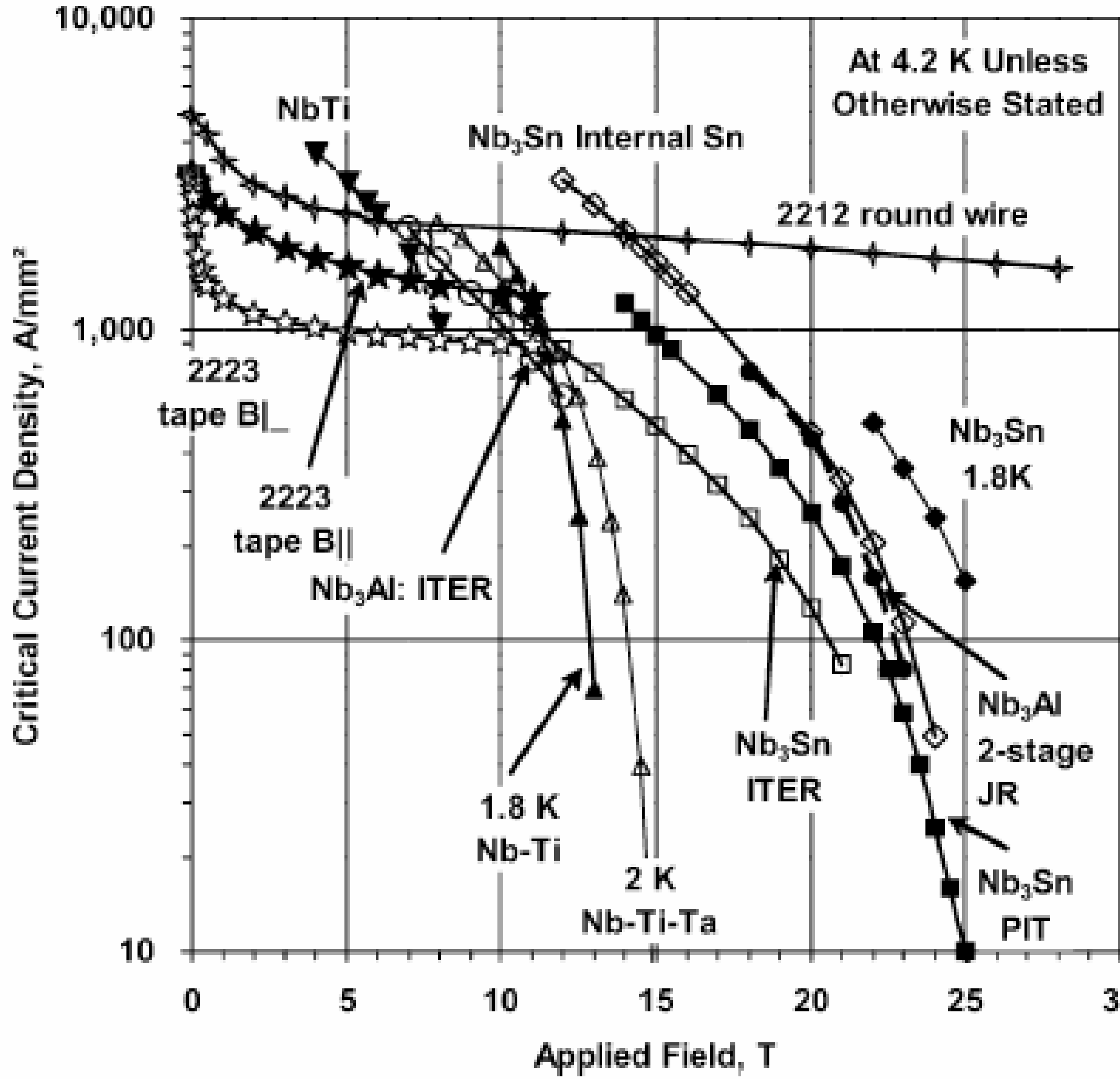
Stellarator magnet options

Electrical/winding issues

- Elegant solution for ARIES-AT does not extrapolate well for ARIES-CS
  - High Temperature Superconductor epitaxially deposited on structure
  - Magnet protection for HTS magnets very difficult because of very low speed of propagation of quench
    - Very good mechanical and thermal contact between HTS and structure makes quench energetically impossible (very high temperature/energy margins)
- Instead ARIES CS magnet wound in structural semi-continuous cases

