2007 DOE/Nuclear Physics Review of RHIC Science and Technology

Nuclear Theory and RIKEN-BNL Theory Groups at BNL

D. Kharzeev

kharzeev@bnl.gov

Office of Science
U.S. DEPARTMENT OF ENERGY

Office of Nuclear Physics
Exploring Nuclear Matter - Quarks to Stars

BROOKHAVEN NATIONAL LABORATORY

Brookhaven Science Associates
U.S. Department of Energy

Our mission

- Excellence in scientific research aimed at reaching the goals set by BNL and DOE Office of Science
- Support and guidance for the experimental programs at RHIC and elsewhere
- Training the new generation of nuclear theorists
- Chart the course for the future developments in Nuclear Physics

Staff of the Nuclear Theory Group

Marcy Chaloupka - Secretary

Permanent Scientific Staff:

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

Research Scientists:

1. T. Lappi
2. H. Warringa

The physics program of BNL Nuclear Theory Group and the NSAC 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

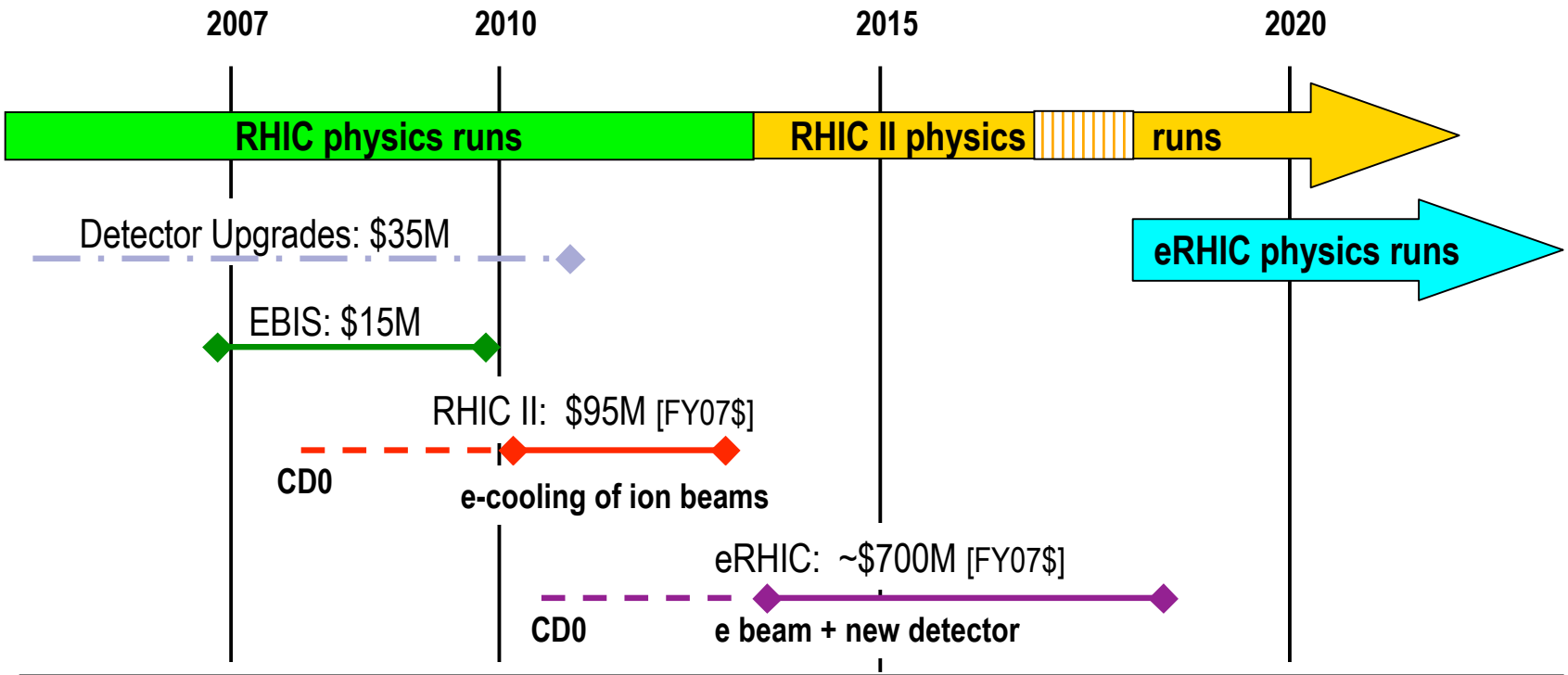
b) complete realistic calculations of jet production in a high density medium for comparison with experiment

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

Nuclear Theory program in the context of BNL long-term plans



NT program is tightly connected to the existing and planned experimental programs at BNL and to the NSAC performance milestones for Nuclear Theory

The physics program of BNL Nuclear Theory Group

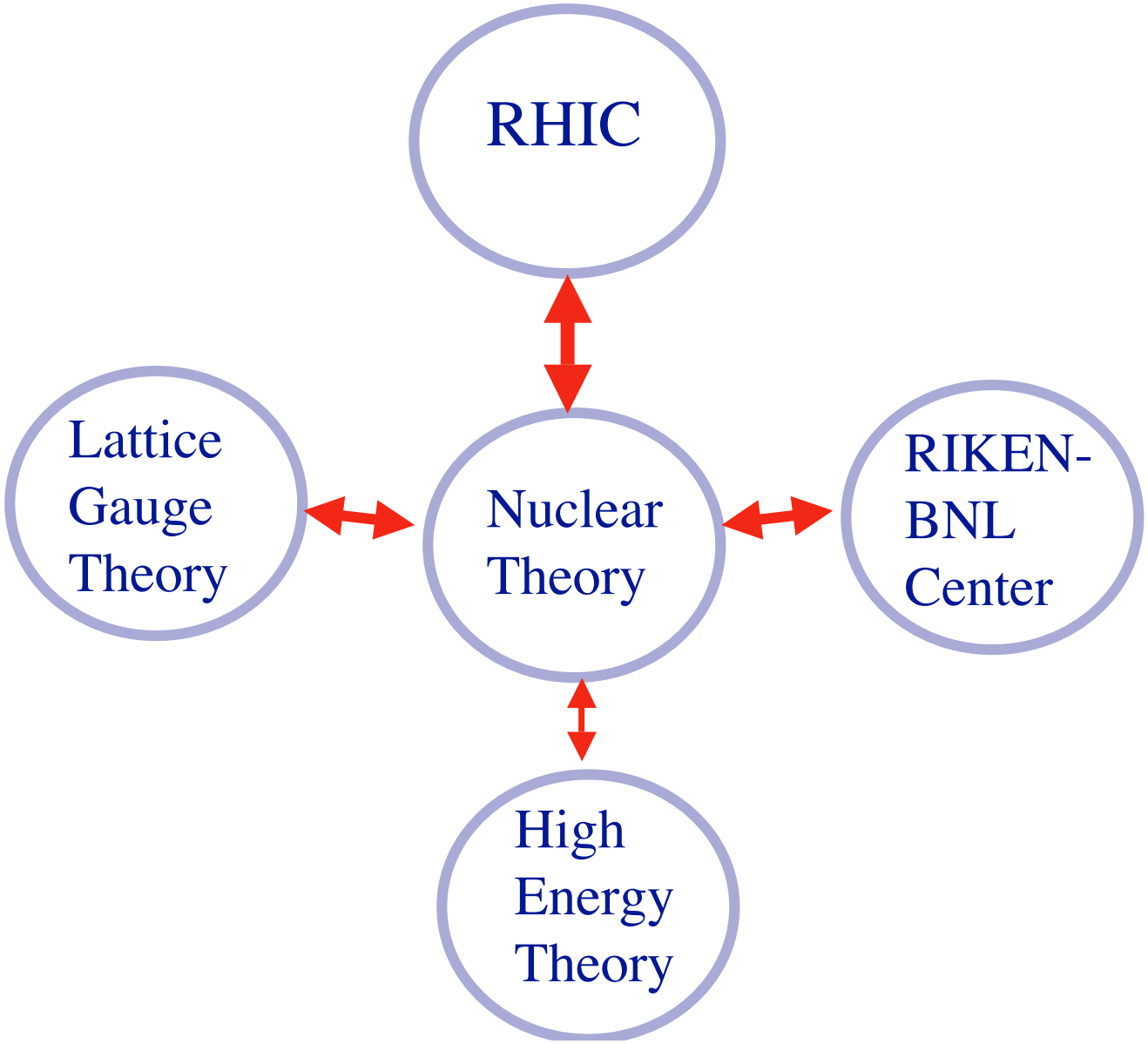
1. Quantum Chromo-Dynamics at finite temperature and density and the physics of Quark-Gluon Plasma

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

Nuclear Theory Group at BNL



RIKEN-BNL Center:

Founded by T. D. Lee

Director: N. Samios

Associate Director: H. Enyo

Theory Group Leader: L. McLerran

Experimental Group Leader: G. Bunce

Funded by RIKEN Institute in Japan

Physics Interests:

Experimental and Theoretical Aspects of Spin and Heavy Ion Collisions

Lattice Gauge Theory and QCDOC

Theory of Strong Interactions

Funds workshops, joint university fellows and postdocs

Recently renewed funding for 5 years

Slides from L.McLerran

RBRC University Fellows Program

University pays 1/2 of academic year salary

University selects candidates

Must be approved by Theory Advisory Committee

Current Theory Fellows:

T. Blum, Connecticut

R. Fries, Texas A&M

D. Molnar, Purdue

P. Petreczky, BNL

K. Tuchin, Iowa State

New Theory Fellows:

C. Lunardini, Arizona State

D. Teaney, Stony Brook

F. Yuan, LBL

18 Tenured Graduates:

S. Bass, Duke

D. Bodeker, Bielefeld

C. Dawson, Virginia

K. Iida, Kochi

T. Izubuchi, Kanazawa

S. Jeon, McGill

D. Kharzeev, BNL

A. Kusenko, UCLA

D. Rischke, Frankfurt

S. Sasaki, Tokyo

T. Schaefer, N. Carolina

M. Stephanov, Illinois

D. Son, Washington

R. Venugopalan, BNL

U. Van Kolck, Arizona

W. Vogelsang, BNL

U. Wiedemann, CERN

T. Wettig, Regensburg

76 Workshops since 1997:

Spin and Pert. QCD 39

Lattice and Computing 11

Quark Gluon Plasma 8

High Energy QCD 2

Jets and Hard Processes at RHIC 4

Flow, Hydrodynamics and Event Simulation 4

Hadron Physics and QCD 4

Color Glass Condensate 3

New Discoveries at RHIC 1

Theory Postdocs:

Cover wide range of topics from pert QCD to RHIC Phenomenology

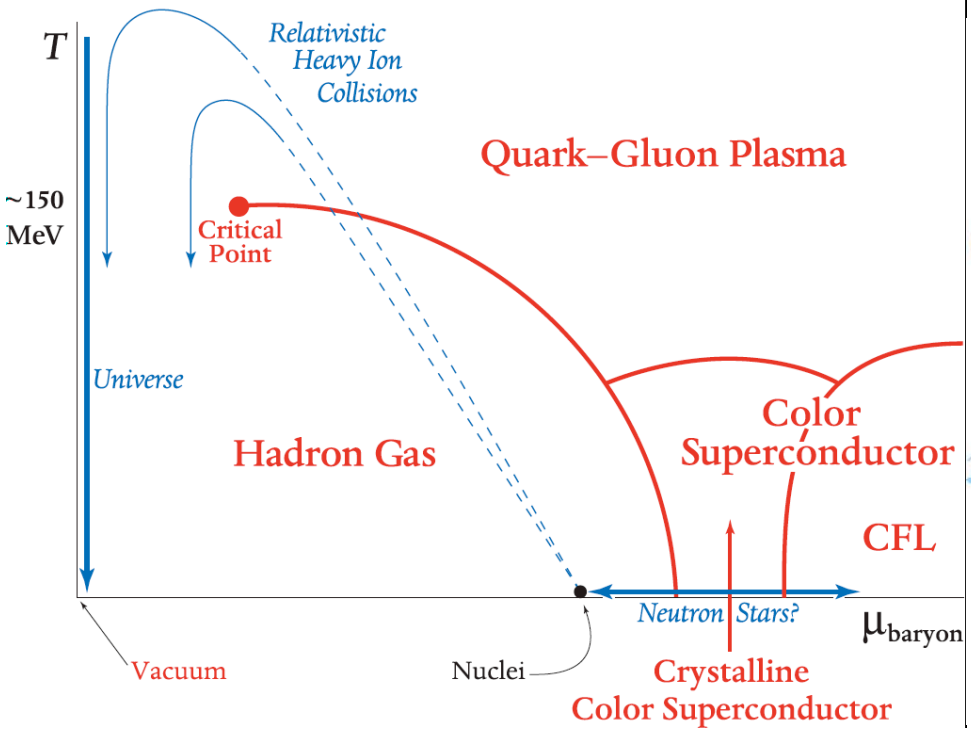
Recent Examples:

