



MADMAX: A QCD Dark Matter Axion Direct-Detection Experiment

17th International Conference on Topics in Astroparticle and Underground Physics (TAUP 2021) ID #362

Chang Lee, Aug. 2021

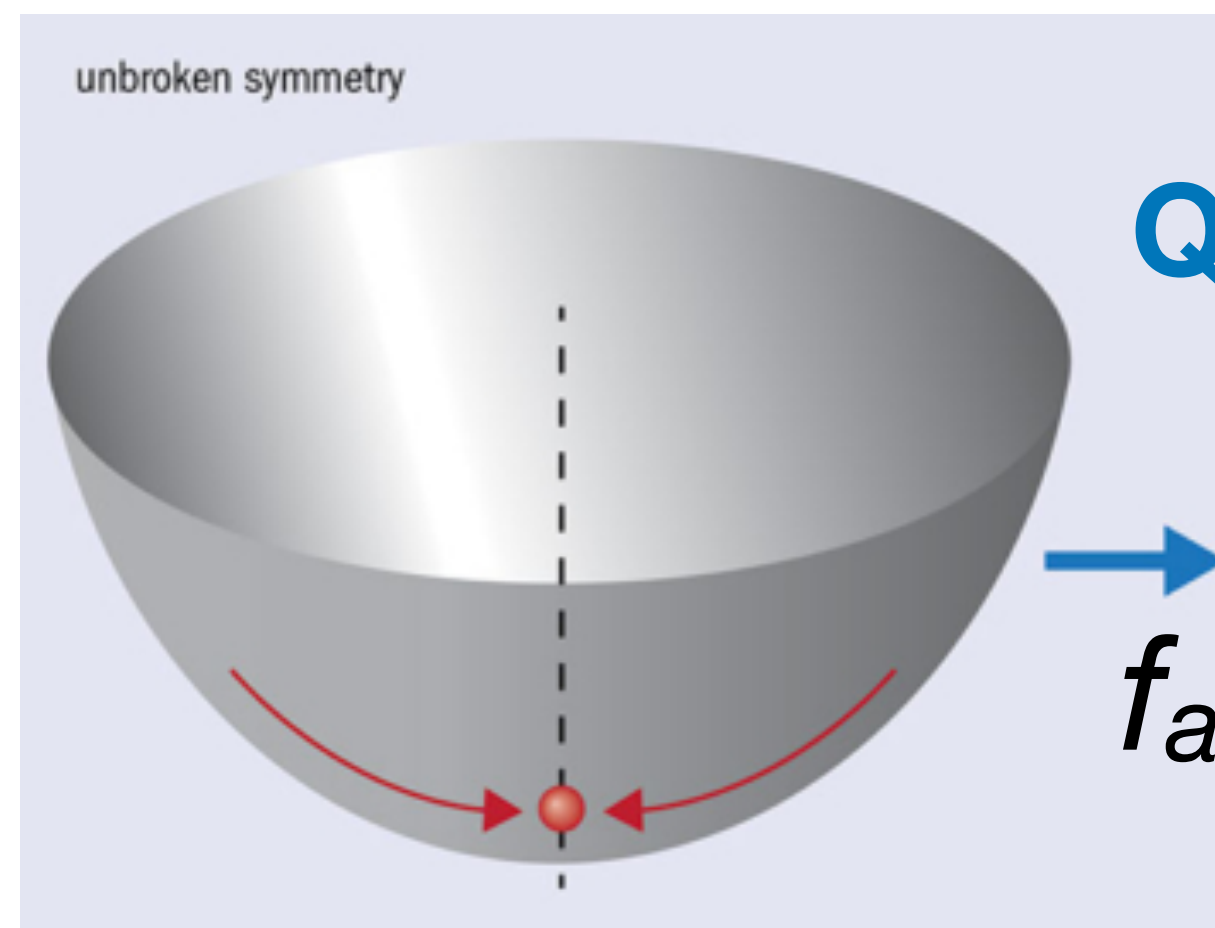
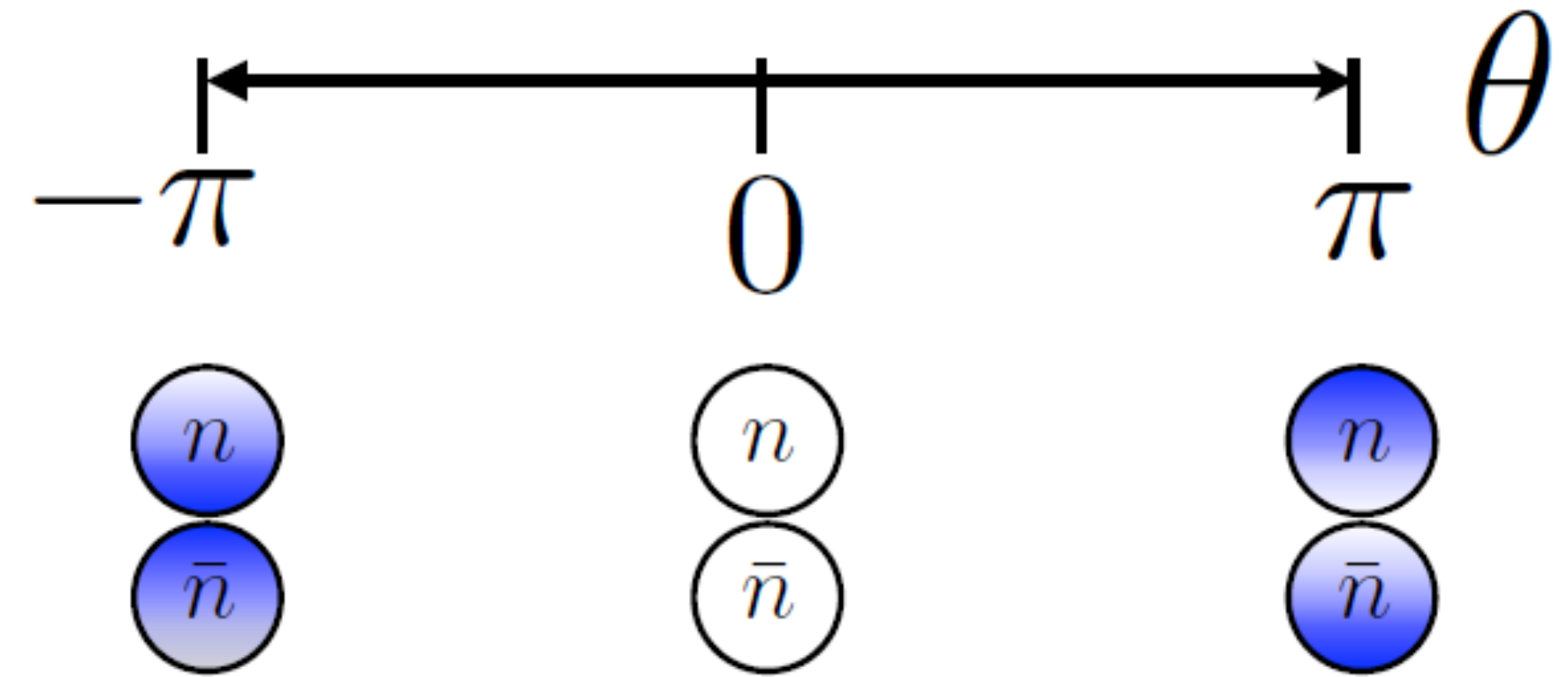
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FÜR PHYSIK



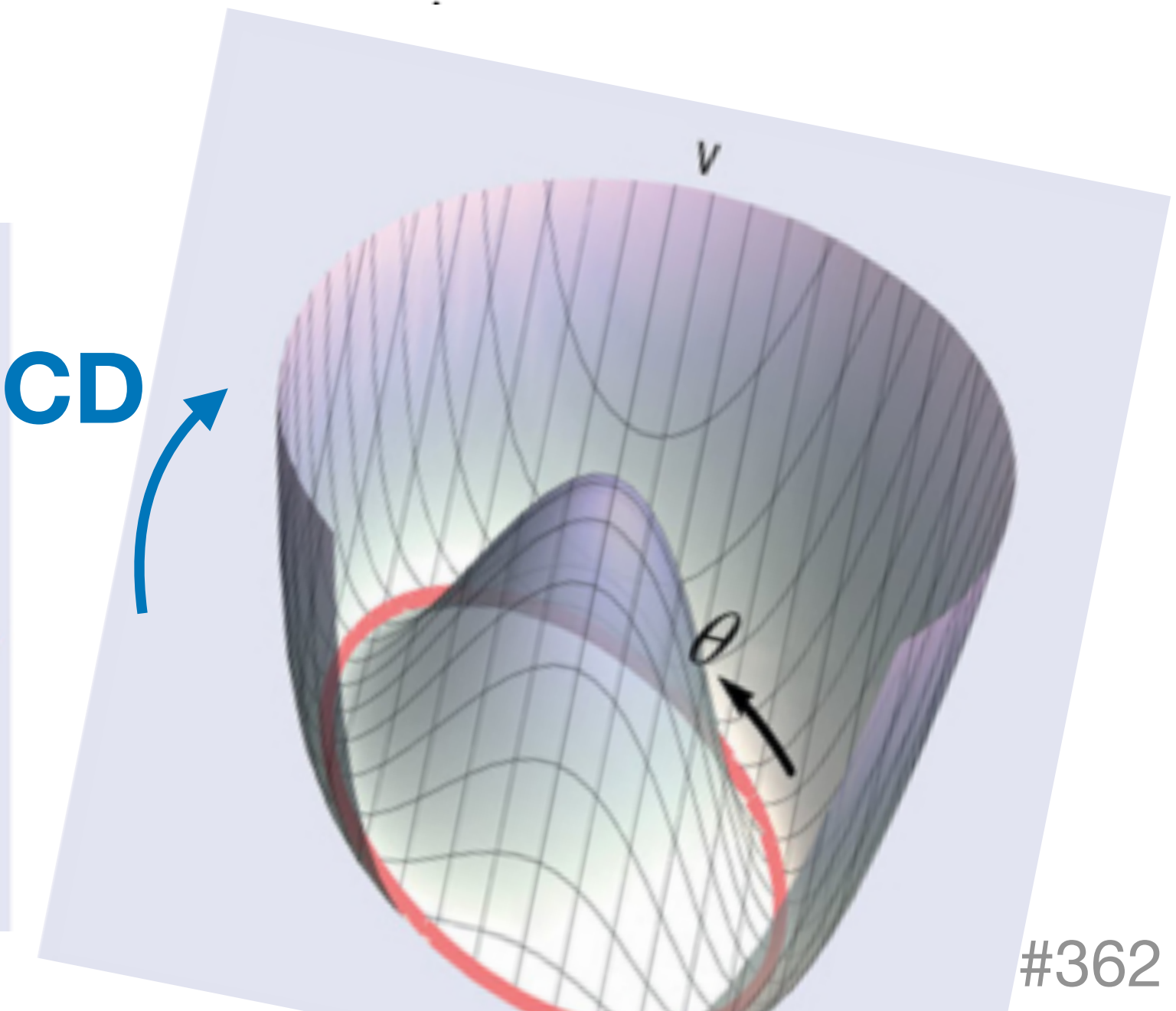
Axion

$$\mathcal{L} = \dots + \theta \frac{g_s^2}{32\pi^2} \mathbf{G}_{\xi\zeta}^a \tilde{\mathbf{G}}_a^{\xi\zeta}$$

- Strong CP problem: why $\theta \approx 0$?
- PQ solution: new dynamic field
- QCD explicitly breaks symmetry \rightarrow Axion.



