Radial Location of the HFT Layers: A study in optimization

The location of the HFT detectors is determined by considerations that are as esoteric as Λ_c reconstruction efficiency and as mundane as staying outside of the beampipe … and also a bit of wisdom learned from prior experiments. But are the canonical radial locations optimized and can we prove it?

The baseline design for the HFT puts the first layer of pixel detectors at a radius of 2.5 cm and the second layer at a mean radius of 7.0 cm. The outer layer is actually staggered and the ladders are alternately located at two different radii; 6.5 cm and 7.5 cm.

In this note, I will explore the overall pointing accuracy, and efficiency, of the HFT system in two different ways. The first exercise will be to keep HFT-1 at the smallest radius possible (2.5 cm) but to move HFT-2 in and out from its canonical position to see if the pointing accuracy and/or efficiency can be improved. The second exercise will be to keep a constant spacing between the HFT layers but to move the pair outwards.

Exercise 1: Keep the inner HFT layer at constant radius but move the outer layer to a different position. Figures 1 and 2 show what happens when the outer layer moves in the range from 5 cm to 10 cm radius.

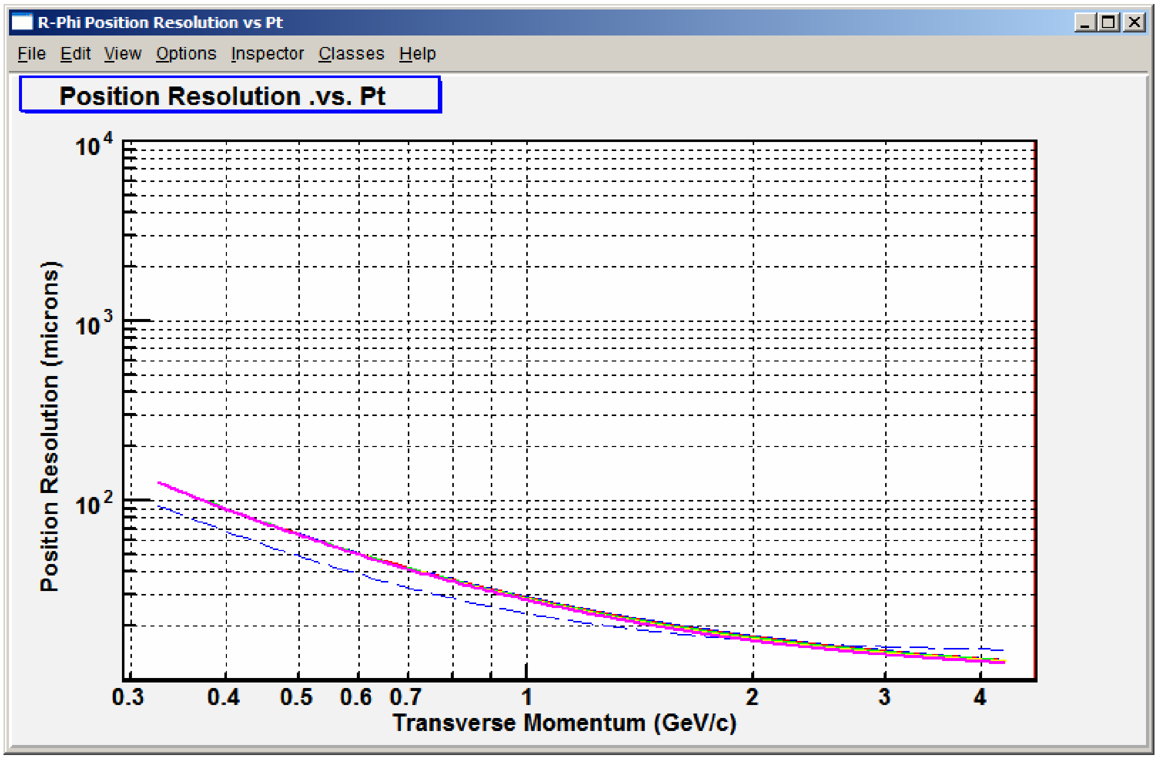

Figure 1: The magenta colored line is a super-position of several identical results. Moving the outer HFT layer outwards in 1 cm steps from 5 to 10 cm does not change the single track pointing resolution. This is because the pointing resolution is dominated by the characteristics of the inner HFT layer … which did not move.

