RHIC Mid-Term Strategic Plan Update

Science Outlook, Goals, Resources

T. Ludlam, July 18, 2007

DOE/Nuclear Physics Science and Technology review of RHIC

Office of Science
U.S. DEPARTMENT OF ENERGY

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

Overview/Summary

The Mid-Term Strategic Plan was submitted to DOE in February 2006.
It is the roadmap for RHIC facility operations, R&D, and upgrades thru ~2011

→ Leading to RHIC II
→ Setting the stage for eRHIC

It is a resource loaded plan.

Some slow-down due to FY 2007 federal budget

- Nonetheless, the plan is proceeding with full user support
- Substantial progress on Machine development and Detector upgrades

The research addresses fundamental questions of broad significance:

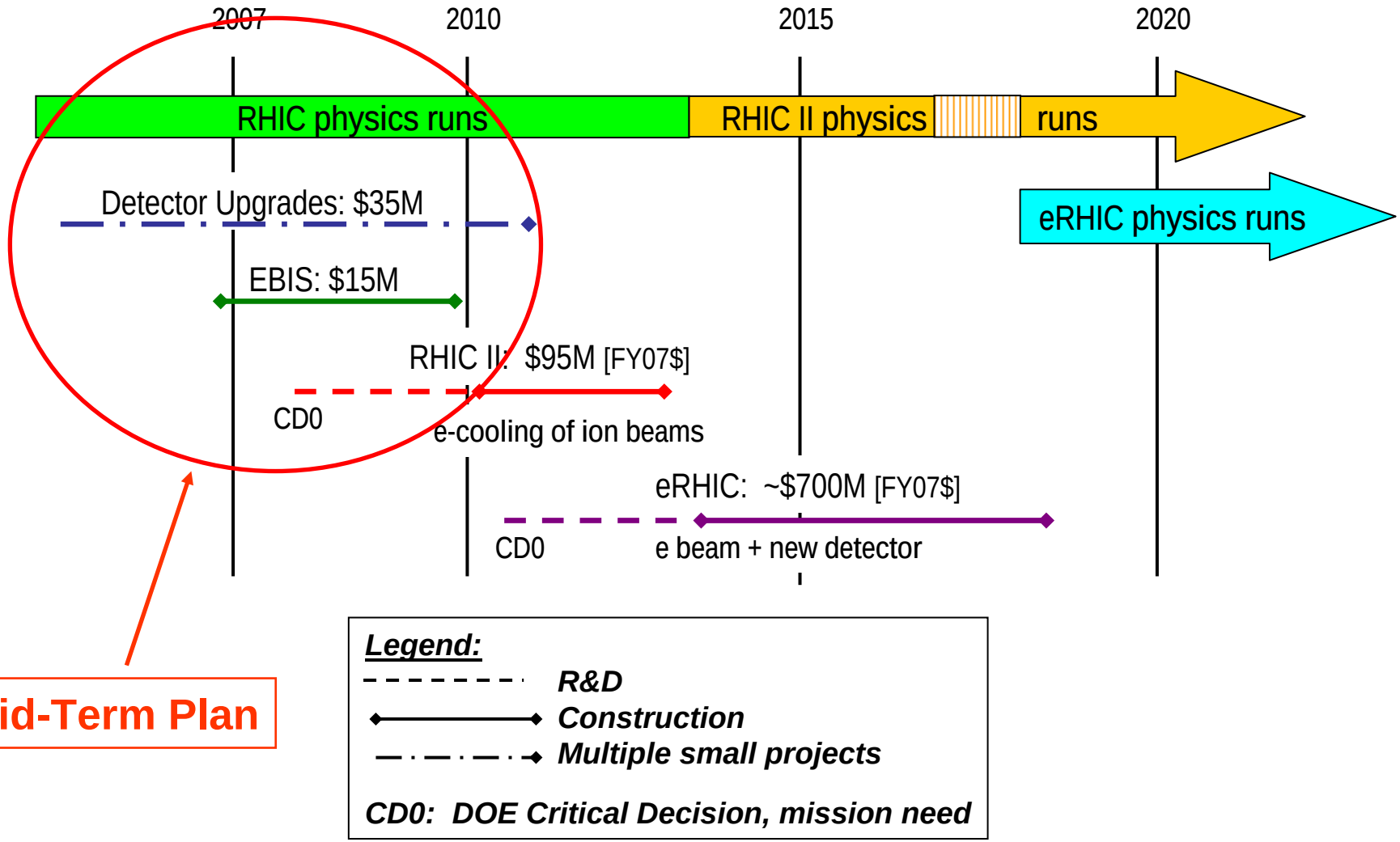
- Endorsed with high priority in the 2007 Long Range Plan discussions

LRP discussions encourage a fast path to implementation of RHIC II

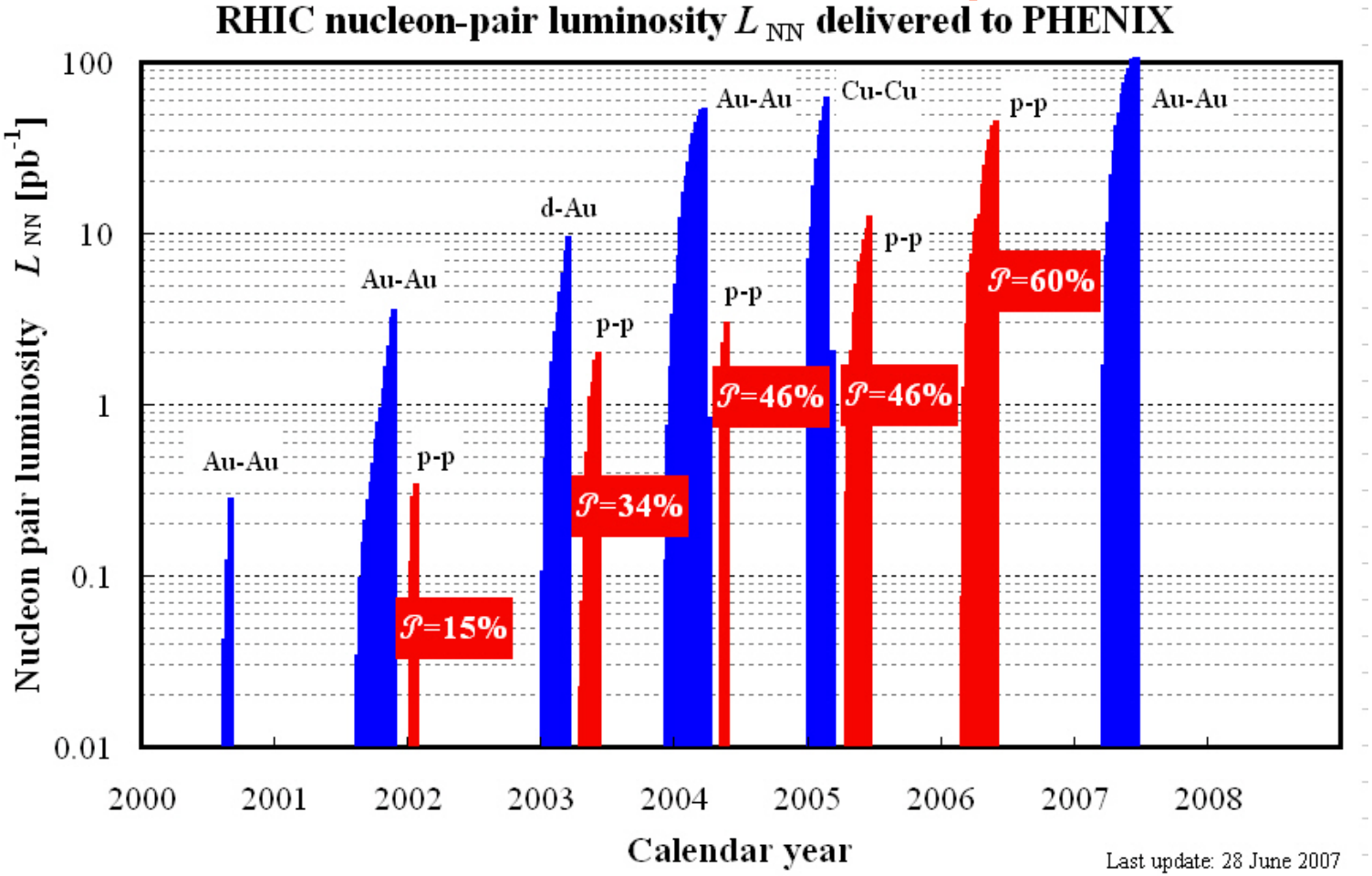
The proposed schedule is driven by:

- Scientific priorities and productivity
- Technical readiness

A Long Term View of RHIC



RHIC Runs to date– Machine performance



Enhanced luminosity (4x design) achieved for Au-Au in Run 7

pp enhanced luminosity and polarization expected by Run 9 for 200 GeV running;
Perhaps in Run 10 for 500 GeV running

