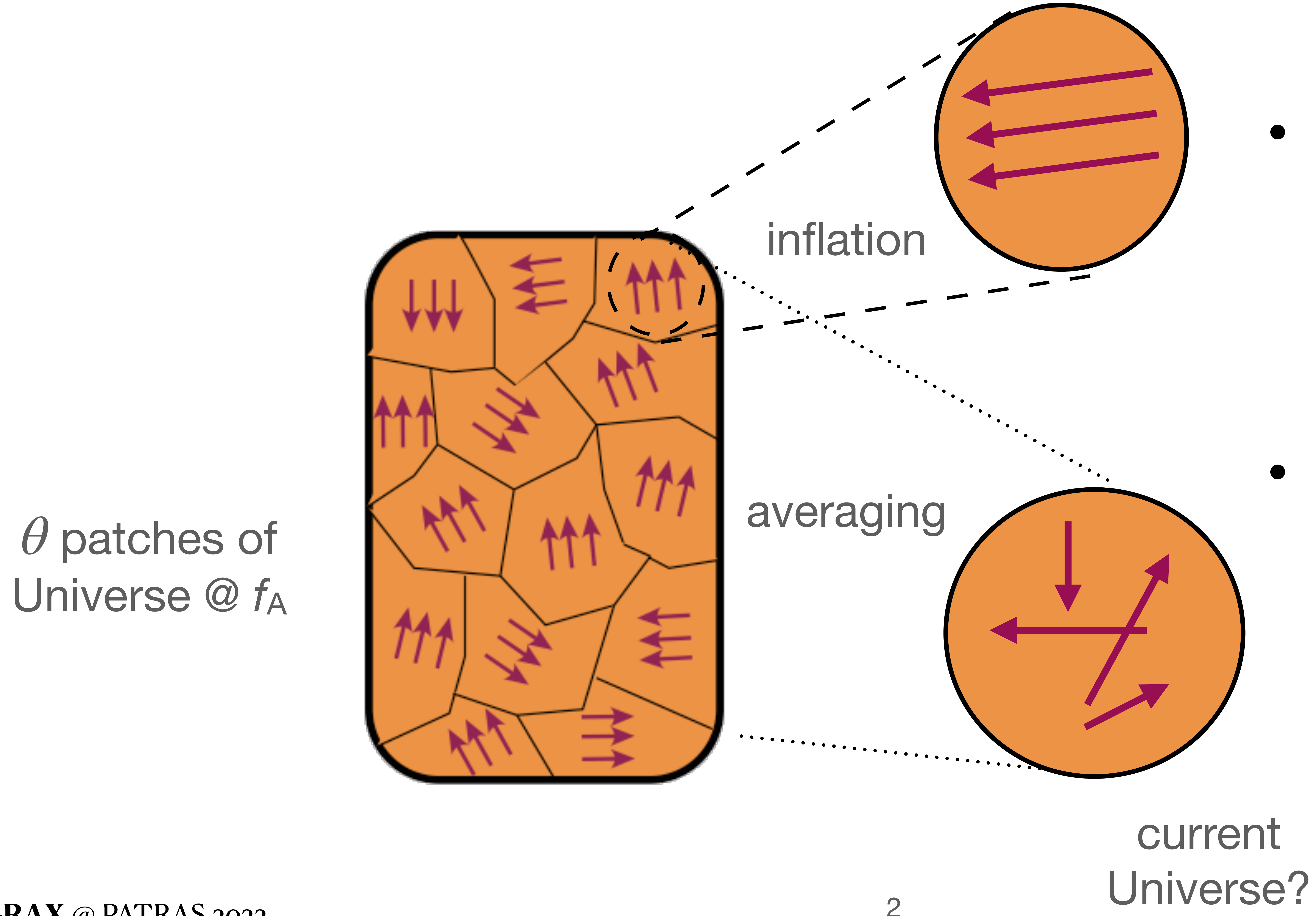
T-RAX :
transversely resonant axion experiment

Chang Lee and Olaf Reimann, Aug. 11, 2022
arXiv: 2203.15487

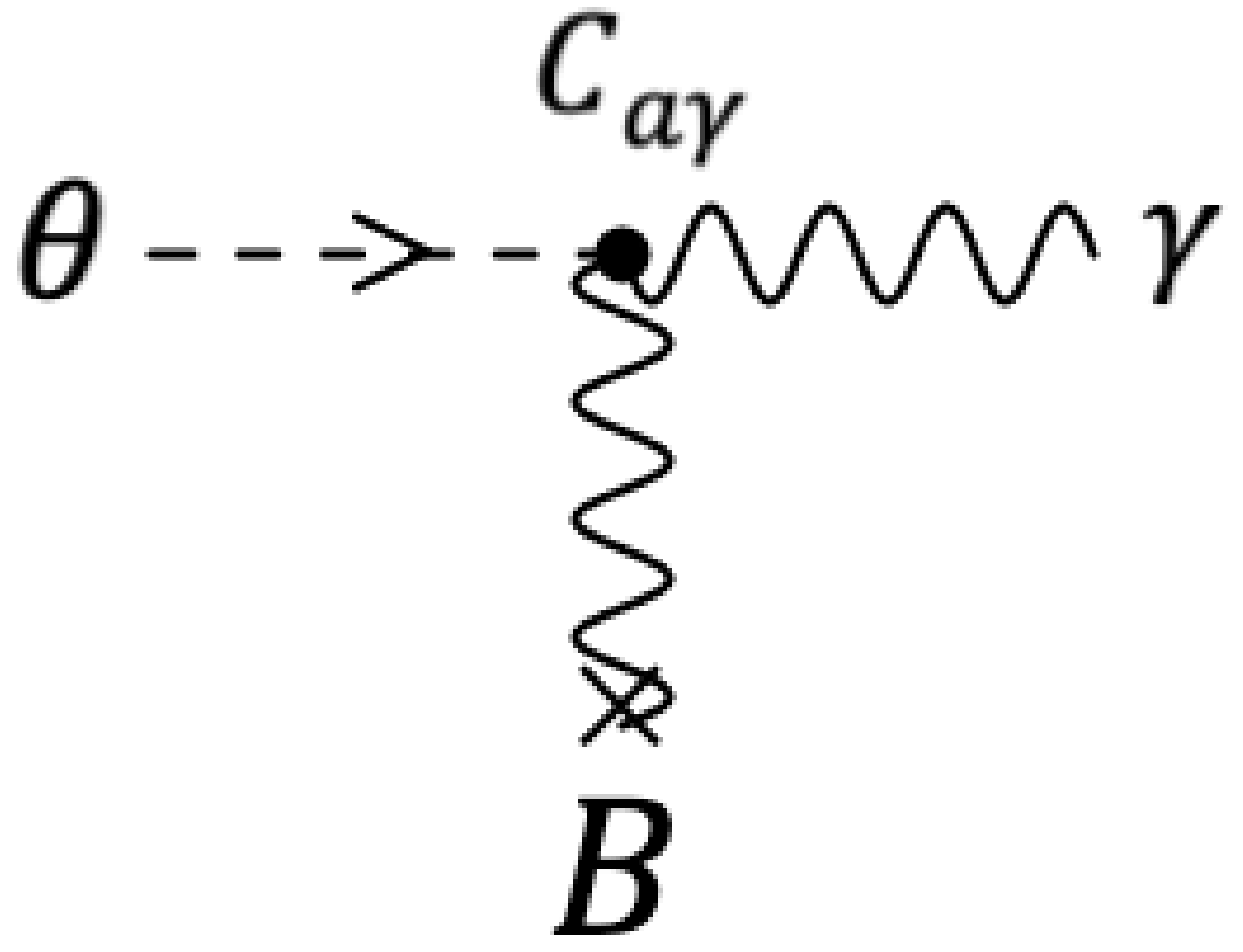
Motivation

Post-inflation scenario

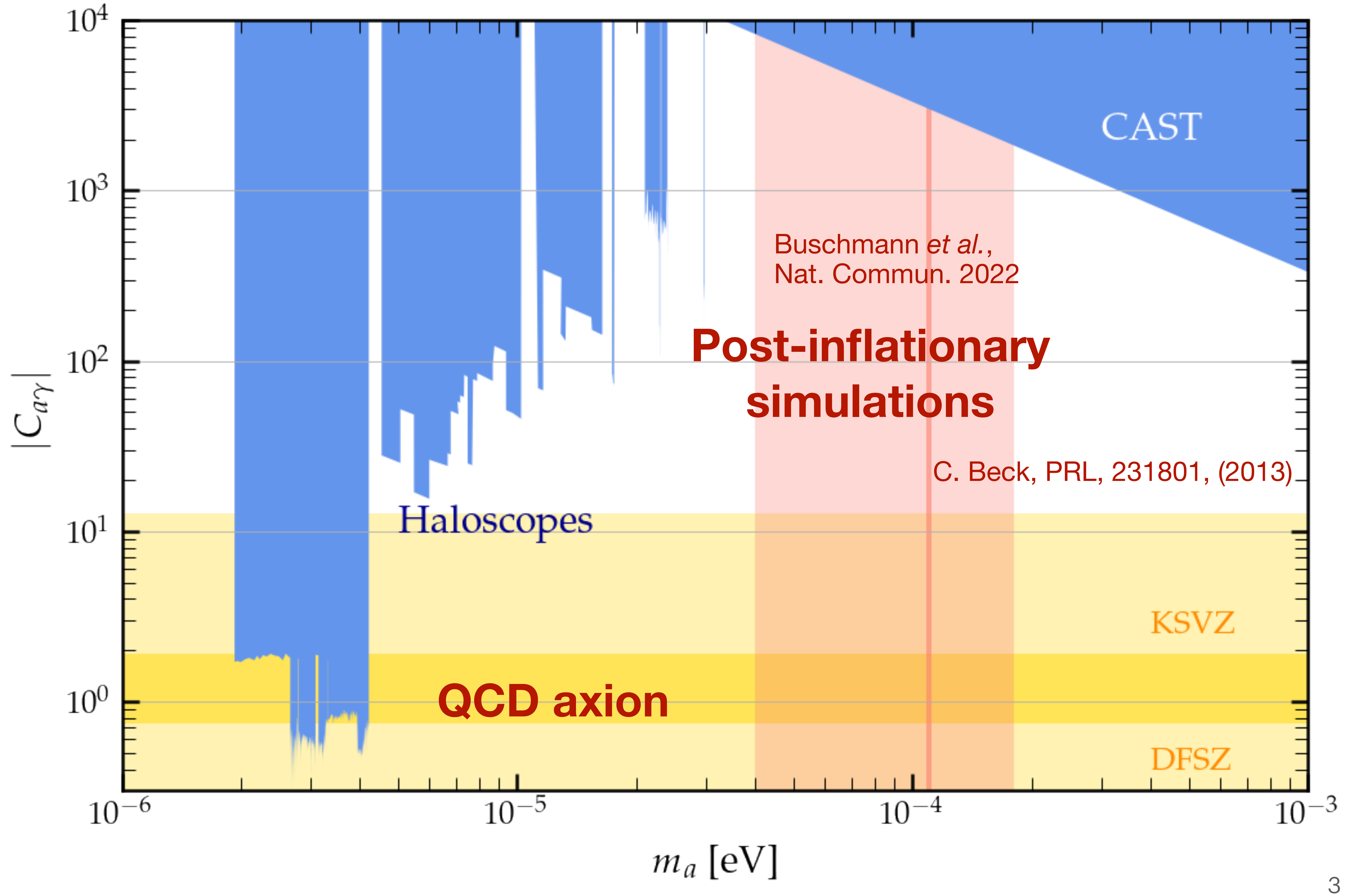


- Pre-inflationary scenarios allows much wider m_a.
- Post-inflationary production prefers m_a : $40 - 180\ \mu$eV.
  Buschmann *et al.*, Nat. Commun. 2022

Motivation



$C_{a\gamma}$
θ
γ
B

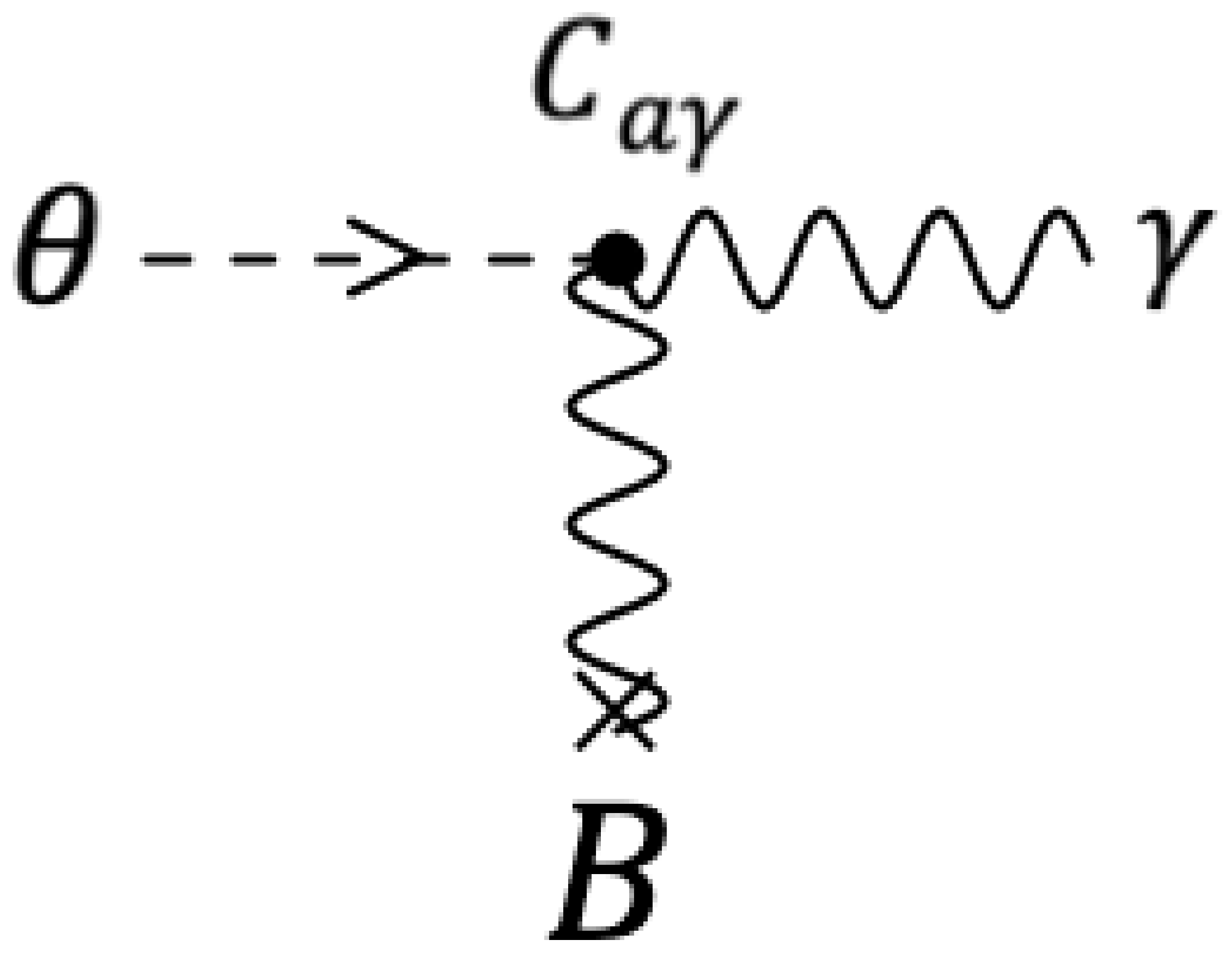


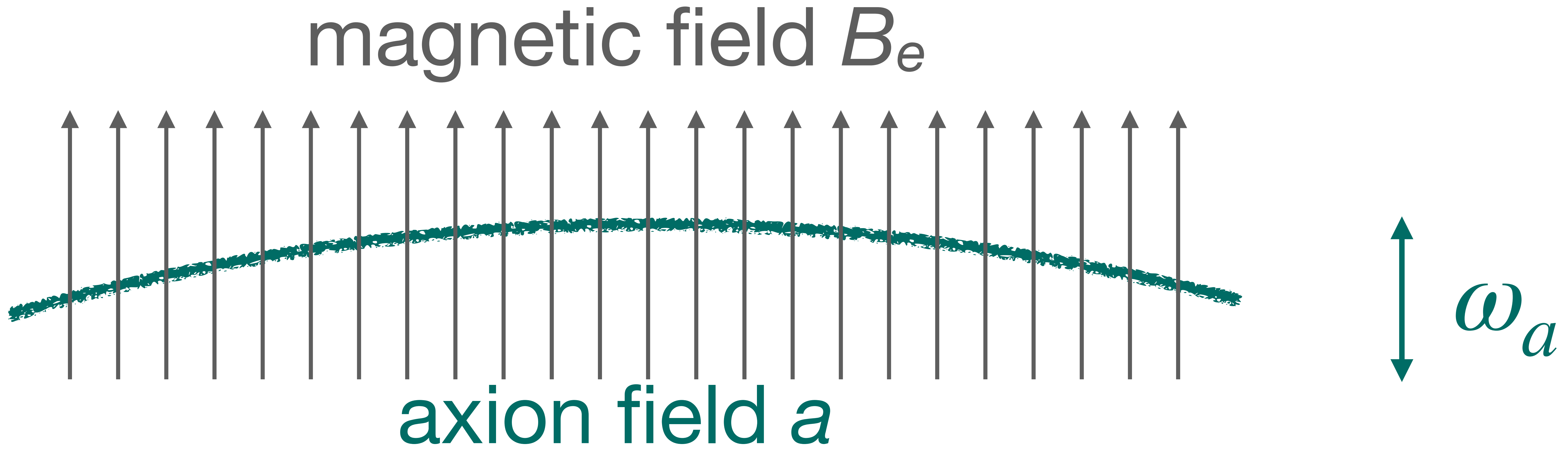
10^4
10^3
10^2
10^1
10^0
$|C_{a\gamma}|$
CAST
Buschmann et al.,
Nat. Commun. 2022
Post-inflationary
simulations
C. Beck, PRL, 231801, (2013)
Haloscopes
KSVZ
QCD axion
DFSZ
10^{-6}
10^{-5}
10^{-4}
10^{-3}
m_a [eV]

