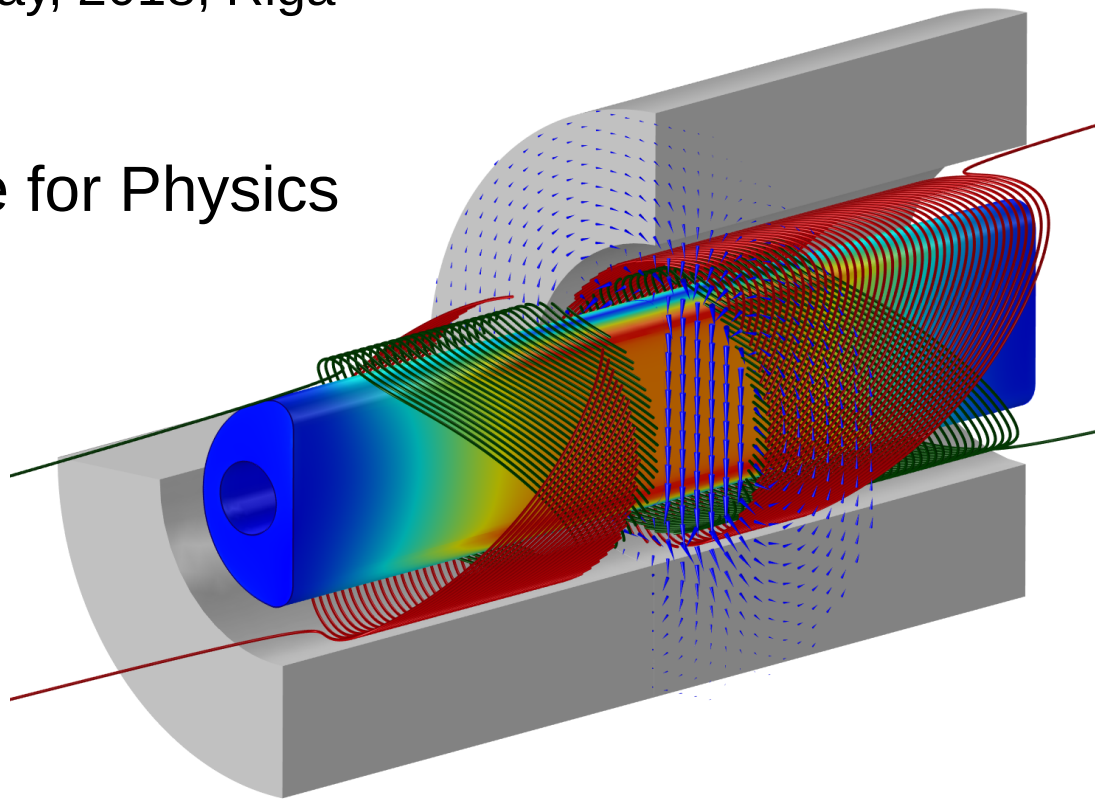
The SuShi test at SM18

1st ARIES annual meeting, 22-25 May, 2018, Riga

Daniel Barna
MTA Wigner Research Centre for Physics
Budapest, Hungary



Outline

- Personal & project history and introduction
- The Superconducting Shield (SuShi) septum concept
- Tests and results at CERN SM18
- Impact of EuCARD-2 + ARIES & side-effects
- Outlook and plans

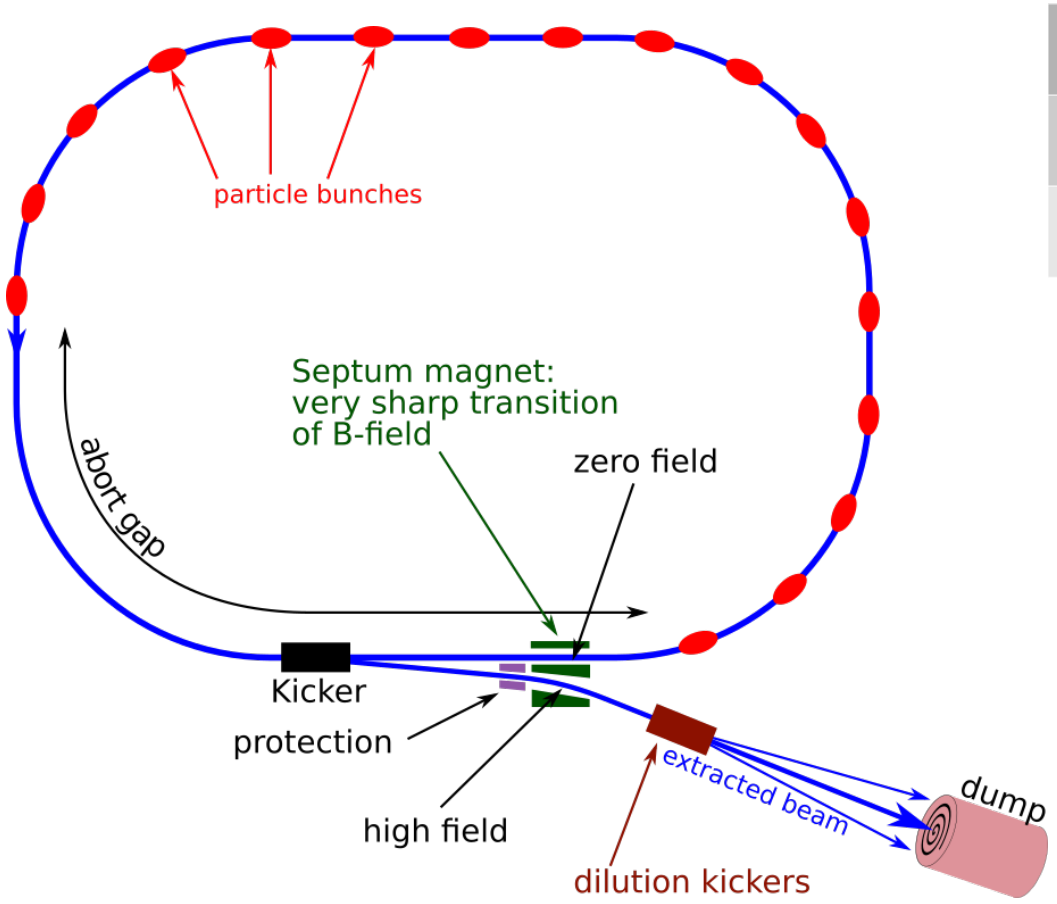
Personal & project history

- 2005-2016: Working @ Asacusa (AD-3) exp. @ CERN, antiprotons
- Last years: participation in electrostatic beamline design/construction/testing for ELENA (Extra Low ENergy Antiproton ring)

- Planning return to Budapest, search topic
- Close work contact to CERN TE-ABT
- FCC is hot topic

- Topic: FCC extraction septum concepts
- FCC MoU signed between CERN-Wigner

Extraction from FCC



Deflection by septa	1.14 mrad
Integrated field	190 Tm
Available space	120 m

- Required field: > 2 T to include valves, pumps, fringe fields, etc
- Higher is better → more compact, especially in high-energy LHC
- Goal: ≥ 3 T field, +/-1.5 % homogeneity
- Apparent septum thickness: <25 mm

The SuShi idea

- **Passive** superconducting **shield** around circulating beam
- **Cool** below T_c **in zero field**
- Ramped-up external field induces **persistent shielding currents**
- Which exclude field and completely shield the circulating beam

- Add an external magnet, optimize shield + magnet to get homogeneous field

Pros & Cons

PROS

- Shielding currents are continuous in 2D, and not discrete
- No quench-protection needed in the shield
- Bulk superconductor
  - No insulation
  - Better heat conductivity
  - Mechanically stronger
- Critical state model:
  $J_{shielding} = J_c$ → thinnest shield

CONS/ISSUES

- Trapped field? Will it distort field homogeneity?
- Needs “thermal reset” to
  ➔ eliminate trapped field?
  ➔ in case of flux jump

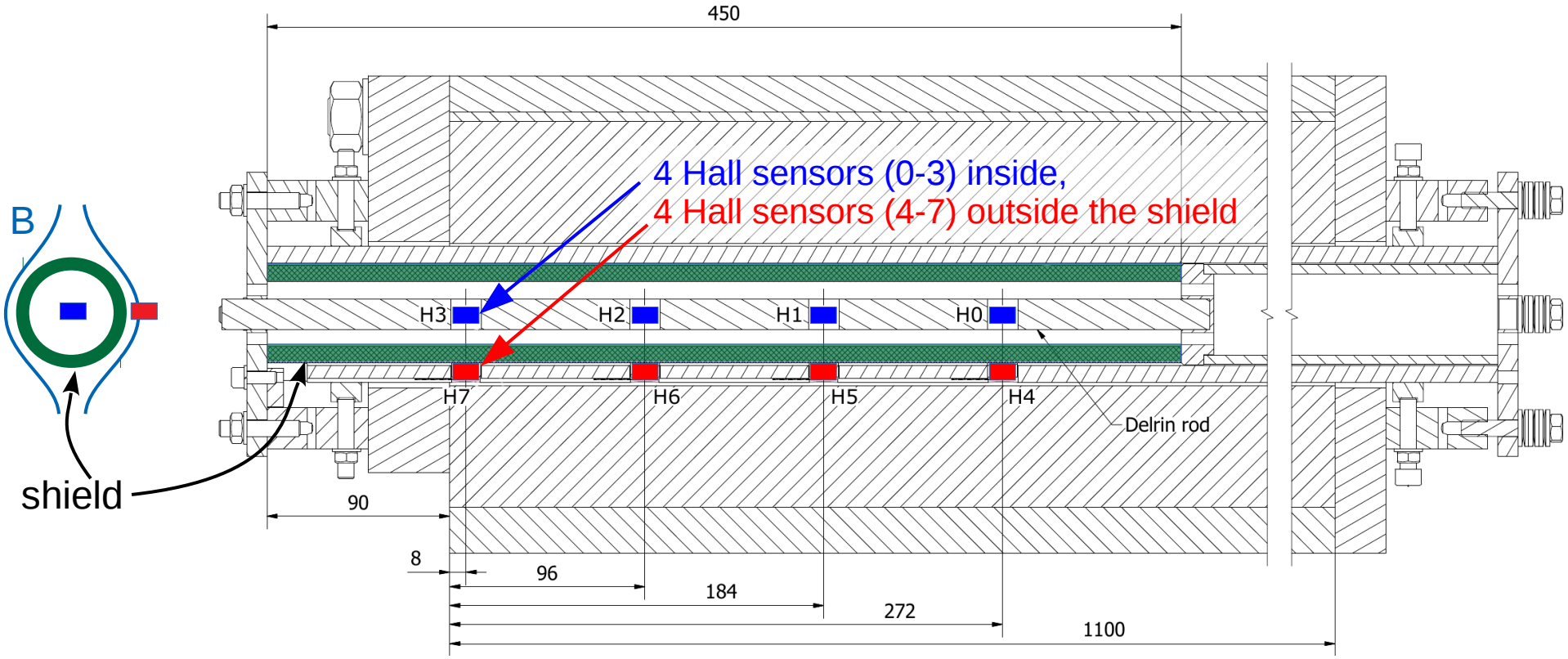
Shield material tests

- Design & construction of a SC magnet is difficult & costly
- Test shield materials in simple setups & existing magnets
  - Maximum shielded field with given thickness?
  - Stability against flux jumps?
  - Early detection methods of flux jumps? (must execute emergency-abort of beam!)
  - Elimination of the trapped field
- Need:
  - Large-bore SC magnets
  - Cryostats
  - Magnet control & protection system
  - Diagnostics

