

# PHENIX Overview: *Physics, Experiment, Collaboration*

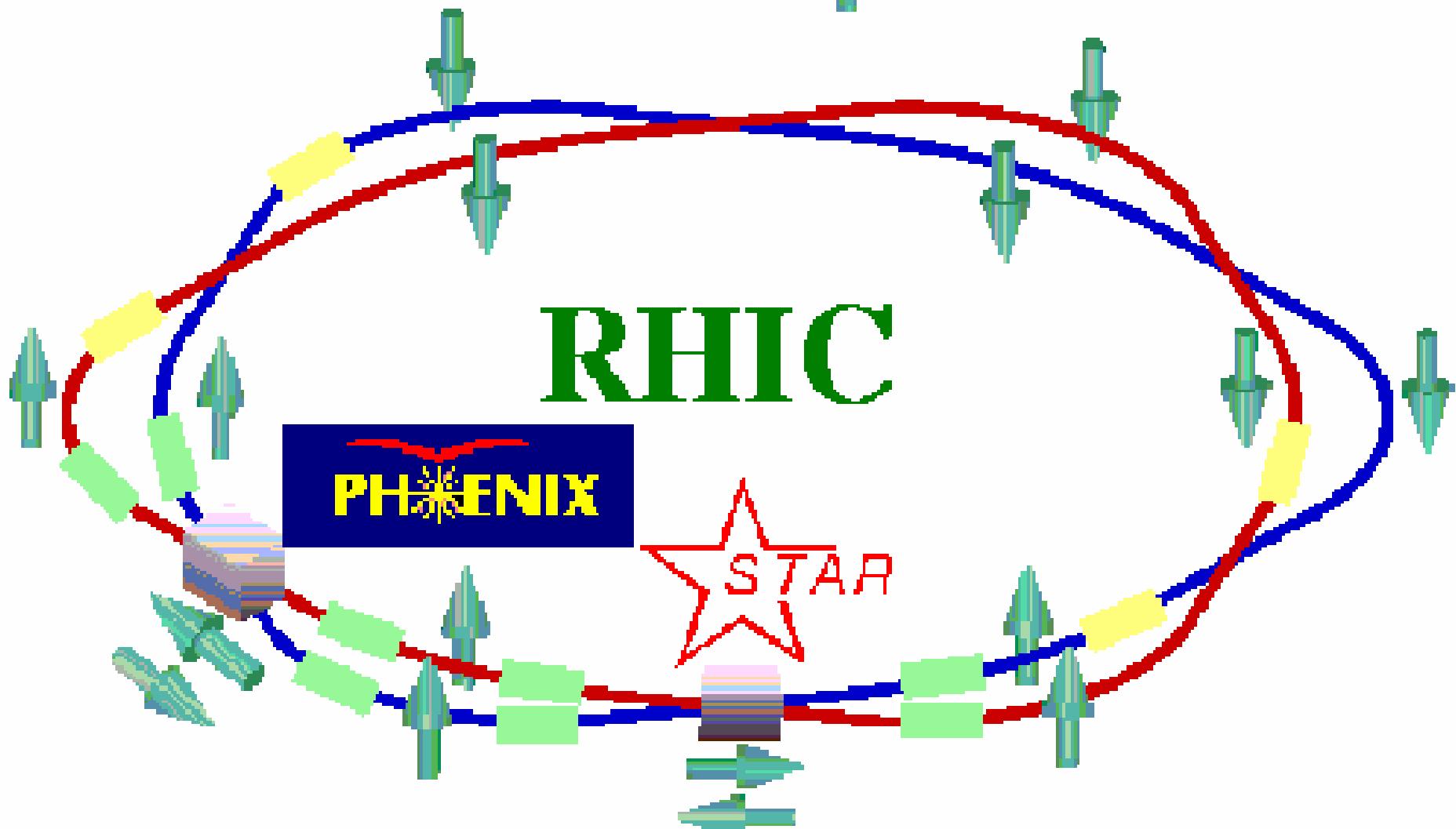
W.A. Zajc  
for the PHENIX Collaboration

- PHENIX is a
  - unique collaboration
  - pursuing unique physics
  - at a unique experimental facility

Siberian Snake

Spin Rotator

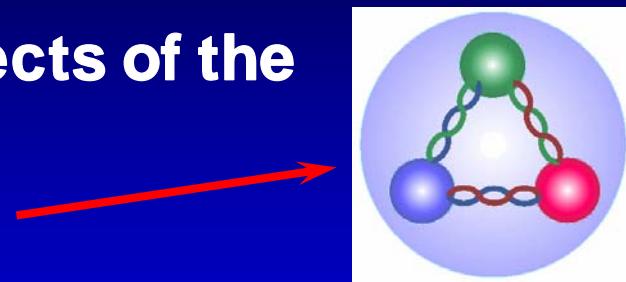
Spin Direction



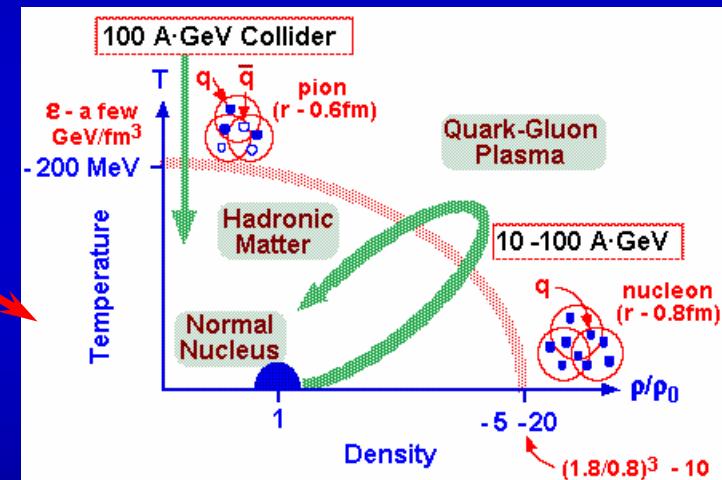
# Why is RHIC?

- To understand fundamental aspects of the strong interaction:

□ Where does the proton get its spin?