Principle

Principle

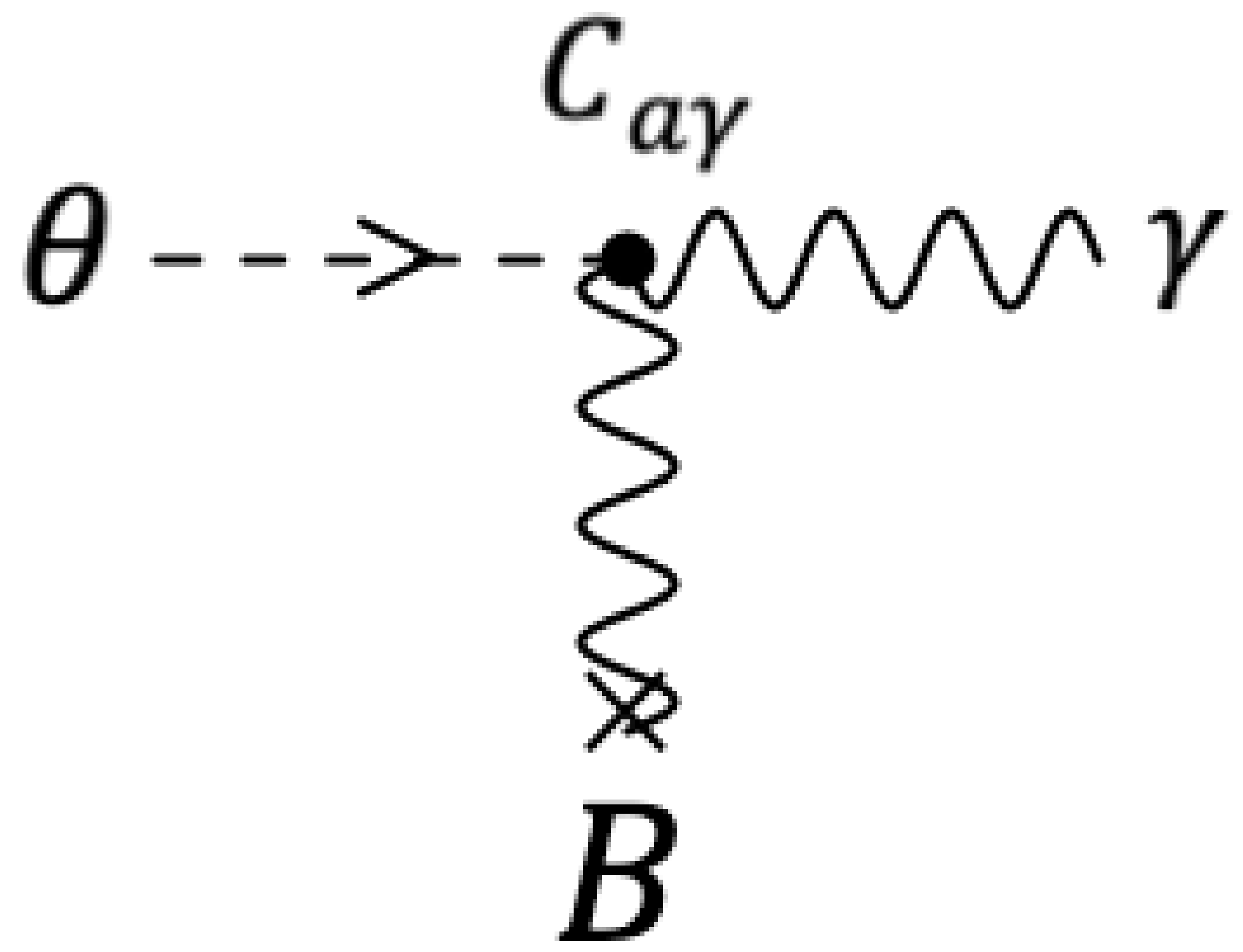
Inverse Primakoff

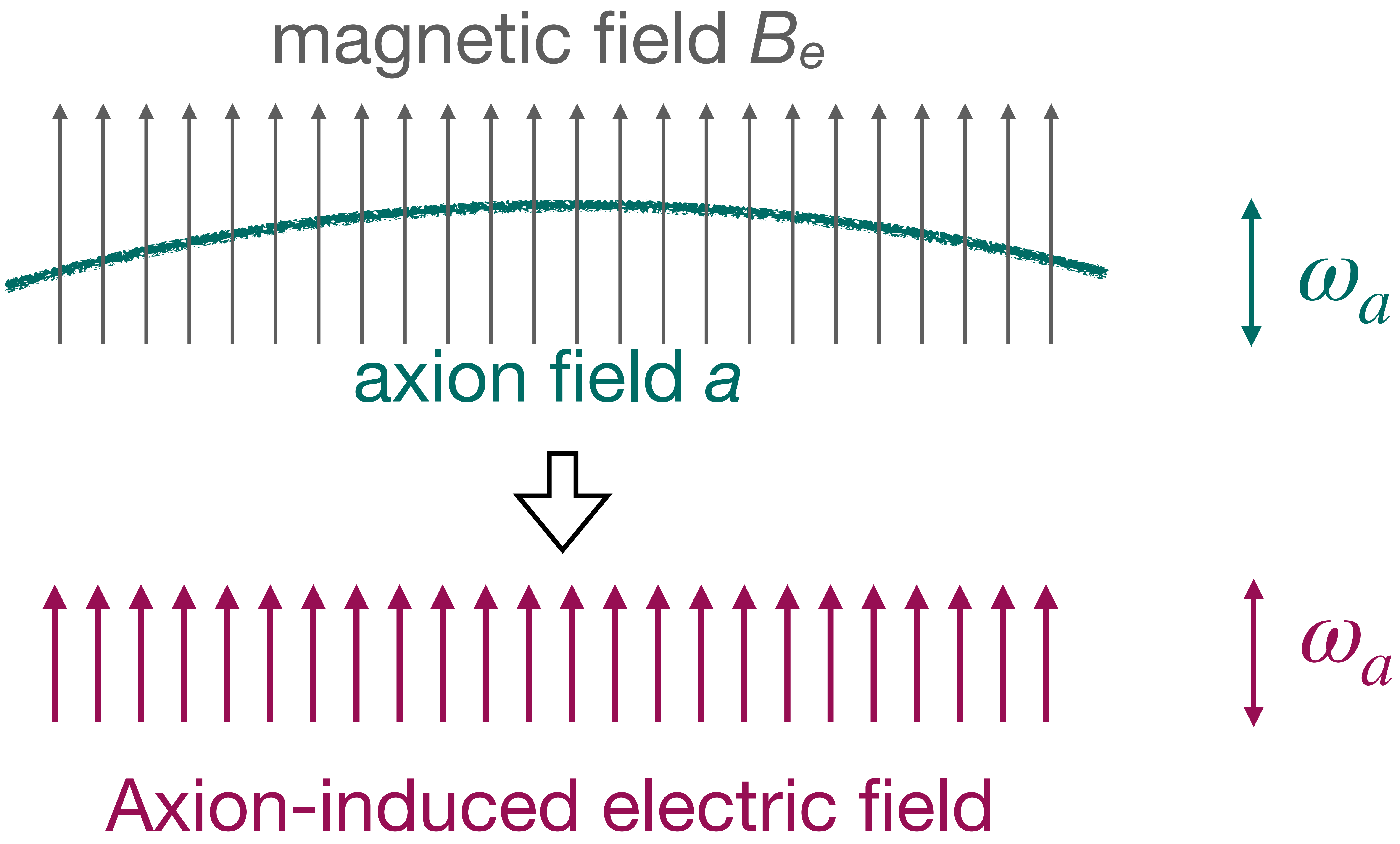




Principle

Inverse Primakoff

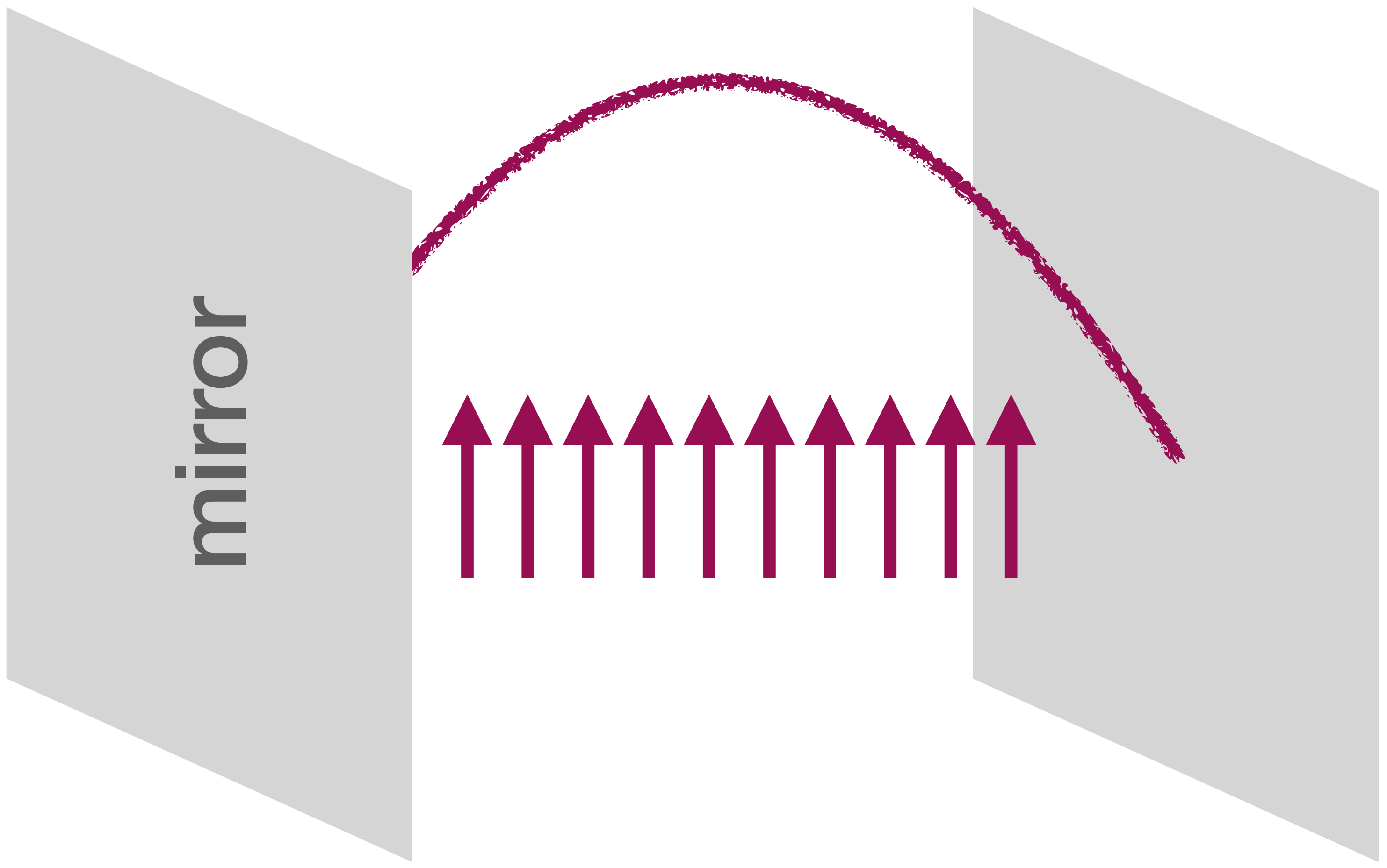




Principle

Dish antenna

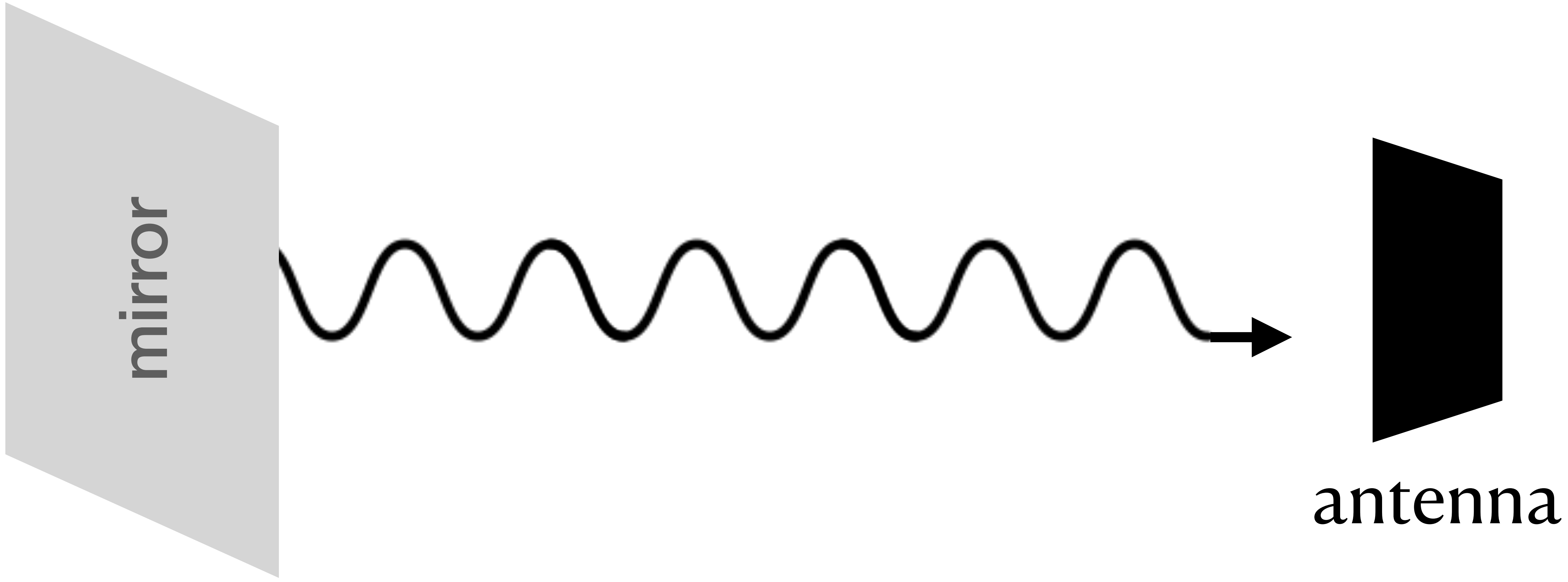
- Cavity: traveling waves from two mirrors form a standing wave



