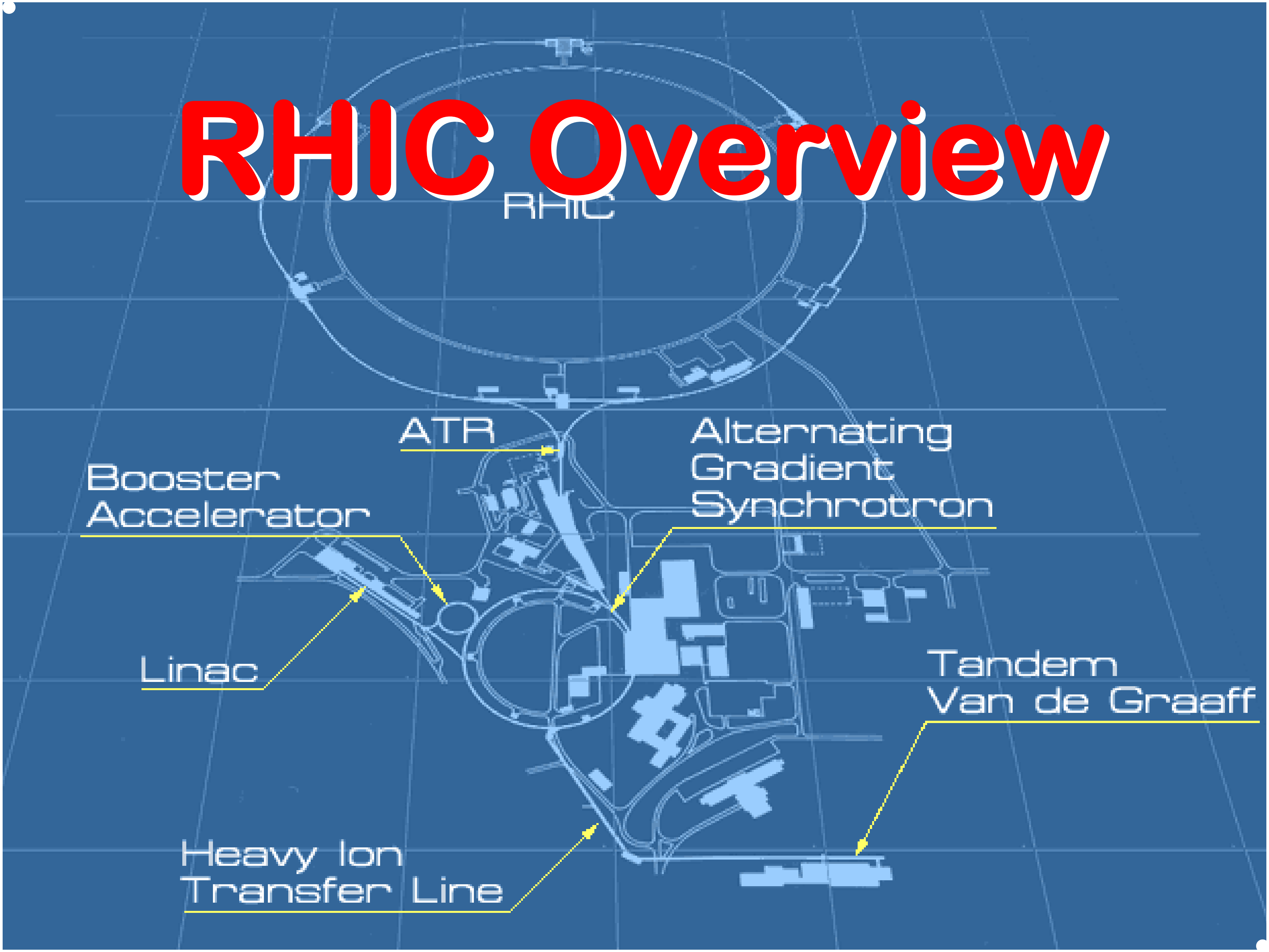
RHIC Overview



Agenda

- Introduction — Franco Bradamante
- RHIC Overview — Bill Zajc
- RHIC Spin+Upgrades — Matthias Perdekamp
- Experience w. W Calorimeters — Andrea Vacchi
- e-RHIC — Ed Kinney

→*Plus informal discussion*

- My world-line (so far)
  - Thesis topic in (relatively) low energy heavy ions (1982)
  - Post-doc at CERN ISR R807 ("discovery" of jets)
  - Asst. professor in pre-history of D-Zero (1985-6)
  - Fixed target heavy ion experiments at AGS (1986-96)
  - PHENIX at RHIC (1992 to present)

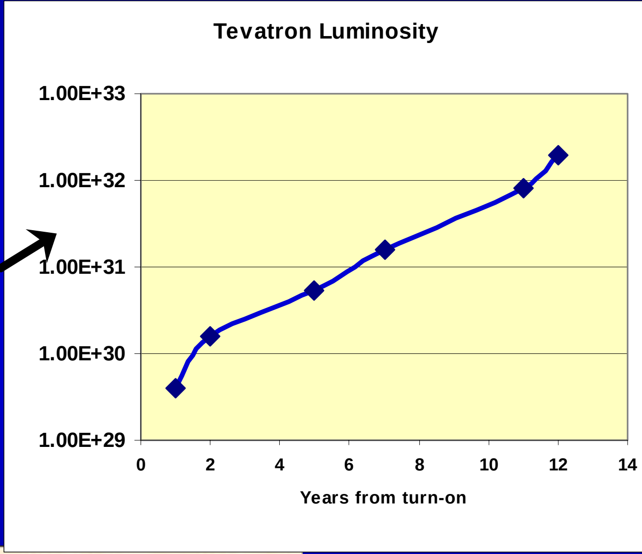
RHIC Surprises (0)

(From a slide I wrote 6 months before RHIC start)

- Much of the interesting physics is luminosity limited
- (Single-species) colliders can take years to reach their full luminosity:

ISR
(Mike Tannenbaum)

FNAL
(Steve Holmes)



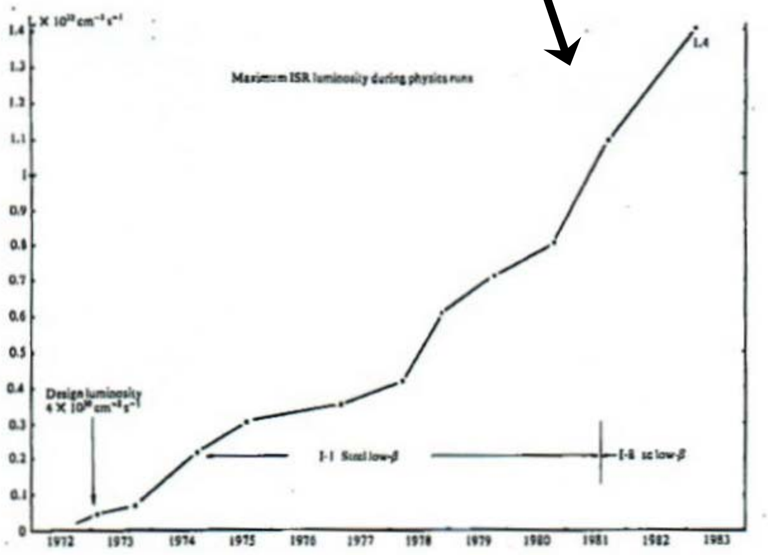
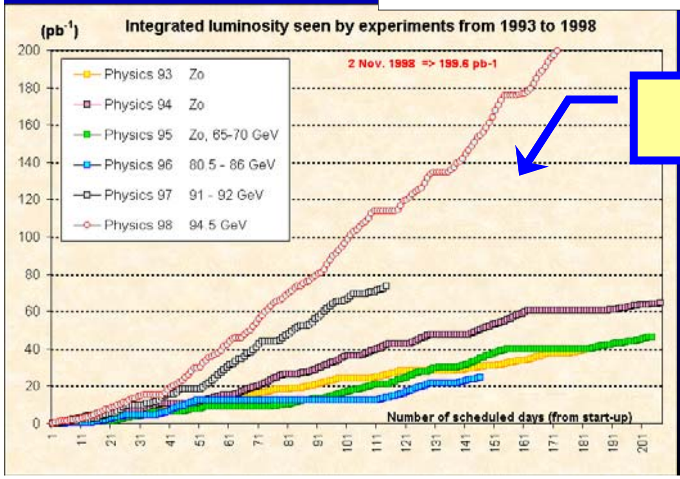


Fig. 9 ISR luminosity during physics runs: September 1971 -- First ISR experiment to be completed, R101; maximum luminosity = 1.3×10^{29} cm^{-2} s^{-1}. December 1982 -- Highest luminosity achieved for physics (R807) = 1.4×10^{32} cm^{-2} s^{-1}.

