Muon Alignment Requirements

Melynda Brooks
Los Alamos National Laboratory

(submitted: 16 May 1995; revised: 16 June 1995)

1 Introduction

The muon subsystem alignment requirements, as determined by simulations, hand calculations, or best estimates will be given separately for the muon tracking system and the muon identification system. The alignment requirements for the separate subsystems will be determined by requiring that the error a misalignment produces is much less than other contributing errors such as detector resolutions and multiple scattering limits. As a rule of thumb, we will try to make the misalignments allowed smaller by a factor of 4 than a misalignment which would produce a noticeable change in a measurement.

The internal alignment requirements for the muon tracking system are rather stringent since a momentum resolution inside the tracking volume of less then 2% is required to obtain a good mass resolution of the upsilon vector meson. In addition to the internal alignment requirements, the mass resolution requirements dictate alignment requirements of the muon tracking system relative to the MVD (or interaction point), the magnetic field, and the between the two muon tracking arms. In addition, there may be some requirement for alignment of the tracking stations relative to the central arm if muon identification systems are added to the central arm.

The muon identification system has much less stringent alignment requirements since the typical pointing resolution of the system is measured in centimeters and the muon ID's main function is to work with the muon tracking system, and not other subsystems. However, since the muon identification system is used in the trigger by finding roads which point back to the vertex, there must be some relative alignment of the measurement pads with the interaction point.

2 Muon Tracking

2.1 Internal Alignment Requirements

The internal alignment of the muon tracking stations in ϕ is determined by the momentum resolution requirements of the tracker. In order to obtain a mass resolution (which is dominated by energy straggling in the material prior to the tracking stations) on the order of 200 MeV/c^2 for the upsilon vector meson, a spectrometer momentum resolution of less than 2% is required. Simulations have shown that this can be obtained by three tracking chambers at each measurement station which have a ϕ resolution of approximately 100 μm (see Figures 1 and 2). In order to retain this momentum resolution, an alignment resolution of much less than 100 μm is desired. We specify a ϕ alignment criterion of 25 μm inside the tracking volume.

Note: An x or y displacement of any station or individual octant will translate directly into a phi error for most octants. Therefore, it is necessary that x or y alignments be known to 25 μm, in addition to needing to know any phi rotations to 25 μm.

If muons which pass from octant 1 in station 1 to octant 2 in station 2, for example, are to be tracked then the octant-to-octant alignment requirements will be the same as the requirements specified above, determined by the momentum resolution requirements. If only tracks which pass through projective octants are to be tracked, then the octant-to-octant alignment requirements will be determined by the opening angle resolution needed to achieve good mass resolutions. The angular resolutions at the vertex are given in the section on aligning the North and South muon arms, and are on the order of 3-9 mRad. If this resolution, which is caused by the multiple scattering in the absorber materials, is to be maintained, then an octant-to-octant alignment on the order of 1.2 mm in the x-y plane is adequate (see North and South arm alignment section).

The muon tracking station-to-station alignment in z affects the ability to measure the sagitta of a track (and thus the momentum) in the tracker, the alignment of the stations with the magnetic field, and the ability to measure

