The STAR Heavy Flavor Tracker and Intermediate Silicon Tracker Working Together

An Introduction and Brief Review of the Technical Design and Physics Goals at Mid-rapidity

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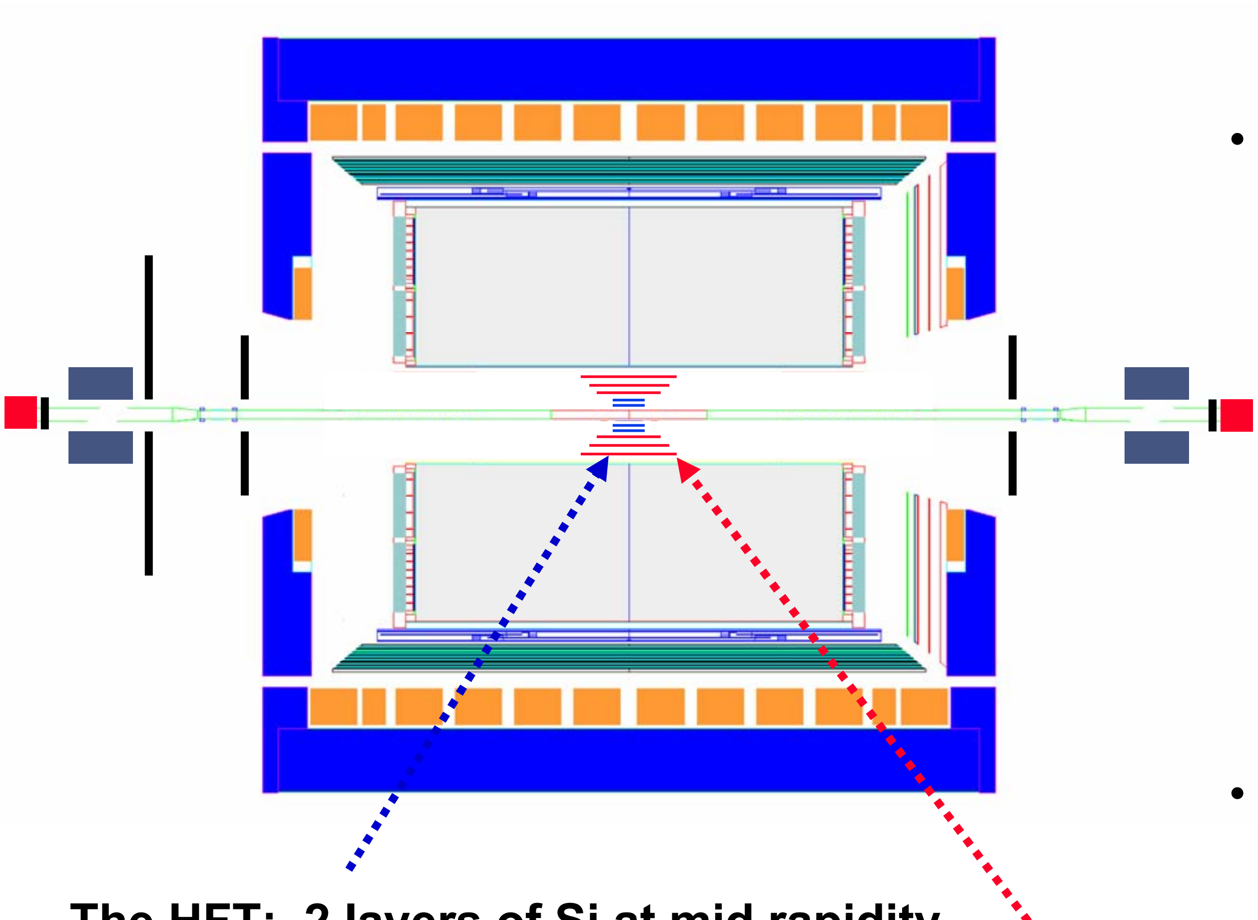
Participating Institutions for the HFT & IST

Argonne National Laboratory
Brookhaven National Laboratory*
IPHC, Strasbourg (R&D)*
Lawrence Berkeley National Laboratory*
Massachusetts Institute of Technology*
Ohio State University
UC Irvine (R&D)
UC Los Angeles
+Individuals

The Heavy Flavor Tracker + IST + SSD

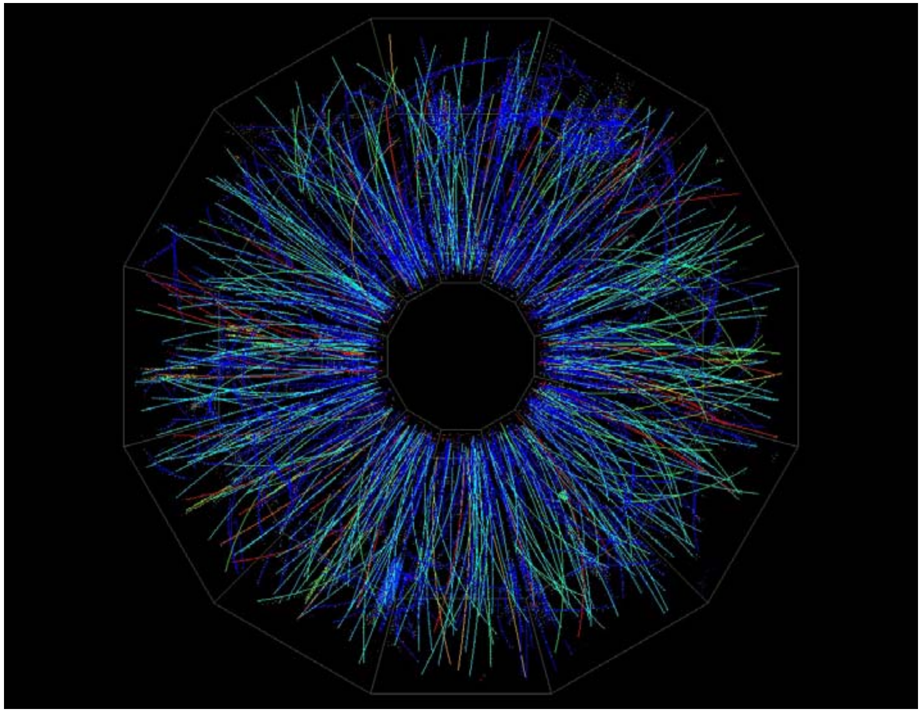


The HFT: 2 layers of Si at mid rapidity

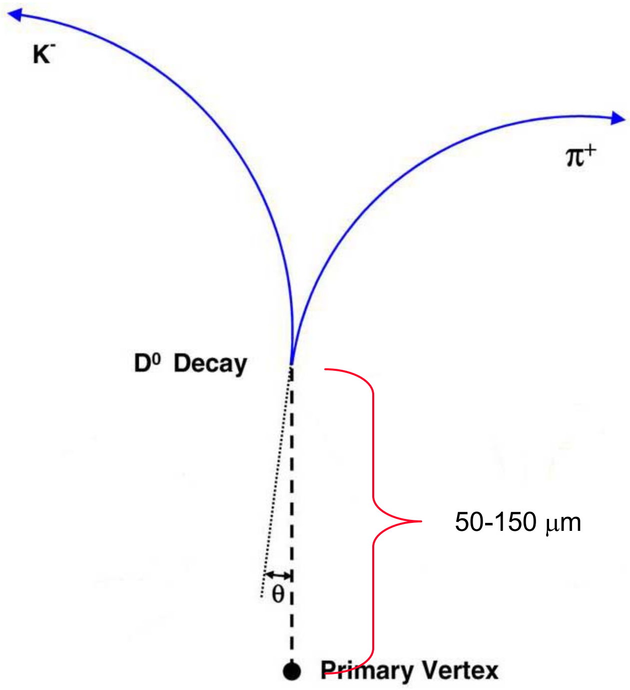
Mid-rapidity Pointing Devices: IST + SSD

- The HFT is a new detector
  - 30 μm silicon pixels to yield 10 μm space point resolution
- Direct Topological reconstruction of Charm
  - Detect charm decays with small $c\tau$, including $D^0 \rightarrow K\,\pi$
- New physics
  - Charm collectivity and flow to test thermalization at RHIC
  - Charm Energy Loss to test pQCD in a hot and dense medium at RHIC
- The proposed Tracking Upgrades include
  - HFT (2 layers)
  - IST (2 layers)
  - SSD (existing layer)

Direct Topological Identification of Open Charm



Goal: Put a high precision detector near the IP to extend the TPC tracks to small radius



The STAR Inner Tracking Upgrade will identify daughters of the decay and do direct topological reconstruction of open charm hadrons.

