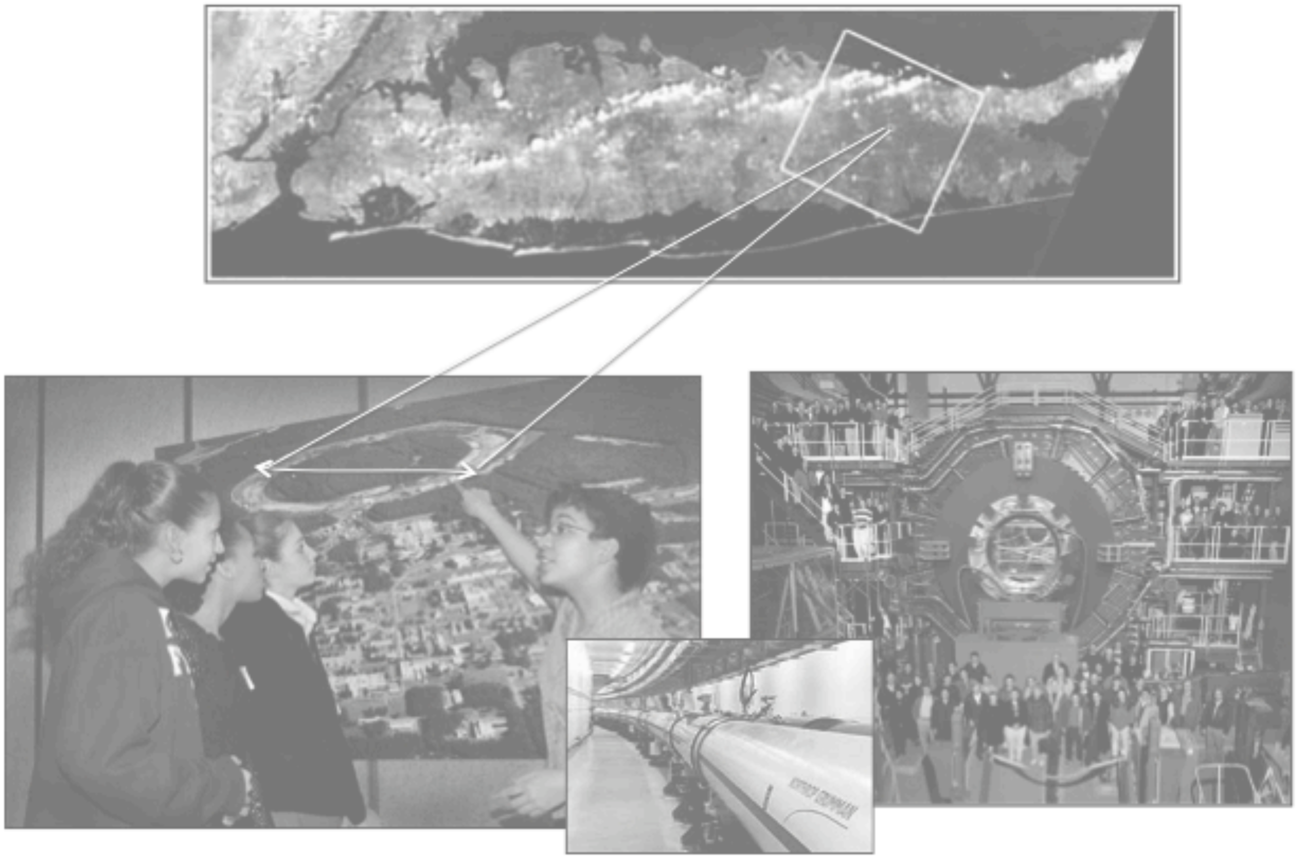
On the interplay of Lattice QCD Calculations and Heavy Ion Experiments

