RHIC Detector Upgrades

BNL Science and Technology Review

July 7-9, 2008

Evolution of the Experimental Program - II

From Tom Ludlam's presentation:
Detector Suite: Upgraded PHENIX and STAR

Measurements for RHIC II Science goals:

- Heavy Ion Physics
  - Heavy Flavor
  - γ- jet
  - Quarkonia
  - Multiparticle correlations
- Proton Spin
  - W production in 500 GeV p-p

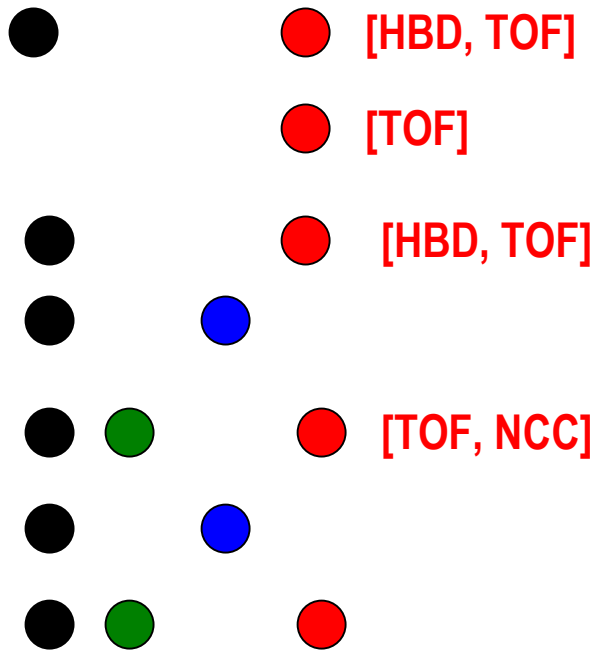
Necessary detector upgrades:

- High data-rate capability: STAR & PHENIX DAQ upgrades
- Hadron and Photon particle ID: STAR TOF; PHENIX NCC
- Precision vertex detectors: Open Charm and Beauty
  PHENIX VTX, FVTX; STAR HFT
- Forward detectors: $W^{\pm}$ in 500 GeV p-p
  PHENIX Muon Trigger; STAR FGT

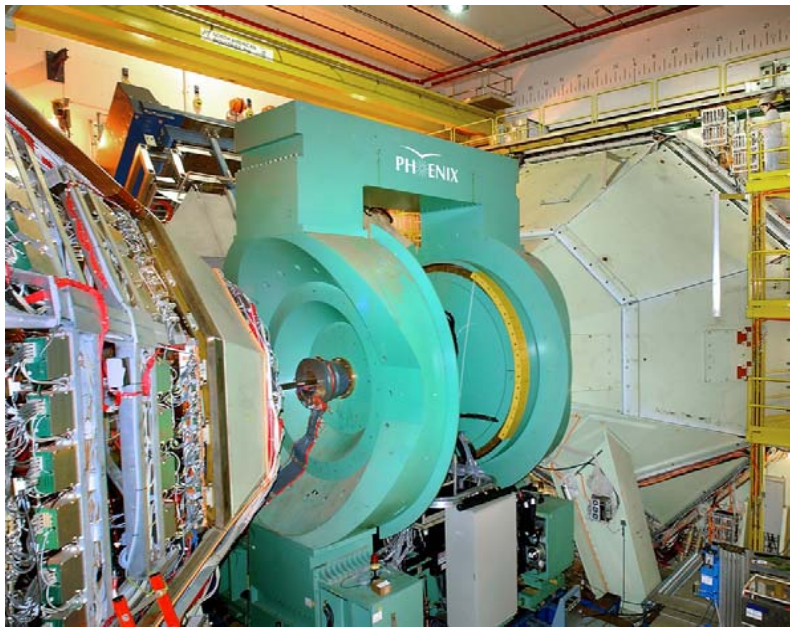
2008 PAC Recommendations & Associated Upgrades

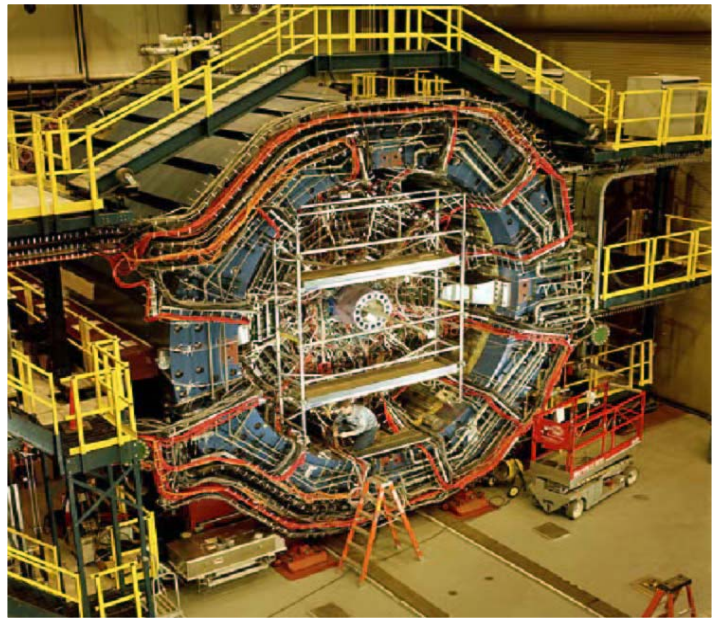
DAQ Vertex Forward Detectors Particle ID

Fiscal Year	Colliding Beam Species/Energy	Comments
2009	500 GeV p+p	Commissioning
2010	200 GeV p+p	A_{LL} measurements
	200 GeV Au+Au	9-10 physics weeks with PHENIX HBD, STAR DAQ1000 & TOF. 1st collision test of transverse stochastic cooling .
2011	Au+Au at assorted low E	Critical point scan.
	200 GeV U+U	1st U+U run with EBIS, to increase energy density coverage
2012	500 GeV p+p	1st long 500 GeV p+p run. Substantial statistics on W production and ΔG measurements
	200 GeV Au+Au	Long production run with full stochastic cooling.
2013	500 GeV p+p	Reach ~300 pb^{-1} to address 2013 DOE performance milestone on W production and sea antiquark polarizations
	200 GeV Au+Au or 2nd low-E scan	To be determined by results of previous runs.



RHIC Detector Upgrades Projects

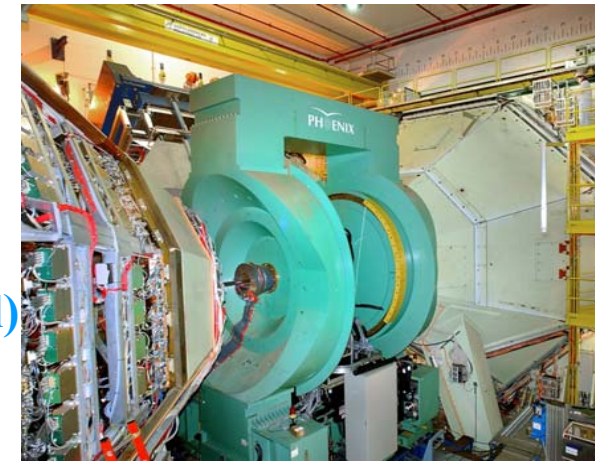


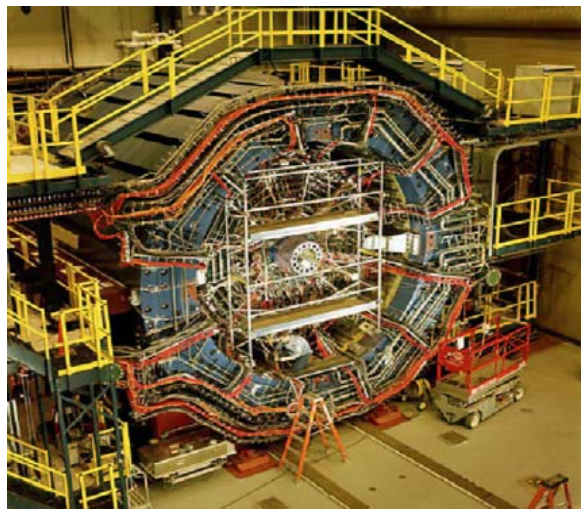


- **DOE Major Items of Equipment**
- **Capital Equipment Projects**
- **Non-DOE funded upgrade projects (Japan, China, NSF…)**

RHIC Detector Upgrades Projects

- **DOE Major Items of Equipment**
  - STAR Time of Flight (Nearing completion)
  - PHENIX Silicon Vertex VTX (Started June 2007)
  - PHENIX Forward Silicon Vertex (Started April 2008)
  - PHENIX Nose Cone Calorimtr(Awaiting DOE approval)
  - STAR Heavy Flavor Tracker (Awaiting DOE approval)
- **Capital Equipment Projects**
  - PHENIX Hadron Blind Detector (Ready Run-9)
  - STAR DAQ1000 (ready Run-9)
  - STAR Forward GEM Tracker (start FY2008)
  - STAR Forward Meson Spectrometer (complete)
  - PHENIX DAQ Improvement (Various)
- **Non-DOE funded upgrade projects (Japan, China, NSF…)**
  - STAR Time of Flight (China: nearing completion)
  - PHENIX Muon Tracker (NSF+Japan+France: Started FY2008)
  - PHENIX Silicon Vertex VTX (Japan: Started FY2006)





PHENIX Upgrades

Charged Particle Tracking:

- Drift Chamber
- Pad Chamber
- Time Expansion Chamber/TRD
- Cathode Strip Chambers(Mu Tracking)
- Forward Muon Trigger Detector (MuTrig)
- Si Vertex Tracking Detector- Barrel (VTX)
- Si Vertex Endcap (FVTX)

Particle ID:

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

Calorimetry:

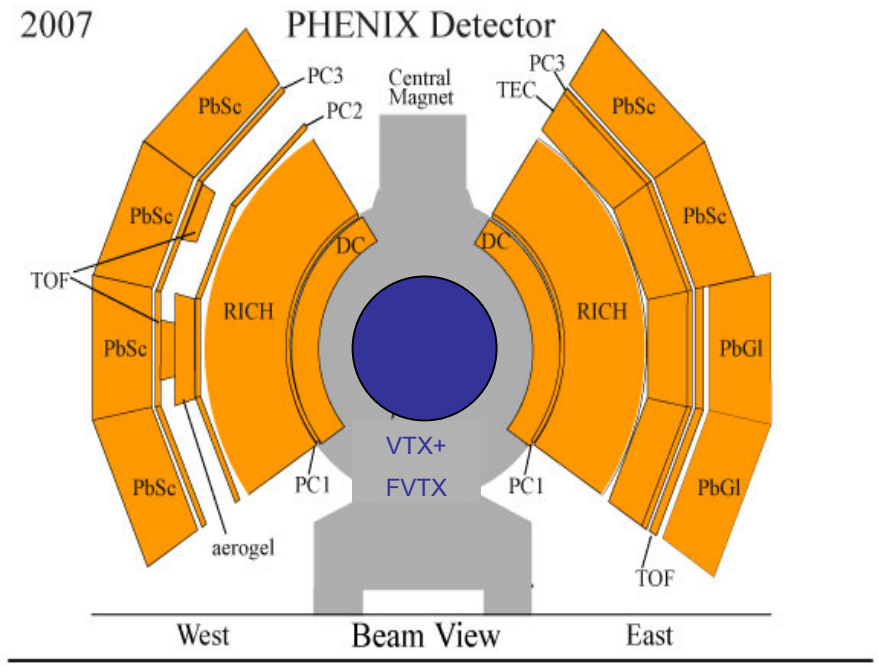
- Pb Scintillator
- Pb Glass
- Nose Cone Calorimeter (NCC)
- Muon Piston Calorimeter

