Magnet Mapping

John Haggerty

What is needed?

- To achieve $\Delta p/p \simeq 0.5\%$ means we need to map the field to a precision of about 0.1% or so which corresponds to about 15 gauss
  - It’s possible we could tolerate a little worse precision, maybe 0.2-0.3%, but we would have to more carefully evaluate the error budget
- At this precision, the field is largely determined by the steel
  - We have measured the B-H curve of a sample of HCAL steel
  - Wuzheng Meng (retired from CAD) has done a 3D OPERA calculation of the field

Mapping the BaBar Solenoid

- Mapped to a precision of 1.7 gauss (RMS) in the tracking volume (5 gauss in entire solenoid)
- "However, systematic errors in the field determination can lead to momentum errors larger than the statistical error. Simulation studies[2] show that systematic field errors of only one or two gauss can produce visible changes in the parameters of reconstructed tracks, indicating that the field should be measured to better than 2 gauss within the tracking volume."

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Field Measurements in the BaBar Solenoid

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Abstract

The magnetic field within the BaBar super conducting solenoid (3.8m long by 3m diameter, at a field of 1.5 Tesla) has been measured with a set of hall probes placed on a mechanical arm that rotated about, and moved along, the axis of the coil. The measurements were fit to a functional model which contains polynomial terms to order 40 for the B_Z and B_R field components, a few trigonometric-bessel terms having one-, two-, and six-fold ϕ symmetry, and 24 dipole terms positioned on the end plates to describe the non-uniform iron distribution of these plates. The measurements and the model agree to 1.7 gauss (rms) within the drift chamber tracking volume, and to 5 gauss in the fully mapped volume ($-1.8 \le Z \le 1.8$m, $R <$ 1.3m).

Overview

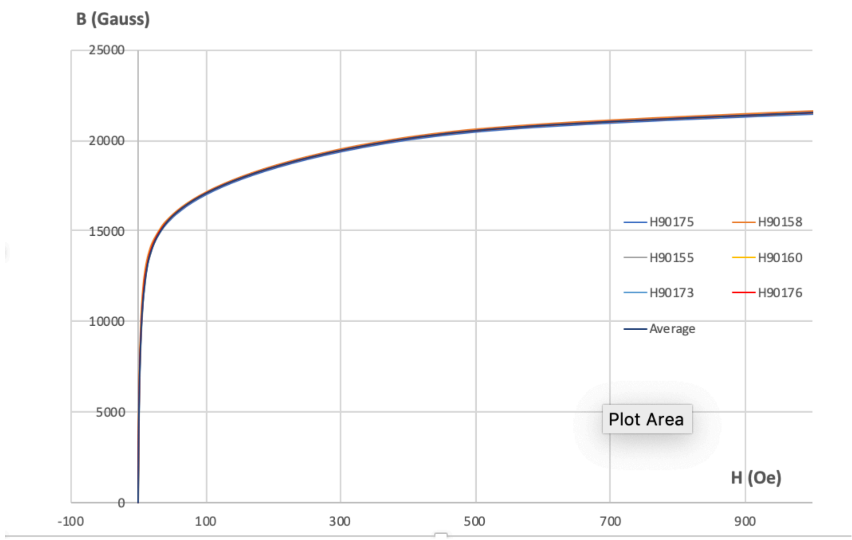
The BaBar detector contains tracking and particle identifying devices that measure properties of tracks produced in the interaction region of the e^+ and e^- beams at PEP II. Two subsystems in the detector, the drift chamber and the silicon vertex chamber, provide the positions and angles of the charged particles. These chambers are also immersed in a 1.5 Tesla magnetic field so that the momentum of charged particles can be measured. The magnetic field is generated by a super conducting solenoid, 3.8m long and 3.0m in diameter. The coil is surrounded by an iron return path that has a hexagonal cross section, and by end plates (doors) that provide the pole faces for the field. An elevation view of the detector is shown in Figure 1. The doors can be moved out of the way for access to the chambers inside. The doors and the hexagonal sides are called the instrumented flux return (IFR) because they are constructed from multiple parallel plates of iron separated by spacers to provide gaps for tracking detectors that measure the trajectory and range of particles passing through the iron.

