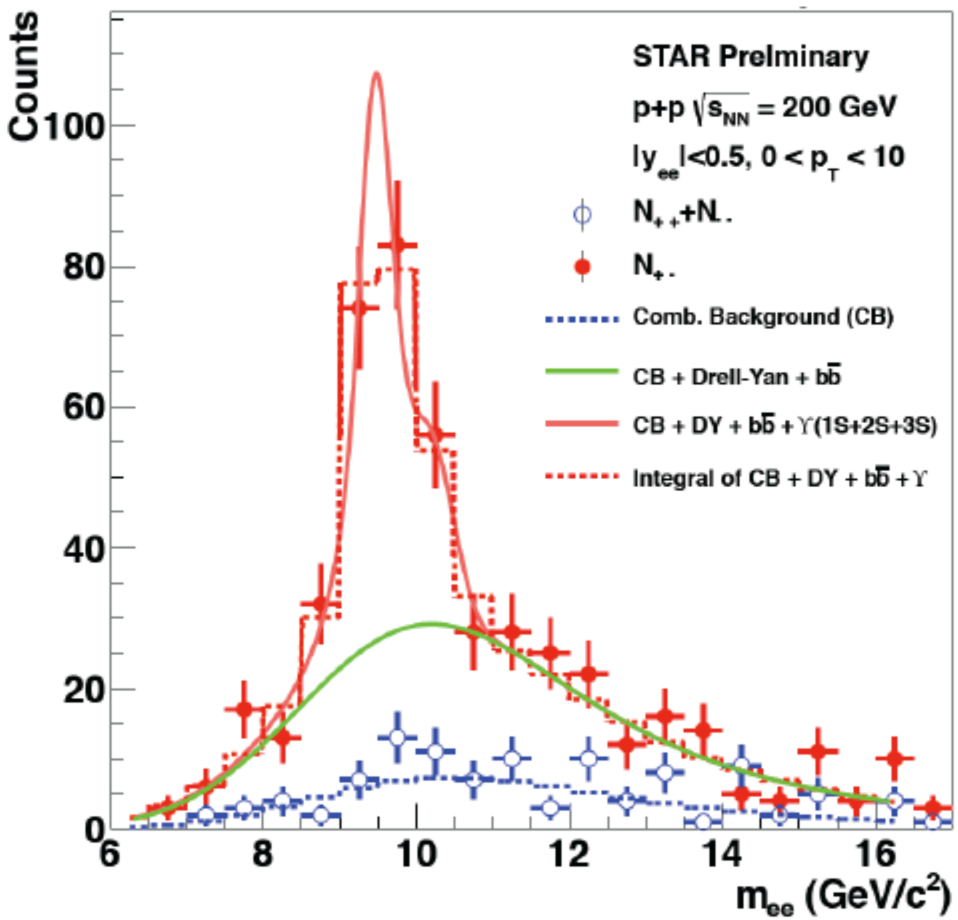

STAR Prelminary
p+p $\sqrt{s_{NN}}$ = 200 GeV
$|y_{ee}|$<0.5, 0 < p_T < 10
N_{++}+N_{--}
N_{+-}
Comb. Background (CB)
CB + Drell-Yan + $b\bar{b}$
CB + DY + $b\bar{b}$ + Υ(1S+2S+3S)
Integral of CB + DY + $b\bar{b}$ + Υ
Counts
0
20
40
60
80
100
6
8
10
12
14
16
m_{ee} (GeV/c^2)

