Review of the Status and Production Readiness of the 162.5 MHz HWR cryomodule for Project X

Cold Testing Results of the Superconducting Solenoids with Dipole Steering Coils

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On Behalf of the ANL Physics Division Accelerator R&D Group

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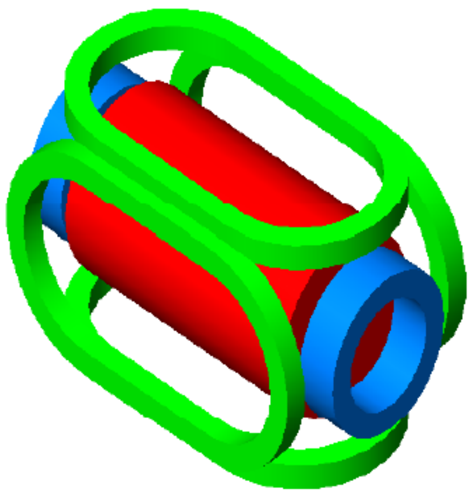
Contents

Introduction

- SC solenoid with steering coils
  - Main solenoid coil in series with reverse-polarity bucking coils
  - Two pairs of dipole steering coils
  - Solenoid: 6 T, Steering coil: 30 T·mm



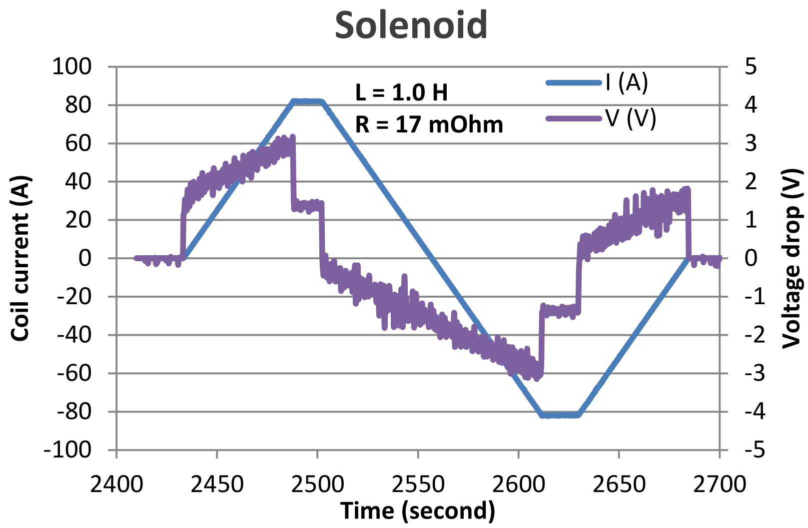
Summary of Electrical Performance Tests

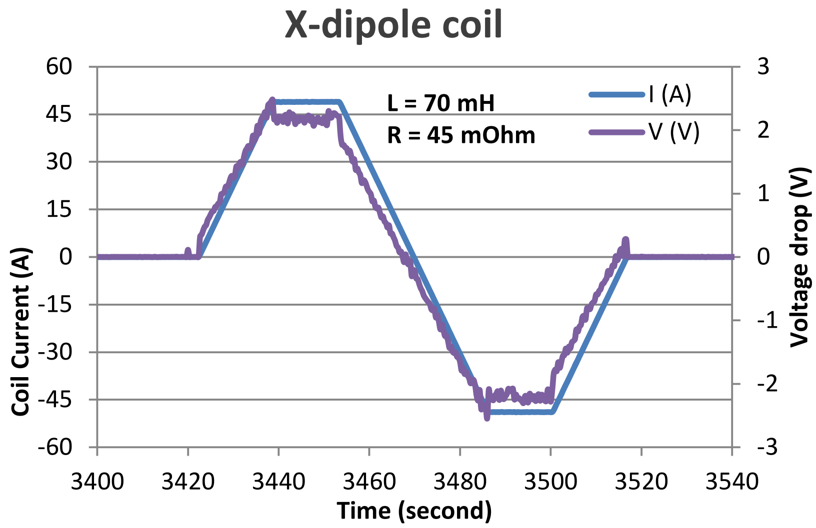
- Measured field strength
  - Solenoid: 6 T at 82.3 A
  - X-dipole: 30 T·mm at 47.3 A
  - Y-dipole: 30 T·mm at 48.2 A
- No quenching/heating on running at those currents.

Test at the vendor site

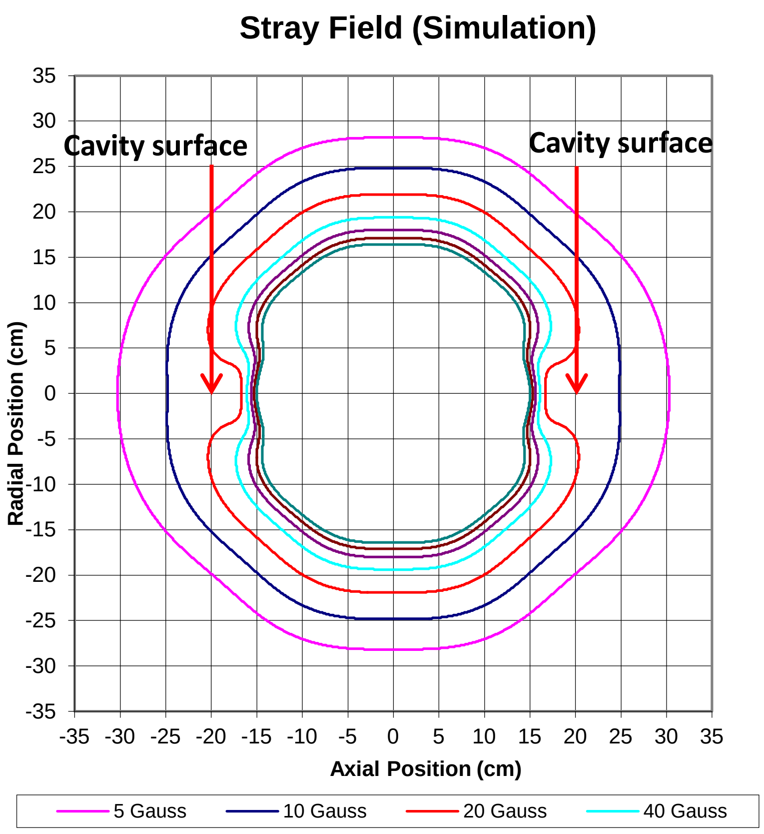
X Coil Current (A)	Y Coil Current (A)	Main Coil Current (A)	Quench Location
0.0	49.00	0.00	No quench
49.00	0.00	0.00	No quench
49.00	49.00	82.36	No quench