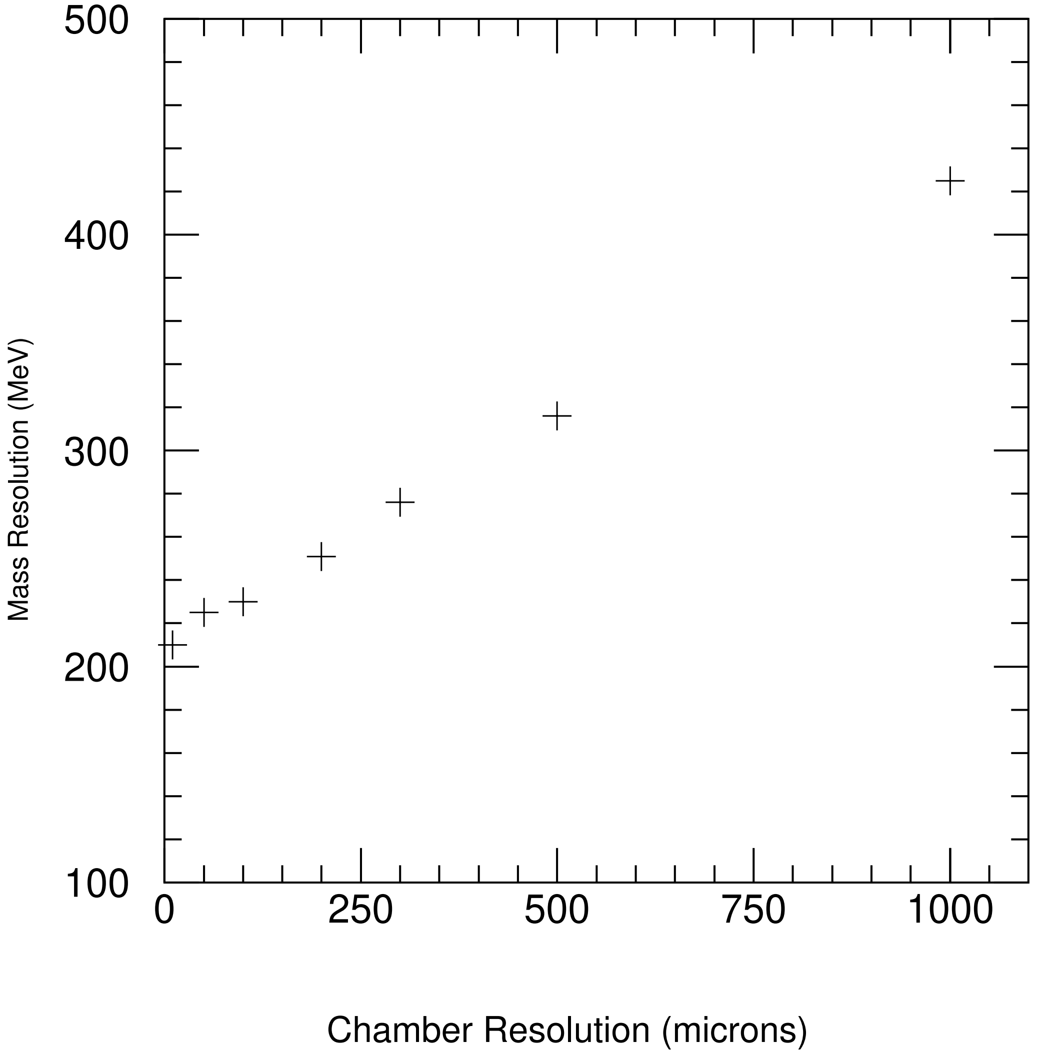

Figure 1: The upsilon mass resolution in the North arm versus the chamber resolution.

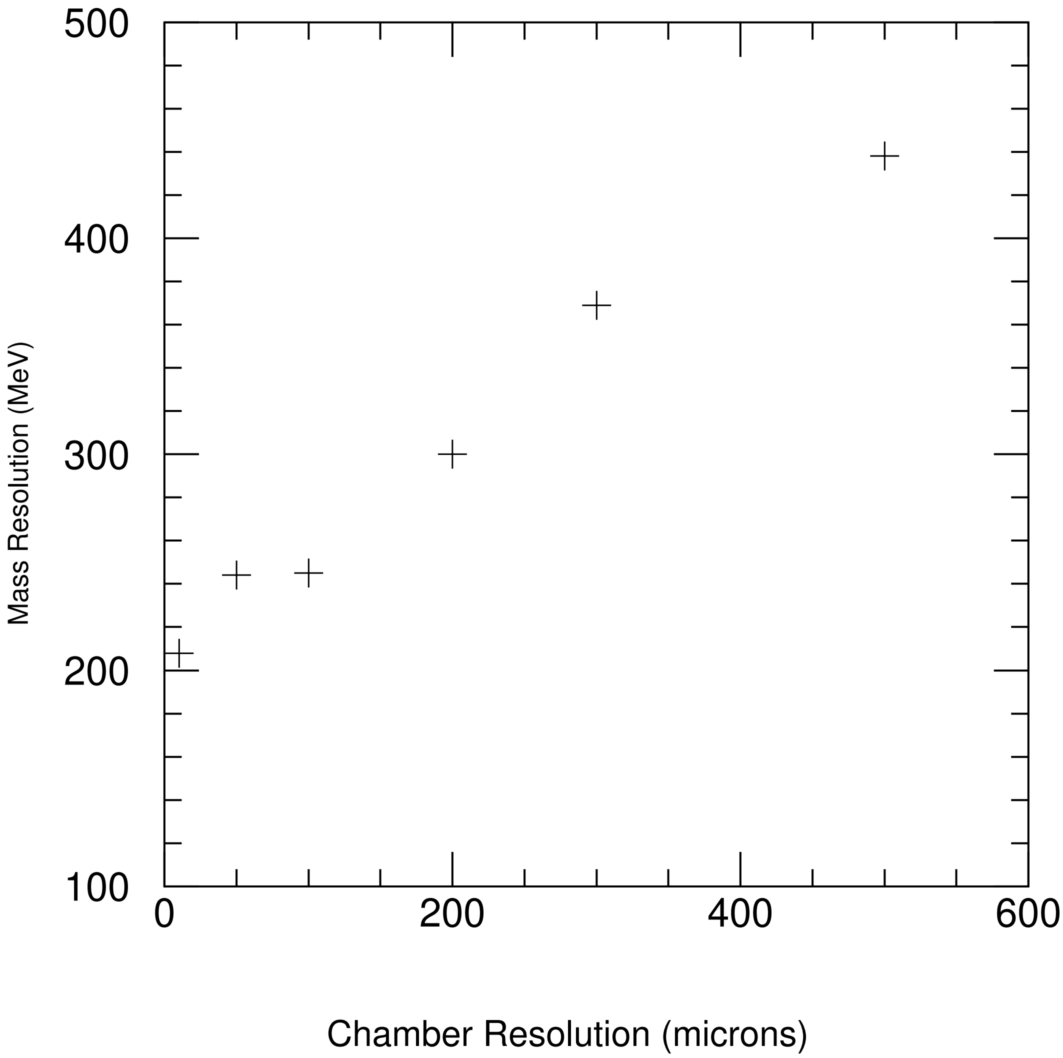

Figure 2: The upsilon mass resolution in the South arm versus the chamber resolution.

the θ angle of a track (and thus the opening angle of dimuons from vector meson decay). To determine exactly what the z alignment requirements are, a GEANT study was done which took hits from upsilon dimuons and displaced all station two hits by a fixed amount with respect to stations one and three. The hits at stations one and three and the displaced station two hits were then fit and the mass resolution of the dimuons was calculated. Figure 3 shows the resulting mass resolution vs. station two displacements. As can be seen 0.5 and 1.0 mm displacements did not affect the mass resolution, but a 1.5 mm displacement increased the mass resolution by 15% to 250 MeV/c^2, and a 5 mm displacement increases the mass resolution to 430 MeV/c^2. We therefore require a station to station alignment in z of at least 1.5/4 mm = 0.4 mm.

