LDC question TR_7: Magnetic Field

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What quality of the field do we need in the
TPC, SIT, and other detectors?

How can we measure and monitor the
field distortions at the required level of accuracy?

Can the large distortions in the large crossing angle
be accounted for?

Can control samples be used to improve the
knowledge of the field map?

Does it make sense to eliminate the plug,
at the cost of a shorter magnet and thus
a less homogeneous field?
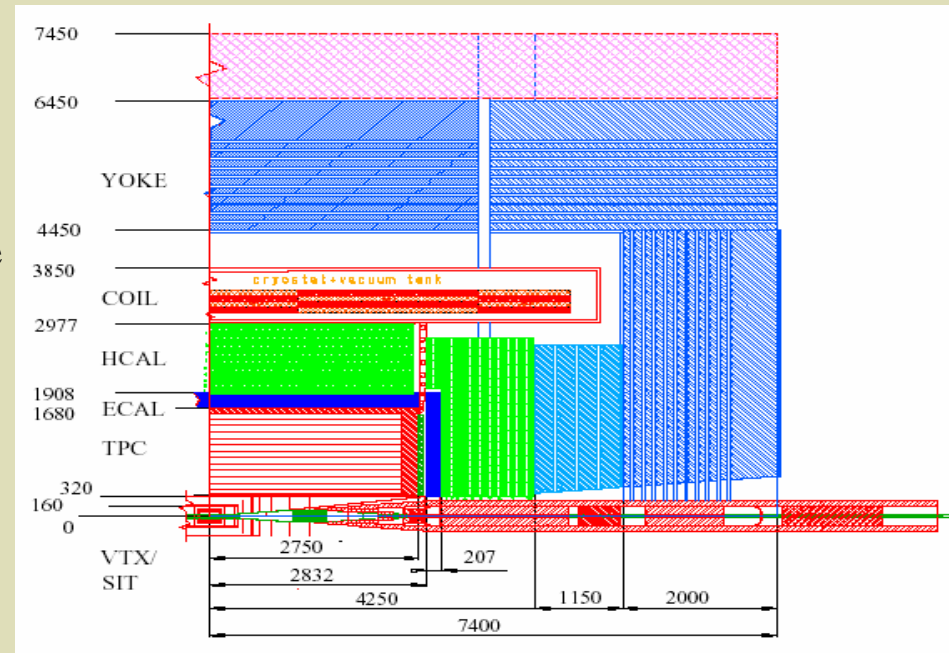
Of course, this is all preliminary.

What quality of the field do we need in the TPC, SIT, and other detectors?

GOAL: TPC momentum resolution: $\delta(1/p) < 2 \times 10^{-4}$ /GeV
System momentum resolution: $\delta(1/p) < 5 \times 10^{-5}$ /GeV

An example of a solution   (Dan's simple MC)

100 μm TPC, IR=.32m, OR= 1.68m $\delta(1/p) = 1.3 \times 10^{-4}$ /GeV

system including
10 μm VTX, 6 layers, IR= 2cm, OR= 6cm
10 μm SIT, 2 layers, 28cm, 30cm $\delta(1/p) = 4.2 \times 10^{-5}$ /GeV

Several ways to spoil resolution
If a magnetic field non-uniformity results in degrading a detector resolution,
the momentum resolution will be quickly spoiled.
160 μm TPC (TPC only) 2.1×10^{-4} /GeV

200 μm TPC (within system) 5.8×10^{-5} /GeV
40 μm VTX, 40 mm SIT   6.5
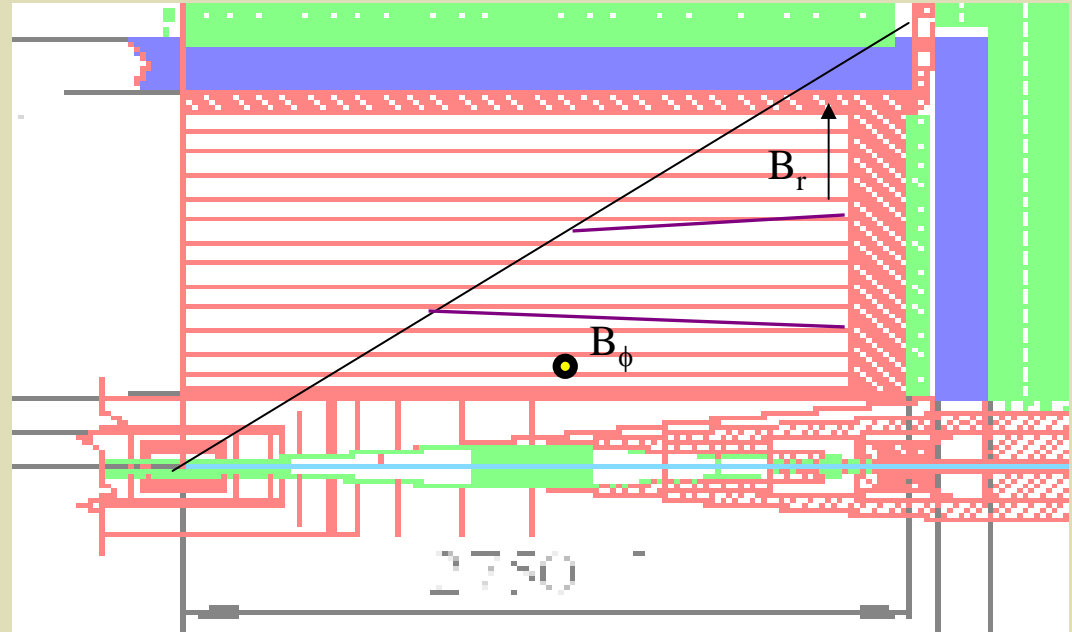VTX and SIT, rotated 25 μm (10 μm resolution)   5.7
 no SIT (still have 10 μm VTX)   5.3

What quality of the field do we need in the TPC, SIT, and other detectors?

There are 2 ways that the magnetic field distortions affect the track.

Distortions in the path of the track directly change the curvature of the track path.

  If the field non-uniformity can not be ignored, a transport fitting method must be used to take the local field into account.

