Superconducting Solenoid-Based Focusing Lenses for HINS Linac

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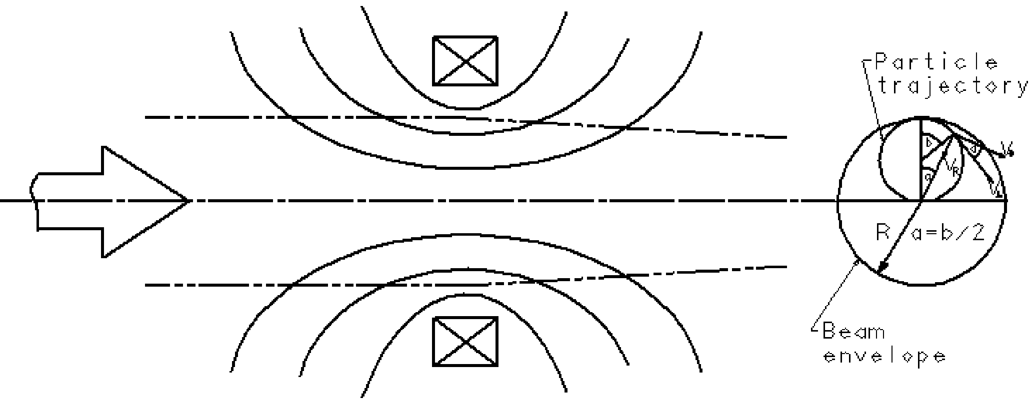
Outline

- Basics of solenoid focusing, requirements, and R&D structure
- RT section lens
- S/C sections lenses
- Cryomodule design approach
- Summary

Why Solenoid Lens?

- One focusing element provides axially symmetric focusing – important for high intensity beams.
- The beam loss is governed by emittance growth and halo formation due to non-linear effects in the low energy sections ($\beta \ll 1$), where Coulomb forces are strong. Solenoids provide smooth axially symmetric focusing that helps to limit emittance growth.

How it works



1. Radial component of a fringe field combined with asymmetric particle rotation provides radial component of the particle velocity;

2. Rotation in the longitudinal field results in different azimuthal position of the particles after the lens.

Focusing length:

$$f = R \cdot \frac{\beta c}{v_R} = 4\frac{m^2}{q^2}\beta^2 c^2 \cdot \frac{1}{B_c^2 L_{eff}} = \frac{8 \cdot \frac{m}{q} \cdot T(eV)}{B_c^2 L_{eff}}$$