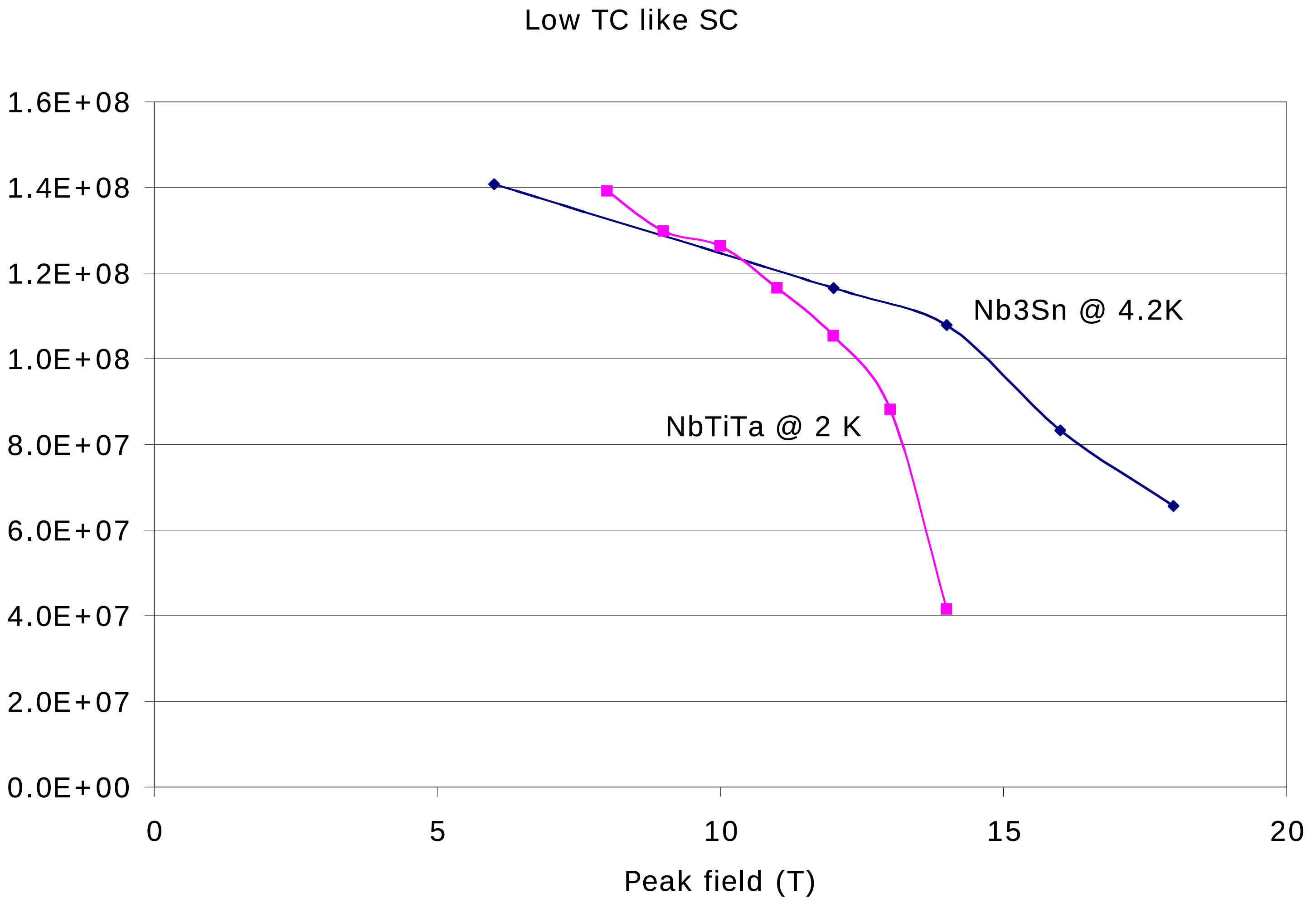
Winding for ARIES-CS

- Need ductile conductor because of strains required during winding process
- Options:
  - NbTi-like SC
    - Helias Stellarator design uses NbTi at reduced temperature (2K)
    - Problem with temperature margin
  - Wind and react Nb_3SN or MgB_2
    - Need to maintain structural integrity during heat treatment (700 C for a few hundred hours)
    - No organic material, difficult to use glass.



At 4.2 K Unless Otherwise Stated
NbTi
Nb_3Sn Internal Sn
2212 round wire
2223 tape B|_
2223 tape B||
Nb_3Al: ITER
Nb_3Sn 1.8K
1.8 K Nb-Ti
2 K Nb-Ti-Ta
Nb_3Sn ITER
Nb_3Al 2-stage JR
Nb_3Sn PIT
Critical Current Density, A/mm²
Applied Field, T
10,000
1,000
100
10
0
5
10
15
20
25
30

