DESIGN CONSTRUCTION AND TEST RESULTS OF A HTS SOLENOID FOR ERL*

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Office of Nuclear Physics
PAC eleven 2011 Particle Accelerator Conference March 28 - April 1, 2011 • New York, U.S.A.

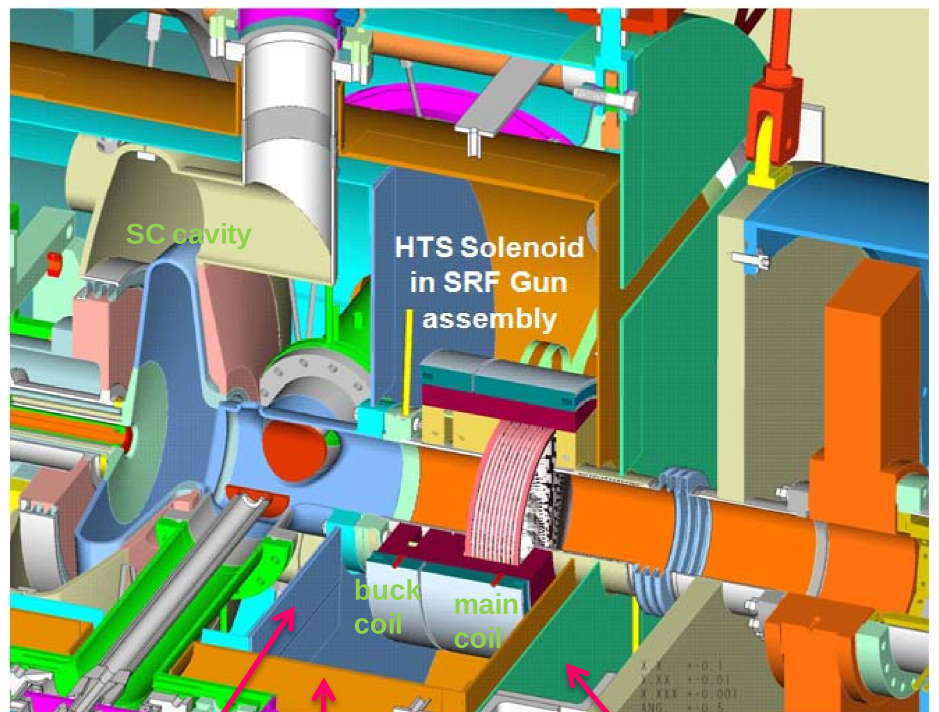
Benefits of HTS Solenoid inside the cryostat

• Solenoid inside the cryostat and very close to cavity provides early focusing which reduces beam emittance. Originally, HTS solenoid was proposed as it can be conveniently placed inside the cryostat in a cold to warm transition region - say ~20 K. NbTi won't work at 20 K and Cu magnet will be too big and create too much heat.

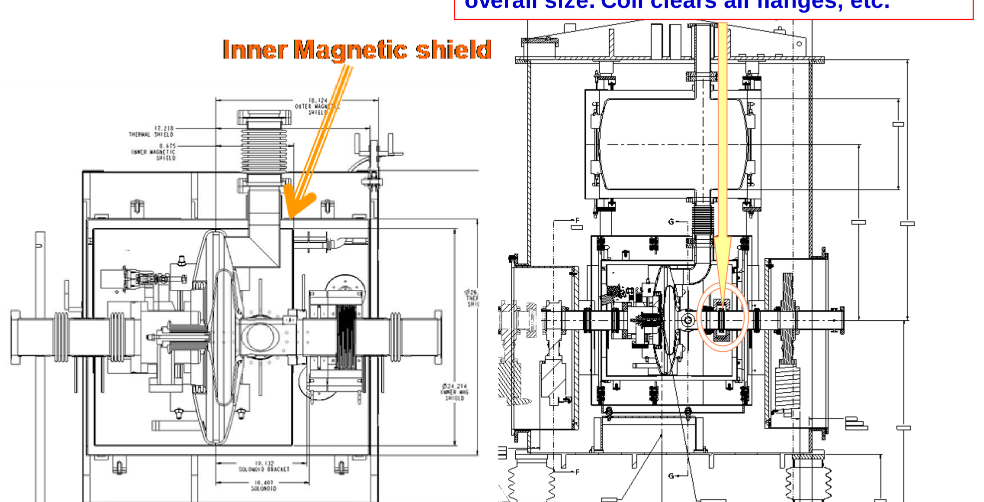
• The major advantage HTS over NbTi continues to be that it allows tests with LN_2 as solenoid is designed to reach the nominal field at 77 K. LN_2 not only makes tests an order of magnitude cheaper than testing in LHe at ~4 K (for NbTi), but also practical. Note: HTS cost is a fraction of overall solenoid cost (design, construction & testing).