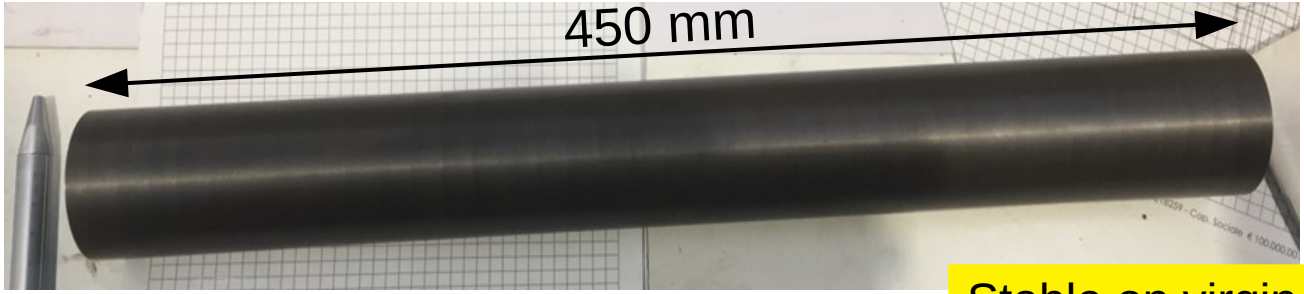
} Not available everywhere

Shield material tests

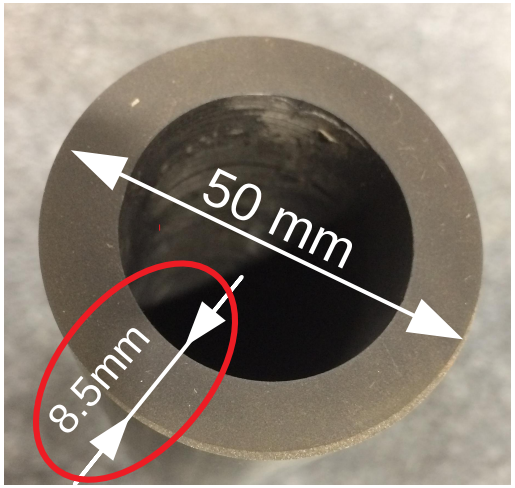
- Shield: 450 mm long tube
- Magnet: LHC spare MCBY dipole (length: 1100 mm, bore: 70mm)



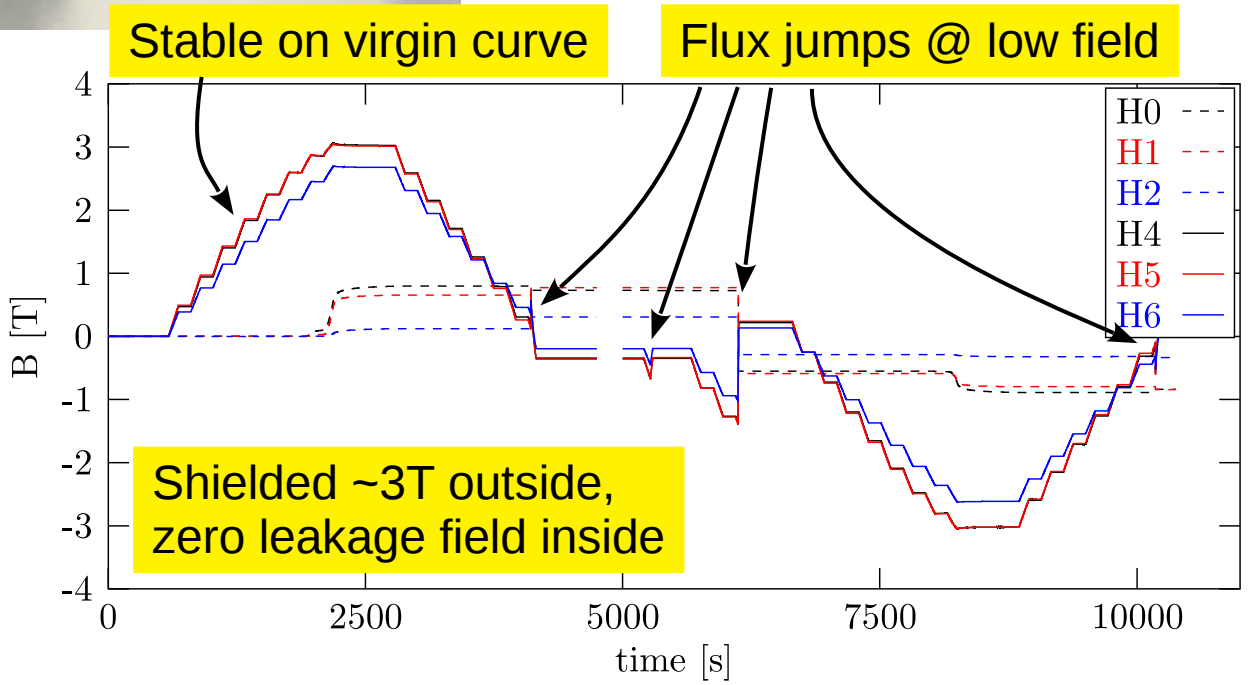
MgB_2



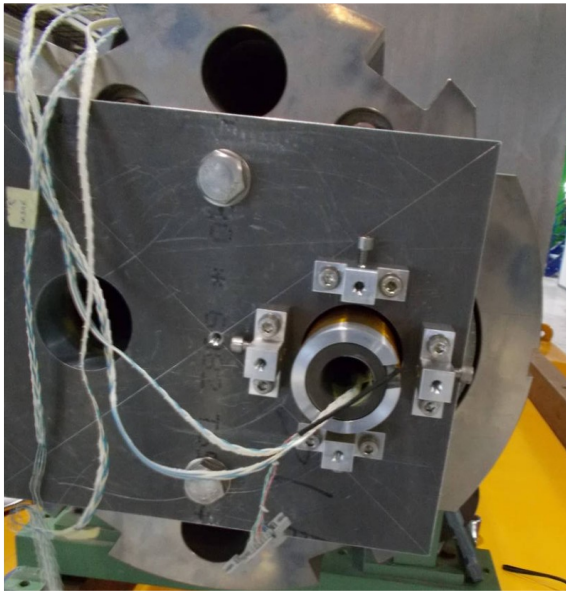
Reported @ FCC Week ‘17

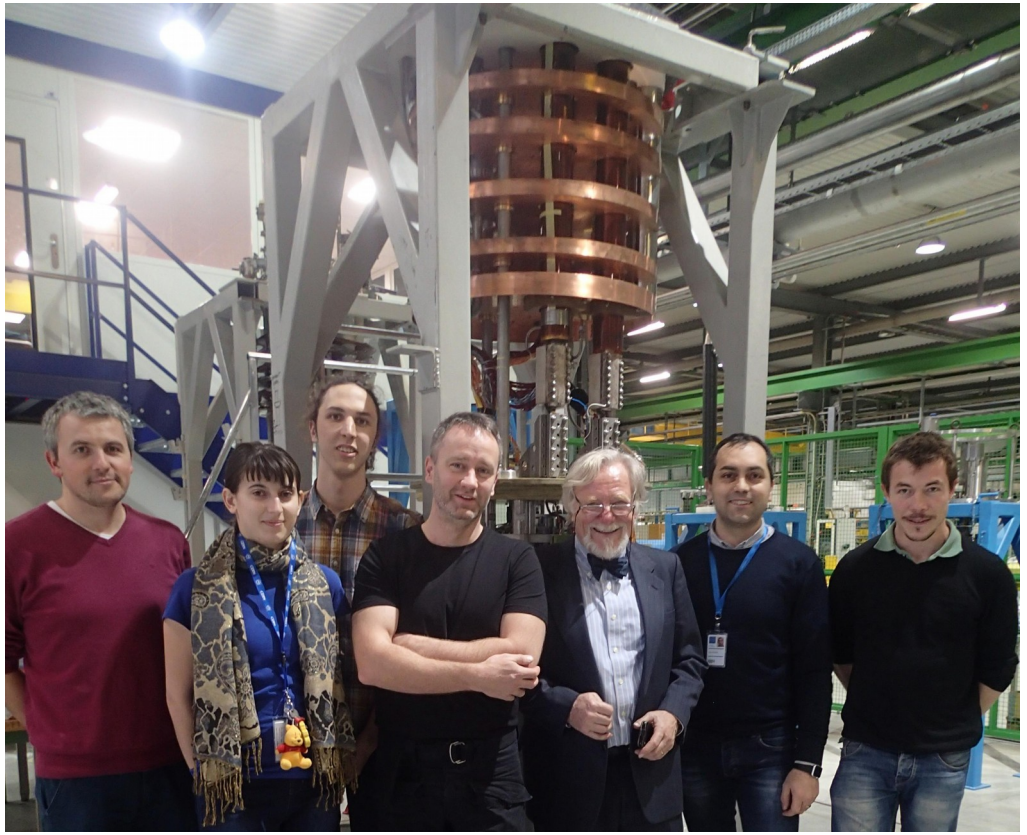


- Produced by the Reactive Liquid Magnesium Infiltration (RLI) process
  (G. Giunchi, Int.J.Mod.Phys.B17,453)