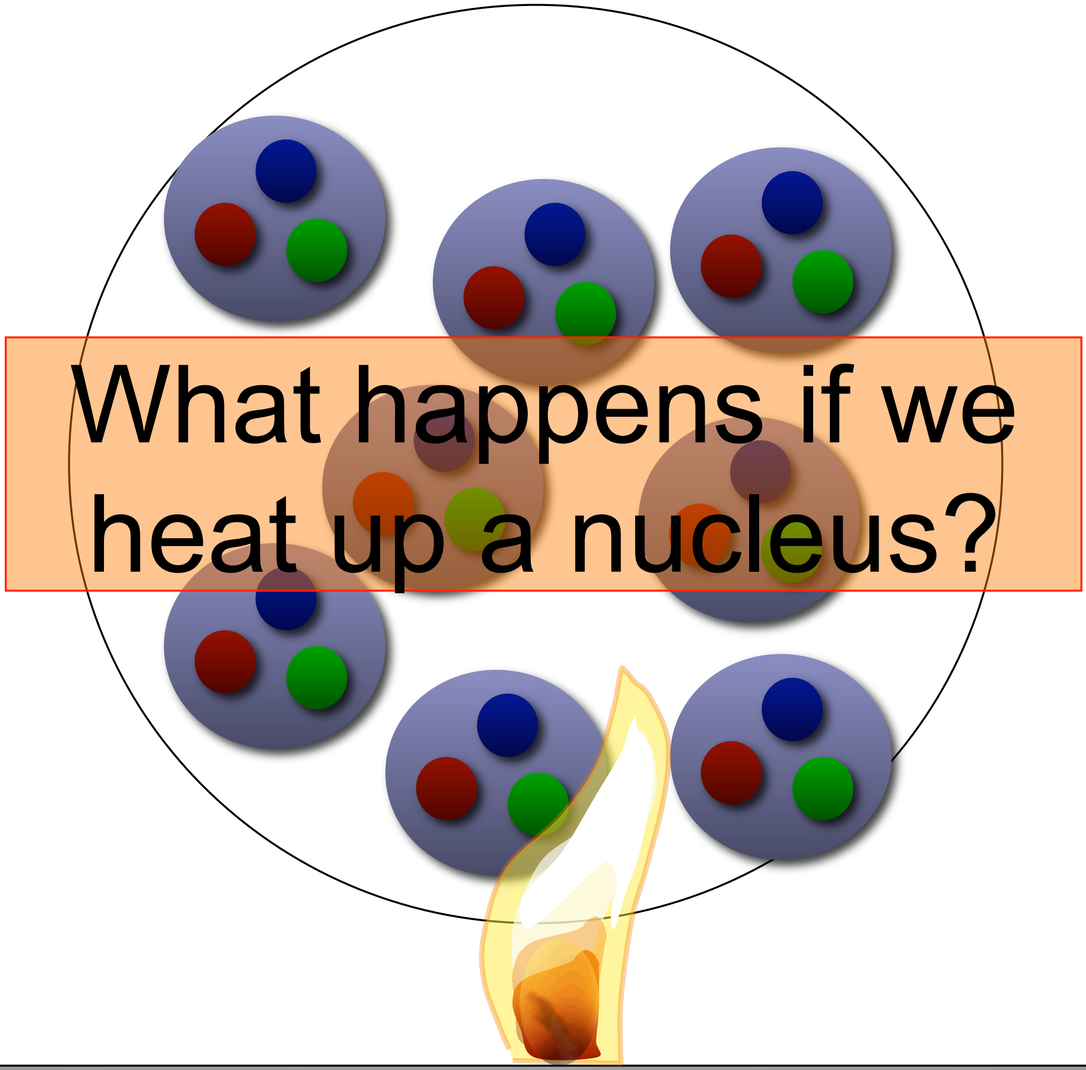
Paul Sorensen

BROOKHAVEN NATIONAL LABORATORY

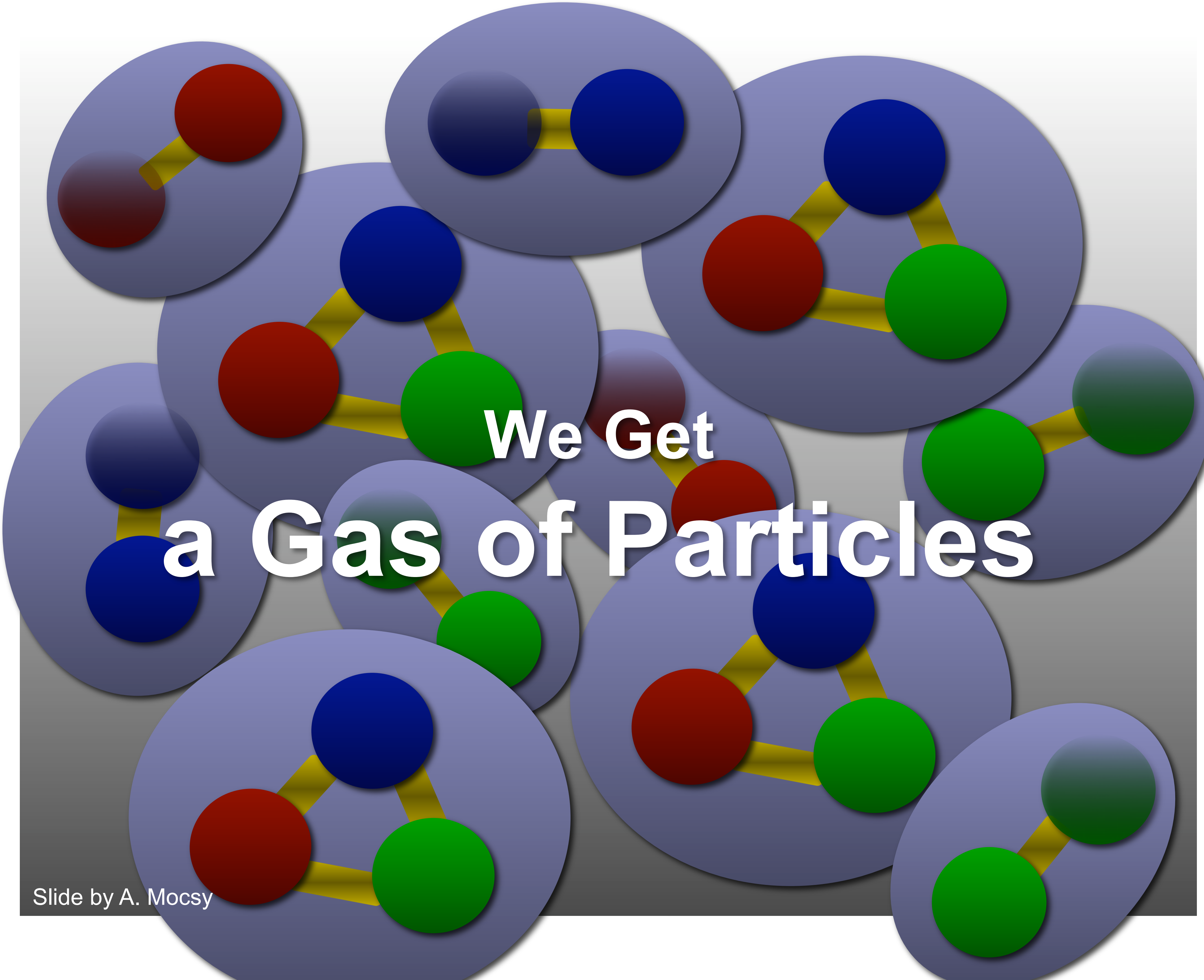


USQCD Collaboration Meeting, April 16th, 2010

Creating Quark Gluon Plasma

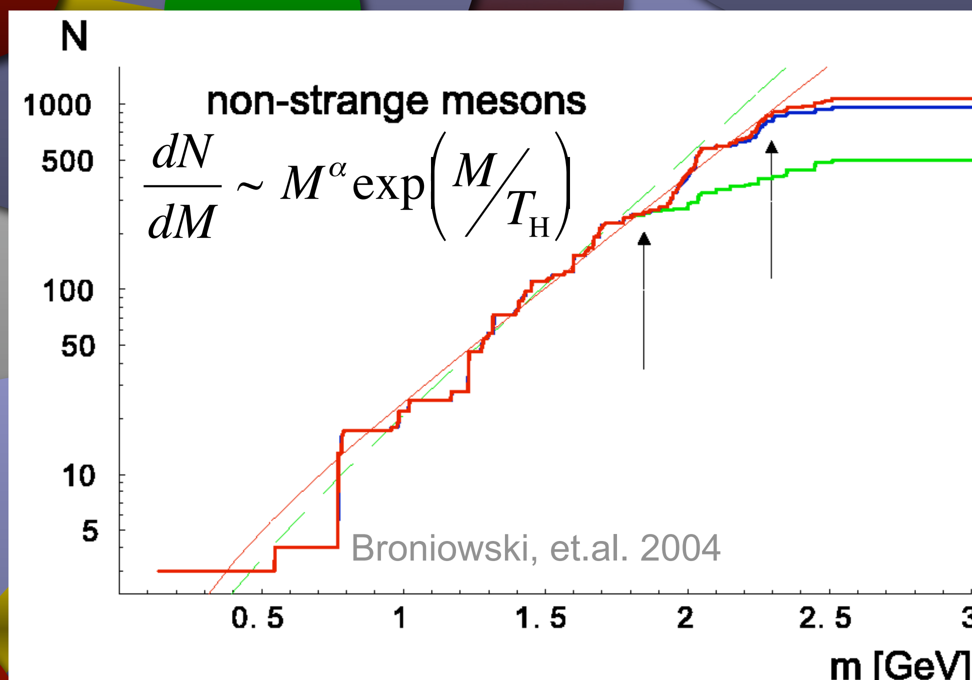


We Get a Gas of Particles

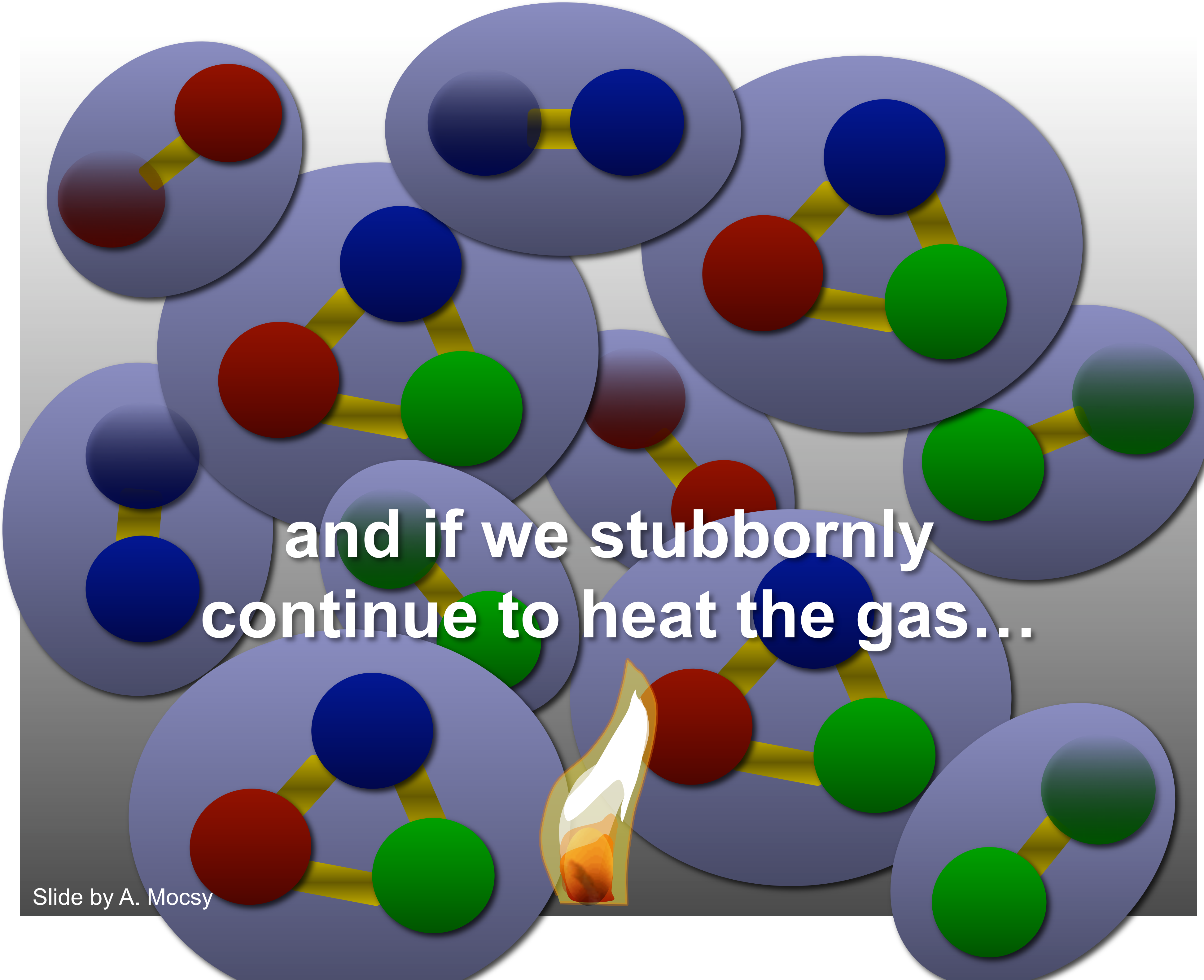


But, the number of hadronic states grows exponentially.

This implies a maximum temperature for a hadron gas [Hagedorn] ***T_H=170 MeV***



Slide by A. Mocsy

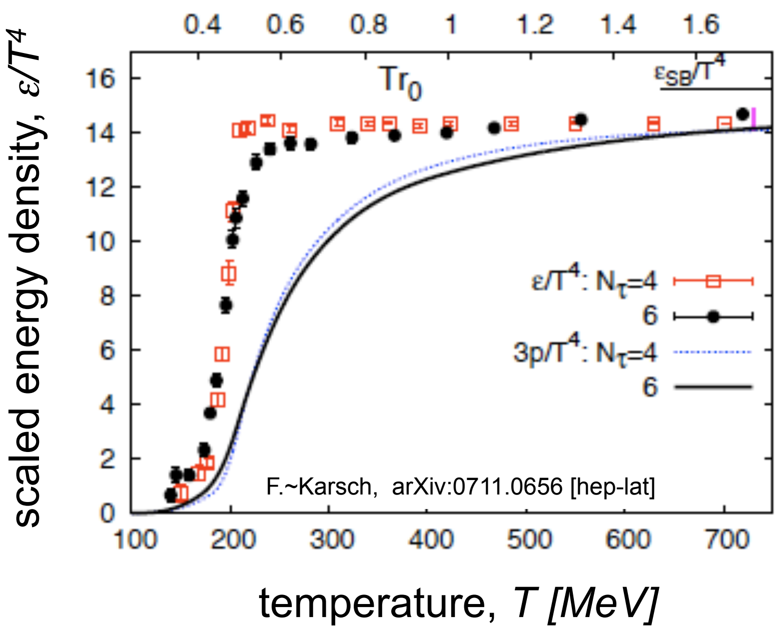

and if we stubbornly
continue to heat the gas…
Slide by A. Mocsy


Deconfinement to the rescue!
quarks become free
A Quark-Gluon
Plasma is formed
Slide by A. Mocsy

QGP and Lattice QCD

Quark Gluon Plasma established theoretically

Lattice calculations indicate a rapid crossover accompanied by an increase in the number of degrees of freedom



How do lattice and experiment intersect?

