Updated Magnet Limitations for the Collider Ring

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INTRODUCTION TO A-B PLOTS

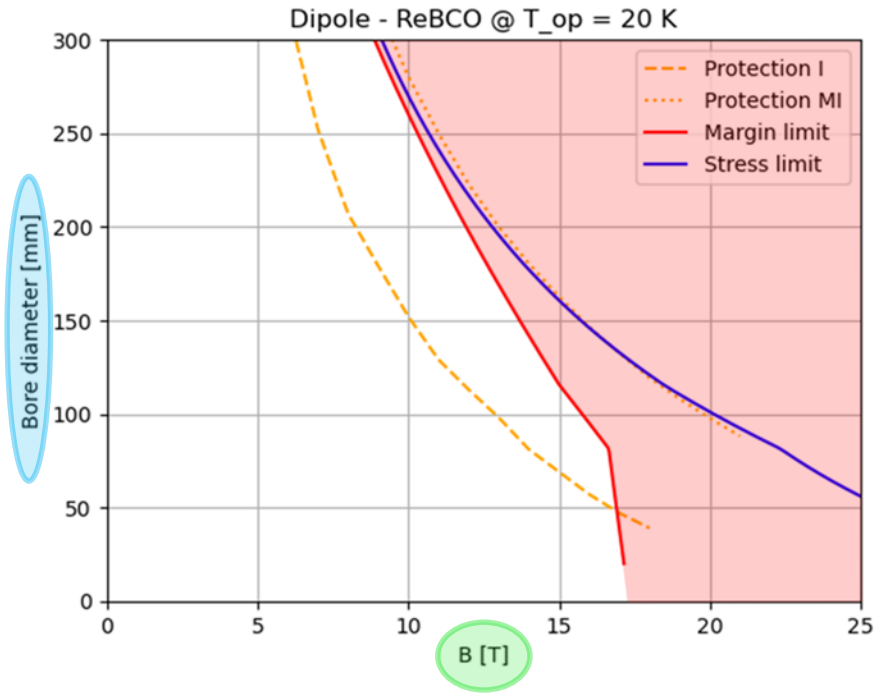
More material:
https://indico.cern.ch/event/1325963/contributions/5791457/
https://indico.cern.ch/event/1325963/contributions/5837724/
https://indico.cern.ch/event/1325963/contributions/5798926/
https://indico.cern.ch/event/1353612/contributions/5775143/
https://ieeexplore.ieee.org/document/10387716

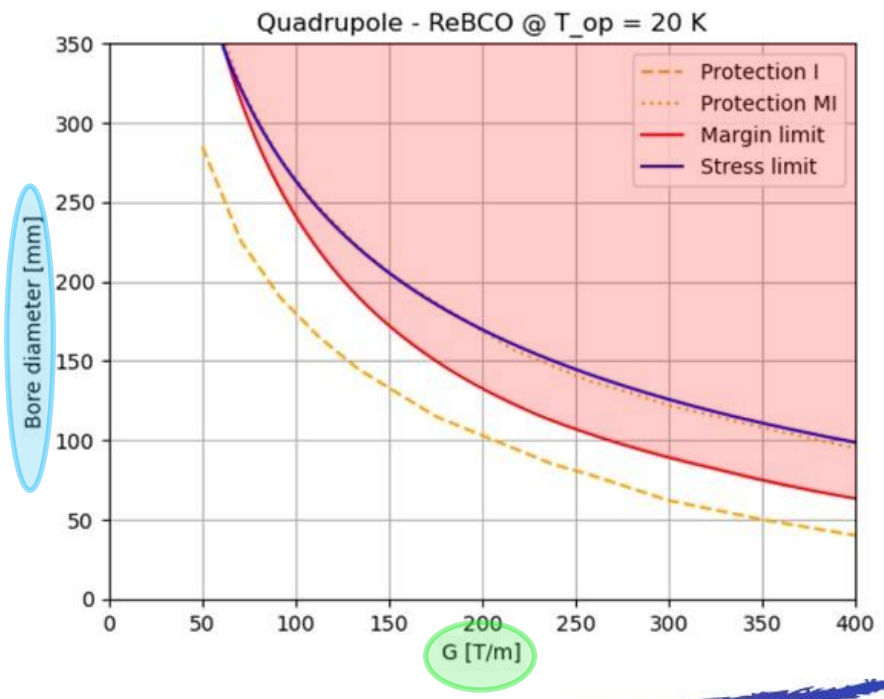
Need for high fields in large apertures

- We perform plots that can show the allowed area between aperture diameter (A) and bore field (B).

✓ Innovative approach, useful for interfacing the needs of beam dynamics with the technological limits (of today and the near future) related to superconducting magnets.