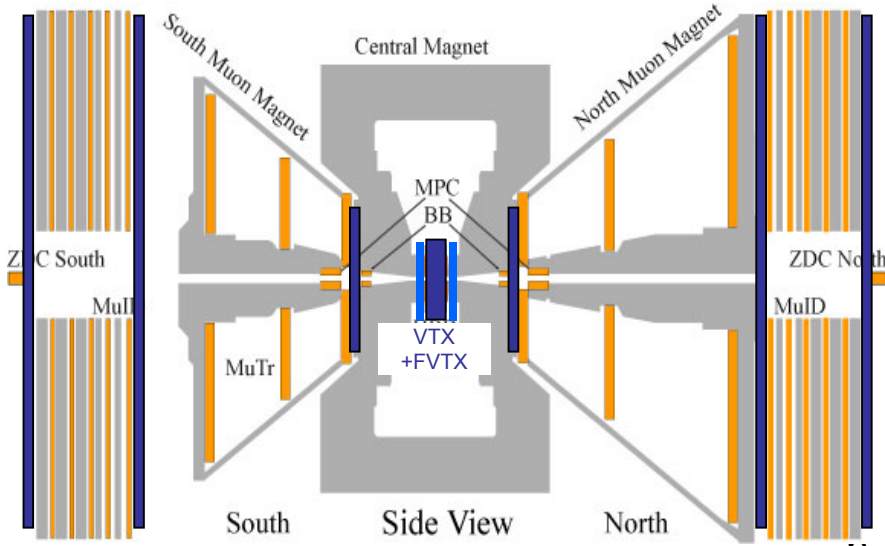
Event Characterization:

- Beam-Beam Counter
- Zero Degree Calorimeter/Shower Max Detector
- Forward Calorimeter
- Reaction Plane Detector

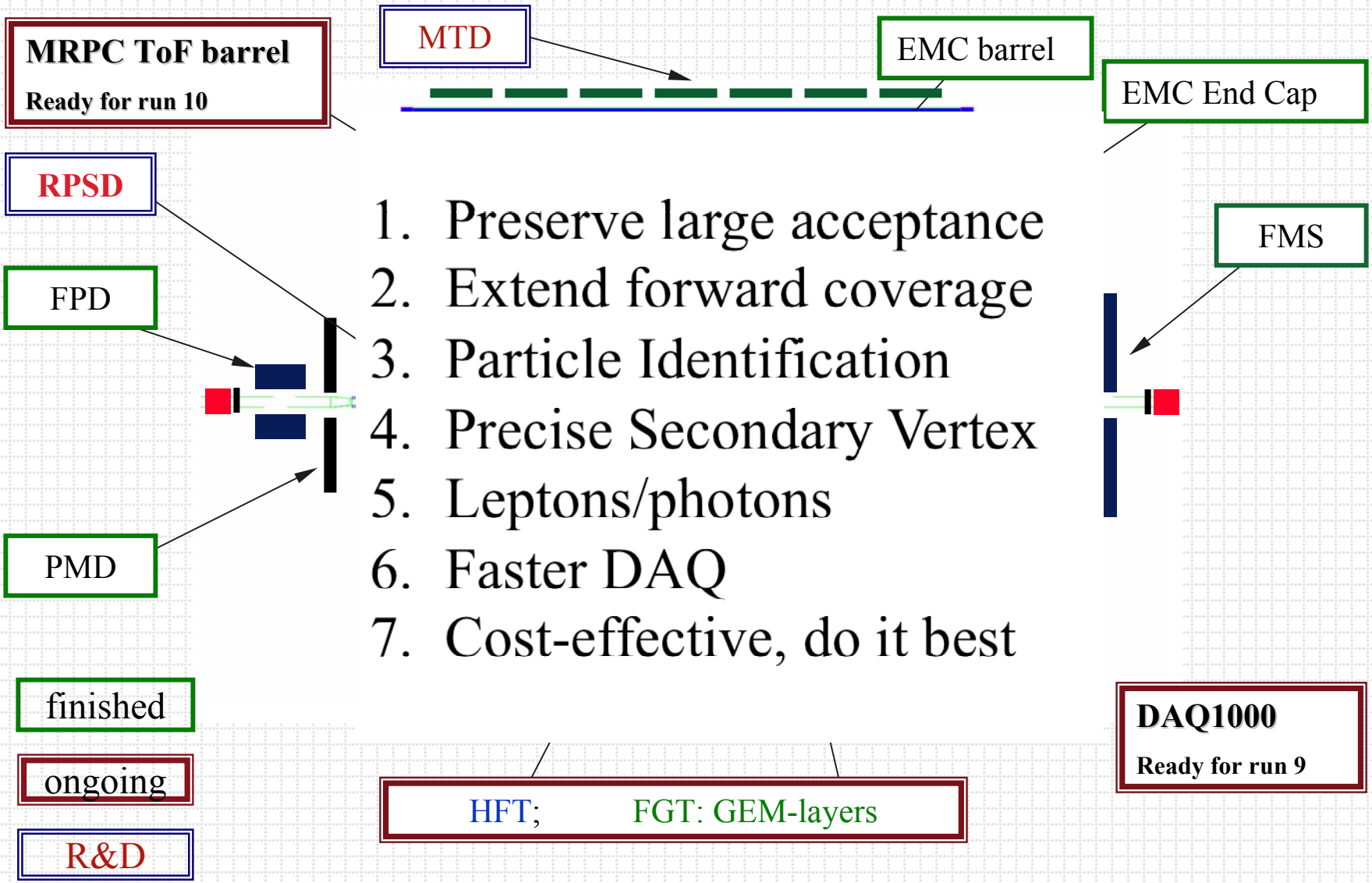
Data Acquisition:

- DAQ Upgrade





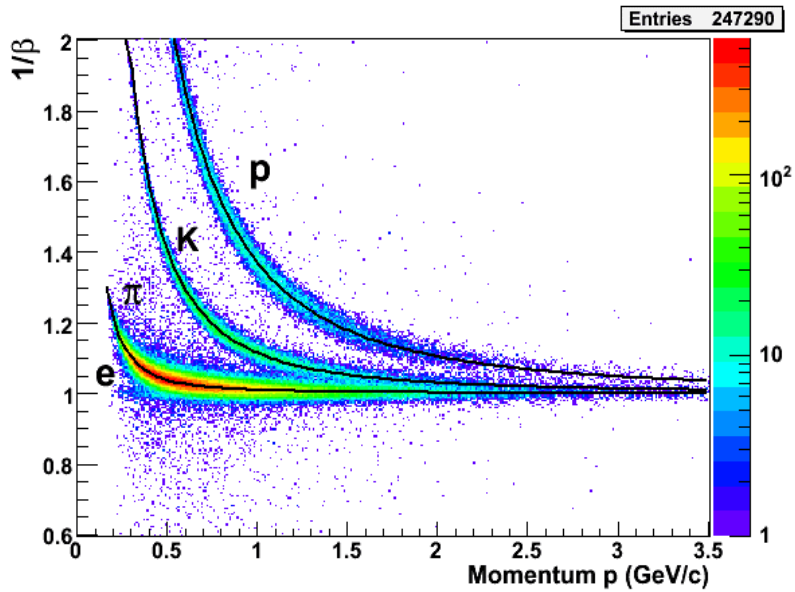
STAR upgrades

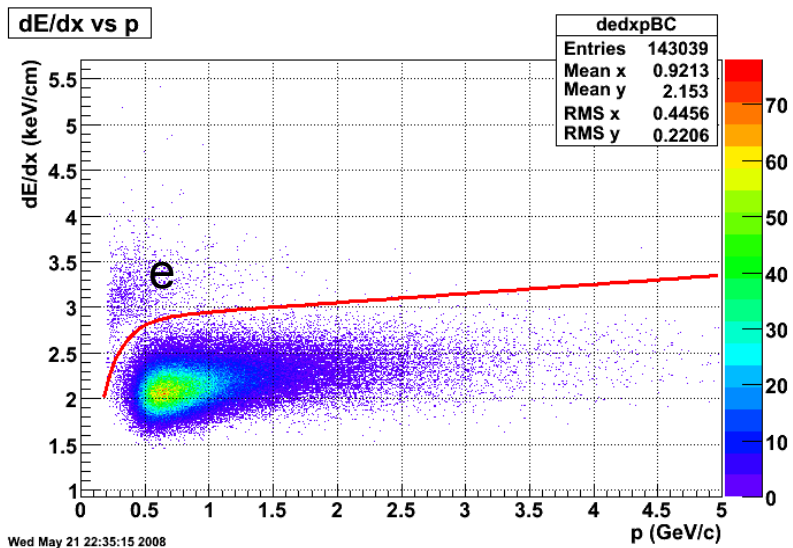


MIE: STAR Time of Flight
Physics Motivation

- Identified hadron spectra
  combined with TPC dE/dx
  identify p,π at p_T=~15 GeV/c
  - Flow and freeze-out dynamics
  - Hadronization mechanism
  - Jet Energy Loss Mechanism
- Identified particle correlations
  Identify >90% of π,K,p at mid-rapidity
  - Chemical and kinetic properties of in-medium jet associated spectra
  - Fluctuations and correlations
- Lepton program
  Identify electrons 0.2<p_T<~3 GeV/c
  - **In-medium vector meson properties**
  - **Heavy flavor**
- Baseline detector for future upgrades
  provide powerful PID tools strengthen
  - Muon detector (BNL LDRD) for muon PID
  - HFT for charm and dileptons

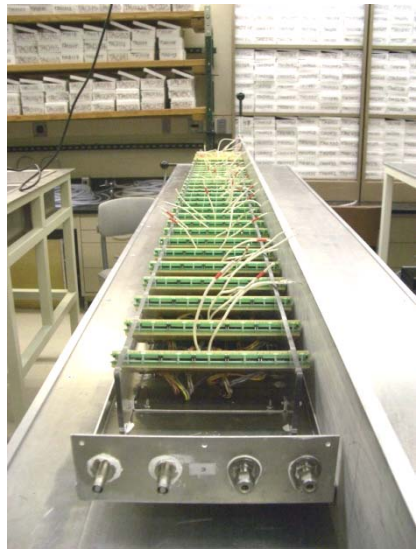
Run8 particle identification, prelim.

