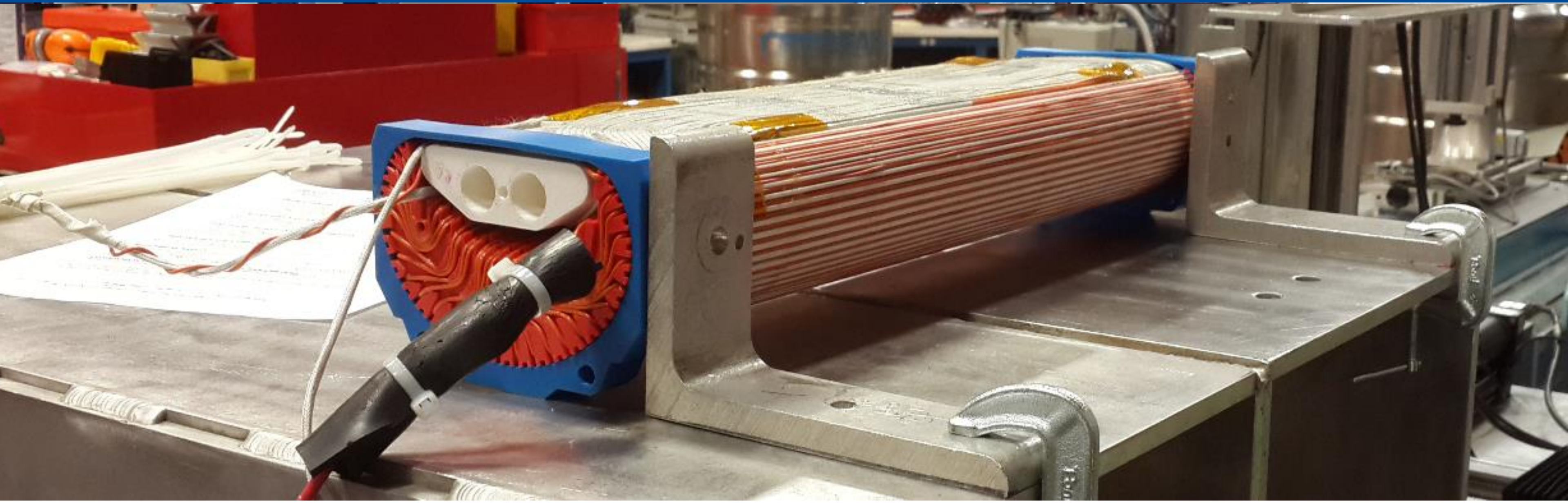


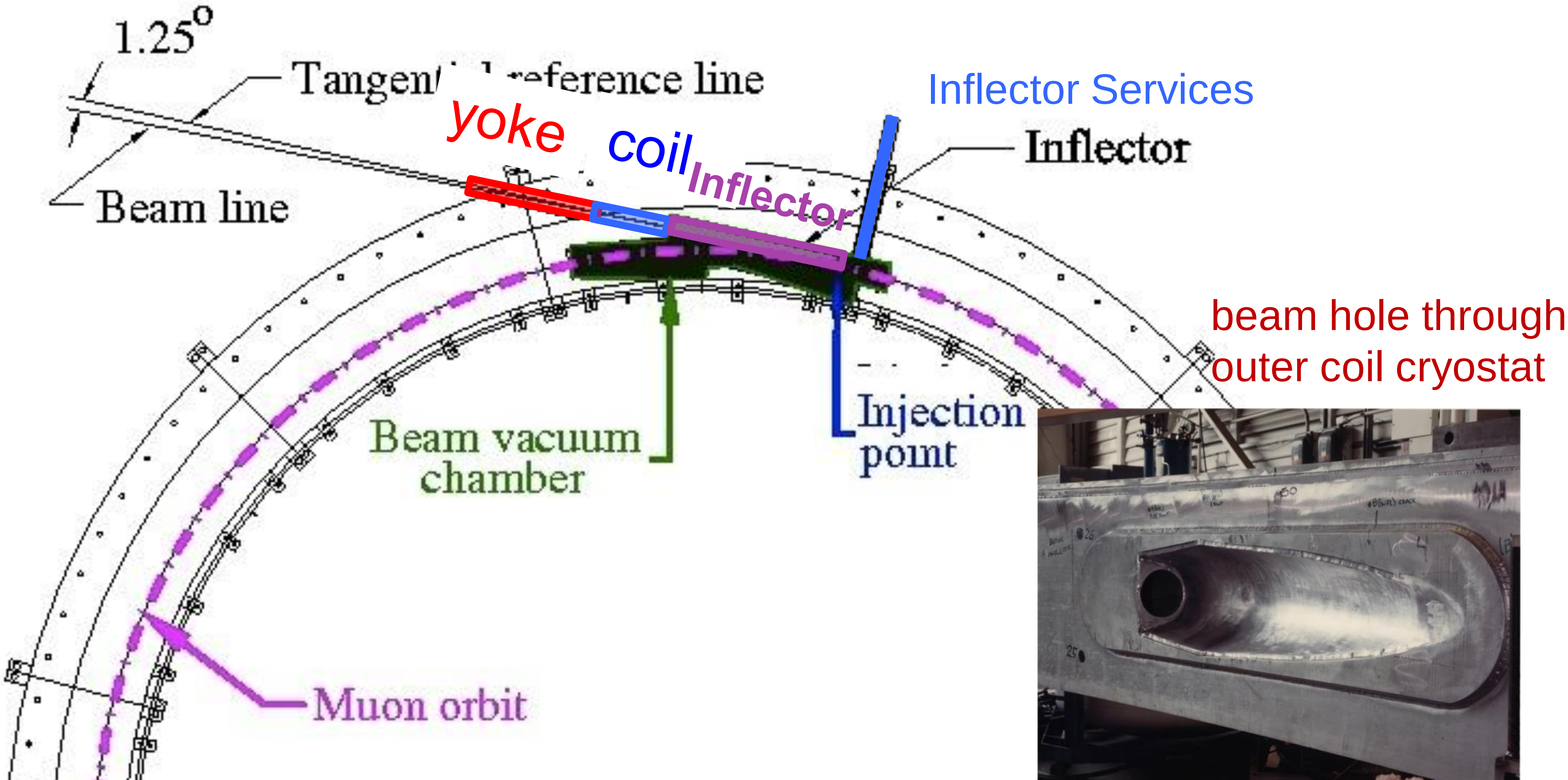
Overview of g-2 Inflector Magnet Parameters and New Design

Vladimir Kashikhin
Technical Division Review
24 June, 2016

Outline

1. Introduction
2. New Inflector requirements
3. Old Inflector
4. Short Model magnetic design
5. Choice of NbTi superconductor
6. Superconducting shield
7. Short model fabrication and measurements
8. Technical Model with open ends
9. New Inflector cold mass design
10. Schedule
11. Risk assessments and reduction
12. Summary

Inflector Magnet Position in the Ring (B.L. Roberts)



- The inflector magnet cancels the field in the magnet gap and permits the muon beam to enter the storage ring undeflected.
- The inflector field is not permitted to leak flux into the storage ring and spoil the precision uniform magnetic field.

