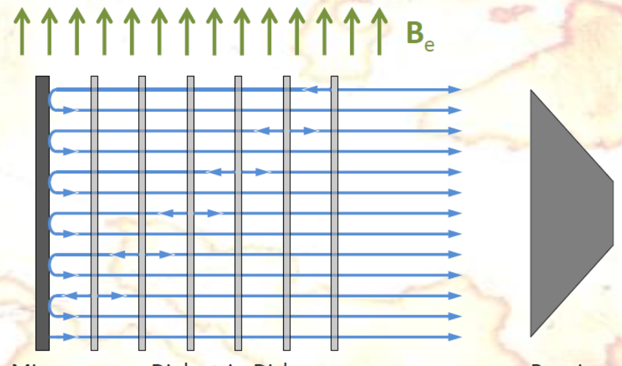
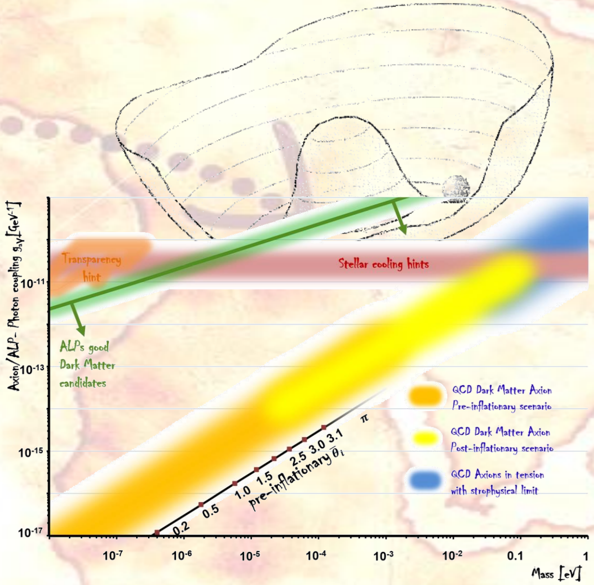
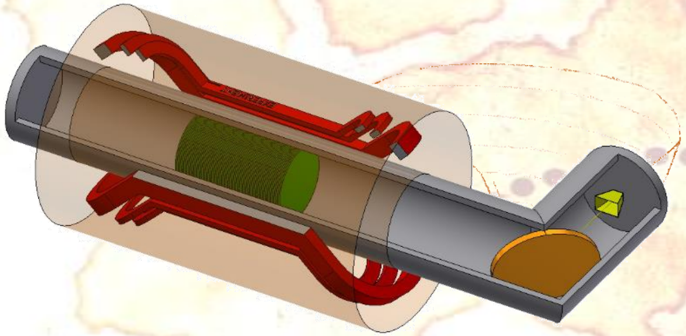
Advances in searching for galactic axions with dielectric haloscope: MADMAX

Béla Majorovits
MAX-PLANCK-INSTITUT FÜR PHYSIK

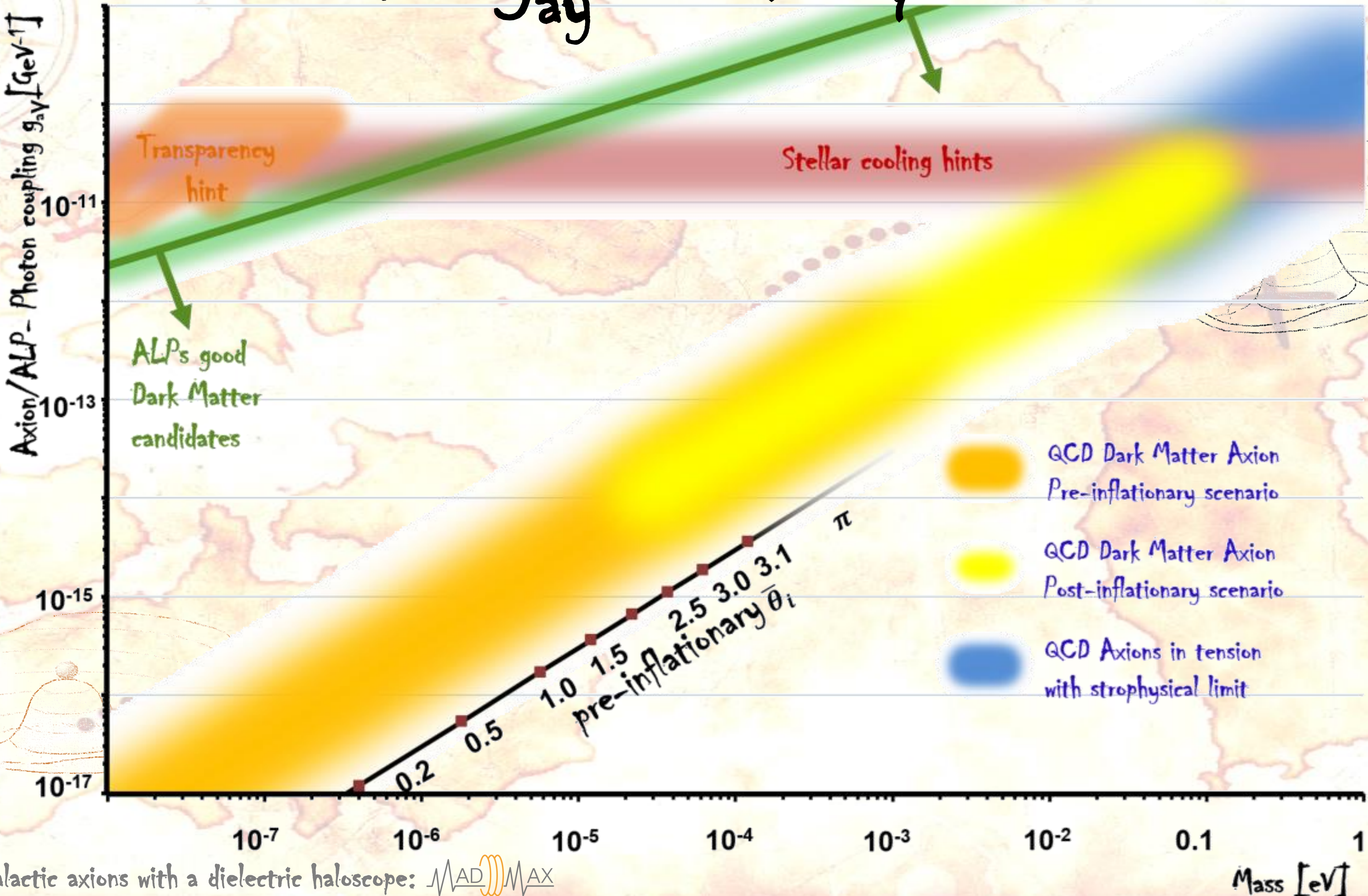


- The axion landscape
- Dielectric haloscope
- MADMAX
- Progress on construction sites