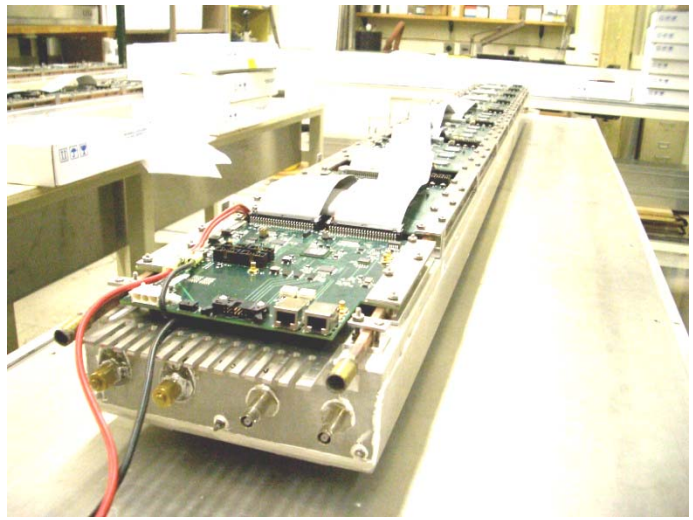




MIE: STAR Time Of Flight
Technologies

- The STAR large-area TOF uses multi-gap RPCs, built and contributed by China (95% complete.)
- The 23k-channel system is subdivided into 120 trays. Each 192-channel tray contains its complete front-end and read-out electronics, and interface.
- The electronics are inaccessible during a RHIC Run when the STAR poletip is closed.





MIE: STAR Time of Flight
Cost, Schedule & Issues

Cost:

TOF Project - FY08 Q2	Baseline	To date	To completion	Estimated cost	Est. Contin.
(Amounts in M$)					
Mechanical Systems	0.9	0.5	0.3	0.8	
Electronics	3.6	2.3	0.9	3.2	
Management	0.3	0.3	0.1	0.4	
Project Total	**4.8**	**3.1**	**1.3**	**4.4**	**0.4**

Schedule:

- **Run 8: 4% installed, preliminary calibration indicates the performance will exceed the design requirement.**
- **Run 9: >50% installed (29% delivered to BNL at this time)**
- **Run 10: 100% installed**

Issues:

- **Commissioning the large number of channels, the firmware and the control software. For example: the firmware needs to seamlessly handle single-event upsets and otherwise monitor the integrity of the system.**

MIE: PHENIX Silicon Vertex Tracker

Physics Motivation

- **Measurement of Heavy Flavor production as probe of QGP**
  - $R_{AA}(p_T)$ of single electrons from c & b
  - $V2(p_T)$ of single electron from c & b
  - Jet tomography (h-h, g-h, c-h)
- **Measurement of gluon $\Delta G(x)$**
  - Measurement of A_{LL} of c and b
  - Measurement of A_{LL} of direct γ + jet

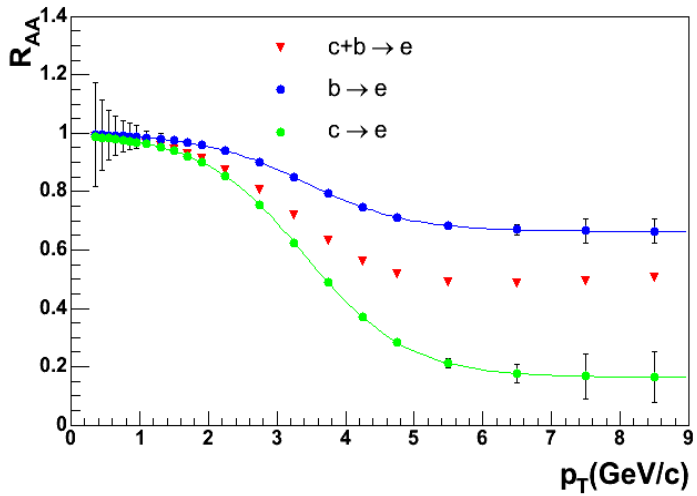
Heavy Flavor tagging and b/c separation requires a good DCA resolution (s_{DCA}~100 mm).

Measurement of recoil jets requires a large solid angle coverage

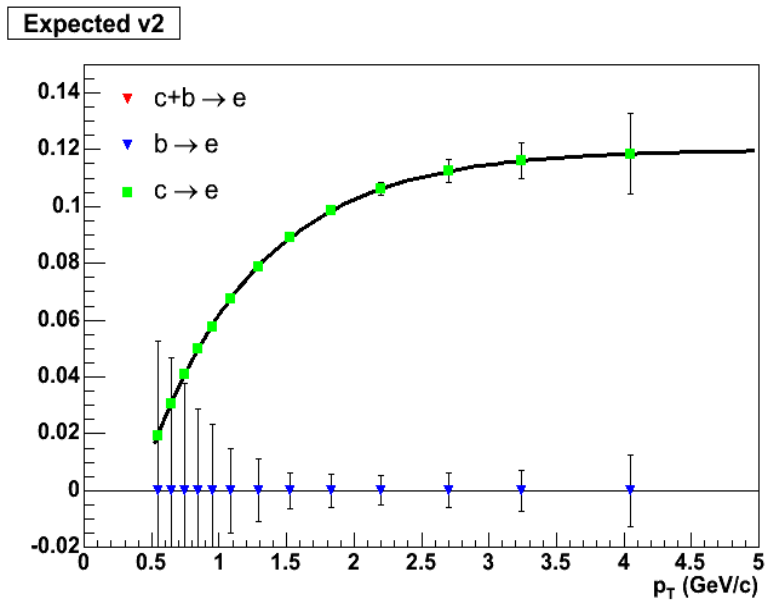
For charm / hadron separation requires enhanced goal of 50 mm DCA

RHIC II ~10 nb^{-1}

R_{AA}

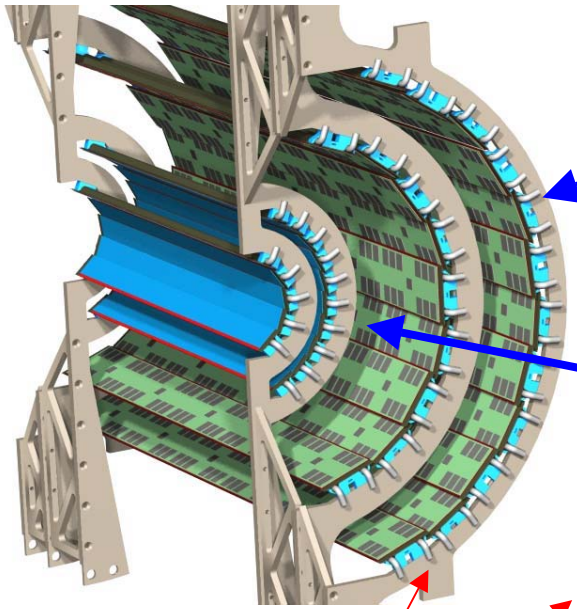


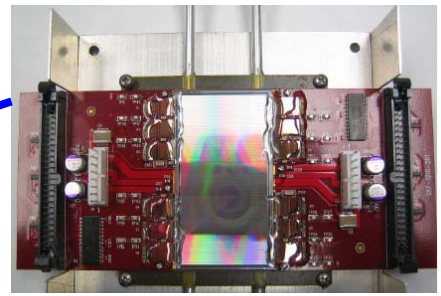
v2



MIE: PHENIX Silicon Vertex Tracker

Technologies

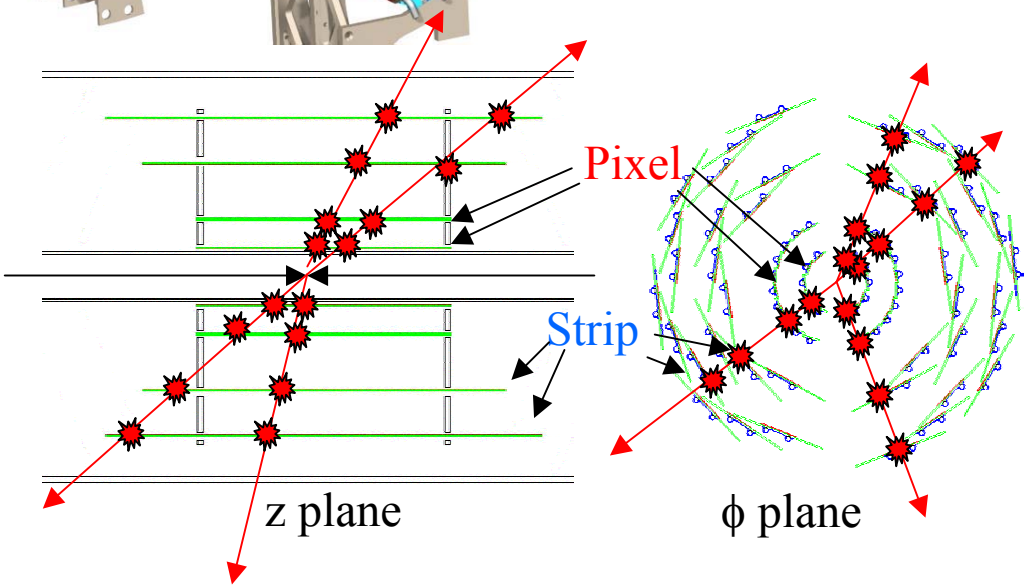




Prototype strip sensor
+ Front End electronics

Prototype pixel ladder

- ✓Fine granularity, low occupancy (2 layers)
  50mm×450mm pixel sensor
- ✓Unique strip sensor (2 layers)
  80mm×1000mm pixel pitch
- ✓Large acceptance
  $|\eta| < 1.2$, almost 2π in ϕ plane
- ✓Self tracking capability
  2 pixel sensor layers (r = 2.5, 5.0cm)
  2 strip sensor layers (r = 10.0, 14.0cm)



MIE: PHENIX Silicon Vertex Tracker

Cost, Schedule and Issues

Cost:

WBS	Item	Baseline (AY k$)	Cost Accrued to date (AY k$)	To Complete (AY k$)	Estimated cost (AY k$)	Contingency (AY k$)	Contingency (% of Est to Comp)
1	VTX	4700	660	3154	3814	886	28.1
1.1	Strip	1676	241	1140	1381		
1.3	DAQ	200	0	160	160		
1.4	Electronics System Integration	705	33	549	582		
1.5	Auxiliary Systems & Integration	1940	386	1138	1524		
1.6	Management	111	0	100	100		
1.7	Installation	68	0	68	68		

Schedule:

- VTX Project start 6/2007
- Pixel ladders assembled 6/2009
- Strip ladders assembled 5/2010
- Project complete 9/2010