Principle

Dish antenna

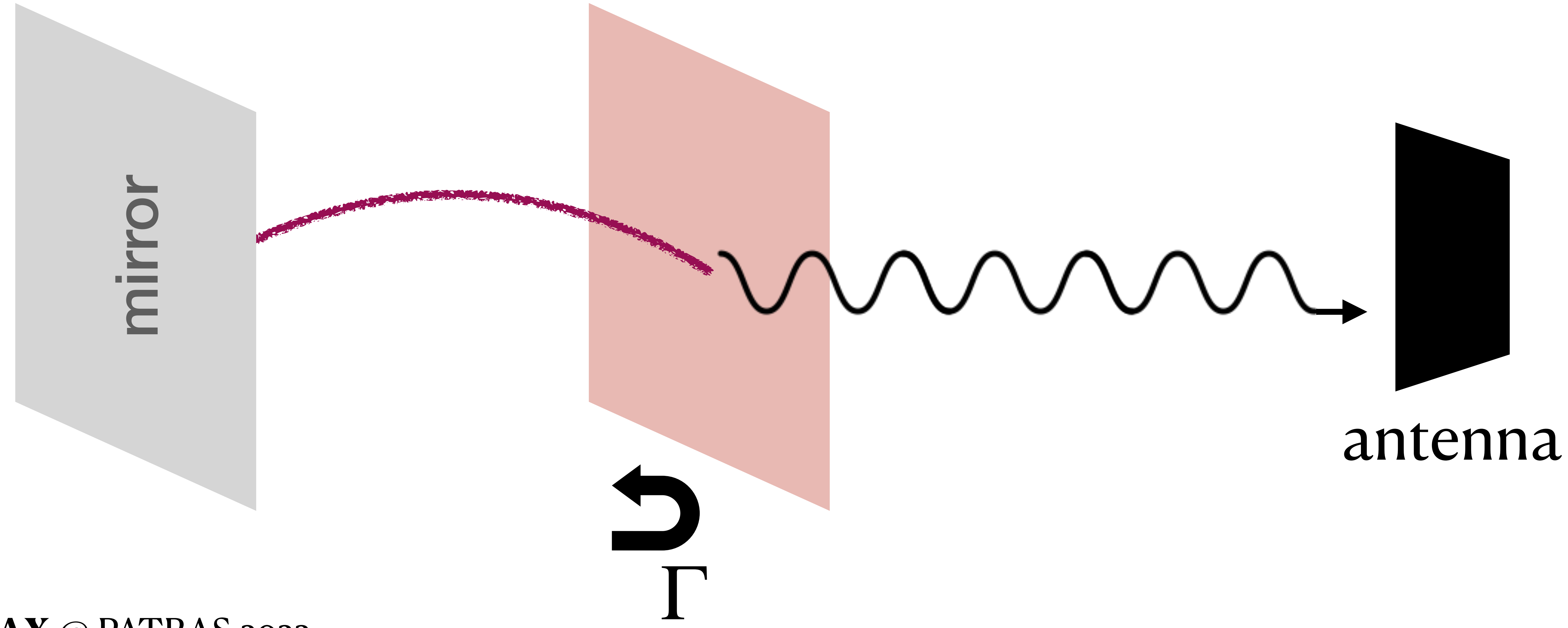
- Axion-induced field generates a "traveling wave" from a conducting surface
  - Dish antenna experiment: detect the traveling wave with an antenna
  - Traveling wave detection, e.g. WG, is less reflective and lossy than coax as the frequency increases.



Principle

Dielectric haloscope

- Dielectric haloscope: replace a mirror with a **dielectric** that reflects the traveling wave with reflectivity Γ. Resonance + more traveling waves from the dielectric



Principle

Dielectric haloscope

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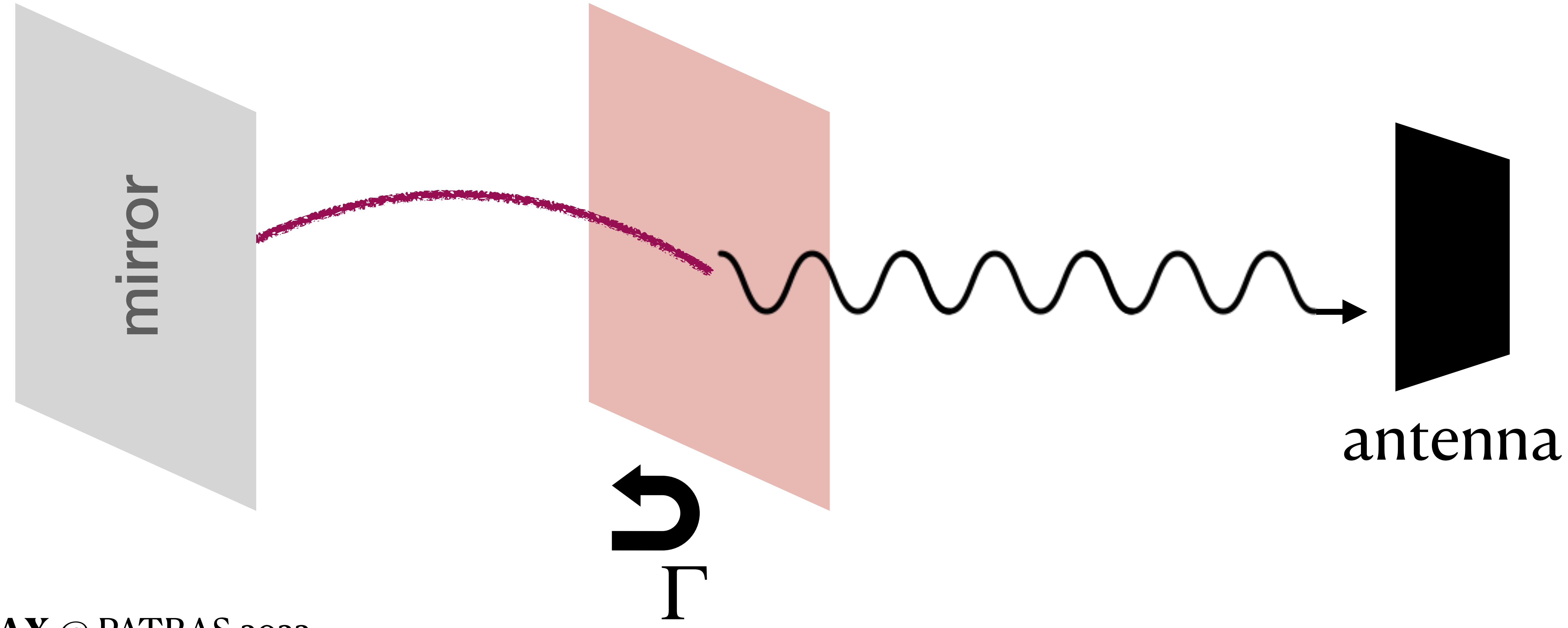
- **Higher** Γ: stronger resonance and **signal power**



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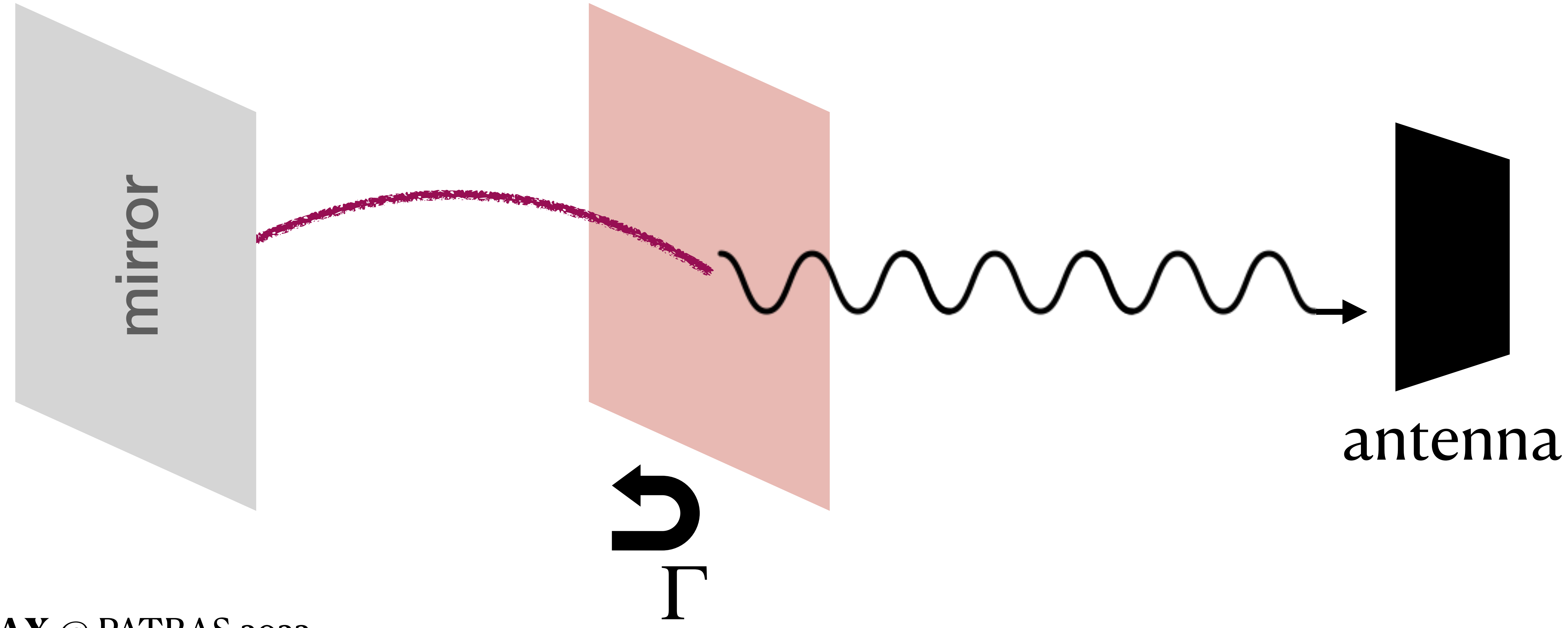
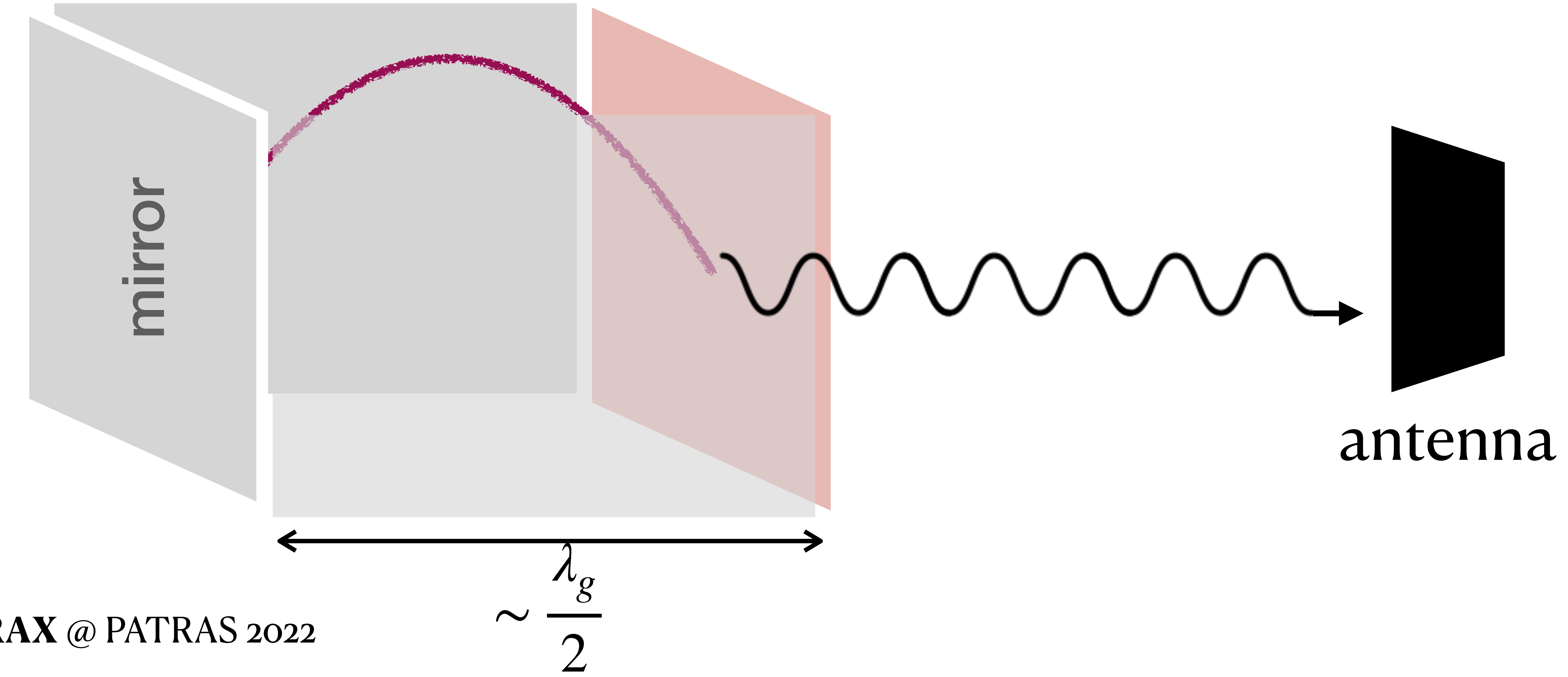


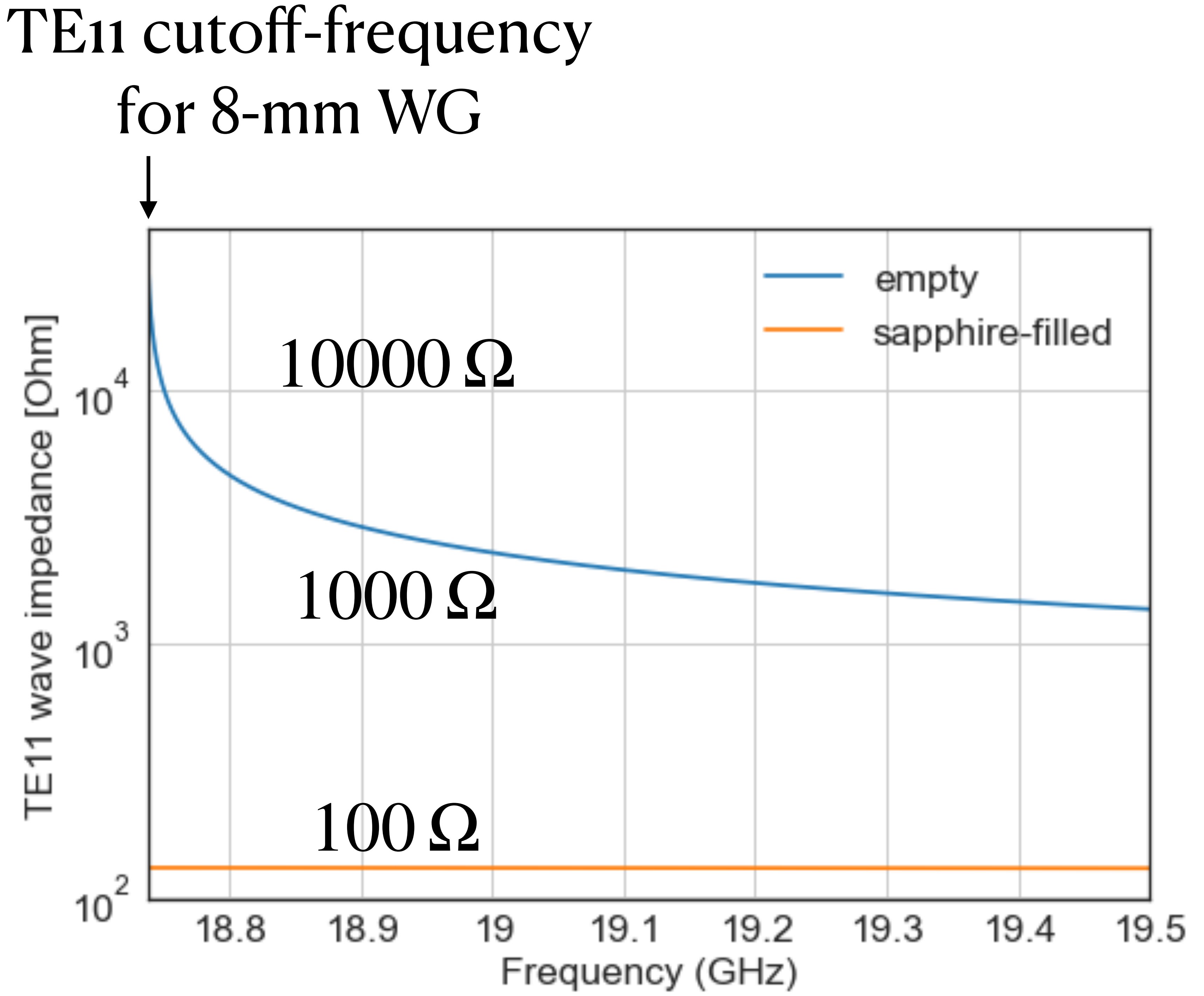
- Can we further increase Γ?

