BERKELEY LAB

Magnets for 45 GHz ECR Ion Source

Mariusz Juchno

SMP Technical Seminar

August 22, 2023

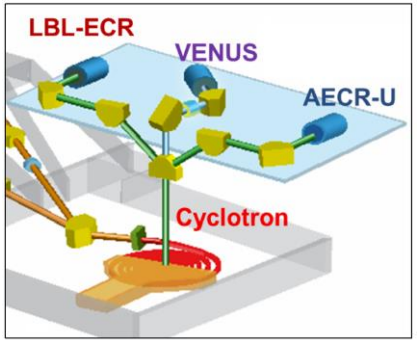
ECR magnets and teams

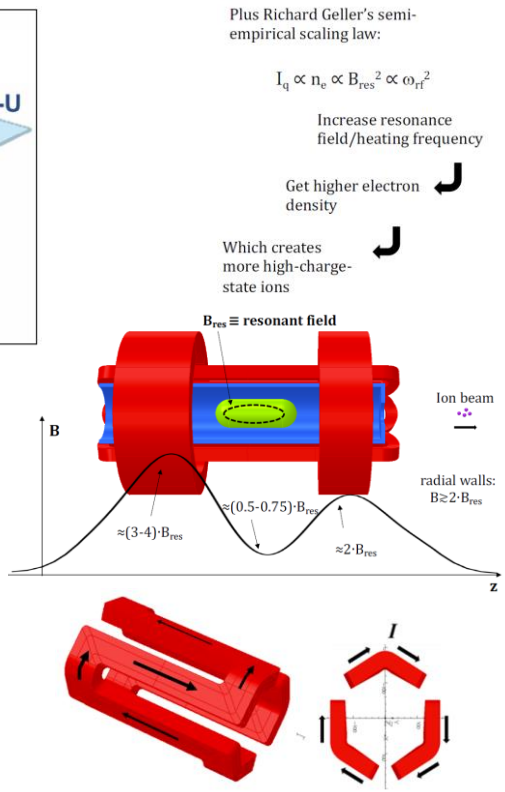
- MARS-D team
  - Nuclear Science Division
    - Janilee Benitez
    - Daniel Xie
    - Damon Todd
    - Lianrong Xu
    - Jaime Cruz Duran
    - Larry Phair
    - Technicians in 88” cyclotron
  - BCMT
    - Paolo Ferracin
    - Mariusz Juchno
    - Ye Yang
    - Jose Ferradas Troitino
    - Tengming Shen
    - Jim Swanson
    - Matt Reynolds
    - SMP Materials team

- Nb_3Sn FRIB team
  - FRIB team
  - BCMT
    - Tengming Shen
    - Ray Hafalia
    - Mariusz Juchno
    - Ye Yang
    - Jose Ferradas Troitino
    - Soren, Paolo
    - SMP Materials team

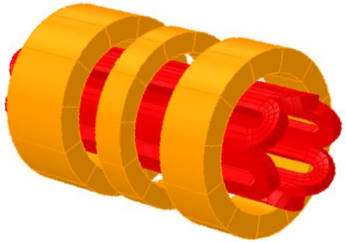
Past seminar

- SMP Materials Seminar
  - Organized by Ian Pong
- Damon Todd
  - Superconducting ECR ion sources: where things stand and how to move forward
- Indico link:
  - https://conferences.lbl.gov/event/905/
- Recording
  - Contact Ian Pong



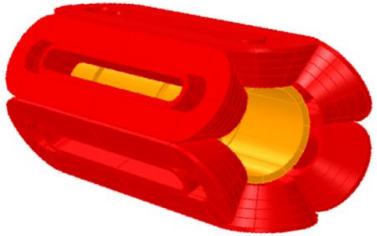


ECR Coil Configurations



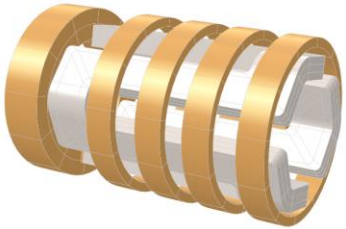
Sextupole-in-Solenoids

- VENUS, FRIB, FECR
- Efficient radial field generation
- Fairly large solenoids
- Complex Lorentz forces
- Longer sextupole coils can reduce Lorentz forces



Solenoids-in-Sextupole

- SECRAL
- Small and efficient solenoids
- Sextupoles in the low field solenoid zone
- Inefficient sextupole generation
- Simpler clamping support can be used

