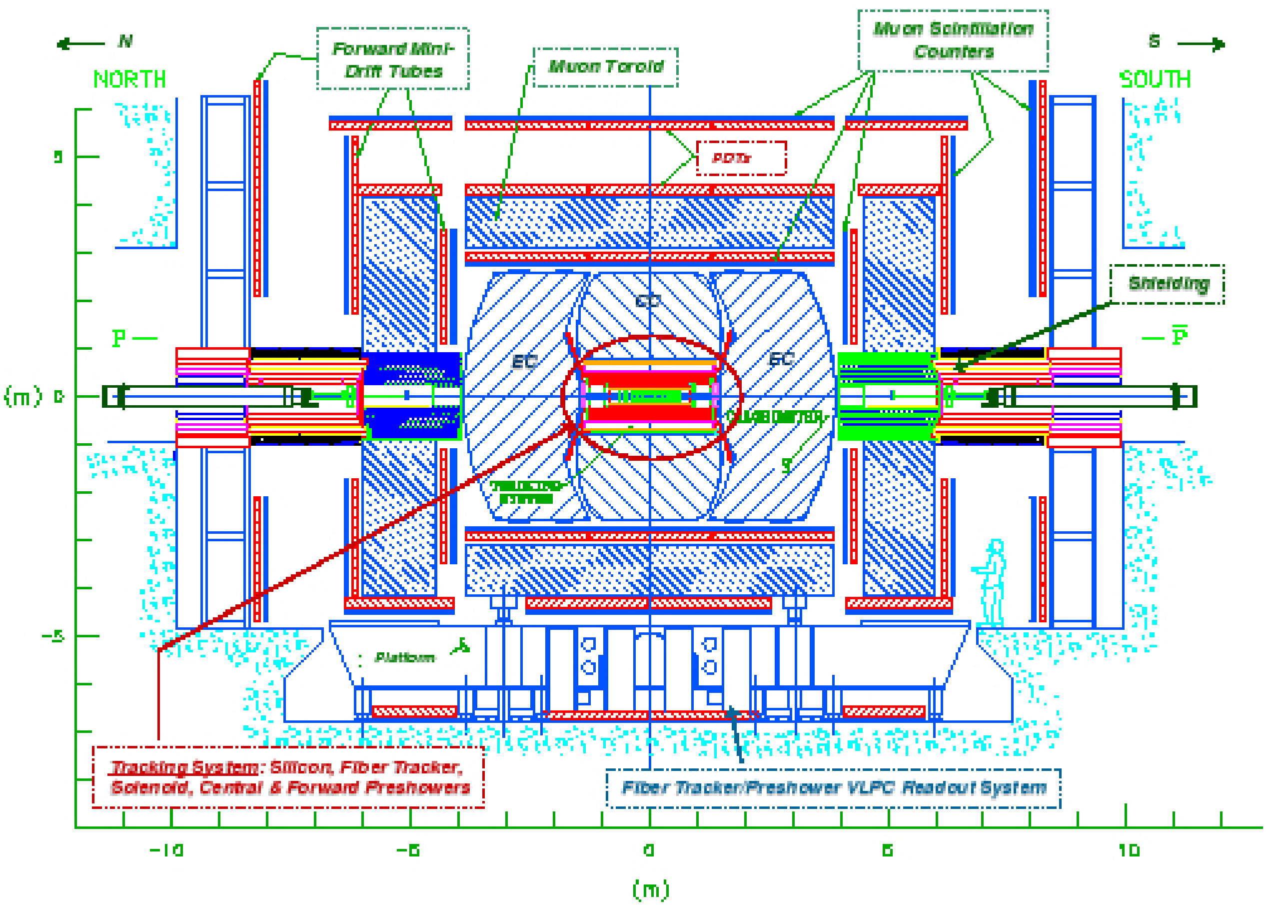
The D0 Magnets

Shifter's Tutorial

R. P. Smith

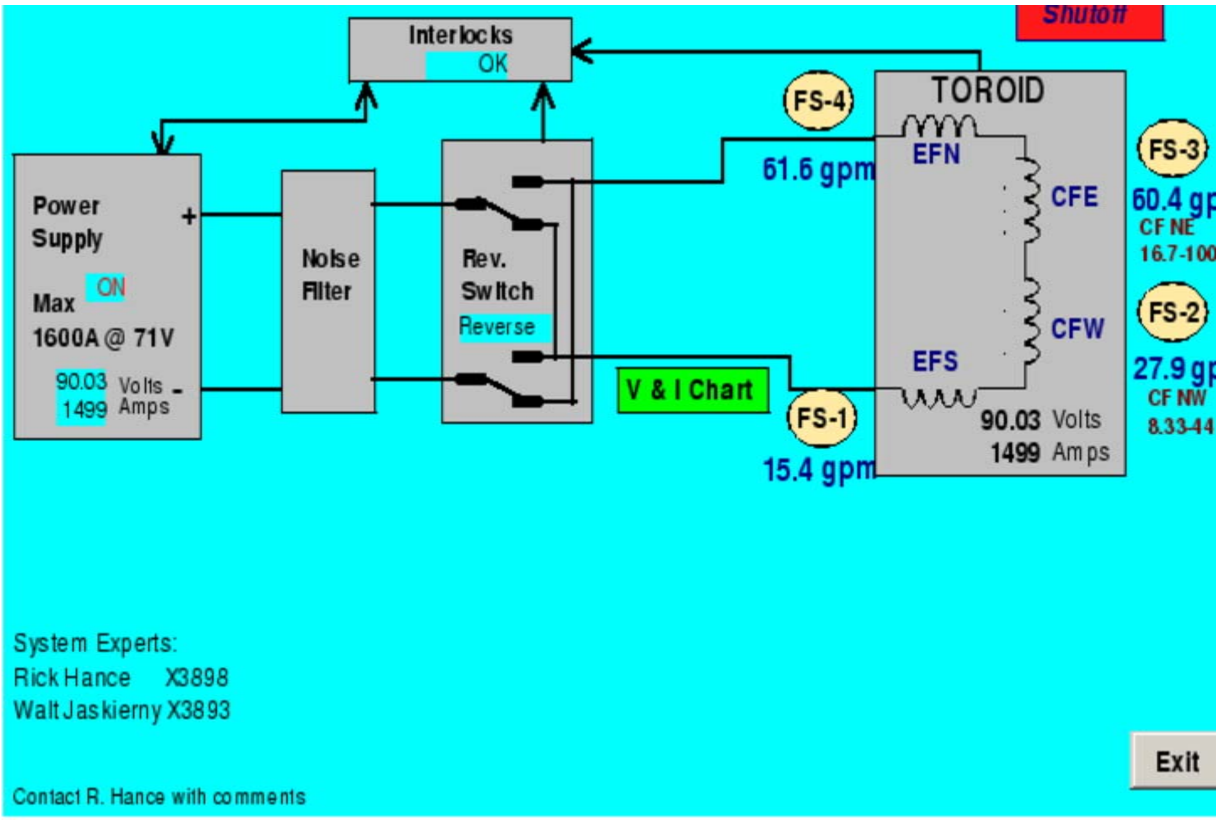
Where are the Magnets?



The D0 Magnets

- Muon Toroids
  - From Run I, modified
    - WAMUS Toroids: CF ($|\eta|<1$), EF($1<|\eta|<2.5$) now electrically in series, Operating current reduced from 2500 to 1500 A (B from 1.9 to 1.8 T) to reduce operating costs
    - SAMUS Toroids ($2.5<|\eta|<3.6$) removed
    - Elegant new control system
    - Large Iron Forward Shields inserted in SAMUS locations
- Central Tracking Solenoid
  - New for Run II
    - Superconducting
    - 2T
    - ~1 X_0
    - Procured to Detailed Specification

A Brand-new Control System for the Toroids

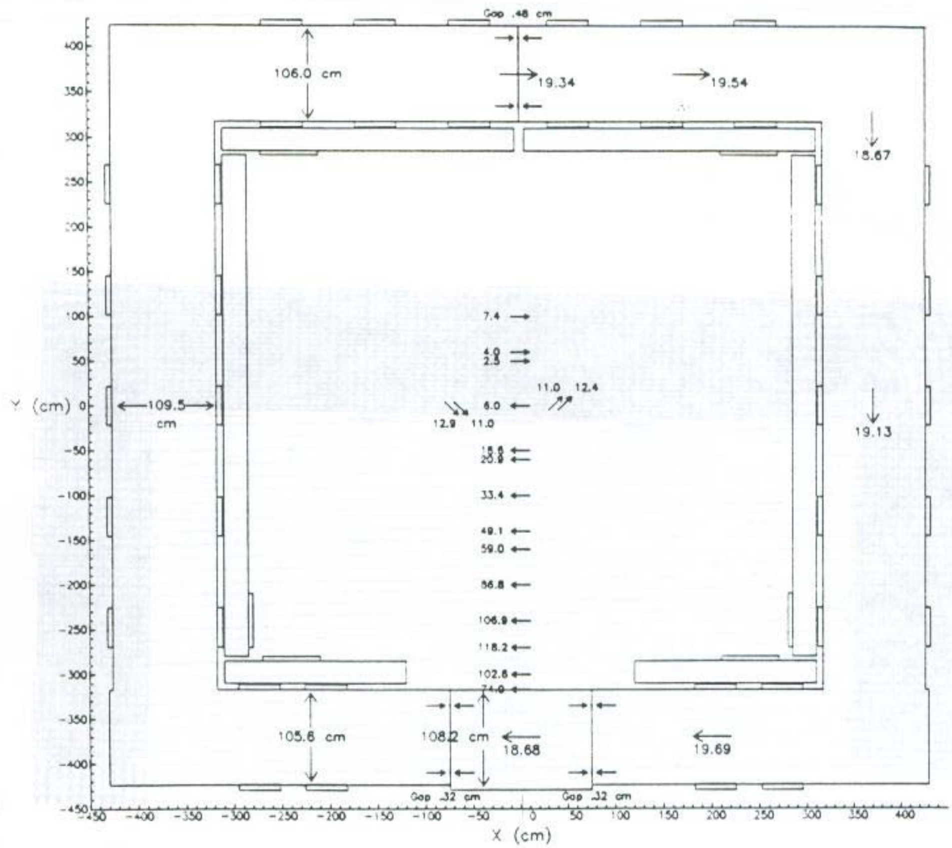


Toroid Fields?

Fig. 3 Geometry of CF Toroid

Calculated Flux Values(in kG) in CF Yoke Avereged Across Its Width(in cm)

& Measured Fringing Field inside CF at Z=140 cm (in Gauss)



Why Must I Degauss My Monitor Each time the Magnets are Charged?

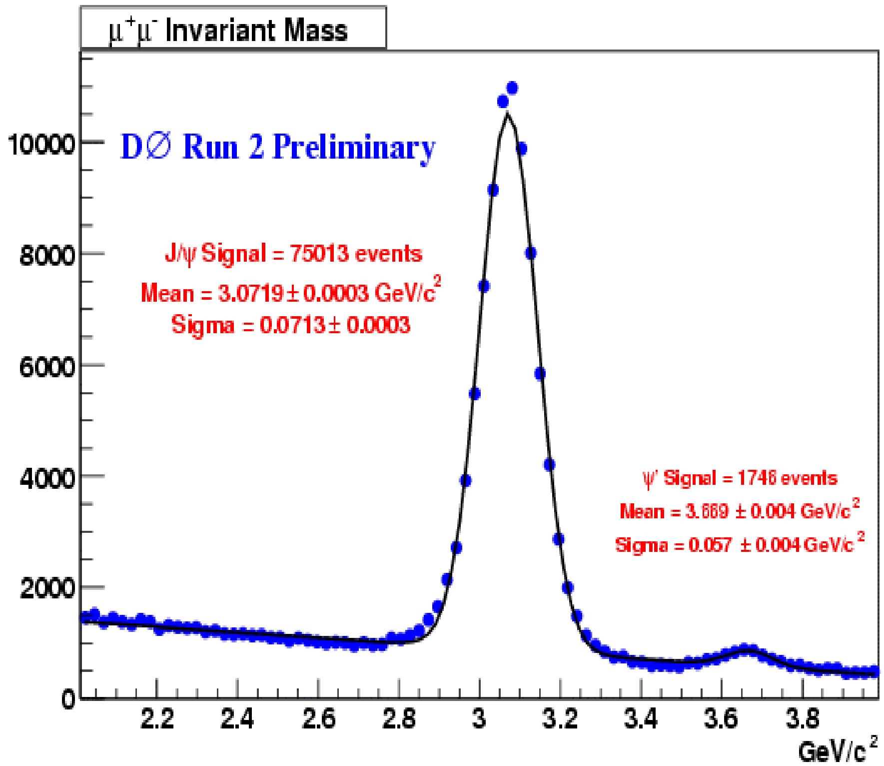
DAB Location	CF +	Sol +, CF +
Catwalk, East End	1.9	2.0
Catwalk, West End	1.0	1.0
Catwalk, Solenoid Current Bus Housing	1.5	90
Catwalk, Top of UPS	1.6	2.5
Catwalk, On Beam Line	2.0	
Ladder Top, Near Vending Machines	1.6	1.8
Third Floor Counting Room	1.5	2.0
Second Floor Counting Room	1.5	3.0
First Floor Counting Room	2.0	2.0
Third Floor Moveable Counting House		2.0
Second Floor Moveable Counting House	2.7	3.0
First Floor Moveable Counting House	2.0	2.0
Cable Winder outside Second Floor MCH	1.0	
DAB 1 CleanRoom South Grill Door	2.0	3.0
DAB 1 CleanRoom Canvas West Wall	1.7	6.0
DAB 1 South Stairwell	1.5	1.5
DAB 1 North Stairwell		1.5
Control Dewar Platform	1.5	3.0
Control Dewar Frostproof Box	1.5	12.0
Control Dewar Current Buses	1.5	100
Assembly Pit South Safety Rope	2.0	7.0
Assembly Pit North Safety Rope	2.0	12.0
Fieldmapper Control Station	3.0	

During Fieldmapping, in AH, no EF

The D0 Solenoid

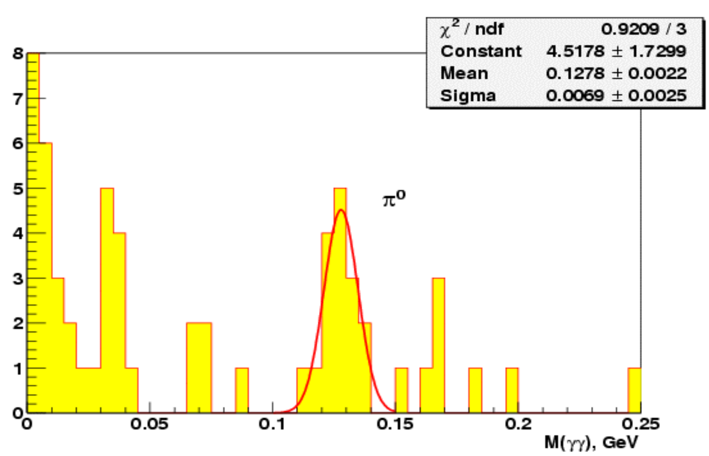
- What does it do?
- Where is it?
- When was it done?
- How does it work?
- Fieldmapping
- Unfinished Business

Castilla at LaThuile

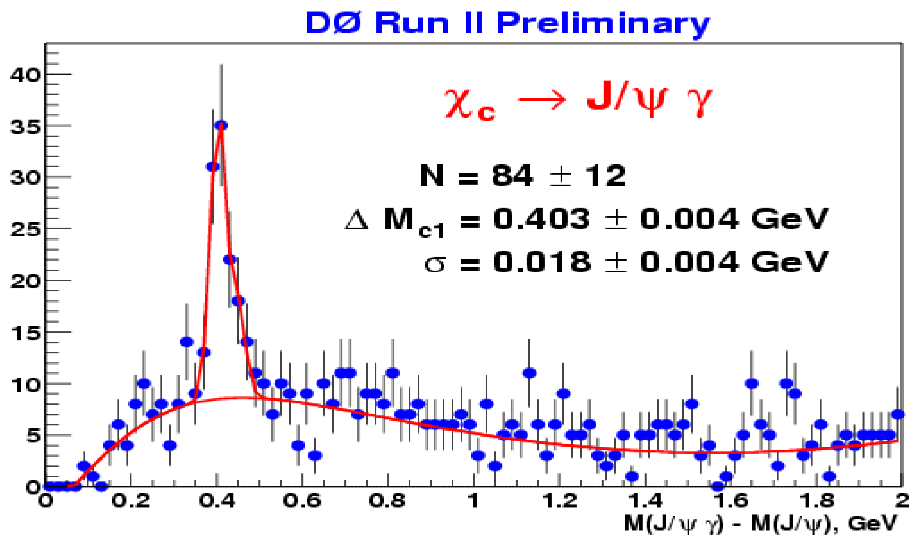


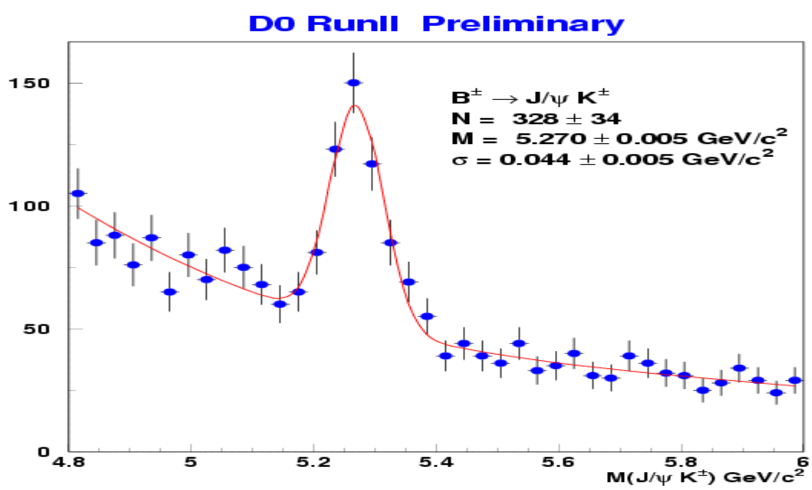
- μ p_T > 1.5 GeV & J/ψ p_T > 3.0 GeV
- SMT hits>3 & CFT hits>4

