Verification of Lorentz Force Velocimetry using a bulk HTS magnet system

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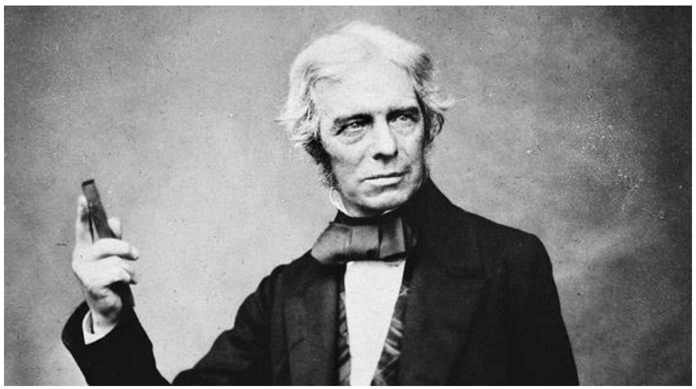
Outline

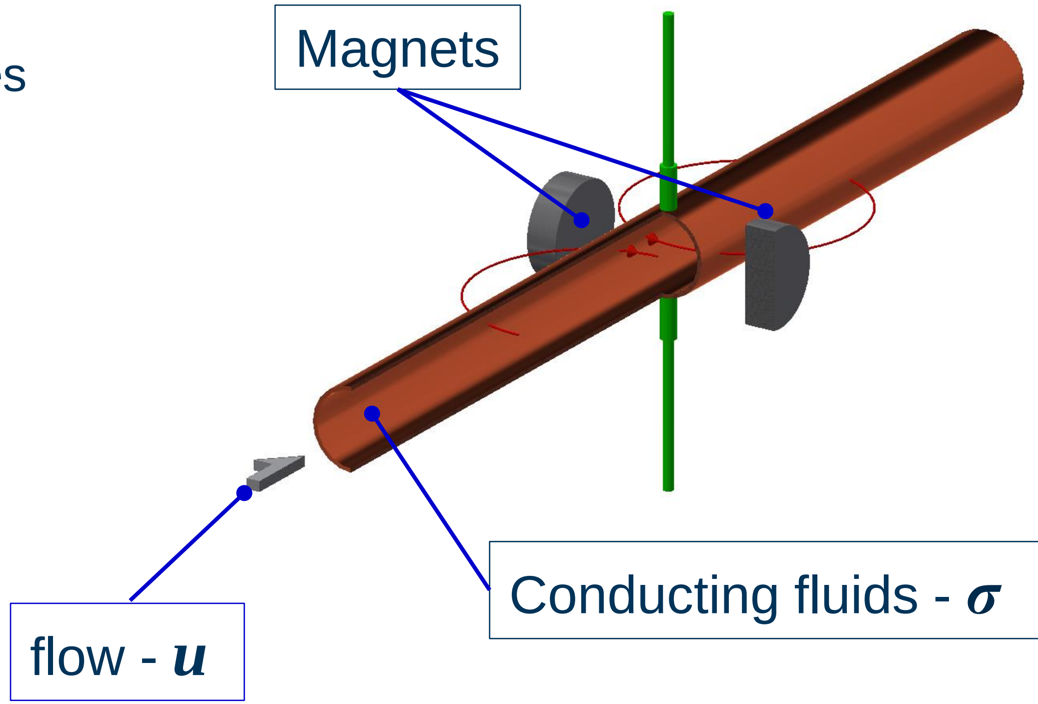
- **Introduction**
- **Fundamentals of Lorentz Force Velocimetry (LFV)**
- **LFV using bulk HTS:**
  - **verification experiment**
  - **model**
  - **results**
- **Toward portatable LFV meter**
- **Outlook & Conclusions**

Faraday experiment

1832 – Faraday: measured velocity of the Thames River by measuring the electric potential difference induced by its flow across Earth's magnetic field lines



