Performance limits of accelerator dipole and quadrupole for a Muon Collider

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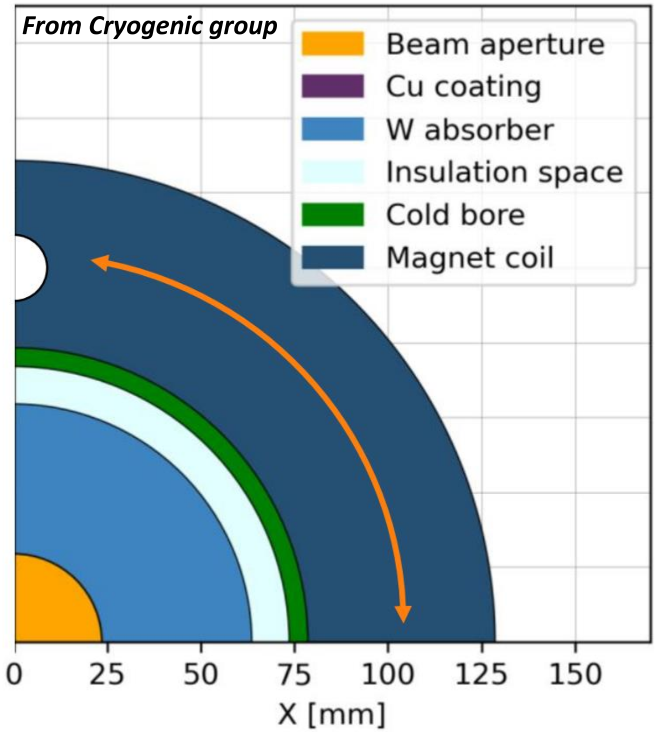
WP7 – Task 4

Introduction

- This work is under the no-iron hypothesis.
- We use a Python code in which we have implemented the analytic formulas for the dipole and quadrupole in cos-theta approximation.
- Approximations are used to validate the procedure, and then we can study more complicated configurations (for example, sector magnets with iron yoke).



Aperture of the collider magnet ~ 150 mm

Temperature of the cold mass: 4 options

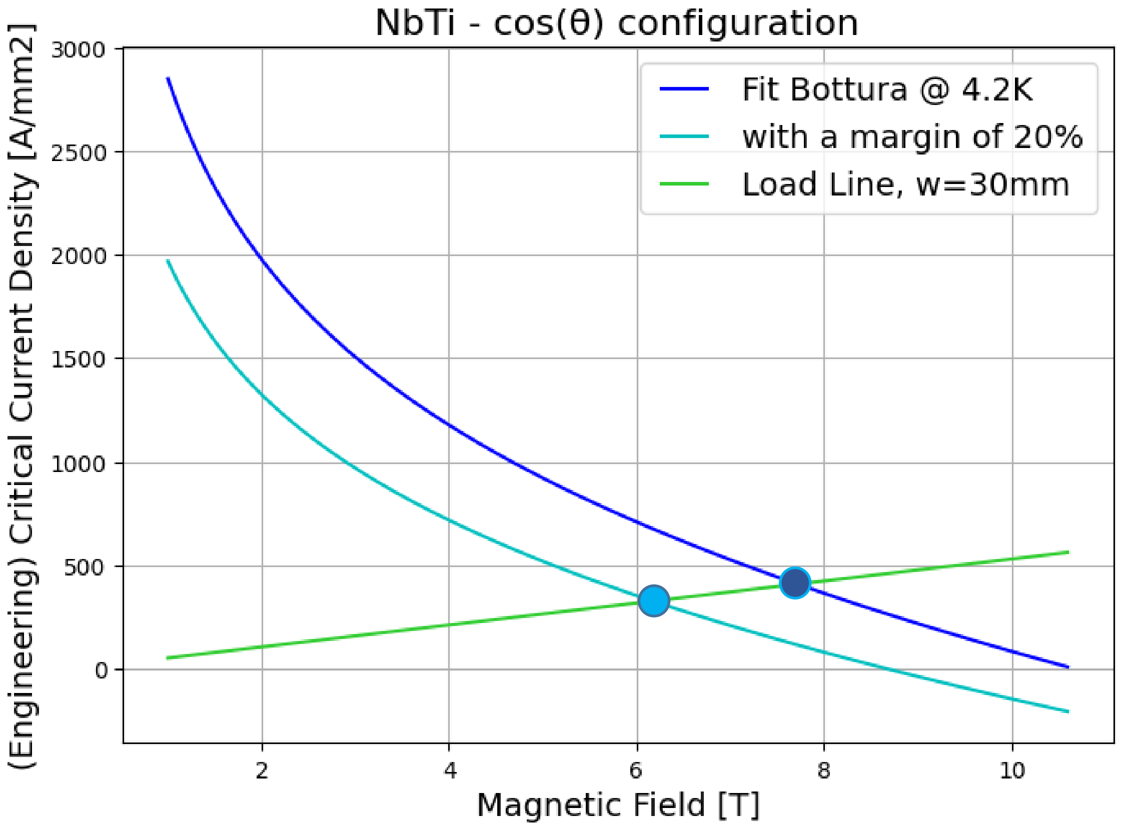
- 1.9 K
- 4.2 K
- 10 K
- 20 K

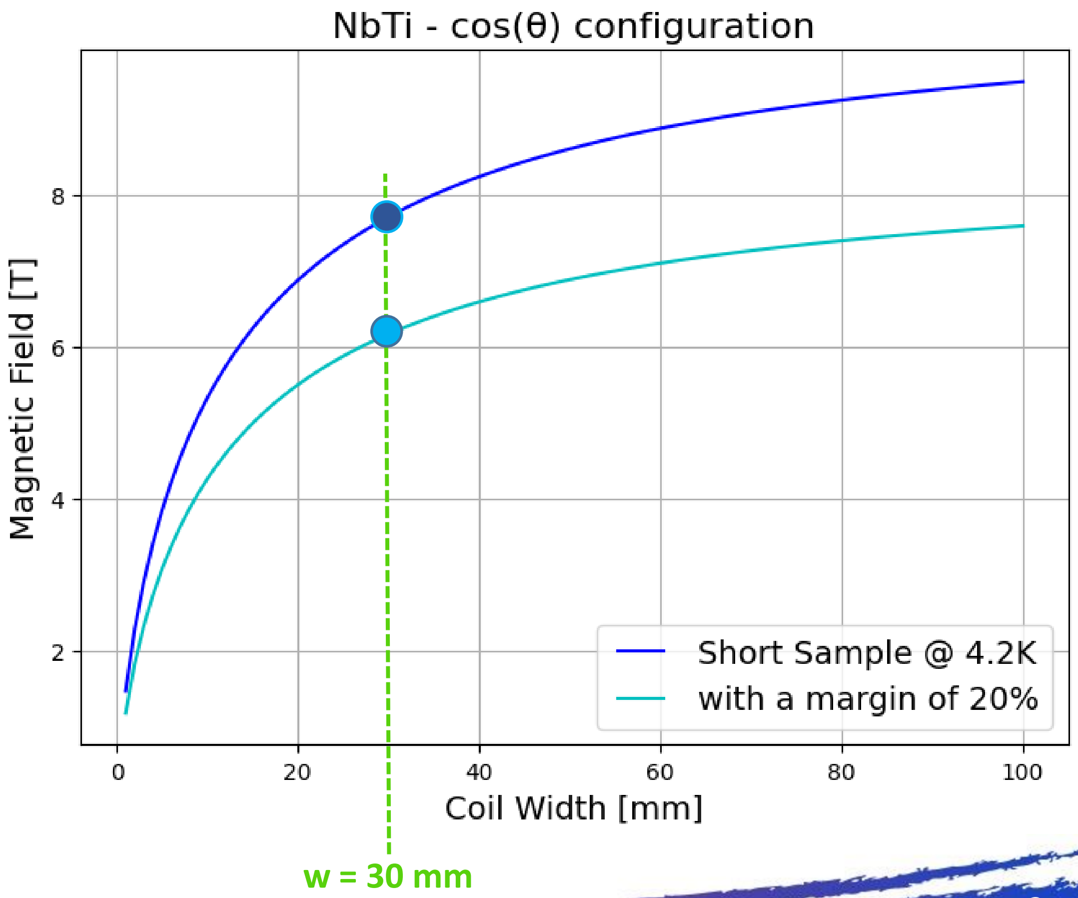
Superconducting materials:

- LTS – NbTi and Nb_3Sn
- HTS - YBCO

Dipole - Performances of NbTi

- Fit's data from the LHC cable
- T = 4.2 K
- Fixed aperture = 75 mm
- Filling factor = 0.3 →
  - Ratio between normal conductor and superconductor.
  - Voids
  - Insulation
- *Cosθ* configuration





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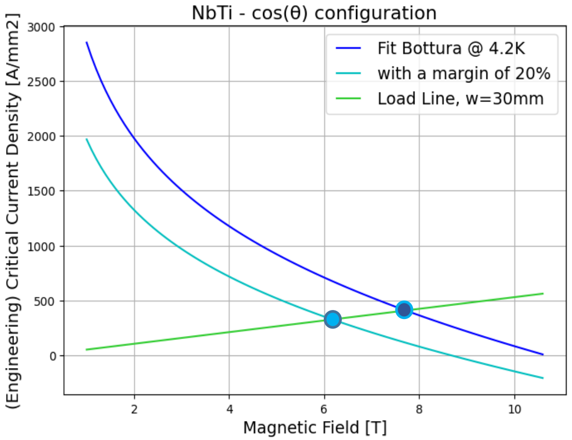

