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DO DETECTORS NEED A YOKE?

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Abstract

We analyze here the use of iron yoke for detectors, installed at IP region of high-energy electron-positron storage rings and planned for future linear colliders. It looks that detector can be made operational without heavy magnet yoke after small investments.

Introduction

Contemporary detector impressed everyone who had a chance to stand nearby. Mostly impressive is the steel yoke, painted typically in red brick. Wires are trying to find an exit from the yoke's inside through any possible hole…

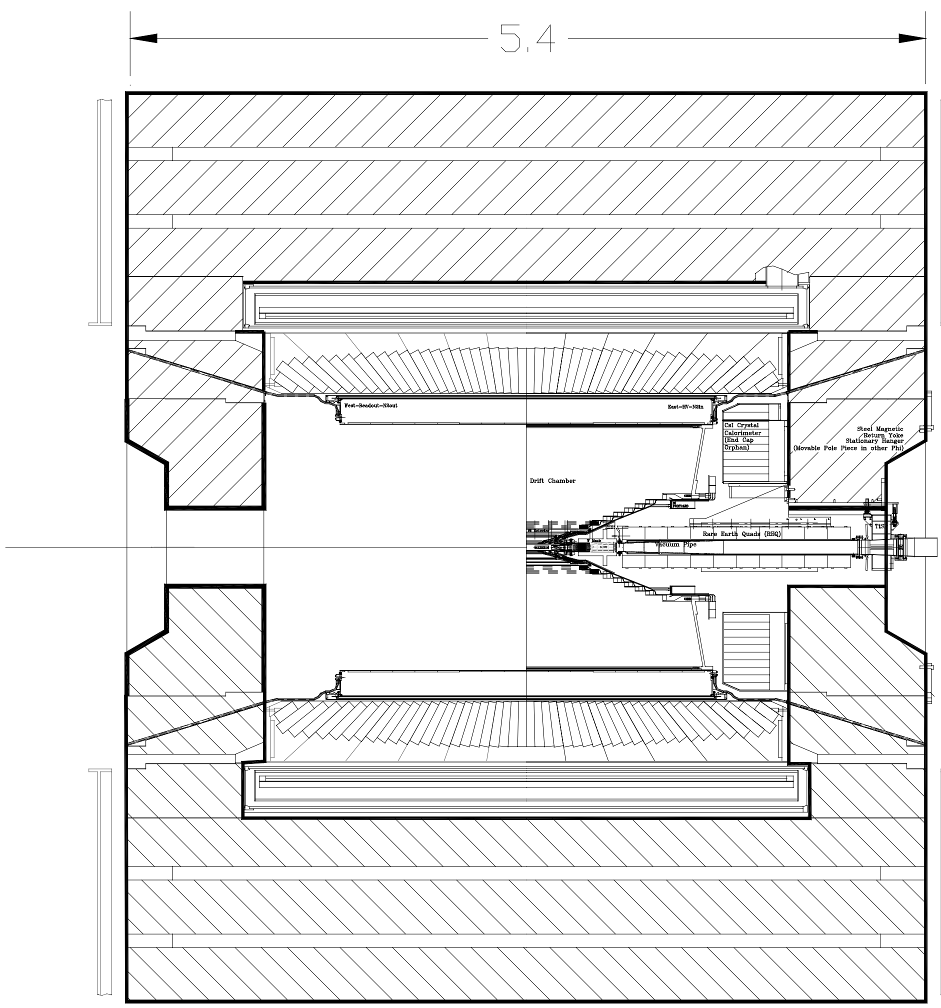

FIGURE 1: Typical detector (CLEO). Dimension is given in meters. Magnet yoke is hatched.

The magnet yoke's role is pretty prosaic, however. It serves as a flux return for magnetic field of superconducting solenoid. This solenoid generates a longitudinal field, which helps in identification of particle's momenta by measuring the curvature of theirs trajectory.

Other important components of particle's identification must be trimmed into the remaining space inside the yoke. They are: the vertex detector, wire chamber (or it's analog on functions), calorimeter, shower detector and some others.

Designers of such impressive device solved for themselves the problem of necessity of the steel yoke a years ago, probably.

As it is not now possible to find these initial considerations[1], I represented here my own impressions on this subject. Probably, the detector concept was developed many years ago, mostly, when superconductivity for solenoid was an option. So this solution, probably, migrate from non-superconducting one to the present days.