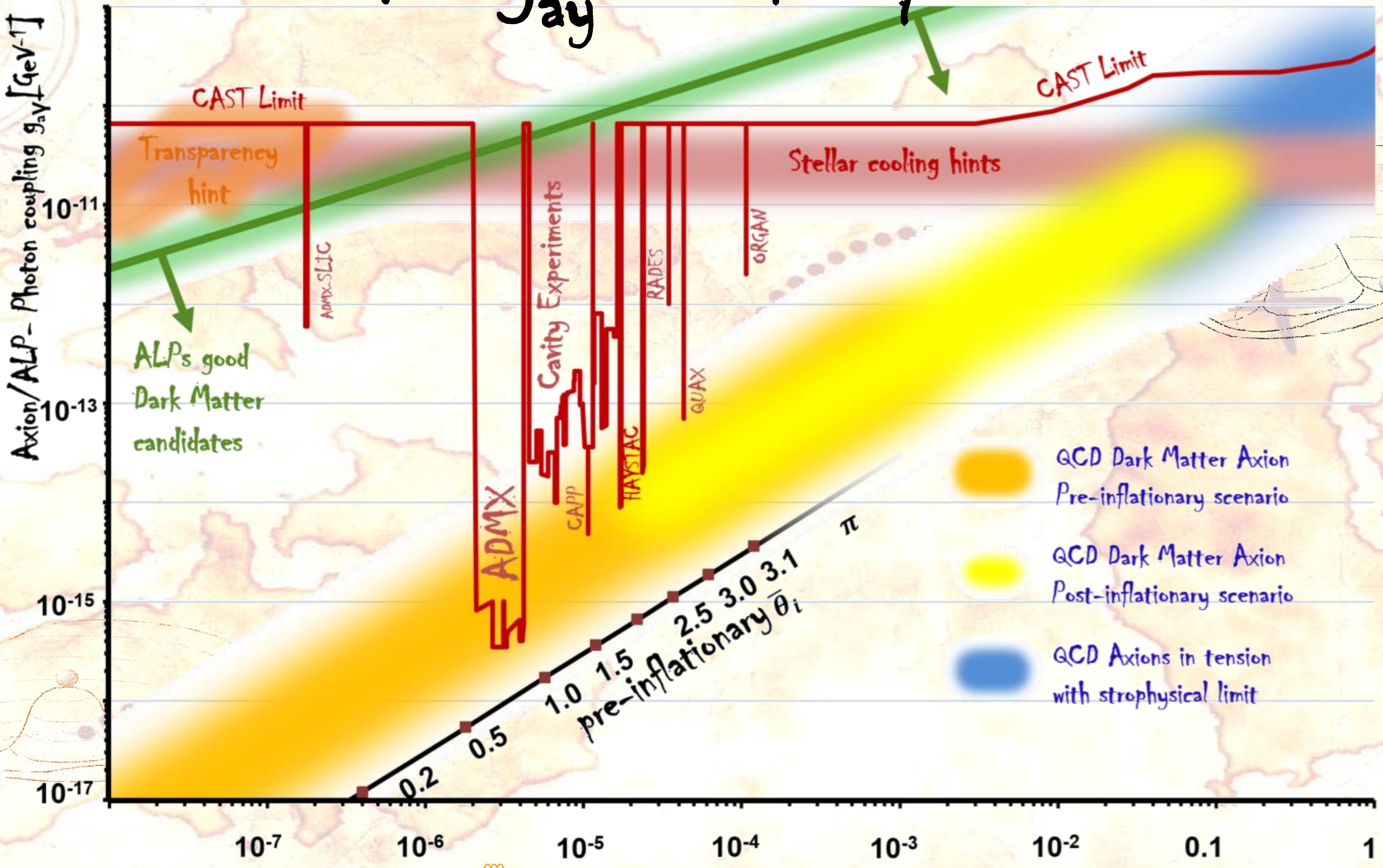




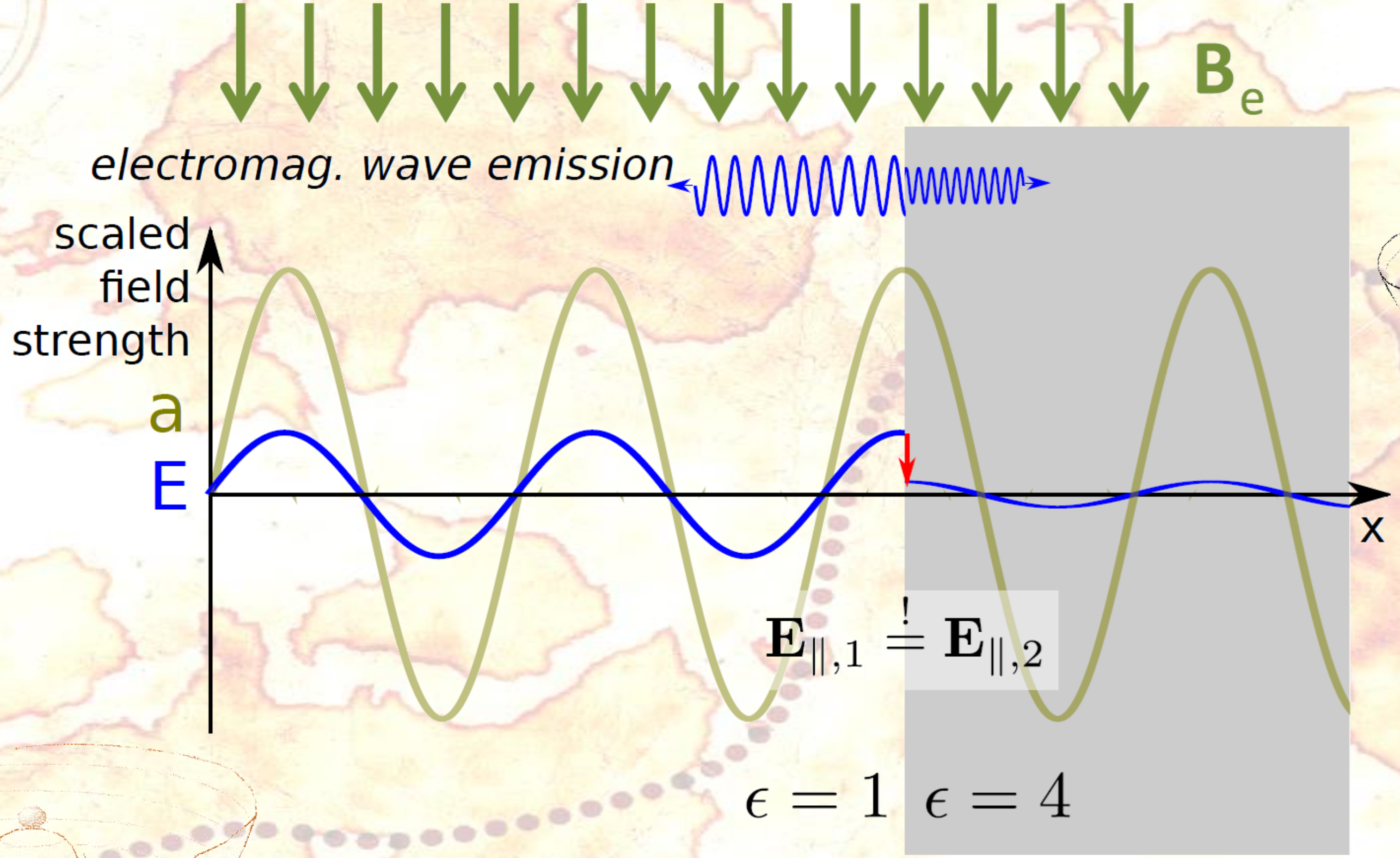
The $g_{a\gamma}$ landscape



The $g_{a\gamma}$ landscape



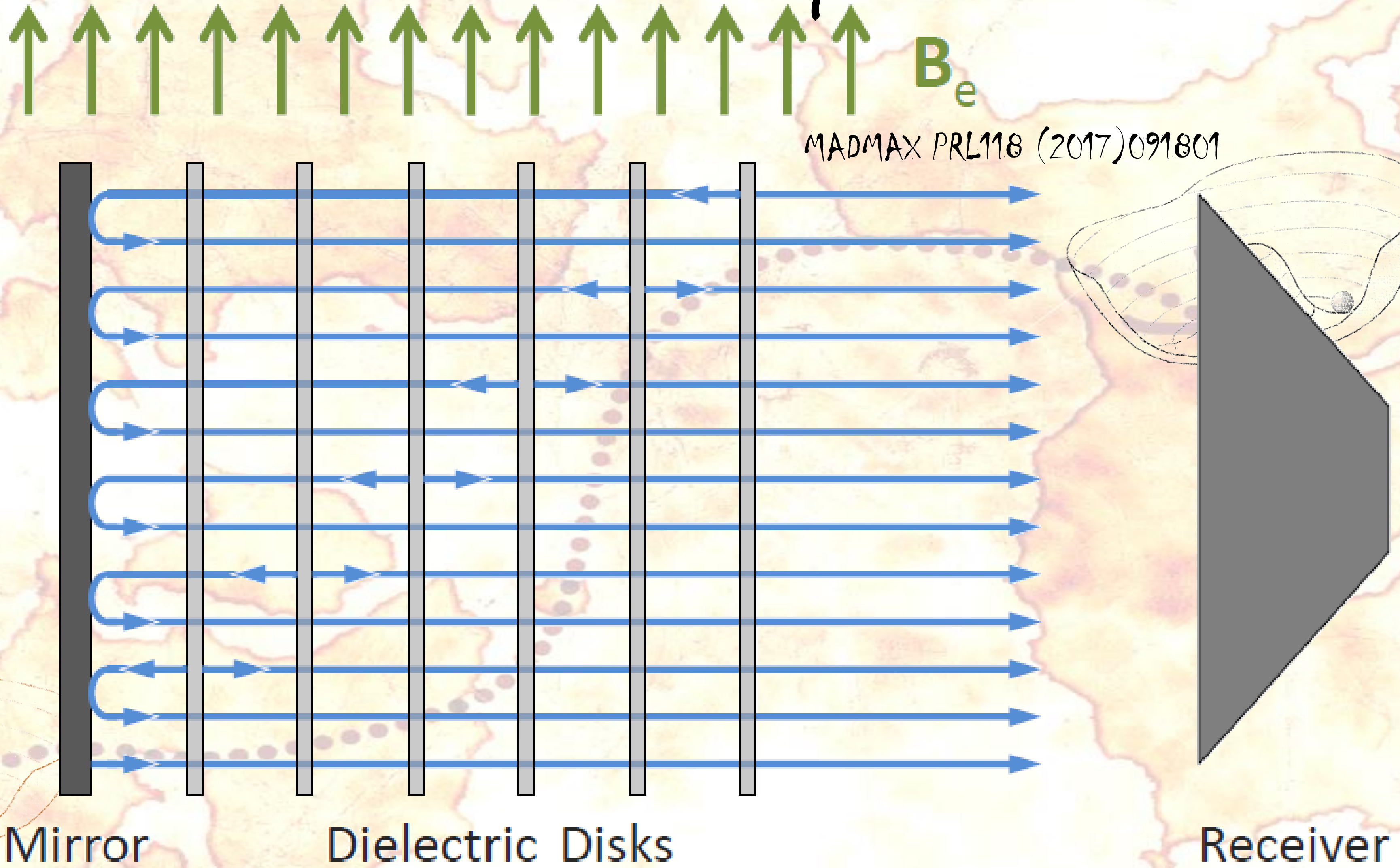
The dish antenna



$$\left(\frac{P}{A}\right)_{mirror} \sim 2 \cdot 10^{-27} \frac{\mathrm{W}}{\mathrm{m}^2} \left(\frac{B_{\|}}{10\,T}\right)^2 (g_{a\gamma\gamma}/m_a)^2$$

Dielectric haloscope

Constructive interference of coherent photon emission at dielectric layers



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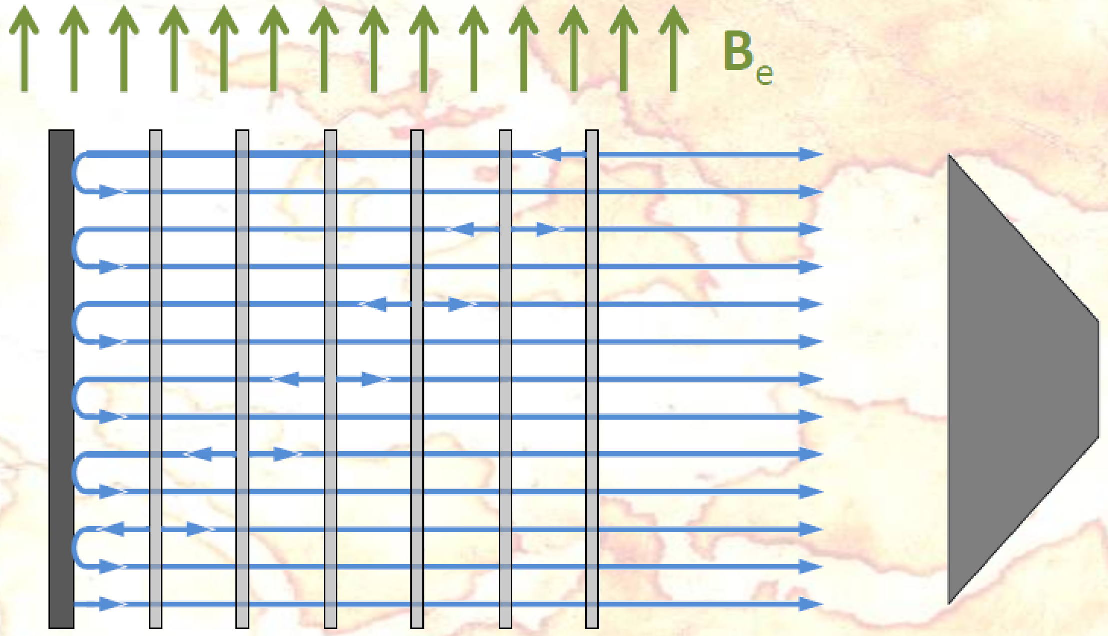
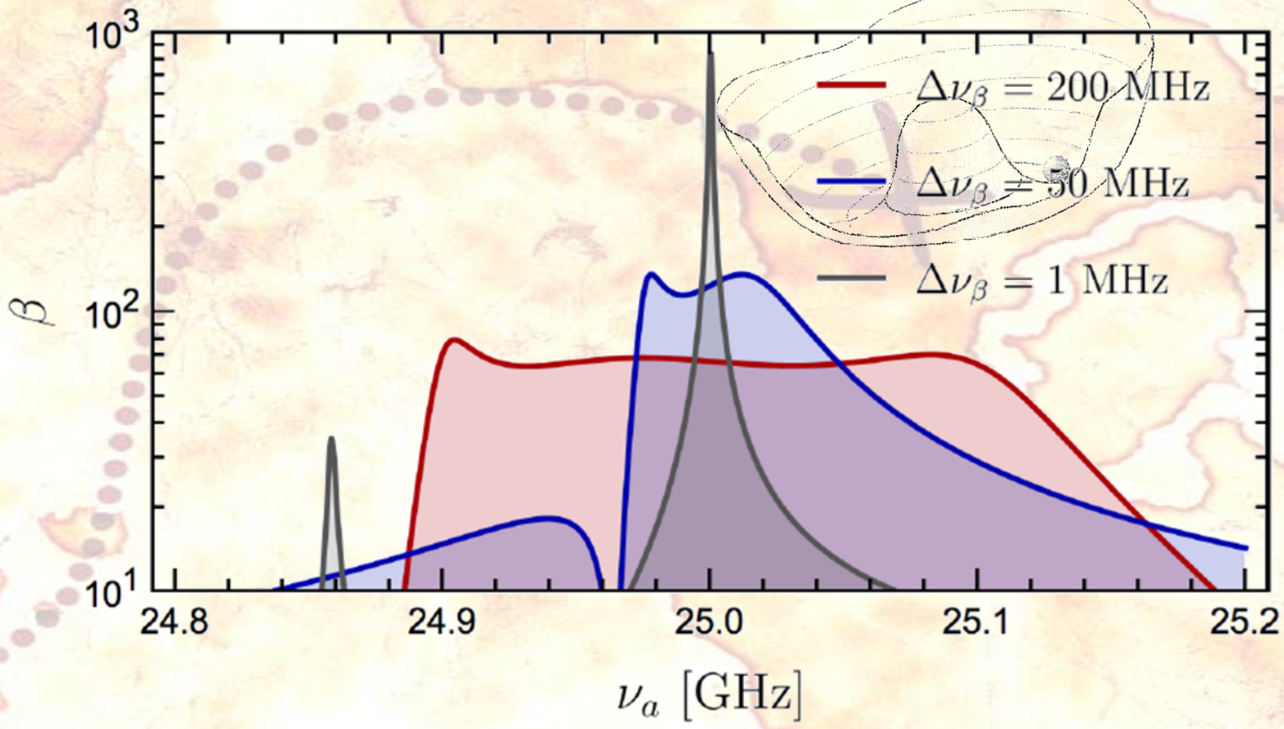
Dielectric haloscope