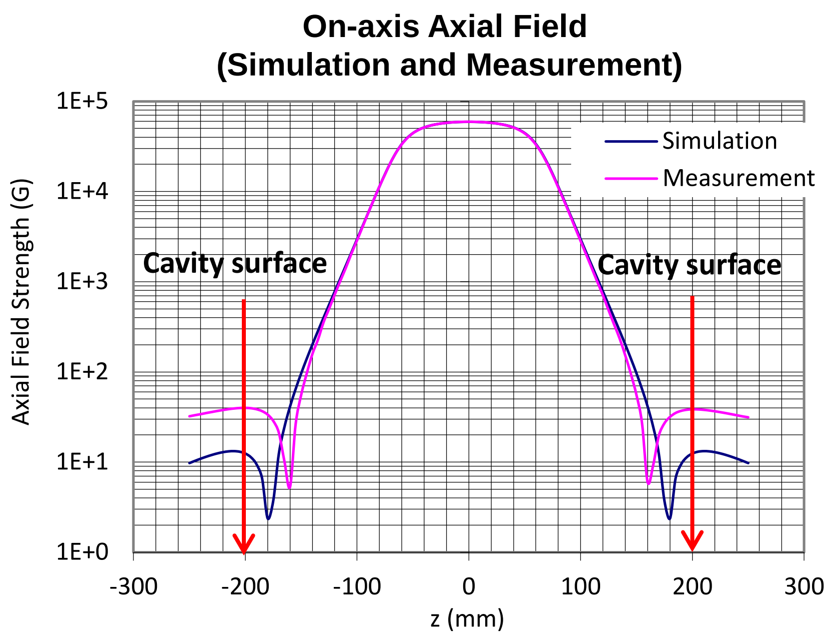
Test at ANL



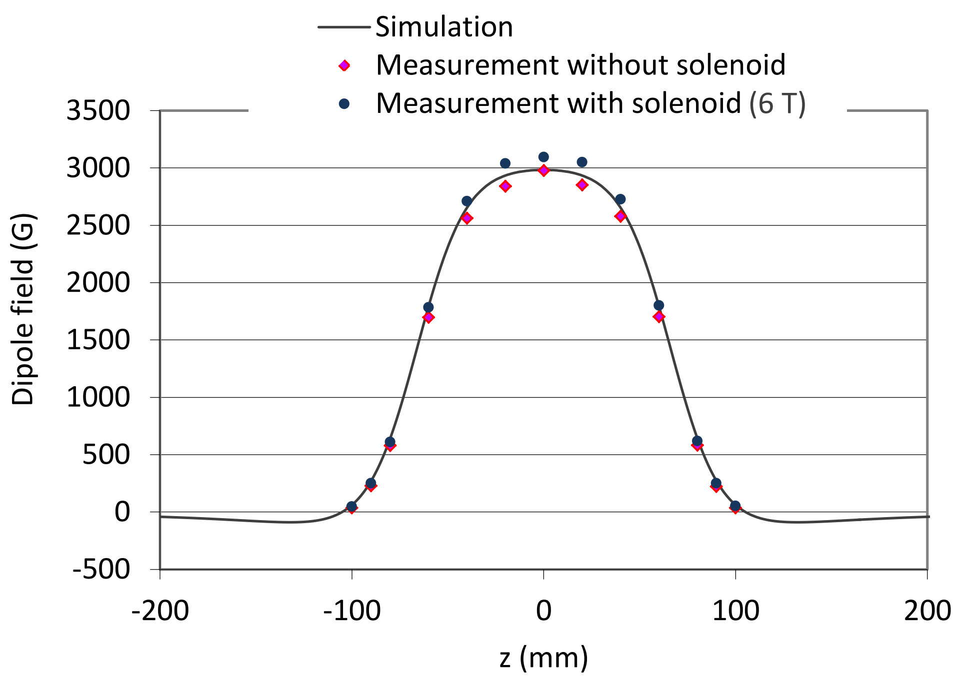


Solenoid Field





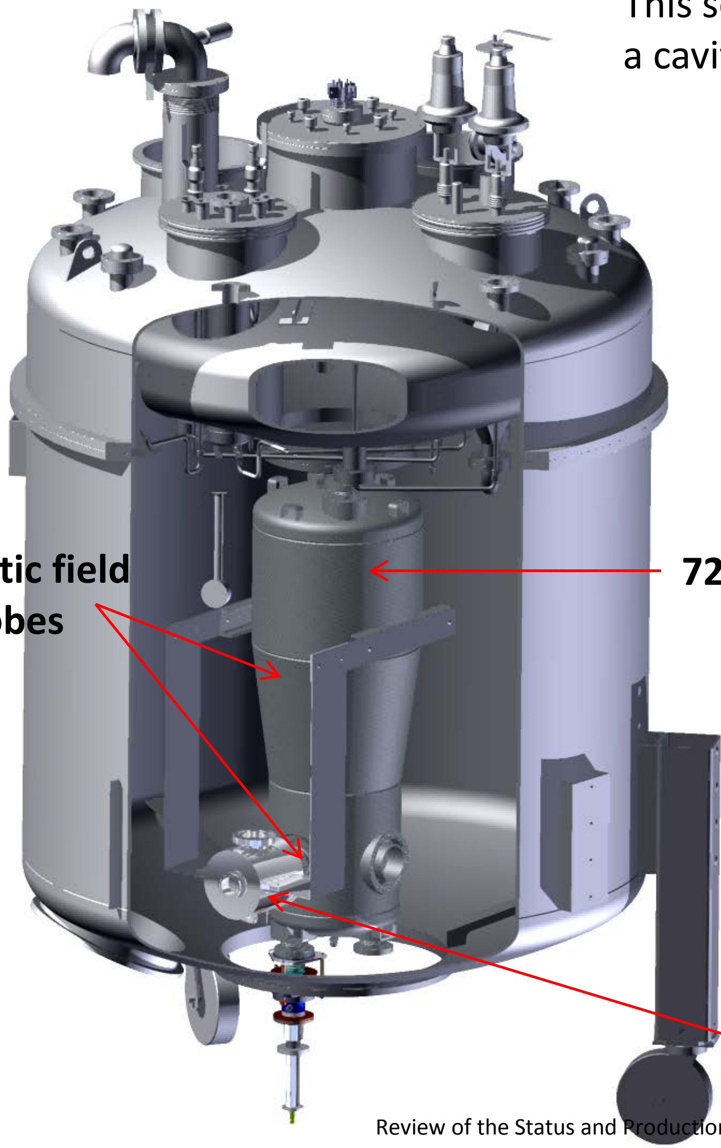
Dipole Field with/without Solenoid Field

