SLAC-PUB-227
September 1966

MAGNETIC DETECTOR FOR A 3-GEV e^+e^- STORAGE RING*

by

A. M. Boyarski,† H. Brechna, F. Bulos, R. Diebold, B. Richter
Stanford Linear Accelerator Center
Stanford University, Stanford, California

ABSTRACT

A superconducting magnet coil has been designed for a particle detector for the proposed 3-GeV e^+e^- storage ring at SLAC. Comparisons are made between such a magnet and a conventional one when used in a storage ring detector. Momentum resolution requirements are discussed. A system of wide gap spark chambers, shower chambers and absorption chambers will be used for particle identification. Cost estimates are given.

*Work supported by the U.S. Atomic Energy Commission.

†Paper presented by A. M. Boyarski at International Symposium on Electron and Positron Storage Rings at Orsay, September 1966.

Investigations have been carried out at SLAC on a magnetic detector to be used with the proposed 3-GeV e^+e^- storage ring.[1] Since the e^+e^- reactions generally produce particles distributed over all of the 4π steradians about the interaction region, a large solid angle detector is needed. At the 3-GeV storage ring energy, separation of pions, kaons and protons is difficult without a magnetic field. Hence the design includes a magnetic field and absorber for identifications of π, K and P, while a set of shower counters and absorber is used for identification of γ, $e^{\pm}$ and $\mu^{\pm}$ particles. Unstable reaction products such as Λ^o, Σ, K^*, etc., will be identified by their decay products.

Magnetic Field Requirement

The error determination of the $(\text{mass})^2$ of the particles can be shown to be (ignoring radiative corrections)

$$\sigma_{m^2} \simeq p^2 \sqrt{2\left(\frac{\sigma_p}{p}\right)^2 + 4\left(\frac{\sigma_{2E_o}}{2E_o}\right)^2}$$

where σ_p/p = the momentum measuring error in each particle of the pair and $\sigma_{2E_o}/2E_o$ = uncertainty in the total $e^+ + e^-$ energy $\simeq$ .16% at 3 GeV. For clear separation of events, it is necessary that $\sigma_{m^2} \lesssim \frac{1}{3}\Delta m^2$, where Δm^2 is the difference of the squares of the different masses. With this criteria, it is possible to calculate the σ_p/p that is required for πK and KP separation as shown in Fig. 1. At 3 GeV the required resolutions are 0.6% and 1.7% for πK and KP separation respectively.

Considering the increased cost and difficulty of attaining the 0.6% resolution, we have chosen a less stringent design figure of

$$\frac{\sigma_p}{p} = 1.0\% \text{ at } p = 3 \text{ GeV/c} \quad .$$

This allows clean KP separation up to E_o = 3 GeV and πK separation to 2.5 GeV.

Identification of reactions with more than two final bodies is more difficult. Calculations performed for some reactions with four final bodies have shown that this momentum resolution will also enable identification of a large fraction of such events.

The uncertainty in the measurement of a particle momentum comes from multiple scattering of the particle in the measuring media, from the measuring error of spark positions and from systematic effects such as optical distortions and coherent displacements of tracks in spark chambers due to electric and magnetic field effects.

The measuring error σ_M of a spark position in a conventional spark chamber is ~ 0.2 mm. This is also the typical scatter of a streamer position from the particle trajectory due to the random diffusion of electrons left by the ionizing particle. By measuring four spark locations, one on each end of a track of length L (meters) and two near the center, the momentum uncertainty is given by

$$\left(\frac{\sigma_p}{p}\right)_M = \frac{0.267}{BL^2} \; p \; \sigma_M$$

where p is the particle momentum in GeV/c

B is the magnetic field in kgauss.

For 1% resolution at 3 GeV/c the requirement is that

$$BL^2 = 16 \text{ kgauss - m}^2 \quad .$$

The magnet configuration that is described here has $B \simeq 11$ kgauss and a track measuring length of 1.2 m to satisfy the above criteria.

The momentum uncertainty due to multiple scattering in the spark chamber plates and gas (radiation length ~ 200 m) is then $\sim 0.3\%$ and is thus negligible.

