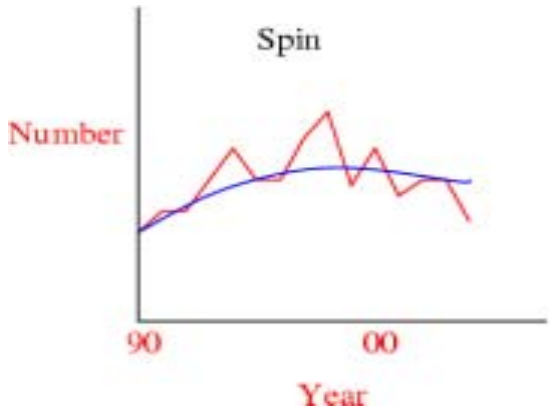
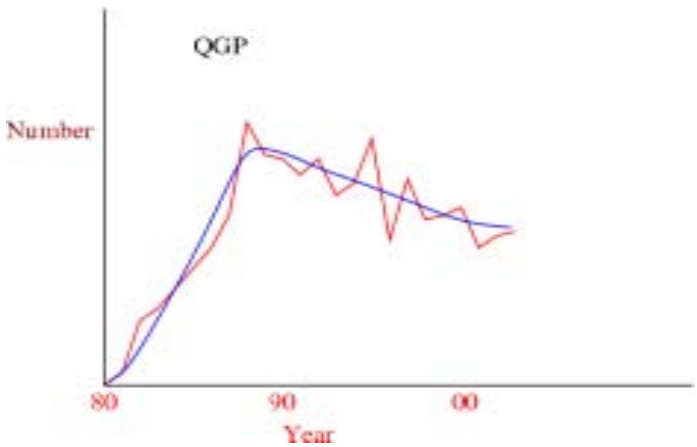
Theoretical High Energy Nuclear Physics:

A Perspective

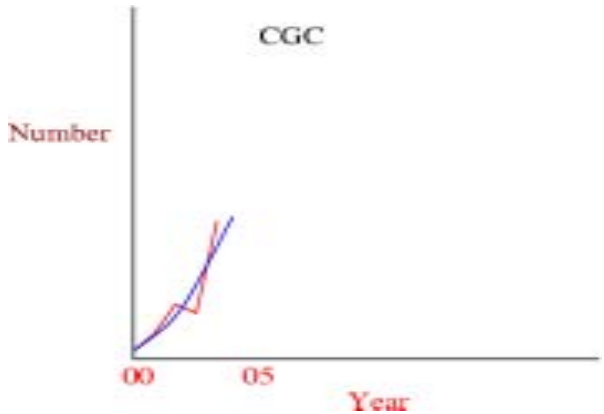
Mature



Developing

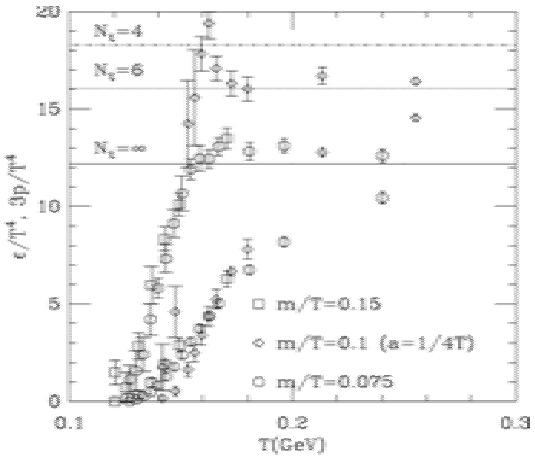


Maturing

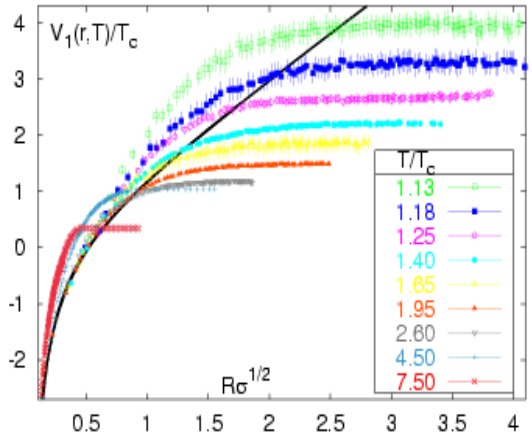


Speculative Growth

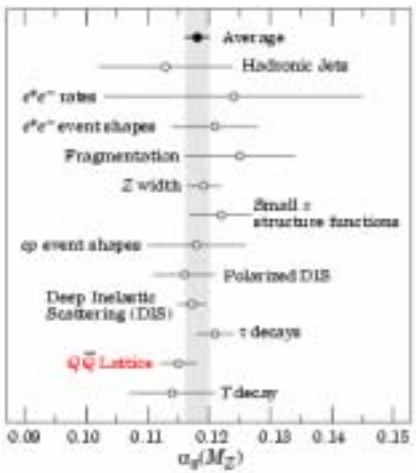
Lattice Gauge Theory



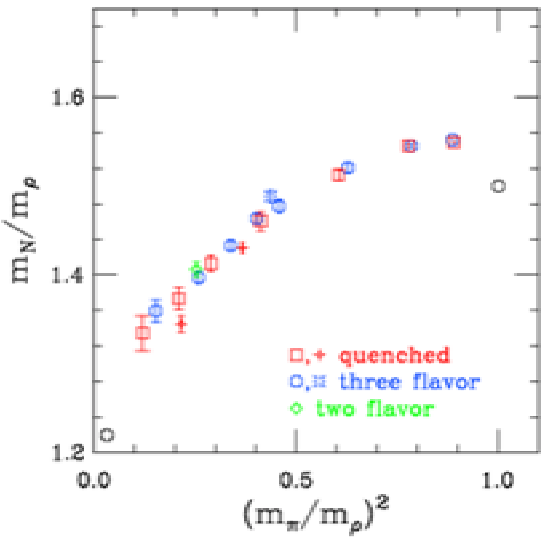
QCD Thermodynamics



The potential



α_S



The spectrum

Meson spectral functions and thermal dilepton rate

Spectral function in the vector channel gives the dilepton rate from charmonia, Thermal quarks as well as thermal photons for $|\vec{p}| = \omega$

