21Q40 Narrow Quadrupole PDR

Mechanical design

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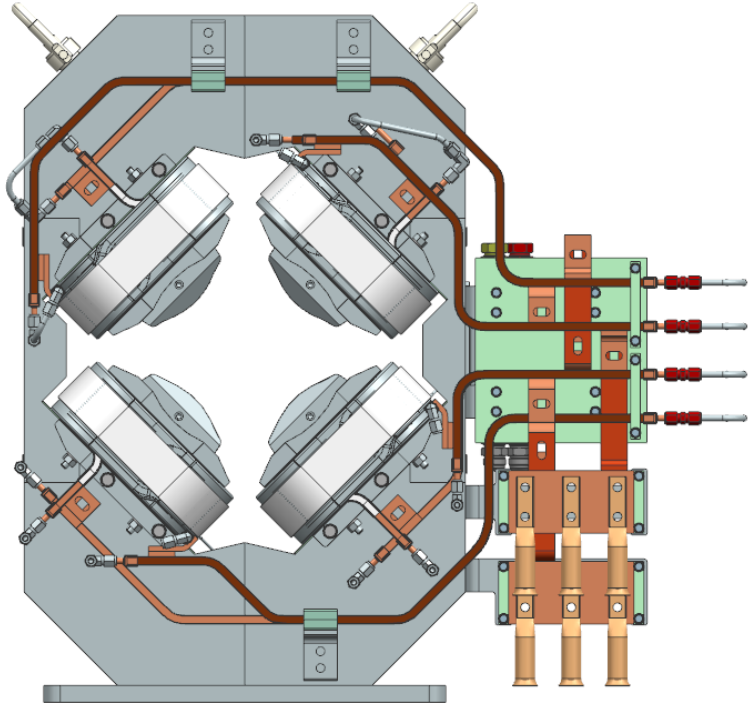
16 April 2024

Outline

- Parameters of quadrupole
- Stages of quadrupole assembly
- Tooling and assembly features
- Electrical and water connection
- Stand interface
- Summary



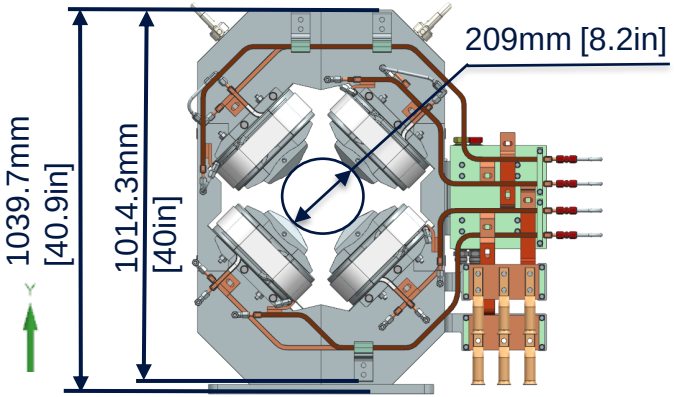
Parameter list

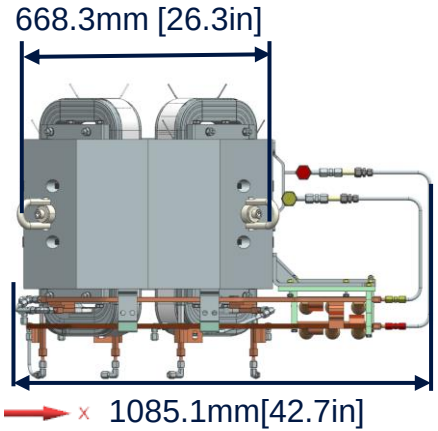
Magnetic field

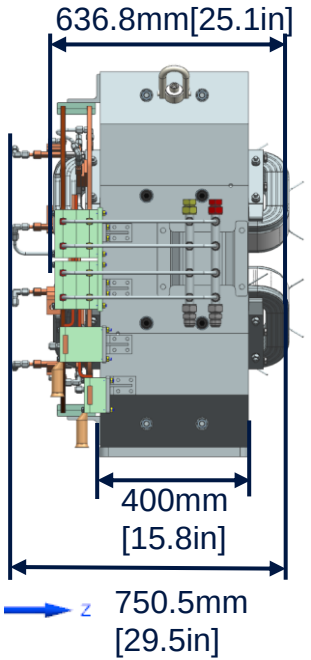
Parameters	Value	Units
Magnetic field	2.938	T
Gradient	5.825	T/m
Integrated field	2.956	T-m/T
Coil amper-turns	27.4	kA

Iron Yoke

Parameters	Value	Units
Aperture	209 8.2	Mm In
Width	668.3 26.4	mm In
Height	1014.3 40	mm In
Length	400 15.8	mm In







Total weight ~ 1706 kg
[3761 lbs.]

Fermilab

Parameter list for cooling system

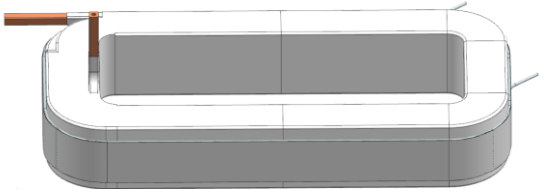
Cooling system

Parameters	Value	Units
Number of coils	4	Quant ity
Parallel branch	4	Quant ity
Number of turns in one parallel branch	28	Quant ity
Copper conductor	0.25x0.25 12.7x12.7	In mm
Diameter of the hole in the conductor	0.25 6.35	In mm
Conductor cross-sectional	0.198 127.7	Sq.inch mm²
Nominal input temperature	30 86	° C ° F
Overheating	77.9612 [24.534]	° C ° F

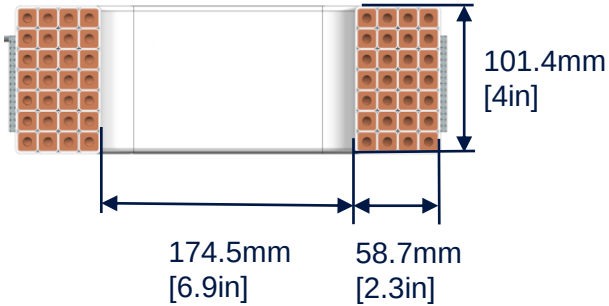
Electrical power (one coil)

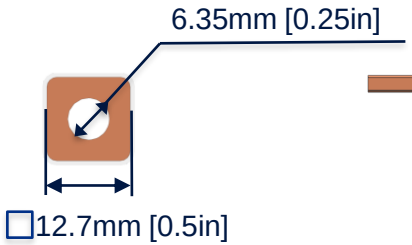
Parameters	Value	Units
Current	978	A
Power losses	5.562	kW
Electrical resistance	0.006	Ohm
Current density	7.65	Amps/ mm²
Voltage drop	5.87	Volt

Coil – 50 kg [110 lbs.]

