PHENIX:
Accomplishments, Status, Perspectives and Issues

W.A. Zajc
for the PHENIX Collaboration

( this talk available at http://www.phenix.bnl.gov/phenix/WWW/publish/zajc/sp/presentations/DOEReviewJul06/ )
Outline

- Accomplishments
  - Past- what made PHENIX PHENIX?
  - Collaboration growth
  - Experiment growth
  - Data set(s) growth
  - PHYSICS IMPACT

- Status
  - Present- what is PHENIX doing?
  - Run-6 achievements

- Perspectives
  - Quo vadis PHENIX?
  - Physics goals
  - Upgrade plans

- Issues
What is PHENIX?

- Pioneering High Energy Nuclear Interaction Experiment

- Goals:
  - Brodest possible study of A+A, p+A, p+p collisions to
    - Study nuclear matter under extreme conditions
    - Using a wide variety of probes sensitive to all timescales
    - Study systematic variations with species and energy
  - Measure spin structure of the nucleon

- These two programs have produced a detector with unparalleled capabilities
Accomplishments
Systematic approach essential:

- **p+p: BASELINE**
  - Establish applicability of pQCD
  - First measurement of $A_{LL}$ ~ gluon polarization

- **d+Au: CONTROL**
  - No suppression in cold nuclear matter

- **Au+Au: NEW EFFECTS**
  - *Strong* suppression in hot nuclear matter
  - Hydrodynamic flow of ~ perfect fluid
PHENIX has an excellent track record of:

- Performing major installations and/or upgrades in each shutdown

while

- Maintaining scientific productivity

See Back-up slides for complete chronology:

- (Most material there provided courtesy of Ed O’Brien, PHENIX Operations Manager)
### Run-1 to Run-3 Capsule History

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<thead>
<tr>
<th>Run</th>
<th>Year</th>
<th>Species</th>
<th>$s^{1/2}$ [GeV]</th>
<th>$\int Ldt$</th>
<th>$N_{\text{tot}}$</th>
<th>p-p Equivalent</th>
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**Run-1**

**Run-2**

**Run-3**
Run-3: Design Configuration!

Central Arm Tracking
- Drift Chamber
- Pad Chambers
- Time Expansion Chamber

Muon Arm Tracking
- Muon Tracker: North Muon Tracker

Calorimetry
- PbGI
- PbSc

Particle Id
- Muon Identifier: North Muon Identifier
- RICH
- TOF
- TEC

Global Detectors
- BBC
- ZDC/SMD Local Polarimeter
- Forward Hadron Calorimeters
- NTC
- MVD

Online Calibration and Production
Run-4 Additions

The Aerogel detector is a threshold Cerenkov counter.
Aerogel is a very low density, SiO₂-based solid.
Aerogel has index of refr. between gases & liquids.
Ident. charged particles in a range inaccessible with other technologies.
TOF-West RPC prototype installed and tested in CuCu running.

Prototype RPC muon trigger chambers.
NSF $1.98M Approved!

**ALSO:**
New LVL1 Triggers (MuID and ERT)
Improved DAQ (>5kHz)
Multi-Event Buffering (95% live)
OnCal calibrations
LVL2 Filtering rare events

Full Aerogel Counter
New Additions for Run-6

- Radiation tests of strip-pixel samples

- Muon Piston Calorimeter (MPC)
  - 192 PbW04 crystals
  - APD read out w. EmCal FEM’s
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<tr>
<td>PHENIX Run Control</td>
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### PHENIX Run Control

- **Command**: run command
- **Control**: run control
- **Download**: run download
- **Exit**: run exit
- **Status**: run status
- **Start**: run start
- **Stop**: run stop

---

**File Options/Mode**

- **Run Number**: 123456789
- **Date/Time/Status**: June 06
- **Event Index**: 0
- **Data Path**: run
- **Run Type**: physics
- **Run Name**: run_name

**Buffer Name**: buffer_name

**Run Control**

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**Run Control**

- **Command**: run_command
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- **Status**: run_status
- **Start**: run_start
- **Stop**: run_stop
Run-6 Accumulations

Transverse Radial Collisions

Longitudinal Collisions

2.7 pb\(^{-1}\) at \(<P> = 0.57\)

7.5 pb\(^{-1}\) at \(<P> = 0.62\)

Days since March 5
Run-6 Data Quality

- Level 2 filter:
  - $\pi^0 \rightarrow \gamma \gamma$
  - $\eta^0 \rightarrow \gamma \gamma$
- Clear $\eta$ peak seen out to $\sim 20$ GeV/c
- Obtained in quasi real-time production on Vanderbilt farm
Raw Data Collected in RHIC Runs

- Plot courtesy of Tom Throwe (RCF)
PHENIX Data Production

- PHENIX is making use of collaboration resources to stay ahead of the incoming data:
  - Run-4 AuAu Data Production at RCF
    - Preliminary results from full dataset for QM05
  - Run-4 Muon Production at Computing Center - France (CC-F)
    - LVL2 filtered production
  - Run-4 pp Production at Computing Center - Japan (CC-J)
  - Run-5 CuCu 200 GeV/62.4 GeV (ORNL farm)
    - LVL2 filtered analysis provided QM05 preliminary results
    - 100 M minbias events produced in counting house (200 GeV)
    - 150 M minbias events produced in counting house (62.4 GeV)
    - Full production at RCF
  - Run-5 CuCu 22.5 GeV
    - All events produced on VA farm in PHENIX Counting House
  - Run-5 pp production at CC-J
    - LVL2 filtered analysis
    - All pp data (270 TB) shipped via network to CC-J during Run-5
  - Run-6 pp production at CC-J
    - LVL2 filtered data run at Vanderbilt
  - Simulation at Vanderbilt, LLNL, New Mexico (all results archived at RCF)

Production for all PHENIX data-sets achieved by start of Run-7
Since 2001:

- 30 PRL’s
- 10 Phys. Rev. C’s
- 3 Phys. Rev. D
- 1 Phys. Lett. B
- 1 Nucl. Phys. A (White Paper)

> 3300 citations

Most-cited paper from RHIC:


12 other papers with > 100 citations
• Summary of PHENIX results from RHIC Runs 1-3
  - 126 pages
  - 56 figures
  - 267 references

• Part of “First Three Years of Experiments at RHIC” special volume in Nuclear Physics A.