In contrast to the pointing resolution shown in Fig 1, the efficiency for reconstructing the D0s *does* change when the outer layer of the HFT occupies different positions. See Fig 2.

In all of these figures, the efficiency is quoted in arbitrary units. The solid line is the single track efficiency for the combination of the two HFT layers. The dashed line is the single track efficiency squared times 0.8, to represent the inefficiency of the rest of the tracking system, and the energy scale has been doubled to represent the summed energy of two mean p_T particles. The dashed line is a simplified estimate of the D0 tracking efficiency and should only be used for relative comparisons.

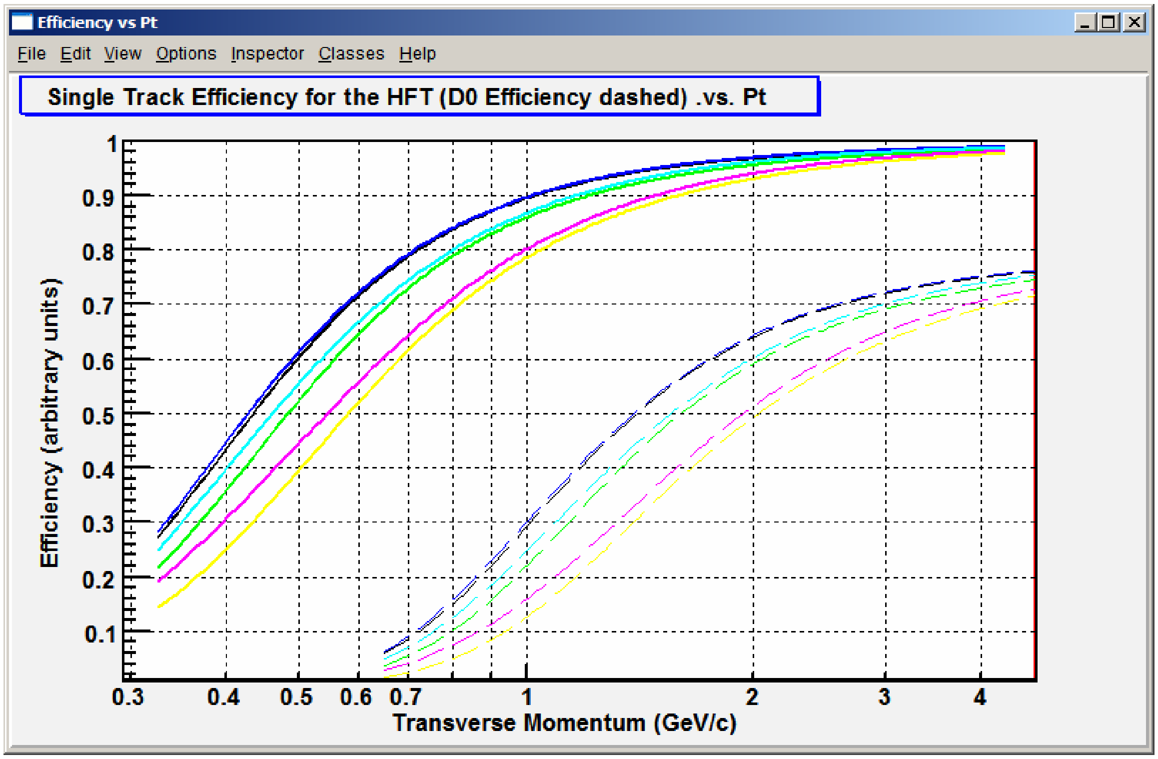

Figure 2: The single track efficiency of the HFT in arbitrary units is shown as a function of transverse momentum. The solid lines represent different locations for the outer HFT layer. The color coding shows HFT-2 at 5.0 cm (Magenta), 6.0 cm (Cyan), 7.0 cm (Blue), 8.0 cm (Black), 9.0 cm (Green), and 10.0 cm (Yellow). There is a maximum efficiency and a plateau between 7 and 8 cm radius which is shown, better, in Fig. 3.

Fig. 3 shows the data points for the single track reconstruction efficiency at 750 MeV as a function of the radial position of HFT-2. The plateau between 6.5 and 8.0 cm is clearly visible.