2.2 Global Alignment Requirements

The spectrometer as a whole must be aligned to the muon magnet in order to accurately track through the highly non-uniform magnetic field, it must be aligned relative to the measured vertex point in order to project the measured momentum vector in the spectrometer to the interaction point, and the North and South muon arms must be aligned relative to each other if dimuons which go into the two arms are to be measured. In addition, if muon identification is added to the central arm then the muon arms will need to be aligned relative to the central tracking chambers.

2.2.1 Alignment to Magnetic Field

Since the magnetic field in the muon tracking region is non-uniform, the tracking stations must be aligned to the field in order to accurately determine the momentum of tracks from their trajectory through the field. To determine what the exact alignment requirements are, the GEANT simulation code was used again. Muons from upsilon decay were tracked through the magnetic field and their hits in the tracking stations were recorded. The hits were then fit to a trajectory using the same magnetic field map that produced the hits, but displacing it by a fixed amount in (x,y), and z. The resulting mass resolutions versus the amount of displacement in the z direction are shown in Figure 4. For the (x,y) displacement, the input map was shifted from (x,y) to (x+offset,y+offset). The resolution versus 'offset' is shown in Figure 5.

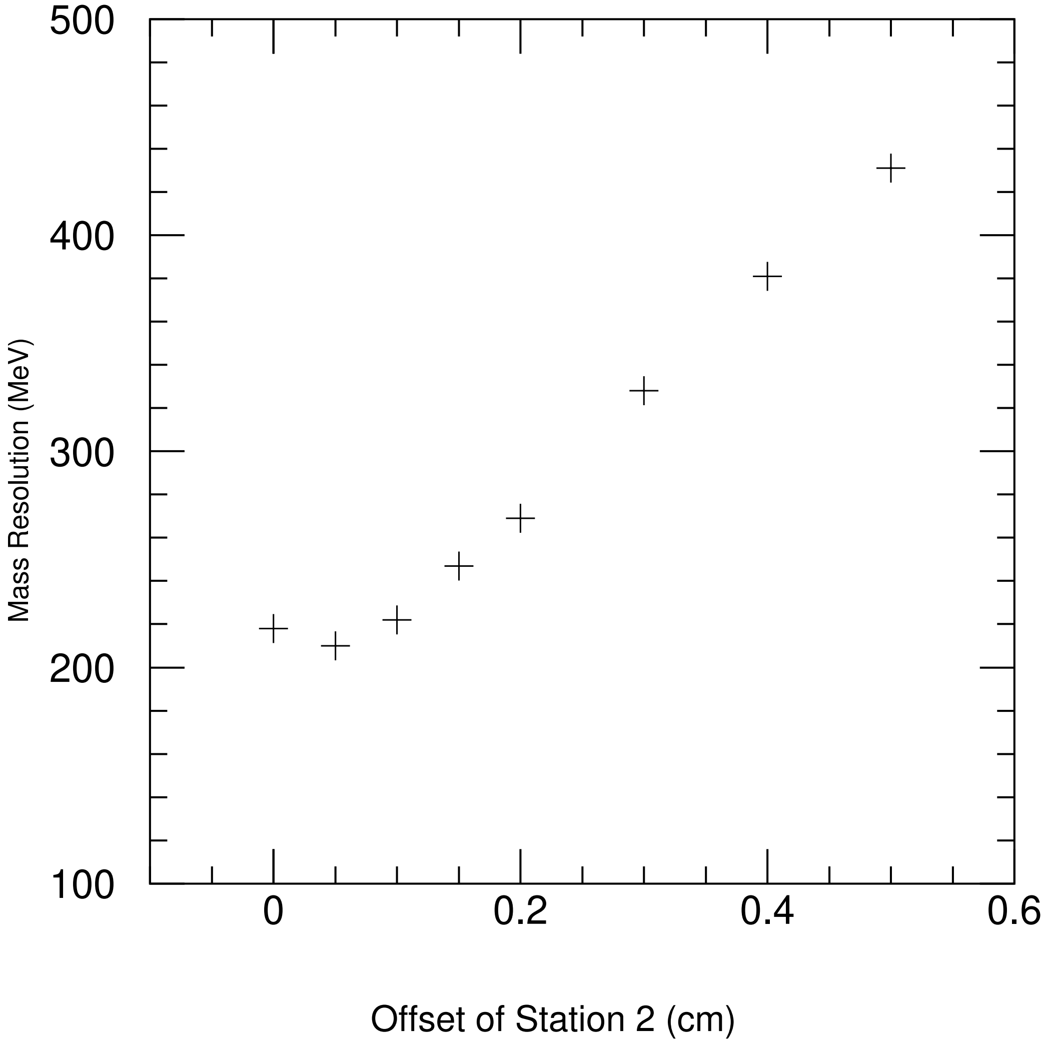

Figure 3: The upsilon mass resolution in the North muon arm versus a displacement of the station two hits.

