How to detect a QCD axion with MADMAX

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On behalf of the MADMAX collaboration

TAUP VIENNA 2023

Overview

Motivation for MADMAX

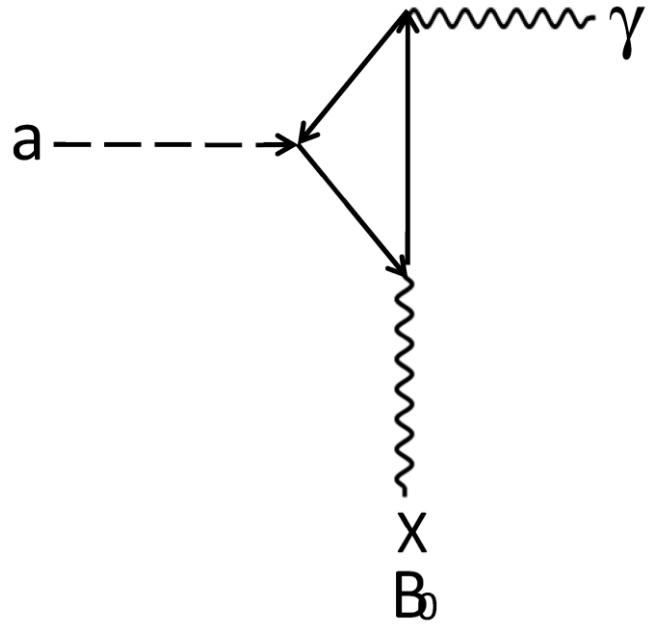
Latest news:

- Run at CERN and monitoring system
- New cryostat
- MADMAX new magnet update

Next steps:

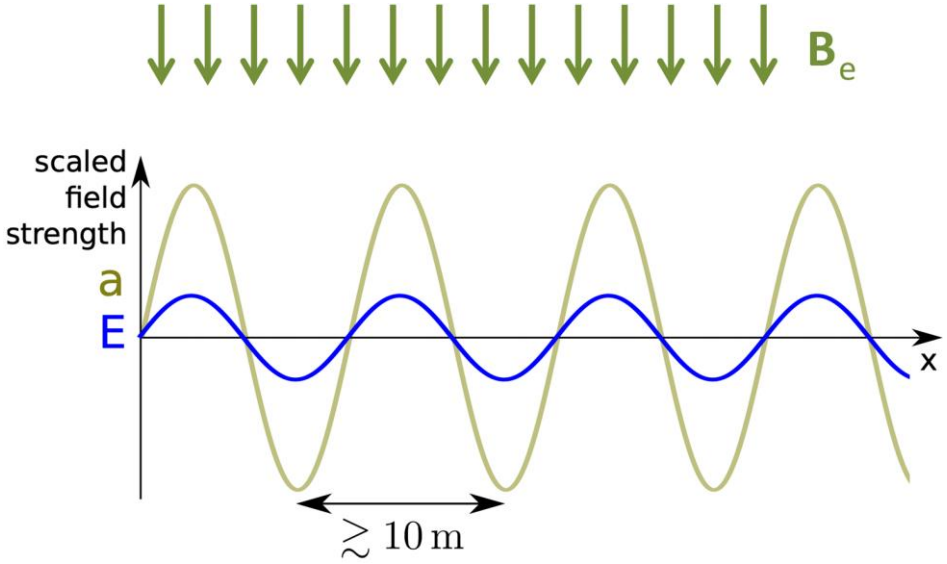
- Cold operation of current prototype
- The next prototype
- Prototype cryostat

The MADMAX experiment

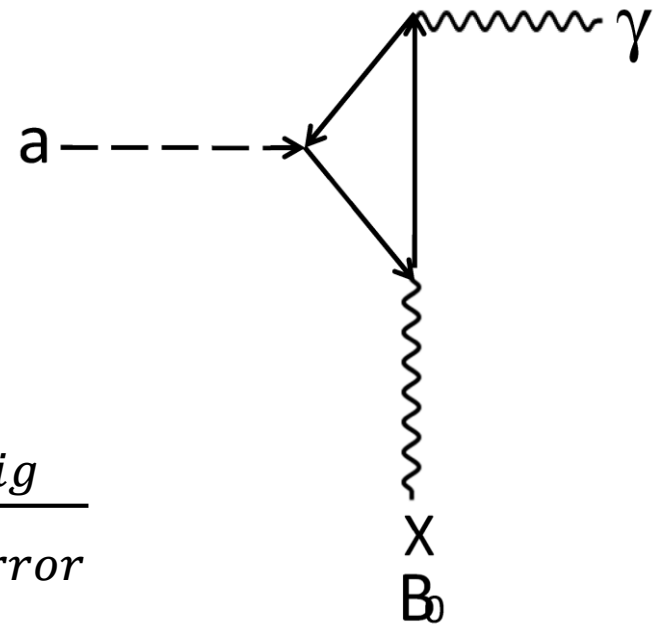


Idea:

1) Induce inverse Primakoff effect in a strong external B field



The MADMAX experiment

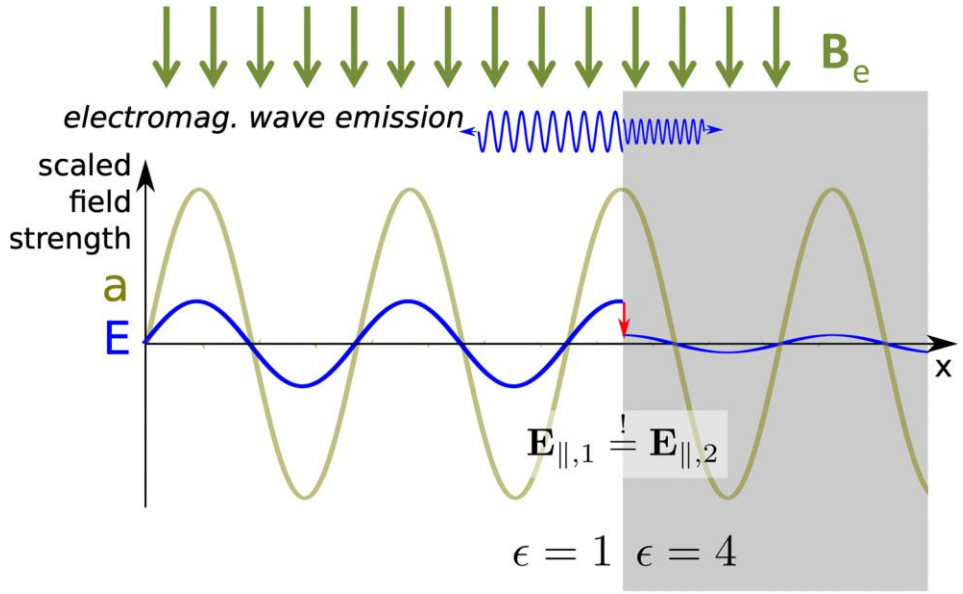


Idea:

1) Induce inverse Primakoff effect in a strong external B field

$$\beta^2 = \frac{P_{sig}}{P_{mirror}}$$

2) Boost the signal using spatially-periodic dielectric discontinuities



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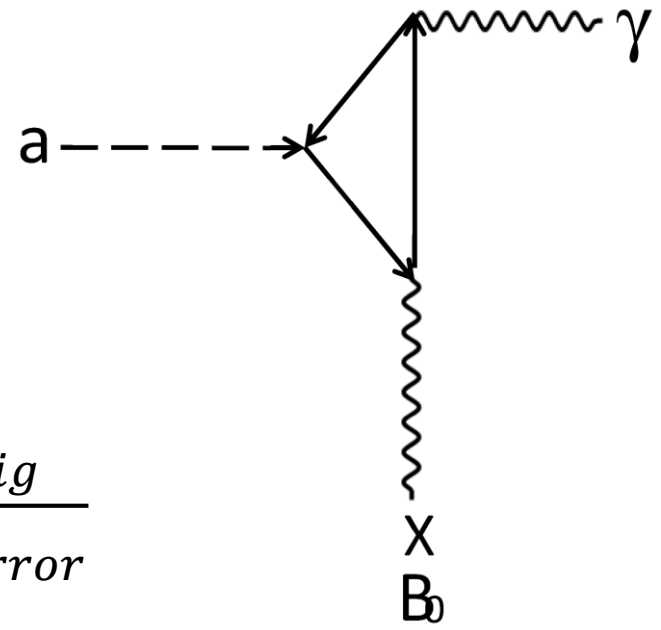


Idea:

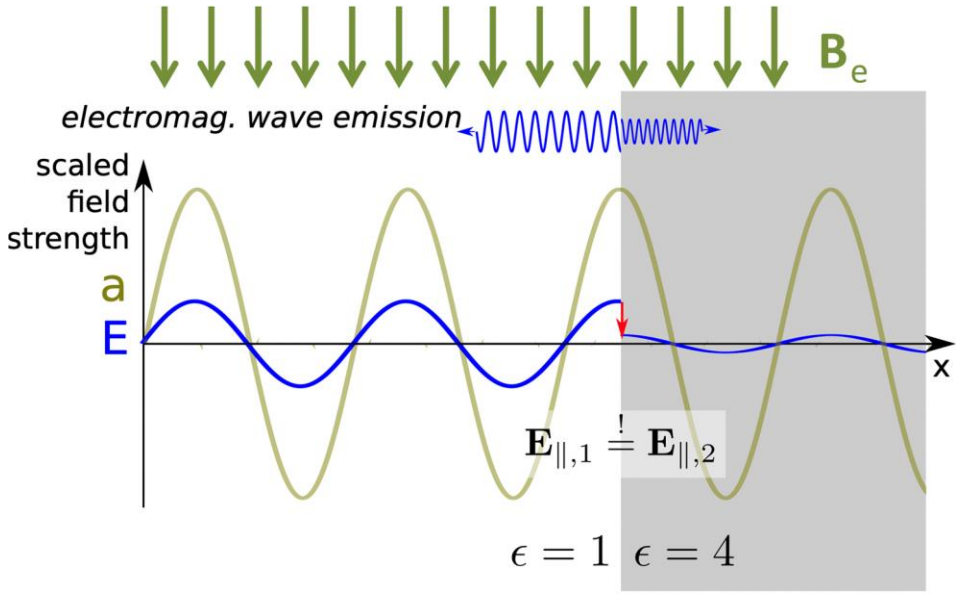
1) Induce inverse Primakoff effect in a strong external B field

$$\beta^2 = \frac{P_{sig}}{P_{mirror}}$$

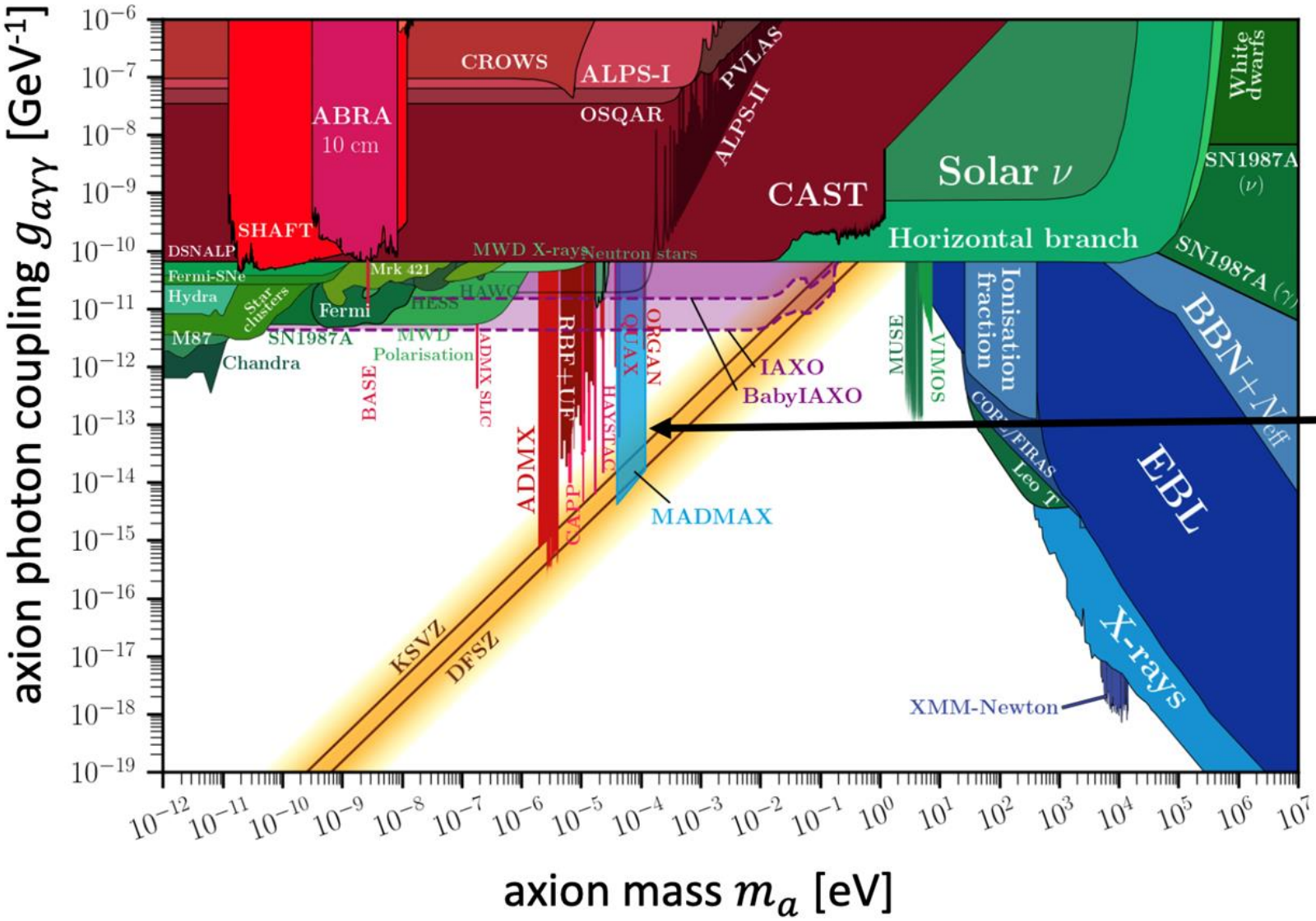
2) Boost the signal using spatially-periodic dielectric discontinuities