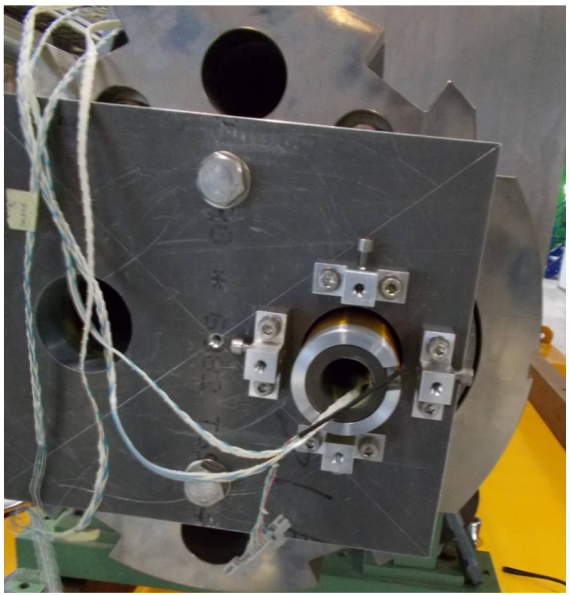


MgB_2

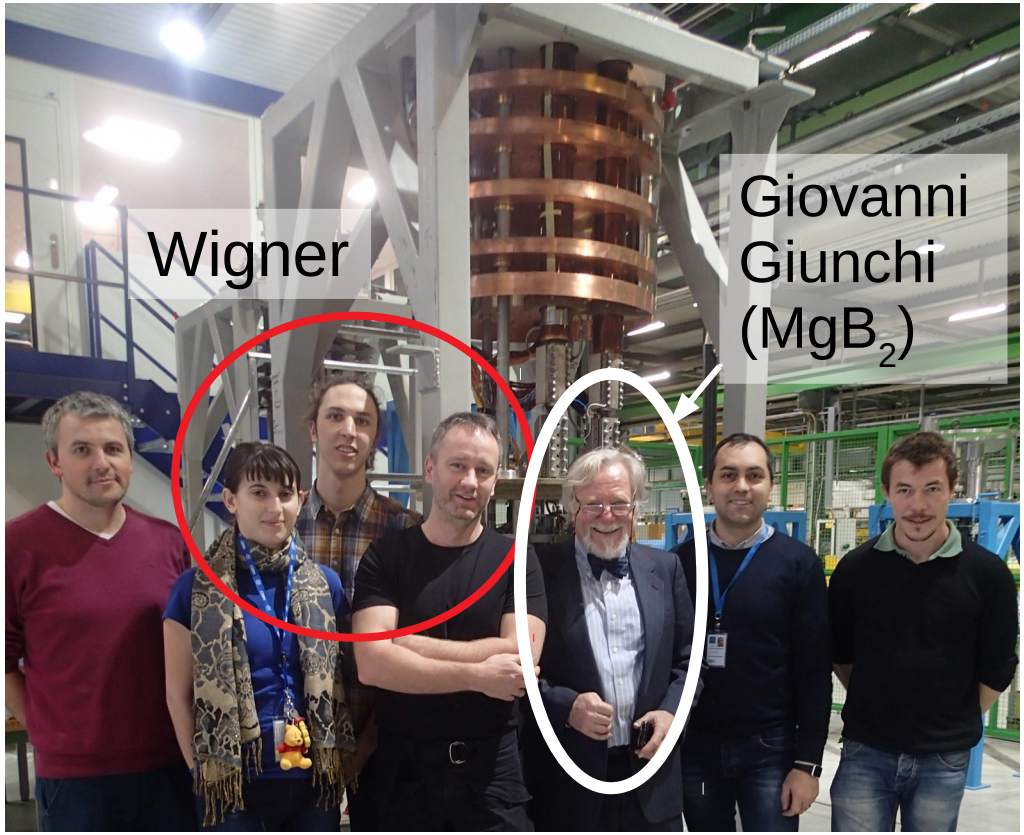




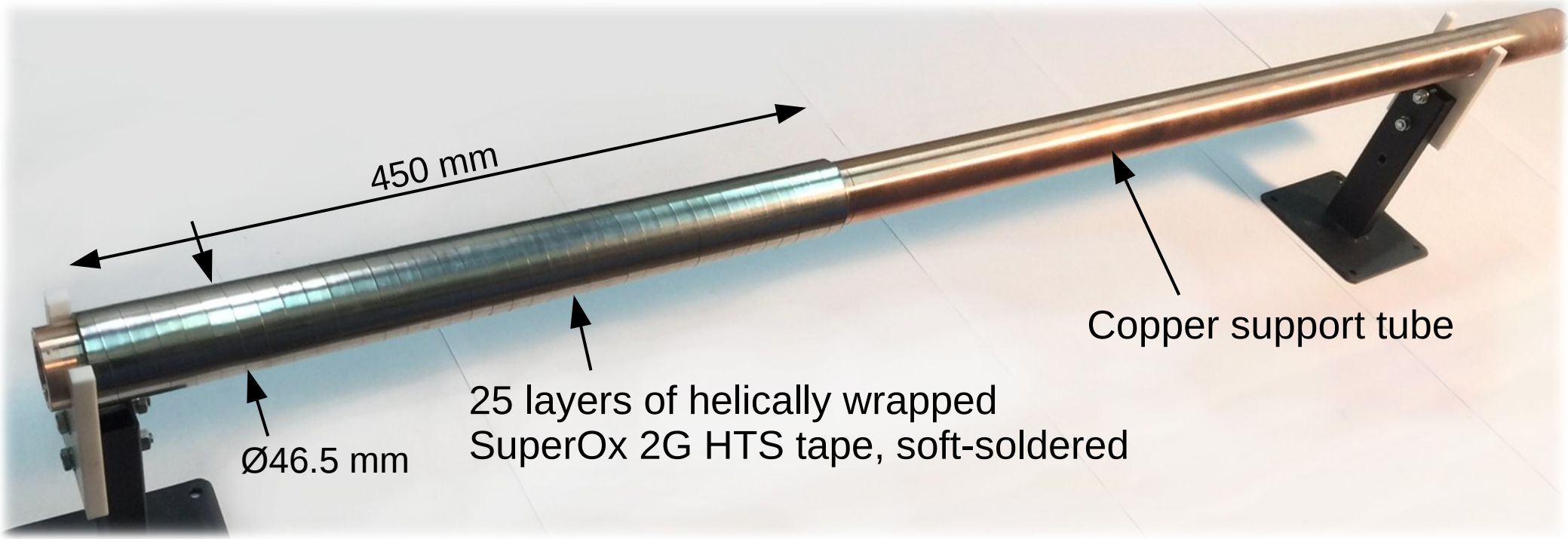
MgB_2



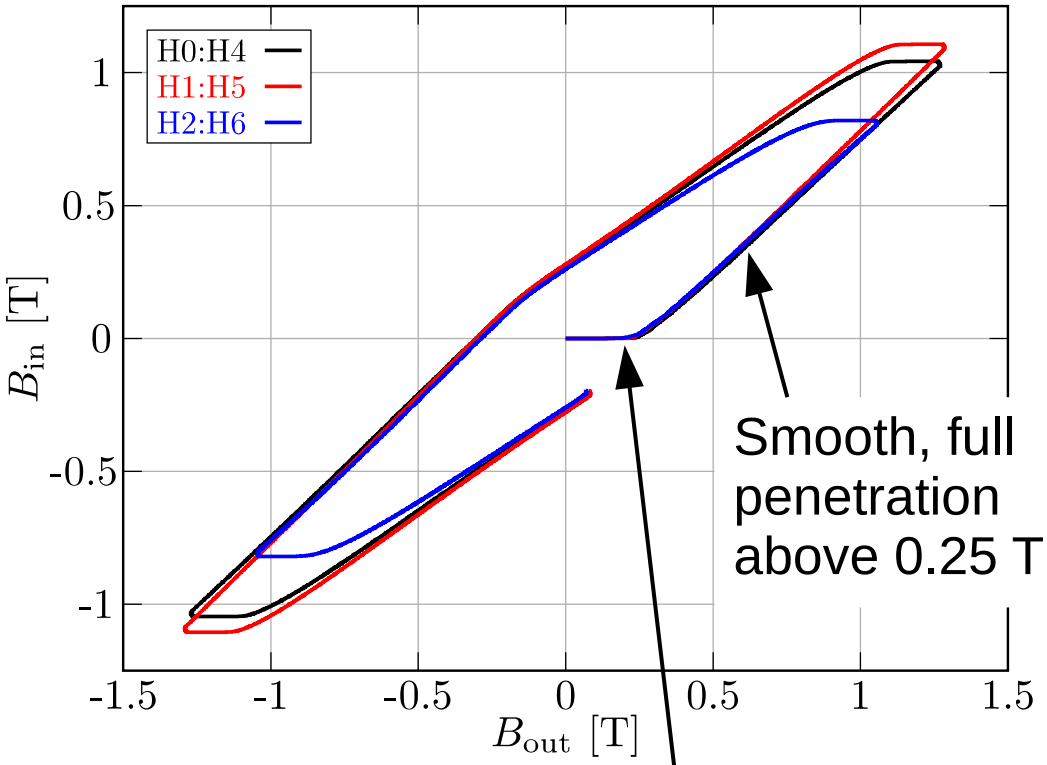
People supported by EuCARD-2



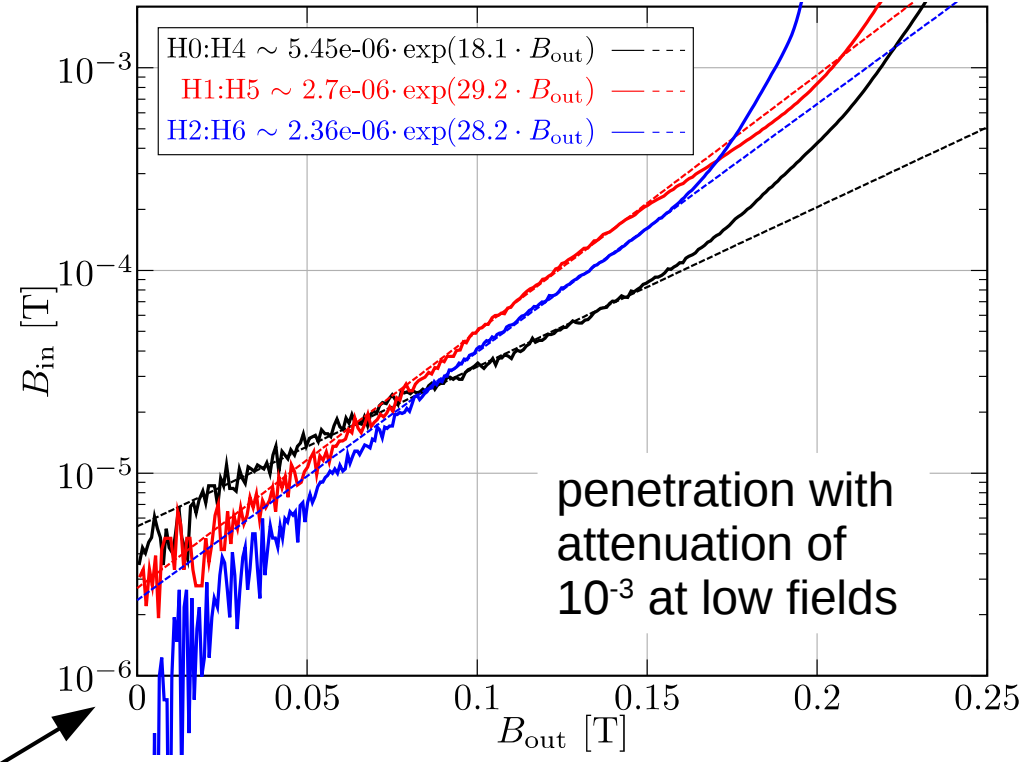
Helically wrapped HTS shield



Helically wrapped HTS shield



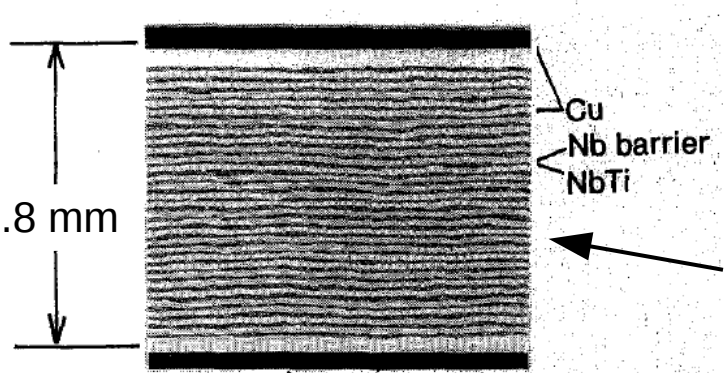
Smooth, full penetration above 0.25 T



penetration with attenuation of 10^{-3} at low fields

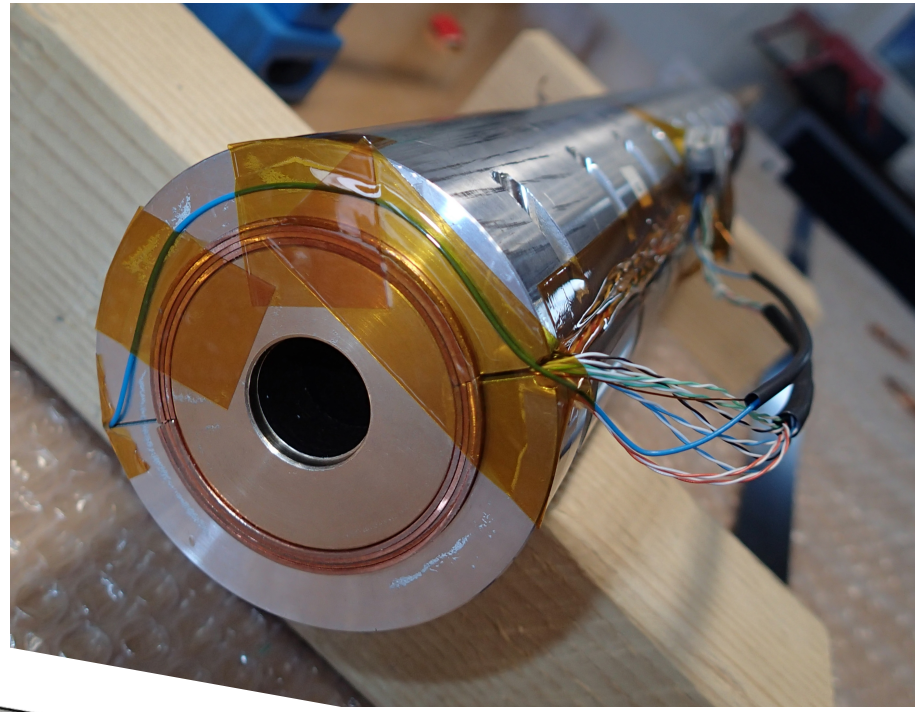
Partially shielding up to 0.25 T

