High Energy Nuclear Physics and the Nature of Matter

Outstanding questions about strongly interacting matter:

How does matter behave at very high temperature and/or density?

What is the nature of gluonic matter?

How does this gluonic matter appear inside of strongly interacting particles?

How are spin and baryon number distributed inside of nucleons?

RHIC addresses all of these.

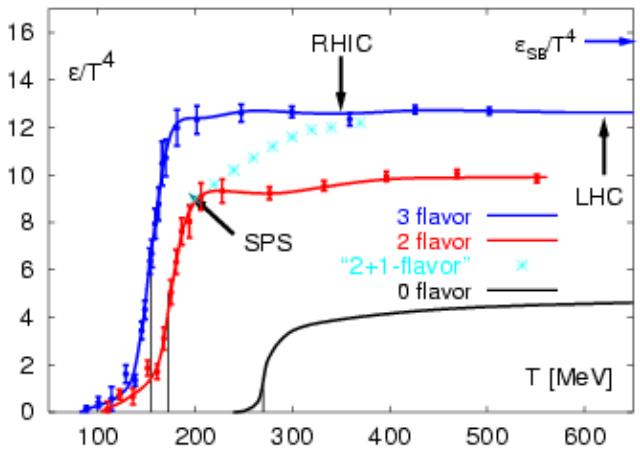
Partially resolved issues:

Spectra, matrix elements and thermodynamics from first principles computation in QCD

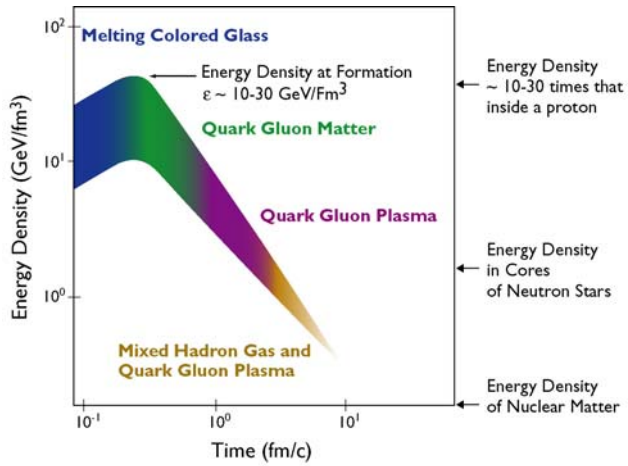
Can QCD be turned into a precision science?

What is the behavior of strongly interacting matter at high temperature and/or density?

