MADMAX-Toward a dielectric haloscope

Novel detector for post-inflationary axion dark matter

Chang Lee on behalf of the MADMAX collaboration, July 8th, 2022, ICHEP Bologna, Italy

Motivation

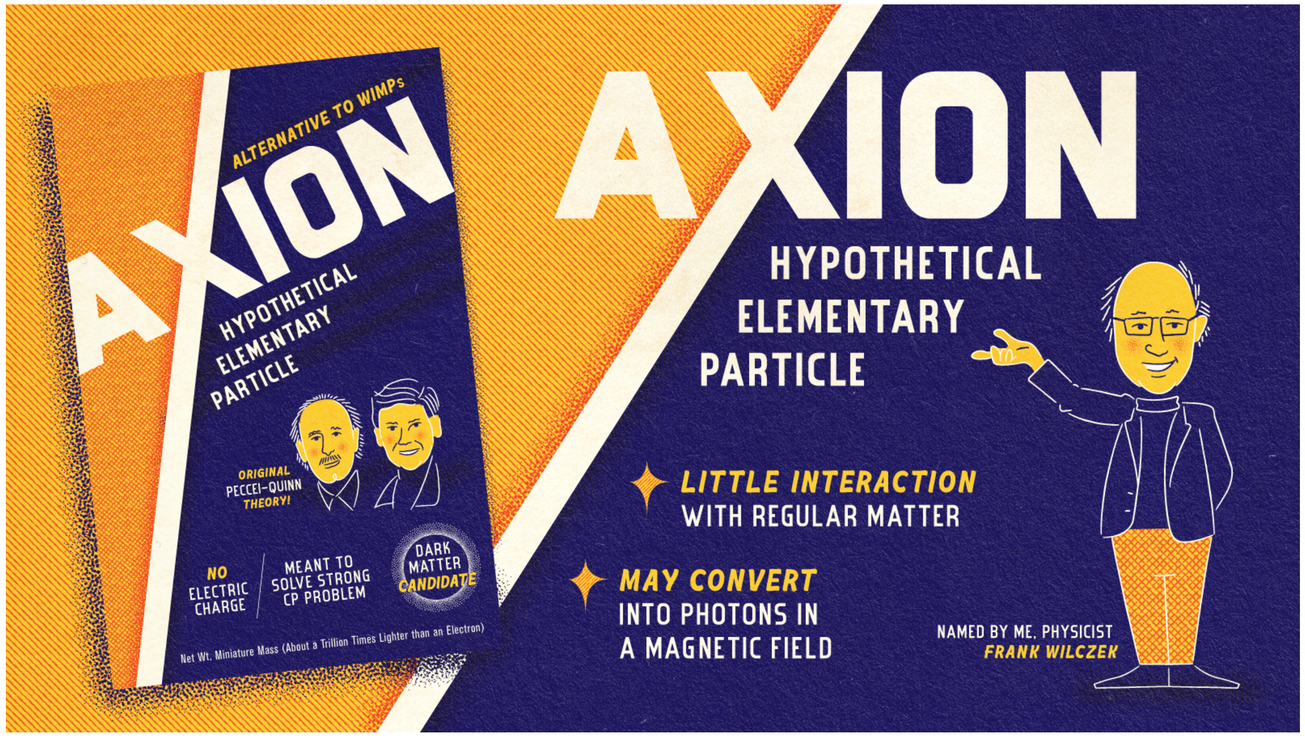
QCD axion DM

- PQ symmetry to solve the strong CP problem
  - Spontaneous symmetry breaking @ f_A: axion
- well-motivated wave CDM candidate
  - Non-thermal: cold
  - Small interaction with SM particles.

$$\mathscr{L} = \frac{1}{f_A} J^\mu \partial_\mu \phi, \quad f_A \gg v_{\text{EW}}$$

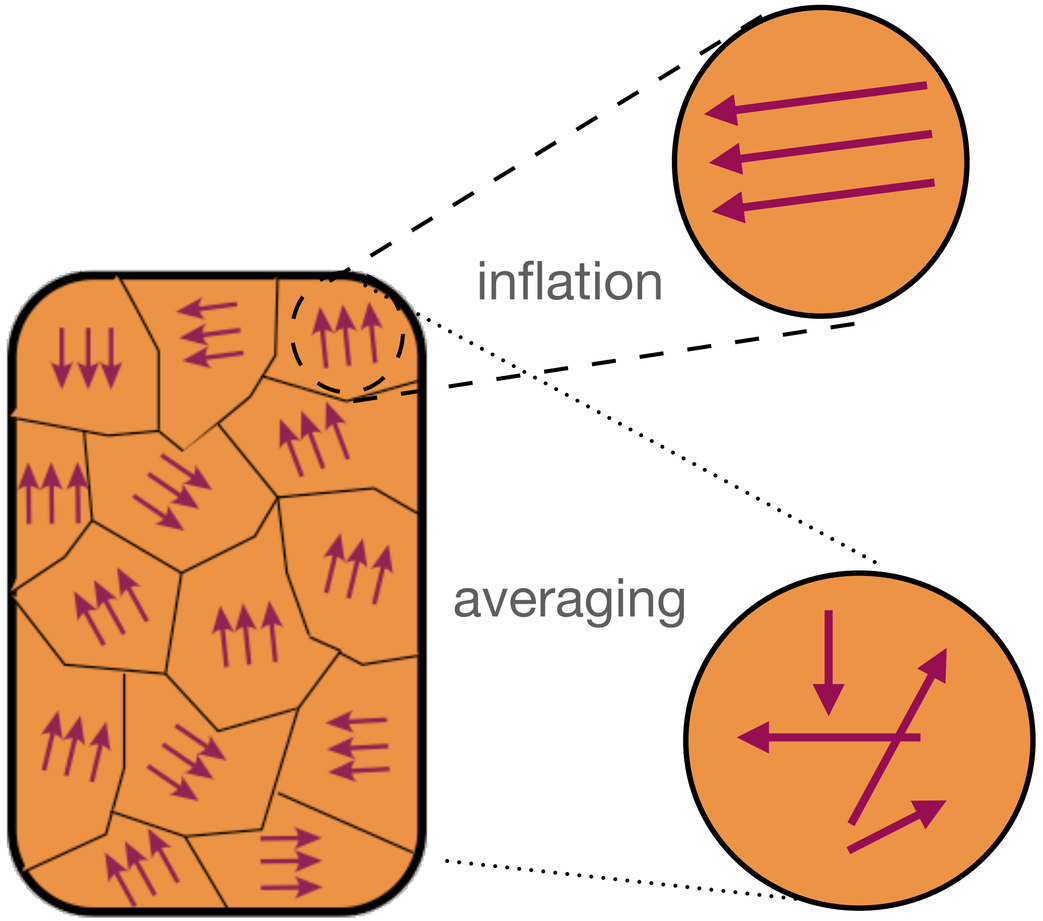
  - Small m_a has a long lifetime.

https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.symmetrymagazine.org%2Farticle%2Fthe-other-dark-matter-candidate&psig=AOvVaw0ANqCII0ryFIaJKtcEvgnS&ust=1643403924692000&source=images&cd=vfe&ved=0CAsQjRxqFwoTCODh_O3q0vUCFQAAAAAdAAAAABA0



Motivation

Post-inflationary axion DM mass

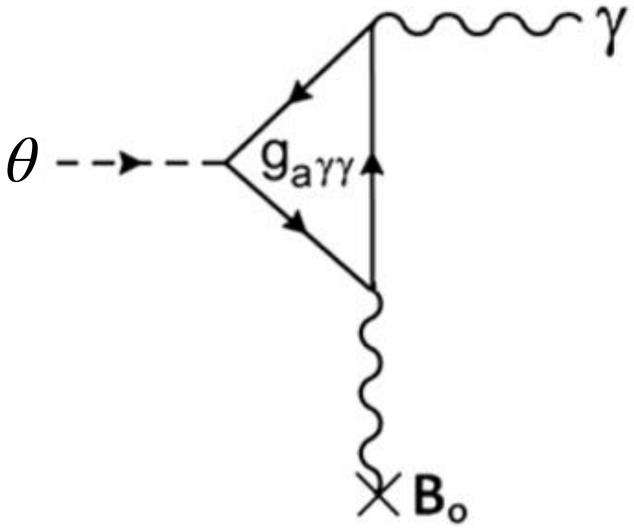


- Pre-inflationary scenarios allows much wider m_a.
- Post-inflationary production prefers $m_a : 40 - 180\ \mu$eV.