Principle

Waveguide near cutoff

- WG Impedance diverges near the **cutoff**: $Z_{TE} \propto \frac{1}{\beta}$, and Γ increases.

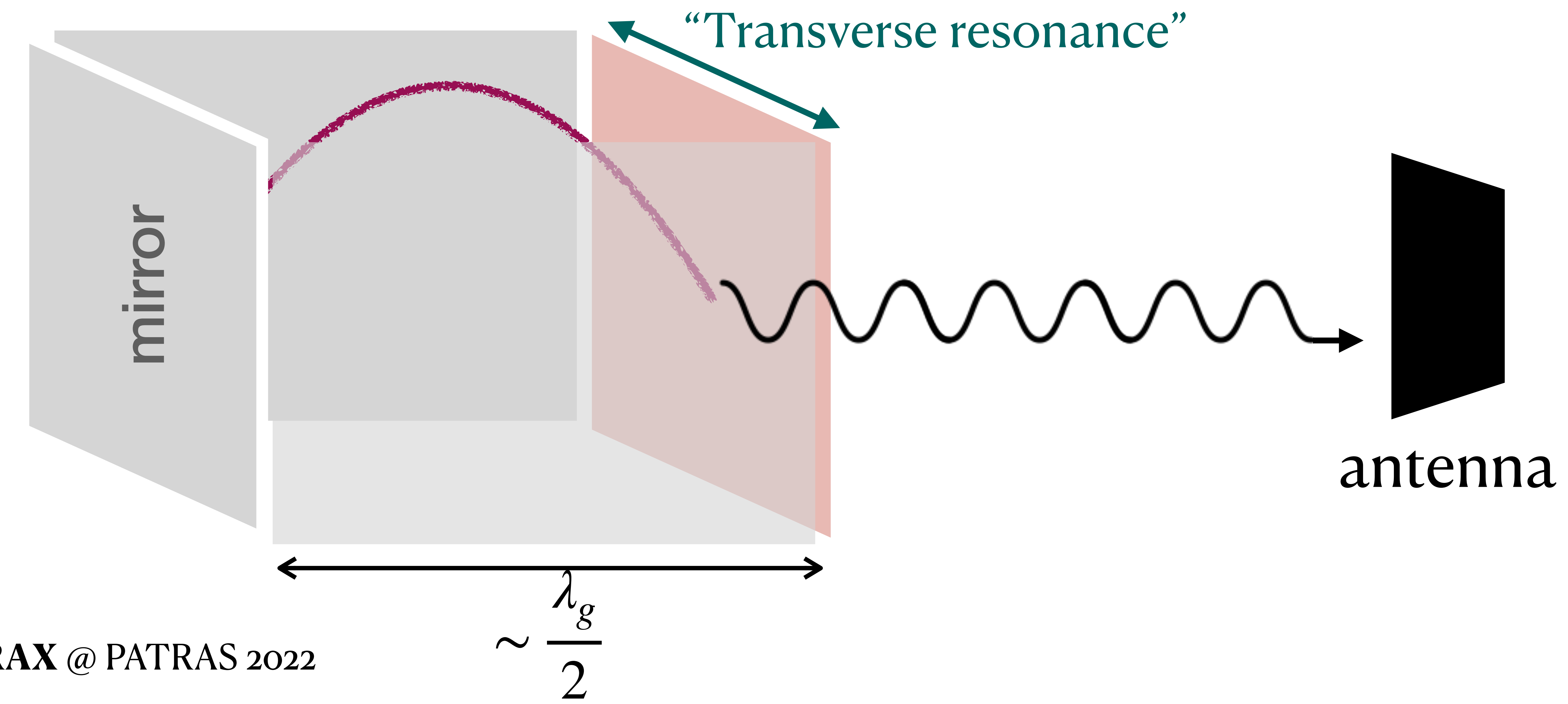




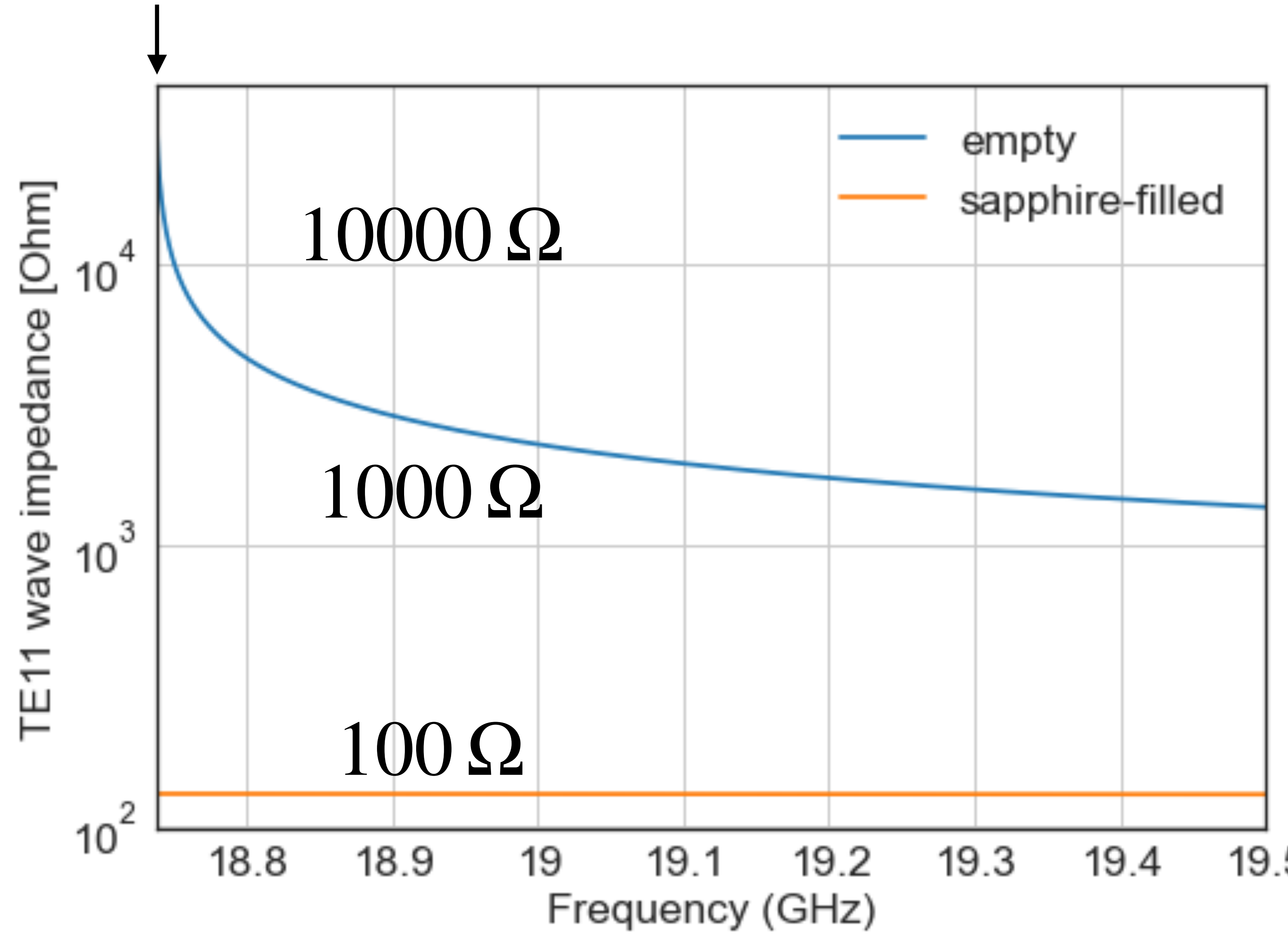
Principle

Waveguide near cutoff

- WG Impedance diverges near the **cutoff**: $Z_{TE} \propto \frac{1}{\beta}$, and Γ increases.
- Transverse Resonance Axion Experiment (**T-RAX**)



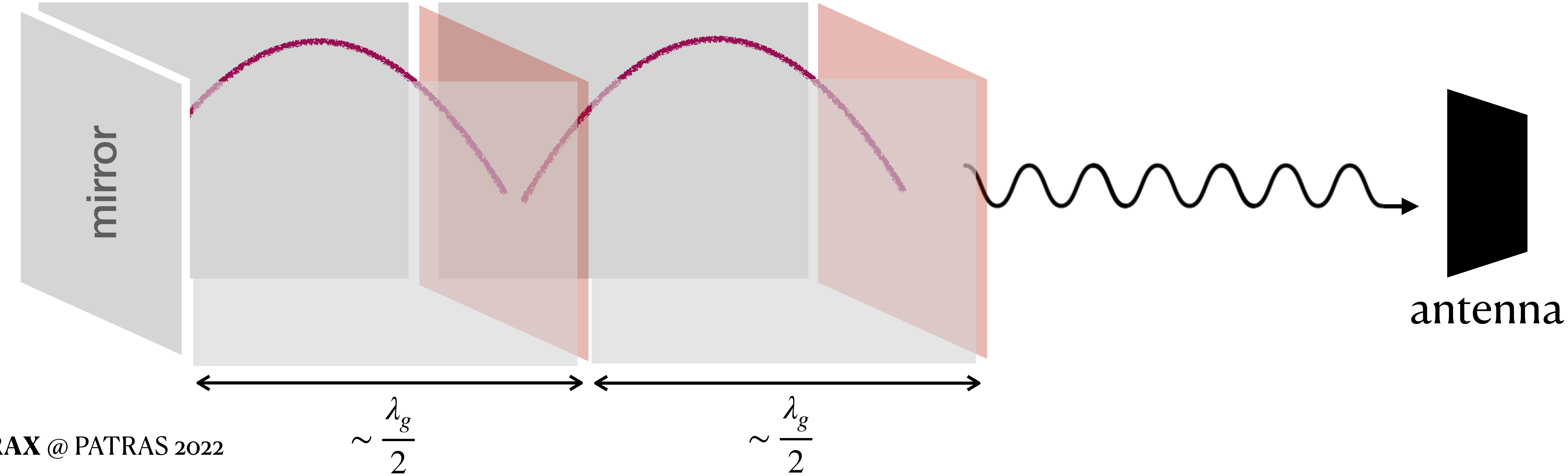
TE11 cutoff-frequency
for 8-mm WG



Principle

T-RAX

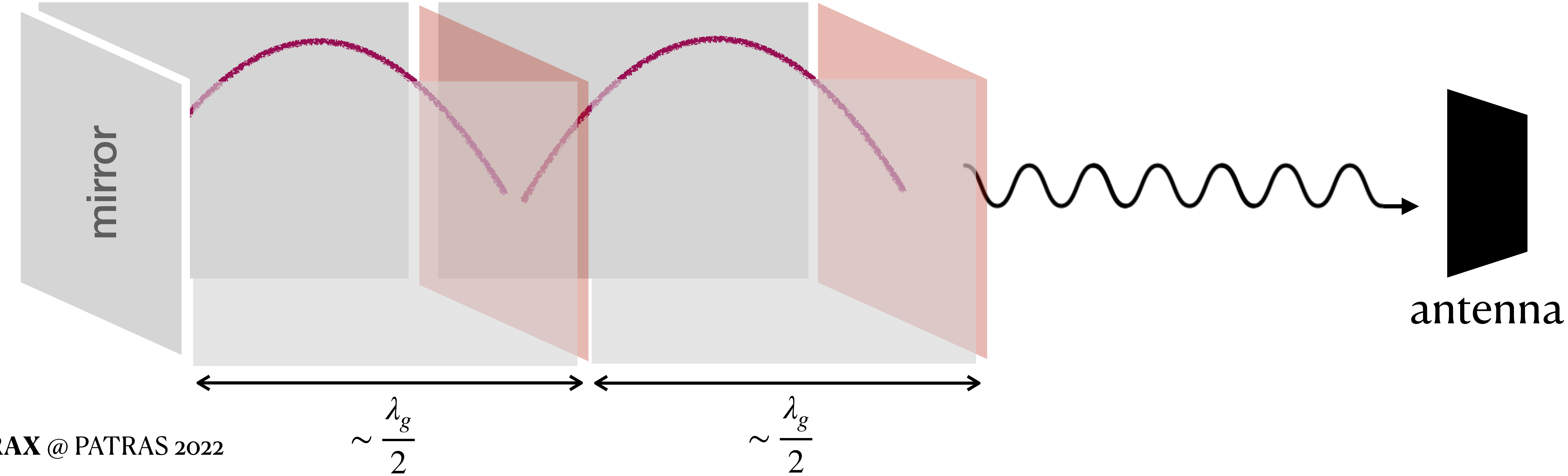
- Multiple "cells" to increase the signal power (coupled oscillator)



Principle

T-RAX

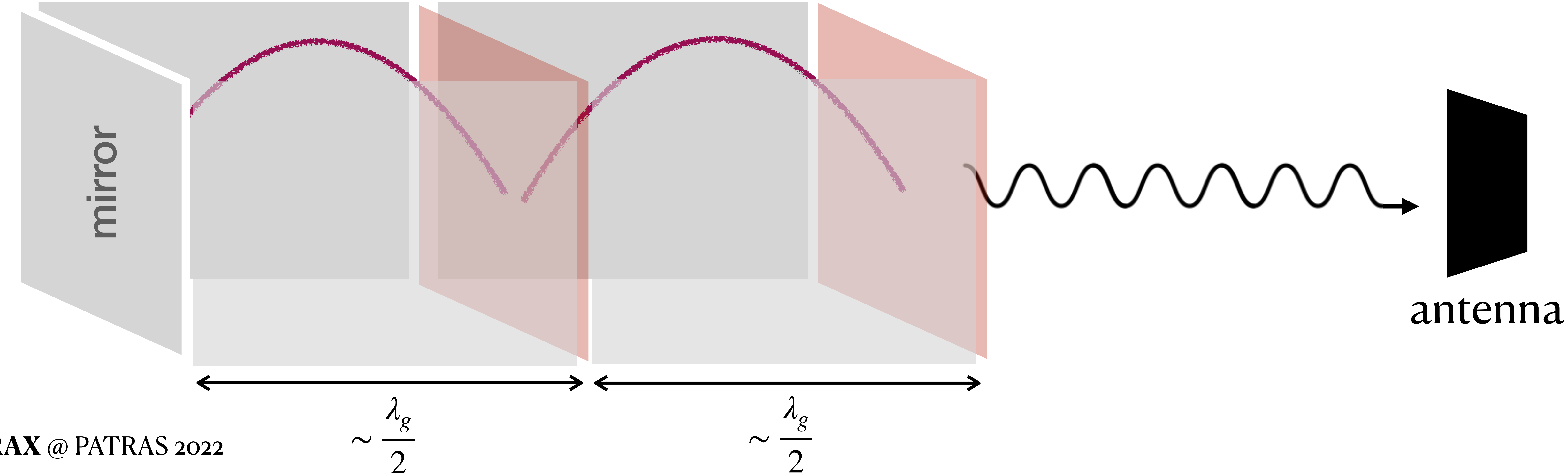
- Multiple “cells” to increase the signal power (coupled oscillator)
  - Dispersion calculation to find the “Axion mode”