✓ Immediate feedback capable of analyzing many possible configurations in a single plot





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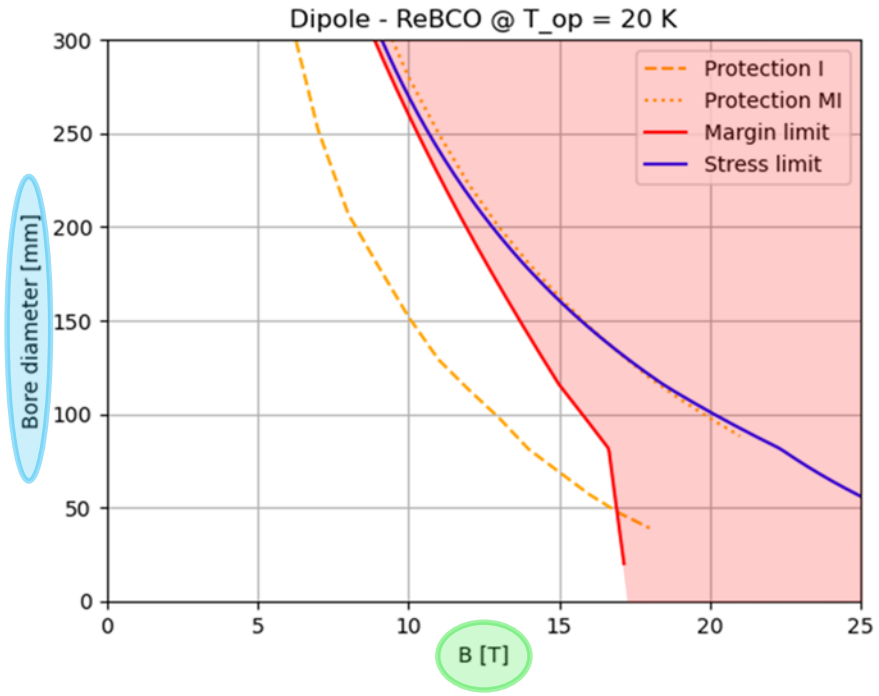
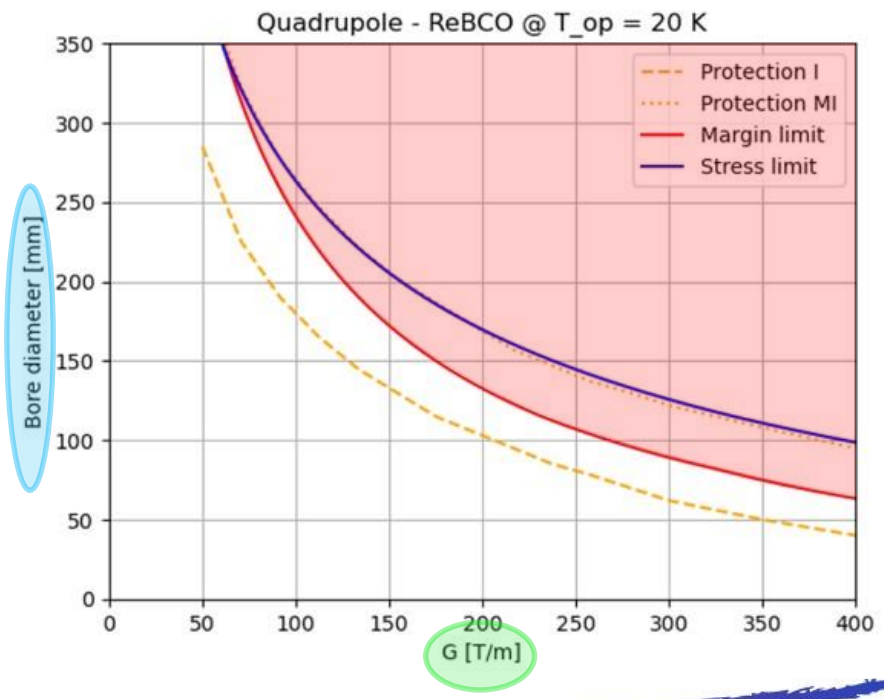
Need for high fields in large apertures

- We perform plots that can show the allowed area between aperture diameter (A) and bore field (B).

- Limit curves are introduced by mechanical challenges (stress limit), critical current density (margin limit) and stored magnetic energy (quench protection), depending on the superconducting material.





COLLIDER MAGNETS REQUIREMENTS

The specifications of magnets in the **0.7** version of the beam optics exceeded the technological limits

v0.7

Final Focusing

- Quads with G_1~±300T/m with radius~60mm
- Quads with G_1~±110T/m with radius~150mm
- Dipole-quads with B_d~8T G_1~±100T/m with radius~140mm
- Dipoles B_d~±16T

Arc

- Dipole-sextupoles with B_d~14T G_2~±7100T/m² with radius~50mm
- Dipole-quads with B_d~8T G_1~±320T/m with radius~50mm
- Dipoles B_d~16T

Magnets

Courtesy of Kyriacos Skoufaris
https://indico.cern.ch/event/1351046/

Chromatic Correction & Matching

- Dipole-sextupoles with B_d~4T G_2~±11555T/m² with radius~70mm
- Dipole-quads with B_d~4T G_1~±240T/m with radius~70mm
- Dipole-quads with B_d~4T G_1~±330T/m with radius~50mm
- Dipoles B_d~16T

These radius values refer to 5σ + tungsten $(4\ cm)$
→ the other components need to be added $(31\ mm)$