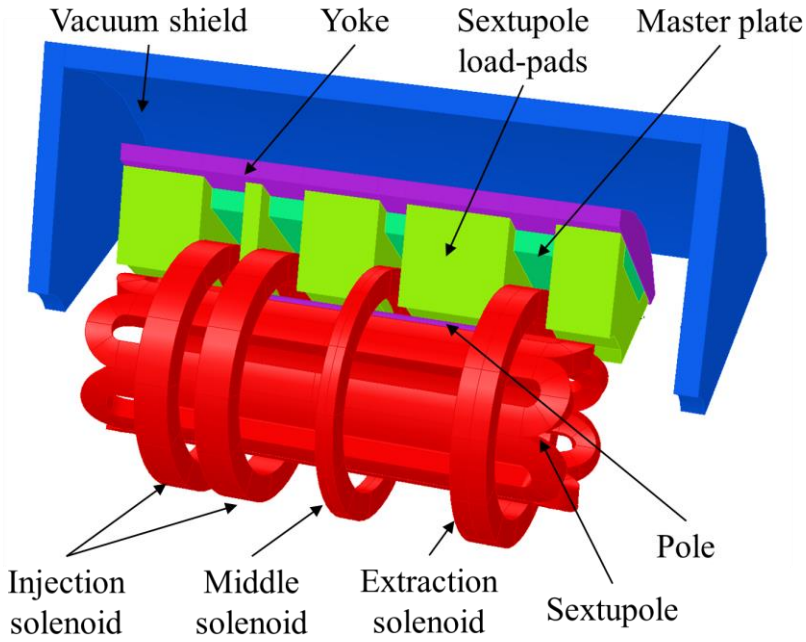


Mixed Axial and Radial System

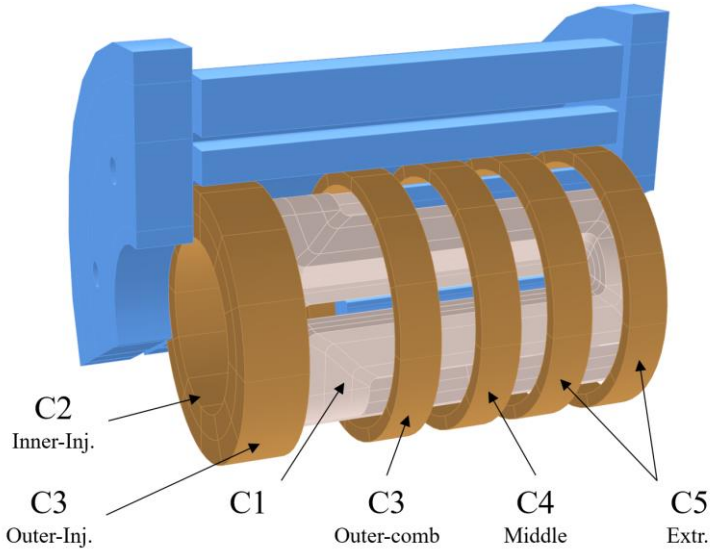
- MARS-D
- Close-loop coil provides radial and solenoid field
- Simpler solenoid system
- Simpler Lorentz force distribution
- Higher field in hexagon “corners”
- Compact
- Complex and labor-intensive winding

Future 45 GHz ECR ion source magnets FECR and MARS

Nb_3Sn FECR



NbTi MARS



Future 45 GHz ECR ion source magnets FECR and MARS

Nb_3Sn FECR

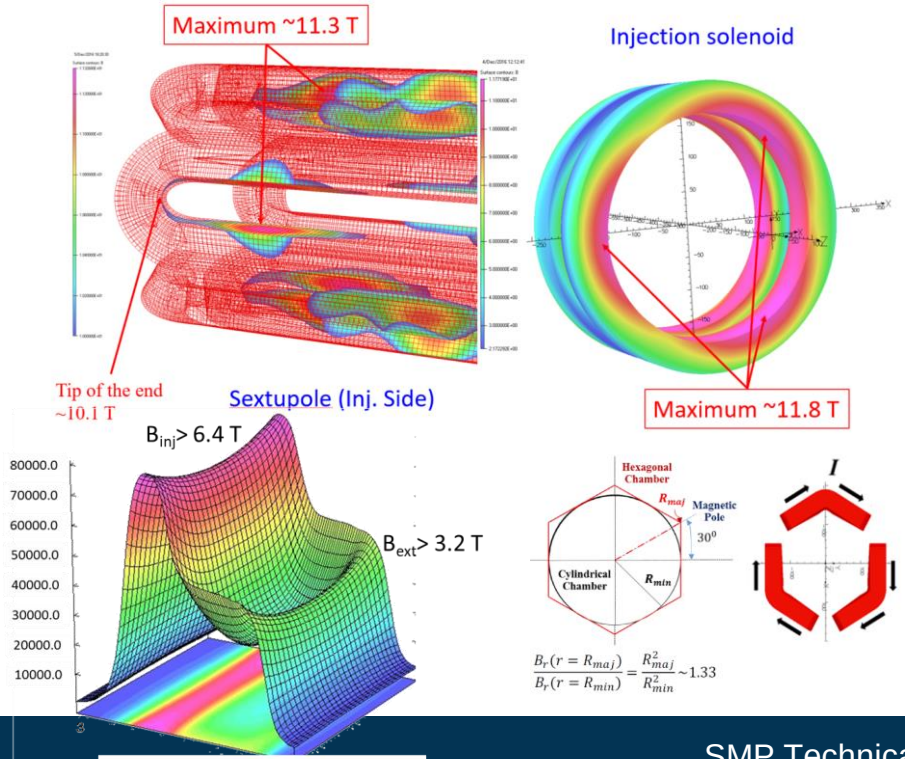
MAGNETIC PARAMETERS OF THE SYSTEM		
PARAMETER	**UNIT**	**VALUE**
Microwave frequency, f_{rf}	GHz	45
Resonant heating field, B_{ECR}	T	1.6
Injection confinement field, B_{inj}	T	>6.4
Extraction confinement field, B_{extr}	T	>3.4
Radial confinement field, B_{rad}	T	>3.2
Mirror length	mm	500
Plasma chamber ID	mm	150
Warm bore ID	mm	170

NbTi MARS

Main Parameters	
Microwave frequency f_{rf}	45 GHz
Resonant heating field B_{ECR}	1.6 T
Injection confinement field B_{inj}	5.7 T
Extraction confinement B_{extr}	3.4 T
Radial confinement field B_{rad}	3.1 T
Stored energy E	560 kJ

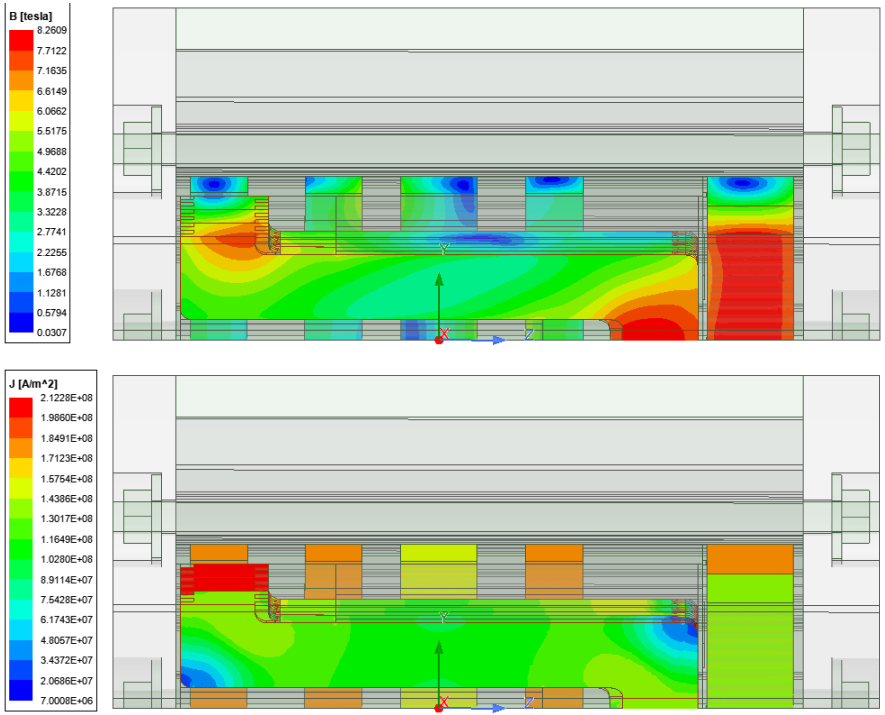
Magnetic field of a 45 GHz ECR magnet FECR and MARS