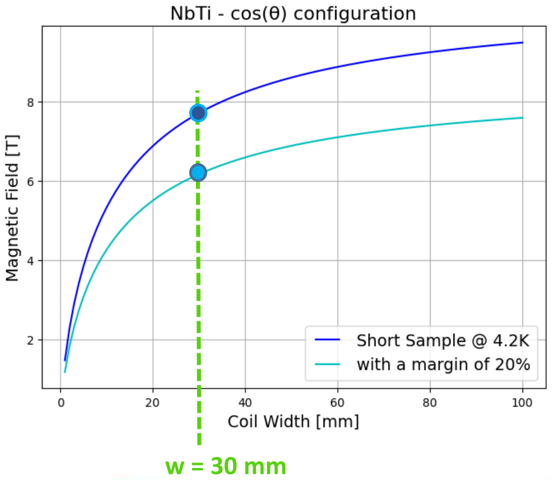

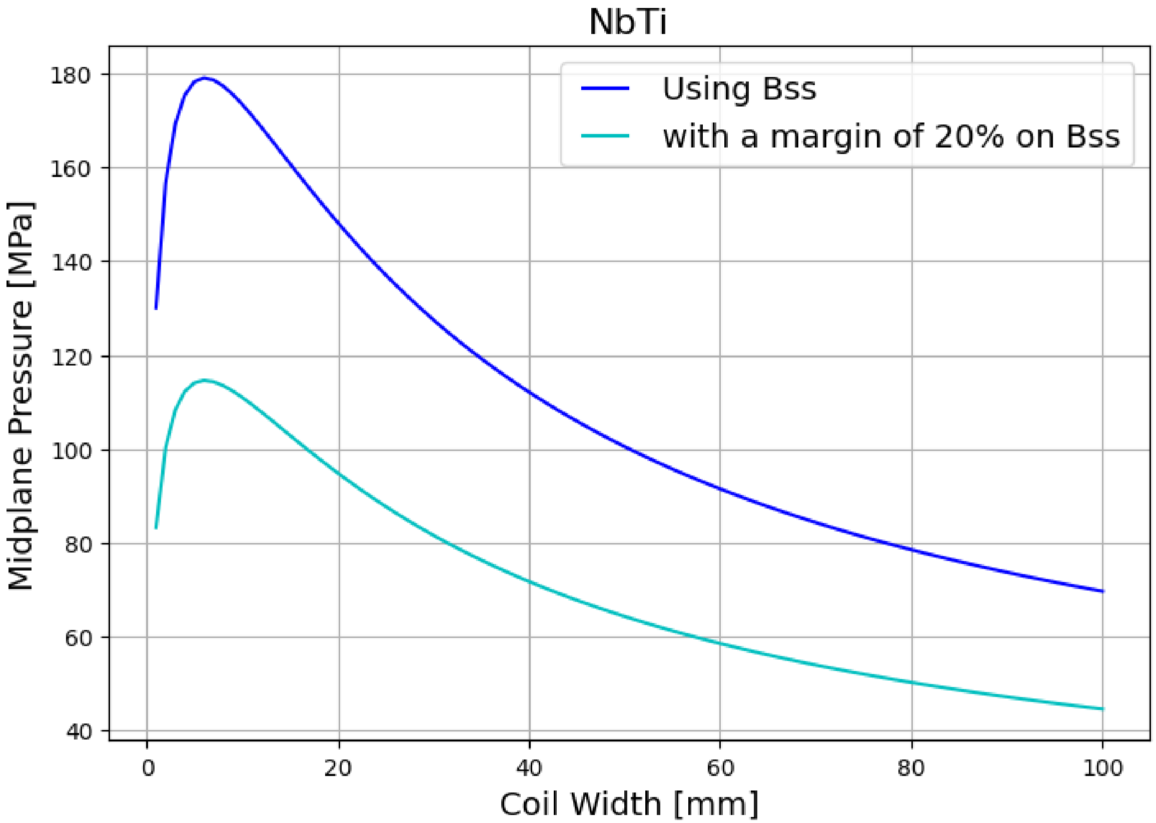

Dipole - Performances of Nb_3Sn

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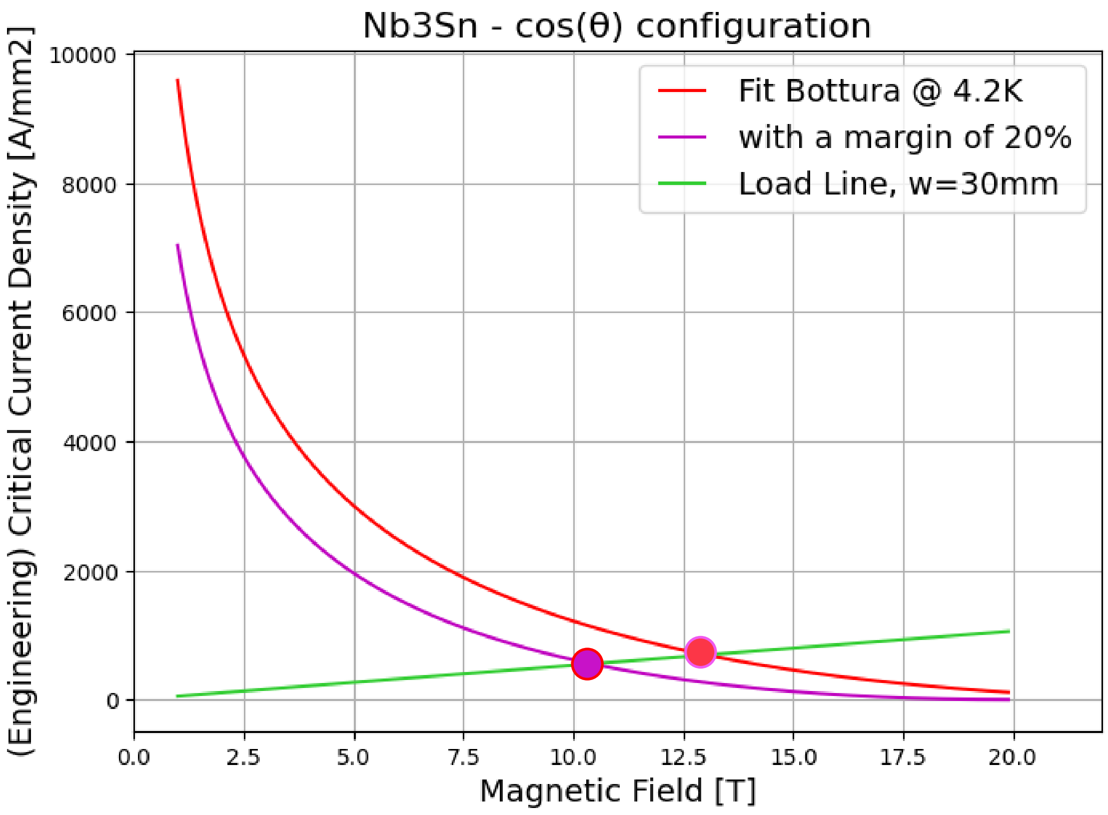
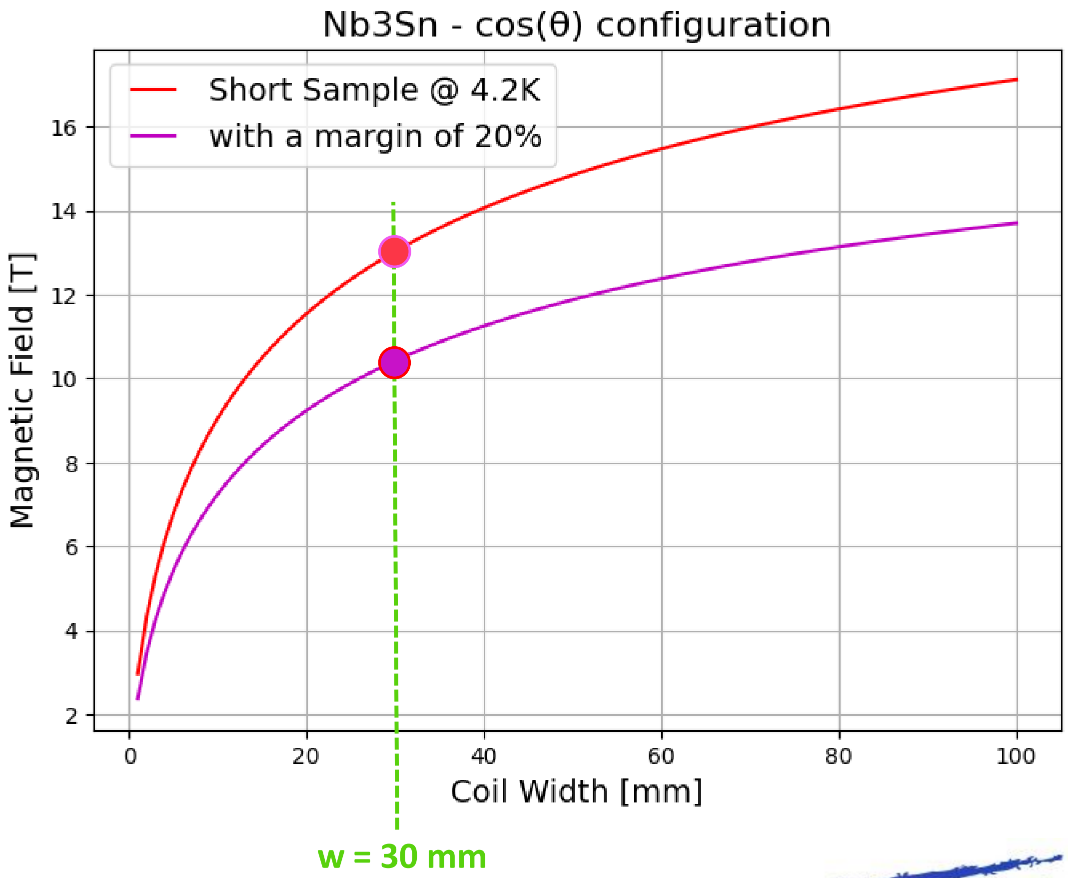
- Fit's data from the FCC target performance
- Filling factor = 0.3
  - Ratio between normal conductor and superconductor.
  - Voids
  - Insulation
- Fixed aperture = 75 mm
- T = 4.2 K
- *Cosθ* configuration





Dipole - Performances of Nb_3Sn

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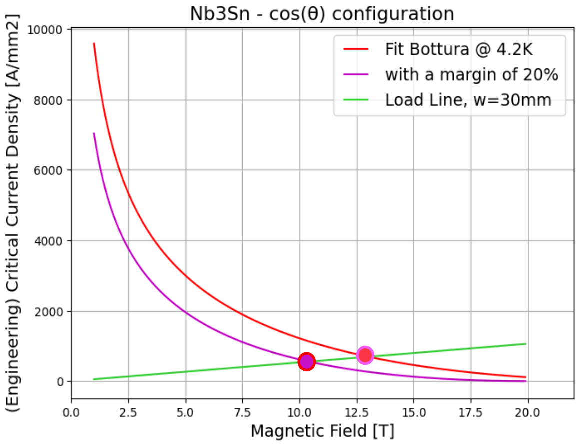
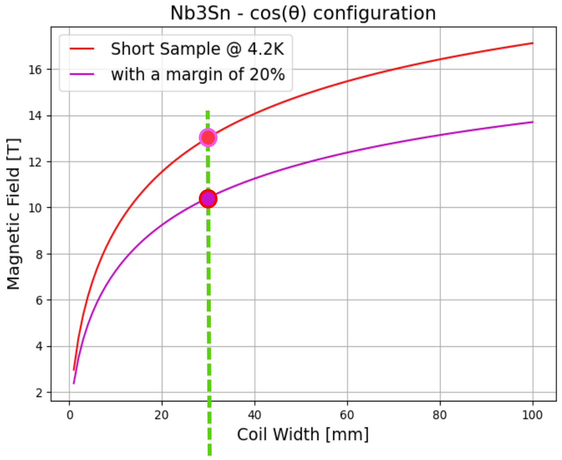
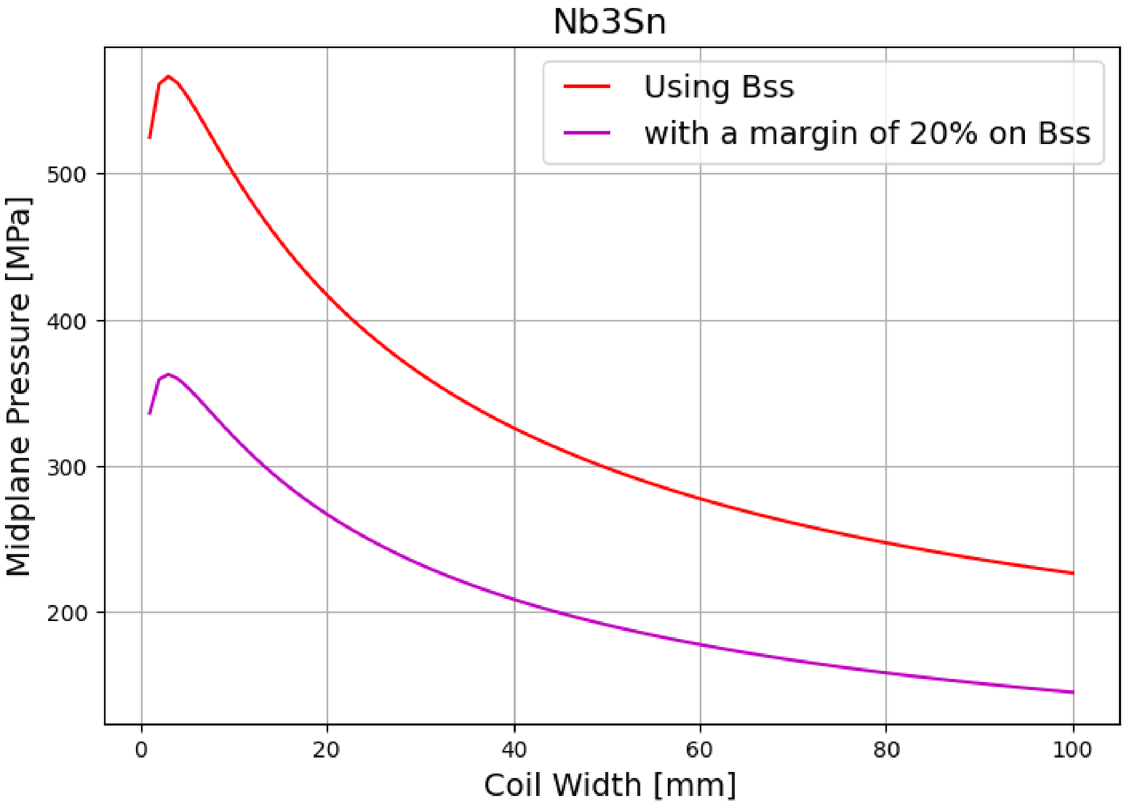


