Physics Opportunities with Heavy Ion Reactions

« Evolution of Physics-goals »

NSAC Subcommittee
on Heavy Ion Physics
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Where do we stand?

Experiment

Some continuity with SPS heavy ion physics

But new phenomena discovered at RHIC

New possibilities, provide new focus for future research

Theory

Some major advances

Experimental discoveries

Many evidences for non trivial phenomena

$$\sigma_{AA} \neq N_{bin}\sigma_{nn}$$

Large energy density achieved $\varepsilon_{Bj} \gg \varepsilon_c$

Collective behaviour observed v_2 (and hydro)

Suppression of charmonium bound states (SPS)

Jet quenching and strong « final state » interactions

Hints of gluon saturation

And much more…

Significant progress in theory

Better understanding of the phase diagram, finite mu, precise determination of critical temperature, etc.
(see talk by F. Karsch)

Weak coupling calculations at high temperature match lattice results on the thermodynamics

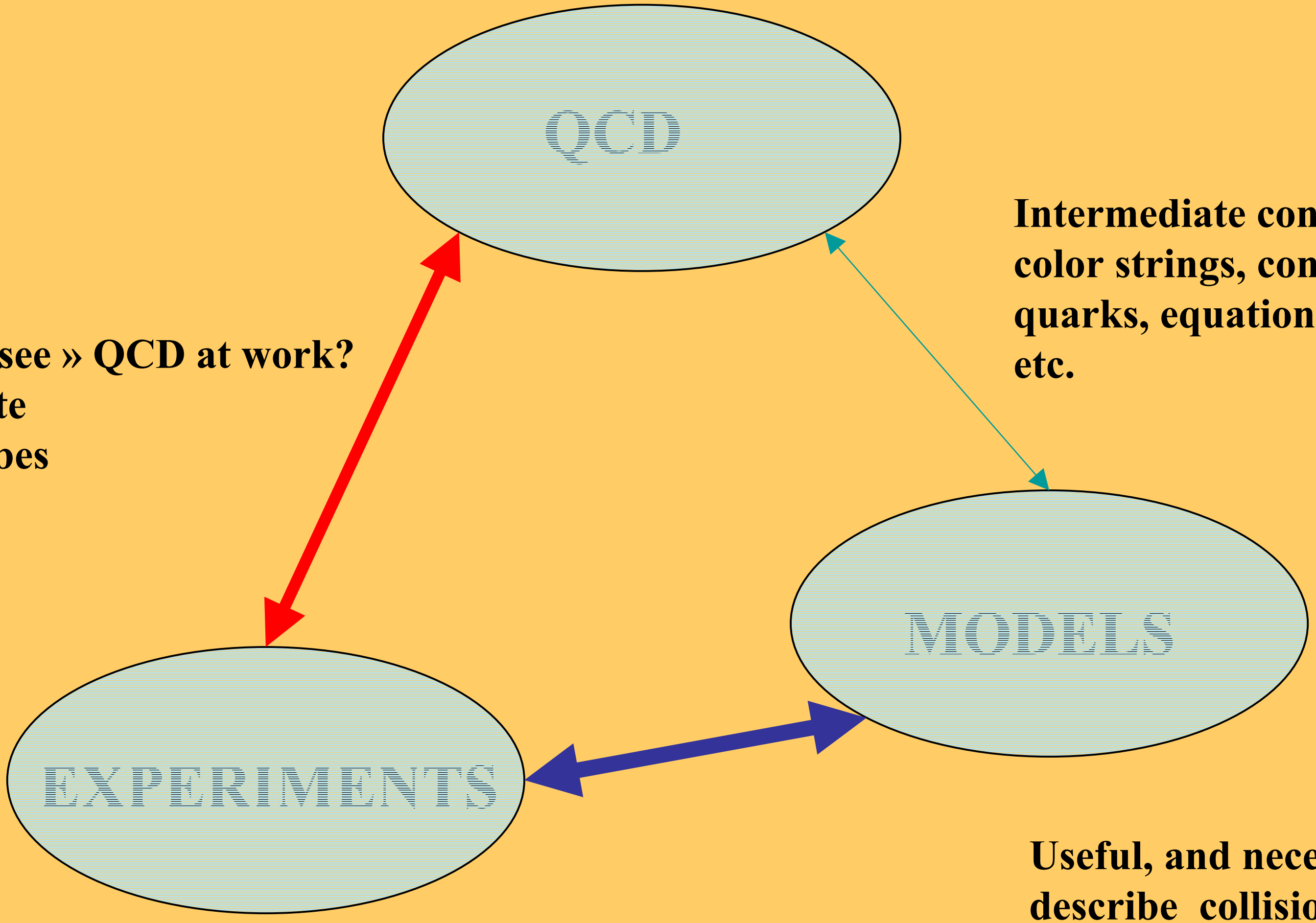
Lattice calculations of spectral functions