Meanwhile utilization of superconducting wire for solenoid brought a lot of new possibilities. These possibilities were not used in full scale, I believe. For example, high current density allowed by SC wire, makes possible to generate any field distribution within the volume required.

The subject might be important in a scope of detectors design for far future, when multi-hundred GeV level will be achievable for electron-positron colliders.

Field inside detector

It is well known that the field has strictly zero value for (infinitely) long solenoid. Field is homogenous inside the (long) solenoid.

Having the field homogenous in region of wire chambers helps in fast reconstruction of the particle's trajectory. The speed of contemporary processors dedicated to this job, allow corrections for the field inhomogeneity to be done in real time, however. Typically, the field variations from the homogeneous one happen at the fringe of main solenoid. In fact, the mostly resolution the wire chamber has at the central region. This makes these corrections less actual is mostly cases. Any way the possibilities of the present day field calculations and measurements make the job of trajectory analyses strict and simple.

In addition, some detectors have (superconducting) final quads inside the magnet field of detector and these quads generate the fields with significant value in region of wire chamber. This makes trajectory analysis more complicated also. Detector physicists are prepared for this and are ready to make all necessary corrections, however (what indicates a potential for further developments). What is important here, that there exist a solution for non-magnetic final focus lenses.

Situation with detectors installed on proton machines is probably different, as the proton/antiproton reactions generate jets, rather than individual trajectories. So the resolution of trajectories is much affected here.

[1] Will be interesting to compare these ideas with described here, if the first ones will be found.

Let first make an exercise with calculation of magnetic field inside detector from Fig.1. For obtaining reference field inside solenoid ~10kG, the total current of 3MA turns must run in whole coil and half of this value in Fig.2. In this figure the magnet lines are shown. As the lines represent the boundary of equal flux, they are not evenly distributed inside the solenoid. Magnetic field is homogenous, however.

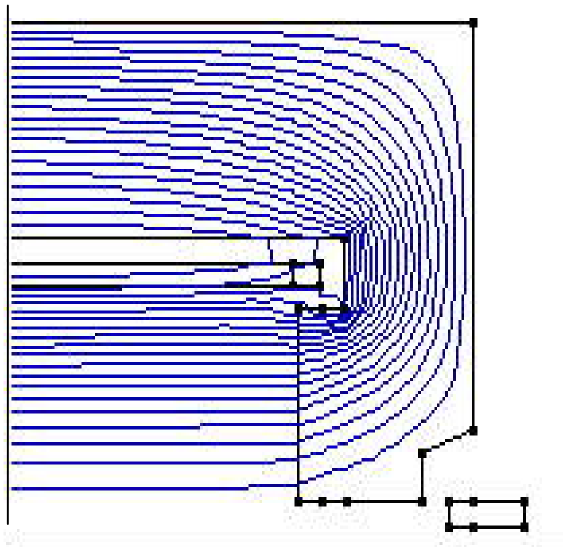

FIGURE 2: Magnetic field lines for detector from Fig.1. A quarter of detector is shown here. Abscise corresponds to longitudinal coordinate, calculated from the midplane of the detector, Ordinate corresponds to radial coordinate. Middle point of detector from Fig. 1 located at (0,0).

Analytical dependence of magnetic field as a function of longitudinal coordinate is represented in Fig. 3. Total integral of magnetic field is two times of ~1891 kGcm. Steel 1010 used for magnetic yoke.