Nb_3Sn FECR



3-D magnetic field distribution

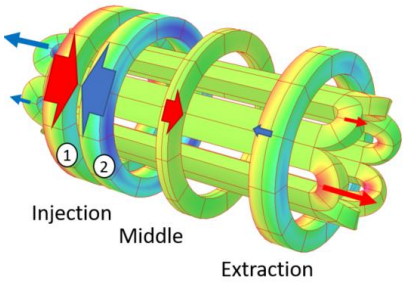
NbTi MARS



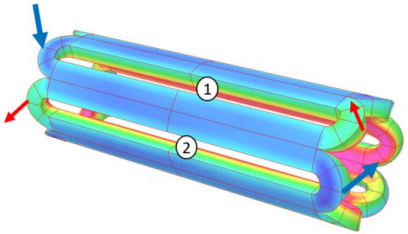
Magnetic Forces FECR 45 GHz

Lorentz forces: Coil ends and solenoids

Axial forces



Radial forces



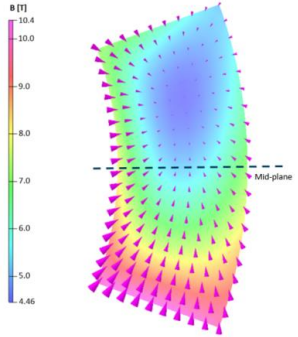
Solenoid forces

Coil	Fz [kN]
Inj 1	+1749.0
Inj 2	-1994.3
Mid	+165.6
Ext	-8.6
Total	**-88.4**

Sextupole coil-end forces

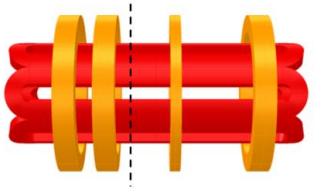
	Fr [kN]	Fz [kN]	Fr [kN]	Fz [kN]
	Extraction side		Injection side	
Sextupole 1	+99.7	+49.4	-105.9	-166.2
Sextupole 2	-121.7	+165.8	+88.4	-55.3

Lorentz forces: Sextupole coil straight section



Forces in the cross-section
(30 mm from injection solenoid face)

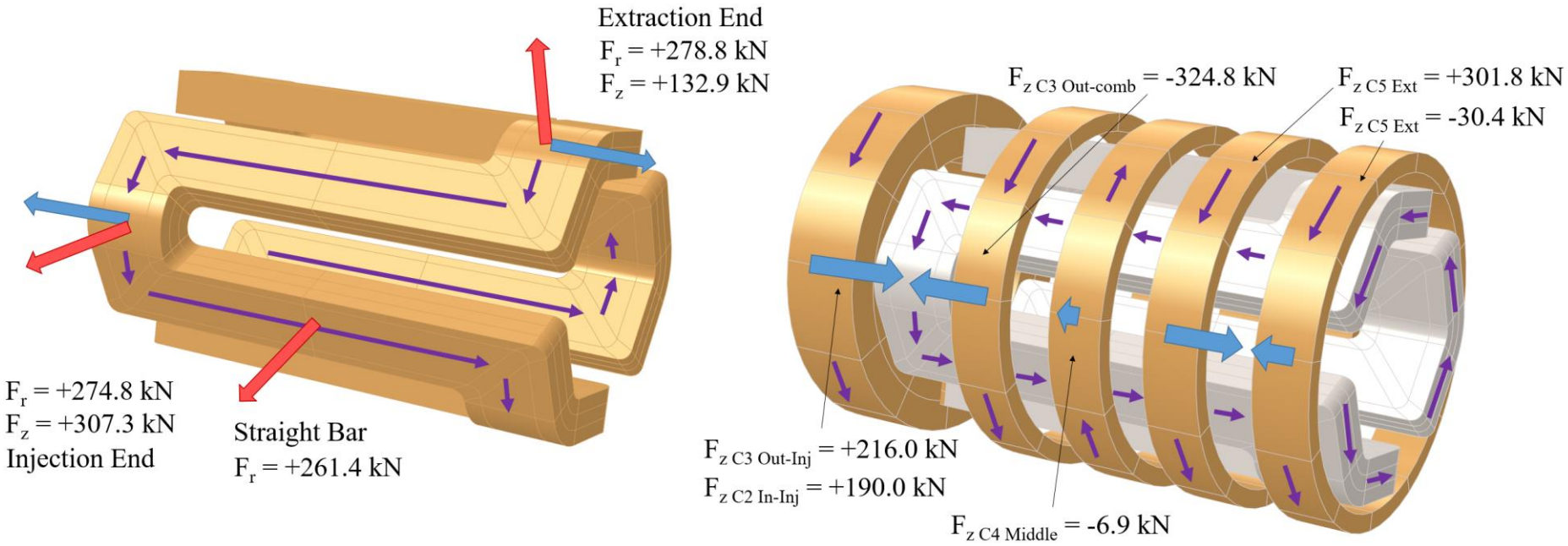
	Fx [kN/m]	Fy [kN/m]
Upper coil	366	-116
Lower coil	744	2701
Total	1113	2585