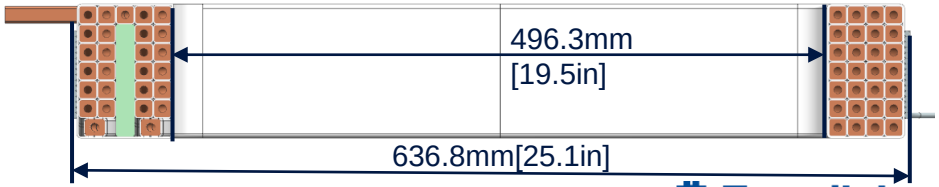


Front cross-section of the coil



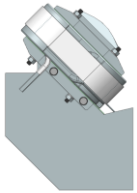


Side cross section of the coil

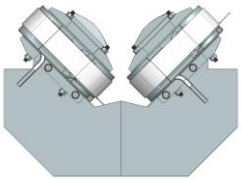


Fermilab

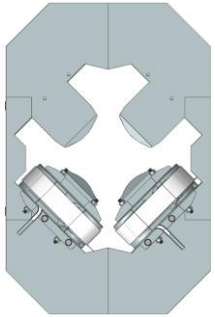
Stages of quadrupole assembly



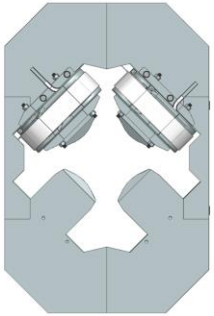
Installing the coil



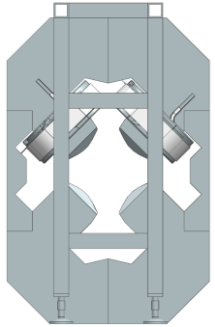
Half assembly



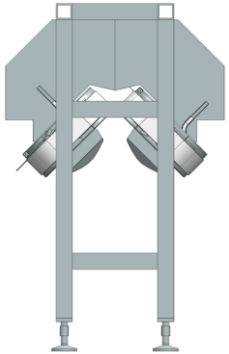
Assembly to perform rotation



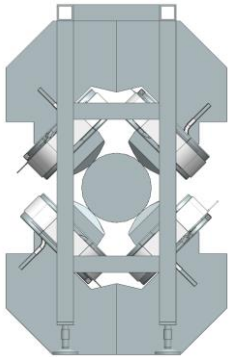
Rotation



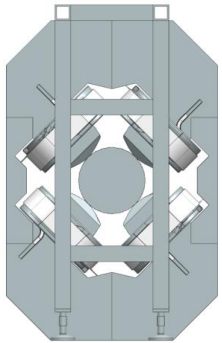
Installation of tooling



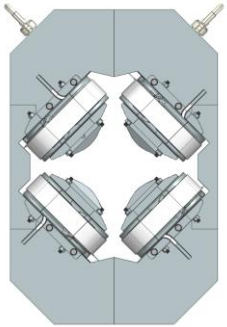
Disassembly



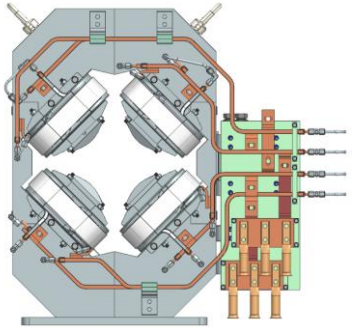
Positioning



Installation of side plates



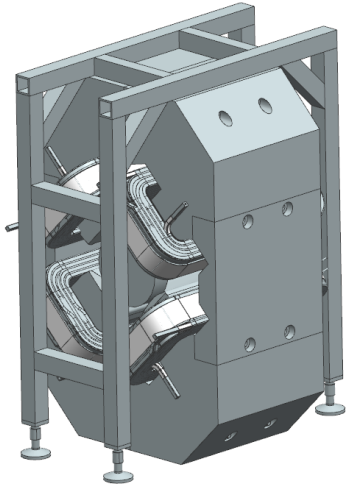
Dismantling the tooling

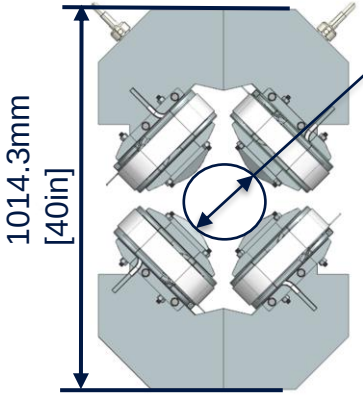


Installation of attachments equipment

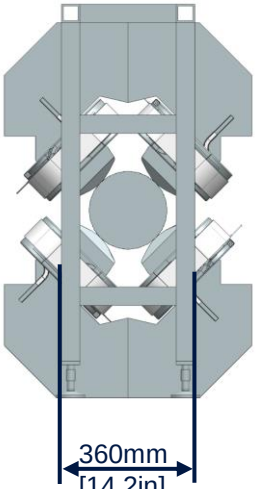
Fermilab

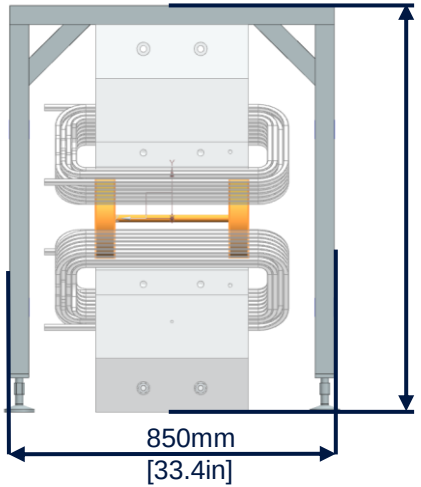
Tooling for assemble



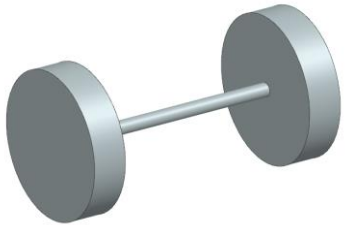


Half assembly
weight ~ 802 kg
[1768 lbs.]





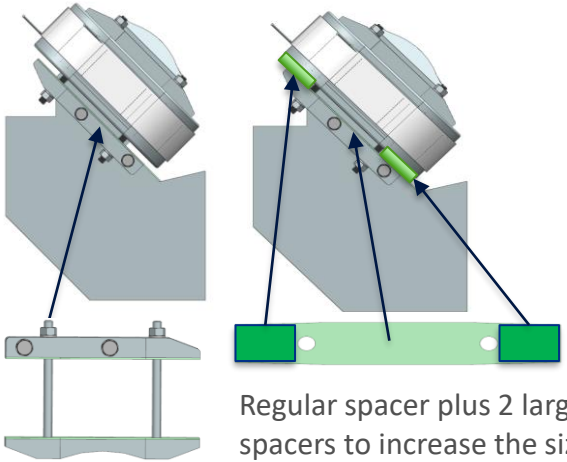
- The special tooling can be used to assemble or disassemble the magnet
- The welded structure made from a square profile must withstand a weight of 802 kilograms[1768 lbs.]



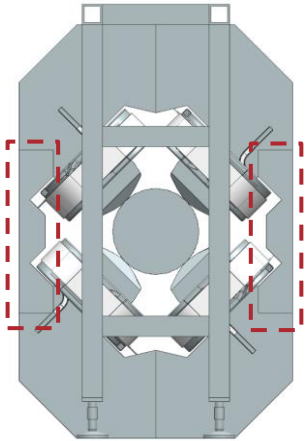
tooling for aligning half-assemblies with each other

Fermilab

Installing the coil

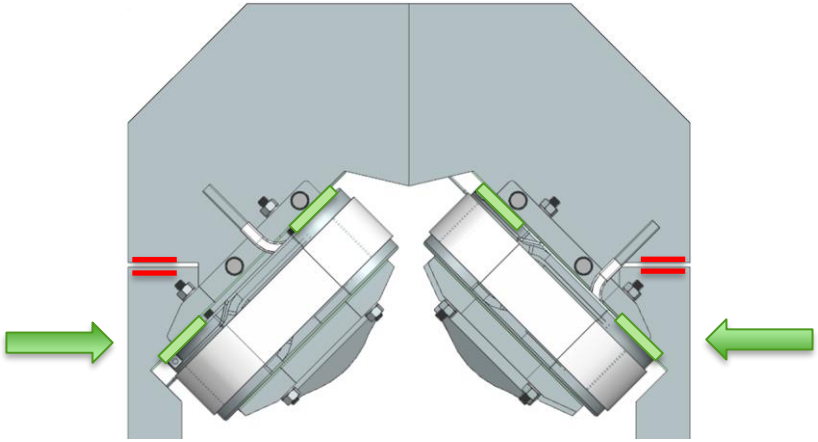


Regular spacer plus 2 larger spacers to increase the size between the coil and the core

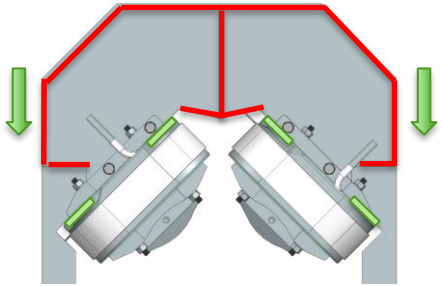


Installation of side plates

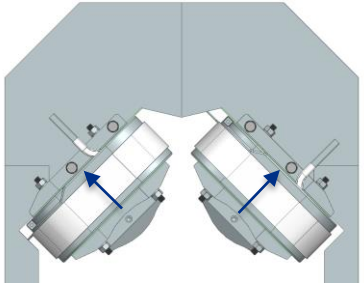
Supporting tooling is not shown



Obtaining the required clearance for installing side plates



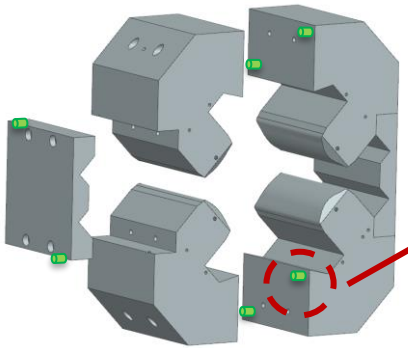
Installation of the upper half-core and its fastening



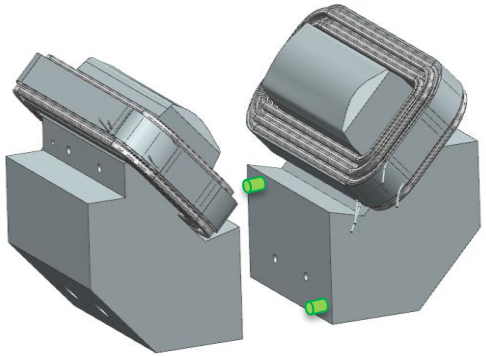
Removing the spacer and tightening the coils

