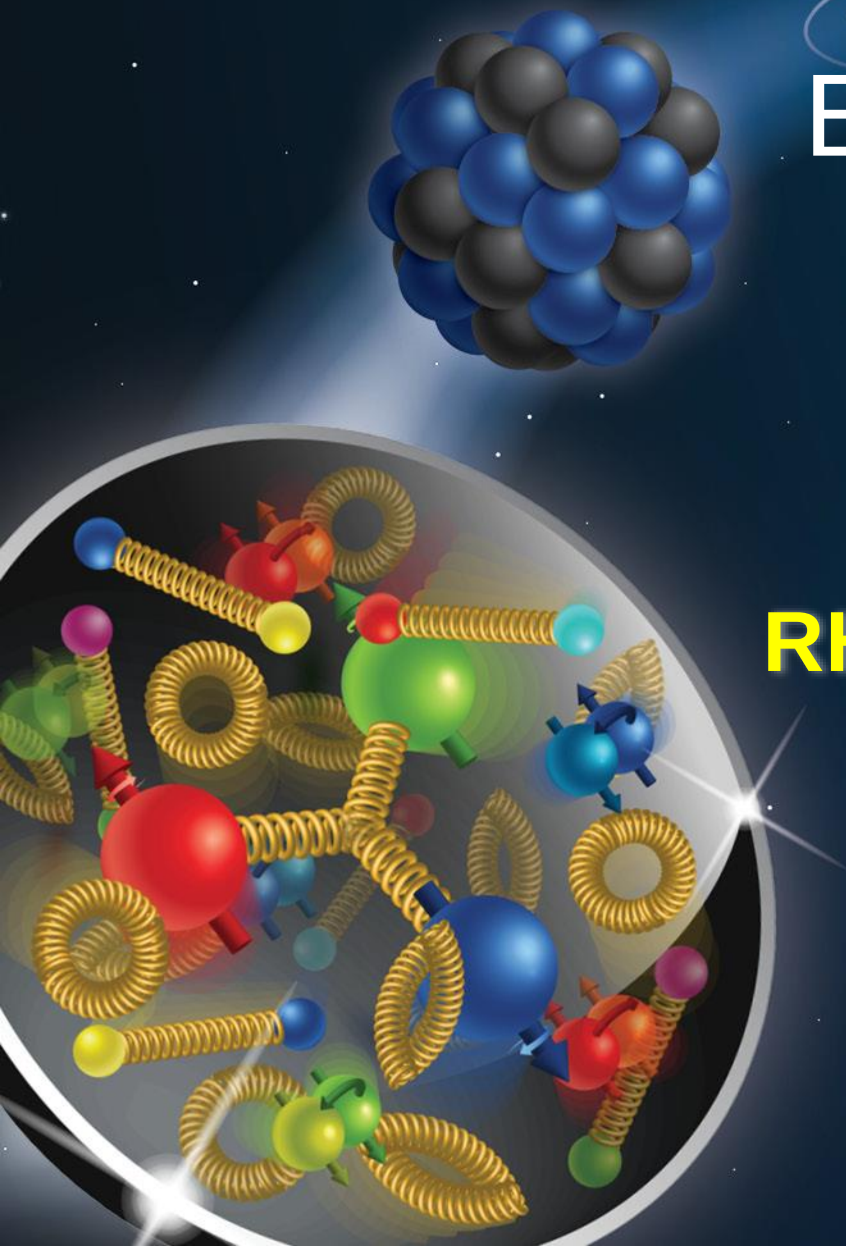
Evaluation of RHIC Magnets for EIC (higher energy and higher temperature)

RHIC Arc Dipole (80 mm)



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September 17, 2020

Electron Ion Collider – eRHIC

BROOKHAVEN NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY | Office of Science

Evaluation of RHIC Arc Dipole (80 mm) for EIC (higher energy and higher temperature)

Basic questions:

Can RHIC magnets operate safely at 275 GeV at elevated temperature?

What is the temperature margin?

How is the field quality (on-axis and off-axis)

The following is an initial evaluation of RHIC 80 mm aperture dipoles.

Magnet stability (from Silvia Verdú Andrés)

- Which is the preferred margin for stable operation (no quench)?
- Does the margin depend on the magnet topology?
- What is the maximum current (or field) for which the RHIC magnets were trained?
- Do we need to train the RHIC magnets to provide the field values required for EIC?
- How close can training bring the magnets to the simulated quench temperature?
- Training involves making the magnet quench. There are two pathways to quench: increase temperature (e.g. by applying dynamic heat load) or increasing current through coils. Which method can be used to train the magnets and is there any limitation? (Note magnets will remain in the RHIC tunnel.)

RHIC 80 mm ARC Dipole
(performance computed, field quality measured)

Table I
Basic design parameters of RHIC arc dipoles

Coil inner, outer radius	40 mm, 50 mm
Yoke inner, outer radius	59.7 mm, 133.4 mm
Field, current at injection	0.40 T, 0.57 kA
Maximum design field, current	3.46 T, 5.09 kA
Computed quench at 4.5° K	8.25 kA
Magnetic length at 3.46 Tesla	9.44 m