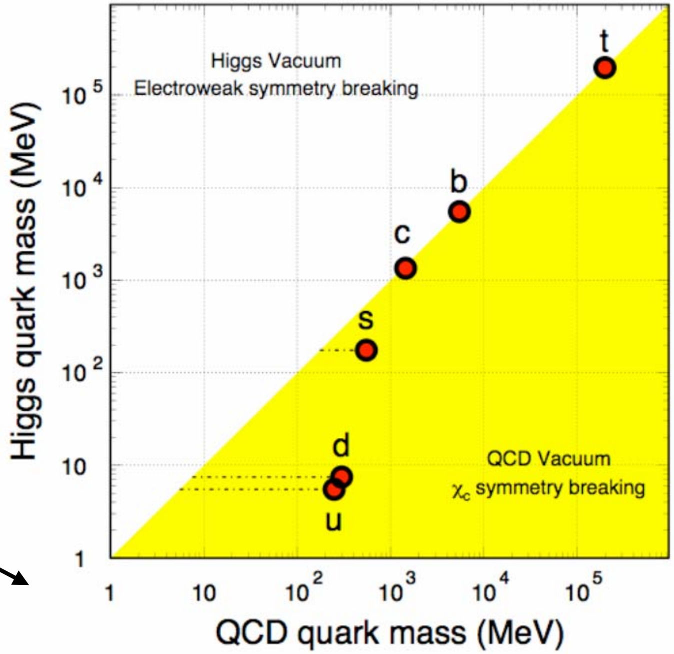
No Mixed events, no random background subtraction.

"Heavy Flavor" is the Next Frontier

- **The QGP is the universally accepted hypothesis at RHIC**
- **The next step in confirming this hypothesis is the proof of thermalization of the light quarks in RHIC collisions**
- **The key element in proving this assertion is to observe the flow of charm … because charm and beauty are unique in their mass structure**

Current quark: a bare quark whose mass is due to electroweak symmetry breaking

Constituent quark: a bare quark that has been dressed by fluctuations in the QCD sea



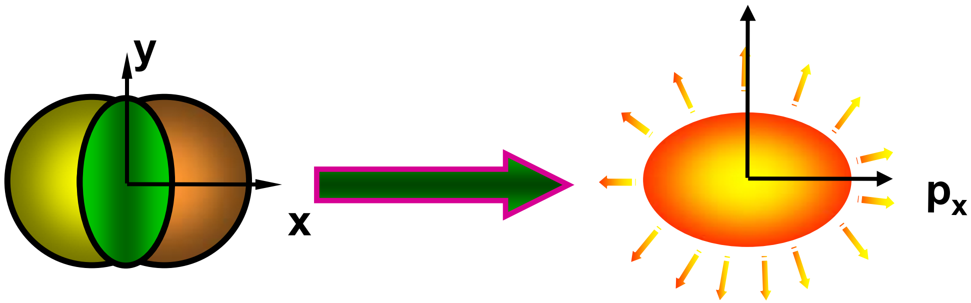
- **If heavy quarks flow**
  - **frequent interactions among all quarks**
  - **light quarks (u,d,s) likely to be thermalized**

