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Session E14 New devices and Novel concepts

All polymer cryogen free cryostat for µ-MRI application at clinical field

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Outline

- **M**agnetic **R**esonance **I**maging
- **S**upraSense **P**roject : **µ-MRI** application at clinical field
- Cryostat design
- Realization of the cryostat
- Cryogenic tests
- First MR images
- Conclusions

Magnetic Resonance Imaging (1/2)

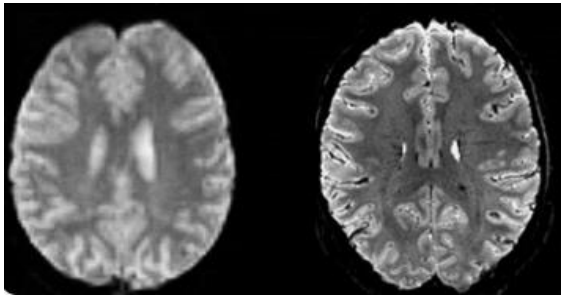
- **Noninvasive imaging technique**, used on a daily basis in medical practice to obtain functional and quantitative information

- Diagnostic for cancerology, neurology, angiography…
- Magnetic field from 1.5 to 3 T
- Resolution of 1 mm^3 with passive or active antennas

- For **volume study improvement**: Higher magnetic field, field stability and spatial homogeneity
  - Brain structural studies, cognitive sciences and neurobiology…

Clinical study

3 T 7 T



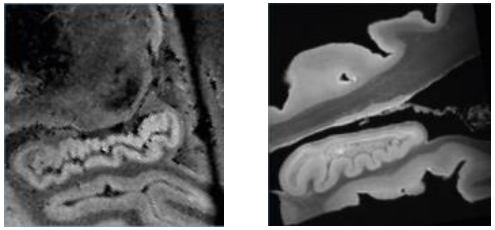
Human brain

Expected resolution 0.01 mm

Whole-body 11,7 T MRI magnet under construction at CEA Paris-Saclay

Pre-clinical study

7 T 11 T

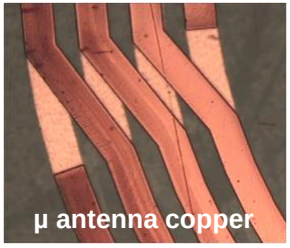


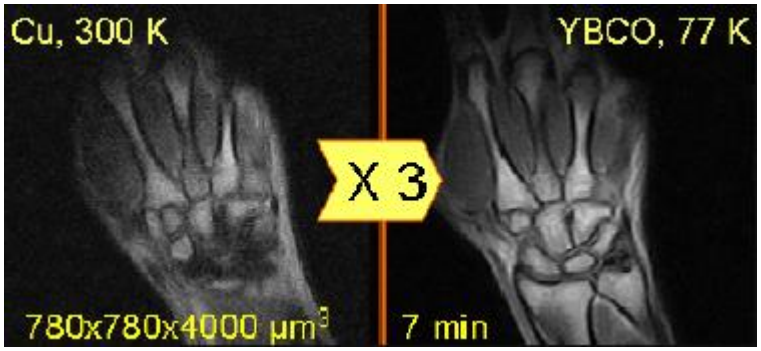
Mouse hippocampus (brain)

Magnetic Resonance Imaging (2/2)

- For **surface study**: Higher antennas excitation and signal-to-noise ratio and reduction of the distance between the antennas and the patient
  - Dermatology, arthritis, osteoporosis, atherosclerosis, cancerology, …