Principle

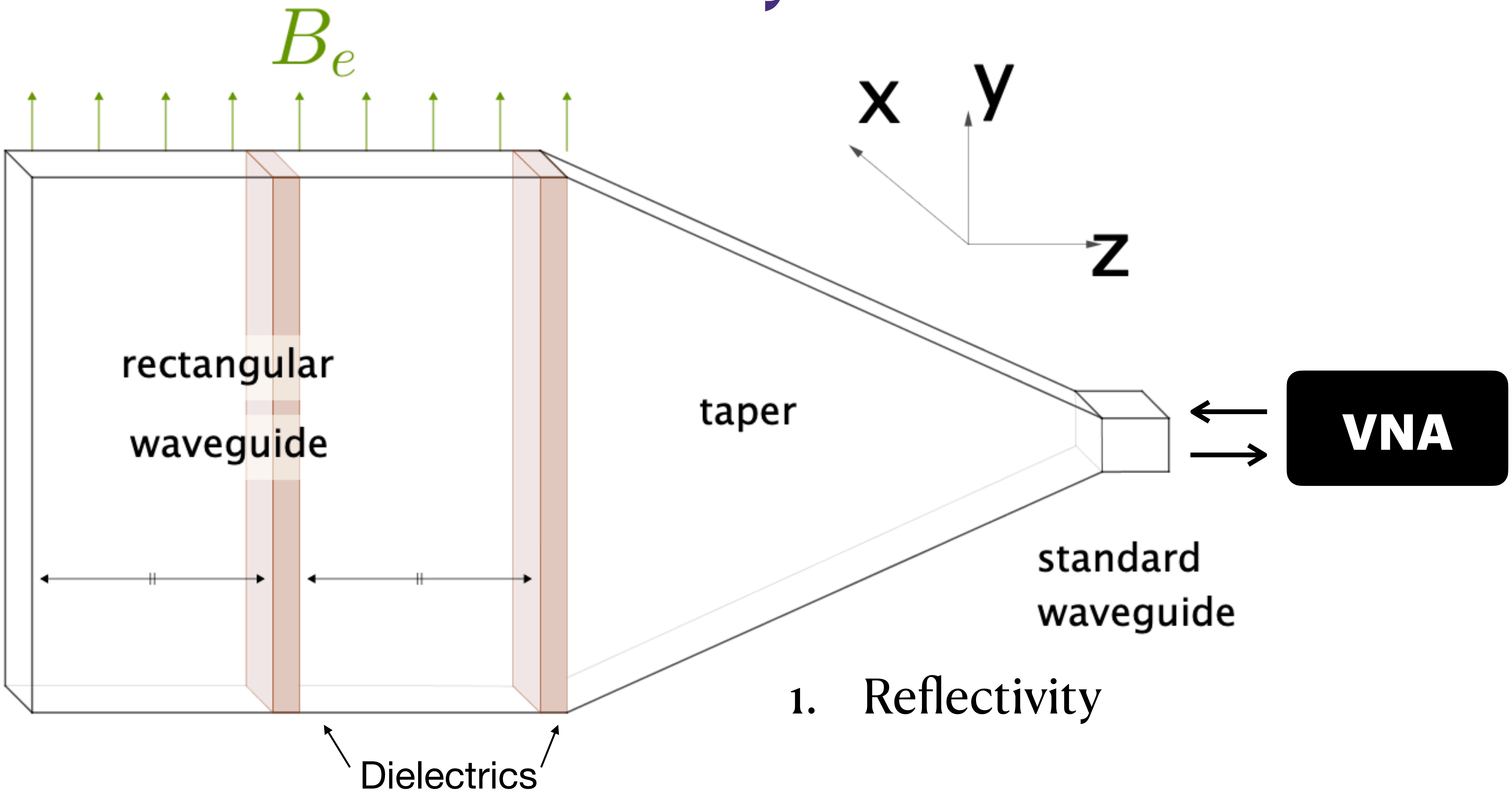
T-RAX

- Multiple “cells” to increase the signal power (coupled oscillator)
  - Dispersion calculation to find the “Axion mode”
  - Monolithic structure simplifies readout



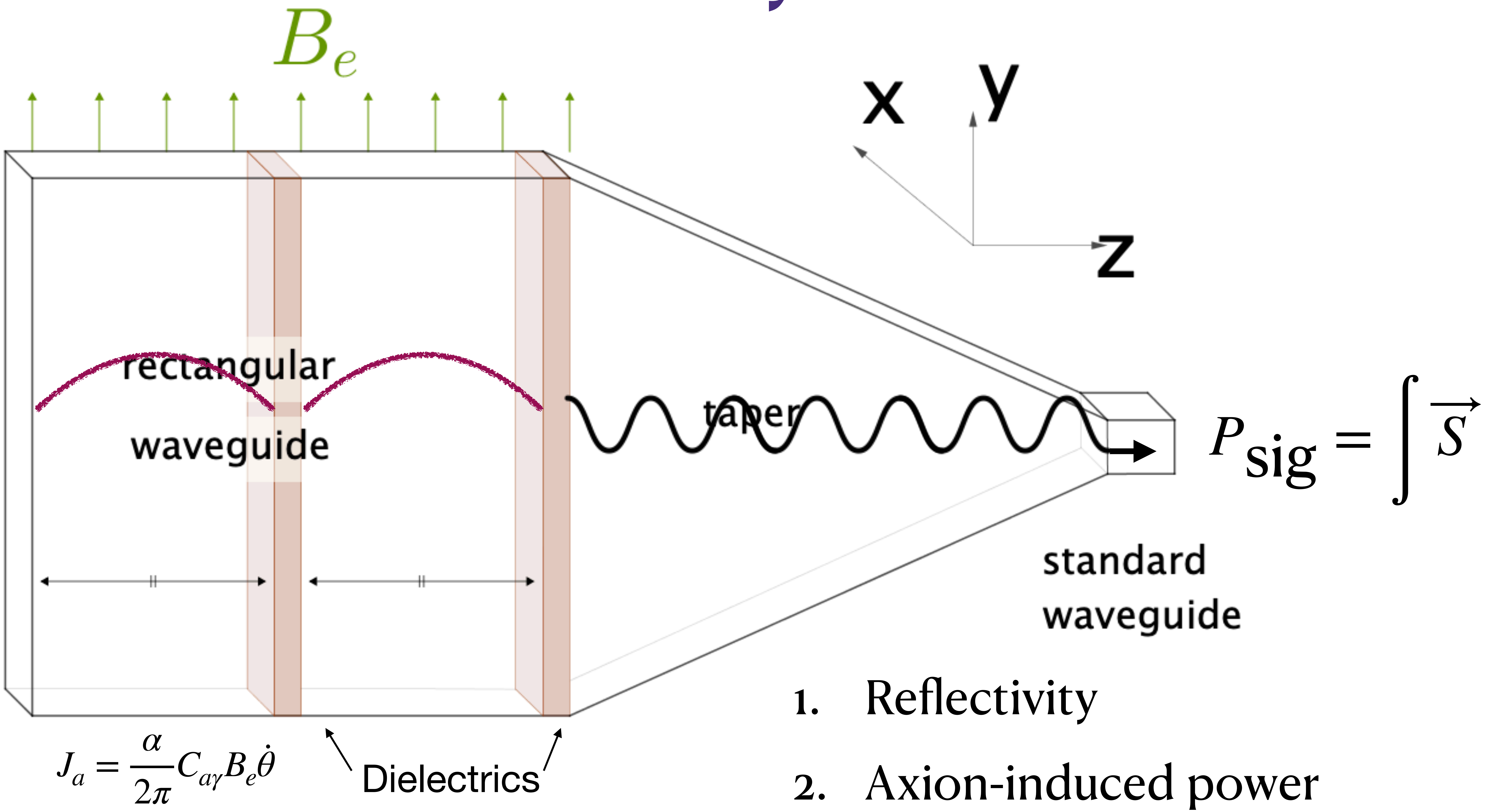
Simulation

Geometry



1. Reflectivity

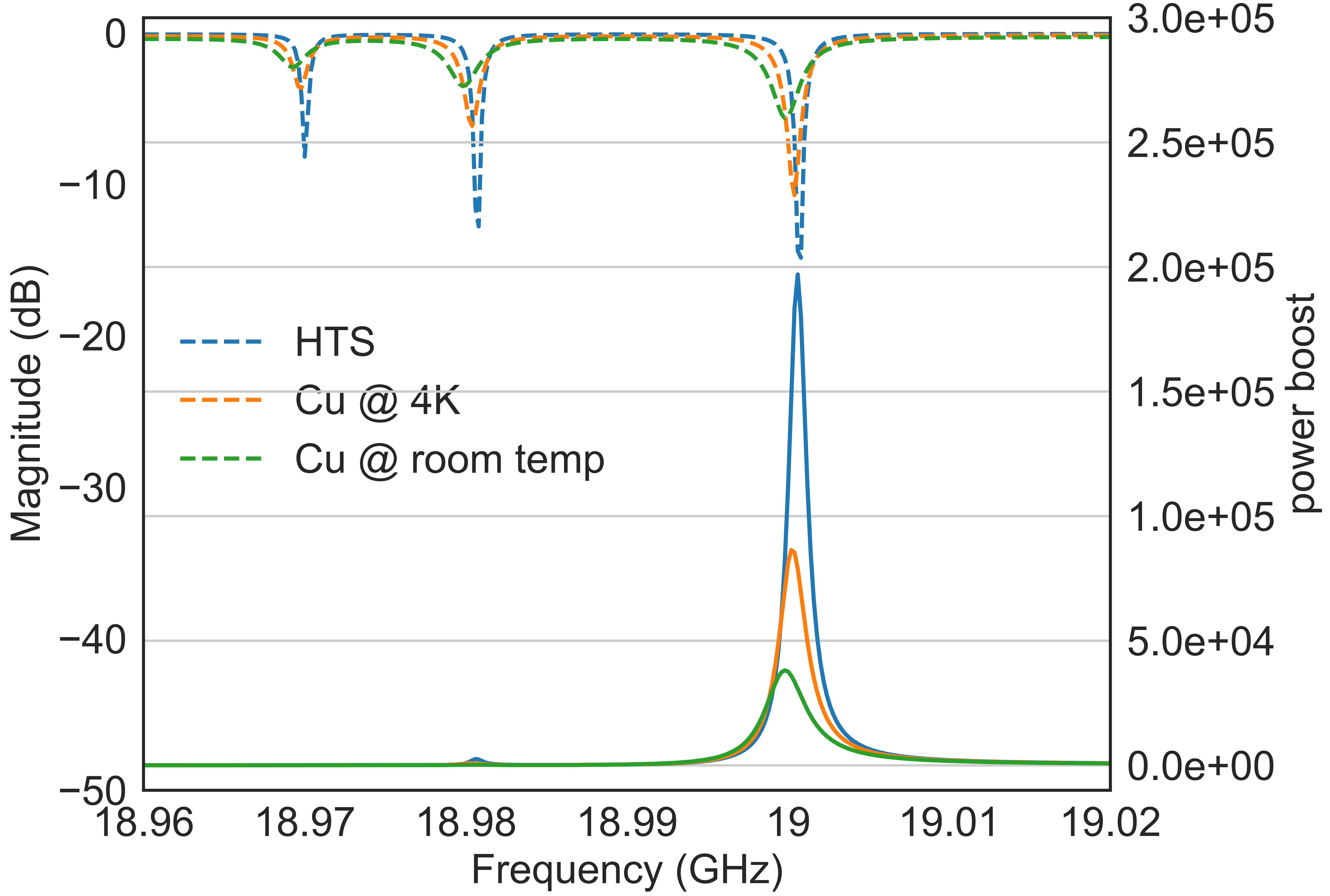
Geometry



1. Reflectivity
2. Axion-induced power

Signal power

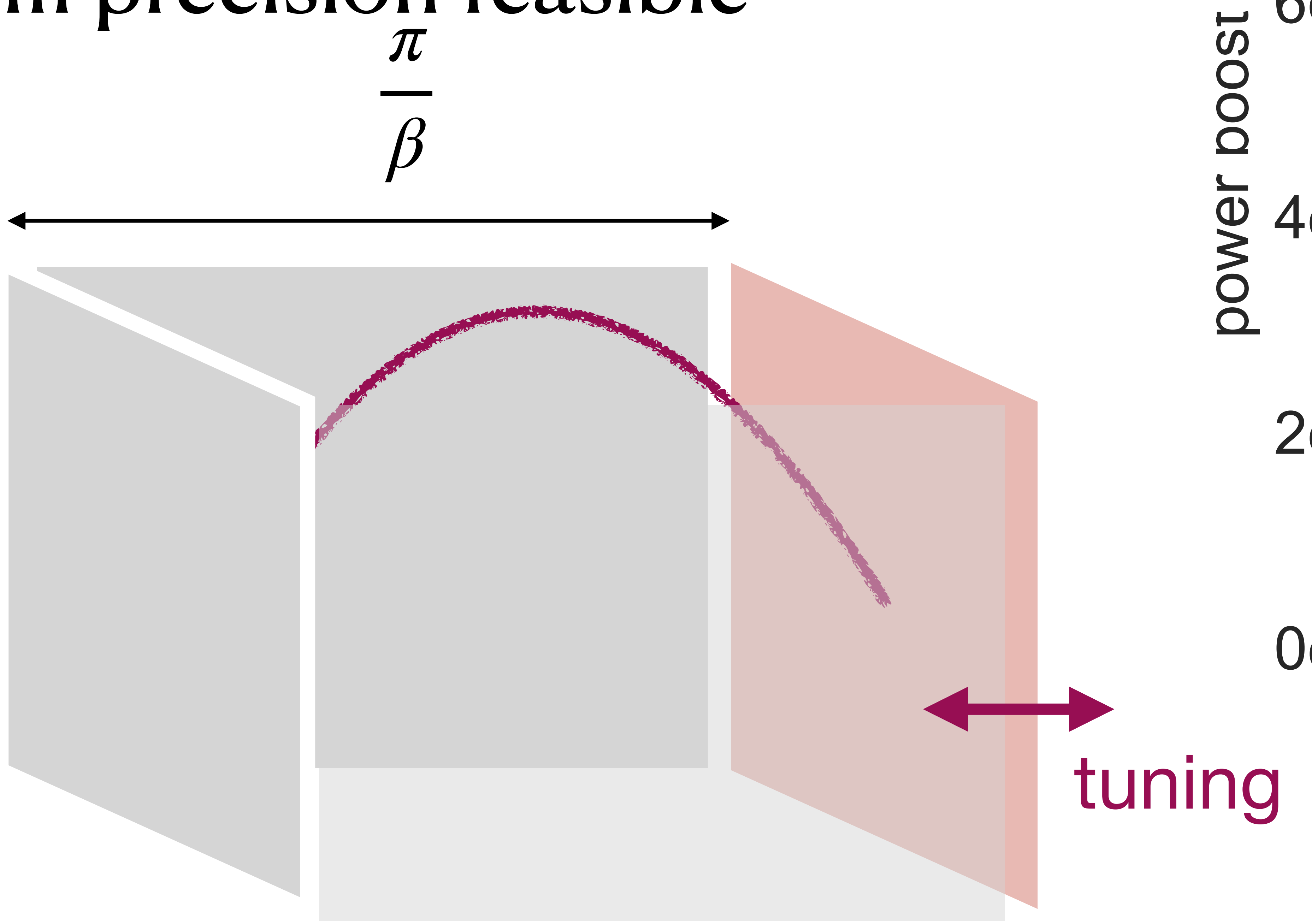
- 80,000 signal power boost from the flat mirror case @ 4K Cu.
- Higher conductivity increases the signal power.