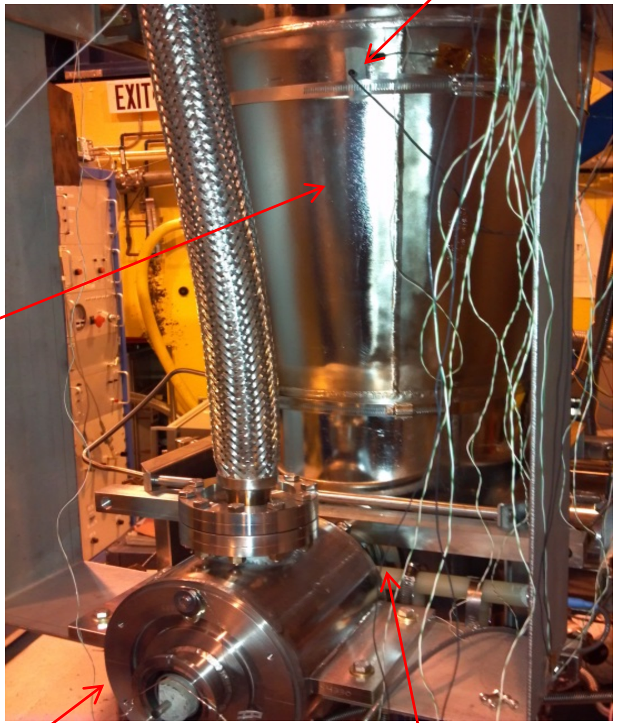


- Screening effect by the solenoid coil is supposed to be negligible around 6 T solenoidal field. (cf. Lower critical field of this solenoid coil ~ 1500 G)
- In measurement at a certain z, solenoid is turned on and off.
  Measured fields are very symmetric with respect to the middle of the dipole coil.
  -> The dipole coil is mechanically stable against Lorentz force induced by the solenoidal field.

Test Setup with SRF Cavity

This setup simulates a similar geometrical relationship between a cavity and a solenoid in the PXIE HWR Cryomodule.





Low field probe
(Fluxgate Magnetometer)

Magnetic field probes

72 MHz QWR

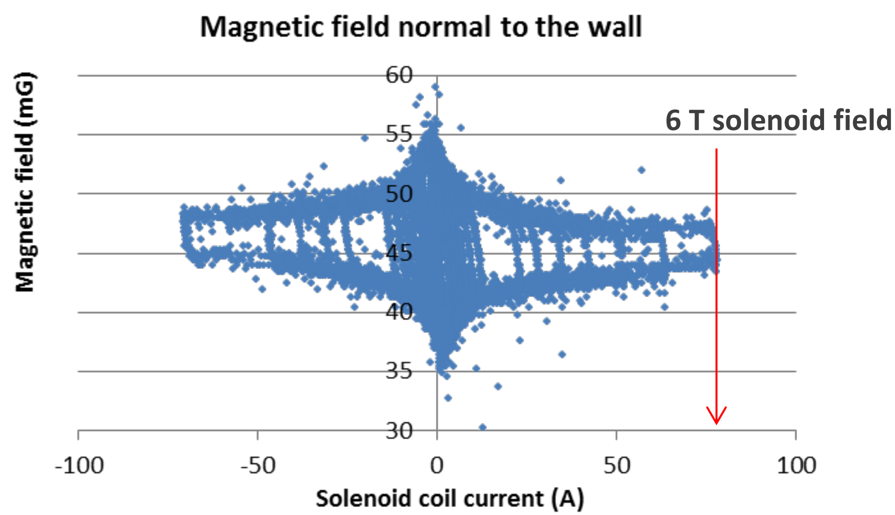
Solenoid

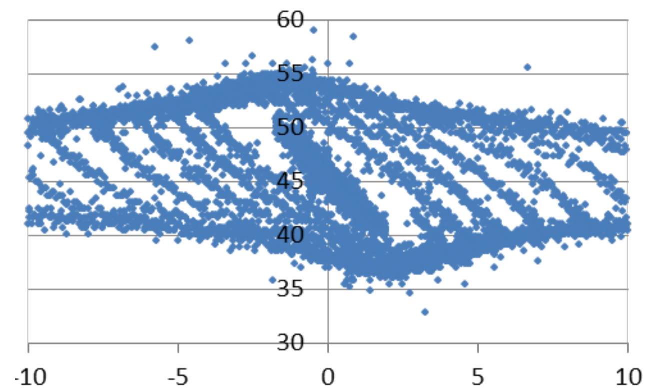
High field probe
(Hall probe)

Magnetic Field on the Cavity Wall

Measured	Residual Field
Before cooldown	45 mG
After cooldown	45 mG
During degaussing	
After degaussing	44 mG
After warm-up	45 mG

