MADMAX

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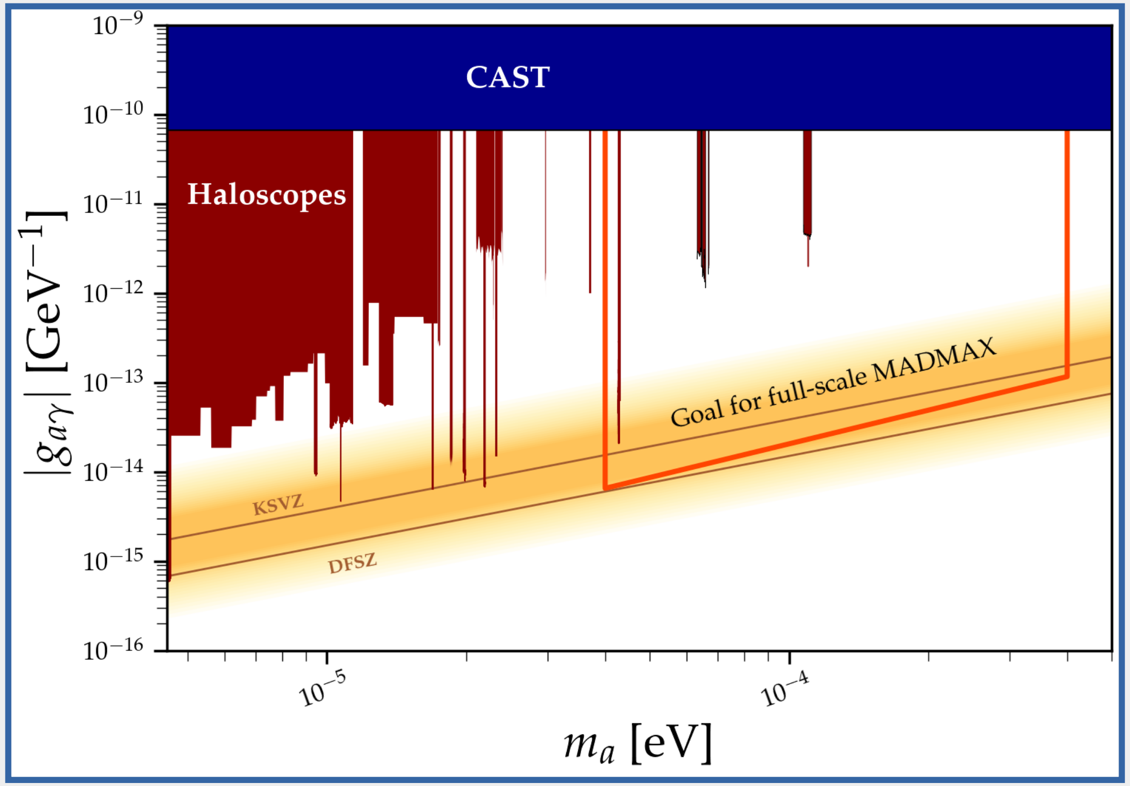
University of Hamburg

On behalf of the MADMAX Collaboration

MADMAX

MADMAX

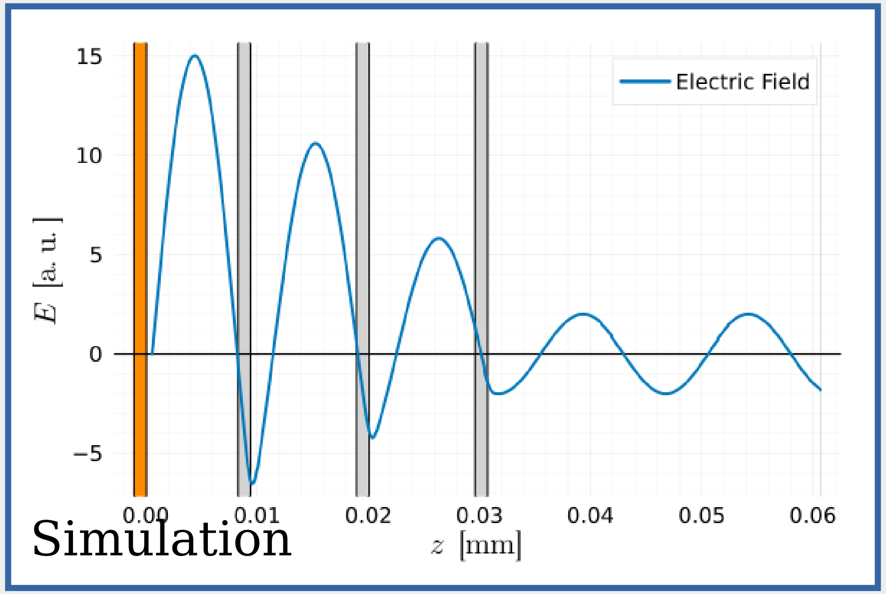
- Tunable haloscope
- Sensitive to dark matter axions
- Detector volume independent of frequency
- Signal amplification for larger axion masses [40-400 µeV]



cajohare.github.io/AxionLimits/

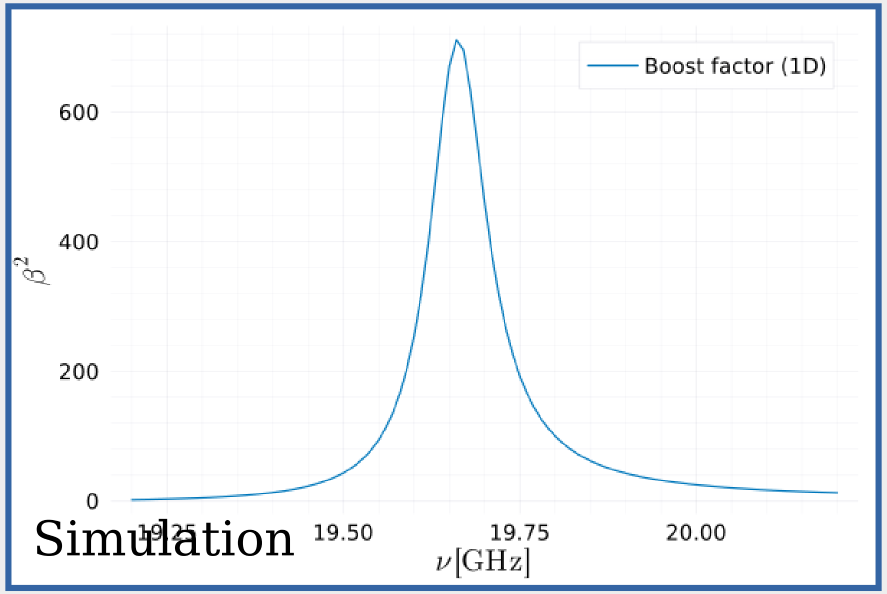
$$g_{a\gamma} \approx 2{\cdot}10^{-14}\,\mathrm{GeV}^{-1} \left(\frac{0.3\,\mathrm{GeV/cm^3}}{\rho_a}\right)^{1/2} \left(\frac{10^5}{\beta^2}\right)^{1/2} \left(\frac{1\,\mathrm{m}^2}{A}\right)^{1/2} \left(\frac{T_{sys}}{8\,\mathrm{K}}\right)^{1/2} \left(\frac{10\,\mathrm{T}}{B_e}\right) \left(\frac{1.3\,\mathrm{d}}{\tau}\right)^{1/4}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

Boost factor



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

J.E. JCAP04(2023)064

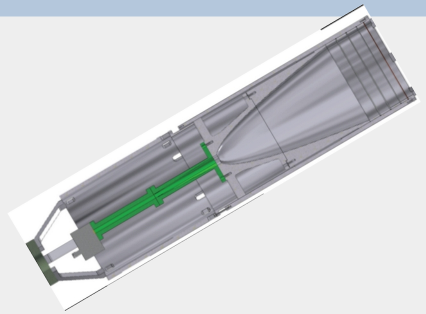


- Boost signal by resonance between dielectric disks
- Tune distance between disks
- In cavity terms: Low quality factor but wavelength independent form factor

Final design with A~1m^2 disks and β^2~10^5:

- V ~ V_{cav} x 10^5 [@20 GHz]

Prototype Program

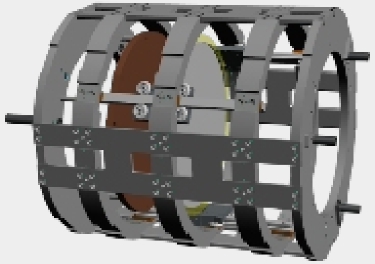


Closed Boosters (CB):

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

Aim:

- Easy to simulate
- Understand receiver chain in B-field

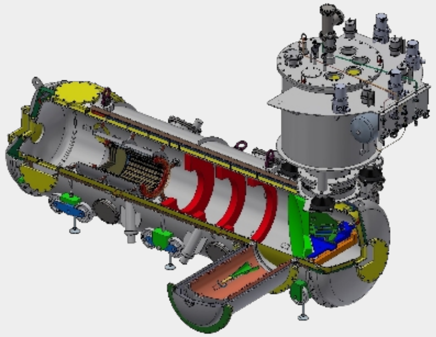


Open Boosters (OB):

