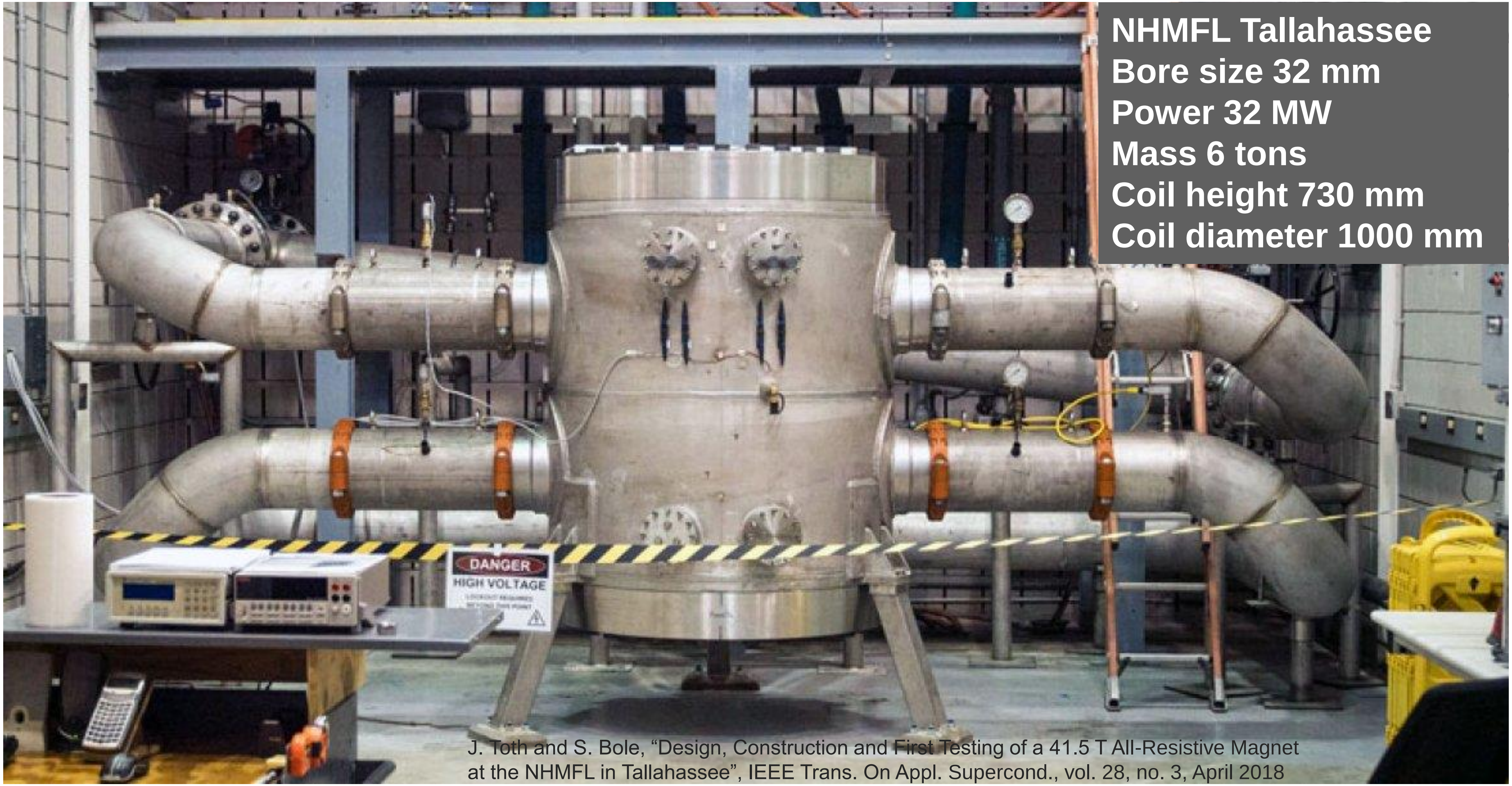
IONS June 19-20-21, 2018
ESI, Archamps

High field NC magnets

Davide Tommasini, CERN

41.5 T normal conducting



NHMFL Tallahassee
Bore size 32 mm
Power 32 MW
Mass 6 tons
Coil height 730 mm
Coil diameter 1000 mm

J. Toth and S. Bole, “Design, Construction and First Testing of a 41.5 T All-Resistive Magnet at the NHMFL in Tallahassee”, IEEE Trans. On Appl. Supercond., vol. 28, no. 3, April 2018

Introduction

Every time I am consulted about magnets for medical application I am asked for the following characteristics:

Large aperture (>> 50 mm)

High field (> 1.5 T)

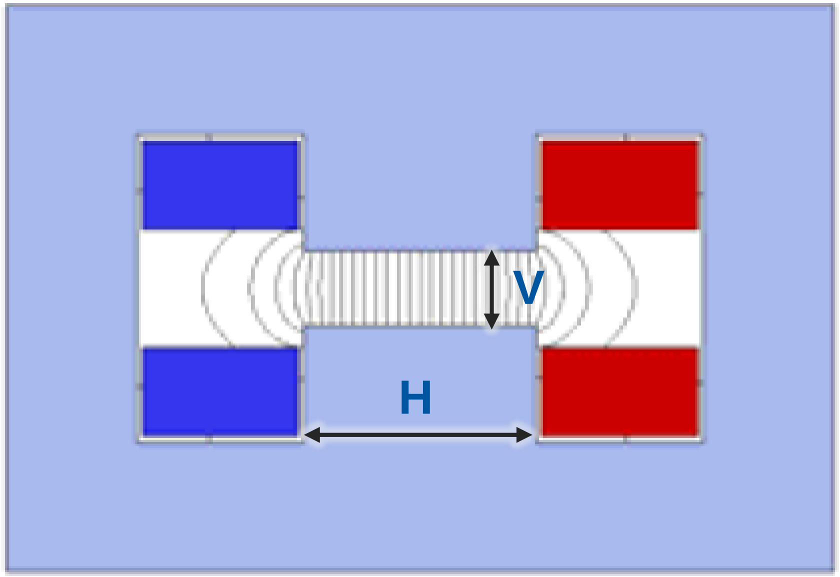
Fast response (ms range)

