MadMax: a new QCD Dark Matter Axion search

A. Caldwell, G. Dvali, C. Gooch, A. Hambarzumjan, B. Majorovits, A. Millar, G. Raffelt, O. Reimann, F. Simon, F. Steffen
MPI für Physik, München, Germany

J. Redondo
University of Zaragoza, Spain

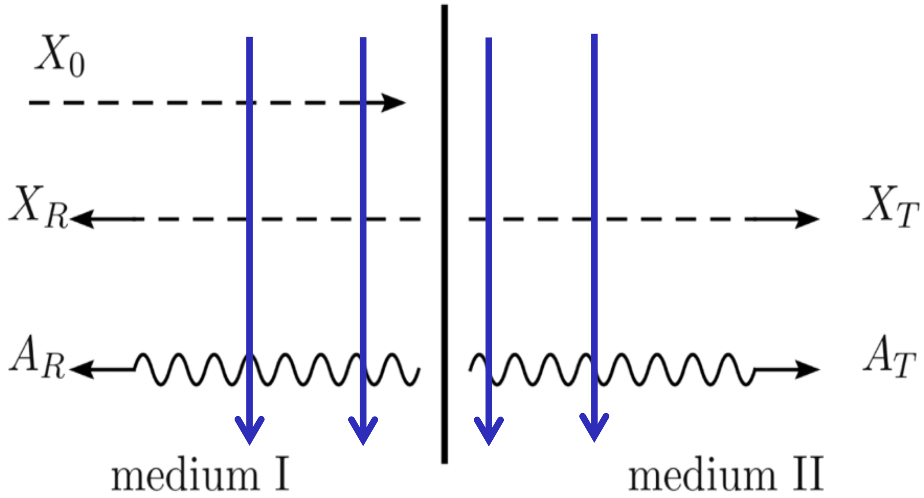
- **Axion to photon conversion at surfaces**
- **The open structure idea & simulations of boost factor**
- **Experimental idea & first measurements with Seed project setup**
- **Design ideas for magnet**
- **Further plans**

Axion to photon conversion at surfaces:

Axion mixes with photon in a static B-field

At surfaces (reflecting or change in refractive index): emission of photons in both directions

D. Horns, J. Jaeckel, A. Lindner, A. Lobanov, J. Redondo and A. Ringwald JCAP 1304 (2013) 016 *[arXiv:1212.2970]*.



$$(P/A)_{\text{single surface}} \sim 2 \cdot 10^{-27}\ \text{W/m}^2 \cdot (B_{\parallel}/10\text{T})^2 \cdot c_\gamma^{\,2} \cdot f(\varepsilon_{m1}, \varepsilon_{m2})$$

ε_{m1} , ε_{m2} dielectric constant of media I and II

$f(\varepsilon_{m1}, \varepsilon_{m2})$ increases with increasing $\Delta(\varepsilon_{m1}, \varepsilon_{m2})$

Vacuum-mirror transission: $f(0,\infty)=1$

Axion to photon conversion appears as source term in Maxwell equations

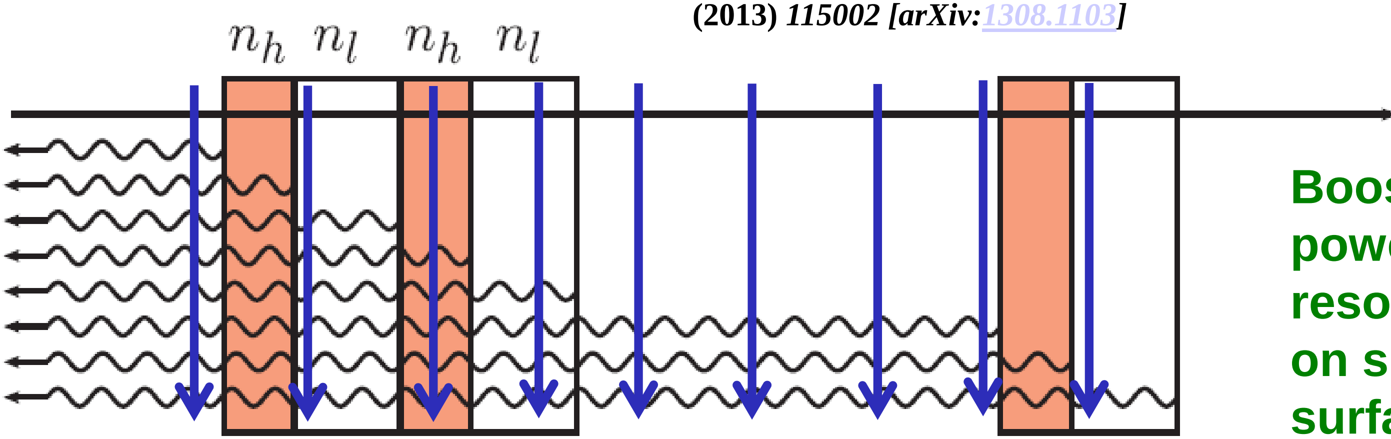
Axion to photon conversion at surfaces:

Many surfaces:

→ constructive interference of photon part of wave function

→ "photon boost"

J. Jaeckel and J. Redondo, Phys. Rev. D 88 (2013) *115002 [arXiv:1308.1103]*



Boost factor β: power emitted by resonator/power emitted on single metallic ($\varepsilon_r=\infty$) surface

$$(P/A)_{\text{resonant cavity}} \sim 2 \cdot 10^{-27}\ \mathrm{W/m^2} \cdot (B_{\|}/10\mathrm{T})^2 \cdot c_\gamma^{\,2} \cdot f(\varepsilon_{m1}, \varepsilon_{m2}) \cdot \beta$$

β **: Boost factor, depends on:**

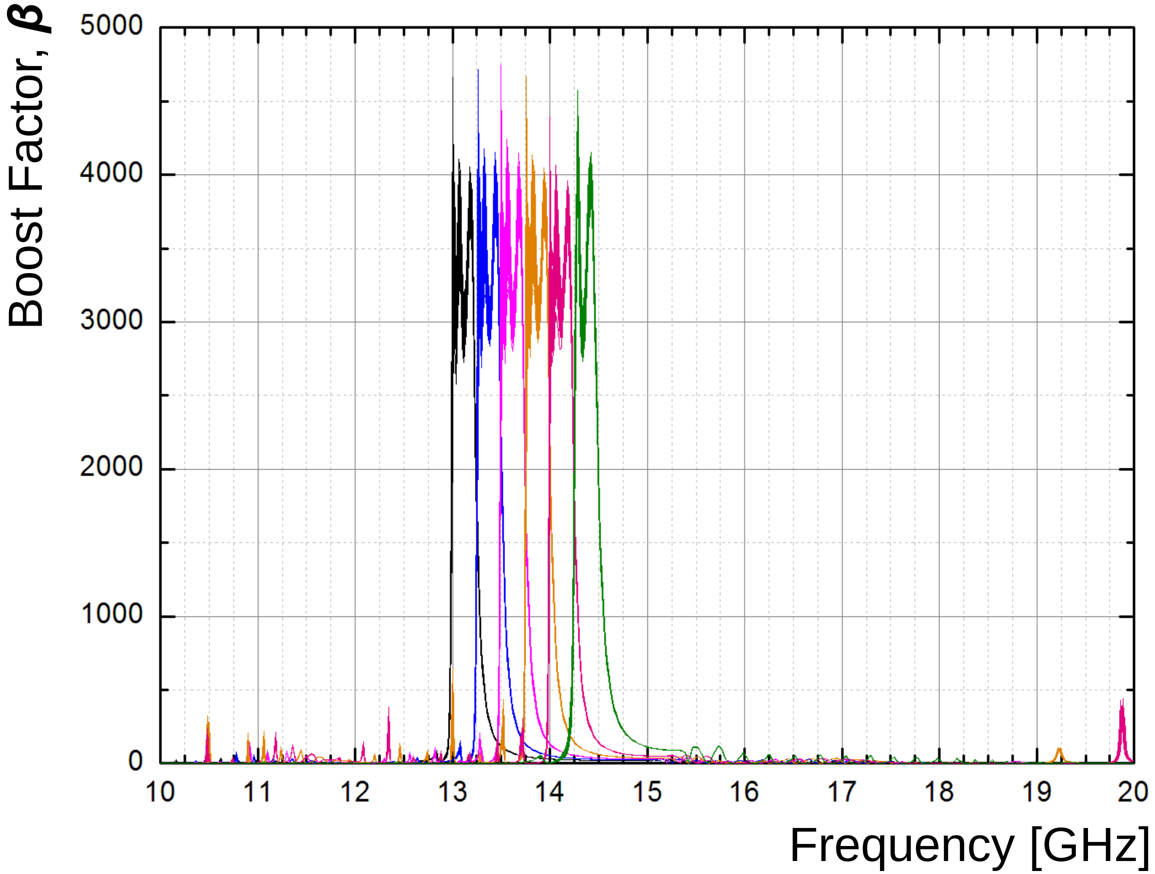
frequency (axion mass), ε of materials, number of surfaces, displacement between surfaces, etc.