• Conduction cooling and current leads become simple and attractive as temperature gradient is no longer an issue with a large thermal margin in case of HTS.

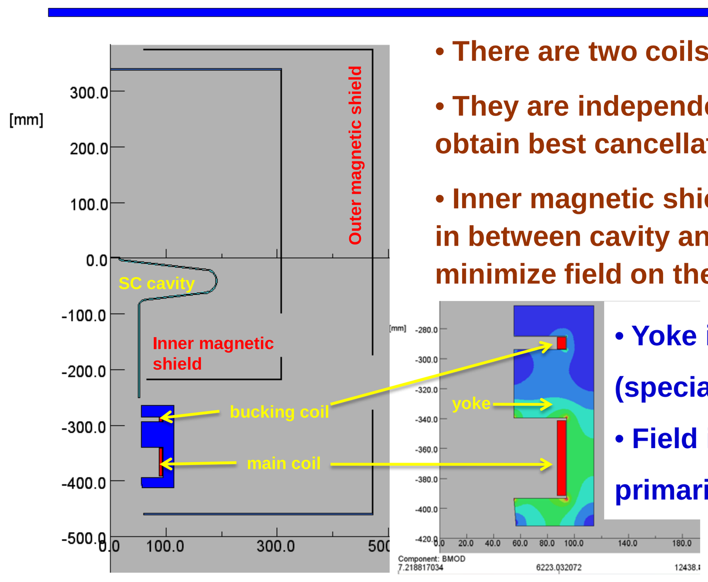
• Because the solenoid reaches the design field at ~80 K while cavity is still normal, one can go through the demagnetization cycle while cavity is still cooling down and has not yet reached the superconducting state.



HTS Solenoid over the bellows. This reduces overall size. Coil clears all flanges, etc.



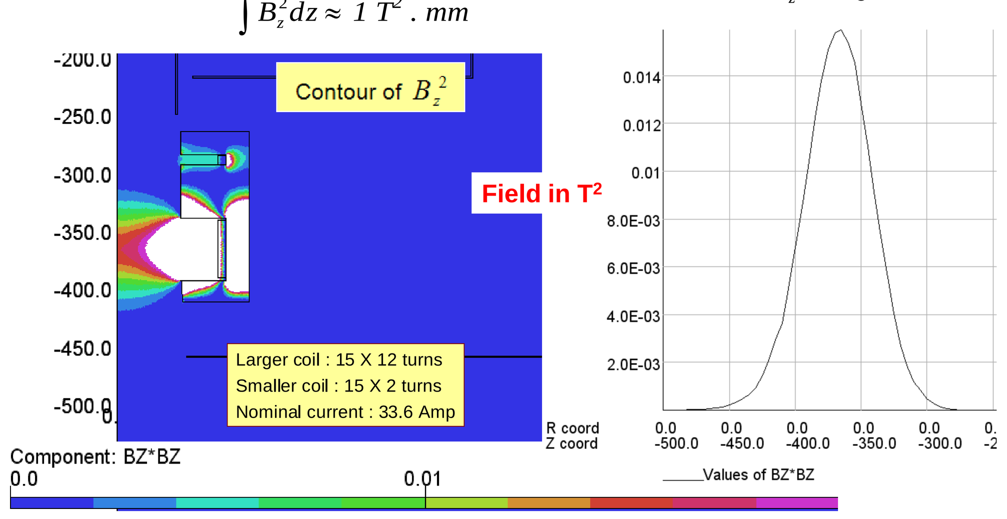
Magnetic Design



• There are two coils – main and bucking
• They are independently powered to obtain best cancellation of field outside
• Inner magnetic shield has been placed in between cavity and solenoid to minimize field on the cavity
• Yoke is not saturated (specially on the cavity side).
• Field inside the solenoid is primarily determined by yoke.

