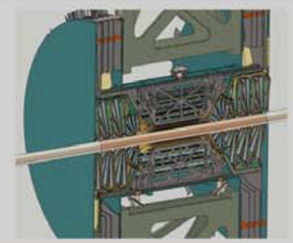
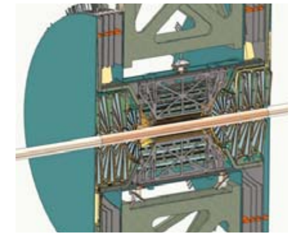


Workshop on Heavy Quark Physics in Nucleus-Nucleus Collisions, UCLA, January 2009

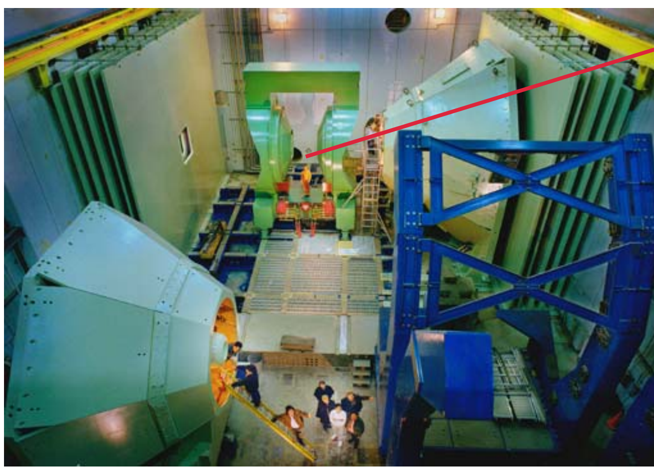
# PHENIX Silicon Upgrade Detectors

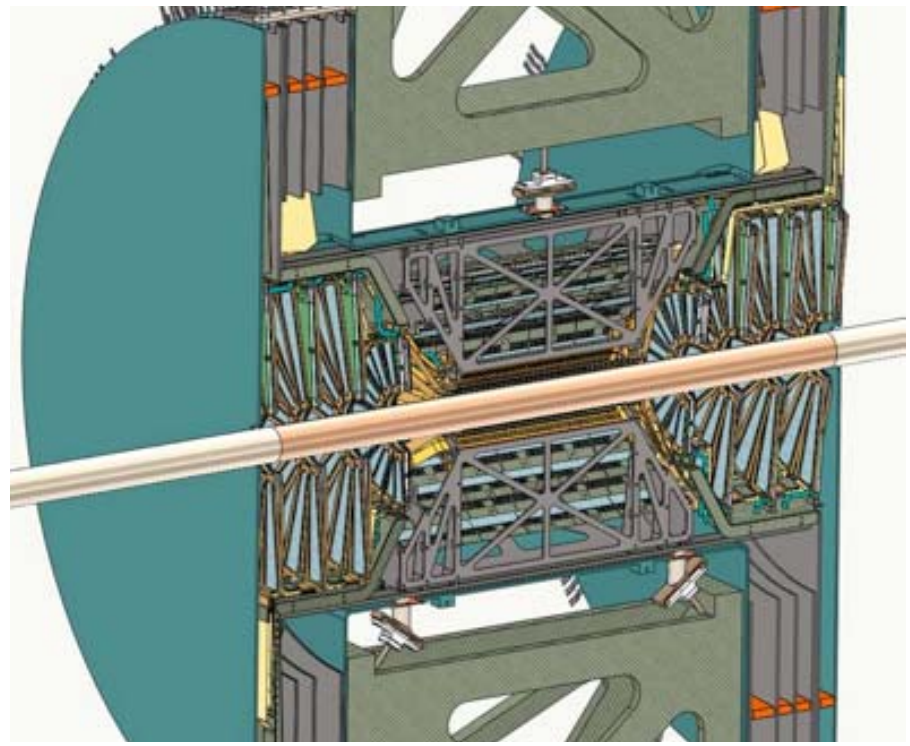
Melynda Brooks
Los Alamos National Laboratory



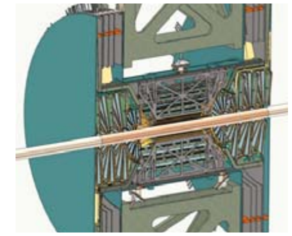
# Talk Outline

- Physics Summary Rehash
- Open Physics Questions
- Limitations of Current PHENIX Detector
- How Upgrades will Address Limitations
- Upgrades Design
- Improved Physics Performance
- Status and Schedule

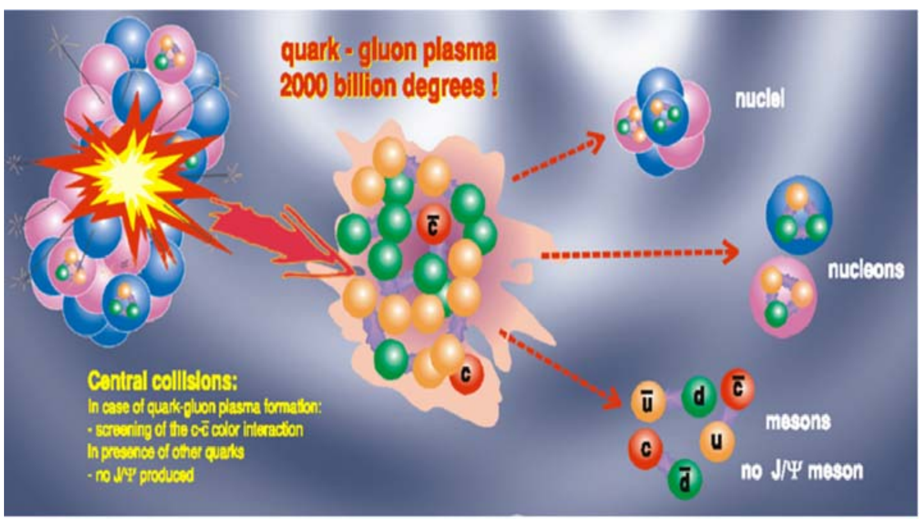


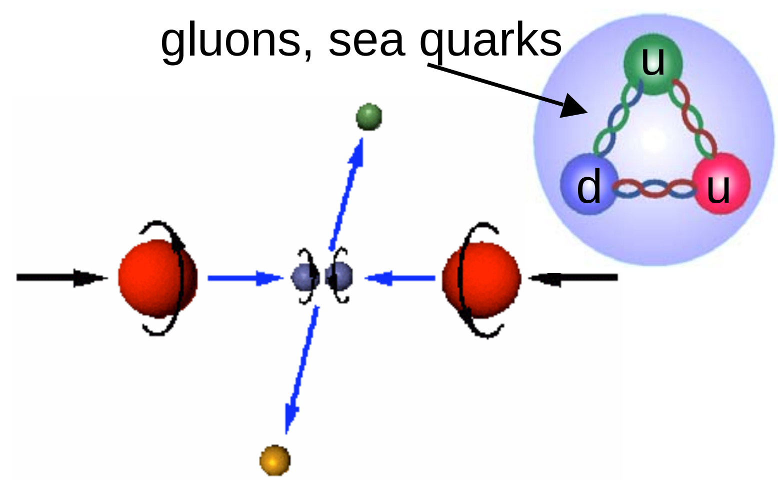


# RHIC Physics Program

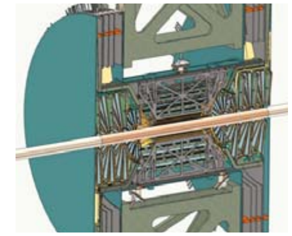


- When large energy densities are produced in heavy ion collisions, are the quarks and gluons freed from their normally bound state, and what can we learn about these fundamental particles by studying the property of the matter formed?
- What portion of particle production modification in A+A collisions comes from the (cold) nucleus and what from the hot matter formed?
- The valence quark constituents of a proton (up and down quarks) cannot account for the spin.  Using polarized p+p collisions, can we extract the proton spin contributions from gluons, sea quarks, orbital angular momentum?

