Towards the operation of a dielectric haloscope in cryogenic temperatures

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What I will talk about

1. Motivation
   - Why the (QCD) axion
   - How to detect it
   - Why MADMAX
   - Why my project
2. Towards a cold calibration and operation of the experiment
3. Summary and next steps: Measurements at CERN 2024

Why (QCD) axion?

Strong CP problem

There is an allowed CP violating term in the QCD lagrangian

$$L_\theta = \theta \frac{g^2}{32\pi^2} F^a_{\mu\nu} \widetilde{F^{\mu\nu}_a}$$

which induces an electric dipole moment of the neutron

$$d_n \approx 10^{-16}\, \theta \text{ e cm}$$

This, however, is not observed in nature

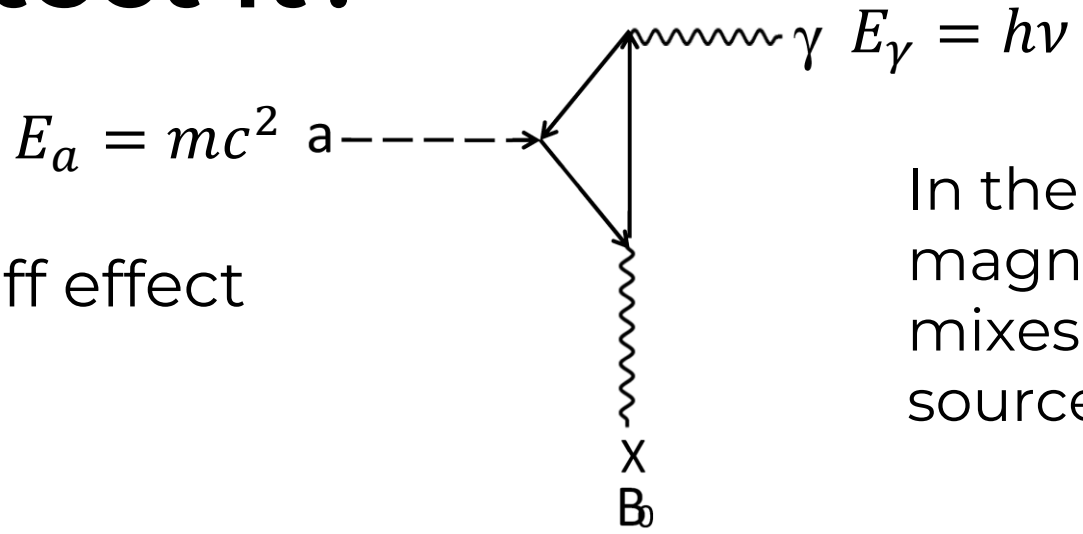
$$\theta < 10^{-10}$$

Dark Matter

~5 times more dark matter than baryonic matter. Cold, Feebly interacting, not in the Standard Model

Main unknown: DM particle mass → **tuning needed**

How to detect it?



Inverse Primakoff effect

In the presence of a magnetic field, an axion mixes with a photon and sources an electric field.