Fermilab

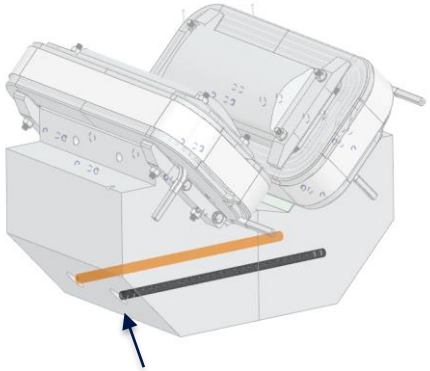
Pinning scheme



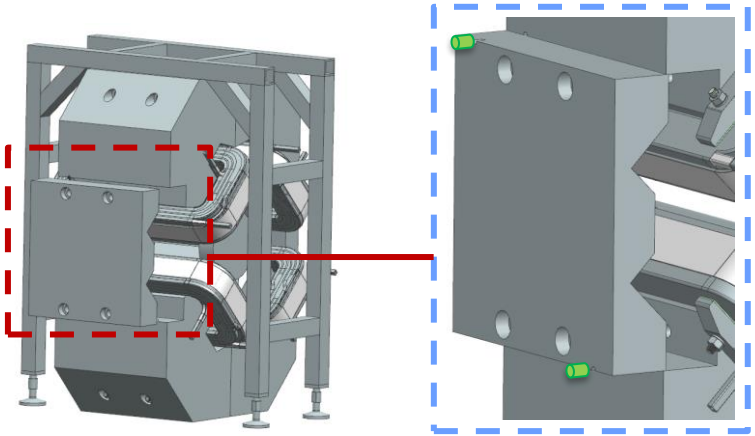
Pins layout scheme

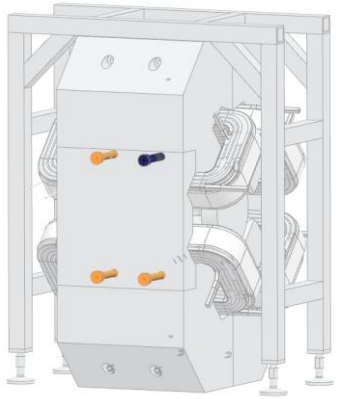


Half assembly

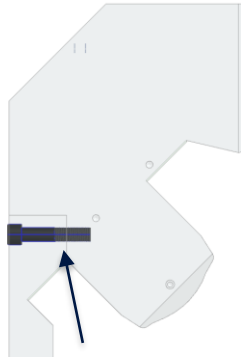


THREADED RODS M16
CLASS12.9





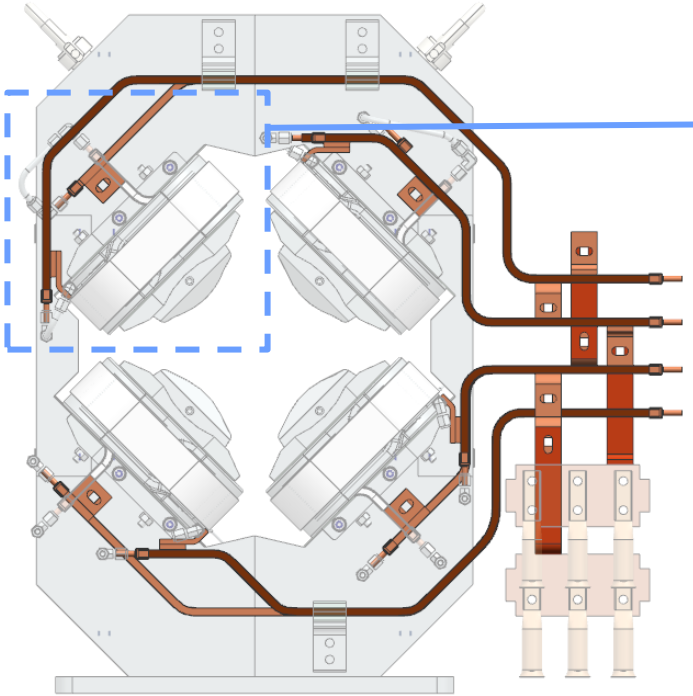
Installation of side plates

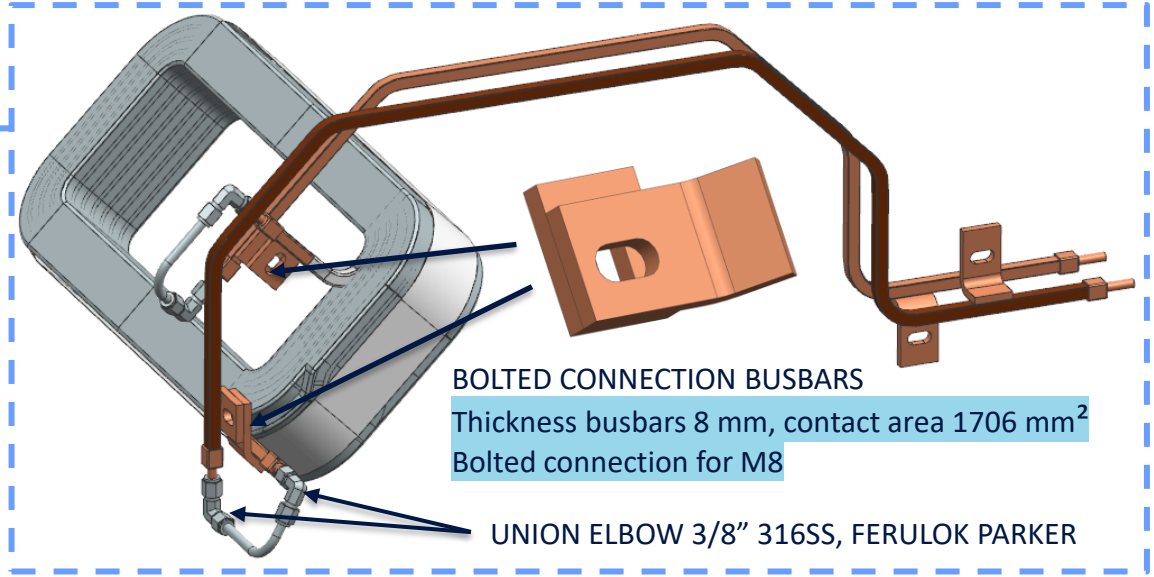


BOLTS M20 CLASS12.9

Fermilab

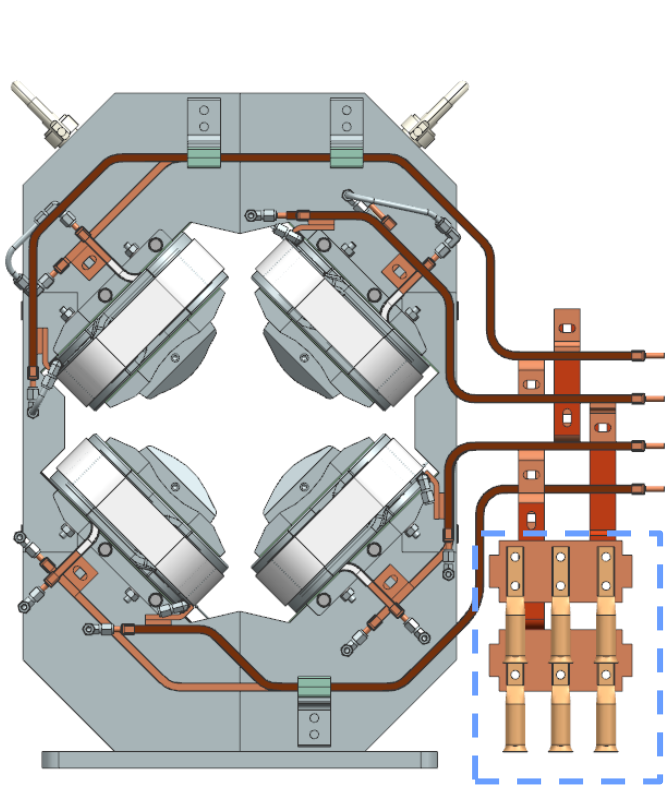
Electrical and water connection

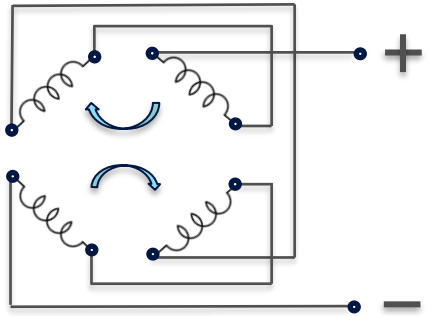




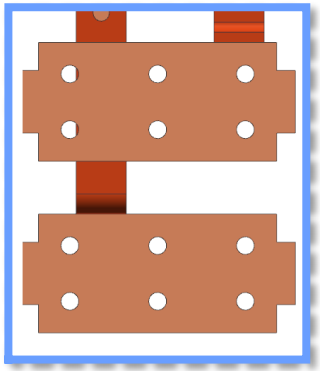
- Each coil is a parallel branch
- All coils have detachable connections for water and electricity

