FRIB

HTS Magnets in High-Radiation Areas

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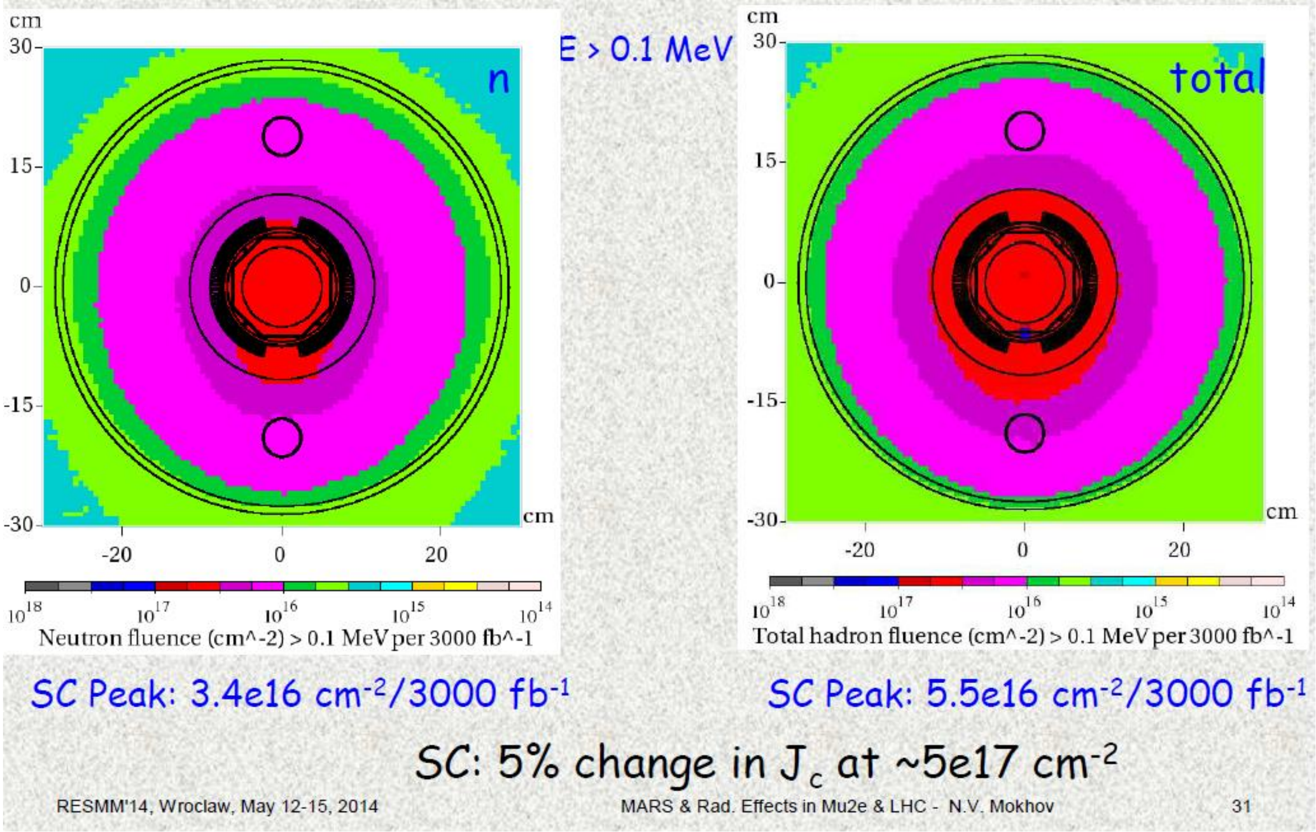
Outline

- Why use HTS?
  - Mostly answered in the many talks given here
  - Beam line magnets have different requirements than detector magnets
- Are HTS materials radiation resistant?
- What about insulation?
- Summary

LHC Upgrade Radiation



Neutron fluence (cm^-2) > 0.1 MeV per 3000 fb^-1

Total hadron fluence (cm^-2) > 0.1 MeV per 3000 fb^-1

SC Peak: 3.4e16 $cm^{-2}/3000\ fb^{-1}$

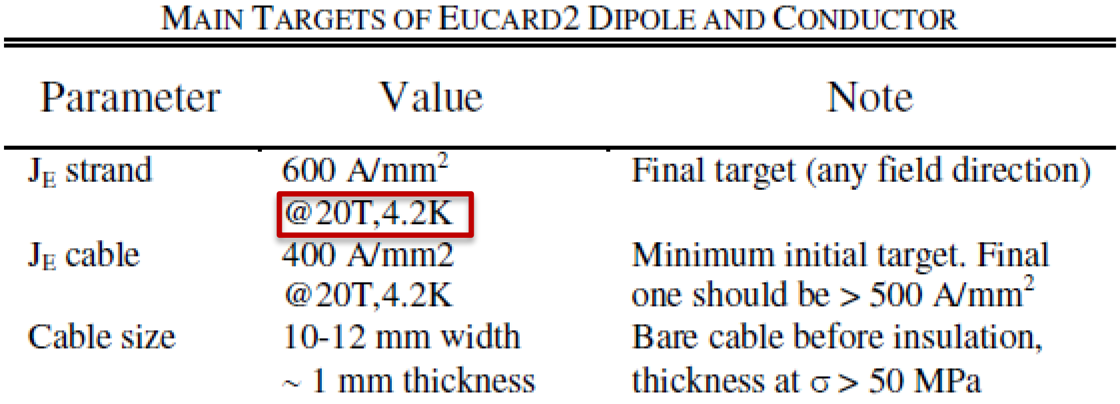
SC Peak: 5.5e16 $cm^{-2}/3000\ fb^{-1}$

SC: 5% change in J_c at ~5e17 cm^{-2}

RESMM'14, Wroclaw, May 12-15, 2014 MARS & Rad. Effects in Mu2e & LHC - N.V. Mokhov 31

Accelerator Beam Line Magnet Requirements

- High current density at high magnetic field
- Cable
- Radiation tolerant
- Operation at 4.2 K