Human wrist

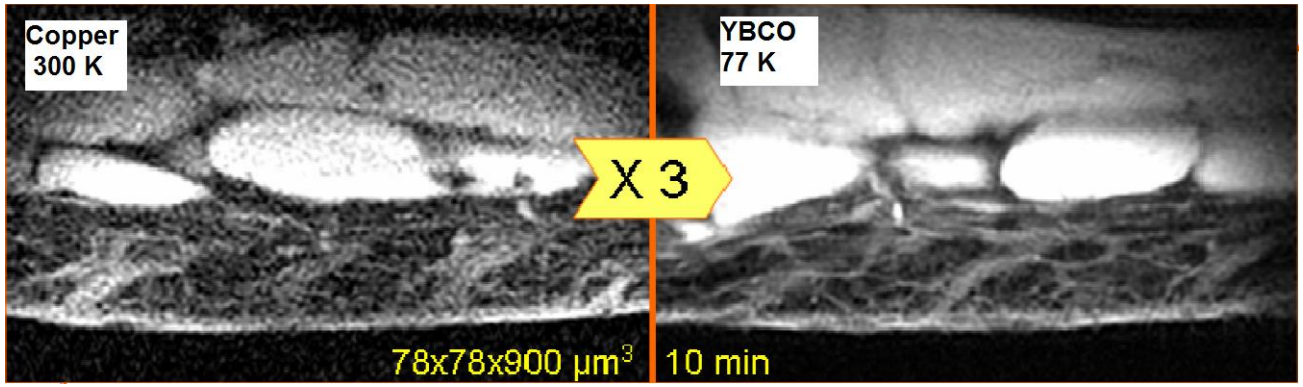




Penn, IEEE Trans Appl Supercond 9 (1999)

1.5 T Ø 1.2 cm

Epidermal carcinoma cancer



J.-C. Genefri, et al. Magn. Res. Med. 32 (2001)

0.15 T Ø 10 cm

The goals of the SupraSence project (1/2)

- **SupraSense project**
  - Improvement of the µ-MRI antennas
  - Construction of a “plug and play” cryostat

- Improving the measurement capabilities of **µ-MRI antennas** for surface imaging
  - Resonators in YBCO
  - 1 or several antennas
  - Temperature below 77 K
  - Activation/deactivation by HF loop
  - Distance between the antennas network and the patient below 5 mm

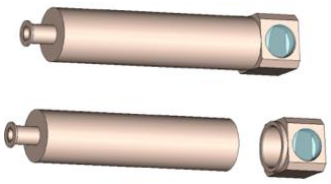
Miniature high-temperature superconducting (HTS) surface coil for in vivo micro-imaging of the mouse in a standard 1.5T clinical whole-body scanner

1.5 T
Ø 1.2 cm
YBCo
77 K

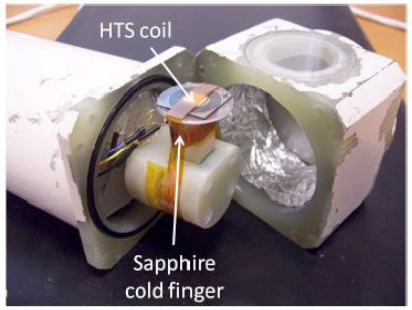
M. Poirier-Quinot et al., Mag. Res. Med. 60 (2008)

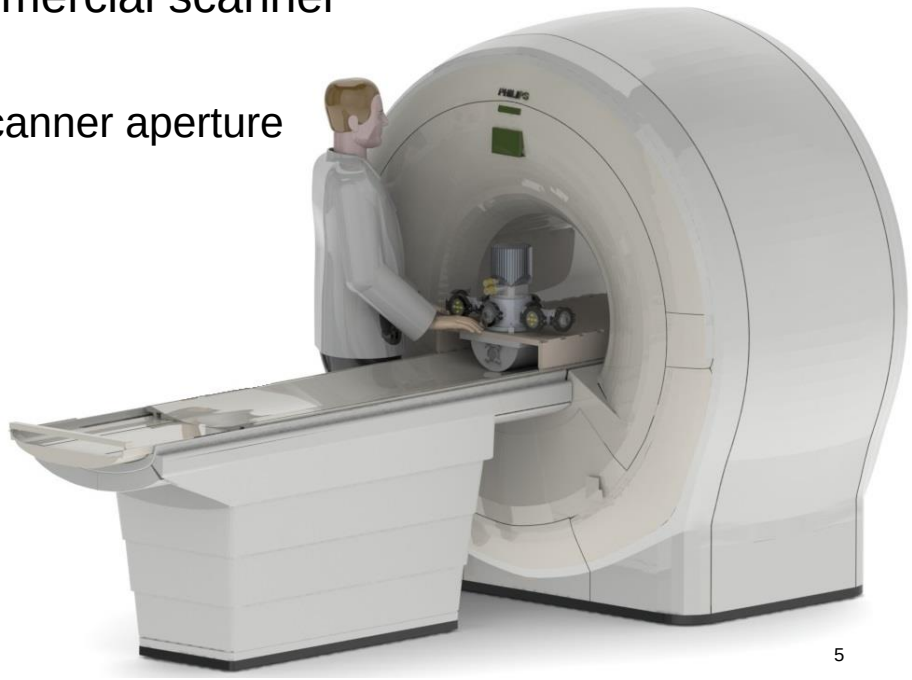
The goals of the SupraSence project (2/2)

