From concept to reality: Advancements in the MADMAX experiment

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19th Patras Workshop on Axions, WIMPs and WISPs

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CPPM

Dielectric haloscope

arXiv:1611.05865 [PRL 118.9 (2017)]

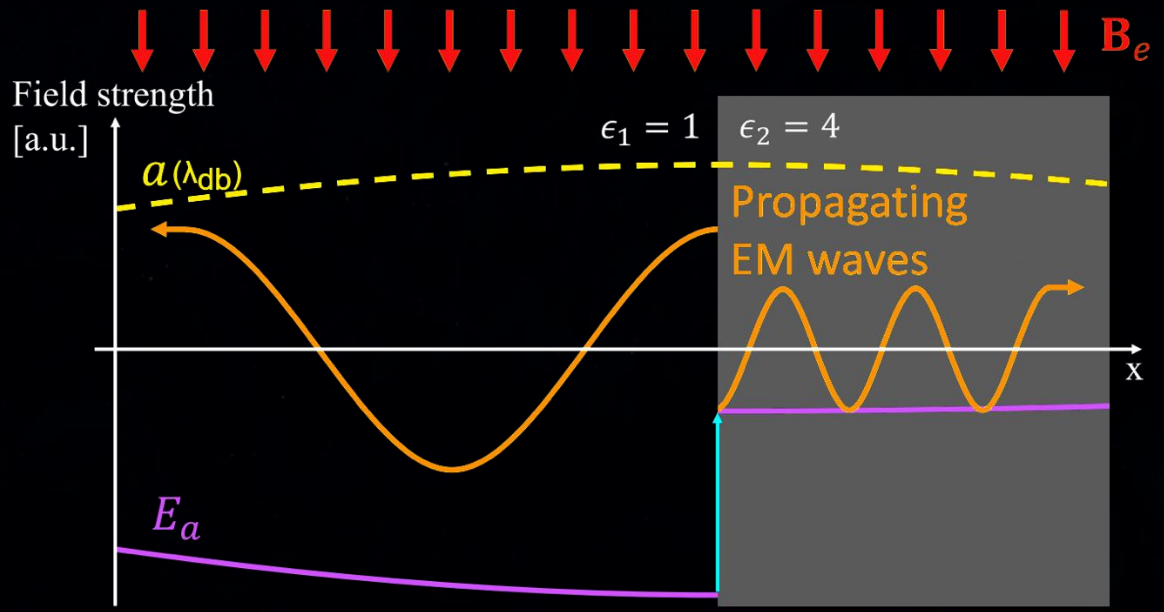
1) Induce inverse Primakoff effect in a strong external B field

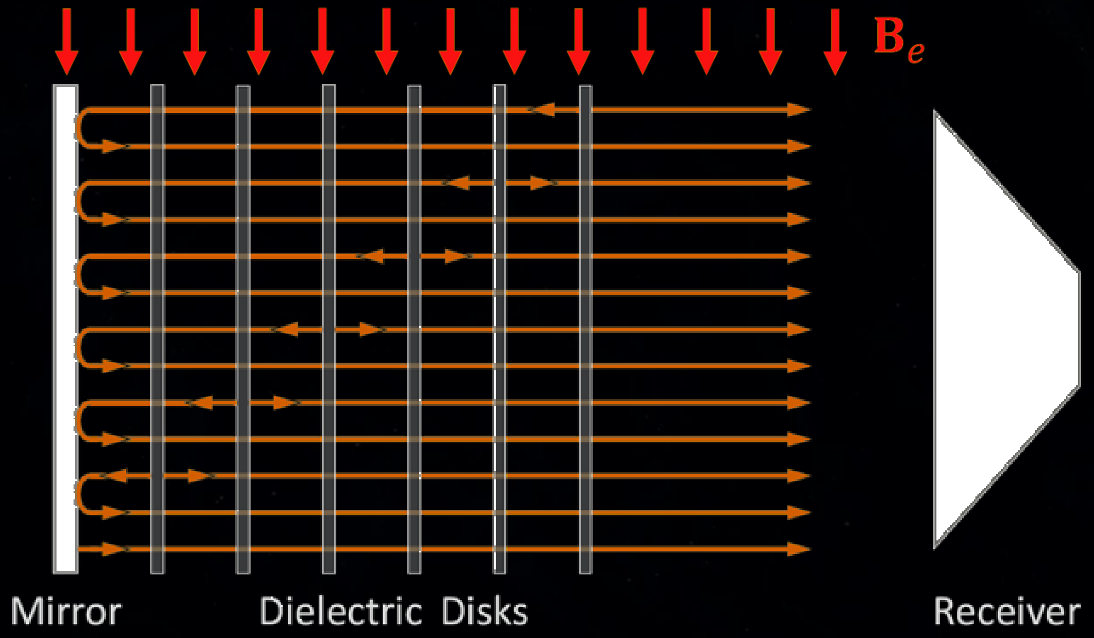
$$\overrightarrow{E_a} = -\frac{g_{a\gamma}\overrightarrow{B_e}}{\epsilon} a_0 \cos(m_a t)$$

2) Boost the signal using dielectric discontinuities (constructive interference and resonance effects)