MAIN TARGETS OF EUCARD2 DIPOLE AND CONDUCTOR

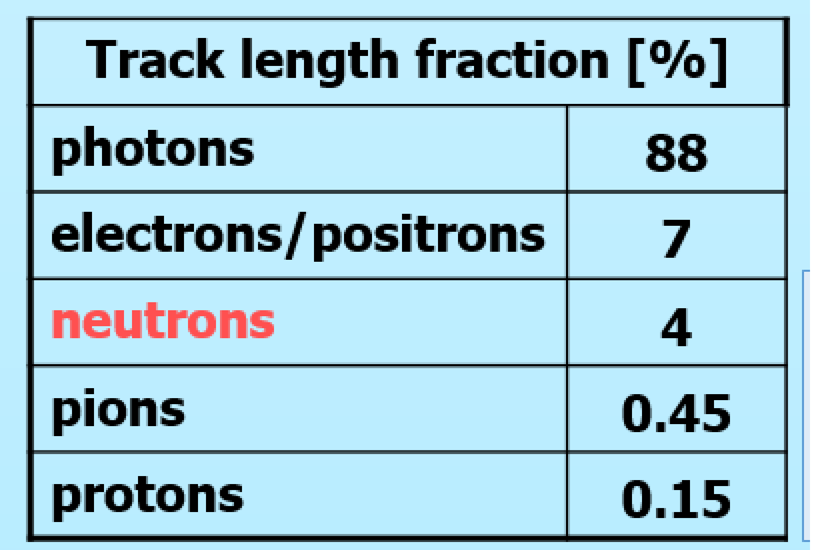
Parameter	Value	Note
J_E strand	600 A/mm^2 @20T,4.2K	Final target (any field direction)
J_E cable	400 A/mm2 @20T,4.2K	Minimum initial target. Final one should be > 500 A/mm^2
Cable size	10-12 mm width ~ 1 mm thickness	Bare cable before insulation, thickness at σ > 50 MPa

Fig. 5: Roebel cable concept (left); a first 15 tape Roebel cable manufactured by KIT for preliminary EuCARD2 investigation (right).

Rossi, et al., ASC-14 presentation

Radiation Spectra

Beam line magnets



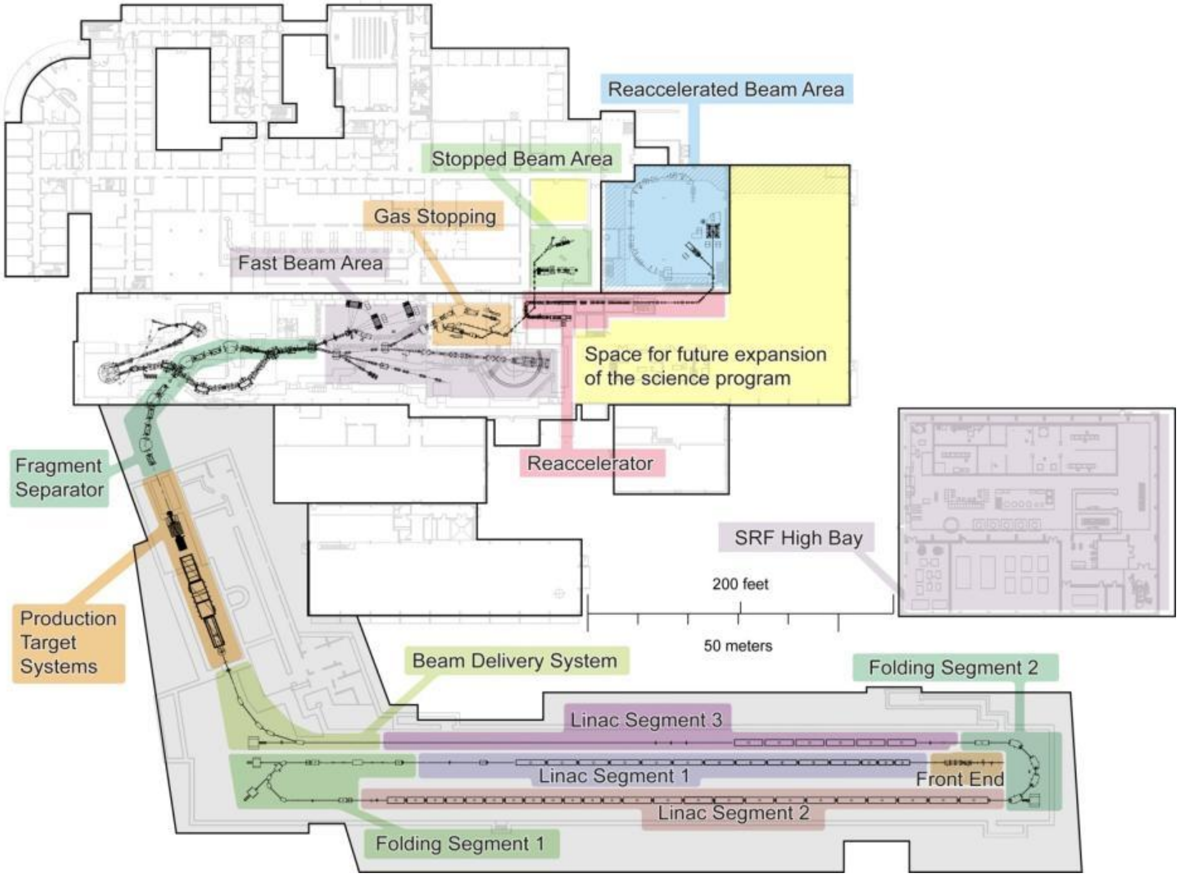
Track length fraction [%]	
photons	88
electrons/positrons	7
neutrons	4
pions	0.45
protons	0.15

Flükiger, RESMM'13

Spectrometer magnets:
90% neutrons

FRIB - Facility for Rare Isotope Beams
at Michigan State University

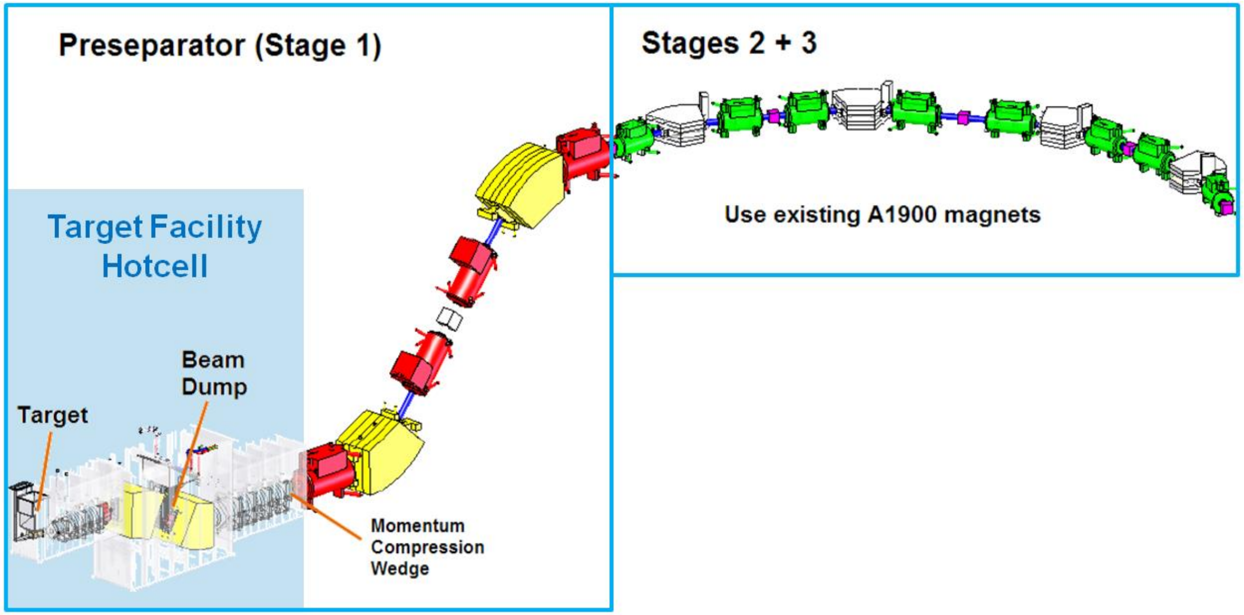
- Rare isotope production via in-flight technique with primary beams up to 400 kW, 200 MeV/u uranium
- Fast, stopped and reaccelerated beam capability
- Upgrade options
  - Energy 400 MeV/u for uranium
  - ISOL production – Multi-user capability