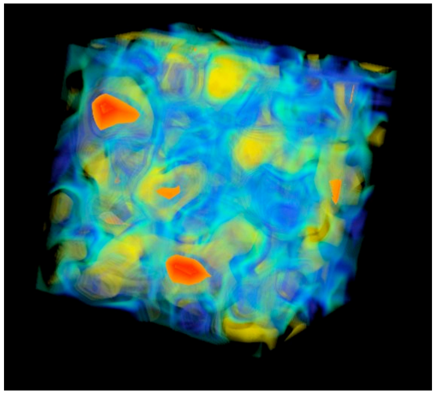
Intersection of Lattice and Experiment

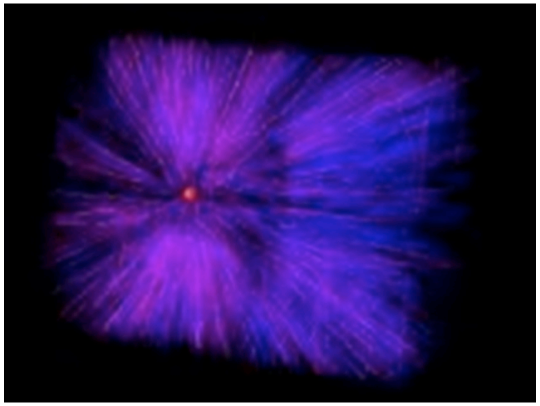
Quarkonium as a QGP Thermometer

QCD Phase Diagram

- The Phase Boundaries
- The Critical Point Search
- Hadronic Fluctuations

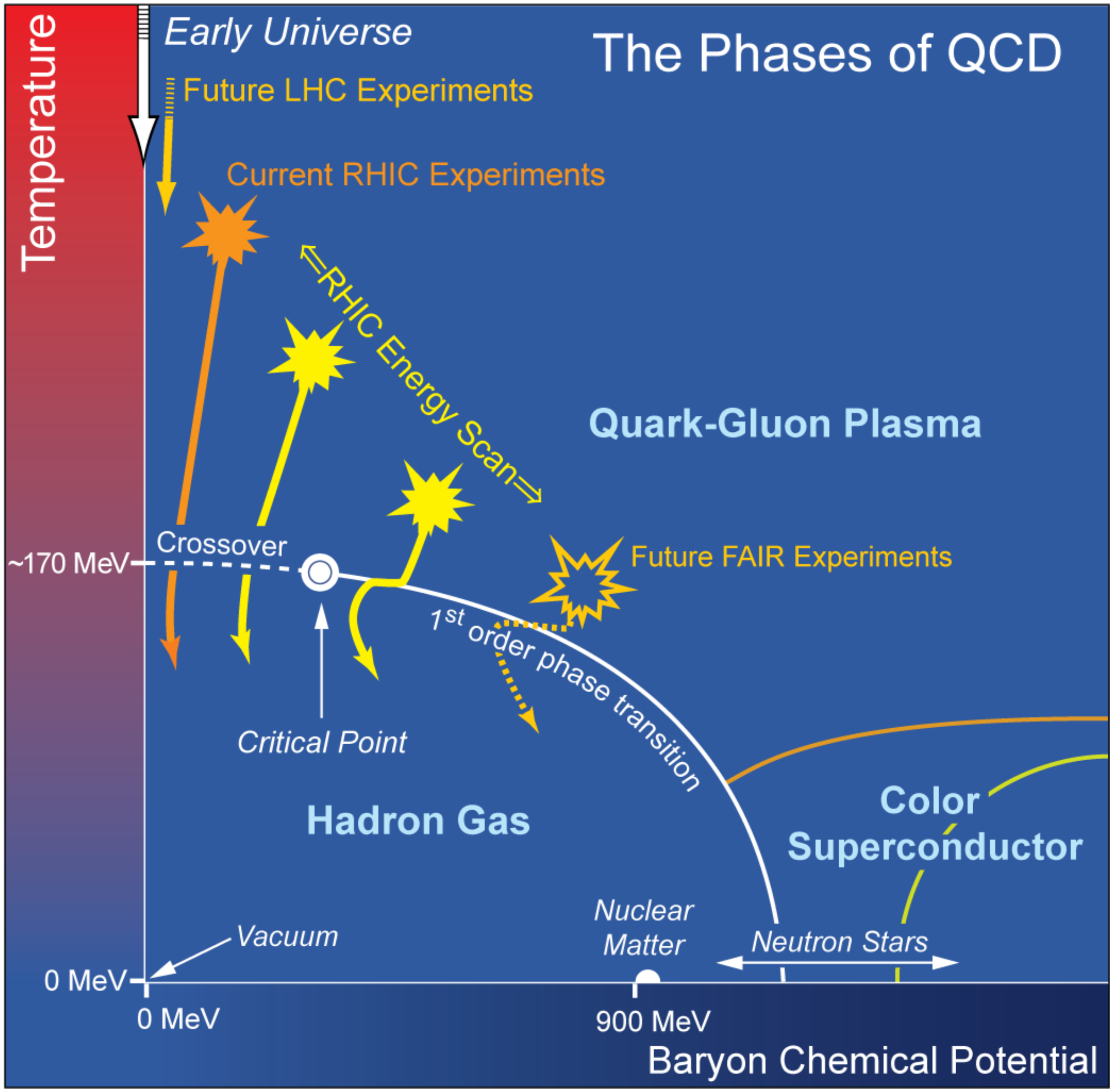
Equation of State and Expansion Dynamics



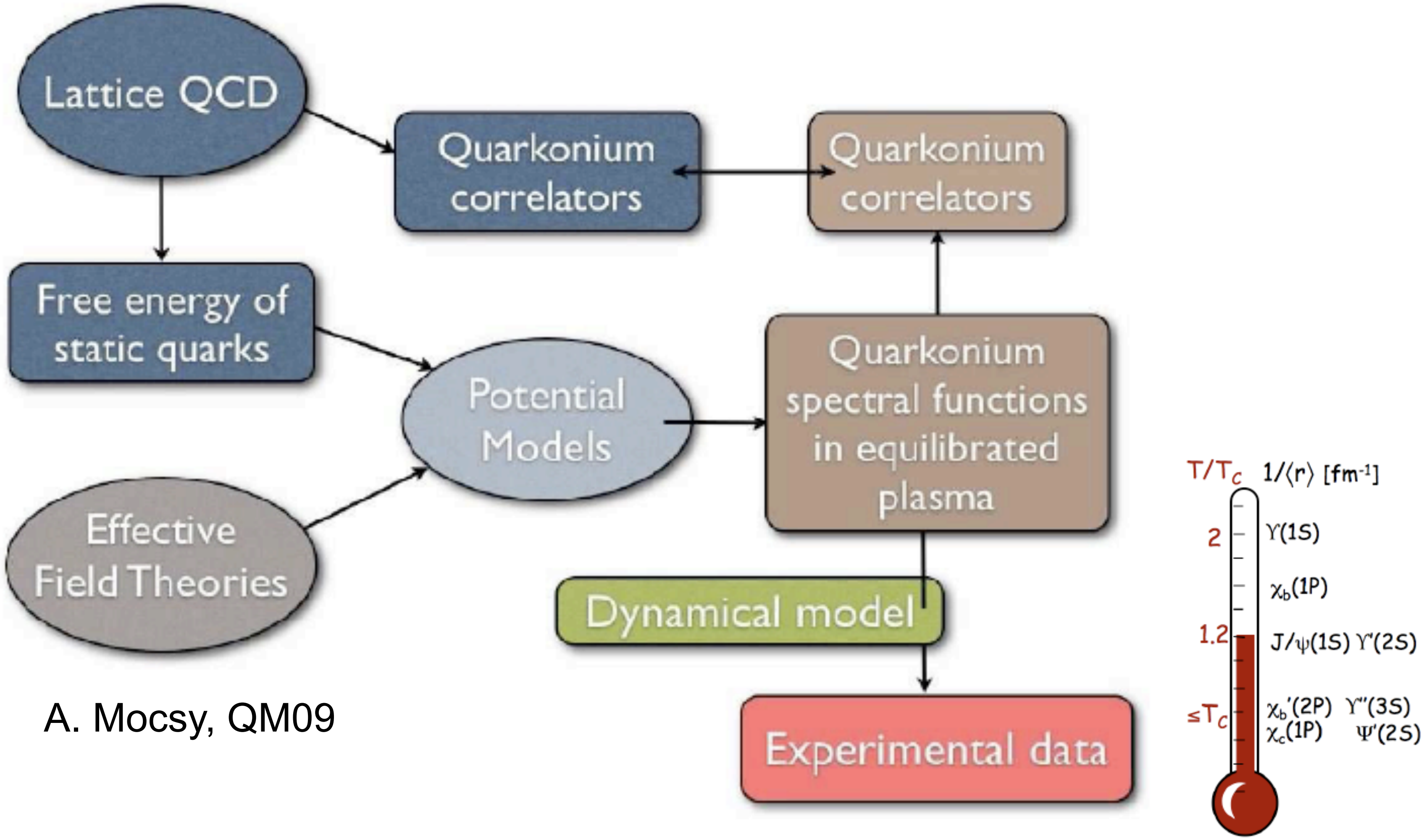



Critical Point and Onset of Deconfinement
5th International Workshop • June 8 – 12, 2009
Brookhaven National Laboratory, Long Island, New York, USA
TOPICS
PHASE DIAGRAM OF QCD
DECONFINEMENT AND CHIRAL SYMMETRY RESTORATION
EQUATION OF STATE AND TRANSPORT PROPERTIES
CORRELATIONS AND FLUCTUATIONS
EQUILIBRATION AND HADRONIZATION
EXPERIMENTAL RESULTS FROM RHIC AND SPS
FUTURE EXPERIMENTS
INTERNATIONAL ADVISORY COMMITTEE
F. Becattini, Florence
M. Gazdzicki, Frankfurt
K. Rajagopal, MIT
D. Röhrich, Bergen
P. Senger, GSI
P. Seyboth, MPI-Munich
E. Shuryak, Stony Brook
M. Stephanov, Chicago
W. Zajc, Columbia U.
LOCAL ORGANIZING COMMITTEE
F. Karsch, Chair
T. Ludlam
T. Satogata
P. Sorensen
G. Stephans
CONTACT
CPOD09, BNL, Upton, NY 11973 USA
cpod09@bnl.gov, http://www.bnl.gov/cpod

