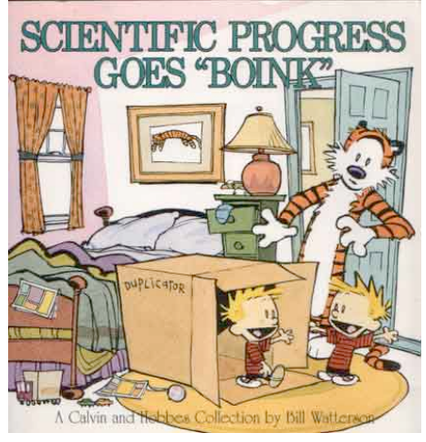
“New Directions”

Jamie Nagle, Peter Steinberg, Berndt Mueller

2005 RHIC PAC Meeting
November 3-4, 2005

Progress



There is real value in small group discussions,
only loosely-coupled to programmatic planning.

Less about "brand new" ideas than about clear thinking
"Self-assessment" for the RHIC II Science case.

1. "Boulder Workshop", March 2005
2. 1st RHIC II workshop, April 2005
3. 2nd RHIC II workshop, June 2005
4. Various e-mail chains (in rhicii-new-l archives):
"s" in sQGP, phonons, quasiparticles

June 2005 Archives by thread

- **Messages sorted by:** [subject] [author] [date]
- **More info on this list...**

Starting: *Tue Jun 7 11:12:43 EDT 2005*
Ending: *Wed Jun 29 12:12:09 EDT 2005*
Messages: 25

Talking is good, but writing it down is better

White Paper Worksheet

(from April 2005 meeting)

1. What are the most basic physics questions?
2. How do you connect these to observables?
3. How do you measure the observables?
4. Implications for experiments

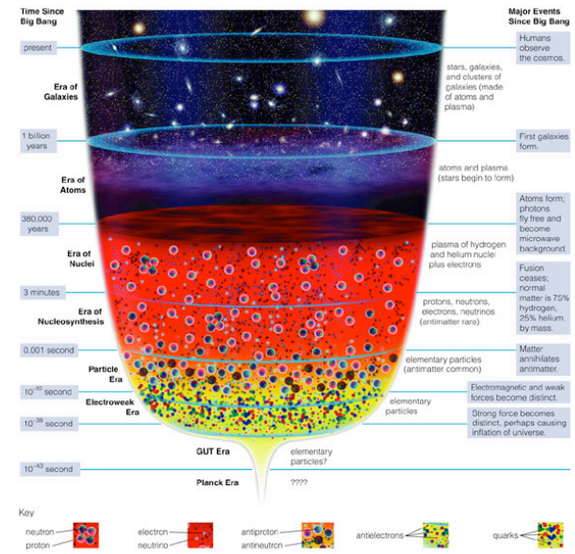
Worked Example #1

1. How do you understand Baryon asymmetry in the present-day universe?

2. Neutrino mixing matrix (e.g. Θ_{13}) contains information on CP violation

3. Reactor experiment to measure Θ_{13}

4. Braidwood (conceptual design)



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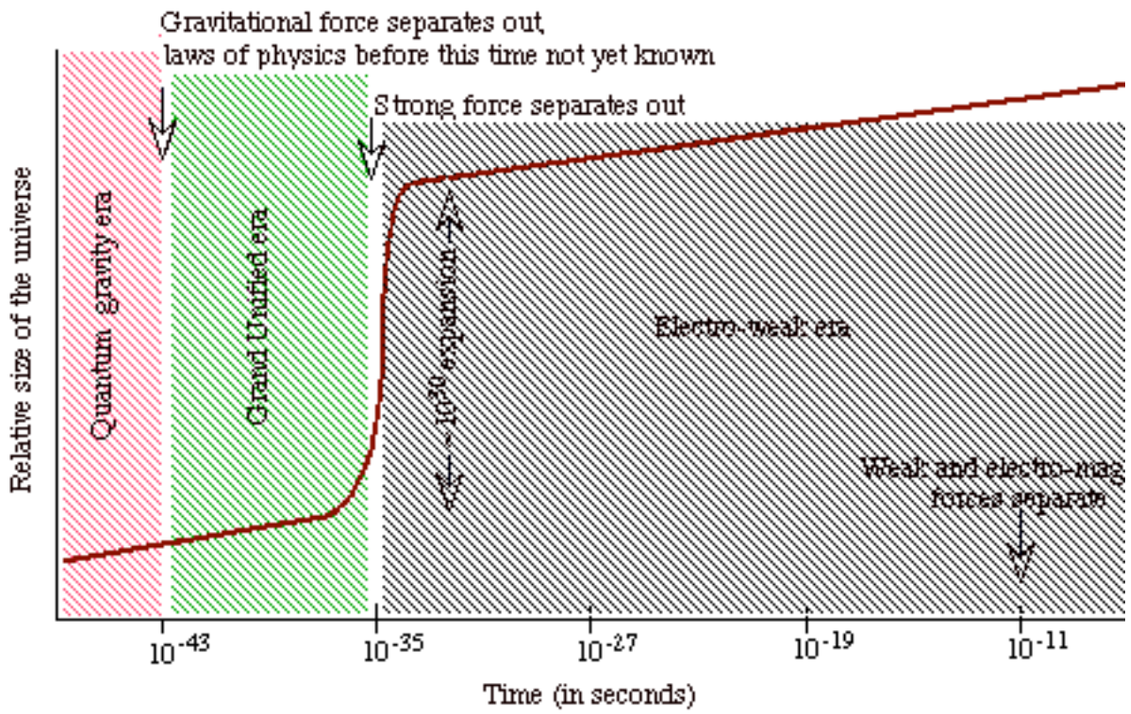
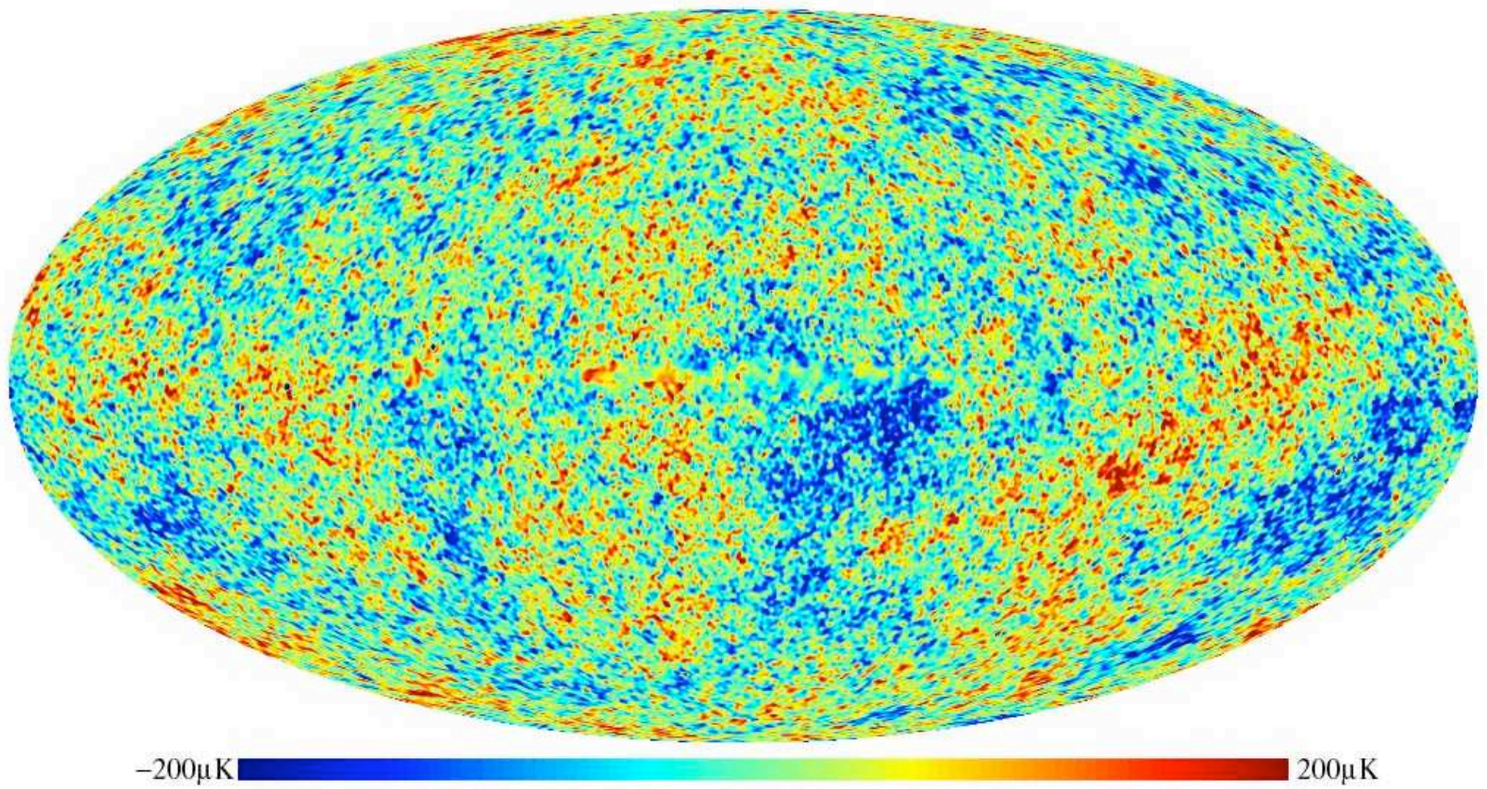
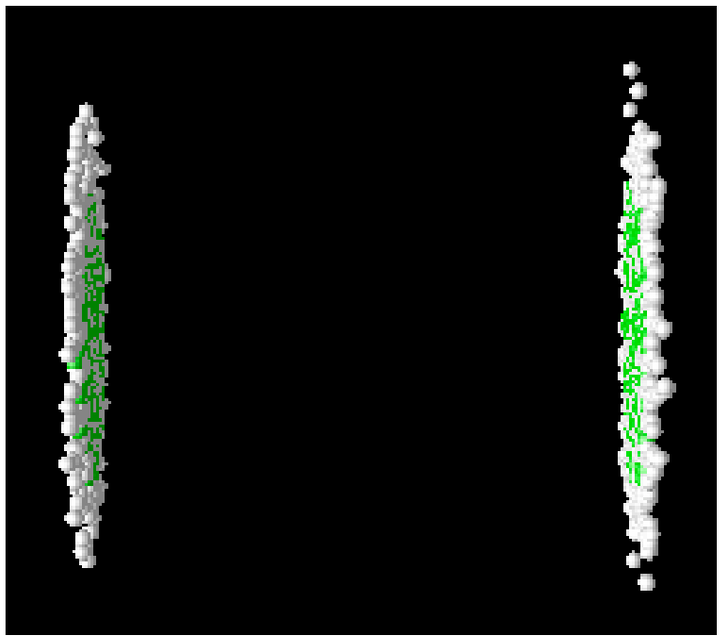
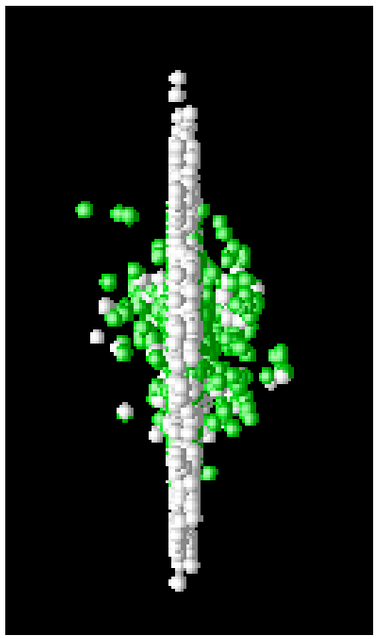
"Worked Example #2"