L G T

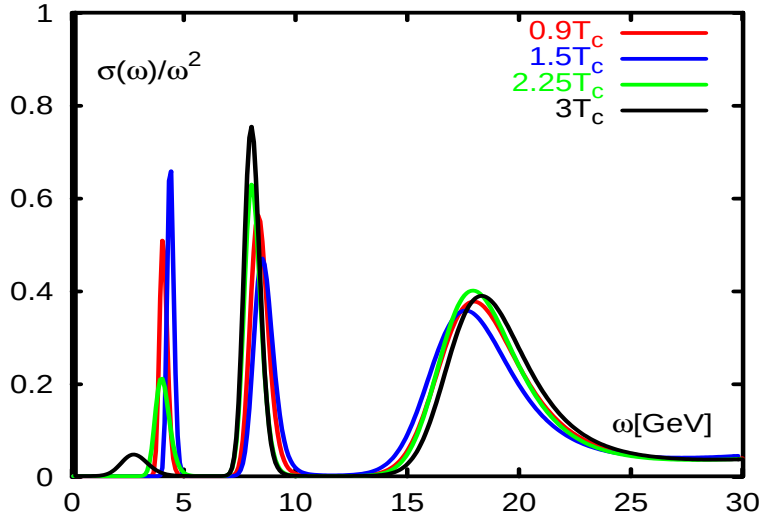
$$\frac{\mathrm{d}W}{\mathrm{d}\omega \mathrm{d}^3p} = \frac{5\alpha^2}{27\pi^2} \frac{1}{\omega^2(\mathrm{e}^{\omega/T}-1)} \sigma_V(\omega, \vec{p}, T)$$

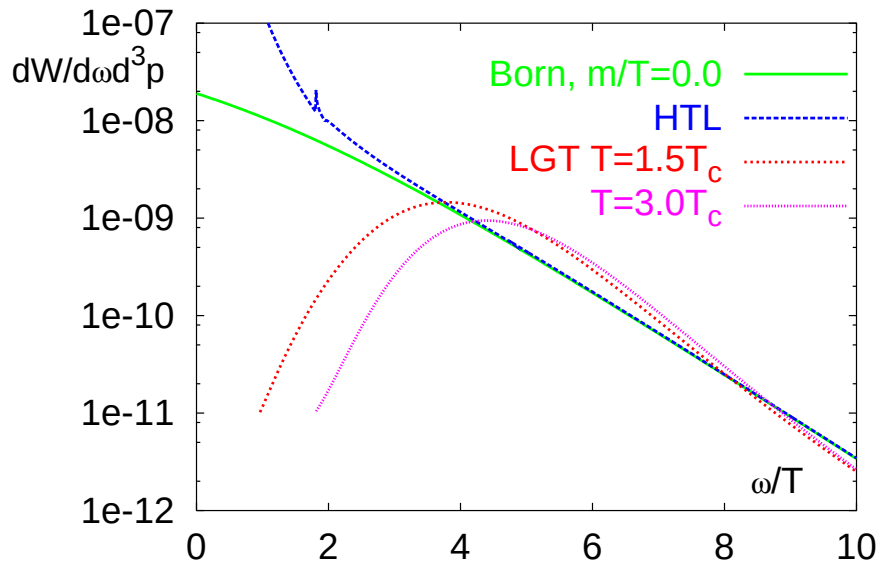
Experiment

$G_T(\tau, \vec{p})$ → MEM → $\sigma(\omega, \vec{p})$

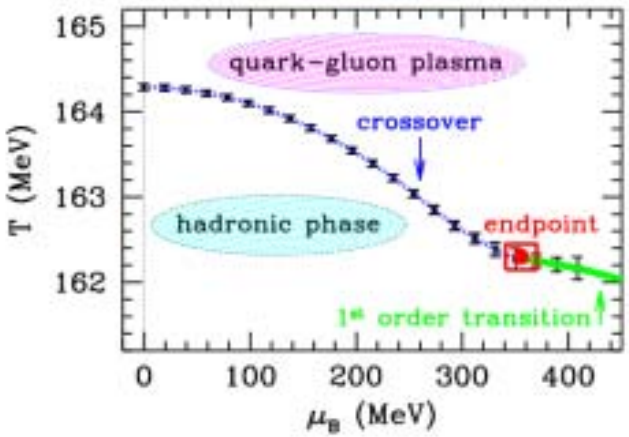
Karsch, Laermann, Petreczky, Stickan Wetzorke, PLB 530 (2002) 147

Datta, Karsch, Petreczky, Wetzorke, hep-lat/0312037





Lattice Gauge Theory: The Future



Finite baryon density?

Mass spectrum in QCD to 1% ?

