Design of a Superconducting Magnet for Magnetic Density Separation

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HTS2018 MODELLING

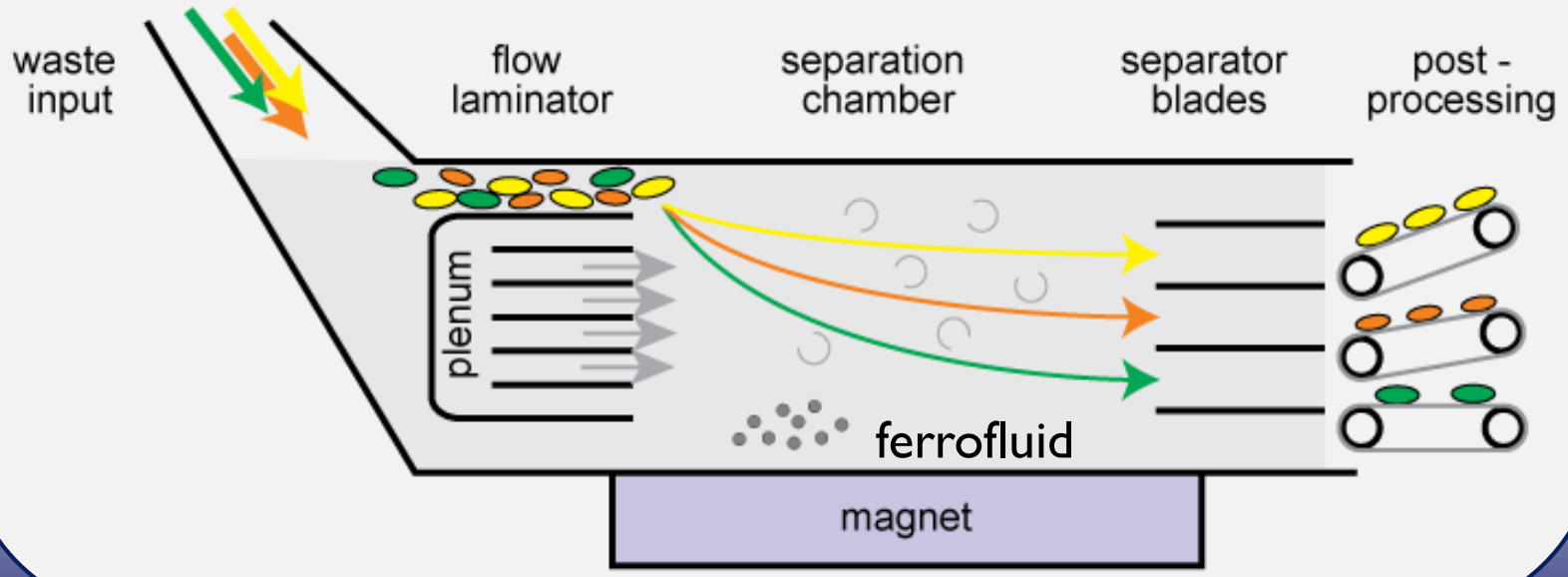
NWO Applied and Engineering Sciences

Magnetic Density Separation (MDS)?

MDS: novel recycling technology

Ferrofluid +Vertical magnetic field gradient

Particles are separated by mass density



Goals of the research

- NbTi demonstrator magnet
- MgB_2 prototype magnet
- Show benefits of superconductivity for MDS

Contents

- What is MDS?
- How does MDS work?
- What kind of magnet is needed?
- Cryostat
- Conclusions & outlook

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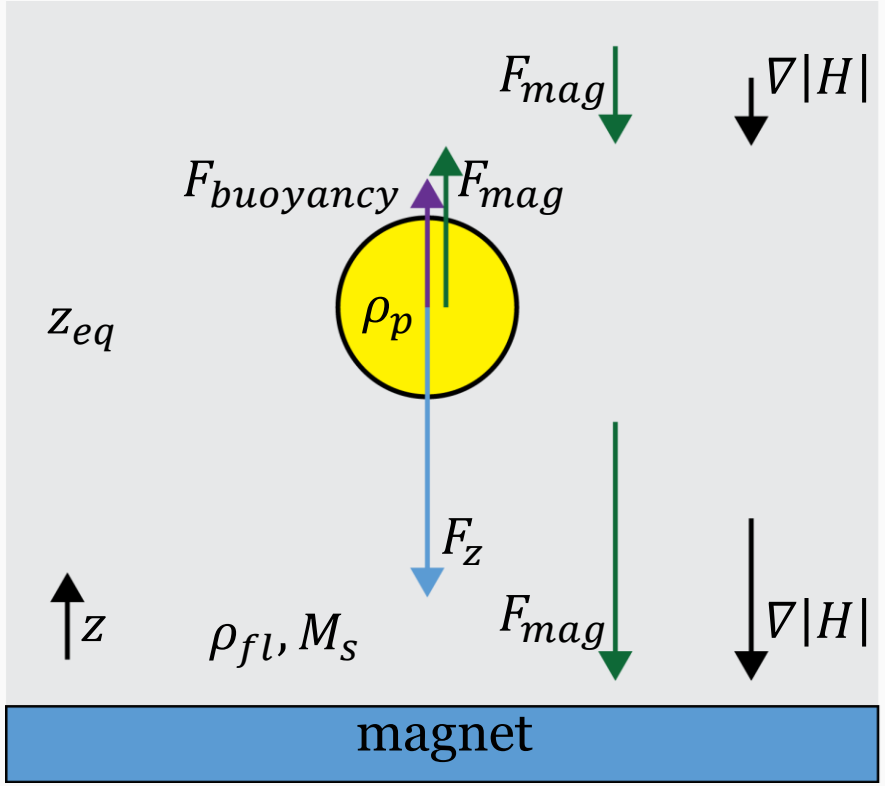
How does MDS work?

At a height z_{eq}, the net force on the waste particle is zero.

$$F_z + F_{buoyancy} + F_{mag} = 0$$
$$= (\rho_{fl} - \rho_p)V_p g - \mu_0 M_s \nabla|H|$$

Assuming $|H|(z) = H_0 \exp(-2\pi z/\lambda)$, the stable equilibrium height depends on the mass density ρ_p as

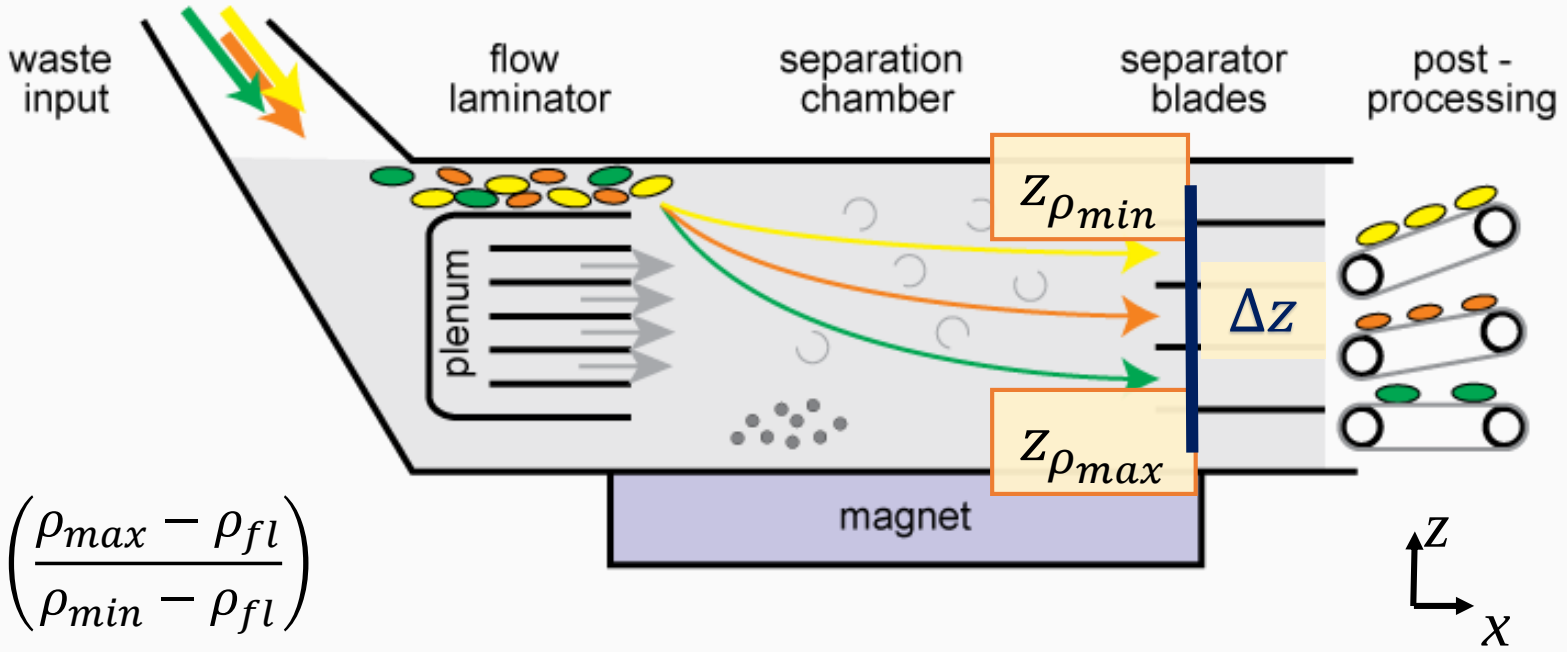
$$z_{eq} = \frac{\lambda}{2\pi} \ln\left(\frac{2\pi\mu_0 \boldsymbol{M_s H_0}}{g\lambda(\rho_p - \rho_{fl})}\right)$$