⌀ = 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

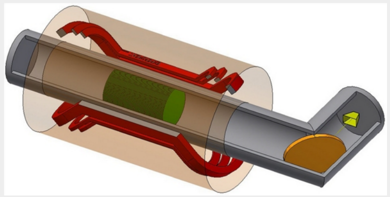


Large bore (⌀ = 760 mm) cryostat

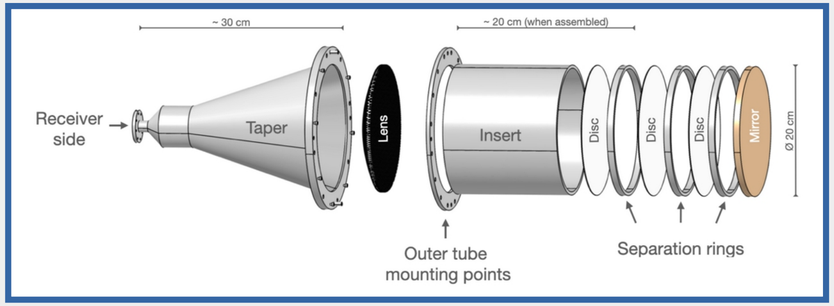
allows operation of all prototypes
Fits into the 1600 mm warm bore of MORPURGO magnet at CERN

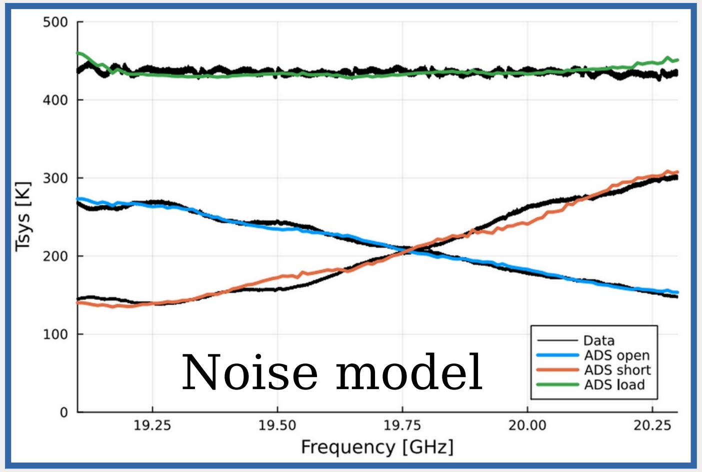
Goal:

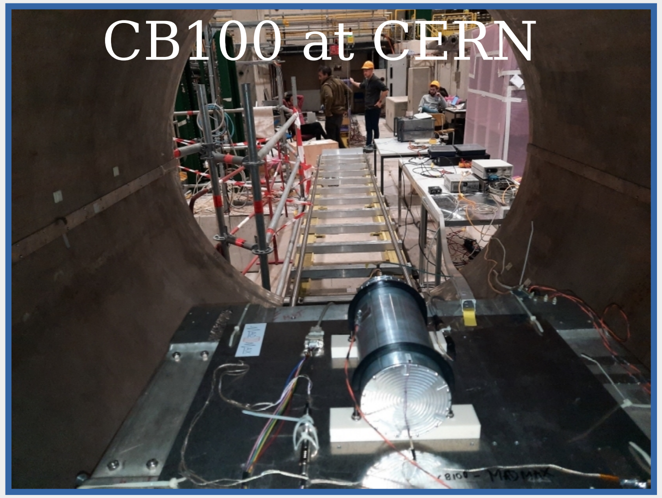
- Many large disks
- Strong magnetic field
- QCD axion sensitivity



Closed Booster





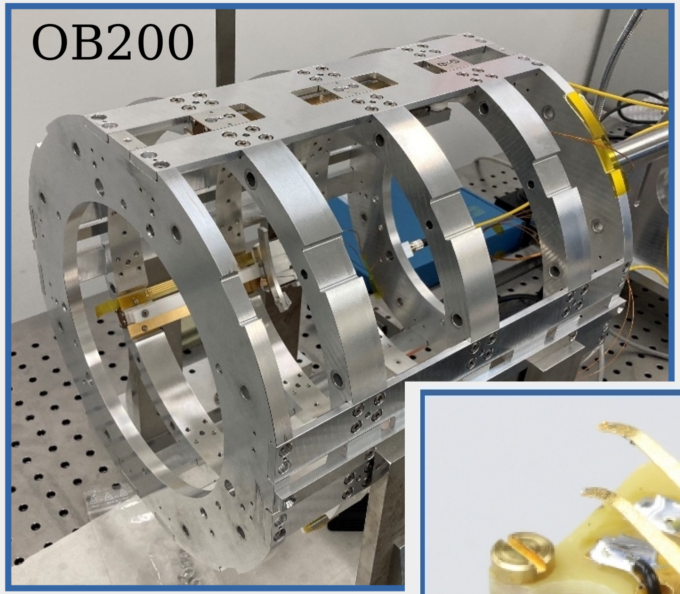


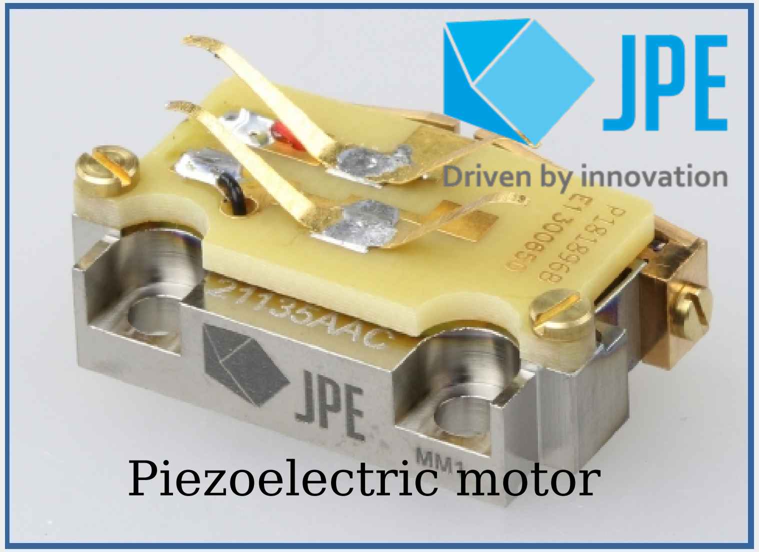
- Closed system with fixed distances
- Test bed for RF understanding and operations in B-field
- Establish noise model for receiver calibration

Test runs 2022&2023:

- Data taking under realistic conditions
- Full calibration and analysis chain (from data to limit)

Open Booster Mechanics





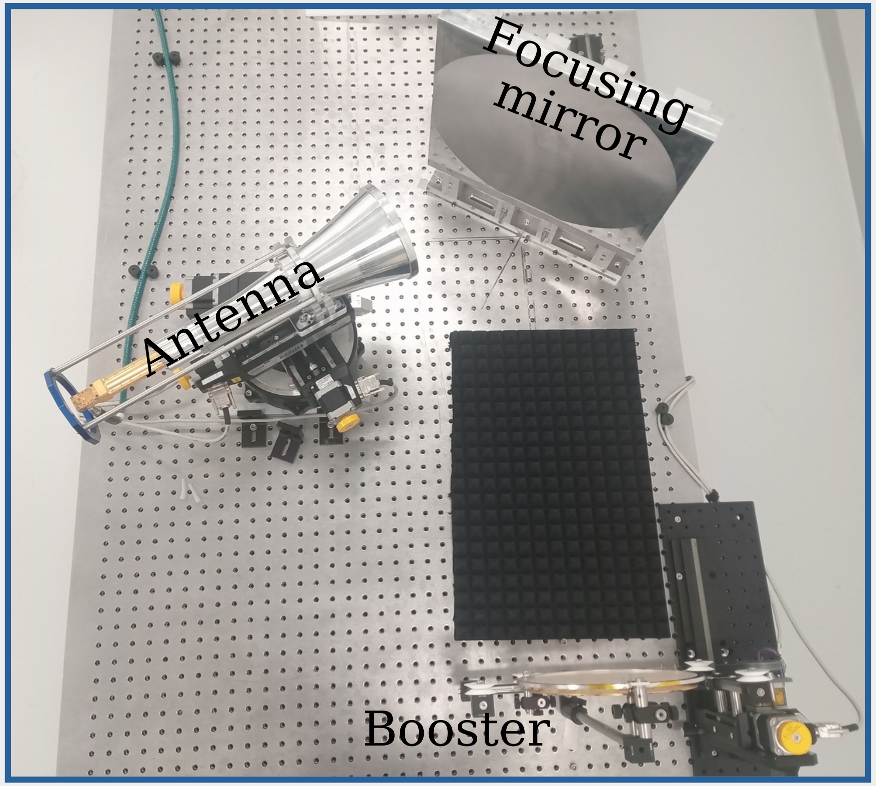
Piezoelectric motor

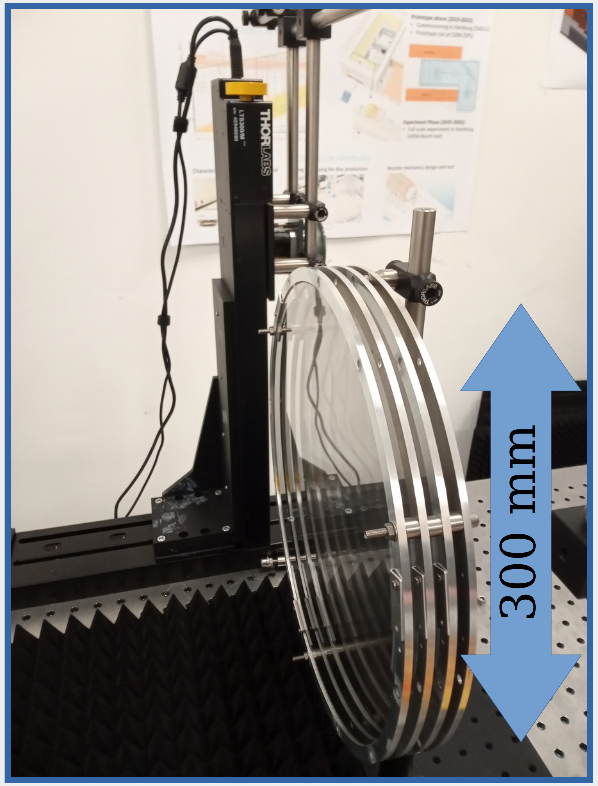
Mechanical demonstrator with:

- One 200 mm sapphire disk
- Three JPE piezo motors
- Interferometer for displacement measurement
- Successful tests at CERN cryolab (4K) and Morpurgo magnet (1.6 T)
- Motors work according to specifications[1)]

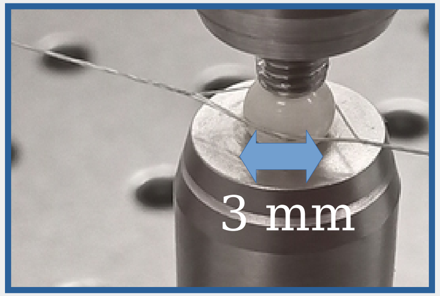
[1)]JINST 18 P08011

Open Booster Electromagnetics



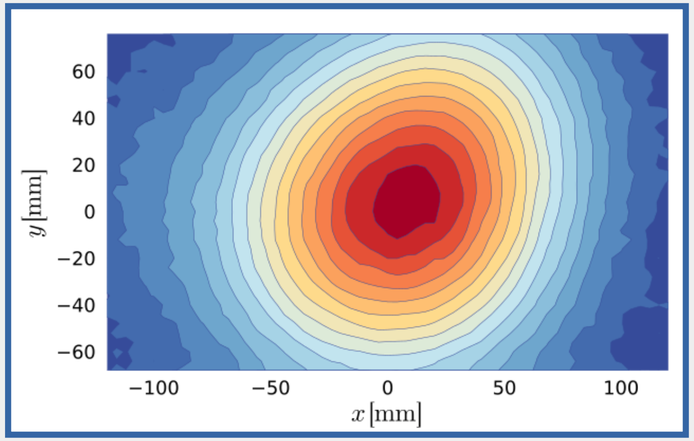


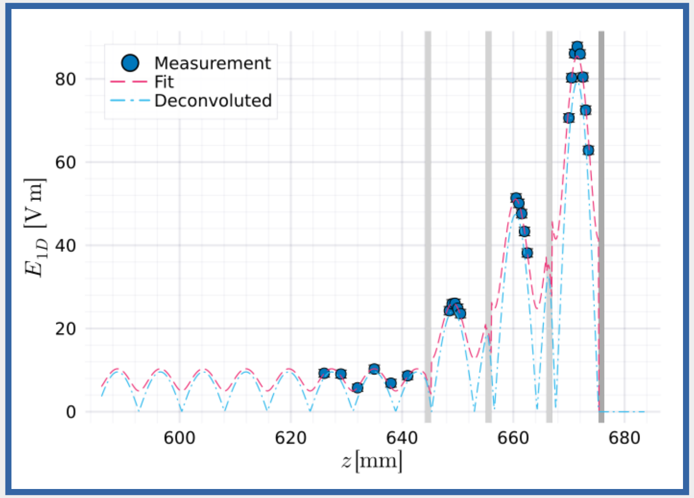
- Set up a simple three disk open booster
- Fixed distances
- Study electromagnetics with bead-pull method



Dielectric bead

Boost factor determination



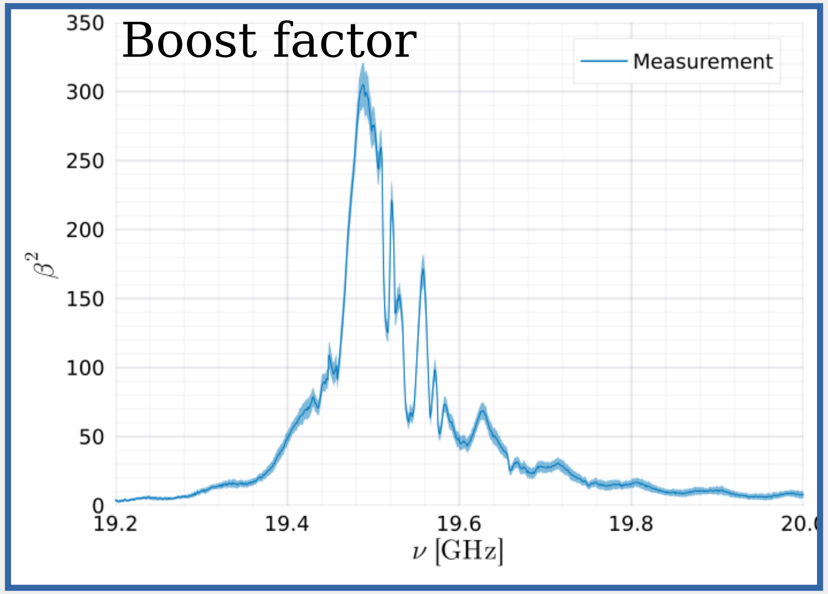


- Measure the electric field
- Calculate boost factor from measurement
- Bandwidth ~ 65 MHz
- Off-resonance: Still a dish antenna ($\beta^2 \sim 1$)

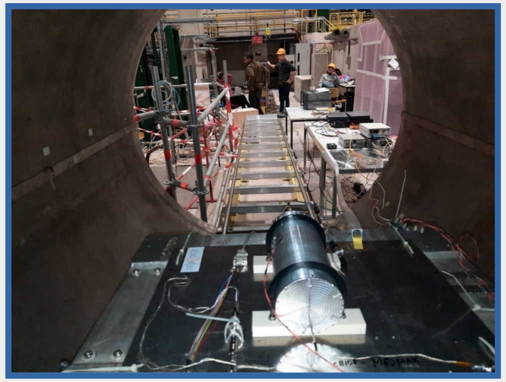
$$\beta^2 \propto \left| \int_{V_a} dV\, \boldsymbol{E} \right|^2$$

