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SDC
SOLENOIDAL DETECTOR NOTES

SHORT SOLENOID v.s. LONG SOLENOID
- EFFECTS ON TRACKING -

Y. Takaiwa

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Short Solenoid *v.s.* Long Solenoid — Effects on Tracking —

Y. Takaiwa,
KEK, Tsukuba, Ibaraki 305, Japan

Abstract

The effects of choice of solenoid design, short or long, on tracking is discussed. In particular, field non-uniformity effect is discussed. The emphasis is on the fact that no serious difference exists except available tracking volume sizes which cannot be decided solely by the tracking and solenoid system designs.

1 Introduction

Solenoidal detectors which will be built for the SSC experiments has to choose a design for the *solenoid.* There may be a few types of them. One extreme among them is a compact solenoid with rather high field to get enough analyzing power for the tracking device inside the solenoid which allows good hermeticity of the calorimeter outside. And the other extreme is a large solenoid to get good analyzing power of inner tracker with moderate field strength [1,2]. Before getting into dicussions of dependence on the solenoid types, the requirements to the inner part from the outer parts of the detector can be discussed as general comments. For example, calorimeter system, which is usually located after the inner tracker and the solenoid, does not like any thick material in front which causes premature shower development and dissipation of shower energy before the calorimeter. Also it does not like any structure giving dead or insensitive areas of the calorimters such as vessel walls and supports, cable paths, chimneys and even beam holes; they are causing bad hermeticity of the calorimeter system. Another fact to consider is that bigger size of the inner part requires bigger size and more material of the detector, which directly effects on its cost as a consequence.

Possible choices of the solenoid design are listed below and also requirements from the tracking system which might be relevant to the solenoid designs are also listed.

A)	Long	or Short
B)	Large	or Compact
C)	High Field	or Low Field
D)	Floating	or Close Return Yoke
E)	Thick	or Thin

wider η (pseudo rapidity) coverage	length	A) D)
long lever arm, large $Bd\ell$	radius, field strength	B) C)
simple in tracking analysis	field quality	D)
less problems due to background events (hit rate, radiation level, electric noises, etc.)	radius, field strength	B) C)
trigger efficiency for high p_T tracks	field quality	D)

Looking at these tables, the issues are categorized into two types; one is closely related to designing and engineering issues such as the size of the tracking volume and the other is relevant to capability of data processing mechanisms. The issues of the former type need to be discussed among the collaboration and the discussion will last until finallize the detector design, therefore I leave them to the discussion of the later time. In this note, the issue which is thought as a major problem related to the choice of the solenoid is discussed. That is the effect of non-uniform magnetic field which obviously classified into the second type mentioned above.

2 Magnetic Field Uniformity

It seems that two types of solenoid designs are seriously proposed for the general purpose detectors at the SSC which make significant difference in uniformity of the field; one is long solenoid and return yoke is closely attached to it, and the other is the air core type solenoid (ACS) which allows calorimeter system to surround tracking system with less inside structure putting return yoke at rather distant location. For the long type solenoid uniform field can be achieved well enough, however, it puts some structure of material in front and within the calorimeter region. On the other hand, ACS type solenoid gives non-uniform field within the tracking volume, whose effects are the main subjects of this note. The analysis of tracking is simple when the field is uniform and it is probably easier and for triggering and event pre-selection. However, we would like to see the effect in detail to make final decision of the whole detector design; which difficulty is the more serious one, field non-uniformity to the tracking analysis or non-uniform structure of the calorimetry system. In order to start such studies the non-uniformity character of the ACS type solenoid is reviewed in this section. In the next section, the effect of it on the tracking is discussed.

In the ACS design used for this memo, a solenoid magnet has dimension of 1.8 m for inner radius and 2.0 m for outer radius of cryostat with 1.9 m of coil conductor radius and length is about 8 m for the cryostat and 7.7 m for the coil and it gives the field strength of 2.0 Tesla at the center. The liquid Ar calorimeter system covers it upto $\eta = 3$ and then muon toroid system which is also used as the flux return for the solenoid is put at the back of it. Because of this geometry magnetic flux generated by the solenoid is diffusing at the edge of the solenoid. The resulting magnetic field gives not only stray field in the calorimters but also non-uniformity inside the tracking volume.