World-leading next-generation rare isotope beam facility

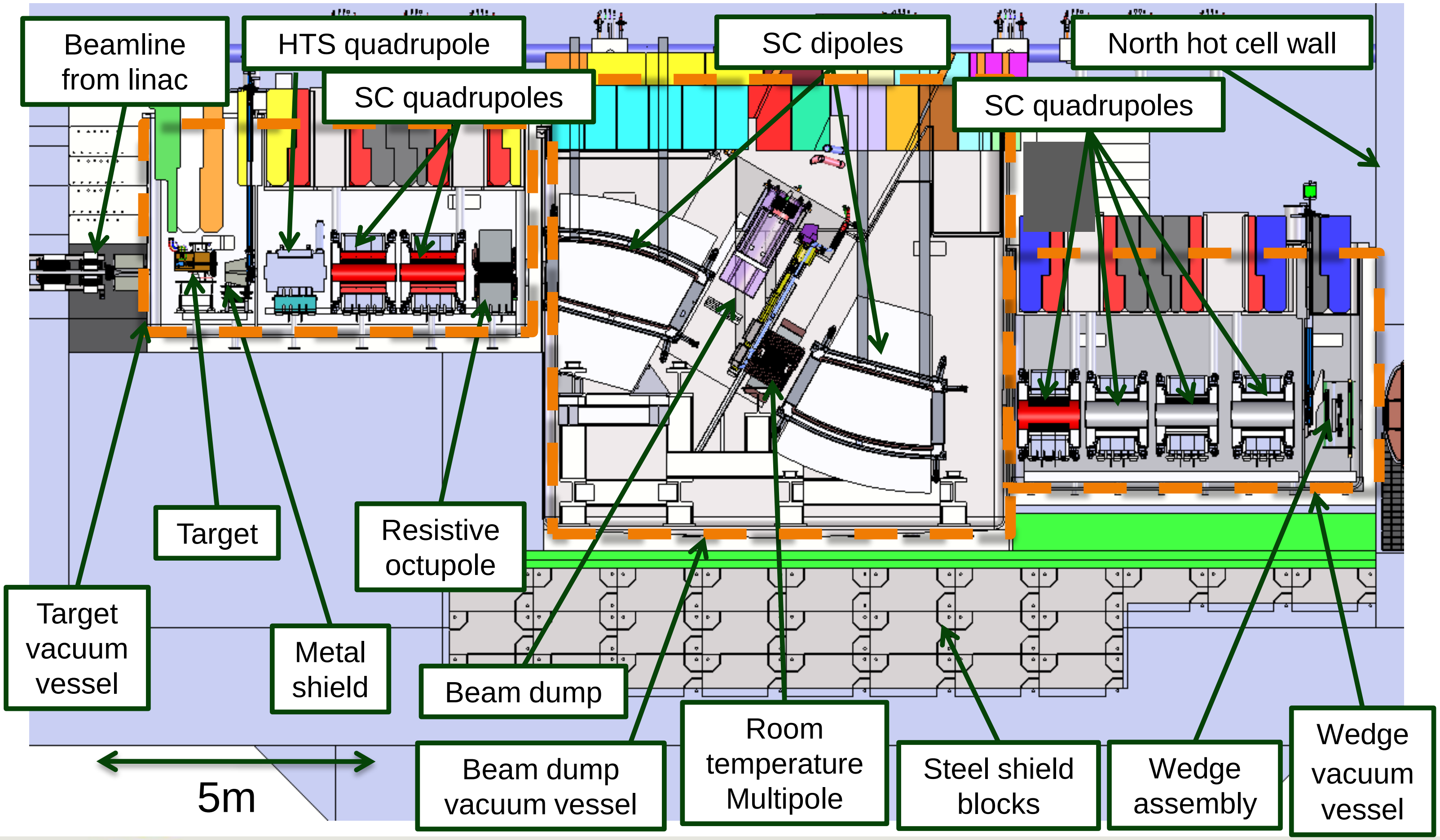
Overview Experimental Systems
Fragment Separator

- Scope
  - In-flight separation of rare isotopes with high acceptance and high resolution
    - » Leverage rare isotope production at 400 kW beam power
    - » Provide purest-possible rare isotopes beam to maximize science reach



Fragment Separator Mechanical Design

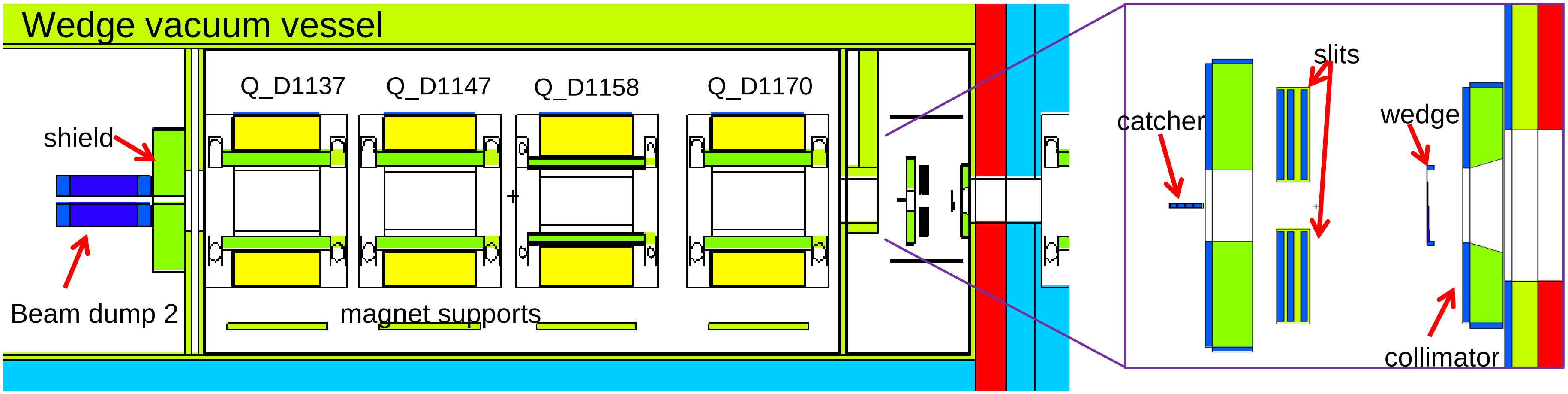
- All components in high radiation area in vacuum vessels ~200 t)