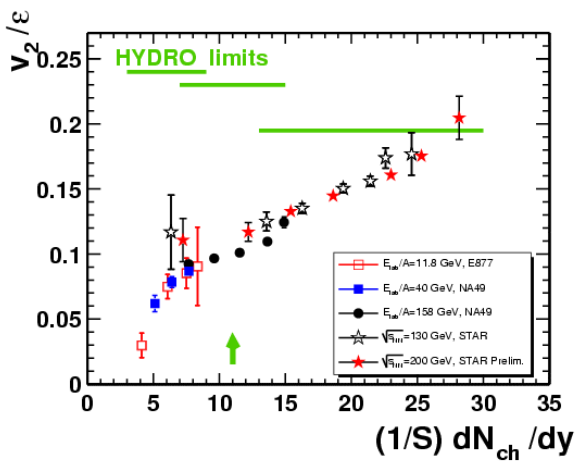
QCD predicts QGP

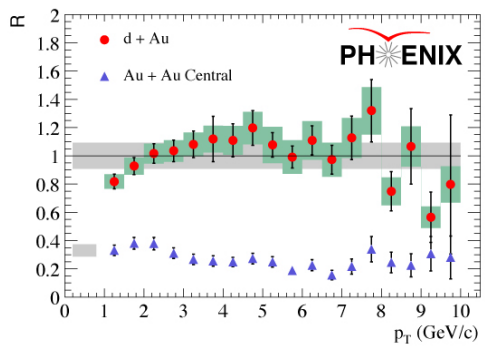


Consensus: Energy density big enough



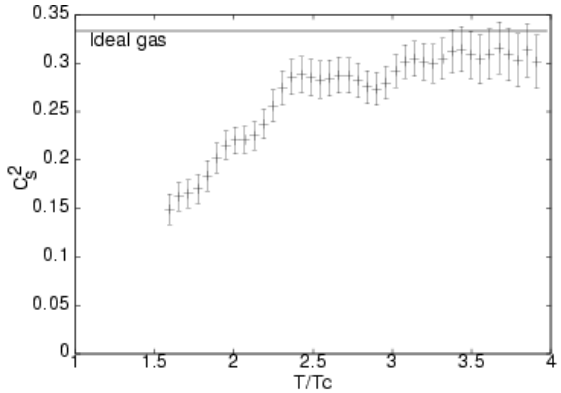
Consensus: Matter strongly interacts with itself; should be thermalized





We want to measure:

Sound speed



Properties of resonances in media and relationship to:

Confinement and mass generation?

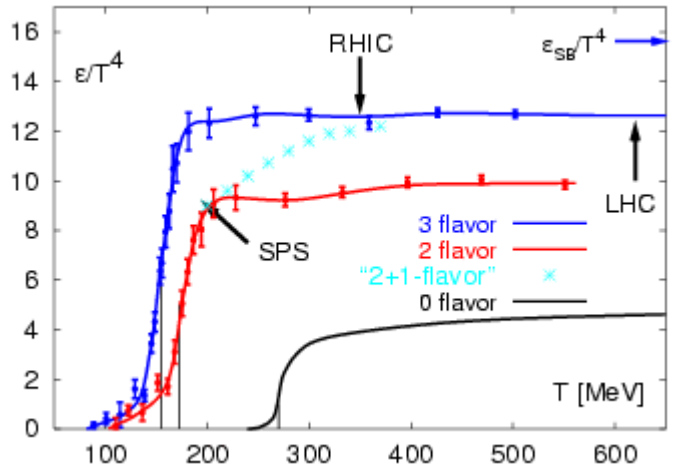
Screening length?

Temperature?

Baryon number excess at moderate pT?

Number of degrees of freedom?

Change in energy density from hadron gas to quark gluon plasma?

