Nuclear Theory Group @ BNL

D. Kharzeev

The physics program of BNL Nuclear Theory Group

1. Quantum Chromo-Dynamics at finite temperature and density and the physics of Quark-Gluon Plasma

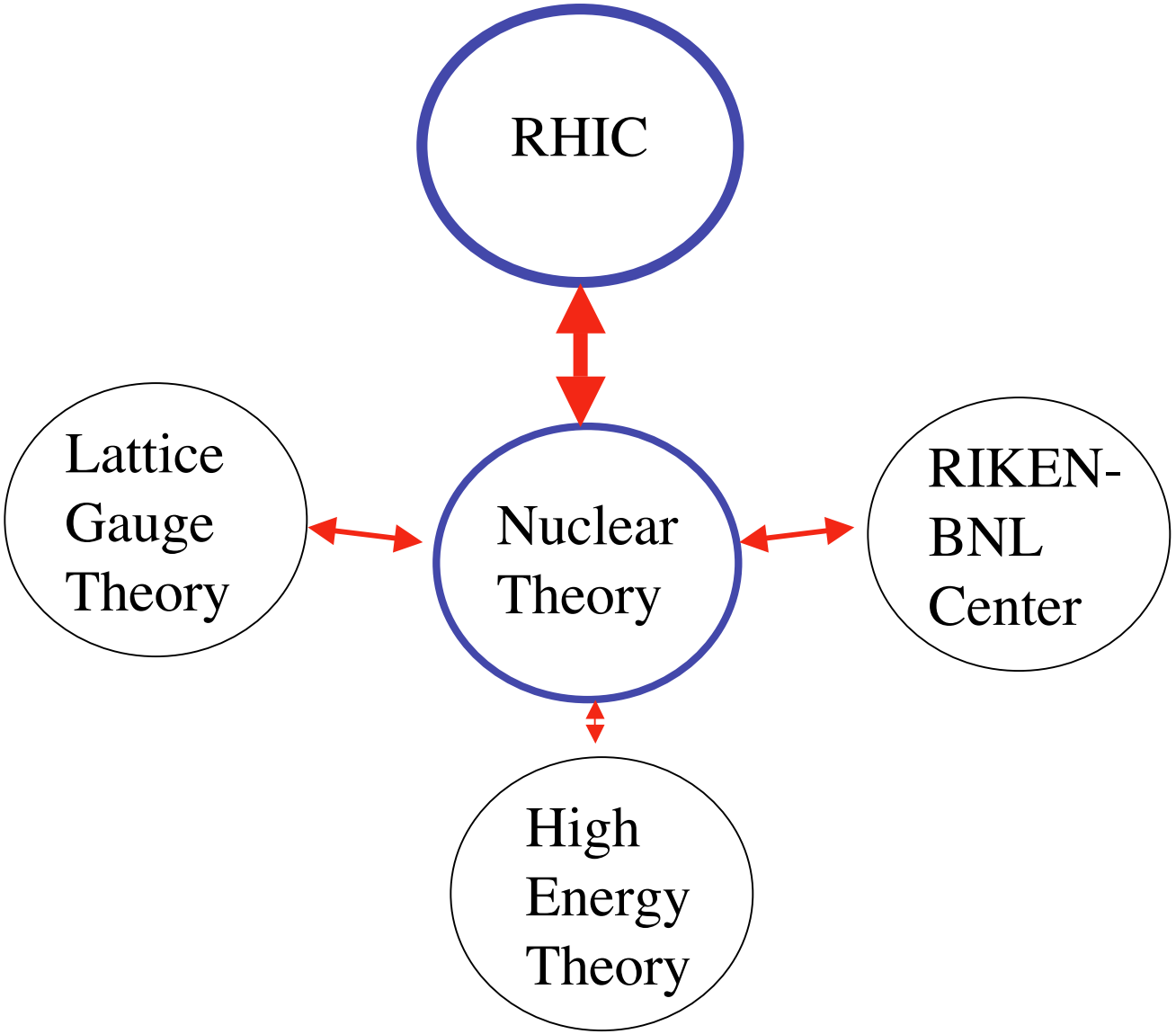
2. QCD at high energies and small x and the physics of the Color Glass Condensate

3. Perturbative QCD and the spin structure of the nucleon

4. Electromagnetic interactions of nuclei at high energies and nuclear structure

All of these topics are tightly connected to the existing and planned experimental programs at BNL and to the NSAC performance milestones for Nuclear Theory

Nuclear Theory Group at BNL



Staff of the Nuclear Theory Group

Marcy Chaloupka - Secretary

Permanent Scientific Staff:

1. A. Baltz
2. D. Kharzeev
3. L. McLerran
4. J. Millener
5. R. Pisarski
6. R. Venugopalan
7. W. Vogelsang

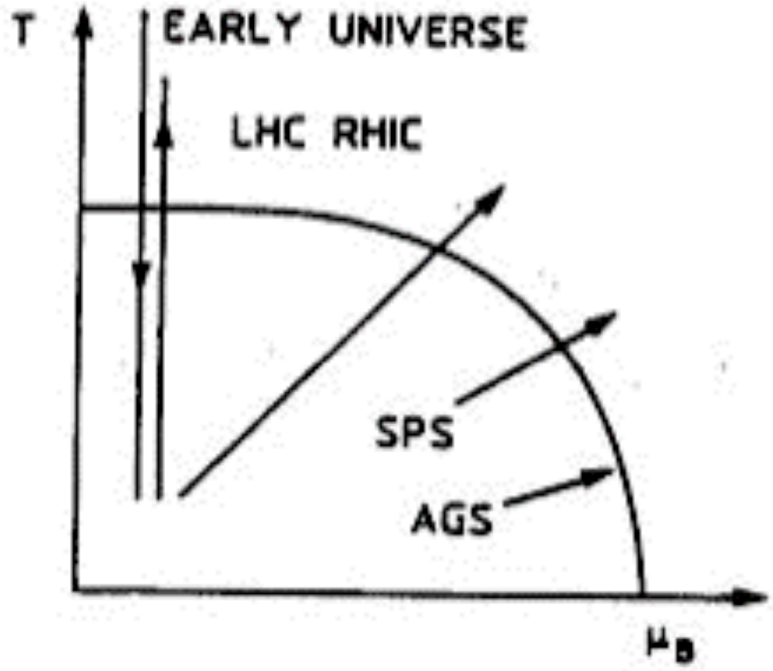
Research Scientists:

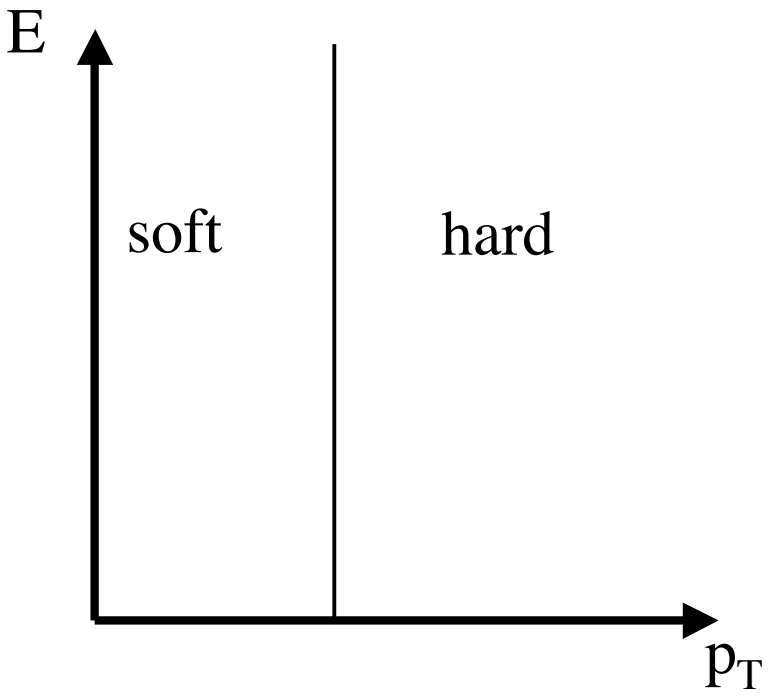
1. A. Stasto
2. T. Lappi

Significant accomplishments in FY05/06

1. Developed a realistic non-perturbative approach to the equation of state of Quark-Gluon Plasma, which is a necessary step towards achieving both of the NSAC performance milestones. RP
2. Performed a realistic numerical 3D simulation of the evolution of matter in heavy ion collisions at RHIC based on the initial conditions developed in the Group; estimates of the viscous effects also made. DK, LMcL, RV
3. Performed realistic calculations of the production and propagation in dense hadronic matter of heavy quarks and quarkonia DK, TL, RV
4. Developed a theory of the structure of nuclei and hadrons at small x, and formulated its experimental tests at RHIC DK,LMcL,AS,RV,WV
5. Performed Next-to-Leading order perturbative QCD calculations vital for the measurements of the proton spin structure at RHIC WV

QCD diagrams, late XX century
(pre-RHIC)