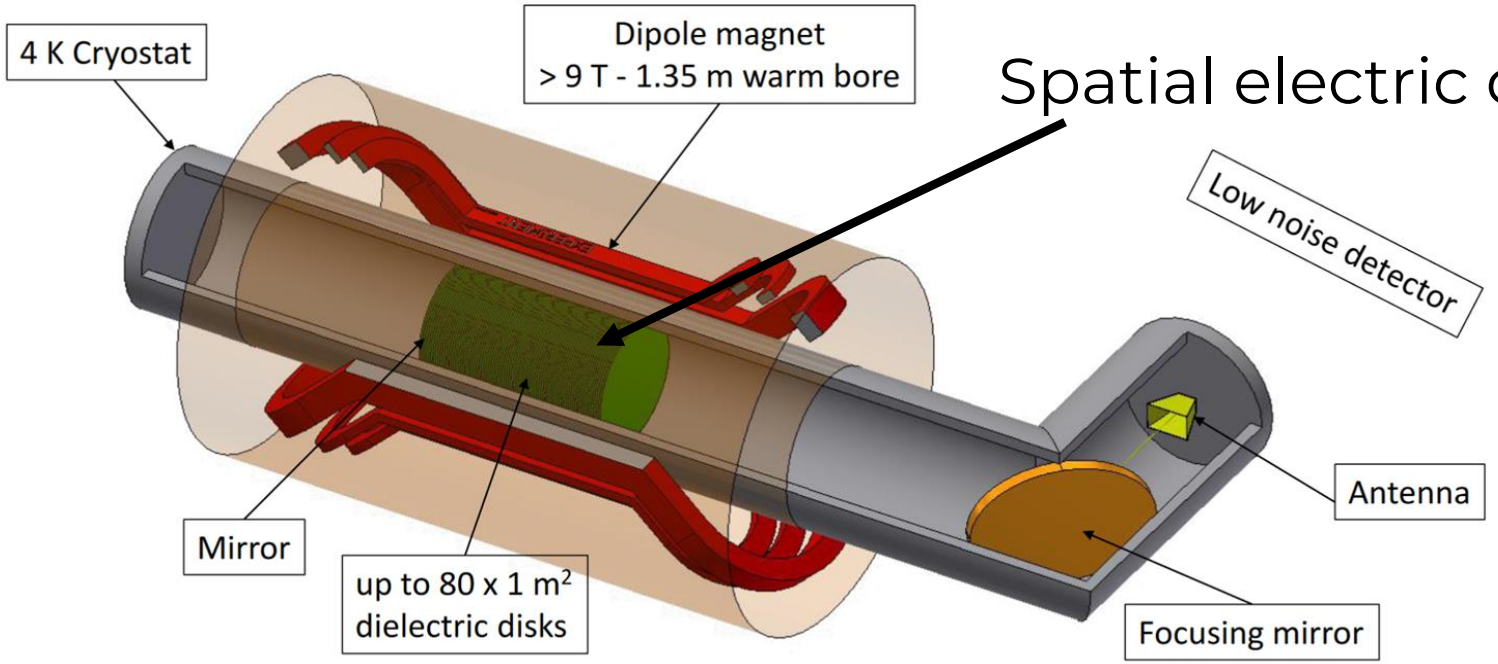
However, there are many other EM sources. For example, thermal radiation!

Axion-induced photons ~ 6 per day

Minimum detectable flux ~ 1 photon per second → Signal **amplification needed**

At ~300K there are ~ 100 times more thermally radiated photons per second than at 4K → **cooling needed**

Why MADMAX?



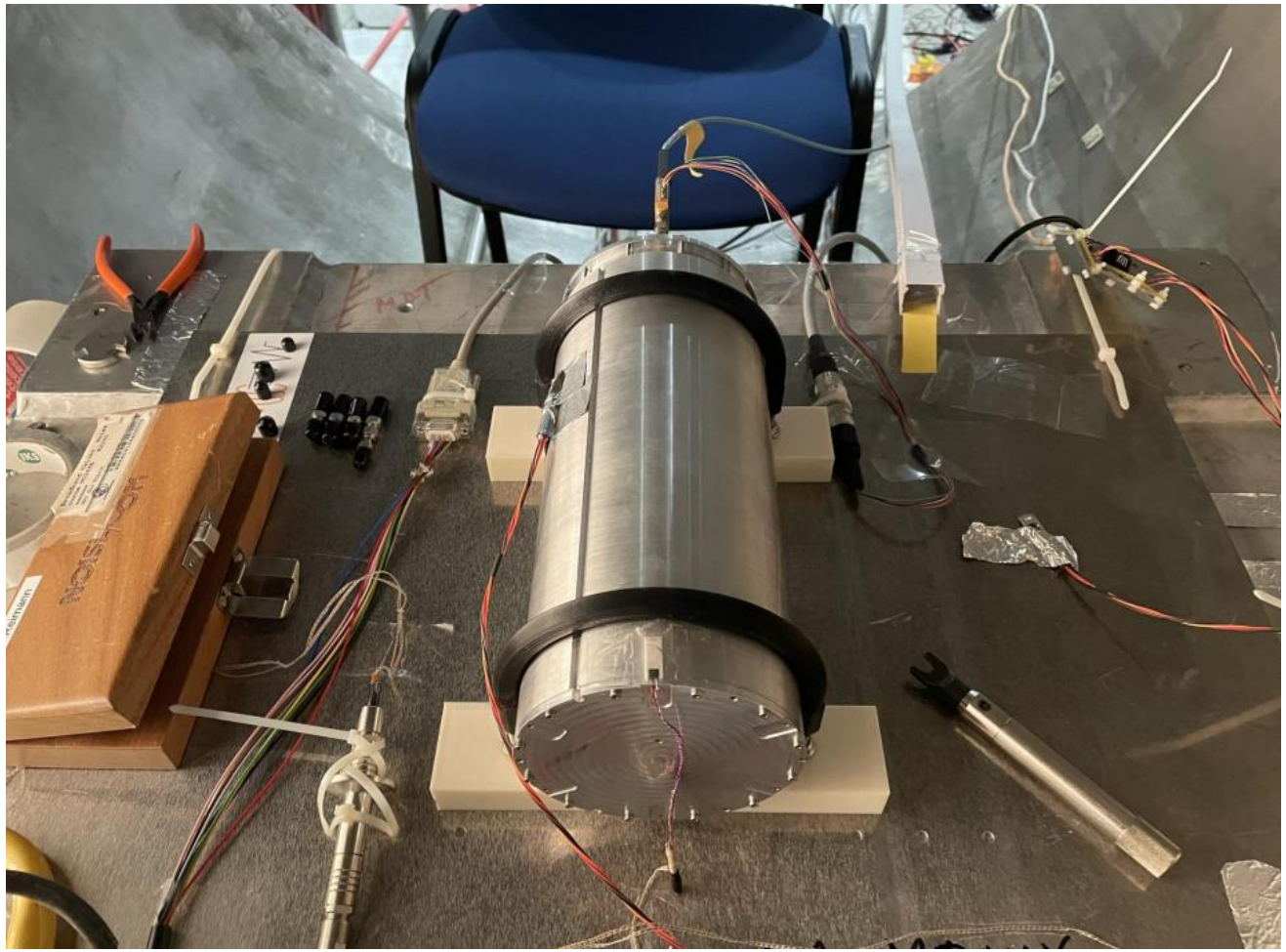
MADMAX addresses the **amplification, cooling** and **tuning** problem in a very well motivated range.