Optical and systematic errors can in principal be determined by calibration measurements or compensation techniques. These sources of error will be assumed to be less than the spark position measuring error above. Hence the criteria $BL^2 = 16$ kgauss - m^2 will be used for the magnitude and extent of the magnetic field.

Choice of Magnet Configuration

In this report a solenoidal field configuration is described with the magnetic field aligned along the beam direction. Such a configuration provides good momentum resolution over a large solid angle with no conductor material between the beam interaction region and the magnetic field. The large solid angle is especially useful for detecting events with many final bodies.

Such a configuration does have difficulties, however. The magnetic field along the beam orbit couples horizontal and verticle betatron oscillations, preventing the storage ring from operating with a thin ribbon beam. This results in loss of luminosity. Compensating solenoids placed on either end of the detector solenoid eliminate this coupling problem when adjusted to give $\int B \cdot d\ell = 0$ along the beam orbit in the region of the solenoids. Another difficulty of the solenoid field is that it does not have good momentum resolution at small angles ($\lesssim 35^{\circ}$) to the beam direction. Photography of spark chambers is hindered by the beam pipe, compensating coils and quadrupoles. Other magnetic field configurations can be chosen which do not have some of these problems, but then the solid angle over which momentum measurements can be made is not as large.

A usable magnetic field volume of 3.0 meter diameter $\times$ 2.4 m length has been chosen in this design. Allowing an average radius of 0.3 m for the vacuum chamber and trigger counters, this leaves $\sim$1.2 m of measurable particle track length in the magnetic field. A larger magnetic field volume increases the difficulty of photographically locating a spark to the 0.2 mm value over the full volume. On the other hand, a smaller volume with a similar diameter to length ratio produces a larger B field at the orbit if BL^2 is kept constant, which then requires larger compensating coils. The beam pipe and trigger counter would then occupy a larger fraction of the magnetic field volume. If superconductor coils are used, then the total amount of superconductor material would increase since the allowable current density of a superconductor decreases with increasing magnetic field on the wire. A three-meter diameter magnetic field size is a reasonable compromise.

Superconductor versus Conventional Conductor

A stabilized superconductor consisting of a superconducting material such as NbTi embedded in a normal conductor such as copper or aluminum, can carry an order of magnitude more current than a normal copper conductor. For a storage ring detector, this makes it possible to consider designs in which particles pass through the coil walls.

In the case of the solenoid design, the shower chamber can now be placed outside of the coils, with the coils themselves contributing the first ~ 2 radiation lengths in the shower detector. With conventional coils, the shower chambers would have to be placed within the coils, with considerable loss in the usable size of the magnetic field volume. The thinner coil also allows a somewhat smaller diameter for the iron shell placed around the coil. Cost estimates made for both types of coils indicate that for a similar diameter coil, the superconductor can provide twice the magnetic field as a conventional coil for about the same total construction cost. A superconducting magnet is therefore preferable for this detector.

Solenoid Detector Design

Figure 2 shows the overall arrangement of the magnet and spark chamber areas. Streamer chambers are shown in the region within the coils to provide particle detection over a large solid angle. Other geometries, such as cylindrical spark chambers, may also be used.

The magnet coils have been split to provide more B field for particles at small production angles, and also for possible 90° stereo of the interaction region. The stabilized superconductor coil size is 300 cm diameter × 70 cm length × 2.5 cm thick per coil. A current density of 8000 A/cm^2 is used. The coils are immersed in liquid He at $4.2^{\circ}K$, which in turn is thermally insulated from the casing by a 2.5 cm vacuum and superinsulation region on both sides of the dewar. The total thickness of the casing is 13 cm. Long support structures (not shown) will hold the coils to the iron structures around the coil to minimize the thermal conduction between the $4.2^{\circ}K$ dewar and the iron at room temperature. The thermal conduction through the supports and cables is estimated to be 60 watts. Compensating coils are shown on either end of the solenoid.

With 3×10^6 ampere-turns, the field inside the solenoid is typically 11 kgauss. The expected momentum resolution of such a coil configuration (without the iron) is shown in Fig. 3. A resolution $\sigma_p/p \lesssim 1\%$ at 3 GeV/c is obtained over 8.8 steradians ($|\cos\theta| < 0.70$) with a progressively poor resolution at larger values of $|\cos\theta|$. The compensating coils decrease the resolution at large values of $|\cos\theta|$, but only slightly.

