Independent IST Pointing Resolution

At last week's phone conference, Dick Majka asked if it was possible to calculate the pointing resolution of the IST acting alone (i.e. no Pixel layers active). The answer is 'yes' and the results are shown below.

The motivation for doing these calculations is to try to understand whether it is possible to trigger on B physics in p-p collisions assuming that the Pixel Detector layers are too slow to participate in a fast trigger decision. The TPC+SSD+IST detectors will have to pick out non-zero vertex decays at the trigger level in order for us to do physics with these collisions.

I have studied three cases:

1.) TPC + SSD + IST2 + IST1 (Blue)
2.) TPC + IST2 + IST1 (Red)
3.) TPC + SSD + IST1 (Green)

The Pixel Detector layers are 'dead' in all three cases; in other words, they contribute to the MCS but do not contribute to the overall resolution of the system.

The vertex pointing resolution in the R-ϕ direction for all three cases is shown in Fig. 1. The pointing resolution is about 200 microns at 1 GeV/c in all three cases. The figure is rather dull, but differences will show up in the Z pointing resolution and in the overall efficiency for recording good tracks (non-ghost tracks). See figure 2 through 4.

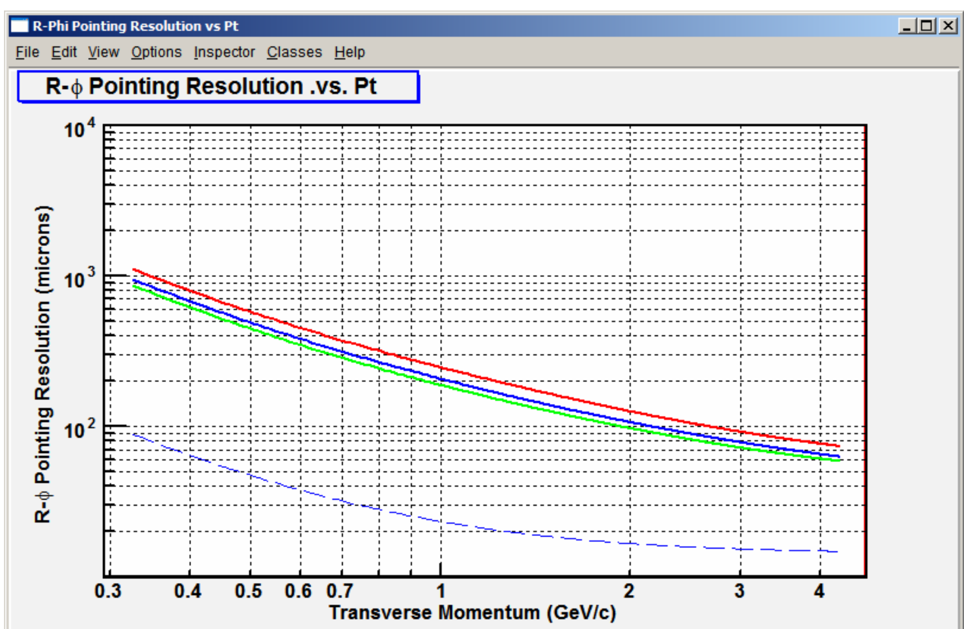

Figure 1: The R-Phi pointing resolution measured at the vertex for the IST detectors acting alone. (Solid Blue Line) The dashed line is a reference line showing the maximum resolution of the HFT when the Pixel Detectors are active. The color code is TPC + SSD + IST2 + IST1 (Blue), TPC + IST2 + IST1 (Red), TPC + SSD + IST1 (Green).

Figure 2 shows the Z pointing resolution at the vertex for all three cases. The figure shows that the pointing resolution is degraded if IST2 is eliminated from the system (solid Green line). This can easily be explained because IST2 is the only detector in the system with good Z resolution. The TPC, SSD, and IST1 all have 1 mm resolution, or worse, in the Z direction at 1 GeV/c so that a system without the IST2 layer and without Pixel layers can never achieve better than 1 mm resolution at the vertex in the Z direction.