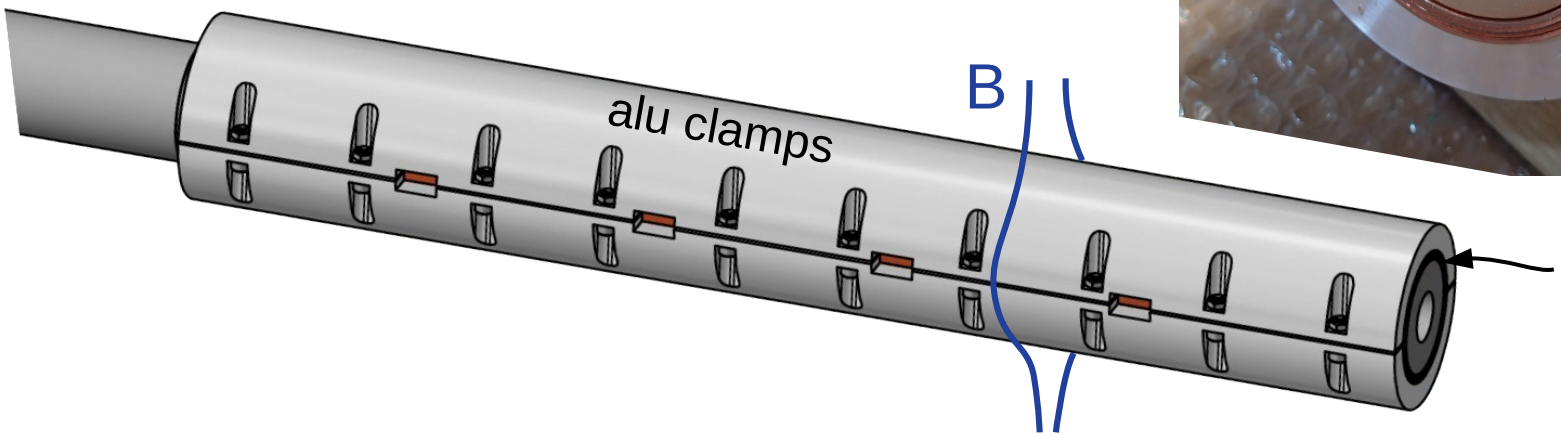
NbTi/Cu multilayer sheet (Nippon Ltd)



30 layers of
9 µm thick
NbTi

I. Itoh, T. Sasaki, IEEE.Trans.Appl.Supercond.3 (1993), 177

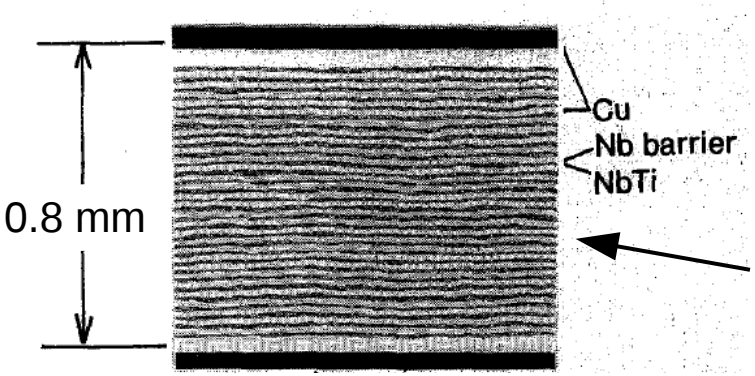




two half-cylinders,
each of 4 sheets

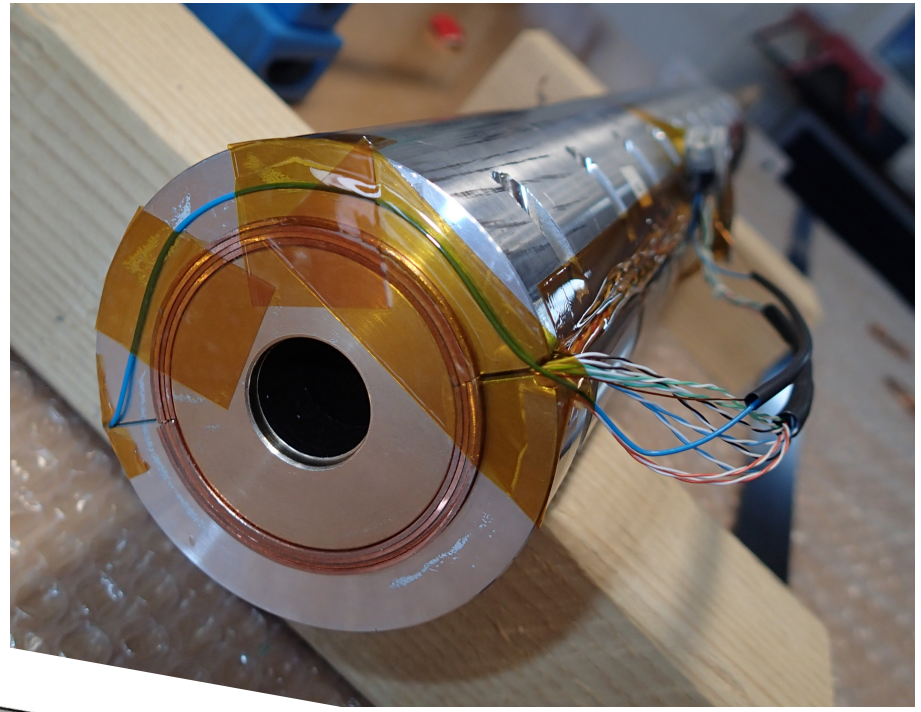
tot. thickness 3.2 mm

NbTi/Cu multilayer sheet (Nippon Ltd)



30 layers of
9 μm thick
NbTi

I. Itoh, T. Sasaki, IEEE.Trans.Appl.Supercond.3 (1993), 177



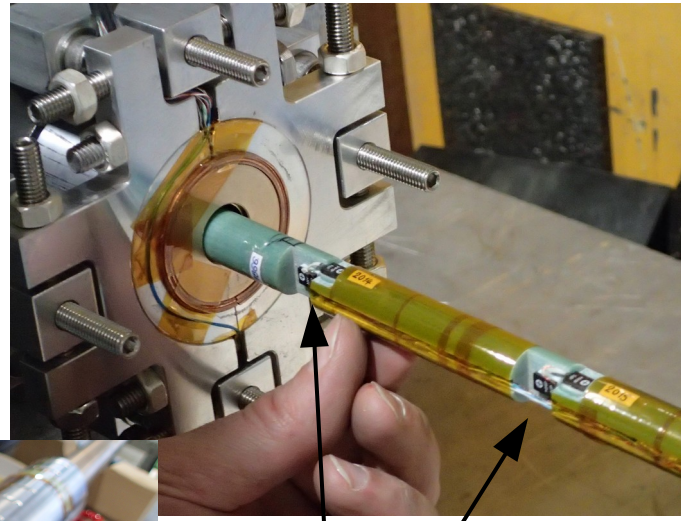
- Shielded field: 3.1 T
- No flux jumps!

