Rate, Resolution, and Radiation Length Guidelines for an Intermediate STAR Tracker

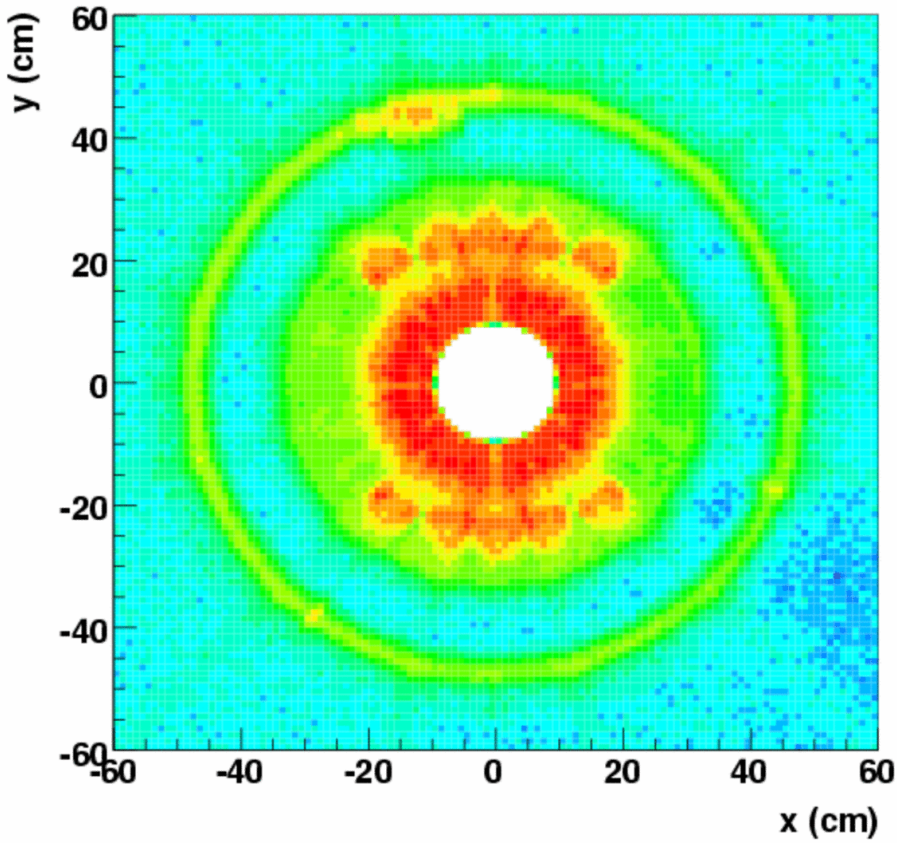

Figure 1: An x-ray photograph of the interior regions of the STAR detector. The figure was derived by reconstructing π^0 decays in the TPC and plotting the location of the conversion point. The figure shows the Inner Field Cage of the TPC, ten modules of the SSD, and the SVT. One of the TPC resistor chains can be seen near the top of the IFC. A new intermediate tracker is envisioned to replace the SVT. Figure courtesy of Alexander Wetzler.

Radii: The location of the IST layers is determined by the outer radius of the HFT and the inner radius of the SSD. The Heavy Flavor Tracker will occupy space out to a radius of approximately 7.5 centimeters and the SSD occupies space into a radius of approximately 19 centimeters. These are rough numbers and the exact numbers need to be worked out carefully with the HFT and SSD designers. However, as a general rule of thumb, it is desirable to have the IST as close as possible to the HFT and therefore the most probable radii for IST layers falls in the range from 10 to 15 centimeters.

Multiplicity: If the first layer of the IST is located at a radius of 10 cm, then it will be subject to a particle fluence of approximately 2 particles per square centimeter per central Au+Au event. The first layer should be capable of resolving these hits and it is desirable to keep the occupancy below 10% and preferably near 1%, or it must be shown that the

tracking software can efficiently resolve the ghost hits on the crossed strips if a higher occupancy is employed.

Mass: The mass requirements for the IST are defined by the heavy ion physics requirements in the mid-rapidity region. While this is a long discussion, it is relatively simple to parameterize the maximize allowable mass for the detector by noting that the vector meson program, going to di-electrons, is marginal given the existing mass of the SVT in the rapidity window ±1 unit of rapidity. Similarly, the upsilon program is marginal with the existing mass of the SVT. So a new tracker should strive to be as thin or thinner than the current ϕ averaged 4.5% radiation lengths of the SVT.