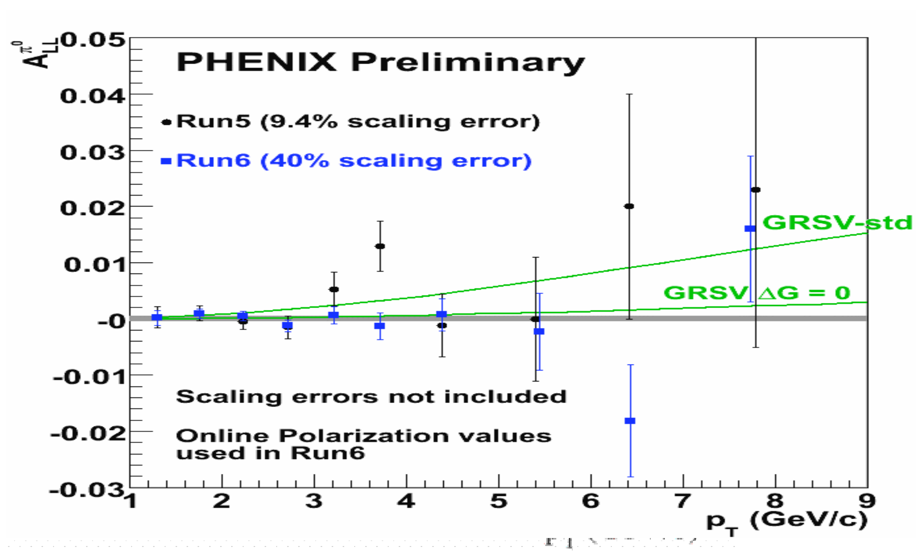


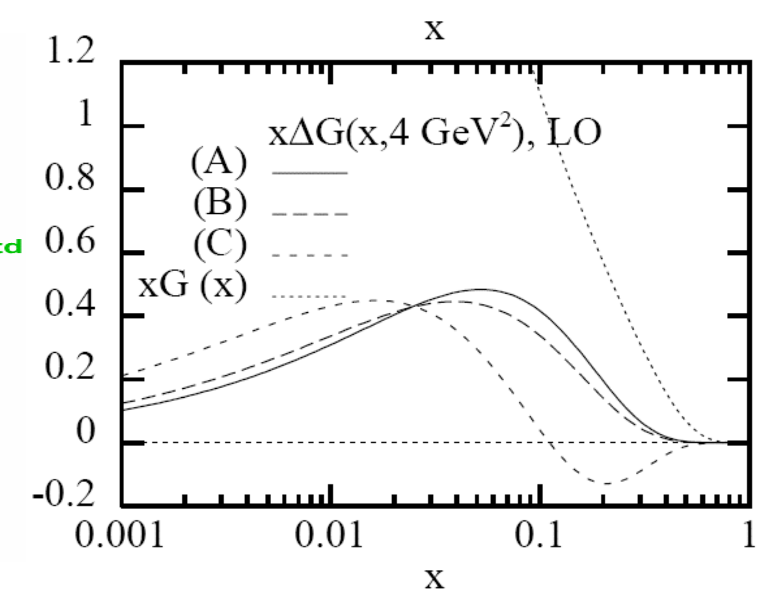



# Some Open Physics Questions at RHIC

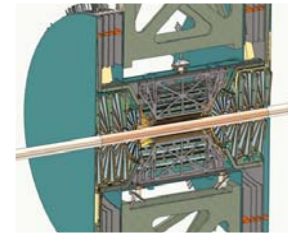


- What is causing the *surprising* flavor-dependence of particle suppression in heavy-ion collisions?
- What contributes to measured J/ψ production: Debye screening? Recombination? Significant cold-nuclear matter effects?
- Do small measured asymmetries at central rapidity mean small total gluon contributions or contributions primarily at small x?
- Can we access other contributions to the proton's spin (angular momentum, sea quarks)



# What We Would Like to Add to PHENIX



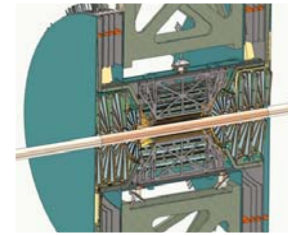
- Precision Heavy Flavor Measurements via direct (e.g. $D \rightarrow K\pi\pi$) and indirect (e.g. $D \rightarrow l\nu$) measurements to distinguish different energy loss mechanisms in the plasma-->better determination of plasma properties

- Separation of D and B measurements

- Complete set of -onium measurements to understand Debye screening contributions from the plasma

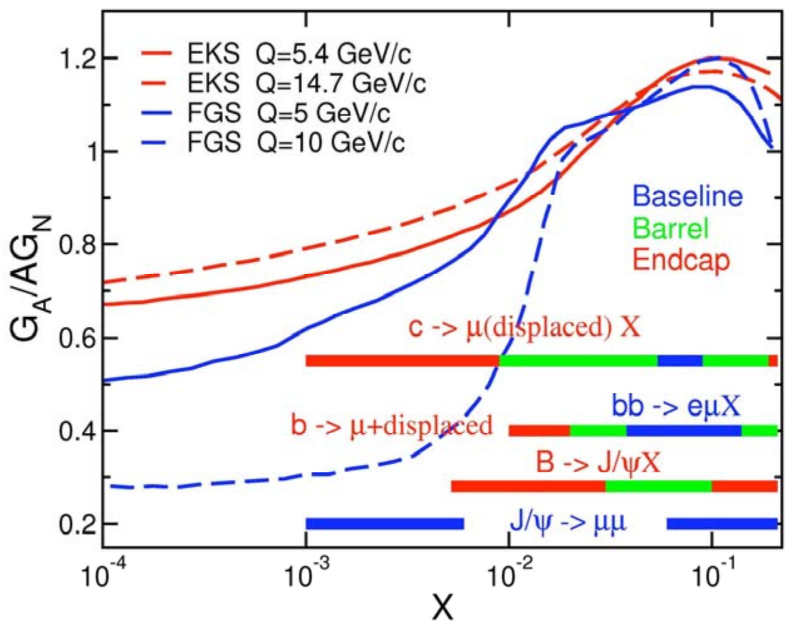
- Removal of di-lepton combinatorial background allows better open heavy flavor measurements, Drell-Yan becomes possible

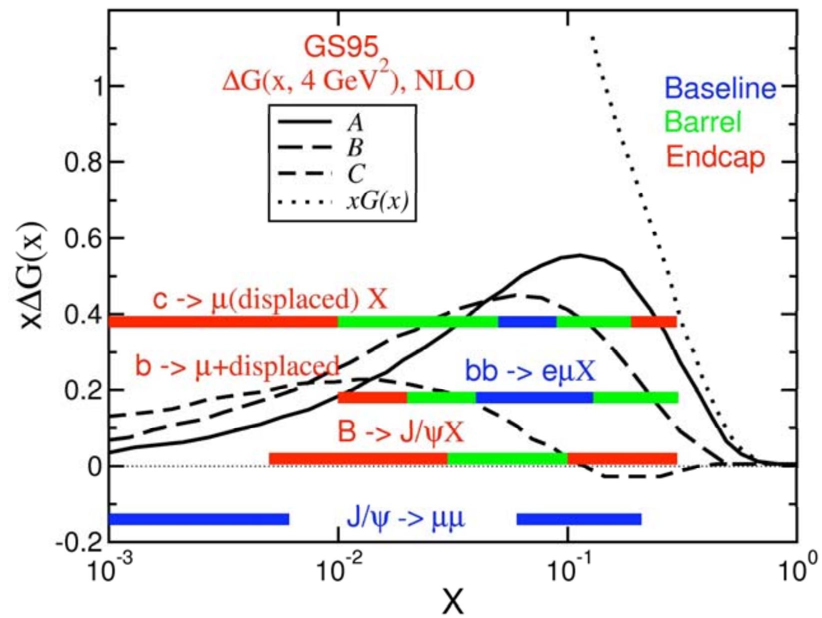
- Forward and Central rapidity measurements of open and closed heavy flavor to understand cold-nuclear matter effects and how they extrapolate to heavy-ion collisions

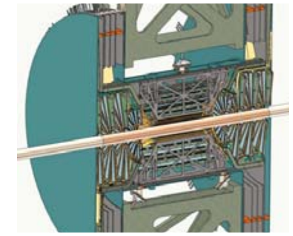


# Kinematic Coverage Very Important

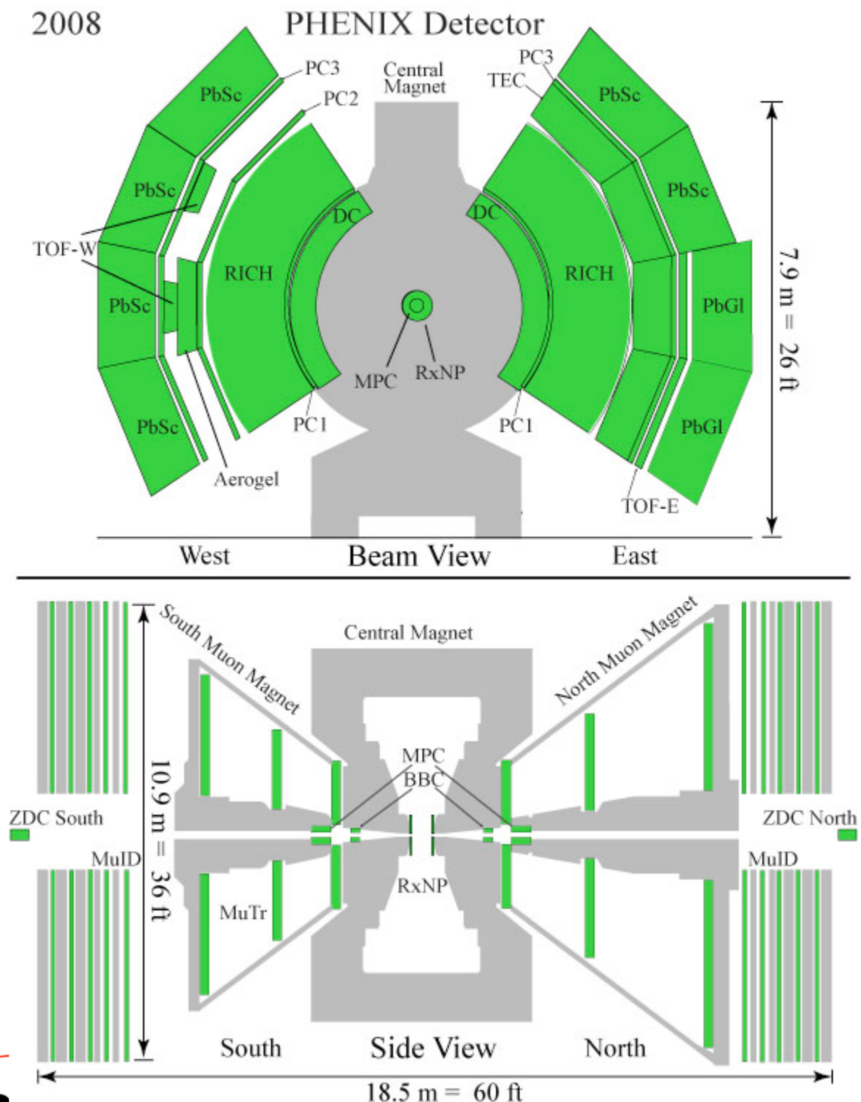
- Forward and central rapidity measurements needed to understand cold nuclear matter effects
- Forward and central rapidity measurements needed to get x-coverage for spin measurements