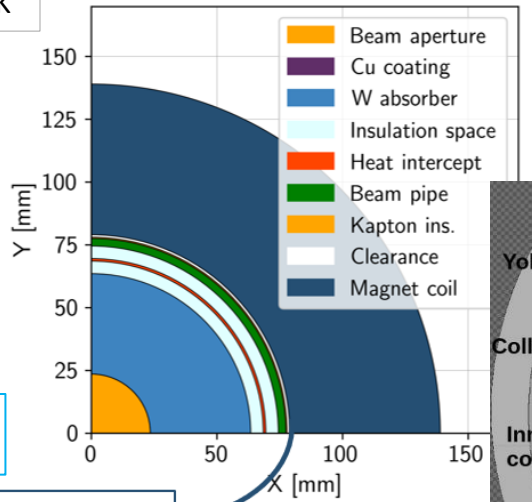
Dipole Radial Build

Assuming 10 TeV machine and coil at 4.5 K

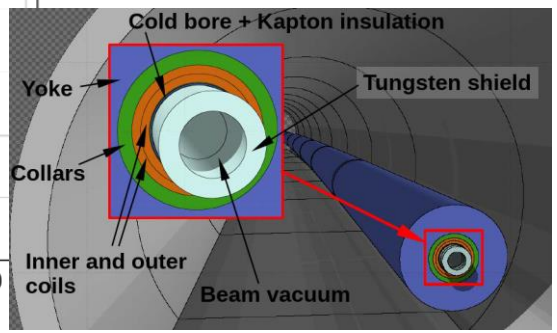
• Beam aperture (5σ)	23.5 mm radius
• Cu layer beam screen	0.01 mm thick
• Tungsten absorber	40 mm thick
• Insulation space	5 mm thick
• Heat intercept	1 mm thick
• Insulation space	5 mm thick
• Beam pipe	3 mm thick
• Kapton insulation	0.5 mm thick
• Clearance	1 mm thick
• Coil pack*	(60 mm thick)

*thickness TBD, placeholder

Courtesy of Patricia Borges de Sousa
https://indico.cern.ch/event/1250075/contributions/5357594/