How does MDS work?

$$z_{eq} = \frac{\lambda}{2\pi} \ln\left(\frac{2\pi\mu_0 \boldsymbol{M_s H_0}}{g\lambda(\rho_p - \rho_{fl})}\right)$$

$$\Delta z = z_{\rho_{min}} - z_{\rho_{max}} = \frac{\boldsymbol{\lambda}}{2\pi} \ln\left(\frac{\rho_{max} - \rho_{fl}}{\rho_{min} - \rho_{fl}}\right)$$



λ determines distance between different densities

What determines λ, and how to generate $|H|(z) = H_0 \exp(-2\pi z/\lambda)$?

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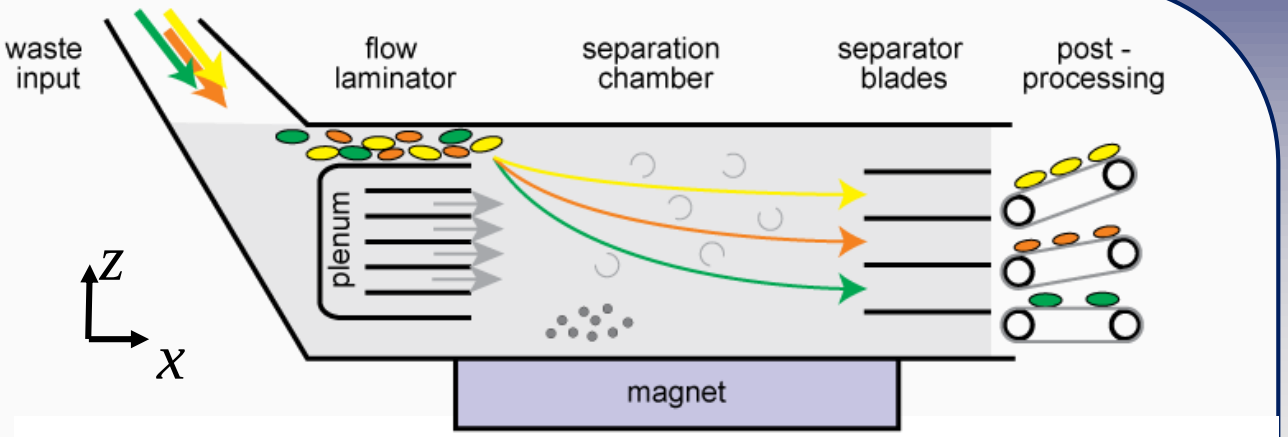
What kind of current distribution is needed?

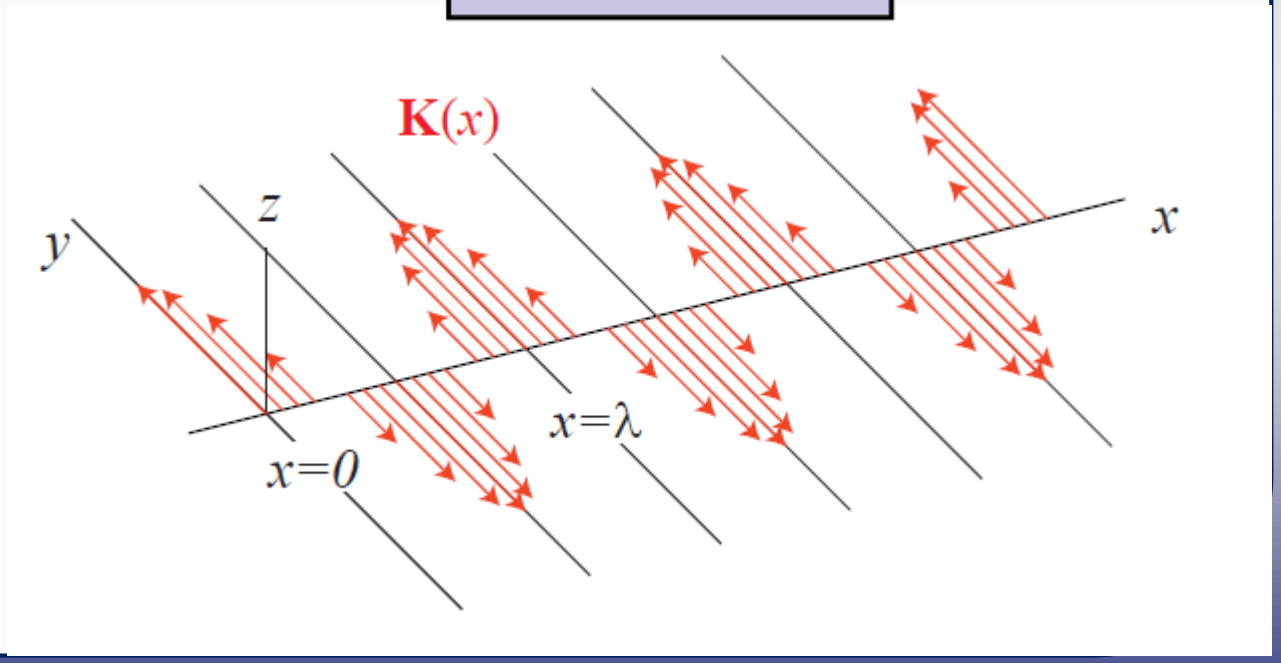
MDS requires a **strong vertical gradient**, that depends only on z-coordinate.



Harmonic current distribution generates

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

Decay rate scales with periodicity λ of current distribution.



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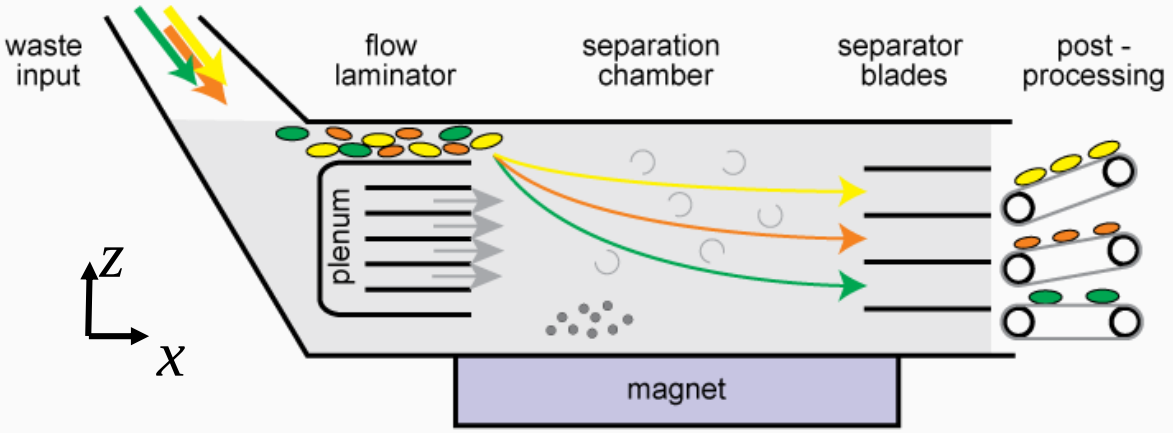

