Wave-Like Dark Matter Detection

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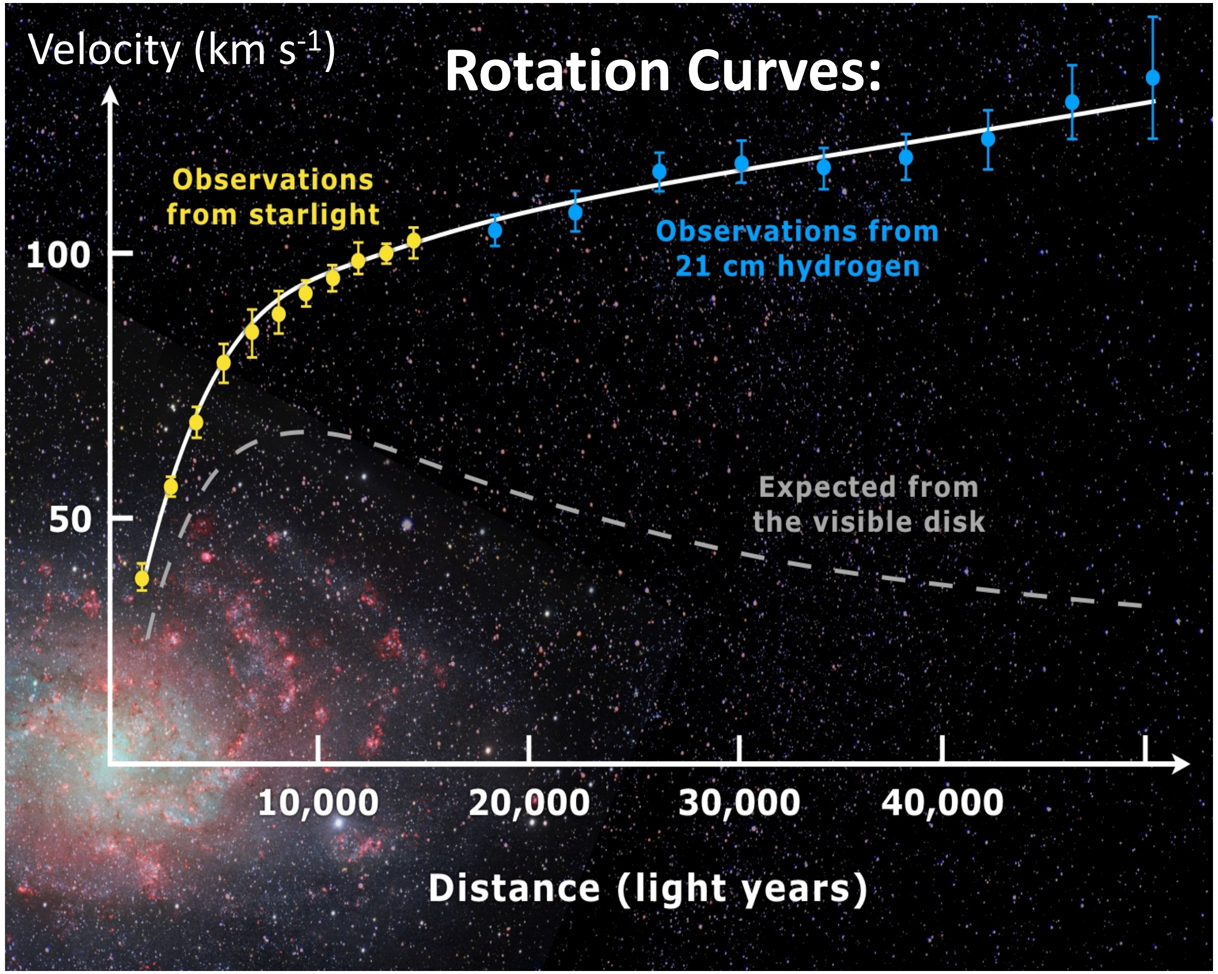
Fermilab

