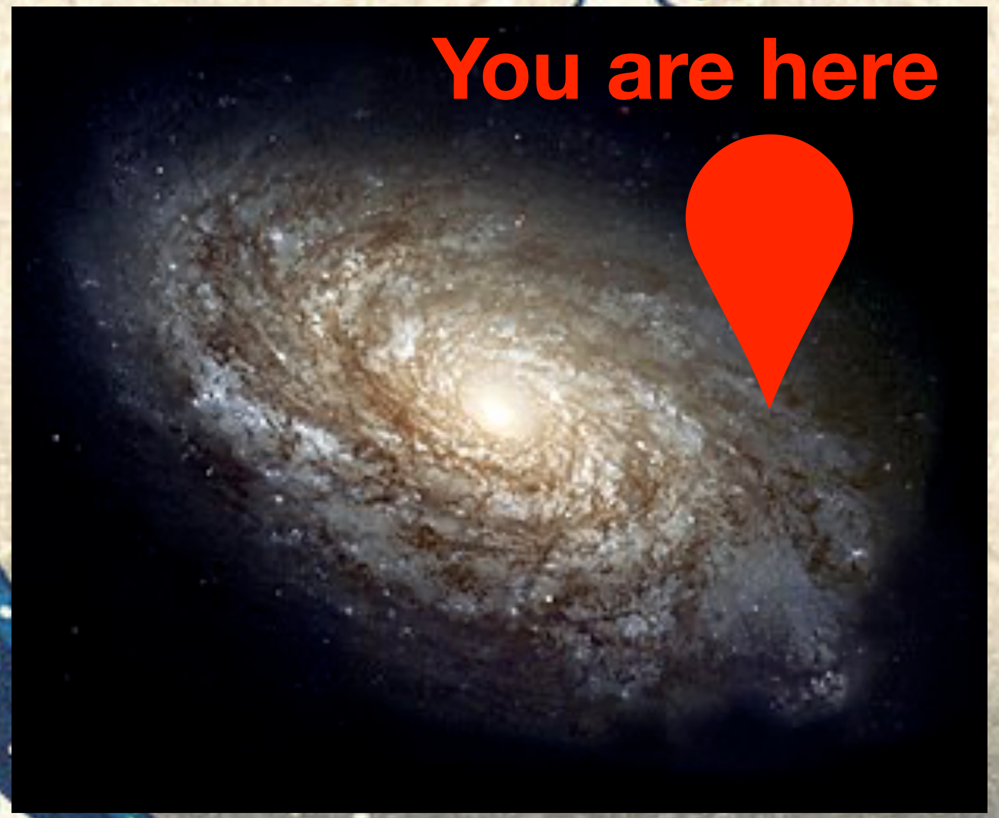
T-RAX: transversely resonant axion experiment



Novel experiment for post-inflationary axion dark matter, arXiv: 2203.15487

Chang Lee, Olaf Reimann,
Max Planck Institute for Physics

Motivation

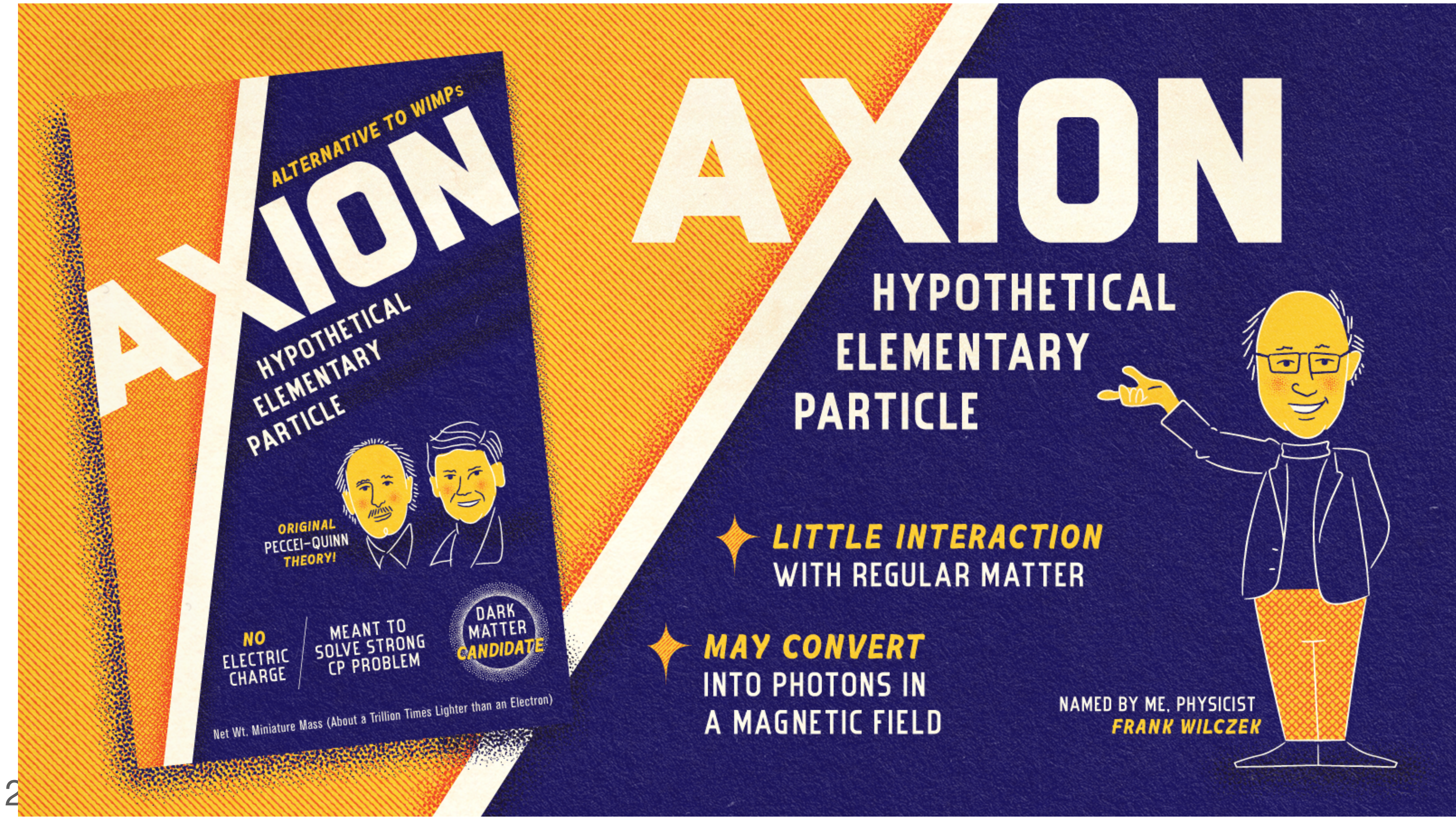
QCD axion DM

- PQ symmetry to solve the strong CP problem
  - Spontaneous symmetry breaking @ f_A: axion
- well-motivated wave CDM candidate
  - Non-thermal: cold
  - Small interaction with SM particles.

$$\mathscr{L} = \frac{1}{f_A} J^\mu \partial_\mu \phi, \ \ f_A \gg v_{\mathrm{EW}}$$

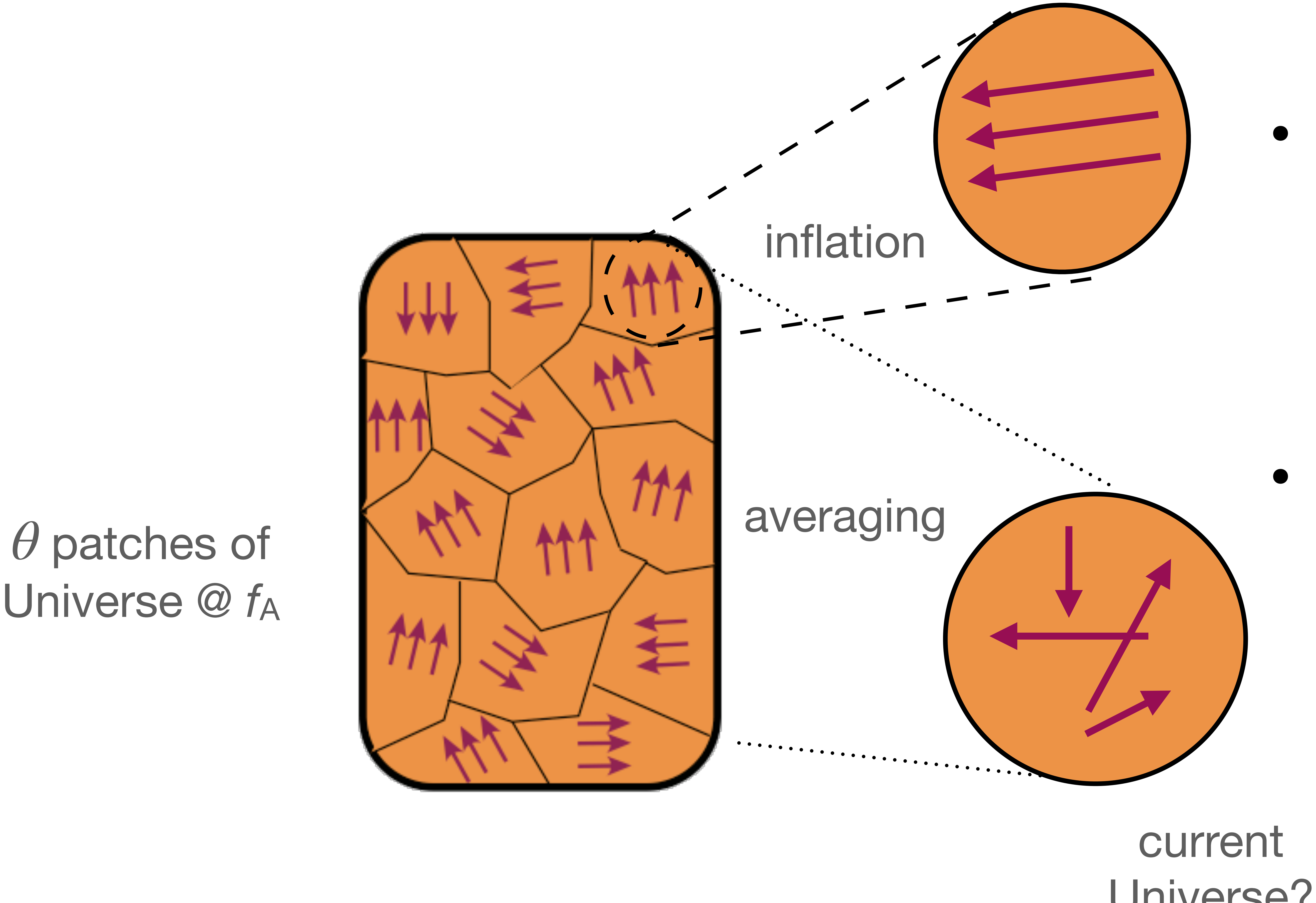
  - Small m_a has a long lifetime.

https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.symmetrymagazine.org%2Farticle%2Fthe-other-dark-matter-candidate&psig=AOvVaw0ANqCIl0ryFIaJKtcEvgnS&ust=1643403924692000&source=images&cd=vfe&ved=0CAsQjRxqFwoTCODh_O3q0vUCFQAAAAAdAAAAABA0