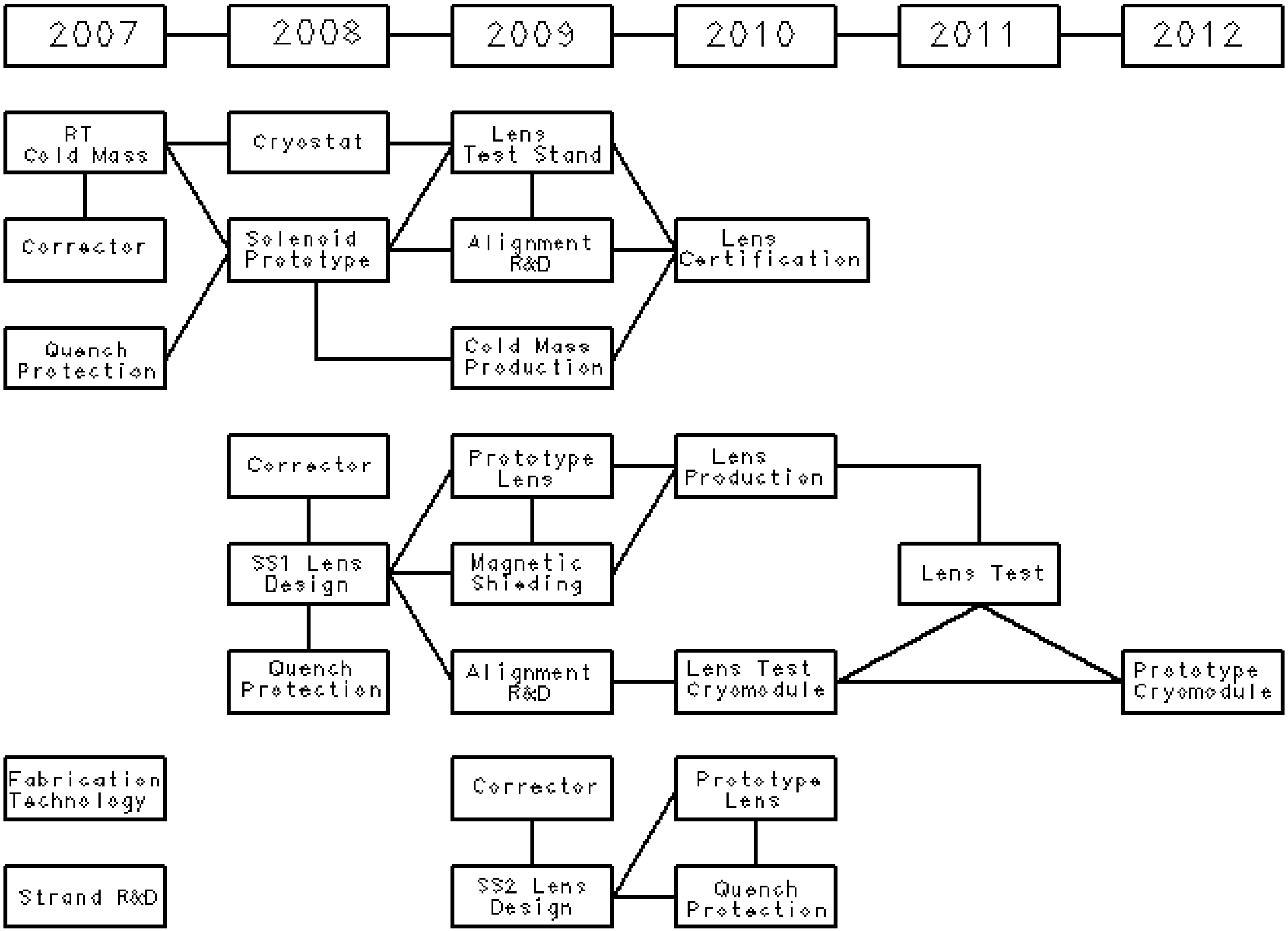
Project X

Requirements

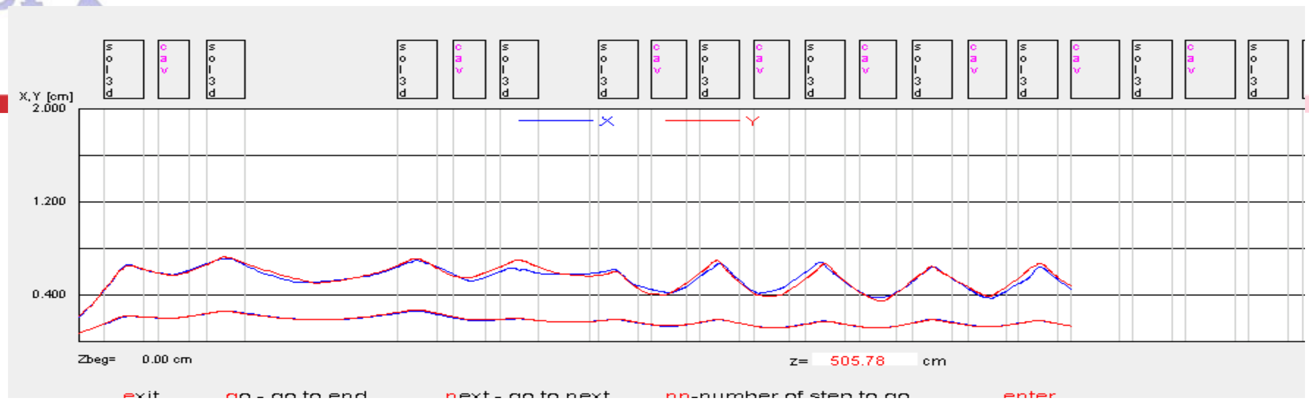
Section	MEBT	RT / CH	SS1	SS2
# of Lenses	4	19	18	18
Bore (mm)	20	20	30	30
Type	Warm	Warm	Cold	Cold
Length Strength: $\langle B^2 \cdot L \rangle$ (T^2-cm)	180 @ 200 A	180 @ 200 A	300 @ 175 A	580 @ 180 A
Incertion gap (mm)	235	235	315	320
Corrector Strength: $\langle B \cdot L \rangle$ (T-cm)	0.25 @ 50 A	0.25 @ 50 A	0.5 @ 30 A	0.5 @ 20 A
Embedded BPM	+	+		
Magnetic field at RF cavity walls (T)	N/A	$\sim 10^{-2}$	$<10^{-5}$	$<10^{-5}$