# The PHENIX Detector



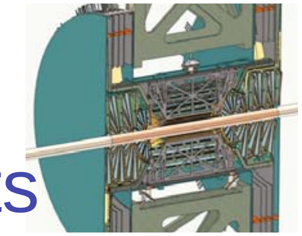

## 2 central arms:

### electrons, photons, hadrons

- charmonium $J/\psi, \psi' \rightarrow e^+e^-$
- vector meson $\rho, \omega, \phi \rightarrow e^+e^-$
- high $p_T$ $\pi^o, \pi^+, \pi^-$
- direct photons
- open charm, beauty $(D,B \rightarrow e)$
- hadron physics

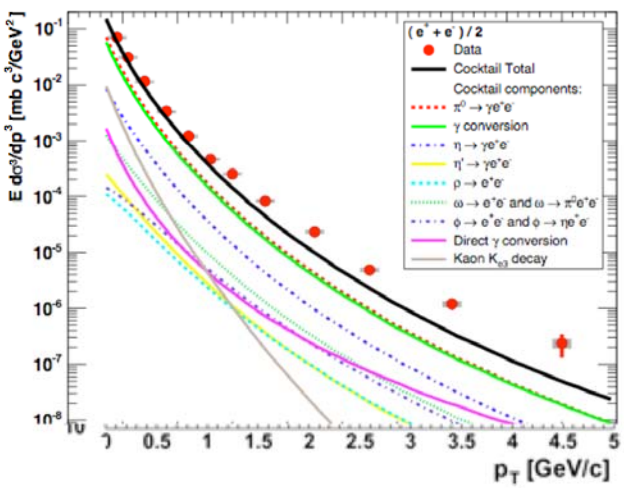
## 2 muon arms: muons

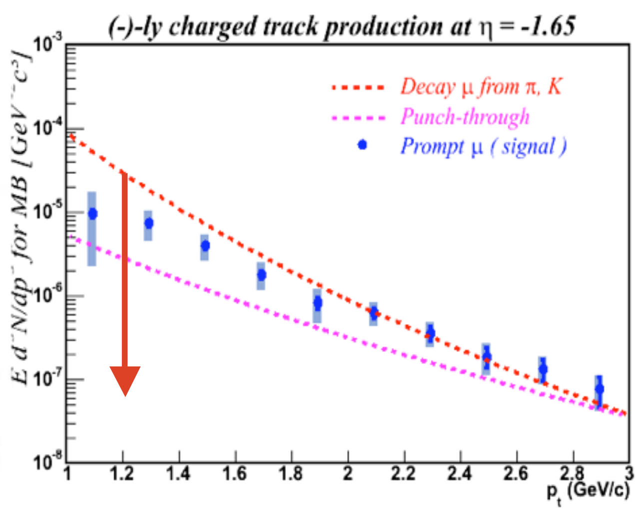
- "onium" $J/\psi, \psi', \Upsilon \rightarrow \mu^+\mu^-$
- open charm, beauty (D,B→ μ )

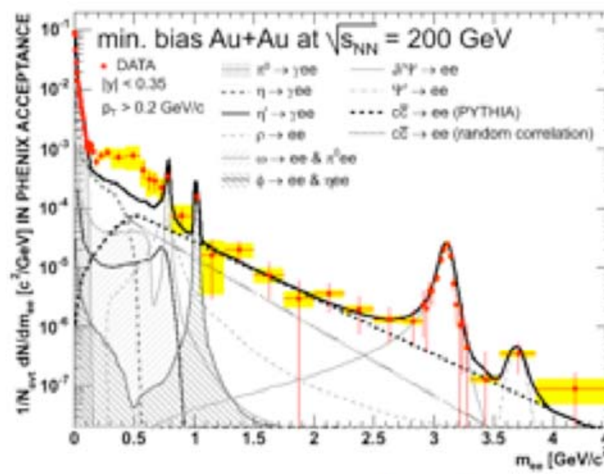


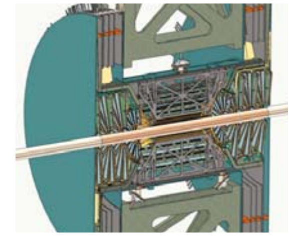
# How to Improve Heavy Flavor Measurements

- Improved background rejection in semi-leptonic decay measurements would allow systematic errors to be reduced
- Separation of charm/beauty allows quark mass dependence to be mapped out
- Add additional quarkonia measurements with improved mass resolutions, background rejection, added acceptance



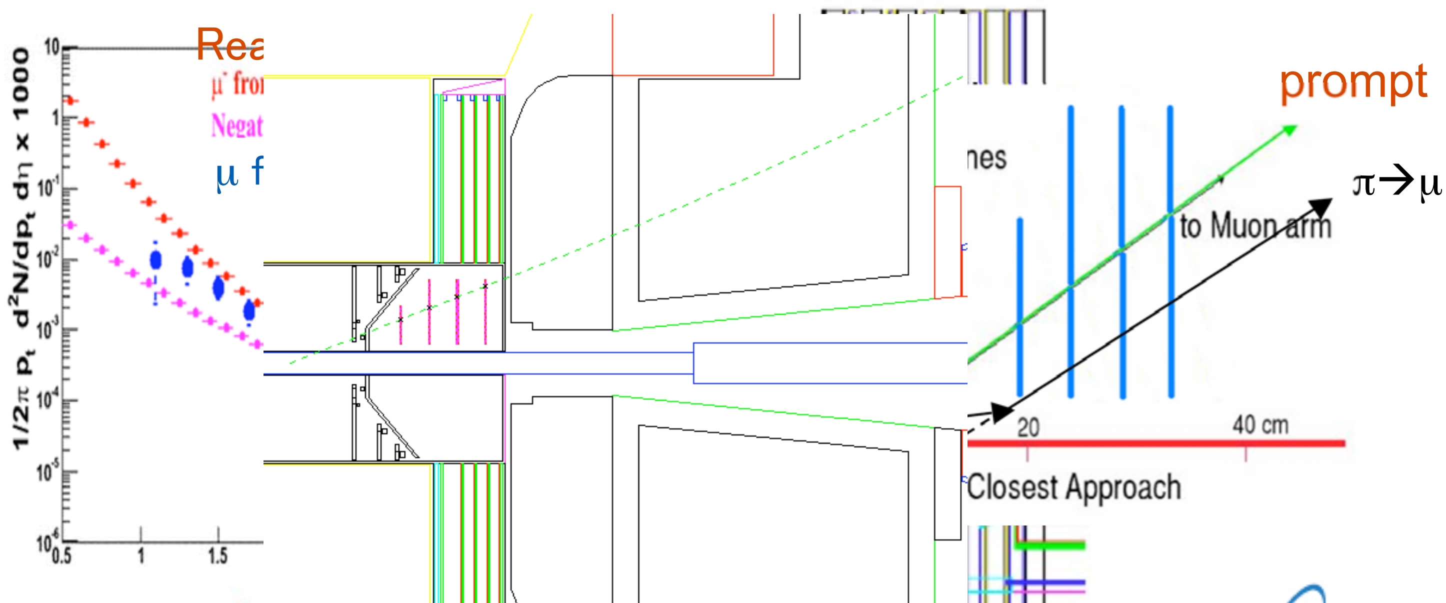



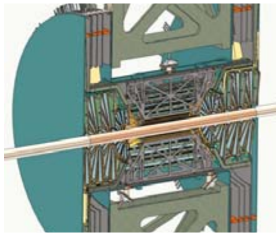





# Current Limitations/What Silicon Brings

- Cannot cleanly identify source of single leptons→measure track origins
- Having most initial particles removed (good for muon tracker) severely limits event information→measurement of all particles near vertex
- Track resolution limited by multiple scattering and energy loss straggling in absorber, DC track resolution→track hits near event vertex desired
- Minimal track hits in Muon Tracker, difficult to identify mis-reconstructed tracks, hadrons which decay in flight→More track hits along flight path desired