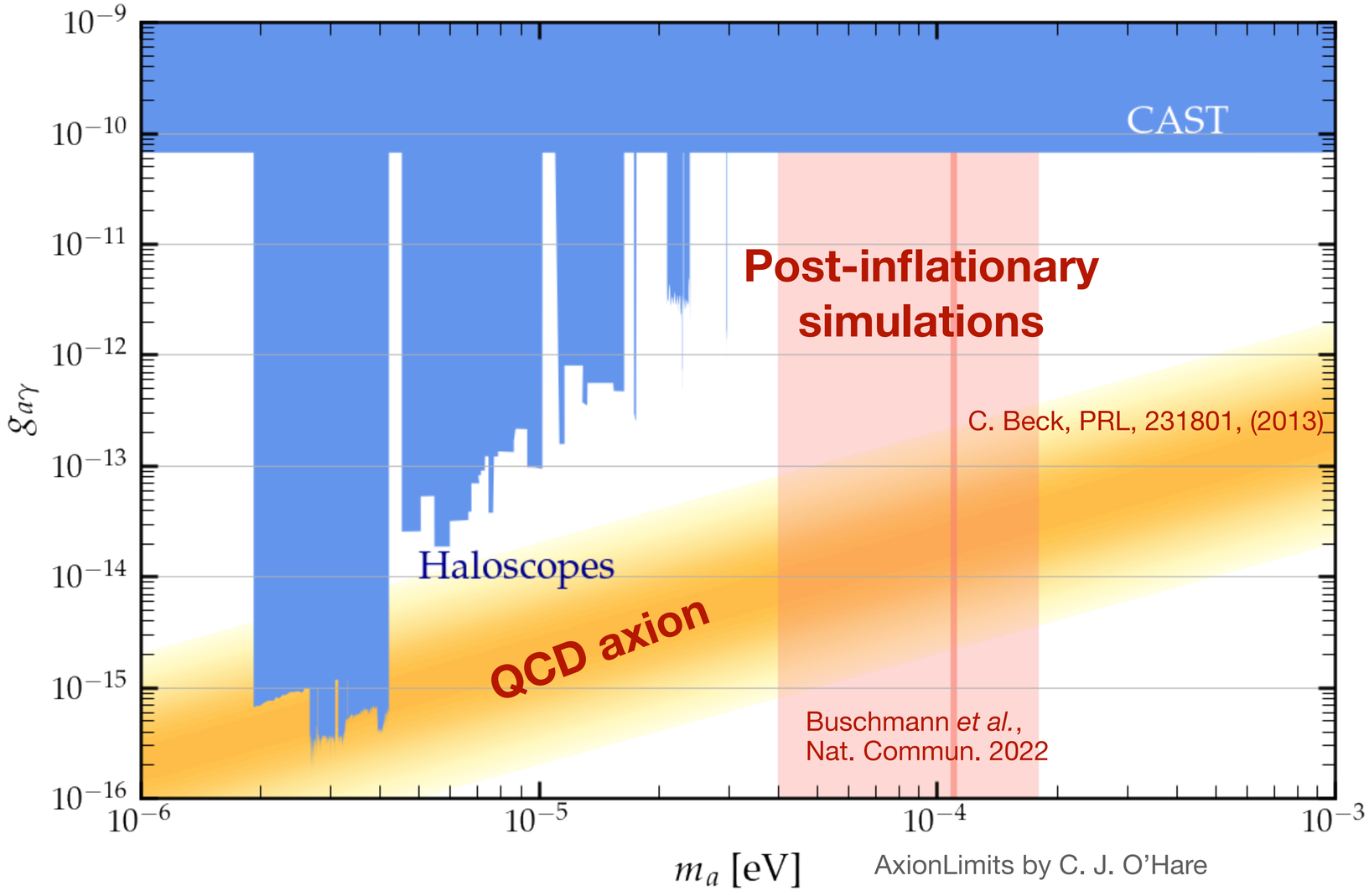
Buschmann *et al.*,
Nat. Commun. 2022

DM axion detection status

axion-photon coupling



- $\gamma \sim 20\,\mathrm{GHz}$



AxionLimits by C. J. O'Hare

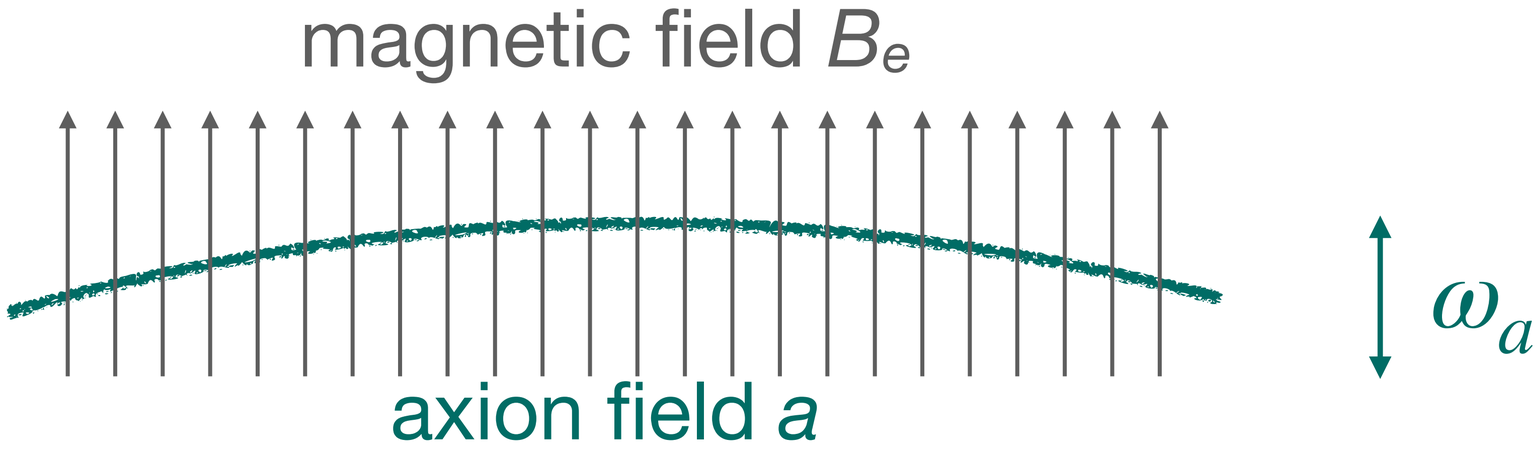
Principle

Principle

Axion-induced E-field

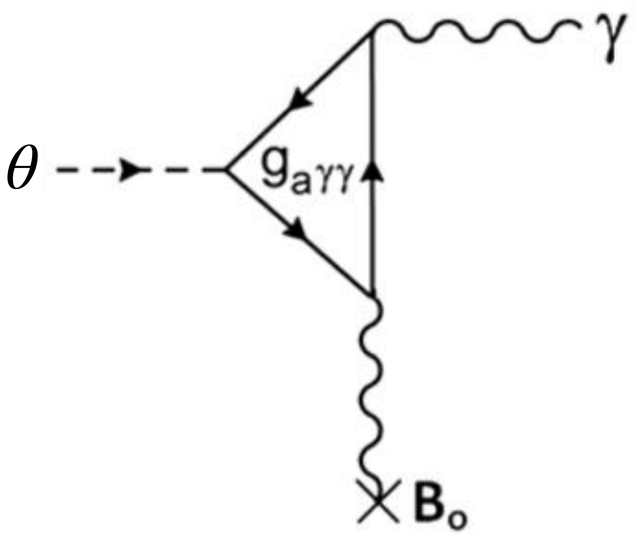
Principle

Axion-induced E-field

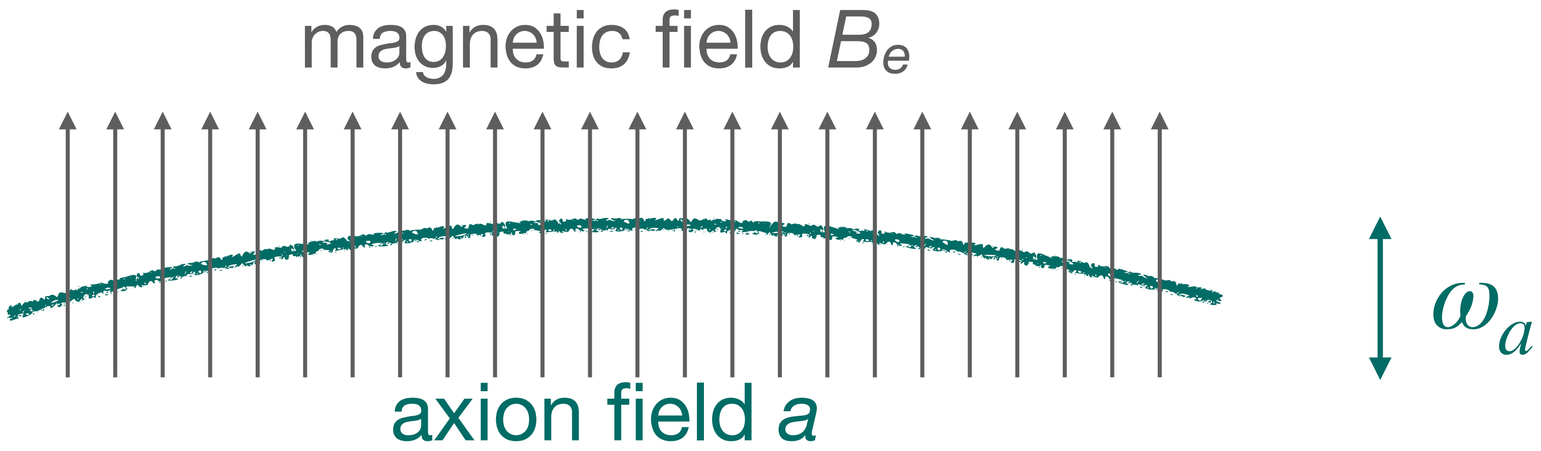


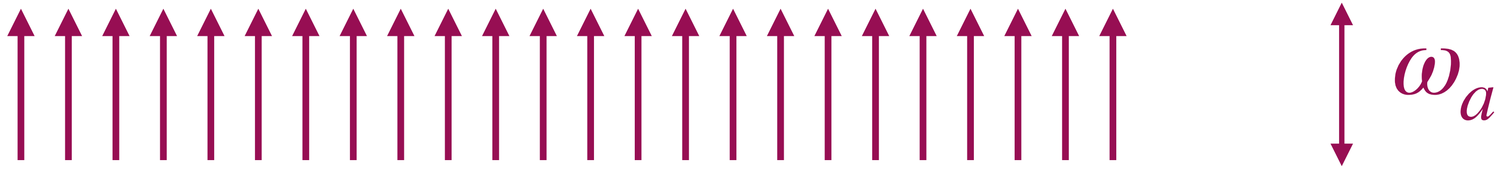
Principle

Axion-induced E-field



$$E^{\alpha} = -\frac{g_{a\gamma} B_e}{\varepsilon} a$$





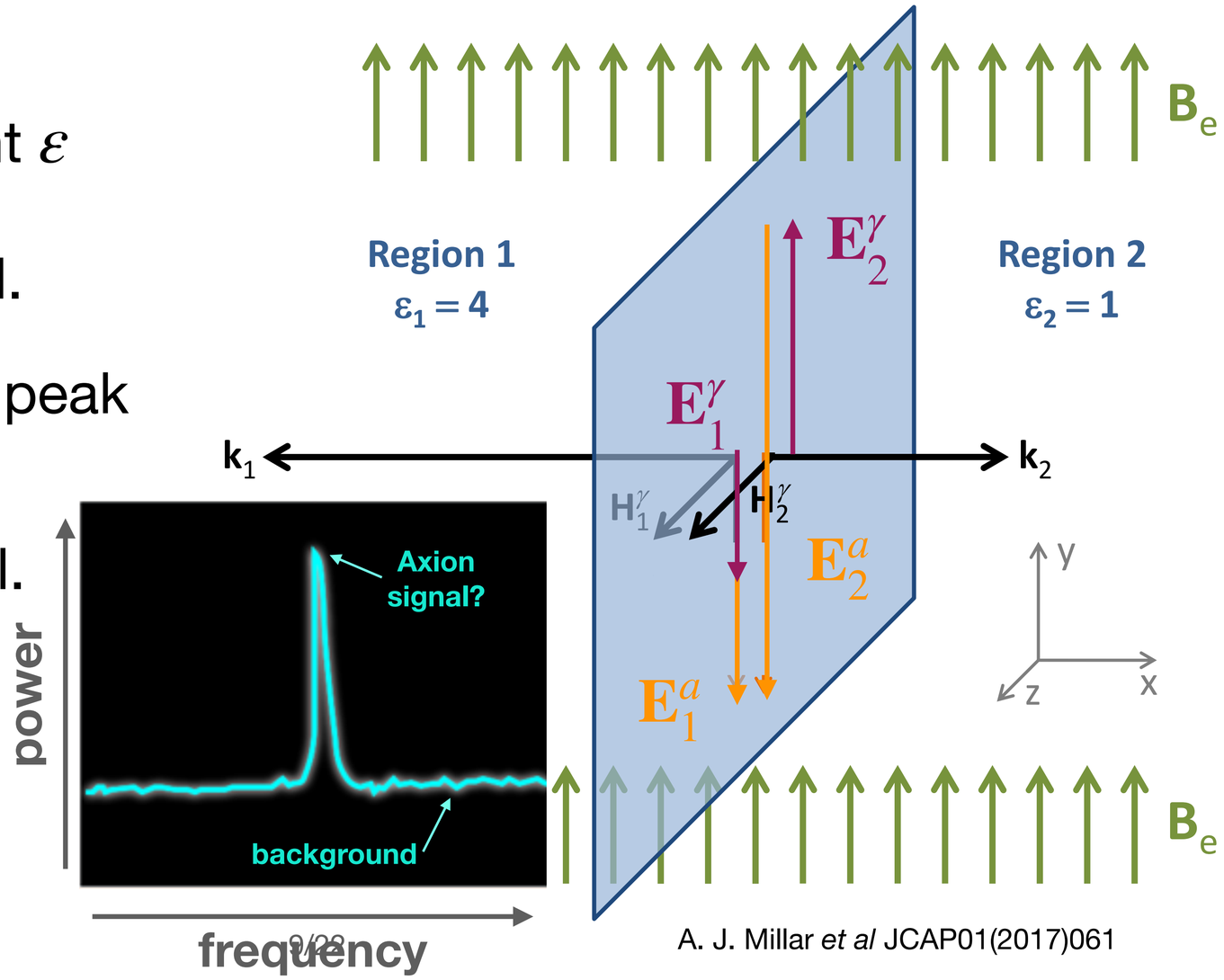
Axion-induced electric field

Traveling wave from dielectrics