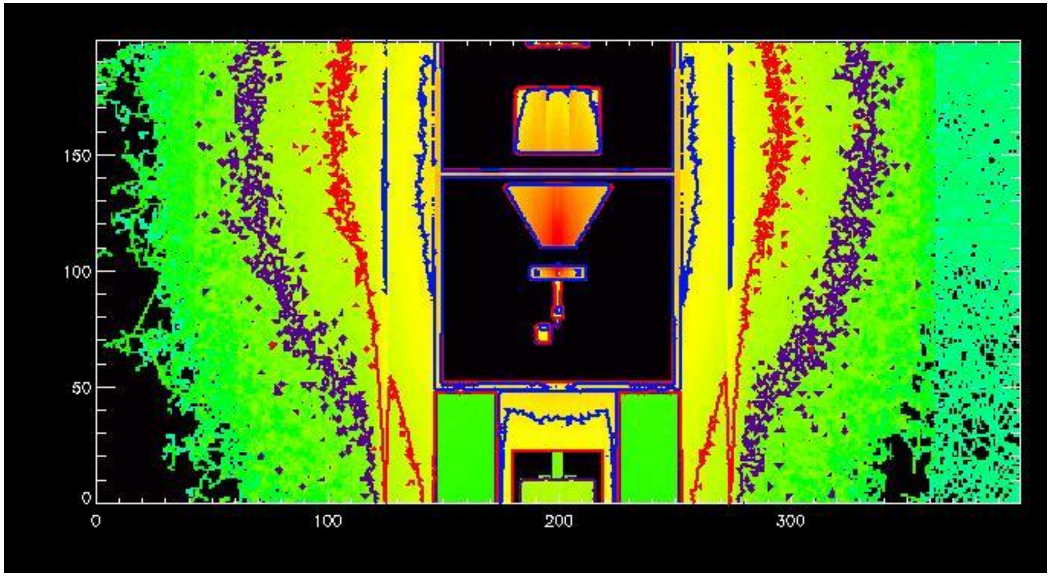
Detailed Magnet Models for Simulations

Basis for Reliable Prediction of Radiation Effects

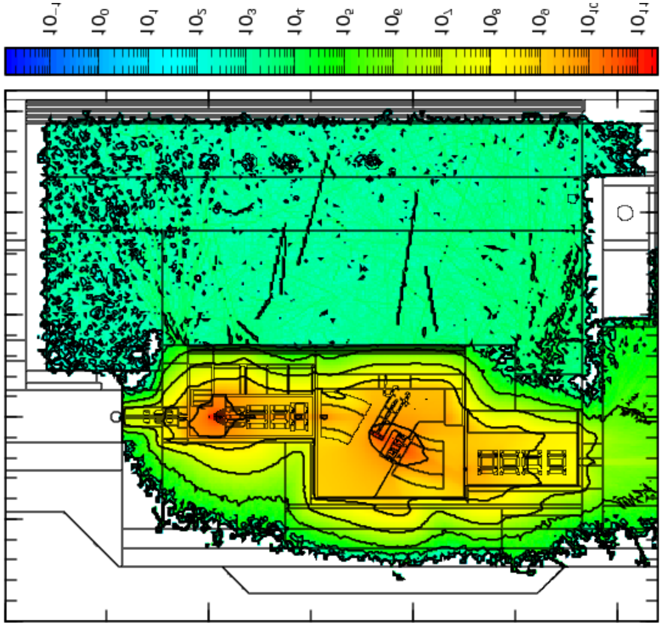
- Power deposition in magnet structures drives the detailed design of magnet components, non-conventional utilities, cooling water loops, cryogenic requirements
- Liquid helium capacity fixed. Can't change the plant size.