□ How does nuclear matter “melt”?

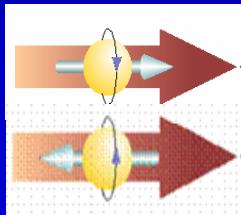


- We have a theory of the strong interaction:

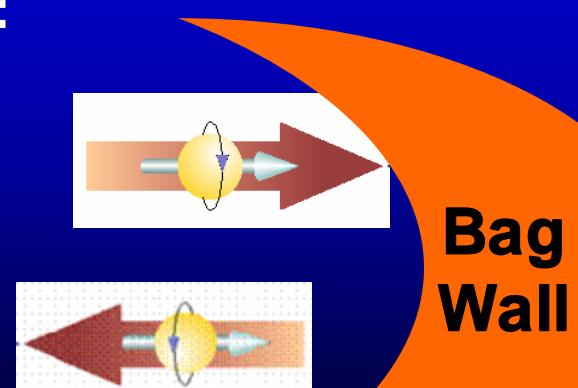
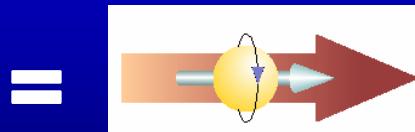
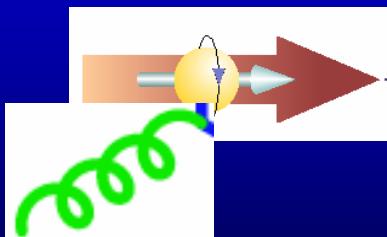
$$L = i\bar{\psi}D\psi - \frac{1}{4}\tilde{F}_a^{\mu\nu}F^a_{\mu\nu} - \bar{\psi}\hat{M}\psi$$

**It works well except when the interaction is strong!**

- These two aspects of the RHIC program are closely related
- The unifying concept: **CHIRALITY**
  - In particle physics, *chirality* refers to the orientation between the spin and momentum of a particle
  - In QCD,
    - ◆ right-handed quarks
    - ◆ and
    - ◆ left-handed quarks
- A gluon can not change a quark's chirality:

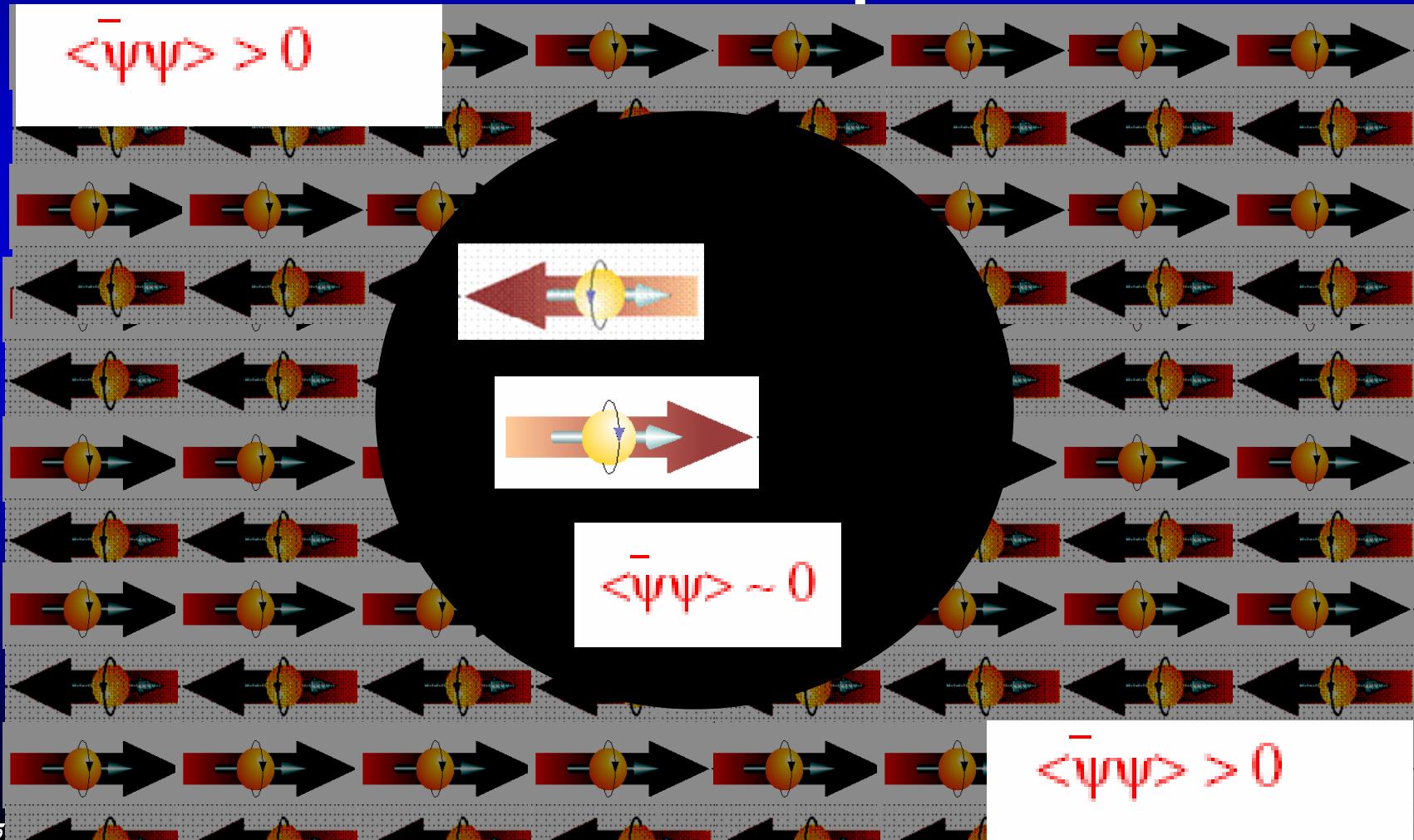


- are independent degrees of freedom
- However, confinement necessarily mixes this degrees of freedom:

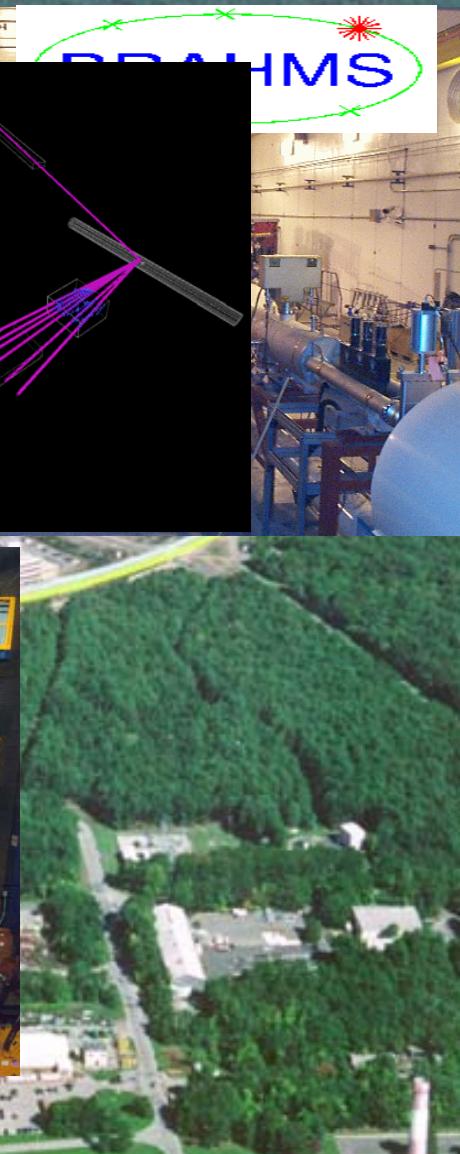
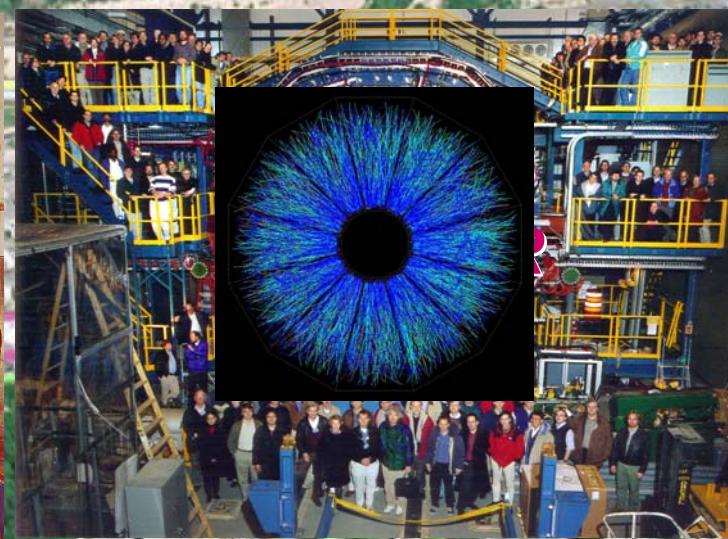
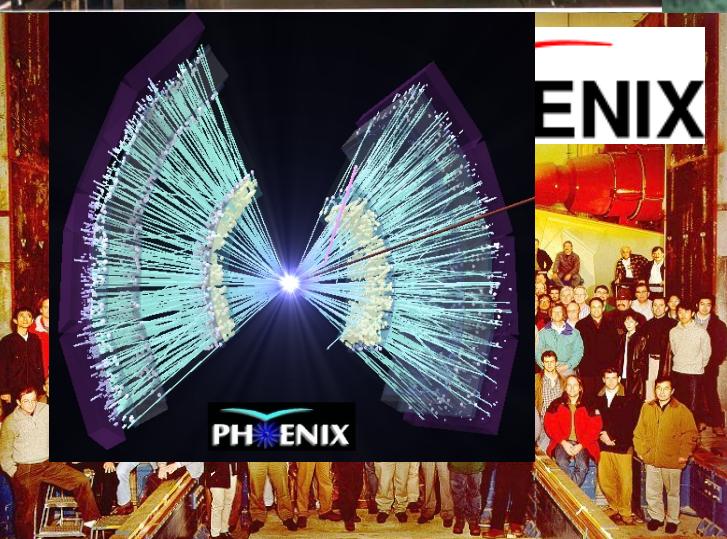
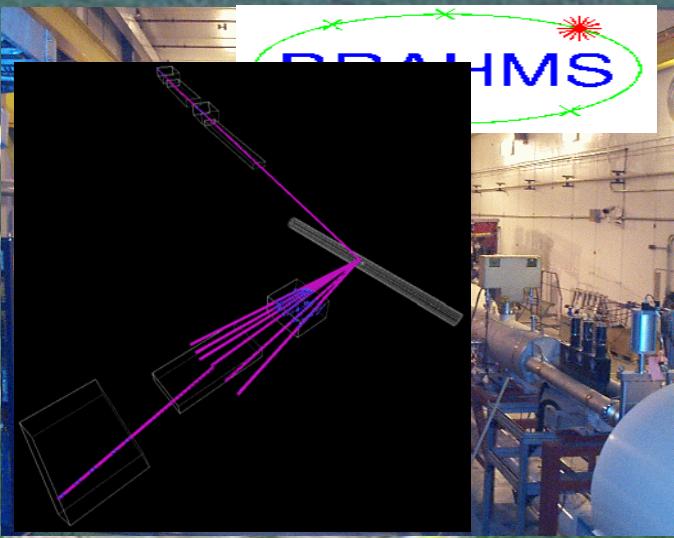
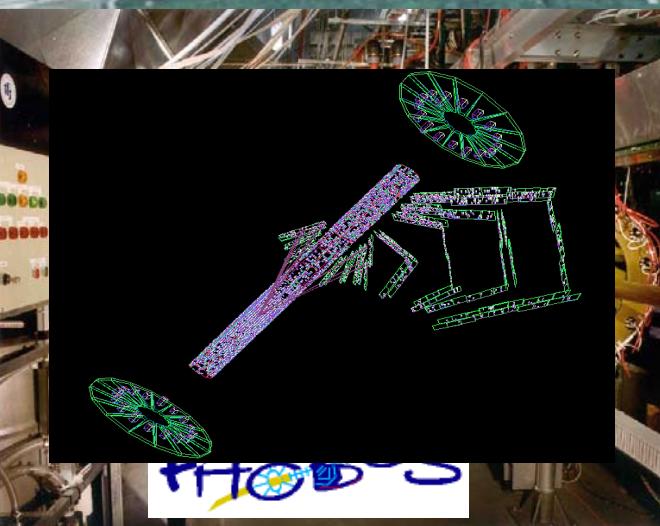