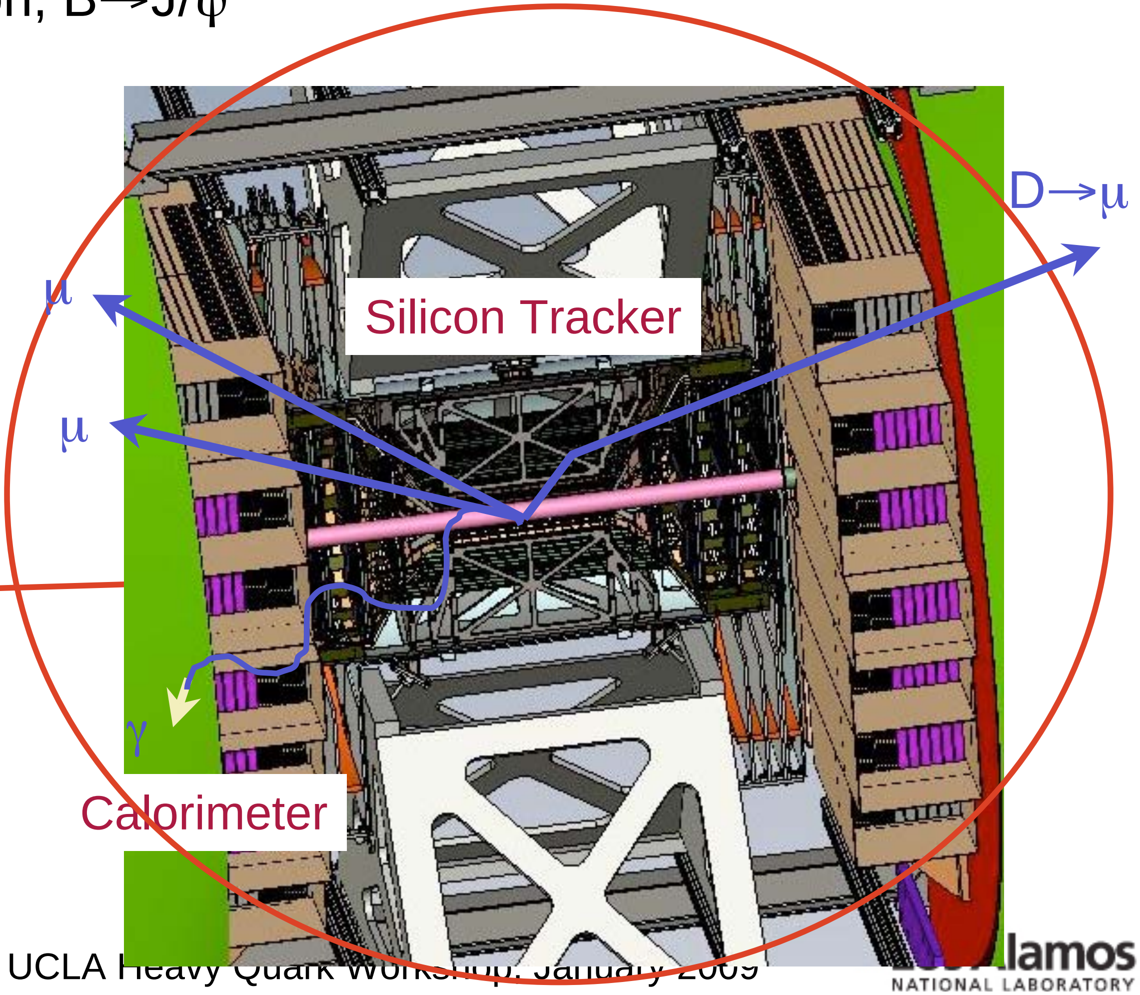
# PHENIX Upgrade Capabilities

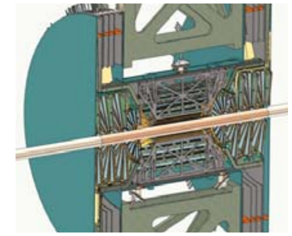
Silicon Vertex Trackers (VTX and FVTX)

- Displaced vertex tagging of D, B decay products
- Direct D reconstruction, $B \rightarrow J/\psi$
- $\Psi'$, upsilons

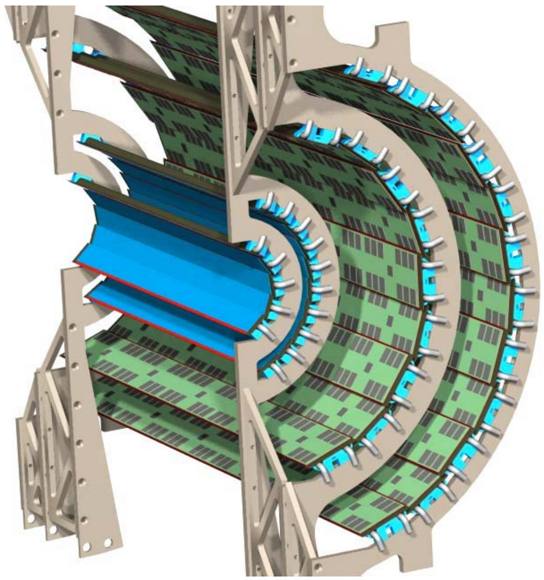
Forward Calorimeter

- $\chi_c$

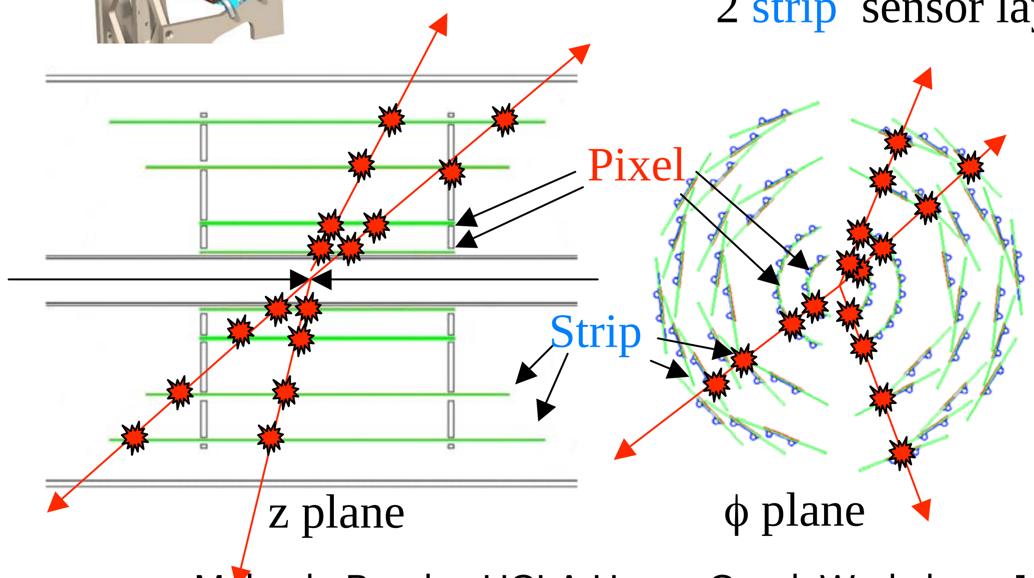




# Overview of VTX (Central Rapidity)

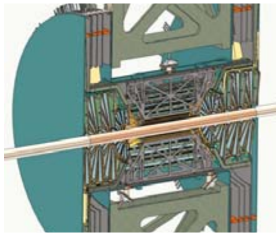


- ✓Fine granularity, low occupancy
  - 50μm×450μm pixel sensor at inner 2 layers.
- ✓Unique strip sensor
  - 80μm×1000μm pixel pitch
- ✓Large acceptance
  - $|\eta|<1.2$, almost $2\pi$ in $\phi$ plane
- ✓Self tracking capability
  - 2 pixel sensor layers (r = 2.5, 5.0cm)
  - 2 strip sensor layers (r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



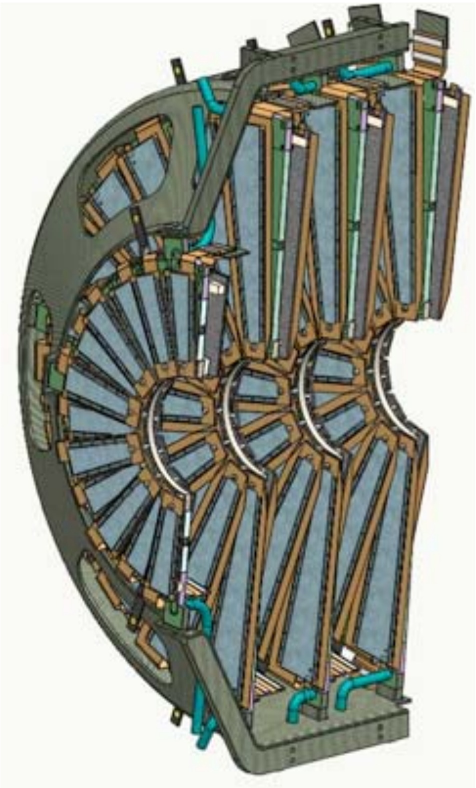

VTX will be installed in 2010.

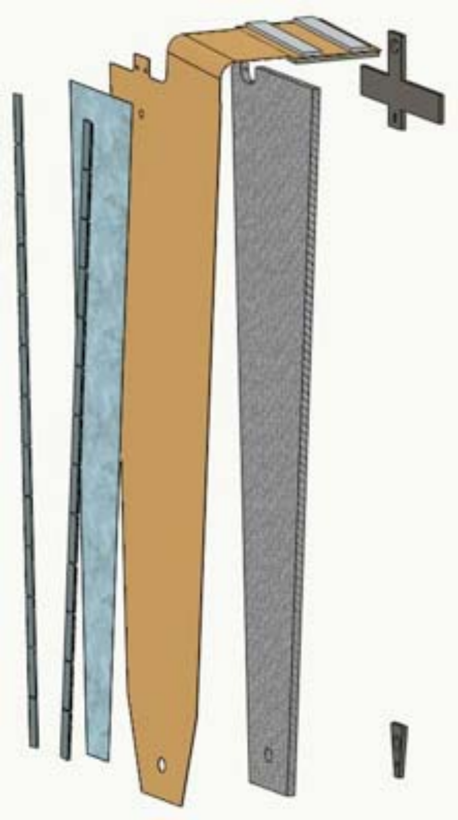
# Overview of FVTX (Forward Rapidity)

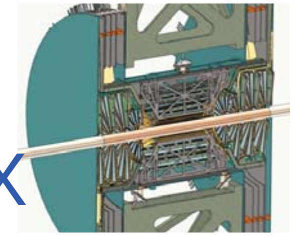


## Two Arms, Four tracking stations with full azimuthal coverage

- 75 μm pitch strips in radial direction, 3.75° staggered phi strips
- Radiation length < 2.4%/wedge to minimize multiple scattering
- Outer Support and Cooling outside active area
- Kapton cable plant primarily outside active area