• PHENIX paper has already received 185 citations
Perspectives
48 PHENIX physics papers to date either published or submitted to scientific journals

Topics in those papers cover a broad range
- J/ψ production in HI collisions
- High pT suppression and energy loss
- Observation of direct photons
- Elliptic flow including flow of heavy quarks
- Jet behavior
- Charge fluctuations
- Anomalous Baryon/meson ratios
- Double spin asymmetry $A_{LL}$ in polarized proton collision
- Single spin asymmetry $A_N$
- Nuclear modification factors in d-Au collisions

Future topics and the motivation for detector upgrades
- Flavor-tagged high pT physics (Energy loss, baryon/meson anomaly)
- Low mass electron pair continuum (Thermal radiation, chiral symmetry)
- Heavy quark behavior (c, b quark characteristics in dense medium)
- charmonium spectroscopy ($J/\psi$, $\psi'$, $\chi_c$ and $\Upsilon(1s), \Upsilon(2s), \Upsilon(3s)$)
- gluon spin structure ($\Delta G/G$) through g-jet correlations
- quark spin structure ($\Delta q/q$) through W-production
- Transversity
- $A_2$, $p_{T}$, x-dependence of the parton structure of nuclei
- gluon saturation and the color glass condensate at low x
• Outlined in
  □ 150+ pages
  □ 60+ figures
  □ 10+ tables
  □ 160+ references

• Will tour portions of Executive Summary relevant to upgrade plans

• Clearly a synopsis of a synopsis of a . . .
The PHENIX Collaboration has developed a plan for the detailed investigation of quantum chromodynamics in the next decade. The demonstrated capabilities of the PHENIX experiment to measure rare processes in hadronic, leptonic and photonic channels, in combination with RHIC's unparalleled flexibility as a hadronic collider, provides a physics program of extraordinary breadth and depth. 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.
Each of these fundamental fields of investigation will be addressed through a program of correlated measurements in some or all of the following channels:

- Particle production at high transverse momentum, studied via single particle inclusive measurements of identified charged and neutral hadrons, multi-particle correlations and jet production.

- Direct photon, photon+jet and virtual photon production.

- Light and heavy vector mesons.

- Heavy flavor production.
A portion of this program is achievable using the present capabilities of PHENIX experimental apparatus, but the physics reach is considerably extended and the program made even more compelling by a proposed set of upgrades which include:

- An aerogel and time-of-flight system to provide complete π/K/p separation for momenta up to ~10 GeV/c.
- A vertex detector to detect displaced vertices from the decay of mesons containing charm or bottom quarks.
- A hadron-blind detector to detect and track electrons near the vertex.
- A muon trigger upgrade to preserve sensitivity at the highest projected RHIC luminosities.
- A forward calorimeter to provide photon+jet studies over a wide kinematic range.
### Future (Compelling) Physics

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- **Flavor Tagged high pT Physics**
- **Low mass di-electrons**
- **γ-jet, jet tomography, heavy quark spectroscopy**
- **γ-jet, CGC, jet tomography, heavy quark spectroscopy**
- **γ-jet, CGC, W-polarization, jet tomography, heavy quark physics**
- **Quark spin structure, W-polarization**
- **New subsystems, higher luminosity, higher data rates**

**Legend:**
- Red: R&D Phase
- Blue: Construction Phase
- Blue circle: Ready for Data
The Upgraded PHENIX Detector

Charged Particle Tracking:
- Drift Chamber
- Pad Chamber
- Time Expansion Chamber/TRD
- Cathode Strip Chambers (Mu Tracking)
- Forward Muon Trigger Detector
- *Si Vertex Tracking Detector- Barrel (Pixel + Strips)*
- Si Vertex Endcap (mini-strips)

Particle ID:
- Time of Flight
- Ring Imaging Cerenkov Counter
- TEC/TRD
- Muon ID (PDT’s)
- Aerogel Cerenkov Counter
- Multi-Resistive Plate Chamber Time of Flight
- Hadron Blind Detector

Calorimetry:
- Pb Scintillator
- Pb Glass
- Nose Cone Calorimeter

Event Characterization:
- Beam-Beam Counter
- Zero Degree Calorimeter/Shower Max Detector
- Forward Calorimeter

Data Acquisition:
- DAQ Upgrade
“An aerogel and time-of-flight system to provide complete $\pi/K/p$ separation for momenta up to ~10 GeV/c.”

- Project well underway
  - Aerogel completely installed
  - first physics results now available

- TOF-W (‘Time-Of-Flight-West’)
  - Partial funding: J. Velkovska (Vanderbilt) OJI
  - Prototypes tested in Run-5
  - System will be installed in current shutdown
• 48 Scintillator paddles with lead converter at $1 < |\eta| < 3$ for reaction plane measurement
  • Resolution improves by ~ factor 2
  • Trigger counter for low energy running, where $\eta$ is reduced from beam energy

RXNP Installation starts in 2 weeks
“A hadron-blind detector to detect and track electrons near the vertex.”

Dalitz rejection via opening angle
- Identify electrons in field free region
- Veto signal electrons with partner

HBD: a novel detector concept:
- Windowless CF4 Cherenkov detector
- 50 cm radiator length
- CsI reflective photocathode
- Triple GEM with pad readout

Funding: DOE + $250K (NSF) + $100K (Weizmann) + $57K (SUNY-SB)
• Construction completed at the Weizmann

• In the glove box at Stony Brook
“A muon trigger upgrade to preserve sensitivity at the highest projected RHIC luminosities.”

