MADMAX

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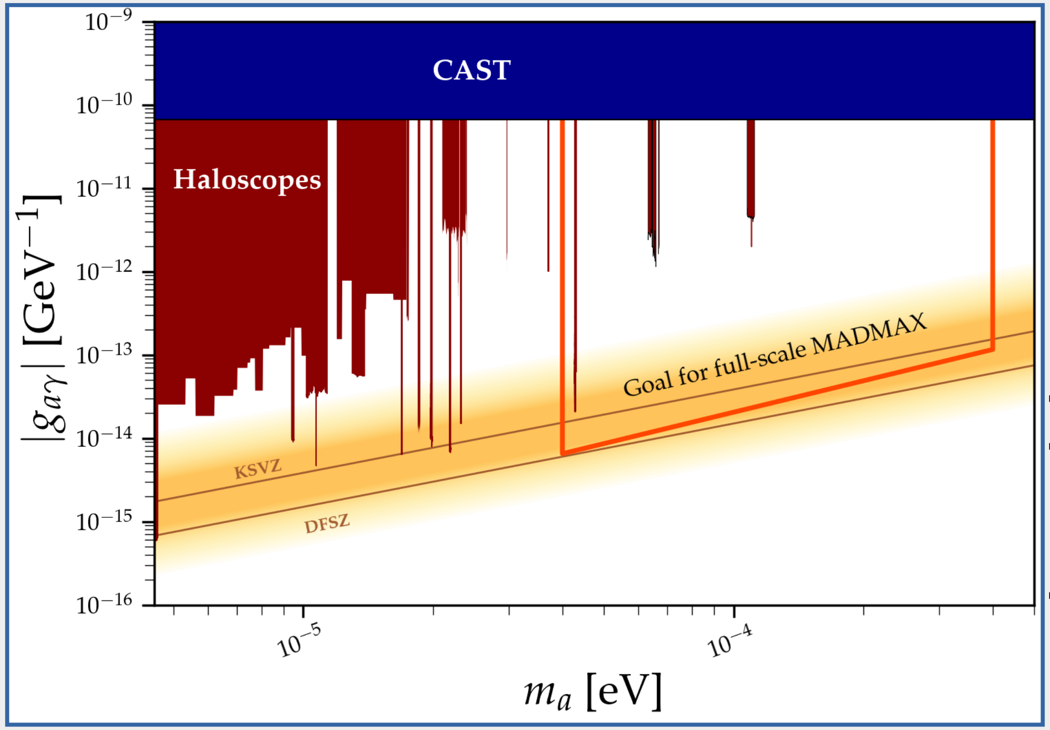
On behalf of the MADMAX Collaboration

MADMAX

Magnetized **D**isk and **M**irror **A**xion E**x**periment

- Tunable dielectric haloscope
- Sensitive to dark matter axions or dark photons
- Detector volume independent of frequency
- Signal amplification for larger axion masses [40-400 µeV] predicted by post-inflationary scenario[1]



cajohare.github.io/AxionLimits/

$$g_{a\gamma} \approx 2{\cdot}10^{-14}\,\mathrm{GeV}^{-1} \left(\frac{0.3\,\mathrm{GeV/cm^3}}{\rho_a}\right)^{1/2} \left(\frac{10^5}{\beta^2}\right)^{1/2} \left(\frac{1\,\mathrm{m}^2}{A}\right)^{1/2} \left(\frac{T_{sys}}{8\,\mathrm{K}}\right)^{1/2} \left(\frac{10\,\mathrm{T}}{B_e}\right) \left(\frac{1.3\,\mathrm{d}}{\tau}\right)^{1/4} \left(\frac{SNR}{5}\right)^{1/2} \left(\frac{m_a}{100\,\mu\mathrm{eV}}\right)^{5/4}$$

[1] Nat. Com. 13 (2022) 1, 1049

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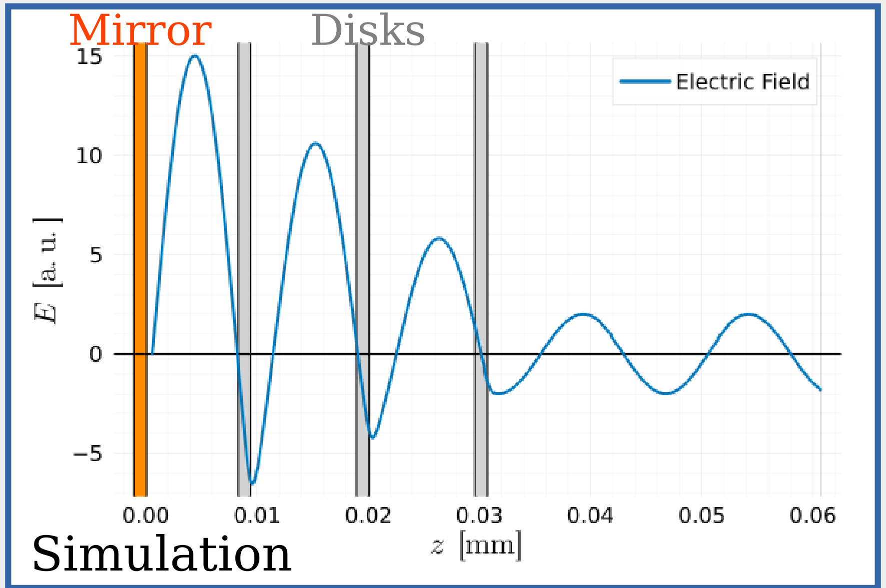
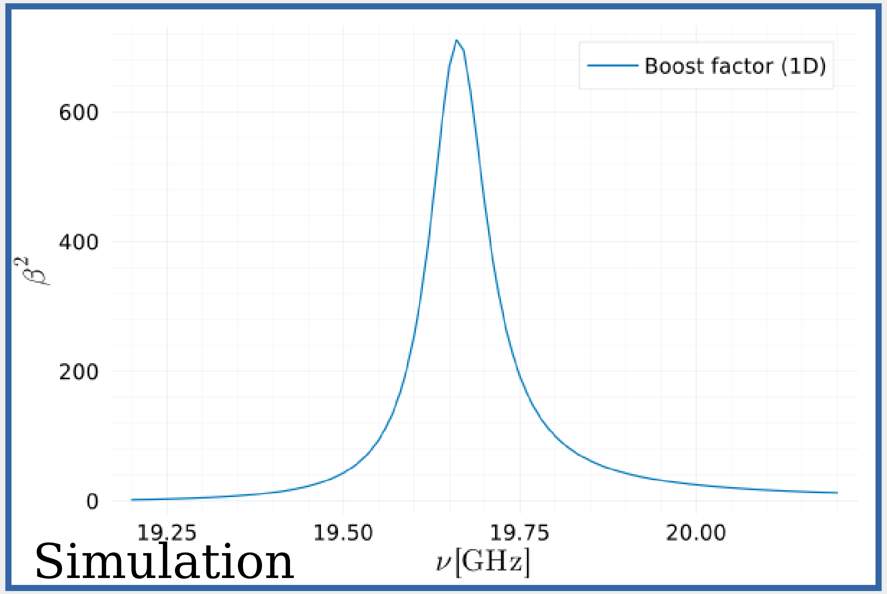
Working principle