The efficiency for successfully associating the correct hit with a track depends on two terms; the pointing resolution of the detector telescope and the piled-up hit density on the next layer of the system. So in Fig. 3, HFT-2 does not do a very good job of pointing at HFT-1 when it sits at 10.0 cm radius due to the relatively long distance to HFT-1 and the multiple Coulomb Scattering in HFT-2. However, the pointing resolution of the system improves as HFT-2 moves to a smaller radius and is closer to HFT-1. At about 7.5 cm radius the efficiency is maximum, and at smaller radii, the hit density on HFT-2 starts to become a problem because the hit density increases as the radius decreases and the efficiency of the IST+SSD tracker starts to suffer as a result of the increased number of false hits falling within the 1 sigma limit of the IST+SSD system pointing at HFT-2. The interference between these two terms causes the plateau.

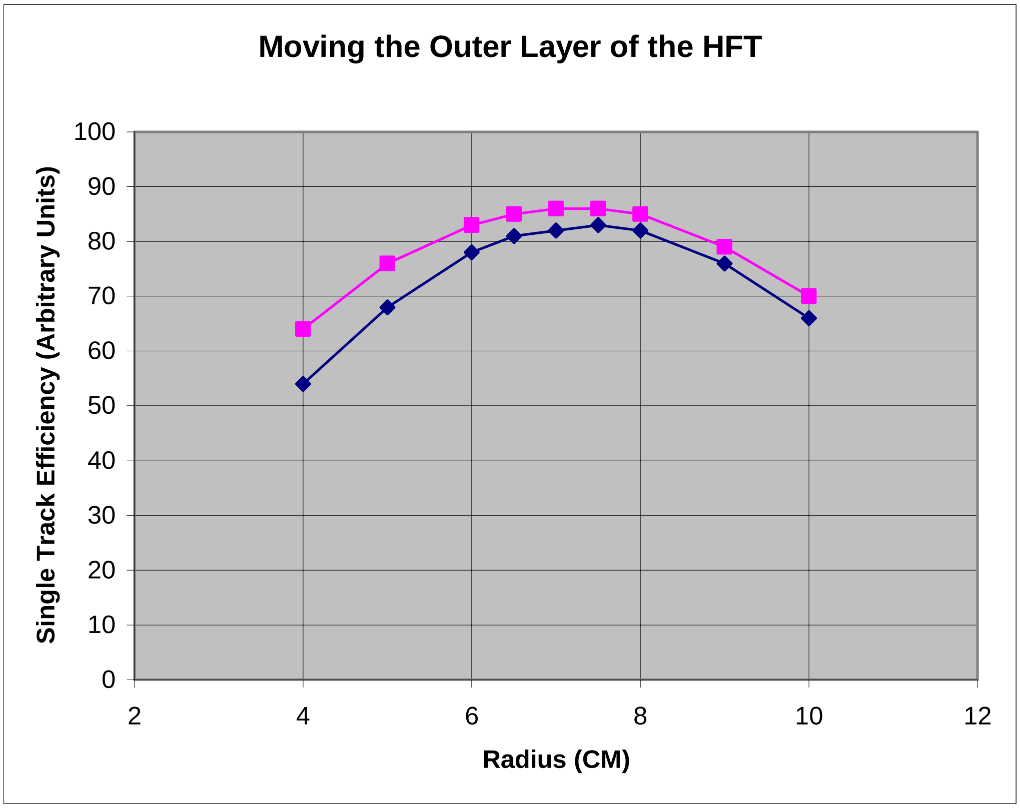

Figure 3: The efficiency for reconstructing a 750 MeV Kaon with the HFT detector telescope. In this study, the position of HFT-2 is changed from 4 cm to 10 cm radius. The position of HFT-1 does not change. The efficiency is maximal between 6.5 and 8.0 cm radius. Since the nominal design of the HFT puts the HFT-2 ladders at staggered radii of 6.5 and 7.5 cm, we can conclude that these locations are very well chosen.

