Magnetic Density Separation Magnet — Nb-Ti magnet demonstrator

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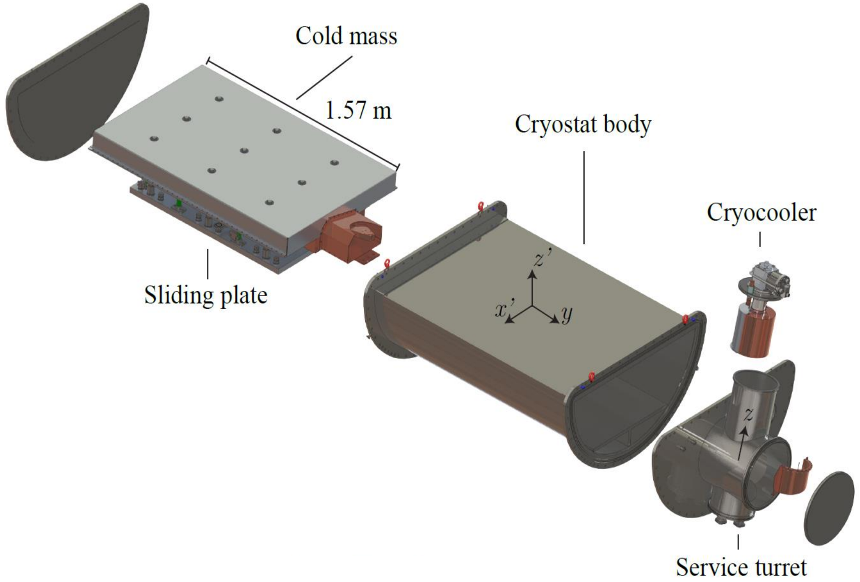
[1] University of Twente; [2] Technical University of Delft; [3] Umincorp Rotterdam



Outline:

- MDS principle
- Magnet system design
- First cooldown and energizing
- Sorting tests at user: Umincorp company
- Follow up

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Magnetic Density Separation

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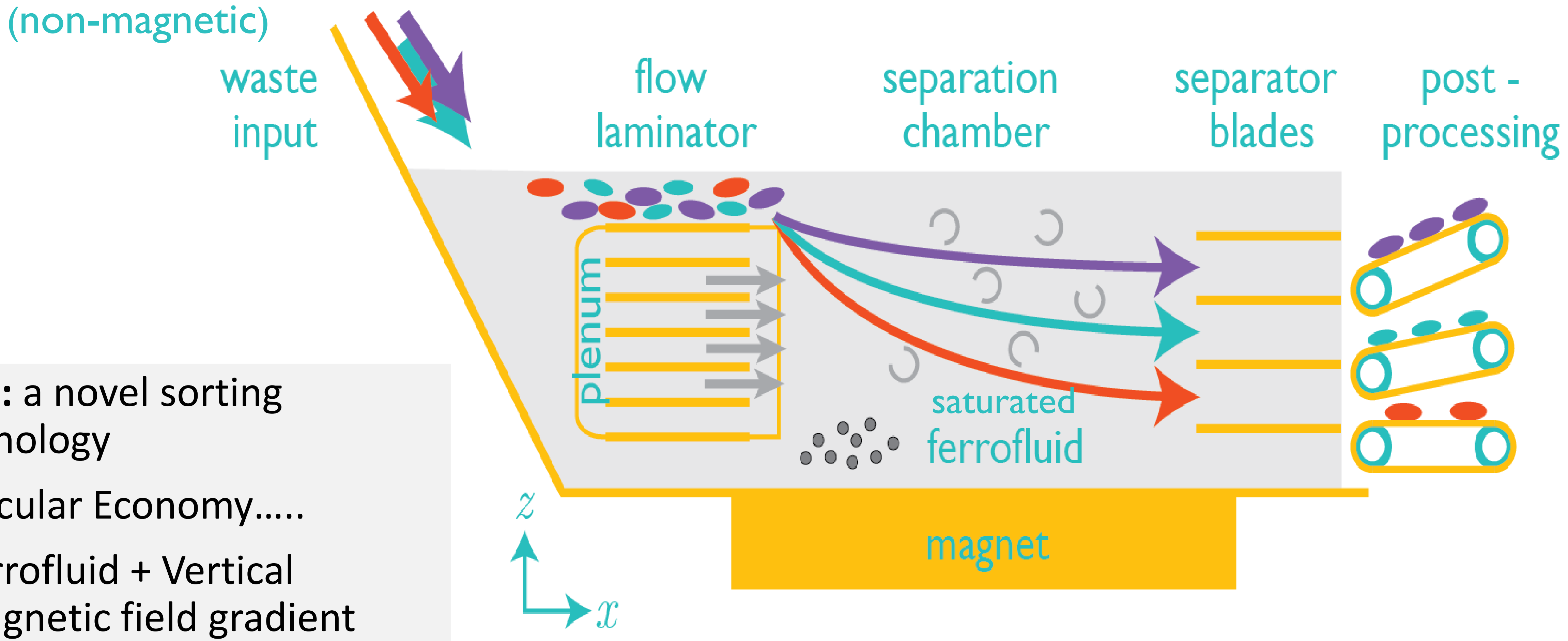


MDS: a novel sorting technology

- Circular Economy…..
- Ferrofluid + Vertical magnetic field gradient
- Non-magnetic particles are sorted by **mass density.**

E. Bakker, P.C. Rem and N. Fraunholcz. "Upgrading mixed polyolefin waste with magnetic density separation". In: Waste Management 29.5 (2009), pp. 1712–1717.

Magnetic Density Separation - principle

Vertical decaying magnetic field:

$$|H|(z) \approx H_0 \exp\left(-\frac{2\pi}{\lambda} z\right)$$

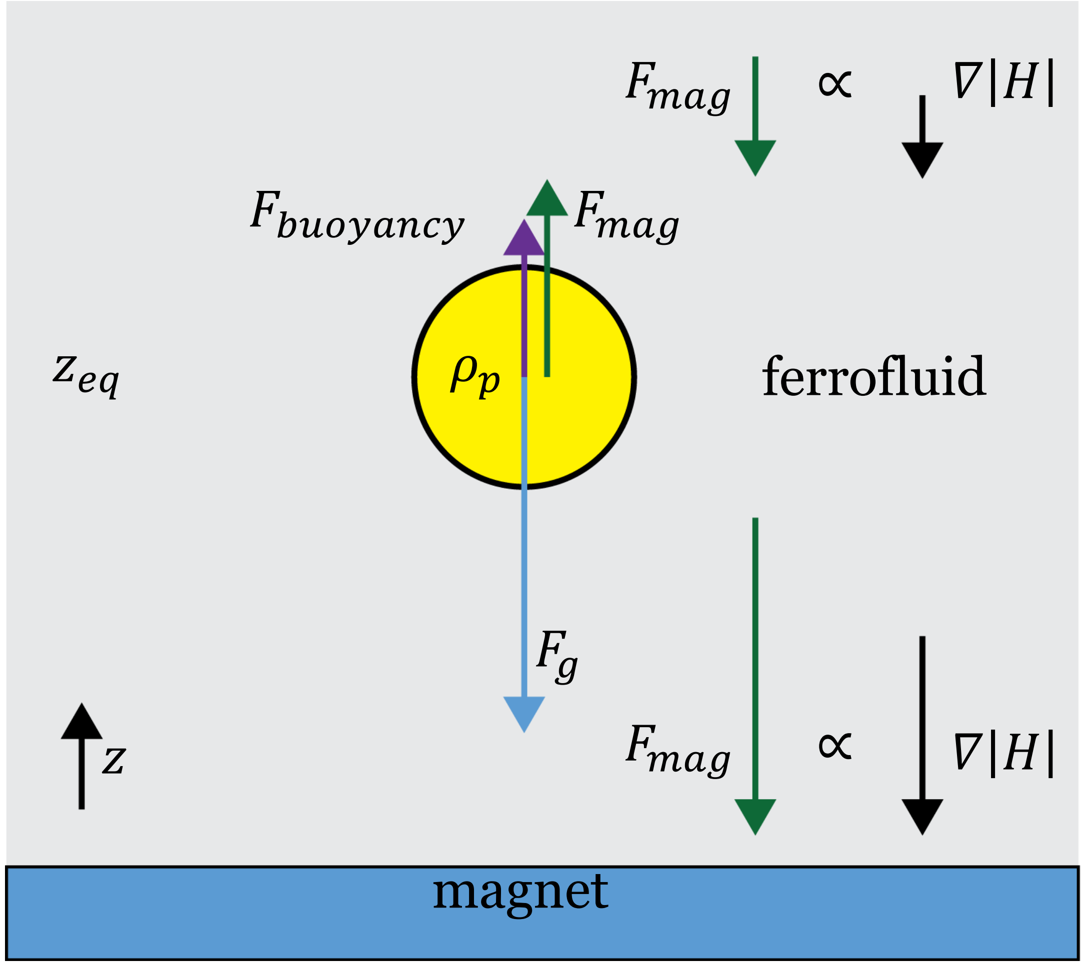
Vertical decaying magnetic force:

$F_{mag}(z) \propto |H|(z)\, \boldsymbol{M_s}$

Equilibrium height based on mass density:

$$F_{mag} = F_g - F_{buoyancy}$$

$$\mu_0 \nabla_z |\mathrm{H}|(\mathrm{z} = \mathrm{z_{eq}})\, \mathbf{M_s} = (\rho_{\mathrm{fluid}} - \boldsymbol{\rho}_\mathbf{p})\mathrm{g}$$



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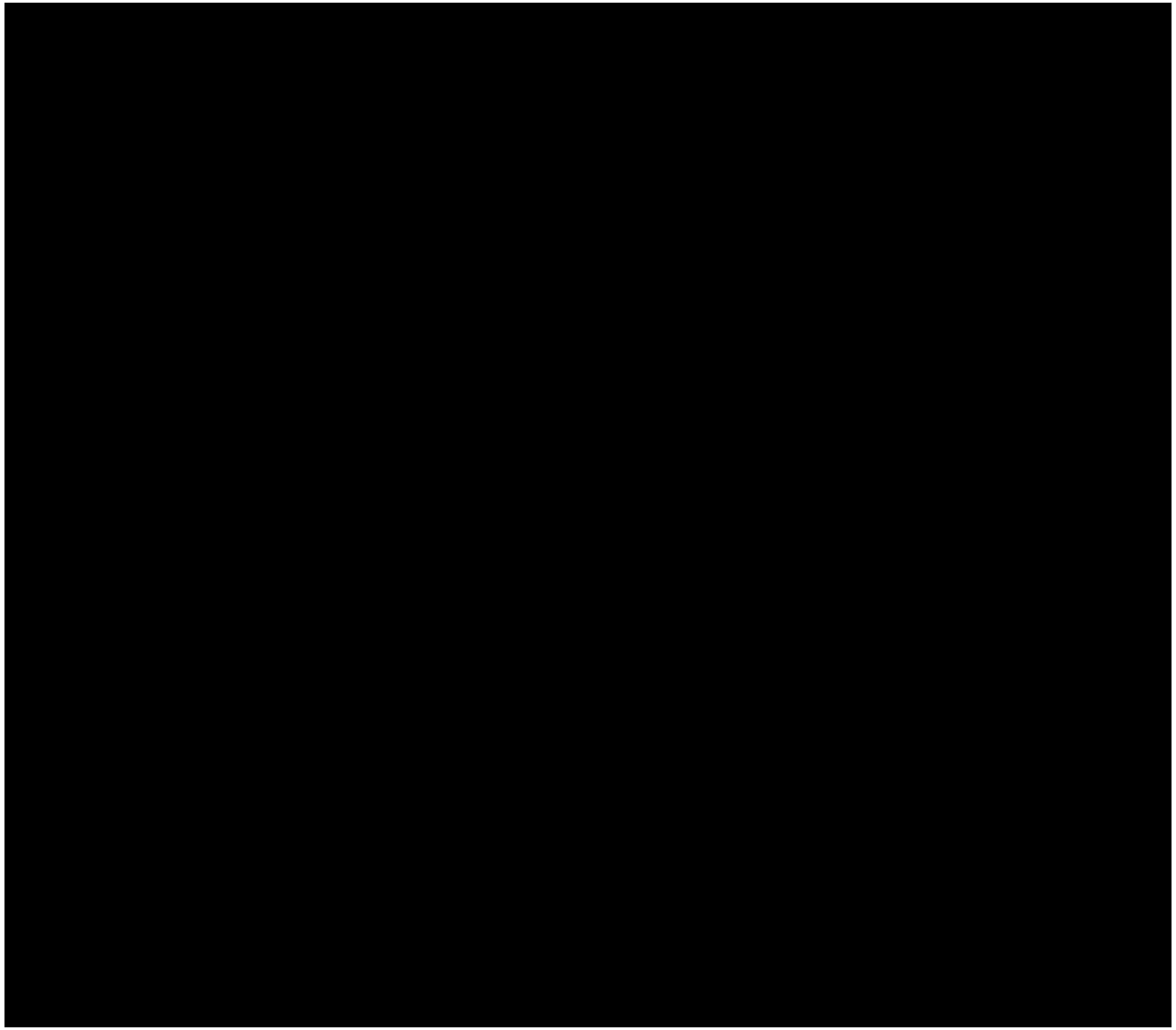

How to use *superconductors* in MDS

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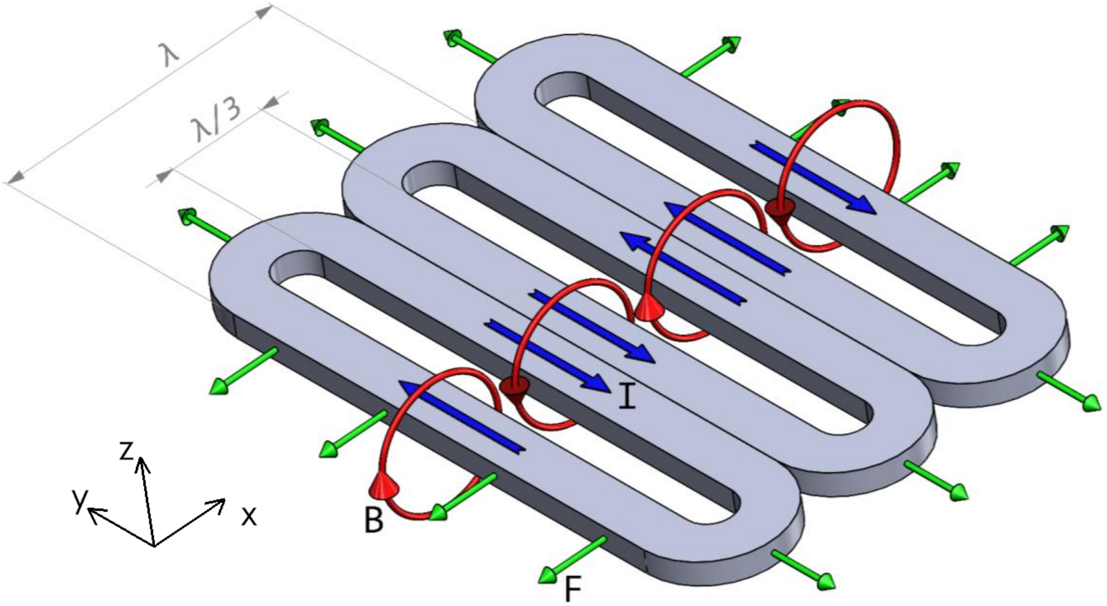
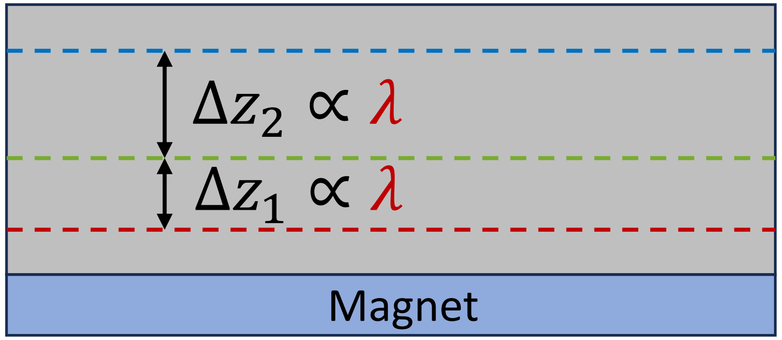
$$|H|(z) \approx H_0 \exp\left(-\frac{2\pi}{\lambda} z\right)$$