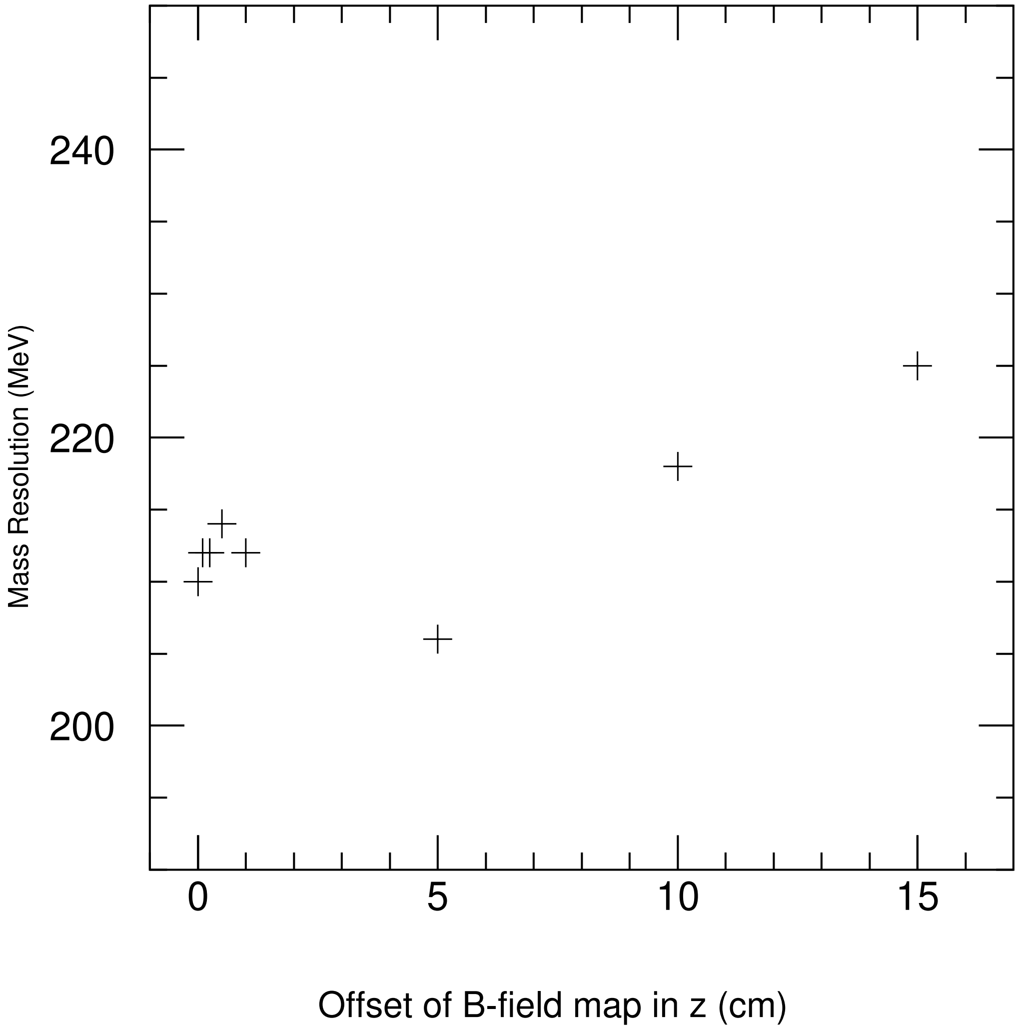

Figure 4: The upsilon mass resolution in the North arm versus a z displacement of the magnetic field map.