Axion to photon conversion appears as source term in Maxwell equations

→ Can treat problem classically!

First simulations: the boost factor

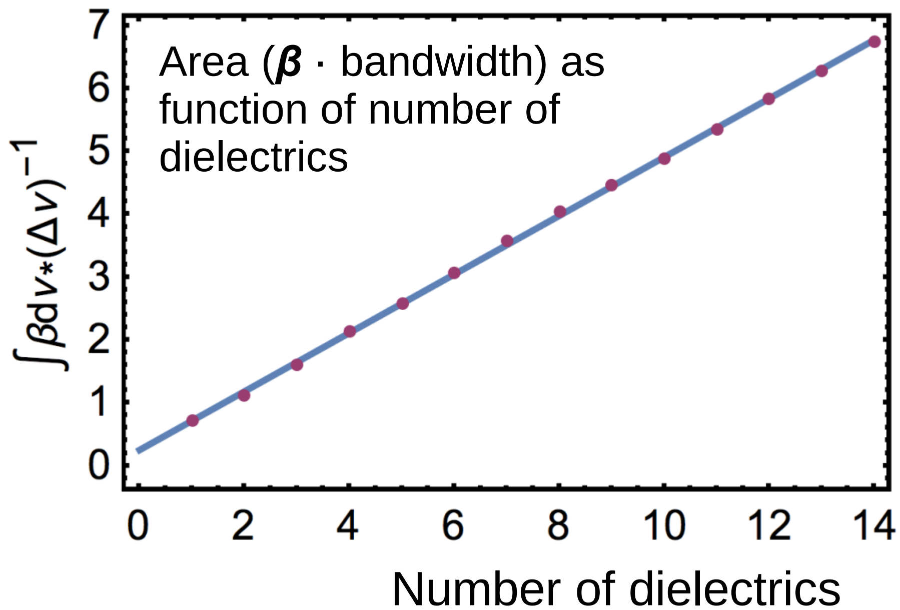
20 plates with ε_r = 24 ($LaAlO_3$) for bandwith 250 MHz



It is possible to adjust disc setting to reach sizeable *β* over broad bandwidth

Here: bandwidth per setting: ~250MHz
Estimated precision of placement of discs needed: ~few μm

First simulations: the boost factor

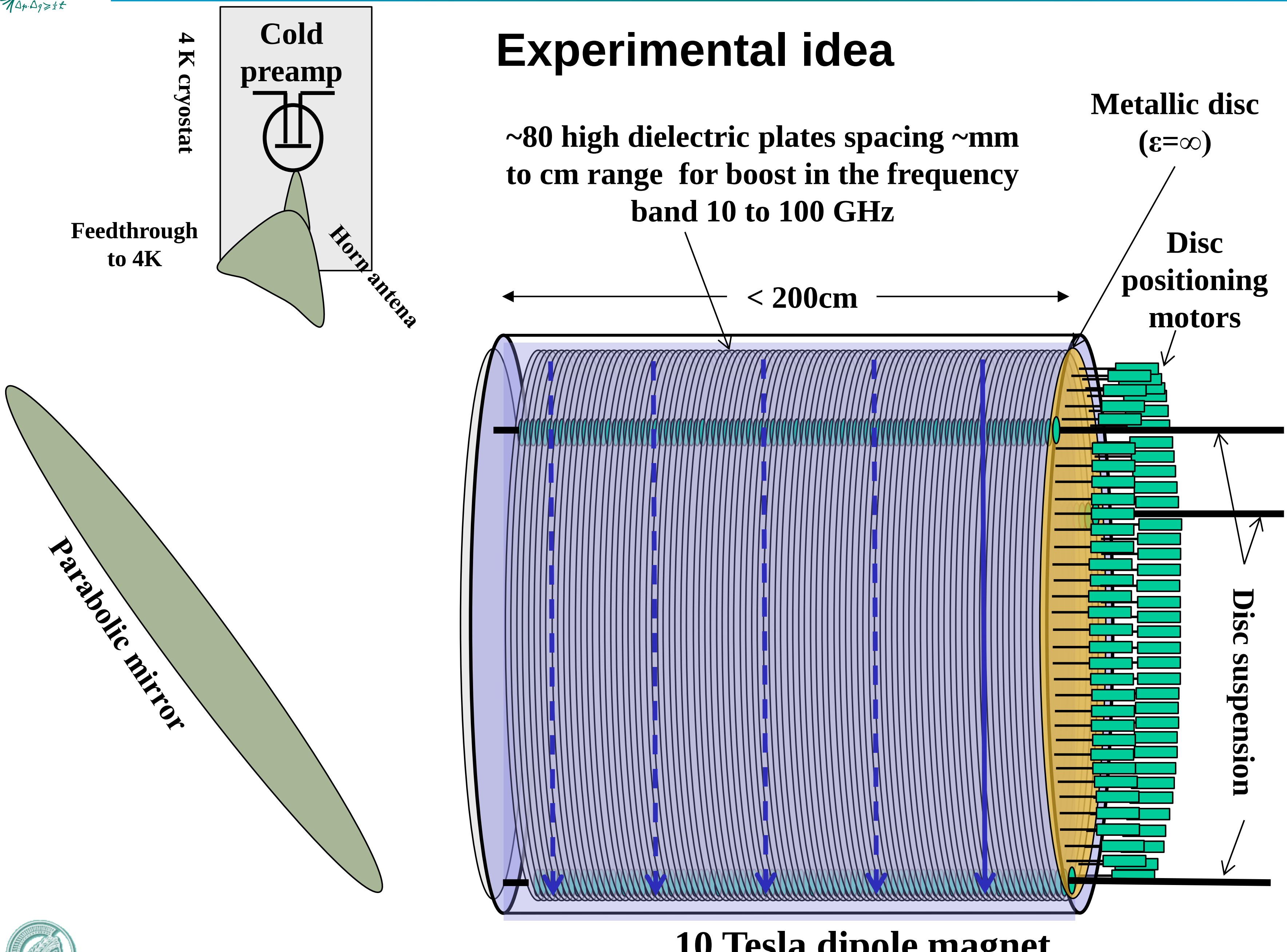


→ **Area of boost peak scales ~linearly with number of discs**

Simulations: disc placement (80 discs) with precision of ~ µm enough for $\beta \sim 10^5$ with bandwidth of tens of MHz

Boost factor can be probed by reflectance and transmittance measurements

Experimental idea



Experimental idea

Chose dielectric material:

- High dielectric constant ε (for large boost & conversion)
  - Low loss → low tan δ (reduce photon losses)
    - Stable
    - Cheap

→ Sapphire (Al_2O_3) @ 300K, 10 GHz:

$$\varepsilon \sim 10; \qquad \tan\delta \sim few \cdot 10^{-5}$$

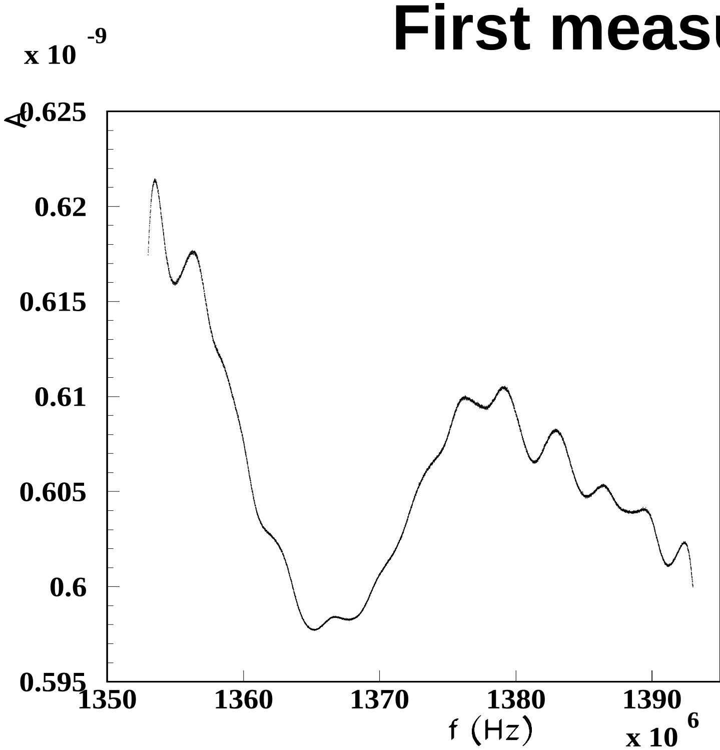
→ Lanthanide Aluminate ($LaAlO_3$) @ 77K