- At the **boundaries**, different ε produce different E^{α}, and traveling waves are emitted.
- Signature: mono-energetic peak above background.
- Problem: signal is too small.

$$E^{\alpha} = -\frac{g_{a\gamma} B_e}{\varepsilon} a$$

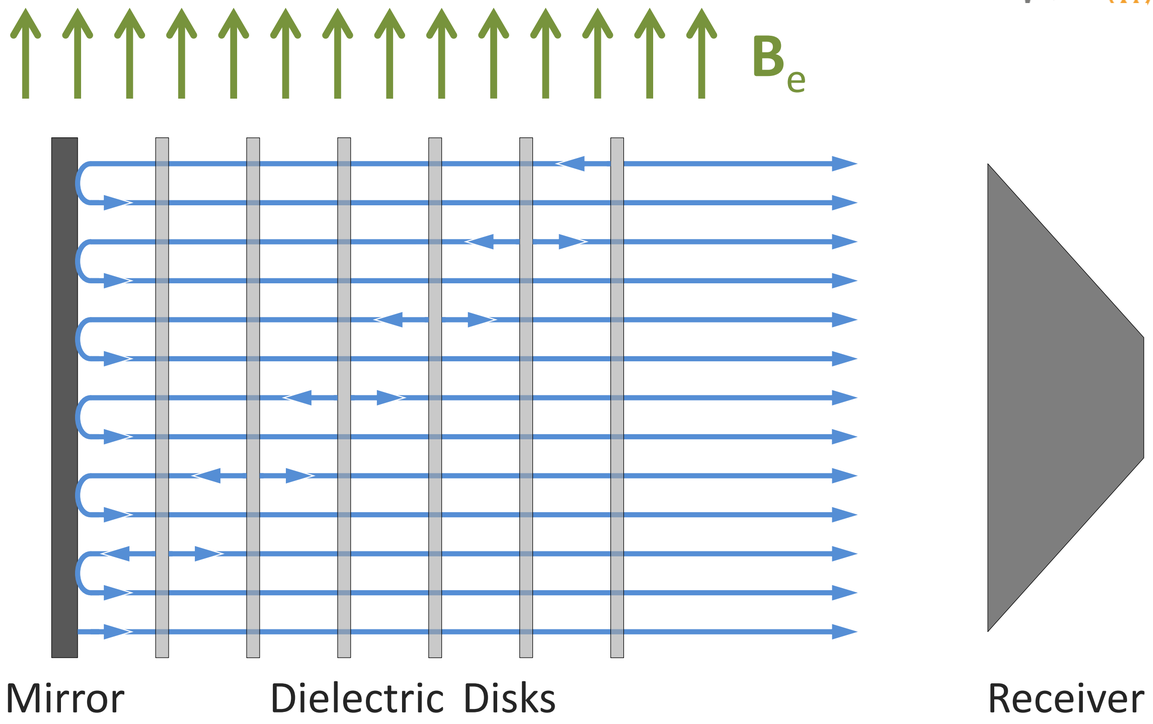
$$\sim 10^{-13}\ \text{[V/m/T]}$$

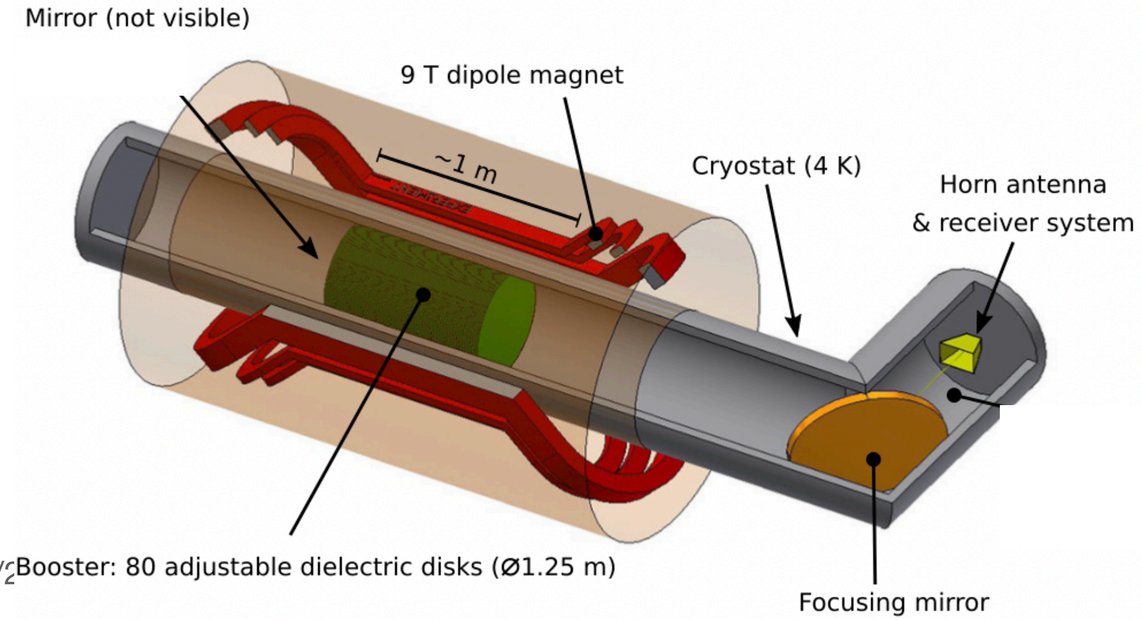


A. J. Millar *et al* JCAP01(2017)061

Dielectric haloscope

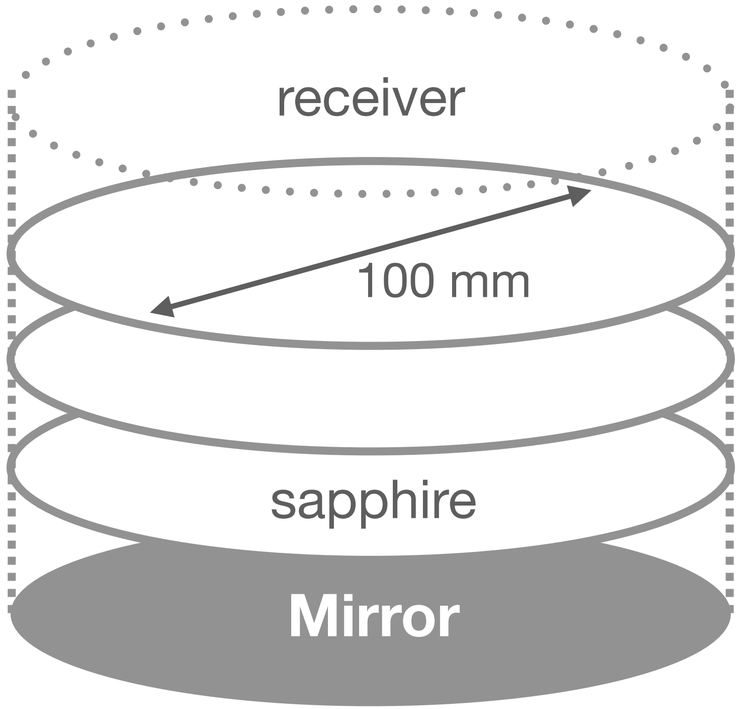
- Solution: constructive **interference** of signal from **multiple boundaries**
- Scale-up on transverse dimensions, sensitive to the QCD-axion
- Tuning by moving disks
  - Antenna couples only to the axion mode (ideally)