- Construction of a µ-MRI antennas cryostat
  - **Non-magnetic cryostat**
    - Minimizing the effect on the MRI magnetic field
    - Minimizing the effect on the antennas magnetic field
  - Temperature of the superconducting coils (YBCO): 60 ± 0.5 K
  - Cold surfaced : 6400 mm²
  - No cryogenic fluid →"**Cryogen-free" system**
  - « Plug & Play » system → **"Cryogenist-free" system**
- First version to be implemented in a commercial scanner
  - 1.5 Tesla in the room bore
  - Residual field 50 mT at 700 mm from the scanner aperture



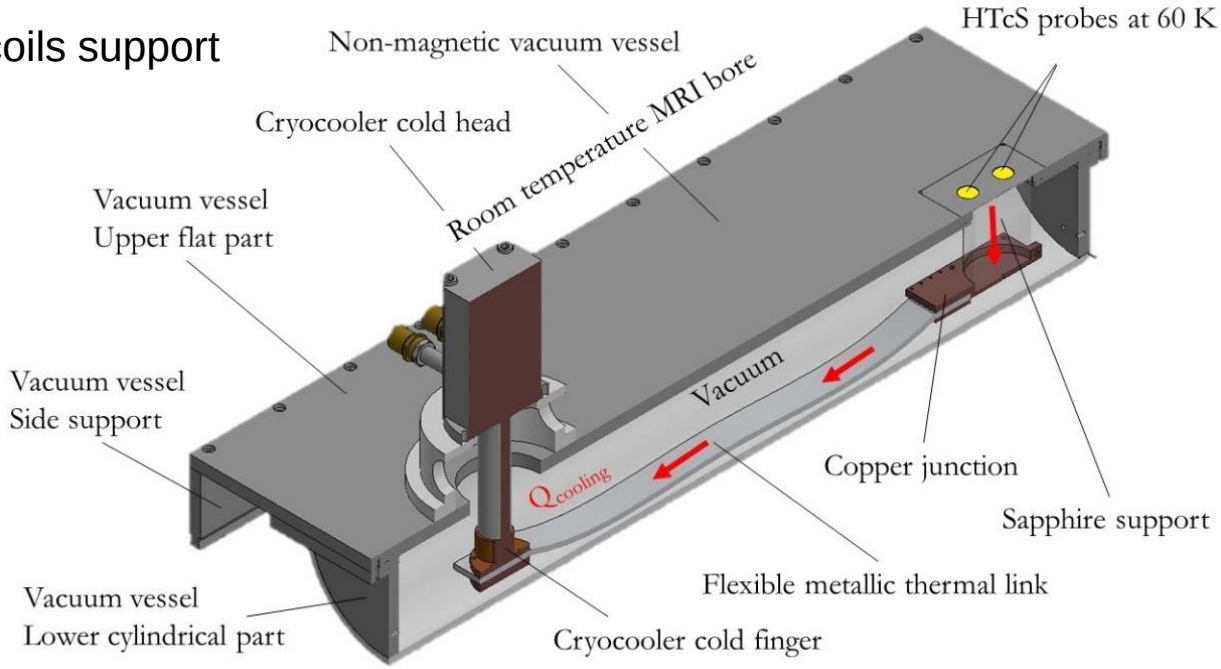
LN_2 G10 system





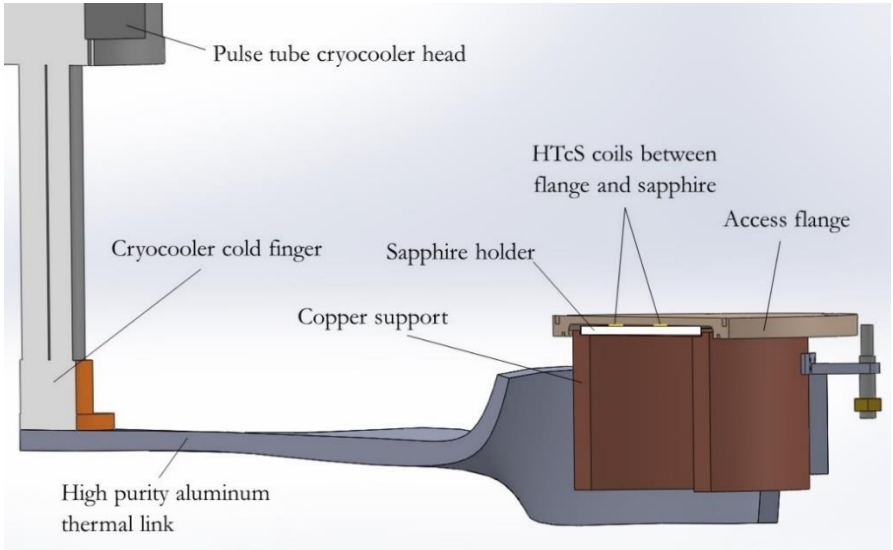
General layout

- Cold source : cryocooler
  - Remote motor and Air cooler
- Non-magnetic vacuum vessel to minimize the electromagnetic perturbations