Flow: Probing Thermalization of the Medium

Semiperipheral collisions

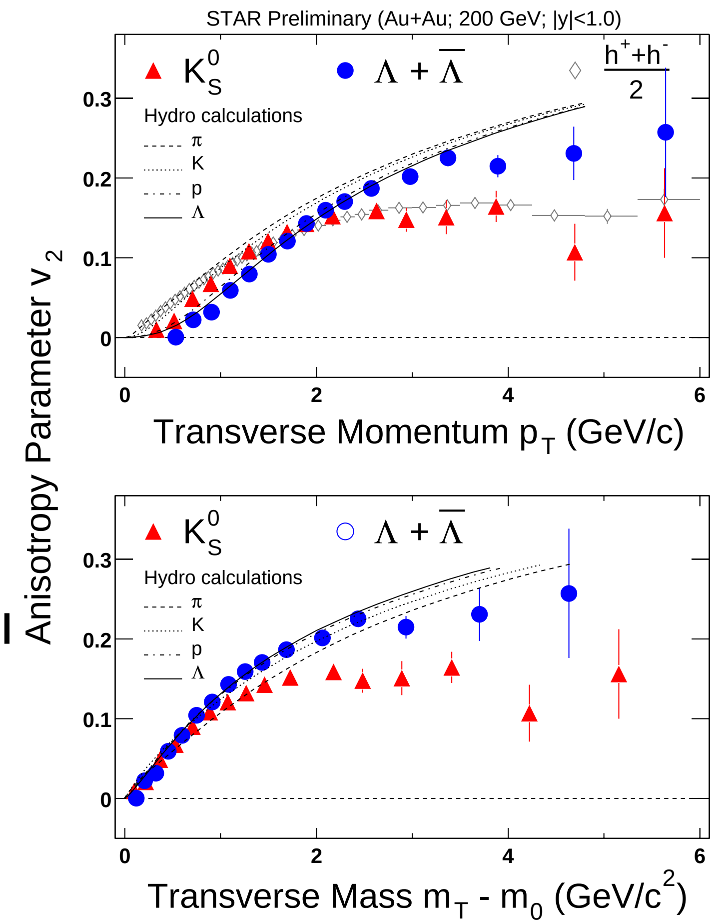
Coordinate space: initial asymmetry

Momentum space: final asymmetry



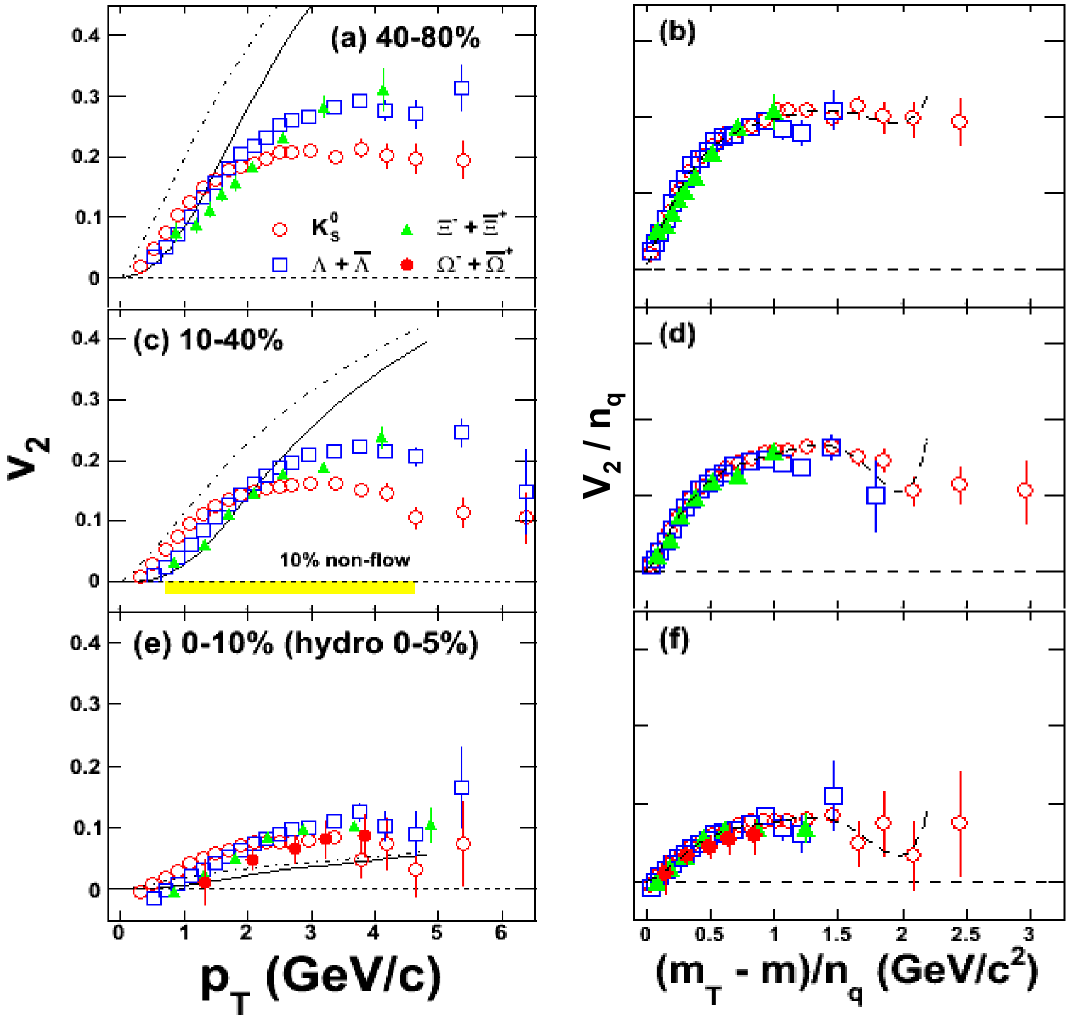
$$v_2 = \langle \cos 2\varphi \rangle, \quad \varphi = \tan^{-1}\left(\frac{p_y}{p_x}\right)$$

Signals early equilibration ($t_{eq} \leq$ 0.6 fm/c)



Scaling as a Function of $(m_T - m_0)$

STAR Preliminary work by Yan Lu



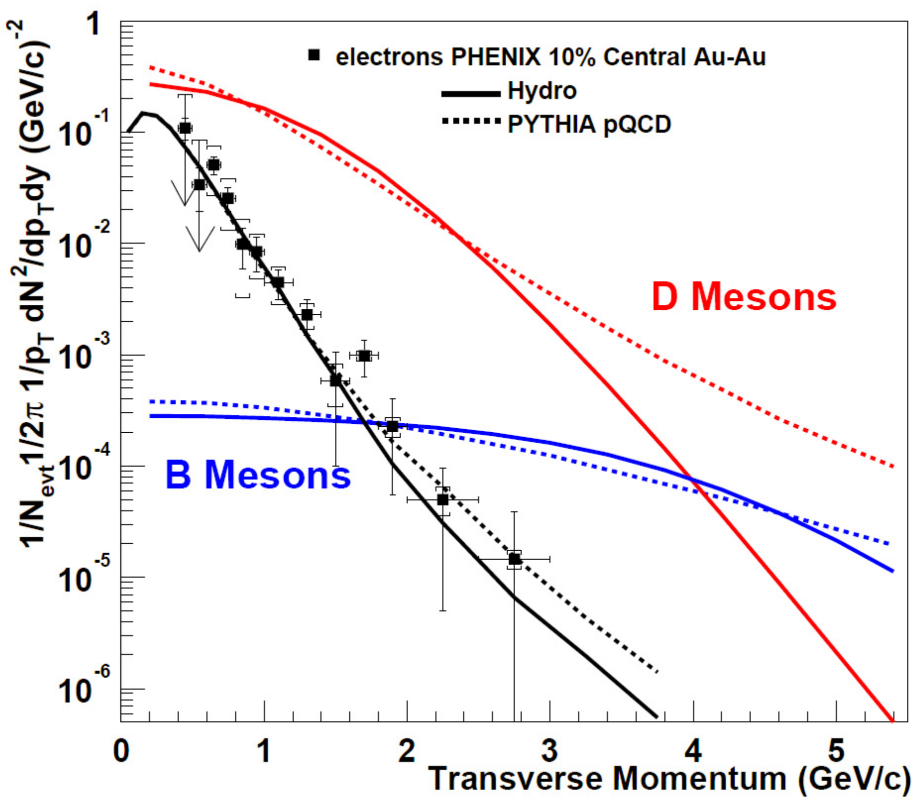
Yuting Bai, QM 2006 for the STAR Collaboration

- The light quark sector scales beautifully with v_2/n_q .vs. $(m_T - m_0)/n_q$
  - Note that $p_T < 1$ GeV always did scale !
- The strange quark sector also scales with $<v^2>$ and the scaling holds at all centralities
- Even the ϕ meson
  - See S. Blythe QM2006

Does it work in the Charm Sector?

A strong test of the theory

Single Electron Spectra … are not sufficient

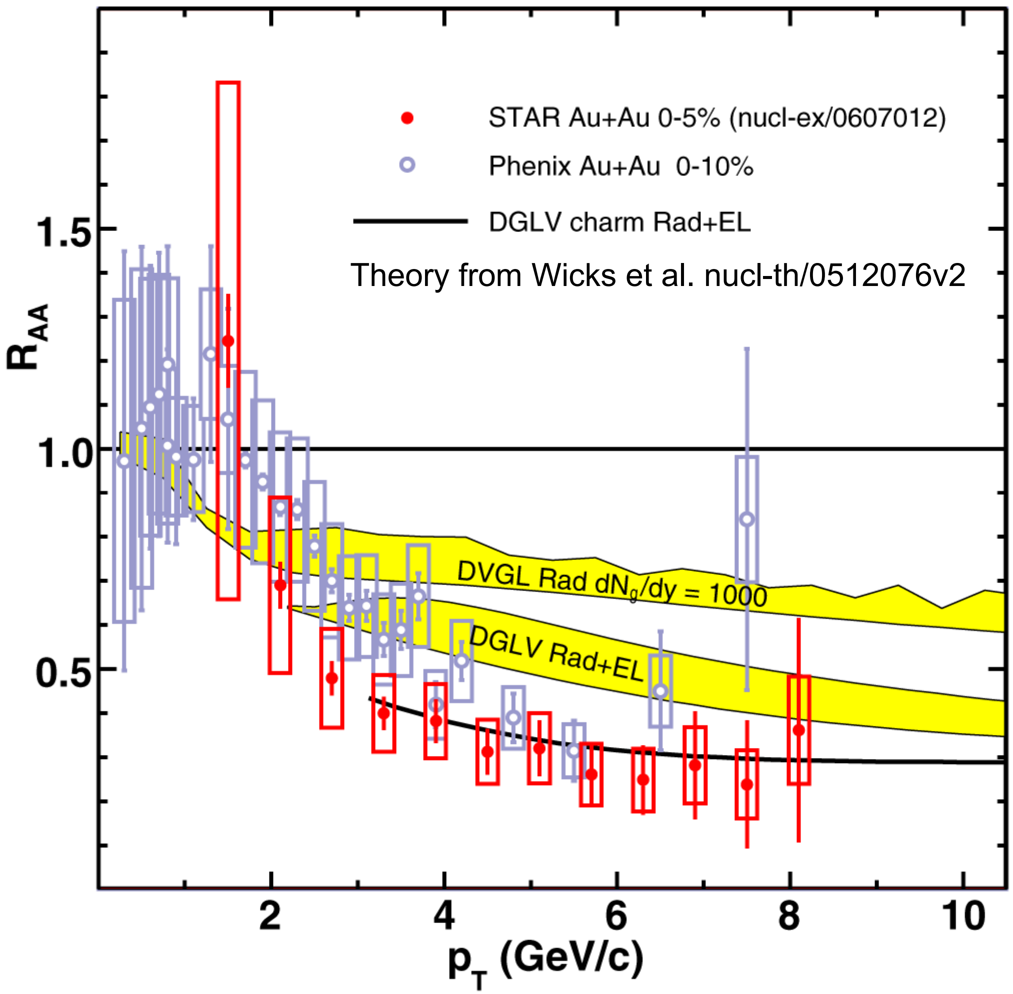


S. Batsouli et al., Phys. Lett. B 557 (2003) 26.

We need direct topological identification of Charm

- **Hydro and Pythia are extreme models on opposite ends of the model spectrum**
  - **Charm in red, Beauty in Blue … Hydro is the solid line, Pythia is dashed**
- **Single electron spectra make it difficult to distinguish hard and soft physics below 3 GeV**
  - **Also true for R_{AA} measurements**
- **The decayed spectra are shown in black. The sensitivity to the original spectra are reduced.**
- **We heard this message many times at QM**