Issues:

- Improve S/N performance of strip sensor
- Assembly of strip read out card difficult due to component density
- Cost of carbon fiber support frames 1.5-2x more than planned
- Project schedule is aggressive

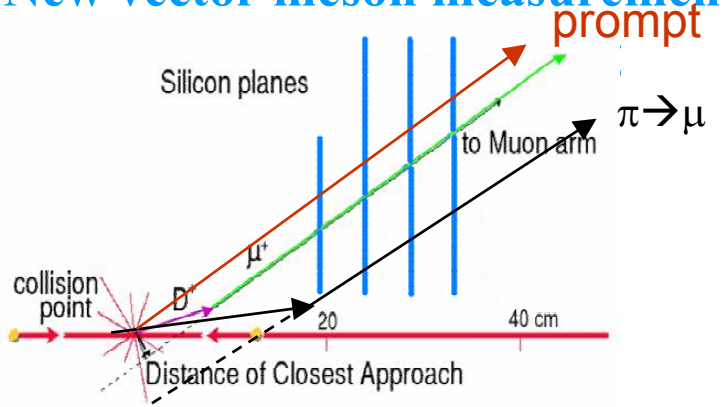
MIE: PHENIX Forward Silicon Vertex
Physics Motivation

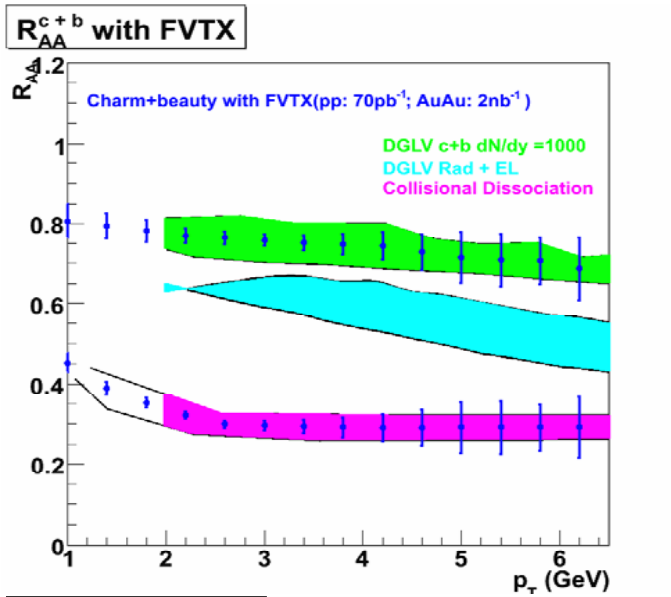
Precision Charm/Beauty Measurements :

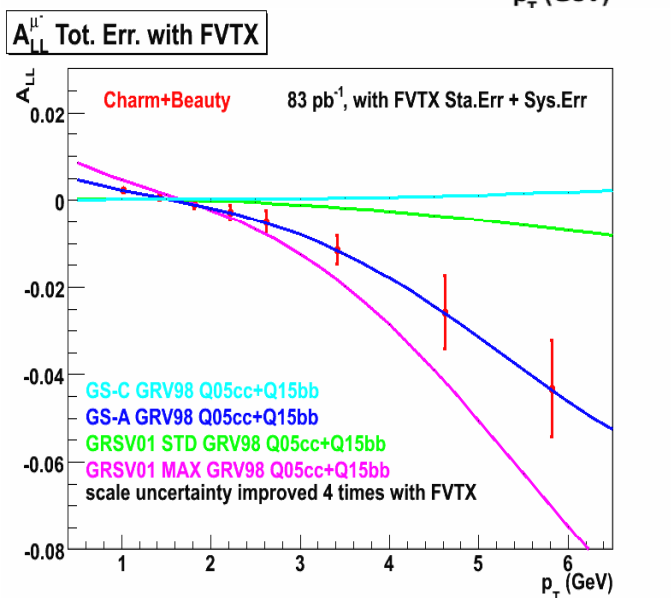
- Unravel energy loss mechanisms in QGP
- Provide new channel, new kinematic coverage to study gluon contribution to proton's spin

B→J/ψ, Drell-Yan, ψ' :

- First direct beauty measurements
- Drell-Yan tests Sivers universality
- New vector meson measurements to







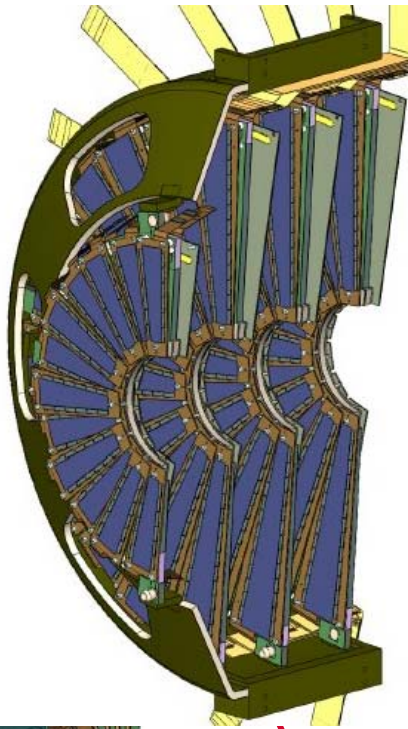
MIE: PHENIX Forward Silicon Vertex
Technologies

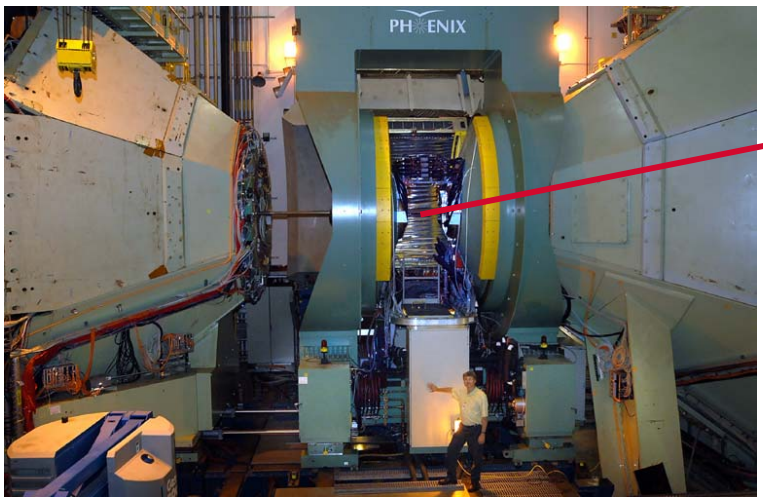
Four Layers of silicon mini-strips, covering Muon Arms

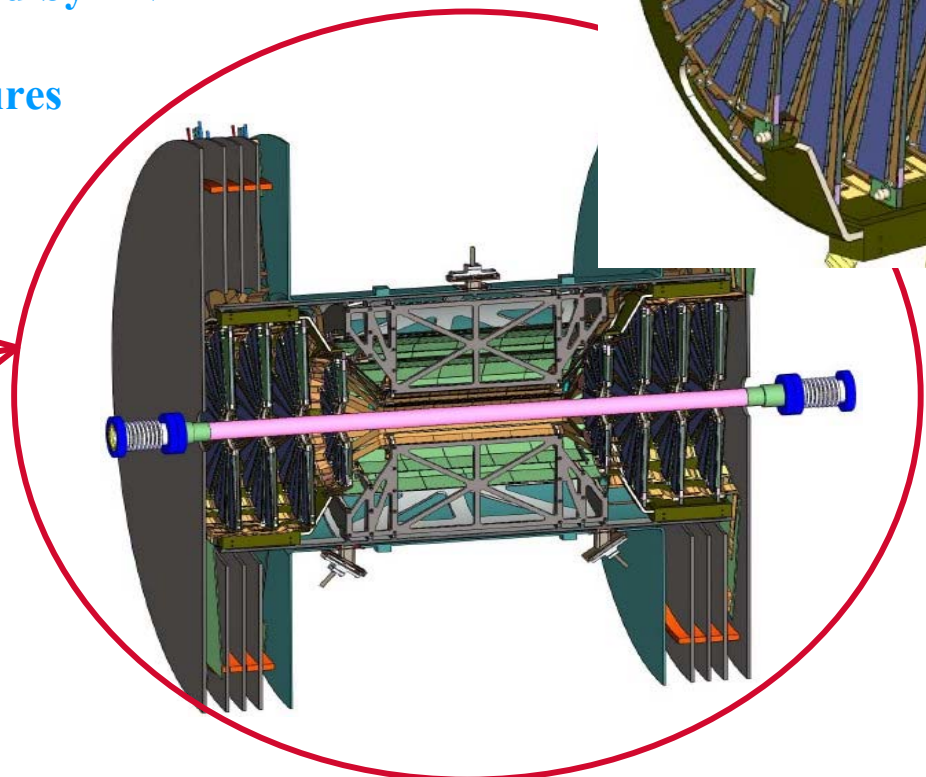
- 75 μm x few mm strips --> clear separation of prompt muons, heavy flavor decays, and π/K decays
- Improved dimuon mass resolutions

Technology Choices

- Standard silicon strip technology
- "Data-Push" readout chip developed by FNAL
- PHENIX-DAQ-compatible readout
- Low mass, rigid mechanical structures







MIE: PHENIX Forward Silicon Vertex
Cost, Schedule & Issues

Total project cost $4.88 M in at-year dollars

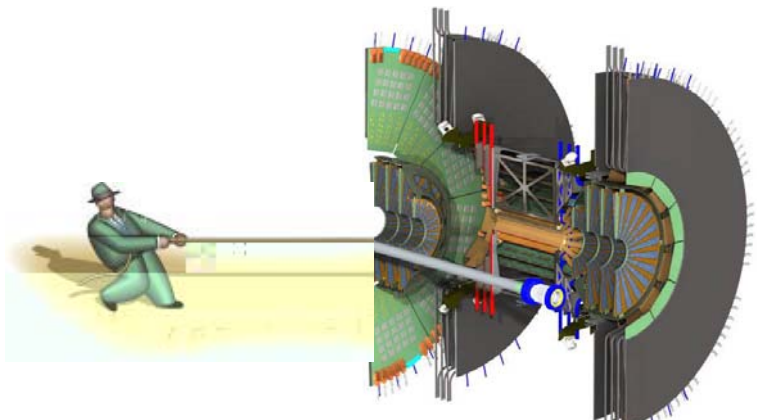
- Manufacturer quotes on most items
- Risk-based analysis of contingency-->26% overall contingency

Scheduled Install into PHENIX Q2 FY11, construction started in April 2008

- Sensor, chip, readout prototyping FY08 (first wedge assembly this summer)
- Prototyping completed, Production Procurements mostly complete in FY09
- Detector assembly, testing in FY10
- Installation into PHENIX Q2 of FY11

Issues

- FPHX chip development at FNAL
- Continuing Resolution in FY09 = challenging funding profile