J.E. JCAP04(2023)064

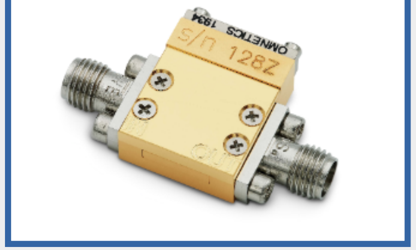
J.E. arXiv:2311.13359



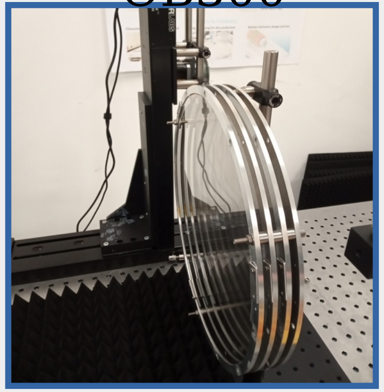
CB100 at CERN

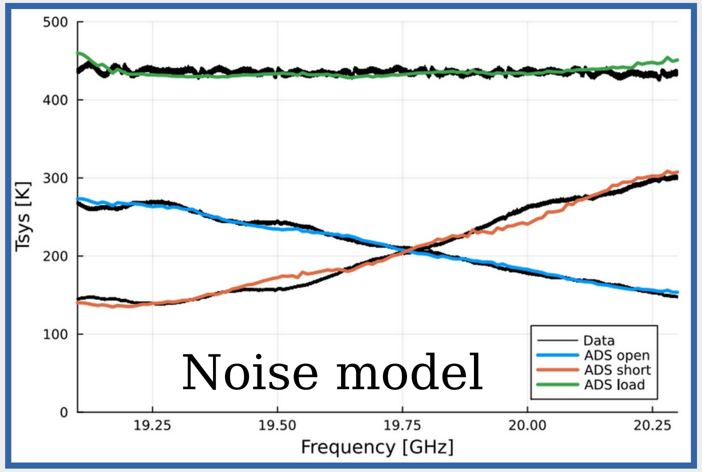


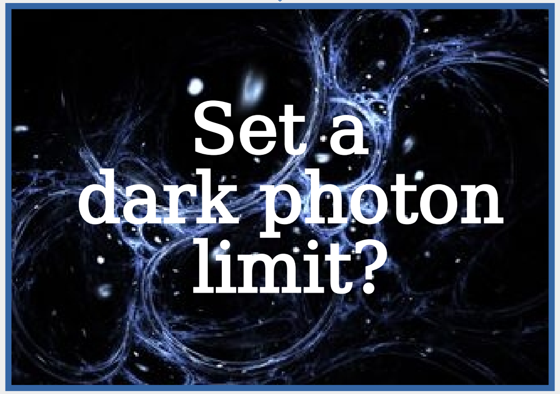
Receiver chain

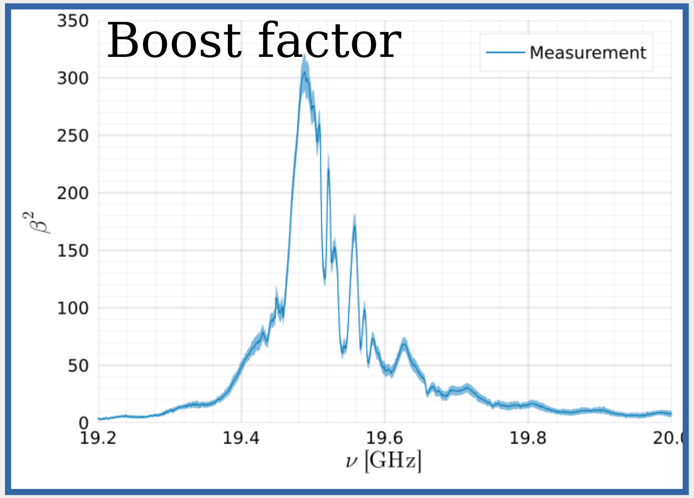


OB300

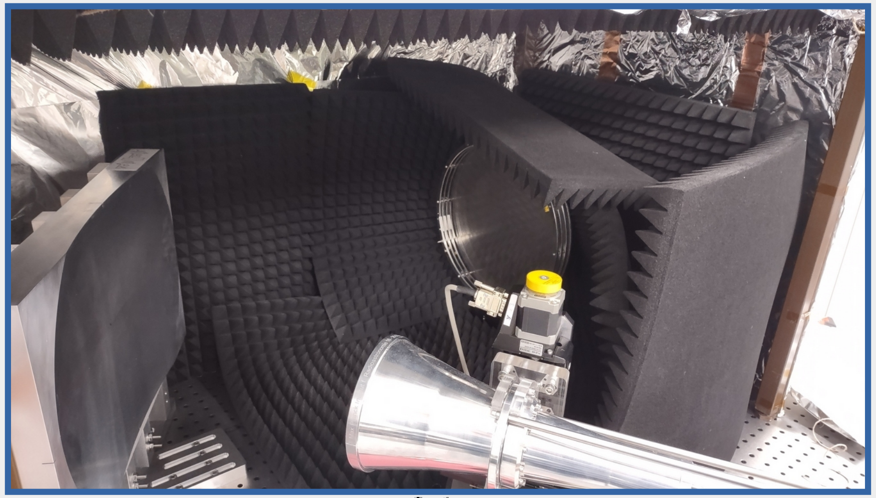


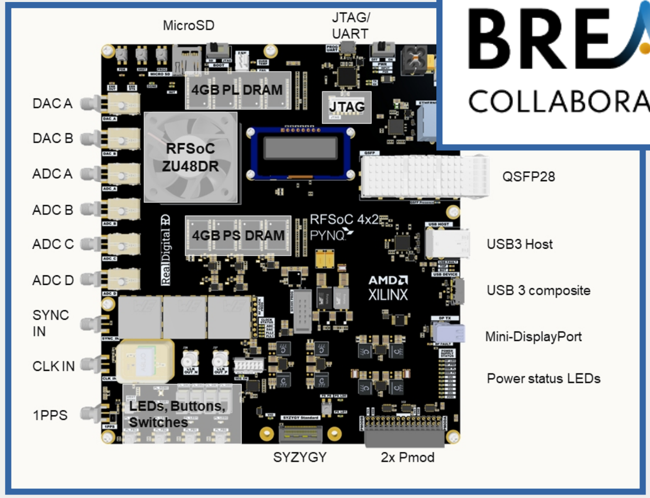




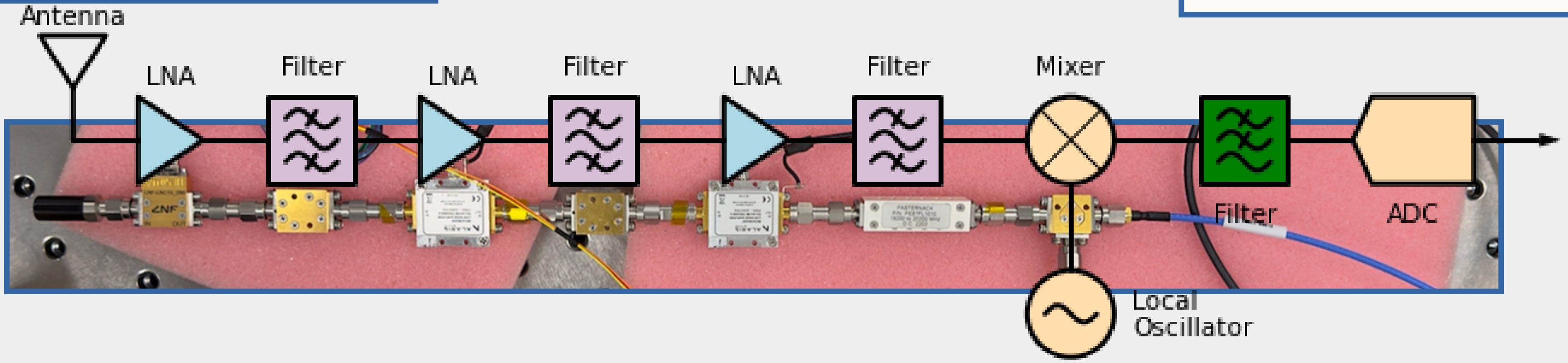


Setup





BREAD COLLABORATION



Thanks to the BRASS group for lending us vital equipment!

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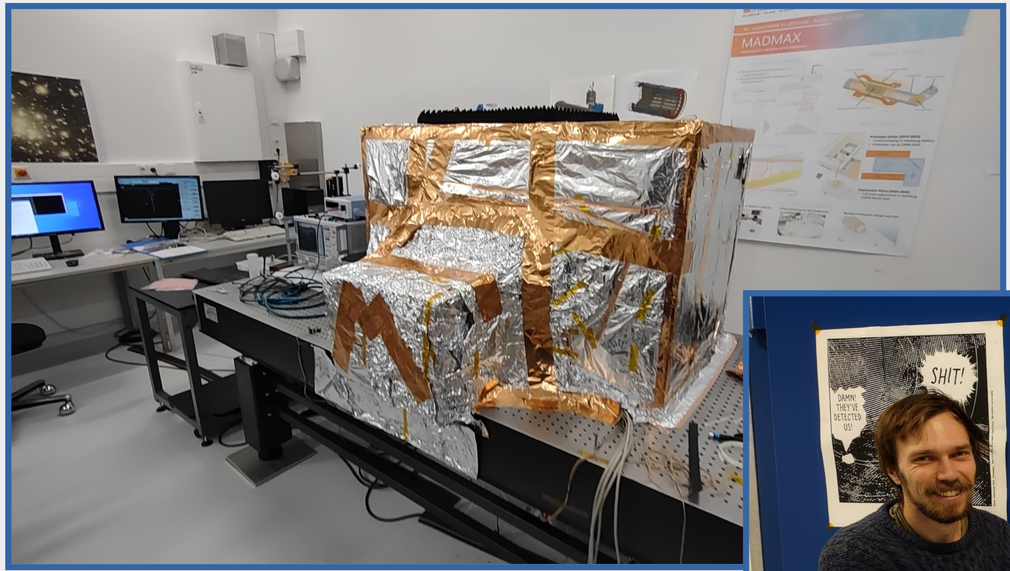
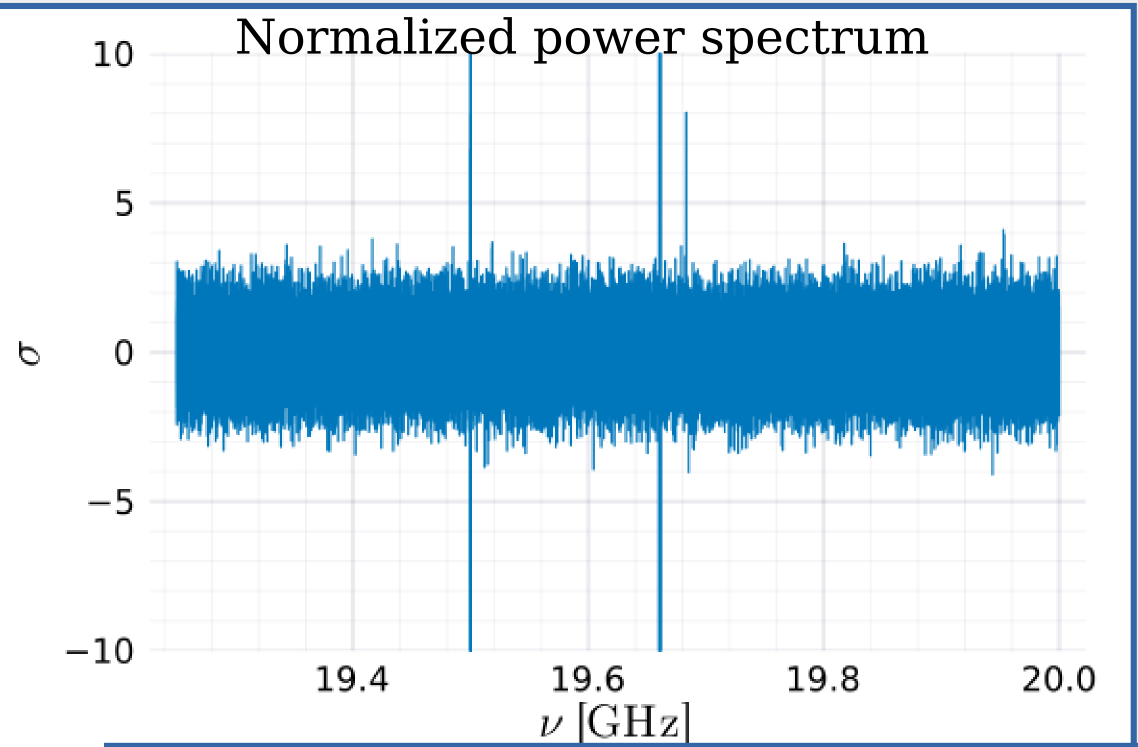
Two weeks later