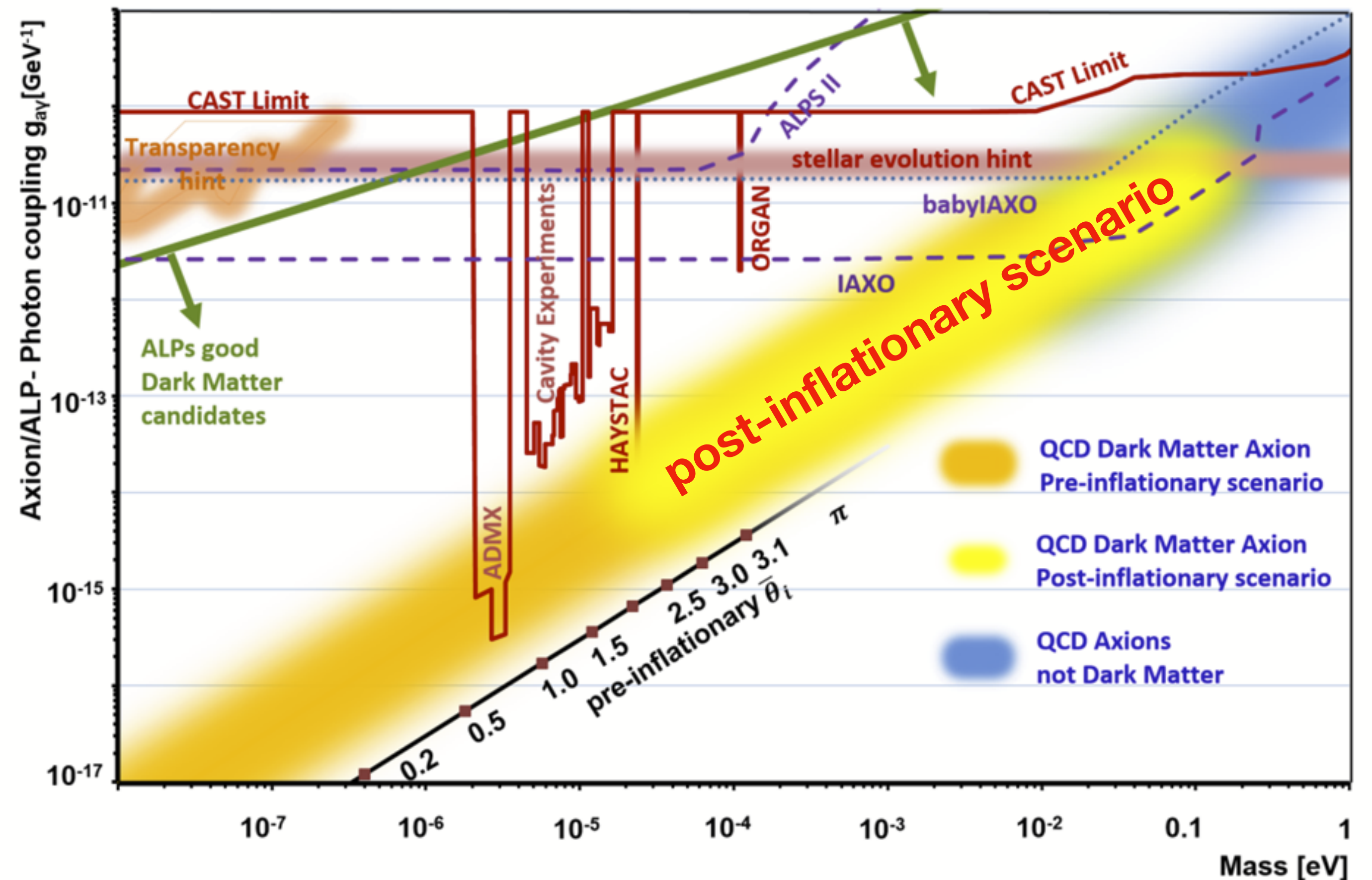
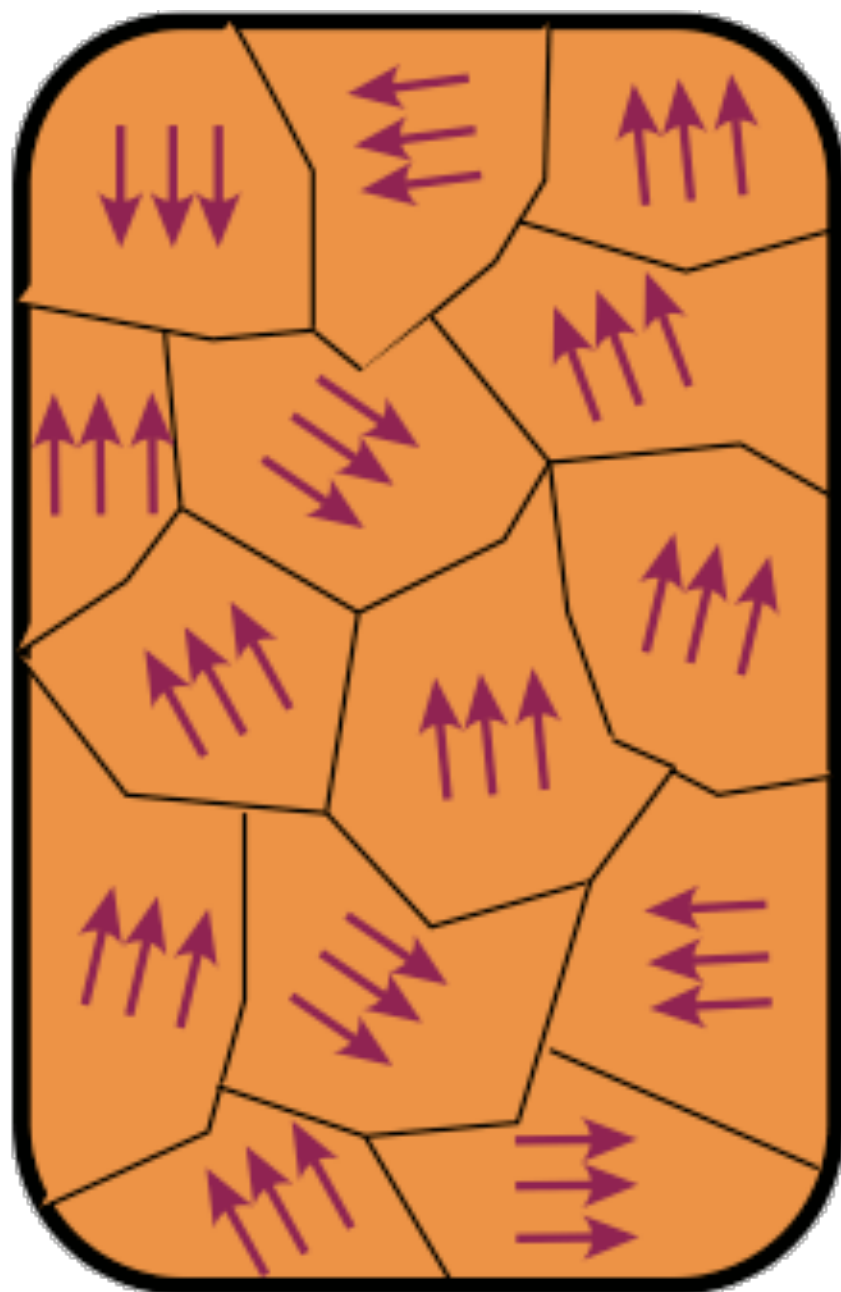
QCD