RHIC Runs to date – Physics data

Year	Run Plan	Delivered Lum.	Physics
2000	Au-Au at 130 GeV/A	20 μb^{-1}	First look at RHIC collisions
2001-2002	Au-Au at 200 GeV/A Commission/run pp at 200 GeV Au-Au at inj. E: 19 GeV/A	260 μb^{-1} 1.4 pb^{-1} 0.4 μb^{-1} (1 day)	Global properties; particle spectra; first look at hard scattering. Comparison data and first spin run Global connection to SPS energy range
2003	d-Au at 200 GeV/A pp at 200 GeV	74 nb^{-1} 5 pb^{-1}	Comparison data for Au-Au analysis; low-x physics in cold nuclear matter Spin development and comparison data
2004	Au-Au at 200 GeV/A Au-Au at 62 GeV/A pp at 200 GeV	3740 μb^{-1} 67 μb^{-1} 7.1 pb^{-1}	"Long run" for high statistics, rare events Energy Scan Spin development; commission jet target; first measurements with longitudinal spin polarization
2005	Cu-Cu at 200 GeV/A Cu-Cu at 62 GeV/A Cu-Cu at 22 GeV/A pp at 200 GeV pp at 410 GeV	42 nb^{-1} 1.5 nb^{-1} 18 μb^{-1} (39 hrs) 30 pb^{-1} 46% pol 0.1 pb^{-1} (1 day)	Comparison studies: surface/volume & impact parameter effects; Energy scan First long data run for spin High energy spin development
2006	pp at 200 GeV pp at 62.4 GeV pp at 500 GeV	93 pb^{-1} 60% pol 1.0 pb^{-1} 50% pol 45% pol	Long data run for spin Energy scan; reference data Test run at top pp energy
2007	Au-Au at 200 GeV/A Au-Au at 9.2 GeV/A	6.5 nb^{-1} few x 1000 events (1 day)	High-statistics run at top Au-Au energy Test run for Critical Point Search

Note: "Delivered Luminosity" is summed over all experiments

(Ratio of delivered/recorded sample size ~ 3-4; varies with experiment)

2007 Au-Au: PHENIX recorded luminosity = .83 nb^{-1}

STAR recorded luminosity = .65 nb^{-1}

The Science: Where do we stand now?

- A new state of matter has been observed, with extraordinary properties.

The hottest, densest matter ever studied in the laboratory flows as a (nearly) perfect liquid, with systematic patterns consistent with quark degrees of freedom.

We want to understand its behavior, its properties, its origins, and it's relationship to fundamental natural phenomena.

- First measurements of hadronic spin interactions have been made, in the high-energy regime where perturbative QCD interactions can be used to measure non-perturbative spin structure.

RHIC is poised to exploit absolutely unique opportunities to determine how the spin of the proton emerges from its seemingly complex QCD structure.

The Long Term view of RHIC addresses…

QCD at high temperature and density: QGP … sQGP

QCD at high energy and low x: Physics of strong color fields

QCD and the structure of hadrons: What is the origin of nucleon spin?

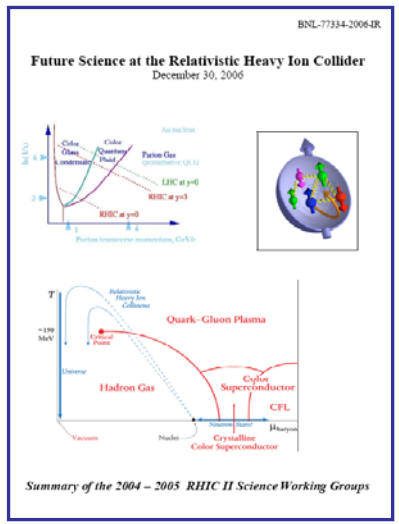
The need for improved detectors and higher luminosity

Science Drivers for the future program at RHIC

- What are the properties of the new medium and how does it evolve?
- Can we directly observe a QCD phase transition and find the critical point?
- What is the initial state in heavy ion collisions?
  - Is the Color Glass Condensate a correct description?
- Mapping the partonic contributions to the nucleon spin wave function

We have learned how to address these questions by utilizing elemental QCD processes generated in the collisions themselves, such as…

- Formation and transport of heavy quarks, and quarkonium bound states
- Fragmenting jets from high energy partons
- High energy photons
- Proton spin observables in hard QCD processes, including leptons from W production and Drell-Yan



Typically these are rare processes:
Future progress requires improved detector capability and machine performance.

The Goal for RHIC II: Annual recorded data samples >10 nb^{-1} per expt. for Au-Au collisions

Detector strategy for the next phase of RHIC and RHIC II

Two Large Detectors

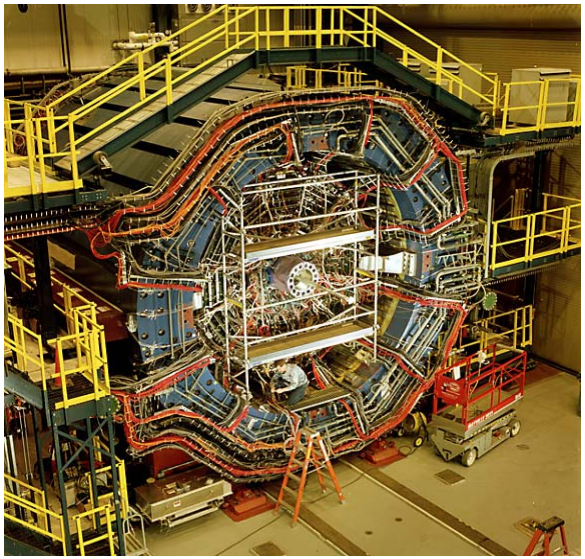
- Upgrades to transform PHENIX and STAR:
  - Increase PHENIX acceptance for tracking and calorimetry
  - Increase STAR rate capability
  - High resolution vertex detectors for charm and beauty in both detectors
  - Enhanced tracking, calorimetry and trigger capability at forward rapidities

- Maintain the critical advantage of two complementary & competing detectors:
  - Confirmation and refinement of complex and often surprising results
  - Combined spin analyses, with multiple sets of probes

- No costly interruption to build a major new detector

RHIC Detector Upgrades

STAR



PHENIX

Forward Meson Spectrometer -completed – Hadron Blind Detector

DAQ & TPC electronics
Time of Flight barrel
} ongoing { Muon Trigger
Silicon Vertex Barrel (VTX)

Heavy Flavor Tracker
Barrel Silicon Tracker
Forward Tracker
} in preparation { Forward Silicon
Forward EM Calorimeter

Costs: DOE $35M; RHIC base $6M; NSF $2.2M; In-kind and non-US $9.5M

Total Cost: $51M

The RHIC Mid-Term Strategic Plan

Submitted to DOE in February 2006, and currently being updated.
It is the roadmap for RHIC facility operations, R&D, and upgrades thru ~2011.

Phased implementation of key upgrades for PHENIX and STAR, plus EBIS, over the next 5-6 years.

Annual data runs during this period will exploit these upgrades for critical advances in the Heavy Ion and Spin physics programs—
Along with continued improvements in machine performance.

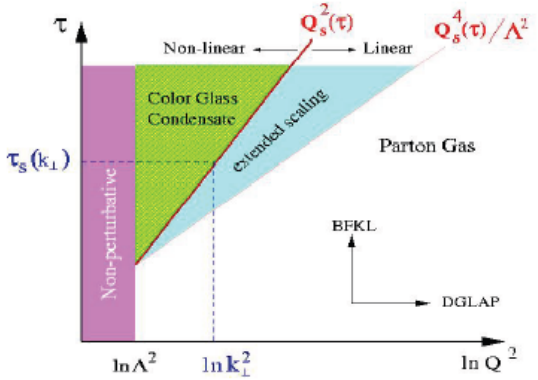
With the help of funding and collaborative resources outside of DOE, this strategy is realized with a sequence of MIE detector projects totaling ~$35M over 6 years.

