PHENIX STATUS

W.A. Zajc
Columbia University
for the PHENIX Collaboration
- Collaboration Status
- Experiment Status
- Physics Status
  - Run-1
  - Run-2
  - Run-3
- Future Prospects
  - Physics
  - Upgrades
- Conclusions
**What is PHENIX?**

- **Goals:**
  - Broadest 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
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<td><strong>12 Countries; 57 Institutions; 460 Participants</strong></td>
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*as of July 2002*
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Two winners of the (new) RHIC/AGS Users’ Thesis Award:

2002:
- Jane Burward-Hoy
- Title: “Transverse Momentum Distributions of Hadrons Produced in Au+Au Collisions at 130 GeV Measured by the PHENIX experiment at RHIC BNL”
- Adviser: B. Jacak (SUNY–Stony Brook)

2003:
- Hiroki Sato
- Title: “J/ψ Production in p+p Collisions at \( \sqrt{s} = 200 \) GeV”
- Adviser: K. Imai (Kyoto)
**Shift support:**
- 230 visiting scientists took PHENIX shifts in 2003
- 37 BNL staff took PHENIX shifts in 2003
- 84 paid visitors (could cover per diem, housing, airfare, car)
- ~167 visitors were non-US citizens

**“Essential personnel” (in response to potential SECON1):**
- 106 essential personnel
- 28 BNL employees
- 78 visiting Scientists
- 59 non-US citizen visiting Scientists

**Analysis:**
- BNL staff make up >25% of the essential personnel to run PHENIX
- Non-US citizens from outside institutions make up >50% of PHENIX essential personnel
- ~1/3 of all PHENIX visitors receive some kind of financial support or subsidy.

*PHENIX operations depends in an essential way on the contributions from both many outside institutions and from non-U.S. citizens. Every effort must be made to make access to BNL as straightforward as possible.*
- 2 central spectrometers
- 2 forward spectrometers
- 3 global detectors
Run-3: Design Configuration!

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

Muon Arm Tracking
- Muon Tracker: North Muon Tracker

Calorimetry
- PbGl
- 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-3 to Run-4 shutdown schedule

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>JUNE</th>
<th>JULY</th>
<th>AUG</th>
<th>SEPT</th>
<th>OCT</th>
<th>NOV</th>
<th>DEC</th>
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<tbody>
<tr>
<td>Open Up for Access</td>
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<tr>
<td>Remove Big Rolling Door and Plug Door</td>
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<tr>
<td>East Carriage to Asm. Hall</td>
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<tr>
<td>Test and Remove MVD</td>
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<tr>
<td>Remove MM N &amp; S Lampshades</td>
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<tr>
<td>Complete new A/C Installation in IR</td>
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<td>CM Inner Coil Set up and test</td>
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<td>Coil Bus and Hoses</td>
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<td>Interlocks &amp; Controls</td>
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<tr>
<td>Run &amp; Test</td>
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<tr>
<td>CM Mapping with Inner Coil (All magnets operating)</td>
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<td>Muon Tracking Detector Maintenance</td>
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<tr>
<td>Replace Lampshades when Done</td>
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<tr>
<td>Install Aerogel Detector Infrastructure</td>
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<tr>
<td>Rack Platforms</td>
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<tr>
<td>Racks w/ Power, Water, Cabling etc.</td>
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<tr>
<td>New Access System for West Carriage</td>
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<td>Install Aerogel Detector in West Carriage</td>
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<tr>
<td>East Carriage Detector Maintenance</td>
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<tr>
<td>East Carriage Roll into IR and Set Up</td>
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<td>Install MVD</td>
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<td>Safety System Checkout</td>
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<td>Rebuild and Close Rolling door</td>
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<tr>
<td>BEAM START</td>
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</tbody>
</table>
• Run-1:
  ● Au–Au at 130 GeV
    ◆ Expectation: 20 $\mu$b$^{-1}$
    ◆ Reality: $\sim$ 1 $\mu$b$^{-1}$
    ◆ Output: 11 publications (to date; 1 pending)

• Run-2:
  ● Au–Au at 200 GeV
    ◆ Expectation: 300 $\mu$b$^{-1}$
    ◆ Reality: $\sim$ 24 $\mu$b$^{-1}$
    ◆ Output: 4 submissions (to date; 8 others pending)
  ● p–p at 200 GeV
    ◆ Expectations: 3 pb$^{-1}$
    ◆ Reality: 0.15 pb$^{-1}$
    ◆ Output: 1 submission (to date; 1 other pending)