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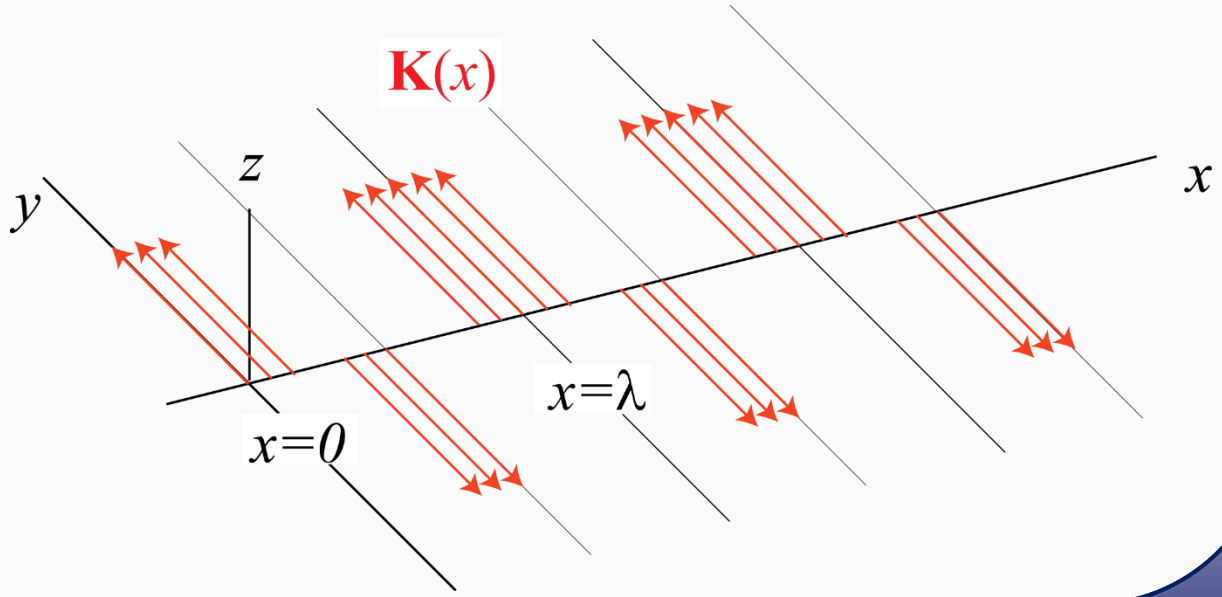
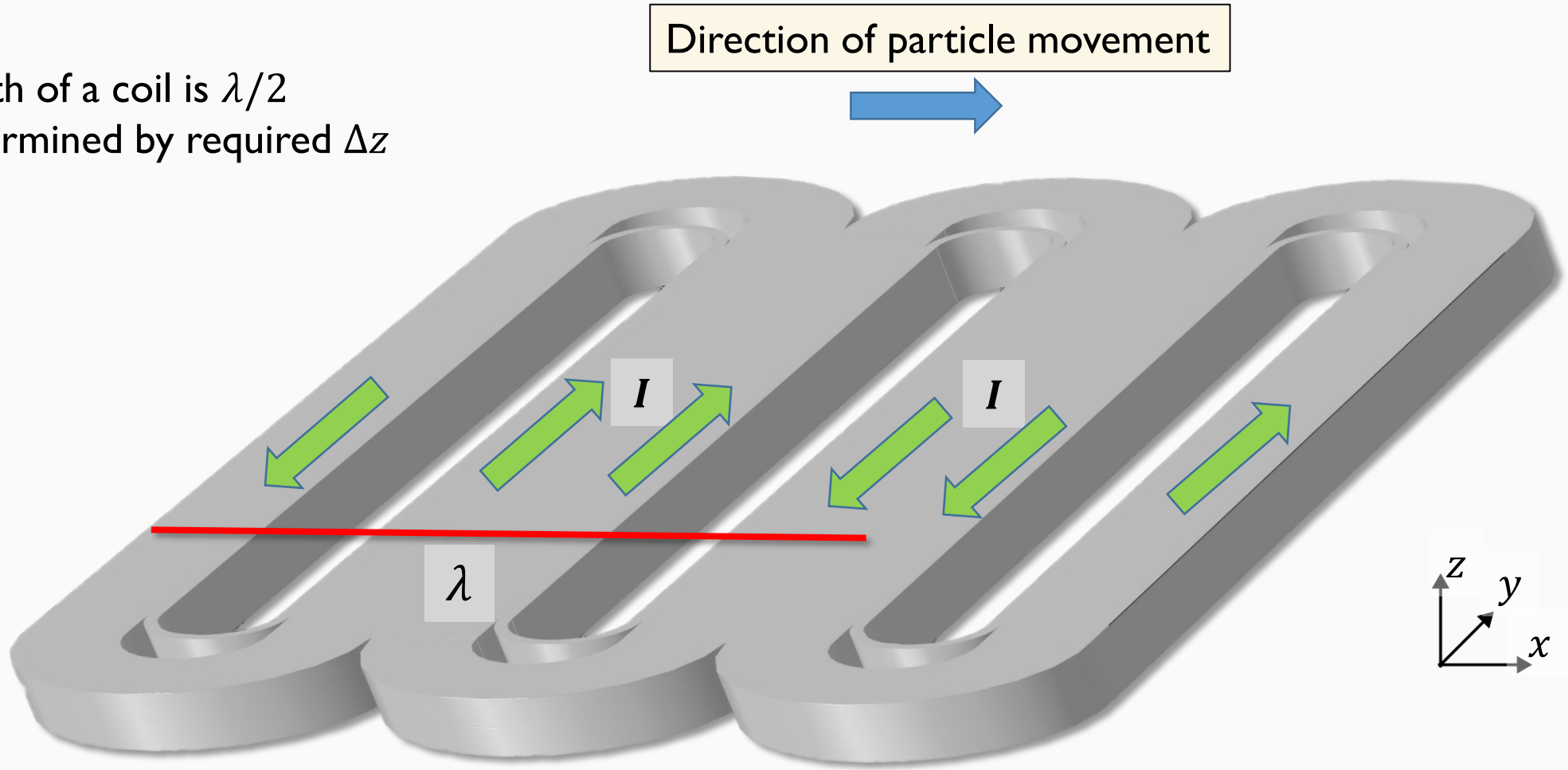
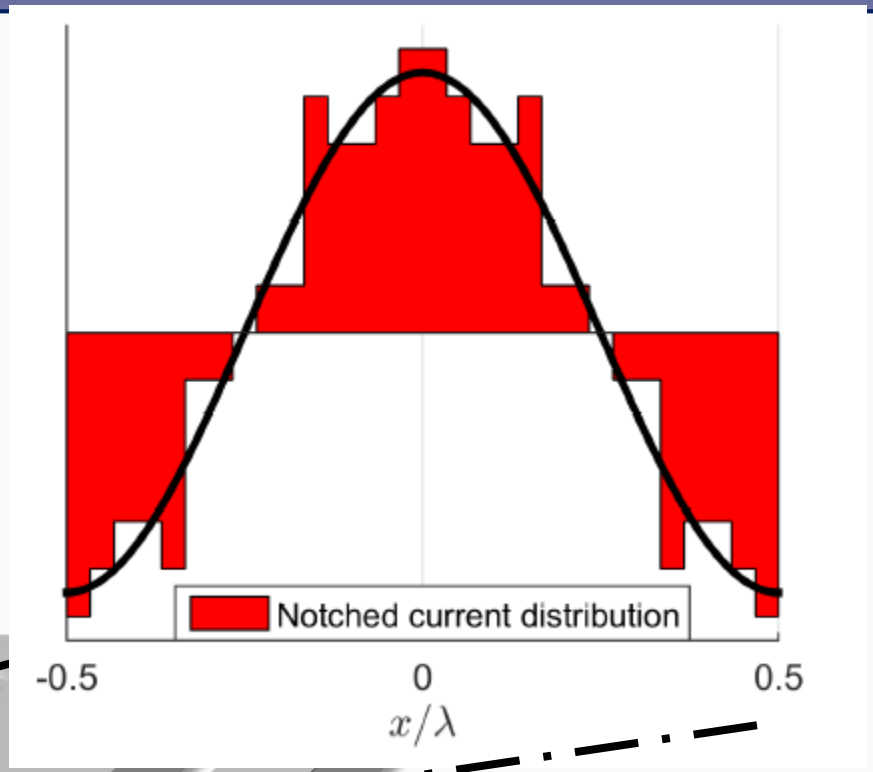