Boost of axion to photon conversion



$$\left(\frac{P}{A}\right)_{cavity} \sim 2 \cdot 10^{-27} \frac{\mathrm{W}}{\mathrm{m}^2} \left(\frac{B_{||}}{10\,T}\right)^2 \left(g_{a\gamma\gamma}/m_a\right)^2 \beta^2$$

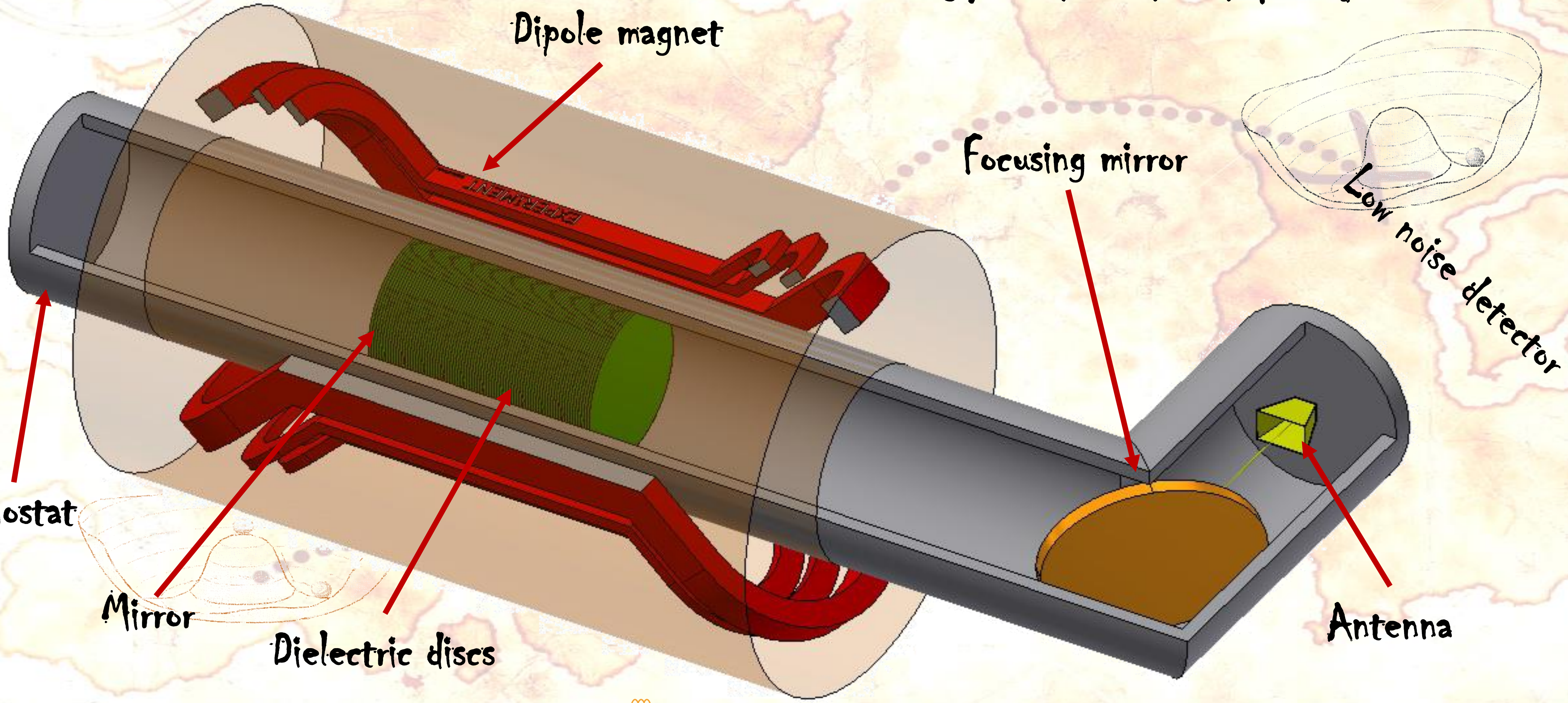
The power boost factor $\beta^2 = \frac{P_{cavity}}{P_{mirror}}$



Area under β curve constant

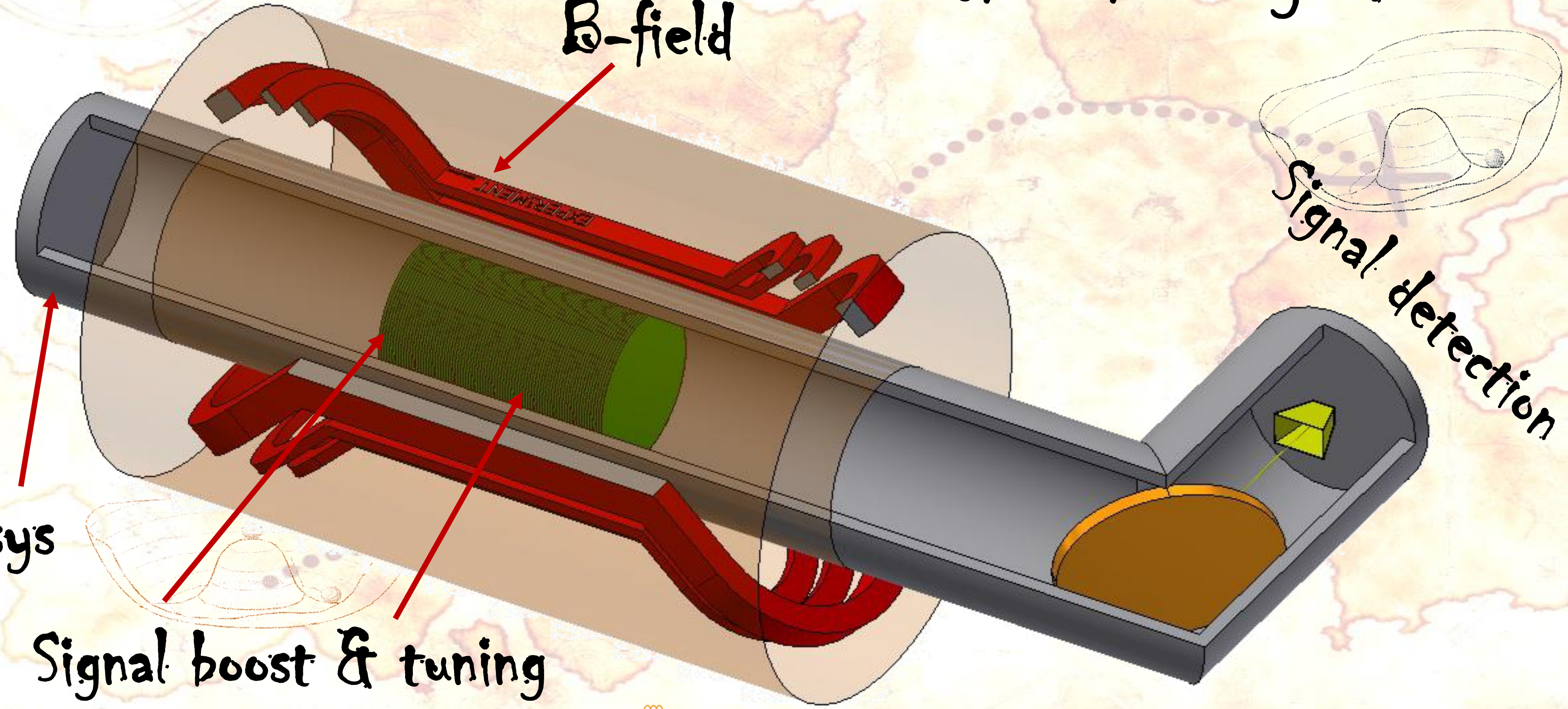
-> scan strategy!

MADMAX as dielectric haloscope the basic idea:



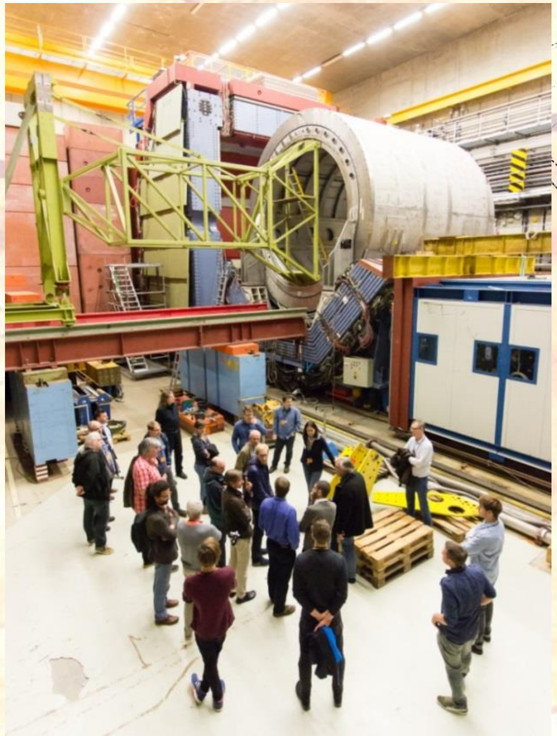
MADMAX as dielectric haloscope

the challenges:



MADMAX collaboration

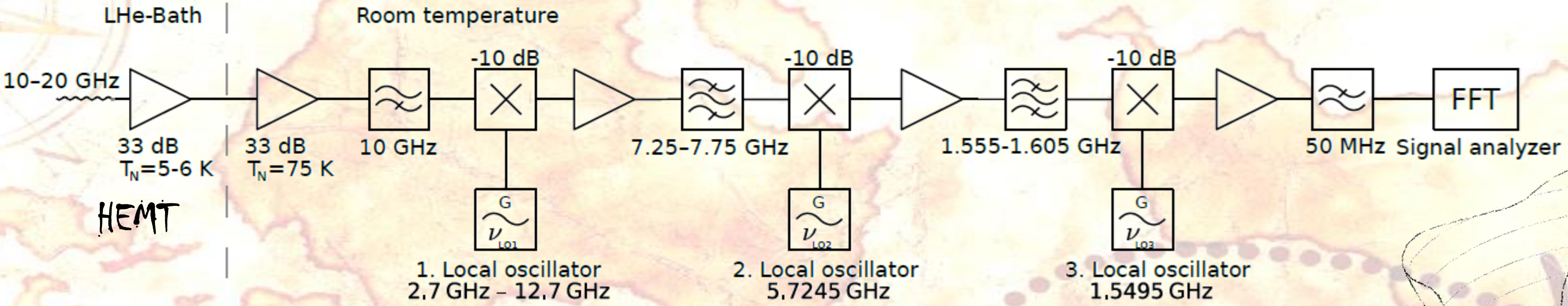
MAgnetized disk and Mirror Axion eXperiment