# Physics Programs Accessible with VTX/FVTX

Single Leptons:

- Precision heavy flavor measurements at central and forward rapidity
- Separation of charm and beauty
- W background rejection improved

Dileptons:

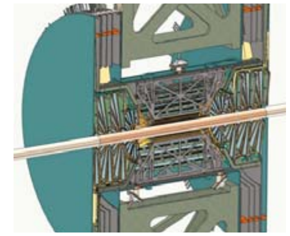
- First direct bottom measurement via $B \rightarrow J/\psi$
- Separation of $J/\psi$ from $\psi'$ with improved resolution and S:B
- First Drell-Yan measurements from RHIC
- Direct measurement of c-cbar events via $\mu^+\mu^-$ becomes possible

Hadrons:

- $D \rightarrow K\pi$, di-hadron correlations

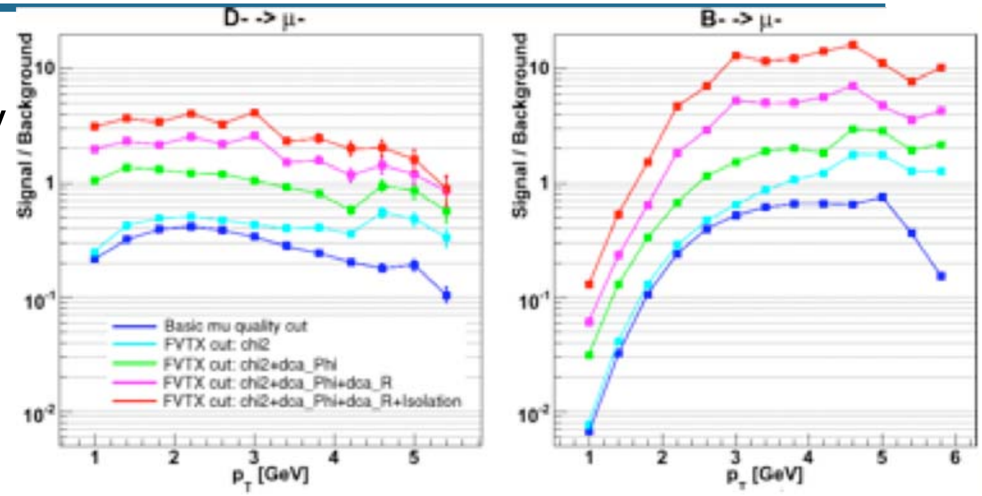
Physics:

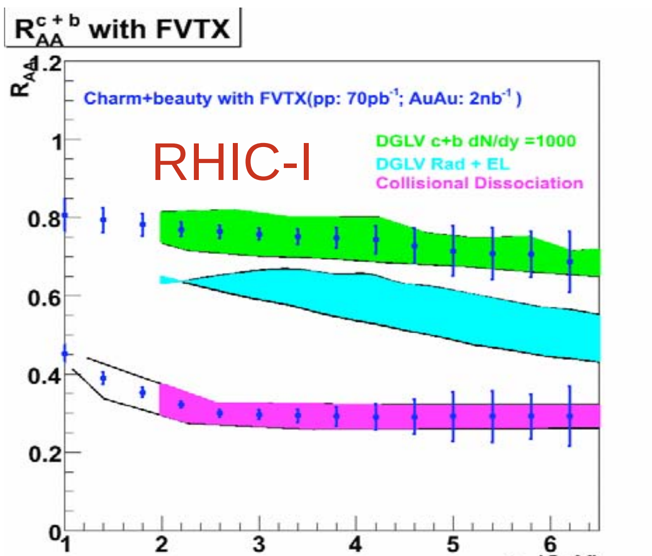
- Advance understanding of energy loss, by adding precise heavy flavor measurements of $R_{AA}$ and flow.
- First detection of $\psi'$ plus heavy quark allow detailed understanding of vector meson production and modification
- Separation/Understanding of Cold Nuclear Matter and QGP effects with rapidity coverage
- Precise Reaction Plane measurements,



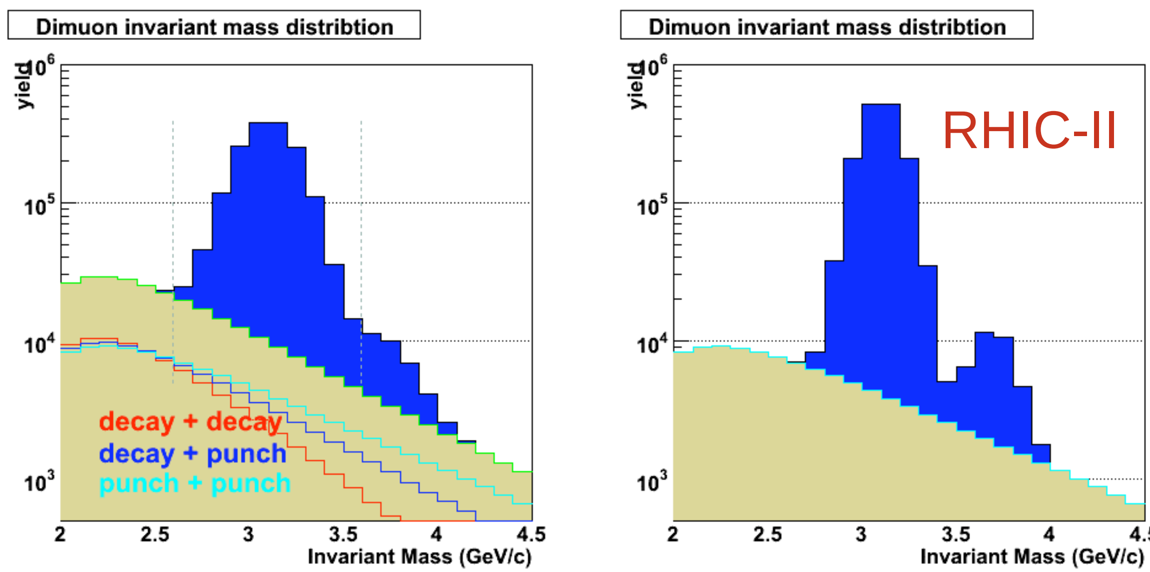
# Simulated FVTX Performance

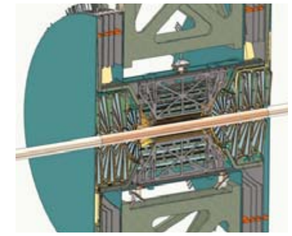
- Improved S:B in heavy flavor via single muons allows precision heavy flavor $R_{AA}$, $A_{LL}$ measurements
- J/ψ resolution improves as does background rejection



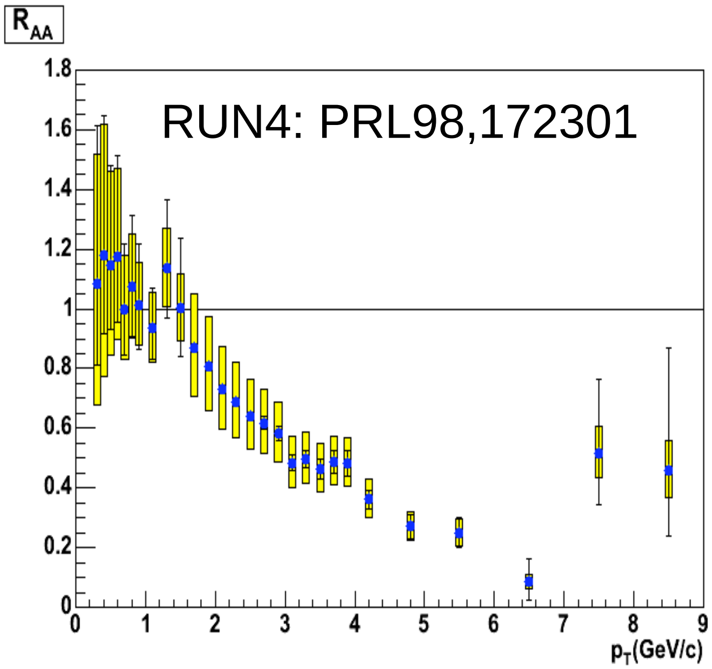




Simulated Shown for Two Different E-Loss models

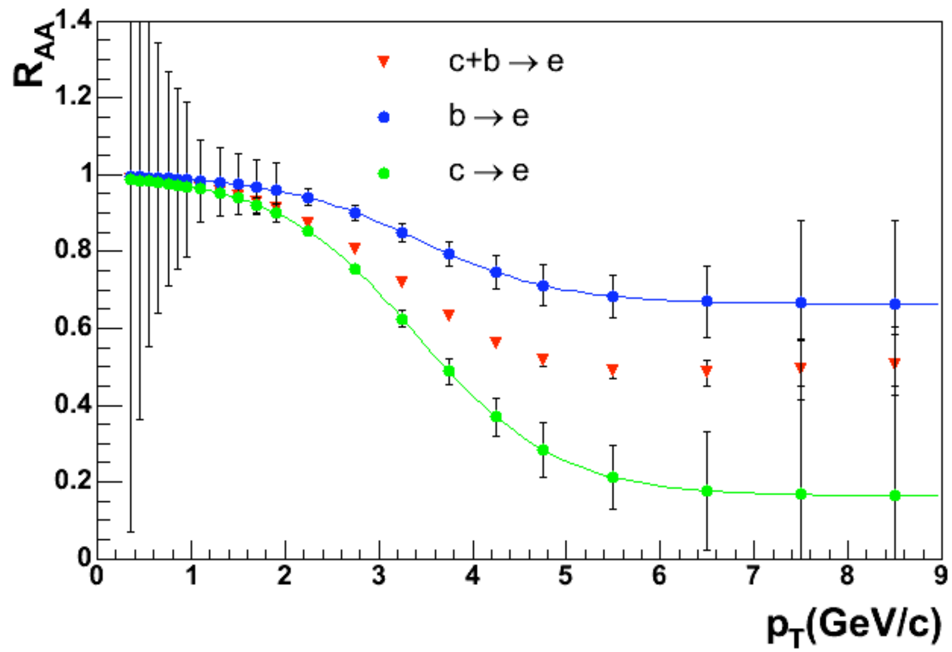




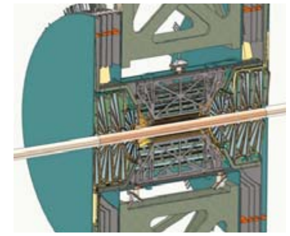
# Expected $R_{AA}$(b→e) and $R_{AA}$(c→e) with VTX