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

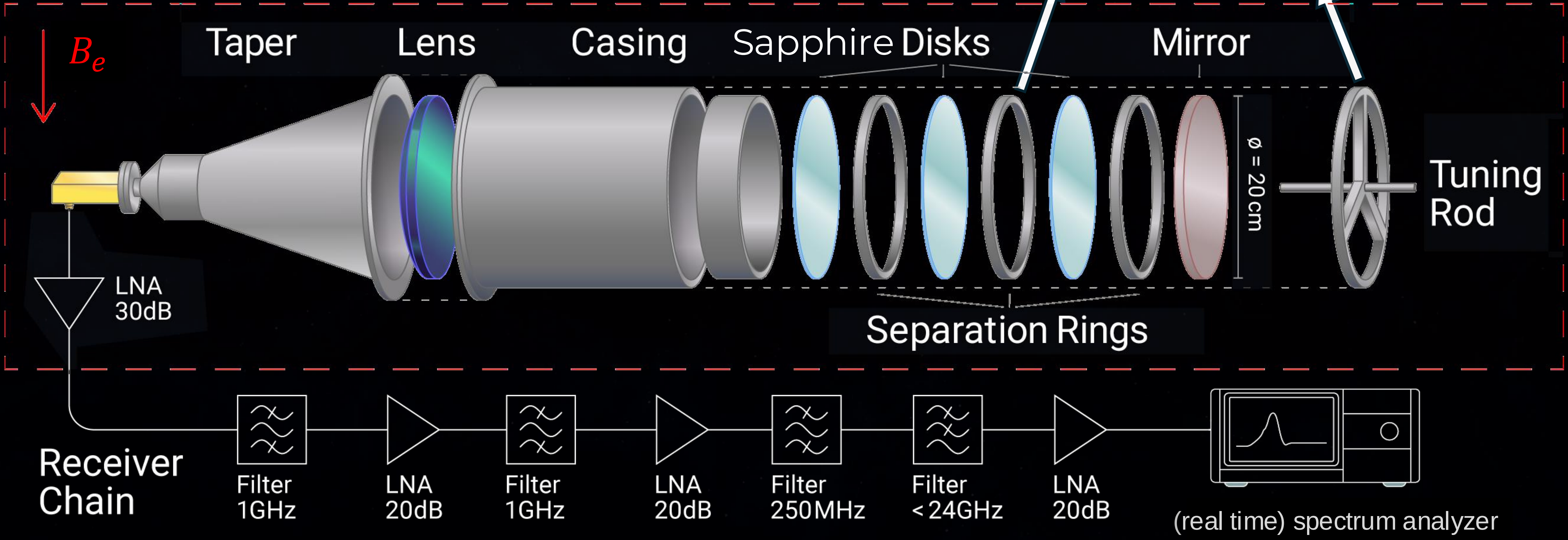
3) Maximize signal, minimize noise





Prototype: Closed Booster

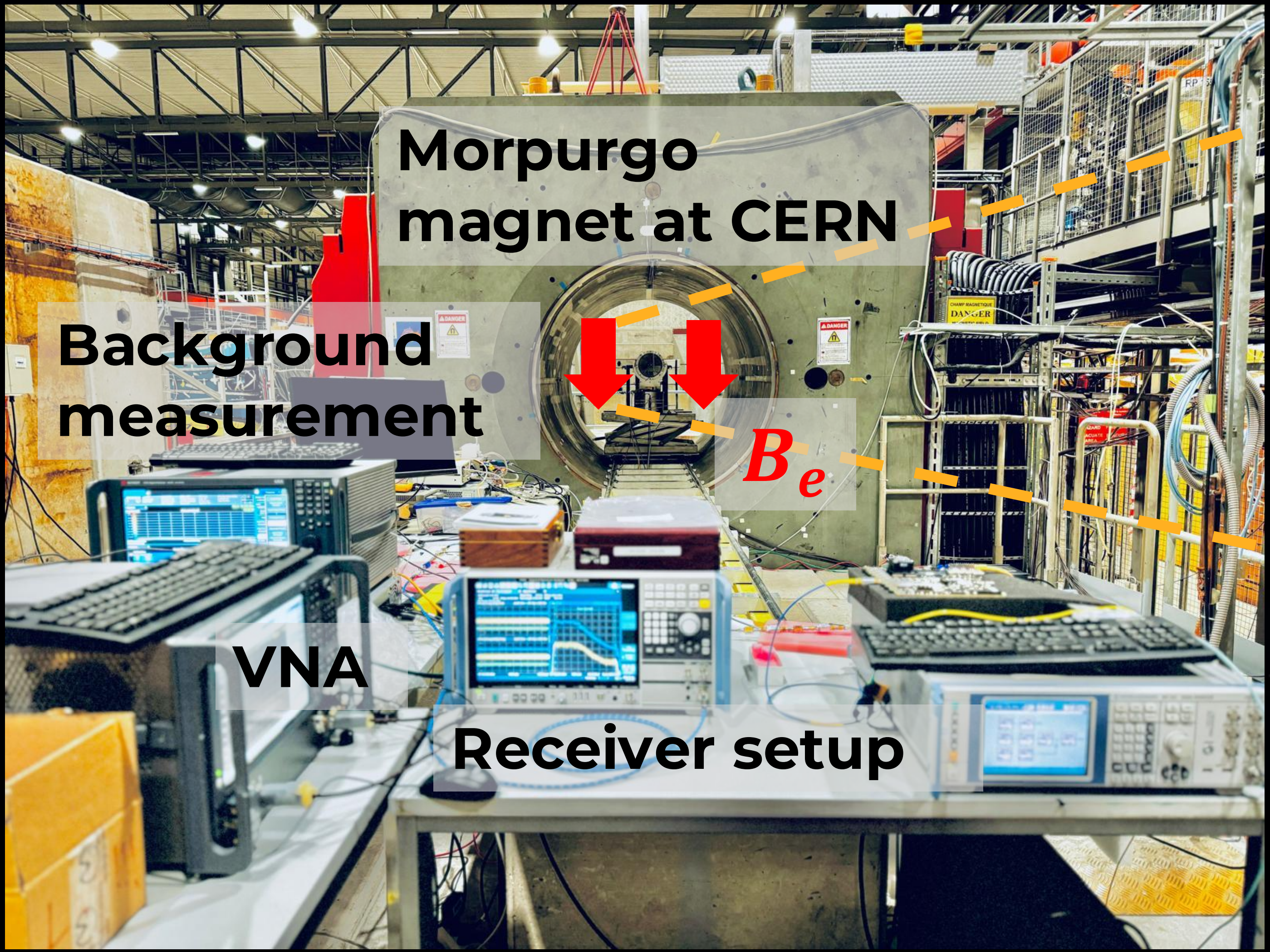
Manual tunability by rod and spacer thickness

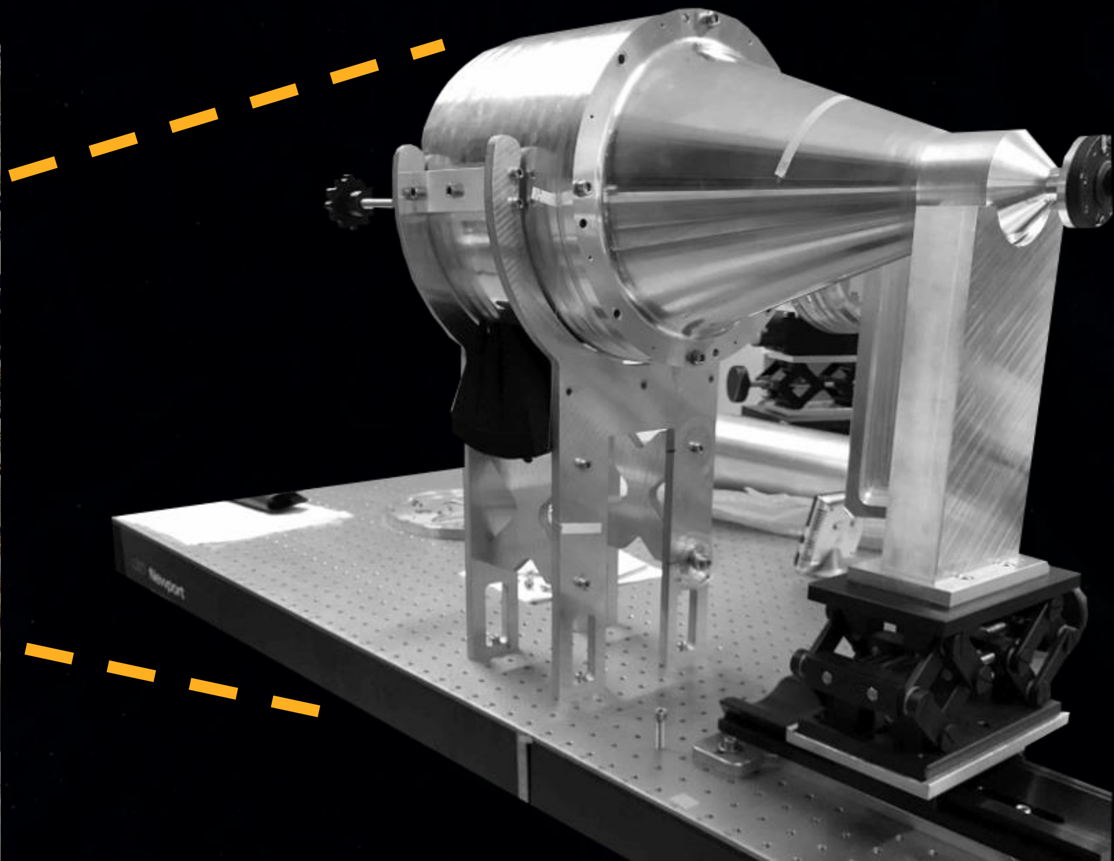


For more, see Erdem Öz's poster just outside

$$|g_{a\gamma}| = 4 \times 10^{-11}\,\mathrm{GeV}^{-1} \left(\frac{2000}{\beta^2}\right)^{\frac{1}{2}} \left(\frac{T_{\mathrm{sys}}}{300\ \mathrm{K}}\right)^{\frac{1}{2}} \left(\frac{0.1\ \mathrm{m}}{r}\right) \left(\frac{1\ \mathrm{T}}{B_e}\right) \left(\frac{1.3\ \mathrm{days}}{\tau}\right)^{\frac{1}{4}} \left(\frac{\mathrm{SNR}}{5}\right)^{\frac{1}{2}} \left(\frac{m_a}{80\ \mu\mathrm{eV}}\right)^{\frac{5}{4}} \left(\frac{0.3\ \mathrm{GeV/cm^3}}{\rho_a}\right)^{\frac{1}{2}}$$