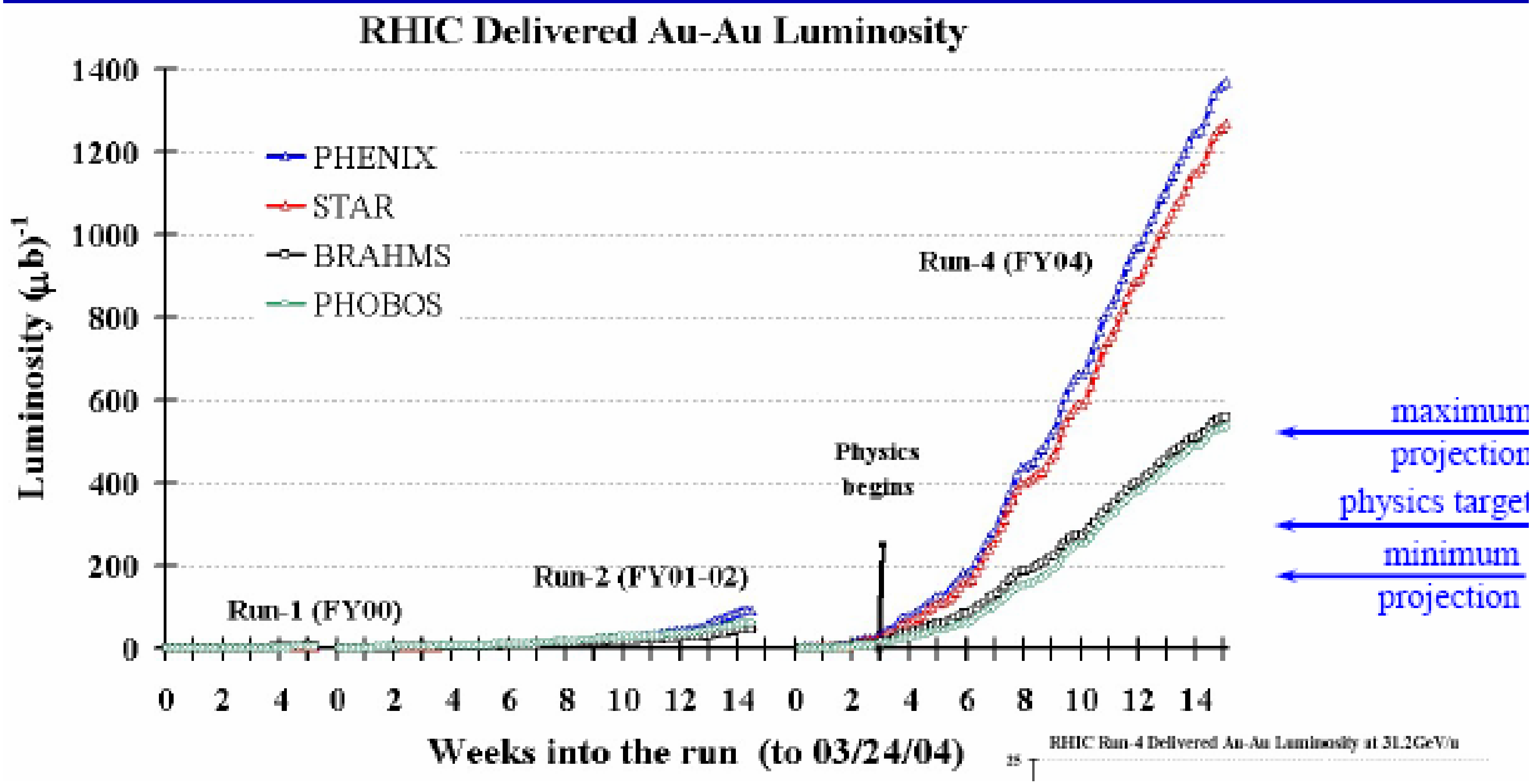
LEP



W.A. Zajc

RHIC Surprises (1)

- Design luminosity for Au+Au achieved in second year of operations
- In Run-4, routine operation at twice design luminosity



RHIC Surprises (2)

(From a slide I wrote 6 months before RHIC start)

Again, learn from the past:

First CDF publication:

***Transverse-Momentum Distributions of Charged Particles Produced in p-pbar Interactions at 630 and 1800 GeV*, F. Abe et al., Phys. Rev. Lett. 61, 1819 (1988).**

- **~One year from data-taking.**
- **Much simpler final state!**

➔ ***We will be hard-pressed to reach this goal***

➔ ***And much harder-pressed to maintain "CDF-like" rate***

VOLUME 61, NUMBER 16 PHYSICAL REVIEW LETTERS 17 OCTOBER 1988

Transverse-Momentum Distributions of Charged Particles Produced in $\bar{p}p$ Interactions at $\sqrt{s}$ =630 and 1800 GeV

F. Abe,[16] D. Amidei,[3] G. Apollinari,[11] G. Ascoli,[7] M. Atac,[4] P. Auchincloss,[14] A. R. Baden,[6] A. Barbaro-Galtieri,[9] V. E. Barnes,[12] F. Bedeschi,[11] S. Belforte,[11] G. Bellettini,[11] J. Bellinger,[17] J. Bensinger,[2] A. Beretvas,[14] P. Berge,[4] S. Bertolucci,[5] S. Bhadra,[7] M. Binkley,[4] R. Blair,[1] C. Blocker,[2] J. Bofill,[4] A. W. Booth,[4] G. Brandenburg,[6] D. Brown,[6] A. Byon,[12] K. L. Byrum,[17] M. Campbell,[3] R. Carey,[6] W. Carithers,[9] D. Carlsmith,[17] J. T. Carroll,[4] R. Cashmore,[4] F. Cervelli,[11] K. Chadwick,[4,12] T. Chapin,[13] G. Chiarelli,[11] W. Chinowsky,[9] S. Cihangir,[15] D. Cline,[17] D. Connor,[10] M. Contreras,[2] J. Cooper,[4] M. Cordelli,[5] M. Curatolo,[5] C. Day,[4] R. DelFabbro,[11] M. Dell'Orso,[11] L. DeMortier,[2] T. Devlin,[14] D. DiBitonto,[15] R. Diebold,[1] F. Dittus,[4] A. DiVirgilio,[11] J. E. Elias,[4] R. Ely,[9] S. Errede,[7] B. Esposito,[5] A. Feldman,[6] B. Flaugher,[14] E. Focardi,[11] G. W. Foster,[4] M. Franklin,[6,7] J. Freeman,[4] H. Frisch,[3] Y. Fukui,[8] A. F. Garfinkel,[12] P. Giannetti,[11] N. Giokaris,[13] P. Giromini,[5] L. Gladney,[10] M. Gold,[9] K. Goulianos,[13] C. Grosso-Pilcher,[3] C. Haber,[9] S. R. Hahn,[10] R. Handler,[17] R. M. Harris,[9] J. Hauser,[3] T. Hessing,[15] R. Hollebeek,[10] L. Holloway,[7] P. Hu,[14] B. Hubbard,[9] P. Hurst,[7] J. Huth,[4] H. Jensen,[4] R. P. Johnson,[4] U. Joshi,[14] R. W. Kadel,[4] T. Kamon,[15] S. Kanda,[16] D. A. Kardelis,[7] I. Karliner,[7] E. Kearns,[6] R. Kephart,[4] P. Kesten,[2] H. Keutelian,[7] S. Kim,[16] L. Kirsch,[2] K. Kondo,[16] U. Kruse,[7] S. E. Kuhlmann,[12] A. T. Laasanen,[12] W. Li,[1] T. Liss,[3] N. Lockyer,[10] F. Marchetto,[15] R. Markeloff,[17] L. A. Markosky,[17] P. McIntyre,[15] A. Menzione,[11] T. Meyer,[15] S. Mikamo,[8] M. Miller,[10] T. Mimashi,[16] S. Miscetti,[5] M. Mishina,[8] S. Miyashita,[16] N. Mondal,[17] S. Mori,[16] Y. Morita,[16] A. Mukherjee,[4] C. Newman-Holmes,[4] L. Nodulman,[1] R. Paoletti,[11] A. Para,[4] J. Patrick,[4] T. J. Phillips,[6] H. Piekarz,[2] R. Plunkett,[13] L. Pondrom,[17] J. Proudfoot,[1] G. Punzi,[11] D. Quarrie,[4] K. Ragan,[10] G. Redlinger,[3] J. Rhoades,[17] F. Rimondi,[4] L. Ristori,[11] T. Rohaly,[10] A. Roodman,[3] A. Sansoni,[5] R. Sard,[7] V. Scarpine,[7] P. Schlabach,[7] E. E. Schmidt,[4] P. Schoessow,[1] M. H. Schub,[12] R. Schwitters,[6] A. Scribano,[11] S. Segler,[4] M. Sekiguchi,[16] P. Sestini,[11] M. Shapiro,[6] M. Sheaff,[17] M. Shibata,[16] M. Shochet,[3] J. Siegrist,[9] P. Sinervo,[10] J. Skarha,[17] D. A. Smith,[7] F. D. Snider,[3] R. St. Denis,[6] A. Stefanini,[11] Y. Takaiwa,[16] K. Takikawa,[16] S. Tarem,[3] D. Theriot,[4] A. Tollestrup,[4] G. Tonelli,[11] Y. Tsay,[3] F. Ukegawa,[16] D. Underwood,[1] R. Vidal,[4] R. G. Wagner,[1] R. L. Wagner,[4] J. Walsh,[10] T. Watts,[14] R. Webb,[15] T. Westhusing,[7] S. White,[13] A. Wicklund,[1] H. H. Williams[10] T. Yamanouchi,[4] A.Yamashita,[16] K. Yasuoka,[16] G. P. Yeh,[4] J. Yoh,[4] and F. Zetti,[11]