Distortions in the drift path affect the point of ionization collection on the endplate.

  If the field non-uniformity can not be ignored, the drift trajectory can be corrected either with a mapping or using a transport method through the field.

What quality of the field do we need in the TPC, SIT, and other detectors?

Consider the case of
magnetic field distortions in the drift path,
  in particular, the effect of
  a B_ϕ with the following characteristics.
    B_ϕ=0 at z=0,
      and increases linearly with z.
    B_ϕ is maximum at R=0,
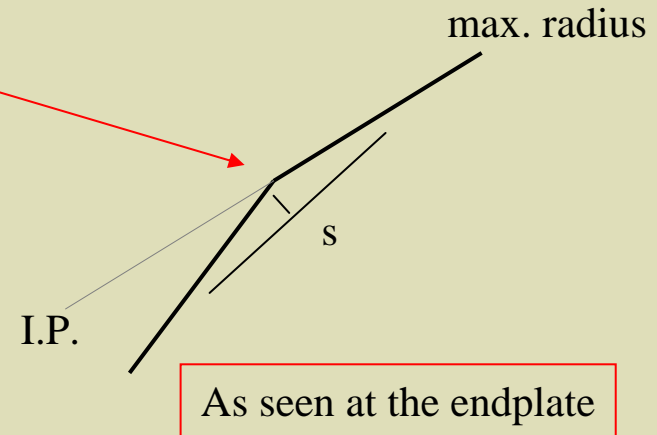   and decreases linearly to zero at mid-radius.
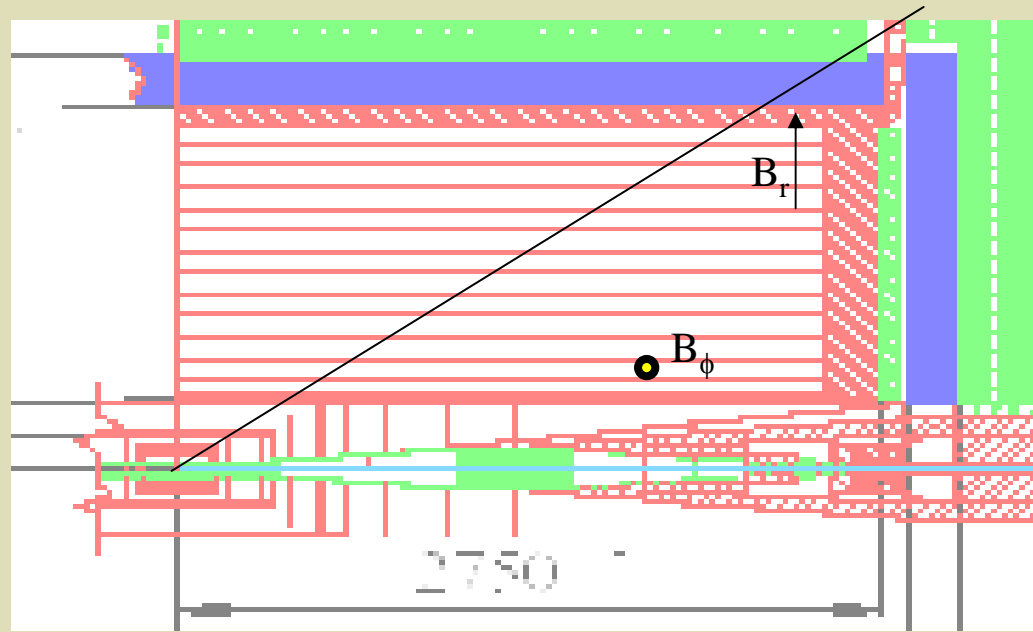
There will be a kink observed in the track.

Suppose that the maximum distortion is 1% of the field.

Ionization follows the magnetic field lines,
        which have a maximum slope of 1%.
The sagitta is ½ of the motion. The arm is ½ of the TPC radius.
The fitted sagitta will be about ½ of that shown.

As seen at the endplate

The systematic error in the fitted sagitta is then (1.6 m) (1/8) (1%) = 0.002 m, which is huge!

From the figure to the right, the sagitta is,
$s = L^2/(8R)$, where R is the radius of curvature of the helix.

The momentum of a track is related to R;
$P_t = R B \times (.3 \text{ GeV})/(\text{m Tesla})$; $1/R = B/P_t \times (.3 \text{ GeV})/(\text{m Tesla})$

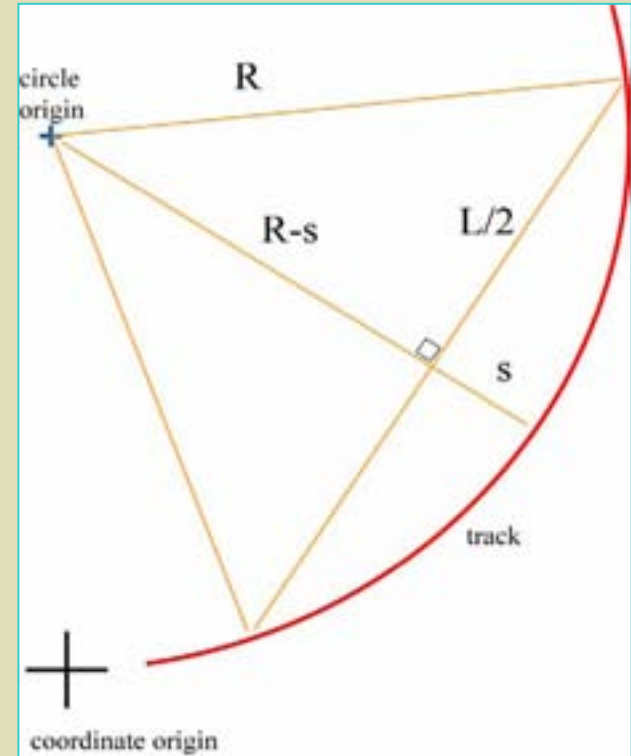Thus, substituting for $1/R$ in the first equation,
$P_t = (1/s) \times (L^2 B) \times (.3/8)(\text{GeV})/(\text{m Tesla}))$

Then the momentum resolution limit becomes
$\delta(1/P_t) = \delta s / ((L^2 B) (.3/8) (\text{GeV})/(\text{m Tesla})) < 5 \times 10^{-5} /\text{GeV}$

With L=1.6m, B=4 Tesla,
$\delta s < 19 \times 10^{-6}$ m

Note: the above limit is derived from the system resolution.
The 19 μm sagitta limit is probably relevant for the VTX and SIT.

