Relativistic Heavy Ion Physics – the PHENIX Experiment

Tony Frawley, Kushal Das

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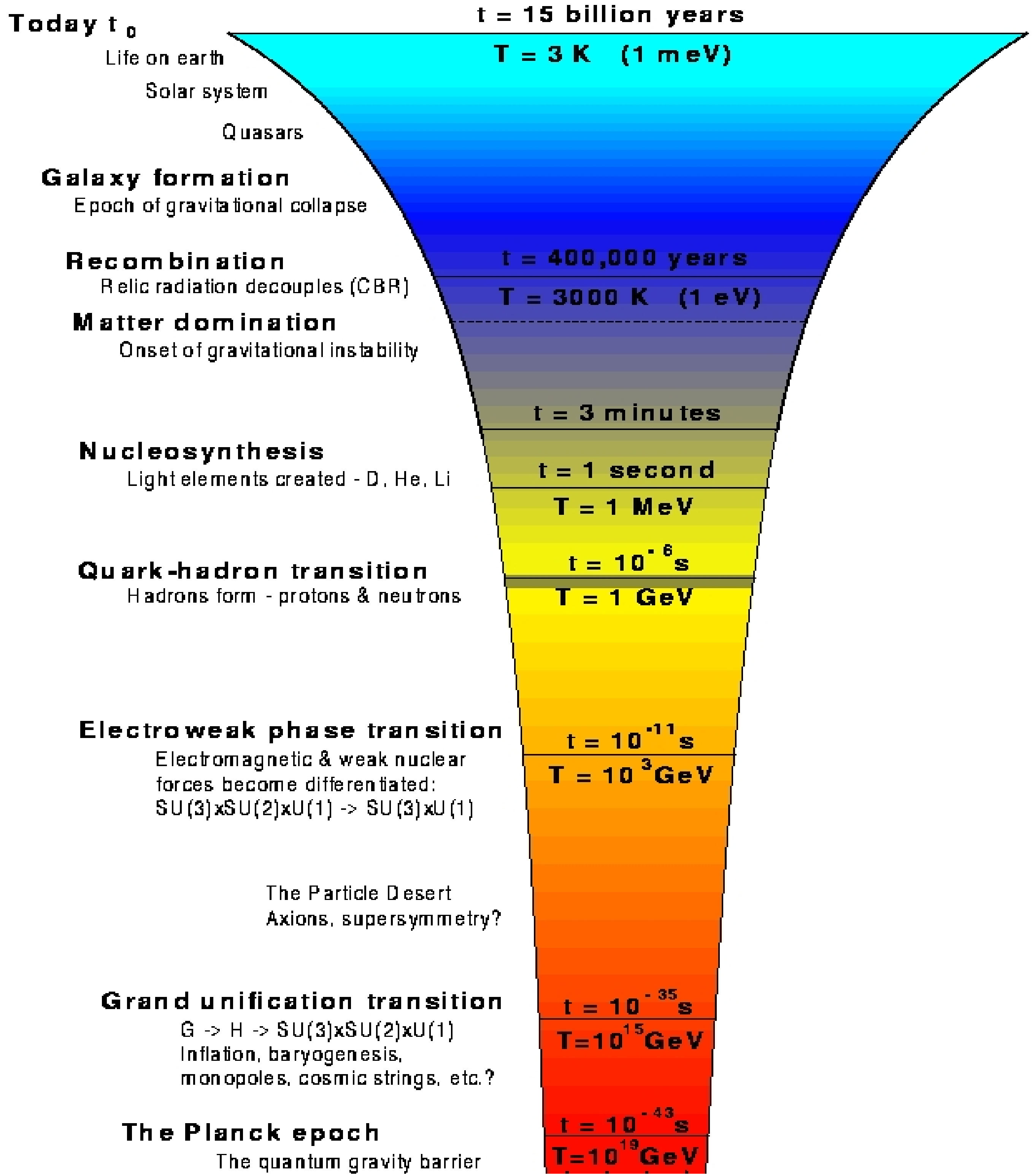
Timeline of the universe

The **symmetry breaking phase transitions** that occurred in the first microsecond of the history of the universe defined the universe as we know it.