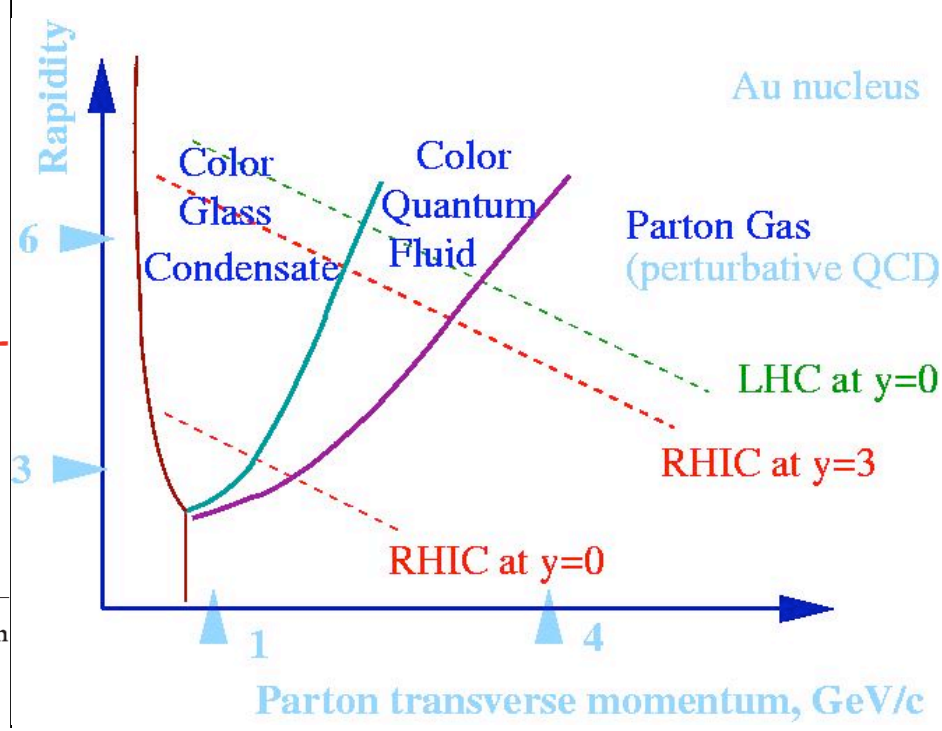
K. Itakura: Permanent staff at KEK (CGC)

T. Hirano Ten. Asst. Prof at Tokyo (RHIC Phenomenology)

K. Fukushima, Asst. Prof. at Yukawa Institute (Color Superconductivity and CGC)

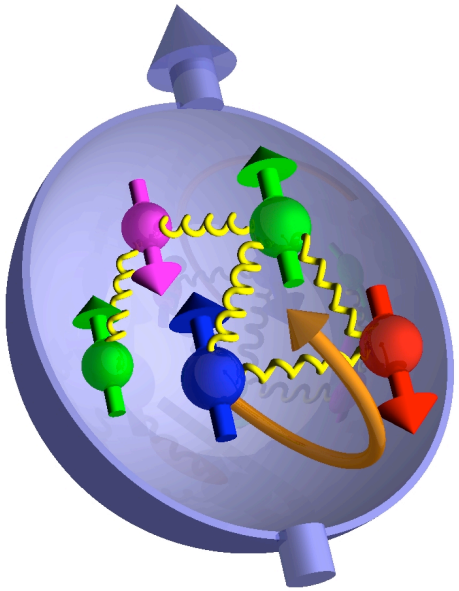
Research highlights:
QCD at high densities and energies





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

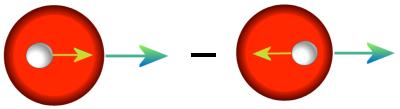
Gluon spins

Quark and gluon orbital ang. mom.

only ≈ 20 %

??

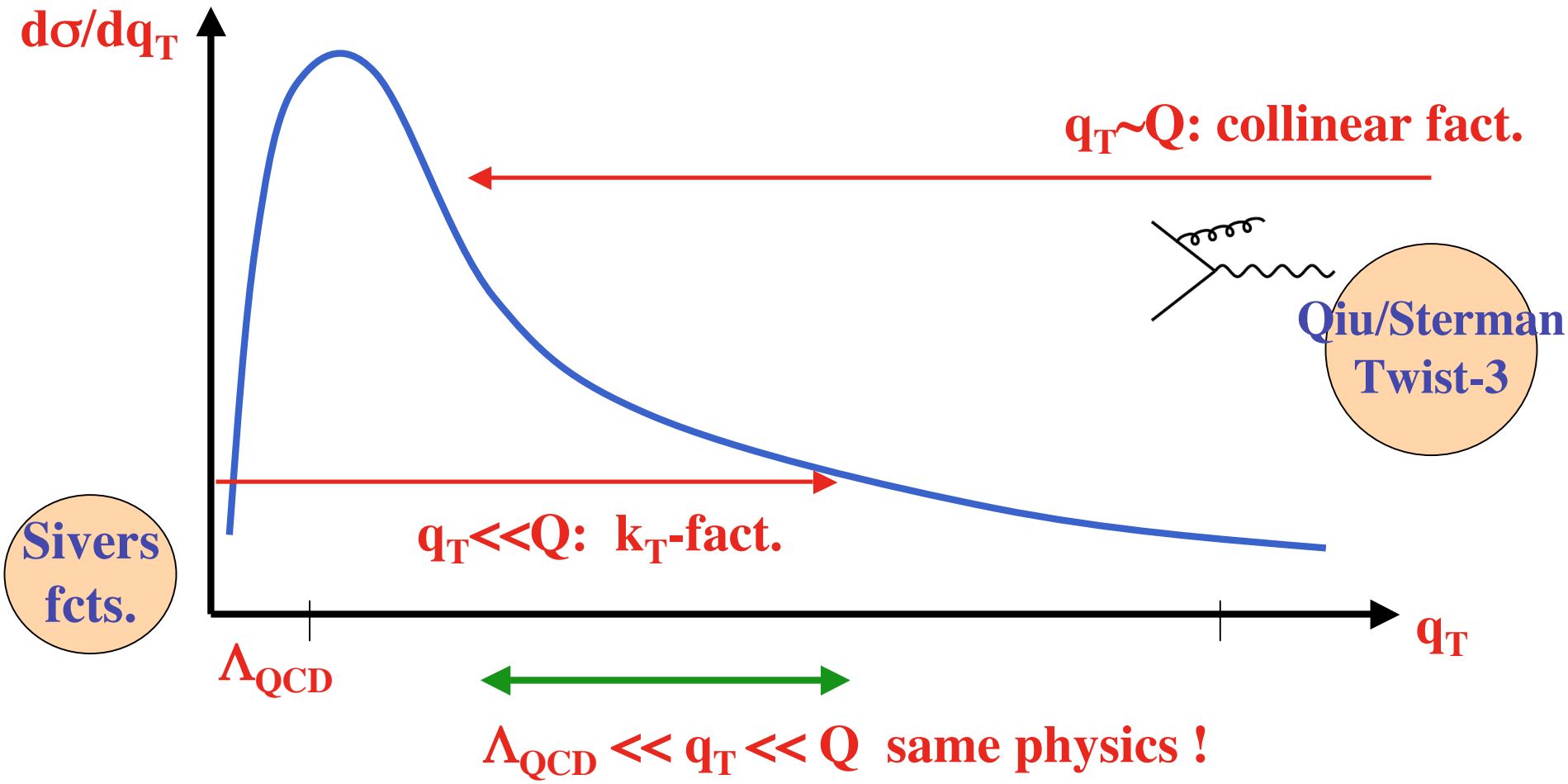
??



-

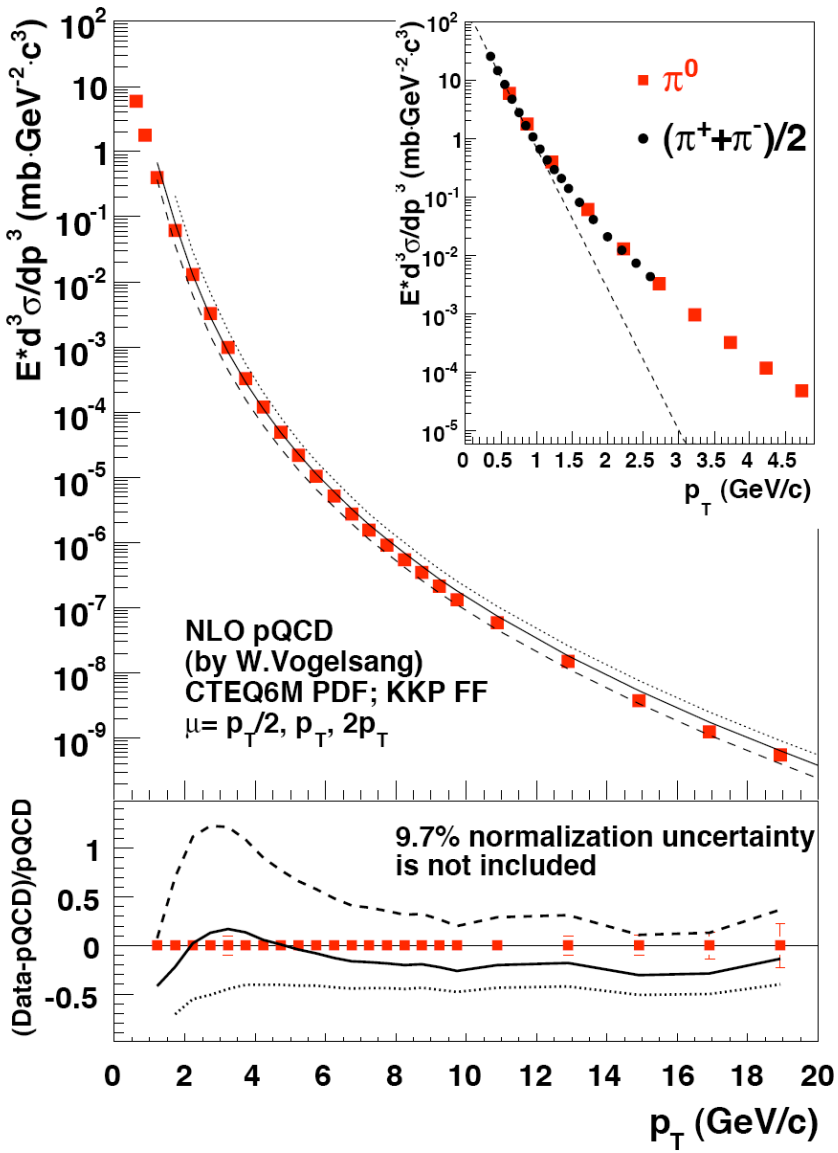
- **BNL Nuclear Theory devotes a major effort to QCD spin physics, in particular for RHIC**

Connection between two mechanisms for single-spin asymmetries: for example, Drell-Yan

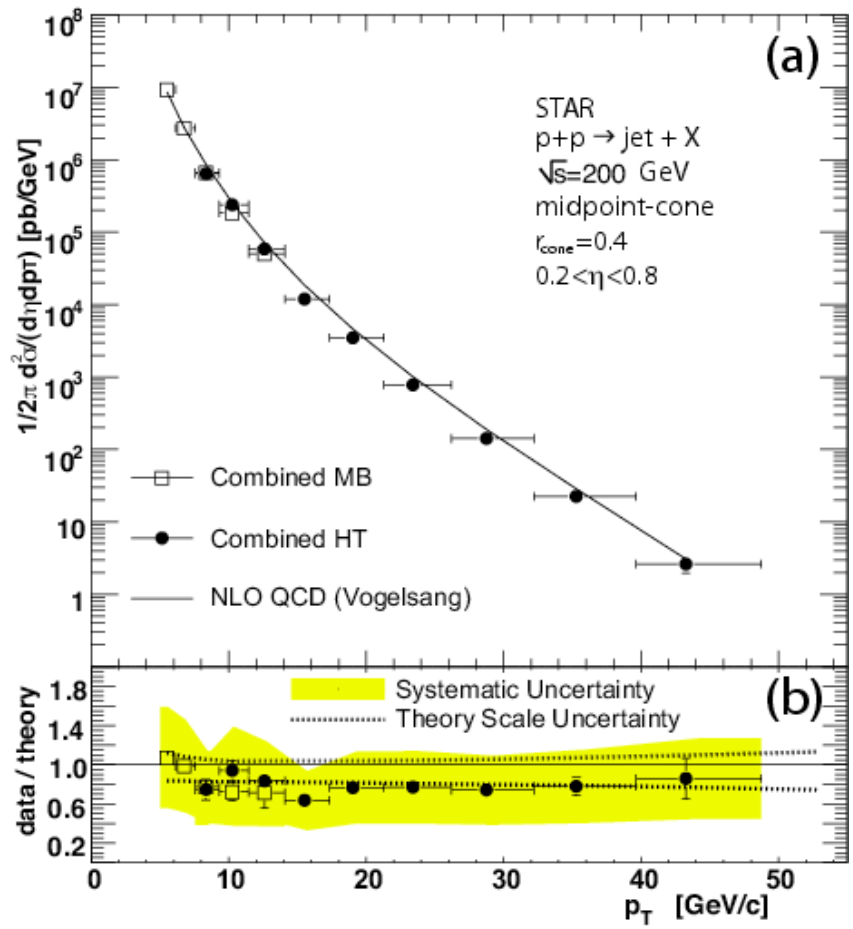


Ji, Qiu, Vogelsang, Yuan PRL97 (2006) 082002, PRD73 (2006) 094017, PLB638 (2006) 178
Qiu, Vogelsang, Yuan, to appear in PLB 2007, arXiv:0706.1196 [hep-ph]