Desired Focusing from the Solenoid

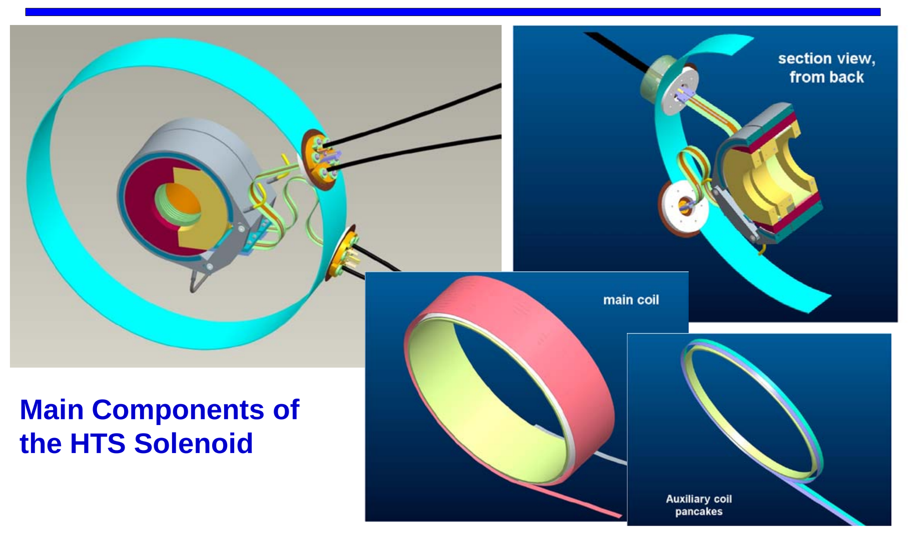
Basic Requirement : $\int B_z^2 dz \approx 1\ T^2 . mm$



Major Parameters of the HTS Solenoid

Parameters	Value
Coil Inner Diameter	175 mm
Coil Outer Diameter	187 mm
No. of Turns in Main Coil	180
No. of Turns in Bucking Coil	30 (2X15)
Coil Length (Main Coil)	~56 mm
Coil Length (Bucking Coil)	~9 mm
Conductor (First Generation HTS)	BSCCO2223 Tape
Insulation	Kapton
Total Conductor Used	118 meter
Nominal Integral Focusing	1 T². mm (axial)
Nominal Current in Main Coil	54.2 A
Nominal Current in Bucking Coil	-17 A
Max. Field on Conductor, Parallel/Perpendicular	0.25 T/0.065 T
Stored Energy	~25 Joules
Inductance (main coil)	0.13 Henry
Yoke Inner Radius	55 mm
Yoke Outer radius	114 mm
Yoke Length (+ Bucking)	147 mm

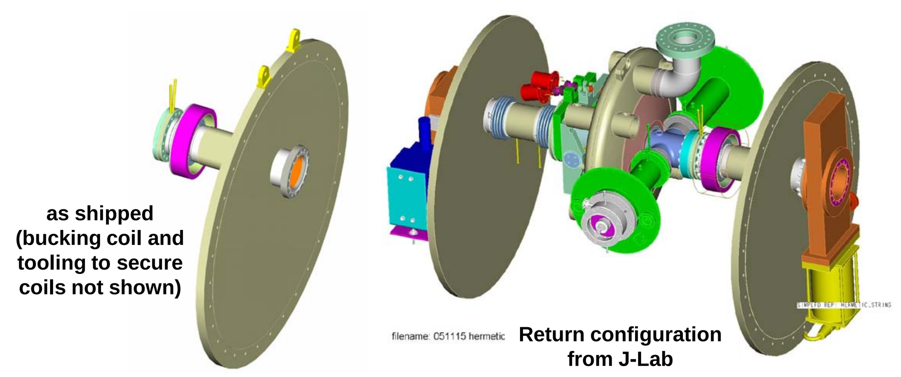
Mechanical Design and Assembly



Main Components of the HTS Solenoid

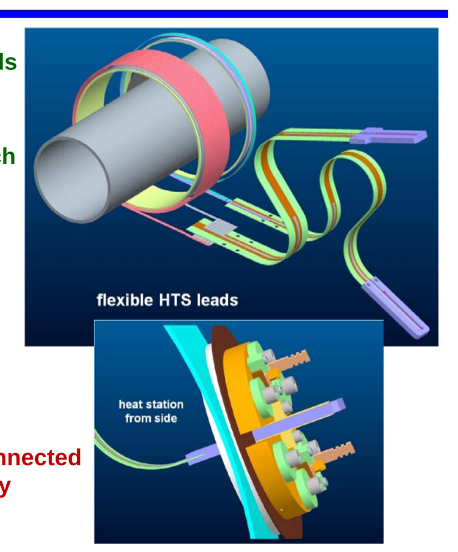
Ship to and Return from Configurations J-Lab