Results



- No unknown 5 sigma excess
- RFI peaks are known
- Full statistical analysis pending
- Assume worst case β^2 for now
- Set a preliminary sensitivity reach
- Unpolarized dark photon dark matter

$$\chi \approx 1.7 \times 10^{-13} \left(\frac{0.45\,\mathrm{GeV/cm^3}}{\rho_A}\right)^{1/2} \left(\frac{230}{\beta^2}\right)^{1/2} \left(\frac{707\,\mathrm{cm}^2}{A}\right)^{1/2} \left(\frac{T_{sys}}{340\,\mathrm{K}}\right)^{1/2} \left(\frac{11\,\mathrm{d}}{\tau}\right)^{1/4} \left(\frac{SNR}{5}\right)^{1/2}$$

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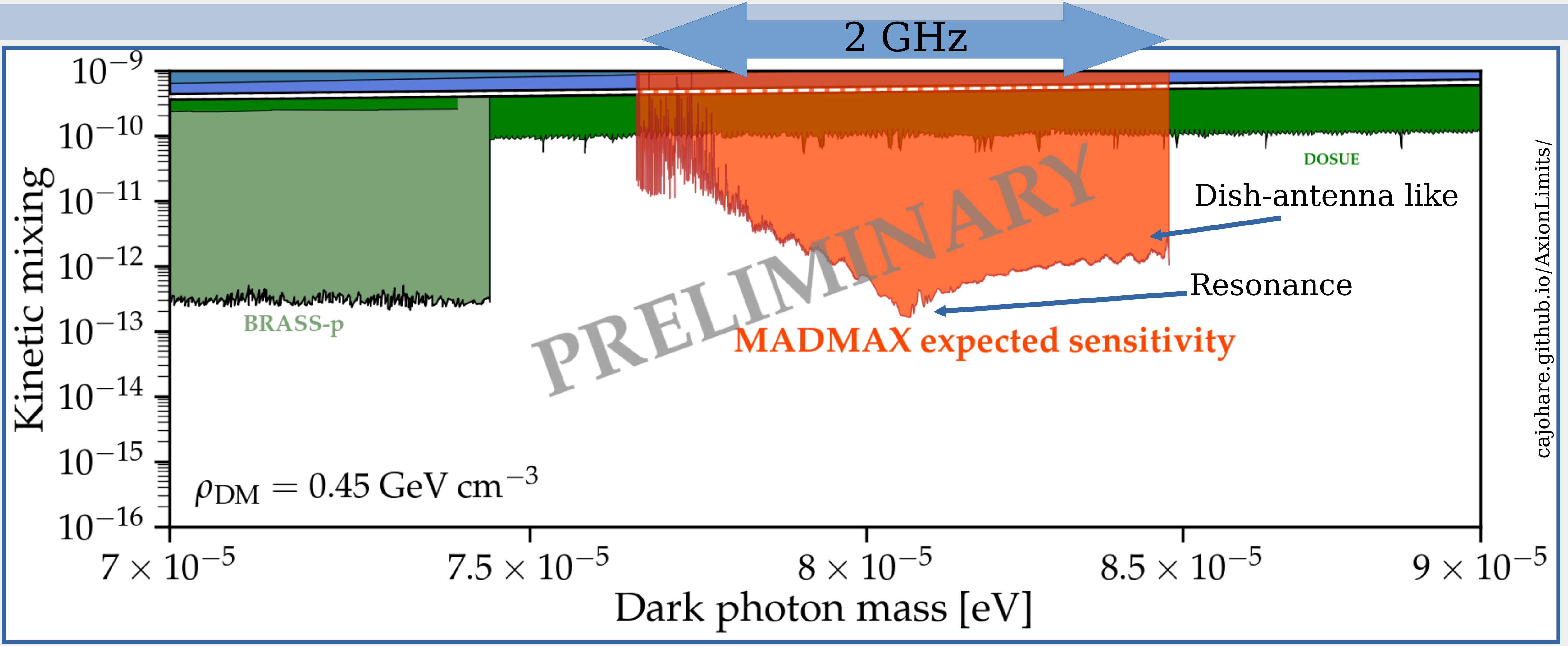
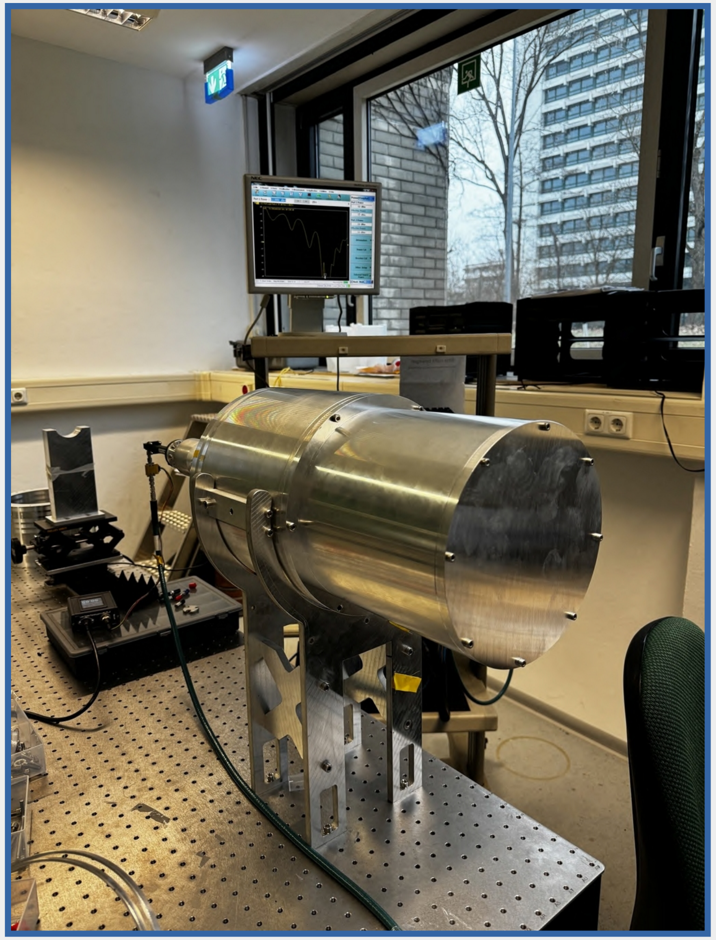
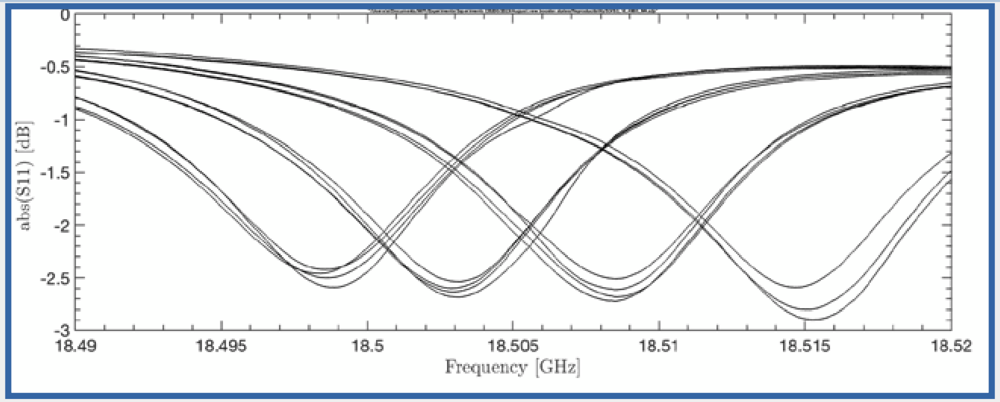
Physics Reach



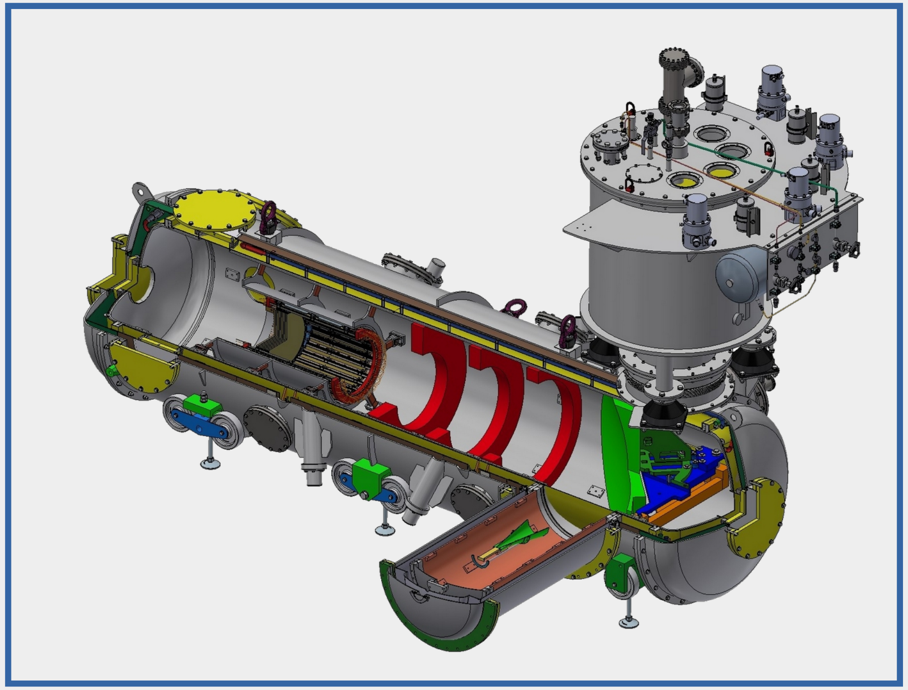
What's next?