Is the deconfinement transition really a crossover?

What are the mean free paths in the sQGP?

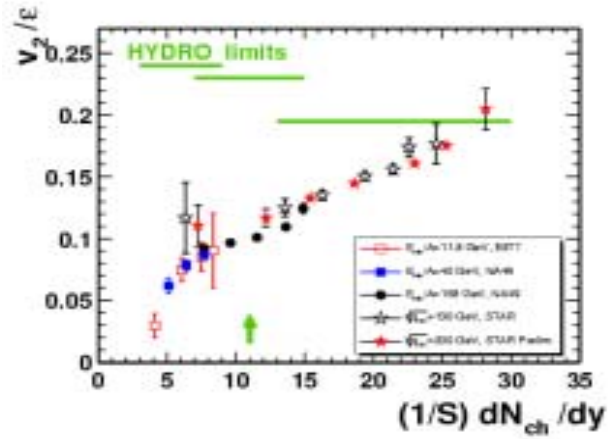
Can we compute moments of structure functions? Spin?

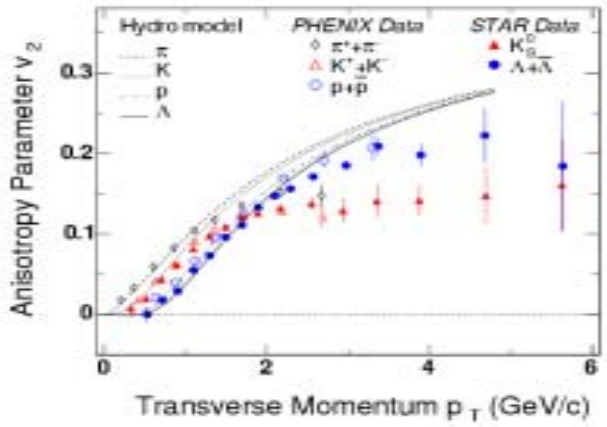
The small x limit in the CGC and solving evolution equations?

Glueballs? Pentaquarks? Unstable particles?

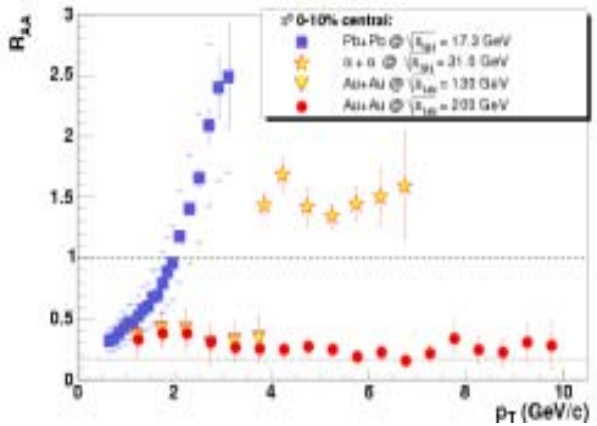
10 Tflop soon. Probably need 1 Petaflop in ~ 10 Yrs

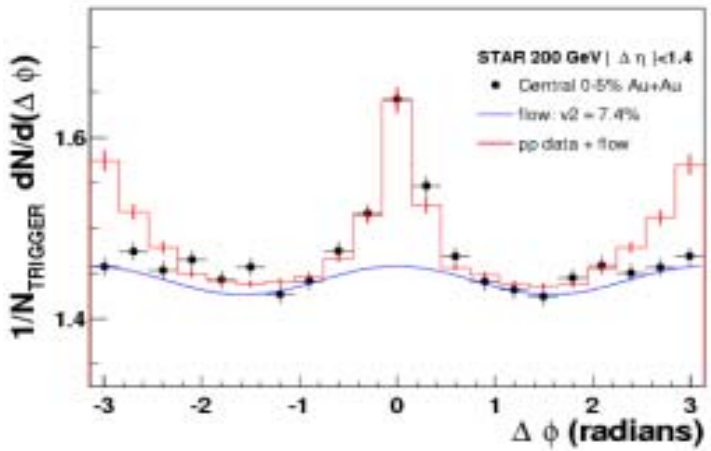
The Quark Gluon Plasma





Hydro works!



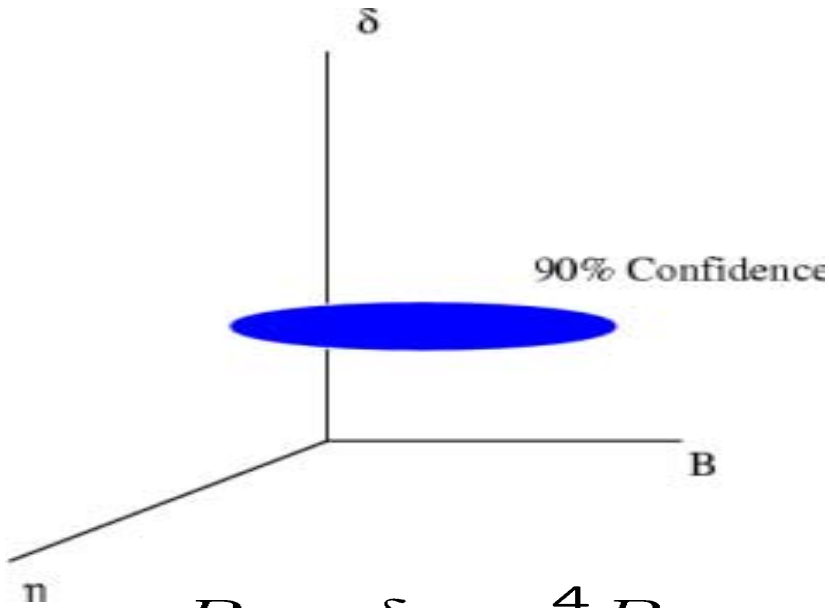


Jets are quenched!