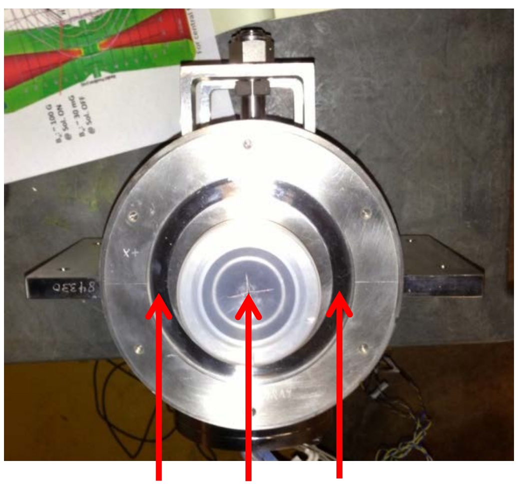
The probe is normal to the cavity wall and placed 24 mm distant from the cavity outer surface.





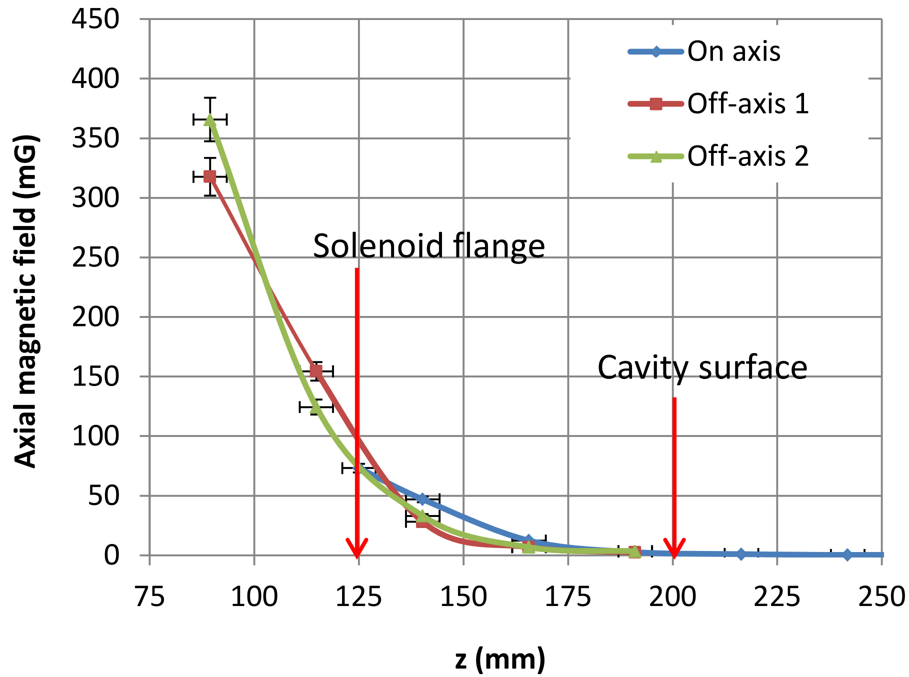
- No significant magnetic material other than NbTi.
- At the end of degaussing, magnetic field goes to the center of the hysteresis curve.

Residual Magnetic Fields on the Axis



Off axis 1 On axis Off axis 2

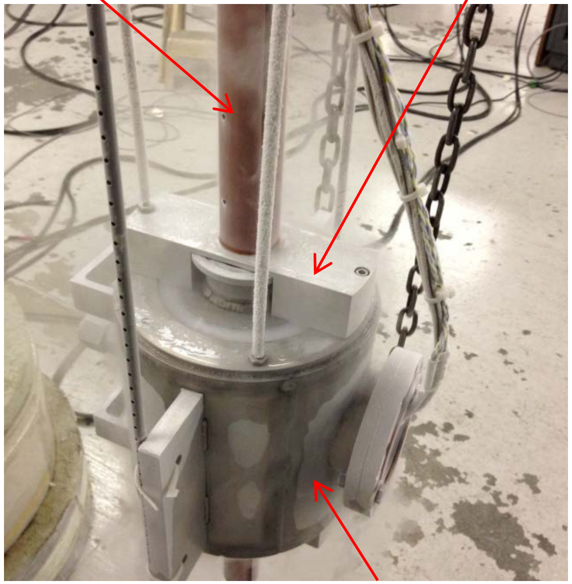
- ~100 mG residual magnetic fields were found on the solenoid flange inside of the cryostat after warm-up.
- The source of that residual fields is inside of the solenoid but it is reduced to 2~3 mG at the cavity surface (cf. R_H = 1 nOhm @ 9 mG, 162.5MHz).



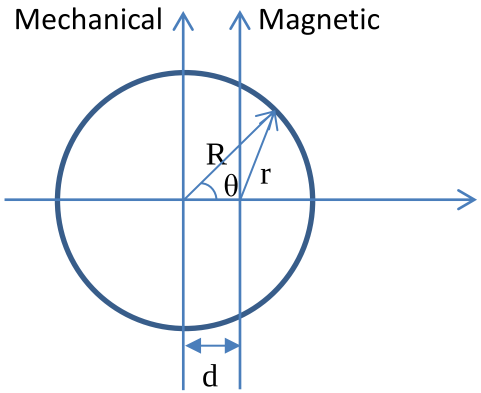
Magnetic Axis Measurement

Rotating rod: Bakelite (Hall sensor attached)