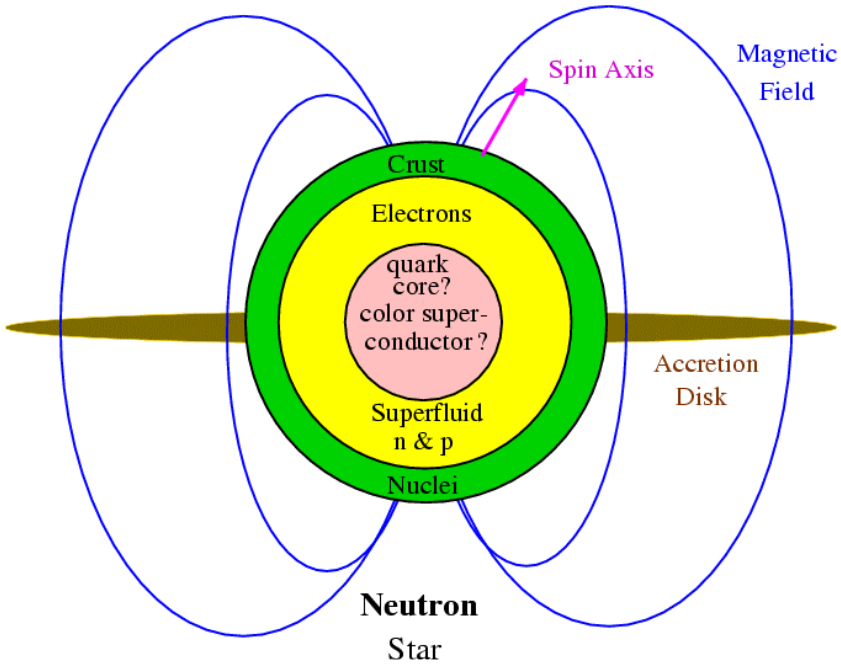


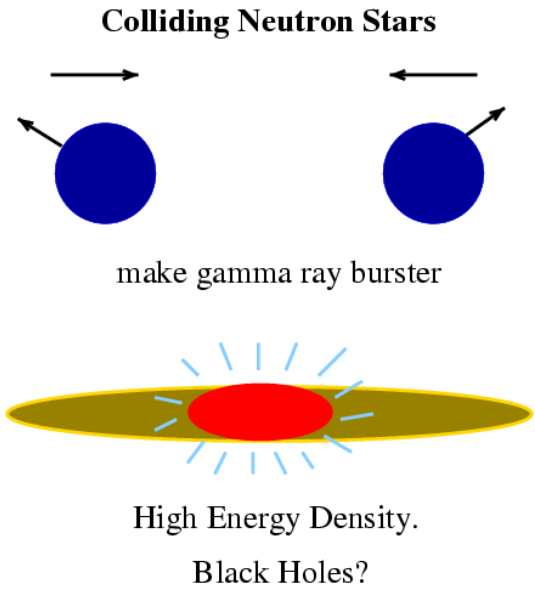
Partially resolved puzzle of comparing measured lifetimes and sizes from computation with measurement.

Mass generation?

Is this relevant for naturally occurring phenomena?

Matter at very high baryon density and low T:





T small, density ~ 10-20 baryons/fm ^{3}

Some gamma ray bursters sit around for days to years after supernova explosions before going hypernova.

Black hole formation? Metastable QGP?

Many RHIC theorists also think about such things!

Hydro tools, theory of high energy density matter

The QGP began in the theory of high baryon density matter!

What is the nature of gluonic matter?

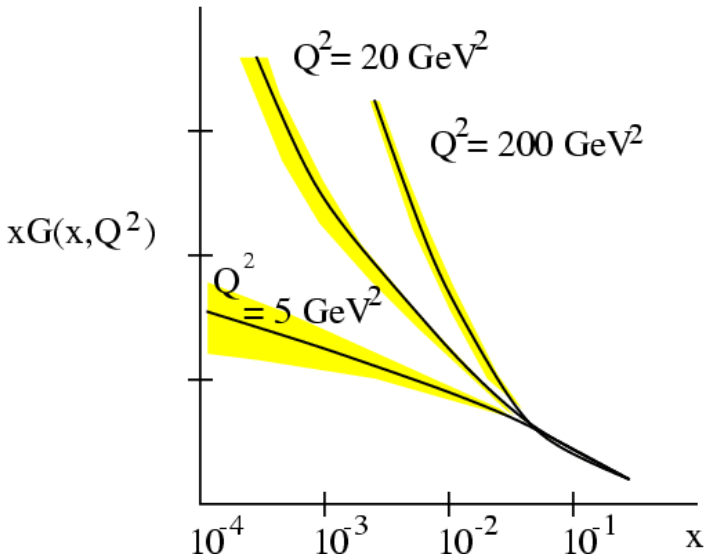
How does this matter appear in strongly interacting particles?

Glue binds all quarks inside of hadrons.

It is ½ of the momentum of a high energy proton.

It is responsible for confinement and mass generation.

By an order of magnitude, the soft degrees of freedom of a high energy strongly interacting particle is glue.



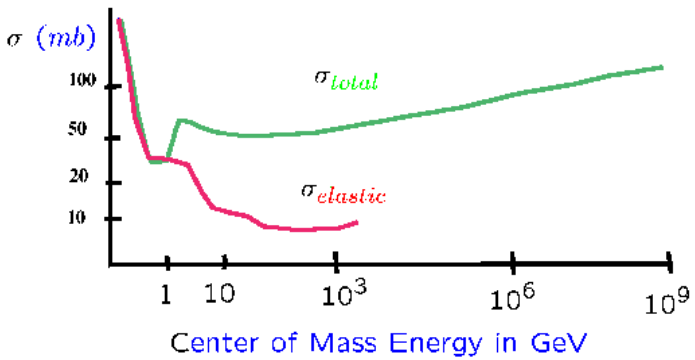
HERA

We understand very little about this gluonic matter!