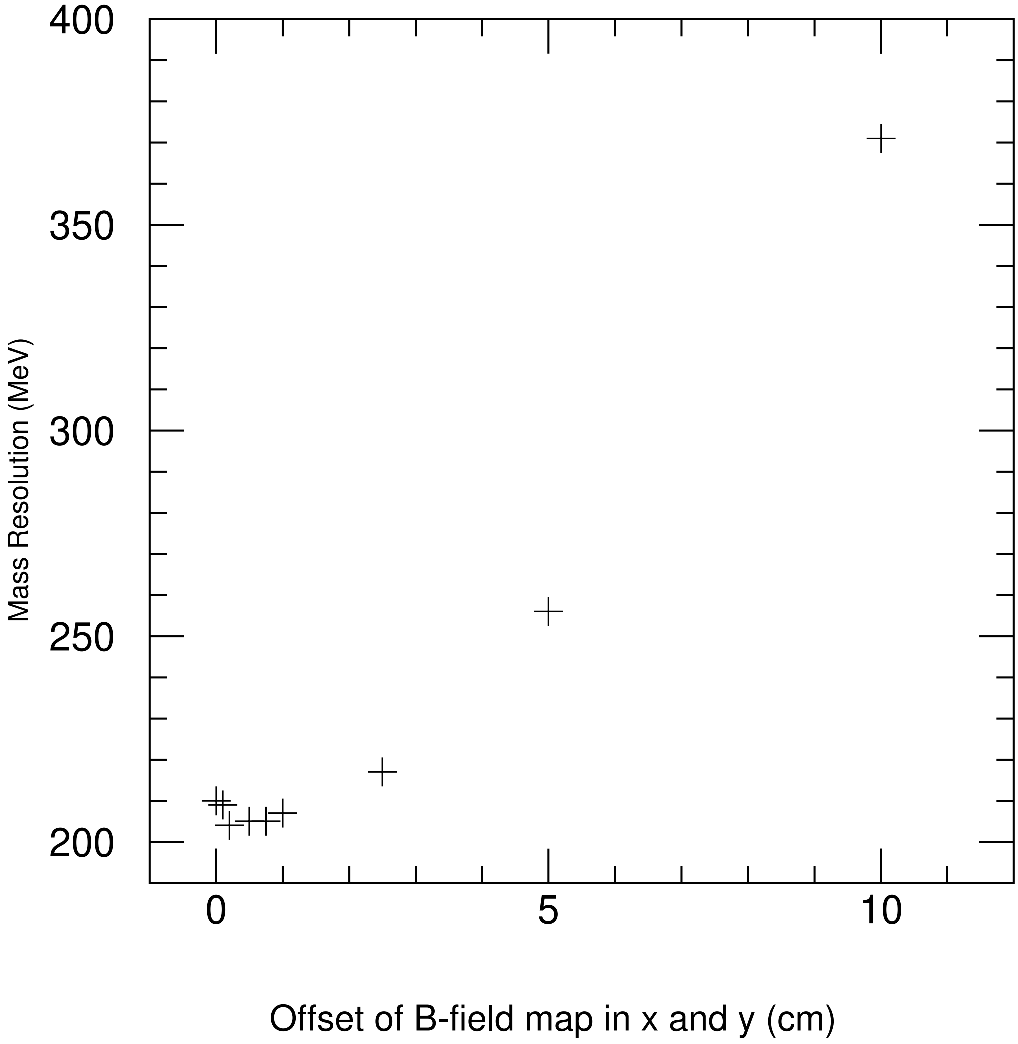

Figure 5: The upsilon mass resolution in the North arm versus a (x,y) displacement of the magnetic field map. The offset in the figure was applied as (x,y)→(x+offset,y+offset).

As can be seen, the spectrometer as a whole can actually be displaced a fair amount before the mass resolution begins to suffer. The z displacement is the least sensitive since the magnetic field integral does not change quickly if the map is just displaced in the z direction. The magnetic field integral does change rather quickly with θ as shown in table 1 so the mass resolution depends more strongly on a displacement in the x and y directions. No change in the mass resolution was seen for displacements up to 1 cm, a small increase in the resolution was seen for a displacement of 2.5 cm, and at 5 cm displacement the mass resolution increased by 20% to 256 MeV/c^2. Given these studies, we require that the spectrometer as a whole be aligned to the magnetic field to at least 2.5/4=0.6 cm in x and y, and only has to be aligned to within several centimeters in the z direction.

	15 deg	20 deg	25 deg	30 deg
North Arm	7311.33	4921.06	3594.15	2775.69
South Arm	7737.99	4937.44	3442.67	2549.4

Table 1: The integrated magnetic field, $\int Bdl$, in Gauss$\times$m for each arm obtained by W. Sondheim.

2.2.2 Alignment to the Interaction Point

The creation point of the vector mesons must be known so that the muon momentum vectors that are measured in the tracking stations can be projected through all of the absorber material to the vertex, and the original vector meson mass reconstructed. The GEANT reconstruction code uses an input resolution in z, and assumes the r/phi interaction point is (0,0). To determine how the vertex resolution affects the projection of the momentum vector to the vertex, a perfect momentum resolution was taken inside the spectrometer, and the z resolution of the vertex was varied from perfect resolution to 2 cm resolution. The resulting mass resolutions (for the North muon arm) are shown in Figure 6. The mass resolution dependence on the z resolution was essentially the same when it was run for the South muon arm. As can be seen, the mass resolution does not begin to degrade until the resolution gets as large as 2 cm, and then it only degrades by approximately

7%. We therefore require that the spectrometer be aligned to the vertex to less than 2.0/4=0.5 cm. The same requirement is applied to the x-y plane giving an alignment requirement of 1-3.5 mm over the 10^o-35^o acceptance of the spectrometer.

To see if displacement of the spectrometer with respect to the vertex provided a tighter alignment constraint than smearing the vertex resolution, the muon tracking stations as well as the magnetic filed were displaced by a fixed amount relative to the interaction point, and vector mesons were reconstructed. The spectrometer could be displaced by 5.0 cm without a noticeable affect on the momentum resolution reconstructed at the vertex, which is larger than the other vertex constraint, so the alignment criterion stated in the previous paragraph will be used for the vertex alignment.

2.2.3 Alignment Between the North and South Muon Arms

The North and South muon arms must be aligned relative to each other if vector mesons which produce one muon which goes into the North arm and one muon which goes into the South arm are to be reconstructed. The alignment requirement is determined by the opening angle resolution that is required to get a good mass resolution of these particles. Alternatively, we can make sure that the error in the angular measurement due to misalignments is much less than the error caused by multiple scattering in the absorber materials so that the opening angle resolution will be determined solely by the absorber material present. For the upsilon vector meson mass resolution, the error in the opening angle measurement caused by multiple scattering in the absorber material (which is on the order of 15 mRad) is comparable to the opening angle resolution that would be required if it were to not contribute significantly to the mass resolution. (If the error in the mass resolution caused by an opening angle error is to be less than 1%, then the angular resolution that is required for an opening angle of 110^o is 14 mRad.) The multiple scattering caused by just the magnet steel is approximately 9 mRad, so the multiple scattering limit if the copper nosecone were not present would be similar. Because the multiple scattering limit is as small or smaller than the limit that would cause the opening angle error to contribute significantly to the mass resolution we will determine the alignment requirements by requiring that the opening angle measurement error caused by misalignments be much less than the error caused by multiple scattering.

