My Recommendations for an Intermediate Tracker at Mid Rapidity:

The primary goal of an intermediate tracker for STAR is to provide excellent spatial resolution for finding hits to be associated with tracks. The Si trackers to be placed inside the TPC should be thin and have increasingly good resolution as the radius shrinks in order to find hits on the 'next' layer of Si without too many ambiguous hits on that layer due to projective geometry or due to background and piled-up-event issues.

All of the proposed technologies do this job; but some are better than others. For example, the HPD is the best technology for STAR at 9.2 cm radius. But it is not a complete solution, by itself, for finding hits on the HFT.

The original proposal that we considered last summer for the HPD plus IST layers had all of the strips in these systems aligned in the same direction. This yields excellent resolution in the R-phi direction but essentially none in the Z direction other than what is provided by the TPC acting alone. This configuration does a less than perfect job of finding hits to be associated with a track, and thus it limits our physics potential.

HFT1 at 2.5 cm
HFT2 at 7.0 cm
HPD at 9.2 cm
IST1 at 12 cm
IST2 at 17 cm
SSD at 23 cm

The Z resolution problem can be solved by rotating one of the Si tracking layers by 90 degrees, and the IST layers are the best candidates for this rotation due to the engineering design of the other detectors (including the SSD). For a detailed discussion of the improved tracking results that can be achieved by rotating one of the IST layers, see:

http://rnc.lbl.gov/~jhthomas/public/HFT/ISTOrientation.pdf

The key issue to be resolved is that we should define the smallest possible area on the surface of the HFT for hit-finding and for associating those hits with a track. Thus, Z resolution is as important as R-Phi resolution in reducing the area to search. Yan Lu has done a nice piece of work and he has shown that rotating the outer IST layer (IST2) is better than rotating IST1 in trying to solve the Z search problem.

So IST2 is a good detector for improving the Z resolution of the intermediate tracking system.

IST1 is also a good detector, and an excellent technology. It works at 12 cm radius but it suffers from too many ambiguous hits if it is pushed into a smaller radius. See:

http://rnc.lbl.gov/~jhthomas/public/HFT/ISTat12cm.pdf and
http://rnc.lbl.gov/~jhthomas/public/HFT/AmbiguousHits.pdf

This problem will not be uncovered by our Monte Carlo simulations because ambiguities and ghosts are not built into the Monte Carlo simulations. They can only be estimated by a Monte Carlo after-burner or with hand calculations.

Thus, it is not a good idea to replace the HPD with an IST layer at the same radius.

It is a curious result that the IST layers at 12 and 17 cm (including rotation by 90 degrees) yield about the same hit-finding performance as the HPD plus SSD … if you consider each of them as a stand-alone system. The reason they are equivalent, at low luminosity, is because the better R-phi resolution of the HPD is compensated for by the better Z resolution in IST2. The performance is not the same in any one dimension, but the product of the resolutions in each-of-two dimensions is about the same.

http://rnc.lbl.gov/~jhthomas/public/HFT/ACuriousResult.pdf

So the performance of the two tracking systems, considered as stand-alone systems, is roughly equivalent.

Can these systems be optimized? Yes; absolutely.

The original proposal for the IST included a layer of strips AND a layer of pads at each detector location. Overall, it was a four layer system; pads plus strips at two locations. However, the pads are not a powerful tool and they do not provide any more discrimination between ambiguous (ghost) hits on the IST layers than can be provided by the TPC, alone.

http://rnc.lbl.gov/~jhthomas/public/HFT/PadsNotNecessary.pdf

So I recommend removing the pad layers from the IST's. This will reduce the cost and complexity of the system; especially at the 17 cm radius location where the area of the detector is largest.

The HPD can also be improved if we can find a way to provide additional Z resolution for the detector system. The essential problem is that the strips of the HPD are aligned with the strips in the SSD, and this cannot be changed, and so there is very little Z resolution in the system other than what the TPC can provide, alone. This problem is most important at high luminosity and RHIC II running conditions. See:

http://rnc.lbl.gov/~jhthomas/public/HFT/ZeeTroubleWithZeeHPD.pdf

Figure 2 of this document shows that the Z resolution of the HPD+SSD tracking system can be improved.