They were responsible for the creation of net baryon number, and confinement of quarks and gluons into hadrons, for example.

One of these, the **quark hadron phase transition** that left the vacuum in its ground state, is accessible to us through **very high energy heavy ion collisions**.

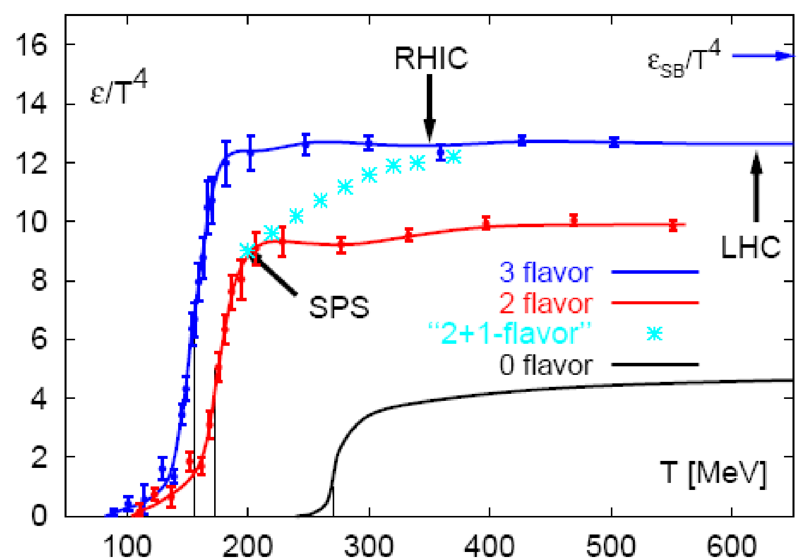