The experiment – Prototype closed booster





15 days data-taking
Room temperature
Two configurations
3 discs at 1.6 T B field

The experimenters

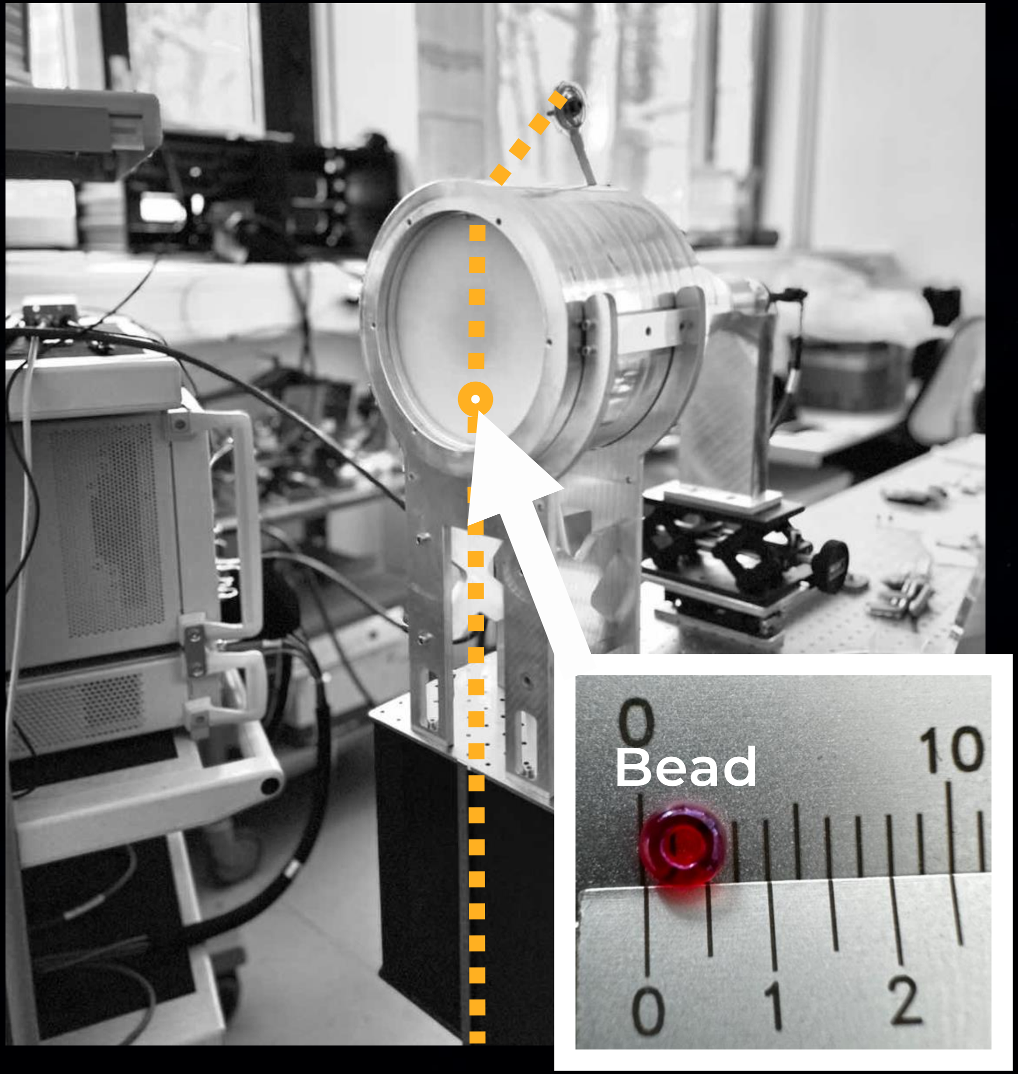
Calibration and analysis procedure

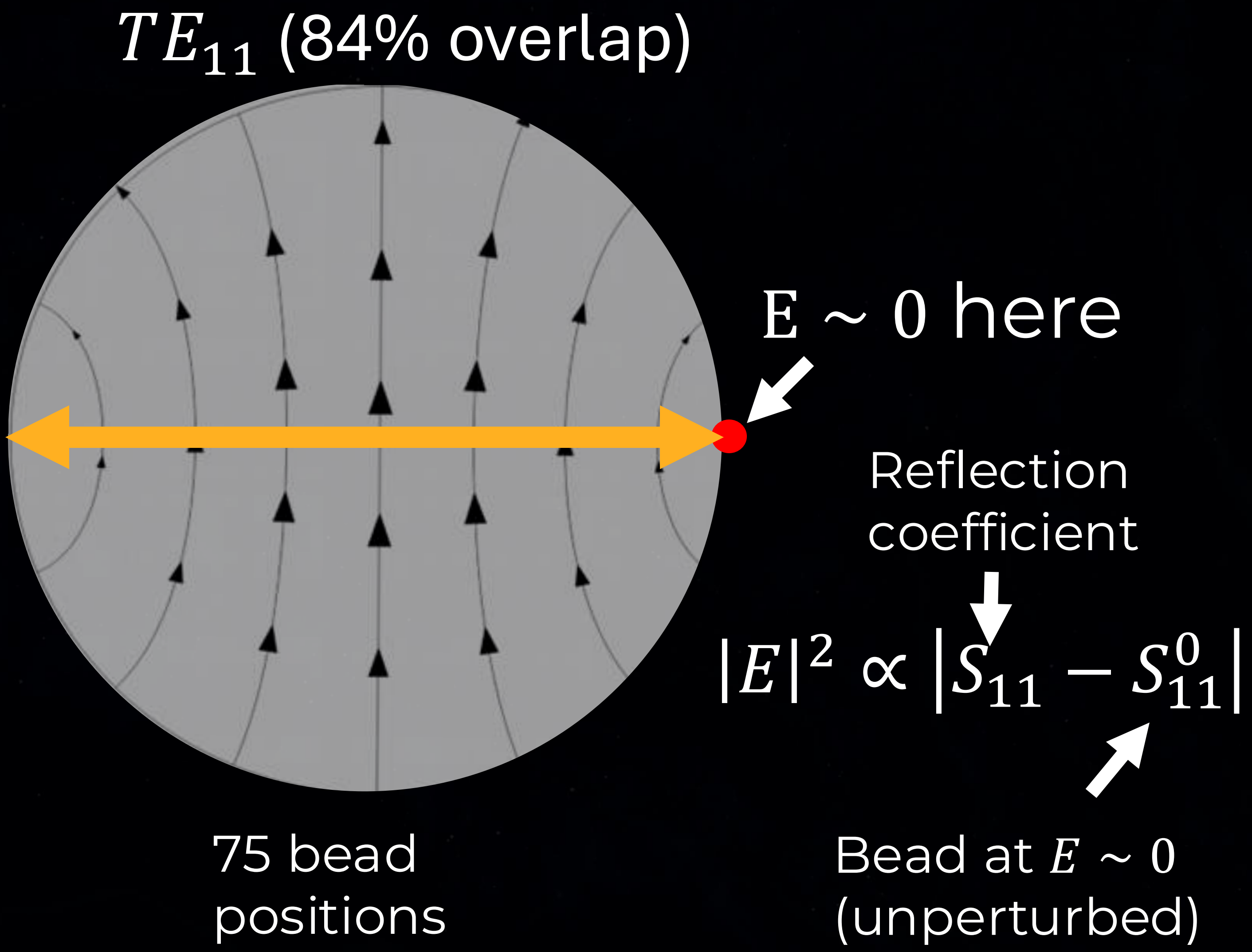
Booster mode identification

Boost factor determination

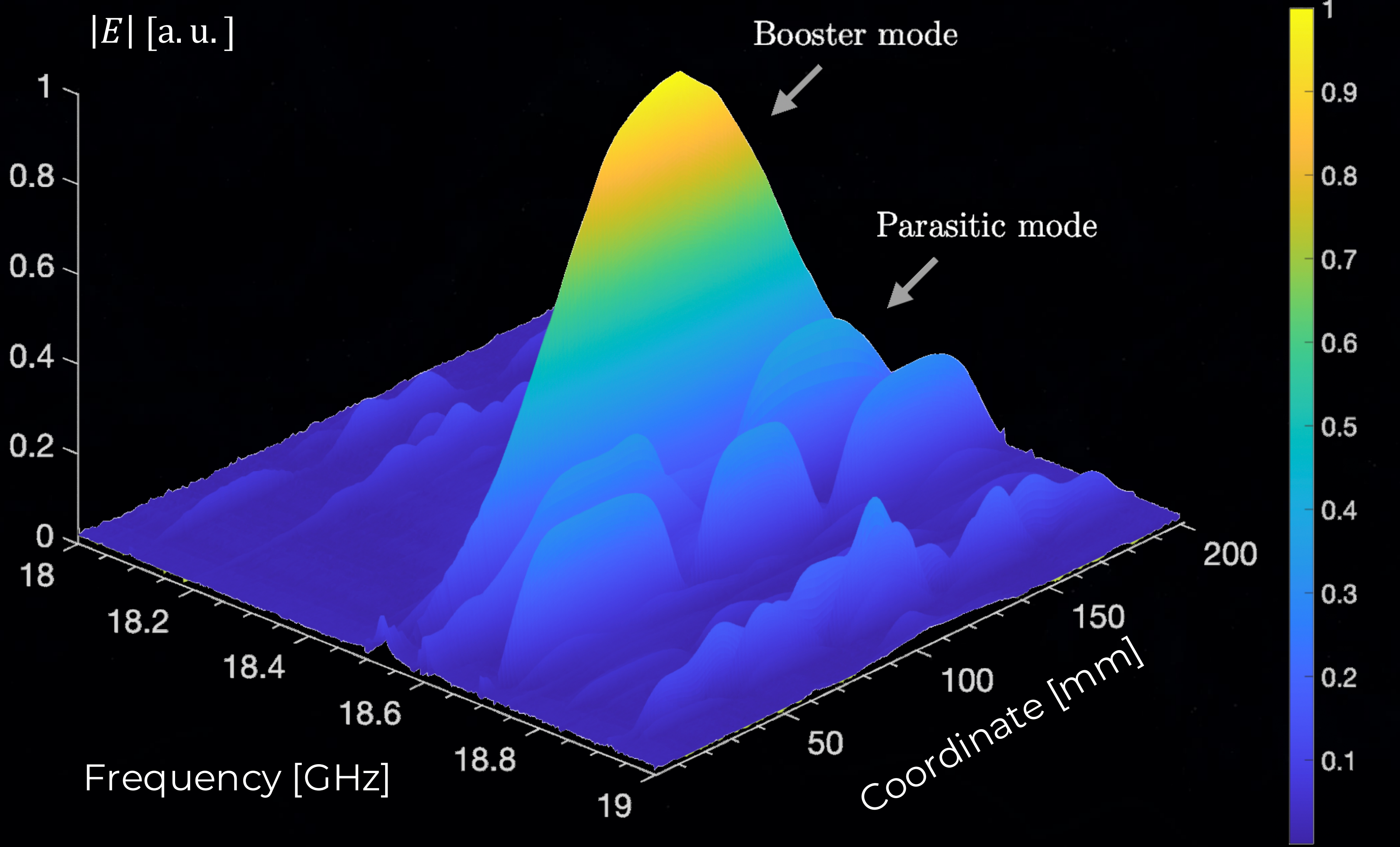
Dark matter search data analysis

