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SDC
SOLENOIDAL DETECTOR NOTES

ALIGNMENT RESOLUTION STUDIES OF THE MUON SYSTEM

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This brief memo summarizes some matrix calculations I made on the effect of alignment errors on the momentum resolution obtainable with our proposed SDC muon system both at the trigger and analysis level. I hope such calculations can be used to set criteria on the necessary survey and monitoring accuracy for the system. This memo is concerned with alignment issues for the barrel muon system.

1. Technique

The proposed central muon system is constructed out of three stations which are separated by large radial distances and in some cases massive walls of iron. We assume that alignment within a station can be maintained so as not to significantly degrade chamber resolution (eg through the use of precision end plates , etc). This memo is concerned with the station-to-station alignment error. Since we anticipate that the muon system will be build out of a large number of modules, it might make sense to model miss-alignment as an additional Gaussian distributed coordinate error with perfect correlations within a single station.

In my resolution package this is accomplished by the adding separate alignment errors to the coordinate covariance matrix of the form:

$$< \delta x_i \, \delta x_j > \rightarrow < \delta x_i \, \delta x_j > + \sum_a \hat{(} u_i \cdot \hat{v}_a) \, (\hat{u}_j \cdot \hat{v}_a) \, \sigma_a^2 \, \Theta_{ij}^{(a)} \qquad (1)$$

where:

1. The sum over a is a sum over possible alignment errors.
2. σ_a represents the RMS value of the miss-alignment and $\hat{v}_a$ is the direction of the miss-alignment.

3. $\hat{u}_i$ and $\hat{u}_j$ are the read-out directions of the i and j coordinate.

4. $\Theta_{ij}^{(a)}$ is zero or one depending on whether or not the a ' th alignment error applies simultaneously to both the i 'th and j 'th measurement plane (ie $\Theta_{ij}^{(a)} = 1$ if i and j are in the given station relevant to a).

2. Results for "Triggering" Resolutions

We consider the affects of station-to-station alignment error on the so-called θ trigger, where z measurements from stations within and outside the barrel muon toroid are used to measure the momentum. The fractional momentum error will be of the form (at $\eta = 0$):

$$\frac{\sigma P}{P} = \mathcal{R}\sqrt{\left(\frac{P}{P_*}\right)^2 + 1}$$

$$\text{Where } \mathcal{R} = \frac{.014}{.3\ B\ \sqrt{\Delta\ x_o}} \approx 16\% \text{ and } P_* = \mathcal{R}\ \frac{.3\ B\ \Delta}{\sigma(\theta_{bend})} \tag{2}$$

The 16% low momentum fractional error assumes a toroid thickness (Δ) of 1.5 meters, $B = 1.7\ T$, and an iron radiation length of $x_o = 0.0176\ m$. The $\sigma(\theta_{bend})$ in the effective momentum expression gives error on the bend angle due to the measuring capabilities of the detector and does not include the MCS of the toroid. The form for the relative momentum error given by Eqn. (2) will not strictly be true if the space points are weighted in a way which includes their MCS error, but calculations (eg running the program both with and without MCS weighting) show that this is a very minor effect for the θ trigger with external coordinate measurement.

I model a standard 4 θ layer drift station by two space points separated by 10 cm with intrinsic space point resolutions of either 177 microns (the average of two 250 micron measurements) or 283 microns (the average of two 400 micron measurements). Each standard station is thus capable of defining an angle to σ = 2.5 milliradians (or 4 milliradians). If one estimated the momentum using **one**

4 layer θ stations inside the toroid and **one** 4 layer station outside the toroid, one would get a P_* of 36.5 GeV (or 22.8 GeV). which would be adequate to construct a sharp second level trigger with thresholds of 60 GeV (or 40 GeV). Since such a momentum measurement is based on entering and exiting angles defined by a single station, it is totally robust against alignment errors.