A tale of five Inflectors (B.L. Roberts)

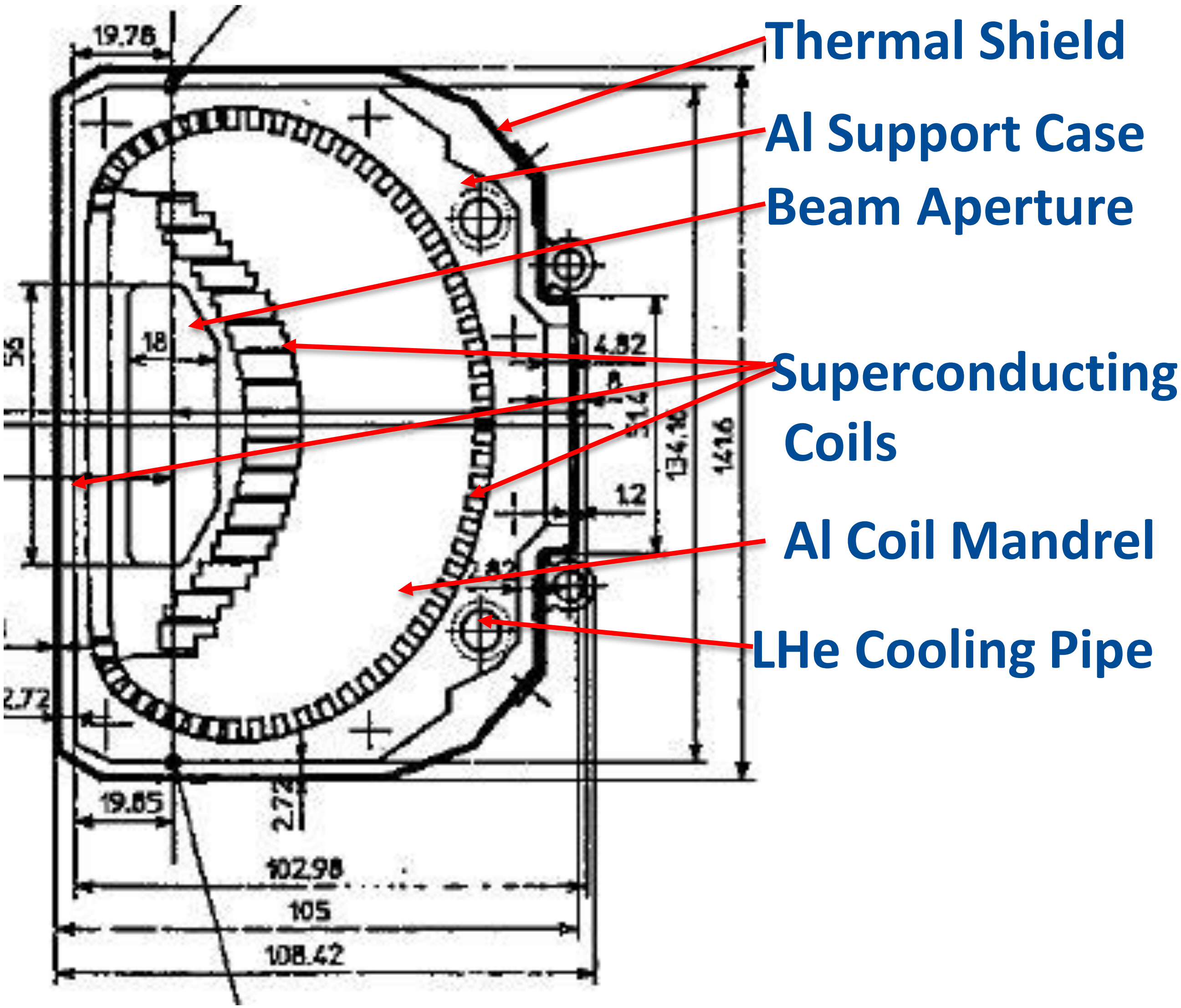
- There are five inflectors mentioned in this talk, 3 from E821
  1. The short prototype with one open, one closed end.
  2. First inflector that was damaged in commissioning, repaired and initially used in E821
     - it leaked flux, producing a 0.2 ppm systematic error, and was replaced after the 1999 run.
     - destructively dismantled in TD to reverse engineer and salvage parts
  3. Current inflector – replaced the damaged one; was installed into E821 in late 1999. We are reusing it as our baseline plan.
  4. Full-scale technical model – a full-scale prototype that we are proposing to build largely out of recycled parts from V2.
     - we hope that we can use it in the experiment
  5. All New inflector – made entirely from new parts, only if needed

New Inflector Requirements

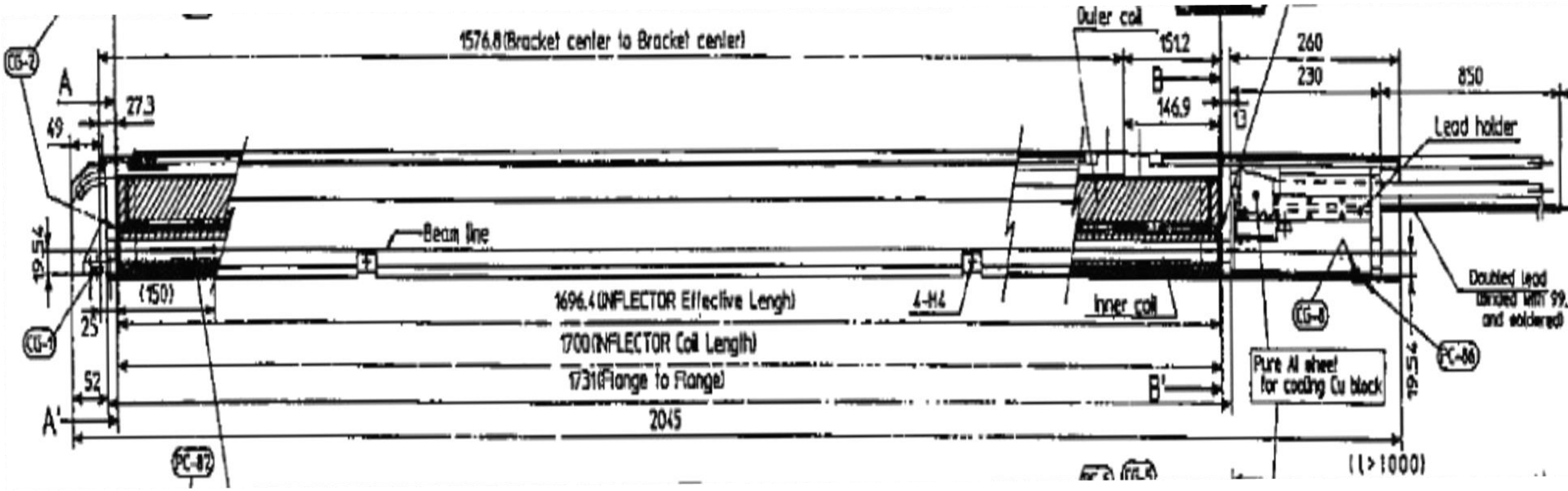
- Magnet cold mass should fit an existing vacuum vessel.
- Magnet should generate 1.45 T field to cancel the same value of main magnet field in the beam bore.
- Beam bore dimensions are the same as for the old magnet: 18 mm x 50 mm.
- Magnet bore should have open ends.
- Use as much as possible old parts for the first model.
- Magnet should use the old LHe cooling scheme.
- Coil current should be less than 3 kA.
- Superconducting shield should eliminate the magnet external field to less than 1 ppm value in the circulating beam area.

Open ends Inflector increases to 60% muon injection efficiency.