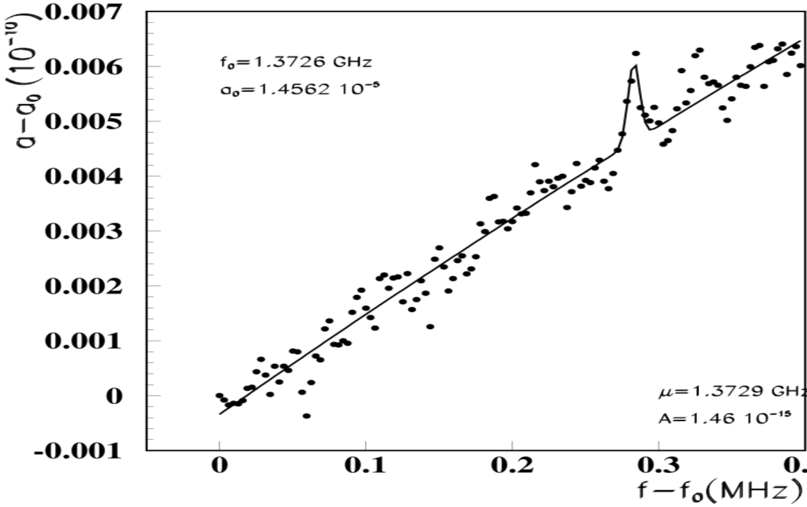
$$\varepsilon \sim 24; \qquad \tan\delta \sim 3 \cdot 10^{-5}$$

→ Titanium dioxide – Rutil (TiO_2)

$$\varepsilon \sim 100; \qquad \tan\delta \sim ???$$

First measurements: sensitivity





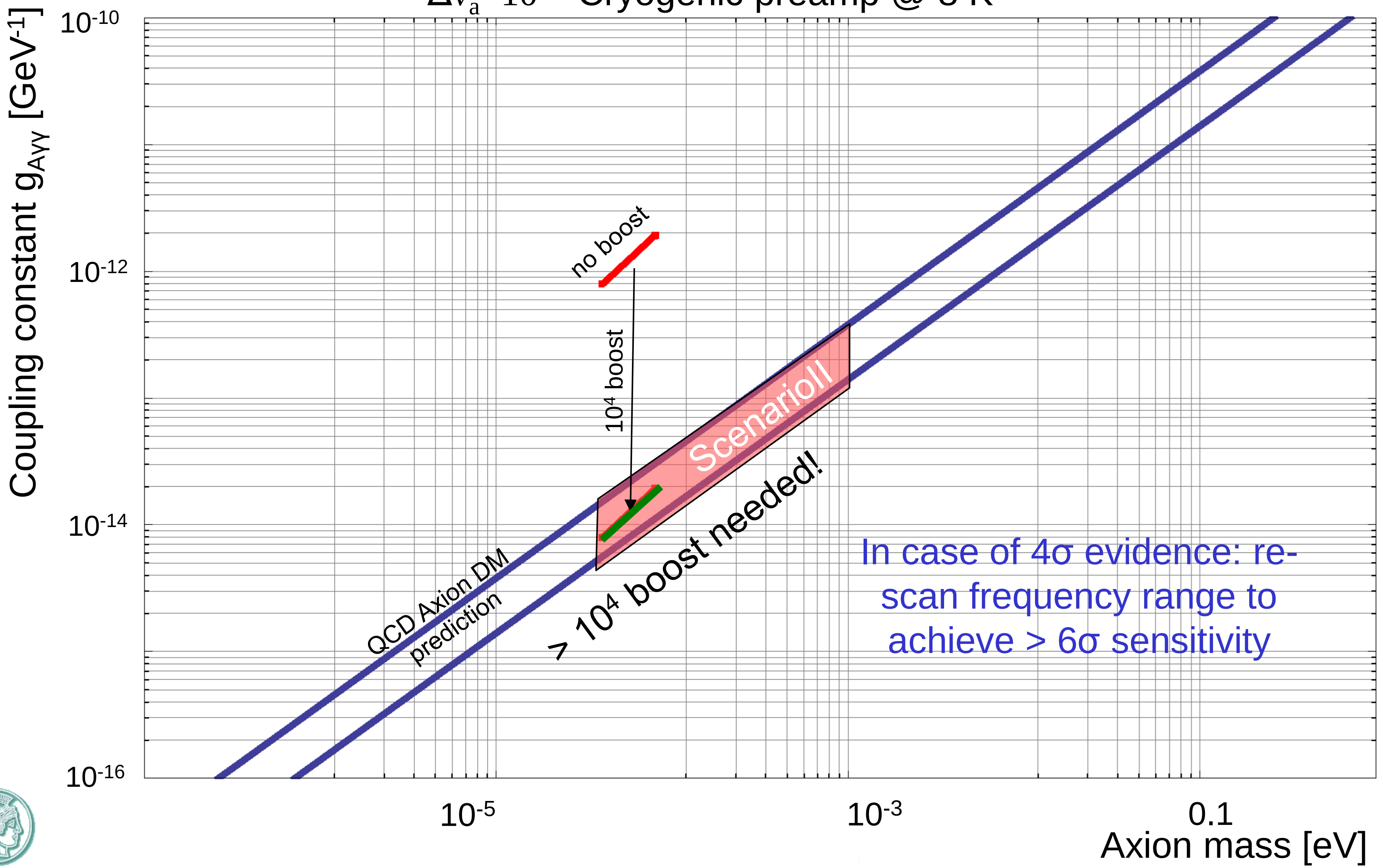
- Inject fake axion signal with $3 \cdot 10^{-21}$ W power
- Measurement for one week (integrate signal): Receiver at Room Temp.

→ Independent „blind“ analysis
→ found > 6σ signal succesfully

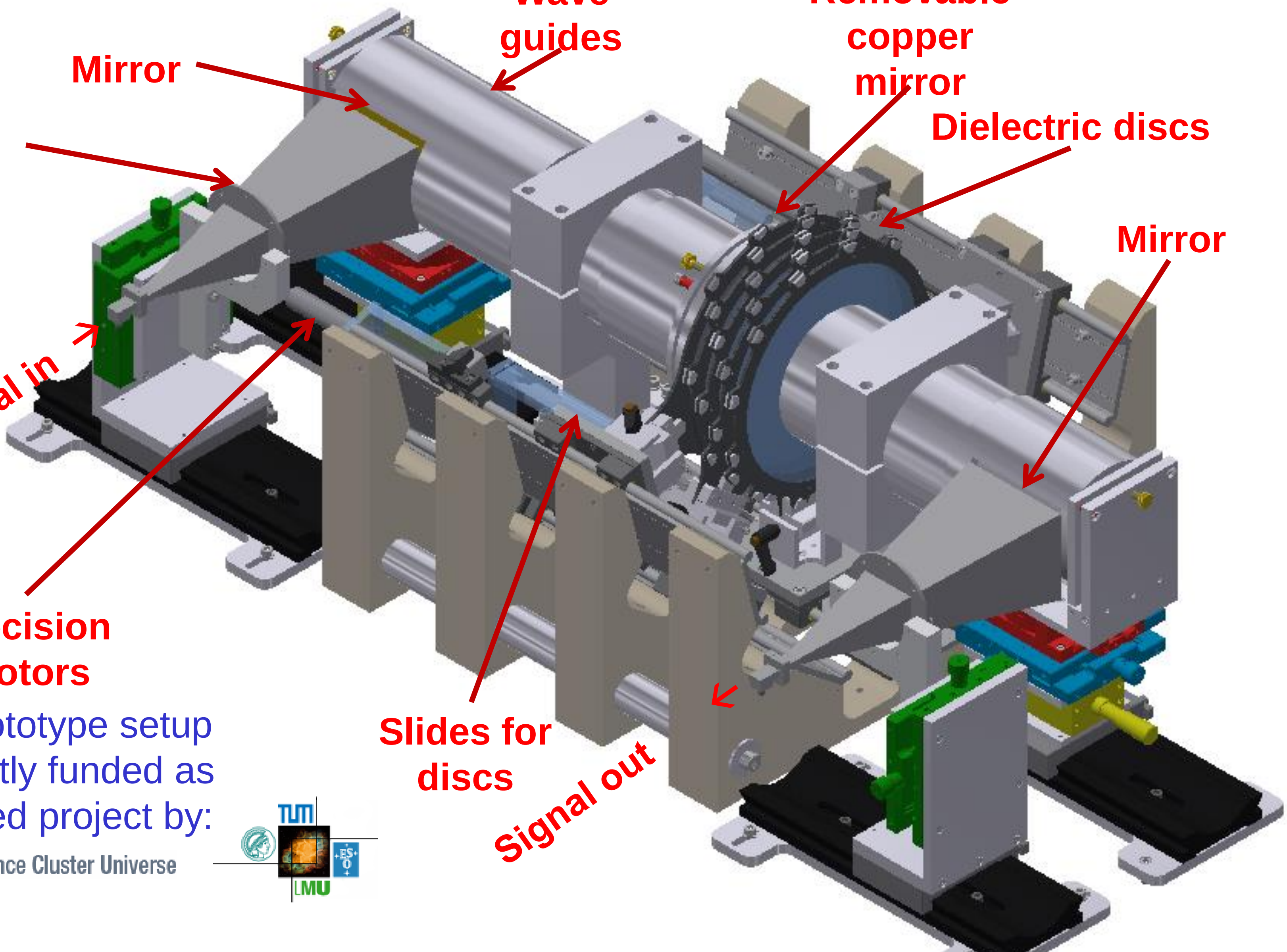
→ At LHe: noise level factor 100 better
→ Sensitivity at the level of 10^{-23} W expected