Simulation

$$\beta^2 \propto \left| \int_V dV\, \boldsymbol{E} \right|^2 \propto Q_L C V$$

J.E. JCAP04(2023)064

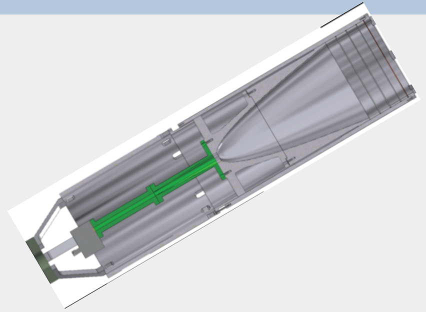


Simulation

- Boost signal by resonance between dielectric disks
- Tune distance between disks
- In cavity terms: Low quality factor (Q_L) but wavelength independent form factor (C)

Final design with A~1m^2 disks and β^2~10^5:
- V~λ^3 x 10^5 [@20 GHz]

Prototype Program

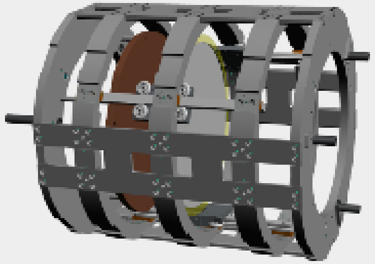


Closed Boosters (CB):

⌀ = 100 mm (**CB100**), 3 Al_2O_3 disks
⌀ = 200 mm (**CB200**), 3 Al_2O_3 disks

Aim:

- Easy to simulate
- Learn how to control unwanted modes
- Understand receiver chain in B-field

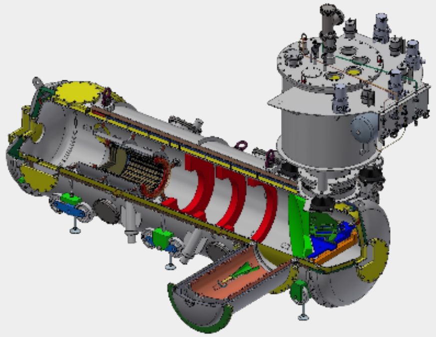


Open Boosters (OB):

⌀ = 200 mm (**OB200**), 1 Al_2O_3 disks
⌀ = 300 mm (**OB300**), 3 disks (Al_2O_3 & $LaAlO_3$)

Aim:

- Tunability, motor control @cryo and B-field
- MADMAX proof-of-concept

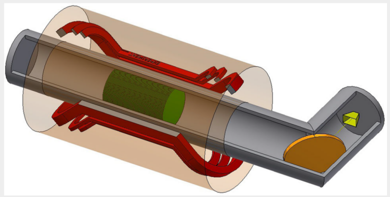


Large bore (⌀ = 760 mm) cryostat

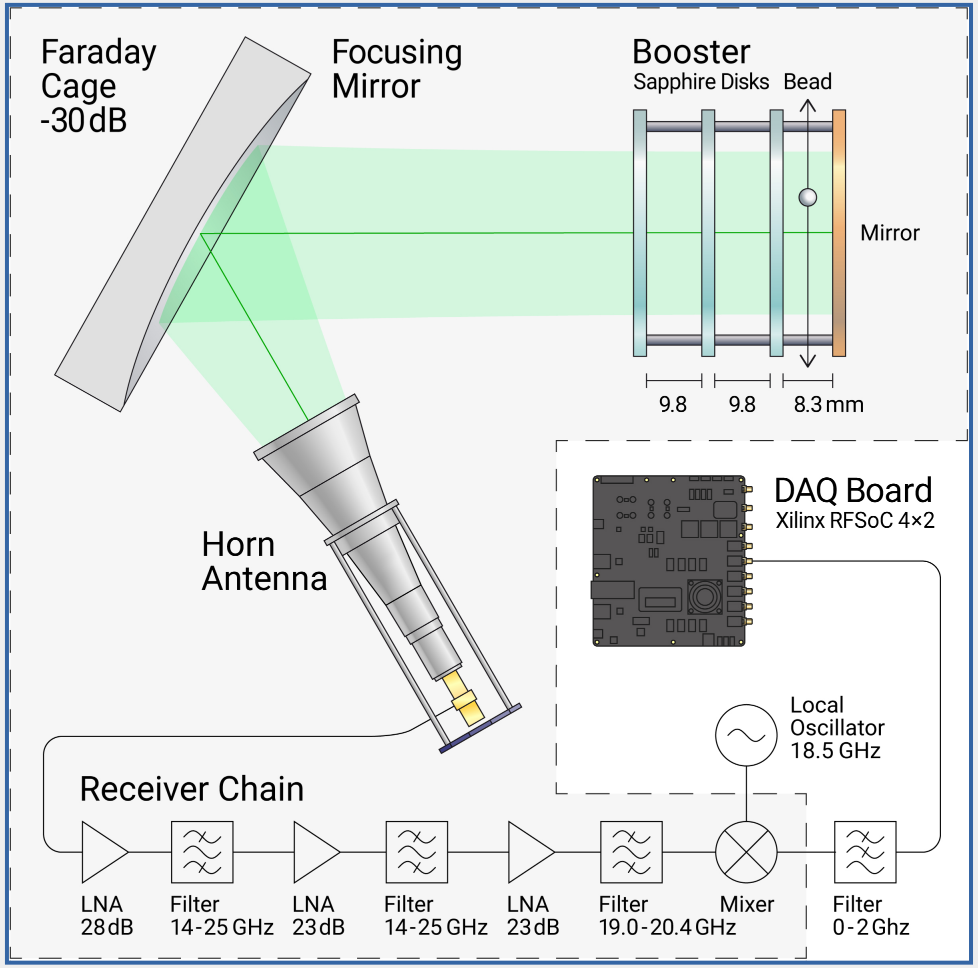
allows operation of all prototypes
Fits into the 1600 mm warm bore of MORPURGO magnet at CERN