Axion Search

- Cold dark matter candidate
- Post-inflationary: $m_a \sim 100\mu\text{eV}$

<http://physicsstuff.com/how-do-magnets-work/>



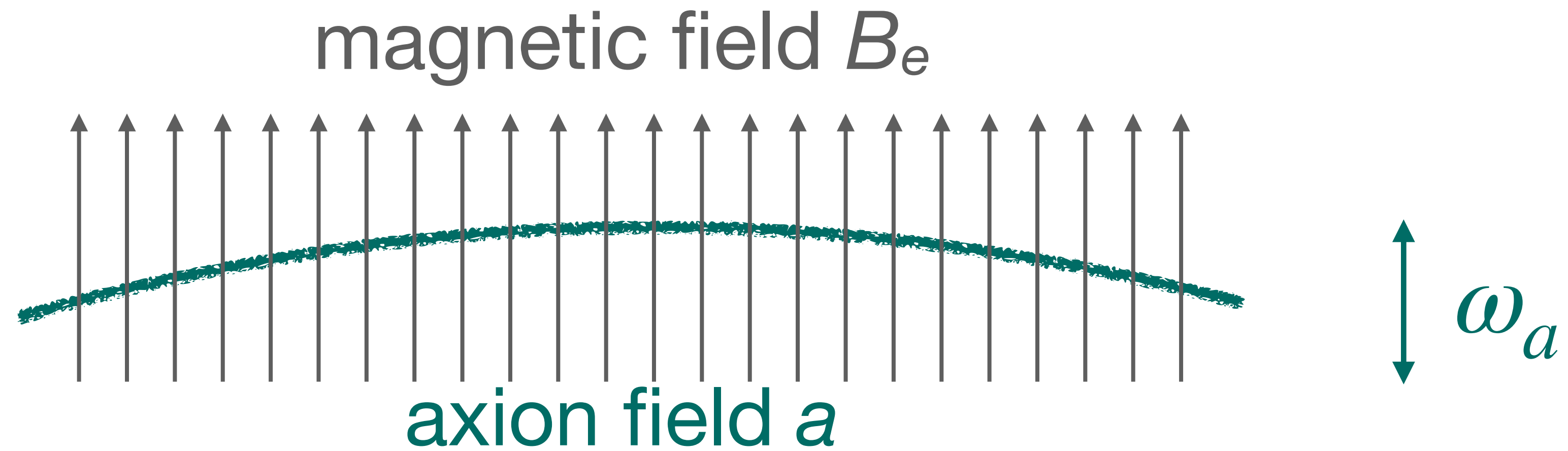
Axion-induced emission

Inverse-Primakoff



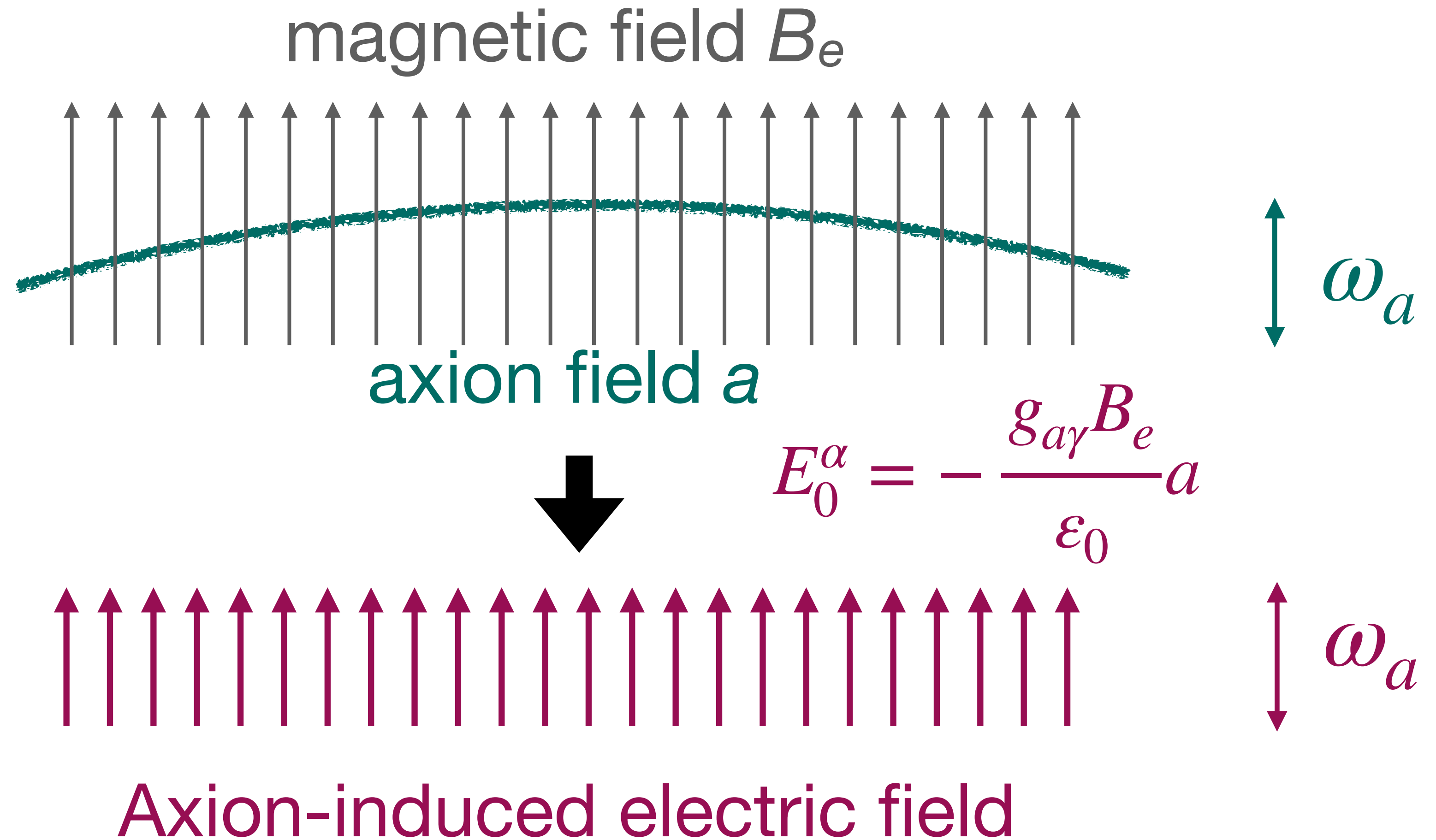
Axion-induced emission

Inverse-Primakoff



Axion-induced emission

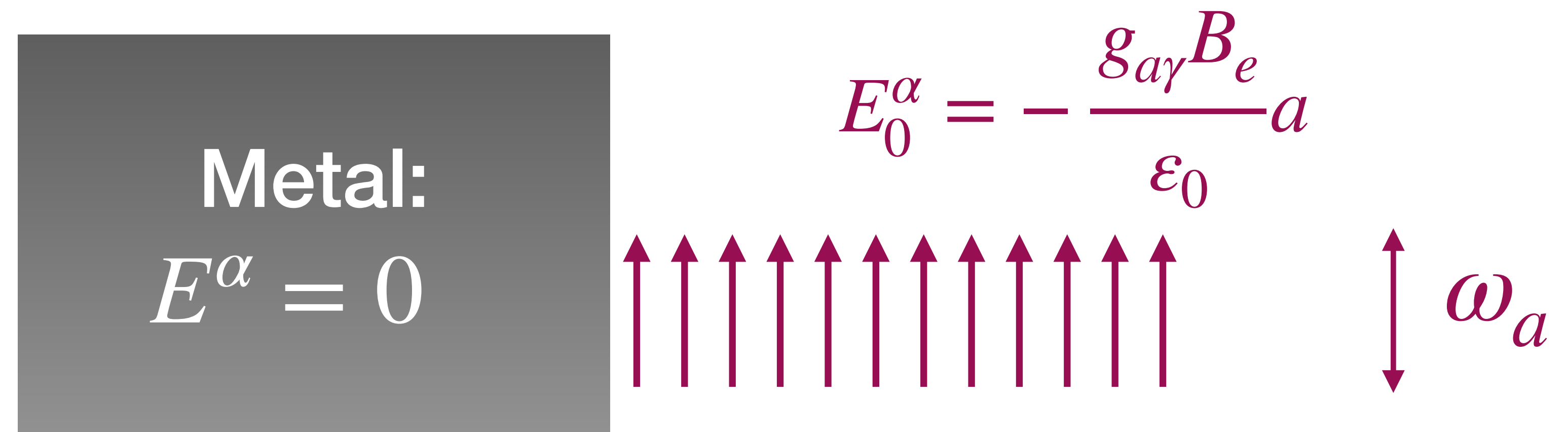
Inverse-Primakoff



Axion-induced emission

E-field discontinuity

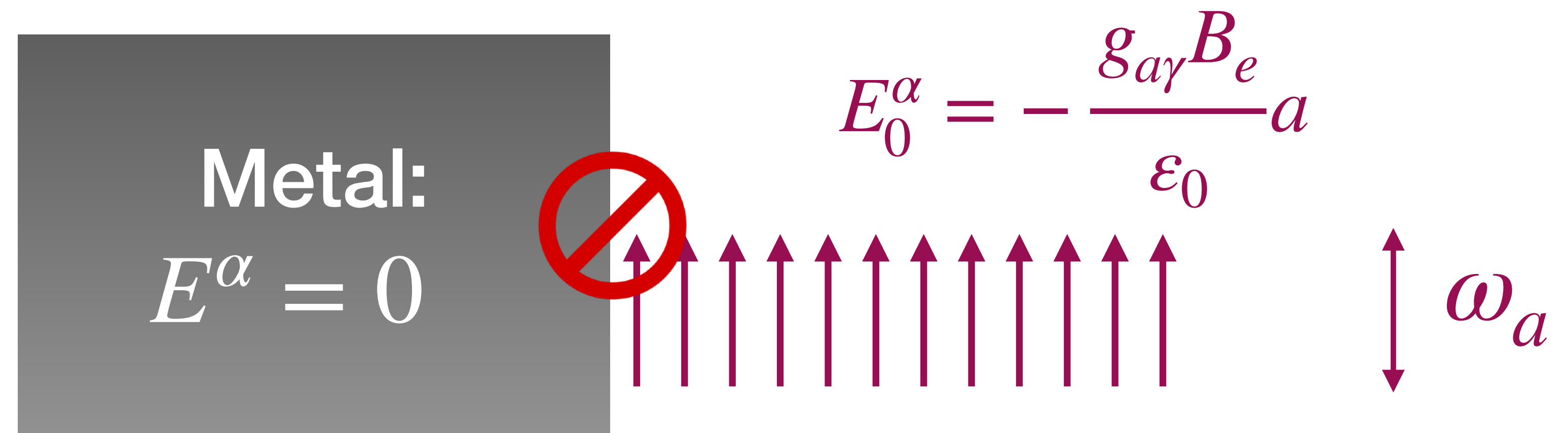
- No E field inside metal



Axion-induced emission

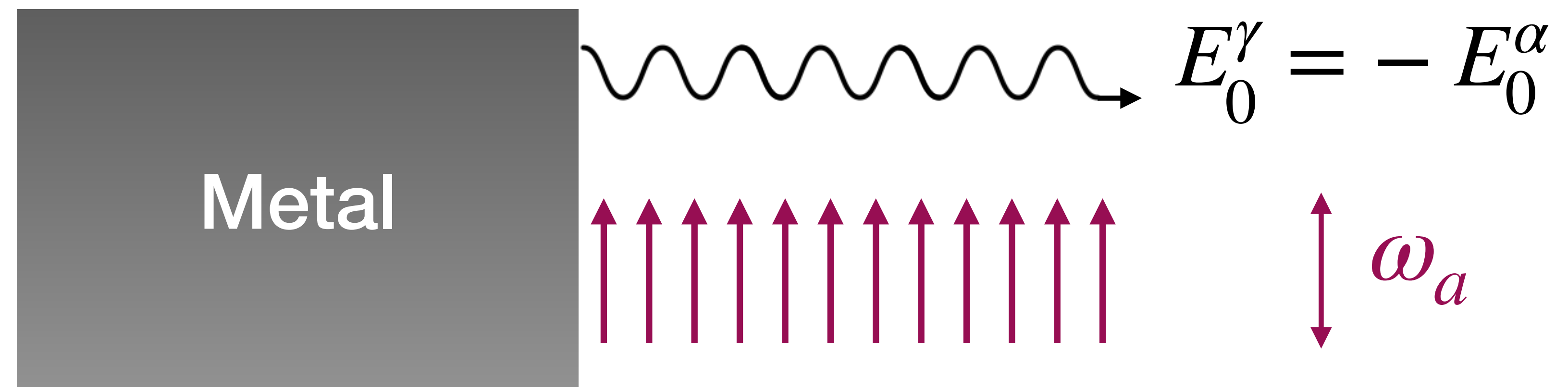
E-field discontinuity

- E-field can not be discontinuous.



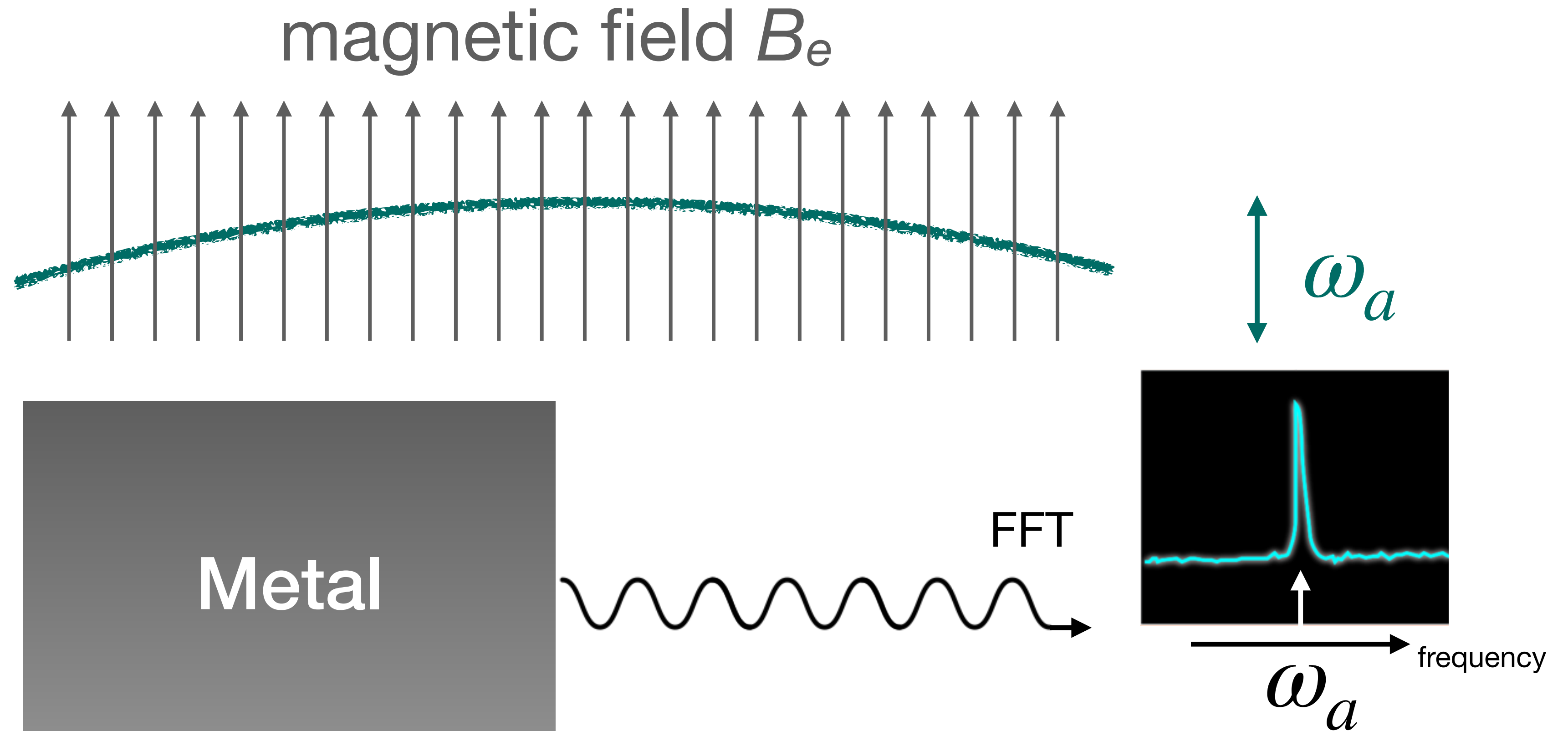
Axion-induced emission

traveling wave



Axion-induced emission

traveling wave



“Dish antenna”, BREAD, and FUNK

Detection?
< 0.5 photons per hour
(25 GHz, 1m², 10T)

Axion-induced emission

“Boost” by dielectrics

- What if we reflect back the radiation?



Axion-induced emission

“Boost” by dielectrics

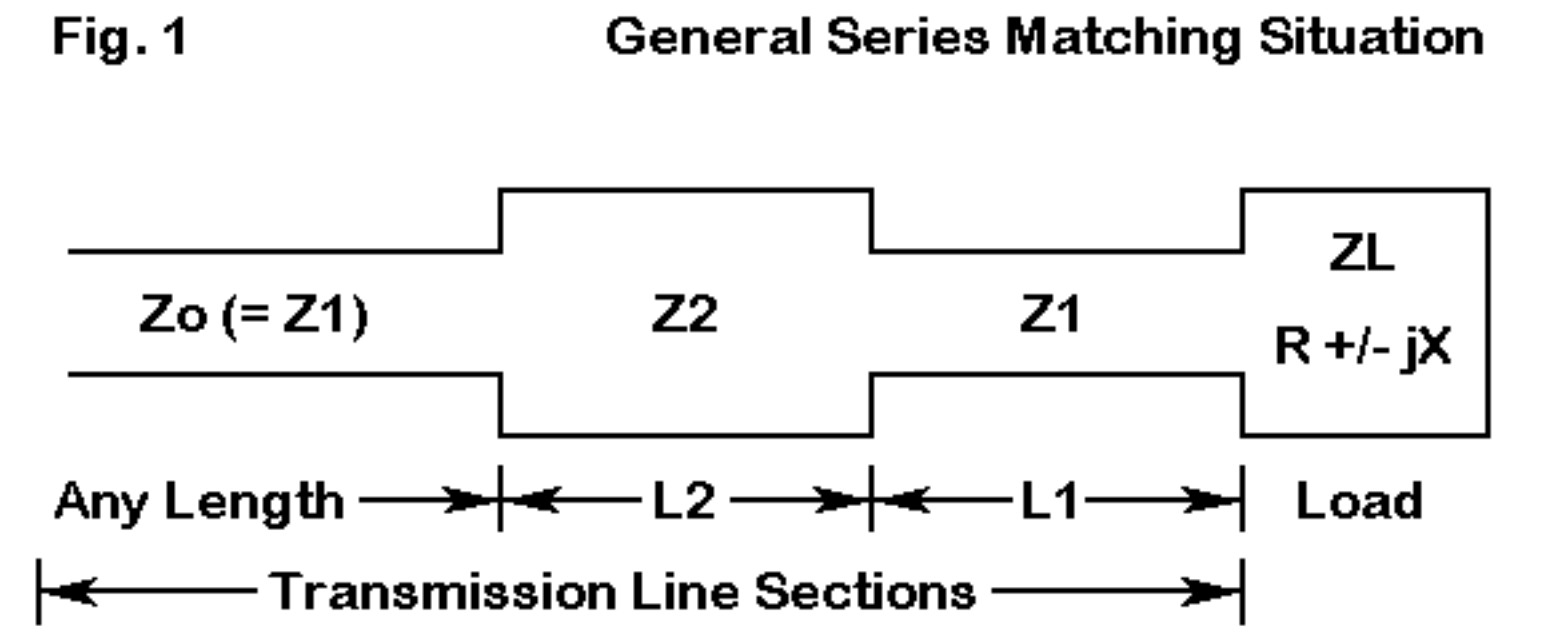
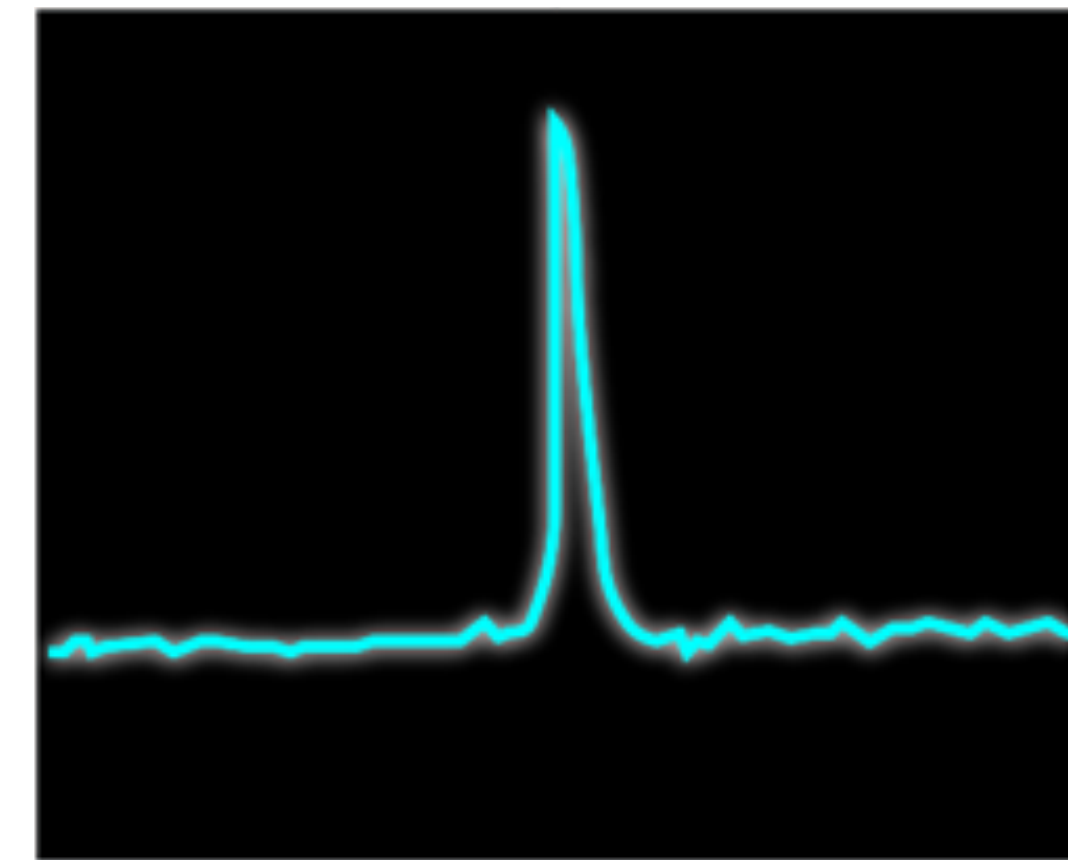
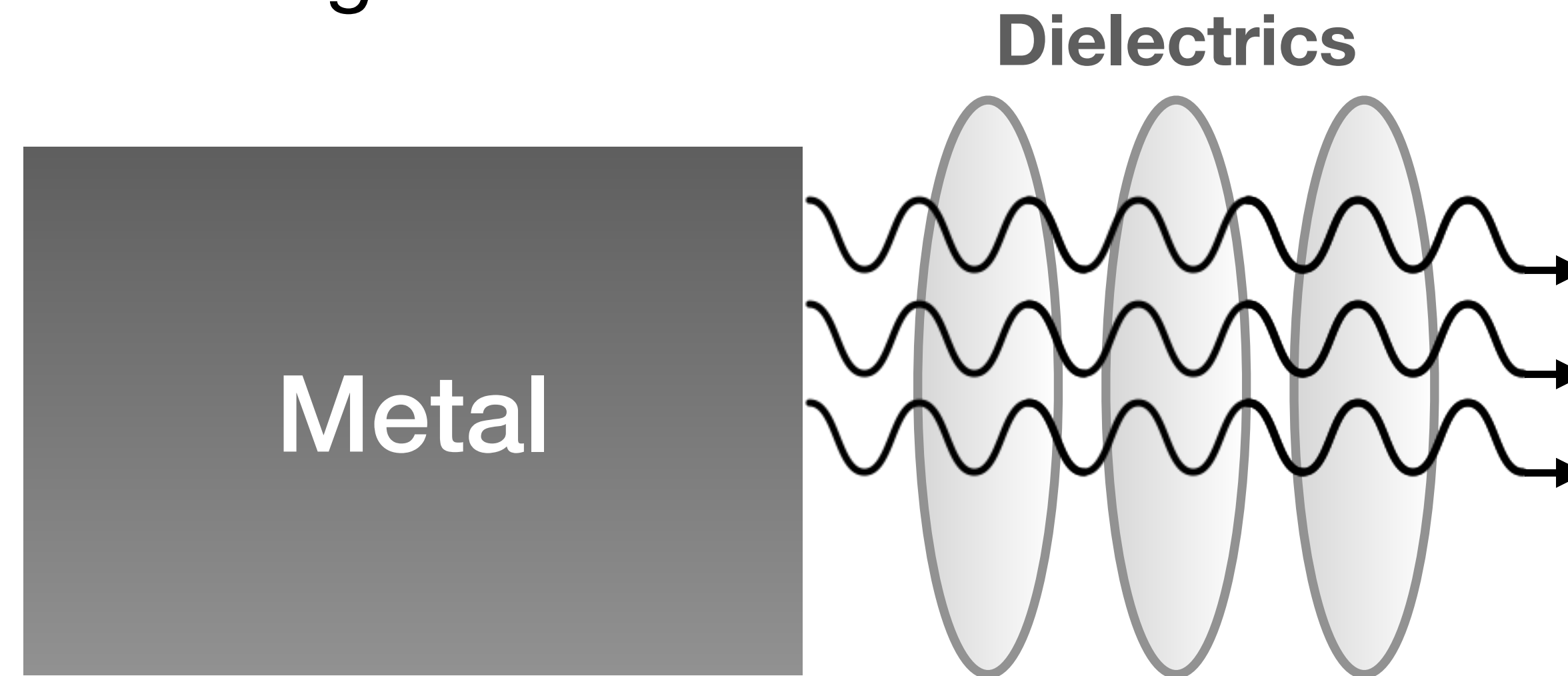
- E^α changes by $\frac{1}{1 + \Gamma}$, so does E^γ .
- $\Gamma \rightarrow -1, E^\alpha \rightarrow \infty$.