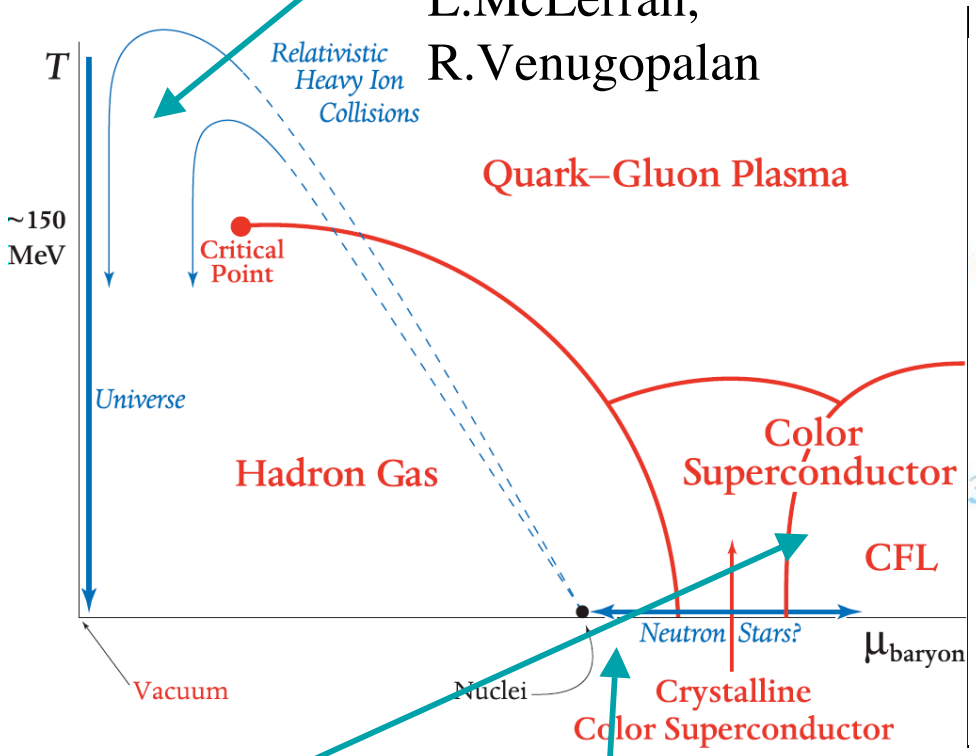


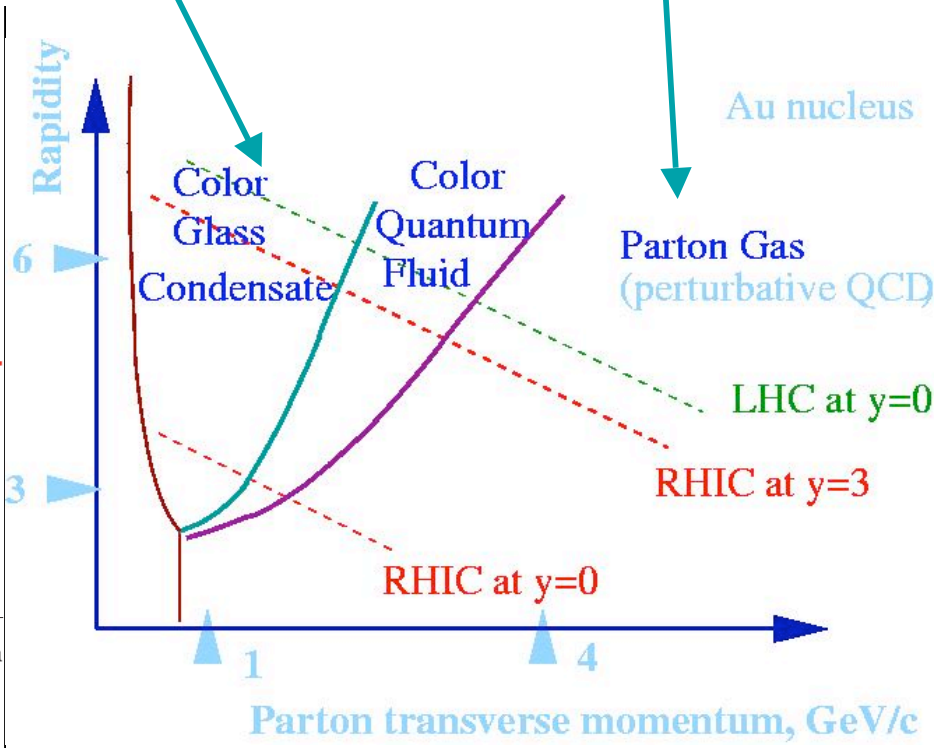
QCD diagrams, early XXI century

R.Pisarski,
D.Kharzeev,
L.McLerran,
R.Venugopalan

L.McLerran,
R.Venugopalan,
D.Kharzeev

W.Vogelsang

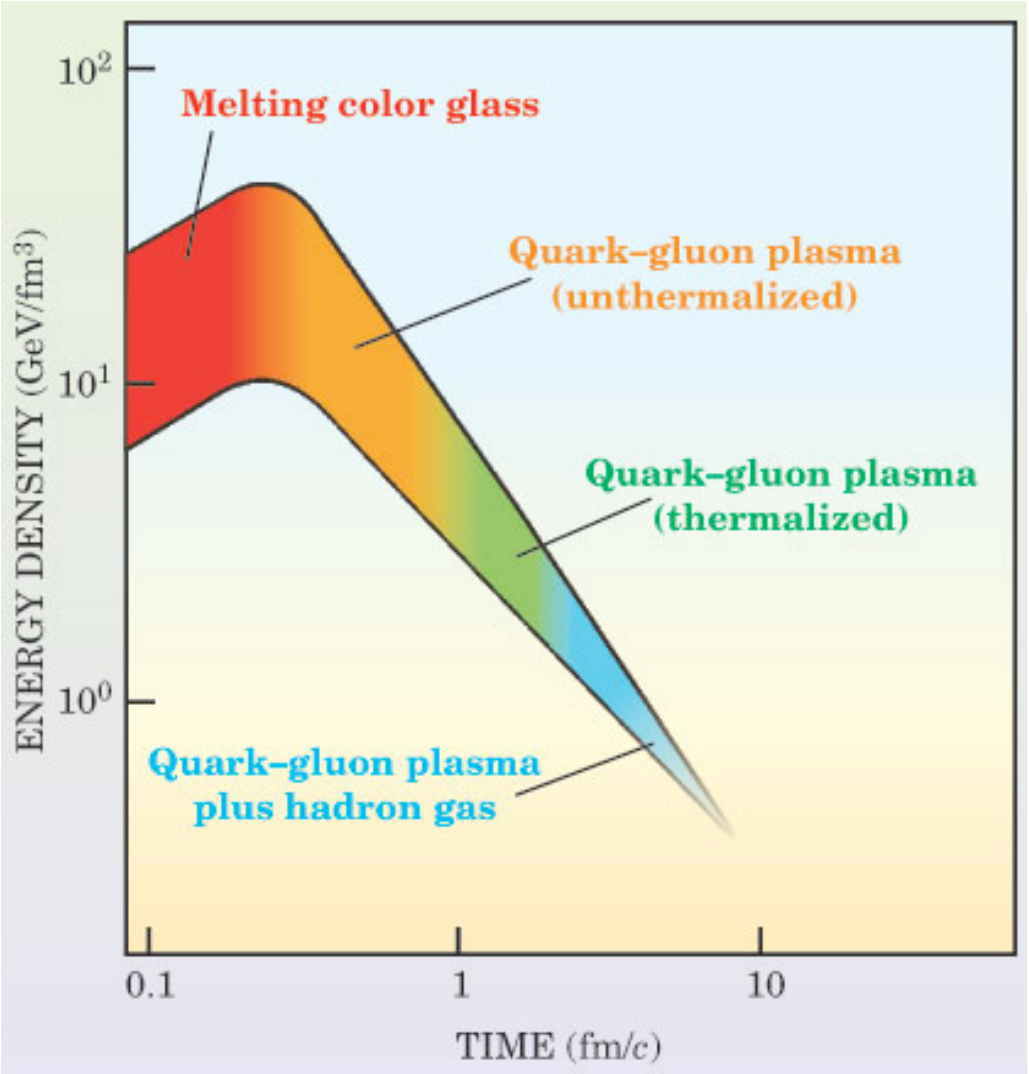




R.Pisarski

A. Baltz, J. Millener

Time evolution in heavy ion collisions



T. Ludlam,
L. McLerran,
Physics Today
October 2003

The physics of Quark-Gluon Plasma

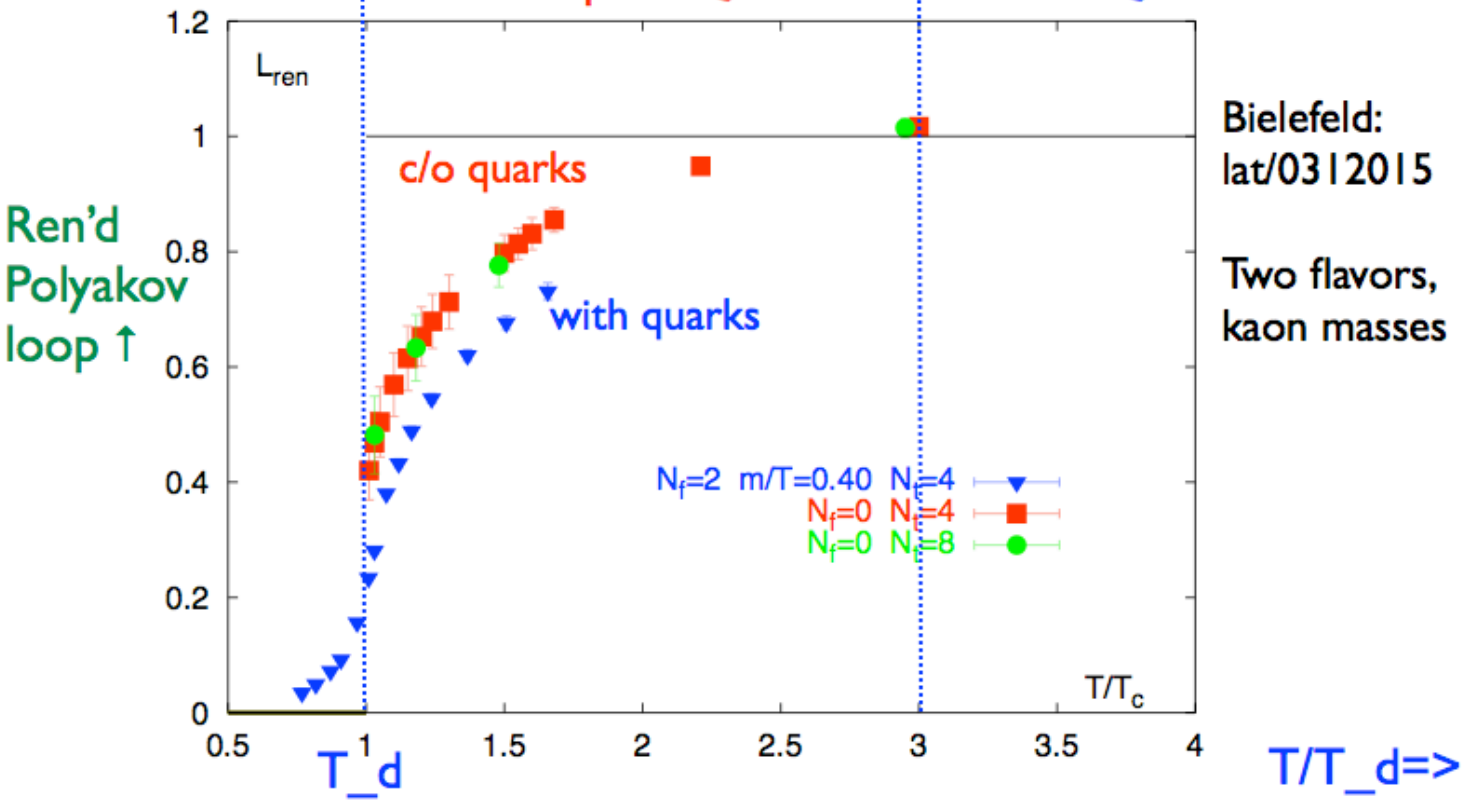
R. Pisarski

Non-perturbative QGP

