LCTPC and the Magnetic Field for ILD: Update 2010

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Abstract

This note is a further development of the ideas presented in Refs. [1][2][3][4]. The recent issue is that the LCTPC [5] collaboration in conjunction with the ILD [6] has decided not to specify a limit on the uniformity of the magnetic field. The reason is that large gradients will result from the anti-DID (Detector Integrated Dipole)[7][8], which will be implemented to reduce backgrounds in the detector. Since now a uniformity-limit will not be defined, the corrector windings in the solenoid can be eliminated. This decision had not been published as LCNote in 2010 and will be documented here.[2] The TPC for CLIC is also addressed.

1 Introduction

A short overview: the motivation for a TPC as tracker for a linear collider detector is described in the ILD LOI[6], and the R&D to achieve the goals for its performance are covered in a recent report to the Physics Review Committee at Desy[9].

In Ref. [2], ways were suggested for measuring and monitoring the inhomogeneous B-field so that the LCTPC could maintain its tracking-performance goals. The formulae derived there indicated that no requirement on the B-field homogeniety was needed as long as the field was well measured.

In Ref. [3], two concrete procedures were proposed for correcting the B-field inhomgeneities: 1) by evaluation of the "displacement integrals" or 2) by an "inverse drift method". These correction methods were simulated for the Large Prototype TPC in PCMAG [5] and shown to be accurate to about 10μm.

In Ref. [4], the measurement of the B-field in the case of a TPC for CLIC was studied, where the precision of B-field was approached from a slightly different point of view. The result was that the B-field map will have to be measured to 1 G, which is somewhat more demanding than in Ref. [2]. An additional aspect in Ref. [4] was the calculation of the B-field for CLIC using POISSON [10] and showed that the gradients in certain regions would cause a displacement so large that the drifting electrons hit the TPC wall before reaching the padplane. This effect is further analyzed in Sec. 5.3.

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[2]To guard against misunderstandings, we point out that the words "correct", "correction", etc are used here in two different ways: one for the coils in the solenoid which can "correct" the B-field to be more homogeneous, and the other for the adjustments which are applied to point measurements to "correct" for the displacements due to a B-field gradient.

2 The ILD Workshop 2010

The discussion at the ILD [6] workshop in Paris, January 2010 [11] had resulted in the decision that it is not necessary to place a limit on the non-uniformity of the magnetic field, which had been previously defined by the relation $\int_{\ell_{\text{drift}}} \frac{B_r}{B_z} dz < 2 - 10\text{mm}$; the homogeneity had been furnished by corrector windings in the solenoid. The reason for this decision is that much larger gradients (up to $\int_{\ell_{\text{drift}}} \frac{B_r}{B_z} dz \sim 50\text{mm}$) will arise from the field of the anti-DID [7][8], which will be important for reducing backgrounds originating from the beams inside the detector at the ILC. Because of the anti-homogeneity effect of the anti-DID, the original homogeneity tolerance was no longer defendable. More information about this issue follows next.

3 Magnetic Field Accuracy, Ref. [2]

In this note, the discussion will be based on the ideas presented in Ref. [2].

To achieve the required tracking performance, as formulated in [2], systematic effects in the TPC track reconstruction should be corrected to an accuracy of about $\sigma_0 \simeq 30 \ \mu\text{m}$. The 30 μm was somewhat arbitrary and will be re-examined in Sec. 5.

The relevant equations in [2] for the field map were the following. The main requirement proposed was that the uncertainty in the field map be smaller than σ_0:

$$\delta(\Delta r\varphi) = \frac{(\omega\tau)^2}{1 + (\omega\tau)^2} \delta \left(\int_z^{z_{max}} \left(\frac{B_\varphi}{B_z} + \frac{1}{\omega\tau} \frac{B_r}{B_z} \right) dz \right) < \sigma_0. \tag{1}$$

The total uncertainty in the $\Delta(r\varphi)$-displacement correction, due to both B_r and B_φ components which are statistically-independent measurements, is from Eq. 1,

$$\sigma_{\Delta r\varphi_i} = \frac{1}{\sqrt{N_i}} \frac{z_i}{B_z} \sqrt{\sigma_{B_\varphi}^2 + \frac{1}{\omega^2\tau^2}\sigma_{B_r}^2}, \tag{2}$$

where $\Delta z = z_i/N_i$, Δz is the step in z taken by the B-field-measuring apparatus and N_i is the number of points measured up to point z_i ($i = 0$ for zero drift).