Member of ADMX, BREAD and MADMAX

ADMX AXION DARK MATTER EXPERIMENT BREAD COLLABORATION MADMAX

Problem 1: Dark Matter

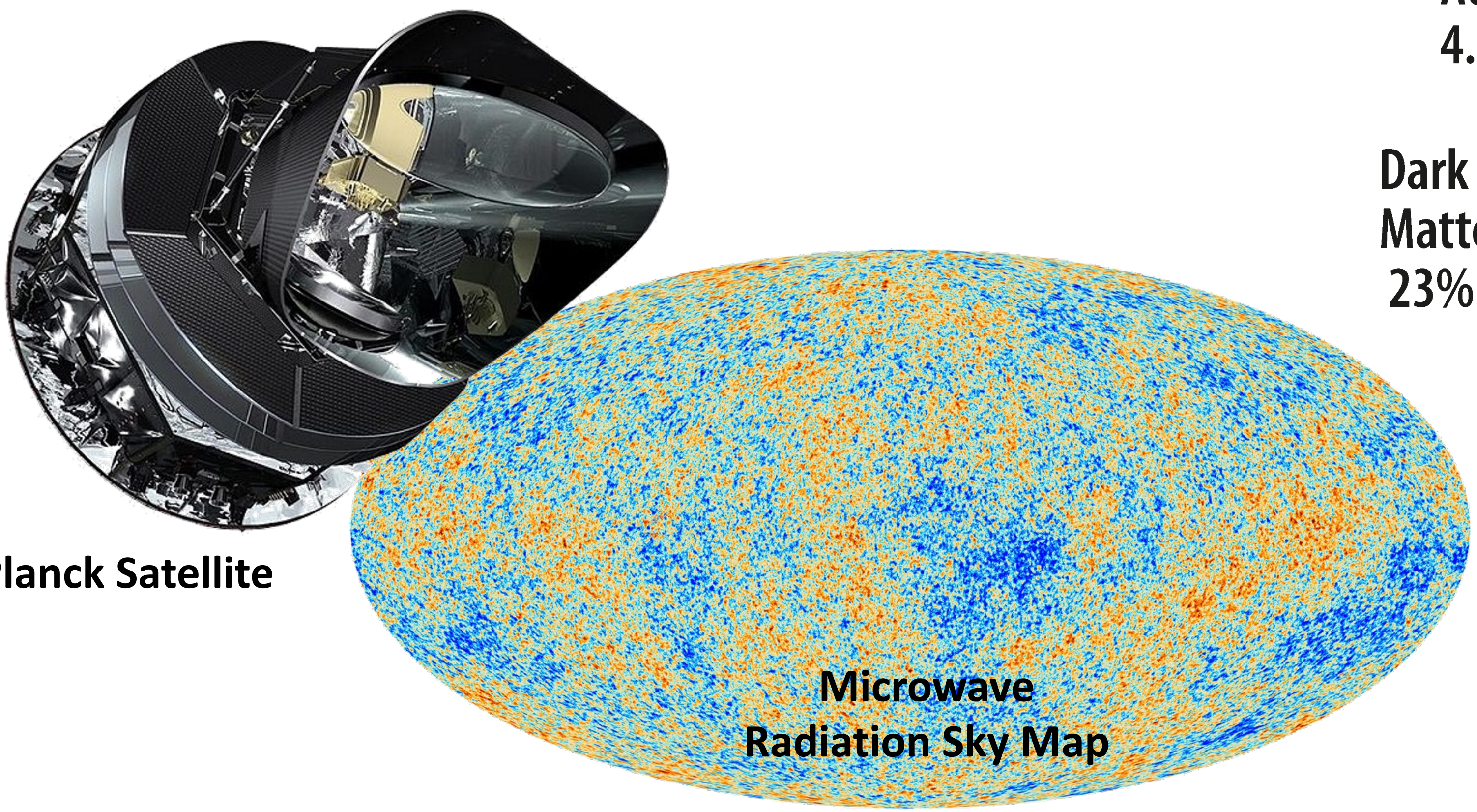


→ most of matter in Universe unknown

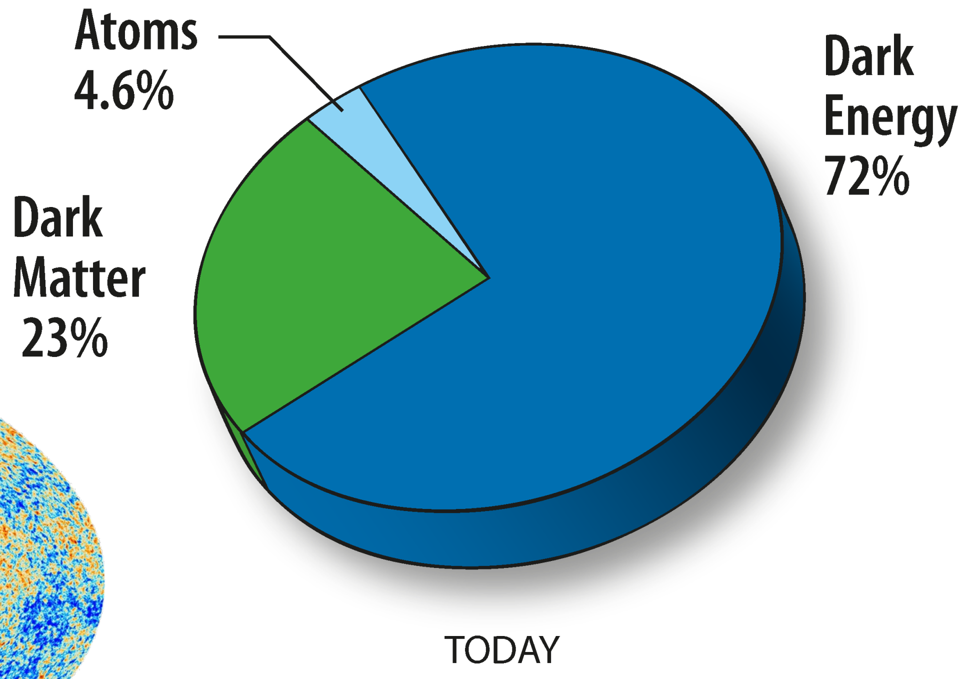
https://chandra.harvard.edu/photo/2006/1e0657/more.html
https://commons.wikimedia.org/wiki/File:Rotation_curve_of_spiral_galaxy_Messier_33_(Triangulum).png

Problem 1: Dark Matter

Cosmic Microwave Background:

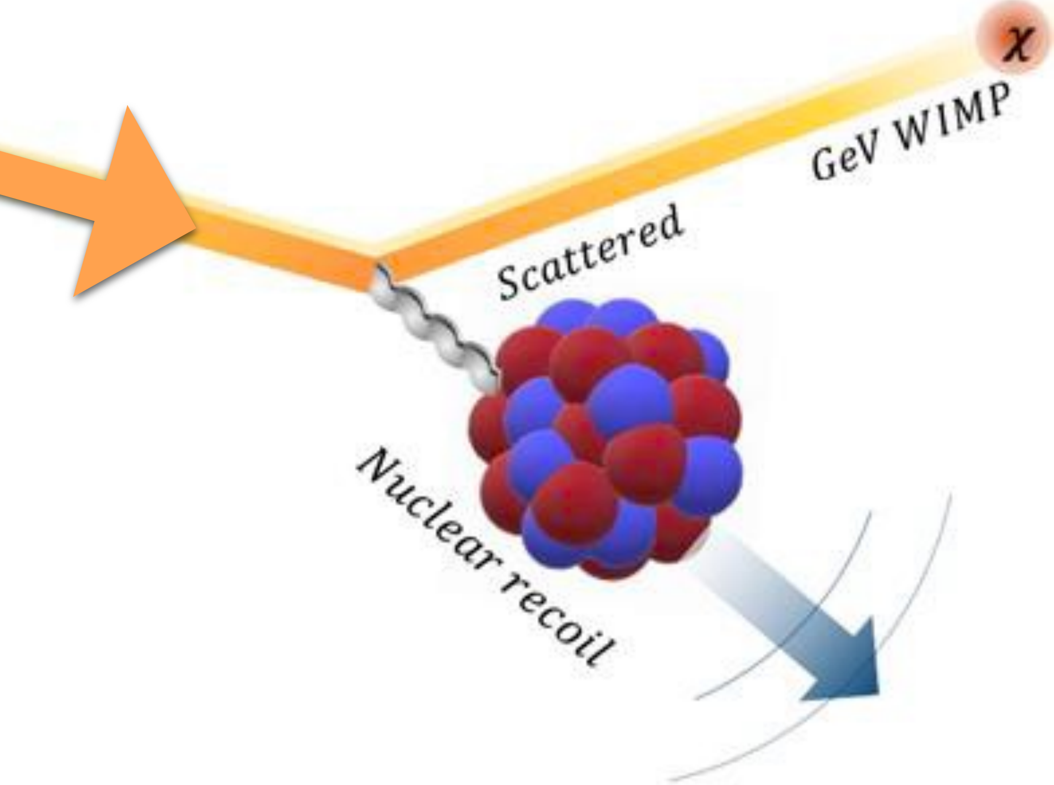


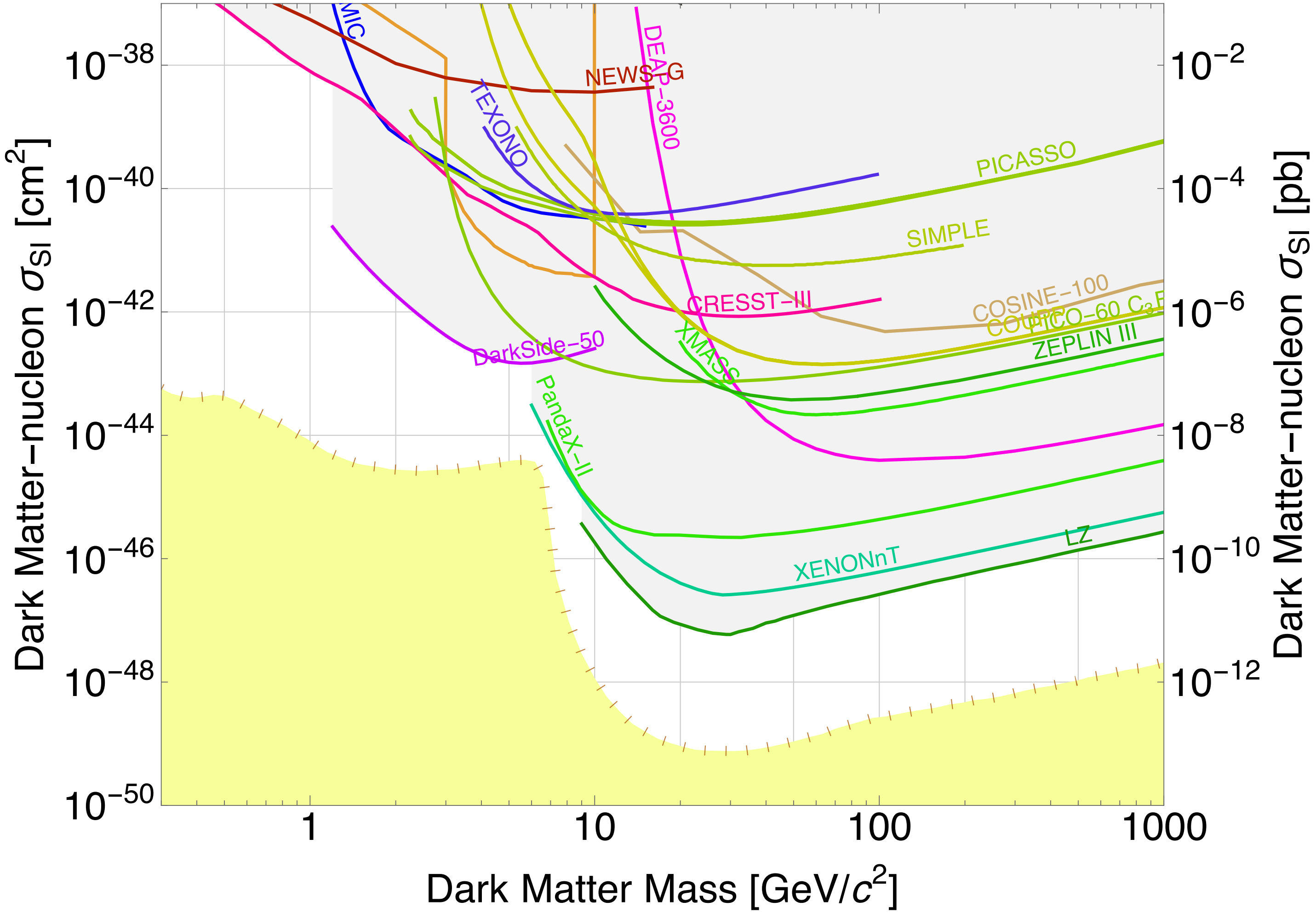
Planck Satellite



→ most of matter in Universe unknown

Previous Work: “Weakly Interacting Massive Particles” (WIMPs)