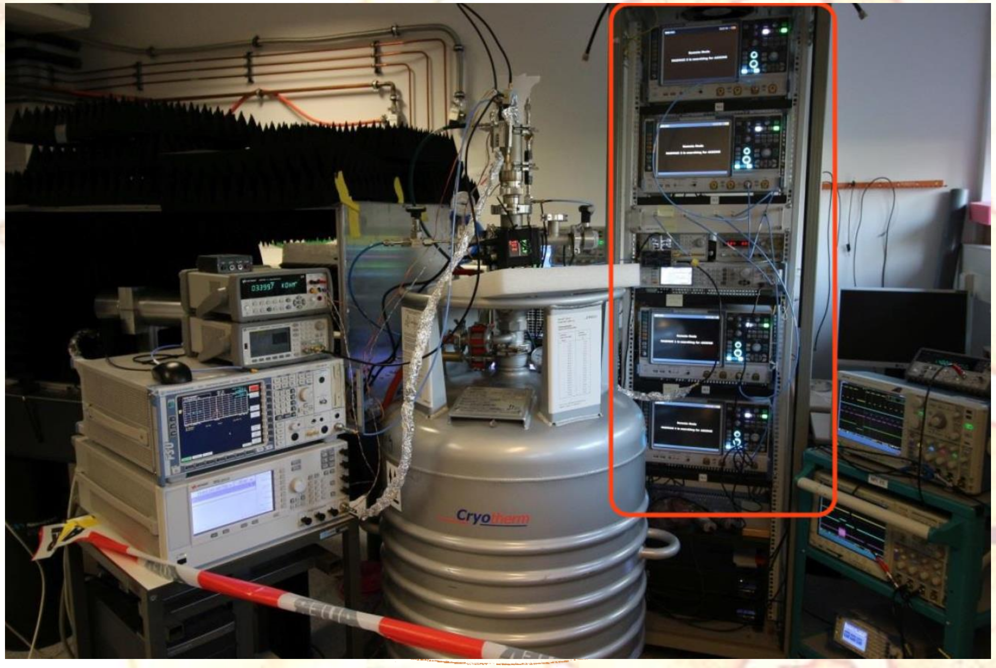


Collaboration forming on 18th Oct. 2017

RWTH AACHEN UNIVERSITY · NÉEL institut · DESY. · Universität Hamburg DER FORSCHUNG | DER LEHRE | DER BILDUNG · CPPM · MAX-PLANCK-INSTITUT FÜR PHYSIK · EBERHARD KARLS UNIVERSITÄT TÜBINGEN · Universidad Zaragoza

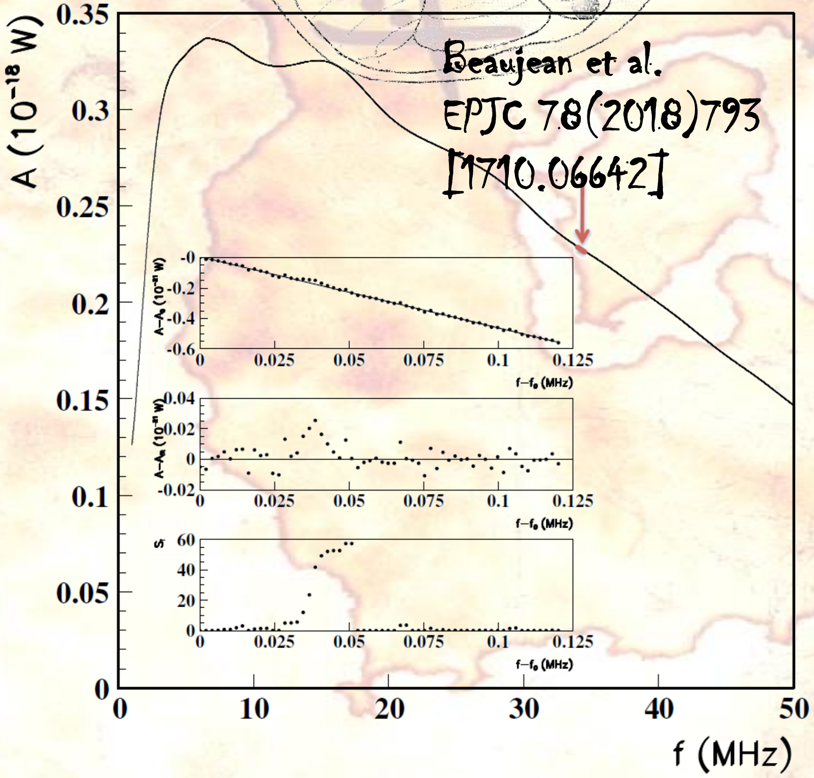
Receiver chain





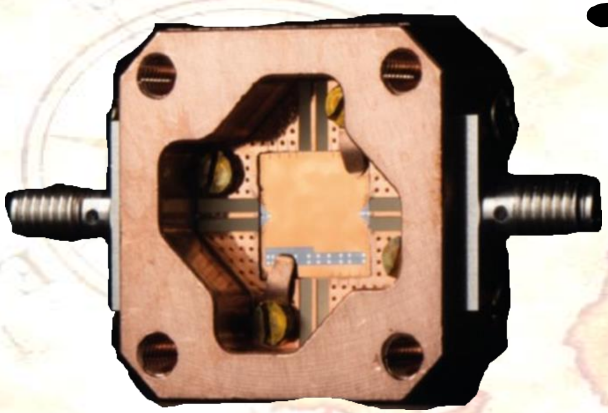
MADMAX [2003.10894]

Detection of 1.8GHz
~10^{-22} W signal
using LNF-HEMT
preamp in ~4 days



Beaujean et al.
EPJC 78(2018)793
[1710.06642]

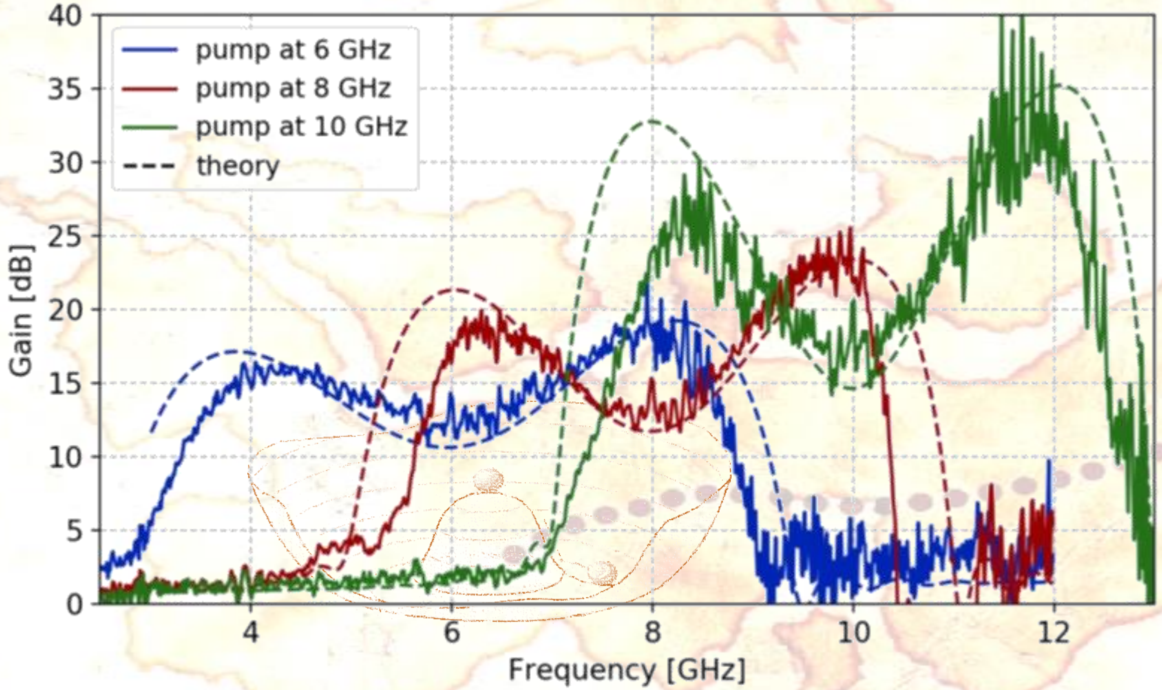
TWPA as broadband preamp:



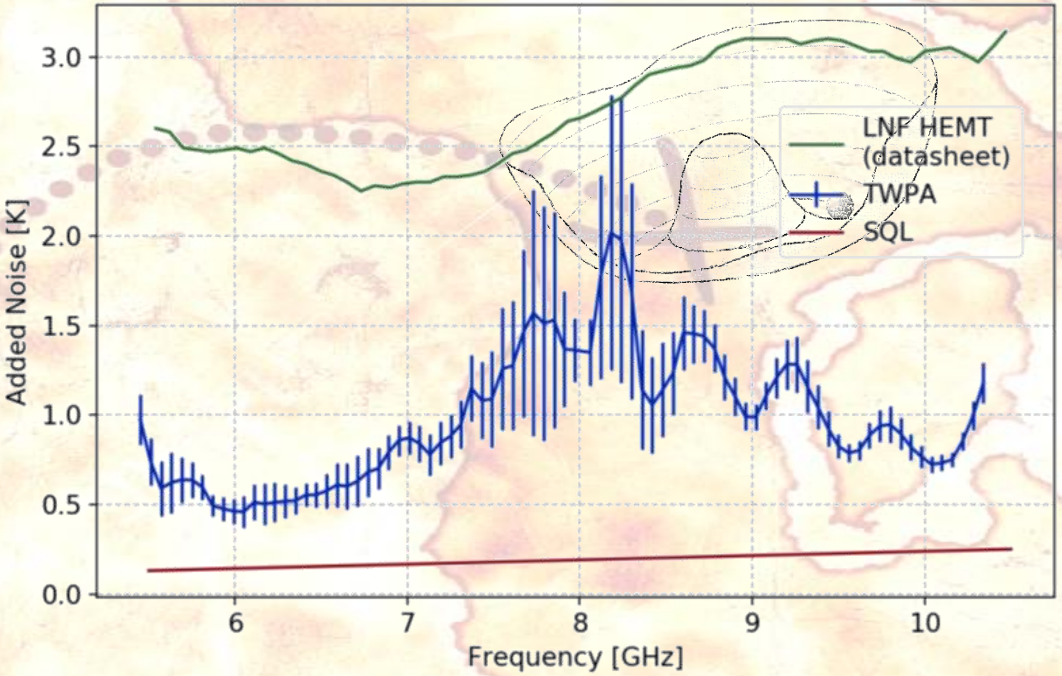
First 10 GHz TWPA produced and characterized

Ranadive et al.[2101.05815]