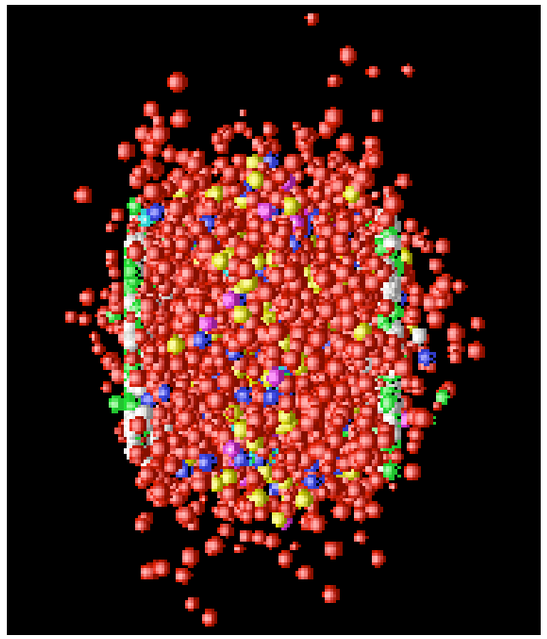


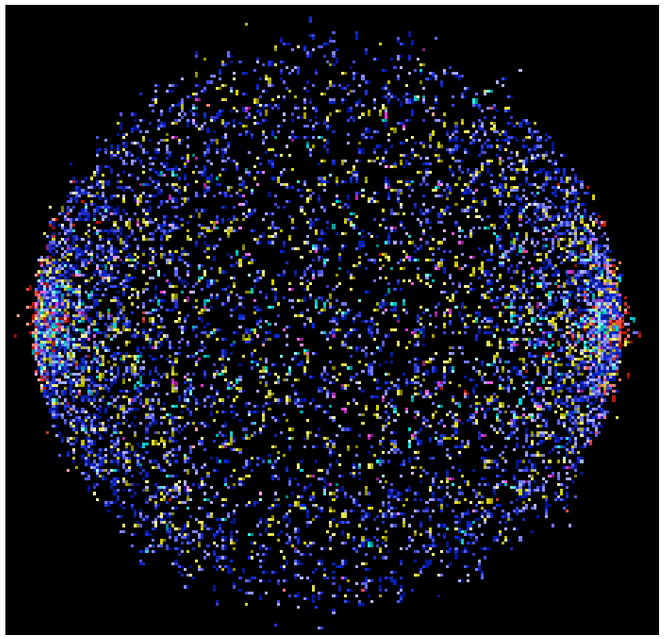
Get Out Your #2 Pencil





Entropy Generation





Degrees of freedom, Phase Transitions

Entropy Generation

1. How do we evolve from a low-entropy initial state to a (maximal?) entropy state on such short time scales

2. Mechanisms are unknown: CGC? Can string theory help? In some sense, this is <u>the</u> big question!

3. What is connection from final state entropy to initial state (e.g. how much viscosity in system)?

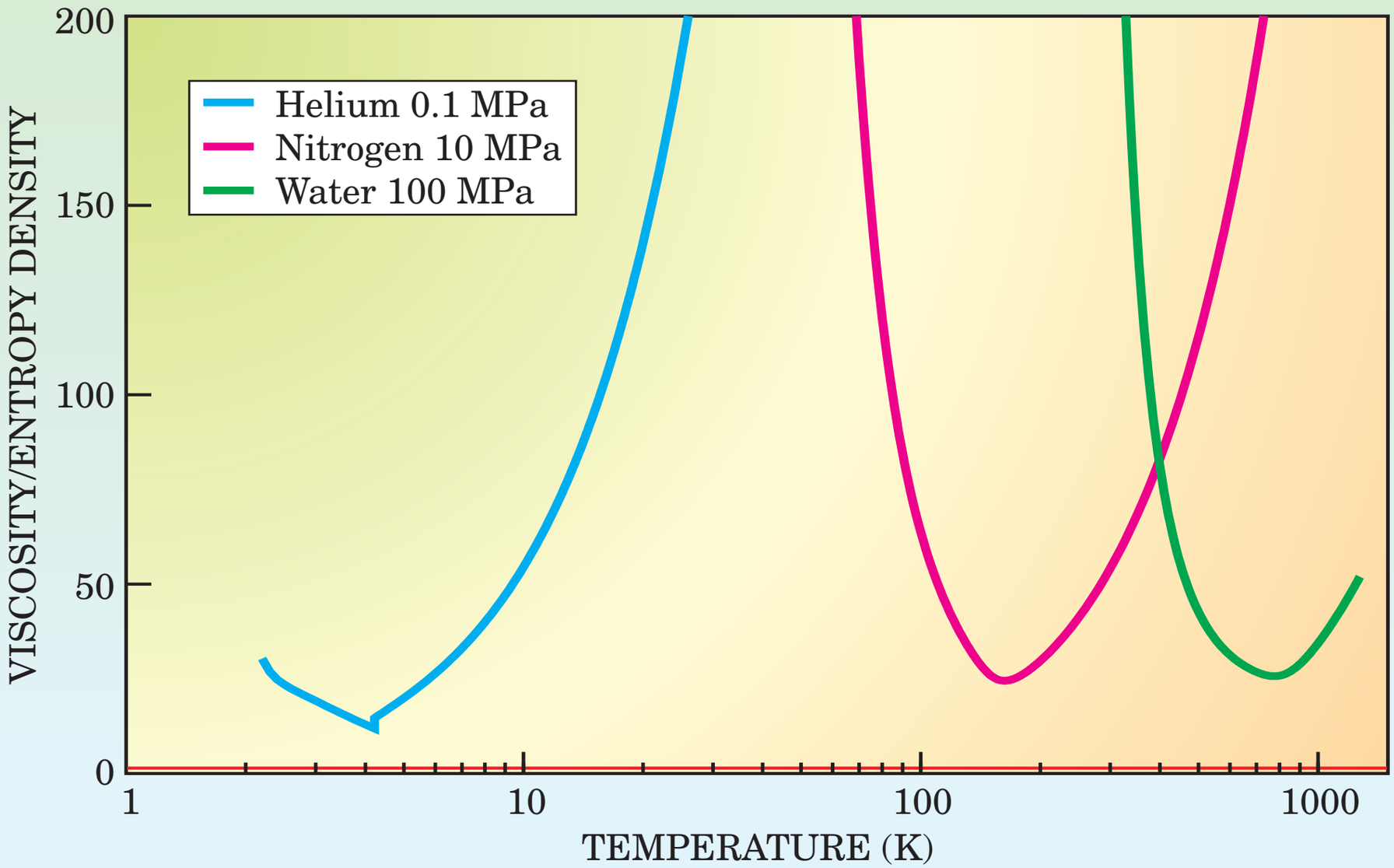
4. ...eRHIC?

Jet quenching also suggested to be an example of an isolable "thermalization" process

Lower Viscosity Bound

Physics Today, May 2005

P. K. Kovtun, D. T. Son, A. O. Starinets, *Phys. Rev. Lett.* **94** 111601 (2005).



Degrees of Freedom

1. Do the degrees of freedom in the initial state have deconfined (quasi-free) color charges?
(Or are there new non-hadron bound states [BSBS]?)

2. Expect color screening for deconfinement, (new "resonances" for BSBS)

3. Quarkonia dissociation for set of states with a range of binding energies vs. T, L, v. Improvements to lattice techniques.