RHIC I Luminosities (2009-12):
- Resistive Plate Chamber technology chosen by PHENIX
  - Cheap – wide coverage possible
  - Can leverage existing RPC R&D from CMS
  - 3-dim space point enhances pattern recognition
- Two small prototypes successfully tested in Run05
- Funded as NSF MRI for $1.98M
  - $100K UIUC
  - $100K UCR
  - $50K ISU
  - $30K RBRC

RHIC II Luminosities (2012+):
- Fast read-out of muTr FEE
- JSPS funding $1.5-2.0M for MuTr trigger (JFY07 start)
Detector R&D at GSU, Nevis, Colorado and UIUC.
“A vertex detector to detect displaced vertices from the decay of mesons containing charm or bottom quarks.”

- ~$3M committed by RIKEN
- MIE proposal submitted to DOE Aug-04:
  - “Project Readiness” review Jan-05
  - Total Project Cost = $4.6M
  - In President’s Budget for FY07
  - Very active ongoing R→D program
- Favorable DOE Review May 4-5, 2006
- Goal: Ready for data-taking in Run-10

- Pixels: active area
  - $\Delta r \Phi$: 1.28 cm = 50 $\mu$m x 256
  - $\Delta z$: 1.36 cm = 425 $\mu$m x 32
- **Baseline:**
  - 4 layers
  - Tilted to make tracks ~normal-incidence
  - 50 mm radial pitch, 7.5° phi segmentation (2 – 13 mm)
  - Maximize z and r extent to give good resolution and ≥3 hits/track as much as possible
  - 2*0.86M channels

- **Scope**
  - Recently favorably reviewed for FY08 start
  - Bootstrapped by LANL LDRD funds to construct one octant prototype
“A forward calorimeter to provide photon+jet studies over a wide kinematic range.”

Forward physics with PHENIX
- Large acceptance calorimeter
- EM calorimeter ~40 X/Xo
- hadronic section (1.6 λ/λo)
- Tungsten with Silicon readout

Extended physics reach with NCC
- Extended A-A program
  - high pT phenomena: π0 and γ-jet
  - χc → J/ψ + γ
- Small x-physics in p-A

Scope
- Recently favorably reviewed for FY08 start
- New expert groups join R&D
  (Moscow State, Czech groups)
- Construction FY08 – FY10
Provides displaced vertex & jet measurement over $2\pi$

- **endcap VTX**: $1.2 < |\eta| < 2.7$
- **barrel VTX**: $|\eta| < 1.2$

Displaced vertex:
- **VTX**: silicon tracker
- **FVTX**: forward Si

Jet measurement:
- **NCC**: nose cone calorimeter

Other detectors:
- **HBD**: hadron blind detector
- **Muon trigger PID in west arm**
(i) $\pi^0$ and direct $\gamma$ with combination of all electromagnetic calorimeters
(ii) heavy flavor with precision vertex tracking with silicon detectors
combine (i)&(ii) for jet tomography with $\gamma$-jet

(iii) low mass dilepton measurements with HBD + PHENIX central arms
Schedule

- 2 central spectrometers
- 2 forward spectrometers
- Forward detectors:
  - Triggering
  - Centrality
  - Local polarimetry
  - Luminosity monitoring

- Runs 4-5: AGEL
- Run-6: MPC
- Run-7: TOF-W
- Run-7: MPC
- Run-7: HBD
- Run-9: muTrig
- Run-10: Si-VTX
- Run-11: FVTX
- Run-11: NCC
- Run-10: muTrig

Years:
- 1999
- 2000
- 2001
- 2002

Dates:
- 24-Jul-06
### Collaboration

- **Institutional Board**

### PHENIX Management

- **Spokesperson** - William Zajc (Columbia U)
- **Dpty Spokesperson** - Yasuyuki Akiba (RIKEN)
- **Dpty Spokesperson** - Matthias Grosse-Perdekamp (UIUC)
- **Operations Manager** - Edward O’Brien (BNL)
- **Upgrade Manager** - Axel Drees (Stony Brook U)

### Executive Council

- **Chief Engineer** - D. Lynch (BNL)
- **DAQ Coor.** - J. Haggerty (BNL)
- **Computing Coor.** - D. Morrison (BNL)
- **Analysis Coord.** - R. Averbeck (Stony Brook)
- **Trigger Coor.** - J. Nagle (UColorado)
- **Run Coord.** - A. Deshpande (Stony Brook)
- **PHENIX Admin** - B. Johnson (BNL)

### Detector Council

### Physics Working Groups

- Members of PHENIX propose upgrade to PM
- EC/DC approve
  - Design
  - Construction
- PM & DC manage project to completion
- Large projects require BNL & DOE approval

### Coordinators
PHENIX view of RHIC Upgrade Plans

- **Near term: Base line**
  - 2004 2005 2006 2007
  - Analysis of data on tape
  - Near term detector upgrades of PHENIX TOF-W, HBD, VTX, μTrig

- **Medium term: first upgrades**
  - 2008 2009 2010 2011 2012
  - Commissioning
  - Long term upgrades FVTX, NCC, ...

- **Long term: full detector and RHIC upgrades**
  - 2013 2014 2015 2016 2017 2018
  - 40x design luminosity for Au-Au via electron cooling
  - RHIC luminosity upgrade

**PHENIX upgrades**

- RHIC baseline program
  - Au+Au ~ 250 μb⁻¹ at 200 GeV
  - Species scan at 200 GeV
  - Au+Au energy scan
  - Polarized protons ≥ 150 nb⁻¹

- Extended program with 1st detector upgrades:
  - Au+Au ~ 1.5 nb⁻¹ at 200 GeV
  - Polarized p at 500 GeV
  - (start p+A program)

- **Full utilization of RHIC opportunities:**
  - Studies of QGP with rare probes: jet tomography, open flavor,
    - J/ψ, ψ', χc, Υ(1s), Υ(2s), Υ(3s)
  - Complete spin physics program p+A physics
Gluon polarization can be measured by double-spin asymmetry $A_{LL}$ of direct photon and heavy quark production in polarized pp collisions.