Therefore, I recommend that we take advantage of the beautiful R-phi resolution of the HPD and supplement it with a stripped down and economical IST layer at 17 cm. This is my recommendation for an intermediate tracker at mid-rapidity for STAR.

The IST layer at 12 cm is not needed because the pointing resolution of the HPD is better than IST1 and the HPD does not suffer from a problem with ambiguous and ghost hits. Furthermore, the pads on IST2 are not needed, as mentioned above.

I believe that this is the best system we can build. It has the best performance, the technologies are within reach, and the costs have been minimized by eliminating thee layers of Silicon from the system that we proposed last summer.

Performance of HFT1 + HFT2 + HPD + IST2(no pads) + SSD + TPC :

It is interesting to compare the performance of the **HPD+IST2** tracker to the HPD+SSD and the IST1+IST2 trackers as pointing devices for the HFT.

I will do this under fairly conservative conditions (meaning difficult conditions) … which means RHIC II running conditions and Au-Au minbias collisions. The full parameter set is listed at the end of this note.

As shown in Figure 1, The R-Phi resolution of the HPD+SSD system is better than the IST1+IST2 system because the HPD has very fine strips (50 microns) and it is closer to the surface of the HFT and thus has a shorter lever arm to amplify the effects of MCS. Also, the HPD does not suffer from a serious occupancy problem. The strips are relatively short (425 µm) compared to the length of the strips in the IST (3.8 cm).

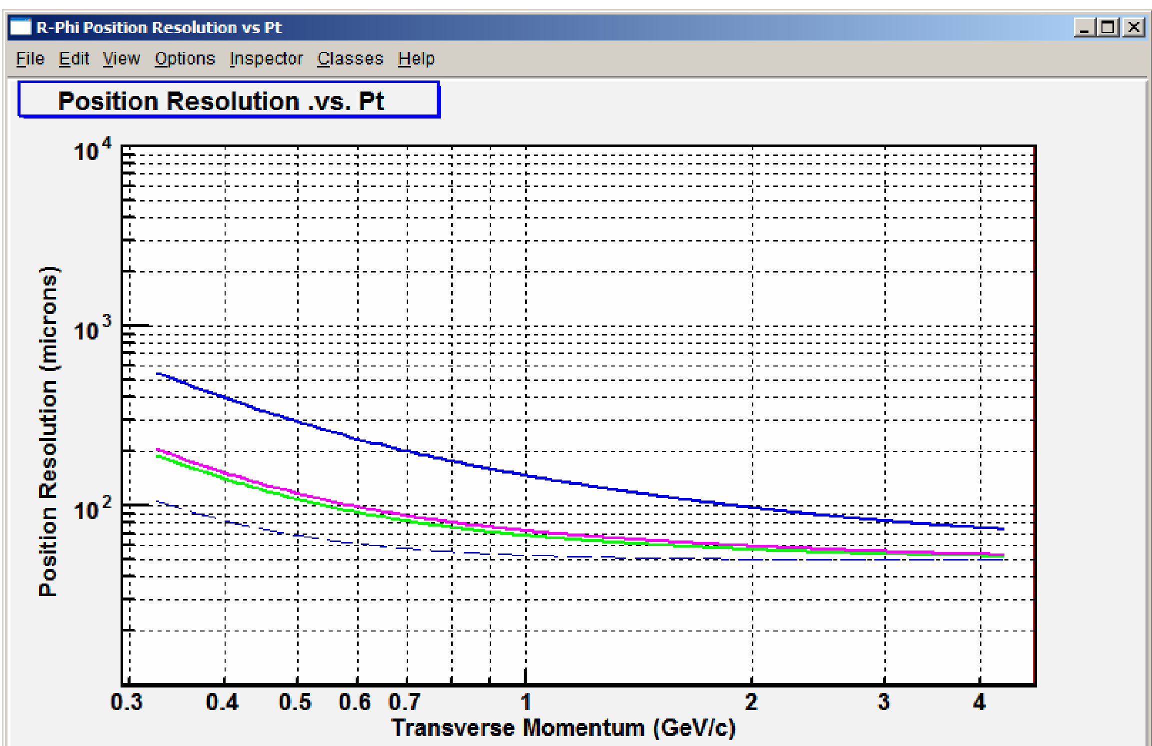

Figure 1: The blue lines show the R-Phi pointing resolution for the IST1+IST2 tracker on the outer surface of the HFT. The green lines show the resolution of the HPD+SSD tracker, and the magenta lines shows the pointing resolution for the HPD+IST2.