QCD is the **only** fundamental theory with a phase transition accessible to experiment.



What is the Quark Gluon Plasma?

Lattice QCD reveals a rapid increase in the degrees of freedom associated with the deconfinement of quarks and gluons.

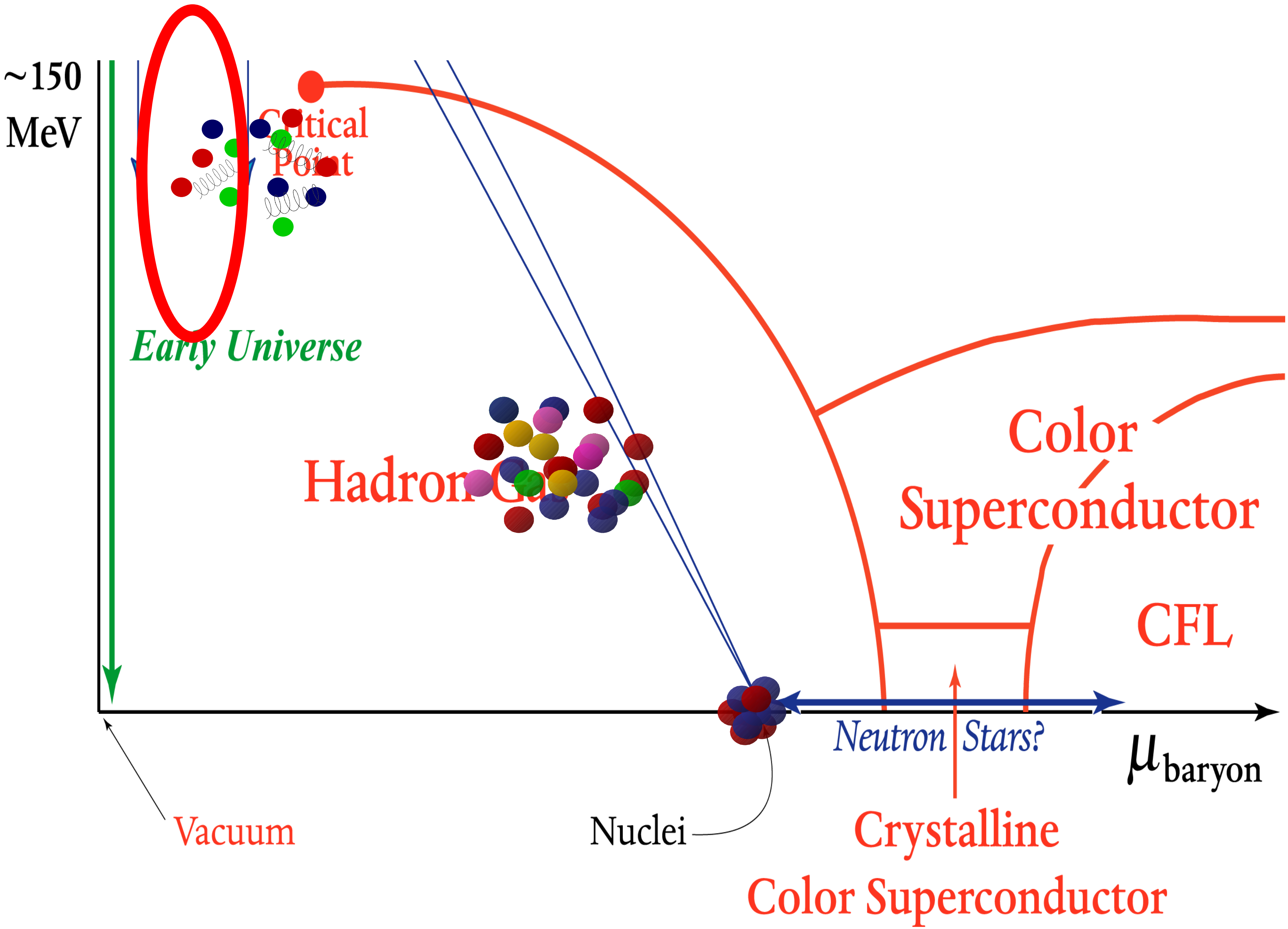
F. Karsch, Prog. Theor. Phys. Suppl. 153, 106 (2004)