Today application:
Inductive flow-meters



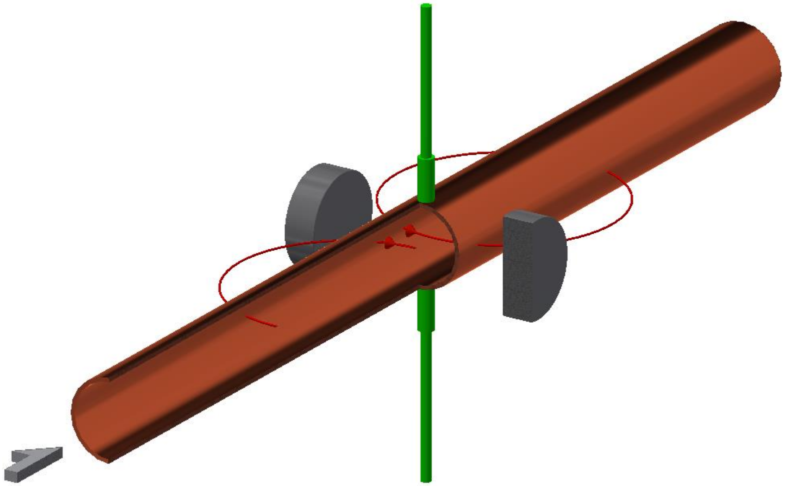
Aggressive fluids

Liquid metals

780° C

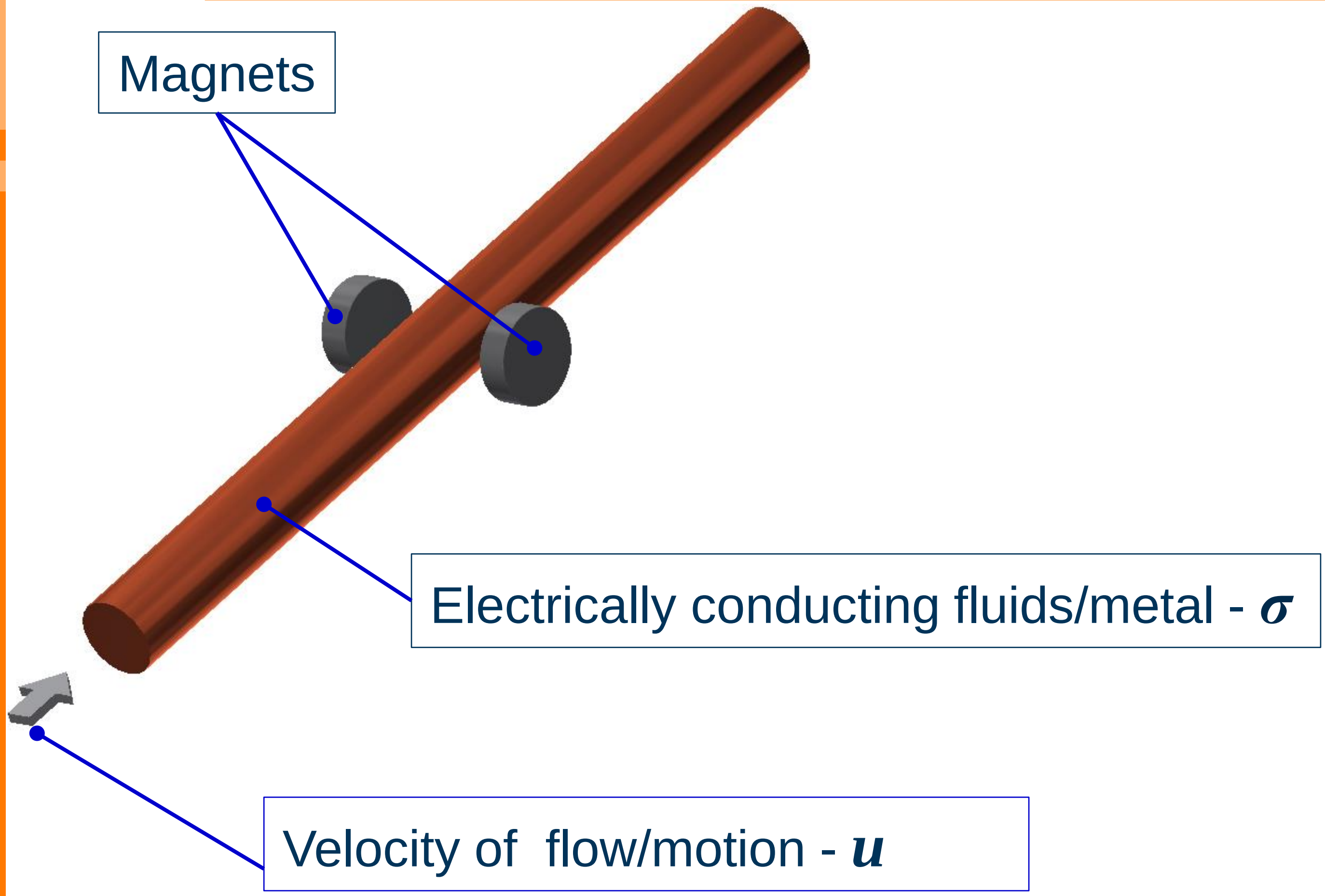
Glass melts

(1000 – 1300)° C

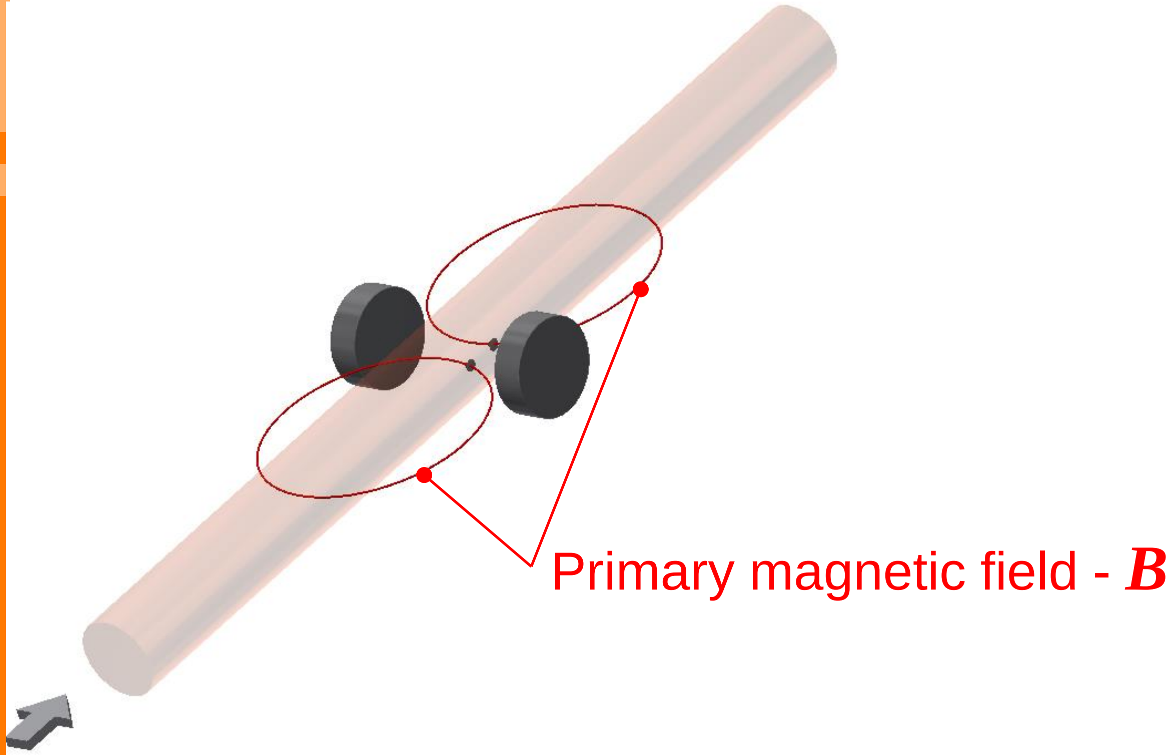


- Electrodes contact a fluid

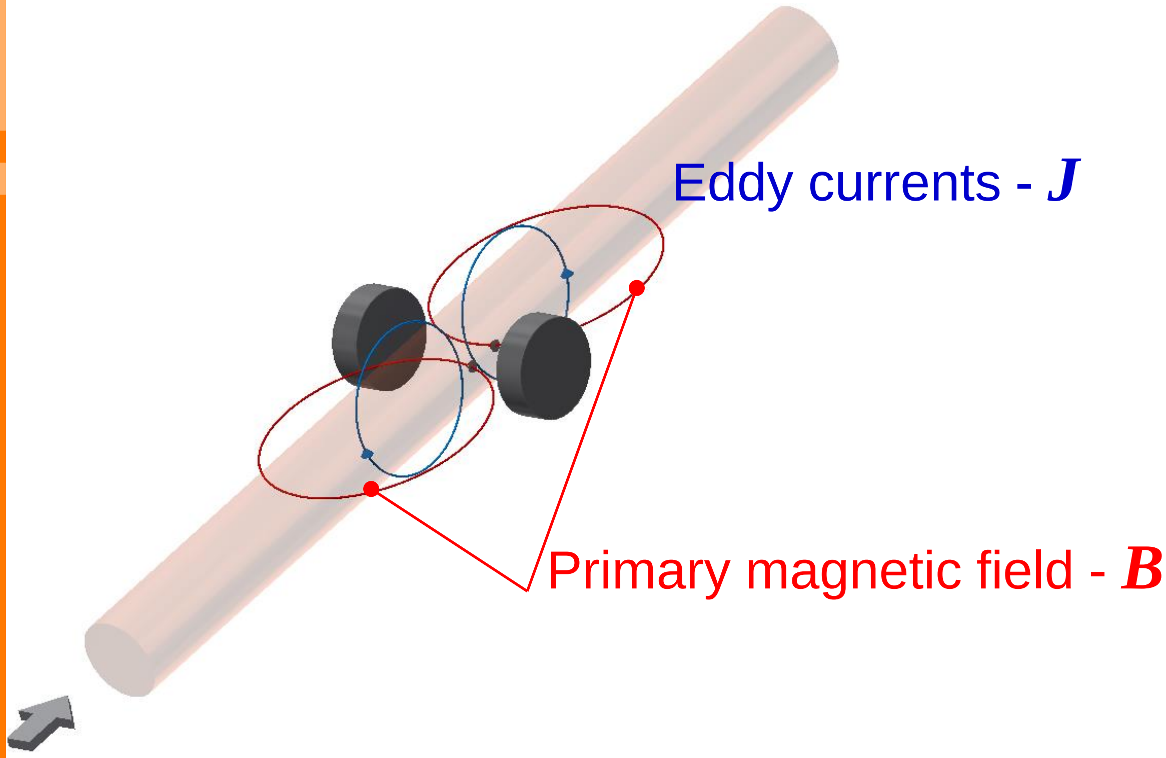
Fundamentals of LFV



Fundamentals of LFV



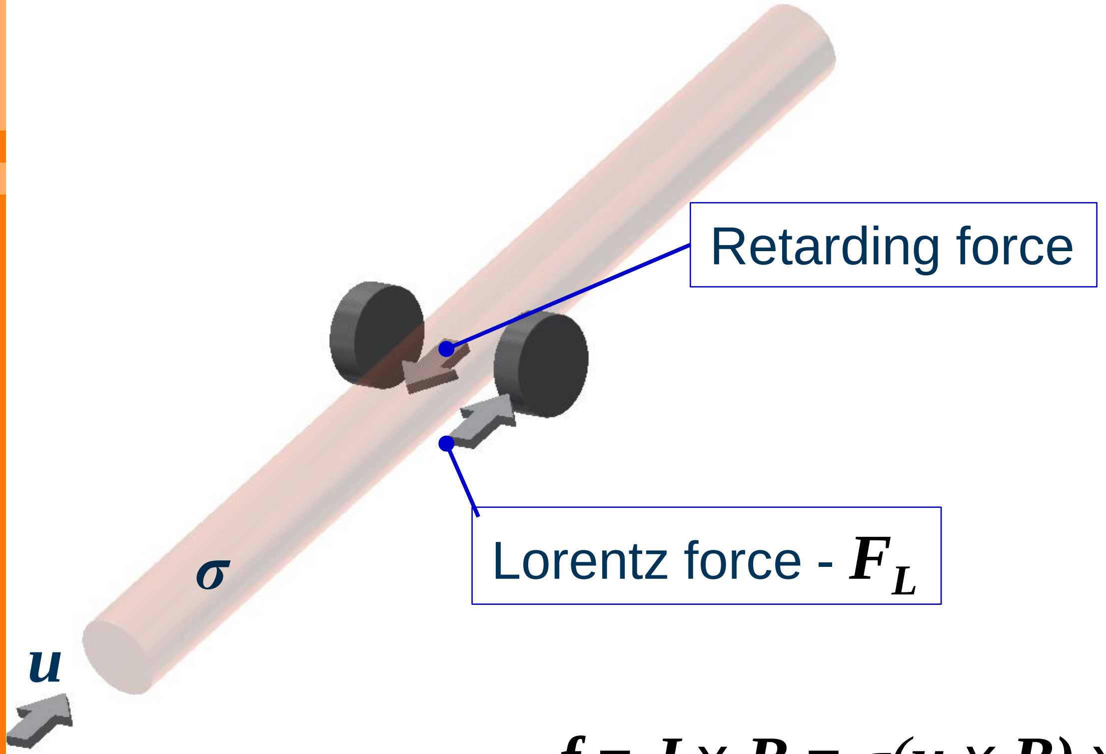
Fundamentals of LFV



$$\boldsymbol{J} = \sigma(\boldsymbol{E} + \underline{\boldsymbol{u} \times \boldsymbol{B}})$$

$$\boldsymbol{f} = \boldsymbol{J} \times \boldsymbol{B} = \sigma(\underline{\boldsymbol{u} \times \boldsymbol{B})} \times \boldsymbol{B}$$

Fundamentals of LFV



$$f = J \times B = \sigma(\underline{u \times B}) \times B$$

$$F \sim \sigma \cdot u \cdot B^2$$

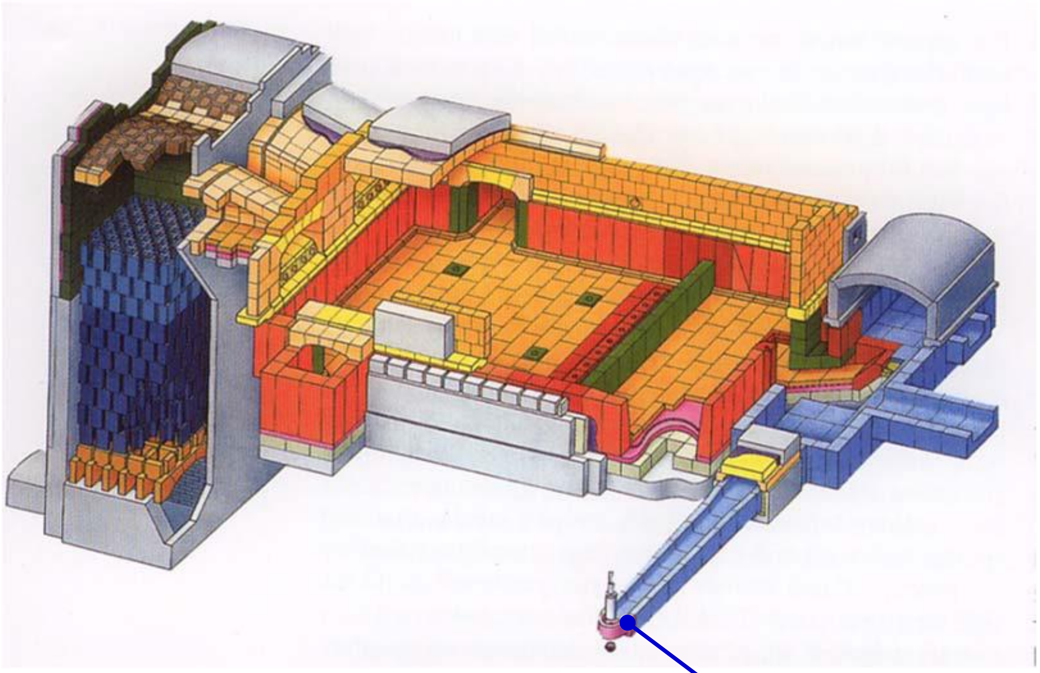
- DE 10 2005 046 910 B4, Thess, A. et al.
- **Thess, A. et al., *Lorentz Force Velocimetry*. PRL 96, 164501, 2006**
- Thess et al., *Theory of the Lorentz force flowmeter*. New J. Phys 2007

Motivation

Strict control of production process using **flow measuremenrs** in glass industry

Glass melts

(1000 – 1300)° C



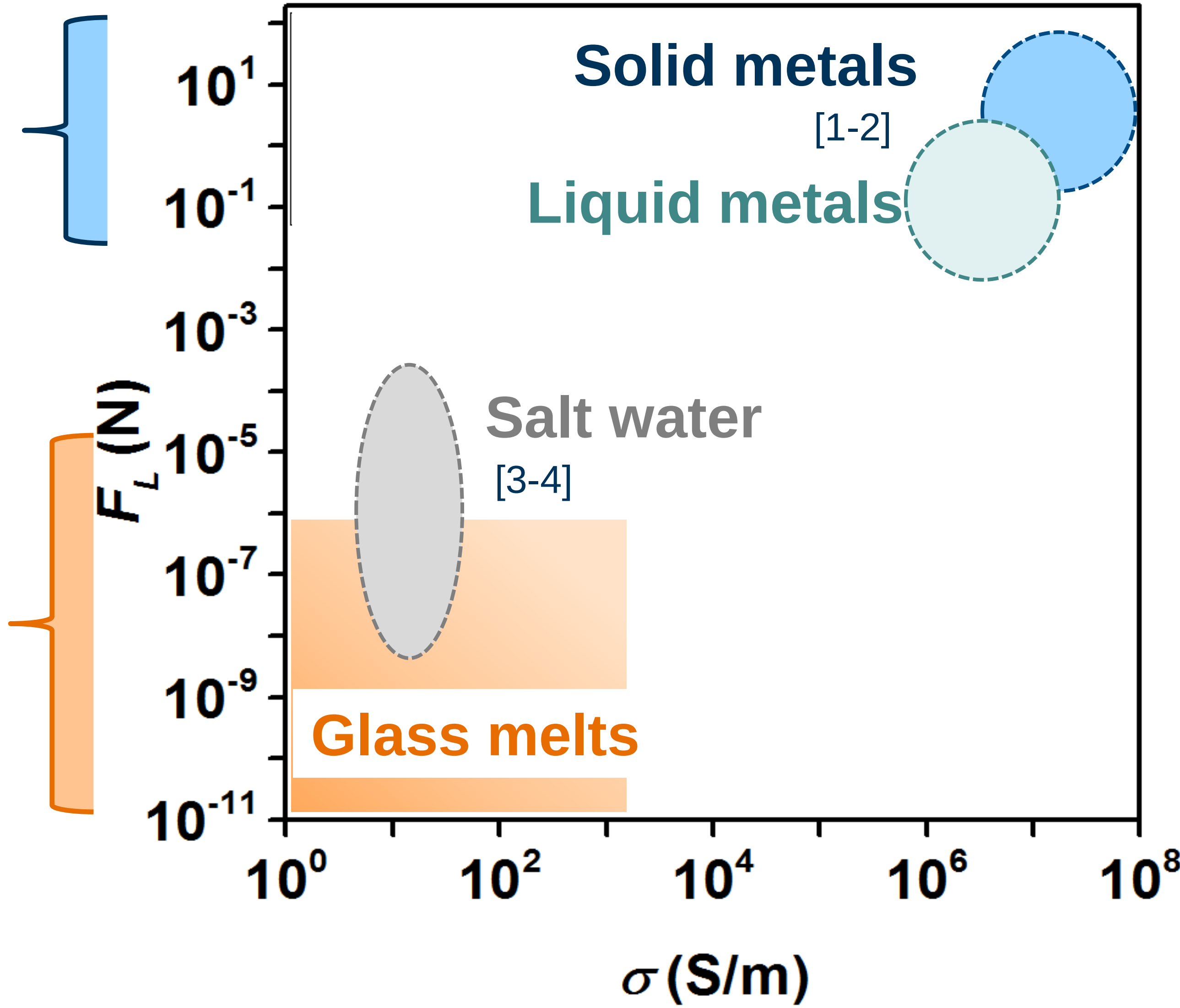
Glass tank feeder

Fluids (F-σ) diagram

- Commercial force sensors
- Permanent magnets

Special high-precision sensors
- low dead load

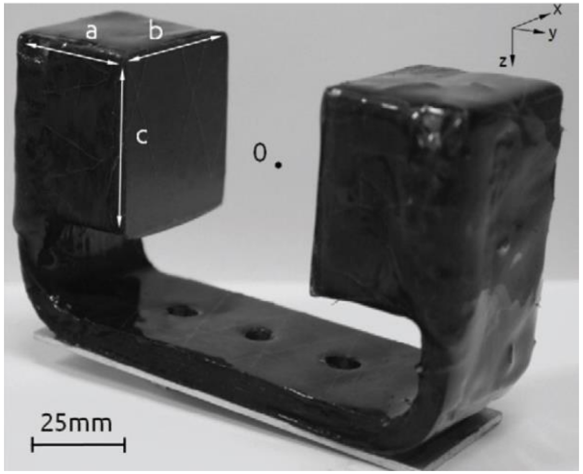
High magnetic
- bulk HTS



1. Kolesnikov Y. et al., Metallurgical and Materials Transactions B, 42(3):441–450, 2011
2. Weidermann Ch.,PhD Thesis 2013
3. Halbedel, B. et al., Flow Turbul. Combust, Vol. 92, pp. 361–9, 2014
4. Vasilyan, S. et al., Meas. Sci. Tech., Vol. 26, pp. 115302, 2015

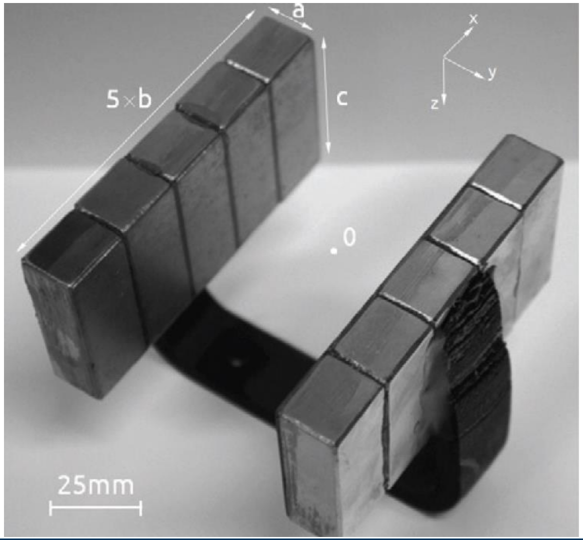
LFV magnet system

NdFeB magnets



Cubic magnets

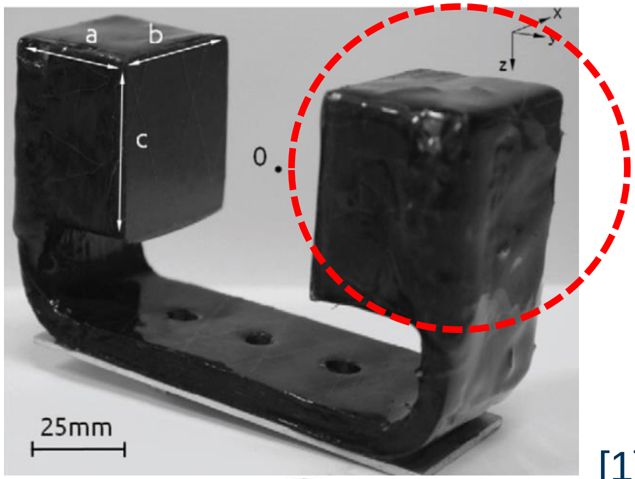
[1]



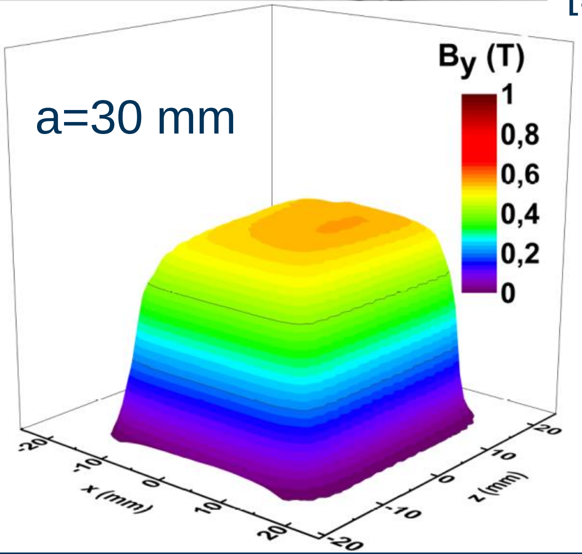
Halbach configuration

LFV magnet system

NdFeB magnets (N48)