J/ψ's: 75,013

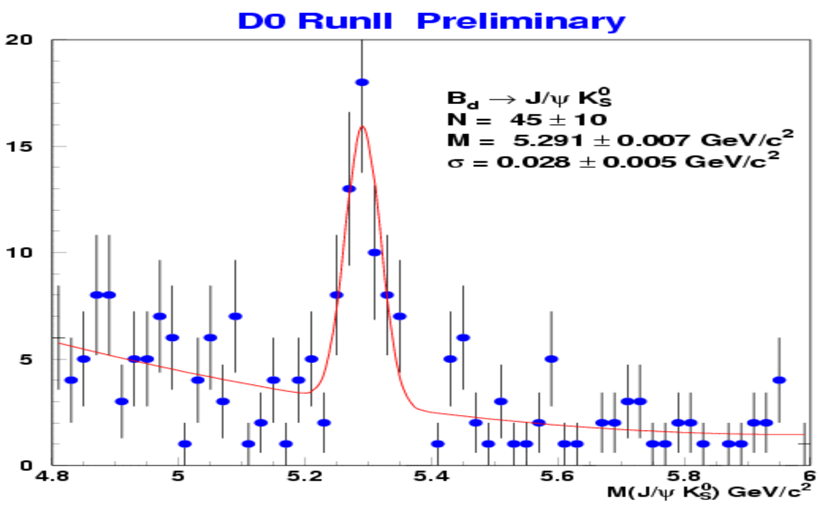


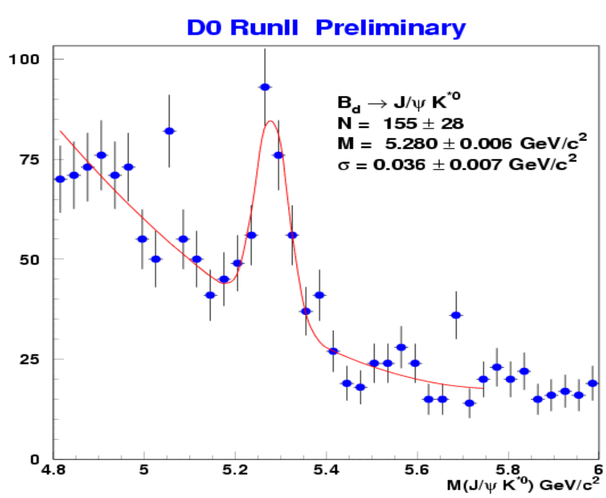
More LaThuile





Yet More LaThuile

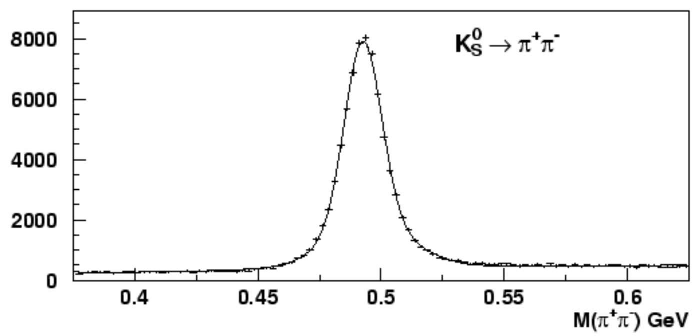


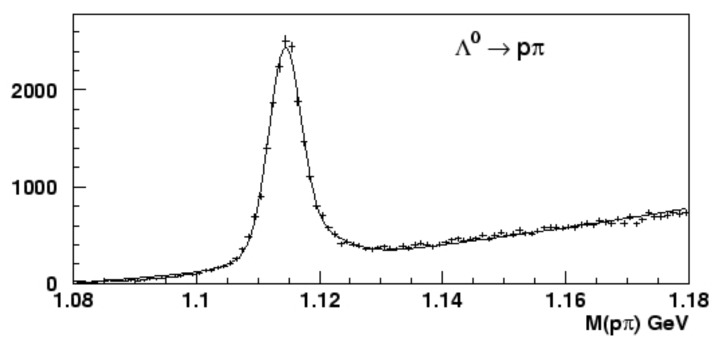


And Filthaut at Moriond

Tracking

Yes, we do see K_S, Λ





Cuts:

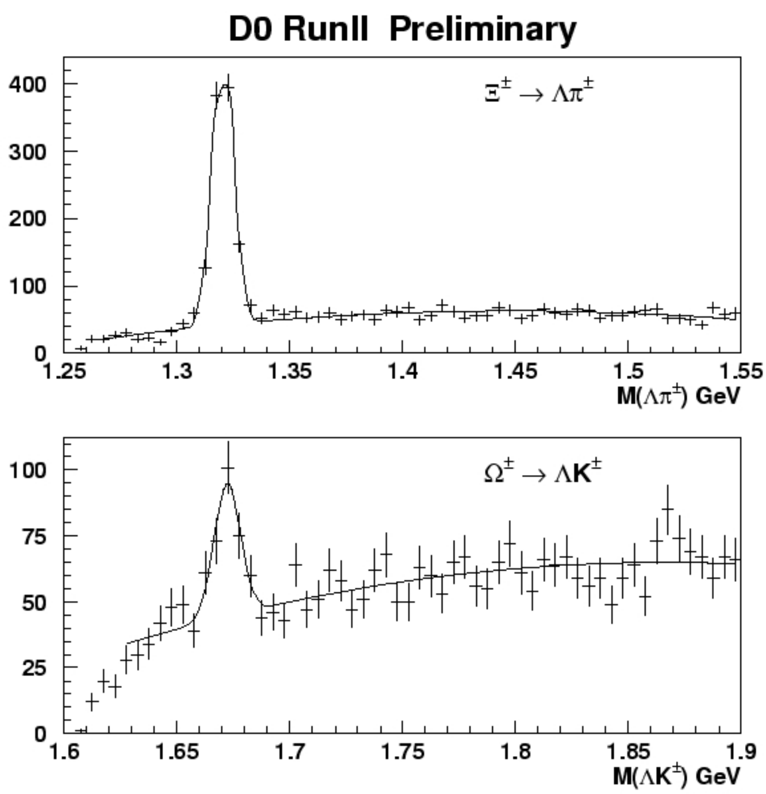
- both tracks measured in Central Fiber Tracker
- track $(d_{xy}/\sigma_{xy})^2 + (d_{sz}/\sigma_{sz})^2 > 16$
- vertex $\chi^2 < 25$
- vertex $d_{xy}/\sigma_{xy} > 4$

XXXVIII Recontres de Moriond   15–22 March 2003

More Moriond

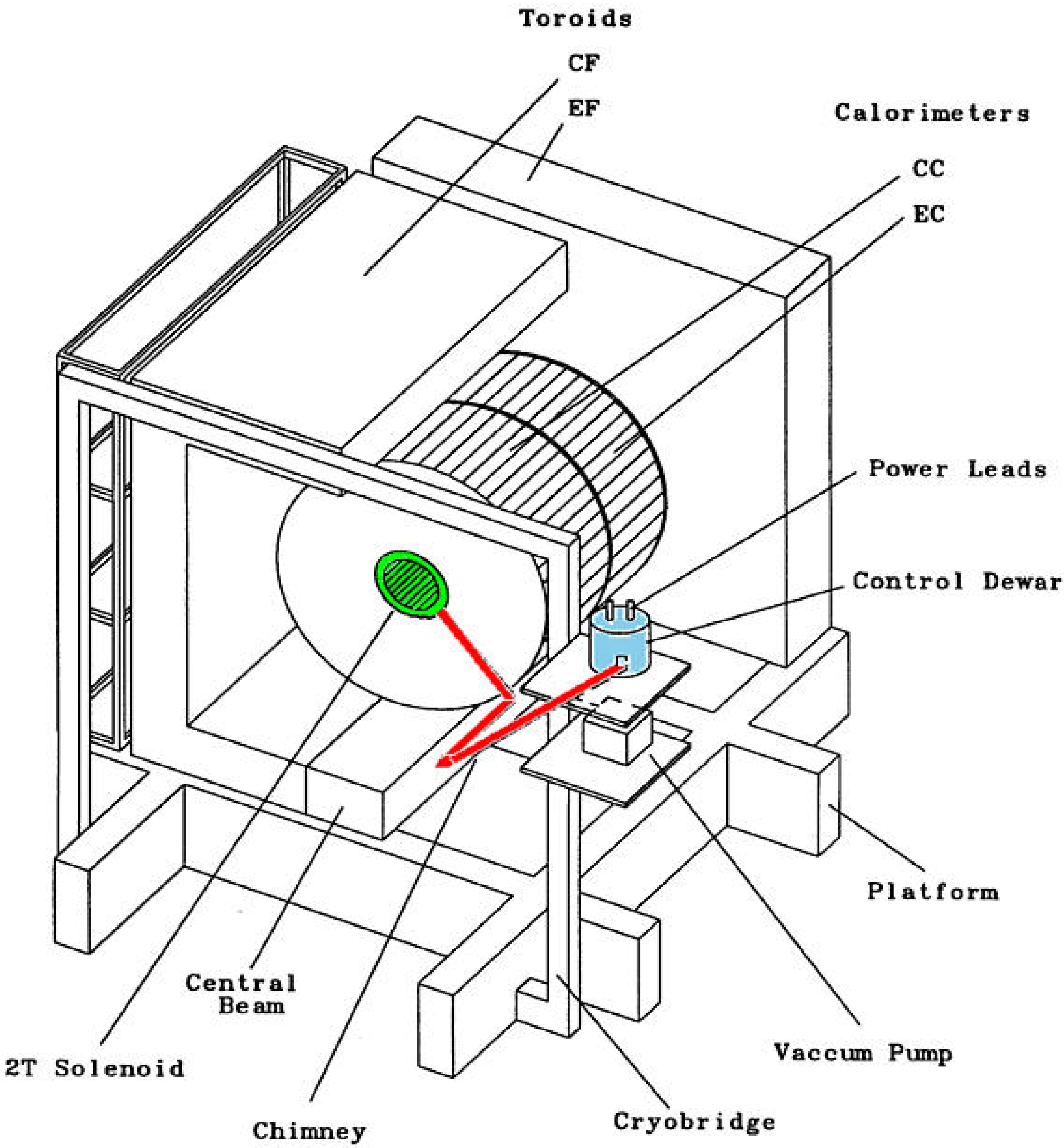
Tracking

. . . and their parents



XXXVIII Recontres de Moriond 15–22 March 2003

Highlighting the Solenoid



View During Run II Roll-in

Upgrade Wish List

Requirements

- **Field:** Good momentum and mass resolution with tracking: sagitta ~ BL^2
  B as high as prudent (Zeus = 1.8 T?)
  Transparent
  Must fit in Δr
  => **2T**

- **Geometry:** Must fit and be radially thin.
  2.8m long; 55 < R < 70cm; “No” Fe return yoke

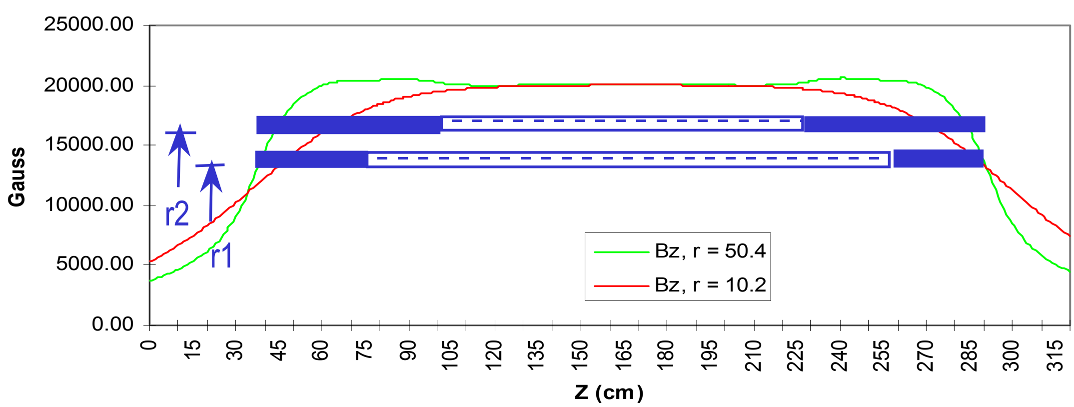
- **Field Uniformity:**
  Graded winding; higher current density at the coil ends (ala Zeus, Aleph)

- **Thin coil:**
  1 X_o of Al: Coil + bobbin, cryostat

What Is It?

Central Field	2.0 T
Operating Current	4820 A
Cryostat Warm Bore	1.067 m
Cryostat Length	2.729 m
Integrated Field Homogeneity	+/- 0.005
Stored Energy	5.6 MJ
Inductance	0.48 H
Conductor	High Purity Al Stabilized
Cooling	Indirect, 2-phase forced flow helium
Cold Mass	1500 kg approx
Transparency	0.9 Xo

- Two winding layers with 1.3 J at ends for improved field homogeneity:



- Two Conductor Sizes for 1.0 J, 1.3 J:

Technical Specifications

initiated by the subcontractor until the related approval has been granted.

5.1.15 Although Fermilab shall approve the final engineering design of the magnet system, the design of the fixtures as specified in 5.12, and the testing and fabrication plans specified in 5.13, prepared by the subcontractor, it shall remain the sole responsibility of the subcontractor to provide a system that meets the full requirements of this specification.

5.1.16 Should it appear advantageous or necessary that any element of the subcontractor's design, testing or fabrication plan be changed after it has been approved by Fermilab, this change shall be proposed by the subcontractor and made only if approved by Fermilab.

5.1.17 All approval drawings specified in 5.1.13 and fixture drawings specified in 5.12 shall be transmitted to Fermilab in hardcopy form, plus in electronic IGES format in a manner to be agreed upon between Fermilab and the subcontractor. A full set of the system drawings, revised as necessary to include all "as built" modifications, shall be forwarded to Fermilab in both hardcopy and electronic IGES format prior to the completion of the contract.

5.2 MAGNETIC FIELD REQUIREMENTS

5.2.1 The magnet shall produce a solenoidal field of not less than 2 tesla at the center of the magnet clear bore (R = 0.0, Z = 0.0) at design operating current.

5.2.2 The design field shall have an inhomogeneity not greater than ±0.5%. The inhomogeneity is defined as the integral along any line at angle θ with respect to the axis of the solenoid:

$$Inhomogeneity(\theta) = \frac{1}{B_0 L}\int_0^{P(\theta)} (B_z - B_0)dl,$$

where the straight-line path integral over dl extends from the center of the magnet to a point $P(\theta)$ on the radial perimeter of the clear bore along a line at an angle θ from the axis of the magnet. The length of the path is L = R $/sin(\theta)$ where R is the inside radius of the cryostat vacuum vessel, B_z is the axial magnetic field and B_0 the central field value. The angle θ shall range from 0.45 radians (26 degrees) to 2.69 radians (154 degrees) with the geometry as illustrated on Fermilab drawing 3823.111-MA-317047.

$\eta \sim 1.47$

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Technical Specifications

5.1.1 The solenoid system shall be fully contained within the "stay clear" zone as defined in Fermilab drawing 3823.111-ME-317041, Sheet 1. This drawing indicates the volume allowed for the magnet cryostat, the allowed pathway for the service chimney, and the relative location and allowed volume for the control dewar. Fermilab drawing 3823.111-MD-317156 specifies the required mounting/support holes that shall be provided on the end flanges of the magnet cryostat outer vacuum vessel. No exceptions to this specification shall be permitted.

5.1.2 Fermilab drawing 3823.111-MC-317049 enumerates the cryogenic, mechanical, electrical, instrumentation, and control interfaces for the magnet system in DAB.

5.1.3 The magnet overall radial thickness in radiation lengths shall be 0.9 + 0.1/-0.0, excluding the cold mass supports and the portions of the cryostat beyond the ends of the outer support cylinder.