A field map of the ACS is calculated by POISSON code and the contour maps of B_z and B_r for typical ACS solenoid is shown by Yamamoto in a previous talk. According to this it is seen that, although the central value of the longitudinal component of the field, B_z, is 2.0 Tesla, B_z at the edge of the solenoid is about 1.1 Tesla which is about 50% of deviation from the uniformity. Also the field has a radial component, B_r, which increases with increasing z and r, and it amounts to about 20% or 30% of central B_z value around the same region. To see the effect of this, it is useful to see the "analyzing power" of the solenoid, which is defined as an integral of the field strength that is felt by a moving charged particle, so called $Bd\ell$. In the case of solenoidal geometry, $Bd\ell$ is calculated as $\int B_z d\ell_T$, for longitudinal component only where the integral is made along the particle path. If, however, the radial component exists this should be modified to the form of $\int |\vec{B} \times d\vec{\ell}|$. The plots for them are shown in Figure 1. In this figure, integrals of $B_z d\ell_T$ and $|\vec{B} \times d\vec{\ell}|$ together with the case of uniform field are plotted against pseudo rapidity, η. In long solenoid design the field uniformity within the same tracking volume is so good that a curve for uniform field can represent as the long solenoid case.

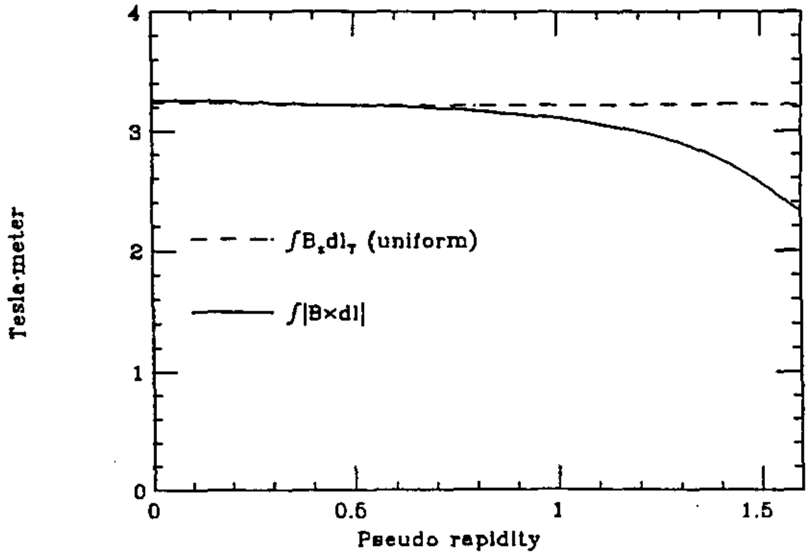

Figure 1: $Bd\ell$ in non-uniform Field

3 Tracking in non-uniform field

It is possible to perform track fitting no matter how the magnetic field is inhomogeneous if we know precise field map information in such field as we know from the experiences of bubble chamber and fixed target experiment data analysis. The procedure may be complicated and time consuming for really general cases, however, it can be simple and fast when the configuration of field is restricted to a certain type. As an example for this kind of situation is, in fact, a solenoid type magnetic field, as demonstrated by AMY experiment at TRISTAN.

The AMY is an existing detector that has similar non-uniform magnetic field of the solenoid [4], not because of the location of the return yoke but by the reason of strong field in a compact tracking volume, about 1.6 m in both diameter and length with 3 Tesla magnetic field at the center and field line generated by the solenoid is shown in Figure 2. The deviation from the uniformity in AMY is about 30% at the region of the edge of the solenoid, which is comparable to the ACS solenoid design. and the method of AMY to treat such field non-uniformity may be applicable to the ACS type solenoidal detector for the SSC experiments.