Where do the gluons go?

Cross sections grow slowly.

The total hadronic cross section:

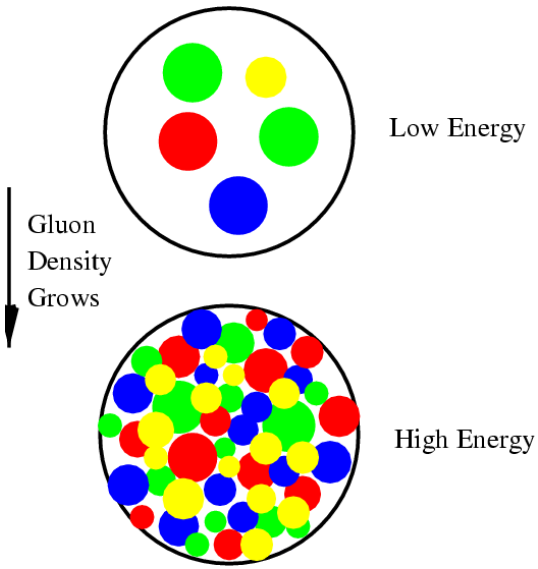


In rest frame

Valence quarks and occasional glue and sea quarks

In infinite momentum frame

Wall of lots and lots of glue at near light speed



Gluon density grows very rapidly.

QCD coupling becomes weak, but interactions are strong because of coherence

Heavy ions at high energies are a gluon wall

What is the Color Glass Condensate?

Glue at large x generates glue at small x

Glue at small x is classical field

Time dilation -> Classical field is glassy

High phase space density -> Condensate

Phase space density: $\frac{dN}{dyd^2p_Td^2x_T} = \rho$ $y = ln(1/x)$

Attractive potential $V \sim -\rho$ Repulsive interactions $\sim \alpha_{strong}\rho^2$

Phase Space Density $\rho \sim 1/\alpha_{strong}$

α_{strong} is small

ρ is big

Why is the Color Glass Condensate Important?

It is a new universal form of matter:

Matter: Carries energy; Separation of gluons is small compared to size of system; Number of gluons is large

New: Can only be made and probed in high energy collisions

Universal: Independent of hadron, renormalization group equations have a universal solution.

Universality <=> Fundamental

It is a theory of:

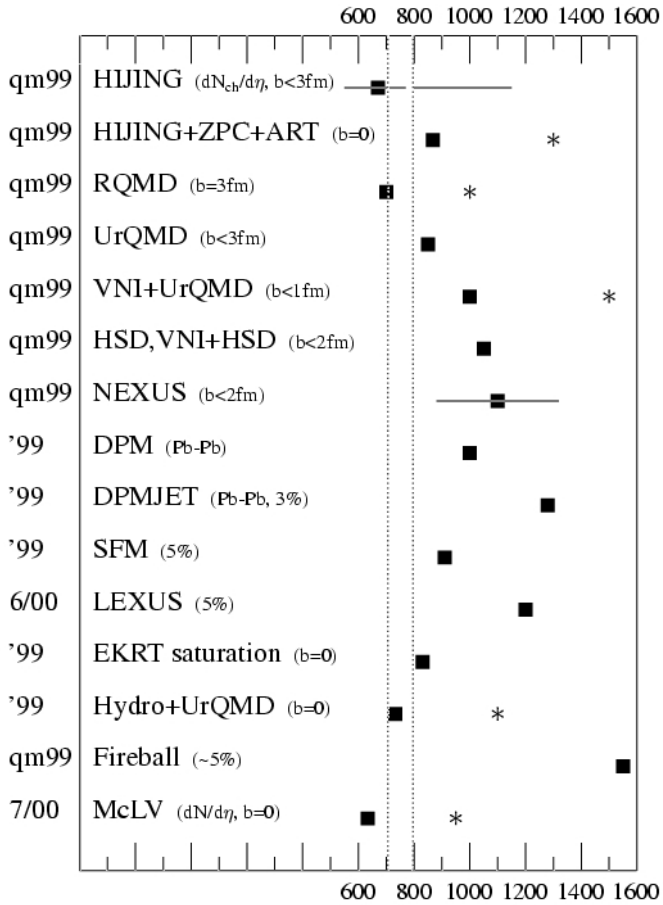
Origin of glue and sea quarks in hadrons