5.1.4 The cold mass supports shall be designed to minimize radiation-length thickness in the radial direction and the heat leak to the helium system, while meeting all of the mechanical requirements specified in 5.1.5 and 5.5.

Plus seismic loadings, iron decentering, FNAL ES&H, etc., etc.

5.1.5 The magnetic axis of the coil shall align to the axis of the outer vacuum vessel to within ± 1.0 milliradians angular deviation, and the coil position with respect to the vacuum vessel shall be known and fixed to within ± 2.0 mm in any transverse or axial direction, when the magnet is cold and energized. The maximum relative motion of the coil with respect to the vacuum vessel shall be limited to ± 2.0 mm in any radial or axial direction upon energization of the magnet accompanied by the decentering forces specified in 5.5.1.3. Fiducial marks shall be provided on the outside of the end bulkheads of the cryostat which reference the location of the coil inside by means of a table of values or the equivalent, sufficient to measure unambiguously the offsets between each fiducial and the corresponding location of the coil inside when it is cold. No exceptions to this specification shall be permitted.

5.1.6 The service chimney which connects the magnet cryostat with the control dewar shall be designed to permit it to be parted between the magnet and the control dewar as specified in Fermilab drawing 3823.111-ME-317041 to facilitate the shipping of the system to Fermilab after completion of the system tests at the subcontractor's facility as specified in 5.14.8, and to facilitate the separate installation of the magnet cryostat and the control dewar into the DØ apparatus at Fermilab before the service chimney is fully reconnected between them. Furthermore, the service chimney design shall incorporate sufficient temporary flexibility

6

Technical Specifications

3. Demonstrate operation of data logger installed as required by 5.14.8, item 9;

5.14.8 Operational tests of the fully integrated magnet, service chimney and control dewar system

1. Pressure test of the Helium and Nitrogen systems;
2. Leak test of the helium, nitrogen, and vacuum systems;
3. Room temperature flow test of the helium and nitrogen systems;
4. High potential test between one current lead and the control dewar "ground" as specified in 5.4.4, with leakage current not to exceed 0.1 mA with full vacuum in service chimney;
5. Cool the system to operating temperature, logging coil temperatures vs. time; note that in this and all subsequent tests thru 17 below, the helium supply to the magnet shall be at the temperature specified in 5.7.5 and the flowrate as specified in 5.7.7;
6. Repeat the high potential tests of item 4, except that now all internal components are at full cold operating temperatures and pressures;
7. Measure heat leak to the helium and nitrogen systems at zero current;
8. Operate power supply to small current and verify proper connection and operation of all potential taps and temperature instrumentation;
9. Charge the magnet incrementally to at least six increasingly larger current values of 32%, 44%, 63%, 78%, 90% and 100% of design current at the specified charge rate appropriate to the current level with fast and slow discharges at the end of each current plateau. Log versus time the magnet current and magnet terminal voltages, coil and shield temperatures, and helium flow rate, temperature, and pressure in the coil, and temperature, voltage drop and helium flow rates in the vapor cooled current leads, and the temperature of the protection resistor, during this and all tests specified in 10,11,12,13, 14,16, and 17 below. Logging rates for quantities recorded shall be sufficiently rapid to display the useful time-dependent detail in each parameter, especially during quenching;
10. Verify that the magnet can be charged to design operating current in the time specified in 5.4.7, and measure inductance of magnet;

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And I= 105% for 8 Hrs

When Was it Done?

• D0/Fermilab Magnet Study Team Formed:	10/3/92
• PAC Approval of D0 Upgrade w/ Magnetic Tracking:	7/27/93
• Fermilab Review of Magnet Conceptual Design:	8/11/93
• Fermilab Magnet Procurement Readiness Review:	12/13/93
• SEB Formation:	2/23/94
• AIP Approved	5/13/94
• Final Draft Magnet Technical Design Report:	5/13/94
• Director's Review D0 Upgrade	5/27/94
• SEB Report:	12/15/94
• Subcontract Award to Toshiba	1/18/95
• PDR 1 (at FNAL)	3/15/95
• PDR 2 (at FNAL)	5/31/95
• FDR 1 (at Keihin)	7/22/95
• FDR 2 (at Keihin)	10/3/95
• FDR 3 (at Keihin)	3/19/96
• FPR 1 (at Keihin)	4/22/96
• FPR 2 (at Keihin)	7/23/96
• FPR 3 (at Keihin)	10/14/96
• CD Test (at Keihin)	12/3/96
• System Test (at Keihin)	2/26/97
• Magnet System arrives at Fermilab	5/12/97
• Magnet (+ Preshower Detector) Installed in Detector	6/16/98
• Magnet at 2.0 T at FNAL	9/11/98

Who Did It?

Fermilab:

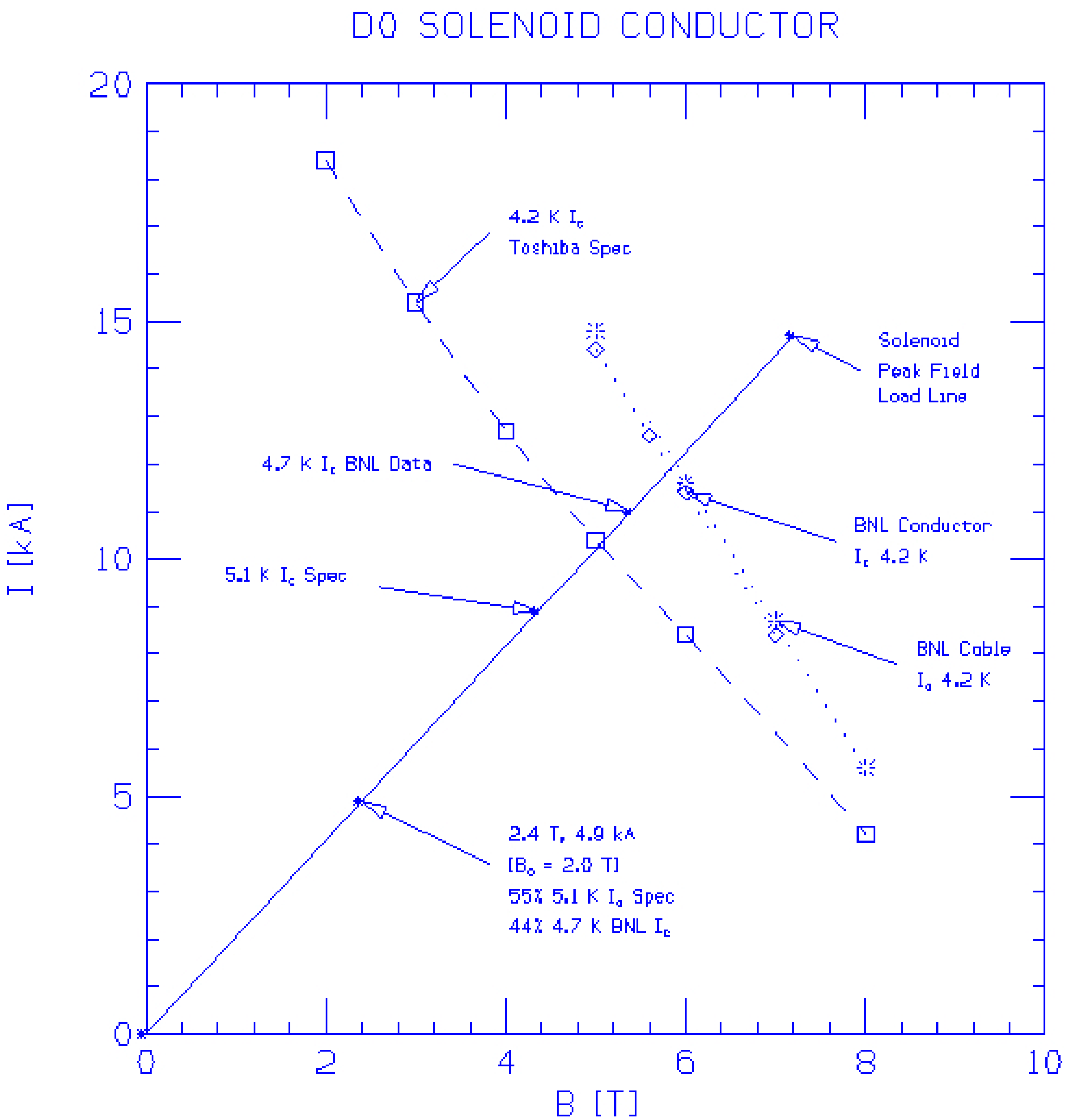
- H. E. Fisk, R. P. Smith, R. Yamada ("ret"), M. Mostafa , K. Krempetz, R. Rucinski, D. Markley, R. Hance (ret), W. Jaskierney, Del Miller and crew, R. L. Schmitt, B. Squires, R. Fast(ret)

- R. Kephart, A. Tollestrup, P. Martin, P. Mantsch, T. Nicol, J. Strait, R. Walker, R. Huite

Toshiba:

- S. Mine, T. Kobayashi, K. Kimura, W. Odashima, H. Kozu, S. Ito

QC Checking


D0 SOLENOID CONDUCTOR
4.2 K I_c
Toshiba Spec
Solenoid
Peak Field
Load Line
4.7 K I_c BNL Data
BNL Conductor
I_c 4.2 K
5.1 K I_c Spec
BNL Cable
I_c 4.2 K
2.4 T, 4.9 kA
[B_o = 2.0 T]
55% 5.1 K I_c Spec
44% 4.7 K BNL I_c
I [kA]
B [T]
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0
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4
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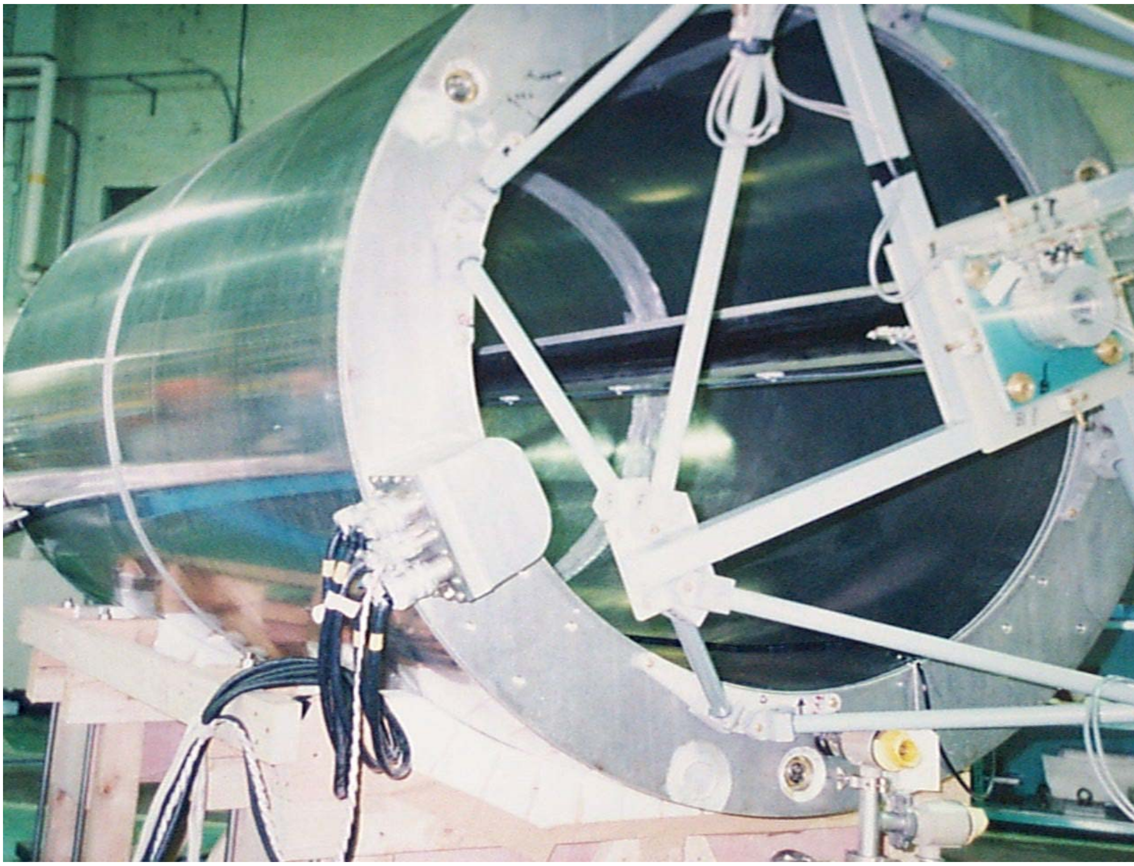
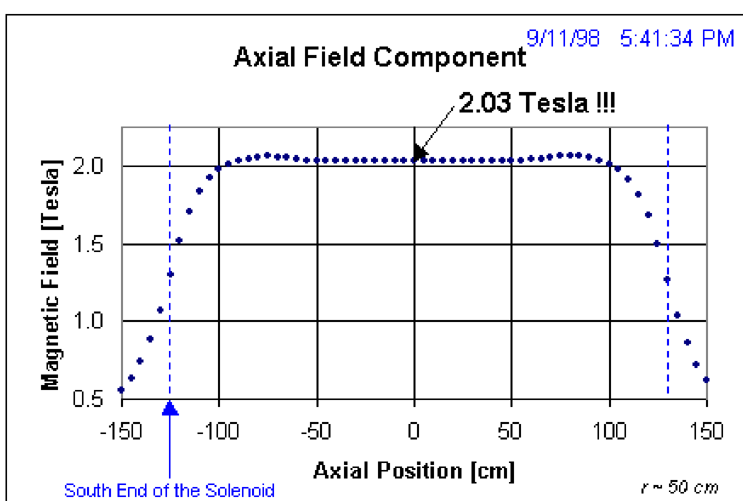
8
10