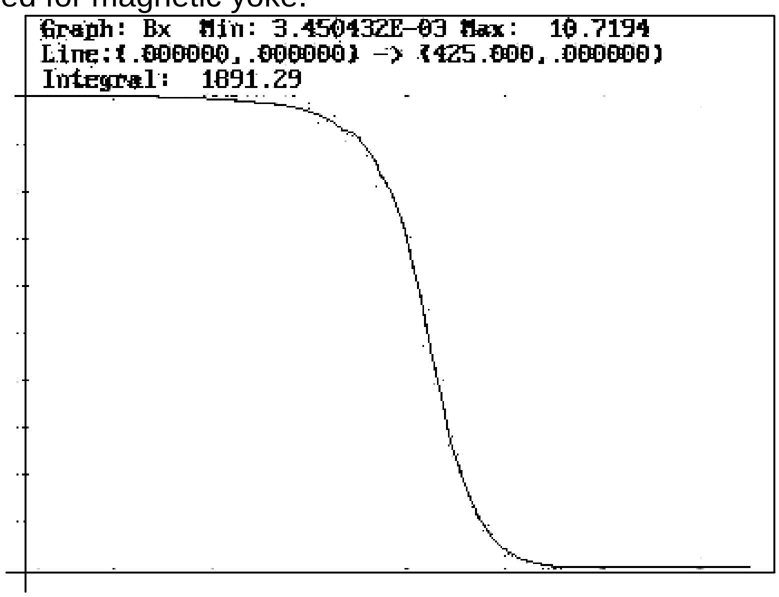

FIGURE 3: Magnetic field (ordinate) distribution in detector magnet as a function of longitudinal coordinate (abscissa), for magnet from Figs.1-2. Field at central region ~10 kG.

Now if just a material of yoke chosen made on air (what is an equivalent to the absence of iron at all), the field inside solenoid drops about 25% in a value at the center and decreases more toward the ends.

This can be compensated, however, by appropriate current distribution on the coil carcass. Let us consider an example of solution of problem with additional Ampere-turns at the end. This configuration can be called as solenoid plus Helmholtz coils type. We just added a total 1.2 MA turns at the end. The field distribution is shown in Fig. 3. We also added here an anti-solenoid for compensation of the field integral.

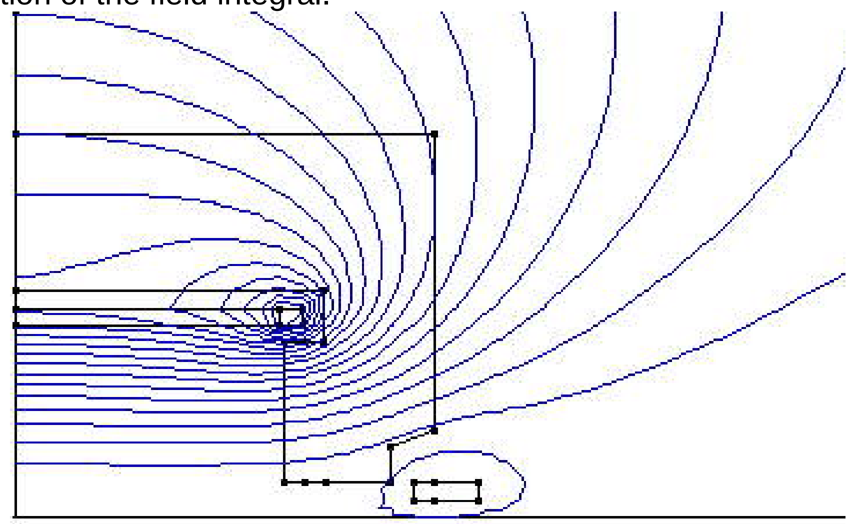

FIGURE 4: Magnetic lines map for main solenoid with additional current at the end region and anti-solenoid for integral compensation. Yoke shown for the reference and filled with air. The values of the field see in Fig4.

Xmin= .000000 Ymin= .000000
Xmax= 600.000 Ymax= 600.000

		.504			.113
.682	.618		.371	.231	.133
.693	.633	.511	.389	.250	
.719	.665	.549	.419	.273	.163
.755	.705	.599	.466	.310	.197
.803	.762	.658	.518	.361	.241
	.842	.747	.593	.411	.299
.930	.950	.923	.675	.455	.331
1.01	1.10		.822	.578	.398
1.09	1.31	1.48	1.11	.635	.421
1.15	1.59	2.06	1.20	.720	
1.18	2.08	3.14	1.66		.461
1.13	2.32			.944	.523
9.66	10.7	6.17	2.28	1.09	.549
9.84	11.1	8.99	2.98	1.20	.545
		9.00	3.08	1.28	.582
9.96	10.5	8.27	3.29	1.28	.579
10.0	10.0	7.41			
10.0	9.80	4.85	7.16	1.26	.550

FIGURE 5: Numerical values for the field amplitude from Fig.3. The contours of the coils and detector are visible here. Frame has dimensions 6x6 meters^2.

This anti-solenoid added here for possible compensation of coupling. Other solution is rotated quads.