In the body of the TPC, it may be more relevant to use the TPC only resolution requirement.
Thus, requiring $\delta(1/p) < 2 \times 10^{-4} /\text{GeV}$ would yield a requirement $\delta s < 76$ μm.

However, I will advocate aligning the silicon with TPC tracks
without introducing systematic errors; the 19 μm requirement is relevant.

Two slides back,
a magnetic field distortion in the drift path,
with magnitude 1% and
particular z and r dependence,
created an error in sagitta of $\Delta s = 2 \times 10^{-3}$.
This is 100x the limit derived on the previous slide $\delta s < 19 \times 10^{-6}$ m.

Field quality, or uniformity, of 1×10^{-4} (1% / 100) probably can not be achieved.
Systematic uncertainties must be limited to this value.
(And, that brings us to the next question.)
All track trajectories must be corrected by a transport fitter.
All drift trajectories must be corrected with a map.

The goal of the Aleph field map was an internal self-consistency of 1×10^{-4}. (rds)
This is a difficult measurement; 5×10^{-4} was achieved. (rds)
We should have an independent measurement for consistency.

How can we measure and monitor the
field distortions at the required level of accuracy?

It would be convenient to measure the magnetic field distortions with the tracks.

It would also be convenient to align the endplate sub-panels with the tracks.
Due to correlations, we probably can not do both.

There are competing distortions that must be eliminated, or solved simultaneously :

magnetic field distortions affecting the track trajectory,

magnetic field distortions affecting the drift trajectory,

alignment of the TPC to the silicon detectors, and

alignment of the sub-panels of the readout of the TPC.

(In a drift chamber, the problem of
magnetic field distortions of the drift
trajectory is replaced by the problem
of simultaneously solving the details
of the drift function and t_0 .)

Some competing distortions must be measured, with
12μm (.0005 inch) certainty, independent of the tracks.

How can we measure and monitor the
field distortions at the required level of accuracy?

Some competing distortions must be measured,
with 12μm certainty, independent of the tracks.
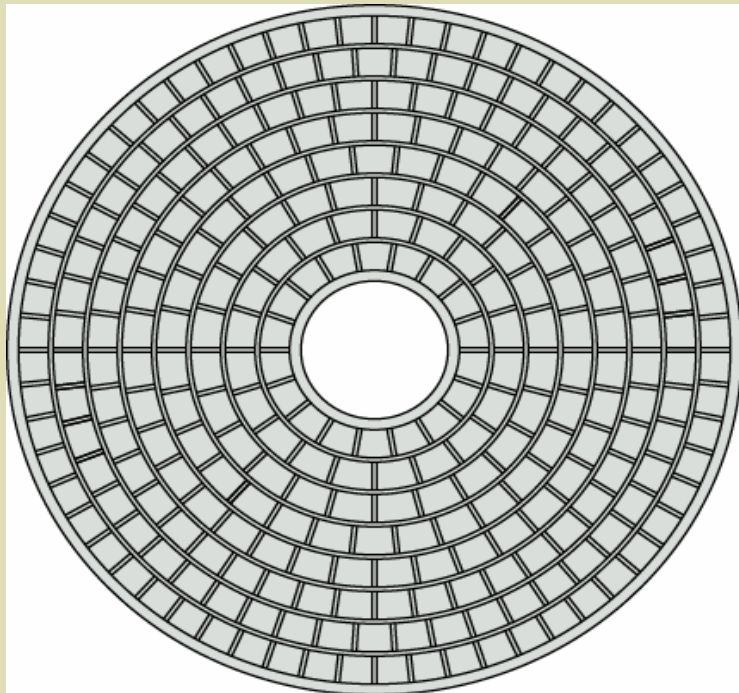
Endplate frame cartoon
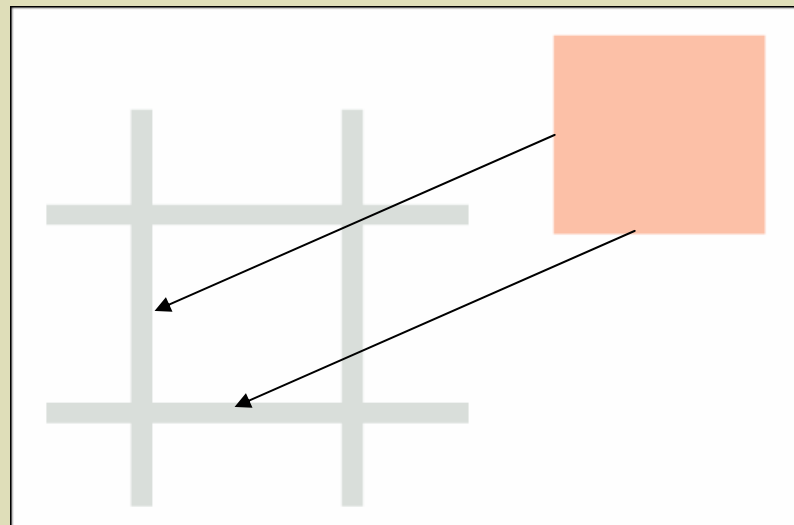
The sub-panels must be aligned to 12μm
  (roughly half of the sagitta uncertainty limit)
to separate distortion of the readout
from distortion of the drift path in the magnetic field.

To provide alignment of the sub-panels of the TPC readout,
the frame must have reference edges defined to 12μm.

Coordinate-Measuring-Machines allow
 (.0005 inch) 12.7μm over 1m, (.002 inch) 50μm over 4m.

We will be required to find a way to achieve
the better resolution over the larger object.

How can we measure and monitor the
field distortions at the required level of accuracy?