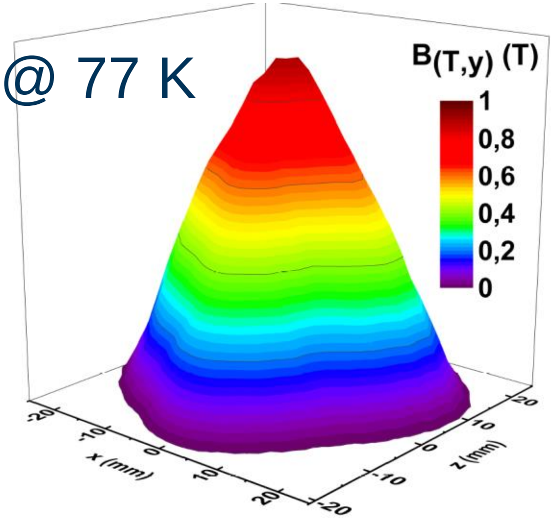


[1]



Bulk HTS

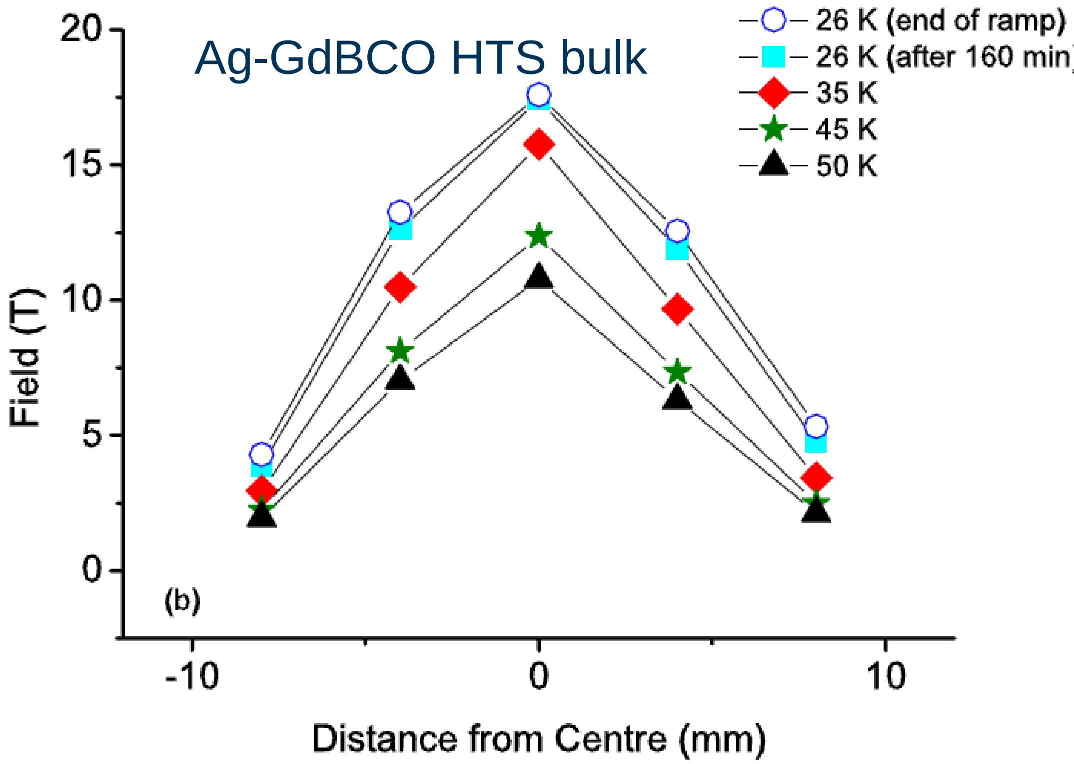
[2]



1. Vasilyan, S. et al., Meas. Sci. Tech., Vol. 26, pp. 115302, 2015
2. ATZ Company , Torgau (Germany)

Potential of HTS magnet system

- **with T↓ → $B_{trapped}$ ↑**
- **B > 17T, @ 29 K**



Durrell et al., SC. Sci. Tech. 2014

Outline

- **LFV using bulk HTS – verification experiment**

FC magnetisation

Y-Ba-Cu-O Bulk HTS
Diameter   46 mm
Thickness 16 mm

FC magnetisation

Y-Ba-Cu-O Bulk HTS

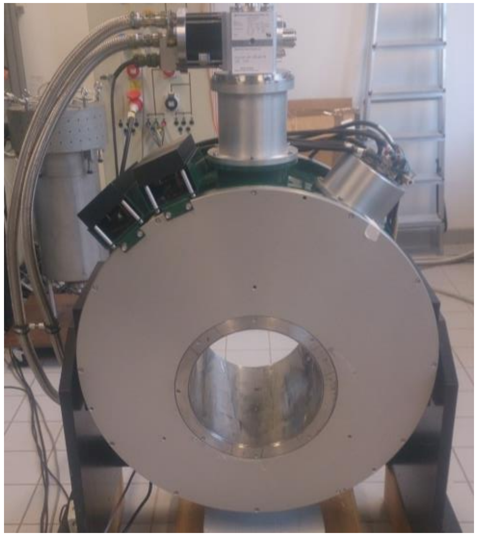
Diameter 46 mm

Thickness 16 mm

Superconducting Solenoid

bore 300 mm

B_{ap} = 1.5 T



FC magnetisation

Y-Ba-Cu-O Bulk HTS
Diameter 46 mm
Thickness 16 mm

Superconducting Solenoid
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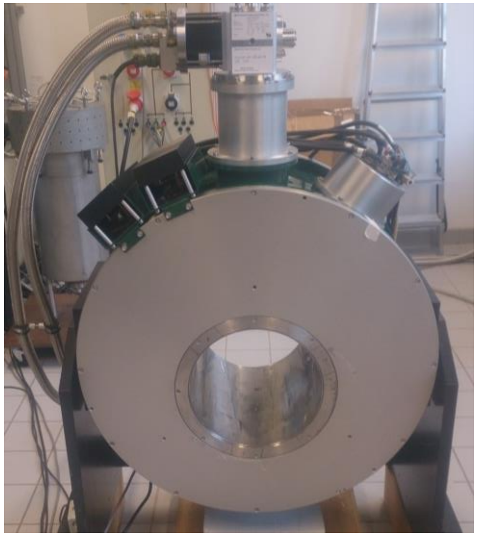
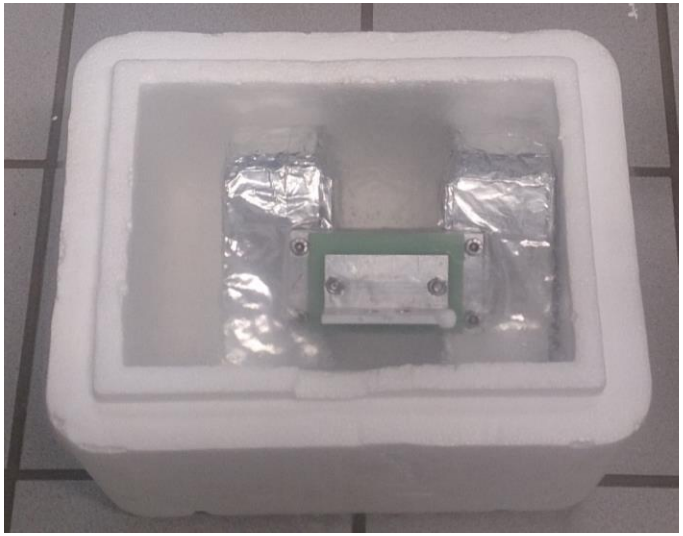
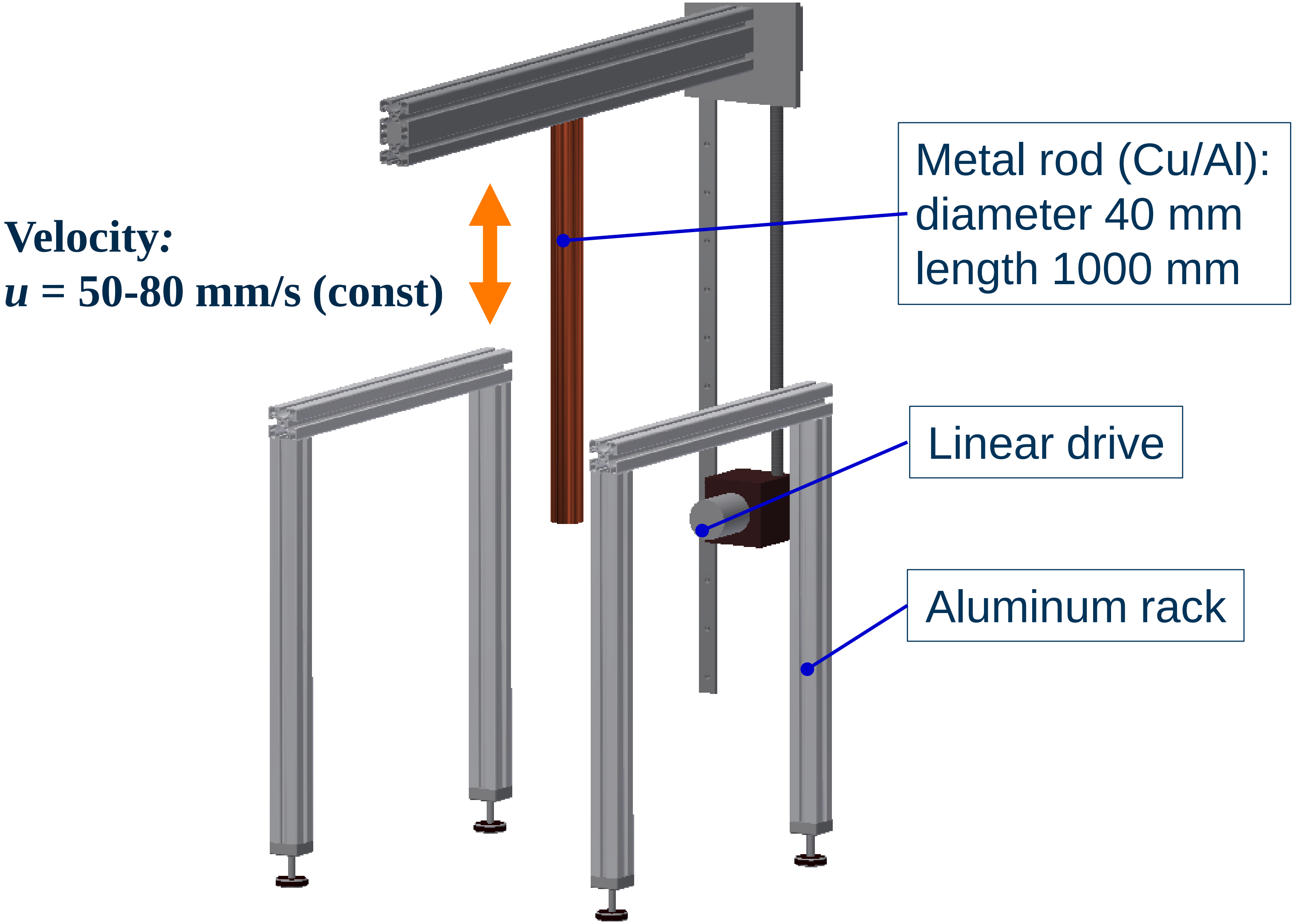