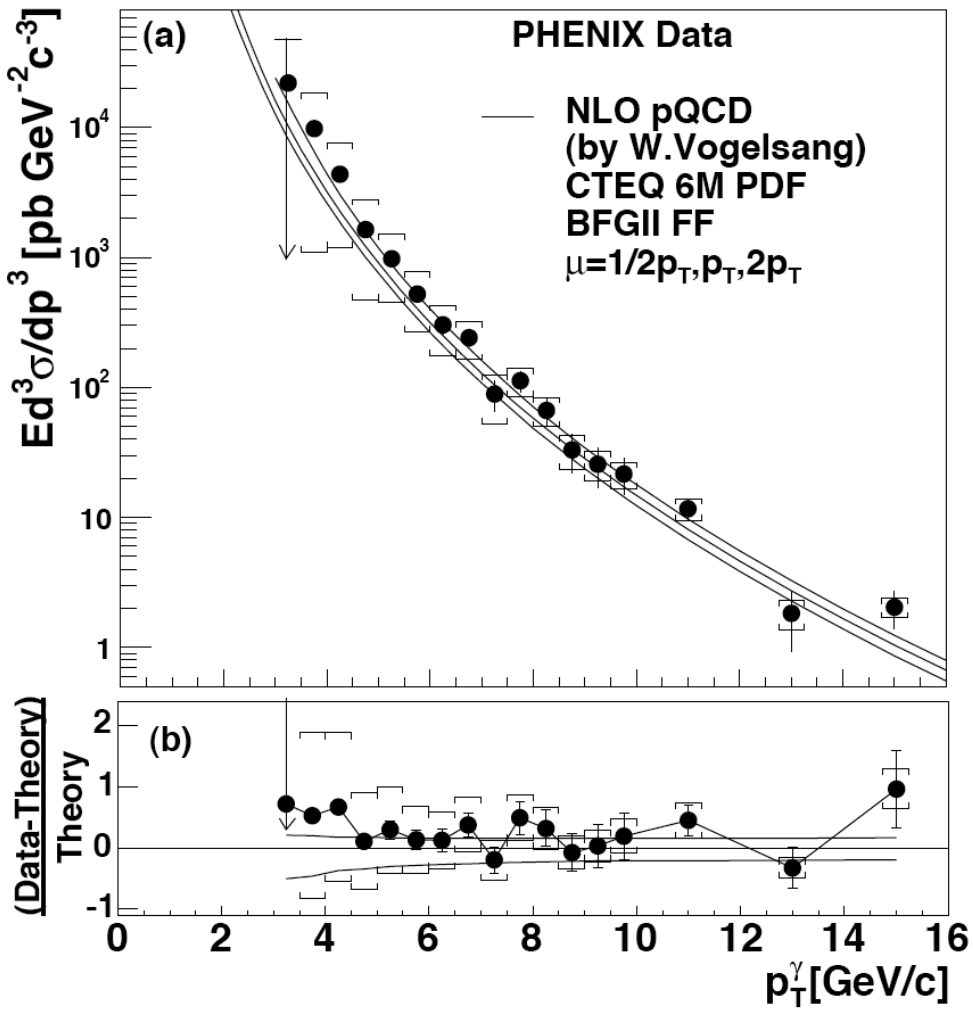
$pp \to \pi^0 X$ **PHENIX**



$pp \to \text{jet } X$ **STAR**



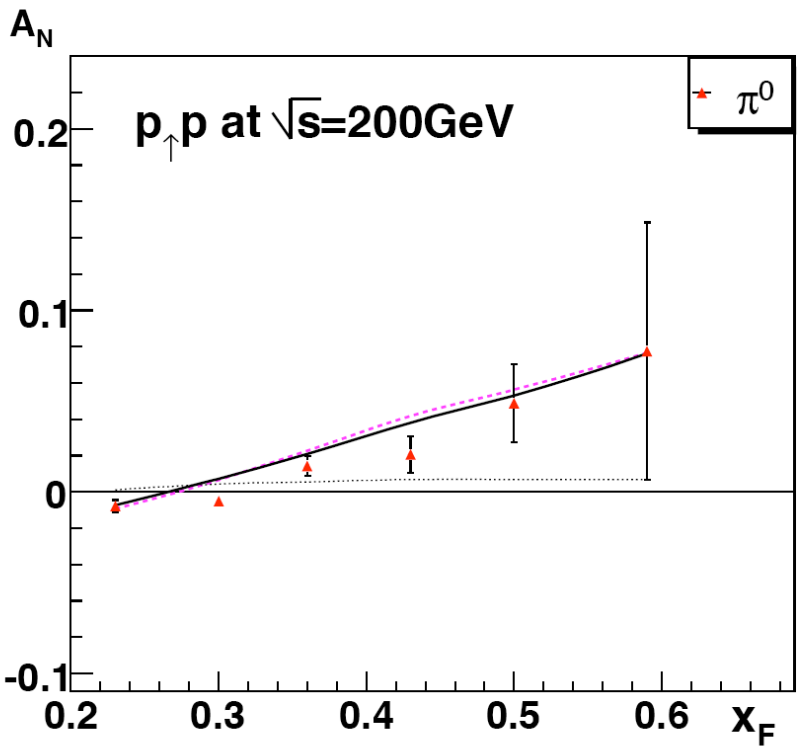
$pp \rightarrow \gamma X$ PHENIX

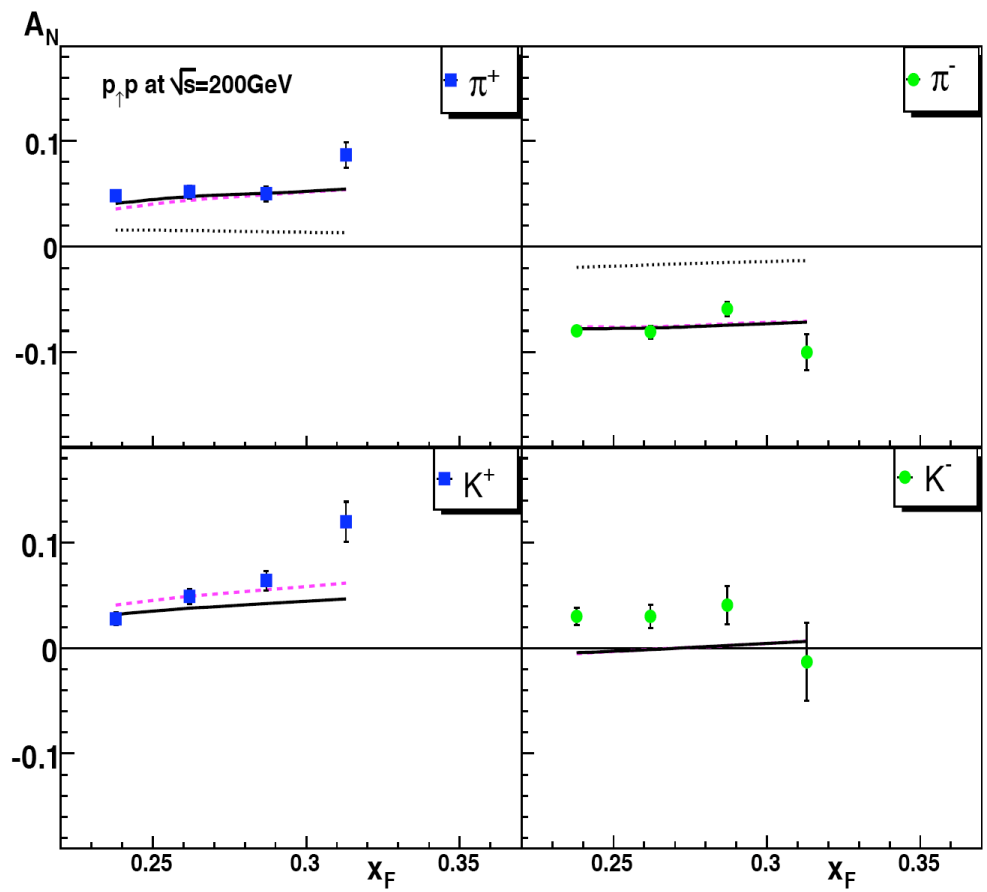


Reliable
"baseline"
pQCD calculations

New analysis of single-spin asymmetry in pp→π X at RHIC:

Kouvaris, Qiu, Vogelsang, Yuan
Phys. Rev. D74 (2006) 114013

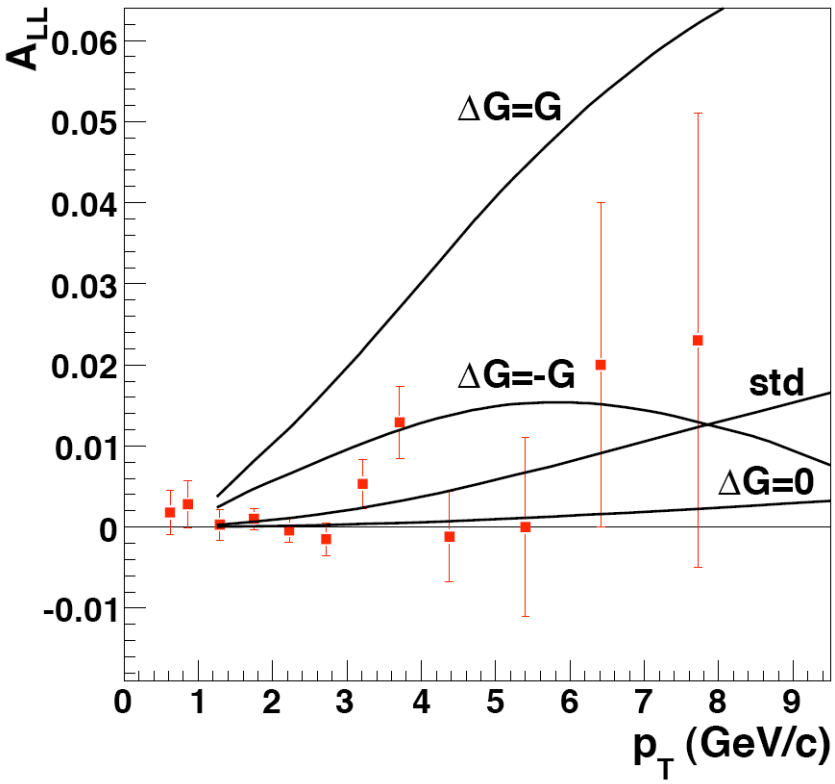


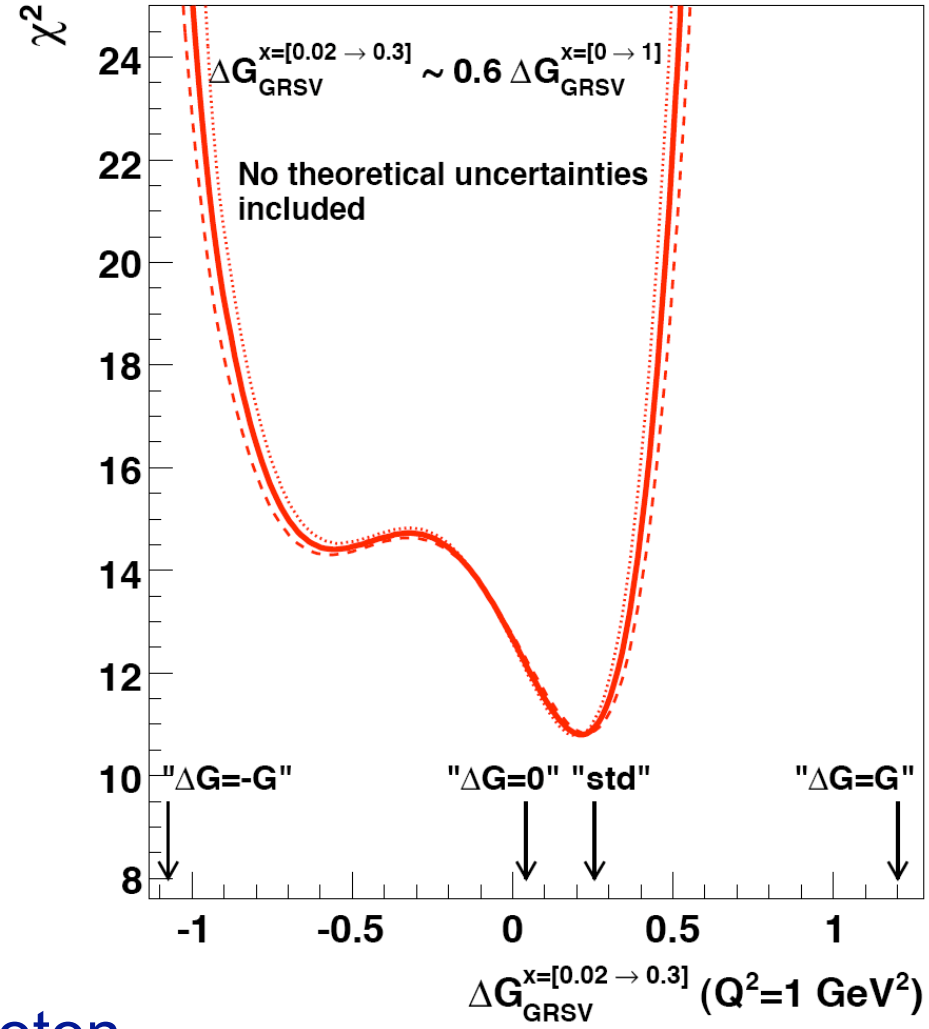


STAR

BRAHMS

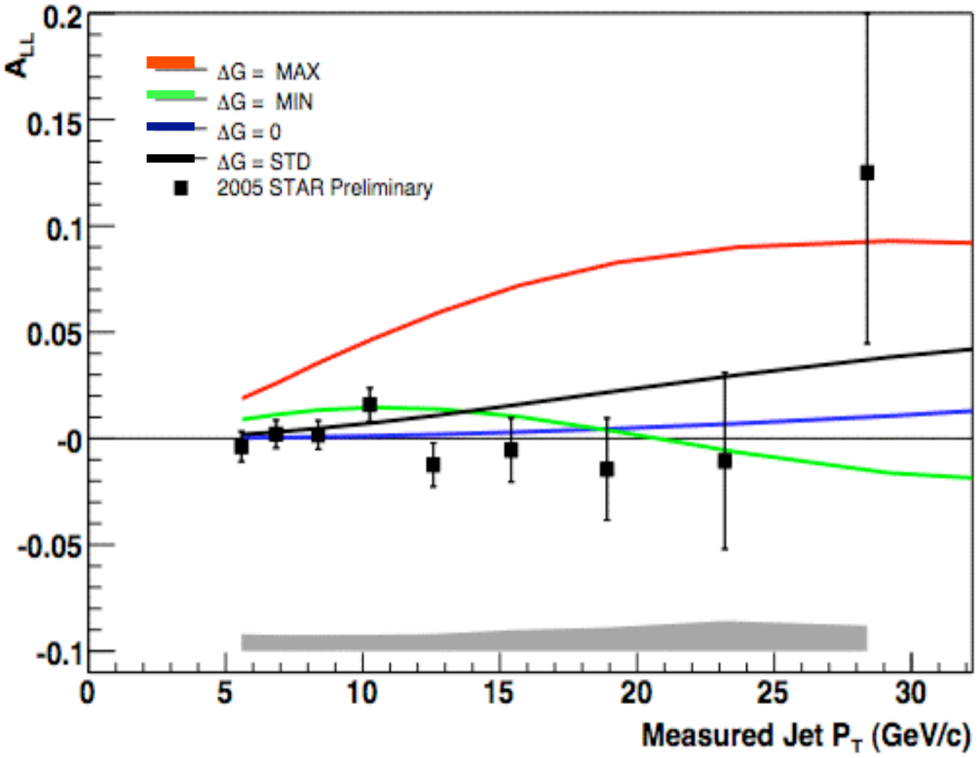
$pp \to \pi^0 X$ **PHENIX**

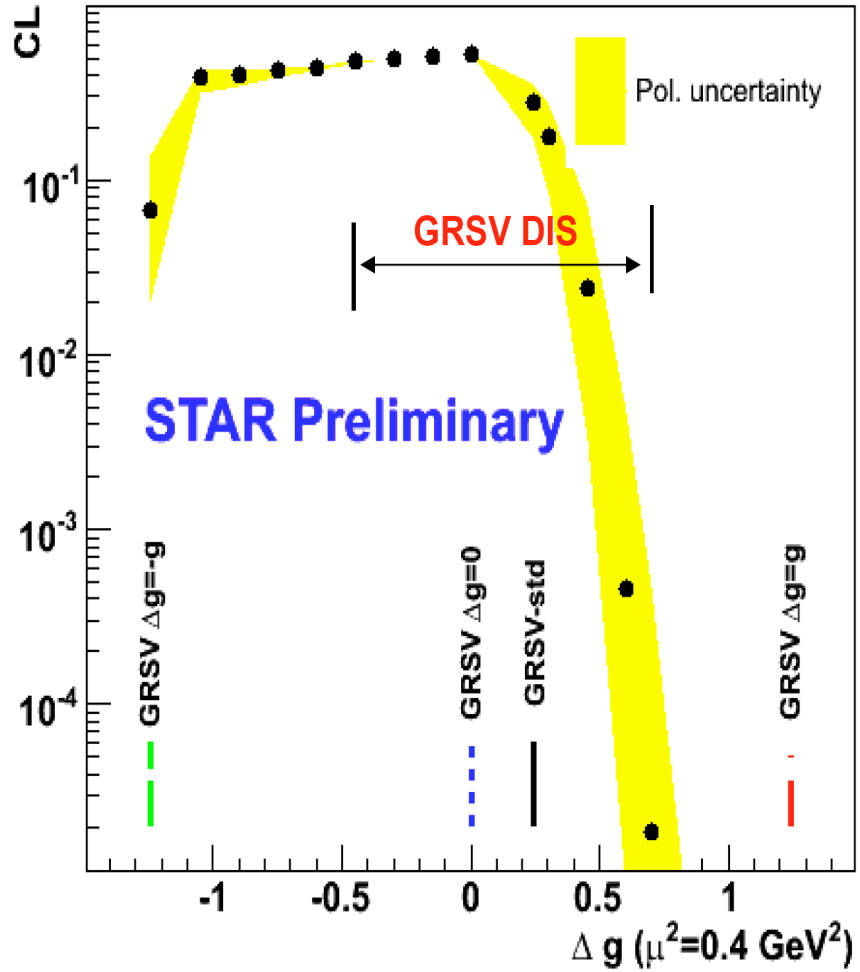




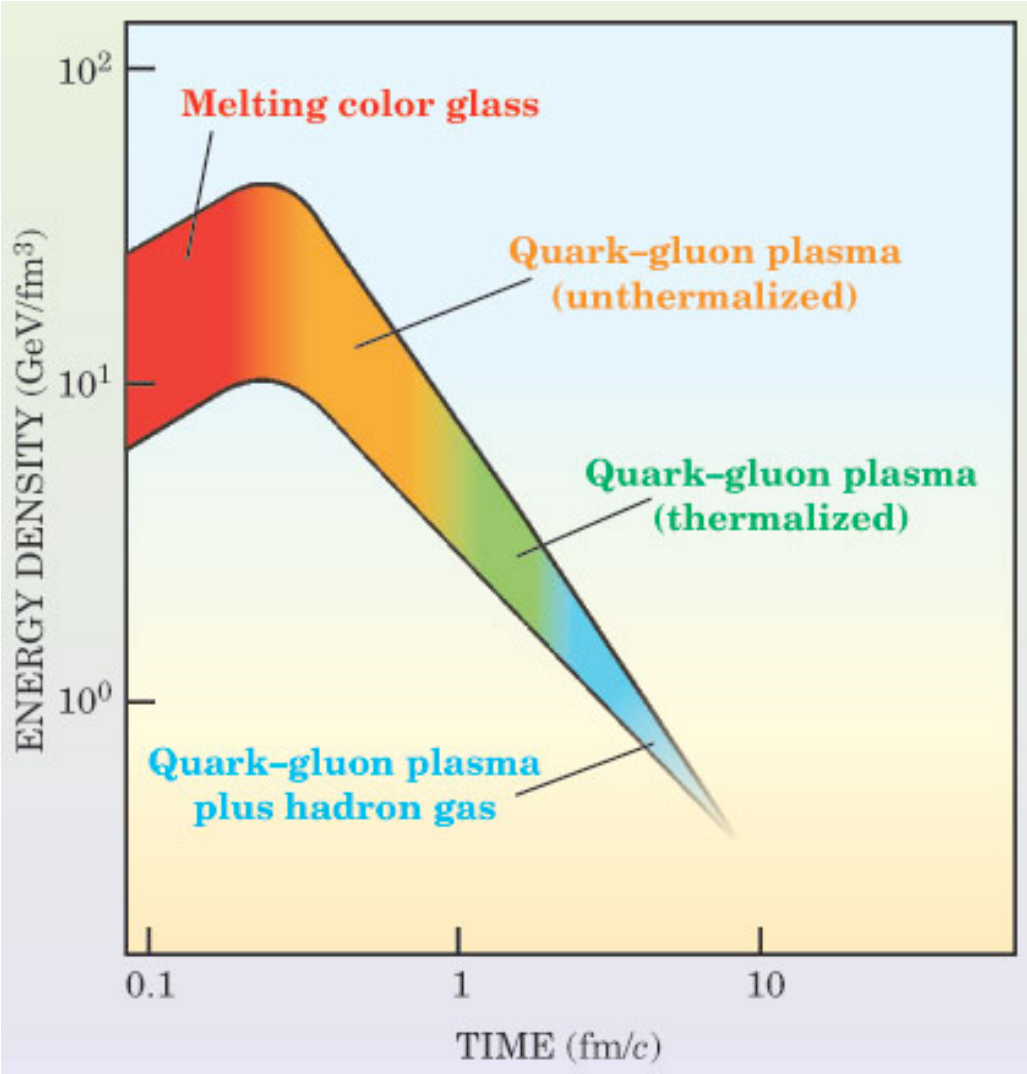
Towards extracting the gluons' contribution to the spin of the proton

$pp \rightarrow \text{jet } X$ **STAR**



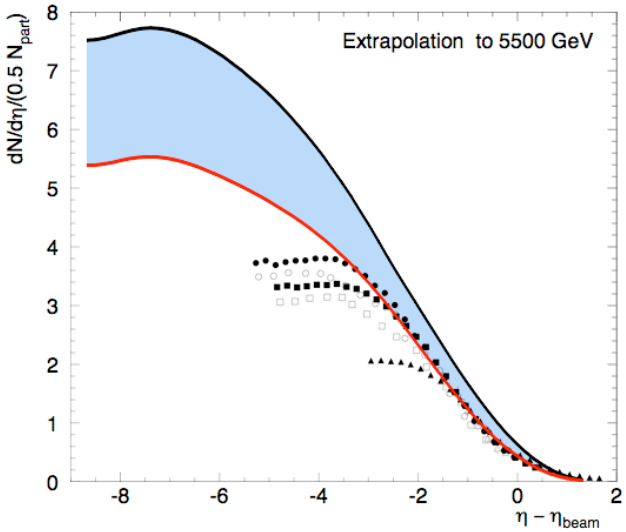


Time evolution in heavy ion collisions



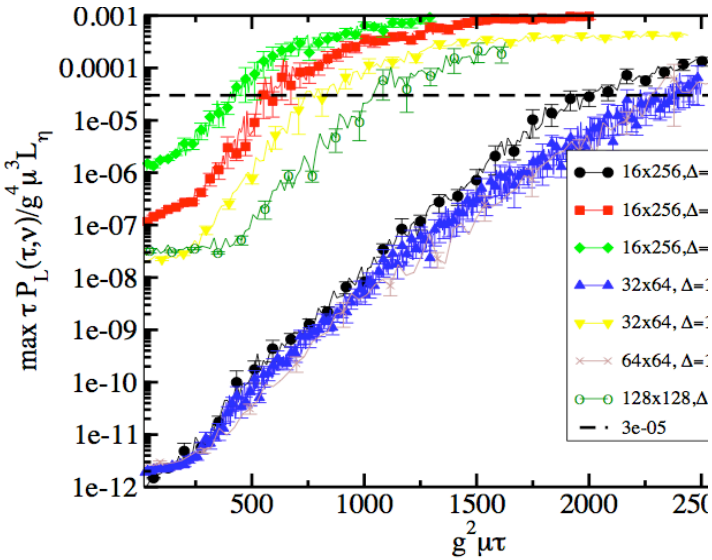
T. Ludlam,
L. McLerran,
Physics Today
October 2003