The magnetic field along the beam axis (no iron) is shown in Fig. 4. The compensating coils are such that $\int B_z dz = 0$. The long range field will be reduced by the iron return path. One end of the coil is blocked by an iron plate both to provide a return path and also to serve as an absorber for particles produced at small angles. The other end must be left open to allow photography of the spark chambers. Iron will be placed here wherever possible. It may also be possible to enclose both ends of the solenoid if cameras with very wide angle ($>90^{\circ}$) lenses are placed within the enclosed solenoid. Such photography requires spark mode wide gap chambers with transparent, wire mesh walls. Alternatively, a system of digital readout spark chambers could be used.

The magnet is energized from a 20 volt, 2000 ampere battery bank charged continuously from a rectifier power supply. A regulation of 0.1% is required for stable operation of the superconductor.

A closed system refrigerator will supply the liquid He. Such a liquifier will require 200 kW of power.

The shower chambers, consisting of a total of 10 radiation lengths of lead, are shown surrounding the coils. A total of 40 cm of iron (~ 2 interaction lengths) is then placed around the coils and shower chambers. Electrons are identified by their showers in the lead while pions, kaons etc., are identified by their absorption in the iron.

Trigger counters are placed in three places. Inner trigger counters lie next to the vacuum chamber, outer trigger counters are placed within the shower counters (at the shower maximum) and a set of cosmic ray anti-counters is placed outside of the iron shell. The outer (shower) trigger counters and the anti-counters will also be used to reject e^+e^-, $\mu^+\mu^-$, $\gamma\gamma$ events while studying the strongly interacting events with their low rates.

Table I gives the specifications of the detector.

Table II gives the cost estimates for the magnetic detector. This estimate does not include contingency or overhead.

TABLE I

MAGNETIC DETECTOR SPECIFICATIONS

Solenoid length (Helmholtz)	2.4 m
Solenoid coil inside diameter	3.0 m
Magnetic field	11 kilogauss
Ampere turns	3×10^6
Magnet power	superconducting
Nominal momentum resolution at 3 GeV/c	$\frac{\sigma_p}{p} \leq 1\%$ over 8.8 steradians
Weight of stabilized coils	3.5 tons
Weight of iron	206 tons
Weight of lead	23 tons
Refrigerator power requirement	200 kW

TABLE II

COST ESTIMATES (× 1,000)

Coil	$130
Coil structure and supports	60
Dewar and vacuum vessel	175
Cryostat	175
Power supply	10
Lead	45
Iron and supports	240
Compensating magnets (2)	80
Cameras, spark chambers, electronics	565
Total Materials	$1,480

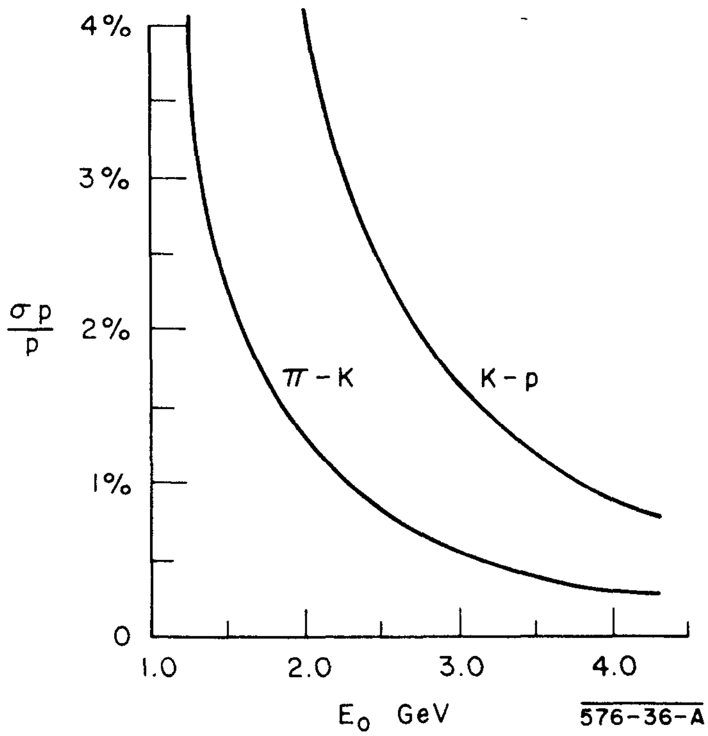

FIG. 1 -- The standard deviation momentum resolution necessary to distinguish particle pairs by three standard deviations, as a function of the particle energy, E_0.