Fieldmapping at Keihin



Mapping at Keihin, 1997

Mapping at Batavia, 1998

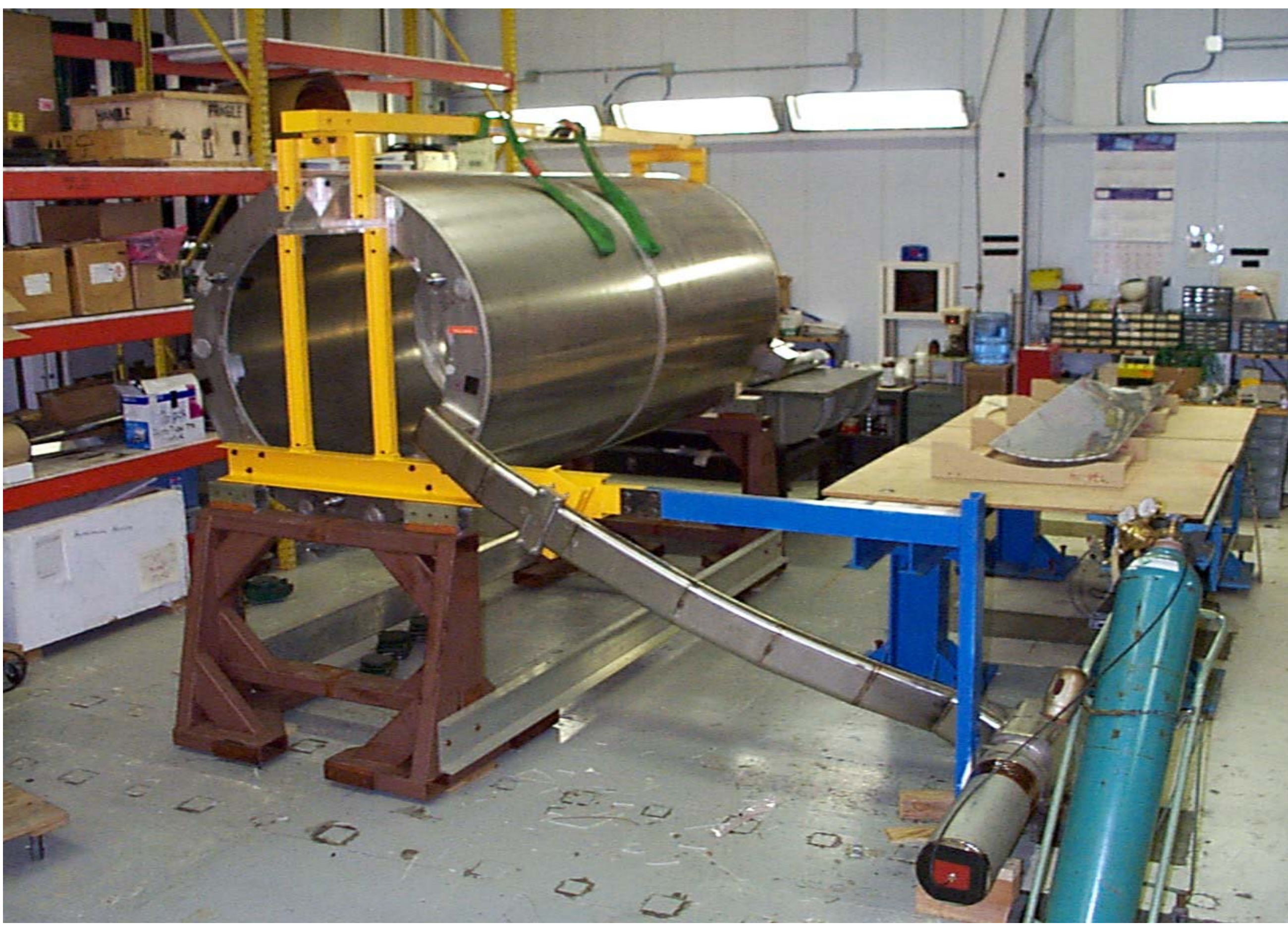


Delivery – Keihin to Batavia

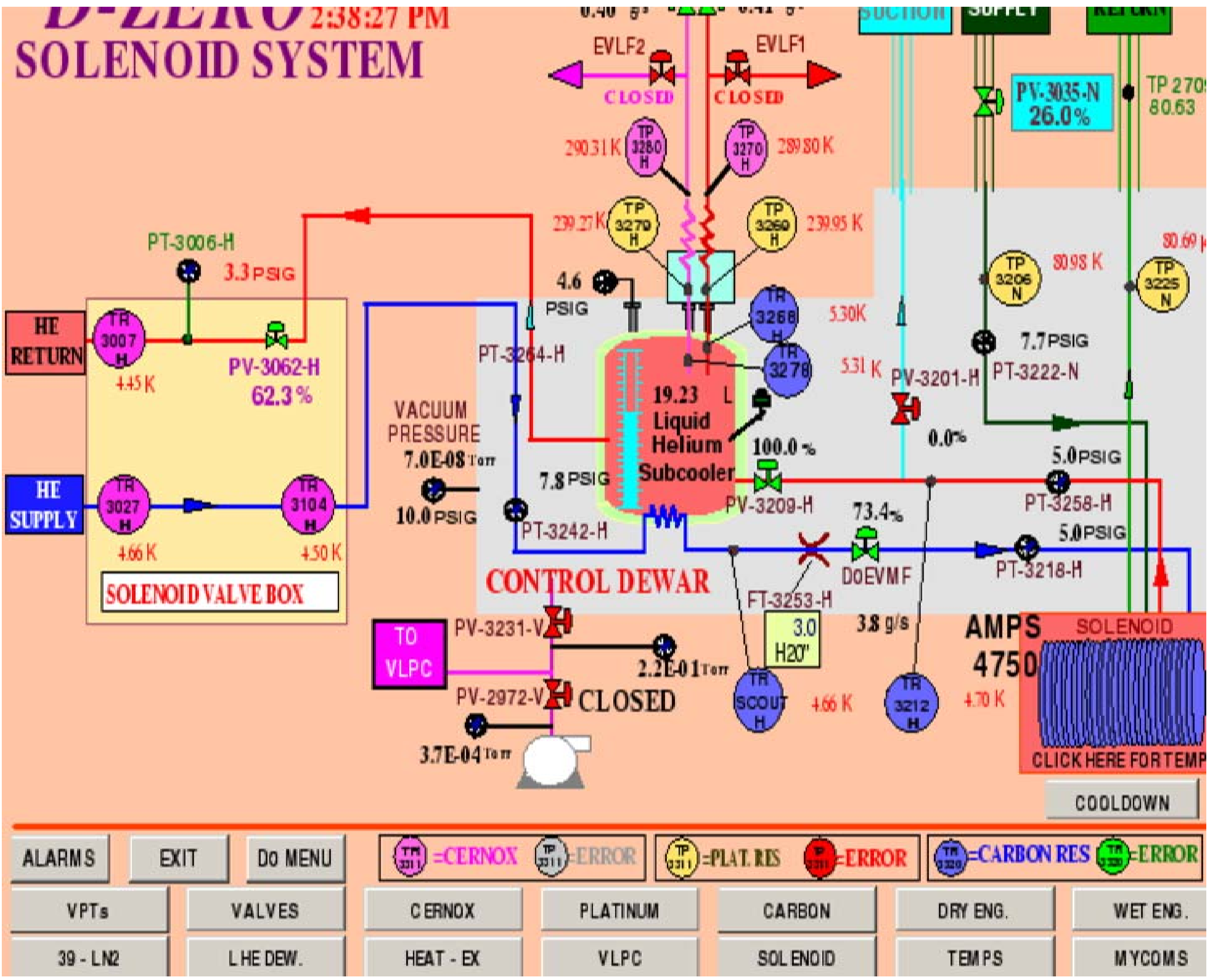
Solenoid Arrival at Fermilab, May 12, 1997

Solenoid + "Obround" Chimney Segment

Ready for Installation of Preshower Detector



Detail for Solenoid Cryo System



Cryo Energization Permit

2:35:33 PM 3/21/2003

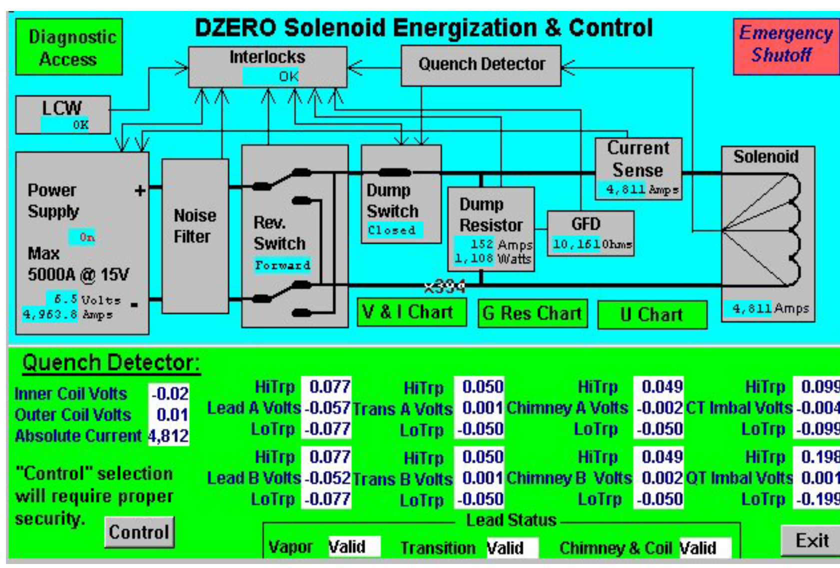
	VALUE	STATUS	OVERRIDE
CD SUBCOOLER LEVEL	19.30 L	>12.0 L (1m)	ENABLE
CD INSUL VAC	7.0E-08 Torr	<1E-4 Torr (1m)	ENABLE
SOL He MASS FLOW	3.83 g/s	>1 g/s (1m)	ENABLE
TR 3343	4.83 K	< 5.5K (1m)	ENABLE
TR 3344	4.67 K	< 5.5K (1m)	ENABLE
TR 3345	4.95 K	< 5.5K (1m)	ENABLE

EXIT

Cryo Sum Status Permit

Energization System can charge Magnet iff Cryo Permit is Enabled, Accelerator Permit Enabled

Solenoid Energization System Control



Fast (τ ~ 11 sec) Emergency Discharge: Quench Detected

Slow (τ ~ 300 sec) Discharge: All Other

Solenoid Protection System

D0 Eng. Note 3823.111.EN-418

The following interlocks are processed by the "Interlocks and quench detection/protection chassis". A summation signal "Interlock chassis permit" is provided to the power supply as listed above. Each of these signals is provided to the control system for remote monitoring. In addition, each of these is provided a second time to the control system by the "first fault" module to provide diagnostic capability.

Interlock Chassis Processed Interrupts	Type	Description
Accelerator permit	SD	Permit from accelerator = closed contact
Bus temperature permit	SD	String of thermal switches on bus closed = OK
Control system permit (see below)	SD	Control system permit = closed contact
Crash buttons permit	SD	String of crash buttons OK = closed contact
Cryo Permit	SD	Contact from cryo control system PLC
DC Overcurrent	SD	Power supply current and holec current below trip level
Dump switch permit	SD	Switch & resistor normal = closed contact
Filter permit	SD	Filter ground/hi pot switch in normal position
Flow permit	SD	LCW is flowing = closed contact
Gate permit	SD	Microswitch on RM511 security gate
Ground fault permit	SD	From GFD module = closed contact if OK
LCW Permit	SD	From LCW system OK = closed contact
Steel closed permit	SD	Muon steel closed = closed contact
Quench detection permit	FD	Quench det. modules OK = closed contact
Reversing switch permit	SD	Reversing switch is not cycling = closed contact
Smoke permit	SD	Contact from RMI in controls rack - smoke detector
Xducer valid permit	SD	Power supply current and holec current agree

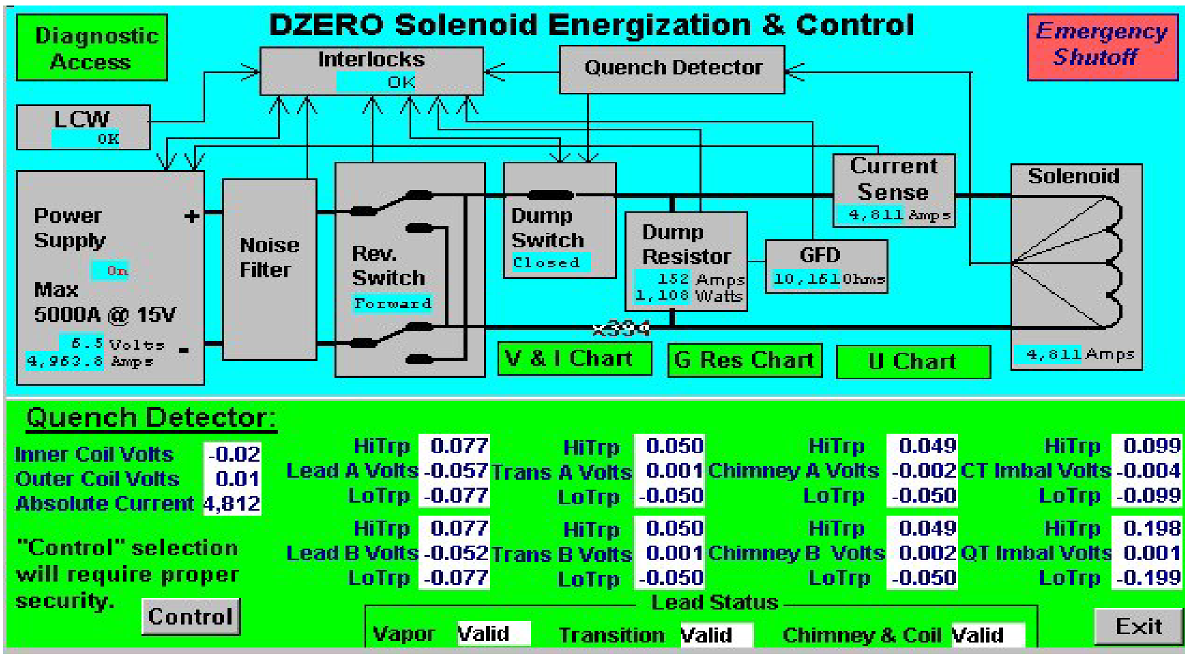
Fast Dump

The following parameters of the solenoid systems are examined by the **control system** software and summed to produce the signal "Control system permit" which is fed to the interlock chassis. The signal is in the form of a normally open relay contact which is held closed if all conditions are satisfactory. The term "OK" will be replaced with quantities as this specification develops. These values shall also be displayed at the operators console.

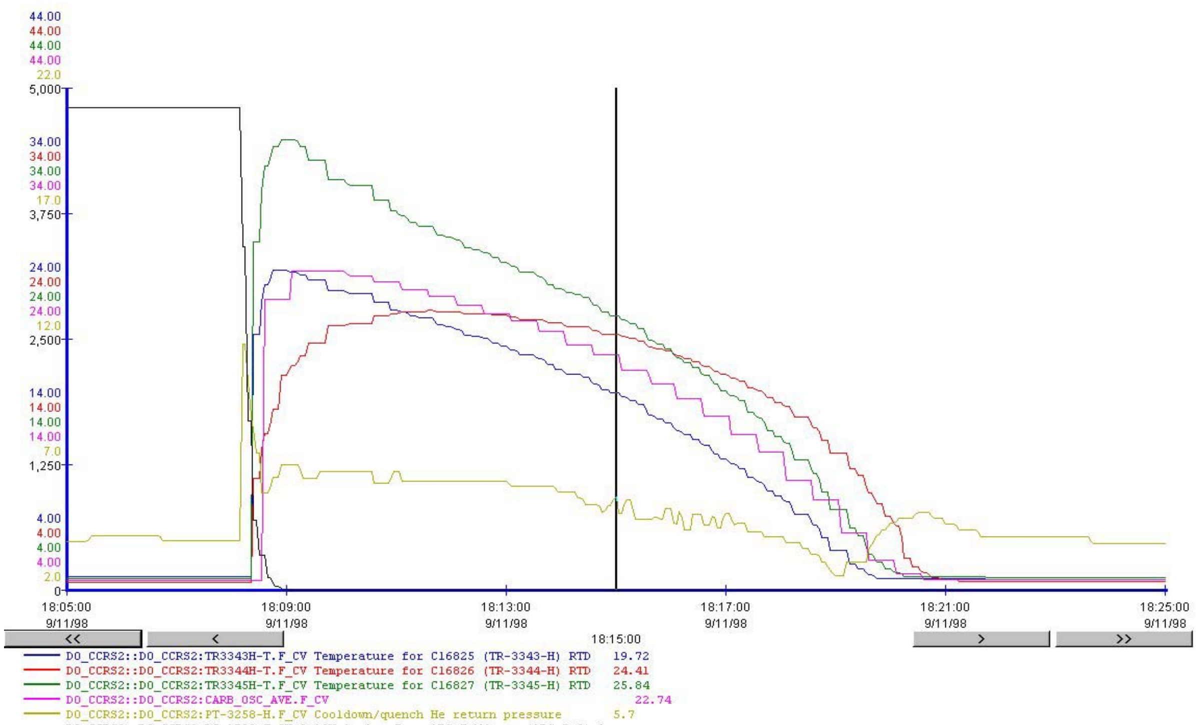
Parameter	Type	Description
VC lead temp	SD	Vapor cooled lead temperatures OK
Vapor Cooled lead flow	SD	Vapor Cooled lead flow OK
Cryostat vacuum pressure	SD	Cryostat vacuum pressure OK
Radiation shield temperature	SD	Radiation shield temperature OK
Solenoid cold mass temperature	SD	Solenoid cold mass temperature OK
Control dewar helium level	SD	Control dewar helium level OK
Helium supply temp	SD	Helium supply temp OK
Helium supply dewar level	SD	Helium supply dewar level OK
Helium pressure in solenoid	SD	Helium pressure in solenoid OK
Helium flow rate in solenoid	SD	Helium flow rate in solenoid OK
De-centering forces	SD	De centering forces OK
PLC	SD	Programmable controller OK
UPS battery	SD	UPS battery OK
Vapor cooled lead voltage	SD	Software limit on vapor cooled lead voltage

Revision Date: 01/19/99 1:39 PM 20 H950116A.DOC

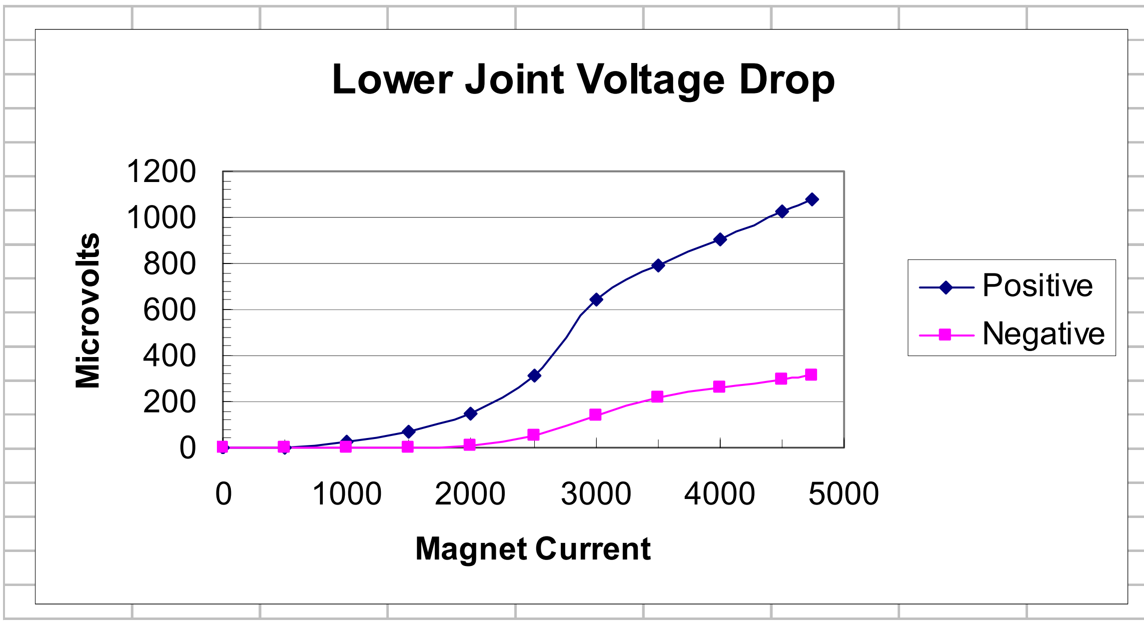
D0 Solenoid Energization Control Console