  - Polymer material such as PEEK or PCTFE
- Solid thermal links
  - In metal up to 100 mm from the HTS coils
  - In sapphire for the HTS coils support



Thermal link

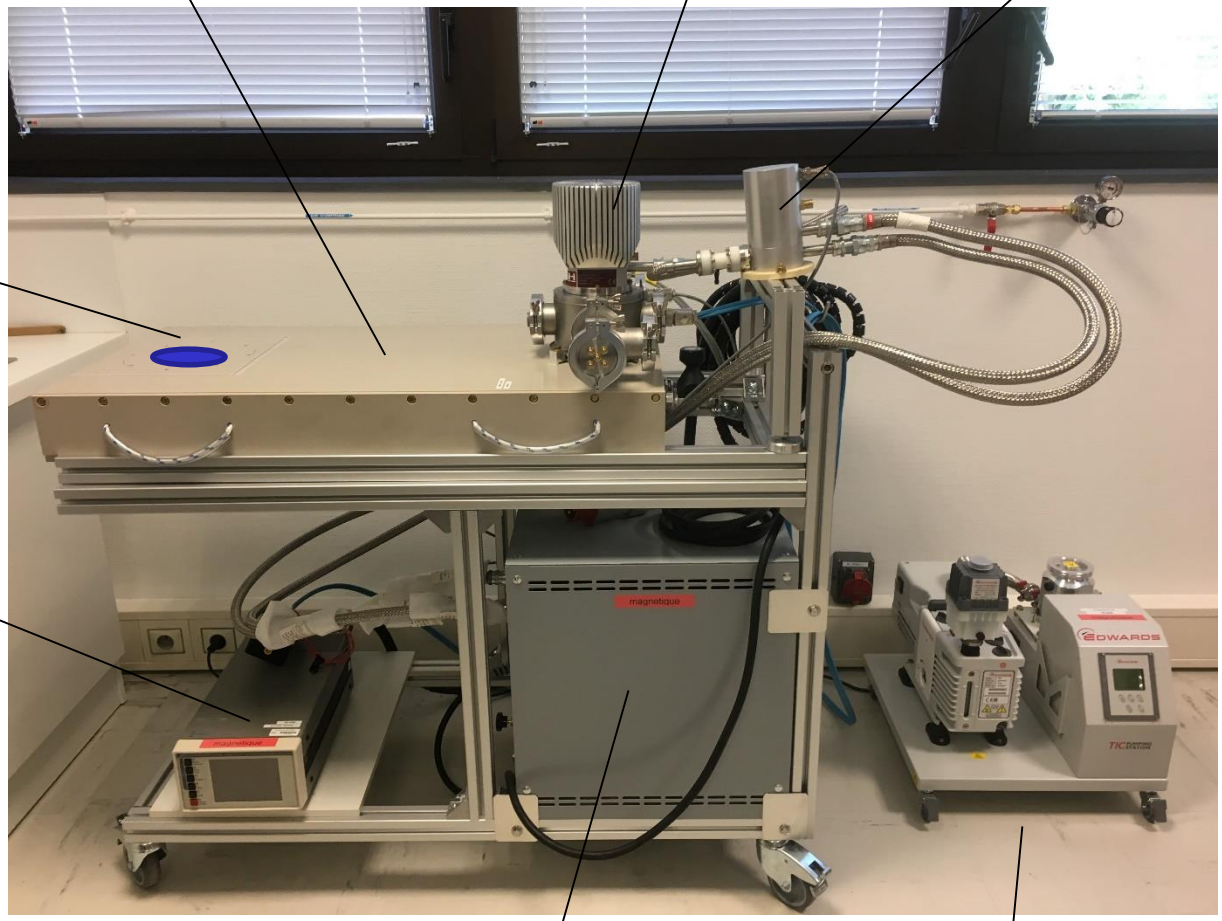
- HTS coils very sensitive to vibrations and cannot be too close to a metallic part
- Design ensure that no metallic part is within 100 mm from the coils
- Sapphire HTS coils older
  - Directly located on the sapphire cylindrical holder (λ=1000 W/m.K at 77 K)
  - Diameter of 150 mm and a height lower than 10 mm
- Large hollow cylindrical copper
  - Transferring the heat and keeping the coils below few mm from the access flange
  - Cu-OF (RRR=80) with λ=531 W/m.K at 77 K and 1.5 T
  - 70 mm high and the maximum thickness is 15 mm



