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HTS Magnet technology as path to Fourth and Fifth Generation ECR ion sources

BCMT

Tengming Shen, Laura Garcia Fajardo, Daniela Leitner, Soren Prestemon, GianLuca Sabbi

Abstract

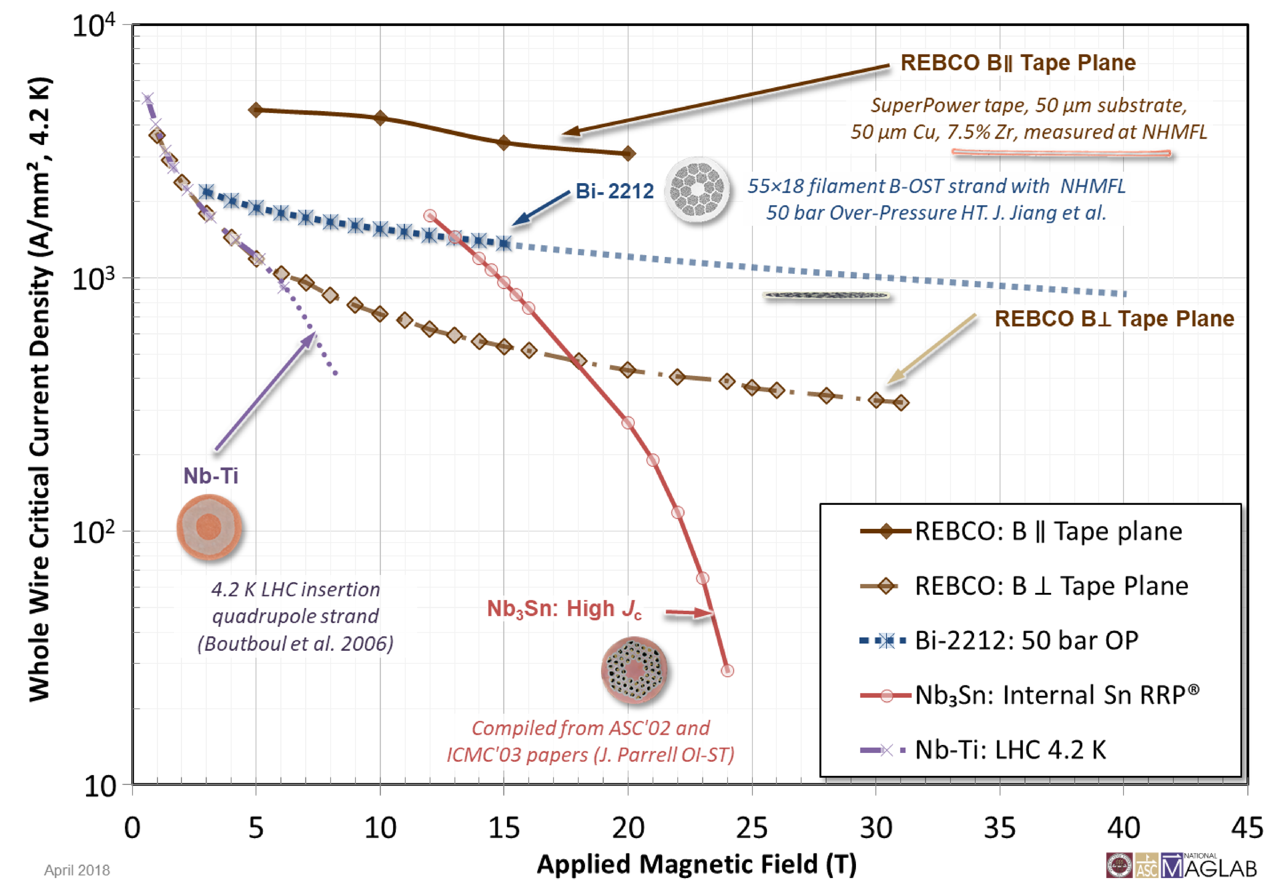
- ➔Novel superconducting magnet systems for ECR ion sources (ECRIS) operating at frequencies ≥ 28 GHz are a core technology to be developed over the next many years.
- ➔ Current state-of-the-art magnet systems are based on the Nb-Ti technology at 4.2 K and are the new standard injectors for next generation heavy ion beam facilities.
- ➔ Nb_3Sn provides an immediate option for reaching higher frequencies, which would further improve the performance of high charge state ECR ion sources. However, Nb_3Sn designs are limited to about 56 GHz.
- ➔High temperature superconductors (HTS) have the potential to become a versatile future option for operating at frequencies ≥ 37.5 GHz, at ≥ 20 K, not being limited to 56 GHz due to the greater than 100 T magnetic field limit of several HTS materials.
- ➔Superconducting ECR ion sources at 20 K will allow to optimize ECR ion sources independently from the x-ray load restrictions that is present at 4 k and 2 K cryogenic systems.
- ➔This poster presents a conceptual option for such a magnet system, based on REBCO technology.