First measurements: sensitivity

Expected 4σ detection sensitivity with and without boost
for 80 discs, 1m² disc surface, 10T B-field, τ=200h, 50MHz boost bandwidth,
$\Delta\nu_a=10^{-6}$; Cryogenic preamp @ 8 K



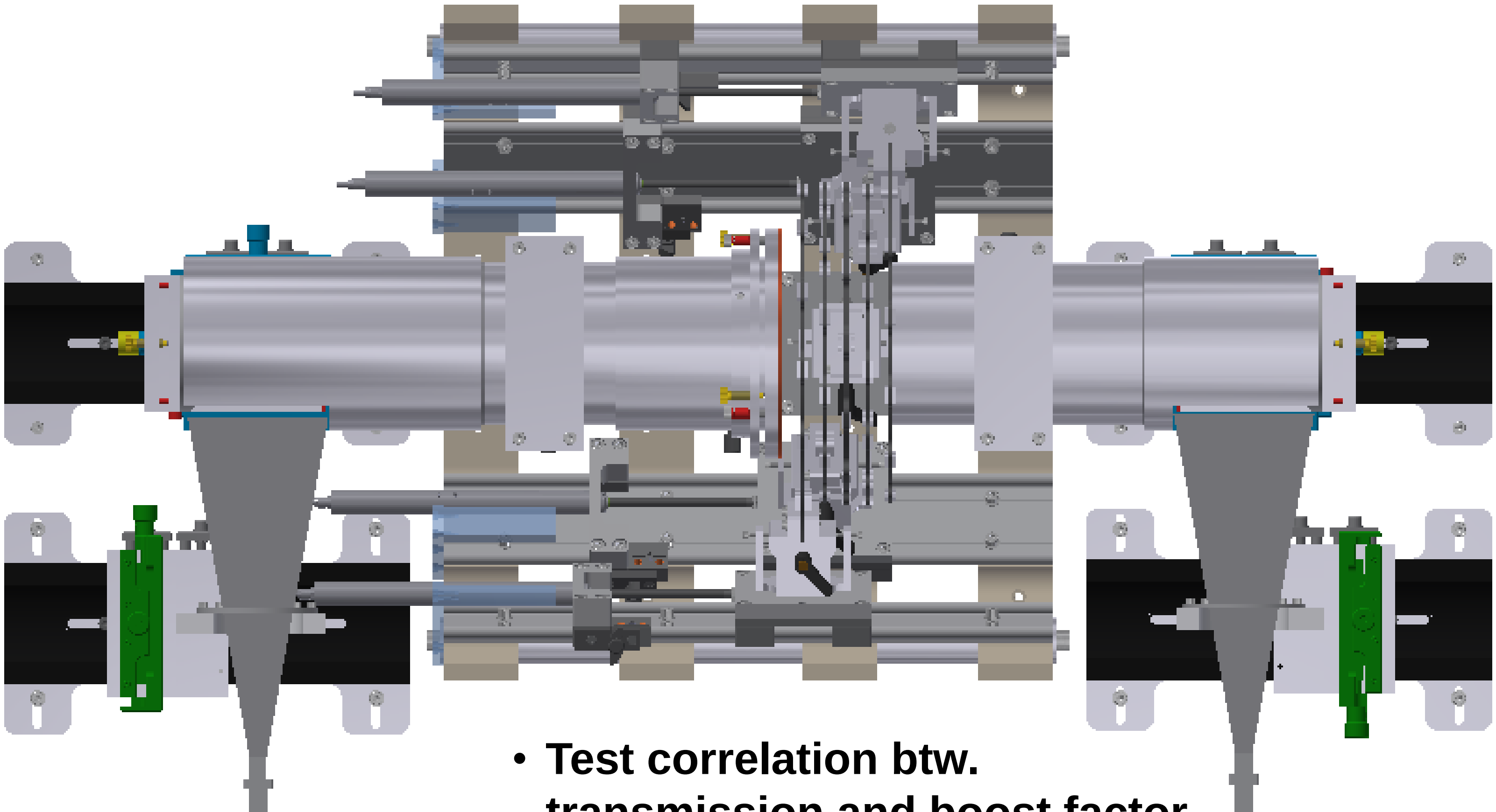
First prototype setup at MPI



Prototype setup partly funded as seed project by:

Excellence Cluster Universe

First prototype setup at MPI



- Test correlation btw. transmission and boost factor
- Test needed disc precision
- Evaluate uncertainties
- R&D on tiling

Prototype setup partly funded as seed project by:

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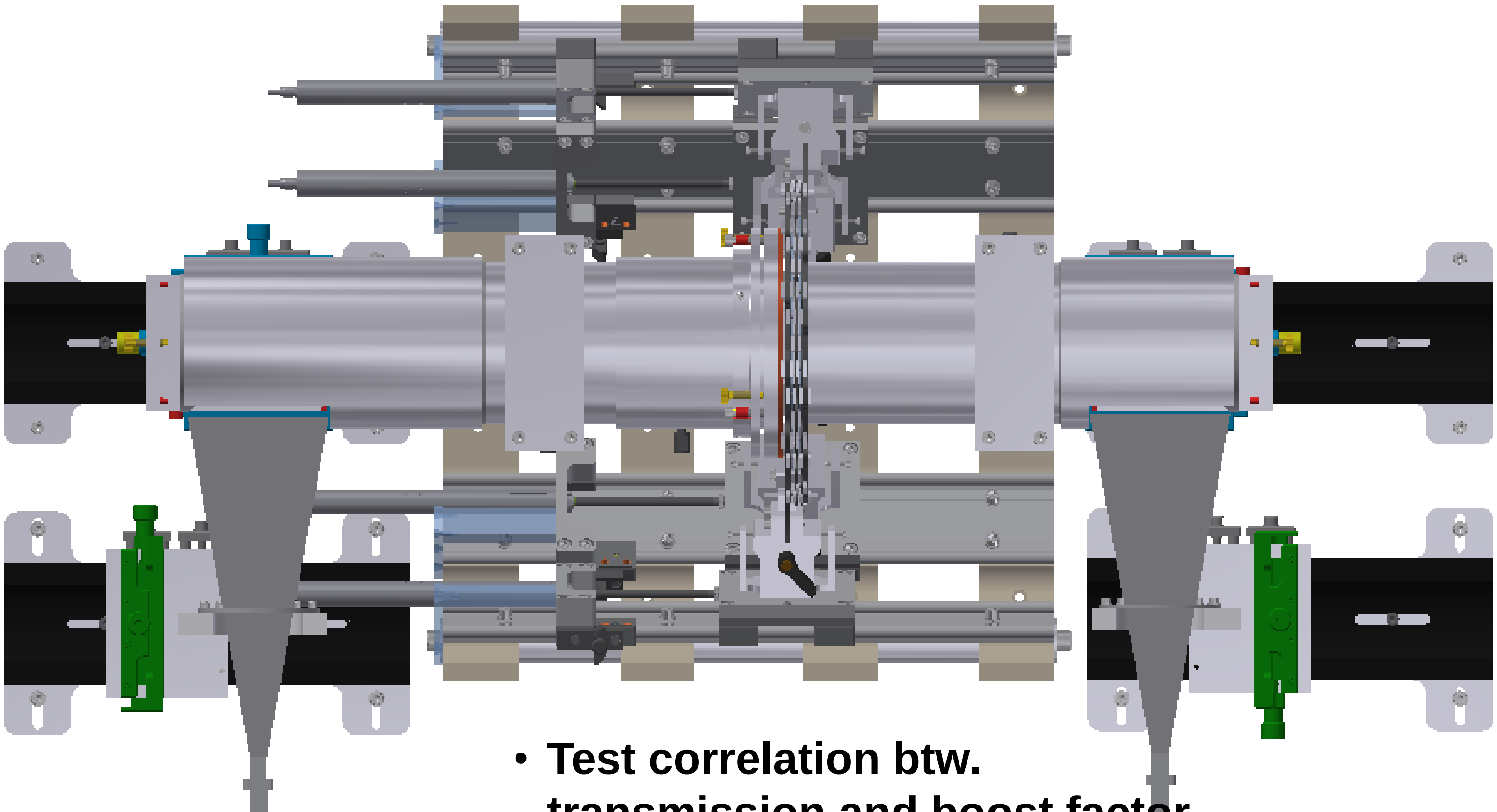
First prototype setup at MPI



- Test correlation btw. transmission and boost factor
- Test needed disc precision
- Evaluate uncertainties
- R&D on tiling