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[12]*Purdue University, West Lafayette, Indiana 47907*
[13]*Rockefeller University, New York, New York 10021*
[14]*Rutgers University, Piscataway, New Jersey 08854*
[15]*Texas A&M University, College Station, Texas 77843*
[16]*University of Tsukuba, Ibaraki 305, Japan*
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(Received 8 June 1988; revised manuscript received 5 September 1988)

Measurements of inclusive transverse-momentum spectra for charged particles produced in proton-antiproton collisions at $\sqrt{s}$ of 630 and 1800 GeV are presented and compared with data taken at lower energies.

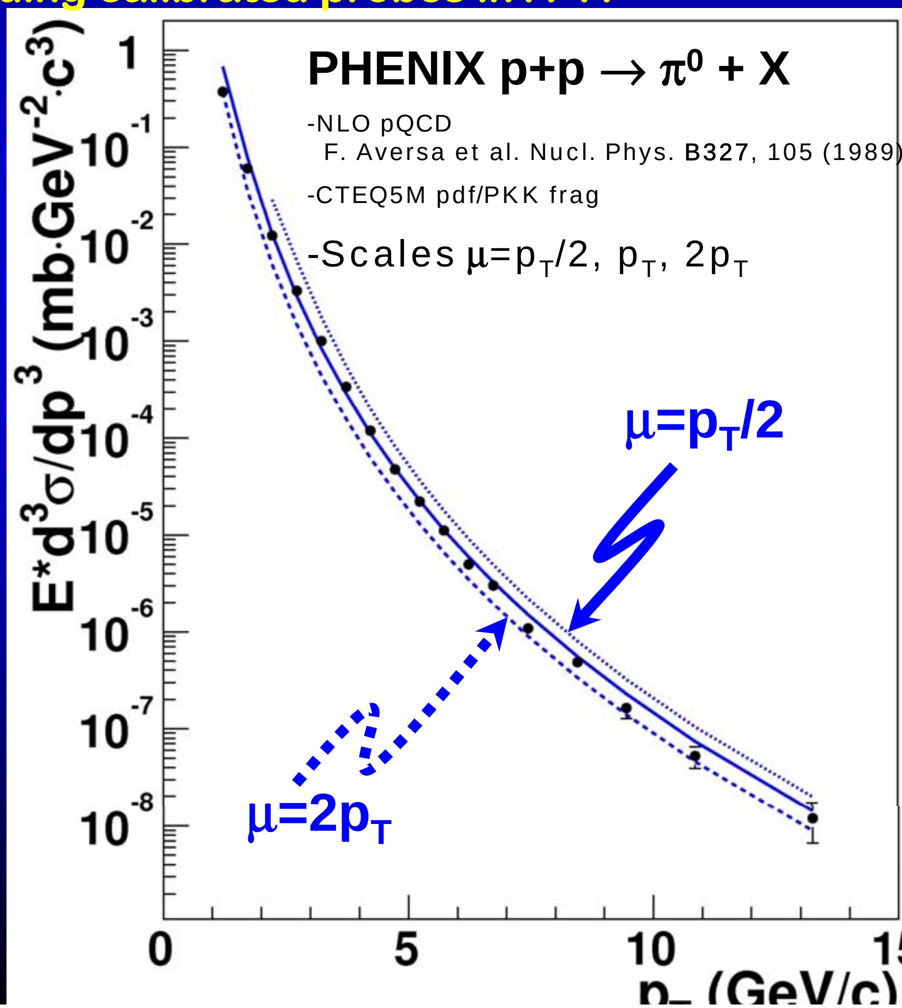
PACS numbers: 13.85.Ni

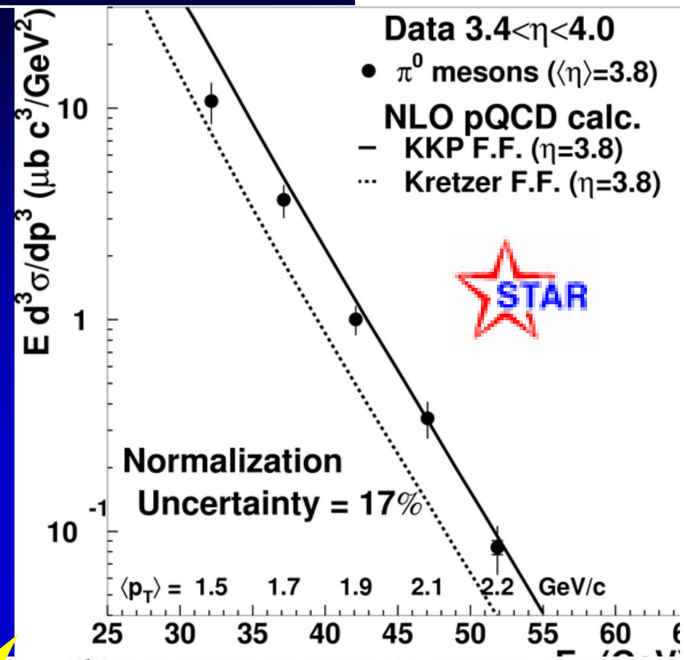
The *Real* RHIC Surprises

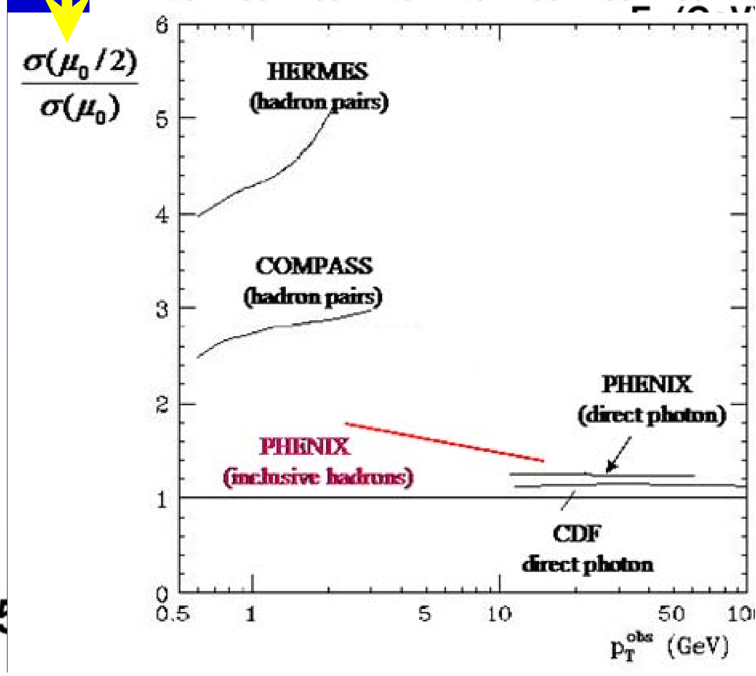
- **Machine :**
  - Runs 1-4:
    - Au+Au: operation at 4 energies (19, 62, 130, 200 GeV)
    - d+Au comparison run (200 GeV)
    - p+p baseline (200 GeV)
  - Routine operation in excess of twice design luminosity !
  - First polarized hadron collider !
- **Experimental Operations:**
  - Routine collection, analysis of 100 Tb datasets
  - >50 publications in Physical Review Letters !
  - Excellent control of systematics and inter-experiment comparisons
- **Experimental Results:**
  - Record densities created ~100 times normal nuclear density
  - New phenomena clearly observed ("jet" quenching)
  - Strong suggestions of a new state of matter