Axion-induced emission

“Boost” by dielectrics

- $\Gamma \rightarrow -1$ with more dielectric layers. “Boost” E^γ further.
 - “Series section matching”



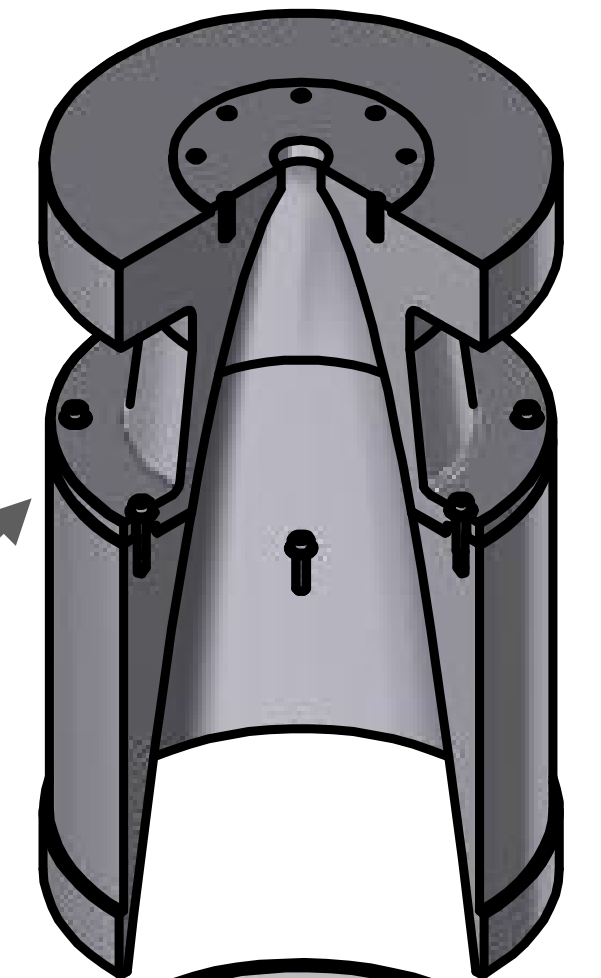
Proof-of-principle




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parabolic taper

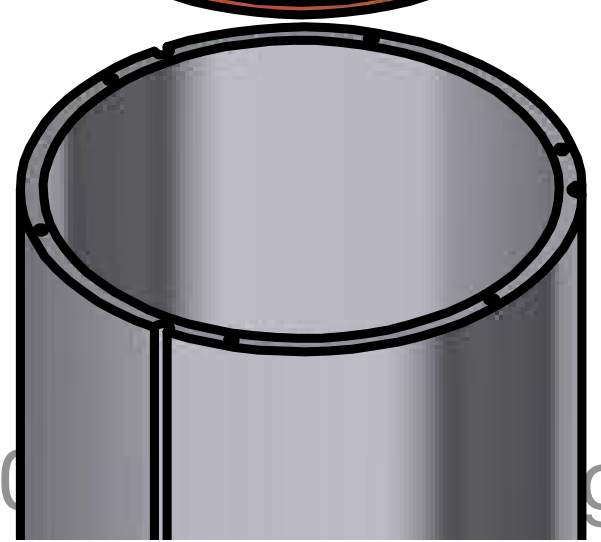
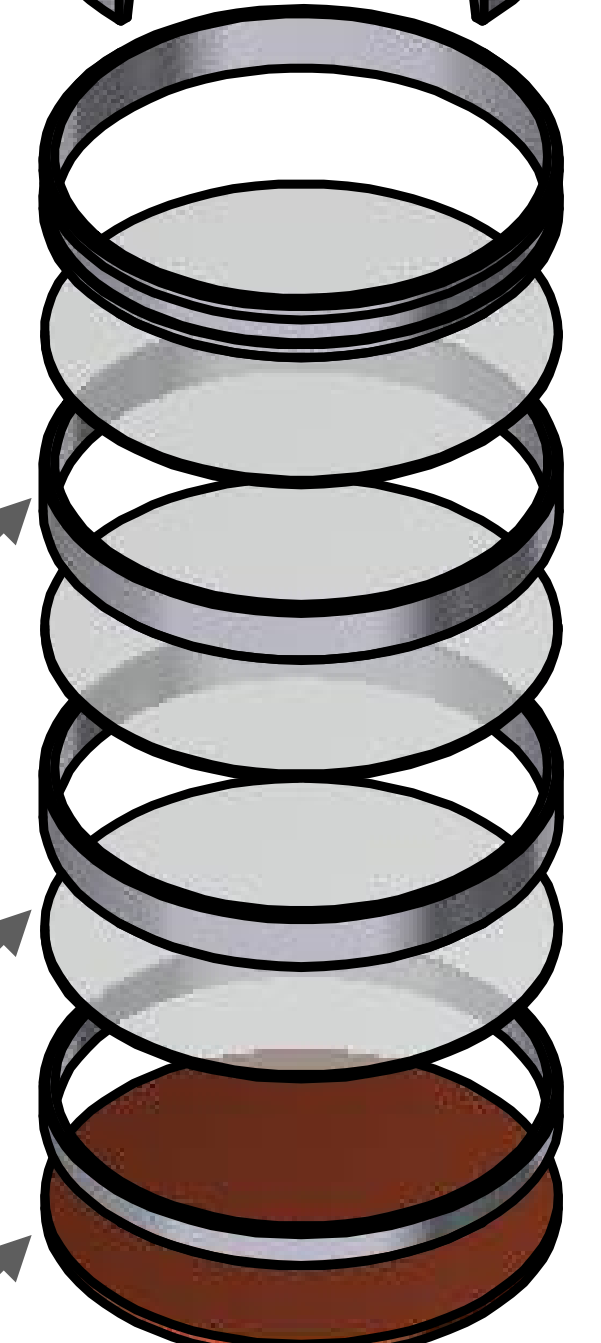
J. Doane, Int. J. Infrared
Milli. Waves 5 (1984)