Motivation

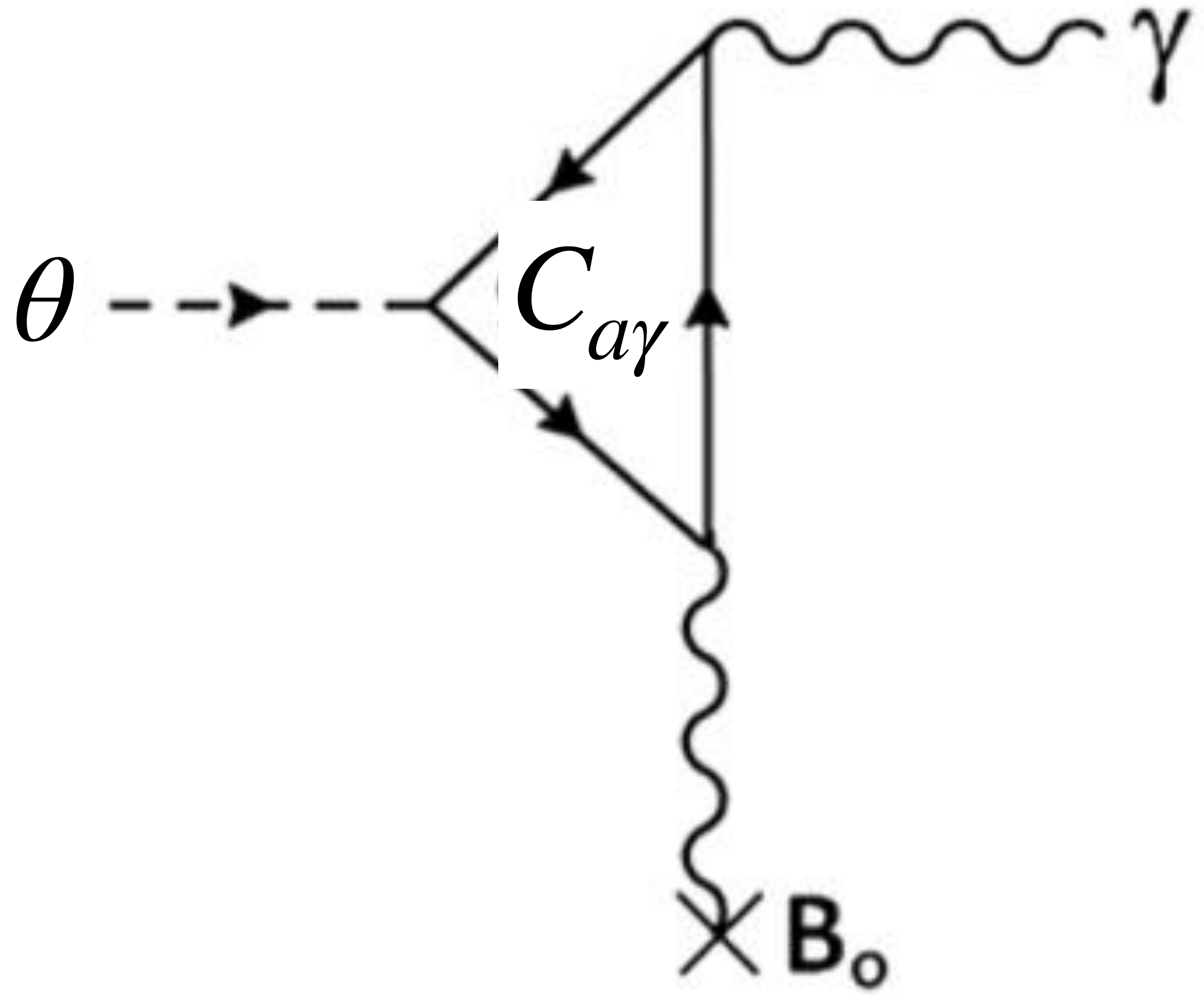
Post-inflationary axion DM mass



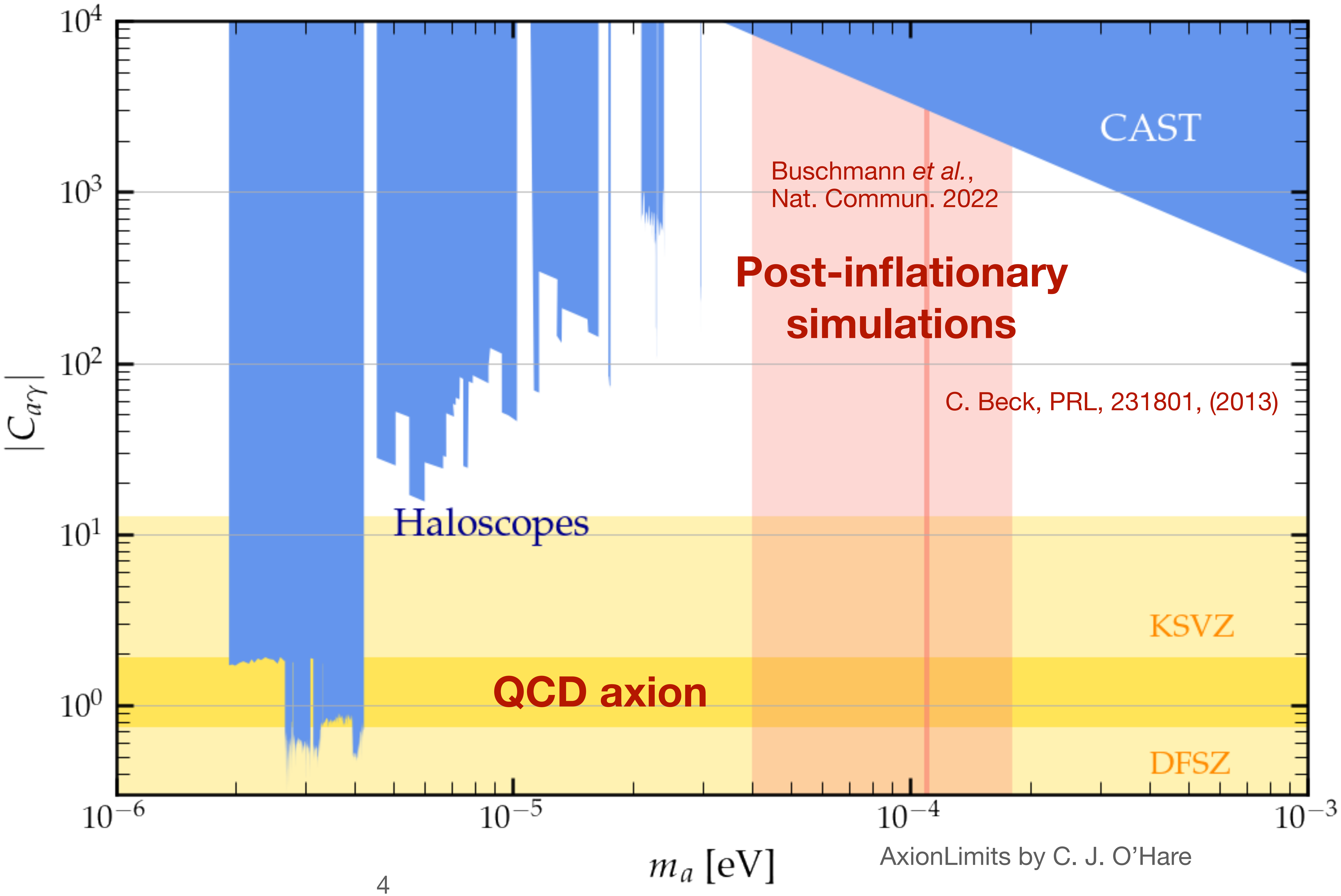
- Pre-inflationary scenarios allows much wider m_a.
- Post-inflationary production prefers m_a : 40 – 180 μeV.
  Buschmann *et al.*,
  Nat. Commun. 2022

DM axion detection status

axion-photon coupling



- $C_{a\gamma} \propto \sqrt{P_{\text{sig}}}$
- Scan speed $\propto P_{\text{sig}}^2$