Why my project?

The system at 4K is different: thermal contraction ~ photon wavelength

The current MADMAX prototype (CB-100) needs ~**10 independent measurements** to be calibrated

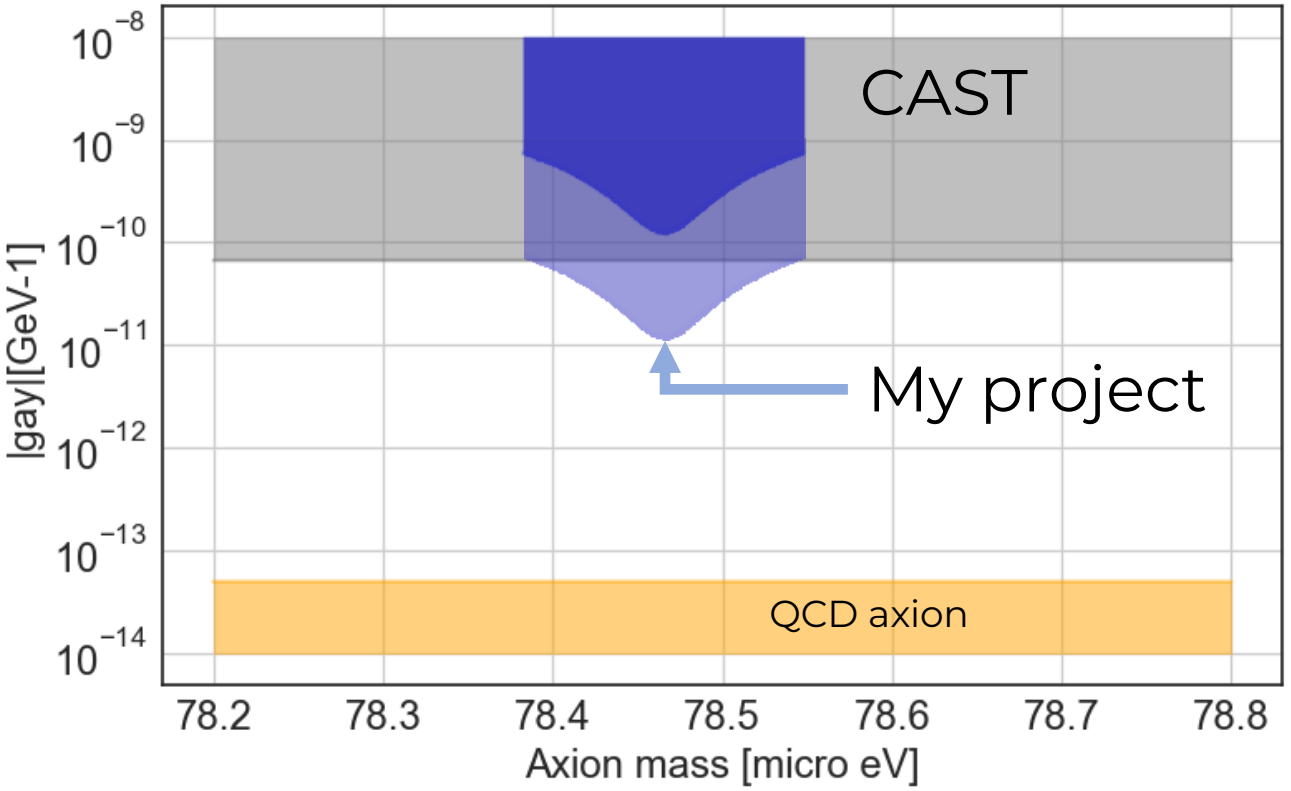
At 300K, this is done manually in ~3 hours, but at 4K this would require a **~1-month** long calibration with reduced stability.