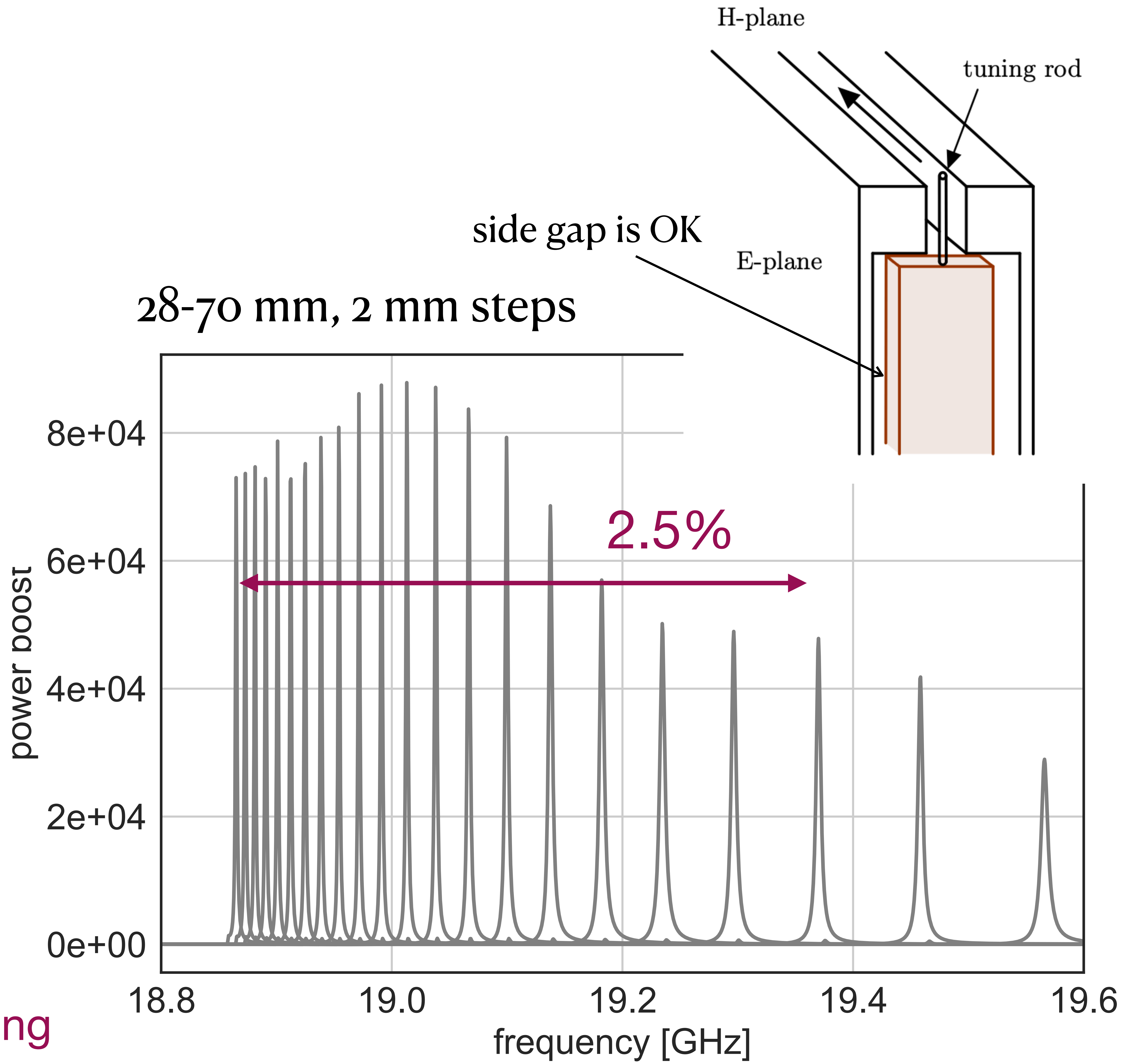


Signal power

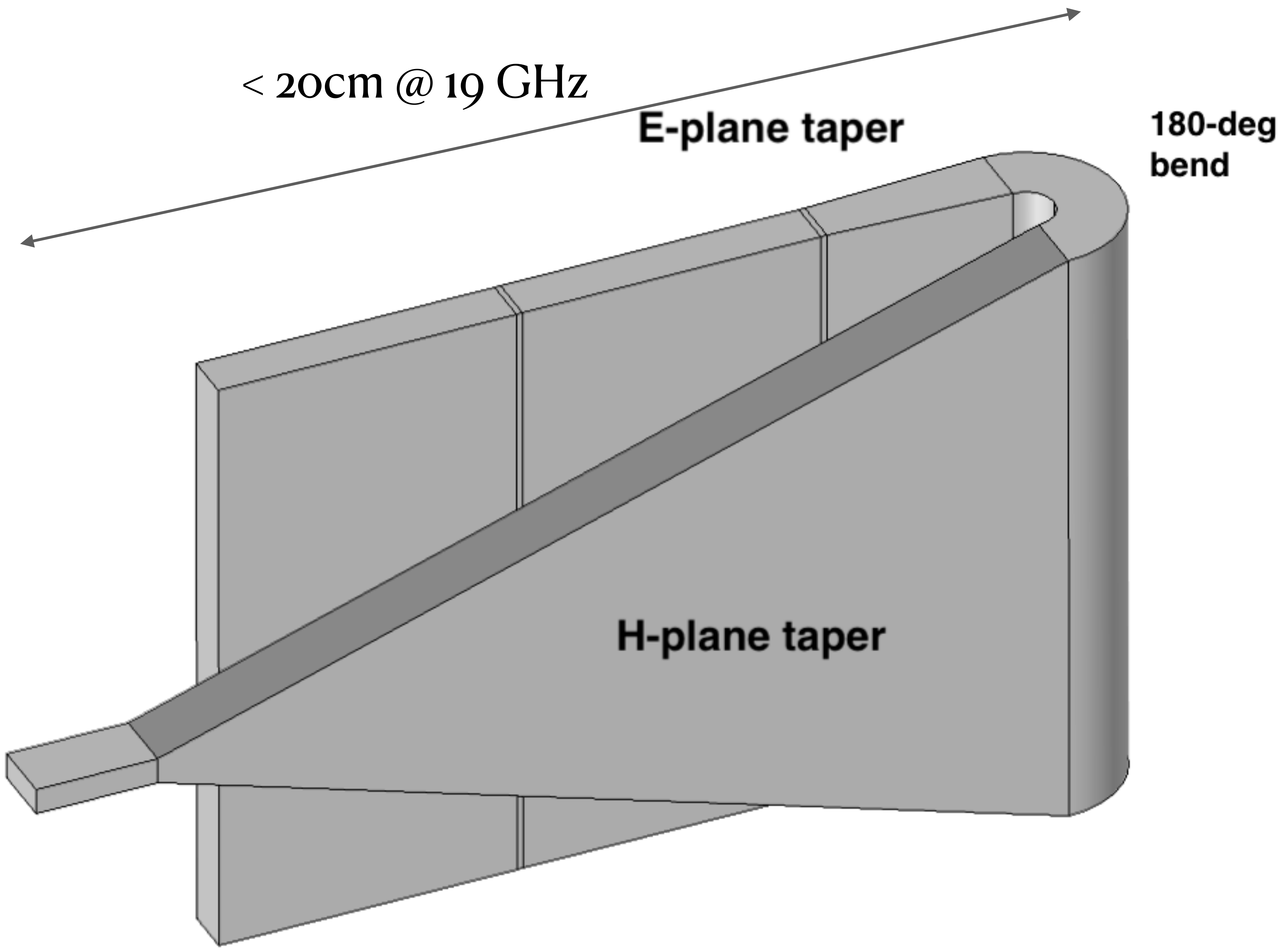
Tuning

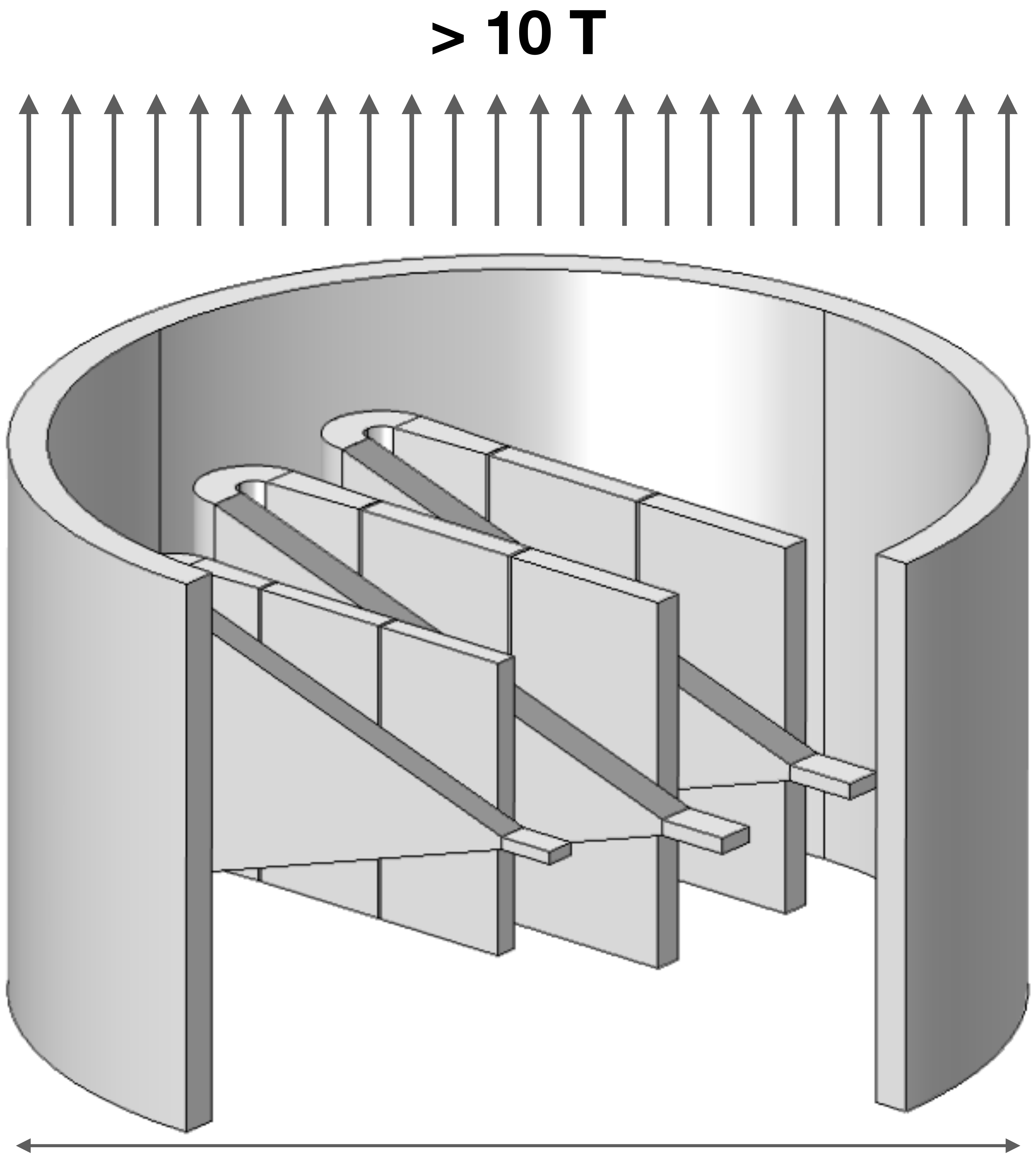
- Scan a wider mass range by changing the dielectric spacing
- 50 μm precision feasible





Magnet

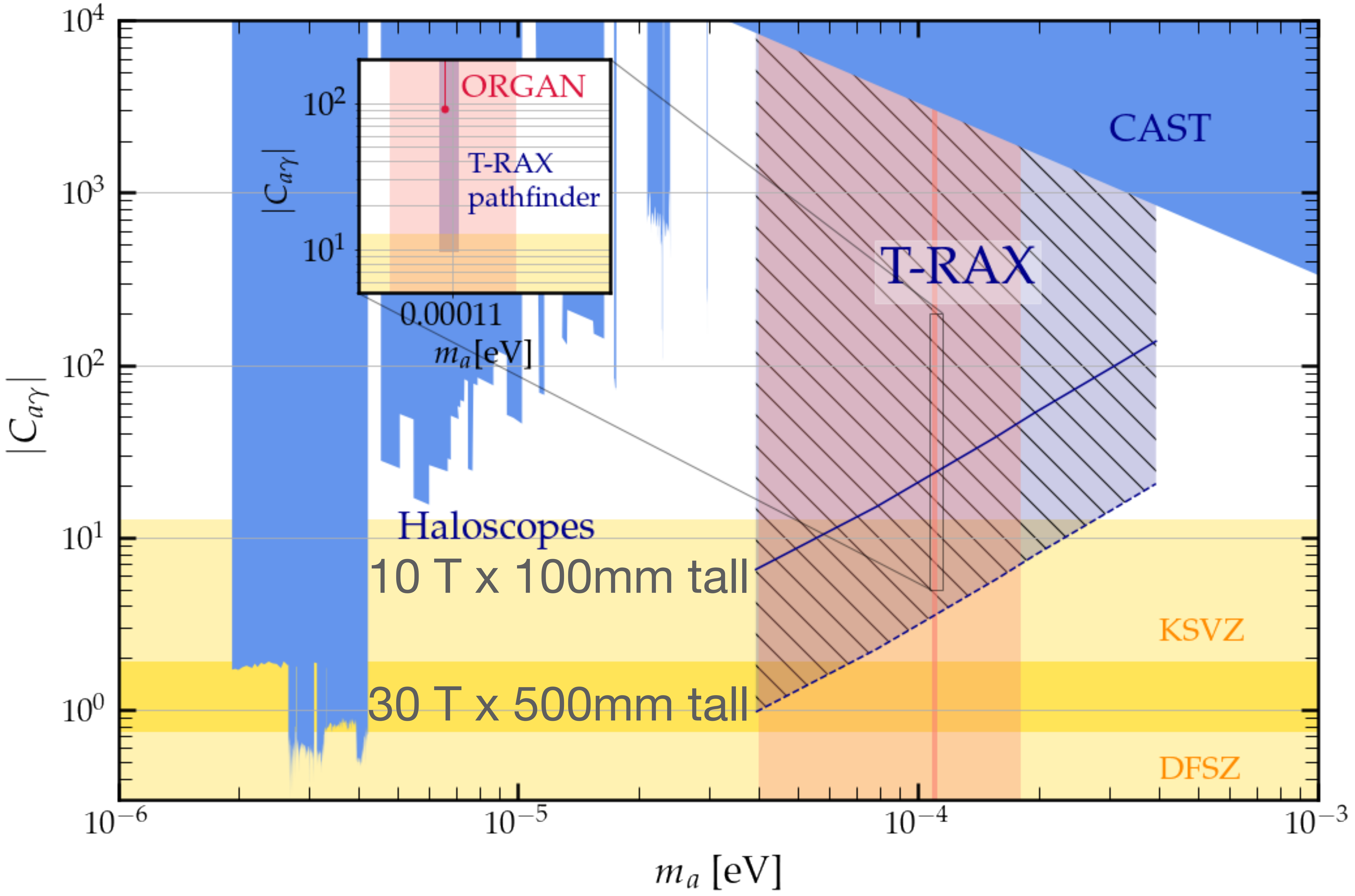




The 180-deg bend is reflect little (RL ~40 dB) far above the cutoff frequency

Sensitivity

- $$C_{a\gamma} = 15.1 \left(\frac{300\,\mathrm{MeV/cm^3}}{\rho_a}\right)^{\frac{1}{2}} \left(\frac{80{,}000}{\beta^2}\right)^{\frac{1}{2}} \left(\frac{8\,\mathrm{mm}\times 100\,\mathrm{mm}}{A}\right)^{\frac{1}{2}} \left(\frac{10\,\mathrm{T}}{B_e}\right) \left(\frac{T_{\mathrm{sys}}}{0.9\,\mathrm{K}}\right)^{\frac{1}{2}} \left(\frac{SNR}{5}\right)^{\frac{1}{2}} \left(\frac{0.85}{\eta}\right)^{\frac{1}{2}} \left(\frac{\Delta\nu_a}{19\ \mathrm{kHz}}\right)^{\frac{1}{4}} \left(\frac{1\ \mathrm{day}}{\tau}\right)^{\frac{1}{4}}.$$
- Single quantum limit, Cu @ 4K