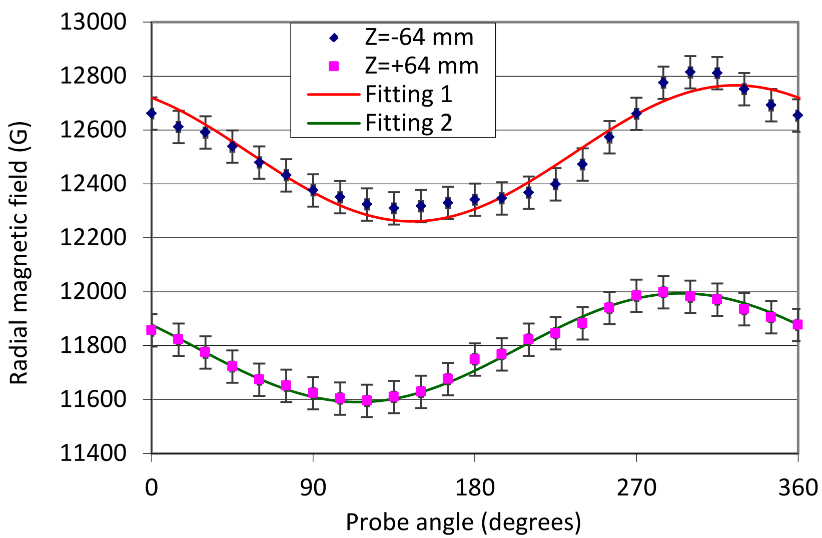
Rotation guide: Aluminum



Solenoid housing: Stainless steel 304



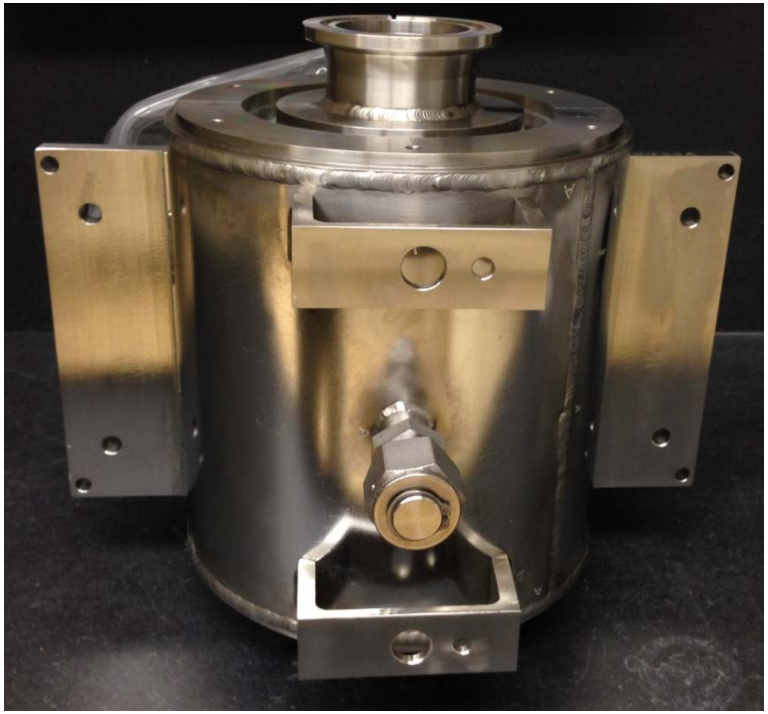
$$B_r(r) = kr$$
$$\cong kR\left(1 - \frac{d}{R}\cos\theta\right), \text{if } d \ll R$$

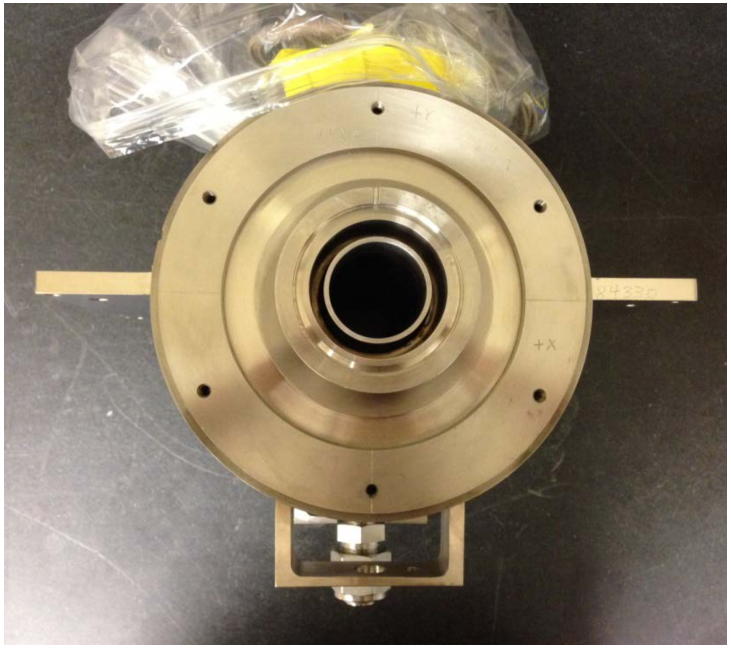


Magnetic centers at flanges (unit: mm)		
	x	y
Flange 1	-0.30 ± 0.07	0.17 ± 0.04
Flange 2	-0.08 ± 0.02	0.26 ± 0.07

Fiducials on the Solenoid Housing

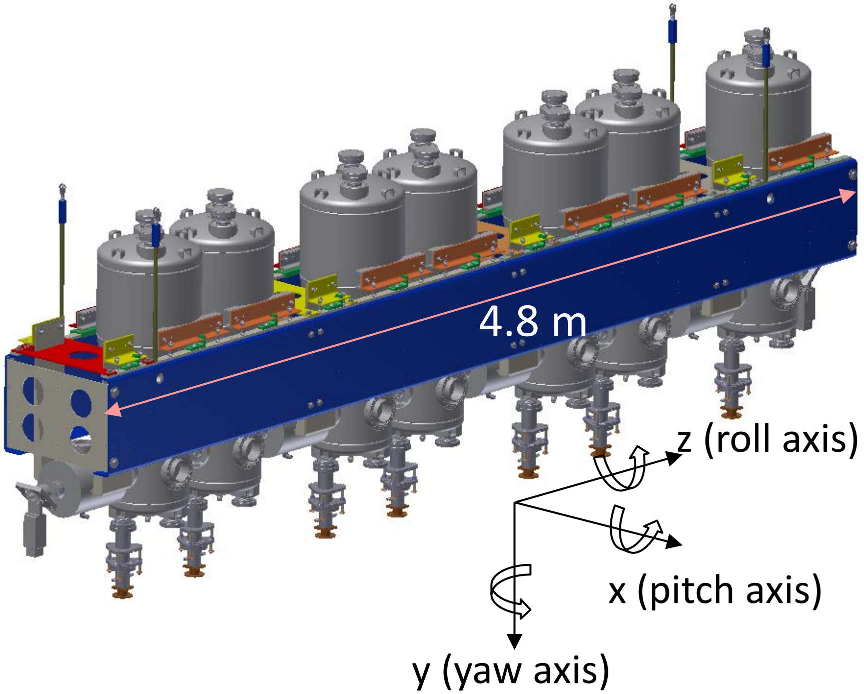
Fiducials were finely machined referenced to the mechanical axis (centers of the solenoid bore at both ends, a scribed mark for the angle reference) used in the magnetic axis measurement.





