RHIC Experiments
Physics Department Perspective

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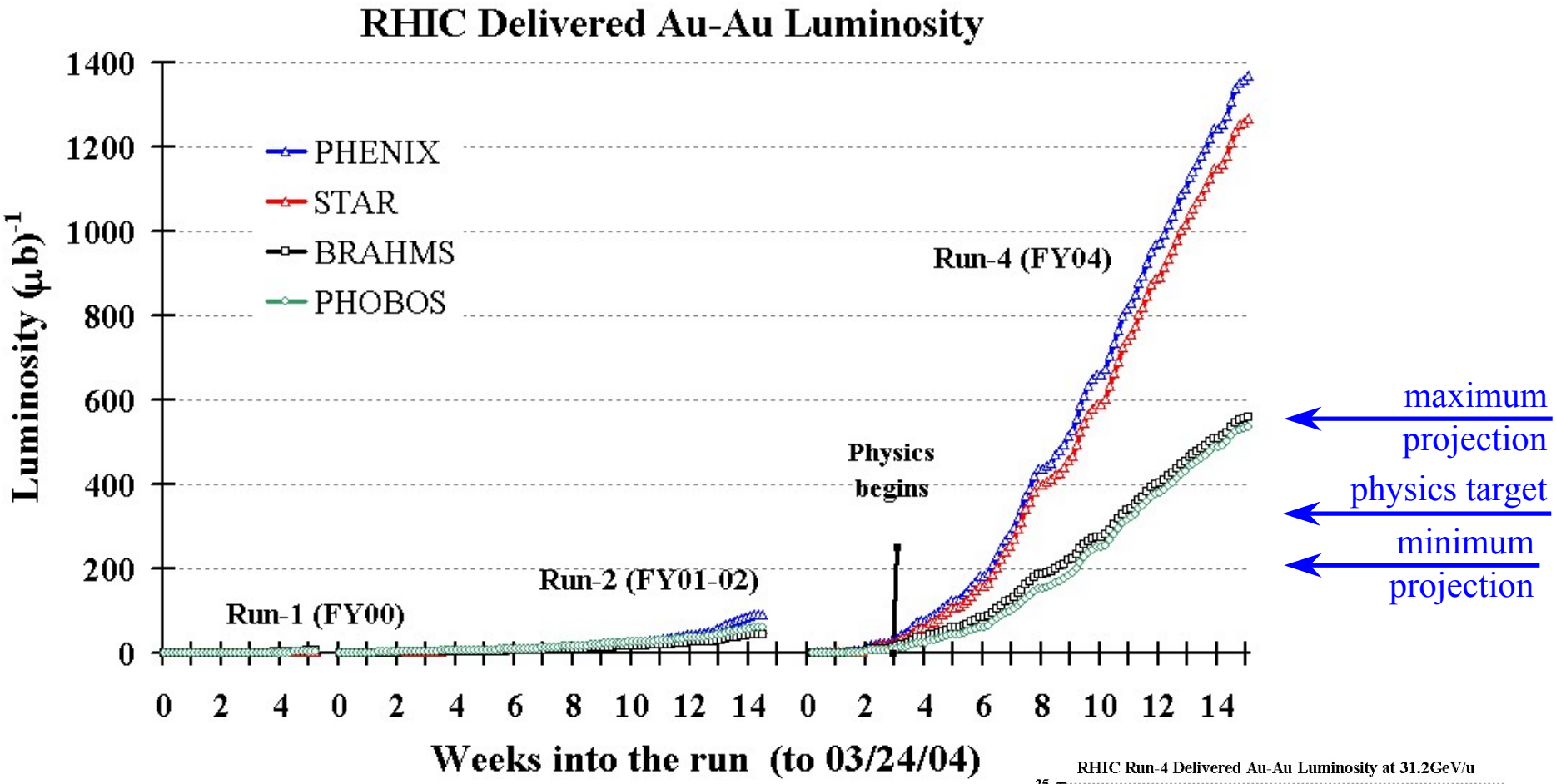
RHIC Program Review
June 30, 2004

Office of Science
U.S. DEPARTMENT OF ENERGY

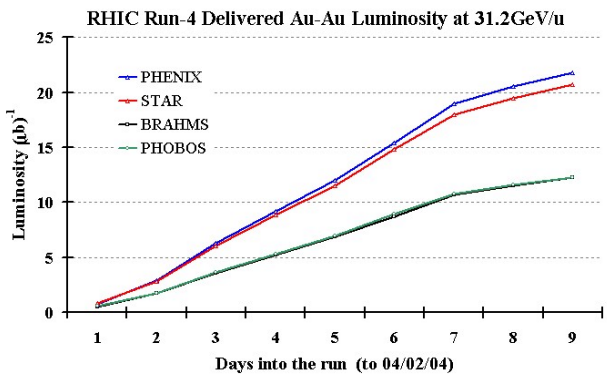
BROOKHAVEN NATIONAL LABORATORY
Brookhaven Science Associates
U.S. Department of Energy

Outline:
A current view of the experimental program at RHIC

- **Recent Progress:**
  - RHIC Run 4
  - Progress toward “Discovery”
  - Recent experimental results
  - Ongoing detector improvements
- **Planned research program**
- **Issues… the Constant Effort budget scenario**
- **Productivity of scientific staff**



	100GeV/u $(\mu b)^{-1}$	Relative to Run-2	31.2GeV/u $(\mu b)^{-1}$
PHENIX	**1370**	**15x**	**21.8**
STAR	**1270**	**21x**	**20.7**
BRAHMS	**560**	**13x**	**12.2**
PHOBOS	**540**	**7x**	**12.3**



The Run 4 Au Au scorecard

STAR:

Beam Use Request Goal	Result
30M central events for D meson spectra	✓ 30.4M recorded
π^0 triggers to p_t = 15 GeV/c	✓ On tape
50 M Min Bias events for Ω flow	✓ 47.5M recorded
>10 M Min Bias events at 62 GeV	✓ 13.3M recorded

PHENIX:

123 μb^{-1} recorded (1640 J/ψ N. arm; π^0 triggers to p_t = 15 GeV/c)	✓ 240 μb^{-1} recorded
45 μb^{-1} recorded at 62 GeV (RUN 6)	9 μb^{-1} recorded

PHOBOS:

110M-240M events	✓ 230M recorded
Charged hadrons to $p_T \geq 4$ GeV/c at 62 GeV	✓ 23M recorded

BRAHMS:

240 μb^{-1} full energy AuAu mapping	✓300 μb^{-1} recorded
15 μb^{-1} at 62 GeV (Run 5)	8 μb^{-1} recorded

Run 4 achievements in spin program

p p development run (see later talks)

- New working points for the machine were demonstrated that work well for both luminosity and polarization improvement.

- Stores were routinely achieved with average L ~ 5×10^{30} $cm^{-2}Sec^{-1}$ with polariztion ~40-45% (This equals the p-p design value for RHIC luminosity at 100+100 GeV. The ultimate luminosity goal for spin is L ~ 20×10^{30} $cm^{-2}Sec^{-1}$.)

- Absolute polarization was measured at RHIC injection and at top energy with the newly installed Hydrogen jet target.

