Physics Priorities for RHIC and LHC

- Quark Gluon Plasma: sQGP
- Color Glass Condensate: CGC

- Future A-QCD Physics priorities

1. Precision and Rare probes
2. Heavy Quark flow and quench
3. 6D correlators tomography
4. Y<<-1 and Y>>1 Au+D
5. Novel nuggets CP, Penta-qs,…
6. γ Tagged jet tomography
7. Denser QCD/CGC at LHC

M.Gyulassy and L. McLerran, nucl-th/0405013

Four major physics discoveries published @ RHIC so far

22 (4 PRL) from BRAMHS

92 (15 PRL) from PHENIX

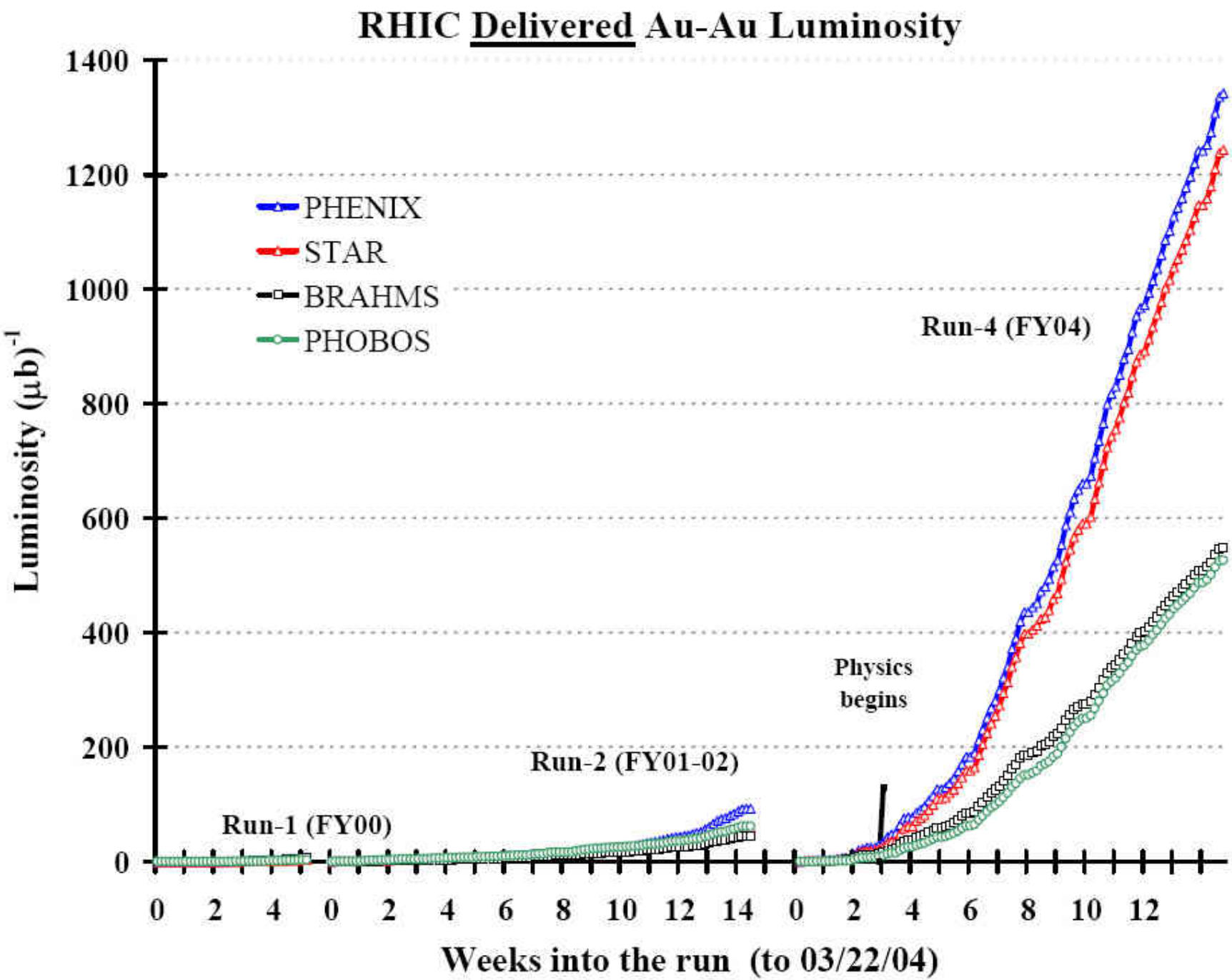
34 (6 PRL) from PHOBOS

127 (21 PRL) from STAR

Beams	$\sqrt{s_{NN}}$(GeV)	$\int \mathcal{L}dt$(nb^{-1})
Au+Au	20	small
Au+Au	130	0.02
Au+Au	200	0.24
$\vec{p}+\vec{p}$	200	1600
d+Au	200	75
Au+Au (2004)	200	~2
Au+Au (2004)	62.4	~0.05

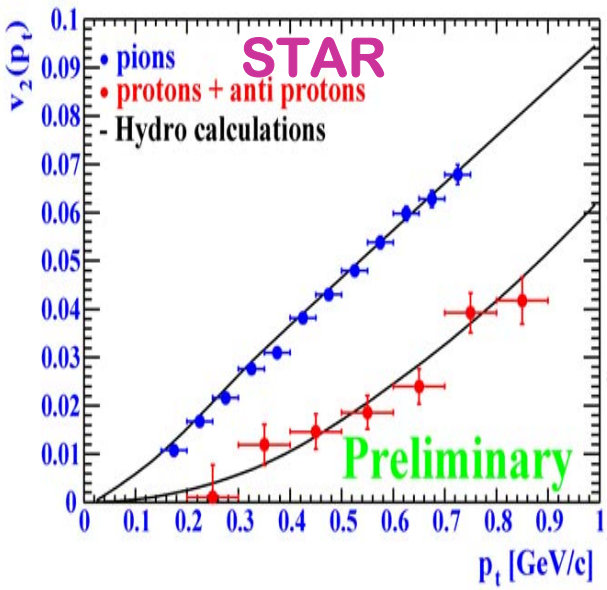
On top of extensive SPS/CERN data base
E_{cm}=5 - 20 AGeV

(NA49/35, NA50/38, CERES/NA45,WA98/80,NA57/WA97)

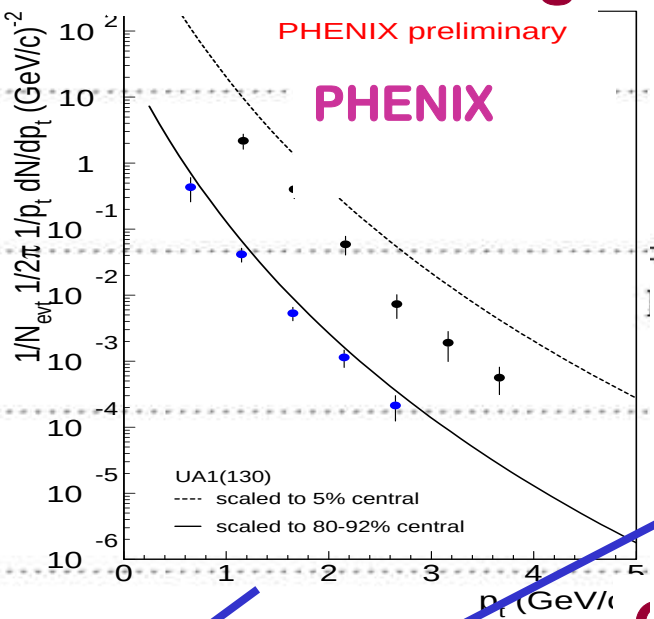

RHIC Delivered Au-Au Luminosity
Luminosity (μb)-1
1400
1200
1000
800
600
400
200
0
PHENIX
STAR
BRAHMS
PHOBOS
Run-4 (FY04)
Physics
begins
Run-2 (FY01-02)
Run-1 (FY00)
0 2 4 0 2 4 6 8 10 12 14 0 2 4 6 8 10 12
Weeks into the run (to 03/22/04)