3) Reduce thermal background with cryogenics

4) Analyze boosted signal



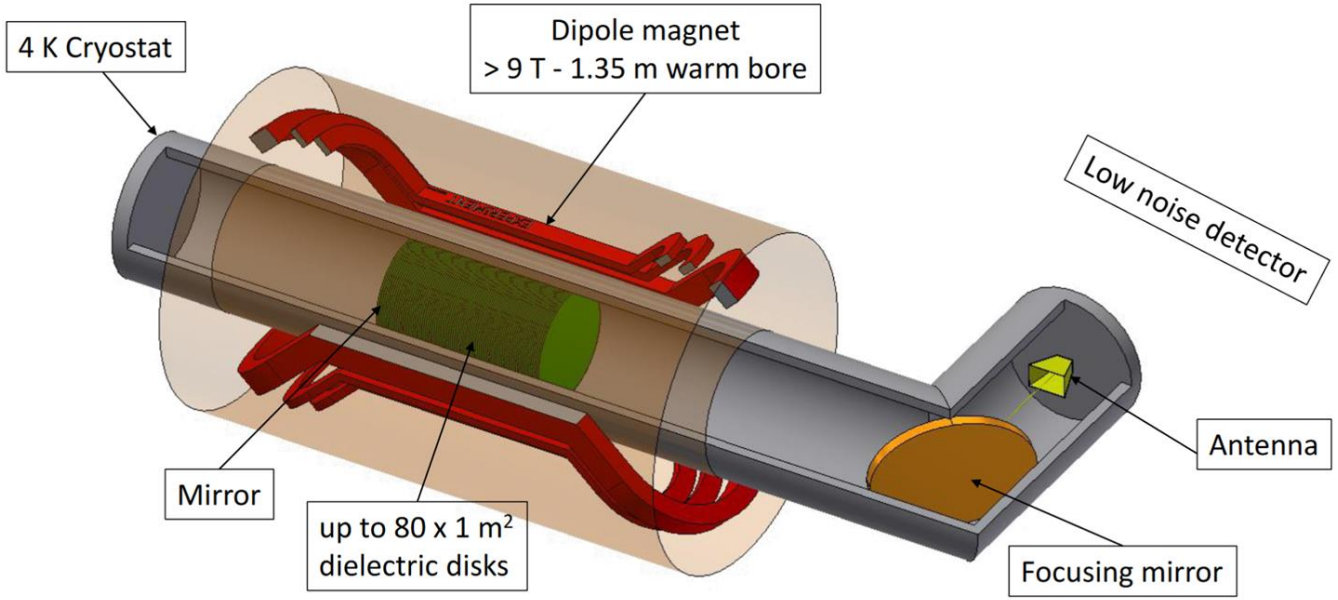
Status of axion experiments



Aspirational setup

Probing the QCD axion between 40-400 μeV

The MADMAX experiment



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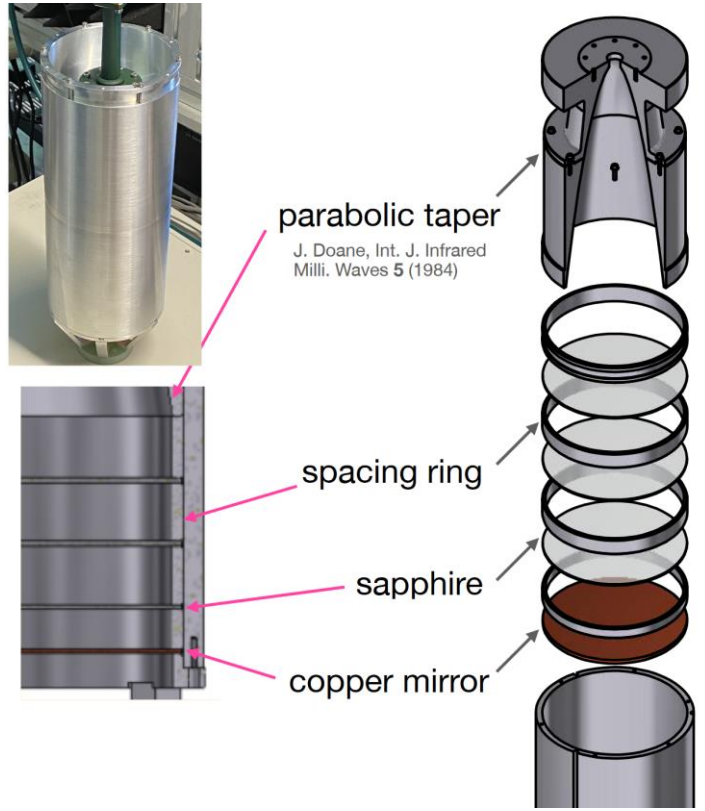
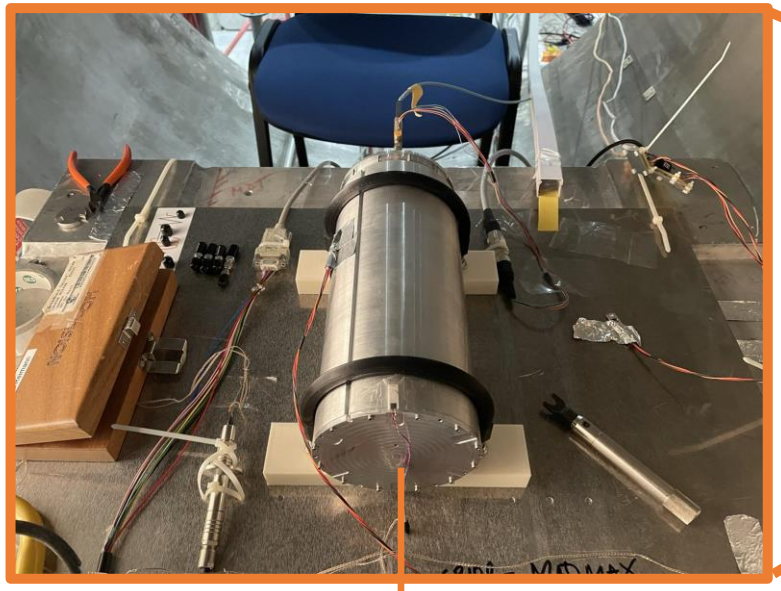


