MAGNETIC SHIELDING FOR THE D0 DETECTOR SOLENOID UPGRADE

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Abstract

A proposal to add a superconducting solenoid to the D0 detector at Fermilab has recently been approved. During collider operations, the detector is currently traversed by beams from both the Tevatron and the Main Ring. The Main Ring beam is accelerating protons for antiproton production, while the Tevatron beams are colliding. In the event where the D0 solenoid upgrade would be completed before the Main Injector – a replacement ring for the Main Ring, located in a separate tunnel – the Main Ring beam would have to be shielded from the solenoid leakage flux. Using 3D calculations, we estimate that it would be feasible to keep the stray field along the Main Ring beam at level that would not cause orbit control or beam stability problems. We estimate the mechanical forces both on the solenoid and on the magnetic shield.

Introduction

In the present mode of operation, the Main Ring simultaneously accelerates protons used for antiproton production while the Tevatron proton and antiproton beams are colliding. In order to minimize detector background, a special Main Ring overpass was built for CDF, the first detector put in service. For various reasons, which include high cost and additional complexity introduced by vertical bends, no elaborate overpass was built for D0, the second of the two detectors. As a result, the Main Ring beam now circulates through D0 approximately 2 m above the the Tevatron beam and the interaction region (Figure 1). All problems and inconveniences resulting from this state of affair will be eliminated as soon as the Main Injector – a new machine, housed in a completely separate tunnel – is put into service. This is scheduled to happen in January 1999.

A decision was made this year to upgrade the D0 detector by the addition of a 2 Tesla superconducting solenoid. There is a small possibility that the D0 detector would have to take data with the new solenoid in before the Main Injector is ready. As shown in Figure 2, if no special precautions are taken, the magnetic field due to the solenoid along the Main Ring beam path is expected to be on the order of 200-500 Gauss. Since almost all available volume inside the detector is already occupied by calorimeters, it is not possible to use a large iron structure to channel the return flux of the solenoid. We have therefore investigated the possibility of magnetically shielding the Main Ring beam with a soft iron pipe.

Effects of Stray Magnetic Fields

It is sufficient to consider separately the effect of the longitudinal and transverse components of the magnetic field. While the longitudinal component of the field introduces a small amount

*Operated by the Universities Research Association, Inc., under contract with the U.S. Department of Energy.

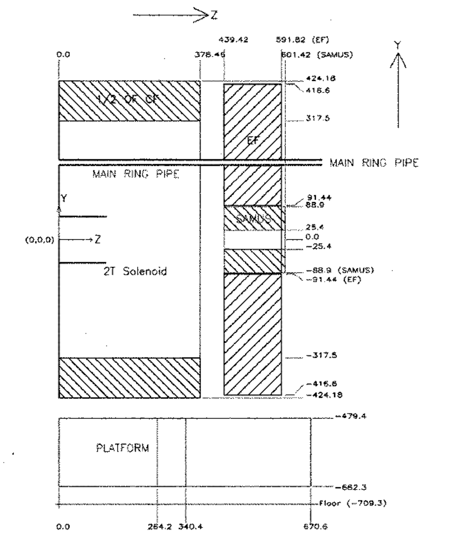

Figure. 1. Side view of the D0 detector. Only one half of the detector is shown. All dimensions are in cm.

of coupling of between the horizontal and vertical motion, the transverse component deflects the beam. Using Ampere law, it is not difficult to show that along the beam path, $\int_{\infty}^{\infty} B_z\,dz = 0$. With the origin at the center of the detector, $z = 0$ one has by symmetry, $B_y(-z) = -B_y(z)$ and therefore, no net angular deflection. Nevertheless, the net closed orbit distortion does not vanish. For a practical solenoid, any residual coupling due to the longitudinal field is expected to be extremely small and easily correctable. The main function of the magnetic shield is therefore to minimize

$$
\begin{aligned}
I &= \left| \int_{-\infty}^{\infty} \left[\int_{-\infty}^{z} B_{\perp}(z')dz' \right] dz \right| \\
&= \left| \int z B_{\perp}(z) dz \right|
\end{aligned}
$$

To limit the background due to halo particles hitting the beam pipe and Main Ring operation, a rough estimate shows that I should be kept below 0.01 T-m^2.