• Run-3:
  ● d–Au at 200 GeV
    ◆ Expectation: 10 nb$^{-1}$
    ◆ Reality: 2.7 nb$^{-1}$
    ◆ Output: 1 submission (to date)
  ● p–p at 200 GeV
    ◆ Expectation: 3 pb$^{-1}$
    ◆ Reality: 0.35 pb$^{-1}$
    ◆ Output: TBD
<table>
<thead>
<tr>
<th>Run</th>
<th>Year</th>
<th>Species</th>
<th>$s^{1/2}$ [GeV]</th>
<th>$\int Ldt$</th>
<th>$N_{tot}$</th>
<th>p-p Equivalent</th>
<th>Data Size</th>
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<tr>
<td>01</td>
<td>2000</td>
<td>Au-Au</td>
<td>130</td>
<td>1 $\mu$b$^{-1}$</td>
<td>10M</td>
<td>0.04 pb$^{-1}$</td>
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<td>02</td>
<td>2001/2002</td>
<td>Au-Au</td>
<td>200</td>
<td>24 $\mu$b$^{-1}$</td>
<td>170M</td>
<td>1.0 pb$^{-1}$</td>
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<td>p-p</td>
<td>200</td>
<td>0.15 pb$^{-1}$</td>
<td>3.7G</td>
<td>0.15 pb$^{-1}$</td>
<td>20 TB</td>
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<td>03</td>
<td>2002/2003</td>
<td>d-Au</td>
<td>200</td>
<td>2.74 nb$^{-1}$</td>
<td>5.5G</td>
<td>1.1 pb$^{-1}$</td>
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<td>p-p</td>
<td>200</td>
<td>0.35 pb$^{-1}$</td>
<td>6.6G</td>
<td>0.35 pb$^{-1}$</td>
<td>35 TB</td>
</tr>
</tbody>
</table>
Run-1
- 11 publications, 1 submission
- 4 “Top Cites”

Run-2
- Au-Au: 4 submissions
- p-p: 2 submissions

Run-3
- d-Au: 1 submission (accepted)
Run-1 Publications

- “Centrality dependence of charged particle multiplicity in Au-Au collisions at $\sqrt{s_{NN}} = 130$ GeV”, PR L 86 (2001) 3500
- “Measurement of the midrapidity transverse energy distribution from $\sqrt{s_{NN}} = 130$ GeV Au-Au collisions at RHIC”, PRL 87 (2001) 052301
- “Net Charge Fluctuations in Au+Au Interactions at $\sqrt{s_{NN}} = 130$ GeV.” PRL 89, 082301 (2002).
- “Measurement of the lambda and lambda^bar particles in Au+Au Collisions at $\sqrt{s_{NN}} =130$ GeV”, PRL 89, 092302 (2002).
- “Centrality Dependence of the High $p_T$ Charged Hadron Suppression in Au+Au collisions at $\sqrt{s_{NN}} = 130$ GeV” accepted for publication in Physics Letters B (28 March 2003) nucl-ex/0207009
Recent PHENIX results

- **Run-2 final results:**
  - High $p_T \pi^0$ (Au+Au @ 200 GeV): submitted to PRL nucl-ex/0304022
  - High $p_T \pi^0$ (p+p @ 200 GeV): submitted to PRL hep-ex/0304038
  - Elliptic flow of identified particles (Au+Au @ 200 GeV): nucl-ex/0305013
  - J/Psi yields (Au+Au @ 200 GeV): submitted to PRC nucl-ex/0305030
  - J/Psi yields (p+p @ 200 GeV) to be submitted to PRL
  - Inclusive charged particle at high $p_T$ (Au+Au @ 200 GeV) to be submitted to PRC
  - Identified charged particle spectra/yields (Au+Au @ 200 GeV), to be submitted to PRC
  - $p,\bar{p}$ high $p_T$ enhancement (Au+Au @ 200 GeV): submitted to PRL nucl-ex/0305036

- **Run-2 preliminary results:**
  - $dN/dy$ and $dE_T/dy$ (Au+Au @ 200 GeV)
  - $\phi \rightarrow KK$ (Au+Au @ 200 GeV)
  - Event-by-event fluctuations (Au+Au @ 200 GeV)
  - Di-Lepton continuum (Au+Au @ 200 GeV)
  - Two-pion correlations (Au+Au @ 200 GeV)
  - $d$ and $\bar{d}$ bars (Au+Au @ 200 GeV)

- **Run-3 final results:**
  - High $p_T \pi^0$ (d+Au @ 200 GeV) nucl-ex/0306021
  - High $p_T$ inclusive charged particles (d+Au @ 200 GeV) nucl-ex/0306021
Run-2 Au-Au Results on High $p_T$ Yields (Peripheral)

- PHENIX (Run-2) data on $\pi^0$ production in peripheral collisions:
  - Excellent agreement between
    - PHENIX measured $\pi^0$'s in $p$-$p$ collisions
    - PHENIX measured $\pi^0$'s in Au-Au peripheral collisions
    - scaled by the number of collisions over ~ 5 decades
    \[ N_{\text{collisions}}^{70-80\%} = 12.4 \pm 4.2 \]

\[ \frac{1}{[2 \pi p_T^2]} \frac{d^2 N_{\pi^0}}{dp_T^2} (\text{GeV/c})^2 \]

- $\pi^0$ at AuAu 200 GeV [70–80%]
- $\pi^0$ pp at 200 GeV [Ncoll(70–80%) scaled]
- Uncertainty in $N_{\text{coll}}$ pp scaling

PHENIX Preliminary
Q: Do all processes that should scale with $N_{\text{coll}}$ do just that?

A: No!

Central collisions are different.