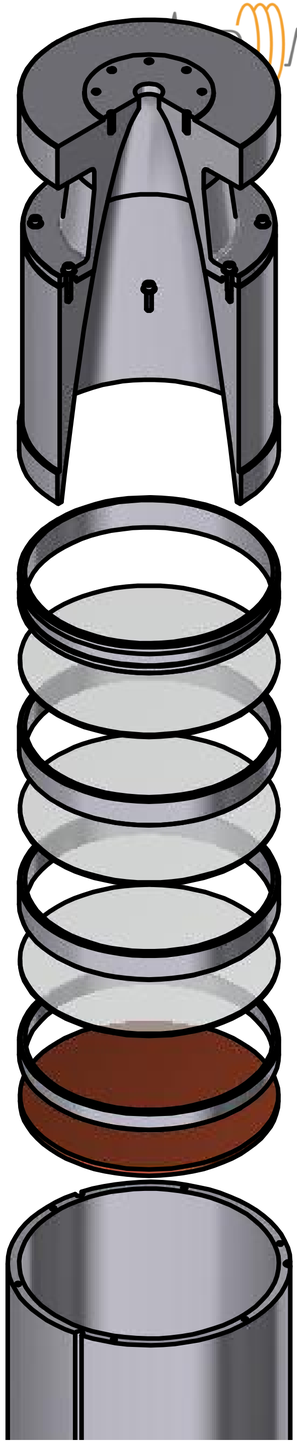




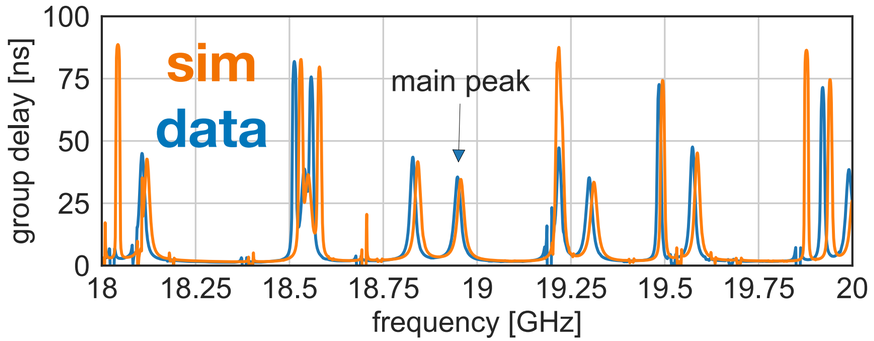
Closed booster

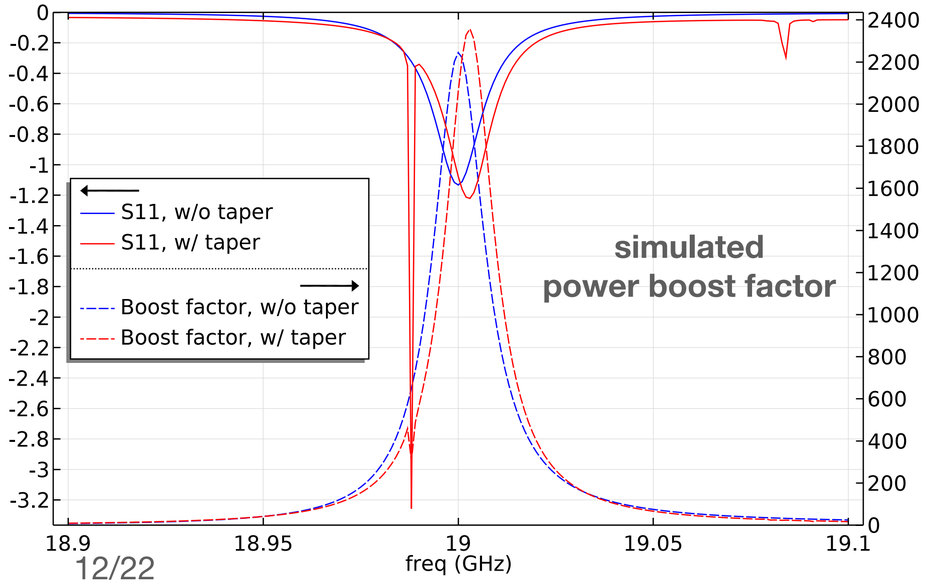
Verification of concept





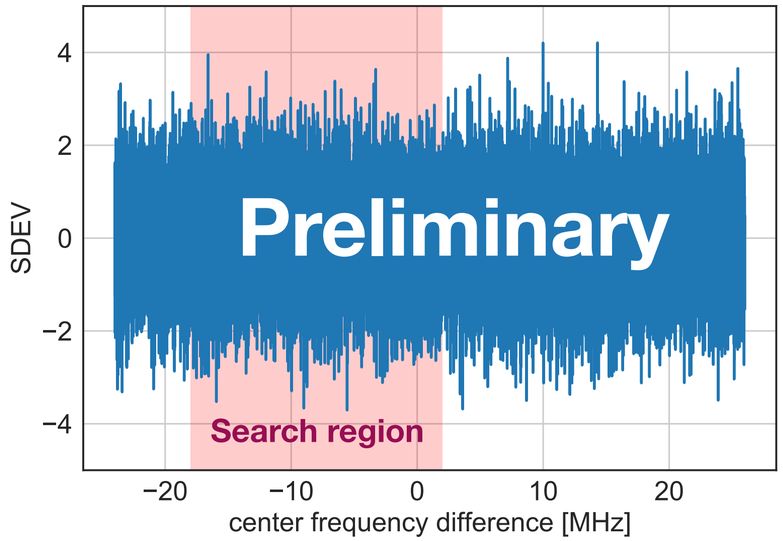
- A small & simple dielectric haloscope
  - “Closed”: conducting boundary
  - Understand the detector & its noise
  - First Axionic DM search
- Measured reflectivity agrees with the simulation

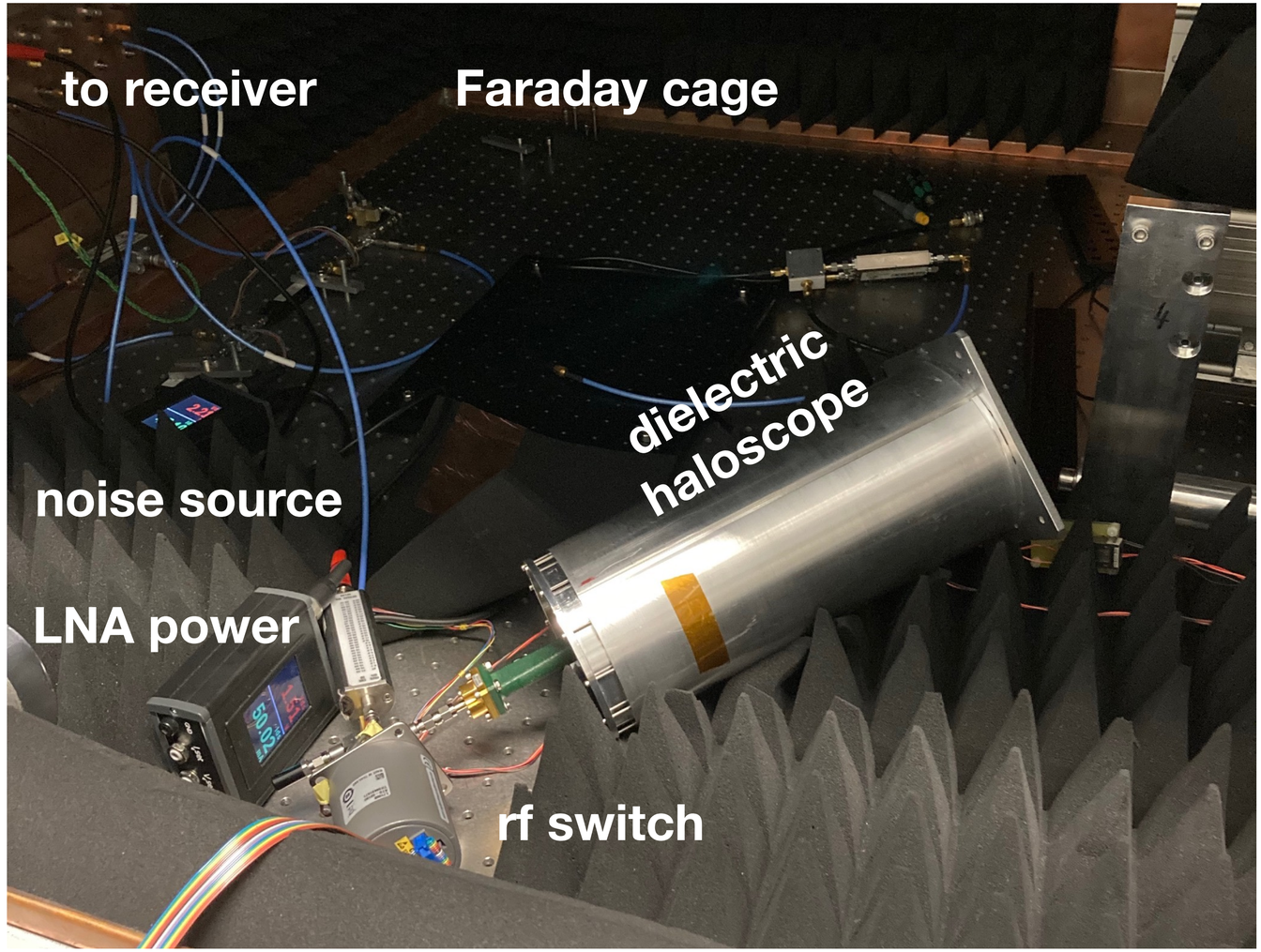




Hidden photon search @ MPP

- Hidden photon to microwave conversion w/o *B* field.
- 32 days, 200K effective T_{sys}
- No excess power observed