Field measurement setup





Identification of booster mode

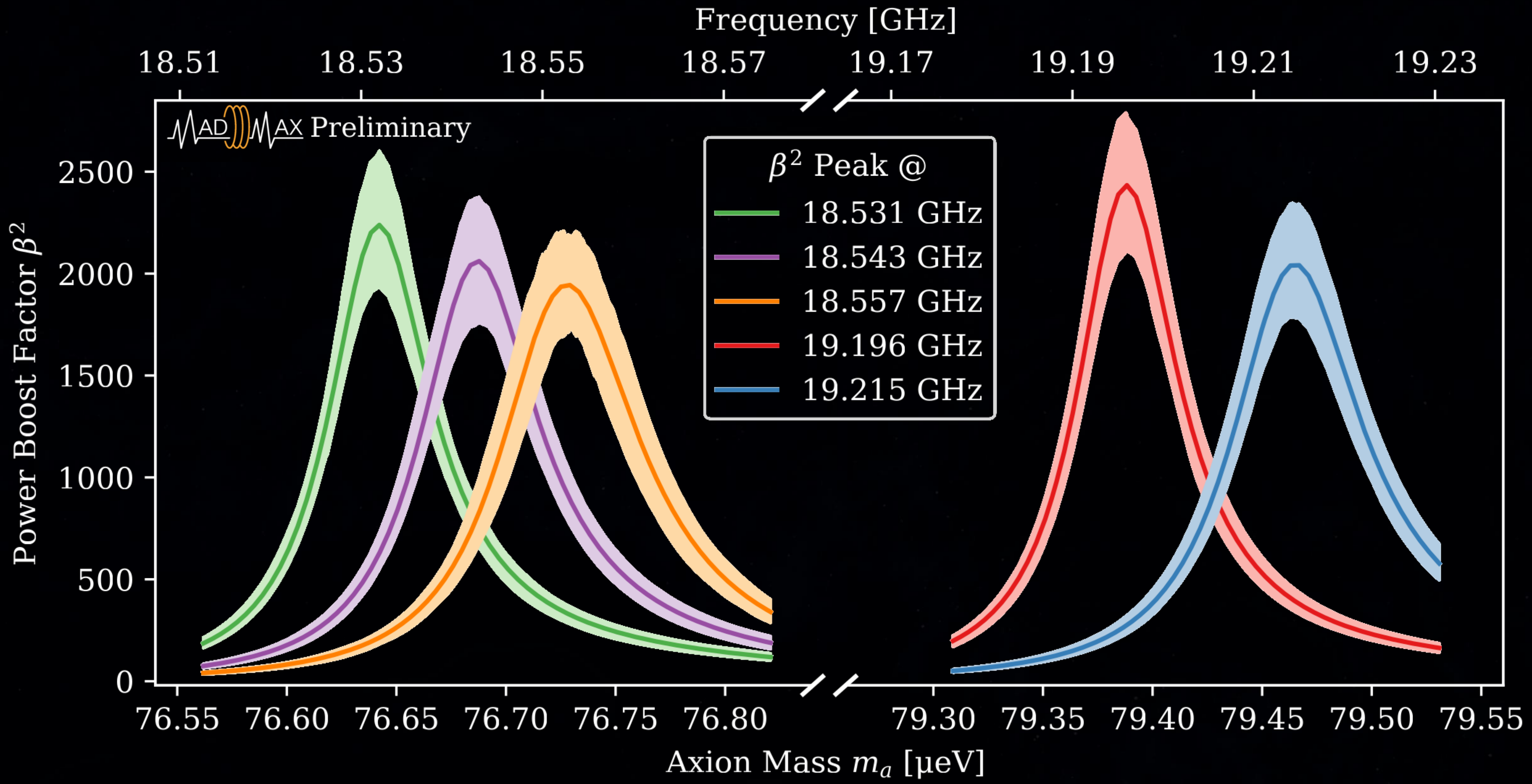


Experimental identification of the booster mode.

Clear distinction of TE_{11} with respect to parasitic/higher order modes

Modeled boost factor distributions

arXiv:2409.11777



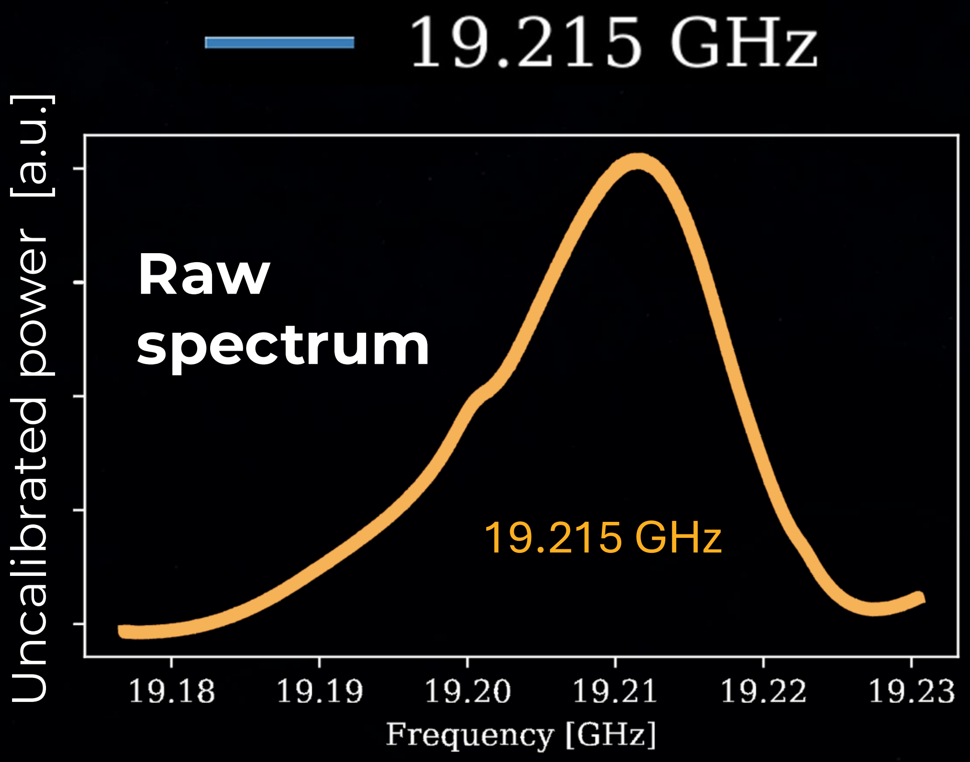
β^2 around 2000 with only 3 disks + mirror. Uncertainties of around 15%.