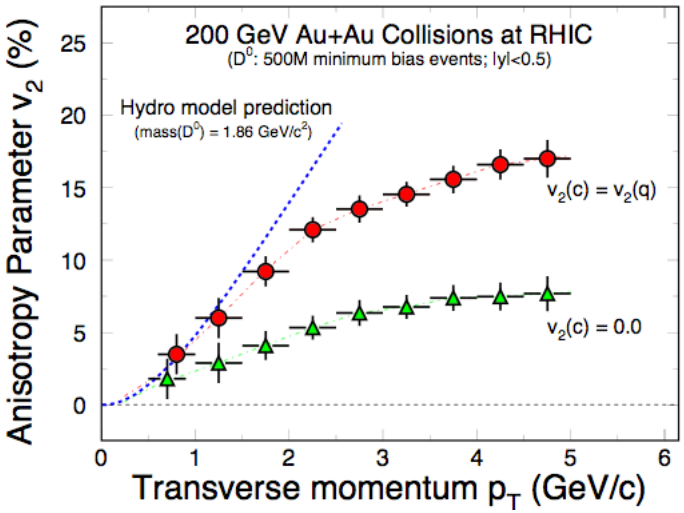


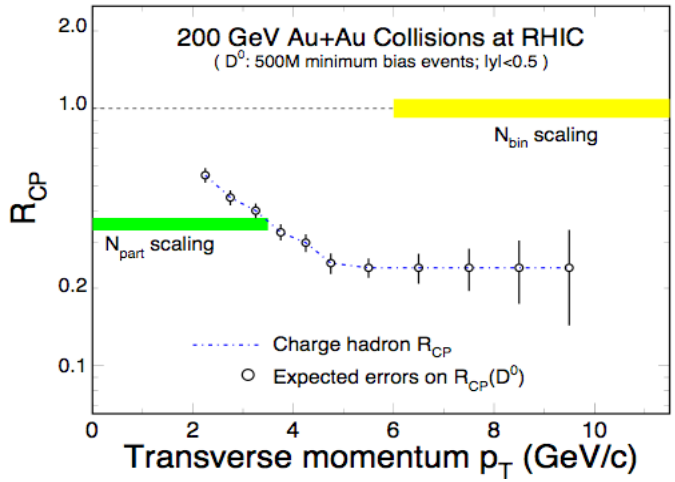
MIE: STAR Heavy Flavor Tracker (HFT)
Physics Motivation

STAR detector + HFT are unique:

- Reconstruct Charm- and Bottom-particles directly via hadronic decay in the same detector and at the same time.

- Will utilized RHIC-II luminosity for the physics program: QGP properties at RHIC energies.



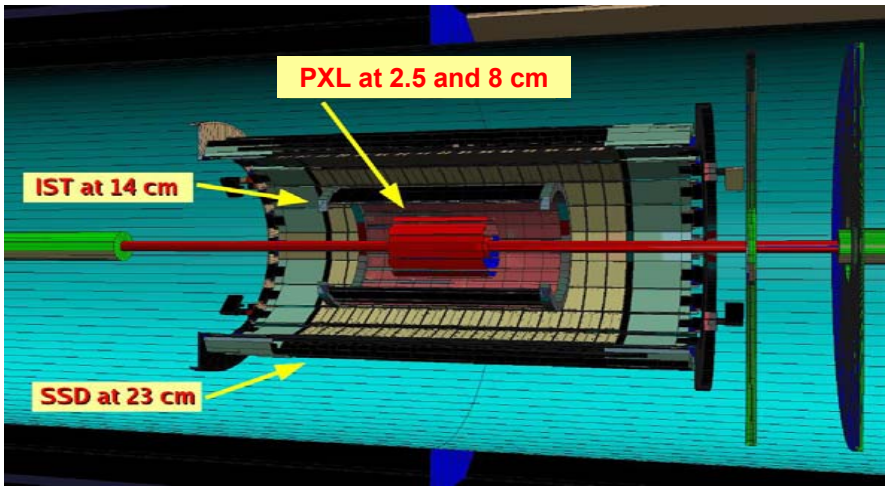


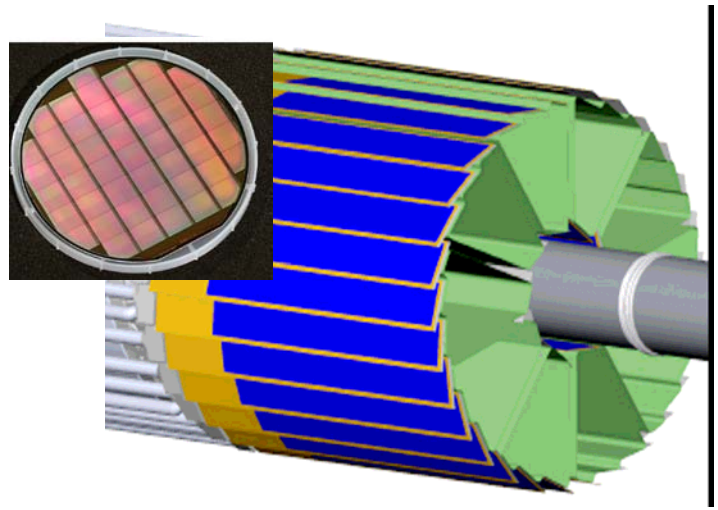
- 200 GeV Au+Au minimum biased collisions (500M MB)
- Charm collectivity ⇨ drag/diffusion constants ⇨ ***medium properties!***

Charm R_{AA} ⇨ ***energy loss mechanism, e.g. collisional vs. radiative!***

Extend study of baryon-meson anomaly to charm sector by measuring Λ_C

MIE: STAR Heavy Flavor Tracker
Technologies





- **Thin 50 mm Si Active Pixel Sensor detector reduce limitation and give 10 mm space point resolution; x/x0 ~ 0.28% per layer**
  - **Data reduction and formatting on chip**
  - **Rapid insertion and removal**
  - **Precision positioning**
- **Pointing of TPC tracks provided by existing SSD and new Inner Silicon Tracker (IST) ; 1 layer ~ 1% x/x0.**
- **Coverage in $|\eta|<1$, matches to 2π TOF coverage.**

Test telescope installed at STAR proves viability of pixel concept

MIE: STAR Heavy Flavor Tracker
Cost, Schedule & Issues

Cost:

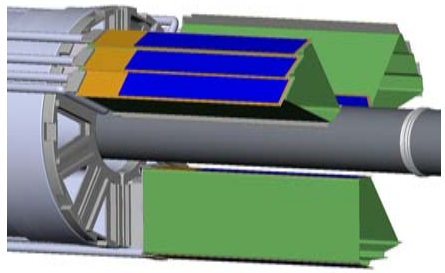
- Estimated in range $11-14.5M

Schedule:

- CD-0 review in February 08

Technically Driven Milestones

- CD-1 October 08
- CD2/3 August 09
- Installation of engineering prototype Sept. 10
- Pixel detector in beam January 2012
- IST installed July 2012
- Project Complete FY13

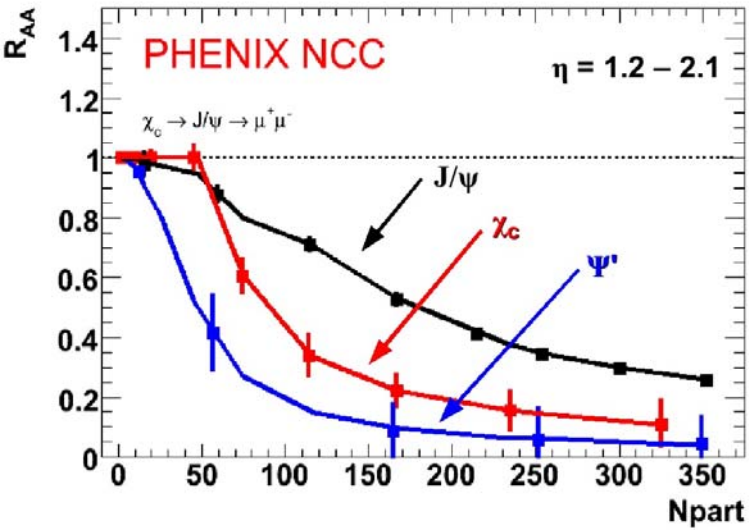


Issues:

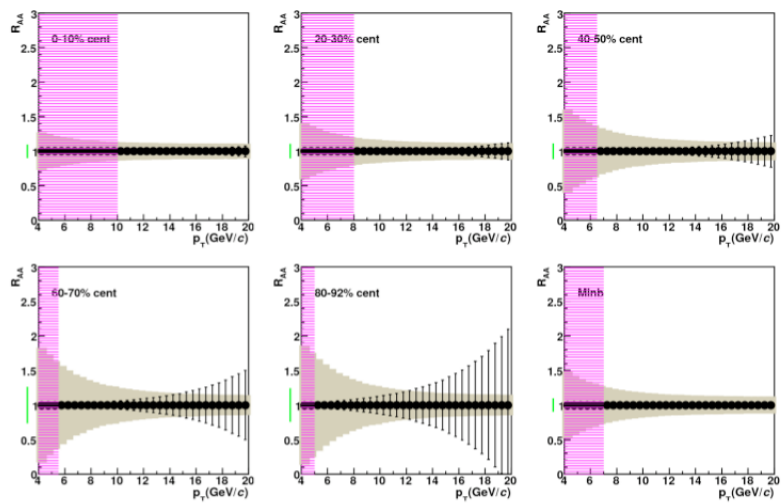
- Sensor development, Kinematic mount, SSD
  - Mitigated by R+D
- Critical R&D on APS, precision mechanical structure ongoing, and IST Needs significant funding in 09
- Timely construction, to take advantage of the development of RHIC-II, is crucial for the STAR physics program.

