IRON-FREE DETECTOR SYSTEM FOR THE LINEAR COLLIDER WITH MULTIPLE RETURN SOLENOIDS

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Abstract

We investigate the iron-free magnetic system for implementation in a detector for future linear collider. One peculiarity is in usage of many small-diameter solenoids for the flux return [1]. Machine-detector interface is discussed also.

INTRODUCTION

Identification of momenta p of particle in detectors planned for High Energy Colliders, ILC, CLIC, provided by measurement of curvature of its trajectory in magnetic field created by central solenoid of detector.

Solenoidal magnetic field well fits into axial symmetry of final focusing system of colliding beams. The magnetic field value defined by the requirement of momentum resolution, which is $\Delta p/p \sim p\sigma_s/(B_0 D^2)$ where B_0 stands for the axial field in a central solenoid, D is its diameter, σ_s is a spatial resolution of tracking system. One can see that the resolution is a trade between allowable magnetic field value in solenoid and its diameter D. Stronger dependence on D allows reduction of the field value obviously. Increasing diameter of solenoid and hence the volume of tracking system with electronic requires careful evaluation of cost. Nevertheless, higher magnetic field is desirable as in this case the free parameter comes to diameter only. Now examples of high field operation of SC cables are known, see [2, 3, 4].

Other requirement to the field in central region- is its homogeneity. This required by coordinate system, especially by TPC technique. Longitudinal distance required for allocation of coordinate system could be estimated as ±2m, where variation of the field level should be $\Delta B/B_0 \leq 10^{-3}$. Clu-Cou technology is more relaxing for the same spatial resolution [5].

Typically, the magnetic field created with the help of superconducting solenoid with induction of 4*Tesla* (ILD)-5*Tesla* (SiD). Magnet yoke of detectors for colliders have ~13kT of Iron (Eifel tour Iron weights 7.3kT). Yoke serves for re-direction the magnetic field flux from one end of solenoid to the opposite one. From the other hand it is known, that the magnetic field value outside of the (long) solenoid is zero. So there appears a desire to avoid usage of heavy Iron yoke at all. With elimination of iron yoke the detector becomes a lightweight and non-sensitive to saturation phenomena. One self-consistent proposal on how to eliminate the Iron was demonstrated in detector, suggested for ILC (4th Concept) [6, 7]. In this current publication we continuing development of Iron-free detector line, launched many years ago [5, 8]

We are projecting parameters of such detector for usage with a multi TeV-scale colliding beams which inevitably will appear in a future for investigations in a post-Standard Model of the Universe.

STABILITY REQUIREMENTS FOR THE LENSES OF FINAL DOUBLET

In addition, detector has typically superconducting final quads located inside the magnet and theirs field have significant value in a region where the coordinate system is located. This makes trajectory analysis more complicated also. Detector physicists are prepared for this and are ready to make all necessary corrections, (what indicates a potential for further developments). Let us make one preliminary remark, which could be addressed to the accelerator community. The final lenses located at both sides of detector provide each-side beam focus at IP in both transverse directions x and y. If however, the quadrupole lens at one side is shifted transversely from its position, the focal point, which is IP, becomes shifted transversely. The kick generated by displacement of lens can be calculated as

$$\alpha = x' = e\Delta x \cdot \int G(s)ds/mc^2\gamma \cong \Delta x \cdot G \cdot l/(HR) \,, \qquad (1)$$

where $(HR)[Gs\cdot cm] = E[eV]/300$ is magnet rigidity of the high energy beam, l stands for effective length of the lens, $G(s)$ describes its longitudinal dependence with maximal gradient G at the center. For 300GeV beam the magnetic rigidity comes to $(HR) \cong 10^9[G\cdot cm]$. Propagation of kick $x'(s_0) = \alpha$ from its origin at the lens location s_0 to the IP located at s_1 counted from the lens's center, described by well-known formulas

$$x(s_1) = \alpha\sqrt{\beta_x(s_1)\beta_x(s_0)}\,Sin(\Delta\Phi)\,,$$

$$x'(s_1) = \alpha\sqrt{\beta_x(s_0)/\beta_x(s_1)}\left[Cos(\Delta\Phi) + \tfrac{1}{2}\beta_x'(s_1)Sin(\Delta\Phi)\right] \qquad (2)$$

$$\Delta\Phi \equiv \Delta\Phi_x(s_1,s_0) = \int_{s0}^{s1} ds/\beta_x(s)$$

where $\beta_x(s_1)$, $\beta_x(s_0)$ stand for envelope functions values at the IP and at the lens respectively (for other coordinate, y, the functions are $\beta_y(s_1)$, $\beta_y(s_0)$). As the IP is the focusing point for this lens, then $Sin(\Delta\Phi) \cong 1$ as the betatron phase changes to $\Delta\Phi \cong \pi/2$ during transformation to IP.