Fast Discharge Test (Causes Quench)

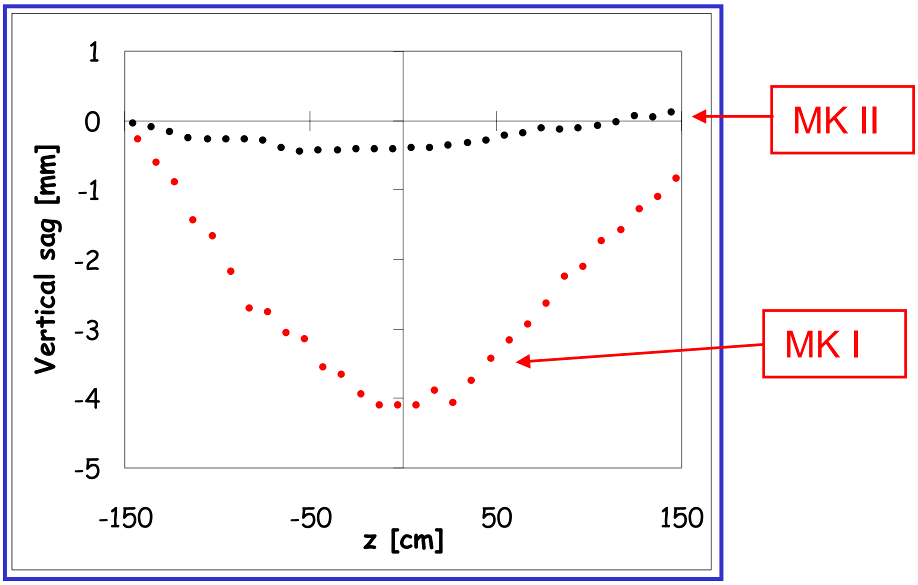


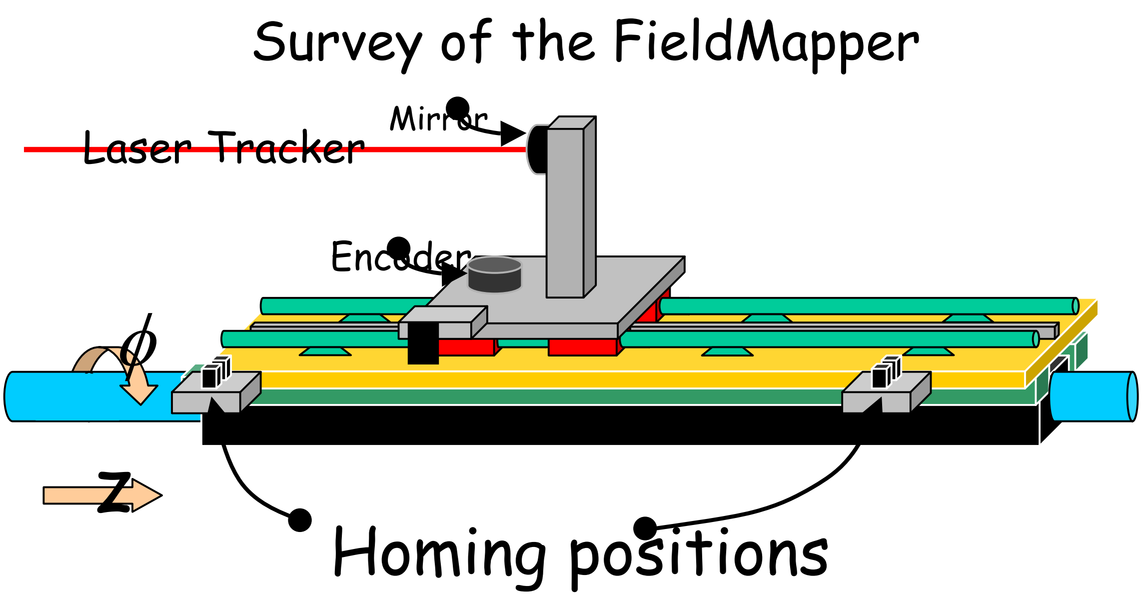
Lower Field Joint Voltage Drops



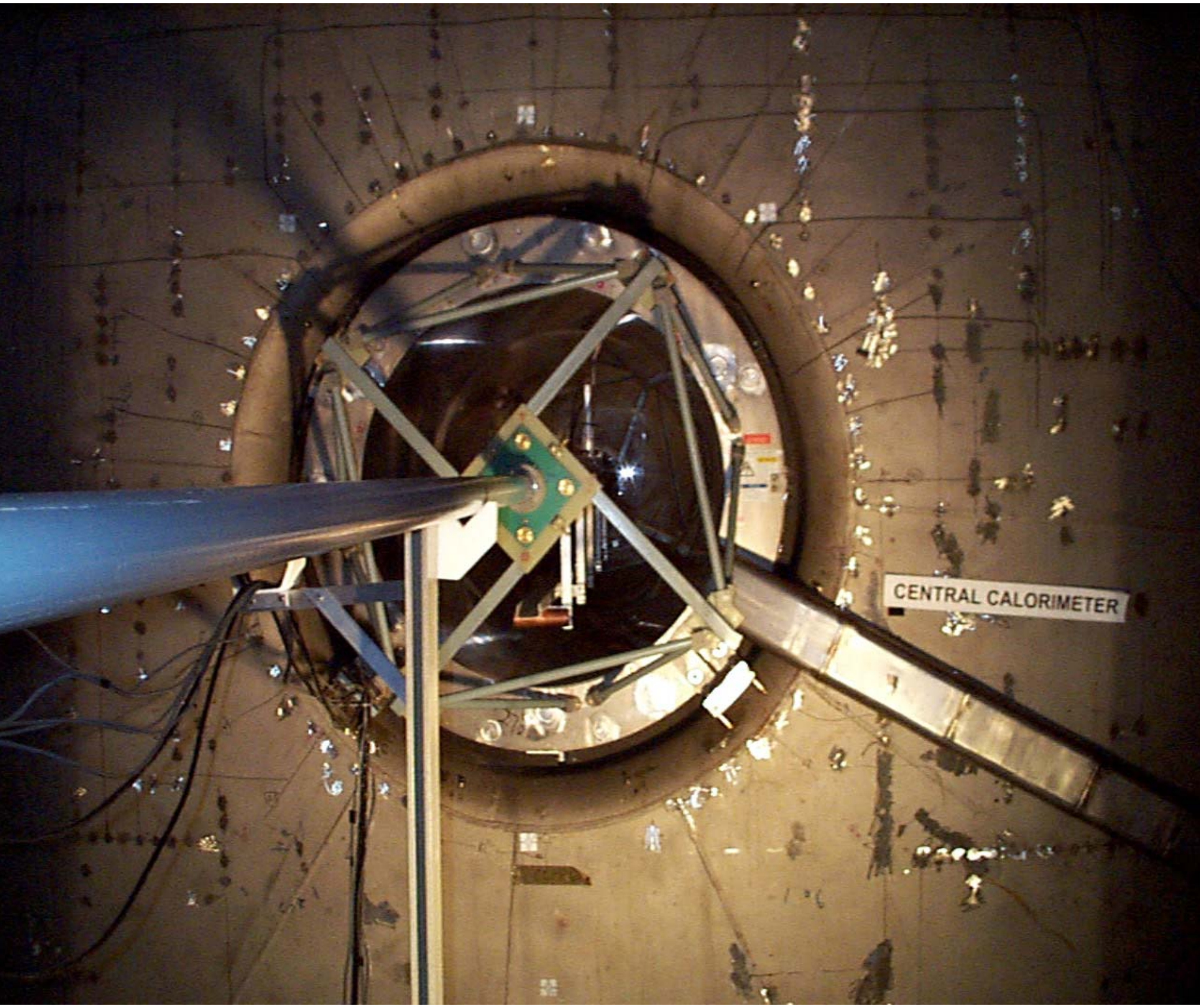
Solenoid in D0 Detector

Fieldmapper MK II

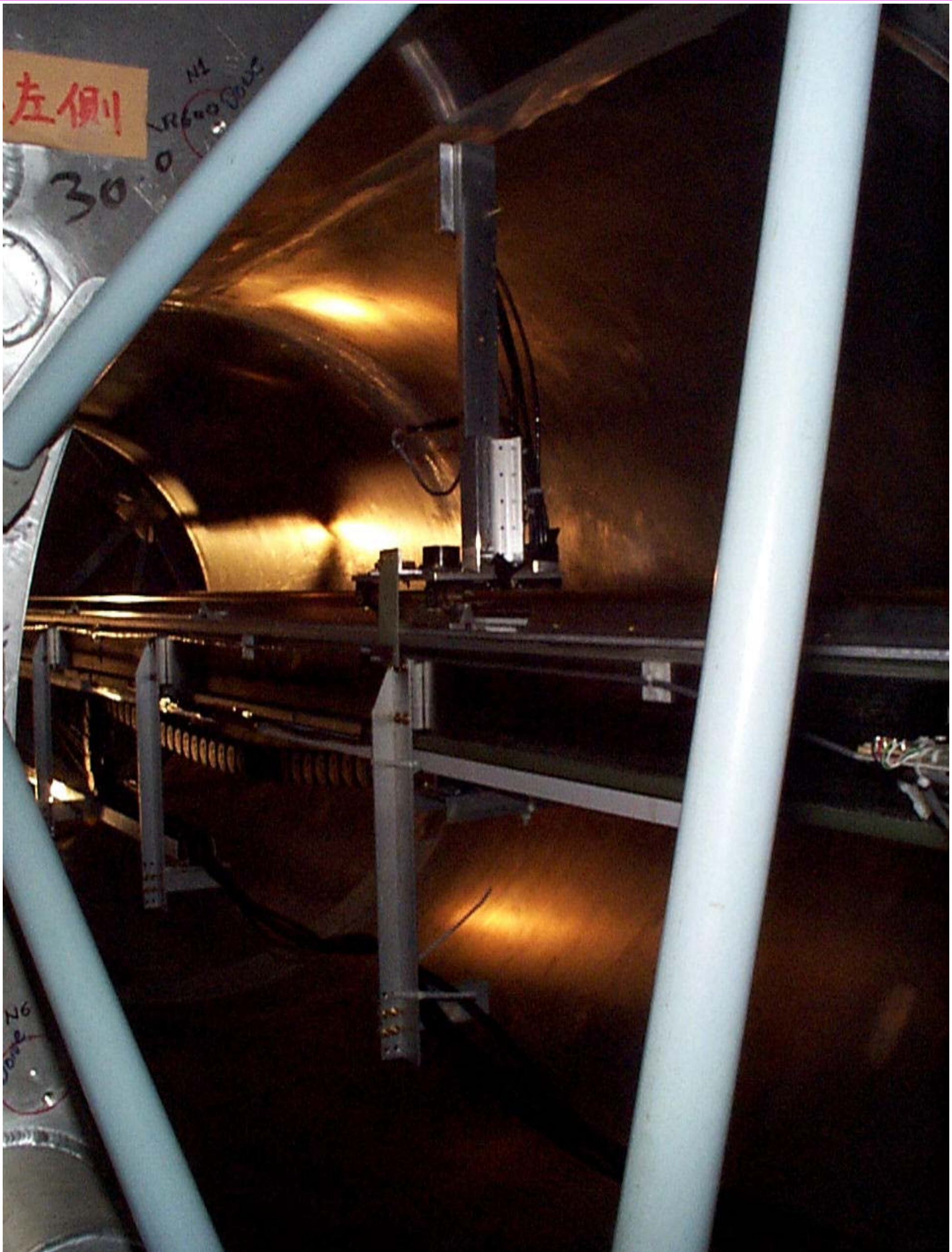




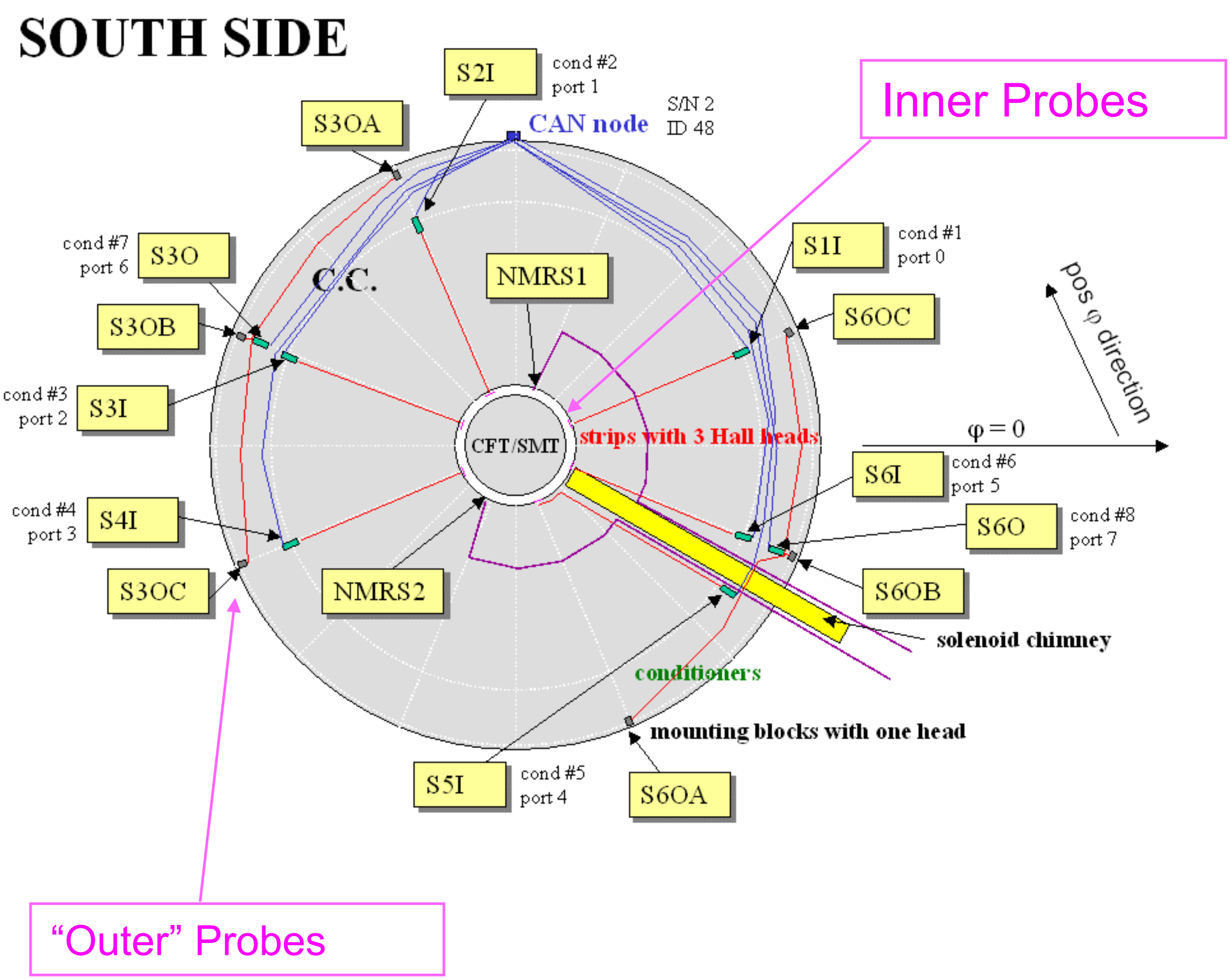
Fieldmapper in Solenoid



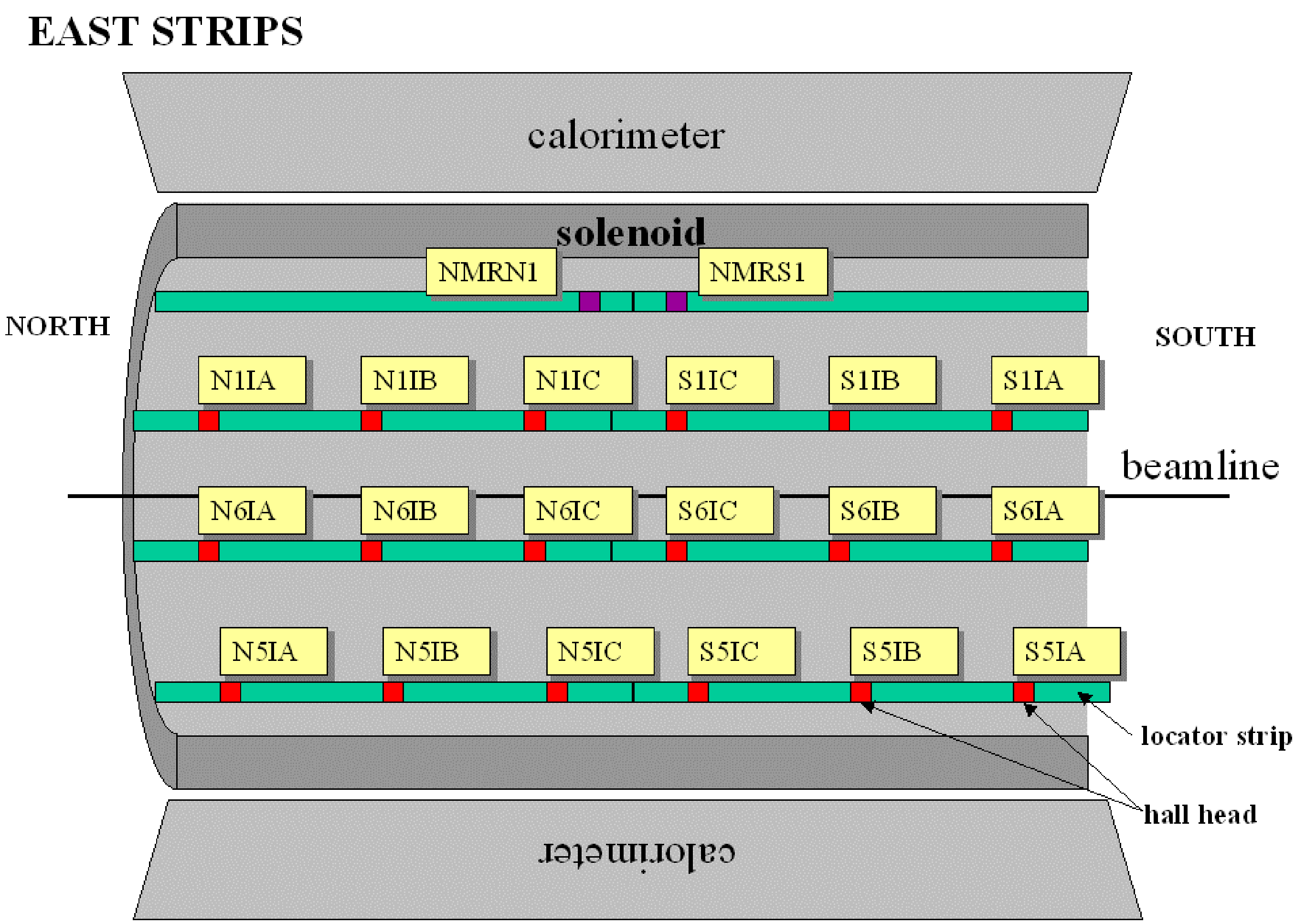
Fieldmapper Moving Arm with Hall Probes



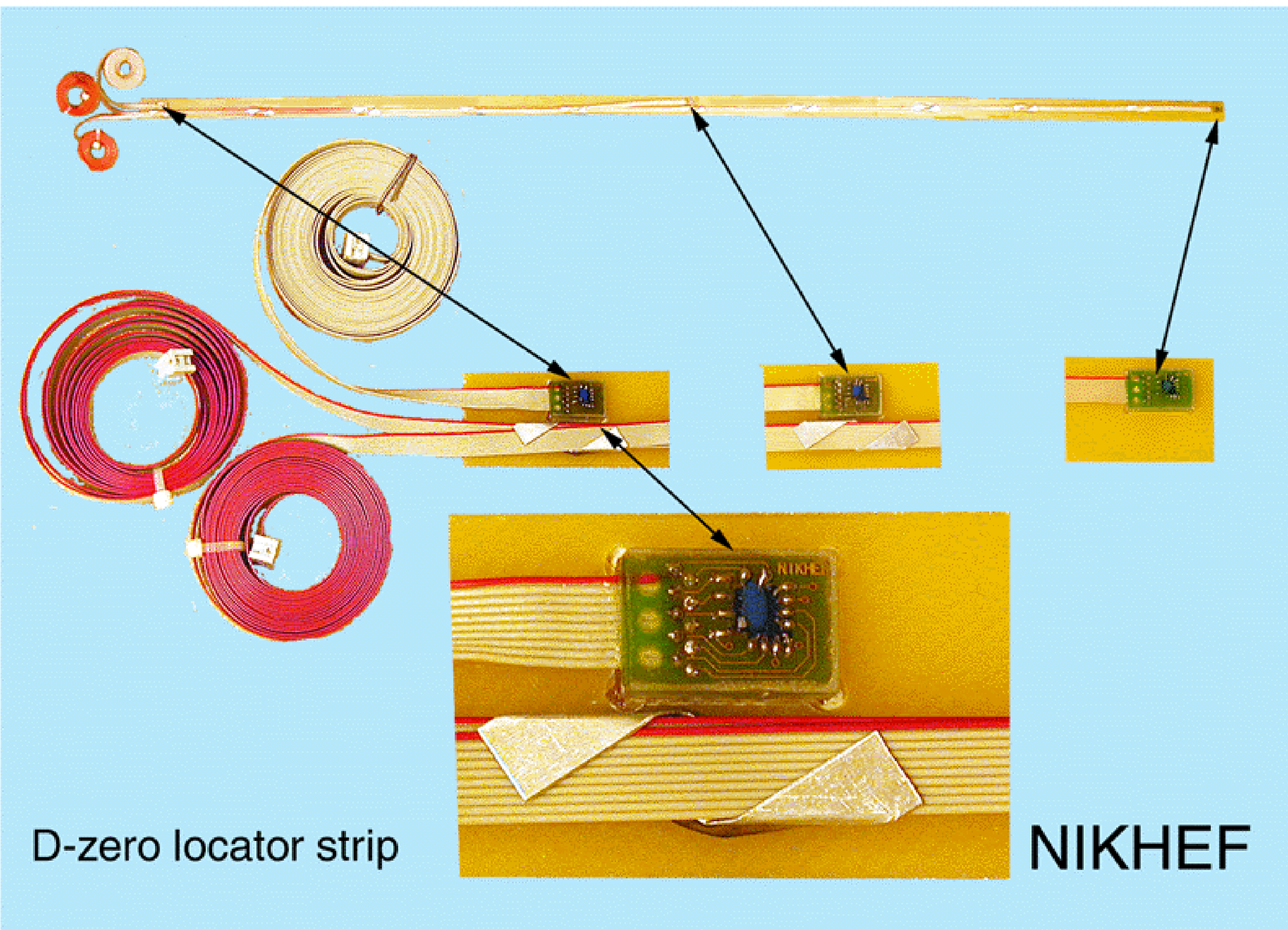
NIKHEF Hall Probes



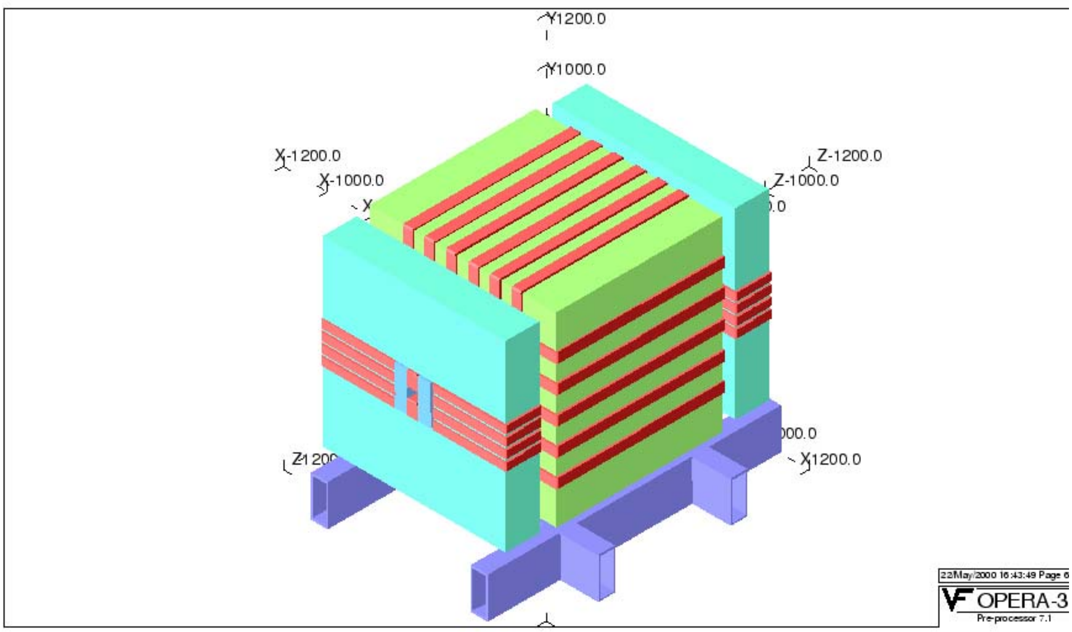
NIKHEF Inner Hall Probes
FNAL NMR Probes