Better theory of parton propagation in a dense medium

Non linear evolution equations for parton distributions
Color glass condensate

And much more…

QCD perspectives
on hot and dense matter



Can we « see » QCD at work?
Initial state
Hard probes

Intermediate concepts, color strings, constituent quarks, equation of state, etc.

Useful, and necessary, to describe collision dynamics, final state interactions, etc.

« Predictions »

Precise statement of what should be seen
in a given experimental setup
Arbitrary accuracy can be achieved, in principle,
and estimates of uncertainties given

« Directions »

« Qualitative predictions », things to look at

No accurate/quantitative description of what one should find in a given experiment (too much complexity)

Examples: J/Psi suppression, strangeness enhancement, jet quenching, etc…

Here experiment is leading

Various regimes of QCD

Perturbative QCD

Non perturbative QCD

Dense and hot matter

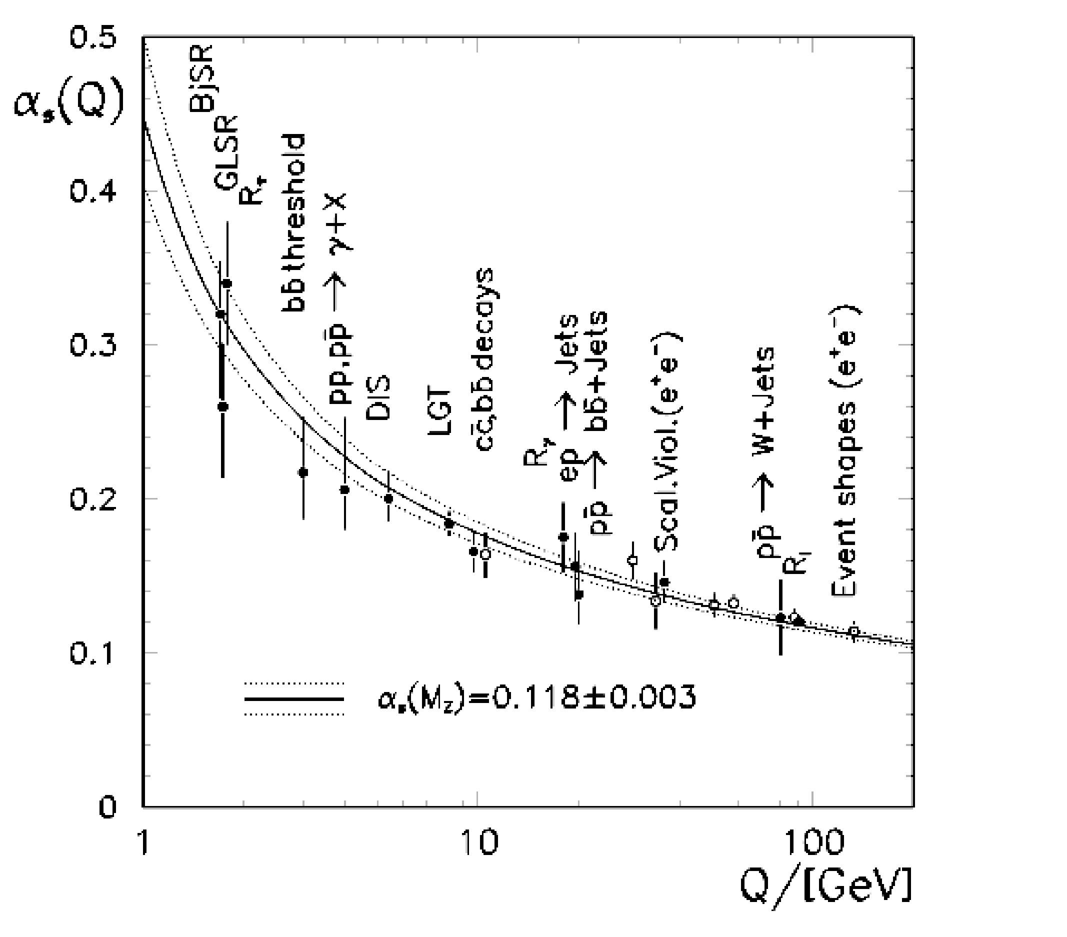
Perturbative QCD

Weak coupling, few particles

Acurate calculations can be done

Factorisation theorems

QCD Interactions Weaken at High Energy



$$\alpha(Q) \approx \frac{1}{Ln(Q^2/\Lambda_{QCD})}$$

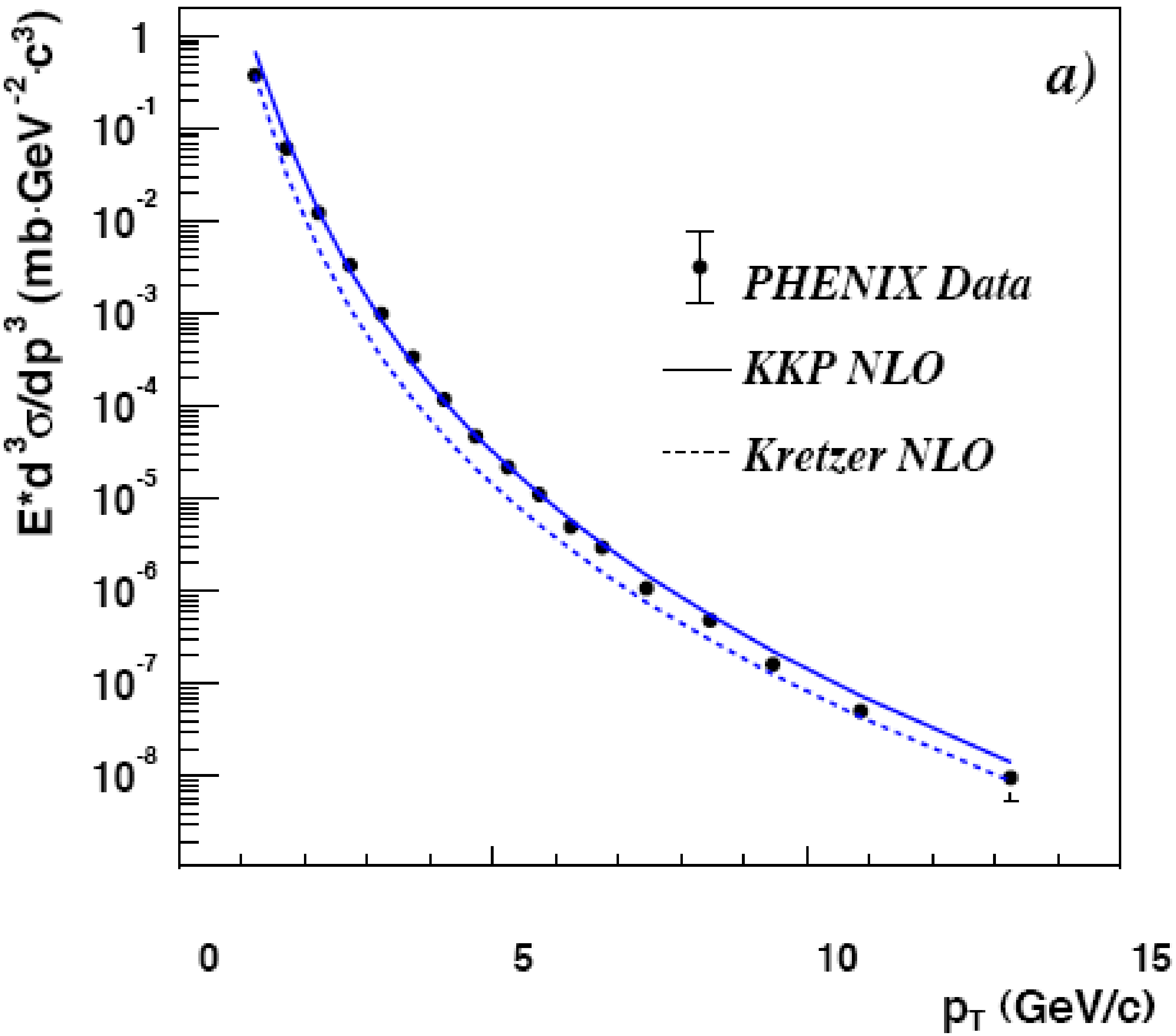
Factorization theorems of pQCD

$$E_h \frac{\mathrm{d}\sigma_{AB}}{\mathrm{d}^3 p} \simeq K \sum \int \mathrm{d}z_c \mathrm{d}x_a \mathrm{d}x_b \; f_{a/A}(x_a, Q_a^2) f_{b/B}(x_b, Q_b^2) \; \frac{\mathrm{d}\sigma^{(ab \to c+.)}}{\mathrm{d}\hat{t}} \; D_{h/c}(z_c, Q_c^2)$$