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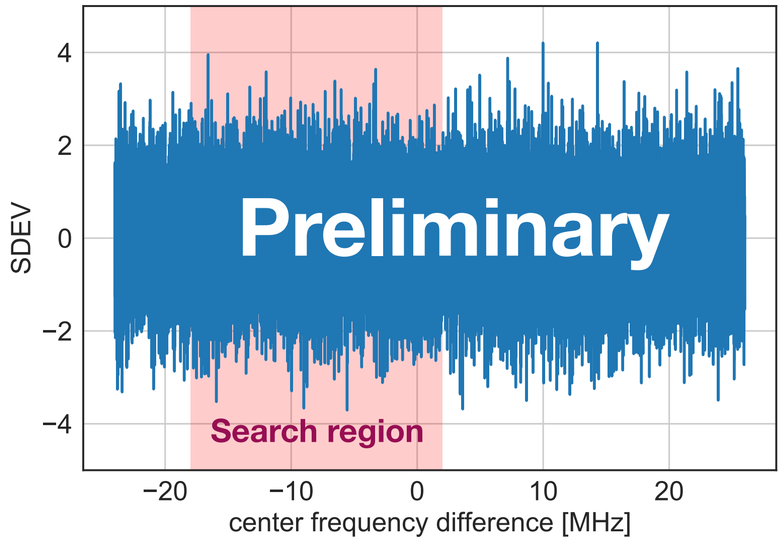
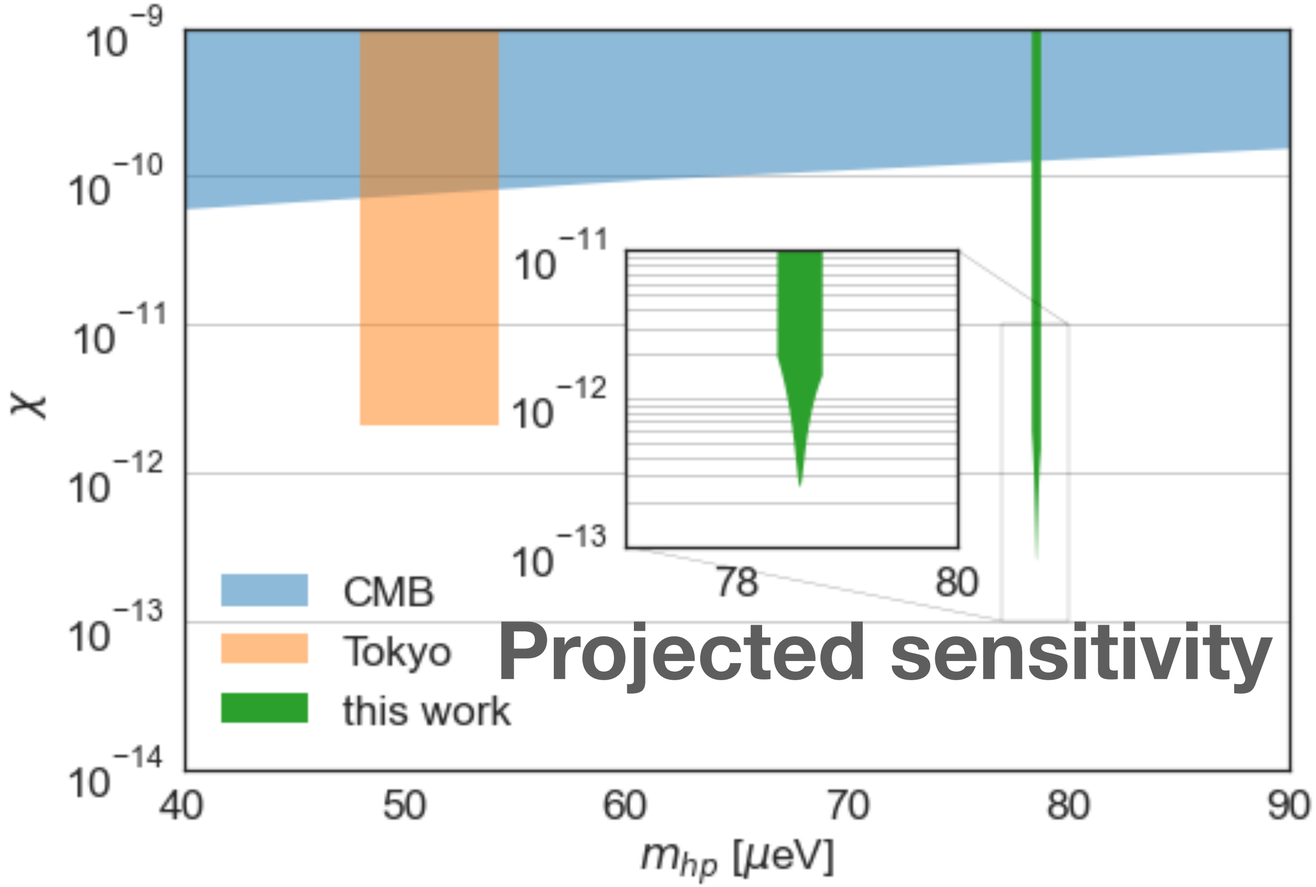
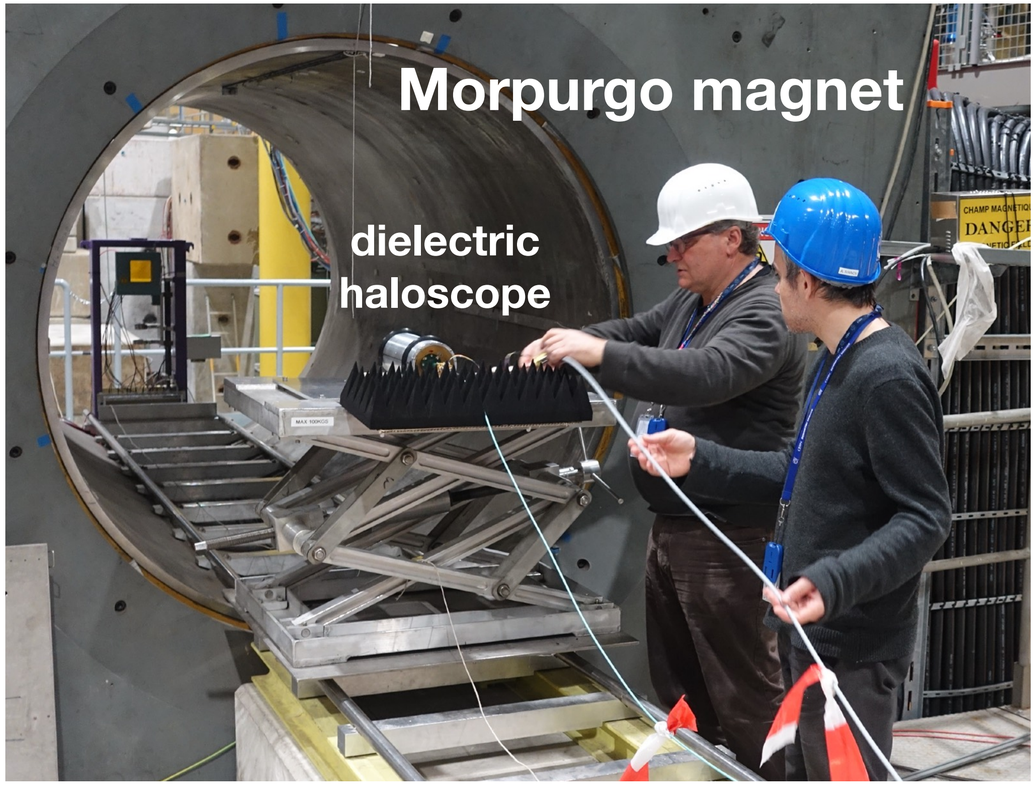