Extra slide showing CLEO measurements
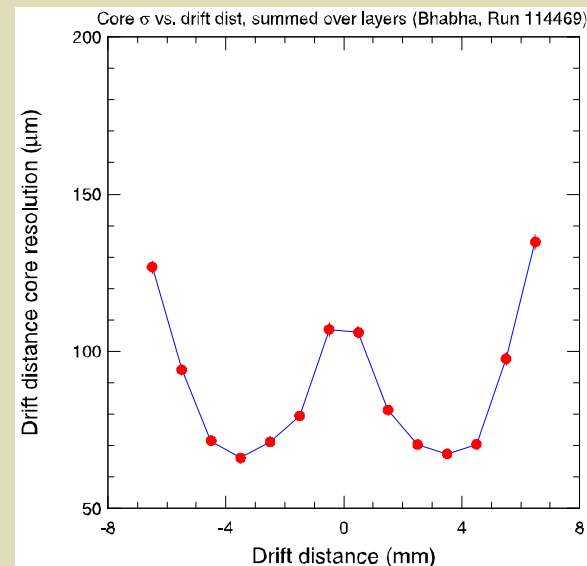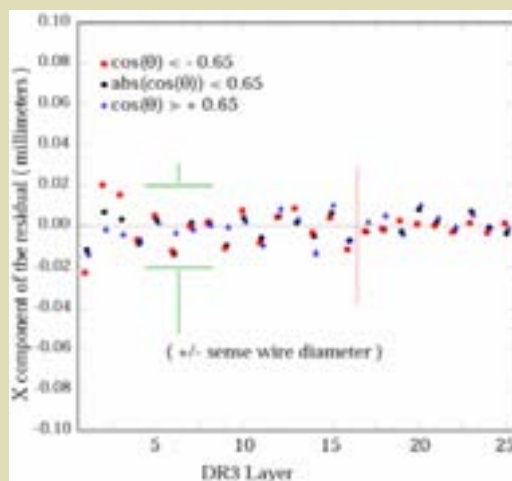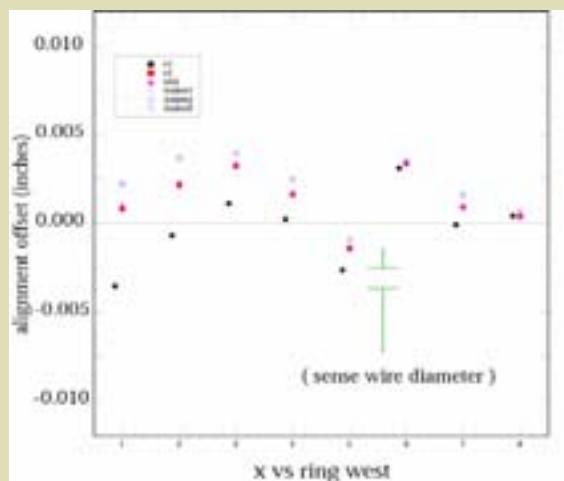
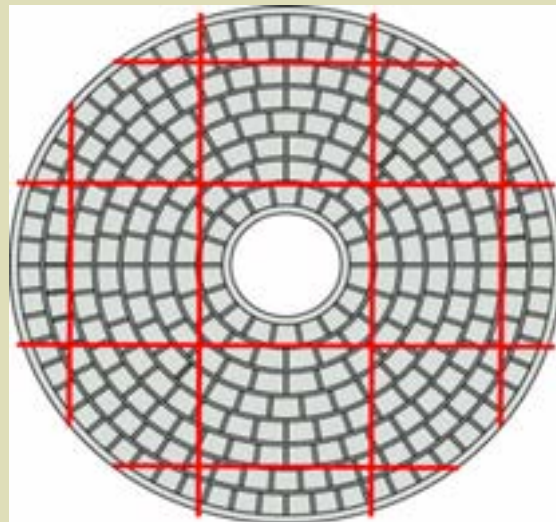## Magnetic field distortions affecting the drift trajectory

With proper quality control and measurement
during manufacture, the TPC readout will be accurate
enough to measure the magnetic field distortions.

It will require a set of laser beams.
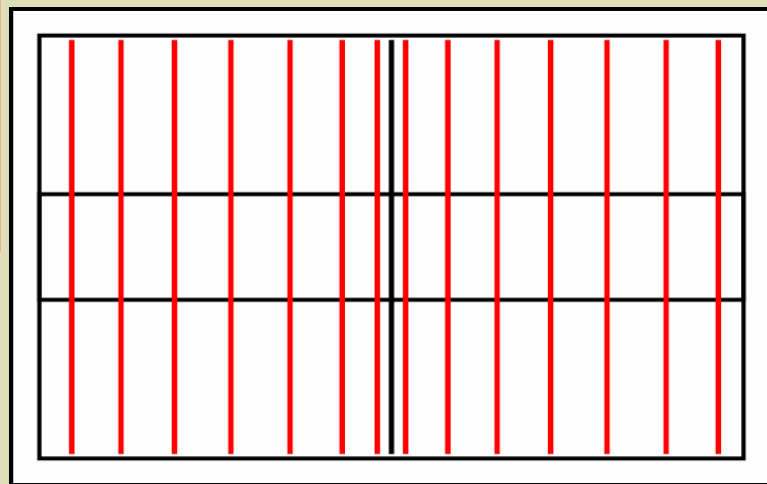(Not all experience shows they are useful.)

Figures show a possible configuration.
Laser beams cross the chamber in a way to provide
radial and azimuthal distortion measurements
at several longitudinal positions.

Magnetic field distortions affecting the track trajectory

The field map can be derived from the drift map.
Consistency can be made with tracks.

Magnetic field measurements
The field should be mapped with an accuracy of 1×10^{-4} , with all iron and compensation
magnets in place, for a consistency check of the laser measurements.

Can control samples be used to improve the knowledge of the field map

The CLEO tracking group uses e^+e^- and $\mu^+\mu^-$ events,
    e^+e^- when we need higher statistics,
    $\mu^+\mu^-$ when we are concerned about the charge asymmetry.