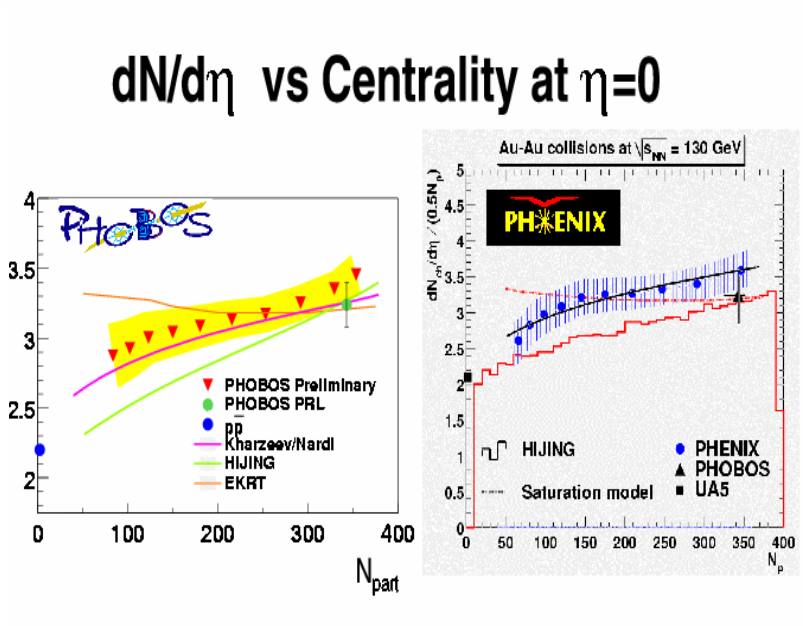
Cross sections

Initial conditions for formation of Quark Gluon Plasma in heavy ion collisions

Nuclei provide highest density and largest sizes => Simplicity

CGC predicted particle production at RHIC

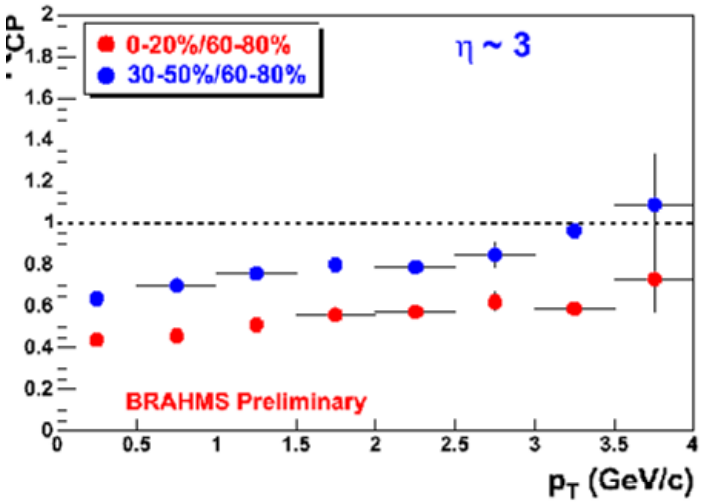




$$\frac{dN}{dy} \sim \frac{1}{\alpha_{strong}} \pi R^2 Q_{sat}^2 \sim A ln(A)$$

Proportionality constant can be computed.