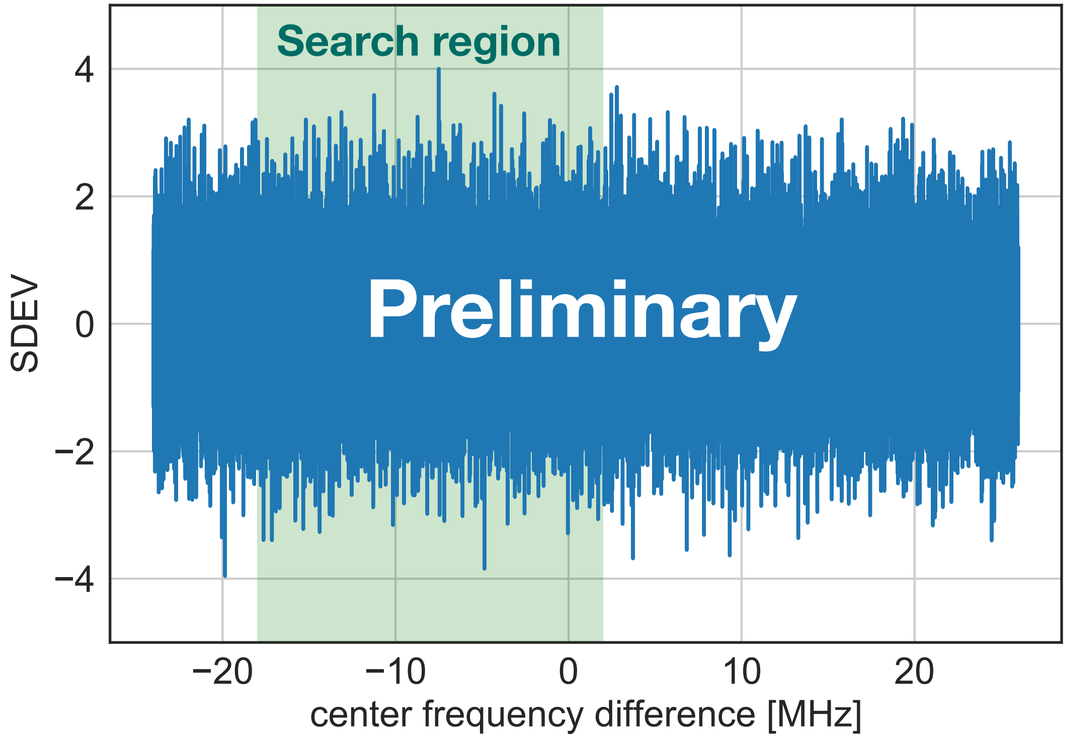


ALP search from CERN's Morpurgo magnet

- MPP group traveled to CERN to use Morpurgo magnet for ALP search!
  10 hrs @ 1.6T, No excess power found.

- Planning upgrade with a 4K system.





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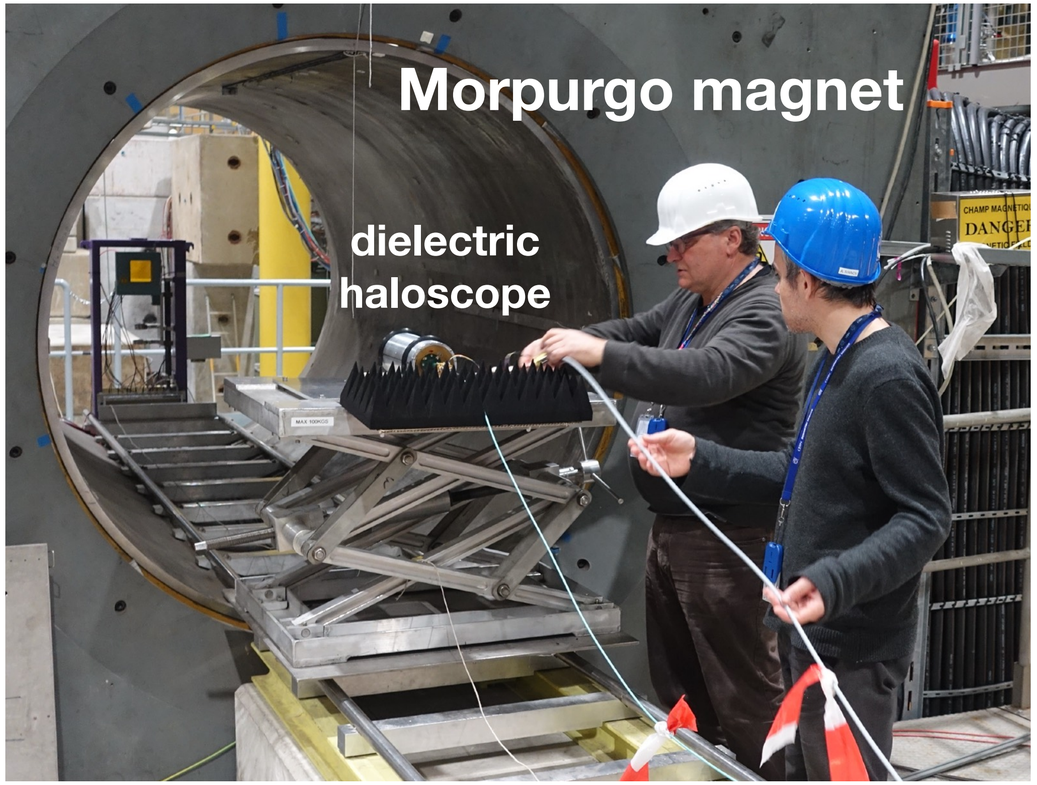
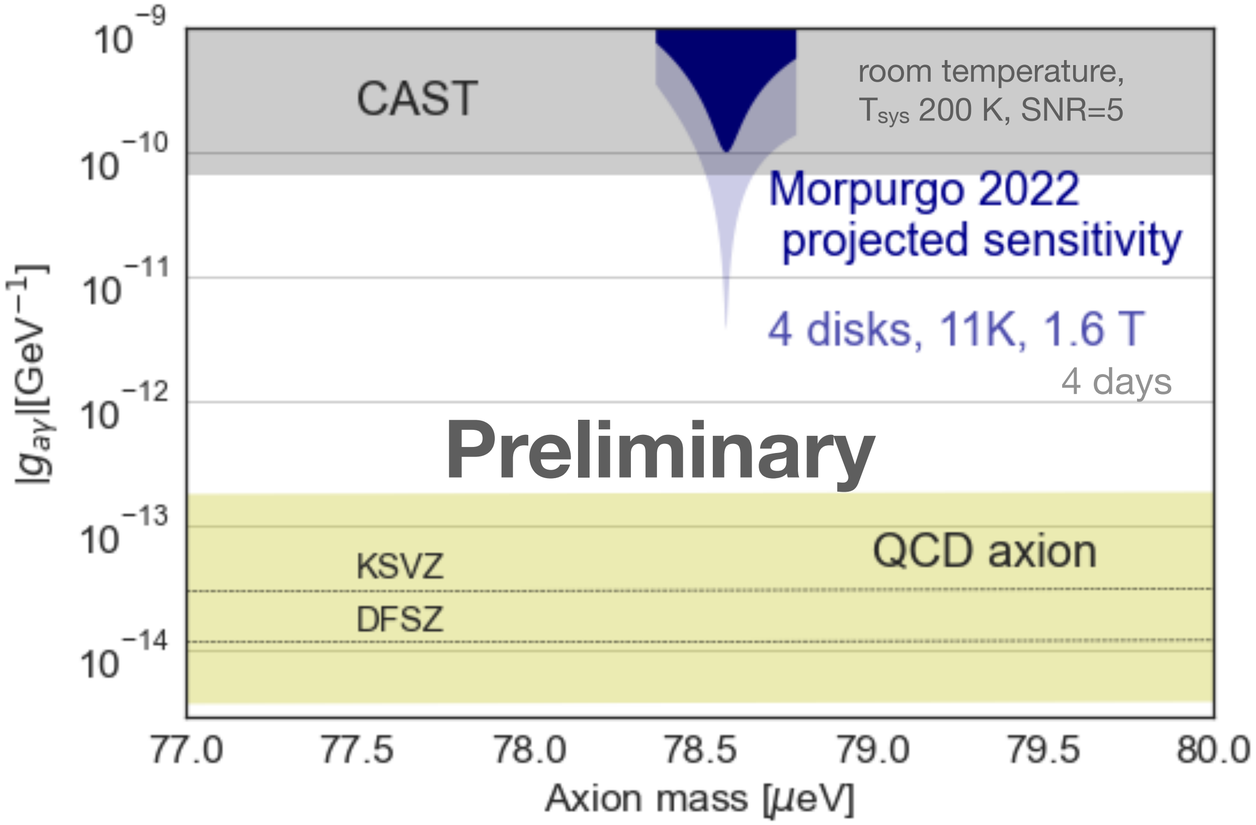
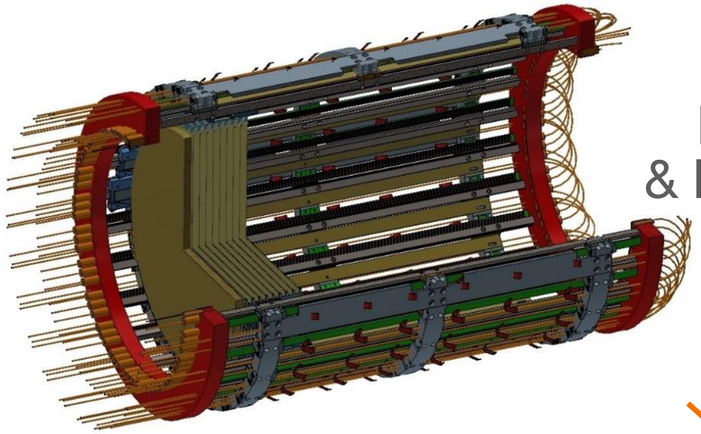