(Huge deficit at high $p_T$)

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?
Is the suppression new?

- Yes—all previous nucleus-nucleus measurements see enhancement, not suppression.
- Effect at RHIC is qualitatively new physics made accessible by RHIC’s ability to produce:
  - (copious) perturbative probes
  - (New states of matter?)
- Run-2 results show that this effect persists (increases) to the highest available transverse momenta
- Describe in terms of scaled ratio $R_{AA}$

$$ R_{AA} \equiv \frac{Yield_{Au-Au \, \text{Events}}}{(A \cdot B)(Yield_{p-p \, \text{Events}})} = 1 \text{ for "baseline expectations"} $$
Discovery of high $p_T$ suppression (Run-1)

Extended to truly high $p_T$ (Run-2)
● d-Au proposed as a critical test of the suppression

- 2.7 nb⁻¹ collected in Run-3
- Recall this ~equivalent to Run-2 Au-Au “parton-parton” flux

$p_T$ spectra of similar reach

PHENIX Collab. submitted to PRL
nucl-ex/0306021
Is $d+A$ a good approximation for $p+A$?

- **Min Bias:**
  - 1.7 deuteron participants
  - 8.5 collisions
  - 5 coll./part.

- **Tagged neutron:**
  - 1.0 deuteron participants
  - 3.6 collisions
  - 3.6 coll./part.
$R_{AA}$ vs. $R_{dA}$ for Identified $\pi^0$

Initial State Effects Only

Initial + Final State Effects
- Dramatically different and opposite centrality evolution of \( \text{Au} + \text{Au} \) experiment from \( \text{d} + \text{Au} \) control.
- Jet Suppression is clearly a final state effect.
“Truly delighted by this news and very proud of the achievement.”
  - R. Orbach (via Peter Rosen)

“My own congratulations on what appears to be the discovery of a new phenomenon.”
  - Peter Rosen

“...the data came out remarkably fast—it’s truly impressive.”

“This milestone is what RHIC was built to do”

“It has the potential for changing the way we look at the universe”
  - Dennis Kovar
2002–2003 p+p run

- Integrated luminosity 350nb\(^{-1}\) from 6.6\(\times\)10\(^9\) BBC LL1 triggers
- Average polarization \(~27\%\)
- Figure of merit
  \[ \int P_Y^2 P_B^2 L dt = 1.8 \text{ nb}^{-1} \]
Transverse Spin Asymmetries

- **RUN-2**: Neutron asymmetry observed in IP12 while testing a local polarimeter designed to look for $\pi^0$, $\gamma$ asymmetries:

  - "Left-Right" asymmetry measured for different slices in phi:
Successful measurement of forward neutron asymmetry.

Understood (?) in terms of single pion exchange.

Large asymmetry gives good figure of merit for local (PHENIX) polarimetry.

\[ A_N = \frac{1}{P_B} \frac{\sqrt{N_{UL}N_{LR}} - \sqrt{N_{UR}N_{LL}}}{\sqrt{N_{UL}N_{LR}} + \sqrt{N_{UR}N_{LL}}} \]

calculated using square root formula

Local Polarimeter at PHENIX

Spin Rotators OFF

Spin Rotators ON, Current Reversed

Spin Rotators ON, Almost…

Run–3

Spin Rotators ON, Correct!

$P_B = 35.5\%$

$P_B = 37\%$

Essential to success of Run–3 spin physics!
- **Next step:** Measure cross-section as a test for perturbative QCD at
- In Run-2, precise measure of $\pi^0$ cross-section.
- Agreement with pQCD indicates we can extend $A_{LL}$ analysis to lower $p_T$, important for increasing statistical precision with Run-3 data set.

submitted to PRL, hep-ex/0304038
- $\pi^0 A_{LL}$ expectation
- Only the beginning...

$L = 0.35 \text{pb}^{-1}$, $<P> = 27\%$
PHENIX is well suited to the study of spin physics with a wide variety of probes.

- $\Delta G$ with prompt $\gamma$, heavy flavor via electrons, light hadrons
- Anti-quark helicity distribution via $W$ decay
- Transversity
- Physics beyond the standard model

Run–2 gave us a baseline for transverse spin asymmetry and cross-sections (and local polarimetry)

In Run–3, we commissioned with longitudinal polarized protons (successful spin rotators) and took data for our first $A_{LL}$ measurements using $\pi^0$.

We have studied our relative luminosity systematics and can make an $A_{LL}$ measurement that is statistics limited.