Experience with Alignment of Cavities and Solenoids in ATLAS Intensity Upgrade Cryomodule

ATLAS Intensity Upgrade Cryomodule



7 QWRs and 4 solenoids operated at 4 K

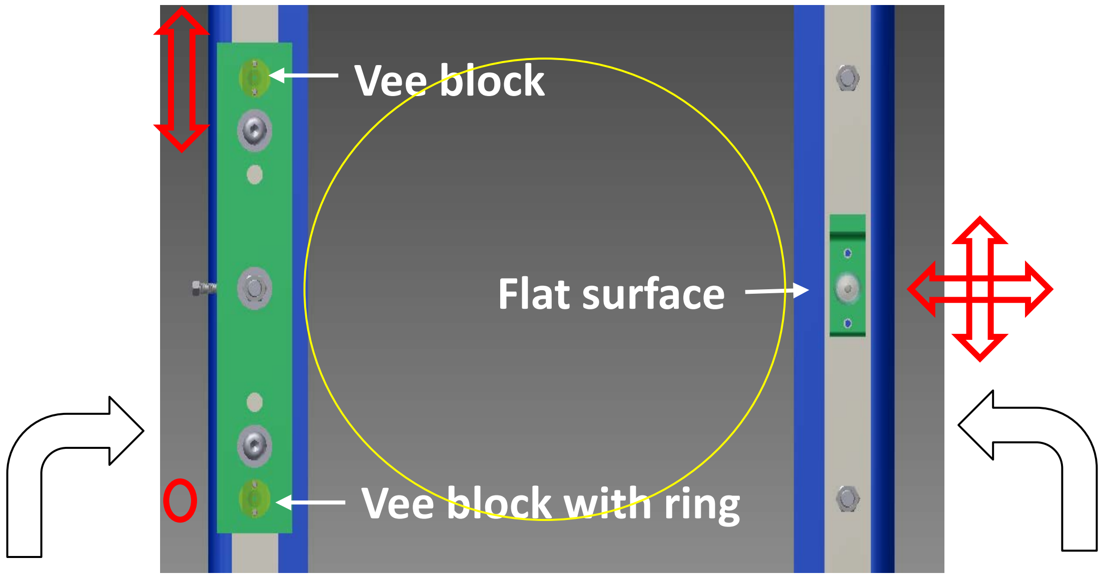
Alignment Tolerances

Coordinate	ATLAS Energy Upgrade*	ATLAS Intensity Upgrade**	PXIE HWR	
			FRS***	Goal
x (mm)	±0.5	±0.25	±0.5	±0.25
y (mm)	±0.5	±0.25	±0.5	±0.25
z (mm)	±2	±1	±0.5	±0.5
Pitch (degrees)	±0.2	±0.1	±0.06 (S) ±0.14 (C)	±0.06
Yaw (degrees)	±0.2	±0.1	±0.06 (S) ±0.14 (C)	±0.06
Roll (degrees)	±1	±0.1	±0.06 (S) ±0.14 (C)	±0.06

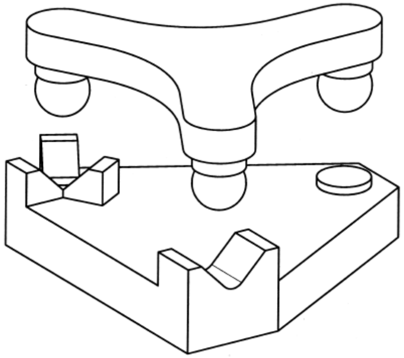
*,** Alignment tolerances for solenoids only
*** Half-Wave Resonator Cryomodule for Project X Functional Requirements Specification, Feb. 2012

Kinematic Mounts

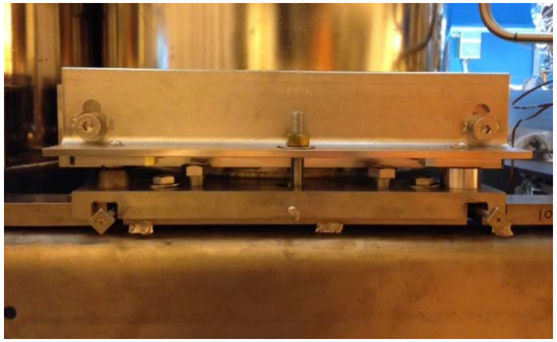
Kelvin-type kinematic coupling used in cavity/solenoid mount