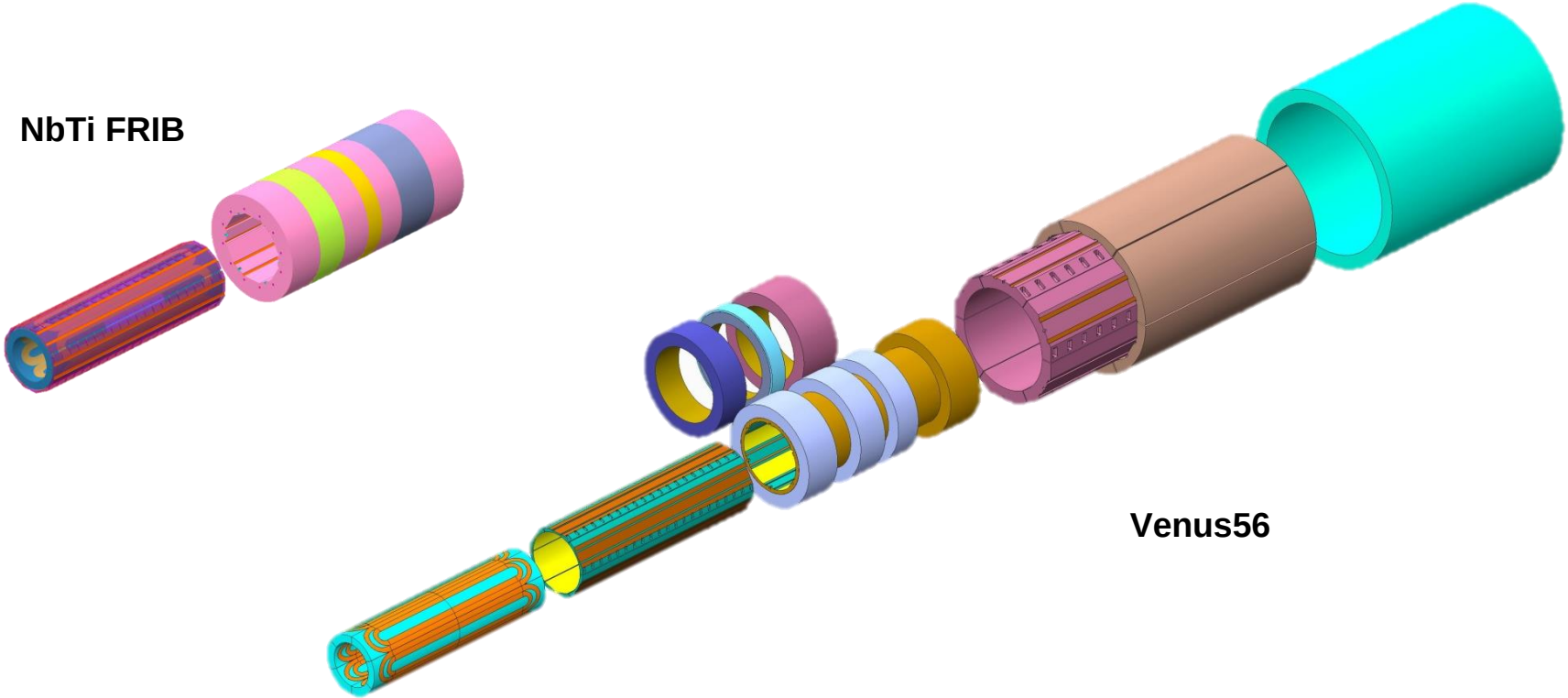
Integrated forces in the straight section

	Fx [kN]	Fy [kN]
Upper coil	421	-1057
Lower coil	406	994

Magnetic forces MARS-D



Design of other ECR magnets



FECR 45 GHz
IMP (Lanzhou, China)

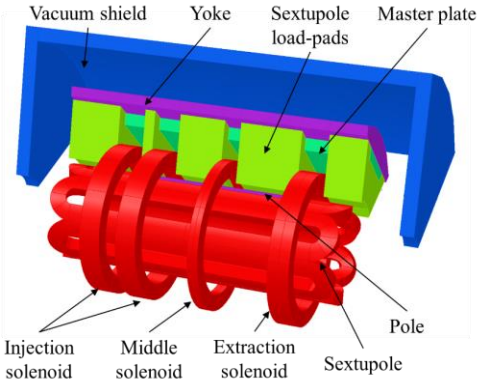
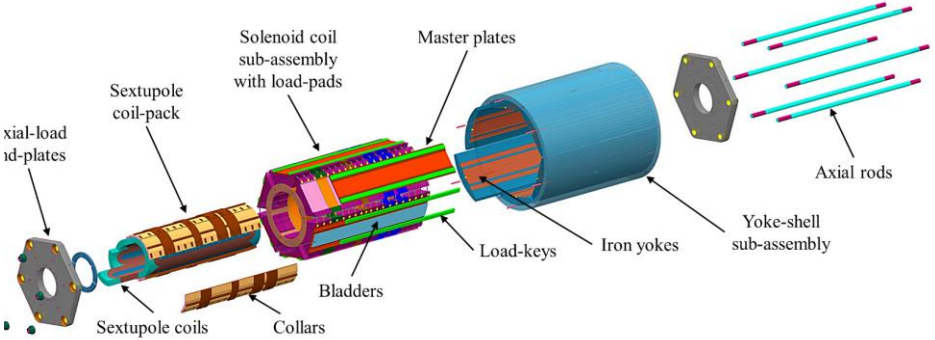


Figure 5: Picture of completed FECR 1/2 size prototype cold mass ready for test.

L. Sun, et. al. "FECR ION SOURCE DEVELOPMENT AND CHALLENGES"



Magnetic Parameters of the System

Parameter	Unit	Value
Microwave frequency, f_{rf}	GHz	45
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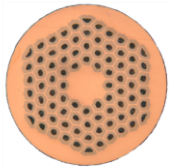
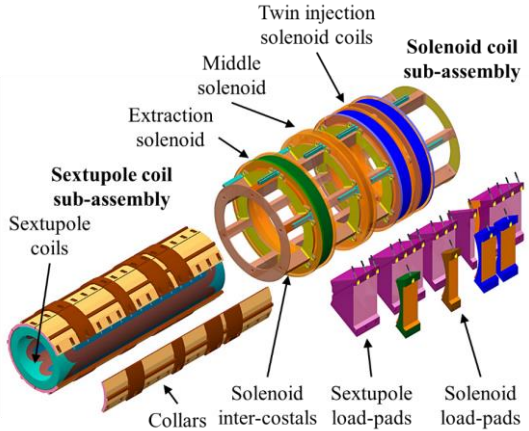
Mirror length	mm	500
Plasma chamber ID	mm	150
Warm bore ID	mm	170

Conductor Parameters

Parameter	Unit	Value
Critical current density at 4.2 K, 12 T	kAmm^{-2}	2.4
Wire diameter	mm	1.3
Copper/non-Copper ratio	-	0.96
RRR of the copper matrix	-	250
Filament twist pitch	mm	42
Insulation thickness	μm	65