By way of contrast, we consider a momentum measurement constructed out of $\mu 2$ inside the toroid, and $\mu 3$ and $\mu 4$ which are separated by 2 meters and lie outside the toroid. We first consider the case where all three stations are 4 θ layer drift chambers modeled as described above. **Figure 1** shows the effective momentum as a function of the σ_z alignment error (solid curves) for this three station measurement. A separate Gaussian alignment error of σ_z is independently added to each of the three stations. It is convenient to think of this as an alignment error with respect to a fixed point such as the CTD system. About a factor of 10 improvement in performance relative to the two station measurement is possible if station-to-station alignment errors can be kept within $\sigma_z < 100\mu$! Such a system would be capable of producing a second level trigger with a **sharp threshold up to 700 GeV** (or 450 GeV) without any need of linking to CTD azimuthal stubs! Why is the system so good? By maintaining a good alignment between the outer two muon chambers, the outer track segment (measured by two widely spaced chambers) can be precisely extrapolated to the (radial) center of the toroid. The muon entering angle can then be measured by using the space points provided by $\mu 2$ and the mid-toroid extrapolation to make a high quality measurement angle measurement over an ≈ 75 *cm* lever arm.

If, however, the mid-toroid extrapolation point is ruined by miss-alignment, one expects that the bend angle will measurement will only improve by a factor of $\sqrt{3/4}$ (owing to the fact that the exiting muon angle is measured twice) over the case with two stations thus producing a system with an effective momentum of 42 GeV (or 26 GeV). This behavior is borne out by the matrix calculations of Figure 1. Roughly 1/2 the benefit of a three station measurement would be lost if alignment errors exceed $\sigma = 200\ \mu$.

Anticipating this argument at the last muon group meeting, Duncan Carlsmith suggested increasing the effective angular lever arm of $\mu 2$ by adding two more θ measuring layers as an "out-rigger" to form a 6 layer θ station for $\mu 2$. The **dotted** curves of Figure 1 show the effective momentum for a system where two additional Z measurements are made in $\mu 2$ with a lever arm of 0.5 meters for the case where all three stations have independent alignment errors of σ_z. The **dashed** curves assume that that the outer stations ($\mu 3$ and $\mu 4$) are precisely aligned relative to each other but both the $\mu 3 - \mu 4$ system and $\mu 1$ system (with out-riggers) have the indicated alignment errors relative to the CTD reference point. In the dashed scenario, excellent performance is maintained independent of alignment error. The 2 meter lever arm between the outer chambers and the .5 meter lever arm using the 6 layer $\mu 2$ provide a bend angle resolution of about 0.58 milliradians and thus an effective momentum of 355 GeV for the case of 177 micron position resolution.

The dotted scenario (where the outer chambers can still be relatively miss-aligned) a sharp momentum threshold can be set up to 300 GeV even for $\sigma = 1\ mm$ miss-alignment. Eventually, however, the poor exiting angle information for a poorly aligned $\mu 3$ and $\mu 4$ will dominate the bend angle measurement for the case of an "out-rigger" $\mu 1$ station and effective momenta would greatly be reduced to 72 GeV (or 45 GeV). Certainly out-riggers for $\mu 3$ would eliminate even this alignment difficulty.

3. Results for Analysis Resolutions

We next consider the effect of Z and $R\ \phi$ miss-alignment for case where the muon system and CTD both contribute to the overall momentum resolution. The **solid** curve of **Figure 2** shows the relative momentum error for an $\eta = 0$ muon as a function of Pt for the case of a perfectly aligned muon system working in conjunction with the a CTD. To be conservative, I used the Dallas chamber layout with 283 μ resolution. The **dotted** curve shows the (de-scoped) CTD resolution of 26 % at 1 TeV. The three **dashed** curves marked 2 mm , 1 mm , and 0.5

mm show the relative momentum resolution under the scenario of independent alignment errors for each of the three muon chamber stations. We assume the indicated RMS alignment errors in **both** the Z and $R\phi$ direction. It would be highly desirable to maintain alignment to the level of $\sigma < 500\mu$ in order to get maximum use of the muon system for high energy muons. The **dashed and dotted** curve assumes that the outer two muon stations have perfect relative alignment. The curve is drawn for $\mu 2$ and $\mu 3 - \mu 4$ independent alignment errors of $\sigma = 1\ mm$.