Cooling with LN_2

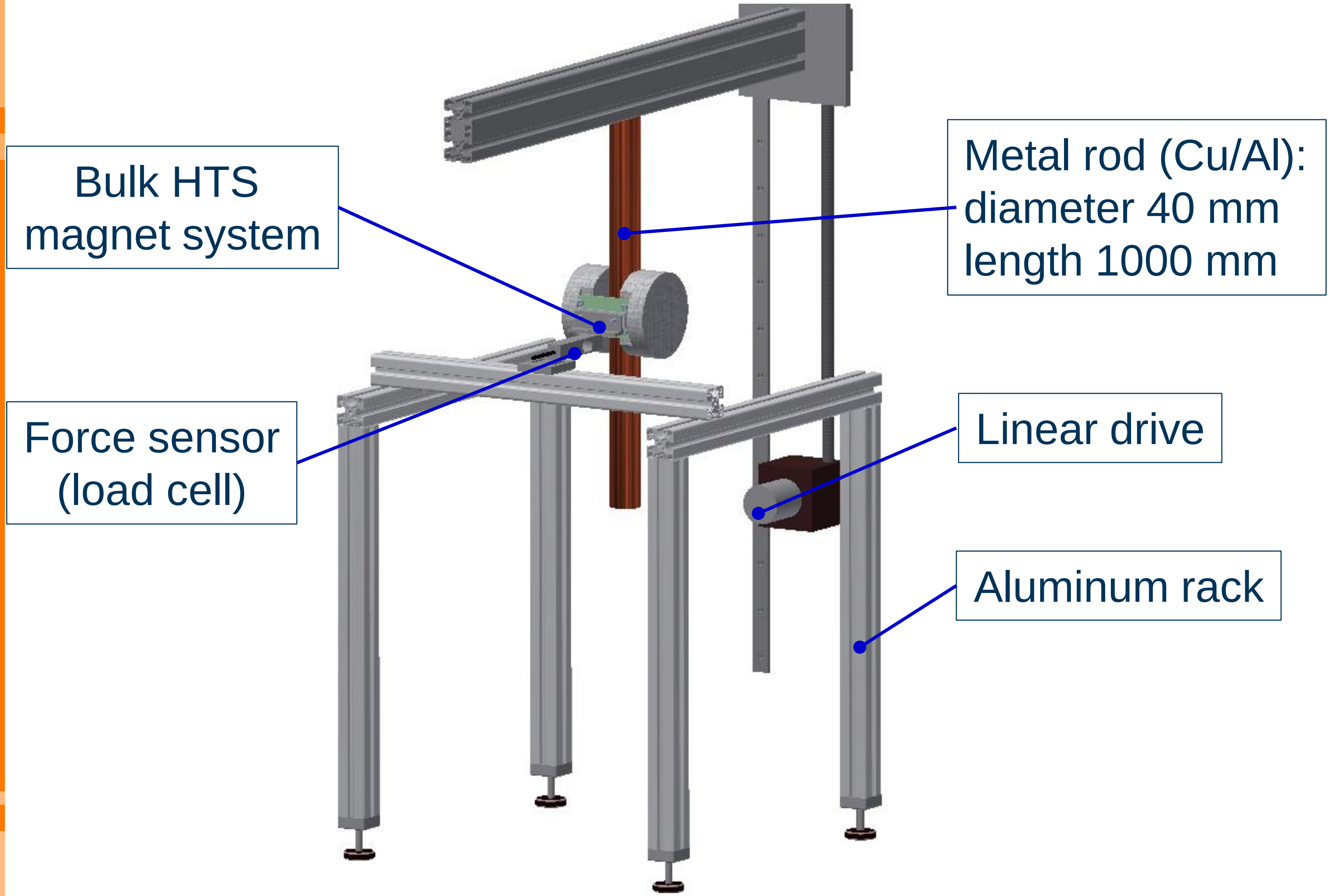
77 K



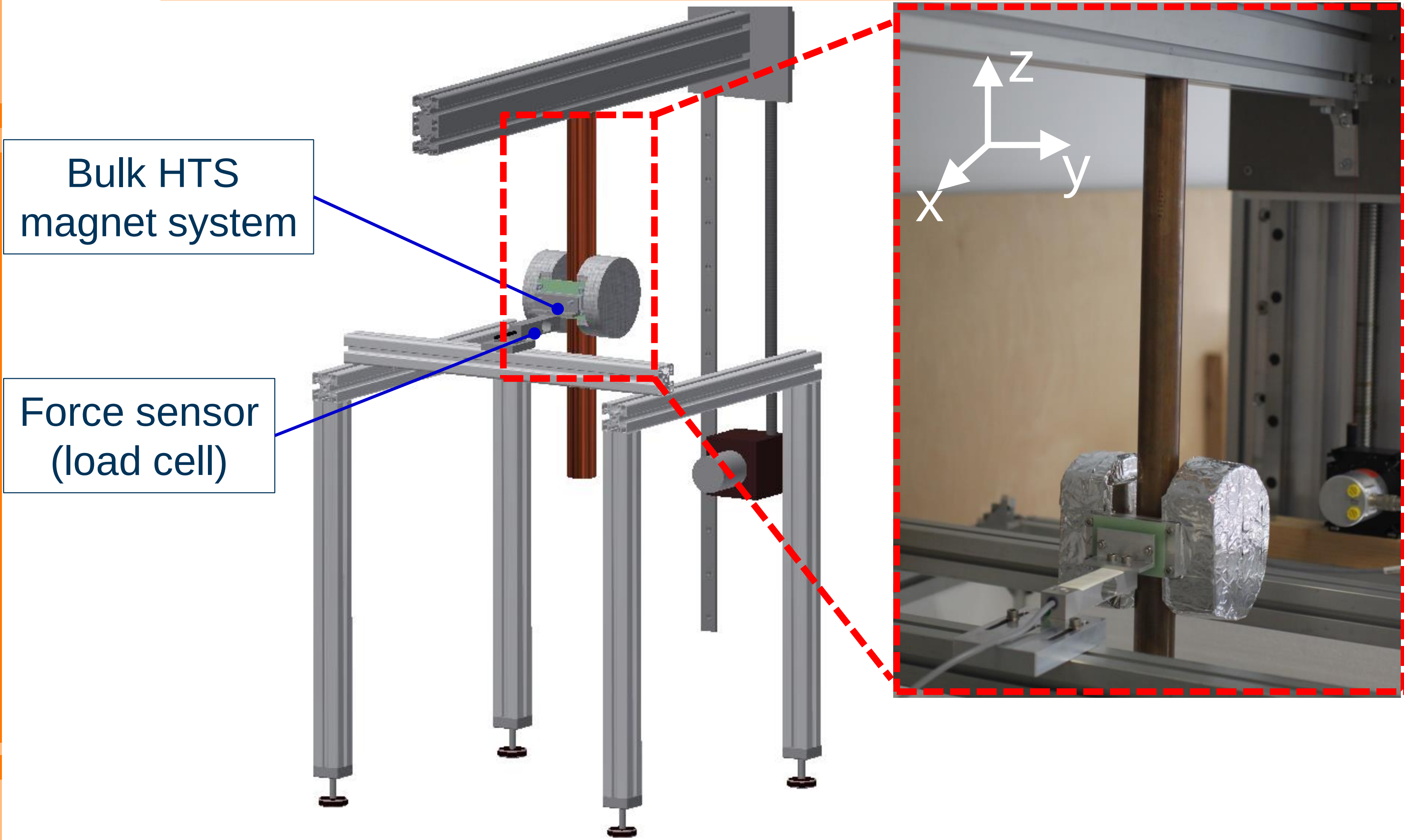
Experimental Setup



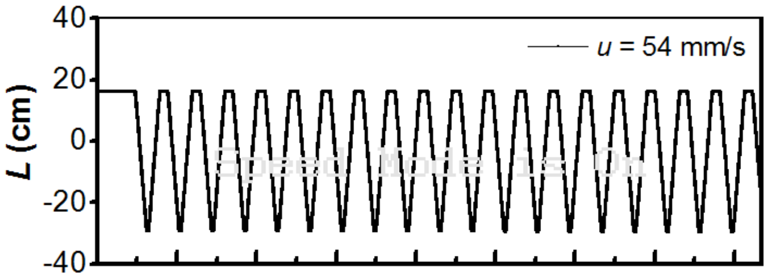
Experimental Set-up

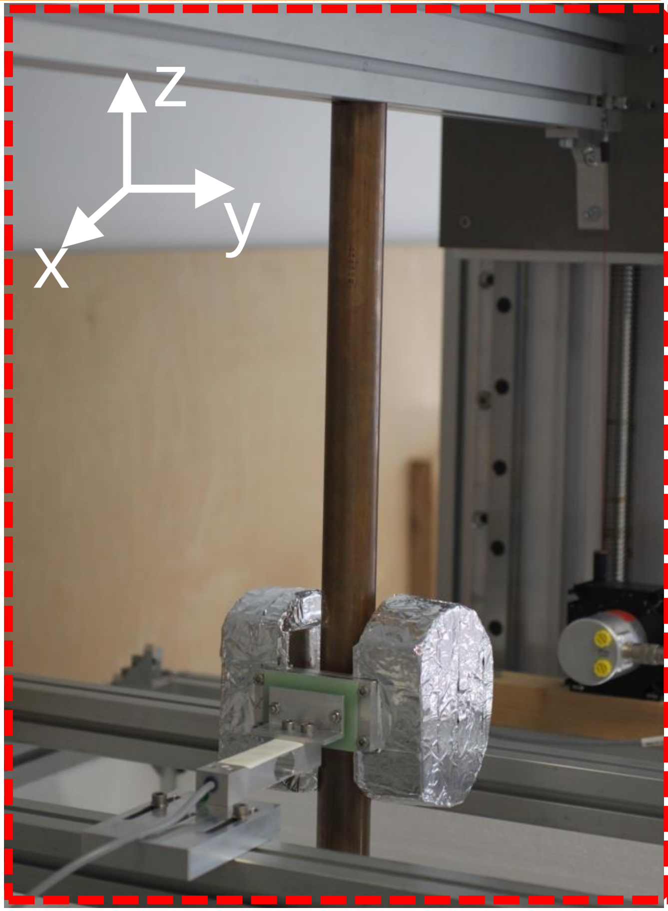


Experimental Set-up



Experimental Set-up





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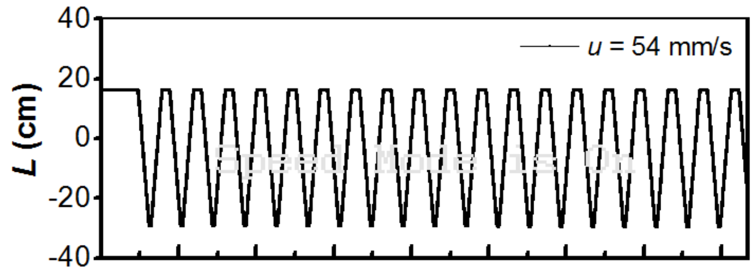

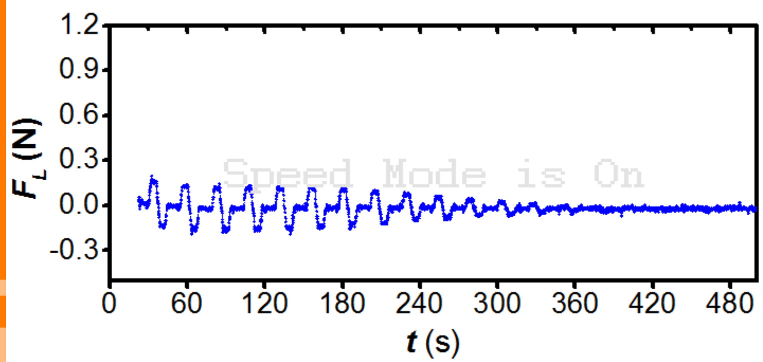

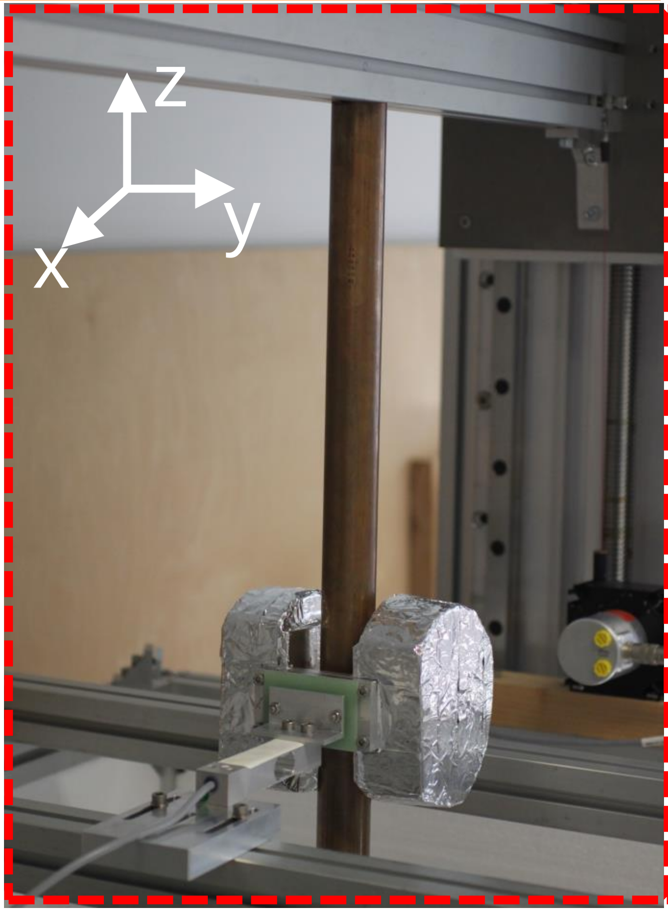

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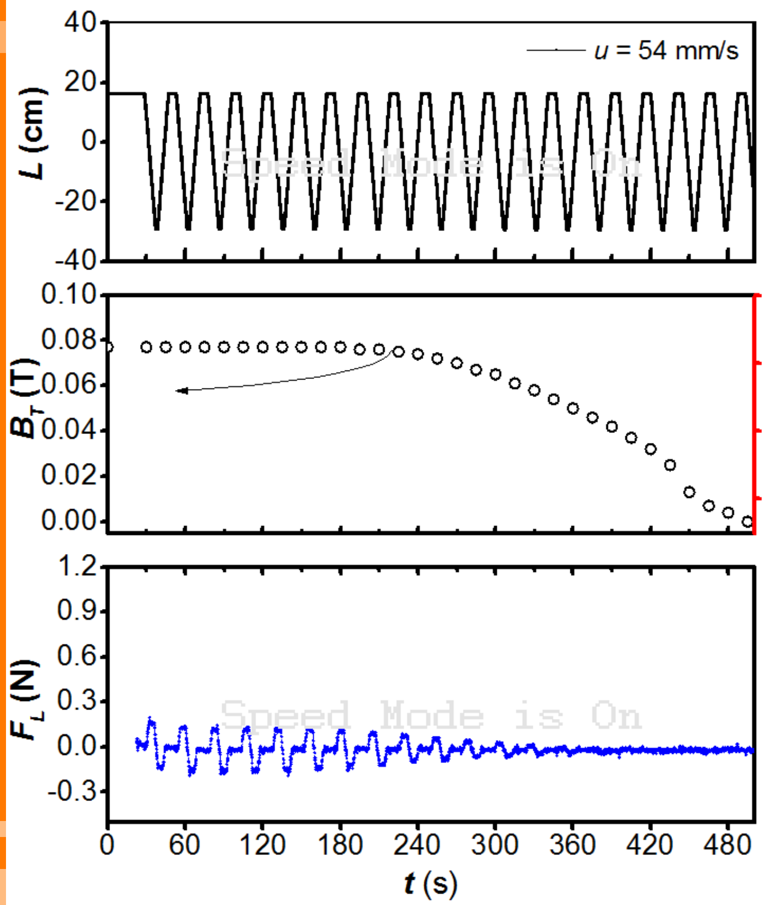