T ~ 170 MeV
ε ~ 1.0 GeV/fm^3

The deconfinement is brought about by screening of the long-range confining potential due to a very high density of color charges in the quark gluon plasma – a general property of plasmas.

QCD Phase Diagram

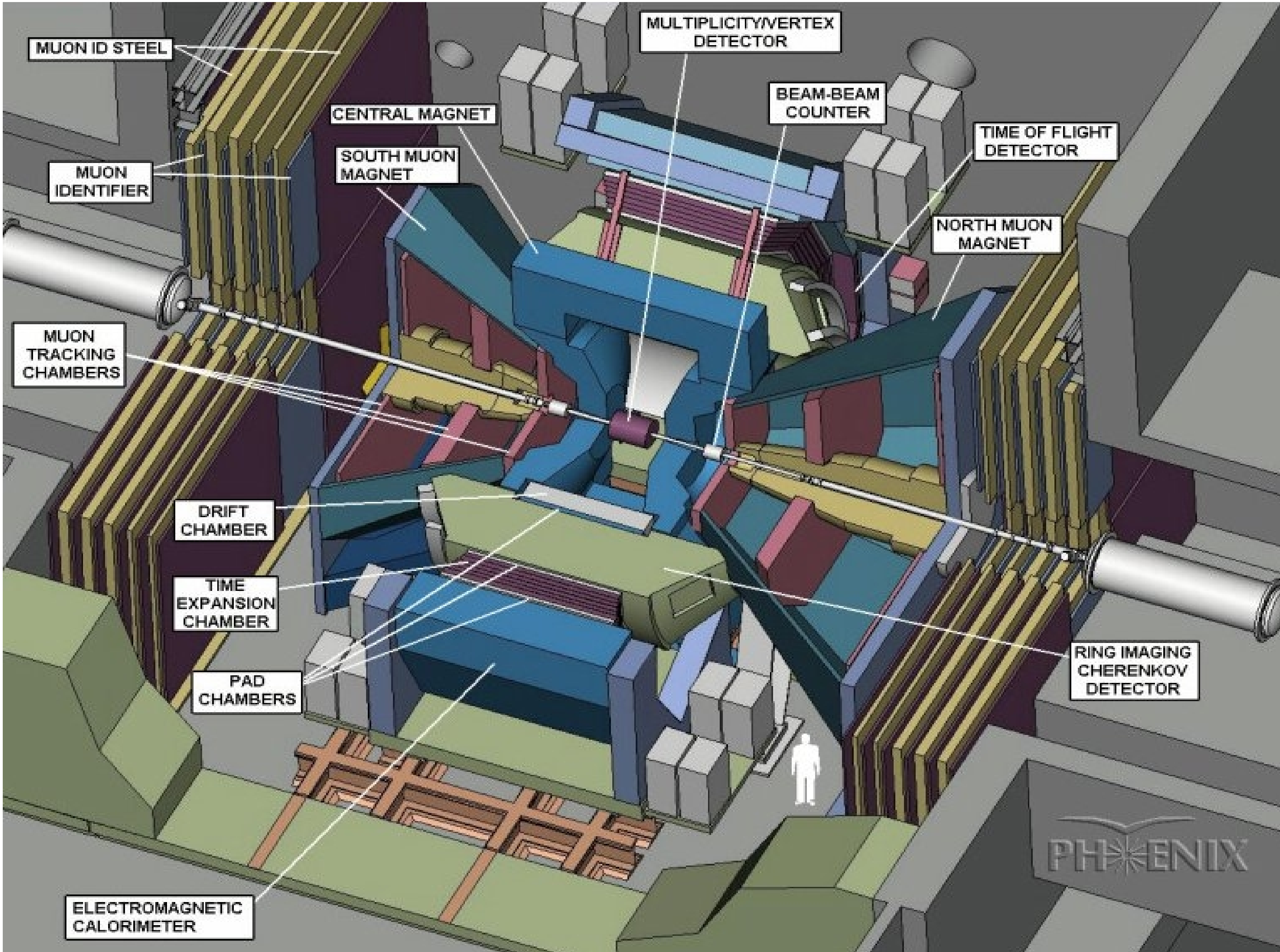


RHIC at Brookhaven National Laboratory

RHIC is the first dedicated heavy ion collider
It can collide Au nuclei at 200 GeV/nucleon center of mass energy.