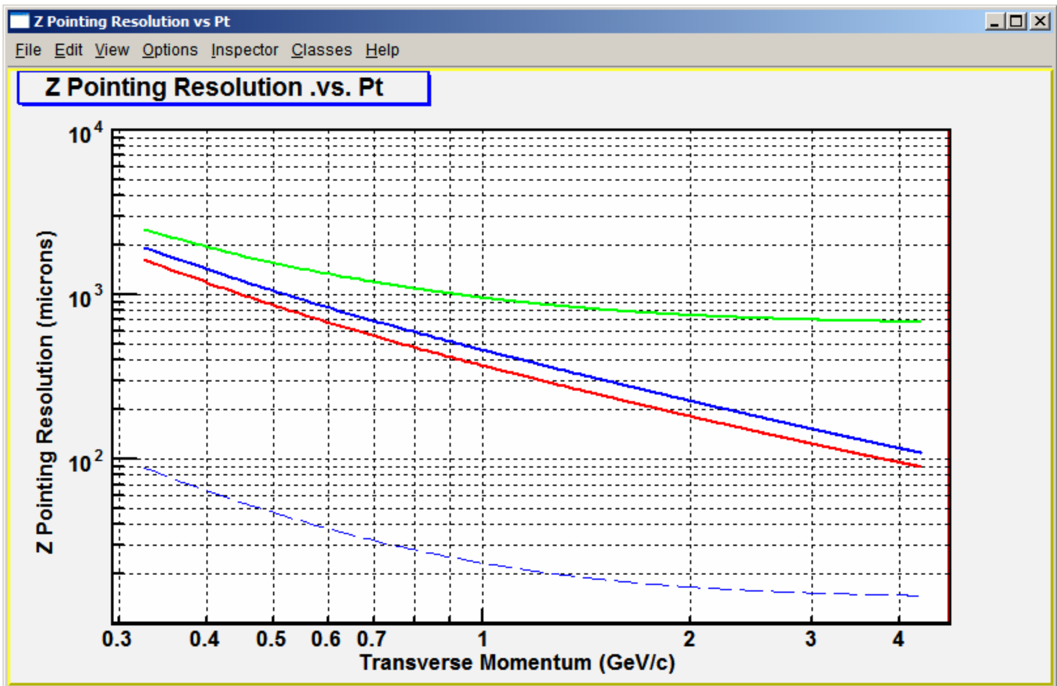

Figure 2: The Z pointing resolution measured at the vertex for the IST detectors acting alone. The Z resolution at 1 GeV is about 450 microns unless one of the IST detectors is removed from the system (Green) and then it goes up to a millimeter. The color code is TPC + SSD + IST2 + IST1 (Blue), TPC + IST2 + IST1 (Red), TPC + SSD + IST1 (Green).

In all cases, I have thrown kaons rather than protons or pions and the magnetic field was set to 0.5 Tesla.

Figure three shows the *relative* improvement in the independent IST pointing resolution for the three cases. The case of the missing IST2 detector (Green) is the reference and the figure of merit is SQRT(R-ϕ resolution * Z resolution). The figure shows that the TPC+SSD+IST2+IST1 combinations of detectors has the best pointing resolution at the vertex and is about 70% of the pointing resolution when IST2 is removed from the system.