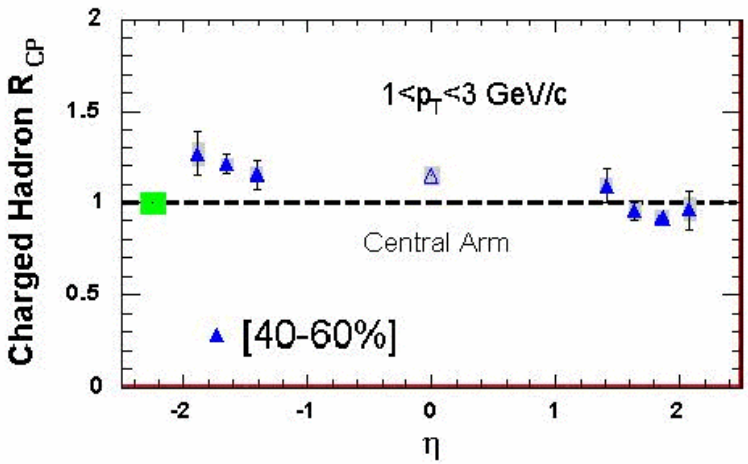
Data from dA collisions at RHIC Consistent with CGC

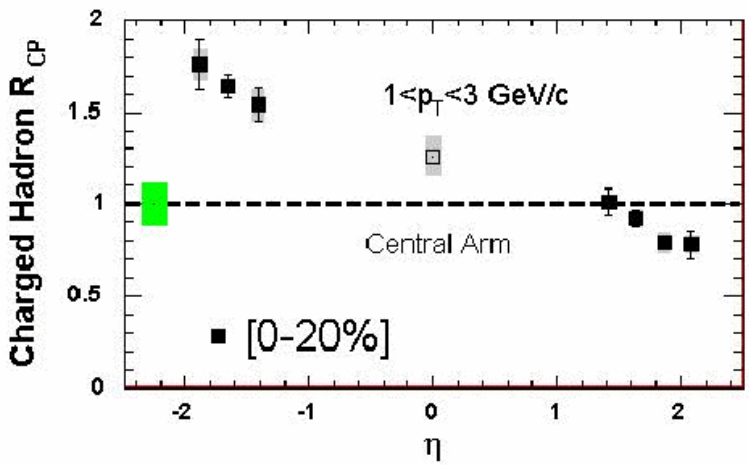


Look for fragments of deuteron since they measure them smallest x properties of the nucleus

Back to back jet correlations seen in STAR?

Detailed studies of x dependence?





How are spin and baryon number distributed inside of nucleons?

Spin and baryon number carry the valence quantum numbers of hadrons

They involve collective excitations of the glue with quark degrees of freedom and/or topological excitations

They typically generate **much** more transfer of valence quantum numbers to the soft (small x or wee) degrees of freedom than one had naively expected.

They are of immense theoretical interest, and there is considerable controversy in understanding their properties

Little is known about the distribution of spin from experiment.

Quark Gluon Plasma and Color Glass Condensate at RHIC, LHC and eRHIC

RHIC:

RHIC HAS DEMONSTRATED IT CAN PRODUCE AND STUDY QGP

SPIN PROGRAM IS UNIQUE

QGP measurements involve much study of correlated phenomena sometimes in different environments =>

TIME AND LUMINOSITY IMPORTANT

Has and will measure many properties of CGC before LHC has dA or pA

BEING FIRST IS ALWAYS GOOD

eRHIC:

Study of spin and CGC becomes a precision science.

Electron probes much less sensitive to final state physics

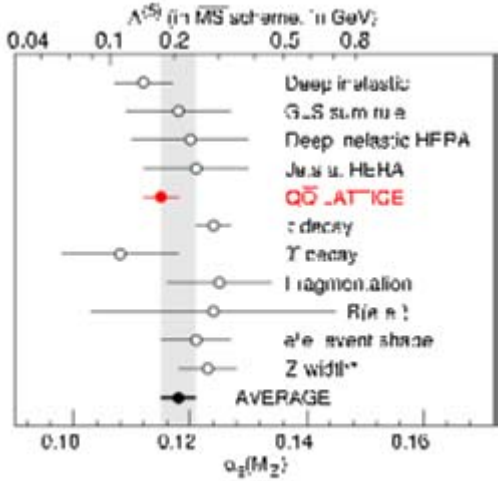
LHC:

QGP study is harder because CGC strongly modifies gluon distributions in nuclei relative to proton.