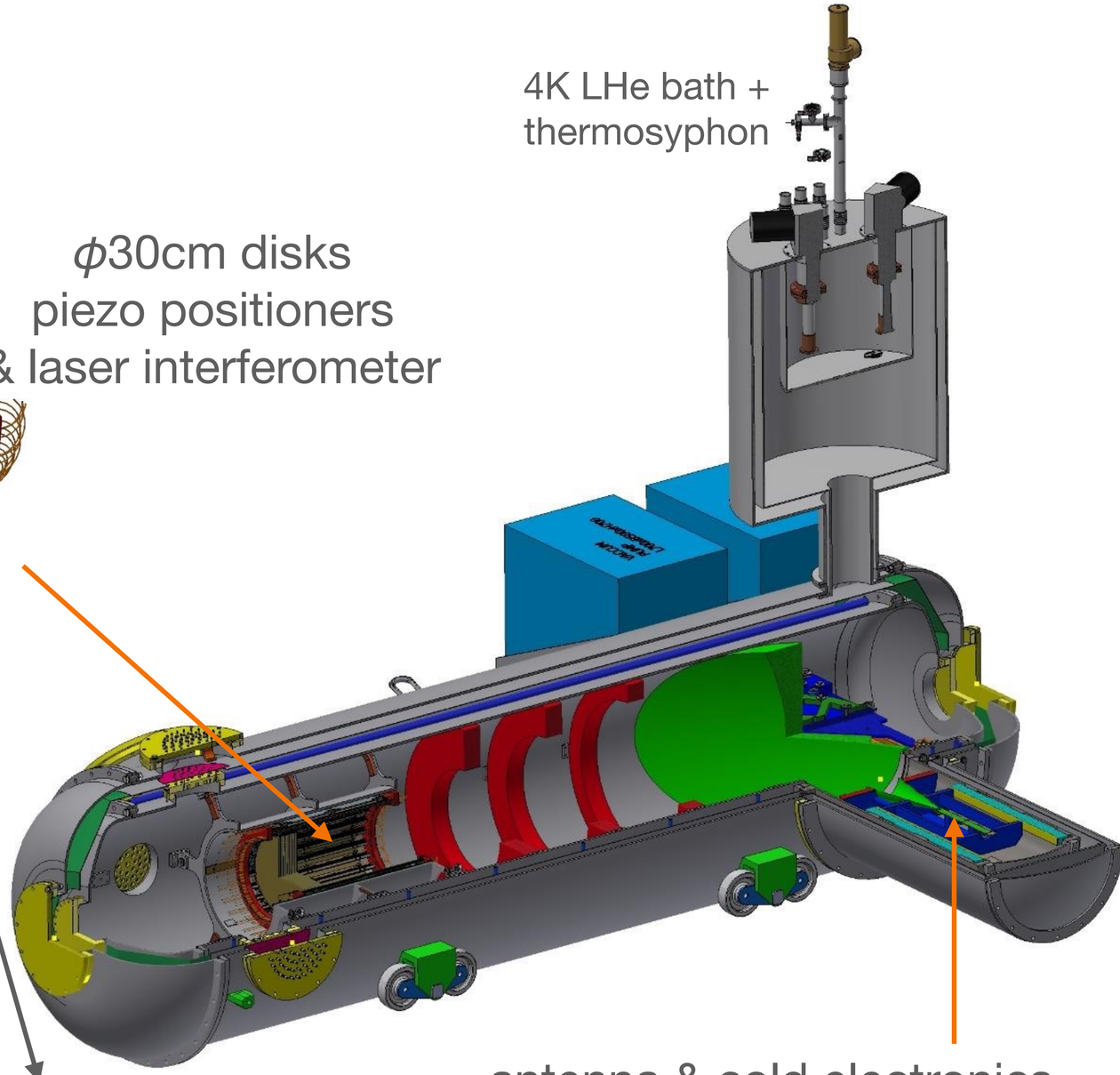
Future

MADMAX prototype



ϕ30cm disks
piezo positioners
& laser interferometer

4K LHe bath +
thermosyphon



ϕ1.2 m

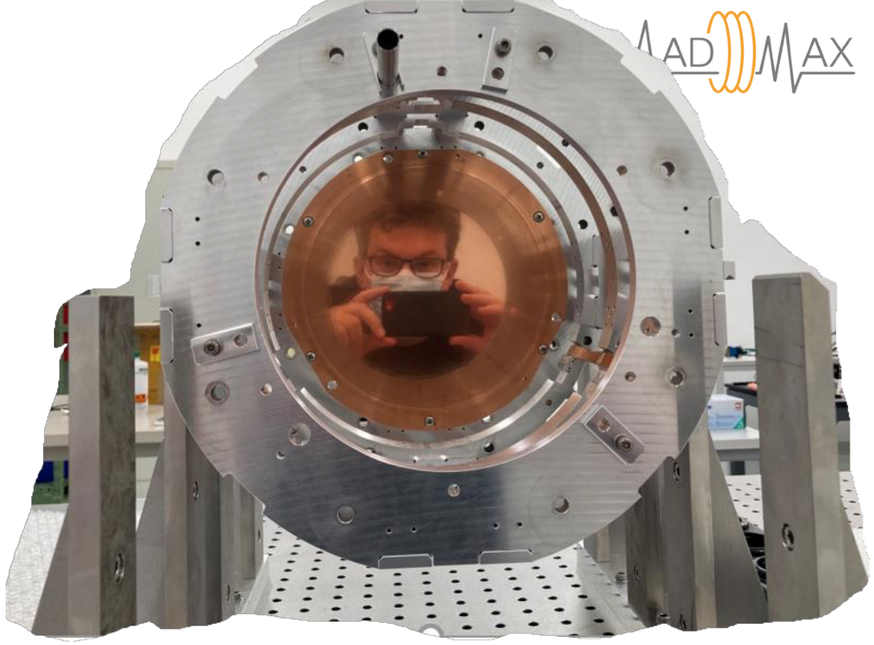
antenna & cold electronics

- Mechanical and rf feasibility test
- DFG funded!

  To be commissioned at UHH
- Operation in Morpurgo until 2025
  during the beam SPS shutdown periods

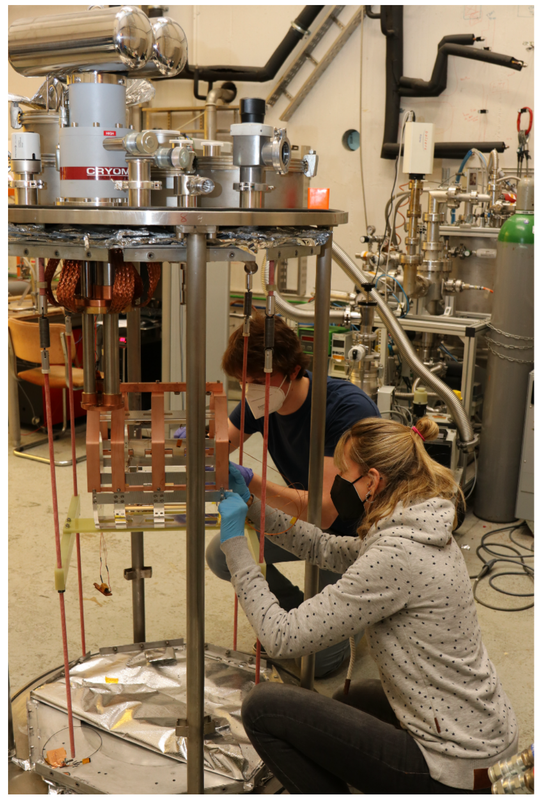
Mechanical feasibility R&D

Milestones achieved!

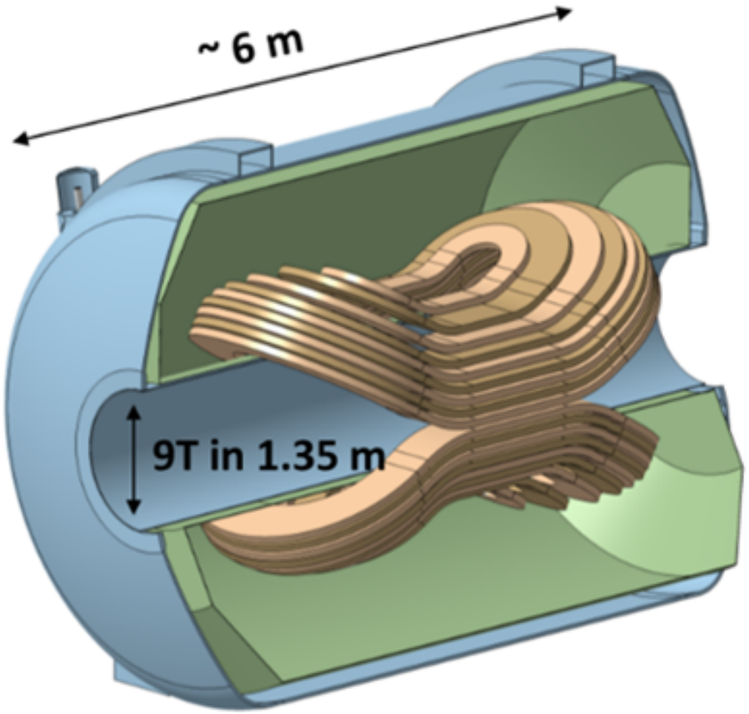


- Can we operate the dielectric haloscope in high B, cryogenic temperature?
- Project200 (ϕ200mm disks) successfully tested at CERN's cryolab and Morpurgo
- Piezo-motor operated inside the 5T ALPS II