- Ship partial assembly to J-Lab
- J-Lab builds hermetic string
- Ships back along with other components



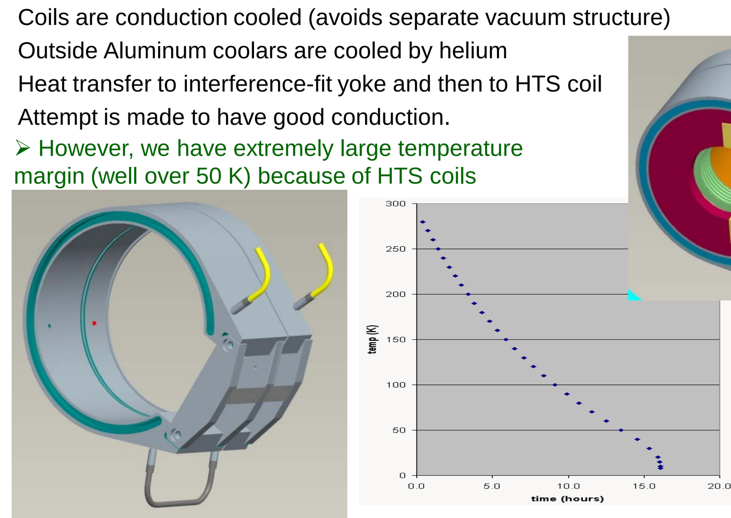
Flexible HTS Leads & Heat Stationing

- We have developed flexible HTS leads for this application
- HTS lead with Kapton over top
- Laminated G-10 sheet, .015 thick each
- Motion during cooldown
  - radial = .011 inches cooldown
  - axial = +/-0.043 max
- Heat shield at 77K
- Copper terminals thermally connected to boss, but isolated electrically



Cooling

- Coils are conduction cooled (avoids separate vacuum structure)
- Outside Aluminum coolars are cooled by helium
- Heat transfer to interference-fit yoke and then to HTS coil
- Attempt is made to have good conduction.
  ➢ However, we have extremely large temperature margin (well over 50 K) because of HTS coils