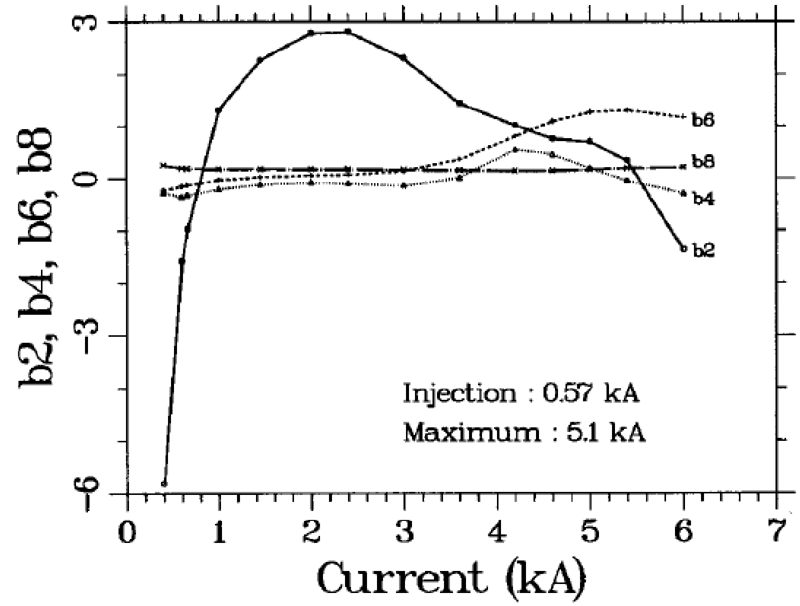


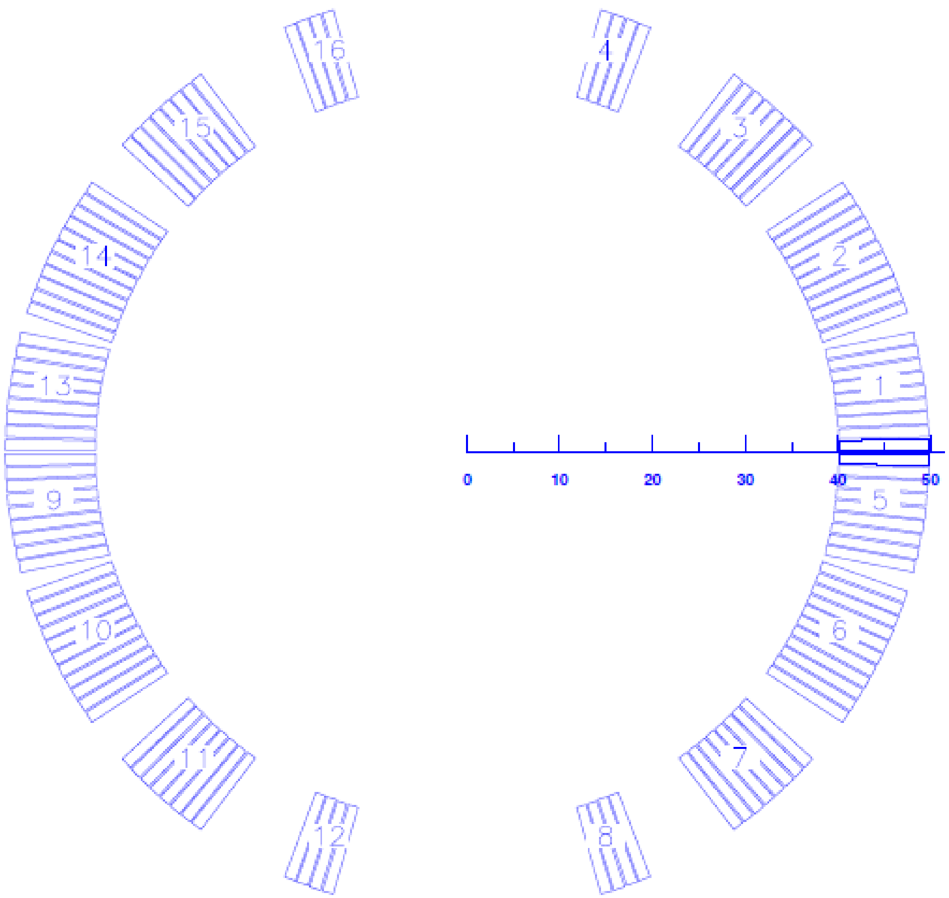
Figure 2. The measured current dependence of harmonics during up ramp (and 20 second wait) in RHIC arc dipoles.

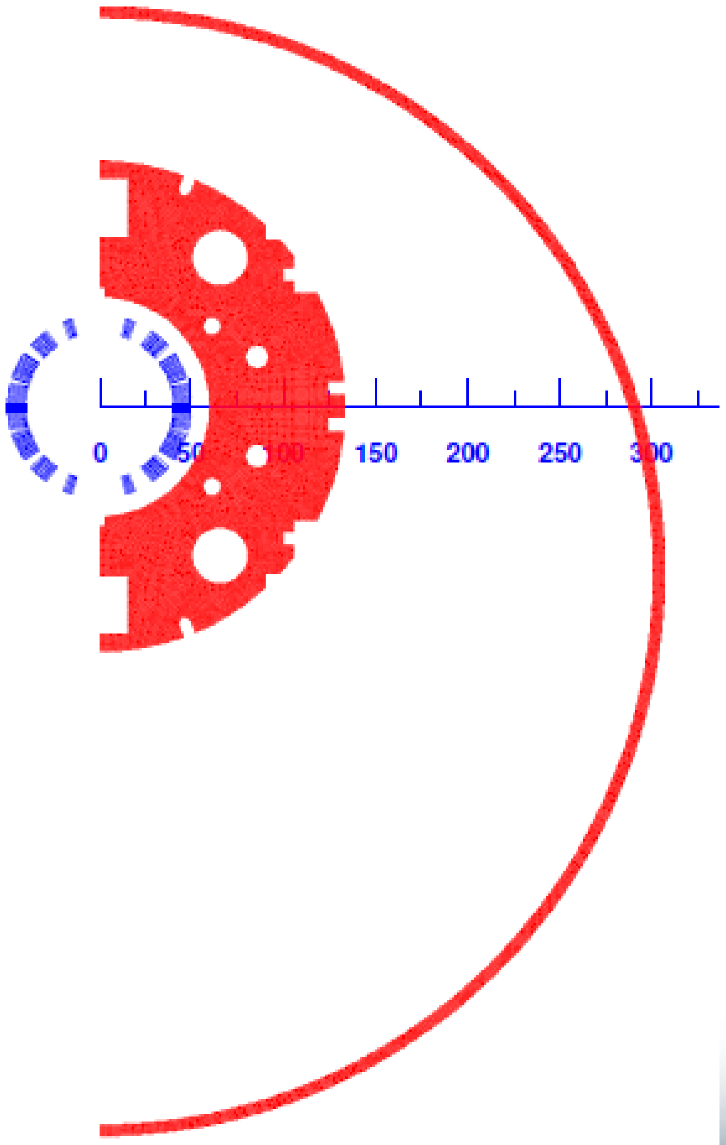
R. Gupta, et al., Field Quality Control Through the Production Phase of RHIC Arc Dipoles, Proceedings of the 1995 International Particle Accelerator Conference, Dallas, Texas (1995).

Temperature Margin at different fields

- Specific evaluation with ROXIE models (today)
- A broader evaluation with the basic properties of the superconductor used in various RHIC magnets (next presentations)
- These calculations assume perfect magnets and ignore training quenches, etc. (this could be a significant issue for insertion magnets unless field or field gradient reduced)
- Desired higher requirements for sextupole

ROXIE Model





Model Calculations at RHIC Design Field (250 GeV@3.46 T)

Validation of the ROXIE Model

Values from the reference paper:

Maximum design field, current	3.46 T, 5.09 kA
Computed quench at 4.5° K	8.25 kA

Good Agreement

```
MAIN FIELD (T):3.46
PEAK FIELD IN CONDUCTOR (T): 4.03
CURRENT IN CONDUCTOR (A): 5090
PERCENTAGE ON THE LOAD LINE :76.17
QUENCHFIELD (T): 5.28
TEMPERATURE MARGIN TO QUENCH(K):1.12
PERCENTAGE OF SHORT SAMPLE CURRENT: 61.5
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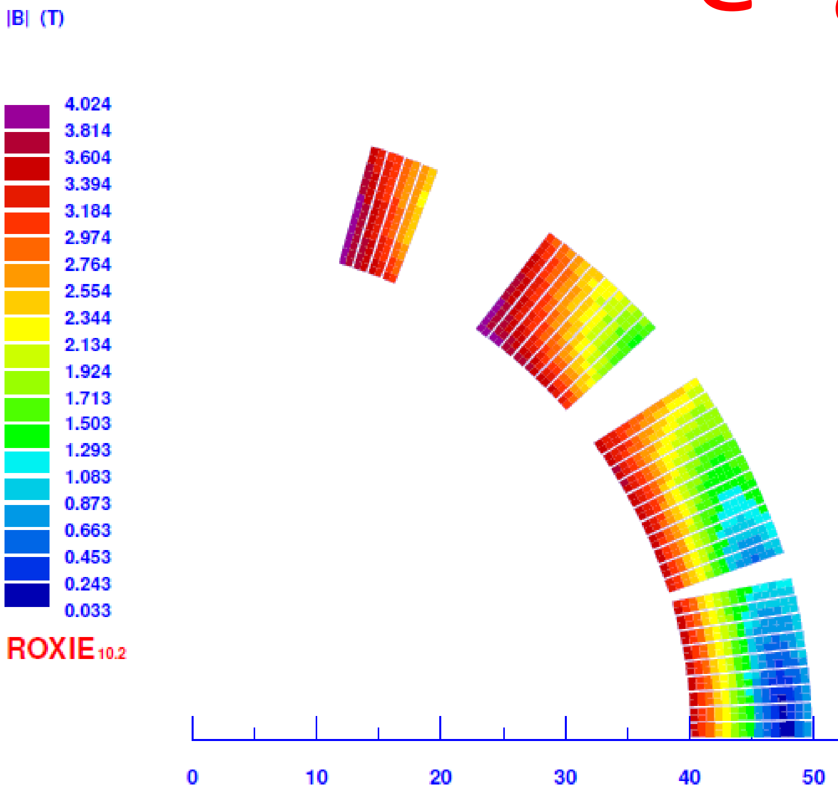
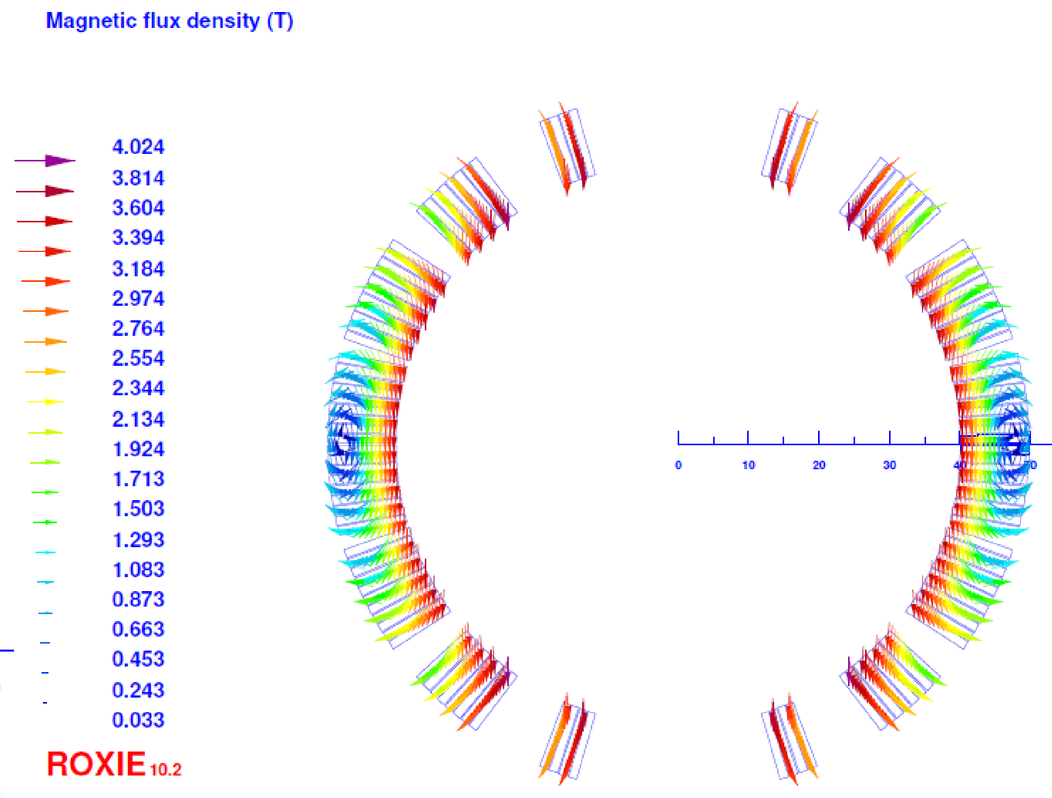
8.27 kA

Field in conductor at RHIC design field

@B_o = 3.46 T