Compact size

Low consumption

Too easy to ask for this, we need to think out of the box

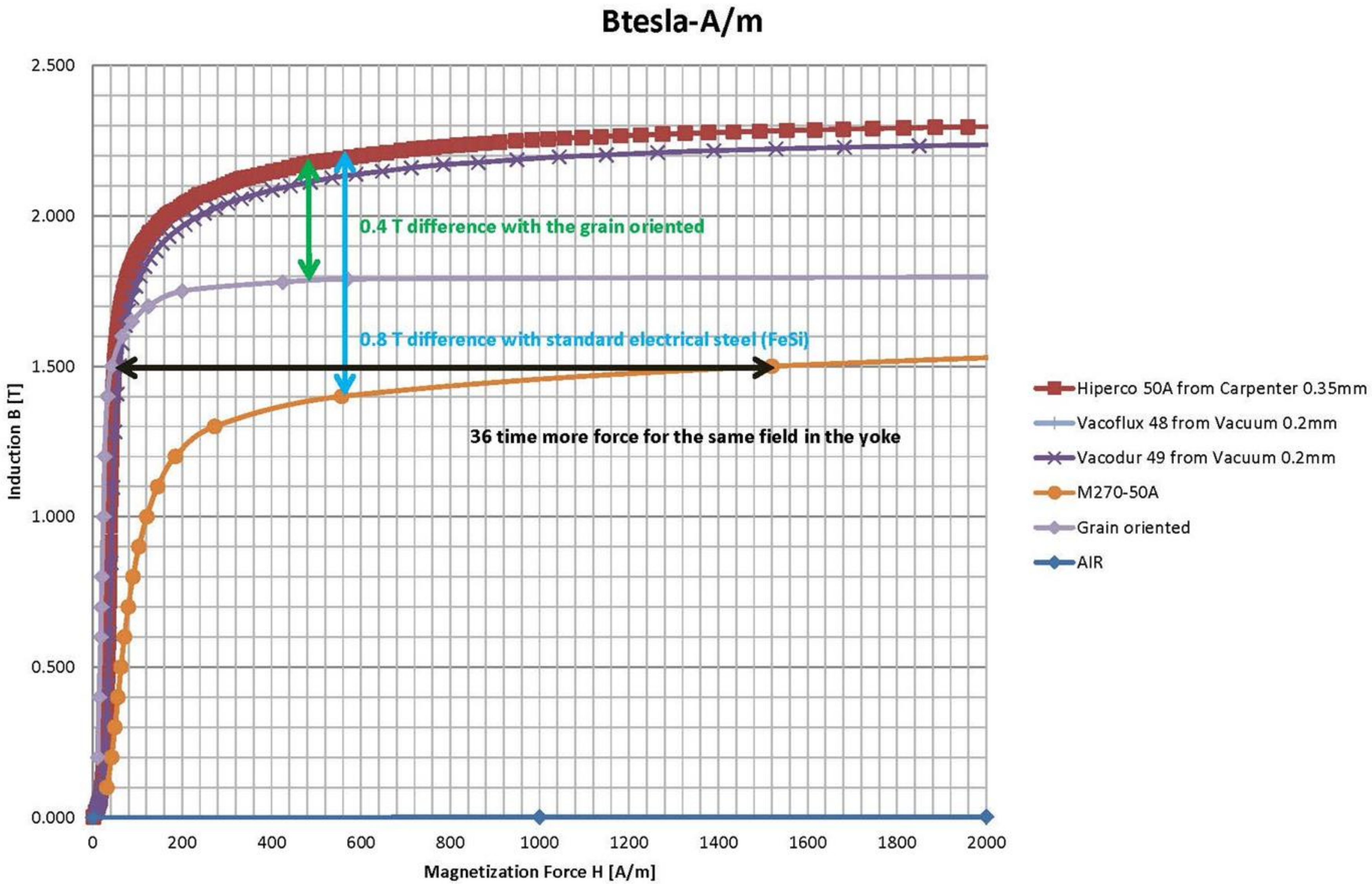
Keys for success: physical aperture



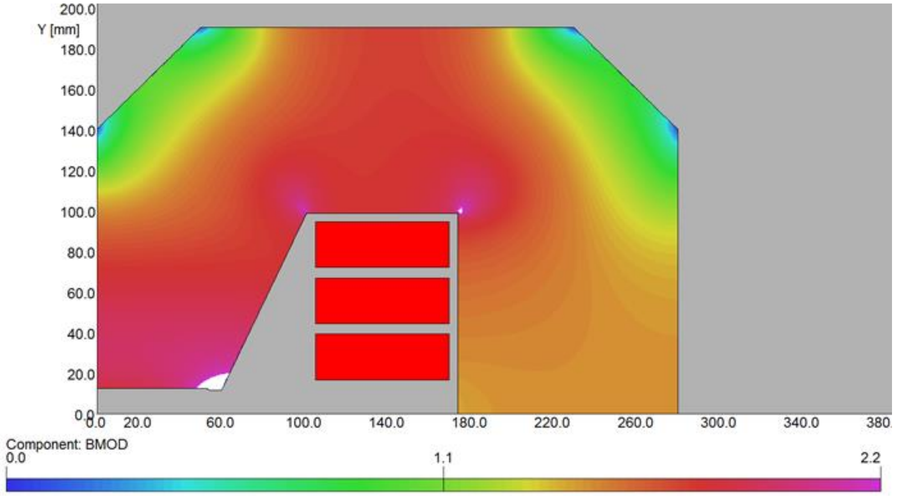
Field 1.2 T
Current density 5 A/mm^2