AxionLimits by C. J. O'Hare

Principle

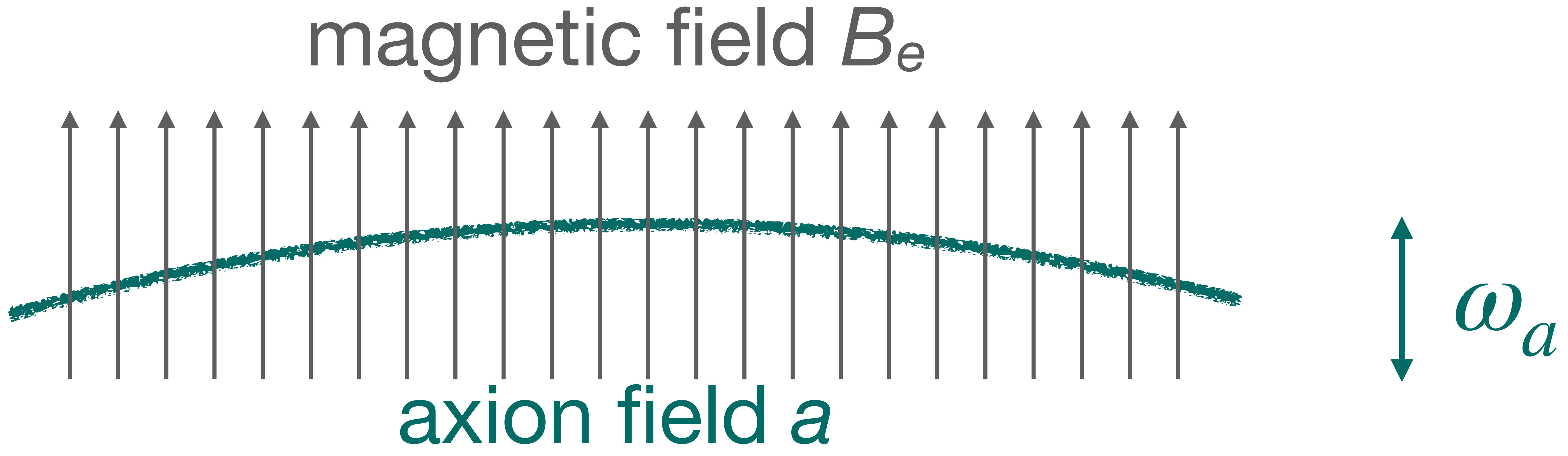
Principle

Axion-induced E-field

axion field a

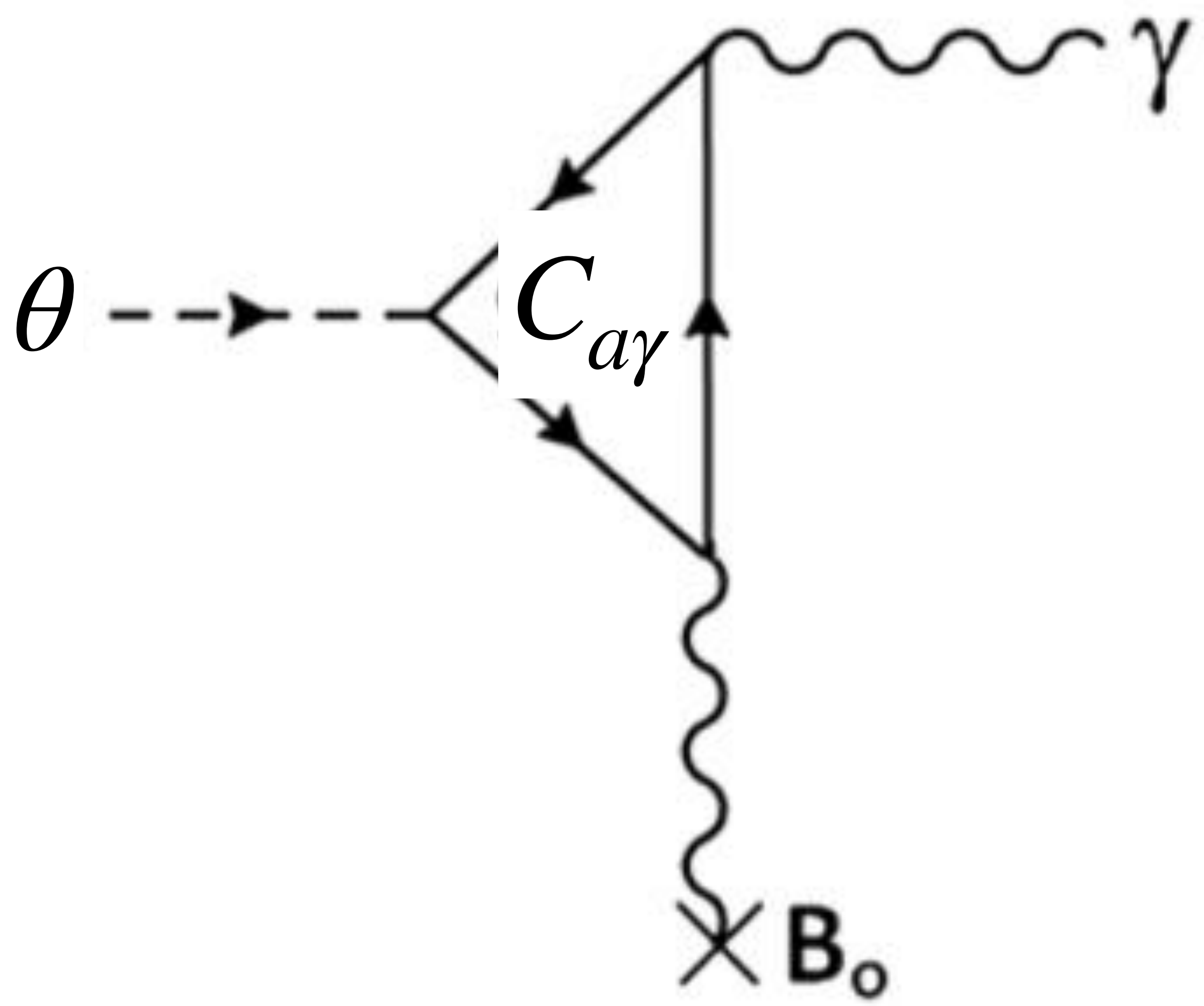
Principle

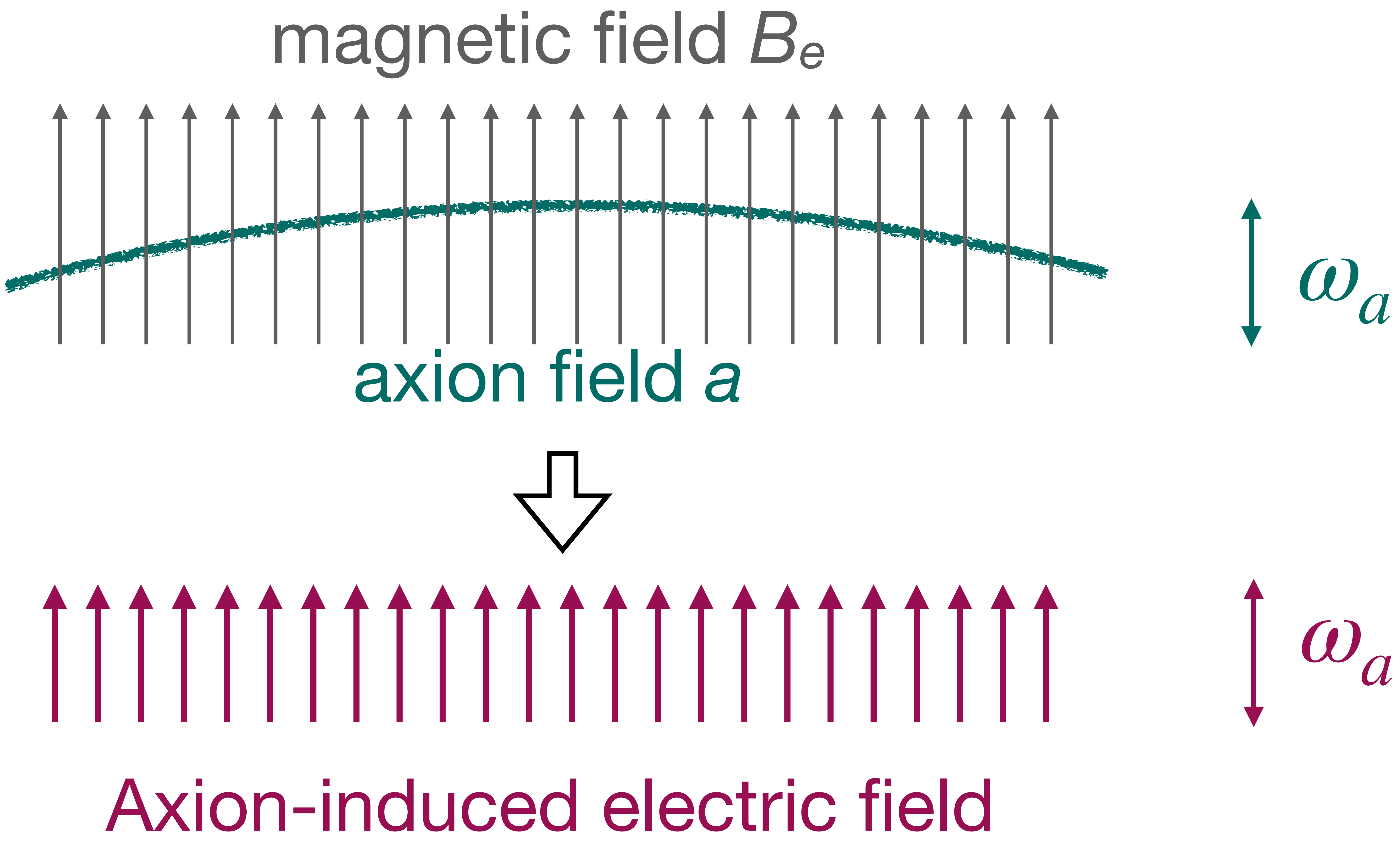
Axion-induced E-field



Principle

Axion-induced E-field





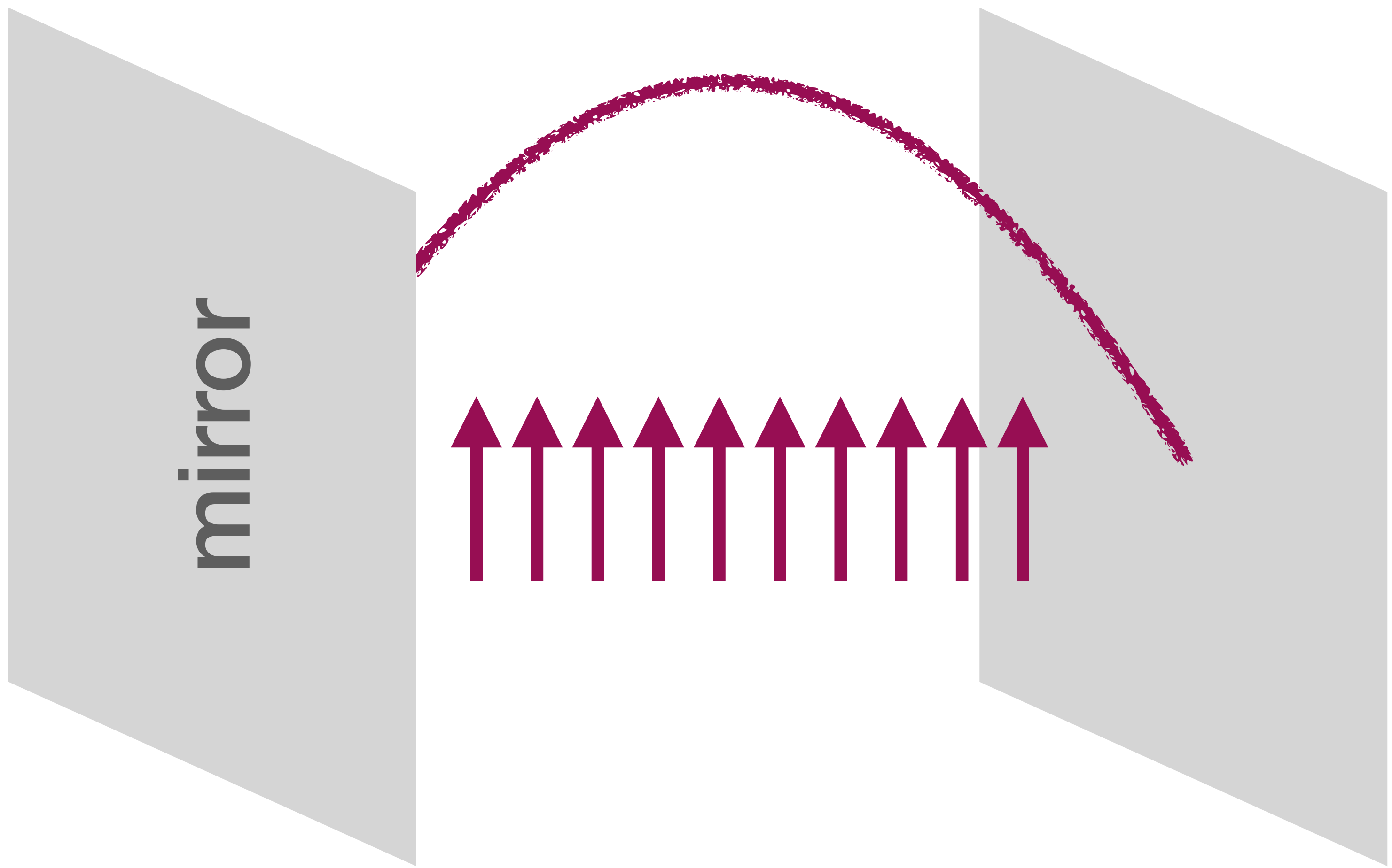
$$E_0 \propto C_{a\gamma} B_e \theta$$

$$\sim 10^{-13} \text{ [V/m/T]}$$

Principle

Cavity

- Axion-induced E-field excites resonance in a cavity
  - Cavity experiments “sense the field” using a dipole antenna



Principle

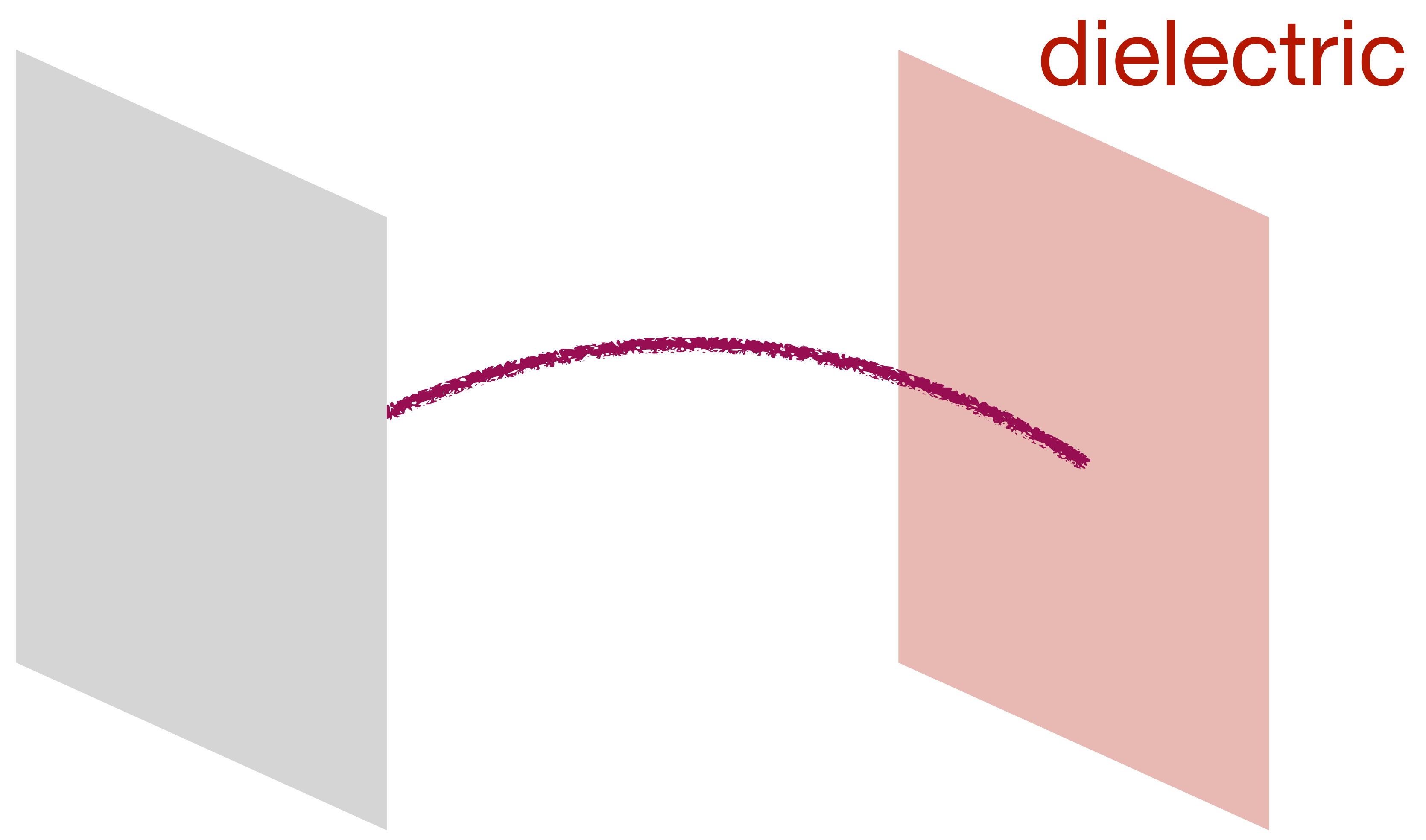
Cavity

- Axion-induced E-field excites resonance in a cavity
  - Cavity experiments “sense the field” using a dipole antenna
  - $P_{\text{sig}} \propto U_{EM} \propto \nu^{-2}$, or ν^{-3} due to mode-crossing