Progress toward "Discovery"

Strong interactions at the RBRC Workshop, May 2004
First look at "white paper" assessments from the collaborations, June 2004

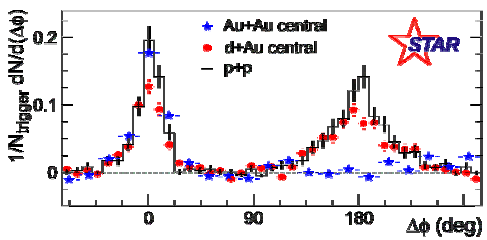
"New forms of QCD Matter Discovered at RHIC"

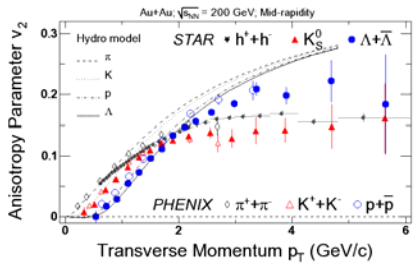
"…in our opinion the case for the QGP is now overwhelming…"
M. Gyulassy and L. McLerran

"[the QGP is] *the most ideal fluid ever formed*" E. Shuryak

"We have *discovered* a strongly interacting medium with extremely *high energy density* whose description in terms of simple *hadronic* degrees of freedom is not appropriate."

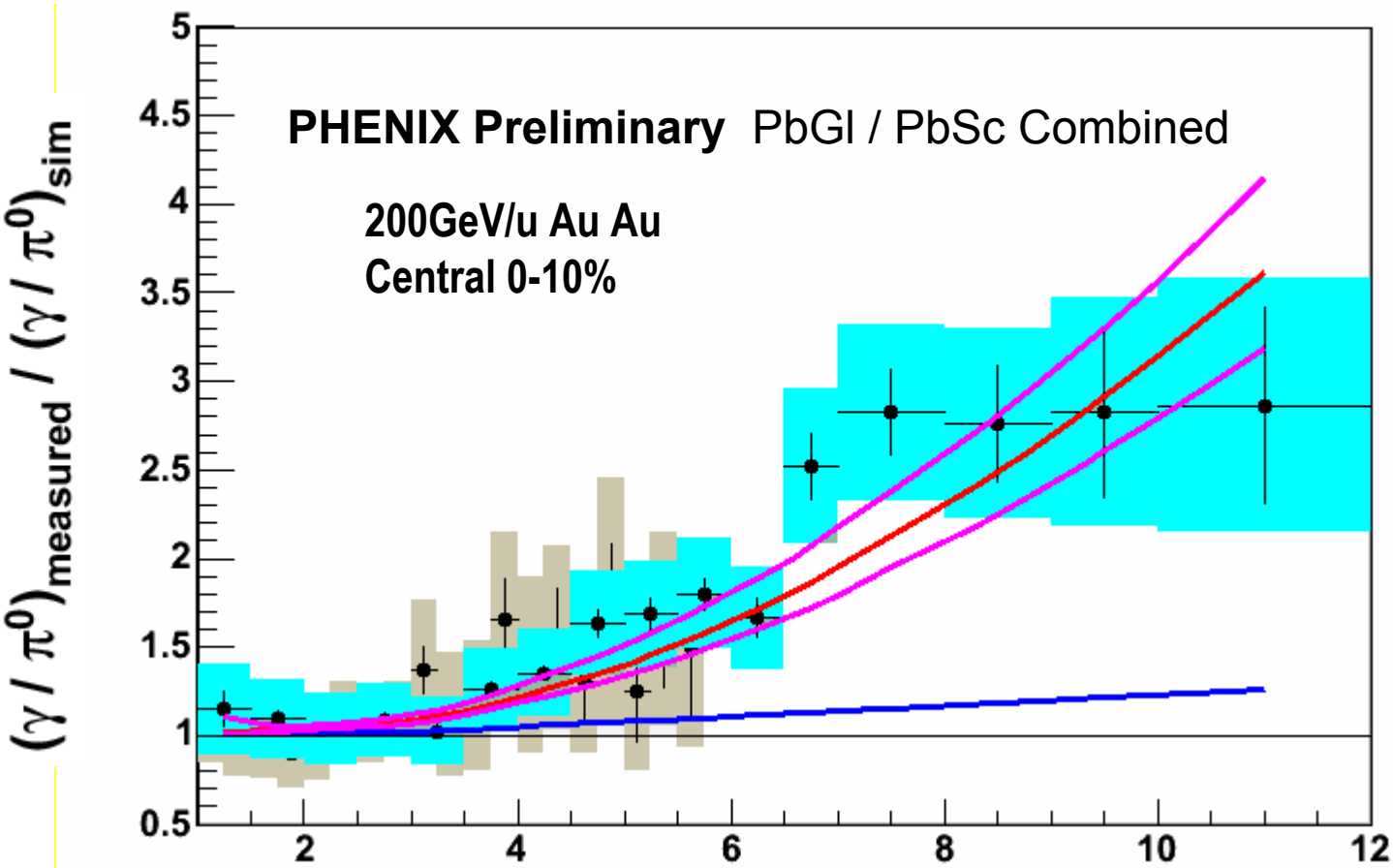
"To date, in Heavy Ion Collisions, *there is no evidence* for the weakly interacting QGP, as naively imagined by a large segment of the community before RHIC turn-on…" W. Busza