Since the B_r and B_φ measurements with Hall plates are technically equivalent, the error distributions with widths σ_{B_r} and σ_{B_φ} will be about the same. Thus the B_r contribution will be damped by the $\omega\tau$ factor.

The B_r component was used define the homogeneity in the past and in Sec. 2 above. It can be seen from this equation that the B_φ is the more sensitive component, which is however zero for an ideal solenoid. B_φ is non-zero in reality due to several effects (e.g., the iron yoke) and is non-zero due to the anti-DID, as will be seen in Sec. 4. Since it turns out that the B_r and B_φ components have similar magnitudes in the final set-up (Ref. [12]), both components are used to illustrate the effects.

4 B-field Configurations, Ref. [12]

Possible configurations for the ILD solenoid[12] are shown in Figs. 1–4. The axes are: vertical axis = $\int_{\ell_{\text{drift}}} \frac{B_r}{B_z} dz$ in mm; left horizontal axis = radius in mm; right horizontal axis = aziumthal angle in degrees.

For ILD[11] the configuration in Fig. 3 is the most logical choice, since corrector windings change the shape of the gradients but do not change $\int_{\ell_{\text{drift}}} \frac{B_r}{B_z} dz$ significantly[3] in the presence of the anti-DID. The implications for the B-field map are discussed in Sec. 5.

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[3]...meaning, not as significantly as without the anti-DID: the ratio of Fig. 1 to Fig. 2 is about 5.4 maximum, while for Fig. 3 to Fig. 4, it is less than 1.7.
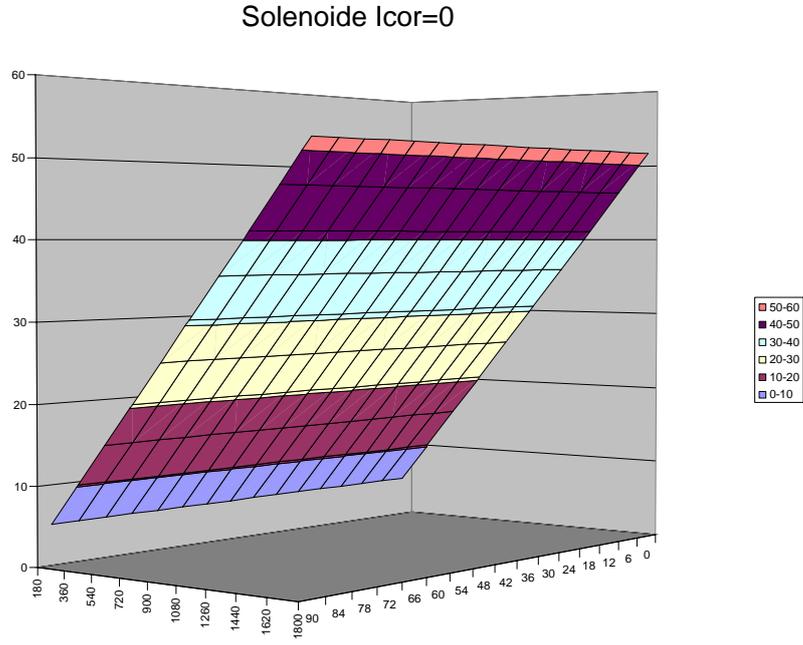
Figure 1: Configuration 1 for the coil: no correction coils, no anti-DID $\int_{\ell_{\mathrm{drift}}} \frac{B_r}{B_z} dz \simeq$ 54mm max.
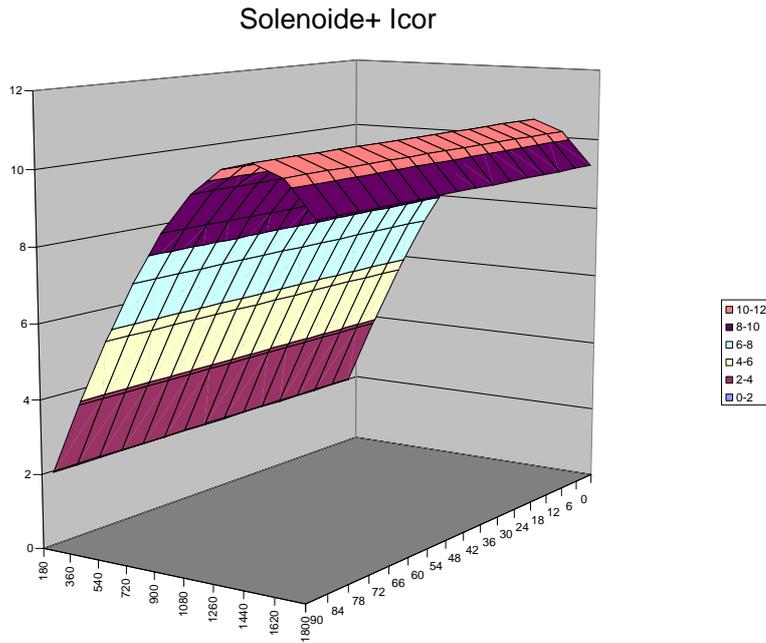