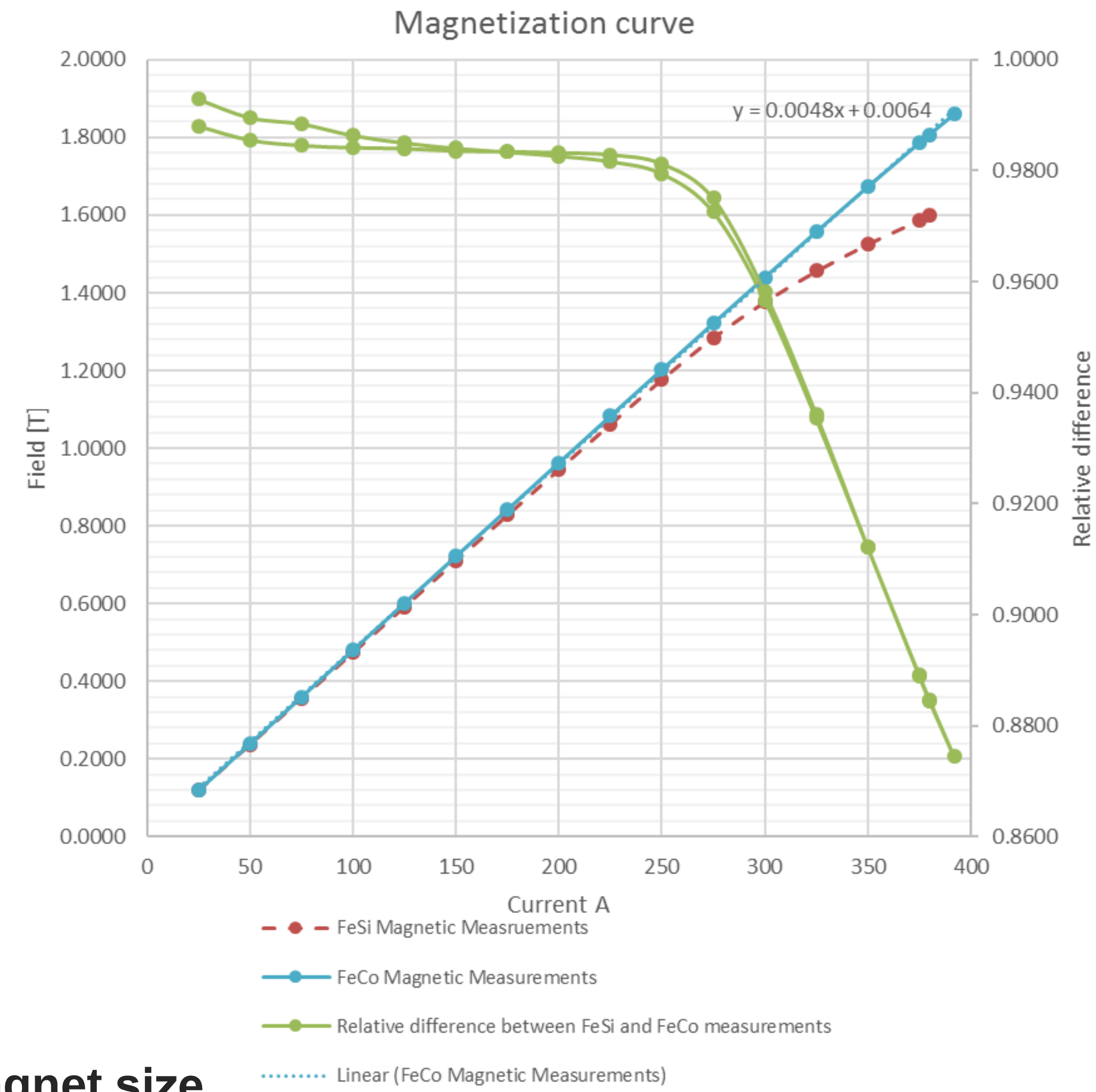
V [mm]	H [mm]	Mass/m	Power [kW/m]
10	20	70	2
	50	150	
	100	350	
	200	1000	
20	-	-	4
	50	220	
	100	450	
	200	1200	
50	-	-	10
	-	-	
	100	700	
	200	1500	
100	-	-	20
	-	-	
	-	-	
	200	2000	