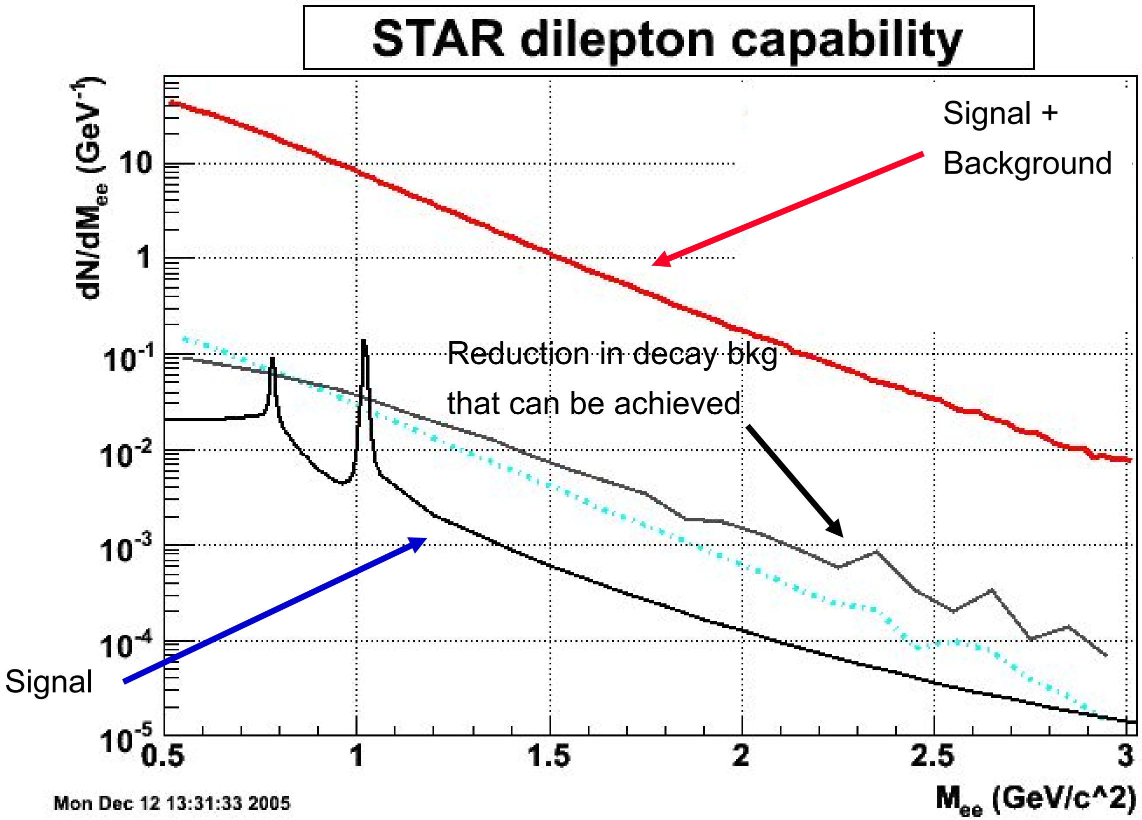
Heavy Flavor Energy Loss … R_{AA} for Charm



Where is the contribution from Beauty?

- **Heavy Flavor energy loss is an unsolved problem**
  - **Gluon density ~ 1000 expected from light quark data**
  - **Better agreement with the addition of inelastic E loss**
  - **Good agreement only if they ignore Beauty …**
- **Beauty dominates single electron spectra above 5 GeV**
- **We can separate the Charm and Beauty by the direct topological identification of Charm**

Measuring Vector Mesons with Dileptons



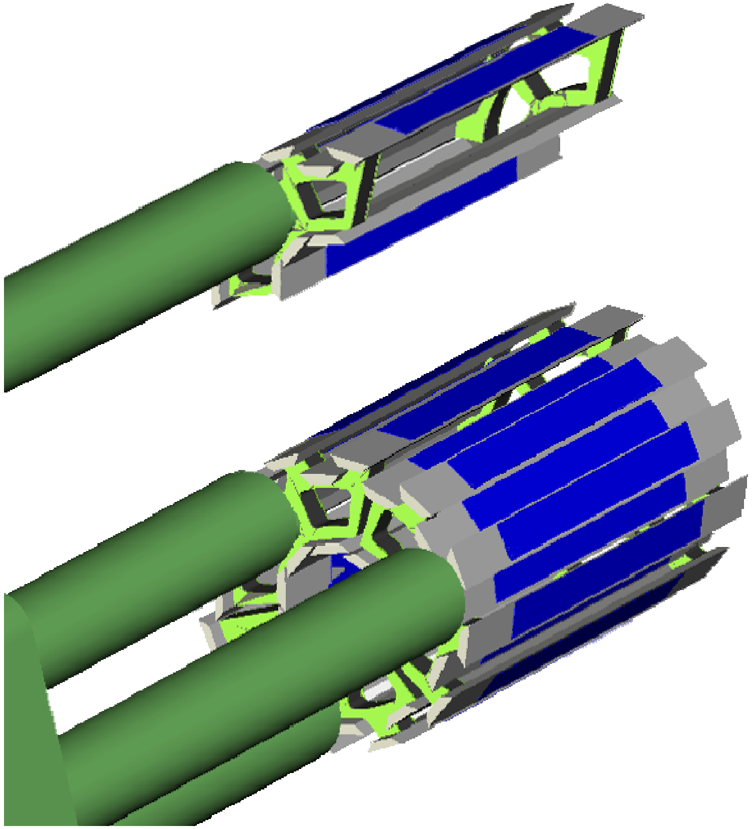
Pulling the Signal out of the Background

- **Dileptons are a valuable probe of the early stages in a HI collision**
- **However, the signals are relatively rare and the backgrounds are high (Signal in Black)**
- **Red Curve shows the sum or all backgrounds into the 2004 detector (including the SVT)**
- **Grey curve is e^+e^- spectrum after rejection by the HFT**
- **Blue dashed curve is Dalitz decays after rejection by the TPC**