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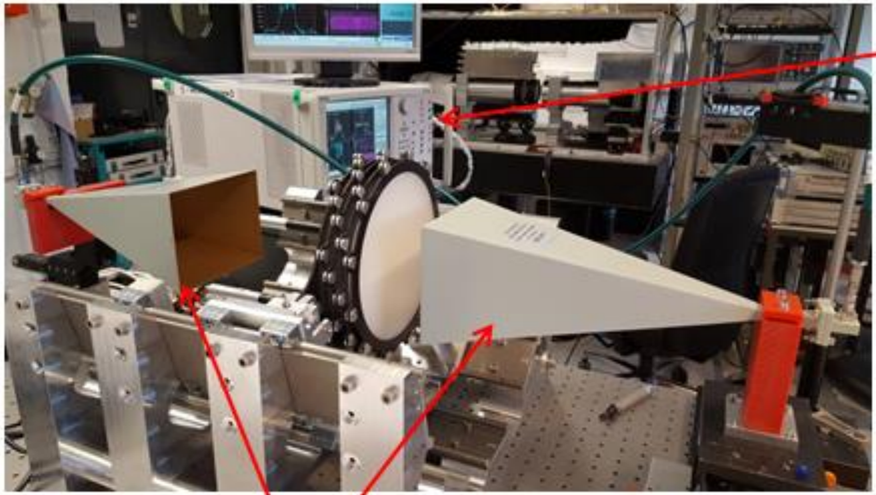
First prototype setup at MPI

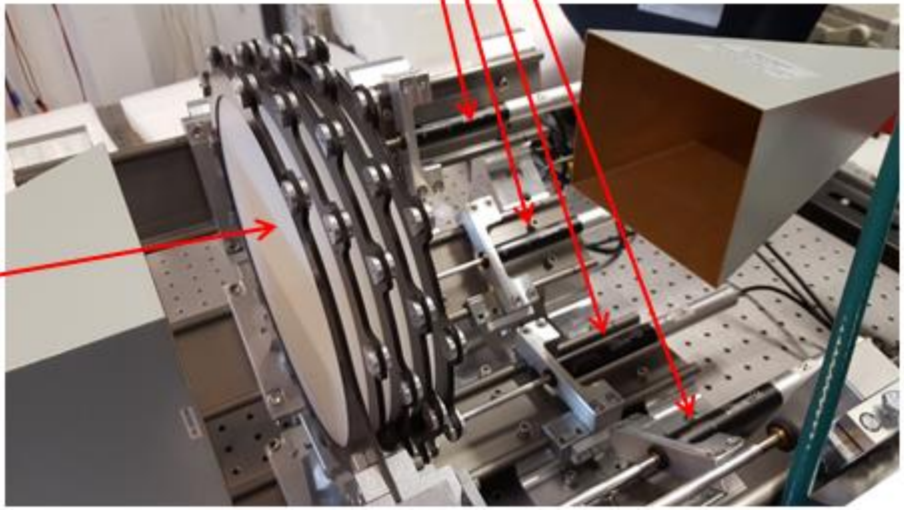
Transmission and reflection measurements



Network Analyzer

Motors

Antenas

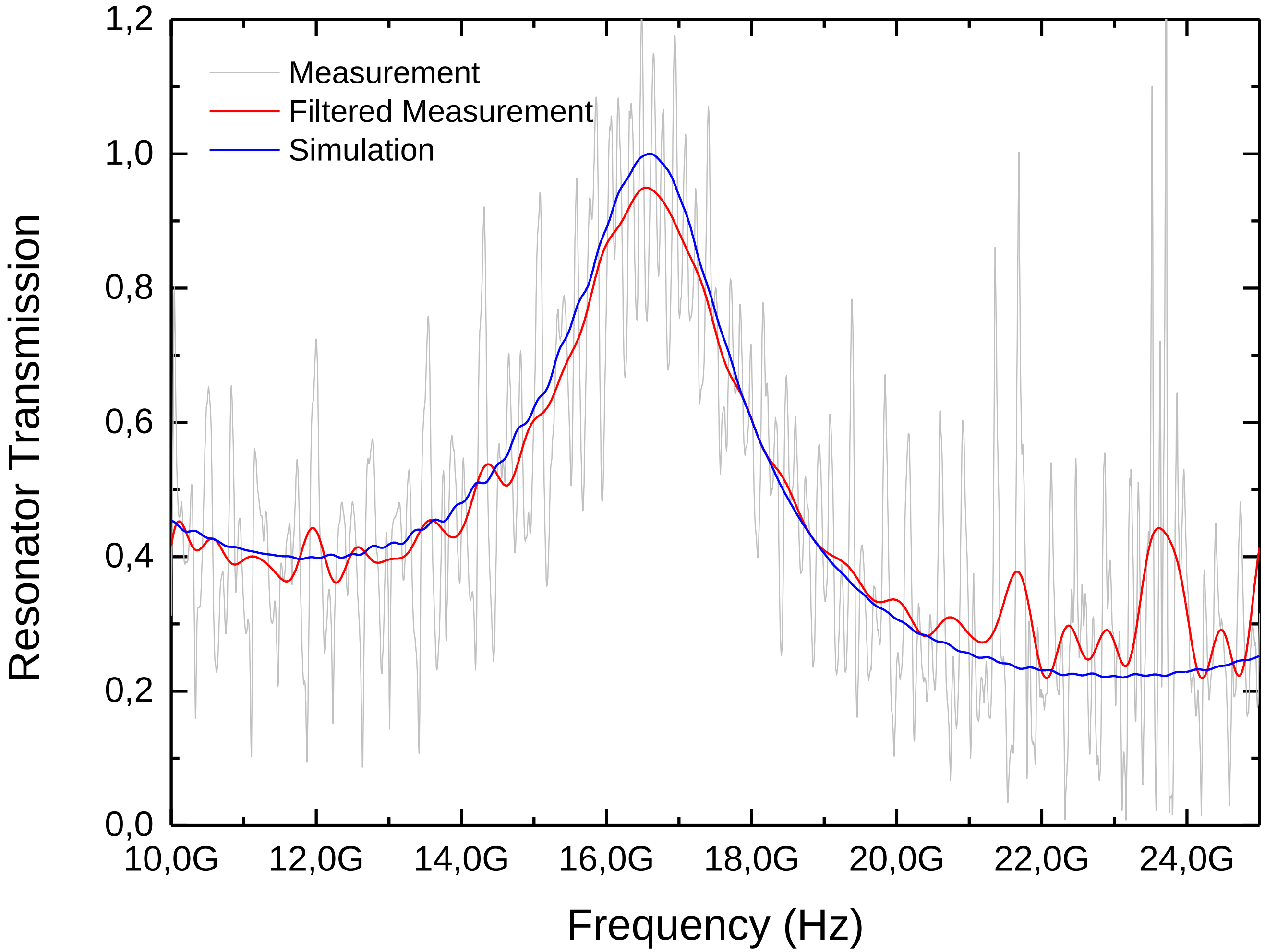


Saphire discs

Prototype setup partly funded as seed project by:

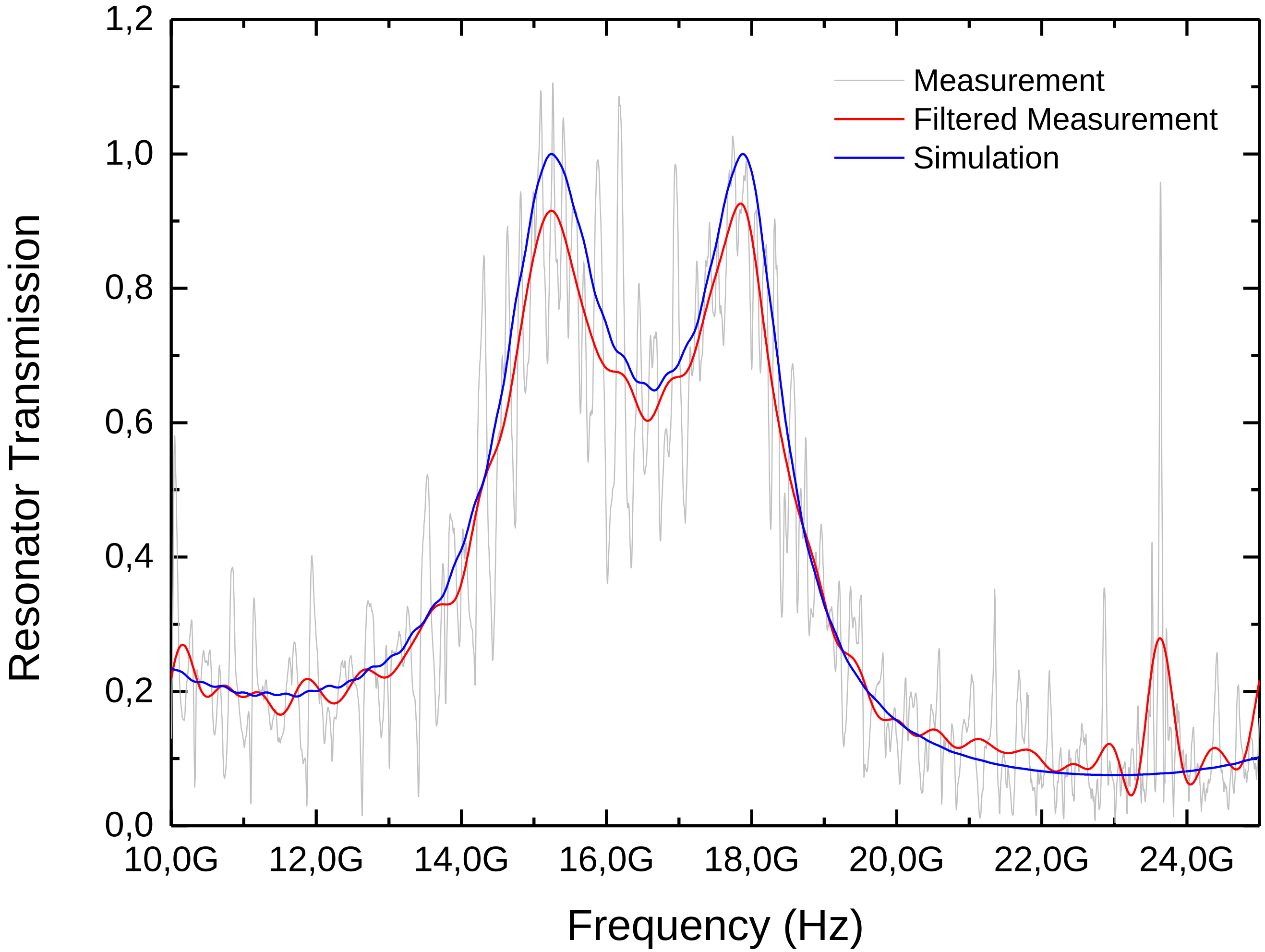
Excellence Cluster Universe

Transmission measurements: 2 discs



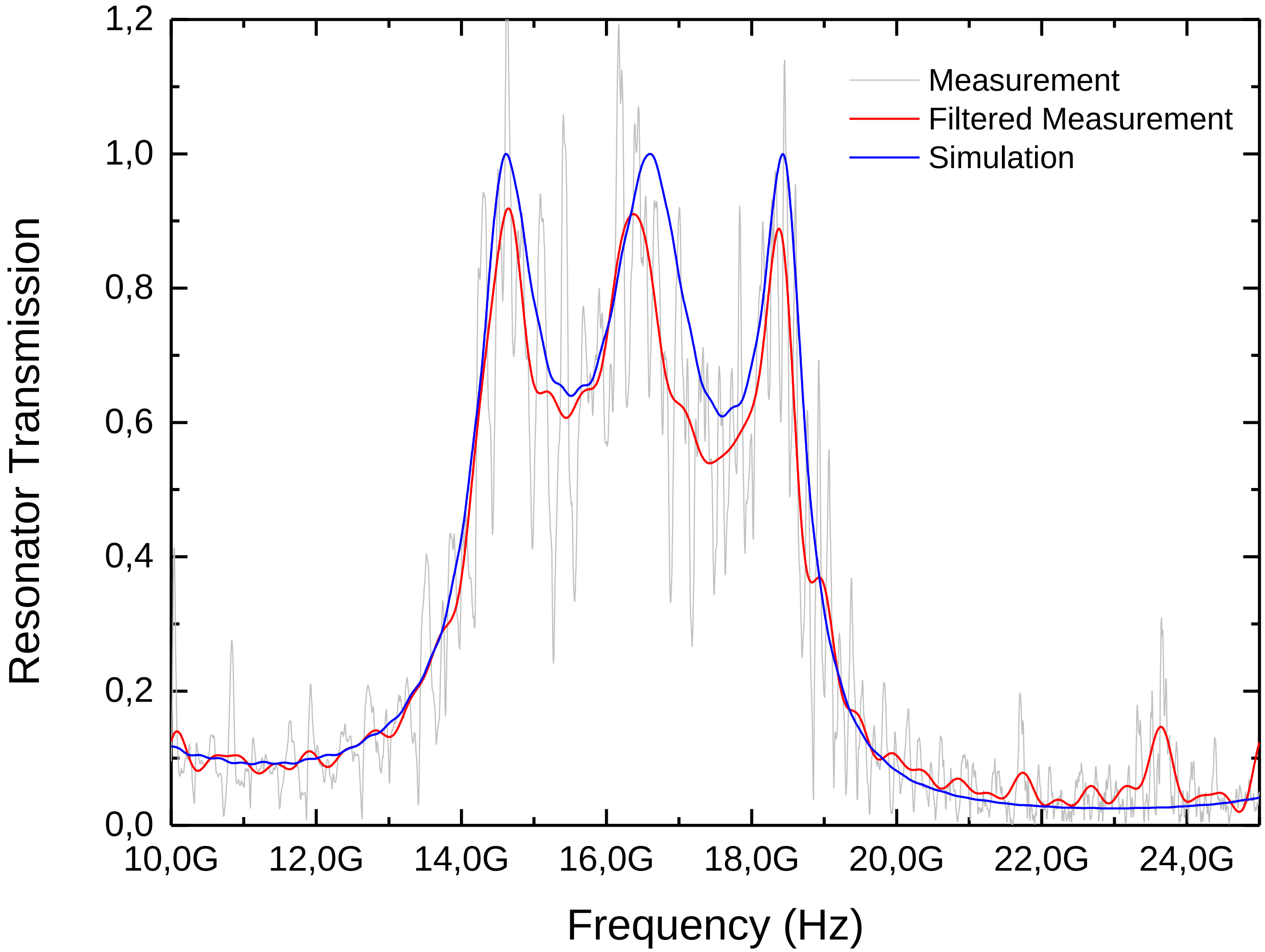
- **2** AlO_3 discs with diameter 200mm Disc positions **transmission** curve
  - Prediction (red) fits measurement (black) well.

Transmission measurements: 3 discs



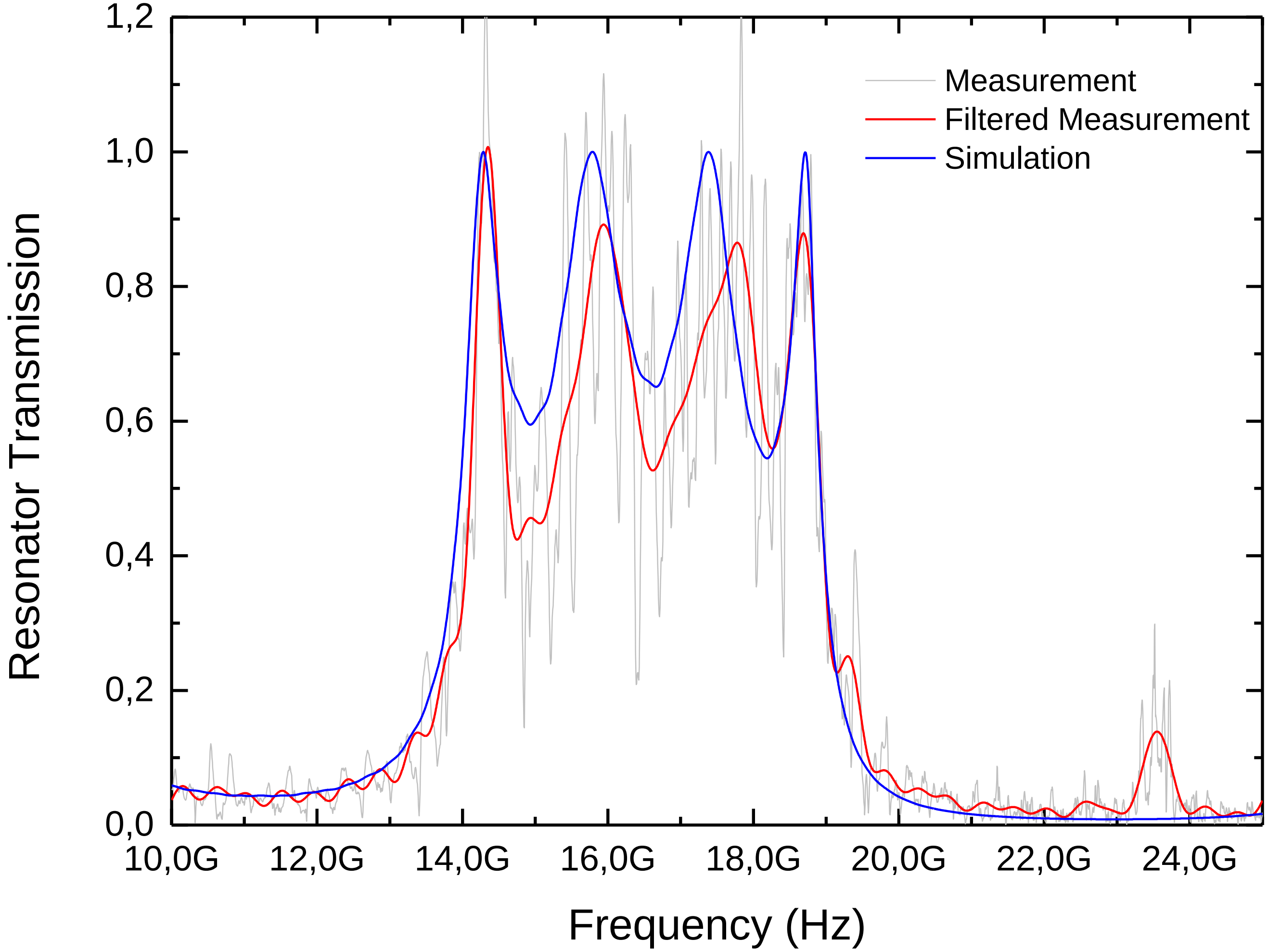
- **3** AlO_3 discs with diameter 200mm Disc positions **transmission** curve
- Prediction (red) fits measurement (black) well.