Recent Experimental Results…

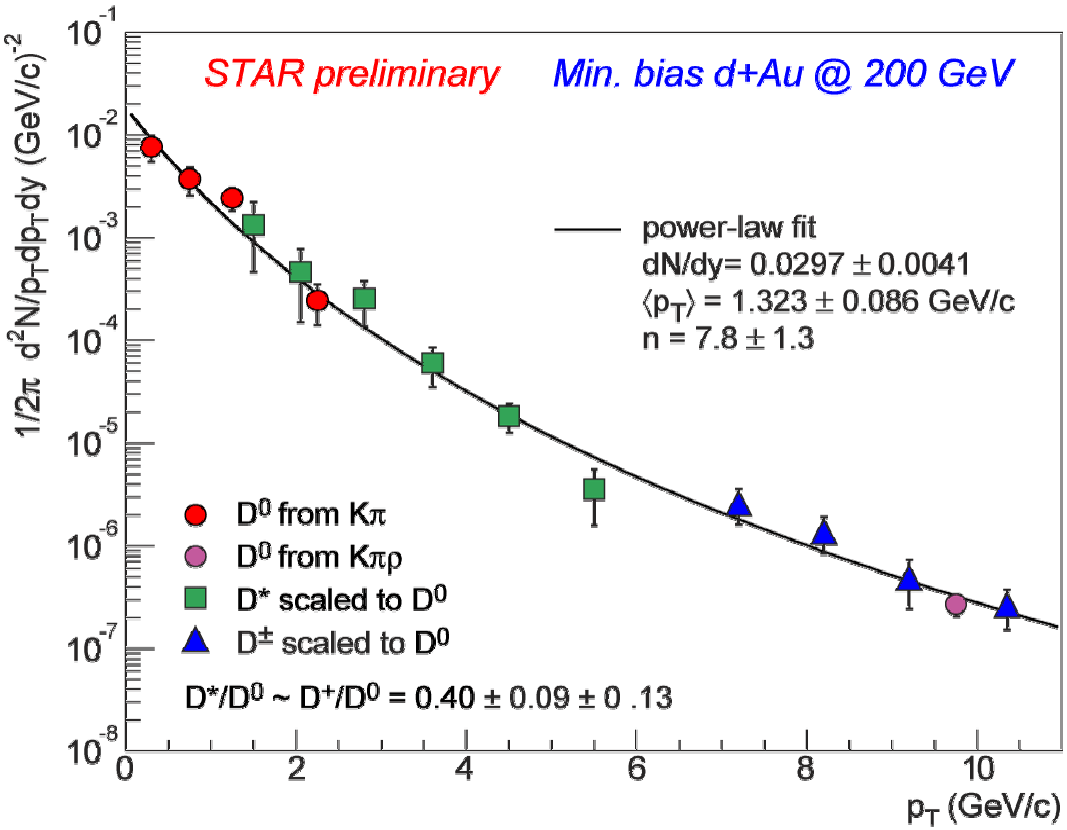
PHENIX: direct photons

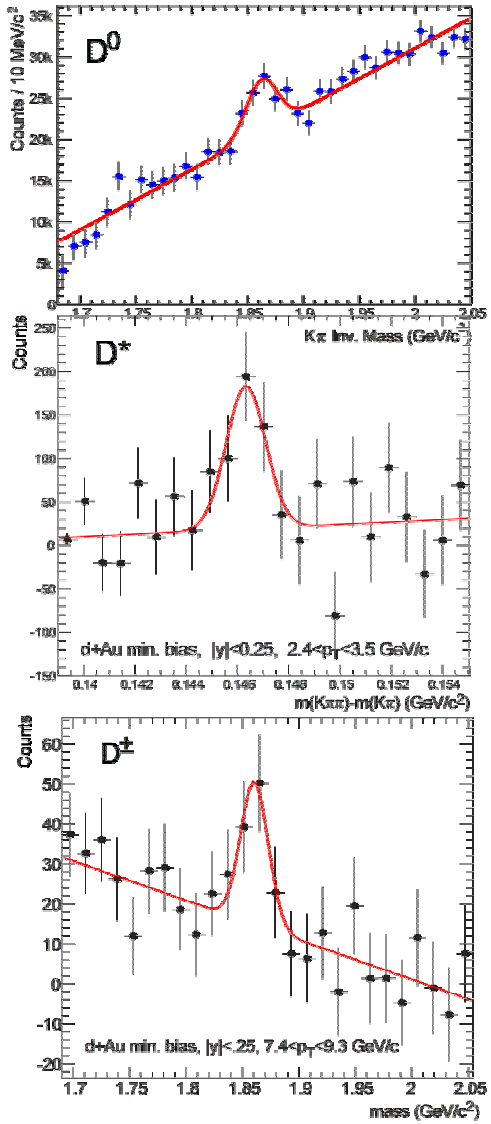


Theory curves based on PQCD calculations (W. Volgelsang)