Keys for success: materials



In a H-Type magnet FeCo allows full linear 1.8 T



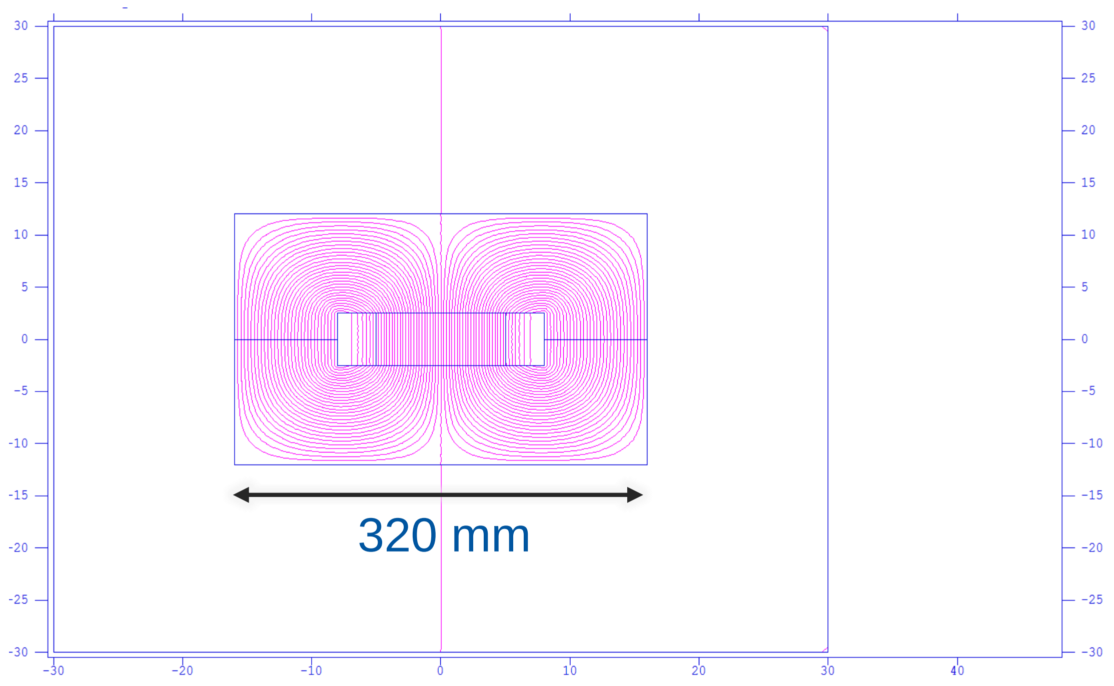


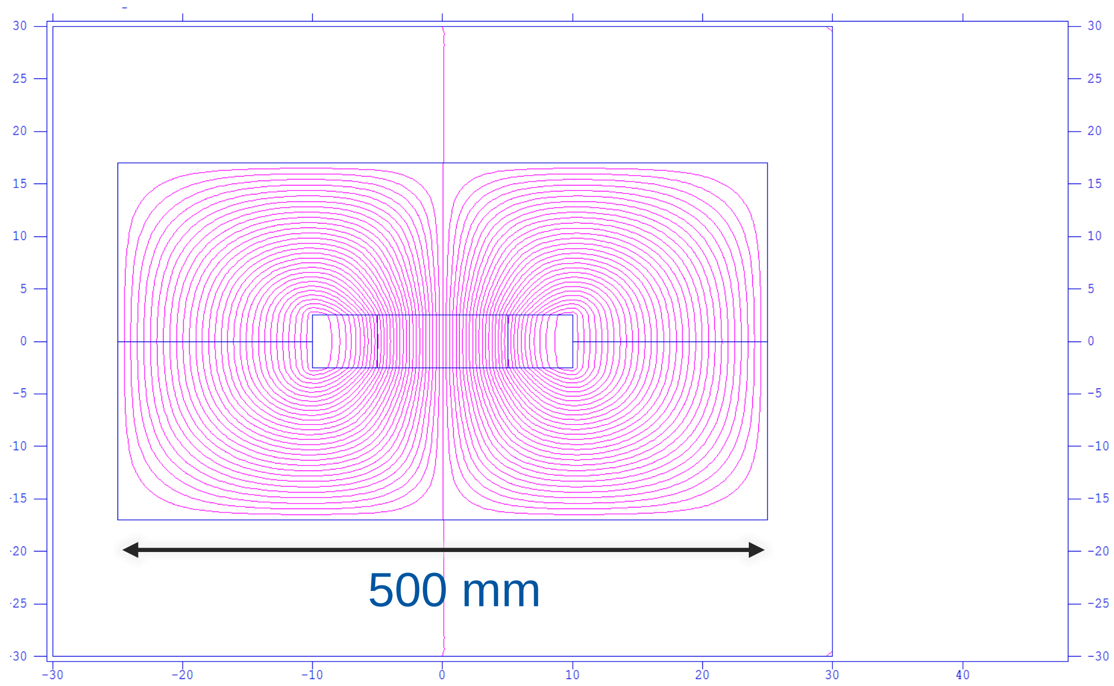
FeCo enables higher fields for the same magnet size …
… or more compact magnets (30% in weight) for the same field … however it is expensive

Beyond 2 T: operation mode

Pulsing with low repetition rate can considerably lower the I_{rms}
Ideally, this shall be such to allow using window-frame magnets instead than H-type or C-type magnets
To an extreme, we may even imagine costheta conventional magnets

2 T and 3 T window-frame magnet with I_{rms} ~ I_{max}/50 (one 10 ms cycle every 10 s)
H = 50 mm, W = 100 mm





Beyond 2 T: brute force H-Type

- The ferromagnetic «pole» progressively disappears above 2 T.
- Adding more ampereturns correspond to an increase of «gap», thus requiring even more ampereturns
- Ideally, one would like adding the ampereturn in a concentrated way, to avoid increasing the pole height
- This corresponds to increasing the current density: we are converging towards a superconducting magnet !