However, the relative performance of the detectors is reversed when we consider the pointing resolution in the Z direction. The IST1+IST2 tracker achieves relatively good Z resolution because the IST2 layer is assumed to be rotated by 90 degrees. Figure 2 is a graph of the Z pointing resolution for all three cases, including the HFT+IST2. As shown in the figure, zee problem with the HPD+SSD is that zee strips in the HPD are aligned with zee strips in the SSD … and so the Z resolution for the HPD is constant, as a function of pt. The Magenta line in the figure shows the improvement that is possible with an IST layer (without pads and rotated by 90 degrees) located at 17 cm radius.

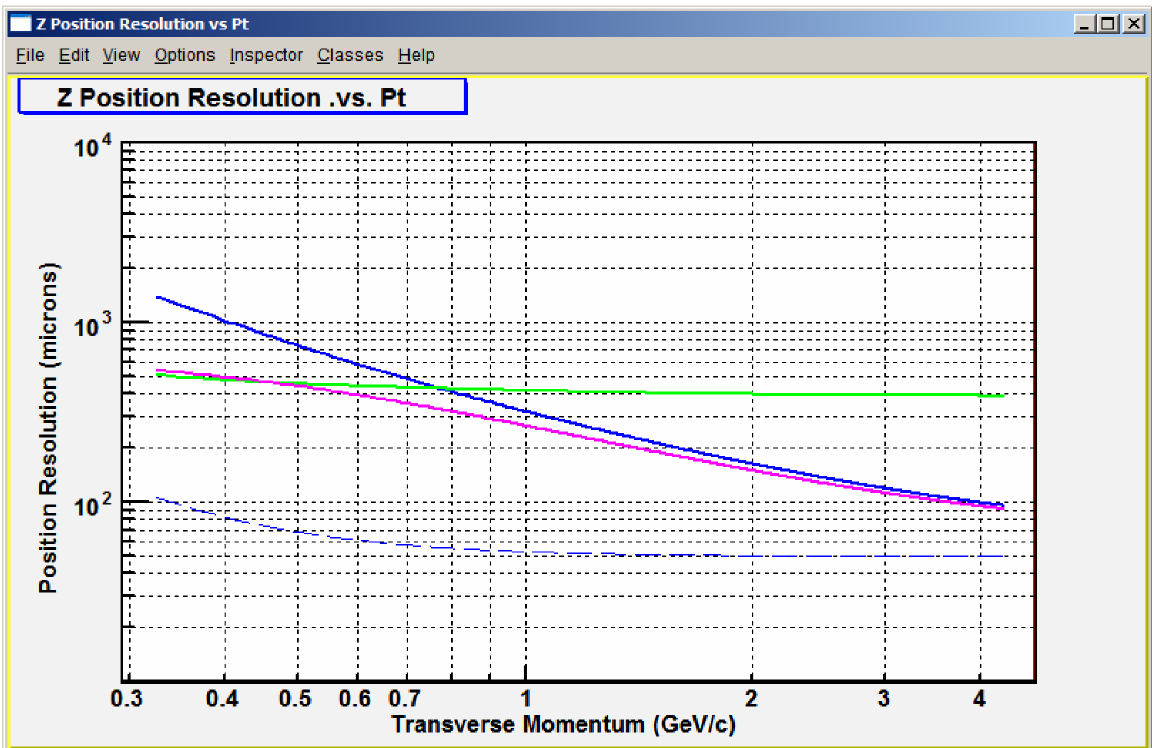

Figure 2: The blue line shows the Z pointing resolution for the IST1+IST2 tracker onto the surface of the HFT. The green lines show the pointing resolution of the HPD+SSD tracker and the magenta line shows the improvement than can be achieved by adding IST2. The HPD+IST2+SSD tracker is the best combination.