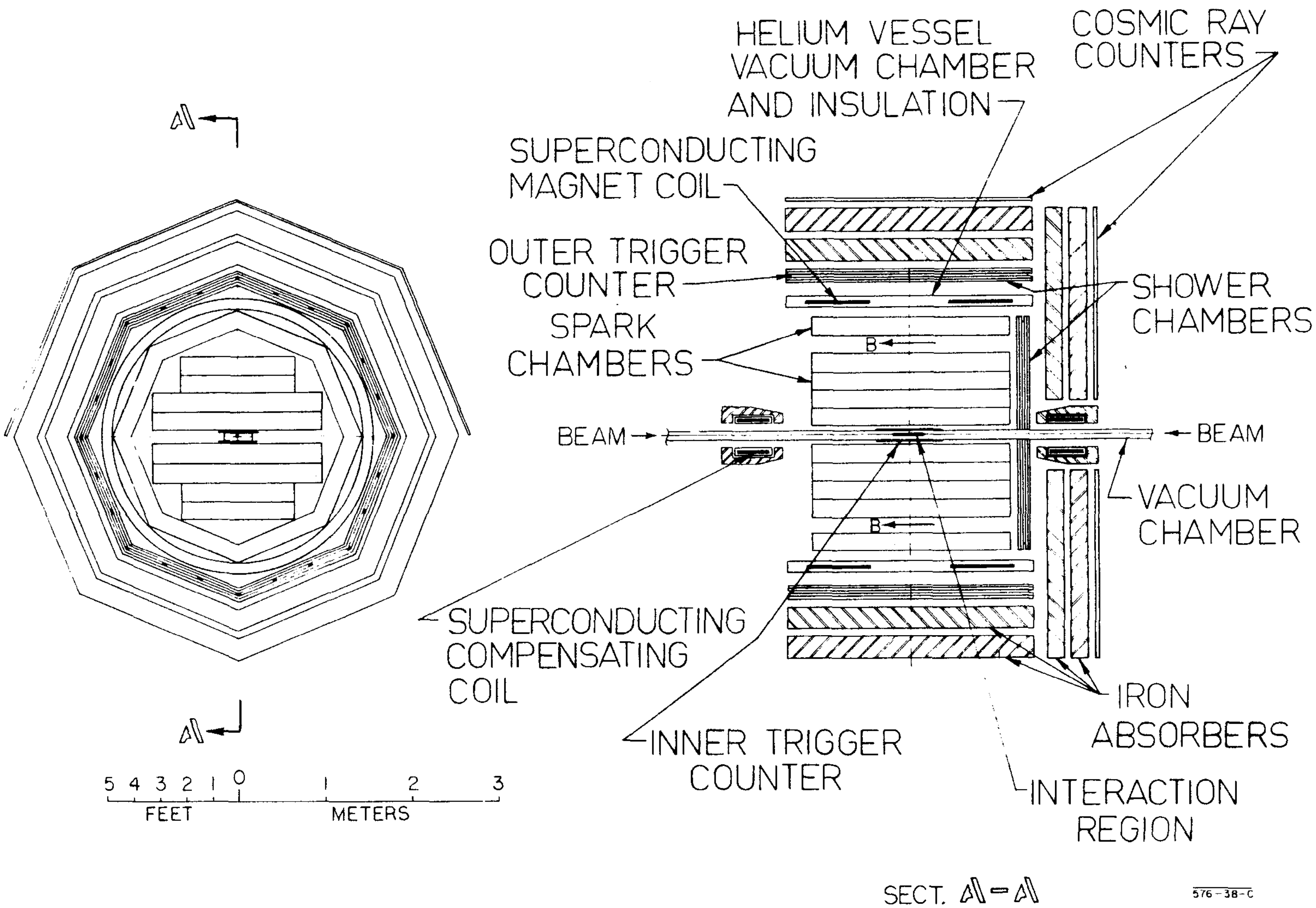

Fig. 2 — SUPERCONDUCTING MAGNET DETECTOR

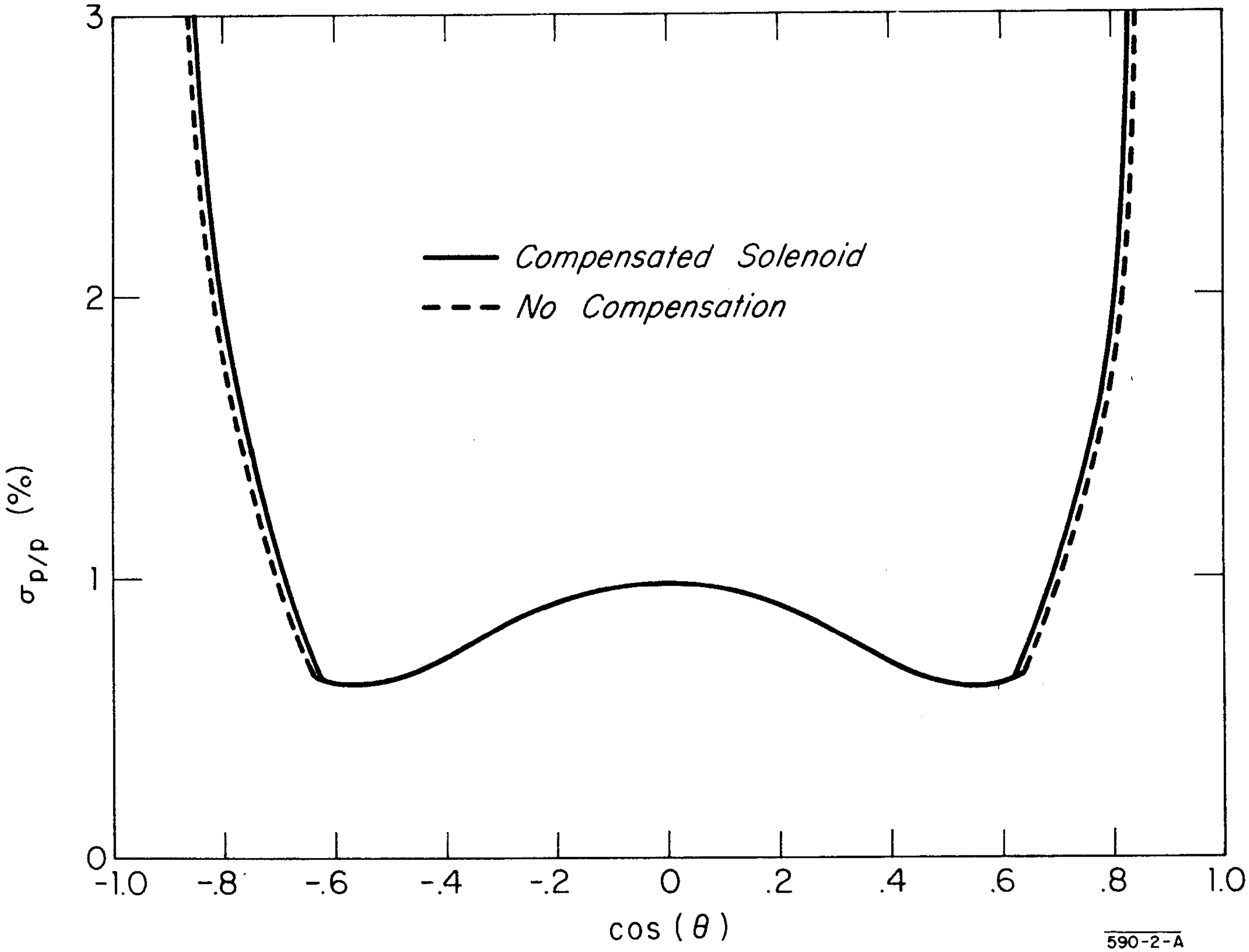

Fig. 3 ESTIMATED MOMENTUM RESOLUTION $\sigma_{p/p}$ (%) vs PRODUCTION ANGLE θ OF A 3 GeV/c PARTICLE