If displacement is bigger, than the transverse beam size of incoming bunch, which is between 3.5–9.9 *nm*, according to BDR ILC, the beams do not collide, so the requirement for the displacement at IP comes to

$$\sqrt{\gamma\varepsilon_x \cdot \beta_x(s_1)/\gamma} > \alpha\sqrt{\beta_x(s_1)\beta_x(s_0)}\,, \qquad (3)$$

where $\gamma\varepsilon_{x,y}$ stand for invariant emittance for appropriate coordinate (left side is just beam size at IP) . Substitue

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here (1), (2) for vertical emittance $\gamma\varepsilon_x \cong 10^{-5} m\cdot rad$, $\gamma\varepsilon_y \cong 4\cdot 10^{-8} m\cdot rad$, the vertical jitter emerges as the mostly serous. Let us estimate the tolerances for QF1 as if it is based at the tunnel site and its jitter is not correlated with the location of other lenses. For gradient in lens $G \cong 10 kG\cdot cm$, effective length of lens l=200cm, $\beta(s_0) \cong 10^4 m$, for 300-GeV beam energy, the vertical jitter (coordinate y) limited to 13nm [1]. This shift corresponds to the complete miss of bunches i.e. mismatch of the order of the beam transverse beam size sigma, so for partial mismatch this number must be reduced at least 10 times for 10% reduction of luminosity, coming to restriction of the order $\Delta y_m \leq 1.3 nm$. That is why allocation of final lenses on the same frame as the detector becomes crucial for design of any detector for colliding beams, see Fig.1. SO the final lenses become inevitable component of Detector.

IRON-FREE DETECTOR MAGNETS

The yoke is an element of the magnet circuit only, so anyone can consider a review for its elimination. For realistic diameter/length ratio homogeneity of field in a central region will drop, naturally with elimination of Iron. However with additional ampere-turns at the end region of superconducting solenoid (Helmholtz-type) the field can be made homogenous again to any level required.

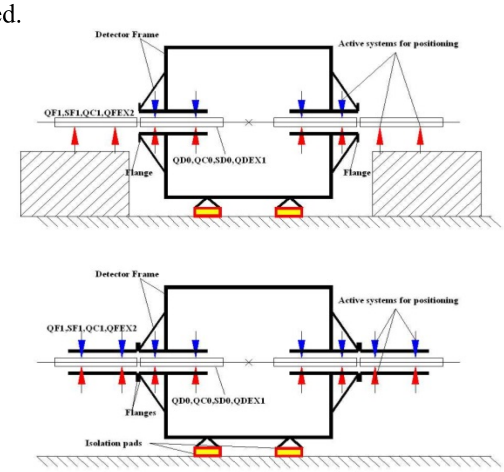

Figure 1: Top-Typical allocation of final doublet (ILC, CLIC), Bottom-recommended allocation concept.

These additional turns can be located, naturally, inside the same cryostat.

A family of Iron-free detectors is represented in Fig.2. It starts from just a single, solenoid, a). This single-solenoid system is inexpensive, compact, but it generates stray-field in transverse direction [9]. This stray field does not affect the beam dynamics however. Dual solenoid system b) is much better in this aspect. One minus of dual solenoidal system is that the field of outer solenoid, having opposite to the main solenoid polarity reduces the field in a central region (about 1.6 T for the 4th). Next member of this family is a triple solenoid system -c). There is no reduction of field at IP in this system. Minus of this system is that it requires additional big-size solenoid, although the field generated by this outer solenoid is much weaker, than the inner one. The next member of family is a one with multiple flux-return solenoids -d). This type [1] requires fabrication of many solenoids, but as the diameter of solenoids is small, these ones could be fabricated with much less effort, than the additional solenoid in b) and c). Finally, the last magnetic system, e) represents the multiple-return solenoid system with segmented solenoids for better coverage of volume by magnetic field. These regions used for spectrometry of muons.