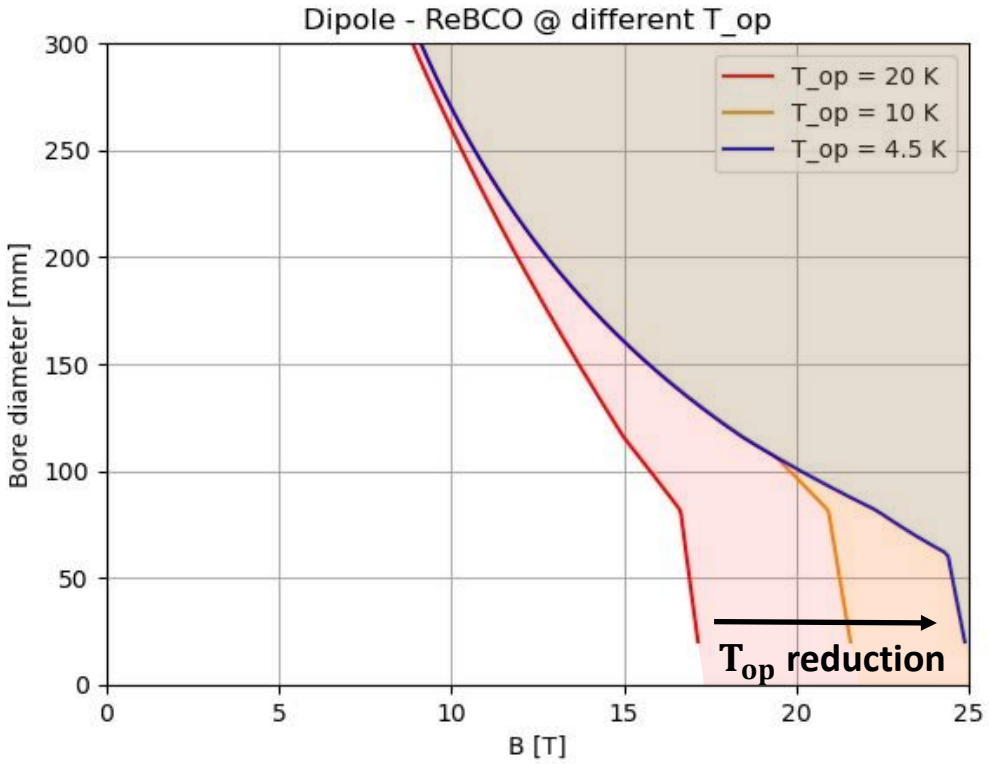


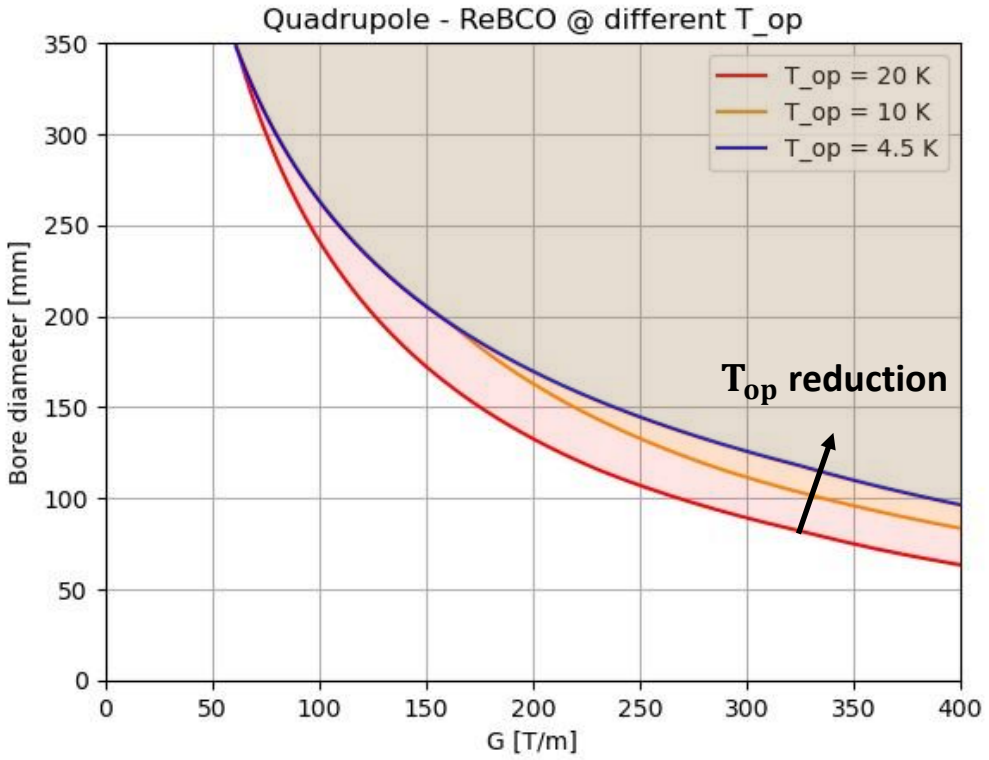
Coil aperture 158 mm



The new version **0.8** has different requirements for **final focusing** magnets

A-B Plots behaviour for HTS



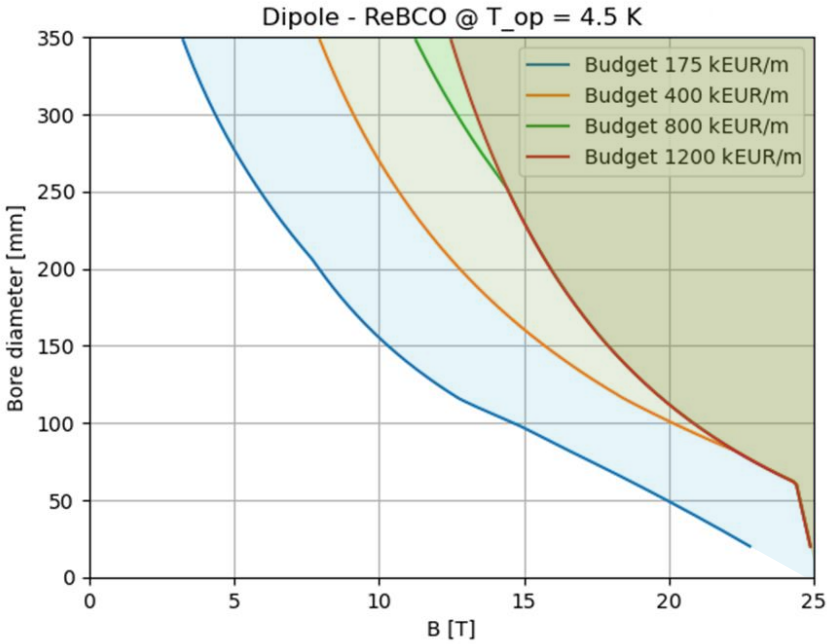


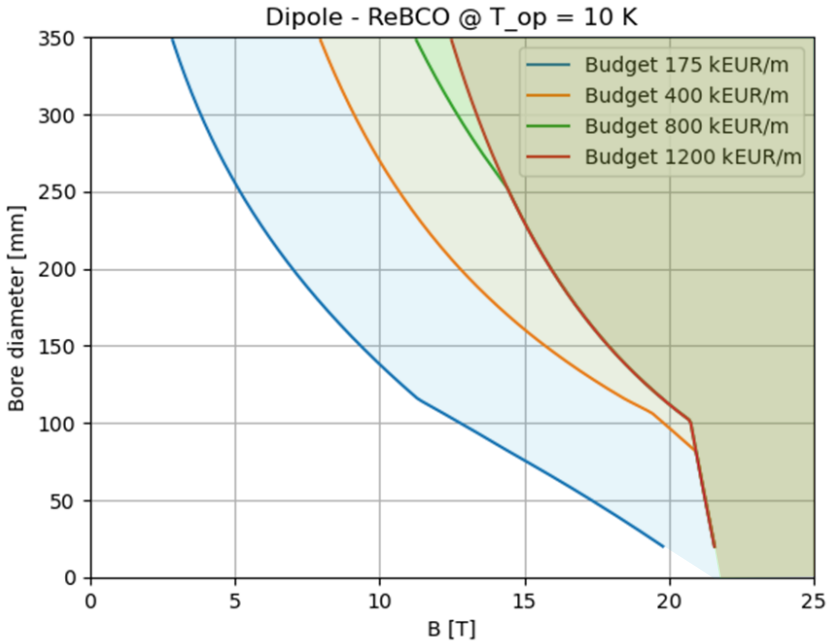
A reduction of operating temperature will result in wider design A-B range