Low temperature SC winding pack current density

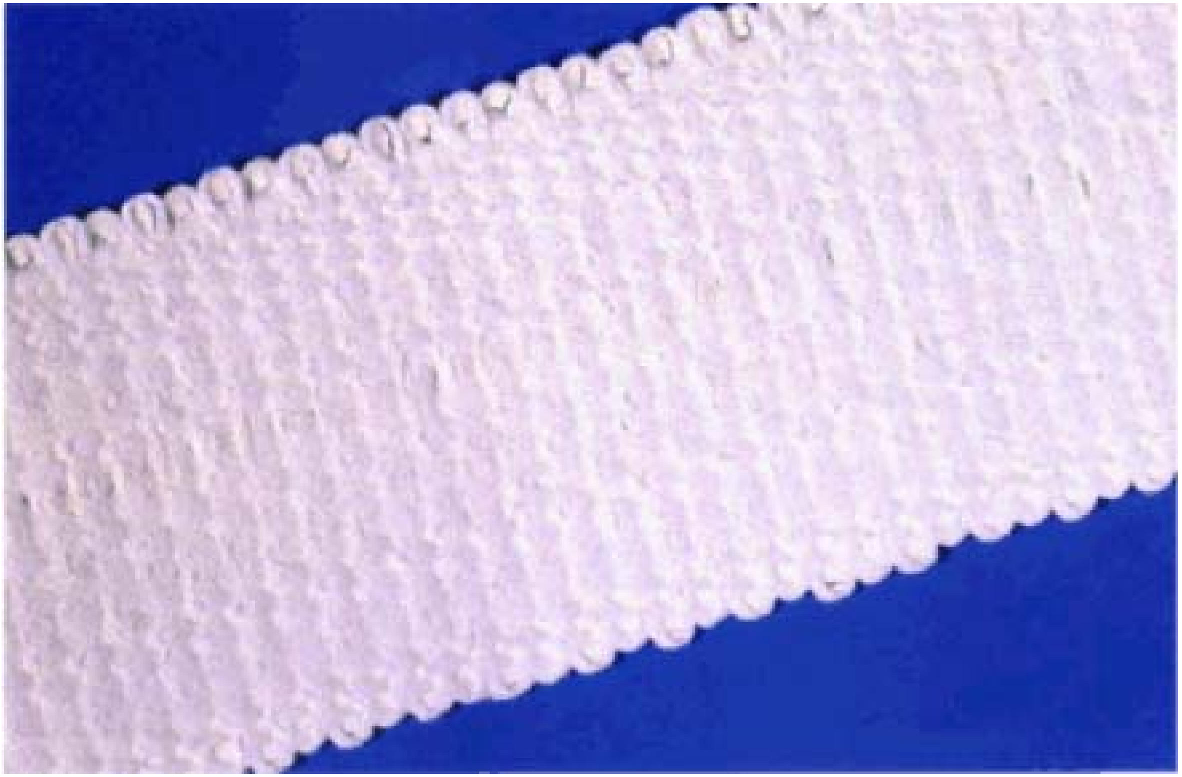


Issues that need to be addressed for Wind-and-React magnets

- Minimization of the conductor size
  - Ease the winding process

- Inorganic insulation, assembled with magnet prior to winding and thus capable to withstand the Nb_3Sn heat treatment process.
  - Two groups (one in the US, the other one in Europe) have developed glass-tape that can withstand the process
  - The US process uses organic resin/epoxy after heat treatment
  - The EU process uses all inorganic process

EU process tape (clay/glass, with glass tapes)



A. Puigsegur et al., *Development Of An Innovative Insulation For Nb3sn Wind And React Coils*

- The dielectric strength at 4.2 K is ~ 75 kV/mm
  - similar to traditional insulations with vacuum-impregnated of epoxy resin

Quench protection

- To minimize size of conductor for winding, minimize copper in conductor
  - J_{Cu} ~ 200 A/mm^2 (200 MA/m^2)
  - Magnet dump < 4 s, preferable ~ 2 s (150 K)
  - 50 GJ stored energy
  - 20 kV maximum voltage (0.5 mm thick insulation)
  - 2 dump circuits per coil
  - Conductor current ~ 40 kA
  - Conductor size ~ 3.5 cm^2
  - Substantially smaller than ITER conductor
  - Can it be wound inside case?

Consistency

- Magnet design
  - Use Nb_3Sn, wind and react
  - Use 0.5 mm inorganic insulation w/o organic resin/epoxy (20 kV max voltage)
  - Use 40 kA winding pack current
  - Use 2 dump-circuits per coil (~50 pairs of current leads)
  - 0.1 W/kA, ~500 W cooling
- Not pretty, but self-consistent
- Need to provide costing to system code

Future work

- Work with UCSD and ORNL for a better definition of the coil structure
  - Coil looks wimpy in the outside, very thick in the inside
  - Bucking vs wedging
    - Heat loads to coil
    - Transfer of loads to warm support