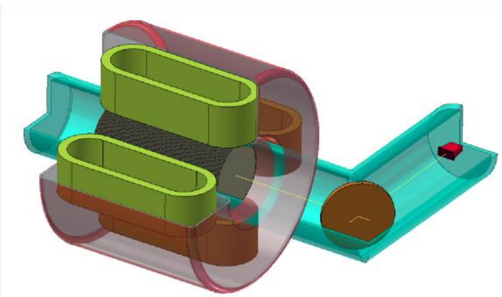
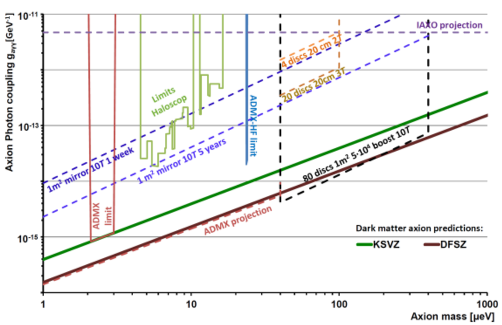
MADMAX: A new road to axion dark matter detection

Béla Majorovits
MPI für Physik, München, Germany

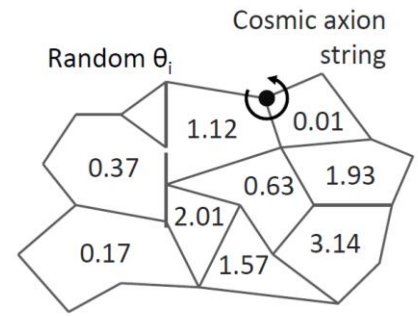
for the MADMAX interest group

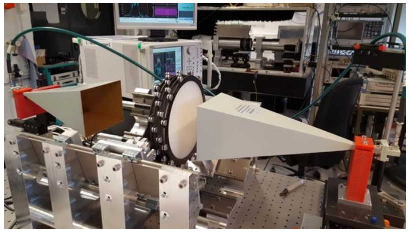




OUTLINE:

- Axions as dark matter: The post inflationary scenario
- Experimental idea
- First proof of prinicple measurements
- Outlook





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CEA IRFU, Saclay

DESY Hamburg

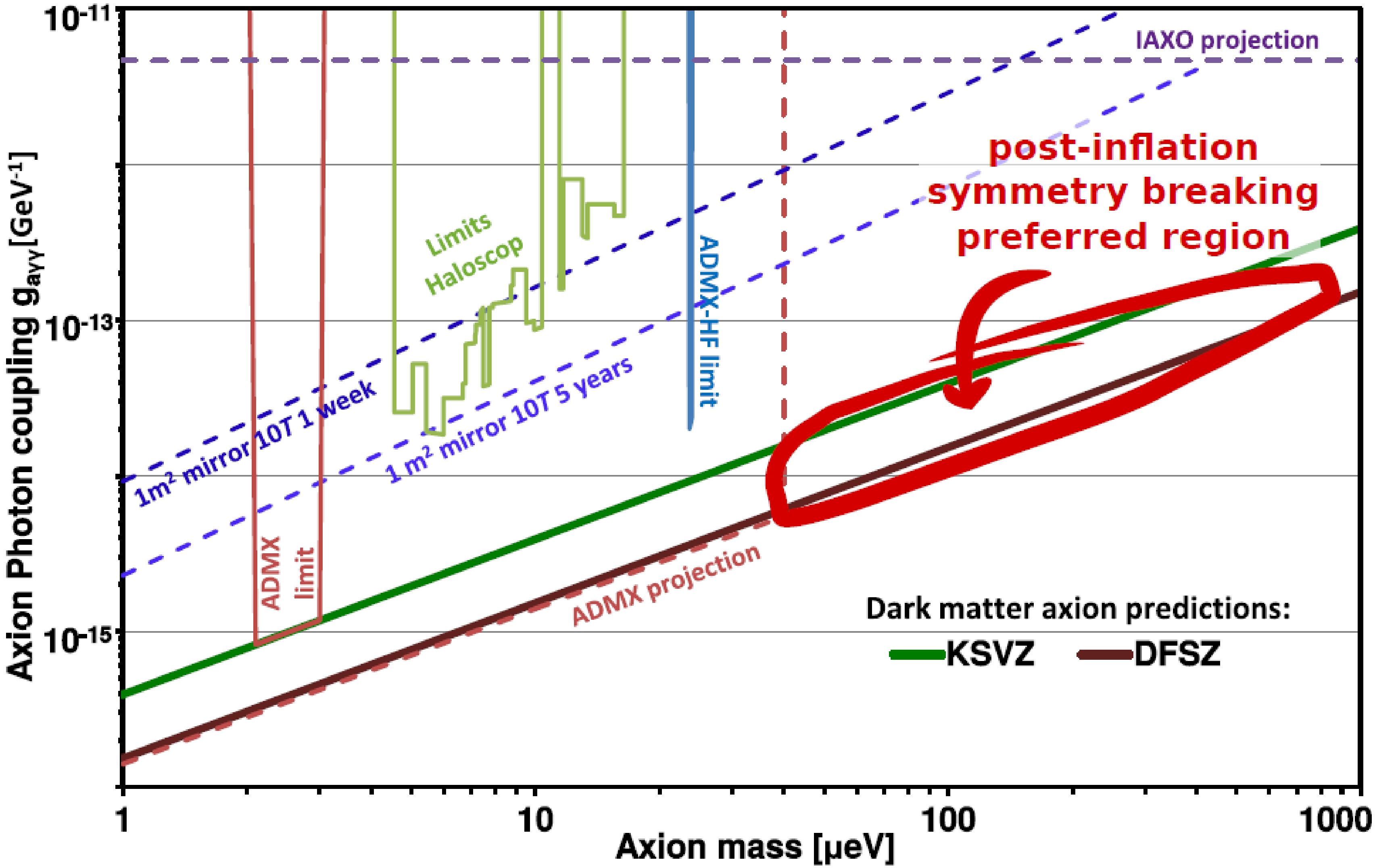
MPI für Radioastronomie, Bonn

MPI für Physik, München

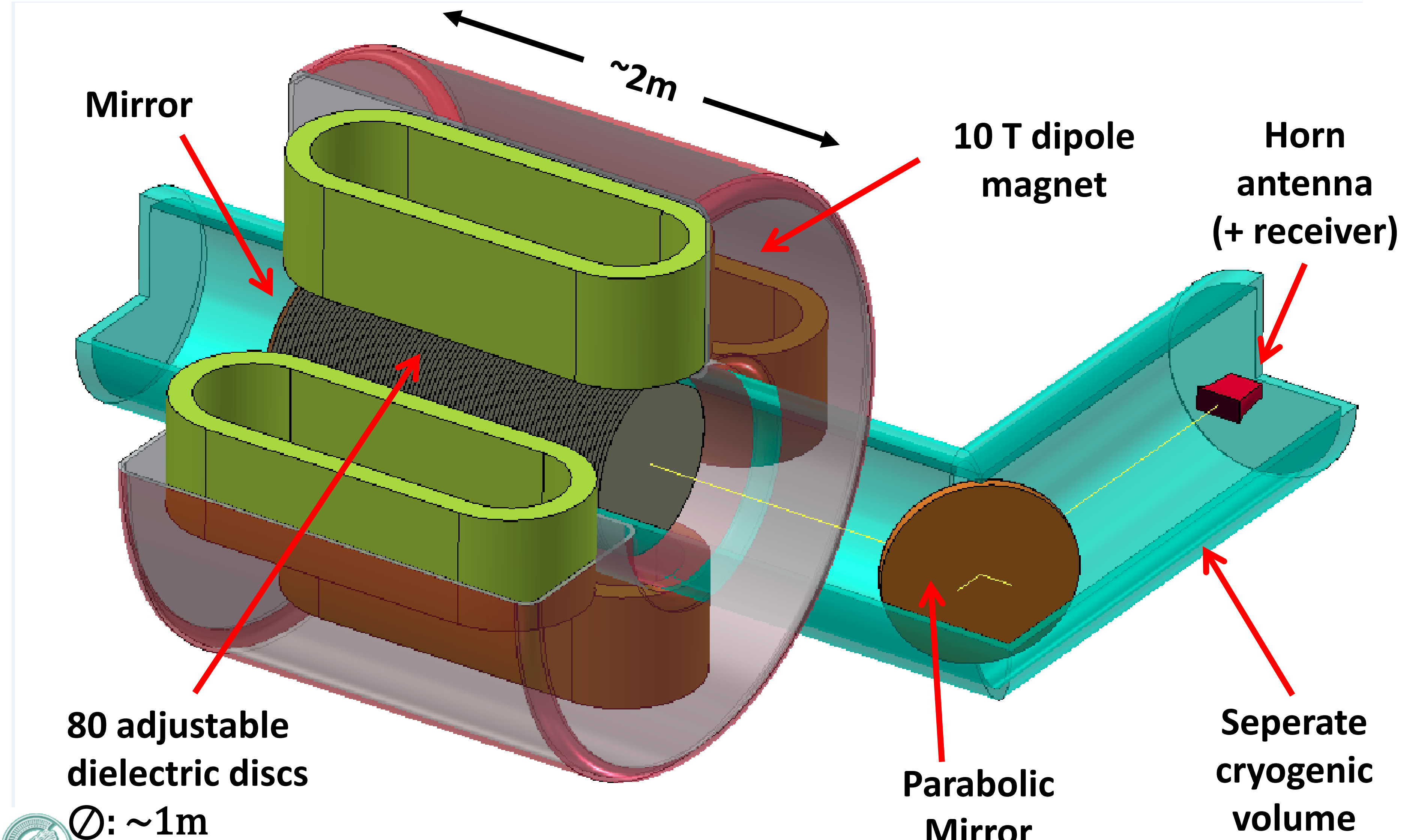
University of Hamburg

University of Zaragoza

Axion DM: Scenario PQ – Inflation



MADMAX
MAgnetized Disc and Mirror Axion eXperiment



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:

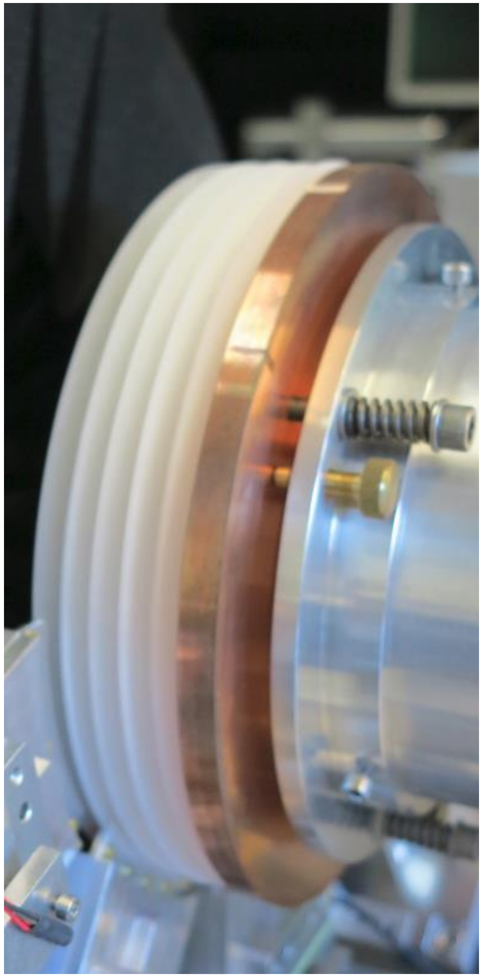
$$\varepsilon \sim 10; \qquad \tan\delta \sim few \cdot 10^{-5}$$

→ Lanthanide Aluminate ($LaAlO_3$) @ 77K

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

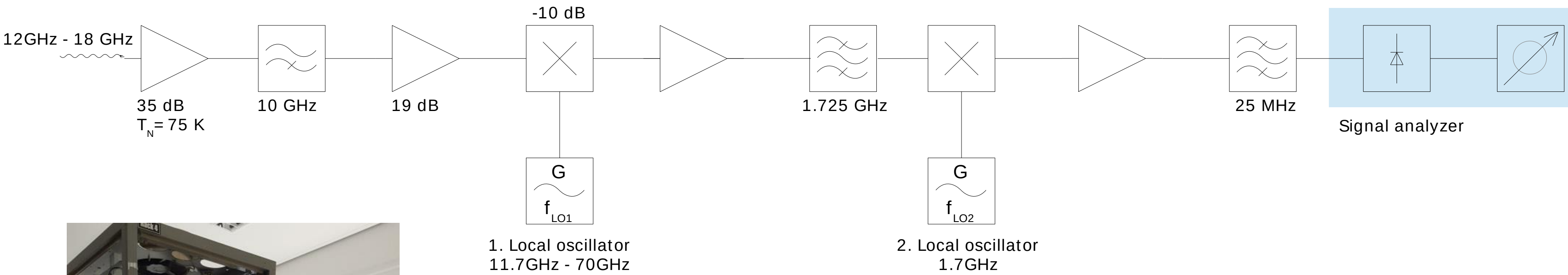
→ Titanium dioxide – Rutil (TiO_2)

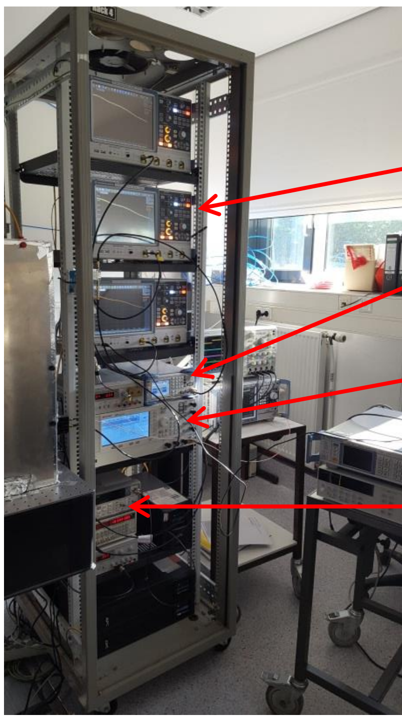
$$\varepsilon \sim 100; \qquad \tan\delta \sim 0.001(?)$$



Experimental idea

Heterodyne detection:



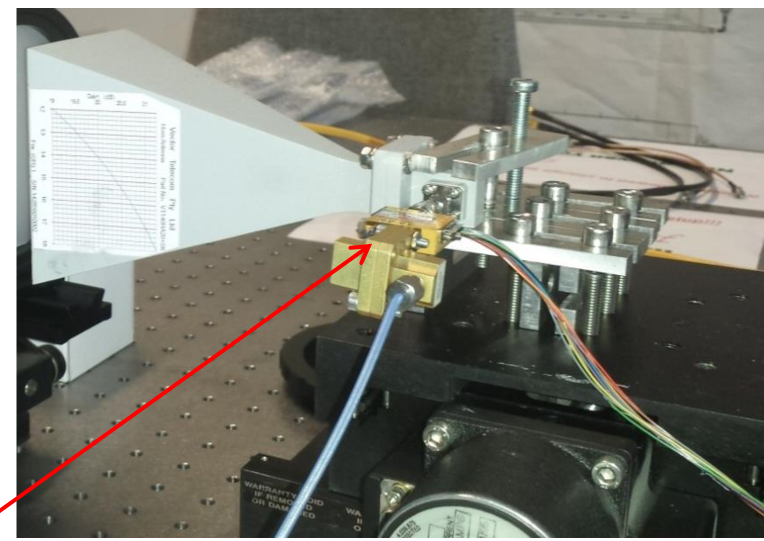


Signal analyzer (3 samplers)

2. local oscillator

1. local oscillator

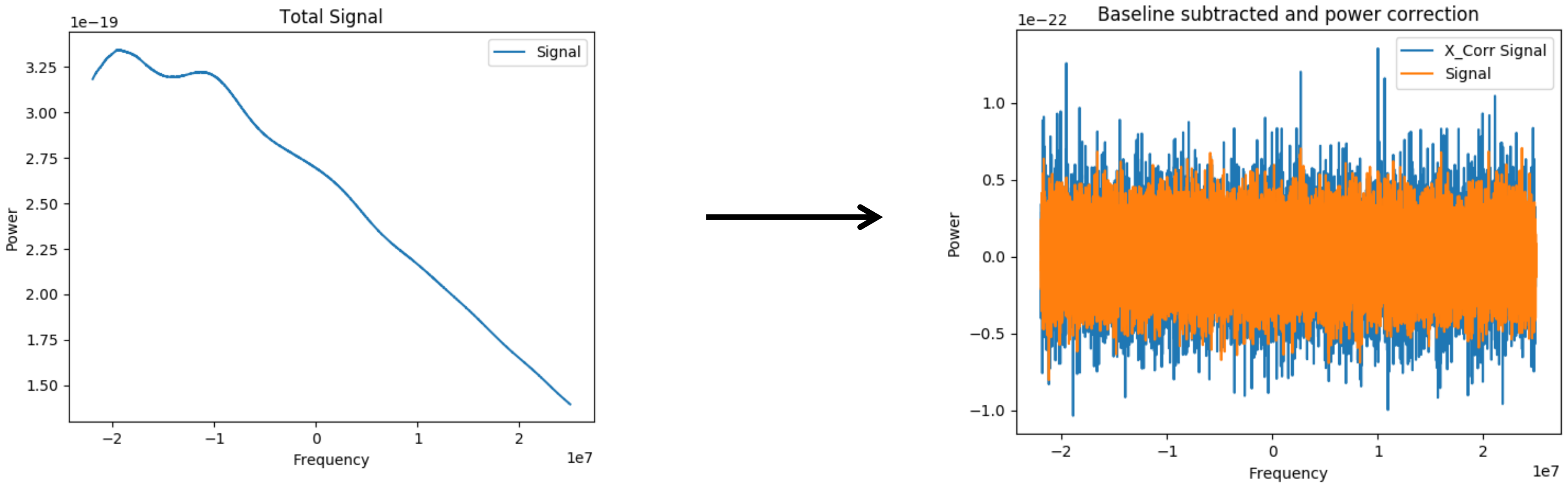
Rubidium time standard (oscillator and sampler synchronization)



1. Amplifier + high pass

First measurements:

Low noise preamp:



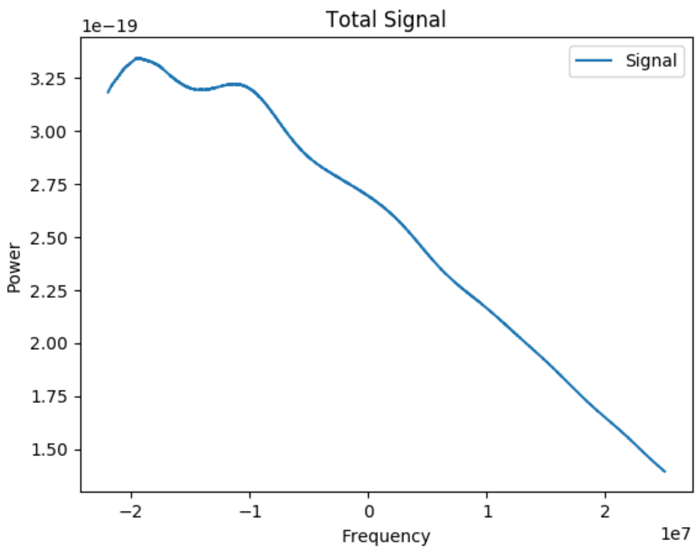
- **Inject fake 18GHz axion signal with $1 \cdot 10^{-22}$ W power**
  - **Measurement for 28 hours (integrate signal): Receiver at LHe temp.**

→ Cross correlation analysis (8kHz Lorentz shaped)
→ found > 6σ signal succesfully

→ For 1 week measurement: expect Sensitivity at the level of ~ few 10^{-23} W (t.b.c.)

First measurements:

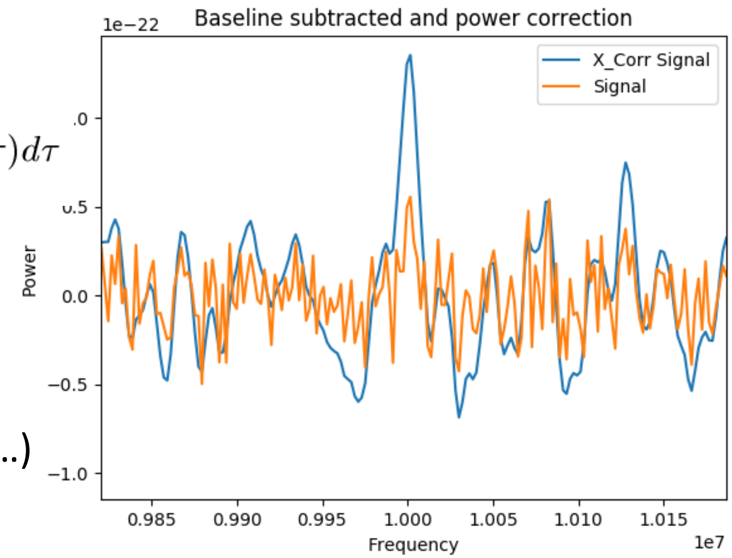
Low noise preamp:



$$X(\tau) = \int s(t)\, T(t+\tau) d\tau$$

→

s: Signal
T: Testfunction
(Lorentz, Gauss, …)



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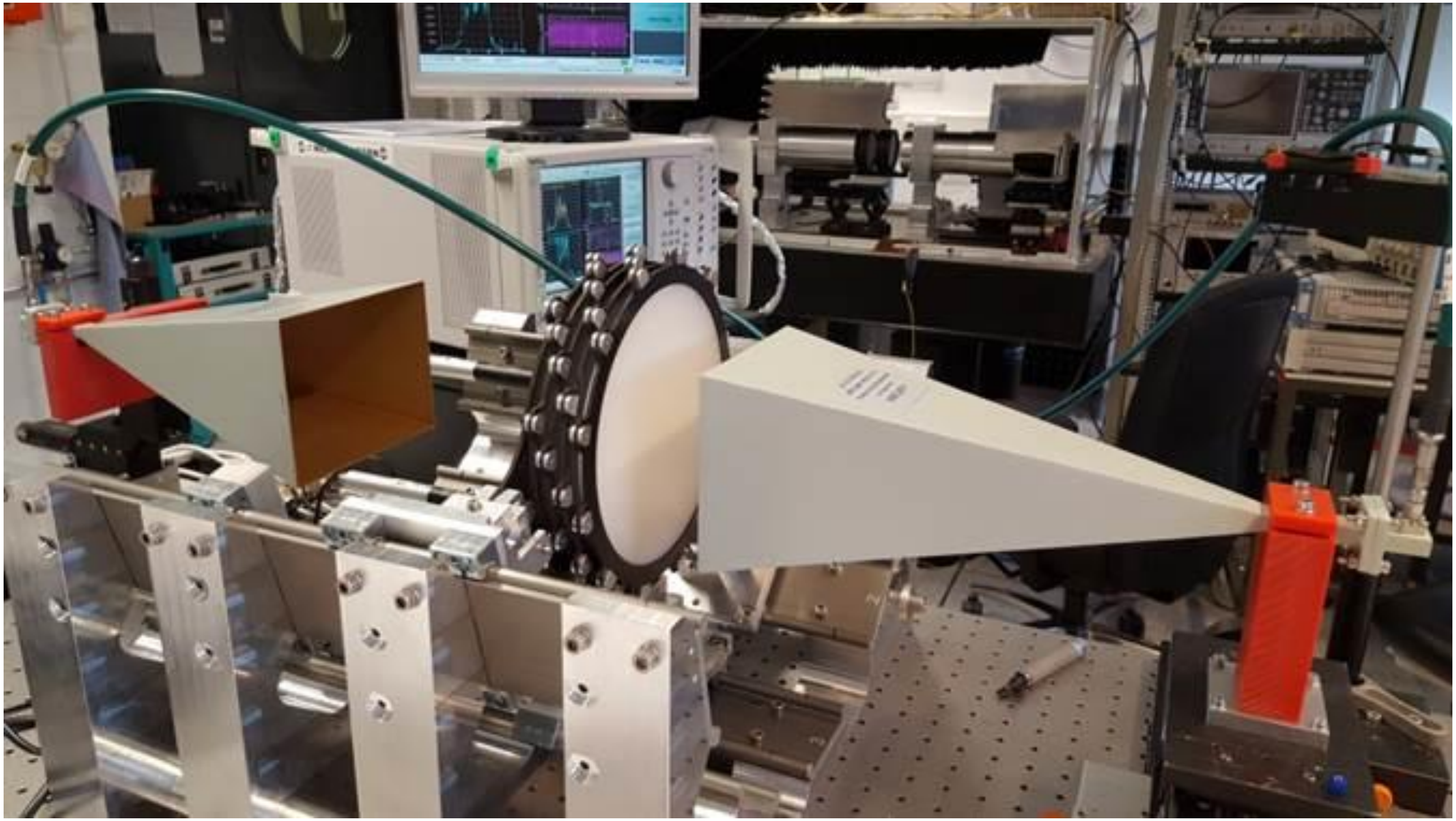
First prototype booster setup:

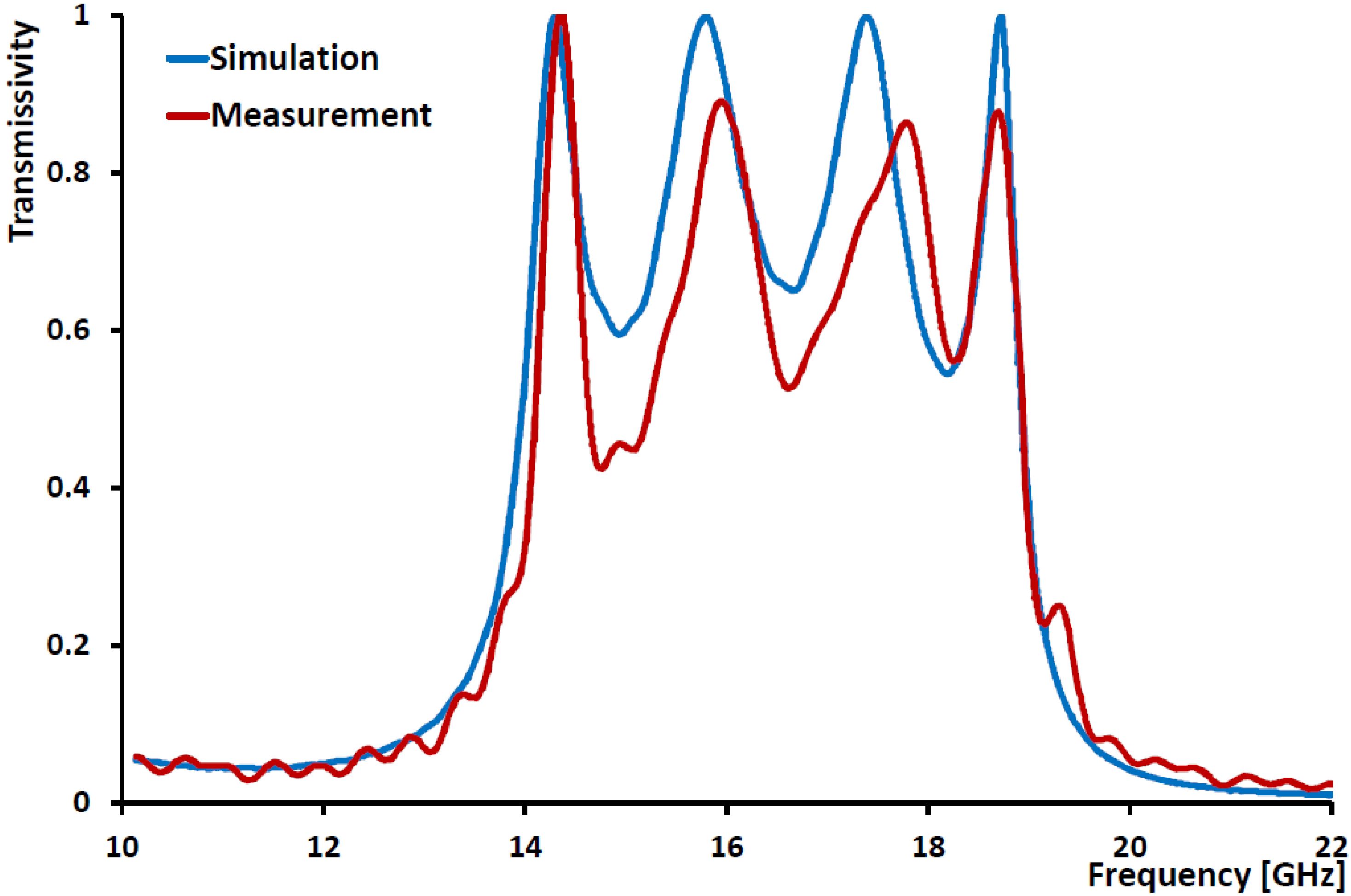
Transmissivity measurement:



Excellence Cluster Universe

First prototype booster setup:

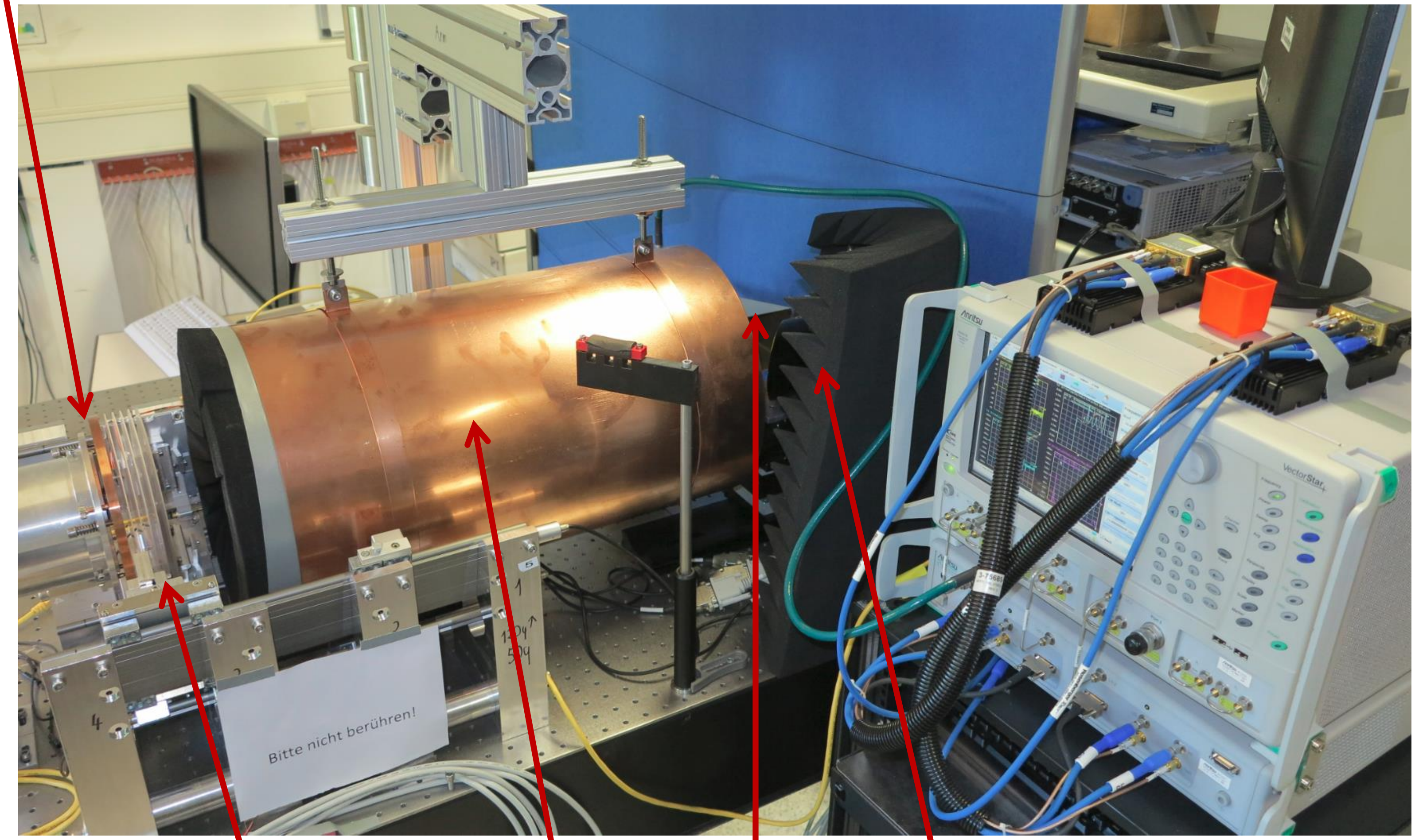
Transmissivity measurement:



First prototype booster setup:

Reflectivity measurement:

Removable copper mirror



Dielectric discs (Saphire)