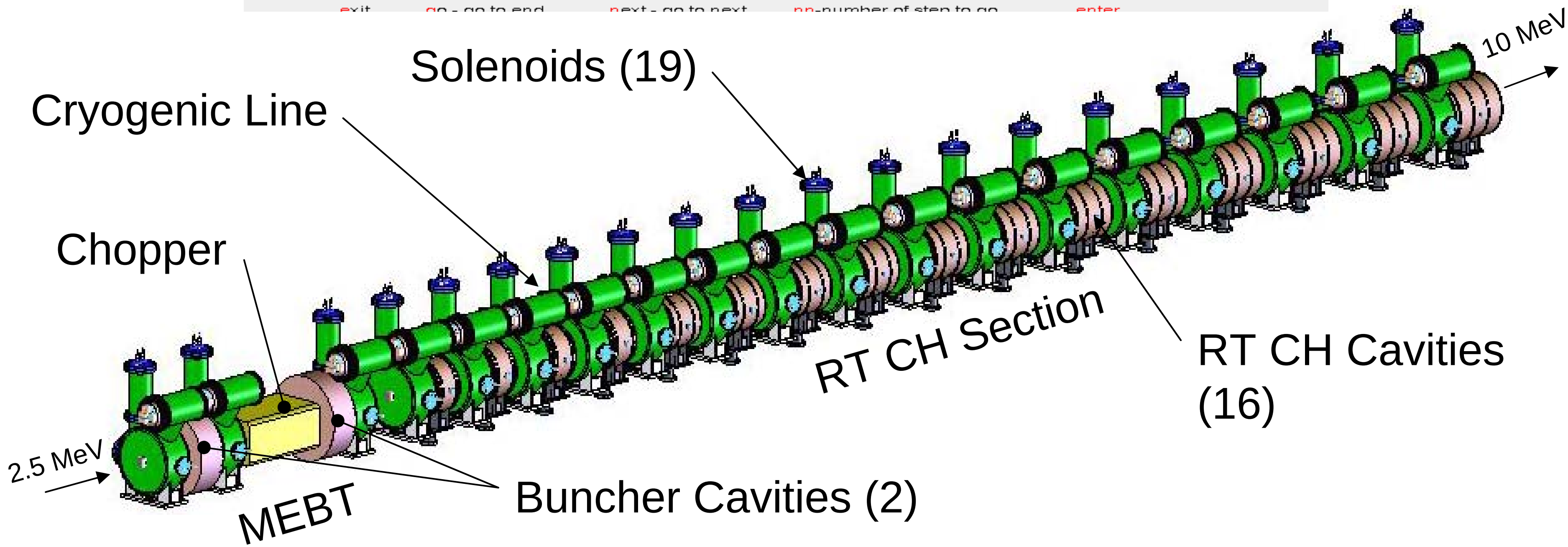
Project Structure

Project X



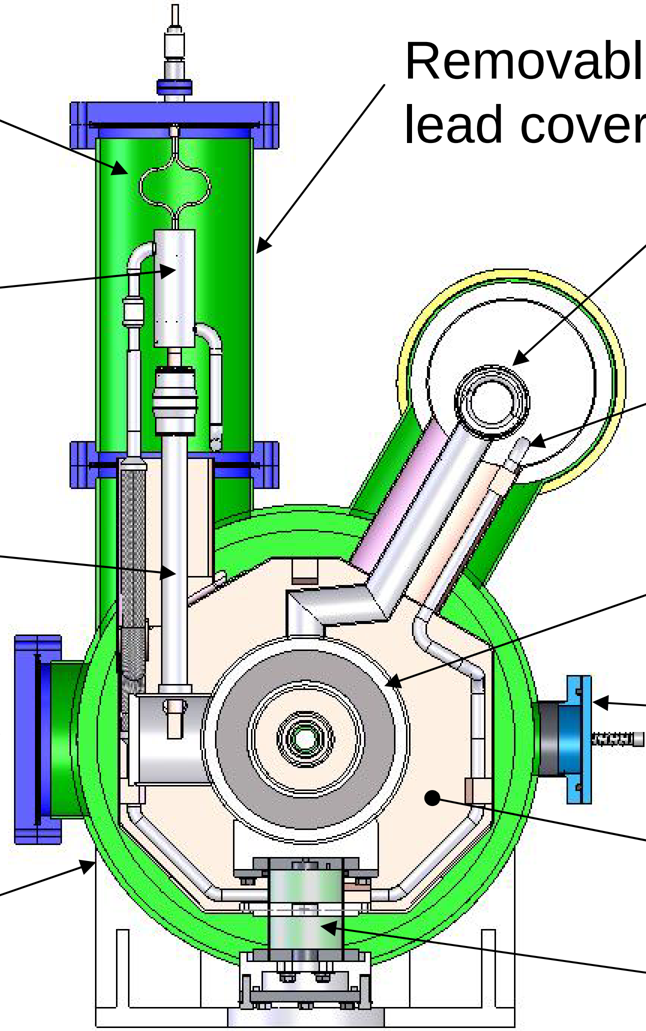
RT Section Lens



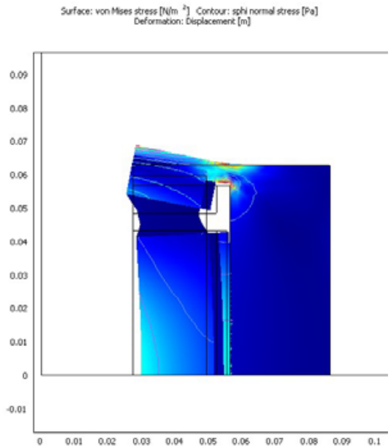


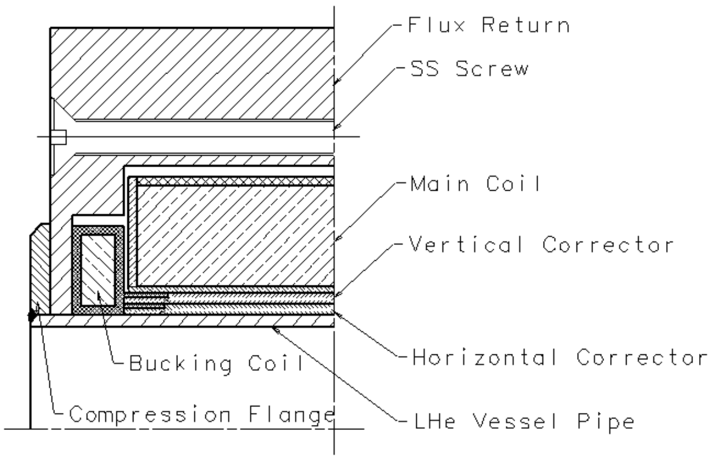
Project X

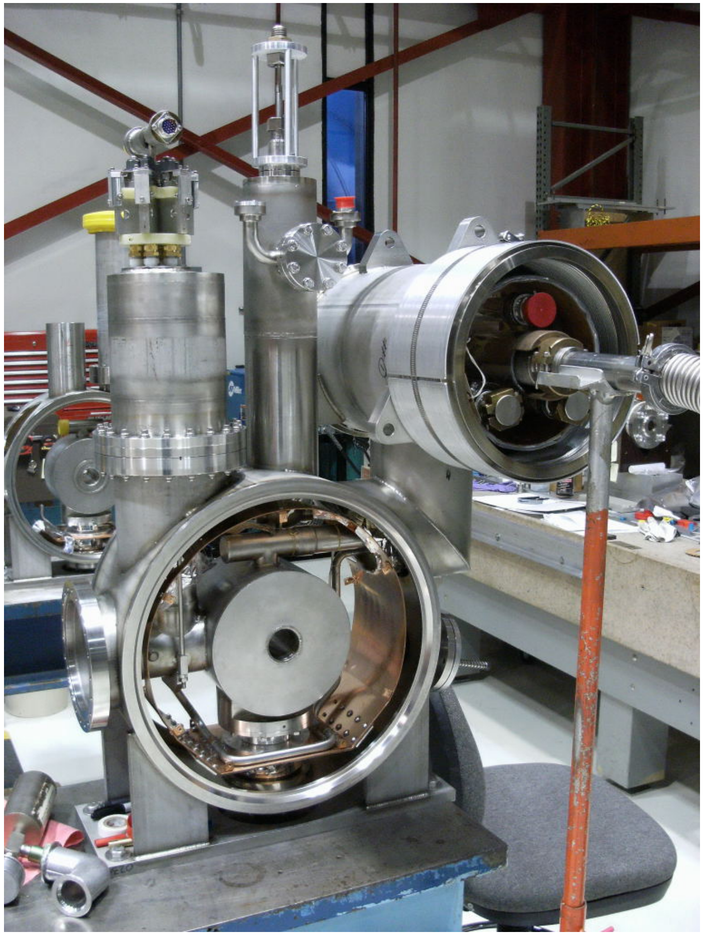
Lens Design



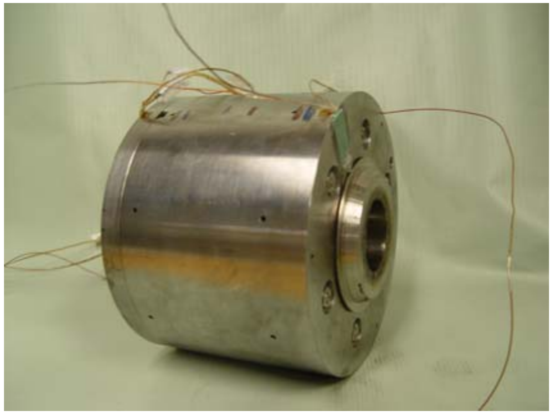
Lens Fabrication







Corrector Assembly

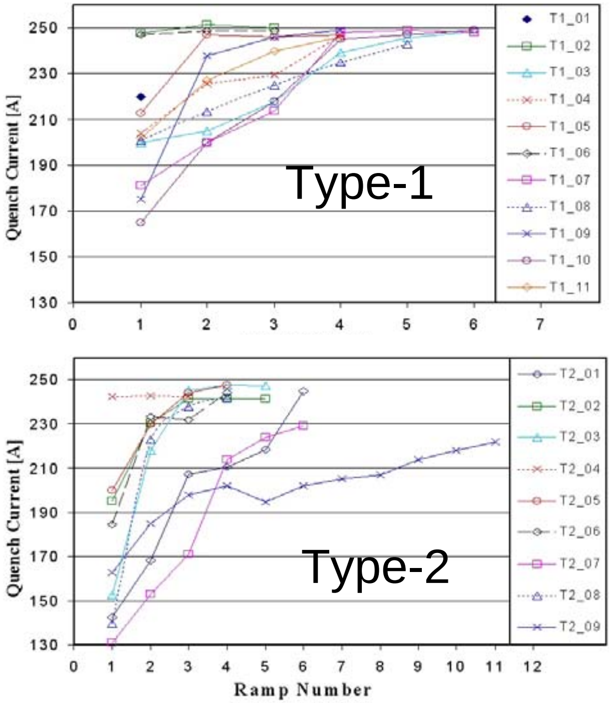


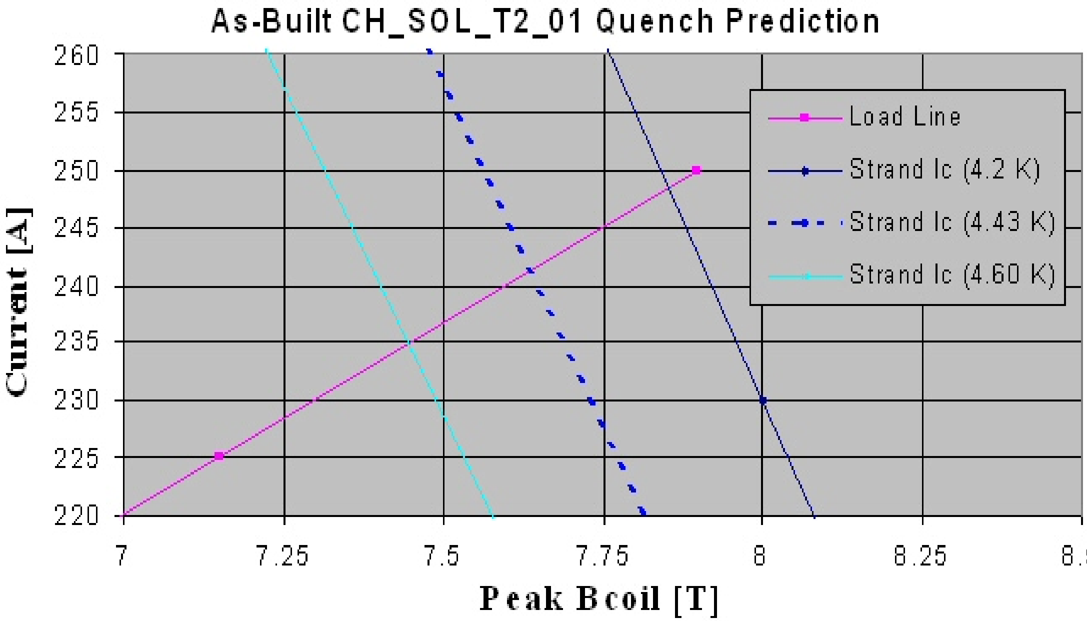
Lens Performance

Project X

CH SOLENOID PRODUCTION STATUS:

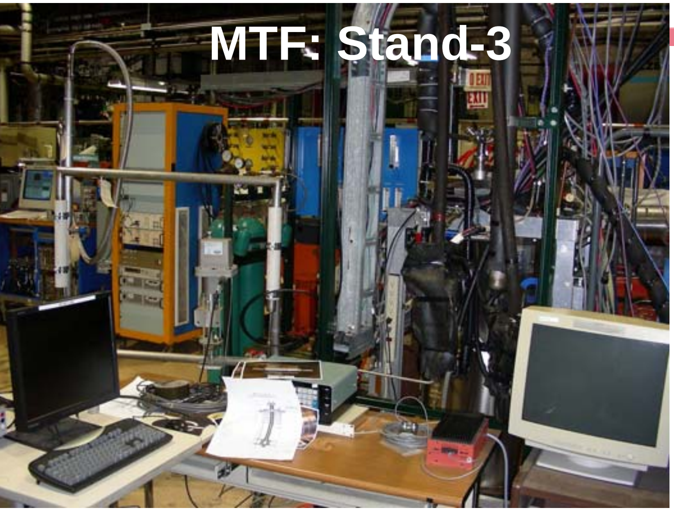
13 Type-1 (without Steering Dipoles): 11 tested
10 Type-2 (with Steering Dipoles): 9 tested
Quality Assurance Re-testing at Fermilab
First 4, then 1 of every 4: 4 T2, 3 T1 done; two tests pending