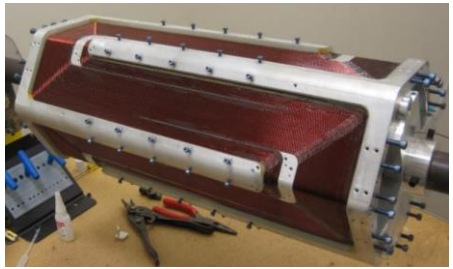


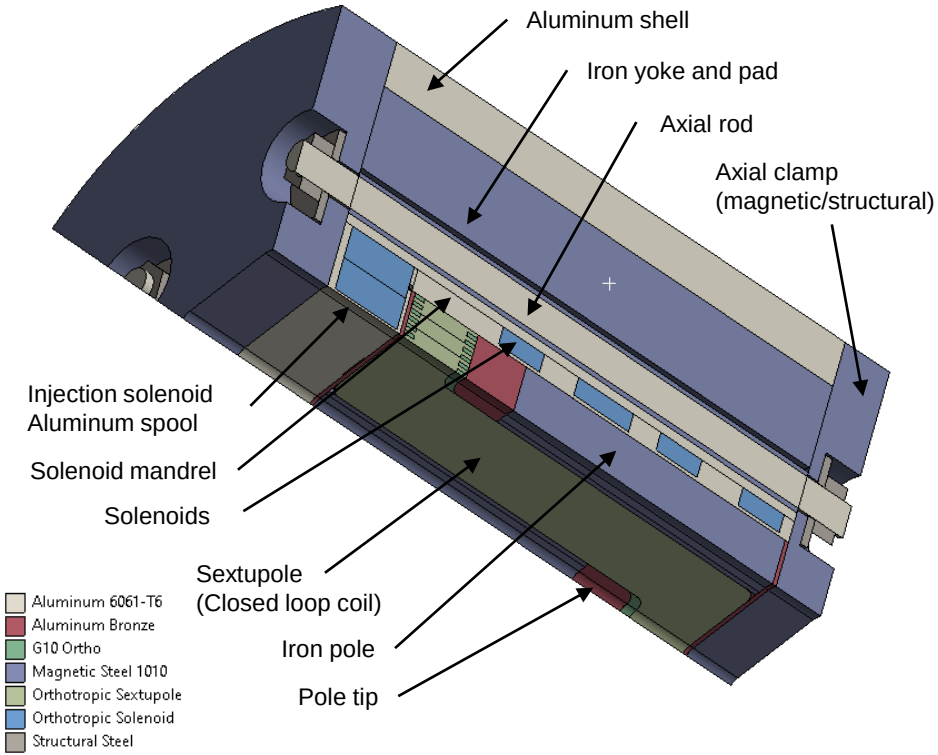


MARS-D 45 GHz

Main Parameters	
Microwave frequency f_{rf}	45 GHz
Resonant heating field B_{ECR}	1.6 T
Injection confinement field B_{inj}	5.7 T
Extraction confinement B_{extr}	3.4 T
Radial confinement field B_{rad}	3.1 T
Stored energy E	560 kJ

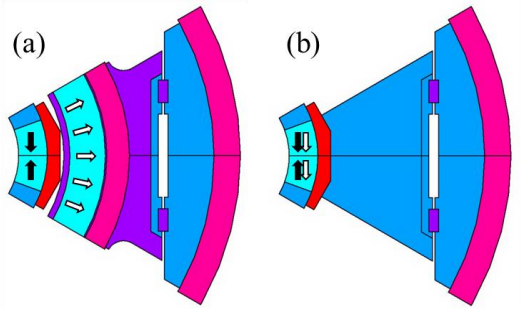
Rectangular NbTi wire	
Bare wire	1.84 mm x 1.16 mm
Cu/Sc	~1.3
RRR	99
Twist	58 mm
Insulation	35 um

