The Role of the BNL/PHENIX Group in RHIC Research and Experimental Ops: Productivity, Accomplishments and Issues

Group Leaders: M. J. Tannenbaum (scientific staff), C. L. Woody (non-scientific staff), E. O’Brien (deputy)

Speaker: D. P. Morrison, PHENIX Computing Coordinator
The main responsibility of Ed O’Brien (as Ops manager) and many members of the BNL/PHENIX group is the operation of PHENIX.

- PHENIX requires upgrades to improve the physics capability of the detector. The burden to keep new and existing systems running has required greater effort from our group. This has a strong impact on the BNL/PHENIX group's physics research effort.

- The BNL/PHENIX group finds itself under great demand as new detectors are integrated since we provide most of the systems support such as data acquisition, on-line computing, calibration, monitoring, off-line computing and data processing.

- Coping with the increasing ops demand is our major difficulty as we move into the era of ever more refined analyses and detectors.

- Contributions of collaborating institutions with full time presence at BNL are a possible solution (A good example is the Level-1 trigger which was built and is operated by ISU, with a permanent presence at BNL as well as excellent long-distance support), but operating a mature and evolving detector requires a certain expertise that can only be provided by the BNL/PHENIX group.
The Group at a Glance

Research Funding

Group Size

new members (and scope)
from PHOBOS

2 Years Past PhD

42
BNL/PHENIX Group Members

- Recruited by Universities
  - S. Mioduszewski: TAMU (2005)
  - possibly a few more in the works

- S. Aronson former group leader
PHENIX Experiment Organization 2007

PHENIX Management

Spokesperson    Barbara Jacak         Stony Brook U
Operations Manager Edward O’Brien  BNL
Dpty Spokesperson Rich Seto         UC- Riverside
Dpty Spokesperson Yasuyuki Akiba    RIKEN
Dpty Spokesperson Matthias Grosse-Perdekamp UIUC
Upgrade Manager  Axel Drees          Stony Brook U

Coordinators 4/7 BNL

Chief Engineer  D. Lynch  BNL
DAQ Coor.       J. Haggerty BNL
Computing Coor. D. Morrison BNL
Analysis Coor.  R. Averbeck Stony Brook
Trigger Coor.   J. Nagle UCColorado
Run Coor.       M. Leitch LANL
PHENIX Admin    B. Johnson BNL

Executive Council 1/14 BNL

Detector Council 8/24 BNL

Physics Working Groups 1/15 Conveners BNL

PM & Coordinators manage PHENIX
EC advises PM on all Physics matters
DC advises PM on all technical matters
PWGs oversee analyses and paper prep
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<td>Y. Akiba RIKEN</td>
<td>C.Y. Chi Columbia</td>
<td>C. Aidala UMass</td>
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<td>A. Deshpande SUNYSB</td>
<td>O. Draper E Polytech</td>
<td>A. Bazlevsky BNL-Spin</td>
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<td>O. Drapier E Polytech</td>
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<td>S. Bathe UCR</td>
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<td>T. Chuo Tsukuba</td>
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<td>A. Frawley FSU</td>
<td>A. Franz BNL</td>
<td>A. Enokizono LLNL</td>
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<td>T. Hemmick SUNYSB</td>
<td>V. Greene Vanderbilt</td>
<td>J. Franz SUNYSB</td>
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<td>M. Grosse-Perdekamp UIUC</td>
<td>H. Hamagaki CNS-Tokyo</td>
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<td>J. Lajoie ISU</td>
<td>I. Tserruya WIS</td>
<td>T. Hemmick SUNYSB</td>
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<td>A. Lebedev ISU</td>
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<td>D. Lynch BNL</td>
<td>C. Ogilvie ISU</td>
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<td>N. Saito Kyoto</td>
<td>C. Maguire Vanderbilt</td>
<td>K. Ozawa UTokyo</td>
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<td>Y. Miake Tsukuba</td>
<td>T. Sakaguchi BNL</td>
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<td>W. Zajc Columbia</td>
<td>D. Morrison BNL</td>
<td>K. Tanida RIKEN</td>
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<td>B. Johnson* BNL</td>
<td>J. Nagle U. Col.</td>
<td>A. Taranenko SUNYSB</td>
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<td>S. White BNL</td>
<td>M. Purschke BNL</td>
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<td>S. White BNL</td>
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<td>D. Winter Columbia</td>
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* = Chair
* = Secretary
PHENIX: not a typical collider detector