Expected with VTX (0.4/nb)

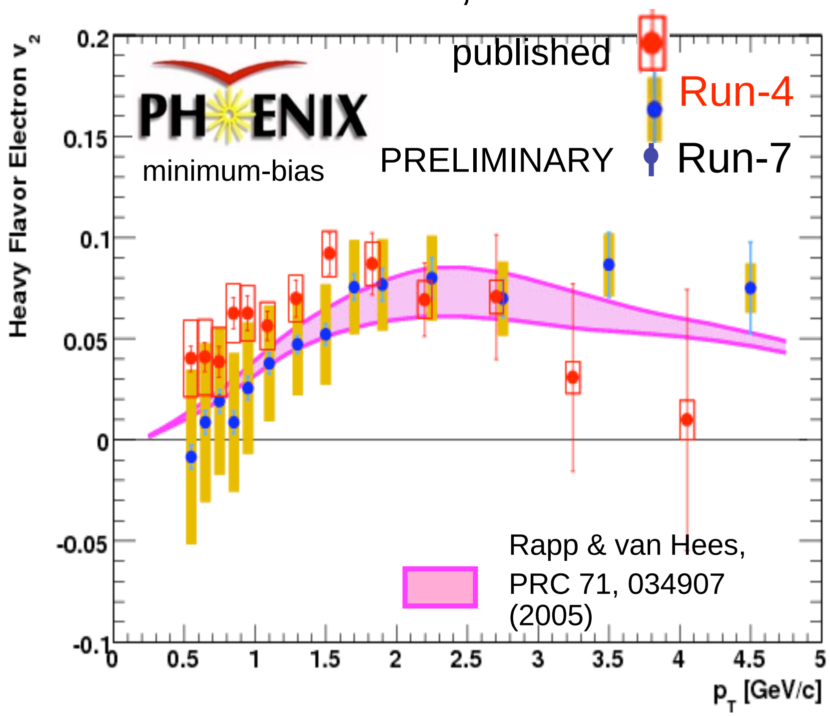



- Strong suppression of single electrons from heavy flavor decay is one of the most surprising results in RUN4
- The present measurement is mixture of b→e and c→e
- VTX can separately measure $R_{AA}$ of b→e and c→e

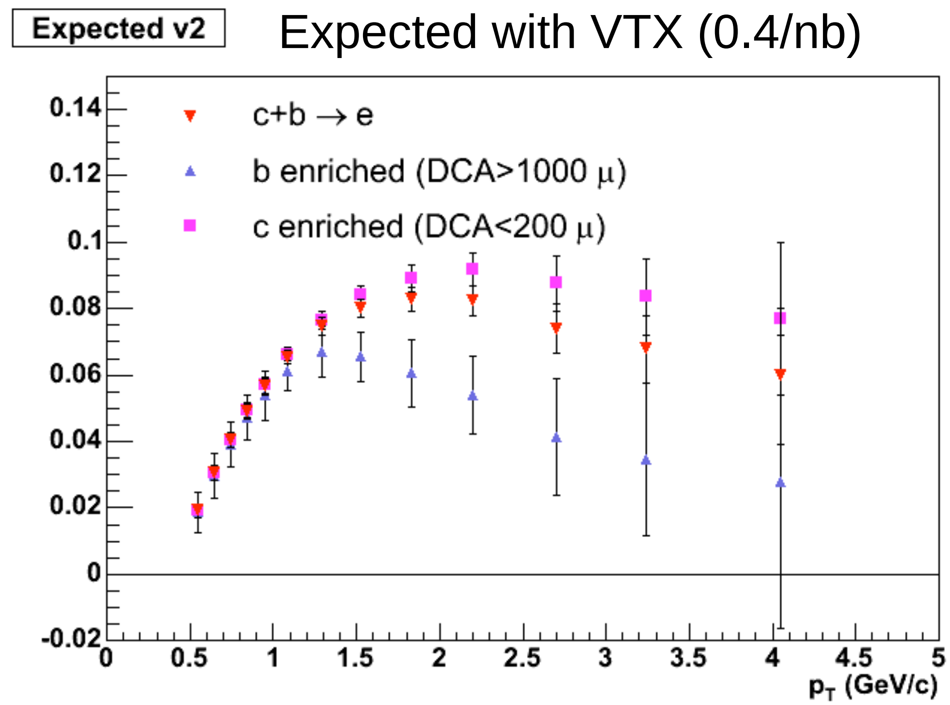


# Expected $v_2(b \rightarrow e)$ and $v_2(c \rightarrow e)$ with VTX

RUN4 PRL98,172301




Expected with VTX (0.4/nb)

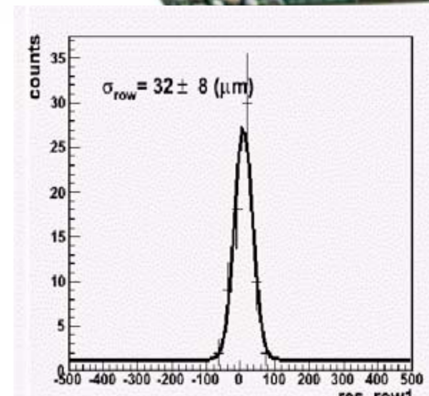


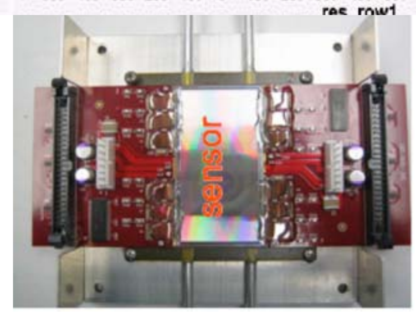

- $v_2$ of single electron is measured by PHENIX in RUN4
- The measured $v_2$ is mixture of $b \rightarrow e$ and $c \rightarrow e$
- With VTX, we can separate $b \rightarrow e$ and $c \rightarrow e$ component
- Additional factor of >10 improvement in RHIC-2

# VTX Technical Progress

## Pixels

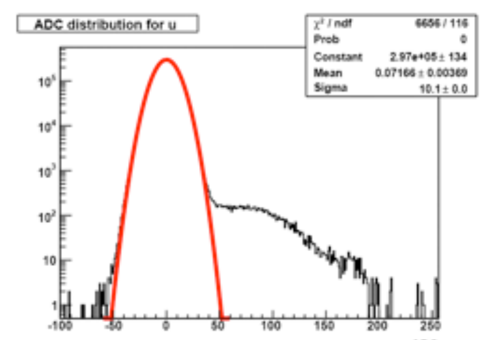
- Full prototype ladders produced and tested
- Readout cards fully tested in chain tests, cosmic ray, and beam tests
- Successful beam test completed at FNAL
- 135 sensors bonded to readout chips by VTT
- Production of buses started
- Staves from LBNL will be available soon, for full assembly
- Pixel modules expected completed Q3 FY09

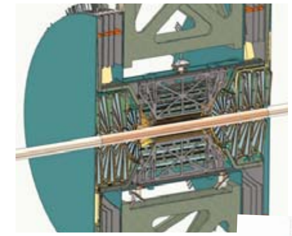



## Strip Pixels

- Sensors and readout chips (SVX4) in hand
- Prototype modules and readout boards-v3 produced
- Successful beam test completed at FNAL
- Conceptual Design and Assembly plan complete
- Next round readout card expected soon



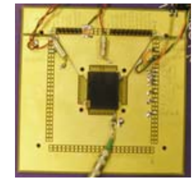


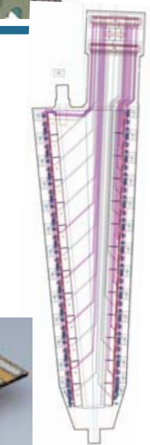
# FVTX Technical Progress

## Wedge Components

- Prototype sensors procured and delivery expected Oct. 30
- 1st round FPHX chip delivered in August and testing in progress
- HDI layout completed, prototype not in hand yet

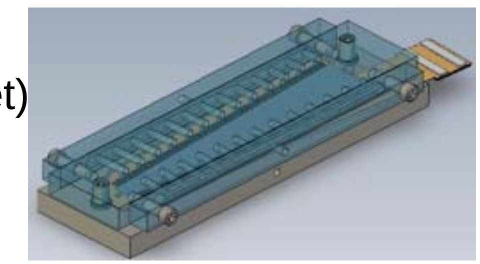
FPHX





## Detector Assembly

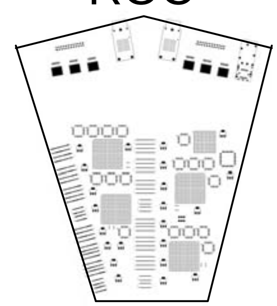
- Wedge assembly prep at FNAL Silicon Fabrication Facility (SiDet)
- Wedge assembly fixtures designed and out for procurement
- Steve Pate working on assembly areas at BNL