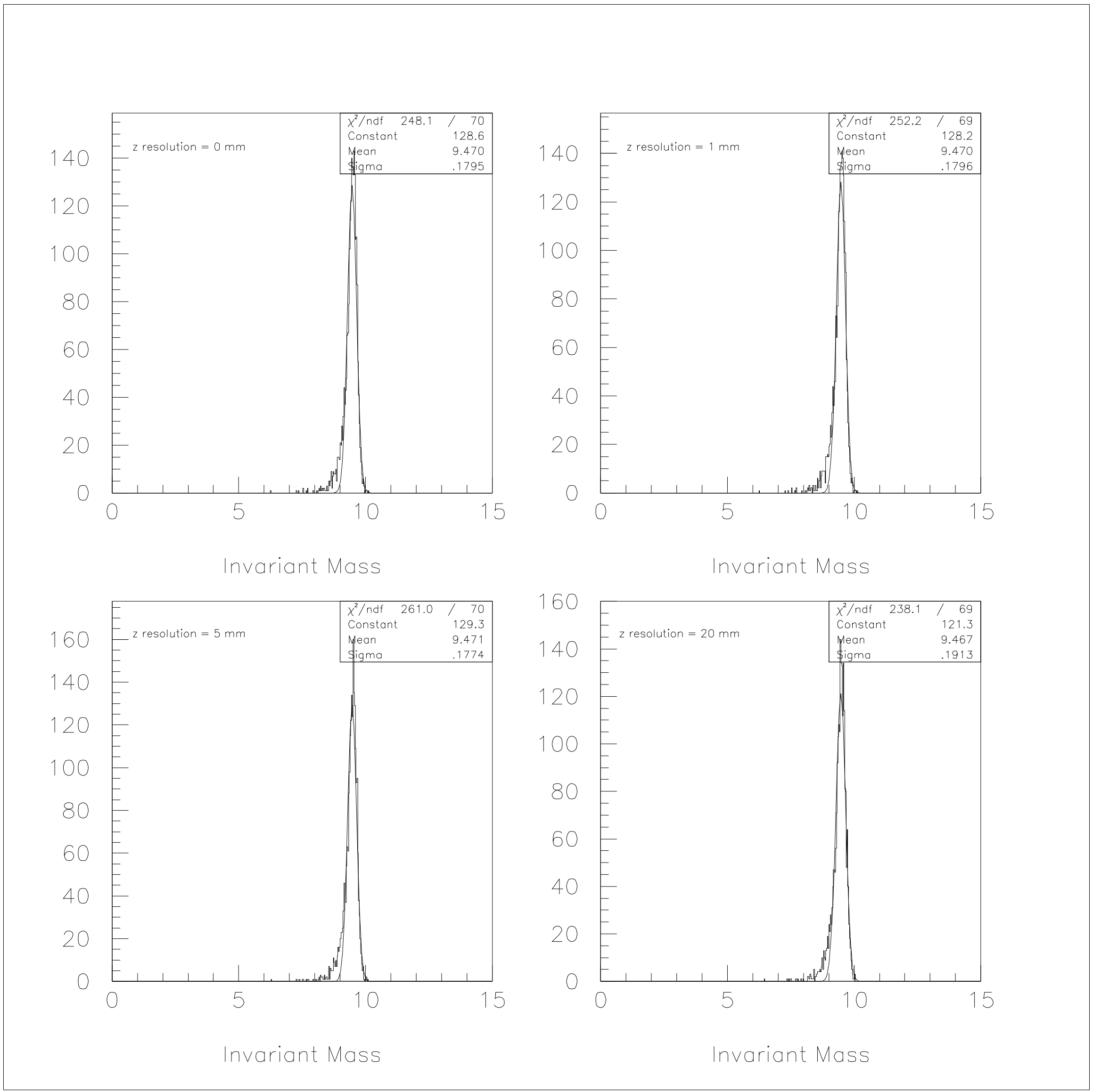

Figure 6: The mass resolution in the North muon arm of the upsilon versus various vertex z resolutions. (Perfect spectrometer resolutions were used for these calculations so that the contribution from just the projection to the vertex could be seen.)