Figure 2: Configuration 2, add correction coils $\int_{\ell_{\mathrm{drift}}} \frac{B_r}{B_z} dz \simeq$ 10mm max.
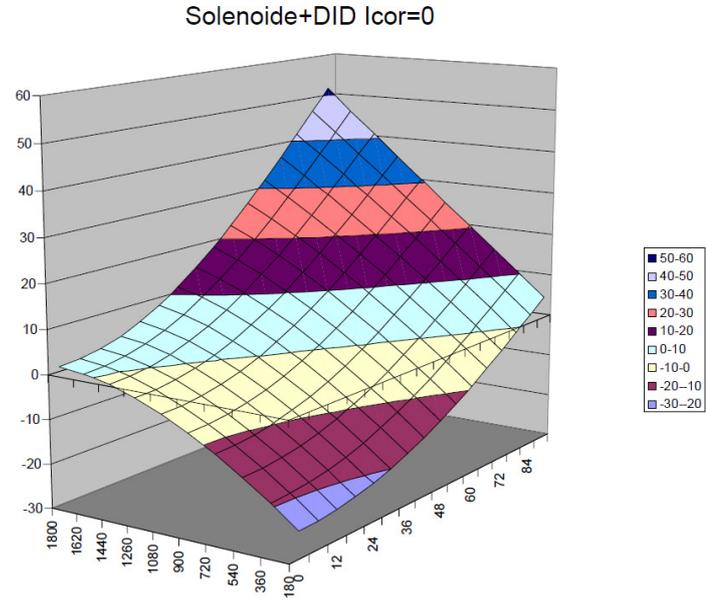
3

Figure 3: Configuration 3, no correction coils and with anti-DID $\int_{\ell_{\text{drift}}} \frac{B_r}{B_z} dz \simeq 50\text{mm}$ max.
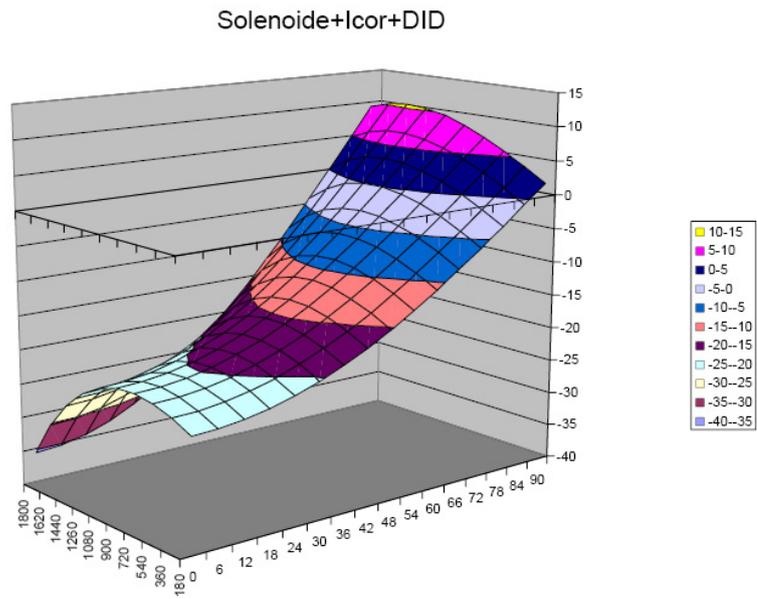

Figure 4: Configuration 4, add anti-DID $\int_{\ell_{\text{drift}}} \frac{B_r}{B_z} dz \simeq 35\text{mm}$ max.