Two large detectors well equipped for RHIC II physics

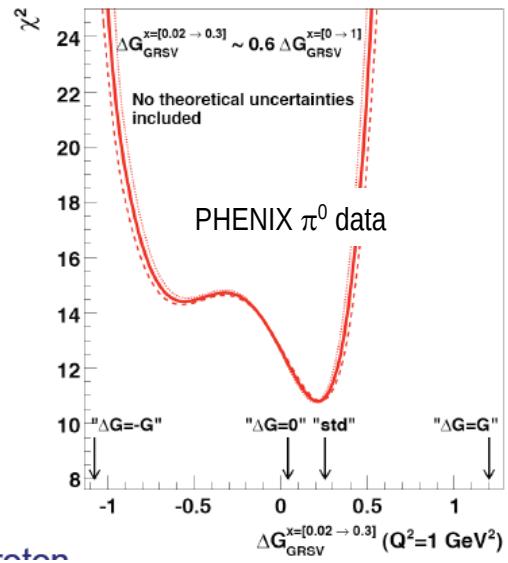
R&D to realize RHIC II luminosity upgrade (e-cooling) along technically-driven schedule

The Key Role of Theory

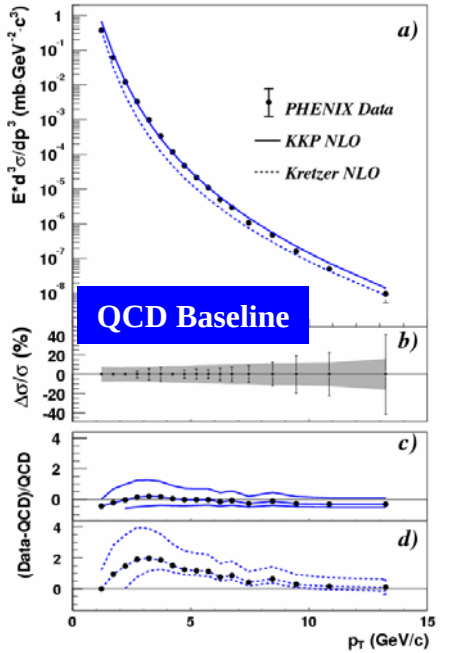
Gluon saturation and Color Glass



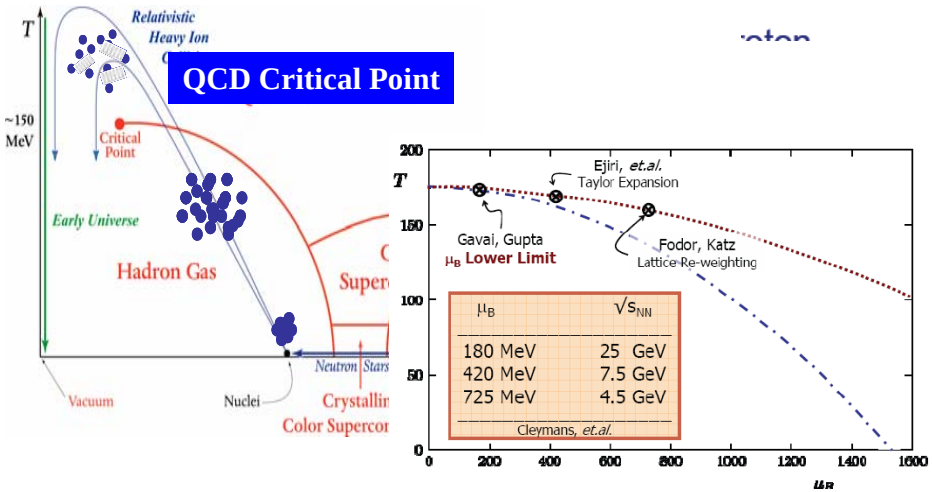
Extracting ΔG from spin data



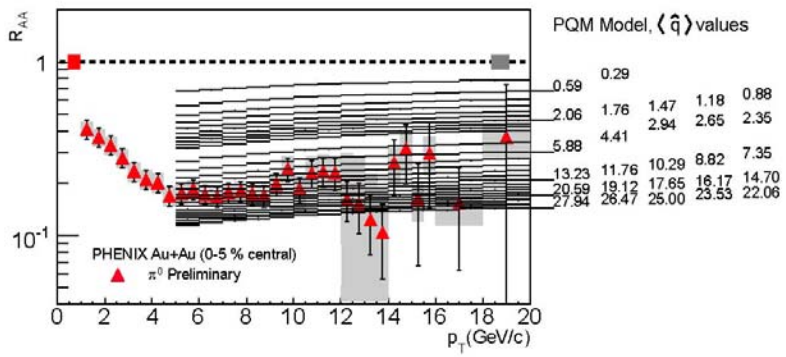
QCD Baseline



QCD Critical Point



Quantitative comparison with data



The Facility: Where Do We Stand Now?

EBIS Construction: CD-3 in place; DOE and NASA funding begun.

Despite funding reduction in 2007, plan to have EBIS Operational for Run 11

Aggressive progress toward enhanced luminosity goals:

Au – Au Luminosity goal (200 GeV/nucleon) : 8×10^{26} cm^{-2} s^{-1} (4x design)

Achieved during Run 7: 12×10^{26} cm^{-2} s^{-1}

Successful operation of longitudinal stochastic cooling during Run 7 offers promise of further gains, with implementation of longitudinal and transverse stochastic cooling in both rings.

Enhanced spin goals:

p-p Luminosity goal (200 GeV): 6×10^{31} cm^{-2} s^{-1}

p-p Luminosity goal (500 GeV) : 1.5×10^{32} cm^{-2} s^{-1} 16x design

} 70 %Polarization

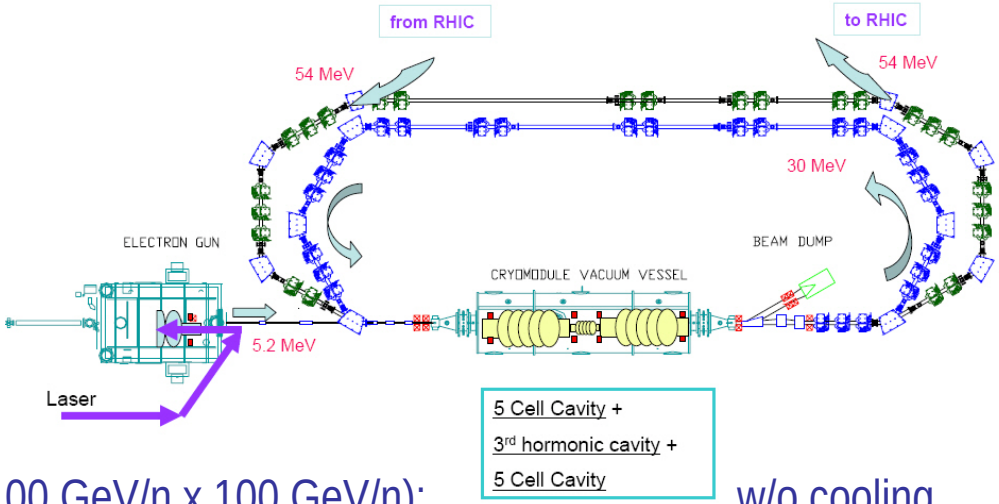
Achieved in Run 6 (200 GeV): 2×10^{31} cm^{-2} s^{-1}. No spin operation in Run 7

Expect to reach 200 GeV goal after spin runs in 2008 and 2009.

The goal for RHIC II: an additional ~10x increase in Au-Au luminosity.

Annual recorded data samples >10 nb^{-1} per experiment

RHIC II Luminosity Upgrade: Electron Cooling



Gold collisions (100 GeV/n x 100 GeV/n):	w/o cooling	with e-cooling
Ave. store luminosity [$x10^{26}$ cm^{-2} s^{-1}]	8	70
Pol. Proton Collision (250 GeV x 250 GeV):		
Ave. store luminosity [$x10^{32}$ cm^{-2} s^{-1}]	1.5	5.0

- Stochastic cooling will complement e-cooling
- ERL development continues. Proof-of-principle for e-cooling has been achieved.
  Ensures a path for meeting performance requirements of RHIC II and eRHIC
- Avenues for reducing the cost of RHIC II upgrade are being explored
  Including possible re-direction of operations funds

Planning for RHIC II "Mission Need" review by DOE early in FY 2008

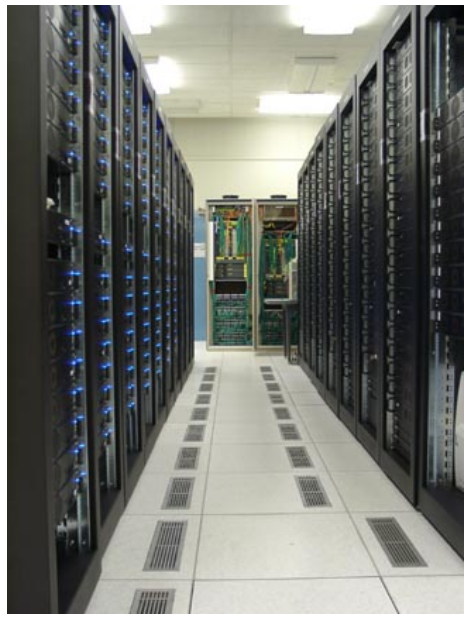
RHIC Computing Facility...

Data Transfer and processing from all four experiments.