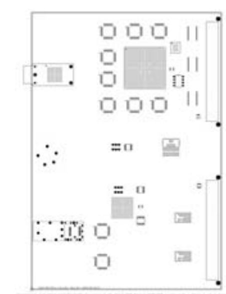
## DAQ

- ROC prototype in process of being manufactured
- FEM prototype still needs to go into layout

ROC

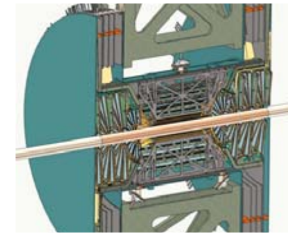


FEM



## Mechanics

- Cage, backplane and disk designs completed 1st round

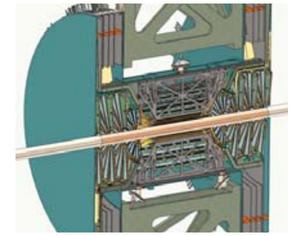


# Schedule Summary*

| | |
|---|---|
| Installation of VTX Pixels | Summer 2009 |
| 500 GeV p+p, 200 GeV Au+Au | Run 2010 |
| Full VTX Complete | December 2010 |
| Low Energy Scan Au+Au | Run 2011 |
| FVTX Complete | October 2011 |
| 500 GeV p+p, 200 GeV Au+Au | Run 2012 |

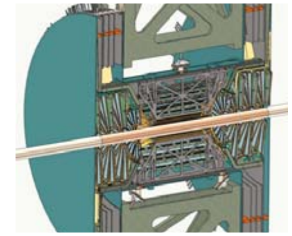
Heavy Ion physics program with the Vertex Trackers starting in 2010 and in full swing by 2012.

*Run schedule has been known to change



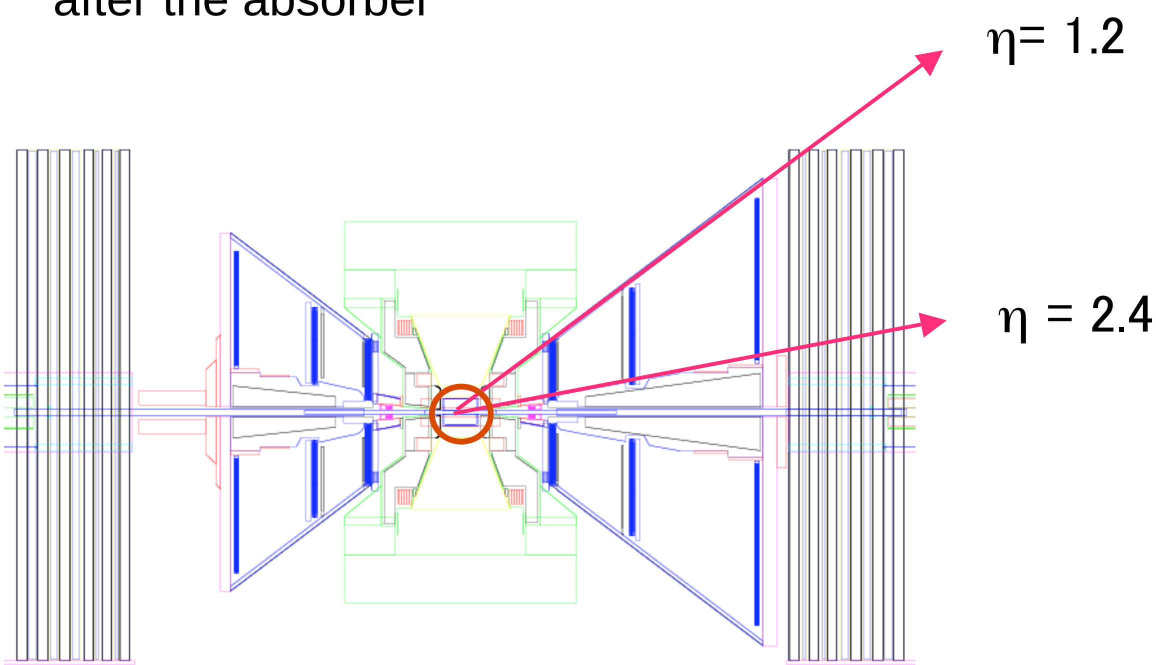


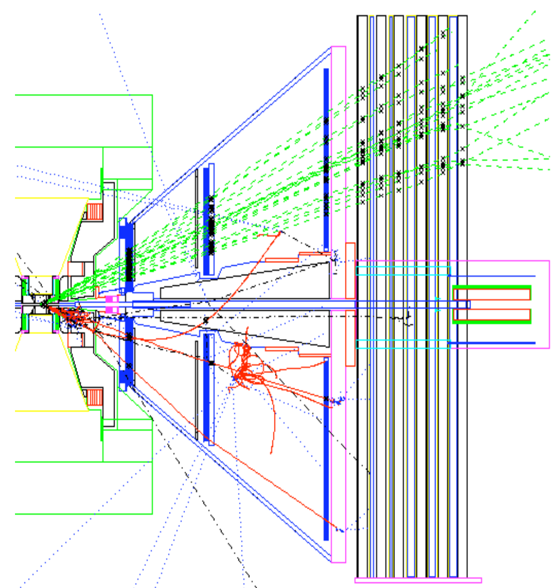
# Backups

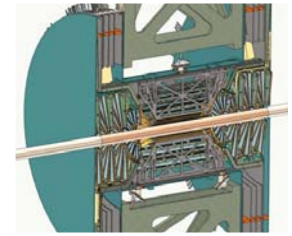


# Forward Measurements in PHENIX

- Initial absorber to reduce hadrons that reach the active detectors
- Muon Tracking stations inside magnet to find tracks and measure momentum
- Muon Identifier of tracking and absorbers to further separate muons and hadrons, provide Lvl-1 trigger
- ~1% "punch through", ~1% decay into muon before absorber, ~1%*15% decay after the absorber





# Performance Requirements

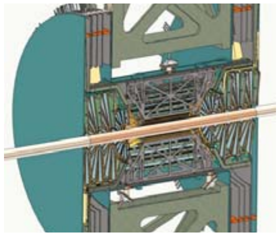
Silicon Sensors - good efficiency and resolution, low noise, minimize radiation length

DAQ - keep up with expected data rates, ability to participate in Lvl-1

Integration into PHENIX - seamless integration into PHENIX data-taking

| | Minimum Acceptable | Expected Performance |
|---|---|---|
| Mini strips active | >90% | >95% |
| hit efficiency | >95% | 99% |
| Radiation length per wedge | < 2.4 % | 1.5% |
| Detector hit resolution | < 25 μm | ~15 μm |
| Noise hits/chip | <1% | <<1% (thresh:noise=5) |
| LVL1 latency | 4 μs | |
| LVL1 Multi-Event buffer depth | 4 events | |
| Read-out time | < 40 μs | |
| Read-out rate | > 10 kHz | |

# FVTX Performance - c/b Separation

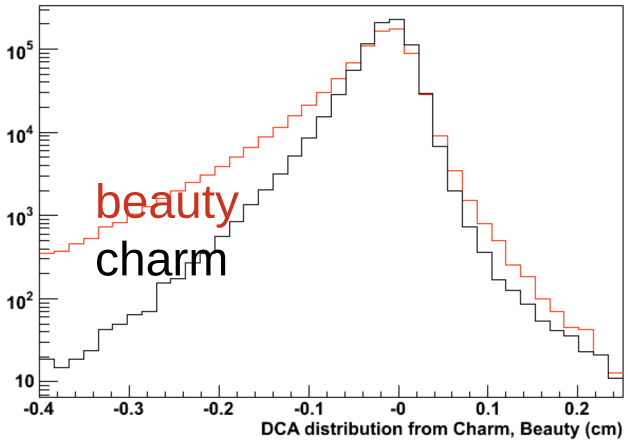


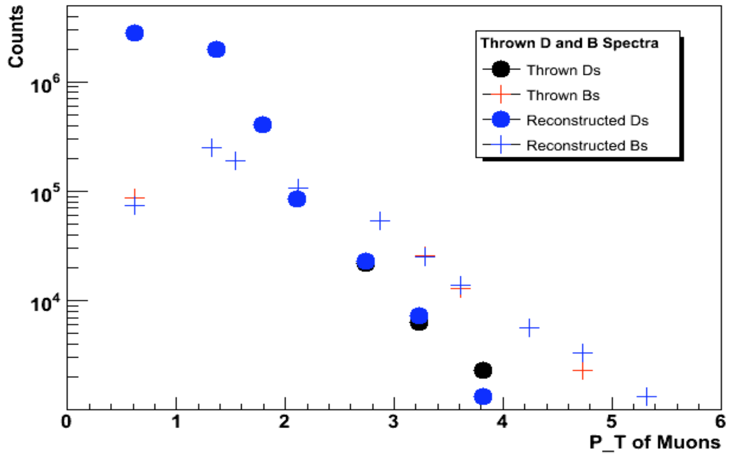
DCA distributions can disentangle D and B contributions to spectrum