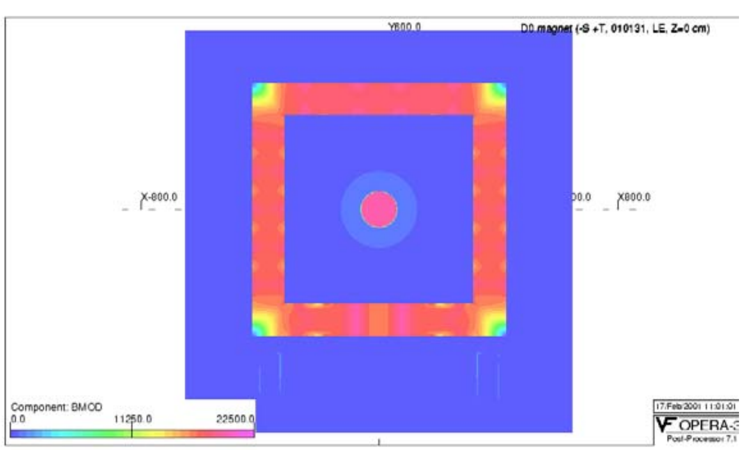


Typical NIKHEF Inner Probe Locator Strip with 3 Probes

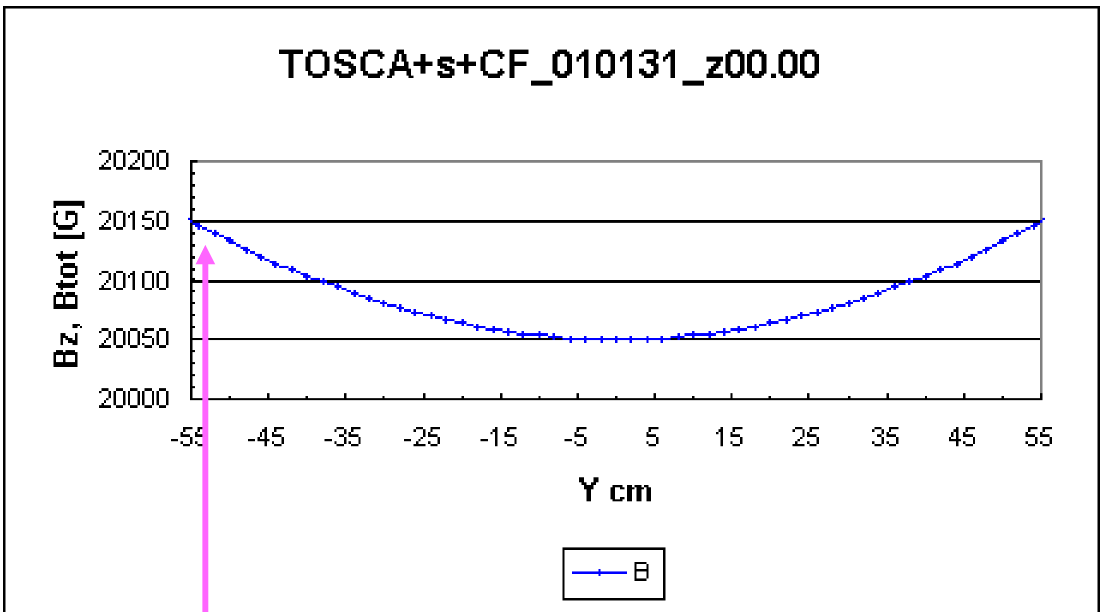


TOSCA 3D Model





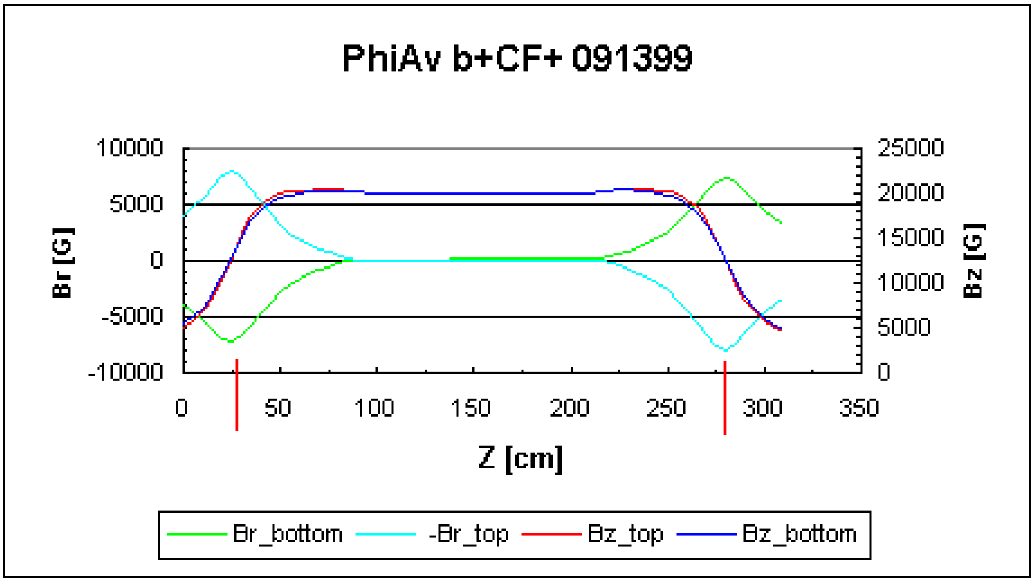
TOSCA Predictions ?

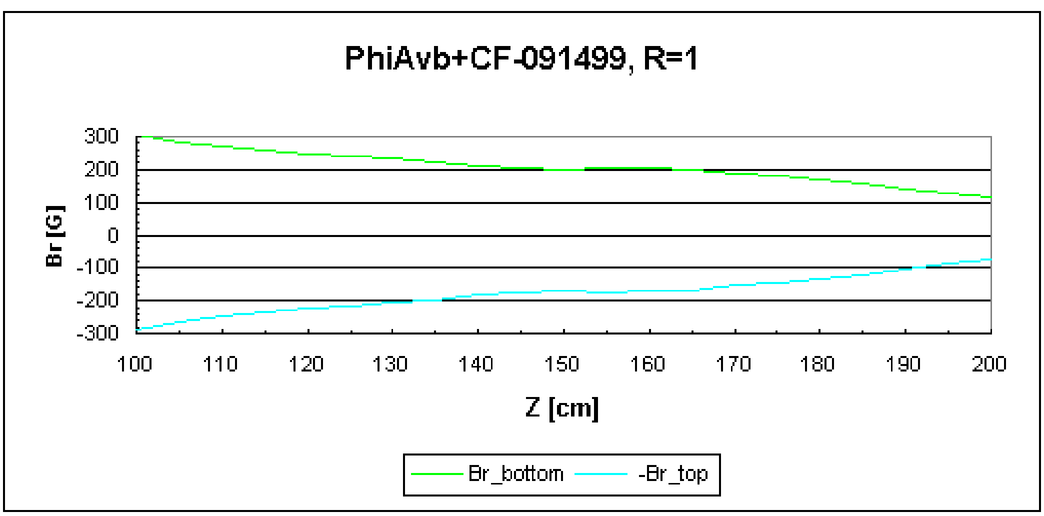


NMR (R = 53) = 20143 +/- 3

Hall Probes (same R) ~ 20130 +/- 10

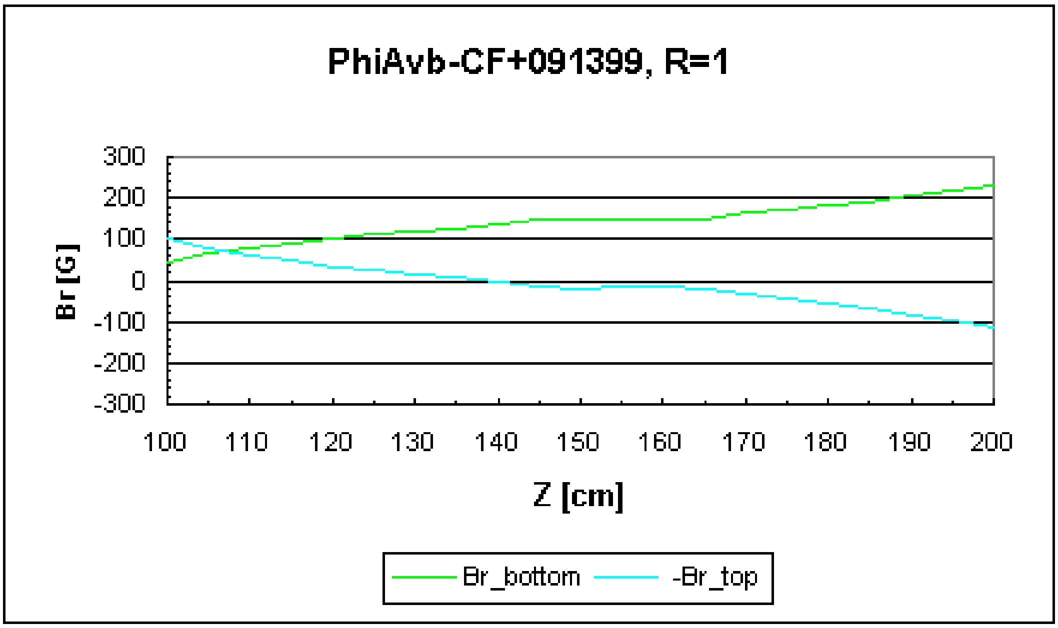
“Looks” OK





Br(HallProbe) = Brcos(α)+Bzsin(α)

Not So Fast…



PhiAvb-CF+091399, R=1
300
200
100
0
-100
-200
-300
Br [G]
100
110
120
130
140
150
160
170
180
190
200
Z [cm]
Br_bottom
-Br_top

How Do Hall Probes Work?