The Evidence for the sQGP is Overwhelming!

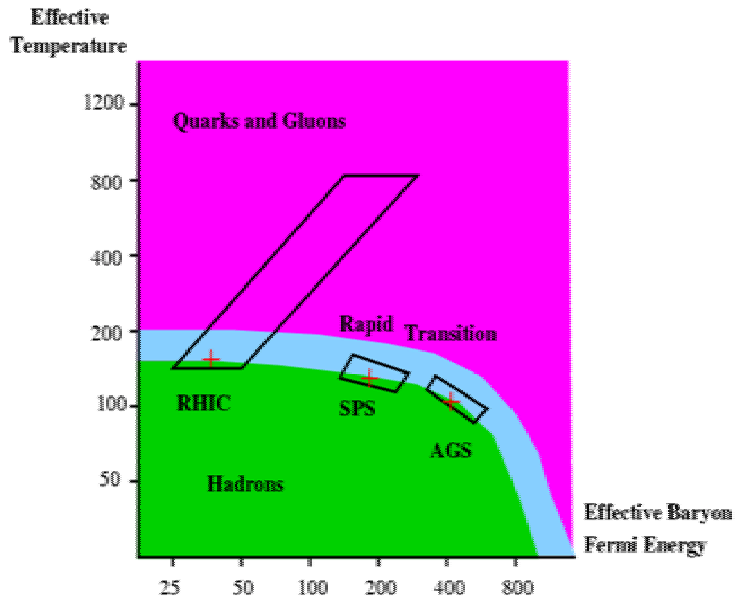
The Quark Gluon Plasma

Energy density is so high its degrees of freedom are gluons and quarks.
It is to a good approximation thermalized.
It is very strongly interacting.
We know very little about its properties.



$$P = \delta\epsilon - \frac{4}{3}B$$

Uncertainty in sound velocity, B and viscosity



Effective T goes from $T_{thermal}$ to Q_{sat}

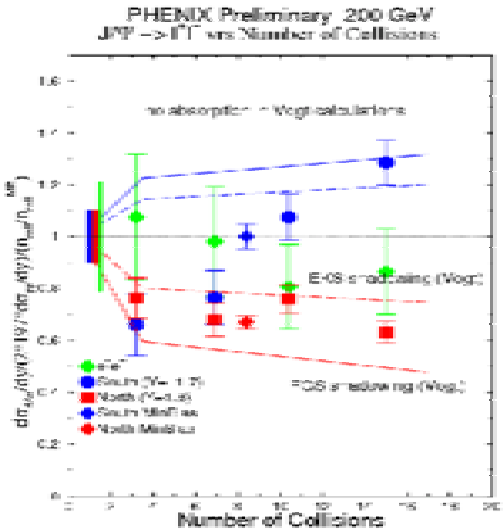
The Quark Gluon Plasma

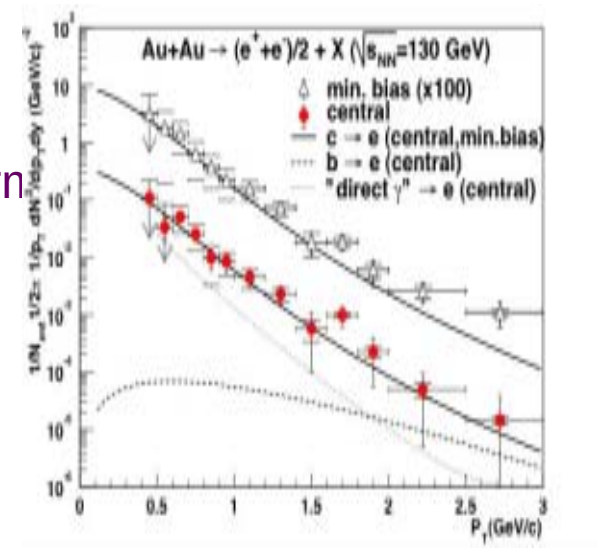
Issues which will attract theoretical effort:
Will involve detailed study with attention to error analysis and systematic checks from data.
Gee Whizz Physics is over!

Confinement: J/Psi?

Lattice information must be improved.
Requires systematic experimental and theoretical study.
Modifications due to initial state: dA
Modifications due to charm recombination: open charm
Modifications due to media.

Requires much systematic and careful study.





Quark Gluon Plasma

Issues which will attract theoretical effort:

Chiral Symmetry Restoration?

Di-lepton spectra: If we are lucky!

Thermalization and Hard Processes:

Detailed jet measurements: Correlations at various pT's and rapidities
Jets at highest pT's and quenching: LHC and RHIC II
Direct photons: Precise measure of glue in nuclei and evolution in collisions?
With a lot of luck, can get info on plasma from direct photons
Heavy flavor production

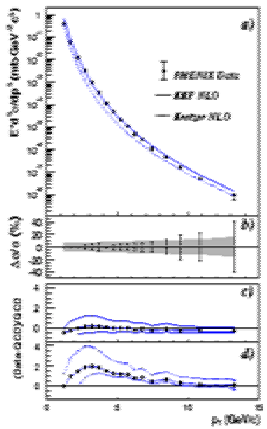
Many other interesting experimental topics such as flow, low pT particles, HBT, fluctuations. Theory largely worked out.