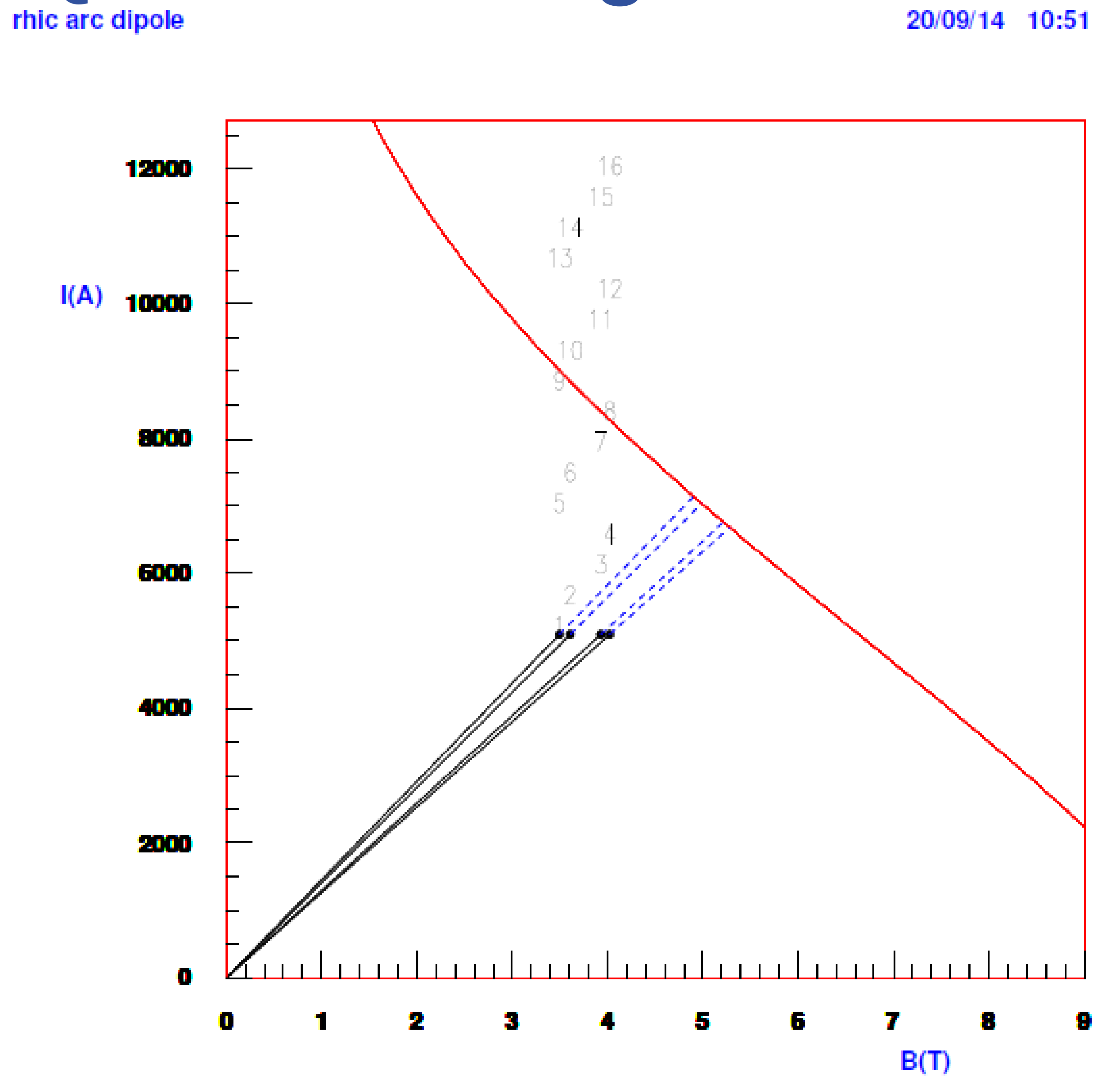


Computed Quench Margin

@B_o=3.46 T

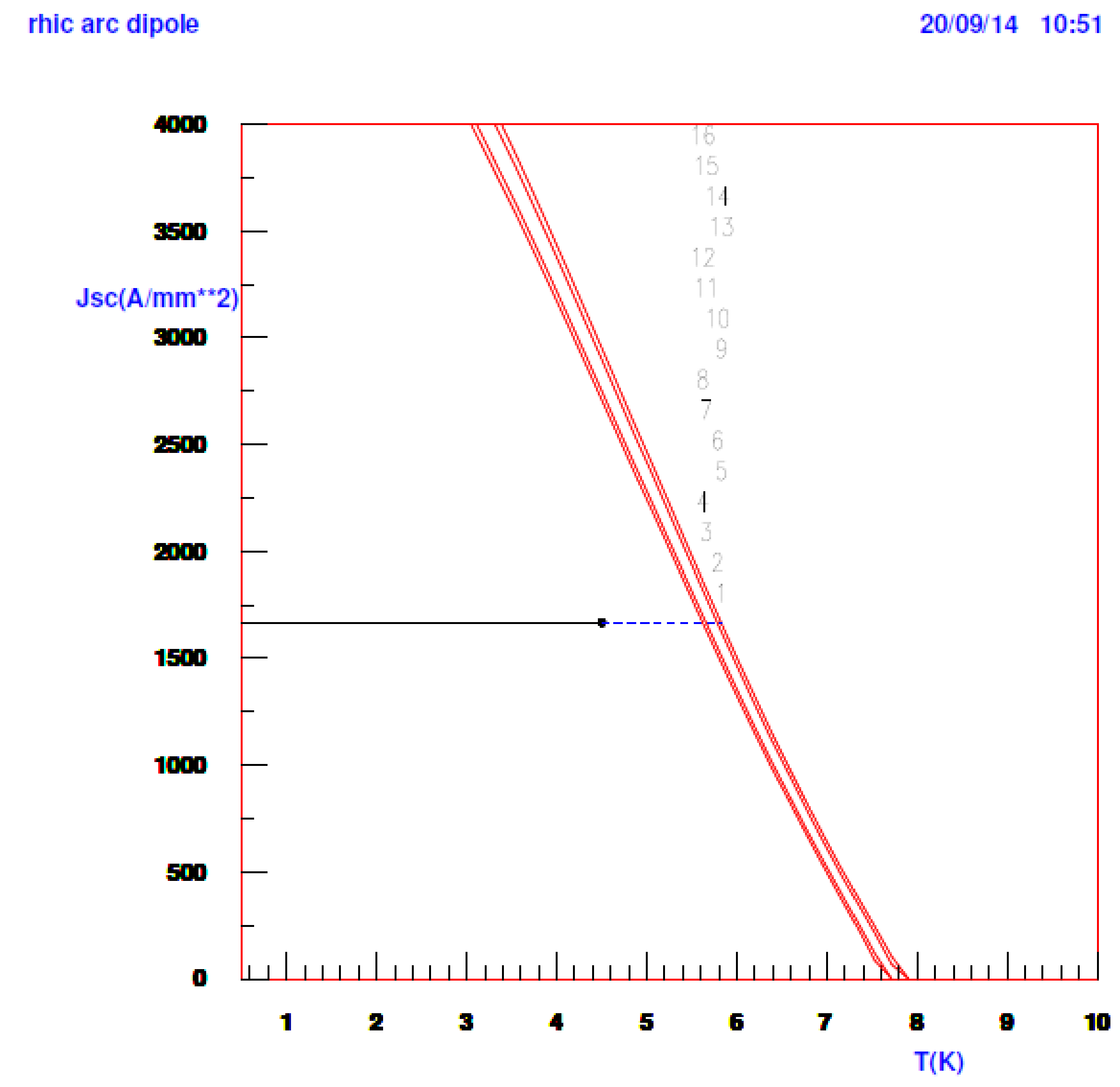
I = 5.09 kA

T = 4.5 K



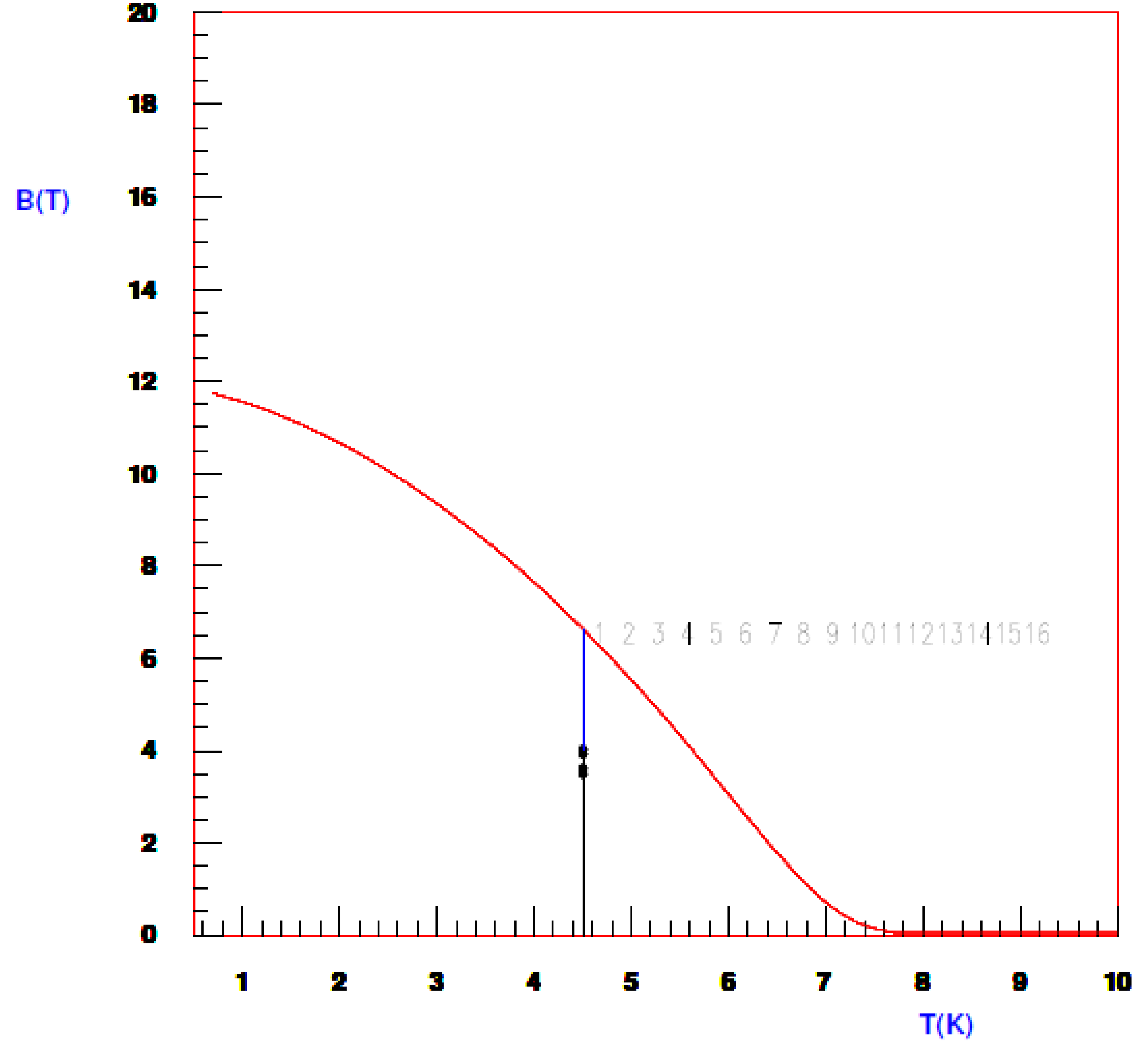
Computed Quench Temperature Margin

@B_o=3.46 T
I = 5.09 kA
T = 4.5 K



Computed Quench Field Margin

@B_o=3.46 T
I = 5.09 kA
T = 4.5 K



Model Calculations at EIC Design Field (275 GeV@3.81 T)

Temperature: 4.5 K

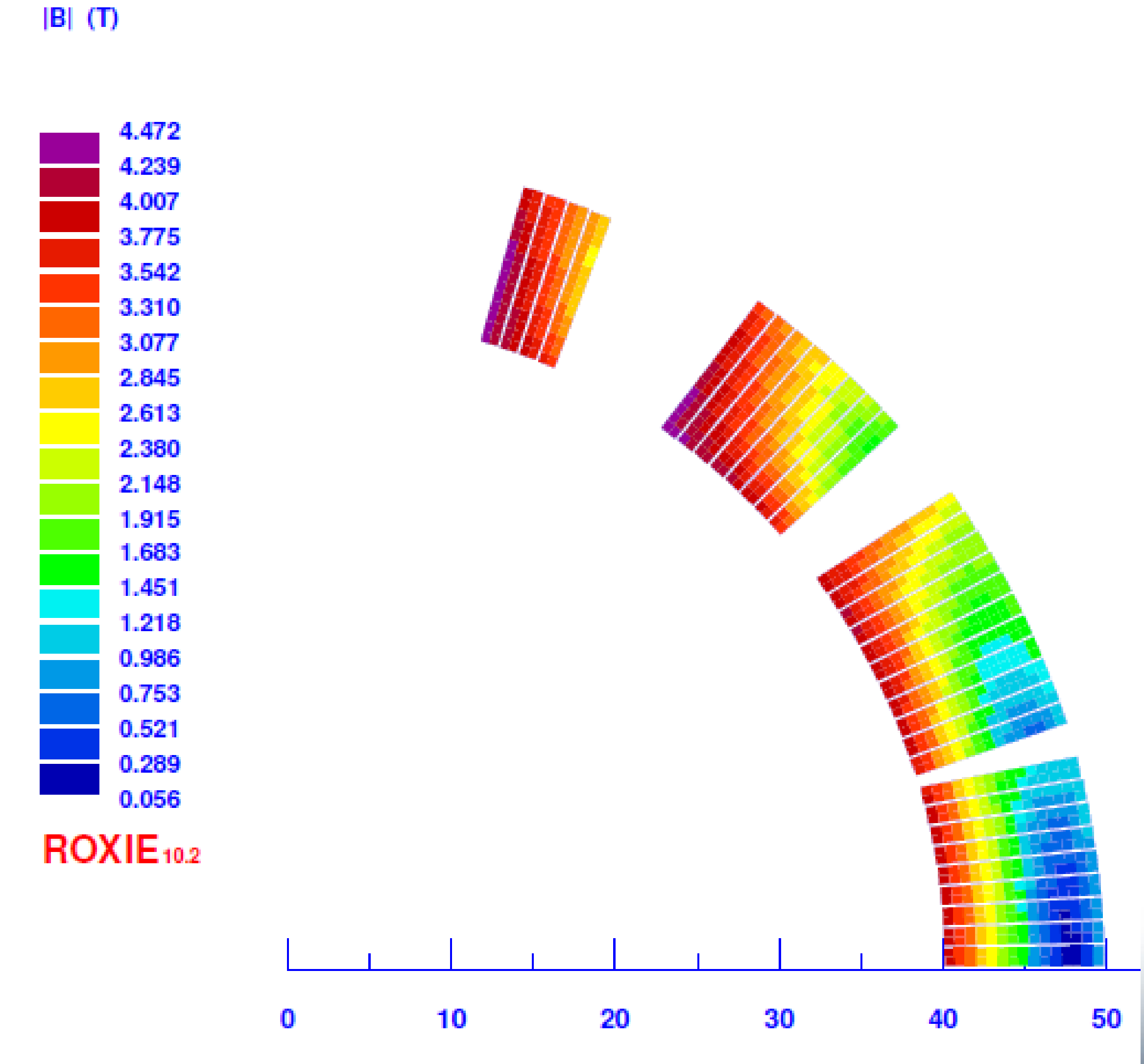
Summary of Calculations for 275 GeV @4.5 K

MAIN FIELD (T)	-3.841283

BLOCK NUMBER	16