Design Parameters For High Performance ECR Ion Sources

- $B_{ECR} = F_{rf}(GHz)/28(GHz) \cdot T$
- $B_{inj}/B_{ECR} = 4$
- $B_{rad}/B_{ECR} = 2$
- $B_{ext} \approx 0.9 B_{rad}$

For the minimum B-field of the trap one can find

- $B_{min} \approx 0.4 B_{rad}$ and
- $0.4 < B_{min}/B_{ECR} < 0.8$



Critical current density (J_e) of different HTS and LTS technologies at 4.2 K

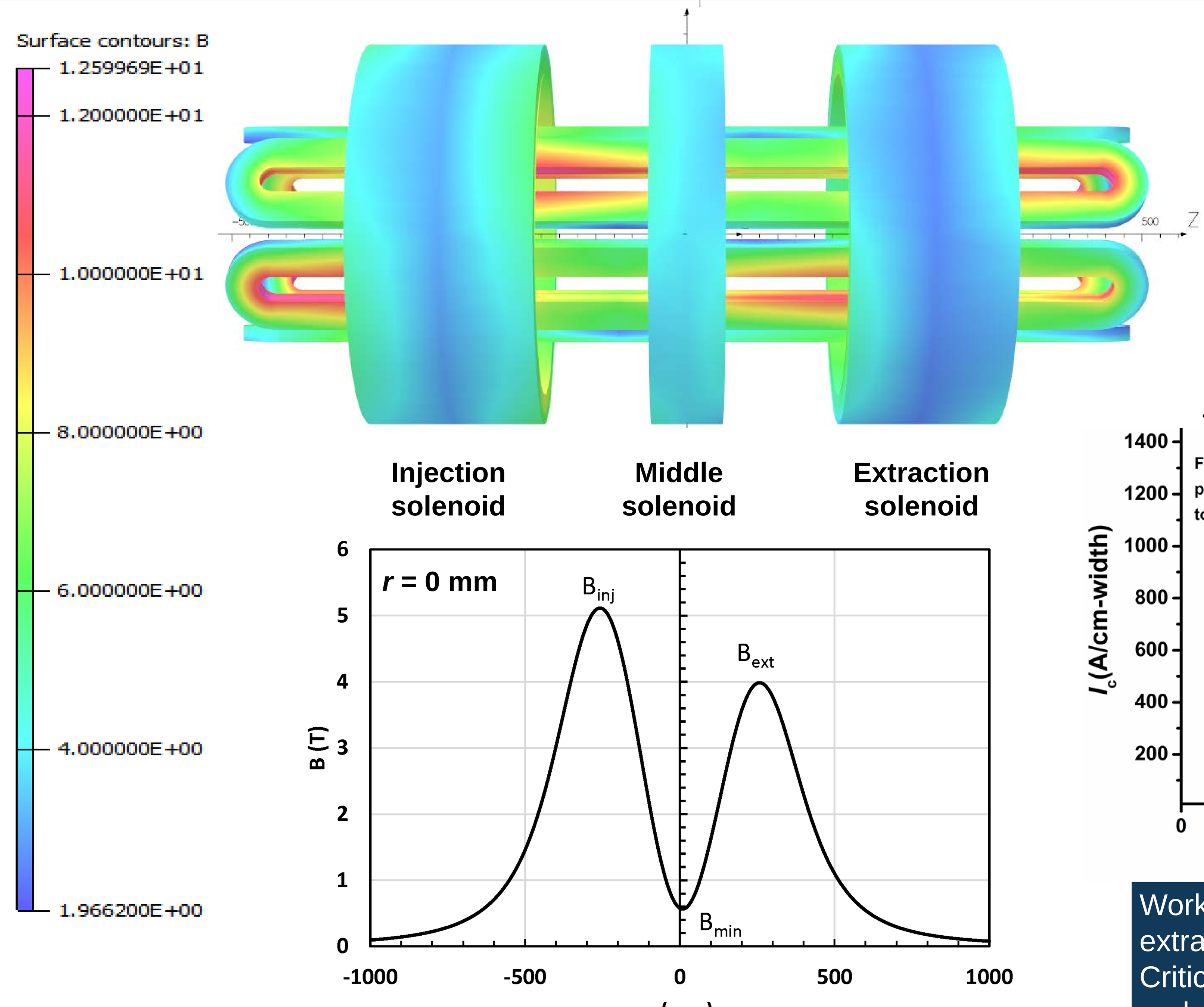
- ➔ Notice the higher J_e of REBCO tapes and Bi-2212 round wires at higher magnetic fields, compared to the J_e of LHC Nb-Ti wires and RRP Nb_3Sn wires for the LHC high luminosity upgrade.
- ➔ Notice that J_e of REBCO tapes strongly depends on the orientation of the magnetic field: when the field is applied parallel to the tape's surface, J_e is much higher than when the field is applied perpendicular to the tape's surface.