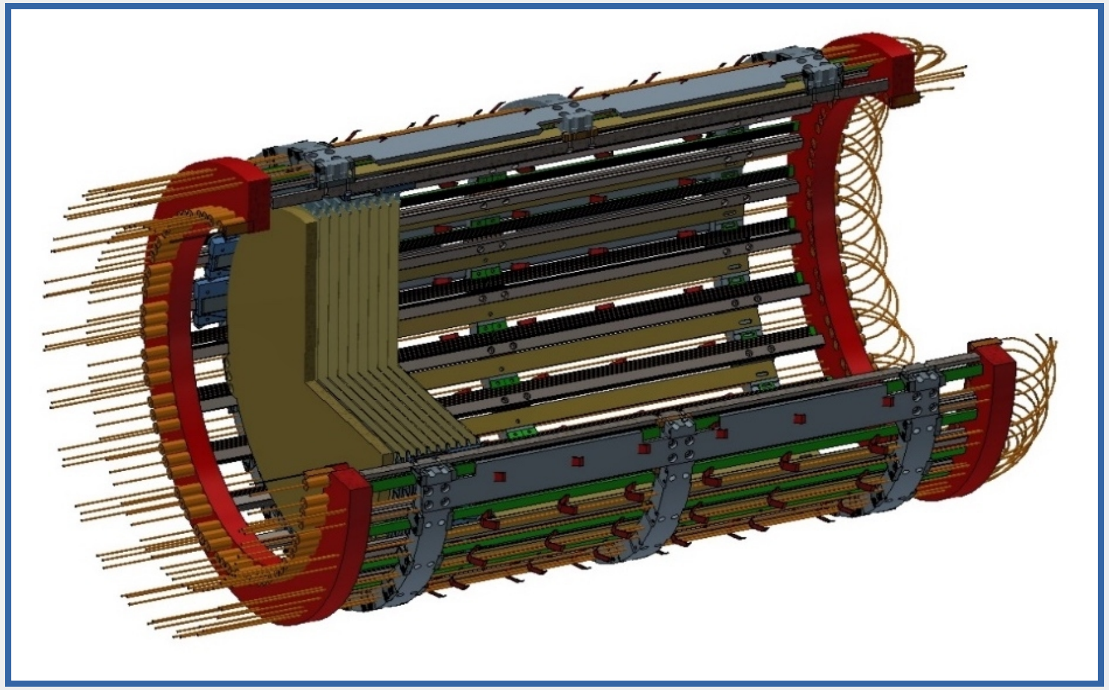


- March 2024: Run with CB200 in Morpurgo magnet at CERN (1.6 T)
- Smaller than OB300 but larger boost factor
- Frequency tuning by manually changing distances
- 40 MHz tunability for each configuration
- Additionally: CB100 @4K to demonstrate cold calibration

Tunable cryogenic open booster



- MADMAX Prototype Cryostat (MPC)
- Cryogenic temperature (4K)
- Coming this spring



- Tunability (up to 20 disks)
- Under construction

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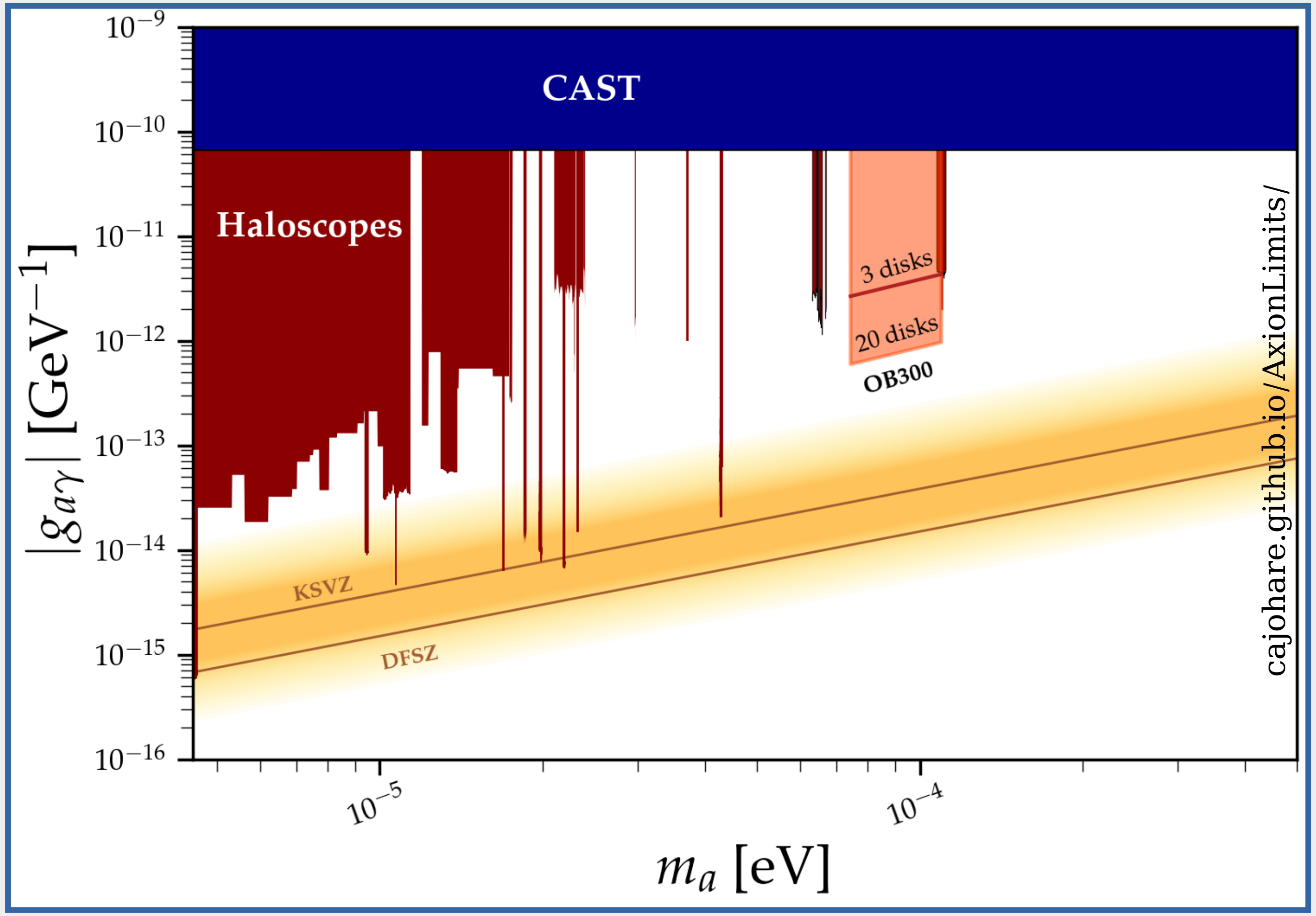
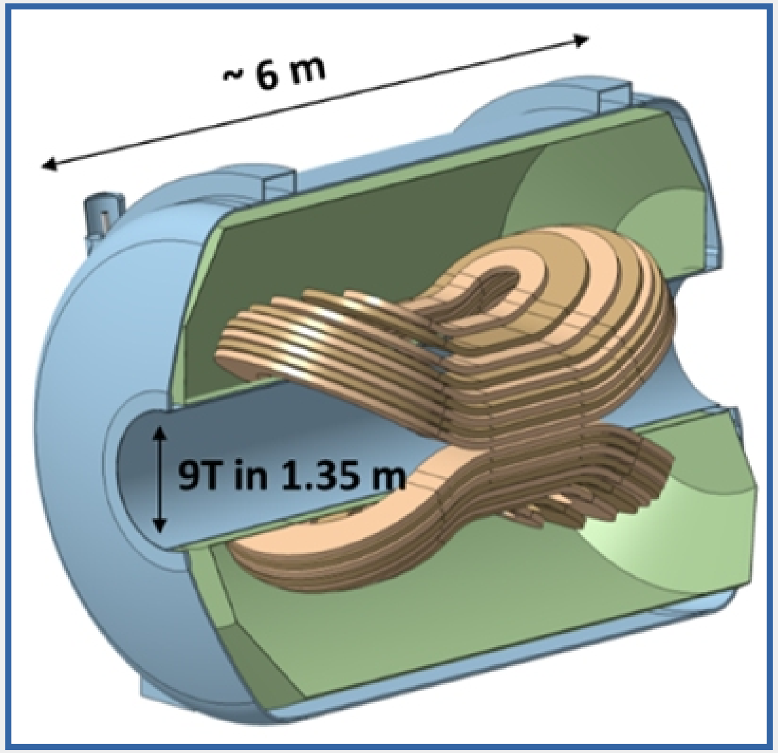
Near Term Projection