Initial conditions and approach to thermalization



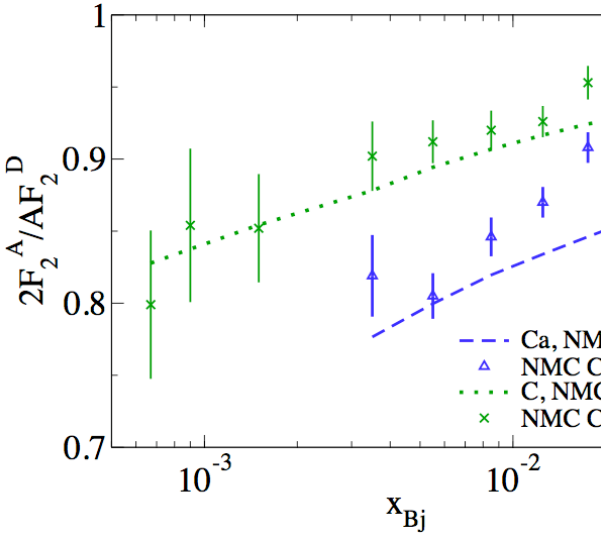
CGC prediction: limiting fragmentation fits to RHIC data give charged particle multiplicity of 1000–1400 at y=0 in Pb+Pb at the LHC

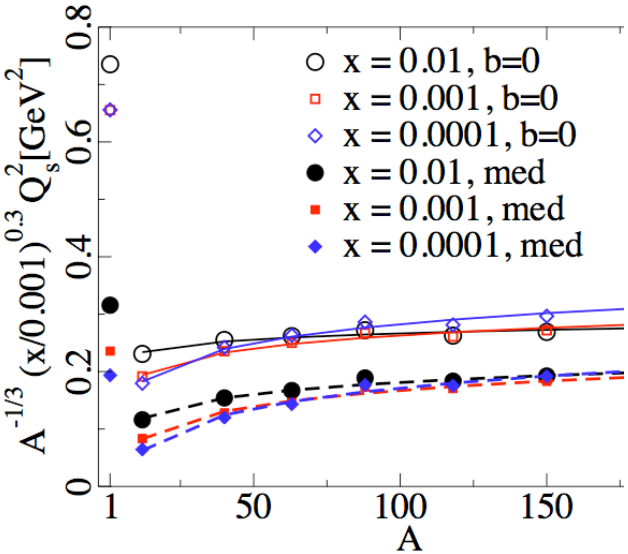
F. Gelis, A. Stasto and R. Venugopalan, Eur. Phys. J C48 (2006):489.



3+1-D numerical simulations of Yang-Mills equations: demonstrates explosive growth of "glasma" gluon fields in heavy ion collisions-may hold clue to early thermalization

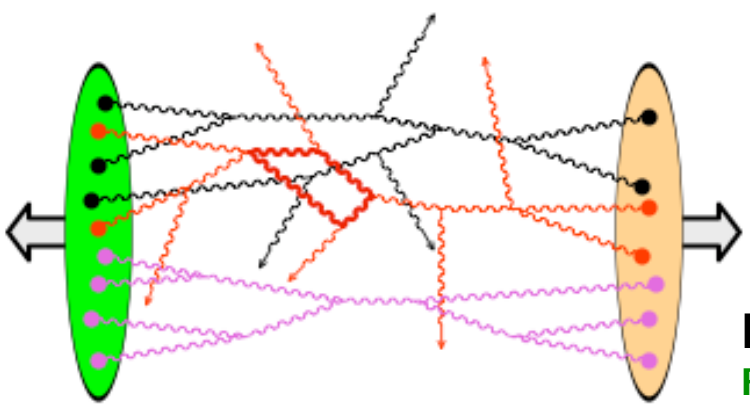
P. Romatschke and R. Venugopalan, Phys. Rev. Lett. 96:062302 (2006)
Eur. Phys. J. A29: 71 (2006)
Phys. Rev. D74:045011 (2006)





H. Kowalski, T. Lappi and R. Venugopalan, arXiv:0705.3047[hep-ph], submitted to Phys. Rev. Lett.

Left: Fits of CGC models to HERA data give parameter free comparison (theory curves) to NMC shadowing data.
Right: Extracted saturation scale scales as $(A/x)^{0.3}$ –responsible for nuclear "oomph" that makes EIC attractive.



New theory of NLO particle production in HI collisions.

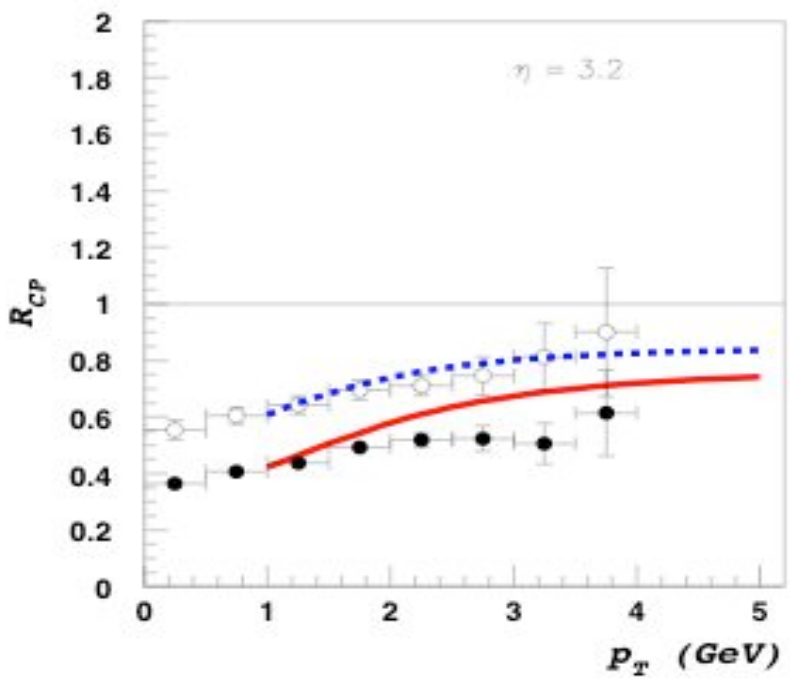
F. Gelis and R. Venugopalan,
Nucl. Phys. A776: 135 (2006)
Nucl. Phys. A779: 177 (2006)
Acta. Phys. Polon. B37:3253 (2006).

First derivation of Glasma kinetic equation

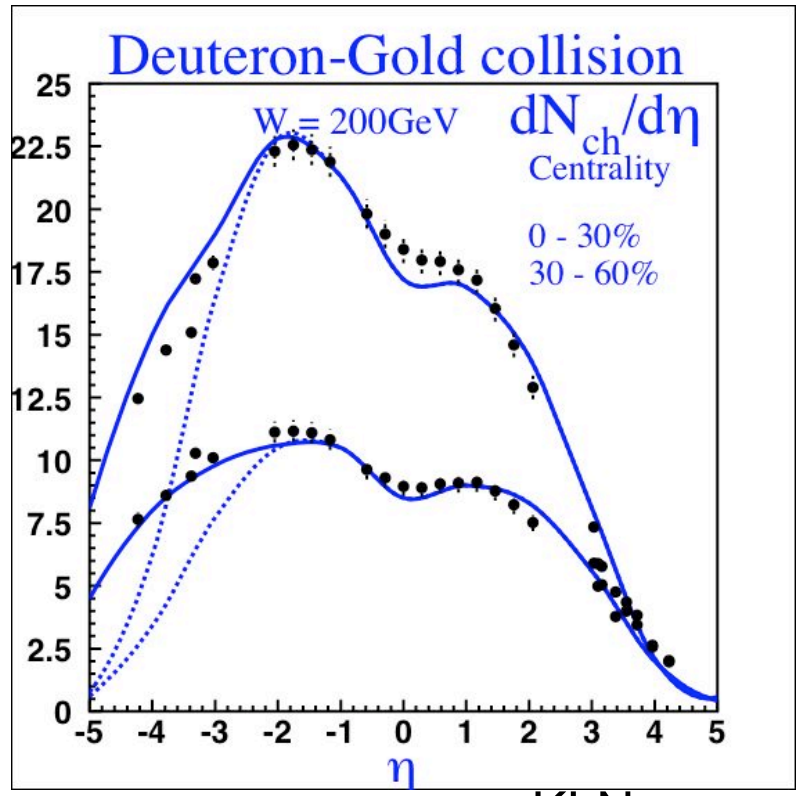
F. Gelis, S. Jeon and R. Venugopalan,
arXiv: 0706.3775 [hep-ph]

Color Glass Condensate at RHIC

Synergy between Nuclear Theory group and
RHIC experimentalists



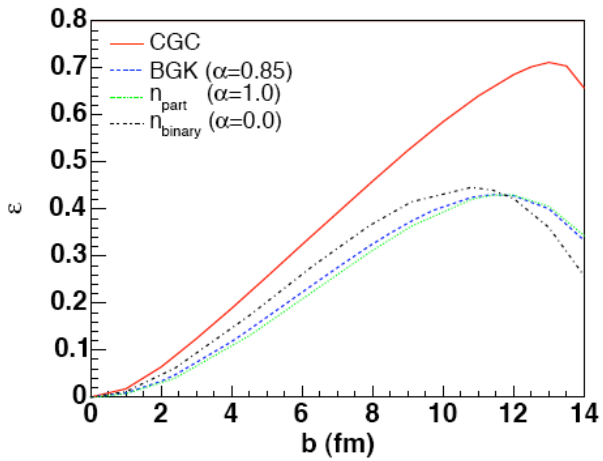
KKT

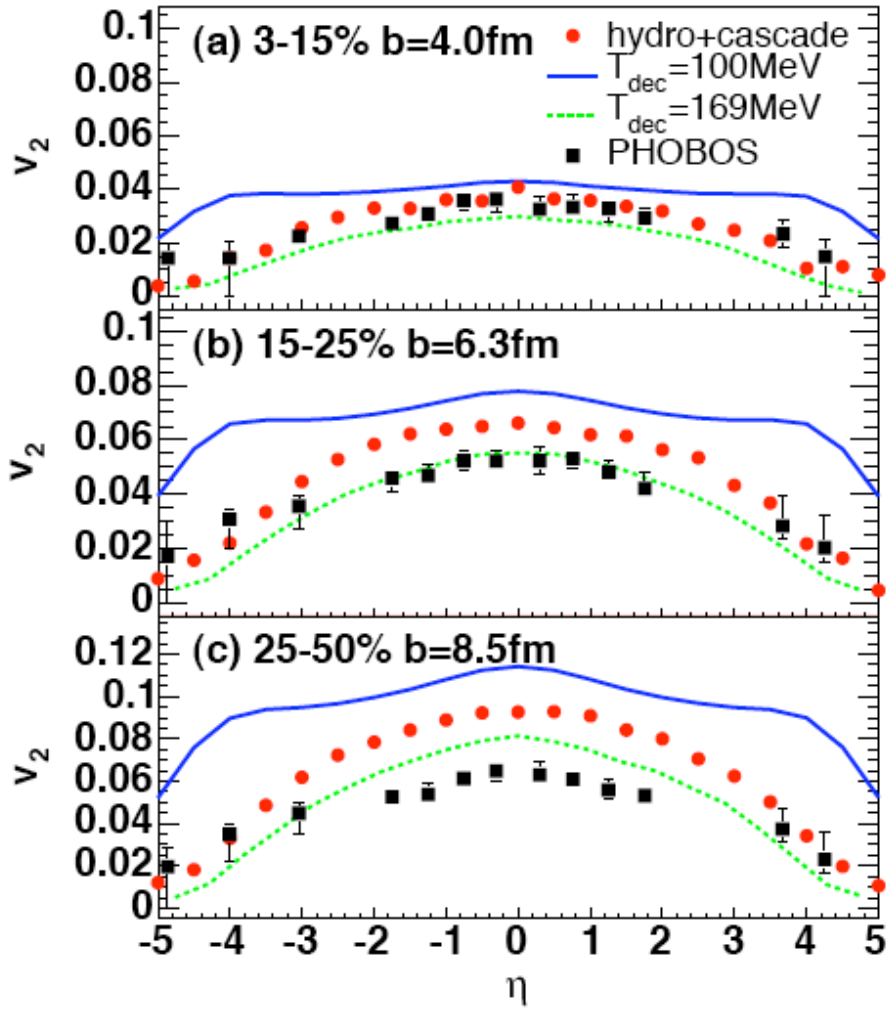


KLN

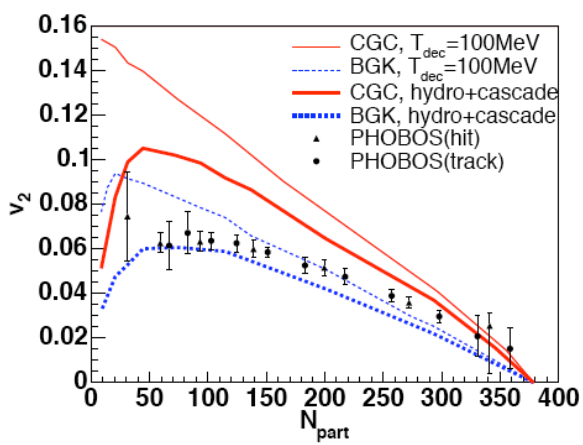
How small is the viscosity of sQGP?