Four major "day 1" discoveries

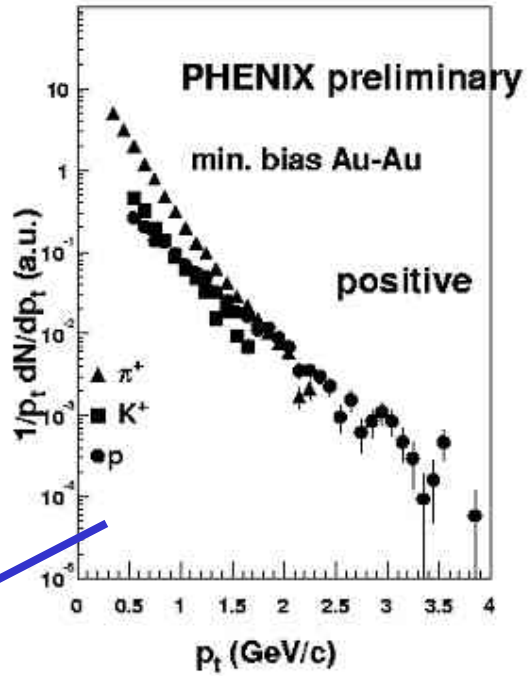
Collective Flow



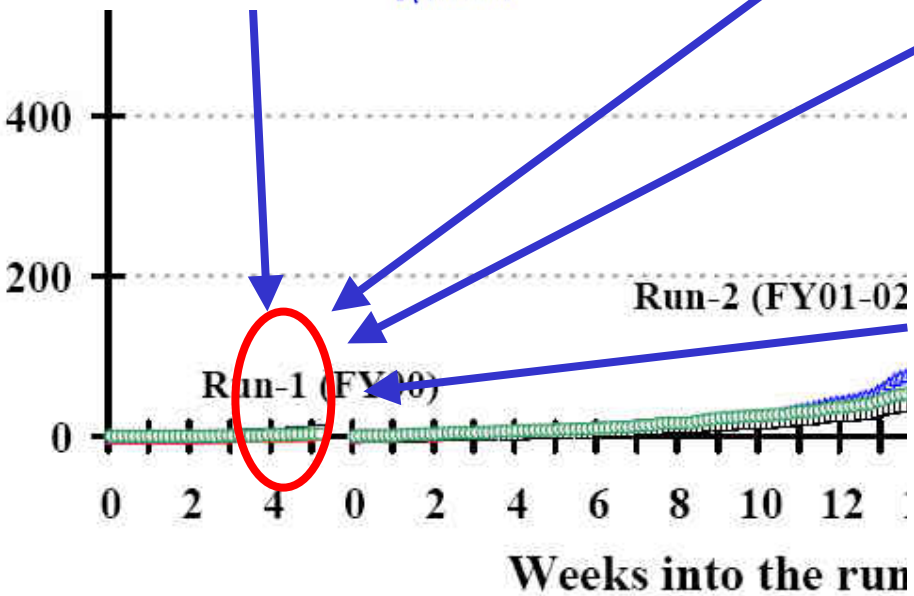
Jet Quenching

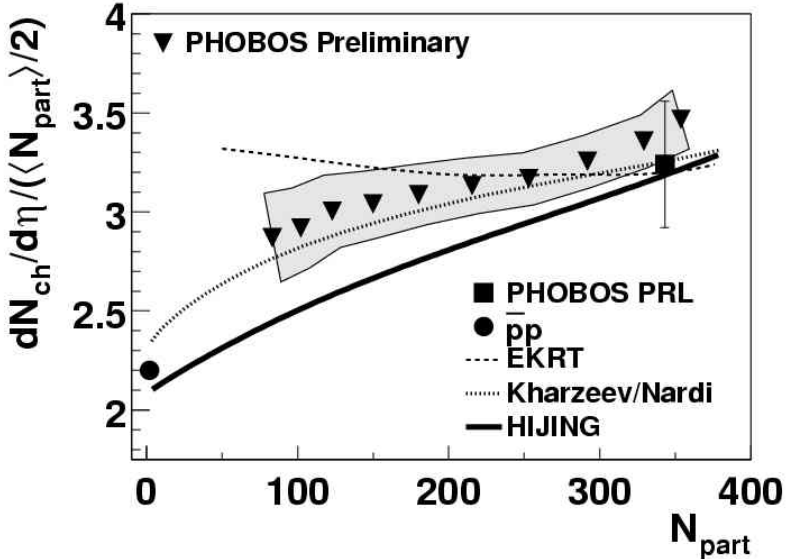


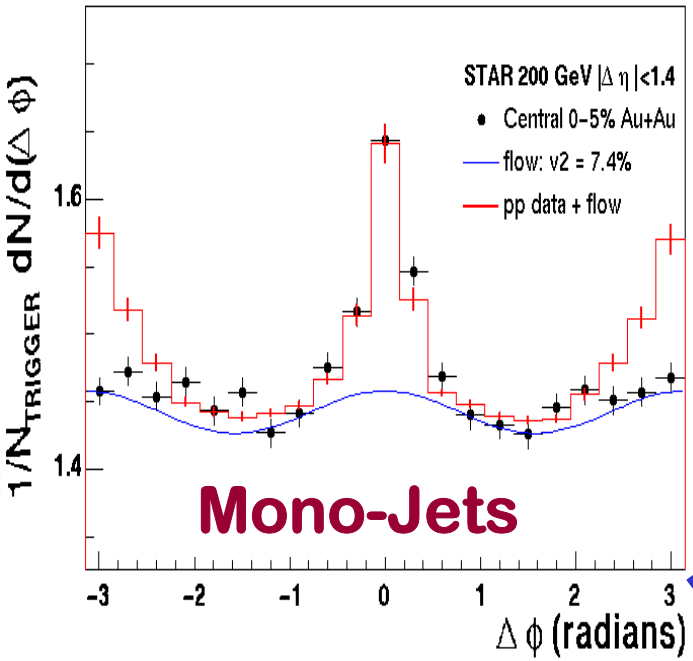
Baryon anomaly

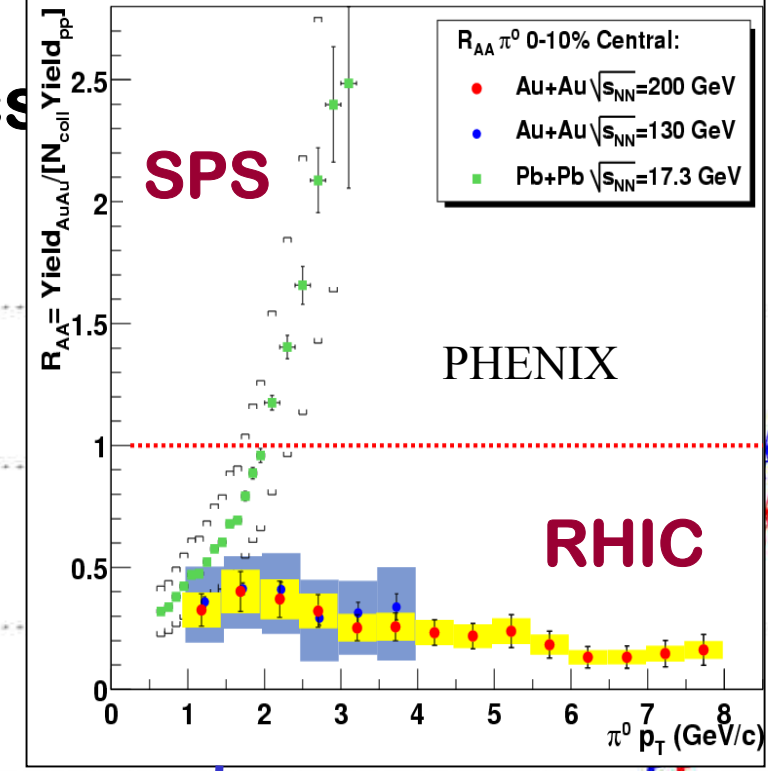


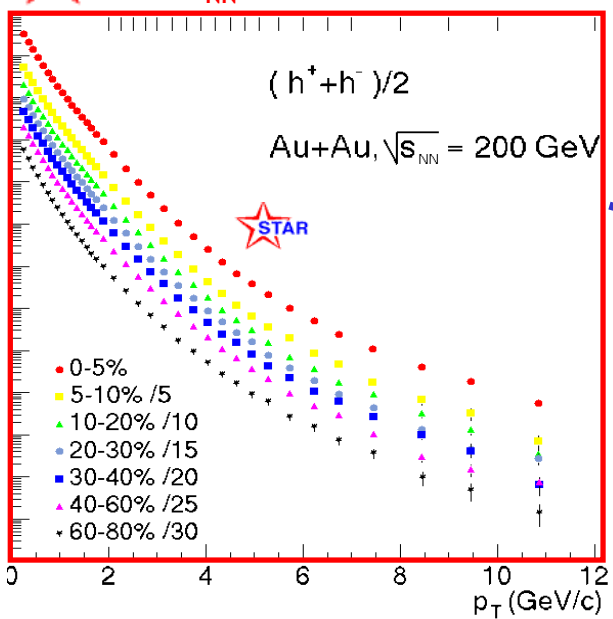
CGC saturation

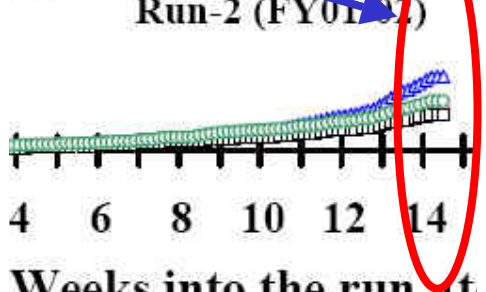


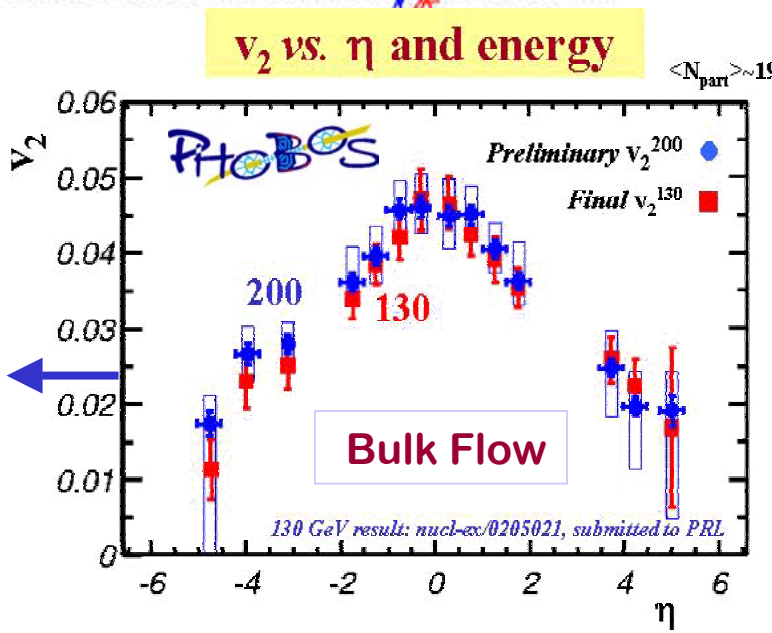



STAR 200 GeV |Δ η|<1.4
Central 0-5% Au+Au
flow: v2 = 7.4%
pp data + flow
1/N_TRIGGER dN/d(Δ φ)
Δ φ (radians)
Mono-Jets

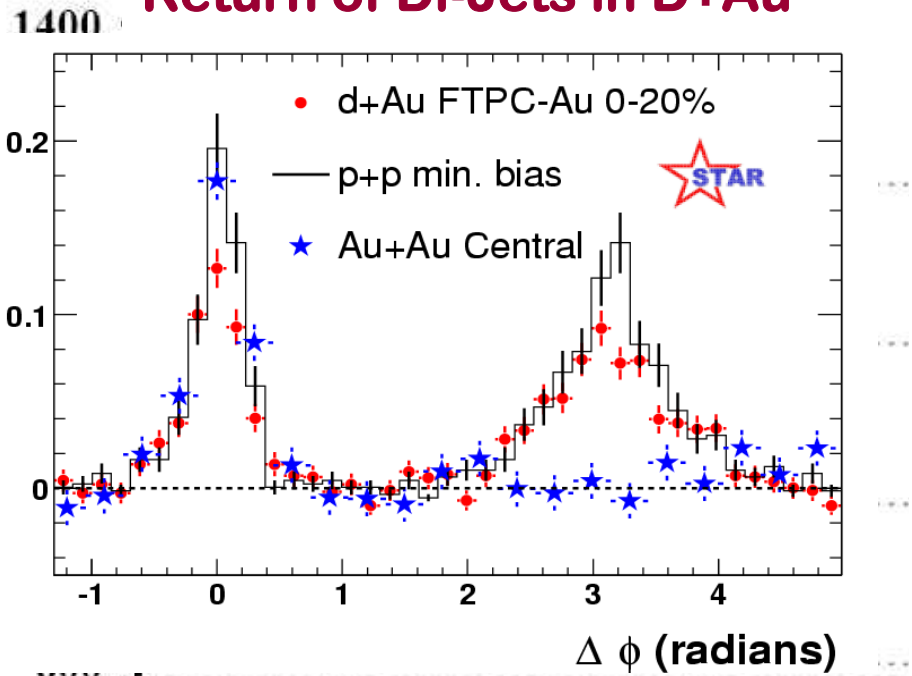

R_AA π⁰ 0-10% Central:
Au+Au √s_NN=200 GeV
Au+Au √s_NN=130 GeV
Pb+Pb √s_NN=17.3 GeV
SPS
PHENIX
RHIC
R_AA= Yield_AuAu/[N_coll Yield_pp]
π⁰ p_T (GeV/c)