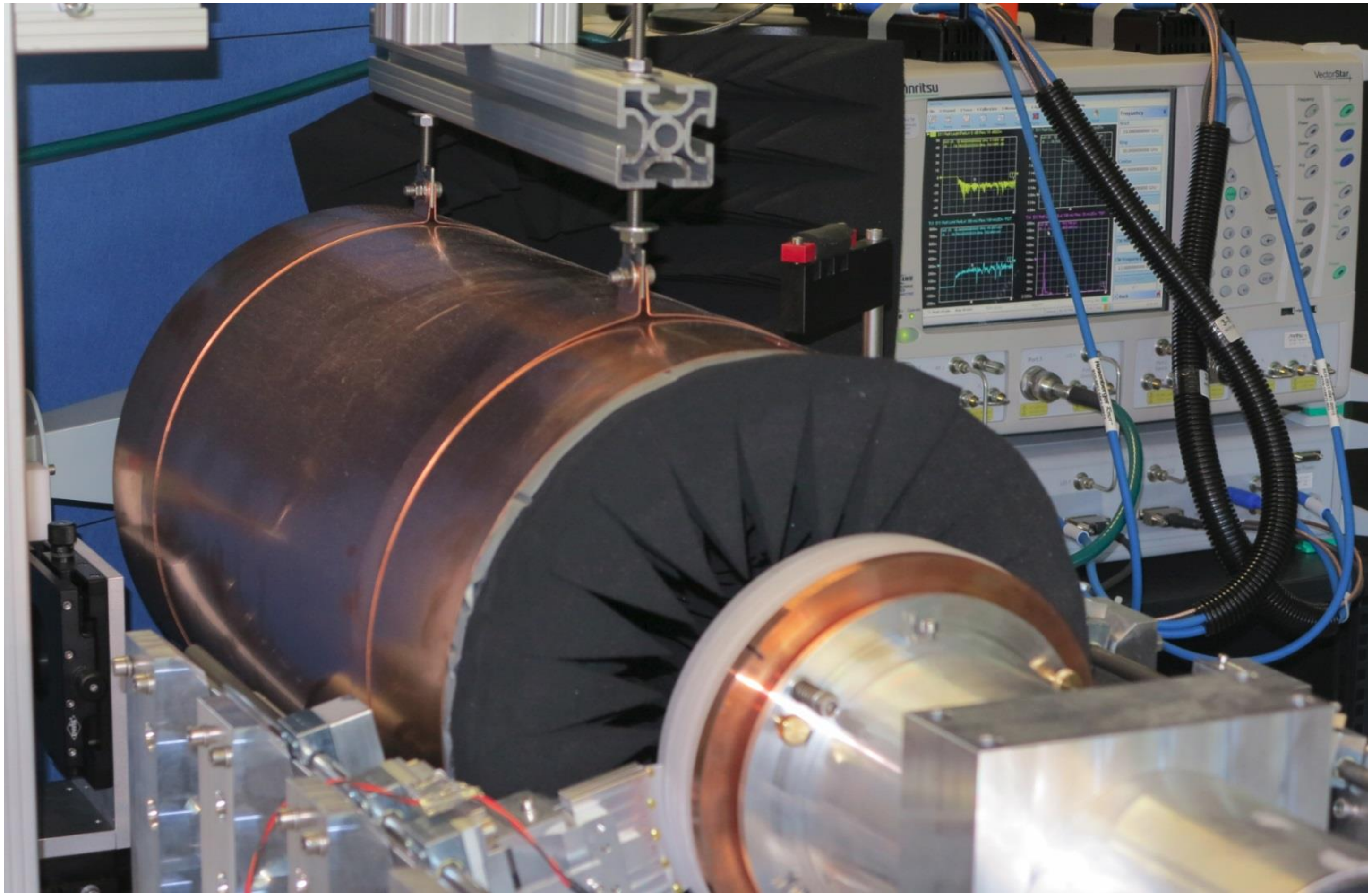
„Wave guide“

Horn antenna

Mirror

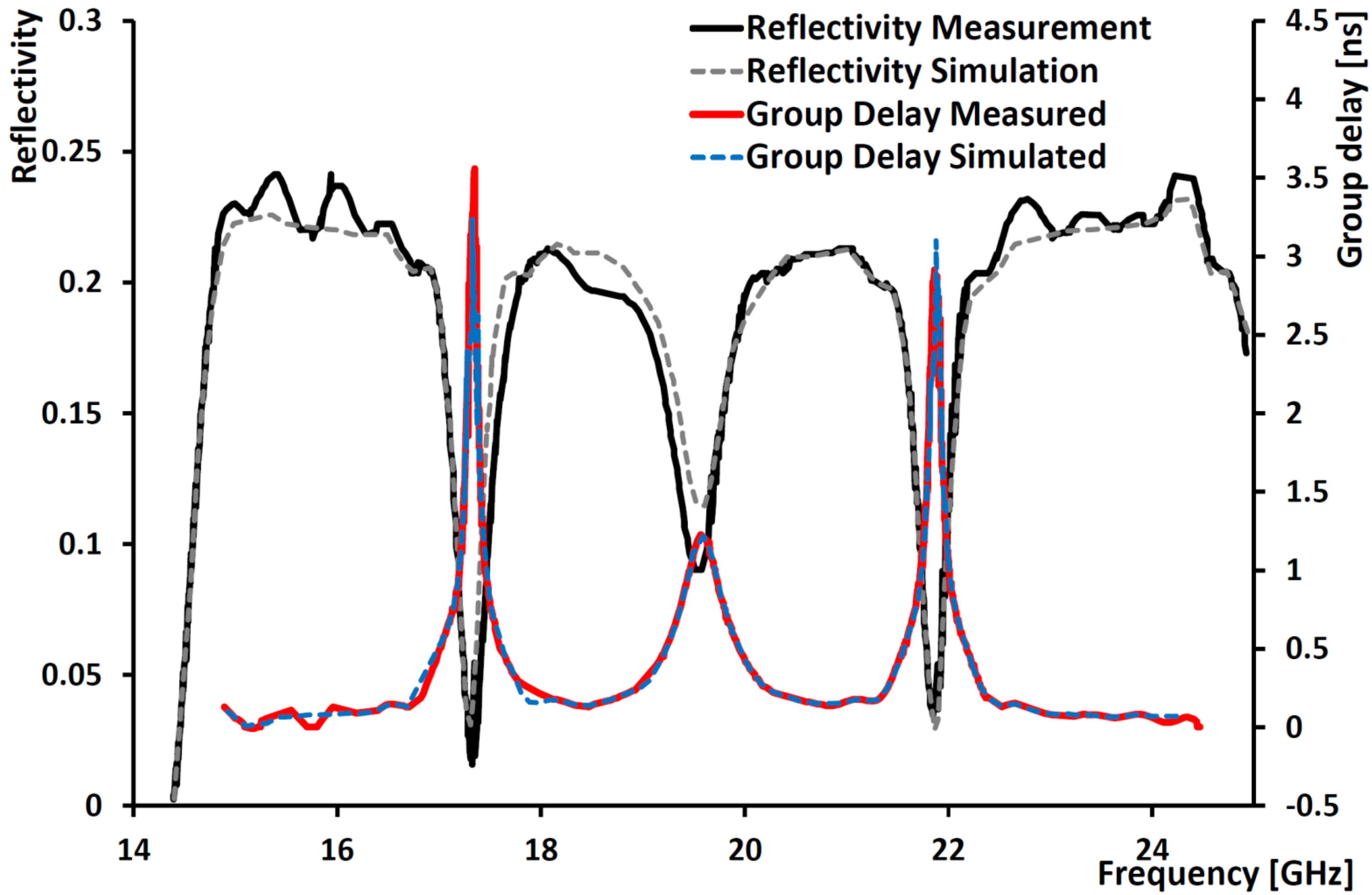
First prototype booster setup:

Reflectivity measurement:



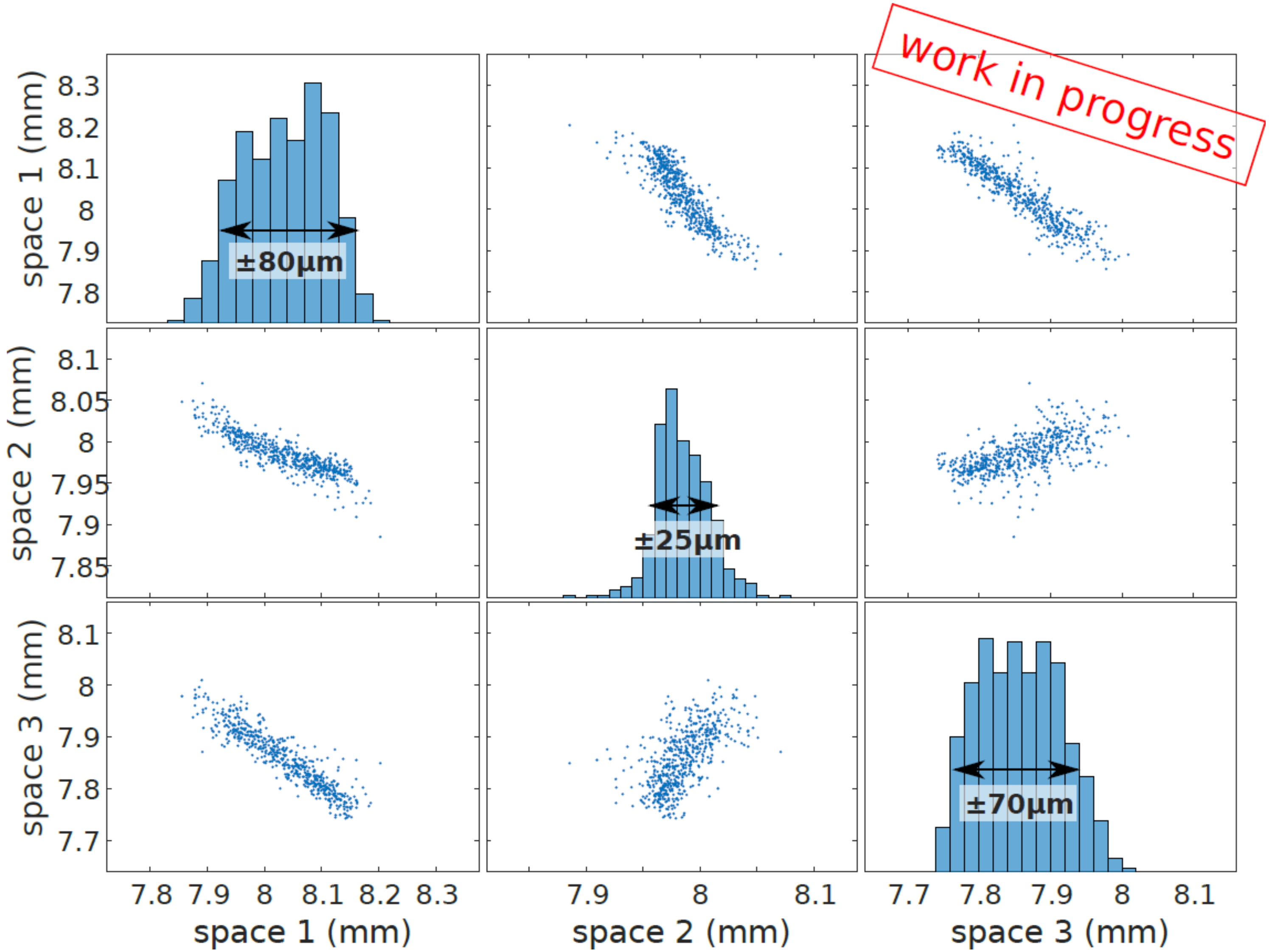
First prototype booster setup:

Reflectivity measurement:



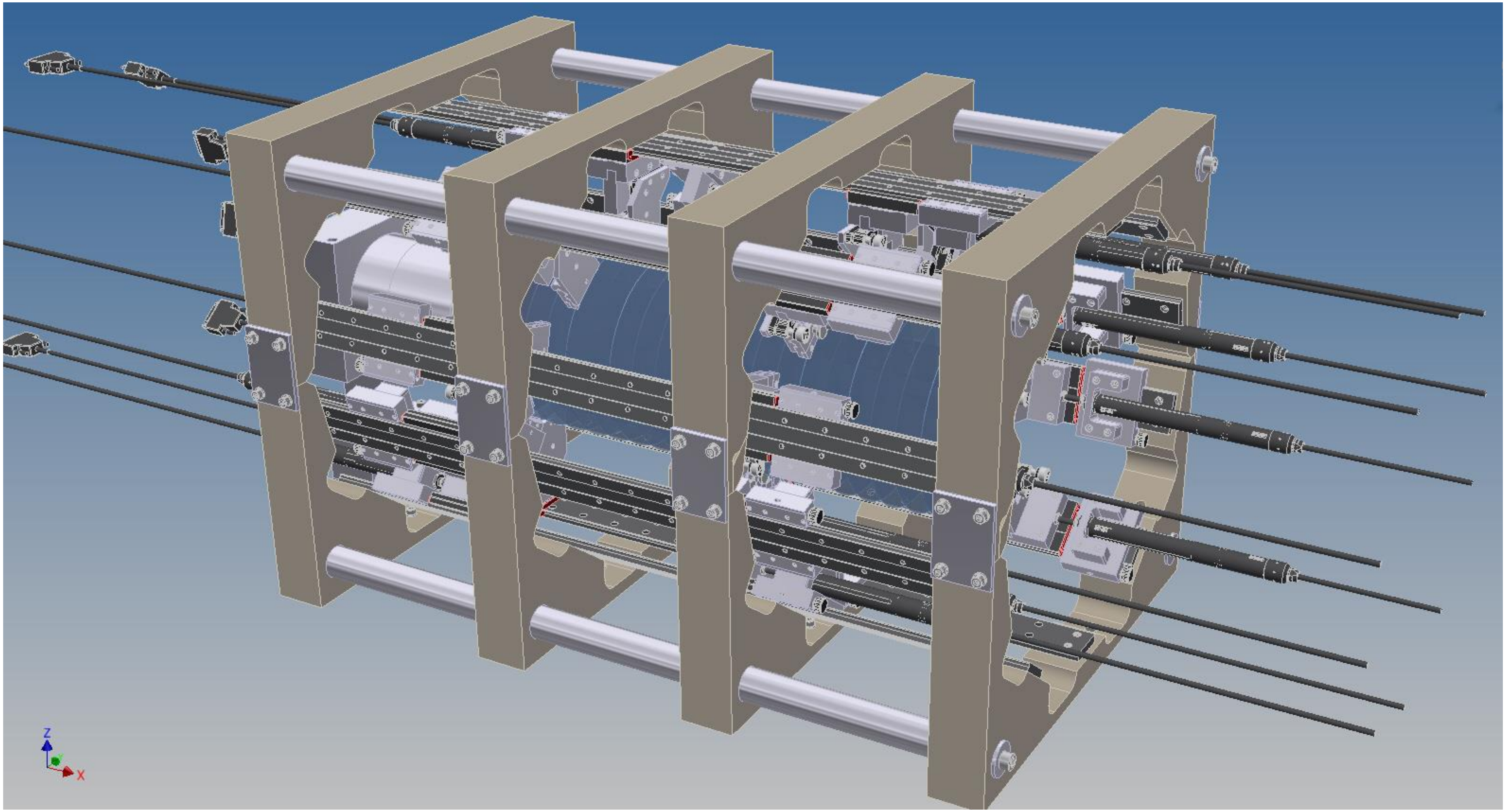
First prototype booster setup:

Position reproducibility:



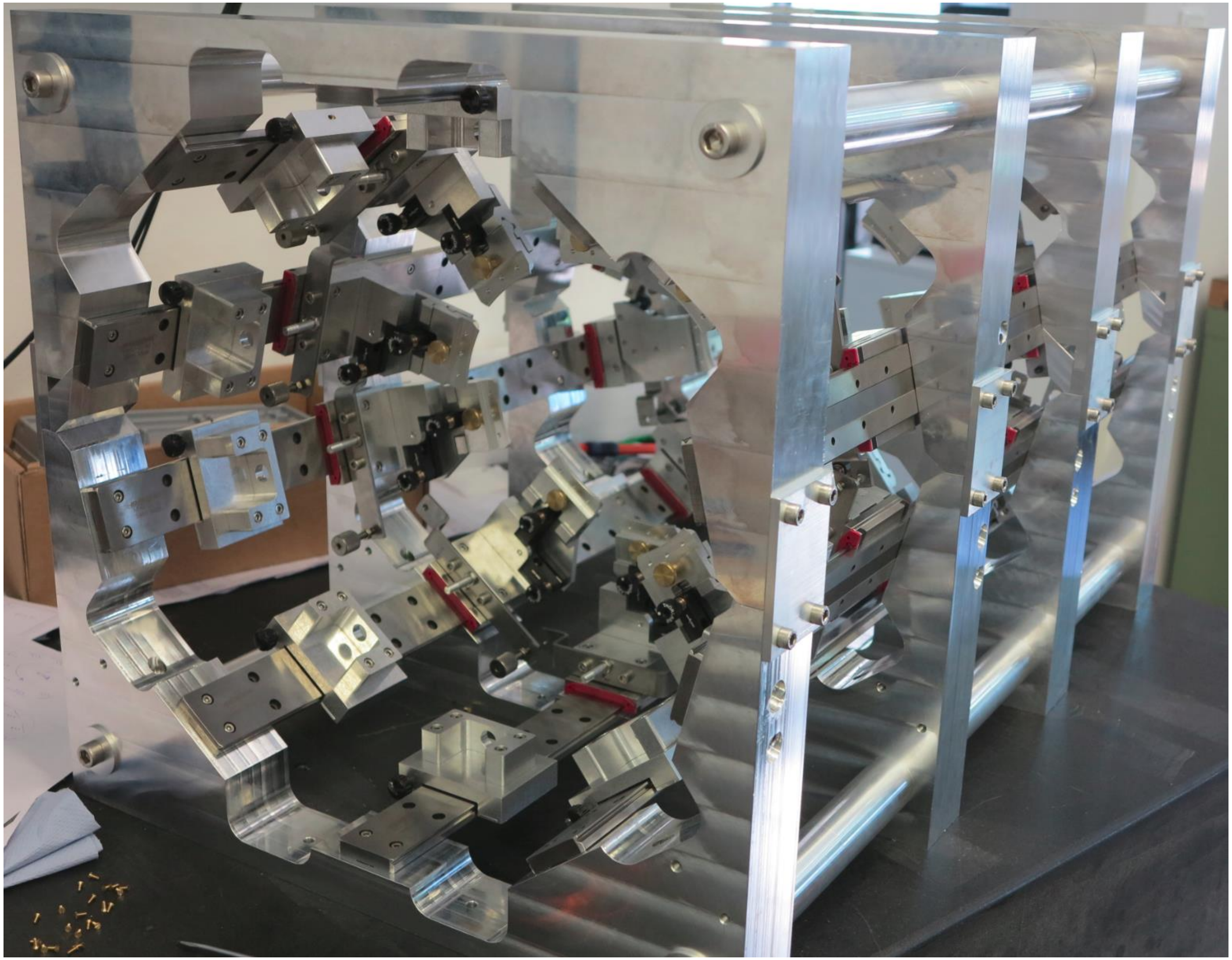
Prototype booster Upgrade:

20 disc setup:



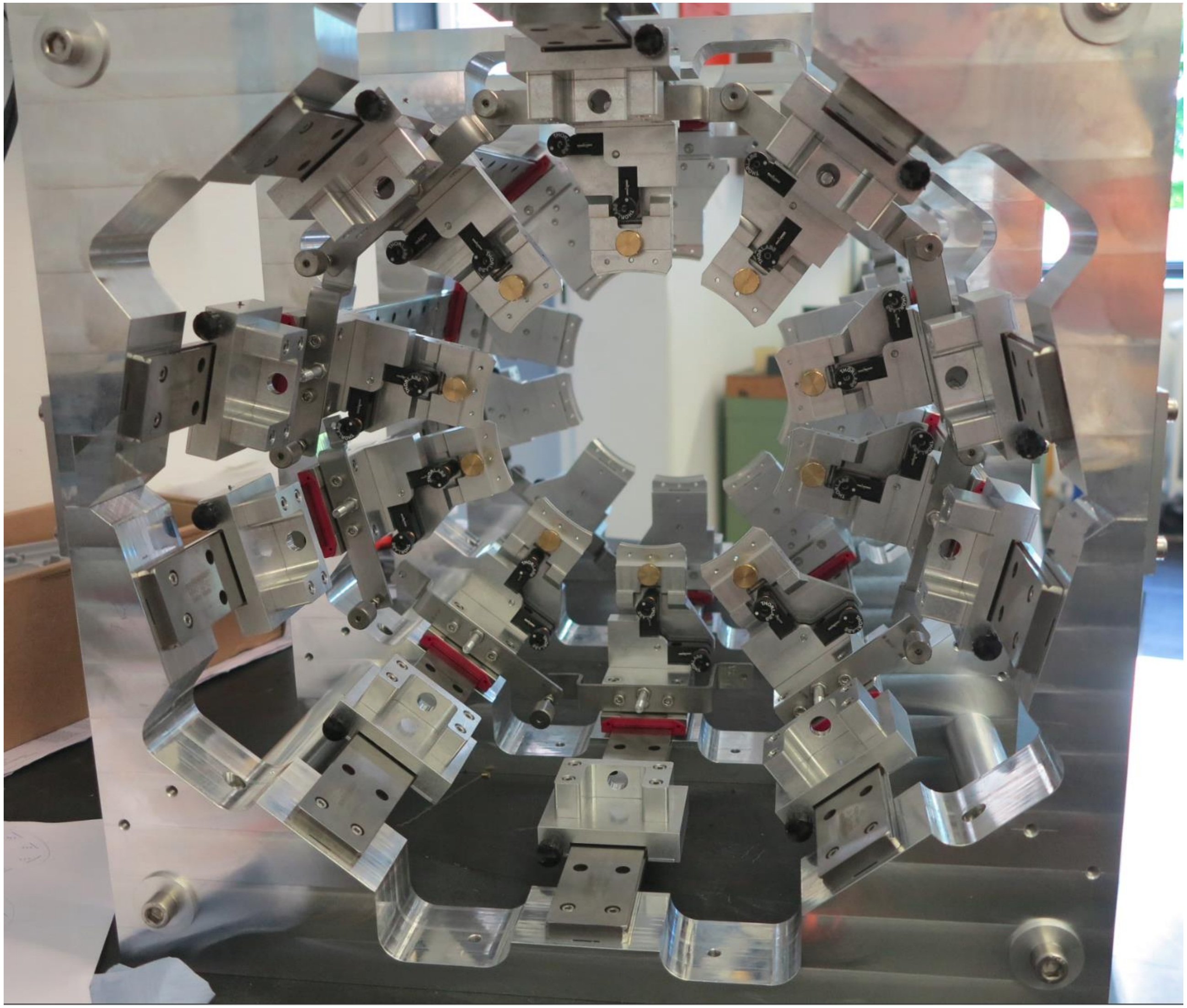
Prototype booster Upgrade:

20 disc setup:



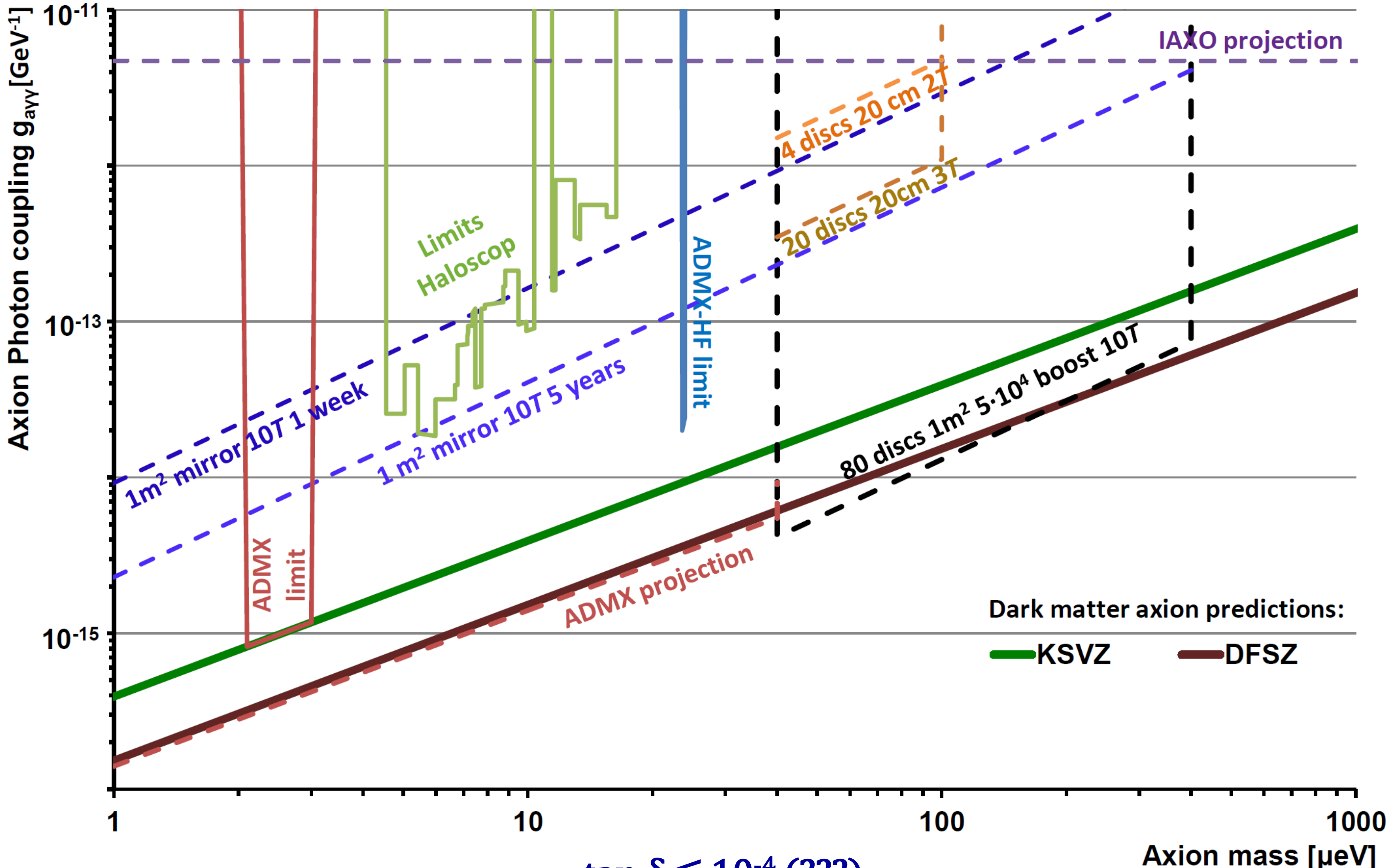
Prototype booster Upgrade:

20 disc setup:



OUTLOOK:

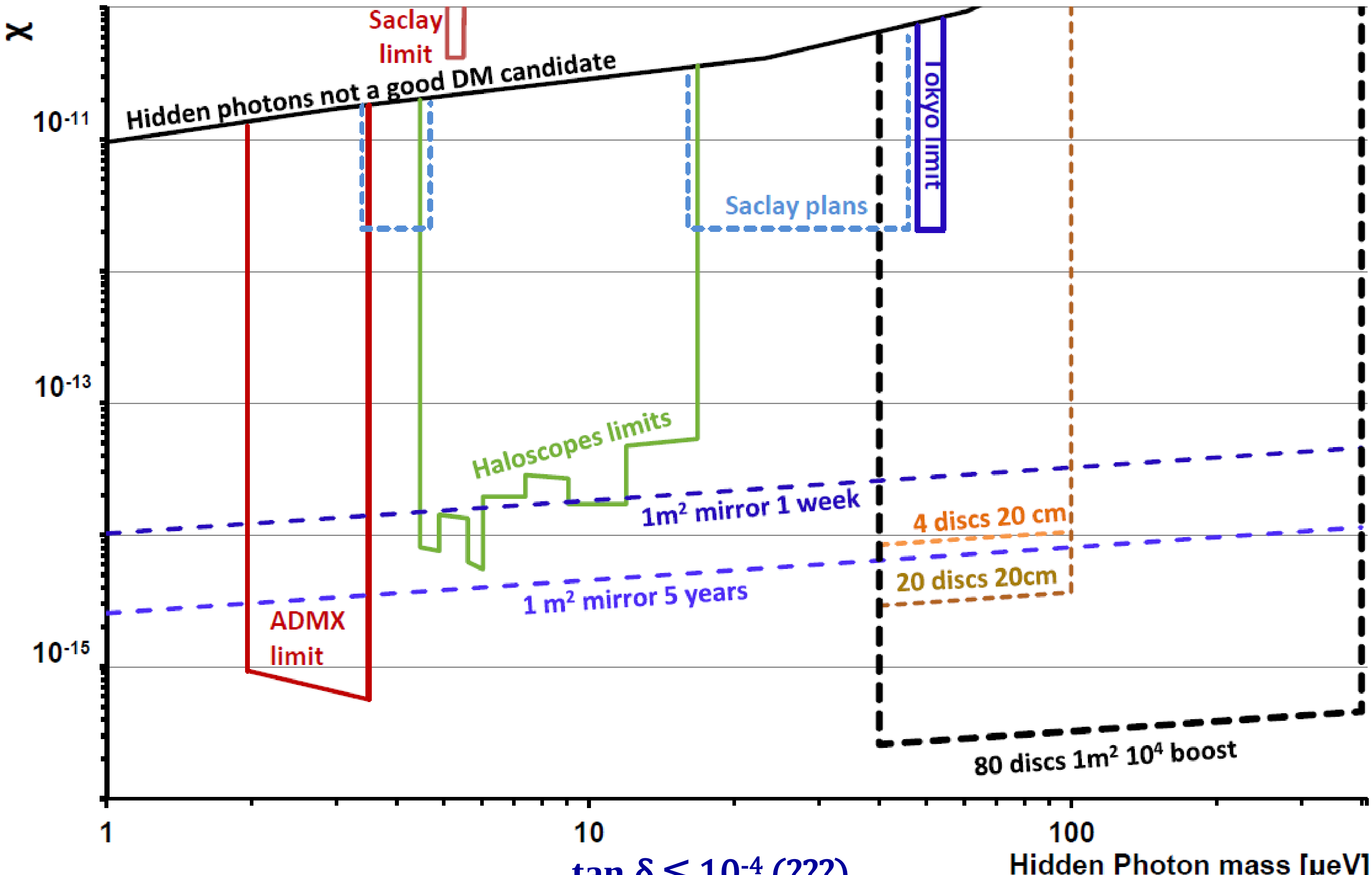
Sensitivty for QCD dark matter axions with A=1m², $B_{||}$=10T, T_{sys}= 8K, β^2=5·10⁴



tan $\delta \lesssim 10^{-4}$ (???)