Subsystems originated, built, or operated by BNL/PHENIX group:

- TEC/TRD Time Expansion Chamber
- ZDC/SMD Zero Degree Calorimeter
- On-Line Control System
- Data Acquisition
- EMCal (PbSc)
- Magnets
- Pad Chamber
- Offline Software/Tracking
- Muon Piston Calorimeter
- Reaction Plane Detector
- Hadron Blind Detector
Data Archiving Rates <-> BNL Group

All in MB/sec

- PHENIX Run-2
- PHENIX Run-3
- PHENIX Run-4
- PHENIX Run-5, 6, 7
- ALICE
- CDF
- D0
- LHCb
- ATLAS
- CMS
- STAR
- PHENIX Run-2
- PHENIX Run-3
- PHENIX Run-4
- PHENIX Run-5, 6, 7

PHENIX Integrated Luminosity vs Day

- Integrated Luminosity: 813 μb^-1
- Days Since 3/27/07

- Office of Science
- Brookhaven National Laboratory

9/24
Success of the BNL/PHENIX ops group is indicated by the ever increasing data acquisition rate and the outstanding Integrated luminosity of $813/\mu\text{b}$ recorded in Run-7=$3.4 \times$ Run 4 including the installation and commissioning of 4 new detectors: TOF-W, MPC-N, HBD, RXNP.

BNL/PHENIX ops group is also responsible for managing:

- All PHENIX Collaboration/Experiment activities at BNL
- ~250 PHENIX Visitors to BNL each year
- Safety and Work Planning for all PHENIX activities at BNL
- Coordination of data runs, and shutdown work and all technical activities of PHENIX
- Administration of all publications
- The budgets and schedules for all PHENIX activities at BNL
- Production of all Data
BNL Group plays a leading role in the physics of PHENIX

Research activities in which the group plays a leading role follow from the detector and technical activities and vice-versa:

- high $p_T \pi^0$ and identified hadrons
- direct photons
- charm and $J/\Psi$
- event-by-event averages/fluctuations
- global event characterization
- jet properties via 2-particle correlations

In last year, 25 analyses in PHENIX in various stages of preparation for publication; BNL/PHENIX involved in 14.
π⁰ yield suppressed by factor of five compared to point-like scaling for 3 < p_T < 20 GeV/c

h± and π⁰ behave differently at intermediate p_T 2–6 GeV/c

p±/π± ratio much larger than from jet fragmentation
p & $\bar{p}$ Correlations

submitted to PLB, nucl-ex/0611016

opposite sign pairs: CORRELATED

same sign pairs: NO CORRELATION

consistent with jets: at LEP $p$ and $\bar{p}$ come from same-side jet

$\bar{p}/\bar{p} = 0.25$  $\bar{p}/p = 0.8$

$p-\bar{p}$ pair correlations nearly independent of baryon excess
A new result: $\pi^0 R_{AA}$ 62.4 GeV

Before: p+p reference from fit to ISR data

Now: p+p reference measured at RHIC!

Suppression in 62.4 GeV now approaches 200 GeV result
Theory comparison including systematic error

Presented at QM2006. Journal article to be submitted soon.

Model values from C. Loizides hep-ph/0608133v2

\[ \langle \hat{q} \rangle = 10^{+2.5}_{-1.0} \text{ GeV}^2/\text{fm} \]
$R_{AA}$ vs. reaction plane probes details of theory

$3 < p_T < 5$ GeV/c

$R_{AA}$ is absolute, $v_2$ is relative so no hint of this in $v_2$ measurements. This result also suggests that $v_2$ for $p_T > 2$GeV/c is due to anisotropic energy loss not flow.
The biggest result at QM2006

**QM2005**

p+p dir. γ reference is pQCD

**QM2006**

dir γ reference is run 5 msmt.