Principle

Leaky resonator

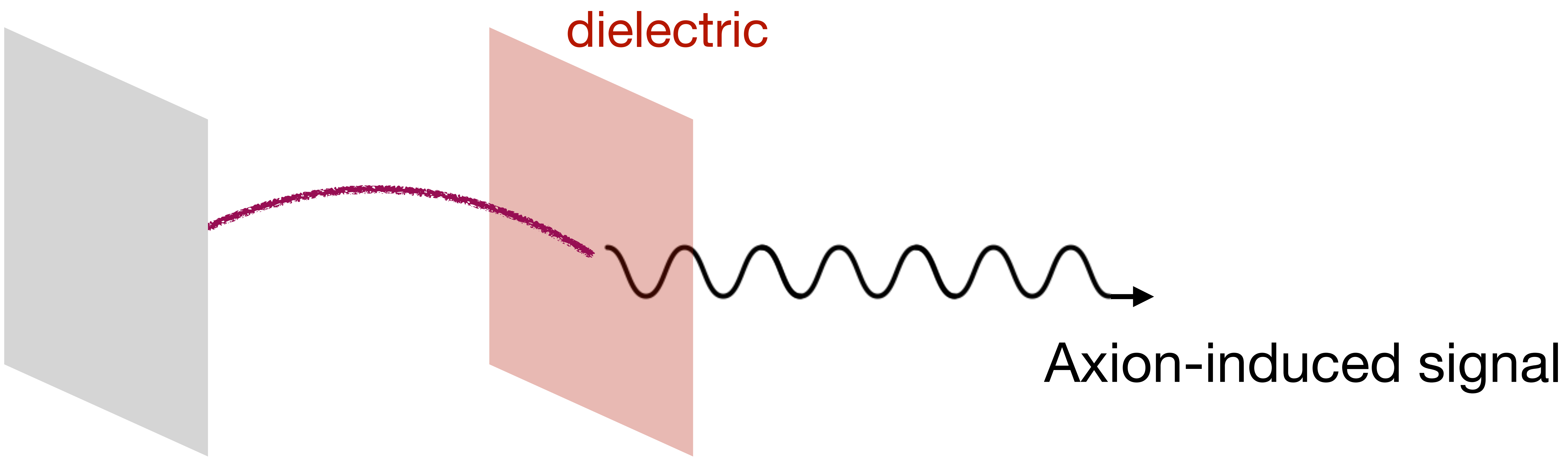
- Replace one wall with a **dielectric**.



Principle

Leaky resonator

- Replace one wall with a **dielectric**.
- The axion signal leaks through the dielectric window
  P_{sig} is **independent of ν!**



Principle

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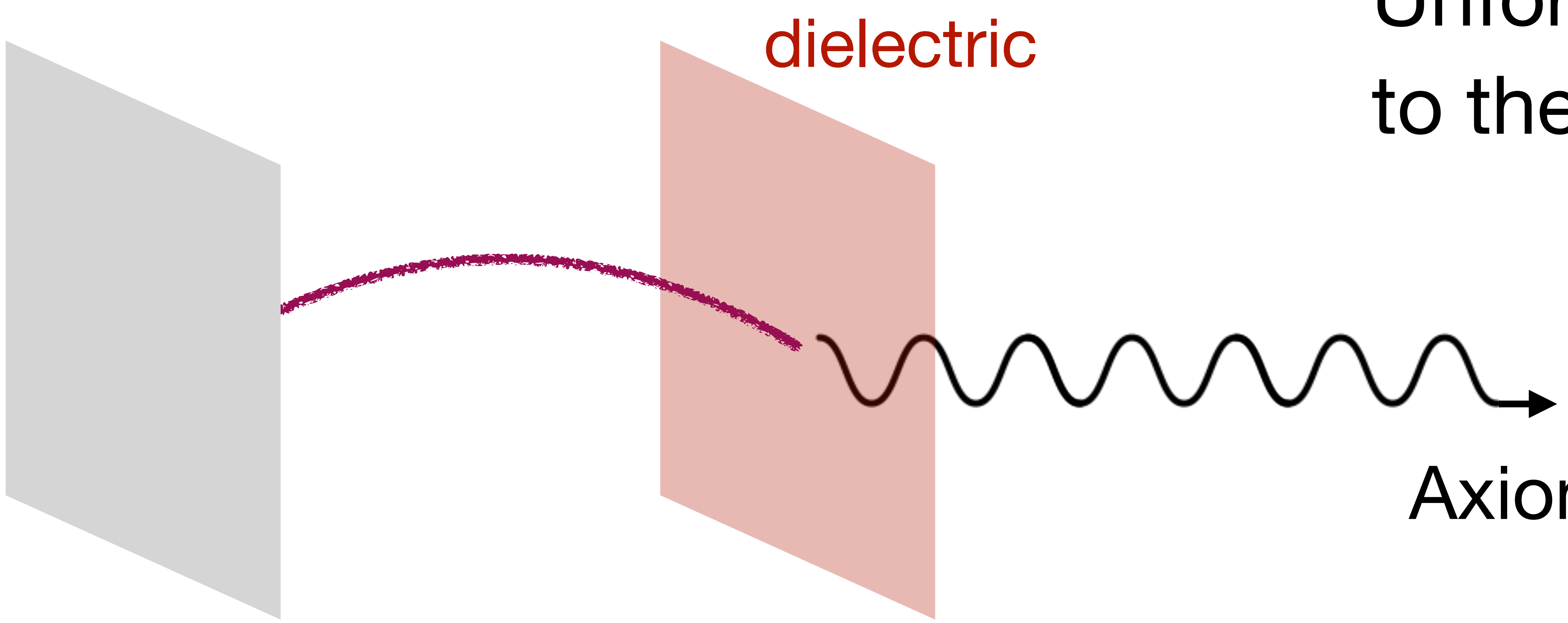
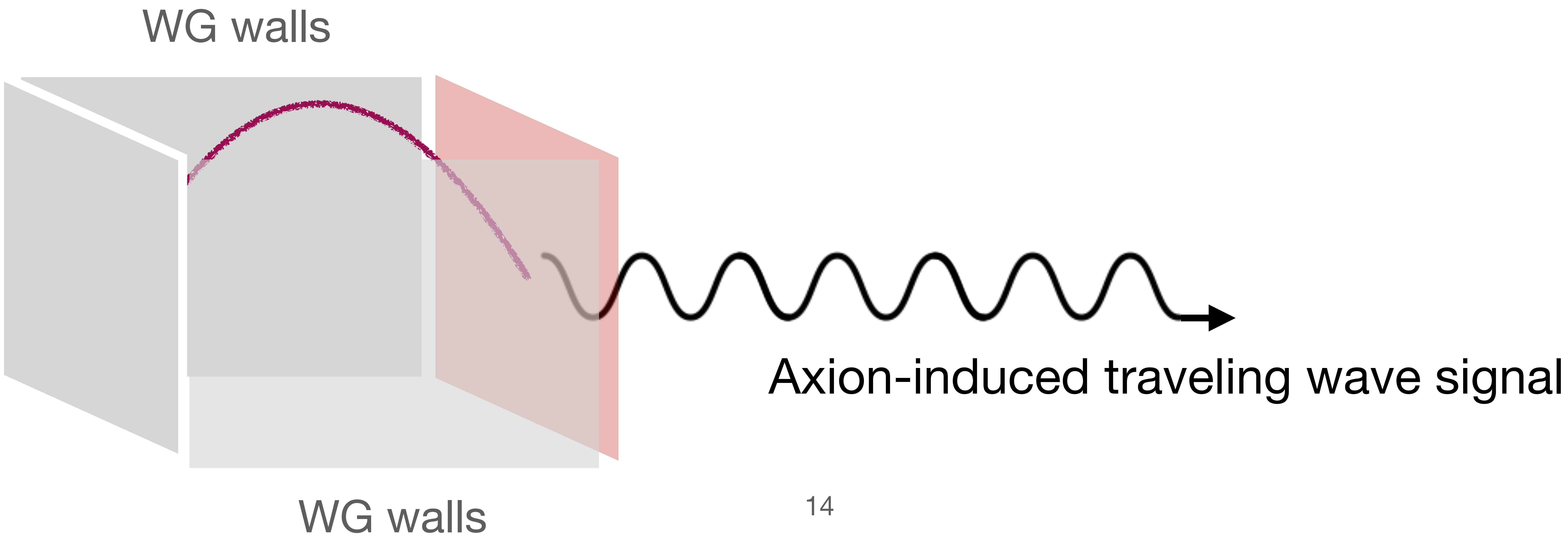


Unfortunately, P_{sig} is smaller due to the low dielectric reflectivity

Principle

Boost near cut-off

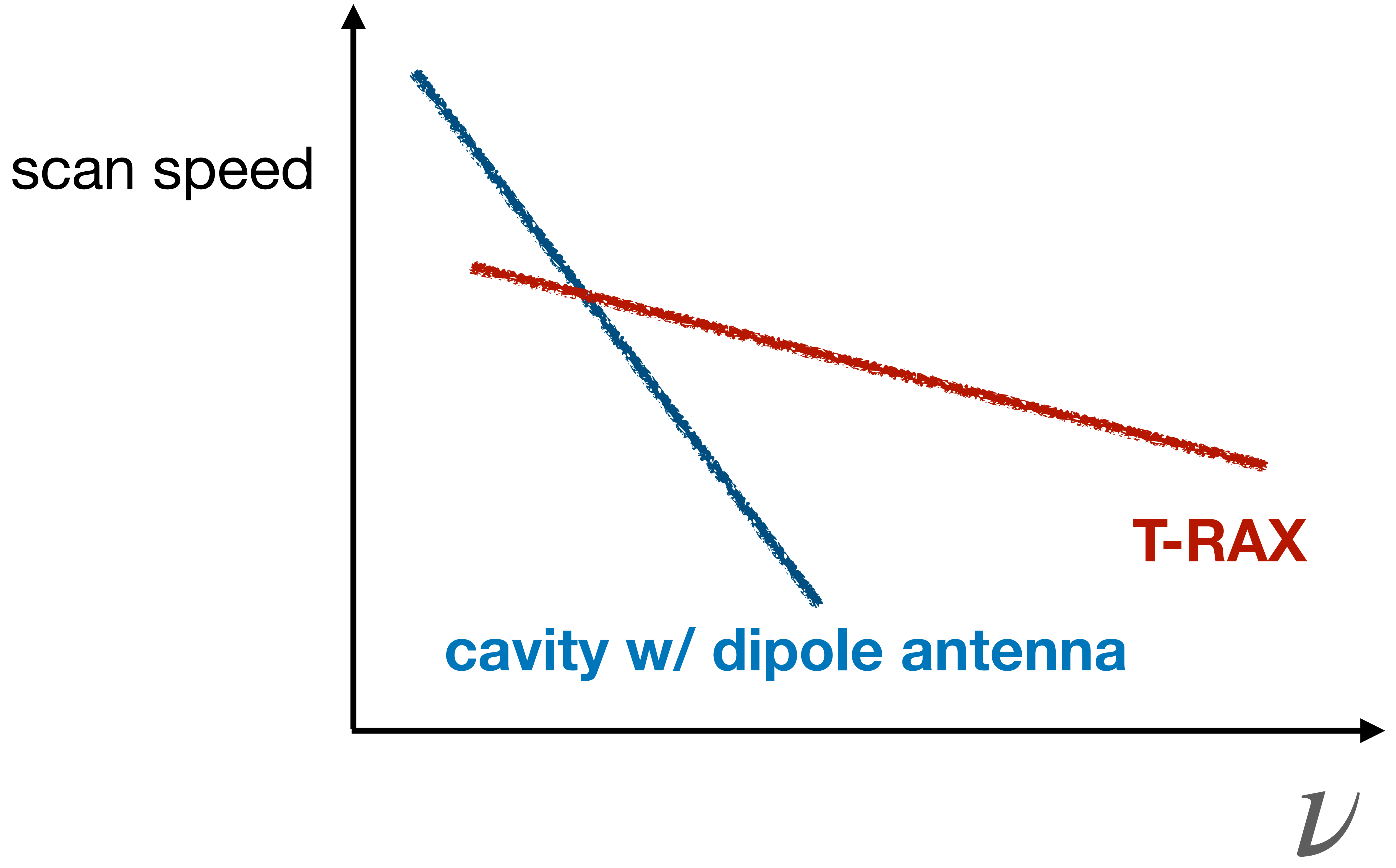
- T-RAX: **waveguide walls** on the side.
- Reflectivity increases near the waveguide cut-off ($\beta \to 0$), and P_{sig} is **boosted**!