PEAK FIELD IN CONDUCTOR 128 (T)	4.4723
CURRENT IN CONDUCTOR 128 (A)	-5600.0000
LOWEST FIELD IN CONDUCTOR 125 (T)	2.6075
SUPERCONDUCTOR CURRENT DENSITY (A/MM2)	-1833.8841
COPPER CURRENT DENSITY (A/MM2)	-818.6983
PERCENTAGE ON THE LOAD LINE	84.2163
QUENCHFIELD (T)	5.3105
TEMPERATURE MARGIN TO QUENCH (K)	0.7574
PERCENTAGE OF SHORT SAMPLE CURRENT	72.8420

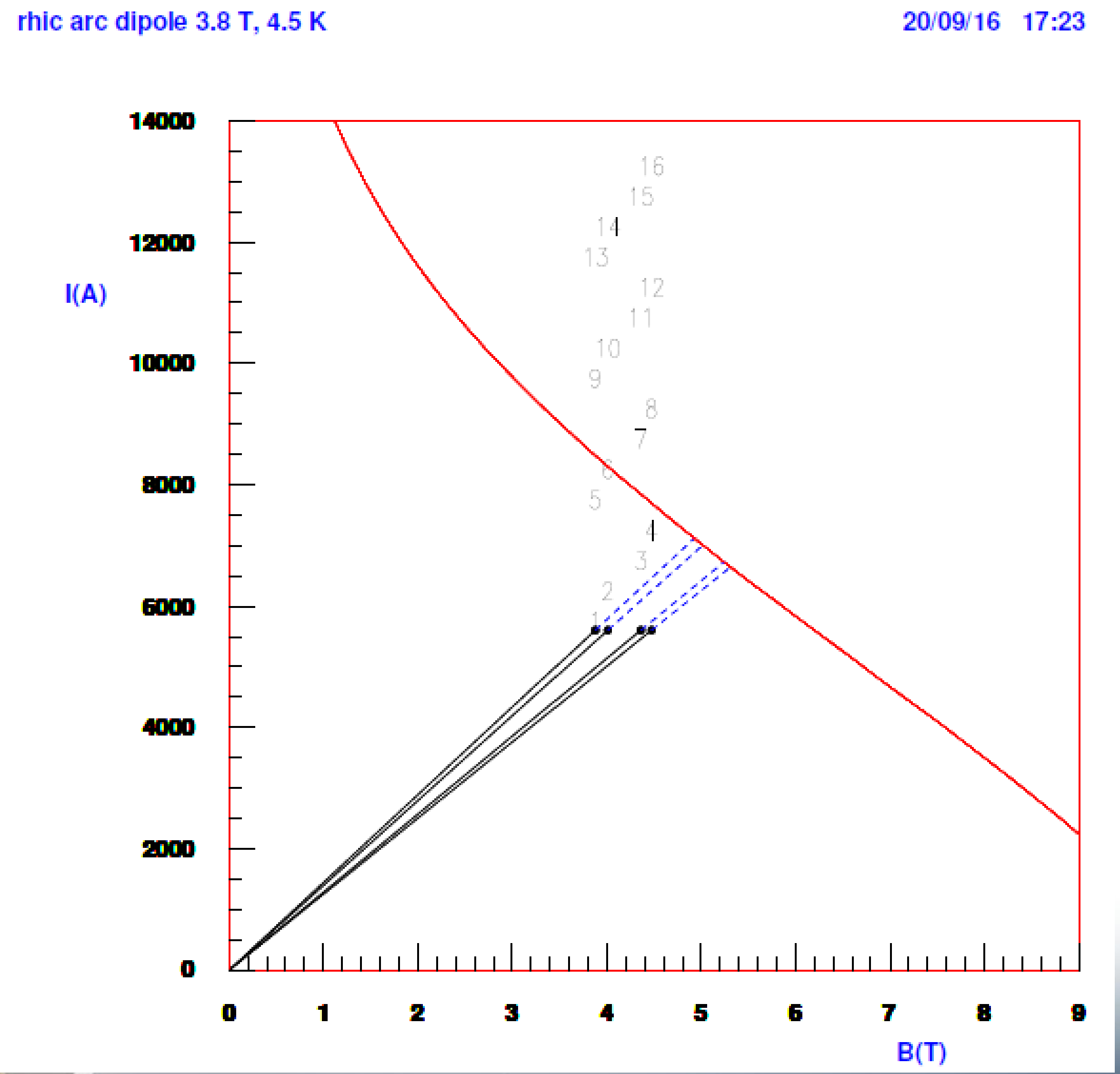
Field in conductor at EIC design field

@B_o = 3.8 T



Computed Quench Margin

@B_o=3.8 T
I = 5.6 kA
T = 4.5 K

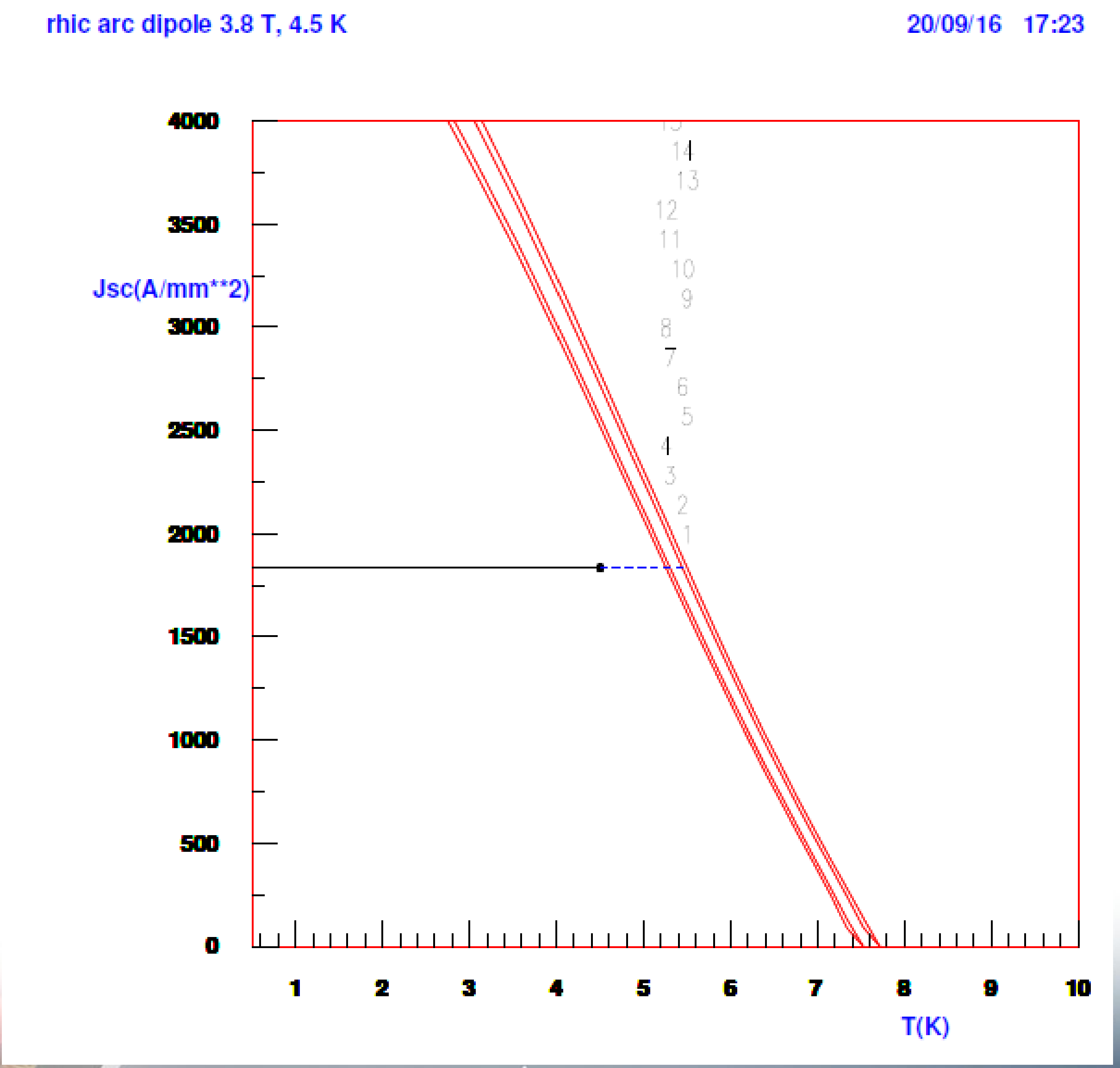