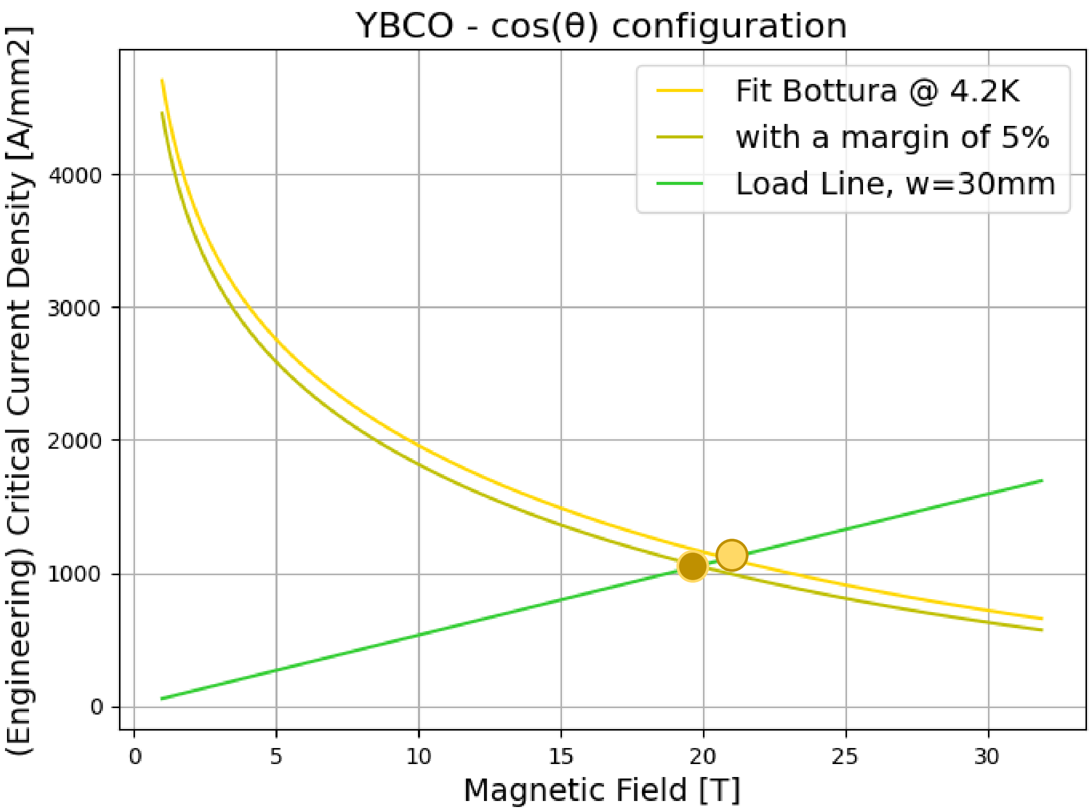


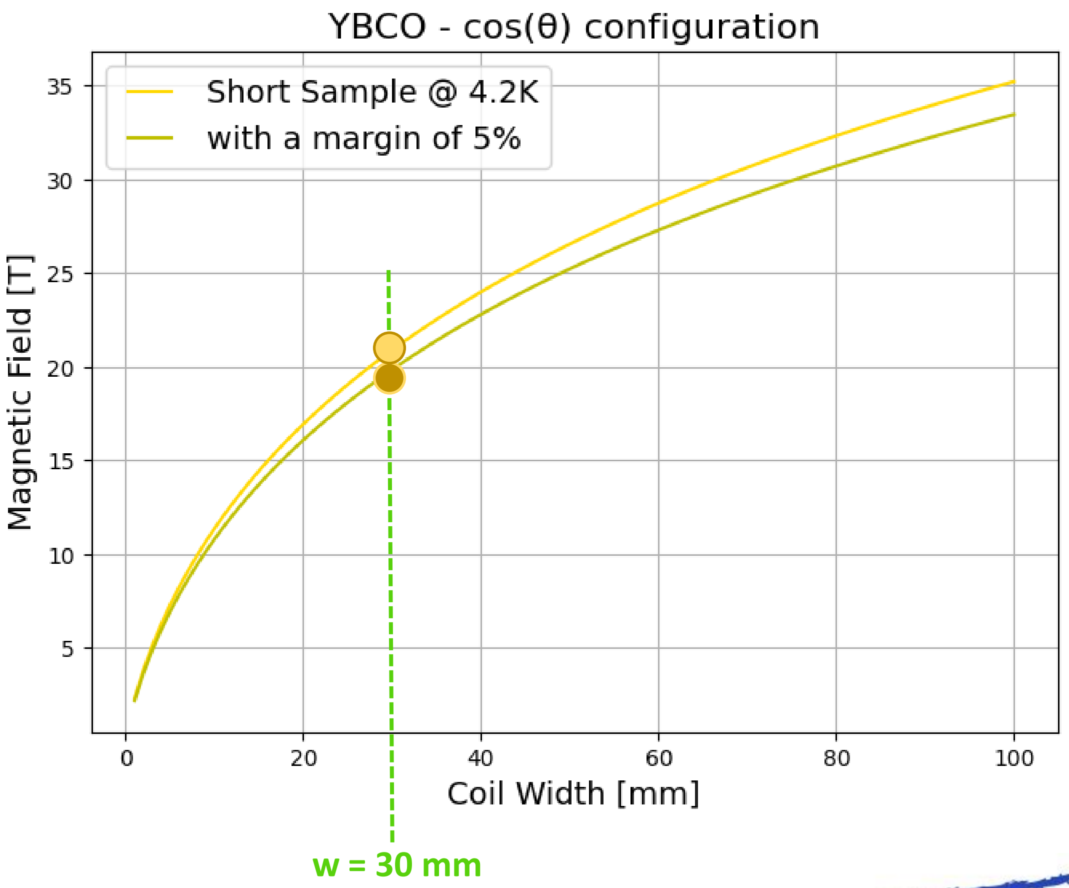
w = 30 mm



Dipole - Performances of YBCO

- Fit's data from the Fujikura FESC AP tape
- Fixed aperture = 75 mm
- T = 4.2 K
- Filling factor = 0.02 →
  - Ratio between the total area of the cable to the superconductor area.
- *Cosθ* configuration





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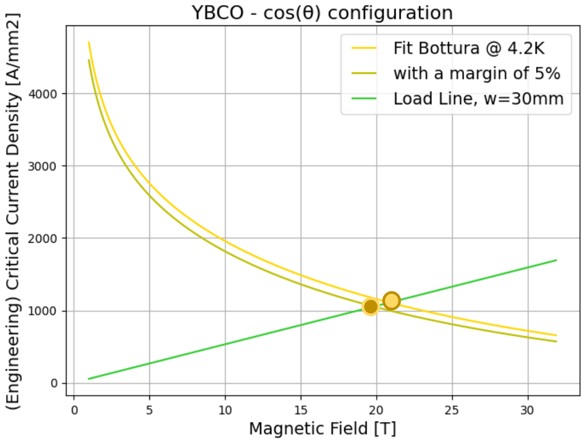
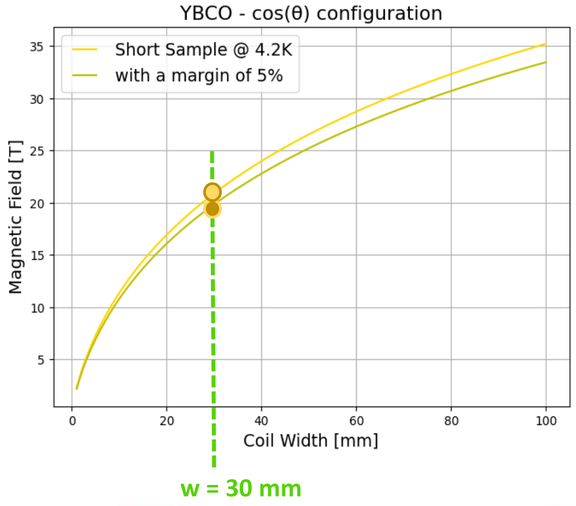
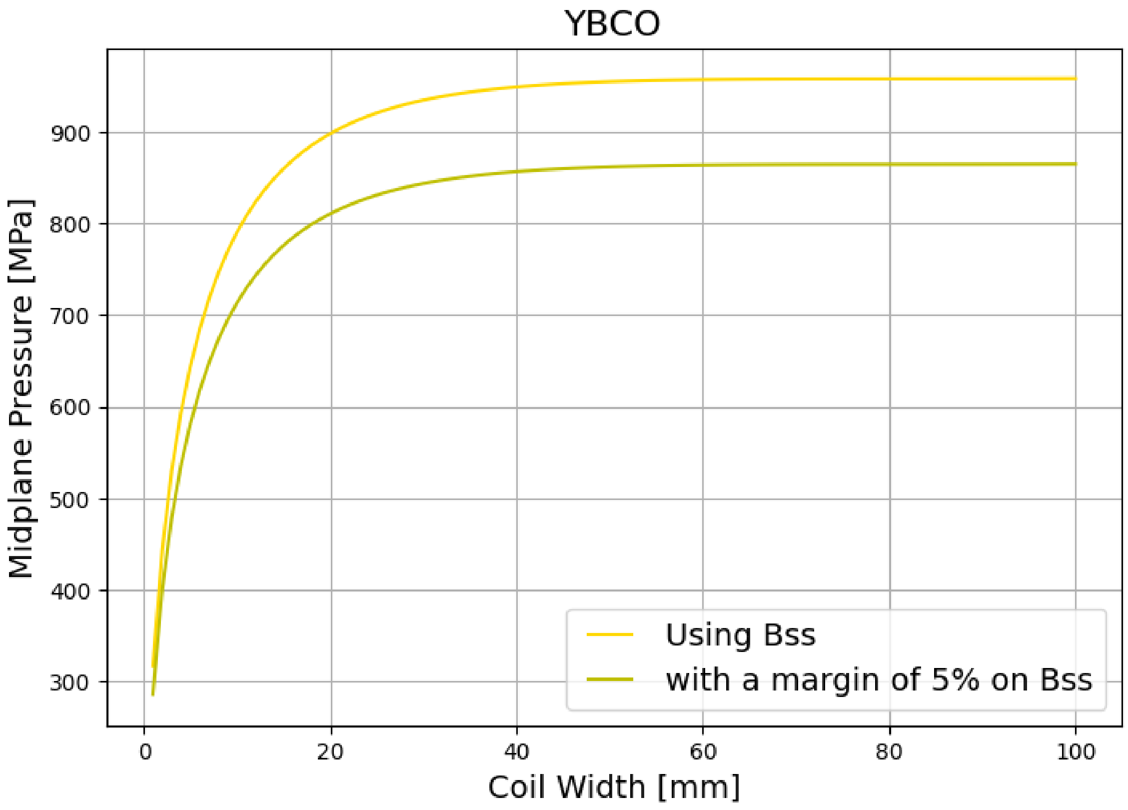


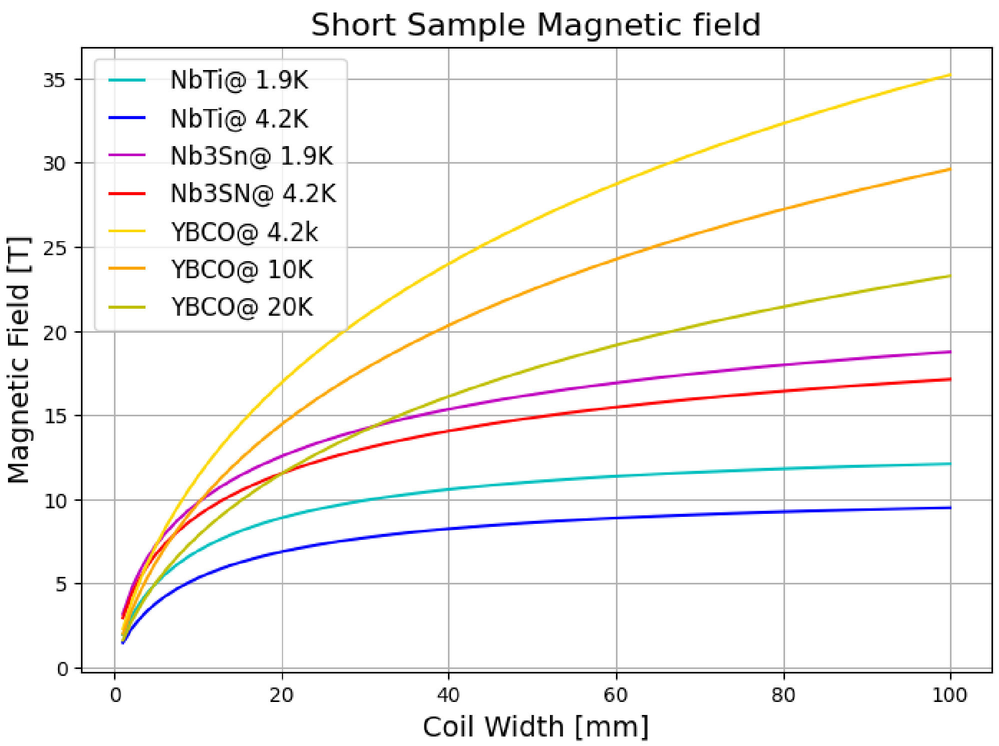


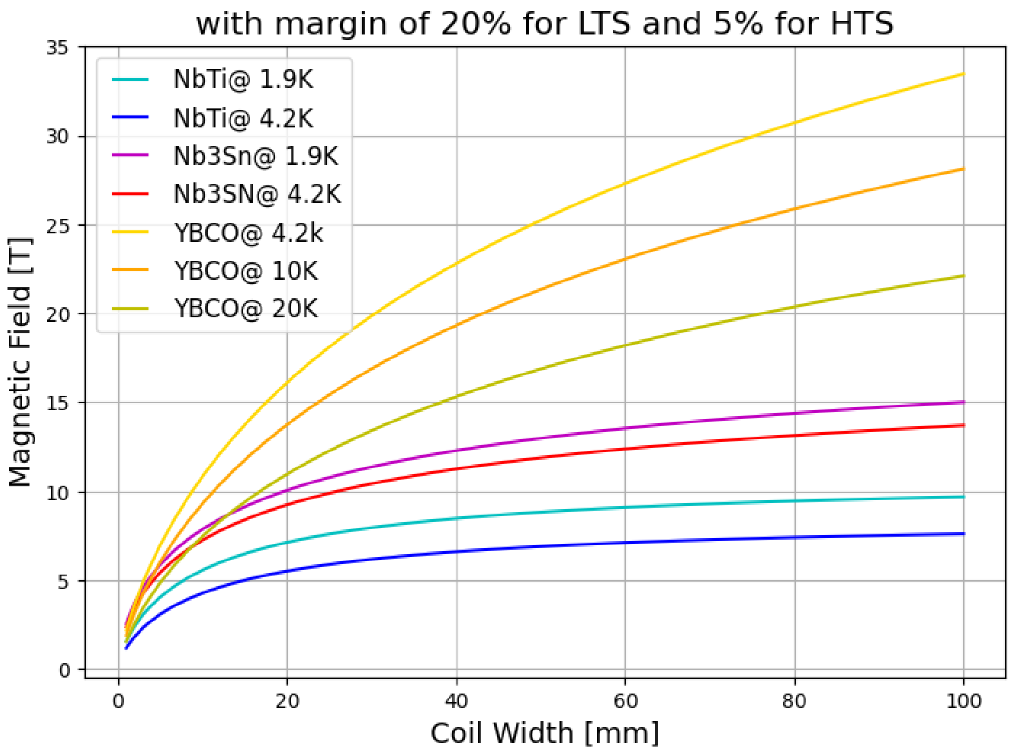


Dipole – Different temperatures

- Four different temperatures
- Fixed aperture = 75 mm

- 1.9 K → NbTi, Nb_3Sn
- 4.2 K → NbTi, Nb_3Sn, YBCO
- 10 K → YBCO
- 20 K → YBCO





From Dipole to Quadrupole

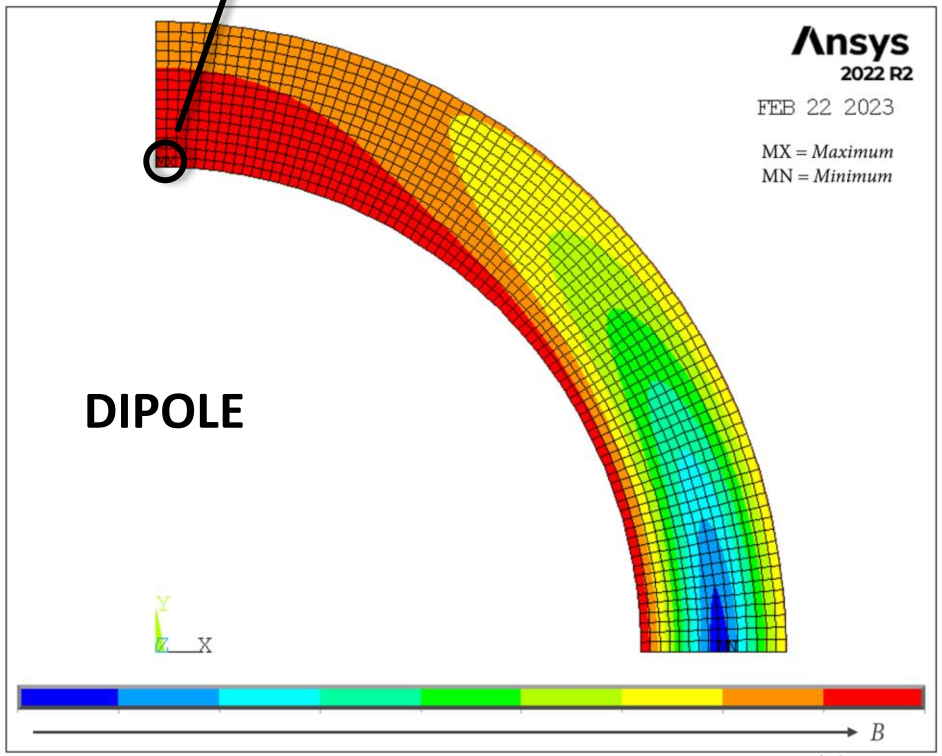
$$\theta = \frac{\pi}{2}, r = R$$

For continuity, the peak field in the conductor is the same as the field in the aperture.