STAR
√s_NN = 200 GeV
(h⁺+h⁻)/2
Au+Au, √s_NN = 200 GeV
0-5%
5-10% /5
10-20% /10
20-30% /15
30-40% /20
40-60% /25
60-80% /30
p_T (GeV/c)

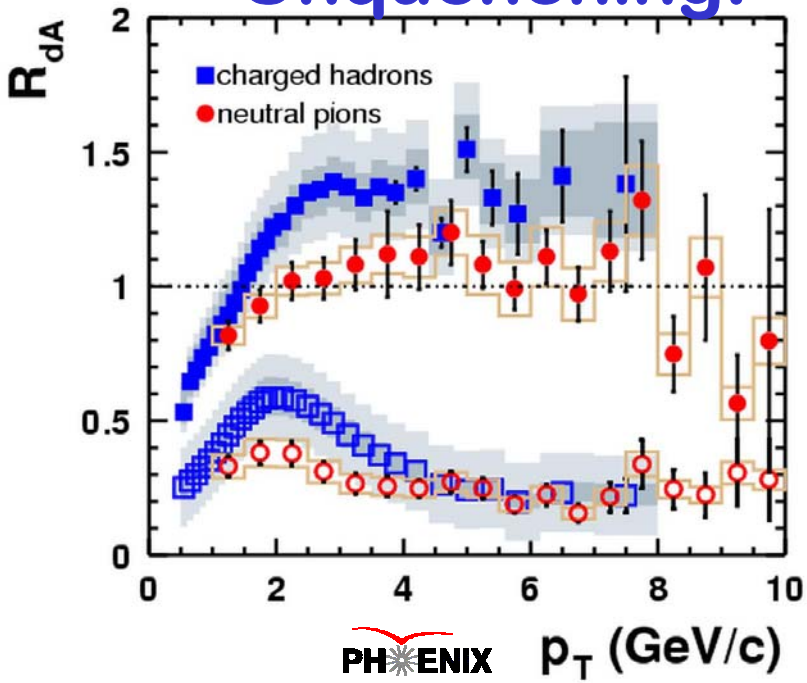

Run-2 (FY01-02)
Weeks into the run (t


v2 vs. η and energy
PHOBOS
Preliminary v2^200
Final v2^130
200
130
Bulk Flow
130 GeV result: nucl-ex/0205021, submitted to PRL
v2
η

Return of Di-Jets in D+Au

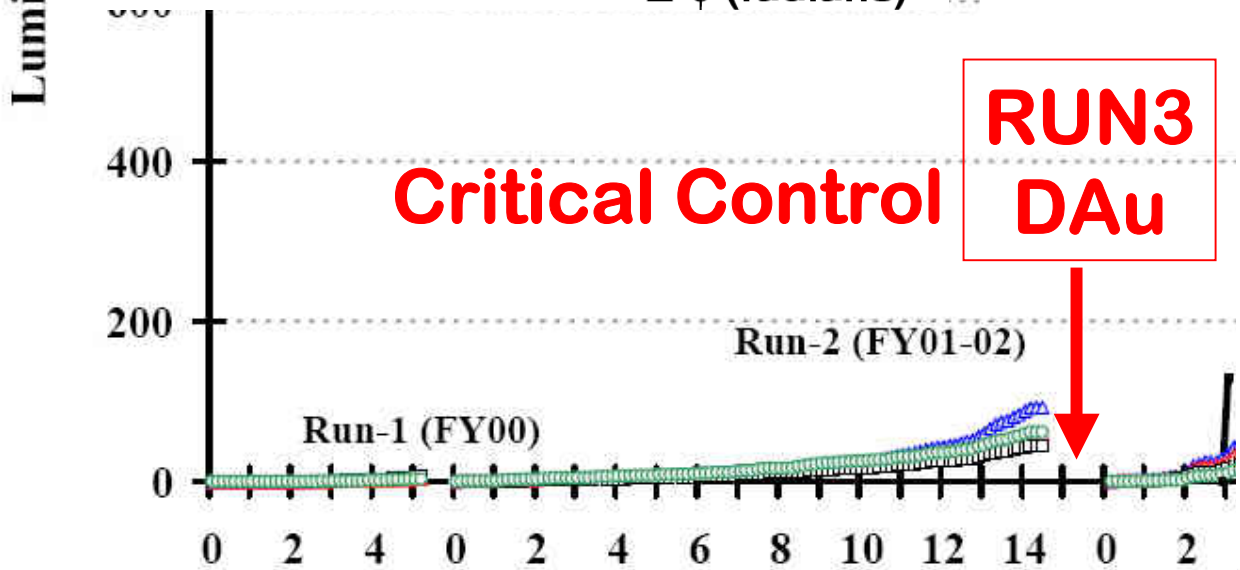


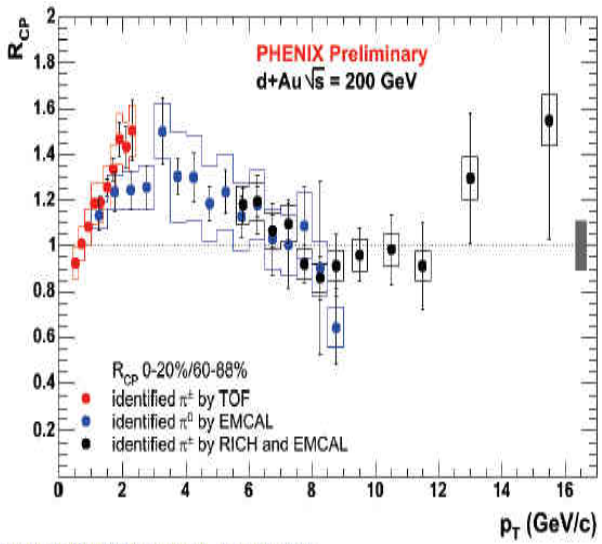
Unquenching!



Critical Control

RUN3 DAu





Quark Matter 2004, Oakland, Jan. 14, 2003

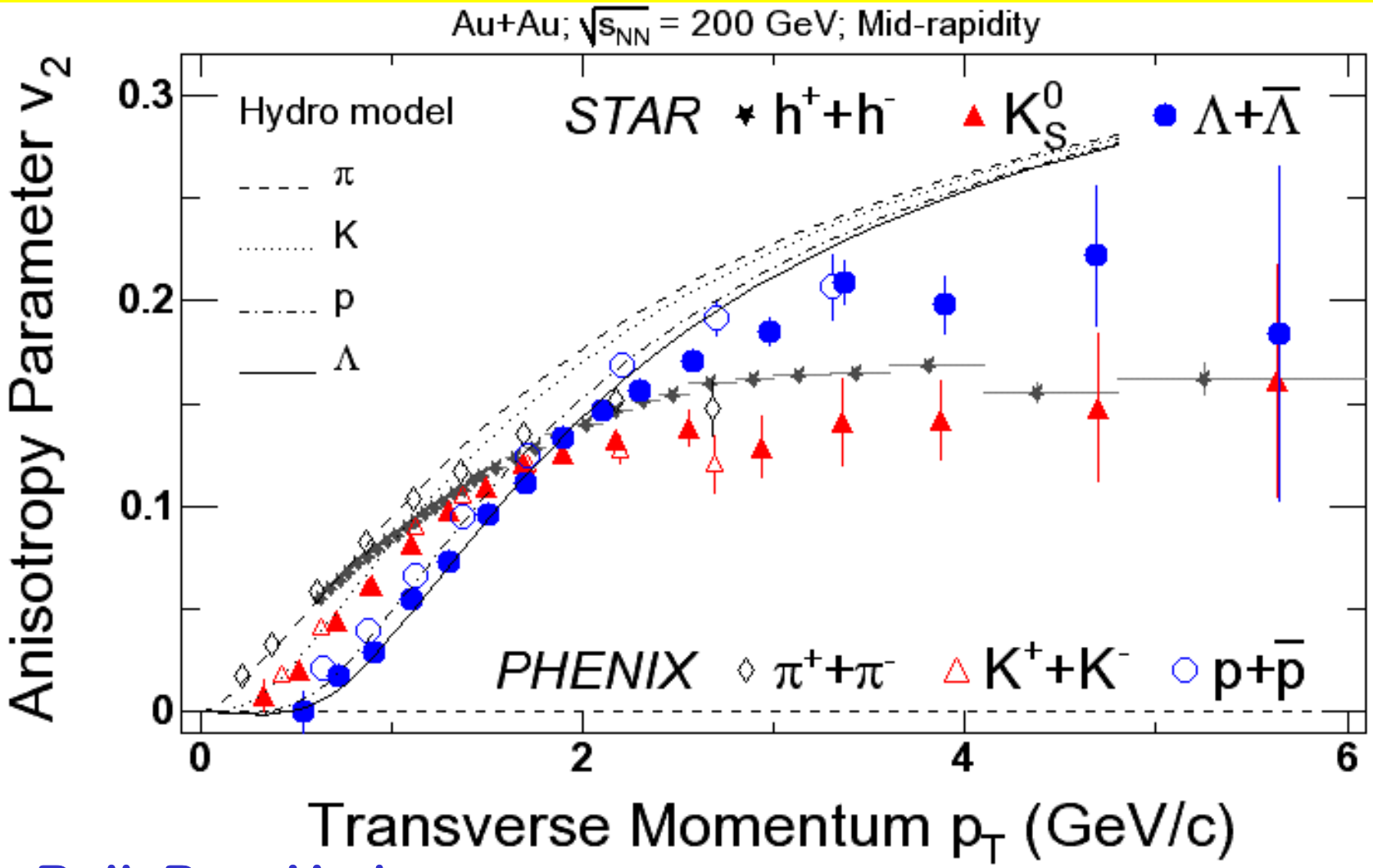
Three Lines of Empirical Evidence have converged to sQGP

$$\text{sQGP} = P_{QCD} + \text{pQCD} + \text{dA}(y=0) = v_2 + (R+I)_{AA} + (R+I)_{DA}$$

- Unique long wavelength collective properties
  - Elliptic flow ⇔ P_{QCD}
- Unique short wavelength dynamical properties
  - Jet Quenching ⇔ pQCD
- dA control on CGC Initial State dynamics

sQGP = strongly coupled, color opaque QCD fluid

The QGP Fingerprint at RHIC = Fine Structure of collective flow is the barometric measure of $P_{QCD}(T)$



Bulk P_{QCD} Hydro

pQCD Jets

qqq Coalescence

P.~Huovinen, P.~F.~Kolb, U.~W.~Heinz, P.~V.~Ruuskanen and S.~A.~Voloshin,
%``Radial and elliptic flow at RHIC: Further predictions,''
Phys.\ Lett.\ B {\bf 503}, 58 (2001)
[arXiv:hep-ph/0101136].