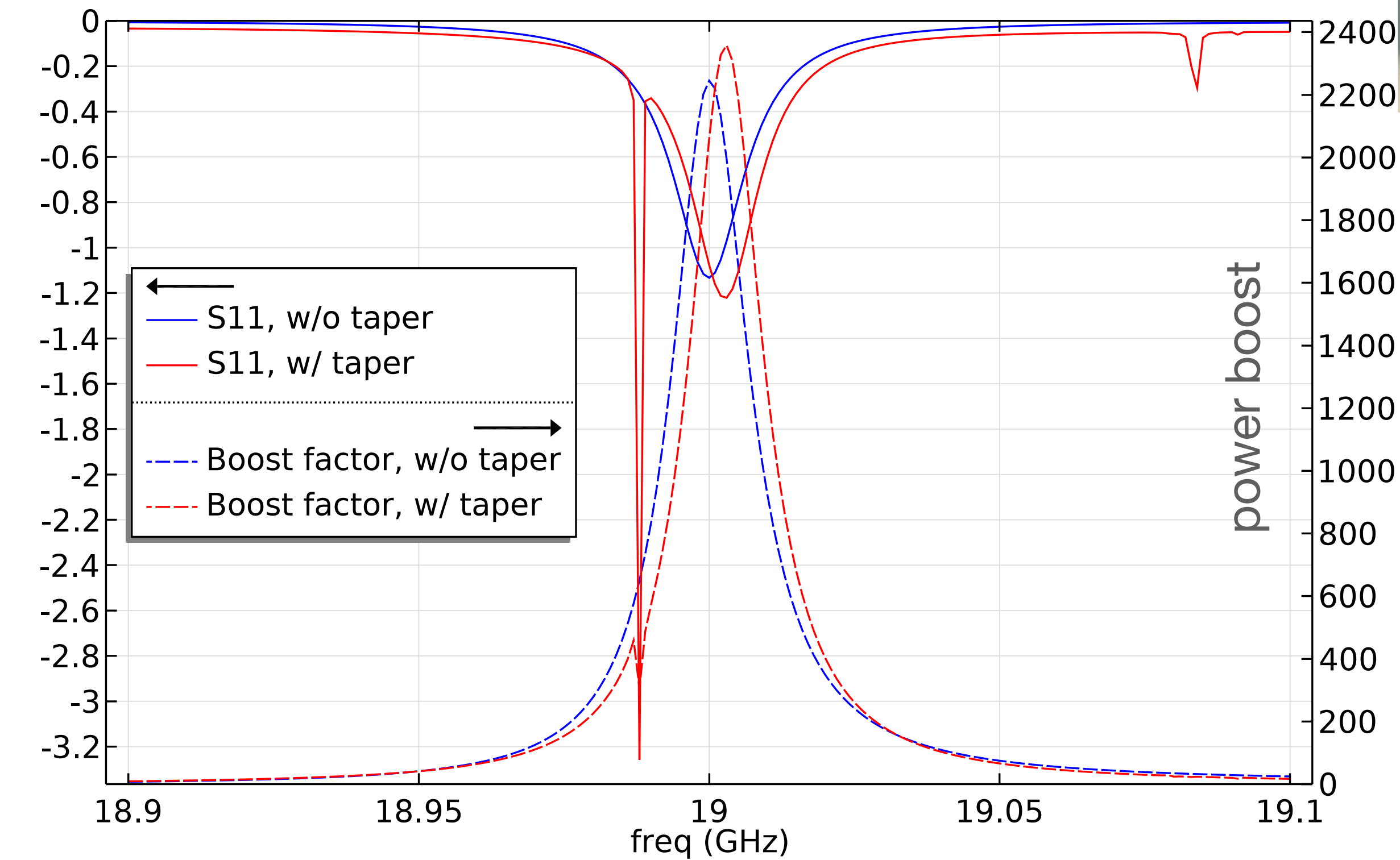
spacing ring

sapphire

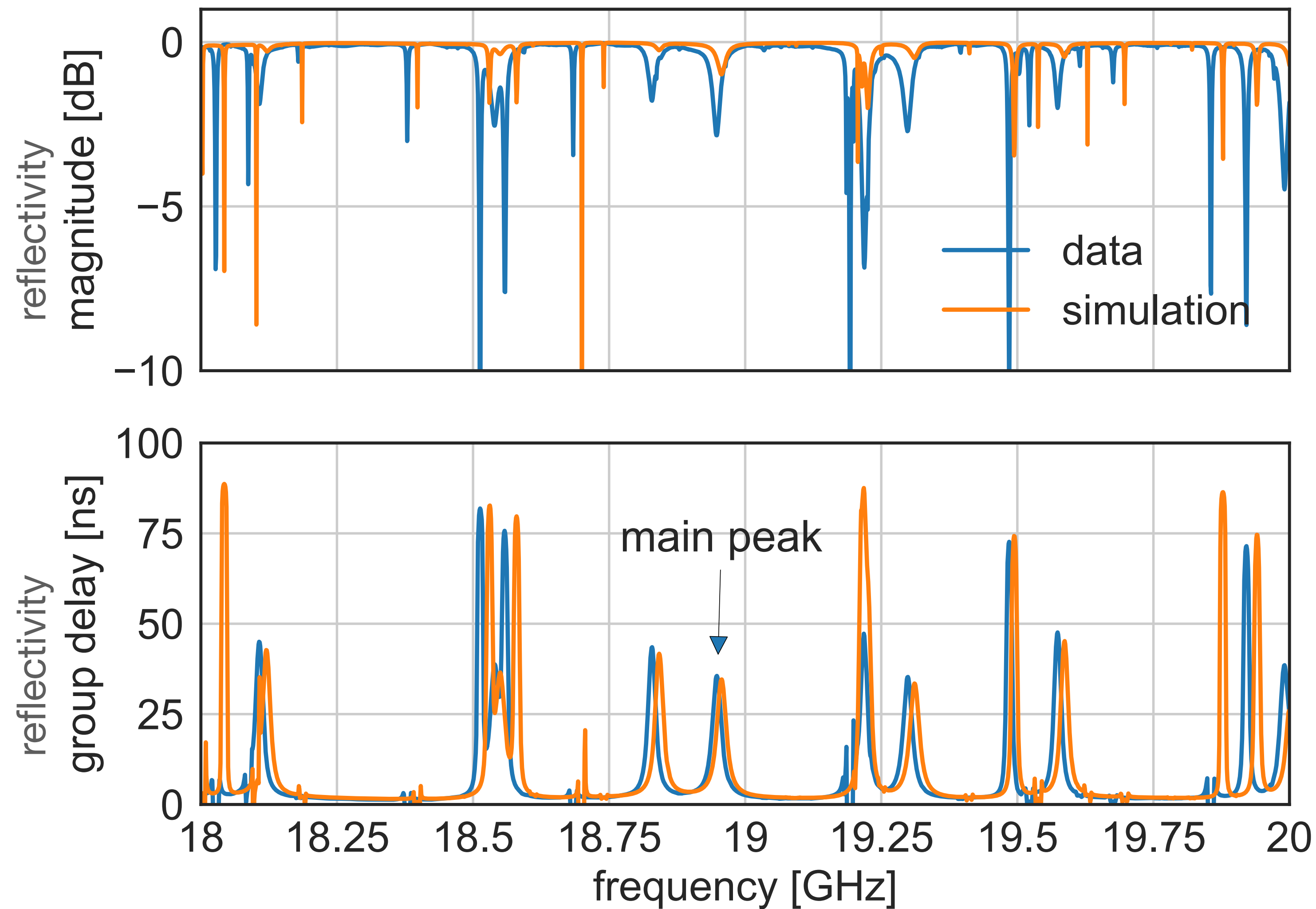
copper mirror



reflectivity magnitude [dB]



Room temp reflectivity



Cryogenic measurement ongoing:
hidden photon search

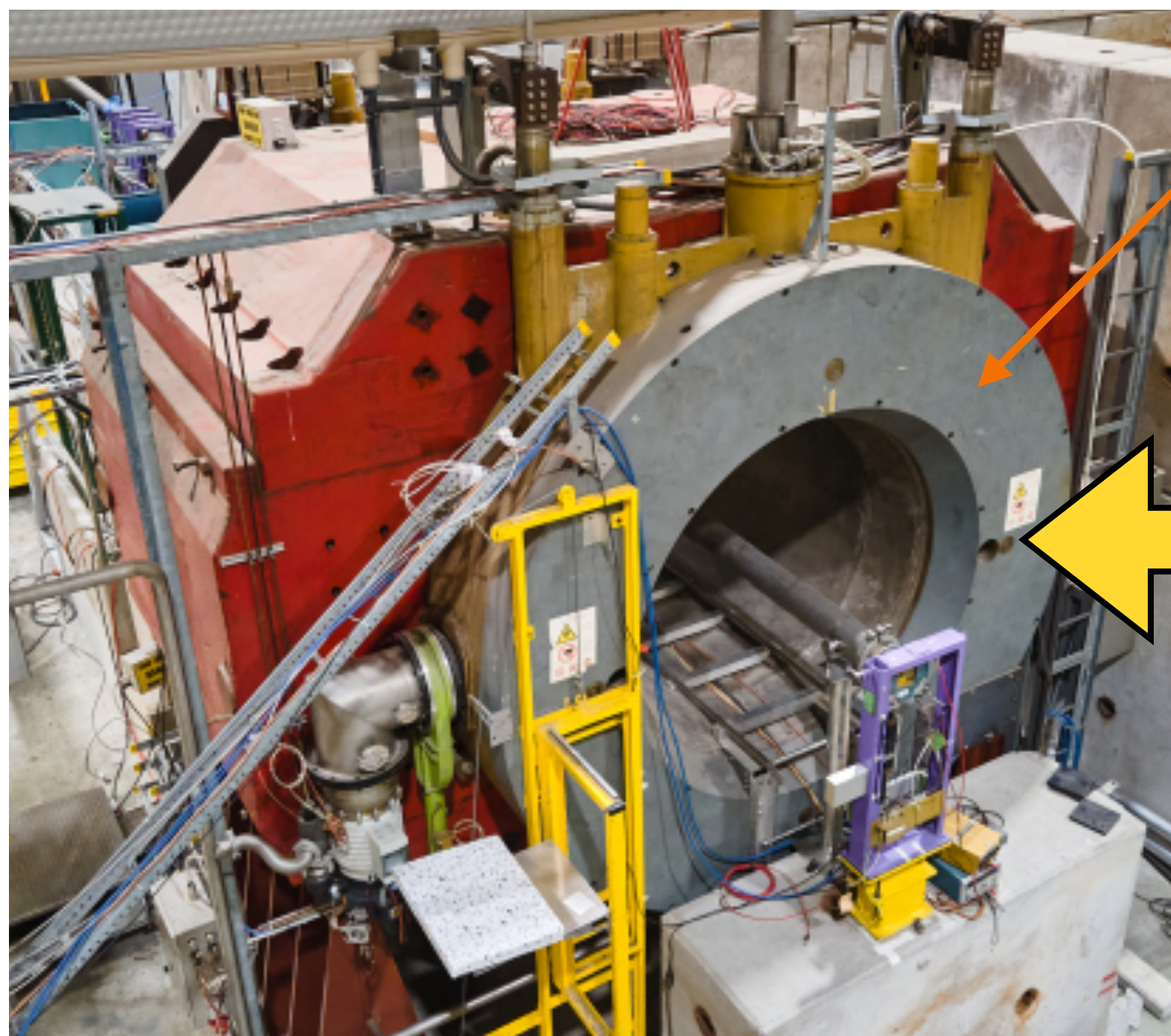


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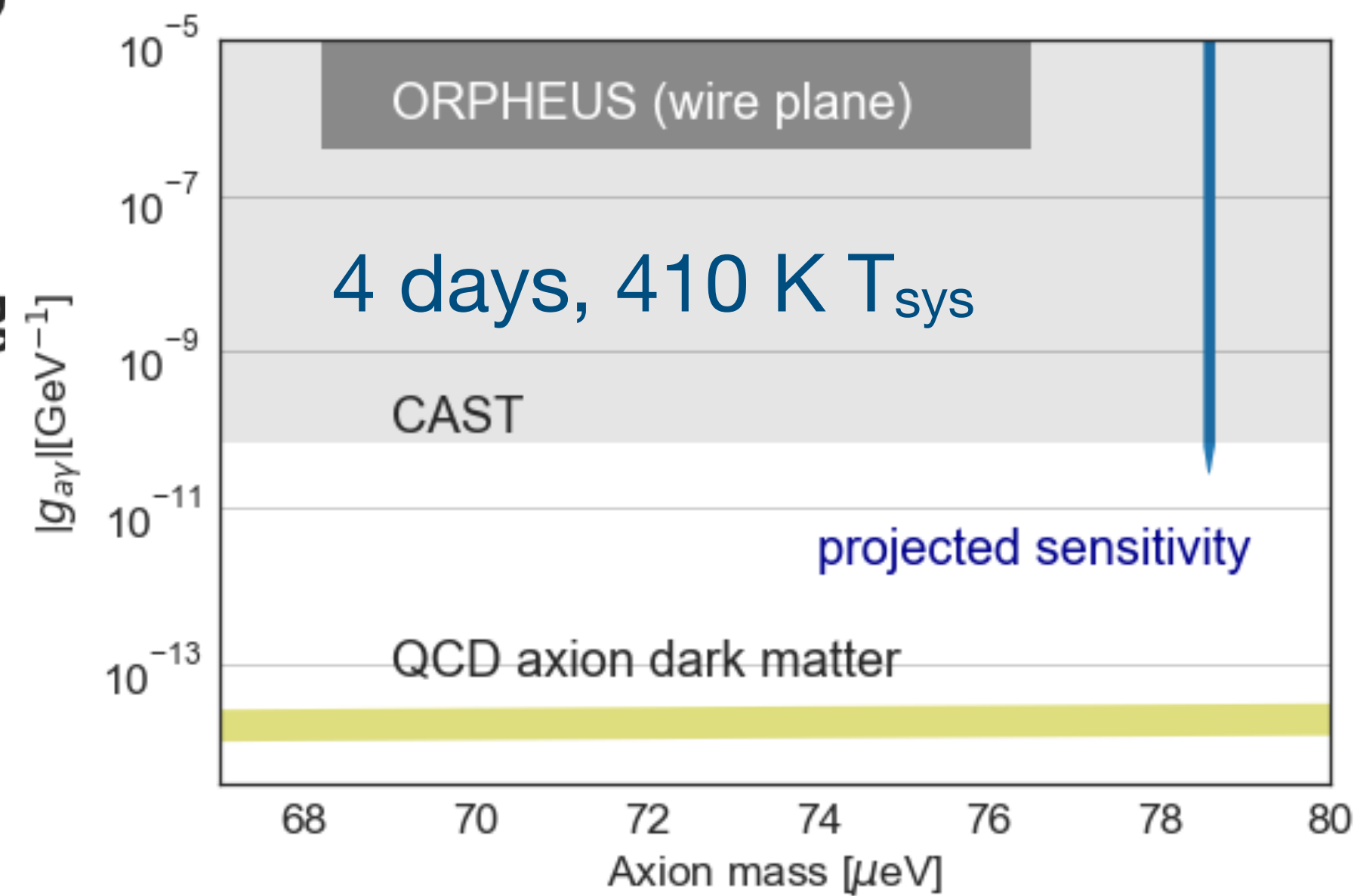
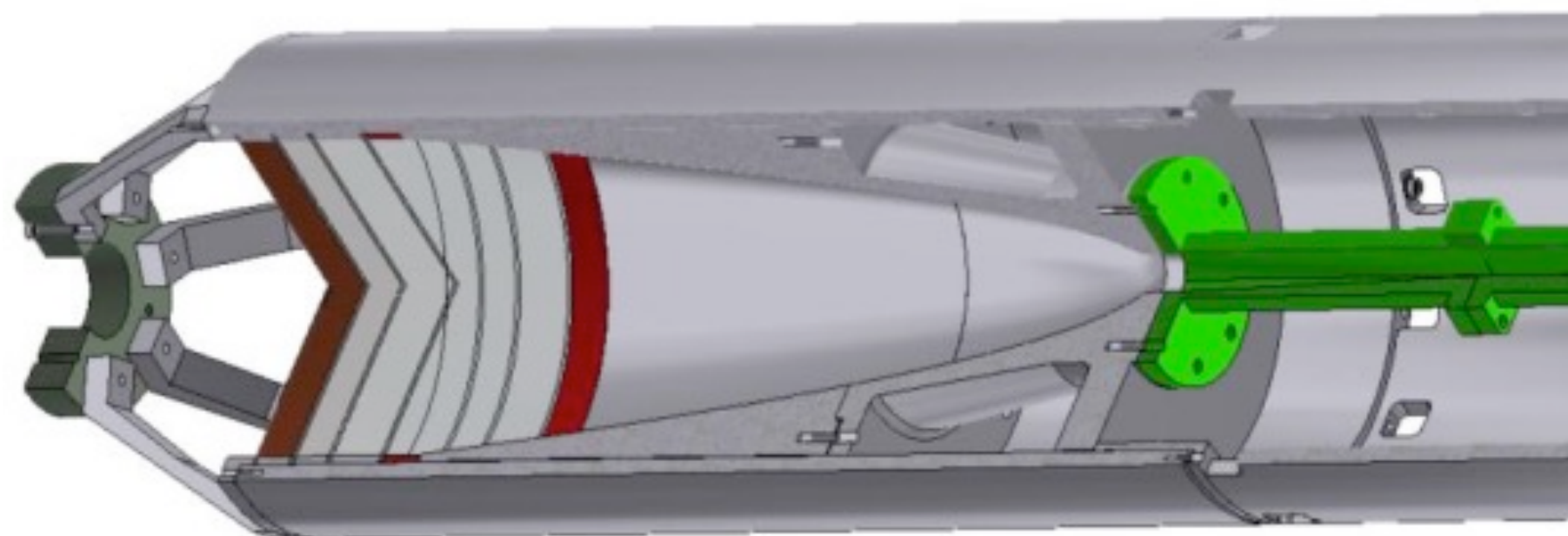
MADMAX and CERN's Morpurgo magnet