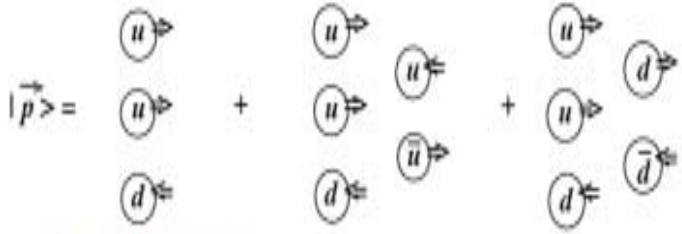
At LHC, QGP lives longer, expands to larger size and Ti is bigger so various approximations are better under control. Surprises?
How does this make life easier?

Spin Physics and Perturbative QCD

Predictions for pp collisions at RHIC – W. Vogelsang & S. Kretzer

- NLO QCD calculations of cross section for high-p_T pion production





- $\Delta u > 0,\ \Delta \bar{d} < 0$?
- strange quark polarization

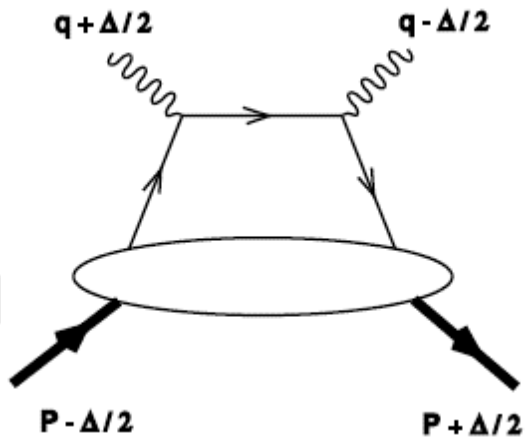
What is the spin in the sea?

What spin is carried by gluons?

Jet Fragmentation

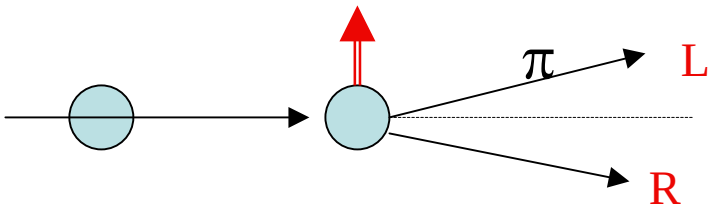
$$H_q(x,\xi,\Delta^2),\ E_q(x,\xi,\Delta^2)$$

$$J_q = \frac{1}{2}\lim_{\Delta^2\to 0}\int dx\, x\,\left[H_q(x,\xi,\Delta^2) + E_q(x,\xi,\Delta^2)\right]$$



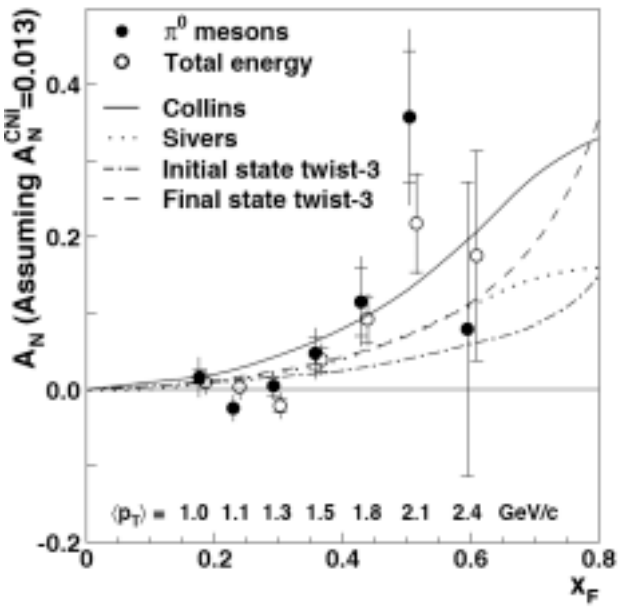
Virtual Compton Scattering

Spin and Perturbative QCD

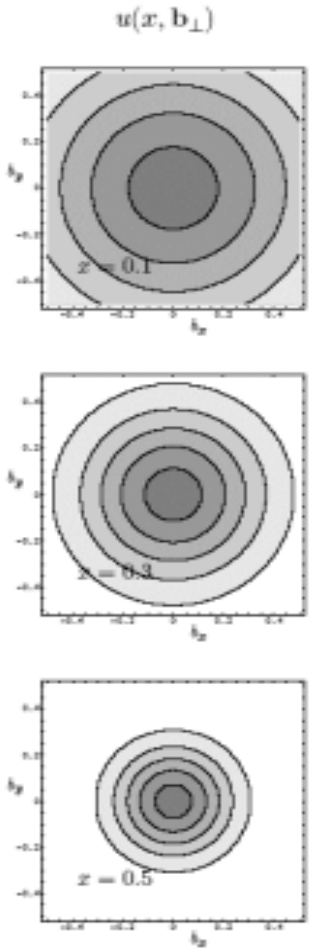


$$A_N = \frac{L - R}{L + R}$$

What is the origin of large spin-spin asymmetries?