Old Inflector Magnet Cross-Section



Old Inflector Magnet Longitudinal View



Total magnet length - 2045 mm

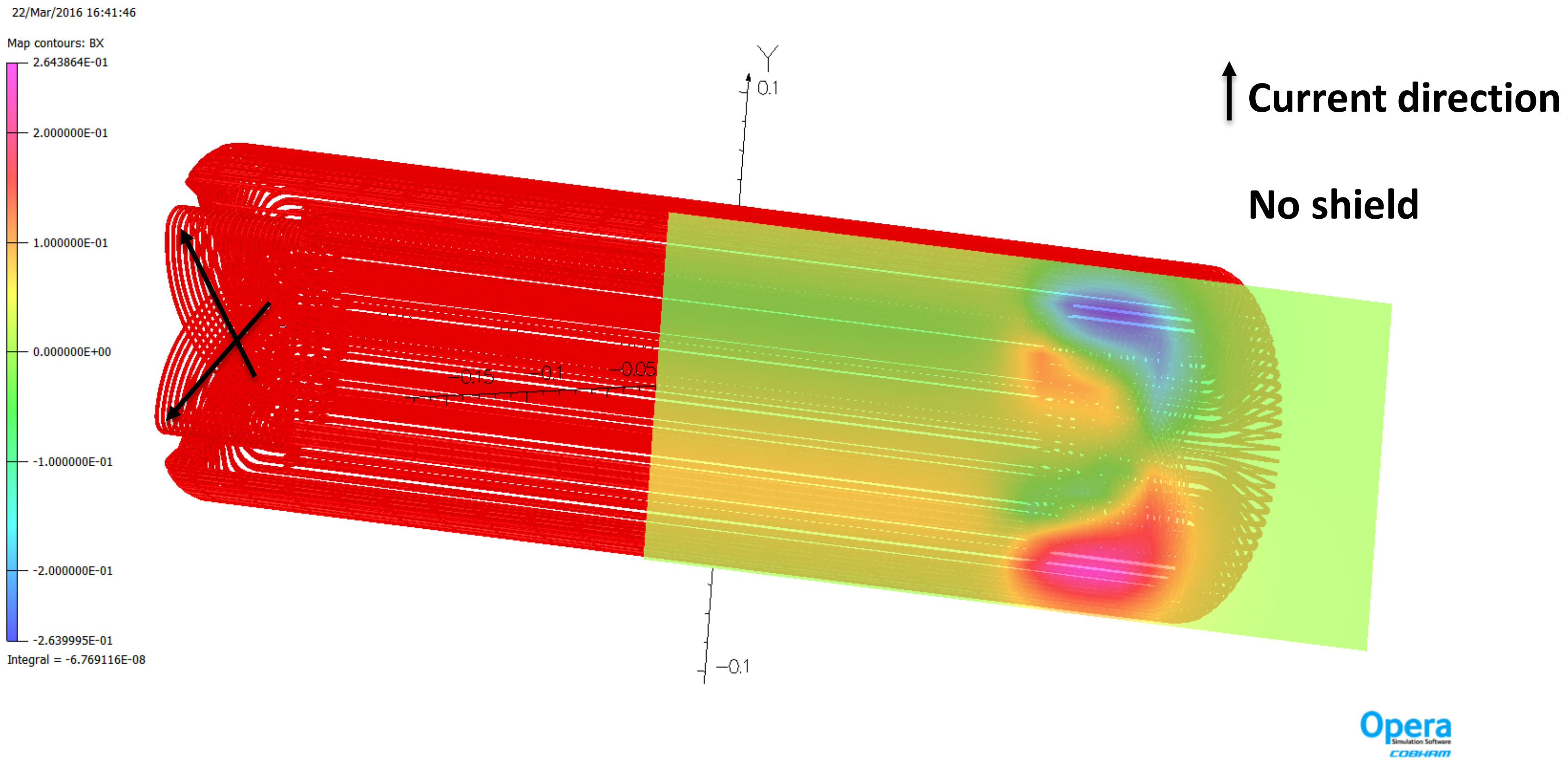
Width 110 mm

Height 142 mm

Old vs. New Magnet Parameters

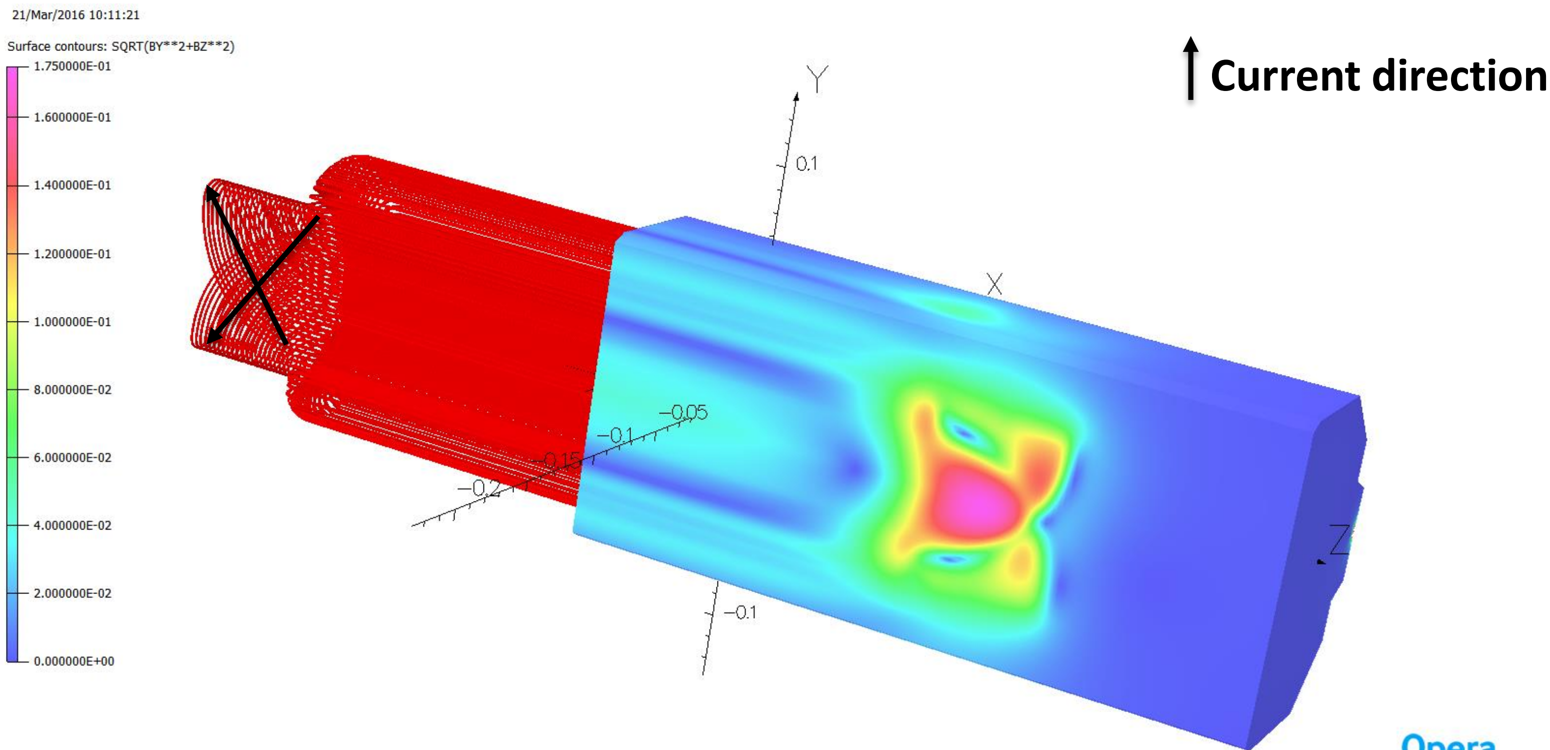
Parameter	Units	Old Magnet	New Magnet
Beam aperture	mm	18 x 56	18 x 56
Effective length	mm	1686	1577
Dimensions	m	0.11x0.15x2.025	0.11x0.15x2.025
Nominal current	A	2685	1457
Number of turns		88	176
Aperture field without main field	T	1.45	1.55
Integrated field	T-m	2.44	2.44
Superconductor peak field at 1.45 T main field	T	3.5	3.6
Inductance	mH	2.0	7.1
Stored energy	kJ	7.25	7.54