Jet + direct $\gamma \rightarrow$ constraint on $x_g$

- charm and bottom identification by displaced vertices
- Jet identification with larger acceptance
Complementary Overlaps

- Synergetic overlaps in upgrades greatly improve physics reach

- Example #1: Muon Trigger Upgrade
  - Primary motivation: Improve trigger rejection for W physics in 500 GeV p+p running
  - Collateral benefit: Space-points will greatly enhance pattern recognition in highest multiplicity A+A collisions

- Example #2: NCC + VTX
  - Primary(?) motivation: Allow complete kinematic reconstruction ($x_1$ and $x_2$) in p+p high $Q^2$ events
  - Collateral benefit: A powerful combination for studying wake-fields associated with tagged heavy flavor jets
“The stress tensor of a quark moving through $\mathcal{N}=4$ thermal plasma”, J.J. Friess et al., hep-th/0607022

- Our 4-d world
- The stuff formerly known as QGP
- Jet modifications from wake field
Who?
Collaboration, 2005

- 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, Brehova 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), Universite de Clermont-Ferrand, 63 170 Aubiere, Clermont-Ferrand, France
- Dapnia, CEA Saclay, Bat. 703, F-91191 Gif-sur-Yvette, France
- IPN-Orsay, Universite Paris Sud, CNRS-IN2P3, BP1, F-91406 Orsay, France
- Laboratoire Leprince-Ringuet, Ecole Polytechnique, CNRS-IN2P3, Route de Saclay, F-91128 Palaiseau, France
- SUBATECH, Ecole 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, Varanasi, 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 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
- Physics J 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 "Institution fo 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, Politechnicheskaya, 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
Collaboration Status

- **Healthy**
  - **Wide-ranging participation in**
    - Data analysis
    - Shift support (~300 individuals in Run-6 !)
    - Upgrades program
  - **Continued growth:**
    - Year     Institutions       Nations     Participants
      2001     53                       11                  420
      2003     57                       12                  460
      2005     62                       13                  550
  - **Recent Additions**
    - Jyvaskyla University (Finland)
    - University of Maryland
    - Ehwa Women’s University (Korea)
    - Muhlenberg College
(Partial) Listing of Awards

- Presidential Early Career Awards for Scientists and Engineers
  - V. Cianciolo (ORNL)
  - S. Mioduszewski (BNL)
- Outstanding Junior Investigator (DOE)
  - J. Nagle (Colorado)
  - J. Velkovska (Vanderbilt)
- Sloan Fellowship
  - J. Nagle (Colorado)
- RHIC/AGS Thesis Award
  - J. Burward-Hoy (Stony Brook)
  - H. Sato (Kyoto)
  - C. Klein-Boesing (Muenster)
  - A. Sickles (Stony Brook)
- Sambamurti Award
  - J. Mitchell (BNL)
  - S. Mioduszewski (BNL)
- Gertrude Goldhaber Memorial Award
  - A. Sickles (SUNY-Stony Brook)
- Luise Meyer-Schutzmeister Memorial Award
  - C. Aidala (Columbia)
- “Best Young Researcher”, Westfaelische Wilhelms-University of Muenster
  - K. Reygers (Muenster)
- Intel Science Talent Finalist
  - B. Huang (Longwood High School; Advisor: Prof. T. Hemmick, SUNY-Stony Brook)
Issues
Recently completed survey of projected “Members in Good Standing” (≡ qualifying authors) shows decline in out-years.

Partially expected as European groups emphasize LHC.

Exacerbating factors

- Perception of funding uncertainties for RHIC

Ameliorating factors

- Upgrades program
- Low-energy program at RHIC
- (near-future) Reality of LHC schedule
- (out-years) Reality of LHC priorities (?)
We are still dealing with the impact of past budget uncertainties

- Perception of no long-term future for RHIC
- Will take time (and stable budgets!) to correct

The upgrade program provides clear opportunities for new collaborators

- Again, clear prospects for stable funding necessary for timely progress

Participation by the European DIS community in RHIC spin is hindered by funding agencies

- Negotiation at DOE level may be necessary
For Run-7 and beyond, various PHENIX upgrades become (or are already) available:

- Hadron Blind Detector
- Si-VTX
- Muon trigger
- Nose Cone Calorimeter
- FVTX

These greatly extend our physics reach, and make re-visiting various canonical systems very attractive.

NSAC guidance:

"Invest in near-term detector upgrades of the two large experiments, PHENIX and STAR, to take full advantage of the existing accelerator capabilities."
NSAC Performance Measures

- **Heavy Ion:**
  - e-pair mass spectrum
    - “Hadron Blind” Dalitz pair rejection
  - Open charm measurements in AA
    - High Resolution vertex detection
  - Charmonium Spectroscopy
    - High luminosity; precision vertex, particle ID
  - Jet Tomography
    - High luminosity; increased acceptance; enhanced particle ID
  - Gluon shadowing; low-x in d-Au
    -Particle detection at forward rapidity

- **Spin:**
  - Complete initial $\Delta G/G$ measurement
    - No upgrades needed
  - Transverse spin measurements
    - Forward particle measurement
  - W measurements at 500 GeV
    - Forward tracking/triggering in PHENIX

*DOE performance milestones set by NSAC*
PHENIX successes in Runs 1-6 have paralleled those of the accelerator

Ongoing, productive enterprise engaged in timely publication of an extraordinarily broad spectrum of results (Au+Au, p+p, d+Au)

Proposed upgrades will
- Open new channels for investigation
- Extend investigation of rare processes to address fundamental questions in heavy ion physics
- Extend demonstrated spin physics capabilities to higher $p_T$ and to new channels