The blue line in Fig. 3 is the efficiency for the nominal HFT/IST design. The pink line is the efficiency for an IST without the usual pad layers. Note that the difference between the two lines is larger at smaller radius … this is because removing the pad layers on the IST provides a strong improvement in the pointing resolution of the system and this improvement is needed because HFT-2 has a serious pile-up problem at these smaller radii. The difference between the two lines is smaller at large radii because the pile-up and inefficiency in HFT-2 is not so important … rather the pointing resolution onto HFT-1 by HFT-2 has become the dominant inefficiency and the pointing resolution of the IST layers is, now, not so important.

Thus the current location of the HFT layers is very good. The maximum efficiency is achieved between 6.5 and 8 cm, however, cost considerations drive us toward wanting to stay near the smaller radius. The nominal design of the HFT puts the HFT-2 ladders at staggered radii of 6.5 and 7.5 cm and these are well chosen.

Exercise 2: Keep the spacing between the HFT layers constant but move both of them outwards. The canonical distance between HFT-1 and HFT-2 is 4.5 cm. Fig. 4 shows the effect of moving the layers of the HFT outward in 0.5 cm steps. The blue line is the standard configuration with HFT-1 located at 2.5 cm radius. The figure shows that the pointing resolution of the system gets worse as the HFT telescope moves further away from the vertex.

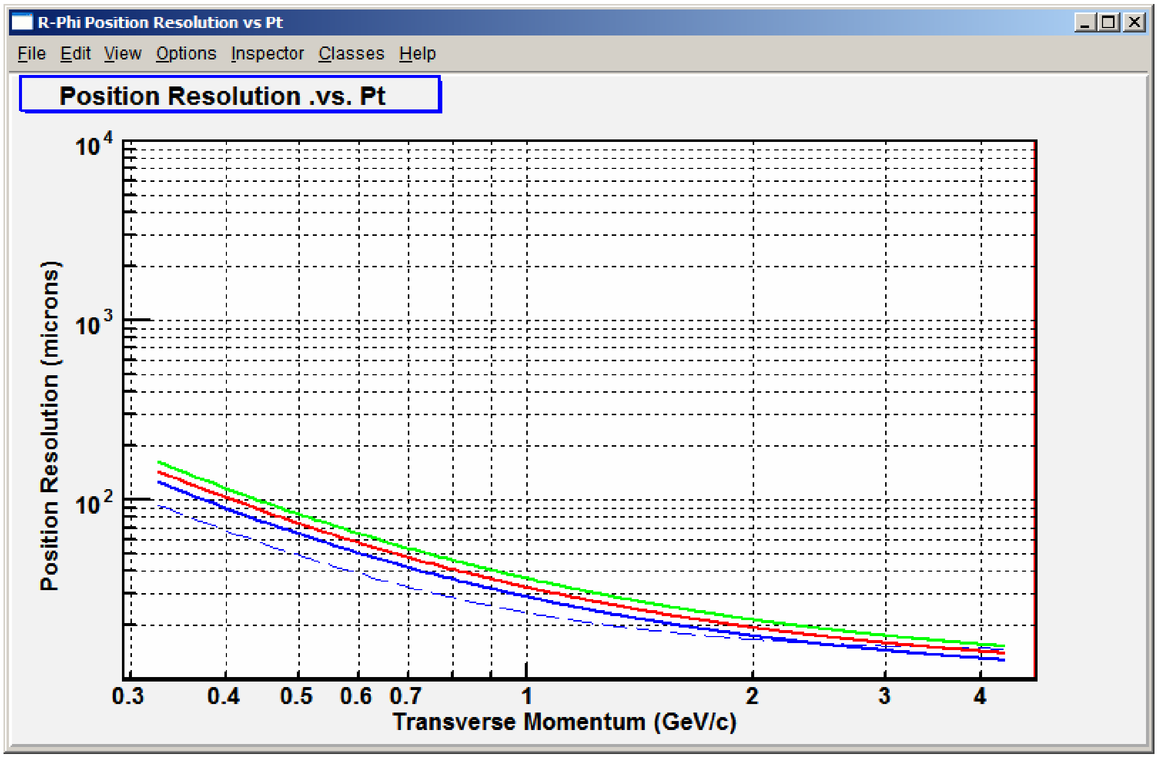

Figure 4: Stepping out both HFT-1 and HFT-2 by 0.5 cm steps. The distanced between the layers is kept constant. The blue shows the position resolution of the HFT when the detectors are in their nominal position (i.e. HFT-1 at 2.5 cm and HFT-2 at 7.0 cm radius). The red line shows what happens when HFT-1 moves out to 3.0 cm radius and the green line shows the results for HFT-1 at 3.5 cm radius.