If $R^{π}_{AA} = R^{γ}_{AA}$ concept of energy loss changes: perhaps no effect for $p_T > 20$ GeV/c

Au+Au $\sqrt{s_{NN}} = 200$ GeV central collisions
Au+Au results point to need for structure function ratios cut on centrality

\[ R_{AA} = \frac{1}{A_f A_f} \frac{d^2 \sigma_{\gamma}^{AA}}{dp_T^2 dy_{\gamma}} \left|_{f} \right. \frac{d^2 \sigma_{\gamma}^{pp}}{dp_T^2 dy_{\gamma}} \approx \frac{F_{2A}(x_T)_{f}}{A_f F_{2p}(x_T)} \times \frac{g_{A}(x_T)_{f}}{A_f g_{p}(x_T)} \]

Experimental needs: RHIC p+A, eRHIC
$\Delta \phi$ correlations: “shoulder” persists to low $p_T$

$0.2 < p_{T_1}, p_{T_2} < 0.4 \text{ GeV}/c; |\Delta \eta| < 0.1$

Similar structure seen also in 62.4 GeV Au+Au data

nucl-ex/0701062
Muon Piston Calorimeter (MPC): $\pi^0$ $A_N$ at high $x_F$

$p^\uparrow + p \rightarrow \pi^0 + X$ at $\sqrt{s}=62.4$ GeV

- Large asymmetries at forward $x_F$ – possible valence quark effect?
- $x_F$, $p_T$, $\sqrt{s}$, and $\eta$ dependence provide quantitative tests for theories

**PHENIX Preliminary**
- 20% polarization uncertainty on $A_N$ scale
- 10% energy calibration uncertainty on $x_F$ scale

- $3.0 < \eta < 4.0$

$\langle p_T \rangle = 0.56 \ 0.67 \ 0.84 \ 0.98$

process contribution to $\pi^0$, $\eta = 3.3$
$\sqrt{s} = 200$ GeV

**PLB 603,173 (2004)**
Hadron Blind Detector concept for e ID: $\pi^0$ Dalitz rejection

Windowless CF$_4$ Cerenkov detector
CsI reflective photocathode
Triple GEM with pad readout
PHENIX Upgrades

VTX, FVTX and NCC alone and combination make the following measurements possible:

- Heavy quark behavior (c, b quark characteristics in dense medium)
- Charmonium spectroscopy (J/ψ, ψ’, χc and ϒ)
- Gluon spin structure (ΔG/G) through γ-jet correlations
- Transversity
- A-, pT-, x-dependence of parton structure of nuclei
- Gluon saturation, color glass condensate at low x

central region of PHENIX
Issue: the growing Ops burden

• PHENIX in its prime, but needs steady maintenance to sustain optimal performance.

• Many factors tend to increase burden on BNL group
  ✓ Plethora of “smaller” tasks result in inevitable calls on BNL group
  ✓ Increased size and complexity of data sets require additional efforts from DAQ, Trigger, ONCS and Data Production groups. These tasks each contain a large BNL component.
  ✓ New detectors require BNL effort to integrate. Work falls to the home team.
  ✓ Policy changes increase workload (e.g., cybersecurity)

• Incremental increases in responsibilities could be dealt with under a constant effort budget, however flat-flat budgets result in pressure on research activities of the group.
  ✓ officially 50% Ops : 50% Research in recent past.
    • now in 2007 officially 60% Ops: 40% Research
  ✓ “flat-flat” budgets for five years → fairly steady decline in research size of group
  ✓ past reviews have recommended increasing staff
Summary