Why my project?

Goal: Perform a **semi-automatic calibration** of the experiment **minimizing the number of thermal cycles** and **maximizing reproducibility** and **stability**

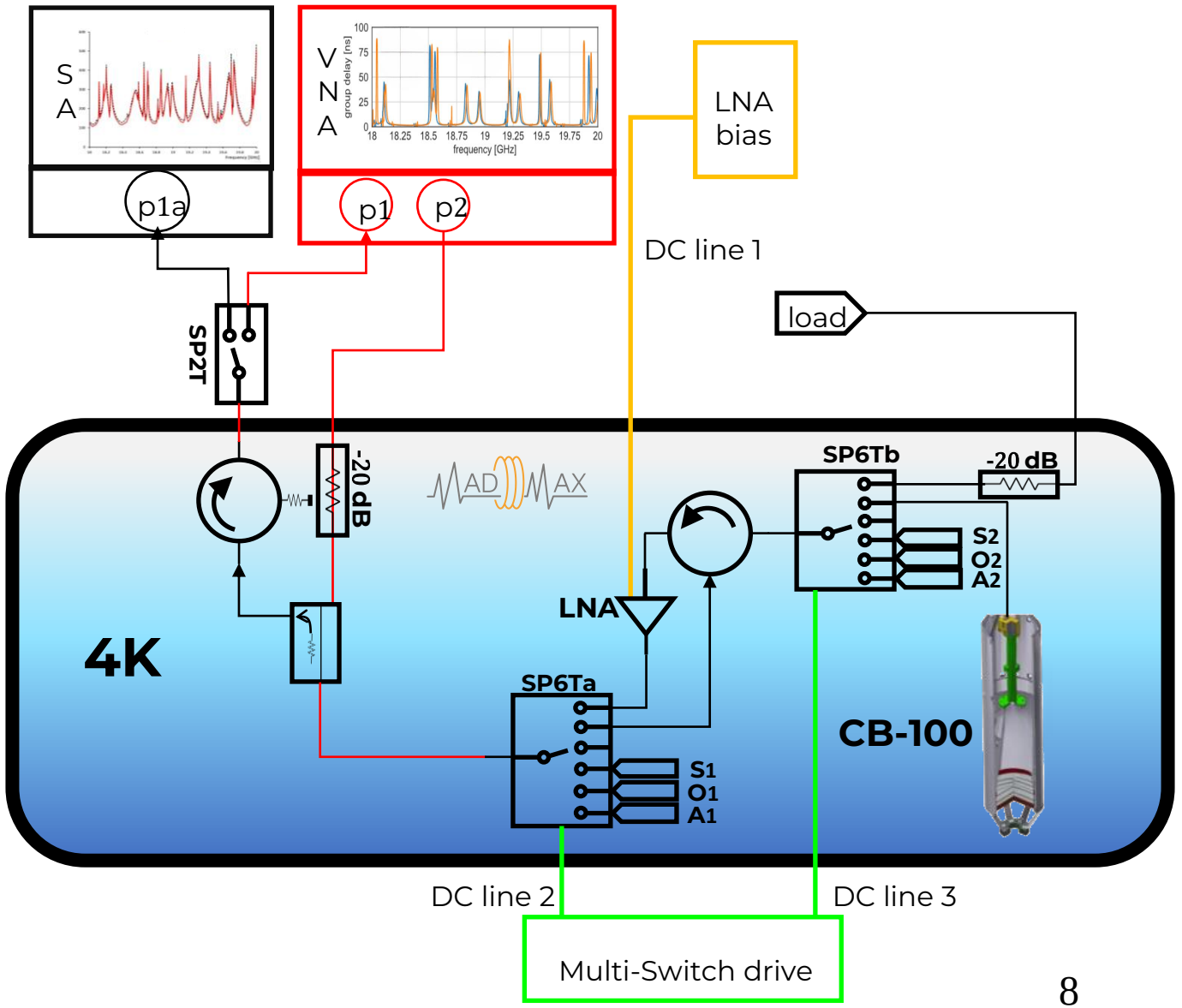
Why? ~1 order of magnitude increase in sensitivity, allowing **DM searches** in so far **unexplored regions**