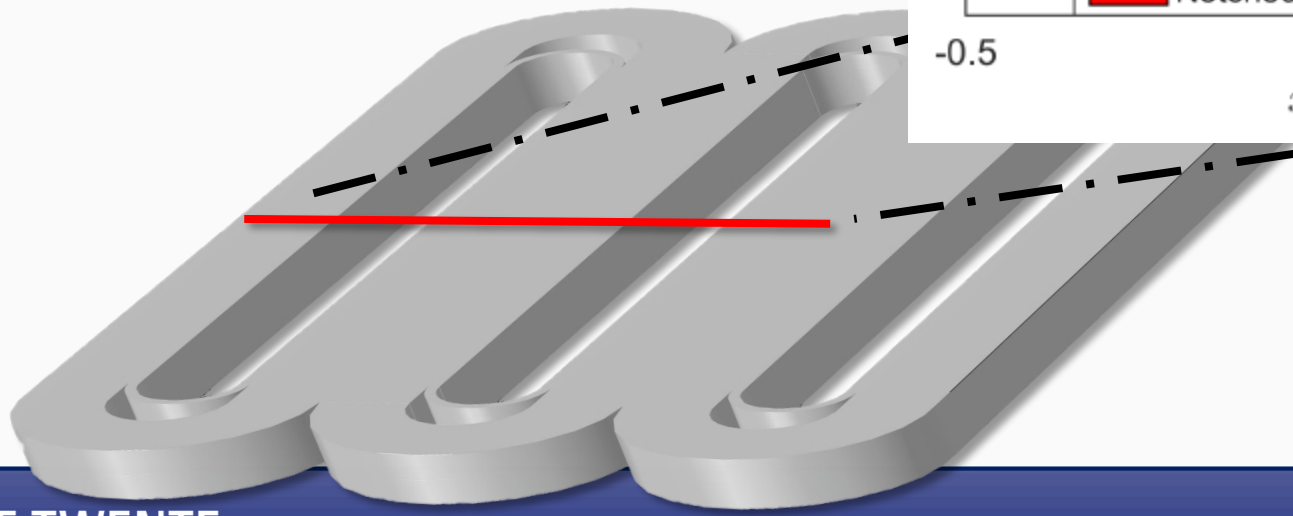
Approximate ideal distribution with racetracks

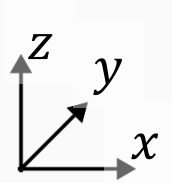
Width of a coil is $\lambda/2$
Determined by required Δz



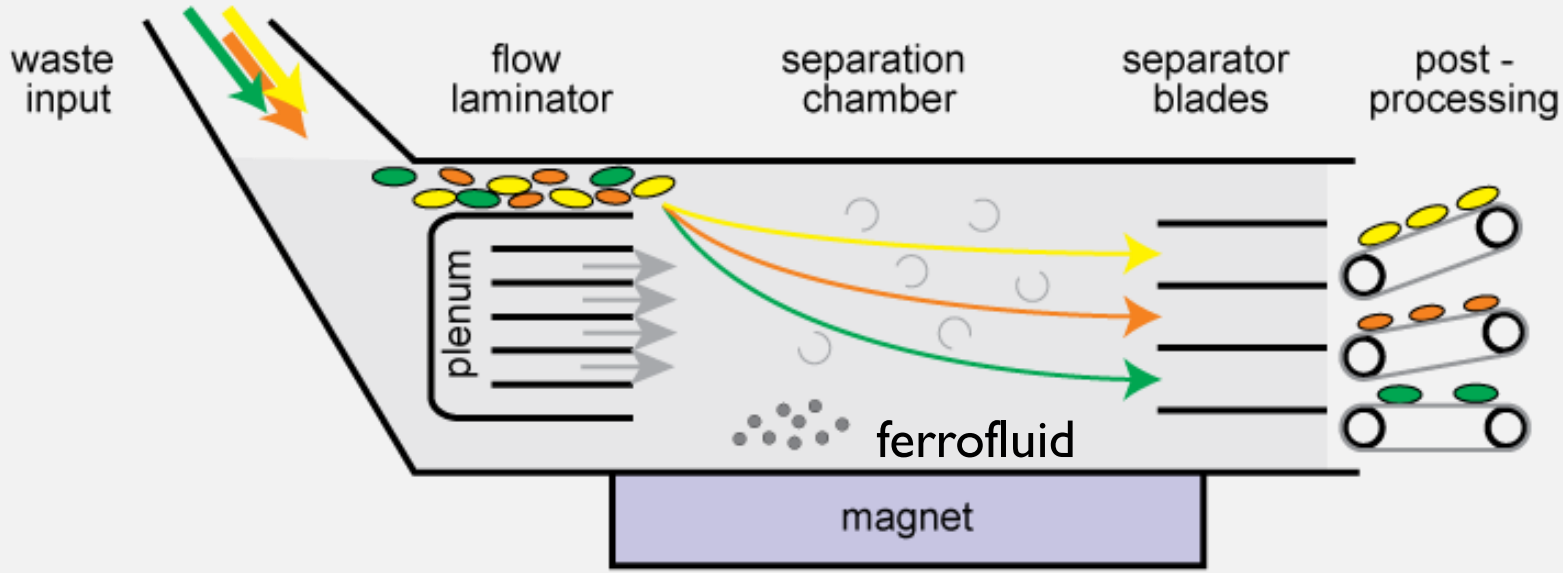
More accurate approximation possible







“Conventional” MDS



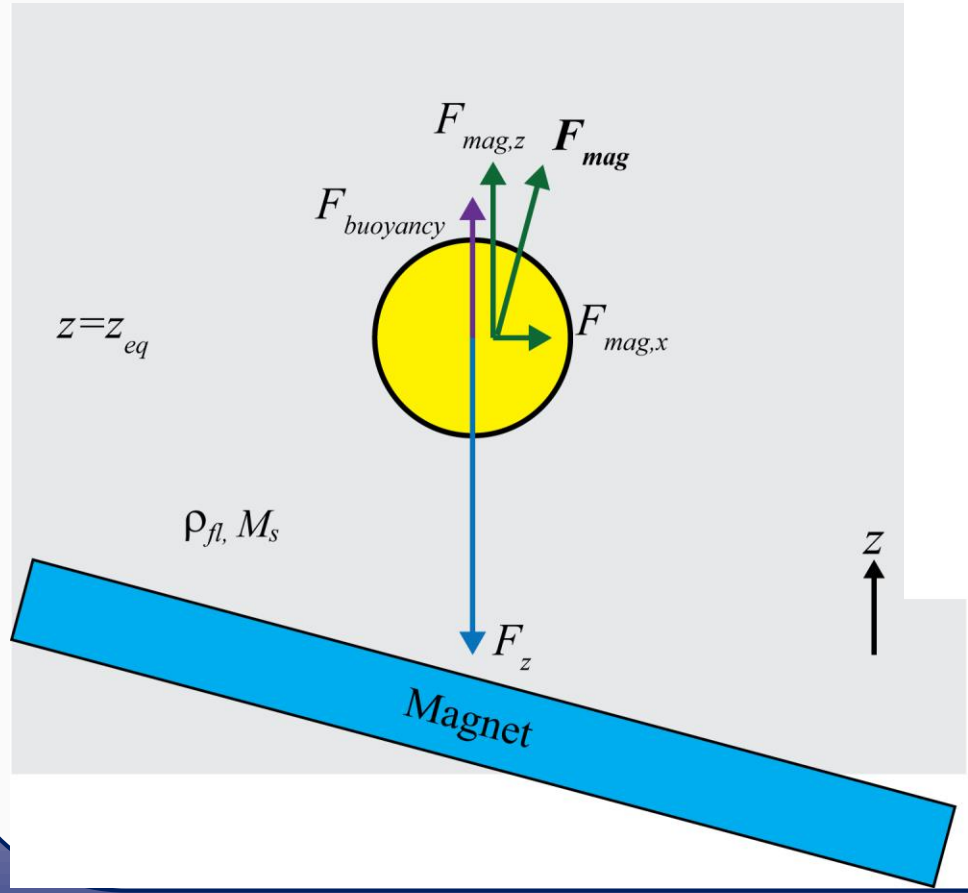
- Horizontal gradient components can slow down/stop particles→minimum flow speed