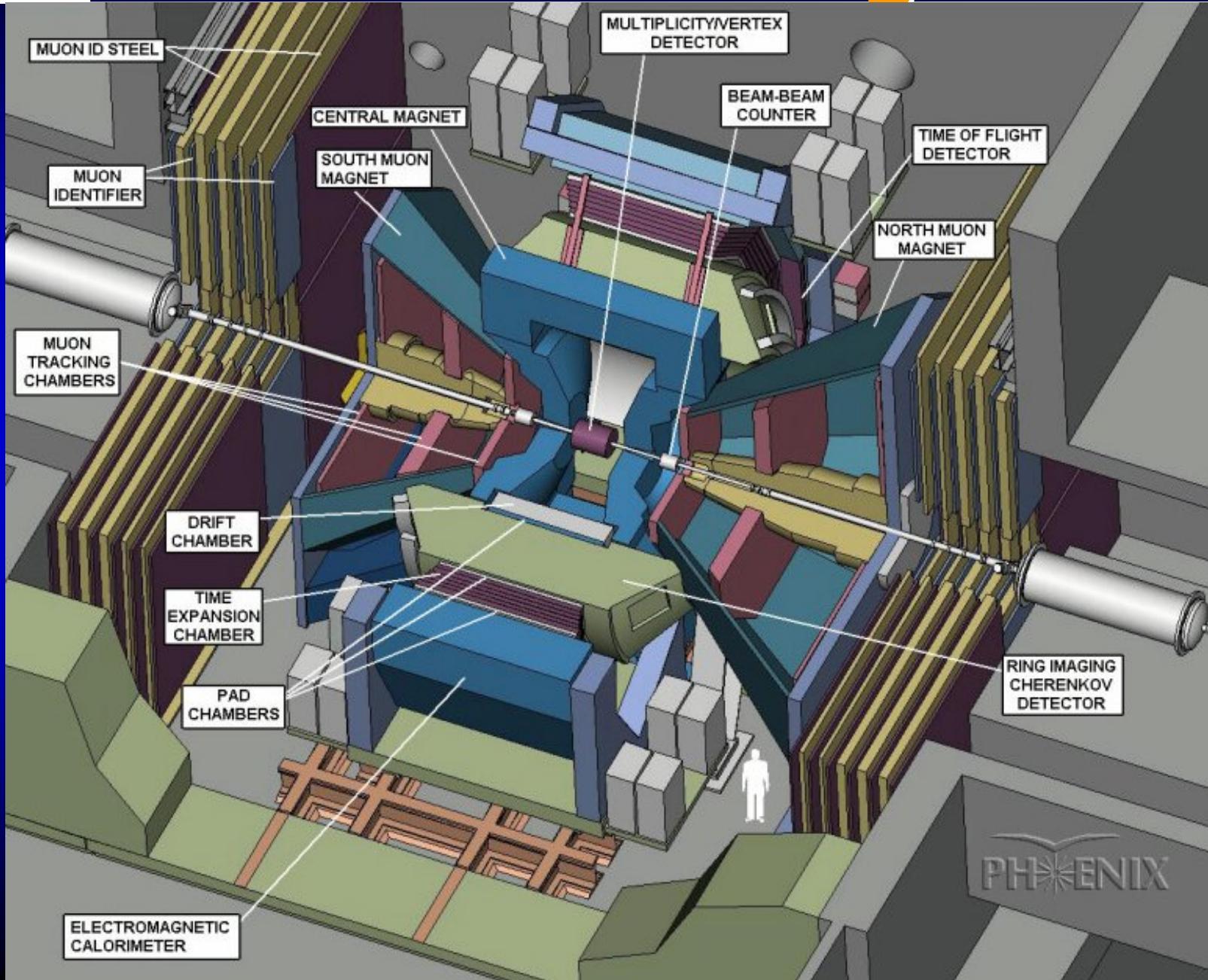
- But confinement requires chirality change:

- The chirality changes required by confinement are mediated by the “chiral condensate” which fills the “vacuum” except inside hadrons:



# RHIC's Experiments





- University of São Paulo, São Paulo, Brazil
- Academia Sinica, Taipei 11529, China
- China Institute of Atomic Energy (CIAE), Beijing, P. R. China
- Peking University, Beijing, P. R. China
- Charles University, Faculty of Mathematics and Physics, Ke Karlovu 3, 12116 Prague, Czech Republic
- Czech Technical University, Faculty of Nuclear Sciences and Physical Engineering, Břehova 7, 11519 Prague, Czech Republic
- Institute of Physics, Academy of Sciences of the Czech Republic, Na Slovance 2, 182 21 Prague, Czech Republic
- Laboratoire de Physique Corpusculaire (LPC), Université de Clermont-Ferrand, 63 170 Aubière, Clermont-Ferrand, France
- Dapnia, CEA Saclay, Bat. 703, F-91191 Gif-sur-Yvette, France
- IPN-Orsay, Université Paris Sud, CNRS-IN2P3, BP1, F-91406 Orsay, France
- Laboratoire Leprince-Ringuet, Ecole Polytechnique, CNRS-IN2P3, Route de Saclay, F-91128 Palaiseau, France
- SUBATECH, École des Mines at Nantes, F-44307 Nantes France
- University of Muenster, Muenster, Germany
- KFKI Research Institute for Particle and Nuclear Physics at the Hungarian Academy of Sciences (MTA KFKI RMKI), Budapest, Hungary
- Debrecen University, Debrecen, Hungary
- Eötvös Loránd University (ELTE), Budapest, Hungary
- Banaras Hindu University, Banaras, India
- Bhabha Atomic Research Centre (BARC), Bombay, India
- Weizmann Institute, Rehovot, 76100, Israel
- Center for Nuclear Study (CNS-Tokyo), University of Tokyo, Tanashi, Tokyo 188, Japan
- Hiroshima University, Higashi-Hiroshima 739, Japan
- KEK - High Energy Accelerator Research Organization, 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan
- Kyoto University, Kyoto, Japan
- Nagasaki Institute of Applied Science, Nagasaki-shi, Nagasaki, Japan
- RIKEN, The Institute of Physical and Chemical Research, Wako, Saitama 35 0198, Japan
- RIKEN – BNL Research Center, Japan, located at BNL
- Physics Department, Rikkyo University, 3-34-1 Nishi-Ikebukuro, Toshima, Tokyo 171-8501, Japan
- Tokyo Institute of Technology, Oh-okayama, Meguro, Tokyo 152-8551, Japan
- University of Tsukuba, 1-1-1 Tennodai, Tsukuba-shi Ibaraki-ken 305-8577, Japan
- Waseda University, Tokyo, Japan
- Cyclotron Application Laboratory, KAERI, Seoul, South Korea
- Kangnung National University, Kangnung 210-702, South Korea
- Korea University, Seoul, 136-701, Korea
- Myong Ji University, Yongin City 449-728, Korea
- System Electronics Laboratory, Seoul National University, Seoul, South Korea
- Yonsei University, Seoul 120-749, Korea
- IHEP (Protvino), State Research Center of Russian Federation "Institute for High Energy Physics", Protvino 142281, Russia
- Joint Institute for Nuclear Research (JINR-Dubna), Dubna, Russia
- Kurchatov Institute, Moscow, Russia
- PNPI, Petersburg Nuclear Physics Institute, Gatchina, Leningrad region, 188300, Russia
- Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Vorob'evy Gory, Moscow 119992, Russia
- Saint-Petersburg State Polytechnical University, Politehnicheskaya str, 2



**13 Countries; 62 Institutions; 550 Participants\***

- Lund University, Lund, Sweden
- Abilene Christian University, Abilene, Texas, USA
- Brookhaven National Laboratory (BNL), Upton, NY 11973, USA
- University of California - Riverside (UCR), Riverside, CA 92521, USA
- University of Colorado, Boulder, CO, USA
- Columbia University, Nevis Laboratories, Irvington, NY 10533, USA
- Florida Institute of Technology, Melbourne, FL 32901, USA
- Florida State University (FSU), Tallahassee, FL 32306, USA
- Georgia State University (GSU), Atlanta, GA, 30303, USA
- University of Illinois Urbana-Champaign, Urbana-Champaign, IL, USA
- Iowa State University (ISU) and Ames Laboratory, Ames, IA 50011, USA
- Los Alamos National Laboratory (LANL), Los Alamos, NM 87545, USA
- Lawrence Livermore National Laboratory (LLNL), Livermore, CA 94550, USA
- University of New Mexico, Albuquerque, New Mexico, USA
- New Mexico State University, Las Cruces, New Mexico, USA
- Department of Chemistry, State University of New York at Stony Brook (USB), Stony Brook, NY 11794, USA
- Department of Physics and Astronomy, State University of New York at Stony Brook (USB), Stony Brook, NY 11794, USA
- Oak Ridge National Laboratory (ORNL), Oak Ridge, TN 37831, USA
- University of Tennessee (UT), Knoxville, TN 37996, USA
- Vanderbilt University, Nashville, TN 37235, USA

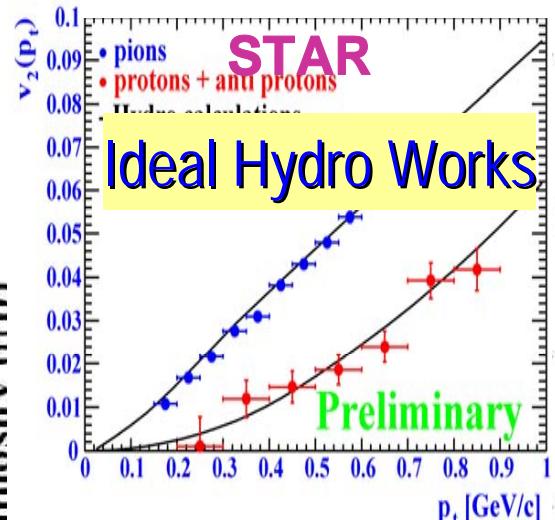
- Healthy
  - Wide-ranging participation in
    - ◆ Data analysis
    - ◆ Shift support ( 309 individuals in Run-5 !)
    - ◆ Upgrades program

- Continued growth:

Year	Institutions	Nations	Participants
2001	53	11	420
2003	57	12	460
2005	62	13	550