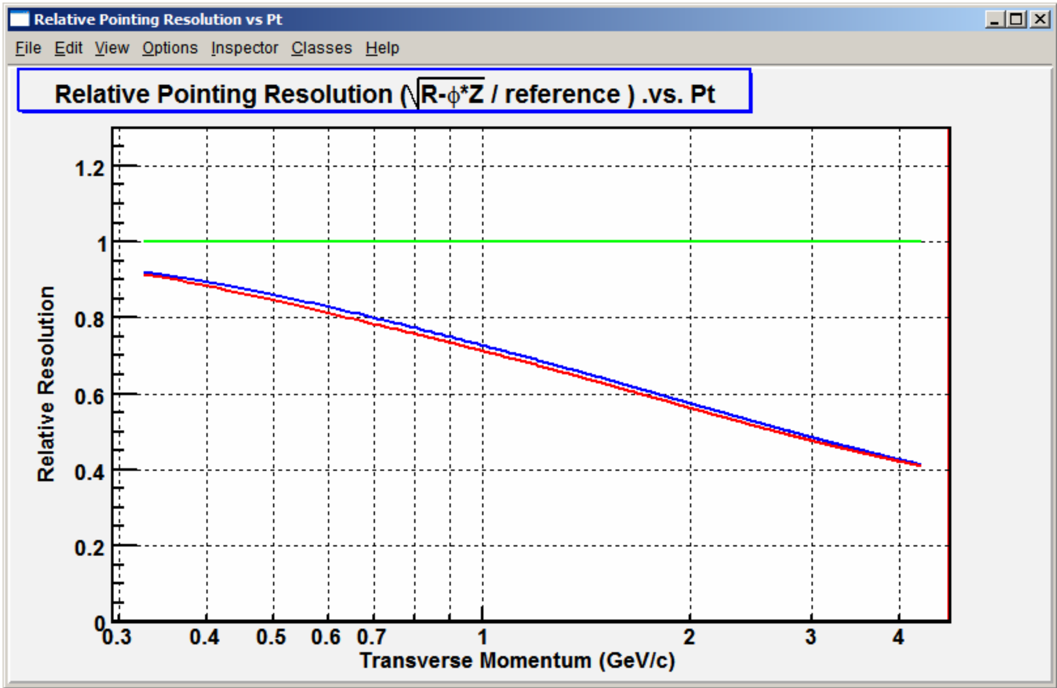

Figure 3: The relative pointing resolution at the vertex for the three standard cases studied. The reference is the green line which is the TPC+SSD+IST1. The resolution of the other two cases is better (smaller) than the reference. The color code is TPC + SSD + IST2 + IST1 (Blue), TPC + IST2 + IST1 (Red), TPC + SSD + IST1 (Green).

Now comes a surprise. If I forget about p-p collisions and instead think about Au-Au collisions and apply Au-Au hit densities to a 200 microsecond Si Pixel detector, I will find that the pointing resolution arguments are still valid but the efficiency of the system is affected by the presence if IST2.

The pointing resolution results shown in figures two and three are intuitively explained because IST2 was designed to improve the Z resolution of the tracking system. This is true in Au-Au. However, the next step is to calculate the efficiency of the system for capturing and recording good tracks, or expressed conversely, now we will calculate the inefficiency in the system that is caused by ambiguous hits leading to ghost tracks.

Figure 4 shows the result of calculating the probability of recording a good track (without ghost hits) in the detector system. The efficiency calculations were done according to the prescription derived by Howard Wieman, Gene VanBuren and Victor Perevoztchikov. The essential idea is that the probability of finding the correct hit using a weighted chi-square fit is:

(1) $P(\text{good}) = 1 / (1+S)$

Where $S = 2\pi\, \sigma_x \sigma_y\, \rho$

σ_x is the convolution of the detector resolution and the projected track error in the 'x' direction, σ_y is the convolution of the detector resolution and the projected track error in the 'y' direction, and ρ is the density of hits.

With a minor bit of algebra, it is easy to show that

2) $P(bad) = S / (1 + S)$

and when S is small

3) $P(bad) \approx S = 2\pi \, \sigma_x \, \sigma_y \, \rho$

We clearly want S to be small because it is a measure of the inefficiency of the system.

The result shown in Eq. 3 is intuitively very appealing and easy to remember because the probability of a bad hit is just the area of the ellipse defined by the detector and pointing resolutions; times the density of hits. So the bad hit probability is equal to the number of ambiguous hits found inside the ellipse (times 2). The extra factor of two is related to the fact that we are working with Gaussian probability distributions that extend to infinity. For additional details, see;

http://www-rnc.lbl.gov/~wieman/HitFinding2DXsq.htm,
http://rnc.lbl.gov/~wieman/GhostTracks.htm
http://rnc.lbl.gov/~wieman/HitFindingPadVsStrip.htm

Note that σ_x and σ_y are Gaussian errors in two orthogonal dimensions. They are needed because assigning a hit to a track constitutes a measurement of the distance between the point where the projected track intersects a detector –and- the location of a candidate-hit on the detector. σ_x and σ_y are thus the errors in measuring the distance between the projected track location and the hit; but these errors are themselves a quadrature sum of projected track error and the measurement error assigned to a hit on that layer. Thus,

$$\sigma_x = \sqrt{(\sigma^2_{xp} + \sigma^2_{xd})}$$

$$\sigma_y = \sqrt{(\sigma^2_{yp} + \sigma^2_{yd})}$$

This is all fairly simple when the errors are symmetric and the detector resolution is smaller than the projected track error. However, it gets complicated when the errors are asymmetric and the detector resolution is long in one dimension and the projected track error is long in the other. The crossed terms make for low efficiencies because the largest terms dominate in the quadrature sums. See equation 3.

Figure 4 shows the overall efficiency for the three pointing systems studied. In all three cases, we assume that the detectors were exposed to Au-Au central collision hit densities from primary tracks, and without any background hits or tracks. The TPC+SSD+IST2+IST1 detector combination (blue) is about 78% efficient at 1 GeV/c.