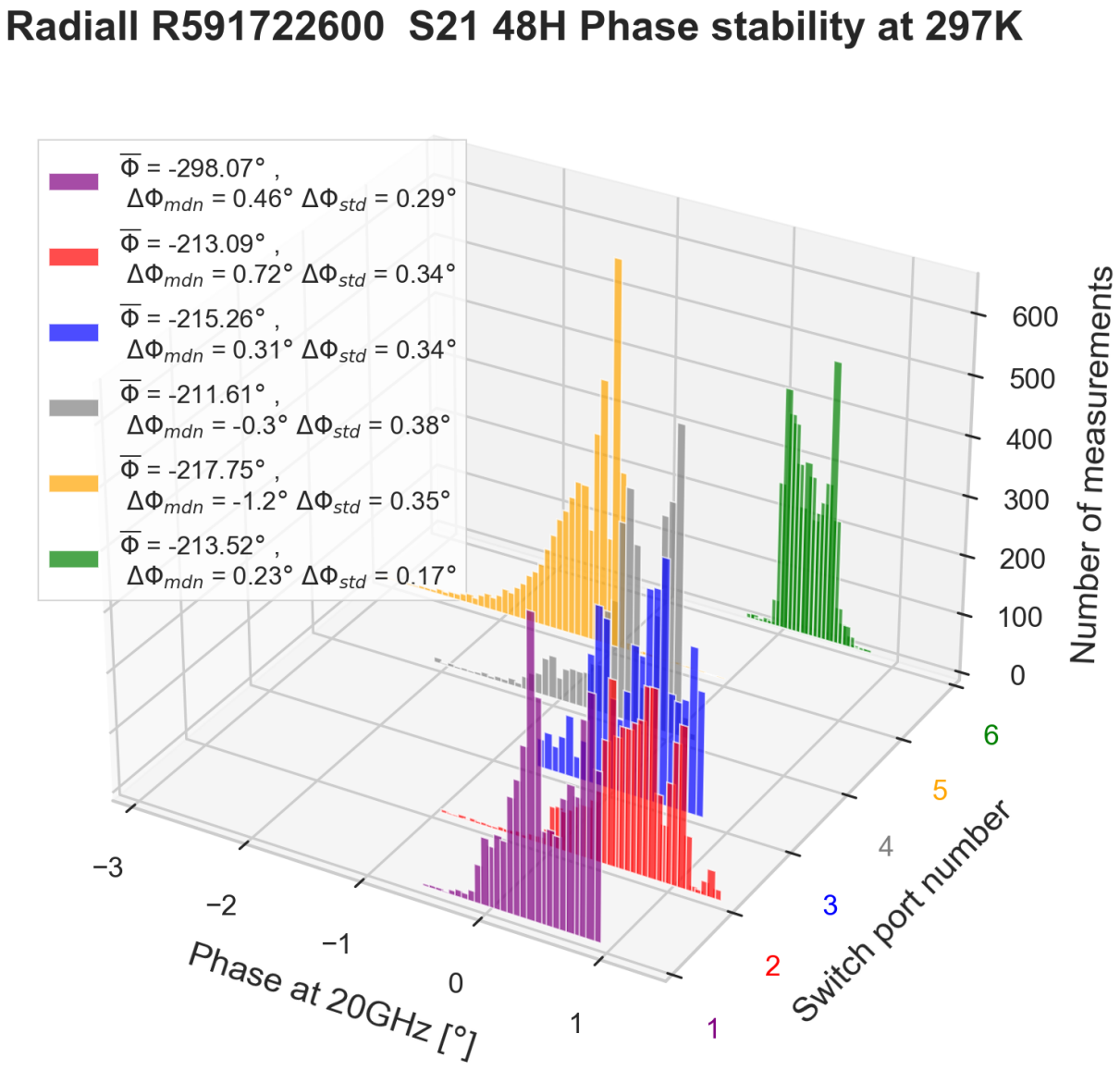
Towards a cold calibration (+ operation)

My idea: a **single thermal cycle setup** to perform noise calibration, reflectivity calibration, and data taking