• PHENIX is operating very well and producing extremely interesting physics results in a timely manner
• The BNL/PHENIX group is very productive, has accomplished a lot, and is crucial both to the operation of PHENIX and to the analyses leading to its highly-cited physics output
• The main issue we face is the continued growth in the fraction of the group’s effort that is devoted to PHENIX operations
• Modest additional support would significantly increase the research productivity of the group
Additional Information
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<td>&quot;Quantitative Constraints on Hot Nuclear Matter Opacity from Semi-Inclusive Single Pion Suppression in Au+Au Collisions at sqrt(s_NN) = 200 GeV&quot;</td>
<td>Nagle(Colorado) Tannenbaum, Buesching, Isobe</td>
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<td>&quot;Enhancement of the dielectron continuum in sqrt{s_NN} = 200 GeV Au+Au collisions&quot; arXiv:0706.3034</td>
<td>Toia (SB), Dahms, Drees, Hemmick, Tserruya</td>
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*Red italic bold means BNL/PHENIX Group major involvement*
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| 74     | "Transverse momentum and centrality dependence of dihadron correlations in Au+Au collisions at sqrt(s_{NN})=200 GeV: Jet-quenching and the response of partonic matter"  
        | arXiv:0705.3238 [nucl-ex]                                             | Jia (BNL-HIRG/SB), Frantz, Lacey, Stankus, Zhang                | Lajoie (ISU), Sickles, Nystrand   |
| 73     | "Elliptic flow of phi meson and deuteron in Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV"  
        | nucl-ex/0703024                                                        | Taranenko (SB), Masui, Esumi, Lacey                             | Fraenkel (WI), Sorensen, Takagui  |
| 72     | "Correlated Production of p and p^{bar} in Au+Au Collisions at sqrt(s_{NN}) = 200 GeV"  
<p>| 71     | &quot;J/psi Production in Cu+Cu Collisions at sqrt(s_{NN}) = 200 GeV&quot;       | Frawley (FSU), Silvermyr (ORNL), Akiba, Das, Xie, Oda, Bickley, Cianciolo, Fleuret, Glenn, Rakotozafindrabe |                                  |
| 70     | &quot;Scaling Properties of Multiplicity Fluctuations in Au+Au and Cu+Cu Collisions at sqrt(sNN)=62 and 200 GeV&quot; | Mitchell (BNL), Tannenbaum, Homma, Nakamura, Armendariz          |                                  |</p>
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<td>Constantin (LANL), Holzmann, Jacak, Lajoie, McCumber</td>
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<td>Averbeck (SB), Akiba, Dion, Kajihara, Sakai</td>
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<td>Akiba (RIKEN), Averbeck, Dion, Kajihara, Themann</td>
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<td>Bazilevsky (BNL-spin), Boyle, Bunce, Deshpande, Fukao, Saito</td>
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<td>Zhang (ORNL), Cianciolo, Nagle, <strong>Sickles</strong></td>
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<td>Frantz (Columbia/SB), Cole, d'Enterria, Klein-Boesing, <strong>Mioduszewski, Tannenbaum</strong></td>
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<td>Matathias (SB), Devismes, Hemmick, Jacak, Velkovska</td>
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<td>Rak(ISU), Ajitanand, Constantin, Jacak, <strong>Tannenbaum, Fields</strong></td>
<td>Kinney(Colorado) Klein-Bosing, Okada</td>
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Detecting electrons means detecting all particles: PHENIX=BNL/PHENIX

- **ElectroMagnetic Calorimeter** measures Energy of photons and electrons
  - reconstructs $\pi^0$ from 2 photons. Measures decent Time of Flight
  - hadrons deposit Minimum Ionization, or higher if they interact
- **For electron ID require RICH (cerenkov) and matching energy in EMCal**
  - Electron and photon energy can be matched to < 1%—No nonlinearity problem
  - momentum +TOF=charged particle ID
  - High Resolution TOF completes the picture giving excellent charged hadron PID
Sideview cut through one TEC/TRD chamber