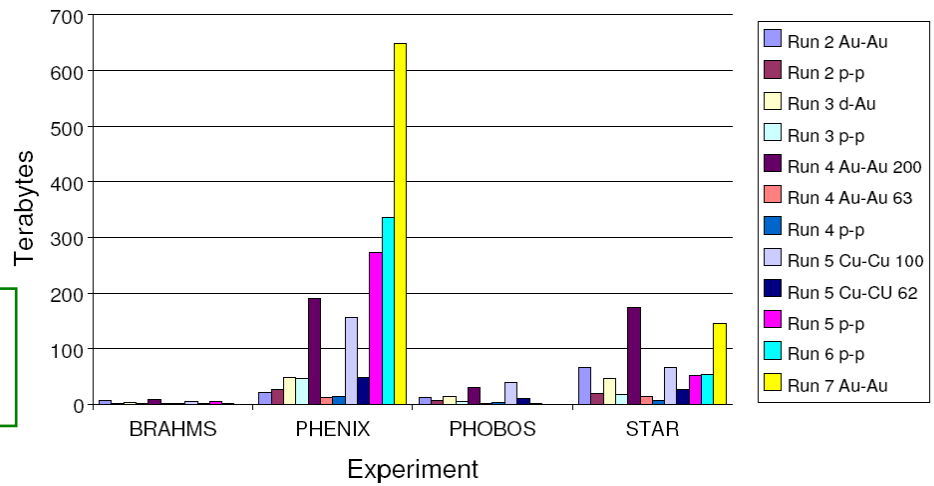
FY 2007 capacity

- Mass Storage System:
  - 5 StorageTek robotic tape silos ~7 PBytes
  - 67 tape drives ~ 2.4 GB/Sec
- CPU:
  - 3900 CPU Intel/Linux processor farm
    ~5400 kSPECint2000 (~8 Tflops)
- Central Disk:
  - 260 Tbytes RAID 5 storage
  - 4.3 Gbyte/sec disk I/O capacity
  - 1300 Tbytes distributed disk

Initial investment: ~$8M (FY 2000$)
Annual equip. funds of ~$2M for upgrades



Raw Data Collected in RHIC Runs



RHIC Computing Facility

The five-year plan is based on the overall mid-term strategic plan.

- The concept of a scalable architecture for CPU, disk, and mass storage, with annual replacement of ~1/4 of the installed hardware has been successful to date.
  Have not met the goal of $2M/year equipment replacement in FY06 or FY07.

- Algorithms for estimating the required resources, based on volumes of raw data collected, have worked well for flexible planning and cost estimates based on multi-year beam use plans. Requires constant communication with experiments.

- Due to machine and detector upgrades, need for annual equipment replacement for RCF will increase from present level of $2M to $3M in 2011.

- Both detector collaborations make use of non-RCF computing resources for data simulation, and some processing. Evolution toward GRID computing.

Physical infrastructure is a serious, short-term issue. It is being addressed by the Laboratory.

M. Ernst talk tomorrow

Measurements that drive the upgrades

Required Upgrades

Heavy Ion:

- e-pair mass spectrum — PM: 2010
  - "Hadron Blind" Dalitz pair rejection
- Open charm measurements in AA
  - High Resolution vertex detection
- Charmonium Spectroscopy — PM: 2010
  - High luminosity; precision vertex, enhanced particle ID
- Jet Tomography
  - High luminosity; increased acceptance; enhanced particle ID
- Gluon shadowing; low-x in d-Au — PM: 2012
  - particle detection at forward rapidity

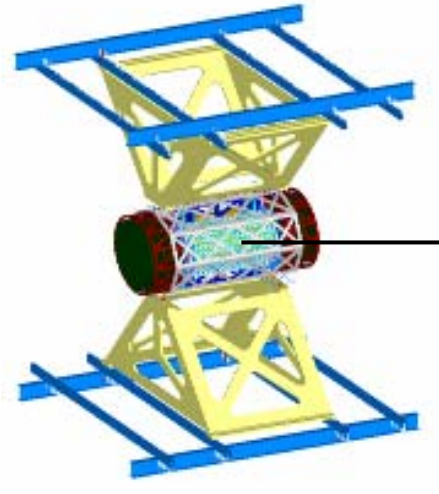
Spin:

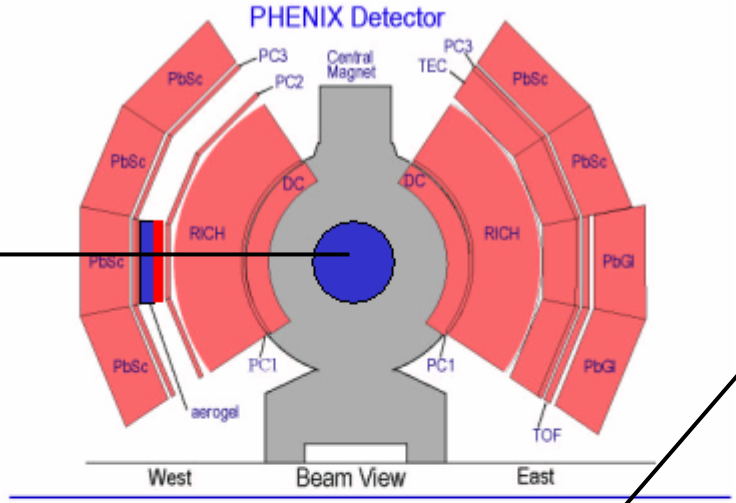
- Complete initial $\Delta G/G$ measurement — PM: 2008
  - No upgrades needed
- Transverse spin measurements
  - Forward particle measurement
- W measurements at 500 GeV — PM: 2013
  - Forward tracking/triggering upgrades