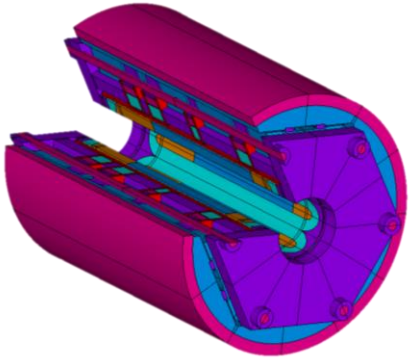




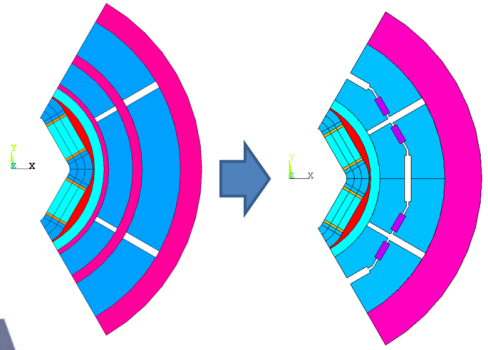
Mechanical models

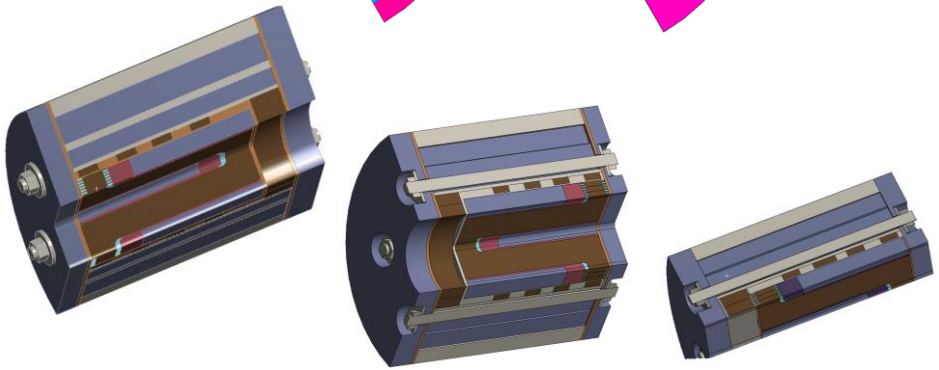
Nb_3Sn FECR





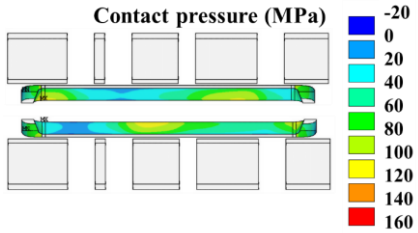
NbTi MARS

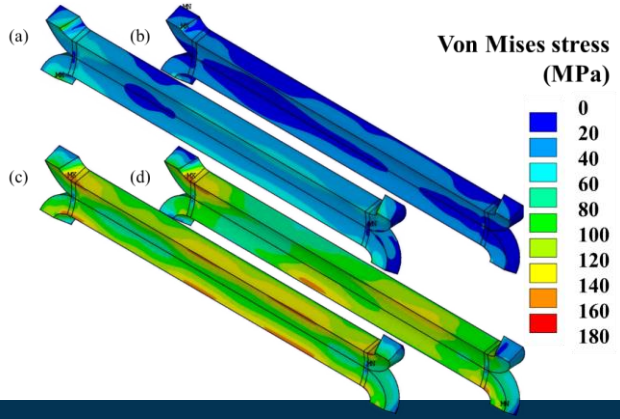




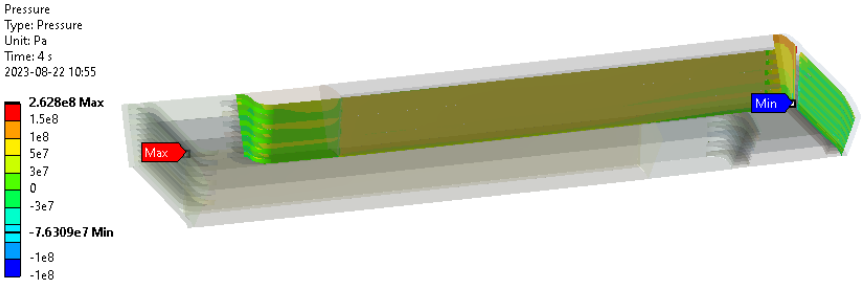
Stress in the superconductor

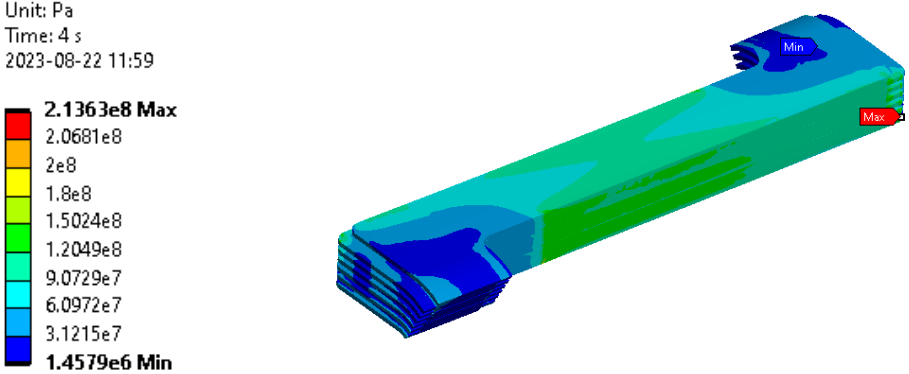
Nb_3Sn FECR



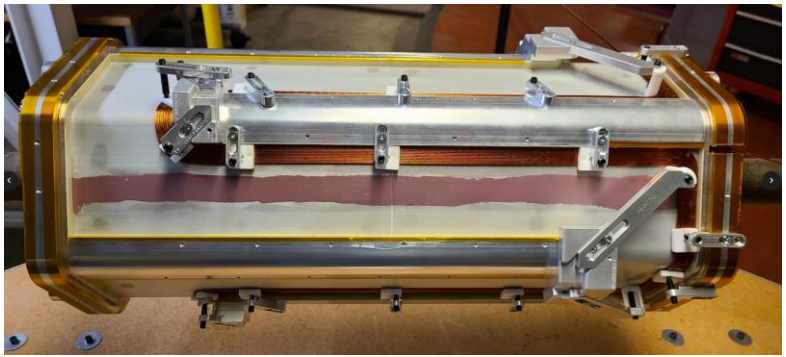


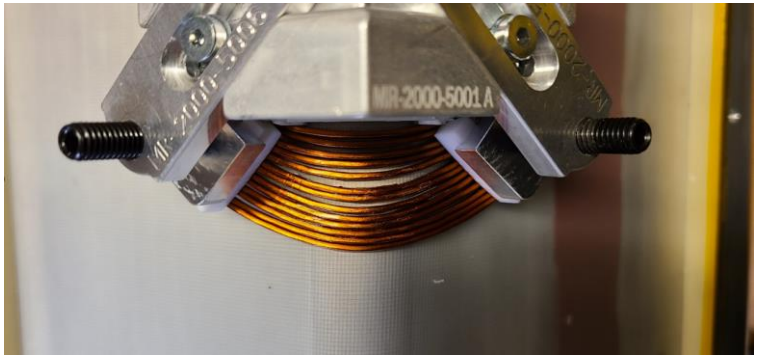