The dashed line at the bottom of figures one and two is a reference line to guide the eye. It is a theoretical estimate of the HFT vertex resolution if the HFT could act alone … no other detectors, and no other sources of MCS.

Is the poor Z resolution of the HPD+SSD important? Yes, it turns out to be noticeable. The reason it become important is because the intermediate tracker is used to define an 'area' on the outer surface of the HFT and this area is searched for good hits. The area is elliptical in shape, where $A = 2\pi R_{R\text{-}Phi} R_Z$, and if this area is large enough relative to the occupancy and pileup in the HFT, then the tracker will find a false hit before finding the right hit. The effects of the changing Z resolution can be seen in Figure 3 where graph shows the pointing resolution for the various tracking systems and estimate the D0's reconstruction efficiencies. The inefficiencies due to poor Z resolution are even more important for the Λ_c because it has a three body final state.

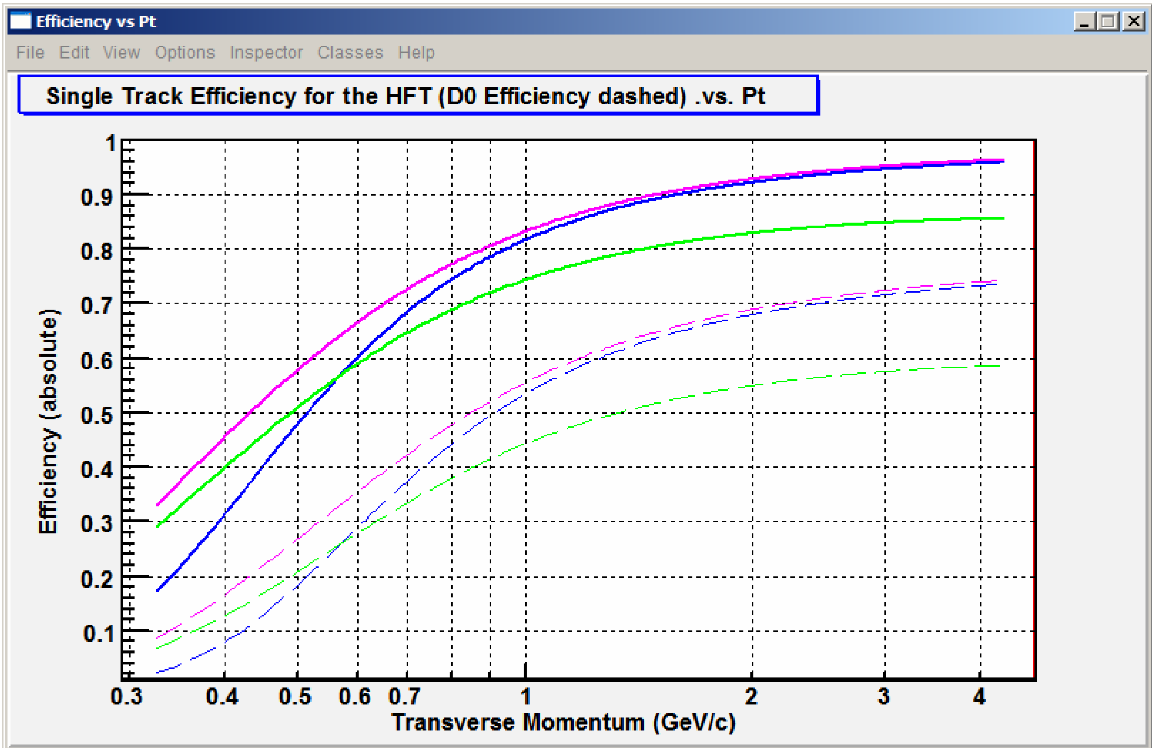

Figure 4: The solid blue line shows the efficiency for finding a kaon in the HFT with the IST1+IST2 tracker. The green line shows the efficiency for finding a kaon with the HPD+SSD tracker. The magenta line shows the efficiency for finding a kaon with the HPD+IST2 (rotated and without pads) tracker. The HPD+IST2 tracker is the best. The dashed lines represent the square of the solid lines (times 0.8 to displace the curves) and is a very crude estimate of the D0 track finding efficiency in each case. The region of most interest is from 750 MeV to 1 GeV.