QGP Thermometer



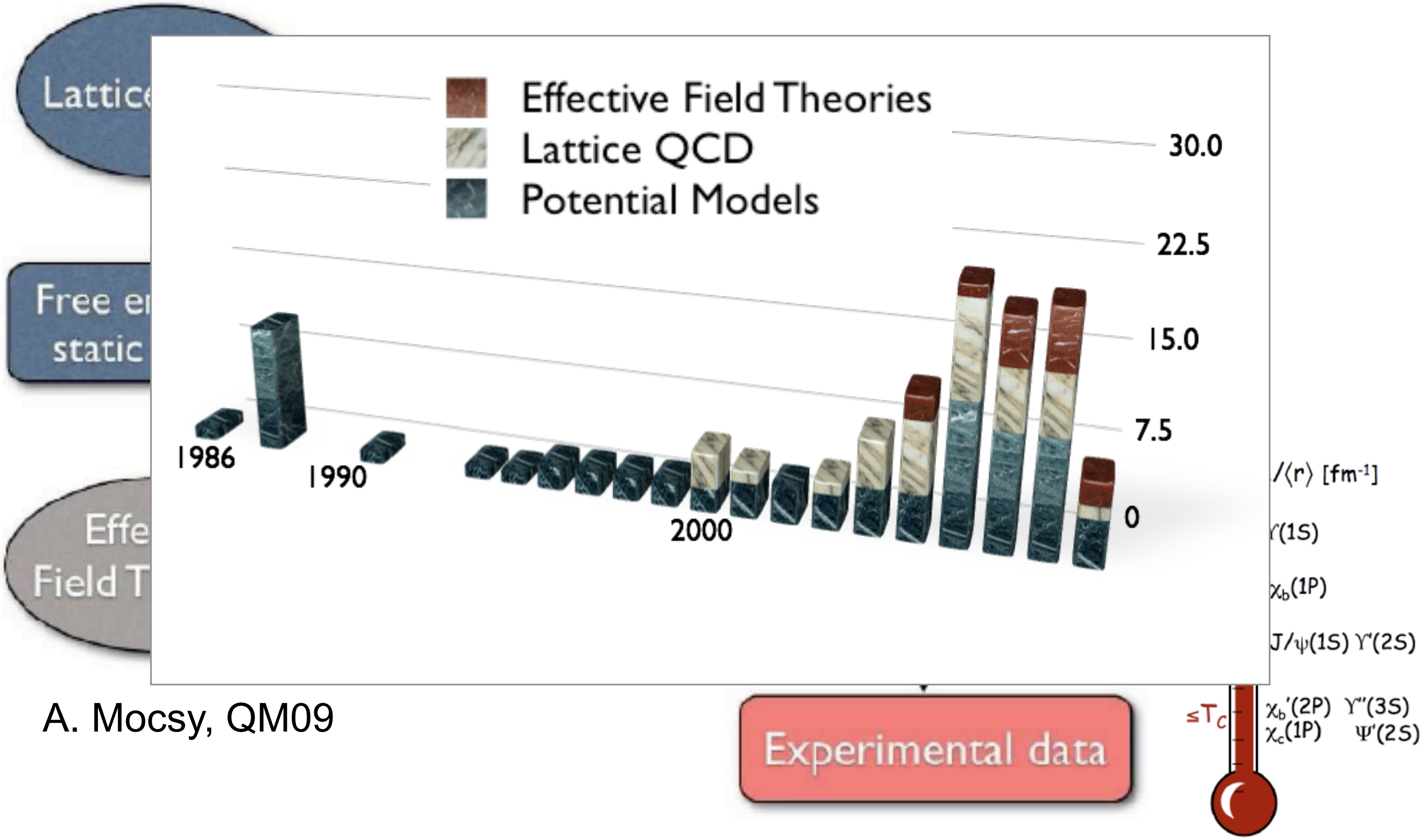
Calibrating the QGP Thermometer



A. Mocsy, QM09

Lattice Correlators and Free Energy are key components

Calibrating the QGP Thermometer

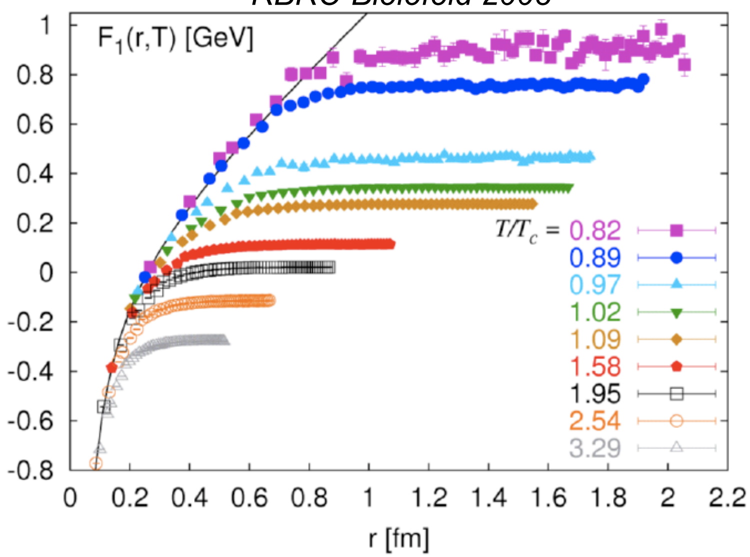


A. Mocsy, QM09

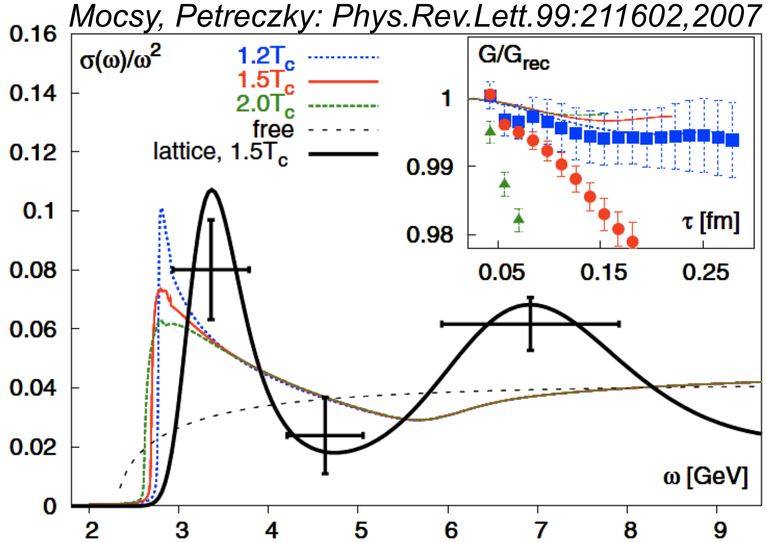
Lattice Correlators and Free Energy are key components

Lattice and Quarkonium

RBRC-Bielefeld 2008



Mocsy, Petreczky: Phys.Rev.Lett.99:211602,2007



Lattice calculations for the QQbar free energy clearly show screening

But lattice correlators show little modification

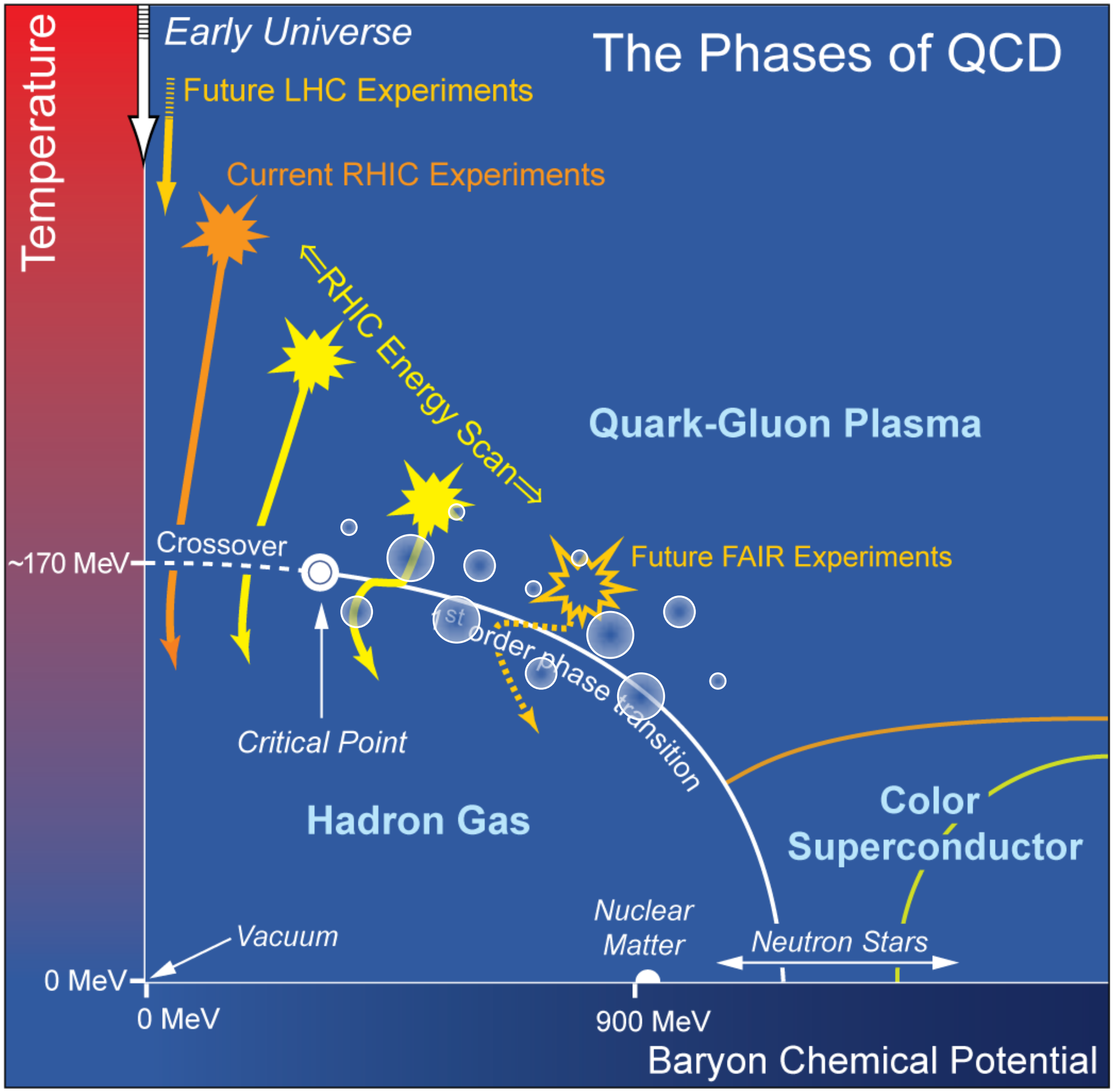
Lattice U and F used to constrain the potential in a potential model