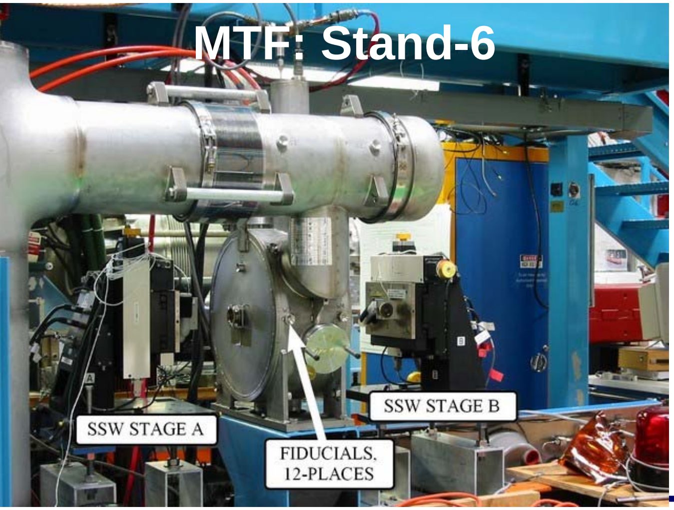


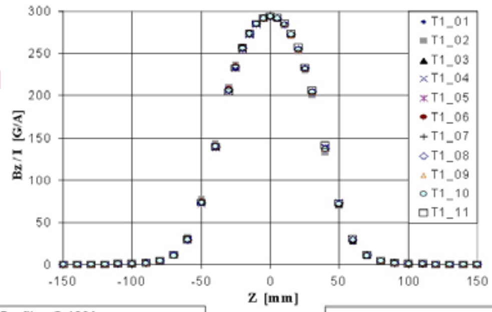


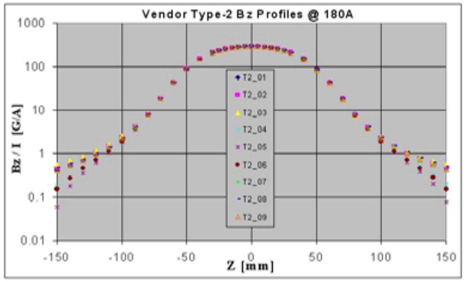
Lens Testing

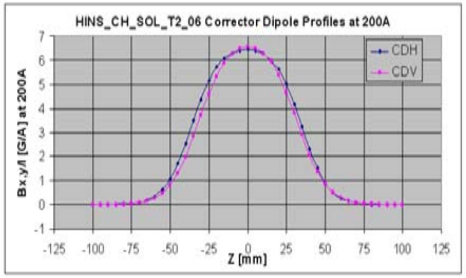
Project X

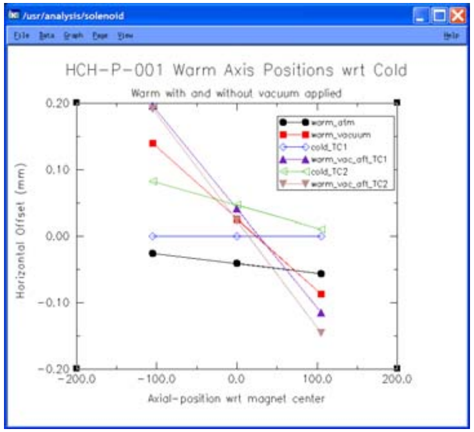


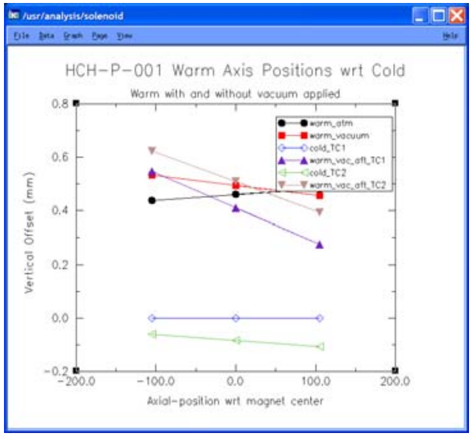






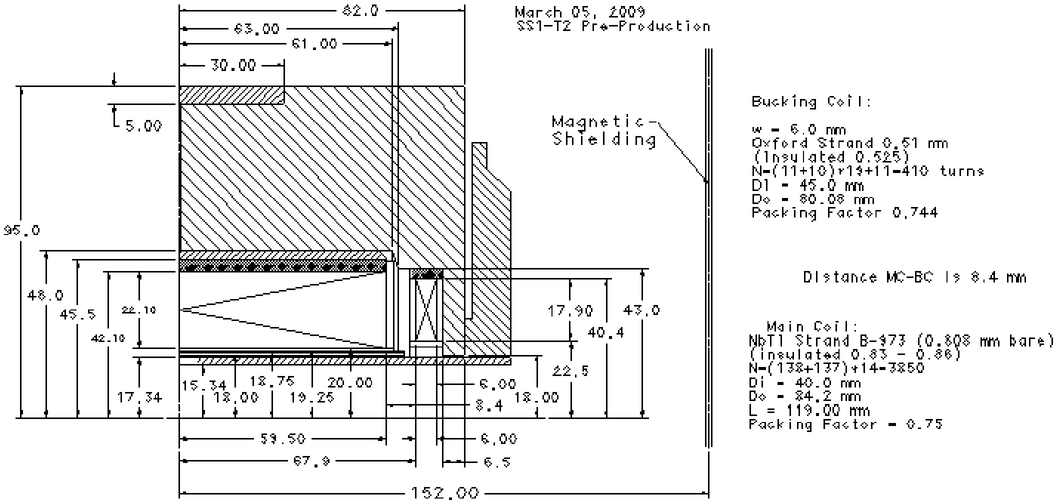


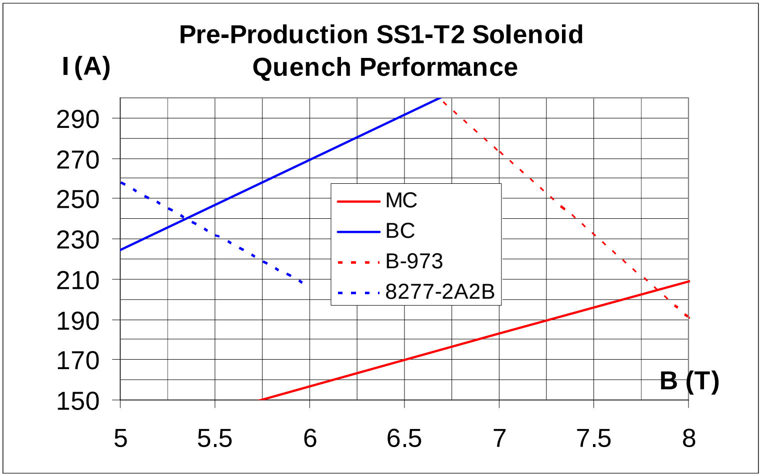


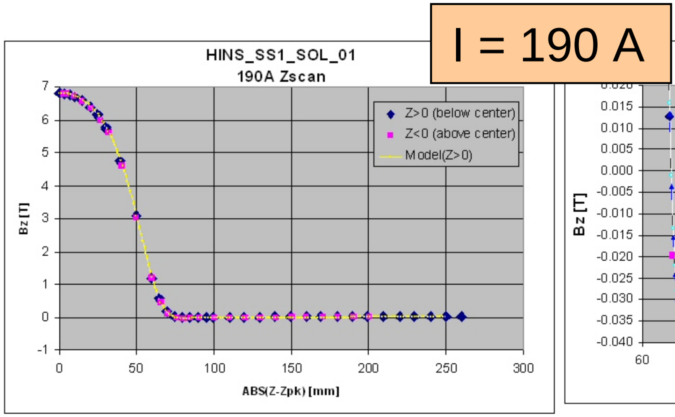


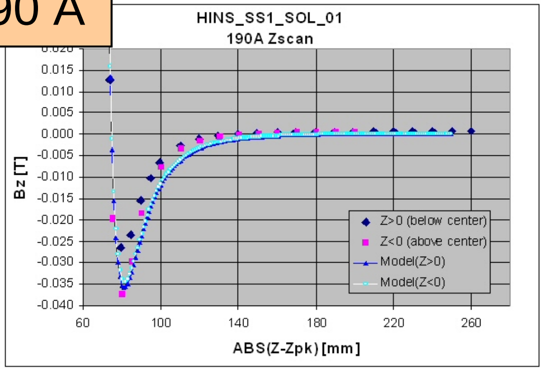
Superconducting Section Lenses

- Cold bore design
- Corrector field quality
- 10^{-5} T fringe field
- Alignment issues