Initial wave function

Elementary cross-section

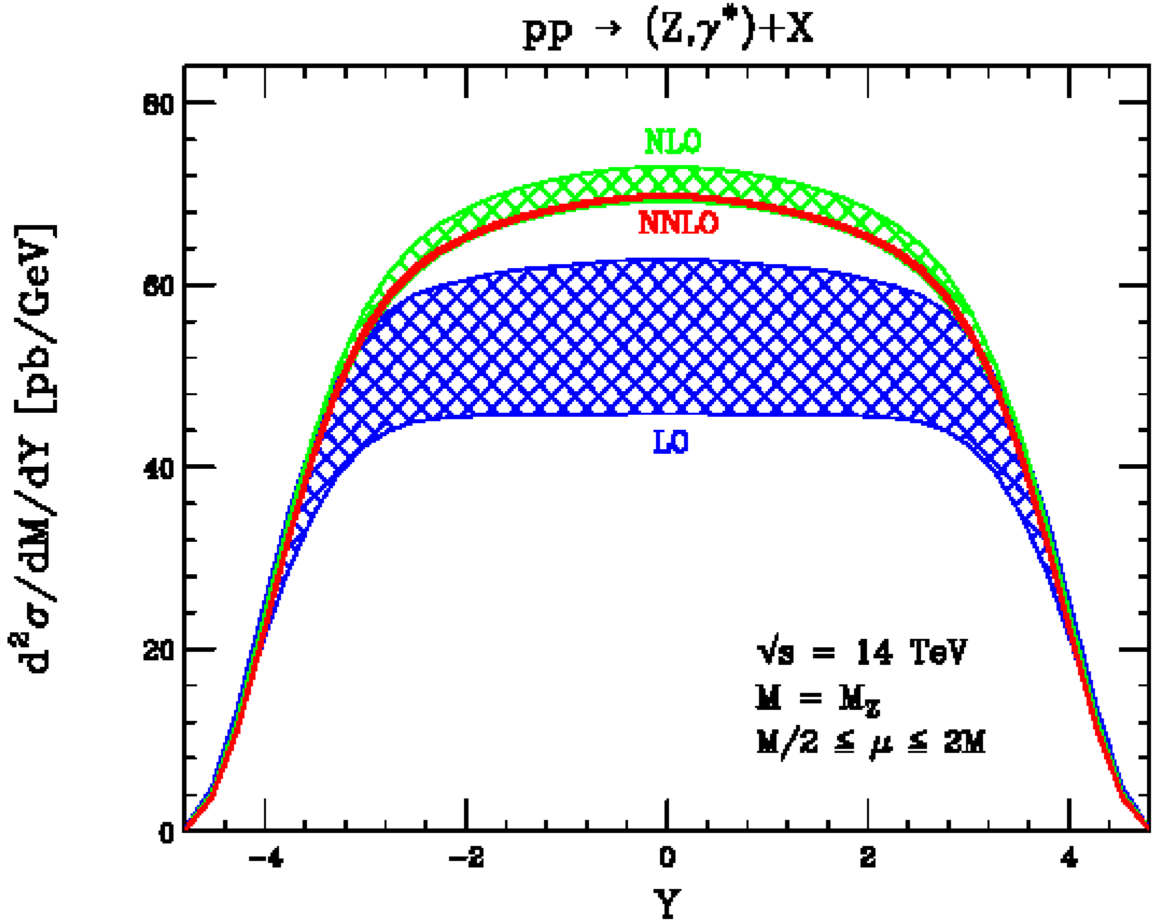
Fragmentation function



(PHENIX, hep-ex/0304038)

$$\frac{d\sigma^V}{dY} = \sum_{ab} \int_{\sqrt{\tau}e^Y}^1 \int_{\sqrt{\tau}e^{-Y}}^1 dx_1 dx_2 \; f_a^{(h_1)}(x_1) f_b^{(h_2)}(x_2) \; \frac{d\sigma_{ab}^V}{dY}(x_1, x_2)$$