Recent Experimental Results…
STAR: open charm

Deuteron-Au collisions

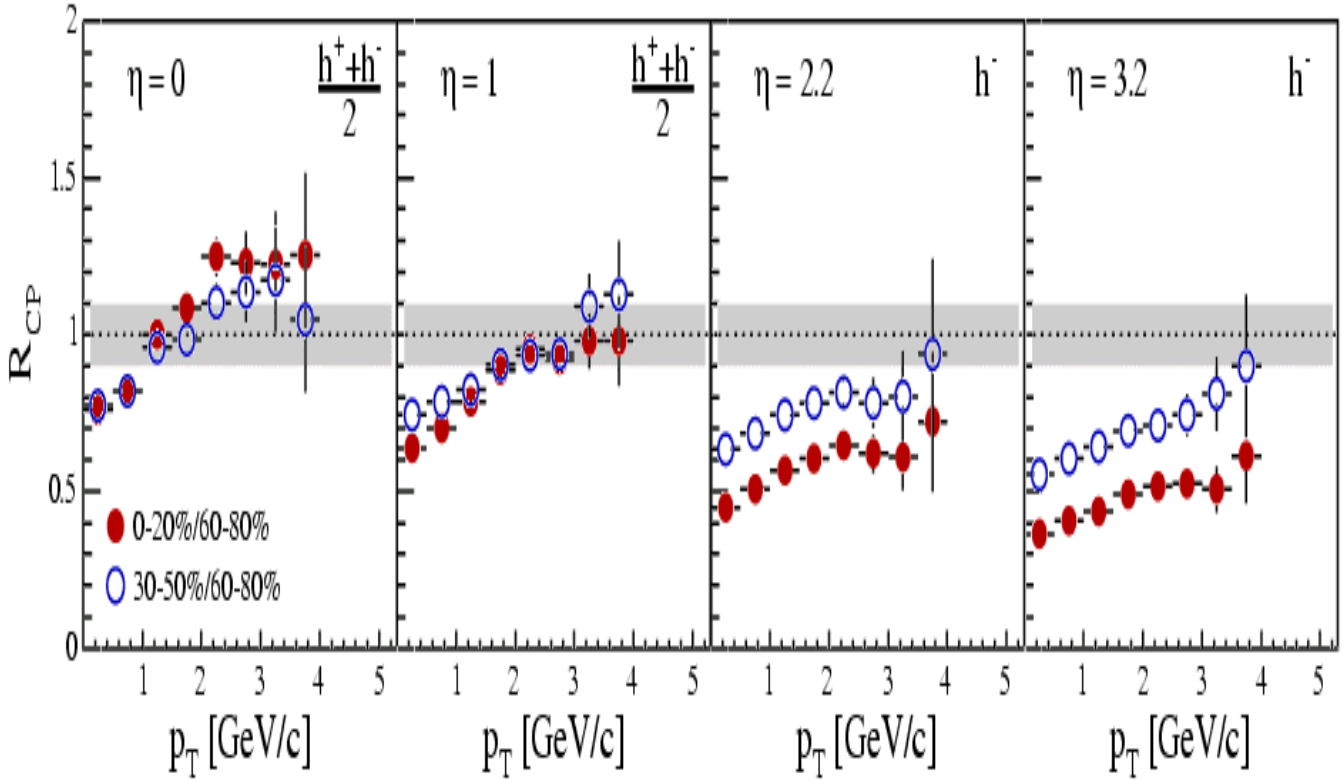




Recent Experimental Results…

BRAHMS: high p_T suppression at large y

Deuteron- gold collisions

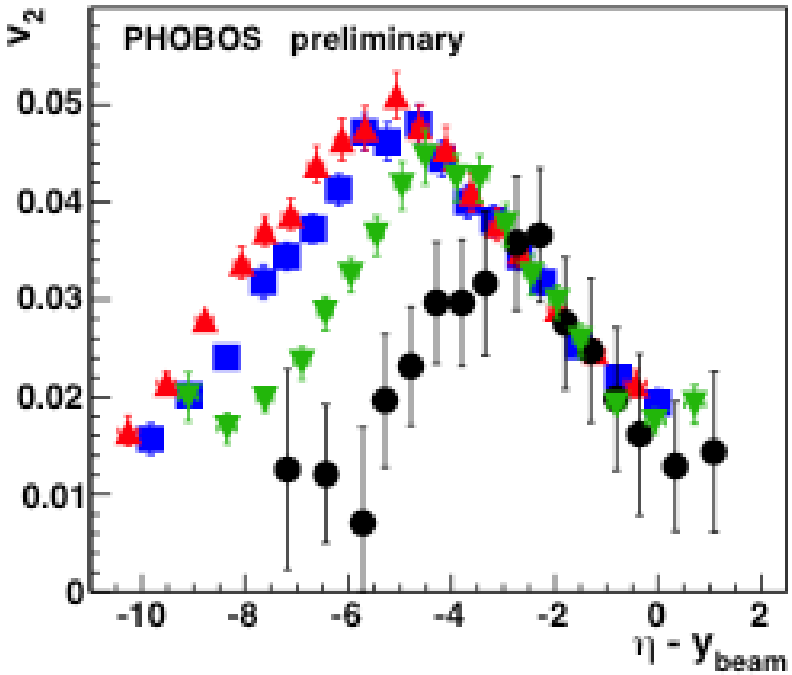


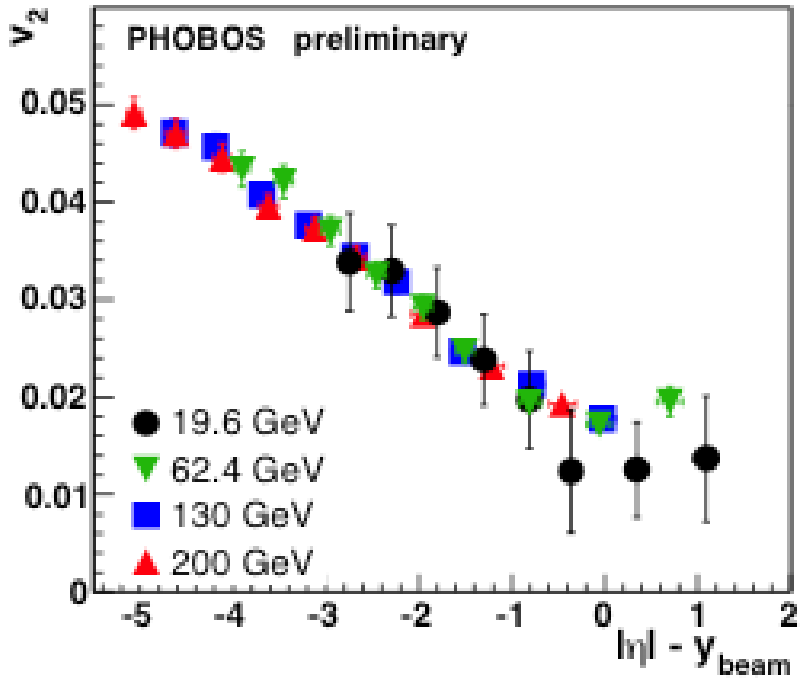
A hint of color glass at small x in d-Au?

Recent Experimental Results…

PHOBOS: energy and pseudorapidity dependence of flow

Au Au collisions, $\langle N_{part} \rangle \approx 200$



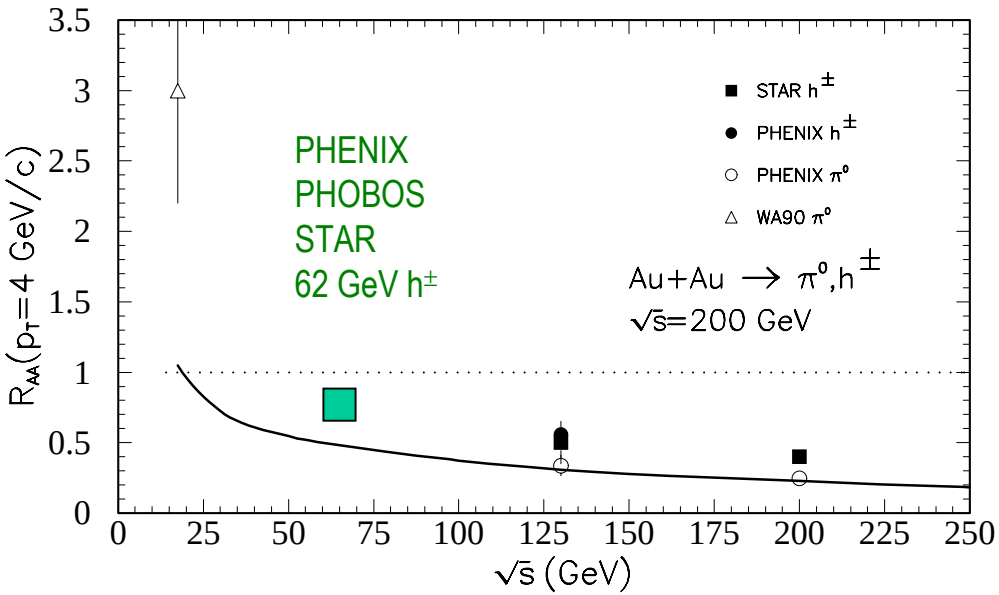


Absence of boost-invariant central region
Limiting fragmentation?