Plans provide for a program of continued discovery and extended precision for the next decade
<table>
<thead>
<tr>
<th>Given Name</th>
<th>Family Name</th>
<th>Thesis Topic</th>
<th>Completion Date</th>
<th>Institution</th>
<th>Adviser</th>
<th>Second Adviser</th>
<th>Other Institution</th>
<th>PWG</th>
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<tbody>
<tr>
<td>Andrew</td>
<td>Adare</td>
<td>Jet Physics in 200 GeV Cu+Cu Collisions</td>
<td>2005</td>
<td>University of Colorado</td>
<td>Nagle</td>
<td>Photo/Hard</td>
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<td>Anna</td>
<td>Abulage</td>
<td>Measurement of A_{NN} and A_{CP} through Neutral and Charged Pions</td>
<td>2004</td>
<td>New Mexico State University</td>
<td>Papavassiliou, Liu</td>
<td>Spin</td>
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<td>Abilash</td>
<td>Abatanen</td>
<td>Measurement of A_{NN} for transverse single-spin from 62.4 GeV and 200 GeV collisions</td>
<td>2004</td>
<td>New Mexico State University</td>
<td>Papavassiliou</td>
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<td>Aziz</td>
<td>Al-Jamel</td>
<td>Upsilon production properties from polarized proton-proton collisions at 200 GeV</td>
<td>2004</td>
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<tr>
<td>Stefan</td>
<td>Bathe</td>
<td>Momentum Fluctuations and Production of Neutral Mesons in Ultra-Relativistic Heavy-Ion Collisions</td>
<td>2002</td>
<td>University of Muenster</td>
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<td>Robert</td>
<td>Bennett</td>
<td>Forward-backward spin asymmetry of Photon Production in Polarized Protons at 200 GeV</td>
<td>2002</td>
<td>University of Muenster</td>
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<td>Kieran</td>
<td>Boley</td>
<td>Spin in Polarized Protons at 200 GeV</td>
<td>2002</td>
<td>SUNY-Stony Brook (Physics)</td>
<td>Deshpande</td>
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<td>Heiner</td>
<td>Buesching</td>
<td>Azimuthal Photon Correlations in Ultra-relativistic pA, p+Au and Au+Au Reactions</td>
<td>2002</td>
<td>University of Muenster</td>
<td>Santo</td>
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<td>Jane</td>
<td>Burward-Hoy</td>
<td>Transverse Momentum Distributions of Hadrons Produced in Au+Au Collisions at 130 GeV Measured by the PHENIX experiment at RHIC</td>
<td>2001</td>
<td>SUNY-Stony Brook (Physics)</td>
<td>Jacak</td>
<td>Global/Hadron</td>
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<td>Sergey</td>
<td>Bulayk</td>
<td>Charm production in 200 GeV p+p collisions</td>
<td>2001</td>
<td>SUNY-Stony Brook (Physics)</td>
<td>Averbeck</td>
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<td>Sarah</td>
<td>Campbell</td>
<td>Measuring Double-particle Spin Asymmetry of p+p Production</td>
<td>2001</td>
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<td>Matthew</td>
<td>Clevenger</td>
<td>Nuclear Modification Factor in Semi-leptonic Heavy Flavor decays at 200 GeV</td>
<td>2001</td>
<td>Columbia University</td>
<td>Zeja</td>
<td>Colorado</td>
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<td>Christopher</td>
<td>Clevenger</td>
<td>Heavy Flavor Production and the Reaction Plane in Heavy Ion Collisions at RHIC</td>
<td>2001</td>
<td>Georgia State University</td>
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<td>Yann</td>
<td>Cobigo</td>
<td>Production de J/psi dans les collisions proton-proton de 200 GeV</td>
<td>2001</td>
<td>Columbia University</td>
<td>Dapnia/Adare</td>
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<td>Paul</td>
<td>Constantin</td>
<td>Extraction of all properties from two-particle azimuthal correlations in p+p and Au+Au collisions at √s = 200 GeV</td>
<td>2001</td>
<td>Iowa State University</td>
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<td>Spin</td>
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<td>Kushal</td>
<td>Das</td>
<td>Measurement of Protons via Correlation with the PHENIX Experiment at RHIC</td>
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<td>Florida State University</td>
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<td>Cesar</td>
<td>Lutz</td>
<td>Study of Vector Mesons with the PHENIX Detector</td>
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<td>University of Sao Paolo</td>
<td>Distach, Rosati, Iwa State</td>
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<td>John</td>
<td>Macnab</td>
<td>Longitudinal Double spin asymmetry of Photon Production in Polarized Protons at 200 GeV</td>
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<td>Ben</td>
<td>Maday</td>
<td>Measuring Charged Particle Multiplicity with the Multiplicty and Vertex Detector at the PHENIX Detector at RHIC</td>
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<td>Janice</td>
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<td>Justin</td>
<td>Frantz</td>
<td>Measuring Charged Particle Multiplicity with the Multiplicty and Vertex Detector at the PHENIX Detector at RHIC</td>
<td>2001</td>
<td>UC-Riverside</td>
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<td>Tashina</td>
<td>Ferdousi</td>
<td>Double spin asymmetry in 200 Au+Au collisions</td>
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<td>Sebastian</td>
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<td>Open charm in Cu+Cu at 200 GeV</td>
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<td>Taka</td>
<td>Gaijntvil</td>
<td>Single Muon Production and Implications for charm in 200 + 200 Au+Au Collisions</td>
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<td>University of Tennessee</td>
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<td>Andrew</td>
<td>Glenn</td>
<td>Jet correlations from p+p and Au+Au collisions</td>
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<td>Taku</td>
<td>Gunji</td>
<td>Upsilon Decay in Au+Au Collisions at RHIC</td>
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<td>Takashi</td>
<td>Hachisu</td>
<td>Measurement of charm production in p+p collisions at 200 GeV</td>
<td>2001</td>
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<td>Kimitake</td>
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<td>Study of charm production in p+p collisions at 200 GeV</td>
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<td>Ali</td>
<td>Hamana</td>
<td>Event-by-event fluctuations in relativistic heavy-ion collisions</td>
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<td>Eva</td>
<td>Hanihagai</td>
<td>Measurement of the Partonic Orbital Angular Momentum in the Proton from Two Particle Azimuthal Correlations at PHENIX in Run2</td>
<td>2001</td>
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<td>Andrew</td>
<td>Hooper</td>
<td>The PHENIX Mean Spacetime Intensity and Spin Production in 200 GeV Au+Au collisions</td>
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<td>Takahito</td>
<td>Hirose</td>
<td>Direct photon production in polarized proton-proton collisions at PHENIX</td>
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<td>Keisuke</td>
<td>Hisamatsu</td>
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<td>Ishii</td>
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<td>Xiaoying</td>
<td>Jang</td>
<td>High pT Charged Hadron Suppression in Au+Au Collisions at √s = 200 GeV</td>
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<td>Measurement of J/psi Production in the e+e- Channel in d+Au collisions at √s = 200 GeV</td>
<td>2001</td>
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<td>Measurement of decay and production of polarized proton-proton collisions at PHENIX</td>
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**PHENIX Students (I)**
<table>
<thead>
<tr>
<th>Given Name</th>
<th>Family Name</th>
<th>Thesis Topic</th>
<th>Completion Date</th>
<th>Institution</th>
<th>Adviser</th>
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<td>Young Gook</td>
<td>Kim</td>
<td>PHENIX Event Characterization Using Charged Particle Multiplicities measured with the MVD</td>
<td>2004</td>
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<td>Kim</td>
<td>J/ψ Production in d+Au and p+p Collisions as √s=200 GeV</td>
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<td>Study of Identified Hadron Spectra and Yields at Mid-rapidity in √sNN = 200 GeV</td>
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<td>Production of Neutral Pions and Direct Photons in Ultra-Relativistic Au+Au Collisions</td>
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<td>Study of chiral symmetry restoration in relativistic heavy-ion collisions at RHIC</td>
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<td>Measurements of production cross section of J/ψ in √sNN = 200 GeV Au+Au reactions at RHIC</td>
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<td>J/ψ Production in Heavy ions at RHIC, using PHENIX muon arms</td>
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<td>Paul</td>
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<td>Experimental studies of particle production in ultra-relativistic heavy ion collisions</td>
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<td>Measurement of Vector Mesons in the e+e- Channel in Cu+Cu Collisions</td>
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<td>Photon production in Au+Au Collisions at √sNN = 170 GeV</td>
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<td>J/ψ Production in Cu+Cu Collisions</td>
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<td>Measurement of the spectral shape of light mesons produced in relativistic ion collisions through hadron decay modes</td>
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<td>J/ψ Production in Heavy ions at RHIC, using PHENIX muon arms</td>
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<td>Resonance studies in Heavy ions collisions at RHIC</td>
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<td>Fluctuations in the Charged Particle Multiplicity Distributions</td>
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<td>Study of initial and final state effects in Ultrarelativistic Heavy Ion Collisions</td>
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<td>Spectra of π0’s, η’s and direct photons in 200 GeV Au+Au Collisions</td>
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<td>Azimuthal Correlation and Conditional Yield Measurements in √sNN=200GeV in Au+Au, p+p and p+p Collisions at RHIC</td>
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<td>David</td>
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<td>Aspects of Hadron Production in High Energy Heavy-Ion Collisions</td>
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<td>Catherine</td>
<td>Silvestre</td>
<td>Spectra of J/ψ Production in Au+Au Collisions at RHIC</td>
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<td>Steven</td>
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<td>A scalable analytic model for single event shapes in radiation-hardened field programmable gate arrays in the PHENIX interaction region</td>
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<td>Mikhail</td>
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<td>Charm production in 200 GeV polarized p+p collisions</td>
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<td>Peter</td>
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<td>Single Transverse-spin asymmetry in forward neutron production in p+p collisions at 200 GeV and 410 GeV</td>
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<td>Manabu</td>
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<td>J/ψ Production in Proton-Proton Collisions at √s = 200GeV</td>
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<td>Study of the production of J/ψ’s in the collisions or or to 200 GeV per par e of nucleons ins l’expérience PHENIX</td>
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<td>Thomas</td>
<td>Svensson</td>
<td>Tracking Chambers with 2-Dimensional Readout for the PHENIX Experiment at RHIC</td>
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<td>Quarkonia in Au+Au and Cu+Cu Collisions at 200 GeV</td>
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<td>Oliver</td>
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<td>Azimuthal and direct photon spectra from 200 GeV Au+Au and pp-data</td>
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NSAC Performance Measures