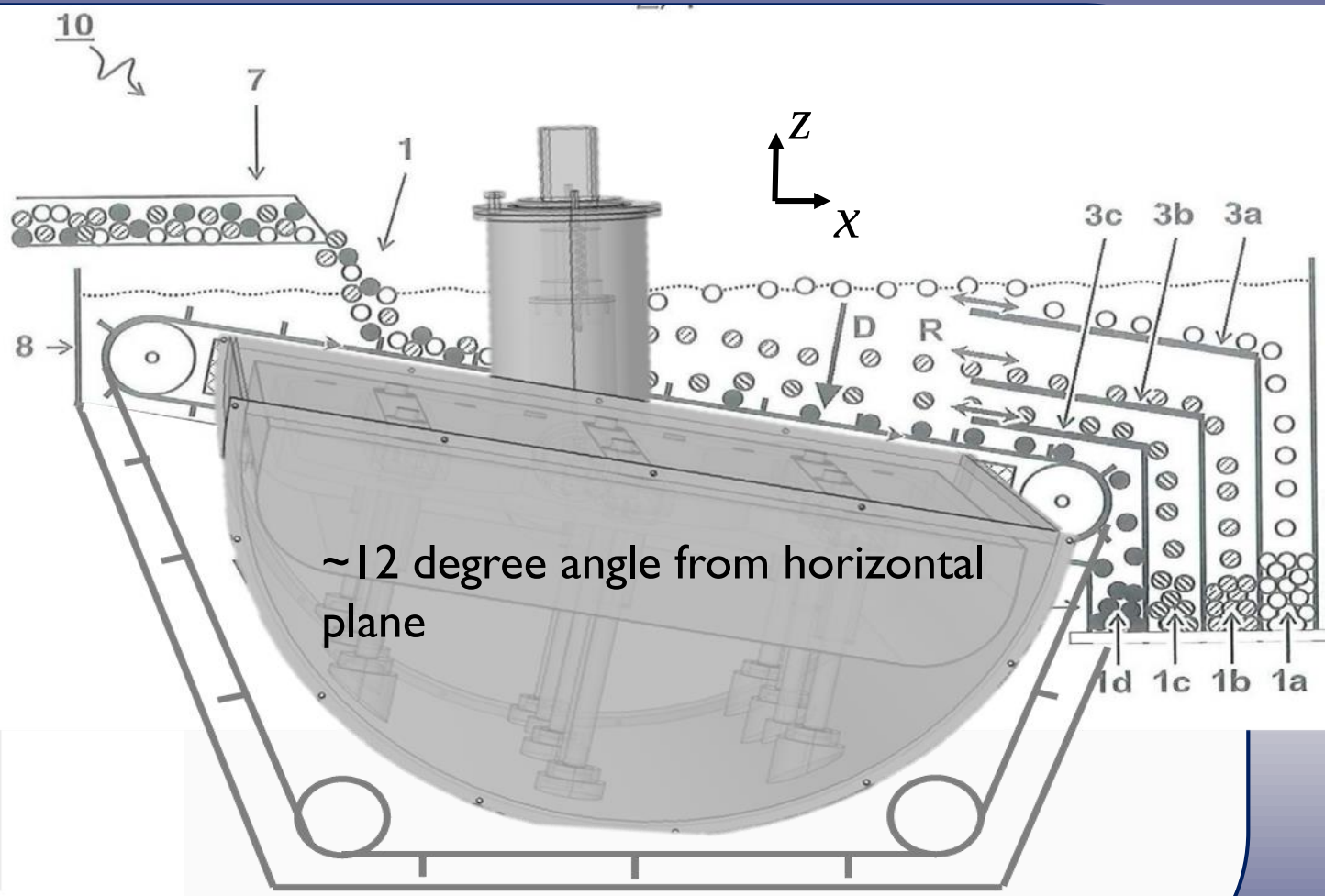
➡ Minimum system length

- Particles need time to reach z_{eq}

Angled MDS magnet

Particles move to the right by horizontal magnetic force component





~12 degree angle from horizontal plane

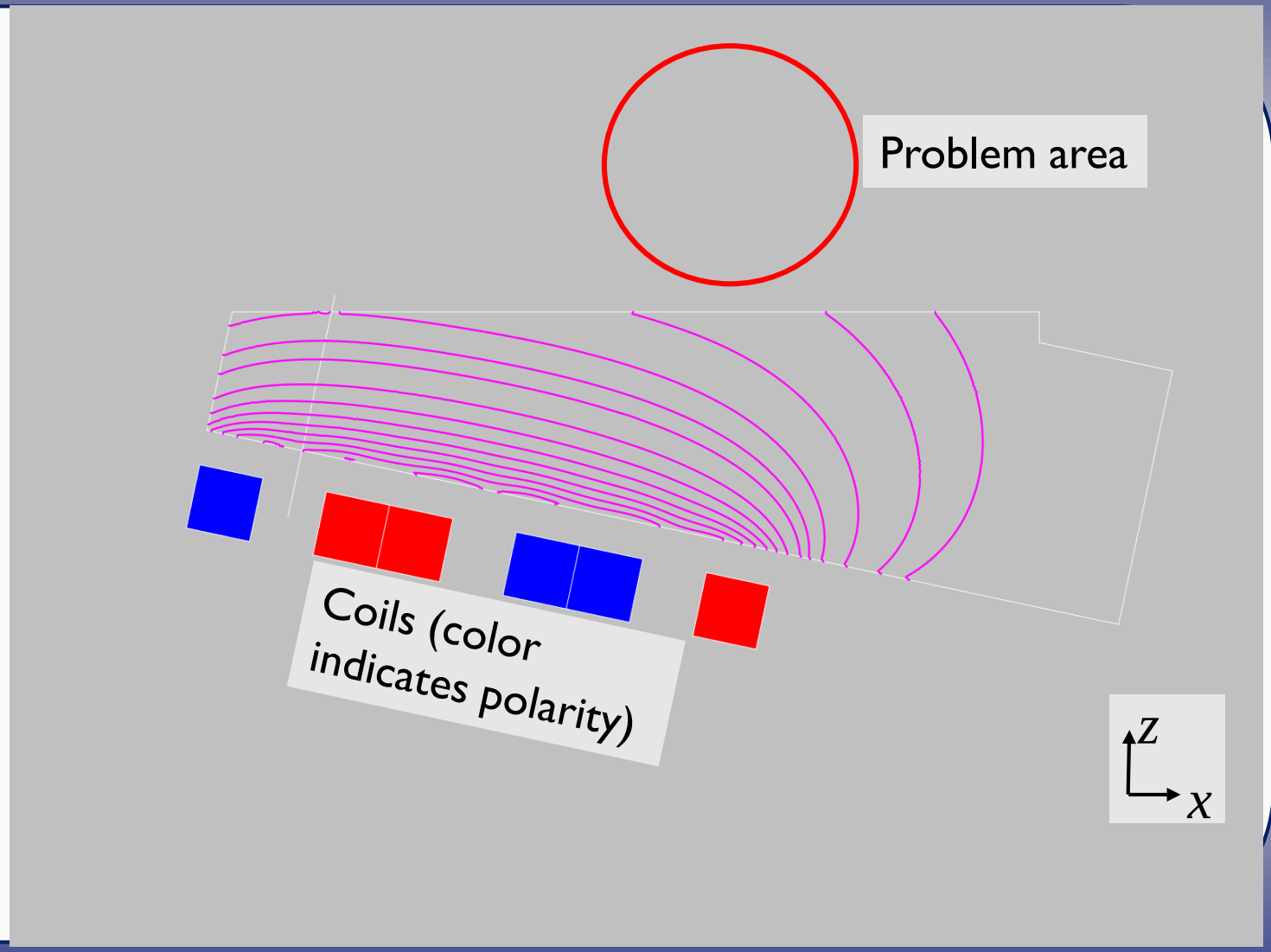
P. Rem, Patent number WO 2017/111583

Angled MDS magnet

Magenta lines:
particle equilibrium heights

Particles will tend to
follow these lines.
But in the right direction?