Open Ends Short Model



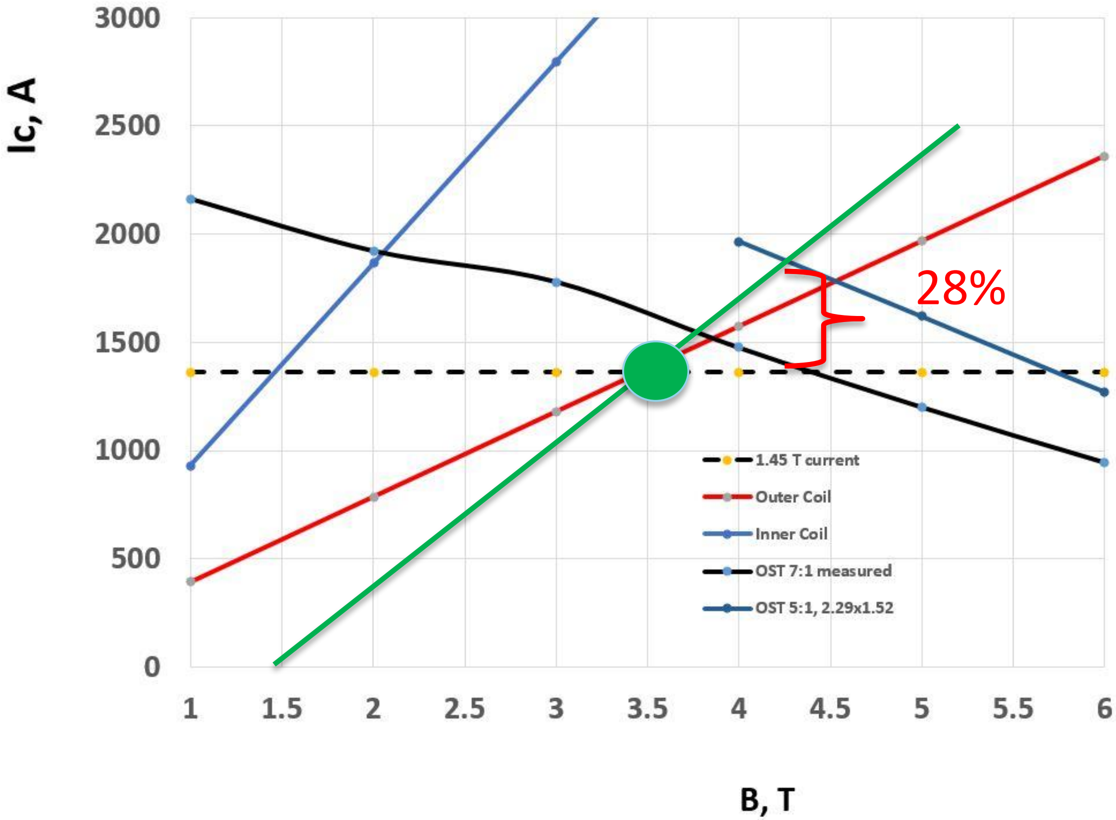
- New inner coil ends configuration decreased the peak field in the shield area to 0.26 T. Opposite current directions at coil ends reduce about two times the peak field component at the shield. Inner coil has 2 layers.
- Two times reduced the peak current to accommodate the double layer inner coil configuration.
- 18 mm beam bore width allows to use old coil Al mandrels.

Short Model with Shield



- Shield surface field is Byz,max=0.18T-0.23T which corresponds to the shielding currents Is=63A – 82A at the shield thickness d=0.45 mm.
- The SC shields critical current at 1.5 T external field: Ic= 180 A - 300 A (new 0.45mm shield), Ic=31 A – 468 A (old 0.22mm).
- The 3.6 T peak field is on the outer coil.
- 18 mm beam bore width allows to use old coil Al mandrels.

Superconductor Choice



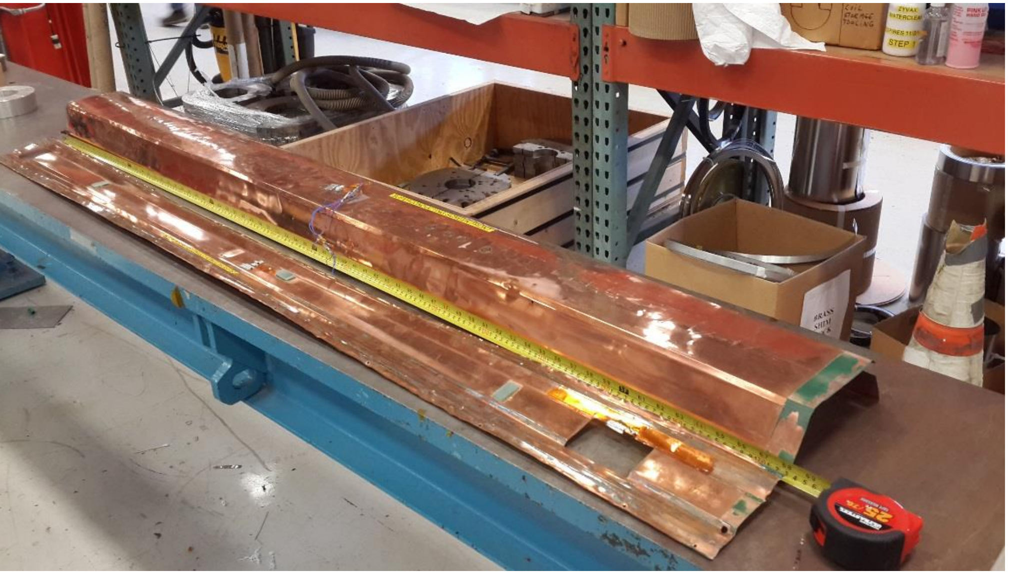
Inner Coil: NbTi wire-in-channel superconductor of OST:

Ic>1210 A @ 4 T, 4.2 K, Cu:SC=7:1 (existing), Ic>1965 A @ 4 T, 4.2 K, Cu:Sc=5:1 (ordered).

Bare conductor dimensions: 2.29 mm x 1.52 mm, with polyester insulation 2.56mm x 1.77 mm.

Outer Coil: Bmax=3.6 T, superconductor critical current is 28% above the nominal operating current.

Superconducting Shield



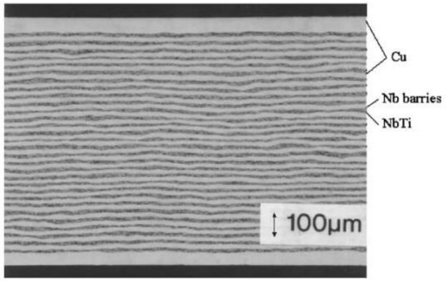


Fig. 13. Cross-section of the multilayer sheet.

- ✓ Old shield had thickness 0.22 mm.
- ✓ After magnet/shield repair the fringe field in the circulating beam area increased in several times.
- ✓ New shield thickness will be 0.45 mm as in the magnet installed now, and critical parameters will be higher.

Shield Parameters	Units	Old	New
Thickness	mm	0.22	0.45
Number of NbTi layers		30	30
Critical current at 1.5 T, 4.5 K (parallel field)	A	160/468*	300
Critical current at 1.5 T, 4.5 K (perpendicular field)	A	31/110*	180

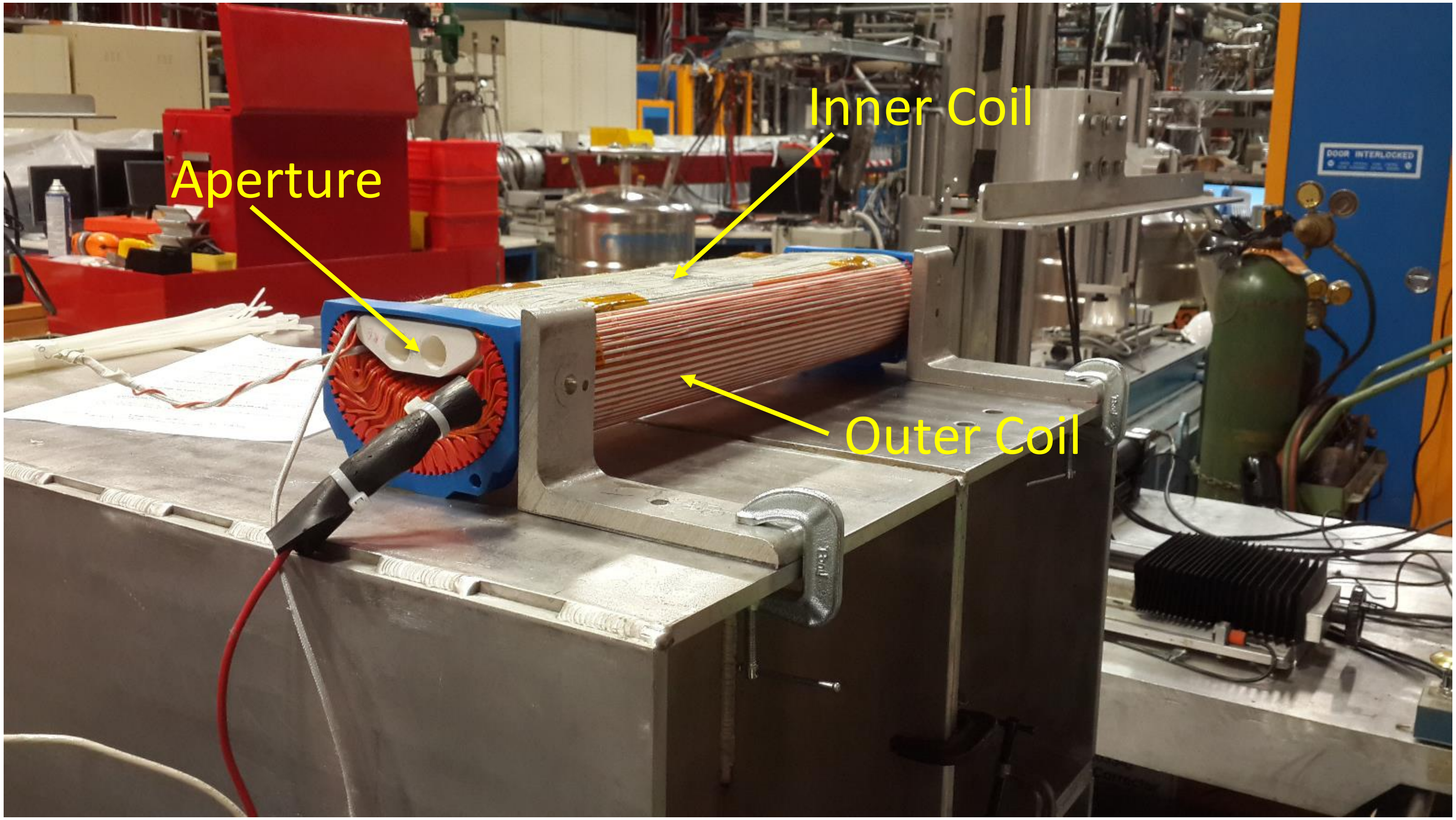
* Measured by D. Turrioni, E. Barzi samples with the cut parallel/perpendicular to the material rolling direction.