COILS TECHNOLOGY

SC conductor cable 0.5”×0.1” made with 30 NbTi wires, embedded into grooves made in Al alloy carcasses. We advocate the direct cooling in liquid Helium bath (Fig. 3).

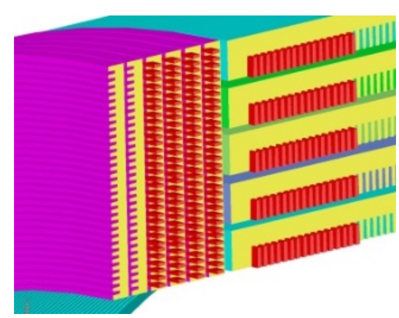

Figure 3: The cable soldered in carcasses made from Aluminium alloy. At the left- geometry for the Helmholtz end. At the right-geometry for regular part of solenoid is shown.

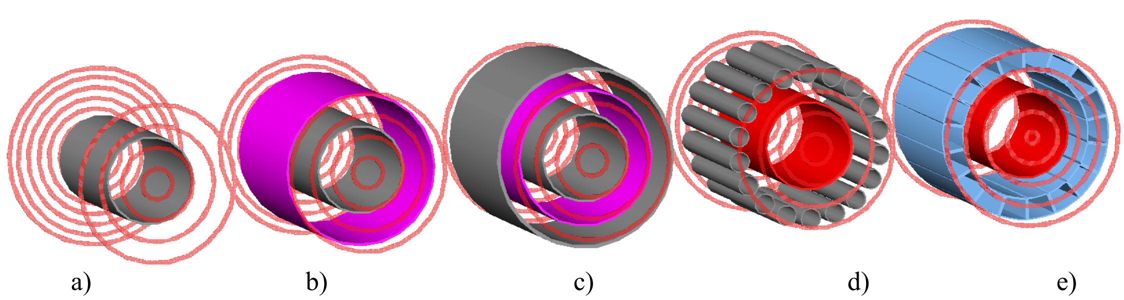

Figure 2: A family of Iron-free detectors: a)-single solenoid, b)-dual solenoids, c)-triple solenoids, d)- many return-flux solenoids. e)-many return-flux solenoids with sectorial shape. Each system of solenoids surrounded by the end-cap coils (front ones are shown diluted, see Fig.5).

Lowering temperature down to superfluid one is desirable option. For fabrication of grooves besides usual milling technology we are suggesting usage of 3D printing the entire carcasses (or its sections) from Al alloy.

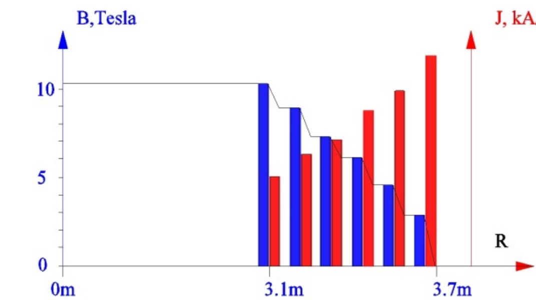

Figure 4: Linear current distribution by layers (red) and axial magnetic field (blue) as functions of radius of coil.

Central solenoid coil is sectioned by radius, Fig.4. In case of quench the current runs in each Al carcasses. For increasing the speed of establishing of magnets field, the conductance of Al alloy is reduced.

This type of magnet system is less expensive than the 4th Concept one due to reduced dimensions of solenoids involved and traditional detectors with Iron yoke. It is flexible for rearrangement of inner configuration for serving specific requirements of experiment (asymmetries while operating with polarized particles, different energies of colliding beam for better spatial resolution, etc.). Multi-solenoidal flux return allows higher magnetic field at IP, as there is no subtraction of field by outer solenoids. Absence of saturated Iron makes possible quick revers of field in detector defined only by the speed of reversing of current in central solenoid; this might be useful for exclusion of asymmetries of registration system.