$$F_{mag}(z) \propto \frac{d}{dz} |H|(z)\, \boldsymbol{M_s}$$





$z \propto \lambda \ln H_0$

How to use *superconductors* in MDS

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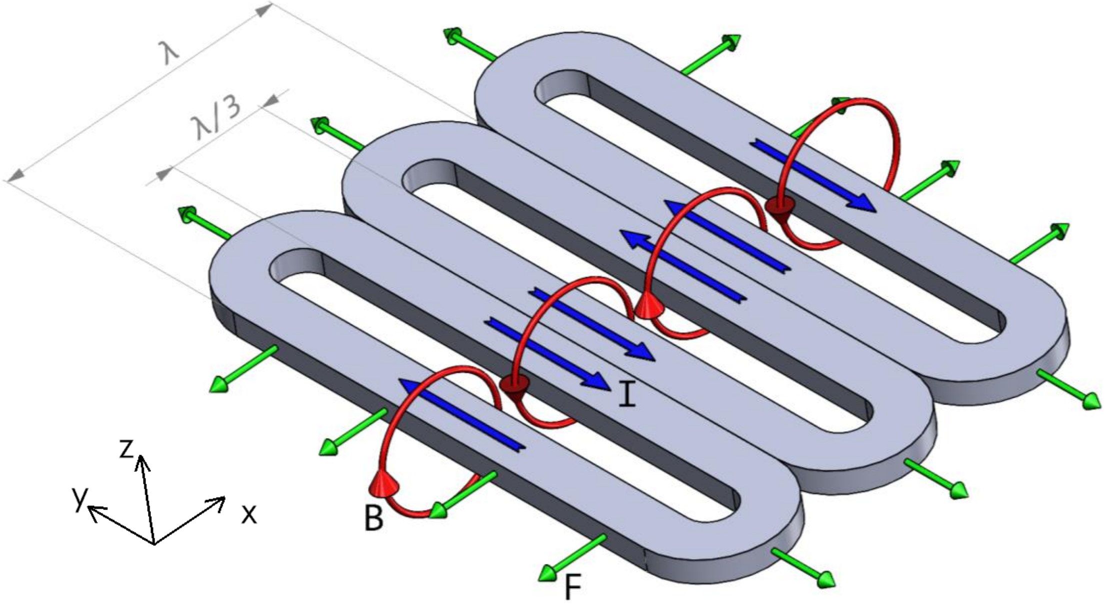

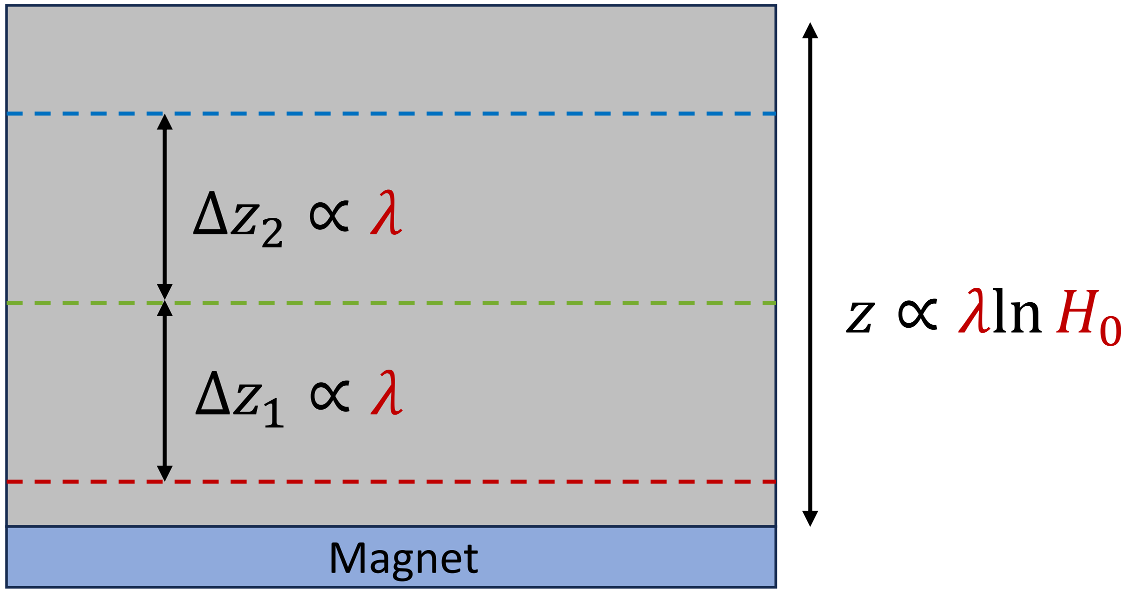

Why superconducting magnets for MDS

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$$|H|(z) \approx H_0 \exp\left(-\frac{2\pi}{\lambda} z\right)$$

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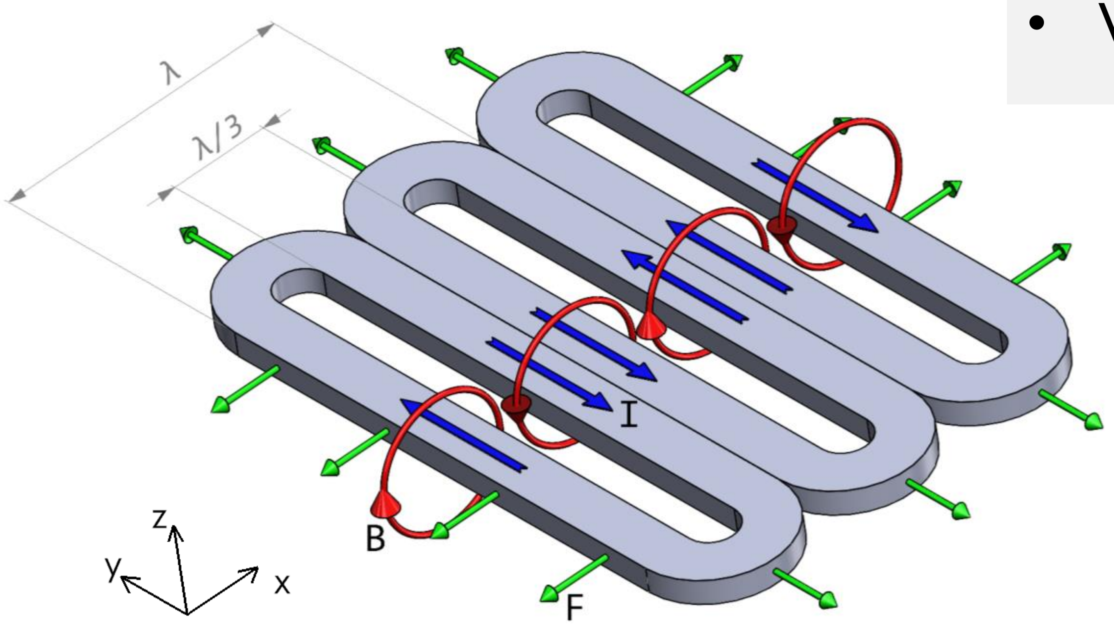

Higher magnetic **field** (H_0) & **Larger periodicity** (λ):

- Enhanced separation **resolution** (e.g. similar plastics)
- **Deeper** usable fluid bed (higher throughput)
- Lower operating expenses, more **dilute** ferrofluid possible
- Wider density **range** (e.g. electronic waste)

Project goal: demonstrator magnet

- **3 Nb-Ti/Cu racetrack coils**
- 5 T peak magnetic field
- λ = 600 mm
- Targeted application: electronic waste!

J. J. Kosse et al. "Optimum Coil-System Layout for Magnet-Driven Superconducting Magnetic Density Separation", IEEE Transactions on Magnetics (2021)
J. J. Kosse et al. "Fundamental Electromagnetic Configuration for Generating One-Directional Magnetic Field Gradients", IEEE Transactions on Magnetics (2021)
J. J. Kosse et al. "Mechanical design of a superconducting demonstrator for magnetic density separation", SuST (2021)
J. J. Kosse et al. "Thermal and electrical design of superconducting demonstrator for magnetic density separation", SuST (2022)