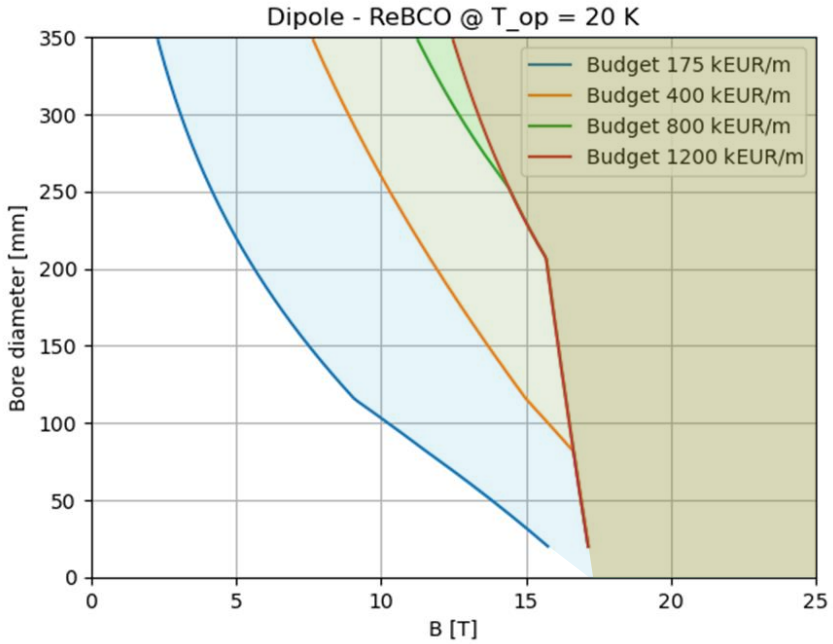
The curves shown in the plots are the limit curves, i.e., for each aperture value the strictest limit is taken, excluding the limit for insulated magnets.

Reducing the cost of HTS or a larger budget will result in a wider A-B range. (next slides)

A-B PLOTS FOR HTS DIPOLES







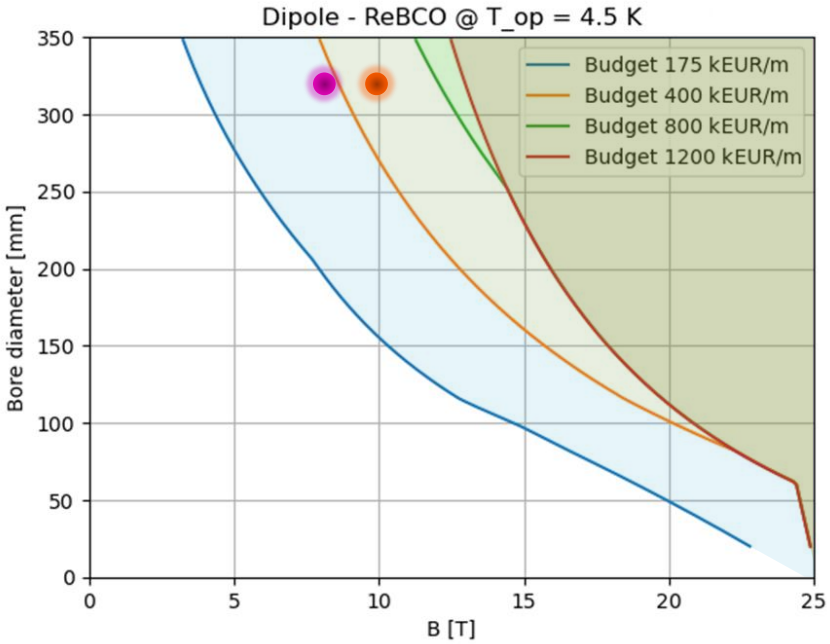
Summary of cost assumptions:

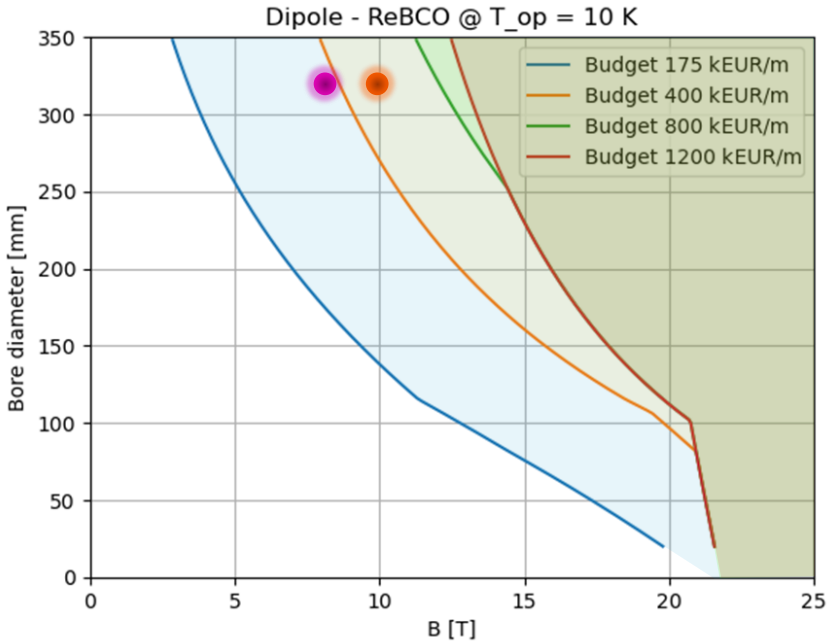
- We use the ReBCO's aspirational cost 2500 EUR/kg
  - Today's price is around 8000 EUR/kg
- The starting budget of 175 kEUR/m for each magnet is taken from the FCC cost model
  - We can assume a higher budget than FCC because we have a smaller circumference and less magnets.
- Cryogenic, protection and shielding costs are not taken into account.