Radiation Transport



Heat map of zone close to Target



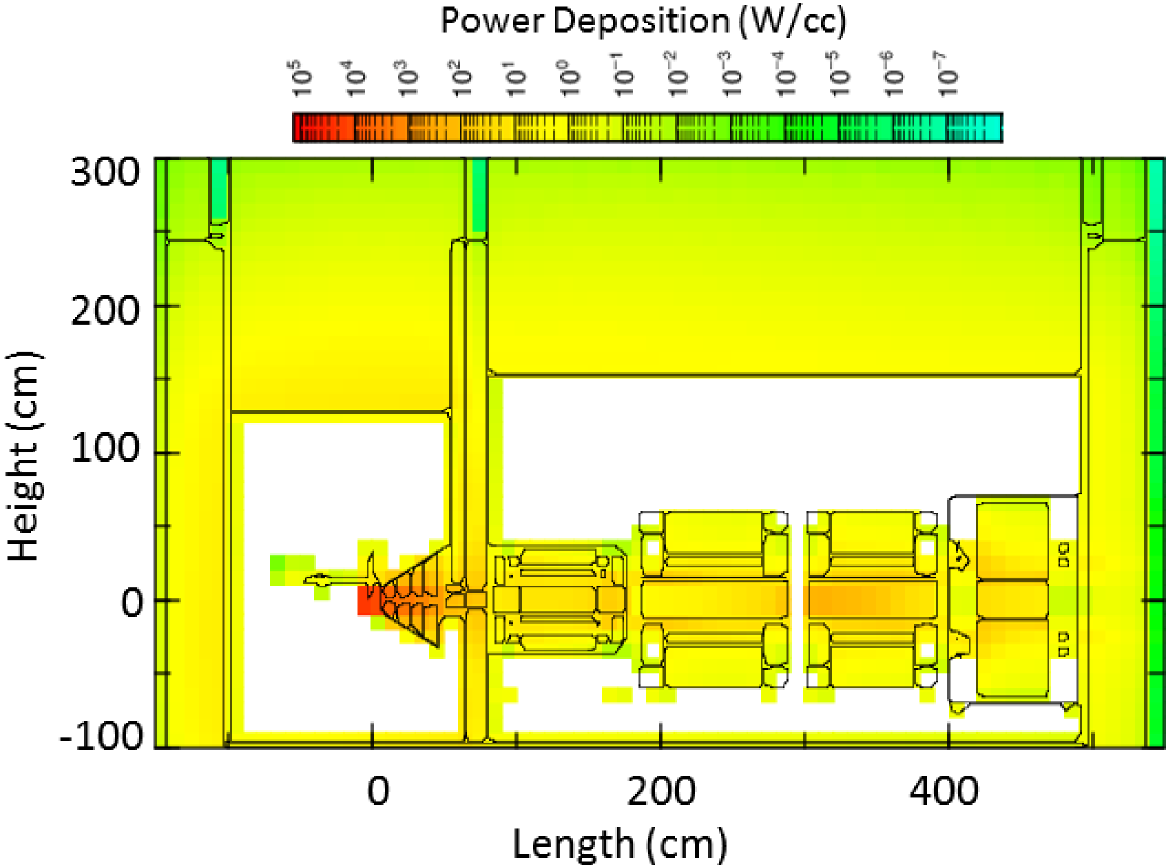
Hot Cell Dose Rates

Calculations of Radiation Power Deposition

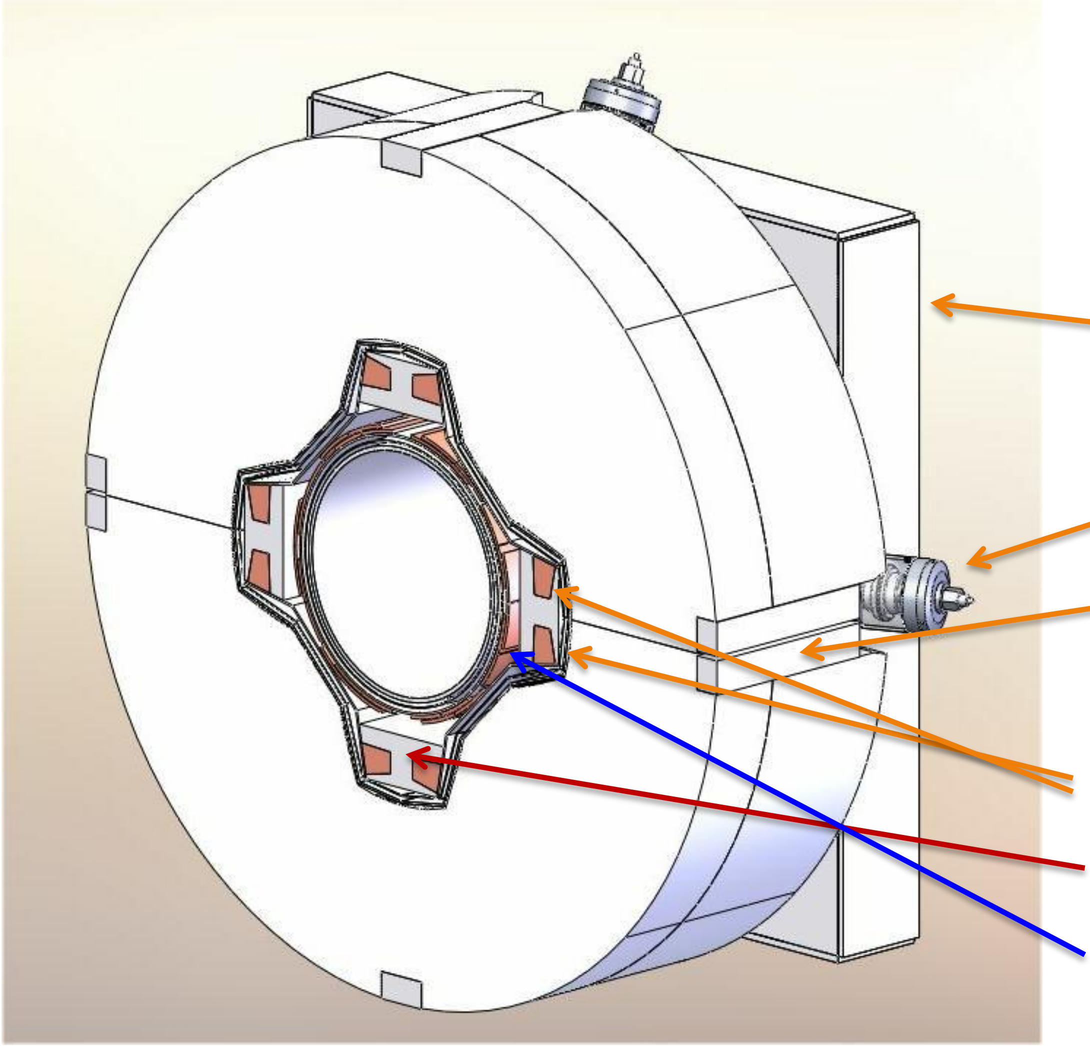
Drives Choice of Tehnology: HTS or LTS

- Power deposition drives detailed vacuum vessel and external shielding design

Radiation power deposition from ^{48}Ca beam at 549 MeV/u (upgrade energy)



FRIB Warm Iron Quad (Section)



FRIB and BNL designs similar

Connection box

Link

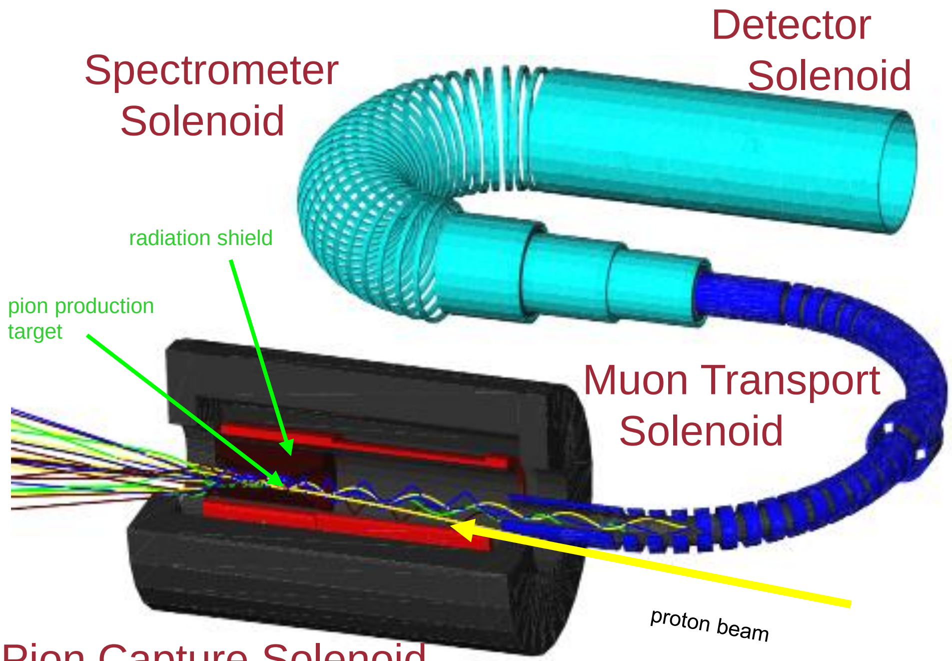
Yoke key

Quad Coil

Support

Multipole coils

COMET (JPARC)