4. Dilepton measurements + extensions, e.g. χ_c. Upgrades to existing detectors.

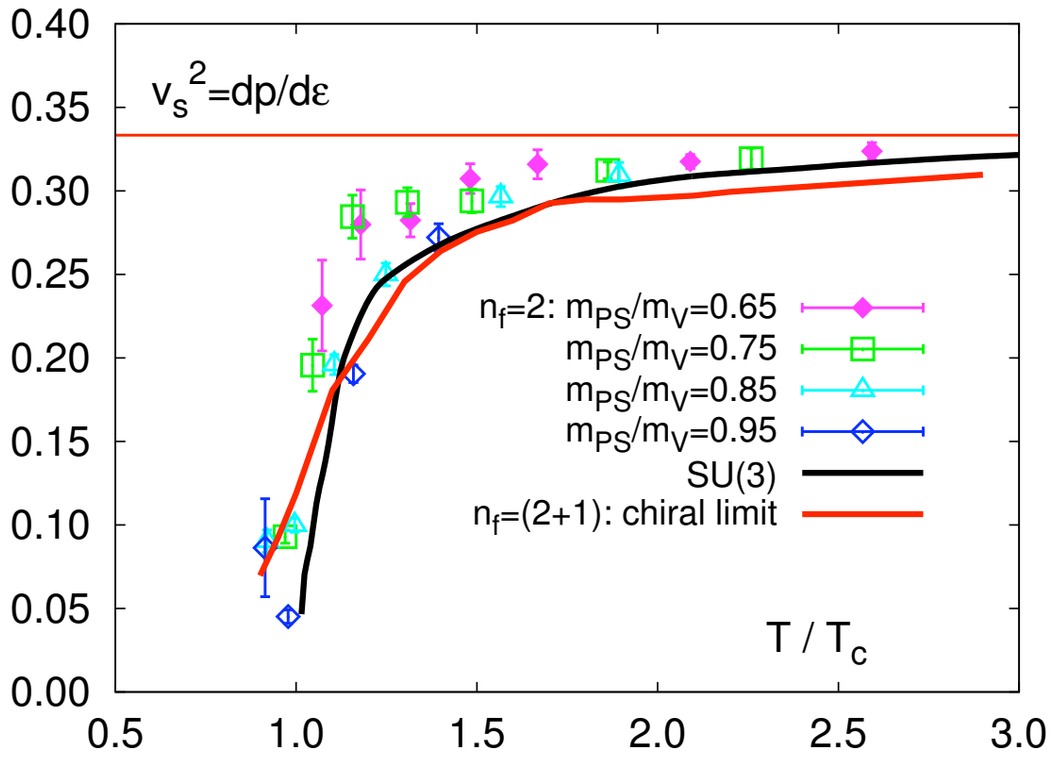
QCD Phase Transition

1. Is there a QCD phase transition?

2. "Softest point" in QCD equation of state

3. 3D Hydro models (with full exploration of parameter space) compared with data

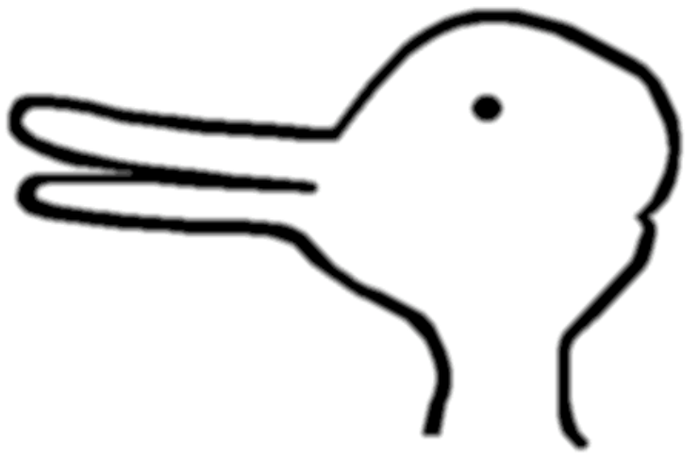
4. Detector with large rapidity coverage and PID. Jet correlations (and wakes) to study speed of sound (& rapidity dependence)



“Everything that can be said, can be said clearly.”

- Ludwig Wittgenstein

What do we mean when we talk about "RHIC Physics"?



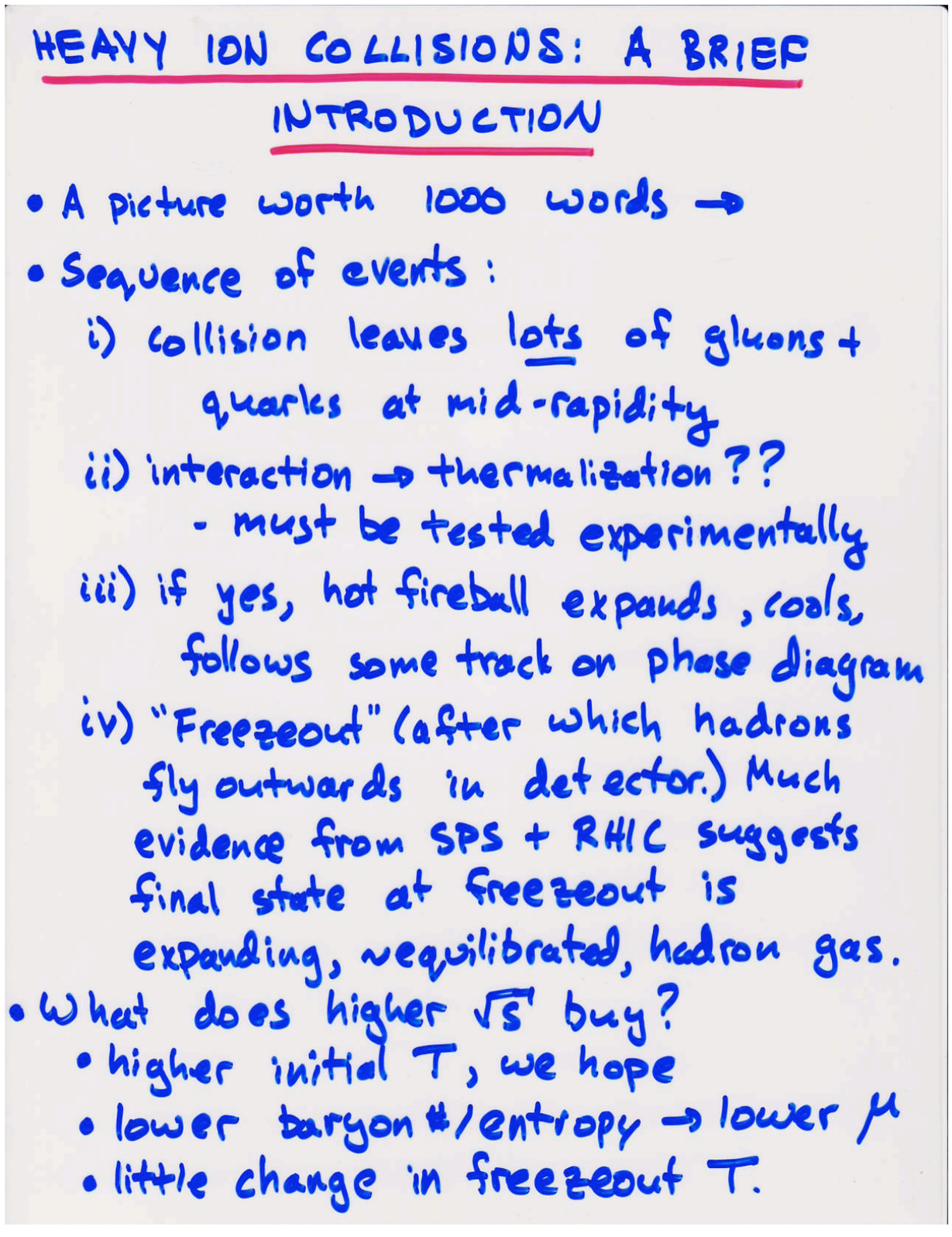
"Duck or Rabbit?"

1. Entropy Generation (Thermalization)
2. Degrees of freedom
3. Phase Transitions

How and when does RHIC Physics start?

The canonical picture:

1. "Stopping"
2. "Rescattering" of q,g at $\eta=0$
3. Establishment of equilibrium



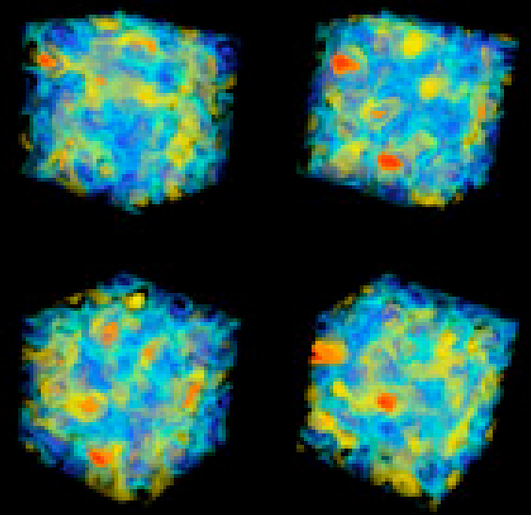
K. Rajagopal, PANIC05

Dynamical Regimes of QCD

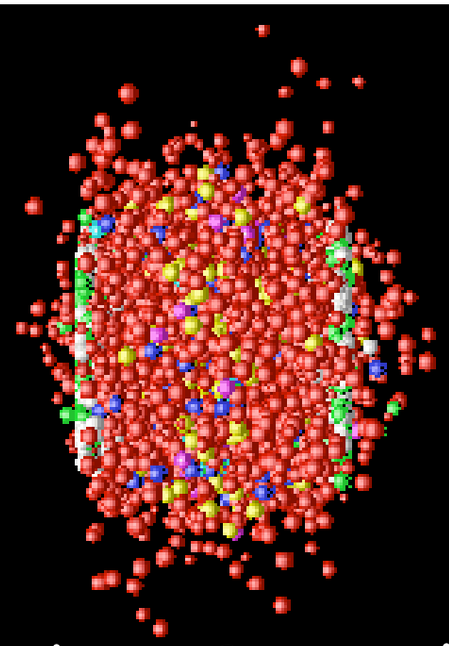
Large opacity

Small opacity

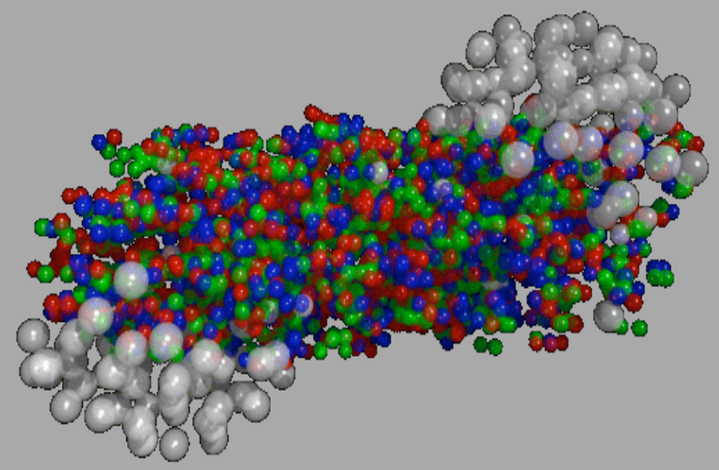
Perfect Fluid?



Lattice QCD?



Parton Cascade?