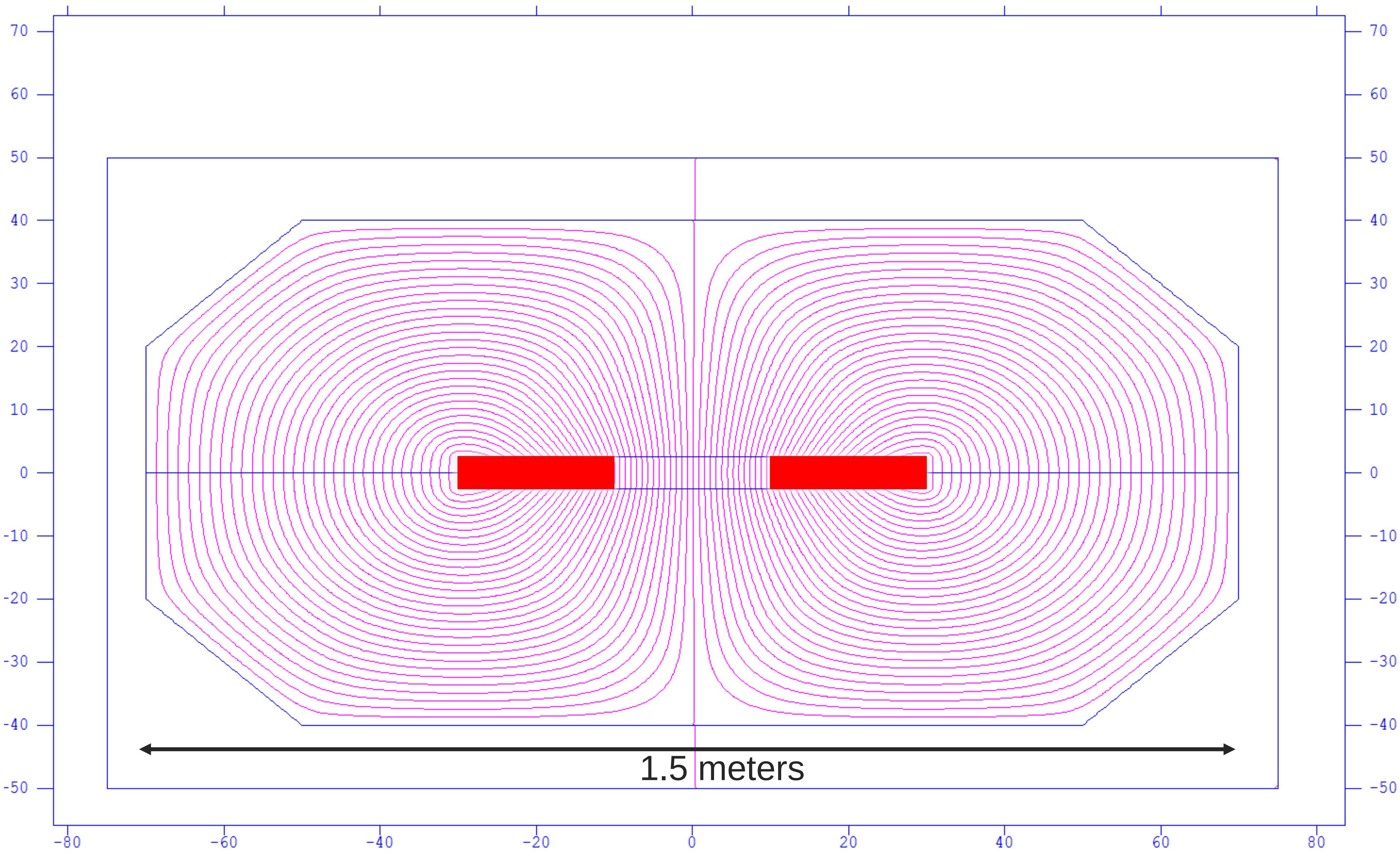
Beyond 2 T: brute force split solenoid

- In principle high fields with resistive magnets become possible.
- Power consumption becomes huge because of the long magnetic circuit in air.