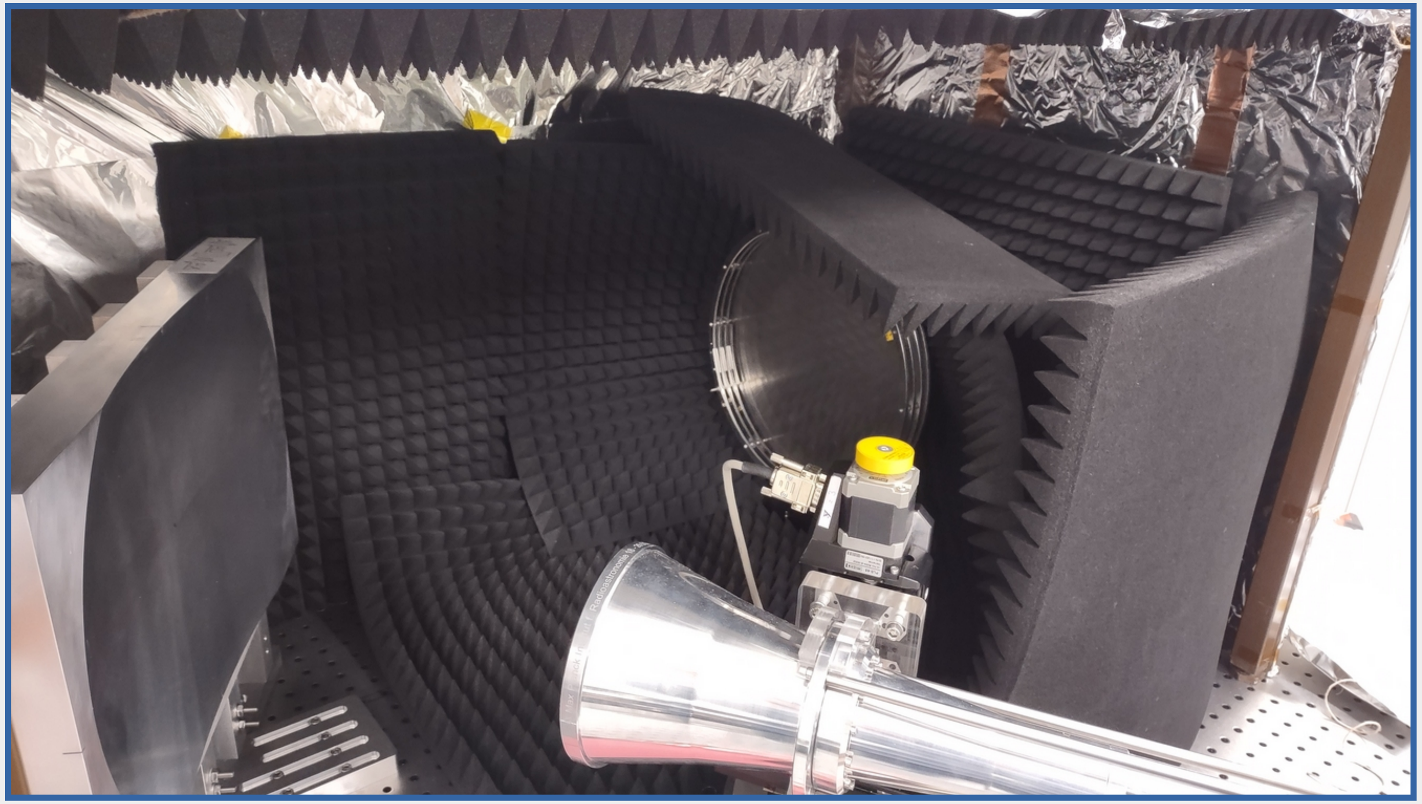
Goal:

- Many large disks
- Strong magnetic field
- QCD axion sensitivity

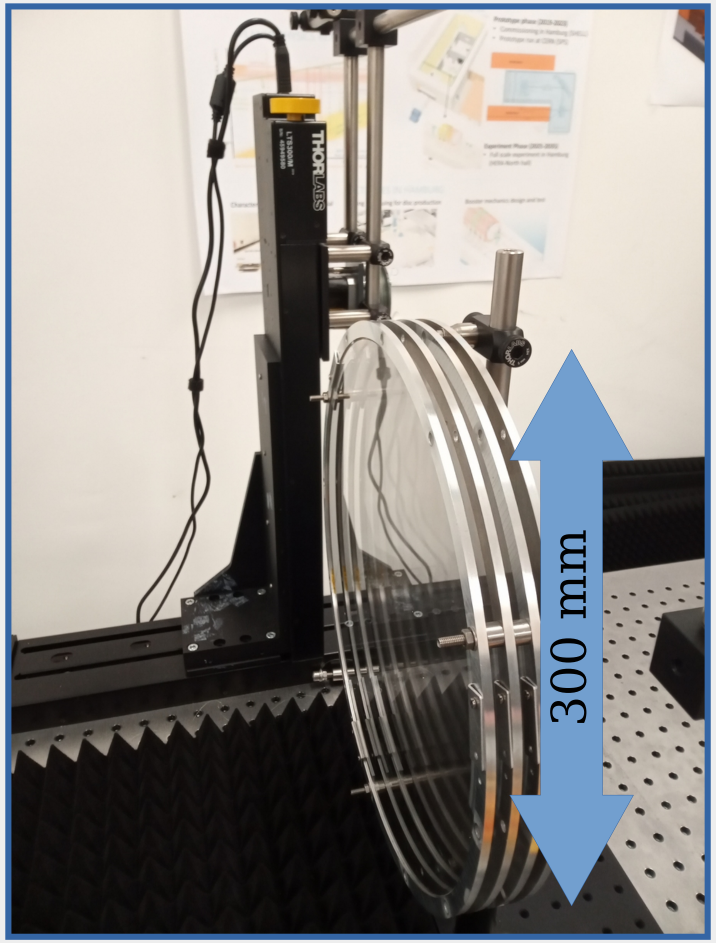


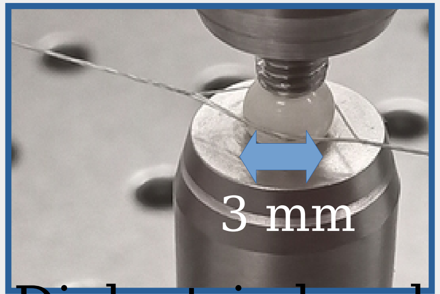
Open Booster



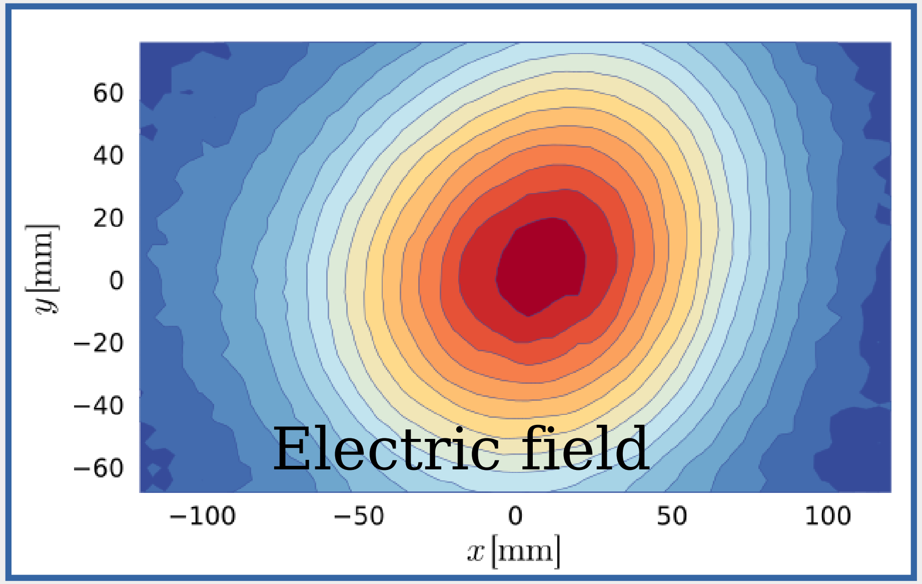


Booster Electromagnetics





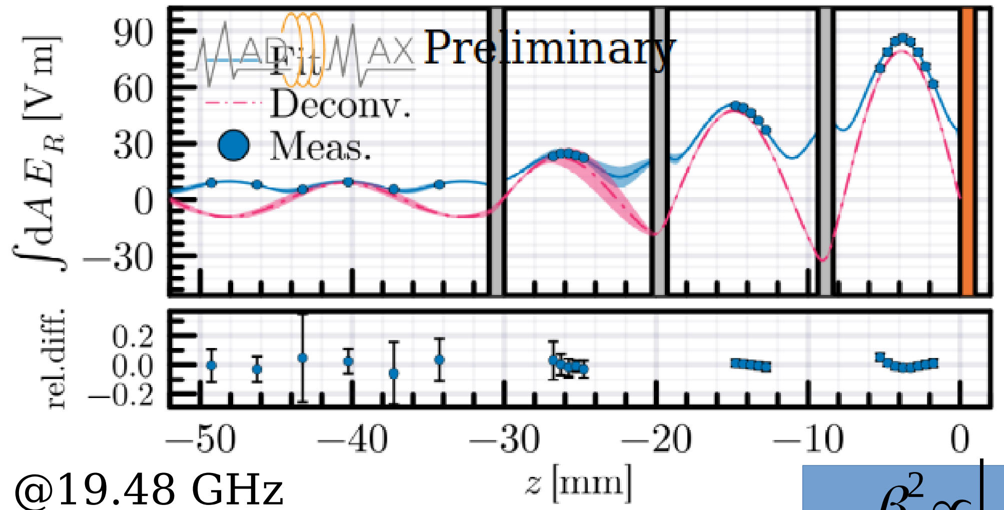
Dielectric bead



- Set up a simple three disk open booster
- Fixed distances
- Study electromagnetics with bead-pull method