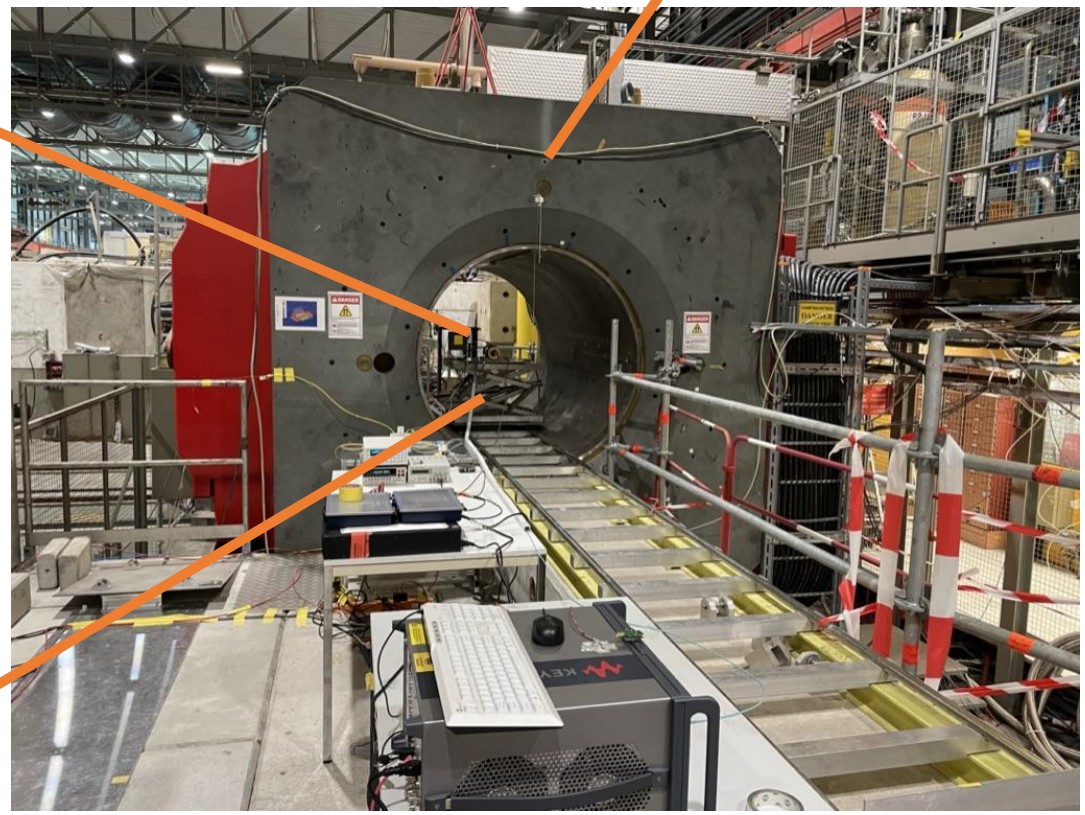
Prototype: CB-100

$$g_{a\gamma} = 0.2 m_a \left(\frac{50000}{\beta^2}\right)^{\frac{1}{2}} \left(\frac{10\mathrm{T}}{B_e}\right) \left(\frac{1\mathrm{m}^2}{A}\right)^{\frac{1}{2}} \left(\frac{SNR}{5}\right)^{\frac{1}{2}} \left(\frac{T_{\mathrm{sys}}}{4\mathrm{K}}\right) \left(\frac{1.8\ \mathrm{days}}{\tau}\right)^{\frac{1}{4}} \left(\frac{\Delta\nu}{20\ \mathrm{kHz}}\right) \left(\frac{300\ \mathrm{MeV\ cm}^{-3}}{\rho}\right)^{\frac{1}{2}}$$

CERN runs

Morpurgo magnet:
1.6 T dipole field



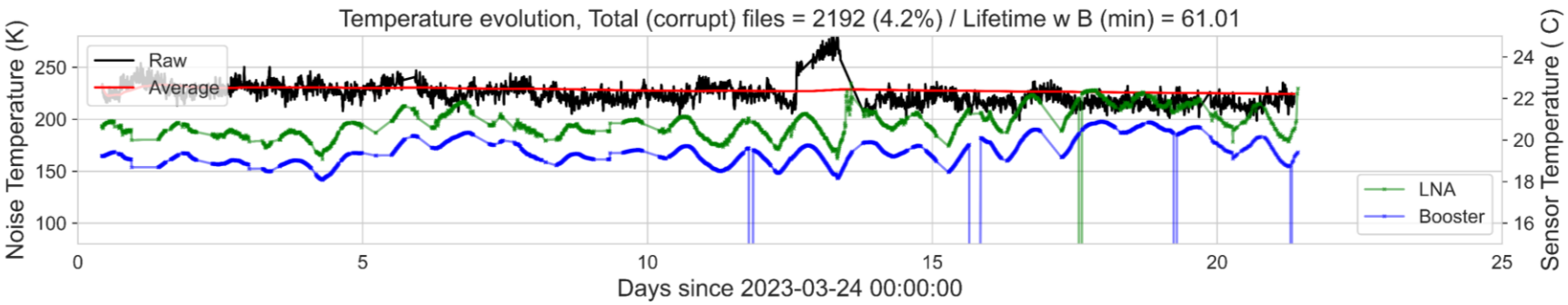


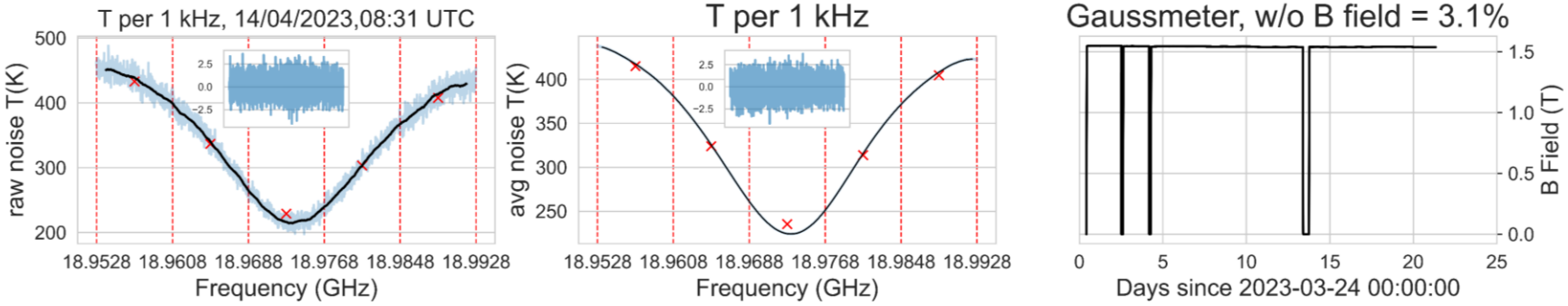
- CB-100 at room temperature
- ~10 hours integration time