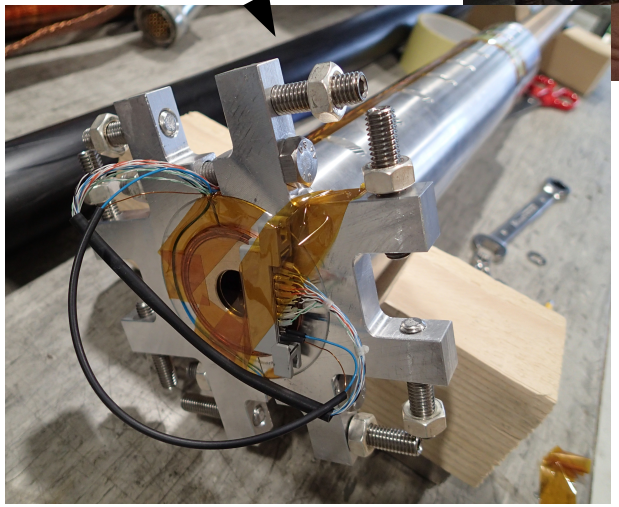
two half-cylinders,
each of 4 sheets

tot. thickness 3.2 mm

NbTi/Cu multilayer test setup

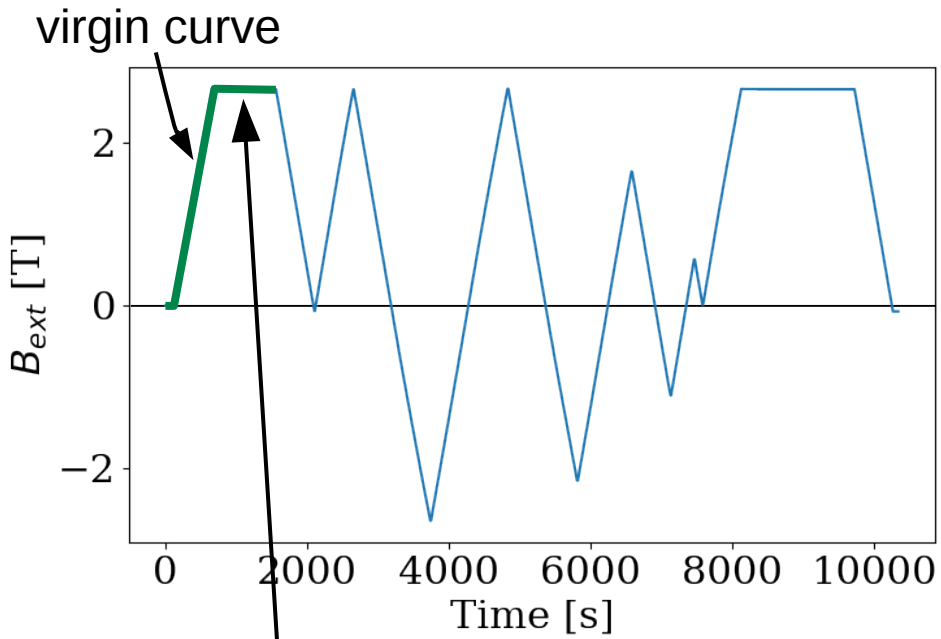
Alignment bolts

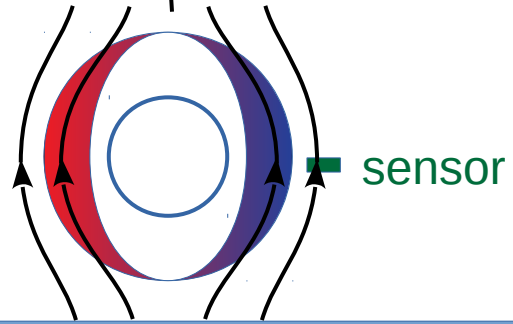


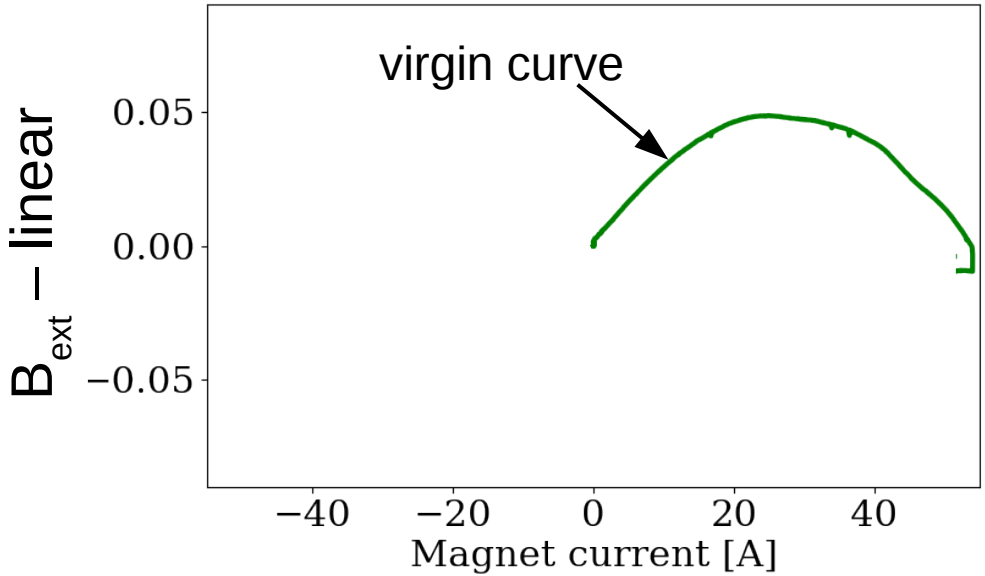


Inner Hall sensors

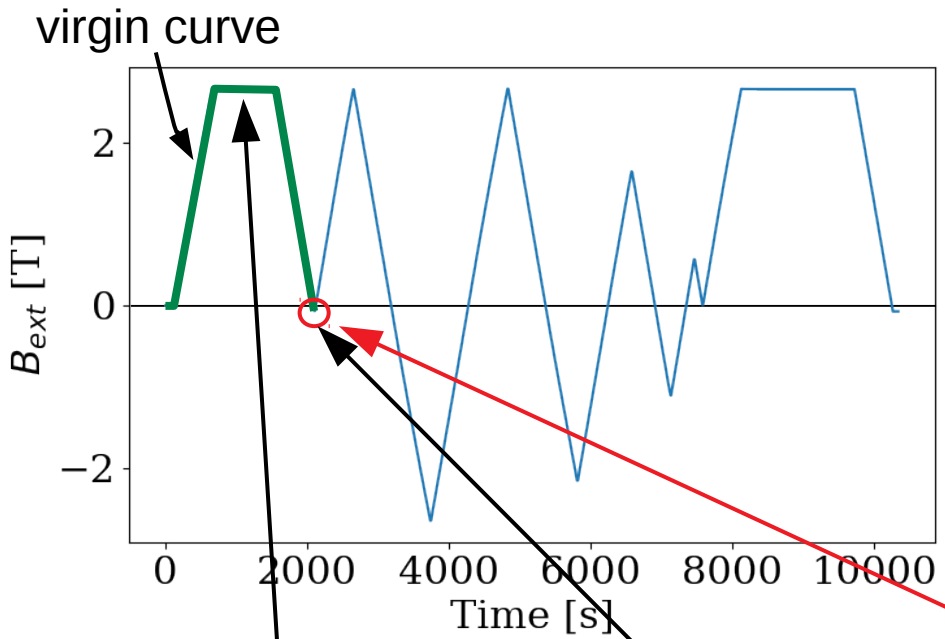
Eliminating trapped field: demagnetization