The RHIC *Non*-Surprise

- The high $\sqrt{s}$ of RHIC
  - makes contact with rigorous pQCD calculations
  - minimizes "scale dependence"
- A huge advantage in
  - Spin program
  - Providing calibrated probes in A+A







RHIC Surprises (3)

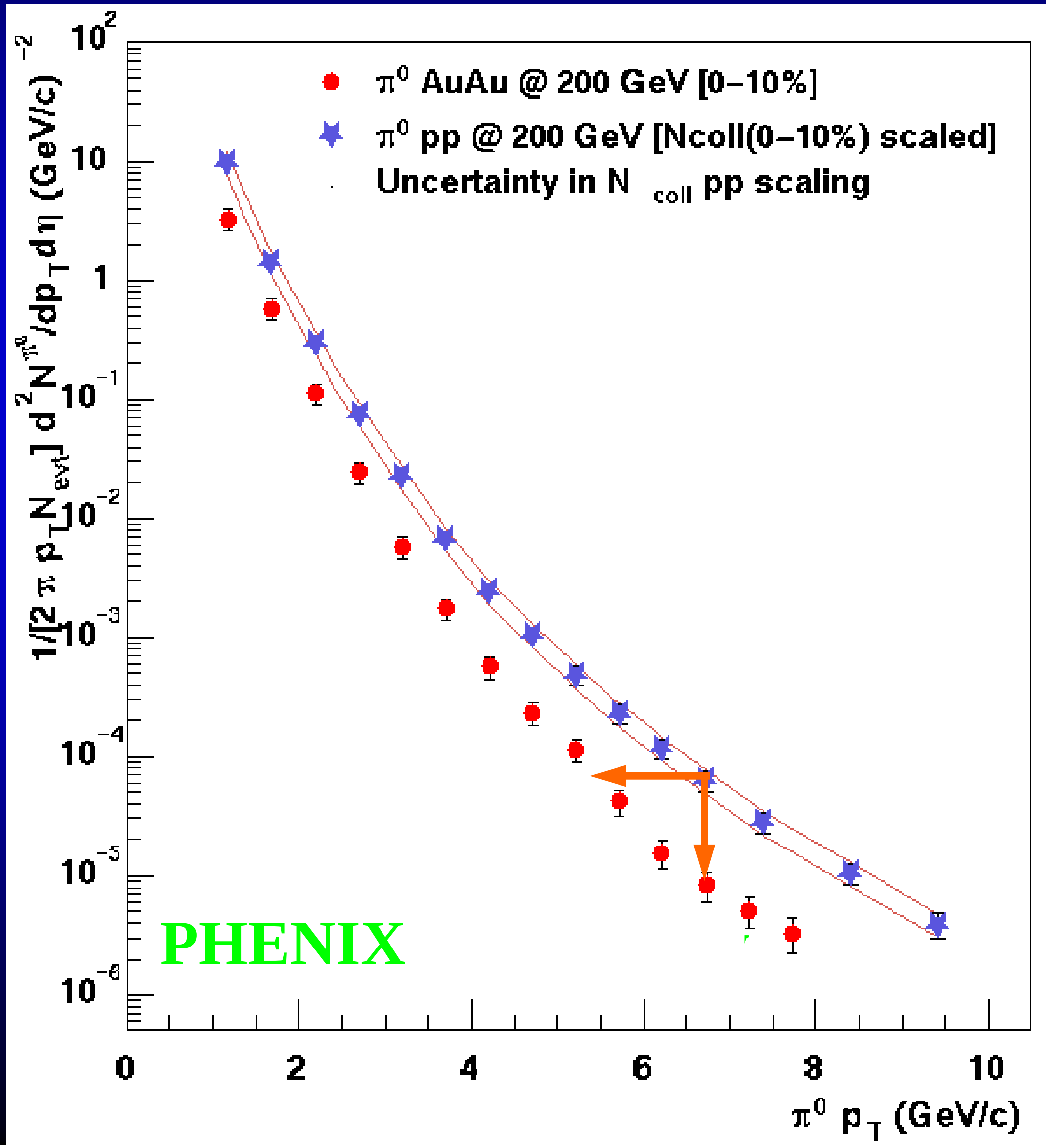
➡ ***The study of truly high p_T processes has revolutionized heavy ion physics.***

- Provides "first-principles" calculations of expected yields

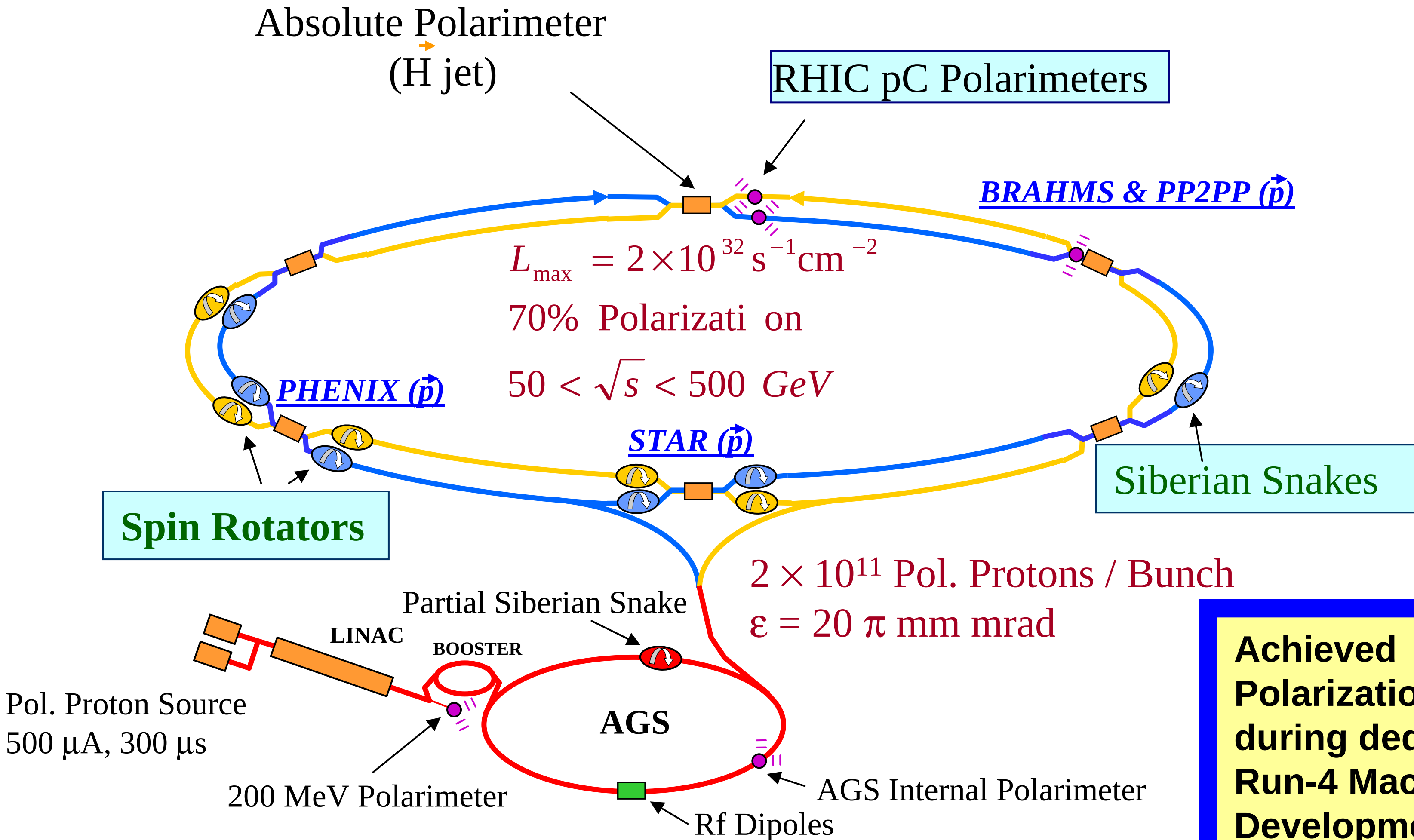
➔ Central collisions show *huge suppression*.