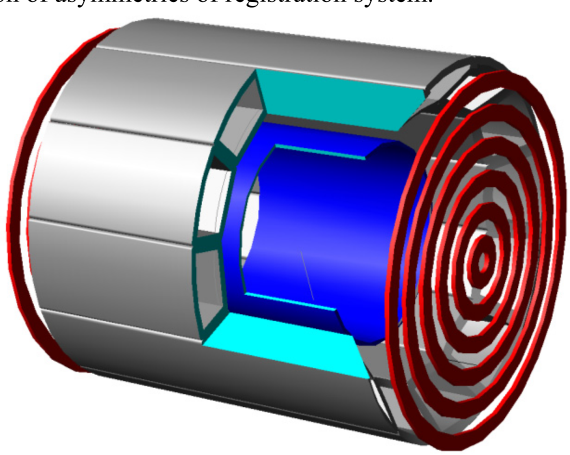

Figure 5: Many return-flux solenoids made with the shape of segments. This is done for better coverage the volume with magnetic field.

One example of similar system might be a central solenoid for Tokamak ITER (Ø4.3m x18m) [4], with magnetic field ~ 13 T. It uses Nb_3Sn square Incoloy jacket, segmented into six modules.

Result of calculations illustrated in Figs. 6, 7.

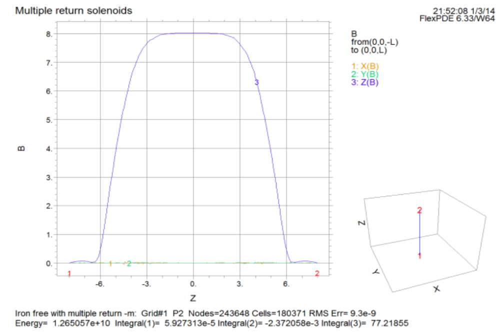

Figure 6: Elevation of magnetic field along central axis. Field value in *Tesla*.

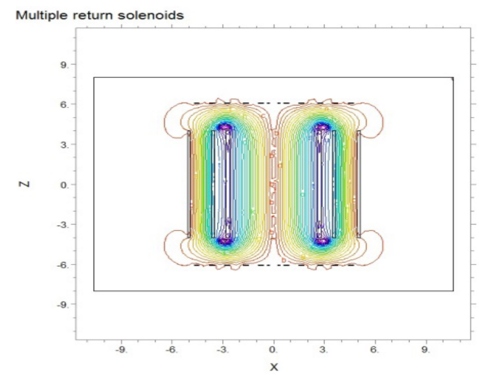

Figure 7: Lines of magnetic field in cross section.

CONCLUSION

By redirecting the magnetic field flux from one end of solenoid to another one by many small-diameter solenoids instead of a single one or with heavy Iron yoke making fabrication and cost of such system much less expensive,

Energy of magnetic field stored~300 MJ in a central solenoid, 32MJ in return solenoids coming to ~9GJ total, could be tolerable by proper arrangement of energy recuperation by sections. Anyway the stored energy associated, mostly with central solenoid (~8 T field).

REFERENCES

[1] A.Mikhailichenko, "*Iron-Free Detectors for Linear Collider*", arXiv:1407.5056 [physics.ins-det] Jul 18, 2014, 26pp.
[2] E.Barzi *et.al*., 3MF-02(and JPS=02 andJPA-04) FermiLab, October 9, 2012.
[3] A.V.Zlobin *et al*., "*Development of Nb_3Sn 11 T Single Aperture Demonstrator Dipole for LHC Upgrades*", Proc. of PAC2011, New York, USA, WEOS2.
[4] ITER design report, Jul 2001, EDA ser., No22.
[5] A.Mikhailichenko, "*Detector for Linear Collider*", CBN 02-3, Cornell, LEPP, Oct. 6, 2002, 7pp.
[6] S. Park *et al*, Contributed to 23rd Int. Symp. on Lepton-Photon Conf.: C07-08-13 Proceedings e-Print: http://arxiv.org/pdf/0708.0142.pdf
[7] N. Akchurin *et al.*, 2013. 10 pp. e-Print: arXiv:1307.5495 [physics.ins-det].
[8] A.Mikhailichenko, "*Do Detectors Need a Yoke*?", CBN 01-20, Cornell, LEPP, Oct. 6, 2001, 6pp.
[9] A.Mikhailichenko, "*Single Solenoidal Magnetic System for Iron-free Detector*", Jul 23, 2015, arXiv:1507.06694.

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