EMCal energy / momentum counts

No TR cut

TR > 0

TR > 2

TR variable, based on ionization loss along the particle trajectory

Year - 5 pp data

EMCal energy / momentum

TRD fibers
CCRS: Discovery of direct $e^\pm \sim 10^{-4}\pi^\pm$ at ISR

These direct $e^\pm$ are due to semi-leptonic decay of charm particles not discovered until 1976, 2 years later: Hinchliffe and Llewellyn-Smith NPB114(1976)45
QM2006-Direct $e^\pm$ in Au+Au: a theoretical crisis

BNL PHENIX group does not play a leadership role on these analyses at present; but we designed the detector based on our ISR experience so that they could be done. Same for J/$\Psi\rightarrow e^+ e^-$. 

p-p beautiful agreement of $e^\pm$ with $c b$ production PHENIX PRL97(2006)252002

Au+Au PHENIX PRL 98 (2007)172301
p+p collisions at RHIC: $\pi^0$ production

$e^{-5.6p_T}$

$\pi^0$ from p+p at $\sqrt{s}=62$ GeV, PHENIX Preliminary

NLO pQCD
(by W.Vogelsang)
CTEQ6M PDF; KKP FF
$\mu = p_T/2, p_T, 2p_T$

$19\%$ norm uncertainty is not included

\( \pi^0 \) invariant cross section in p-p at \( \sqrt{s}=200 \text{ GeV} \) is a pure power law for \( p_T > 3 \text{ GeV/c} \), \( n=8.10\pm0.05 \). New 62.4 GeV measurement agrees with CCOR shifted up in \( p_T \) by 3.3%.
Theoretical prediction of photon generation in the medium via the partonic reaction $q+g \rightarrow \gamma + q$ predicts opposite $v_2$ for $\gamma$ from hadrons. Not seen to within errors. Needs big improvement. A factor of $\sim 3$ reduction in the errors should be achieved in Au+Au run7: 3x Lums increase together with a new higher resolution reaction plane detector.

Centrality 00-92%:
- Direct photon $v_2$
- Proton $v_2$
- $\pi^0$ $v_2$
Direct $\gamma$ with respect to the reaction plane

Turbide, Gale & Fries, PRL 96 (2006) 032303 predict that if jet(parton) suppression is due to $g+q\rightarrow g+q\ (+g)$ in the medium then the reaction $g+q\rightarrow \gamma+q$ should create a source of direct photons proportional to the distance traversed through the medium-fewer on the mid-plane more vertical, the opposite of $\pi^0$ and other hadronic jet fragments

![Graph](image)
Direct-γ Measurements at QM2006

p_T region in p-p is extended to 24 GeV/c
cf. just published PRL 98 (2007) 012002

QM06: Run-4 Au+Au extended to 19 GeV/c
For Au+Au min bias direct $\gamma$ $R_{AA}$ is simple: given by the Structure function Ratio

$$R_{AA} = \frac{d^2\sigma_{\gamma AA}/dp_T^2 dy_\gamma}{AA d^2\sigma_{\gamma pp}/dp_T^2 dy_\gamma} \approx \left( \frac{F_{2A}(x_T)}{AF_{2p}(x_T)} \times \frac{g_A(x_T)}{Ag_p(x_T)} \right)$$

Do the structure function ratios actually drop by ~20% from $x=0.1$ to $x=0.2$?

\( \omega \) in p-p dAu 3 body decays
p-p correlations
away side ($x_E$) distribution does not measure the fragmentation function* It measures the ratio of $p_T$ of away jet to trigger jet

* contradicts Feynman, Field and Fox, Nucl. Phys. B128(1977)1-65

trigger ($p_{Tt}$) away ($p_{Ta}$)

$$x_E \sim \frac{p_{T_{Ta}}}{p_{T_t}}$$  Ratio of $p_{Ta}$ to $p_{Tt}$ of away side to trigger particles

$$\hat{x}_h = \frac{\hat{p}_{T_{Ta}}}{\hat{p}_{T_t}}$$  Ratio of jet transverse momenta

$n$ is the power of invariant $p_{Tt}$ spectrum

PHENIX
PRD74, 072002 (2006)
Near side and away side correlations the same for meson and baryon triggers (AuAu)