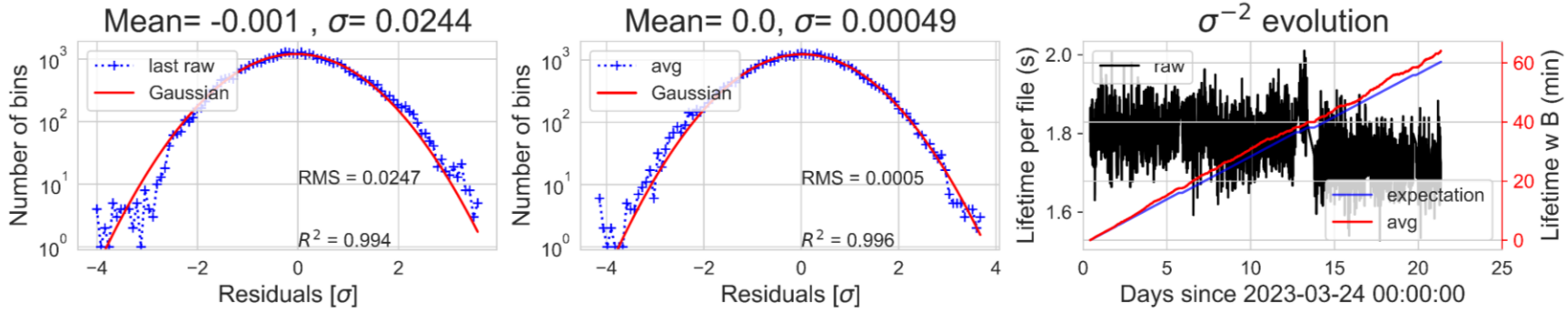
Data analysis ongoing

Successful test: booster in magnet running continuously

Monitoring system







24/7 experiment monitoring

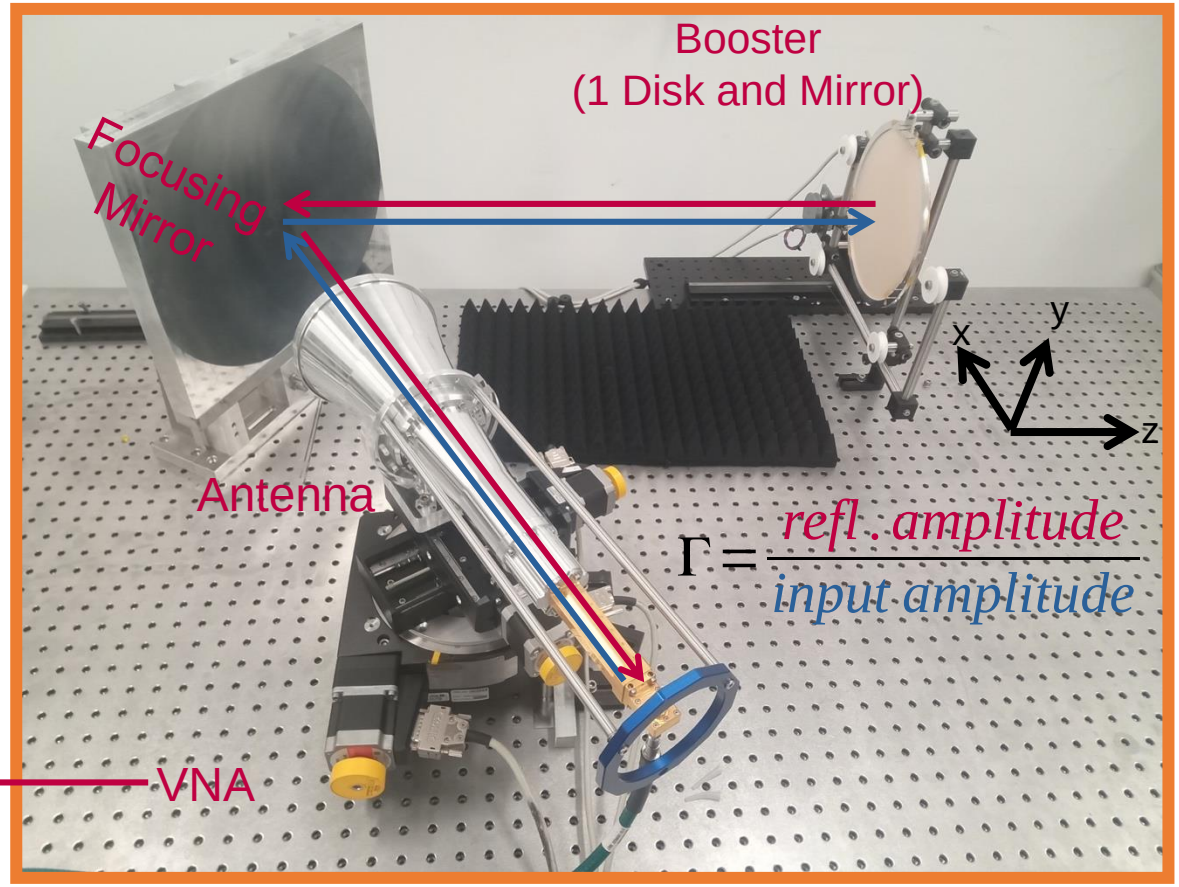
- Noise gaussianity
- Frequency dependent linearity
- Magnetic field
- Overheating
- Allan variance and total integration time
- Shifters incorporated
- E-mail alarms for urgent action (B field off, DAQ frozen, etc.)