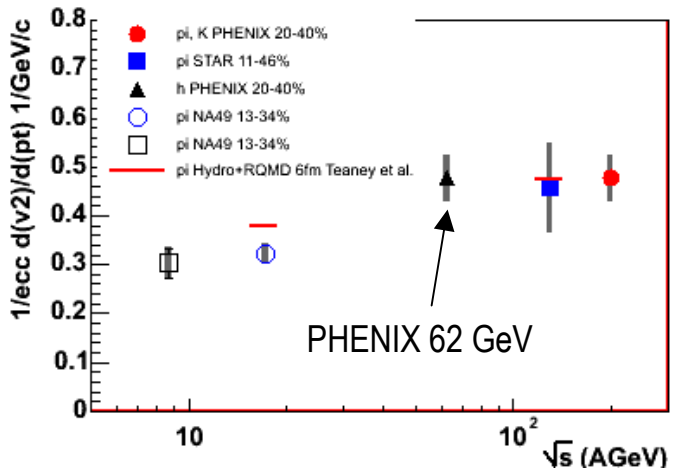
Early Results from Run 4: 62 GeV data

No sharp thresholds seen yet in energy dependence

R_{AA} vs. collision energy

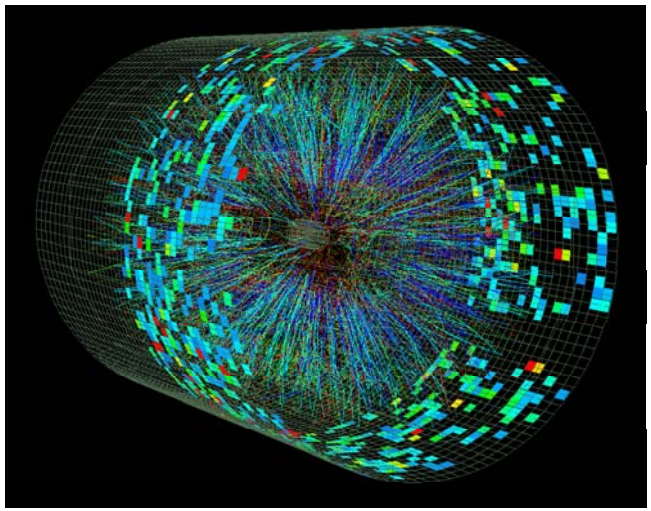


Elliptic flow vs. collision energy



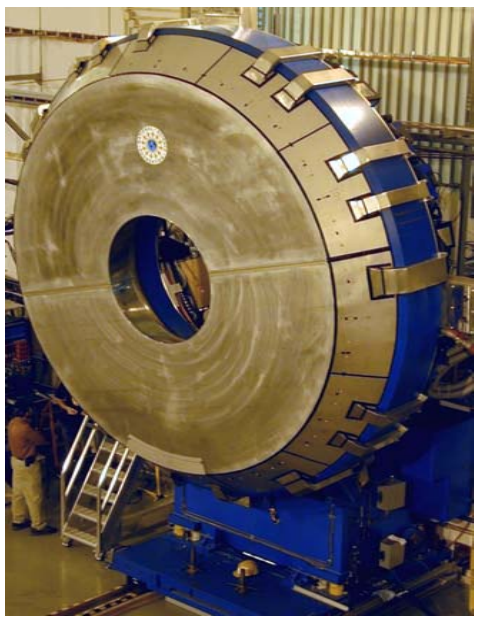
Ongoing detector improvements

STAR Calorimeters

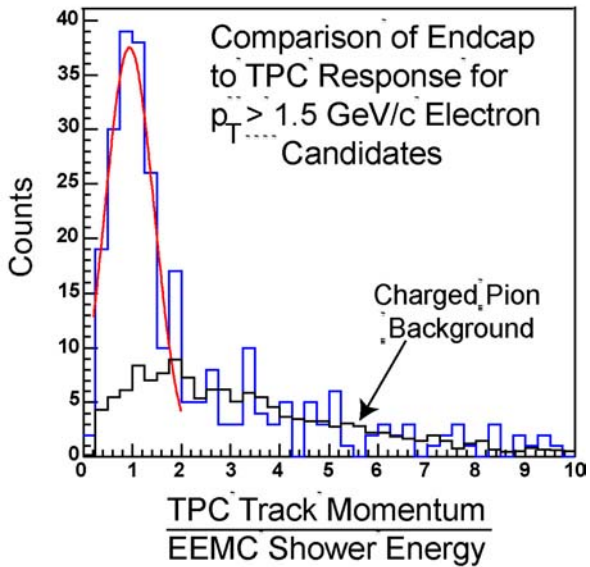


Barrel EM Calorimeter:
70/120 modules installed. 60 modules (1/2 of TPC cylinder) instrumented and active in Run 4.

Provided High p_T and π^0 spectra for Au Au runs

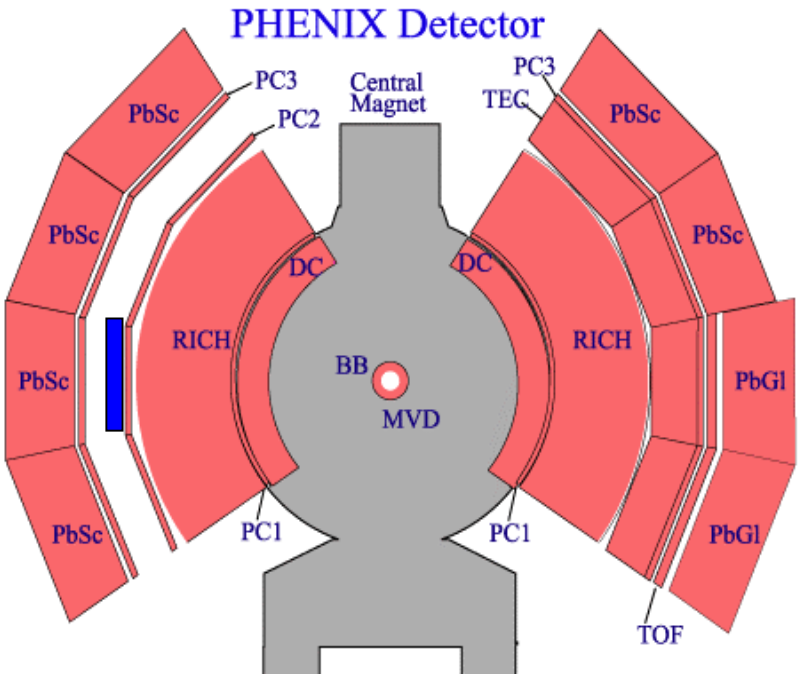


Endcap EM Calorimeter: All active elements installed.

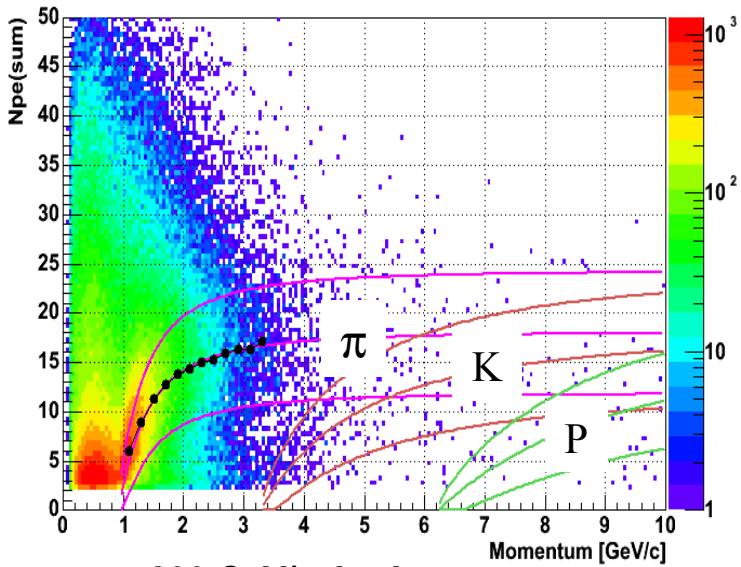


Full tower read-out; 1/3 shower max, preshower, postshower were functional for 2004 run