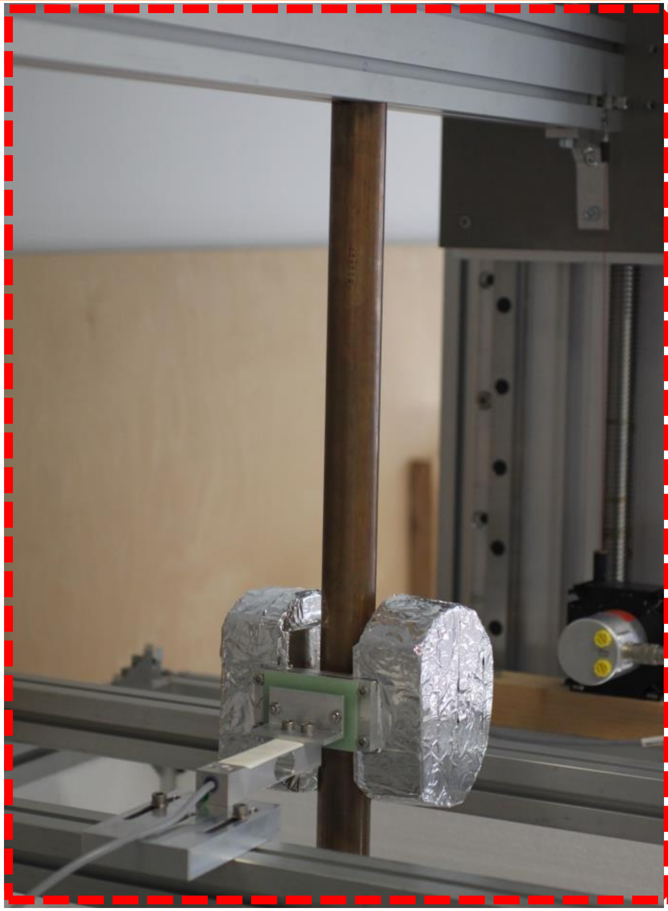

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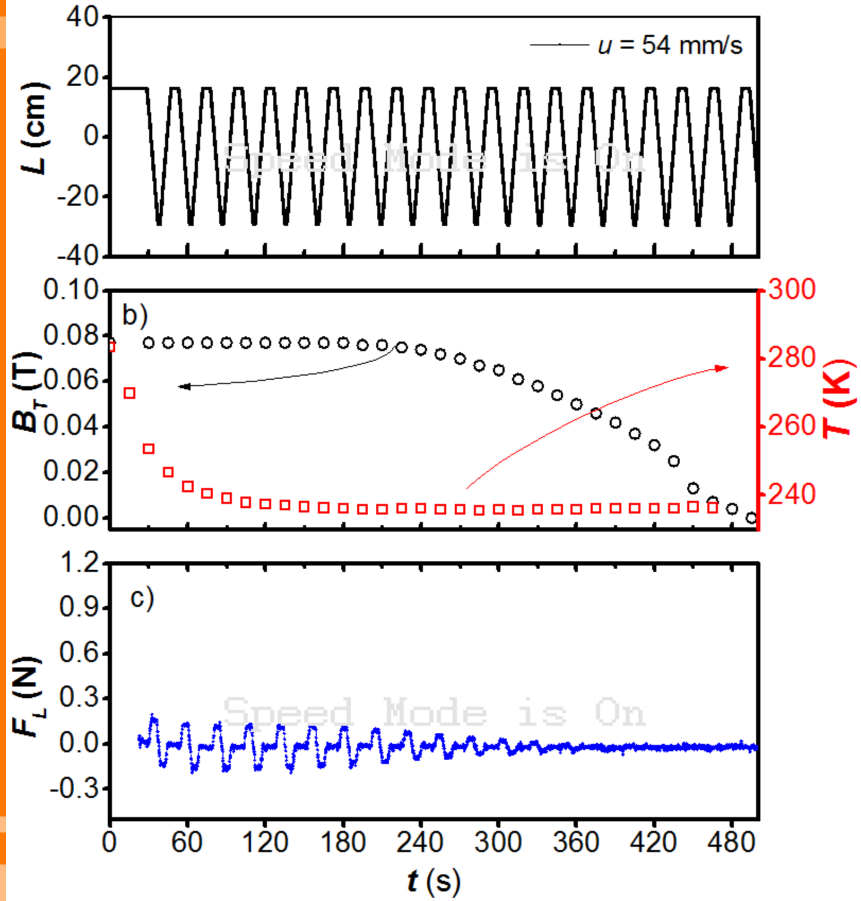

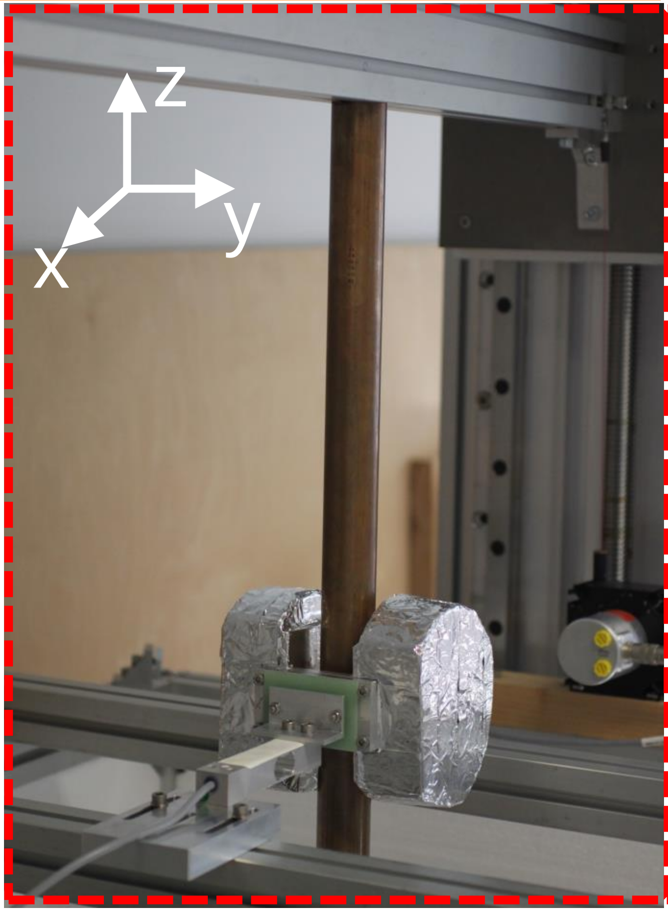

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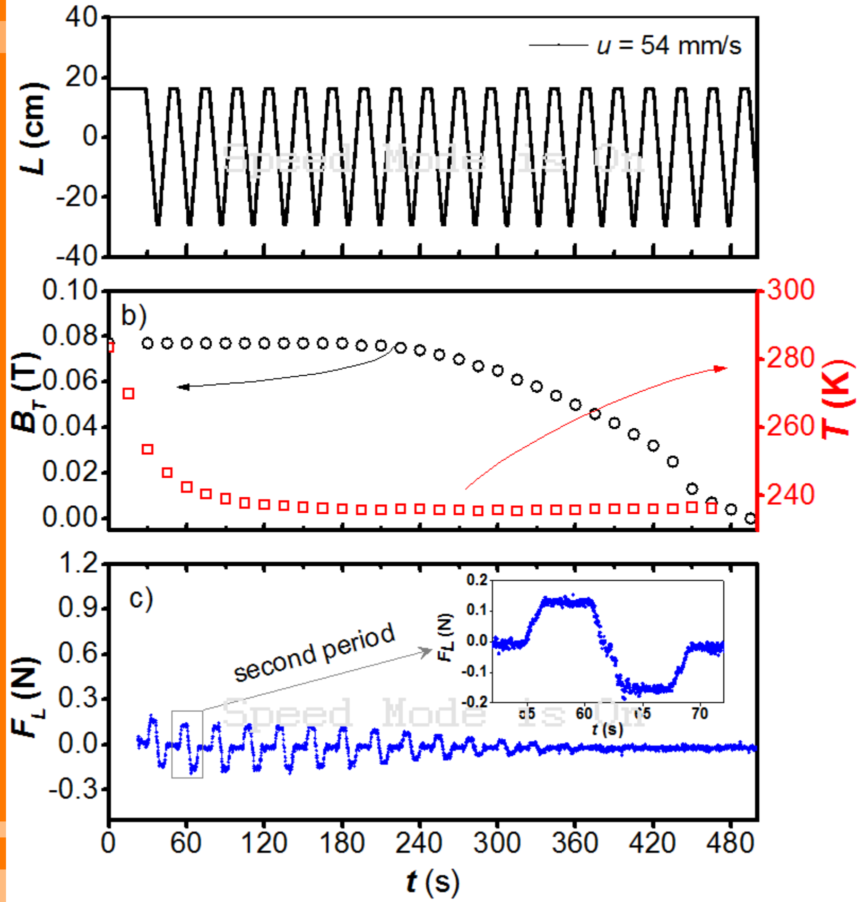
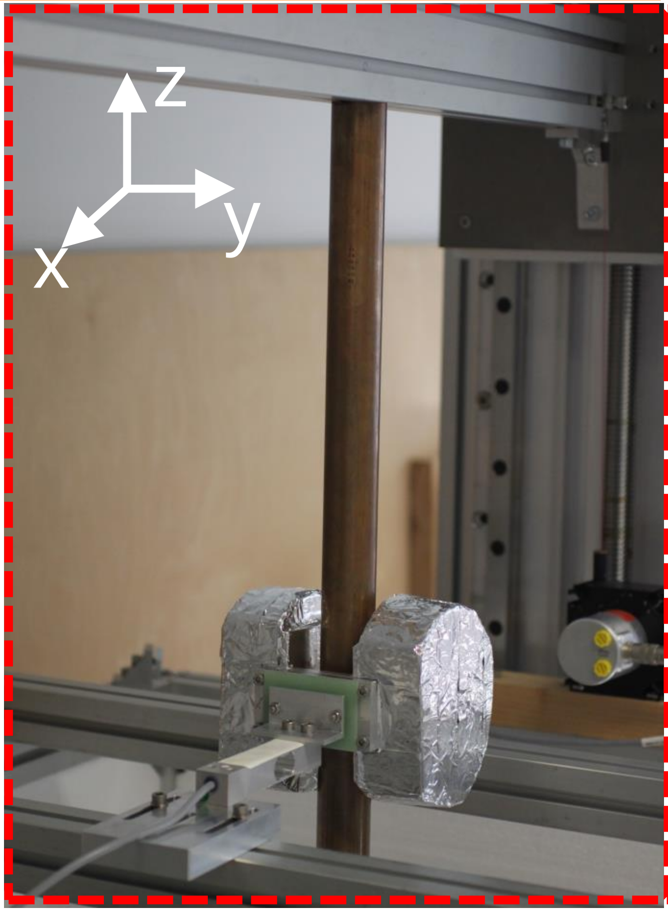




Outline

- **LFV using bulk HTS – model**

Numerical Modelling

General comments

Bulk HTSc

- 3D model
- H-formulation
- Time-independent
- Full magnetisation

Metal rod

- Solid Body Approximation [1]
  - replace the **flow** with moving **metal rod**
  - low-Re-number: R<<1
  - $F_L \sim u; u$ is mean velocity

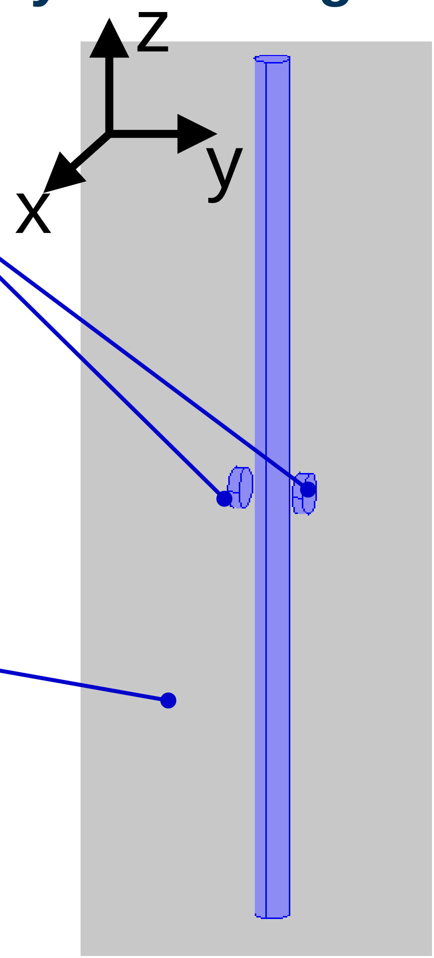
Comsol 5.3a

1. Alferenok et al, Meas. Sci. Tech., Vol. 24, pp. 065303, 2013

Numerical Modelling

Geometry & FC magnetisation

Y-Ba-Cu-O Bulk HTS
Diameter   46 mm
Thickness 16 mm



Metal rod (Cu/Al):
diameter 40 mm
length 1000 mm

! Corresponds to an expeimental setup

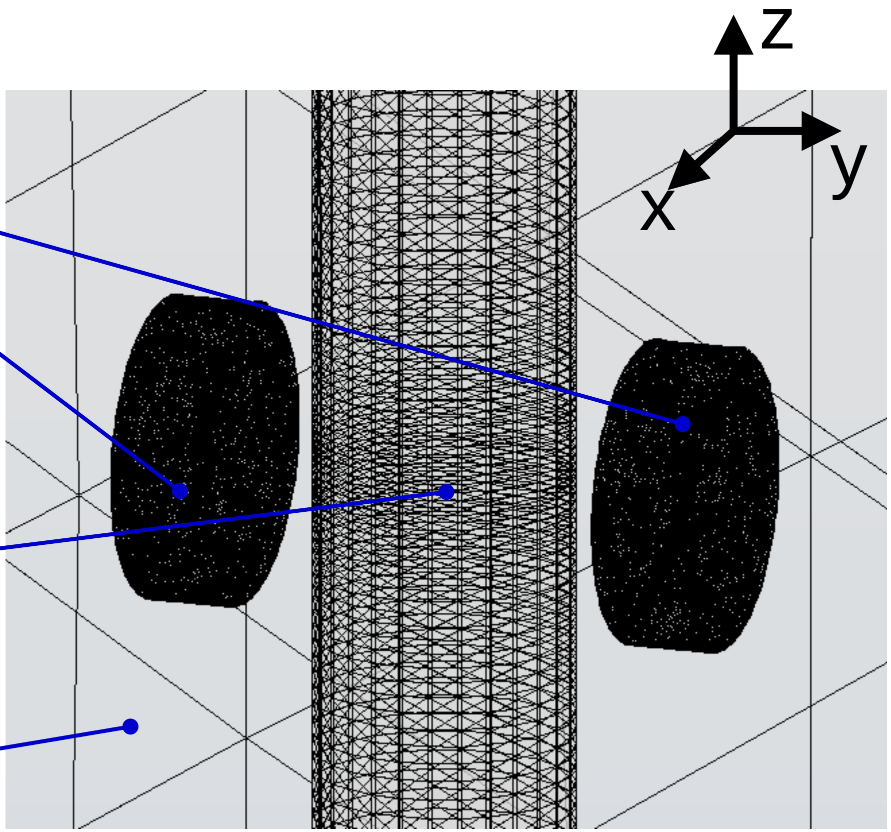
Numerical Modelling

Mesh

Bulk HTS
Tetrahedral: size 1 mm

Metal rod:
Triangular: size 5 mm
- dense near bulk HTS

Space
Tetrahedral: size 100 mm



Numerical Modelling

Govering equations:

Ampers law $$\nabla \times \boldsymbol{H} = \boldsymbol{J}$$

Current conservation $$\nabla \cdot \boldsymbol{J} = 0$$

Bulk HTS: Bean Model

$B_{T,1}$= 1.08 T

$B_{T,2}$= 0.80 T

- J_c=const
- T =const
- full magnetised

$$B_T = k \mu_0 J_c a$$

$$k = \frac{t}{2a} \ln\left(\frac{a}{t} + \sqrt{1 + \left(\frac{a}{t}\right)^2}\right)$$ [1]