***DOE performance milestones set by NSAC**

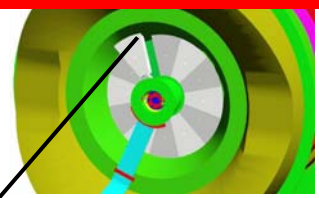
PHENIX Upgrades

Silicon VTX and FVTX

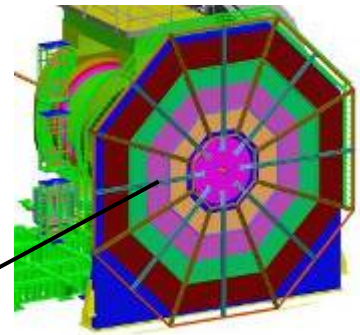


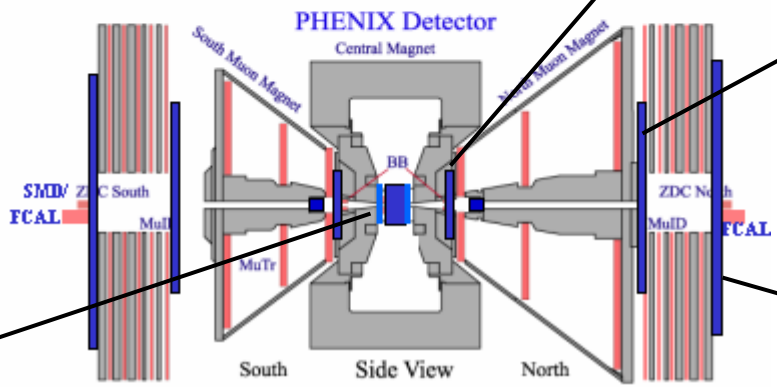


MuTrig Station 1

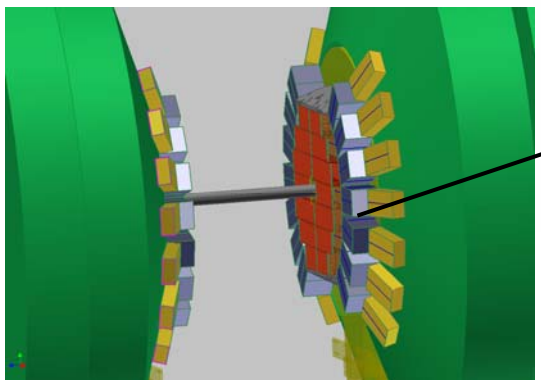


MuTrig Station 2

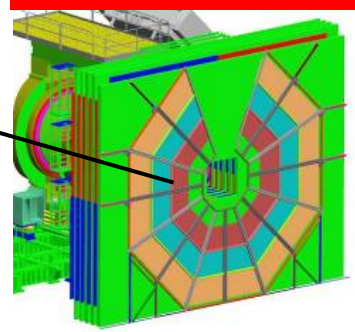




Nose Cone Calorimeter

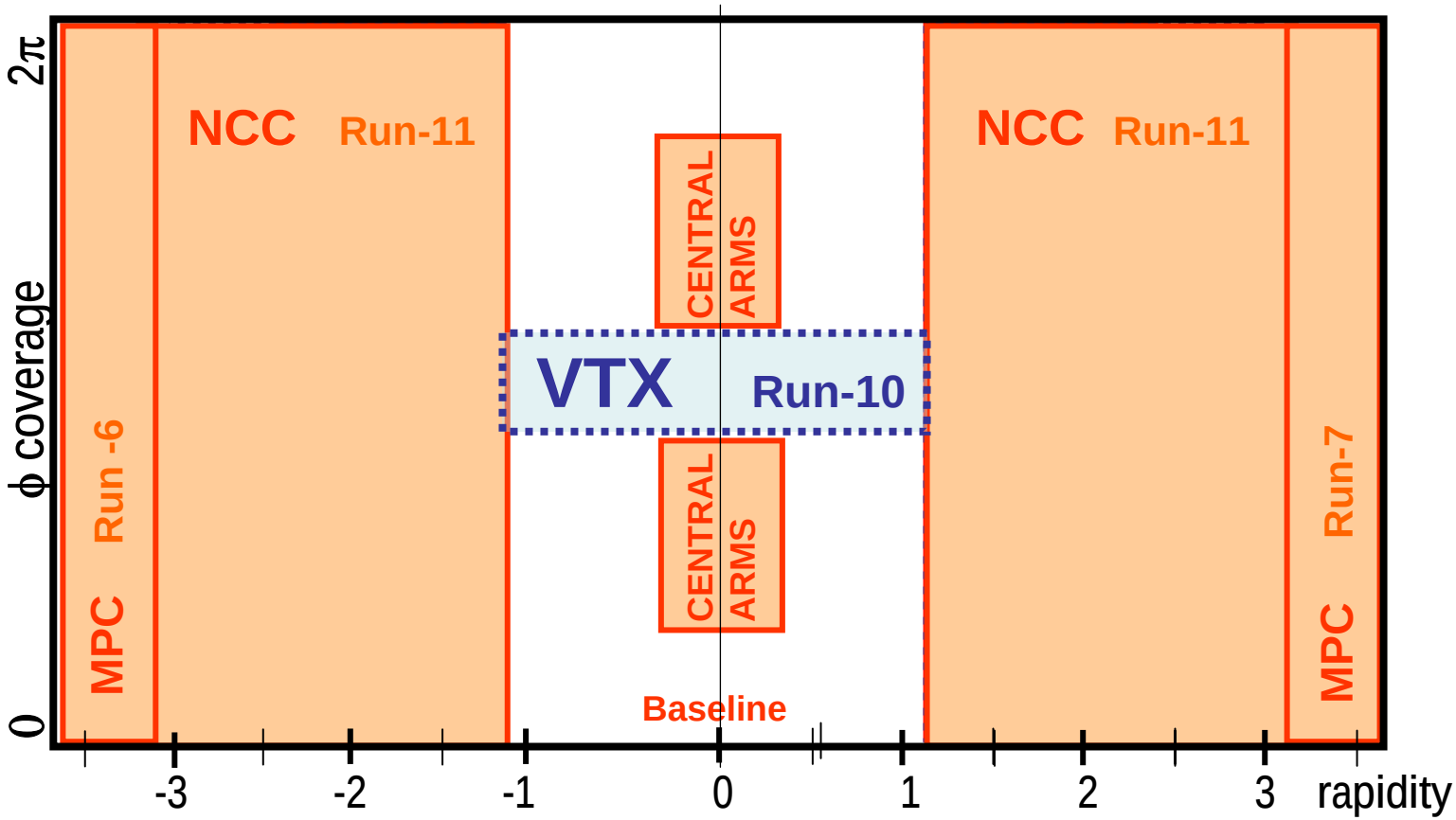


MuTrig Station 3



E. O'Brien 6/22/07

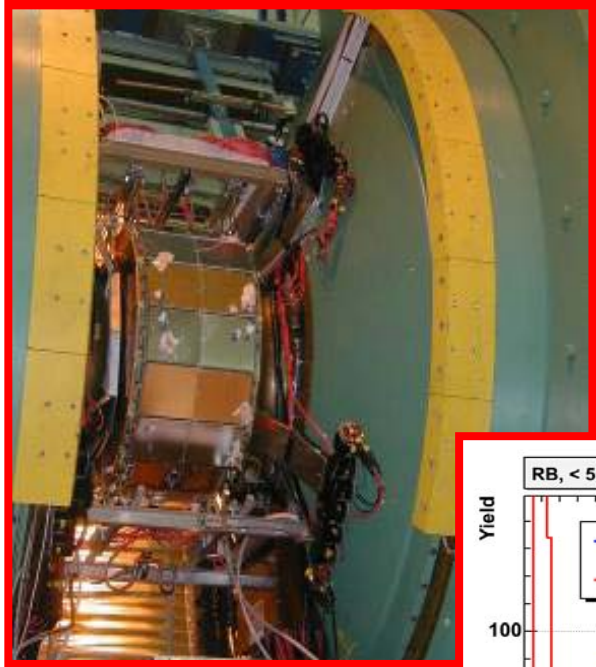
Future PHENIX Acceptance for Hard Probes



a) Heavy flavor with precision vertex tracking with silicon detectors
b) Direct γ and π^0 with combination of all electromagnetic calorimeters
c) Combine a) & b) for jet tomography with γ-jet

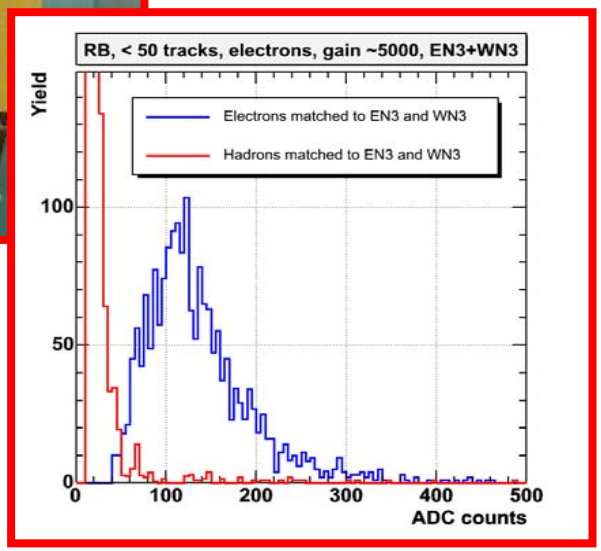
PHENIX Hadron Blind Detector

Hadron Blind Detector

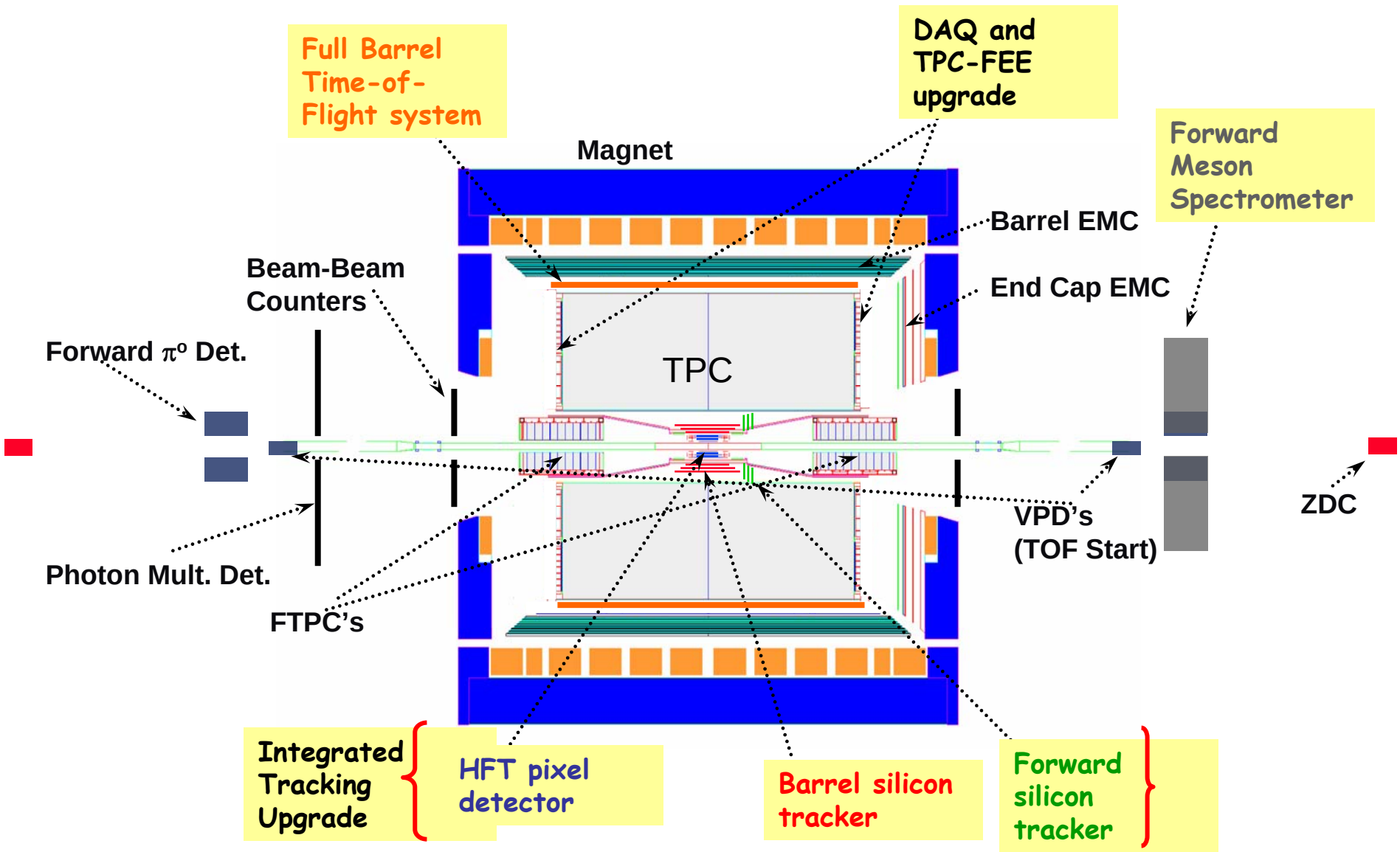


- Installed for Run 7
- Commissioning begun, with some HV problems to be addressed during summer shutdown.