PHENIX is one of the two large RHIC experiments

The PHENIX Experiment

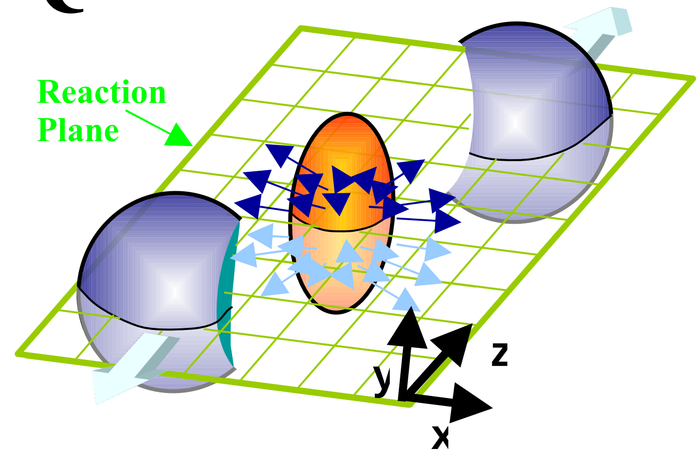


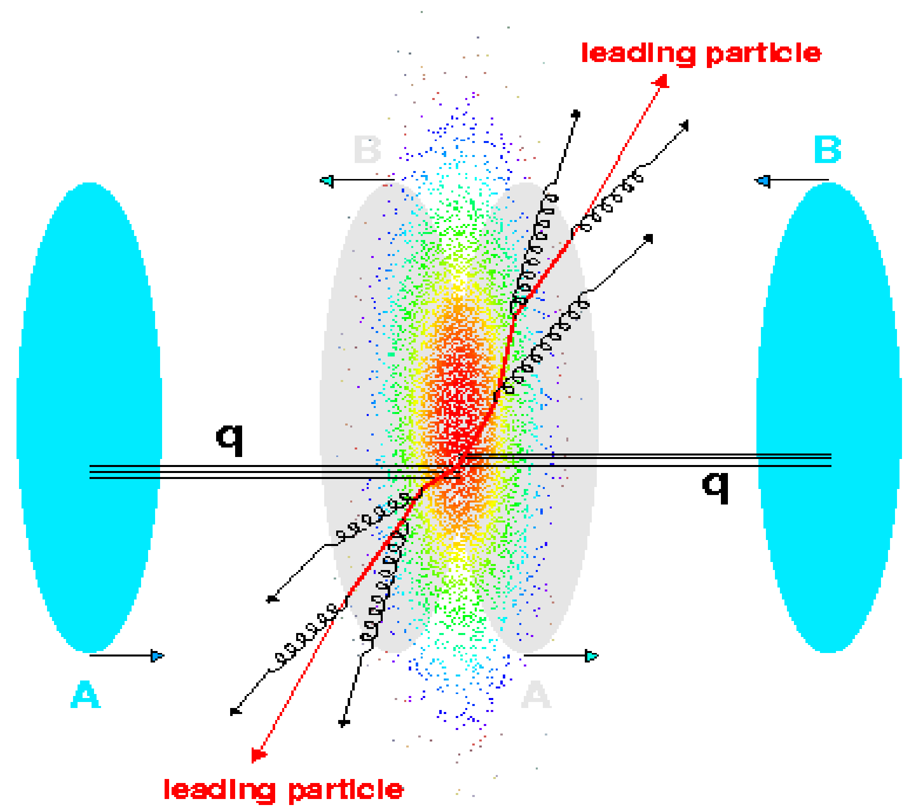
Formation of hot dense QCD matter

A central Au+Au collision at 200 GeV per nucleon can have up to **~ 900 nucleon-nucleon collisions!** This creates an energy density of 15 GeV/fm^3 in a volume smaller than a Au nucleus. This is roughly **100** times **nuclear density**, **15** times **nucleon density**.

We study the effects of this large final state energy density on such things as:

- **Energy loss of quark or gluon jets**
- **Asymmetric acceleration of expanding matter**
- **Destruction of charm and beauty mesons**
- **Detected particle correlations**
- **etc.**





Not to scale! Lorentz contraction factor is really 200 in center of mass!

What have we learned so far?

In the first 5 years of the RHIC program we have learned that we are producing partonic matter that is:

Very dense: at least 15 GeV/fm3
Thermalizes very fast: < 1 fm/c (compare 7 fm/c QGP lifetime)
Very opaque to color: Suppresses parton "jets" but not photons
Very hot: Strongly suppresses J/ψ mesons

I have time to show you only a couple of examples of the data that lead us to these conclusions.