Arrows:
direction of gradient $\nabla|\mathbf{H}|/|\nabla|\mathbf{H}||$

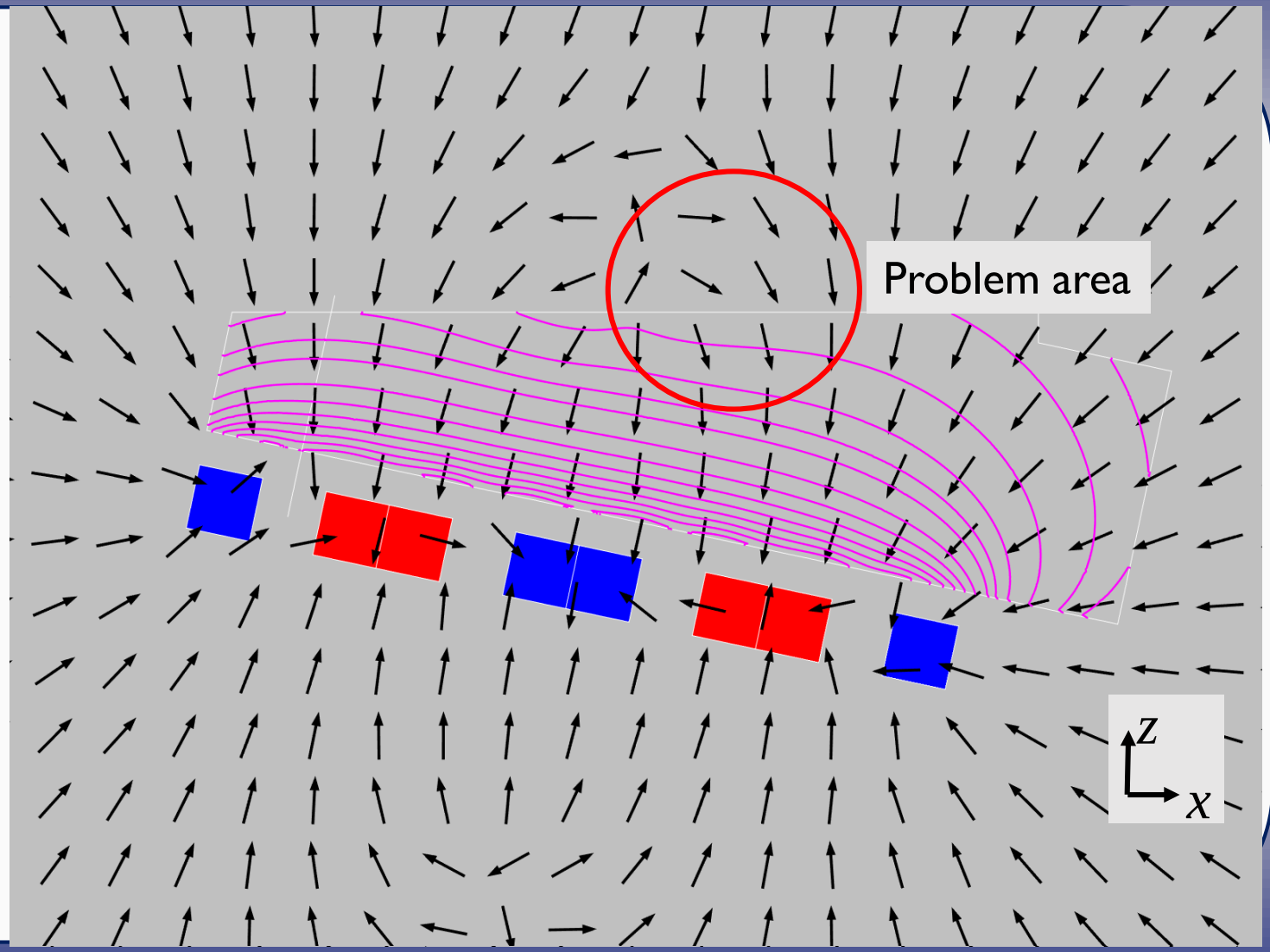


Angled MDS magnet

4 coil system doesn't work!

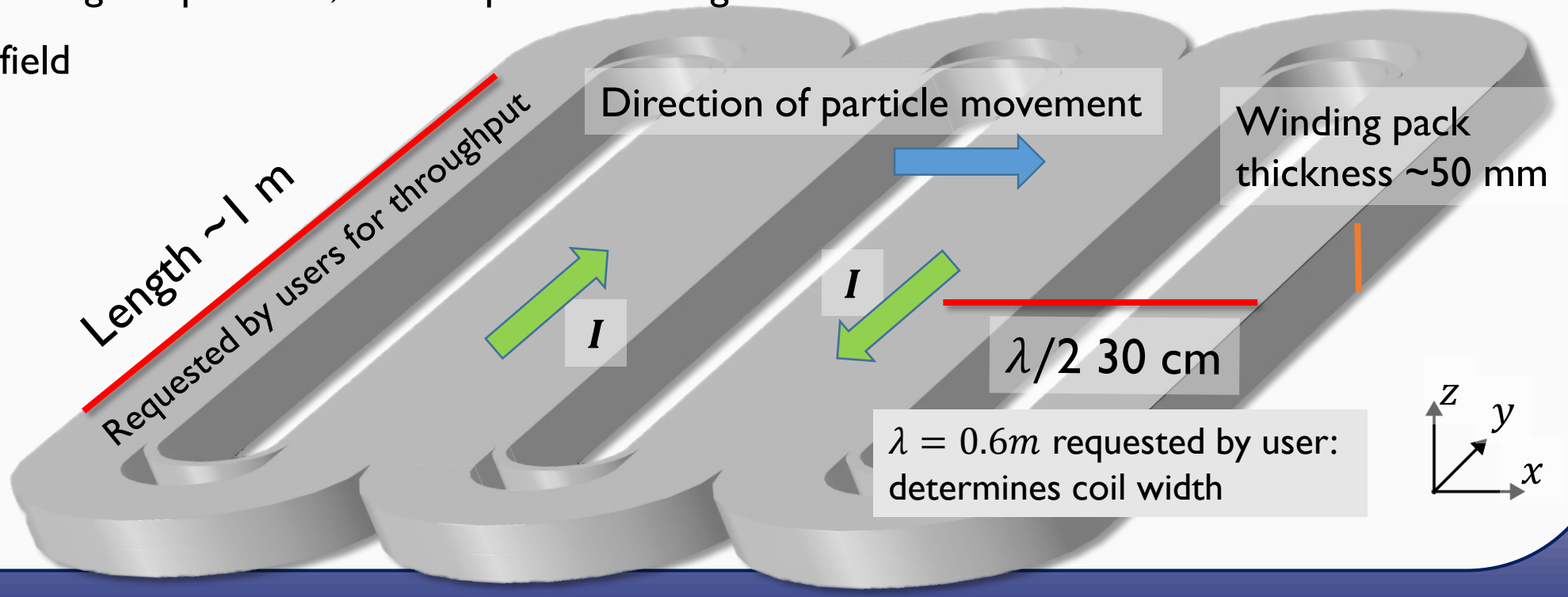
Nor does 2 or 5…

→ 3 coils it is!



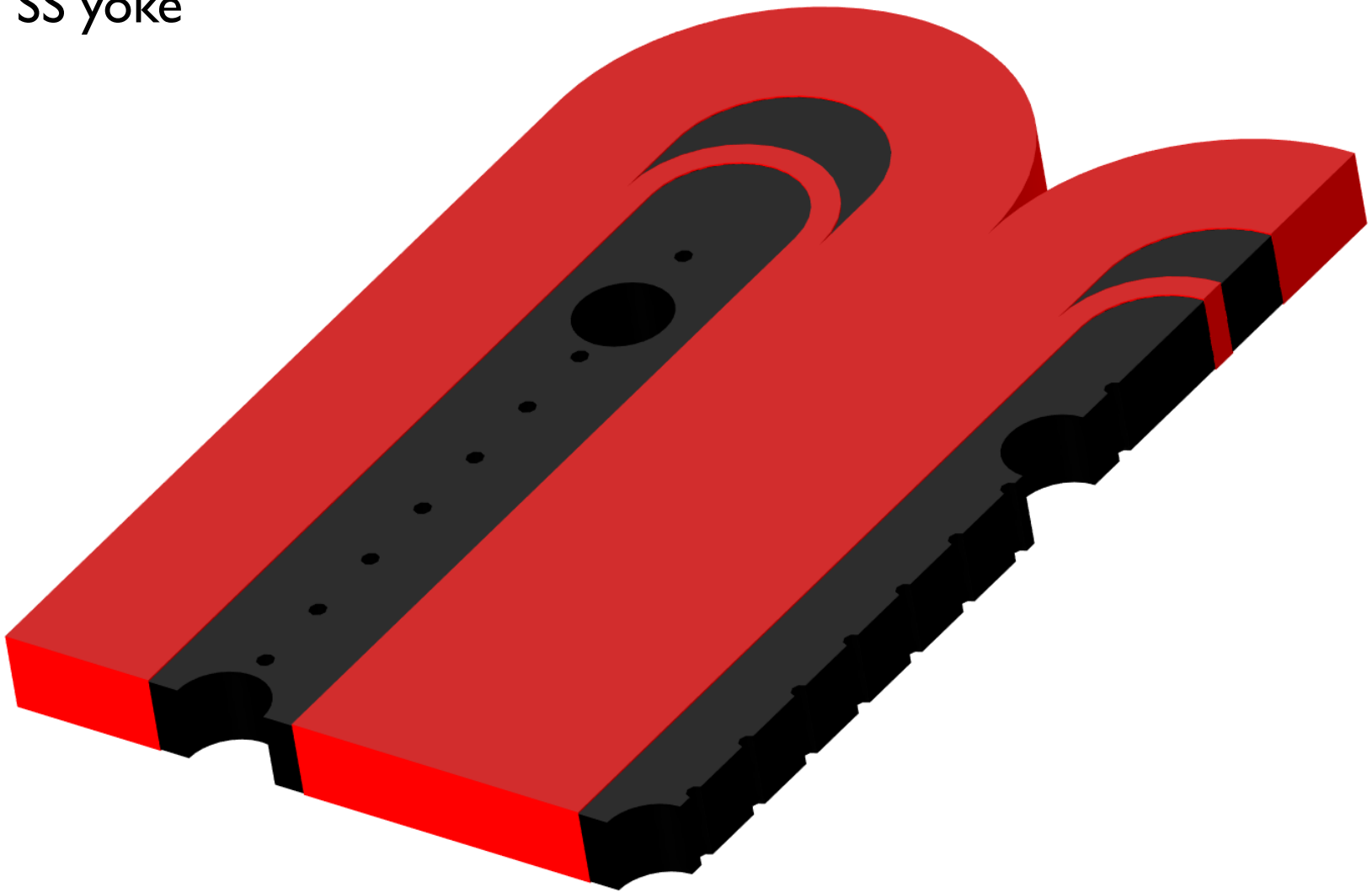
Demonstrator magnet lay-out

- 1.36 mm NbTi wire
- 300A, ~2080 turns/coil
- 4.5K operating temperature, 2K temperature margin
- 5T peak field