$$\tau = \frac{m_V^2}{S}$$



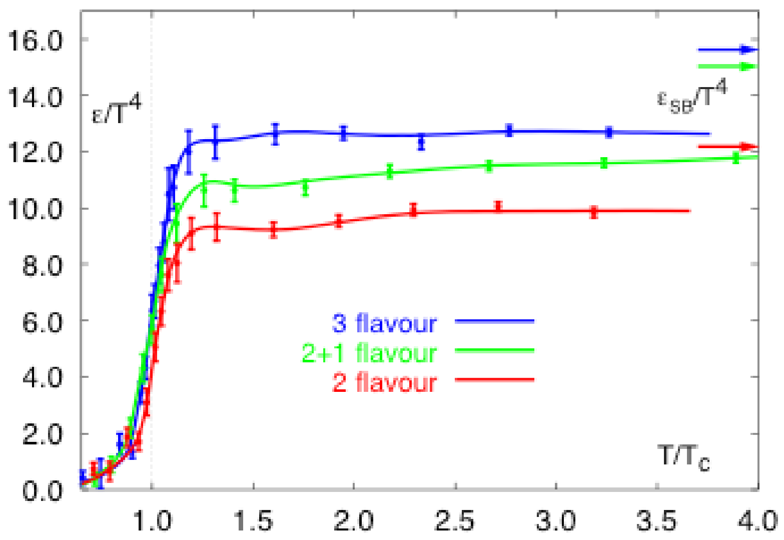
(from C. Anastasiou, L. Dixon, K. Melnikov, F. Petriello, hep-ph/0312266)

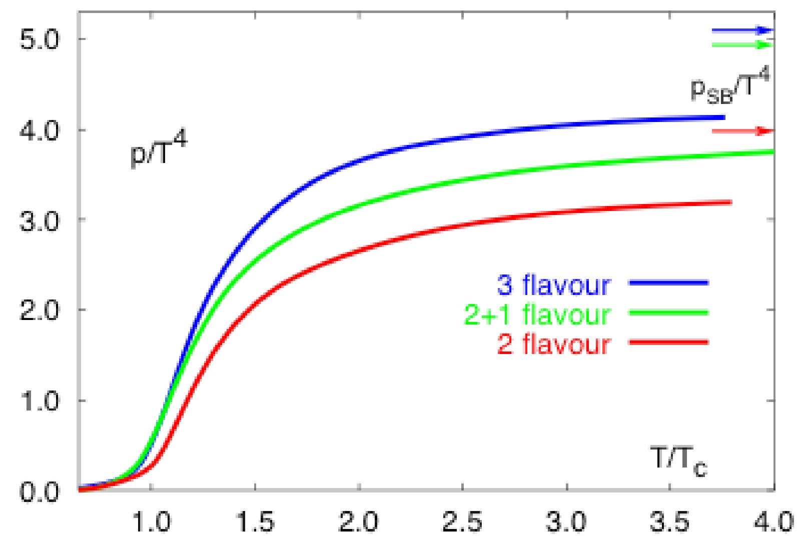
Non perturbative QCD

Effective theories (symmetries, low energy theorems), Intermediate concepts (condensates, constituent quarks, color strings, etc.)

No first principle calculations in terms of quarks and gluons except lattice QCD

Matter at high temperature is « simple »