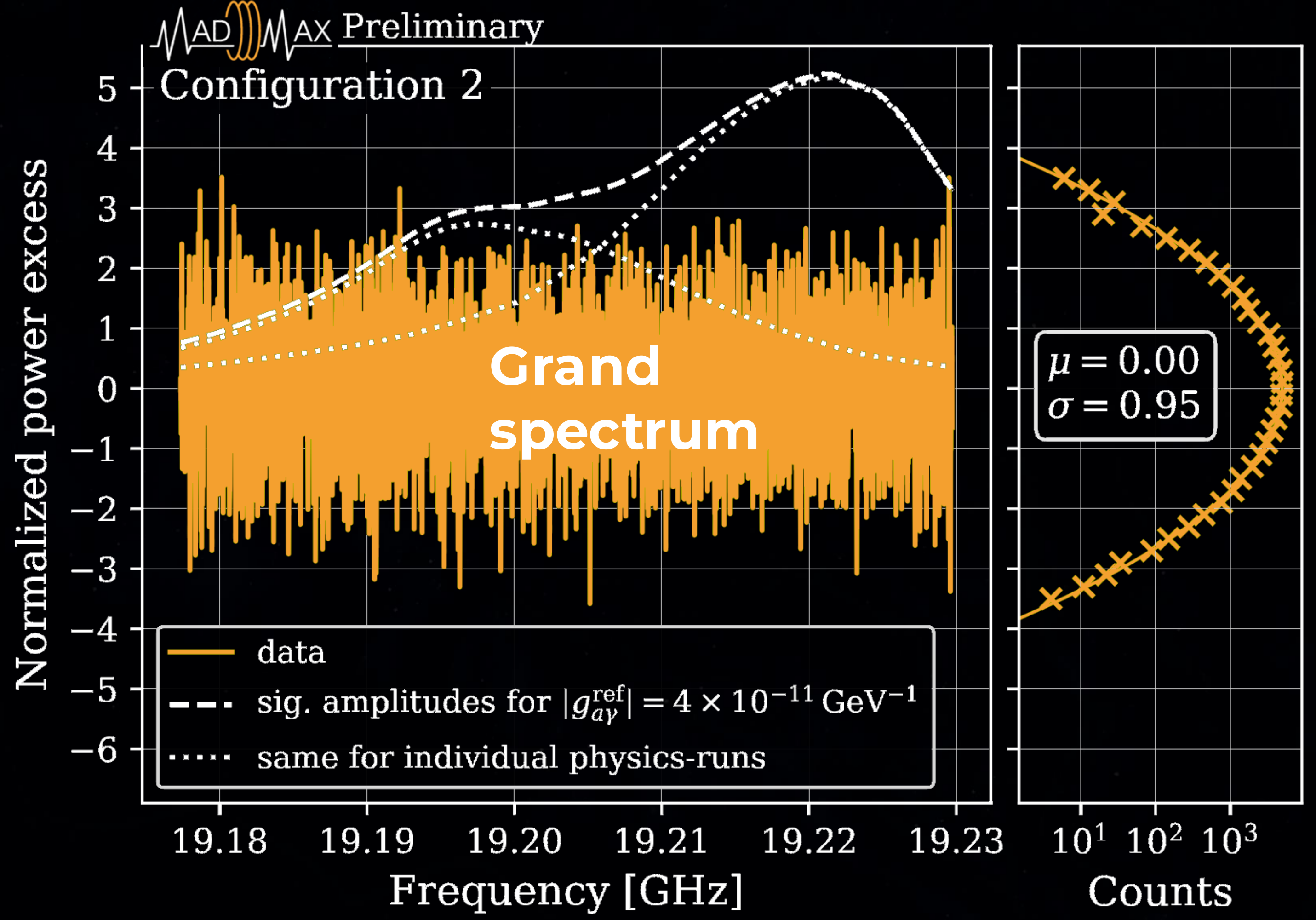
Analysis chain

Based on HAYSTAC: arxXiv:1706.08388 [PRD 96.12(2017)]

Raw spectrum → **Processed spectrum** → **Combined spectrum** → **Rescaled spectrum** → **Grand spectrum** → **Exclusion Limit**

Example from

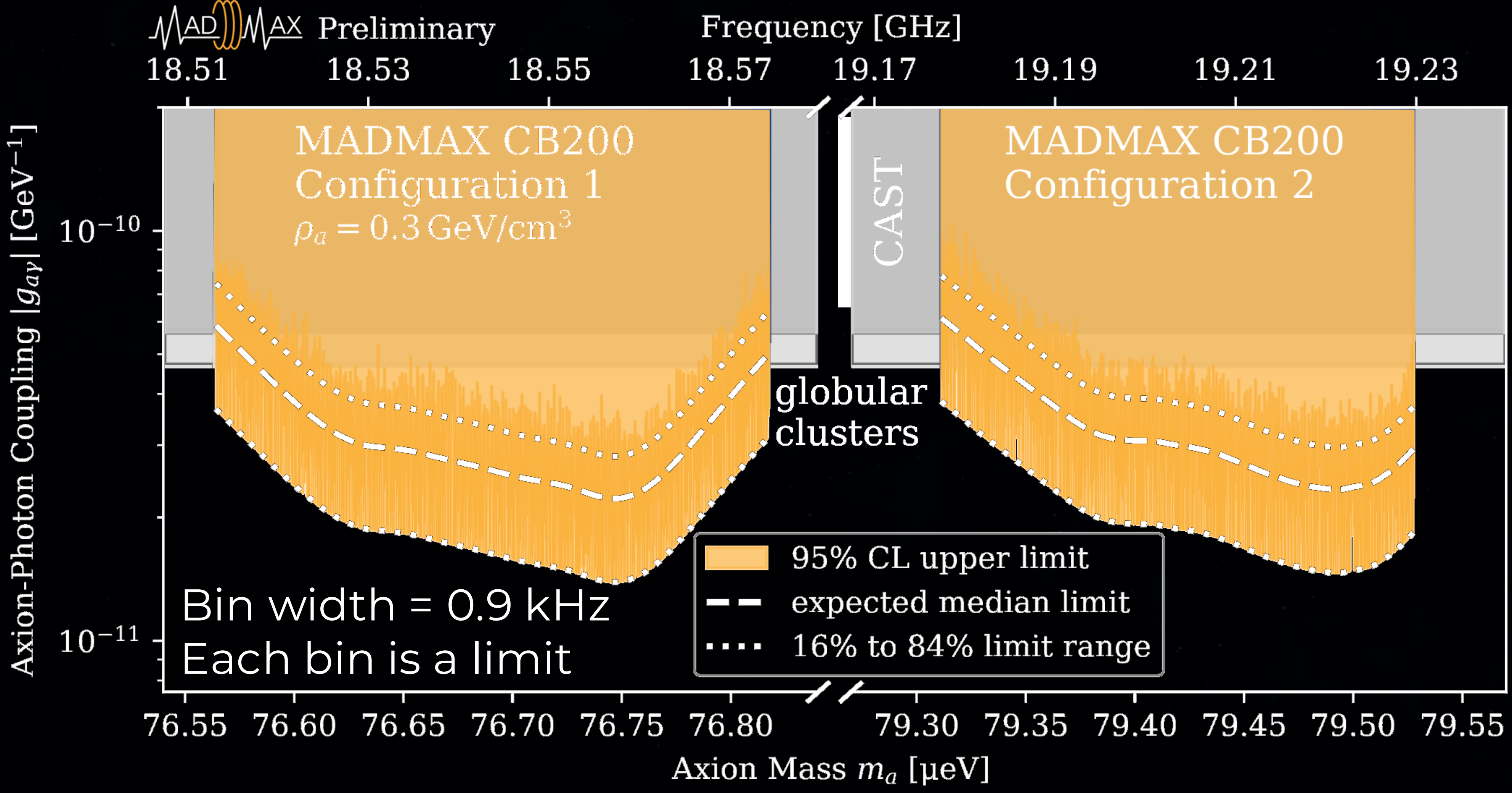




First dielectric haloscope ALP limit

arXiv:2409.11777: On arXiv since today!

World's best limit on this frequency region and first axion-like particle search using a dielectric haloscope