G. Authelet G et al., 2017 IOP Conference Series: Materials Science and Engineering 278 012122 https://doi.org/10.1088/1757-899X/278/1/012122

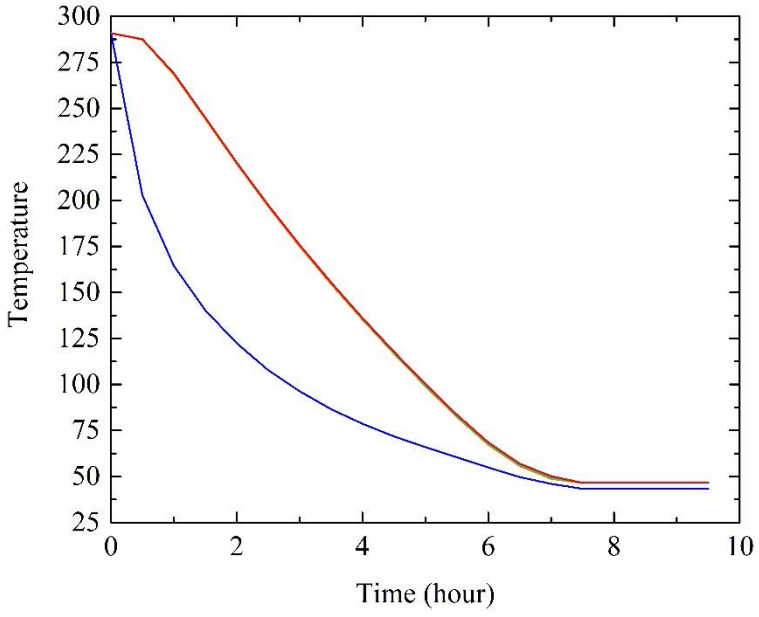
- Long thermal aluminum thermal link
  - 6N aluminum λ=424 W/m.K at 77 K and 1.5 T
  - Composed of several flexible rectangular sheets 700 mm long