Summary:

The HPD and IST detectors are beautiful examples of modern tracking technology. By combining the best of both technologies, a powerful pointing device for STAR can be built. The best combination in terms of performance and cost is to build the HPD in combination with one layer of the IST at 17 cm radius.

The layer at 17 cm should be rotated by 90 degrees, and the pads can be removed. This removes three layers of Si from the proposal that we discussed last summer and yields a thin, low radiation length, cost efficient, but high performance system for doing Heavy Flavor physics in STAR.

The HPD+IST2 tracker is a good system.

Additional Comments:

An interesting feature of a high resolution Si detector system, is that the intrinsic resolution is so high, in each layer, that the resolution on the next layer of tracking is dominated by MCS in the current layer. The tracking performance before the current layer does not play a large role in determining the pointing resolution onto the layer after the current layer. The previous layers are employed to find hits on the current layer, but once found, do not play a dominant role thereafter. This feature is unique to high resolution detectors and this thinking is different than the traditional idea that stacking multiple detectors improves the pointing resolution of the system by a strong function of N, where N is the number of layers. In a closely stacked Si tracker, it is entirely possible to make the pointing resolution of the system worse by adding an additional layer.

Low resolution detectors can assist a high resolution Si tracker because the low resolution detectors may provide important directional information (angle constraint) if the detector elements are distributed over a large distance. The STAR TPC is a good example; it provides a long track segment to seed the search for a track. The TPC does not provide tight translational constraints on the position of a hit at any radius … but it does provide a tight angular constraint on the direction that the track can take. This means that every track segment that starts in the TPC looks like a stiff track to the Si detectors, independent of momentum. The track segment can only go through the Si detectors from a certain direction and so the Si detectors are most useful in constraining the translational location of the track. Thus, radial location of the Si detectors is not as important as it would be if the TPC was not included in the tracking system.