We have an upgrade plan that will give us the triggers and vertex information that we need for precise future measurements of $\Delta G$, $\Delta q$ and new physics at higher luminosity and energy.
Run–2 p–p: J/ψ Invariant Mass Distribution

Final to be submitted to PRL
Run-2 p-p:
Comparison with Previous Experiments

$\langle p_T \rangle \geVc$

$\sqrt{s} \geV$

Final to be submitted to PRL
Luminosity in RHIC Runs to Date

- **Run-1:**
  - Au-Au at 130 GeV
    - Expectation: 20 \( \mu b^{-1} \)
    - Reality: \( \sim 1 \mu b^{-1} \)
    - Output: 11 publications (to date; 1 pending)
- **Run-2:**
  - Au-Au at 200 GeV
    - Expectation: 300 \( \mu b^{-1} \)
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    - Expectation: 10 nb\(^{-1}\)
    - Reality: 2.7 nb\(^{-1}\)
    - Output: 1 submission (to date)
  - p-p at 200 GeV
    - Expectation: 3 pb\(^{-1}\)
    - Reality: 0.35 pb\(^{-1}\)
    - Output: TBD

Shortfall:
- Factor of 20
- Factor of 12
- Factor of 20 (\(\infty\))
- Factor of 4
- Factor of 9 (30-60)

N.B. “Shortfall” defined wrt “optimistic guidance”
$<p_T> = 1.83 \pm 0.25 \text{ (stat)} \pm 0.20 \text{ (sys)} \text{ GeV}$
Run-2 J/ψ Rapidity Distribution from pp

- Integrated cross-section:
  - $3.99 \pm 0.61 \text{ (stat)} \pm 0.58 \text{ (sys)} \pm 0.40 \text{ (abs)} \mu b$
Run-2 $J/\psi$ Centrality Dependence from Au-Au


Proton

A. Andronic et. Al. Nucl-th/0303036

Final to be submitted to PRC
• Our total dimuon sample from Run-2 pp:

- Compared to ~1/3 of our d-Au sample

```
\[ \sigma = 143 \pm 14 \text{ MeV} \]
```

\(
\sim 211 \, \text{J}/\Psi \)'s

\[ 3.11 \pm .02 \text{ GeV} \]
Conclusions:

- All goals accomplished
- As permitted by available integrated luminosity
- For Au–Au (d–Au) only
- Much remains
- Truly rare probes in Au–Au
- Species scans
- Energy scans

Table 3.1: Physics Variables to be Measured by the PHENIX Experiment

<table>
<thead>
<tr>
<th>Quantity to be Measured</th>
<th>Category</th>
<th>Physics Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e^+e^- \mu^+\mu^-$</td>
<td>BCD</td>
<td>Basic dynamics (T, $\tau$, etc.) for a hot gas, transverse flow, etc.</td>
</tr>
<tr>
<td>$\omega \rightarrow e^+e^-/\omega \rightarrow \pi\pi, \delta \rightarrow \pi\pi$</td>
<td>QGP</td>
<td>Mass shift due to chiral transition (C.T.) [2]</td>
</tr>
<tr>
<td>$B-meson$ width and $m_{B^-}$</td>
<td>QGP</td>
<td>Branching ratio change due to C.T. [3]</td>
</tr>
<tr>
<td>$\phi$ meson yield ($e^+e^-$)</td>
<td>ES</td>
<td>Strangeness production (gg $\rightarrow \phi$)</td>
</tr>
<tr>
<td>$J/\psi \rightarrow e^+e^-$, $\mu^+\mu^-$</td>
<td>QGP, QCD</td>
<td>Yield suppression and the distortion of pr spectra due to Debye screening in deconfinement transition (D.T.) [4]</td>
</tr>
<tr>
<td>$T_\gamma \rightarrow \mu^+\mu^-$</td>
<td>ES, QGP</td>
<td>Thermal radiation of hot gas, and effects of QGP [5, 6, 7]</td>
</tr>
<tr>
<td>$m_{T\gamma} &gt; 3 GeV \rightarrow \mu^+\mu^-$</td>
<td>QCD</td>
<td>A-dependence of Drell-Yan, and thermal $\mu^+\mu^-$ [5, 6, 7, 8]</td>
</tr>
<tr>
<td>$\sigma \rightarrow \pi\pi, e^+e^-, \gamma\gamma$</td>
<td>QGP</td>
<td>Mass shift, narrow width due to C.T. [2]</td>
</tr>
</tbody>
</table>

Phosons

- $0.5 < p_T < 3$ GeV/c $\gamma$ (rate and shape)
- $p_T > 3$ GeV/c $\gamma$
- $\eta, \eta'$ spectroscopy
- $N(\pi^\pm)/N(\pi^0 + \pi^-)$ fluctuations
- High $p_T$, $\pi^0, \eta$ from jet

Charged Hadrons

- $p_T$ spectra for $\pi^\pm, K^\pm, p, \bar{p}$
- $\phi \rightarrow K^+K^-$
- $K/\pi$ ratios
- $\pi^0 + \pi^0$ IIBT
- Antinuclei
- High $p_T$ hadrons from jet

Global

- $N_{ch}$ (total multiplicity)
- $dN/dy, dN/dp_T, dE_T/dy$
- $N_{ch}$ (total multiplicity)
- $dN/dy, dN/dp_T, dE_T/dy$
- $N_{ch}$ (total multiplicity)
- $dN/dy, dN/dp_T, dE_T/dy$
- $N_{ch}$ (total multiplicity)
- $dN/dy, dN/dp_T, dE_T/dy$
- $N_{ch}$ (total multiplicity)
- $dN/dy, dN/dp_T, dE_T/dy$
- $N_{ch}$ (total multiplicity)
- $dN/dy, dN/dp_T, dE_T/dy$

*BCD = Basic collision dynamics. ES = Thermodynamics at early stages. QGP = Effect of QGP phase transition. QCD = Study of basic QCD processes.*
The machine achievements in the first 3 years of RHIC operations have been spectacular:

- 3 different colliding species (Au-Au, p-p, d-Au)
- 3.5 energies for Au-Au (19, 56, 130, 200) GeV
- First ever polarized hadron collider
- Design luminosity for Au-Au
- (Etc.)