Ren'd Polyakov loop: = 0 in confined phase, = 1 in pert. thy

Lattice: Z(3) sym. approx in QCD. Loop only near 1 above 3 T_d

<= Confined =><= *Non*-pert. QGP =><= Pert. QGP =>

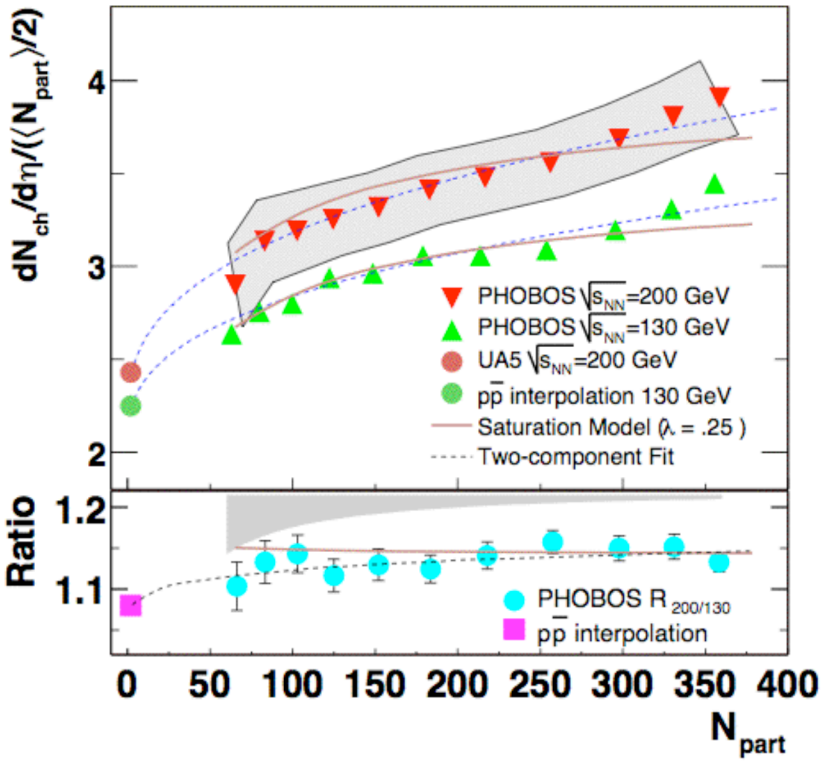


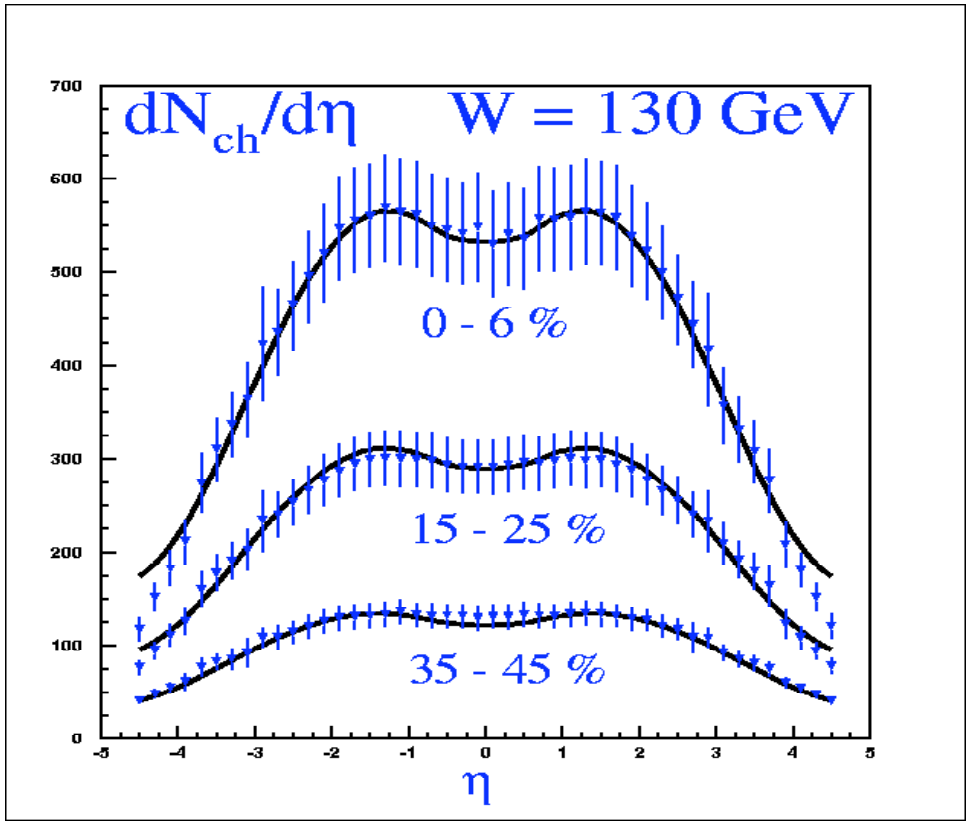
Bielefeld: lat/0312015

Two flavors, kaon masses

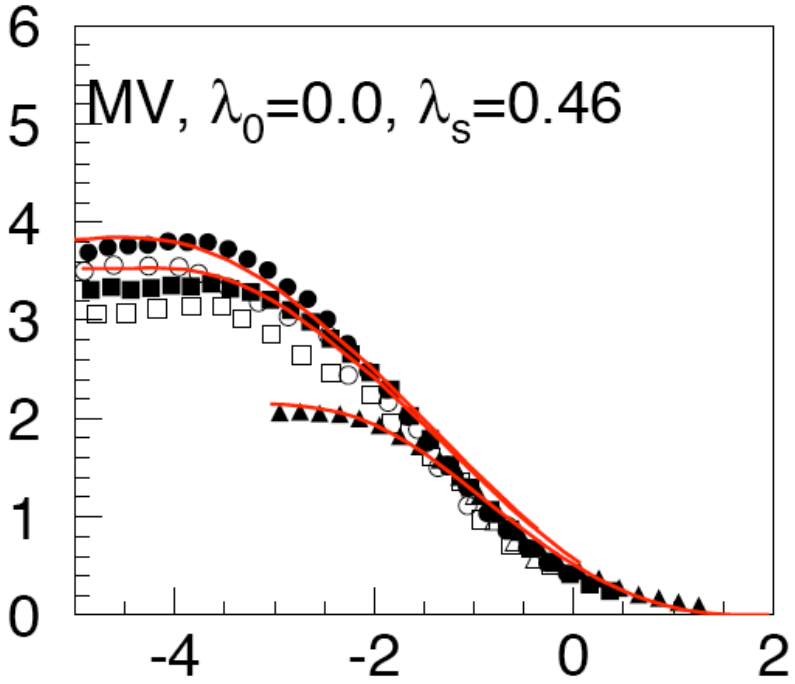
QCD at high parton densities

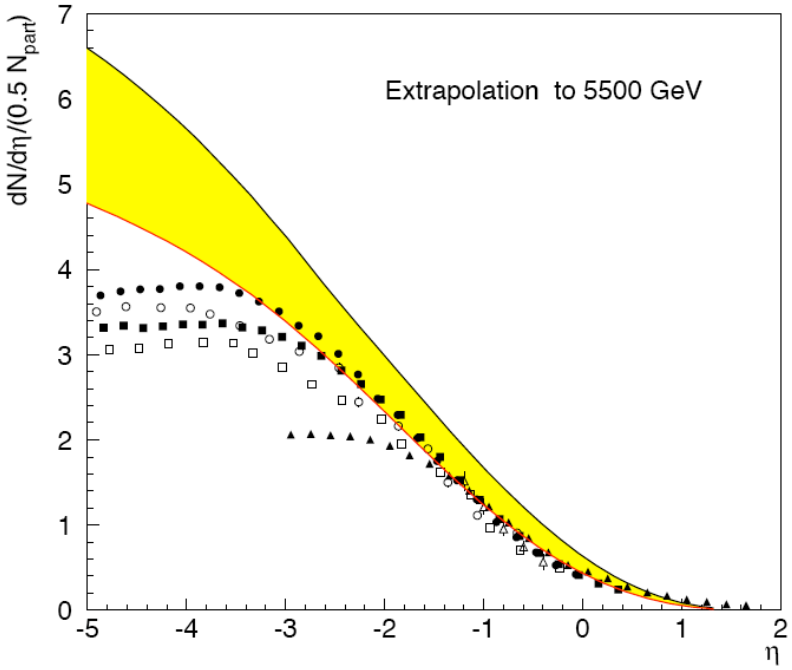
The hadron multiplicities in Au-Au and d-Au collisions are described in the CGC approach