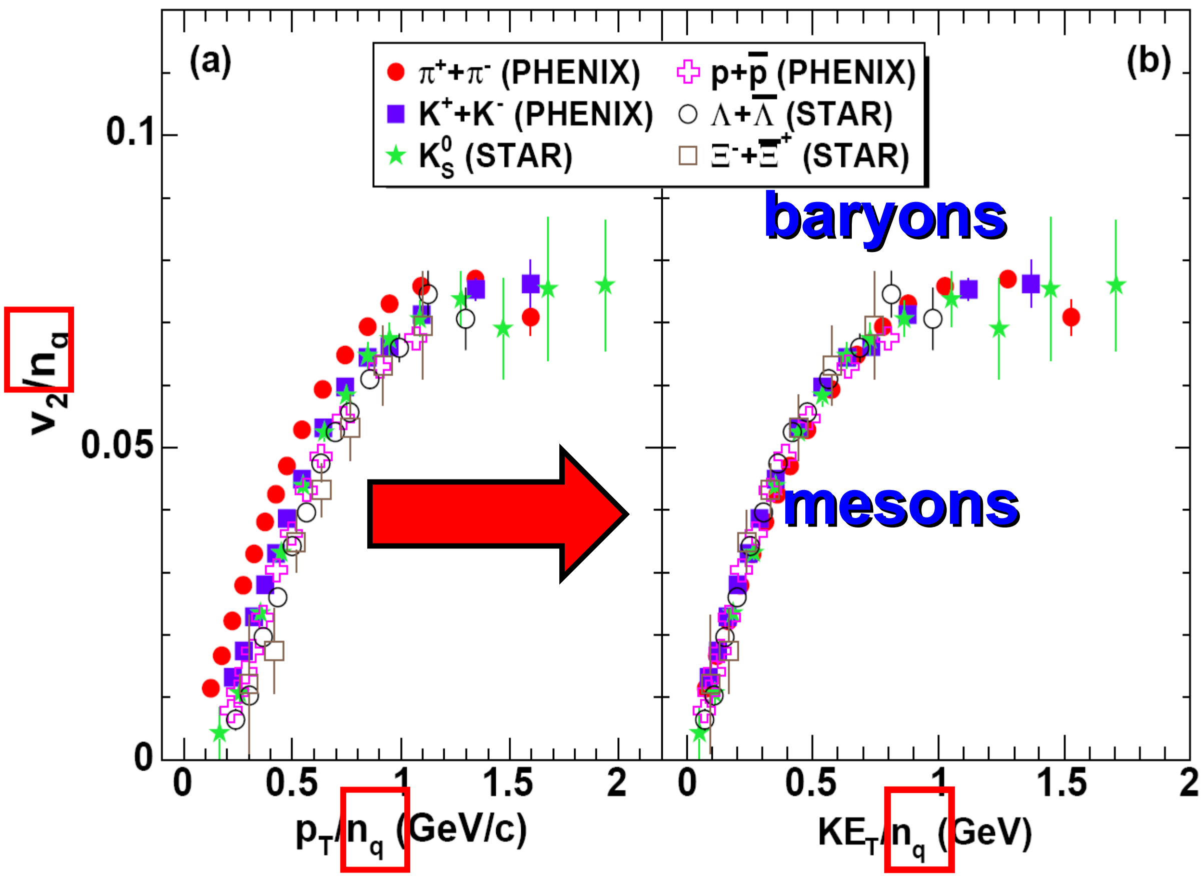
One of the most striking examples is the behaviour of the **"elliptic flow"** parameter (v_2) – a measure of the asymmetry in the particle distributions relative to the reaction plane due to the **asymmetric pressure gradients** in the expanding system.

Flow of Light Quarks

The flow parameter scales with quark number of the hadron ($n_q = 3$ for baryons, $n_q = 2$ for mesons).

Very strong evidence that the "flow" occurs in the partonic phase, before hadronization into baryons and mesons.

Consistent with very rapid thermalization and expansion of matter made of quarks and gluons.



We often use the **“nuclear modification factor”** to quantify the effects of the nuclear matter on measured cross sections. The nuclear modification factor can be written:

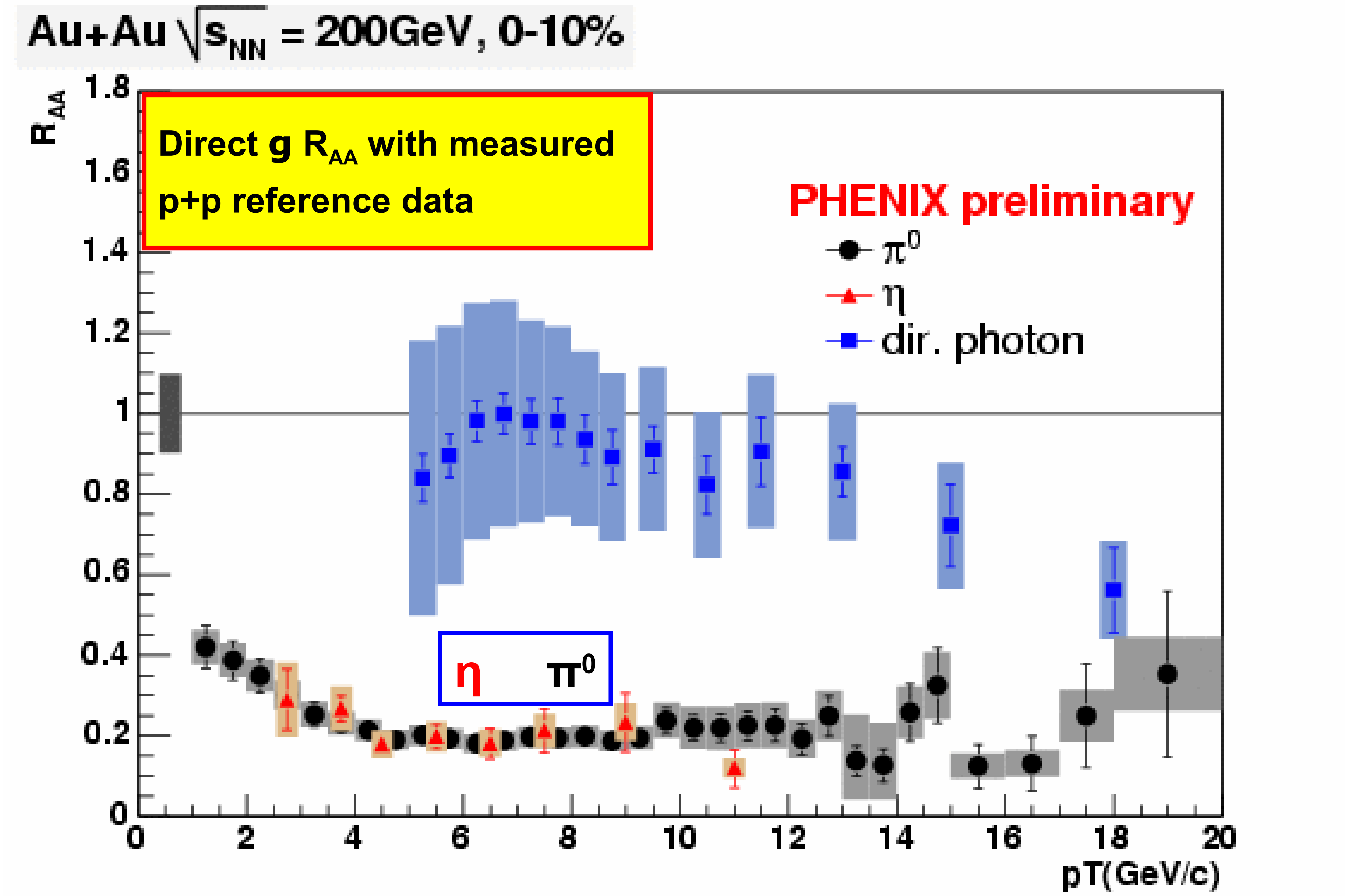
$$R_{AA} = \sigma_{AA}/(\langle N_{coll}\rangle\, \sigma_{pp})$$

where AA denotes a nuclear collision, pp denotes a proton-proton collision, and $\langle N_{coll}\rangle$ denotes the mean number of proton-proton collisions in the nucleus-nucleus collision (we get this from a model).

It can be shown that at RHIC energies “hard processes” (such as large transverse momentum hadron production or heavy quark production) have cross sections that scale with the number of proton-proton collisions.

In the absence of nuclear effects, R_{AA} would be 1.0.

Nuclear modification of yields vs transverse momentum (p_T) for mesons, but not photons – evidence of large energy loss of jets