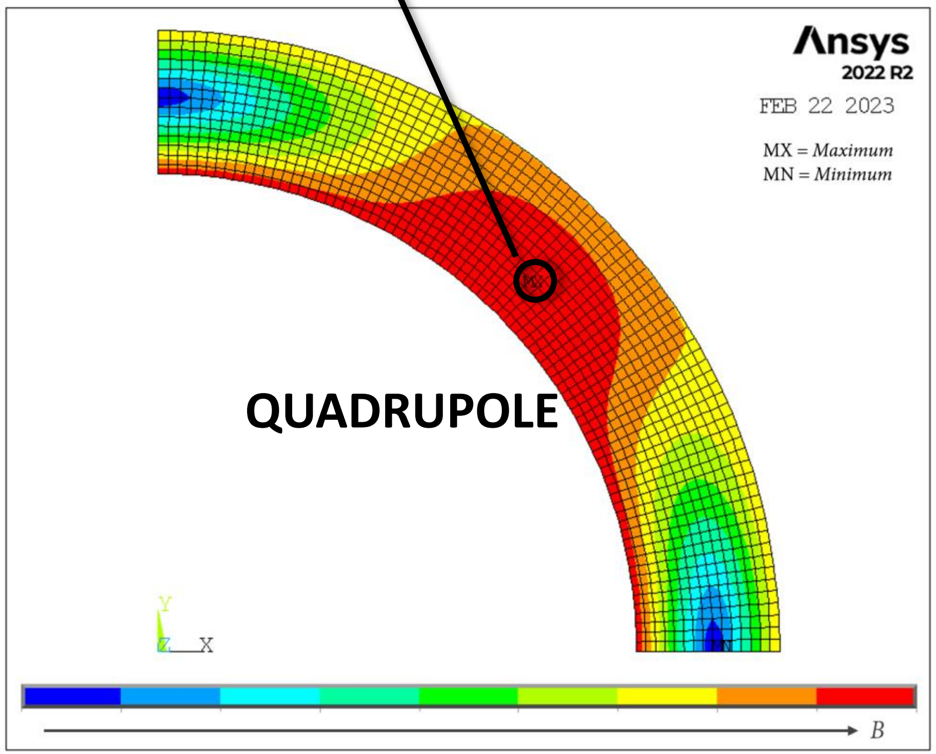
R = radius of the aperture
w = coil width

$$\theta = \frac{\pi}{4}, r = r(R, w)$$

The peak field in the conductor isn't the same as the field in the aperture.



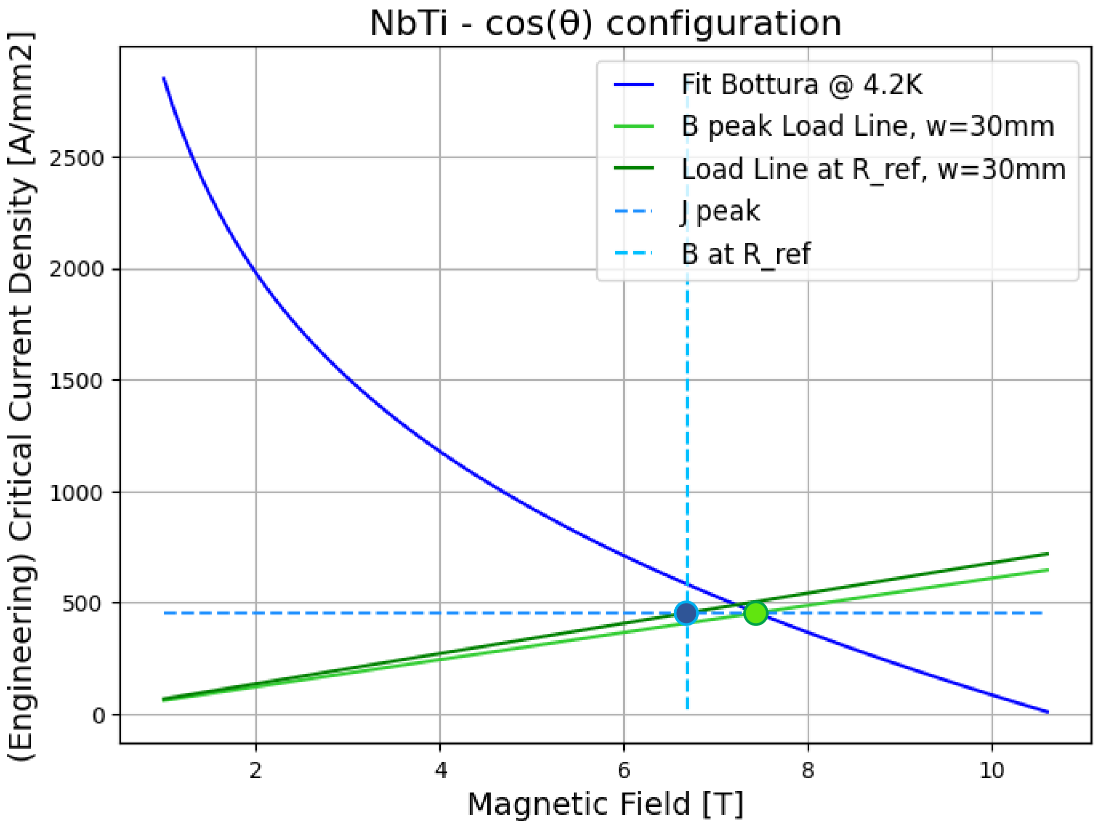
Magnetic Field



Magnetic Field

Quadrupole - Performances of NbTi

- Fit's data from the LHC cable
- T = 4.2 K
- Fixed aperture = 75 mm
- $R_{ref} = \frac{2}{3}R$ where R is the radius of the aperture
- Filling factor = 0.3
  - Ratio between normal conductor and superconductor.
  - Voids
  - Insulation
- $Cos\theta$ configuration



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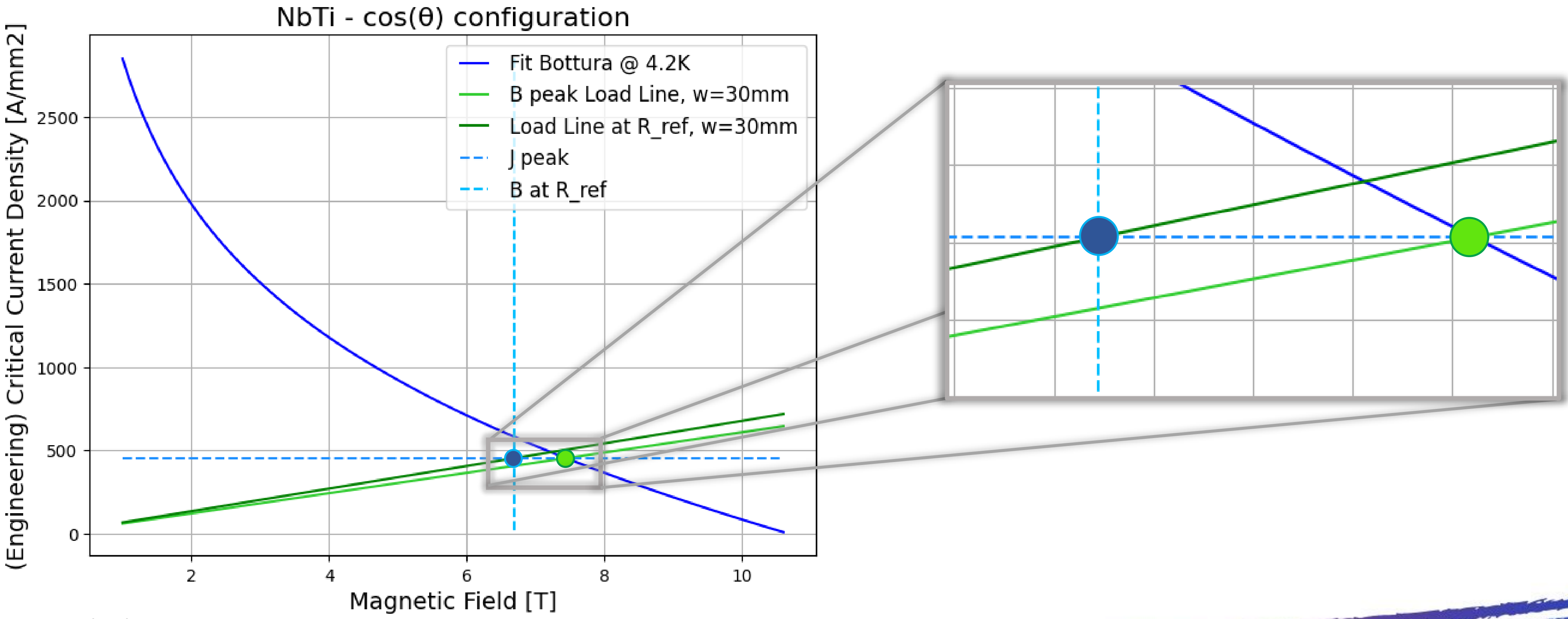

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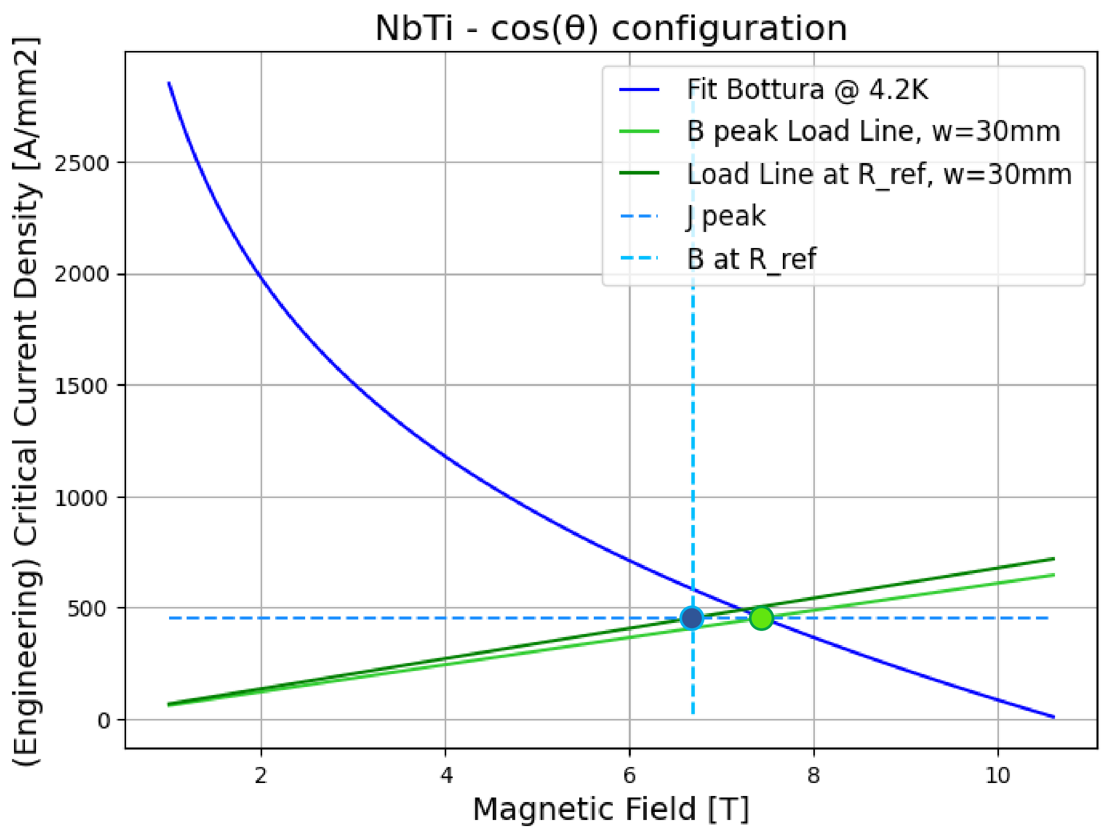