Beyond 2 T: brute force window-frame

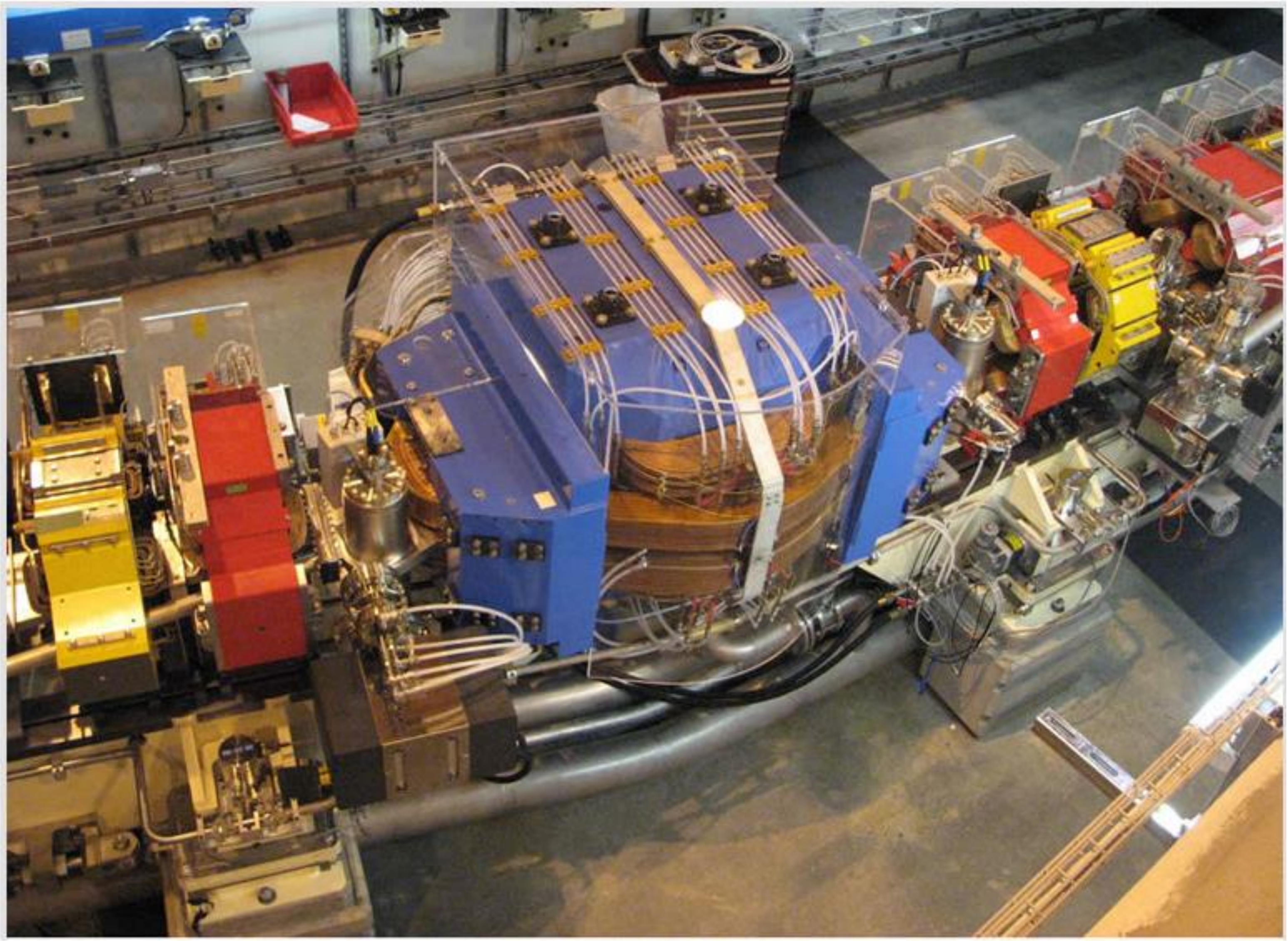
- Fields of 3 T or even above can be produced.
- Power consumption is large because of the small coil size which imposes a high current density.

Beyond 2 T: brute force window-frame



B= 3 T
Gap= 50 mm
NI= 200 000 A
J=20 A/mm^2
P=160 kW/m
Mass= 8 tons/m

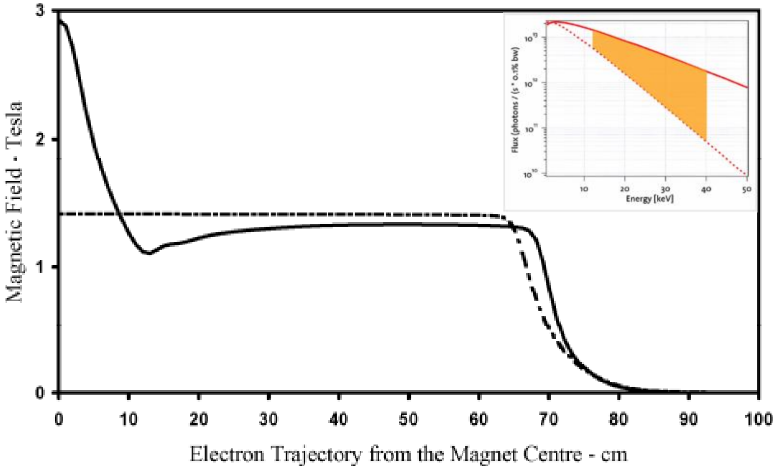
The 3 T superbend of the SLS (PSI)