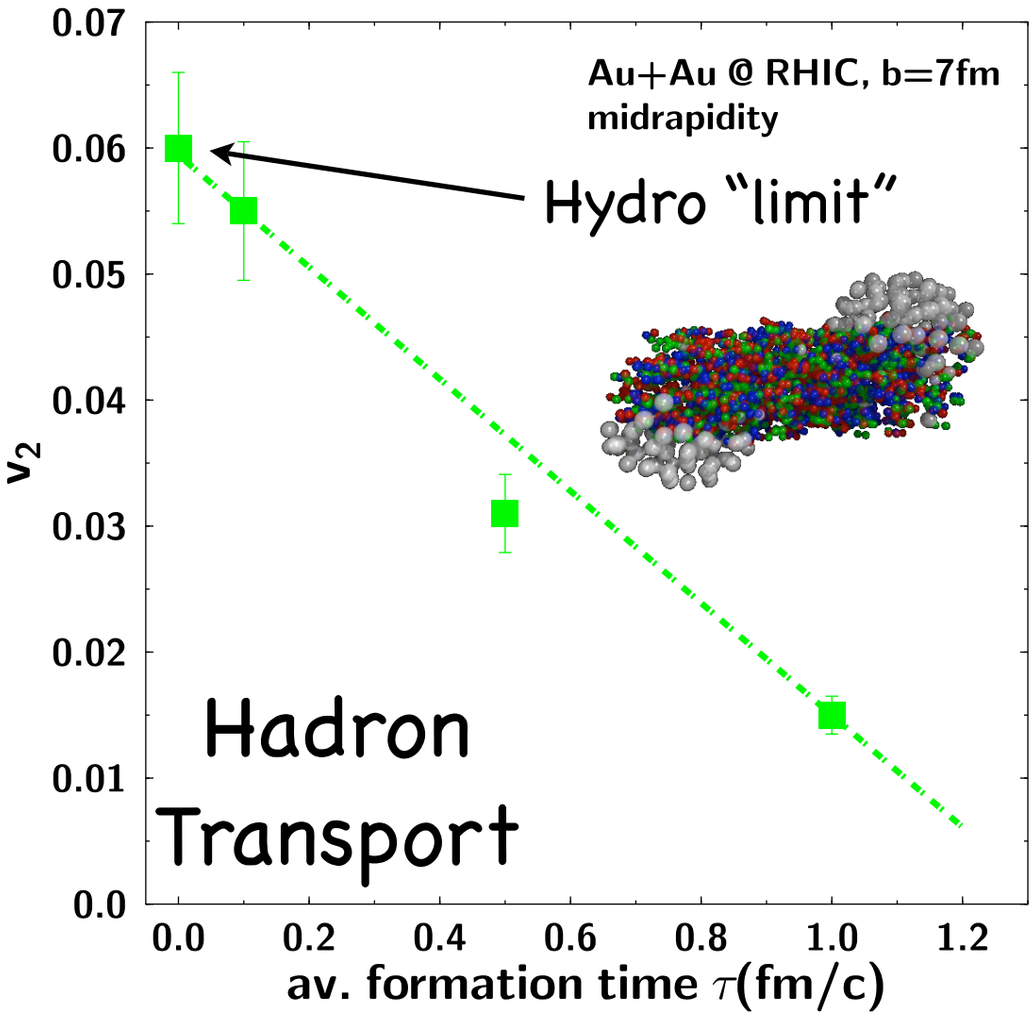


Hadron Cascade?

Short times

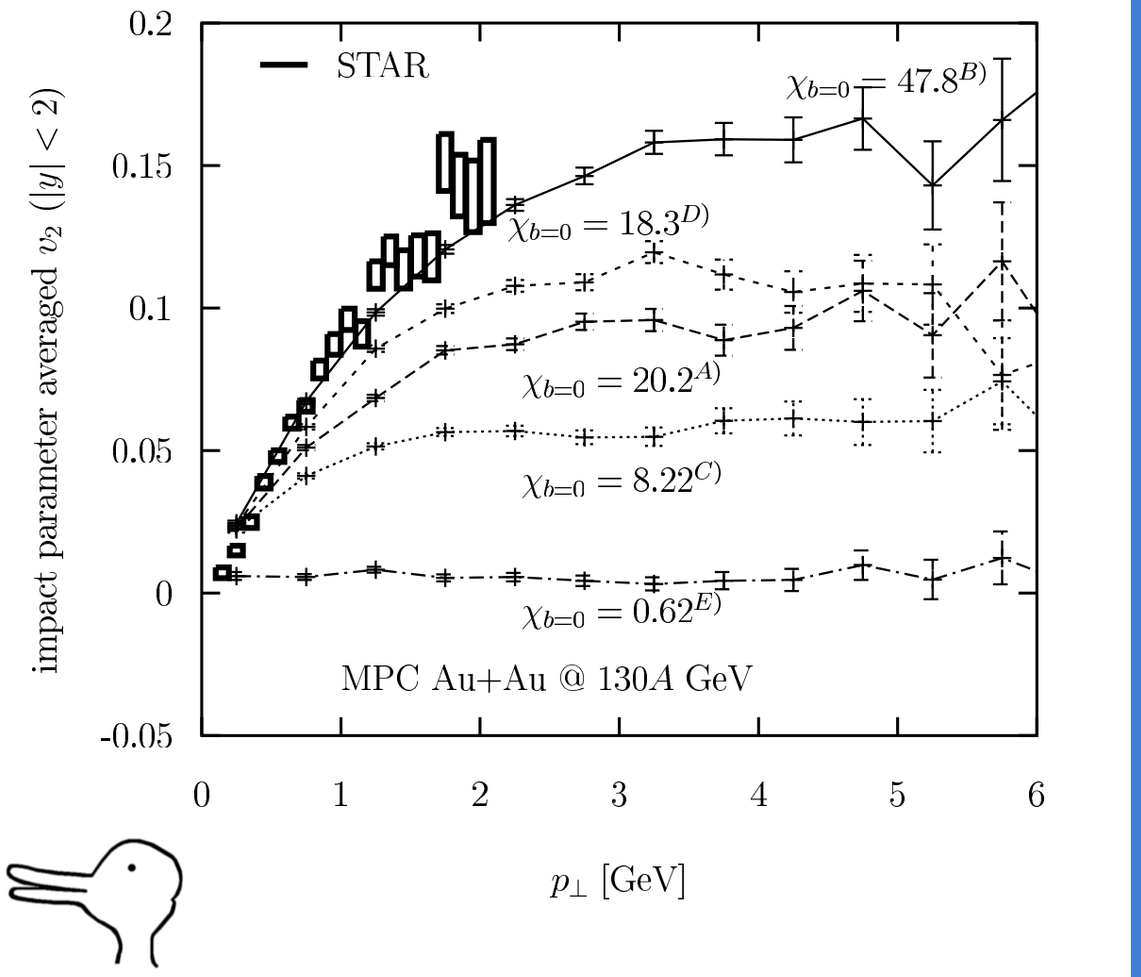
Long times

Modelling approach to hydro



UrQMD (Bleicher/Stocker)

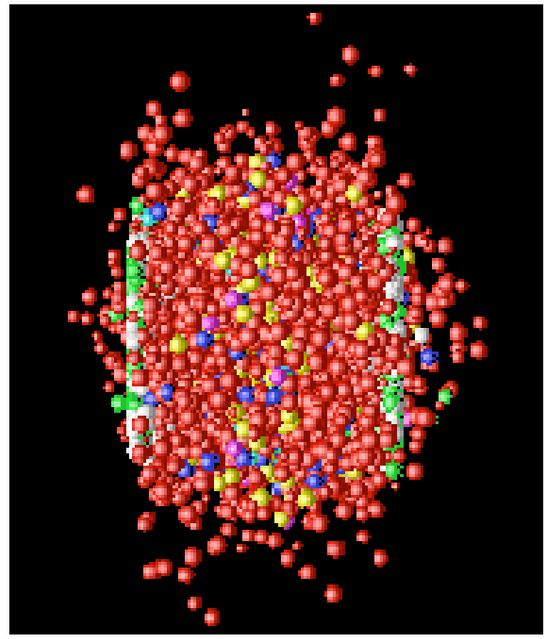
Parton Transport



MPC (Molnar/Gyulassy)

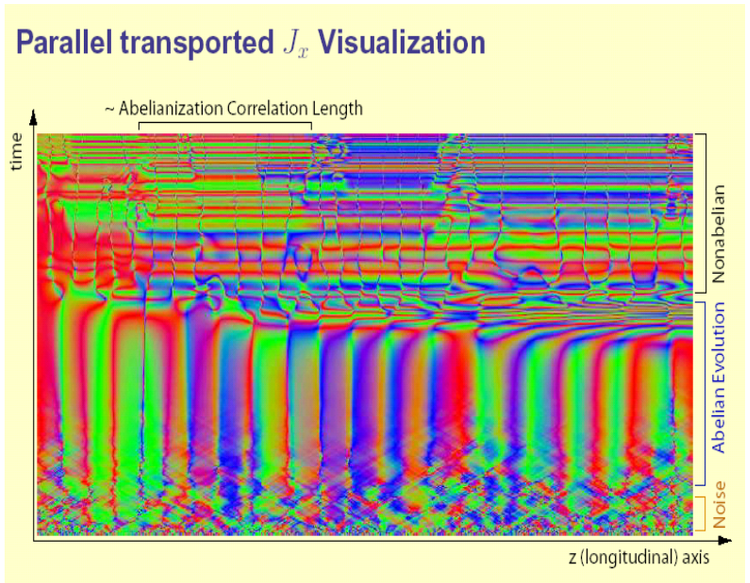
Need early times AND large cross sections to reach hydrodynamic limit ("unphysical"...)