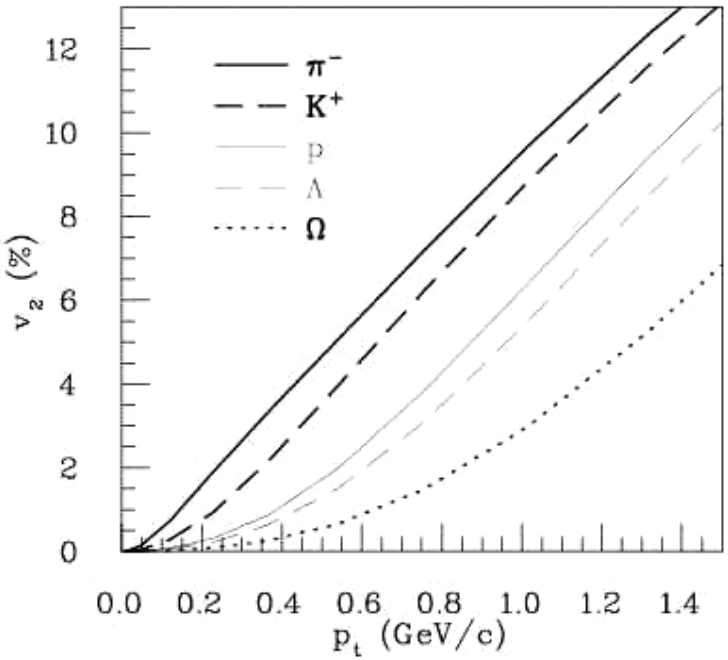


FIG. 3. p_t-differential elliptic flow at midrapidity for various hadrons from minimum bias Au+Au collisions at $\sqrt{s} =$ 130 A GeV for EOS Q(120).

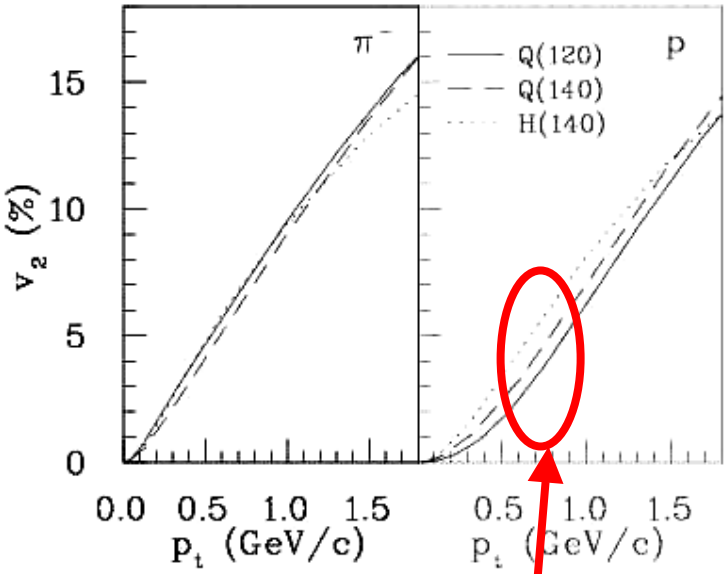
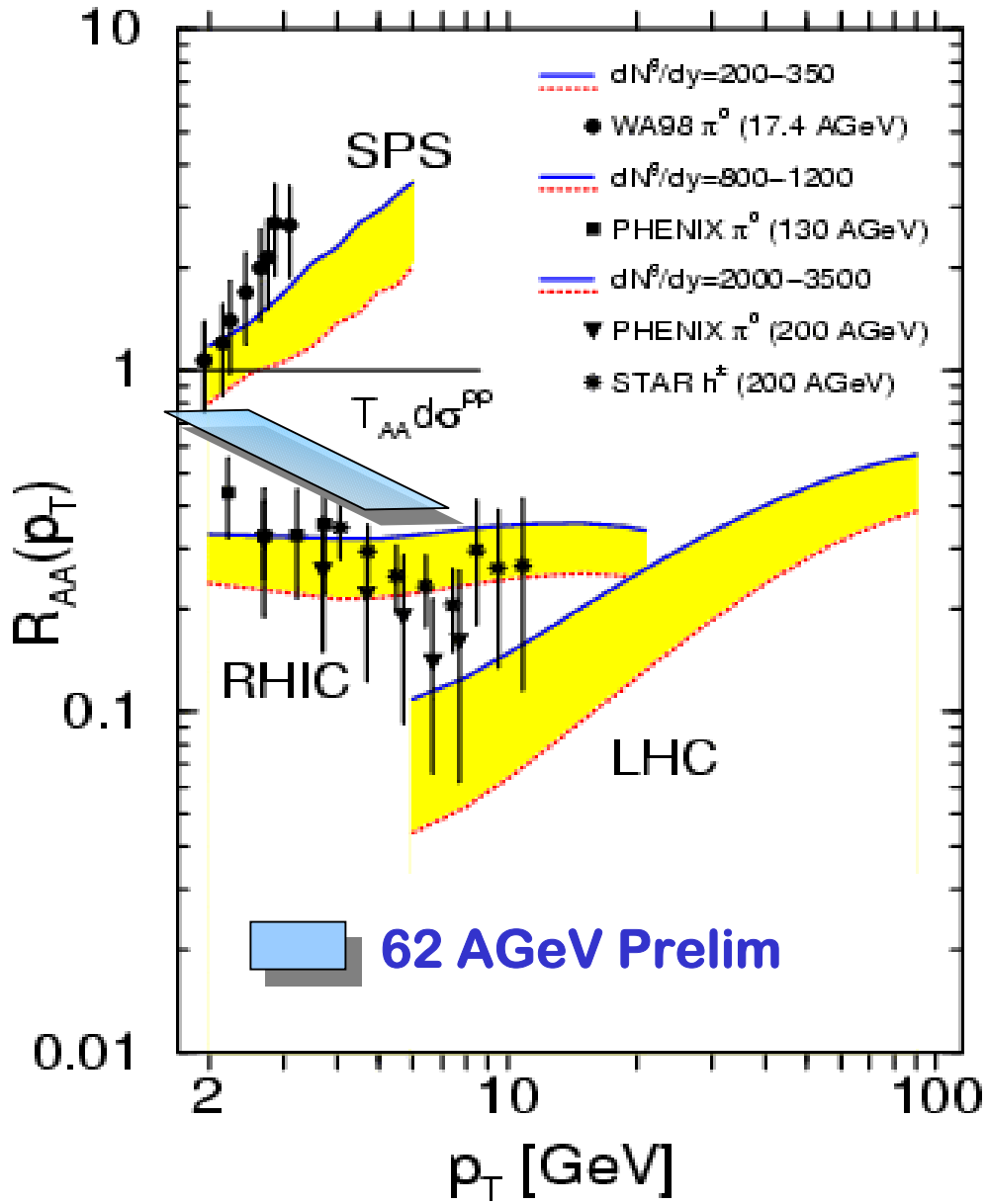


FIG. 4. The effect of the EOS and the freeze-out temperature on the elliptic flow of midrapidity pions (left) and protons (right) from minimum bias Au+Au collisions at $\sqrt{s} = 130\ A$ GeV.

Precision differential flow v_n needed next to improve calibration of P_{QCD} using massive hadrons.

Single Hadron Tomography from SPS, RHIC, LHC

Ivan Vitev and MG, PRL 89 (2002)



1) **Interplay of Cronin , Shadow and Jet Quenching**

AND $xf_{q,g}(x= p_T/\sqrt{s}, p_T^2)$

2) **at 200 AGeV (1) conspires !!**

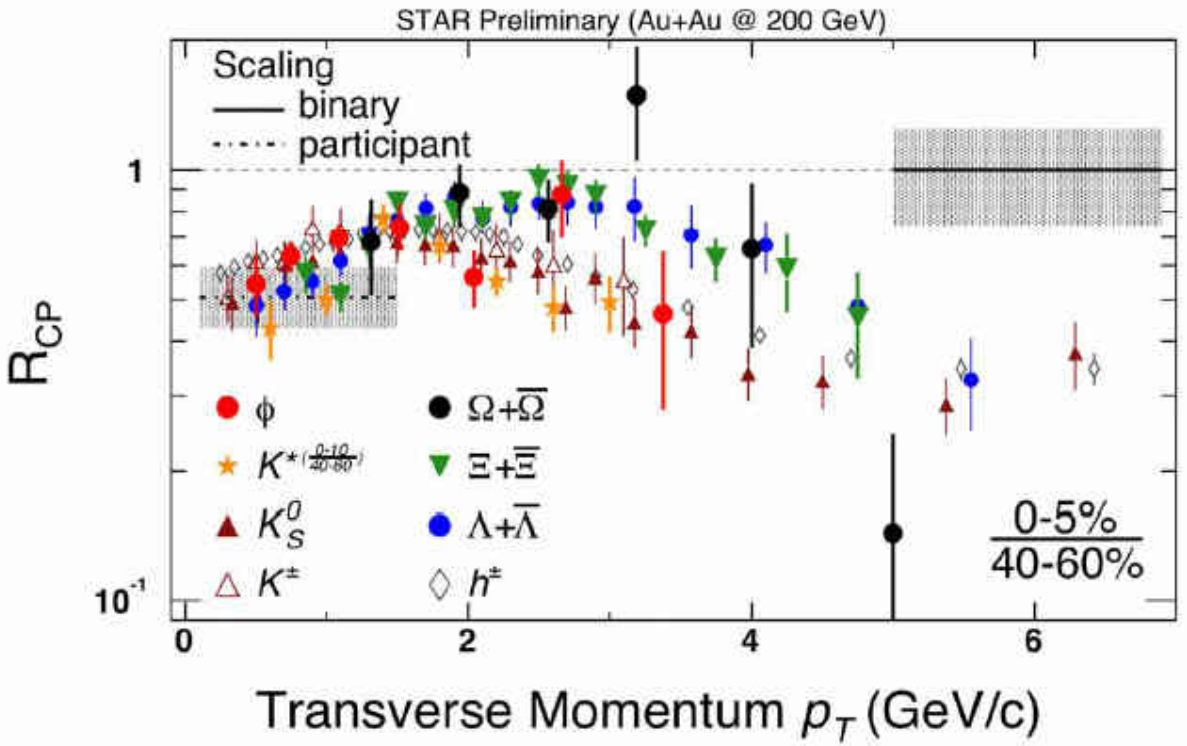
to give ~ p_T independent R_{AA}

$dN_g/dy \sim 1000 \rightarrow \square_g \sim 100\ \square_0$

3) **But strong E_{cm} dep. Of quenching pattern requires systematic energy and A**

future measurements with h ID out to highest pT

Identified particles at intermediate to high-p_t



- Large baryon contribution at least to 4GeV/c
- Particle ID up to p_T>10 important

to solve Baryon anomaly!