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5 Discussion

5.1 B-field Map

The list presented in on p.9 of Ref. [2] contains a set of ideas how to ensure that the B-field will be known with sufficient accuracy. The goal for attaining the required tracking performance was formulated as follows: systematic effects in the TPC track reconstruction should be corrected to an accuracy of about 30 μm. This accuracy was motivated by allowing at most for a 5% increase in the momentum error due to uncertainty in the B-field, that is, $\sigma^2_{point} = (100\mu m)^2 + (30\mu m)^2 = (105\mu m)^2$, where $\delta(\frac{1}{p})$ is proportional to σ_{point} in Gluckstern's formula[13]. This was a proposal for quantifying the field-mapping effect such that the momentum measurement was essentially unaffected.

The question now is, what happens if the gradients are large?

It should be noted that the 5% was a guide; larger values are possible as seen by the following example. Considering the maximum drift length = 2200mm, $N_i = 100$ at the maximum drift length ($z_{100} = 2200$mm, $\Delta z = 22$mm) and $\sigma_{B_\varphi} = \sigma_{B_r} = 10$ G. According to Eq. 2 the error on the $r\varphi$ measurement due to the field map will be $\sigma_{\Delta r\varphi} = .055$ mm. The candidate gases (Fig. 4.3-5(right) on p.75 of Ref. [6]) will allow a σ_{point} of around 70 μm. In this case the overall $\sigma^2_{point} = (70\mu m)^2 + (55\mu m)^2 = (89\mu m)^2$, which would satisfy the requirement in Table 4.3-5 on p.70 of [6] (i.e., $\sigma_{point} < 100\mu$m). Thus the 5% becomes 25% which is still allowed if the errors are added in quadrature.

One can add the errors in quadrature as long as the errors due to the mapping are "statistically" (i.e. randomly) distributed along the tracks. Larger B-field gradients and larger σ_0 are permissable along as the errors due to the corrections are statistical in nature.

5.2 Conclusions

The conclusions of the discussions in Paris[11] and in this note are:

• Higher B-field gradients will not degrade the TPC performance if the B-field Hall-probes are calibrated to 1 or 2 G, the list in on p.9 of [2] is followed, and the procedures involving laser calibration system, Z-peak calibration and Z$\to \mu\mu$ events collected during physics running at $\sqrt{s}$ are applied, and that the errors due to the corrections are added in quadrature.

• If the "1 or 2 G" in the previous bullet is not achievable, then one can compensate by increasing the number of steps during the field mapping. For the example shown above, 10 G Hall-probe accuracy, can be compensated by mapping with $N_i = 100$ steps. This gain is "in theory", while "in practice" systematic effects due to the measuring apparatus may limit the accuracy. The measuring apparatus must be well designed.

• For the overall ILD tracking performance, alignment with other subdetectors will also be important; the discussion is on p.74 of Ref. [6], Sec. 4.3.2.7.

• The Z$\to \mu\mu$ events will allow any remaining systematic effects in regions of large B-bield gradients to be corrected so that fluctuations due to the corrections can be added in quadrature.

• These developments should continue to be documented using the LC-Note systems: http://www-flc.desy.de/lcnotes, http://ilcdoc.linearcollider.org/ and http://lcd.web.cern.ch/LCD/Documents/Documents.html.

5.3 Comment on Ref. [4] and the CLIC and ILC TPCs

In this reference the calculation of a B-field for CLIC (without correction coils) used POISSON [10] resulted that the gradients in certain regions would cause a displacement of up to 63mm of the drifting electrons causing them to hit the side walls of the TPC be lost for the measurement. A reduction in tracking length by 63mm would degrade the momentum resolution by 10% [4].

For the ILC, requiring, somewhat *arbitrarily*, that the degredation is at most 5%, then $\int_{\ell_{\text{drift}}} \frac{B_r}{B_z} dz \simeq 30$mm max. Figure 3 tells us that the fiducial volume of the ILC TPC would shrink by about 5%, and be localized around 90° in azimuth and at the outer radius of the chamber.

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