DOE S&T review, 2005

Nuclear Theory Group at BNL

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 - 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 with existing and planned experimental programs at BNL

Staff of the Nuclear Theory Group

Marcy Chaloupka - Secretary

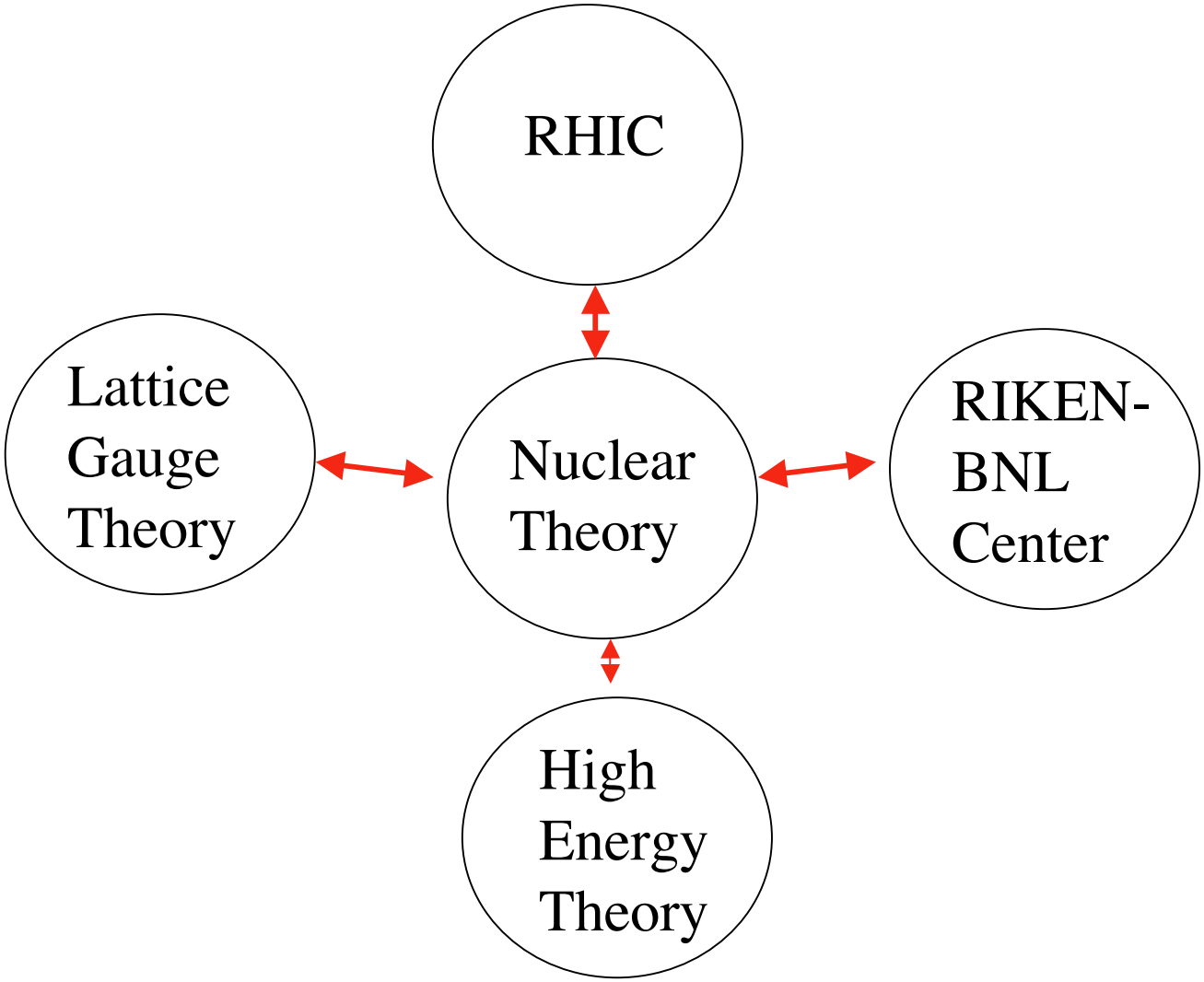
Permanent Scientific Staff:

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. P. Petreczky (Goldhaber Fellow)
2. S. Kretzer (joint with RBRC)
3. C. Schmidt (LDRD)
4. A. Stasto
5. K. Tuchin
6. F. Zantow (LDRD)

Nuclear Theory Group at BNL



Publication and Citation Stats (from SPIRES)

Name	Refereed Publications (2001-)	Citations (2001-)
Baltz	06	69
Kharzeev	25	845
McLerran	29	1114
Millener	04	15
Petreczky	18	437
Pisarski	12	191
Venugopalan	21	422
Vogelsang	20	229

Average publication rate (2001-) = 3.5 ref.pub/year
+ 25 citations/paper

General group stats: 4 “renowned” papers (+500 citations)
72 “important” papers (+100 citations)

Awards (2001-2005)

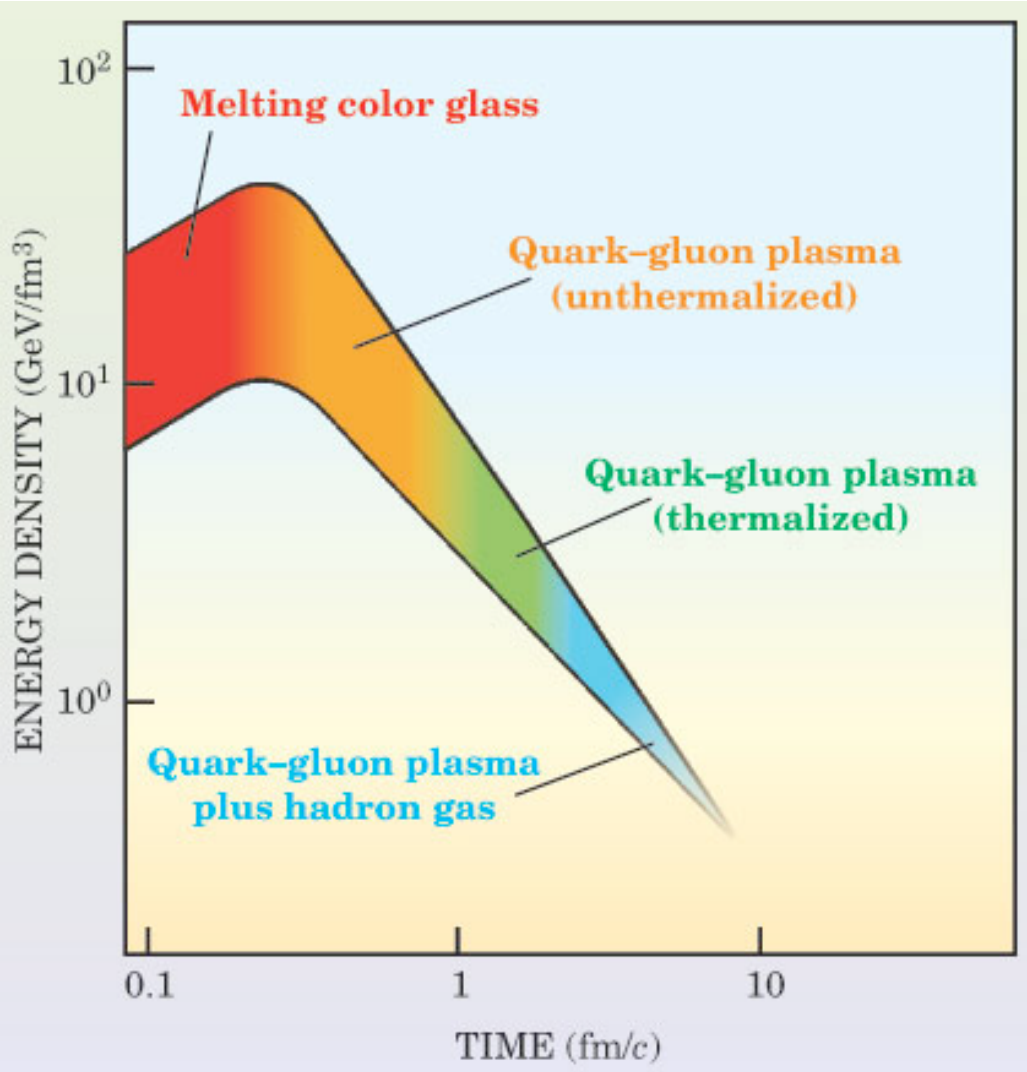
D. Kharzeev: Emilio Segre Distinguished Scholar (2005)
Sackler Fellow (2005)