- Two groups, baryons and mesons
- At ~5 GeV/c baryons and mesons seem to approach each other
- Suggesting relevance of constituent quarks for hadron production
- Coalescence/recombination provides a description between ~1.5-5 GeV/c

Raimond Snellings RBRC 5/15/2004

and test qq , qqq recombination dynamics !!

Growing case for CGC

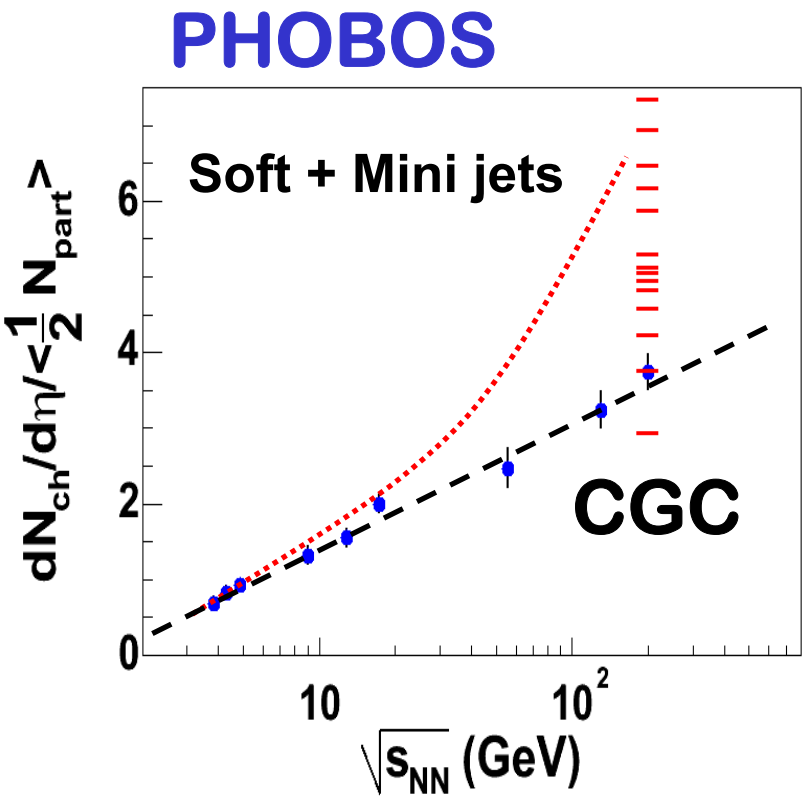
- ***HERA e+p small x scaling ⇔ gluon saturation scale
  $Q_s(x) = (10^4\, x)^{-0.15}$ GeV
- **Energy and Nuclear Geometry dependence
  of Entropy production in Au+Au
- *Deep gluon shadowing in high y D+Au

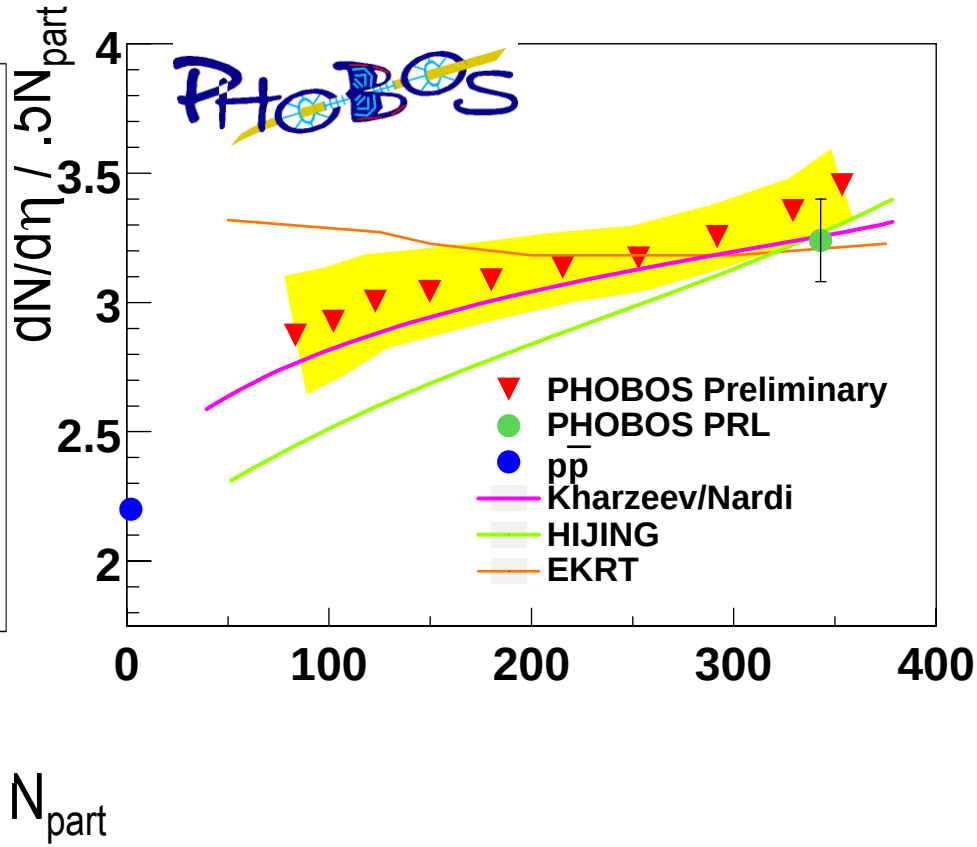
at RHIC: CGC is source of QGP

Entropy Production at RHIC

Slow Centrality and Energy Depend. of dN_{ch}/dy => CGC

P. Steinberg QM01





dN_g/dy~200 **HIJING** ⇒ $\rho_{glue}(\tau_0=0.2\ fm/c)$ ⇒ 5/fm^3

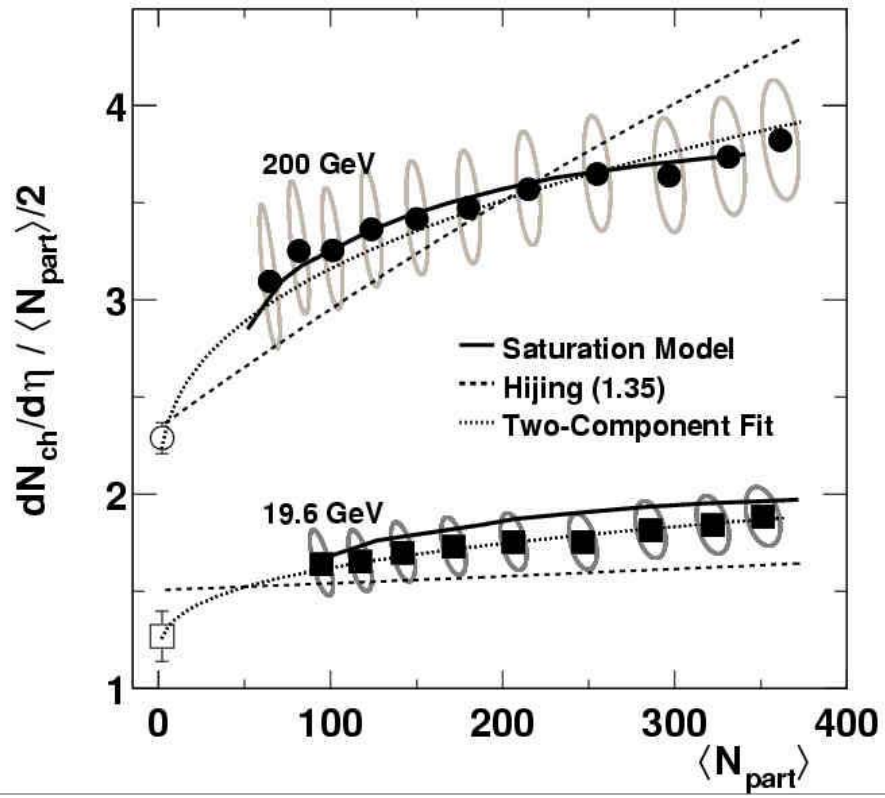
dN_g/dy~1000 **CGC** ⇒ $\rho_{glue}(\tau_0=0.2\ fm/c)$ ⇒ 25/fm^3