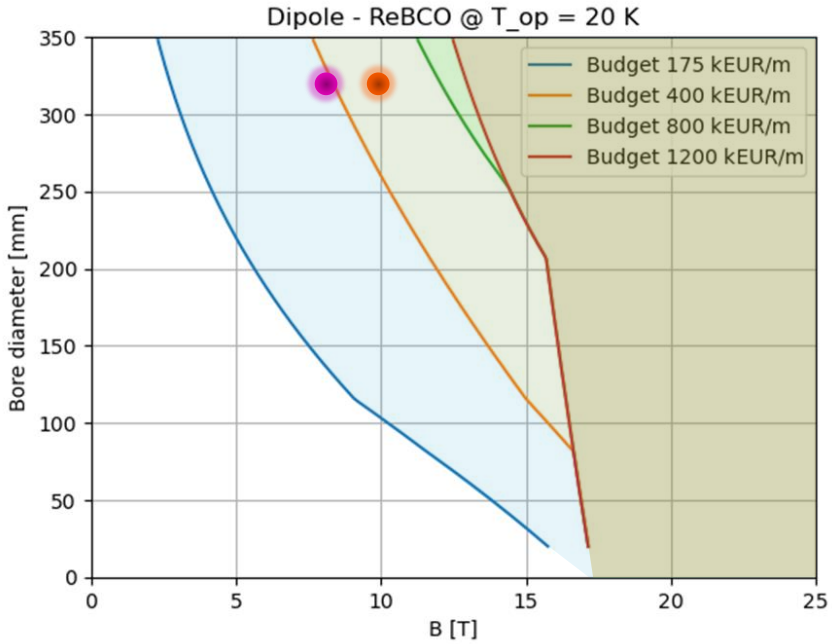
Summary of technical assumptions:

- Single sector coil
- Maximum allowed stress: 400 MPa
- Fujikura Tape, Roebel cable
- Non-insulated or Metal-insulated cable
- Maximum coil width: 80 mm

A-B PLOTS FOR HTS DIPOLES



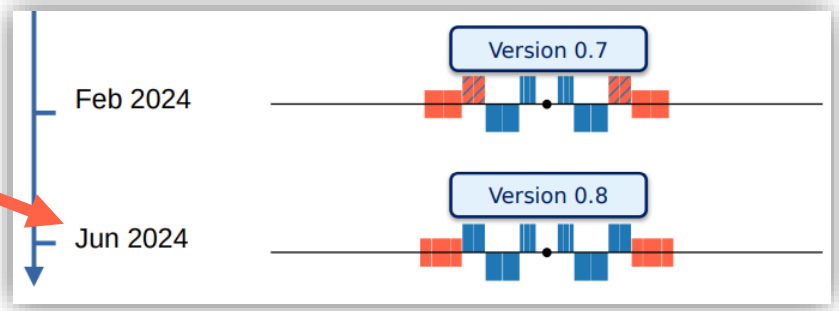




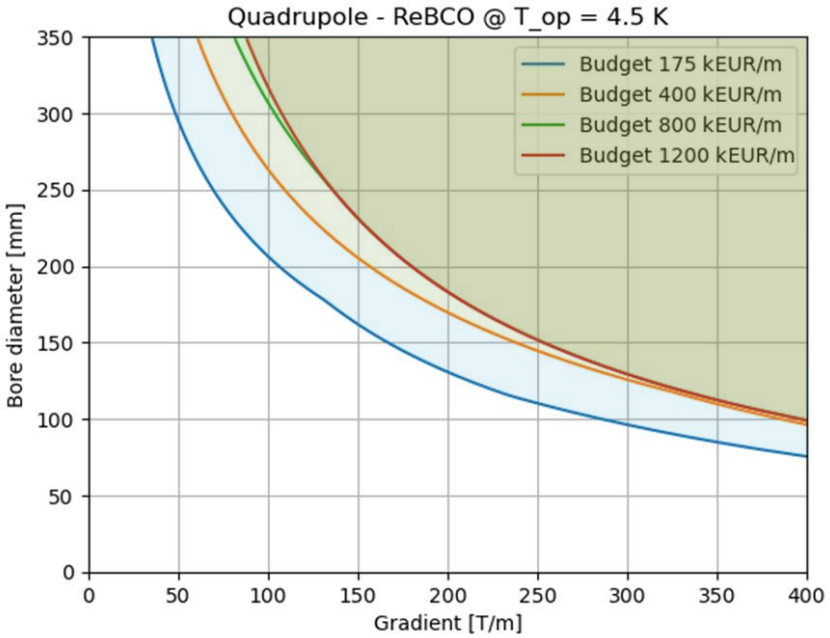
		Dynamic beam aperture [cm]			
Name	**L**	**Upstream**	**Downstream**	**Magnet aperture radius [cm]**	**B field [T]**
IB2	6	8.71	9.00	16	8.1
IB1	10	9.02	9.49	16	-9.7
IB3	6	9.51	9.79	16	8.1