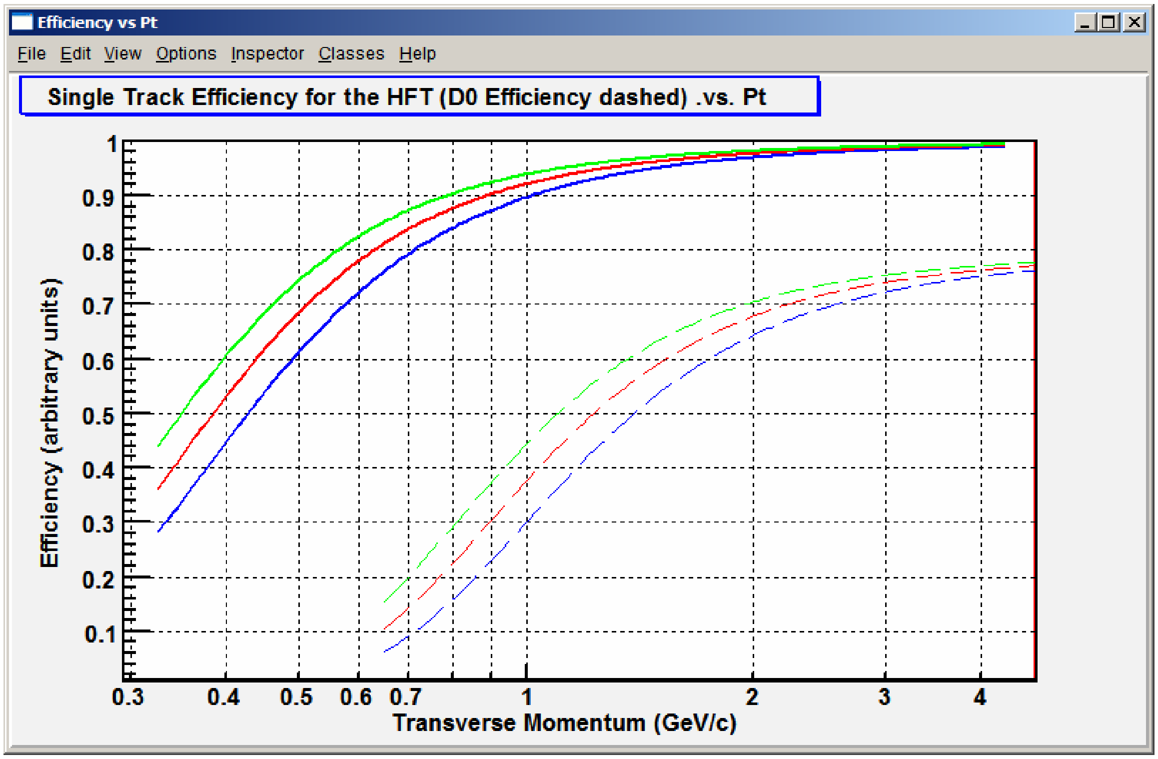

Figure 5: Stepping out both HFT1 and HFT2 by 0.5 cm steps. Blue is the nominal position. The efficiency is quoted in arbitrary units. The solid line is the single track efficiency for the combination of the two HFT layers. The dashed line is the single track efficiency squared times 0.8, to represent the inefficiency of the rest of the tracking system, and the energy scale has been doubled to represent the summed energy of two mean pt particles. The dashed line is a simplified estimate of the D0 tracking efficiency and should only be used for relative comparisons.

Fig. 5 shows the combined single track efficiency for the HFT detector in arbitrary units. If you compare this figure to the results shown in Fig. 4, you will see that the efficiency of the system improves as the pointing resolution of the system gets worse. This curious result is due to the decreasing hit density on HFT-1 (and also HFT-2) as the detectors are moved out in radius. The density on HFT-1 dominates the inefficiency calculation in this configuration and so decreasing the density on HFT-1 improves the efficiency. This result suggests that we may be able to trade pointing resolution for additional efficiency in recovering D0s; however, the gain is probably not large enough to justify moving the detectors out from their canonical positions. My guess is that the closer to the vertex, the better … but it is a non-linear optimization that should include the effect of pointing resolution on invariant mass reconstruction as well as the hit/track matching efficiency … and several other effects. What do you think?