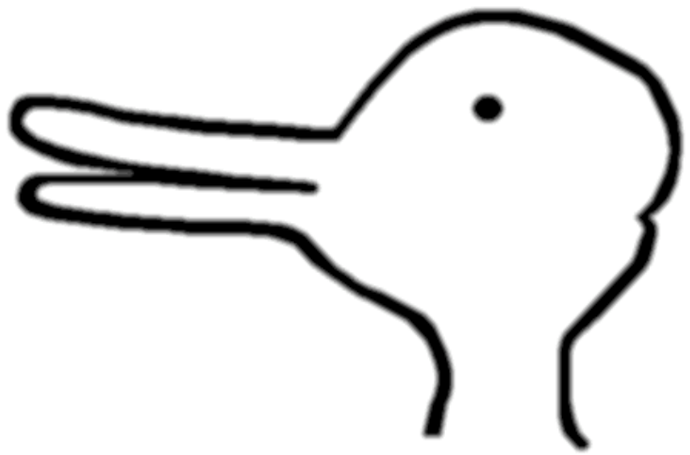
Can rescattering of
free quarks and gluons
rapidly equilibrate?
(Estimates point to no - but
we still use this language!)



"Bottom-up thermalization",
Parton Cascade Model

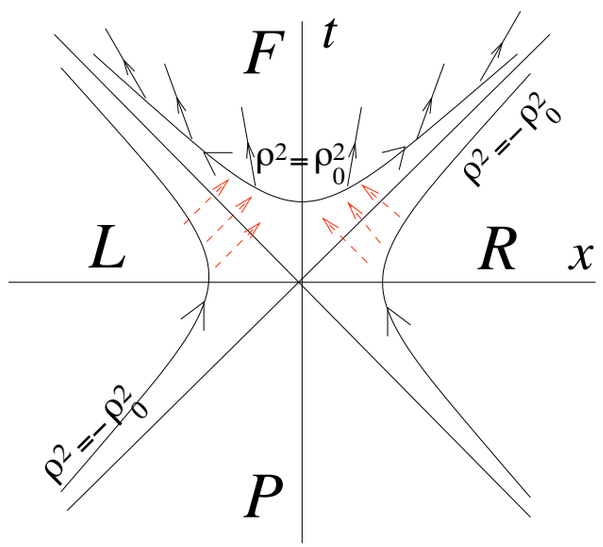
Dumitru, Nara,
Strickland, Venugopalan, etc.



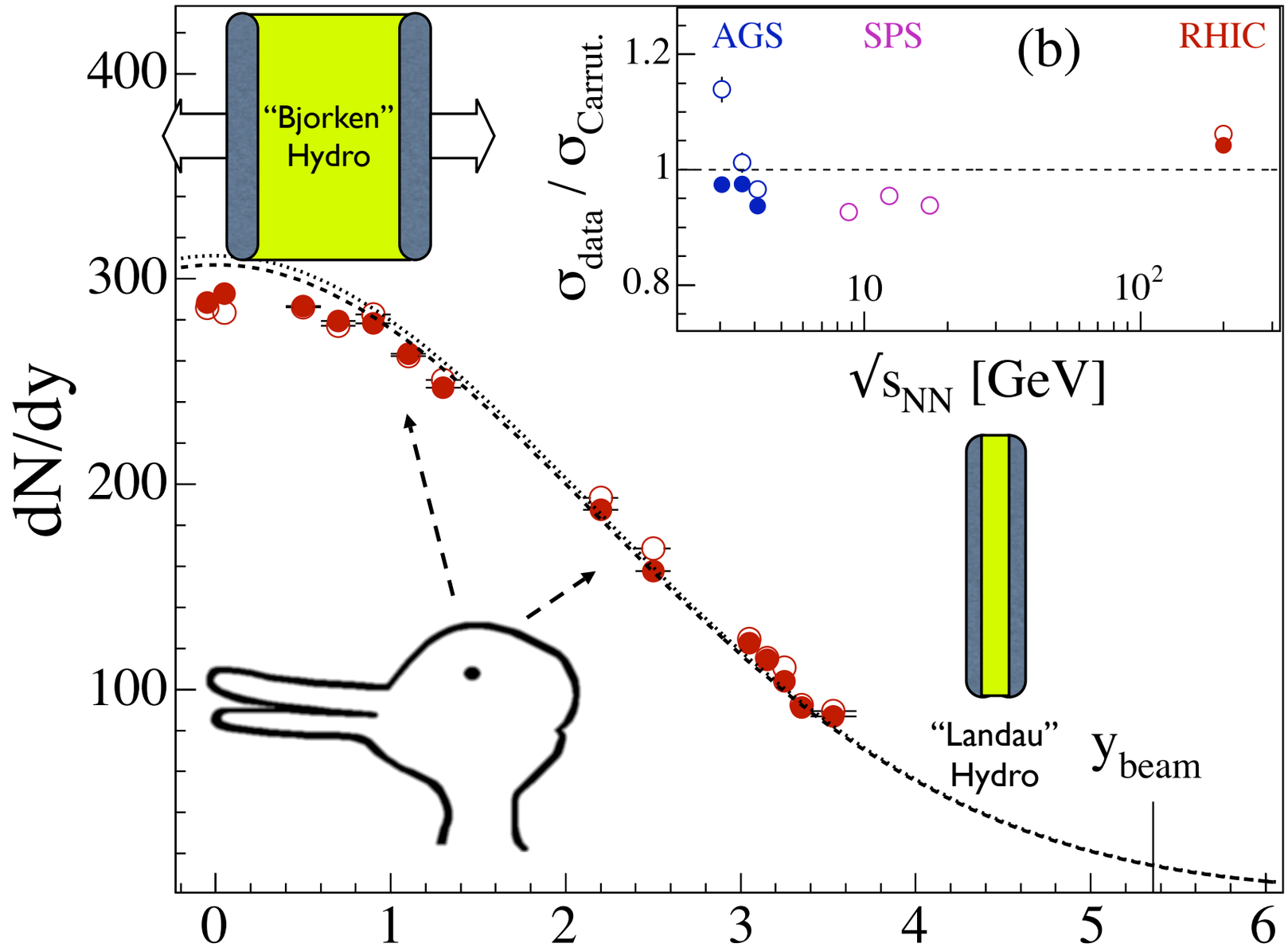


Does radiation tunneling
through a "horizon" just
appear thermal?

"local equilibrium" ~
"isotropization"
QCD fields?



Kharzeev & Tuchin



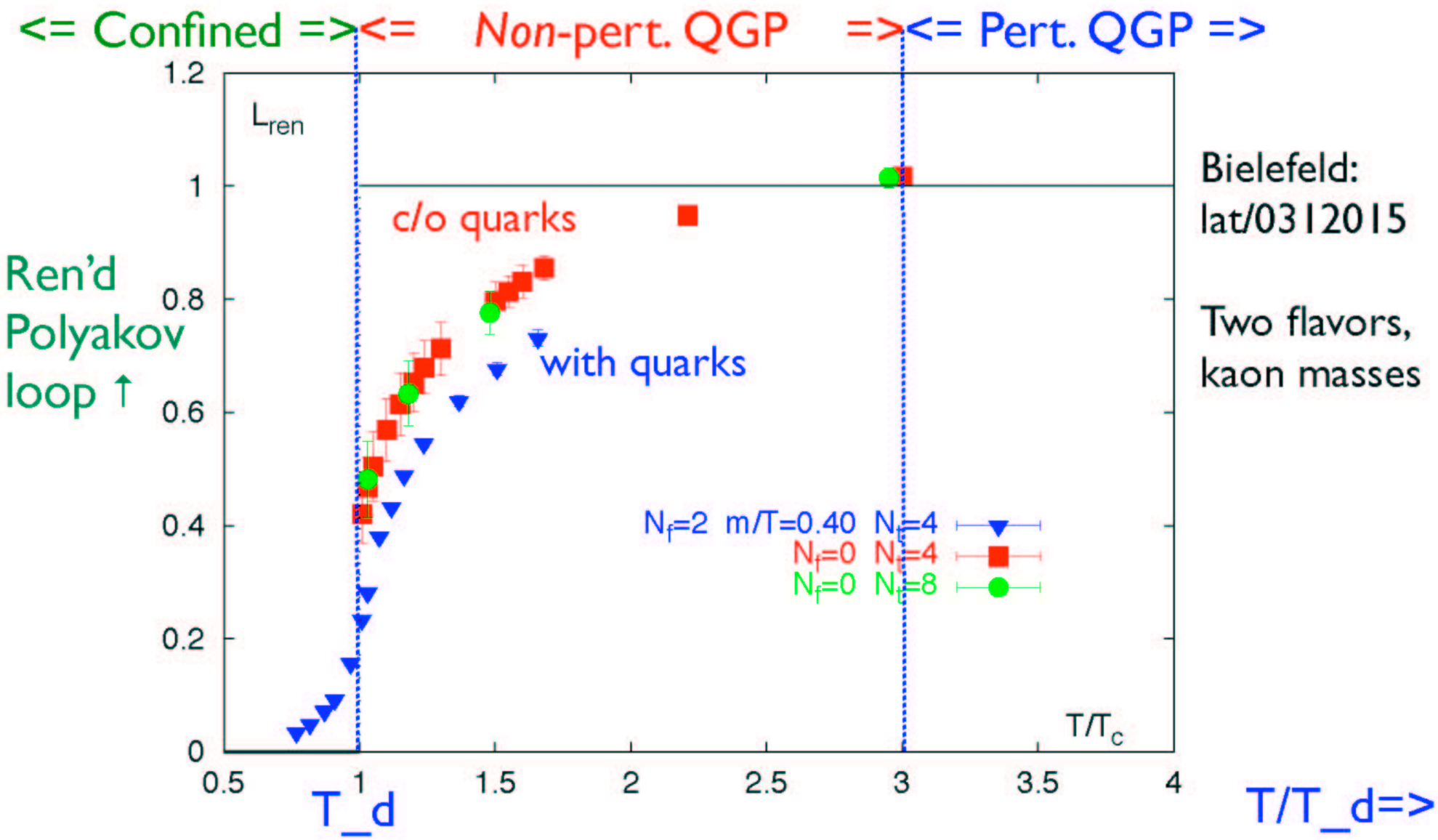
Is thermalization just at η=0 or all η (Landau or Bjorken)?

3+1D viscous calculations (down to t=0) are fundamental

Critical for any discussion of "phase transitions"

(and energy loss, e.g. to track density vs. time)

What does QCD tell us about degrees of freedom?