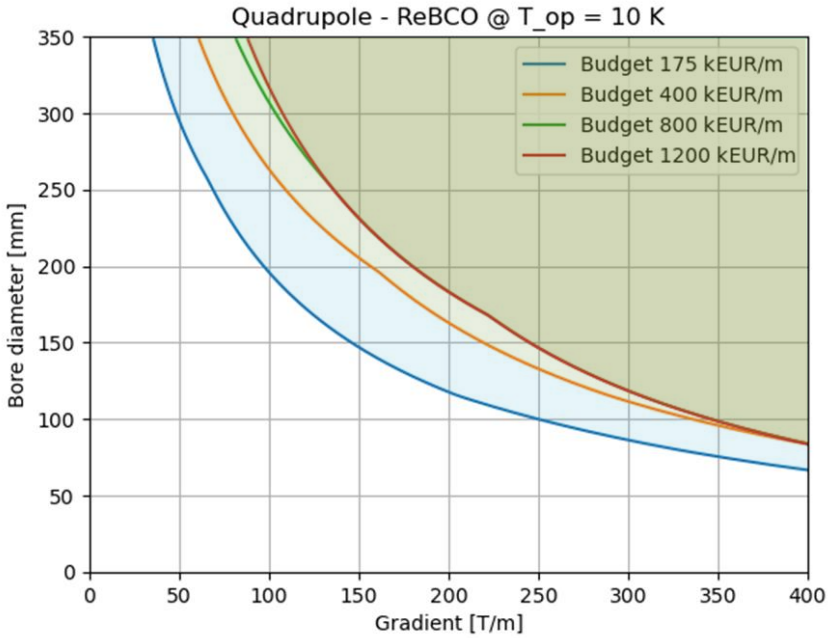
From D. Calzolari,
MDI workshop 25-26 June 2024,
Final Focusing Dipole requirements

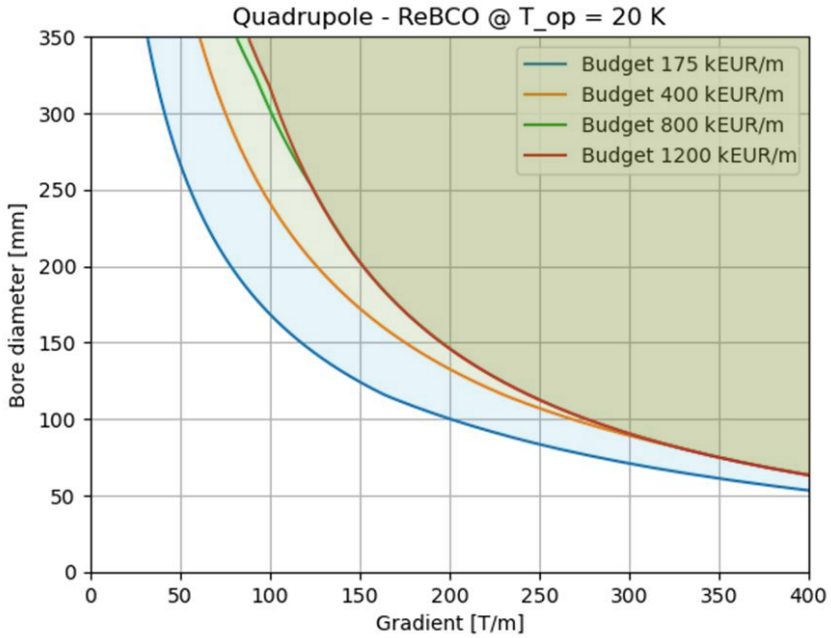
https://indico.cern.ch/event/1402725/contributions/6013056/attachments/2883747/5054157/MDI_workshop_magnet_load.pdf