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

10 NOVEMBER, 2020 | By [Thomas Hortala](#)



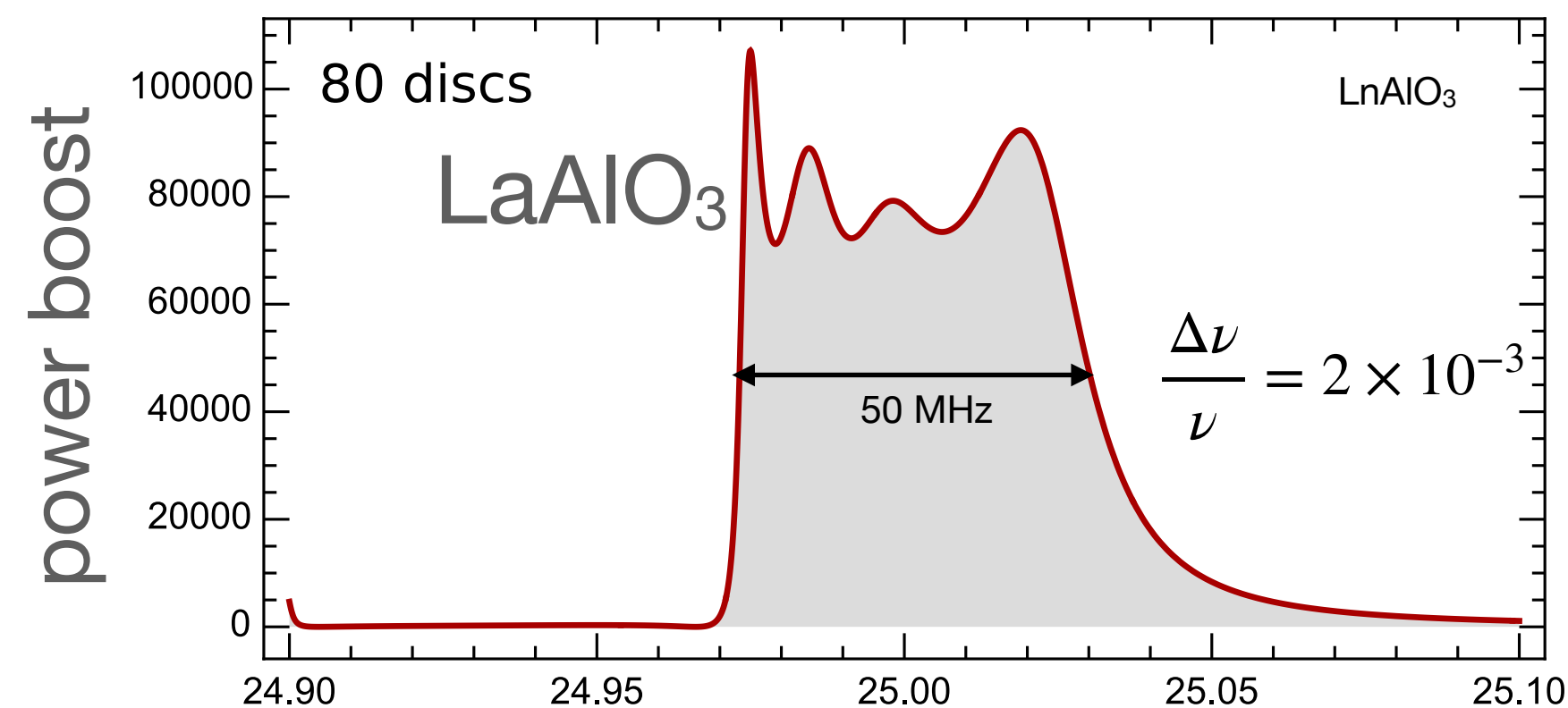
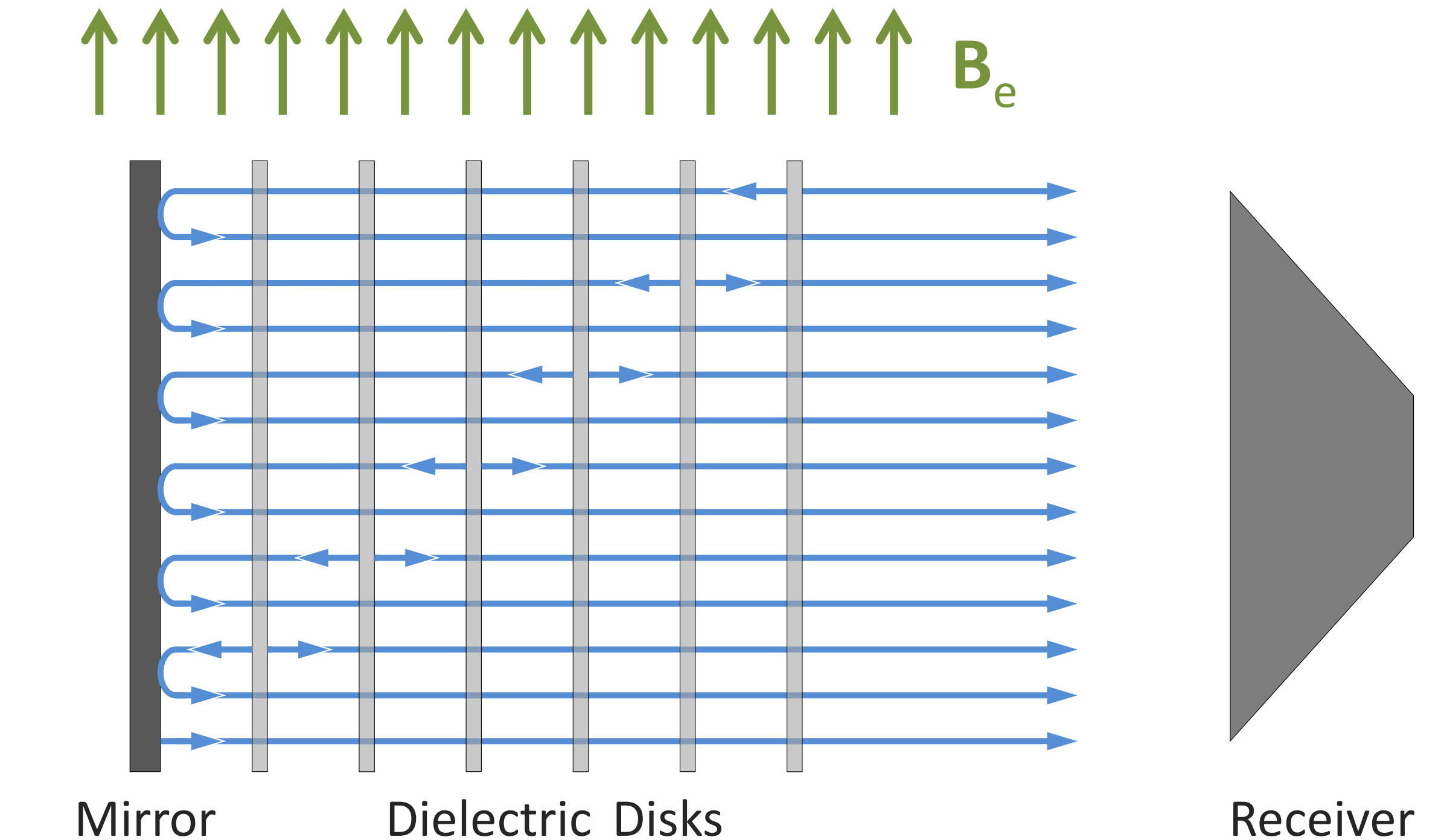
Morpurgo magnet:
1.6 T dipole



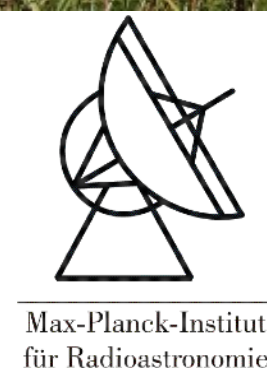
- 100mm system in Mar 2022 during the SPSS shutdown.

Scale-up Toward the QCD axion search

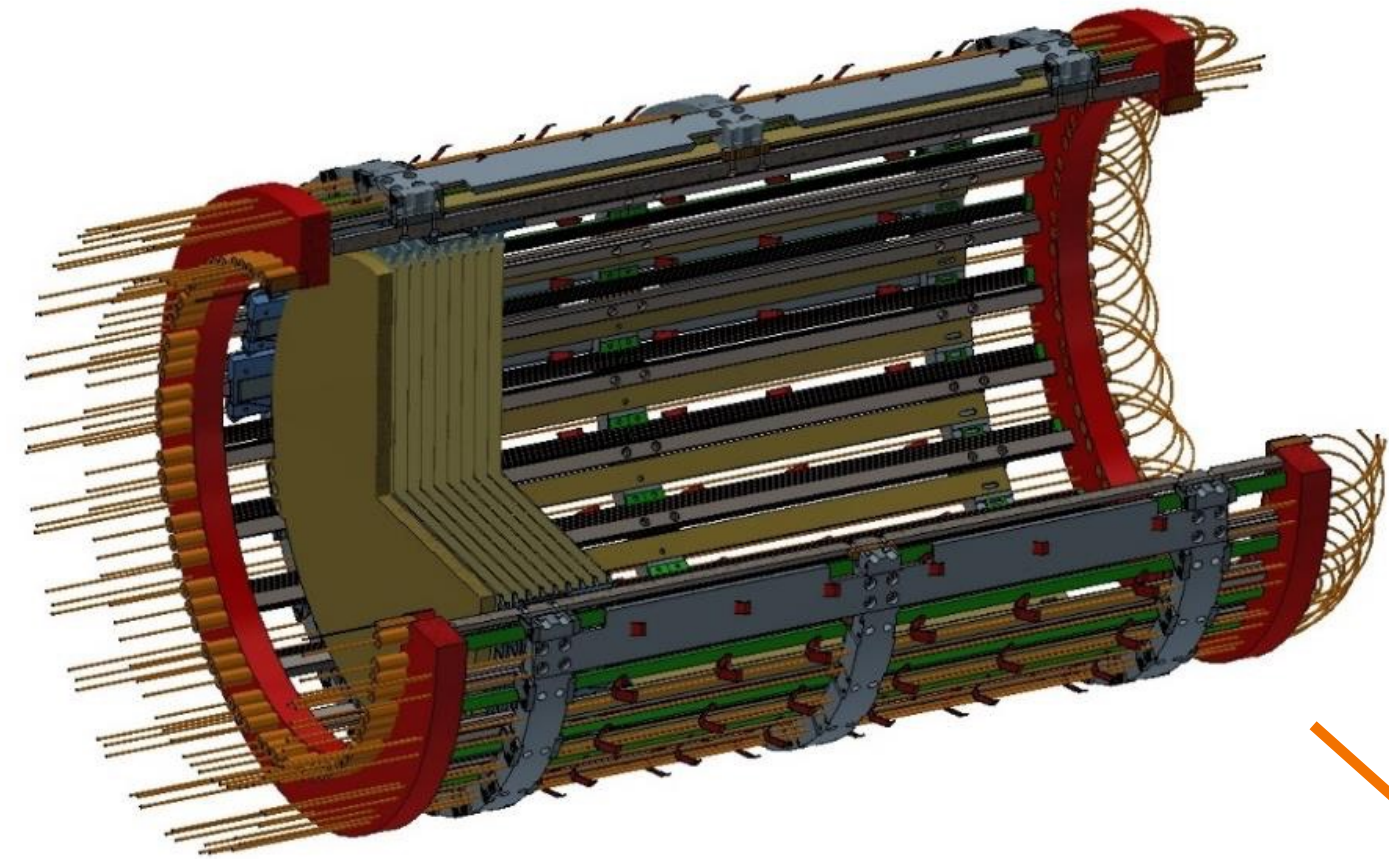
- Larger system
- Power from dielectric boundaries constructively interference.
 - Tuning by moving disks
- Larger magnet
- Cryogenic system & low-noise receiver