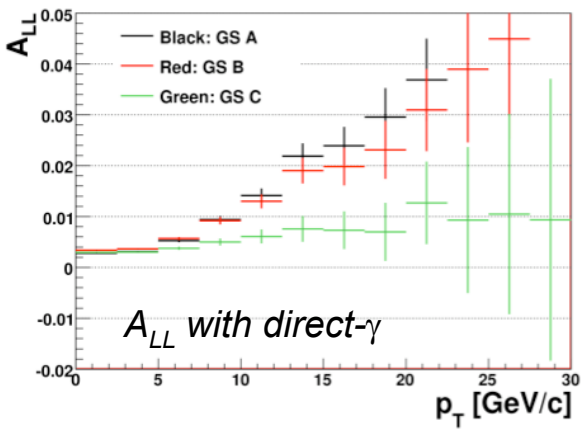
MIE: PHENIX Nose Cone Calorimeter
Physics Motivation

- **Jet energy loss & medium properties in heavy ions**
  - High p_T π^0 R_{AA} at forward rapidity
  - Direct photons and γ-jet measurements
  - Charmonium suppression studies with χ_c
- **Cold nuclear matter in d+Au**
  - Initial state physics
  - Gluon saturation at low-x
- **Spin physics in polarized p+p**
  - ΔG at low-x (to ~10^{-3}) via direct-γ and γ–jet



Direct-γ R_{AA} in Au+Au, error bars for one RHIC-II luminosity run



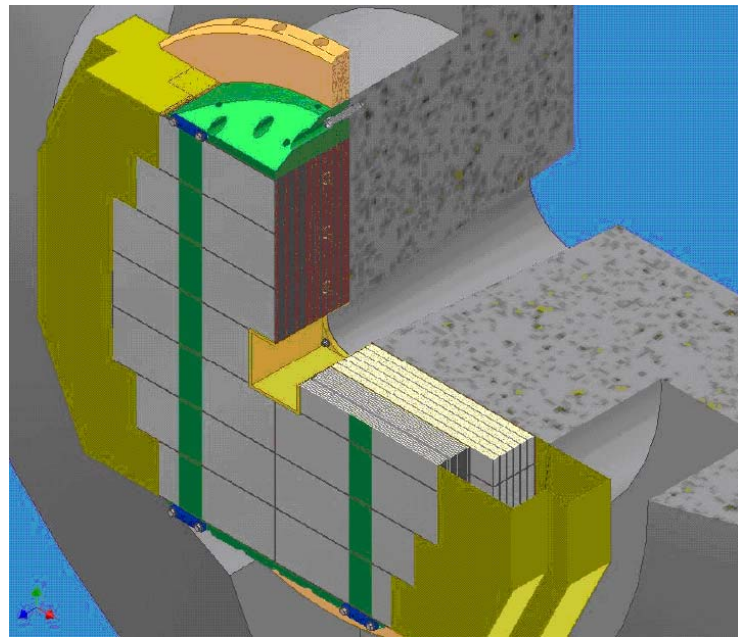


MIE: PHENIX Nose Cone Calorimeter

Technologies, Cost, Schedule

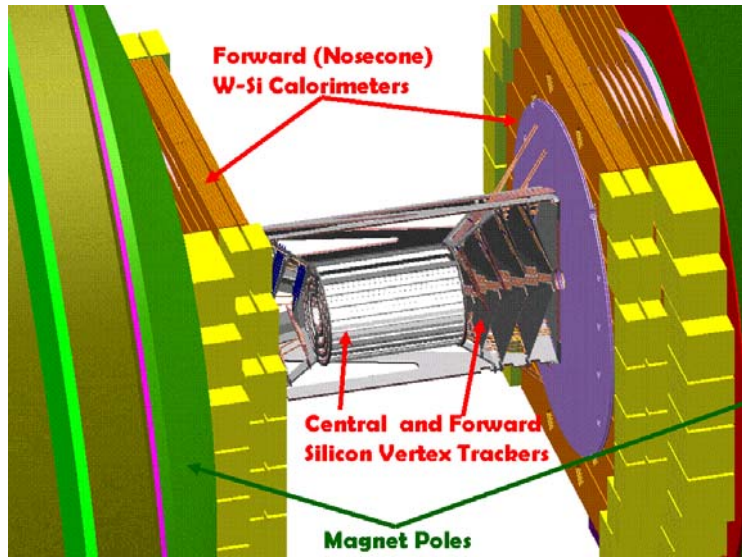
NCC Specs:

- 19 cm thick W-Si sampling calorimeter, 50 cm radius.
- High density: 19.3 g/cm^3, small Molière radius: 9 mm
- Mounted on the magnet pole tip
- Front face 41 cm from nominal vertex
- 3 longitudinal segments (EM1, EM2,HAD)
- Depth 35 X_0 (1.3 L_{int}): (8 + 8 + 19 X_0)
- 2 photon identifiers (PI1, PI2) to resolve single shower π^0s at (2, 3) X_0



Cost:

	FY08	FY09	FY10	FY11
Funding request	$200K	$1200K	$2100K	$1000K



Schedule:

- CERN Test beam of prototype in late Fall
- Awaiting DOE approval
- Installation prior to Run-12

Capital Project: STAR DAQ1000
Technologies

- **Two upgrades:**
  - **DAQ1000 TPC Electronics Upgrade**
  - **STAR DAQ Upgrade (data receivers & processor computers)**
    - **funded by STAR Cap Eq**
- **CERN-ALICE based electronics chips and optical senders & receivers *(keeps the cost way down!)***
  - **PASA – analog preamplifier & shaper**
  - **ALTRO – ADC, storage, digital manipulations**
  - **SIU – optical data sender card**
  - **RORC – optical data receiver card**
- **Designed for STAR TPC geometry, 2 electronics board types:**
  - ***TPC FEE* (front-end electronics cards)**
    - **Built 5200; 32 channels each; preamp, ADC, storage, buffering…**
  - ***TPC RDO* (readout boards)**
    - **Built 170; digital multiplexers with optical senders, power, control…**
- **Installed 1/24 of the TPC (1 whole sector) in the FY08 physics run and took data continuously**

Capital Project: STAR DAQ1000

Cost, Schedule and Issues

Cost:

	"DAQ1000"	
FY06	• ASICs from CERN • Prototyping	810 k$
FY07	• Final prototypes • 1/24 built+installed (1 TPC sector) – took data in FY08!	190 k$
FY08	• Full electronics production • Optical Senders • Installation in progress…	900 k$

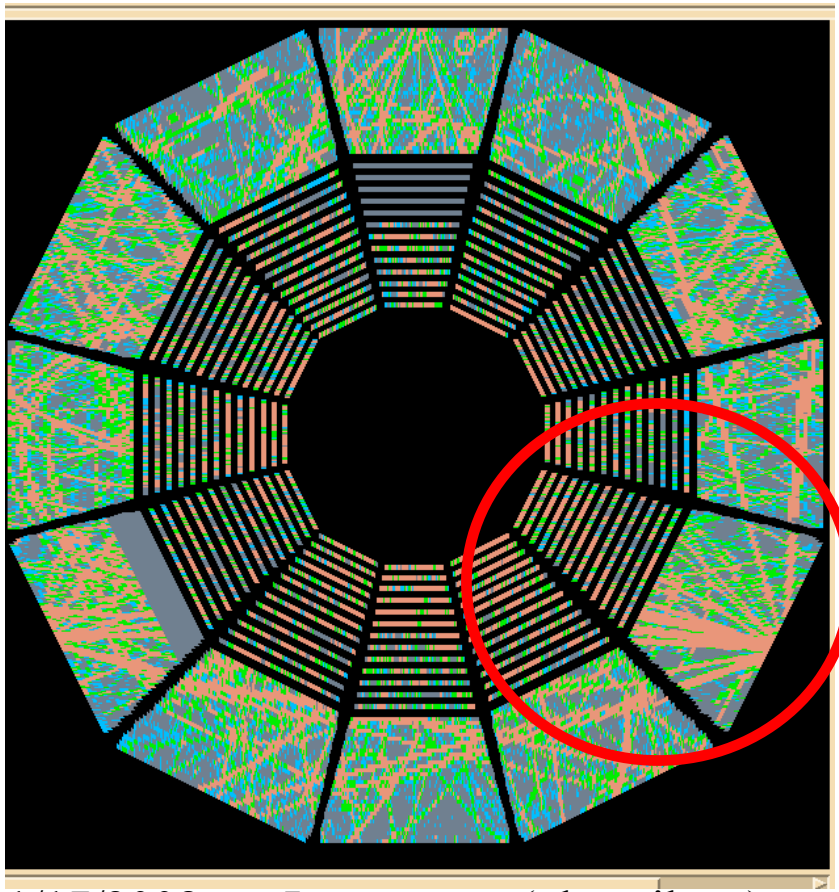
Schedule:

- **All DAQ1000 Readout Boards received and tested**
- **DAQ1000 FEEs being received and tested @ ~400 boards/wk. Delivery expected to be complete by early September.**
- **All DAQ1000 TPC electronics to be installed by Oct 2008. Sectors (24 total) will be tested as electronics are installed.**

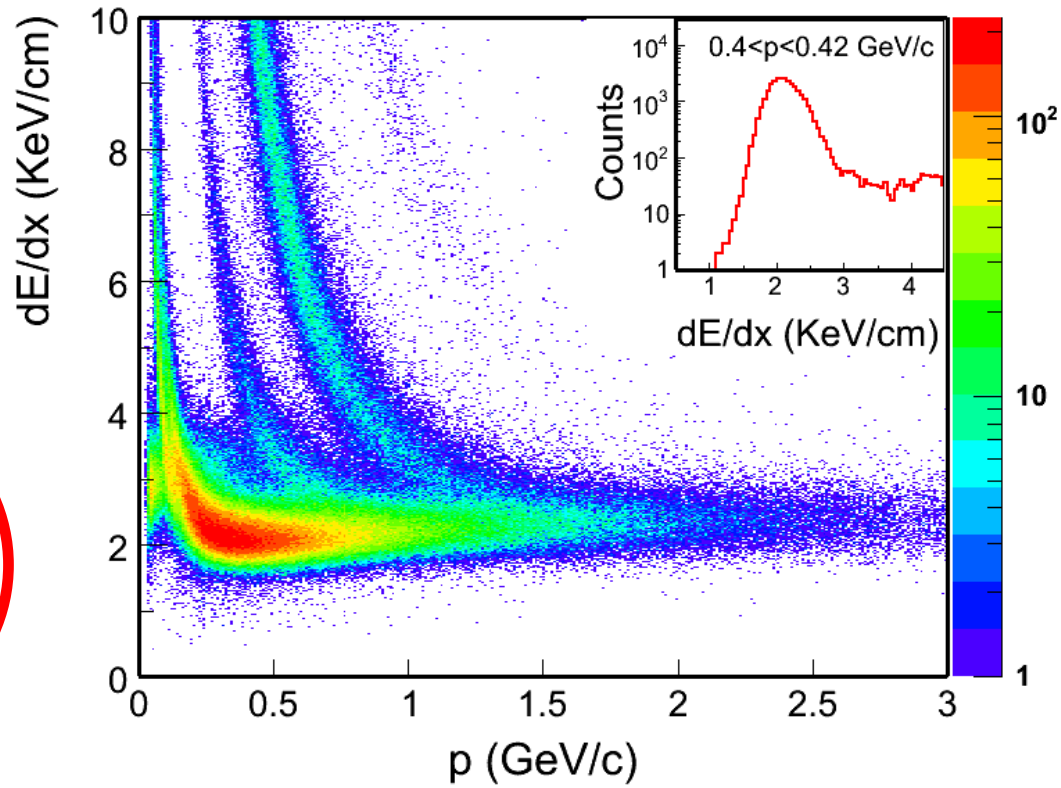
Issues:

- **Commissioning time in Run-9**

STAR DAQ1000 + TOF Commissioning in Run-8



1/17/2008 Laser event (plus pileup)