Since the arms will be independently required to be aligned to the vertex to get good momentum resolutions in the two arms the z alignment of the two arms relative to each other should be taken care of. If in addition the two arms are required to be axially aligned to the beam line, and azimuthally aligned to some common x-y plane target, then the opening angle measurment should be assured. The theta and phi resolutions that are obtained for upsilon decay muons with all of the absorber materials present inside the North and South muon arms are approximately 0.4-0.6 mRad inside the tracking volume, and 3-9 mRad at the vertex as shown in Figure 7. To retain this angular resolution at the vertex, the displacement of the North arm with respect to the beam axis should be much less than (1.8 meters)*tan(3 mRad)=5.4 mm, where 1.8 meters is the z distance of station 1 from the interaction point. Similarly, the phi alignment with respect to a common (to both arms) alignment point should be much less than 3.0 mRad for the upsilon criterion. This corresponds to a displacement at the outer radius of station 1 chambers of (1.58 meters)*tan(3 mRad)=4.8 mm. We therefore require that the two muon tracking arms be aligned relative to a common survey point to 5.4/4=1.4 mm in the r direction, and to 4.8/4=1.2mm in the phi direction at the outer radius of station 1 (or to within 0.8 mRad=2.8 arcmin). The z alignment that is required for the individual arms will be more than adequate to provide the arm-to-arm alignment required.

2.3 Summary of Alignment Requirements

A summary of the alignment requirements of the muon tracking stations, both internal and global, is given in table 2.

2.4 Alignment Monitors and Survey Requirements

For many of the muon tracker alignments, the structural support of the system will be used to hold the stations in place to within the alignment tolerances (relative to the interaction point, magnet, etc.) and the exact placements of the tracking stations will be determined by a survey at installation time. For the internal station-to-station alignment in the x-y plane, however, we will not only survey the positions at installation time, but also plan to actively monitor the positions with line-of- sight monitors after installation because of the tight alignment tolerances.

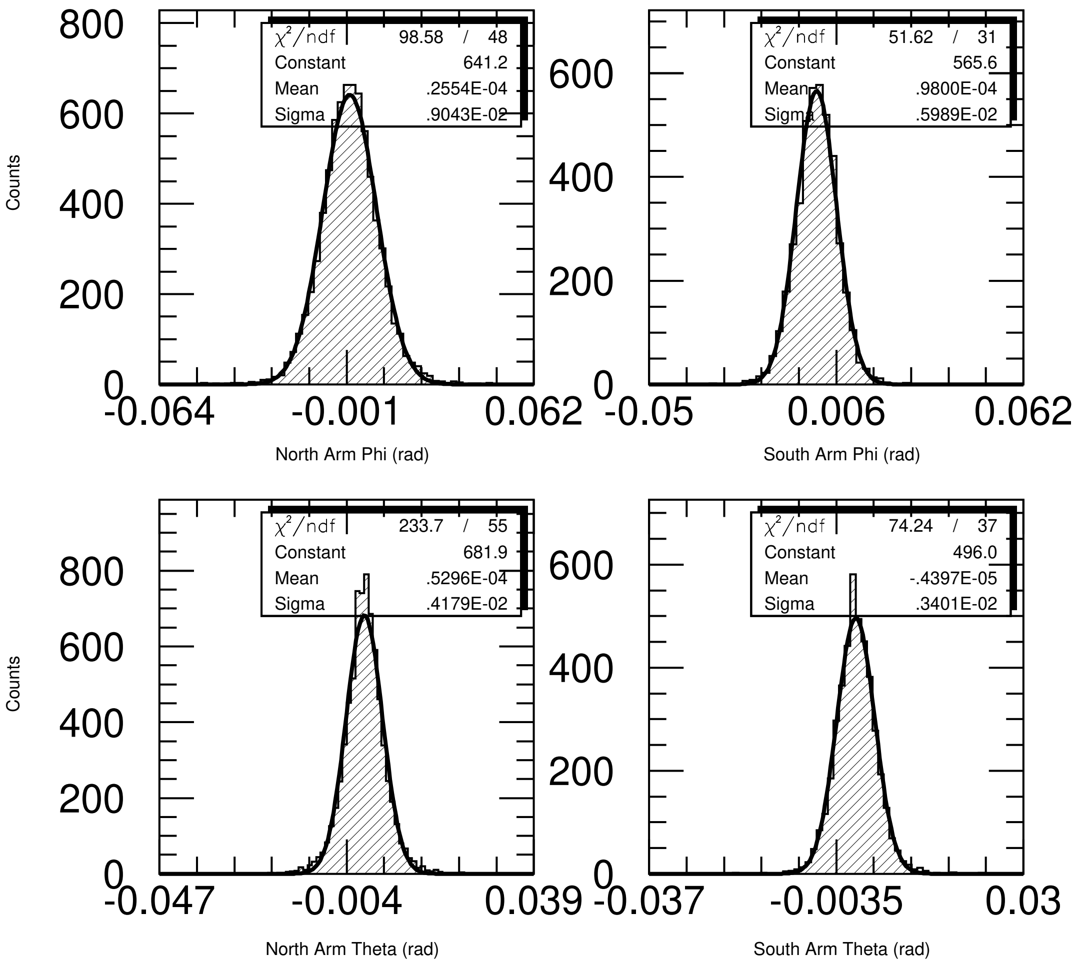

Figure 7: The theta and phi resolutions obtained by tracking muons from upsilon vector mesons through the two muon tracking arms to the vertex. A vertex resolution of 1 mm was used, and the copper nosecone, magnet steel, and copper piston plug absorbers were in place.

Internal requirements			
	x	y	z
	0.025 mm	0.025 mm	0.4 mm
Global requirements			
To Magnet			
	x	y	z
	6.0 mm	6.0 mm	30 mm
To Vertex			
	x	y	z
	1.0 mm	1.0 mm	5.0 mm
North and South Arms			
	x	y	z
	1.2 mm	1.2 mm	5.0 mm

Table 2: The internal and global alignment requirements of the muon tracking stations, as determined by simulations.