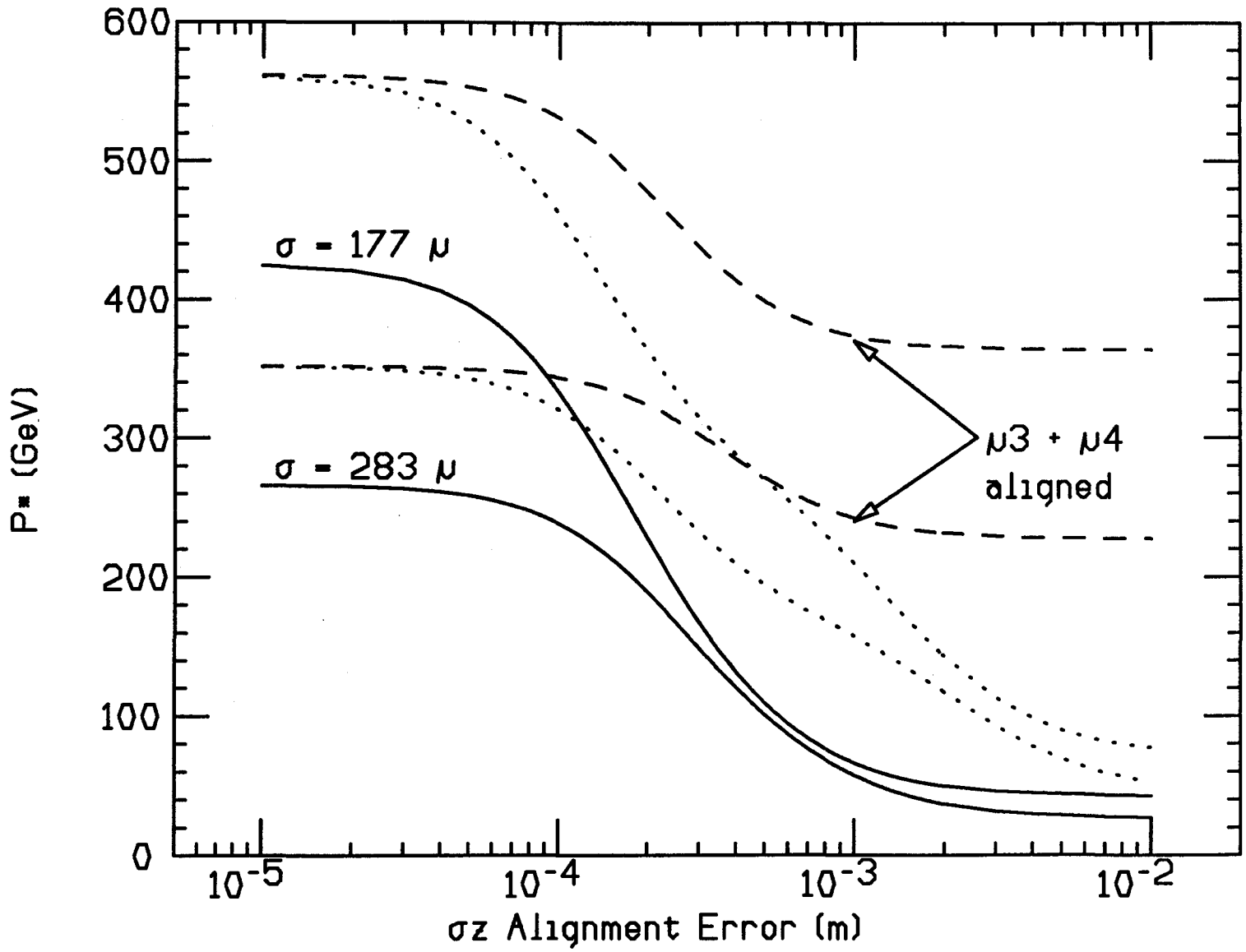
600
500
400
300
200
100
0
P∥ (GeV)
σ = 177 μ
σ = 283 μ
μ3 + μ4
aligned
10^-5
10^-4
10^-3
10^-2
σz Alignment Error (m)

FIGURE 1.