The physics of Limiting Fragmentation

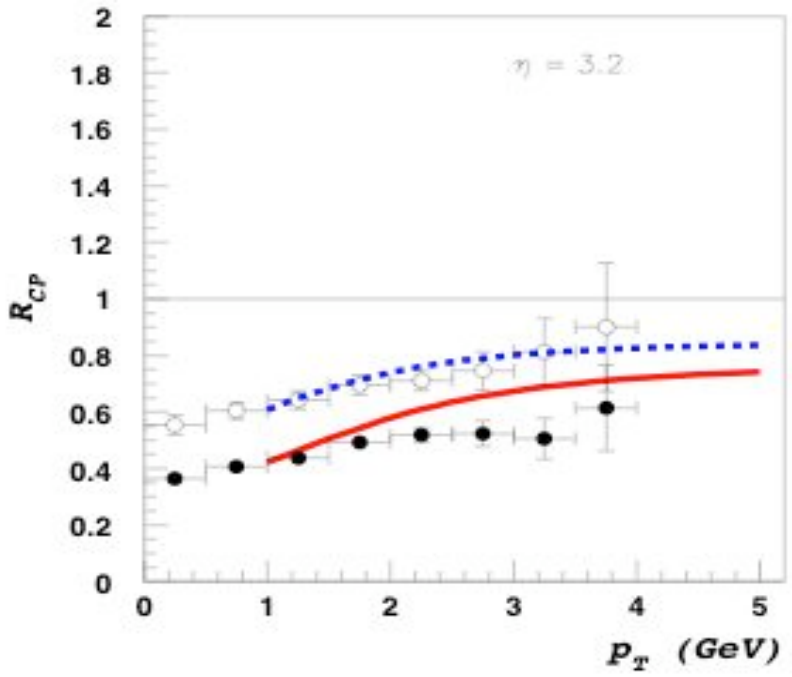




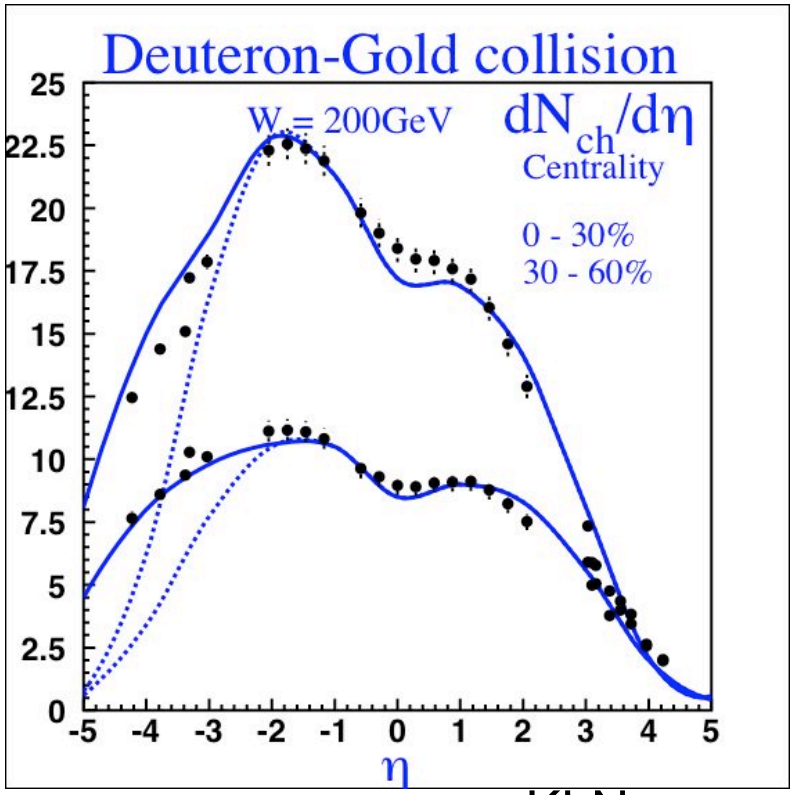
Gelis, Stasto, Venugopalan

Color Glass Condensate at RHIC

Synergy between Nuclear Theory group and
RHIC experimentalists



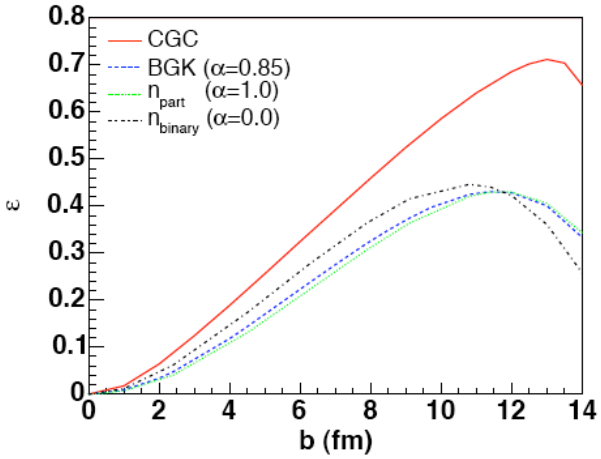
KKT

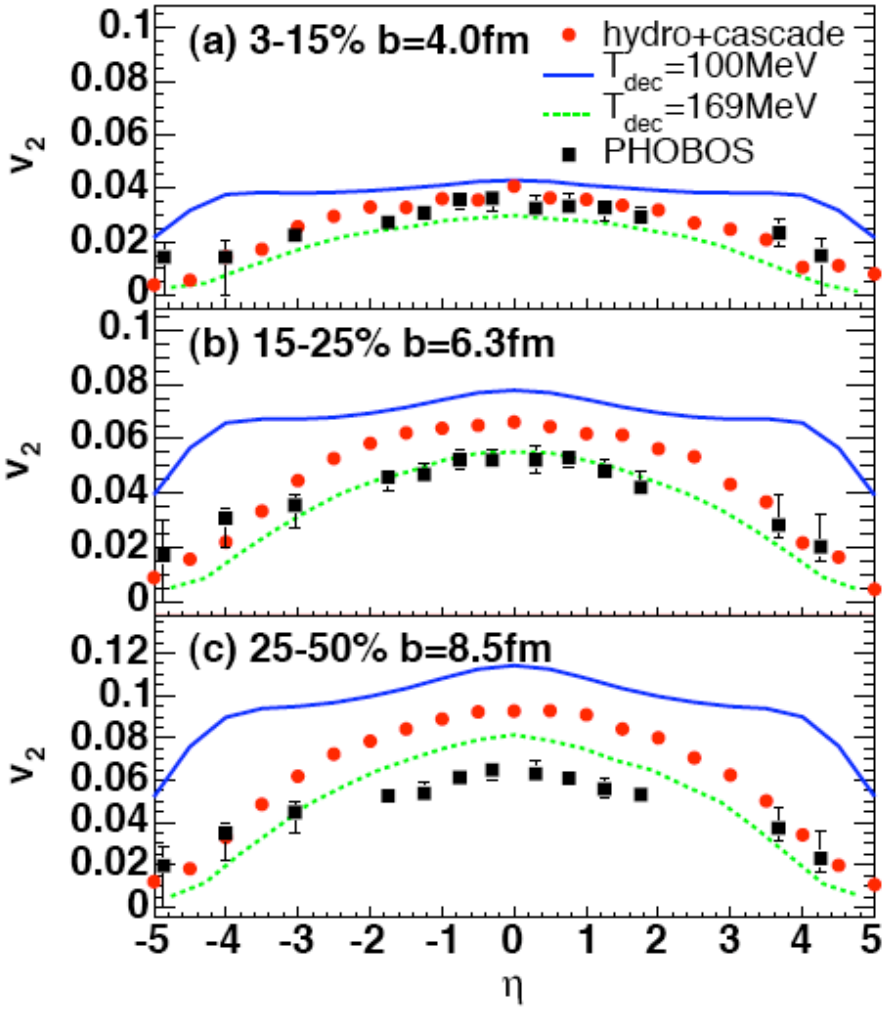


KLN

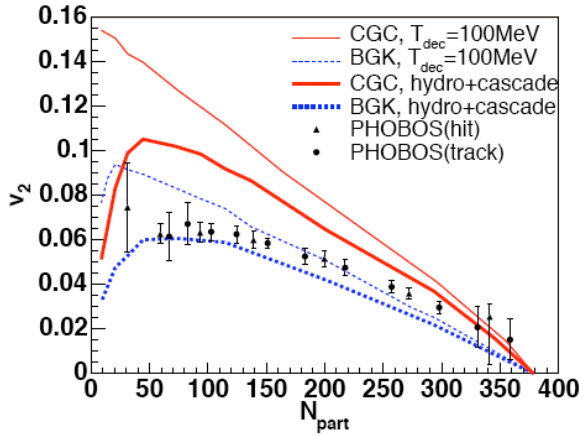
How small is the viscosity of sQGP?

CGC initial conditions lead to larger ellipticity,



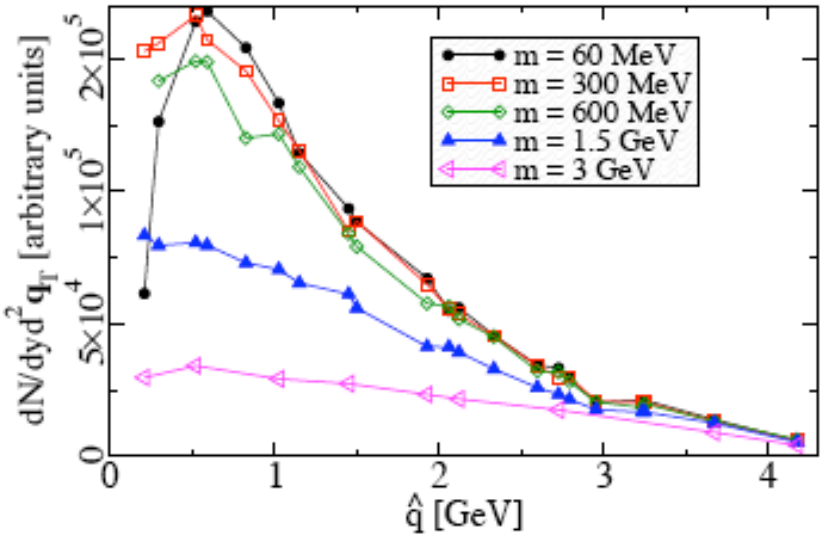


require some viscous effects:

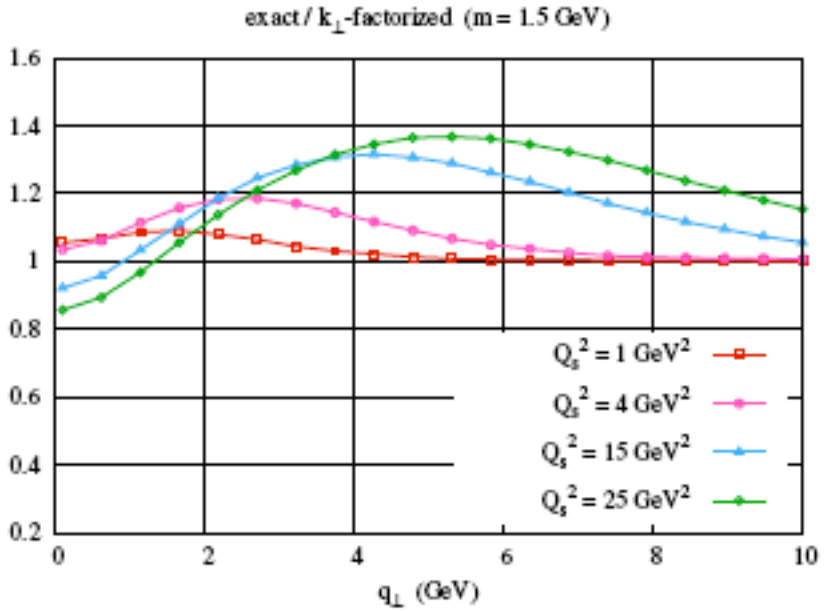


T.Hirano, U.Heinz, DK, R.Lacey, Y. Nara, hep-ph/0511046

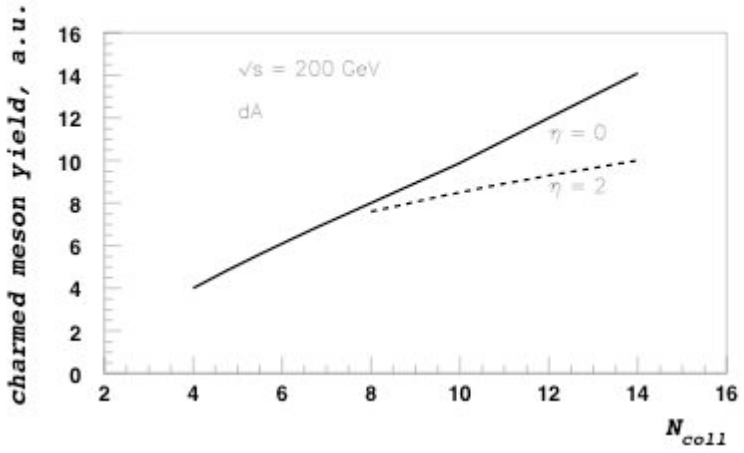
Heavy quark production



Gelis, Kajantie, Lappi



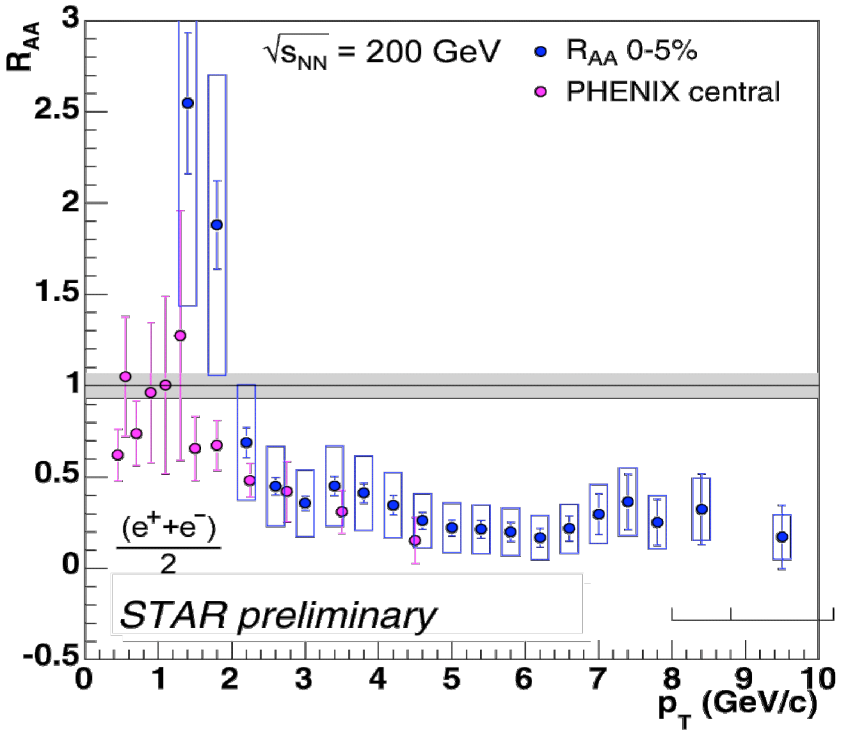
Fujii, Gelis, Venugopalan

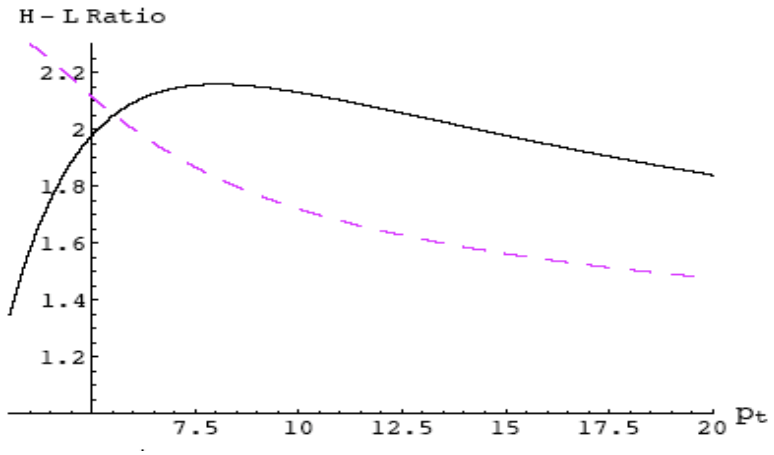


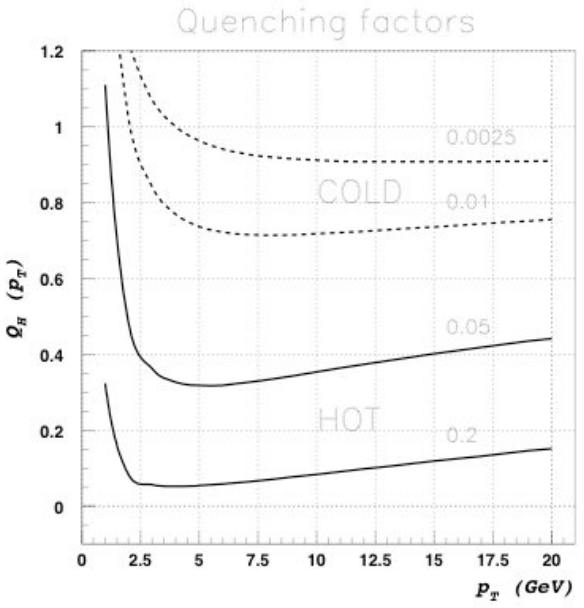
Coherent effort by current and former group members