Physics has been produced at "all" cross-sections:

- **Heavy Ions**
  - barn: $dN_{ch}/d\eta$ vs $N_{part}$  
    - PRL 86, 3500 (2001)
  - mb : $v_2(p_T)$  
    - nucl-ex/0305013
  - $\mu$b : $R_{AA}(p_T)$  
  - nb : $J/\Psi$ (limit)  
    - nucl-ex/0305030

- **Spin**
  - Life (for $A_{LL}$) begins at ~inverse pb
  - A start from Run-3? (0.35 pb$^{-1}$)

Future output of the program:

- Depends **crucially** on developing large integrated luminosities
- Adversely affected by original 37 weeks ➔ 27 weeks per year
- Enhanced by proposed program of upgrades
Looking Ahead

Runs 4, 5, 6 ... :
(Subject to the usual caveats about surprises and flexibility):

- **Au–Au**
  - Major goal: First definitive measurement of $J/\Psi$ production systematics
  - Also: direct photons, $\gamma"jet", \text{light vector mesons, continuum, } ...$

- **Polarized protons**
  - Major goal: First definitive measurement of $\Delta G$ via $\pi^0$ channel
  - Also: beginning of spin physics with rare probes (direct photons, $J/\Psi$, open charm)

- **Light ions**
  - Full exploration of $J/\Psi$ production versus "$N_{\text{binary}}" \sim A(b) \times \bar{A}(b)$ via a series of shorter (?) runs with light ions

---

N.B.: The complexity of species available at RHIC is *unprecedented for a collider*

⇒ *unprecedented scheduling challenge*
Run 1-5: **EXPLORATION**
- Well underway!
- “Complete” data sets for full energy
  - Au-Au
  - d-Au
- 200 GeV p-p
  - “Complete” data set for A-A comparison
  - Strong start on \( \Delta G \) physics

Run 5-10: **CHARACTERIZATION**
- Ion program
  - Species scans
  - Energy “scans”
  - d-A, p-A
- Spin program
  - “Complete” program of \( \Delta G(x) \) at 200 GeV
  - 500 GeV running, sea quark contributions
  - Study of G(x) via direct photons, heavy flavor (energy scan?)
- Upgrades (as available) to extend reach of both programs

Run 11-15: **EXPLOITATION**
- Full upgrades available
- Repeat “complete” measurements with x10-100 sensitivity
**Observations:**

1) Two-mode running has worked well in initial phase of RHIC Ops to
   - Develop many programs (Au-Au, p-p, d-Au, spin)
   - Identify issues with same

2) It is not conducive to efficient usage of machine in “steady-state”

3) If restricted to 27 weeks/year, a transition to one-mode running will
   a) Create short-term dislocations
   b) Result in greater efficiencies for any luminosity-limited program

4) Alternate solution (as per original 37 weeks/year):
   a) Significant increase in running time per year
   b) Major effort to decrease present long setup times
Upgrades in PHENIX

- **Driven** by (new) physics opportunities
- **Conditioned** by available resources
- **Permitted** by new technologies
- **Endorsed** by Detector Advisory Council:
  - “emphasis will shift toward studies with improved sensitivity for rare phenomena.”
  - 1) Measurement of identified hadron yields in the $p_T$ range 3-10 GeV/c and hadron yields beyond 10 GeV/c
  - 2) Charm ... as a valuable probe of QCD dynamics of hot matter
  - 3) Low mass $e^+e^-$ pairs ... (as) a uniquely sensitive probe of the structure of dense and hot QCD matter
New Physics to be Addressed with an Upgraded PHENIX Detector

- Low mass dilepton pairs
  - Chiral symmetry restoration and modification of $\rho,\omega,\phi$
  - Thermal di-leptons
  - Di-leptons from charm pairs
- Improved measurements of heavy flavor (c,b) production
  - Beauty measurement in Au+Au collisions
  - Energy loss of charm/beauty in hot matter
  - $\Delta G$ measurement by heavy quark production in wide x range
  - Gluon shadowing in wide x range
- Jet studies and $\gamma$-jet correlations
- High $p_T$ identified particles
  - meson/baryon ratio in $p_T>5$ GeV
  - Quark recombination or jet fragmentation?
- Truly rare processes
  - Inclusive particle spectra and direct photons out to high $p_T$
  - Drell-Yan continuum above the $J/\Psi$
  - Upsilon spectroscopy – $\Upsilon(1S),\Upsilon(2S),\Upsilon(3S)$
  - W-production