System design

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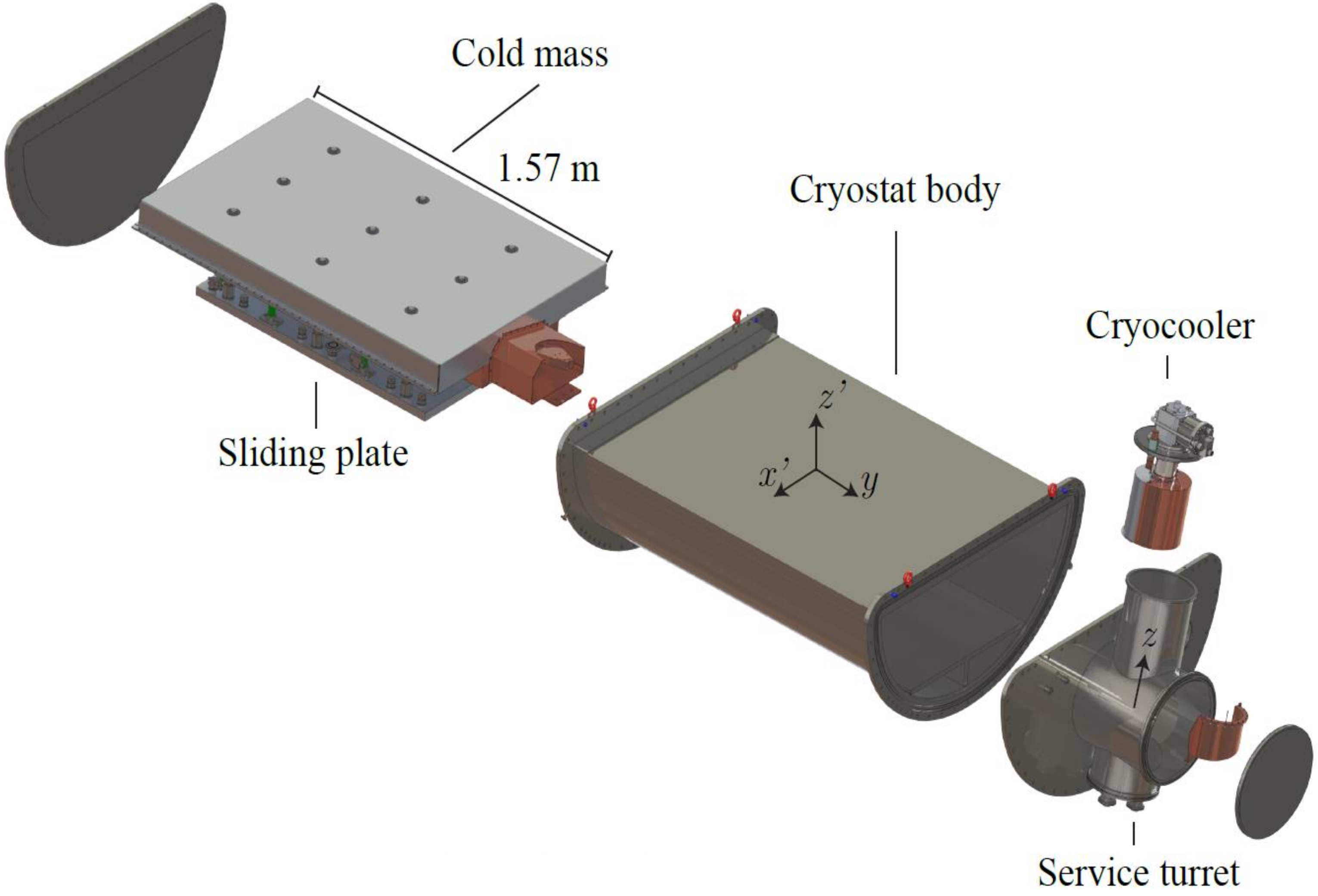

Magnet manufacture In-house

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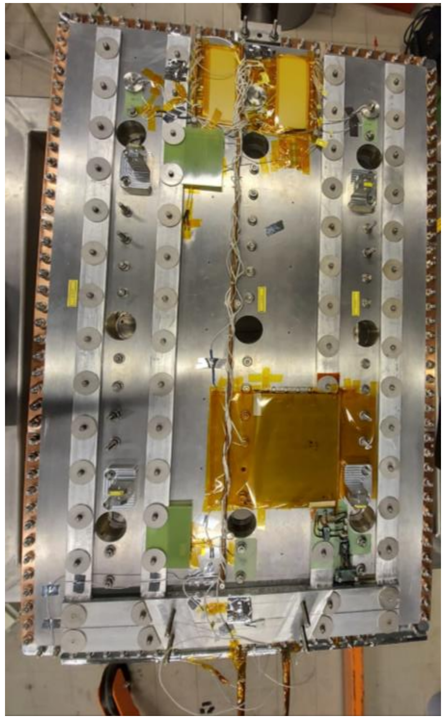