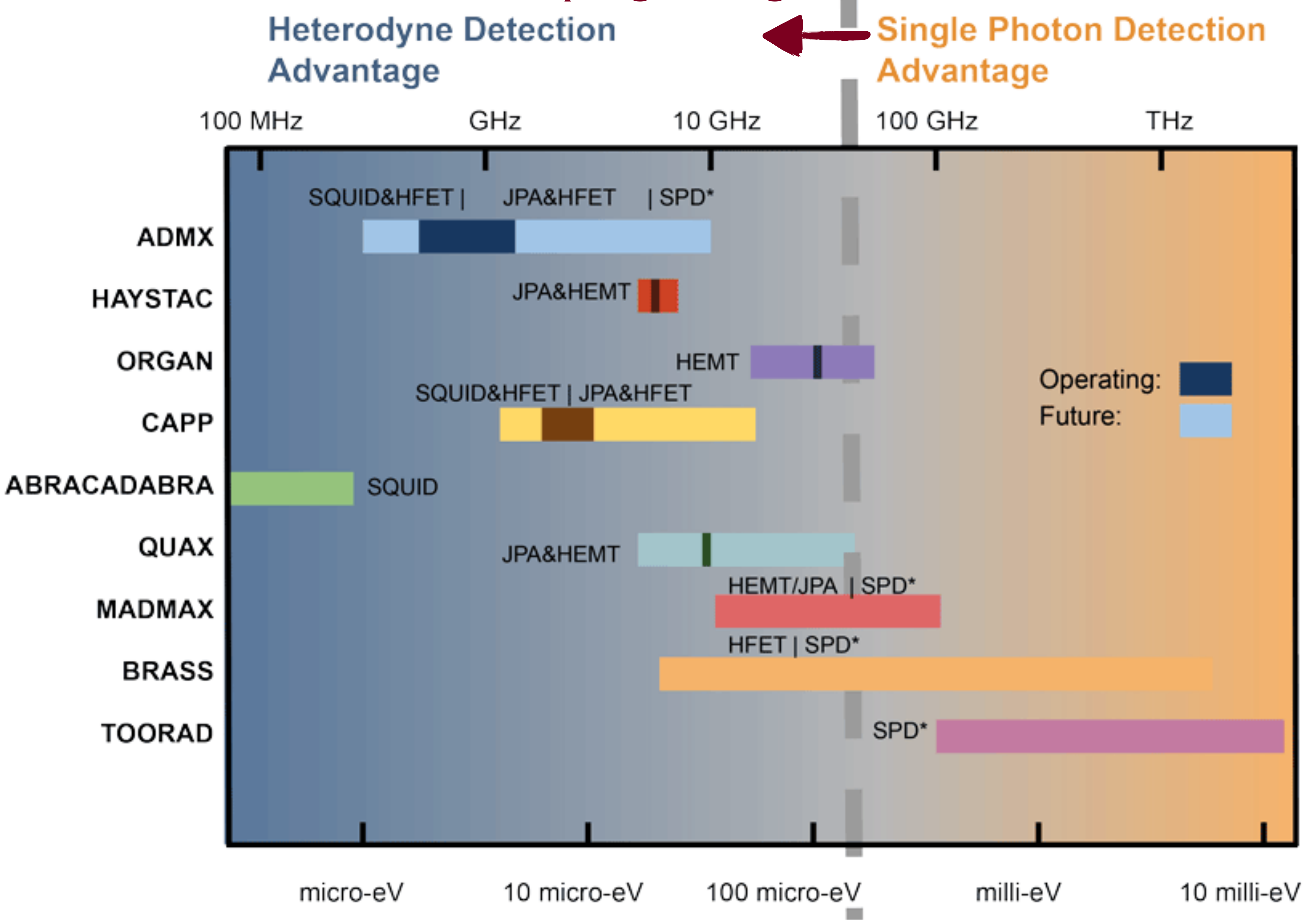


Detector

Toward the QCD axion

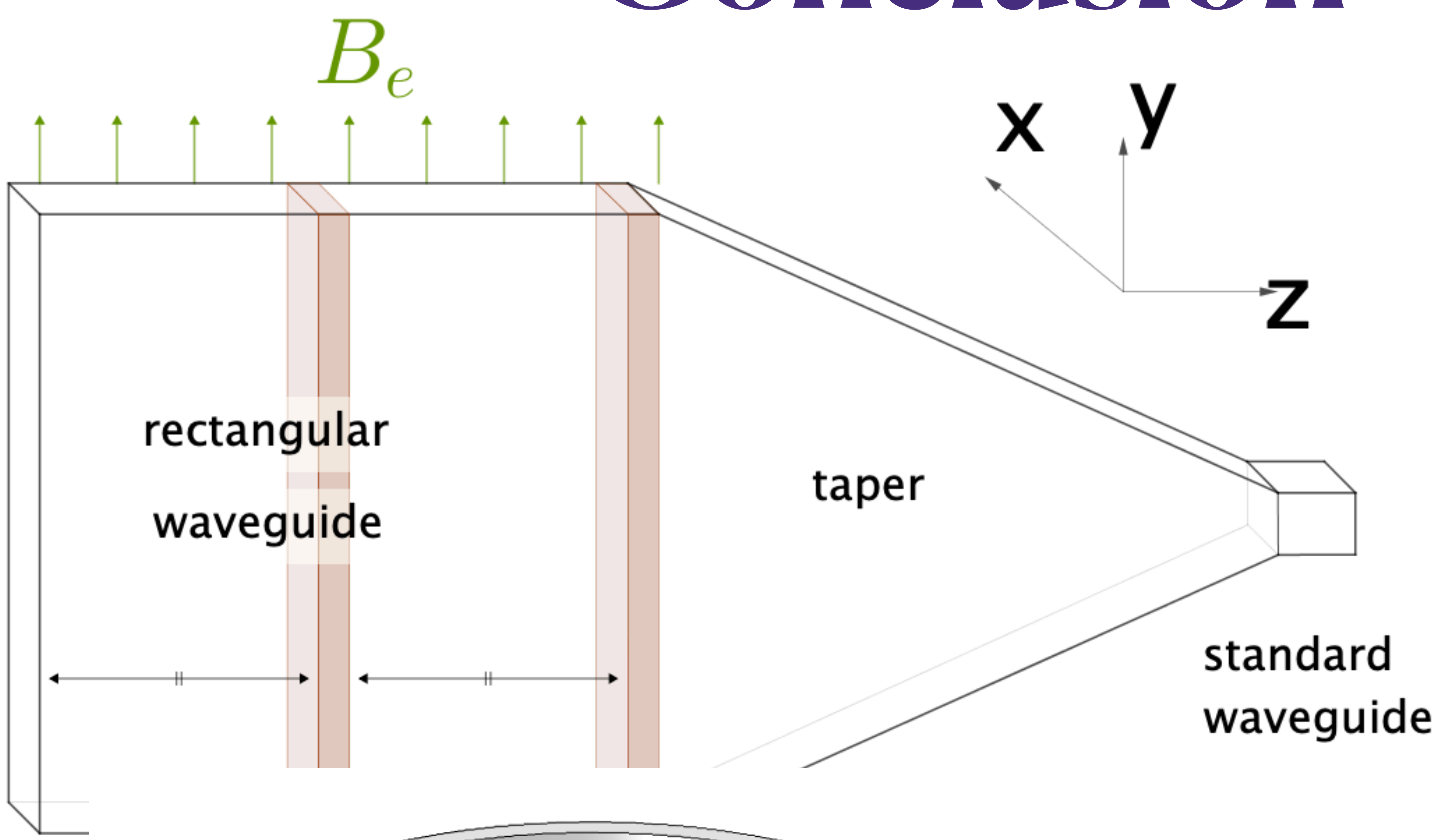
- **Single photon counters** will significantly speed up the search above 10 GHz.
- T-RAX is an ideal platform. Its taper combines the signal power into a **single port** and maximizes the signal-to-noise ratio.
- Major leap toward the QCD axion! Active ongoing developments.

Technology is progressing!!