Field Calculations

Three-dimensional magnetic field calculations were performed with TOSCA, a well established finite element code. Only the effect of the 2 T solenoid was considered. The flux originating from the toroid excitation coils has been ignored. Although this is not exactly the case, the Main Ring beam pipe was assumed to be centered horizontally in order to take advantage of symmetry to reduce the problem

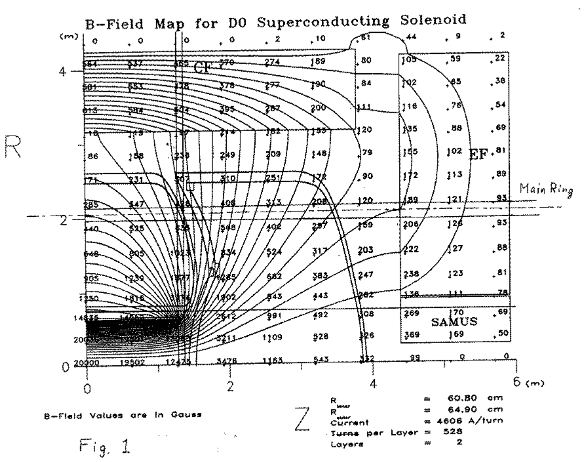

Figure. 2. Magnetic field map of the D0 detector solenoid. 1/4 of the detector is shown. The toroids are not excited.

size. The field distribution of the axial component B_z along the path of the Main Ring beam is presented in Figure 3 and the corresponding transverse component B_y is shown in Figure 4.

Figures 5 and 6 demonstrate the effect of the magnetic shield. The latter is a 6 cm inner radius, 2 cm thick, 8 m long soft iron pipe which is magnetically isolated from the EF toroid. Calculations show that the shield is fairly saturated ($\simeq 1.6$ T) and not surprisingly, the longitudinal component of the field is not significantly reduced. However, the transverse component is reduced by approximately an order of magnitude and so is the integral I. No significant variation in the field are observed for small variations in the transverse position of the beam. The two sharp peaks at $z = \pm 390$ cm in Figure 5 are caused by fringing in the gap between the shielding pipe and the EF toroid. In practice, it would be important to pay attention to the method used to support the shielding pipe in order to minimize high order multipole contribution from the gap region. Although this does not appear to be necessary, the longitudinal field could be reduced by using small bucking solenoids around the shielding pipe. Figure 7 and 8 illustrate the effect of three 200 A solenoids located in the center and at both extremities of the shielding pipe. Note that the transverse field is not affected significantly.

By integrating the Maxwell stress tensor over a surface enclosing the shield, we estimate the attractive force between the solenoid and the shield to 2000 N. The shield mass is approximately 525 kg, so this represents roughly half of the gravitational force.

Conclusions

Although this is a preliminary analysis, we conclude that it is technically feasible to shield the Main Ring beam and operate the D0 detector with a 2 T solenoid. A more detailed analysis would require the inclusion of the toroid coils in the magnetic field calculations. Although it is probably unimportant, the distortion of the solenoidal field in the vicinity of the interaction region caused by the presence of the shield should probably be investigated.

Acknowledgments

The authors would like to thank John Marriner and Glenn Goderre for their valuable comments.

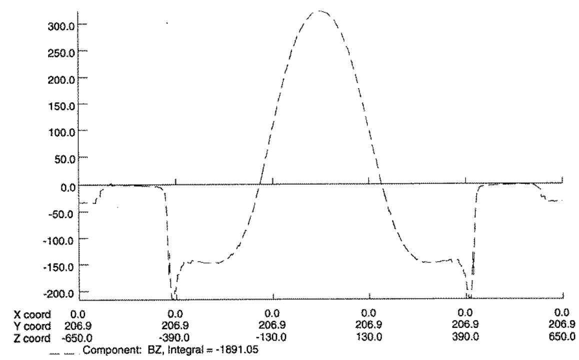

Figure. 3. Longitudinal field along the Main Ring beam path. No shielding.