CLEO uses a constrained fit of the two tracks to decouple the tracks from sub-detector mis-alignment.
    Two tracks, when not constrained, are described by 10 parameters. We require:
    meet at a point (2 constraints),
    back-to-back in the center-of-mass (2 constraints),
    equal momentum in the center-of-mass (1 constraint).
    The two-track fit has a moment arm of 3.2m, compared to 1.3m in the TPC alone.

Hypothetically, the resolution of a two-track fit, without the VTX or SIT,
is $\delta(1/p_t) = 4 \times 10^{-5}$/GeV, and competitive with single track system resolution.

At LDC, we can also use the tracks to measure magnetic field correction in the drift trajectory
if the track trajectory is in a region of high-uniformity magnetic field.
  (It may be necessary to use only track trajectories near z=0.)

The two-track fits can also be used to align the VTX and SIT.

Do you intend to say, "large magnetic field distortions associated with the large crossing angle"?

This is a 2% distortion. (At what radius?)

It has a predictable azimuthal dependence.
It has a less-understood z dependence.

It varies (close to) linearly from a a value of zero at z=0.
This is probably the field at some small radius just outside the "DID".

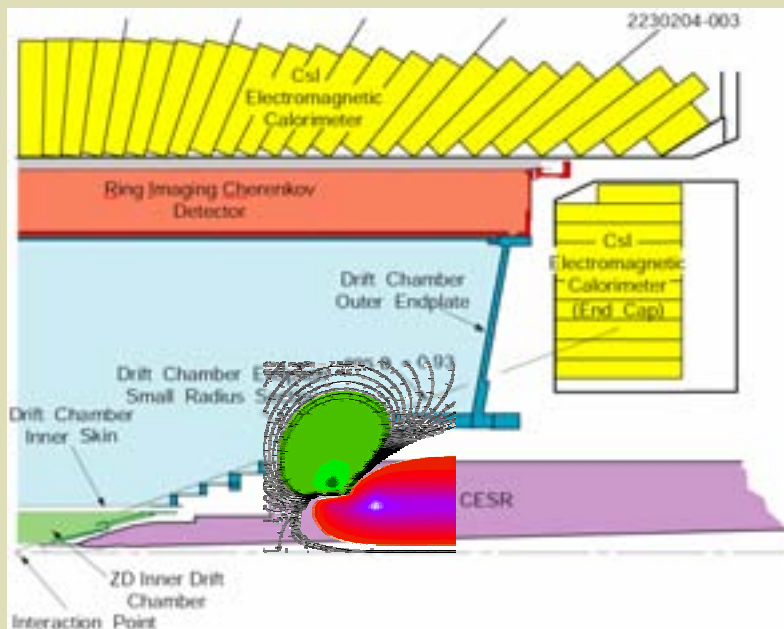This looks similar to the hypothetical magnetic field distortion on page 4, which was 100x the uniformity limit.

The "DID" is 2x the amplitude of page 4.