All polymer cryostat



Cryogenic tests

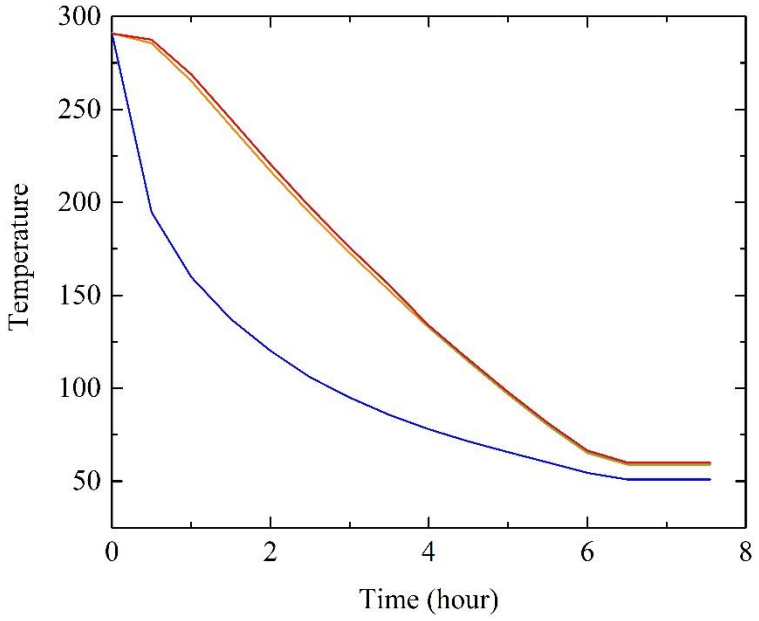
- Cooling-down from 300 K to the minimum temperature
  - No magnetic field
  - No temperature regulation



T_{min} = 46,6 K @ 7h30

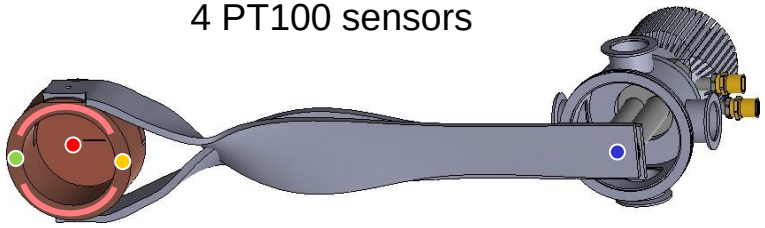
T=60 K @ 6h15

- Cooling-down from 300 K to the regulated temperature
  - No magnetic field
  - Temperature regulation at 60 K



T_{rel} = 60 ± 0,01 K @ 6h45

4 PT100 sensors



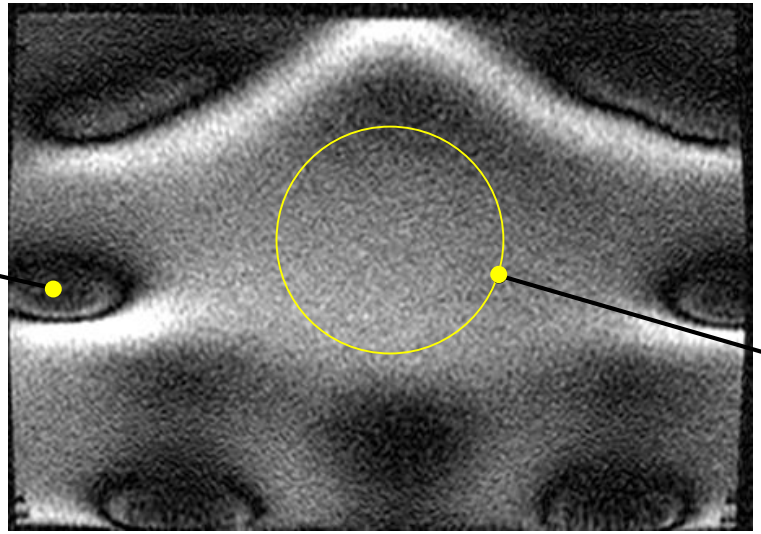
2 Heaters

First MR images in clinical field (1/4)

- Tests realized in a 1.5 T commercial scanner

First MR images in clinical field (2/4)