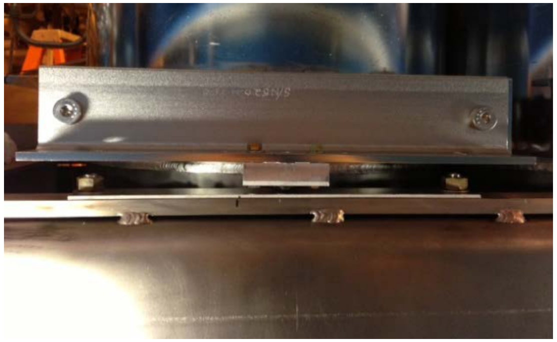


Kelvin type
kinematic coupling

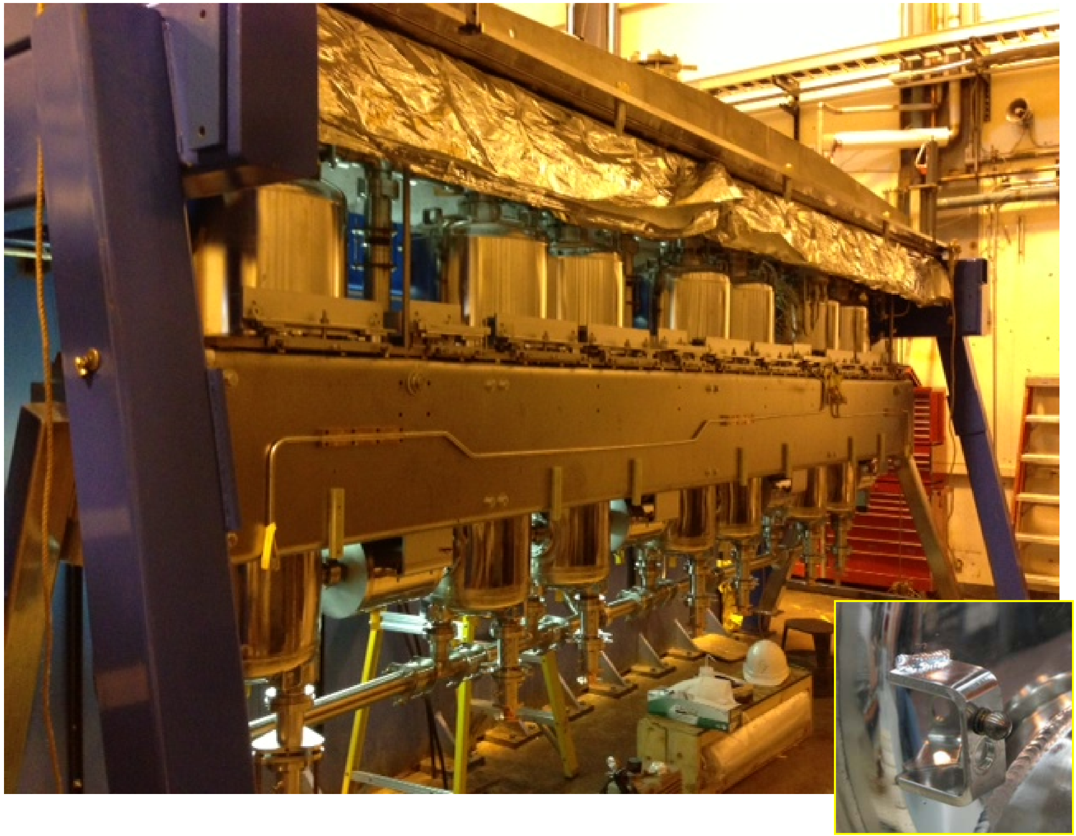


L.C. Hale and A.H. Slocum,
Precision Engineering (2001)





Room Temperature Alignment

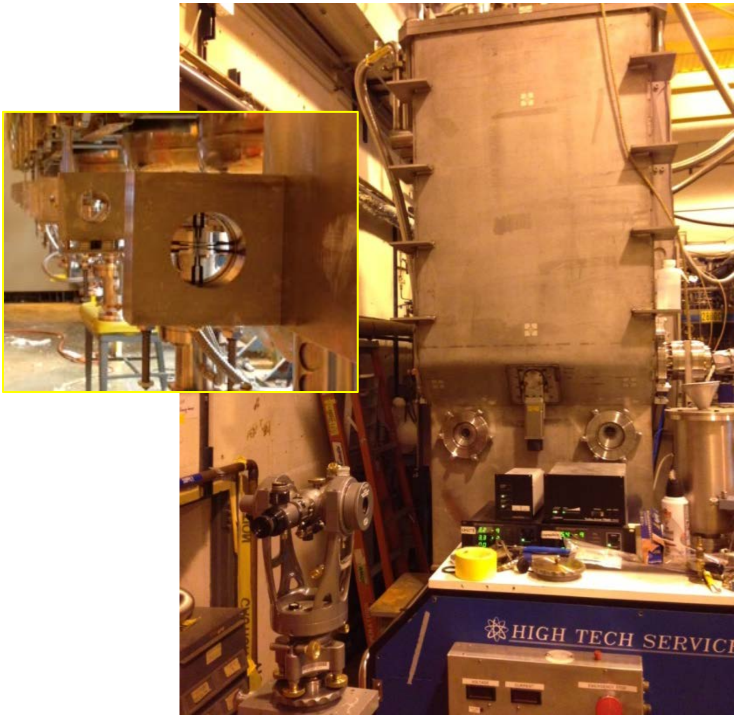


RMS room temperature alignment results

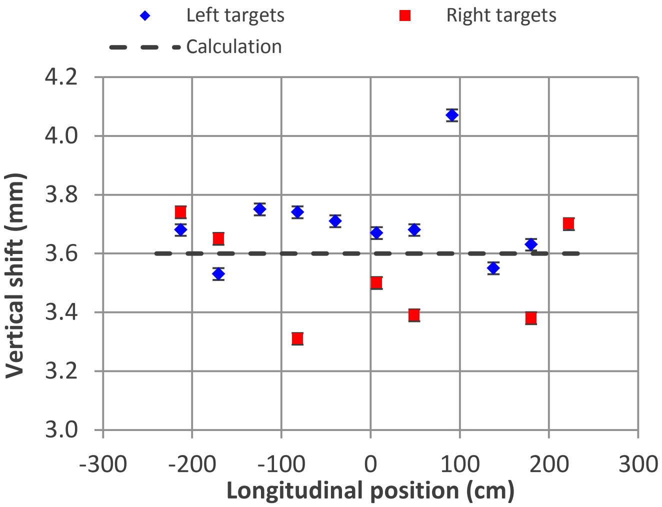
	Solenoids	Cavities
Horizontal offset	0.08 mm	0.36 mm
Yaw angle	0.03°	0.07°
Vertical offset	0.17 mm	0.21 mm
Pitch angle	0.08°	0.15°