Physics window in Runs 8-10, prior to Si VTX installation



STAR Upgrades



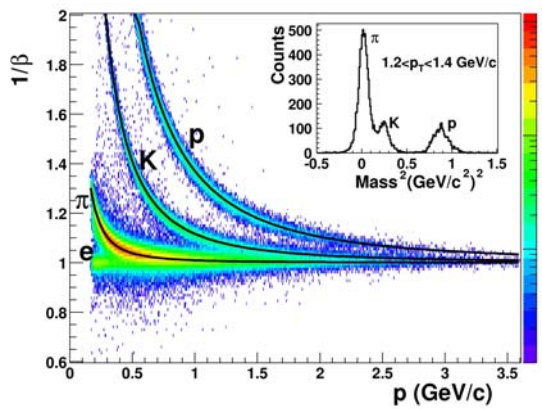
STAR DAQ 1000 Upgrade

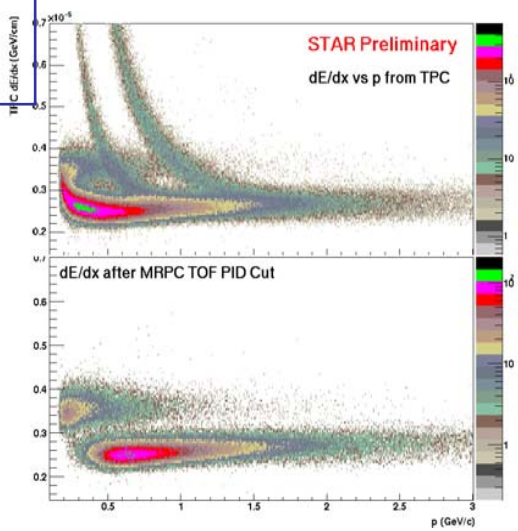
- High-rate, high-luminosity capability for STAR
- Replace TPC readout with fully pipelined system, with >10x current data rate.
- Utilizes CERN chip developments for ALICE/LHC
  - Development phase is complete; construction underway
  - Partial implementation for FY 2008 run (1 TPC sector)
  - Full implementation for FY 2009 run, if budgets allow

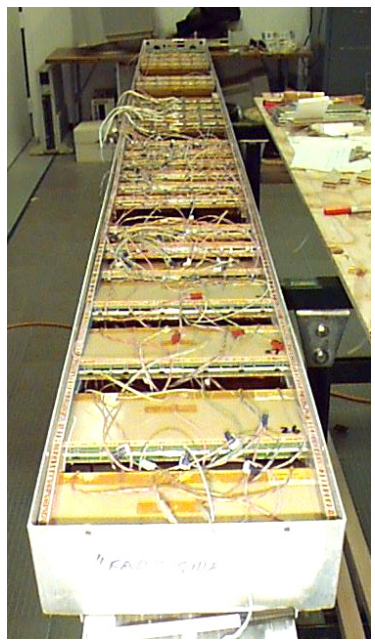
STAR MRPC Time of Flight Barrel: Flavor tagging at large p_T

23,000 channels covering TPC & Barrel Calorimeter

DOE MIE Project
Construction begun December 2005
½ of full azimuth for FY 2009 run
Full detector in Run 10







Precision Vertex Detectors

PHENIX Si Vertex Trackers:

Barrel VTX

Construction started May 2007.

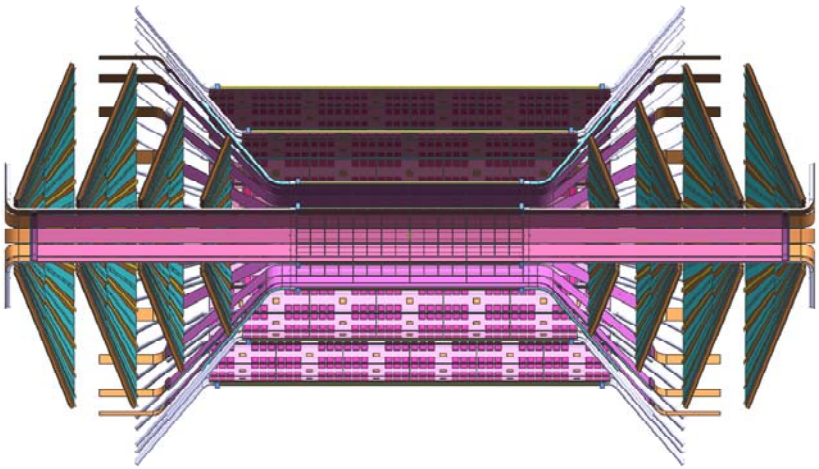
Expect operation Run 10 – 11

Forward VTX detectors

Funded start in FY 2008 Pres. Budget

DOE science review last week

Expect operation Run 11



STAR Heavy Flavor Tracker:

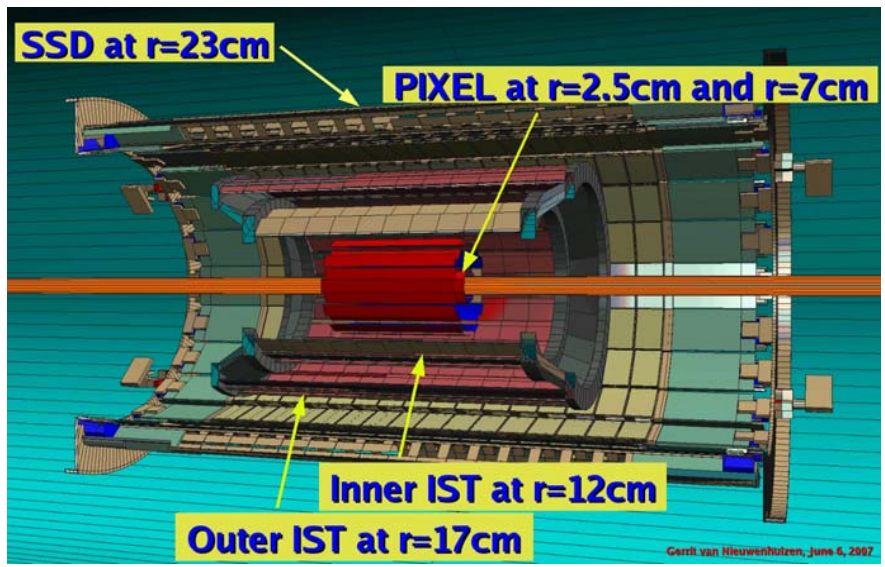
2 layers CMOS Active Pixel sensors, with associated Si pointing detectors.

Development project:

10μm pixels; 50μm detector thickness

Expect science review this year;