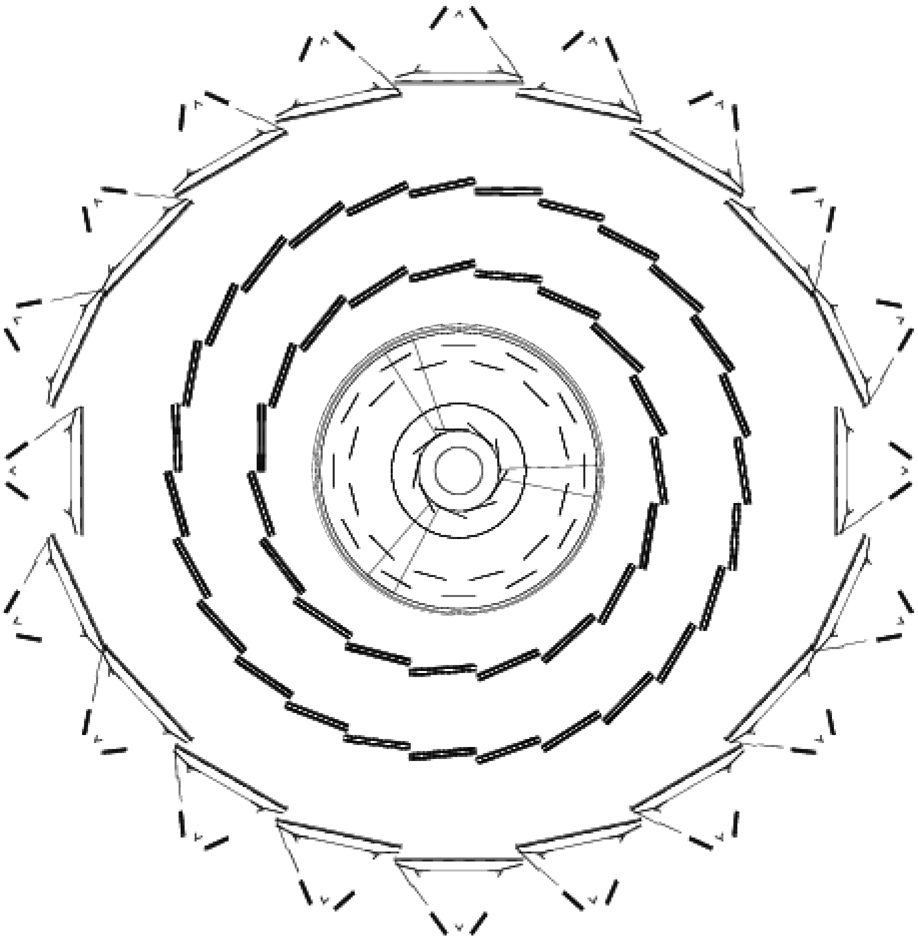
A Rich Physics Program

- There is a rich physics program when all of the STAR physics detectors are working together
  - Flow in the Charm sector
  - dE/dx in the Charm and Beauty sector
  - Recombination and R_{AA} in the Charm and Beauty sector
  - Vector Mesons
  - Charm Angular Correlations
    - now accessible due to STAR's large acceptance
  - non-photonic electrons
  - …

The Methodology: Surround the Vertex with Si



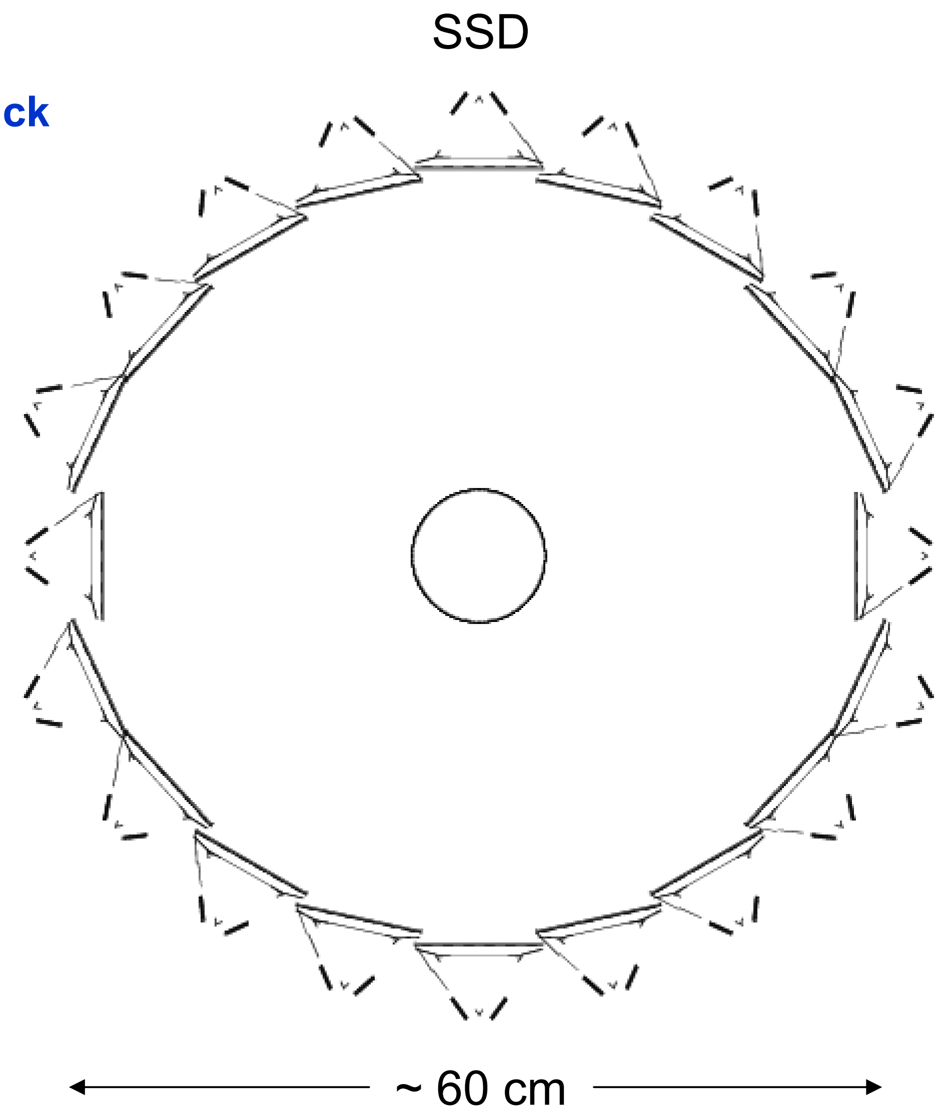
The HFT is a thin detector using 50 μm Si to finesse the limitations imposed by MCS