Lattice gauge evidence for QGP

Dense and hot matter

Weak coupling, but many particles
Calculations possible
QGP, CGC

High density partonic systems

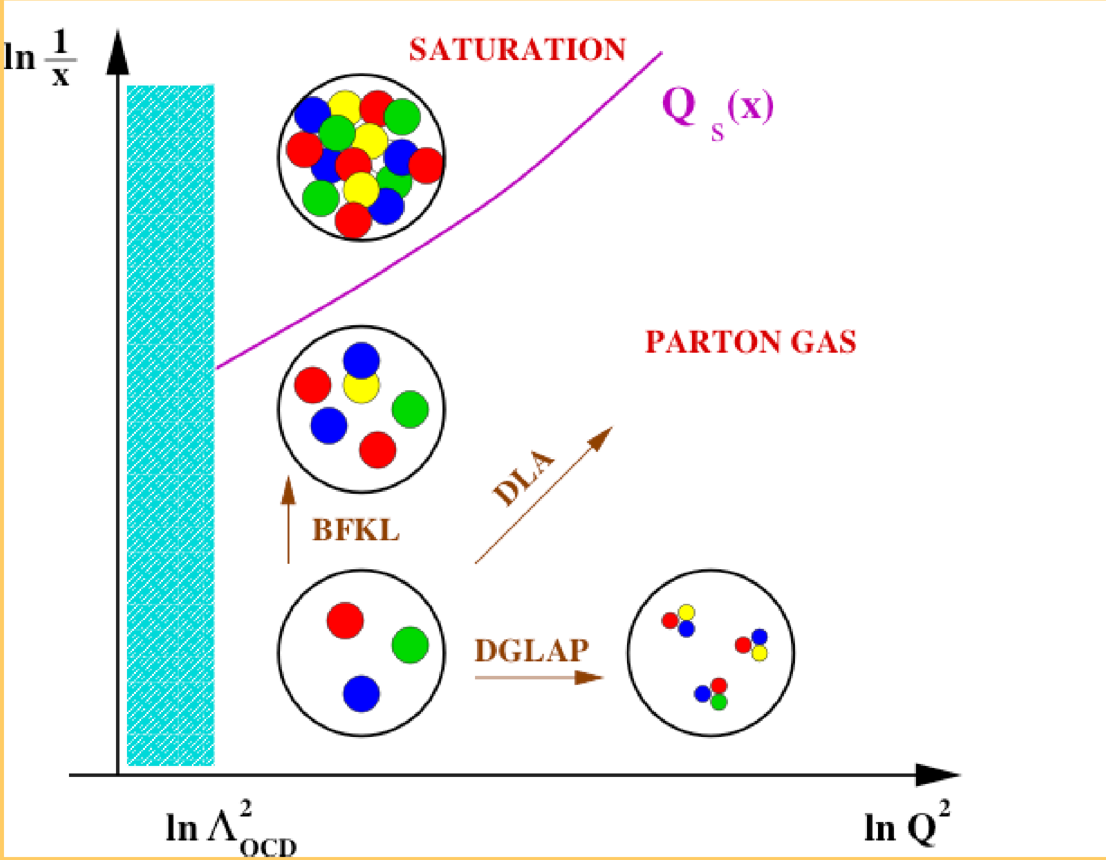
$$Q_s^2 \approx \alpha_s \frac{xG(x,Q^2)}{\pi R^2}$$

Large occupation numbers

$$n \sim \frac{xG(x,Q^2)}{\pi R^2}$$

$$\frac{\pi}{Q_s^2} n \sim \frac{\pi}{\alpha_s}$$

Classical fields



The saturation scale Q_s

From fit to DIS (HERA)