P. Petreczky: Goldhaber Fellow (2002)

R. Pisarski: Senior U.S. Scientist Award (2003),
Alexander von Humboldt Foundation

R. Venugopalan: US Research Fellow (2004),
Alexander von Humboldt Foundation

Quark Gluon Plasma and Color Glass Condensate at RHIC



T. Ludlam
L. McLerran
Physics Today'03

The physics of Quark-Gluon Plasma

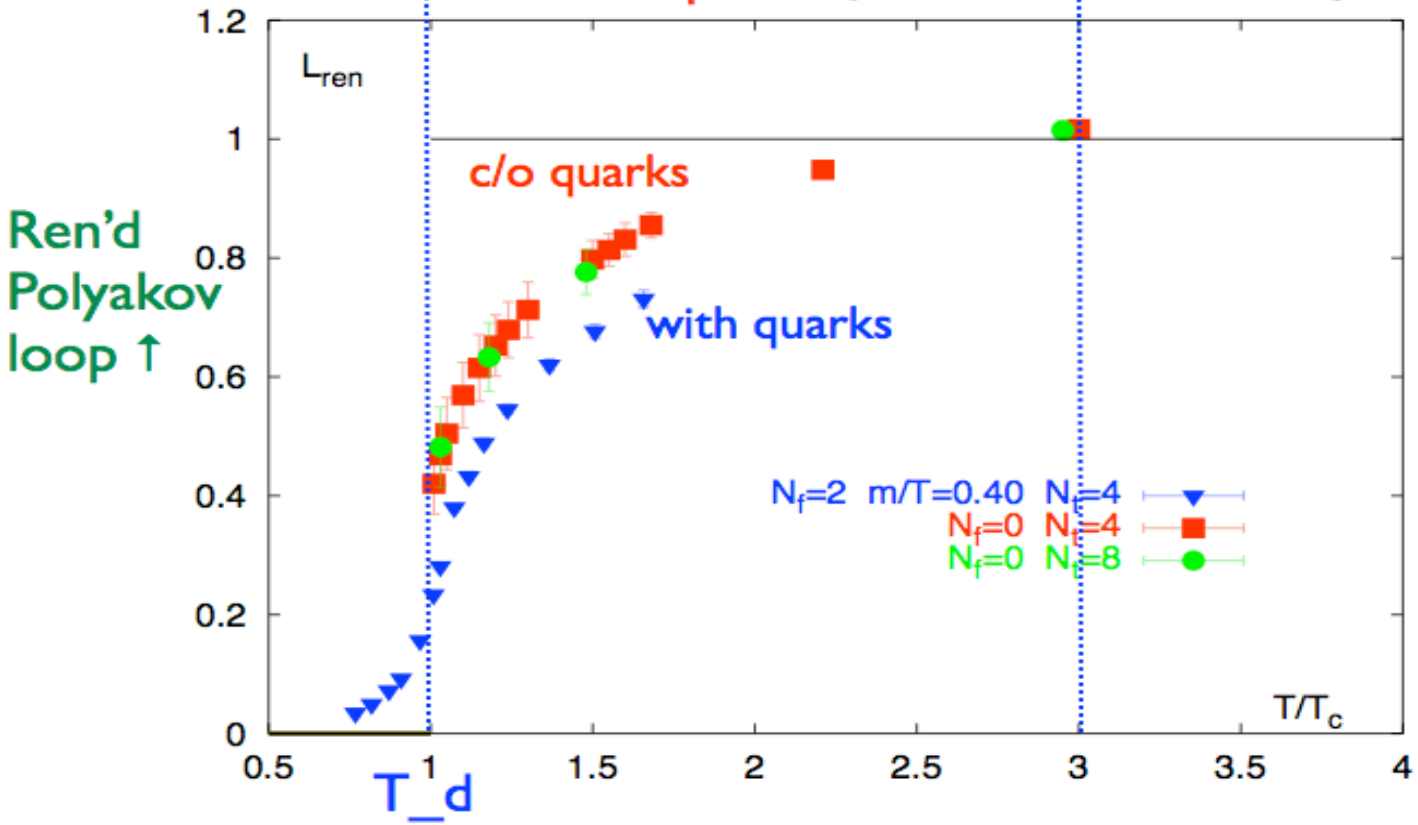
R. Pisarski

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 =>