A threshold enhancement can explain the screening and the correlators

Intersection with experiment:

- ➡ Alters suppression sequence
- ➡ Charm correlations will give low mass dileptons and D-D correlations
- ➡ Charm recombination

Phase Transitions



Do the Little Bangs Boil?

Is there a 1st or 2nd order phase transition at zero μ_B? **No!**

Lattice QCD and Data

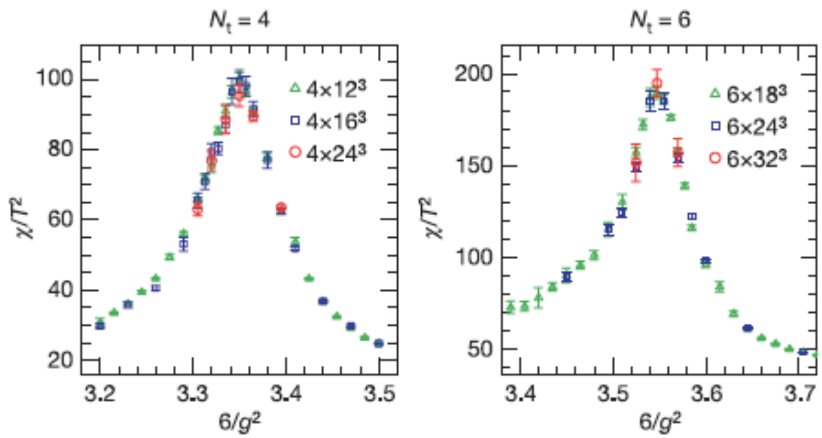
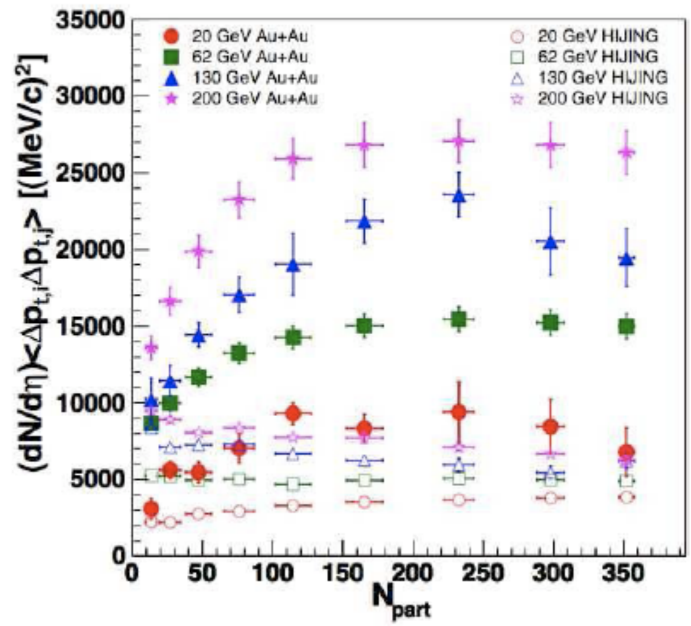


Figure 1 | Susceptibilities for the light quarks for $N_t = 4$ and for $N_t = 6$ as a function of $6/g^2$, where g is the gauge coupling. (T grows with $6/g^2$.) The largest volume is eight times bigger than the smallest one, so a first-order phase transition would predict a susceptibility peak that is eight times higher

Aoki, Y., Endrodi, G., Fodor, Z., Katz, S. D. & Szabó, K. K. *Nature* ***443, 675–678***



$$\sigma_{XY} = \frac{\langle XY\rangle - \langle X\rangle\langle Y\rangle}{\langle N_{ch}\rangle} \propto \frac{\chi_{XY}}{T^2}$$

No evidence for the growth of fluctuations with system-size that one expects for a 1st or 2nd order phase transition:

Do the Little Bangs Boil?

Is there a 1st or 2nd order phase transition at zero μ_B? **No!**

Lattice QCD and Data

Data don't show evidence of fluctuations from a 1st or 2nd order phase transition

consistent with Lattice expectations of a smooth cross-over from QGP to hadron gas at zero μ_B

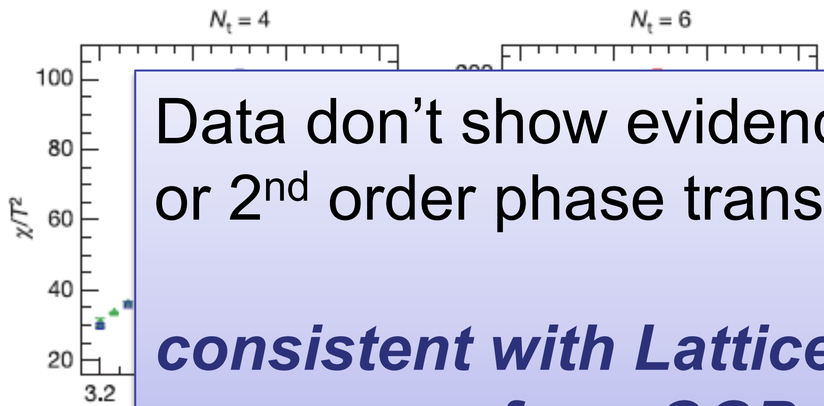
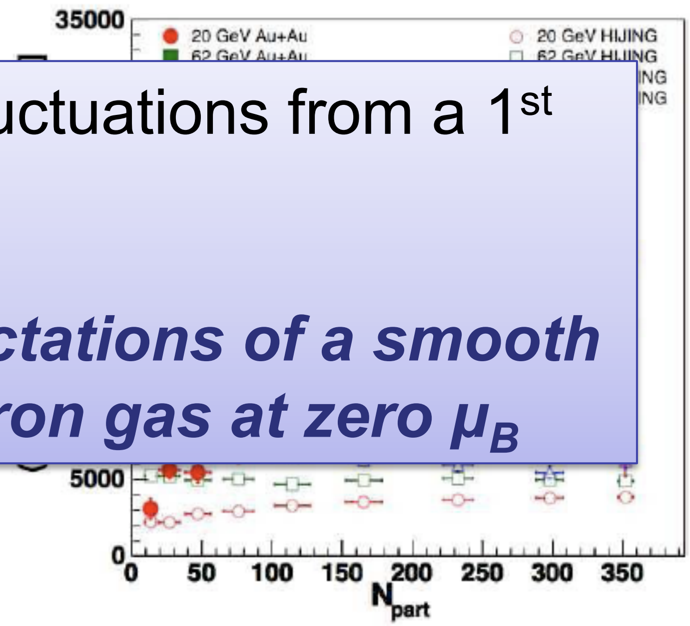


Figure 1 | Su... function of $6/g^2$, where g is the gauge coupling. (T grows with $6/g^2$.) The largest volume is eight times bigger than the smallest one, so a first-order phase transition would predict a susceptibility peak that is eight times higher

Aoki, Y., Endrodi, G., Fodor, Z., Katz, S. D. & Szabó, K. K. *Nature* ***443, 675–678***