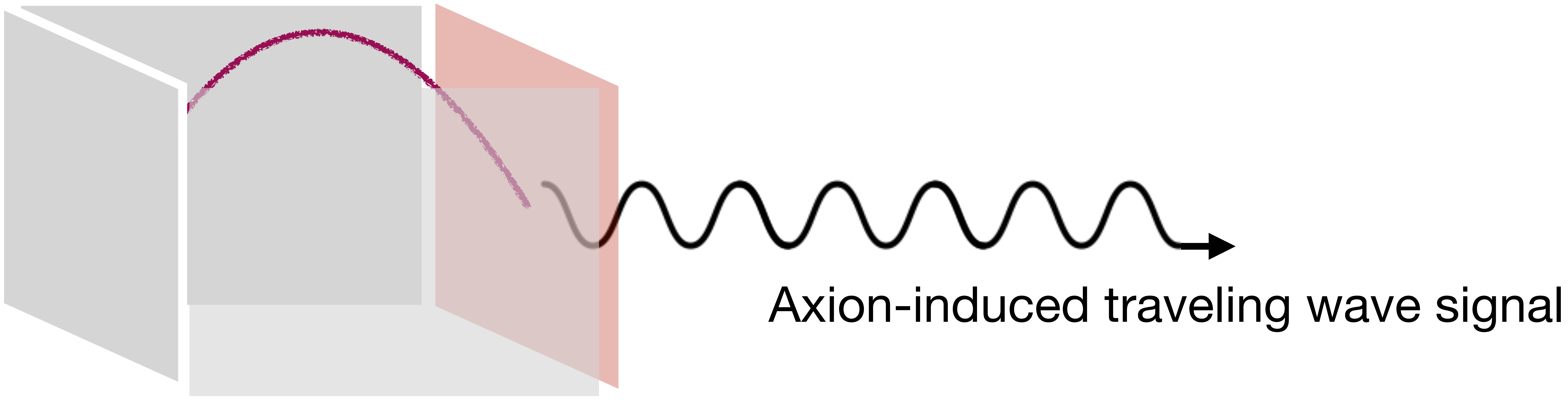


Principle

Scaling vs. frequency ν

- P_{sig} scales $\propto \nu^{-1}$ from the width, faster than a circular cavity's $\propto \nu^{-2}$
- Scan speed $\propto P^2_{\text{sig}}$!

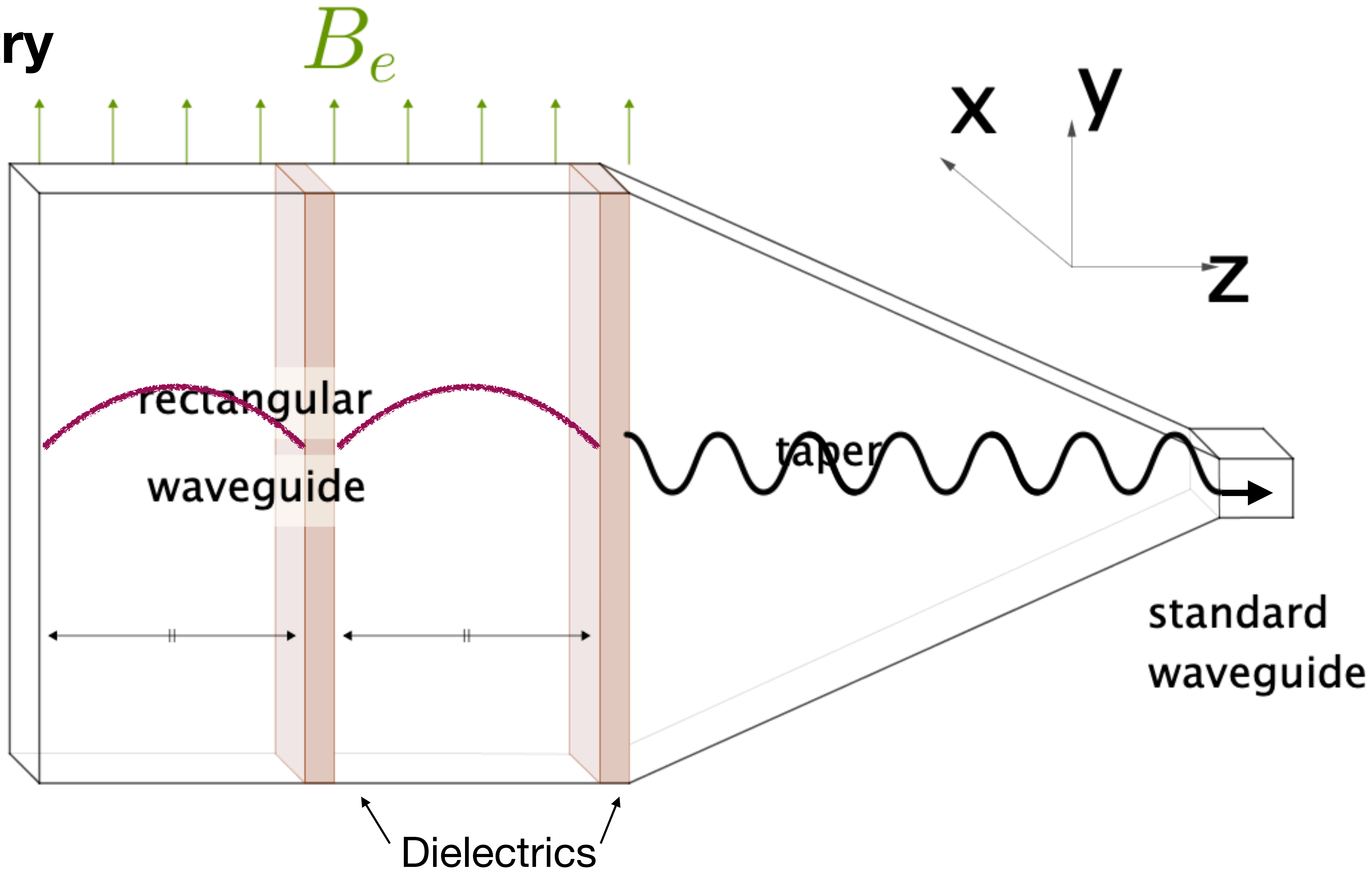




Simulation

Simulation

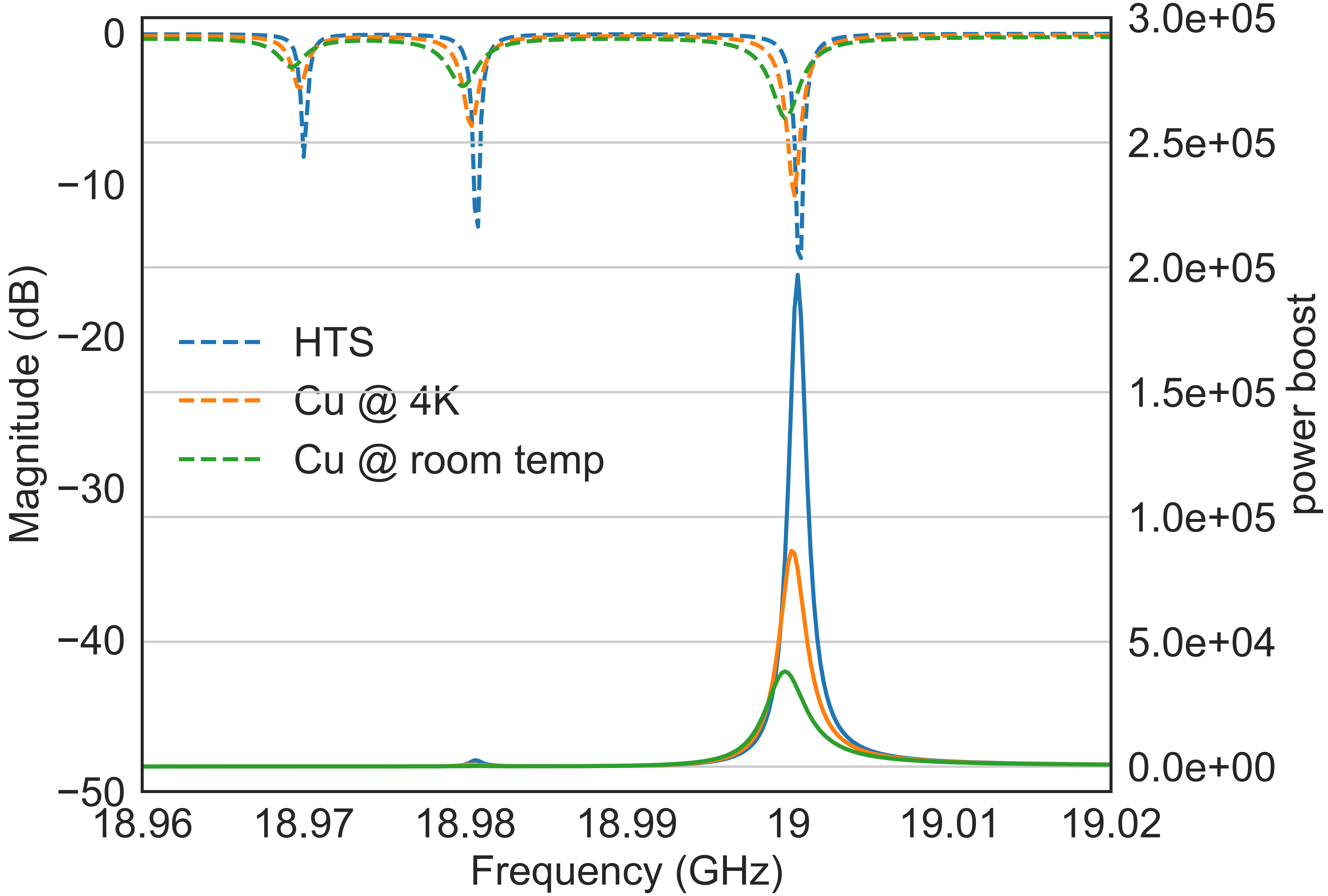
Geometry



Simulation

Results

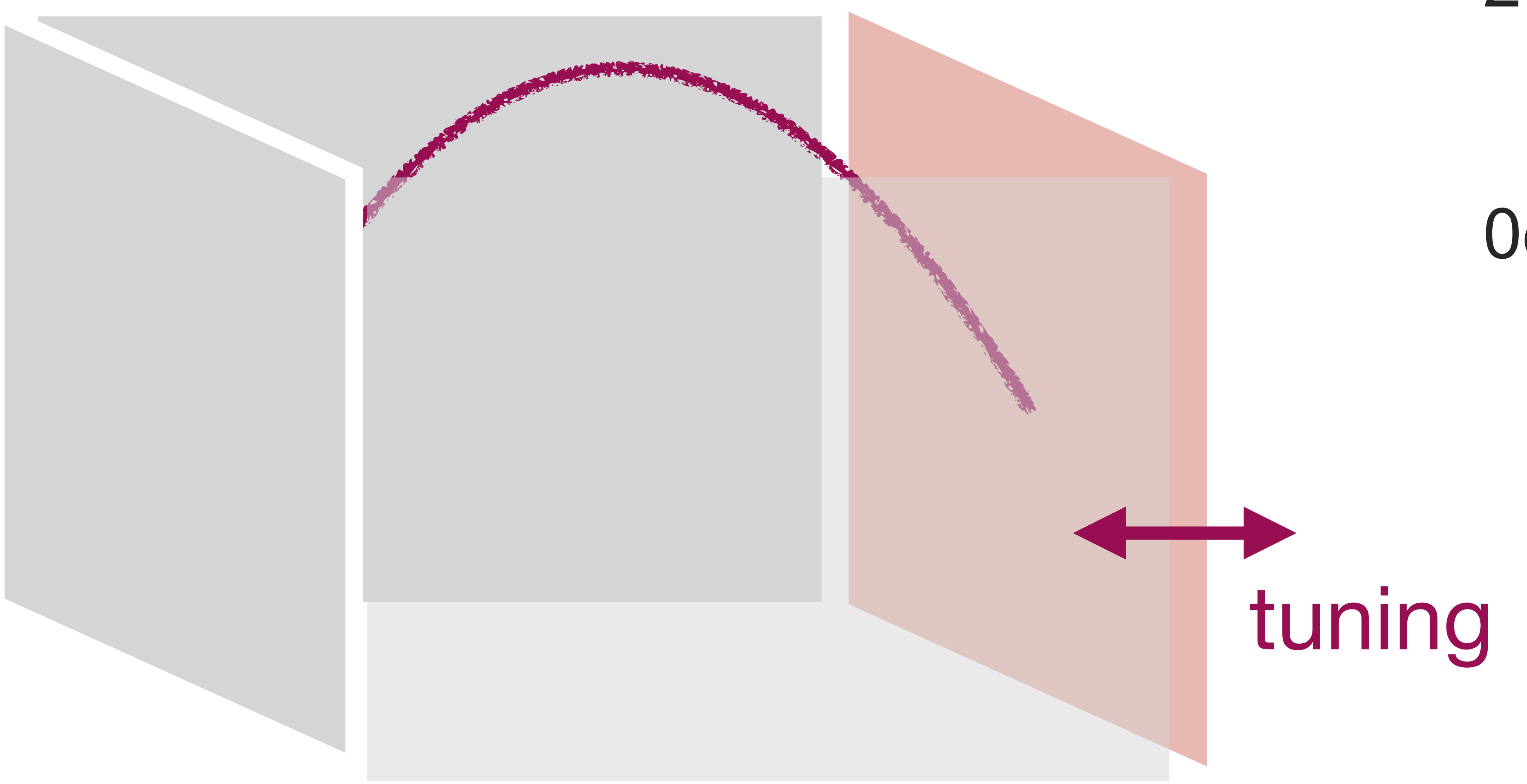
- 80k signal **power boost** from the flat mirror case.
  - > x6 signal power than the ORGAN TM010 mode @ 26.6 GHz (100mm)
- Higher conductivity increases the signal power.