The IST and SSD form the ingredients of an Inner Tracking Upgrade

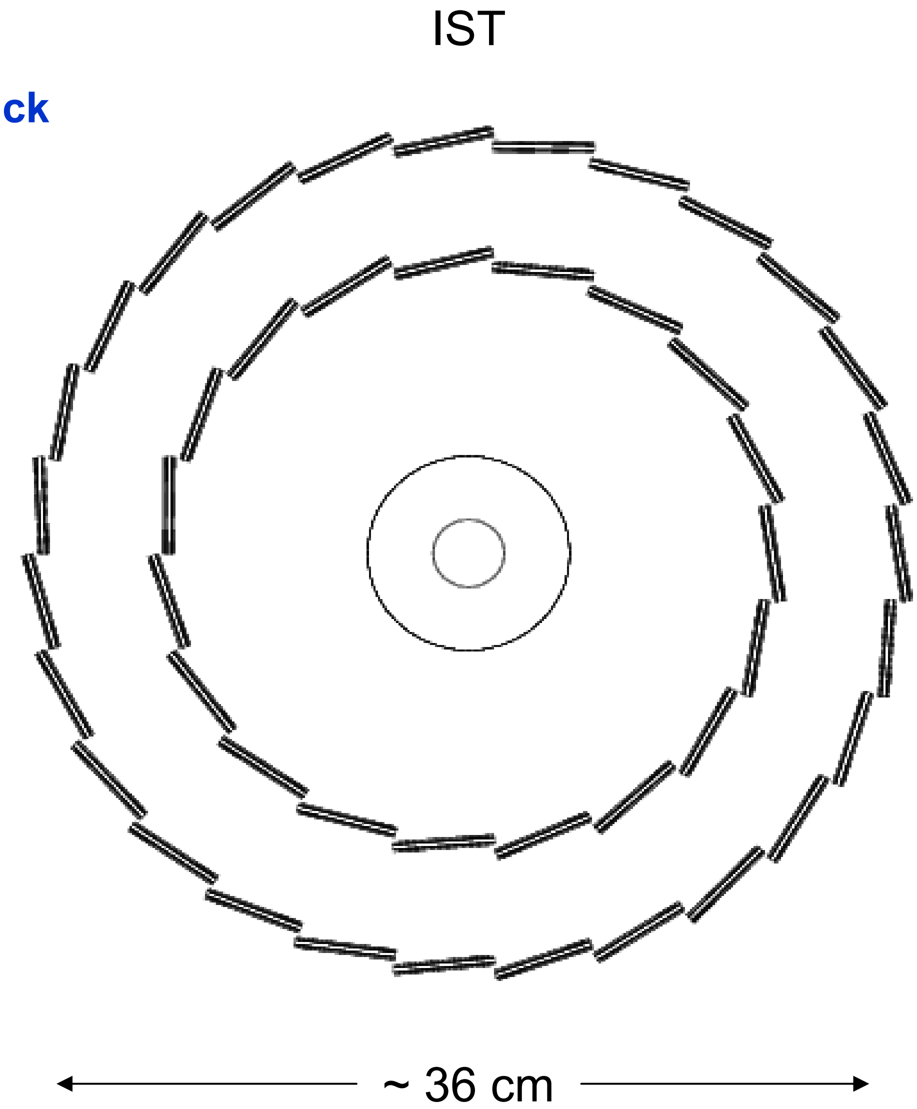
The SSD – An Existing Si Detector

- Double sided Si wafers 300 μm thick with 95 μm x 4.2 cm strips
- Crossed at 35 mrad – effectively 30 μm x 900 μm
- One layer at 23 cm radius
- 20 ladders, 67 cm long
- air cooled
- $|\eta| < 1.2$
- 1 % radiation length @ $\eta = 0$



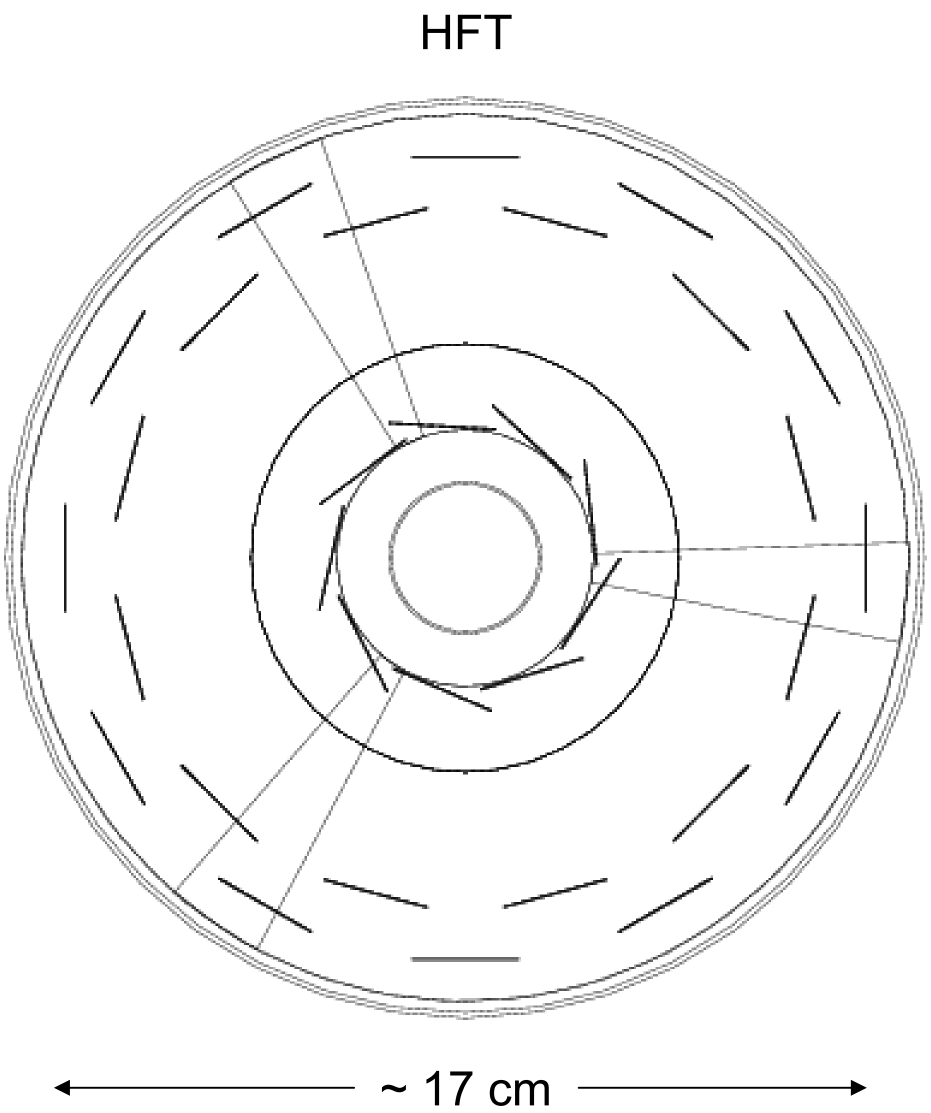
The IST – A New Detector Using Si Strips

- Singled sided Si wafers 300 μm thick with 60 μm x 4.0 cm strips
- Si pads ~ 1 mm**2 on the other side of each ladder
- Two layers at 17 & 12 cm radius
- 27 ladders, 52 cm long
- 19 ladders, 40 cm long
- air cooled
- $|\eta| < 1.2$
- 1.5 % per layer @ $\eta = 0$



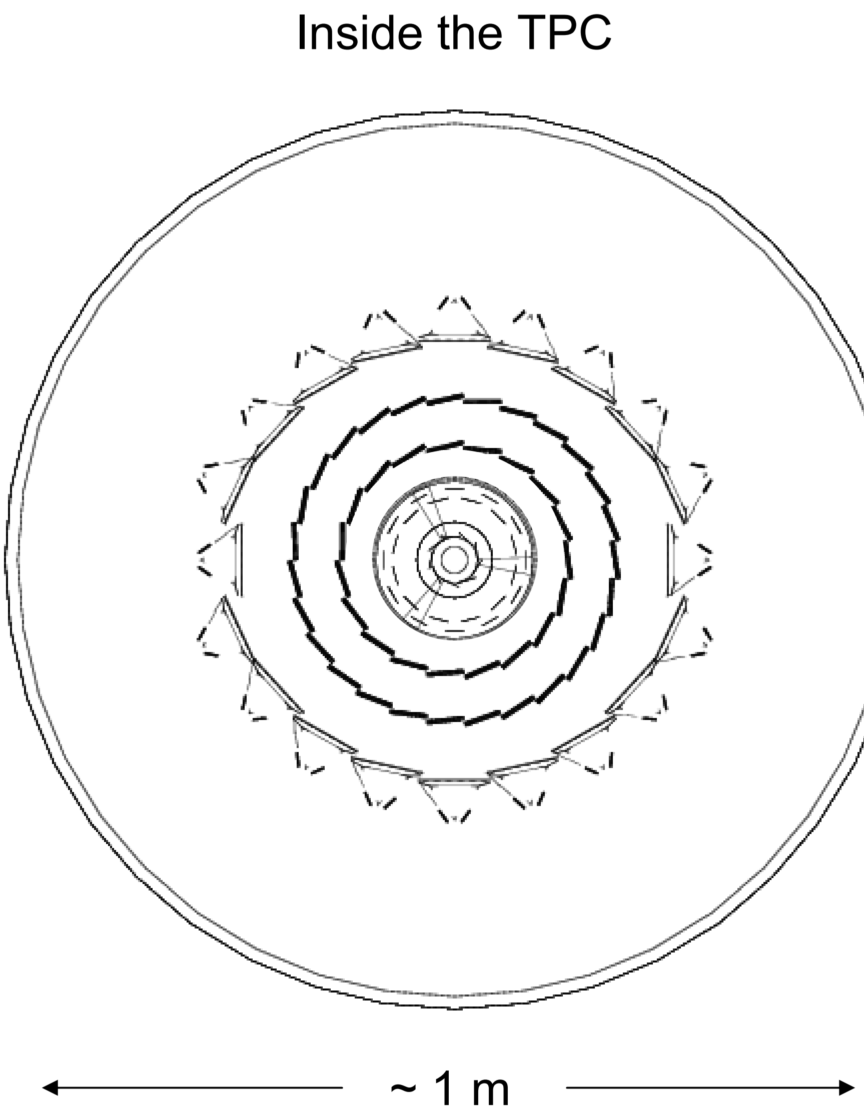
The HFT – A New Detector with Active Pixels