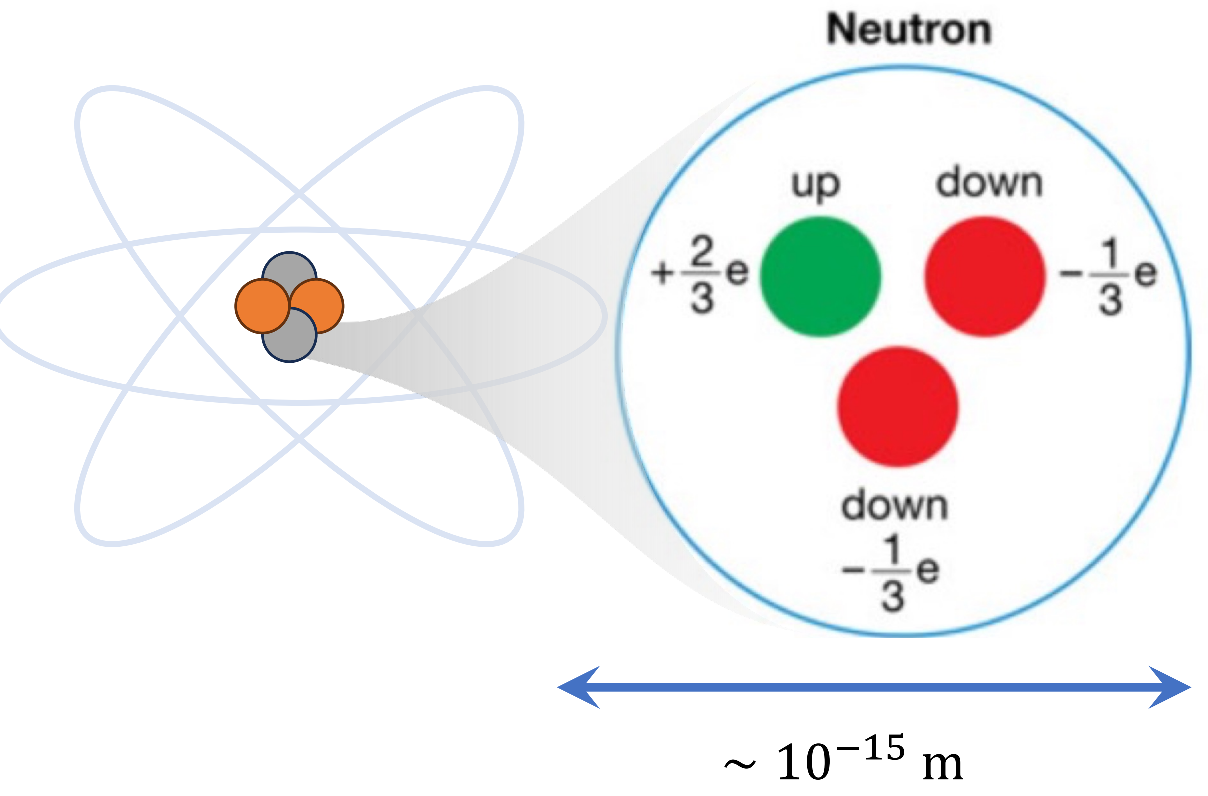




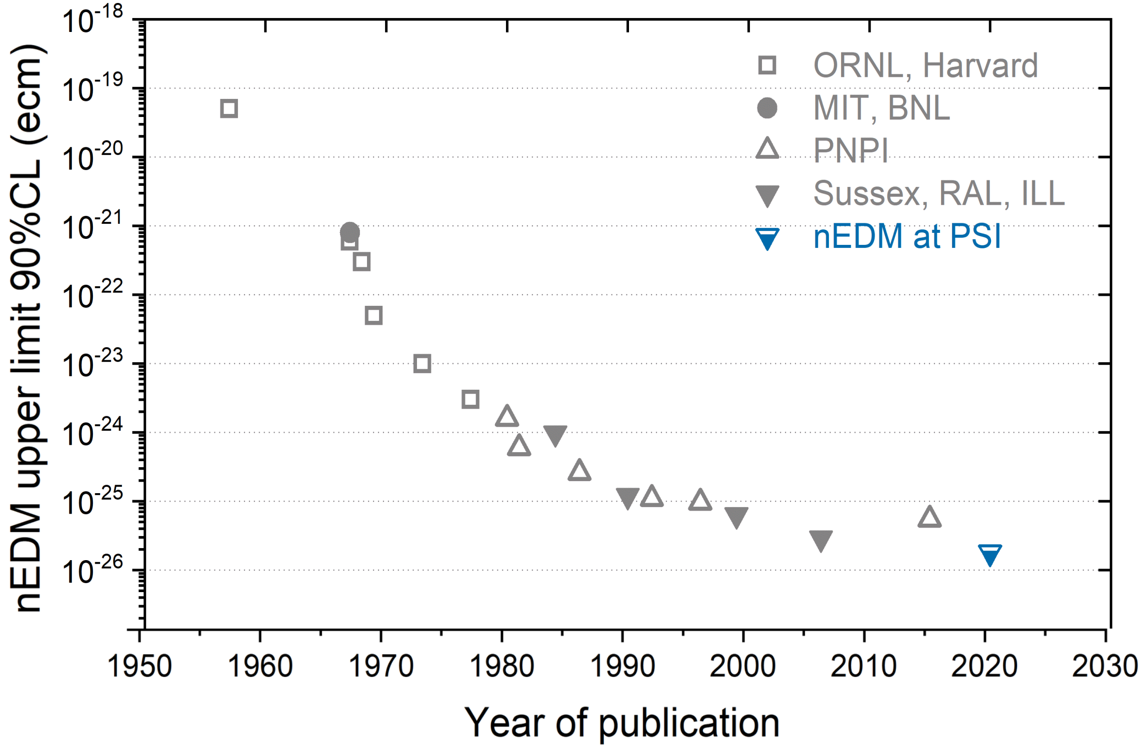
→ No signal!

 https://agenda.infn.it/event/14377/contributions/24488/attachments/17402/19749/Cadeddu_DarkSide_La_Thuile.pdf