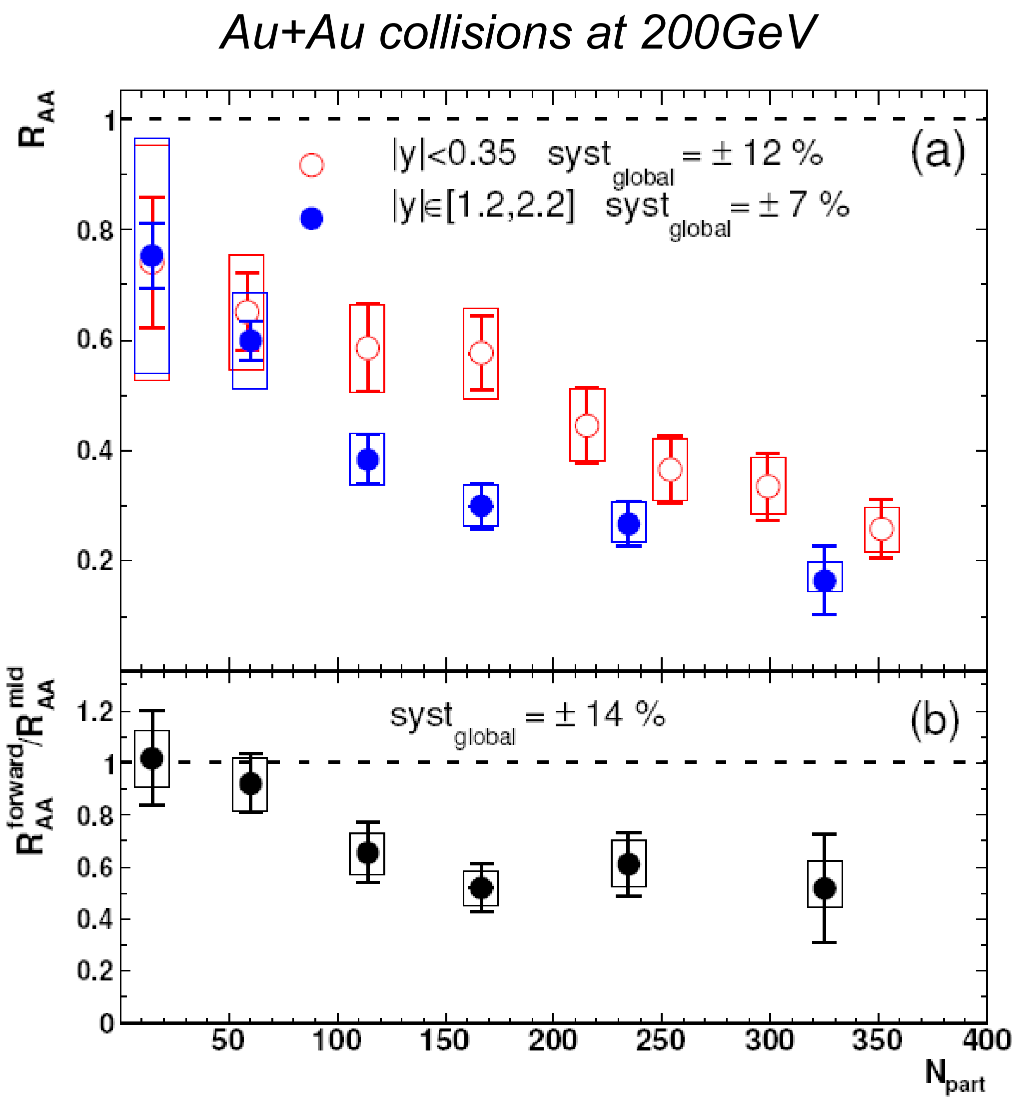
J/ψ R_{AA} in Au+Au Collisions

nucl-ex/0611020
(submitted to Phys. Rev. Lett.)

Less suppression at central rapidity

Suppression is not <u>solely</u> due to local particle density.

One suggestion is that this is due to formation of J/ψ from uncorrelated charm quarks when the QGP hadronizes.



Work at FSU is ongoing on J/ψ production in Cu+Cu collisions at 200 GeV to explore the behaviour of the suppression in the energy density range where the phase transition is expected to occur.

The study of J/ψ production in the central arms of PHENIX in 200 GeV Cu+Cu collisions is Kushal's Ph.D. thesis project.

Exploring Partonic Matter with High Luminosity in PHENIX in the future

2006

Hadron Blind Detector	low mass di-electrons
Reaction Plane Detector	improved reaction plane eg. $v_2(\gamma)$
TOF-West	hadron anomaly
Forward EMC (MPC)	low x, initial state

complete

2006- 2009

Silicon Vertex Tracker	heavy quark physics, jets
Muon trigger	heavy flavor trigger

funded

2008 – 2011

PHENIX upgrades

Forward Vertex Tracker	heavy quark physics, jets
Nosecone Calorimeter	jets, γ-jet, heavy quark physics

RHIC II → 10 x Luminosity

Exploring Partonic Matter with High Luminosity in PHENIX

2006
Hadron Blind Detector
Reaction Plane Detector
TOF-West
Forward EMC (MPC)

Driven by growing interest:

Year	*Institutions*	*Participants*
2001	*53*	*420*
2003	*57*	*460*
2006	*68*	*550*

2006- 2009
Silicon Vertex Tracker — heavy quark physics, jets
Muon trigger — heavy flavor trigger

funded

PHENIX upgrades

2008 – 2011
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RHIC II → 10 x Luminosity