Short Model Fabrication

- 3D printed plastic mandrels for inner and outer coils.
- Inner coil is wound from copper stabilized OST superconductor.
- Outer coil wound by a copper wire.
- Coil has two layers wound that currents at the end go in opposite directions to reduce end fringe field.
- That is a major improvement to implement the open ends configuration.

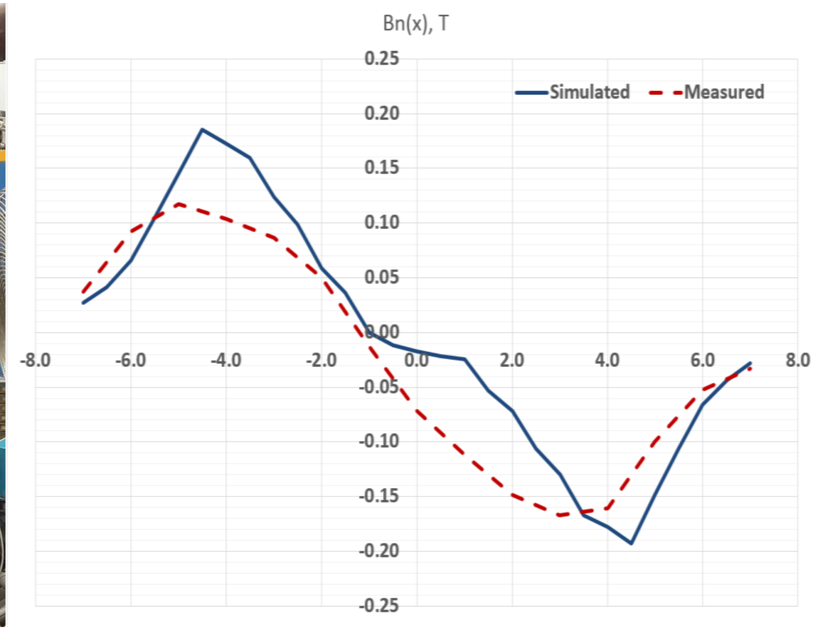
Fermilab

Model Magnetic Measurements



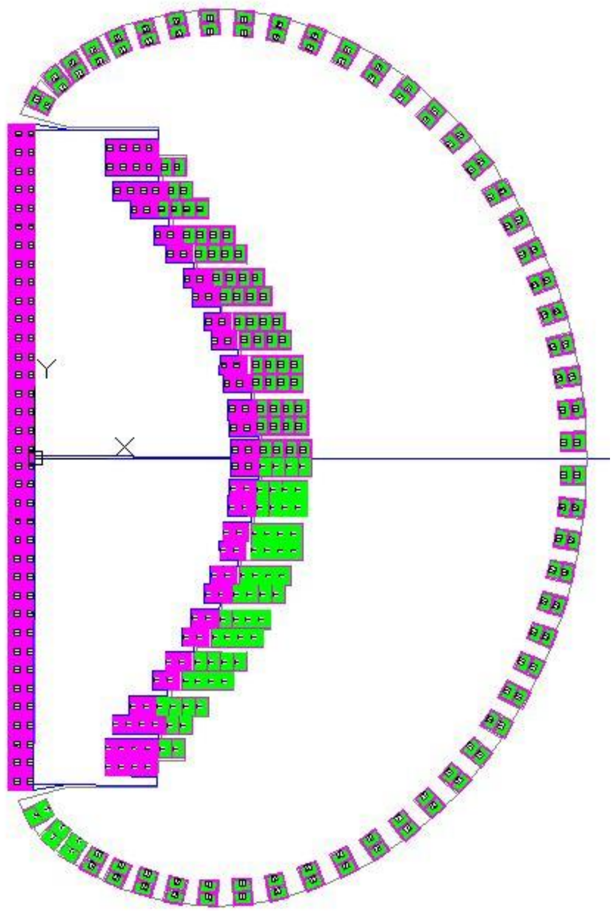
- Field measurements were performed by 1-axis and 3-axis Hall probes with steps 5 mm and 10 mm.
- The fringe field peak area was investigated with small steps.

Magnetic Measurement Results



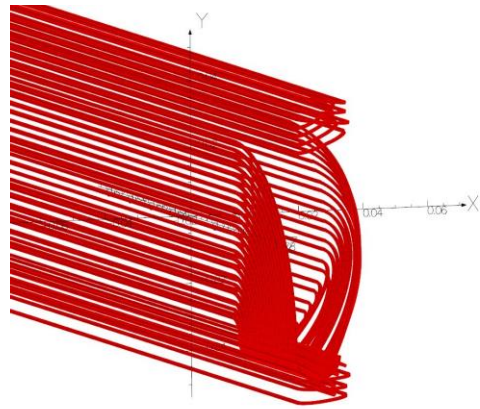
- The model field was measured at 4 A current, and simulated at 1398 A. The distance from the inner coil surface was 8 mm.
- The measured magnet aperture field transfer function is 10.39 G/A, simulated value 10.65 G/A.
- Model measurements confirmed magnetic parameters.

New Magnet Coils Design

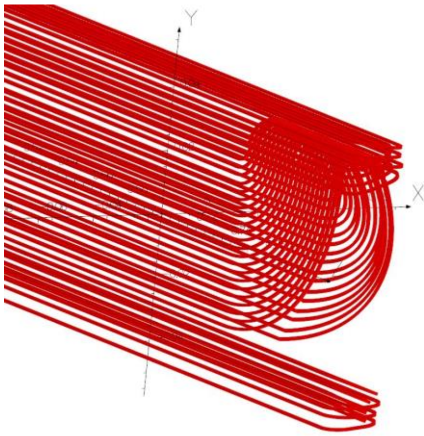


Inner coil (pink)

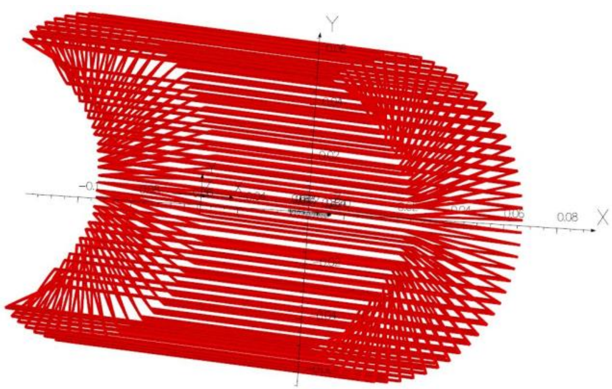
Outer coil (green)