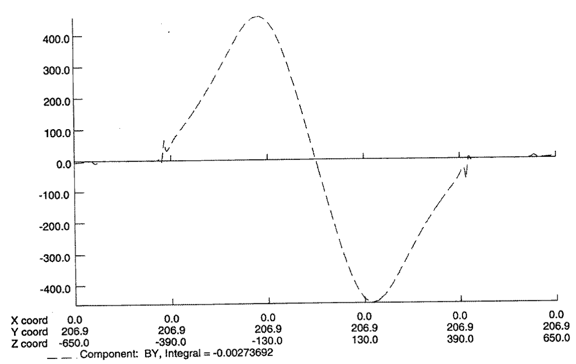

Figure. 4. Transverse field along the Main Ring beam path. No shielding.

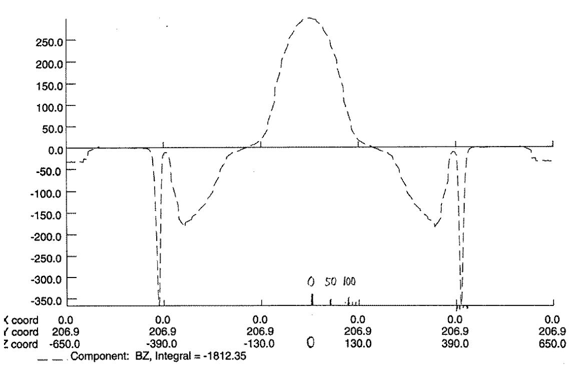

Figure. 5. Longitudinal field along the Main Ring beam path. 2 cm thickness soft iron shield.

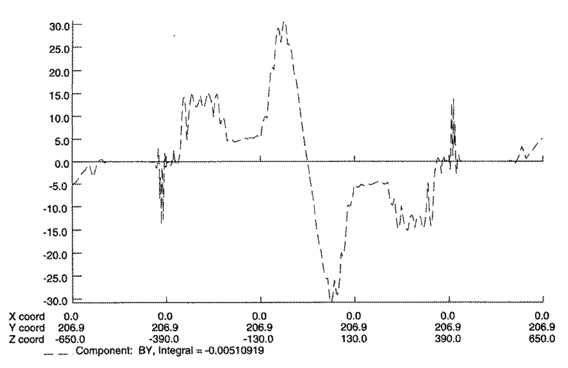

Figure. 6. Transverse field along the Main Ring beam path. 2 cm thickness soft iron shield.

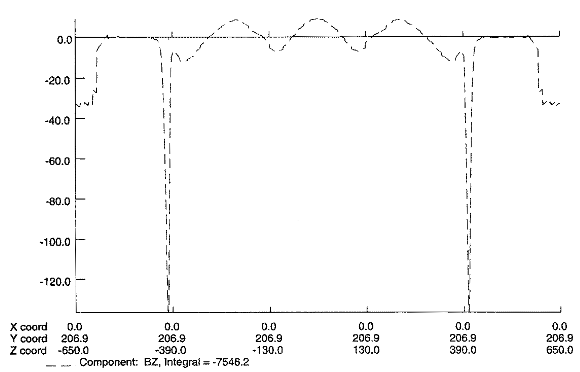

Figure. 7. Longitudinal field along the Main Ring beam path. 2 cm thickness soft iron shield and 3 bucking solenoids.

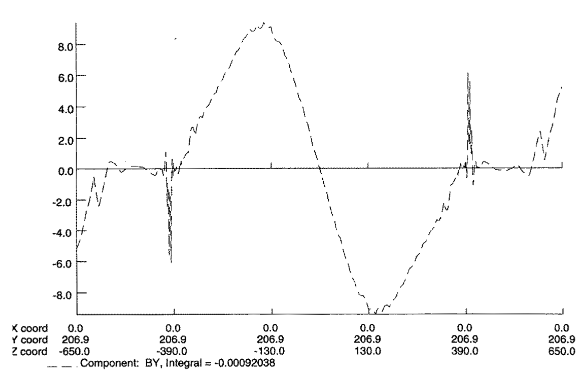

Figure. 8. Transverse field along the Main Ring beam path. 2 cm thickness soft iron shield and 3 bucking solenoids.