Main challenge: Ensure **stability** and **reproducibility** in the setup



Switch at room temperature



Phase stability study

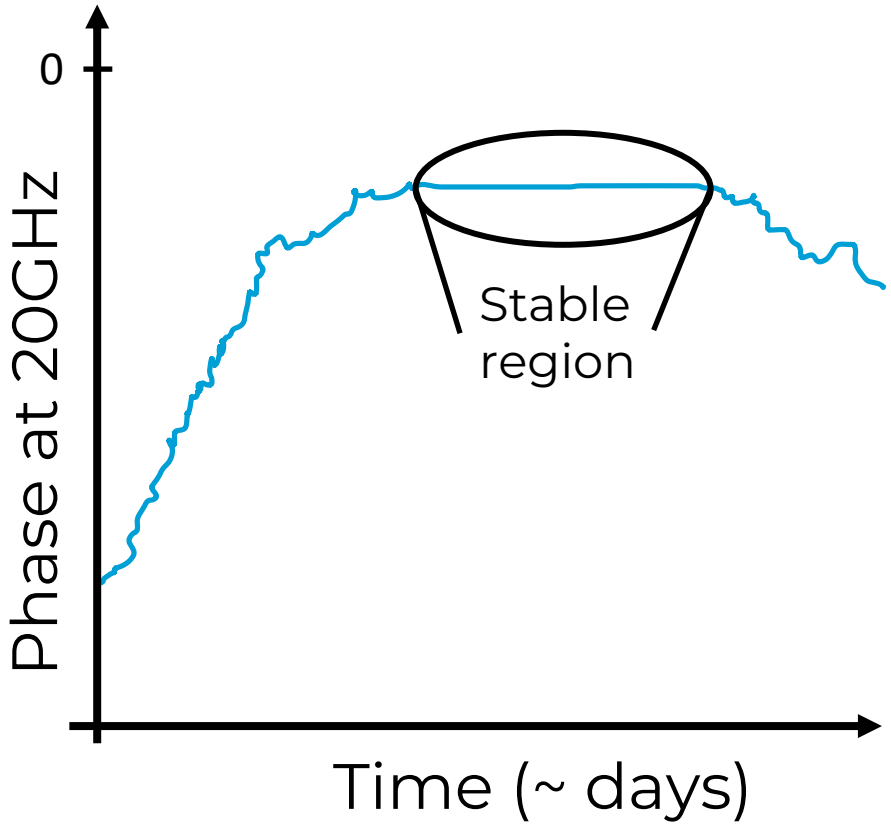
Important parameter: standard deviation

De-embedding length using the statistical median