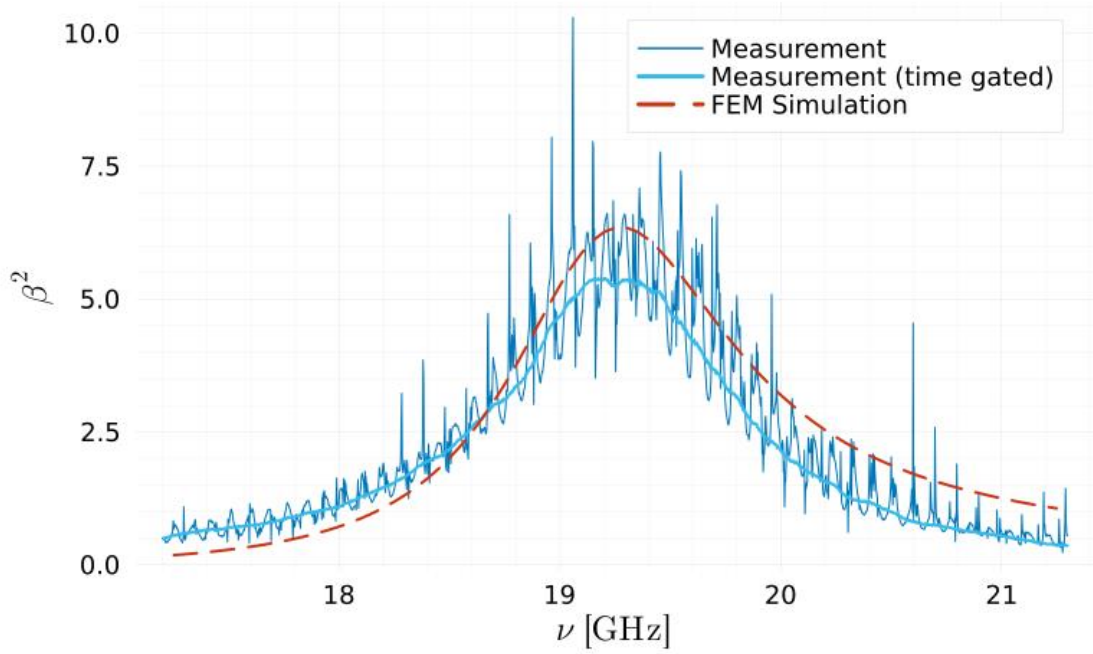
Boost factor determination

Before: Only data-tuned simulations

Now: measurement also possible via bead-pull method

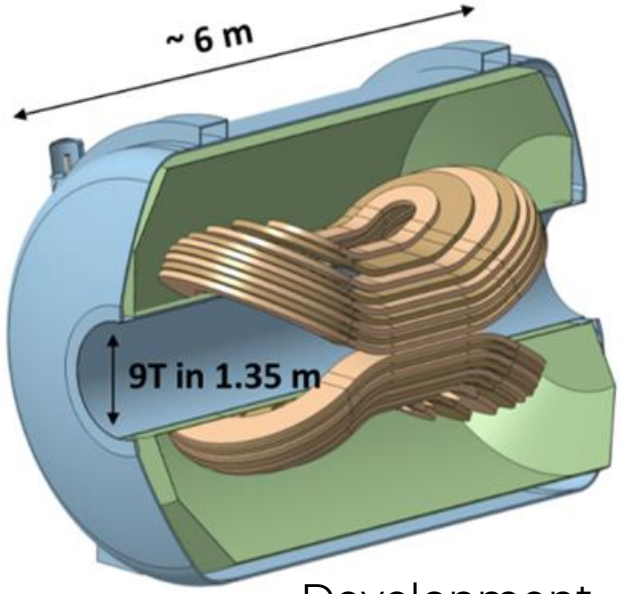
Additional setup to determine β^2 by direct measurement of the field





J. Egge (MADMAX): "Reciprocity approach" https://iopscience.iop.org/article/10.1088/1475-7516/2023/04/064

MADMAX magnet update

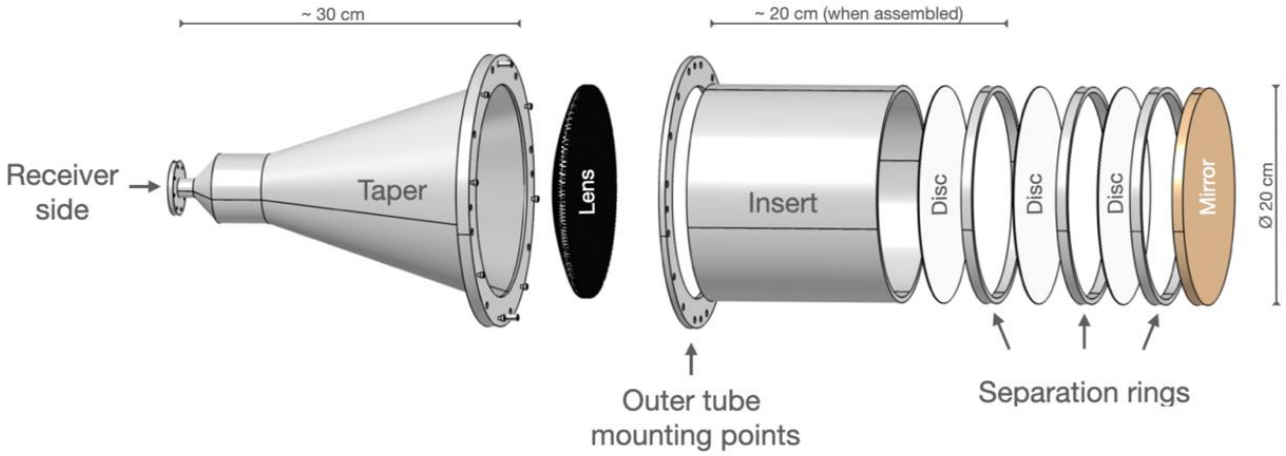


Development in innovation partnership

- Dipole Magnet most critical item for full-size MADMAX
- **Cable in conduit conductor (CICC) with a copper matrix**
  ➔ production is feasible
- Quench propagation velocity was measured in dedicated setup
  ➔ Main project risk mitigated: Quench propagation according to requirements for safe operation

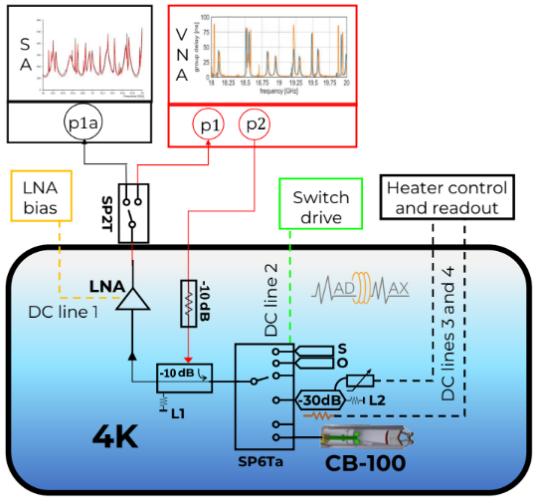
C. Lorin et. al
IEEE Transactions on Applied Superconductivity vol. 33 Issue 7 (2023) 1-11