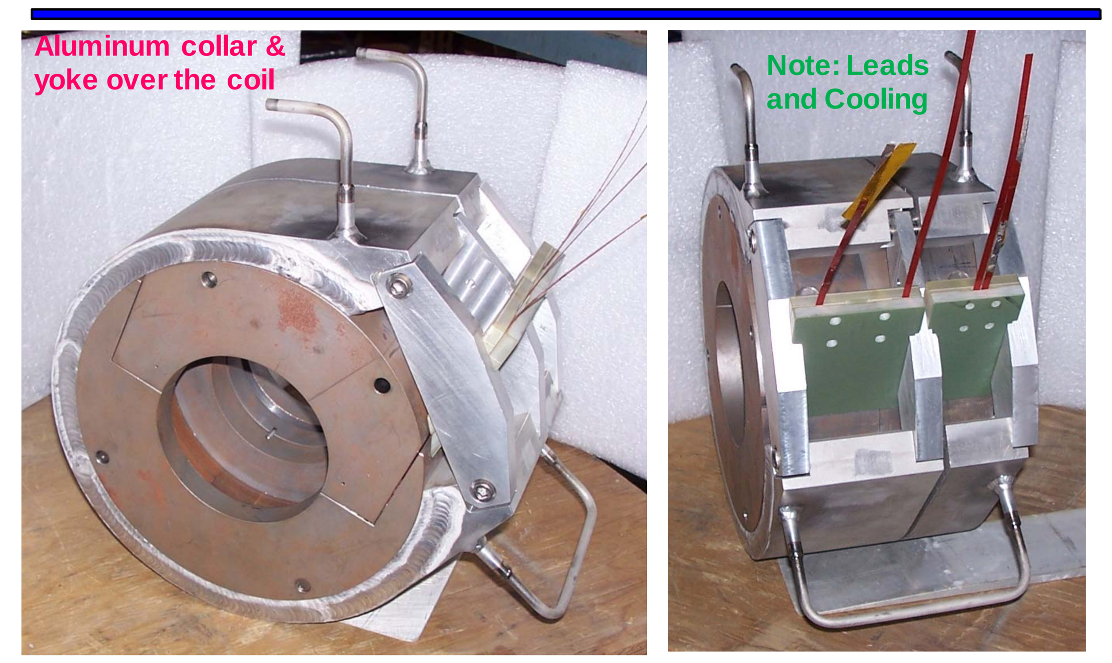
Helium cooldown time to 4.2K: ~16 hours

Construction of HTS Coils

HTS tape was delivered with kapton insulation pre-wrapped on it

Main coil was layer wound (15 layers each with 12 turns) and the bucking coil was wound in double-pancake style

Construction of HTS Solenoid



Construction of Low Cost Test Set-up

• A low cost test set-up is possible because HTS solenoid reaches the desired field at 77K (LN_2).

• The cost was further reduced by imaginative use of surplus equipment from farms, etc.

• Such low cost test would not have been possible for conventional LTS solenoid operating at 4 K with the cost of new test dewar.

Preparation of the Fringe Field Measurements

The goal is to measure (a) field on the axis of solenoid and (b) fringe field at the location of cavity in the operating range with bucking coil and inner magnetic shield in place. We have made initial measurements and are getting ready for more detailed measurements. There is a generally good agreement between calculations and Measurements.

LN_2 Test cryostat with shield in place

Vertical transporter and computer control cart

Warm Finger

Transverse and axial fluxgates

*Work supported by DOE contract DE-AC02-98CH10886.
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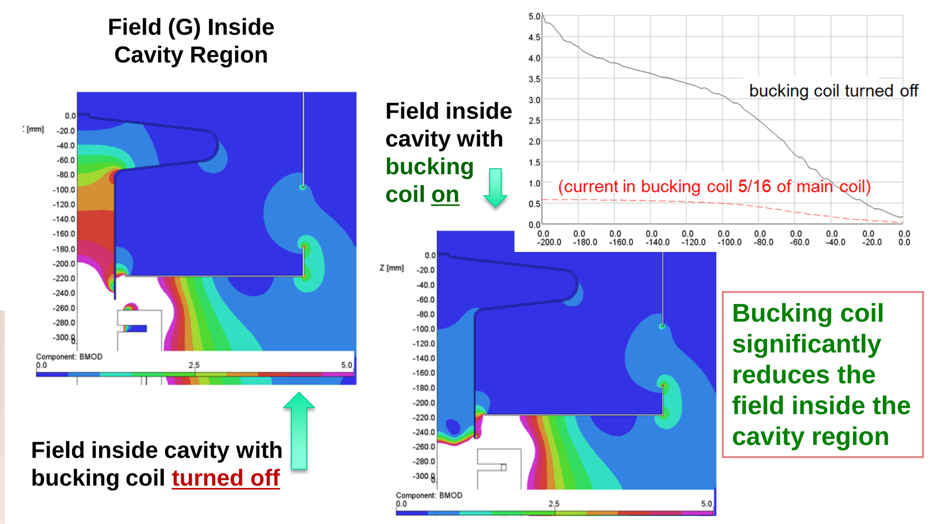
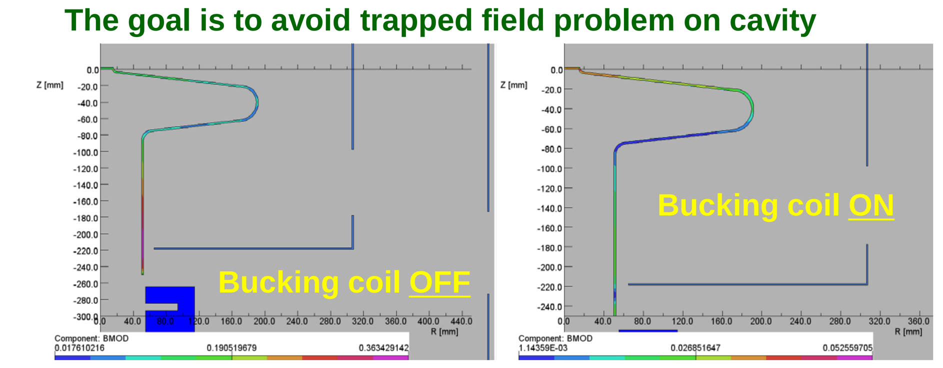
Bucking Coil to Reduce Field inside the cavity (computations)