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

History of STAR

2000 2005 2010 2015

Start

2003: RHIC white papers, discovery of jet quenching, sQGP

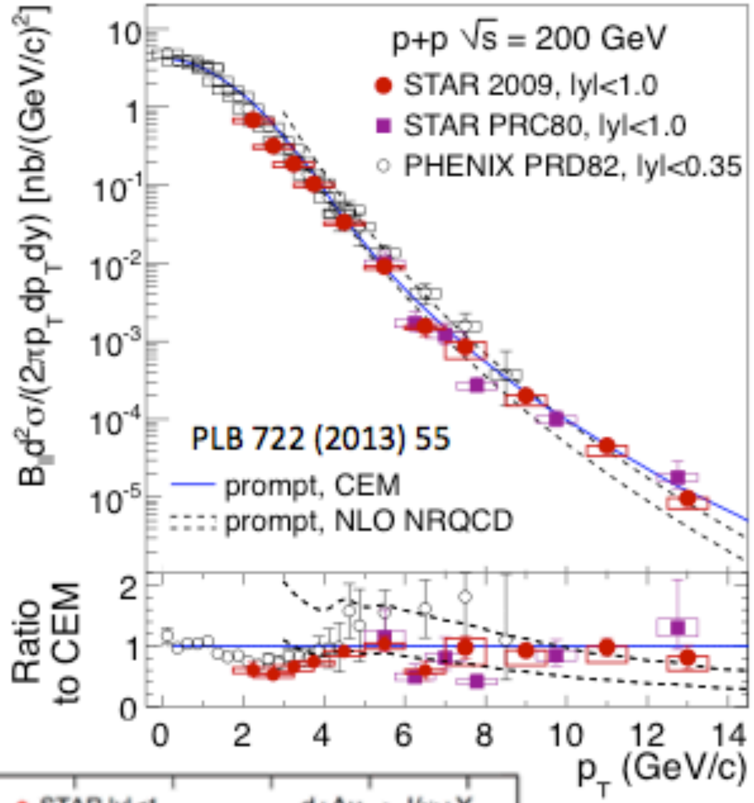
2009: TOF, DAQ upgrade of STAR

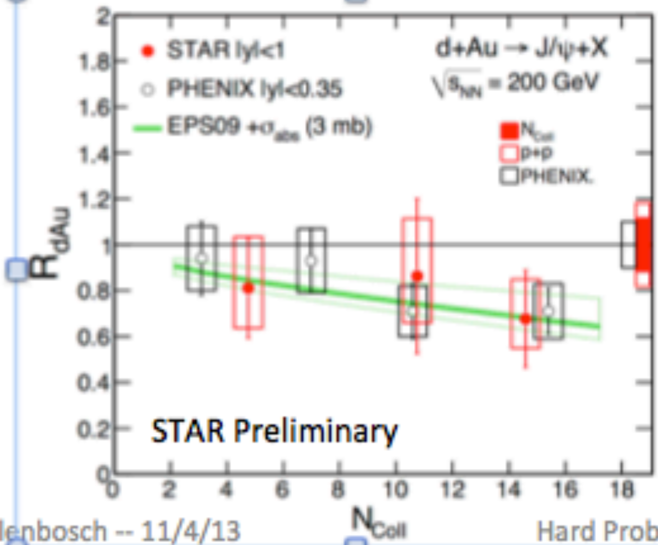
2011: Discovery of Y suppression in AuAu

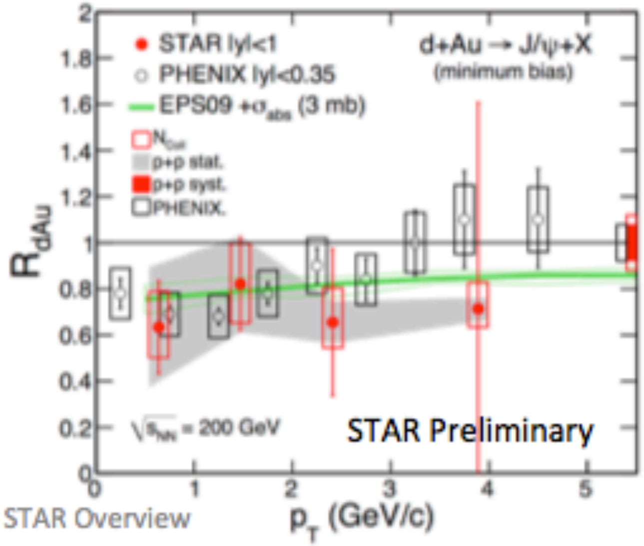
2014: HFT/MTD upgrades of STAR

J/Ψ in p+p and d+Au

- p_T range in p+p extended to 14 GeV/c
  - prompt NLO CS+CO describes data
  - prompt CEM describes data at high p_T
  - direct NNLO CS underpredicts high p_T
- R_{dAu} consistent with model calculations
  - shadowing from EPS09 nPDF
  - nuclear absorption: $\sigma_{abs}^{J/\Psi}$=3mb