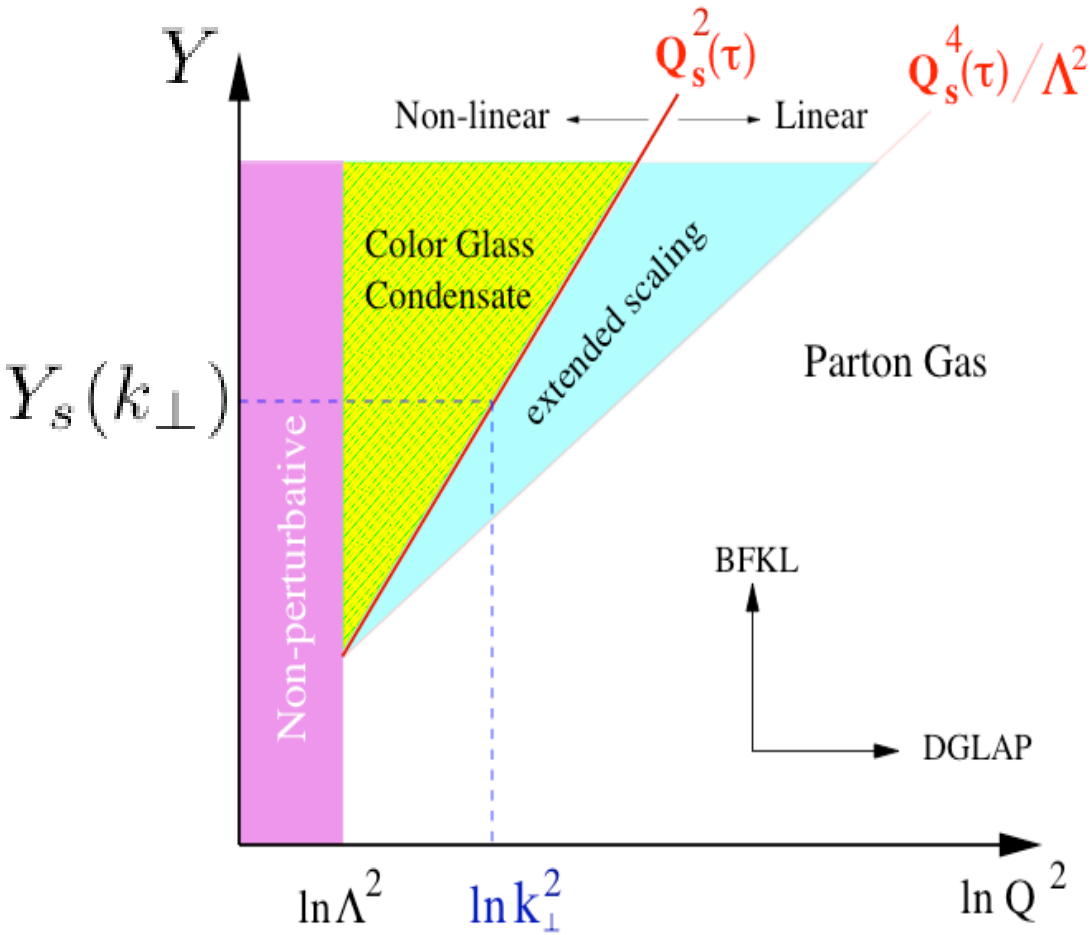


Bielefeld: lat/0312015

Two flavors, kaon masses

T/T_d=>

Novel regime of QCD evolution at high energies



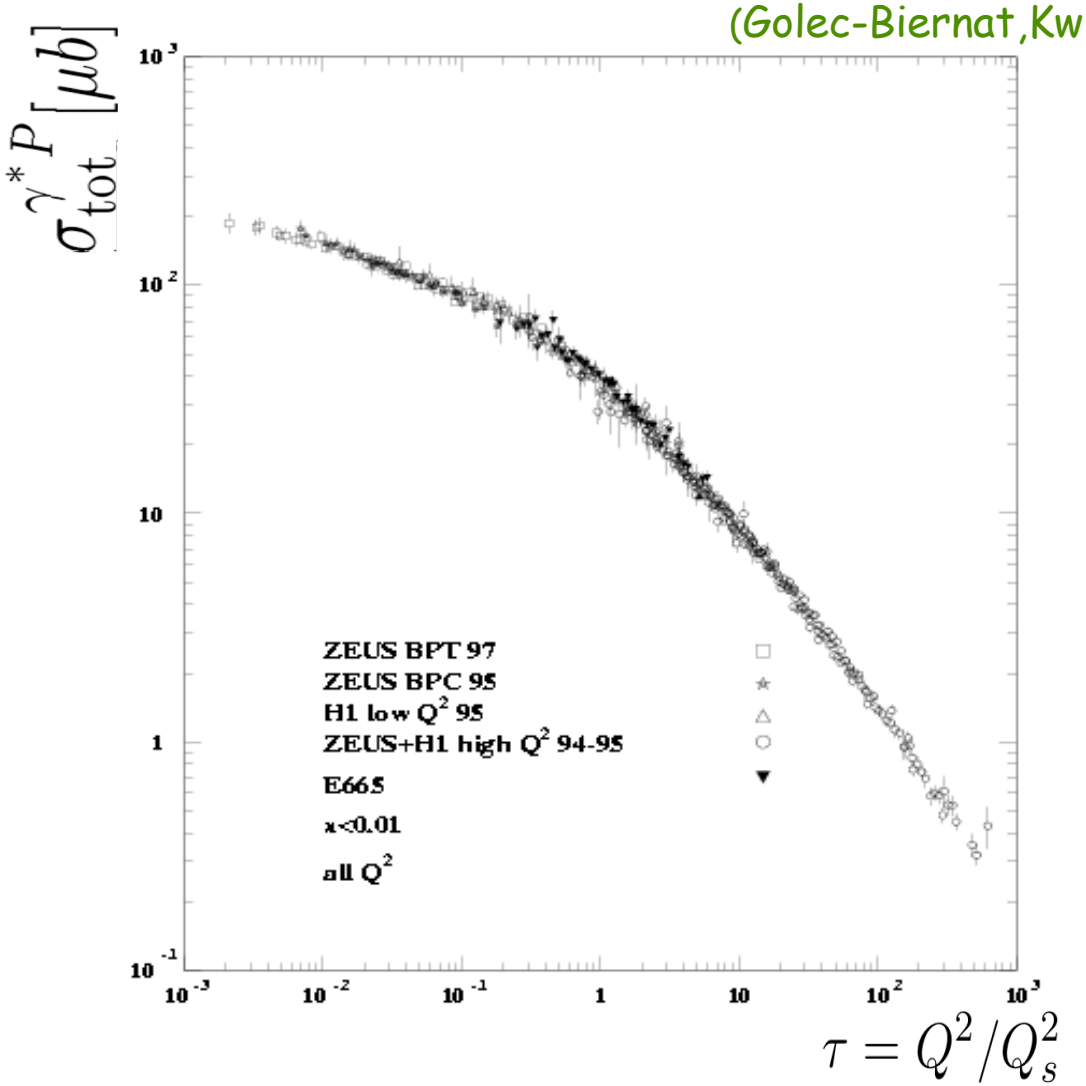
A. Stasto
K. Tuchin

D. Kharzeev
L. McLerran
R. Venugopalan

Iancu & Venugopalan, hep-ph/0303204

Geometrical scaling at HERA

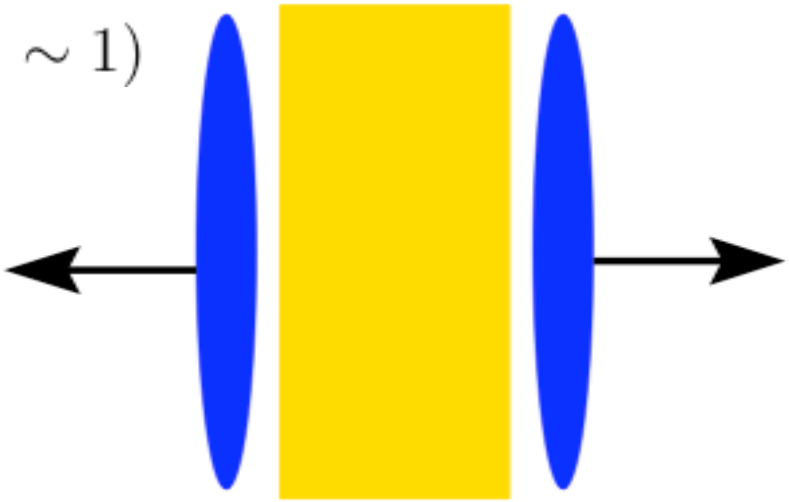
(Golec-Biernat,Kwiecinski,Stasto)