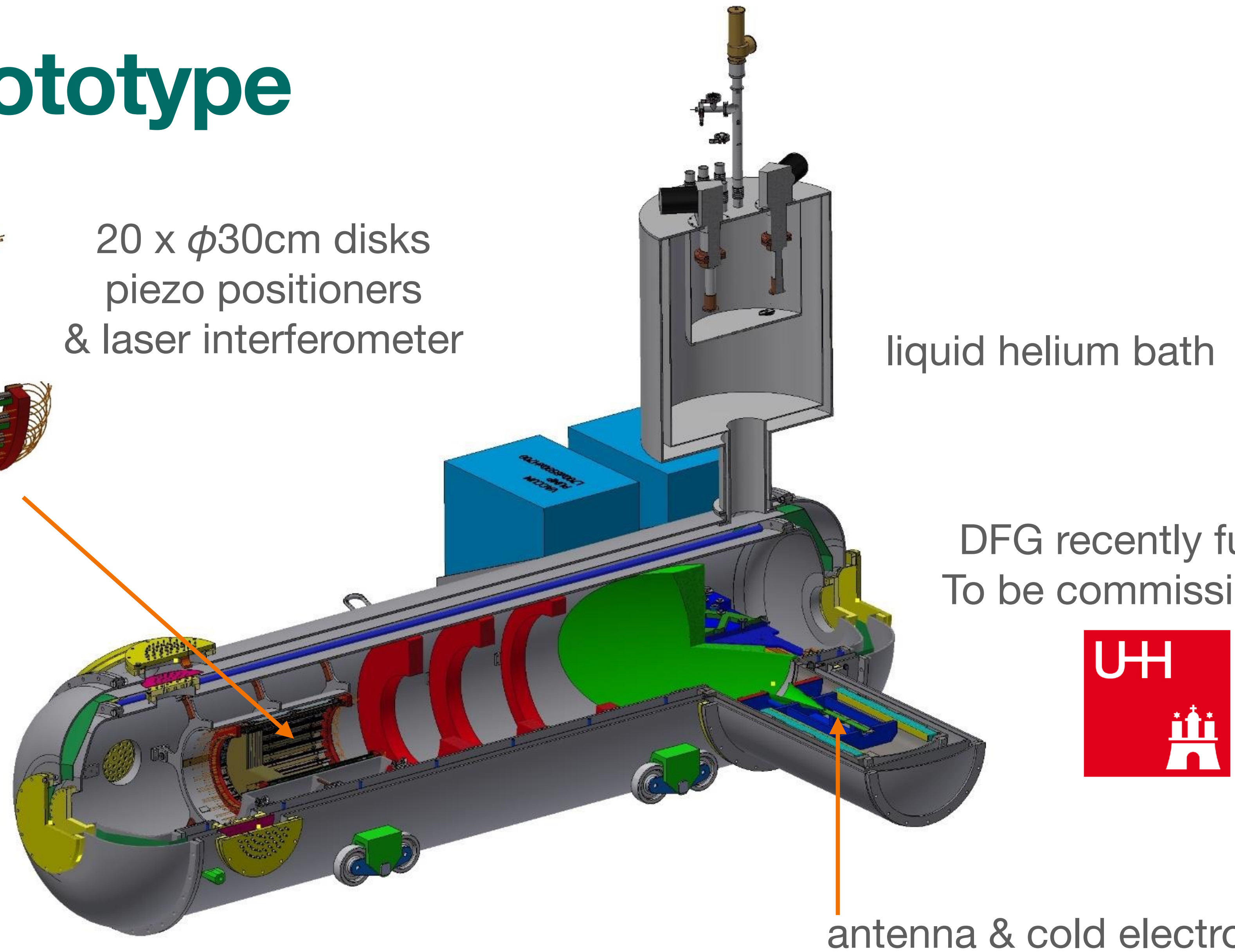
MADMAX collaboration



MADMAX prototype



20 x $\phi 30\text{cm}$ disks
piezo positioners
& laser interferometer



liquid helium bath

DFG recently funded!
To be commissioned in

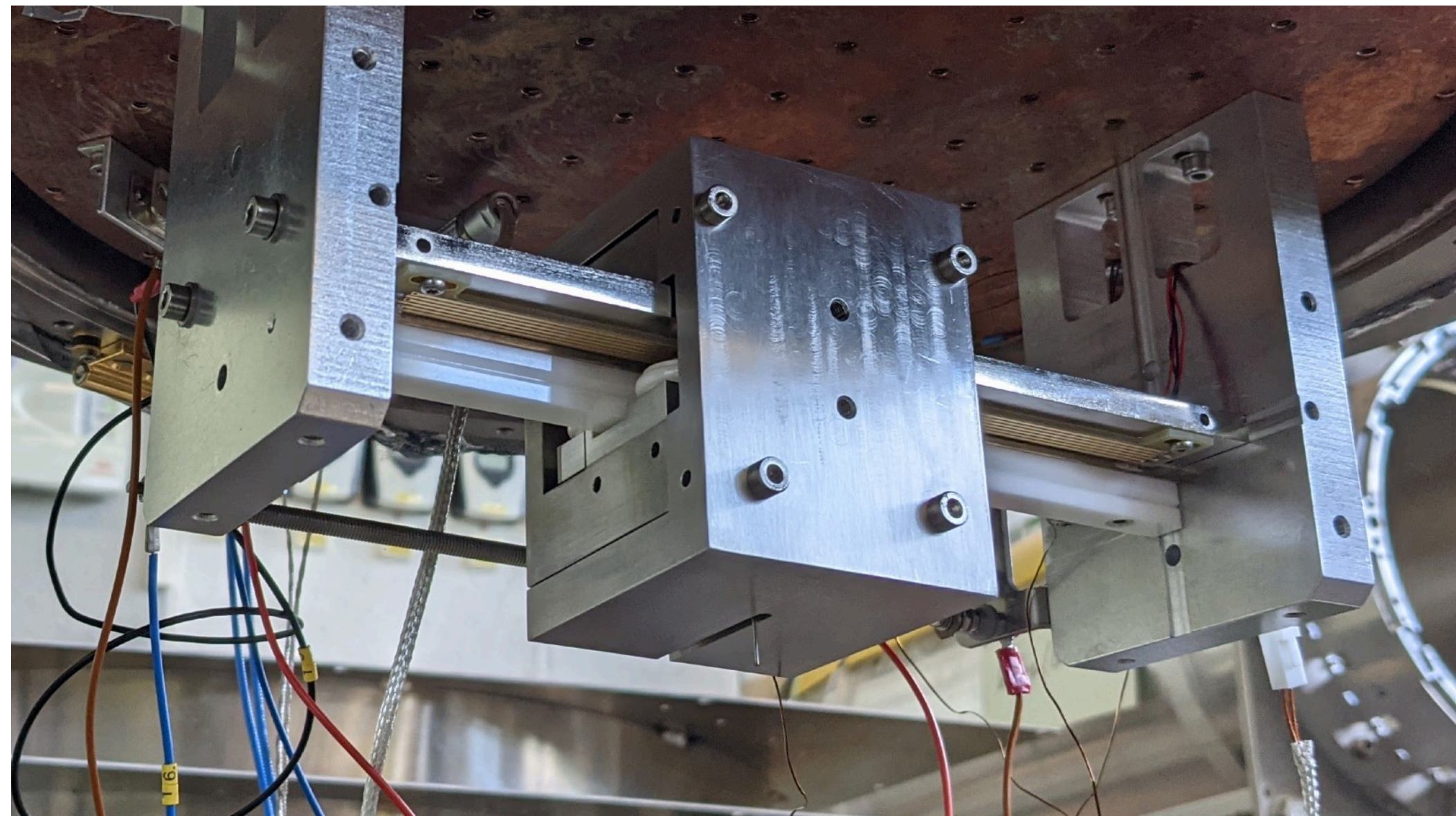


antenna & cold electronics

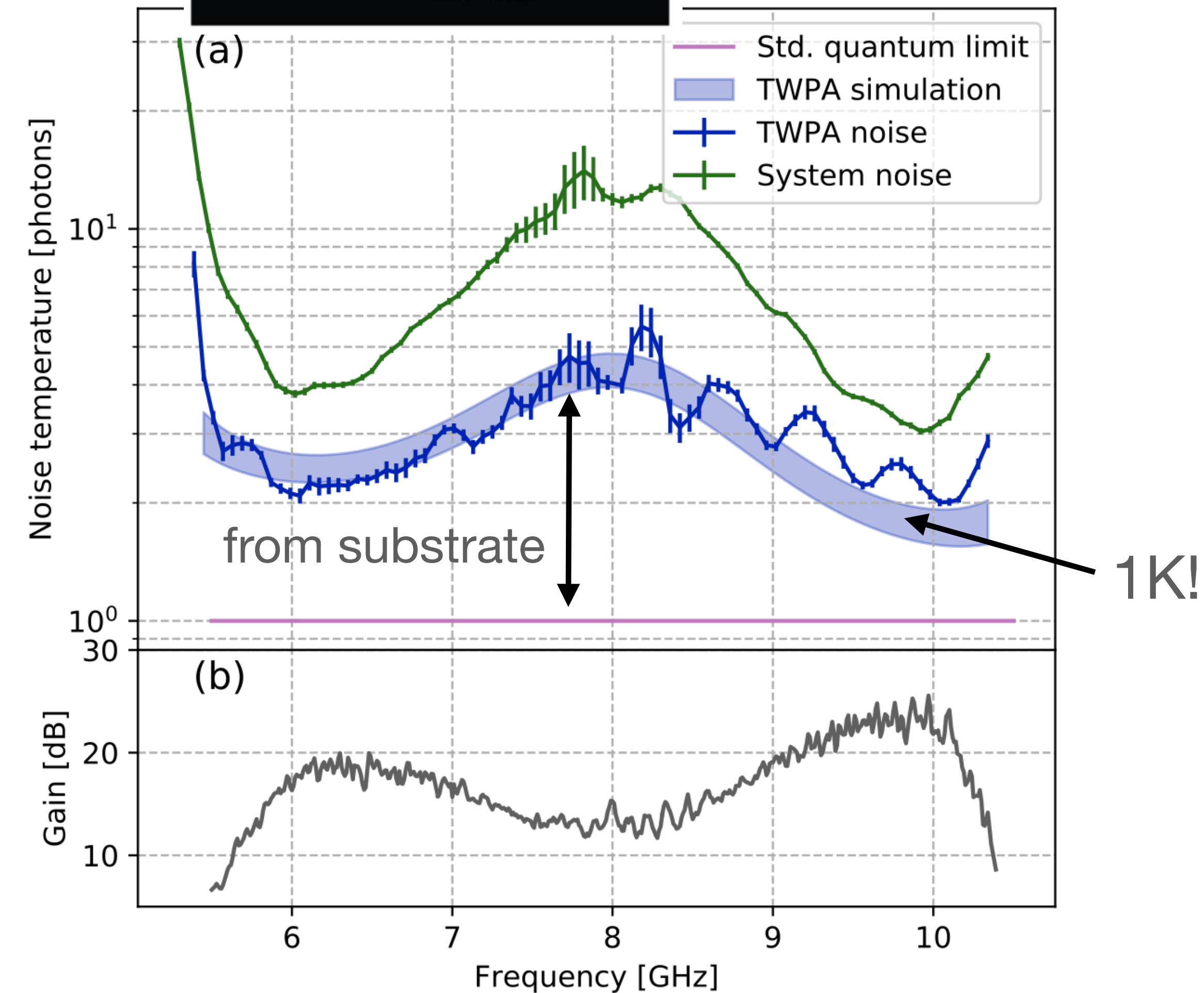
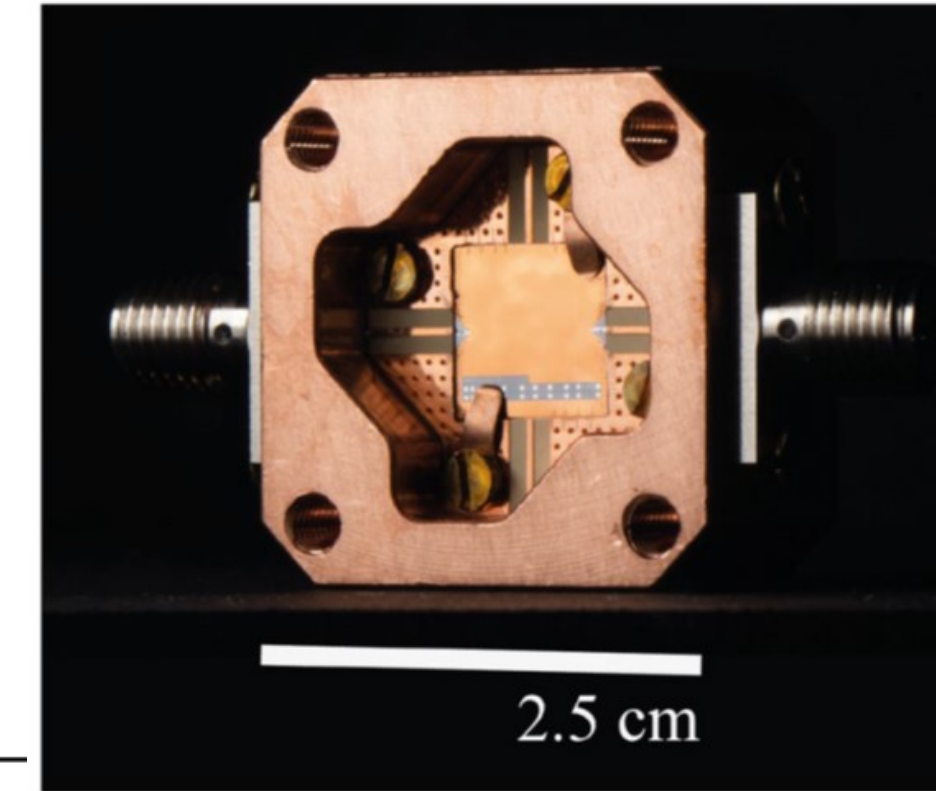


test in MORPURGO during SPSS shutdown 2024

Prototype activities



- Piezo positioner tested @ 4K
- Test @ 5T to follow
- Quantum amplifier with 1K noise temp



Reversed Kerr TWPA arXiv:2101.05815

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Full MADMAX

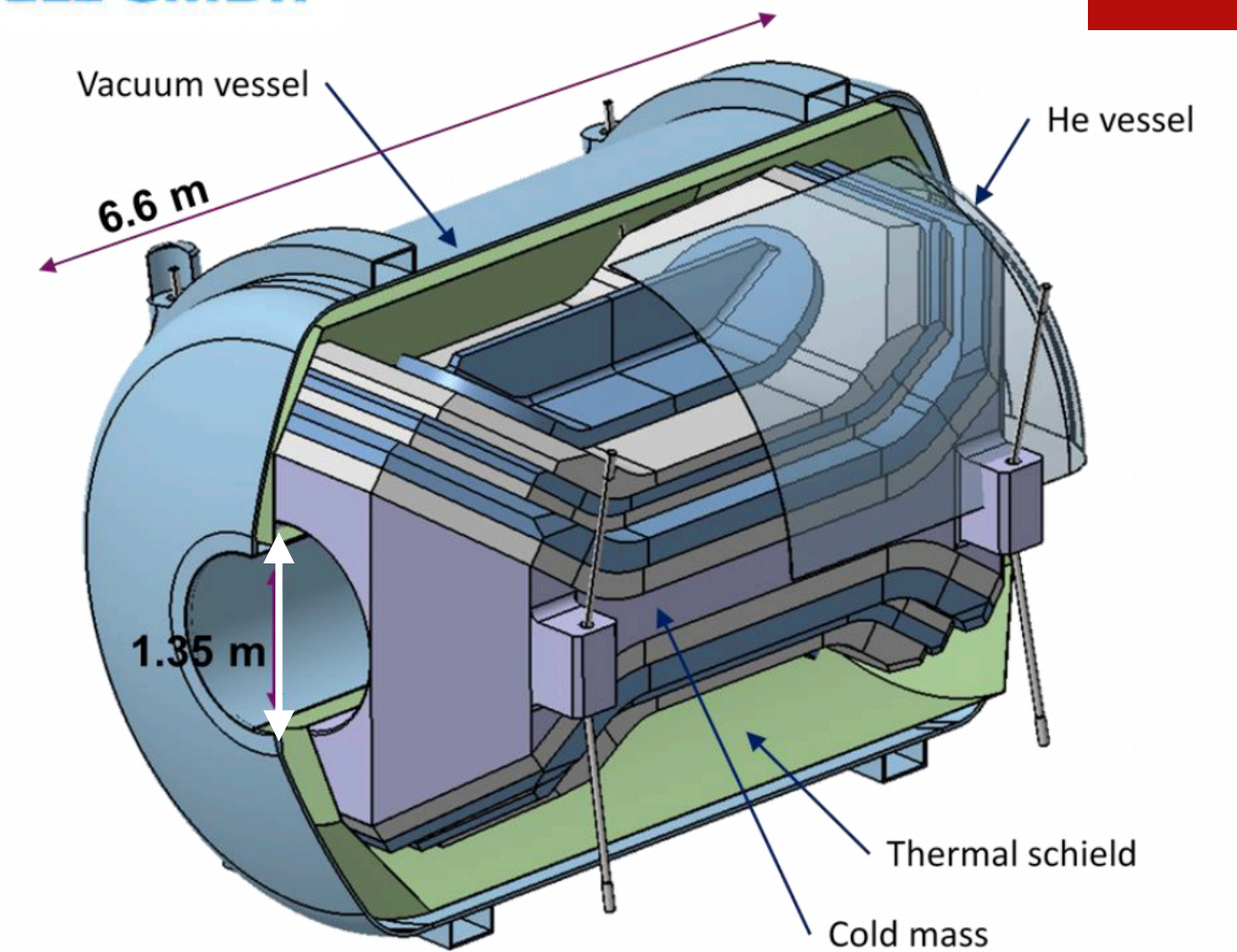


**BILFINGER
NOELL GMBH**

Conductor quench test
successful!