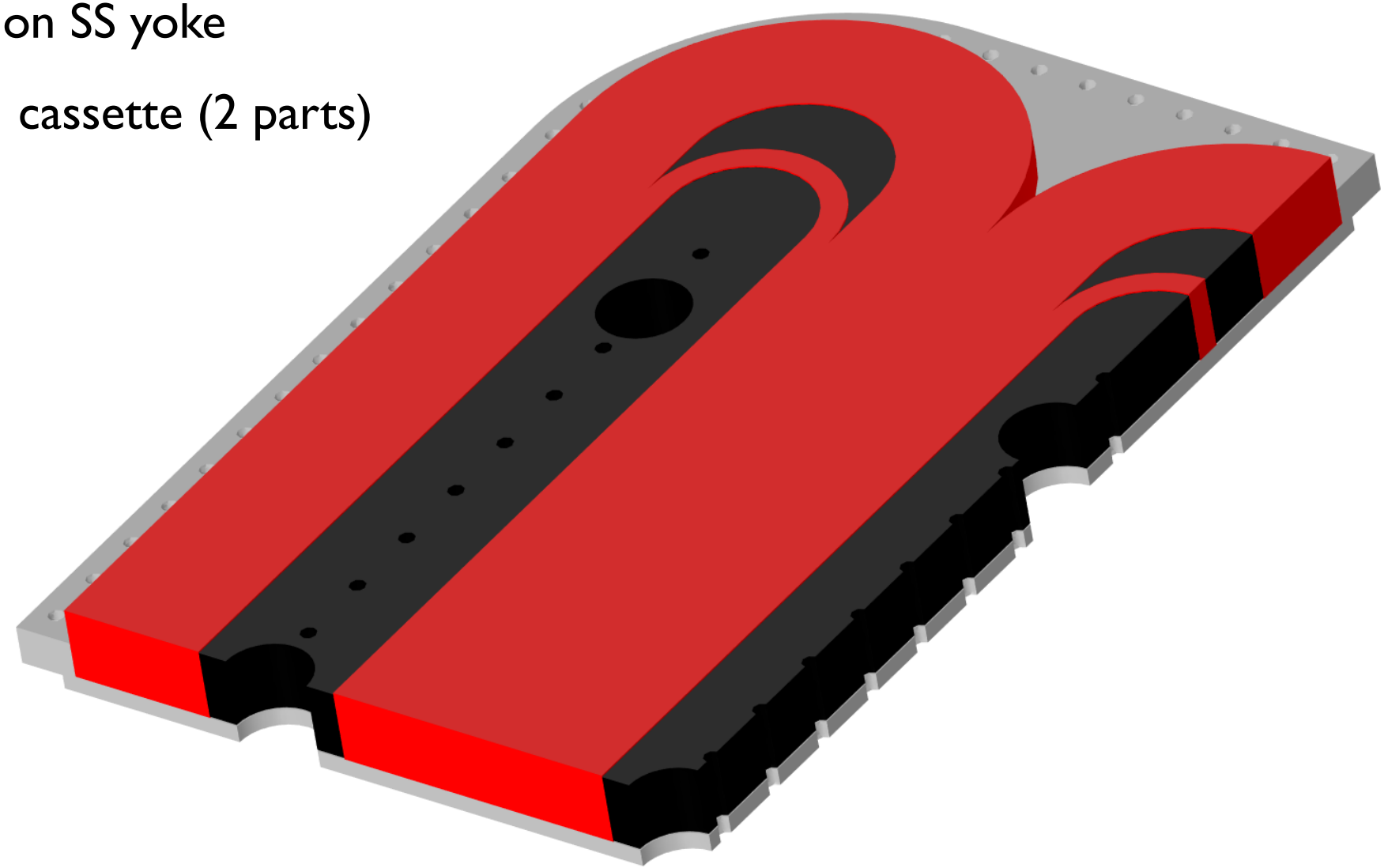
Demonstrator magnet lay-out

- Wet winding on SS yoke



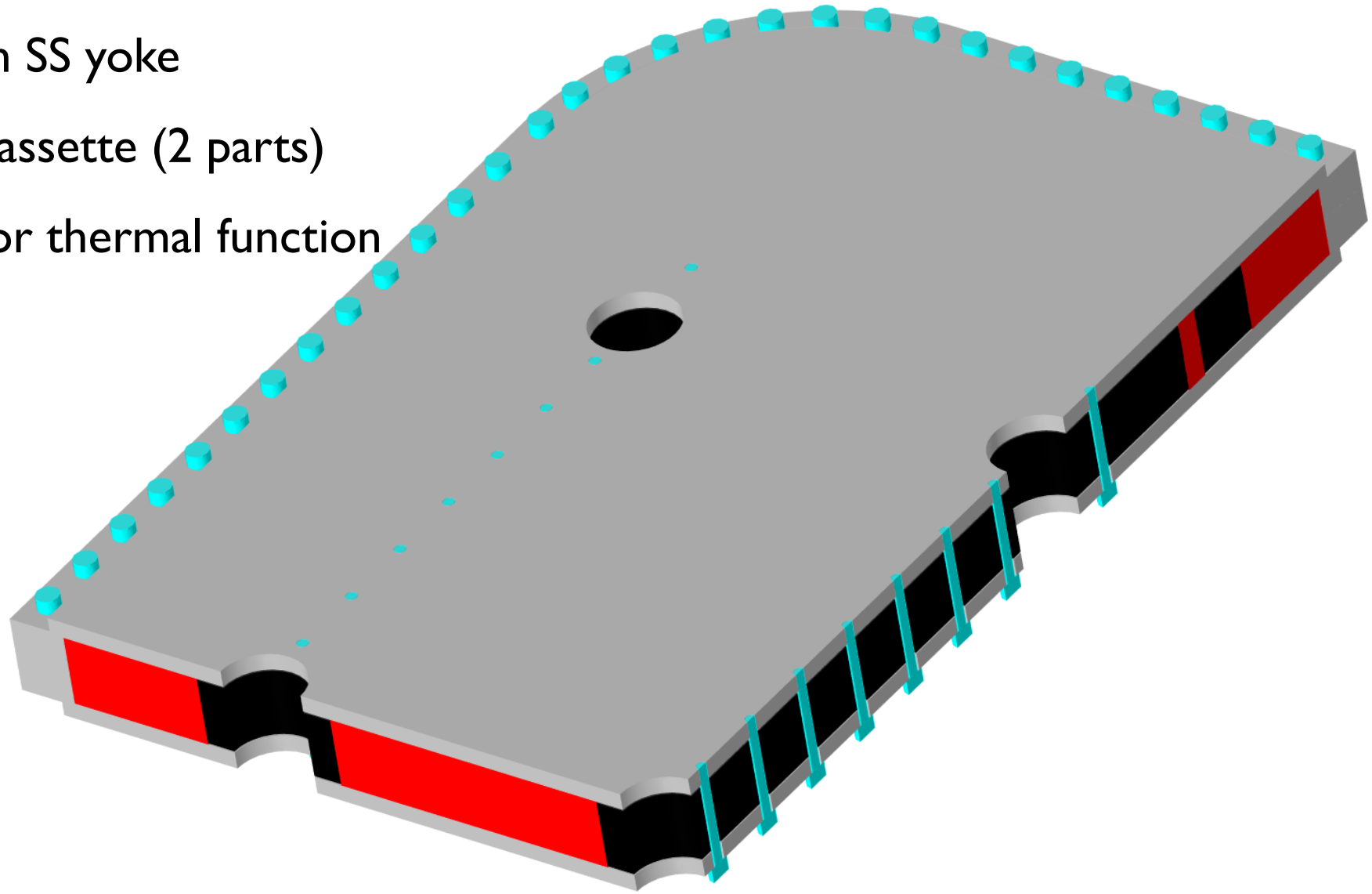
Demonstrator magnet lay-out

- Wet winding on SS yoke
- Al5083-H321 cassette (2 parts)



Demonstrator magnet lay-out

- Wet winding on SS yoke
- Al5083-H321 cassette (2 parts)
- Pure Al strips for thermal function