Gain >20dB for bandwidth ~ 1GHz



Added noise @ 10 GHz ~ 1K

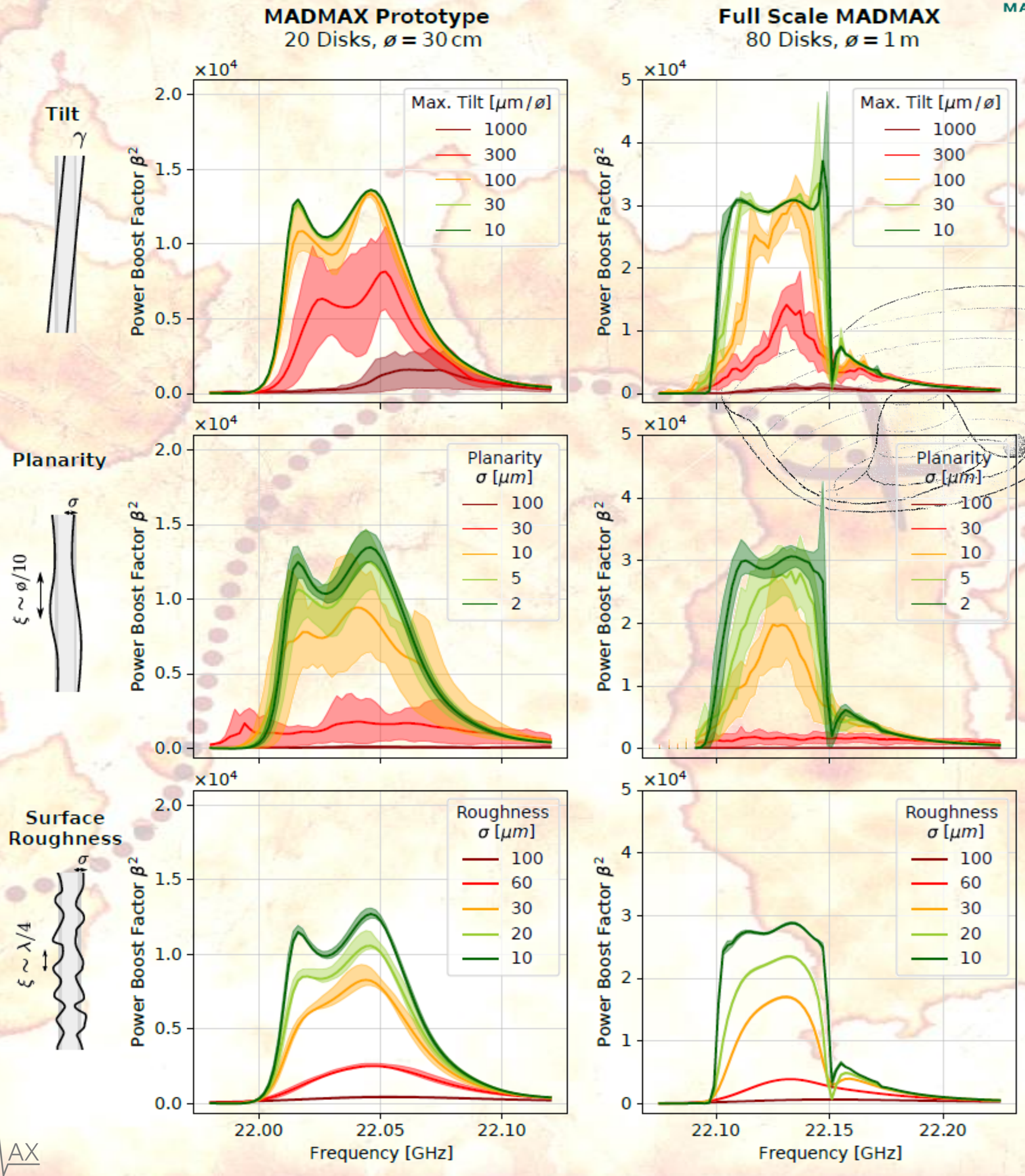


Further activities at NEEL:

- Frequencies up to 20 (30?) GHz
- Further reduce noise (dielectric loss)

Boost factor

1D idealized world
differs from
3D reality
-> Simulations
(idealized)

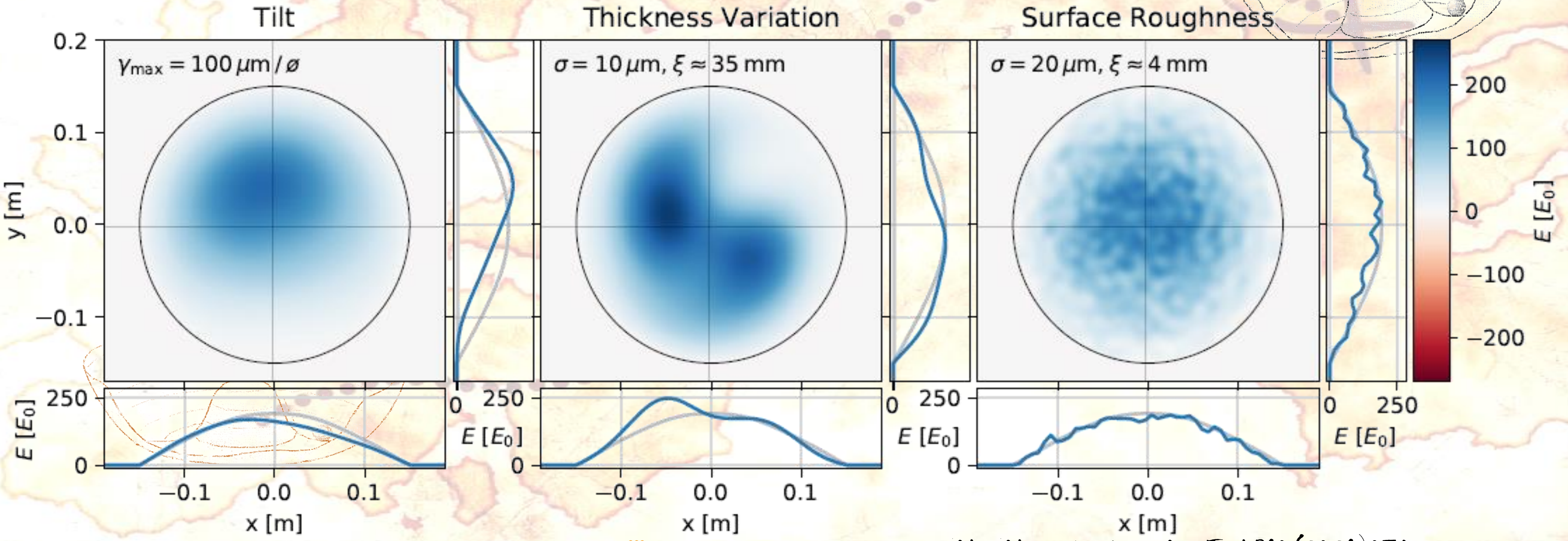


MADMAX: Knirck et al., JCAP10(2021)034

Beam shape

1D idealized world differs from 3D reality

-> Simulations (idealized)



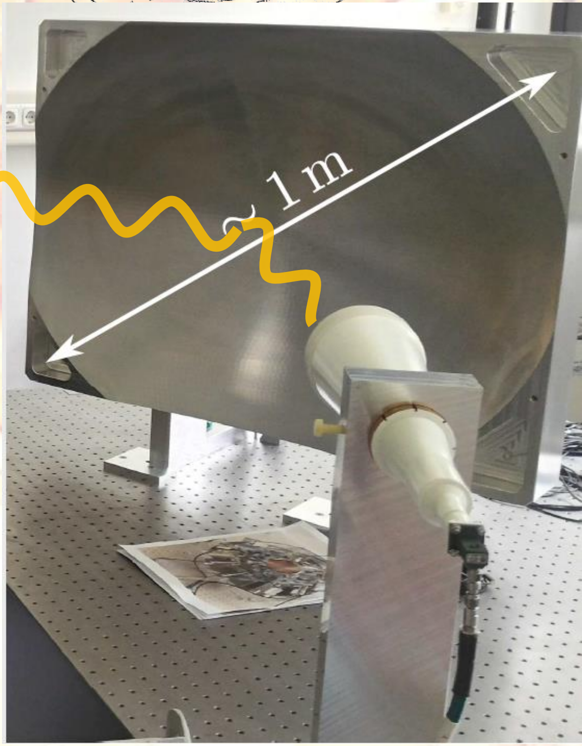
MADMAX: Knirck et al., JCAP10(2021)034

Proof of principle setup

Feasibility of tuning

- Positioning algorithm: achievable accuracy
- Reproducibility
- Correlations

reflectivity vs. boost



Egge et al EPJC80(2020)392 [2001.04363]

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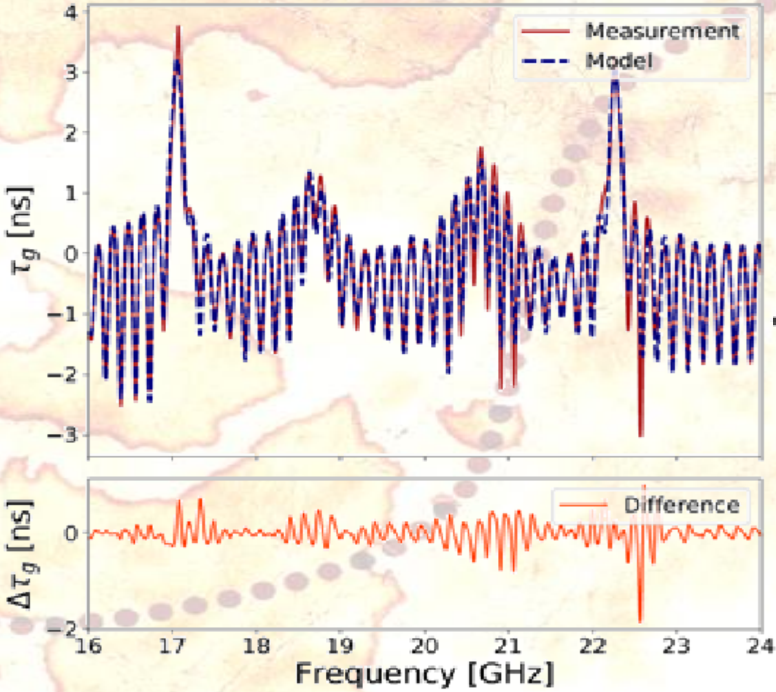
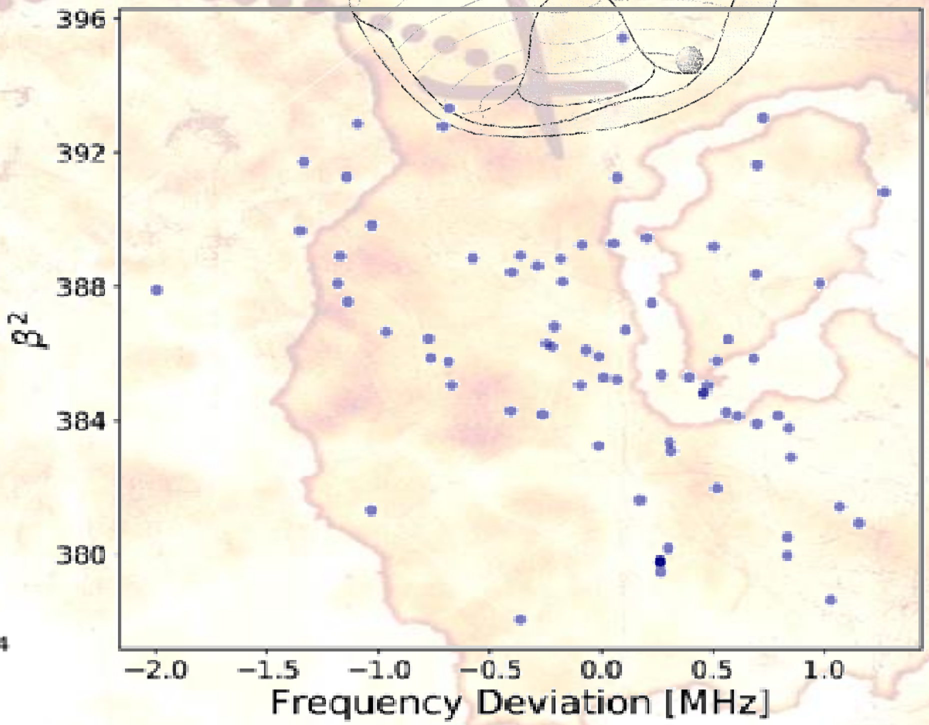