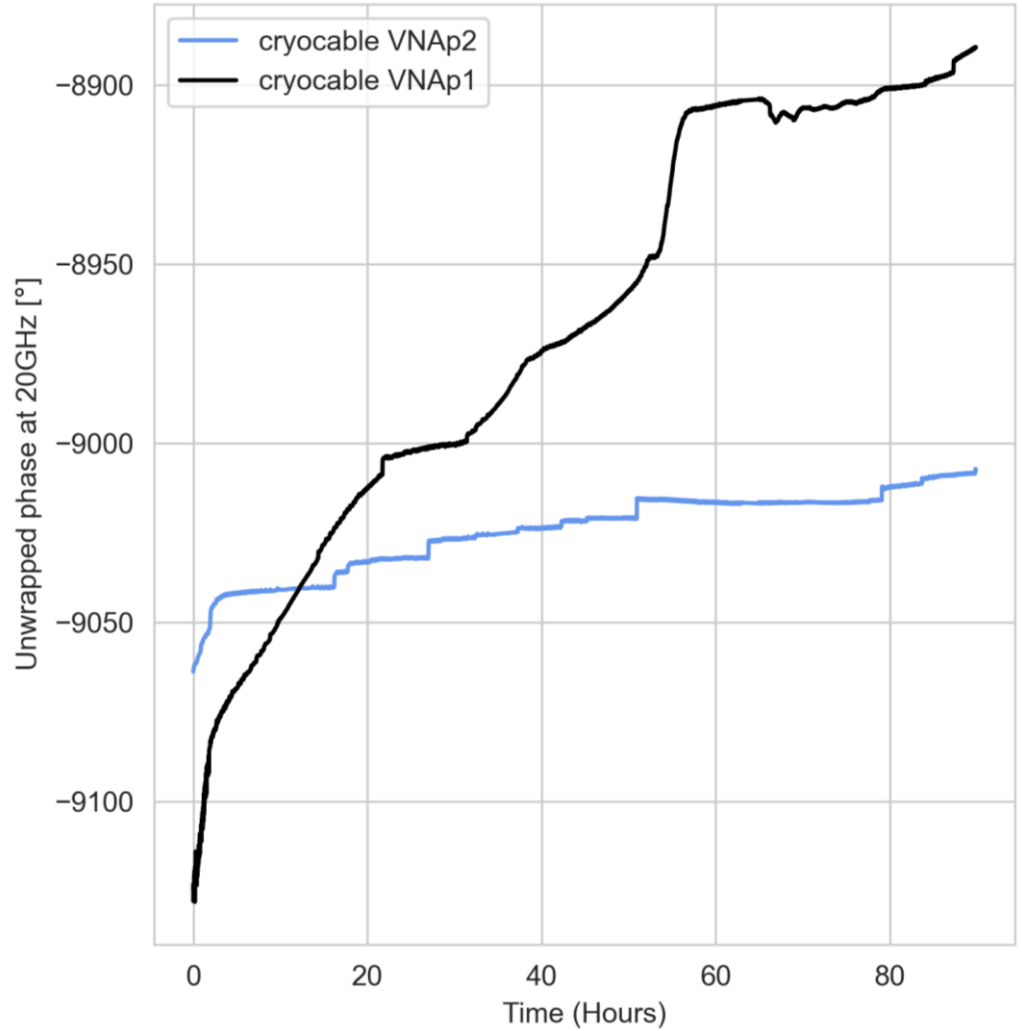
Our requirement: std < 1 degree

Dipstick cryostat

Expectation

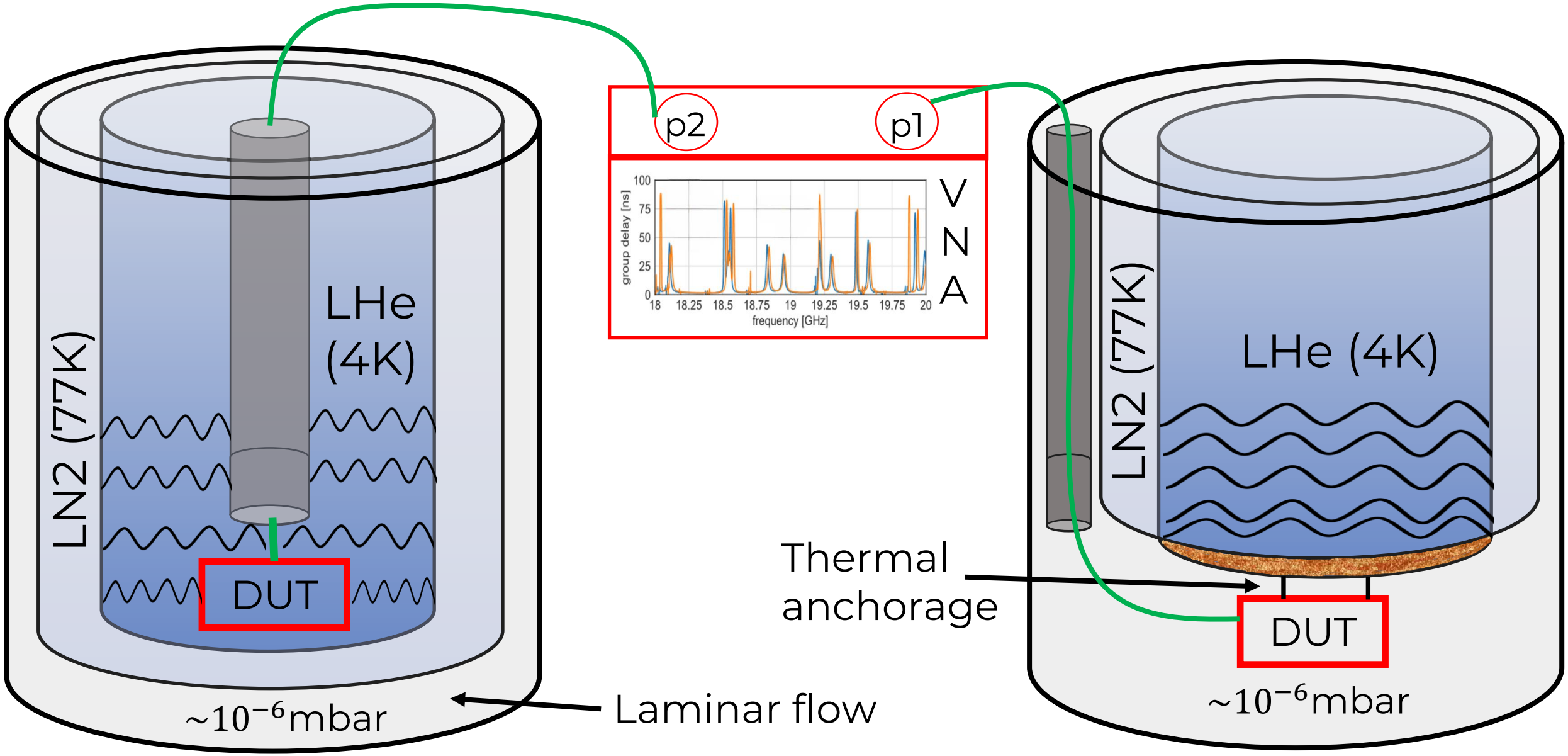


Reality



No stable region was found.
Hypothesis: The LN2 fill level affects the stability of the measurement