COMET Superconducting Magnet System

- 60 W nuclear heating

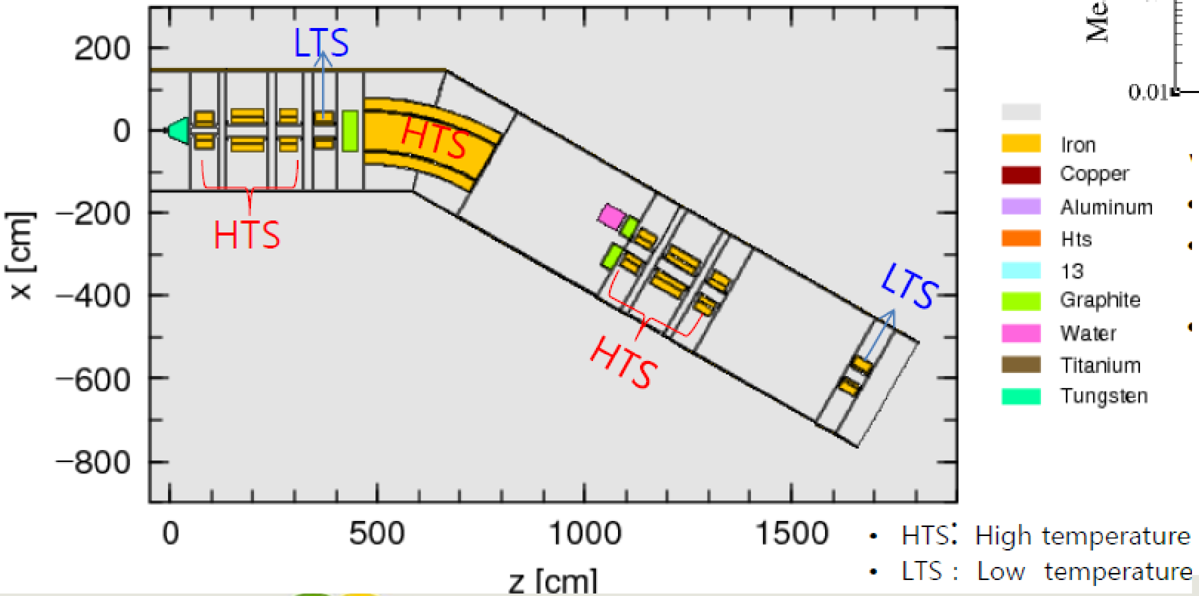
HTS would reduce this by
A factor of ~10

M. Yoshida, RESMM'13 and IPAC'10

RISP (Korea)

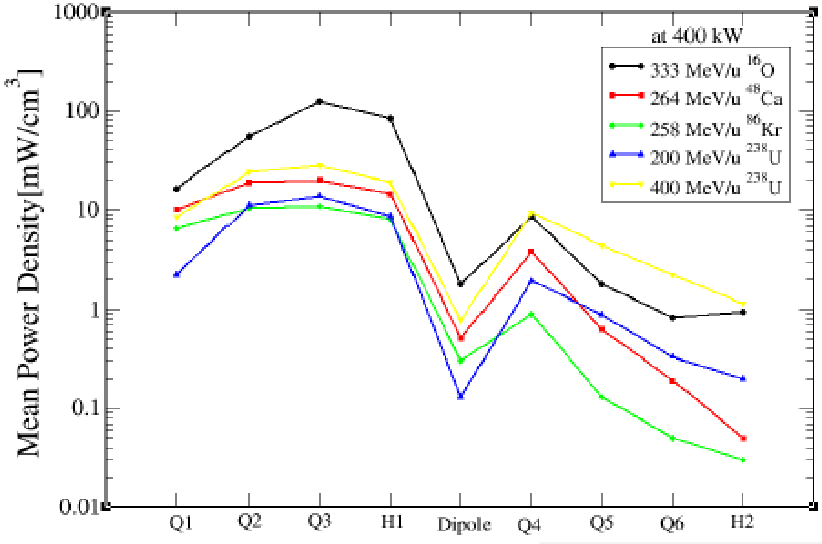
M. Kim, RESMM'14

Note heat input into coils pushing LTS quench limits

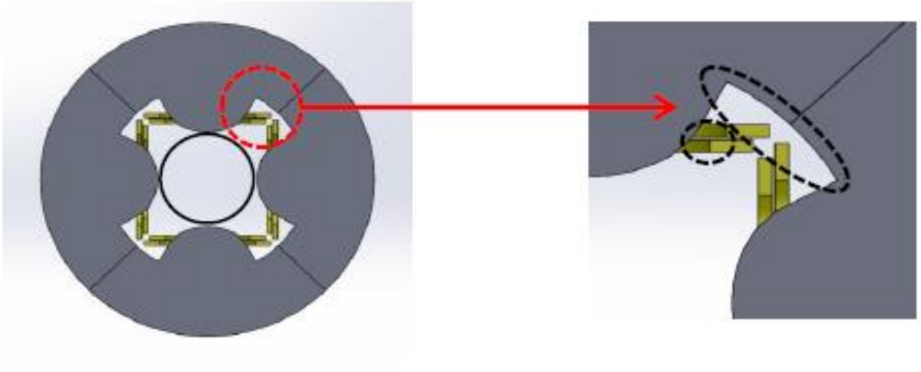


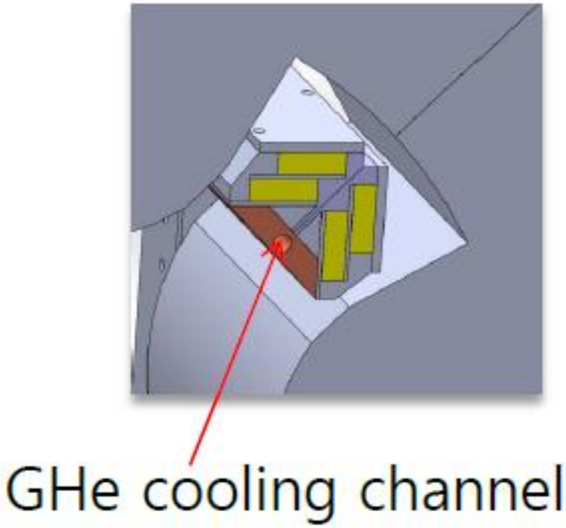
- HTS: High temperature
- LTS : Low temperature