P. J. Lee, Applied Superconductivity Center, National High Magnetic Field Laboratory, Florida State University [Online]. Available: http://www.magnet.fsu.edu/magnettechnology/research/asc/images/jcprog-06-112706col.png

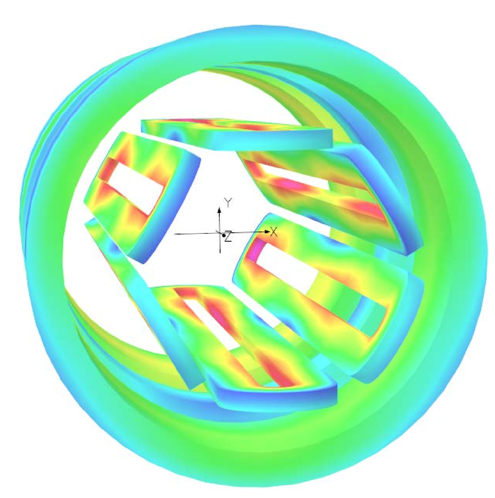
Tuning Considerations

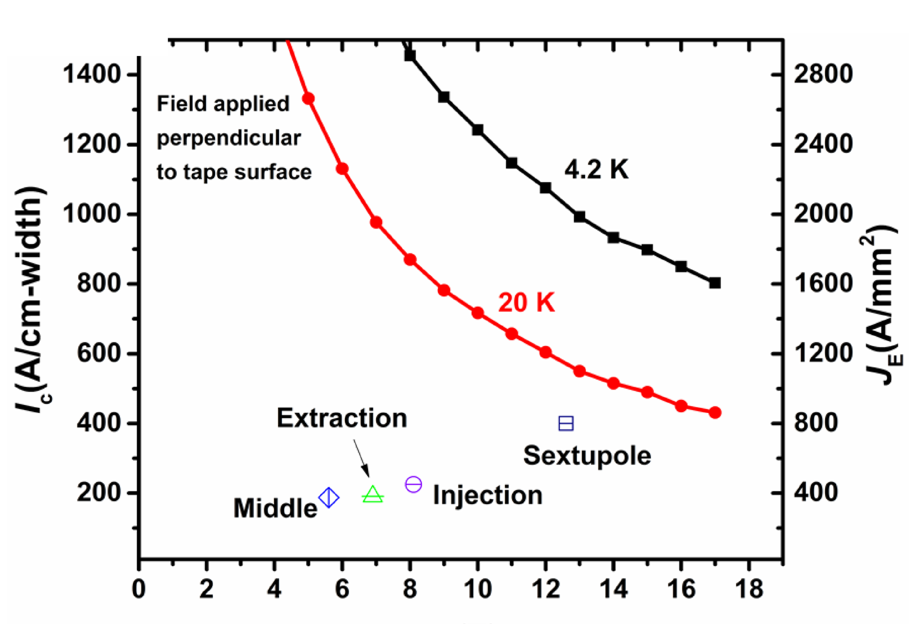
- ➔The high temperature tail of the electron energy spectrum (with energies above 200 keV) is key to establishing the electrostatic confinement necessary for the creation of high charge state ions.
- ➔ The hot electron temperature depends neither on the magnetic field gradient at the ECR zone, as previously believed, nor on the heating frequency. The temperature mainly depends on the absolute value of the minimum B-field.
- ➔ For a given minimum B-field higher heating frequencies will result in higher plasma densities (frequency scaling law still applies).
- ➔ Shallower magnetic field gradients at the ECR zone improves the heating efficiency and allows to reach higher plasma density and performance at a lower power density.
- ➔ Third generation superconducting ECR ion sources compromise between optimum minimum B-field (shallow gradient) and acceptable heat load into the cryostat due to cooling power limitations of the 4 K cryogenic systems.

Case Study for a Magnetic Design of a 37.5 GHz ECRIS Based On REBCO Technology at 20 K



Magnetic field density along the main axis of the ECRIS (at r = 0 mm), when all the magnet coils are powered at the nominal current.