Ongoing detector improvements



PHENIX Aerogel detector:
½ installed for Run 4.
To be completed for Run 5

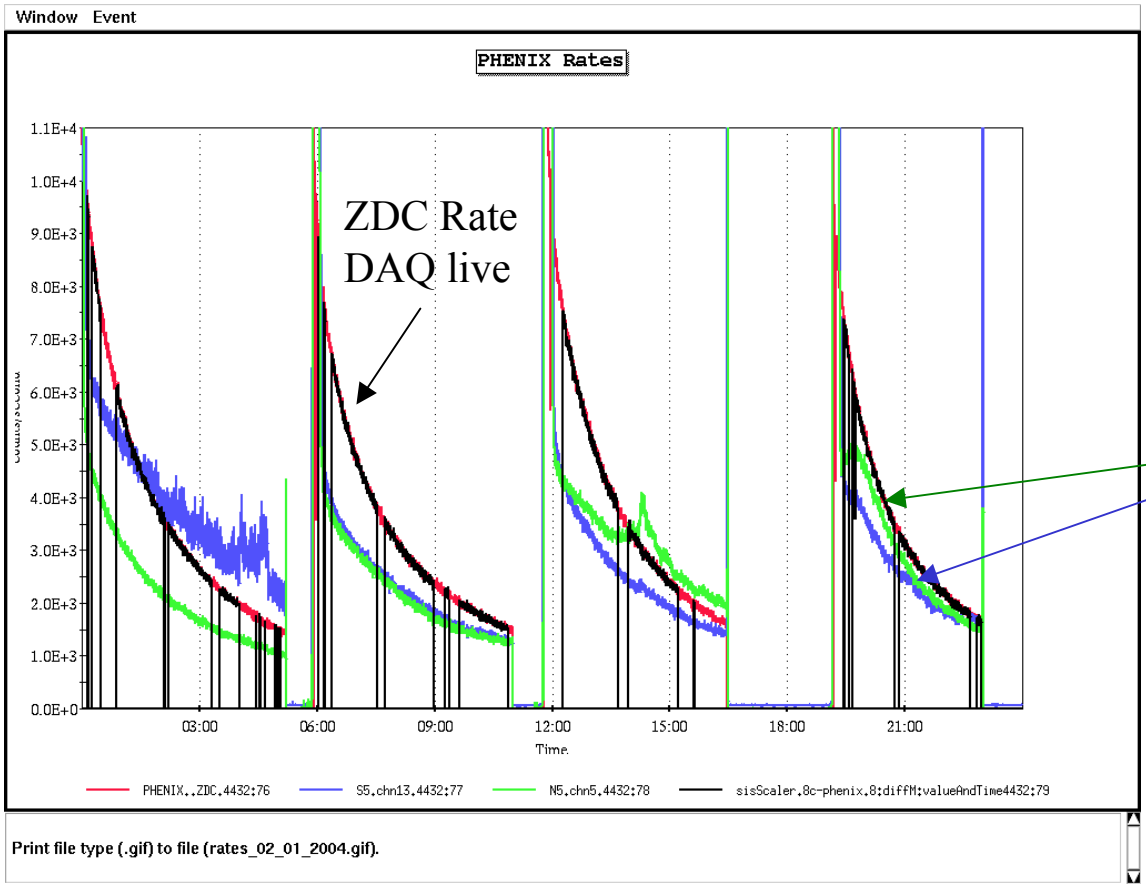


Ongoing detector improvements

Improved backgrounds with PHENIX shielding

A major effort was undertaken by PHENIX and C-A dept. during the summer shut down to reduce beam-related backgrounds that were crippling the MuID detectors

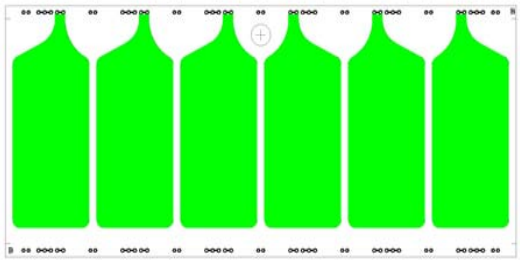
Result: Background Levels @PHENIX good during AuAu and pp Runs