The magnetic field of the "DID" must be understood at the level of 1: 200 .
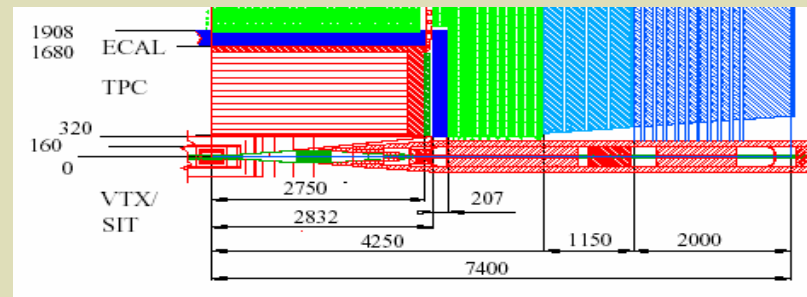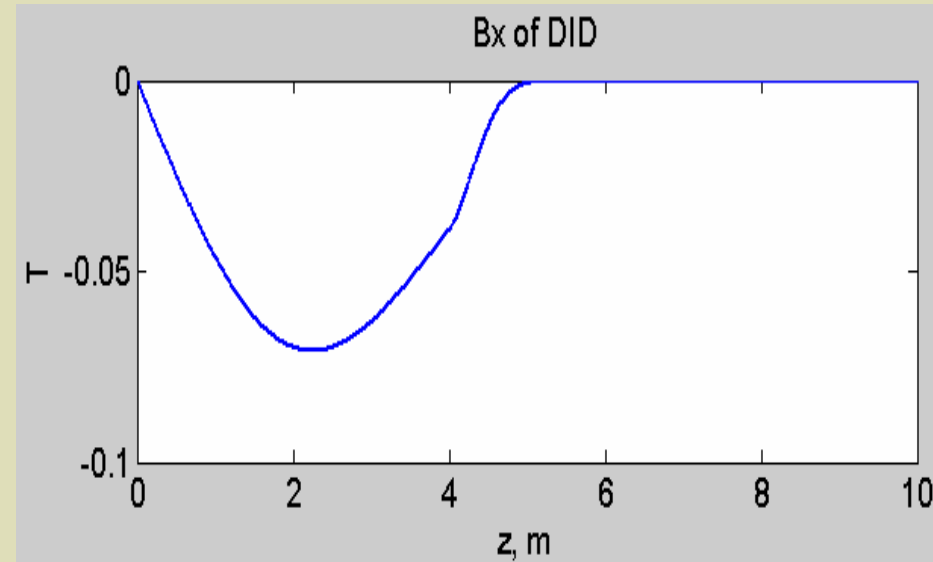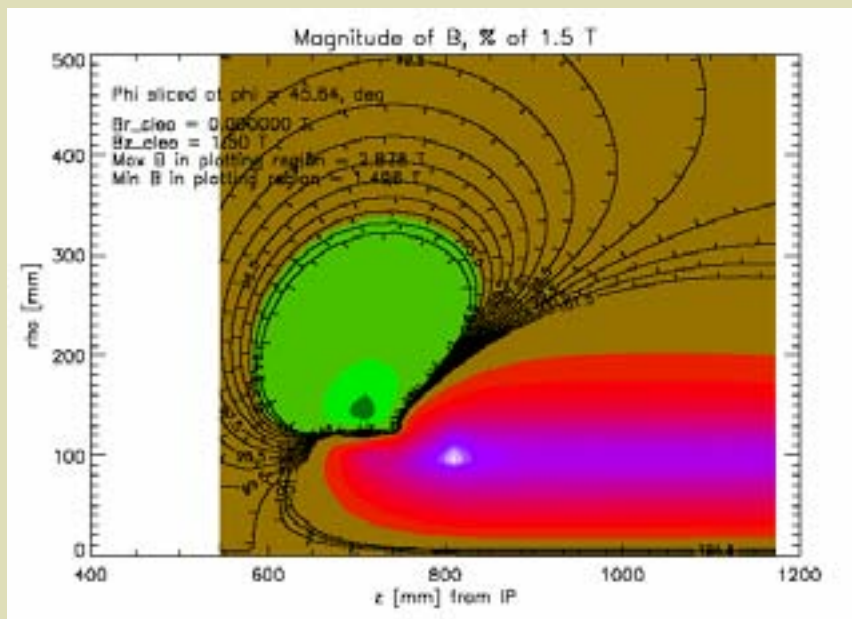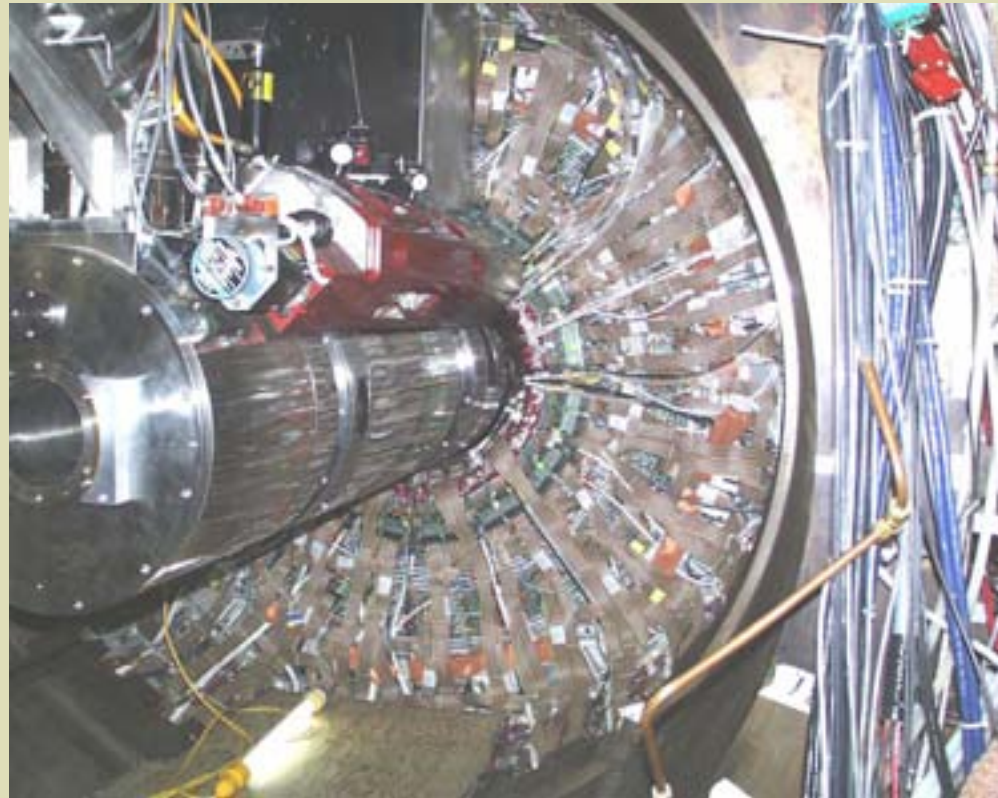
What about the anti-solenoid?

Magnitude of B, % of 1.5 T

CLEO III (c) has a 1.5 (1.0) Tesla solenoid field
with superconducting (and permanent)
quadrupole magnets intruding into the tracking volume.

edge of larger green area is 95%
contours are 0.5 % changes

All track trajectories and ionization trajectories must be corrected using a transport type fitter.

CLEO uses a calculated magnetic field map
    of the contribution from the quadrupole
   to correct for the quadrupole distortions.

The Kalman fit
    is a transport method and, therefore,
    inherently allows
        application of a magnetic field map.

The magnetic field is distorted by the
 fringe field of the final focus quadrupoles
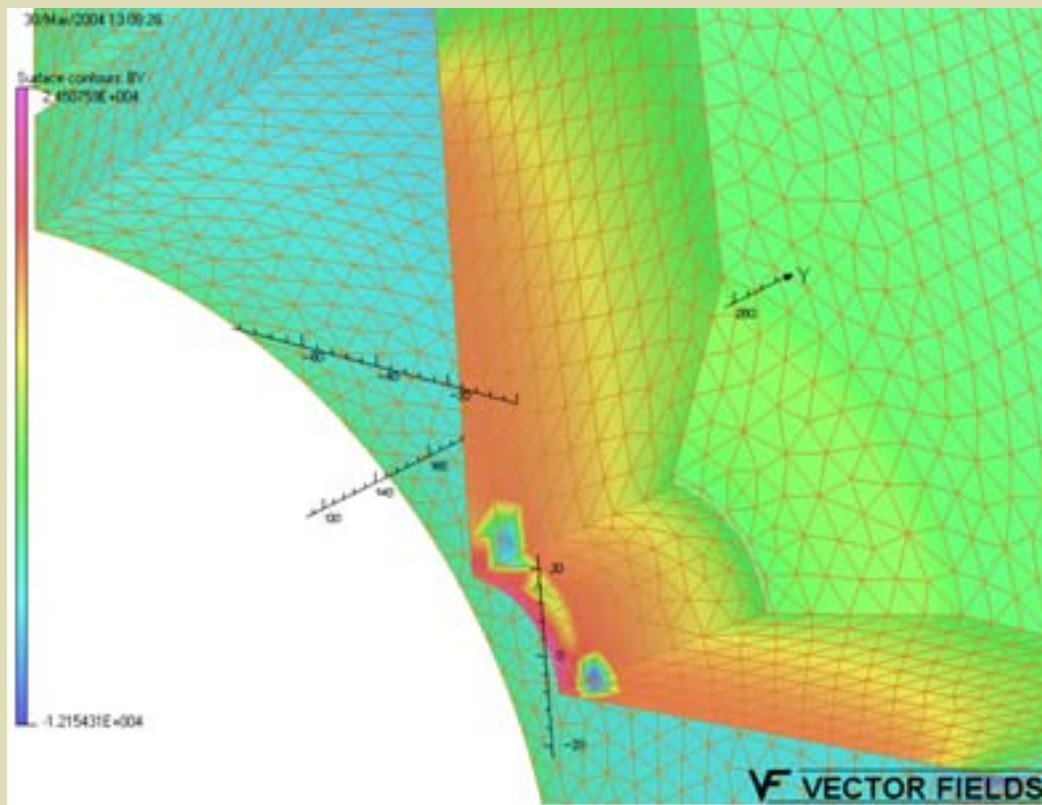 causing a 2-cycle momentum dependence.