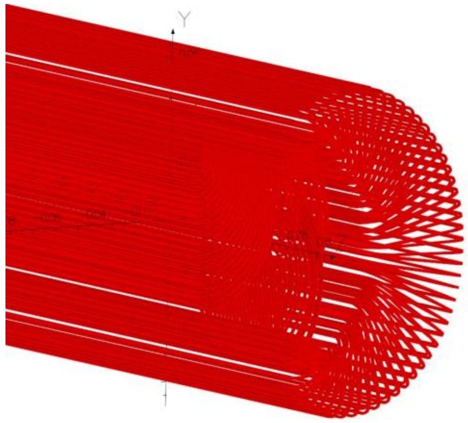
Inner coil layer 1



Inner coil layer 2

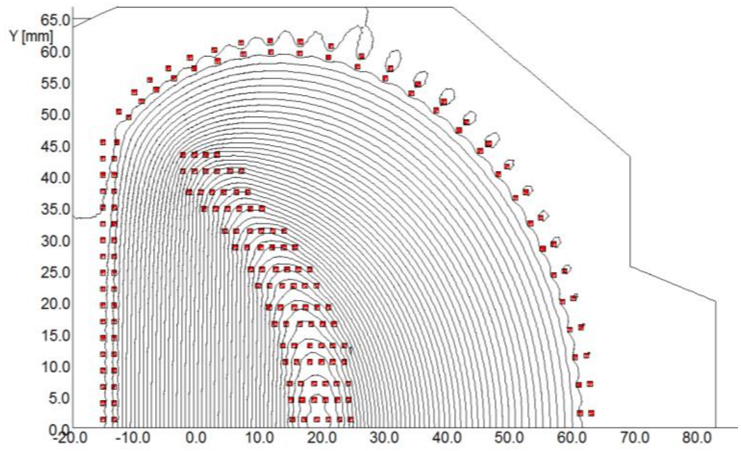


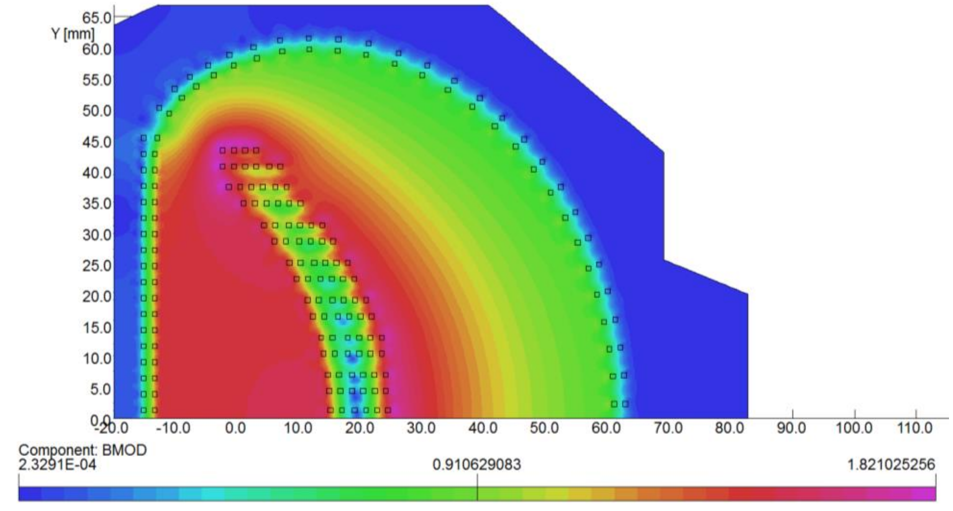
Outer coil

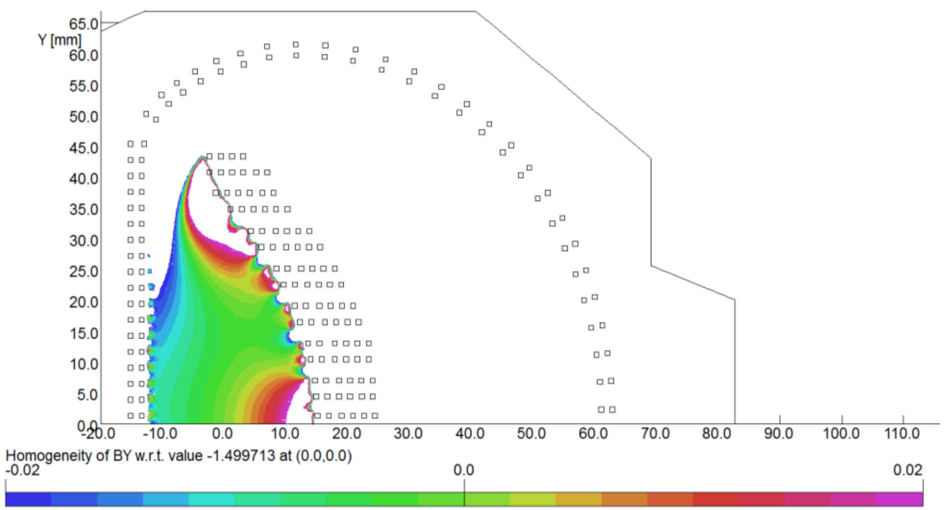


All coils

2D Magnetic Field at Bext=0





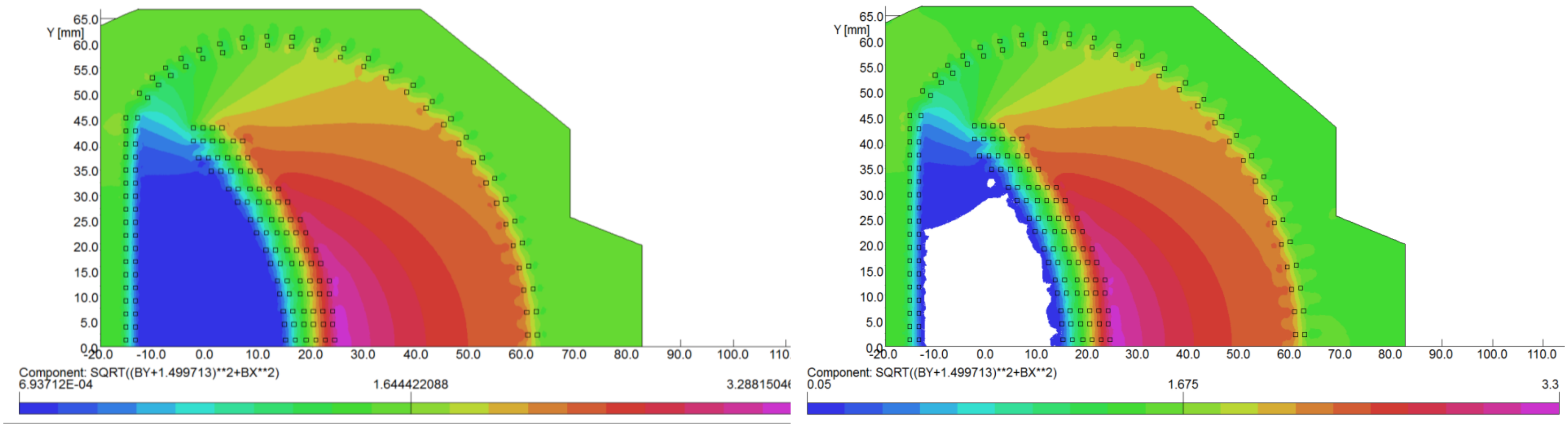


Center field at 1398 A.

Field homogeneity in the aperture +/-2 %.

Superconductor peak field 1.82 T at 1398 A.