~ 2 times more sensitive than CAST and globular clusters limits

Limit set in two regions around 76 μeV and 79 μeV covering ~ 100 MHz

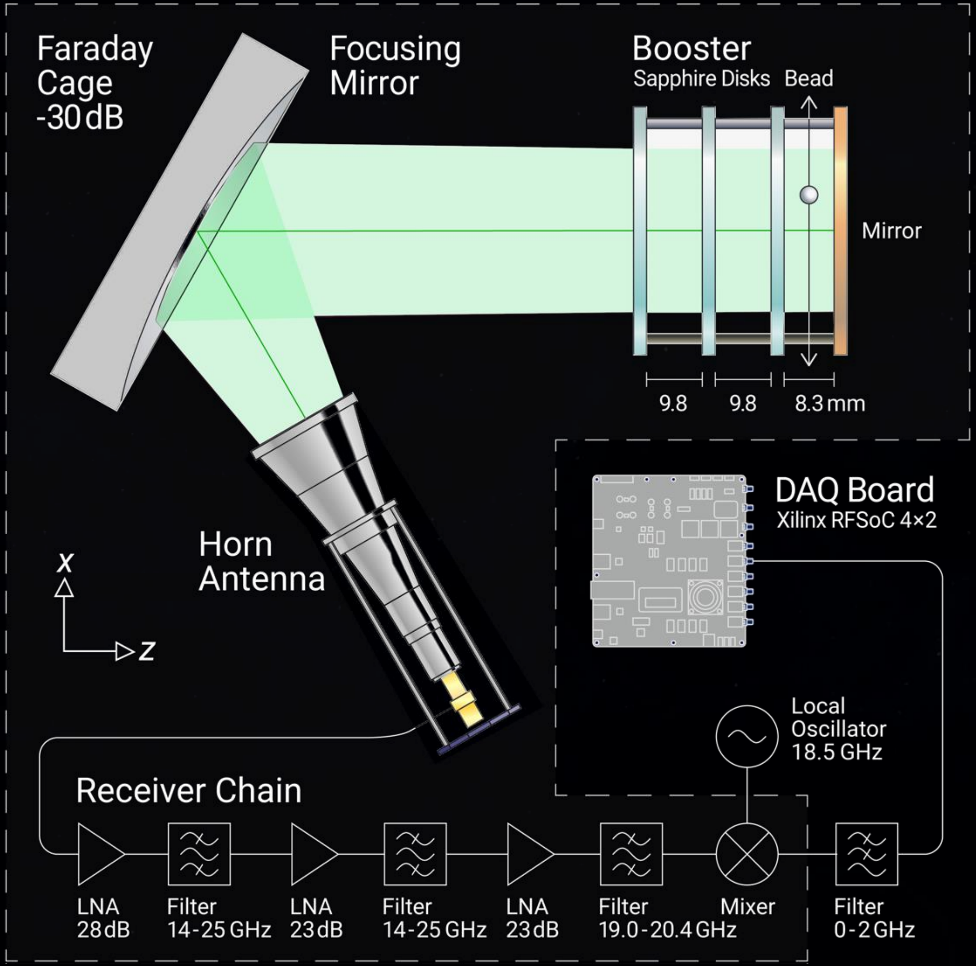
Opening up the system

The open booster setup

Experimental determination of β^2

Dark photon run

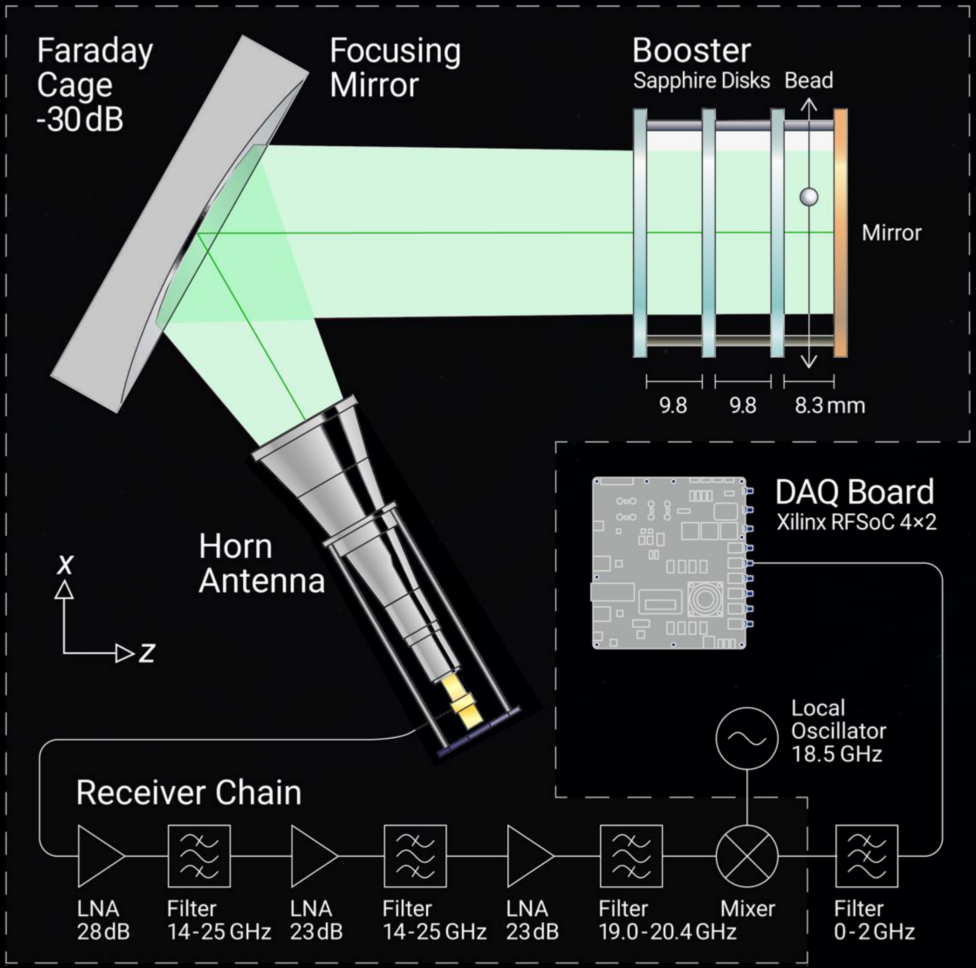
Open booster, 300 mm disk diameter

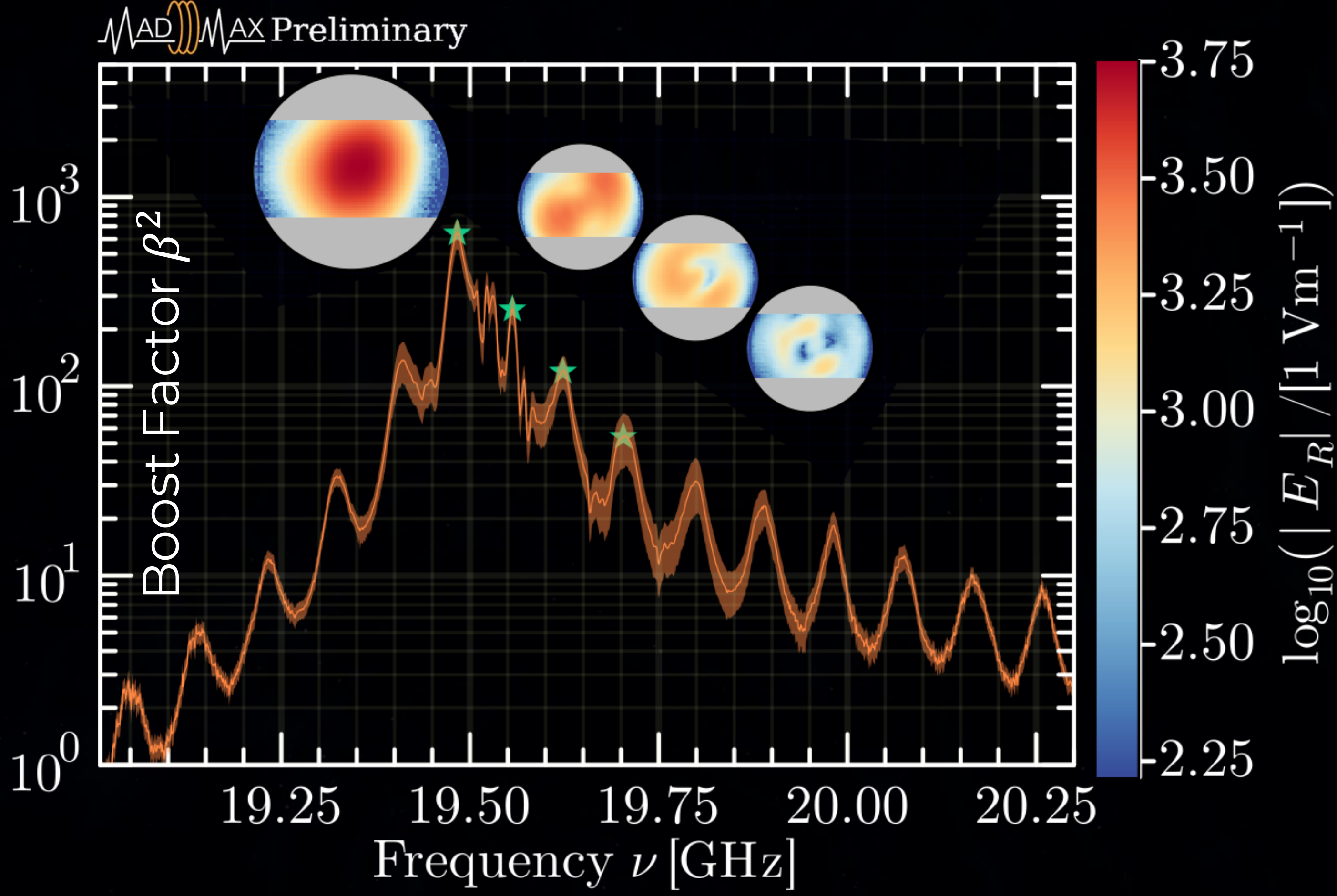


Open booster with 3 sapphire disks
Placed at RT inside an EMC room
RFI under control

Open booster 300 mm

arXiv:2311.13359 : [JCAP04(2024)005]