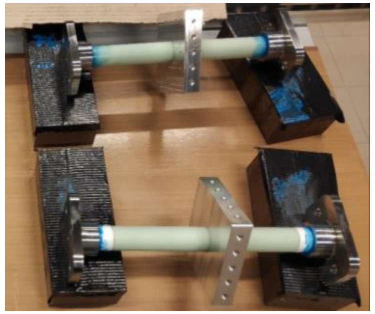
From coil (wet) winding 3X

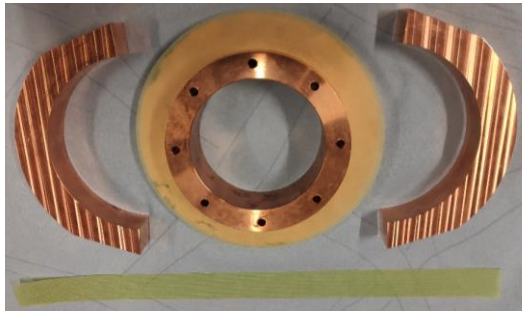
To winding pack assembly,

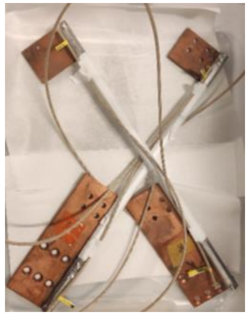
Magnet assembly,

To cold mass assembly,

Components manufacturing and testing







Successful 1st cooldown

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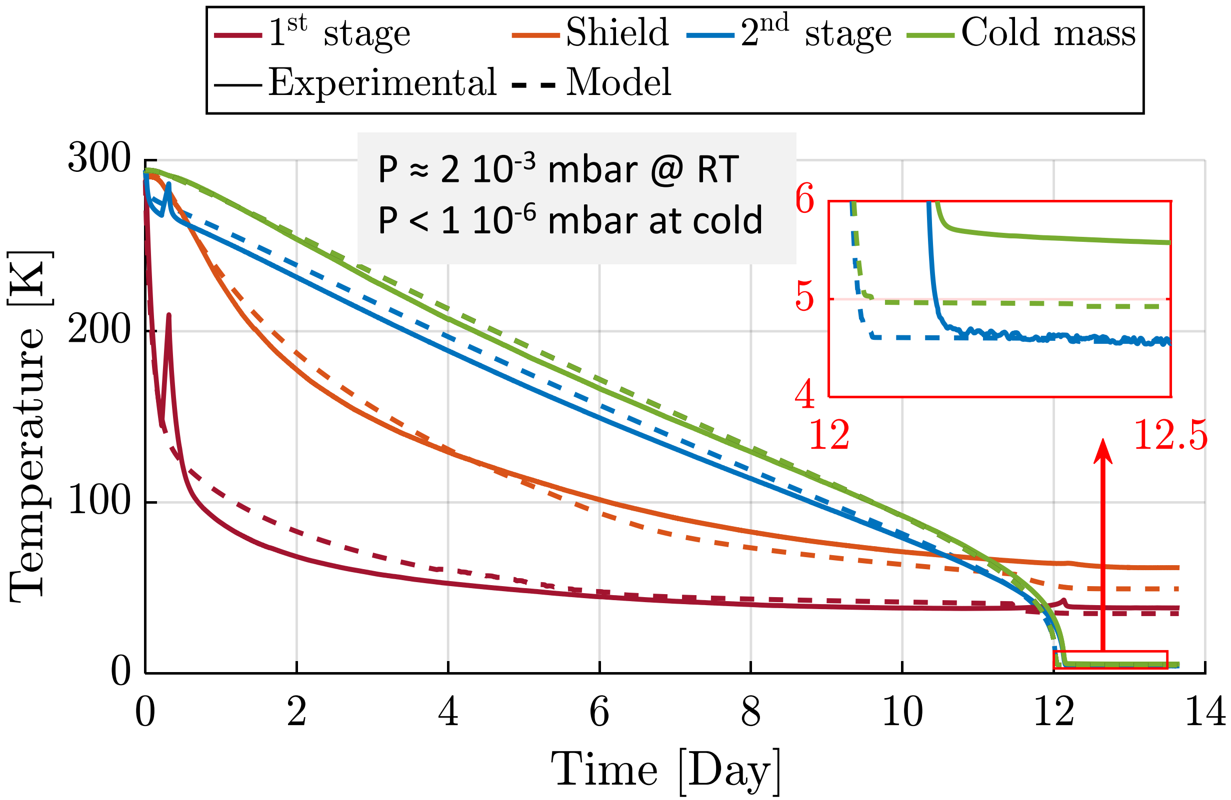
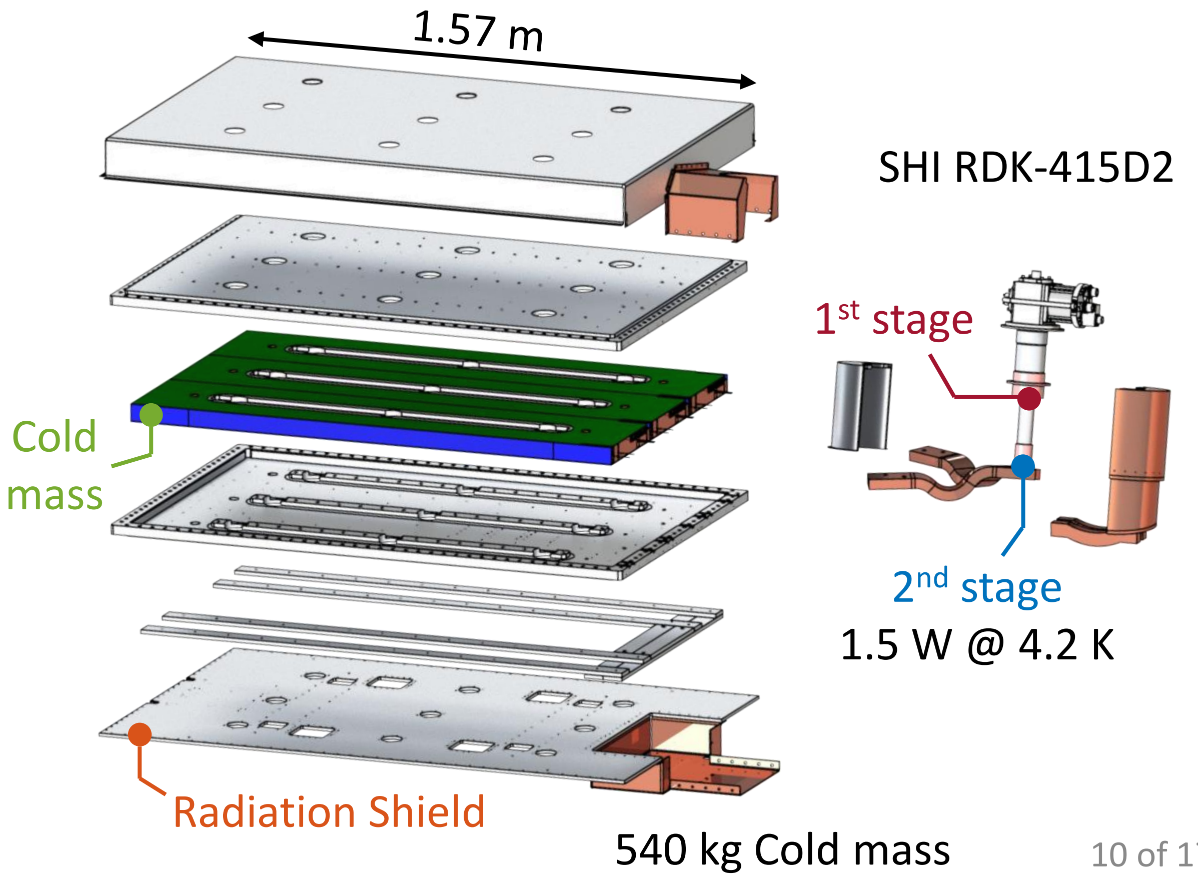
As expected, cool down on 1 cryocooler in 13 days

- Cold mass temperature 5.5 K (1 K higher than expected due to thermal short shield-cold mass)
- 0.7 K margin at design operational current of 300 A





Design current of 300 A reached without training!

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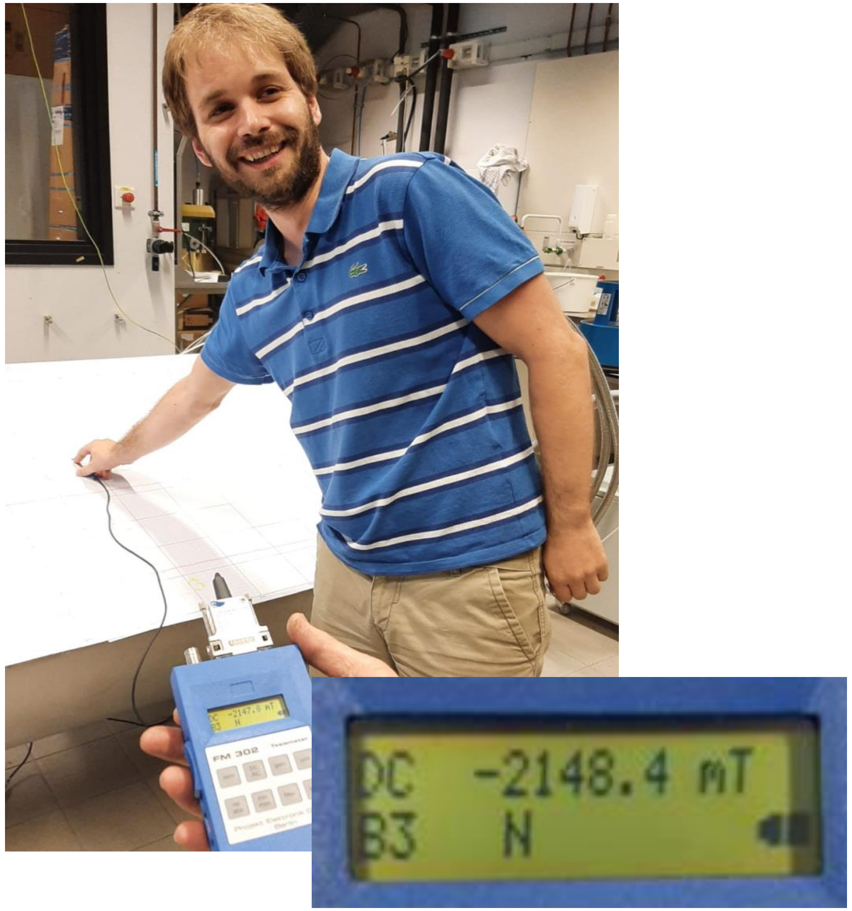
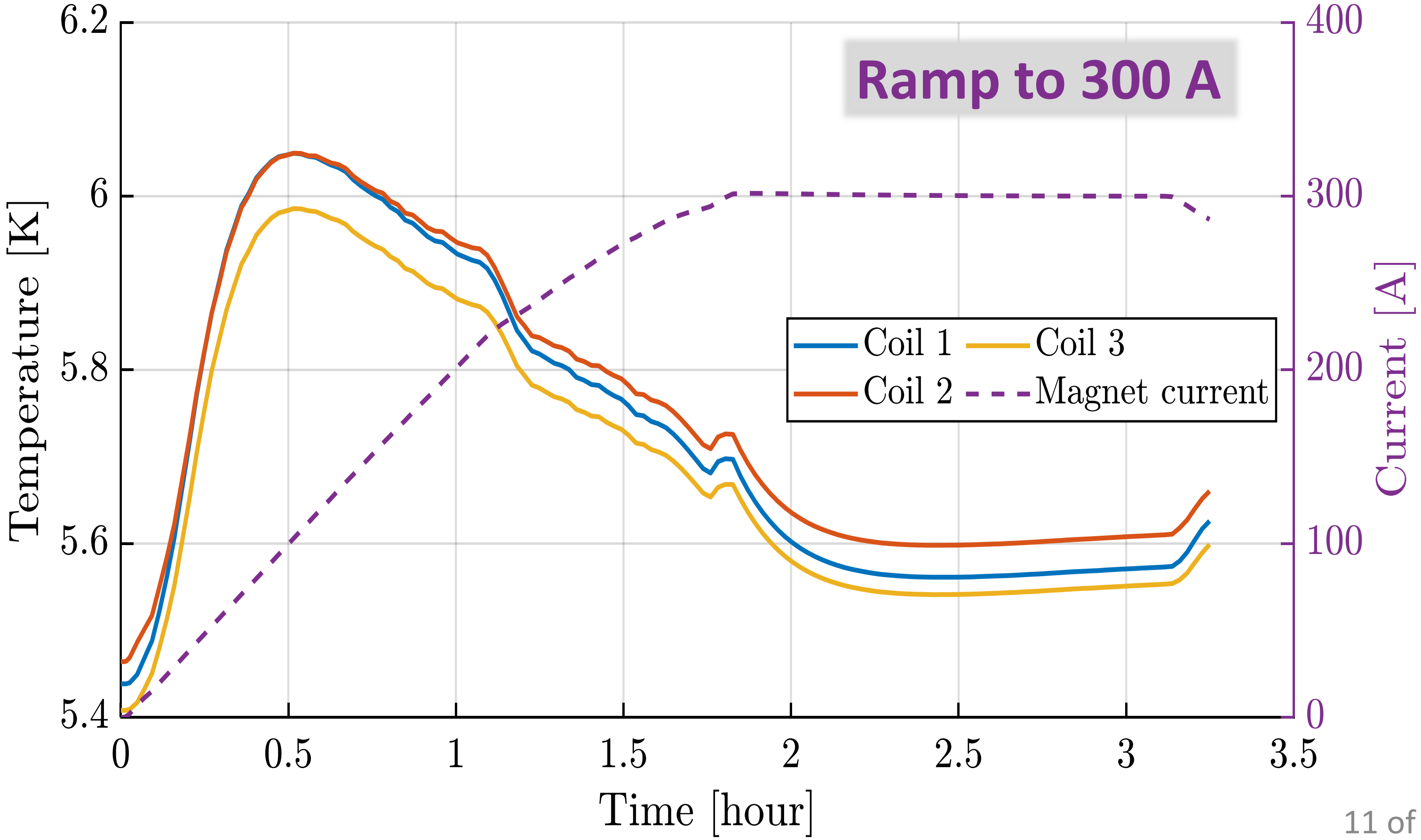
18 May 2022, we got 2.15 T