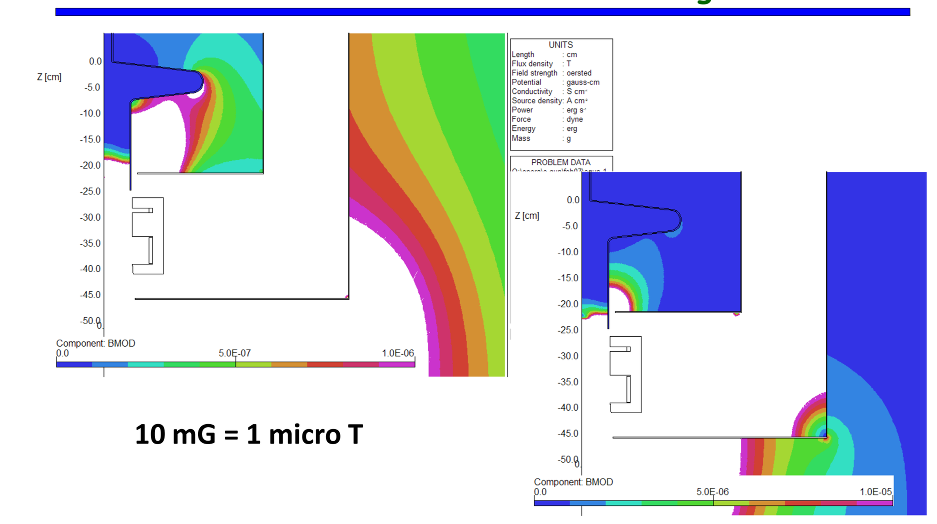
Bucking Coil and Inner Magnetic Shield to Reduce Field on the Superconducting Cavity (computations)

The goal is to avoid trapped field problem on cavity



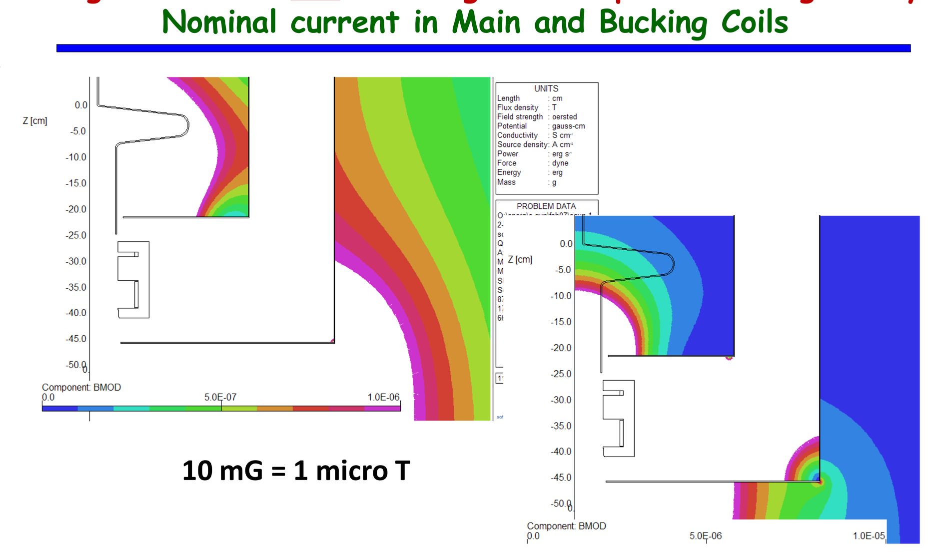
• Inner magnetic shield and bucking coils makes field on the superconducting cavity very small in the operating range of the solenoid
• Field is about 10 mG in the significant part of the critical region
• These critical results are being verified experimentally

Fringe field with the shielding from Superconducting Cavity Nominal Current in Main and Bucking Coils