Boost factor determination

- Measure the electric field
- Calculate boost factor from measurement



@19.48 GHz

$$\beta^2 \propto \left| \int_{V_a} dV\, \boldsymbol{E} \right|^2$$

J.E. JCAP04(2023)064

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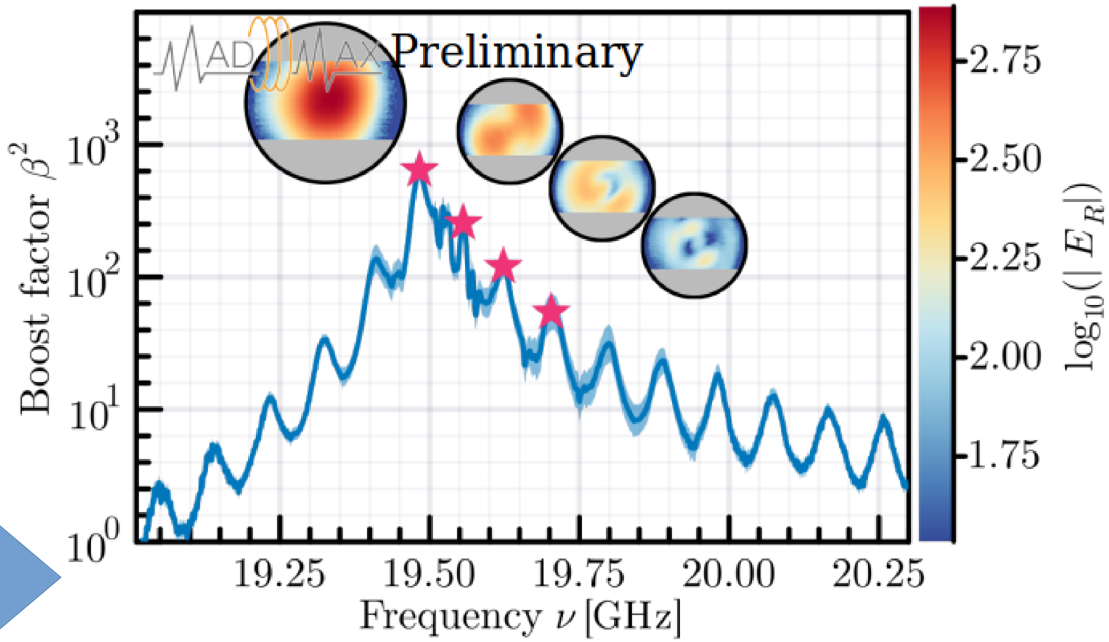
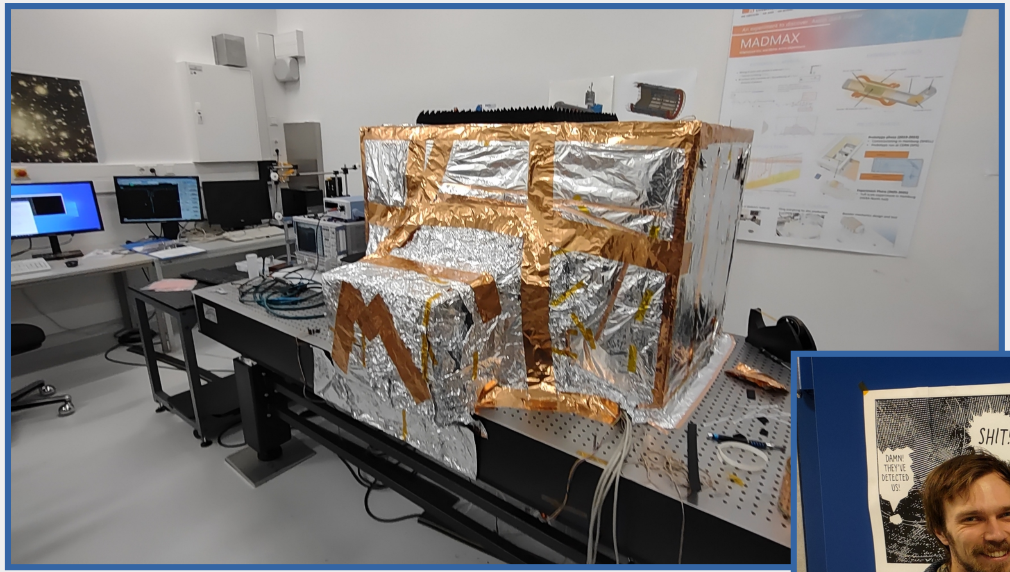
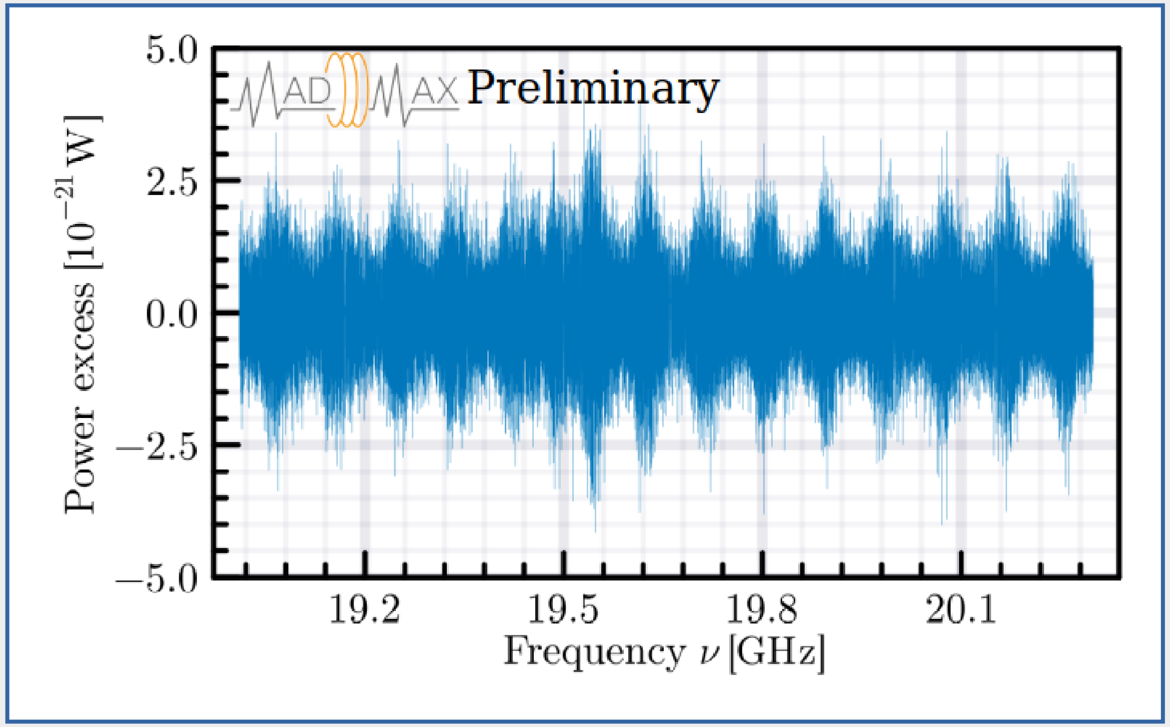