- Active Pixel Sensors, thinned to 50 μm thickness
- 30 μm x 30 μm pixels
- Two layers at 7 & 2.5 cm radius
- 24 ladders, 19.2 cm long
- 9 ladders, 19.2 cm long
- air cooled
- |η| < 1.2
- 0.28 % radiation length @ η = 0



Summary of Si Detectors Inside the TPC

- Goal: graded resolution from the outside → in
- TPC – SSD – IST – HFT
- TPC pointing resolution at the SSD is ~ 1 mm
- SSD pointing at the IST is ~ 300 μm
- IST pointing at the HFT is ~ 200 μm
- HFT pointing at the VTX is ~ 50 μm



Benefits of the Intermediate Si Tracker (IST)

- **The IST is a highly segmented tracking detector**
  - High rate detector for the Heavy Flavor and Spin program in pp
  - High accuracy pointing at the HFT for track finding

- **The IST completes the physics program**
  - The R_{AA} measurements need reference spectra in p-p or d-Au
  - The Flow measurements are good to 60% peripherality with the SSD + HFT alone, but going from 60% to 90% should be possible with the IST
  - The p-p and SPIN program depends on the IST for its high rate capabilities

All of the low multiplicity physics measurements use the IST

± Changes Since Last Year

− Beampipe diameter has increased

− Propose to finish the UltraSTAR detector in FY11
  – This is a completion-date schedule slip of one year
  – All of the R&D that we proposed last year, is required
  – Very important that construction project starts in FY09
  – See cost and schedule talk by J. Thomas

+ Extensive progress on MimoSTAR chip R&D, DAQ and HFT design
  – See talks by Howard Wieman and Michal Szelezniak

+ Extensive Simulations with Geant and ITTF
  – See talk by Mike Miller

+ The IST has two layers of strips and pads
  – Previously the IST had 3 layers, including a layer at small radius
  – Leaner, meaner, and cheaper (aka thinner, and it works even better)
  – See talks by Bernd Surrow

The Beampipe – an Engineering Design Change

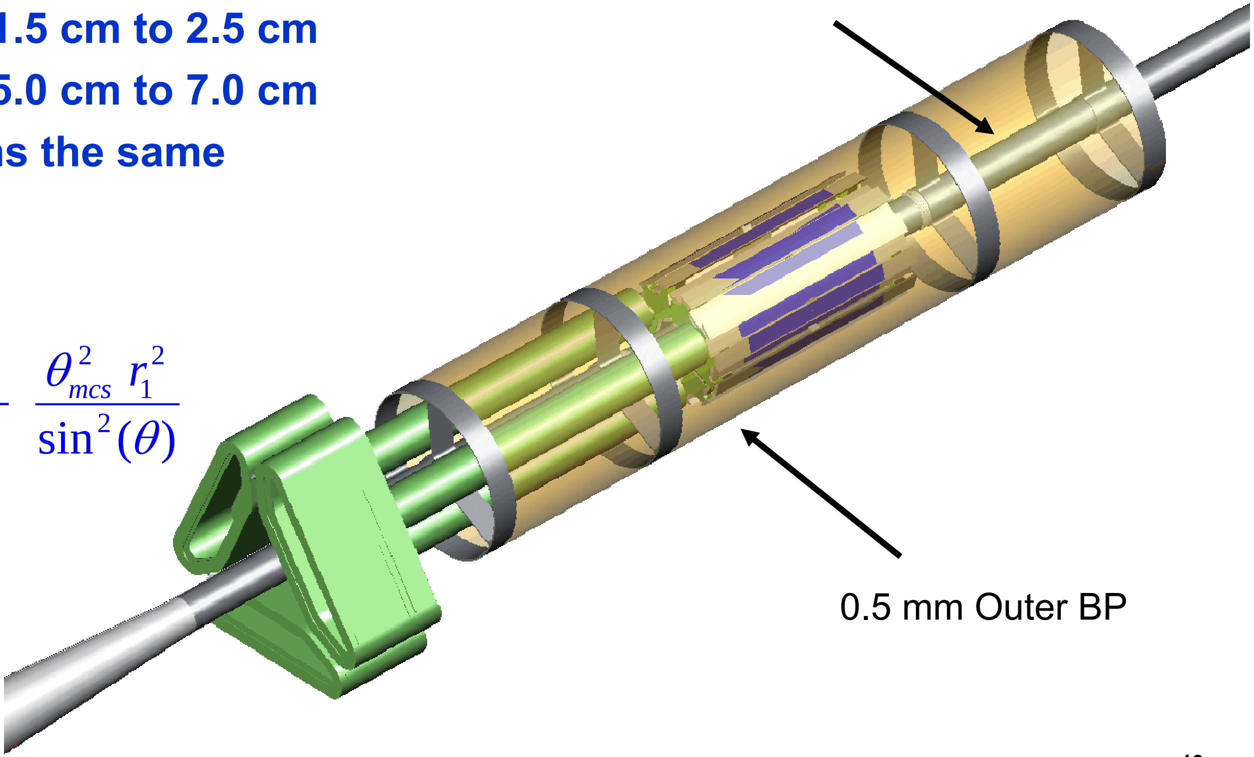
- The Beampipe is 0.5 mm of Be (0.15% X_0)
  - Formerly 3.0 cm in diameter
  - Now 4.0 cm in diameter to comply with request from CAD

- Consequences
  - The HFT detector elements must move
  - HFT-1 goes from 1.5 cm to 2.5 cm
  - HFT-2 goes from 5.0 cm to 7.0 cm
  - IST design remains the same

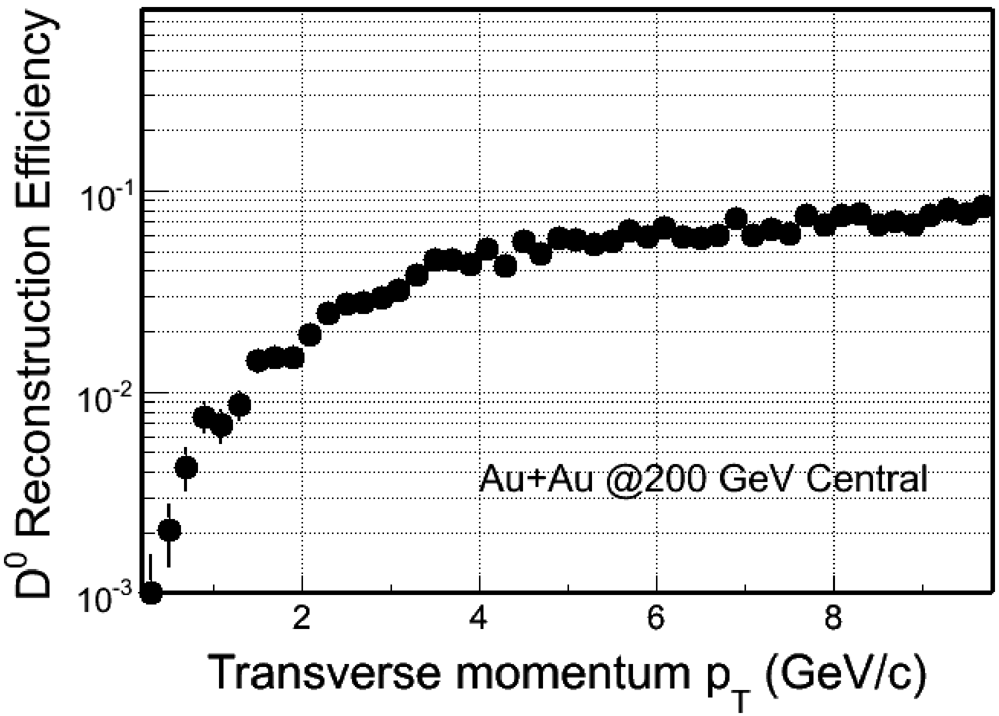
- Does it still work?