Measurements complement and enhance the present physics program

- fully exploit existing rare event capabilities of PHENIX
- PHENIX central and muon spectrometer are essential
Upgrades to PHENIX Detector

- High $p_T$ particle Identification
  - Charm/Beauty measurement
    - Silicon Vertex Tracker
  - Low mass di-leptons
    - TPC/HBD
  - High $p_T$ and jets
    - TPC/Silicon Vertex Tracker
  - High $p_T$ muons ($W$, Upsilon)
    - Enhanced muon LVL1 trigger

Vertex Spectrometer
Physics driving Extended Particle Identification

● From the DAC:
  ❏ “Measurement of identified hadron yields in the pT range 3–10 GeV/c and hadron yields beyond 10 GeV/c”
  ❏ Why?:
    ◆ Different flavor yields in Au–Au collisions indicate
      ○ Modified fragmentation functions?
      ○ Recombination of quarks from a plasma state?

● Present capabilities:
  □ π/K to ~ 2 GeV/c
  □ p(π+K) to ~4.5 GeV/c

● Goal: Extend π, K, p separation to ~10 GeV/c
Aerogel together with TOF can extend the PID capability up to 10 GeV/c
Aerogel Status

Prototype test at PHENIX

- R & D ~complete
  - 3 test beam periods at KEK
  - homogenous ~ 15 p.e. over 12x12x12 cm$^2$ block

- Participating institutions
  - BNL, Dubna, Tokyo, Tsukuba

- Schedule:
  - Run-3: Prototype test
  - Run-4: Partial installation
  - Run-5: Full installation

 Prototype installed in West Arm of PHENIX
From the DAC:

- “Charm ... as a valuable probe of QCD dynamics of hot matter”
- Why?
  - Heavy Ions
    - Do heavy quarks lose energy in quark matter?
    - charm can be produced thermally → charm enhancement
    - critical base line for J/ψ and Y production & dilepton continuum
  - Spin
    - Gluon polarization in wide x range

Present capabilities

- via inclusive electrons
- can not distinguish charm and beauty for $p_T > 4$ GeV/c

Goal: separate charm and beauty by vertex tagging
Detection of decay vertex will allow a clean identifications of charm and bottom decays

<table>
<thead>
<tr>
<th>Particle</th>
<th>Mass (GeV)</th>
<th>cτ (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D⁰</td>
<td>1865</td>
<td>125</td>
</tr>
<tr>
<td>D±</td>
<td>1869</td>
<td>317</td>
</tr>
<tr>
<td>B⁰</td>
<td>5279</td>
<td>464</td>
</tr>
<tr>
<td>B±</td>
<td>5279</td>
<td>496</td>
</tr>
</tbody>
</table>

Detection options:
- Beauty and low p_T charm through displaced e and/or μ
- Beauty via displaced J/ψ
- High p_T charm through D → π K

Need secondary vertex resolution < 50 μm

Beauty and high p_T charm will require high luminosity
Charm/Beauty measurements in Au+Au with SVT

- Charm measurement by barrel + central arm

- Au+Au
  - Robust charm/beauty measurement in Au+Au
  - Energy loss of charm at high Pt
  - Energy loss of beauty

- Beauty measurements by barrel + central arm

[Graphs and data points showing charm and beauty distributions]
Proposed Silicon Vertex Tracker (SVT)

Strawman design under investigation

1.2<|\eta|<2.4

Pixel barrels (50 \mu m \times 425 \mu m)
Strip barrels (80 \mu m \times 3 cm)
Pixel disks (50 \mu m \times 2 m m)

~1.0\% X_0 per layer
barrel resolution < 50 \mu m
forward resolution < 150 \mu m
Spin Physics with SVT Upgrade

- Measurement of Gluon polarization by Heavy flavor production
  - c, b → e, μ + displaced vertex
  - B → displaced J/ψ
  - D → Kπ at high pt

- SVT measurement of displaced vertex
  - Improved S/B → higher sensitivity to ΔG(x)
  - Much broader x-range coverage
**Measurement of gluon shadowing with SVT**

- **Heavy-flavor measurement in p+A**
  - Single lepton and J/Ψ with displaced vertex
- **Heavy-flavor production via g+g → q+ ¯q**
- **Extracting gluon structure function nuclei, shadowing**
  - Vertex detector provides broader range in $x$ into predicted shadowing region ($x \sim 10^{-2} - 10^{-3}$)
**Si l i c o n  V e r t e x  T r a c k e r  R & D**

- **Ongoing R&D**
  - Silicon strip sensor development
  - Hybrid pixels (with ALICE and NA60)
  - Design of support structure

- **Critical contributions supported by R&D proposal**
  - Silicon strip readout & integration into PHENIX
  - Hybrid pixel integration, thinning & bump bonding
  - Development of monolithic active pixel sensors
  - Design of support structure including cooling etc

- **Participating institutions**
  - BNL, ISU, Kyoto U., LANL, ORNL, RIKEN, Stony Brook U.
Source test at RIKEN

Beam test at KEK by RIKEN/Kyoto

- Location at KEK-PS T1 beam line
- Various particles (0.5-2.0 GeV/c)
- We put 7 silicon sensors and 3 scintillators for trigger counters
- CAMAC and VME hybrid