Only for Coils



RISP HTS Quadrupoles

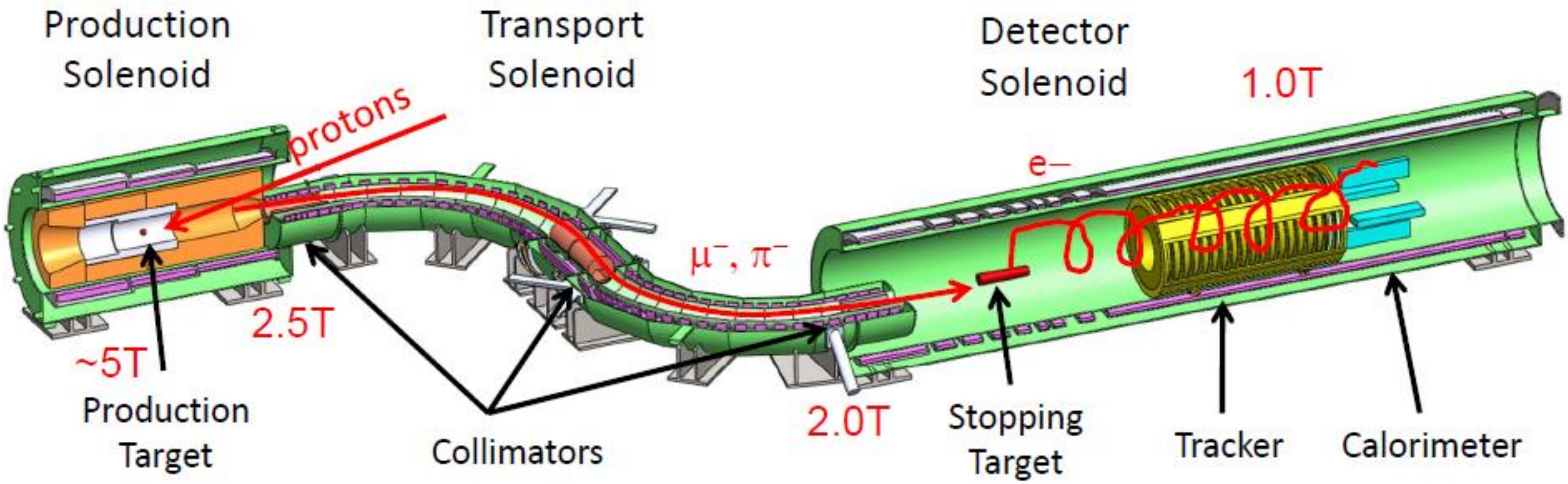




M. Kim, RESMM’14

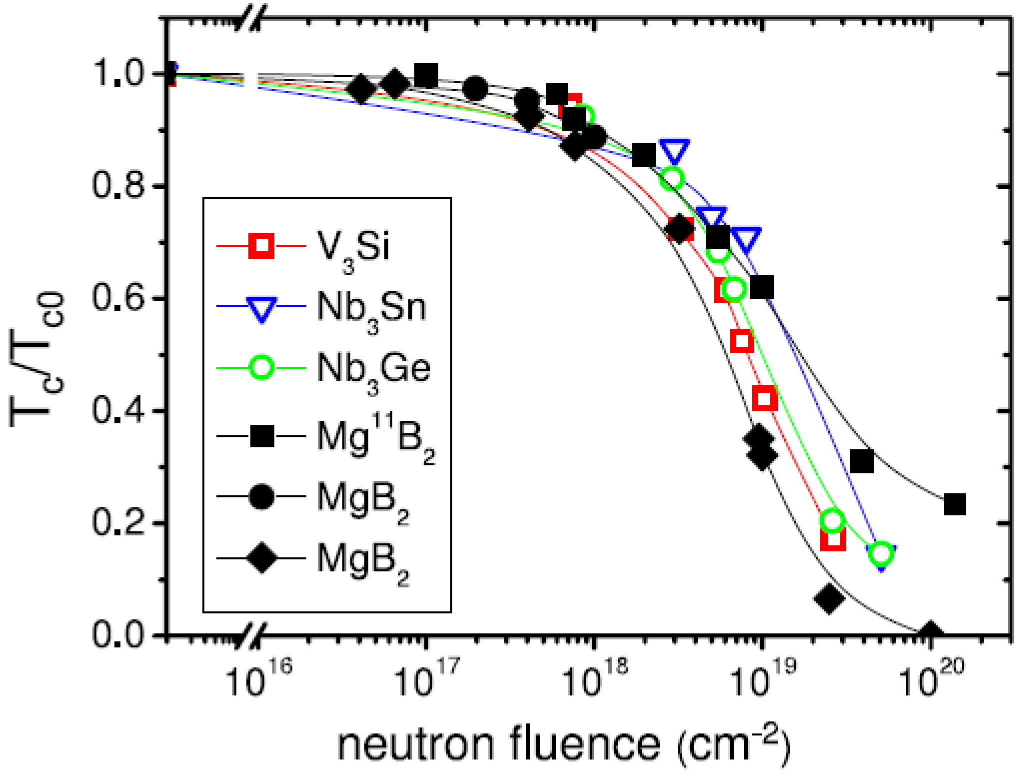
Mu2e (Fermilab)

LTS –> HTS would reduce refrigeration and shielding requirements



M. Lamm, RESMM13

Radiation Resistance MgB2



Putti, Vaglio, Rowell, SST, 043001(2008)

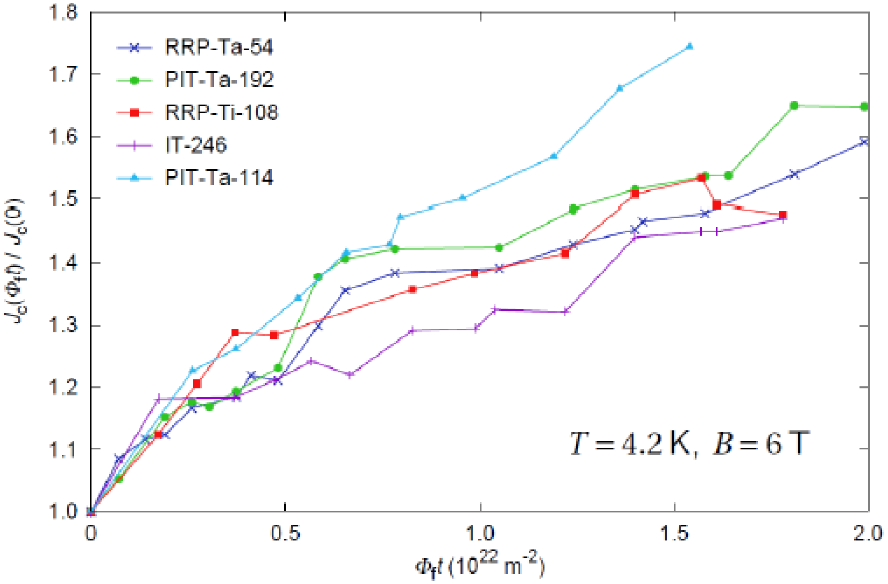
Concern:

High neutron absorption cross section for ^{10}B.