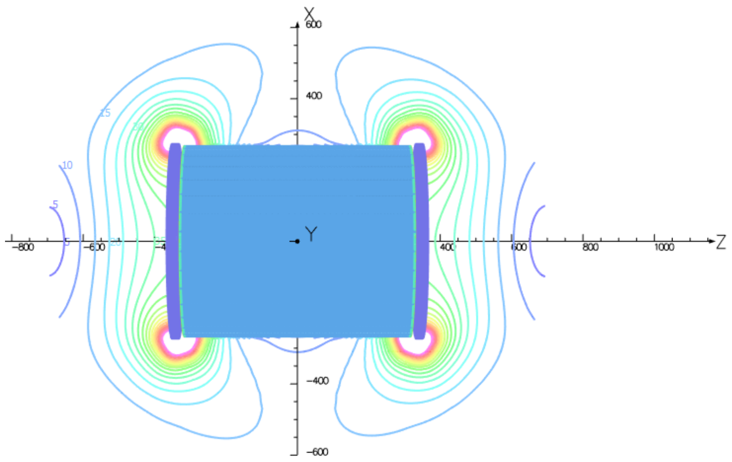
The magnetic field within the tracking volume of the drift chamber ($R<0.8$m, $|Z|<1.4$m, and particle production angles between 17 to 255 degrees) must be known to high precision. The field outside of the tracking volume need not be known that precisely since the particle trajectories in this region are smeared by multiple scattering in the DIRC and calorimeter systems.

This document deals with the magnetic field produced by the solenoid in the absence of any PEPII beam line components, namely the B1 and Q1 permanent magnets located on the axis within the solenoid. These permanent magnets produce fringe fields of approximately 100-200 gauss at the inner layers of the drift chamber[1].

Calculated OPERA maps

- Magnetization of 6 samples of barrel steel have been measured by [Magnetic Instrumentation]()
- Wuzheng Meng has done a full 3D OPERA calculation of the field accounting for magnetic material as carefully as possible (barrel steel plates, end doors, holes for beam pipe and chimney)
  - Model will be carefully compared to engineering drawings
  - Map to be integrated into GEANT4 simulation
  - Forces from eddy currents in a quench have been calculated





Fringe field from 3D OPERA

What needs to be mapped?

Interior of sPHENIX (formerly BaBar solenoid)

- Solenoid dimensions
  - 3.8 m long
  - 2.8 m bore
- Interested in precision mapping in tracking volume:
  - $r < 0.9$ m
  - $|z| < 1$ m

CERN Mapper

- We can buy a map from CERN!
  - Group that mapped ATLAS field
  - $50k of material
  - Cost for CERN technicians and physicists
- Need to cool down solenoid, which happens in 1008 using RHIC cryo in mid-2022

Mapper (from Felix Bergsma at CERN)

http://ep-dep-dt.web.cern.ch/b-field-mapping-magnet-support

Mapping considerations

- The probes must be capable of 0.1% precision
- The orientation of the probe axes must be good to fraction of a mr
- The probe position during mapping must be known to 1 mm or so in three dimensions
- The mapping has to take place with the steel fully assembled and the doors closed in the sPHENIX IR (the mapper has to be inside the TPC volume, with access through the 12” hole for the beam pipe)
- The resulting map from the raw data should account for the errors in field measurement, orientation, and position
  - A possibly ornate fitting procedure may help achieve high precision: http://lss.fnal.gov/archive/other/thesis/maroussov.pdf

Magnetic measurements in operation

- The TPC has been designed to leave space on both ends for Hall probes
- Probes precise to 0.01% are possible, but expensive
  - SMD uses Group3 LPT-141
- Metrolab's Magvector MV2 3-axis Hall probes may be calibratable to 0.1%... which could be done at NSLS II

MV2

- Small 3D Hall probe with ADC
- Inexpensive enough (320 CHF) to allow us to have maybe 50 of them around the TPC
- Have worked with the evaluation kit in the solenoid and Instrumentation magnet… nice
- Can we get adequate precision/accuracy with it?

MagVector™ MV2 3-Axis Magnetic Sensor   v 2.4 r 1.0 – 12/2017   Copyright © 2017 Metrolab Technology SA

MagVector™ MV2 3-axis magnetic sensor
1-Overview

1-1 FEATURES

Measures total field: 3-axis

Selectable measurement ranges:
from 100 mT to 30 T

Low noise: 300 nT/√Hz

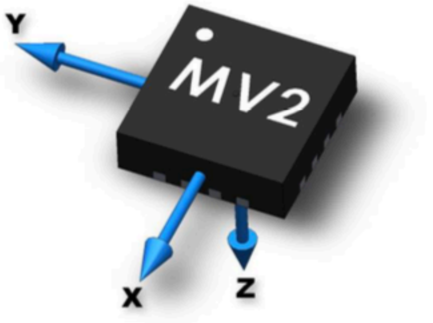
Supply voltage: 3.3 V or 5 V

Analog and digital interfaces

Selectable measurement rate: up to 3 kHz

Selectable resolution: 14 to 16 bits

Non-magnetic package



1-2 SAMPLE APPLICATIONS

High performance embedded applications

Custom multi-probe field mappers

Magnetic flux leakage measurement

https://www.metrolab.com/products/magvector-mv2/

Calibration

- NSLS II has a magnet in 832 that can be used for calibrating probes
- Visited David harder, Todd Corwin and others in NSLS II that run this facility at the end of 2016
- Have to take care with temperature correction