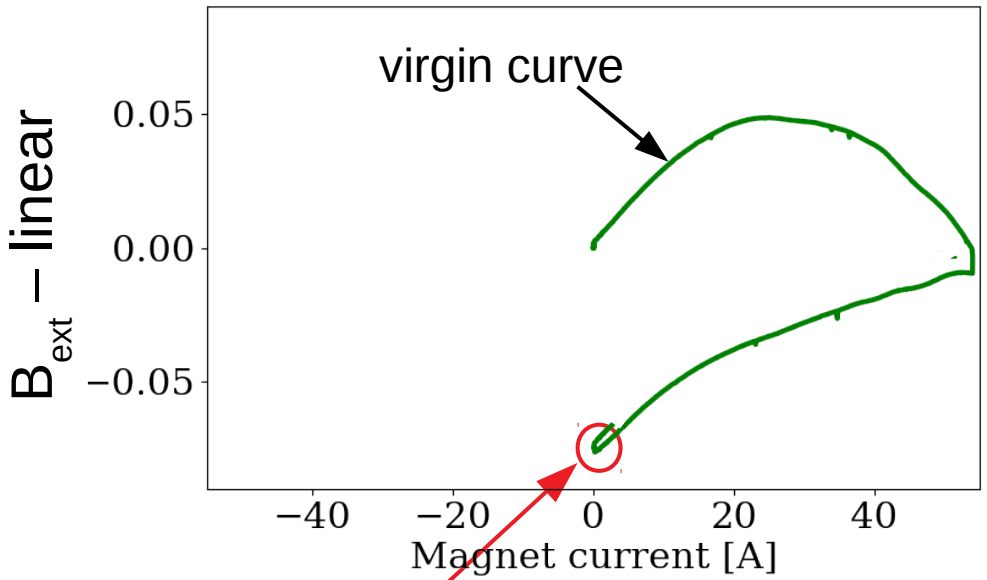


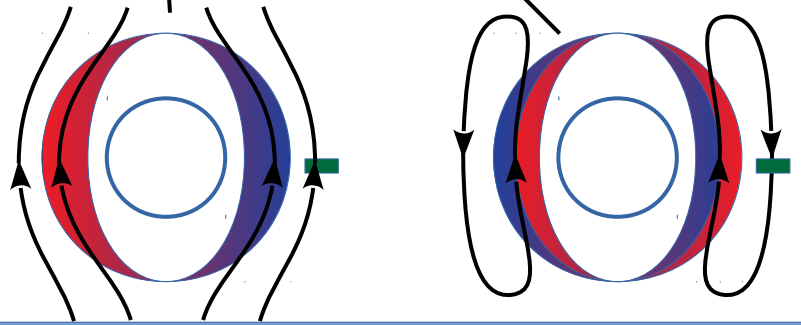




Eliminating trapped field: demagnetization

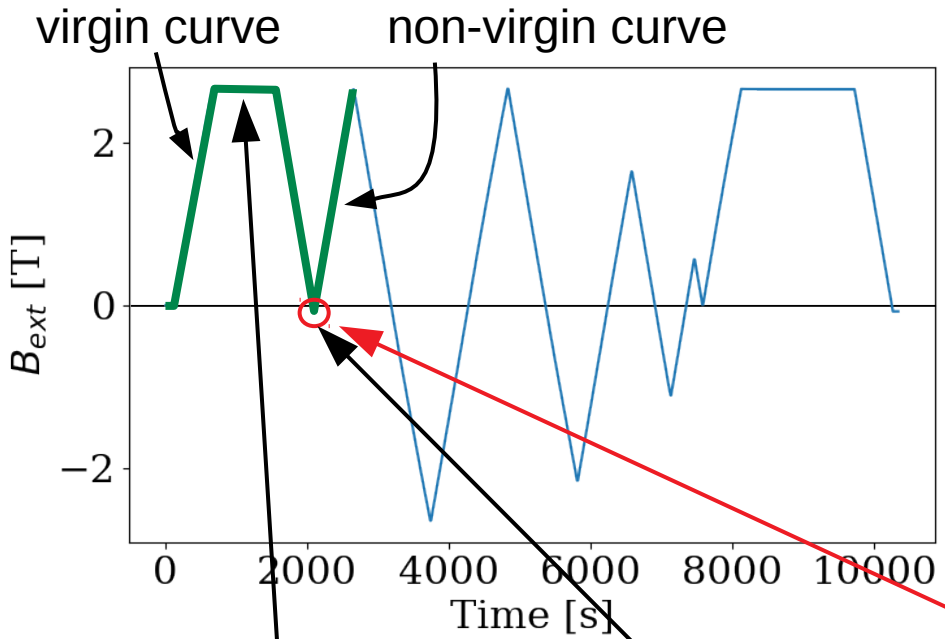


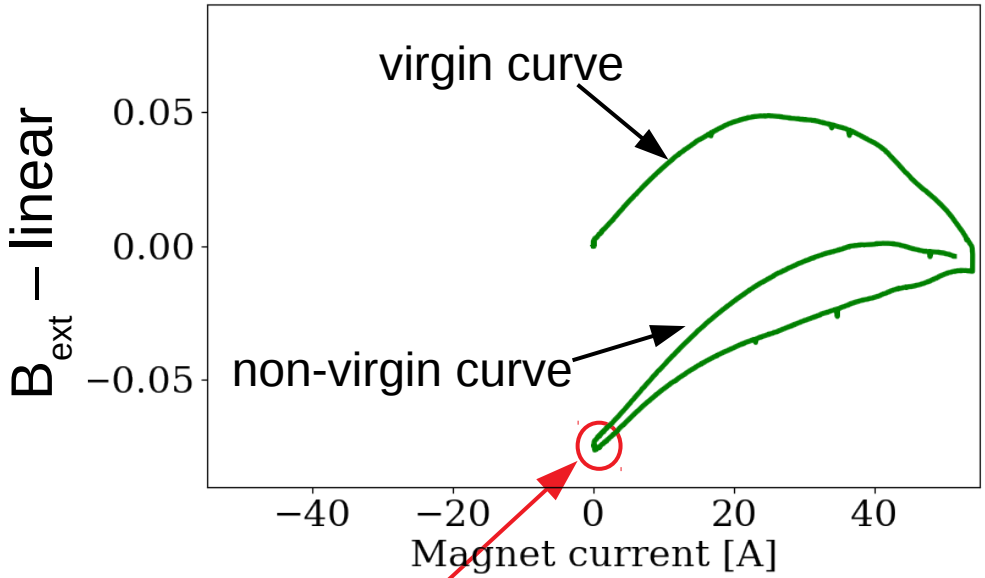


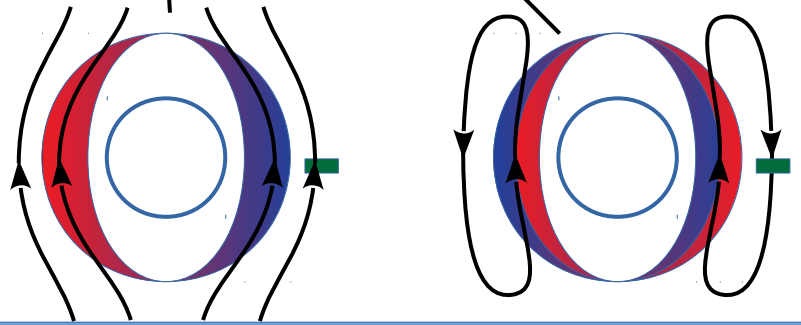


trapped field

Eliminating trapped field: demagnetization

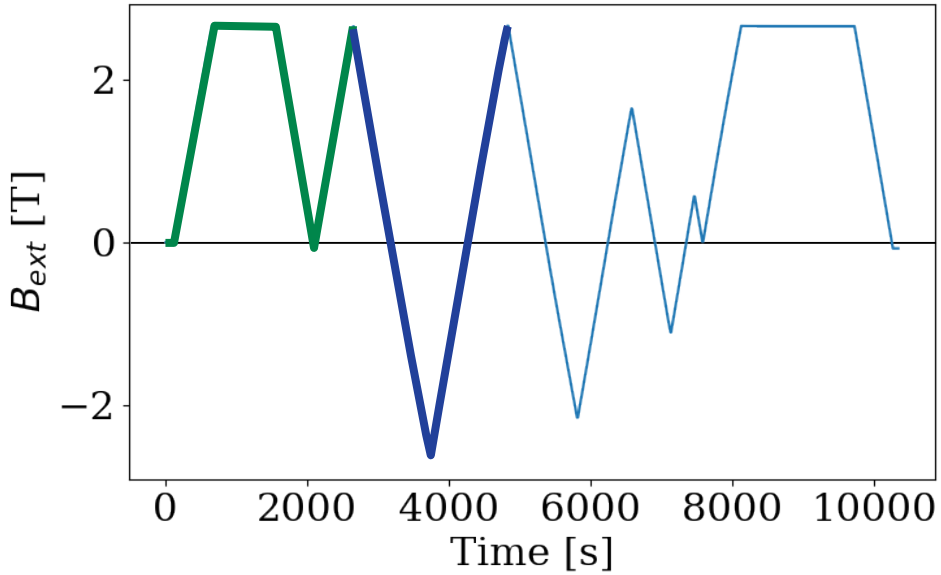


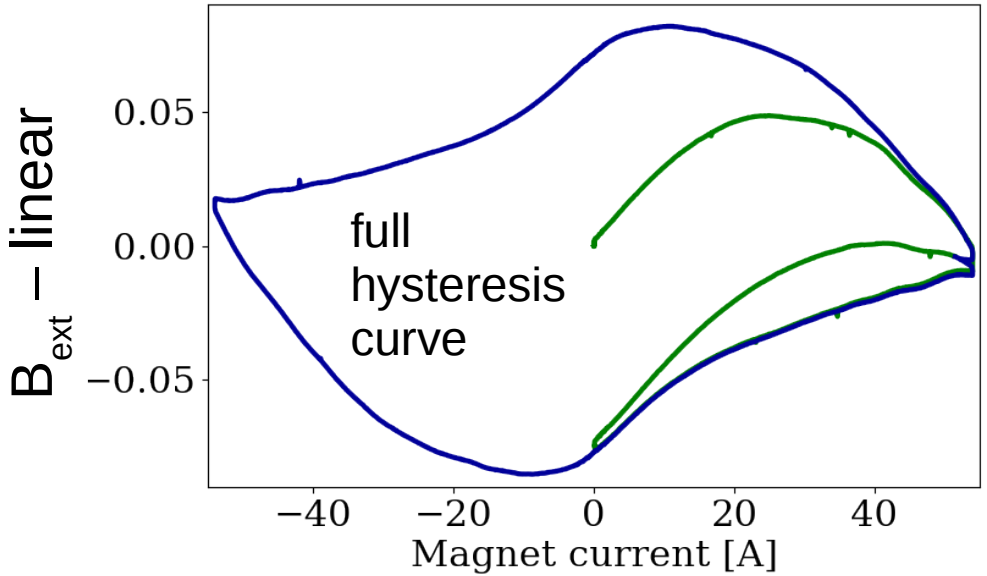


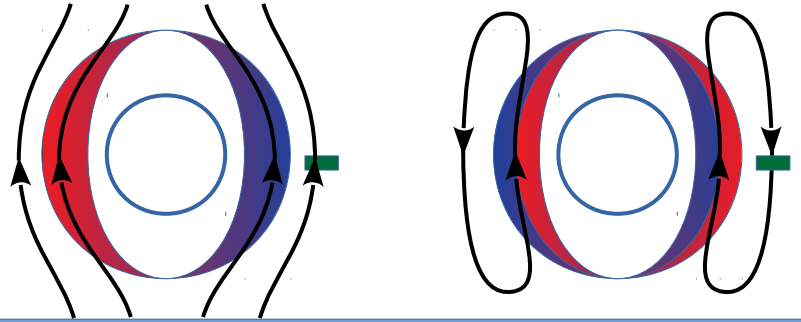


trapped field

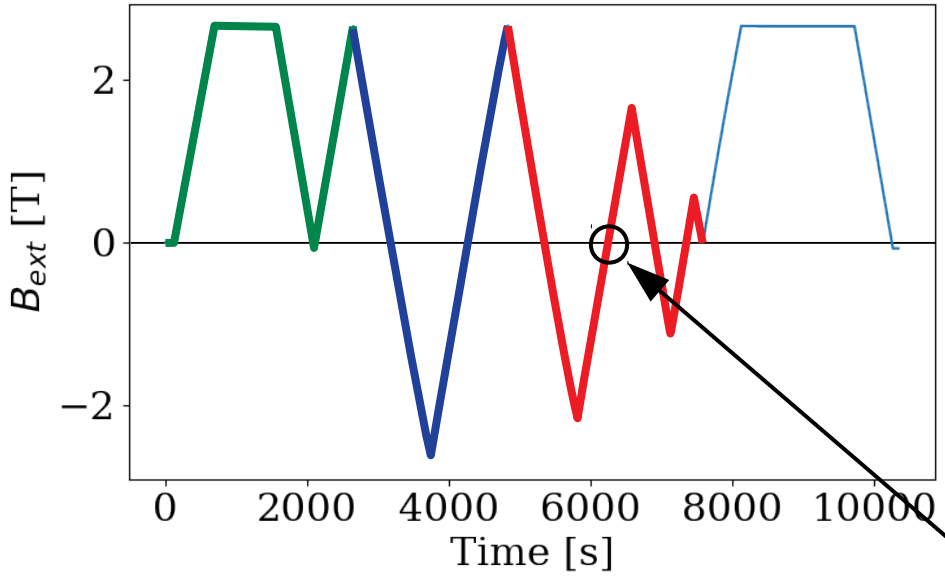
Eliminating trapped field: demagnetization

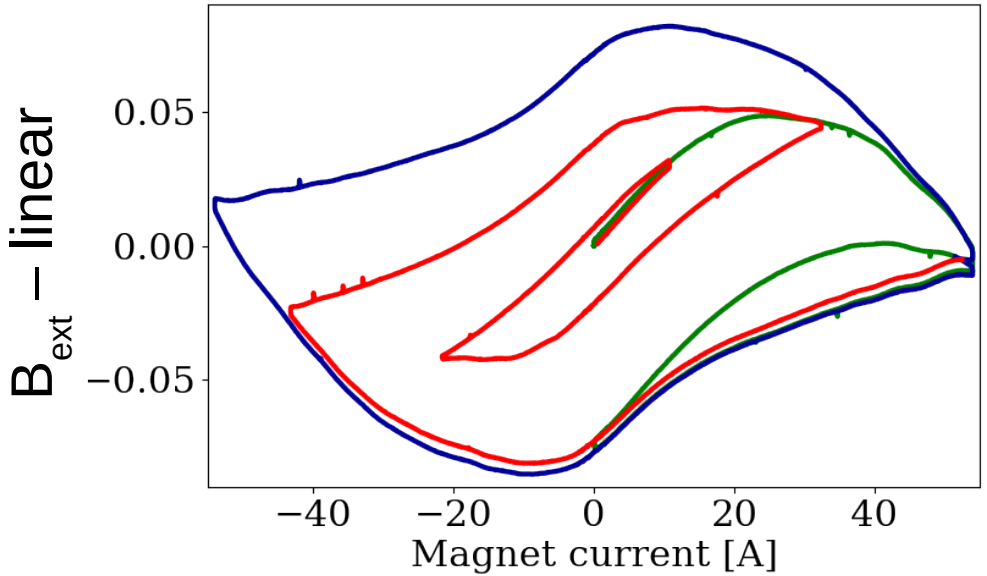


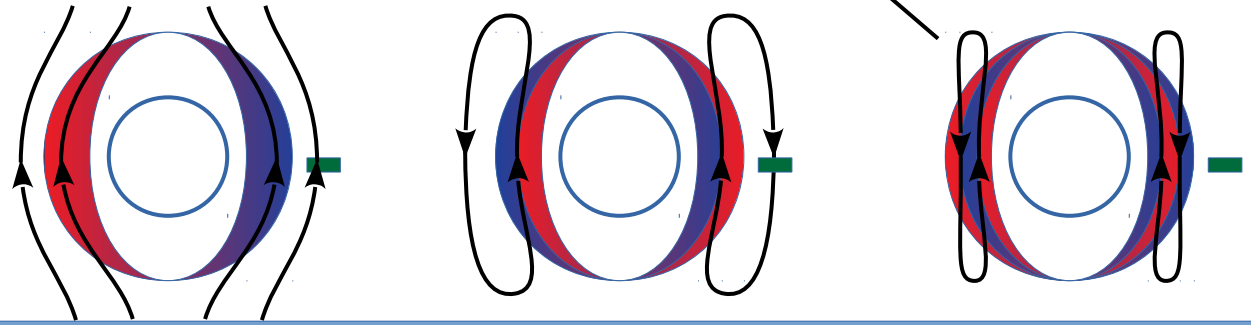




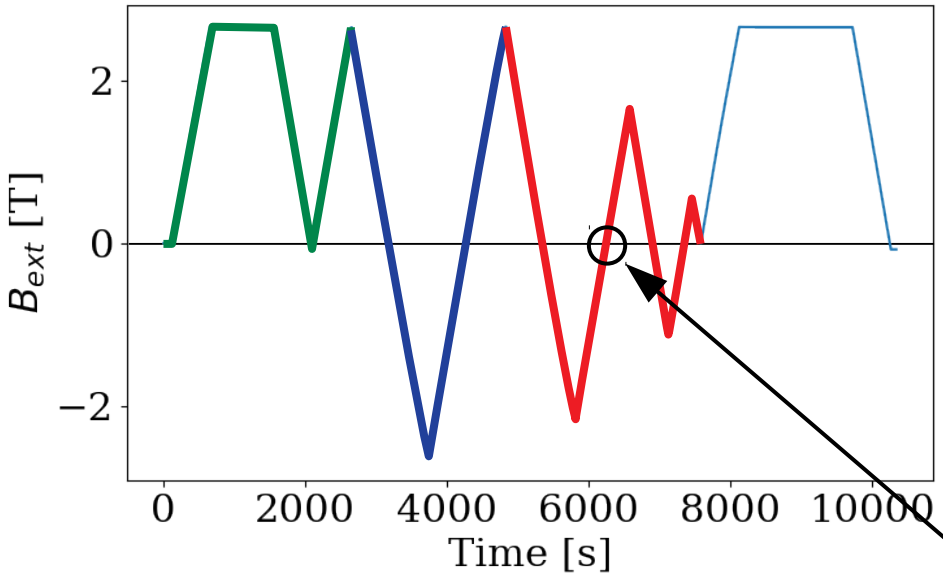
Eliminating trapped field: demagnetization