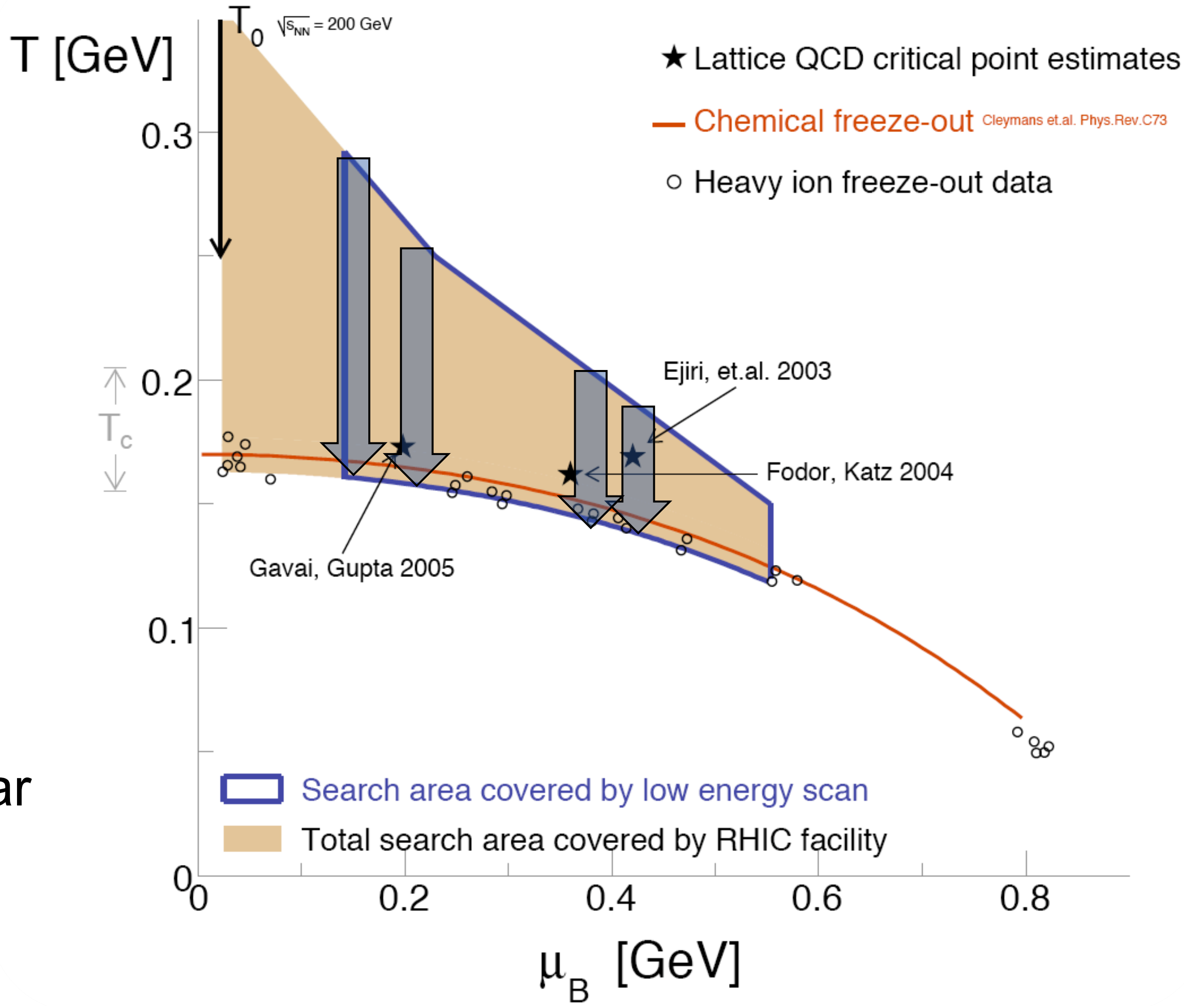
$$\sigma_{XY} = \frac{\langle XY \rangle - \langle X \rangle \langle Y \rangle}{\langle N_{ch} \rangle} \propto \frac{\chi_{XY}}{T^2}$$

No evidence for the growth of fluctuations with system-size that one expects for a 1st or 2nd order phase transition:

Search for a critical point at RHIC

In 1911, Rutherford discovered the nucleus, making him the first nuclear physicist

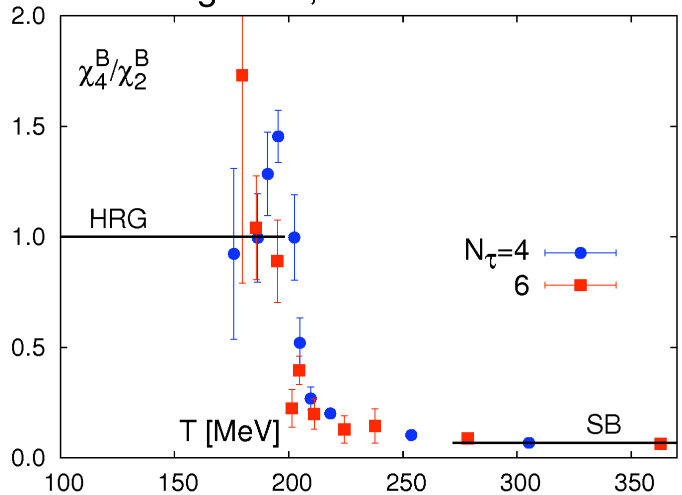
100 years later, RHIC will scan for new landmarks on the nuclear matter phase diagram



The experimental search is underway as we speak

Fluctuation of Conserved Charges and the Critical Point Search

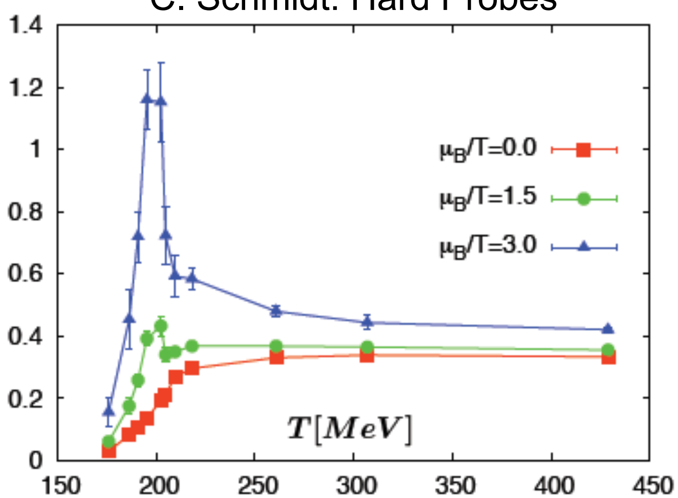
Cheng et al., arXiv:0811.1006

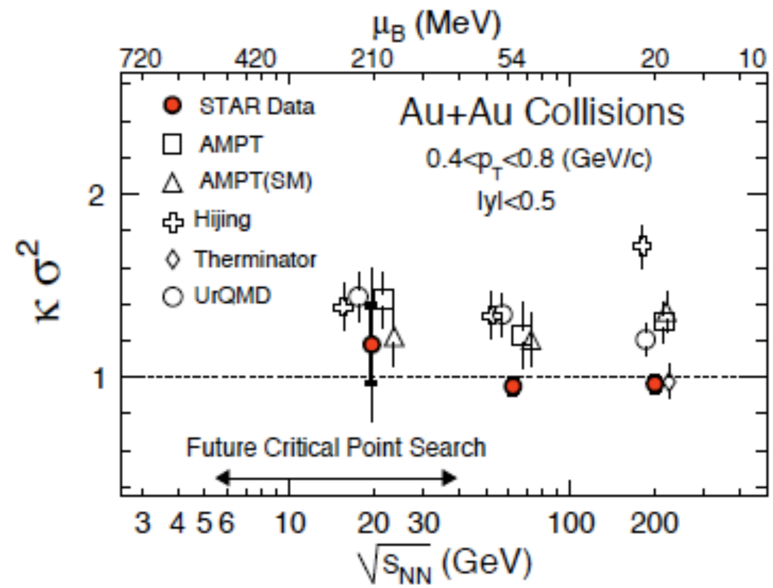


$$\kappa\sigma^2 = \frac{\chi_B^{(4)}}{\chi_B^{(2)}/T^2}$$

Data follow a linear superposition model for all system sizes with kurtosis time variance equal unity