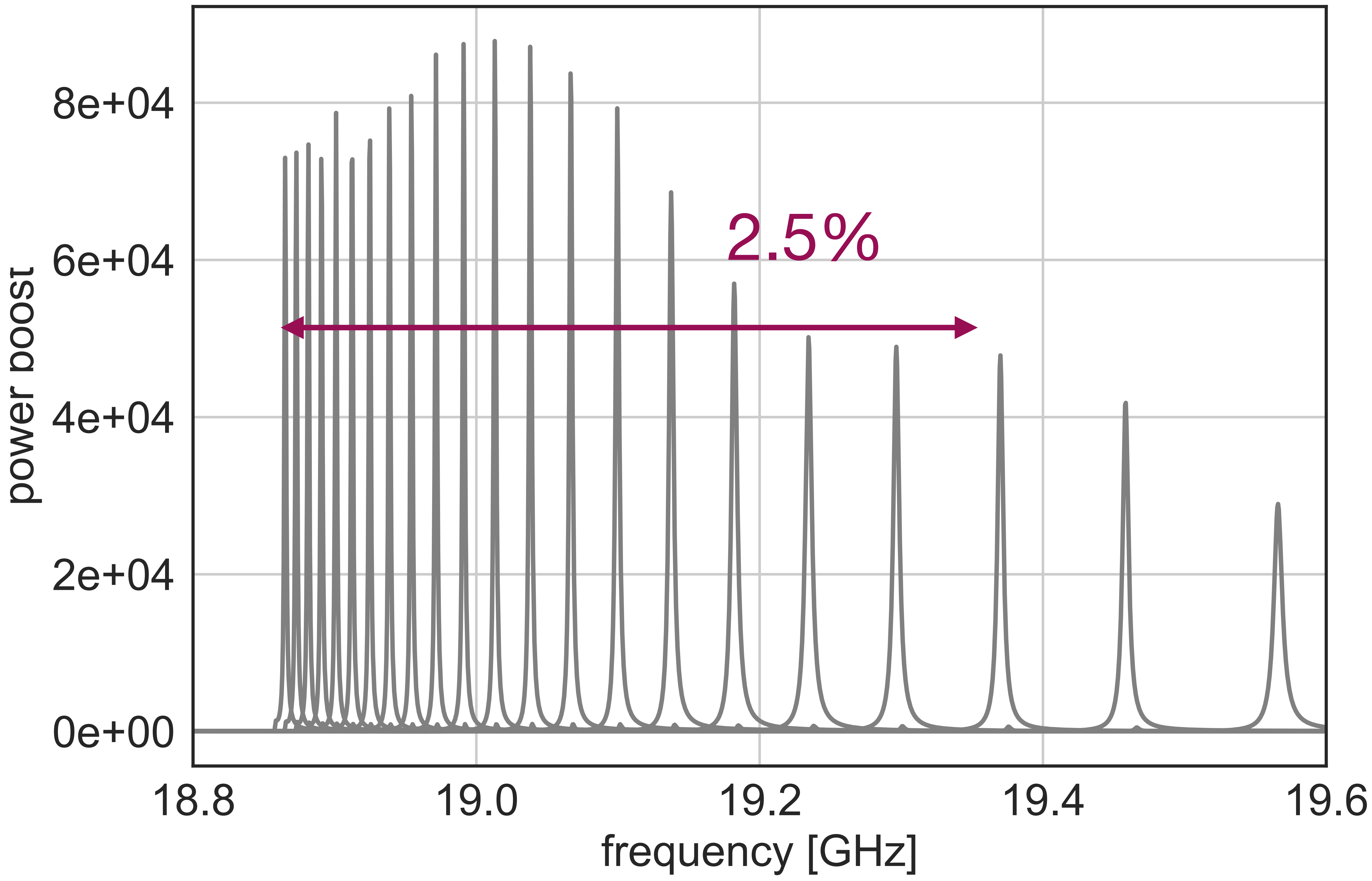


Simulation

Tuning

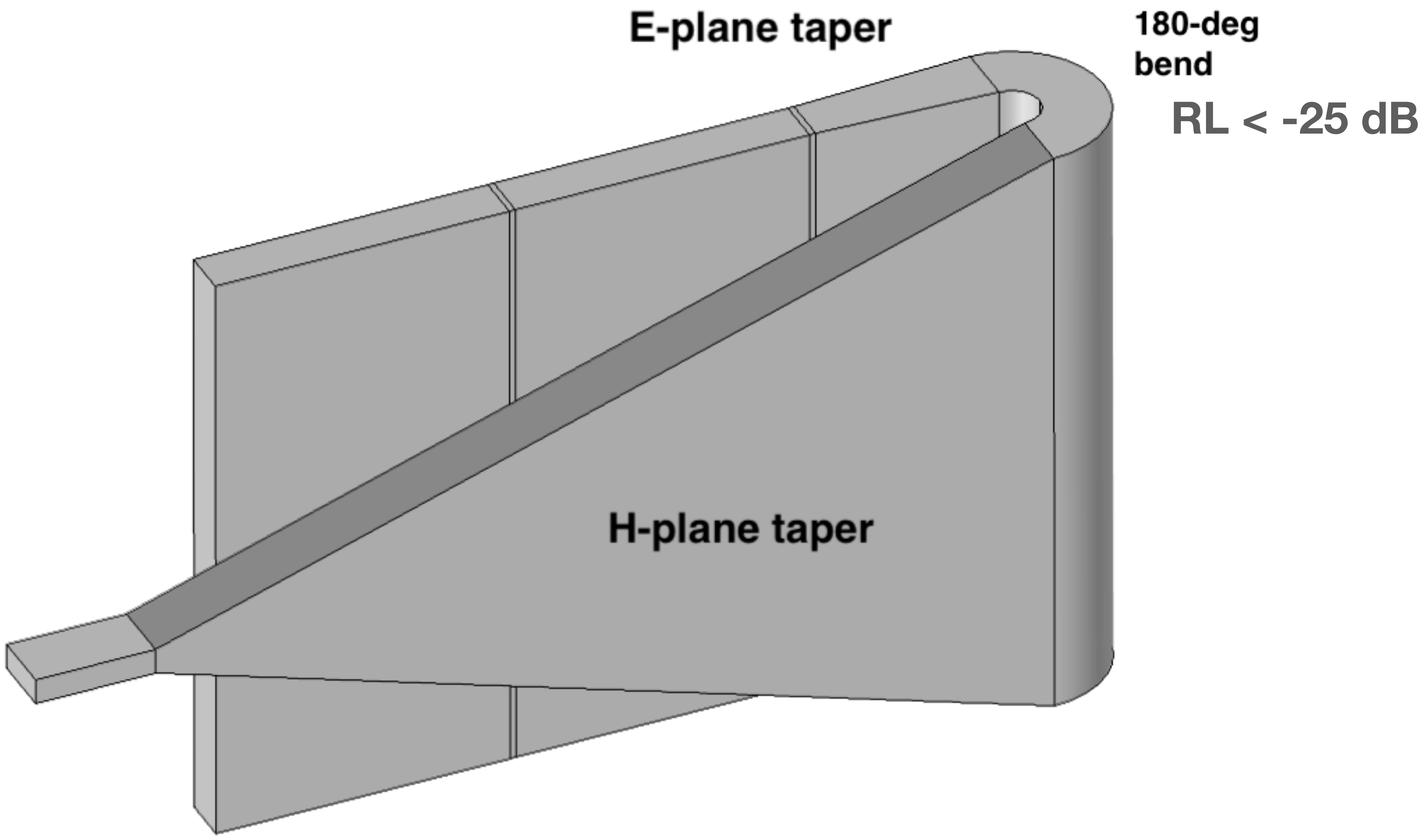
- Scan a wider **mass range** by **moving the dielectrics** (and changing the k_z vector).