- RHIC program of sufficient breadth that it encompasses two broad categories in the **NSAC Performance Measures**:
  - **Physics of High Density and Hot Hadronic Matter**:
    - ✔ 2005 Measure J/ψ production in Au+Au at $\sqrt{s_{NN}} = 200$ GeV.
    - ✔ 2005 Measure flow and spectra of multiply-strange baryons in Au+Au at $\sqrt{s_{NN}} = 200$ GeV.
    - ✔ 2007 Measure high transverse momentum jet systematics vs. $\sqrt{s_{NN}}$ up to 200 GeV and vs. system size up to Au+Au.
    - 2009 Perform realistic three-dimensional numerical simulations to describe the medium and the conditions required by the collective flow measured at RHIC.
    - ✔ 2010 Measure the energy and system size dependence of J/ψ production over the range of ions and energies available at RHIC.
    - ✔ 2010 Measure $e^+e^-$ production in the mass range $500 \leq m_{e^+e^-} \leq 1000$ MeV/c² in $\sqrt{s_{NN}} = 200$ GeV collisions.
    - 2010 Complete realistic calculations of jet production in a high density medium for comparison with experiment.
    - ✔ 2012 Determine gluon densities at low $x$ in cold nuclei via p+Au or d+Au collisions.
  - **Hadronic Physics**
    - ✔ 2008 Make measurements of spin carried by the glue in the proton with polarized proton-proton collisions at center of mass energy $\sqrt{s} = 200$ GeV.
    - ✔ 2013 Measure flavor-identified $q$ and $\bar{q}$ contributions to the spin of the proton via the longitudinal-spin asymmetry of W production.
- **Conclusion:** *All of the experimental measures listed above are achievable via the proposed program of detector and accelerator upgrades.*
The PHENIX Detector

- Detector Redundancy
- Fine Granularity, Mass Resolution
- High Data Rate
- Good Particle ID
- Limited Acceptance

Charged Particle Tracking:
- Drift Chamber
- Pad Chamber
- Time Expansion Chamber/TRD
- Cathode Strip Chambers (Mu Tracking)