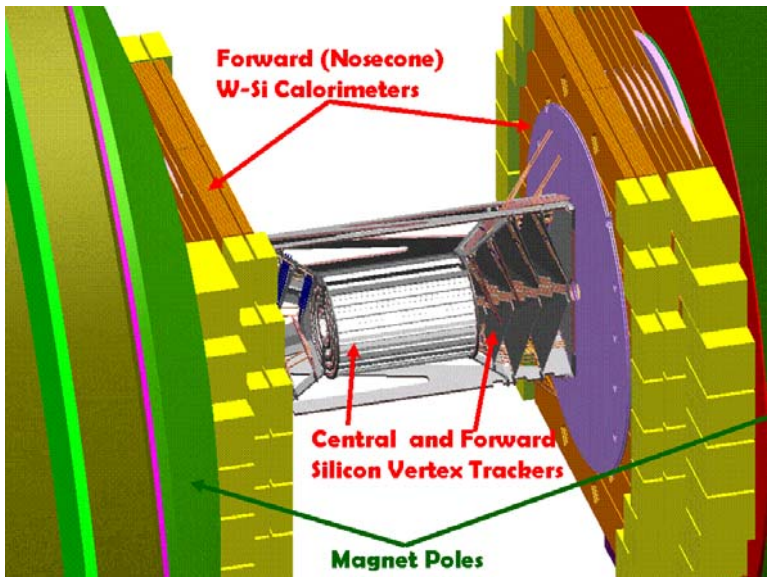
Construction during 2009-2011: ~$12M



Low-x Physics: Color Glass; gluon density

Forward Upgrades .001 < x < 0.1 in Au-Au, d-Au

PHENIX: Nose Cone Calorimeter



Funded for start in FY 2008 Pres. Budget

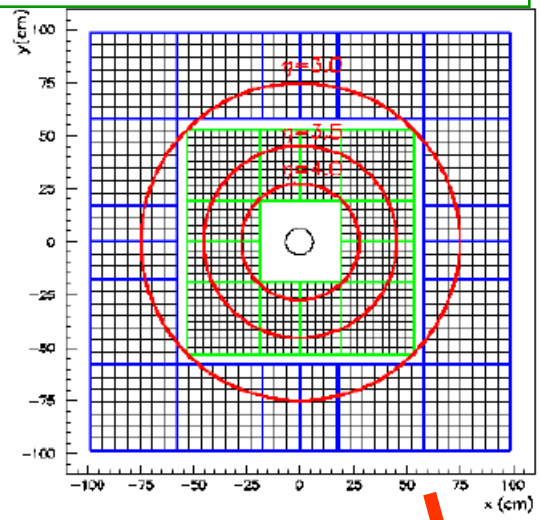
DOE science review last week

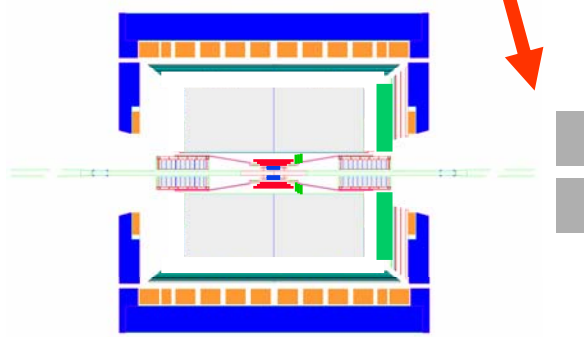
Scheduled completion for Run 11.

Second Nose Cone Cal. May be provided by non-U.S. collaborators

STAR: Forward Meson Spectrometer

Complete.
Operational for FY 08 d-Au Run

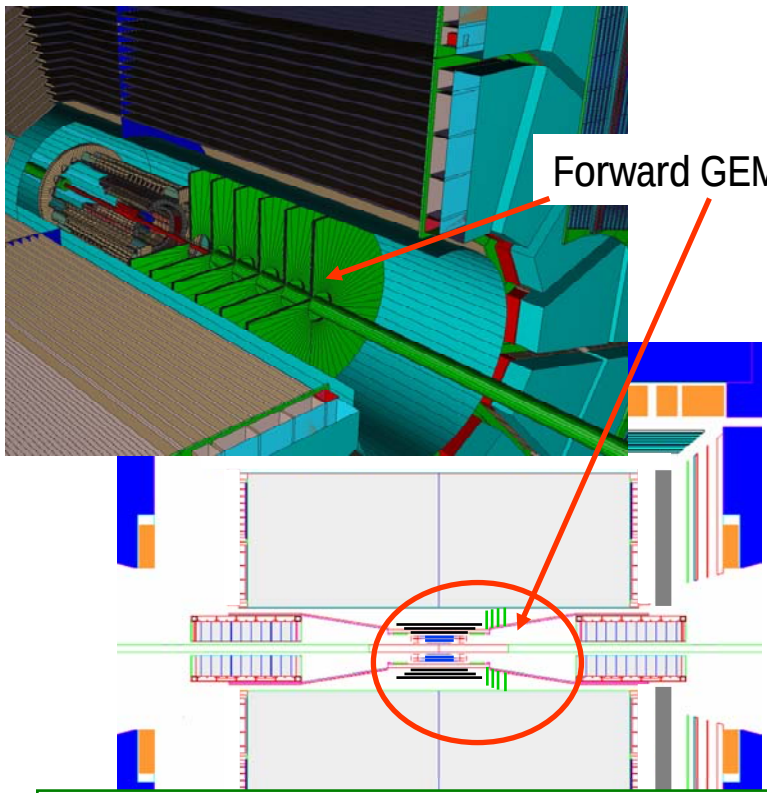




W Physics Upgrades

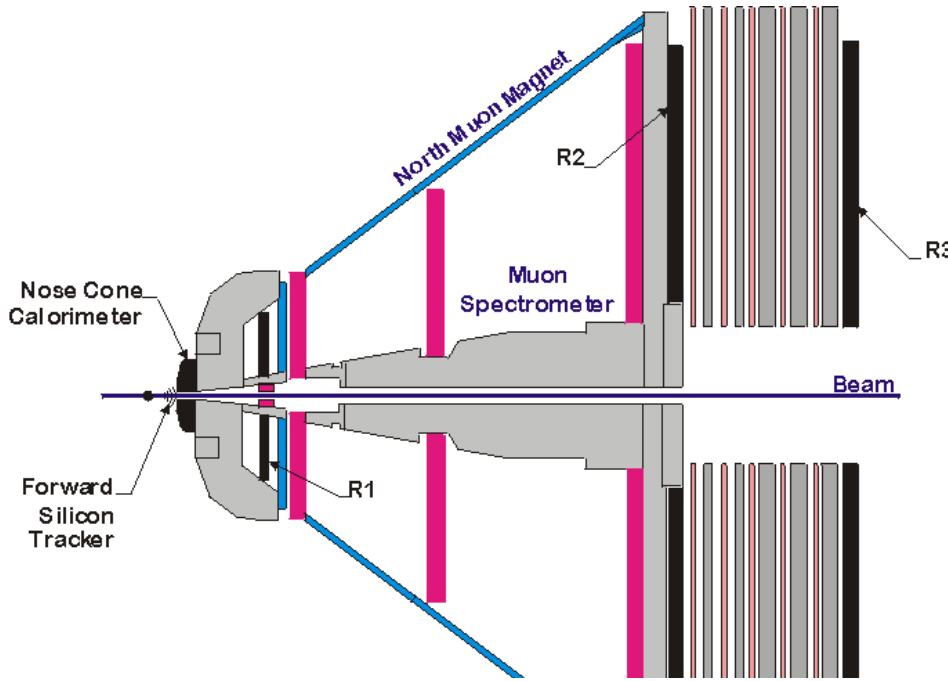
Select and identify forward leptons from $W^{\pm}$ decay

STAR Forward Tracking Upgrade



Development underway:
Expect final design to be reviewed by BNL in calendar 2007; install for Run 10 [Est. cost $1.6-$1.8M]

PHENIX Muon Trigger



Resistive Plate Chambers

Funded by NSF
Complete and installed for Run 10

A timeline for physics operation, detector upgrades, machine evolution

FY 2006	FY 2007	FY 2008	FY 2009	FY 2010	FY 2011	FY 2012

Au-Au, d-Au, Ion scans, critical pt. search
Spin: pp at 200 GeV; 500 GeV development

Ion runs: Hard Probes
500 GeV Spin Runs

Near-term upgrades:
HBD, TOF, DAQ, FMS, Muon Trigger

Mid-Term Upgrades:
Vertex detectors, NCC, forward tracking

EBIS Construction

RHIC II Construction

Machine and detector R&D; continued luminosity improvements; eRHIC development

UPDATED PICTURE

LHC Heavy Ion Program

Near Term Run Plan

PAC recommendations, based on PHENIX and STAR beam use proposals

Assume 30 cryo-weeks per year (~22 physics weeks)

Estimated yields on this slide are delivered luminosity per experiment

Run 8

- 10 weeks d-Au at 200 GeV [150 nb^{-1}]
- 12-13 weeks polarized pp at 200 GeV [130 pb^{-1}; 65%pol.]

Run 9

- 10 weeks Au-Au at 200 GeV [3.5 nb^{-1}]
- 12 weeks polarized pp at 200 GeV and/or 500 GeV

  [if 12 weeks at 200 GeV: 180 pb^{-1}; 70% pol.]

  [if 12 weeks at 500 GeV: ~300 pb^{-1} ; ~60% pol.?]

Run 10

- 14 weeks Au-Au low-energy scan in search of QCD critical point
- 8 weeks polarized pp at 500 GeV [~200 - 300pb^{-1} ?; ~60% pol.?]