Computed Quench Temperature Margin

@B_o=3.8 T

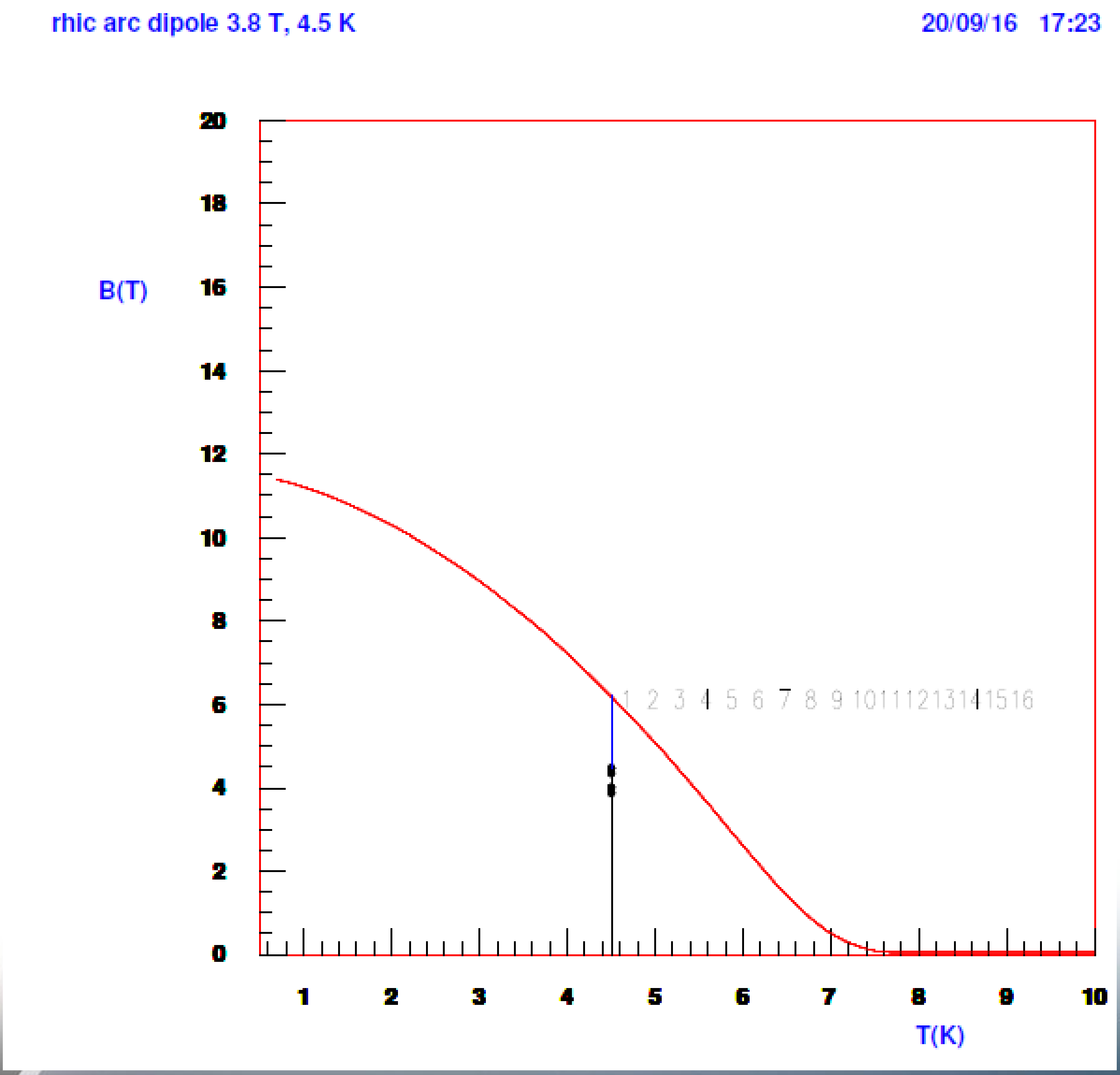
I = 5.6 kA

T = 4.5 K



Computed Quench Field Margin

@B_o=3.8 T
I = 5.6 kA
T = 4.5 K



Model Calculations at EIC Design Field (275 GeV@3.81 T)

Temperature: 5 K

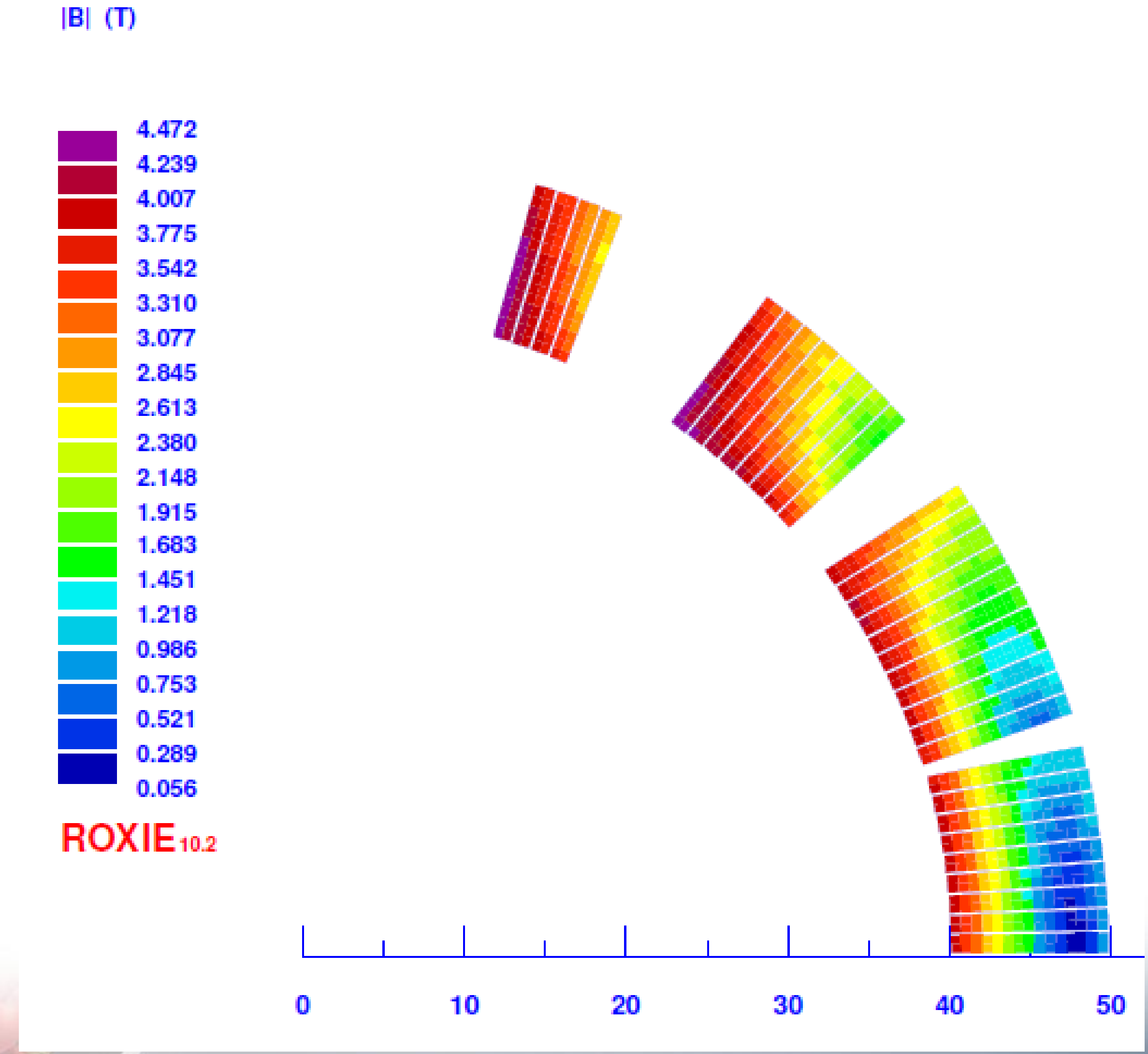
Summary of Calculations for 275 GeV @5 K

MAIN FIELD (T)	-3.841283

BLOCK NUMBER	16
PEAK FIELD IN CONDUCTOR 128 (T)	4.4723
CURRENT IN CONDUCTOR 128 (A)	-5600.0000
LOWEST FIELD IN CONDUCTOR 125 (T)	2.6075