The station-to-station alignment requirements in z of 0.4 mm should be determined by a survey with respect to the nominal interaction point, as specified by a RHIC or PHENIX survey mark which is used by the whole PHENIX detector. If these alignments can be obtained, then the alignment of the tracking stations to the vertex (or MVD), the muon magnet, and between the two tracking arms should be automatically provided at the same time.

The placement of the tracking chambers in the x-y plane must meet the global alignment requirements, and must be good enough for the active alignment monitors to fall into a line-of-sight so that a final alignment of 25 μm can be achieved. Since most active alignment monitor systems that we have looked at are capable of covering a displacement range of 1 to several millimeters, and the global alignment requirements are also on the order of 1 to a few millimeters, we will require the chamber positions to be aligned in the x-y plane relative to a global survey mark to within at least 1 mm. This must be a common survey point which is used by both muon arms, the muon magnet, and the MVD. To maintain the alignment of the outside fiducials and/or alignment monitors to the internal cathode strips, tight tolerances will be required during assembly of the chambers. The tolerances that will be maintained have been covered in the muon note PHENIX-MUON-95-9, by Dave Lee.

The line-of-sight (LOS) monitoring system which we are most actively pursuing uses several LED-lens-detector systems, with the LEDs mounted at one station, the lenses mounted at a second station, and the detectors mounted at the third station. Previous work by the GEM muon system (GEM TN-92-202) has shown that six separate LOS monitors on a chamber are adequate to measure all displacements and rotations which would contribute to an error in the phi measurement. If eight monitors are used, then distortions caused by gravitational sag can also be corrected for. The six monitors would be placed at the four corners of a chamber with two additional monitors on the middle of the inner and outer radius of the chamber, and the eight monitor system would add two more monitors to the sides of chamber. This system would require that the muon tracking volume have several lines-of-sight which extend from station 1 to station 3. For monitors near the piston, this can only be achieved by providing holes in the station 2 chamber frames where lenses could be accurately placed. These lines of sight would also need to be extended through the support structure that is used to hold station 2 in place. Lines of sight at the outer radial edge of station 2 can be provided again by holes in the chamber frames or by making sure that an adequate gap is provided between the outside edge of the chamber frames and the magnet lampshade.

If the lines-of-sight can not be adequately provided, an alternative alignment system that could be used would be to separately align stations 1 and 2 and stations 2 and 3 using similar light source, LED, and detector systems or using a light source, reflector, detector system. All of the light source-detector systems that we have investigated have been able to rather easily achieve displacement measurements of 10 μm or better over several meters of distance.

3 Muon ID

3.1 Internal Alignment Requirements

The internal alignment requirements of the muon identification system are determined by its ability to form particle tracks when the pads are misaligned by a given amount. These tracks are used both to perform muon identification in the offline analysis as well as in the trigger system during data taking. Since the pads are large, the distance from the interaction point is large (7 meters) and the measurement limit from multiple scattering is large the alignment requirements are not very stringent.

A typical pad size for the current muon identification system is 1.0x2.8^o (in theta and phi) or 12.7x6.5 cm at the first detector plane and the innermost radius. The largest pad size is approximately 25x67 cm. Because the pads are so large, the resolution of a track cannot be expected to be much better than $12.7/\sqrt{12}$ cm = 3.7 cm in the theta direction for tracks which go through the smallest pads. If several measurements of resolution 3.7 cm are used, then a projection error of somewhat less than 3.7 cm might be expected. In addition, the multiple scattering in the material between the muon tracking stations and the muon identification planes causes a projection error of at least 1.1 mm (for a 10 GeV/c particle). Because of the pad projection error, the muon-ID only has to be aligned to the muon tracking stations to approximately +/- 1 cm in the x and y directions. Similarly, the plane-to-plane alignment of the pads does not need to be better than approximately 1.0 cm. Since the pad planes are typically 30 cm apart and the largest incident angle is 35^o, the plane alignment in z should be approximately 1.5 cm.

3.2 Global Alignment Requirements

As stated previously, the only global alignment requirement of the muon identification system is an alignment relative to the interaction point. The multiple scattering in the absorber material in front of the muon tracking stations limits the angular resolution of a 10 GeV/c track at the vertex to approximately 3 mRad or more. If this error is projected from the first tracking station to the muon-ID, the position resolution is approximately (5.4 meters)* 3x10^{-3} = 1.6 cm. An additional 1-2 mm of error occurs at each of the absorber layers in the muon-ID detector. Therefore, the muon-ID planes must not need to be aligned to the vertex to better than approximately +/- 4 mm in the x and y directions in order to have alignment errors be negligible compared to multiple scattering errors. The necessary alignment of the muon ID planes to the vertex in z is outside the physical bounds of the space for the muon identifier. Therefore, it is only required that the z positions be measured after they are put in place, and this measurement only has to known to within a few centimeters relative to the vertex.

3.3 Alignment Monitors and Survey Requirements

All muon identification alignments will be achieved by surveys during installation of the detectors. External fiducial marks which are in a known position with respect to the pads will be placed on the outside edges of the muon ID detectors and down the main square hole which contains the beam pipe. All of these fiducials will be aligned with respect to the interaction point.