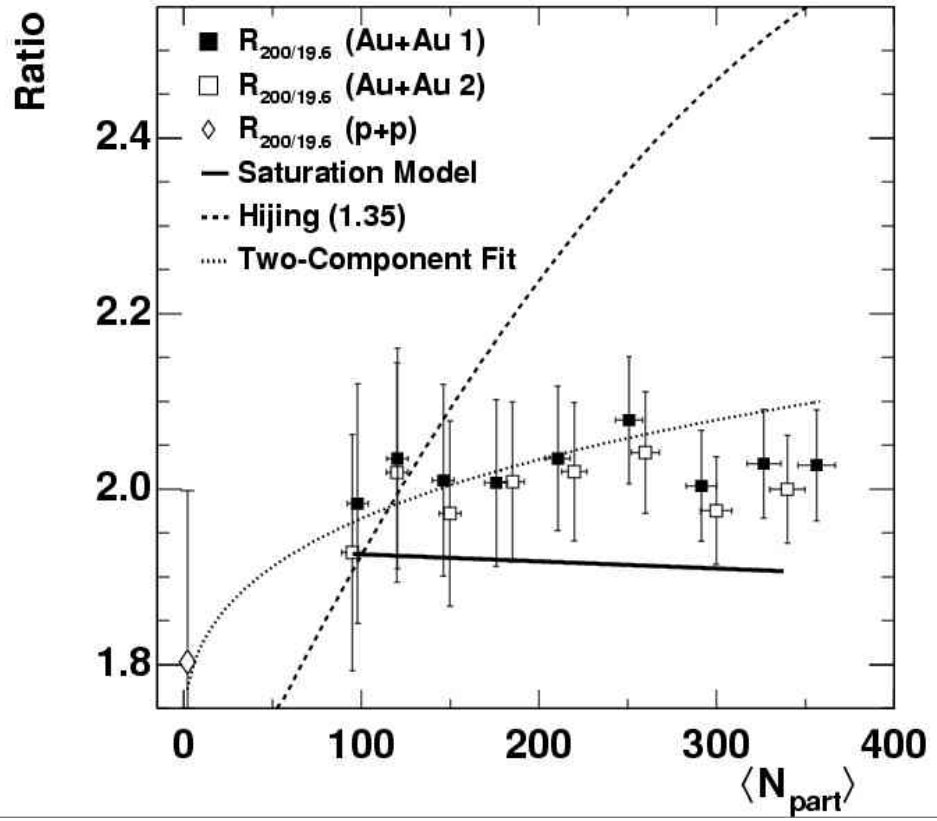
XNWang, MG, PRL86(01)3496

Evidence for MiniJet Saturation

rules out fixed mini-jet scale p_0 models

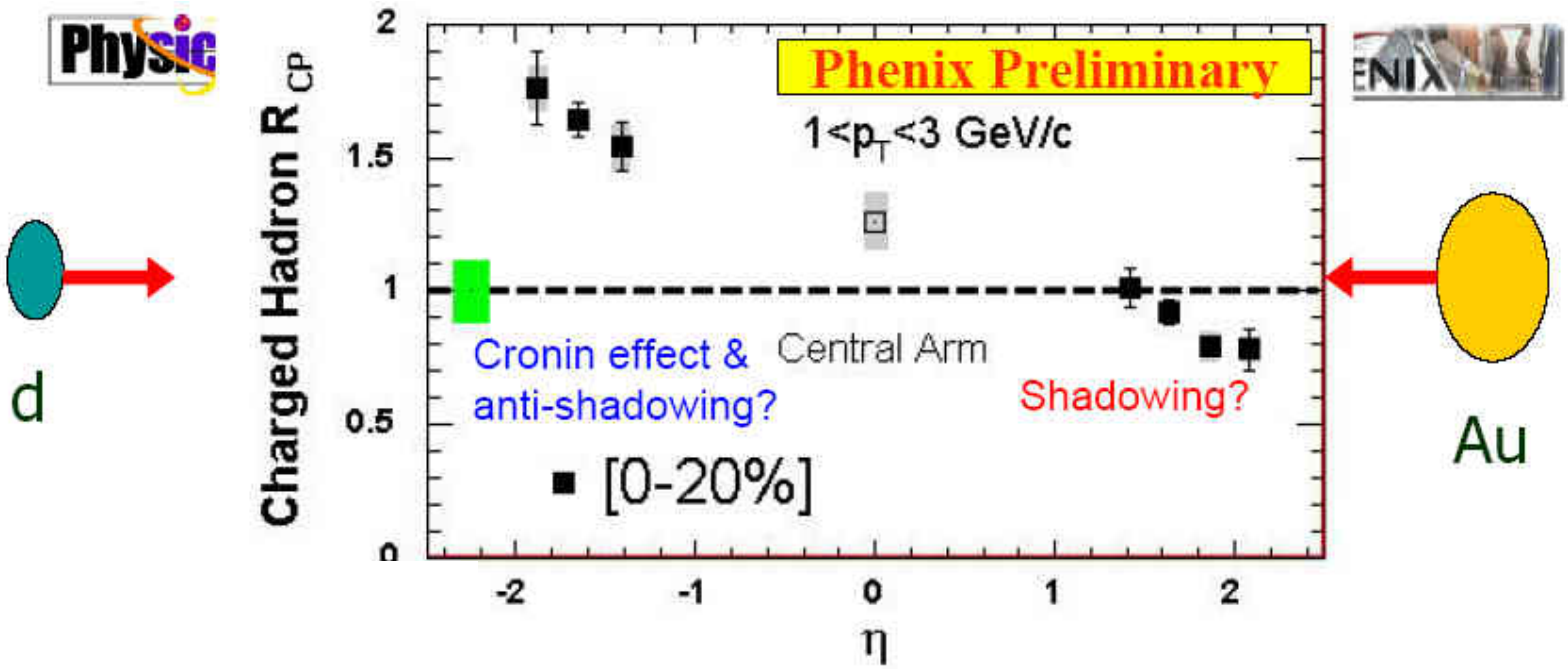
CGC with log $Q_s(x,N_{part})$ consistent with data





B.~B.~Back [the PHOBOS Collaboration],
%``Collision geometry scaling of Au + Au pseudorapidity density from
%s(NN)**(1/2) = 19.6-GeV to 200-GeV,''
arXiv:nucl-ex/0405027.

dA Control shows Cronin and Shadow almost cancel at y~ 0 at 200 AGeV $p_T > Q_s$

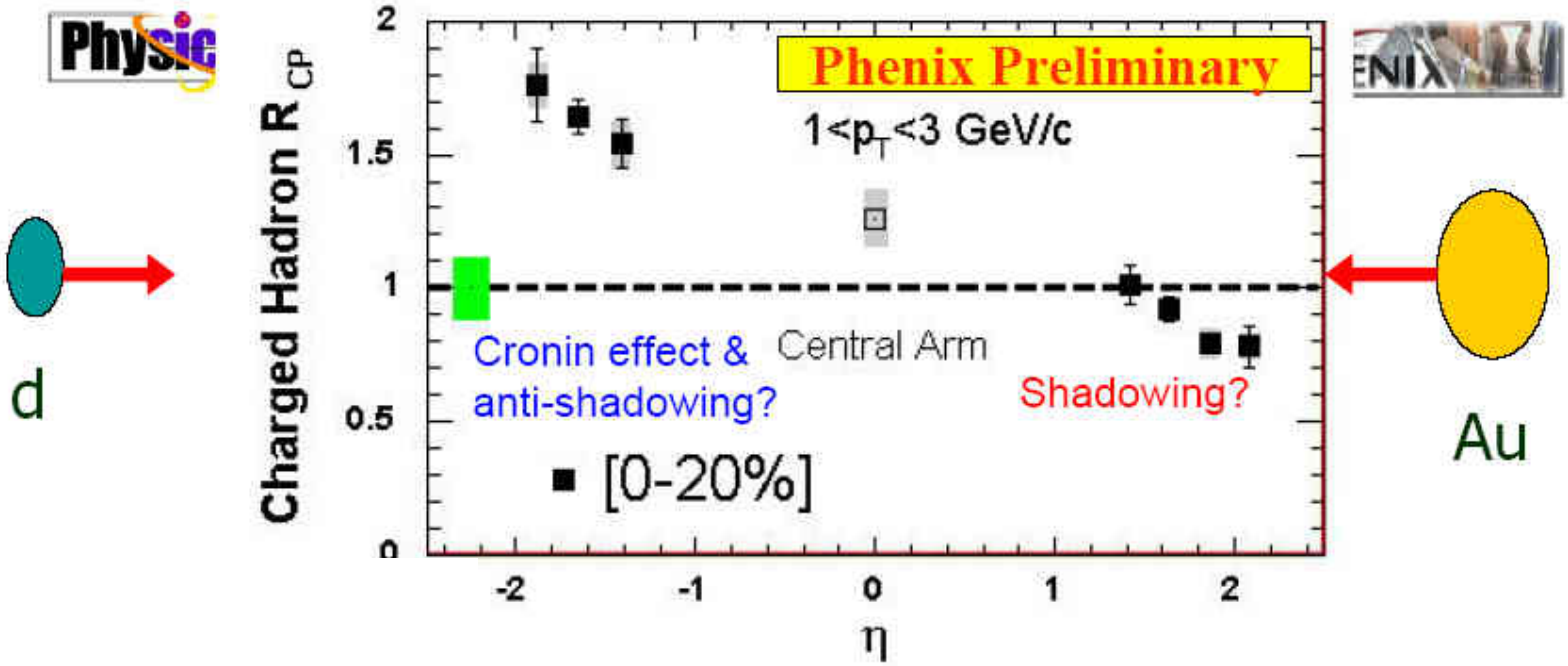


M.Liu QM04

It is "lucky circumstance" at 200AGeV RHIC that there is an ~ undistorted "sweet spot" y ~ 0 window on the sQGP.

(consistent with STAR,BRAHMS,PHOBOS)

But dA Control shows Cronin and Shadow Do Not Cancel at y~ +-2 at 200 AGeV

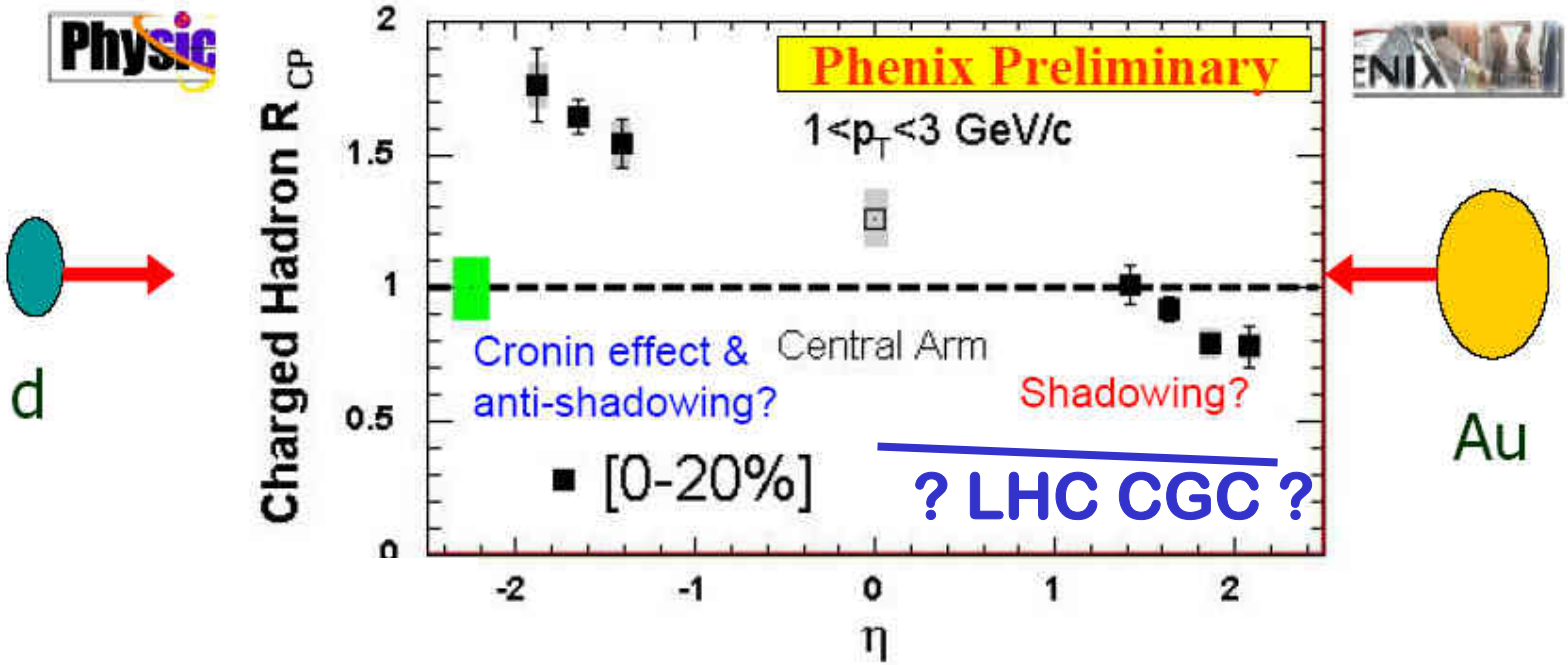


M.Liu QM04

It is "lucky circumstance" at RHIC that there is a wide enough y window to test CGC