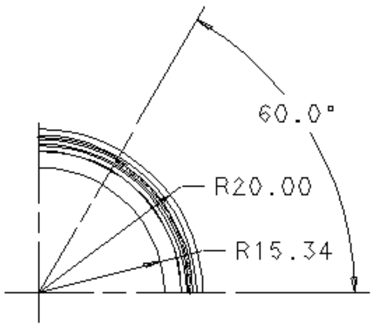


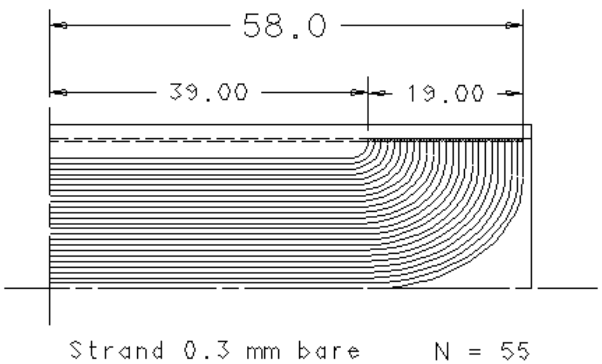


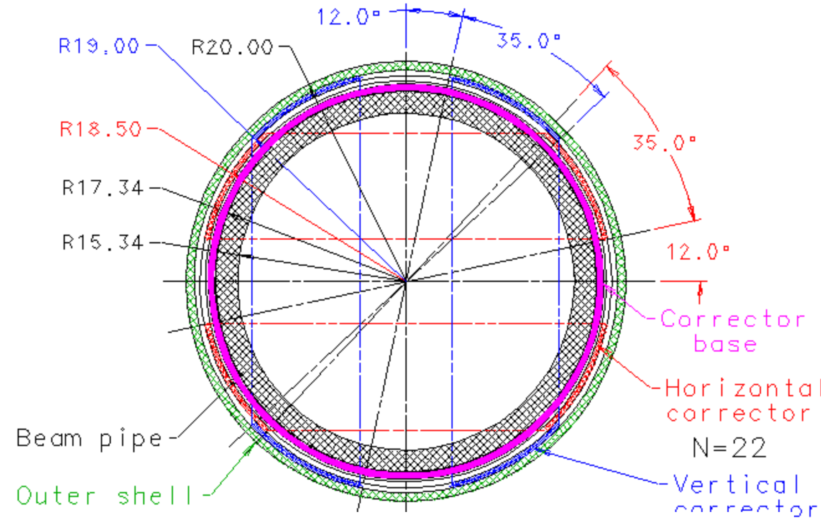


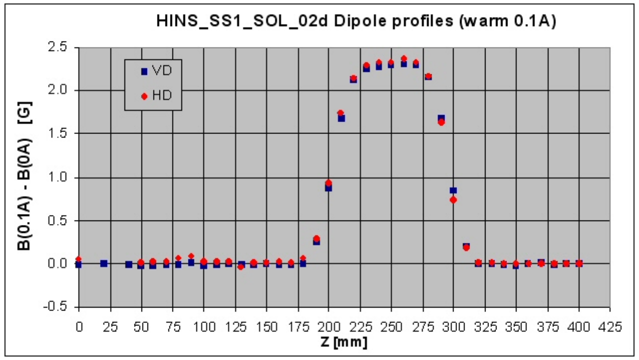


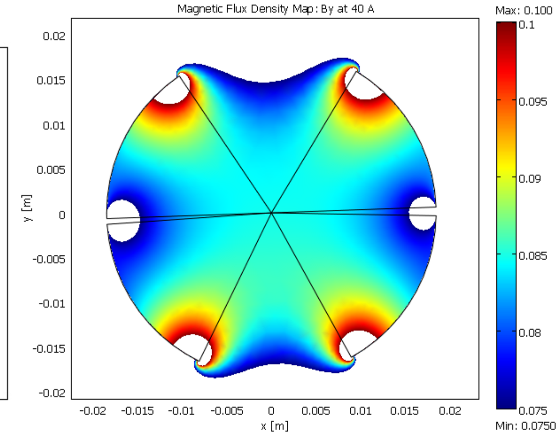
Dipole Corrector



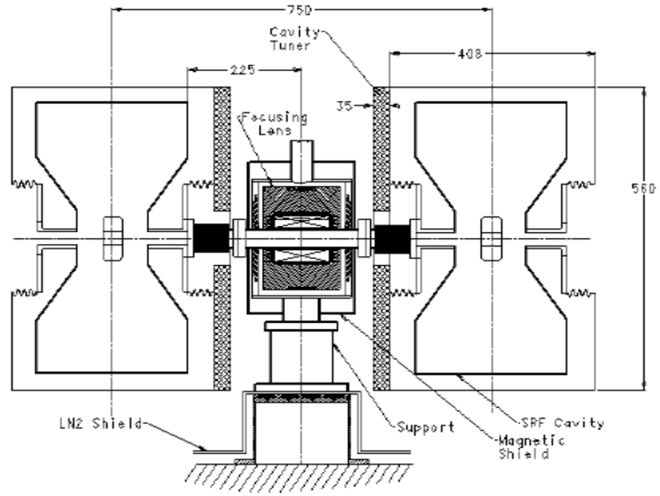






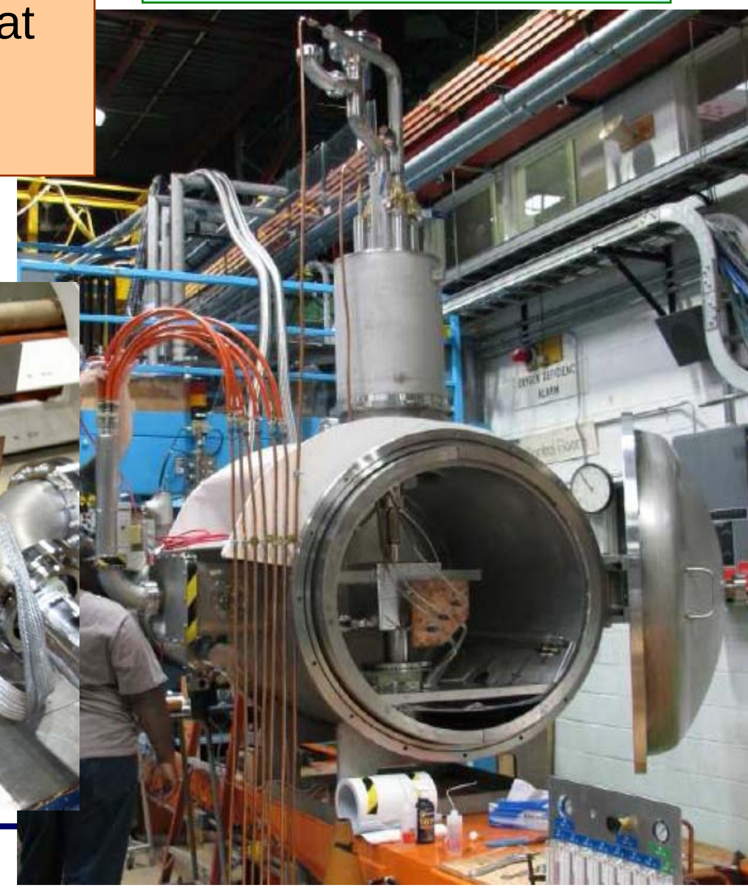


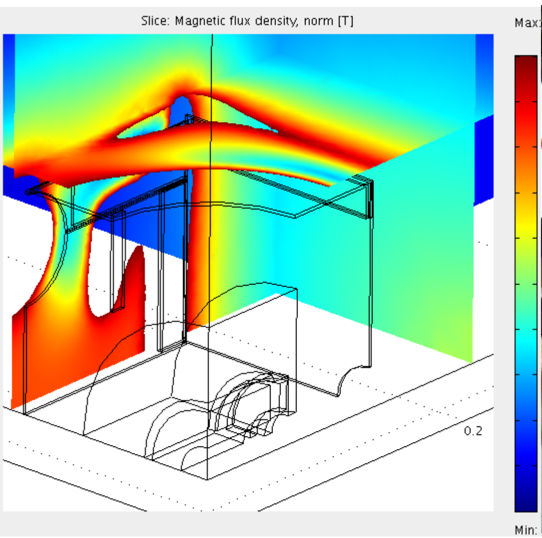
Fringe Field Test

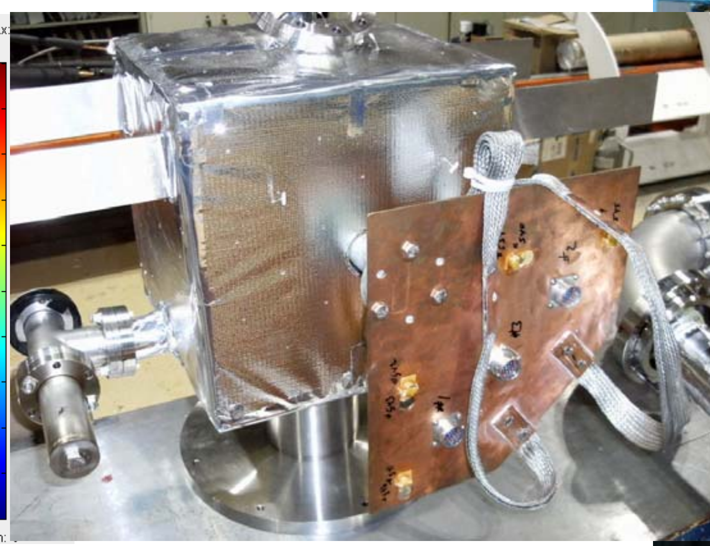


Focusing field at solenoid center: 5 T @ 160 A
Requirement for field at cavity surface: <10 µT @ 225 mm