Power flags

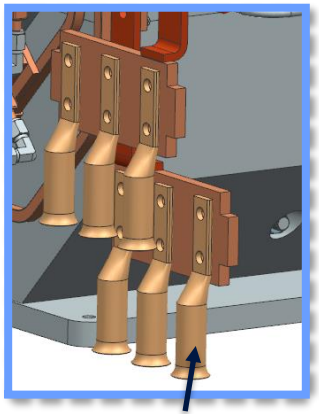




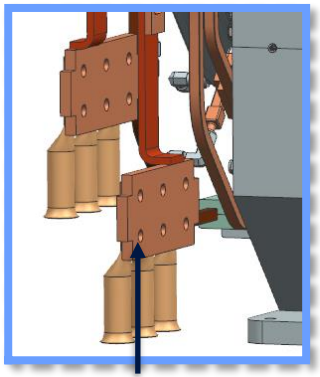
- Electrical diagram



- Thickness busbars 12.7 mm
- Contact area 18588 mm²
- Bolted connection for M12



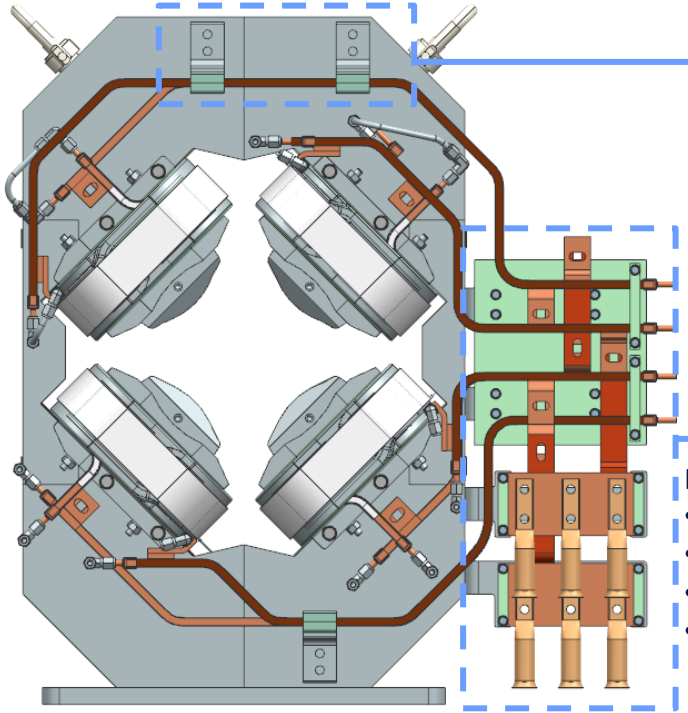
COMPRESSION LUG,2 HOLES, LSSSF500-12-6

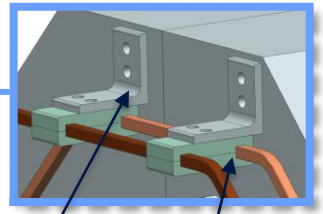


POWER FLAG, NARROW QUAD,ORNL STS

Fermilab

Support and clamping structure





SUPPORT ARM,
BUS CLAMP

CLAMP HALF,
BUS CLAMP

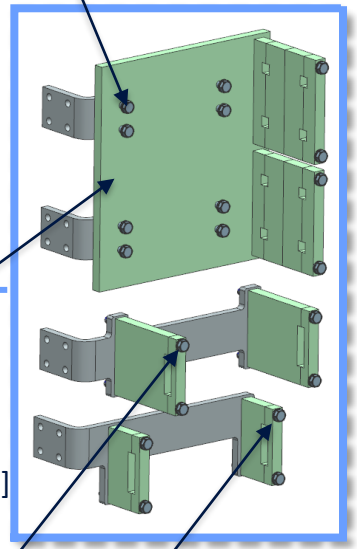
PLATE, BUS SUPPORT
- Material- G-10
- Length - 260mm[10.2in]
- Width – 280mm[11in]
- Thickness – 12.7mm[0.5in]

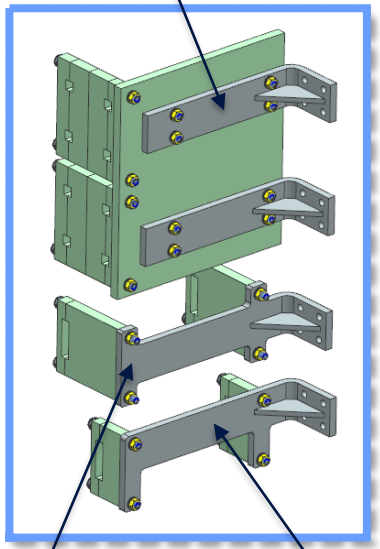
Material all CLAMPS is G-10

Brackets and flag support
- Material- SST 316
- Thickness of 10 mm [0.4in]

HHCS, M8X1.25X40

WELDMENT, BUS BRACKET





HHCS, M8X1.25X140

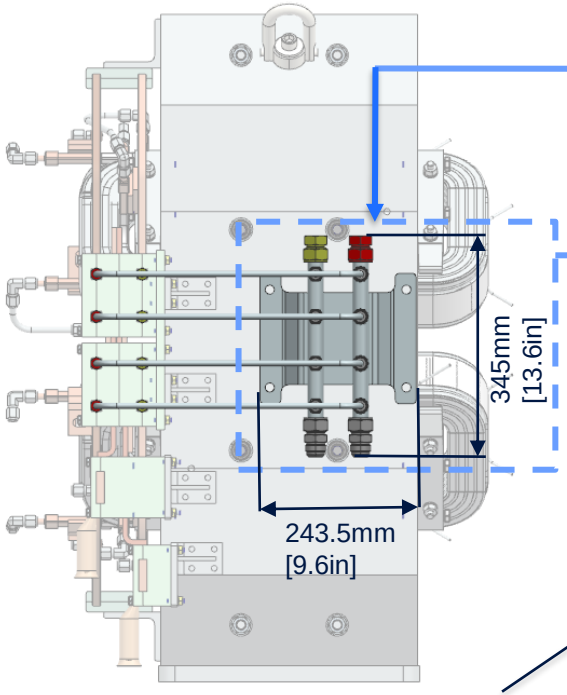
HHCS, M8X1.25X80

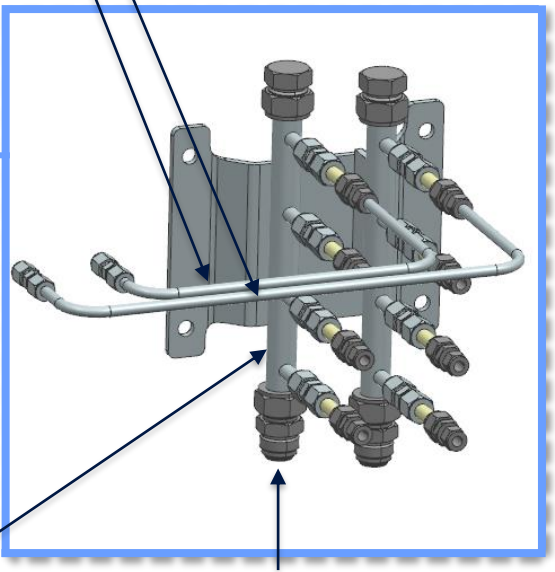
WELDMENT, FLAG SUPPORT UPPER

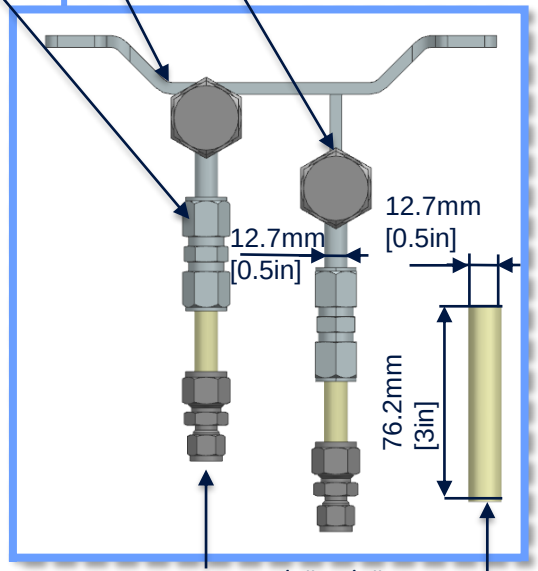
WELDMENT, FLAG SUPPORT LOWER

Fermilab

Manifolds assembly







TUBE, SUPLY TO MANIFOLD,
TUBE, RETURN TO MANIFOLD
OD 9.5 [0.38in], ID 7[0.3in]