$$\sigma^2 = \frac{\sigma_1^2 r_2^2 + \sigma_2^2 r_1^2}{(r_2 - r_1)^2} + \frac{\theta_{mcs}^2 r_1^2}{\sin^2(\theta)}$$

- Yes (whew)
  - σ increases from 22 to 35 μm
  - MCS limited



Charm-hadron Simulation Results



Detector radii:

- TOF
- TPC (50cm)
- SSD (23cm)
- IST2 (17cm)
- IST1 (12cm)
- HFT2(6.9cm)
- HFT1 (2.5cm)

- **The Monte Carlo reconstructed yield of D^0 is very good**
  - **A complex p_T dependence … however efficiency vs p_T is the FOM**
  - **D^0 decay length is ~ 125 μm as compared to the change from 22 to 35 μm**
  - **HFT-1 is now further back from the vertex and see's a lower hit density**
  - **IST helps reduce search radius on HFT and thus reduces ghost track inefficiencies as well as allows more relaxed kinematic cuts on the data**
  - **Kinematic cuts in the software are the dominant contributor to efficiency**

Rates Estimation - v_2

(a) dN/dp_T distributions for D-mesons.

Scaled by <N_{bin} > = 290, corresponds to the minimum bias Au + Au collisions at RHIC.

(b) Assumed v_2 distributions for D-mesons.

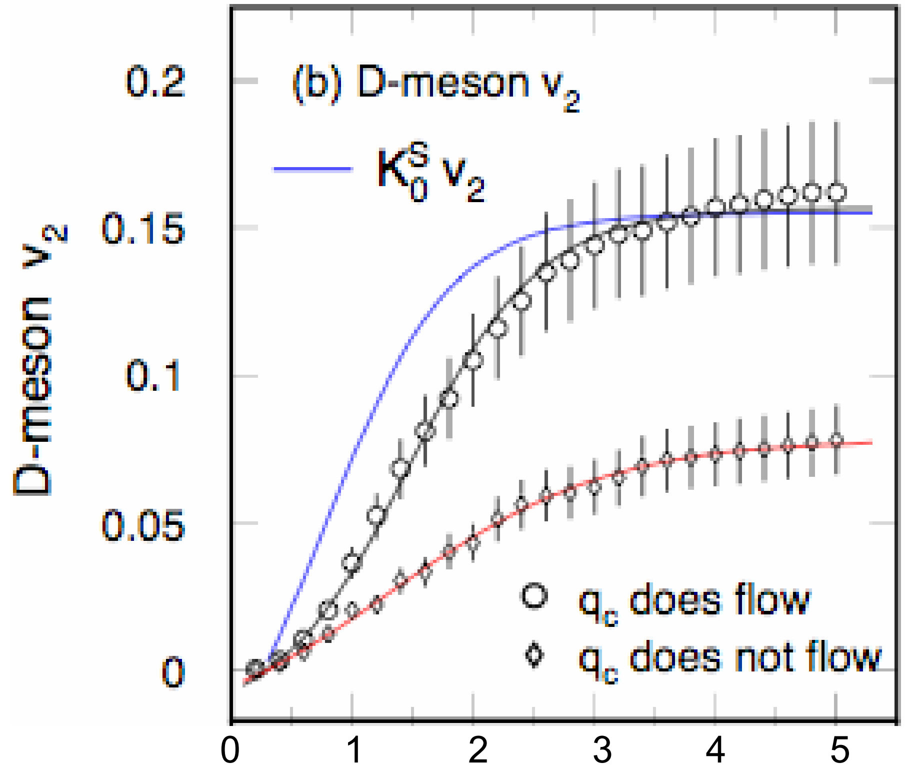
---- PLB 595, 202 (2004)

Error bars shown are from 15% systematic errors

(c) D^0 meson v_2 rates from minimum bias Au + Au collisions at 200 GeV.

The small and large error bars are for 15% and 30% systematic errors, respectively. For the v_2 analysis, 12 bins in φ are used.

500 M Events is achievable with DAQ1000



p_T(GeV/c)	Δp_T(GeV/c)	# events $q_C = q_{u,d,s}$	# events $q_C = 0$
0.6	0.2	260x10^6	525x10^6
1.0	0.5	70x10^6	140x10^6
2.0	0.5	53x10^6	125x10^6
3.0	1.0	390x10^6	270x10^6
5.0	1.0	520x10^6	880x10^6

Good Physics needs Good Technology

- Technologies to explore
  - Silicon Chips for the HFT
    - Further refinement of on-chip electronics
  - Readout Electronics for the HFT and IST
    - speed, heat dissipation, compatibility with STAR DAQ
  - The Mechanical Arms to insert the HFT and allow it to be replaced quickly
    - Alignment and stability
  - Calibration, Tracking & Software
    - New levels of precision
  - IST strips and pads
    - Optimize the pad+strip geometry at each layer
- The R&D profile allows us to complete the development of the MimoSTAR chips and to readout data with a 4 msec frame rate
  - Mount them in STAR – explore the background environment
  - Use the real beam pipe – detectors at 2.5 cm from the vertex
  - Use the real mechanical insertion device – explore calibration and alignment
- The Construction Profile allows us to complete the development of the UltraSTAR chips with 200 μsec frame rate readout by the end of FY11

Summary

- The HFT, IST & SSD will explore the Charm and Beauty sectors
- We will do <u>direct</u> topological reconstruction of Charm
- Our measurements will be unique at RHIC
- The key measurements include
  - V_2
  - Energy Loss
  - Charm Spectra, R_{AA} & R_{cp}
  - Vector mesons
  - Angular Correlations
- The technology is available on an appropriate schedule

Backup slides

The STAR Inner Tracking Upgrade is Unique at RHIC

- The Inner Tracking Upgrade will cover 2π in ϕ azimuth
  - PHENIX Si covers 2π in ϕ but the rest of the detector is 2 arms of $\pi/2$
- The Inner Tracking Upgrade will cover ± 1 unit of η
  - PHENIX Si covers ± 1 unit but the rest of the detector covers 1/3 unit
- The HFT uses 30x30 μm pixels for high resolution tracking
  - PHENIX uses 50x425 μm pixels (i.e. small strips …)
- The HFT uses 50 μm thick Si in each of 2 layers
  - PHENIX uses 350 μm thick Si (sensor plus readout) in 2 layers and 1250 μm thick Si in 2 more layers
- The HFT is 0.25% radiation lengths thick per ladder
  - PHENIX needs cooling … their first layer is 1.2% thick
- The HFT will have 35 μm pointing resolution for a Kaon at 750 MeV/c
  - PHENIX will have 70 μm pointing resolution
- Our p_T threshold for D^0s will be ~700 MeV/c
  - PHENIX will have ~2 GeV ... we get 5 times the spectrum yield
- The large RHIC collaborations have similar physics goals
  - PHENIX does single electron spectra very well
  - We will do this plus the direct topological reconstruction of open Charm!

Si Pixel Developments in Strasbourg

- **Mimosa – 1**
  - 4k array of 20 μm pixels with thick epi layer
- **Mimosa – 4**
  - Introduce Forward Biased Diode
- **Mimosa – 5**
  - 1M array of pixels, 17 μm pixels using AMS 0.6 process
  - 4 msec readout scan rate
- **Mimosa – 8**
  - Fast parallel column readout with internal data sparsification
  - 200 μsec readout scan rate

- MimoSTAR – 1 128x128 pixels using TSMC 0.25
- MimoSTAR – 2 128x128 pixels using AMS 0.35
  - Duct tape these to the STAR Beam Pipe for 07 run
- MimoSTAR – 3 320x640 pixels using AMS 0.35
- MimoSTAR – 4 640x640 pixels production run

- Ultra – 1
- Ultra – 2