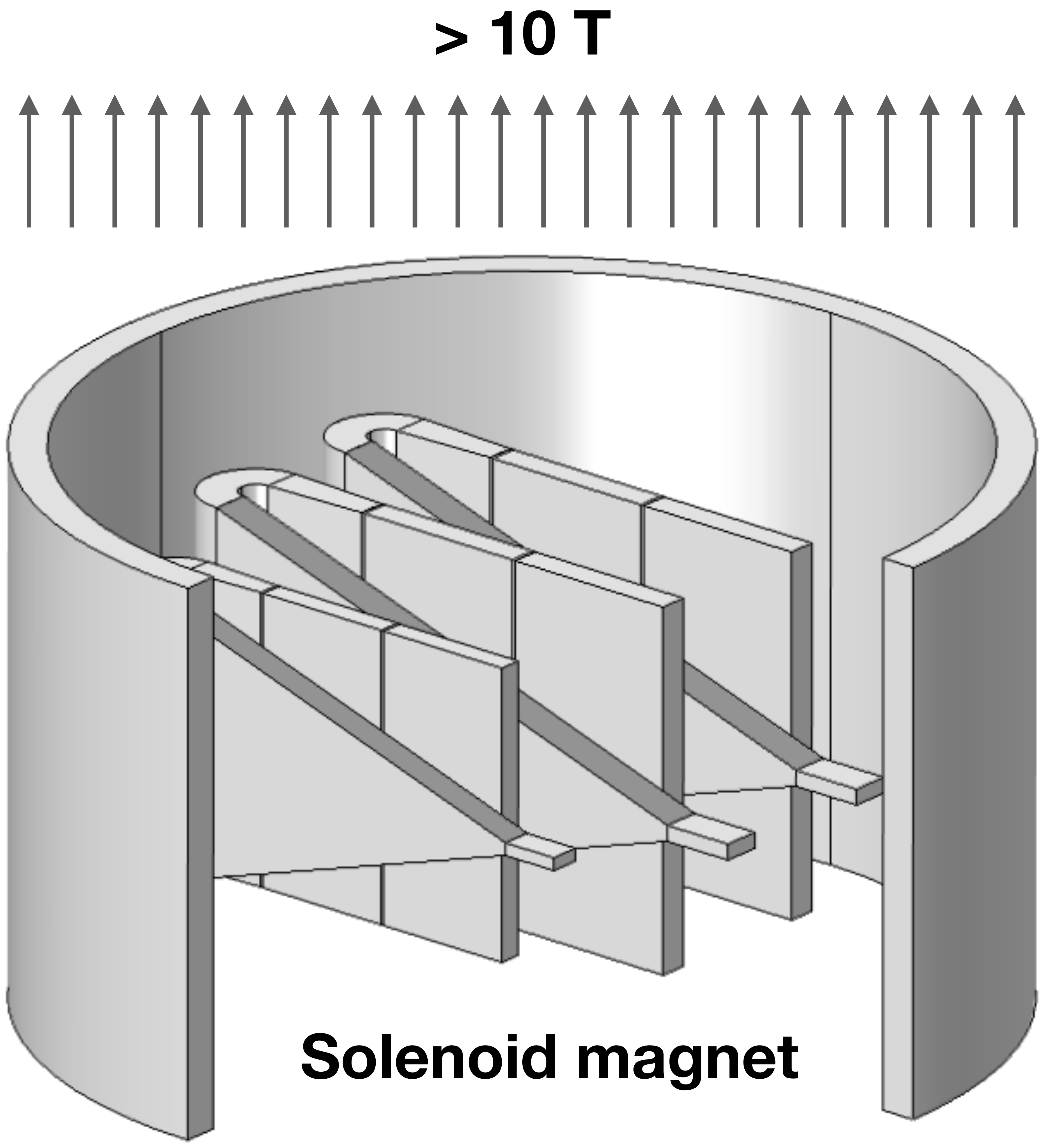




Magnet application

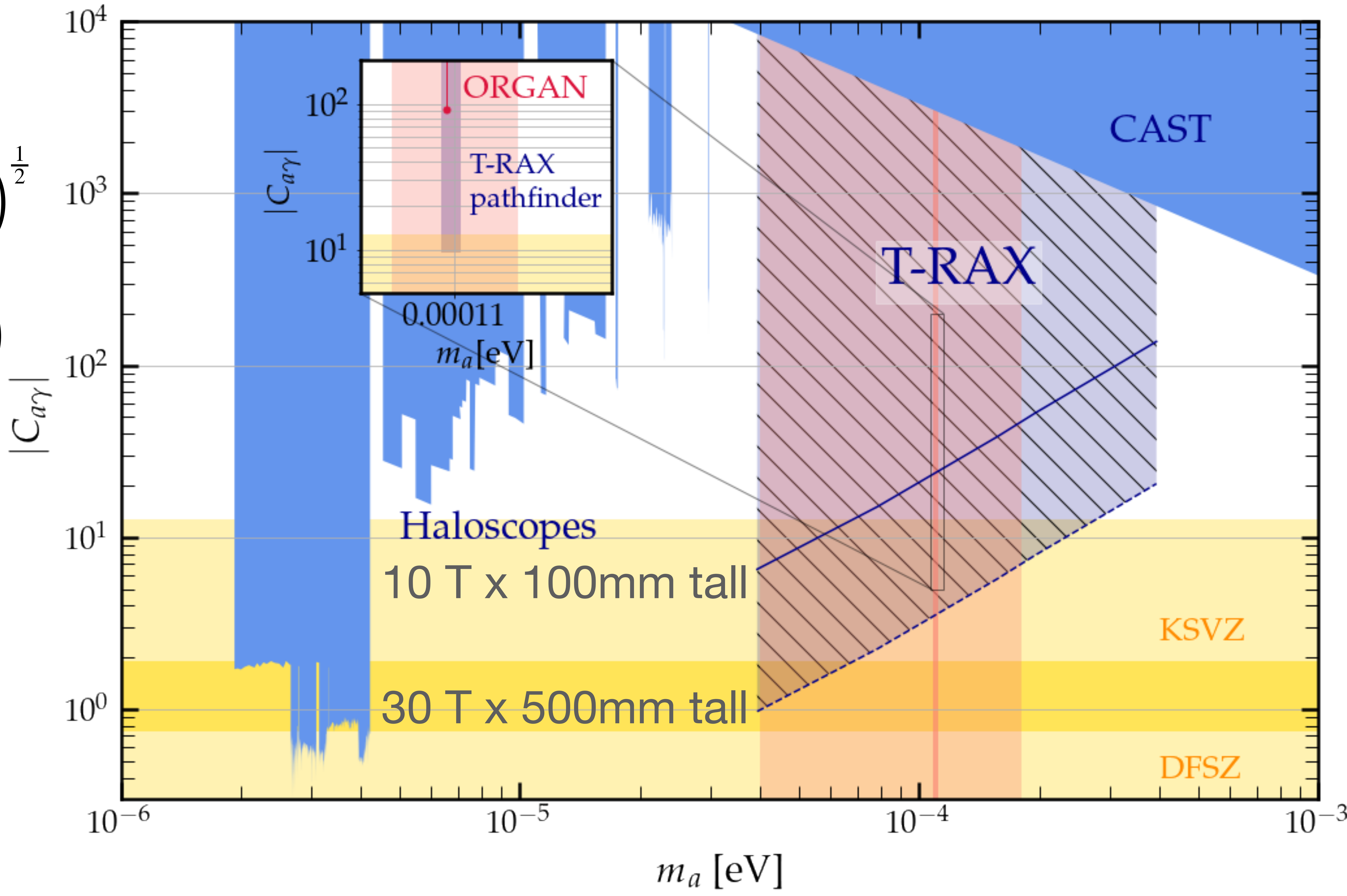
Folding & packing



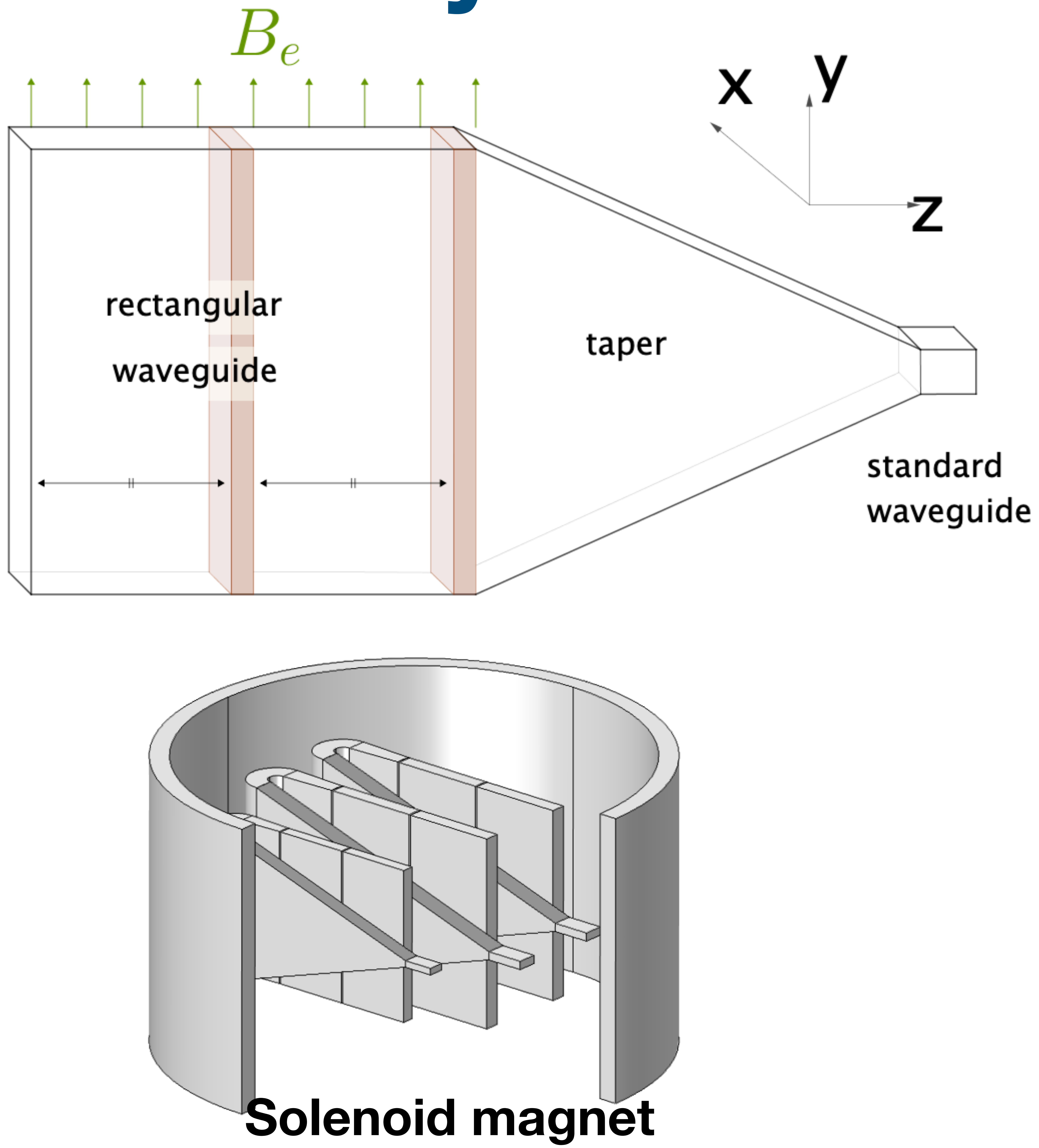


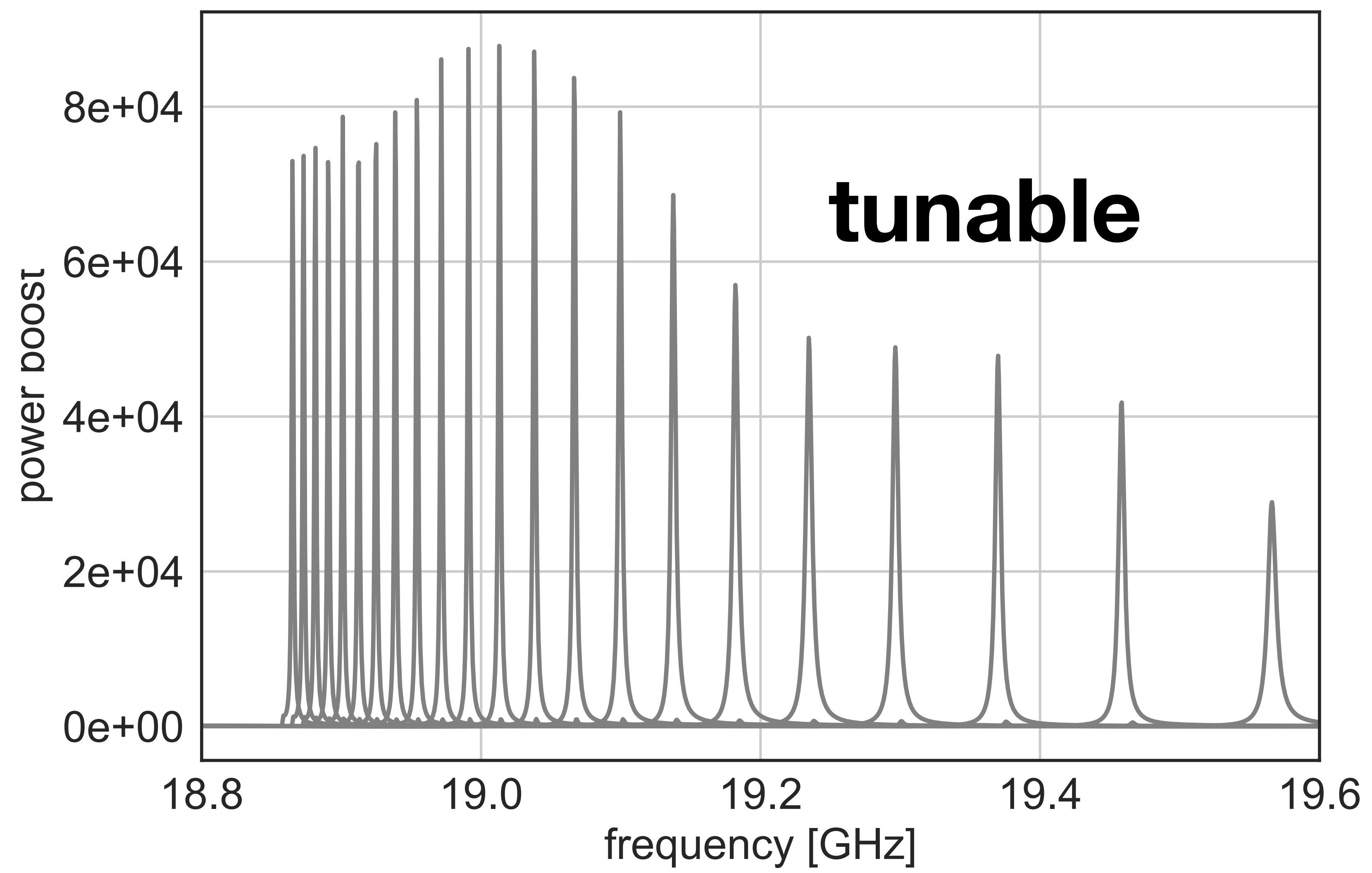
Projected sensitivity

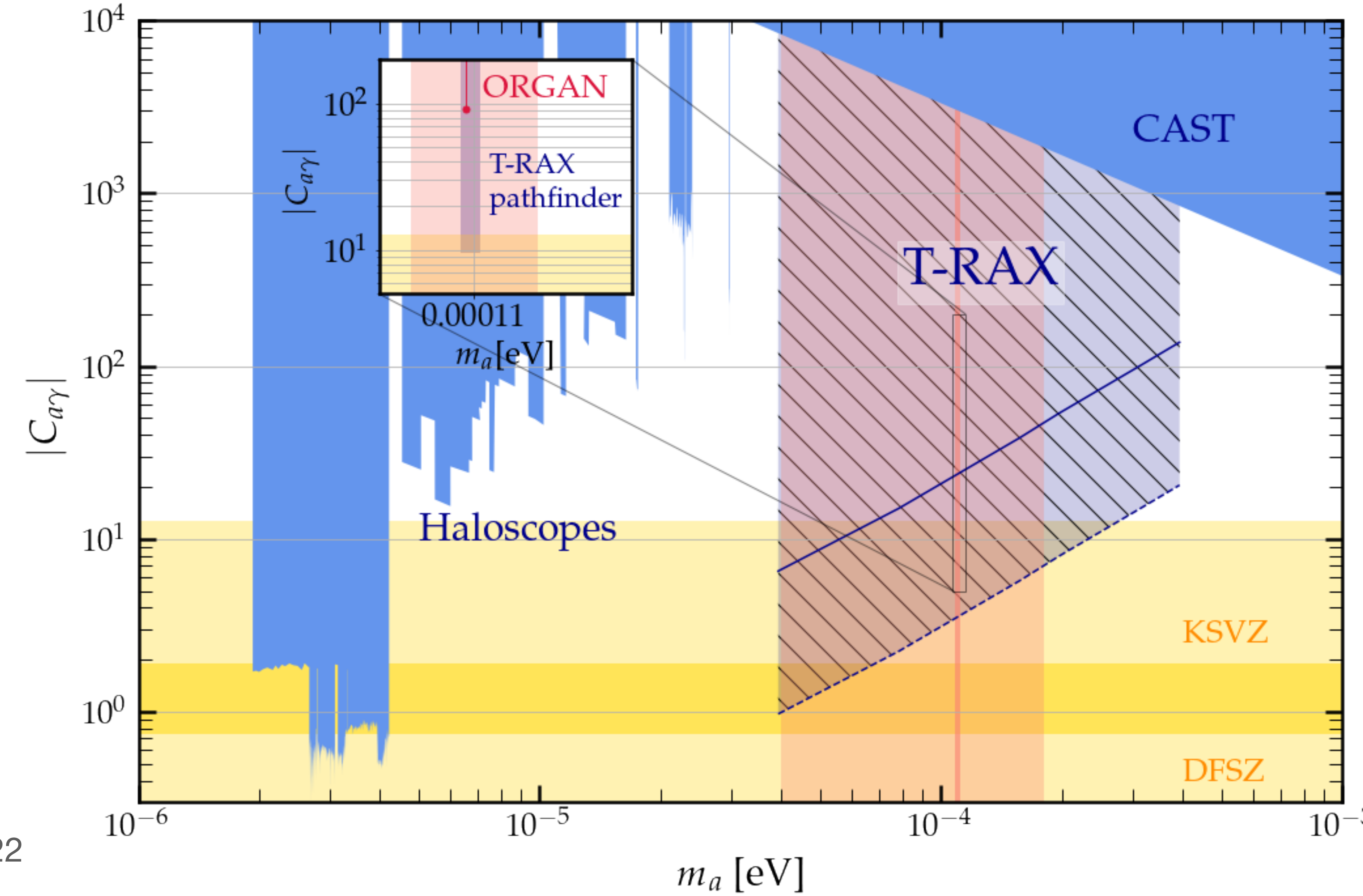
- $$C_{a\gamma} = 15.1 \left(\frac{300\ \mathrm{MeV/cm^3}}{\rho_a}\right)^{\frac{1}{2}} \left(\frac{80{,}000}{\beta^2}\right)^{\frac{1}{2}} \left(\frac{8\ \mathrm{mm} \times 100\ \mathrm{mm}}{A}\right)^{\frac{1}{2}} \left(\frac{10\ \mathrm{T}}{B_e}\right) \left(\frac{T_{\mathrm{sys}}}{0.9\ \mathrm{K}}\right)^{\frac{1}{2}}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



Summary

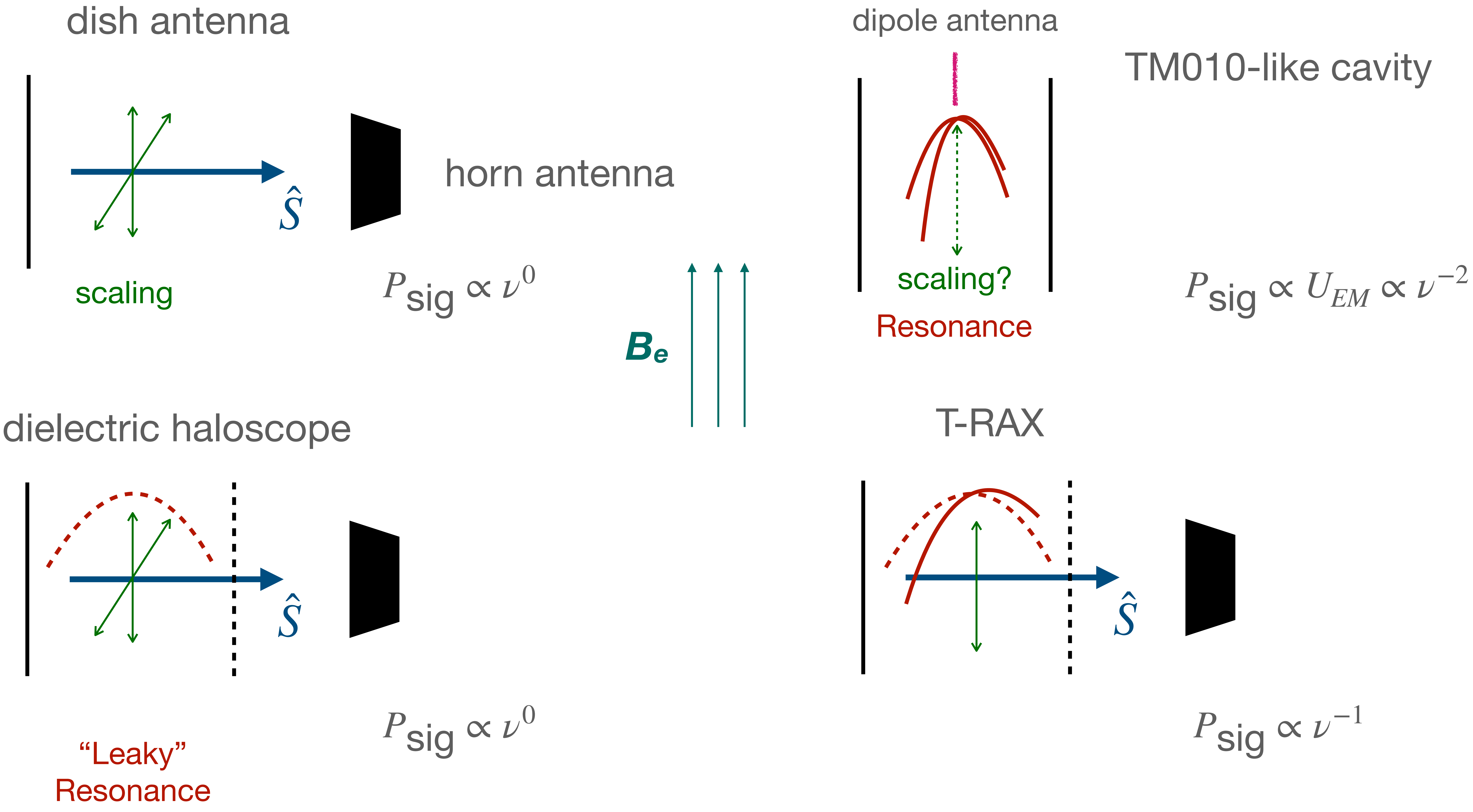

B_e
x
y
z
rectangular
waveguide
taper
standard
waveguide
Solenoid magnet

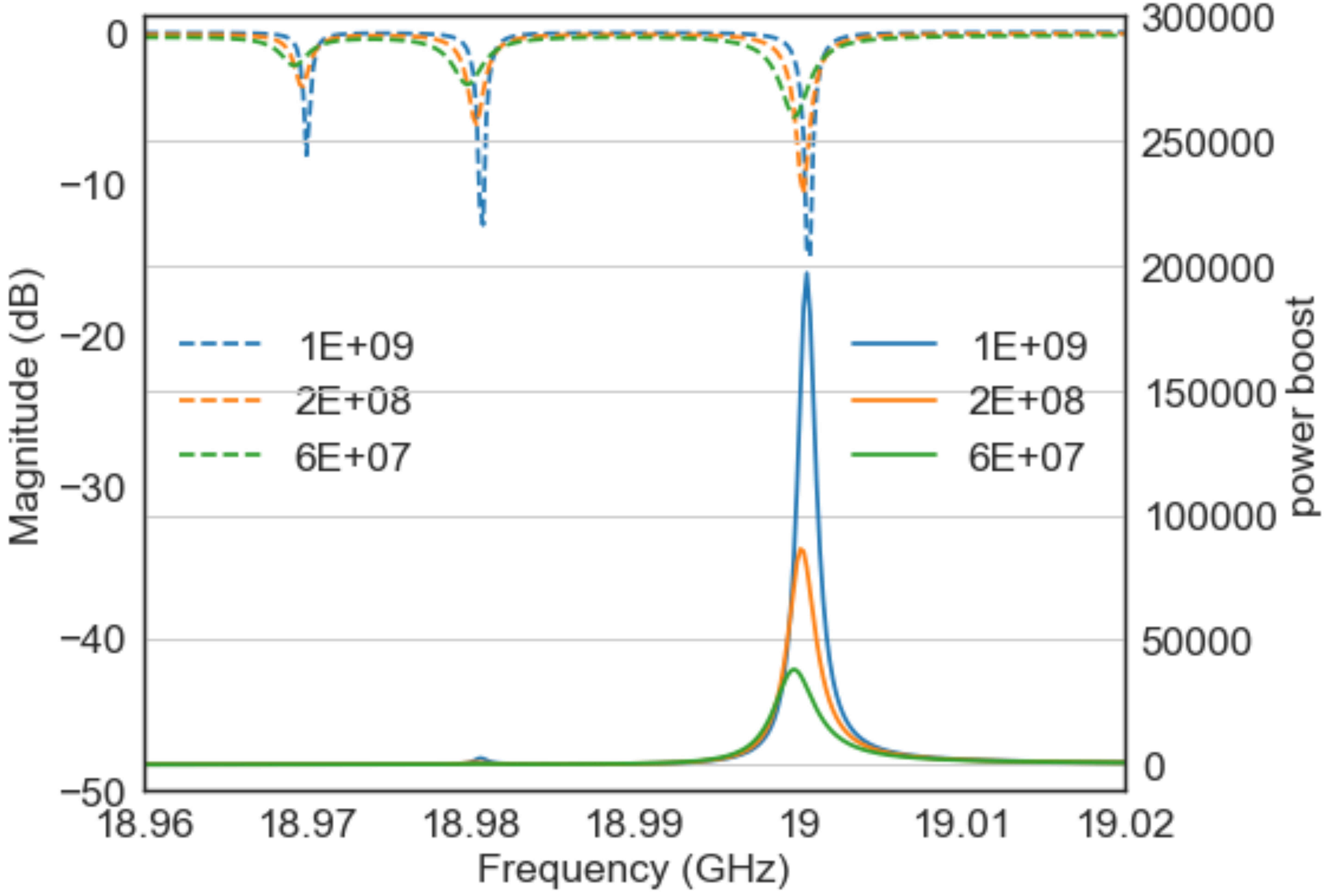

tunable