Υ in p+p and d+Au 200 geV

Historical milestones

1988-89 AGS BNL and SPS CERN:

Discovery that strangeness is enhanced over pions in Si+Au and Au+Au collisions at sqrt(s)(NN)=1-5 GeV

K/π, Λ/π enhancement in A+A over p+A

2000 CERN press release:

Discovery of a new state of matter in A+A collisions at sqrt(s)(NN)=17, 19 GeV

chi_c, Ψ', J/Ψ suppression,

T(direct γ)~200-300 MeV (model fit),

Strangeness enhancement including Omegas, Xis,

T(chem. fr. out)~170 MeV is located near Tc

2003 BNL press release:

Discovery of jet quenching in Au+Au at √s(NN) = 200 GeV, large elliptic flow

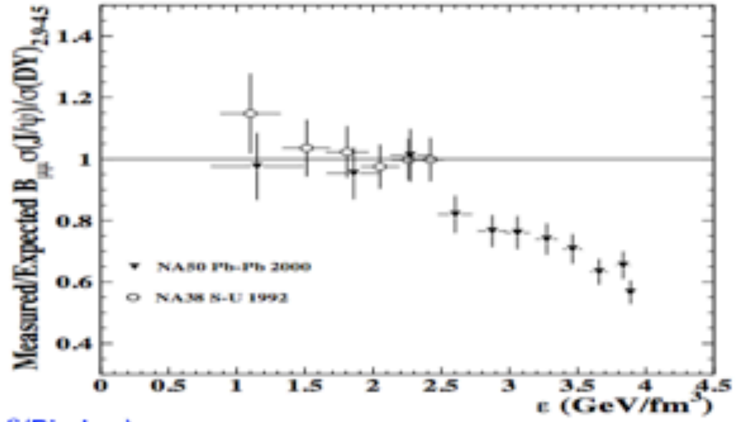
Discovery of a strongly interacting QGP (sQGP)

sQGP found consistent with a perfect liquid

Applications of Anti de Sitter/Conformal Field Theory duality on sQGP

Marks a new era in QCD studies

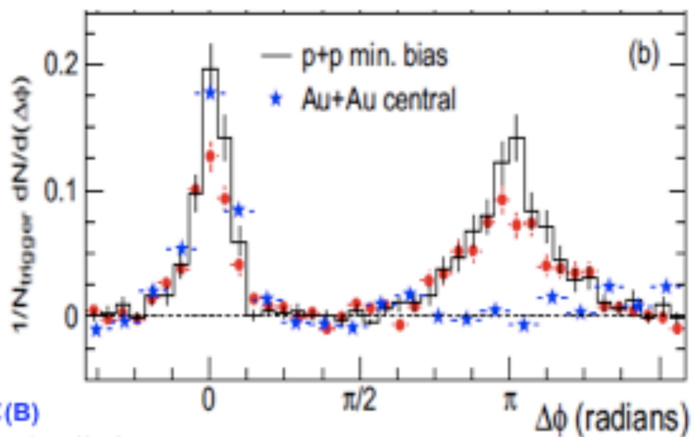
Discovery of J/Psi suppression
NA50 Coll. CERN SPS, 2000



Ɛ(B)= Ɛ(Bjorken)
~3.5 GeV/fm^3

Discovery of jet quenching, RHIC 2003

STAR



Ɛ(B)
~5 GeV/fm^3

Historical milestones

Which are the critical parameters of the phase transition ?:

Several observables where suggestive of an onset of the QCD phase transition at energy lower than top SPS (19 GeV) energy, possibly with ε_c(Bjorken)~1 GeV/fm^3, motivating a low energy scan.

Low energy scan SPS (1999-), RHIC (2009-):

Study onset of transition, search for a possible critical point (as yet inconclusive and ongoing) and map out the QCD phase diagram.

2010: first PbPb collisions at the LHC !

Jet quenching, Quarkonia suppression

ε(B) ~16 GeV/fm^3

2010/11: RHIC upgrades accomplished

lead to largest data sample ever taken at RHIC (a billion Au+Au events) with highly enhanced identification capabilities due to new detectors

-> since 2009 like a "new RHIC collider and experiments"

2011: Y suppression discovered at RHIC and LHC
2012 : Sequential quarkonia suppression at the LHC
2013: First p+Pb run at LHC