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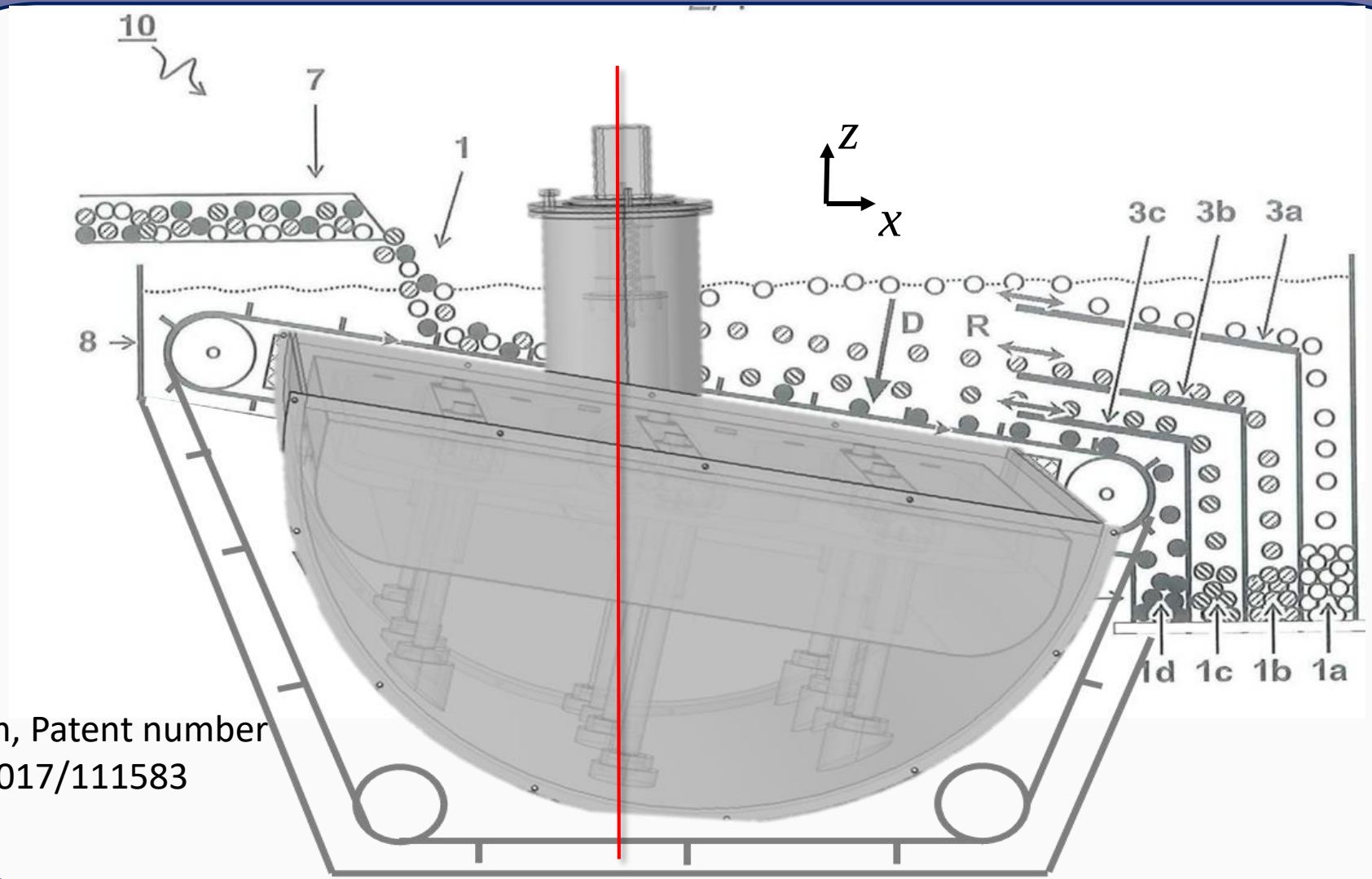
Angled MDS magnet



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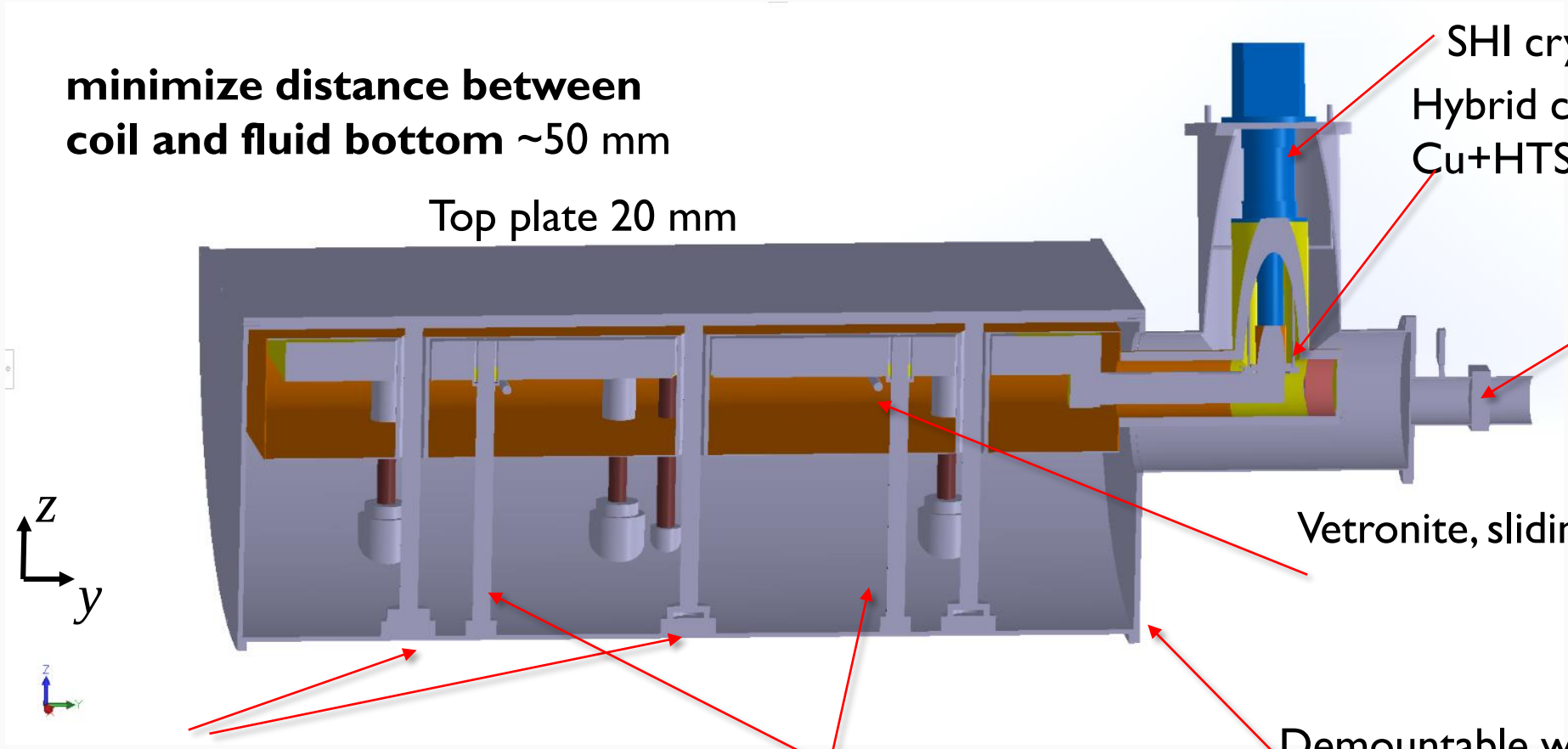
Cryostat of angled MDS magnet

minimize distance between coil and fluid bottom ~50 mm

Top plate 20 mm



SHI cryocooler cold head

Hybrid current lead
Cu+HTS+NbTi

Vacuum port, valve, pressure gauge…

Vetronite, sliding support,

Pillars
C. Zhou

Vetronite, 4 rods

Demountable with screw bolts for both side walls

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Conclusion

- **MDS** is a recycling technology, allows separation based on **mass density**
- **NbTi** demonstrator magnet is starting construction phase
  - Angled, aimed at electronic waste
  - Three-coil lay-out chosen. **Minimizes horizontal gradient components.**
  - Conduction-cooling
  - To be installed at TU Delft
- **MgB_2** prototype system is in material testing phase.
  - Non-angled, aimed at light plastics

Thanks for the attention

This research is part of the program Innovative Magnetic Density Separation (IMDS), which is supported by NWO domain Applied and Engineering Sciences and partly funded by the Dutch Ministry of Economic Affairs.

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