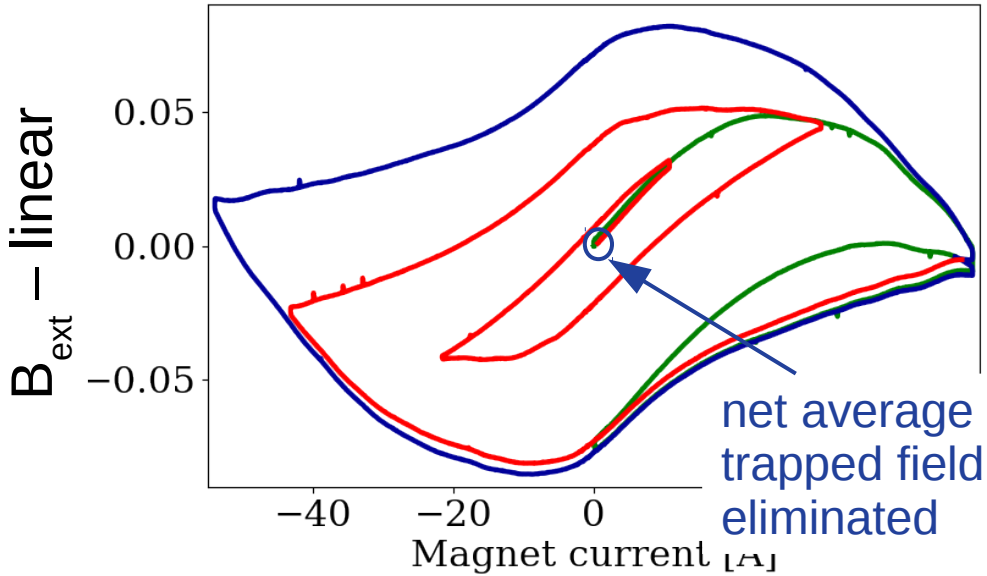


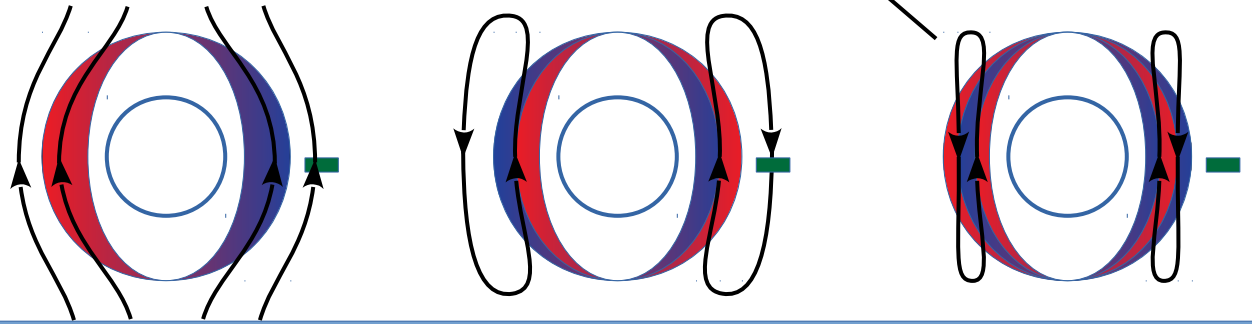




Eliminating trapped field: demagnetization

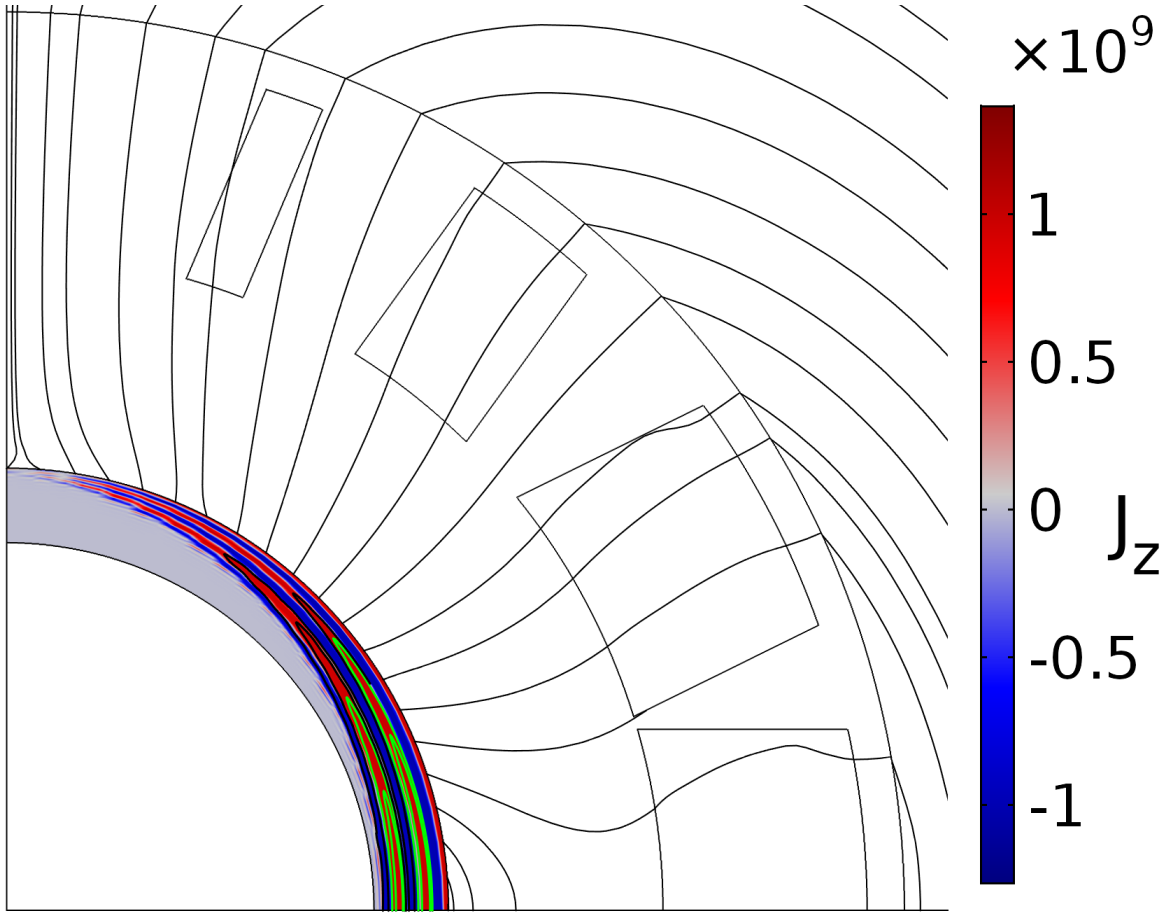


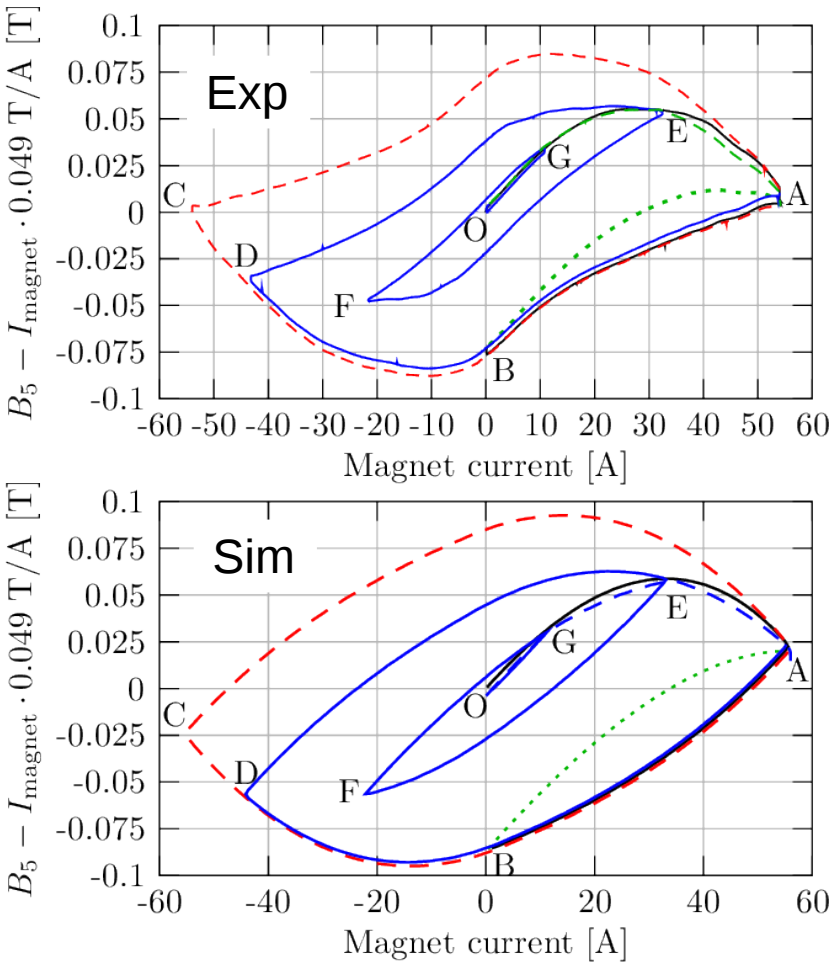




- Trapped field is not an issue
- No “thermal reset”

Demagnetization - simulation





Materials: summary

	MgB2	NbTi/Cu
Thickness [mm]	8.5	3.2
Shielded field [T]	3	3.1
Flux jumps	yes (@ low fields after exposure to high field)	no

Best candidate currently, but discontinued

What we can safely promise:

- **3.2 T** field (maybe higher with NbTi/Cu)
- **15 mm** shield thickness
  - 15 mm bulk MgB_2 is self-supporting (if flux jumps eliminated)
  - 5 mm NbTi/Cu + 10 mm support

Impact of EuCARD-2 & ARIES

- EuCARD-2 & ARIES gave
  - access to unique facilities like SM18
  - travel support

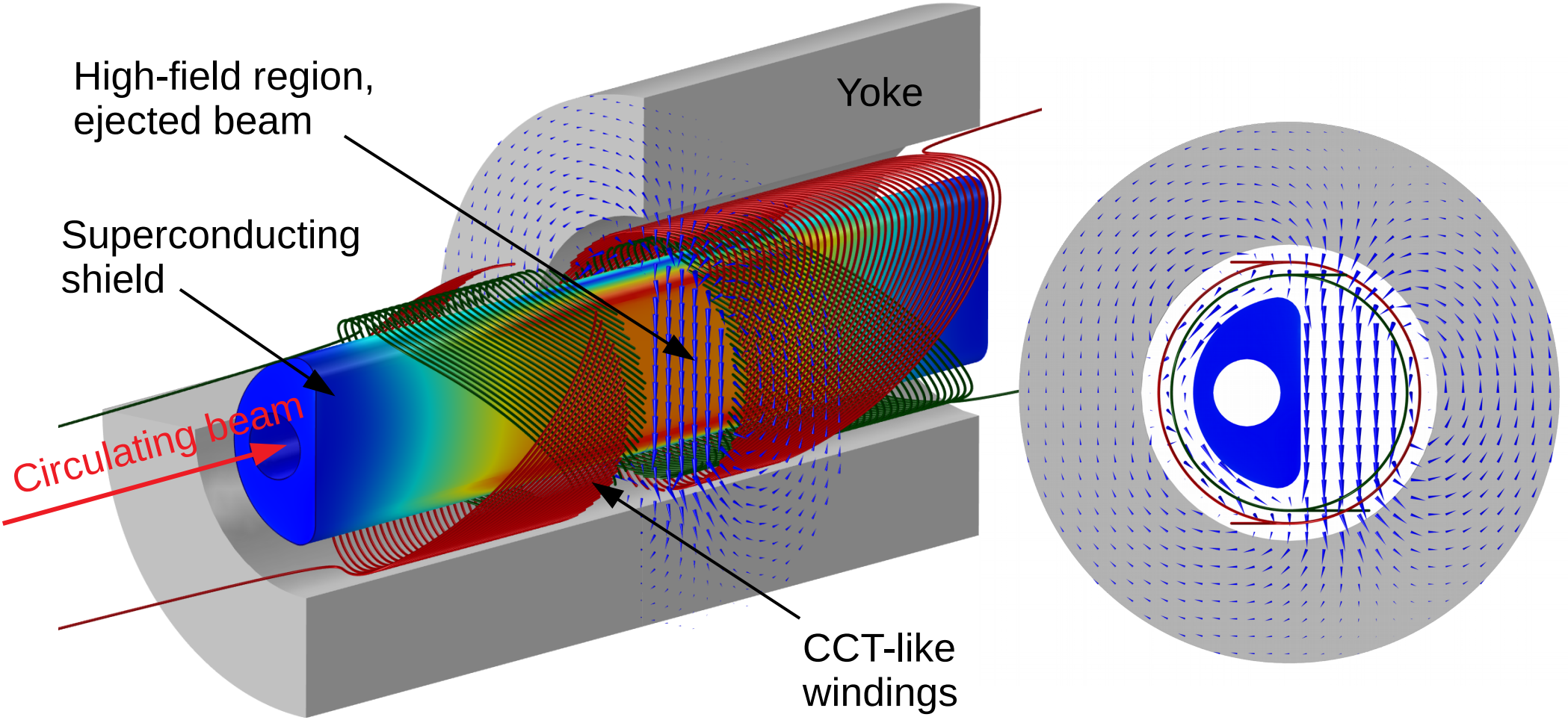
} Both missing at my return to Budapest

- These given – grant application succeeded in Hungary
- EuCARD-2 & ARIES enabled a new player to enter the game
  - building a new group @ Wigner RCP
  - become a new FCC-Collaborator
- 2 MSc diploma this year, continue as PhD
- 2 High-school students involved in the project

ARIES side effects

- SM18 is a nice place to meet a lot of experts
- Building a broad professional network
- Márta Bajkó: “Why don’t you go and see the Hi-Lumi CCT corrector magnet project”
  - This triggered the CCT-SuShi concept
  - 1 student spent 1 month @ CERN to participate in the Hi-Lumi CCT prototype construction