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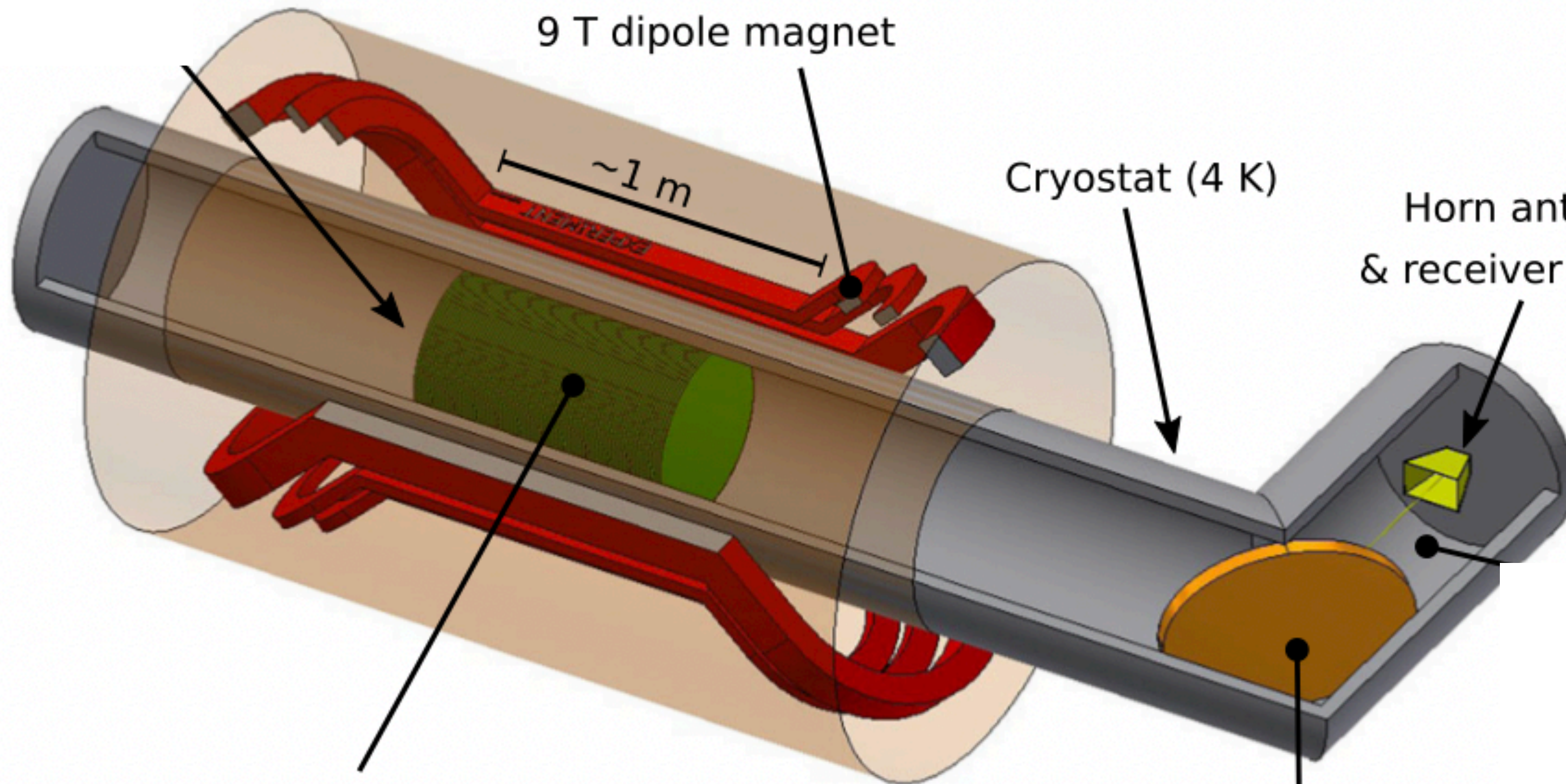
Mirror (not visible)

9 T dipole magnet

~1 m

Cryostat (4 K)

Horn antenn
& receiver syst

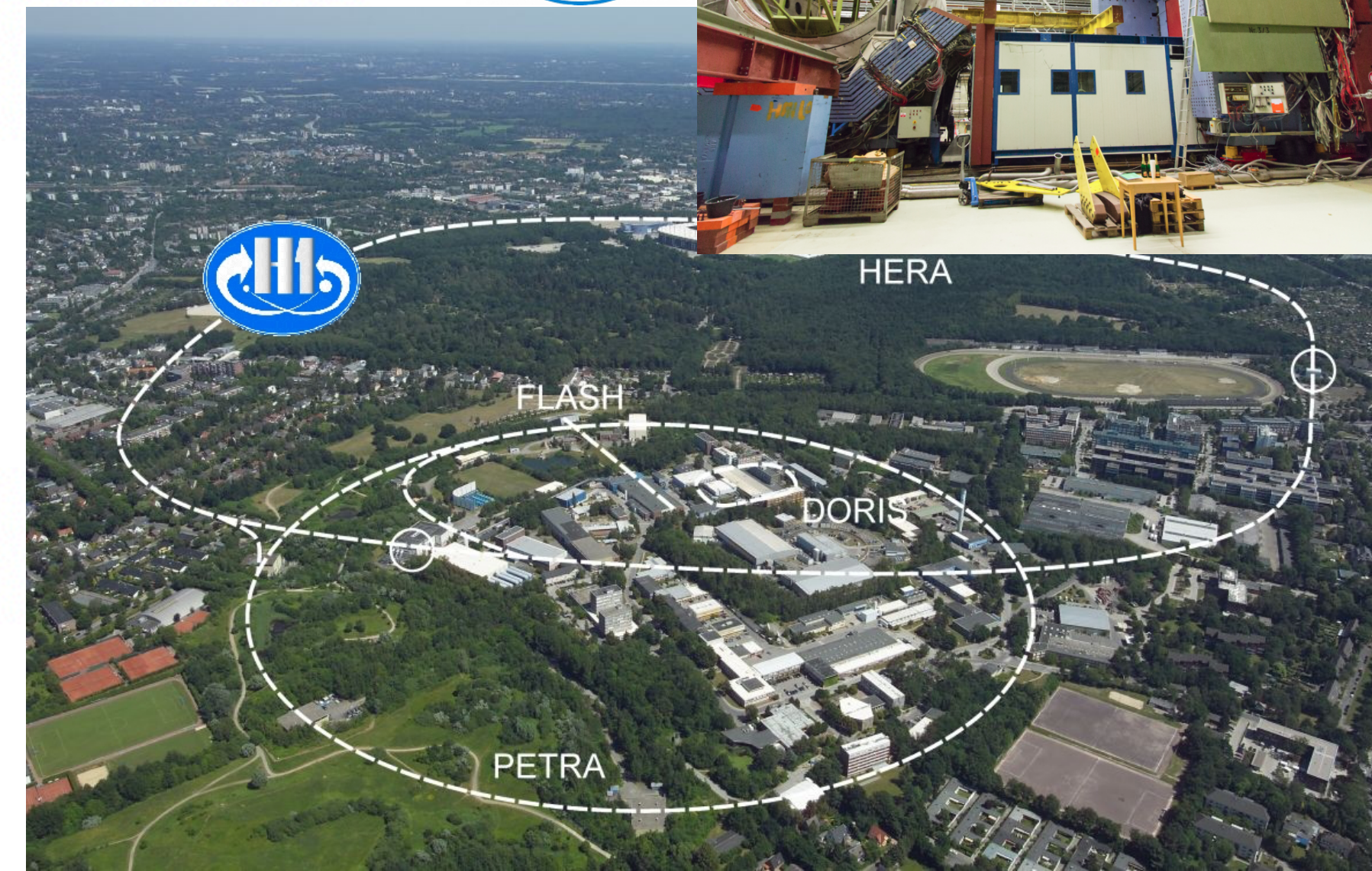


Booster: 80 adjustable dielectric disks (Ø1.25 m)

Focusing mirror



HERA

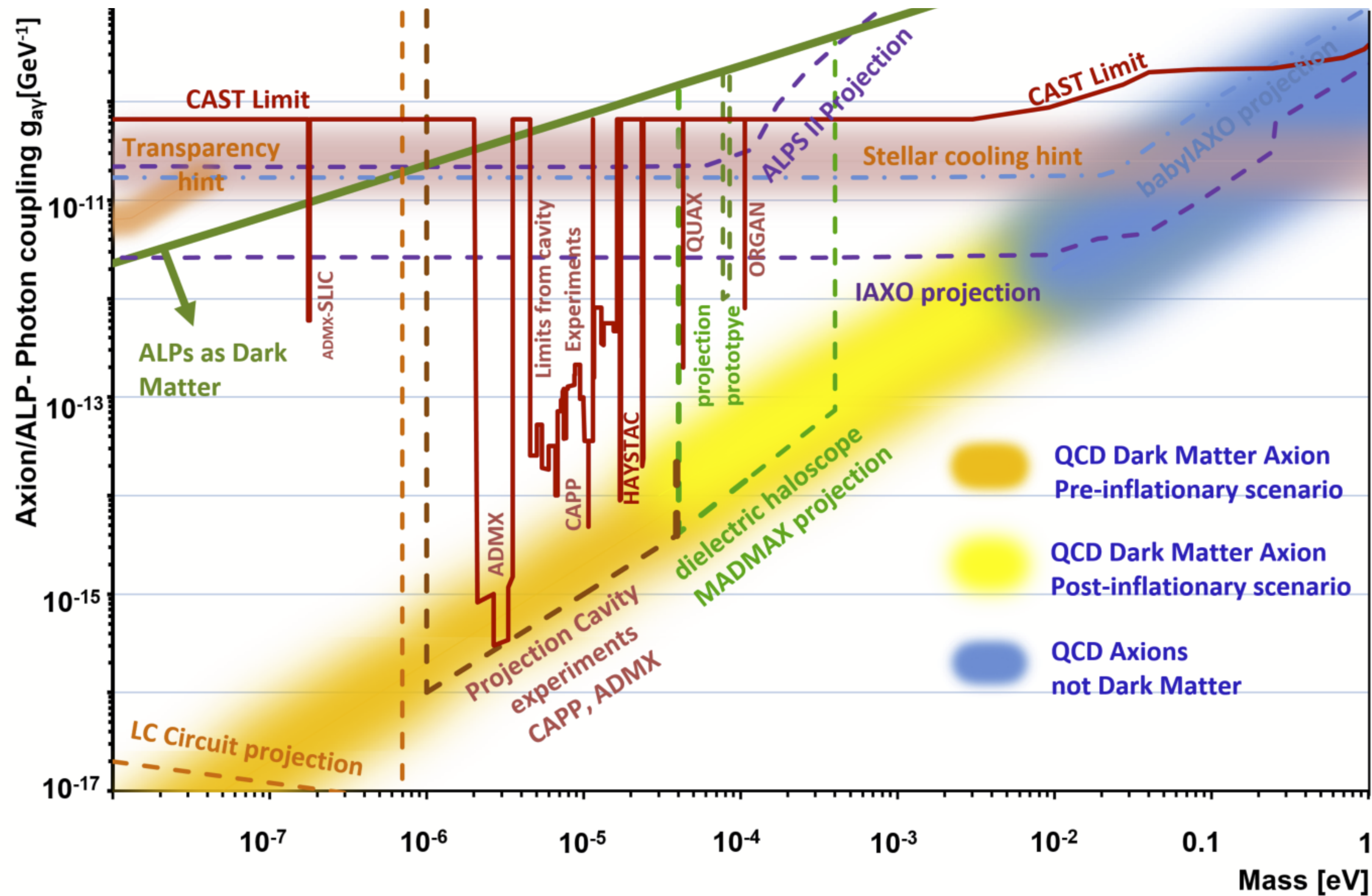


FLASH

DORIS

PETRA

Future projection



Summary

- Axion is a solution for Strong CP problem and dark matter.
- MADMAX: post-inflationary QCD axion search using dielectric haloscope.
- A proof-of-principle setup is ready for data taking this winter
- Prototype: UHH @ 2022/23.
- Both tested in CERN magnet: first physics results.
- Full MADMAX:
Commissioning @ DESY HERA North Hall ≥ 2028 .