This is corrected in the Kalman fit.

    (The residual 1-cycle momentum dependence
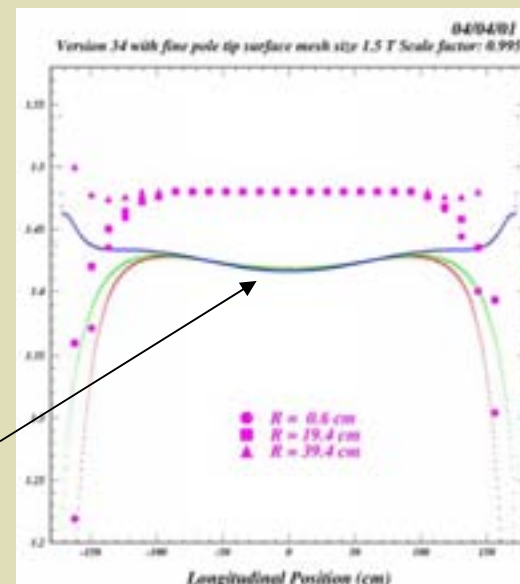   is due to the 2.5 mr crossing angle)
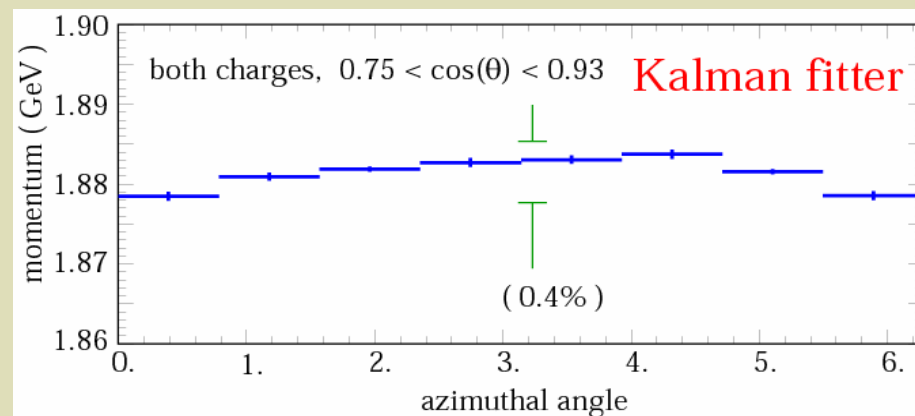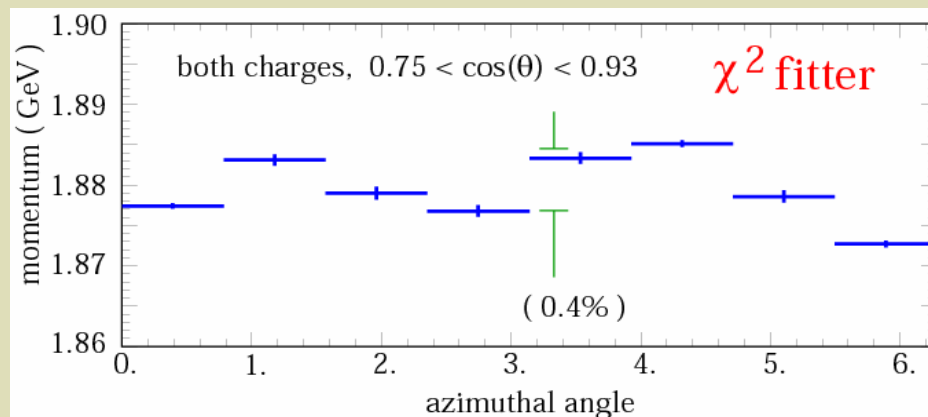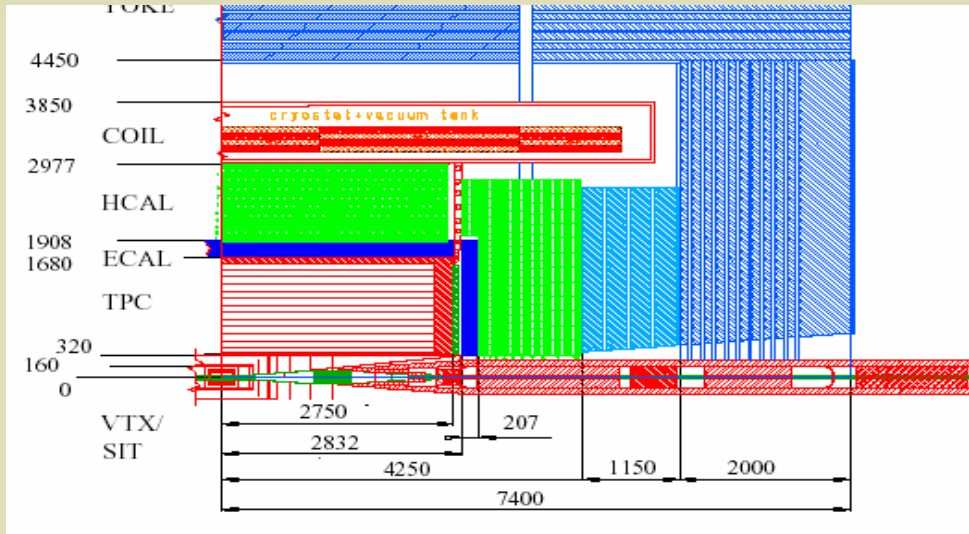
~ .5x10^{-4} variation