Next steps



Next prototype: CB-200

Gain in sensitivity of ~40%

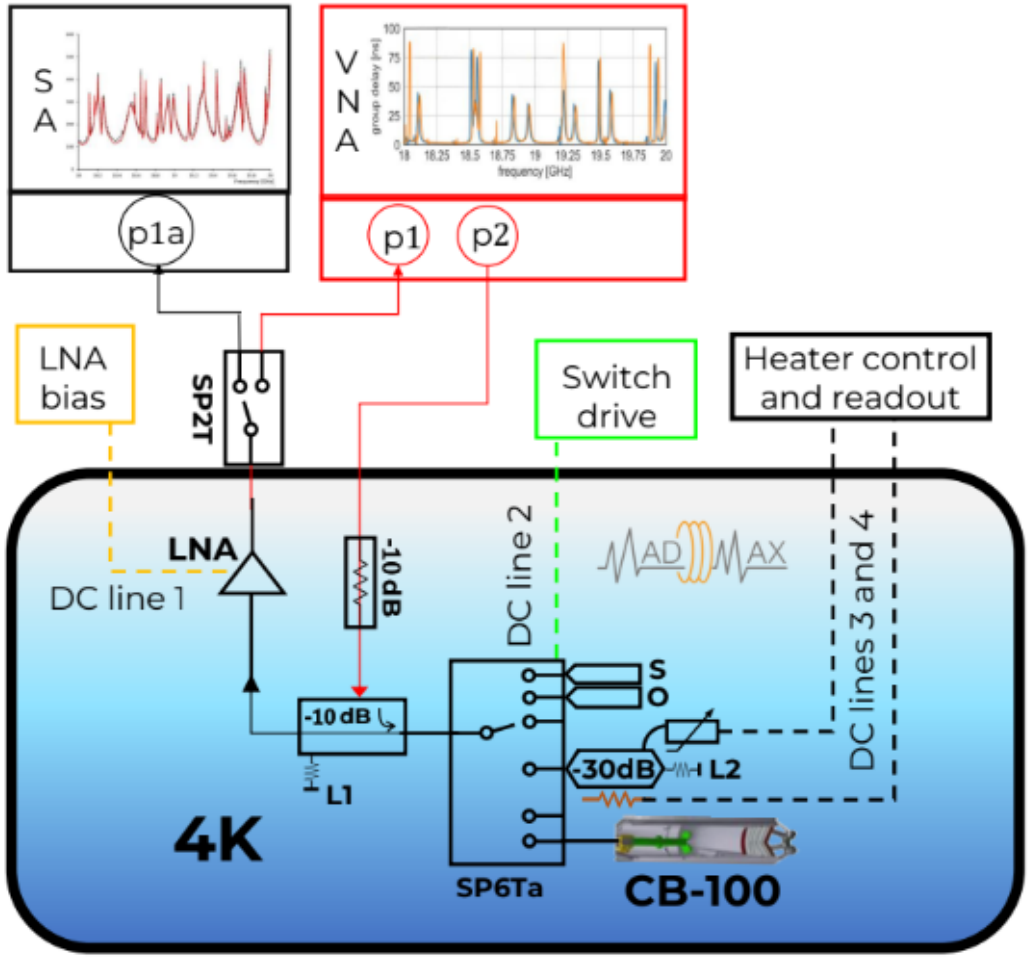


Cold (4K) run with CB-100

Gain in sensitivity of ~1 order of magnitude

For more information see poster
"Towards a cryogenic calibration of a dielectric haloscope for direct dark matter detection" – Juan PA M.

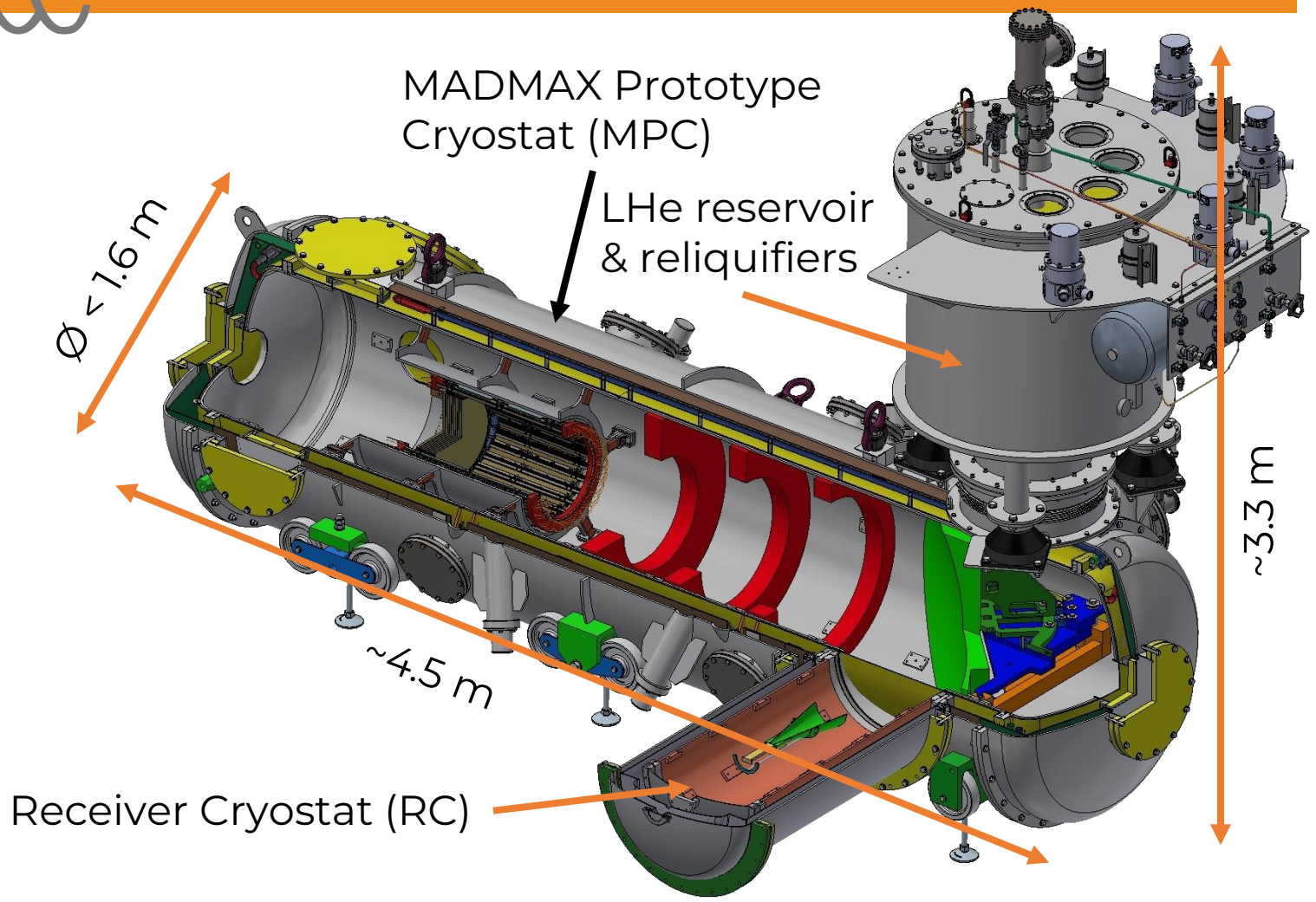
Cold operation idea



Single thermal cycle semi-automatic calibration.