y<-1 anti-shadow is a new challenge for CGC

dA Control may not be NULL at LHC



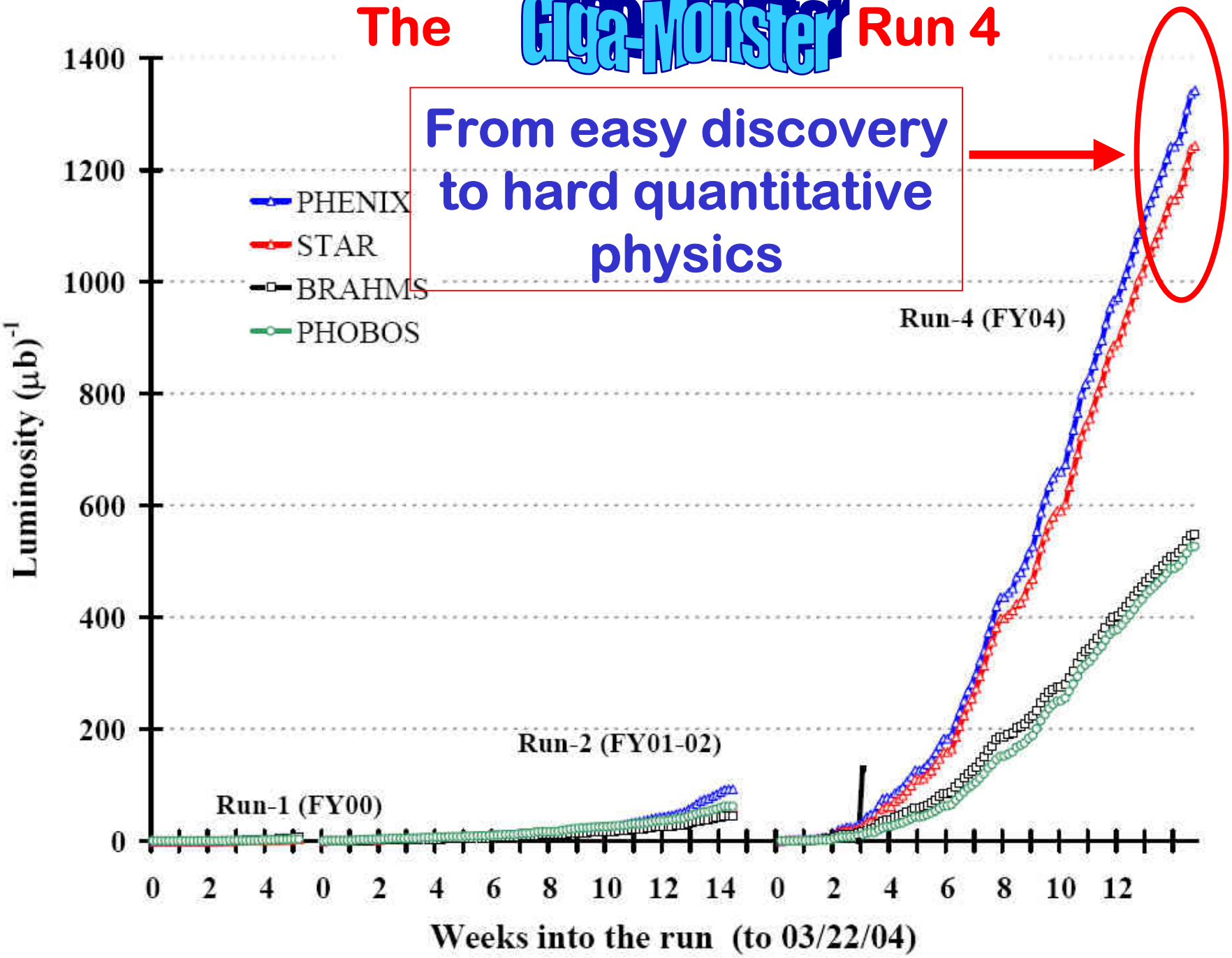
At LHC 5400 AGeV

CGC predicts no such luck for sQGP!

LHC will be a CGC machine in p+A mode

(It may pick some of cherries of eRHIC)

The Giga-Monster Run 4



Toward high resolution correlators

10 X L(04) RHIC II

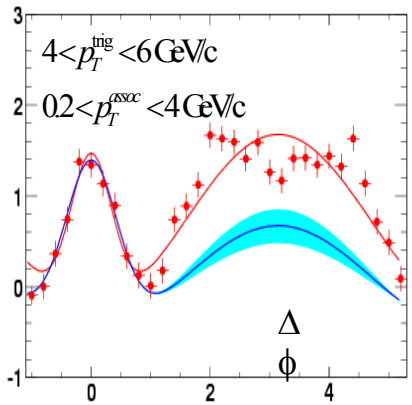
- $C_2(\nearrow_1, \nearrow_2, p_{t1}, p_{t2}, \approx_1, \approx_2; fl_1, fl_2, \text{Mult}, A, B, Ecm)_{2012}$

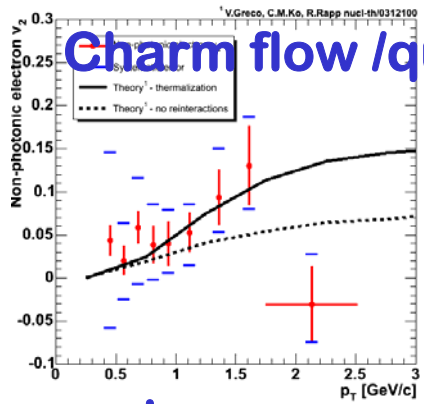
6D microscope

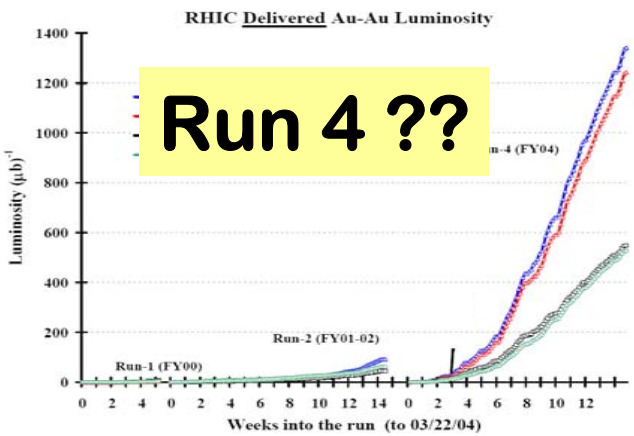
exp. knobs

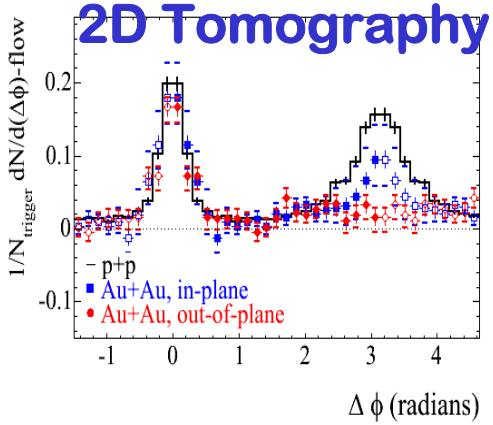
thermalization

4 X L(04) EBIS









NSAC/BNL 6/2/04

RHIC II Highest intensities required to perform controlled

γ tagged* jet tomography of the sQGP
And measure modified frag functions

γ tag

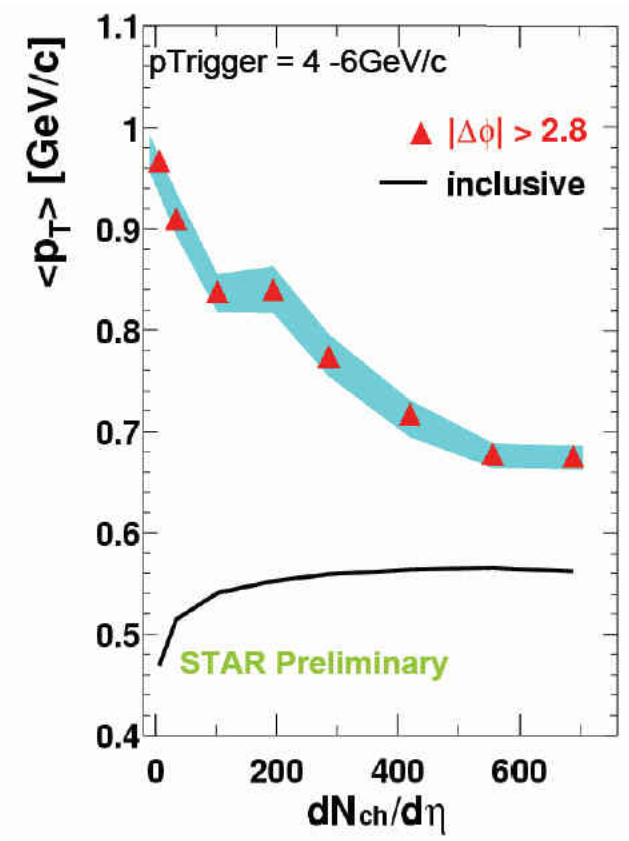
- $C_3(\vec{x}_1, \vec{x}_2, p_{t1}, p_{t2}, \vec{k}_1, \vec{k}_2; fl_1, fl_2, N_{part}, A, B, Ecm, \vec{k}_\gamma$