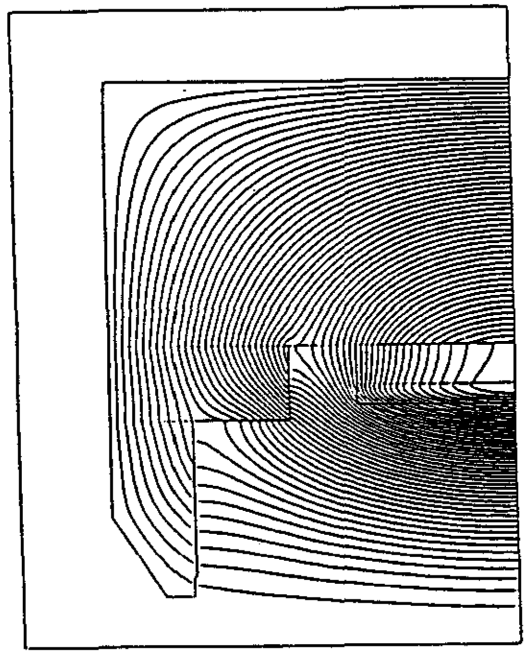

Figure 2: AMY solenoid field lines

The method of AMY called *"IMFIT"* [6] is summarized in the following. Starting from track parameters assuming uniform field, the track is re-fitted with the trajectory function of the particle in the inhomogeneous field. The trajectory function can be written down with a certain approximation for the field which is good enough for high p_T tracks within a reasonable range of η. Then, if necessary, the re-fitting is iterated to get better χ^2 using better approximation for the field.

The approximation to the field is made as the form of truncated power series in r and z assuming that it satisfies Maxwell equation and it can be expressed as

$$B_z(r,z) = B_0\{1 + \alpha(r^2 - 2z^2) + \beta(r^4 + \frac{8}{3}z^4 - 8r^2z^2)\}$$

$$B_r(r,z) = B_0\{2rz\alpha + \beta(-\frac{16}{3}z^3r + 4zr^3)\}$$

$$B_\phi(r,z) = 0$$

where B_0 is the central value of the magnetic field and α and β are the expansion coefficients. When β is small enough, it is not necessary to keep terms of fourth power of r and z and for this approximation ($\beta = 0$), trajectory function,

$$\phi = \phi(r; p_T, d_0, \phi_0, z_0, \cot\theta_0) = \arcsin\{\frac{r^2 - 2\rho d + d^2}{2(\rho - d)r}\} + \Delta\phi$$

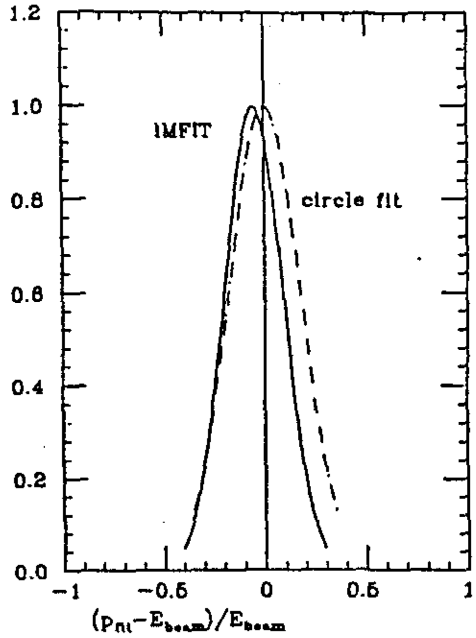

Figure 3: $(p_{fit} - E_{beam})/E_{beam}$ for intermediate angle Bhabha scattering of AMY

can be written down, again using expansion in r and z, where a term expressed by arcsin is the formula for uniform field and $\Delta\phi$ is the correction term. Further approximation that z trajectory function is not affected by the field non-uniformity is made here but it can be improved if necessary. The advantage of this IMFIT is that the trajectory function can be wriiten down analytically and minimization procedure requires no tracing of particles in the field but only calculation of polynomials and trigonometric functions.

Power of this method is demonstrated in analysis of intermediate angle Bhabha scattering of AMY experiment. In Figure 3 the distribution of $(p_{fit} - E_{beam})/E_{beam}$ of $e^{\pm}$ for intermediate angle Bhabha scattering ($\theta < 60°$) is shown. The solid curve is the result of IMFIT and the dashed curve shows the result without IMFIT. The picture shows the shift of the peak due to non-uniformity correction and deviation from the nominal value E_{beam} of IMFIT result is consistent with radiative correction.

For the purpose of illustration a following toy model is considered as a tracking system in the ACS solenoidal field. The ACS magnetic field is well approximated by the form of power series of r and z described above with the values of $\alpha = 0.00876m^{-2}$ and $\beta = -0.000463m^{-4}$. The value of β is small enough to be neglected in application of IMFIT; it is even better than AMY detector.