Scaling seen for all x < 0.01 and $0.045 < Q^2 < 450\,\mathrm{GeV}^2$

Colliding Sheets of Colored Glass at High Energies

$(\rho_{A1}/k_\perp^2,\ \rho_{A2}/k_\perp^2 \sim 1)$



Krasnitz,Nara,

Venugopalan

Classical Fields with occupation # $\frac{1}{\alpha_S}$

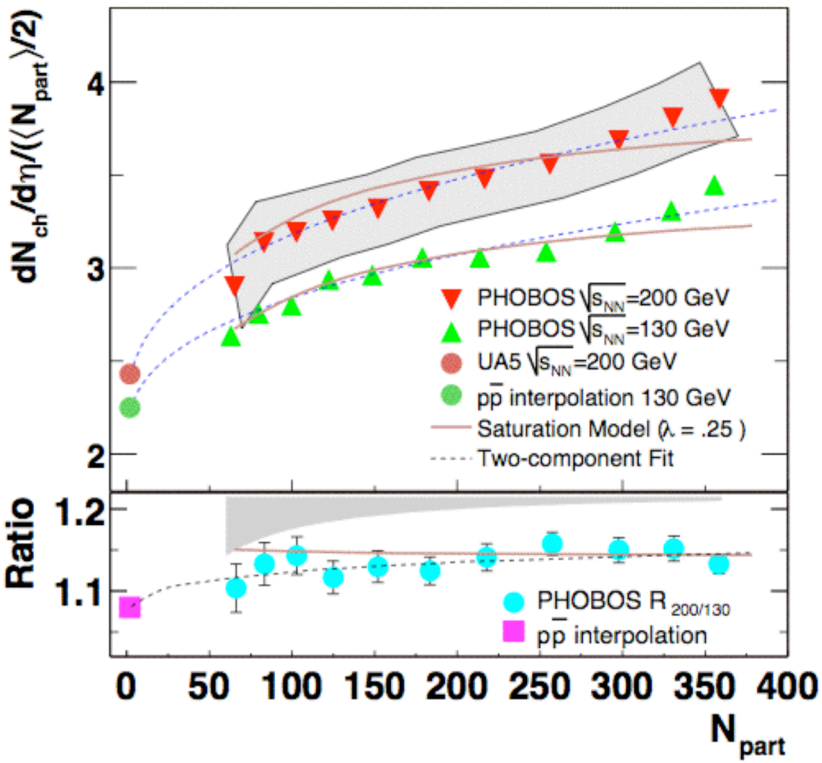
Initial energy and multiplicity of produced gluons depends on Q_s

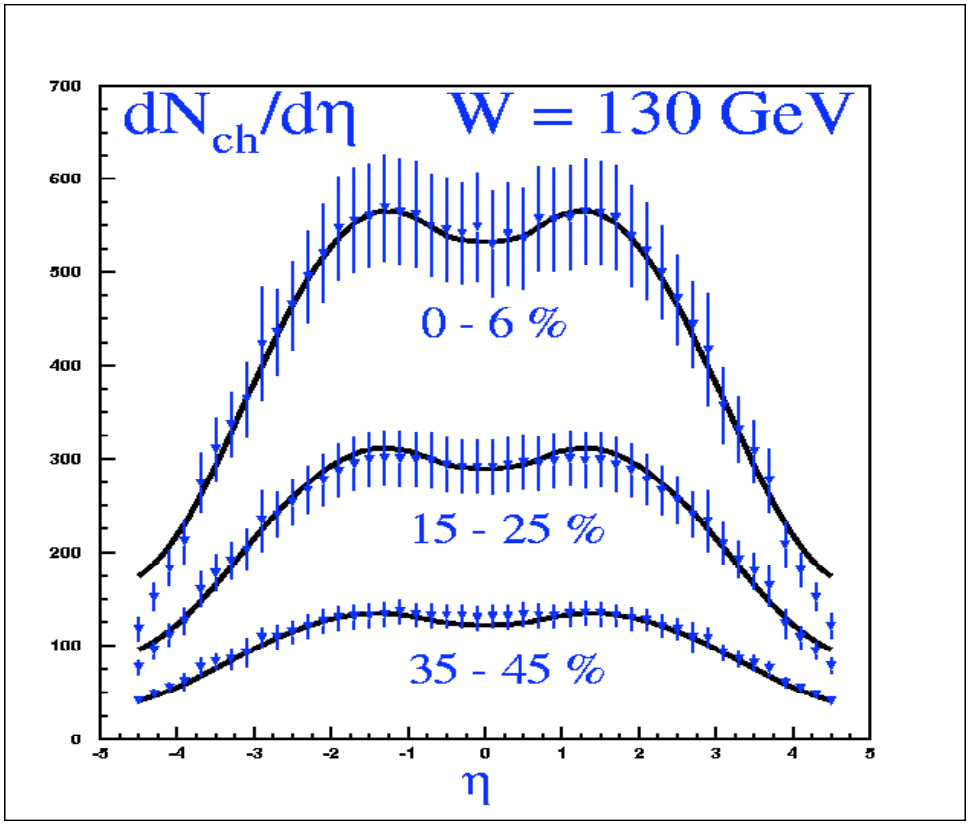
$$\frac{1}{\pi R^2}\frac{dE}{d\eta} = \frac{0.25}{g^2} Q_s^3 \qquad \frac{1}{\pi R^2}\frac{dN}{d\eta} = \frac{0.3}{g^2} Q_s^2$$

Straight forward extrapolation from HERA: Q_s = 1.4 GeV

Classical QCD in action

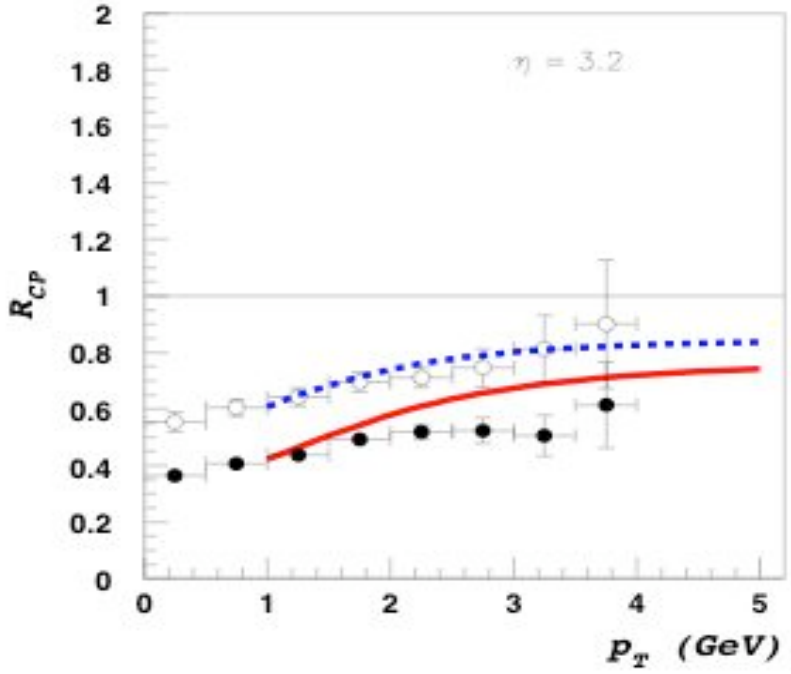
The hadron multiplicities in Au-Au and d-Au collisions are described in the CGC approach: Kharzeev, Levin, Nardi