The principle source of inefficiency is IST2 because is suffers from a high number of ambiguous hits due to the 4 cm length of the strips ($\sigma \approx 1.16$ cm) in one dimension, and the asymmetric resolution of the SSD ($\sigma \approx 650$ μm) in the other. Putting these numbers into equation 2 (or 3) with a density of 0.39 hits per cm^2 yields an inefficiency of 16% for IST2. (If the p-p hit density on IST2 is higher than 0.39 hits per cm^2 then the calculated inefficiency will increase.) The inefficiency of the other detectors accounts for the remaining 6% at 1 GeV/c.

The red line in Fig. 4 shows what happens if we remove the SSD from the detector configuration. The efficiency drops, as expected. The overall efficiency decreases because the pointing resolution from the TPC onto IST2 is rather poor (millimeter scale in both dimensions).

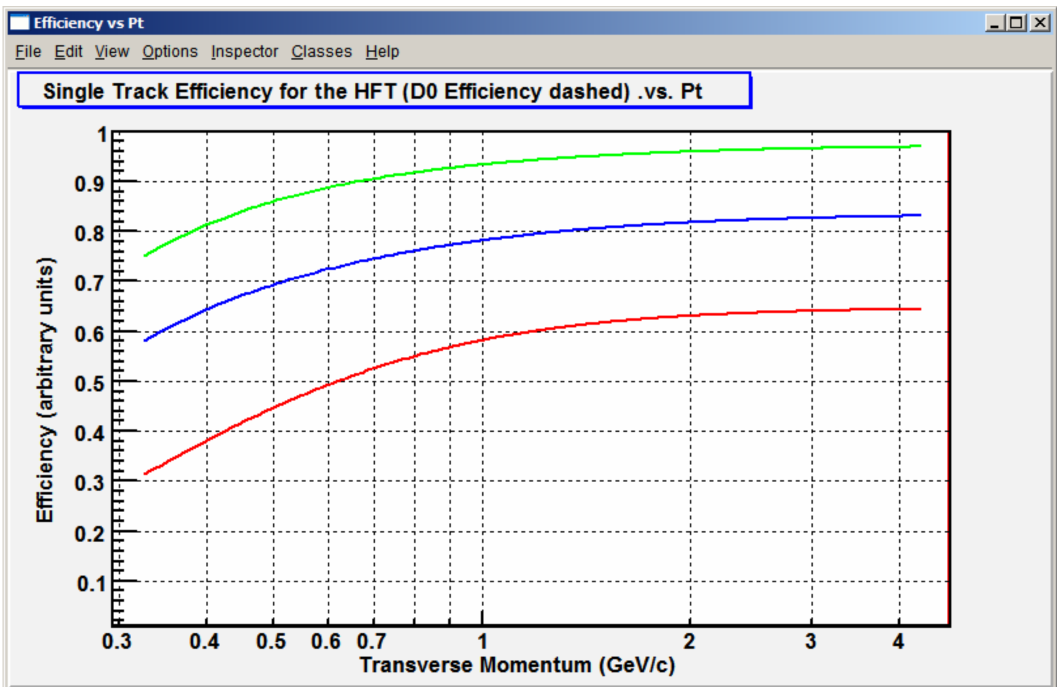

Figure 4: The probability for picking up good hits in the TPC and subsequent layers of the Si detectors. The solid lines show the overall efficiency of the systems studied (i.e. the efficiency of all layers multiplied together). The color code is TPC + SSD + IST2 + IST1 (Blue), TPC + IST2 + IST1 (Red), TPC + SSD + IST1 (Green). The system is less efficient when the SSD is removed from the suite of detectors, as expected, but more efficient when IST2 is removed. This is a surprise.

The green line in Fig. 4 shows what happens if we remove the IST2 layer from the suite of detectors. The overall efficiency goes up. This is surprising because the pointing resolution onto IST1 decreases if we remove IST2 from the system (see Fig. 2). However, the decrease in pointing resolution onto IST1 is not as important as the relative gain in efficiency that is created by dropping the ambiguous hits generated by IST2 … so the overall efficiency actually goes up.

In conclusion, the pointing resolution at the vertex for the TPC+SSD+IST2+IST1 is predicted to be 200 μm by 450 μm in p-p collisions. The efficiency in Au-Au collisions is 78%. However, the efficiency goes up to 94% if IST2 is removed from the system while the pointing resolution degrades to 200 μm by 950 μm. So the answer to Dick's question is that it depends upon what you want to accomplish, higher efficiency in Au-Au or better pointing resolution with the fast detectors (only) in p-p collisions.