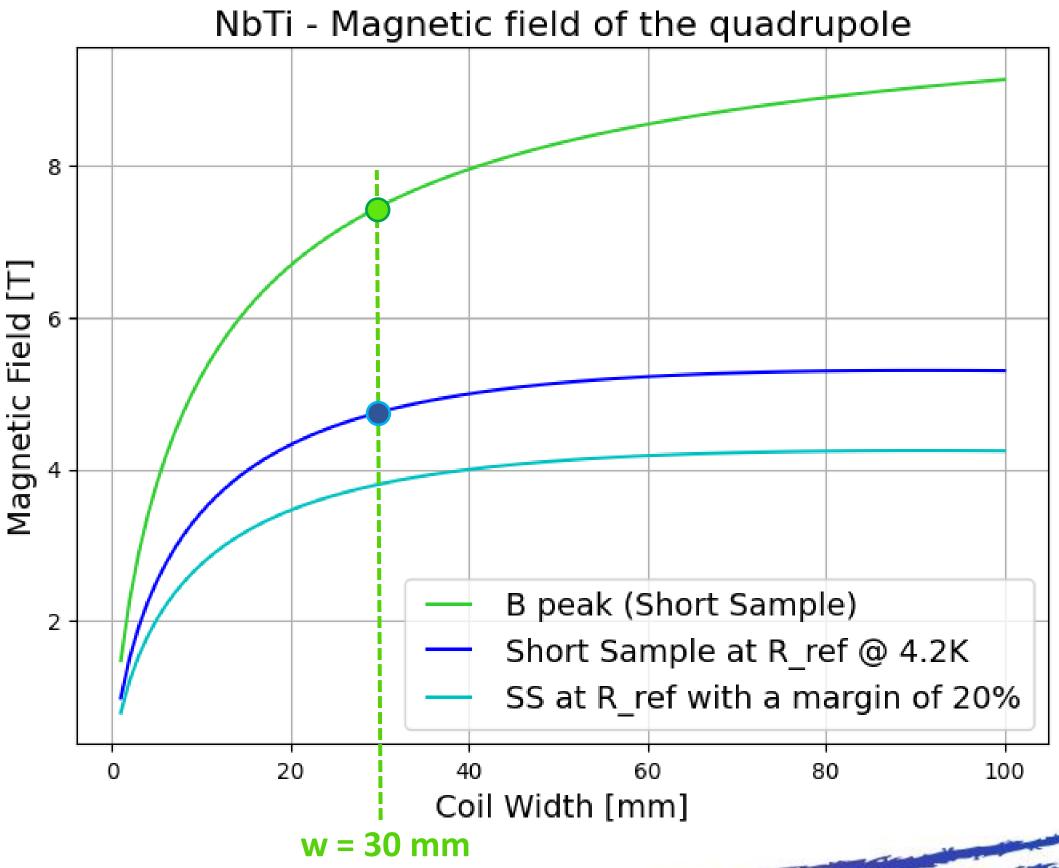

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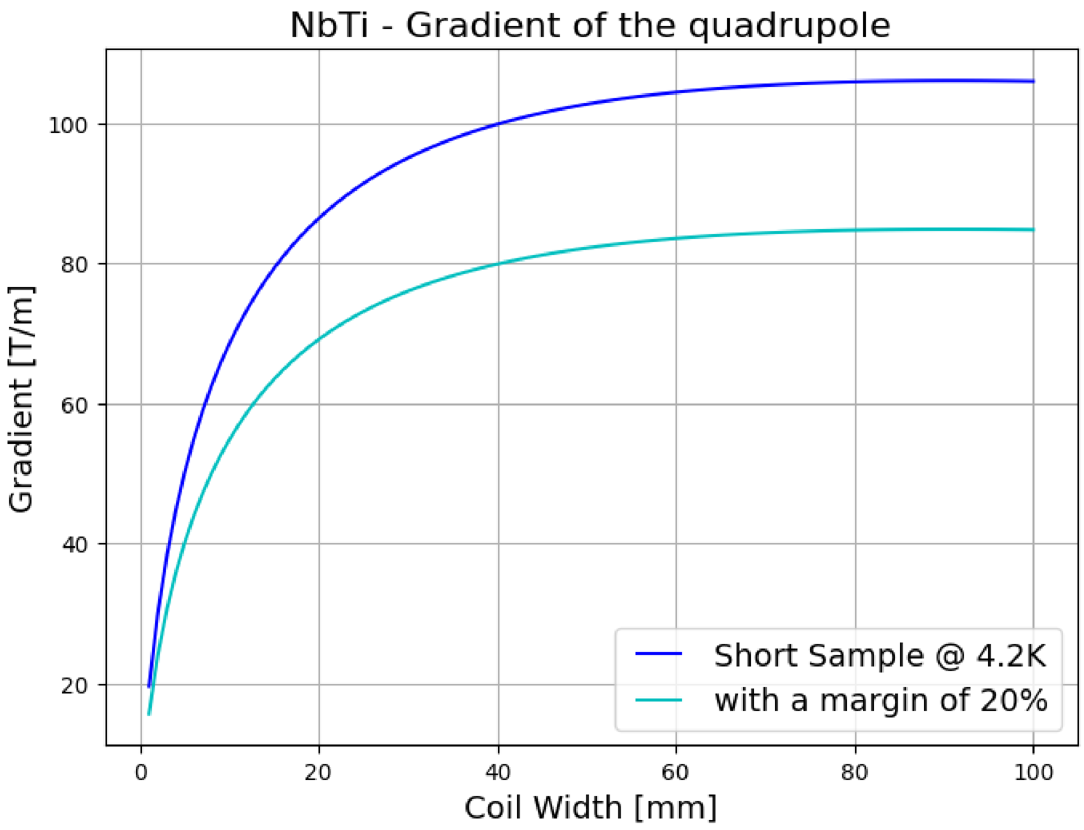
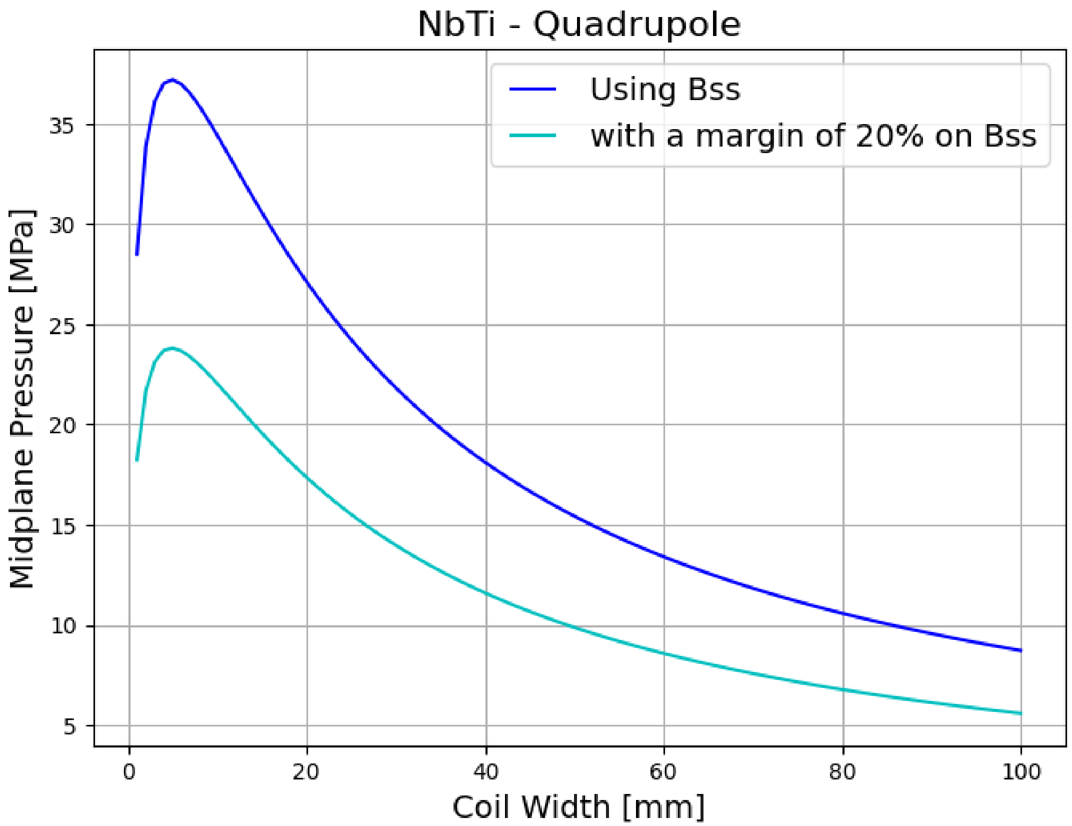
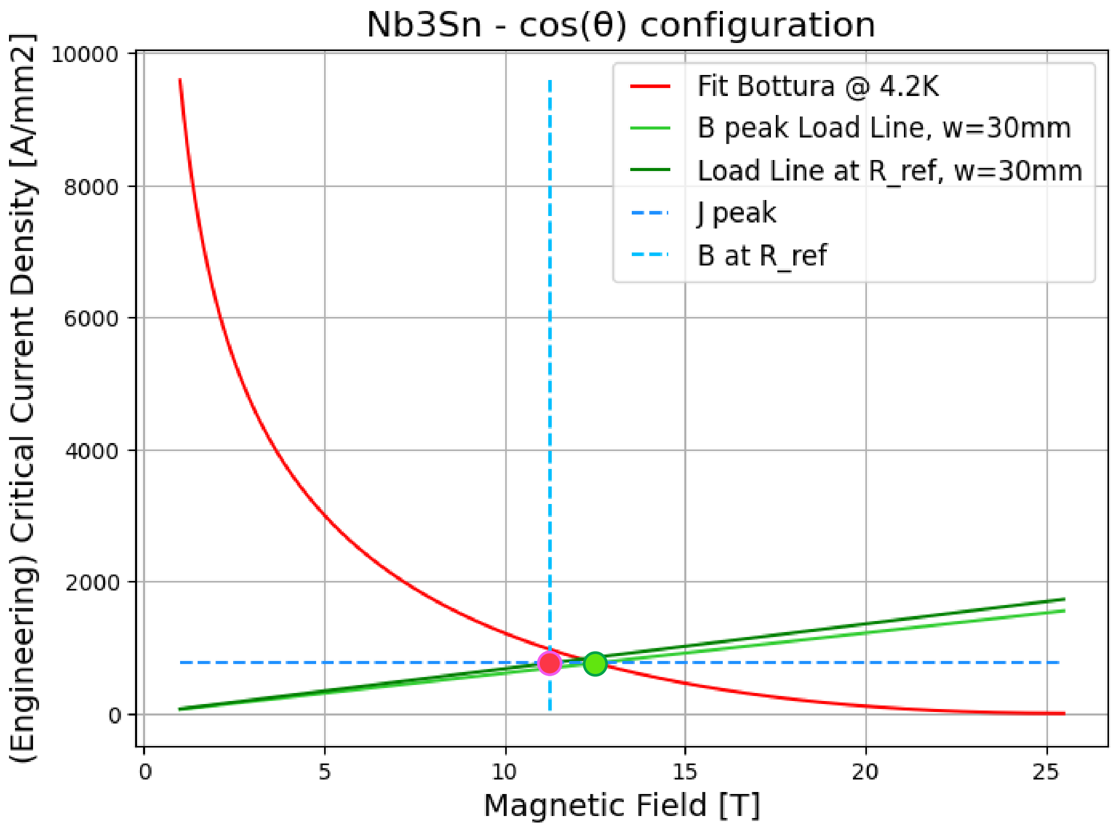
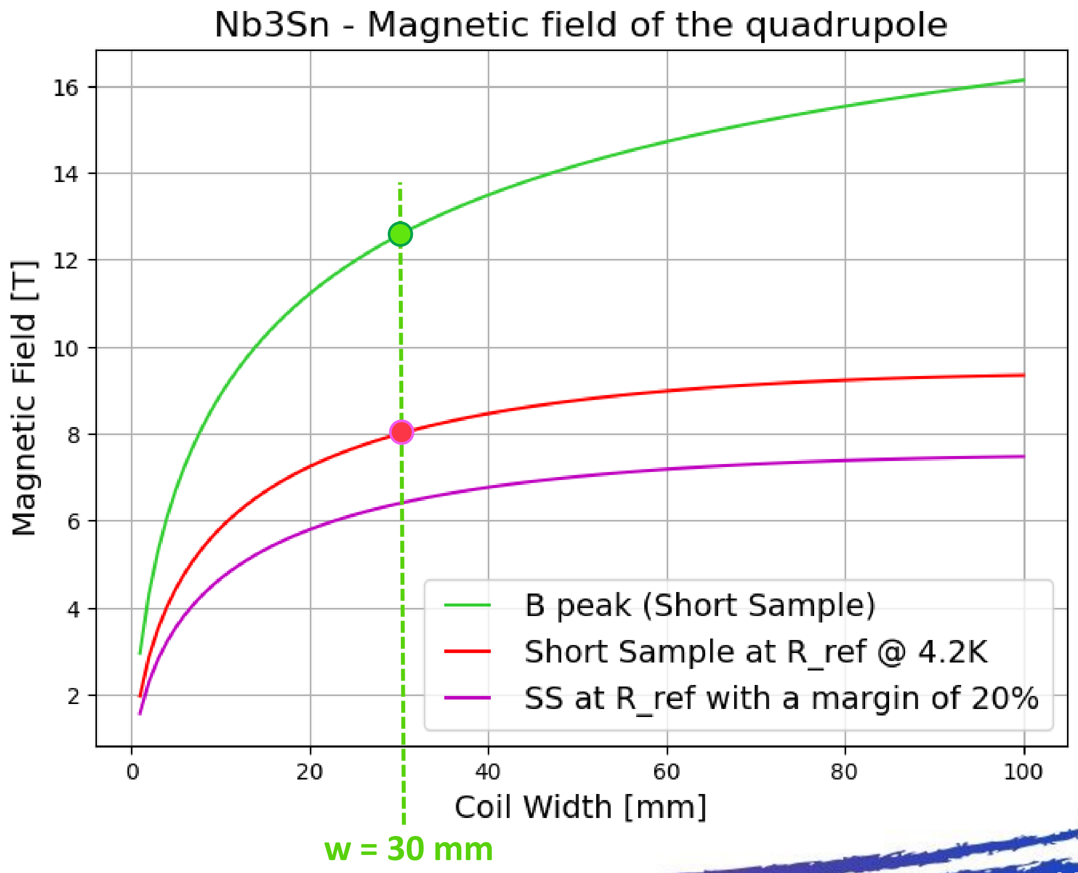