σ = 52μ  σ = 35μ  σ = 45μ  σ = 35μ  σ = 49μ
● PHENIX Internal Letter of Intent prepared, presented to collaboration

● Active R&D effort:
  - Ongoing barrel R&D with ALICE & NA60 on pixel detectors
  - Ongoing barrel R&D RIKEN/BNL/ORN1L strip + SVX4
  - Technology research for endcap strips or mini strips (LANL+FNAL (?) )

● Presentation of proposal for barrel to PAC in September including endcap option

● Proposal for barrel to DOE at ~same time

● Within next weeks present drafts of management plan to DOE including WBS structure
Physics Driving
Low-Mass e+e− Pairs

From the DAC:

- "Low mass e+e− pairs ... (as) a uniquely sensitive probe of the structure of dense and hot QCD matter"
- Why?
  - Directly sensitive to
    - In-medium modification of meson masses, widths
    - Chiral symmetry restoration

Present capabilities:

- Very limited (due to unrejected Dalitz and conversion backgrounds)

Goal: Open this channel for exploration at RHIC

Prime goal of future PHENIX program (as anticipated in 1993 CDR)

Prediction at RHIC

Strong enhancement of low-mass pairs

Significant contribution from open charm

Central Au+Au sNN =200AGeV

R. Rapp nucl-th/0204003

Strong enhancement of low-mass pairs

Graph showing distribution of low-mass e+e− pairs with various contributions.
Huge combinatorial pair background due to copiously produced photon conversion and Dalitz decays:

\[ \gamma \rightarrow e^+ e^- \]
\[ \pi^0 \rightarrow \gamma e^+ e^- \]

<table>
<thead>
<tr>
<th></th>
<th>dN/dy</th>
<th>dN/dy</th>
</tr>
</thead>
<tbody>
<tr>
<td>( e^\pm ) from charm ( p_T &gt; 0.2 ) GeV</td>
<td>0.68</td>
<td>0.54</td>
</tr>
<tr>
<td>( e^\pm ) from ( \pi^0 \rightarrow e^+ e^- \gamma )</td>
<td>8.4</td>
<td>1.1</td>
</tr>
<tr>
<td>( e^\pm ) from ( \gamma \rightarrow e^+ e^- ) ( (1.5 \times X_0) )</td>
<td>18</td>
<td>2.25</td>
</tr>
</tbody>
</table>

Need rejection factor >> 90% of \( \gamma \rightarrow e^+ e^- \) and \( \pi^0 \rightarrow \gamma e^+ e^- \)

\[
\frac{S}{B} \text{ improved by} \gg 20
\]
(irreducible background form charm \( \frac{S}{B} \approx 1/8 \))

Tool to rejection background pairs
- pair with small opening angle/or mass

Need Dalitz and Conversion rejection
Dalitz Rejector and Inner Tracker

- Dalitz rejection via opening angle in HBD
  - HBD is a proximity focused Cherenkov detector with ~ 50 cm radiator length
  - Provides minimal signals for charged particles

- inner tracker with fast, compact TPC helps Dalitz rejection via inv. Mass
  - R<70 cm, L<80 cm, T_{drift} < 4 μsec
  - provides tracking through the central magnetic field
  - δp/p ~ 2% p
  - Provides electron ID by dE/dx
  - e/π separation below 200 MeV

Δφ ~ 2π, |η| < 1.0

GEMs are used for both TPC and HBD

partner positron
Additional benefit: High $p_T$ with TPC

PHENIX presently has no tracking inside magnetic field

Decay and conversion background limits the high $p_T$ charged particle measurements

Tracking in the TPC in the magnetic field will eliminate background

Decays

Conversions

PHENIX presently has no tracking inside magnetic field

Decay and conversion background limits the high $p_T$ charged particle measurements

$B^-$ DC

- DC only
- PC1-PC3 matching
- Random background

Momentum resolution by TPC alone

TPC alone can provide a good momentum measurement in large solid angle $\rightarrow$ Jets measurement
Enhanced Physics with a High Precision Vertex and Tracking Detector

- Separation of charm and bottom decays through inclusive electrons (Central Arm)
  - improve measurement accuracy of c and b cross sections to ~ 10%
  - separate c and b in each p_T bin \(\Rightarrow\) flavor dependence of QCD energy loss

- Direct measurement of D mesons
  - combined with particle ID, can measure \(D \rightarrow K\pi\) modes
  - \(p_T\) spectrum of D's, flavor dependence of QCD energy loss

- Open heavy flavor (Muon Arms)
  \(D \rightarrow \mu X, B \rightarrow J/\psi \rightarrow \mu^+\mu^-\)

- Improved momentum resolution for Upsilon spectroscopy

- Enhanced capabilities for spin physics
  wider acceptance (g-jet & jet-jet studies, transversity), b-tagging

- Enhanced physics capabilities for charm and bottom in pA
Hi g h  r e s o lu tio n   po s i tio n me a s u r e m e n ts  b y  zig-zag cathode pad
Fine “Zigzag” pattern