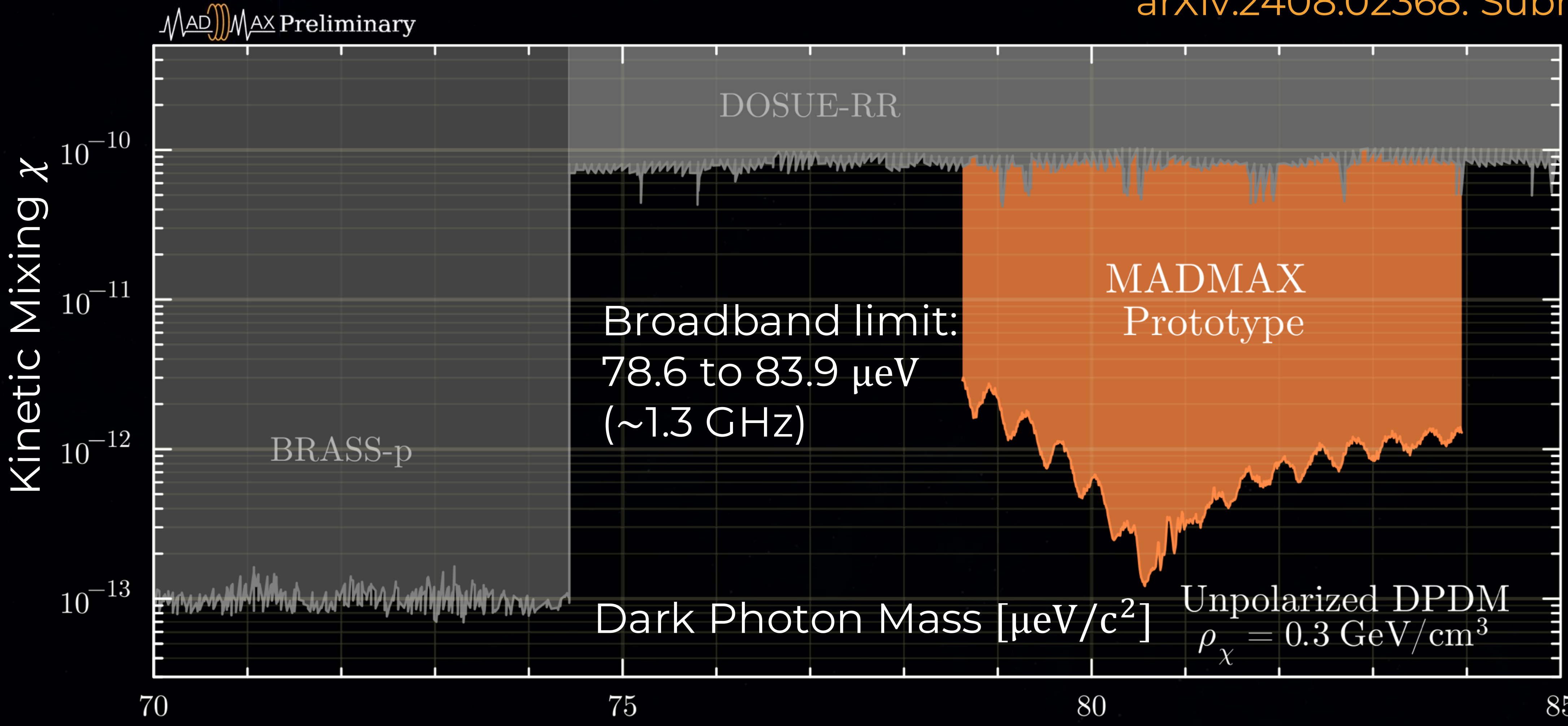


Open booster with 3 sapphire disks
Placed at RT inside an EMC room
RFI under control

Novel method: Boost factor directly reconstructed from field measurement without simulation models

First MADMAX dark photon limit

arXiv:2408.02368: Submitted



15 days data-taking at room temperature with 3 disks in a fixed position

Improved existing limits by ~ 3 orders of magnitude

Scaling up further

First Cryogenic axion search

Magnet and cryostat development

Physics reach

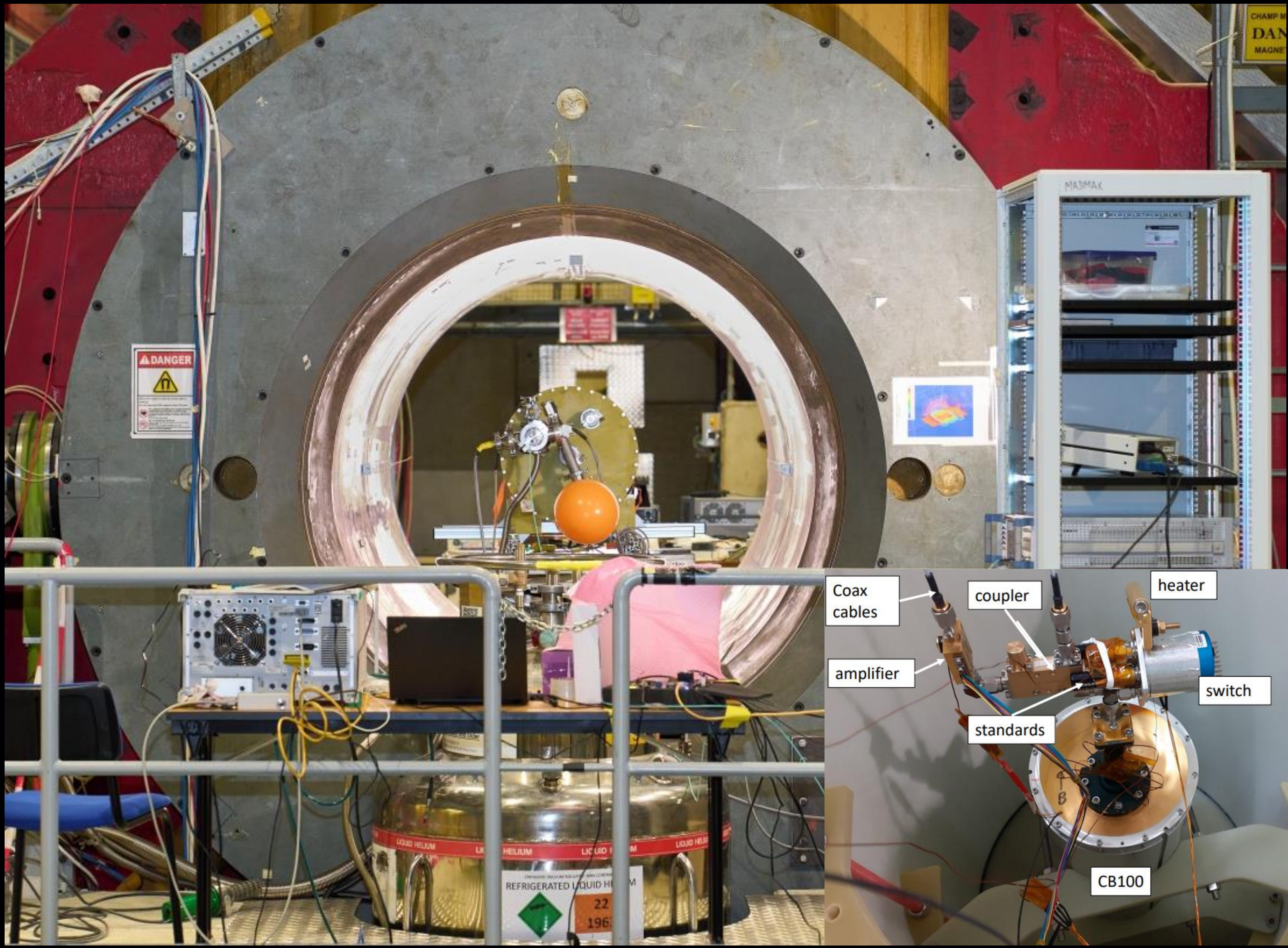
Cold axion / dark photon searches

Single thermal cycle semi-automatic calibration

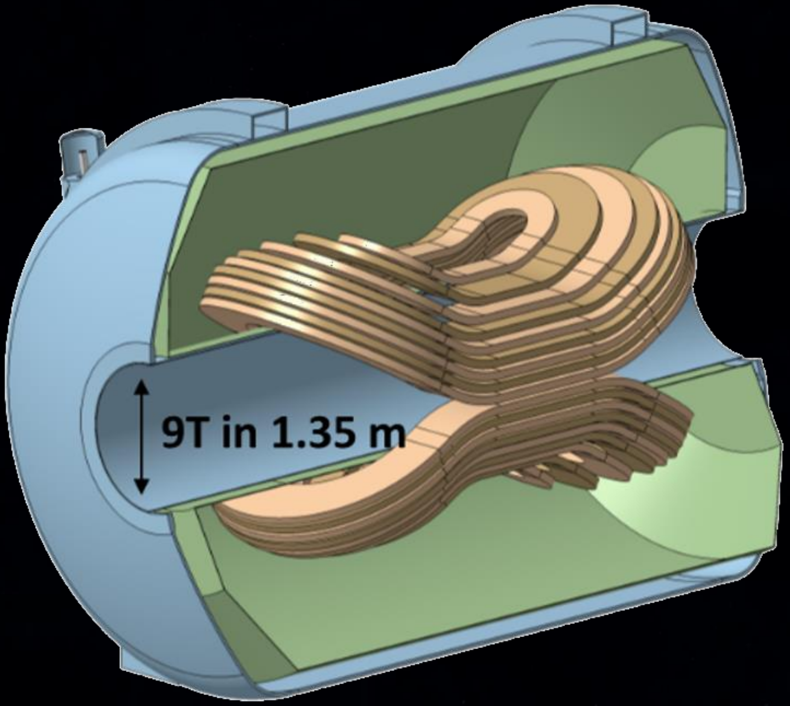
Horizontal non-magnetic cryostat developed with CERN Cryolab