Quadrupole - Performances of Nb_3Sn

- Fit's data from the FCC target performance
- T = 4.2 K
- Fixed aperture = 75 mm
- $R_{ref} = \frac{2}{3}R$ where R is the radius of the aperture
- Filling factor = 0.3
  - Ratio between normal conductor and superconductor.
  - Voids
  - Insulation
- *Cosθ* configuration





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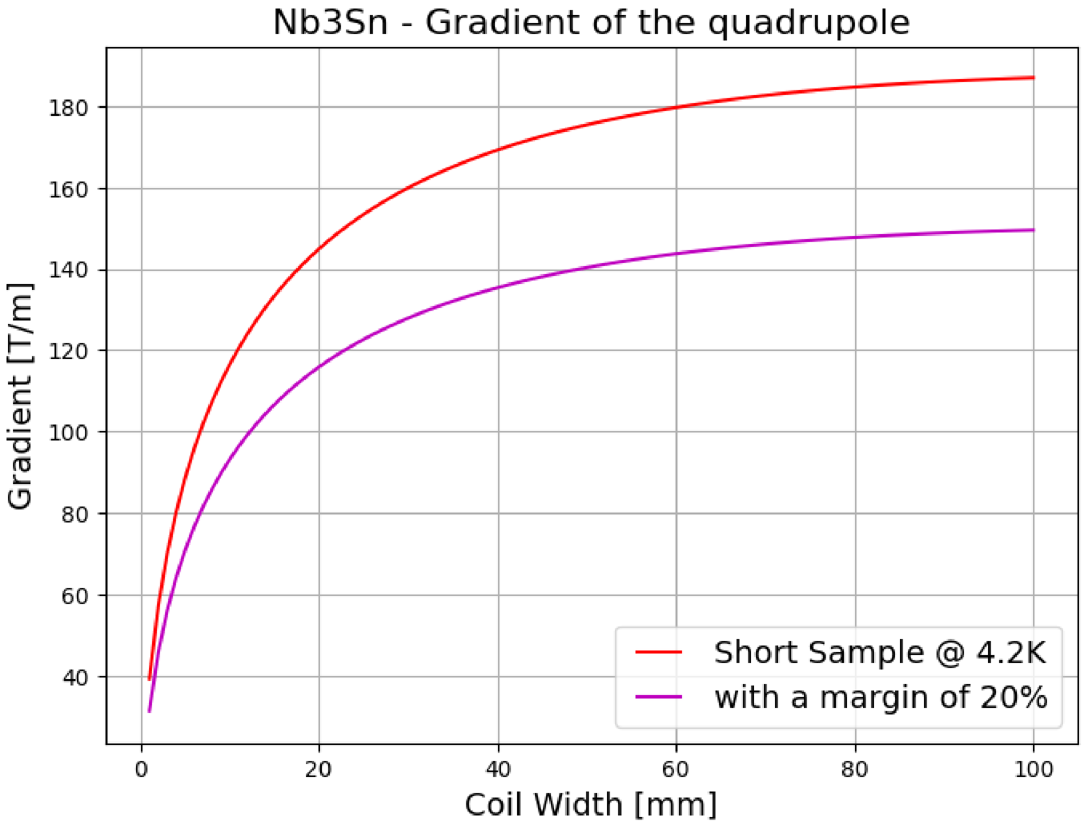
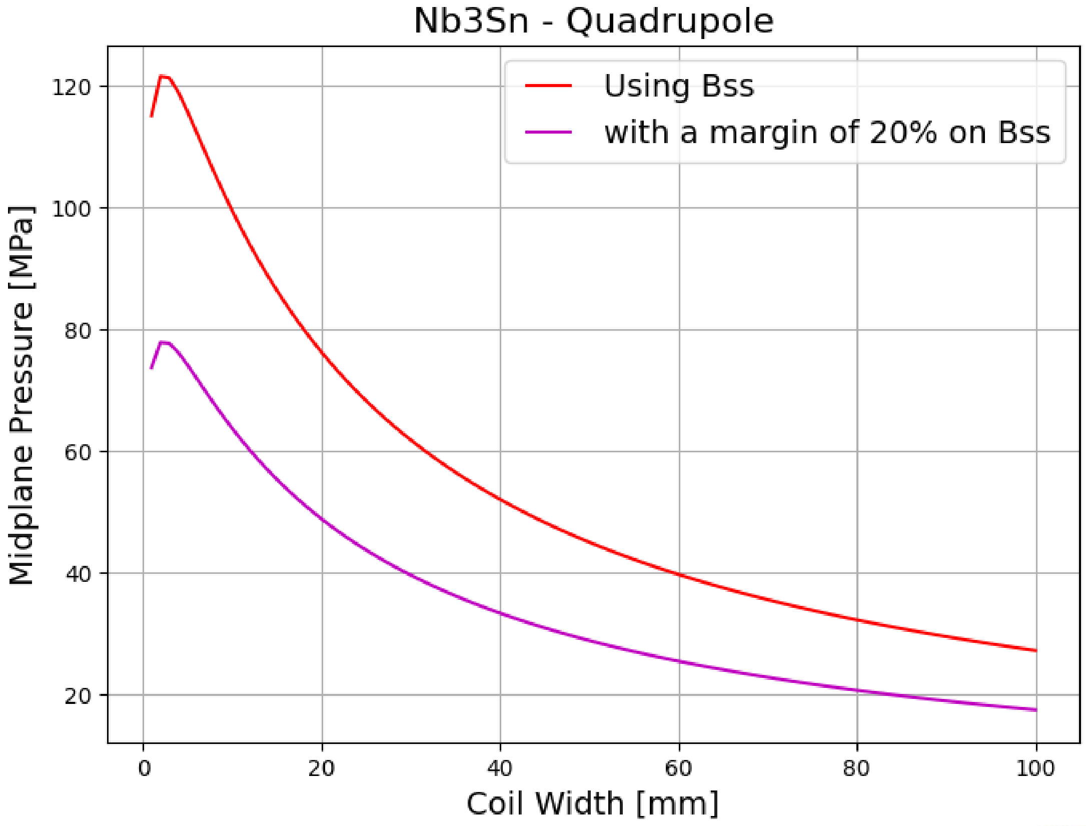
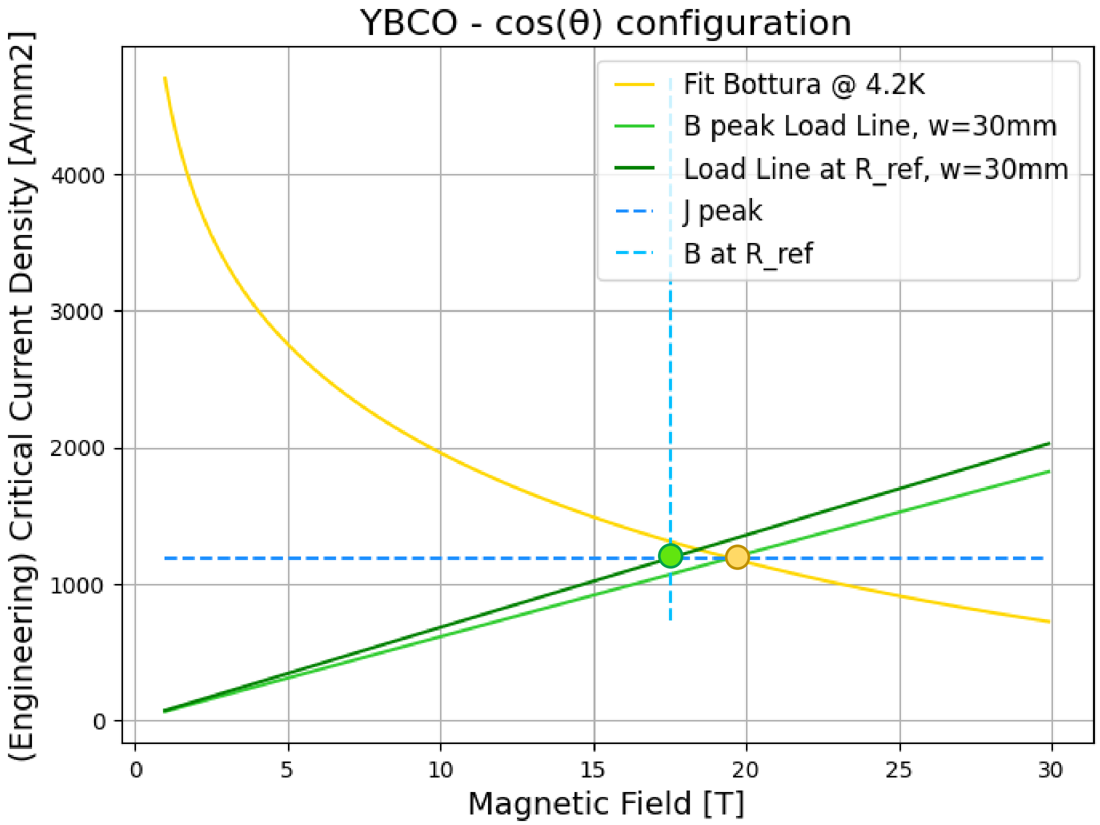
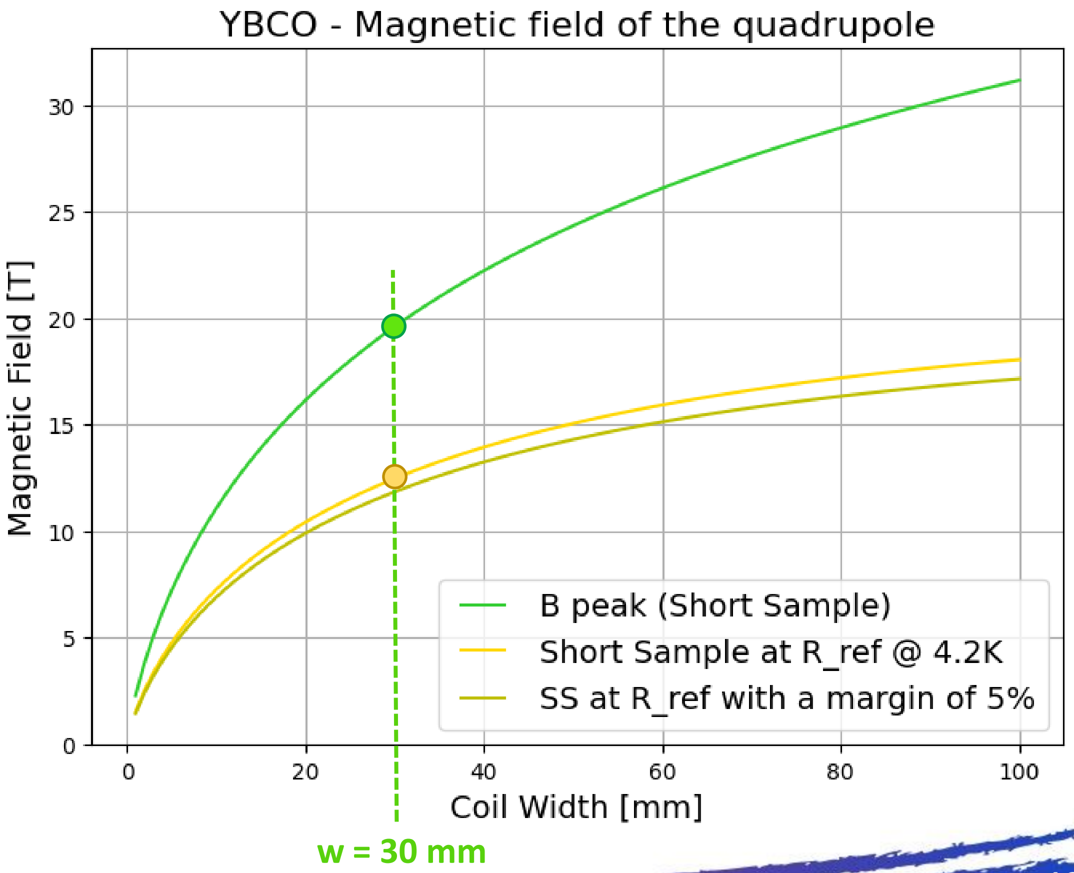




Quadrupole - Performances of YBCO

- Fit's data from the Fujikura FESC AP tape
- T = 4.2 K
- Fixed aperture = 75 mm
- $R_{ref} = \frac{2}{3}R$ where R is the radius of the aperture
- Filling factor = 0.02 → Ratio between the total area of the cable to the superconductor area.
- *Cosθ* configuration