- Cryostat has the same cryogenic thermal performances when inserted the scanner
- Materials of cryostat do not bring any perturbation to the MRI measurements
- Acquired RM images of the part of the cryostat inserted in the MRI system shows non perturbation within a diameter of 150 mm centered on the testing zone



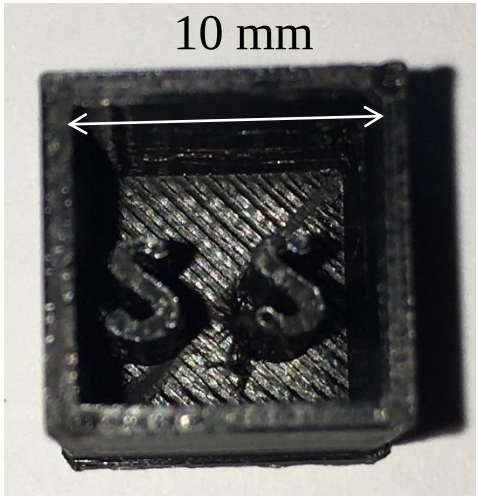
- Cryostat's MRI picture confirms its "**magnetic transparency**"

First MR images in clinical conditions (3/4)

- Test with a HTS RF probe on a dummy container

- Dummy sample is a plastic 3D printed square container representing the logo of the project SupraSense (two S's)

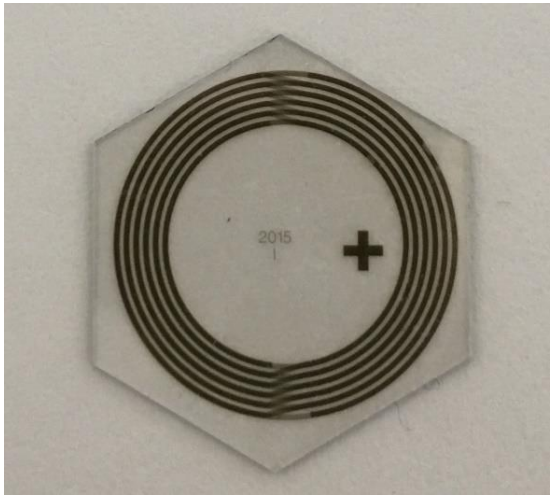
- Filled with water



- HTS probe is a 12 mm diameter multi-turn with 6 concentric loops

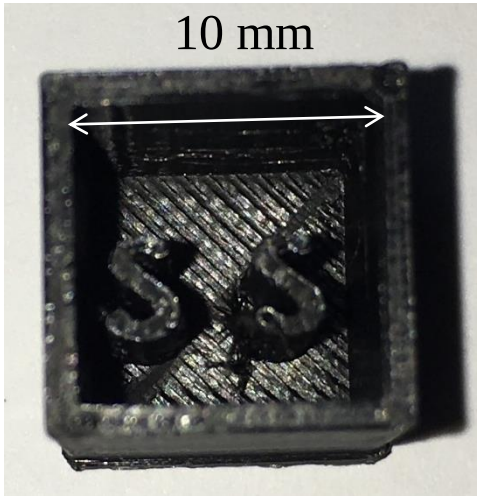
- 60 µm thick YBaCuO circular bands deposited on a sapphire support

- Used for the RF emission and reception



First MR images in clinical conditions (4/4)

- MR images of the dummy container
  - 1.5 T
  - HTS coil tuned to its Larmor frequency (63.897 MHz) at 77.97 K by adjusting the temperature of the sapphire support with the cryostat temperature regulation



Dummy container

MR image of the water in the container

3D rebuilt image from the MR mage

Conclusions and future work

- The all polymer cryogen free cryostat has been constructed and tested successfully under real clinical conditions in a commercial MRI scanner
- The design has proven that the cryostat can be used by non-cryogenist
- The main next development steps :
- Improvement of the resolution of the image by reducing the temperature and tuning the frequency of the coil probe by adding adaptive loops
- Reducing the weight of the cryostat (40~kg) would facilitate the installation of the system MRI scanner patient bed
  - One way to go would be to replace the aluminum thermal link (5~kg) by pulsating heat pipes thermal link that would be several times lighter

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Thank you !

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