$$Q_s^2(x) \equiv Q_0^2 \left(\frac{x_0}{x}\right)^{\lambda}$$

$Q_0 = 1\text{GeV}$ $\quad x_0 = 3 \times 10^{-4}$

$\lambda \approx 0.3$

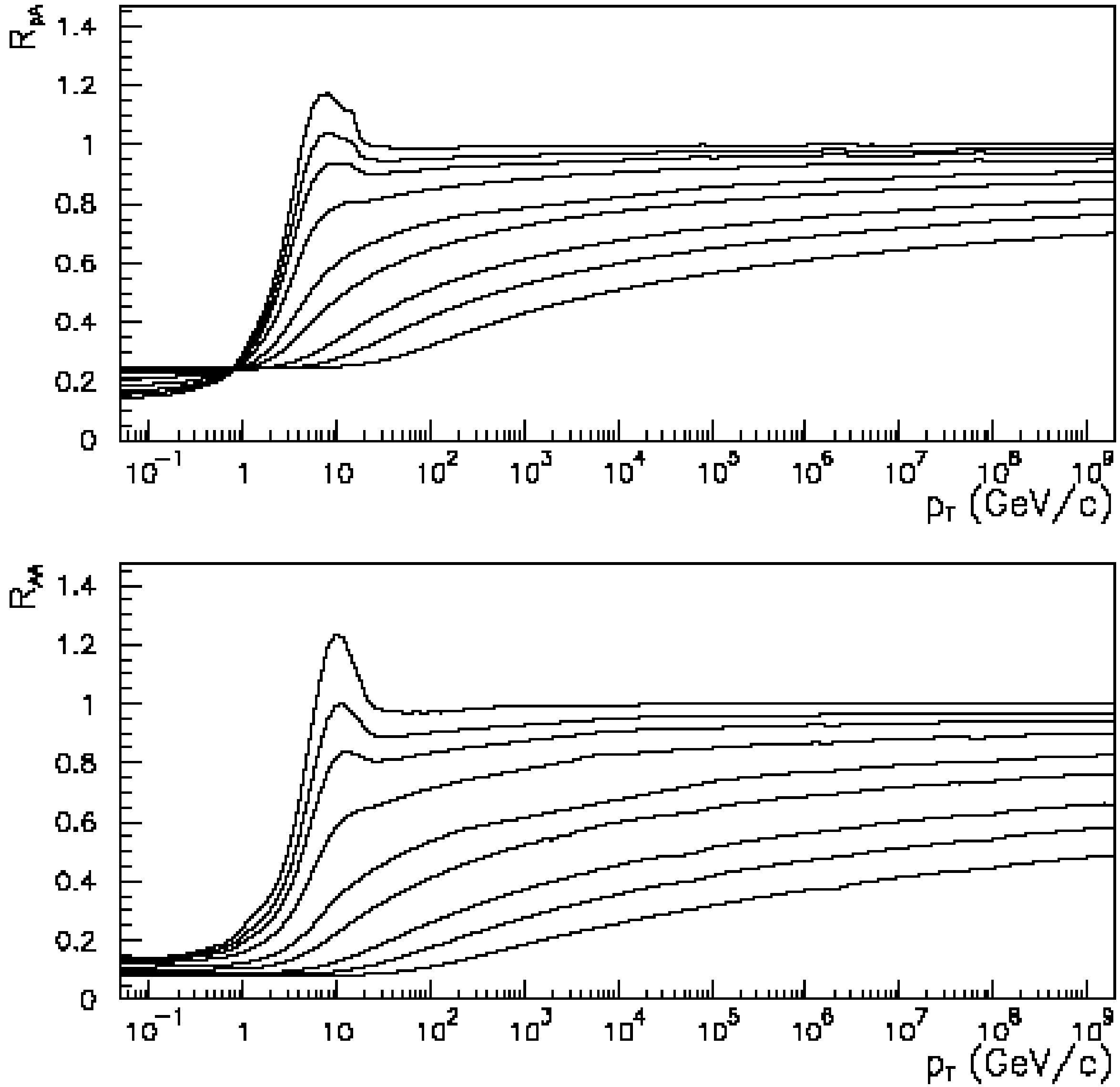
In a nucleus $\quad \dfrac{xG_A(x,Q^2)}{\pi R^2} \sim A^{1/3}$

$$Q_0^2 \to Q_0^2 A^{1/3} \qquad x = 10^{-2} \to Q_s^2 \approx 2\text{GeV}^2 \qquad (\text{for}\, A = 200)$$

The conditions in the central rapidity of a nucleus-nucleus collision at RHIC are similar to those at HERA.

At the LHC

$$\sqrt{s} = 5.5\text{TeV} \qquad x \sim 5 \times 10^{-4} - 10^{-5} \qquad Q_s^2 \sim 5 - 14\text{GeV}^2$$



y

0

0.05

0.1

0.2

0.4

0.6

1

1.4

2

Albacete et al, hep-ph/0307179

(Related analytical work by Iancu, Itakura, Triantafyllopoulos hep-ph/0403103)

$$R_{dA} \equiv \frac{\left.\frac{dN}{dy d^2 \boldsymbol{p}_\perp}\right|_{dA}}{N_{\text{coll}} \left.\frac{dN}{dy d^2 \boldsymbol{p}_\perp}\right|_{pp}}$$