CGC initial conditions lead to larger ellipticity,





require some viscous effects:



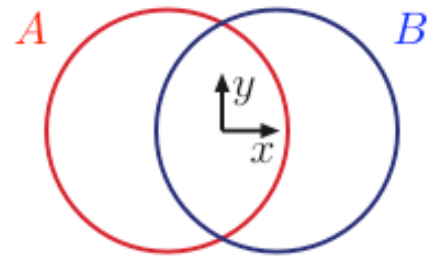
T.Hirano, U.Heinz, D.Kharzeev, R.Lacey, Y.Nara

Eccentricity and universality,

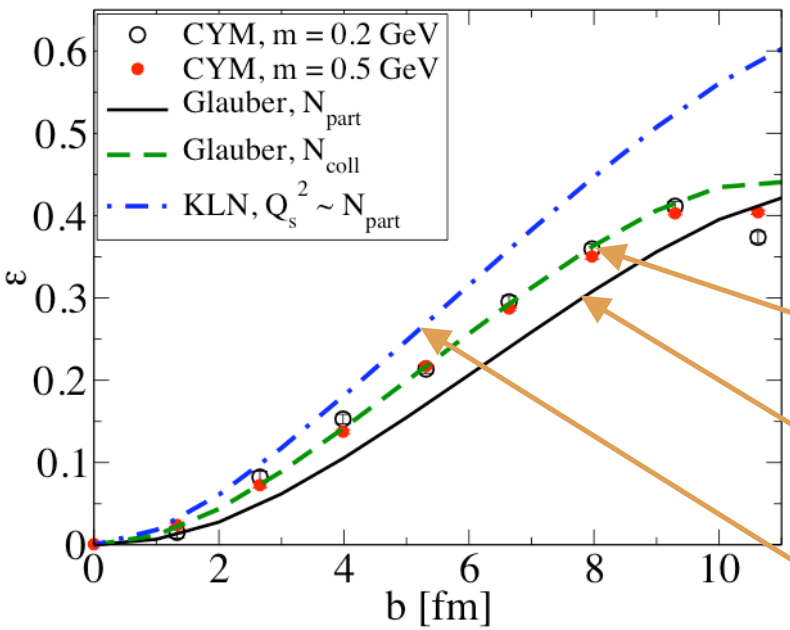
CGC initial conditions for viscous hydro

Lappi, Venugopalan,
Phys.Rev.C74:054905,2006.

Initial eccentricity from CGC initial stage of heavy ion collision



$$\epsilon = \frac{\int d^2\mathbf{x}_T\, \varepsilon(\mathbf{x}_T)\,(y^2 - x^2)}{\int d^2\mathbf{x}_T\, \varepsilon(\mathbf{x}_T)\,(y^2 + x^2)}$$

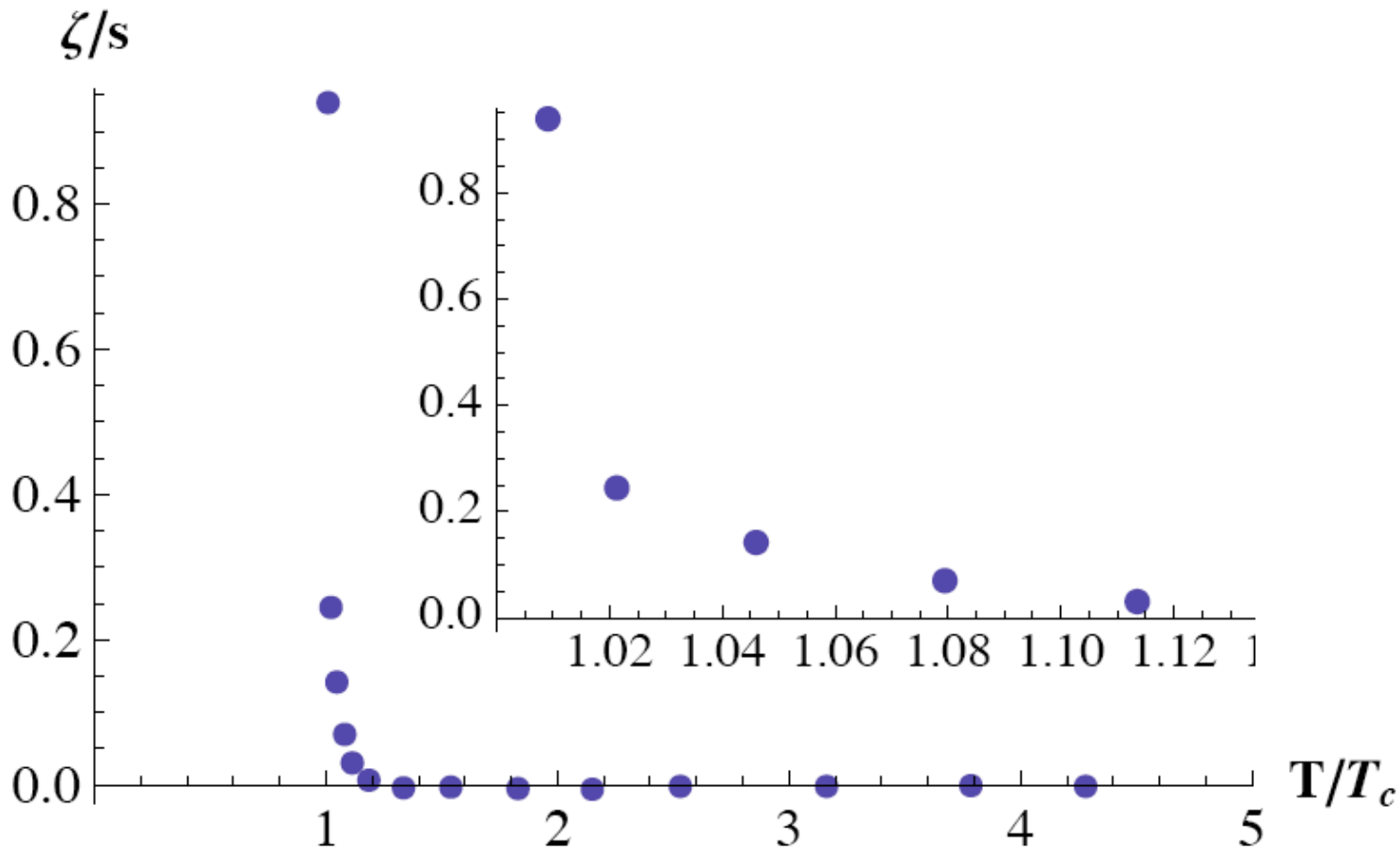


Universal Q_s gives larger eccentricity than traditional Glauber

But smaller than nonuniversal Q_s in KLN model

Essential for using hydro to extract viscosity

Bulk viscosity of sQGP

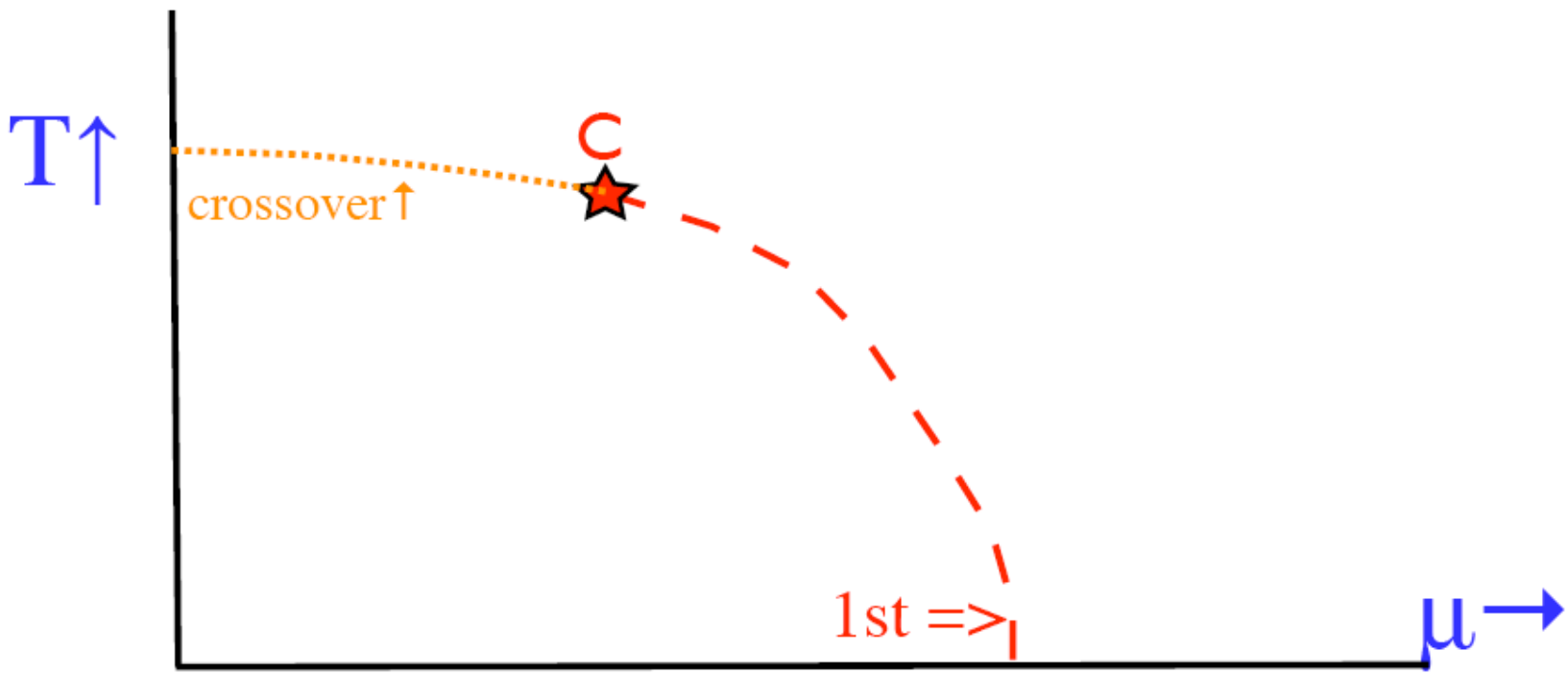


DK, K.Tuchin '07

Used the numerical data supplied by
the Lattice Gauge Theory Group (F. Karsch)

Phase diagram of QCD matter

Transitions versus temperature, T, and chemical potential, μ:
Crossover at RHIC. Maybe a chiral critical end point, C, at "critRHIC"?