NbTi MARS

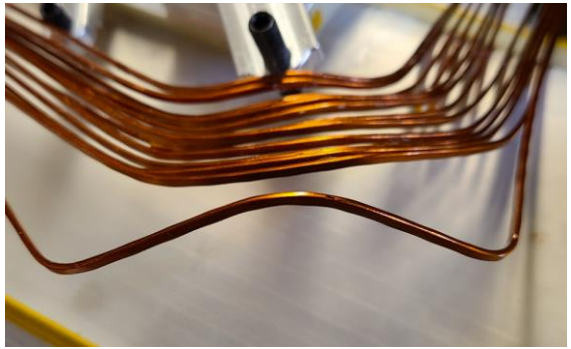


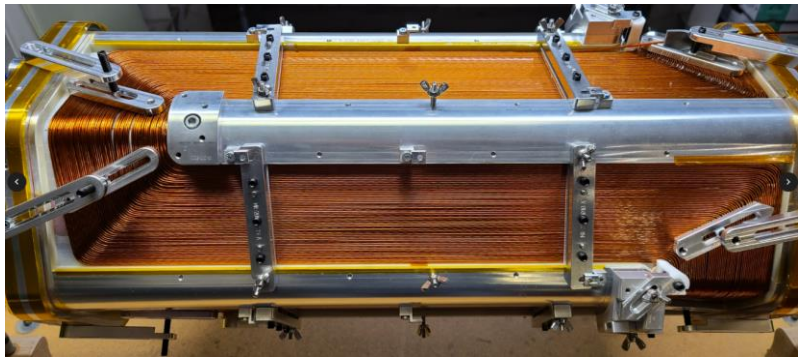


MARS Winding

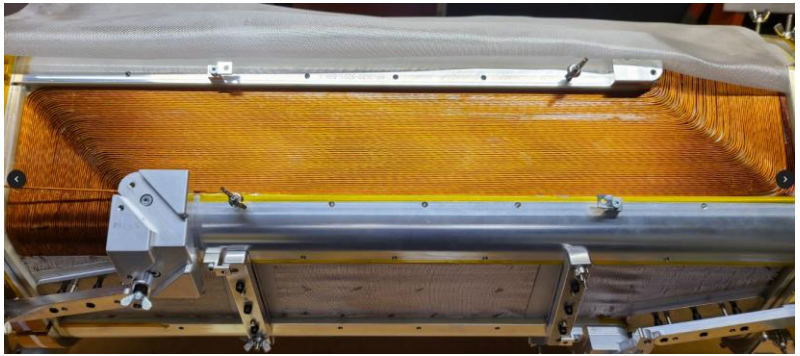


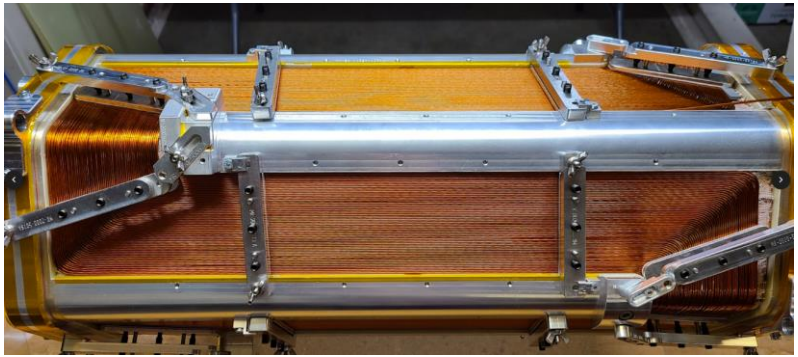


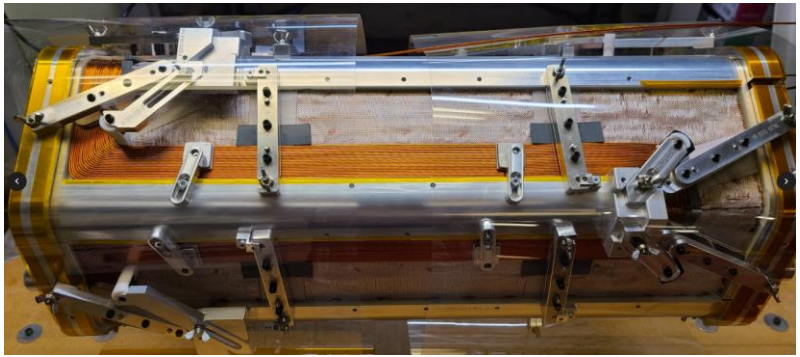




MARS Winding







- 52 turns per layer
- 2 weeks per layer
- 24 layers in total
- Up to 12 months for winding

Tradeoffs

Nb3Sn FECR

- Brittle superconductor
- Wind and react process
- Conductor efficiency (and price)
- Stored energy