We neglect B_ϕ. Then the Hall voltage of a probe oriented to measure B_z can be expressed as[1, 2]

$$V_H = \frac{R}{d} I B_z \cos(\alpha) + \frac{R}{d} I B_r \sin(\alpha) + V_0 - \frac{1}{2}(\alpha_1 - \alpha_2)\rho_0 I B_T^2 \sin(2\psi) + \frac{1}{24}\mu b^2 \left|\nabla B_z\right|^2 \sin(2\varphi) \qquad (1)$$

The thickness of the probe is d and the width is b. $R = \mu/\sigma$ is the Hall coefficient. The first term on the right hand side of (1) is the desired Hall signal. The remaining terms are the leading corrections. The current through the Hall probe is I (and has the direction of $\vec{e}_z \times \vec{e}_r$ if the probe is perfectly aligned). The angle of missalignment of the Hall probe is α. The offset voltage is V_0. The term proportional to $\sin(2\psi)$ is the so called "planar" Hall effect. ψ is the angle between I and the component of $\vec{B}$ in the plane of the probe (which is $\pi/2$ if perfectly aligned). Finally φ is the angle between ∇B_z and I (which is $\pi/2$ if perfectly aligned). Note that if the Hall probe is perfectly aligned only the first and third terms on the right hand side of (1) remain.

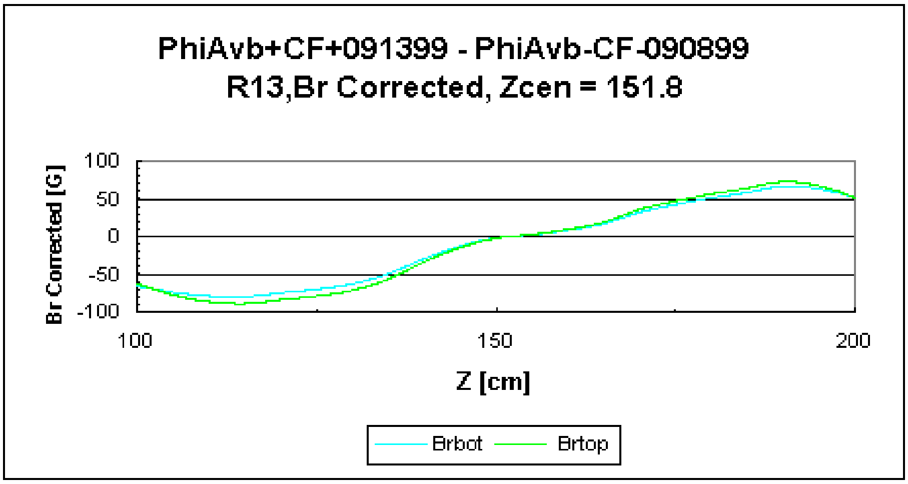
Measurements were done with no EF toroid. To reduce systematic errors we use two measurements, one with +4748 A in the solenoid and, say, -1500 A in the CF toroid, and one with opposite currents: -4748 A in the solenoid and +1500 A in the CF toroid. Changing $\vec{B}$ by $-\vec{B}$ changes ψ to $\psi+\pi$ and φ to $\varphi+\pi$. Therefore apropriately averaging the Hall voltages obtained with $\vec{B}$ and $-\vec{B}$ leaves us with only the first two terms on the right hand side of

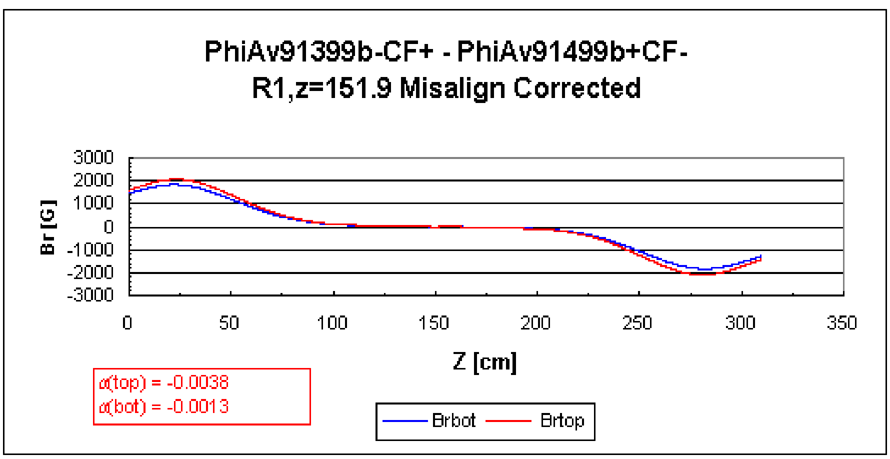
$$V_H = \frac{R}{d} I B_z \cos(\alpha) + \frac{R}{d} I B_r \sin(\alpha) \tag{2}$$

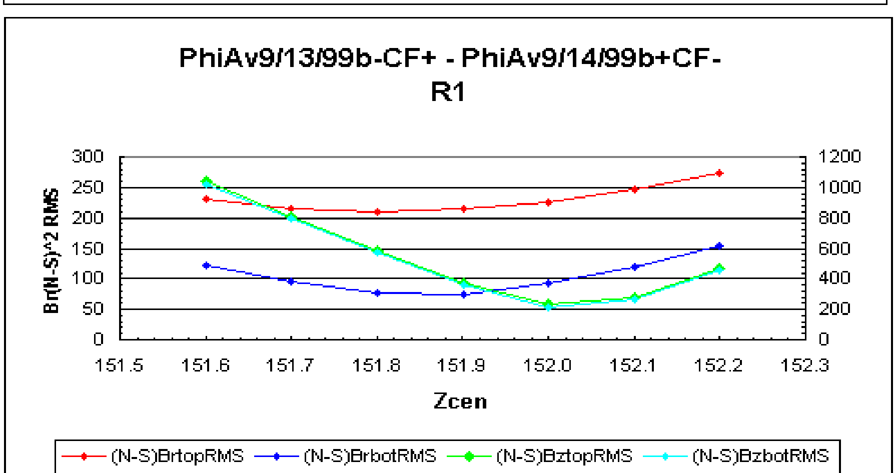
for a Hall probe oriented to measure B_z. For a probe oriented to measure B_r, $\cos(\alpha)$ and $\sin(\alpha)$ are interchanged.

Unfortunately the missalignment angles of the four Hall probes α are unknown. For the probes "B_r top" and "B_r bottom" we set α so that $B_r = 0$ at $z = 0$ as measured at the smallest radius, *i.e.* at r-index = 1. For the probe "B_r top" we obtain $\alpha = 0.004453$. For the probe "B_r bottom" we obtain $\alpha = 0.001872$. With these α's we obtain peak readings of B_r at $z \approx \pm 127.5$ cm symmetric to within 0.1%.