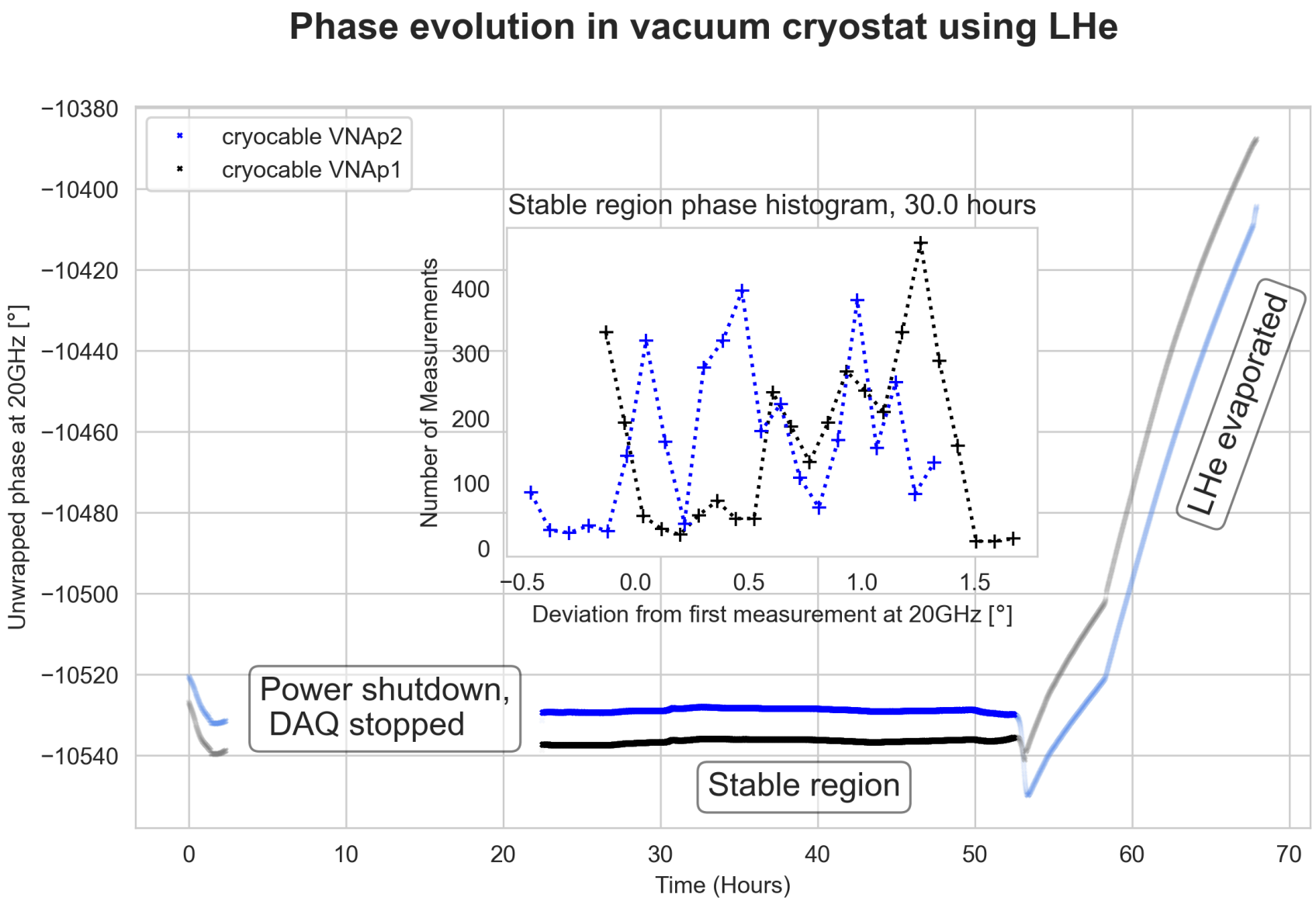
Difference between cryostats



Dipstick cryostat

Vacuum cryostat

Vacuum cryostat



+30 hours of stability!

Deviations < 2° at 20GHz ≈ $55\mu m$

To sum up

- Joined MPP 9 months ago with a **central role** in MADMAX: **approach** the **cryogenic calibration** of CB-100 **minimizing the thermal cycles** required

- Devised a **single-cycle calibration and operation** scheme

- Goal: **lead** the **first** MADMAX **cryogenic** dark matter **search** at CERN in 2024
  - What can be accomplished? ~**1 order of magnitude increase** in the **sensitivity** of the experiment and **first** MADMAX dark matter **limit** in a so far **unconstrained region.**