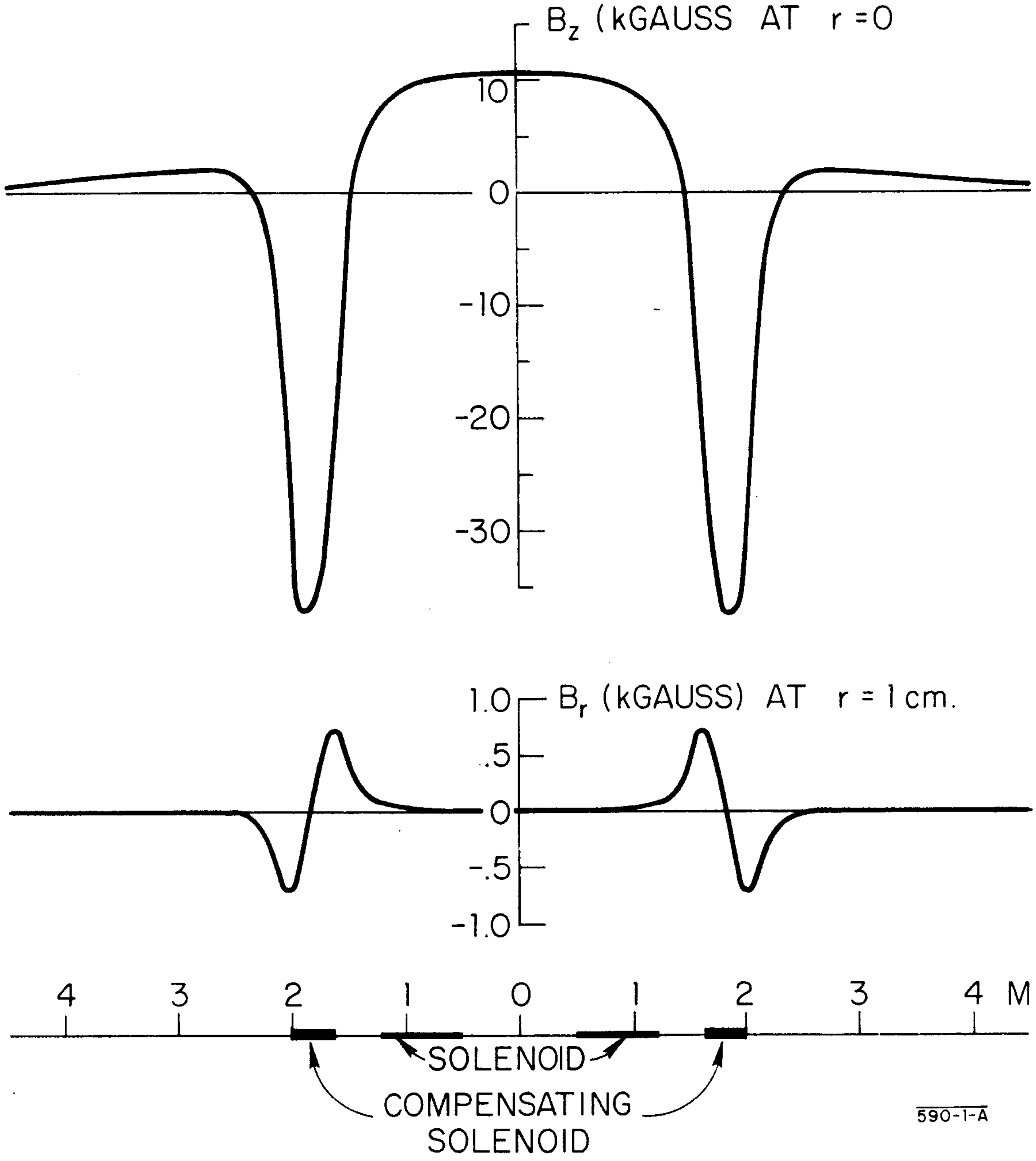

Fig. 4 MAGNETIC FIELD AT AXIS OF COMPENSATED SOLENOID (NO IRON)