power boost
8e+04
6e+04
4e+04
2e+04
0e+00
18.8
19.0
19.2
19.4
19.6
frequency [GHz]


ORGAN
T-RAX
pathfinder
0.00011
m_a[eV]
$|C_{a\gamma}|$
CAST
T-RAX
Haloscopes
KSVZ
DFSZ
m_a [eV]

https://www.redbubble.com/de/i/grußkarte/T-Rex-Dinosaur-Surfing-Ride-the-Wave-mit-Tyrannosaurus-auf-Surf-Dino-Serfer-von-alenaz/38872698.5MT14

Back up


dish antenna
$\hat{S}$
horn antenna
scaling
$P_{\text{sig}} \propto \nu^0$
dipole antenna
TM010-like cavity
scaling?
Resonance
$P_{\text{sig}} \propto U_{EM} \propto \nu^{-2}$
B_e
dielectric haloscope
$\hat{S}$
"Leaky"
Resonance
$P_{\text{sig}} \propto \nu^0$
T-RAX
$\hat{S}$
$P_{\text{sig}} \propto \nu^{-1}$


Magnitude (dB)
0
−10
−20
−30
−40
−50
18.96
18.97
18.98
18.99
19
19.01
19.02
Frequency (GHz)
power boost
300000
250000
200000
150000
100000
50000
0
1E+09
2E+08
6E+07
1E+09
2E+08
6E+07