- This is a *clear* discovery of *new* behavior at RHIC

  - ❑ Suppression of low-x gluons in the initial *state*?
  - ✓ Energy loss in a new state of *matter*?



RHIC Surprises (4)

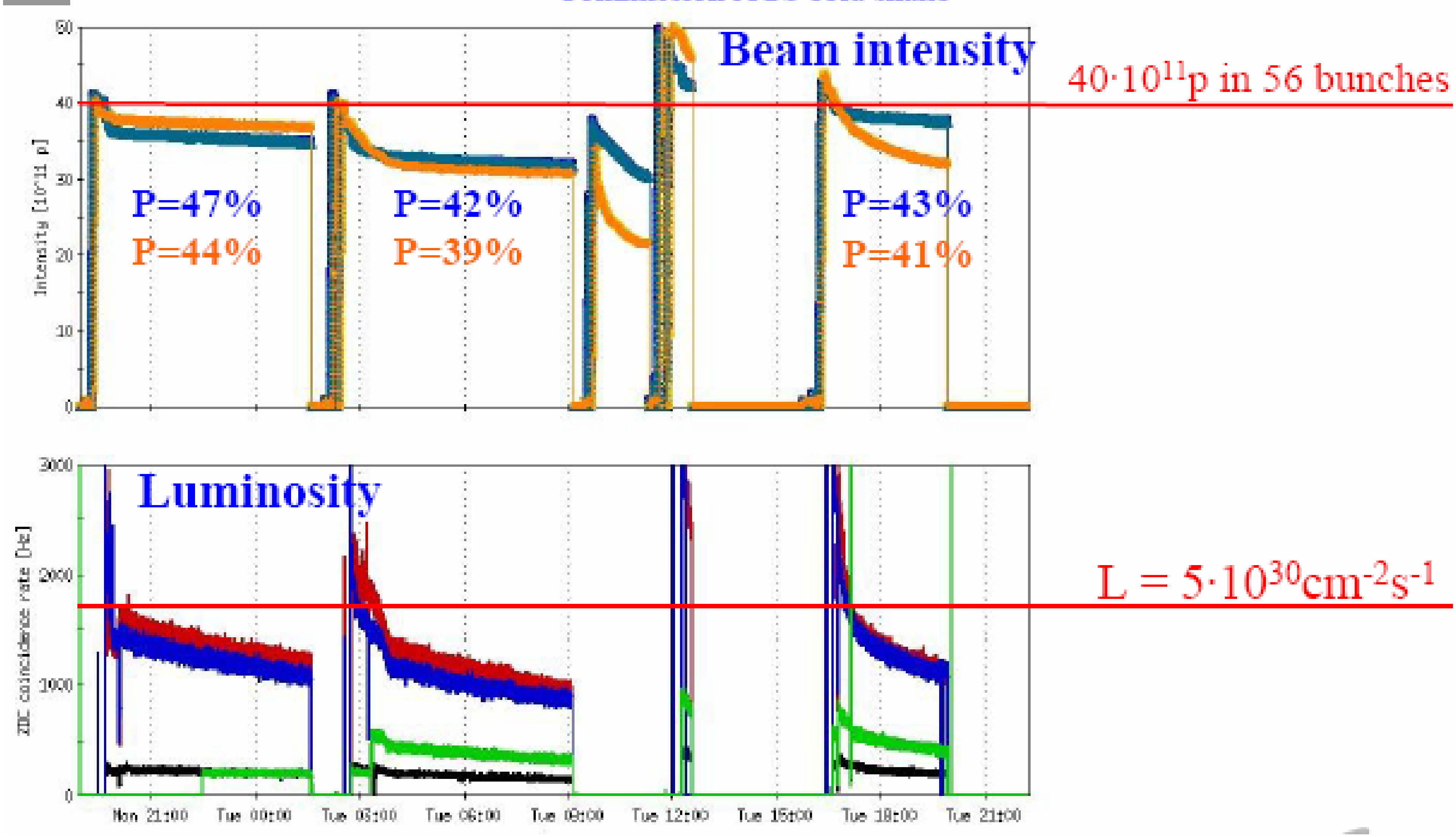


Achieved Polarization 40-45% during dedicated Run-4 Machine Development Period!

RHIC accelerates heavy ions to 100 GeV/A
and polarized protons to 250 GeV

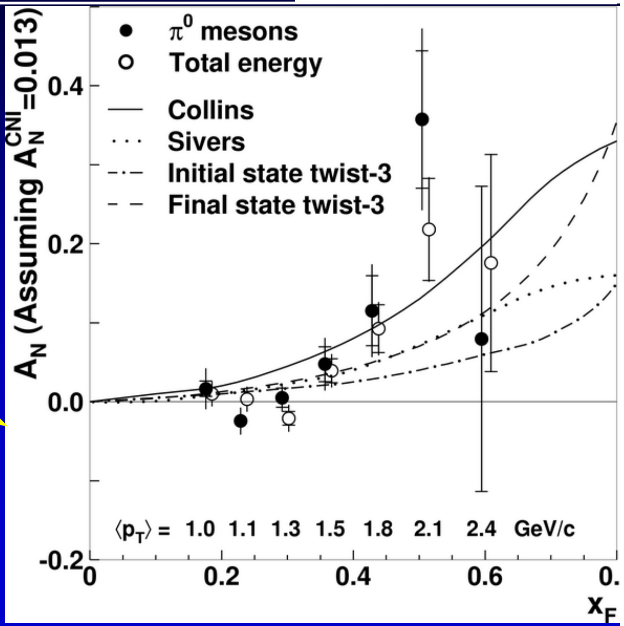
RHIC Run-4 Spin Performance

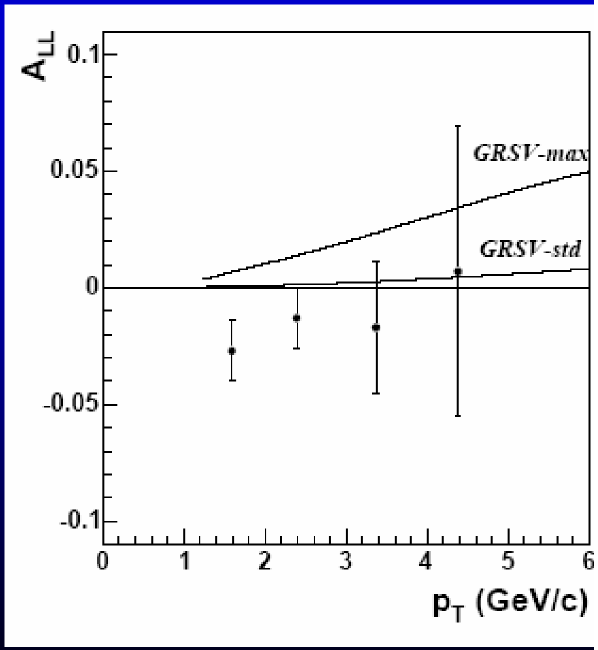
- Exceeded 200 GeV design luminosity (5×10^{30}) in Run-4
- Polarization development on schedule (and polarimetry)



Experimental Spin Status

- To date:
  - Cross Sections and Transverse Single-Spin Asymmetries in Forward π^0 Production from Proton Collisions at $\sqrt{s}$ = 200 GeV, J. Adams *et al.* (STAR Collaboration) Phys.Rev.Lett. 92 (2004) 171801
    - 0.15 pb^{-1}, <P>=16%
  - Double Helicity Asymmetry in Inclusive Mid-Rapidity π^0 Production for Polarized p+p Collisions at $\sqrt{s}$=200 GeV, S. Adler *et al.* (PHENIX Collaboration), to appear in Phys. Rev. Lett.
    - 0.22 pb^{-1}, <P>=27%
- To do (partial list):
  - A_{LL} measurement in many channels at $\sqrt{s}$=200 GeV (Requires ~100 pb^{-1}, <P> ~ 70%)
  - A_L measurement via $W^{\pm}$ at $\sqrt{s}$=500 GeV (Requires ~400 pb^{-1}, <P> ~ 70%)
- Requires
  - (ongoing) beam development
  - Extended running (to begin in Run-5)