$J_{c,1}$= 9.90x10^7 A/m^2

$J_{c,2}$= 7.33x10^7 A/m^2

1. Carwell et al., AIP., 1992

Numerical Modelling

Govering equations: Moving metal rod

Velocity condition (Lorentz force)

$$\boldsymbol{J} = \sigma(\boldsymbol{E} + \underline{\boldsymbol{u} \times \boldsymbol{B}})$$

$$\boldsymbol{f} = \boldsymbol{J} \times \boldsymbol{B} = \sigma(\underline{\boldsymbol{u} \times \boldsymbol{B})} \times \boldsymbol{B}$$

$$\boldsymbol{F} = \int_V F_x \cdot dV = \int_V \left(B_z J_y - B_y J_z \right) \cdot dV$$

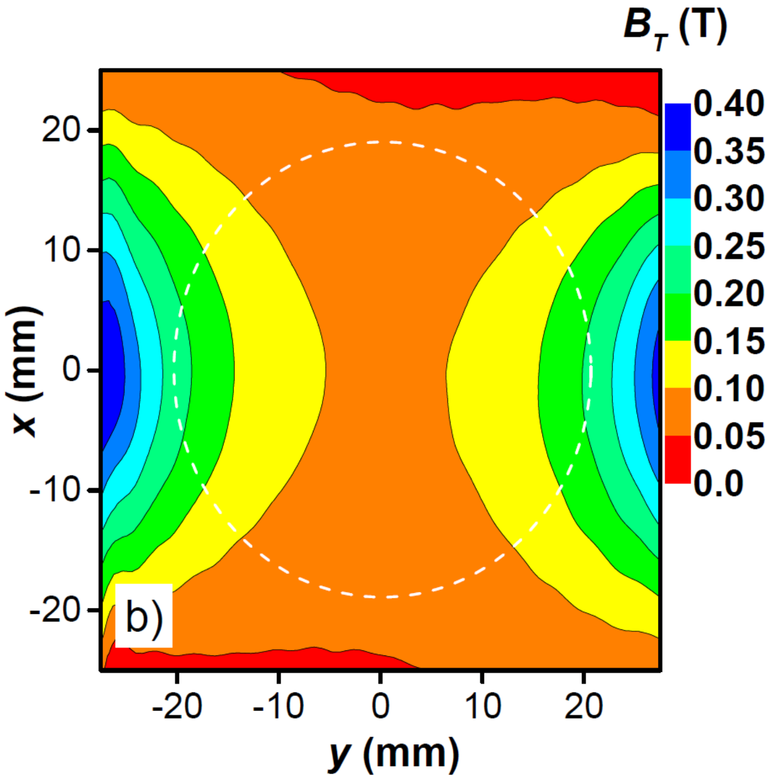
Outline

Results

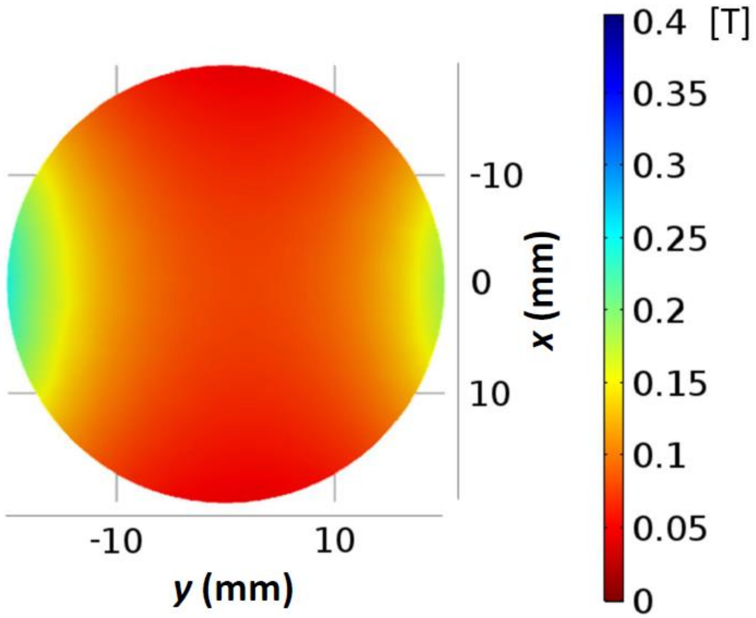
Results

B_T - map in the bulk HTS magnet system gap

Experiment



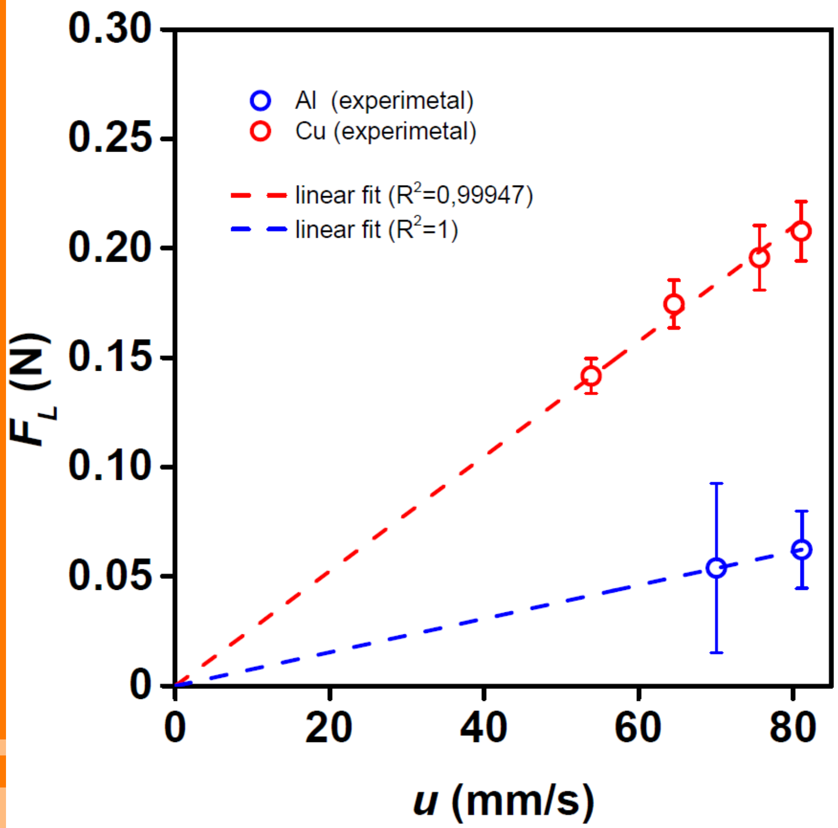
Model



Vakaliuk, O. et al., SUST., Vol. 31/8, 2018

Results

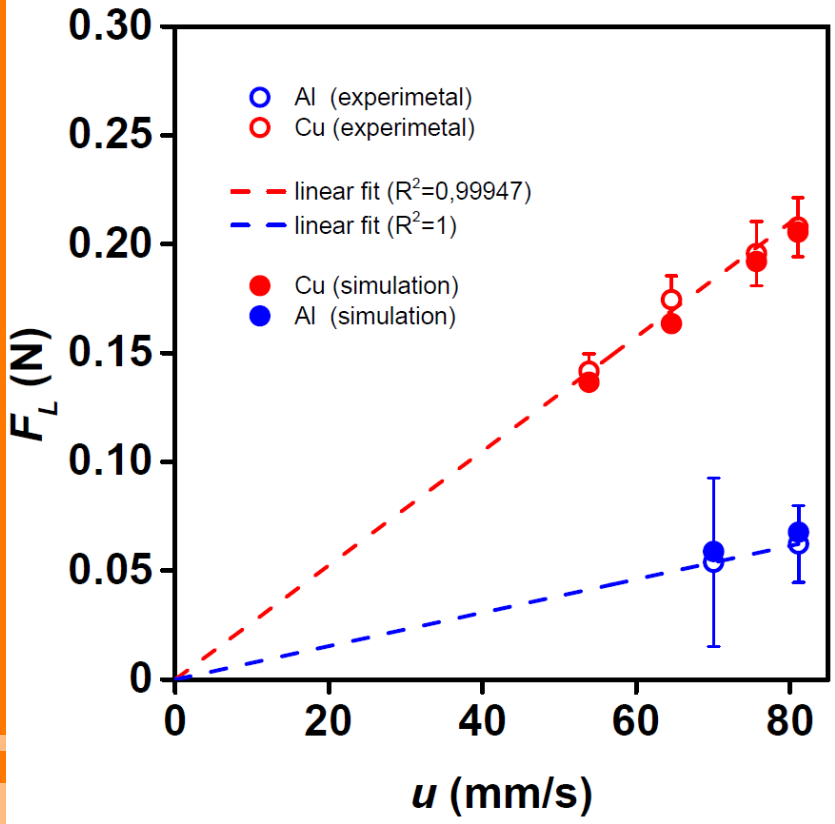
Lorentz Force *vs.* velocity



- $F_L \sim \sigma \cdot u$
- $F_{Cu}/F_{Al} = \sigma_{Cu}/\sigma_{Al}$

Results

Lorentz Force *vs.* velocity

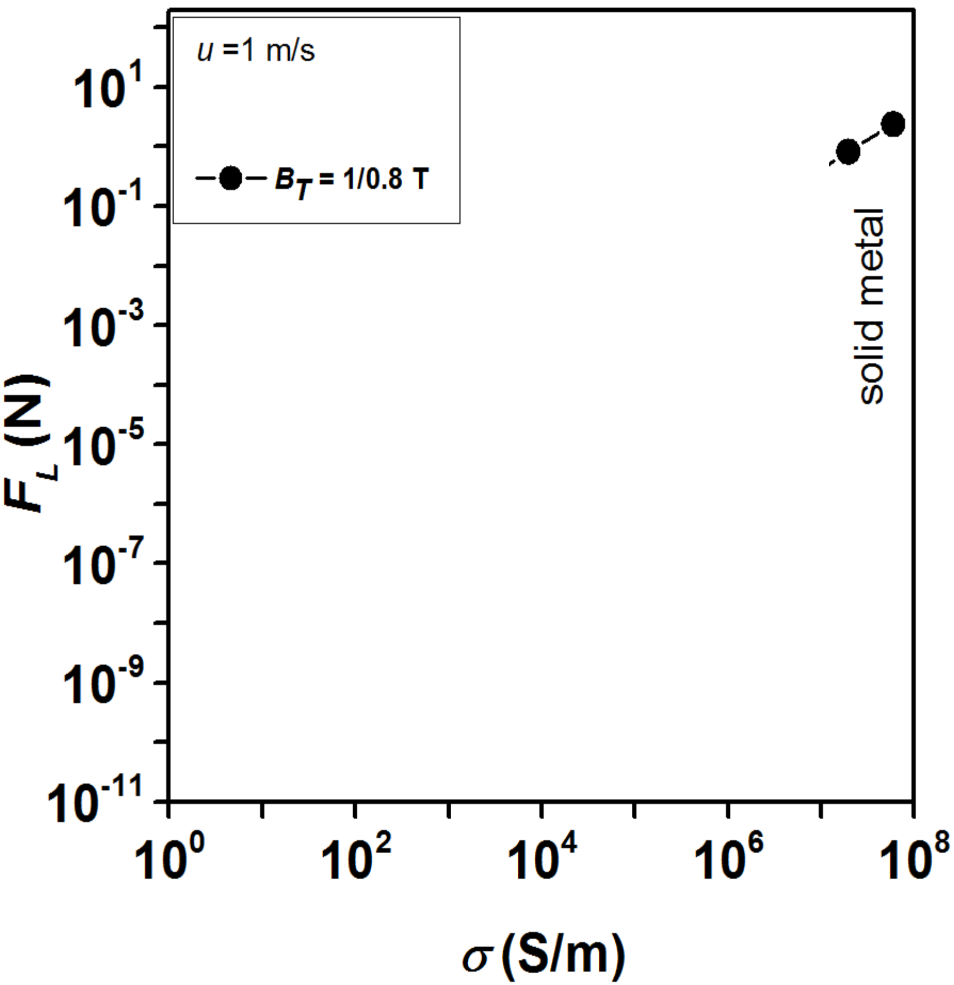


- Experiment & simulation agree well

Results