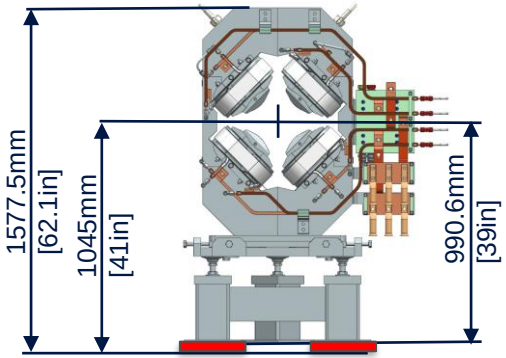
UNION 1/2”x1/2” SS, FERULOK FLARELESS PARKER
BRACKET, MANIFOLD SS316
Thickness 6.35mm[0.25in]
CAP, 1" OD TUBING, SS316

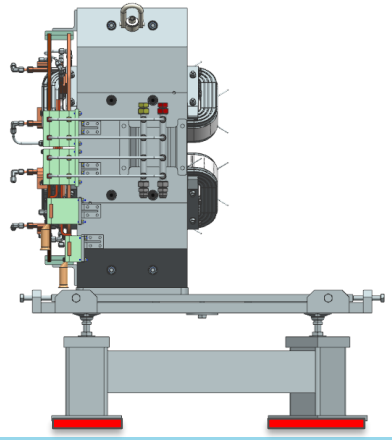
PIPE SS316
Length - 305mm[12in]; OD – 25.4mm[1in];ID – 19.9mm[0.8in]

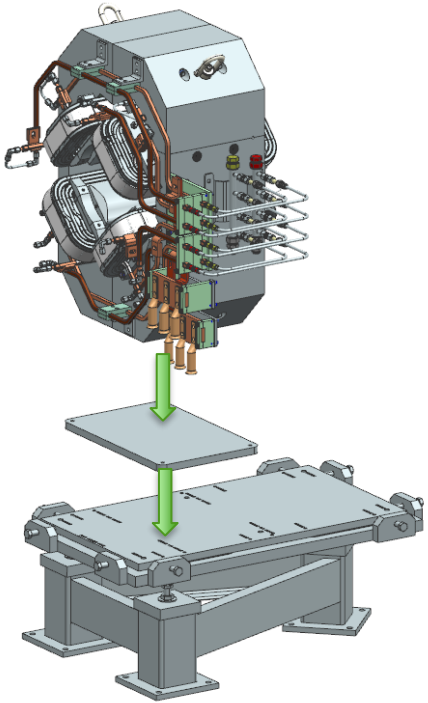
UNION, 1" TUBE OD X 1" AN TUBE FLARE, SS316

REDUCING UNION, 1/2”x3/8”SS316, PARKER A-LOK
INSULATOR, MANIFOLD, PPU MAGNETS, PEEK, GLASS

Stand interface

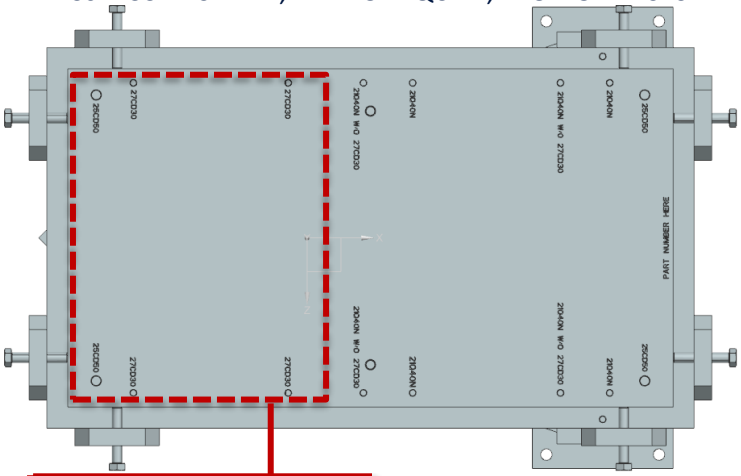






- MOUNTING ELEMENTS
[54.4mm or 2.14in]

FC0123314-STAND, NARROW QUAD, FROMORNL STS



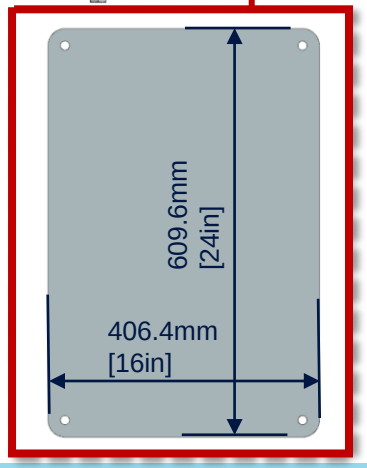


PLATE MAGNET BASE,
Material –SS304
Mass - 50kg [110lb]
Thickness- 25.4mm[1in]

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Summary

- The CAD-model is 80% complete
- The scheme for the assembly of the core and coils has been considered
- Developed a method for connecting coils
- The design of power buses and the manifold is designed to meet the considered of "RTST Extraction Magnet Requirements".
- Design criteria and design parameters are defined
- The project is feasible

21Q40 Narrow Quadrupole PDR

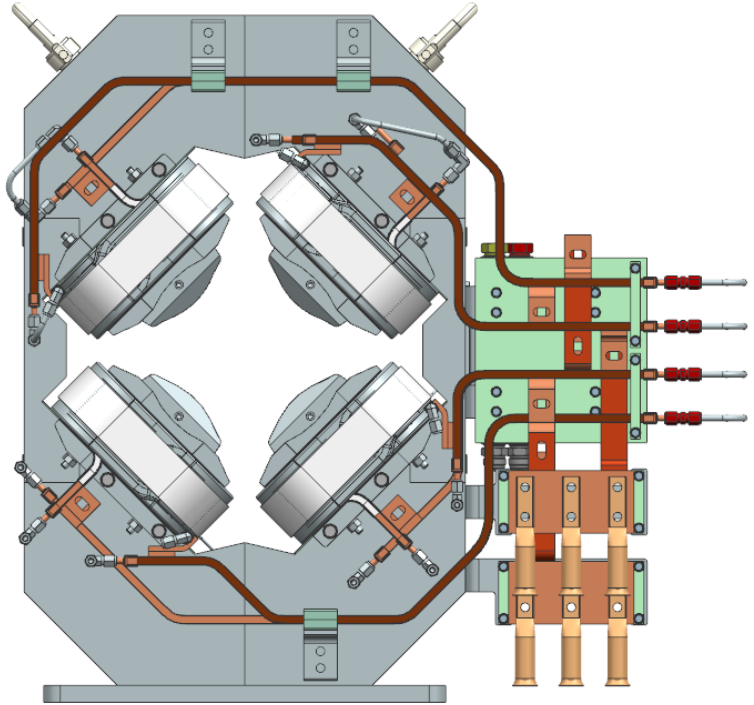
Compliance with Specification

Vitaly Chernenok

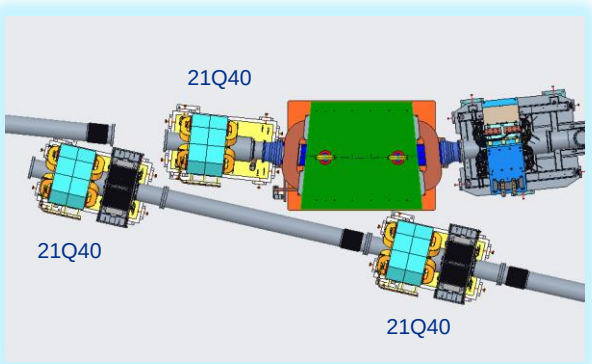
16 April 2024

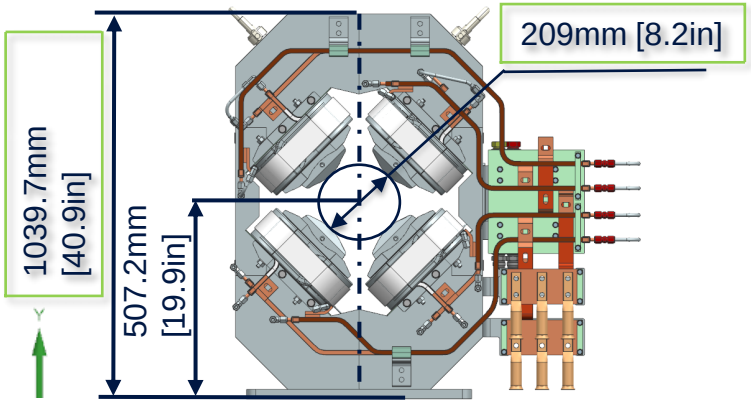
Outline

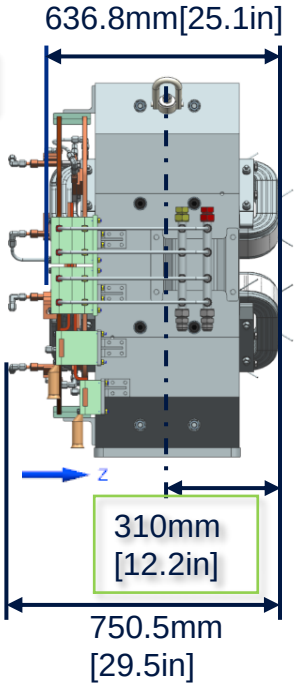
- Geometric dimensions
- Parameter list for cooling system
- Temperature switch
- Grounding and fiducials
- Power flags
- Summary