OUTLOOK:

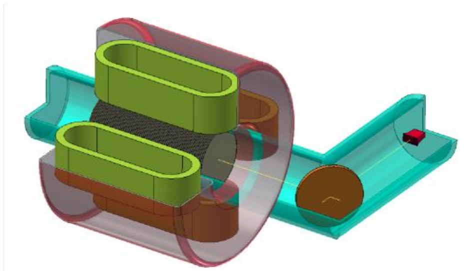
Sensitivty for hidden photons with A=1m², T_{sys}= 8K, $\beta^2=5\cdot10^4$



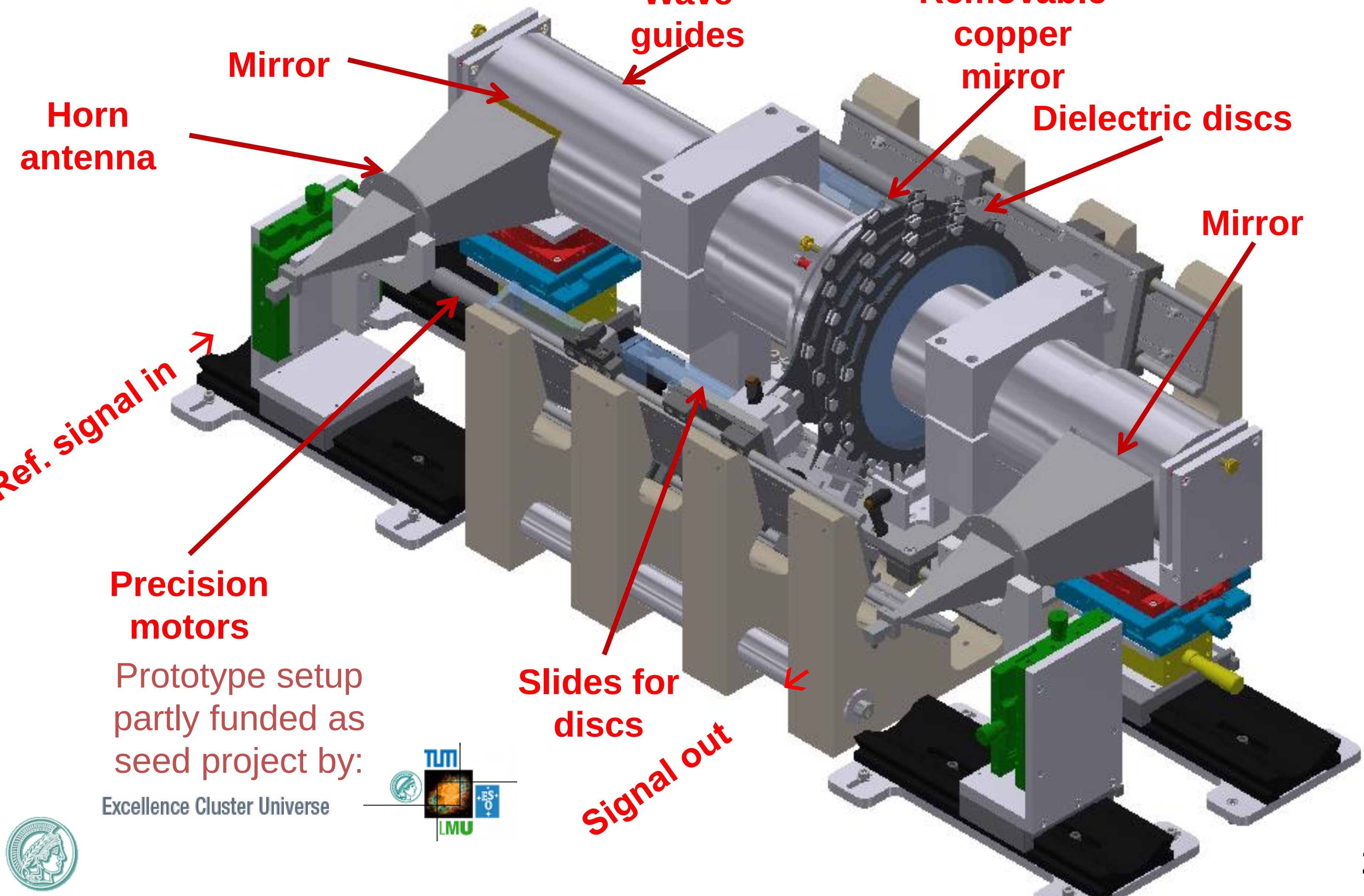
$\tan\delta \lesssim 10^{-4}$ (???)

OUTLOOK:

- Sign MoU → officially establish collaboration
- Magnet innovation partnership with (2018)
 Bilfinger Bacock Noell
 CEA IRFU
- Desin study for booster realization (2018)
- Build prototype 3-4 T magnet &
 20 discs 30cm diameter booster (2021?)
 → First QCD axions results 2021
- Build full scale experiment (>2022)
 Considering DESY as site



First prototype booster setup:



Prototype setup partly funded as seed project by:

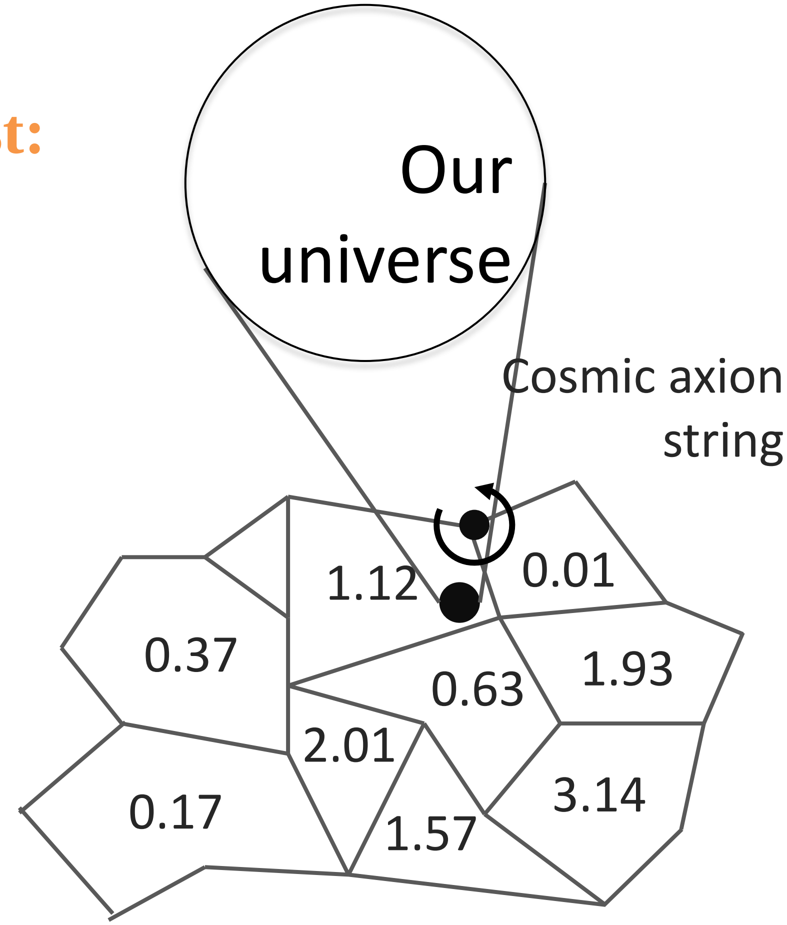
Excellence Cluster Universe

Axion DM: Scenario PQ – Inflation

(Pre Inflationary PQ breaking)

Scenario II: PQ symmetry breaking first:

- θ_i has a single random value which determines the dark matter density
- No “topological defects”



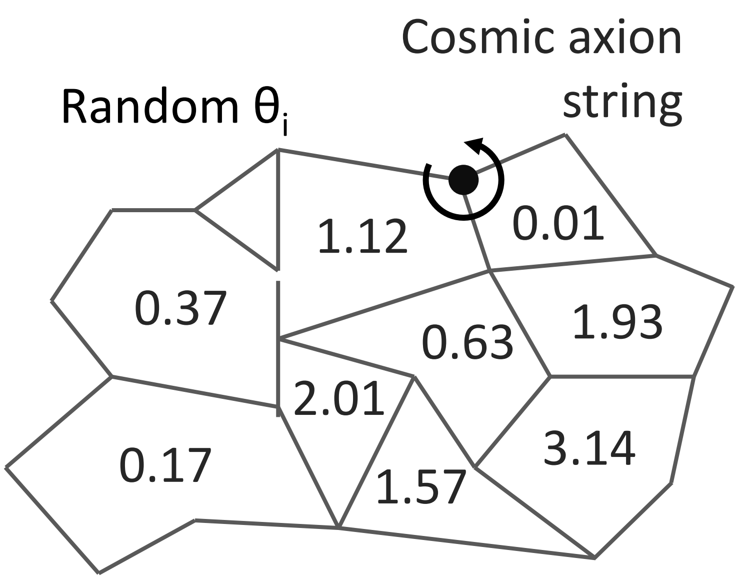
QCD dark matter axions can have any mass ≲1meV!

Axion DM: Scenario Inflation – PQ

(Post Inflationary PQ breaking)

Scenario Inflation first:

- PQ broken after inflation
- θ_i has random values in every casual region, with the dark matter density determined by the average
- Topological defects such as strings and domain walls exist in the early universe
  → decay leads to axion production
  → influence axion density



Predicted axion mass ~ 100 µeV

First measurements:

Low noise preamp:

InP HEMT preamplifier from LowNoiseFactory

Frequency range: 6-20 GHz

detector noise: T~7K (measured, quick and dirty)

T_{ds}~ 6K (data sheet)