DK, Tuchin

Heavy quarks as a probe



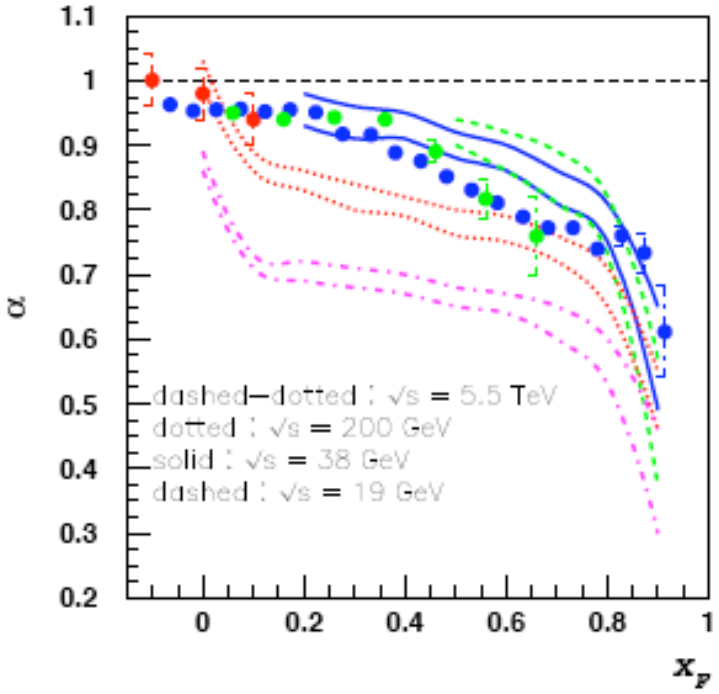




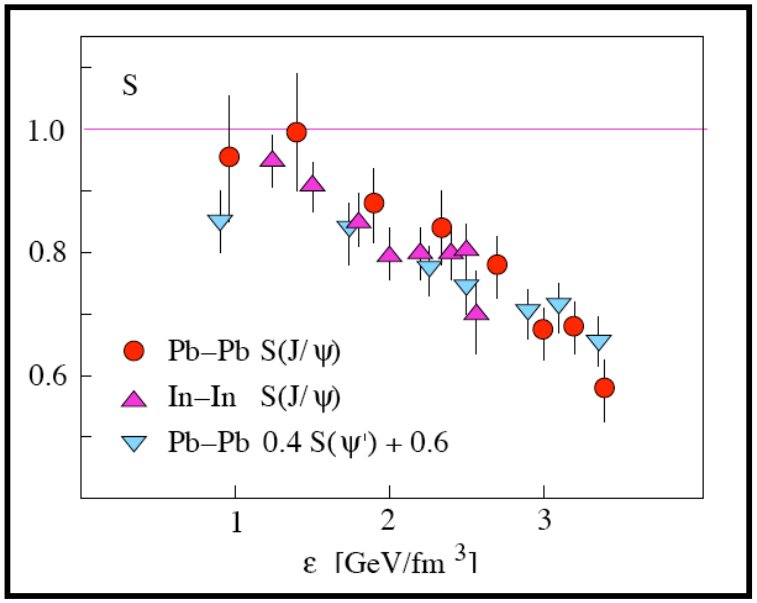
Heavy quark production in the medium - a crucial test of the energy loss mechanism ("dead cone" suppression of radiative energy loss) - Yu. Dokshitzer, DK '01

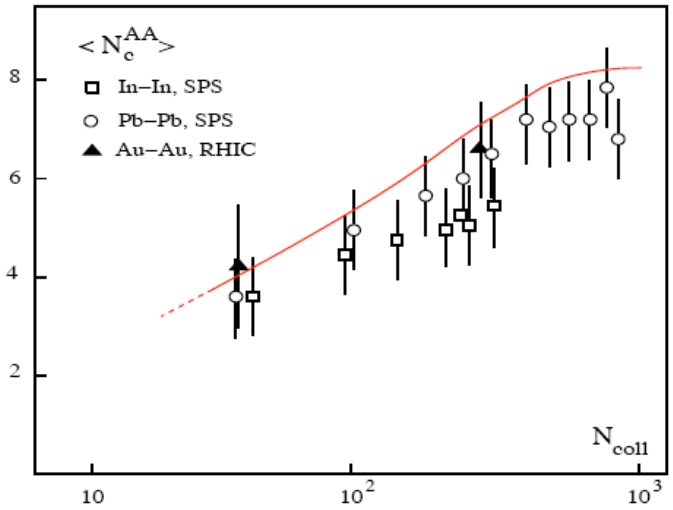
DK, K.Tuchin

Heavy quarkonium as a probe



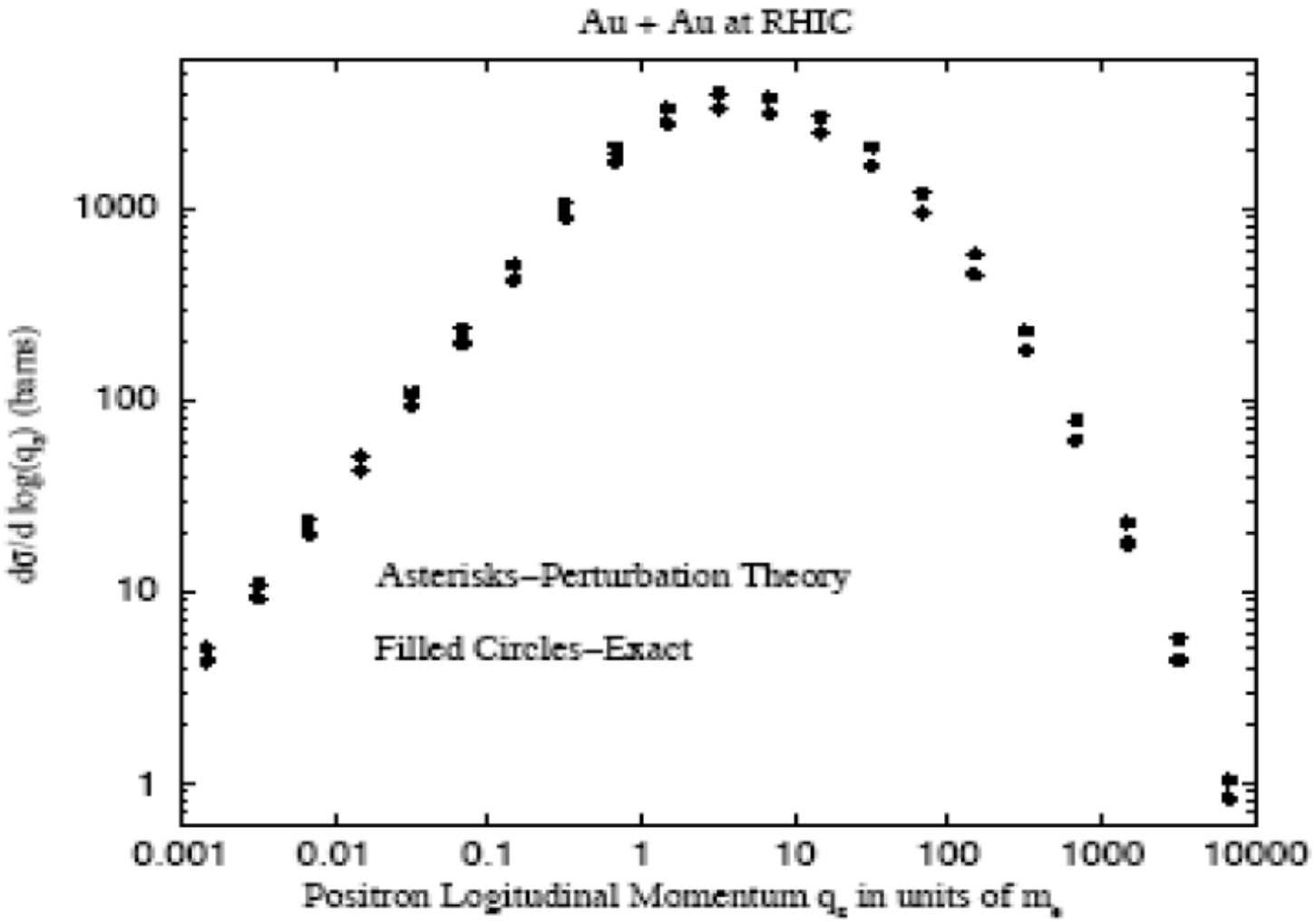
DK, K. Tuchin





F.Karsch, DK, H.Satz

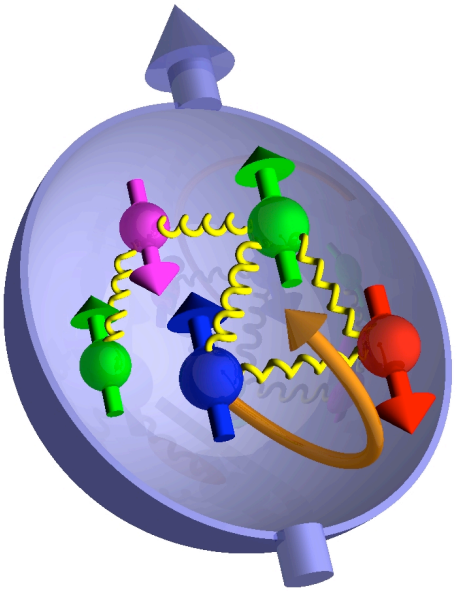
Electron-positron pair creation in heavy ion collisions



A. Baltz

Exciting program with polarized protons underway at RHIC:

What carries the proton spin ?