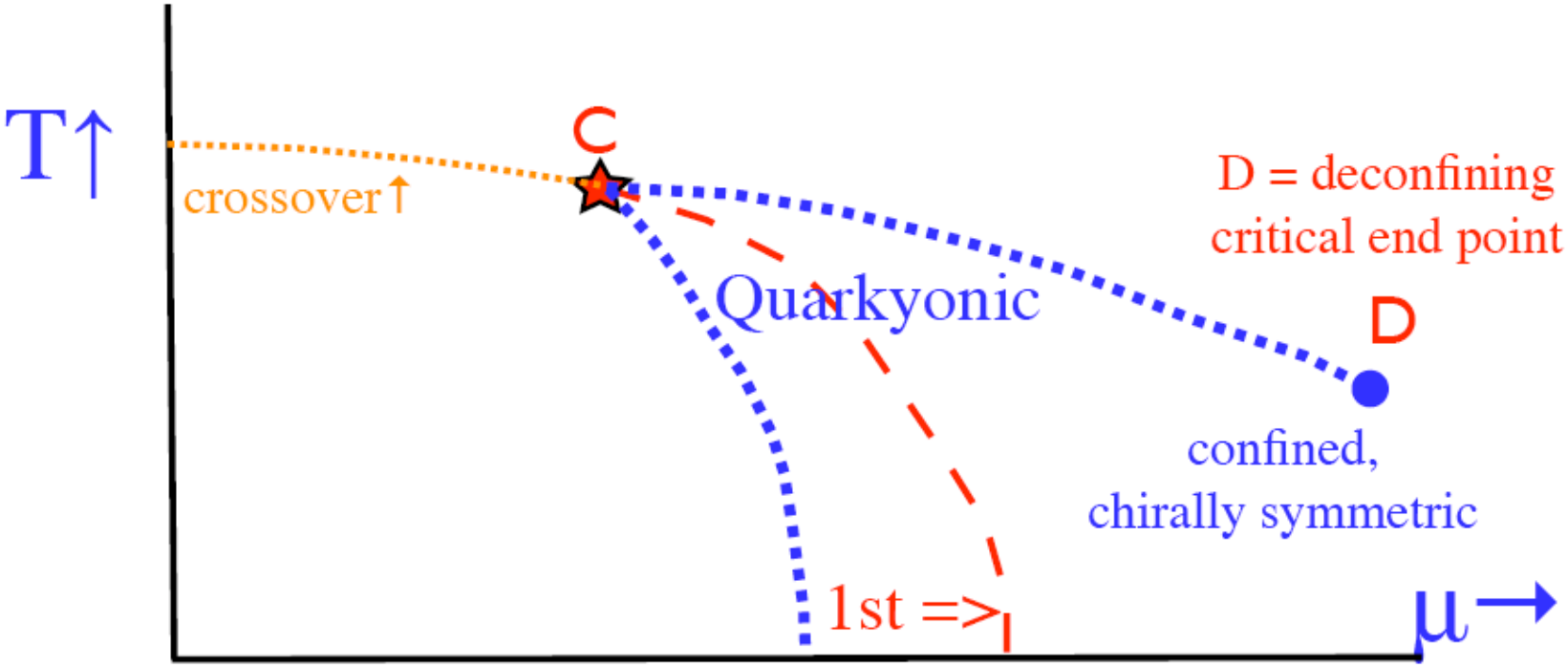


Phase diagram of QCD matter

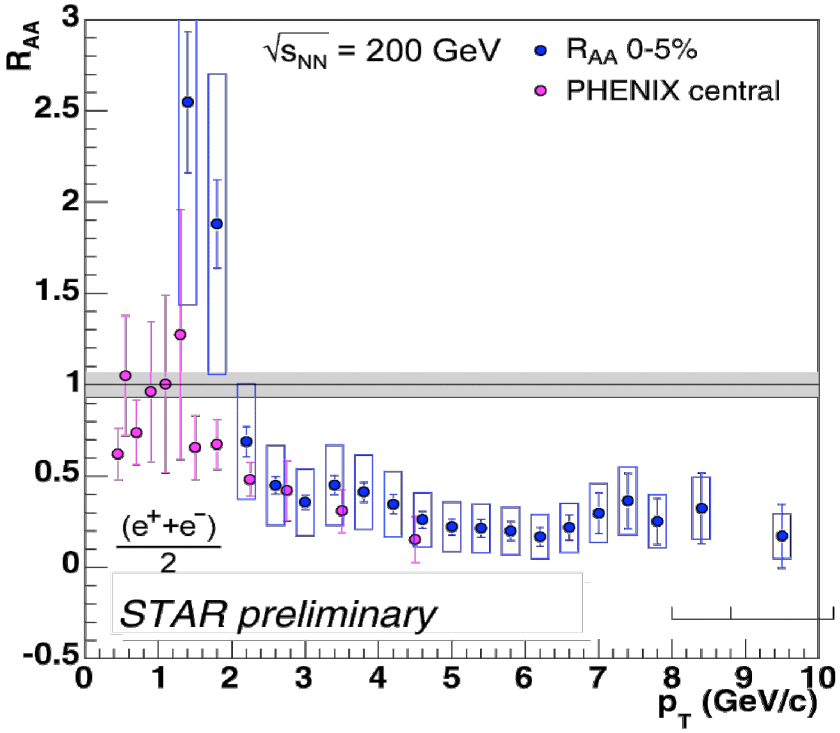
Transitions versus temperature, T, and chemical potential, μ:
Crossover at RHIC. Maybe a chiral critical end point, C, at "critRHIC"?

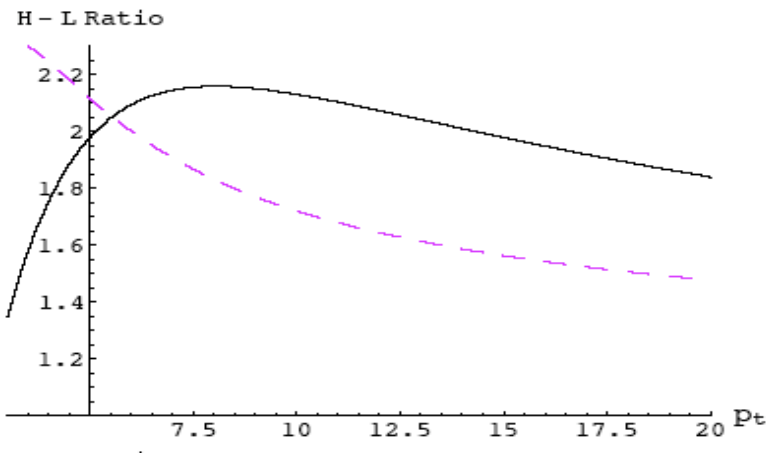
McLerran & Pisarski: large # colors => "quarkyonic" matter
Quarks (deep) in the Fermi *sea*, baryons at the Fermi *surface*.

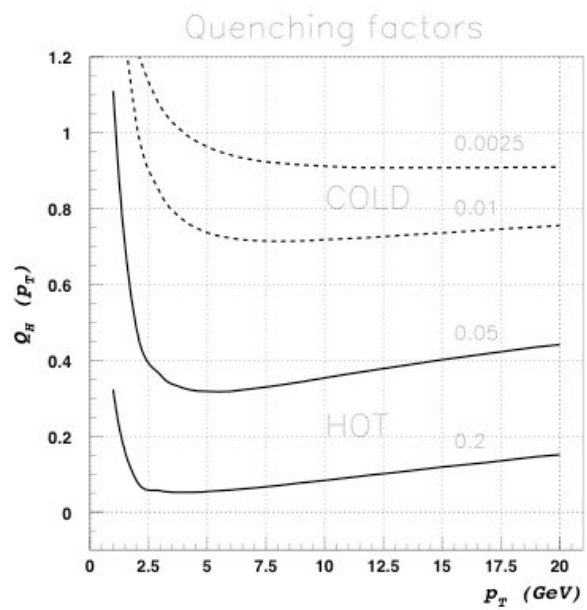
Much richer phase diagram: confined, chirally symmetric phase!
Occurs at *high* T, μ ~ nuclear matter: observable at critRHIC?



Heavy quarks as a probe



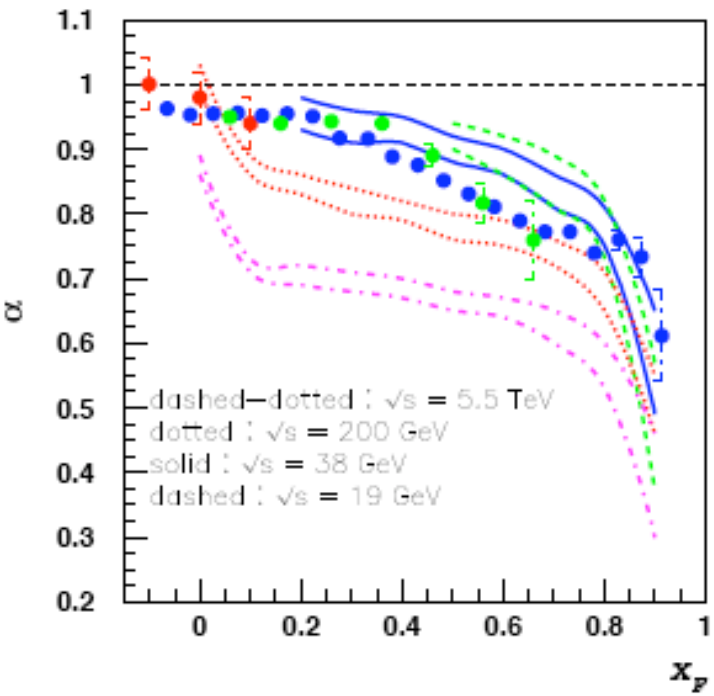




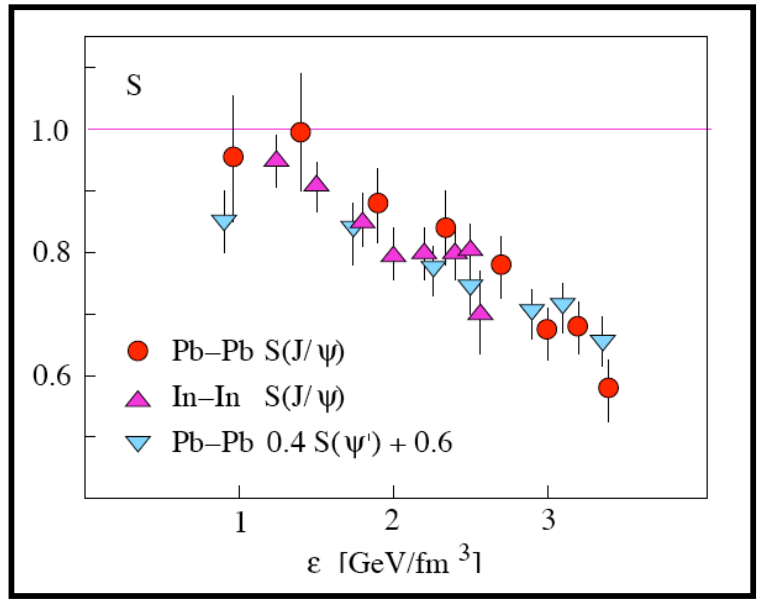
Heavy quark production in the medium - a crucial test of the energy loss mechanism ("dead cone" suppression of radiative energy loss) - Yu. Dokshitzer, DK '01

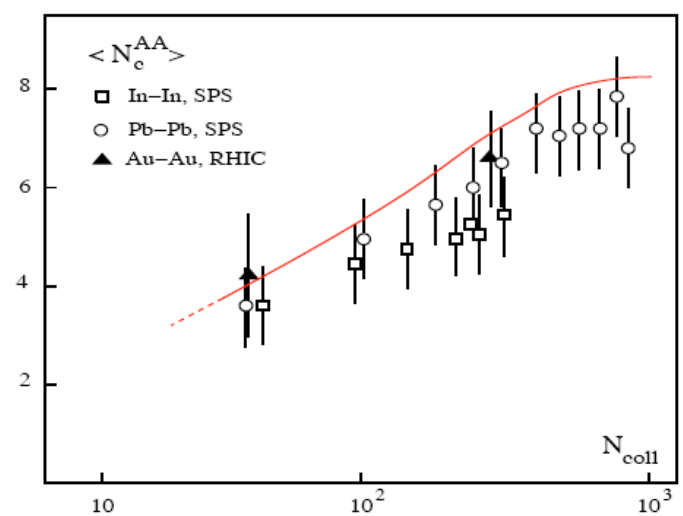
DK, K.Tuchin

Heavy quarkonium as a probe



DK, K. Tuchin





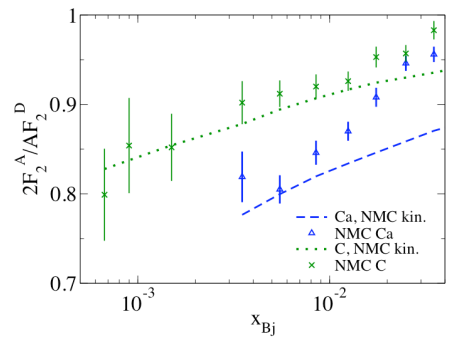
F.Karsch, DK, H.Satz

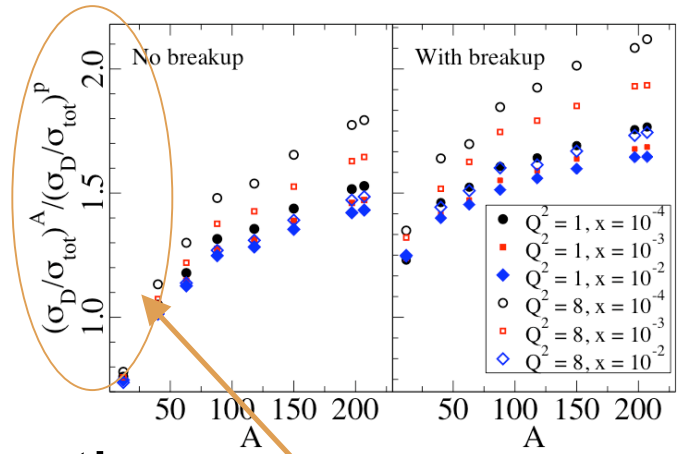
CGC in eA-collisions, the case for EIC

Kowalski, Lappi, Venugopalan, arXiv:0705.3047 [hep-ph]

Saturation model with realistic impact parameter dependence

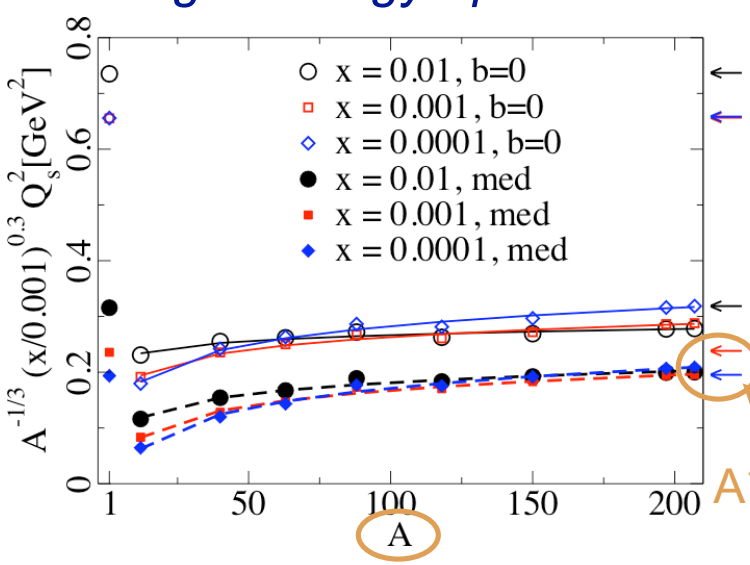
Parameter free description of existing eA data