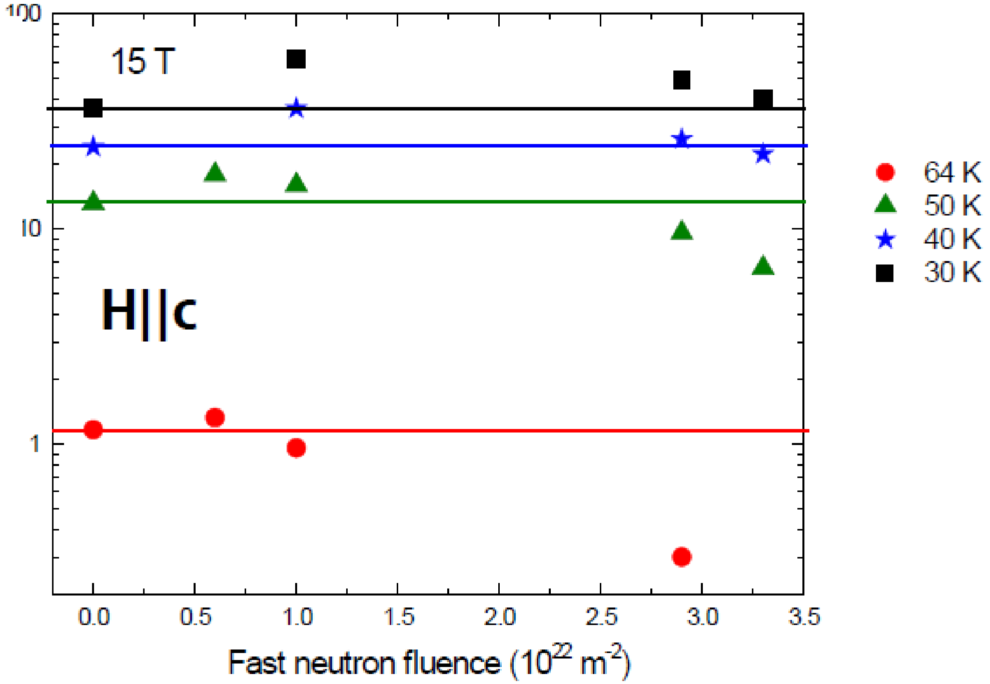
^{10}B is ~20% of natural B

YBCO

Nb_3Sn



YBCO



M. Eisterer, RESMM14

YBCO much better at low temperatures. Looks more like Nb_3Sn.

Radiation Damage

- Significant body of work on radiation damage to YBCO
  - By people at this workshop, among others
  - A summary is that it has sufficient radiation tolerance to be useful
- MgB_2 also has a body of work
  - Again, looks OK at lower temperatures
- BSCCO less studied (Zeller, Adv Cryo Eng 54 416(2010))
  - 2223 looks to be similar to Nb_3Sn
  - Likely 2212 is the same
- Has the necessary radiation tolerance

Radiation Damage to Other Things

- Except for stainless steel insulation for YBCO coils (Gupta, et al, ASC14 and references within), other materials require insulation and/or potting
- Cyanate esters –
  - good radiation resistance even when mixed with epoxy (A. Idesaki, et al., RESMM'13)
  - More: R. Prokopec, et al., Adv Cryo Eng 54 182(2008)

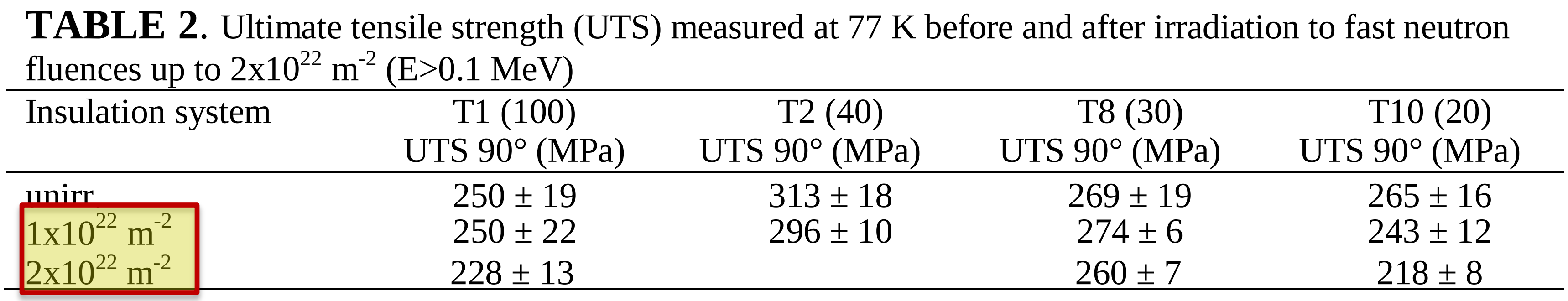


TABLE 2. Ultimate tensile strength (UTS) measured at 77 K before and after irradiation to fast neutron fluences up to $2x10^{22}$ m^{-2} (E>0.1 MeV)

Insulation system	T1 (100) UTS 90° (MPa)	T2 (40) UTS 90° (MPa)	T8 (30) UTS 90° (MPa)	T10 (20) UTS 90° (MPa)
unirr	250 ± 19	313 ± 18	269 ± 19	265 ± 16
$1x10^{22}$ m^{-2}	250 ± 22	296 ± 10	274 ± 6	243 ± 12
$2x10^{22}$ m^{-2}	228 ± 13		260 ± 7	218 ± 8

Note: This is about the same sensitivity as the superconductor

Loose Ends

- Protection issues
  - Copper stabilizer – reduced heat transfer – HTS less of a concern at elevated temperatures (already worse)
  - Parallel wound secondary circuit:
    - High voltages for rapid energy transfer
    - Require insulation for > 1 kV for large systems
      - Sol-gel only good for 200 V (J. Lu, NHMFL research report)
  - Insulation for quench heaters
  - Sensitive electronics close to magnets in high-radiation areas?
- MgB_2 for detector magnets
  - Helium plants produce cold gas at 30-50 K
    - Heat exchanger needed, lose efficiency
    - Radiation damage higher at higher temperatures
  - Some magnets very large. How to wind and react?
    - CICC?
    - Cable?

Summary

- HTS has the necessary radiation resistance
- HTS in accelerator magnets at 4 K support going to higher fields and higher beam energy/luminosity if cabling and fabrication issues solved
  - Radiation resistance better at low temperatures
- Detector magnets can reduce operational costs
  - Better efficiency
  - Need lower material costs