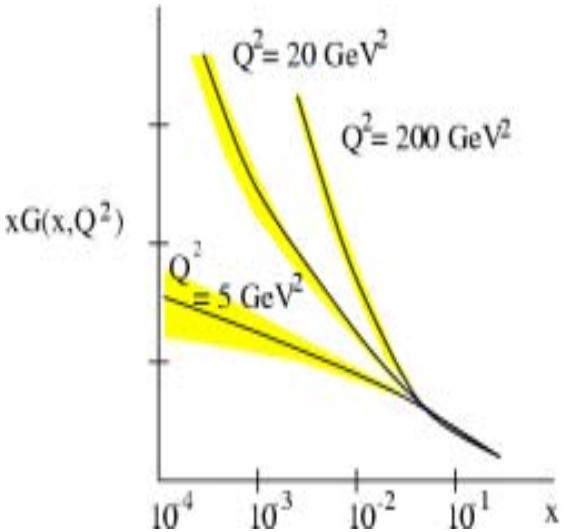


Is intrinsic parton transverse momentum important?

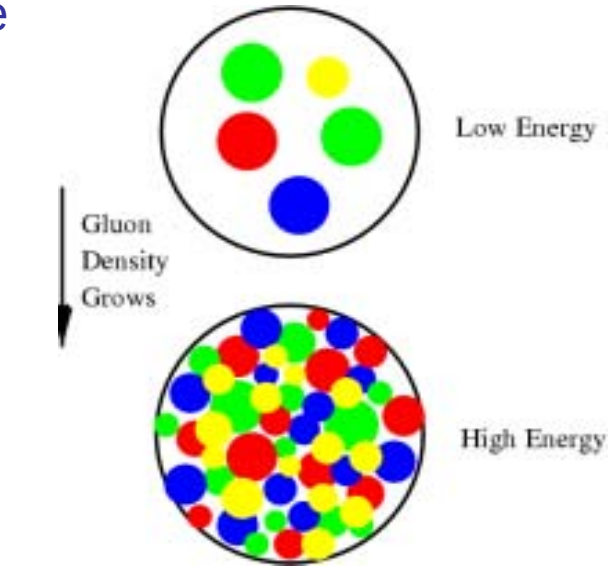


Virtual Compton Scattering and Space-Time Distributions of Quarks and Glue

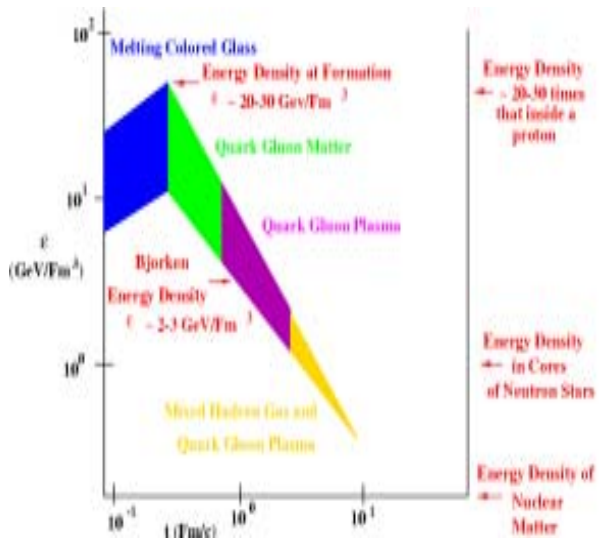
The Color Glass Condensate



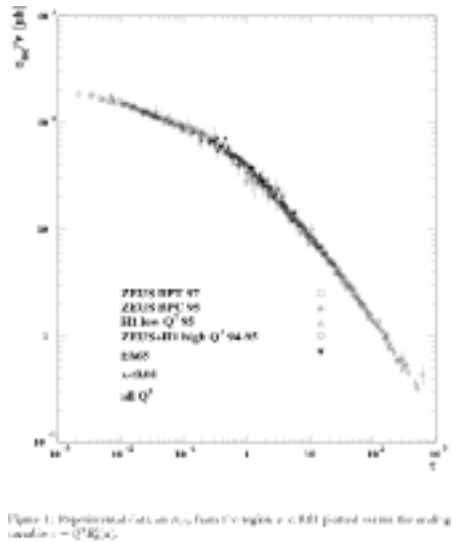
Lots of glue at small x



Gluons get squeezed

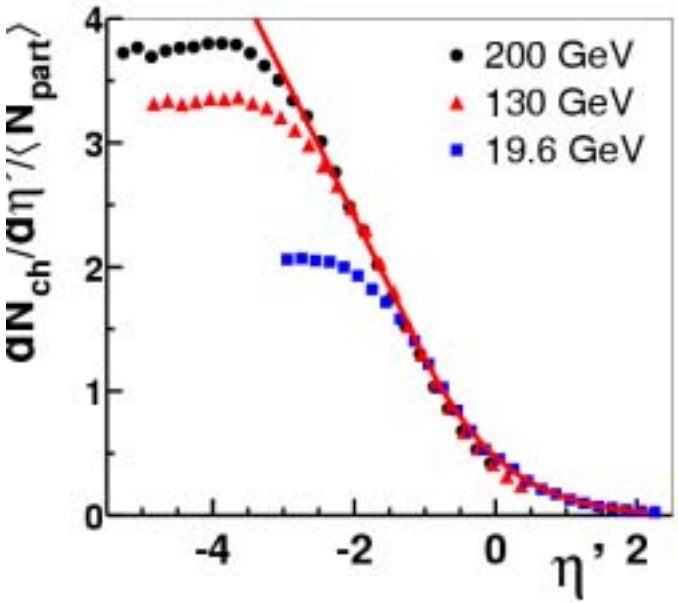


It determines initial conditions

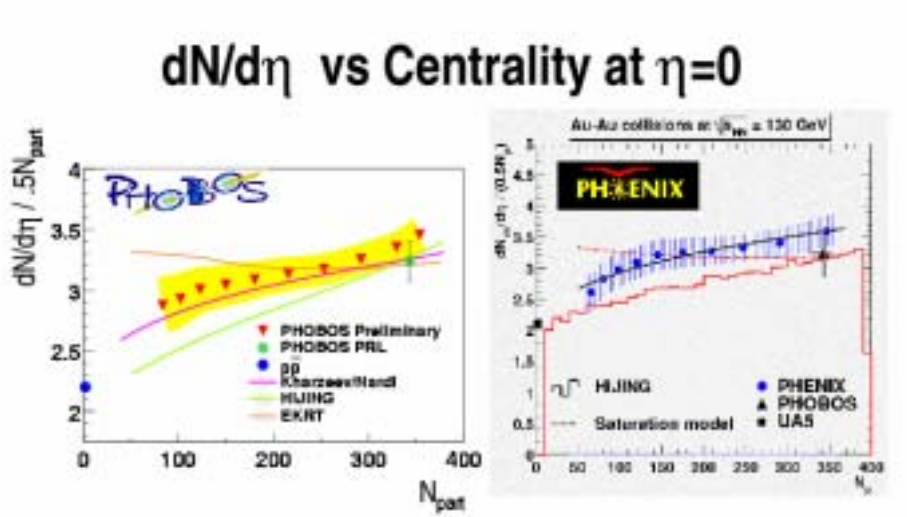


It appears in DIS

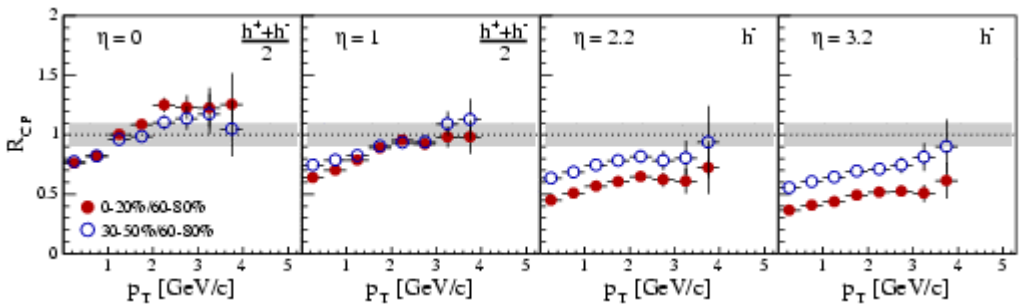