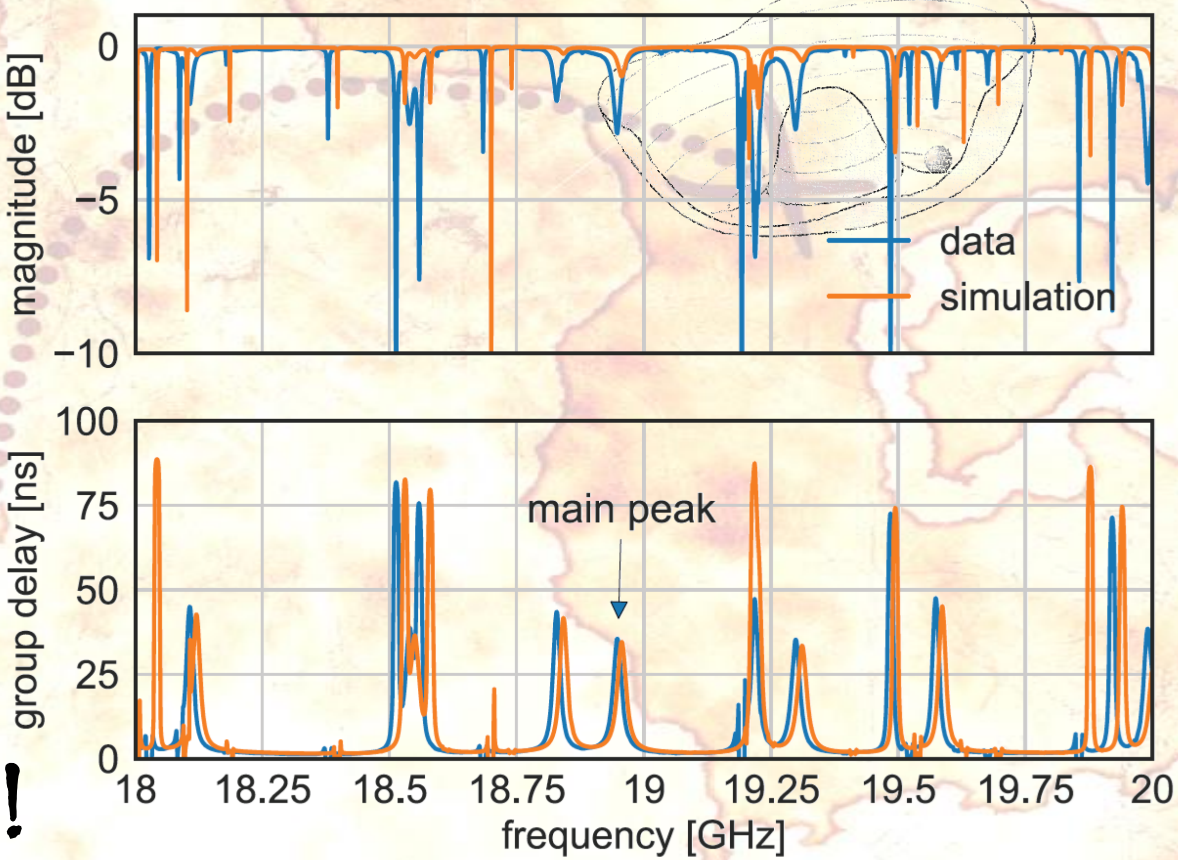
Egge et al EPJC80(2020)392 [2001.04363]

Closed booster setup

Simple well defined 3 disc closed system:

Signal response + 3D simulation -> calibration

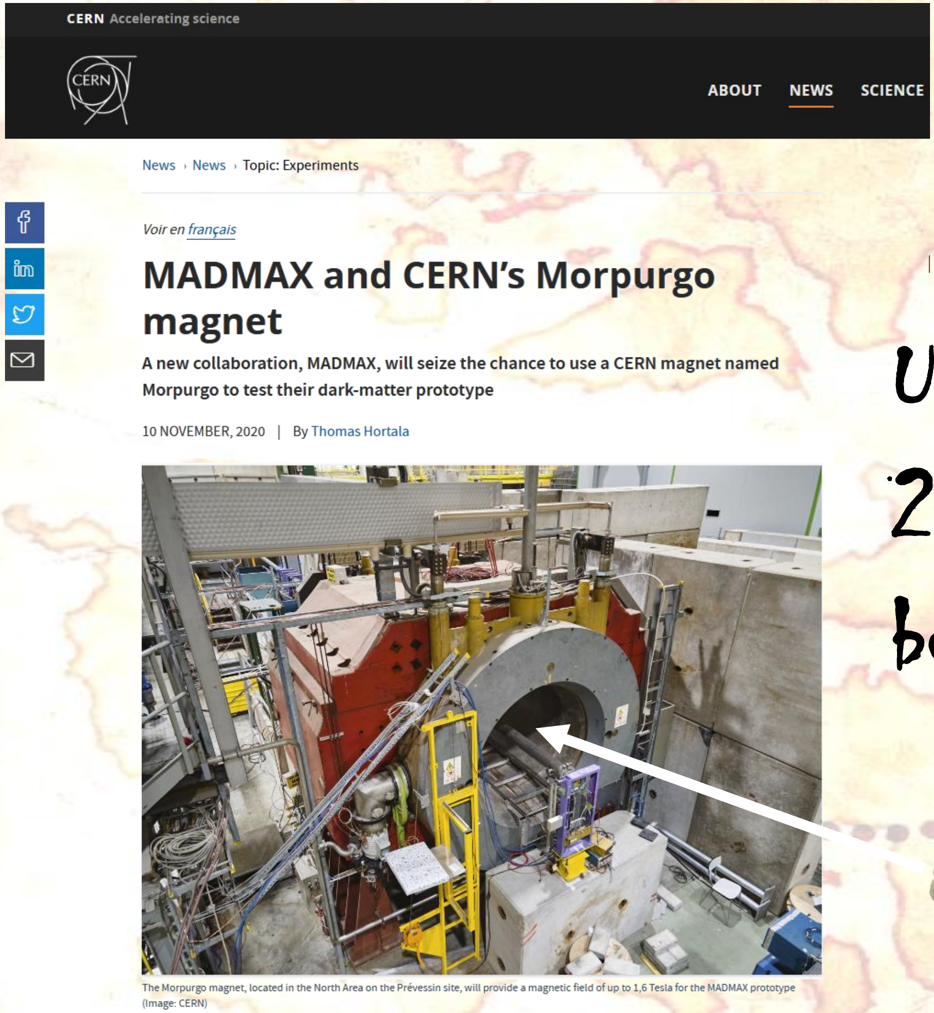
Perform first measurements in B-field and at LHe!



Chang Lee at TAUP 2021

Measurements at CERN MORPURGO magnet

https://home.cern/news/news/experiments/madmax-and-cerns-morpurgo-magnet


CERN Accelerating science

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Voir en français

MADMAX and CERN's Morpurgo magnet

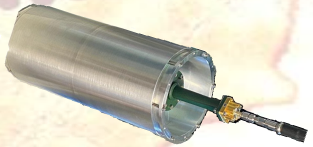
A new collaboration, MADMAX, will seize the chance to use a CERN magnet named Morpurgo to test their dark-matter prototype

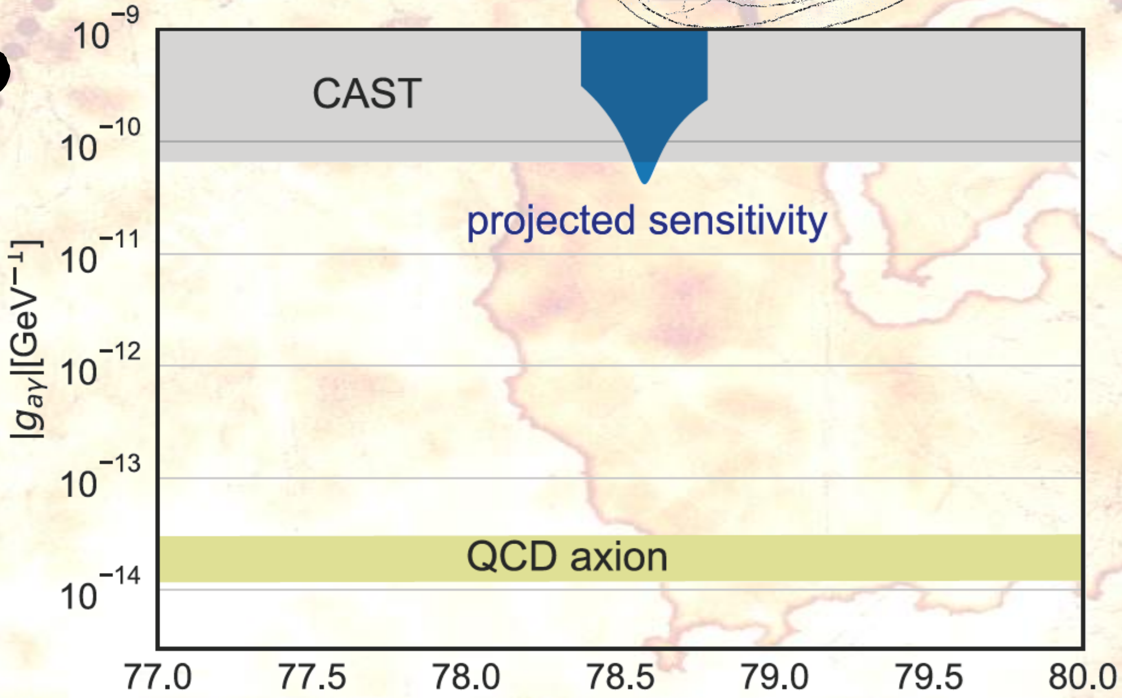
10 NOVEMBER, 2020 | By Thomas Hortala

The Morpurgo magnet, located in the North Area on the Prévessin site, will provide a magnetic field of up to 1.6 Tesla for the MADMAX prototype (Image: CERN)

$$g_{a\gamma} = 4.79\times10^{-11}\left(\frac{300\ \mathrm{MeV}}{\rho_a}\right)^{\frac{1}{2}}\left(\frac{2200}{\beta^2}\right)^{\frac{1}{2}}\left(\frac{1.6\mathrm{T}}{B_e}\right)\left(\frac{A}{7.23\times10^{-3}\ \mathrm{m}^2}\right)^{\frac{1}{2}}\left(\frac{T_{\mathrm{sys}}}{410\ \mathrm{K}}\right)^{\frac{1}{2}}\left(\frac{\mathrm{SNR}}{5}\right)^{\frac{1}{2}}\left(\frac{0.85}{\eta}\right)^{\frac{1}{2}}\left(\frac{\Delta\nu_a}{20\ \mathrm{kHz}}\right)^{\frac{1}{4}}\left(\frac{4\ \mathrm{days}}{\tau}\right)^{\frac{1}{4}}[\mathrm{GeV}^{-1}],$$