- **Operational current reached 300 A**
- **No training quenches observed!**

NbTi superconductor properties at operation point

I	I_c	I/I_c	B_{peak}	T_{op}	T_{cs}
300 A	752 A	0.4	5.4 T	5.6 K	6.3 K





Effective quench protection

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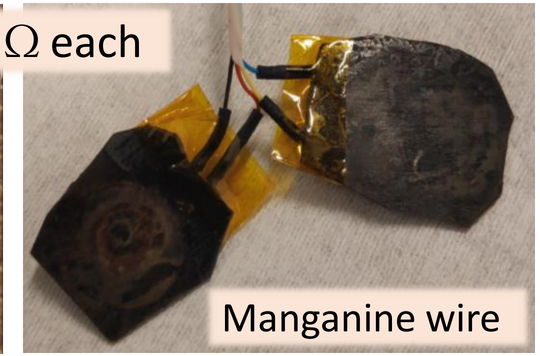
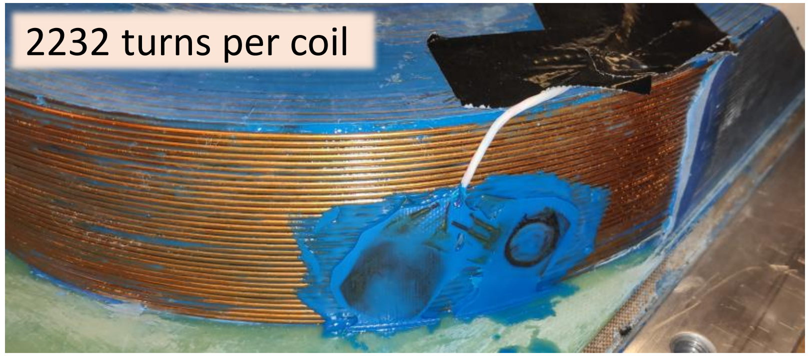
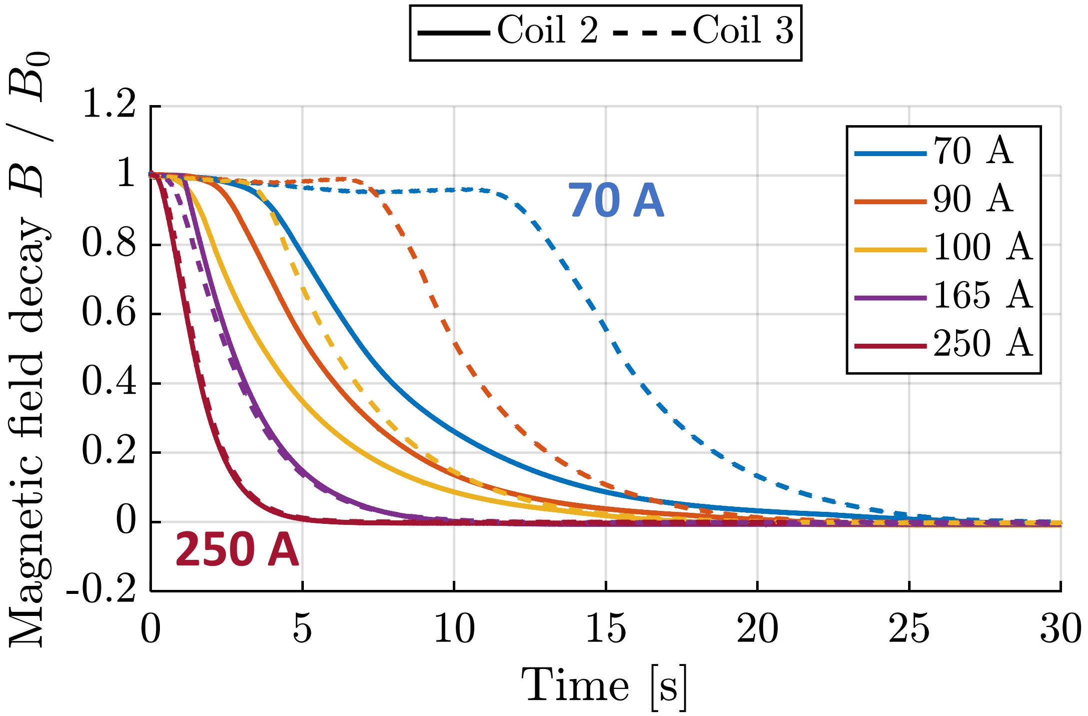
Testing the quench:

- Triggering spot heater at the head of Coil 2.