TPX dE/dx from TOF+TPX events

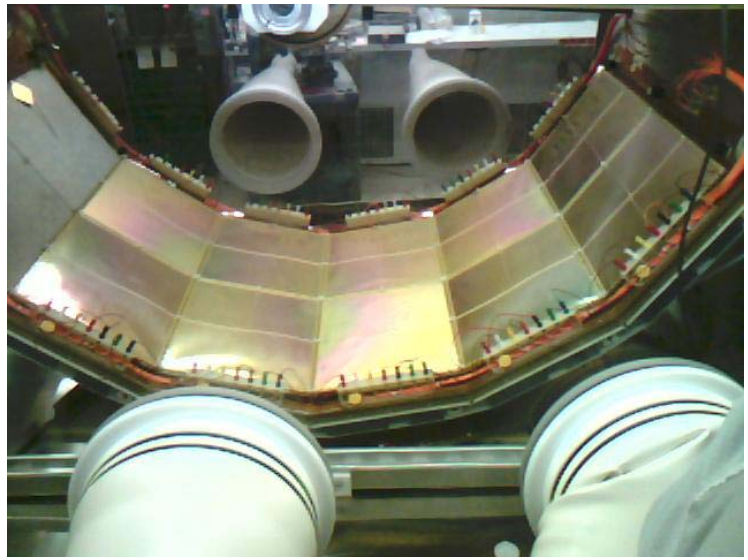
Data from DAQ1000 sector look good

DAQ1K at 1000Hz, 5—7% deadtime

Capital Project/NSF: PHENIX Hadron Blind Detector
Physics Motivation and Technologies

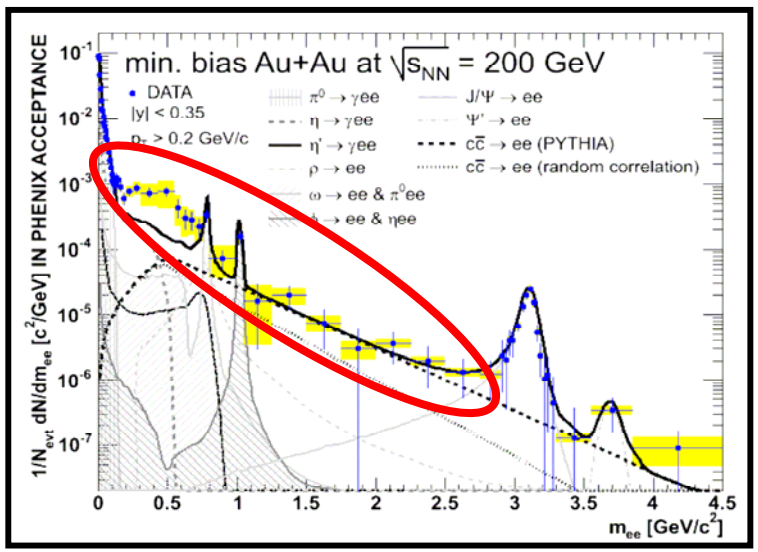
HBD:

- Windowless CF_4 Cherenkov detector
- 50 cm radiator length
- CsI reflective photocathode
- Triple GEM with pad readout
- Covers 2π in azimuth. Built in 2 halves.



Physics:

- Study electron continuum in low M_{ee} region
- Reduce backgrnd from Dalitz & conversions



Capital Project/NSF: PHENIX Hadron Blind Detector Schedule and Status

Schedule:

- **HBD full scale prototype test RHIC Run-6**
- **HBD engineering run RHIC Run-7**
  - **Readout electronics 2X lower noise performance than spec**
  - **Gas system ran with high purity CF4 in recirculating mode (< 3 ppm O_2 contamination, ~30 ppm H_2O)**
  - **Many HV problems reduced active area to ~25% of one half**
  - **Analysis of the data showed that in the operating sections the HBD performance in background rejection is significant and consistent with the expectations of the performance with the observed photo-electron yield.**
- **HBD Physics run RHIC Run-9 + Run-10**

Status:

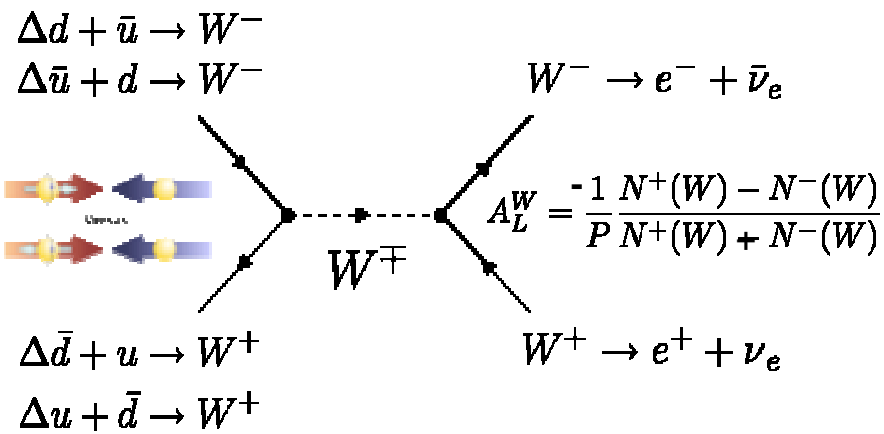
- **HBD West is finished.**
  - **All GEM stacks are simultaneously holding HV higher than required for beam operation.**
  - **Although sparks happen at the few hour frequency, their rate is dropping after a week.**

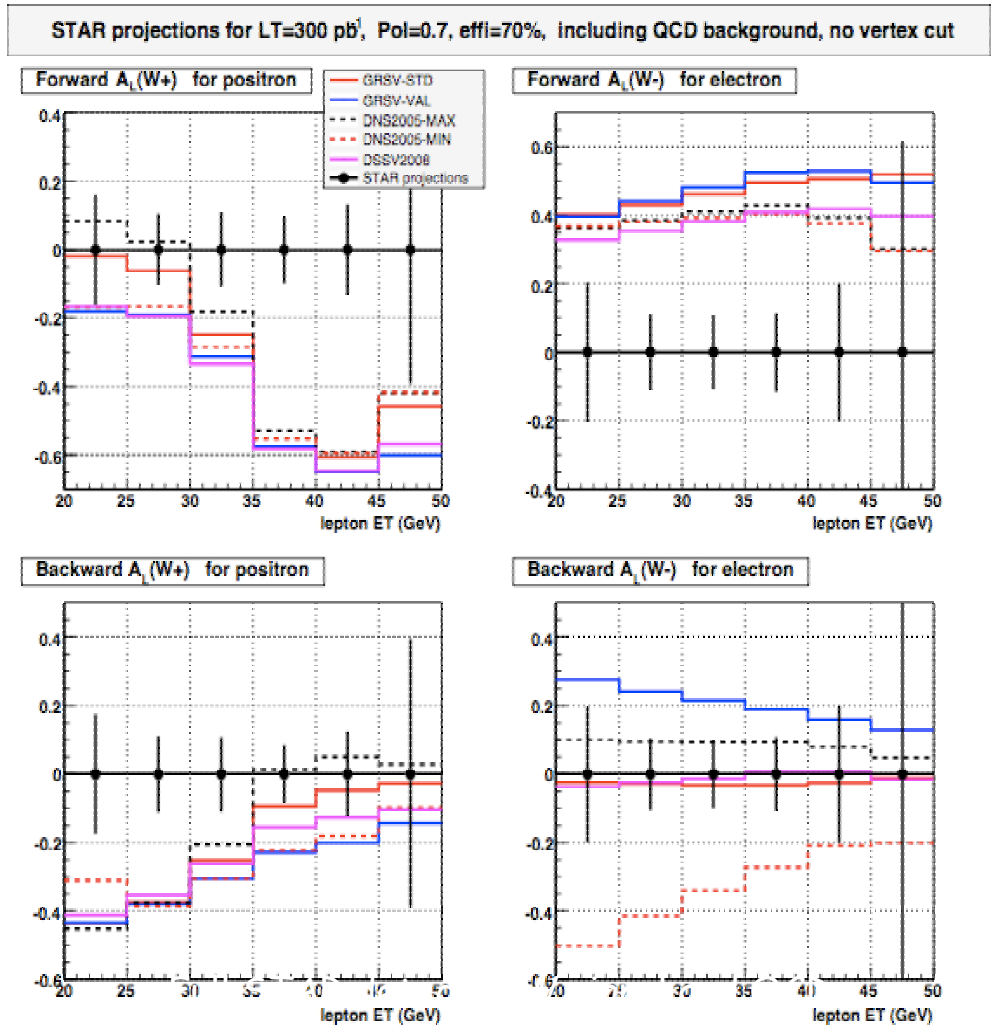
  Gas transparency for Cherenkov light:
  - **At only 1 lpm recirculation on the bench, HBD west shows 14 ppm of water (w/in spec).**
- **HBD East will be ready soon as well**
- **Install in PHENIX IR Fall 2008**

Capital Project: STAR Forward GEM Tracker

Physics motivation

- **Quark / Anti-Quark Polarization - W production**





Key signature: High p_T lepton (e^-/e^+)

(Max. $M_W/2$) - Selection of W^-/W^+ :