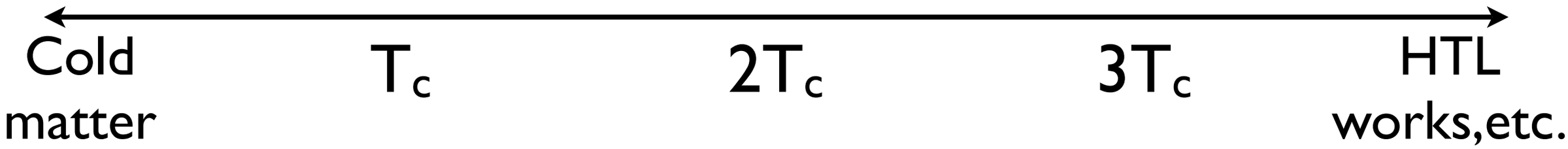


Bielefeld: lat/0312015

Two flavors, kaon masses

This plot is becoming the "new" diagnostic of deconfinement, the region from 1-3 T_c indicative of the sQGP (>3T_c unclear...)

0,1,2,3...∞



Hadrons

Bound States

Shuryak, Brown

Quasi-particles (massive q and g)

HTL

Constituent quarks?

Muller et al, Greco et al

What is the fundamental difference between these various concepts? (quantum numbers, width vs. mass?)

Does this mean that the high-temperature phase of QCD should best be thought as free fundamental excitations taking ballistic trajectories, with the quantum numbers of quarks and gluons?

QGP: q and g DOF
spin-1/2 q, vector g
w/ bare color
(or maybe constituent quark plasma)

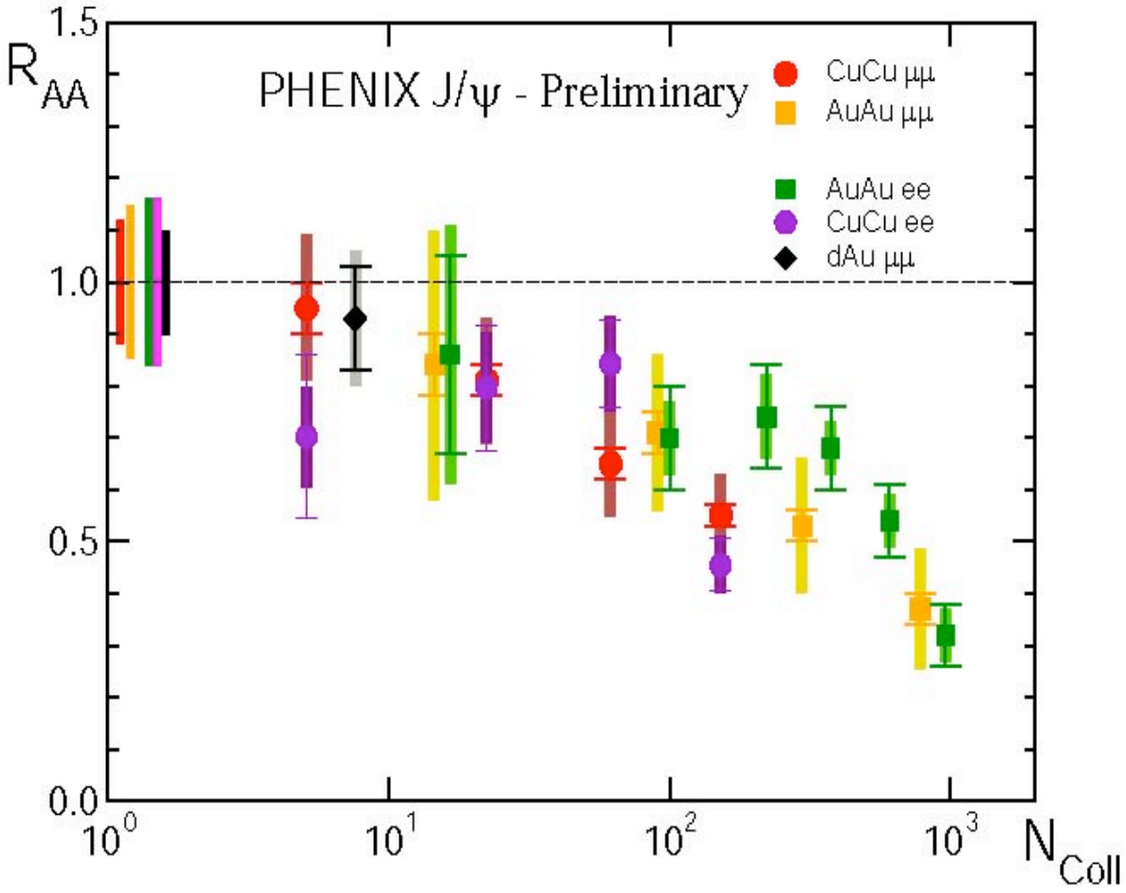
Koch, Majumder
Randrup,

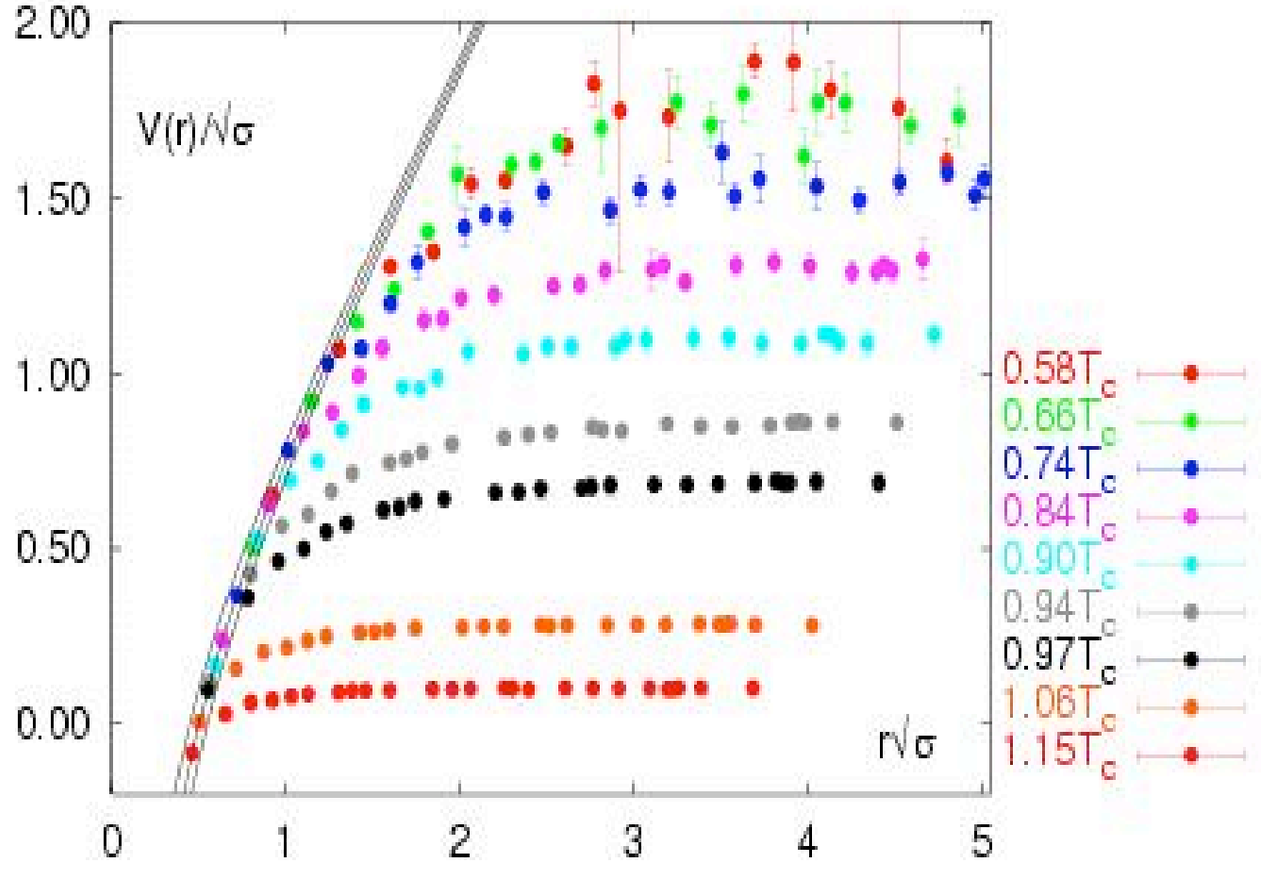
"sQGP" is a "strongly-interacting liquid", no obvious candidate for quasiparticle.
DOF α ϵ/T^4

Son, Rajagopal,
Müller, McLerran

cf. HTL: $m \sim gT$, $\Gamma \sim g^2 T$

What Do Quarkonia Teach Us?

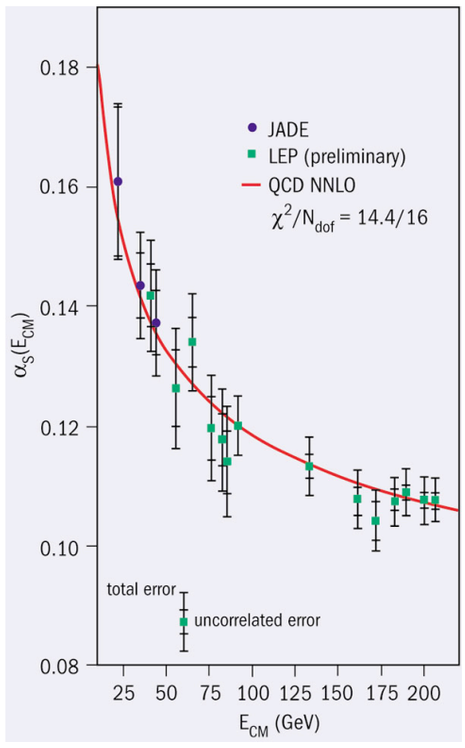


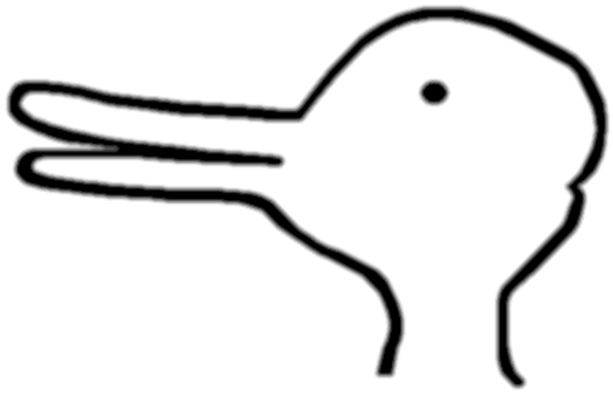


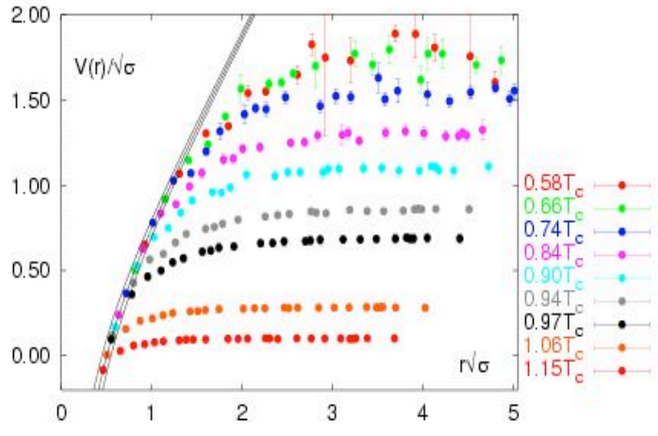
Are we really sensitive to a modified potential, deconfining heavy quarks in onium states?
How does this connect with "thermodynamic" DOFs?
Why do various mechanisms give "N_{part} scaling"?