Maximizes stability and reproducibility of our measurements

Plans for 2024-2025

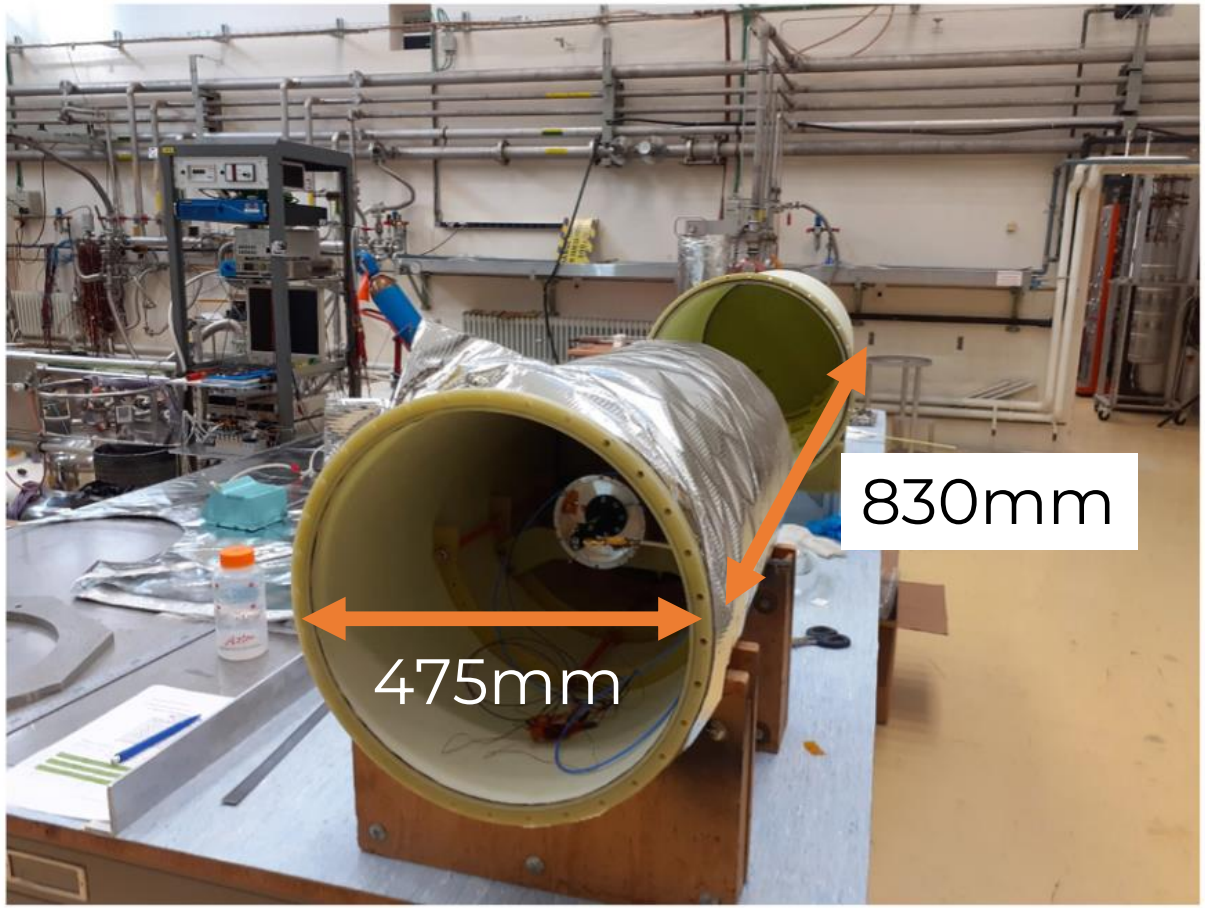


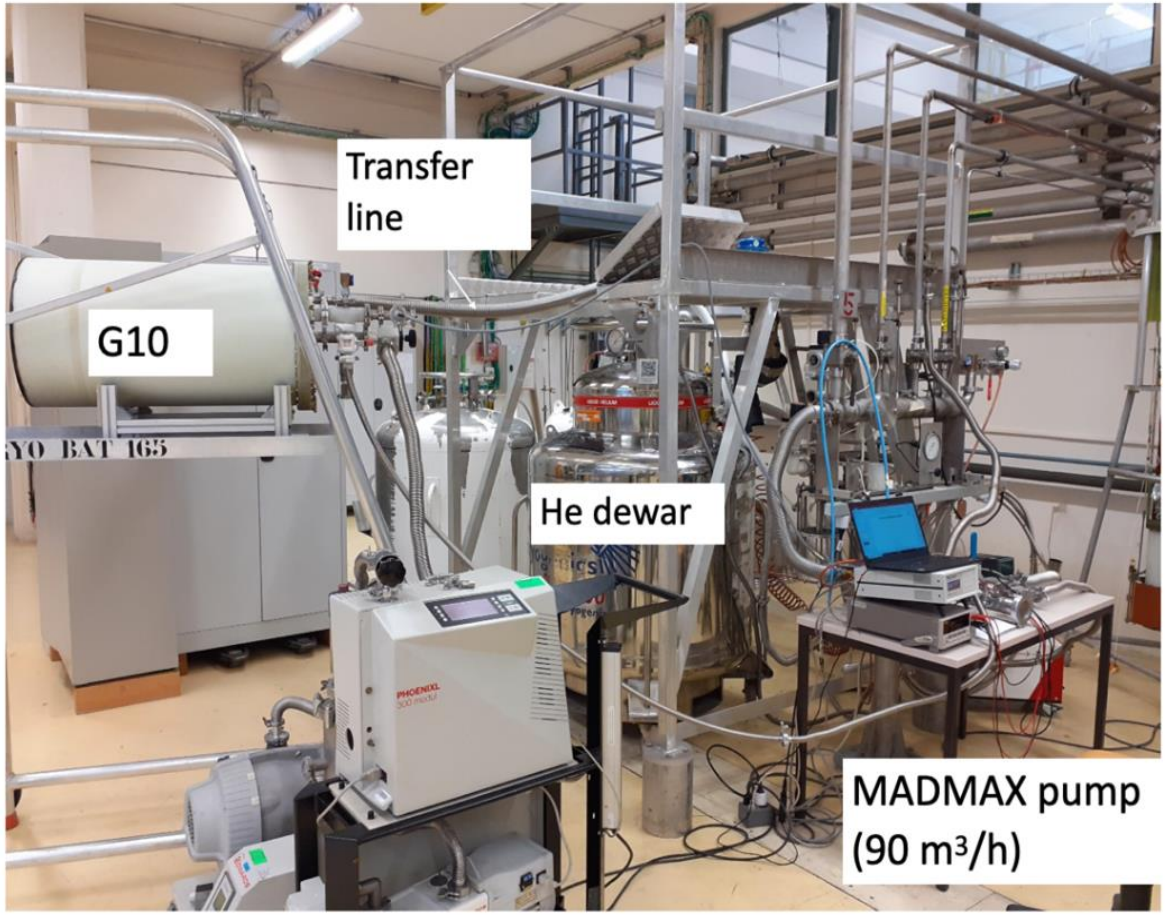
Prototype cryostat

- Delivery expected beginning of 2024
- Commissioning site: Hamburg
- Planned ALP search at CERN in 2025

G10 cryostat

Tested at
CERN cryolab





Stability reached: 24 hours at 10K

Summary

MADMAX will search for axions between 40-400 μeV

First runs with CB-100 at 300K done; data analysis ongoing

Magnet feasibility confirmed

Prototype cryostat soon to be available

G10 cryostat tested and ready to use inside magnet

First cryogenic operation intended for 2024 at CERN

Upgrade of the prototype also planned for 2024