- Operate OB300 in cryostat (8K) and Morpurgo magnet (1.6 T)
- Start end of 2025-spring 2026

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)]
- Budget for first demonstrator coil secured!
- Extend to prototype magnet big enough to house MADMAX prototpyes
- B-field ~3 T
- Designated site: DESY Hall North
- Cryo platform presently being prepared

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

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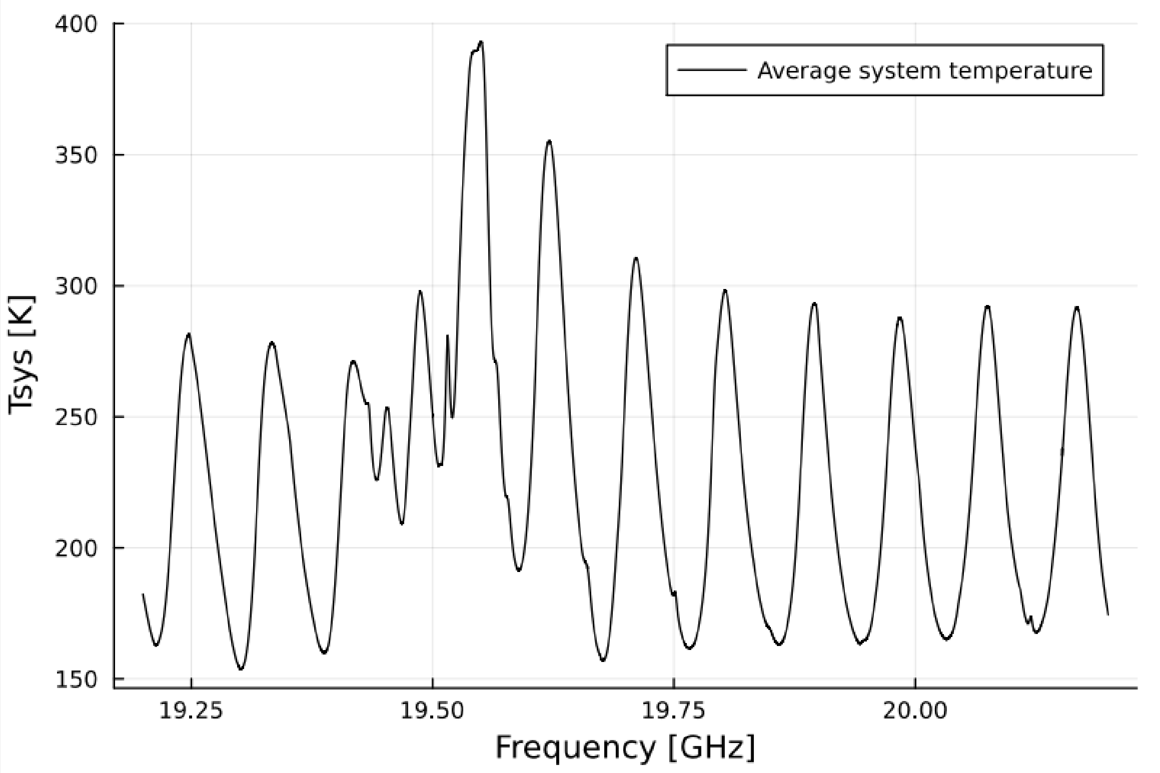
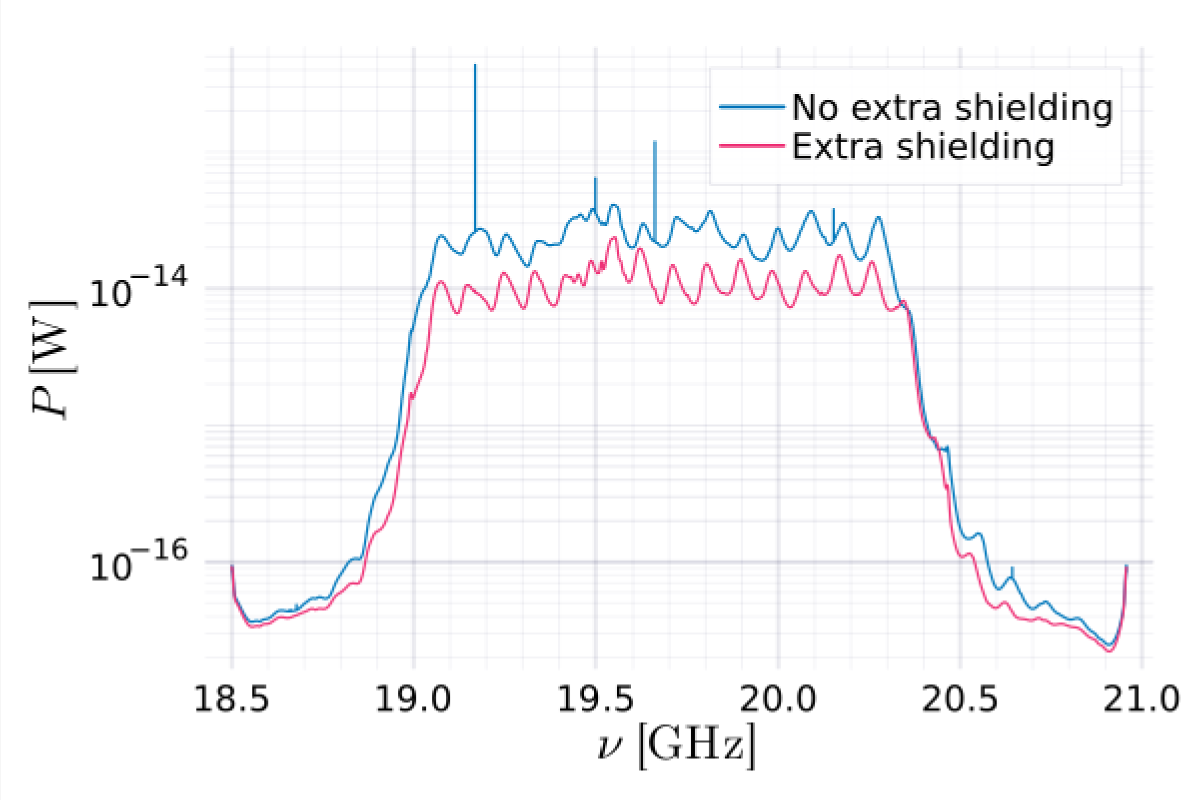
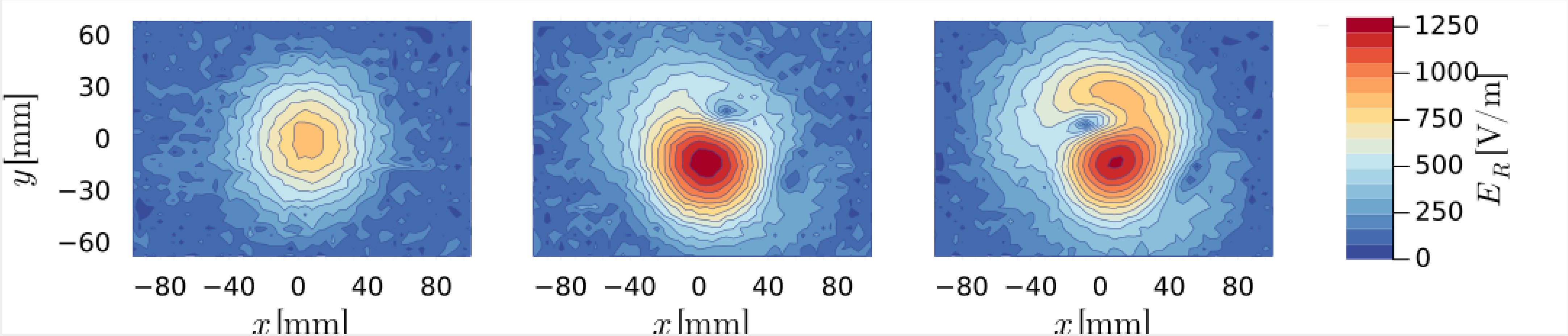
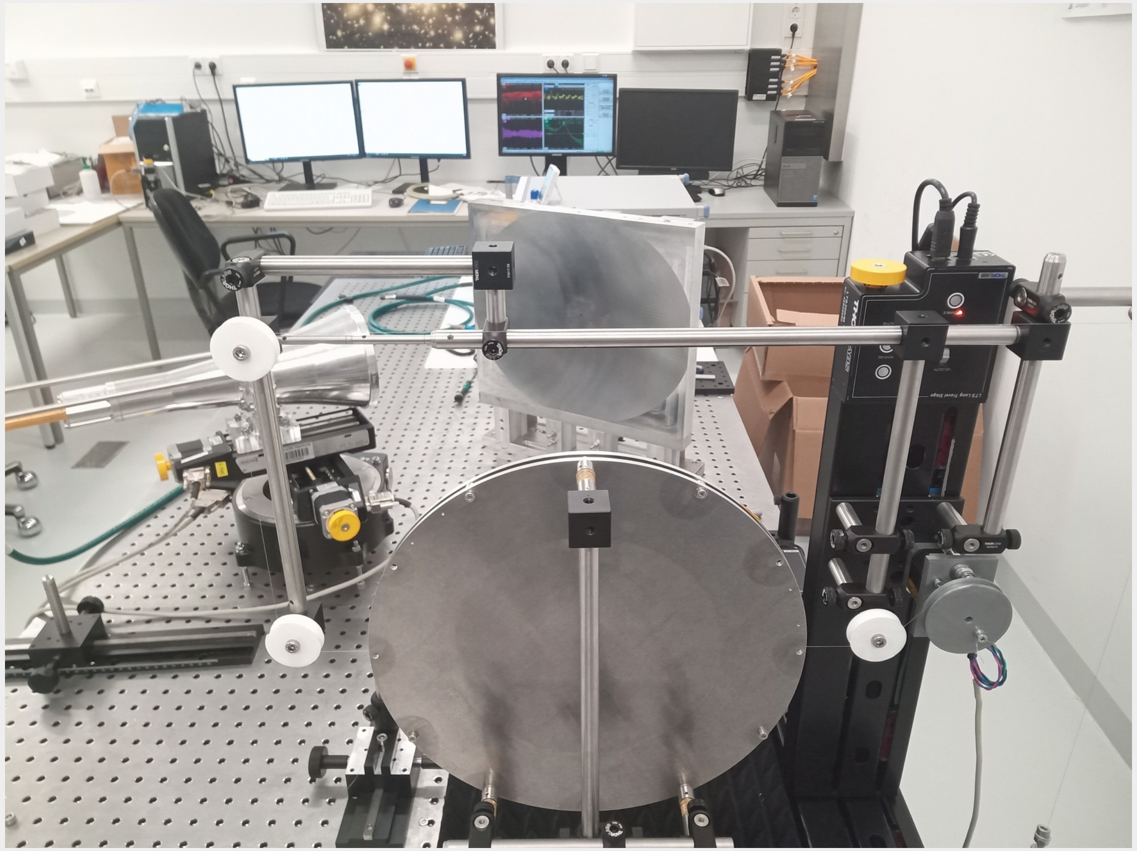
Thank you