C. Schmidt: Hard Probes

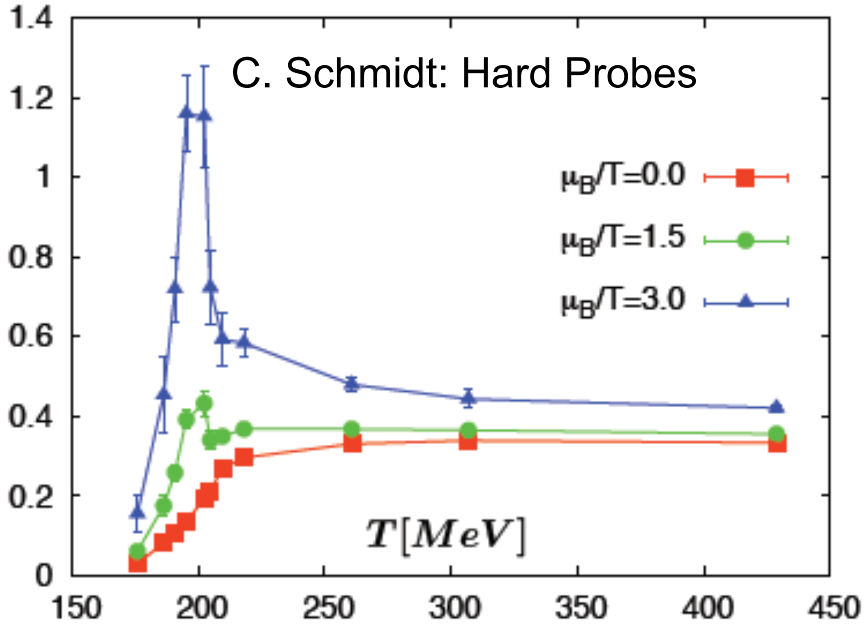


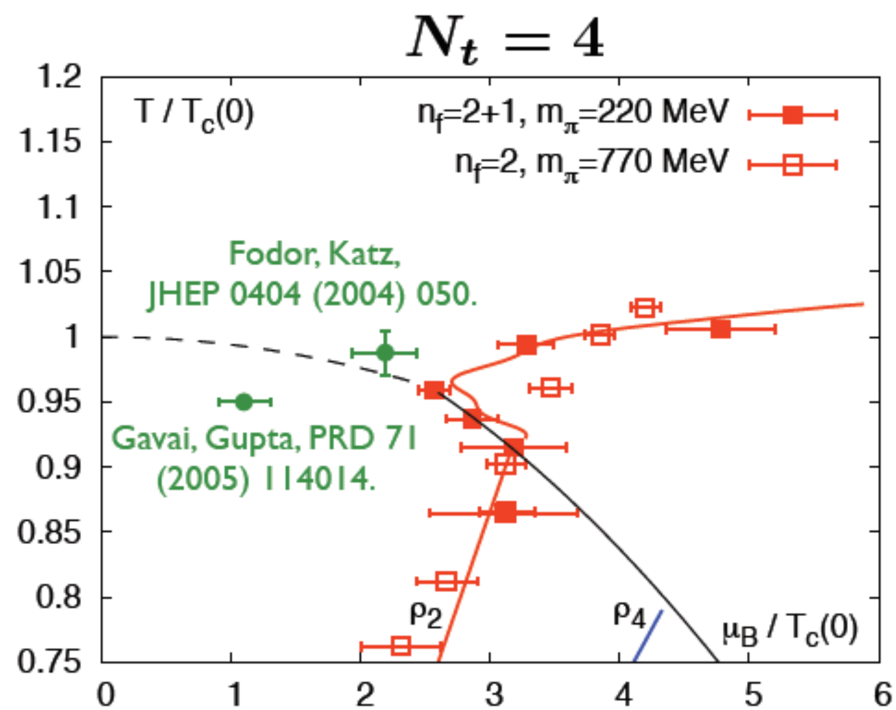


STAR: Submitted to PRL

Information from Lattice for Finite μ_B

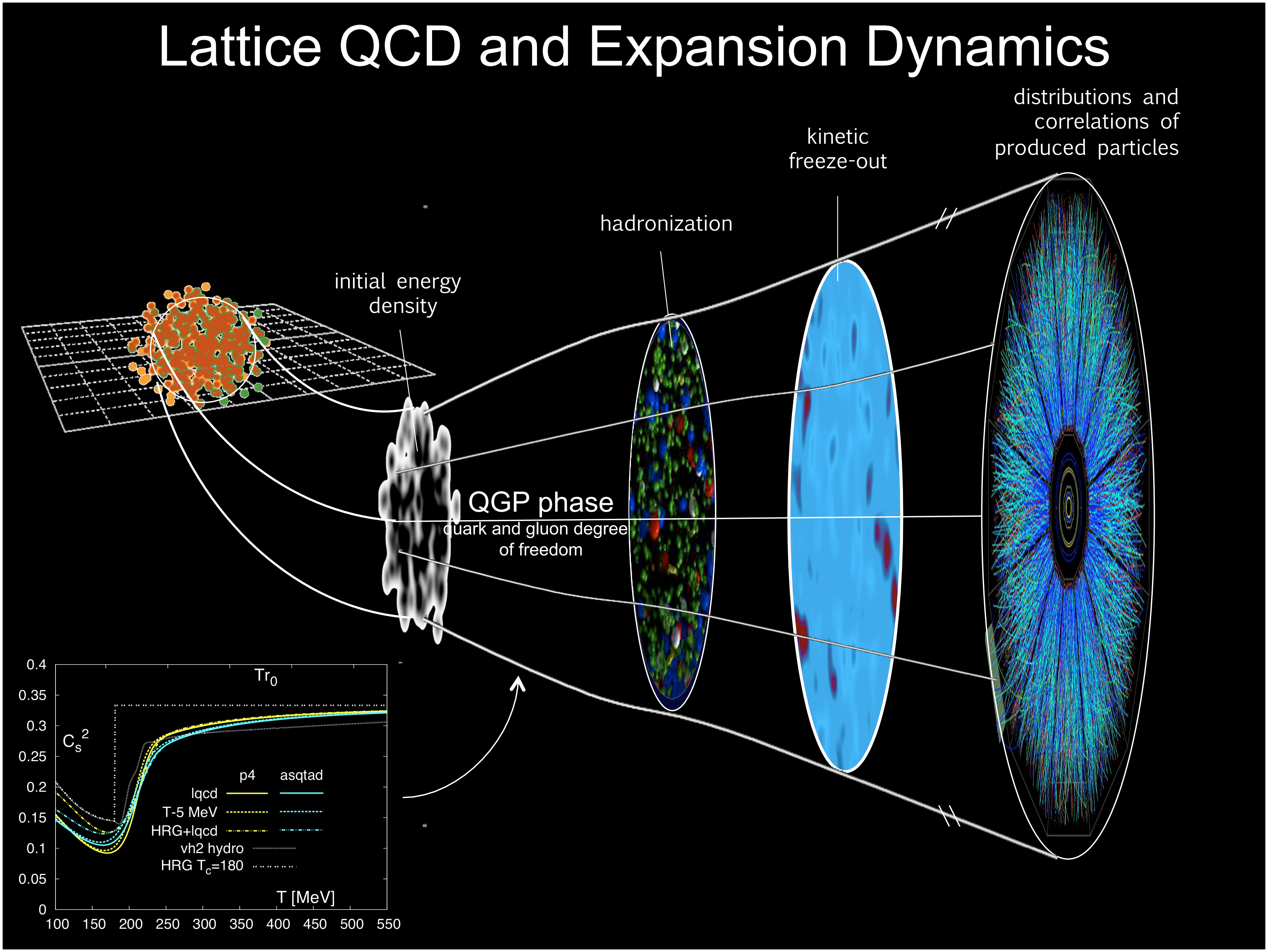
$$\frac{\chi_B}{T^2} = 2c_2^B + 12c_4^B \left(\frac{\mu_B}{T}\right)^2$$





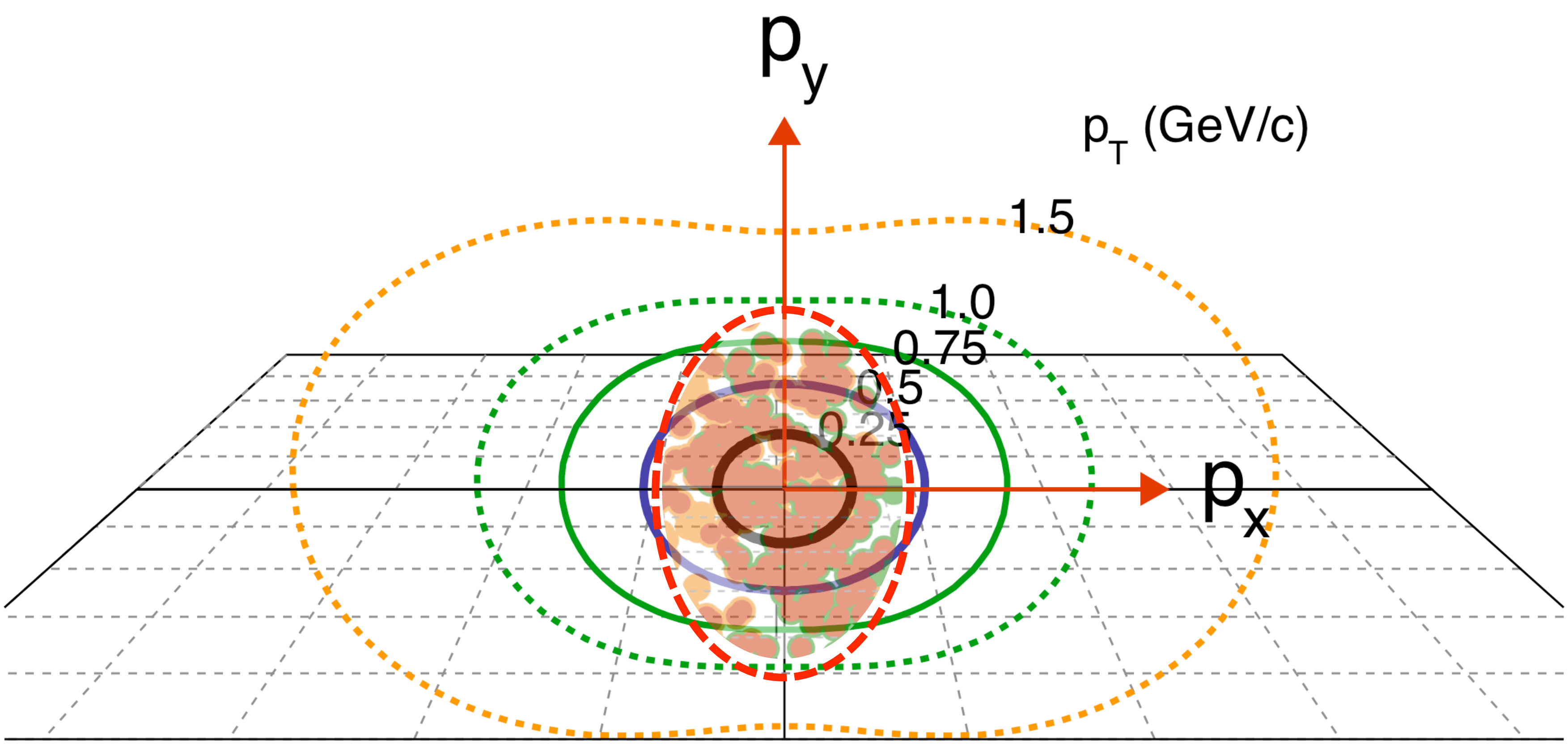
Lattice results at finite μ_B are of obvious importance to the critical point search:

both for where to look and what to look for


Lattice QCD and Expansion Dynamics
distributions and correlations of produced particles
kinetic freeze-out
hadronization
initial energy density
QGP phase
quark and gluon degree of freedom
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Tr_0
C_s^2
p4
asqtad
lqcd
T-5 MeV
HRG+lqcd
vh2 hydro
HRG T_c=180
T [MeV]
100
150
200
250
300
350
400
450
500
550