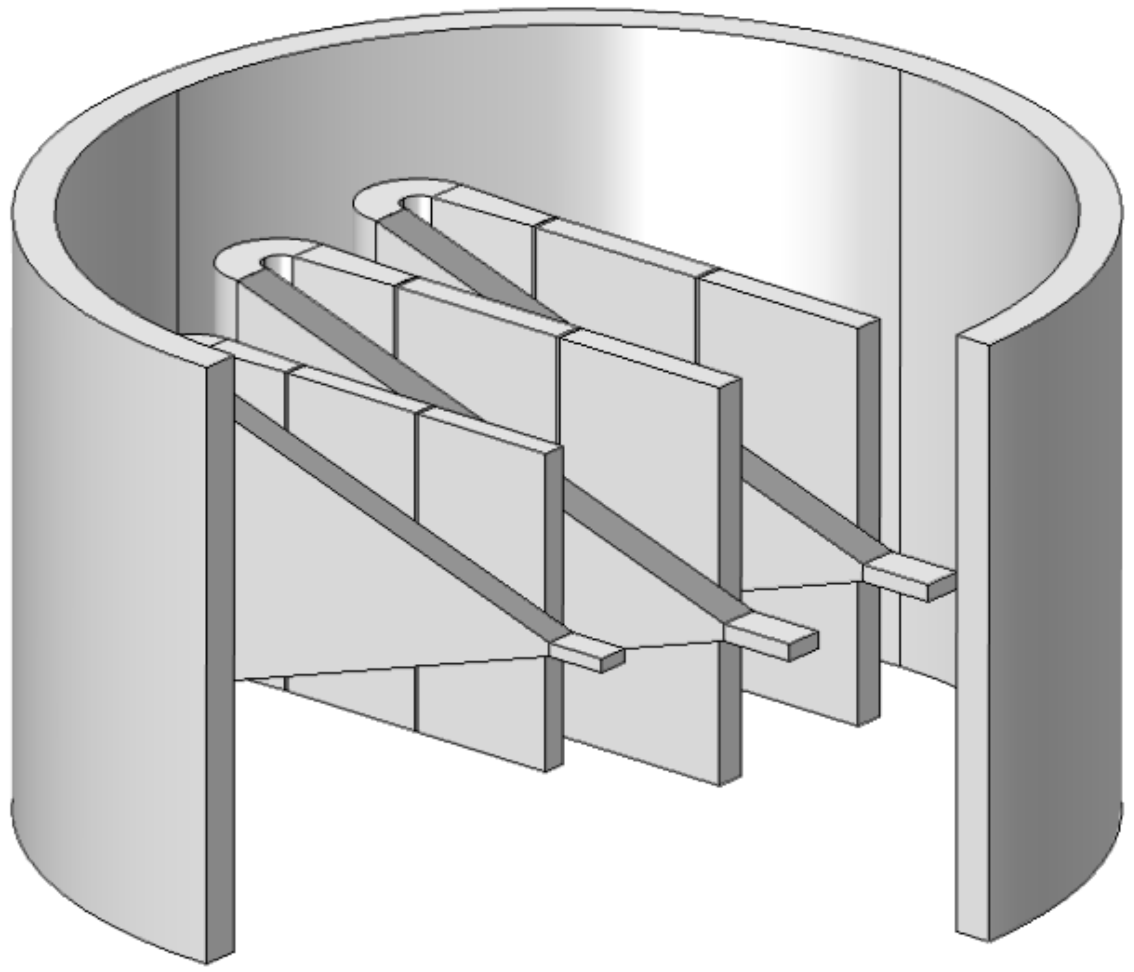


researchoutreach.org

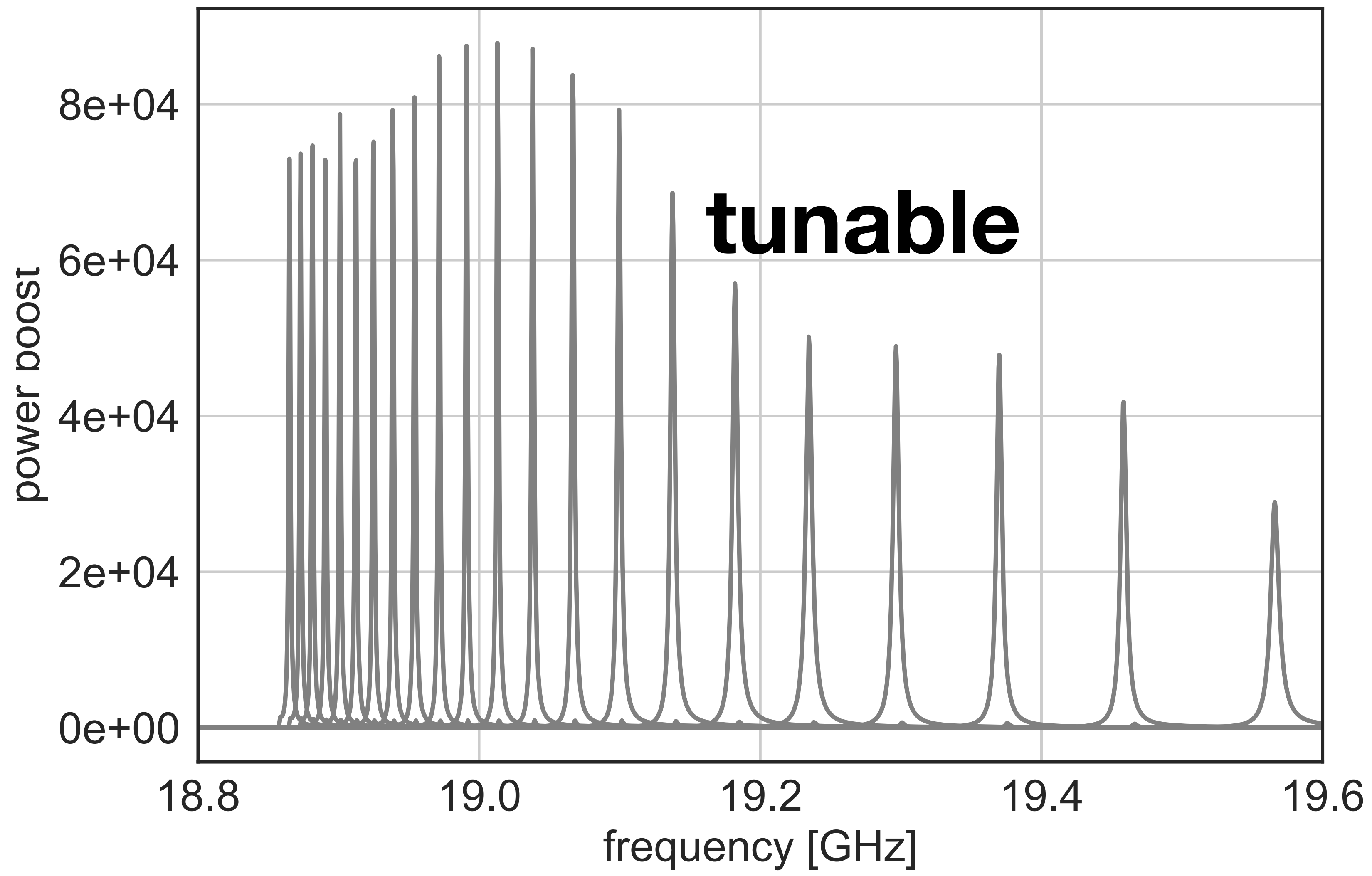
Conclusion



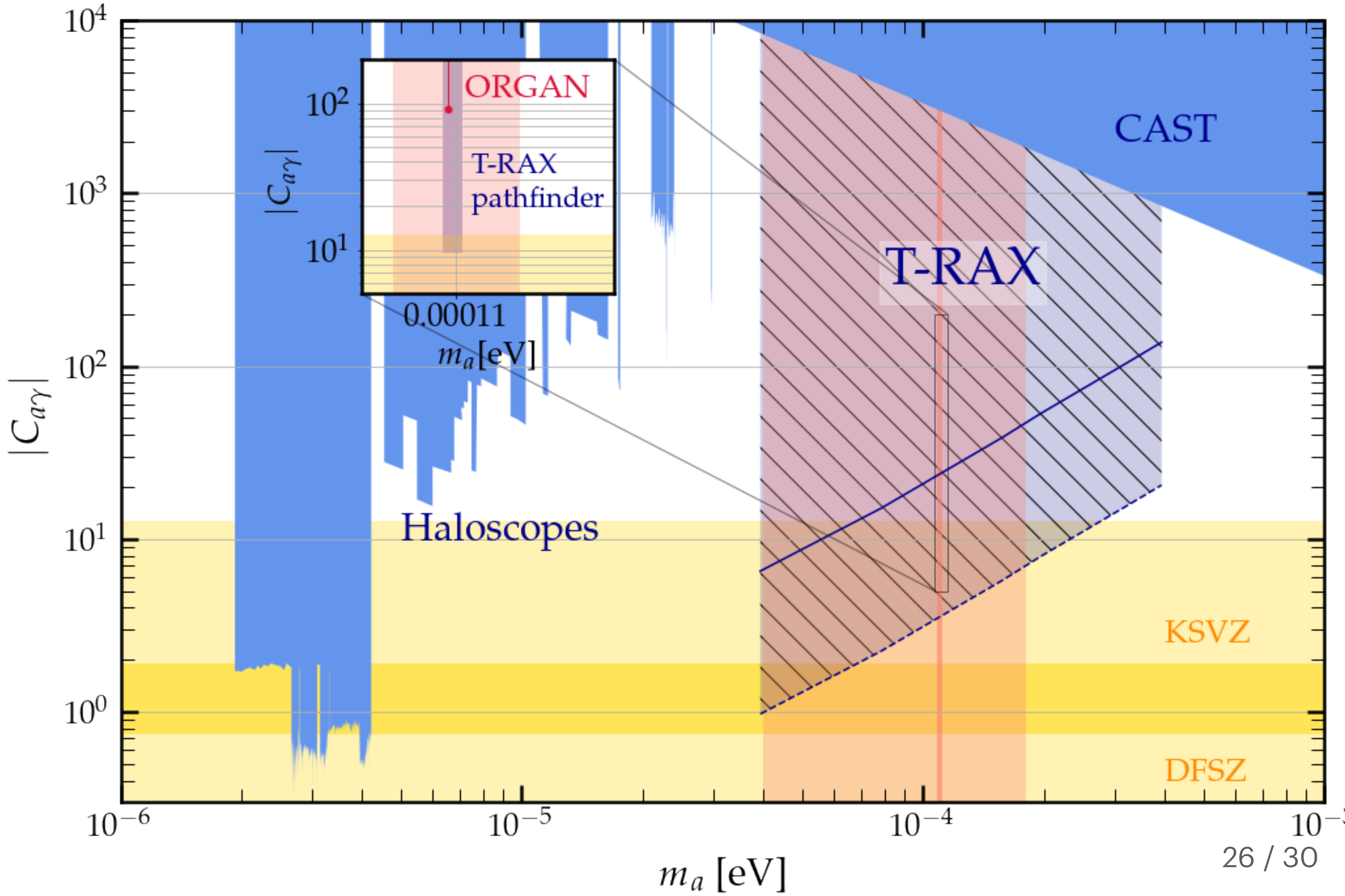
B_e
x
y
z
rectangular
waveguide
taper
standard
waveguide



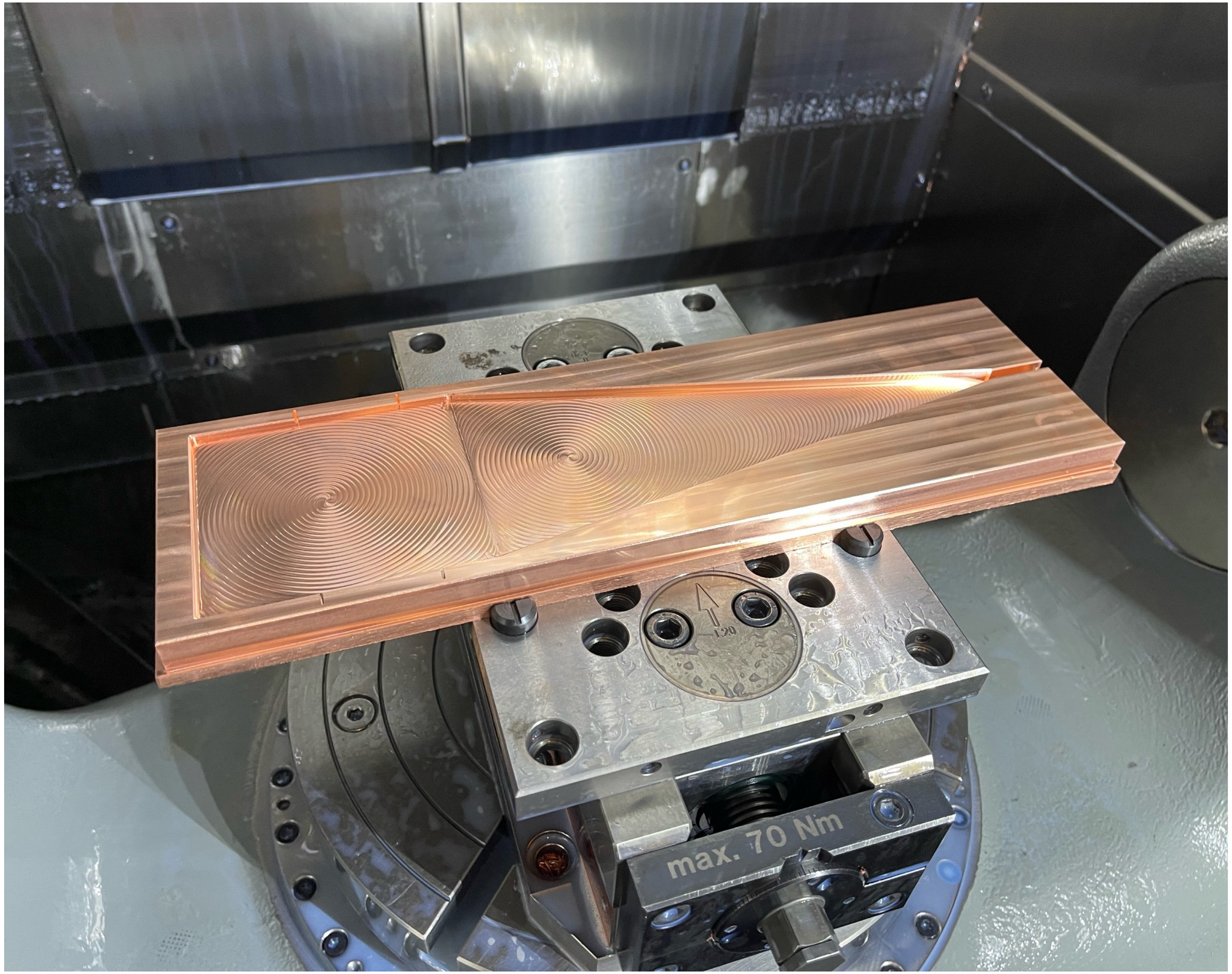
Solenoid magnet

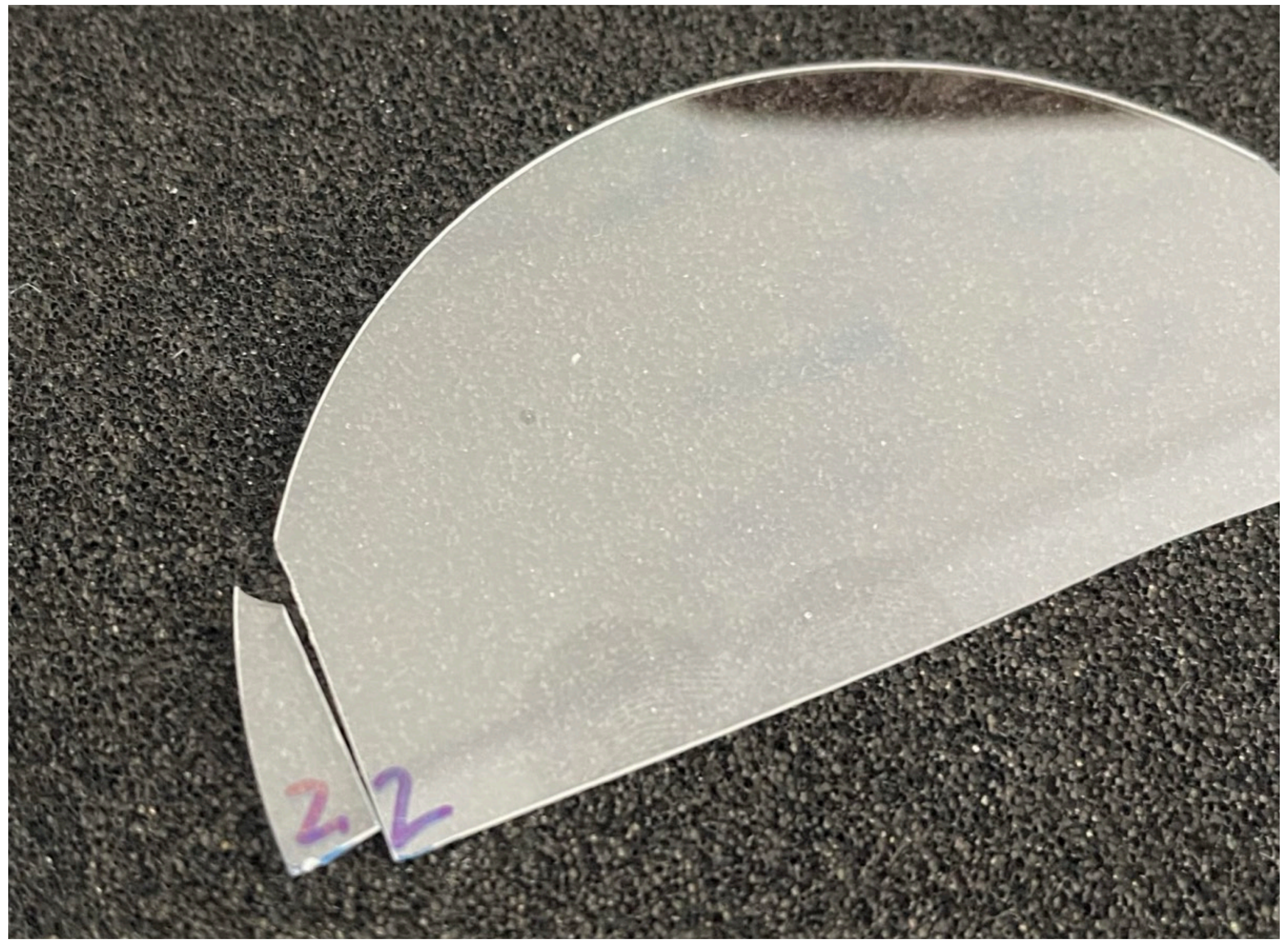


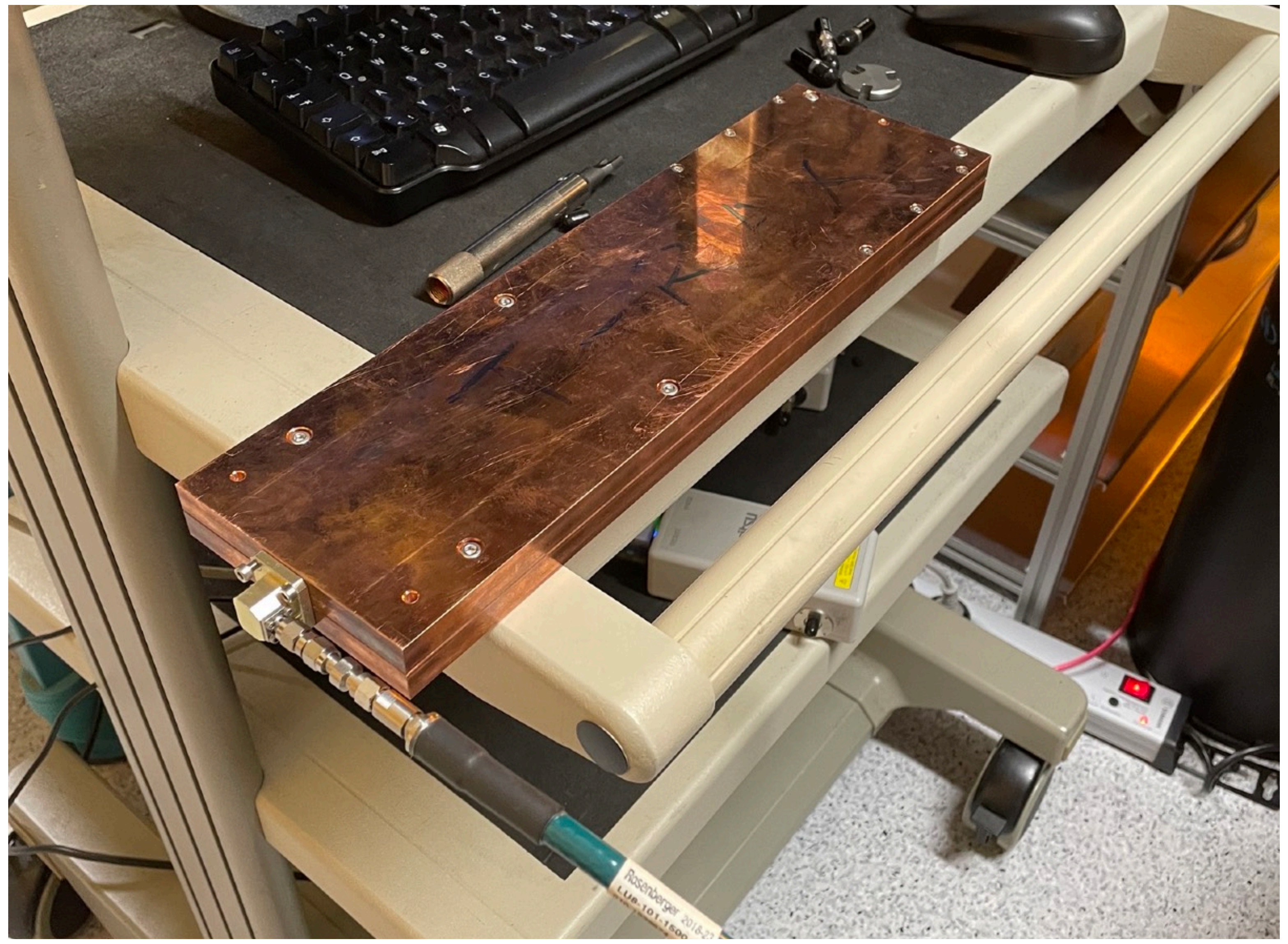
tunable
power boost
8e+04
6e+04
4e+04
2e+04
0e+00
18.8
19.0
19.2
19.4
19.6
frequency [GHz]



$|C_{a\gamma}|$
10^4
10^3
10^2
10^1
10^0
ORGAN
T-RAX
pathfinder
0.00011
m_a[eV]
CAST
T-RAX
Haloscopes
KSVZ
DFSZ
10^{-6}
10^{-5}
10^{-4}
m_a [eV]







Initial measurement last week!

redbubble.com

Dark matter!

Extra

Dielectric positioning