Tracking device with cylindrical (layer) geometry without specifying the technique is

Table 1: layer radius of tracking device

	radii of layers in cm			
super layer 0	$r_1 = 10.0$	$r_2 = 10.4$	$r_3 = 10.8$	$r_4 = 11.2$
	$r_5 = 12.0$	$r_6 = 12.4$	$r_7 = 12.8$	$r_8 = 13.2$
super layer 1	$r_1 = 50.0$	$r_2 = 50.8$	$r_3 = 51.6$	$r_4 = 52.4$
	$r_5 = 53.2$	$r_6 = 54.0$	$r_7 = 54.8$	$r_8 = 55.6$
super layer 2	$r_1 = 70.0$	$r_2 = 70.8$	$r_3 = 71.6$	$r_4 = 72.4$
	$r_5 = 73.2$	$r_6 = 74.0$	$r_7 = 74.8$	$r_8 = 75.6$
super layer 3	$r_1 = 90.0$	$r_2 = 90.8$	$r_3 = 91.6$	$r_4 = 92.4$
	$r_5 = 93.2$	$r_6 = 94.0$	$r_7 = 94.8$	$r_8 = 95.6$
super layer 4	$r_1 = 110.0$	$r_2 = 110.8$	$r_3 = 111.6$	$r_4 = 112.4$
	$r_5 = 113.2$	$r_6 = 114.0$	$r_7 = 114.8$	$r_8 = 115.6$
super layer 5	$r_1 = 130.0$	$r_2 = 130.8$	$r_3 = 131.6$	$r_4 = 132.4$
	$r_5 = 133.2$	$r_6 = 134.0$	$r_7 = 134.8$	$r_8 = 135.6$
super layer 6	$r_1 = 150.0$	$r_2 = 150.8$	$r_3 = 151.6$	$r_4 = 152.4$
	$r_5 = 153.2$	$r_6 = 154.0$	$r_7 = 154.8$	$r_8 = 155.6$

to give hit points of a charged particle on the cylinder surface with specified position resolution. And the system consists of one inner superlayer and six ordinary super layers each of which in turn consists of eight layers of such cylinders and inner super layer has better spatial resolution than the ordinary ones. The radii of these layers are shown in Table 1. A particle starts from the origin with given momentum in this tracking system which is located in the non-uniform field of the ACS solenoid, and the particle trajectory is traced in this volume using usual swimming routine in the magnet field, giving hit points on layers of the tracking devices with spatial resolution of 50 μm for the inner super layer and 200 μm for the ordinary super layers. Those hit points are subject to circle (helix) fit, and the curvature is translated into the p_T using typical B_z, say 2.0 Tesla, in the ACS field. Then the IMFIT is appllied to this model tracker and results are compared with the results without IMFIT.

The result of the game is shown in the Figure 4. for particles with 100 GeV/c of p_T at various η. In this Figure mean of the the fitted values for transverse momentum p_T^{fit} and $\Delta p_T / p_T^{fit}$ are plotted where Δp_T is the $r.m.s.$ of the fitted p_T. The pictures clearly show that when no correction is made the effect of non-uniformity is seen as a shift of mean value of the fitted p_T upwards from the original p_T which is consistent with the fact that the analyzing power of the ACS solenoidal field decreases as η increases towards the