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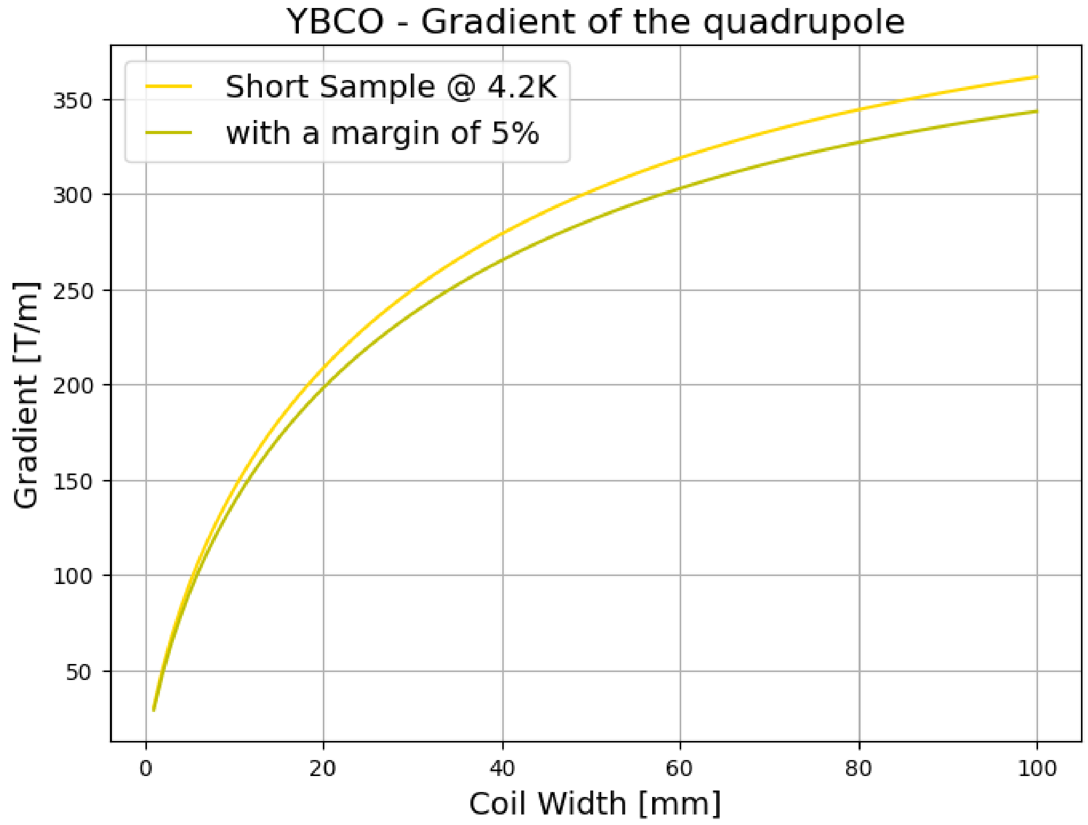

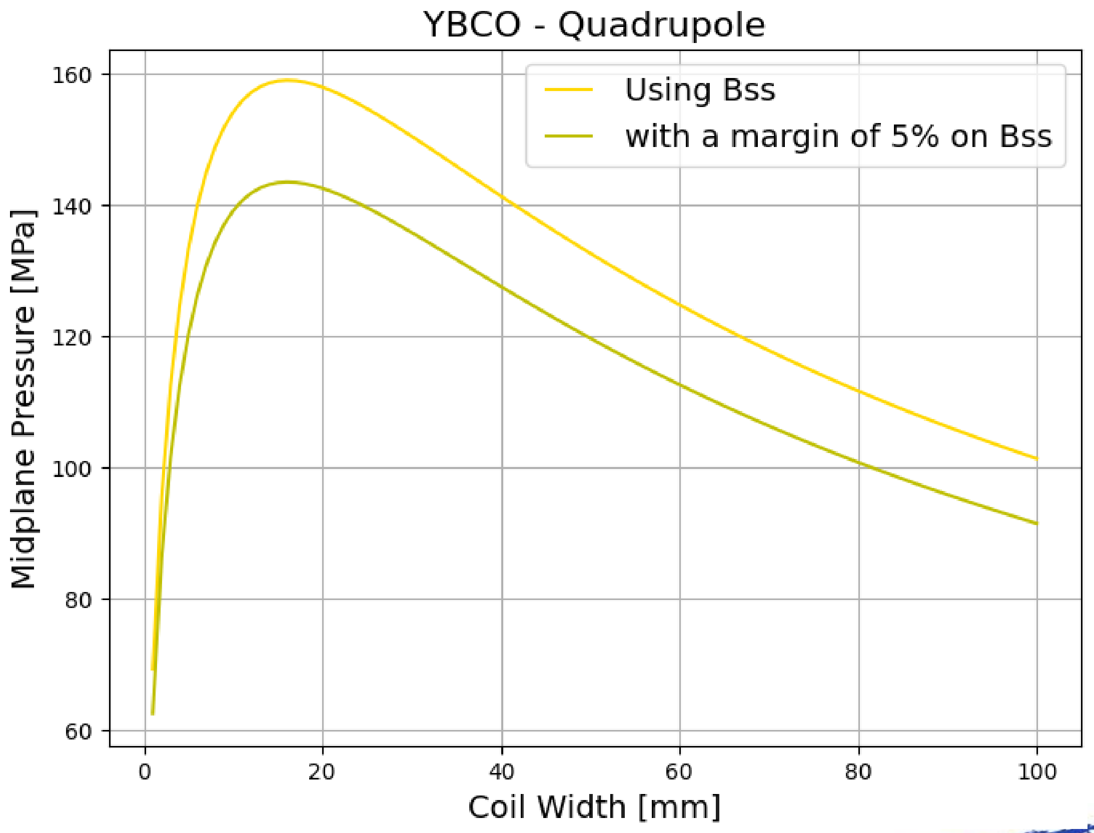

Quadrupole – Gradient

- Four different temperatures
- Fixed aperture = 75 mm

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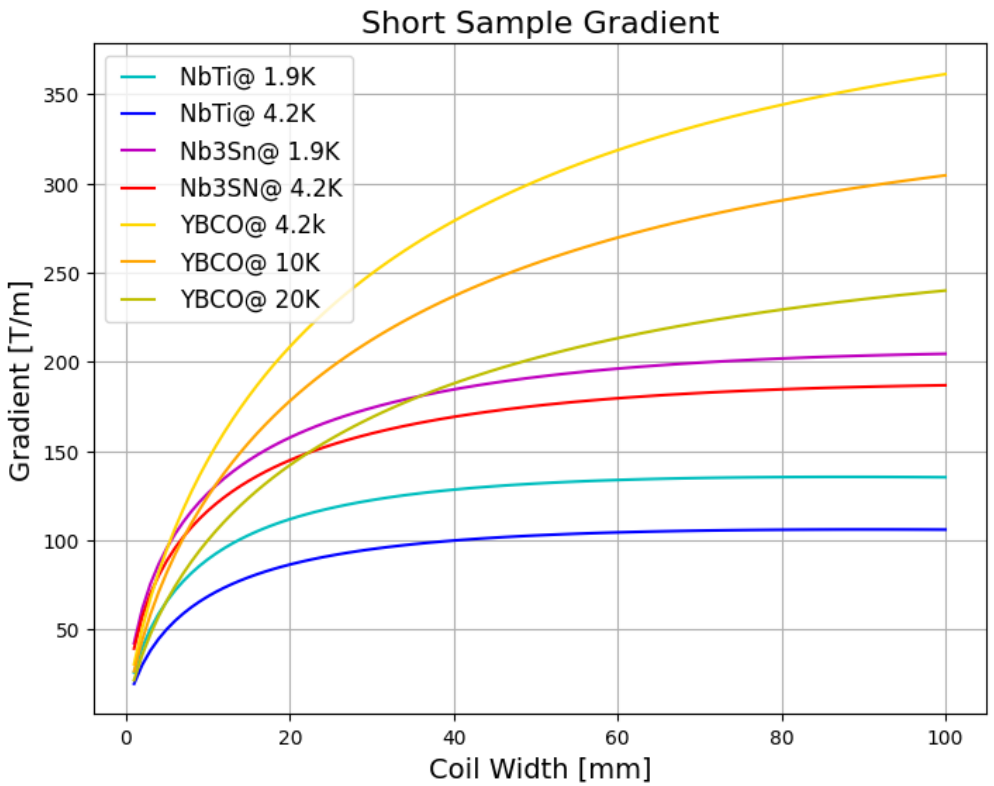
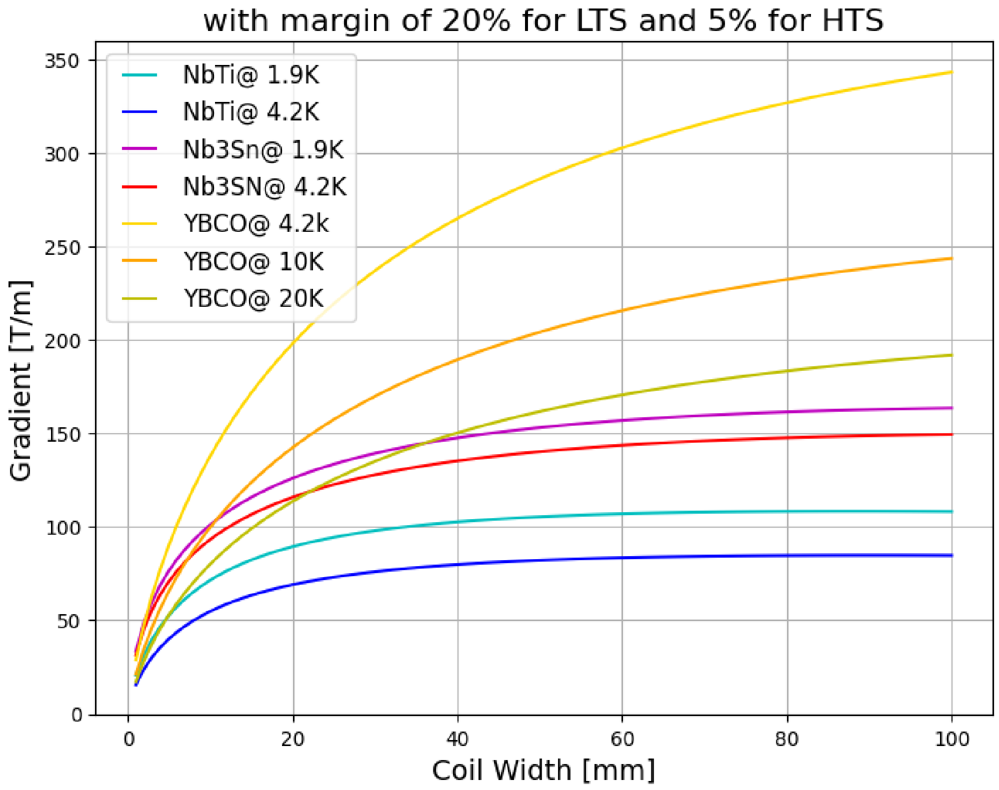
- 20 K → YBCO

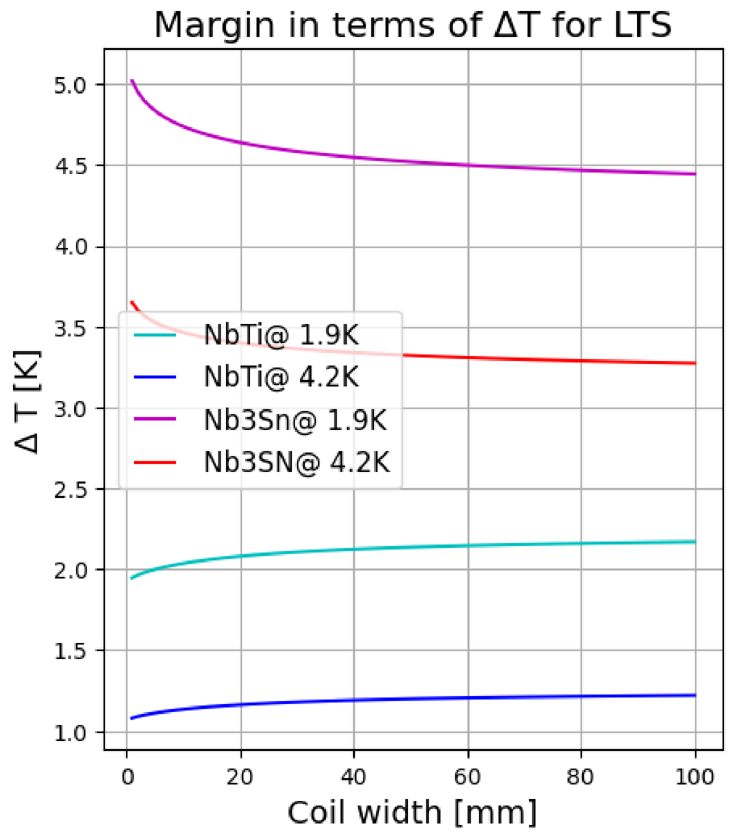




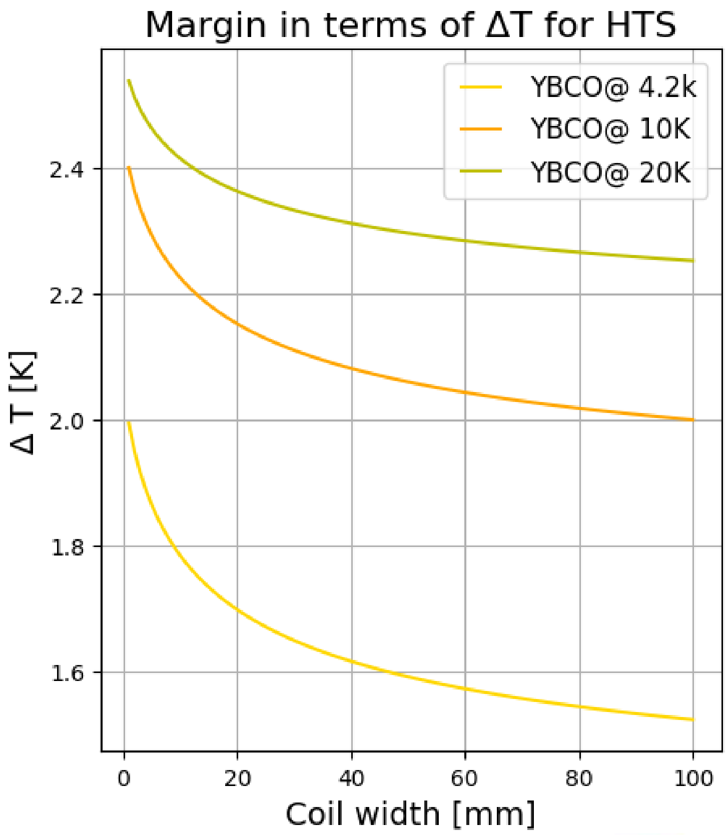
Discussion on the Margin

The margin on the load line can be expressed in terms of margin in temperature.