Predicted Lorentz forces for electrically conducting fluids

Example: particular LFV design



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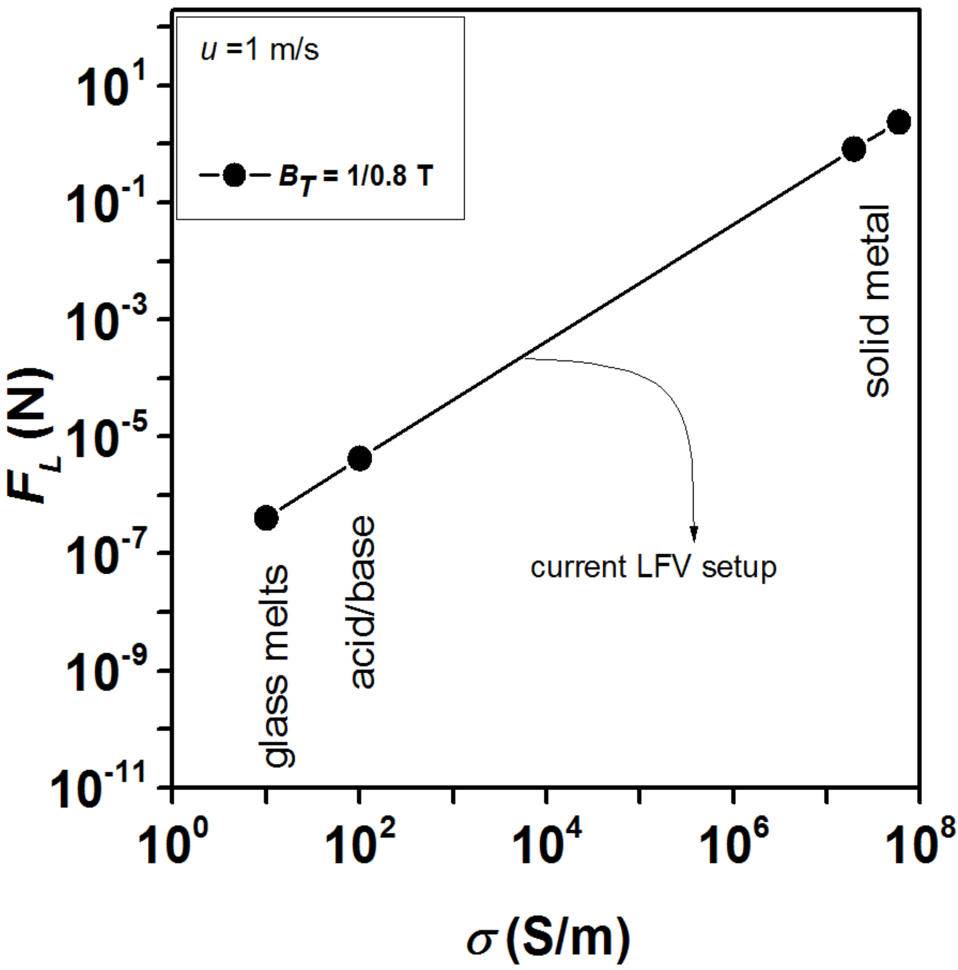
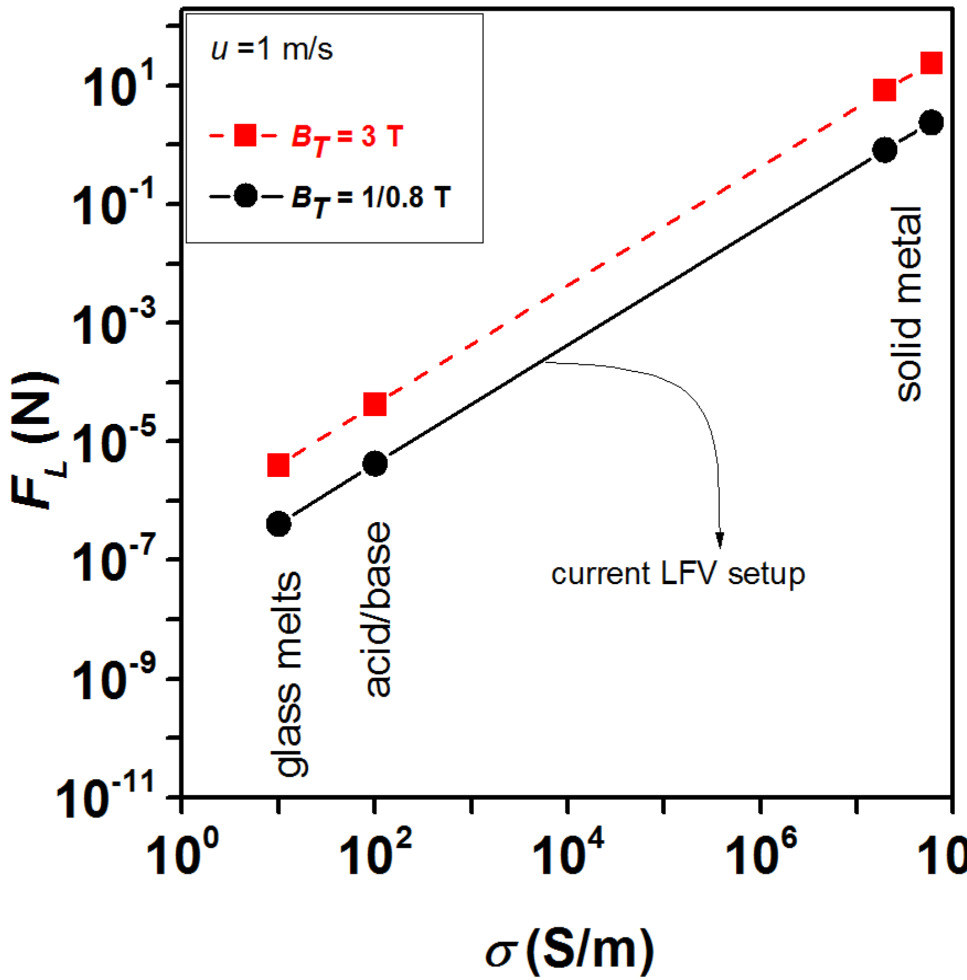
Results

Predicted Lorentz forces for electrically conducting fluids



Results

Predicted Lorentz forces for electrically conducting fluids



Vakaliuk, O. et al., SUST., Vol. 31/8, 2018

Results

Predicted Lorentz forces for electrically conducting fluids

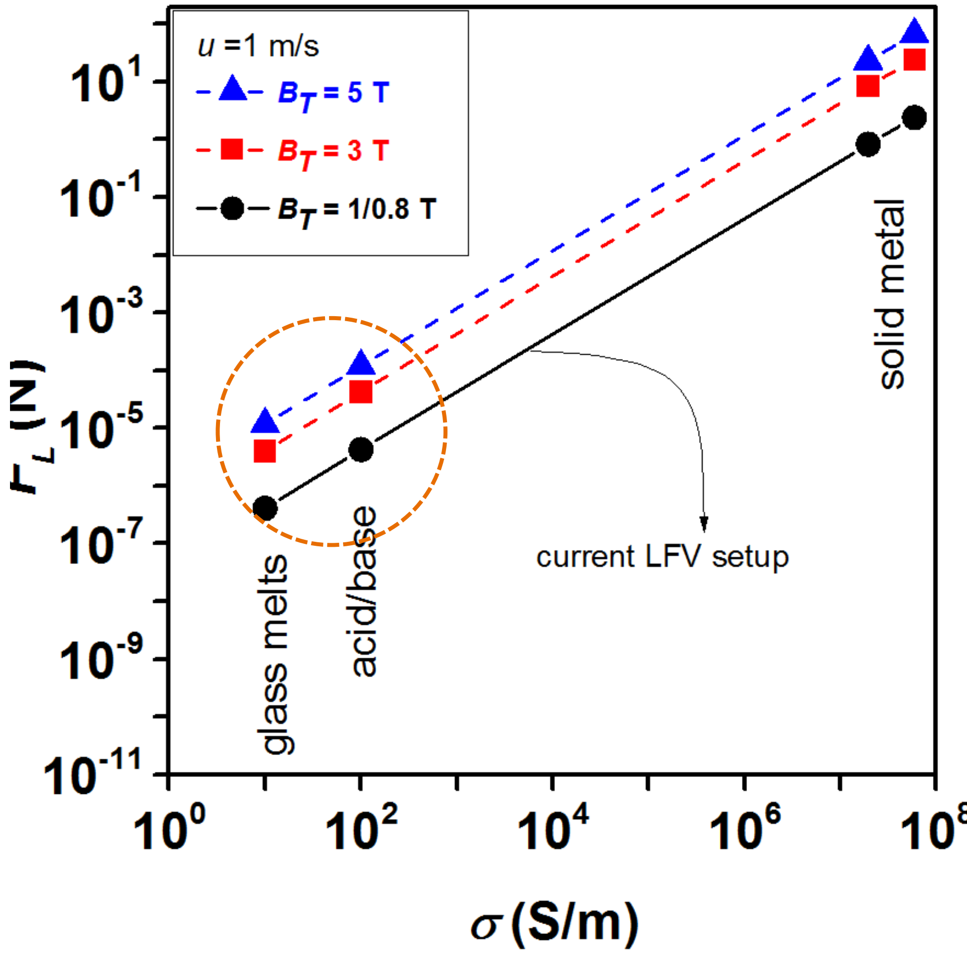
Simulation:

- 3D Model
- Time-indepedent

Outlook:

- time-dependent model
  - flux creep
  - magnetisation (PFM)

- **conductive fluid flow**



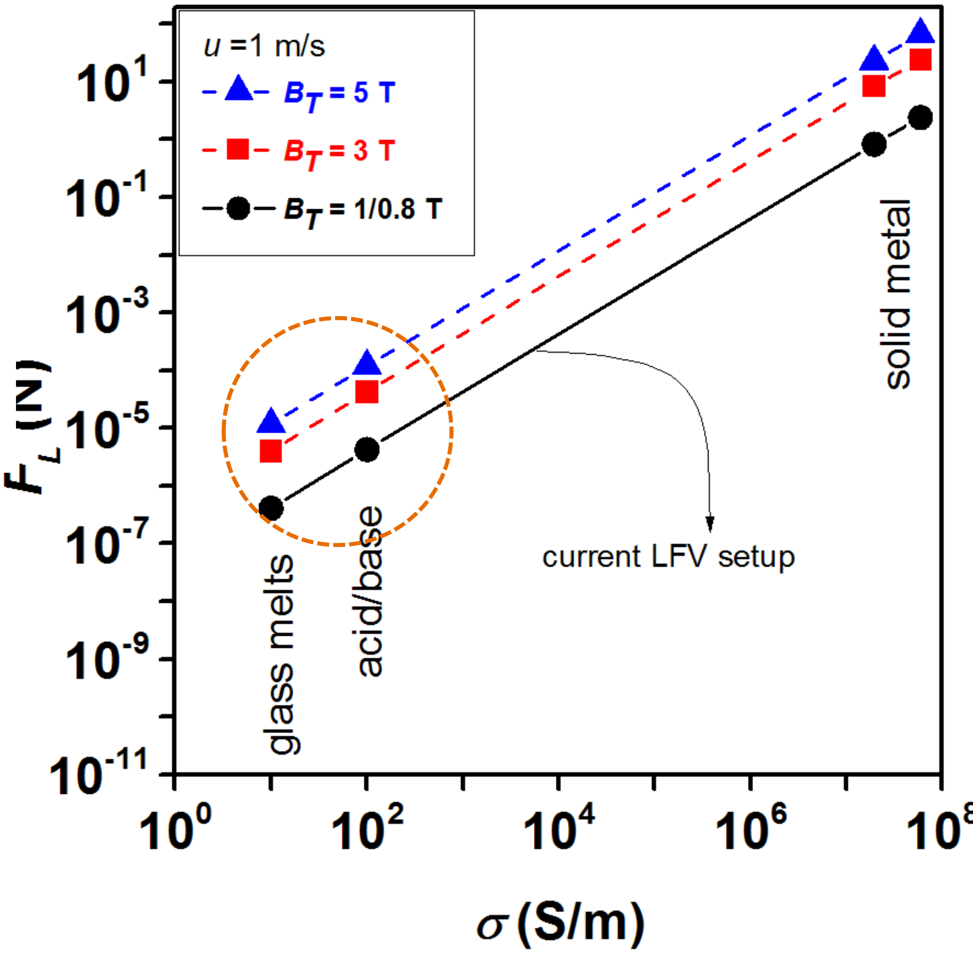
Vakaliuk, O. et al., SUST., Vol. 31/8, 2018

Results

Predicted Lorentz forces for electrically conducting fluids

Experimental challenge:

- **Precision force measurements**
- **Bulk HTS**



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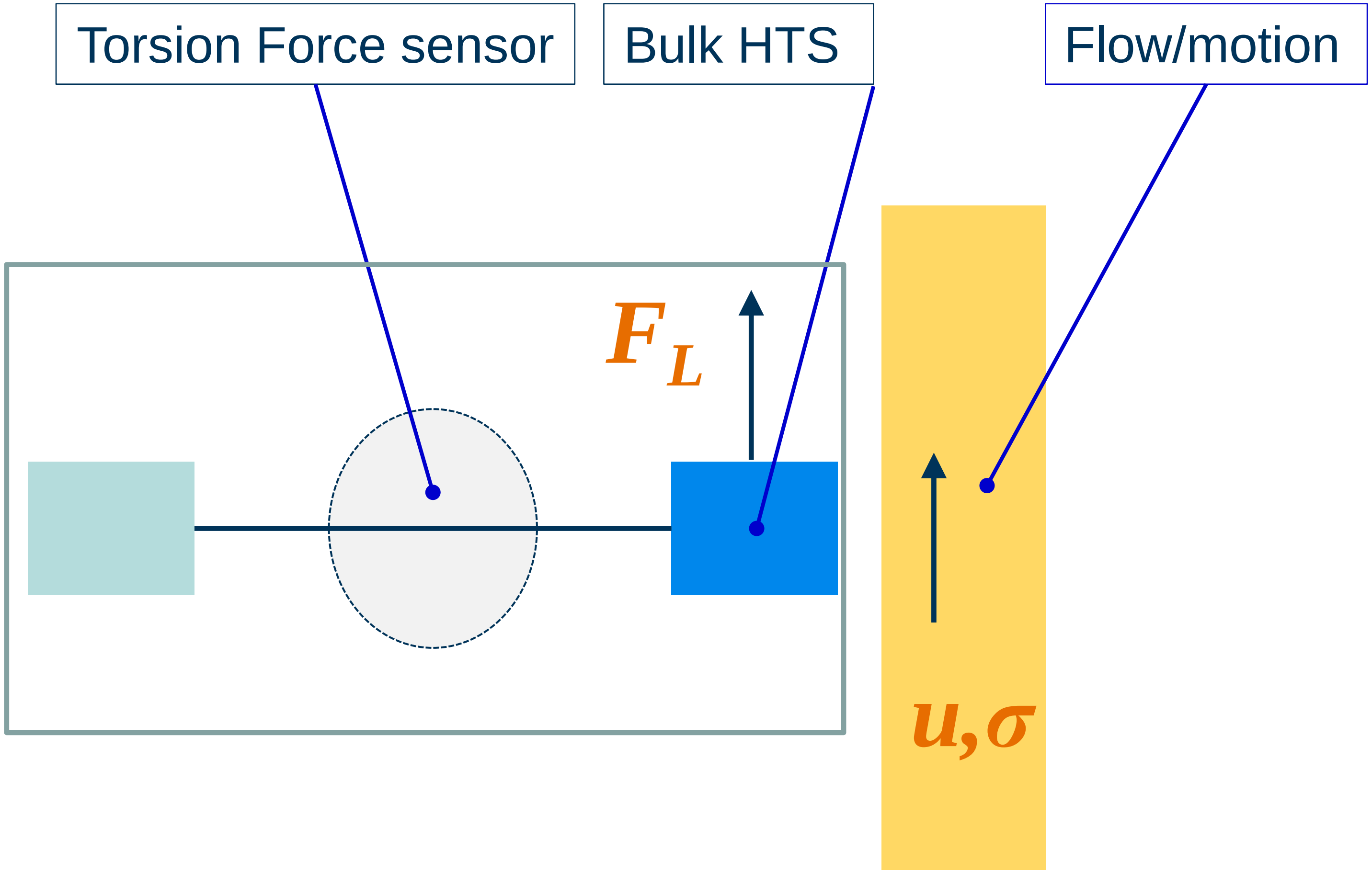
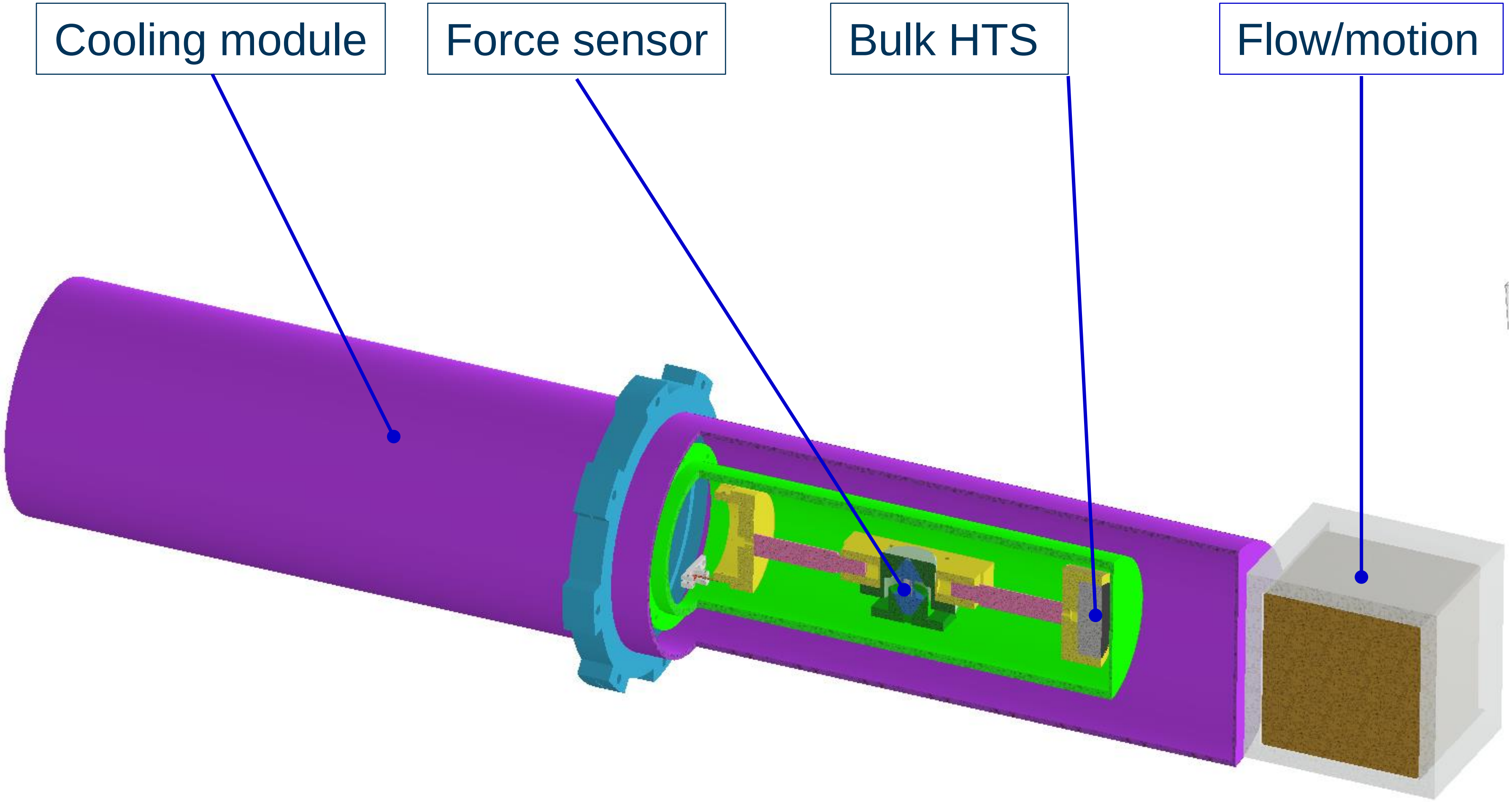
Integrated Cryostat: Idea