# Four major “day 1” discoveries

## Collective Flow

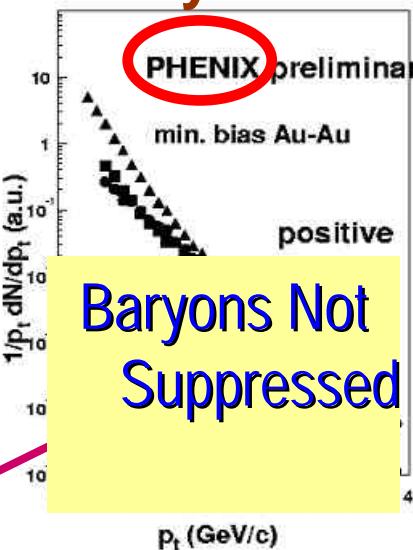


## Jet Quenching



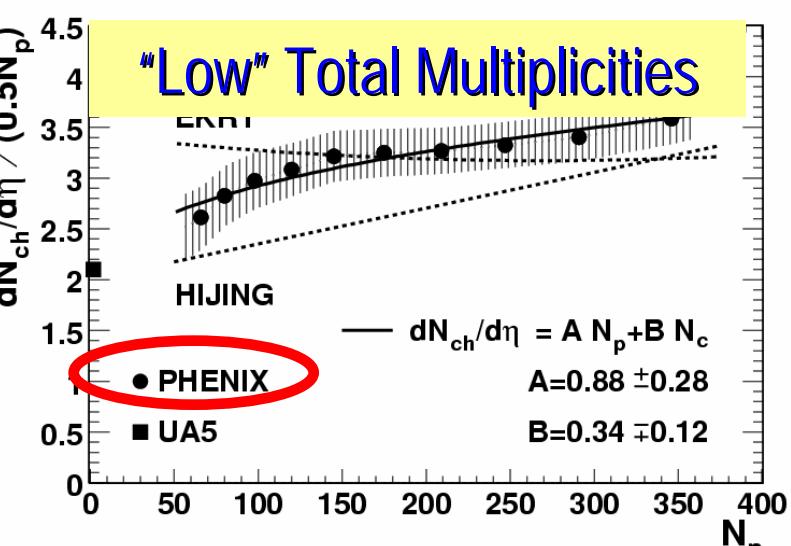
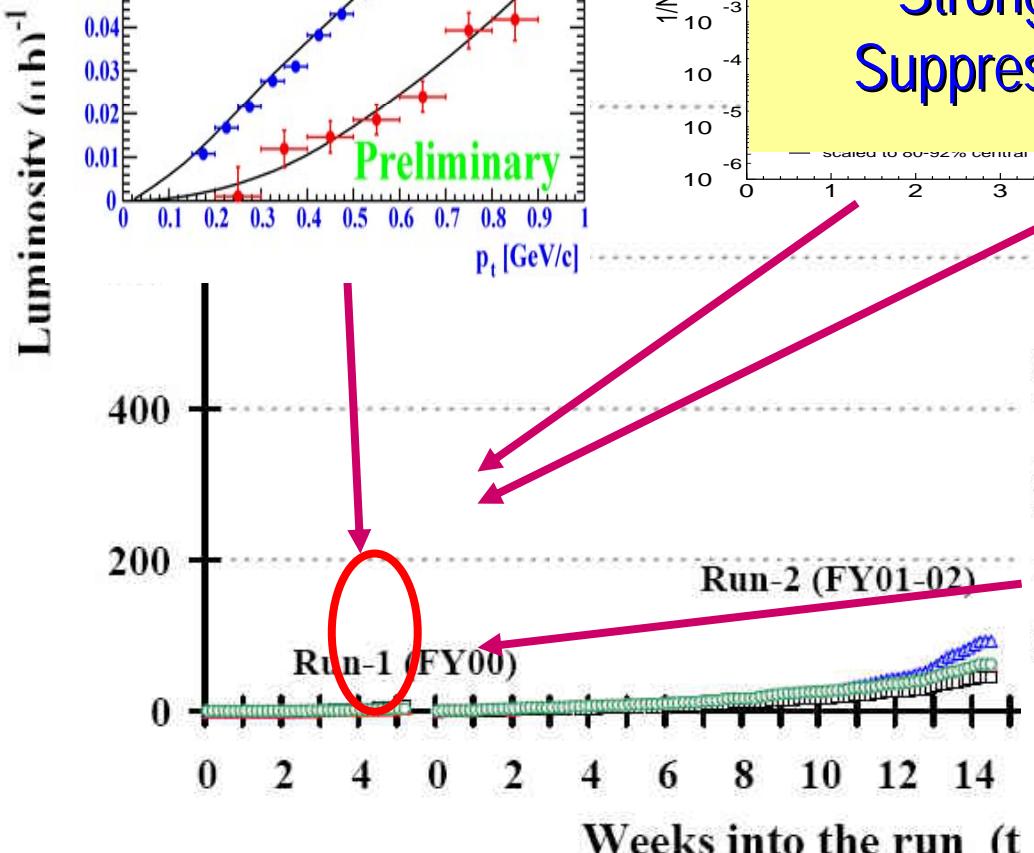
sity

## Baryon anomaly



As presented  
by M.  
Gyulassy  
in June,  
2004 to  
Nuclear  
Science  
Advisory  
Committee

## CGC Saturation





# Accomplishments and Discoveries

- First measurement of the dependence of the charged particle pseudo-rapidity density and the transverse energy on the number of participants in Au+Au collisions at  $\sqrt{s_{NN}} = 130$  GeV; systematic study of same versus energy.
- Discovery of high  $p_T$  suppression in  $\pi^0$  and charged particle production in Au+Au collisions at  $\sqrt{s_{NN}} = 130$  GeV and a systematic study of the scaling properties of the suppression; extension of these results to much higher transverse momenta in Au+Au collisions at  $\sqrt{s_{NN}} = 200$  GeV
- (Co)-Discovery of absence of high  $p_T$  suppression in d+Au collisions at  $\sqrt{s_{NN}} = 200$  GeV.
- Discovery of the anomalously large proton and anti-proton yields at high transverse momentum in Au+Au collisions at  $\sqrt{s_{NN}} = 130$  GeV through the systematic study of  $\pi^\pm$ ,  $K^\pm$ ,  $p^\pm$  spectra; measurement of  $\Lambda$  and anti- $\Lambda$  in Au+Au collisions at  $\sqrt{s_{NN}} = 130$  GeV ; study of the scaling properties of the proton and anti-proton yields , of  $\Phi$  production and d and dbar production n Au+Au collisions at  $\sqrt{s_{NN}} = 200$  GeV.
- Measurement of HBT correlations in  $\pi^+\pi^+$  and  $\pi^-\pi^-$  pairs in Au+Au collisions at  $\sqrt{s_{NN}} = 130$  GeV , establishing the "HBT puzzle" of  $R_{OUT} \sim R_{SIDE}$  extends to high pair momentum; extension of these results to  $\sqrt{s_{NN}} = 200$  GeV
- First measurement of single electron spectra in Au+Au collisions at  $\sqrt{s_{NN}} = 130$  GeV, suggesting that charm production scales with the number of binary collisions.
- Sensitive measures of charge fluctuations and fluctuations in mean  $p_T$  and transverse energy per particle in Au+Au collisions at  $\sqrt{s_{NN}} = 130\text{--}200$  GeV; role of jets in  $p_T$  fluctuations at 200 GeV
- Measurements of elliptic flow for charged particles from Au+Au collisions at  $\sqrt{s_{NN}} = 130$  GeV and identified charged hadrons from Au+Au collisions at  $\sqrt{s_{NN}} = 200$  GeV along with study of the saturation of the azimuthal flow.
- Extensive study of hydrodynamic flow, particle yields, ratios and spectra from Au+Au collisions at  $\sqrt{s_{NN}} = 130$  GeV and 200 GeV.
- First observation of  $J/\Psi$  production in Au+Au collisions at  $\sqrt{s_{NN}} = 200$  GeV.
- Measurement of crucial baseline data on  $\pi^0$  spectra ,  $J/\Psi$  production and direct photon production in p+p collisions at  $\sqrt{s_{NN}} = 200\text{--}250$  GeV.
- First measurement of direct photon production in Au+Au collisions at  $\sqrt{s_{NN}} = 200$  GeV, demonstrating that photon yields scales with the number of binary collisions.
- First observation of heavy flavor flow in Au+Au collisions at  $\sqrt{s_{NN}} = 200$  GeV
- First measurement of  $A_{LL}(\pi^0)$  in p+p collisions at  $\sqrt{s_{NN}} = 200$  GeV
- First study of jet structure or baryon excess in Au+Au collisions at  $\sqrt{s_{NN}} = 200$  GeV
- First study of nuclear modification factor in d+Au collisions in forward and backward region at  $\sqrt{s_{NN}} = 200$  GeV