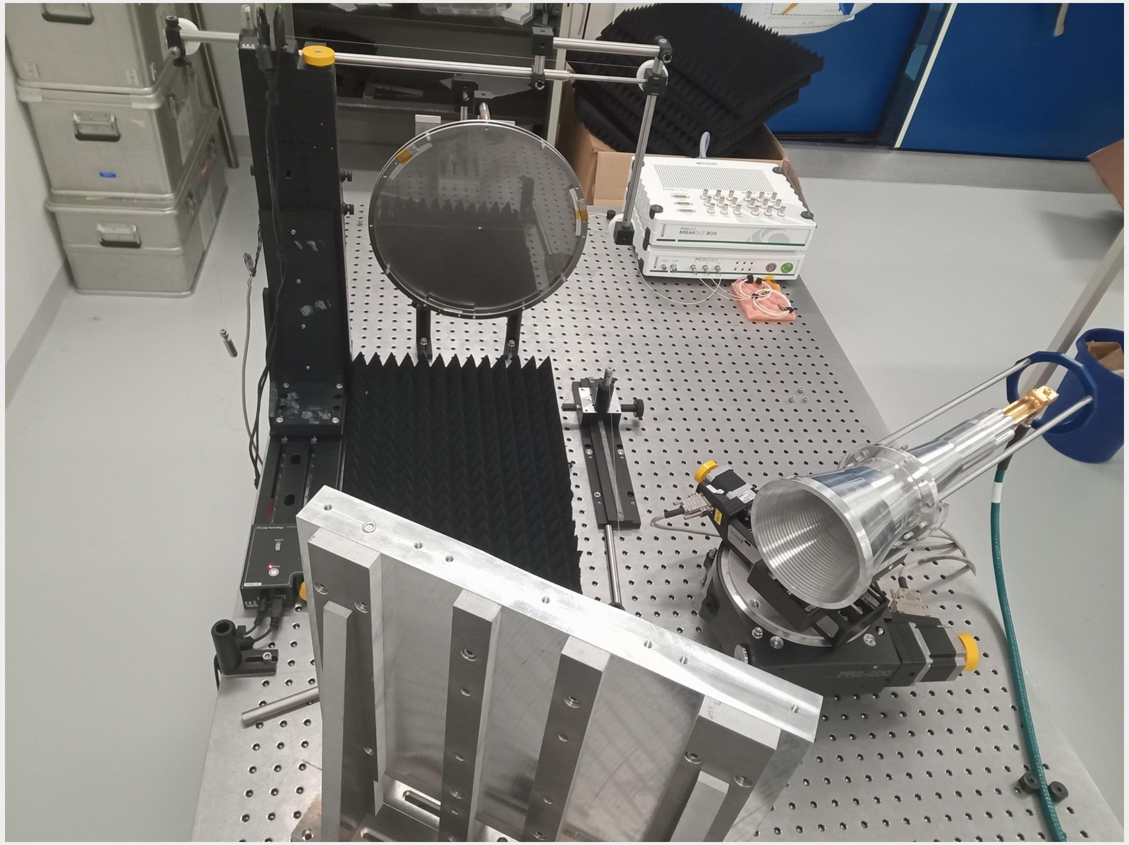
Backup

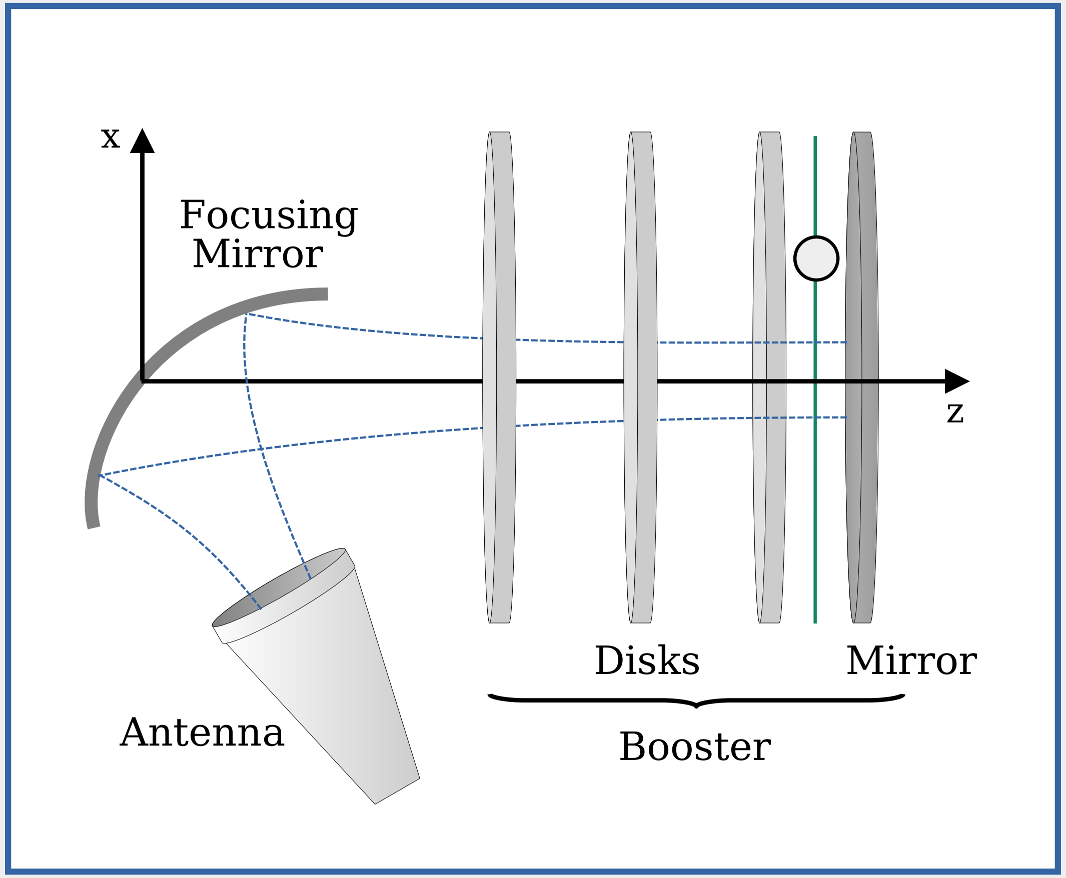

Average system temperature
Tsys [K]
Frequency [GHz]
400
350
300
250
200
150
19.25
19.50
19.75
20.00


No extra shielding
Extra shielding
P [W]
10^{-14}
10^{-16}
18.5
19.0
19.5
20.0
20.5
21.0
ν [GHz]


60
30
0
−30
−60
y [mm]
−80 −40 0 40 80
x [mm]
−80 −40 0 40 80
x [mm]
−80 −40 0 40 80
x [mm]
1250
1000
750
500
250
0
E_R [V/m]






x
Focusing
Mirror
z
Disks
Mirror
Antenna
Booster