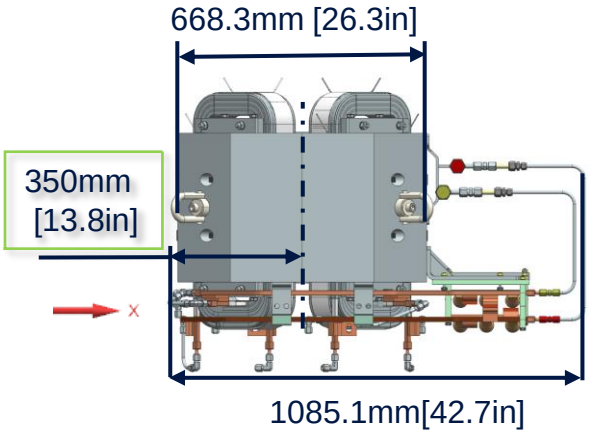


Overall dimensions









ID	Requirements	Traceability [13]
S02.04-R061	The Narrow 21Q40 Quadrupole magnet assembly shall have an aperture ≥ 20.9 cm (8.2 in) diameter.	S02-R006 S02-R009
S02.04-R062	The Narrow 21Q40 Quadrupoles magnet assembly shall fit into a volume such that X ≤ 0.70, Y ≤ 1.10, Z ≤ 0.64 meters Discussion: To avoid interference between the RTST and the RTBT magnets. X is width, Y is height, and Z is along beam axis	S02-R003 S02-R007 S02-R006

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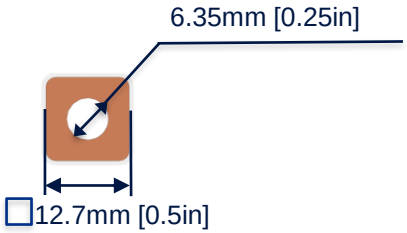
Parameter list for cooling system

ID	Requirement	Traceability [13]
S02.04 -R002	Water-cooled extraction magnet coils should be designed for a current density < 450 Amps/cm2. The current density shall not exceed 1000 Amps/cm².	S02-R004
S02.04 -R024	Each extraction magnet coil shall be made from a single length of conductor. Discussion: This is to avoid splices inside the coil.	S02-R004
S02.04 -R024	The water-cooled extraction magnet coils shall meet the requirements of Specification for Radiation Resistant Fiberglass/Epoxy Insulated Magnet Coils [4]. Discussion: This includes silver plating, hydrostatic test to 300 psi, turn-to-turn insulation test.	S02-R004
S02.04 -R016	Unless otherwise stated, the assembled extraction magnet shall withstand 1000 V DC for one minute between the coil leads and the magnet core without evidence of insulation damage or breakdown, or leakage current > 5 μA.	S02-R004

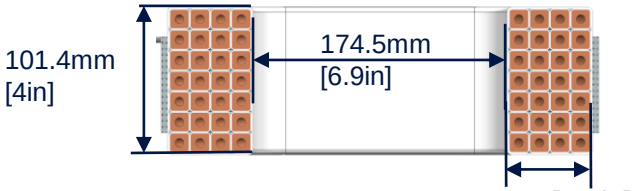


Conductor cross-sectional
127.7 mm² [0.198 Sq.inch]

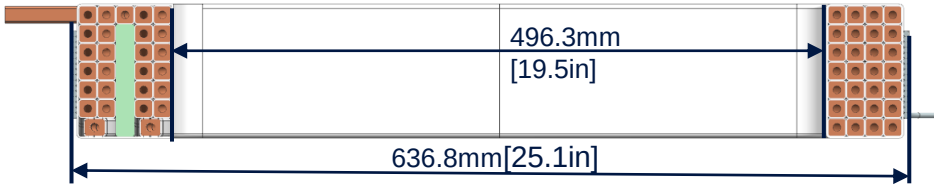
Electrical power (one coil)

Parameters	Value	Units
Current	978	A
Power losses	5.562	kW
Electrical resistance	0.006	Ohm
Current density	765	Amps/cm²
Voltage drop	5.87	Volt

Front cross section of the coil



Side cross section of the coil



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Parameter list for cooling system

ID	Requirement	Traceability [13]
S02.04-R004	Water-cooled extraction magnet coils should be designed to have a temperature rise < 20° C (36° F) at the maximum power supply current with an inlet water temperature between 29.4° C (85° F) and 35.0° C (95° F). Discussion: Desired maximum temperature rise is 11-14° C (20-25° F)	Design Requirement
S02.04-R005	Water-cooled extraction magnet coils should be designed for a water flow velocity < 2 m/s (6.56 ft/s). The water flow velocity shall not exceed 2.4 m/s (8 ft/s). Discussion: From Review of Cooling Water Chemistry at ORNL/SNS [2], "High local water velocities (> 2m/s) … would cause accelerated dissolution of the oxide layer, possibly causing local material loss and increased copper transport. Also need to ensure that the water flow is moderately turbulent (2000 ≤ Re ≤ 100000)."	S02-R004
S02.04-R006	The cooling water pressure differential across the extraction magnets shall not exceed 60 psi (414 kPa) to meet requirement S02.04-R004. Discussion: This is to support a Cooling Water System design pressure ≤ 150 psi. The desired pressure differential is between 30 and 50 psi.	Design Requirement
S02.04-R015	For water-cooled extraction magnets, the assembled magnet shall withstand 300 psi (2068 kPa) hydrostatic (water) test pressure for one hour without evidence of external leakage or internal pressure drop other than that resulting from a change in water temperature. Discussion: 300 psi is 2 x the max targeted water pressure in the SNS water system.	S02-R006

Cooling system

Parameters	Value	Units
Parallel branch	4	Quantity
Number of turns in one parallel branch	28	Quantity
Copper conductor	0.25x0.25 12.7x12.7	In mm
Diameter of the hole in the conductor	0.25 6.35	In mm
Conductor cross-sectional	0.198 127.7	Sq.inch mm²
Nominal input temperature	30 86	° C ° F
Water pressure drop	58 405.3	psi kPa
Total water flow	0.054	l/s
Water velocity	1.71	m/s
Overheating	77.9612 24.534	° F ° C

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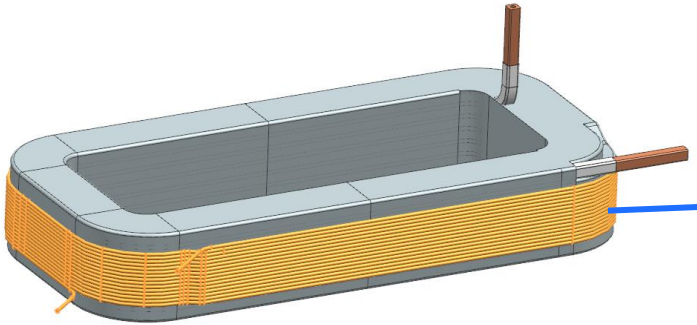
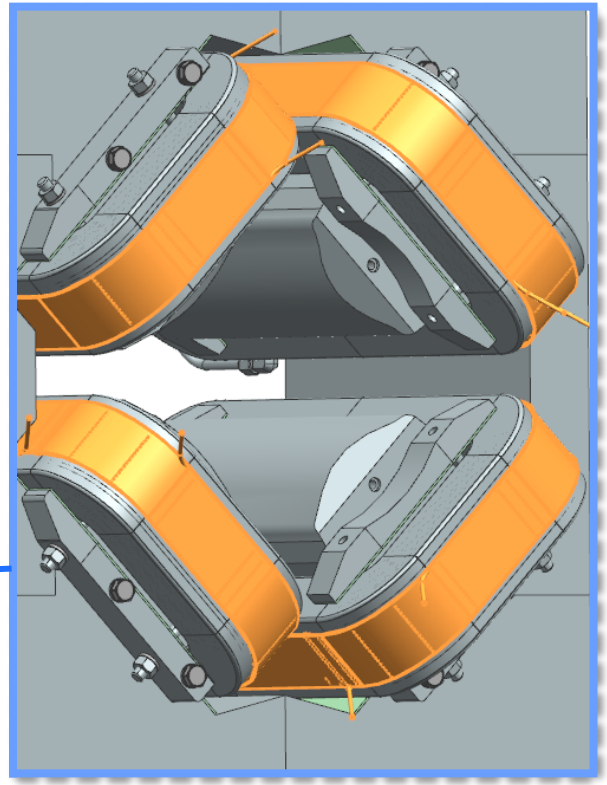
Trim coils