THPC063 Proceedings of IPAC2011, San Sebastián, Spain

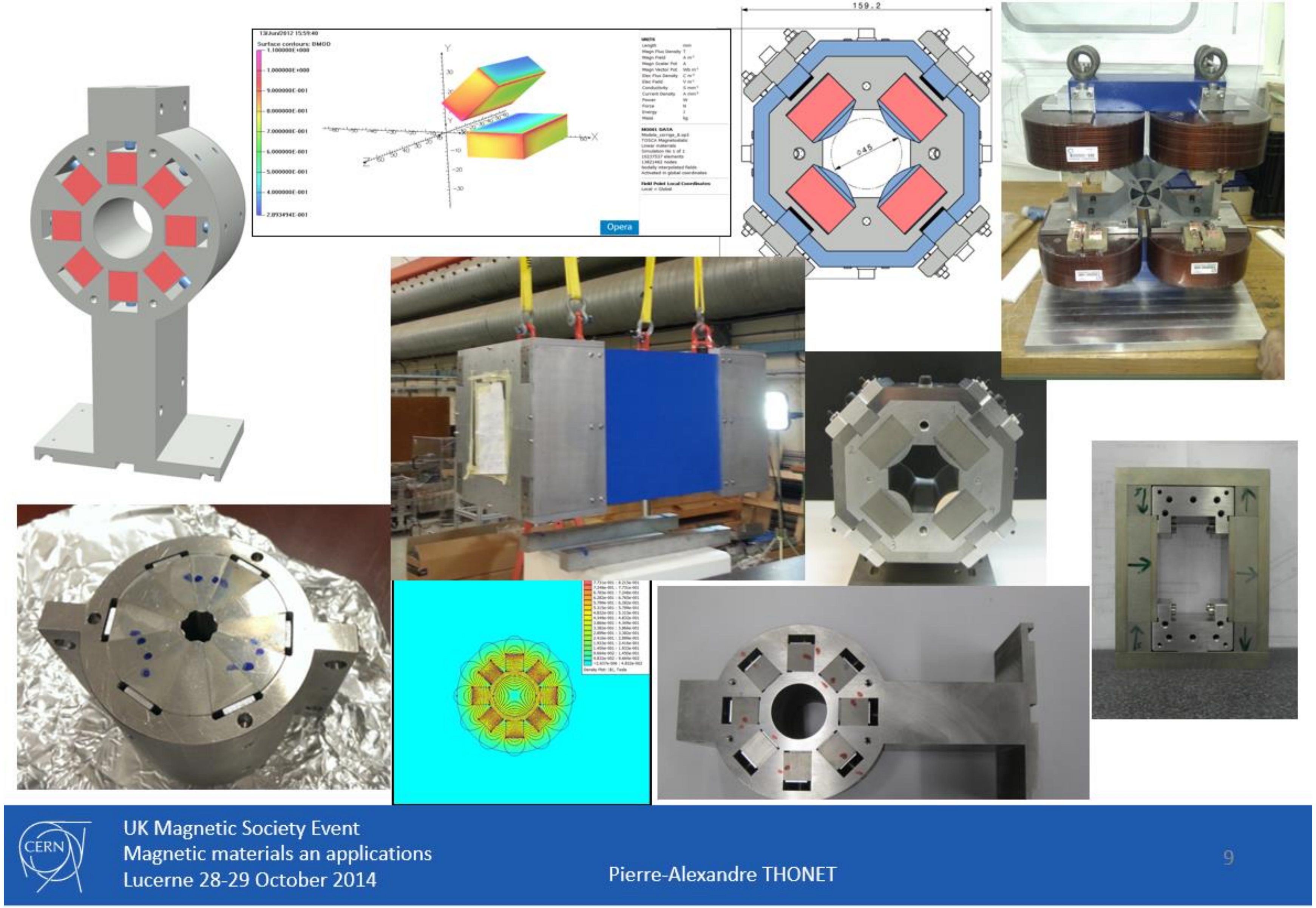
A 2.9 TESLA ROOM TEMPERATURE SUPERBEND MAGNET FOR THE SWISS LIGHT SOURCE AT PSI

Alexander Gabard, David George, Marco Negrazus, Leonid Rivkin, Vjeran Vrankovic, PSI, Villigen, Switzerland
Yuriy Kolokolnikov, Pavel Vobly, BINP, Novosibirsk, Russia



Air gap 40 mm
Peak field 2.95 T
Power 40 kW
Coil mass (main/central) 570/500 kg
Total weight 6700 kg