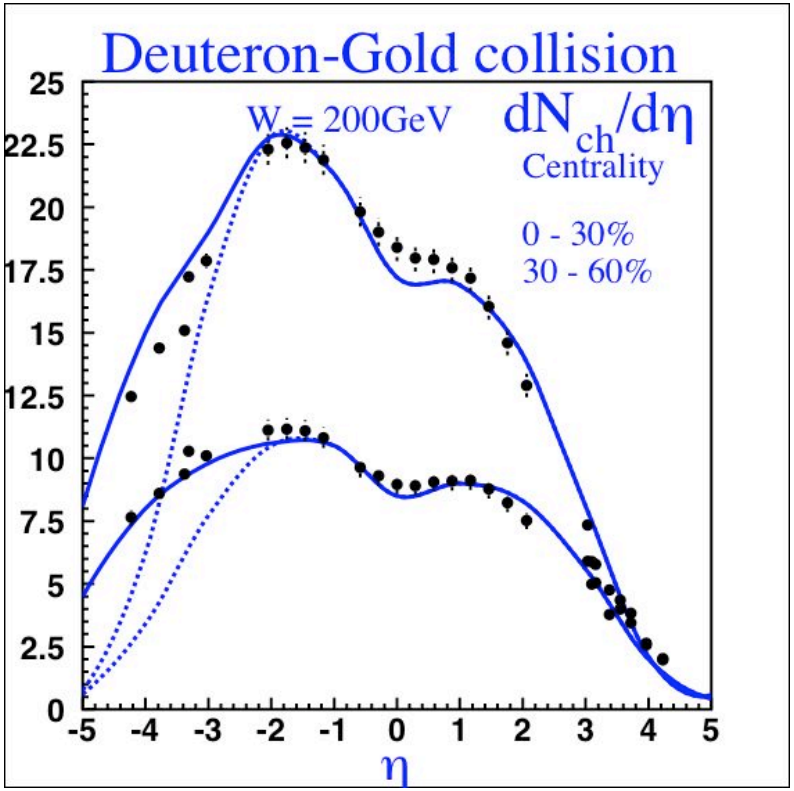


Color Glass Condensate at RHIC

Synergy between Nuclear Theory group and RHIC experimentalists



Kharzeev, Kovchegov, Tuchin

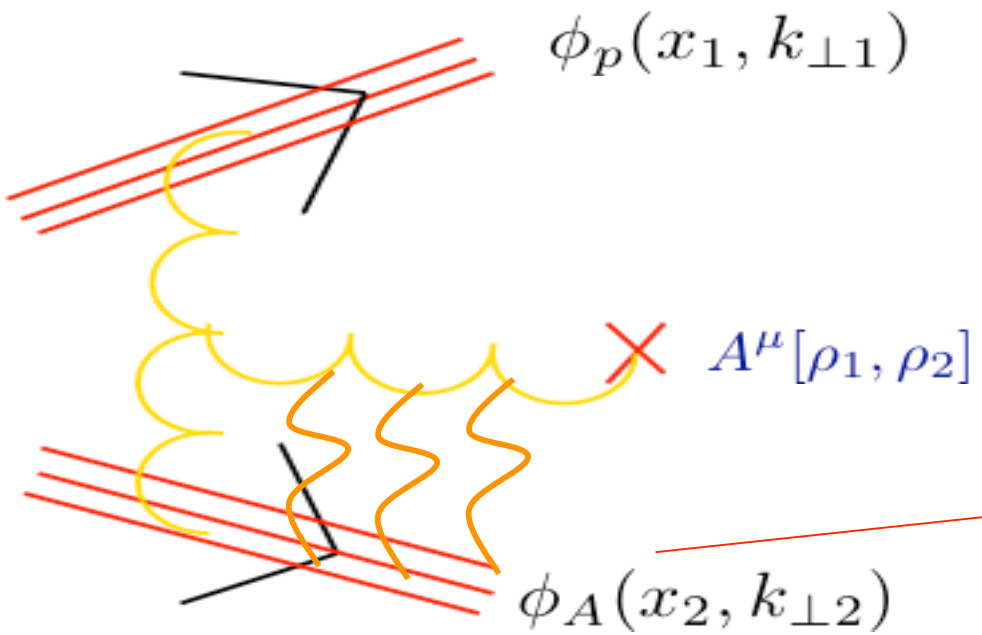


KLN

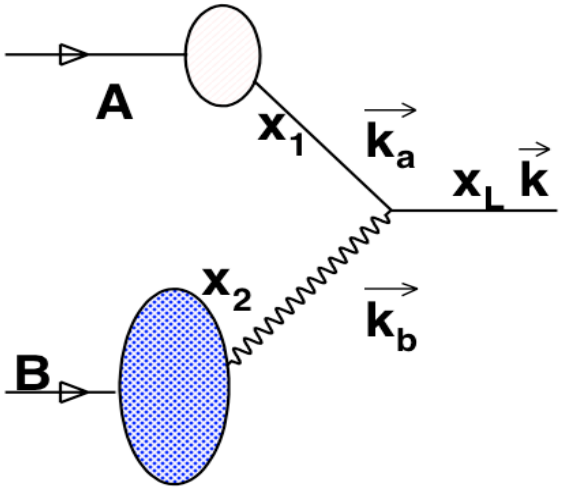
GLUON & QUARK PRODUCTION IN D-A

Blaizot, Gelis, Venugopalan

Kharzeev, Tuchin



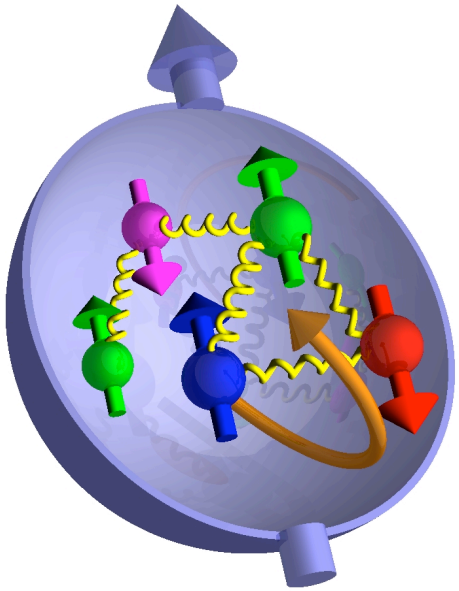
Unintegrated "gluon" distribution-includes all twists **-obeys RG evolution equations**



K_t factorization breaks down for quark production

Exciting program with polarized protons underway at RHIC:

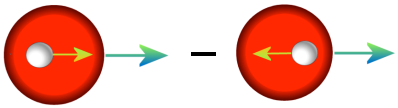
What carries the proton spin ?



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

Quark spins

only ≈ 20 %



Gluon spins

??

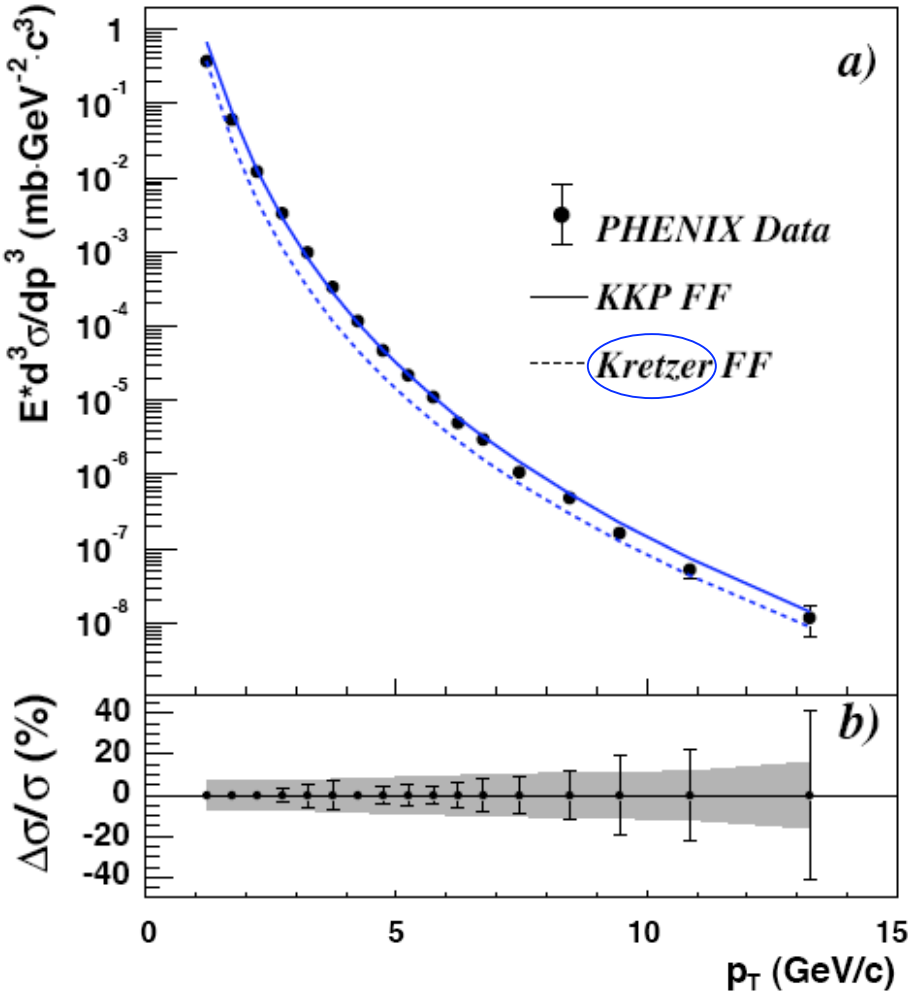
Quark and gluon orbital ang. mom.