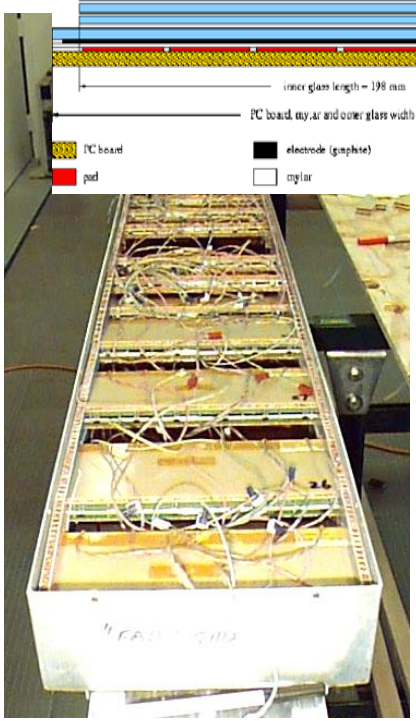


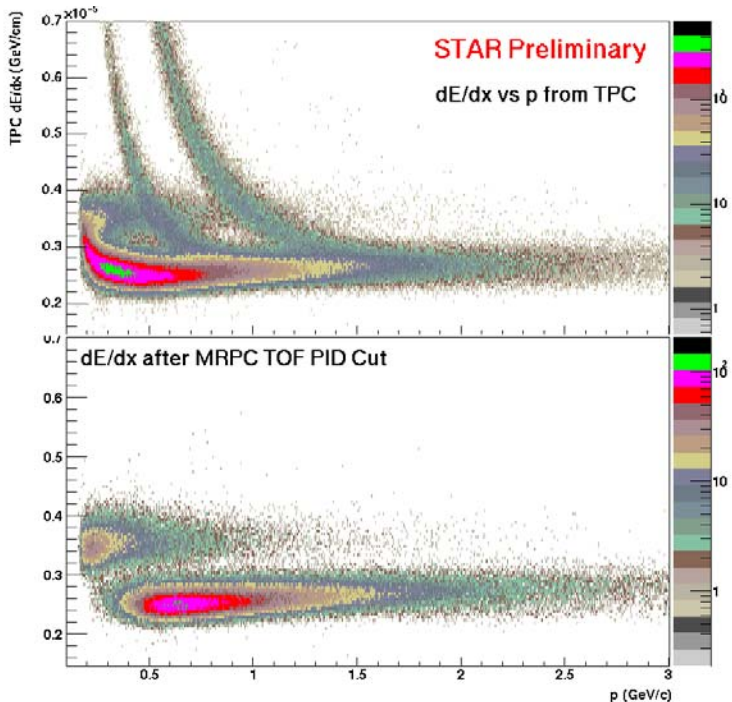
MuID backgrounds

Ongoing detector improvements

STAR TOF prototype

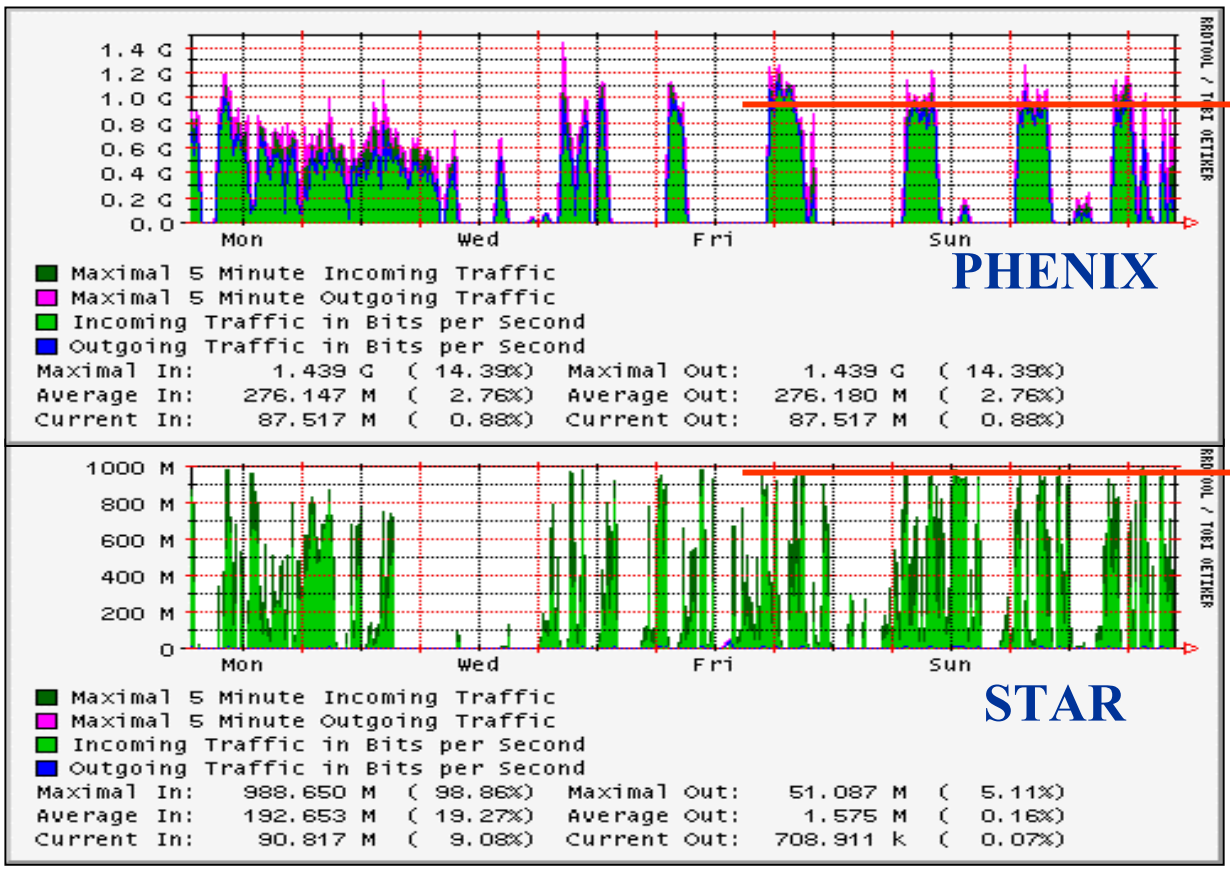






Run 4 Raw Data Recording to RCF

- Aggregate Raw Data 475 TBytes
- Recording Rates to 250 MBytes/sec



120MBytes/sec

120MBytes/sec

RHIC Computing Facility...

Data Transfer and processing from all four experiments.

FY 2004 capacity

- Mass Storage System:
  - 4 StorageTek robotic tape silos **~4.5 PBytes**
  - 40 StorageTek 9940b tape drives **~ 1.2GB/Sec**
- CPU:
  - 2300 CPU Intel/Linux processor farm
    ~1350 kSPECint2000 (~2Tflops)
- Central Disk:
  - 160 Tbytes RAID 5 storage
  - 1.3 Gbyte/sec disk I/O capacity
  - 100 Tbytes distributed disk

Planned research program…Issues

RHIC 20 year plan document, Dec. 2003 www.bnl.gov/henp/

The Critical near-term science goals for RHIC (2004 – 2008):

- Follow up on the watershed results of the first RHIC runs by making definitive experimental statements on the existence of the quark gluon plasma and determining its essential properties

- Obtain spin-polarized p-p data samples of sufficient sensitivity to address the core physics questions of the RHIC spin program, including direct determination of the spin-dependent gluon structure functions

Minimal program to meet the critical goals

- **Last year, the RHIC Planning Group put forth the following run plan to address these two goals:**

Heavy Ions	Physics Data Goals for Experiments
1.	A 200 GeV Au Au run (>300 μb^{-1}) in 2004 to follow-up on high p_T results, and get the first sizeable sample of J/ψ.
2.	Energy scan run: Au Au at 1 or 2 lower energies. 50-100 μb^{-1} total
3.	Species scan run: 1 – 2 lighter ions at 200 GeV. 3-6 nb^{-1} total
4.	A long Au Au run at 200 GeV in 2007 or 2008, with upgraded detector capability for open charm and particle i.d. at high p_T ($\geq$2000 μb^{-1})
Polarized Protons	
1.	15-20 weeks of "development" in 2004 – 2005 (this would include physics data, but is required primarily to get the luminosity and polarization up to required levels).
2.	Full-capability spin data at 200 GeV. $\geq$150 pb^{-1}

- **Some important measurements didn't make minimal list**
  - e.g., more d-Au, more species and energy dependence, p-p @ 500GeV
- **The long Au Au run foreseen in 2007-2008 will require specific detector upgades**

Measurements Beyond the Initial Exploratory Phase

High P_t and Q^2:

- Leading particle/jet spectra to P_t ~30 GeV/c
- Direct photons to P_t > 15 GeV/c
- Photon-tagged jets…*jet tomography*
- Low x, high Q^2….. *Probe Color Glass*

Rare probes:

- Open charm, beauty spectra
- Many x 1000 upsilons
- W production in AA pA pp

These measurements require many data samples ~10 nb^{-1} Au Au equiv.

Very large unbiased event samples:

- Low mass lepton pairs
- γγ interferometry… *Direct EM radiation from plasma*
- Strong CP violation

Extended detector capability:

- Open charm…
- Flavor tagging of jets…
- Low mass lepton pairs; Low P_t Direct Photons…
- Observables at forward rapidity

Vertex resolution ~0.01 mm

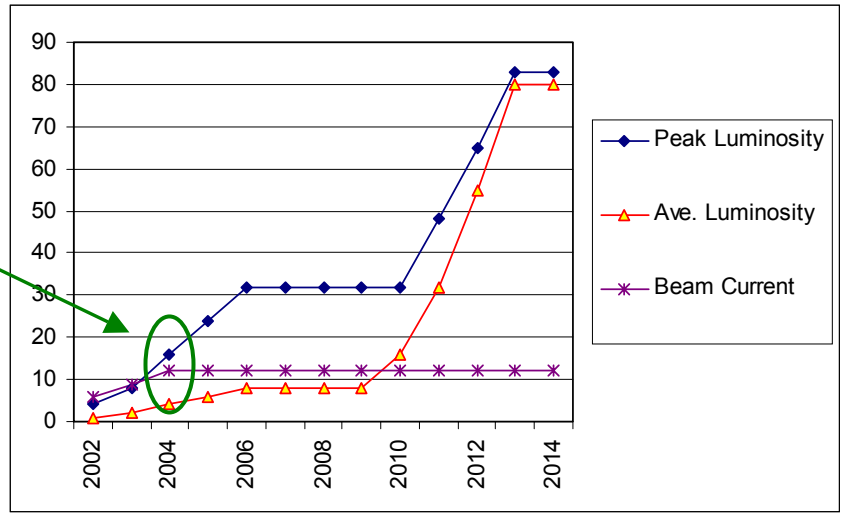
PID at high P_t

Dalitz pair rejection

Forward tracking, PID

RHIC Upgrades: the path forward

Luminosity upgrade plan:
We are here…



Detector Upgrades:

PHENIX:

Si Barrel Vtx tracker***
Si Endcap Vtx tracker
Hadron Blind Detector
Muon Trigger
Nose Cone Calorimeter
TPC Central Tracker

STAR:

Barrel TOF***
MicroVertex Detector
Inner tracker
DAQ & FEE upgrade
Forward Tracker
TPC replacement?