Thickness per layer: 1% to 1.5% radiation lengths per layer of Si tracker has been routinely achieved by RHIC detectors. The STAR SVT is 1.5% radiation lengths thick per layer and the SSD is 1% radiation length thick when averaged over all ϕ. A new tracker should strive to achieve comparable or better results.

Pointing Accuracy: A simple model for the pointing accuracy of a two element detector is given by the following formula:

$$\sigma^2 = \frac{\sigma_1^2 r_2^2 + \sigma_2^2 r_1^2}{(r_2 - r_1)^2} + \frac{\theta_{mcs}^2 (r_2 - r_1)^2}{\sin^2(\theta)} \tag{1}$$

where r_1 and r_2 are the radii of the detector elements, σ_1 and σ_2 are the resolutions of the corresponding elements, θ is the tilt angle of the track in the rapidity direction, and θ_{mcs} is the width of the multiple coulomb scattering angular distribution in the first layer of the tracker (corresponding to r_1).

θ_{mcs} is momentum dependent and is given approximately by:

$$\theta_{mcs} = \frac{13.6\,(MeV/c)}{\beta\ p}\sqrt{\frac{x}{X_0}} \tag{2}$$

where the thickness of the detector is measured in radiation lengths, p is the particles momentum, and $\beta = p/E$. So for example, the multiple scattering width at 750 MeV for a kaon passing through a 1% thick detector is 2.2 milli-radians. This is a useful number because it represents the MCS for kaons carrying half the energy from $D^0 \rightarrow K + \pi$ decays and it is these kaons that we are trying to track with high precision.

For example, the SVT has three layers of Si pointing at the Vertex. The outer two layers of the SVT are a good model for a pointing device for the Heavy Flavor Tracker (in this scenario the innermost layer of the SVT would be removed, unfortunately, in order to make room for the HFT). The outer two layers are located at radii of 10 and 15 cm and each is 1.5 % radiation lengths thick. The HFT is the target and it lies at a radius of 5 cm. The SVT was originally specified to have 20 μm pointing resolution and so using

equations (1) and (2), we find that 750 MeV kaons will point at the HFT with high precision:

$$\sigma^2 = (0.0045)^2 + (0.0133)^2 \quad (4)$$

In other words, the resolution of the SVT-1 configuration is dominated by MCS for 750 MeV kaons. (Note that the MCS contributions are larger at low momentum. Correspondingly, the MCS contributions are lower at high momentum.)

Thus, it is a general conclusion for all types of extremely high resolution pointing devices, such as the SVT, HFT, and IST, that they are MCS limited.

This result means that we can rather easily specify the pointing resolution of a new intermediate STAR tracker. The figure of merit is L * $\sqrt{x/X_0}$, where L is the distance from the detector to the target and x/X_0 is the thickness of the layer closest to the target (in radiation lengths). For example, the SSD is located at a radius of 23 cm from the vertex (or 18 cm from the outer layer of the HFT). It is 1% thick. So the SSD figure of merit is 18 * √1 = 18. The figure of merit for the SVT-1 (not including the first layer) is 6.1, and the figure of merit for the HFT is 0.750. Thus, a new intermediate tracker should have a figure of merit that is approximately 6, or better. It should also achieve a resolution of 30 μm in order for the pointing accuracy to stay below the MCS contributions for kaons at 750 MeV/c and for the quadratic sum of errors not to exceed 150 μm for the Kaons and 125 μm for the pions.

Radii of tracking layers	Range: 10 to 15 cm
Multiplicity @ 10 cm radius	2 per cm^2 per event
Occupancy per strip or pixel	Range: 1% to 10%, lower is better
Total Rad Lengths - (ϕ averaged)	5% or less
Rad Length per layer (ϕ averaged)	1.5% or less
Single Point Resolution	30 μm or smaller
Figure of Merit (L * $\sqrt{x/X_0}$)	6 or smaller

Table 1: Summary and guidelines for the specification of an intermediate tracker.

Other Issues: Additional things that might be included in a full detector specification include the rapidity coverage for the detector, ghost track multiplicities and resolution, the ability to point at the vertex in p-p collisions and how to find multiple vertices at high luminosity.