We have chosen two reasonable values for margins on the load line for LTS and HTS, which are: 20% for the LTS (graph on the left) and 5% for the HTS (graph on the right).



- We can reduce (below 20%) the margin on the load line for the Nb_3Sn.
- We can reduce (below 5%) the margin on the load line for the YBCO at high temperatures.



Conclusions

Upcoming developments:

- We started out using the cos-theta approximation because it is simpler, but we are working on the **sector dipole**.
- We want to include **iron**.

For the future:

- We would like to implement a **Python** code able to work **with** the **Ansys** software, to solve complex configurations that are not analytically tractable, thus making it possible to study **multipole sectors** and **combined function magnets**.

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Thank you for your attention

The YBCO critical current Fit

$$J_c(B,T) = \frac{\widetilde{C_0}}{B}\left(\frac{B}{B_{c2}(T)}\right)^p \left(1-\frac{B}{B_{c2}(T)}\right)^q \left(1-\left(\frac{T}{T_{c0}}\right)^n\right)\left(1-\left(\frac{T}{T_{c0}}\right)^m\right)$$

$$B_{c2}(T) = B_{c20}\left(1-\left(\frac{T}{T_{c0}}\right)^n\right)$$

$$B_{c20} = 274{,}84 \quad T$$

$$T_{c0} = 91{,}317 \quad K$$

$$\widetilde{C_0} = C_0 \cdot \frac{(p+q)^{p+q}}{p^p \cdot q^q}$$

$$C_0 = 2{,}27 \cdot 10^6 \ \frac{A \cdot T}{mm^2}$$

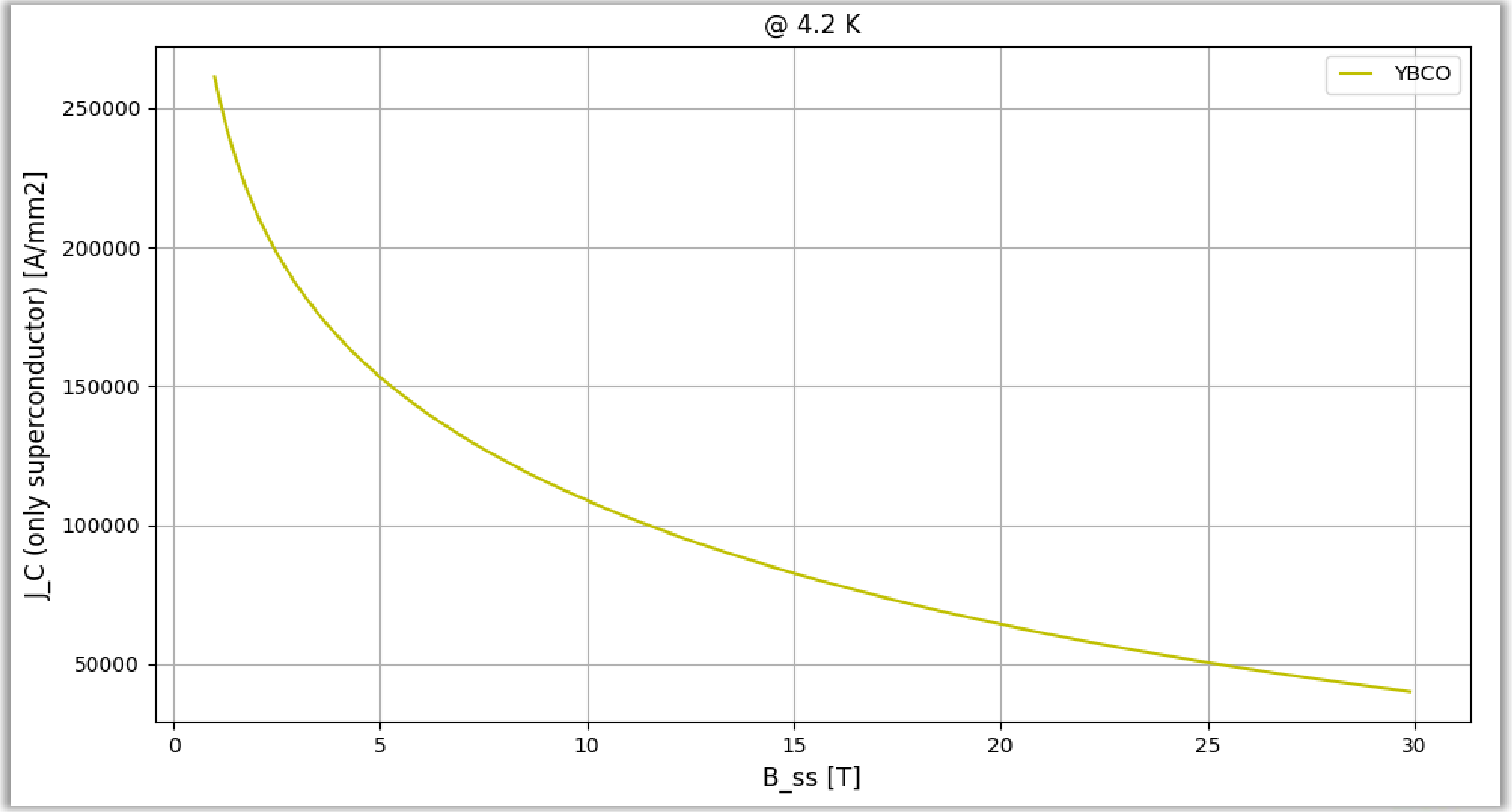
$$n = 0{,}3323$$

$$\mathrm{m} = 0{,}7008$$

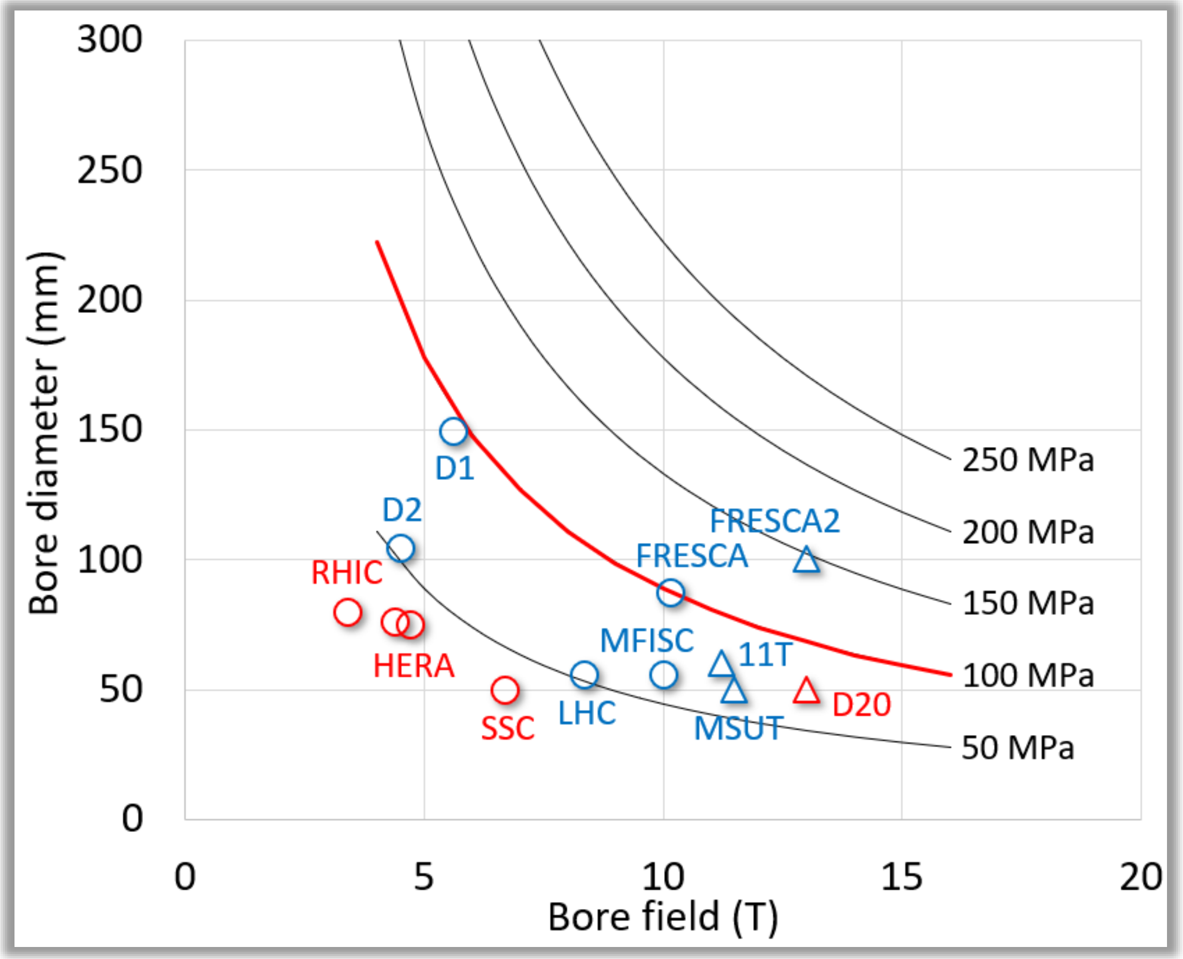
$$p = 0{,}75$$

$$q = 5{,}69$$

These parameters are provided by L.Bottura



Dipole - Bore Diameter vs Bore Field

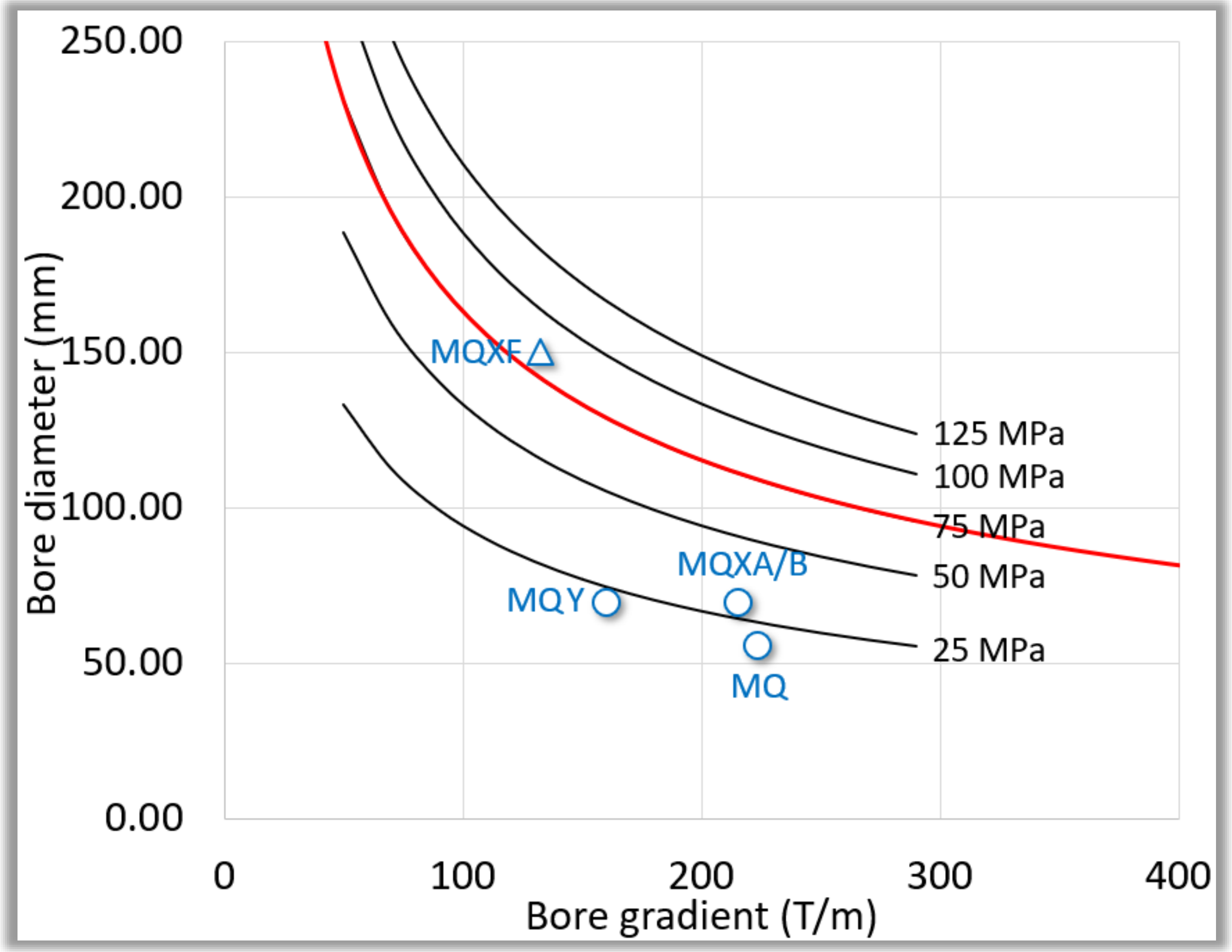


We are working on this graph.

For the moment:

- Empirical approach in which we used the formulas provided by Ezio Todesco in his course on superconducting magnets.
- We fixed the engineering critical current density at 450 $\frac{A}{mm^2}$.
- We have chosen 100 *MPa* as limit value (red line)

Quadrupole - Bore Diameter vs Bore Gradient



We are working on this graph.

For the moment:

- Empirical approach in which we used the formulas provided by Ezio Todesco in his course on superconducting magnets.
- We fixed the engineering critical current density at 450 $\frac{A}{mm^2}$.
- We have chosen 75 *MPa* as limit value (red line)