EIC median Q_s equivalent to

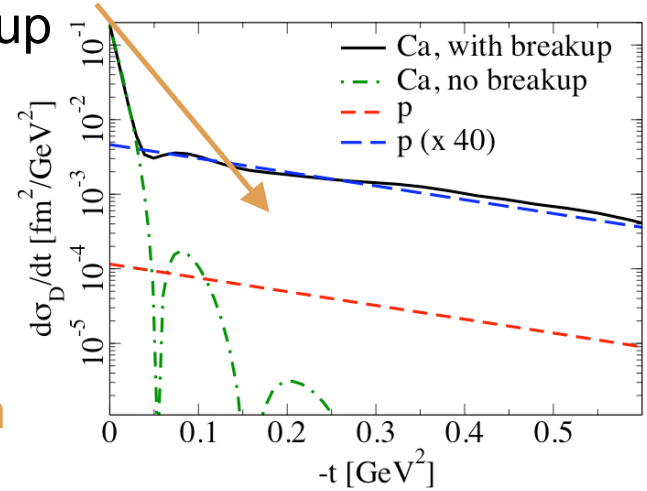
14 times larger energy ep-collider



$A^{1/3}$ x proton

Diffraction:

- Big enhancement wrt ep
- Nontrivial t-distribution and nuclear breakup



Electron-positron pair creation in heavy ion collisions

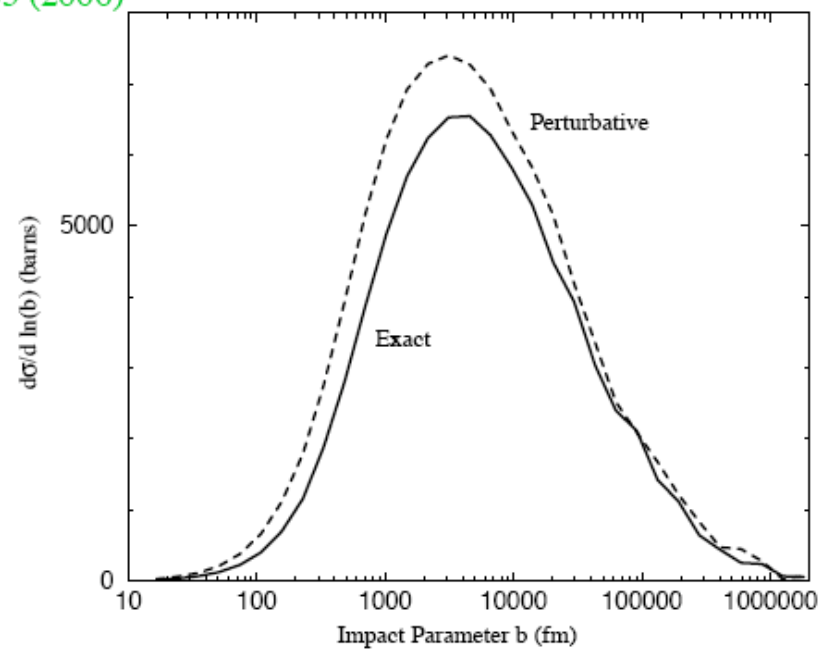
Impact Parameter Dependence of Heavy Ion e^+e^- Pair Production to All Orders in $Z\alpha$

A. J. Baltz, Phys. Rev. C 74, 054903 (2006)

Zero Degree Calorimeter triggering weights smaller impact parameters (b).

b dependence is needed to describe ZDC triggered events such as e^+e^- pairs.

Note that the RHIC total e^+e^- pair production probability is reduced for all impact parameters.



- For the STAR detector, the reduction from perturbation theory is calculated as 27% with ZDC triggering and 17% without.

Hypernuclei and nuclear structure

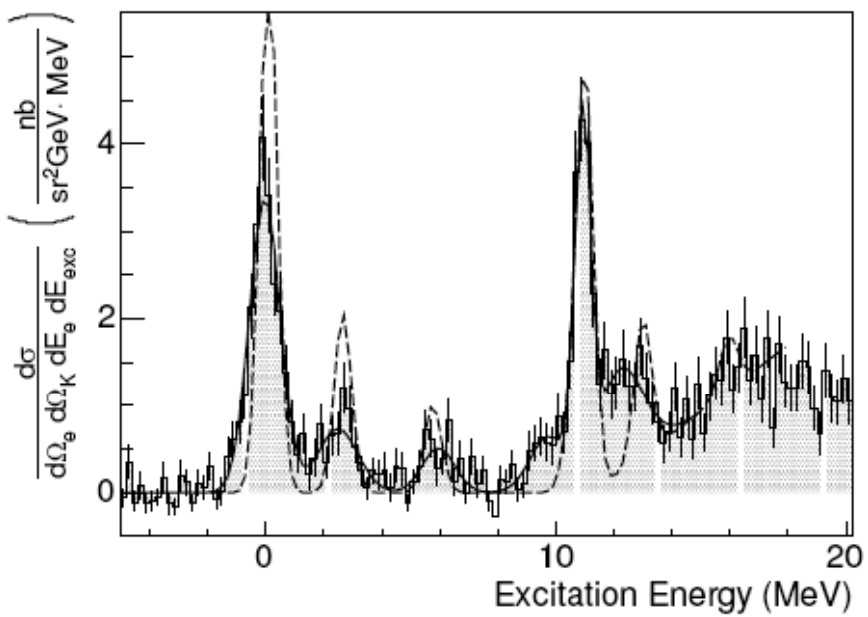
John Millener: Electroproduction of Hypernuclei

Accepted PRL - JLab Hall A

Theory: Millener - structure
Bydzovsky - elementary $p(e,e'K^+)\Lambda$
Sotona - reaction

Solid lines - fit to data
Dotted lines - theory

$^{12}\mathrm{C}(e,e'K^+)^{12}_{\Lambda}\mathrm{B}$

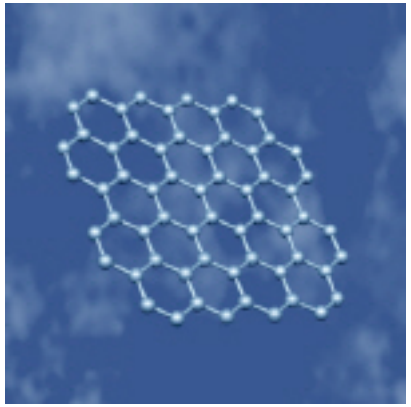


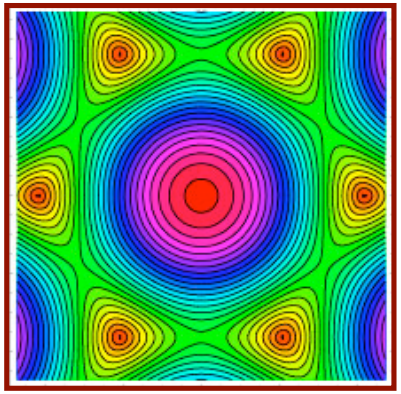
5 theory peaks: $^{11}\mathrm{B}(\frac{3}{2}^-;g.s)\otimes s_\Lambda(1^-/2^-)$, $^{11}\mathrm{B}(\frac{1}{2}^-;2.12)\otimes s_\Lambda(1^-)$, $^{11}\mathrm{B}(\frac{3}{2}^-;5.02)\otimes s_\Lambda(1^-/2^-)$, $^{11}\mathrm{B}(\frac{3}{2}^-;g.s)\otimes p_\Lambda(2^+/3^+)$, $^{11}\mathrm{B}(\frac{1}{2}^-;2.12)\otimes s_\Lambda(1^+/2^+)$

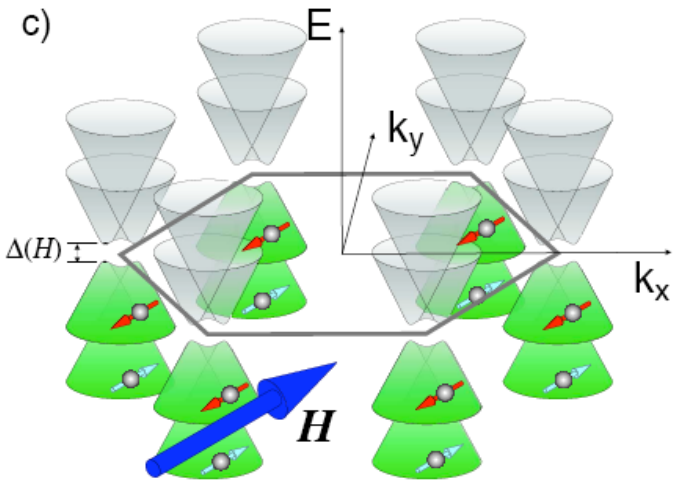
Extra strength on either side of main p_Λ peak should be due to mixing of positive-parity states of $^{11}\mathrm{B}$ coupled to s_Λ - needs full $1\hbar\omega$ shell-model calculation.

Interdisciplinary aspects of Nuclear Science

Strongly correlated systems: graphene and quark-gluon plasma







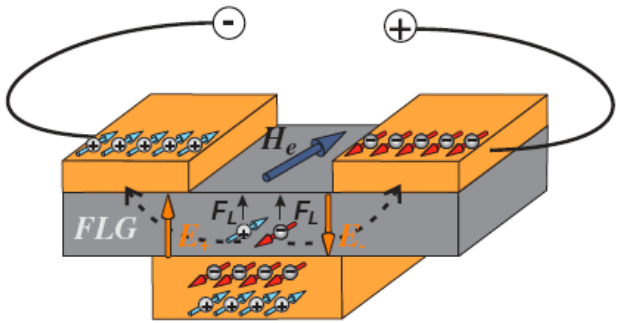
Coulomb attraction between electrons and holes causes instability towards formation of the chiral excitonic condensate (analog of QCD chiral condensate);

The existence of mass gap transforms graphene from a semi-conductor into a dielectric; this may be used for creating spintronic nano-devices…

Interdisciplinary aspects of Nuclear Science

"Spintronic" devices based on graphene-magnet multilayers

("GMM" technology, US pat. 60/892,595, pending)



"This development can open the way for the use of spintronics in practical room temperature devices, an exciting prospect," said DOE Under Secretary for Science Raymond L. Orbach. "The interplay between outstanding facilities and laboratory researchers is a root cause for this achievement, and a direct consequence of the collaborative transformational research that takes place in our DOE laboratories."

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: 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

Conferences organized in '05-07

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 + 9 more

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

D. Kharzeev - Adjunct professor at Yale
W. Vogelsang - Adjunct professor at Stony Brook

Awards (2002-2007)

D. Kharzeev: APS Fellow, 2007
Emilio Segre Distinguished Scholar, 2005
Sackler Fellow, 2005

L. McLerran: BNL Science and Technology Award, 2007

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

R. Venugopalan: Fellow, Andes Foundation, Chile, 2007
Fellow, Alexander von Humboldt foundation, 2003-4

W. Vogelsang: Friedrich-Wilhelm-Bessel Award, Humboldt Foundation 2007

Publications in FY 06

72 papers, from which 51 in refereed journals

Nuclear Theory Budget

- Group size has been unchanged since FY05

  7 senior people, 2 post-docs

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

Not sufficient funding for the Group;

J. Millener has submitted a separate FWP, looking for other means to cut costs; but need also a budget uncrease…

The Future

Detailed 4 year plan for the Group has been prepared; it is aligned with NSAC performance measures and BNL plans and 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

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

Back-up slides

Nuclear Physics Theory
Staffing and Funding Profiles by Fiscal Year

	FY 05 FTE	FY 06 FTE	FY 07 FTE	FY 08 P FTE
STAFFING				
Scientific	7.1	**6.9**	7.0	6.6
Professional	0.0	**0.0**	0.0	0.0
Technical	0.0	**0.0**	0.0	0.0
Administrative	1.0	**1.0**	1.0	1.0
Total:	8.1	**7.9**	**8.0**	**7.6**
COST in K$ (includes O/H)				
Salaries	**1,577**	**1,643**	1,740	1,777
M&S	**195**	**151**	76	128
Other	**285**	**331**	238	259
Total Need:	**2,057**	**2,125**	2,054	2,164
FY BA Guidance:	**2,070**	**2,070**	**2,054**	**2,164**
Other support (G&A exclusion benefits)	269	434	321	150
Combined Support	**2,326**	**2,559**	**2,375**	**2,314**

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