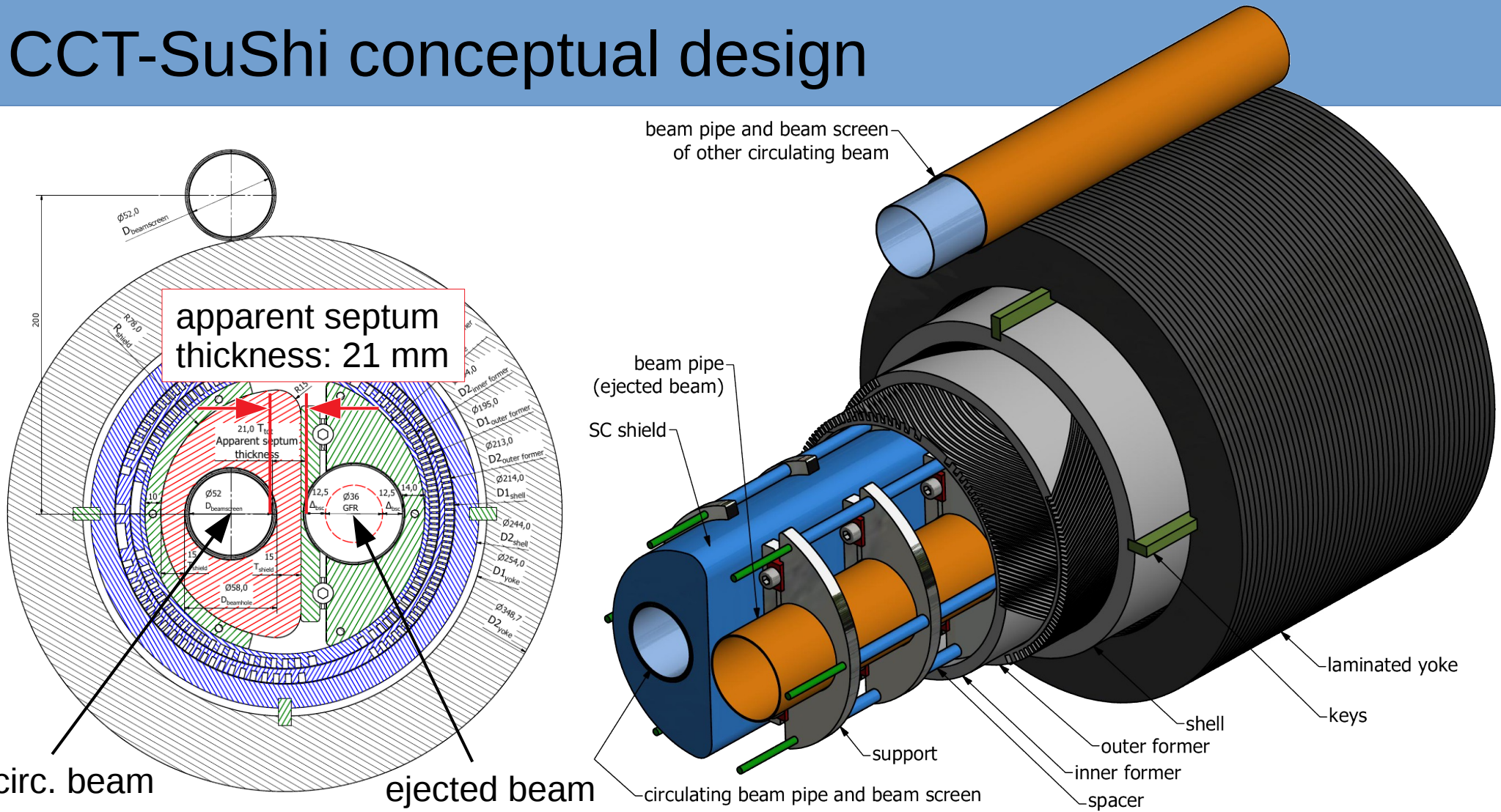
“Side effect”: CCT-SuShi idea



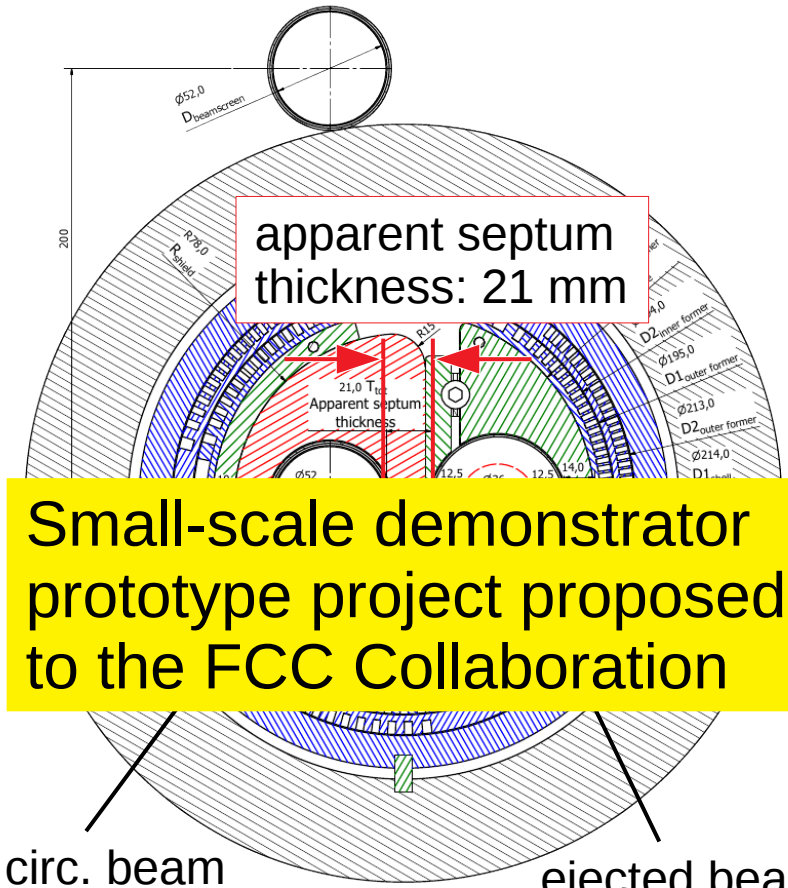
Why a CCT-like magnet?

- Very easy to design and optimize for (almost) arbitrary field patterns
- Very simple, cheap to build
- Few parts, minimal tooling
- Very low stresses, robust, quick (or no) quench training
- Simple quench-protection system
- Active R&D @ CERN: Hi-Lumi CCT corrector magnets
  https://www.researchgate.net/project/LHC-hi-Lumi-orbit-corrector-5Tm-CCT
- Parameters fall close to this – reusing design or even test hardware makes project cheaper

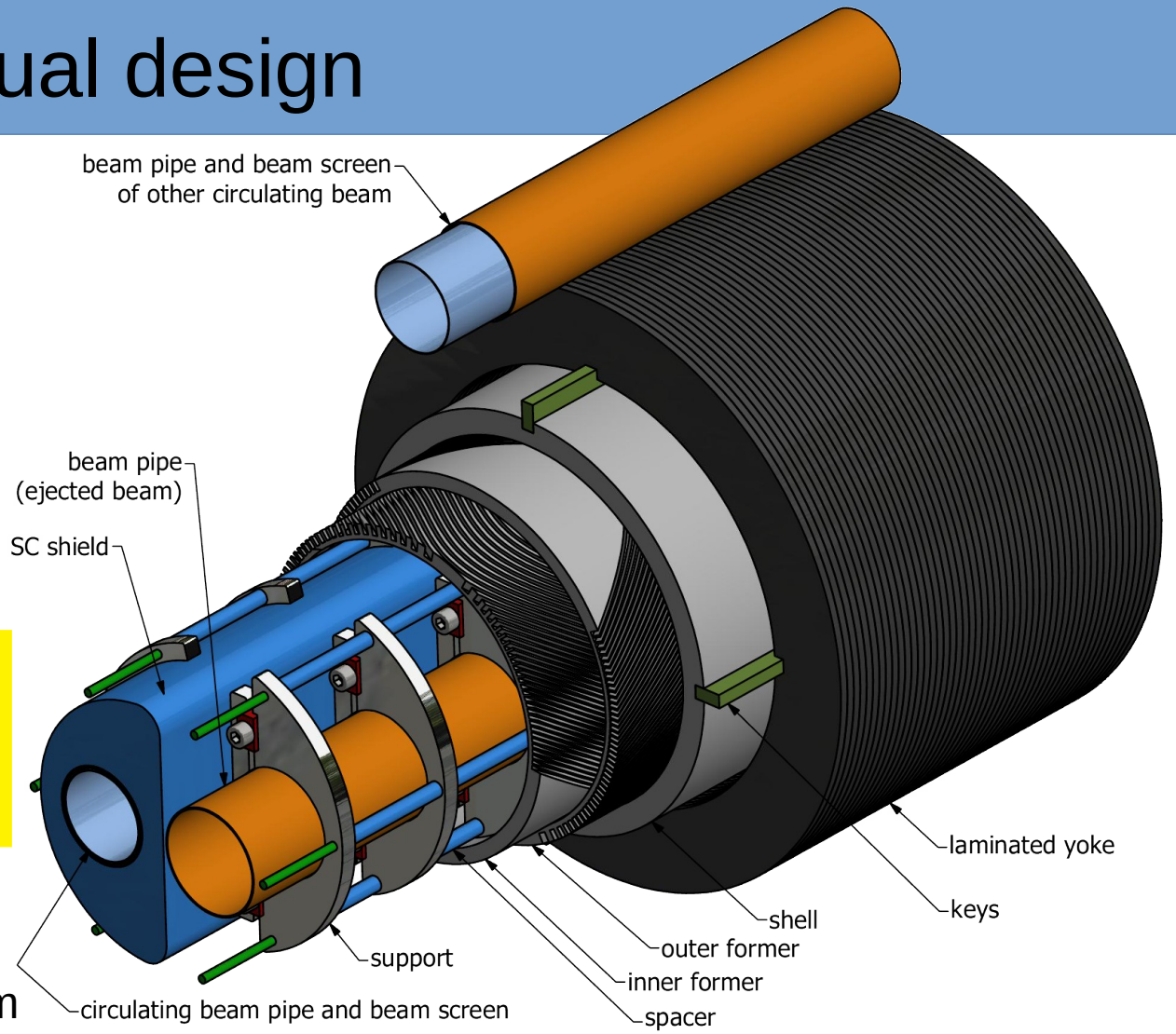
CCT-SuShi conceptual design



CCT-SuShi conceptual design



Small-scale demonstrator prototype project proposed to the FCC Collaboration



ARIES side effect: shield materials

- Promoting shield materials
- Discussions with
  - Giovanni Giunchi (MgB_2)
  - I. Itoh & Nippon Steel Ltd. + Akira Yamamoto (NbTi/Nb/Cu)
- Trying to find market for these materials
    - Let’s get in touch if you see potential application
    - We hope to organize a small workshop (Akira Yamamoto)
- Trying to revitalize their production

Conclusions & Outlook

- EuCARD-2 & ARIES enabled
  - a series of tests of superconducting shielding materials, giving excellent results
  - building a new group to enter the game
- Offshoots of this seed are
  - A new, attractive concept for a high-field septum magnet
  - Revitalization of the magnetic shielding business

Acknowledgements

- European Commission's FP7 Research Infrastructures project EUCARD-2, grant agreement no. 312453
- European Union's Horizon 2020 research and innovation programme (ARIES) under grant agreement No 730871
- Márta Bajkó, Max Pascal, Jerome Feuvrier, Franco Mangiarotti, Frederic Rougemont, Yannick Thuau & the rest of the CERN SM18 team
- CERN TE-ABT group
- Carlo Petrone, TE-MSC-MM – Magnetic diagnostics of the tests
- Glyn Kirby & his team – (hi-lumi CCT design & construction) for discussions, ideas, brainstorming, knowledge sharing
- Akira Yamamoto, Ikuo Itoh, Nippon Steel Ltd. – NbTi/Nb/Cu multilayer
- Giovanni Giunchi – MgB_2
- Alexander Molodyk, SuperOx – HTS tape
- Hungarian National Research, Development and Innovation Office under grant #K124945
- FCC Study Group

Links

- Project webpage: http://cern.ch/sushi-septum-project
- FCC Week ‘17, Berlin: “First experimental tests with the superconducting shield (SuShi) prototypes”, https://indico.cern.ch/event/556692/contributions/2488390/
- FCC Week ‘18, Amsterdam: “Superconducting Shield (SuShi) septum: towards a full prototype”, https://indico.cern.ch/event/656491/contributions/2947265/
- “High field septum magnet using a superconducting shield for the Future Circular Collider”, Phys. Rev. Accel. Beams 20, 041002 (2017)