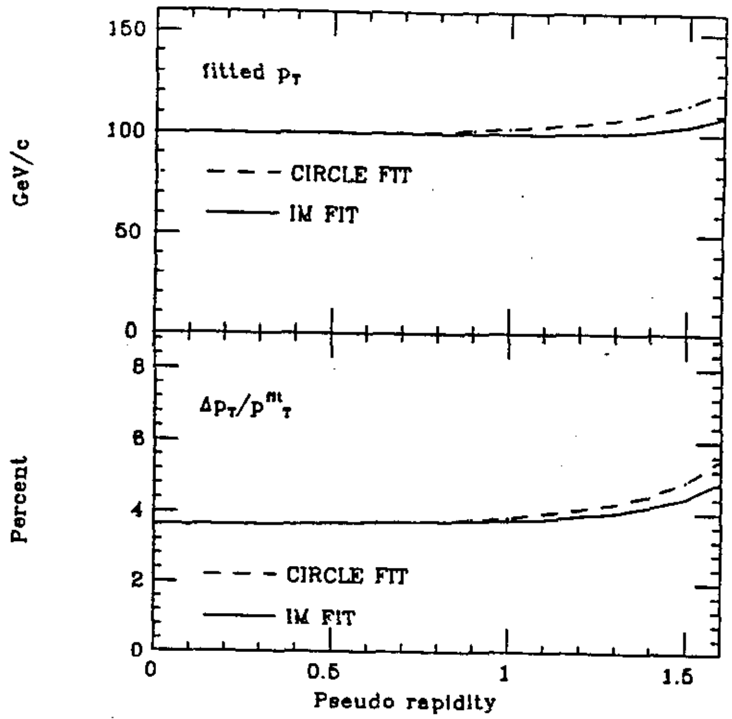

Figure 4: IMFIT for p_T

edge of the solenoid. They also show that $\Delta p_T/p_T^{fit}$ is increasing with increasing η which is also consistent with decreasing $Bd\ell$.

When the IMFIT is appllied the result indicates that the fitted p_T reduces to the true value for more extended region of η although it is still slightly higher than the actual p_T in the higher region of η. The resolution of the fitted p_T represented by the r.m.s. is also decreased from the values with uncorrected fitting result. Now we may hope that the air core solenoid type detector such as the ACS is not so terrible as is thought first, however, it is also true that situation is much simpler if we can achieve uniform field for the tracking volume.

4 Discussions

Observing that non-uniform magnetic field can be managed in the case of ACS solenoid, some discussions on the tracking are given below.

- Effects on Trigger and Fast Filter?

Naive estimate of p_T assuming uniform field is overestimation and more events than required will be selected, however, we won't miss good events. The question is whether we can achieve such accurate resolution that unwanted events are cut sharply at the threshold in any case by the algorithms used in these stages. Even so the effect of non-uniformity, if known in advance, can be managed somehow but the effect of this should not be significant.

- Pattern Recognition?

  Usually pattern recognition is performed by conneting locally constructed track segments (vectors) with adjacent segments, so that there will be no serious differences between uniform and non-uniform field because non-uniformity in such a local area is small. However, whether pattern recognition is possible or not is not a trivial question but requires substantial amount of efforts in both situations. At this stage most of computing power will be consumed in event analysis if general purpose pattern recognition is assumed. It may be better to think of simpler algorithms for certain classes of physics and events which can be used, in particular, for fast event selections.

- Efficient Track Fitting?

  Once pattern recognition is done well enough, then the track fitting is only a matter of computing power and usually it is only a fraction of pattern recognition stage. Addtion due to non-uniform field is not significant compared with the pattern recognition as is discussed above.

- Computing Power?

  It is obvious as dicussed above the pattern recognition will be a dominant part of data analysis for SSC experiments and it should be performed anyway. The question is whether existing algorithms for pattern recognition and track fitting are the realistic ones considering available computing power by the time of experiments. This depends on progress in technology of computing facilities and software which is very hard to predict for more than five years from now. The answer is not trivial and we may have to work until then, although there exists some projects and hope for them.

5 Conclusions

Finally I would like to list up conclusions of my talk.

- Almost of issues of tracking system are independent of the choice of solenoid types.
- The effect of non-uniform field is not a real issue but manageable reasonably well.
- The issues of tracking system are (1) size of $Bd\ell$ (high B field and long lever arm or large radius of the tracking volume), (2) enough η coverage (length of the tracking volume), and (3) the good performance of the tracking devices of the system.
- The size of tracking volume directly effects on the designs of the other parts of the detector system and its cost estimation which should be discussed based upon physics purposes and its cost effectiveness.

Obviously they do not cover all the possible questions, however, it may be said that the choice of the solenoid does not solve all such problems of tracking of SSC experiments. The tracking in SSC environment is really tough and we need to do lots of work in various aspects before final design and realization of the experiments.

References

[1] G. G. Hanson et al., *Proceedings of the workshop on Experiments, Detectors, and Experimental Areas for the Supercollider*, Berkeley 1987, p.340.

[2] J. Kirkby et al., *ibid.*, p.388.

[3] T. Kondo, KEK preprint 89-191, *Talk given at the Fermilab Workshop on Solenoidal Detector for the SSC*, September 25-26, 1989.

[4] K. Tsuchiya, S. Terada, A. Maki et al., *IEEE Trans. Magn. MAG-22 (1987)*

[5] A. Yamamoto, *private communication.*

[6] K. Ueno, *private communication.*