$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L$$

Quark spins

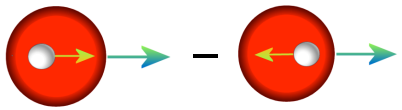
only ≈ 20 %

Gluon spins

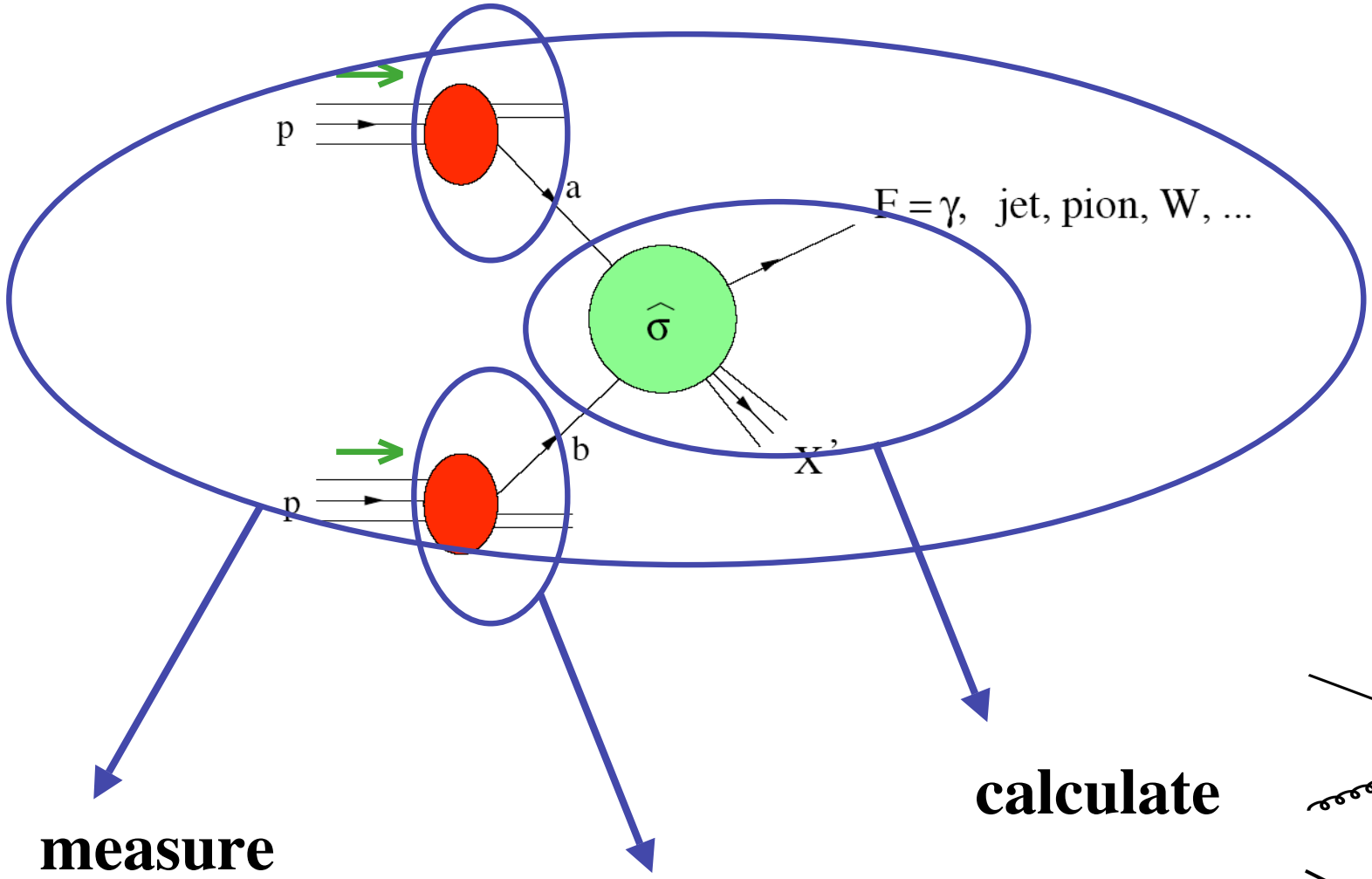
??

Quark and gluon orbital ang. mom.

??



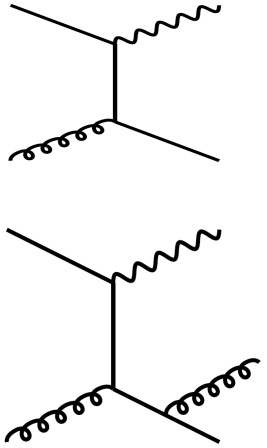
- **RHIC addresses the proton spin structure in new ways**
- **BNL Nuclear Theory devotes a major effort to QCD spin physics, in particular for RHIC**



measure

calculate

→ learn about !



The calculation is the theorist's main task !

needs: precision → higher orders in QCD perturbation th.

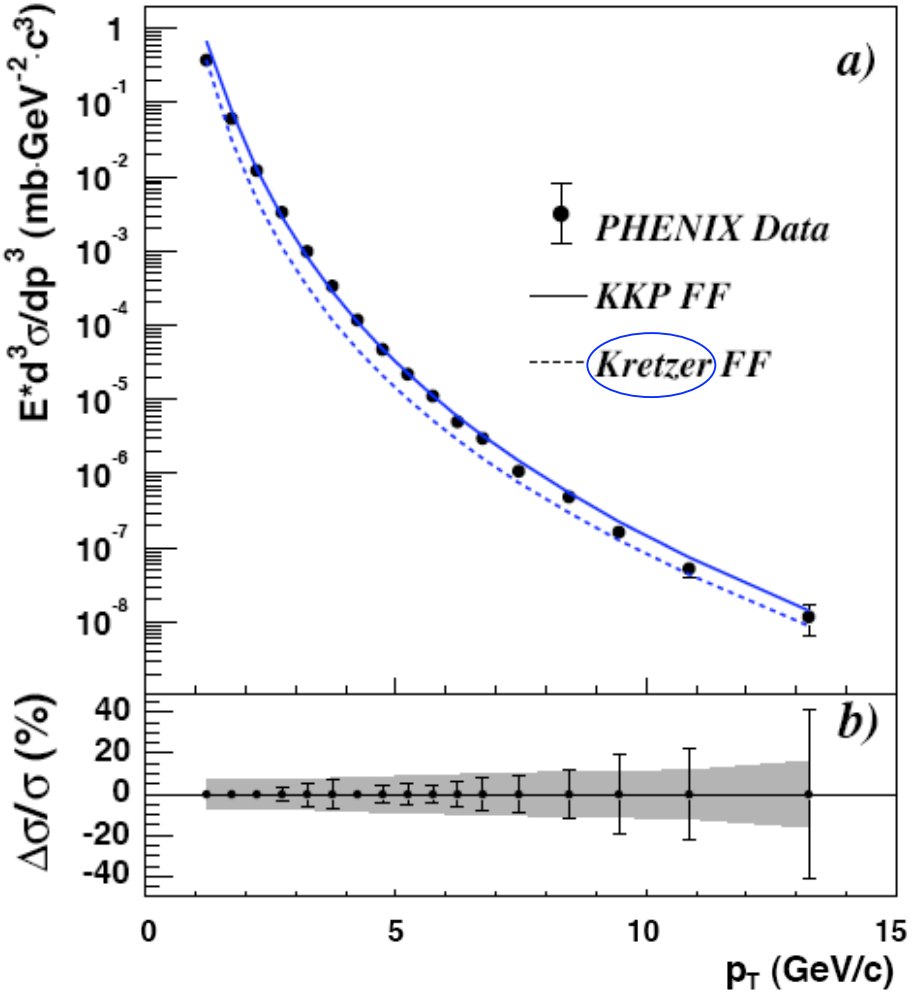
- **BNL Nuclear Theory is leading the efforts to do the relevant "next-to-leading order" calculations. Some examples:**

$pp \rightarrow \pi X$	Jäger, Schäfer, Stratmann, Vogelsang, Phys. Rev. D67 (2003) 054005
	Jäger, Kretzer, Stratmann, Vogelsang, Phys. Rev. Lett. 92 (2004) 121803
$pp \rightarrow jet X$	Jäger, Stratmann, Vogelsang, Phys. Rev. D70 (2004) 034010
$pp \rightarrow \gamma X$	Frixione, Vogelsang, Nucl. Phys. B568 (2000) 60
	Mukherjee, Stratmann, Vogelsang, Phys. Rev. D67 (2004) 114006

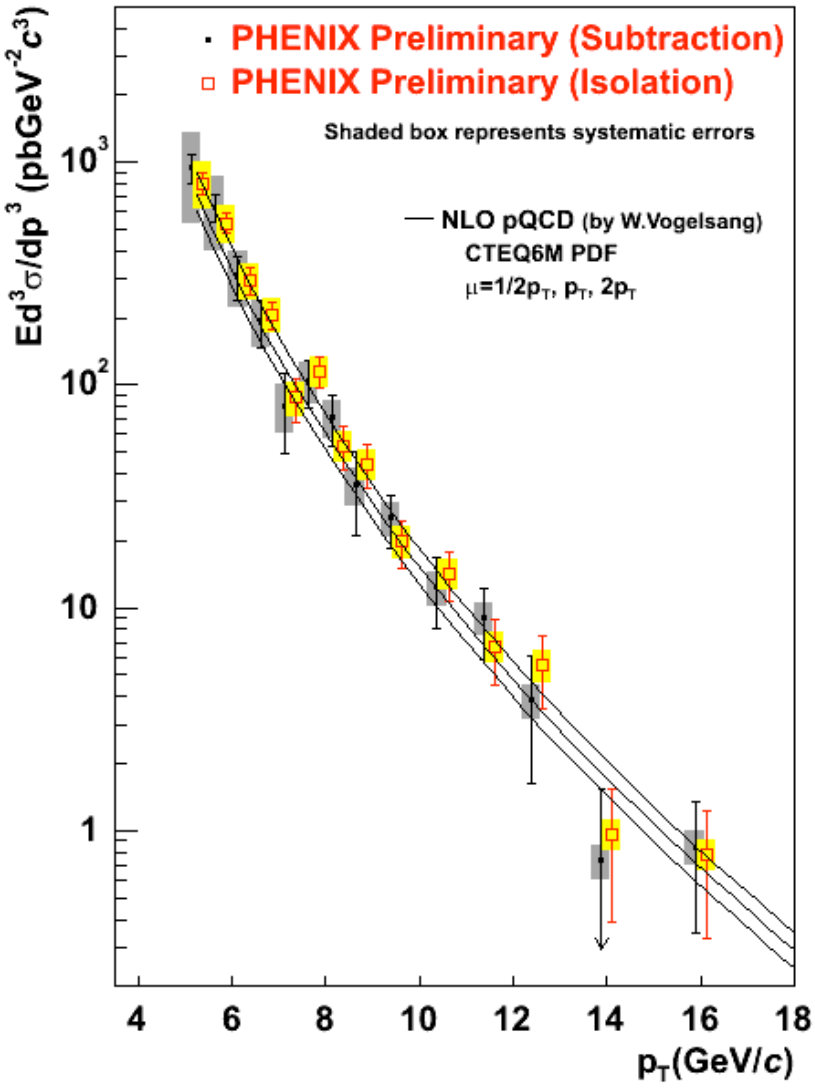
- **plus, work in other areas: neutrino-nucleon interactions, strangeness in the proton, QCD resummations, …**