Testing new shielding material from Amuneal

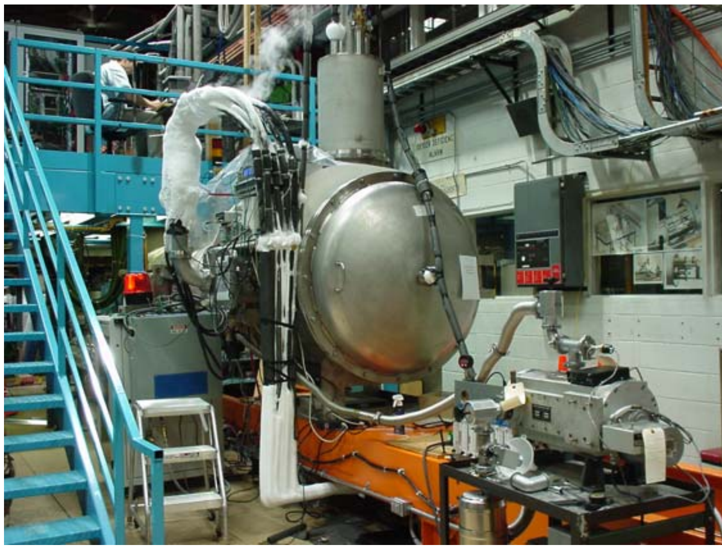


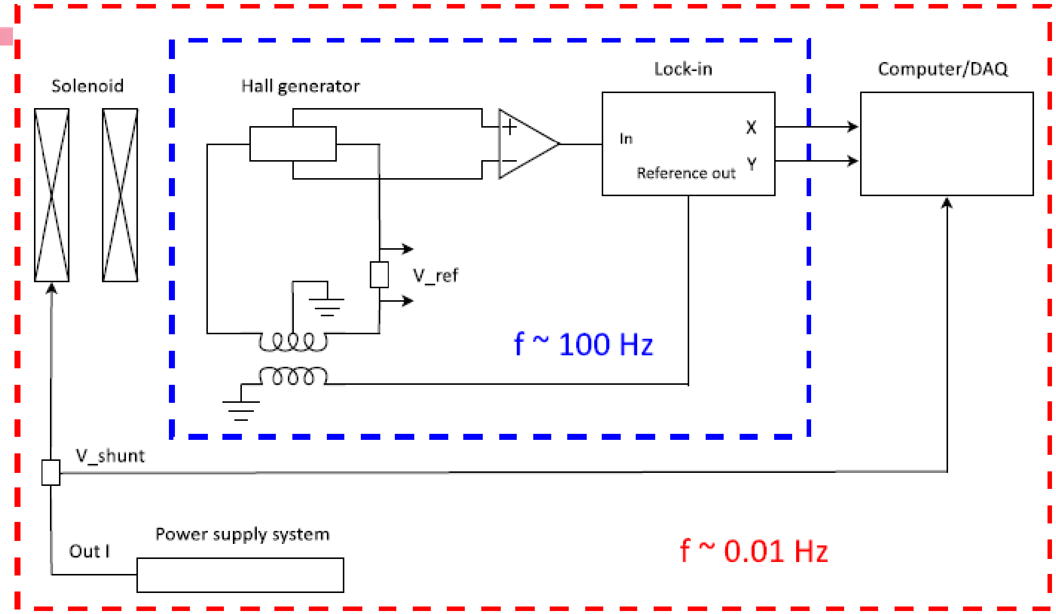


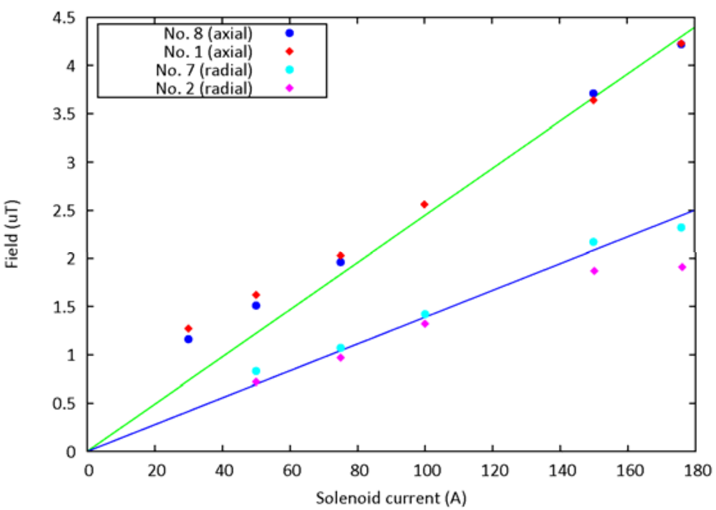


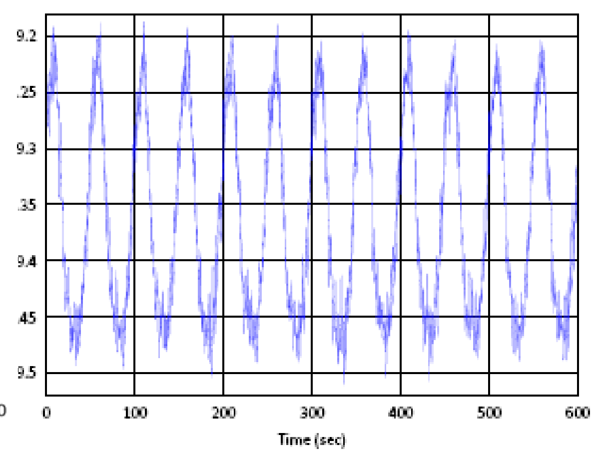
Project X

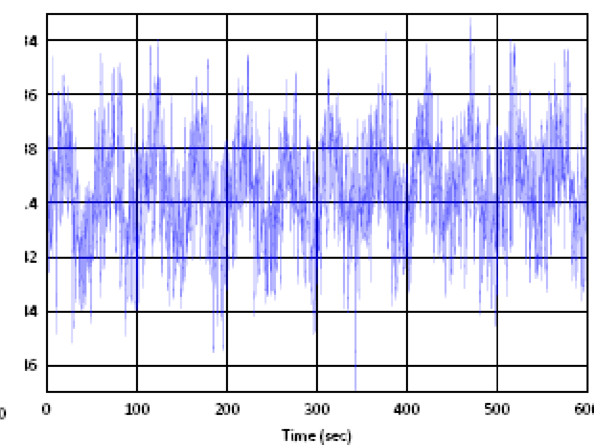
Fringe Field Test









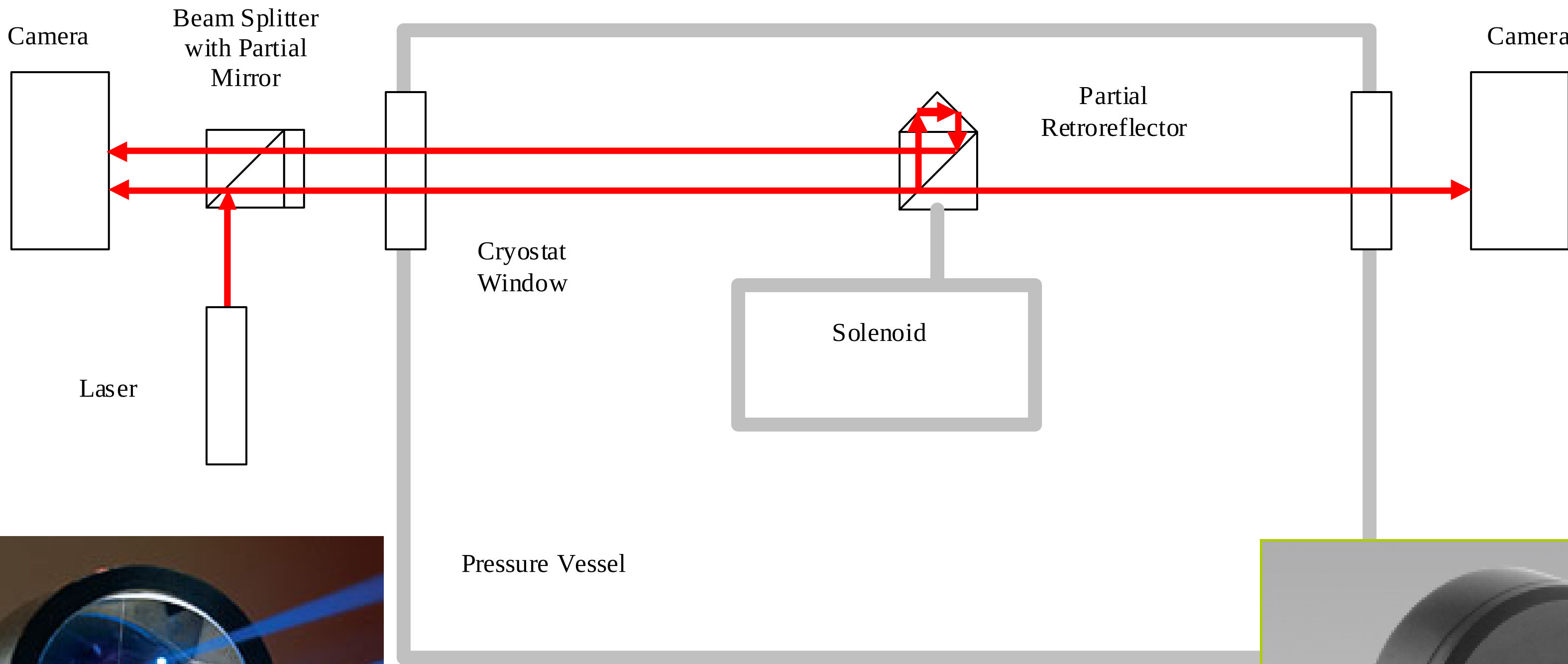


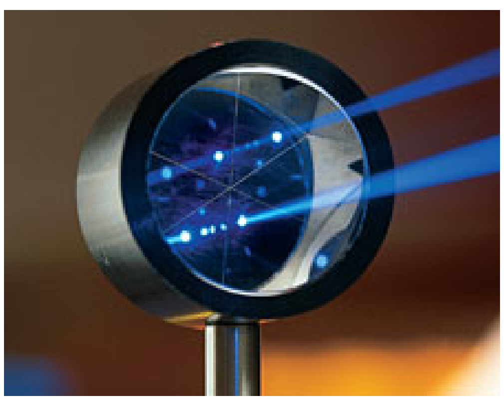
Alignment Requirements

- Alignment requirement: +/-150 µm (with dipole correctors (B*L ~ 0.5 T-cm) and sensitive BPM)
- Cryogenic environment: vacuum + low temperature
- Must allow reproducible assembly on an insertion bench (clean room) and in the cryomodule
- Must allow reliable measurements on the beam line

Promising approach – optical alignment scheme

Optical Alignment





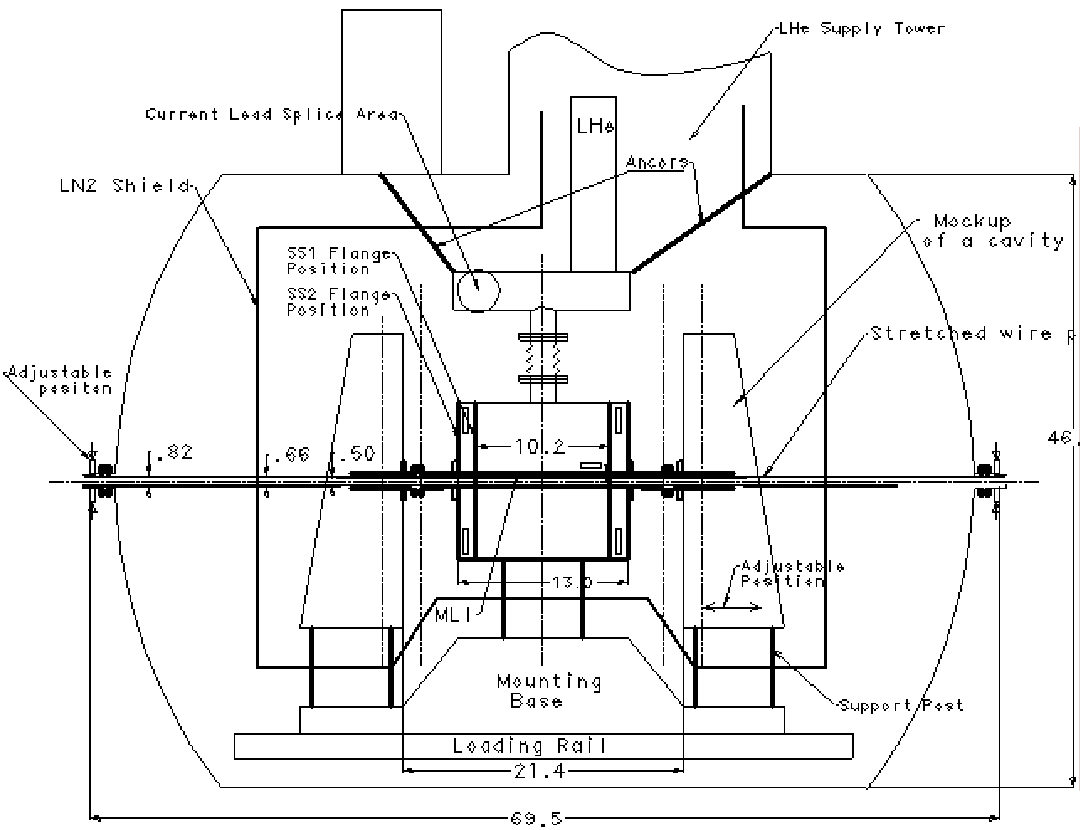
CCD Camera: 1 µm resolution

Corner Reflector

Alignment R&D

- Proof-of-principle test has been made – OK
- Alignment scheme bench test in preparation
- Test cryostat for SS-1 lens certification and for the alignment concept verification by comparison with other alignment methods
- Prototype cryomodule with RF cavities to finalize assembly and alignment procedure. Testing with beam.

Test Cryostat Concept



- Existing cavity test cryostat design
- Warm bore to allow stretched wire technique
- Laser-based alignment system
- Modified position of the current lead assembly
- Prototypes cryomodule design

Conclusion

- Designs of all focusing lenses for the HINS linac have been completed (including ones with embedded dipole correctors); test methods have been developed; lens performance is well understood.
- Room temperature section lenses are in the final production stage; embedded BPM feature is being implemented.
- Lenses for superconducting cavity section are in the final prototyping stage (test of a pre-production lens is ongoing).
- Developed fringe field measurement method can be used to verify shielding efficiency in any RF cryomodule.
- Suggested alignment method is beneficial for any linear superconducting accelerator.
- Testing solenoid-based transport channel is of general importance for accelerator physics.

Acknowledgments

Participant List:

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