Dark photon search



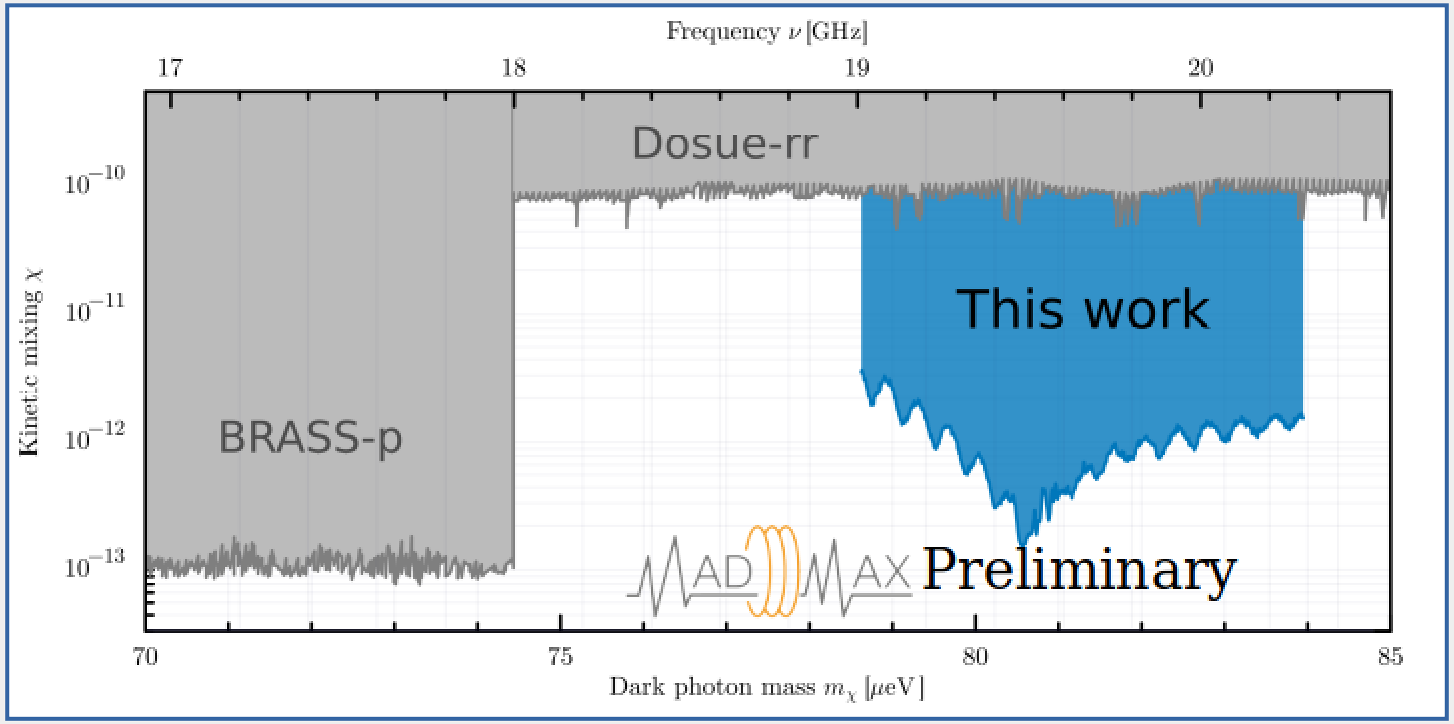
Dark photon search



- No signals of unknown origin
- Sensitive to dark photon signals ~10^{-21} W
- Compute 95% CI upper limit
- Convert to limit on kinematic mixing angle

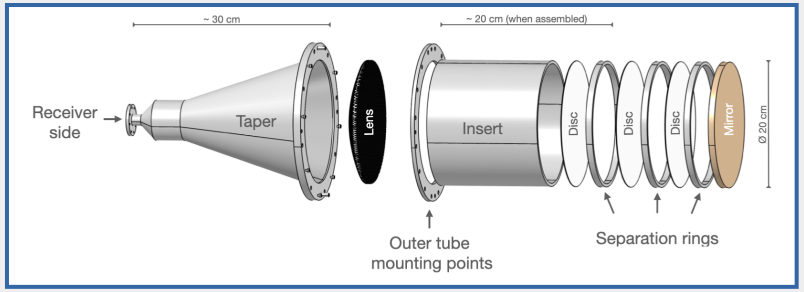
$$\chi = 1.43 \times 10^{-13} \left(\frac{400}{\beta^2}\right)^{1/2} \left(\frac{707\,\mathrm{cm}^2}{A}\right)^{1/2} \left(\frac{T_{sys}}{290\,\mathrm{K}}\right)^{1/2} \left(\frac{11.7\,\mathrm{d}}{\Delta t}\right)^{1/4} \left(\frac{SNR}{5}\right)^{1/2} \left(\frac{0.3\,\mathrm{GeV/cm}^3}{\rho_{\mathrm{DM}}}\right)^{1/2}$$