- **Calculations are already successful in unpolarized pp at RHIC:**

$pp \to \pi^0 X$

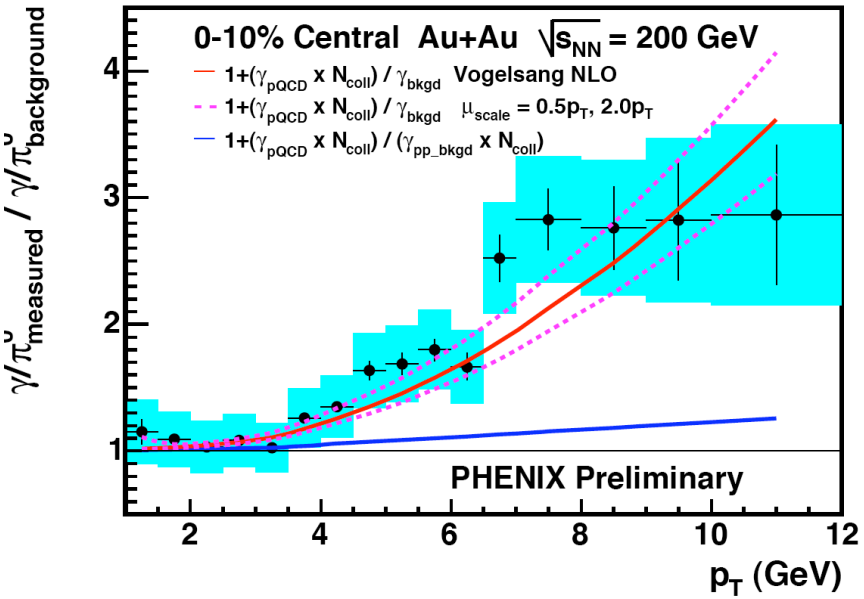


$pp \to \gamma X$

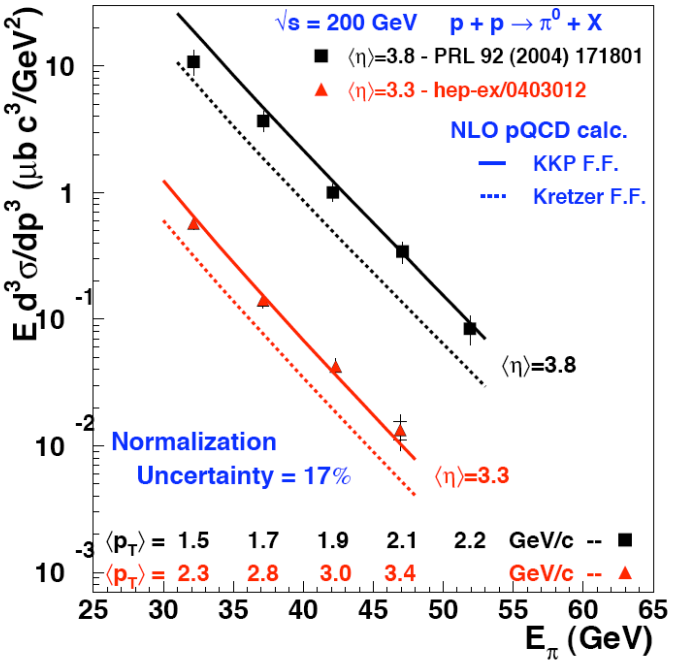


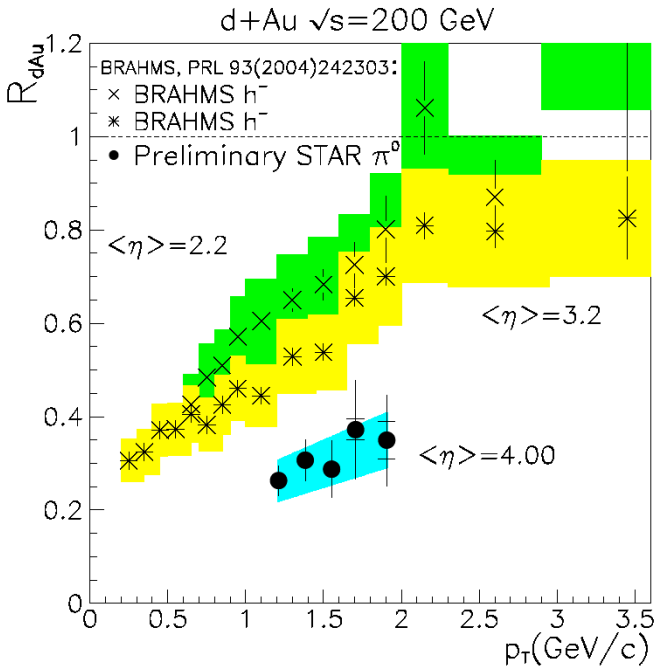
NLO: Jäger, Schäfer, Stratmann, Vogelsang

- **Also important as benchmark for heavy-ion collisions at RHIC**
- **Examples:**



Au-Au

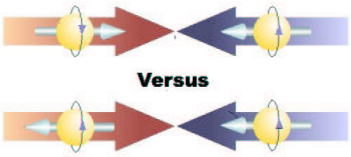




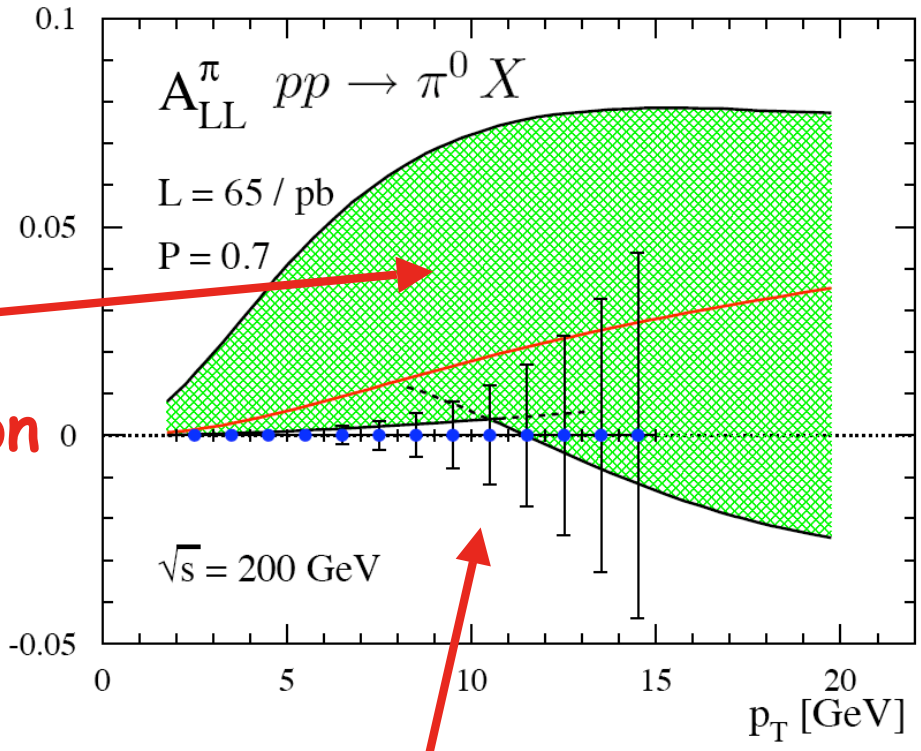
d-Au

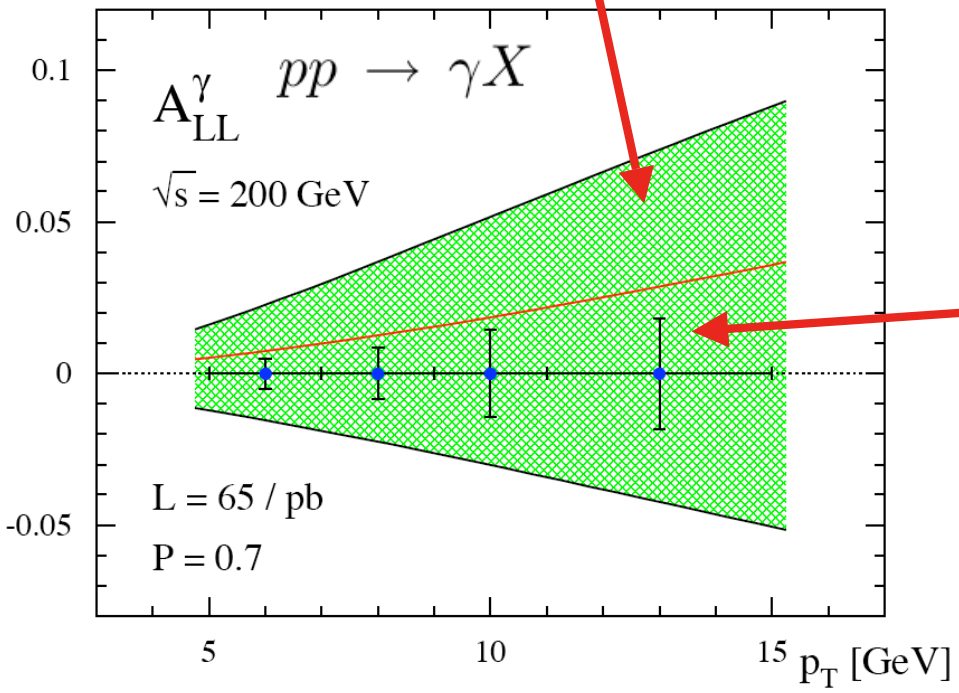
Predicted in
Guzey, Strikman, Vogelsang
PLB 603 (2004) 173

- **Back to RHIC spin …**



Due to current "uncertainty" of gluon polarization



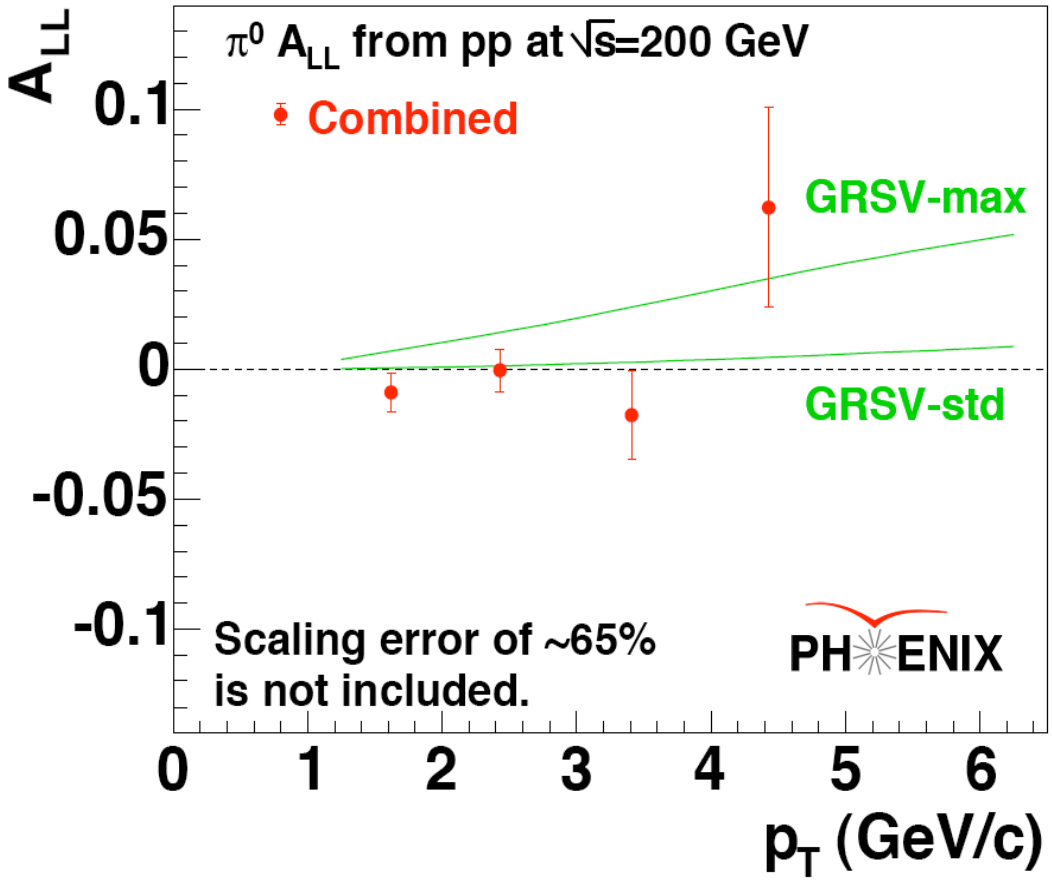


Expected RHIC stat. uncertainties

Glück, Reya, Stratmann, Vogelsang, Phys. Rev. D63 (2001) 094005

Jäger, Schäfer, Stratmann, Vogelsang, Phys. Rev. D67 (2003) 054005

Data are coming in …



- much more expected from just completed RHIC run
- in the future, the challenge will be to directly extract gluon polarization from the measurements

John Millener: $\Lambda N - \Sigma N$ interactions from hypernuclear γ-ray spectroscopy using $(K^-, \pi^-\gamma)$ and $(\pi^+, K^+\gamma)$ coincidence reactions with the Hyperball array of Ge detectors at BNL and KEK

For a p-shell nuclear core, the ΛN spin dependence is given by 4 radial integrals

$$\Delta \; s_n \cdot s_\Lambda + S_\Lambda \; l_N \cdot s_\Lambda + S_N \; l_N \cdot s_N + T \; S_{12}$$

Shell model calculations with a $p^n s_\Lambda$ and $p^n s_\Sigma$ basis give the dependence of energy spacings on Δ, S_Λ, S_N, and T and the strength of the Λ-Σ coupling.