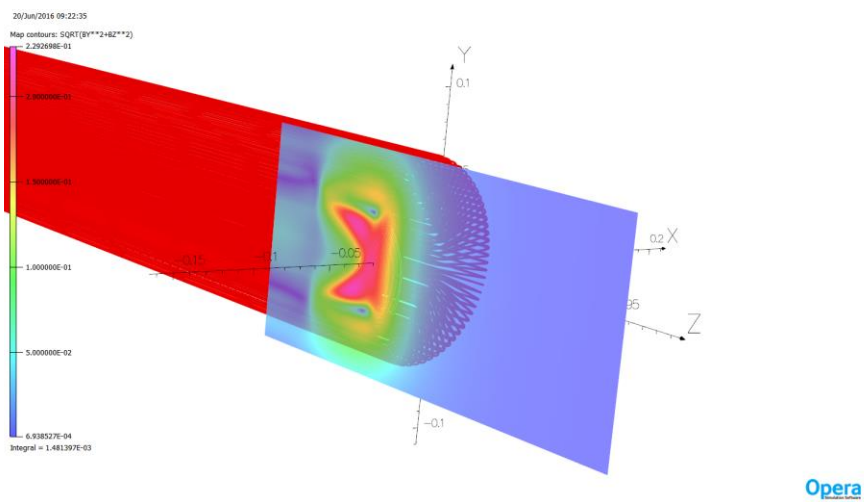
2D Magnetic Field at Bext=1.5T



Center field is 0.0 T at 1398 A and 1.5 T external field.
Superconductor peak field 3.3 T with 1.5 T external field.
Lorentz force on the conductor at 3.6 T and 1500 A: 540 kg/m.
The accumulated peak stress on the epoxy is low: 6.3 Mpa.
Mechanically all turns will be contained inside the Al case and vacuum impregnated by epoxy forming the solid, rigid structure as in previous magnets.

Coil Length Optimization

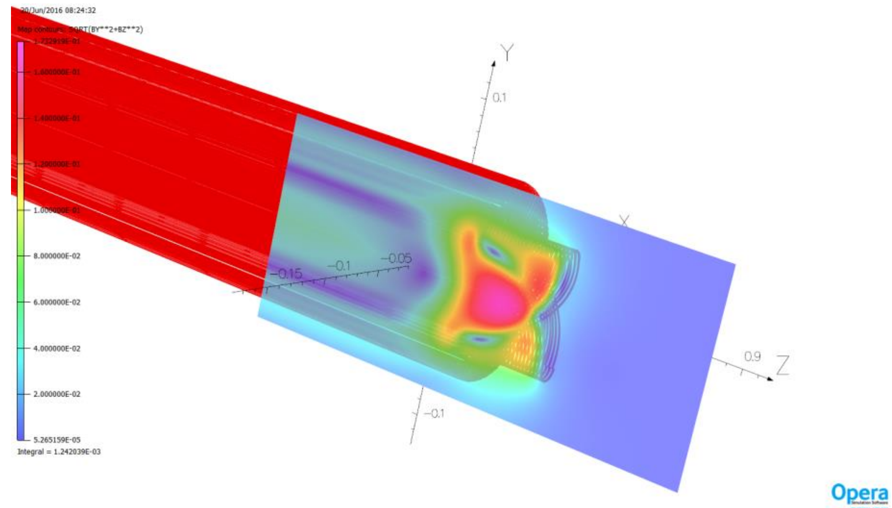
Short Inner Coil



Screen field max: Byz=0.229 T

I=1398 A, By*Leff=2.345 T-m

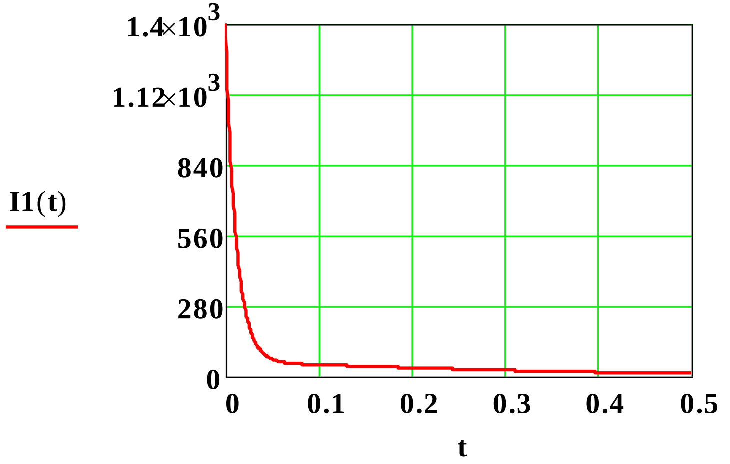
Long Inner Coil

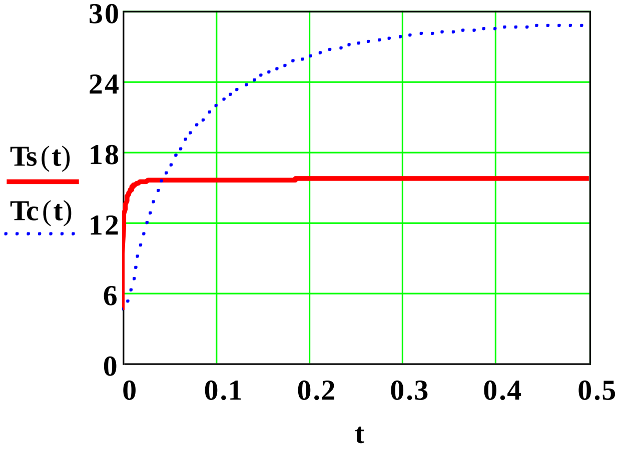


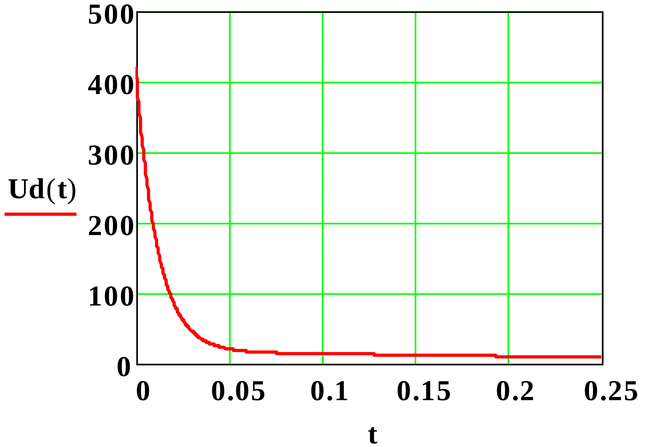
Screen field max: Byz=0.173 T

I=1398 A, By*Leff=2.27 T-m.

Quench Analysis



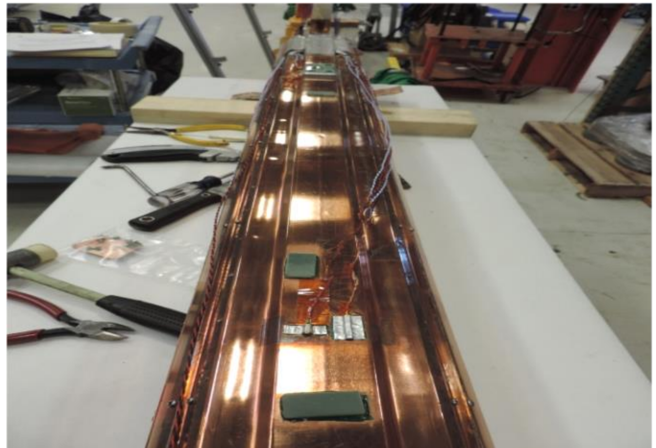
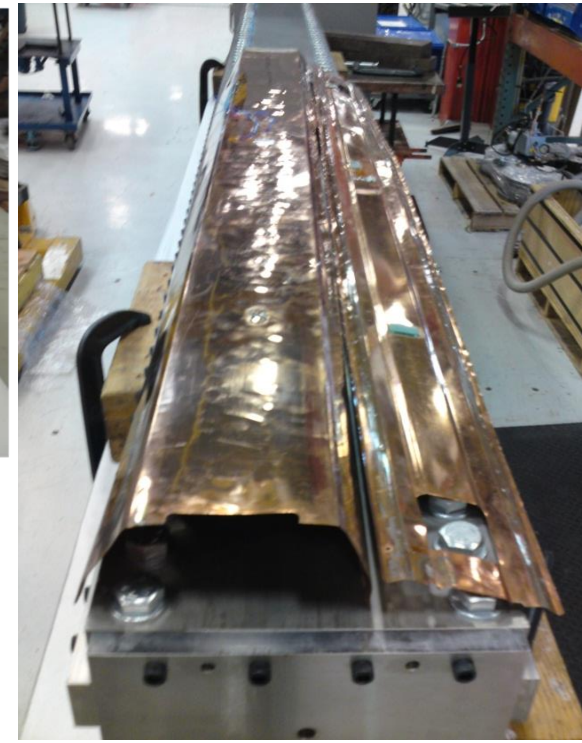




At dump resistor Rd=0.3 Ohm, Tmax=16 K with fast 50 ms magnet discharge.
At Rd=0.01 Ohm the Tmax=124 K with several seconds slow discharge.