Transmission measurements: 4 discs



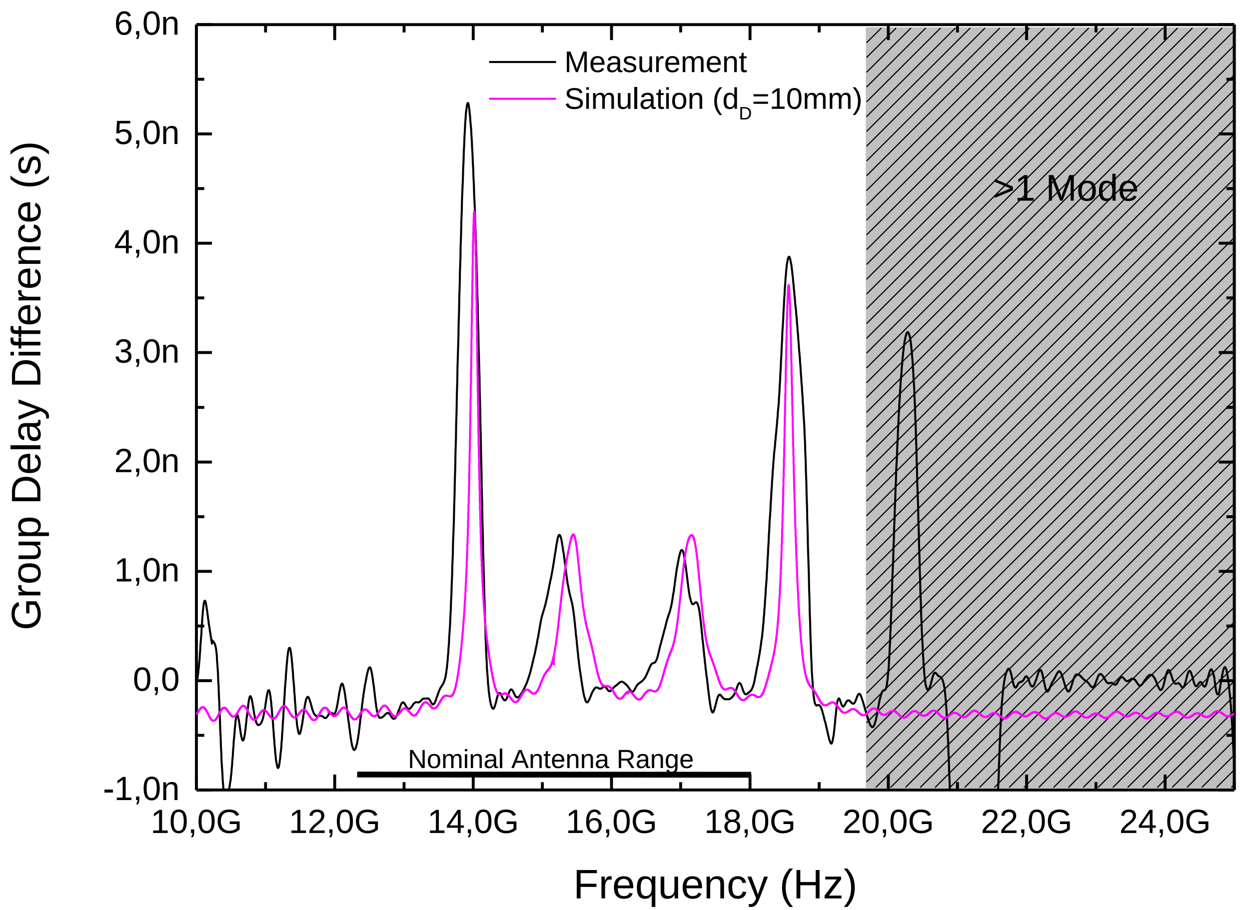
- **4** AlO_3 discs with diameter 200mm Disc positions **transmission** curve
- Prediction (red) fits measurement (black) well.

Transmission measurements: 5 discs



- **5** AlO_3 discs with diameter 200mm Disc positions **transmission** curve
- Prediction (red) fits measurement (black) well.

Reflectivity measurement: 4 discs + mirror

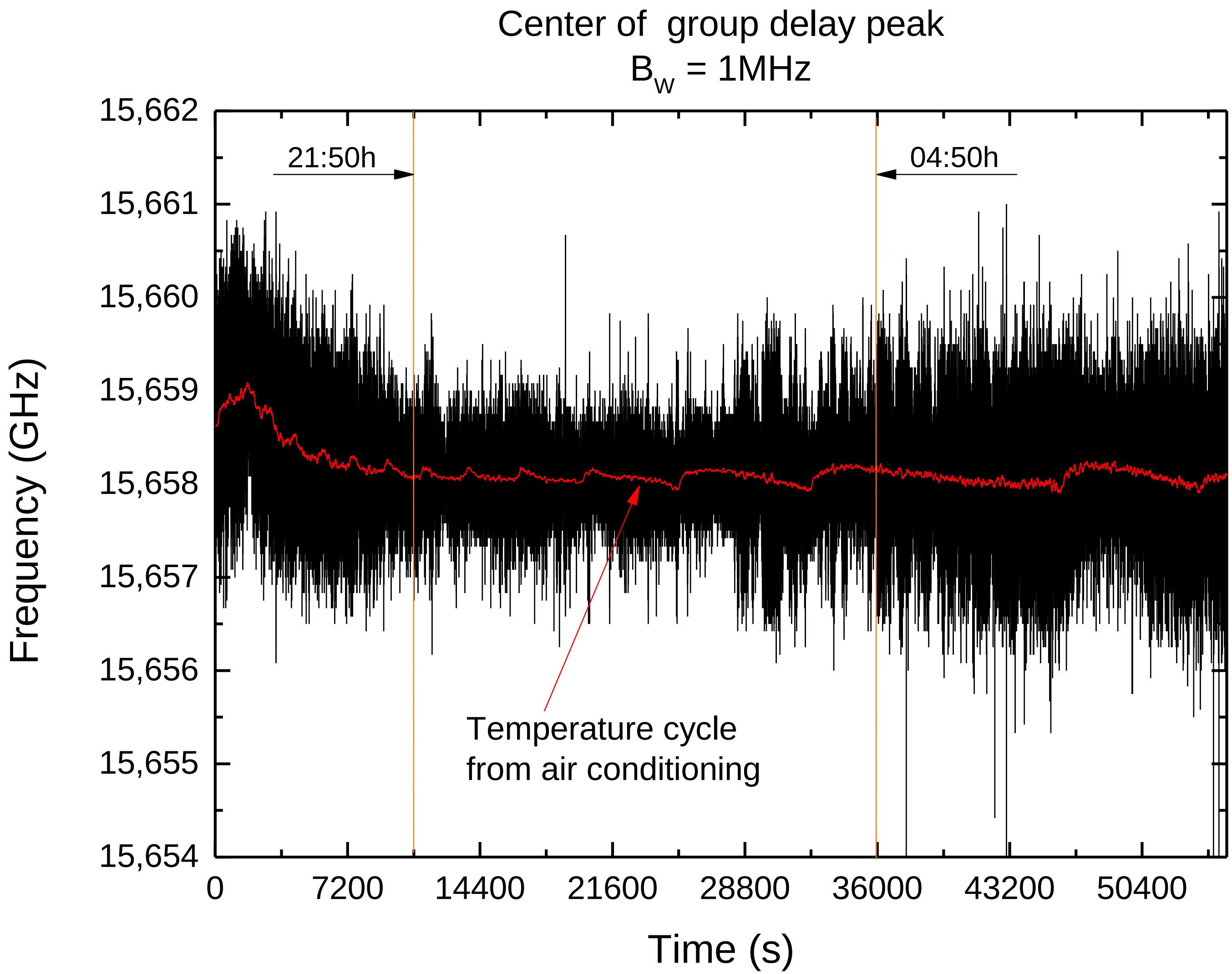


- 4 AlO_3 discs with diameter 200mm plus mirror **reflection** curve
- Prediction (red) fits measurement (black) well.