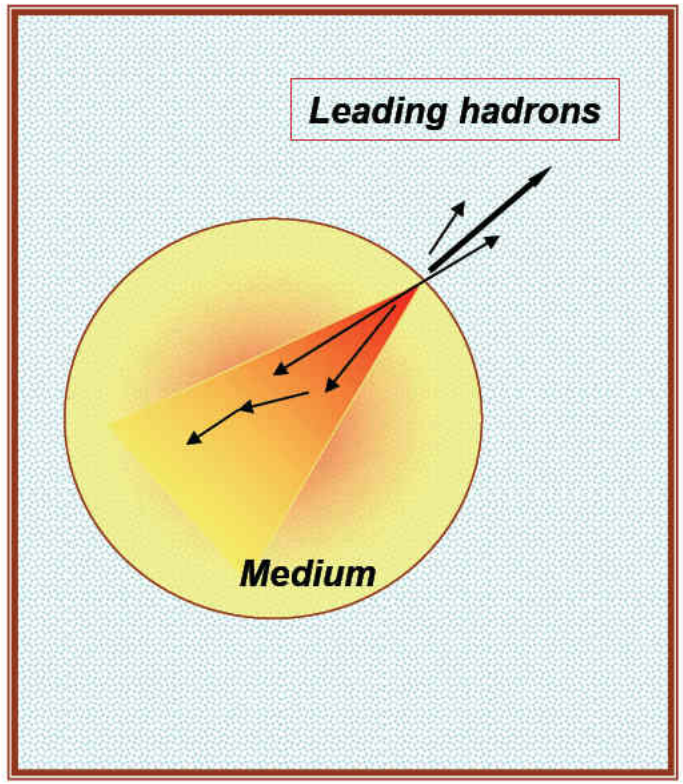
6D microscope — Experimental knobs

direct $\gamma\gamma$ interferometry of the shattering CGC g->q current

*Wang, Huang, Sarcevic PRL77(96)

Leading hadron tagged away side tomography
Snellings RBRC 5/04

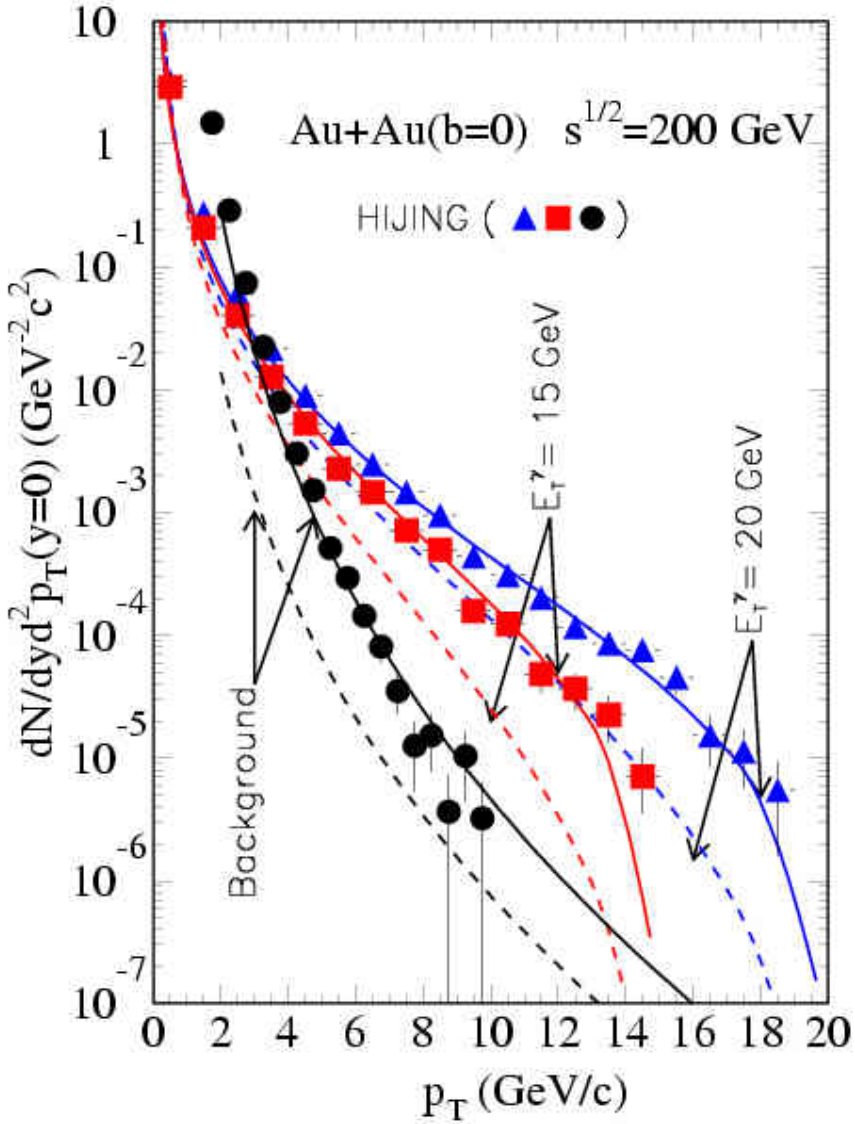


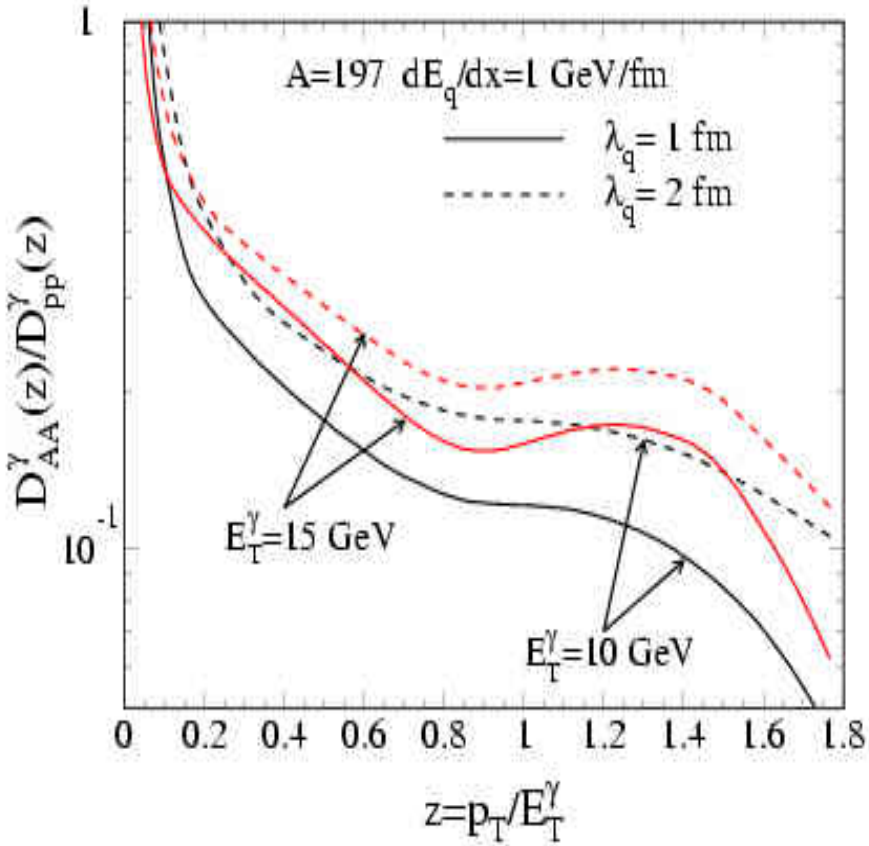


Raimond Snellings RBRC 5/15/2004 7

- Run 4-6 will map out hot spots and fluctuations
- Quantitative tests of dijet tomography

γ tagged jet fragmentation at RHICII





*Wang, Huang,Sarcevic PRL77(96)

Direct γ p_T reach of RHIC II ; LHC reach ~4X higher

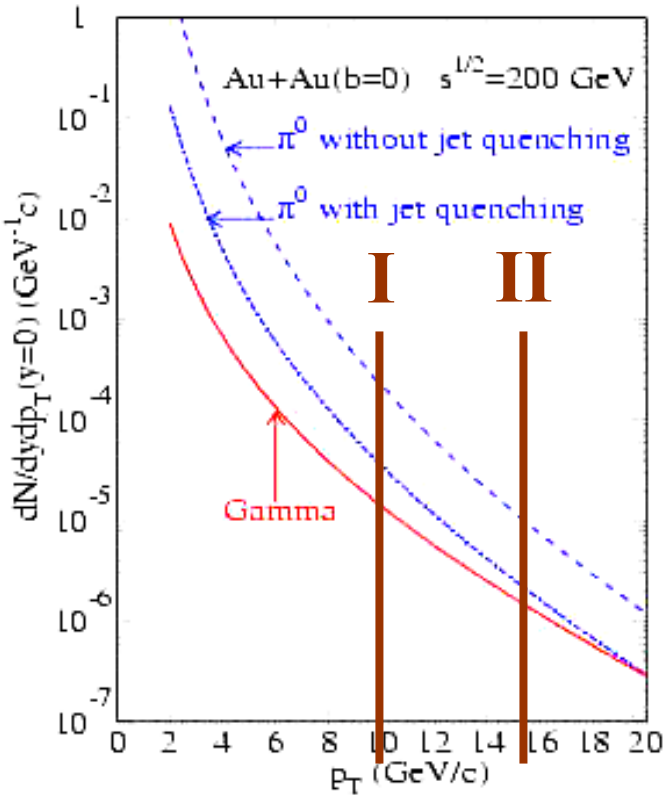


FIG. 13. The spectrum of direct photon production (solid) as compared to π^0 spectrum with (dot-dashed) and without (dashed) parton energy loss ($dE_g/dx = 1$ GeV/fm, $\lambda_g = 1$ fm) in central $Au + Au$ collisions at $\sqrt{s} = 200$ GeV.

E_T^γ (GeV)	7	10	15	20
$dN^{\gamma-jet}/dydE_T$/year	20500	3550	400	70

TABLE II. Rate of direct photon production in central $Au + Au$ collisions at $\sqrt{s} = 200$ GeV, with luminosity $\mathcal{L} = 2 \times 10^{26}$ cm^{-2}s^{-1} and 100 operation days per year.

E_T^γ (GeV)	40	50	60
$dN^{\gamma-jet}/dydE_T$/year	2880	1070	490

TABLE III. Rate of direct photon production in central $Au + Au$ collisions at $\sqrt{s} = 5.5$ TeV, with luminosity $\mathcal{L} = 2 \times 10^{27}$ cm^{-2}s^{-1} and 50 operation days per year.

X.N. Wang, Z. Huang, Phys.Rev. C55 (1997) 3047

A-QCD physics is world class and compelling

Optimization of NSAC constrained priorities required

1. **Invest generously in RHIC I (4X lum) detector upgrades with ID reach, vertex, triggers**

2. **Aim long range toward eRHIC with RHIC II cooling. The10 fold luminosity for rare gamma-jet and heavy quark A-QCD *may* compete with LHC much longer reach.**

3. **Encourage US/LHC "mitarbeiters" within fiscal constraints of 1, 2 . The ride will be spectacular.**

4. **Plan RHIC II detector that can be used at eRHIC also**