For the summed D/B spectrum, a given pT bin will have in each DCA bin:

$$N_{total,p_T,DCA_{bin}} = f_{D,p_T,DCA_{bin}} * D_{total,p_T} + f_{B,p_T,DCA_{bin}} * B_{total,p_T}$$

Use MC to determine the DCA distributions per particle type, with real data extract N equations with 2 unknowns and minimize (ntot-nfit)**2

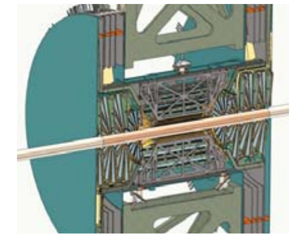


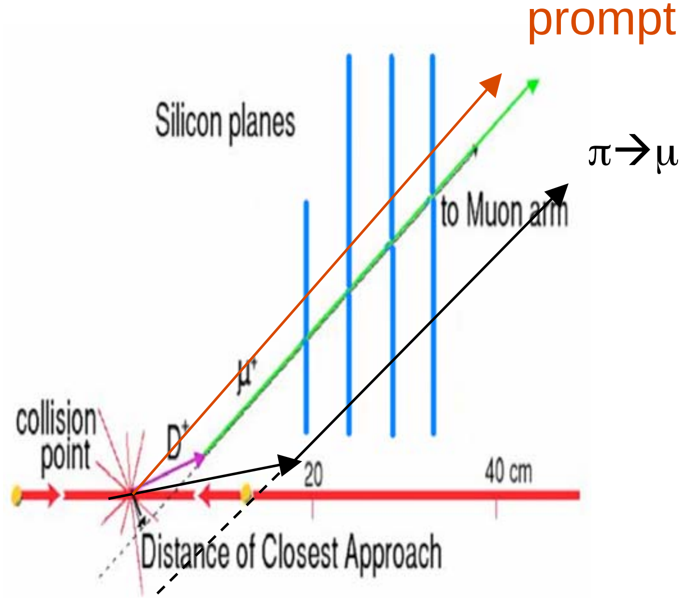

Will improve with (1) weighted fit (2) add dca-phi to dca-r fit
Same technique to separate residual hadron background
*Note: one method of several for separation possibilities

# DCA (Distance of Closest Approach)

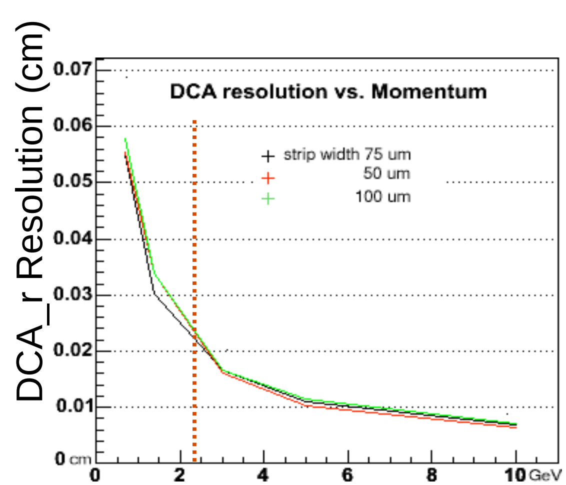




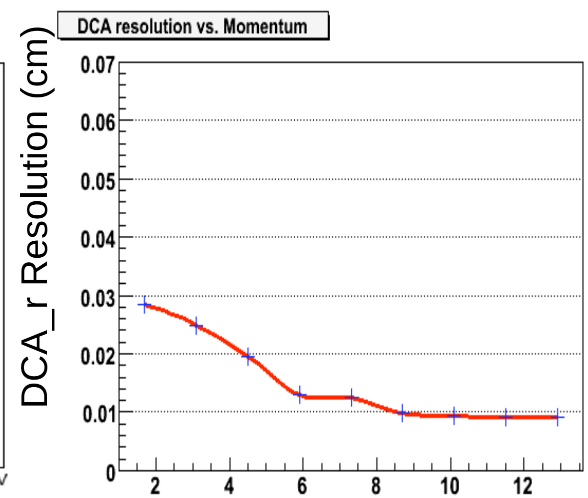
- Use Kalman Filter to fit and project to z_vertex
- Get DCA components in r (good) and phi (less good)
- ~100 μm resolution in DCA_r
- Multiple-scattering dominated resolution
- Sufficient resolution to separate prompt, heavy quark, and light meson decays




DCA_r (old design and simulation in review 2007)

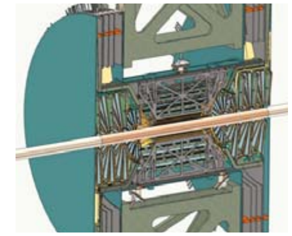



DCA_r (with updated geometry and software )



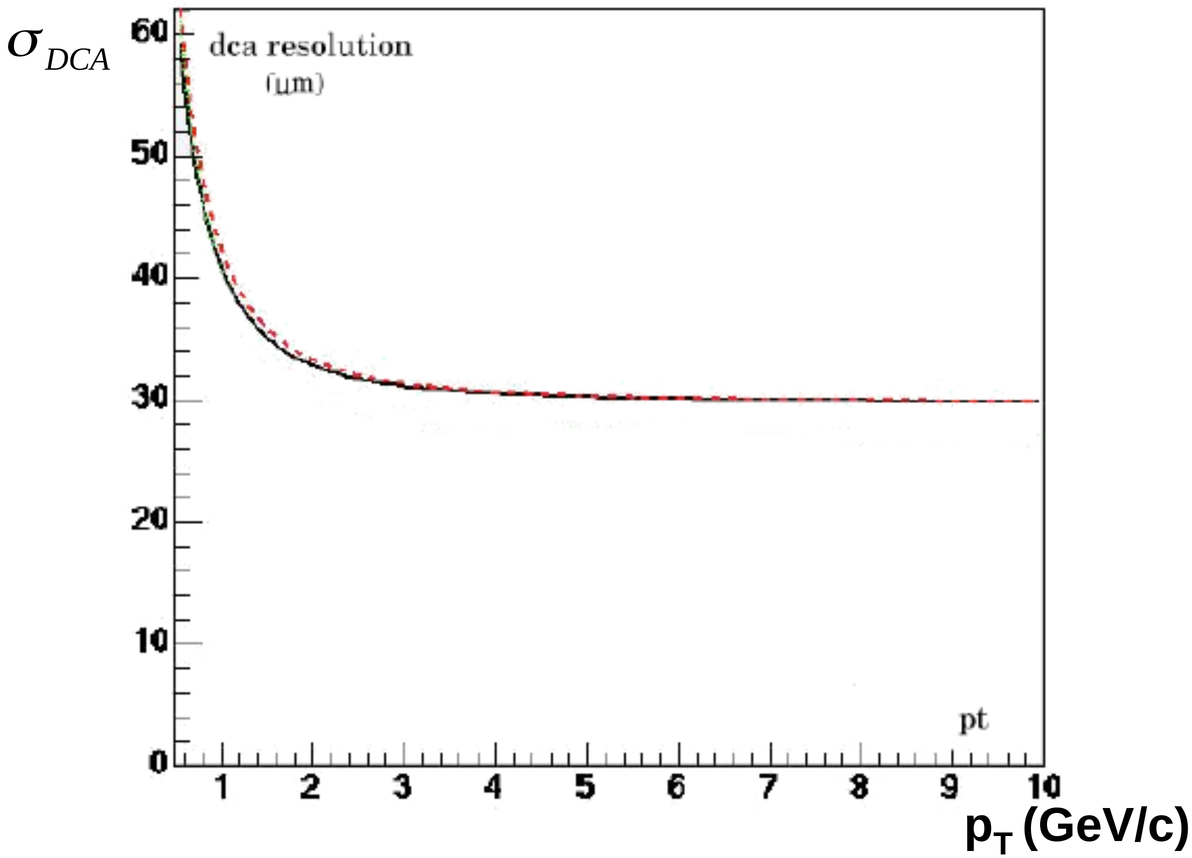
# DCA Resolution





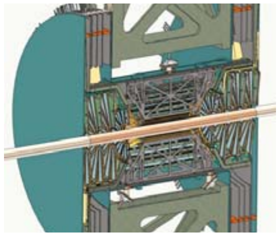
DCA resolution is dominated most inner two layers.

$$\sigma_{DCA}^2 \approx \frac{(\sigma_1^2 r_2^2 + \sigma_2^2 r_1^2)}{(r_2 - r_1)^2} + \theta_{ms}^2 \frac{r_1^2}{sin^2\theta}$$



# Occupancy (PISA Simulation)





**Occupancy of the each layers in the central Au-Au collisions**

- Pixel Layer

$$Occupancy = \frac{N\_hits}{N\_allpix}$$

  - N_hits : hit counts on each layer
  - N_allpix : all pixel numbers on each layer ( 32 x 256 x 4 x 4x 10(or20) )

- Strip Layer

$$Occupancy = \frac{N\_hits}{N\_x(y)strip}$$

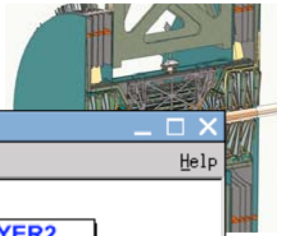
  - N_hits : hit counts on each layer
  - N_x(y)strip : all strip numbers on each layer ( 768 x 5(or6) x 16(or24) )

**Method**

- HIJING 3.17 Au-Au 200GeV/c
- with impact parameter < 2fm
- no magnetic field
- initial vertex is (0, 0, 0)

# *Occupancy (PISA Simulation)*





## Results

- number of track

  9600/event

  with silicon hit

- no charge sharing between strips

- no ghost track