Permanent magnets at CERN

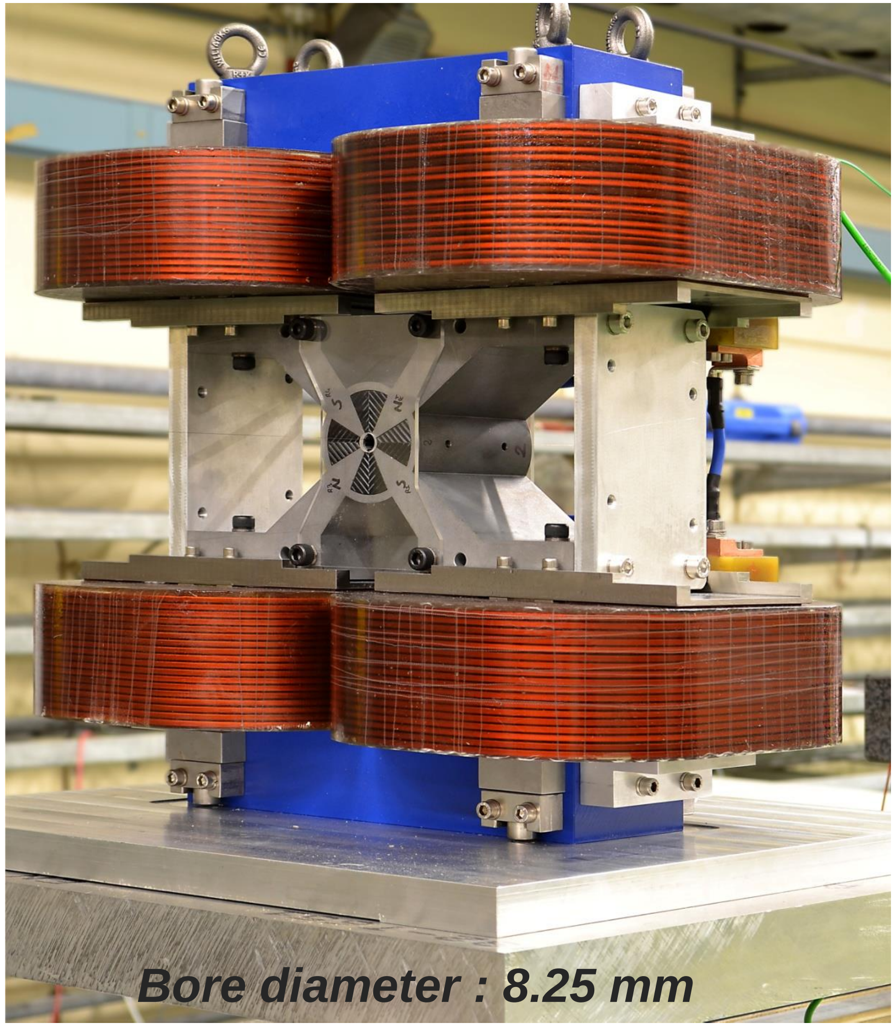


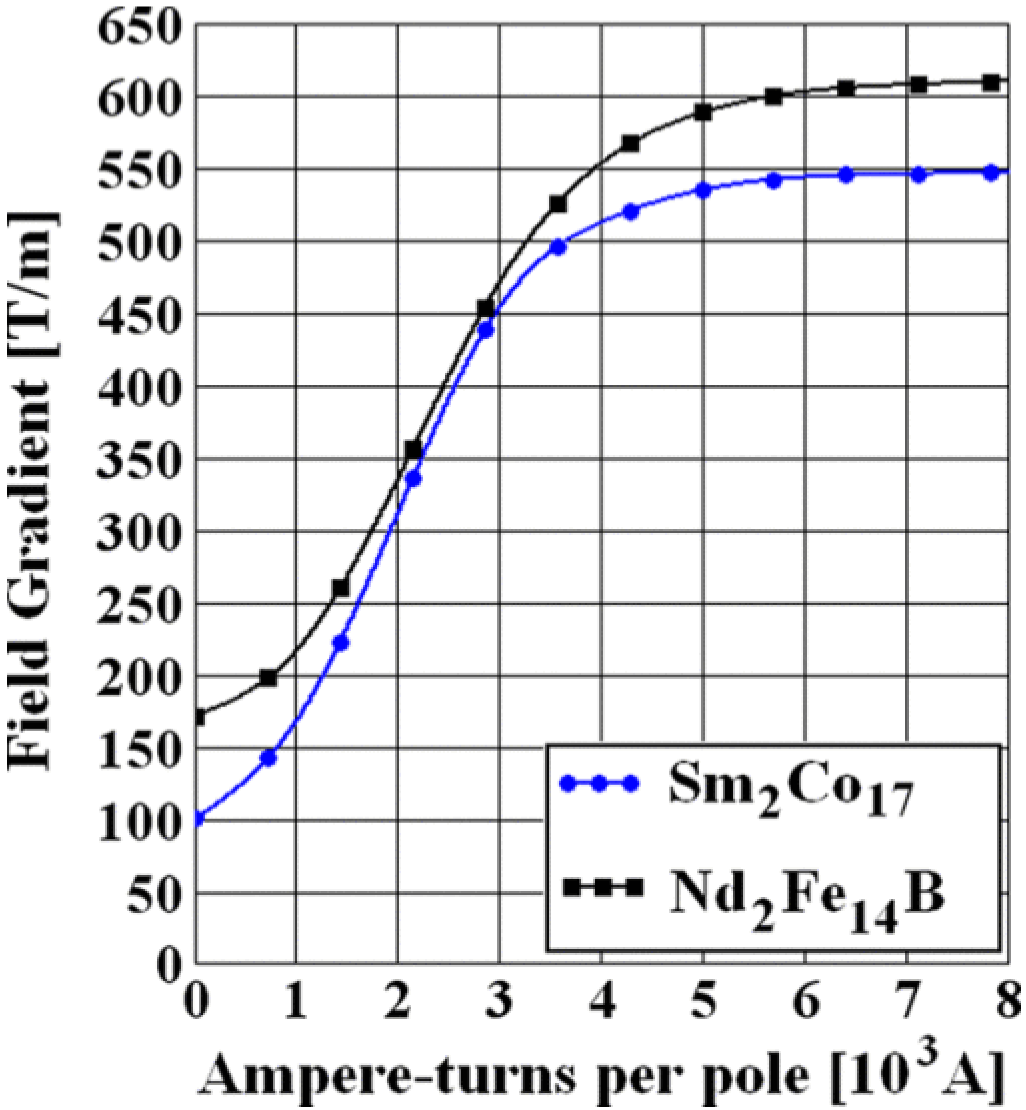
Hybrid Quadrupoles

4000604 IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 22, NO. 3, JUNE 2012

Design and Manufacture of a Hybrid Final Focus Quadrupole Model for CLIC

Alexey Vorozhtsov, Michele Modena, and Davide Tommasini





Conclusion

- Size and power consumption of NC magnets are strongly dominated by the required aperture.
- Above 1.2-1.5 T in the pole gap, magnetic efficient configurations are of window frame type, their drawback is power consumption to keep the coil size compatible with the window height (require high current densities).
- Fast pulsing the magnets can mitigate the above limitations thanks to the reduction of the rms current.
- The use of FeCo can either allow more compact magnets (30% less weight) or higher fields (approaching 2 T) without saturation (linear response). Above 2 T (in the aperture) the advantage of FeCo disappears.
- For a NC dipole a field amplitude around 3 T, where the benefit of the iron is still moderately present, can still be achieved with a "reasonable" construction.
- We should not forget permanent magnets, especially quadrupoles with small to moderate apertures.

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