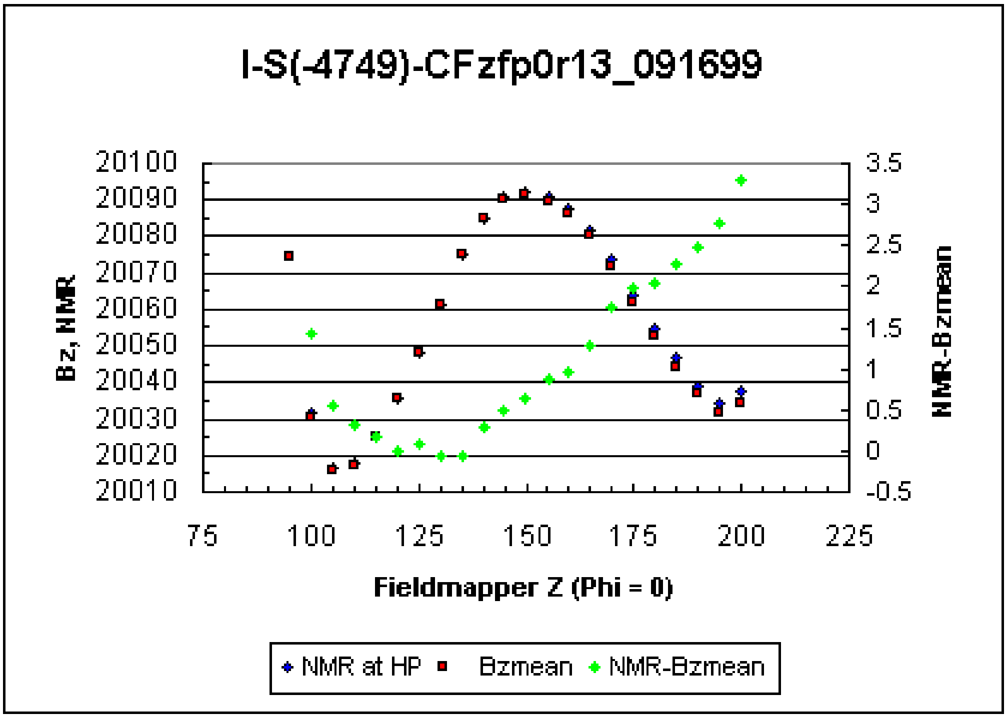
Br Fix at Hand



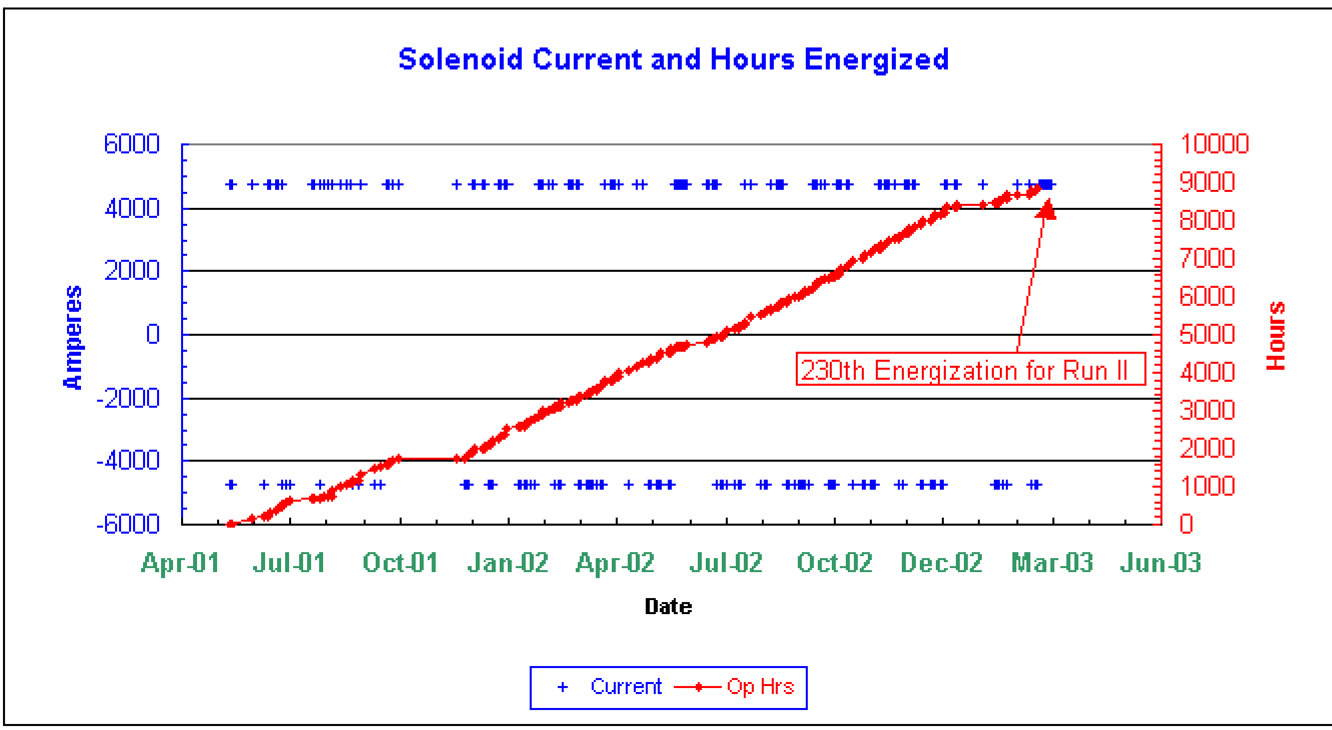




Some Fieldmapping Success

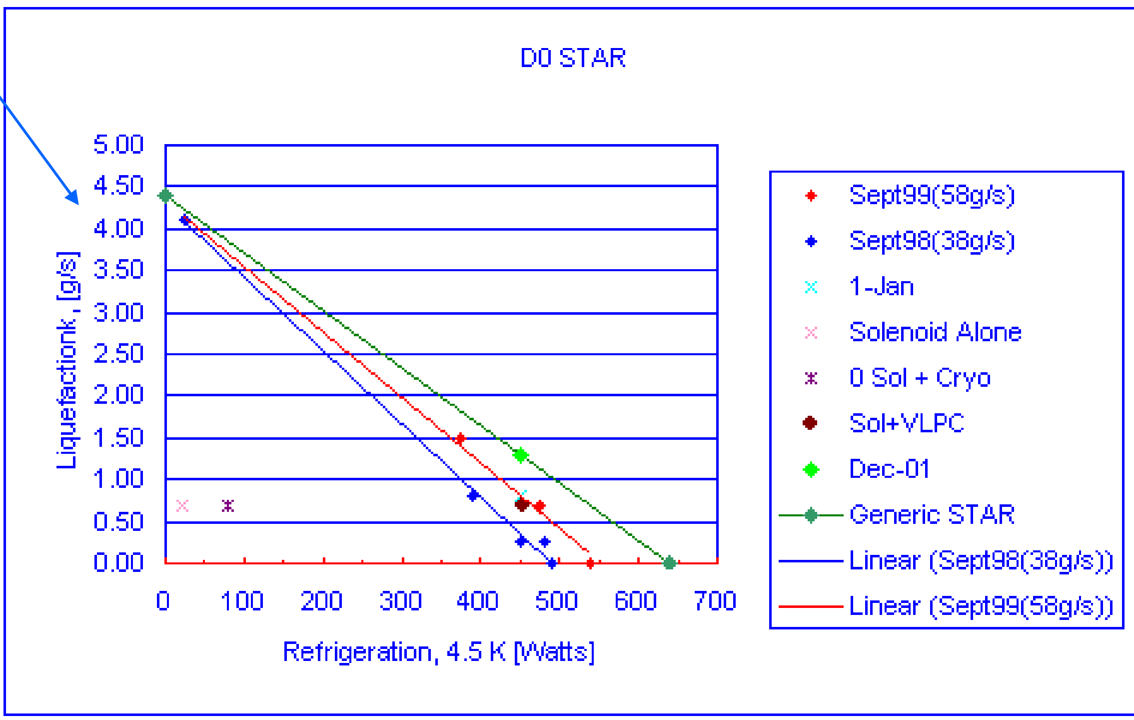


Run II Operation

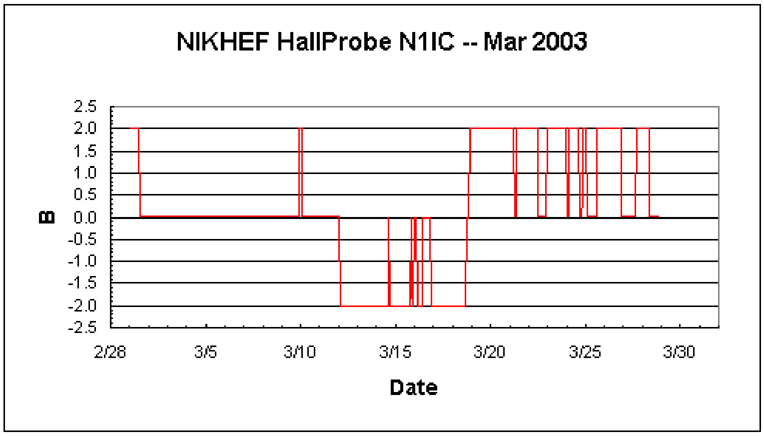


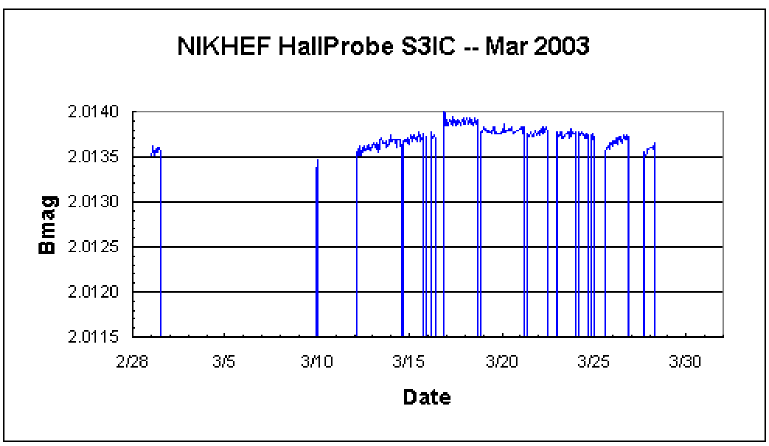
D0 STAR

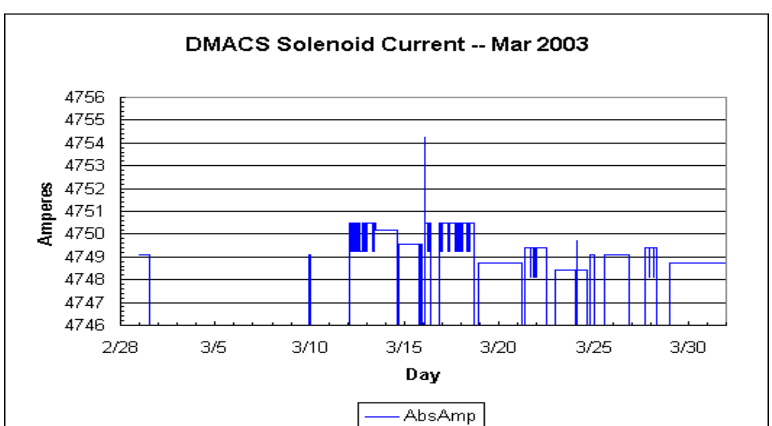
4 g/s = 114 l/hr



Operating Stability ?

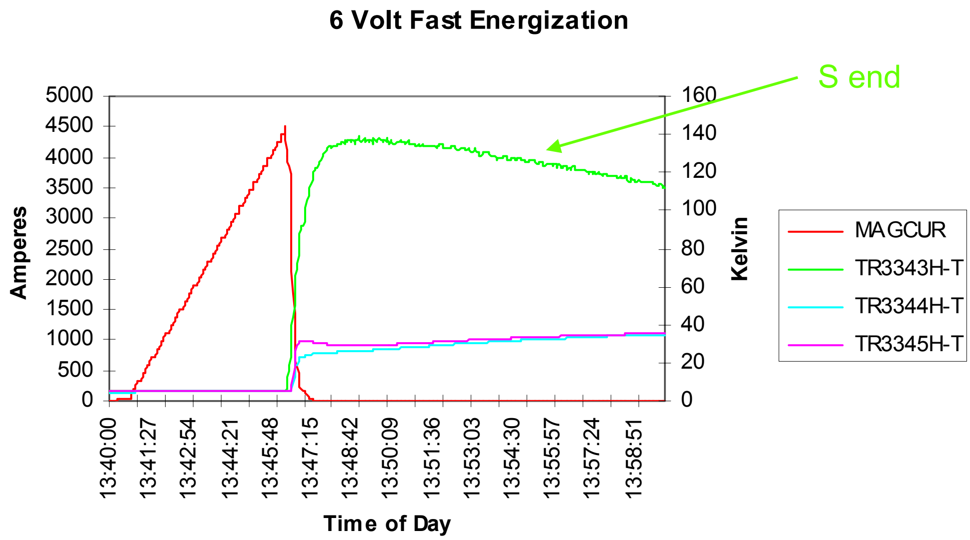




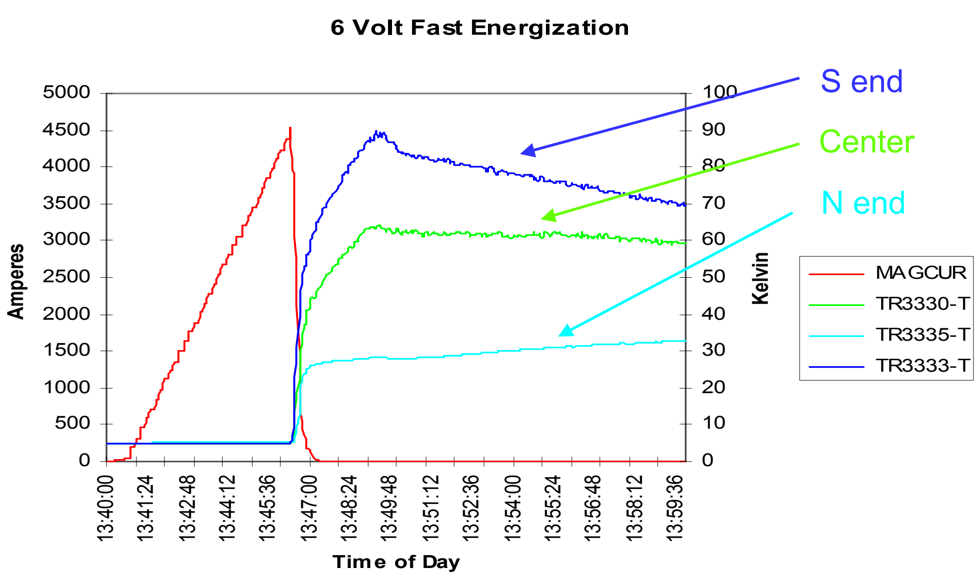


Factory Tests at Toshiba

- **Conductor temperatures**

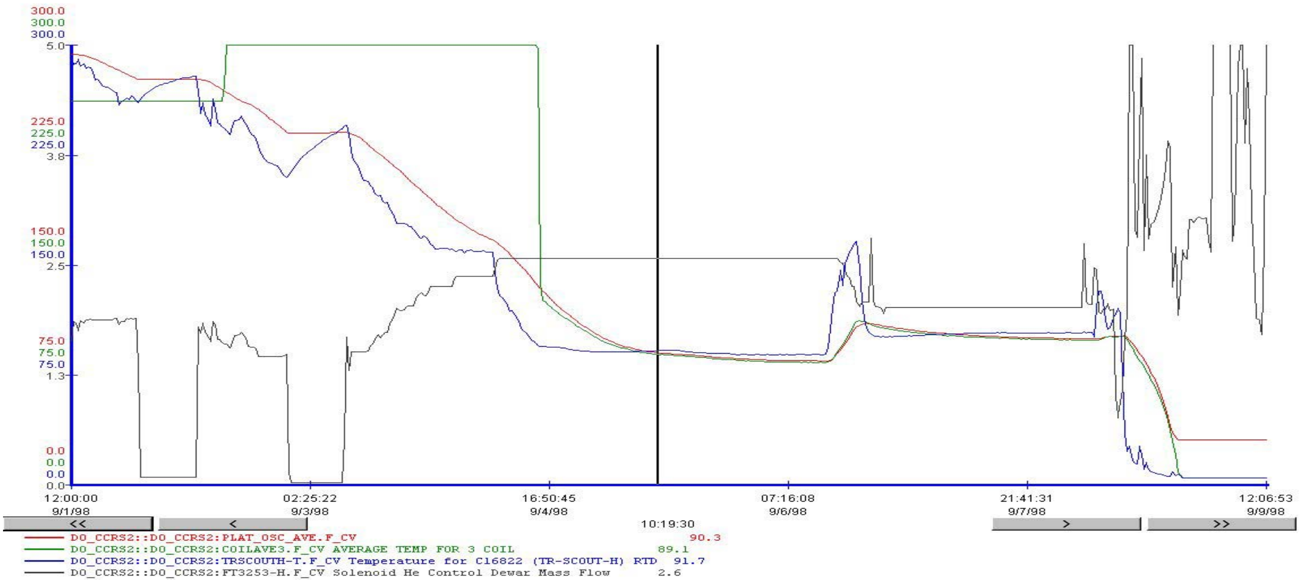


- **Support cylinder temperatures**

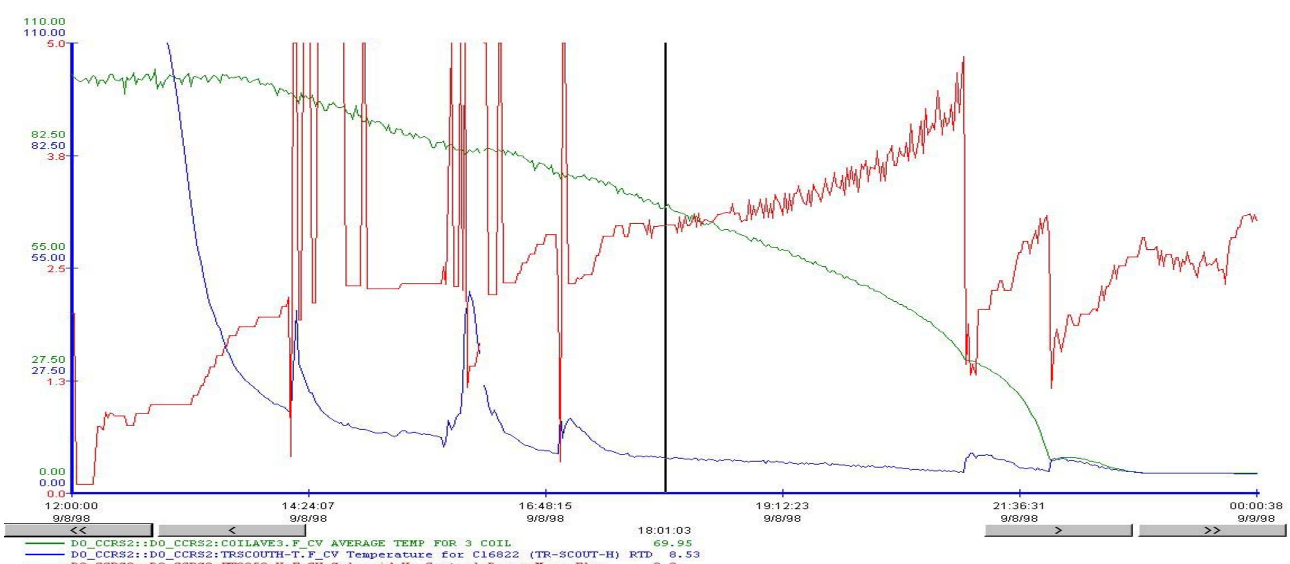


Cooldown

Cooldown from 300 K to 4.5 K

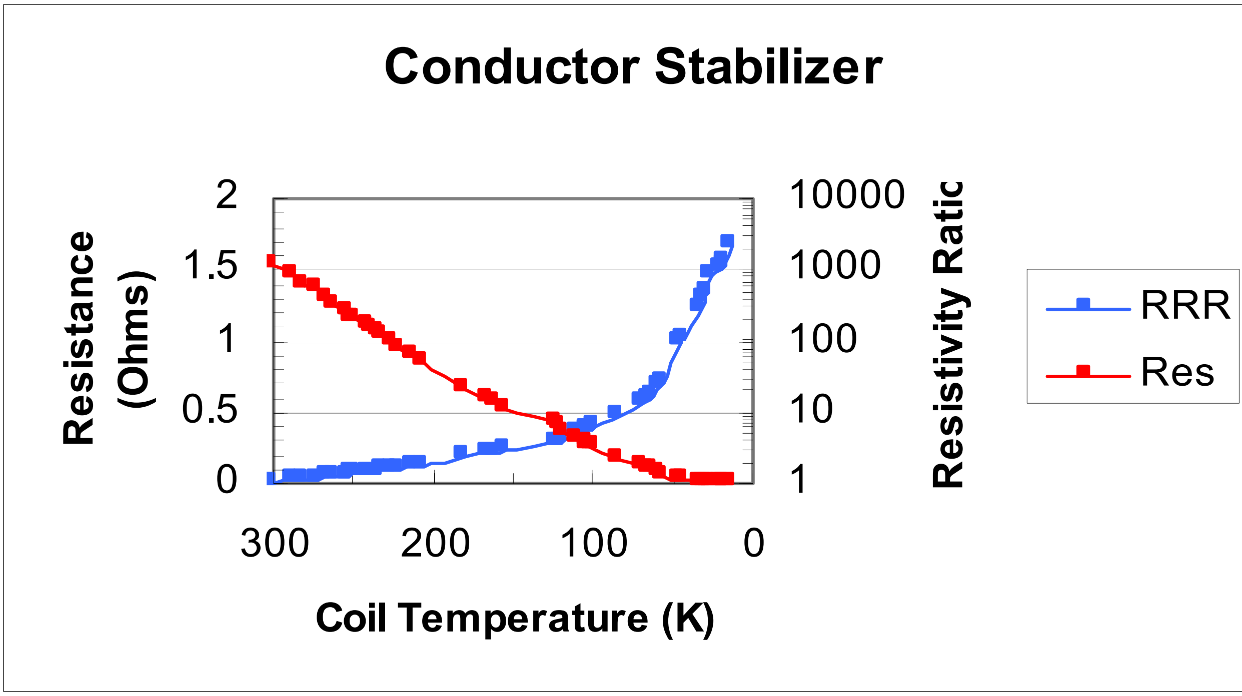


Cooldown detail below 80 K

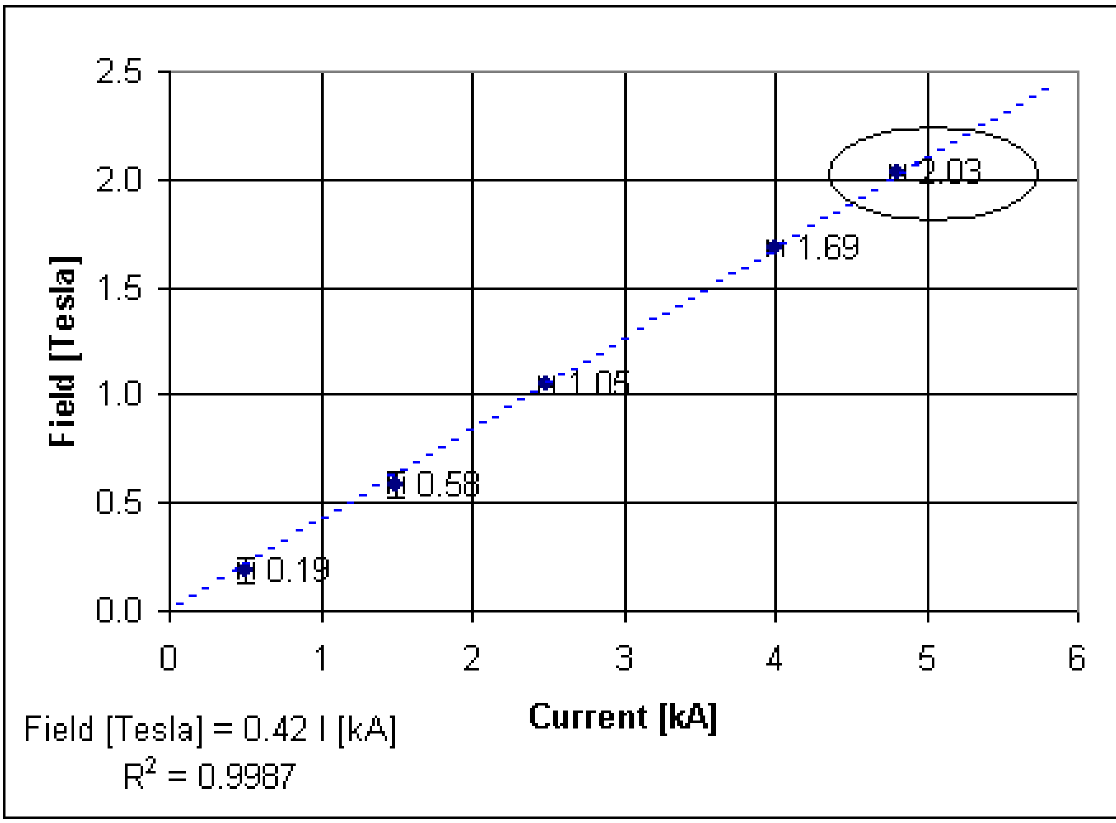


Cooldown

Cooldown from 300 K to 4.5 K



Precision Load Line via NMR



First Fieldmapper Data at D0