SUPERCONDUCTOR CURRENT DENSITY (A/MM2)	-1833.8841
COPPER CURRENT DENSITY (A/MM2)	-818.6983
PERCENTAGE ON THE LOAD LINE	93.8675
QUENCHFIELD (T)	4.7645
TEMPERATURE MARGIN TO QUENCH (K)	0.2574
PERCENTAGE OF SHORT SAMPLE CURRENT	88.7707

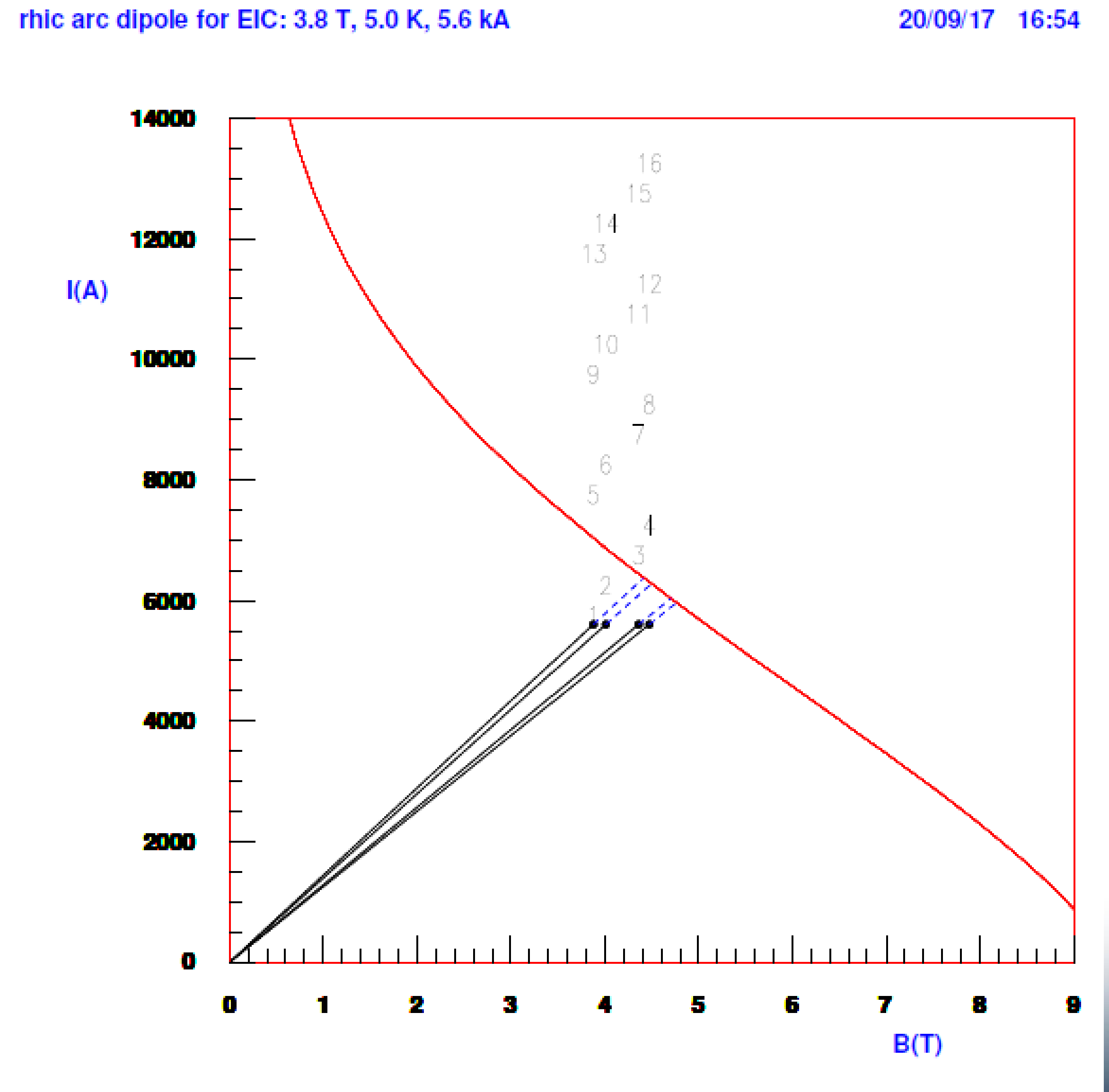
Field in conductor at EIC design field

@B_o = 3.8 T



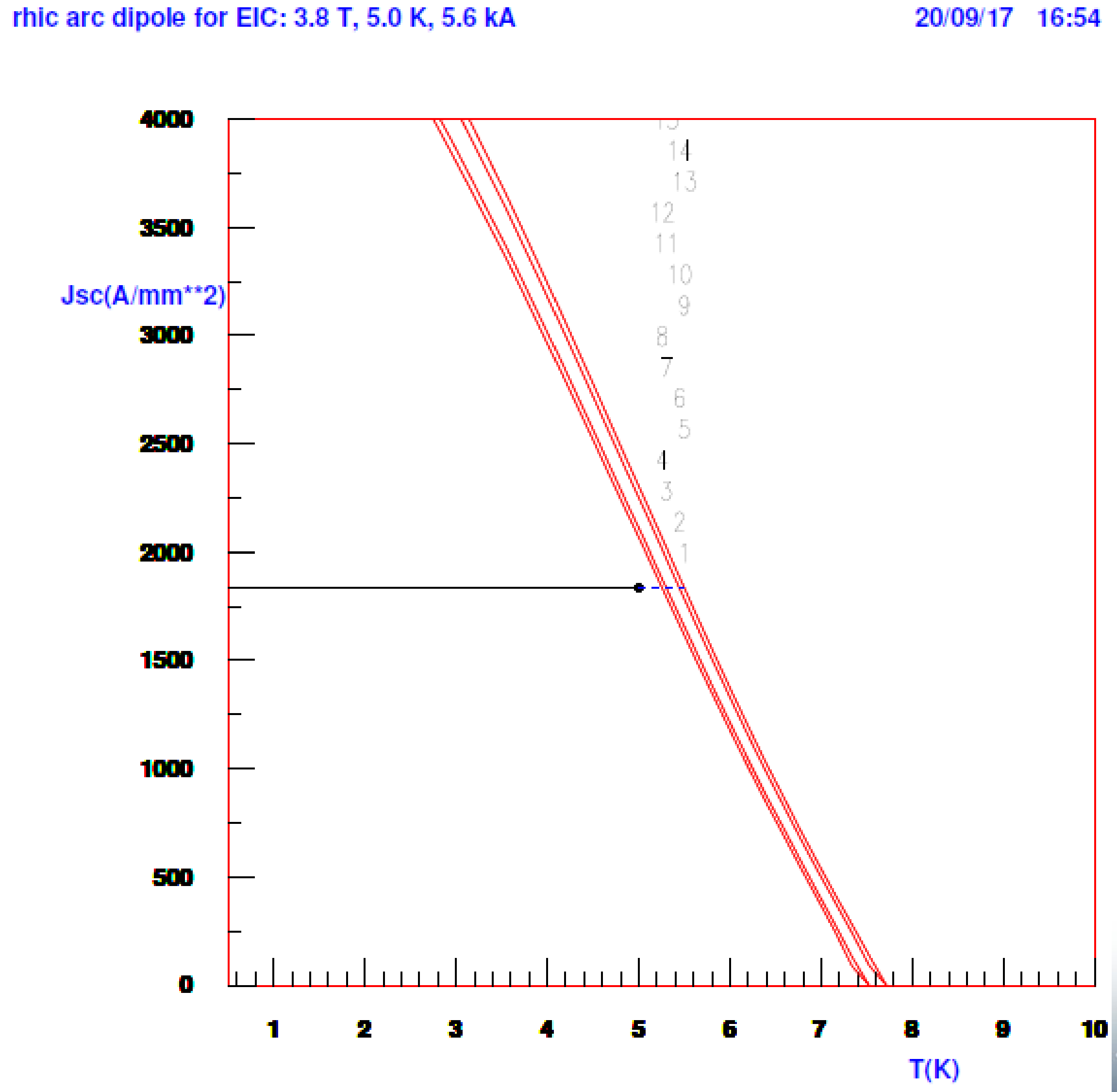
Computed Quench Margin

@B_o=3.8 T
I = 5.6 kA
T = 5 K



Computed Quench Temperature Margin

@B_o=3.8 T
I = 5.6 kA
T = 5 K

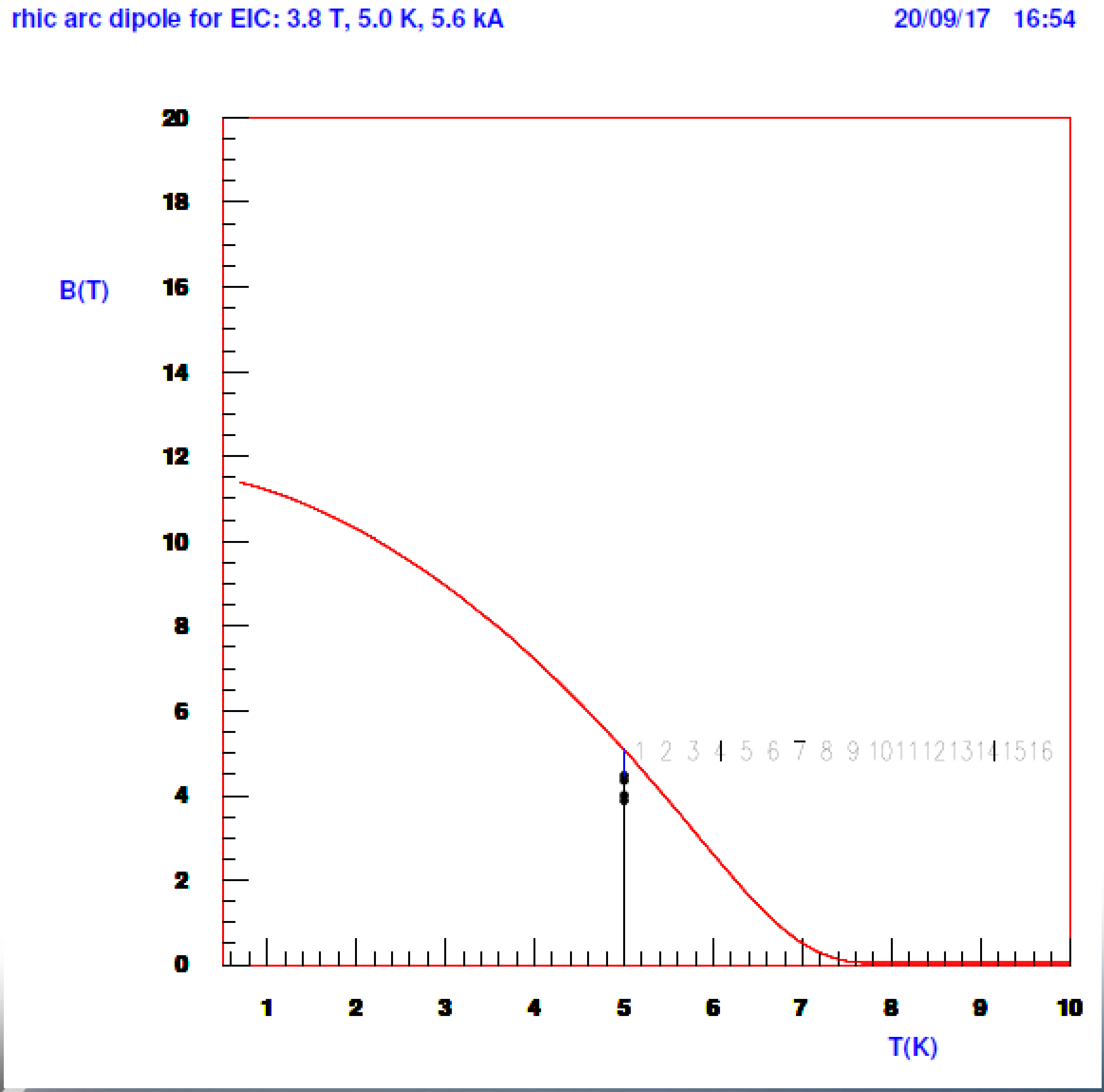


Computed Quench Field Margin

@B_o=3.8 T

I = 5.6 kA

T = 5 K



Summary

- **Initial evaluation of RHIC 80 mm arc dipole made for operating it at 3.8 T for 275 GeV proton.**
- **In addition to higher field, the impact of higher temperature on superconducting coils is of significant interest. Impact is evaluated.**
- **Beside arc quadrupole, arc dipole is the most reliable magnet in the RHIC lattice. Situation may be worse for other magnets for the same lattice.**
- **Initial evaluation point to difficult decisions ahead**