# Public Recognition

BBC NEWS UK EDITION

Big Bang experiment strikes gold

The New York Times  
ON THE WEB

Scientists Report Hottest,  
Densest Matter Ever Observed

Newsday.com  
Thursday June 2

A Matter of Accomplishment

AMERICAN INSTITUTE OF PHYSICS

Intriguing Oddities In High-Energy Nuclear Collisions.

AP Associated Press

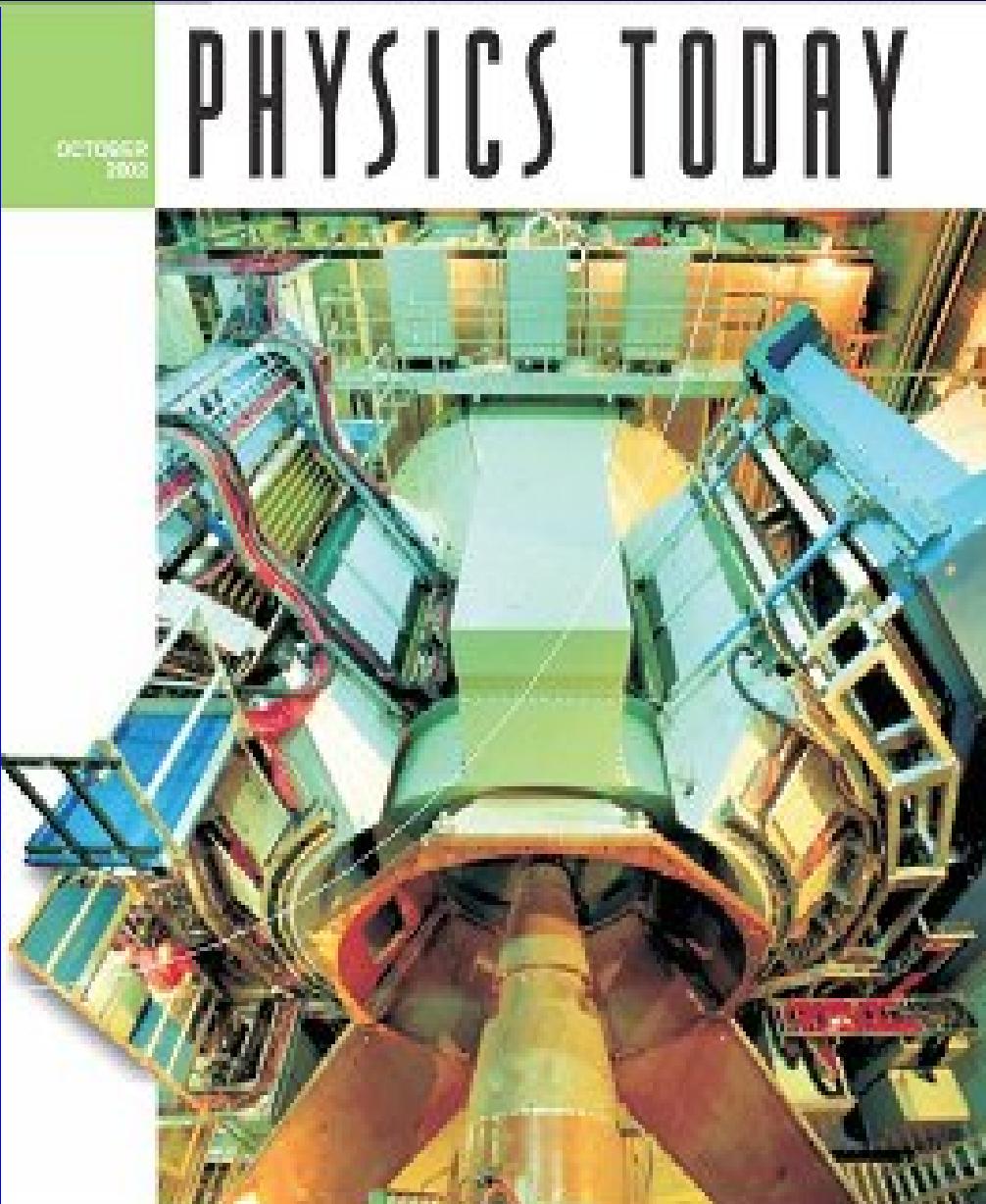
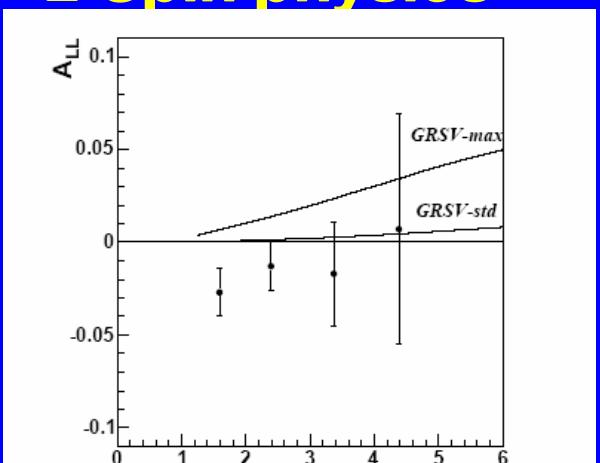
Quark-gluon plasma discovery key in examining universe, scientists say