So what are we talking about (and when are we talking about them)?

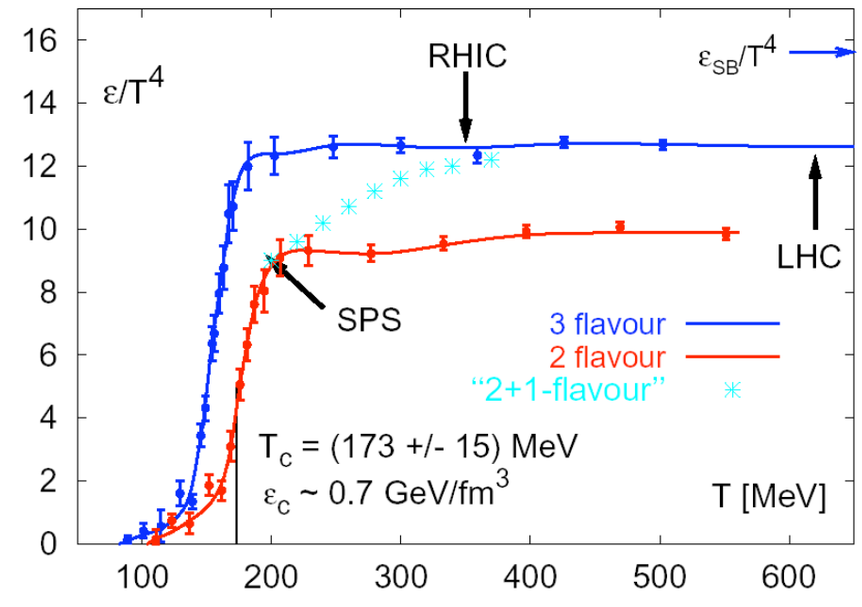
Microscopic DOFs?





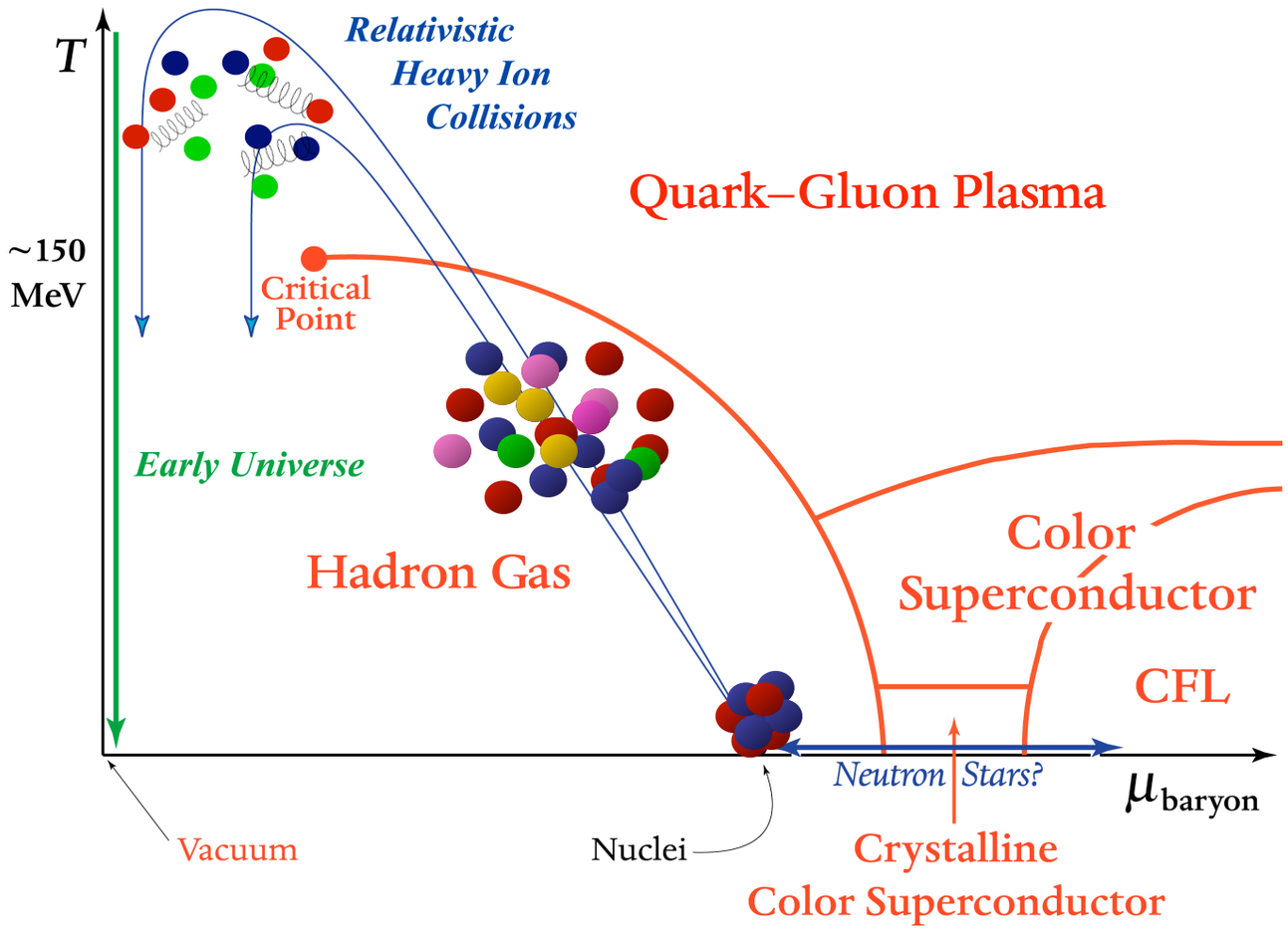


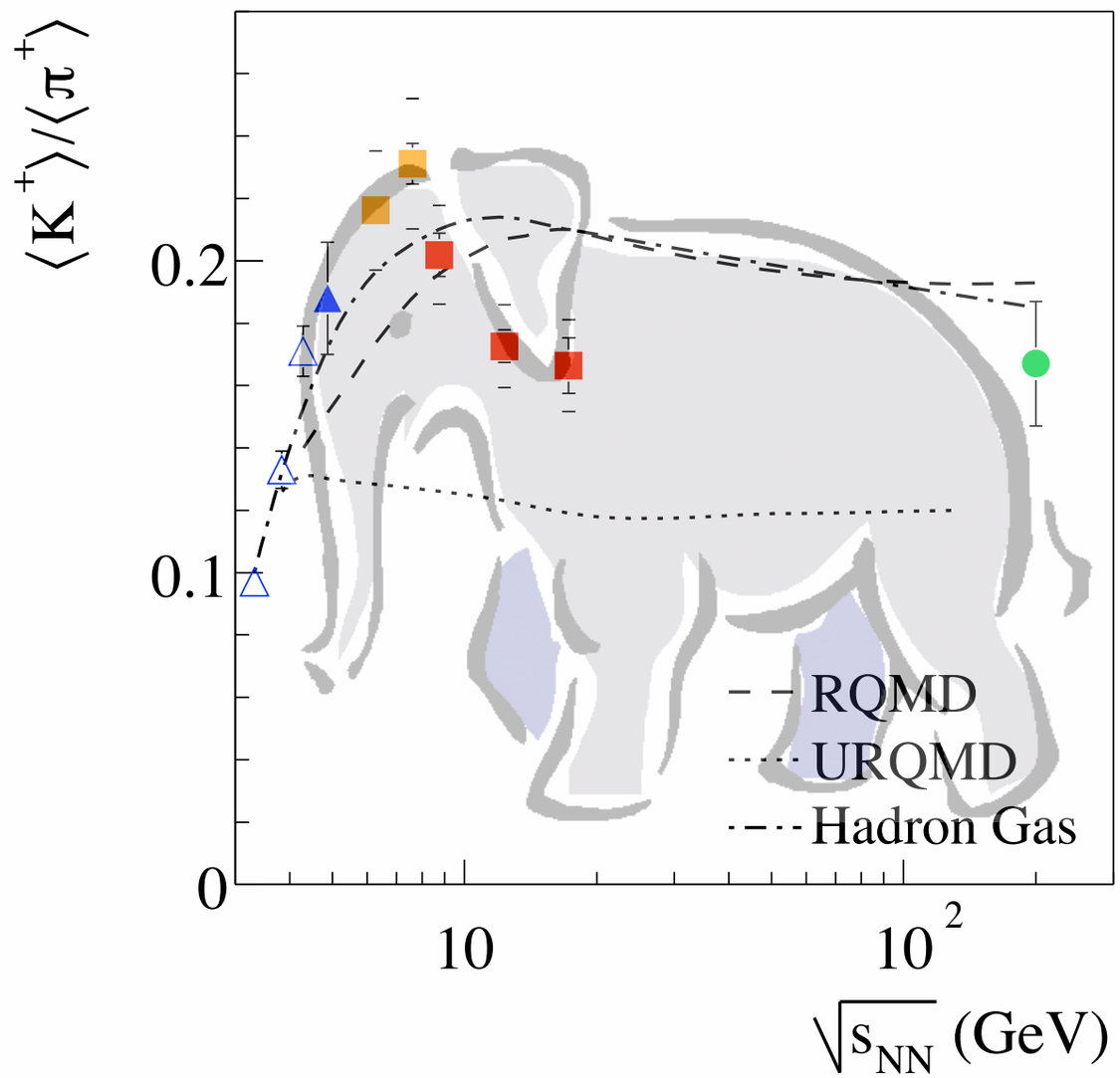
Macroscopic DOFs?