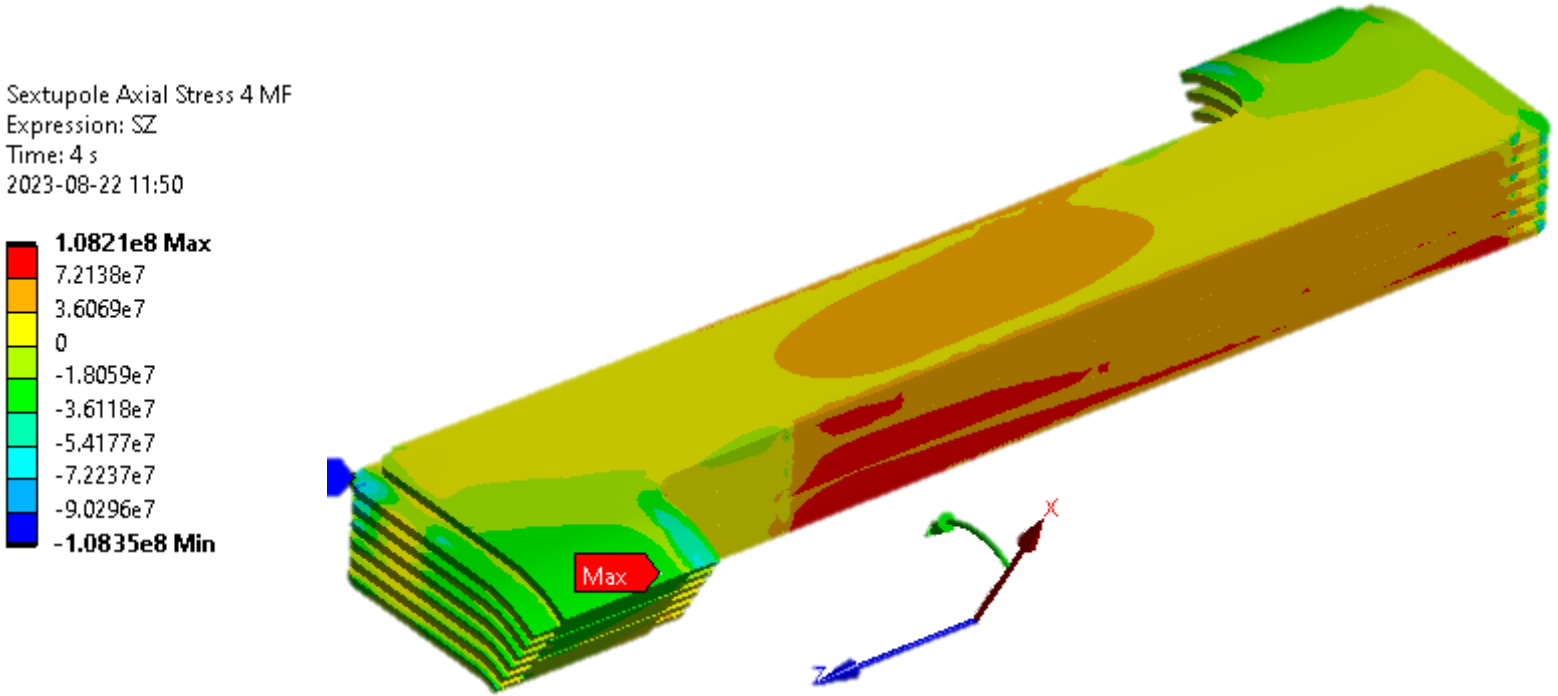
NbTi MARS

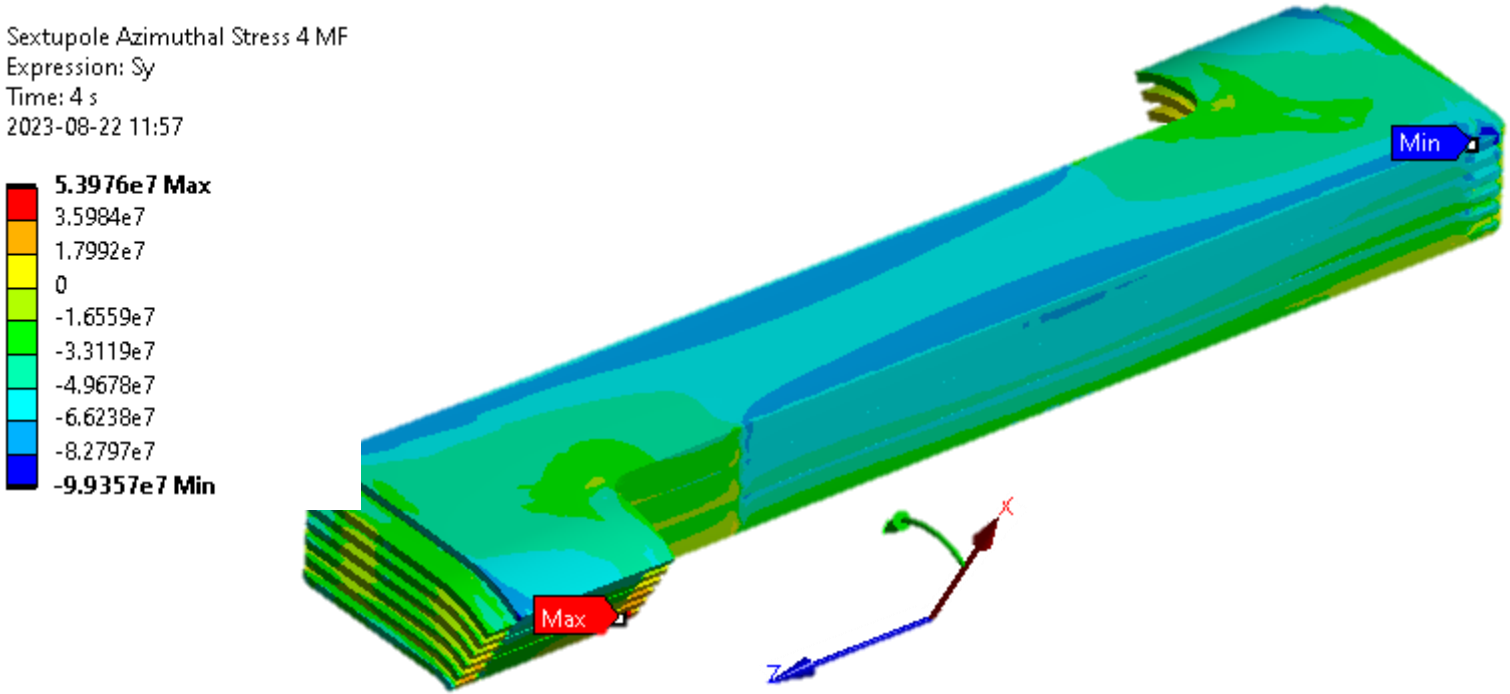
- Low current and temperature margins
- Mutual inductance and quench protection
- **Winding**

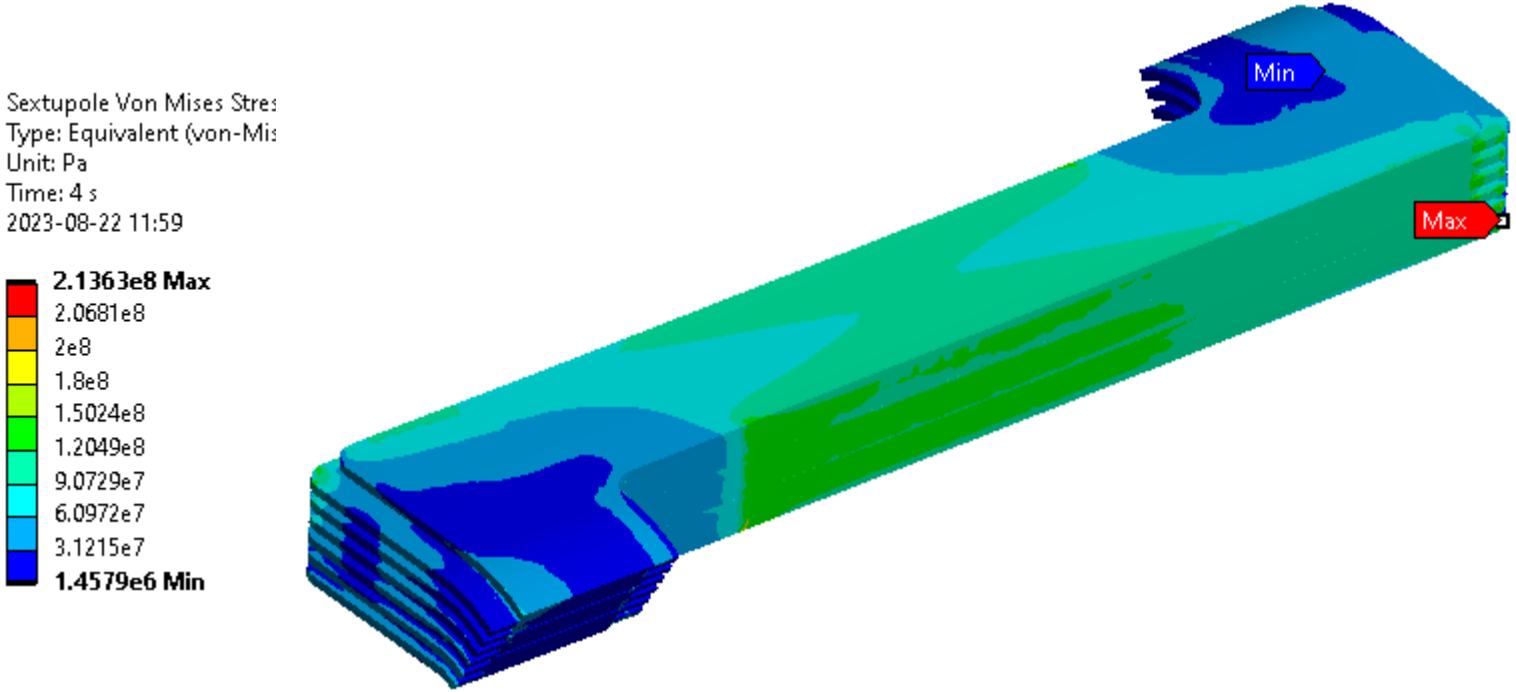
Future?

- Material
  - HTS – higher field, higher temperature margin, no requirement on the field quality
- Conductor
  - Tape or cable vs wire
- Stress Management
  - SM-MARS or CCT
- Support Structure
  - Bladder and key

Thank you!


Sextupole Axial Stress 4 MF
Expression: SZ
Time: 4 s
2023-08-22 11:50
1.0821e8 Max
7.2138e7
3.6069e7
0
-1.8059e7
-3.6118e7
-5.4177e7
-7.2237e7
-9.0296e7
-1.0835e8 Min
Max
X
Z


Sextupole Azimuthal Stress 4 MF
Expression: Sy
Time: 4 s
2023-08-22 11:57
5.3976e7 Max
3.5984e7
1.7992e7
0
-1.6559e7
-3.3119e7
-4.9678e7
-6.6238e7
-8.2797e7
-9.9357e7 Min
Min
Max
X
Z


Sextupole Von Mises Stres
Type: Equivalent (von-Mis
Unit: Pa
Time: 4 s
2023-08-22 11:59
2.1363e8 Max
2.0681e8
2e8
1.8e8
1.5024e8
1.2049e8
9.0729e7
6.0972e7
3.1215e7
1.4579e6 Min
Min
Max