??

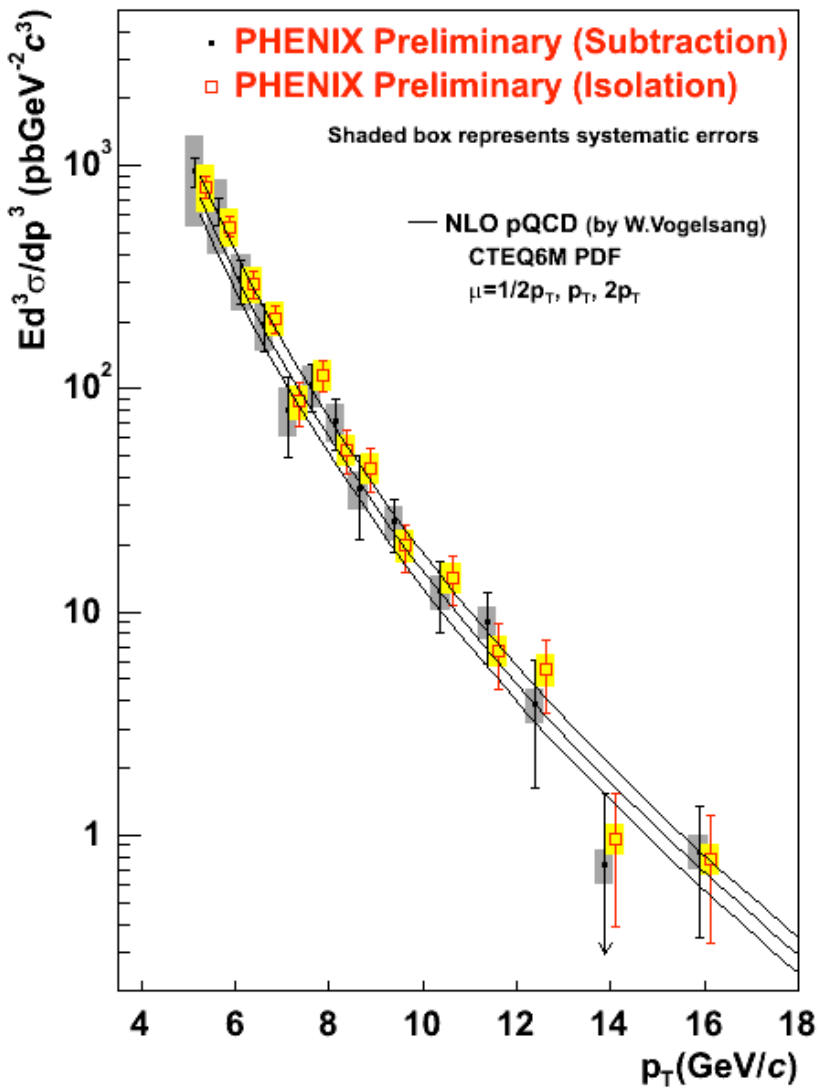
- RHIC addresses the proton spin structure in new ways
- BNL Nuclear Theory devotes a major effort to QCD spin physics- in particular for RHIC

- **Successful NLO calculations in unpolarized pp at RHIC:**

$$pp \rightarrow \pi^0 X$$



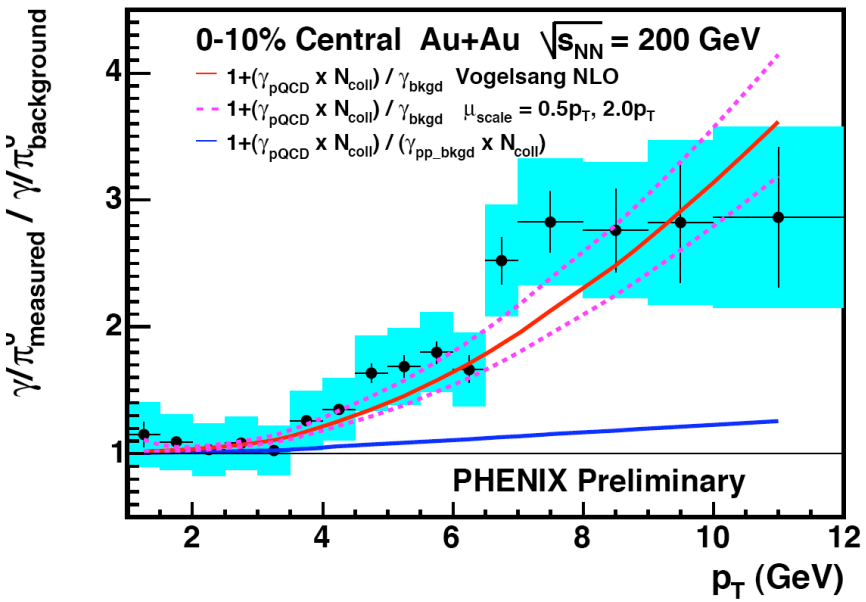
$$pp \rightarrow \gamma X$$



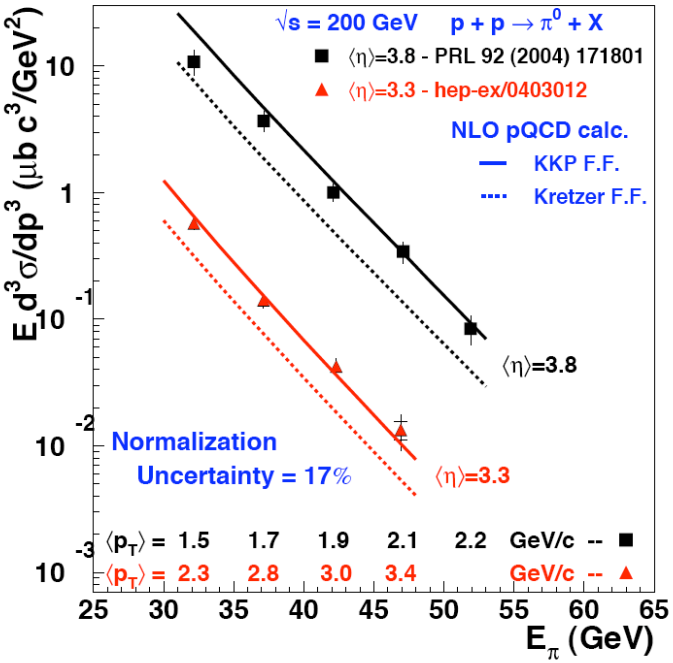
NLO: Jäger, Schäfer, Stratmann, Vogelsang