Particle ID:
- Time of Flight
- Ring Imaging Cerenkov Counter
- TEC/TRD
- Muon ID (PDT’s)
- Aerogel Cerenkov Counter

Calorimetry:
- Pb Scintillator
- Pb Glass

Event Characterization:
- Multiplicity Vertex Detector (Si Strip, Pad)
- Beam-Beam Counter
- Zero Degree Calorimeter/Shower Max Detector
- Forward Calorimeter
- Two central arms
  - Mechanically ~complete
  - Roughly half of aperture instrumented
- Global detectors
  - Zero-degree Calorimeters (ZDCs)
  - Beam-Beam Counters (BBCs)
  - Multiplicity and Vertex Detector (MVD, engineering run)
Run-1 Publications

- "Centrality dependence of charged particle multiplicity in Au-Au collisions at $\sqrt{s_{NN}} = 130$ GeV",\footnote{PRL 86 (2001) 3500}
- "Measurement of the midrapidity transverse energy distribution from $\sqrt{s_{NN}} = 130$ GeV Au-Au collisions at RHIC",\footnote{PRL 87 (2001) 052301}
- "Suppression of hadrons with large transverse momentum in central Au-Au collisions at $\sqrt{s_{NN}} = 130$ GeV",\footnote{PRL 88, 022301 (2002)}
- "Centrality dependence of $\pi^{\pm}$, $K^{\pm}$, $p$ and $p\bar{p}$ production at RHIC,”\footnote{PRL 88, 242301 (2002)}
- "Transverse mass dependence of the two-pion correlation for Au+Au collisions at $\sqrt{s_{NN}} = 130$ GeV”,\footnote{PRL 88, 192302 (2002)}
- "Measurement of single electrons and implications for charm production in Au+Au collisions at $\sqrt{s_{NN}} = 130$ GeV”,\footnote{PRL 88, 192303 (2002)}
- "Net Charge Fluctuations in Au+Au Interactions at $\sqrt{s_{NN}} = 130$ GeV,”\footnote{PRL. 89, 082301 (2002)}
- "Flow Measurements via Two-particle Azimuthal Correlations in Au + Au Collisions at $\sqrt{s_{NN}} = 130$ GeV”,\footnote{PRL 89, 212301 (2002)}
- "Measurement of the lambda and lambda$^\pm$bar particles in Au+Au Collisions at $\sqrt{s_{NN}} = 130$ GeV”,\footnote{PRL 89, 092302 (2002)}
- "Single Identified Hadron Spectra from $\sqrt{s_{NN}} = 130$ GeV Au+Au Collisions”, to appear in Physical Review C,\footnote{nucl-ex/0307010}
From Run-1 to Run-2

Run-1 (2000)
PHENIX Detector - First Year Physics Run

Run-2 (2001-2)
PHENIX Detector - Second Year Physics Run
Work in 2001 Shutdown

- Construction, installation and commissioning of South Muon Spectrometer
- Install and commission PC2, PC3 in West carriage
- Install and commission 5 sectors EMCal electronics
- Install and commission 2 sectors TEC electronics
- Commissioning and operation of MVD (Silicon Vertex)
- Commissioning and operation of PHENIX Event Builder
- Commissioning and operation of PHENIX Level2 Trigger
- Completion of RICH electronics
- Major servicing of Drift Chamber East
Run-2 Publications

- "Suppressed $\pi^0$ Production at Large Transverse Momentum in Central Au+Au Collisions at $\sqrt{s_{NN}} = 200$ GeV", *Phys. Rev. Lett.* 91, 072301 (2003)
- "Bose-Einstein Correlations of Charged Pion Pairs in Au+Au Collisions at $\sqrt{s_{NN}} = 200$ GeV" to appear in PRL, [nucl-ex/0401003](http://arxiv.org/abs/nucl-ex/0401003)

Also contains Run-3 d+Au data
Work in 2002 Shutdown

- MuTrk South Spectrometer removal, service and reinstallation
- MuTrk North Spectrometer prep, installation & commissioning
- MuID shielding installation in MuID cutout N&S
- Installation of TRD radiator packs in Time Expansion Chamber
- Install Central Magnet inner coils
- Replace temporary access scaffold with permanent access system
- Modify Central Magnet nosecones
- Install new BBC rack. Move electronics and recable
- Addition of Two Forward Calorimeter for d-A running
- Upgrade to PHENIX safety systems
- Installation of all electronics for Muon North spectrometer arm muTracking + MuID
- Installation of 2 additional planes of electronics for Time Expansion Chamber
- Upgrades to LVL1 Trigger system (NTC, ZDC, EMCal/RICH, MuID)

PHENIX baseline detector was declared COMPLETE at the beginning of Run-3
Run-3 Publications

- "Absence of Suppression in Particle Production at Large Transverse Momentum in $\sqrt{s_{NN}} = 200$ GeV d+Au Collisions”,
  PRL 91, 072303 (2003)
  - PID-ed particles ($\pi^0$) out to the highest $p_T$’s PHENIX’s unique contribution to June ’03 “press event”

- “Double Helicity Asymmetry in Inclusive Mid-Rapidity neutral pion Production for Polarized p+p Collisions at $\sqrt{s}$=200 GeV ”
  - First measurement of $A_{LL}$ at RHIC.