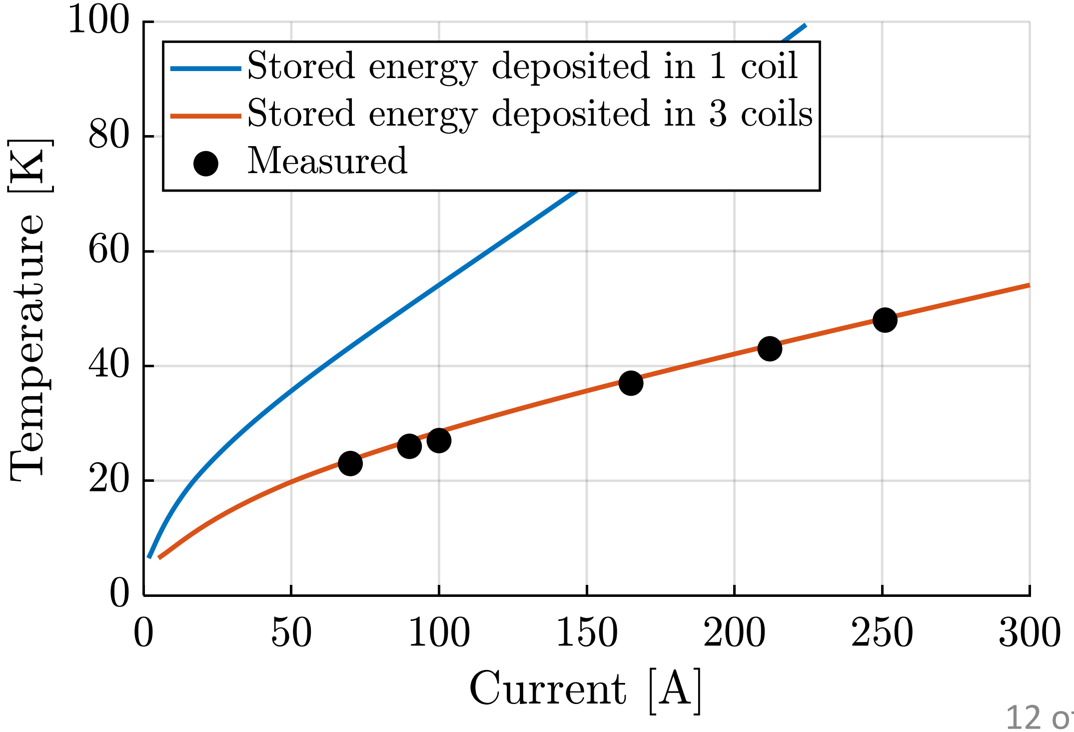





Field decay after initiated Quench



Maximum temperature after quench

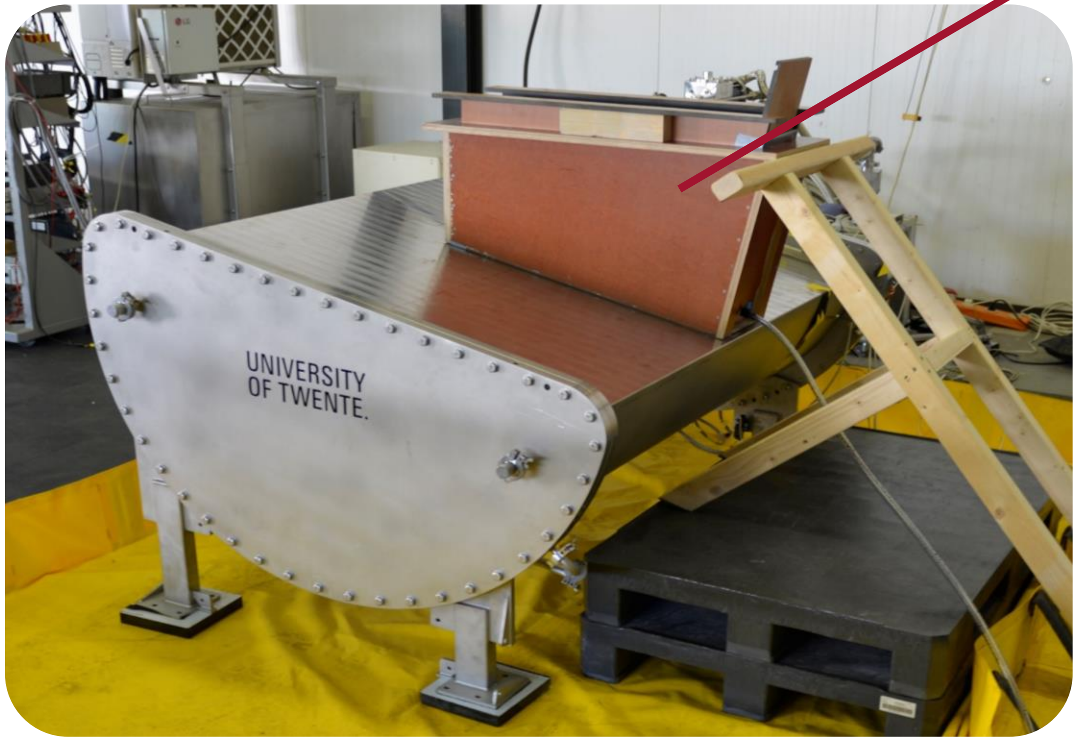


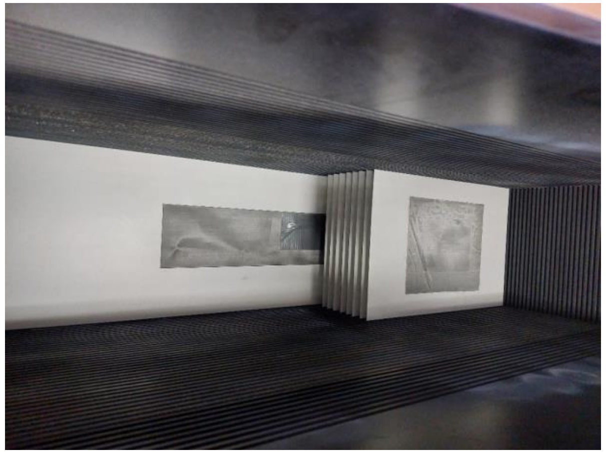
Successful preliminary sorting tests at Umincorp

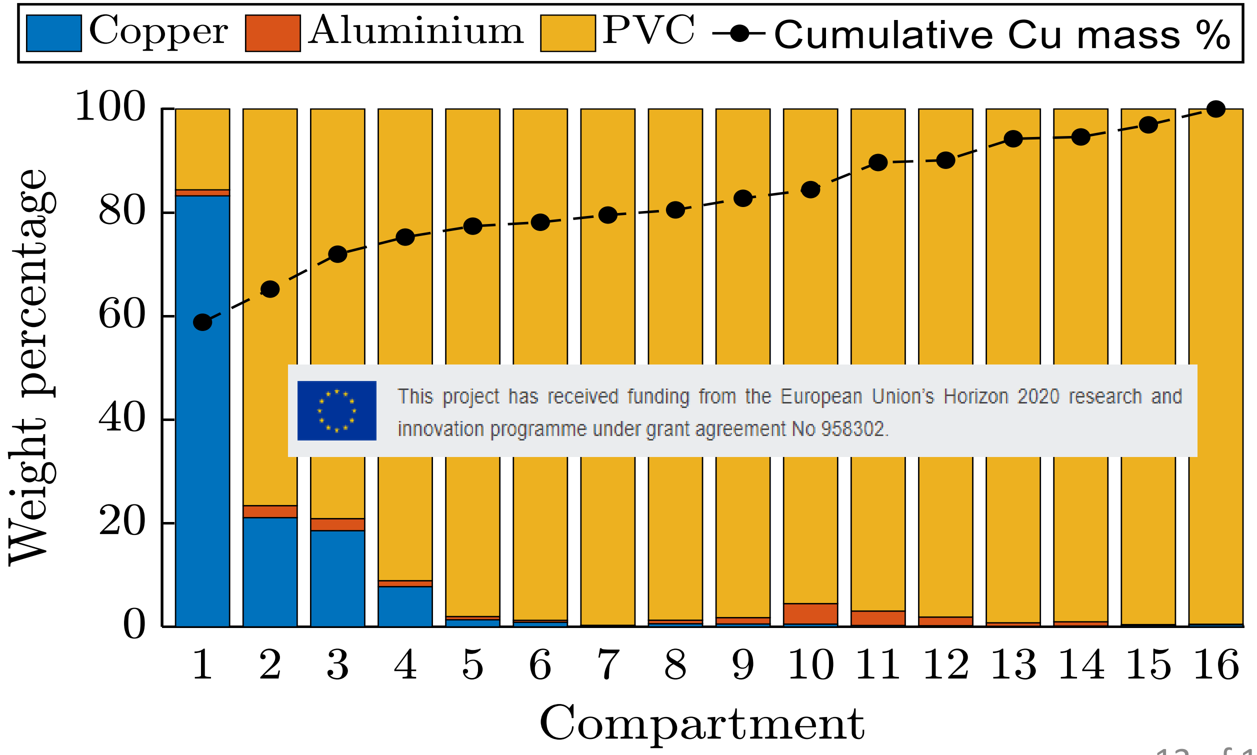
Preliminary tests by: TU Delft, Umincorp & UT

E-waste: high field enables low-cost sorting !

- Recovery of precious metals from shredded electronic components
- **Recovery of metal from shredded cables.**







This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958302.