Science magazine

Has RHIC Set Quarks Free at Last?  
Physicists Don't Quite Say So

- along with *National Public Radio, WCBS, Times of India, Nature, New Scientist, Science News, Public Radio International, Physics Today, Swedish National Radio, The Chronicle of Higher Education, San Francisco Chronicle, Dallas Morning News, Slashdot, Der Spiegel, AOL, Cern Courier, CNN, Discover, Bild der Wissenschaft, Die Welt, Times of London, Yahoo, Fox News, Hungarian National Press, ...*

- Currently the world's most sophisticated nuclear physics experiment
- World-class discoveries and measurements in
  - Heavy ion physics
  - Spin physics



## Data transfer between RCF (BNL) and CC-J (RIKEN):

**data sample:** 260 TB  
**rate** : 60MB/sec.  
**duration** : ~11 weeks

**RIKEN/CCJ:** *Yasuhi Watanabe, Satoshi Yokkaichi, Takashi Ichihara*

**PHENIX** : *Martin Purschke, Mickey Chiu, Hiro Hiejima*

**RCF** : *Dantong Yu, Shigeki Misawa, Terry Healy, Razvan Popescu, John Riordan*



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**PHENIX experiment uses Grid to transfer 270 TB of data to Japan**

During the polarized proton-proton run that ended in June at the Heavy Ion Collider (RHIC) at Brookhaven, Grid tools were used by the PHENIX experiment to send recently acquired data to a remote centre for the experiment in Japan. Brookhaven National Laboratory, Long Island, New York, is home to the RHIC/ATLAS Computing Facility (ACF), which is the main computing centre for experiments at RHIC. The ACF is a computing centre for ATLAS. The PHENIX experiment has its own computing centre in Japan (CCJ) at the RIKEN research centre on its way to Tokyo.

Going into the polarized proton-proton run, the PHENIX experiment faced the challenge that the RCF was not able to reconstruct and analyse going to the CCJ. The experiment had enormous amounts of data recorded in 2004, and the experiment wanted to transfer the data to Japan to make use of the computing resources at CCJ, which are close to the PHENIX portion of the RCF.

The PHENIX experiment can sustain a peak data rate of up to 600 MB/s, and runs at a steady rate of about 250 MB/s while beam is stored in RHIC. The data were being sent from the experimental site before being transferred and archived in the Brookhaven A 35 TB disk-storage system (about 60 h at typical data rates). The experiment used a UNIX to archive and transfer data at a lower steady rate, due to the presence of various breaks in the flood of data. A transfer rate of 600 MB/s declined steadily around the clock was able to keep up with the data stream.

Initially, PHENIX had planned to transfer the polarized proton-proton data by physically transporting tape cartridges to CCJ. During the early part of the run, however, it was found that network transfer rates of 700-750 Mbit/s could be achieved. A dedicated network path was established from the PHENIX counting house to the BNL perimeter network, and the tape option became a fall-back solution. In the end, not a single tape was shipped.

The principal tool used for the transfer was GridFtp, which proved to be very stable. Brookhaven has a high-speed connection (OC48) to ESNET, which is connected to a transpacific line (10 Gbit/s) served by SINET in Japan. Apart from two half-day outages of ESNET, the transfers continued around the clock for the entire 11 week run.

Approximately 270 TB of data (representing 6.8 billion polarized proton-proton collisions) were transferred to CCJ. After a few days of fine-tuning the transfer parameters, the transfers became part of the regular data-handling operation of the PHENIX shift crews, requiring experts to intervene only occasionally.

This seems to be the first time that a data transfer of such magnitude was sustained over many weeks in actual production, and was handled as part of routine operation by non-experts. The successful completion of this large-scale transfer project demonstrates both the maturity of today's Grid tools and the real feasibility of integrating remote resources into the data-handling and processing chain of large experiments.

<http://www.cerncourier.com/main/article/45/7/15>

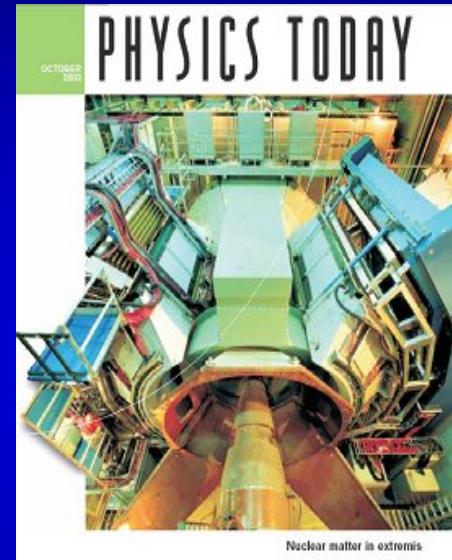
- Present
  - Y. Akiba (RIKEN), Deputy Spokesperson
  - N. Saito (Kyoto), Executive Council
- Past
  - S. Nagamiya (then Columbia), Spokesperson
  - H. En'yo (then Kyoto), Executive Council
  - H. Hamagaki (CNS), Executive Council
  - K. Imai (Kyoto), Executive Council

The “wave-function” of the proton



Spin  
Dynamics

BNL  
QCD



Weak  
matrix ←  
elements

Lattice  
Studies

RIKEN

Heavy Ion  
Collisions

Astro-  
physics →