RHIC Spin Plan target for 200 GeV running thru 2009: 275 pb^{-1}

Achieved so far: 60 pb^{-1} Expected in Runs 8 + 9: ~200-300 pb^{-1}

Projections for Run 11 and beyond

Assume 30 cryo-weeks per year; equally divided between heavy ion and spin runs

Heavy ion running (Au-Au):

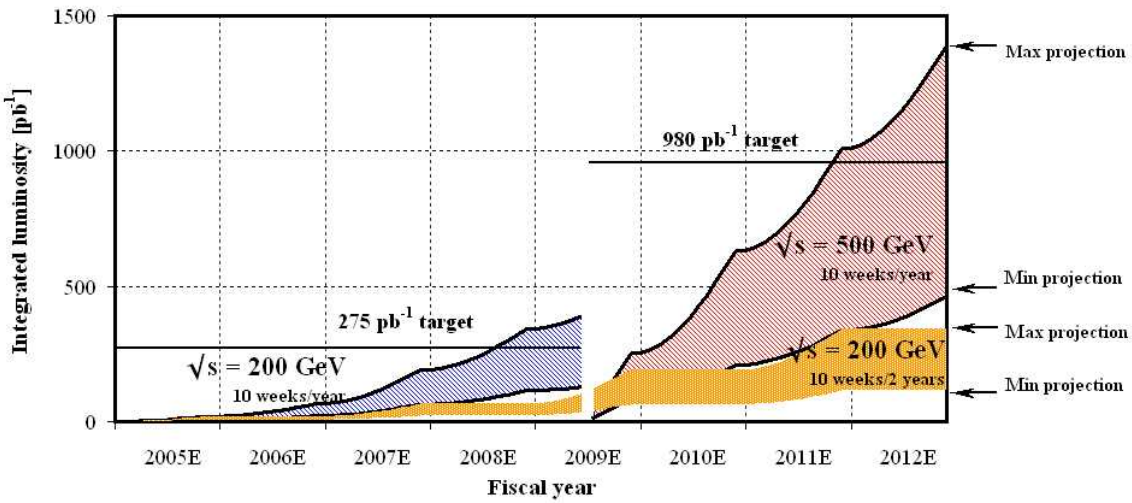
- Some improvement from Run 7 luminosity due to stochastic cooling
- Likely improvement in detector efficiency due to smaller diamond length
- Overall improvement in machine reliability (60% to 80%)

Net result: ~2 nb^{-1} recorded by each experiment per year of Au-Au running

Proton spin running:

- Expect to follow the RHIC Spin Plan projections:

~100 pb^{-1} per year recorded by PHENIX at 500 GeV



Runs 11 ~ 14: Straw-man physics agenda with upgrades in place

- High-statistics Au-Au (and U-U)
  - Direct charm and beauty measurements in PHENIX
  - Full TOF in STAR; commission Pixel Vertex detector
  - γ - jet capability in both PHENIX and STAR
- High-statistics d-Au
  - Forward detector upgrades in place for both PHENIX and STAR
- Low-energy Au-Au scan with enhanced luminosity
  - e-cooling in AGS
- Spin measurements at 500 GeV
  - Enhanced forward particle detection and triggering for both PHENIX and STAR

Commission RHIC II

Detector Upgrade Funding Plan

Actual costs in FY 06 and FY 07; FY 08 President's Budget

	FY 2006A	FY 2007A	FY 2008P	FY 2009	FY 2010	FY 2011	FY 2012	
R&D funds								
PHENIX HBD	0.10							**0.10**
PHENIX MIEs	0.30	0.15						**0.45**
PHENIX DAQ	0.10	0.05	0.20	0.20	0.20	0.20		**0.95**
STAR Tracking	0.50	0.40	1.30					**2.20**
Generic Det. R&D	0.00		0.00	1.00	1.00	1.00	1.50	**4.50**
Total R&D	1.00	0.60	1.50	1.20	1.20	1.20	1.50	**8.20**
Exp. Capital								
PHENIX HBD/TOFW	0.40	0.10						**0.50**
STAR FMS	0.20	0.10						**0.30**
STAR DAQ1000	0.90	0.60	0.30	0.20				**2.00**
STAR FGT			0.35	0.95	0.50	0.00		**1.80**
Exp. Infrastr.	0.60	0.20	0.55	0.75	0.75	0.75	0.60	**4.20**
RCF	1.30	1.70	2.00	2.70	2.90	3.00	3.00	**16.60**
Total Capital	3.40	2.70	3.20	4.60	4.15	3.75	3.60	**25.40**
MIEs								
STAR TOF	2.40	2.40						**4.80**
PHENIX VTX		1.00	2.40	1.20	0.10			**4.70**
PHENIX FVTX			1.40	2.75	0.80			**4.95**
PHENIX NCC			1.00	2.20	1.50			**4.70**
STAR HFT/IST				2.00	4.75	4.75		**11.50**
Total MIE	2.40	3.40	4.80	8.15	7.15	4.75	0.00	**30.65**

Impacts of FY 2007 Budget Process

Delayed start for PHENIX VTX

Project start delayed from October 2006 to May 2007. FY 2007 funding reduced to $1.0M, from planned $2.0M. Project completion delayed 12 months, to 2010.

A year's delay in the key physics of heavy flavor (charm and beauty) probes of QGP

No spin run in FY 2007

Interruption in spin plan for machine development and physics output

Shortfall of capital equipment funds

Delay in completion of STAR DAQ 1000 will roll forward to delay in Forward GEM tracker, reducing STAR's effectiveness in 500 GeV pp runs.

Slowdown in RCF equipment purchases may slow the rate of Run 7 data analysis.

Shortfall of R&D funds

Reduced R&D effort in PHENIX will delay DAQ upgrades, and may delay start of NCC and FVTX.

Reduced development effort on Active Pixel Sensor device and GEM detectors has slowed STAR Tracking Upgrades

Non DOE Contributions to Upgrades

Project	Source	Projected contribution
EBIS	NASA	$4.5M Approved funding
STAR TOF	China	$3.0M In kind
PHENIX HBD	NSF + $64K SBU	$0.3M Approved funding
PHENIX Muon Trigger	NSF	$1.9M Approved funding
PHENIX VTX	Japan (RIKEN)	$3.0M In kind
PHENIX NCC	Europe and Japan	$3.5M In kind

The Scientific Workforce for RHIC

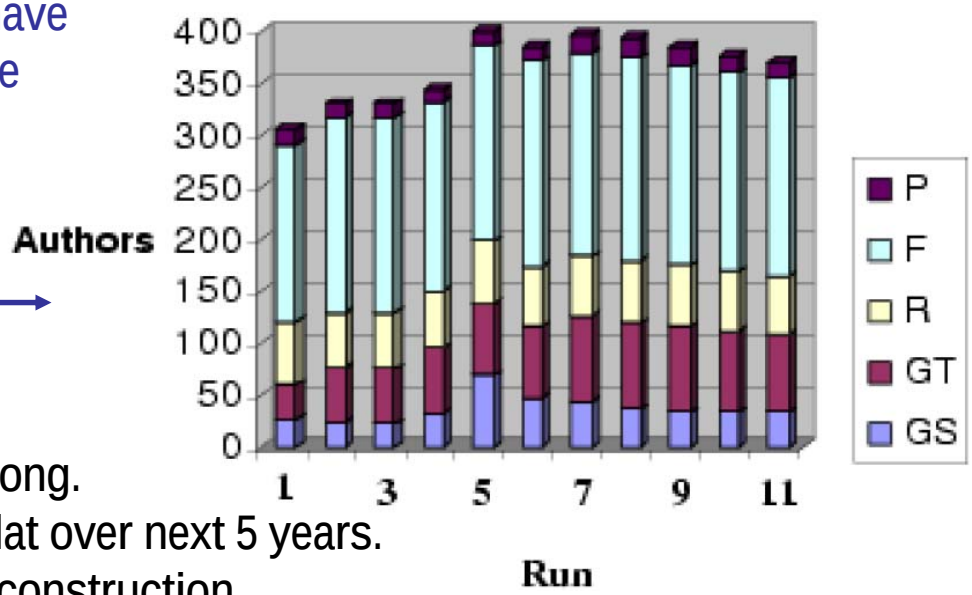
Total no. of users ~1000.

How does this translate to FTEs working on STAR and PHENIX during the Mid-Term period?

- Completion of BRAHMS and PHOBOS: some effort moved to PHENIX and STAR
- Increasing commitments to LHC HI expts. (esp. in the U.S.)
- New groups joining STAR and PHENIX, with specific interest in upgrades

STAR, PHENIX, and Spin collaborations have polled their membership, to determine the level of effort from each individual.

PHENIX: March 2007



Results:

- Scientific commitment remains strong.
- PHENIX and STAR membership ~flat over next 5 years.
- Adequate workforce for upgrades construction
- Some issues regarding ops support for the detectors.

Overview/Summary

The Mid-Term Strategic Plan was submitted to DOE in February 2006.
It is the roadmap for RHIC facility operations, R&D, and upgrades thru ~2011

→ Leading to RHIC II
→ Setting the stage for eRHIC

It is a resource loaded plan.

Some slow-down due to FY 2007 federal budget process

- Nonetheless, the plan is proceeding with full user support
- Substantial progress on Machine development and Detector upgrades

The research addresses fundamental questions of broad significance:

- Endorsed with high priority in the 2007 Long Range Plan discussions

LRP discussions encourage a fast path to implementation of RHIC II

The proposed schedule is driven by:

- Scientific priorities and productivity
- Technical readiness