Exclusion limit



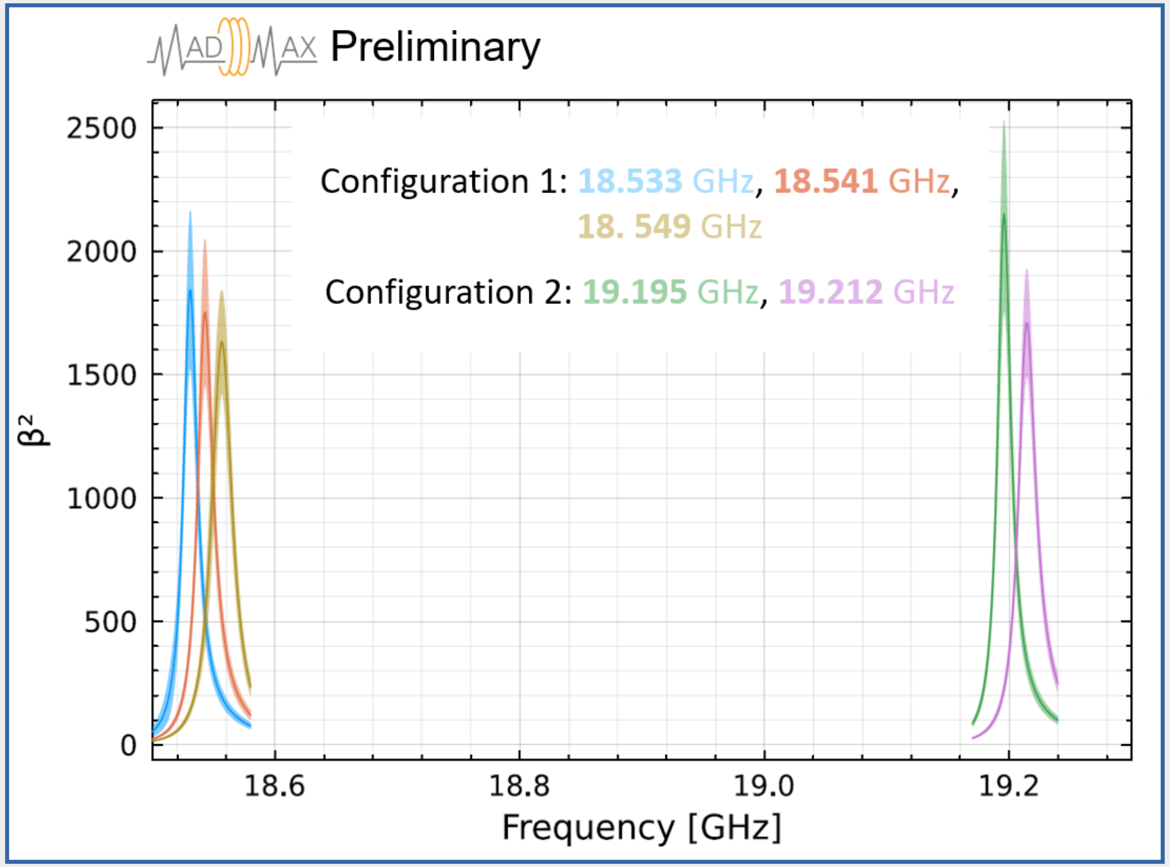
- Assume unpolarized dark photons
- Improve existing limits by ~3 orders of magnitude at peak sensitivity
- Resonant and broadband at the same time

Search for axion-like particles



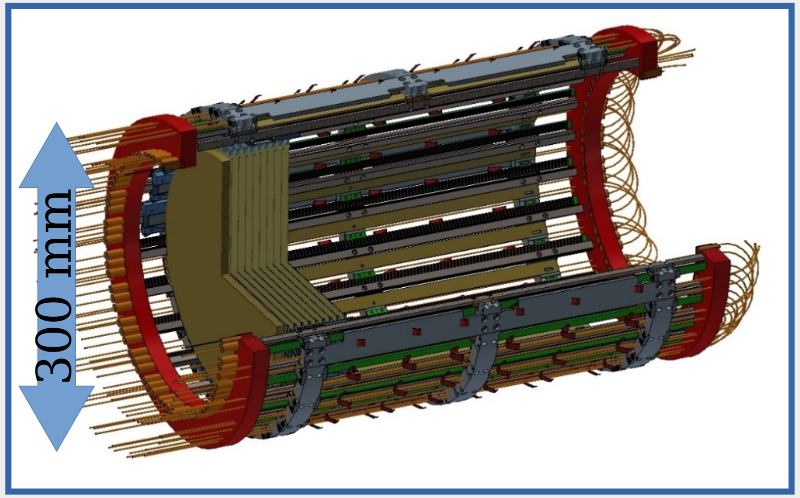
- Feb/Mar 2024: Search for axion-like particles in Morpurgo magnet at CERN (~1.5 T)
- Closed Boosters: Smaller but more resonant setups
- Frequency tuning by manually changing distances

Search for axion-like particles

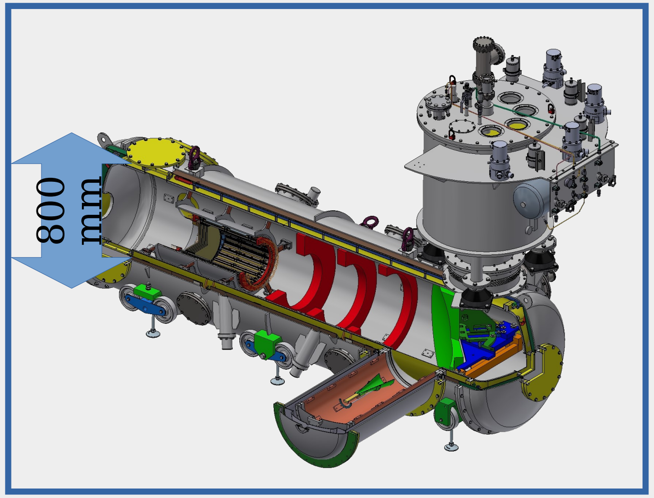


- 5 different frequency ranges with ~10MHz with CB200 at RT
- Additional one frequency range at cryogenic temperature below 10K (CB100)
- Analysis ongoing
- Expected sensitivity to unexplored ALP parameter range with peak sensitivity $g_{a\gamma} \lesssim 3x10^{-11} GeV^{-1}$