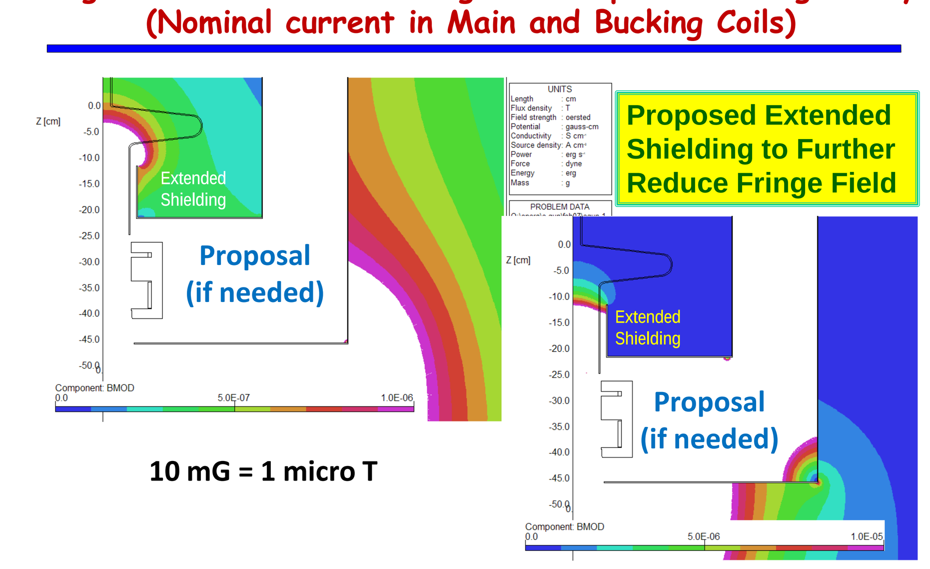
10 mG = 1 micro T

Fringe field with NO shielding from Superconducting Cavity Nominal current in Main and Bucking Coils



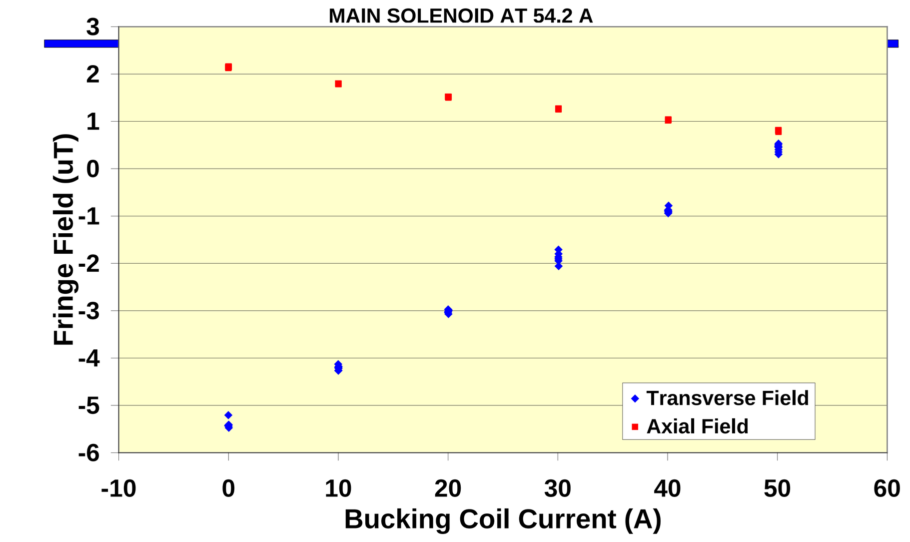
10 mG = 1 micro T

Fringe field with NO shielding from Superconducting Cavity (Nominal current in Main and Bucking Coils)