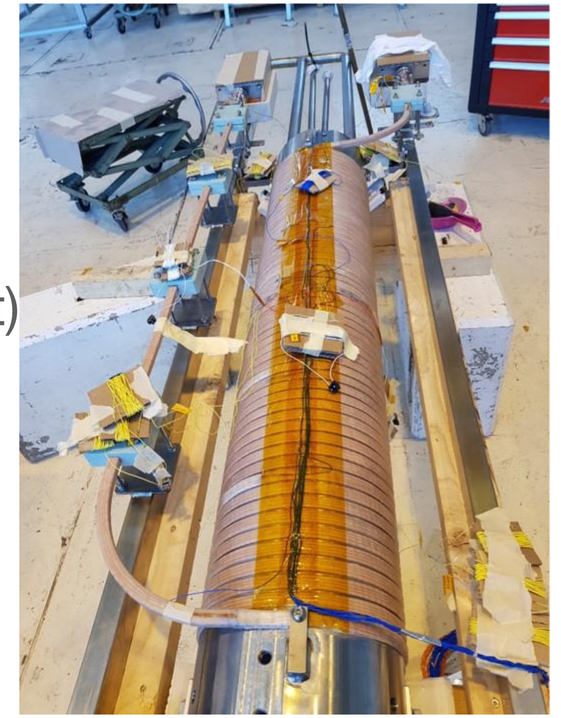
cryogenic
piezo positioners

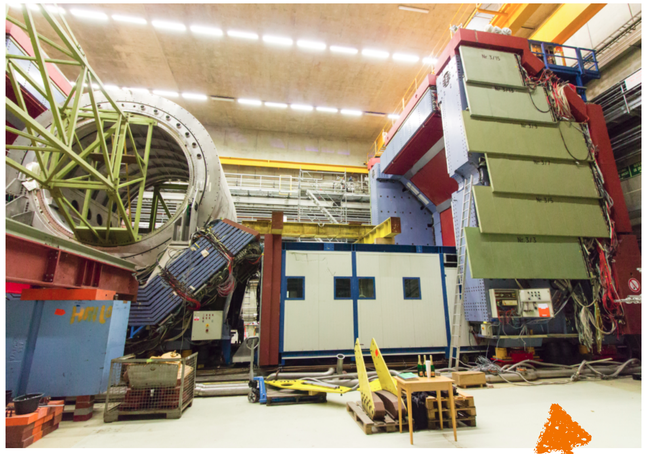


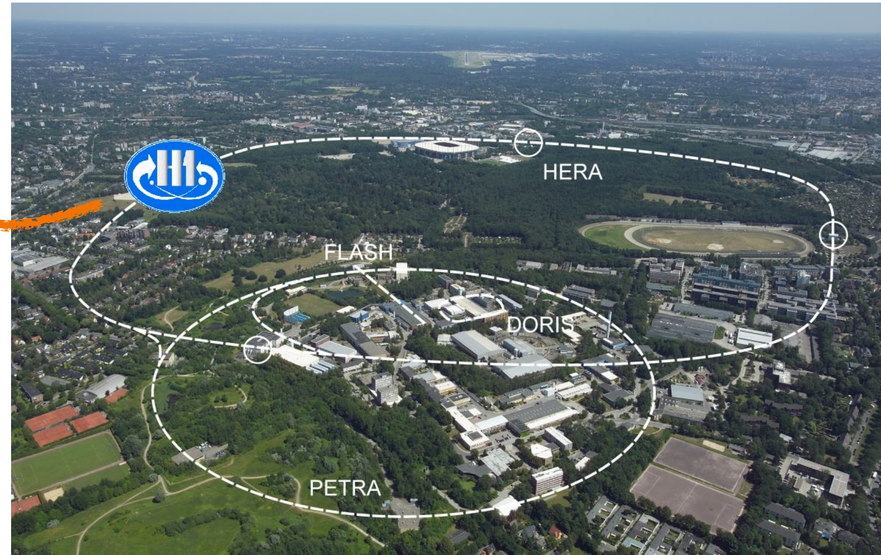
Full MADMAX Magnet



Conductor (NbTi in Cu jacket)
quench test successful!



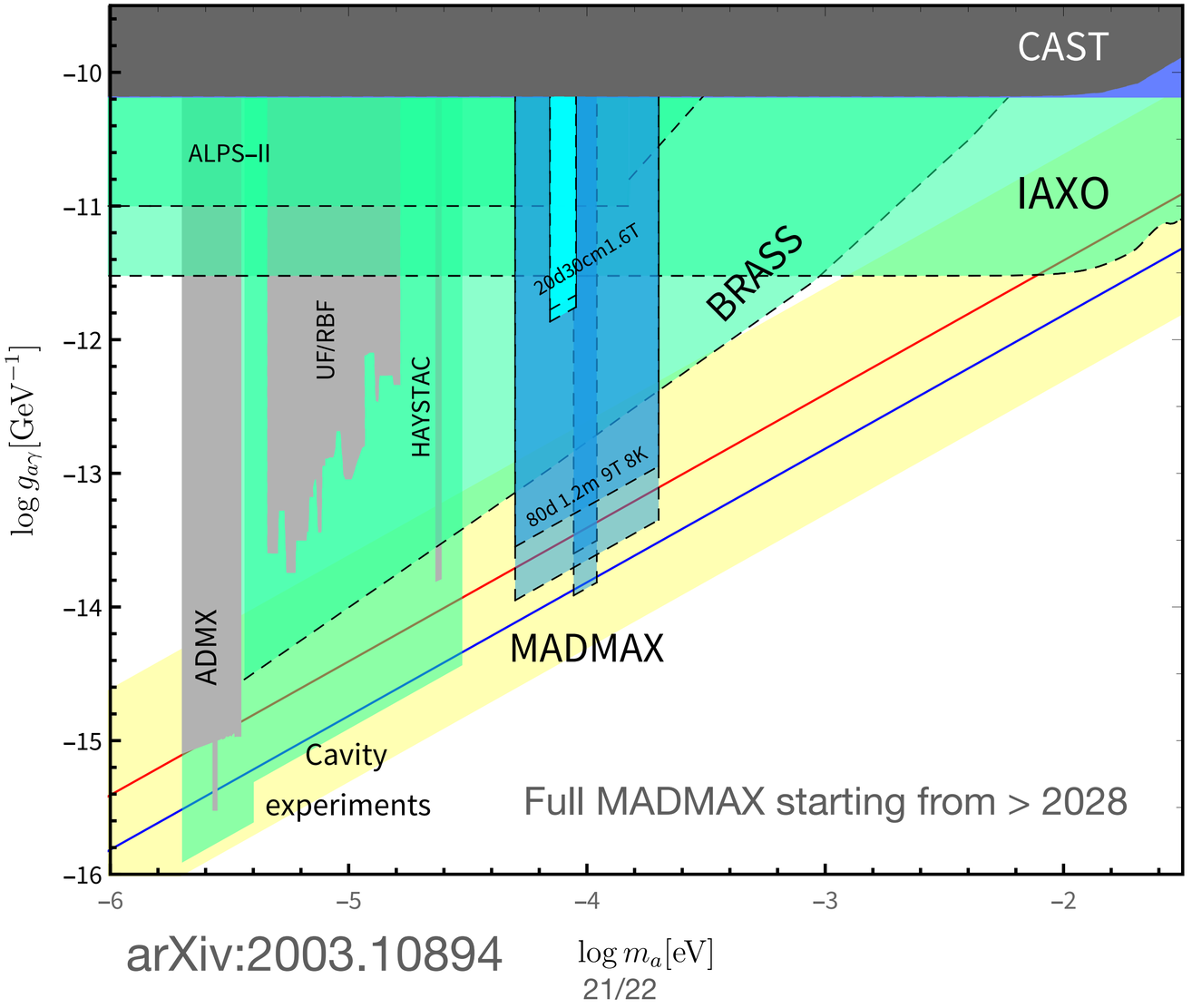




BILFINGER NOELL GMBH

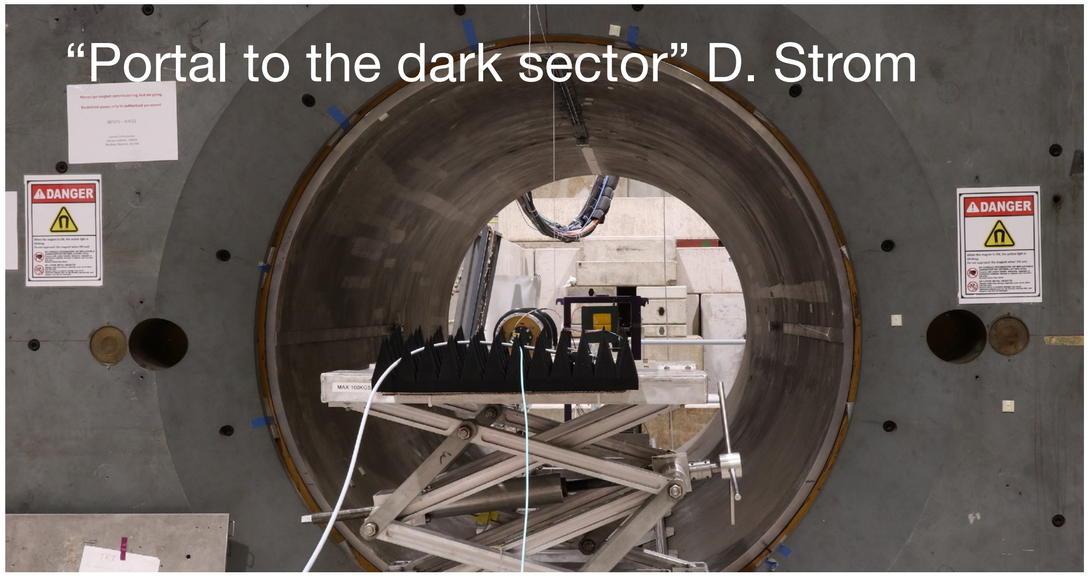
MAX-PLANCK-INSTITUT FÜR PHYSIK

Projected sensitivity



arXiv:2003.10894

Summary & Conclusion



- Axion is a well-motivated DM candidate. Post-inflationary scenarios prefer $m_a > 40\ \mu$eV.
- Dielectric haloscope is a promising concept. Intense activities to validate the concept using the closed booster and prototype.
- Piezo motor and P200 successfully operated in high B-field and cryogenic temperature.
- **First HP and ALP DM search** using a small setup. The analysis is ongoing.