Charge sign discrimination of high p_T

lepton - STAR FGT

Required: Lepton/Hadron discrimination

- STAR EEMC and FGT

Capital Project: STAR Forward GEM Tracker

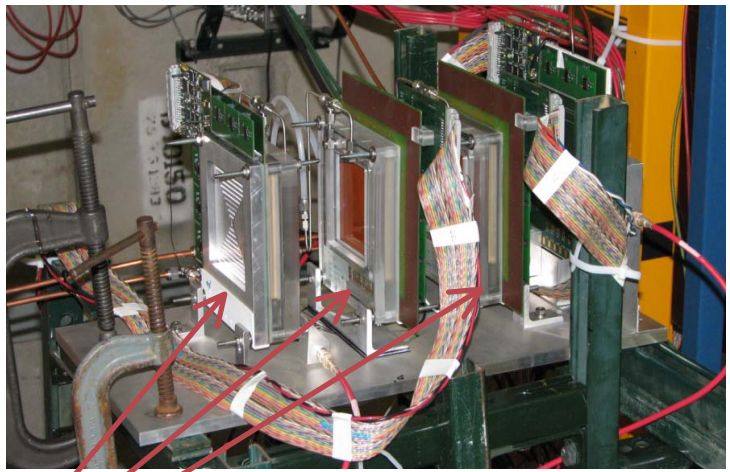
Technologies

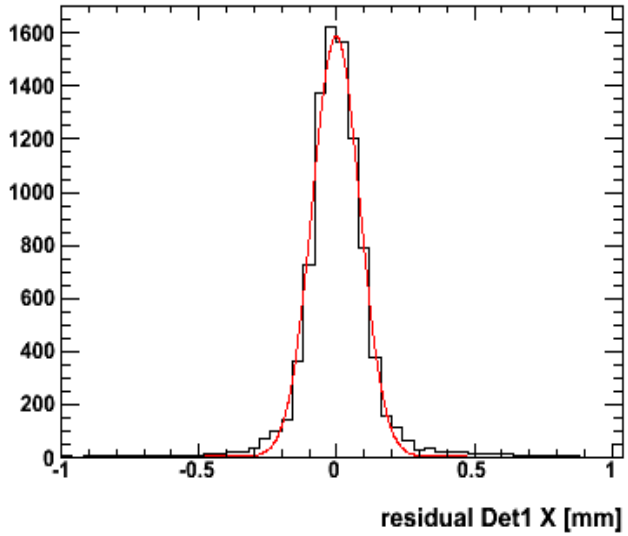
GEM Technology development

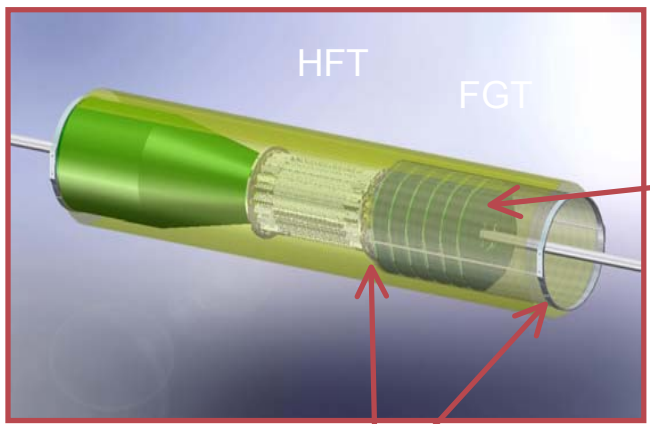
SBIR proposal (Phase I/II): Established commercial GEM foil source (Tech-Etch Inc.)

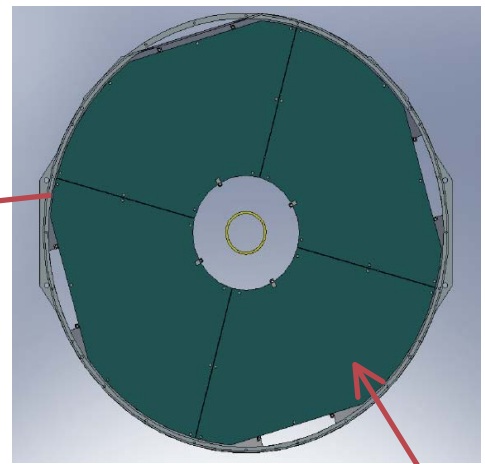
FNAL testbeam of three prototype triple-GEM chambers including APV25 chip readout

Performance meets requirements!









full triple-GEM quarter section in progress

Capital Project: STAR Forward GEM Tracker
Cost, Schedule & Issues

Cost:

- FGT Capital construction funds: $0.2M (FY08) / $0.95M (FY09) / $0.65M (FY10)

Schedule:

Goal is installation in summer 2010 ⇒ Ready for anticipated first long 500GeV polarized pp run in FY11 consistent with STAR 5-year Beam Use Request

- Successful review January 2008 / Beginning of construction funds FY08
- R&D and pre-design work: FY07 / FY08
  - Triple-GEM Detector: Complete prototype tested (Bench and FNAL testbeam)
  - Front-End Electronics (FEE) System: Complete prototype tested / FEE pre-design completed
  - Data Acquisition (DAQ) System: Conceptual layout exists based on similar DAQ with extensive experience (ANL/IUCF): Triple-GEM detector and new support structure
  - GEM foil development: Successful development of industrially produced GEM foils through SBIR proposal in collaboration with Tech-Etch Inc. (BNL, MIT, Yale): Large GEM foil test

Issues:

- Timely funding

NSF/Japan: PHENIX Muon Trigger

Physics Motivation

W-Production in Polarized p-p

Novel Technique to Study Spin Structure

Use parity violation of the weak interaction to measure quark and anti-quark spin polarizations in the proton.

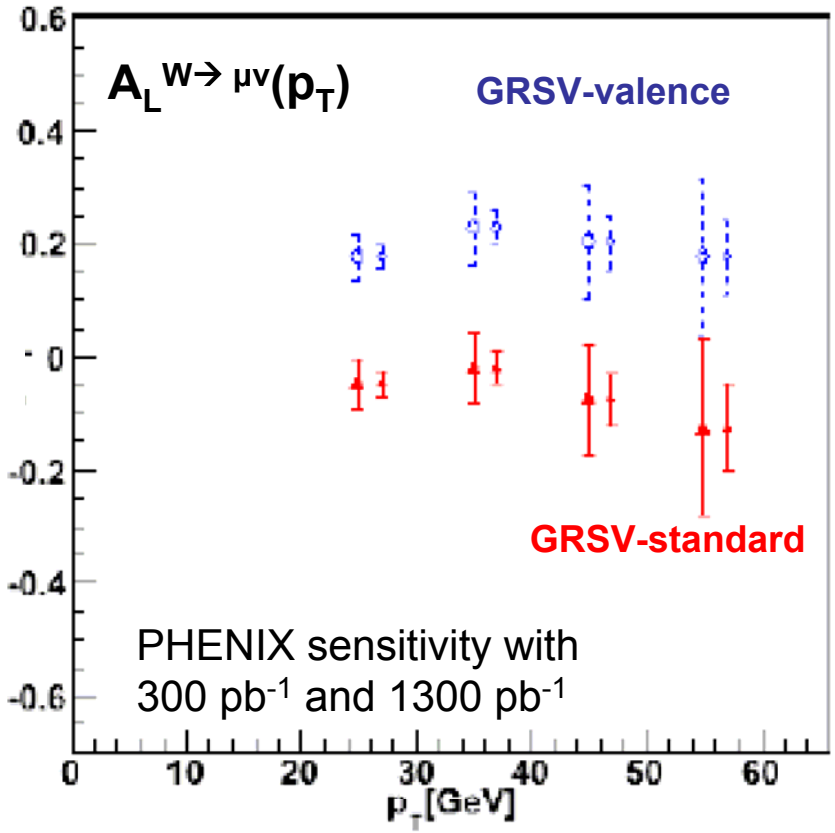
Large $Q^2 \sim M^2_W$: First Direct Measurement

➔ **Free of substantial uncertainties in SIDIS experiments at low Q^2**

➔ **Ab initio NLO framework available for the analysis of inclusive lepton asymmetries**

Example: Sensitivity for $\Delta\bar{u}(x)$

GRSV-valence and standard cannot be distinguished from present SIDIS data !

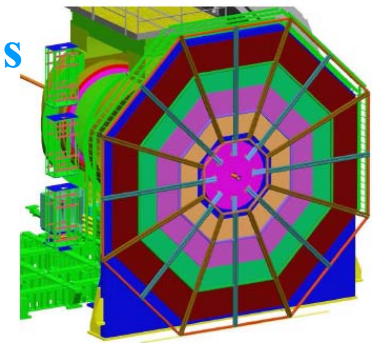


NSF/Japan: PHENIX Muon Trigger Technologies

Goal: Increase muon trigger rejection from 200 to about 10000 by adding track/momentum information to LVL1 muon trigger

Solution: tracking information from muTr

timing + coarse tracking + Θ-resolution from RPCs



MuonTrigger Trigger Electronics

- Add-on trigger boards to take information from the muTr FEEs and send muTr this to first level muon trigger processors.
- Successful in situ tests during run 8.
- Mass production for one arm in progress
- Team: LANL, Kyoto, KEK, RIKEN, Rikkyo, UNM

CMS RPC technology

- Add 3 stations of dedicated trigger RPCs to each PHENIX muon arm.
- Use CMS high rate capability ~2kHz/cm² bakelite RPCs
- First full scale prototypes currently being assembled at BNL.
- Team: ACU, BNL, CIAE, Colorado, GSU, ISU, Korea University, Muhlenberg, Nevis, PKU, RBRC, UCR, UIUC

NSF/Japan: PHENIX Muon Trigger
Cost, Schedule and Issues

Cost and Schedule:

	MuTrg Fee	MuTrg RPC	
Budget	$2.6M JSPS	$1.98M NSF-MRI $0.3M Institutions	
Schedule			
Shutdown 08	North 2-3 Stations South 2 ½ octants	South 2 prototypes	
Shutdown 09	South all Stations	North RPC 2+3	North Ready
Shutdown 10	Complete North	South RPC 2+3	South Ready
Shutdown 11		RPC1 North+South	Max Ready

Issues:

- Synchronization of p+p 500 GeV RHIC running with availability of MuTrigger
- RPC budget under pressure from changes in exchange rate changes and inflation for Bakelite(Italy), RPC Gas gaps (Korea) and Detector boxes (China)

BNL Oversight of the Upgrades

Four levels of Oversight:

- DOE, BNL, PHENIX/STAR Management, Upgrade detector Project Management

Reviews :

- DOE: Annual Review of RHIC program including upgrades (BNL,PHX/STR)
- BNL: Annual review of individual upgrade projects (DOE, PHX/STR, Upgrade PM)
- PHENIX/STAR: Annual internal reviews of upgrades(usually in prep for BNL review) (Upgrade PM)

Reporting:

- DOE: Annual FWP process (BNL, PHX/STR)
- DOE: Quarterly individual upgrade project report (BNL, PHX/STR, Upgrade PM)
- DOE: Monthly phone conference with individual upgrade project (BNL, PHX/STR, Upgrade PM)
- PHENIX/STAR: Monthly reporting from upgrades PM to experiment management
- PHENIX/STAR: Weekly phone conference with upgrades PM

Additional:

- BNL will strengthen involvement with PHX/STR Management oversight of upgrades
  - BNL will participate in PHX/STR internal review of upgrades and overall monitoring of the upgrades projects.
  - Monthly reporting from upgrade PM to PHX/STR Management will also go to BNL Management
  - Evaluate whether BNL can provide additional project management expertise to upgrades:
    - Cost and Schedule tracking
    - Review planning and scheduling
    - Assist in contracts, invoicing, report preparation, scheduling, expediting

Conclusion

- **Many upgrade projects are near completion, underway or in the planning stage for PHENIX and STAR**
- **All upgrades will make important contributions to the RHIC II physics program**
  - **Heavy Ions (Heavy Flavor, γ- jet, Quarkonia, Multiparticle correlations…)**
  - **Proton Spin (W production in 500 GeV p-p…)**
- **The RHIC multi-year run plan has been synchronized with the upgrade project schedules, though uncertainties in RHIC funding and deviations from project schedules means corrections may be need to the RHIC run plan over time**
- **PHENIX/STAR, BNL as well as DOE are all committed to the successful completion of the detector upgrade component of RHIC II**
- **The upgrade projects are critical to the continuing vitality of PHENIX and STAR**

Back Up