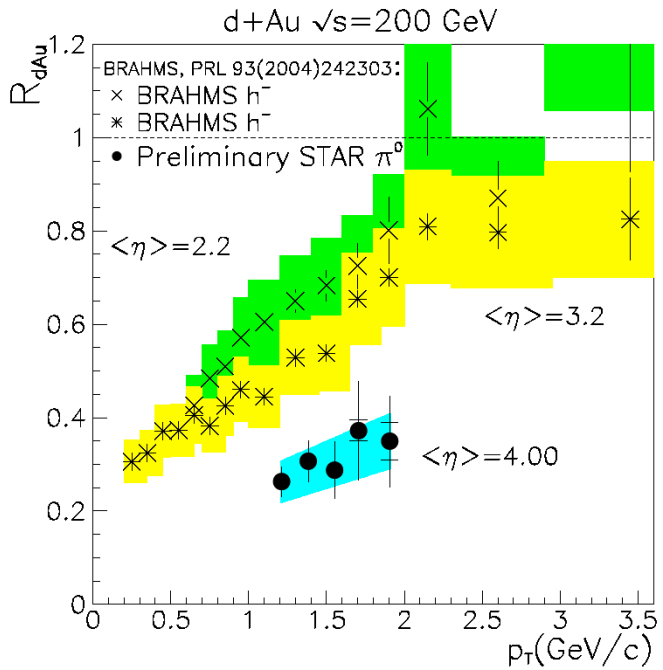
- **Also important as benchmark for heavy-ion collisions at RHIC**

- **Examples:**



Au-Au

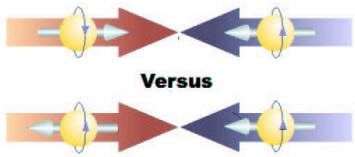


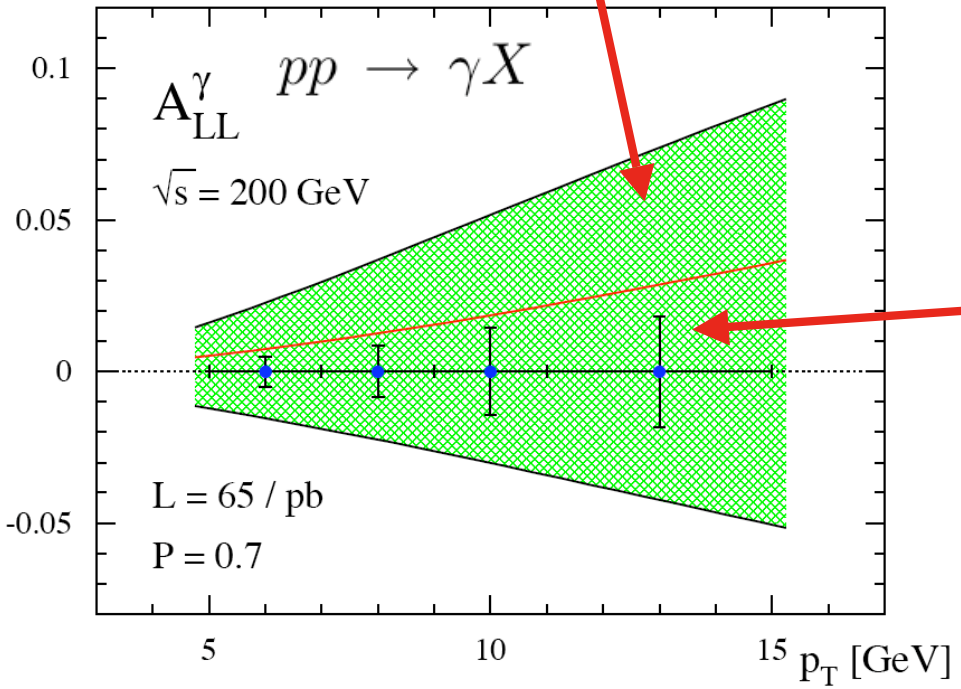


d-Au

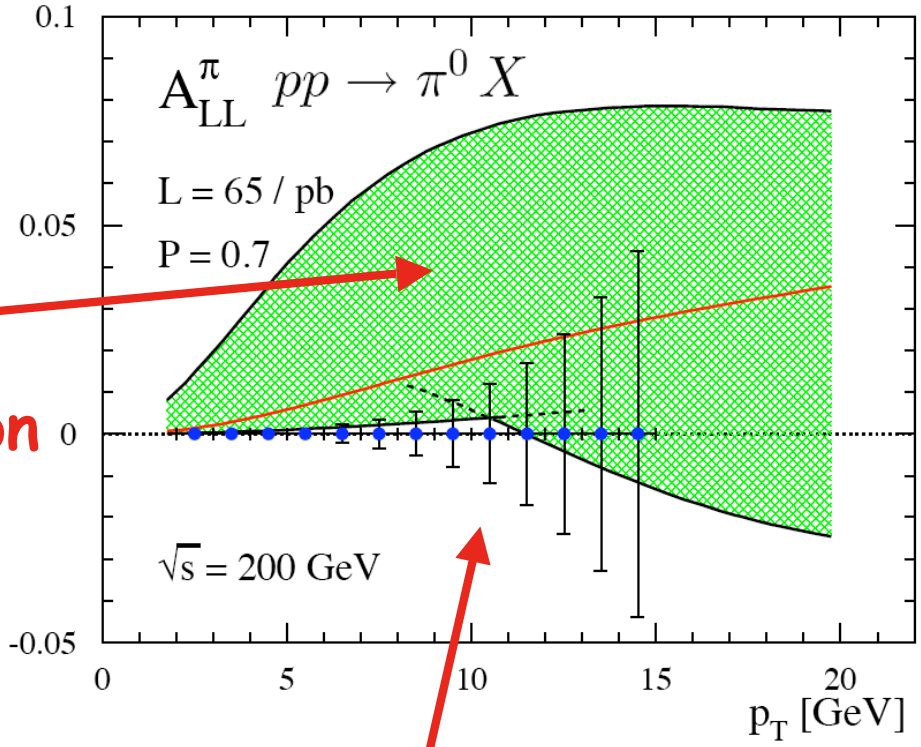
Predicted in
Guzey, Strikman,
Vogelsang
PLB 603 (2004) 173