A-B Plots for HTS quadrupoles







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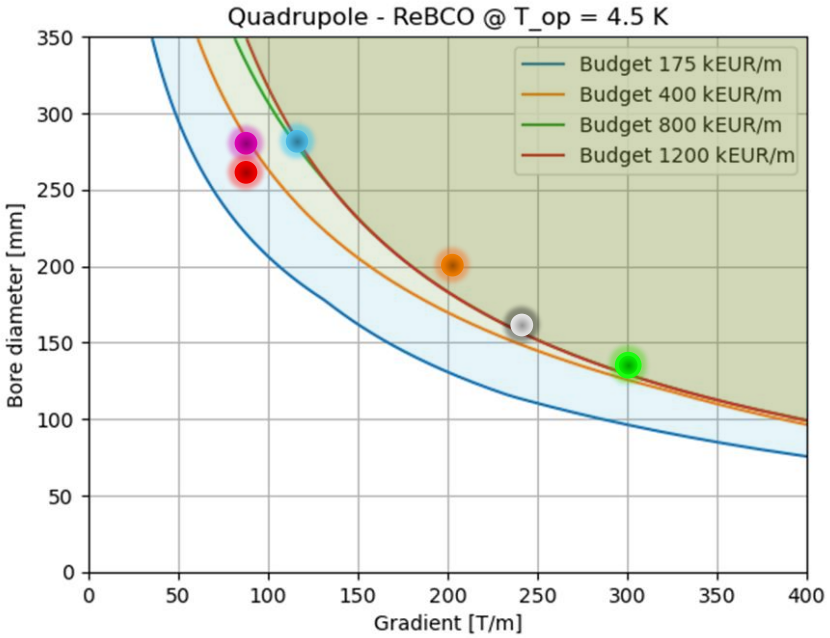
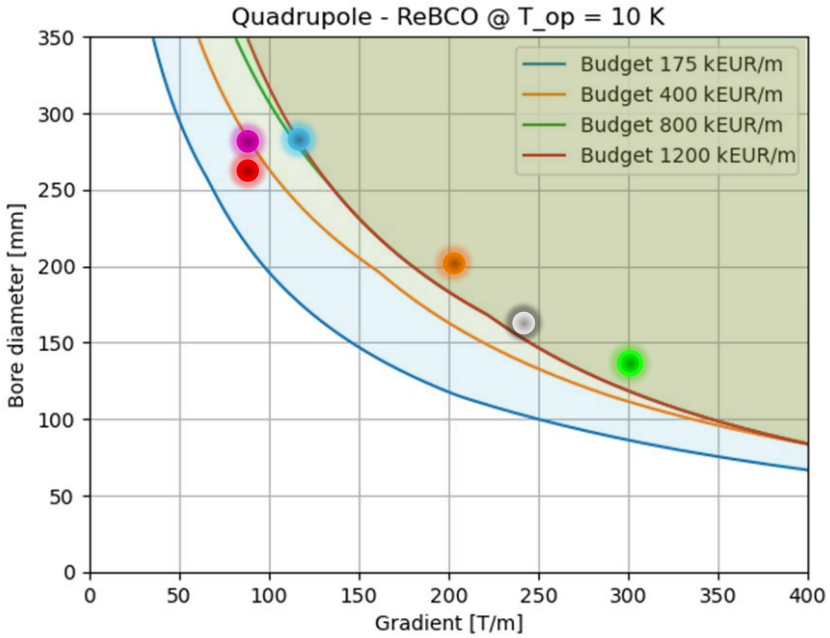
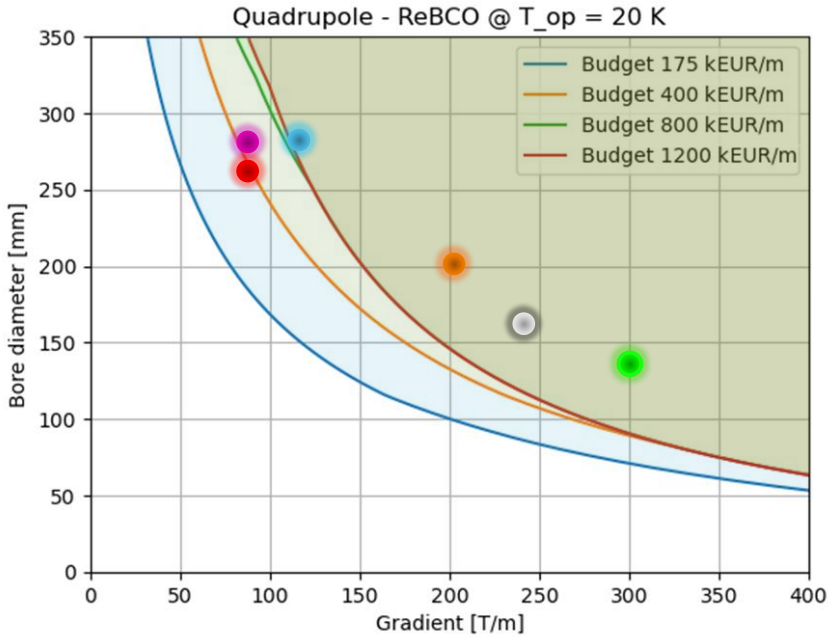
- Maximum coil width: 80 mm

A-B PLOTS FOR HTS QUADRUPOLES







		Dynamic beam aperture [cm]			
Name	L	Upstream	Downstream	Magnet aperture radius [cm]	Gradient [T/m]
IQF2	6	9.81	9.20	14	85.2
IQF2_1	6	9.12	8.84	13.3	85.2
IQD1	9	8.98	10.33	14.5	-115.4
IQD1_1	9	10.28	6.12	14.5	-115.4
IQF1B	2	5.91	4.62	10.2	205.1
IQF1A	3	4.45	2.97	8.6	241.8
IQF1	3	2.84	1.78	7	300.2

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Final Focusing
Quadrupole requirements

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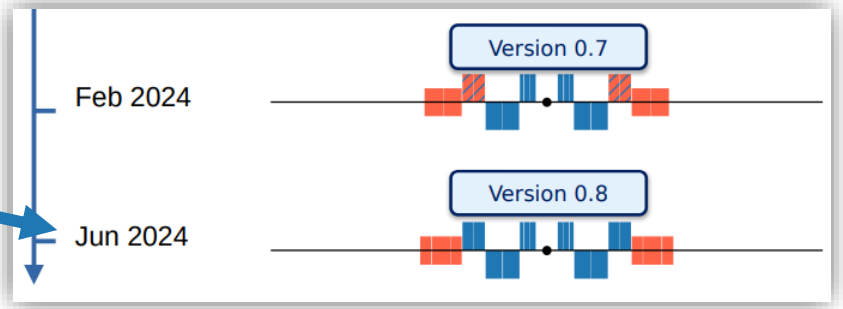

CONCLUSION

D. Calzolari

		Dynamic beam aperture [cm]			
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IQF1B	2	5.91	4.62	10.2	205.1
IQF1A	3	4.45	2.97	8.6	241.8
IQF1	3	2.84	1.78	7	300.2

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IB3	6	9.51	9.79	16	8.1

Baseline:

operating T of 20 K, maximum budget of 400 kEUR/m for each magnet

- In the allowed area
  - @20 K, more than 400 kEUR/m
  - @10K, less than 400 kEUR/m
- In the allowed area
  - @20 K, less than 400 kEUR/m
- On the limit curve
  - @10 K, more than 400 kEUR/m
- Outside the allowed area
- In the allowed area
  - @20 K, less than 400 kEUR/m
- In the allowed area
  - @20 K, more than 400 kEUR/m

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Thank you for your attention