The parameters used in these calculations are listed below:

```
#define        RIDICULOUS               99999.99    // A ridiculously large resolutio
#define        Mass                     0.540       // Mass of the test particle in G
#define        BFIELD                   0.5         // Tesla  (test data taken at 0.2
#define        AvgRapidity              0.5         // Avg rapidity, MCS calc is a fu
#define        Luminosity               1.e28       // Luminosity of the beam (RHIC I
#define        Sigma                    15.0        // Size of the interaction diamon
#define        dNdEta                   170         // Multiplicity per unit Eta  (Au
#define        CrossSection             10          // Cross section for event under
#define        IntegrationTime          0.2         // Integration time for HFT chips
#define        BackgroundMultiplier     1.0         // Increase multiplicity in detec
#define        SiScaleFactor            0.288       // For scaling Si pad sizes.  (eg
#define        EfficiencySearchFlag     1           // Define search method. ChiSquar

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

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

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

#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 de

#define        Ist1Resolution           0.0060      // cm  60 x 4.0  micron  and cm (
#define        Ist1ResolutionZ          4.0000      // cm  60 x 4.0  microns and cm (

#define        Ist1PrimeResolution      0.1920      // cm  1.92 mm x 1.20 mm pads (60
#define        Ist1PrimeResolutionZ     0.1200      // cm  1.92 mm x 1.20 mm pads (60

#define        Ist2Resolution           4.0000      // cm  60 x 4.0
#define        Ist2ResolutionZ          0.0060      // cm  60 x 4.0

#define        Ist2PrimeResolution      0.1200      // cm  1.92 mm x 1.20 mm pads (60
#define        Ist2PrimeResolutionZ     0.1920      // cm  1.92 mm x 1.20 mm pads (60

#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 detecto

#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        Ist1Index                5
#define        Ist1PrimeIndex           6
#define        Ist2Index                7
#define        Ist2PrimeIndex           8
#define        SsdIndex                 9
#define        IFCIndex                 10
#define        TpcIndex                 11
#define        VtxThickness             0.0000  // % Radiation Lengths
#define        BeamPipe1Thickness       0.0018  // % Radiation Lengths (as in 0.01 ==
#define        Hft1Thickness            0.0028  // % Radiation Lengths (0.0028 new 0.
#define        Hft2Thickness            0.0028  // % Radiation Lengths (0.0028 new 0.
#define        BeamPipe2Thickness       0.0018  // % Radiation Lengths
#define        Ist1Thickness            0.0075  // % Radiation Lengths
#define        Ist1PrimeThickness       0.0075  // % Radiation Lengths
```

```
#define        Ist2Thickness            0.0075  // % Radiation Lengths
#define        Ist2PrimeThickness       0.0075  // % Radiation Lengths
#define        SsdThickness             0.0100  // % Radiation Lengths
#define        IFCThickness             0.0052  // % Radiation Lengths
#define        TpcAvgThickness          0.00026 // % Radiation Lengths ... Average pe
#define        VtxRadius                0.0     // cm
#define        BeamPipe1Radius          2.05    // cm (2.05 new 1.50 old)
#define        Hft1Radius               2.5     // cm (2.5  new 1.55 old)
#define        Hft2Radius               7.0     // cm (7.0  new 5.00 old)
#define        BeamPipe2Radius          8.55    // cm (8.55 new 6.05 old)
#define        Ist1Radius              12.0     // cm (12.0 IST,10.0 SVT, option 9.5
#define        Ist1PrimeRadius         12.1     // cm (12.1 IST1Prime)
#define        Ist2Radius              17.0     // cm (17.0 IST,14.0 SVT)
#define        Ist2PrimeRadius         17.1     // cm (17.1 IST2Prime,14.0 SVT)
#define        SsdRadius               23.0     // cm
#define        IFCRadius               47.25    // cm  Middle-Radius of the IFC ... i
#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
#define        RowEightRadius          93.6     // cm
#define        RowFourteenRadius      127.195   // cm
```