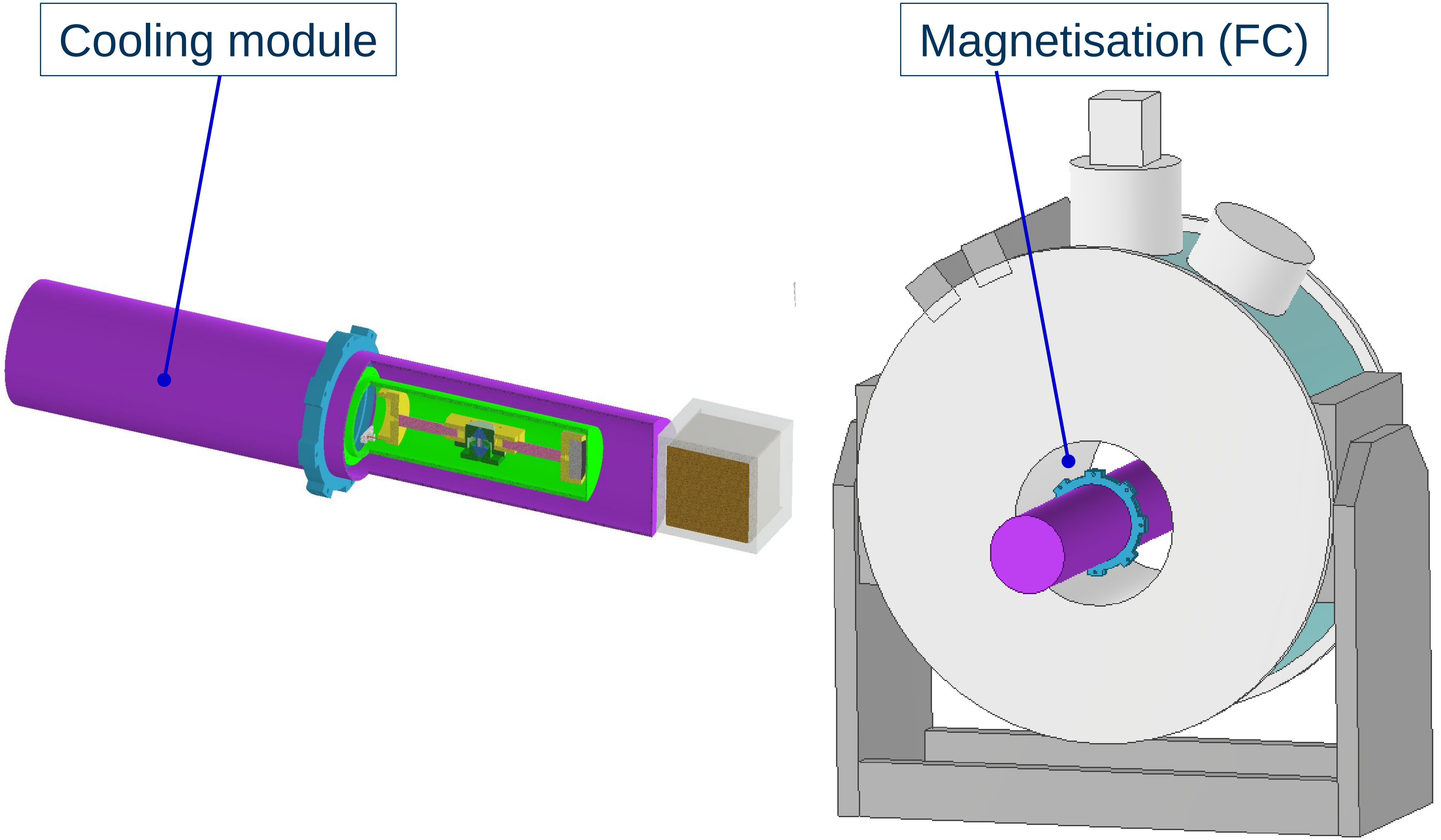


DE 10 2017 010 786.3, Vorrichtung zur Ermittlung von Parametern elektrisch leitfähiger Substanzen und dazugehöriges Verfahren.
B. Halbedel, O. Vakaliuk, Th. Fröhlich, N. Yan, **30.05.2017**

Integrated Cryostat: Idea

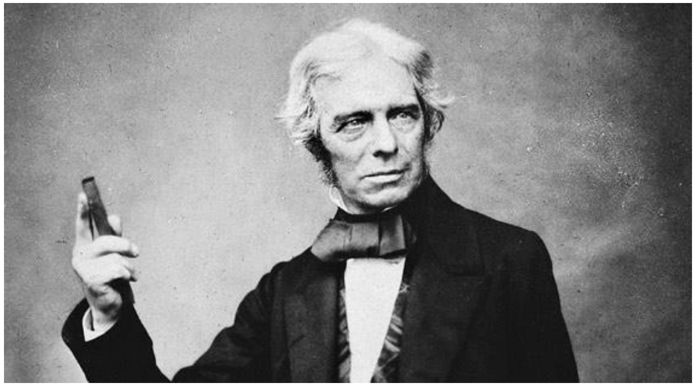


Integrated Cryostat: Idea



LFV: could occur in XIX

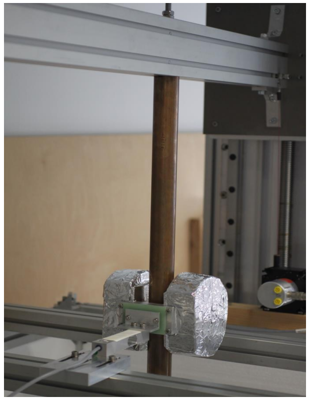
1832 – Faraday: measured velocity of the Thames River by measuring the electric potential difference induced by its flow across Earth's magnetic field lines



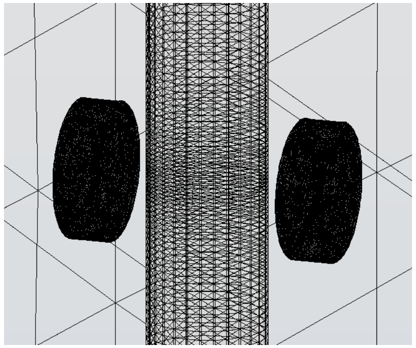
1798 Cavendish's force measurement technology

Summary

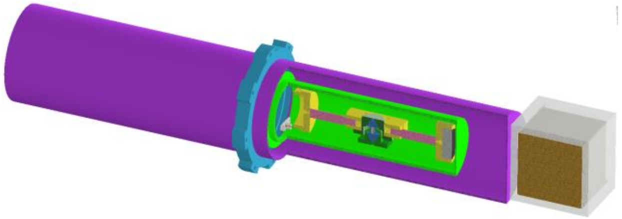
Evidence of Lorentz Force Velocimetry using bulk HTS as magnets source



Validation of nummerical model
Prediction of the LFV performance



Conceptual design for portable LFV meter



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Lorentz force velocimetry using a bulk HTS magnet system: proof-of-concept

O V Vakaliuk[1], M D Ainslie[2] and B Halbedel[1]

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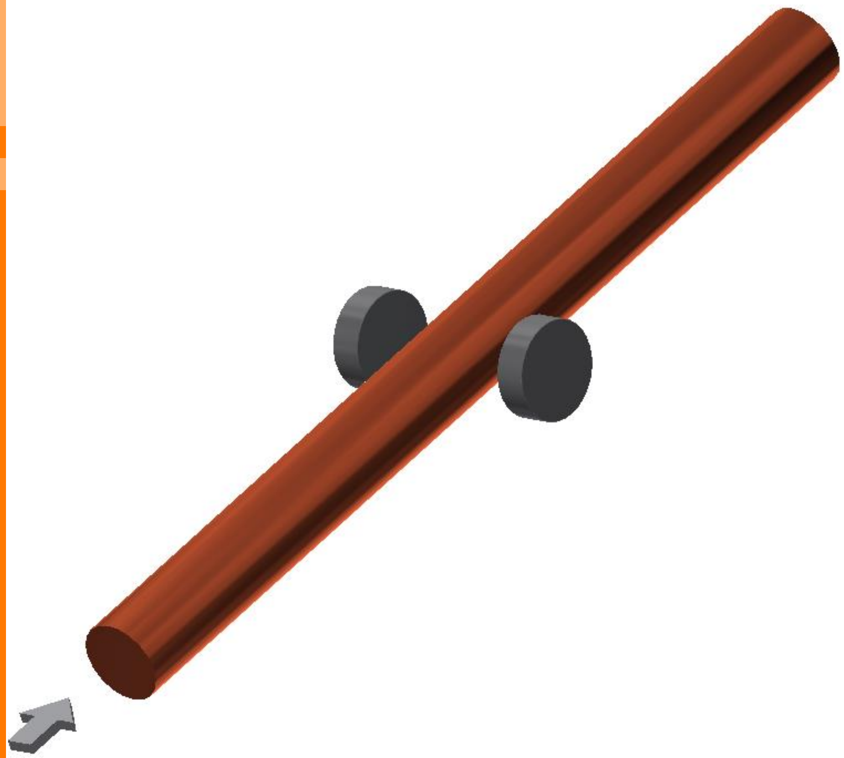
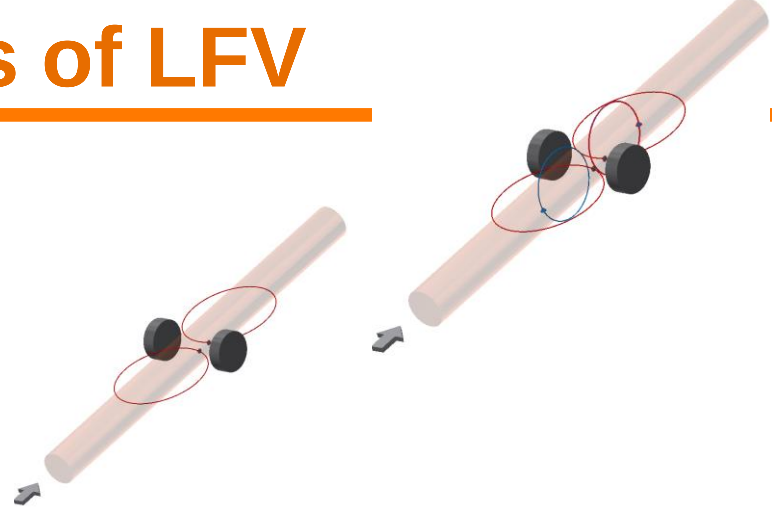
Focus on The Jan Evetts SUST Award 2018

THANK YOU FOR LISTENING!

Fundamentals of LFV





$$\vec{F}_L = (\vec{j}_w \times \vec{B}) \cdot V$$

$$\vec{j}_w = \sigma \cdot (\vec{u} \times \vec{B})$$

F_L - Lorentz force
σ - electric conductivity
u - velocity
j_w - density of eddy currents
B - magnetic flux density
V - measuring volume

DE 10 2005 046 910 B4, Thess, A. et al.

Thess, A. et al., *Lorentz Force Velocimetry*. PRL 96, 164501, 2006

Thess et al., *Theory of the Lorentz force flowmeter*. New J. Phys 2007

Results

B_T - map in the bulk HTS magnet system gap