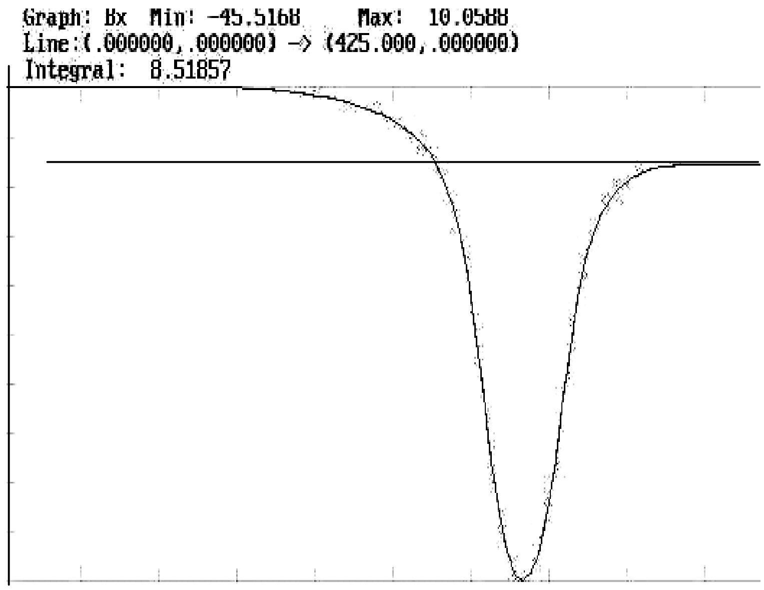

FIGURE 6: Magnetic field distribution along the axis for the picture from Fig. 3. Field value at the center is ~10 kG. Field at the region of compensation solenoid is –45.5 kG. Line represents ~zero field level.

The field homogeneity is not worsen, than for case with iron yoke presence.
One can see, that at the distance of ~1-2 meters the fields naturally drops to ~0.5kG, where local iron shields can be implemented easily. Some local shielding far from the solenoid ends can be implemented easily.

Discussion

If we agree, that the yoke is an element of magnet circuit only, one can consider its elimination. With additional ampere-turns at the end region of superconducting solenoid the field can be made homogenous at any level required. Additional heat and electricity losses are small. These additional tuns can be located, naturally, on the same carcass inside the same cryostat. Separate carcass is also possible.
Of case, shower detector requires some material, but led is more suitable for this purpose. In any case this a problem of different order.
Price for this: a field propagating around the coil can implement some discomfort. This can be easily vanished, however, by magnetic screening *far* from the coil, when the field is small, by thin steel sheets around detector cave for example. Mostly of elements of the vacuum chamber around detector, as a rule, made on nonmagnetic materials, such as StSteel and Copper. Vacuum can be supported by NEG pumps. IP lenses made with SC wire are nonmagnetic.

It is true, that the energy stored in the stray field becomes higher for the case without iron. The energy stored in detector with yoke is about 7MJ in example, considered above. For the system without iron the energy stored in the field is about double of this. This value still manageable, however.
Advantages are evident. Internal parts of detector can be made easy accessible in a new design. The same is valid for electronics and cables at the ends.
The possibility for lightweight alloy utilization is open now. Aluminum and titanium alloys become acceptable now. Detector becomes a lightweight unit as a whole.
Anti-solenoid helps in beam dynamics and is an operational part in some working detectors and storage rings. It was considered here as example of the level of complication. In some laboratories it recognized as negligible and anti-solenoids are use in circular machines for the elimination of coupling, introduced by solenoidal field of detector.
Progress in cryo-design makes possible utilization of appropriate cryo-coolers for the SC cooling. This makes all elements of detector even more compact.
One can consider the scheme with more coils. Say additional Helmholtz type system of room temperature around whole detector can eliminate the mostly field around.
As the yoke is eliminated, there is possible now to consider very high magnetic field. Say 70-100 kG field might be considerable in a future, not practically possible for detectors with iron yoke. This will be important for the detector of the next linear collider. Here the compensation of coupling introduced by solenoidal field is not so important.
This might be interesting for future photon collider as well, as it helps in arrangements of the photon beam optics and it's maintenance.
The same consideration can be applied for any focusing solenoid[2].

Conclusion

We concluding, that there is no apparent limitation for making detector's magnetic field region without heavy iron yoke. Indeed this makes detector more flexible unit for easy upgrade and maintenance.
Designer can get additional freedom in composition of next generation detectors. This freedom will be especially important for the future multi-TeV linear colliders.

Acknowledgments

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[2] (sect #5 on CESR's linac, for example).