Use MORPURGO 2022 & 2023 beam shutdowns



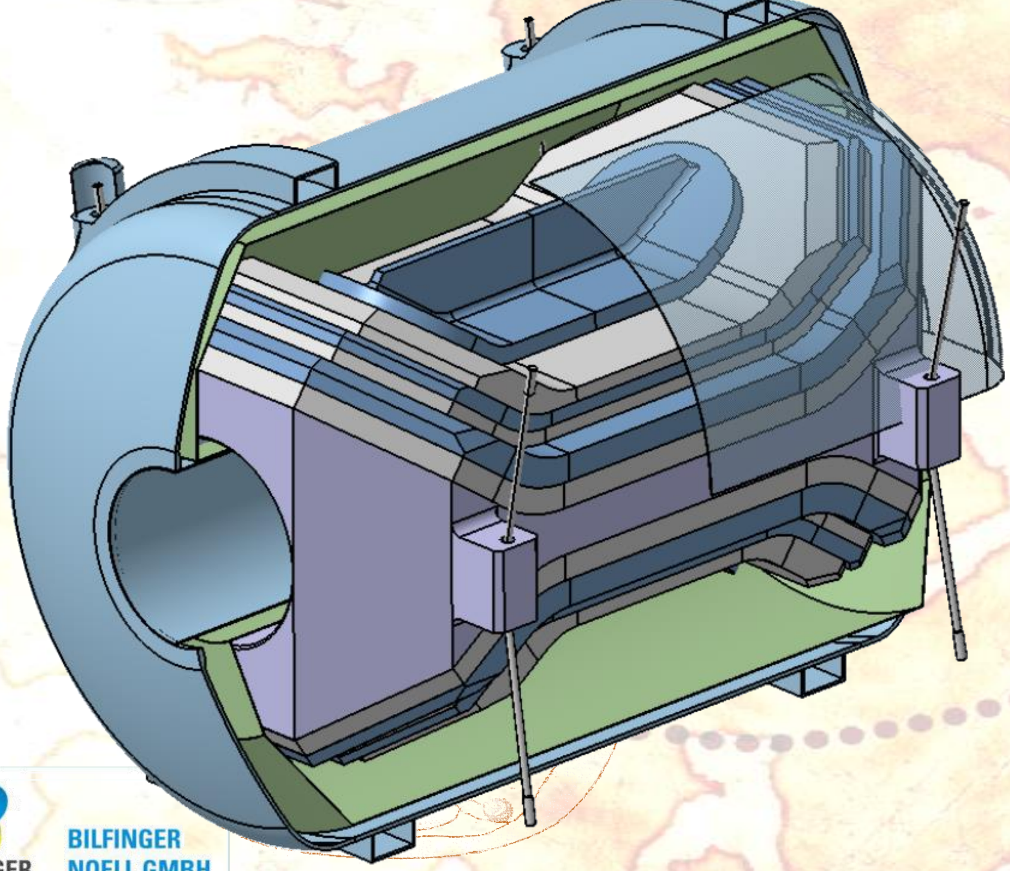


Chang Lee at TAUP 2021

Measurements at LHe temperature

Currently being performed:
stay tuned!

The MADMAX magnet:



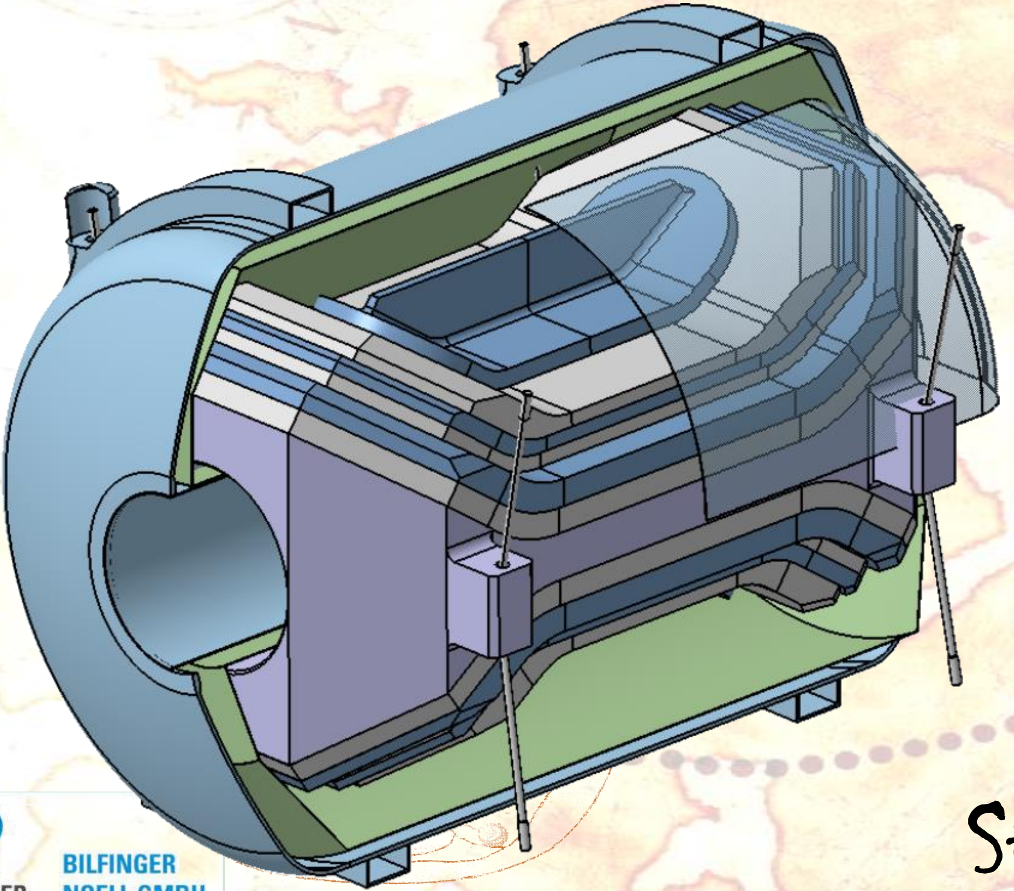
- 9T dipole magnet
- 1.35 m bore
- NbTi based conductor

Main challenges:

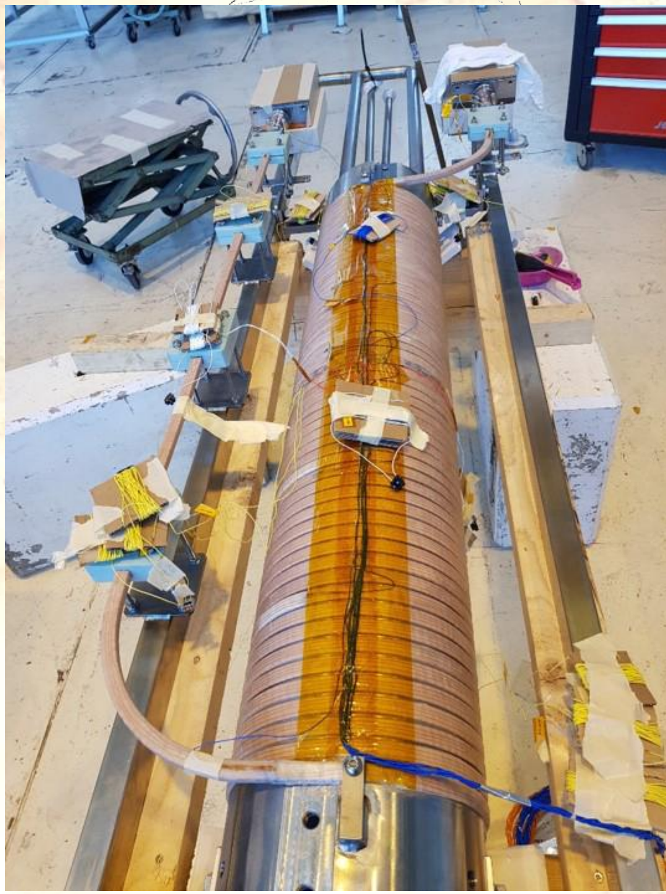
- Quench propagation?
- Peak fields
- Forces

The MADMAX magnet:

Very promising studies ongoing

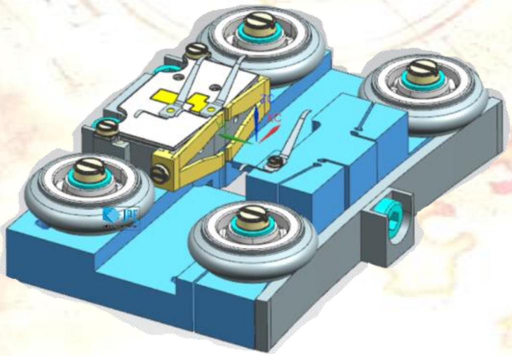


- NbTi Design
- Quench propagation
- Superconductor tests



Stay tuned!

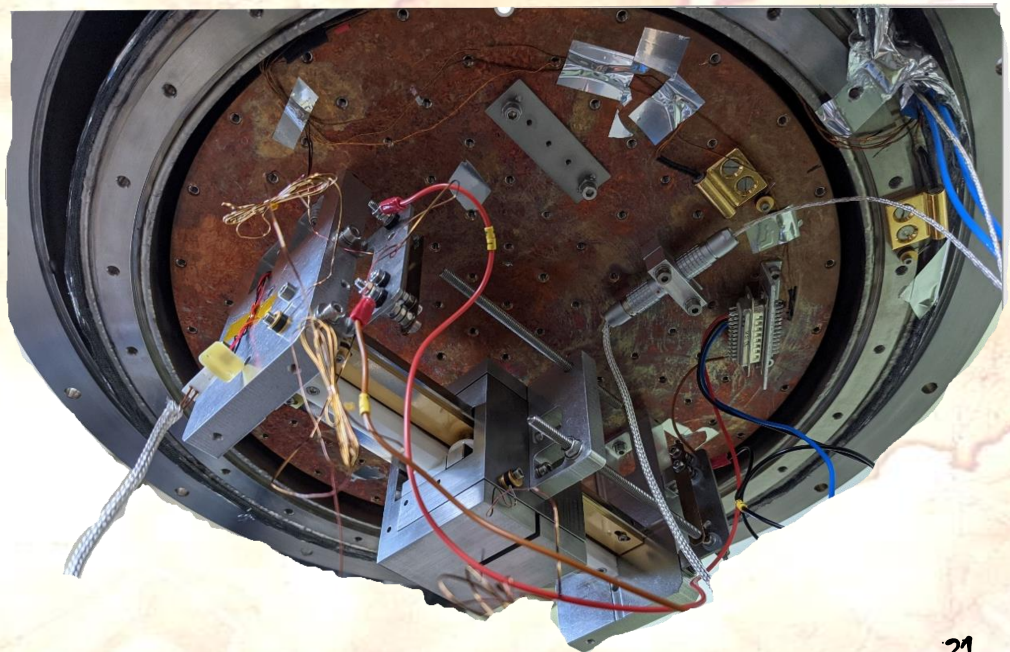
The MADMAX disc drive:



Feasibility of disc displacement at 4K in strong B-field

- Developed Piezo motor drive unit
  Repeatability < 1um
- Characterized at 4.2K ambient temperature
  Speed > 0.1mm/sec
- Soon to happen at DESY:
  test in >5T "cold" surrounding