The Color Glass Condensate



Limiting Fragmentation suggest Renormalization Group



It successfully describes multiplicities



It provides a successful theory of shadowing

New and Fundamental Understanding

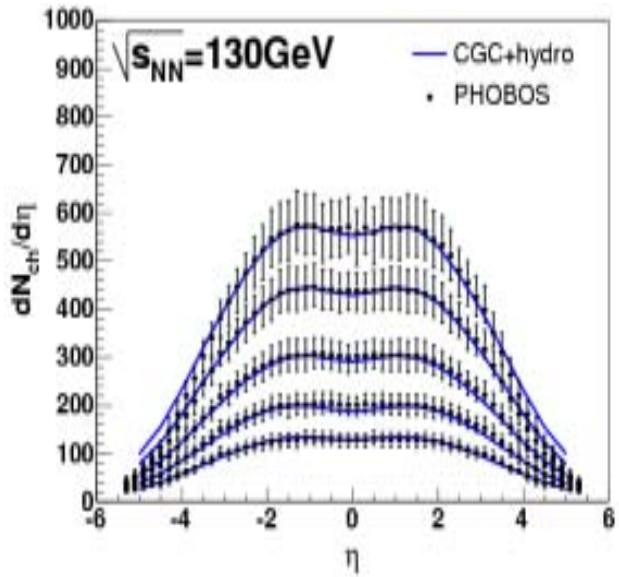
Color Glass Condensate

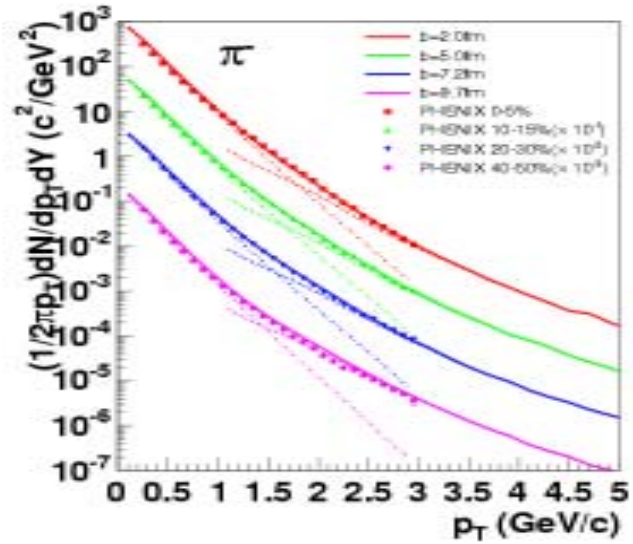
Universal Form of Matter

Fundamental understanding of basic issues in high energy physics:
Cross Sections
Origin of Quarks and Gluons in Hadrons
Shadowing and Diffraction
Average properties of hadronic processes
Theoretical curiosity about a new form of matter