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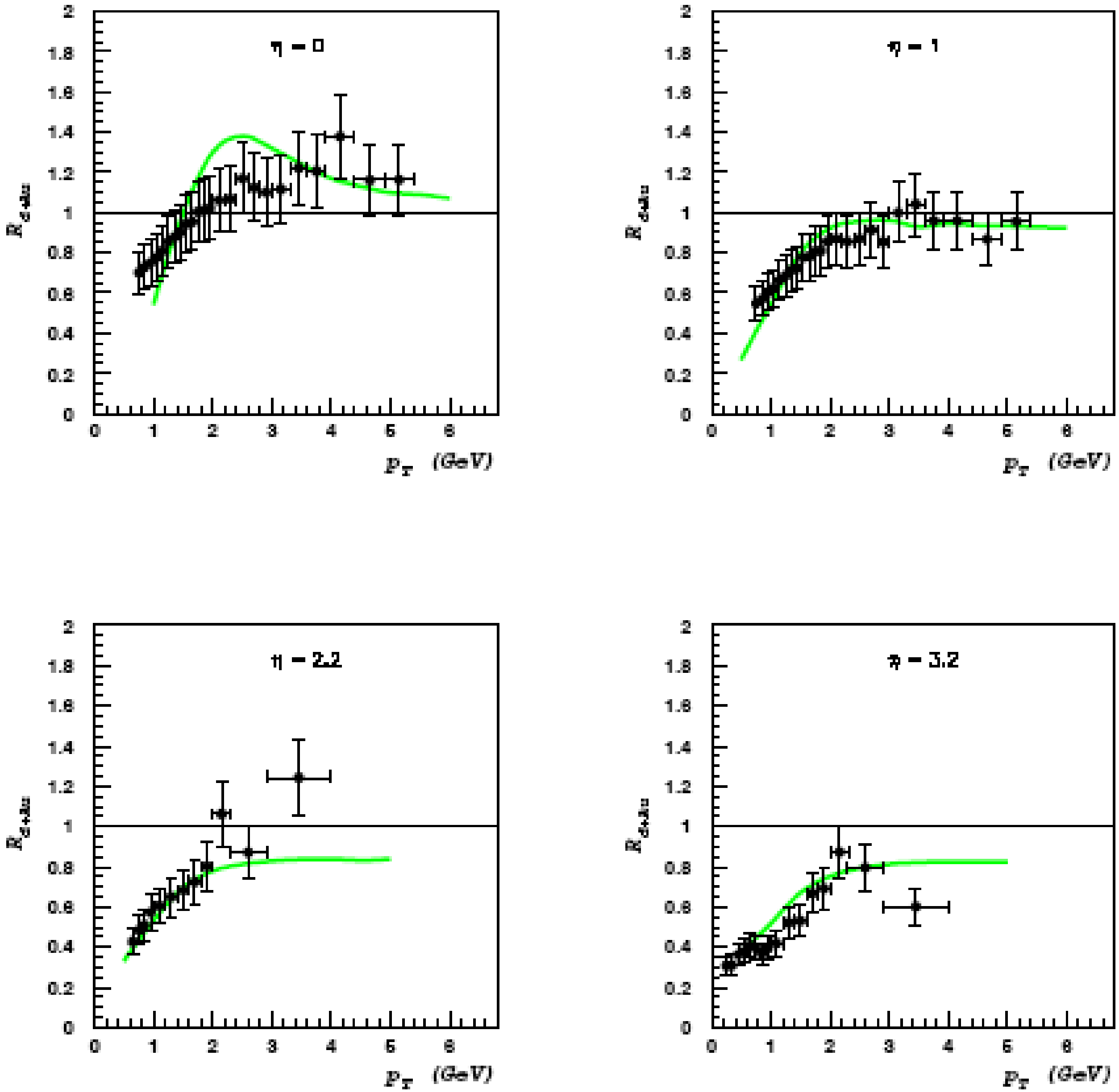
sont requis pour visionner cette image.

I. Arsene, et al., BRAHMS collaboration, nucl-ex/0403005



(Kharzeev, Kovchegov, Tuchin, hep-ph/0405045)

Where are we going?

What can we predict (=calculate accurately) from QCD?

Initial production of hard probes (jets, heavy quarks, etc.)

$$Q^2 \gg \Lambda^2_{QCD} \qquad Q^2 \gg Q_s^2 \qquad Q^2 \gg T^2$$

Binary scaling

Deviations from predictions signal new physics

Ex: J/Psi suppression (?), jet quenching, heavy quark propagation, etc.

Because it is a dedicated machine, RHIC can systematically explore the characteristics of such final state interactions.

New exciting directions (qualitative predictions)

Test of saturation physics, color glass condensate
(genuine, characteristic QCD effect, important to control « intitial conditions » in nucleus-nucleus collisions)

Eliminate as much as possible final state interactions

Ideal collisions are pA (dA) or eA

Exploit possibilities to vary x and A

Look for non trivial correlations

(More in talk by Kharzeev)

pA collisions are an essential reference for AA
but can reveal interesting physics

Coherence effects (color transparency, etc.)

Tests of color glass picture

Partons correlations (e.g. in quark production)

Final remarks

Many experiments are needed to get a better understanding of the dynamics of nucleus-nucleus collisions (models)

Experimental tests of basics assumptions involved in models

Ex: thermalisation (photons, dileptons ?)