Connections (Spin)

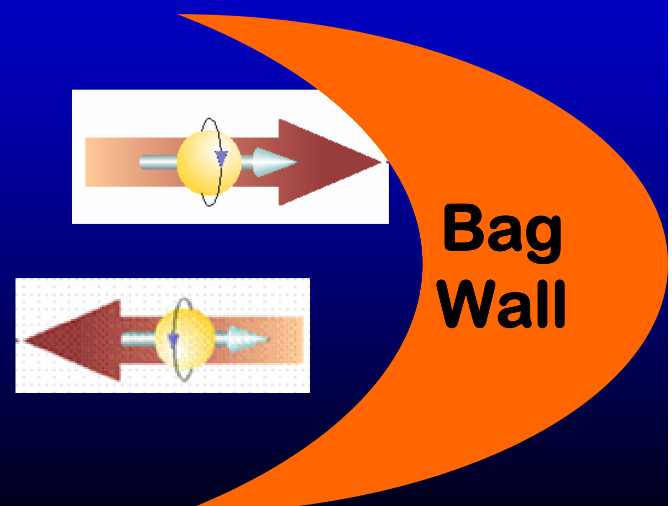
- **An obvious (in fact integral) programmatic connection**
  - **"Spin" sub-systems have proven benefit to A+A, p+A measurements**
    - **E.g., PHENIX Muons**
    - **E.g., STAR Endcap**
  - **Integrated presence in collaborations mutually beneficial**

PHENIX Run Coordinators:
The most important position in PHENIX

Run-3: Matthias Grosse Perdekamp
(now Deputy Spokesperson)

Run-6: May be in this room…

- **An important intellectual connection:**
  - **Confinement**
    ➔ mixing of helicity components
  - **Transversity**
    ➔ requires chiral symmetry breaking
  - ***RIKEN BNL Research Center maintains and fosters that connection***



A Tale of Two Plans

RHIC

- **PHENIX Decadal Plan**

  "A superlative set of measurements to elucidate the states of both hot and cold nuclear matter, and to measure the spin structure of the proton has been identified. The components of this plan include"

  - Definitive measurements that will establish the nature of the matter created in nucleus+nucleus collisions, that will determine if the description of such matter as a quark-gluon plasma is appropriate, and that will quantify both the equilibrium and non-equilibrium features of the produced medium.
  - Precision measurements of the gluon structure of the proton, and of the spin structure of the gluon and sea-quark distributions of the proton via polarized proton+proton collisions.
  - Determination of the gluon distribution in cold nuclear matter using proton+nucleus collisions.

- **STAR Decadal Plan**

  "a vision of the compelling science STAR proposes to accomplish (a picture being developed). Three "Must do" STAR Physics Goals in the next 5+ years that drive the planned use of RHIC:"

  - Have we produced the quark-gluon plasma?
    - p_T dependence of suppression
    - Measurement of open charm and charmonium
    - Full flow systematics (mesons, baryons, multiply strange baryons, open charm)
    - Evolution versus energy/species
  - Gluon contribution to the nucleon spin
    - A_{LL} for mid-rapidity jet production
    - A_{LL} for direct photon + jet
  - Gluon density saturation in cold nuclei at very low Bjorken x
    - Inclusive leading hadrons/jets in d+Au collisions
    - Search for mono-jets in d+Au collisions

PHENIX Run Request

- **Polarized proton running is a major component of our request (also true for STAR)**
- **Brookhaven Program Advisory Committee has explicitly realized priority of spin running:** ***"There was a consensus within the PAC that a 8-10 week pp run at √s = 200 GeV should have the highest priority"***

Table 2: The PHENIX Beam Use Proposal for 31 cryo weeks in Run-5, and 27 cryo weeks in latter years.

RUN	SPECIES	$\sqrt{s_{NN}}$ (GeV)	PHYSICS WEEKS	$\int \mathcal{L}dt$ (delivered)	p+p Equivalent
5	Cu+Cu	200	10	7.0 nb^{-1}	27.6 pb^{-1}
	p+p	200	11	13.1 pb^{-1}	13.1 pb^{-1}
6	Au+Au	62.4	9	111 μb^{-1}	4.3 pb^{-1}
	p+p	200	8	15.0 pb^{-1}	15.0 pb^{-1}
7	p+p	200	20	122 pb^{-1}	122 pb^{-1}
8	Au+Au	200	20	4140 μb^{-1}	161 pb^{-1}
9	p+p	500	20	359 pb^{-1}	359 pb^{-1}
10	d+Au	200	20	91.6 nb^{-1}	36 pb^{-1}

$A_{LL}(\pi^0)$ in Run-5

- **Assumptions:**
  - 11 physics weeks
  - 'Usual' geometric mean of minimum and maximum guidance
  - <P> = 45%
  - ➡ Integrated luminosity: 5.5 pb^{-1}
  - ➡ Figure of merit: ~100 x Run-3
- **Implications**
  - Current errors reduced by > factor of ten
  - p_T reach extended to ~ 7 GeV/c
  - ➡ Access to g+q, in addition to g+g, production mechanism

B. Jäger et al. hep-ph/0211007

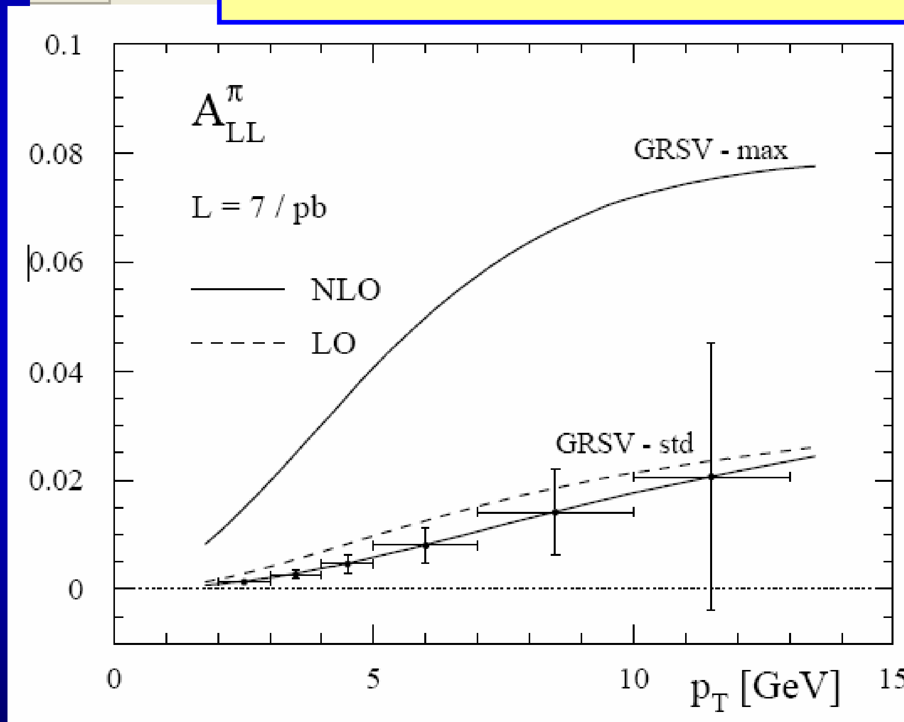
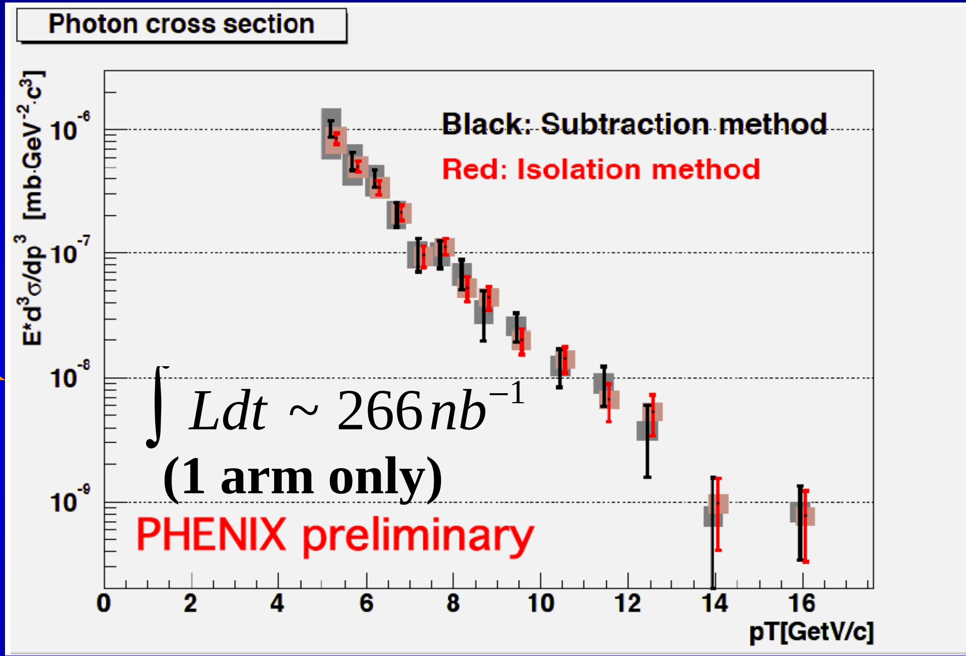