The superconductor has a large fraction of copper: Cu:Sc=5:1 and well protected against quenches. Will be used existing quench protection and detection systems.

Old Inflector Parts

- For the first cold mass prototype will be used parts from the old Inflector:
  - Superconducting NbTi shield of 0.22 mm thickness with possibility to replace by the new one.
  - Inner coil Al mandrel with modified end parts.
  - Outer coil mandrel with modified end parts.
  - Outer cold mass Al case. The longitudinal cut should be repaired.
  - Thermal shield.

Technical Model Prototype

- Use old Al mandrels to wind inner and outer coils.
- Use OST NbTi strand in the Cu channel with Cu:Sc=5:1.
- Design and fabricate winding tooling.
- 3D printing coil end parts for open ends configuration.
- Repair outer Al case cut.
- Wind inner and outer coils, vacuum impregnate coil assembly with epoxy inside the cold mass case.
- Attach an old NbTi shield (new if available) to the outer case surface.
- Assemble the cold mass with the VMTF top head.
- Cold test measuring the magnetic field inside and outside the cold mass at 1.45 T center field.
- If tests successful assemble the magnet.
- Install the magnet in the g-2 ring.

New Inflector Cold Mass

- Update the cold mass design if needed.
- Procure new parts: coil mandrels, outer case, end plates, lead box, thermal shield, etc…
- Use the same superconductor as for the model.
- Improve if needed an electrical insulation.
- Fabricate the cold mass assembly.
- Cold test in LHe at VMTF test stand.
- Final magnet assembly with thermal shield, superinsulation, current leads.
- Magnet installation inside the old vacuum vessel.
- Cold test with the main magnet background field.
- Magnet installation in the vacuum vessel.
- Final conduction cooling test.

Engineering Risk Assessment

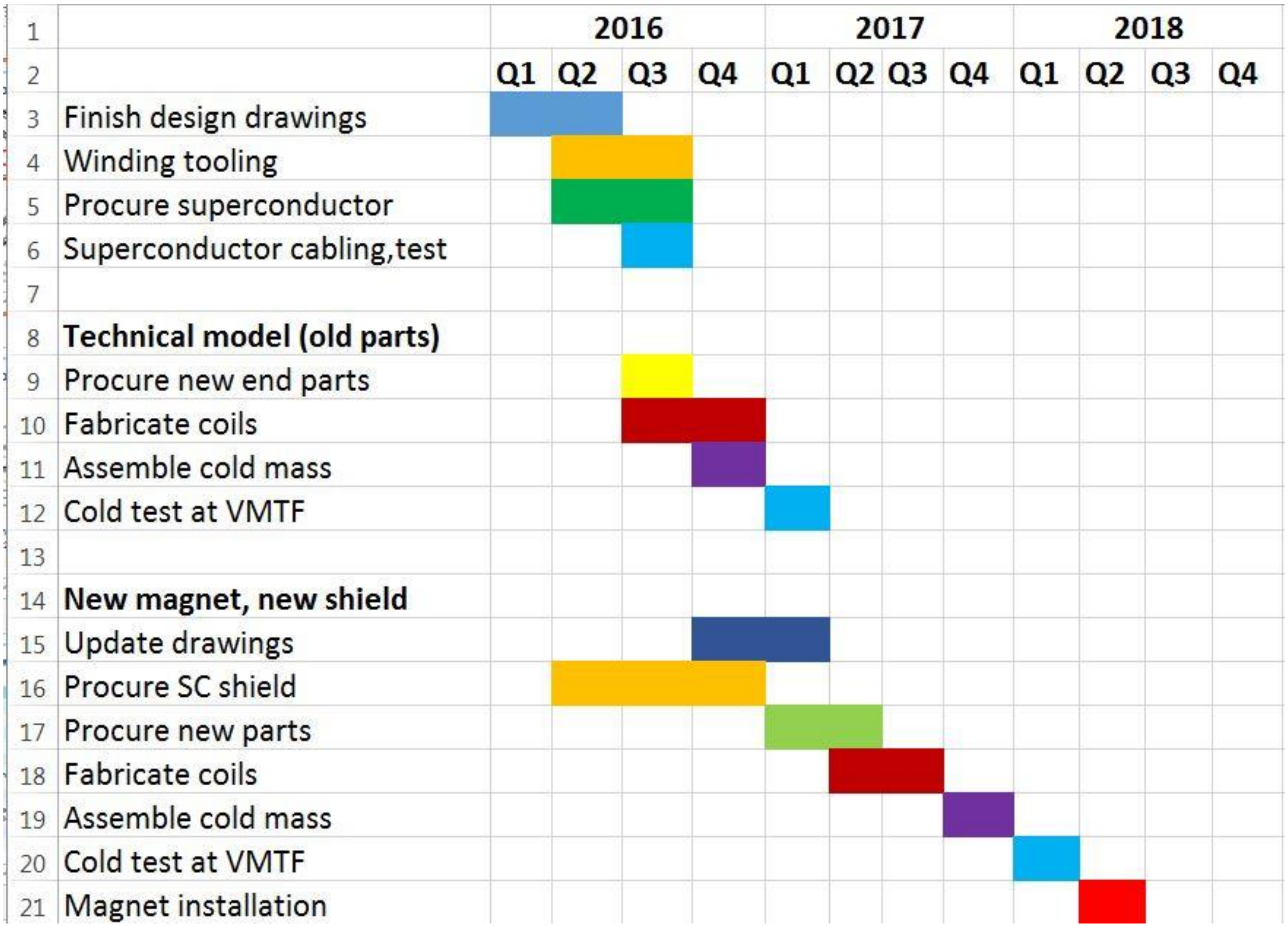
Item	Risk Element	Risk Assessment	Comments
1	Magnetic Design	2	Verified by simulations
2	Mechanical Design	2	Changed only coil ends
3	Thermal Design	1	No changes
4	Superconducting Shield	3	Old raw material
5	Superconductor	1	OST standard
6	Electrical Insulation	3	Cable in Al mandrel slots
7	Quench Protection	1	Low stored energy
8	Coils Fabrication	2	Verified by the model
9	Magnet Test	1	Verified by other magnets at VMTF
10	Magnet Installation	2	The same cold mass external dimensions

1 – Low risk, 2 – Medium risk, 5 – High risk.

Risk Reduction

- Multilayer NbTi superconducting shield:
  - Used old material from Nippon Steel.
  - Final hot rolling process will be supervised by the same expert who fabricate all Nippon Steel SC shields.
- New SC shield and superconductor properties will be verified by samples cold tests.
- The coil winding technology, and magnetic design was proved by the short model fabrication, and warm test.
- Coils electrical insulation will be improved by Al mandrels anodization and proved by Hi-pot tests.
- The cold mass performance will be verified by the Technical Model tests.

Schedule



2016
2017
2018
Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4
Finish design drawings
Winding tooling
Procure superconductor
Superconductor cabling,test
Technical model (old parts)
Procure new end parts
Fabricate coils
Assemble cold mass
Cold test at VMTF
New magnet, new shield
Update drawings
Procure SC shield
Procure new parts
Fabricate coils
Assemble cold mass
Cold test at VMTF
Magnet installation

Summary

- Activity for 2016-2017:
  - Update the design based on the short model test results.
  - Purchase the new NbTi shield material from Nippon Steel and collaborators, Japan.
  - Fabricate the full scale model using old parts.
  - Test the model in the LHe bath in VMTF with old and new shields.
  - If the test will be successful provide the final magnet assembly, and install the magnet in the ring.
- *Activity for 2017-2018 (if needed) :*
  - *Update the design based on the test results.*
  - *Fabricate the new cold mass with new SC shield.*
  - *Verification cold test in VMTF.*
  - *Install the magnet in the ring.*