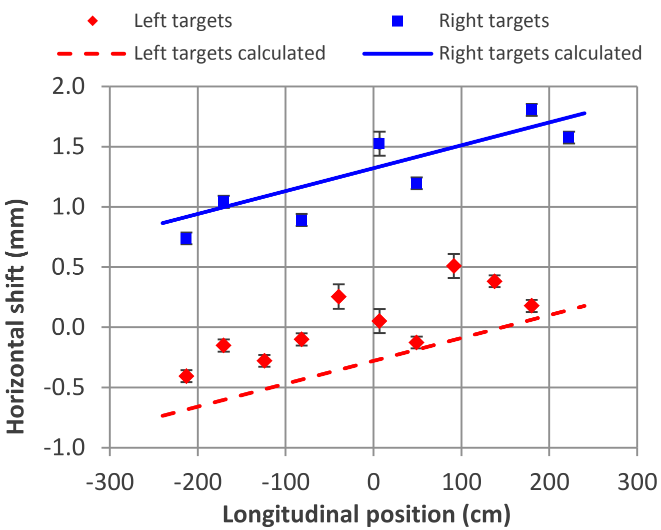
- Fiducials are used as references of the mechanical center of each cavity and solenoid.
- After installing alignment targets, their positions are measured referenced to the beam axis.

Alignment Change on Cooldown



Target shifts on cooldown and evacuation of insulation vacuum



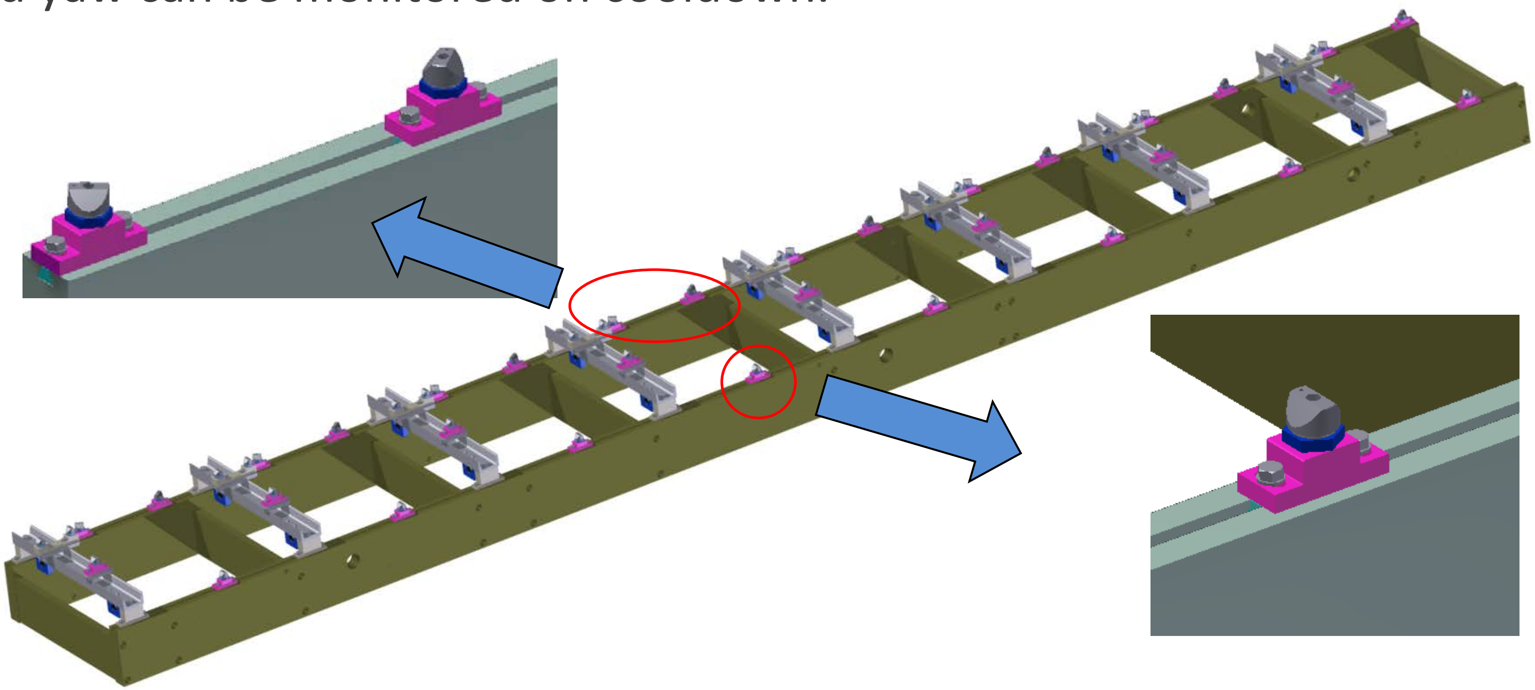


RMS deviation from the fitted beam axis

	Solenoids	Cavities
Horizontal	0.12 mm	0.50 mm
Vertical	0.18 mm	0.28 mm

Improvements in PXIE HWR Cryomodule

- Machined Stock Ti bars will be used for the strongback. It will need less effort in the room temperature alignment with advanced position adjustment system.
- Maxwell kinematic coupling will be used in the cavity and solenoid mounts. The beam axis will not have thermal motion on the kinematic mount plane.
- 4 targets will be attached per each cavity and solenoid. Changes in pitch and yaw can be monitored on cooldown.



Summary

- Performance of the fabricated solenoid is in good agreement with the designed specifications.
- We experimentally verified this solenoid will work well in the cryomodule.
  - The dipole field is well superposed on the solenoid and the dipole coil is mechanically stable.
  - The residual field generated by the solenoid is successfully reduced to 2~3 mG at the cavity surface after degaussing.
  - The position of the magnetic axis is known referenced to the fiducials. Experience with alignment in the ATLAS Intensity Upgrade cryomodule, in which we achieved 0.25 mm transverse alignment tolerances, is adapted to the PXIE HWR cryomodule with improvements in the support and alignment system.