FIG. 3: The measured double spin asymmetry $A^{\pi^0}_{LL}$ versus mean p_T of π^0's in each bin. A scale uncertainty of ±65% is not included. Two theoretical calculations based on NLO pQCD are also shown for comparison with the data (see text for details).

The Challenges For The Next Decade

A. Move from ***exploration of*** new matter formed in A+A collisions to ***characterization of*** its propertie

- ➡ Uses same tools as spin program
  - High p_T identified particles
  - Jets
  - Open Charm
  - J/Ψ's
  - Direct photons



B. Accelerate progress in the developing spin program

C. Upgrade detectors to

- Maximize items A and B
- While maintaining physics program by minimizing shutdowns

D. Upgrade RHIC to

- Maximize items A, B, C and D
- While maintaining physics program by minimizing shutdowns

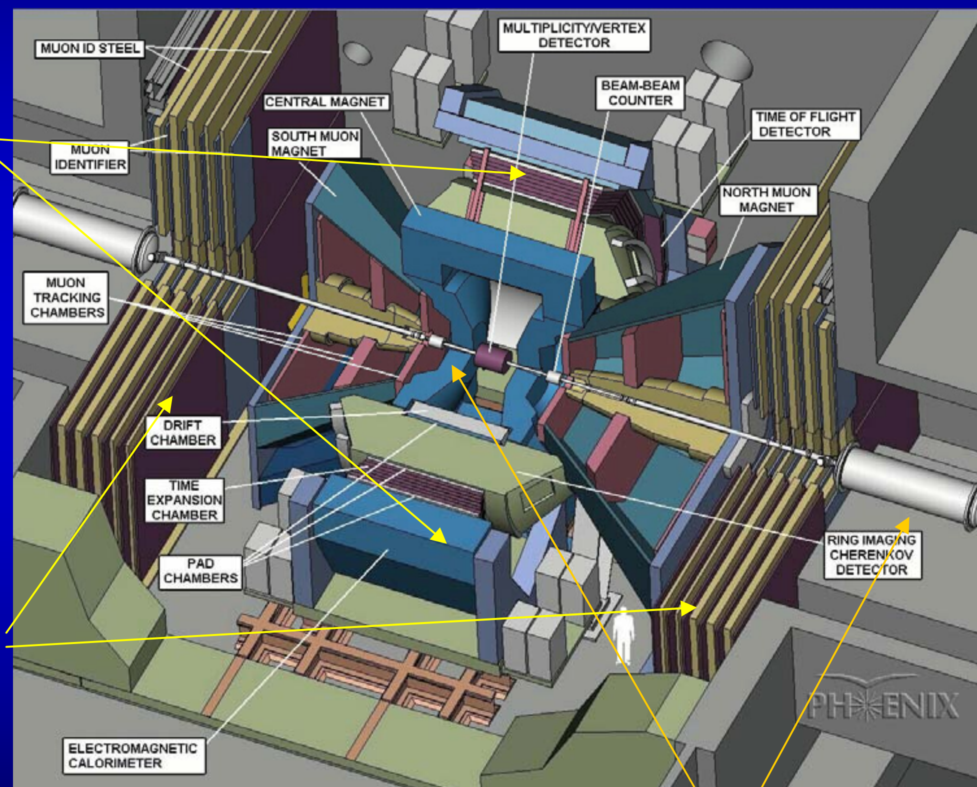
Present PHENIX Physics Capabilities

designed to measure rare probes:

Au-Au & p-p spin

+ high rate capability & granularity
+ good mass resolution and particle ID
- limited acceptance

- **2 central arms:**
  electrons, photons, hadrons
  - charmonium J/ψ, ψ' –> e^+e^-
  - vector meson ρ, ω, ϕ –> e^+e^-
  - high p_T π^o, π^+, π^-
  - direct photons
  - open charm
  - hadron physics



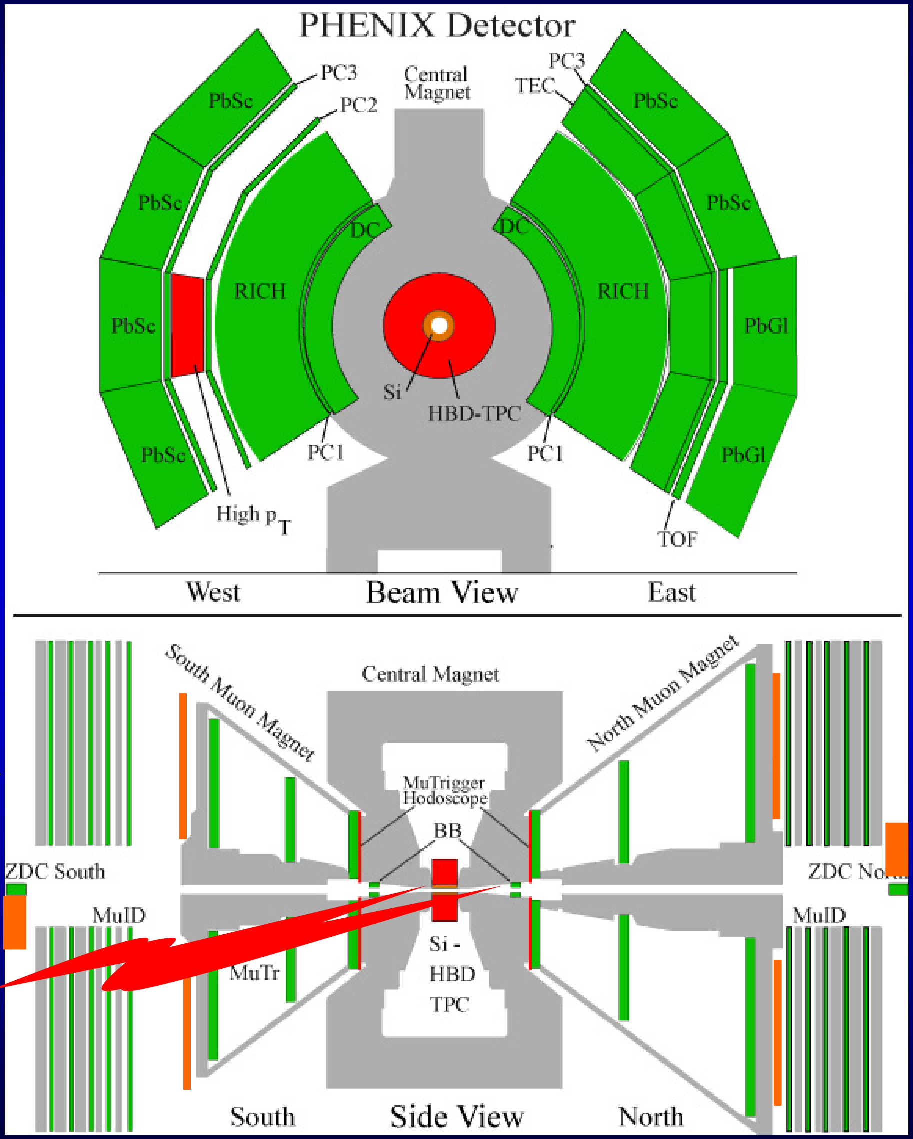
- **2 muon arms:** muons
  - "onium" J/ψ, ψ', Υ –> $\mu^+\mu^-$
  - vector meson ϕ –> $\mu^+\mu^-$
  - open charm