The main magnetic field must be measured.
One can not rely on finite-element-analysis
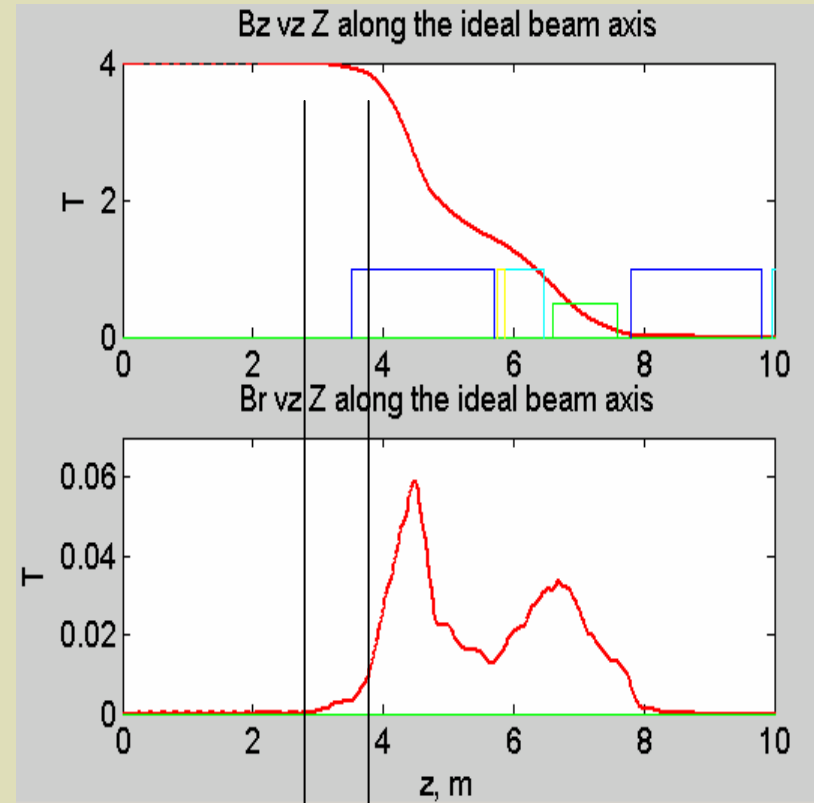as the only measurement when there is
saturated iron.
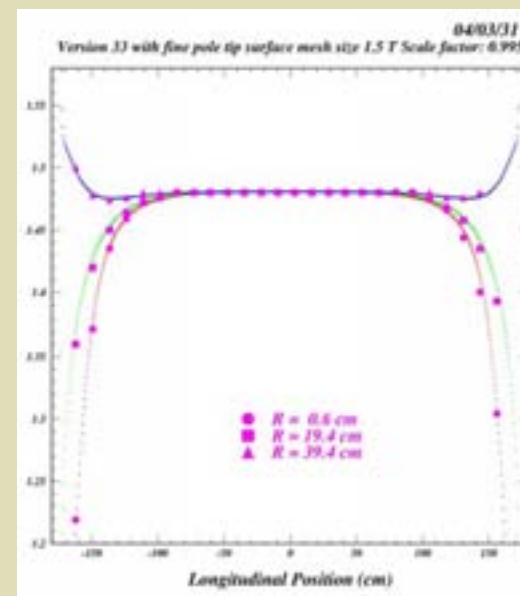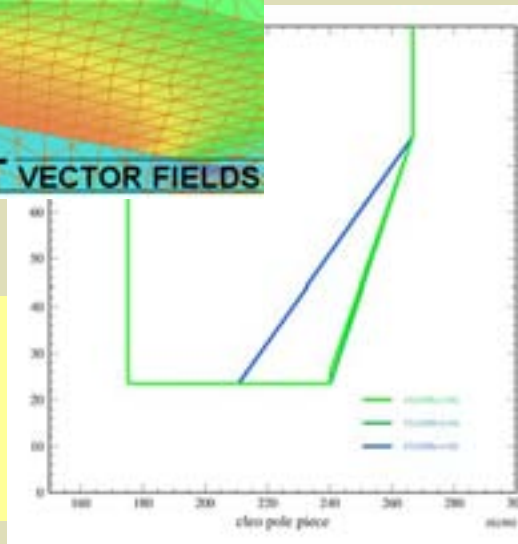
Does it make sense to eliminate the plug,
at the cost of a shorter magnet and thus
a less homogeneous field?

This changes B_z by only 5%, at the maximum Z.
The B_r component of $< \frac{1}{4}\%$.
It is all azimuthal independent.

Does it violate the uniformity of $< 10^{-4}$ close to z=0 ,
as will be needed for the control sample tracks?

Extent of TPC: 2.7m

Field at 3.8m, length of TPC plus
a distance equal to the length of the plug

Conclusions

Field quality, or uniformity, of 1×10^{-4} can not be achieved.

Systematic uncertainties must be limited to this precision
avoid introducing systematic error into the VTX and SIT alignment.

All track trajectories and drift trajectories must be corrected by mapping or a transport fit.

The magnetic field should be measured to an accuracy of 1×10^{-4}
 with all compensation magnets and iron in place.

One can not rely on finite element analysis for the measurement of the solenoid field.

To provide an independent measure of the drift trajectory distortion,
Locate the readout sub-panels to 12 μm. Use lasers to measure the distortion of the drift trajectory.

Hypothetically, the resolution of a two-trackfit, without the VTX or SIT, is $\delta(1/p_t) = 4 \times 10^{-5}$/GeV,
 and is competitive with single track system resolution.

Two-track fits can be used for consistency checks of the drift trajectory distortion.
 and for aligning the VRX and SIT.

The magnetic field of the "DID" must be understood at the level of 1:200 .

Removing the plug appears to be a smaller perturbation that the "DID".
But a field uniformity of 10^{-4} is required near z=0 to for the control sample measurements.