ID	Requirement	Traceability [13]
S02.04 -R057	The Narrow 21Q40 Quadrupole magnet assembly shall have a trim coil wound on each main coil with an integrated quadrupole field of 0.0284 T. Discussion: The Narrow Quad trim coil will have the same field as the existing 21Q40 trim [1].	S02-R007

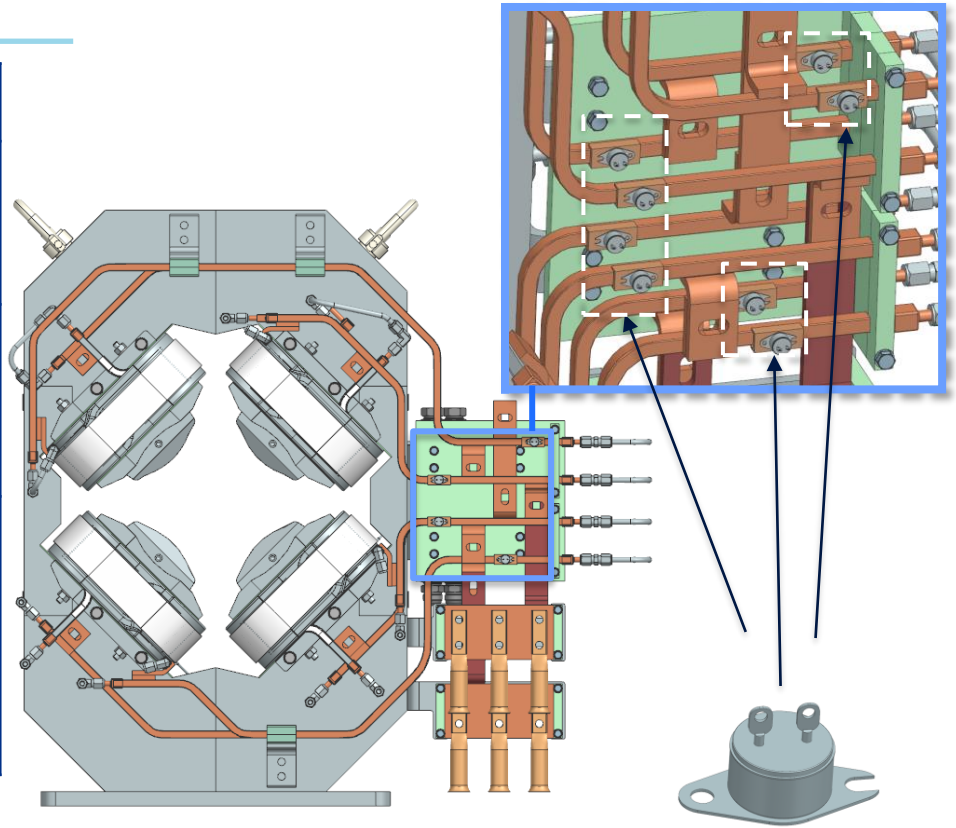




- Trim coils are installed in all main coils

Temperature switch

ID	Requirement	Traceability [13]
S02.04-R007	Each extraction magnet temperature switch shall be hardwired to the magnet power supply to turn off the supply if the temperature limit is exceeded.	S02-R004 S02-R006
S02.04-R008	Water-cooled extraction magnet coils shall have at least one temperature switch per water flow path. The switch shall be mounted on the insulated coil near the cooling water outlet end of the coil.	S02-R004 S02-R006
S02.04-R009	The temperature switch required in S02.04-R008 shall have a specified 170° ± 5° F (76.7° ± 2.8° C) trip point. The switch contacts shall be electrically isolated from the coil. The reset temperature shall be specified to be 150 ± 5° F (65.6° ± 2.8° C). Discussion: The preferred switch is Sensata 4344.	S02-R004 S02-R006

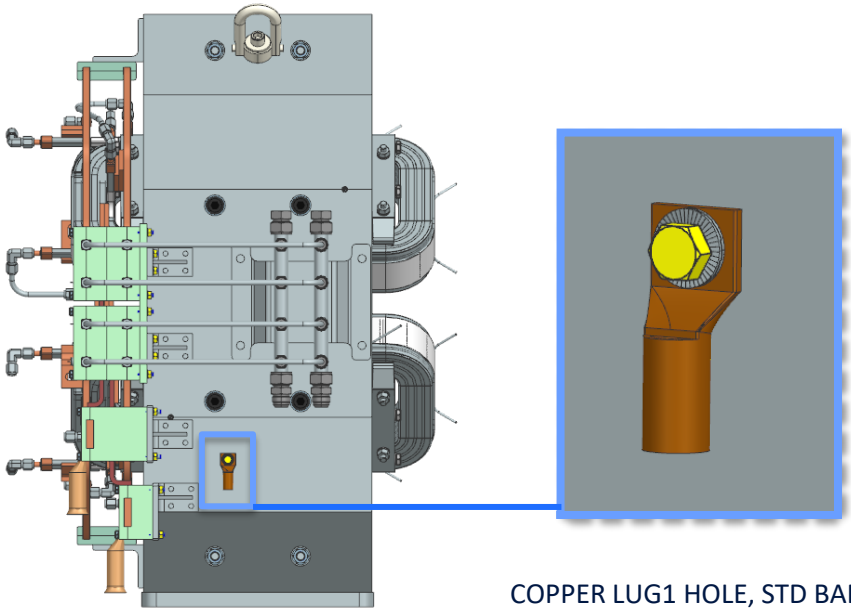


FC0075125-SWITCH, THERMAL, SINGLE POLE SEALED

The Sensata 4344-184 is a KLIXON® Commercial Hermetic 1/2" Thermostat manufactured by Sensata Technologies
Trip point - 170° ± 5° F (76.7° ± 2.8° C).

Grounding and fiducials

ID	Requirement	Traceability [13]
S02.04-R010	All extraction magnet water manifold components shall be electrically grounded to the magnet core.	S02-R009
S02.04-R021	The extraction magnet core shall be grounded to the tunnel ground system.	S02-R009
S02.04-R014	The extraction magnet assembly shall have external fiducials capable of supporting magnet alignment to 100-micron in x/y and 1-mrad yaw, pitch, and roll. Discussion: This requirement is relative to the SNS Coordinate System where the Z axis is along the beam line. The location of fiducials on the magnet is important – details TBD. The positioning along the beam axis is not as critical – within ~ 1 cm.	S02-R003 S02-R007



Currently, locations for fiducials were not determined.

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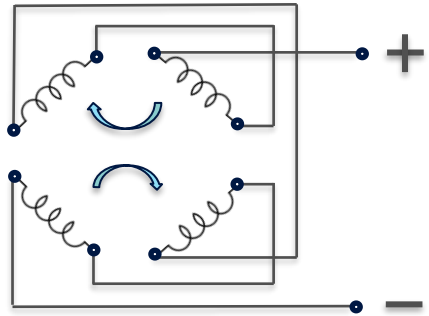
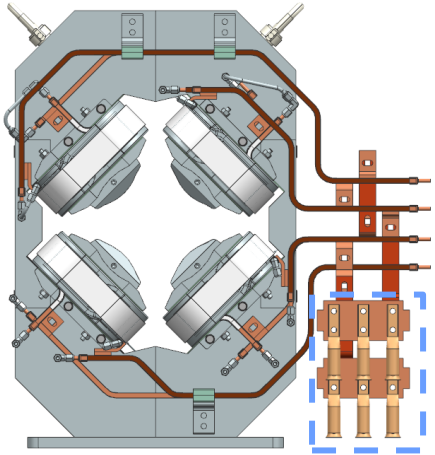
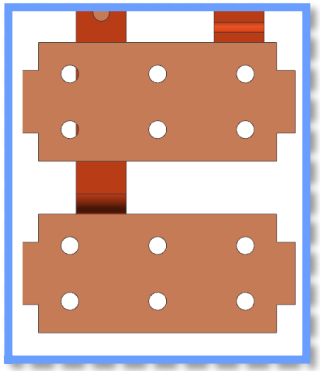
Power flags

ID	Requirement	Traceability [13]
S02.04 -R018	The extraction magnet assembly shall be designed with terminal blocks or flags to mate with cable termination lugs. Discussion: Intent is to conform to SNS standard connections.	Design Requirement