***Critical for next long Au Au run

- **Decadal Plans of PHENIX and STAR address physics goals that reach from the very near term through the RHIC II era.**
- **High priority R&D program, monitored by RHIC Detector Advisory Committee**
- ***Discussion recently initiated of a possible new general purpose detector for RHIC II.***

The near-term plan to meet these goals

All budget guidance at present calls for "Constant Effort" over the next 3 – 5 years

Lab priority under constant effort budget:
Maintain ≥27 weeks/year operating + R&D and upgrades program

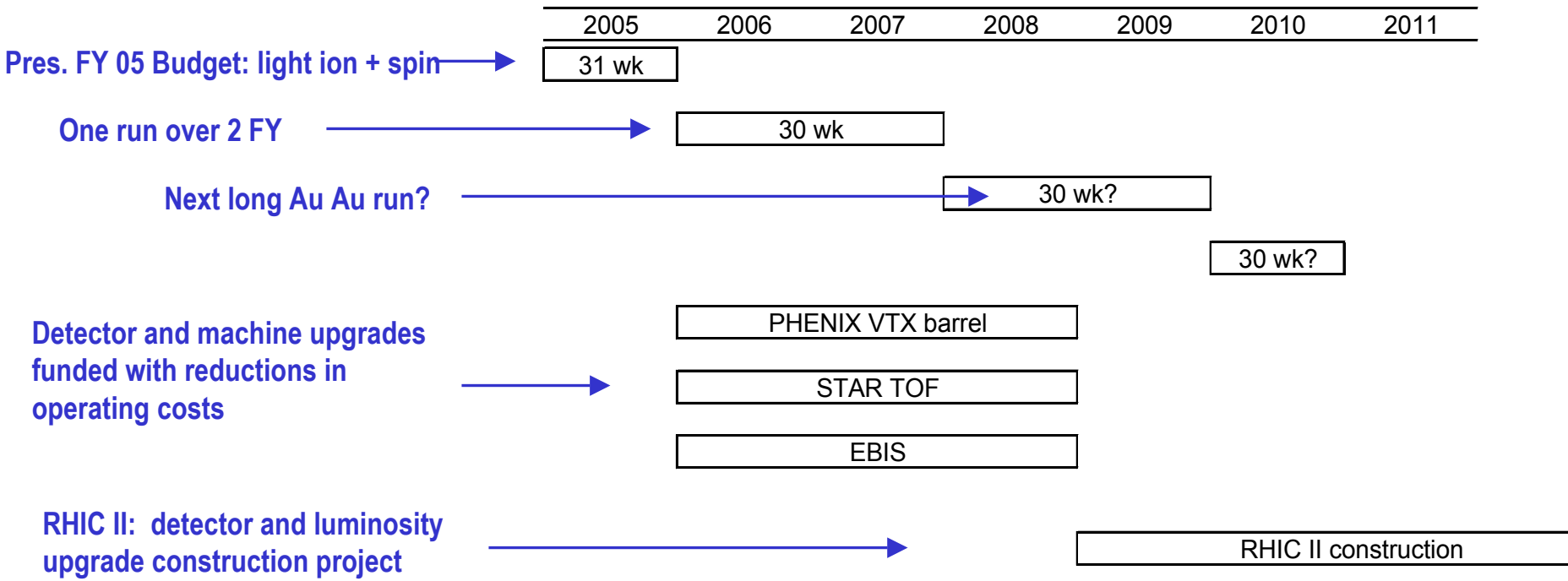
BNL's 20-Year Plan calls for continued detector R&D as well as initiation of 1 or 2 MIE projects for both STAR and PHENIX in '05 -> '08 (Table III)

<u>However</u> :

- This plan relies on "Research Equipment" funds above the Constant Effort baseline.

- The plan misses the constant effort target by a few percent in 2005-2007, due to a bump in RCF equipment costs, and an estimated increase in power cost by ~50% beginning in FY 2006

A True Constant Effort Budget Scenario



Productivity of Scientific Staff

From the RHIC detector collaborations:

~70 scientific papers published in refereed journals 2000 - 2004

~ 55 of these in Physical Review Letters

These papers have gleaned ~3000 citations in scientific literature

~50 PhD theses have been earned since 2000

4 DOE Outstanding Junior Investigator awards have gone to scientists in the RHIC experiments, 2000 - 2004

DOE Outstanding Junior Investigator awards (RHIC experiments):

- 2004 Julia Velkovska, Vanderbilt
- 2003 Fuqiang Wang, Purdue
- 2001 Gunther Roland, MIT
- 2000 James Nagle, Columbia

From Vicki Greene
NSAC Review

RHIC Plan: Table III

(27 weeks/year)

Fiscal Year	2003	2004	2005	2006	2007	2008
PHENIX						
Ops Costs	$6.0M (24K/wk)	5.85M (27K/wk)	5.85M (42K/wk)	5.85M (42K/wk)	5.85M (42K/wk)	5.85M (42K/wk)
R&D	$0.12M	0.5M	0.95M	0.6M	0.3M	---
Ops Equip.	$0.5M	0.89M	0.89M	0.89M	0.89M	0.89M
Res. Equ.			2.5M VTXb	2.5M VTXb	4.2M VTXb/e	4.5M VTXe
STAR						
Ops Costs	$5.9M (38K/wk)	5.75M (40K/wk)	5.75M (40K/wk)	5.75M (40K/wk)	5.75M (40K/wk)	5.75M (40K/wk)
R&D	$0.12M	0.5M	1.0M	1.28M	0.3M	---
Ops Equip.	$0.49M	0.99M	0.99M	0.99M	0.99M	0.99M
Res. Equ.	$3.0M BEMC [$1.5M EEMC]	1.95M BEMC	2.0M TOF	4.0M TOF, MVTX	4.5M MVTX	3.0M MVTX
PHOBOS						
Ops Costs	$0.86M (10K/wk)	0.75M (10K/wk)	0.75M (10K/wk)	0.75M (10K/wk)	.75M (10K/wk)	----------
Ops Equ.		0.185M	0.185M	0.185M	----	
BRAHMS						
Ops Costs	$0.78M (10K/wk)	0.7M (10K/wk)	0.7M (10K/wk)	0.7M (10K/wk)	----------	----------
Ops Equ.		0.11M	0.1M	0.1M		
RCF						
Ops Costs	$5.18M	5.31M	5.6M	5.6M	5.6M	5.6M
Ops Equ.	$2.0M	2.0M	3.4M	2.0M	2.0M	2.0M
C-AD						
Ops Costs	$90.3M (350K/w)	90.7 (350K/wk)	90.9M (350K/wk)	94.9M (500K/w)	94.9M (500K)	92.8M (500K)
R&D	$0.9M	2.0M	2.0M	2.0M	2.0M	2.0M
Ops Equip.	$4.4M	3.9M	3.8M	3.8M	3.8M	3.8M
Res. Equ.	---	---	2.5M EBIS	2.5M EBIS	2.5M EBIS	---
Users/CAP	$0.86M	0.90M	0.90M	0.90M	0.90M	0.90M
Totals						
Ops costs	$109.8M (432K)	$110.1M (437K)	$110.4M (452K)	$114.4M (602K)	$113.8M (592K)	$110.9M (582K)
R&D	$1.1M	$3.0M	$4.0M	$3.9M	$2.6M	$2.0M
Ops Equip.	$7.4M	$8.0M	$9.4M	$8.0M	$7.9M	$7.7M
Ops Total	**$118.4M**	**$121.0M**	**$123.8M**	**$126.3M**	**$124.3M**	**$120.6M**
	Actual: $118.0M	Pres: $121.1M				
Res. Equ.	$3.0M	$1.95M	$7.0M	$9.1M	$11.4M	$7.5M

www.bnl.gov/henp/

Detector R&D and Upgrades

- **Detector Advisory Committee**
  - **Standing committee with a strong scientific and technical membership to evaluate new initiatives and progress in evolving the detectors and advise BNL management**

Peter Braun-Munzinger (chair) - GSI

Russell Betts – UIC

Don Geesaman – ANL

Carl Haber – LBL

Berndt Mueller – Duke

Rick Van Berg – Penn

Jerry Va'vra – SLAC