Still this year:
Integration with sorting facility at TU DELFT

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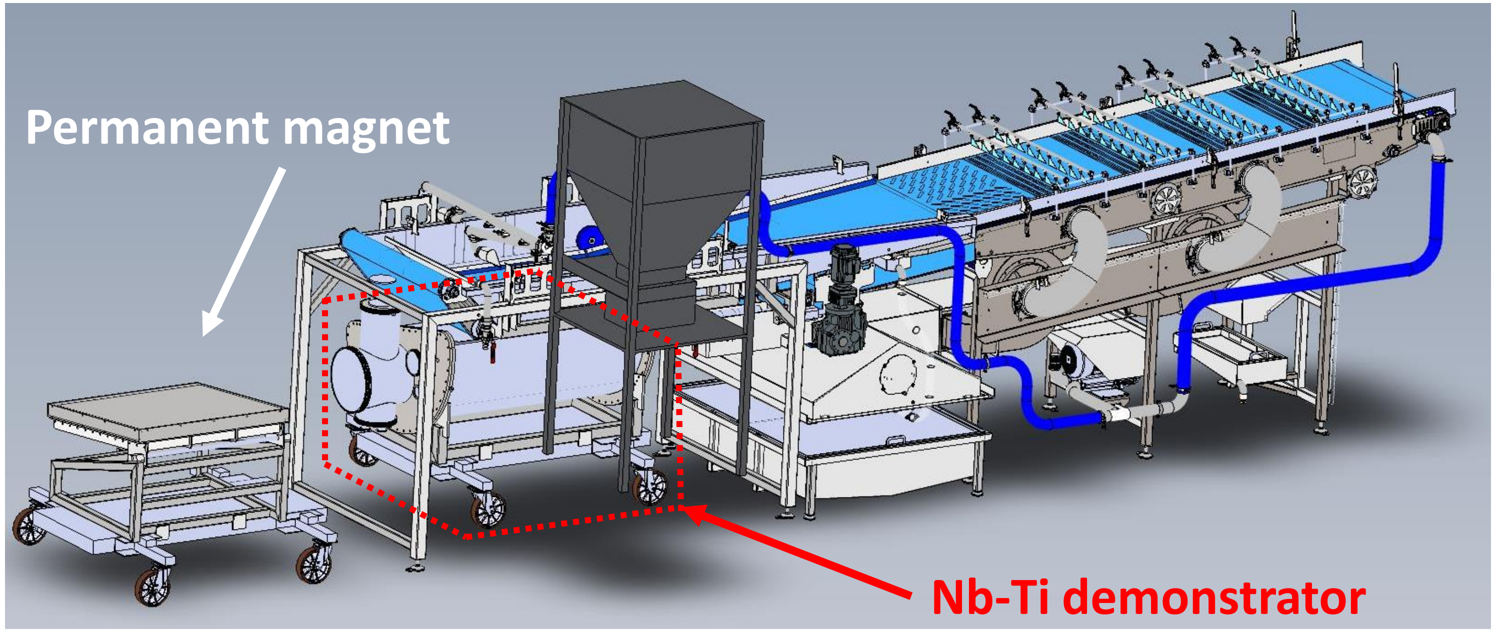
- Sorting tests: **Continuous sorting**
- Performance and economical comparison with a permanent magnet of equal size

- **Potential user for high-field MDS:**
  - Myne, formerly REUKEMA –

    “market leader in processing aluminum, copper and electronic waste”

    225 MT non-ferreous per year



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Follow up

- **Nb-Ti was used for this demonstrator**
- However, economical study reveals that:

  "high-magnetic field magnet pays itself back"

- A *Re*BCO magnet will allow for **high density sorting at lower cost.**

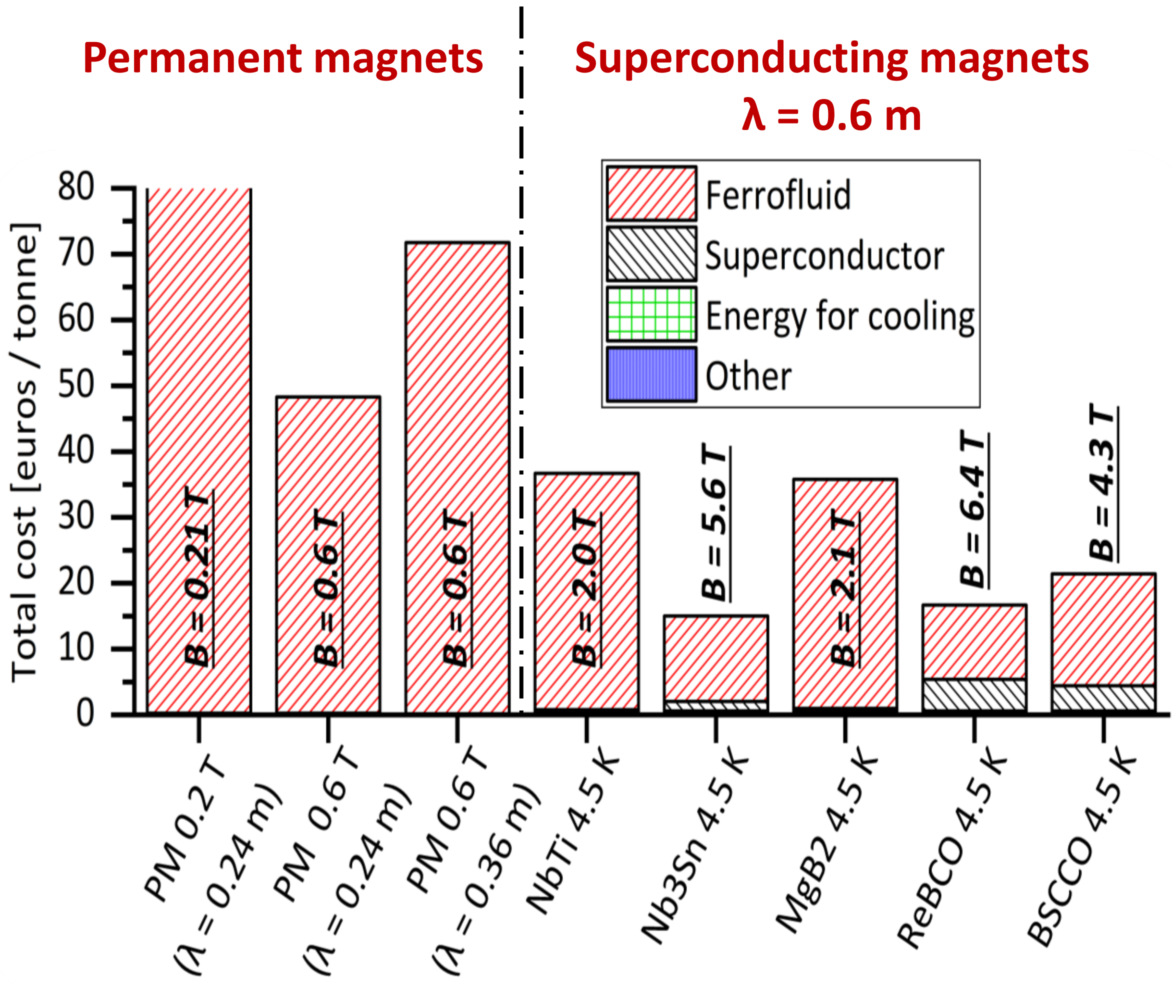
Optimal magnet design
CAPEX + OPEX ↓

Assumptions:

- ρ_{max} = 14 000 kg/m^3
- Pure FF_{cost} = 30 €/L
- *FF_{lost} = 4.8 L/ton

*This value regards diluted ferrofluid. Pure FF_{lost} is proportional to its saturation magnetization value

Over 10 years & 80% running time



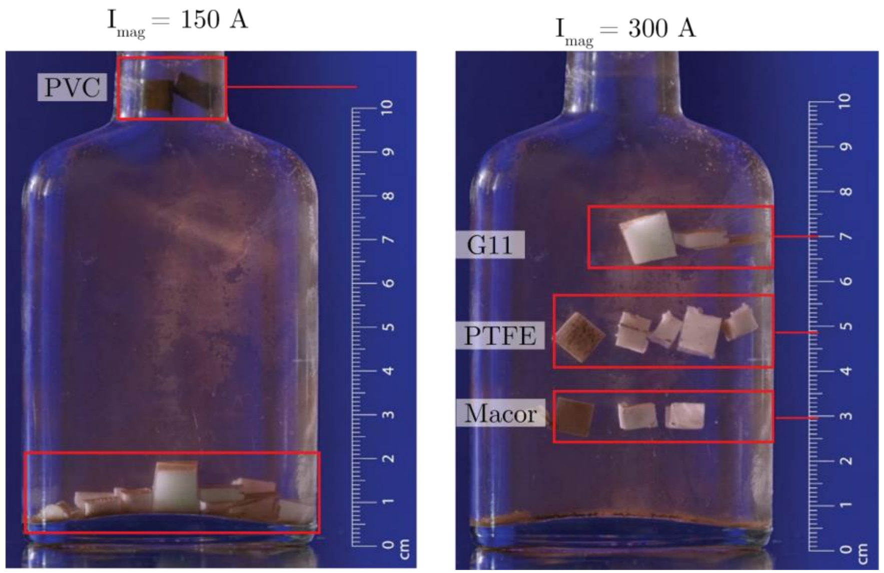
Conclusion

- First conduction cooled superconducting magnetic density separation system assembled successfully.
- Cool down time 13 days, meets expectations.
- Design current of 300 A at 2 T reached within 1.5% of design.
- Successful preliminary waste sorting **tests completed at the Umincorp company facility** in Rotterdam.
- **Next step - Integration with a sorting facility** at the University of Delft.
- **Future** systems, eventually using ***Re*****BCO-coils** can lead to lower operational cost.

MDS prove-of-concept video

- For this demonstration, the Ferrofluid could not be used, because it is [redacted]

- Instead, Manganese(II) chloride tetrahydrate solution $MnCl_2 \cdot 4H_2O$ as it is paramagnetic and transparent.



QR code