BNL E930 $^{16}\mathrm{O}(K^-, \pi^-\gamma)^{16}_{\Lambda}\mathrm{O}$

Determination of T: M. Ukai et al., PRL 93, 232501 (2004)

$^{15}\mathrm{O}(3/2^-)$: $E_x = 6176$ keV

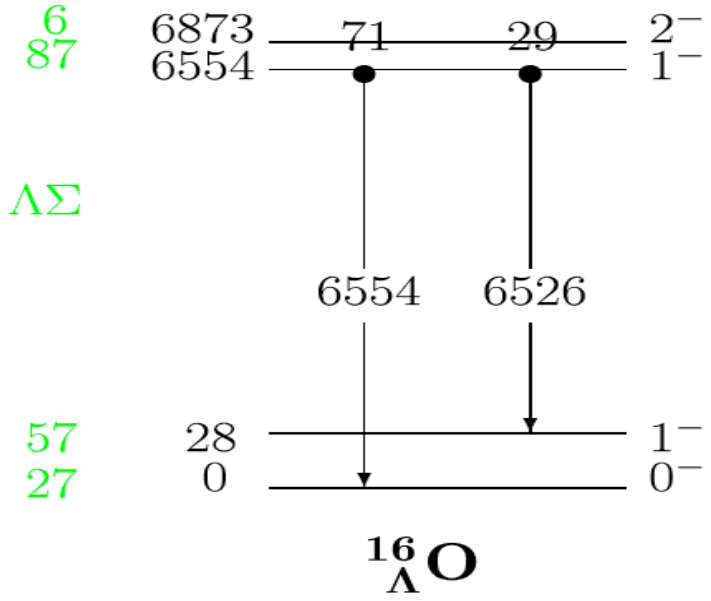
Measurement:

$E(1_2^- - 0_1^-) = 6561.7$ keV

$E(1_2^- - 1_1^-) = 6535.3$ keV

$\Delta E^{th} \sim -\frac{1}{3}\Delta + \frac{4}{3}S_\Lambda + 8T$

$\Delta E^{exp} = 26.4 \pm 1.6$ keV



Publications and citations

Institute for Scientific Information, Essential Science Indicators:
http://www.in-cites.com/institutions/phy_1995-2005.html

Between 1995 and 2005, BNL overall is number 4 in the World
according to the number of citations per paper among
the 578 global research institutions; 3,921 papers, 76,172 citations

BNL: 19.43; behind of: UC SB (21.08), Harvard (20.62), Stanford (20.47);
Ahead of: e.g. Princeton (18.98) , MIT(17.92), CERN(16.59), Caltech(16.15)…

BNL Nuclear Theory Group: 283 papers, 12,146 citations => 42.92
Fraction of total BNL papers: 7.2 % 16%

Note: this statistics includes only the papers by senior staff;
many more papers written by postdocs and long-term visitors

Awards (2001-2005)

D. Kharzeev: Emilio Segre Distinguished Scholar, 2005
Sackler Fellow, 2005

R. Pisarski: Senior U.S. Scientist Award, Alexander von Humboldt foundation, 2003-04

R. Venugopalan: Fellow, Alexander von Humboldt foundation,2003-4

Publications in FY 05

70 papers, from which 53 in refereed journals

Students supervised in the Group during 2001-06

J.Bjoraker, Y.Hatta, B. Jaeger, J.Lenaghan, R.Parwani, V.Peikert, J.Wirstam, H.Yokoya;

Supervised by D.Kharzeev, R.Pisarski,
R.Venugopalan, W.Vogelsang

RIKEN-BNL Theoretical Physics Fellows

Graduates

D. Bodeker, Tenured C-4, Bielefeld
D. Kharzeev , Tenured BNL
D. Rischke, Tenured C-4 Frankfurt
D. Son, Tenured U of Washington
R. Venugopalan, Tenured BNL
T. Wettig, Tenured C-3 Regensburg
M. Stephanov Tenured U of Ill, Chicago
U. Van Kolck, Tenured U of Arizona
T. Schaefer, Tenured U of N. Carolina
A. Kusenko, Tenured UCLA
W. Vogelsang, Tenured at BNL

New Fellows:

D. Molnar: Purdue

K. Tuchin: Iowa State

U. Wiedemann Stony Brook

Current Fellows

S. Bass, Duke
T. Izubuchi, Kanazawa
S. Jeon, McGill
T. Blum, U of Connecticut
P. Petreczky, BNL (LGT)
S. Sasaki, Tokyo (NT)
S. Aoki, Tsukuba
K. Iida, BNL

Next Year:

Texas A&M
Penn State U.
Minnesota?
UCLA?.....

Slide from
L.McLerran

Conferences organized in FY05/06

1. Quark Matter ‘05, Budapest, August 2005 (Int’l advisory committee)
2. Quark-Gluon Plasma in physics and astrophysics, Calcutta, Feb ‘05 (Int’l advisory committee)
3. National School on Relativistic Heavy Ions, Torino, Feb ‘05
4. 22nd Winter Workshop on Nuclear Dynamics, La Jolla, Mar ‘06
5. Strong and Electroweak Matter Conference, BNL, May ‘06
6. Hard Probes ‘06 Conference, Asilomar, June ‘06
7. Quarkonium Workshop, BNL, June ‘06
8. International Nuclear Physics Conference, Rio de Janeiro, Aug ‘06
9. International Conference on High Energy Physics, Moscow, Jul ‘06
10. Strangeness in Collisions Workshop, BNL, Feb ‘06
11. “Can we discover the QCD critical point at RHIC?” Workshop, BNL,Mar’06
12. Quark Matter ‘06, Shanghai, Nov ‘06 (Int’l advisory committee)
13. PANIC eRHIC Satellite meeting, Santa Fe, Oct’05
14. Electron-Ion Collider Conference, Jul ‘06
15. “Partonic structure of hadrons”,Trento,May’05
16. XXIX RHIC Spin Collaboration Meeting, Torino, Oct ‘04
17. “Single spin asymmetries” Workshop, BNL, June ‘05
18. “Odderon searches at RHIC” Workshop, BNL, Sept ‘05 + 4 more

The Future

Detailed 4 year plan for the Group has been prepared; it includes:

1. The physics of RHIC: 3D simulations of parton matter evolution, energy loss of heavy quarks

2. The physics of RHIC-II : heavy quarks, hard processes, forward rapidities

3. Spin physics : W production, transverse spin, …

4. The physics of the eRHIC : Deep Inelastic Scattering off nuclei and polarized protons

Letter of Intent for the topical center of excellence "QARC" (Qcd At Rhic Center)

The goal: to achieve the two performance milestones for Nuclear Theory of the "Physics of High Temperature and High Density Hadronic Matter":
1. Perform realistic 3D numerical simulations to describe the medium and the conditions required by the collective flow measured at RHIC;
2. Complete realistic calculations of jet production in a high-density medium for comparison with experiment

The members: groups at BNL, Columbia, Ohio State, Stony Brook and Yale
PI's: M.Gyulassy, U.Heinz, F.Iachello, D.Kharzeev, E.Shuryak
The timeline: begin the work on October 1, 2006;
achieve the present goals by the end of 2010;
further program will evolve according to the needs of experiments

The budget: $600K per year, to be spent on postdocs and graduate students at BNL, Columbia, OSU and Stony Brook, and 1 grad.student at Yale

Summary

1. Nuclear Theory Group at BNL is among the World leaders in the field of High Energy Nuclear Physics

2. Vigorous research program, aimed at the understanding of fundamental structure of matter

3. Synergy with the experimental program at RHIC, and with the research done by RIKEN-BNL Center, Lattice Gauge Theory Group, and High Energy Theory Group

4. Bright future ahead!

Back-up slides

Response to the recommendations and criticisms made after 2005 review

1. Several Group meetings were held to discuss in detail the recommendations and criticisms made on the basis of the 2005 review; a concrete set of measures intended to improve the coordination of the activities of individual members and to tie it even closer to the NSAC performance measures;

2. A detailed four year research plan of the Group has been prepared;

3. The Letter of Intent for a Center of Excellence “QCD at RHIC” has been submitted together with Columbia, Ohio State, Stony Brook and Yale; the Center would act as a steward of theoretical research in high energy nuclear physics and would attract some of the best students

The physics program of BNL Nuclear Theory Group and the performance milestones

Physics of High Temperature and High Density Hadronic Matter:

a) perform realistic 3D numerical simulations to describe the medium and the conditions required by the collective flow measured at RHIC

b) complete realistic calculations of jet production in a high density medium for comparison with experiment

c) Determine gluon densities at low x in cold nuclei

Hadronic physics: a) Make measurements of spin carried by the glue in the proton

b) Carry out ab-initio microscopic studies of the structure and dynamics of light nuclei + Nuclear Structure and Astrophysics

Publications and citations

SPIRES search; as of 07/13/2006 Publications in refereed journals only

Name	Publ. 1995-	Citations 1995-	Publ. 2001-	Citations 2001-
Baltz	18	458	6	87
Kharzeev	64	2708	31	1181
McLerran	55	3383	34	1535
Millener	11	55	7	22
Pisarski	34	1421	15	257
Venugopalan	42	1706	26	668
Vogelsang	59	2415	30	393
Total:	283	12146	149	4143

Nuclear Theory Budget

- Group size has been unchanged since FY05
  - 7 senior people, 2 post-docs
- FY05, 1 1/2 FTEs supported elsewhere (RIKEN & HEP)
  - FY05: Need $2.06 million
    Budget $2.07 million
- FY06, 1 3/4 FTEs supported elsewhere (RIKEN & department overhead)
  - FY06: Need $2.1 million
    Budget $2.05 million
- FY07, all senior people on DOE NP support
  - FY07: Need $2.65 million
    Budget $2.1 million ←

Can live within this budget with 6 senior people, 1 post-doc

Budget pressure results from transition from a group partially supported by RIKEN and others, to a group entirely supported by DOE

Staff FWP PO6 (BNL Acct 8618)

Chaloupka (100%)
Baltz (60%)
Kharzeev (100%)
McLerran (100%)
Millener (100%)
Venugopalan (100%)
Kretzer (35%)
Lappi (75%)
Pisarski (0%)
Stasto (75%)
Vogelsang (50%)

Currently is in part on the Department overhead (32%) and in part paid by RBRC (8%

Currently on the Departmen overhead; will have to be paid by NT in FY07

FY06: currently 100% on NT as a result of promotion to tenure