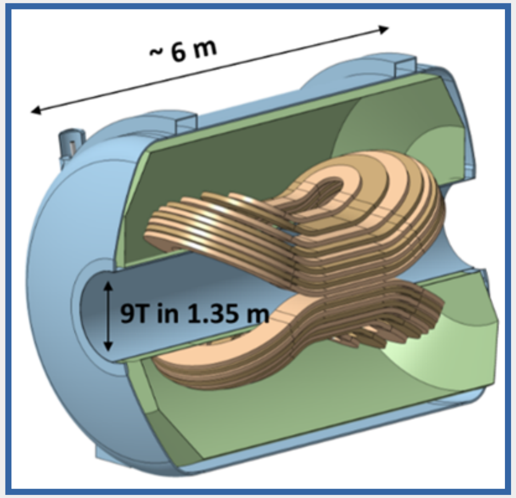
What's next



- Tunability
- Up to N=20 disks
- Scaling of β^2



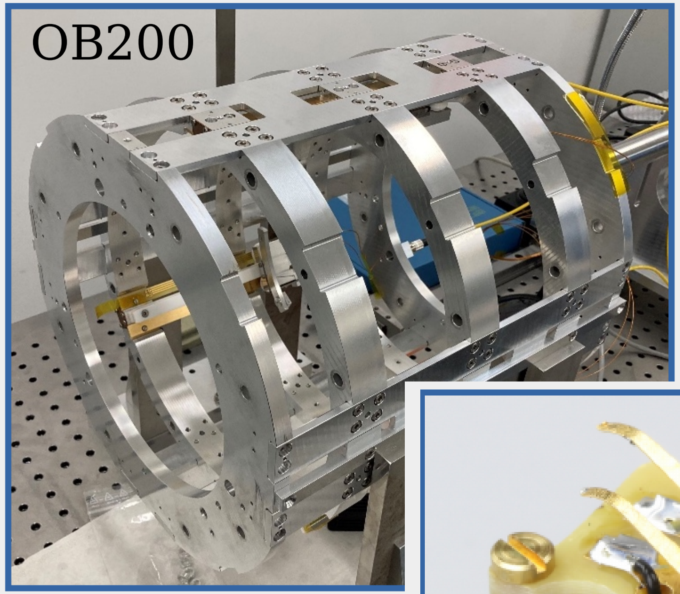
- Prototype cryostat
- T_{sys}~8K

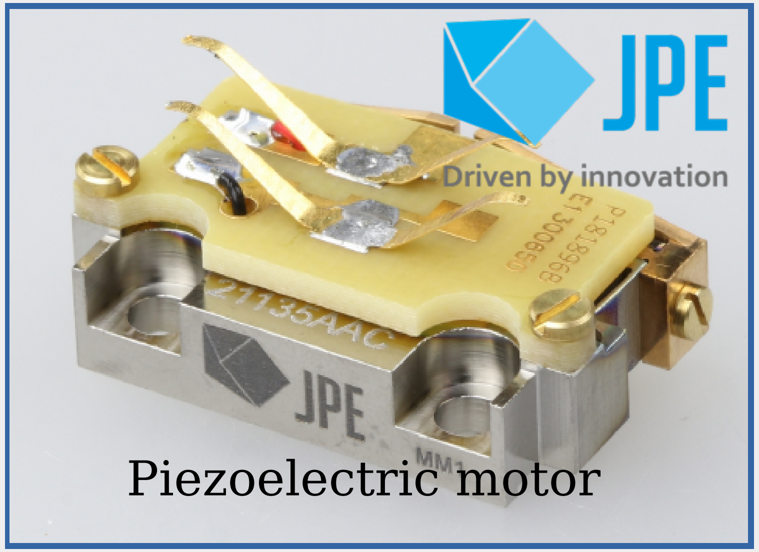


- Dipole magnet
- 1.35 m warm bore
- B~10 T

$$g_{a\gamma} \approx 2\cdot 10^{-14}\,\mathrm{GeV}^{-1} \left(\frac{0.3\,\mathrm{GeV/cm^3}}{\rho_a}\right)^{1/2} \left(\frac{10^5}{\beta^2}\right)^{1/2} \left(\frac{1\,\mathrm{m}^2}{A}\right)^{1/2} \left(\frac{T_{sys}}{8\,\mathrm{K}}\right)^{1/2} \left(\frac{10\,\mathrm{T}}{B_e}\right) \left(\frac{1.3\,\mathrm{d}}{\tau}\right)^{1/4} \left(\frac{SNR}{5}\right)^{1/2} \left(\frac{m_a}{100\,\mu\mathrm{eV}}\right)^{5/4}$$

Tunability


OB200



Piezoelectric motor

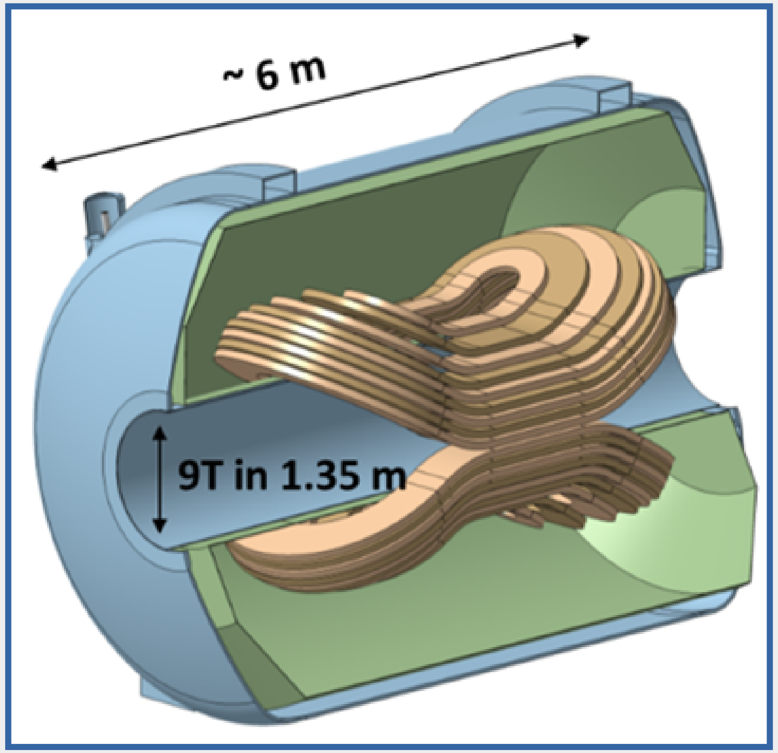
- Piezo electric motors to move disks at cryogenic temperatures and magnetic field
- Interferometer for displacement measurement
- Motor tested at 4.2K & 5.4 T
- Work according to specifications[1)]

1)JINST 18 P08011

Cryostat

- Prototype cryostat close to delivery
- Can house current and future prototypes (⌀~800 mm)
- T_{phys}~4K
- Fits into Morpurgo magnet

Magnet



Development in innovation partnership

BILFINGER
BILFINGER NOELL GMBH
cea
Max-Planck-Institut für Physik (Werner-Heisenberg-Institut)

- Dipole magnet most critical item for full-size MADMAX
- Design for 9 T large bore well advanced
- Novel conductor design studied and feasible[1]
- Conductor design: demonstrated quench protection
- Next step: build demonstrator coils to verify performance
- Budget for first demonstrator coil secured!

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

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Thank you