Parameters used in these calculations:

```
#define        Mass                     0.540       // Mass of the test particle in
#define        BFIELD                   0.5         // Tesla  (test data taken at 0.25
#define        AvgRapidity              0.5         // Avg rapidity, MCS calc is a
#define        Luminosity               1.e28       // Luminosity of the beam (RHIC I ==
#define        Sigma                    15.0        // Size of the interaction diamond
#define        dNdEta                   170         // Multiplicity per unit Eta  (AuAu
#define        CrossSection             10          // Cross section for event under
#define        IntegrationTime          0.2         // Integration time for HFT chips (
#define        BackgroundMultiplier     4.0         // Increase multiplicity in detector
#define        SiScaleFactor            1.0         // For scaling Si pad sizes.  (eg
#define        EfficiencySearchFlag     0           // Define search method. ChiSquare =

// Most likely Detector parameters you may want to tune are in the block starting here:

#define        VtxResolution            0.3000      // cm  Test data wants 3 mm vertex
#define        VtxResolutionZ           0.3000      // cm  Test data wants 3 mm vertex

#define        NewVtxResolution         0.0300      // cm  NewVertex to study effect of a
#define        NewVtxResolutionZ        0.0300      // cm  NewVertex to study effect of a

#define        RefitVtxResolution       0.0030      // cm  Refit Vertex to study effect
#define        RefitVtxResolutionZ      0.0030      // cm  Refit Vertex to study effect

#define        BeamPipe1Resolution      RIDICULOUS  // Beampipe is not active as a

#define        Hft1Resolution           0.0030      // cm  30 x 30   micron pixels
#define        Hft1ResolutionZ          0.0030      // cm  30 x 30   micron pixels

#define        Hft2Resolution           0.0030      // cm  30 x 30   micron pixels
#define        Hft2ResolutionZ          0.0030      // cm  30 x 30   micron pixels
```

```
#define        BeamPipe2Resolution      RIDICULOUS  // Beampipe is not active as a

#define        HpdResolution            0.0050      // cm  50 x 425  micron pixels ...
#define        HpdResolutionZ           0.0425      // cm  50 x 425  micron pixels ...

#define        Ist1Resolution           0.0060      // cm  60 x 1920 micron pixels ... Z
#define        Ist1ResolutionZ          0.1920      // cm  60 x 1920 micron pixels ...
//#define        Ist1Resolution           0.1920      // cm  60 x 1920 micron pixels ...
//#define        Ist1ResolutionZ          0.0060      // cm  60 x 1920 micron pixels ...

//#define        Ist2Resolution           0.0060      // cm  60 x 1920 micron pixels ...
//#define        Ist2ResolutionZ          0.1920      // cm  60 x 1920 micron pixels ...
#define        Ist2Resolution           0.1920      // cm  60 x 1920 micron pixels ...
#define        Ist2ResolutionZ          0.0060      // cm  60 x 1920 micron pixels ...

#define        SsdResolution            0.0095      // cm  95 x 4200  microns double
#define        SsdResolutionZ           0.2700      // cm  95 x 4200  microns double

#define        IFCResolution            RIDICULOUS  // IFC is not active as a detector

#define        TpcResolution            0.0575      // cm  600 x 1500 microns ...Test
#define        TpcResolutionZ           0.1500      // cm  600 x 1500 microns ...Test

// End of 'most likely' block, but there are more parameters, below.

#define        VtxIndex                 0
#define        BeamPipe1Index           1
#define        Hft1Index                2
#define        Hft2Index                3
#define        BeamPipe2Index           4
#define        HpdIndex                 5
#define        Ist1Index                6
#define        Ist2Index                7
#define        SsdIndex                 8
#define        IFCIndex                 9
#define        TpcIndex                 10
#define        VtxThickness             0.0000  // % Radiation Lengths
#define        BeamPipe1Thickness       0.0015  // % Radiation Lengths (as in 0.01 == 1%)
#define        Hft1Thickness            0.0028  // % Radiation Lengths (0.0028 new 0.0036
#define        Hft2Thickness            0.0028  // % Radiation Lengths (0.0028 new 0.0036
#define        BeamPipe2Thickness       0.0015  // % Radiation Lengths
#define        HpdThickness             0.0100  // % Radiation Lengths
#define        Ist1Thickness            0.0150  // % Radiation Lengths
#define        Ist2Thickness            0.0150  // % Radiation Lengths
#define        SsdThickness             0.0100  // % Radiation Lengths
#define        IFCThickness             0.0052  // % Radiation Lengths
#define        TpcAvgThickness          0.00026 // % Radiation Lengths ... Average per
#define        VtxRadius                0.0     // cm
#define        BeamPipe1Radius          2.05    // cm (2.05 new 1.50 old)
#define        Hft1Radius               2.50    // cm (2.5  new 1.55 old)
#define        Hft2Radius               7.00    // cm (7.0  new 5.00 old)
#define        BeamPipe2Radius          8.55    // cm (8.55 new 6.05 old)
#define        HpdRadius                9.2     // cm (9.2  HPD,6.0  SVT)
#define        Ist1Radius              12.0     // cm (12.0 IST,10.0 SVT, option 9.5 IST)
#define        Ist2Radius              17.0     // cm (17.0 IST,14.0 SVT)
#define        SsdRadius               23.0     // cm
#define        IFCRadius               47.25    // cm  Middle-Radius of the IFC ... its
#define        TpcInnerRadialPitch1     4.8     // cm
#define        TpcInnerRadialPitch8     5.2     // cm
#define        TpcOuterRadialPitch      2.0     // cm
#define        TpcInnerPadWidth         0.285   // cm
#define        TpcOuterPadWidth         0.620   // cm
#define        InnerRows1               8
#define        InnerRows8               5
#define        InnerRows               (InnerRows1+InnerRows8)
#define        OuterRows               32
#define        TpcRows                 (InnerRows1 + InnerRows8 + OuterRows)
#define        RowOneRadius            60.0     // cm
```