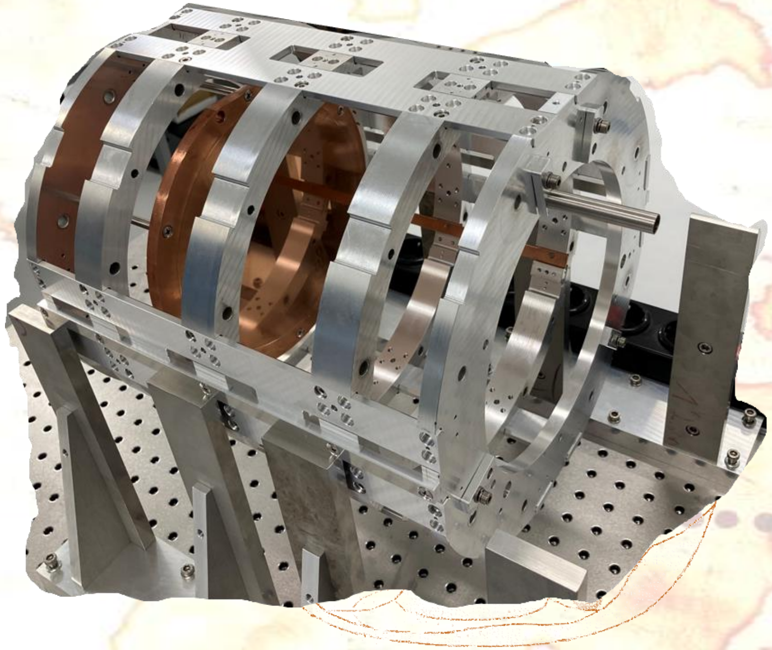
JPE
Driven by Innovation



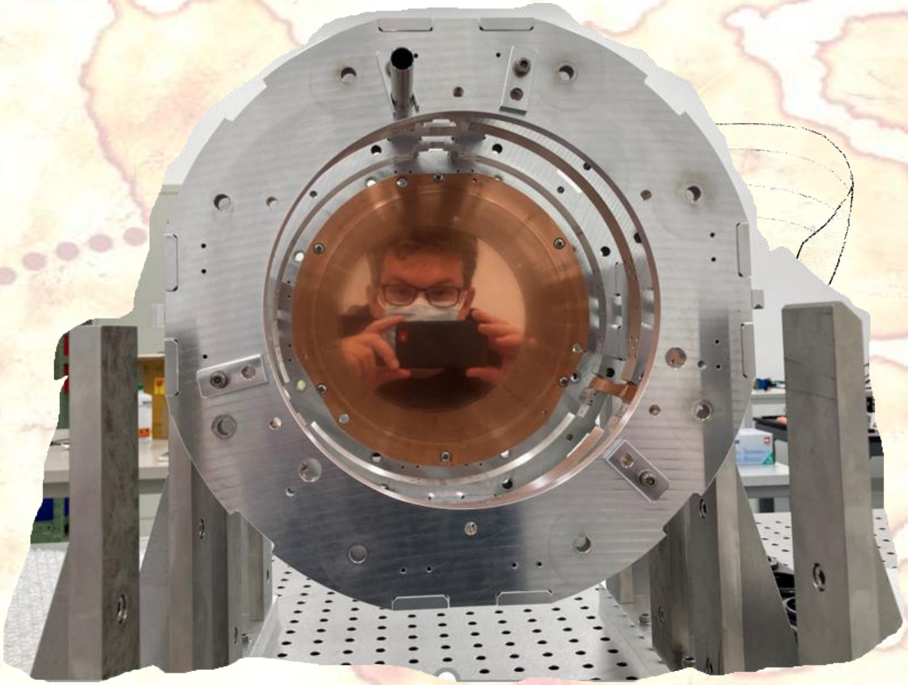
Further MADMAX test: "Project200"

Mechanical test bed:

Verify mechanical feasibility of Baseline design:

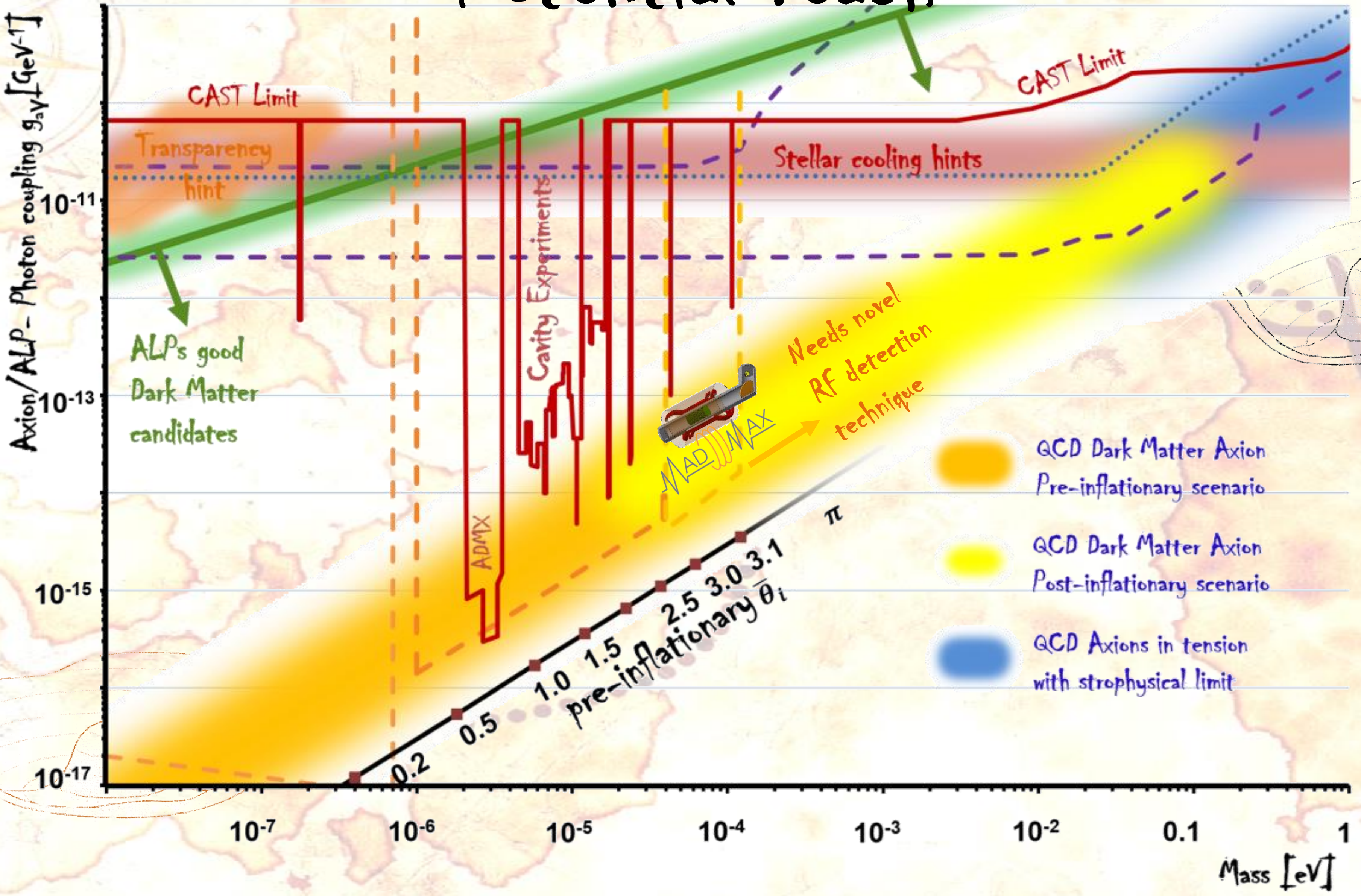


Disc movement with required accuracy at cold in high B-field



Use CERN 4K cryostat and MORPURGO magnet 2022 & 2023

Potential reach!!



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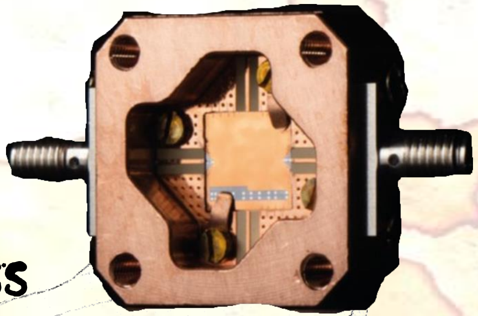
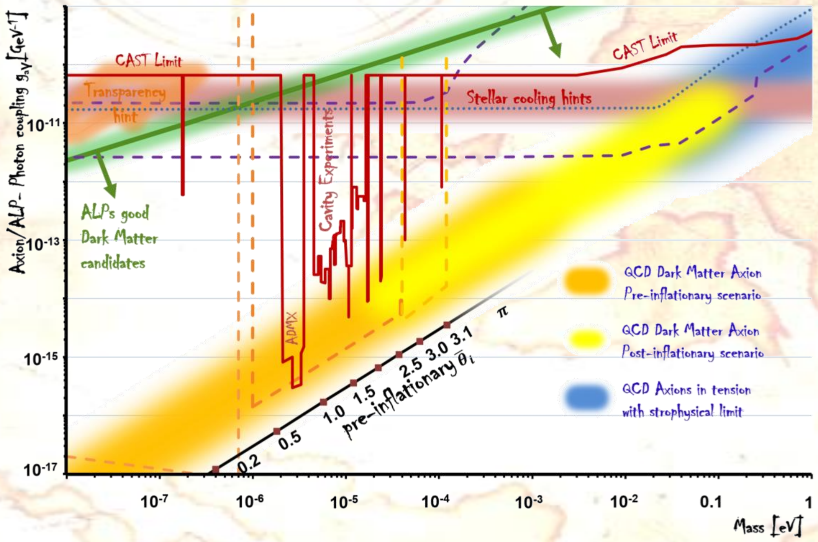
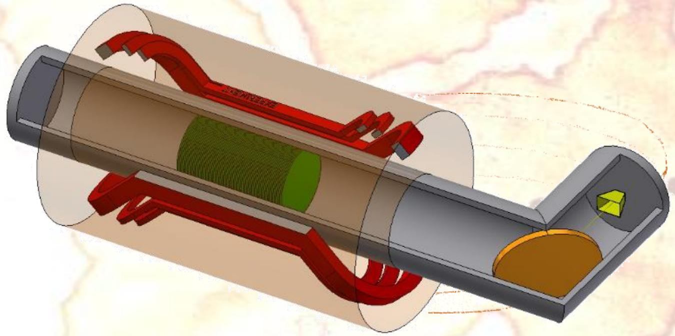
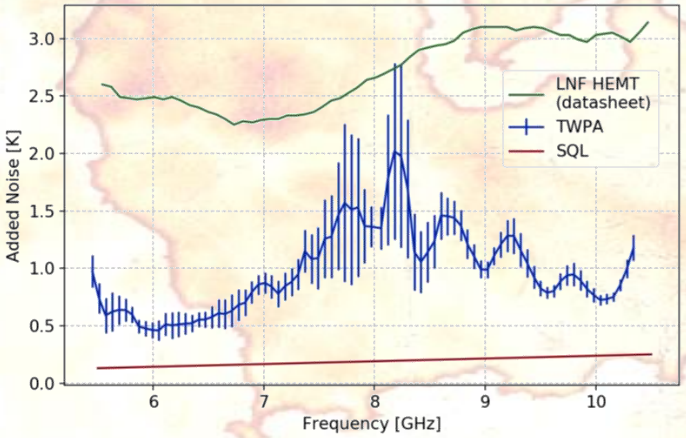
CONCLUSIONS:





- Post inflationary axion: > 30μeV mass
- Dielectric haloscope : promising concept
- TWPA as near quantum limited detector
- Dipole magnet is feasible
- Hardware challenges are being tackled





Thanks for your attention!