→ Needed precision of disc placing according to expectations

→ Gives confidence in boost factor calculation

Reflectivity measurement: 4 discs + mirror



Variation of group delay peak position ~1MHz
→ Long term stability of boost peak seems ok

The 10T dipole magnet challenge:

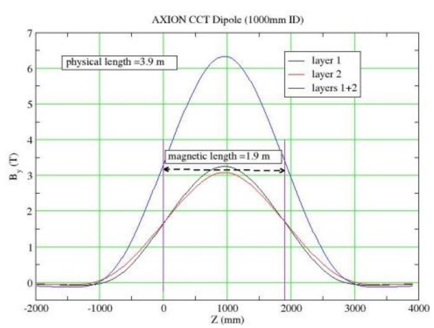
Remember: $P \propto A_{mirror} \cdot B_{||}^{2}$

Sensitivity goal assumes use of 10T dipole magnet with 1m aperture!

Two design concepts available:

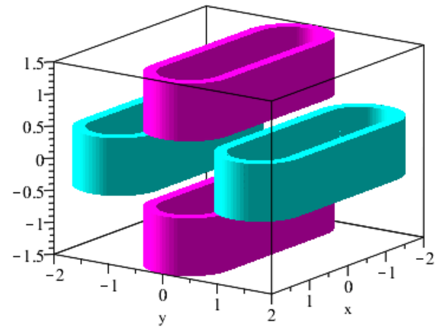
Berkeley superconducting magnet group:

Canted-Cosine-Theta magnet



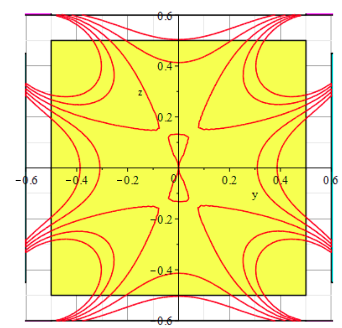
CEA-IRFU Saclay magnet group:

4 racetracks actively shielded configuration



$\delta B = \pm 0.1\ T$

from $10\ T$



Further plans

2016:

- Finish first test measurements at room temperature at MPI
- Test noise of preamplifier at LHe temperature
- Find additional collaborators for specific parts of project. presently in discussion with:
  DESY, MPI-Radio astronomy, CEA-Saclay, LBNL-Berkeley
- Order design study of 10T magnet
- Start to develop technique to cover frequencies above 40 GHz
- R&D on production of large diameter high-ε discs

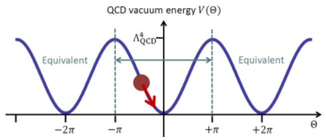
2017-2020:

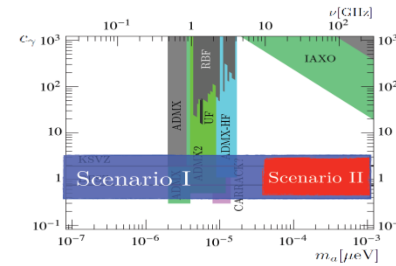
- R&D and Prototype experiments, tests in high B-field
- Design (and construction) of full scale experiment

2020 (?) :

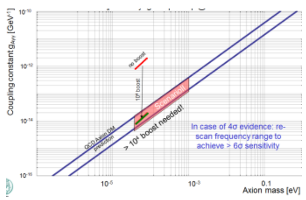
- Start full scale experiment

C O N C L U S I O N S

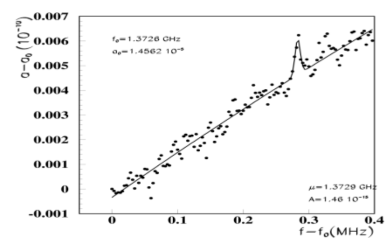


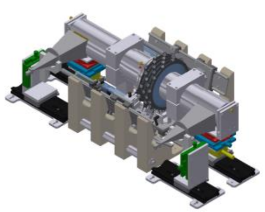


- Axions in mass range ~40-400 µeV could solve strong CP & Dark Matter problem

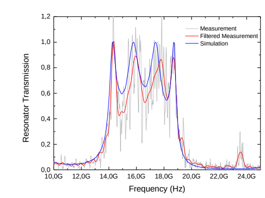


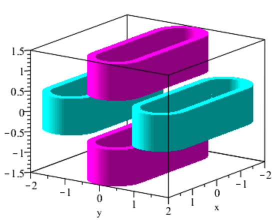
- Open dielectric structure with ~ 80 discs expected to boost axion detection rate by ~5 orders of magnitude





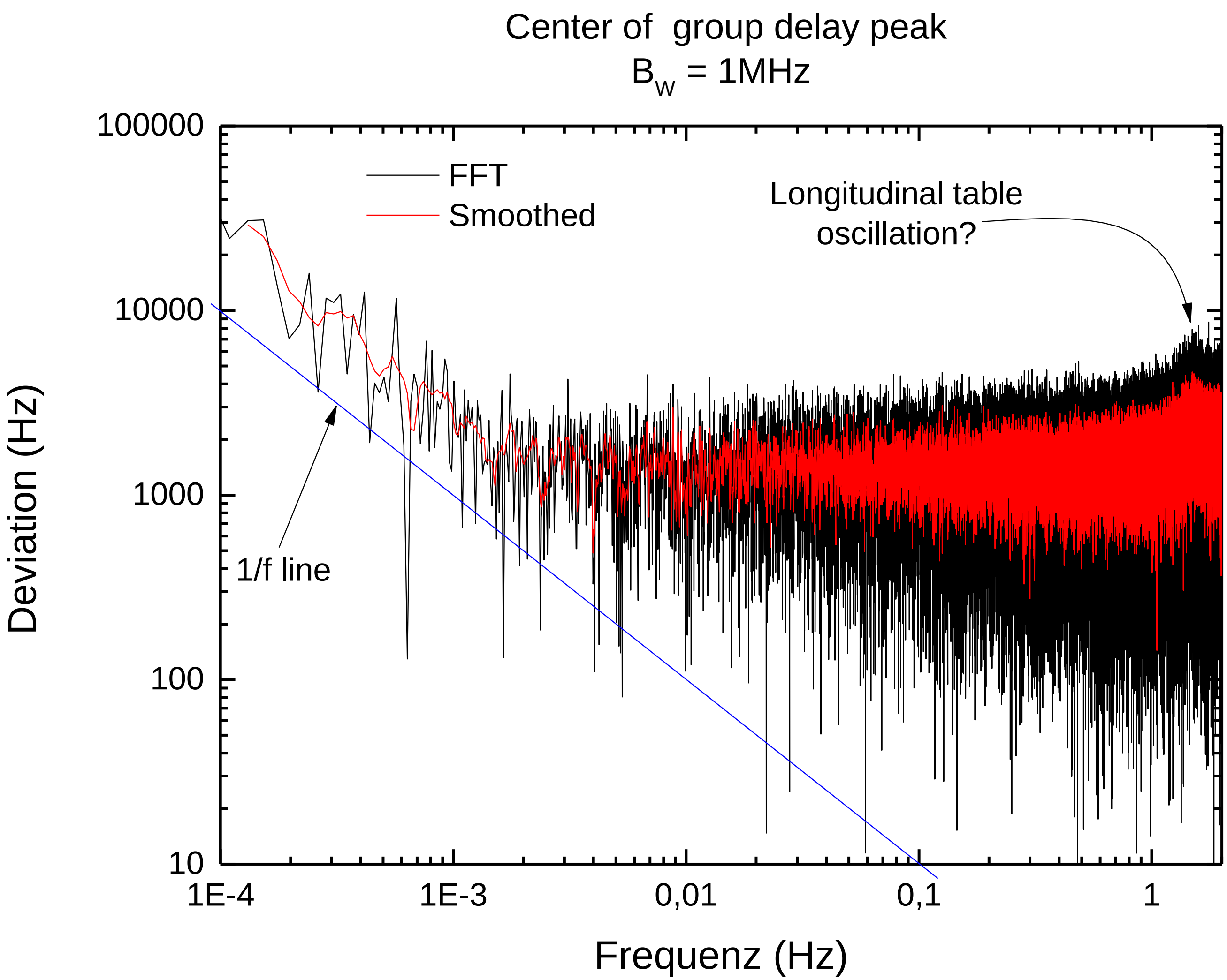
- First measurements with low noise preamp promising: 80 big enough discs in 10 T B-field: sensitivity enough to probe models





- First results from proof of principle setup are promising
- Magnet issue seems solvable (price?)

- We are ready to „go official“


Center of group delay peak
B_W = 1MHz
FFT
Smoothed
Longitudinal table
oscillation?
1/f line
100000
10000
1000
100
10
1E-4
1E-3
0,01
0,1
1
Deviation (Hz)
Frequenz (Hz)