Important Experiments:
Measuring shadowing and nuclear gluon and quark distributions
Smallest possible x and intermediate to large pT
Large A more effective than small x
Good at RHIC, better at LHC in forward region
Ultimately precision measurements in electron machines
eRHIC

QGP Meets the CGC

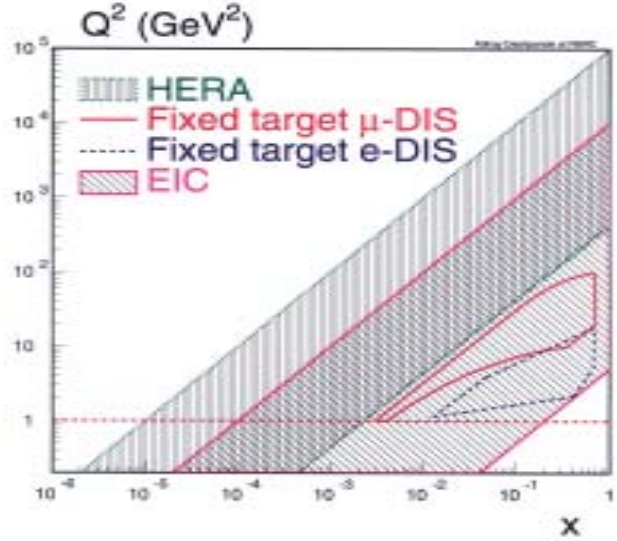


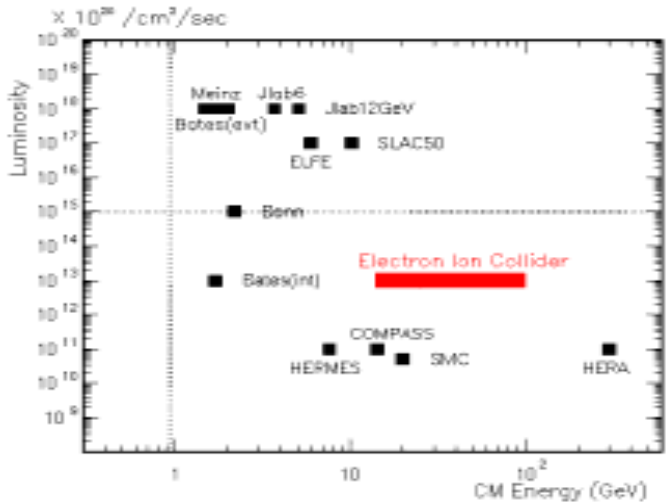


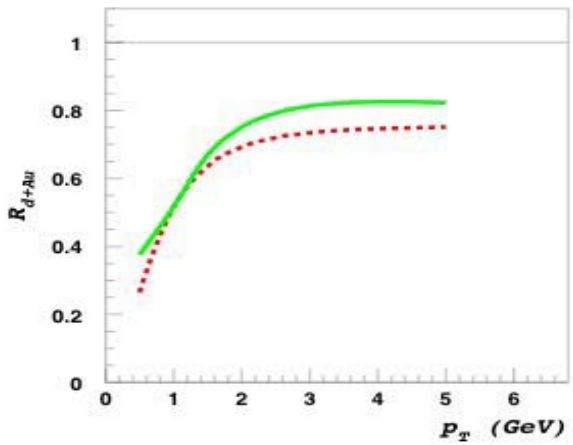
Hirano-Nara Hydro + CGC + Jet Quenching

From the CGC to QGP? Thermalization?

Future Qualitatively New Regions

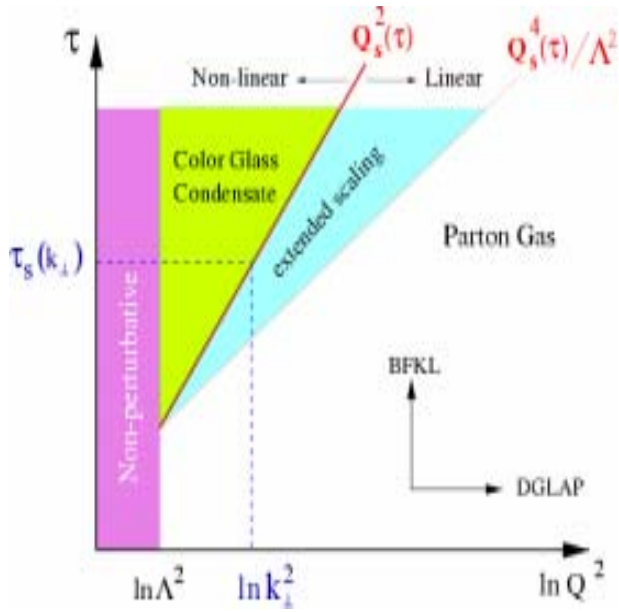






RHIC at eta = 3.2 vs LHC at eta = 0

green:RHIC; red: LHC



x of 10^{-5} can go to p_T of 10 GeV at LHC

Summary

Qualitatively New Regions:
RHIC and LHC at Small x and high pT

Understanding the new regions:
RHIC, RHIC II and eRHIC

RHIC II and eRHIC
Goal is to understand strong interactions and the nature of matter.
Experience at RHIC shows we need a diversity of probes and time (luminosity) to make cross comparisons.
Need increasing precision or CGC

LHC
We also have to search new regions of phase space where there is high discovery potential.
Small x and large pT