Overall position error: 93µm rms
Including ~ 100µm fwhm x-ray p.e. range, 100µm beam width, alignment errors
HBD test setup and GEM+Csl layout (WIS)

- CsI Photocathode coated on GEM
- CF$_4$ for Cerenkov radiator and detector gas (No UV window)
- Large N$_0$
- Large Gain by triple GEM with CsI in CF$_4$ gas has been observed

![Diagram showing HBD test setup and GEM+Csl layout (WIS)]

![Graph showing effective gain for Triple GEM with CsI in CF$_4$]
• Generic detector R&D completed successfully
• Full scale prototype development starts later this year
• Feasibility of HBD without TPC to be studied within next 6 months (as per DAC recommendation)
• Decision on proposal to follow...
Physics Driving an Enhanced First Level Muon Trigger

- From the DAC:
  - “Good vertex identification and a muon trigger will also allow for a significantly improved measurement of the gluon structure of the nucleon and of nuclei by means of heavy quark pair production”
  - Why?
    - W production in pp (@ 500 GeV)
    - single muon (c/b) → gluon shadowing
    - Upsilon spectroscopy in AA

- Goals:
  - LVL1 trigger for high $p_T$ muons with much higher rejection power
  - Present muID Local Level 1 rejection ~500
  - 10,000 rejection required at $2 \times 10^{32}$ cm$^{-2}$s$^{-1}$
  - ~15,000 from muID x Cerenkov

- Status:
  - $120K$ UIUC-NSF, $80K$ UIUC R&D funds
  - NSF MRI to be submitted Jan-04

- Participating institutions:
  - Ecole Polytechnique, Iowa State U., Kyoto U., RBRC, RIKEN, UCR, UIUC, UNM

Simulation: Muon tracking & Cherenkov

- Jet vs W
- Nosecone Calorimeter
- Hodoscope
- Station 1 Anodes
- Cerenkov
- Muon from hadron decays
- Muon from W
- raw decay muons
- with muID lvl1
- with Cerenkov

$p_\mu$ [GeV]
## Time Line for PHENIX Upgrades

<table>
<thead>
<tr>
<th>Year</th>
<th>FY03</th>
<th>FY04</th>
<th>FY05</th>
<th>FY06</th>
<th>FY07</th>
<th>FY08</th>
<th>FY09</th>
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<tbody>
<tr>
<td><strong>R&amp;D</strong></td>
<td>Aerogel</td>
<td>HBD</td>
<td>TPC</td>
<td>Silicon barrel</td>
<td>forward silicon</td>
<td>DAQ/Trigger</td>
<td></td>
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<tr>
<td><strong>construction</strong></td>
<td>Aerogel</td>
<td>HBD</td>
<td>TPC</td>
<td>Silicon barrel</td>
<td>forward silicon</td>
<td>DAQ/Trigger</td>
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<tr>
<td><strong>Upgrade</strong></td>
<td>High p(_T) PID</td>
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<tr>
<td><strong>Physics</strong></td>
<td>Low mass e(^+)e(^-) pair</td>
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<td><strong>Program</strong></td>
<td>Heavy flavor</td>
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<td></td>
<td>Enhanced (\Delta G/G)</td>
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<tr>
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<td>p-nucleus program</td>
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</table>
Upgrades Summary

- **Goal:**
  - extended physics program beyond present PHENIX capabilities

- **Physics observables:**
  - Extended PID at High $p_T$
  - Heavy flavor
  - Low mass lepton pairs
  - High $p_T$ muons ($W$, Upsilon)

- **Required detector additions:**
  - Aerogel Cerenkov
  - Silicon Vertex Tracker
  - HBD/TPC
  - Enhanced muon LVL1 trigger

- **Active R&D program by institutional contributions**
  - Aerogel (BNL, Dubna, Tokyo, Tsukuba)
  - SVT (BNL, ISU, Kyoto, LANL, ORNL, RIKEN, Stony Brook)
  - HBD/TPC (BNL, Columbia, Stony Brook, Tokyo, WIS)
  - Muon trigger (Ecole Polytechnique, ISU, Kyoto, RBRC, RIKEN, UCR, UIUC, UNM)

- **DOE support for upgrade R&D is critical for timely development of this exciting program**
Collaboration Status: Healthy
Experiment Status: Complete
Physics Status: Excellent
  - Run-1: Data analyzed, published
  - Run-2: Data being analyzed, published
  - Run-3: First data analyzed, published

Future Prospects: Tremendous
  - Physics: Critically dependent on integrated luminosity, increased running time
  - Upgrades: Critically dependent on R&D and future funding

Conclusions: (See next slide)
● “The goal of RHIC is not isolated discovery of QGP or anything else. The goal of RHIC is exploration of the complex and ubiquitous environment in which we isolated creatures live”
  J. Marburger

● “It’s very clear a new fundamental phenomenon has been discovered here...I look forward to a future occasion when we’ll hear about such things as J/Ψ suppression or direct photons.”
  Peter Rosen

● “Congratulations, well done, keep up the good work. There’s much still to be done.”
  Dennis Kovar