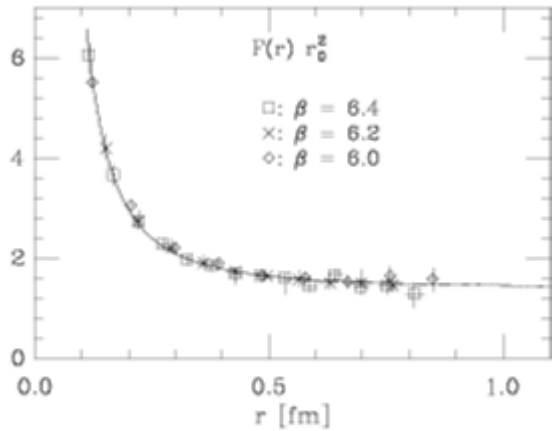
Can probe very small x and very large momenta

Need dA or pA, and time.

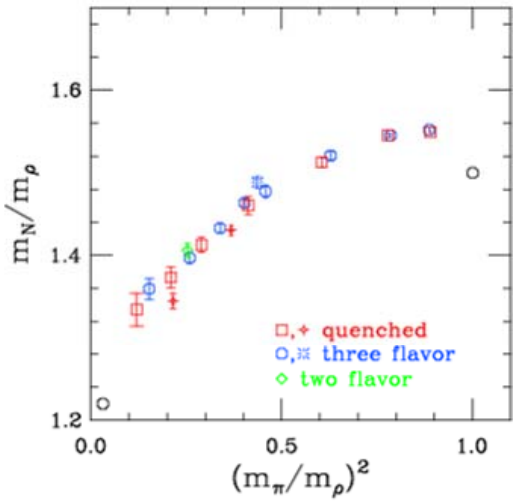
Lattice Gauge Theory



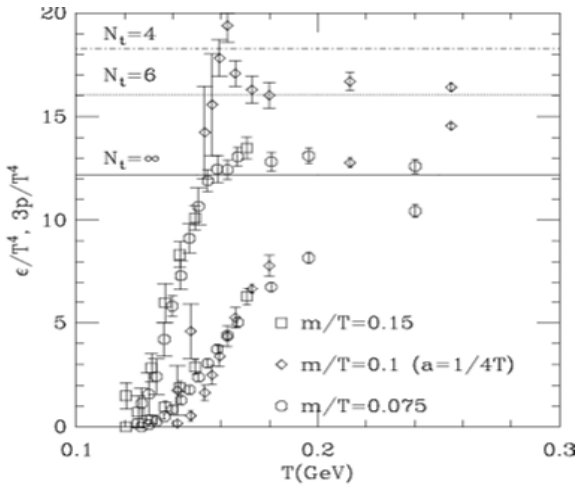
Tests QCD



Tests Confinement



Computes Masses



Compute Finite T QCD

QCDOC Project at BNL promises
10+ TFlops (x 2)
allowing for computations
with realistic quark masses
RBRC

Summary:

RHIC has fundamentally changed our knowledge of strong interactions.

RHIC has made a sQGP

RHIC has probably seen the CGC

What are the theoretical and computing needs of RHIC science and are they available?

Young people want to work on RHIC theory.

Resources for students and postdocs are very tight.

Many group may have to eliminate postdocs and students.

We have successfully placed young people from this field in faculty positions.

RBRC is under stress if spin program at RHIC is weakened.

Young people are our present and our future!

Potential meltdown of lab and university theory efforts:

Resources are people intensive.

RBRC

Computing for lattice gauge theory has new machines.

Effort for simulation of RHIC collisions needs computing and people resources