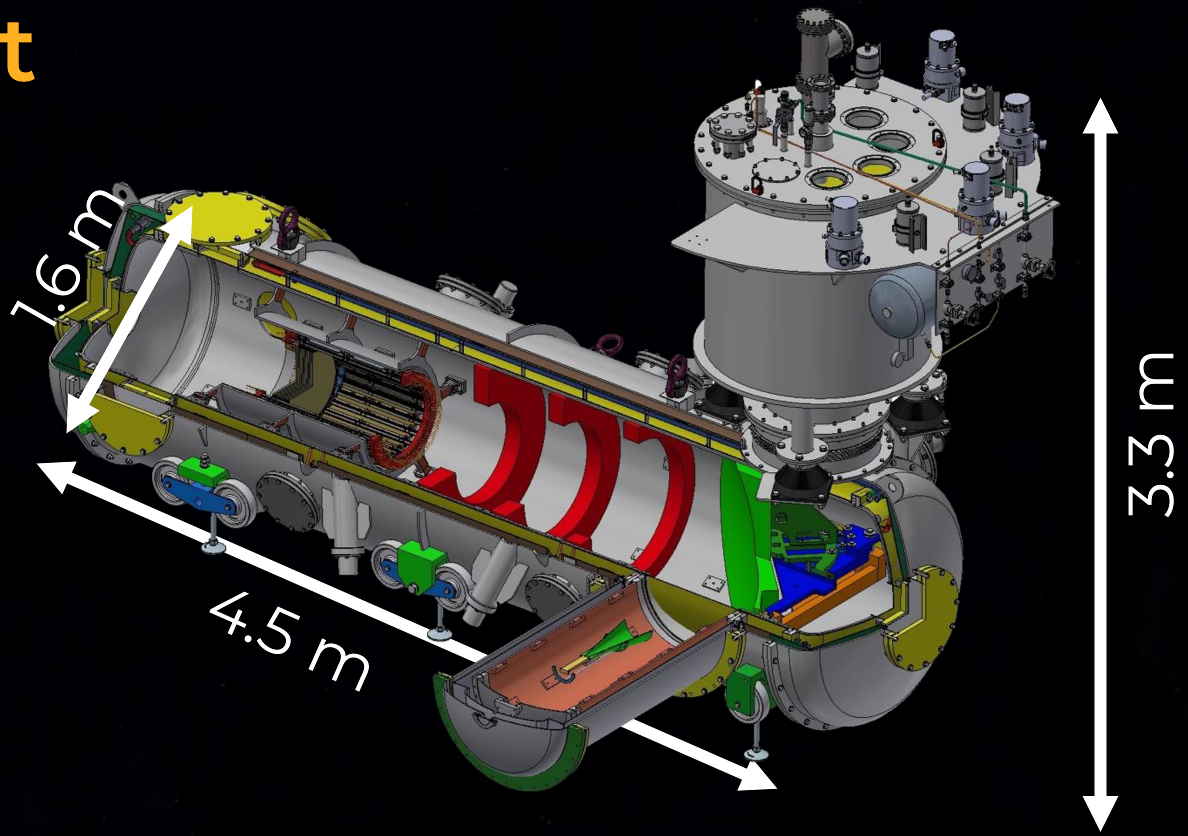
1 day long axion search at 19 GHz at CERN in a 1.6 T field at 14 K system temperature

Stay tuned!



New magnet and cryostat





Quench protection feasible

Supplies for conductor available

Currently designing, producing, and testing a demonstrator coil

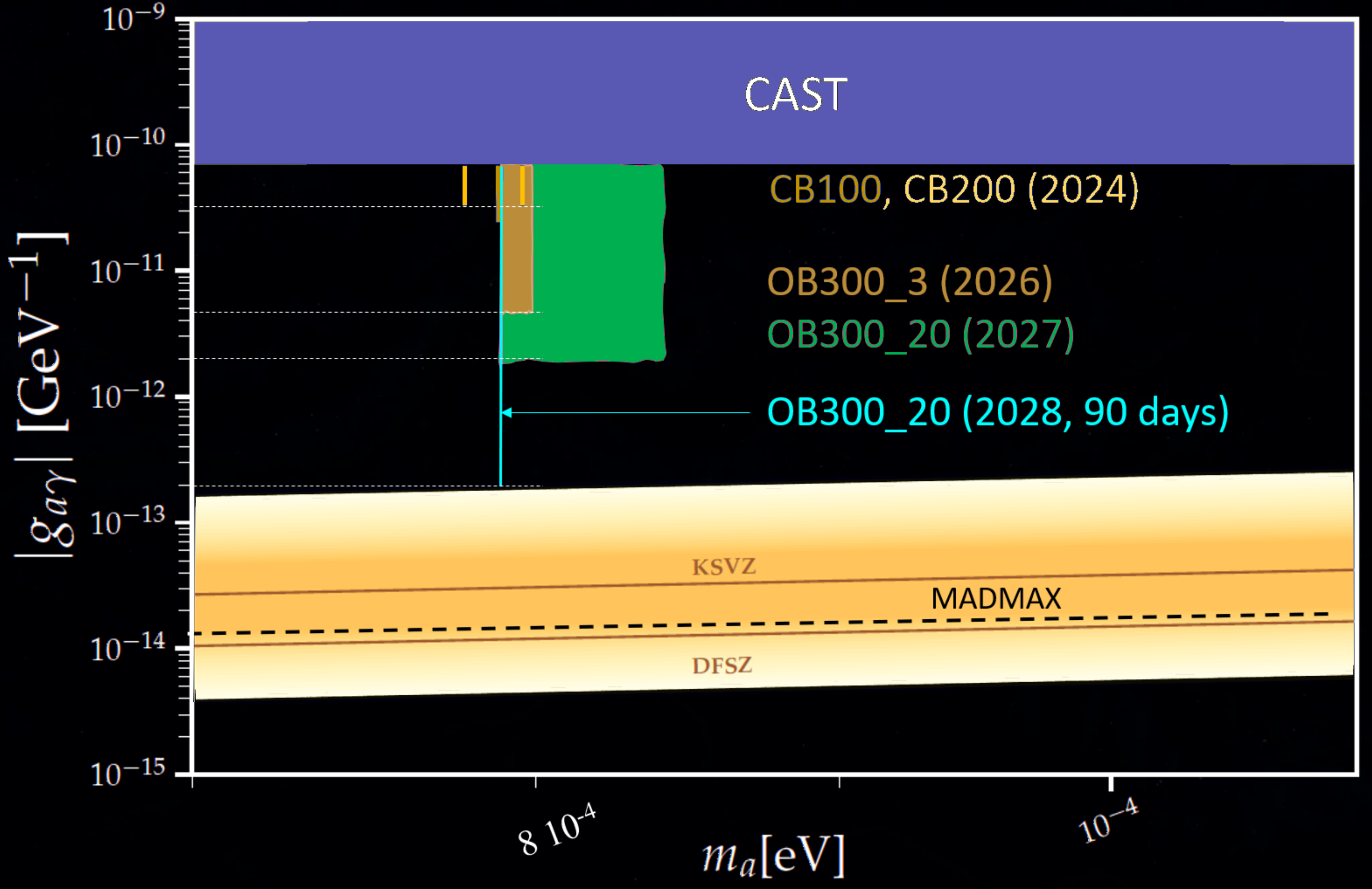
DOI: 10.1109/TASC.2023.3273734: IEEE Transactions on Applied Superconductivity 33.7 (2023)

Prototype cryostat delivery expected in 2025

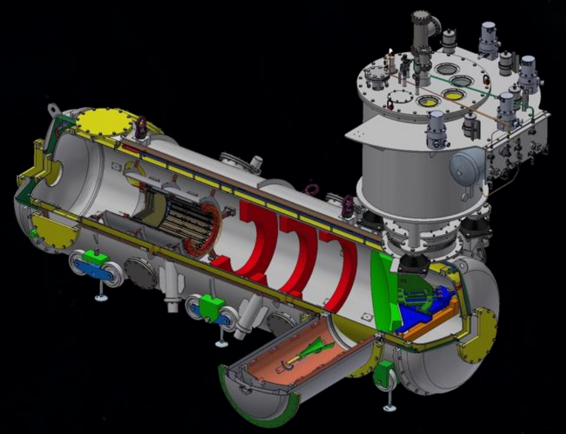
Axion search at CERN: 2026-2028

Next: tuneable cryogenic axion search using the Morpurgo 1.6 T B field

Physics reach forecast



Plans for 2026-2028 at CERN (long shutdown LHC) Morpurgo magnet + prototype cryostat



Take home message

First time a dielectric haloscope sets axion limits

World-leading limits in both dark photon and axion searches around 80 μeV

Booster quickly tuned and recalibrated, larger-range frequency scans possible

Data analysis is ongoing regarding our first cryogenic axion search

Ongoing R&D regarding B field, cryogenics, booster size, and more…