Azimuthal Distributions

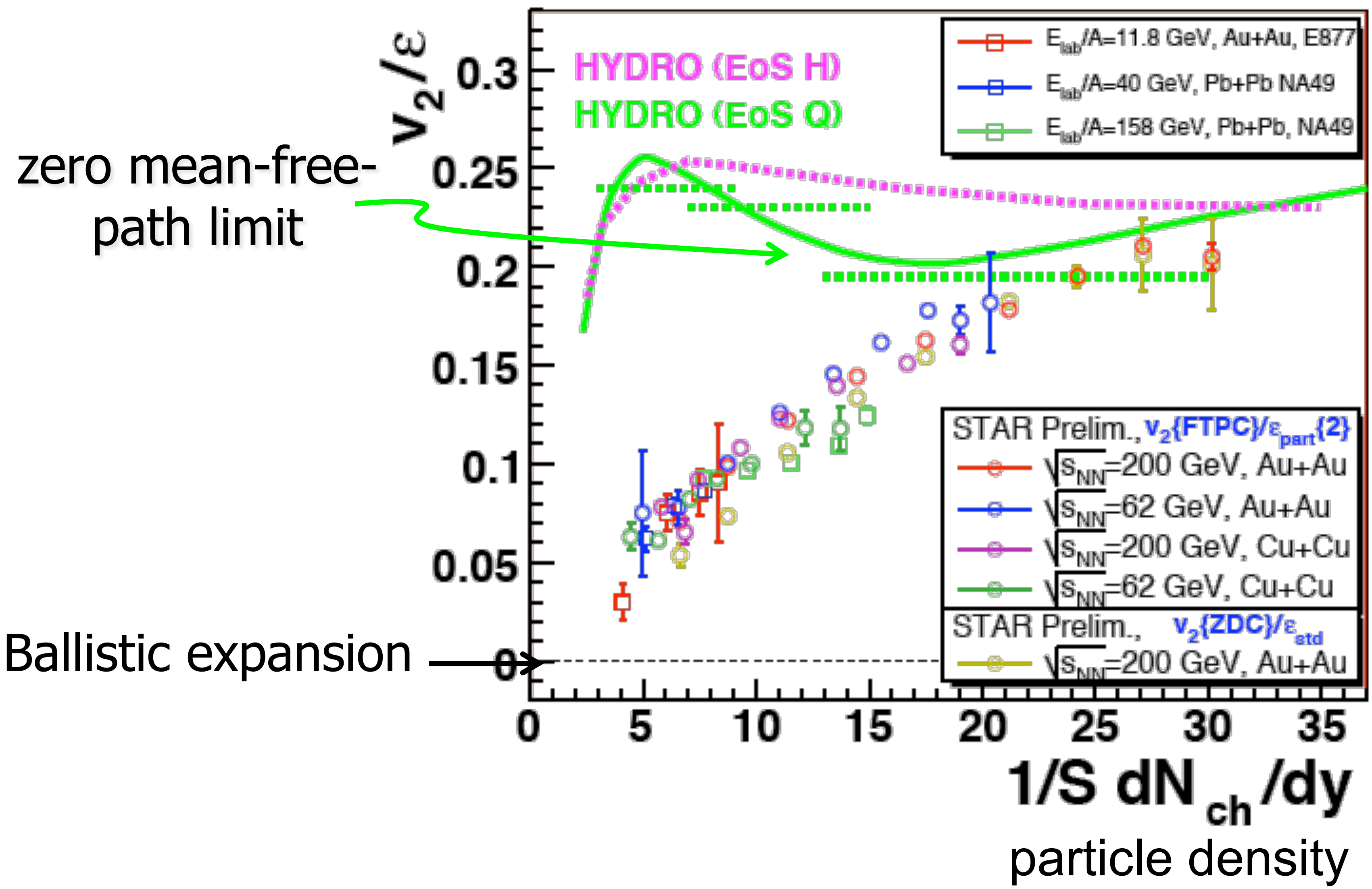
Collision of two Lorentz contracted Gold nuclei



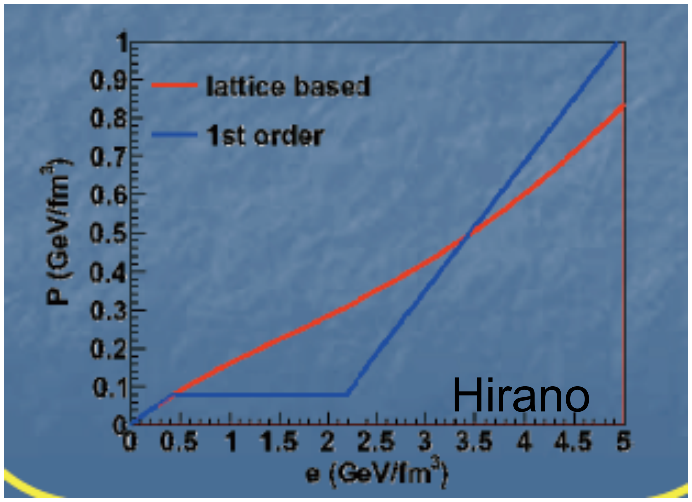
Are particles emitted at random angles?

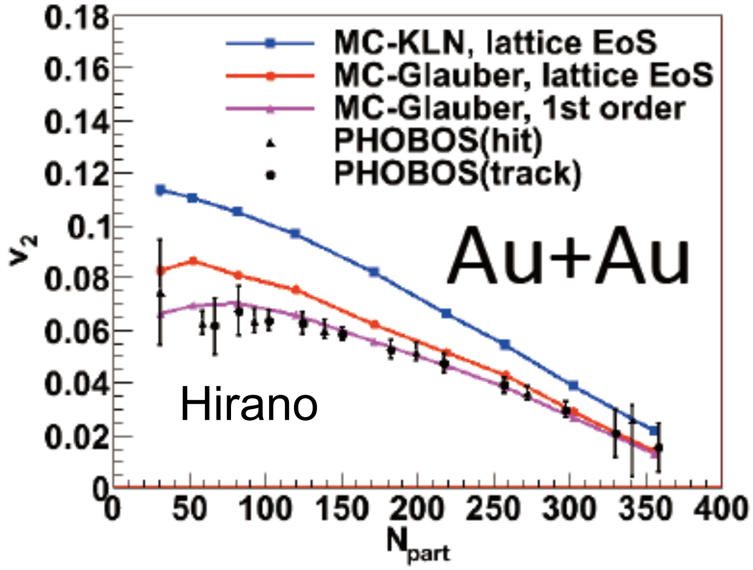
No. They remember the initial geometry!

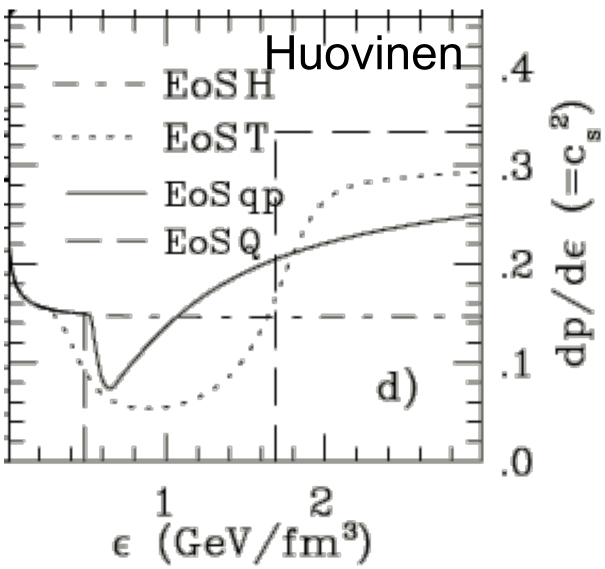
Elliptic Expansion

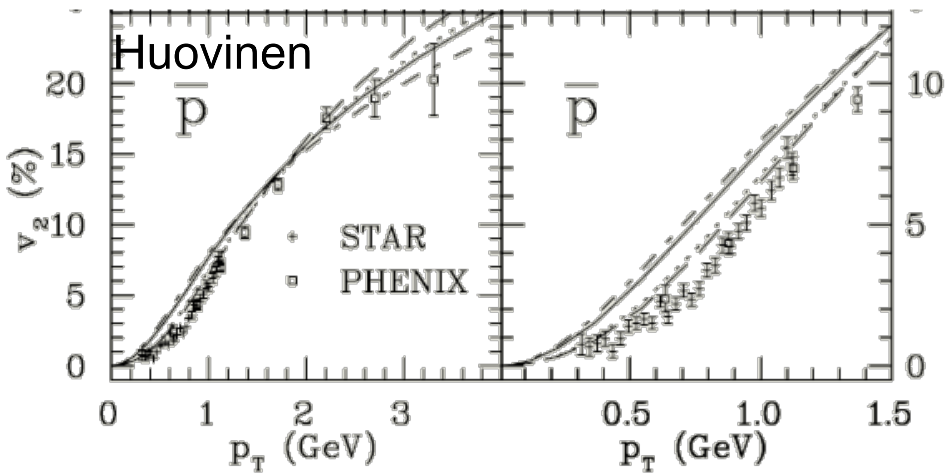


Effect of Lattice EOS on Observables









Interplay of Lattice & Heavy Ion Collisions

We think finite temperature lattice results are important for basically all aspects of heavy-ion phenomenology

I say “think” because experimentalists need to demonstrate that our collisions create a locally equilibrated medium where thermodynamic variables can be defined

The more the models are constrained with lattice data, the easier that will be