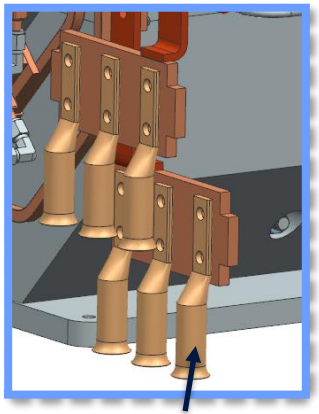


- Electrical diagram

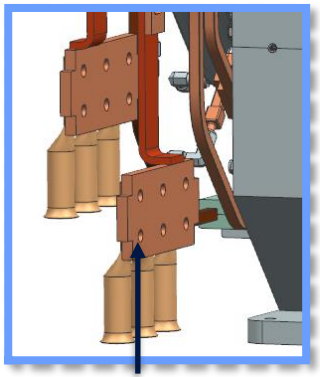




- Thickness busbars 12.7 mm
- Contact area 18588 mm²
- Bolted connection for M12



COMPRESSION LUG,2 HOLES, LSSSF500-12-6



POWER FLAG, NARROW QUAD,ORNL STS

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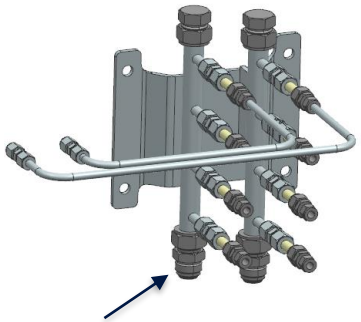
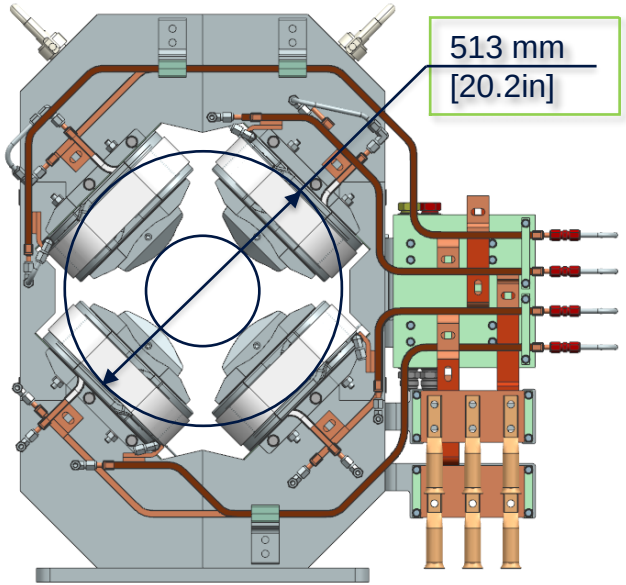
Manifolds assembly

ID	Requirement	Traceability [13]
S02.04 -R028	Extraction magnet water connection ports shall be compatible with female 37° flair JIC (SAE J514/ISO 8434-2) hose fittings, 1 – 1/16 - 12 thread size. Discussion: Intent is to be compatible with Parker p/n 10656-12-12C hose fitting.	Design Requirement
S02.04 -R029	Extraction magnet water hoses shall be routed a minimum of 6” (15.2 cm) away from the magnet aperture. Discussion: Intent is to minimize radiation damage to hoses.	S02-R004



UNION, 1" TUBE OD X 1" AN TUBE FLARE, SS316

- Compatible with female 37° flair JIC (SAE J514/ISO 8434-2)



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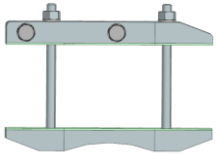
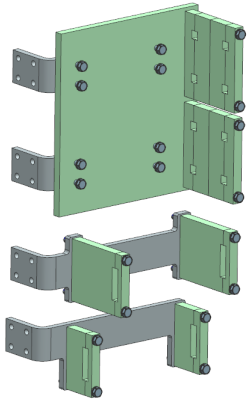
Materials

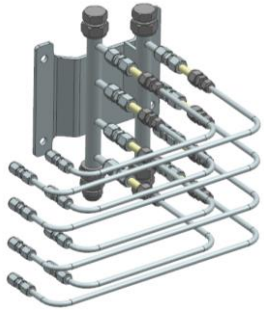
ID	Requirement	Traceability [13]
S02.04 -R027	The extraction magnet assembly wetted parts shall be OFHC copper, stainless steel, ceramic, or approved hose material. Discussion: No aluminum or brass is allowed. OFHC copper and stainless steel are preferred. See Characterization of Particulate Material from Two Filters Associated with the SNS Cooling System [5], and Review of Cooling Water Chemistry at ORNL/SNS [2] for water quality discussions.	S02-R004



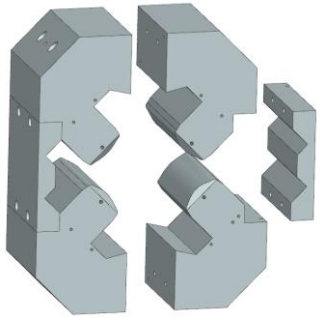
- Stainless steel
- G-10



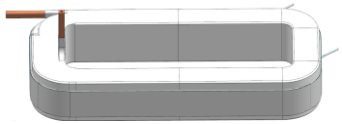
- Stainless steel
- G-10



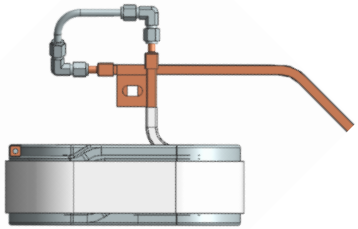
- Stainless steel
- Ceramic



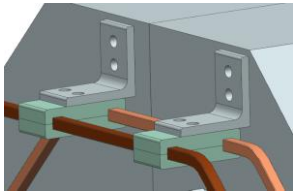
- Steel



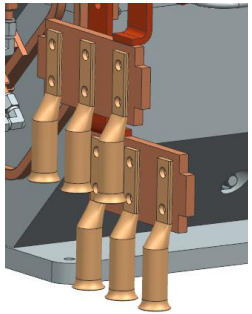
- Copper
- Fiberglass tape
- G-10



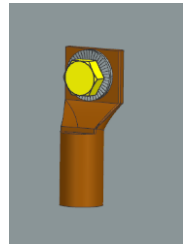
- Stainless steel
- Copper



- Stainless steel
- G-10



- Copper



- Copper

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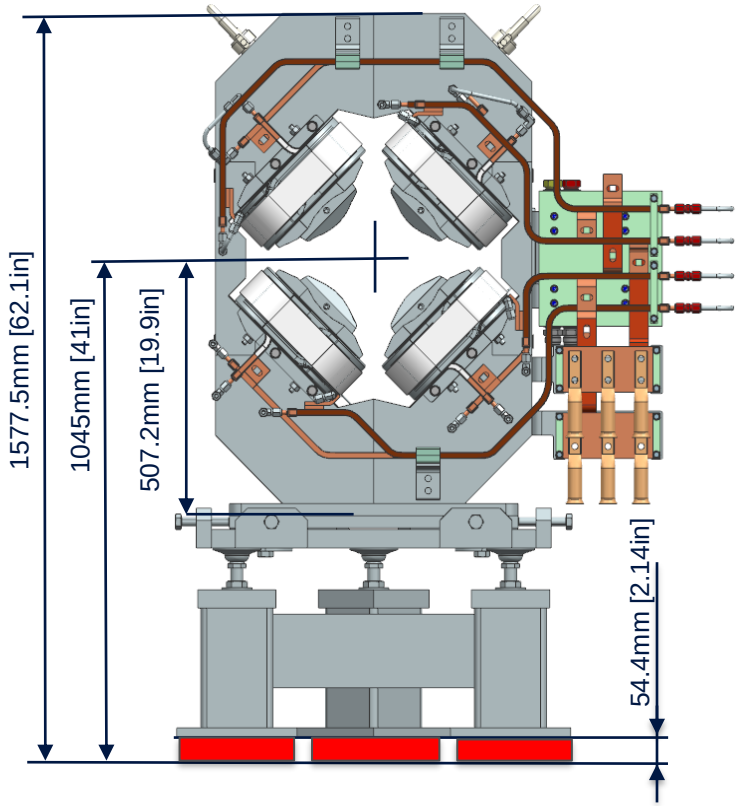
Stand interface

ID	Requirement	Traceability [13]
S02.04-R020	The extraction magnet assembly shall be designed such that the magnet (mechanical) central axis can be placed coincident with the beam path (at a 1.045 m nominal beam height) mounted on a support that meets requirements S02.11-R002 and S02.11-R011. Discussion: This is intended to ensure that there is enough clearance between the magnet and the floor for a support stand with some vertical adjustment. The nominal beam height was derived from the elevations on the Burns and McDonnell RTST Stub drawings. Floor elevation 1076', Beam line elevation 1079.43'. The RTBT beam height is listed in [3] as "approximately 41 inches above the floor"..	S02-R003 S02-R007



- MOUNTING ELEMENTS [54.4mm or 2.14in]

Summary

- The Narrow quadrupole design was reviewed to ensure compliance with the specification.
- The water-cooling parameters in the chapter overheating are agreed upon.
- The fiducial system has not been developed but will be added shortly.
- The presented design corresponds to the required technical characteristics.