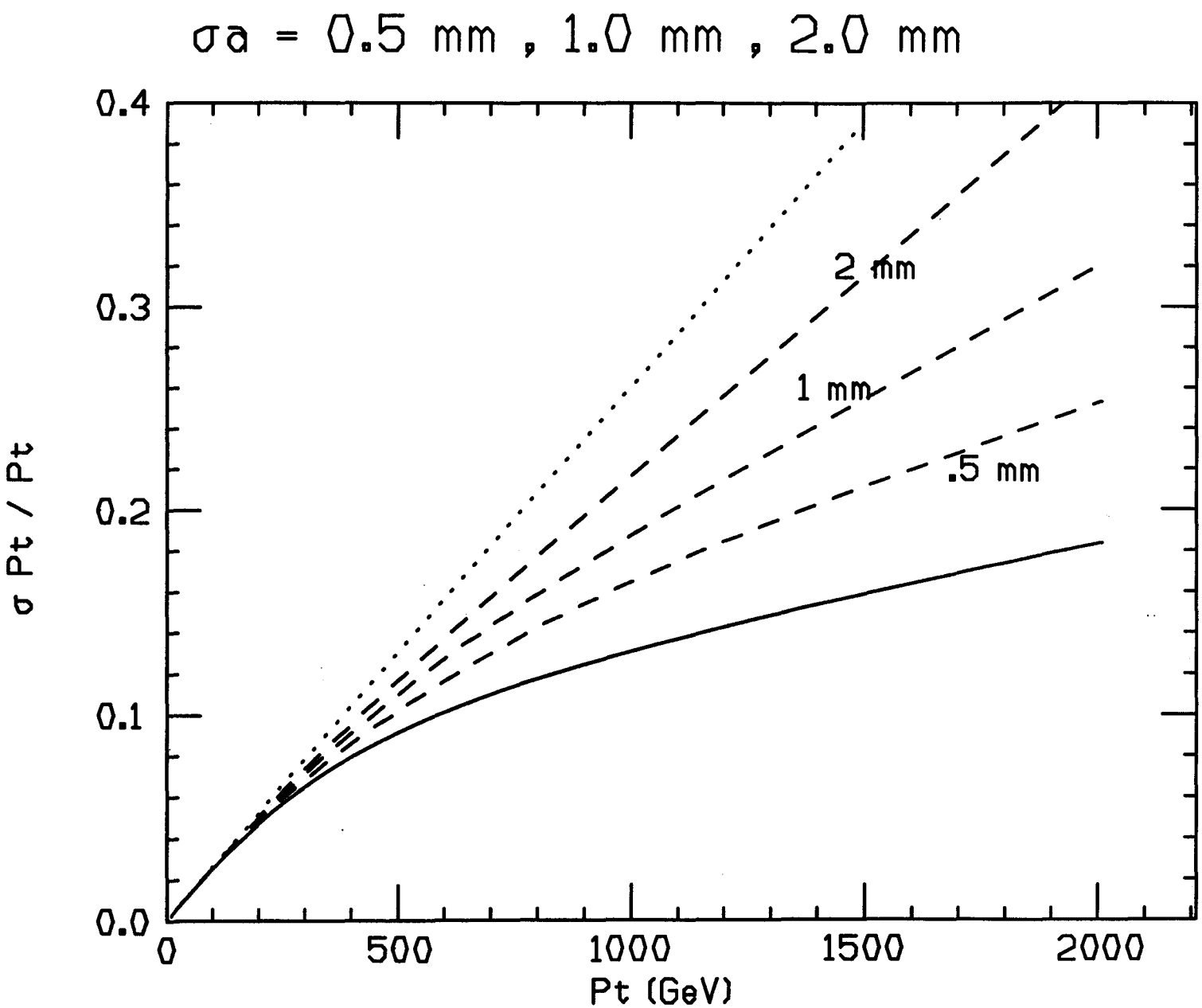
σa = 0.5 mm , 1.0 mm , 2.0 mm
0.4
0.3
0.2
0.1
0.0
σ Pt / Pt
2 mm
1 mm
.5 mm
0
500
1000
1500
2000
Pt (GeV)

FIGURE 2.