Same jet activity for baryon and meson triggers on both same and away side shows baryon anomaly is not due to recombination
p_{T} Evolution of the Jet Shape

Truncated mean p_{Tb} of head indicates jet energy loss with increasing centrality
Au+Au Centrality-Dependent Multiplicity Distributions

Multiplicity distributions are scaled horizontally to \(N/<N_{\text{ch}}>.\) They are scaled vertically in order of decreasing centrality.

\[
P(m) = \frac{(m+k-1)!}{m!(k-1)!} \left( \frac{\mu}{k} \right)^m \left( 1 + \frac{\mu}{k} \right)^{-m-k}
\]

\[
\frac{1}{k} = \frac{\sigma^2}{\mu^2} - \frac{1}{\mu}
\]

PHENIX Preliminary

Next step after arXiv:0704.2894 subm. PRC fully reconstructed tracks cf. field off stubs
Multiplicity Fluctuations: Universal Scaling?

\[ \left( \frac{\sigma^2}{\mu} \right) / \mu = \frac{1}{k_{\text{NBD}}} + \frac{1}{\mu} = \frac{k_B T}{V} k_T \]

All points are scaled to match the 200 GeV Au+Au data curve to illustrate the scaling.

Data can be described by a power law in \( N_{\text{part}} \):

\[ \frac{\sigma^2}{\mu^2} \propto N_{\text{part}}^{-1.40 \pm 0.03} \]
Above $N_{\text{part}} \sim 30$, the data can be described by a power law in $N_{\text{part}}$, independent of the $p_T$ range down to $0.2 < p_T < 0.5$ GeV/c:

$$\Sigma_{p_T} \propto N_{\text{part}}^{-1.02 \pm 0.10}$$
Tungsten-Silicon Calorimeter
- Combination EM and Hadronic section
- Includes both preshower and shower max sections to optimize $\pi^0$ identification
- Smallest practical Moliere radius needed due to location 40 cm from PHENIX IP
- Covers $2\pi$ in azimuth and $1.0 < \eta < 3.0$

500 um pitch Strips (“StriPixels”)

Silicon pads 1.5x1.5 cm$^2$
Readout in 3 longitudinal units

Depth: $42X_0 \ (1.6 \lambda_{\text{ABS}})$
$R_{\text{Moliere}} \approx 1.8 \text{ cm}$

10 GeV electron

$\sigma_E = \frac{18\%}{E} + 4\%$
Run7 HBD status

Where was problem with the HV protection circuit that was used with the HBD that resulted in damage to many of the GEM detectors inside. These was purely an electrical problem and it was determined that the photocathode quantum efficiency was not affected.

The West HBD was taken out during the run and is currently under repair. The East detector will be removed for repair during the summer shutdown. New GEMs are being produced at CERN, framed in Israel and shipped to the Stony Brook where both detectors will be refurbished.

Several other modifications will also be implemented during the refurbishing, including installation of a reliable HV protection system and internal detector modifications to reduce the sensitivity of the photocathode to scintillation light produced in the radiator gas.

Data from a limited part of HBD (about 1/2 of the full detector) is being analyzed and should produce some preliminary results.
The Image plane

- Start with a GEM
- Put a photocathode on top
- Electron from Cherenkov light goes into the hole and multiplies
- Use more GEMs for larger signal
- Pick up the signal on pads
- And why is it Hadron Blind?
  - Mesh with a reverse bias drifts ionization away from multiplication area
- Sensitive to UV and blind to traversing ionizing particles
The design.

Made of 2 units with R~60cm, the volume is filled with CF$_4$ magnetic field is turned off
Electrons emit Cherenkov light
Cherenkov light is registered by 12 photo-detectors in each unit
Signal is read out by 94 pads in each unit, pad size ~ size of a circle
Accumulating ~36 photoelectrons from each primary electron, while most other operational RICHes have ~15 or less.

High statistics allows to separate 2 close electrons even if their signals overlay!