- **Back to RHIC spin …**





Due to current "uncertainty" of gluon polarization

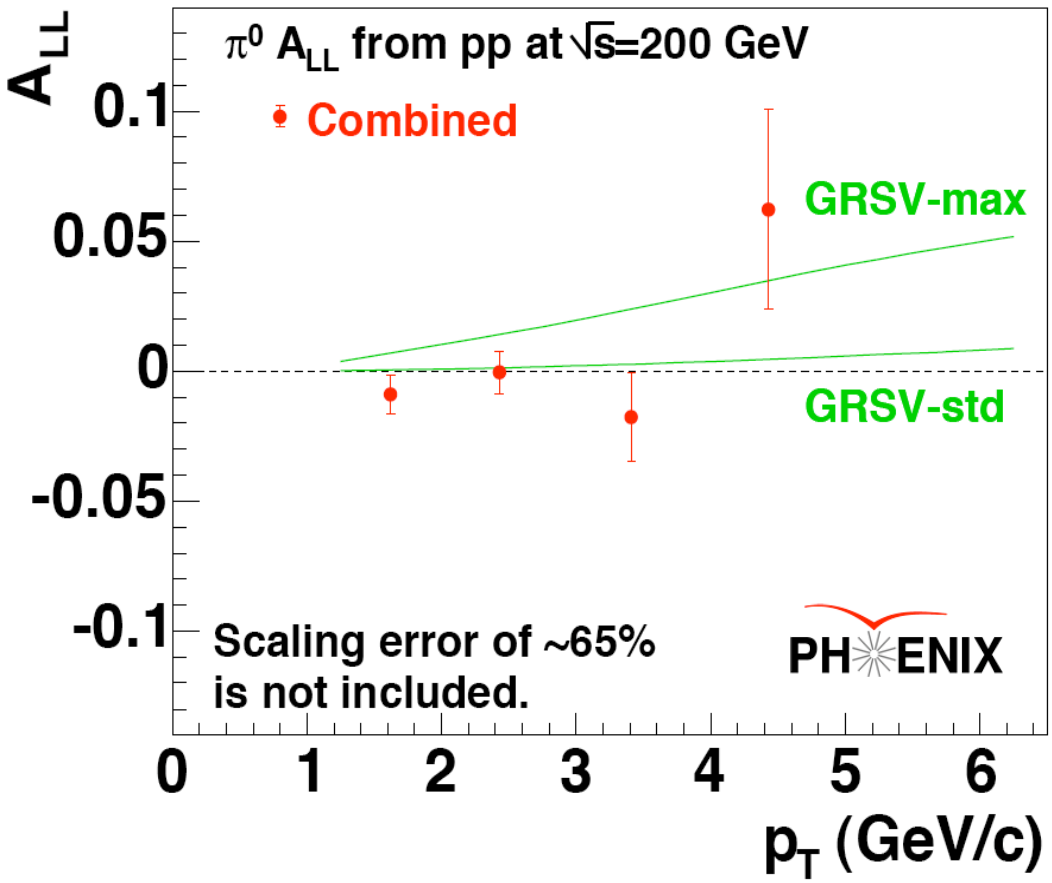


Expected RHIC stat. uncertainties

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

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

Data are coming in …



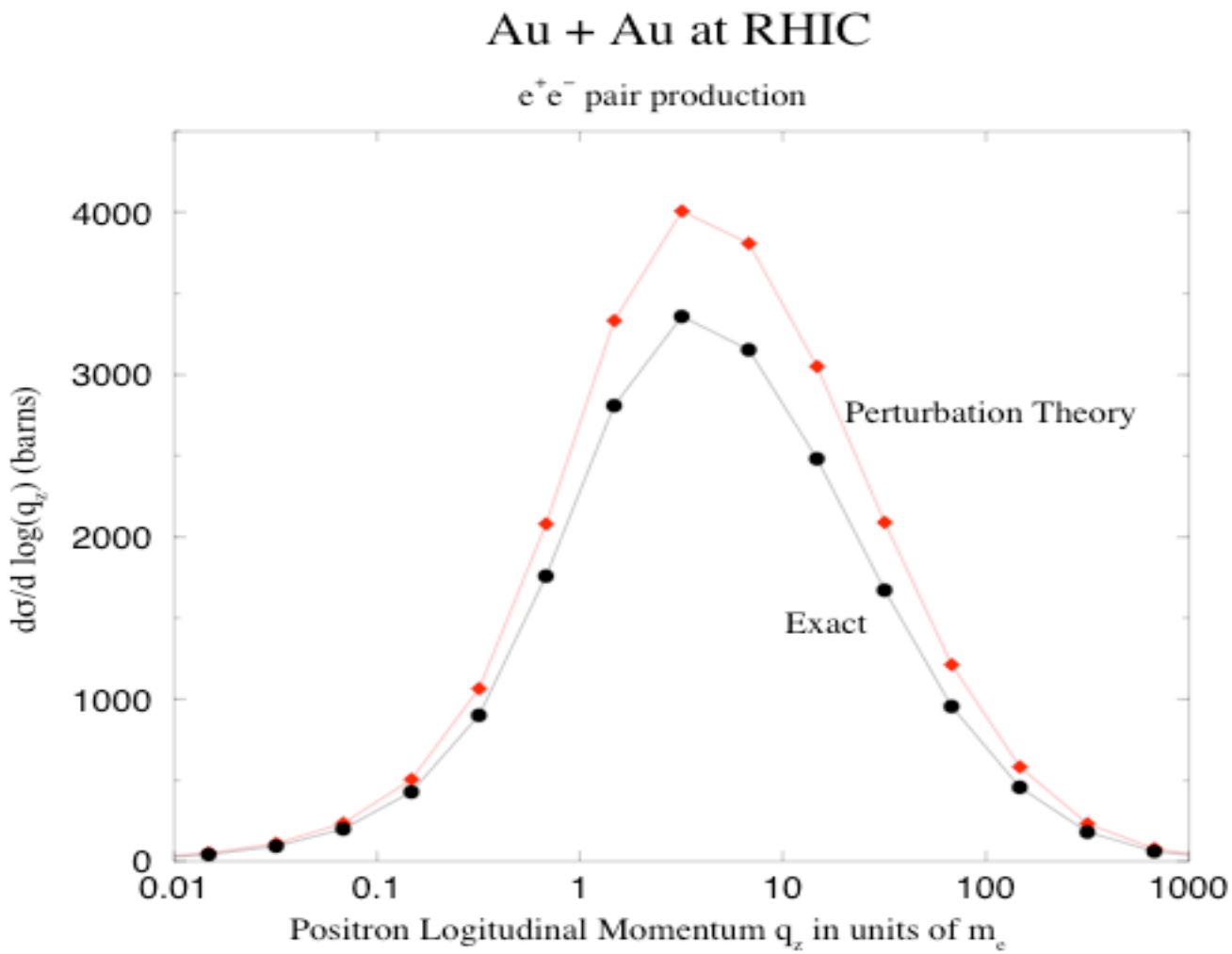
- much more expected from just completed RHIC run
- in future, challenge is to directly extract gluon polarization from measurements

Baltz

Calculation of heavy ion e^+e^- pair production to all orders in $Z\alpha$

A.J.Baltz, Phys. Rev. C 71, 024901 (2005)

- A full numerical evaluation of the "exact" semi-classical total cross section for e^+e^- production with gold or lead ions shows reductions from perturbation theory of 28% (SPS), 17% (RHIC), and 11%(LHC).



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

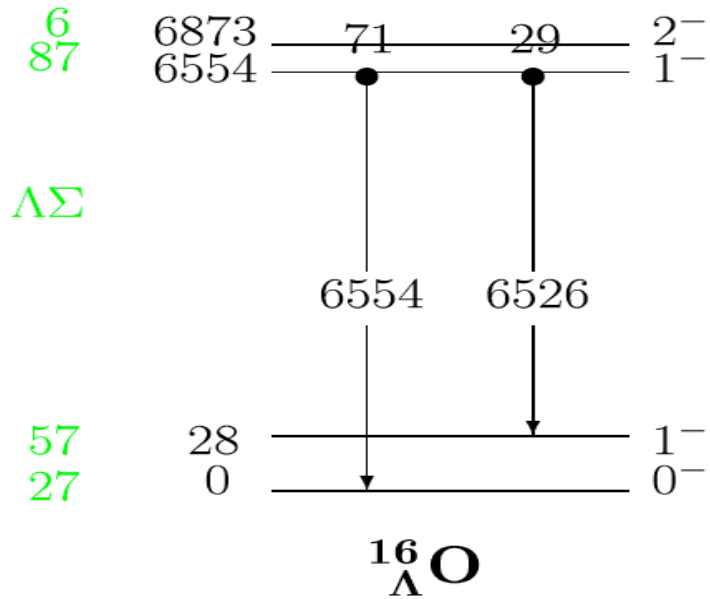
Measurement:

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



The Future

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

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

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

Summary

1. Nuclear Theory Group at BNL is a world leader in High Energy Nuclear Physics

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

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

4. Bright future ahead!