This question must be tackled explicitly and clearly to avoid confusion and contradiction later

Phase Transitions





If RHIC *can* address the NA49 "horn" (trunk?)
(low-luminosity, low-energy scan)
then we probably *should* (to remove ambiguity )

So we have (at least)
3 big questions about QCD:

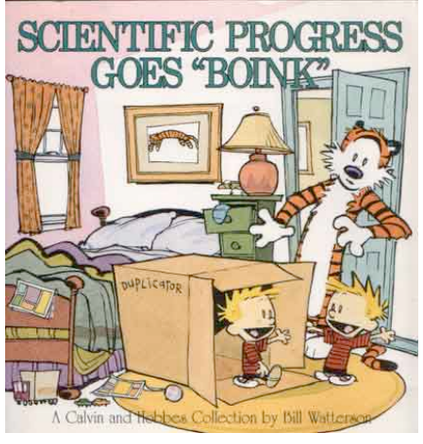
1. Entropy Creation (Thermalization)
2. Degrees of freedom (Hydro Evolution)
3. Phase Transitions (Freezeout)

Do we have the raw material to clearly formulate "4 Questions" for each of them?

"New Directions" group thinks yes.

Necessary for RHIC II science case.

Paths to Progress



Few completely "New Directions" for the field
(in the sense of brand-new measurements or calculations)

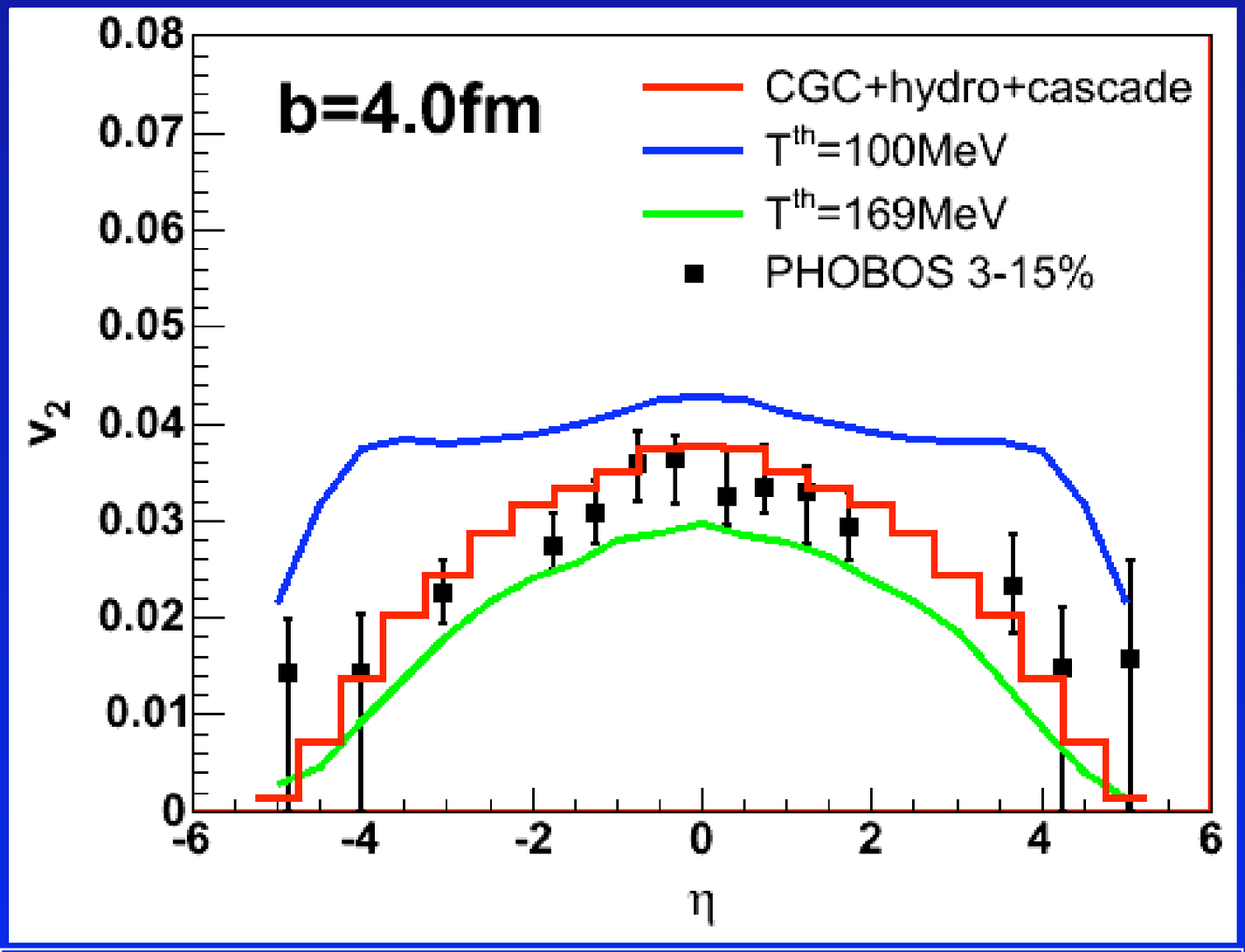
There is still a lot of interesting ground to map out,
even in "familiar" physics topics

Still a lot of room for additional work

- Small group discussions (e.g. Boulder Workshop II)

- What about a new "yellow book" for the field,
including critical discussions of basics?

$v_2(\eta)$ from CGC + Full 3D Hydro + Hadronic Cascade



Perfect fluid sQGP core + dissipative hadronic corona picture works in forward region!

PHOBOS data:
"Triangle shape"
prop. to $dN/d\eta$

$T^{th}=100$MeV:
"Trapezoidal shape"
Typical hydro result

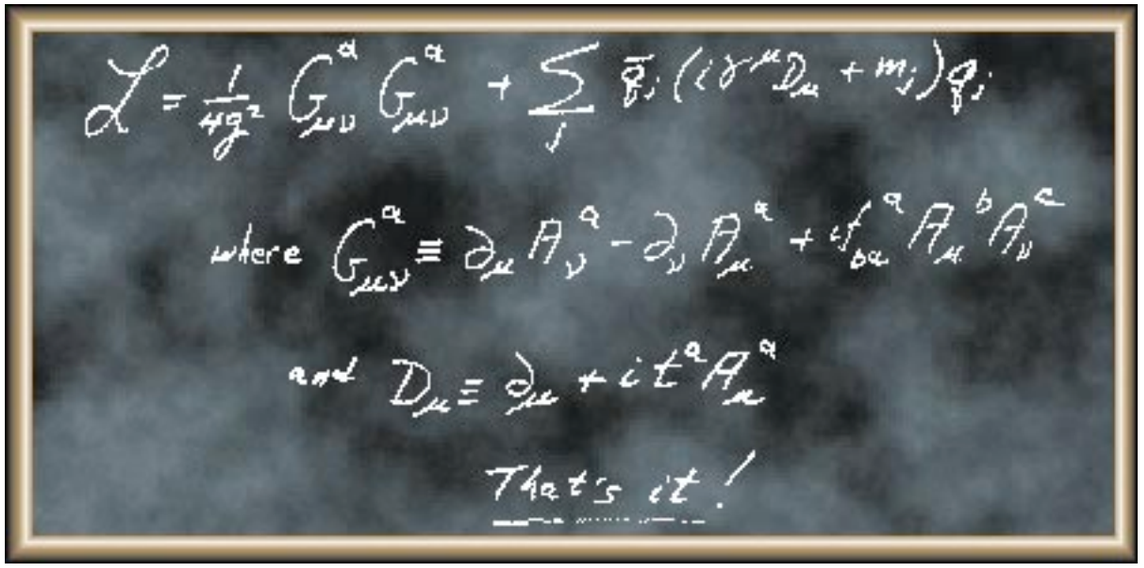
$T^{th}=169$MeV:
Triangle shape!
Just after hadronization

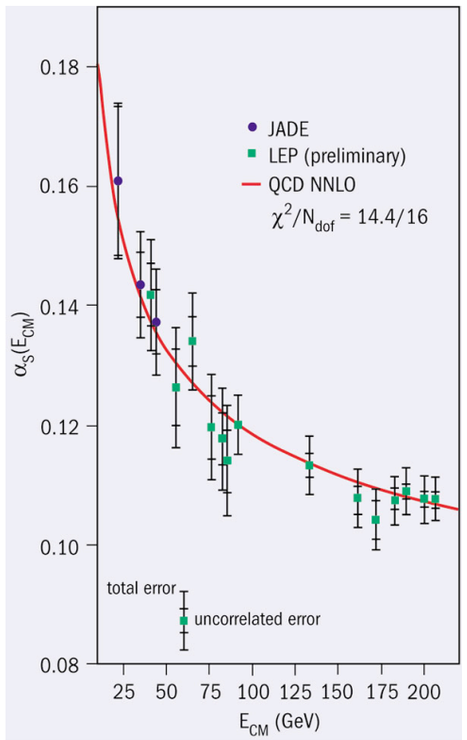
CGC+hydro+cascade:
Good agreement!

T. Hirano, QGPTH05
(August 20005, Vienna)

QCD:

Lagrangian tells us that "free" quarks and gluons are the primary degrees of freedom in nature





pQCD:

Factorization theorems suggest that we can abstract away the "soft" physics in the limit of large Q^2

Lattice:

At high temperatures, there is a change in the the number of degrees of freedom