- **global detectors**
  forward energy and multiplicity
  - event characterization

- **combined central and muon arms:**
  charm production DD –> $e\mu$

Upgrades of PHENIX Detector

- enhanced particle ID
  - ☑ TRD (east)
  - ☑ Aerogel/TOF (west)
- enhanced muon trigger
  - ❑ forward hodoscopes
  - ❑ anode readout
  - ❑ Cerenkov detector
  - ❑ Nosecone calorimeters
- DAQ/trigger



- Vertex Spectrometer
  - ☑ flexible magnetic field
  - ❑ silicon vertex tracker
  - ❑ TPC/HBD
- pA centrality detectors
  - ☑ forward calorimeter

An International Collaboration

RHIC

PHENIX

Brazil — University of São Paulo, São Paulo

China — Academia Sinica, Taipei, Taiwan
China Institute of Atomic Energy, Beijing
Peking University, Beijing

France — LPC, University de Clermont-Ferrand, Clermont-Ferrand
Dapnia, CEA Saclay, Gif-sur-Yvette
IPN-Orsay, Universite Paris Sud, CNRS-IN2P3, Orsay
LLR, Ecòle Polytechnique, CNRS-IN2P3, Palaiseau
SUBATECH, Ecòle des Mines at Nantes, Nantes

Germany — University of Münster, Münster

Hungary — Central Research Institute for Physics (KFKI), Budapest
Debrecen University, Debrecen
Eötvös Loránd University (ELTE), Budapest

India — Banaras Hindu University, Banaras
Bhabha Atomic Research Centre, Bombay

Israel — Weizmann Institute, Rehovot

Japan — Center for Nuclear Study, University of Tokyo, Tokyo
Hiroshima University, Higashi-Hiroshima
KEK, Institute for High Energy Physics, Tsukuba
Kyoto University, Kyoto
Nagasaki Institute of Applied Science, Nagasaki
RIKEN, Institute for Physical and Chemical Research, Wako
RIKEN-BNL Research Center, Upton, NY
University of Tokyo, Bunkyo-ku, Tokyo
Tokyo Institute of Technology, Tokyo
University of Tsukuba, Tsukuba
Waseda University, Tokyo

S. Korea — Cyclotron Application Laboratory, KAERI, Seoul
Kangnung National University, Kangnung
Korea University, Seoul
Myong Ji University, Yongin City
System Electronics Laboratory, Seoul Nat. University, Seoul
Yonsei University, Seoul

Russia — Institute of High Energy Physics, Protovino
Joint Institute for Nuclear Research, Dubna
Kurchatov Institute, Moscow
PNPI, St. Petersburg Nuclear Physics Institute, St. Petersburg
St. Petersburg State Technical University, St. Petersburg

Sweden — Lund University, Lund

*12 Countries; 57 Institutions; 460 Participants**

USA — Abilene Christian University, Abilene, TX
Brookhaven National Laboratory, Upton, NY
University of California - Riverside, Riverside, CA
University of Colorado, Boulder, CO
Columbia University, Nevis Laboratories, Irvington, NY
Florida State University, Tallahassee, FL
Georgia State University, Atlanta, GA
University of Illinois Urbana Champaign, Urbana-Champaign, IL
Iowa State University and Ames Laboratory, Ames, IA
Los Alamos National Laboratory, Los Alamos, NM
Lawrence Livermore National Laboratory, Livermore, CA
University of New Mexico, Albuquerque, NM
New Mexico State University, Las Cruces, NM
Dept. of Chemistry, Stony Brook Univ., Stony Brook, NY
Dept. Phys. and Astronomy, Stony Brook Univ., Stony Brook, NY
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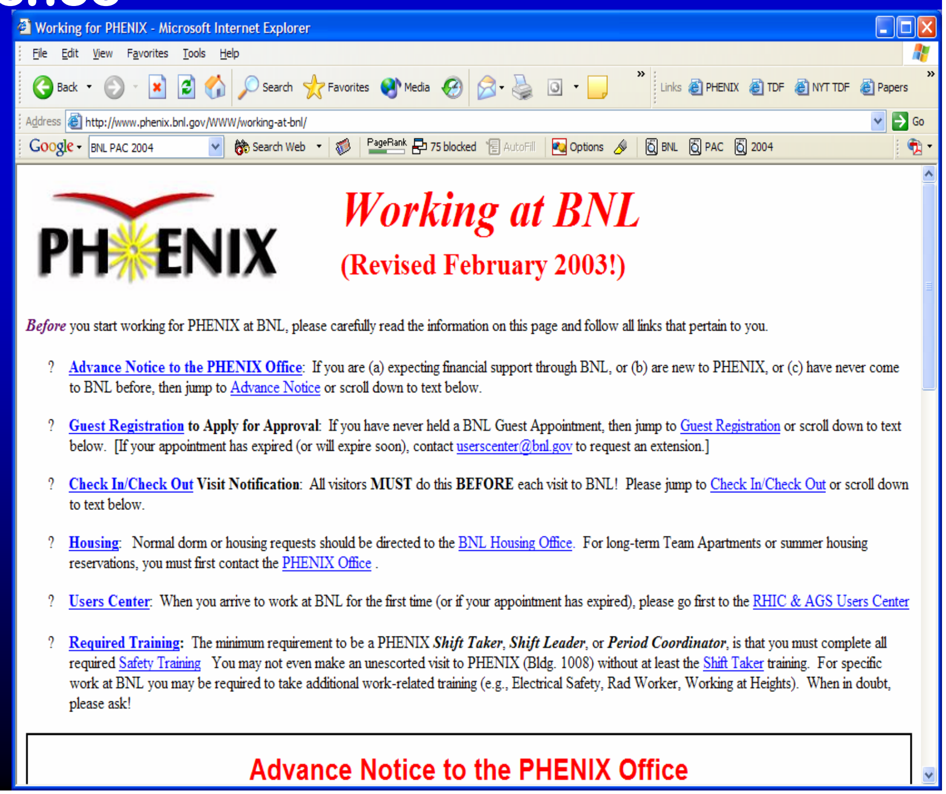
University of Tennessee, Knoxville, TN
Vanderbilt University, Nashville, TN

*as of July 2002

The Inevitable Visa Question...

- The RHIC User Community is an *international* community:
  - > 1000 Members
  - < 30% U.S. Citizens
- Visa issues minimized by active
  - Users' Center
  - Support staff in collaborations
- Informal ranking of PHENIX experience

U.S.	
France	
Sweden	
Germany	~ None
Israel	
Brazil	
Hungary	
Korea	
Japan	Occasional
Russia	
China	
India	Challenging



Working for PHENIX - Microsoft Internet Explorer

http://www.phenix.bnl.gov/WWW/working-at-bnl/

PHENIX

Working at BNL

(Revised February 2003!)

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? **Check In/Check Out Visit Notification**: All visitors **MUST** do this **BEFORE** each visit to BNL! Please jump to Check In/Check Out or scroll down to text below.

? **Housing**: Normal dorm or housing requests should be directed to the BNL Housing Office. For long-term Team Apartments or summer housing reservations, you must first contact the PHENIX Office .

? **Users Center**: When you arrive to work at BNL for the first time (or if your appointment has expired), please go first to the RHIC & AGS Users Center

? **Required Training:** The minimum requirement to be a PHENIX ***Shift Taker***, ***Shift Leader***, or ***Period Coordinator***, is that you must complete all required Safety Training You may not even make an unescorted visit to PHENIX (Bldg. 1008) without at least the Shift Taker training. For specific work at BNL you may be required to take additional work-related training (e.g., Electrical Safety, Rad Worker, Working at Heights). When in doubt, please ask!

Advance Notice to the PHENIX Office

Summary

- **2000-2004: A period of unprecedented discovery in the initial operation of RHIC**
- **2005-2009: RHIC as the premiere QCD facility in the world**
- **2010-2015: RHIC II as the premiere QCD facility in the world**
- **2015++ : eRHIC and RHIC II as the premiere QCD facility in the world**

With outstanding opportunities for participation in an ongoing program of compelling detector upgrades and compelling physics