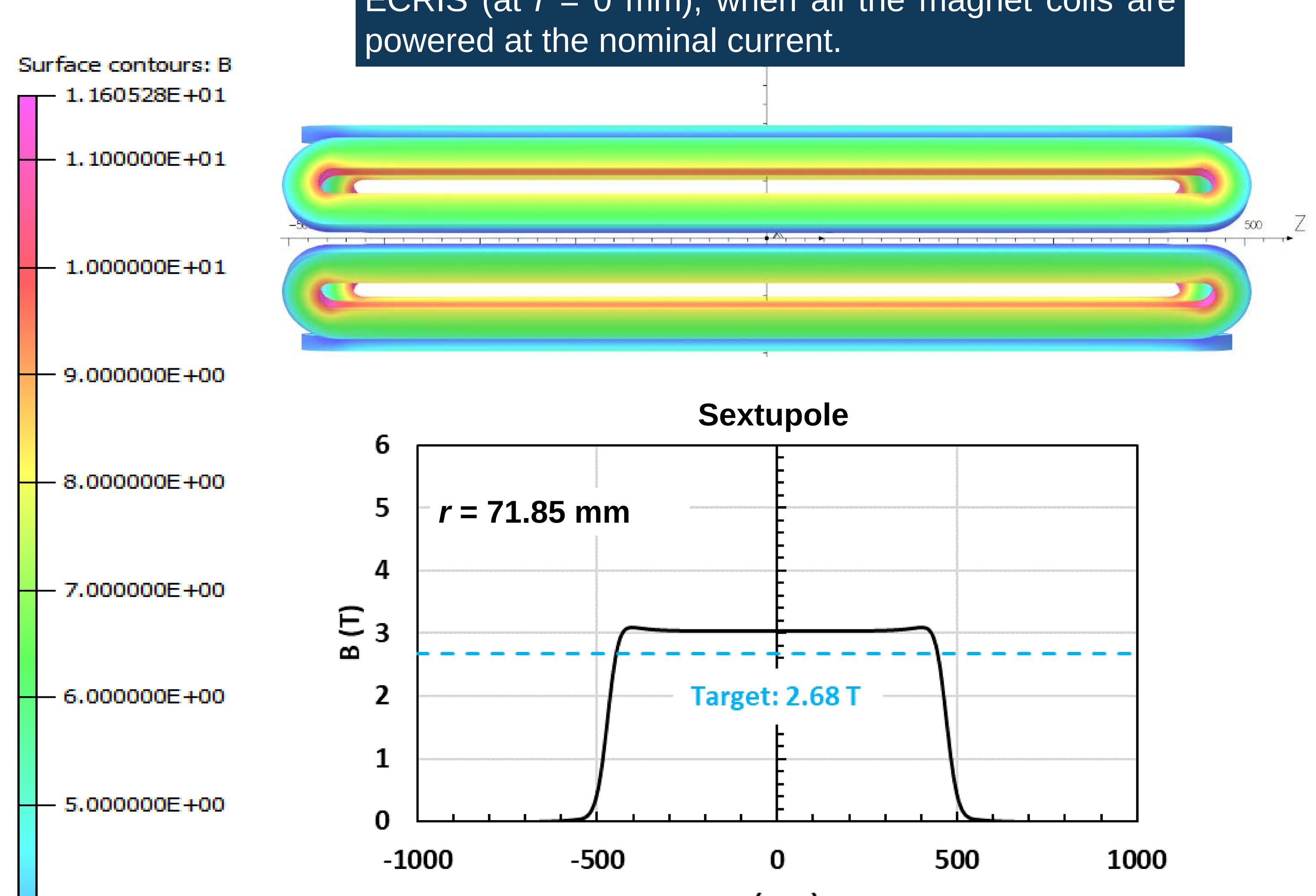




Working point of the injection, middle and extraction solenoids, and the sextupole. Critical surface of the REBCO tape at 20 K and 4.2 K, considering the field applied perpendicular to the tape's surface.

Coils	Sextupole
Fabrication Method	2-layer flat racetrack coil wound using the double-pancake technique
Bore Diameter (mm)	200
Coil inner winding radius (mm)	15
Coil total length (mm)	1000
Coil thickness (mm)	36
Coil width (mm)	16
REBCO tape thickness (mm)	0.05
REBCO tape width (mm)	8
Insulation	None between turns
J_{coil} (A/mm²)	800
Operation current I (A)	320
B_{peak} (T)	12.6
Piece length/sextupole coil (m)	3185
REBCO tape total length (m)	19110

Key parameters of the sextupole coils for a conceptual of 37.5 GHz ECRIS REBCO magnet working at 20 K.
The REBCO tape is not insulated. The current density is 800 A/mm².



Magnetic field density parallel to the main axis of the ECRIS (at r = 71.85 mm), when only the sextupole coils are powered at the nominal current.

Coils	Injection solenoid	Central solenoid	Extraction solenoid
Fabrication Method	A stack of double pancake coils		
Coil inner diameter (mm)	352	352	352
Coil length (mm)	194.4	64.8	145.8
Coil thickness (mm)	32	32	32
z-location at the central axis of the solenoid (mm)	-250	0	250
B (T) at x = 0, y = 0, z = 0	5.4	0.5-1	3.8
J_{coil} (A/mm²)	310	250	255
REBCO tape width (mm)	8	8	8
REBCO tape thickness (mm)	0.05	0.05	0.05
Insulation	Stainless steel, 25 μm in thickness	Stainless steel, 25 μm in thickness	Stainless steel, 25 μm in thickness
Operation current I (A)	186	183	168
B_{peak} (T)	8.6	5.4	6.8
I (A) for 1 cm width	232.5	229	210
Peak hoop stress (MPa) Ballpark BJR calculation	469	290	335
Number of Double Pancakes	12	4	9
REBCO tape piece length (m) per double pancake coil	1040	1040	1040
REBCO tape total length (m)	12480	4160	9360

Key parameters of the solenoids for a conceptual design of 37.5 GHz ECRIS REBCO magnet working at 20 K. The REBCO tape is partially insulated