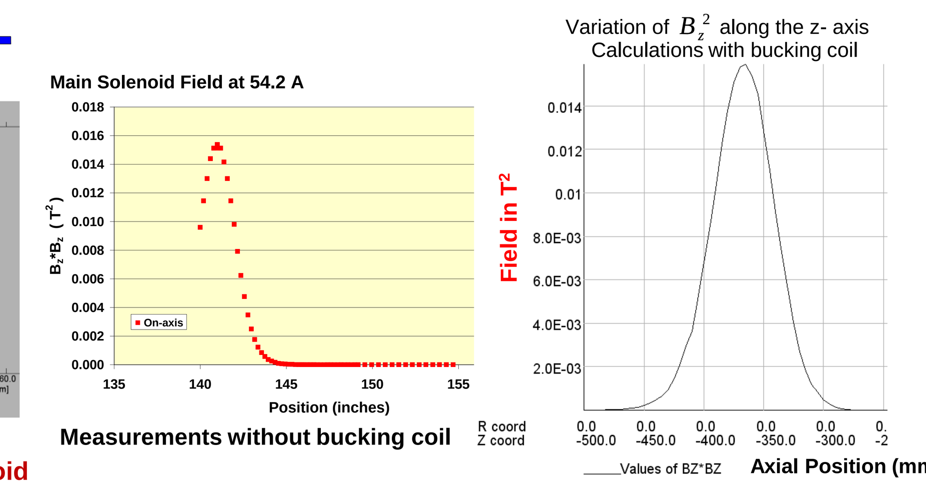


10 mG = 1 micro T

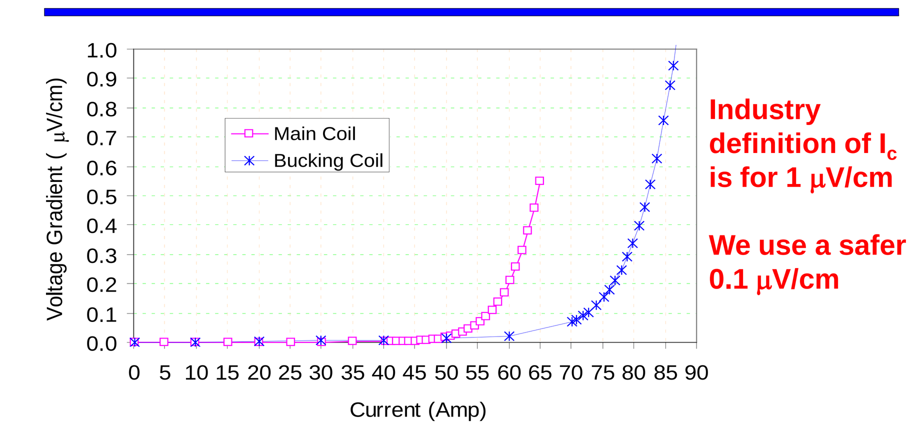
Fringe Field with Bucking Coil



Axial Field

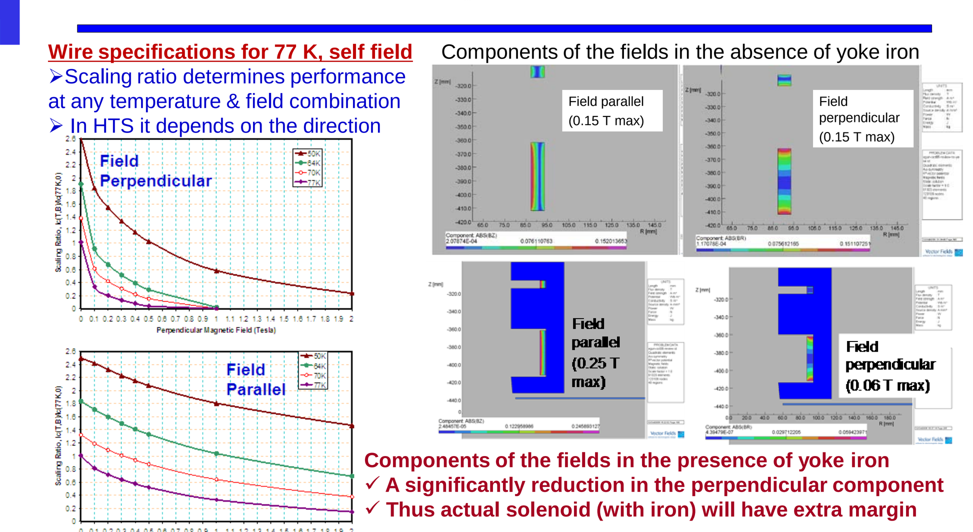


Performance of HTS Coils in LN_2



• Both coils exceed design current (~54 A & ~17 A) at 77 K itself
• These tests were performed with no iron yoke over the coils

HTS Solenoid Has More Margin with Iron Yoke



Summary

- HTS solenoid offers a unique solution
  - It allows solenoid very close to cavity
  - It allows a conduction-cooled design with large margin
  - It allows critical tests to be performed at liquid nitrogen itself which not only significantly reduces the cost of the overall system but make some of them possible as well
- Measurements show that HTS solenoid reaches the design field at 77K itself (would have a large margin at operating temperature <20 K)
- Measurements demonstrate effectiveness of bucking coil and iron shielding in reducing fringe field on the axis and in the superconducting cavity region