- "Nuclear Modification Factors for Hadrons At Forward and Backward Rapidity in Deuteron-Gold Collisions at $\sqrt{s_{NN}} = 200$ GeV”
  Phys. Rev. Lett. 94, 082302
  - Clever extension of PHENIX hadron capabilities to the muon arms
Work in 2003 Shutdown

- Reinstall Photon Shields
- Muon N&S Servicing
- Complete and commission TRD Xenon system
- West Carriage platforms for Aerogel
- Installation of Aerogel ½ sector
- Complete Inner Coil buswork
- Magnet mapping with Inner Coil
- New MuTracking Gas System
- New IR air conditioning
- Improve IR Rack cooling water
- Improve shielding in the tunnel for Muon Arms
- General Detector Maintenance
- Electronics Maintenance
- Improve TEC LV situation
- Replace Drift Chamber East dc/dc converters
- Fab MuID N LL1 boards
- Finish configuration of gigabit Ethernet EvB switch
- More LVL2 code development
- Fix Pad Chamber Multi-event buffering
- Change Databases (Objy to PostgreSQL)
- Complete installation of TEC/TRD electronics
- Complete ERT/MuID S LL1
- Fab Smart Partitioner Modules for MuTracking
Work in 2004 Shutdown

- General maintenance on PHENIX subsystems
- 2nd ½ of Aerogel Sector completed and installed
- Drift Chamber E Window repair
- DC W dc-dc converter replacement
- Magnet mapping
- Lots of Gas system work
- Extra Tunnel Shielding for Muon Arms
- Fix Multi-event buffering (MuTracker, EMCal)
- Improve FEM Data Formatting (MuTracking, EMCal)
- LL1 trigger work (MuID, ERT)
- EvB improvements (convert to LINUX)
- Implement 4X data buffering capability in 1008 (32 TB)
- TOF-W prototype installed in West Arm
- New Scalers for pp running

Built, install Summer 05
• New Aerogel ½-sector completed and installed
• Multi-event buffering for MuTracking, EMCal implemented
• Event Builder converted to Linux, plus other improvements.
• With DAQ & EvB improvements expect 5+ kHz event recording rate (Data rate max 1 GB/s uncompressed).
• 32 TB additional buffering capacity in 1008.
  – Increase bufferboxes from 4 to 6
• New maps of the magnetic field
• Tests of TOF-West prototype
• Gas system improvements for MuID, TRD
• Additional tunnel shielding for Muon Arms
• LL1 working for MuID and ERT
• Improvements to PHENIX Safety system
• New Scalers available for pp run
Four major “day 1” discoveries

Collective Flow

Jet Quenching

Baryon anomaly

Ideal Hydro Works

Mesons Are Strongly Suppressed

Baryons Not Suppressed

CGC Saturation

“Low” Total Multiplicities

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

PHENIX

Scientific Impact
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 \( \sqrt{s_{NN}} = 130 \text{ GeV} \); **systematic study of same versus energy**.
- **Discovery** of high \( p_T \) suppression in \( \pi^0 \) and charged particle production in Au+Au collisions at \( \sqrt{s_{NN}} = 130 \text{ GeV} \) 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 \( \sqrt{s_{NN}} = 200 \text{ GeV} \).
- **(Co)-Discovery** of absence of high \( p_T \) suppression in \( d+Au \) collisions at \( \sqrt{s_{NN}} = 200 \text{ GeV} \).
- **Discovery** of the anomalously large proton and anti-proton yields at high transverse momentum in Au+Au collisions at \( \sqrt{s_{NN}} = 130 \text{ GeV} \) through the systematic study of \( \pi^\pm, K^\pm, p^\pm \) spectra; **measurement of \( \Lambda \) and anti-\( \Lambda \) in Au+Au collisions at \( \sqrt{s_{NN}} = 130 \text{ GeV} \); study of the scaling properties of the proton and anti-proton yields, of \( \Phi \) production and \( d \) and \( d\bar{b} \) production in Au+Au collisions at \( \sqrt{s_{NN}} = 200 \text{ GeV} \).
- **Measurement of HBT correlations** in \( \pi^+ \pi^+ \) and \( \pi^- \pi^- \) pairs in Au+Au collisions at \( \sqrt{s_{NN}} = 130 \text{ GeV} \), establishing the "HBT puzzle" of \( R_{OUT} \sim R_{SIDE} \) extends to high pair momentum; **extension of these results** to \( \sqrt{s_{NN}} = 200 \text{ GeV} \).
- **First measurement** of single electron spectra in Au+Au collisions at \( \sqrt{s_{NN}} = 130 \text{ GeV} \), 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 \( \sqrt{s_{NN}} = 130 \text{ GeV} \); **role of jets in \( p_T \) fluctuations** at 200 GeV.
- Measurements of elliptic flow for charged particles from Au+Au collisions at \( \sqrt{s_{NN}} = 130 \text{ GeV} \) and identified charged hadrons from Au+Au collisions at \( \sqrt{s_{NN}} = 200 \text{ GeV} \) 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 \( \sqrt{s_{NN}} = 130 \text{ GeV} \) and **200 GeV**.
- **First observation** of \( J/\Psi \) production in Au+Au collisions at \( \sqrt{s_{NN}} = 200 \text{ GeV} \).
- Measurement of crucial baseline data on \( \pi^0 \) spectra, \( J/\Psi \) production and direct photon production in p+p collisions at \( \sqrt{s_{NN}} = 200 \text{ GeV} \).
- **First measurement** of direct photon production in Au+Au collisions at \( \sqrt{s_{NN}} = 200 \text{ GeV} \), demonstrating that photon yields scales with the number of binary collisions.
- **First observation** of heavy flavor flow in Au+Au collisions at \( \sqrt{s_{NN}} = 200 \text{ GeV} \).
- **First measurement** of \( A_{LL}(\pi^0) \) in p+p collisions at \( \sqrt{s_{NN}} = 200 \text{ GeV} \).
- **First study** of jet structure of baryon excess in Au+Au collisions at \( \sqrt{s_{NN}} = 200 \text{ GeV} \).
- **First study** of nuclear modification factor in d+Au collisions in forward and backward region at \( \sqrt{s_{NN}} = 200 \text{ GeV} \).
PHENIX has already achieved quite clean single electron measurement from c or b decay. (S/B ~ 2 at pT~2 GeV/c) (left figure)

The main purpose of VTX is to separate c→e and b→e component. This can be achieved by relatively modest DCA resolution. The right plot shows a PYTHIA simulation of DCA distribution of B→e and D→e. The different color corresponds to different DCA resolution (black:0, red: 50μ, green:100μ, and blue: 150μ).

DCA resolution of 150 micron does not make much difference to DCA cuts of 700 micron or larger, where we have clear separation of B and D component.