Problem 2: Neutron Electric Dipole Moment

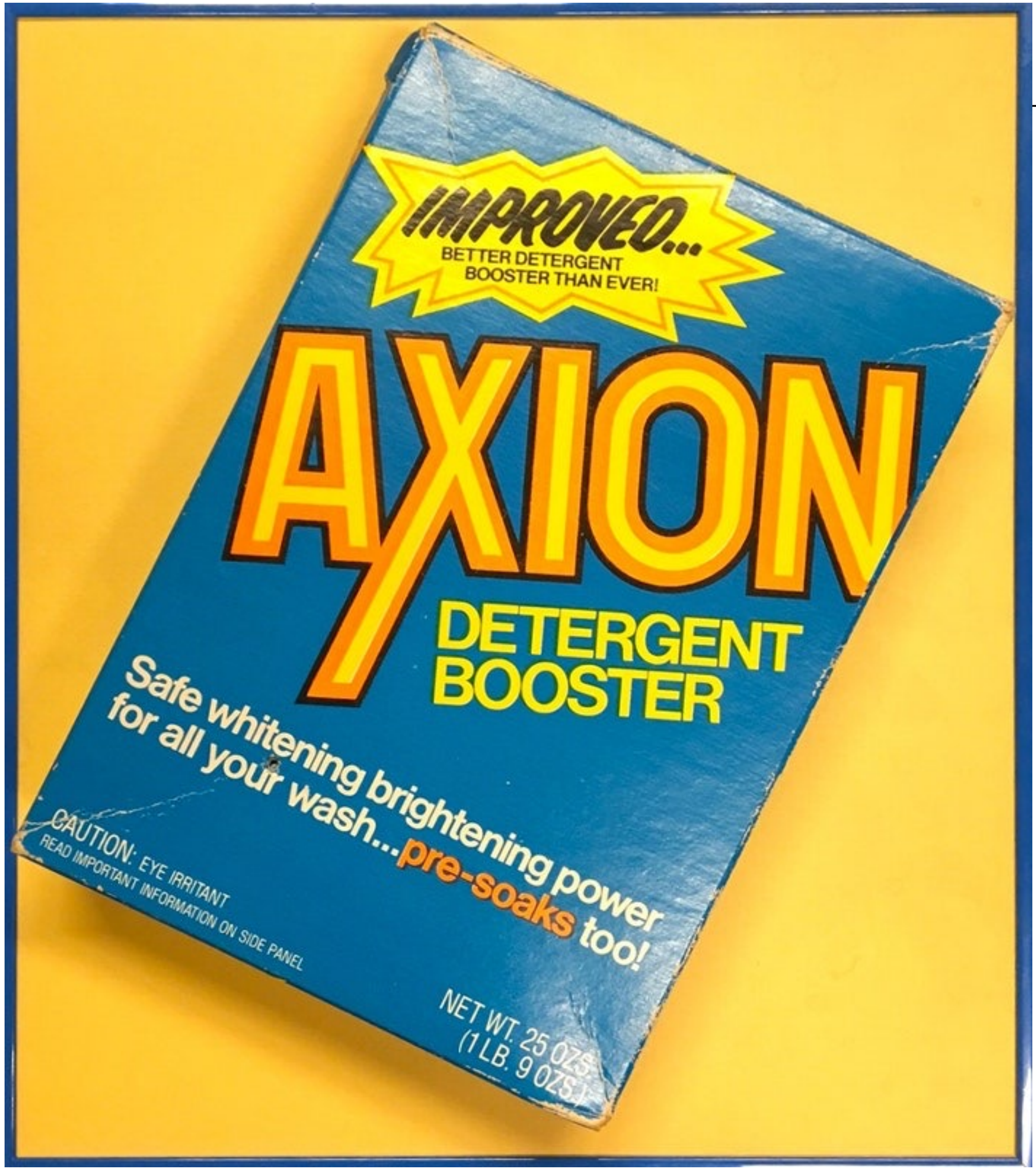


Measurement:

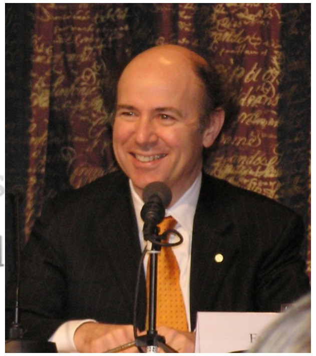


$d_n \sim 10^{-16}\, e\, \mathrm{m}$? **NOT OBSERVED**

→ Strong Interaction **10 orders of magnitude** more symmetric than expected!



One to solve it all: The Axion

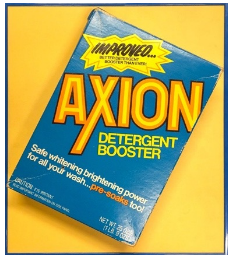


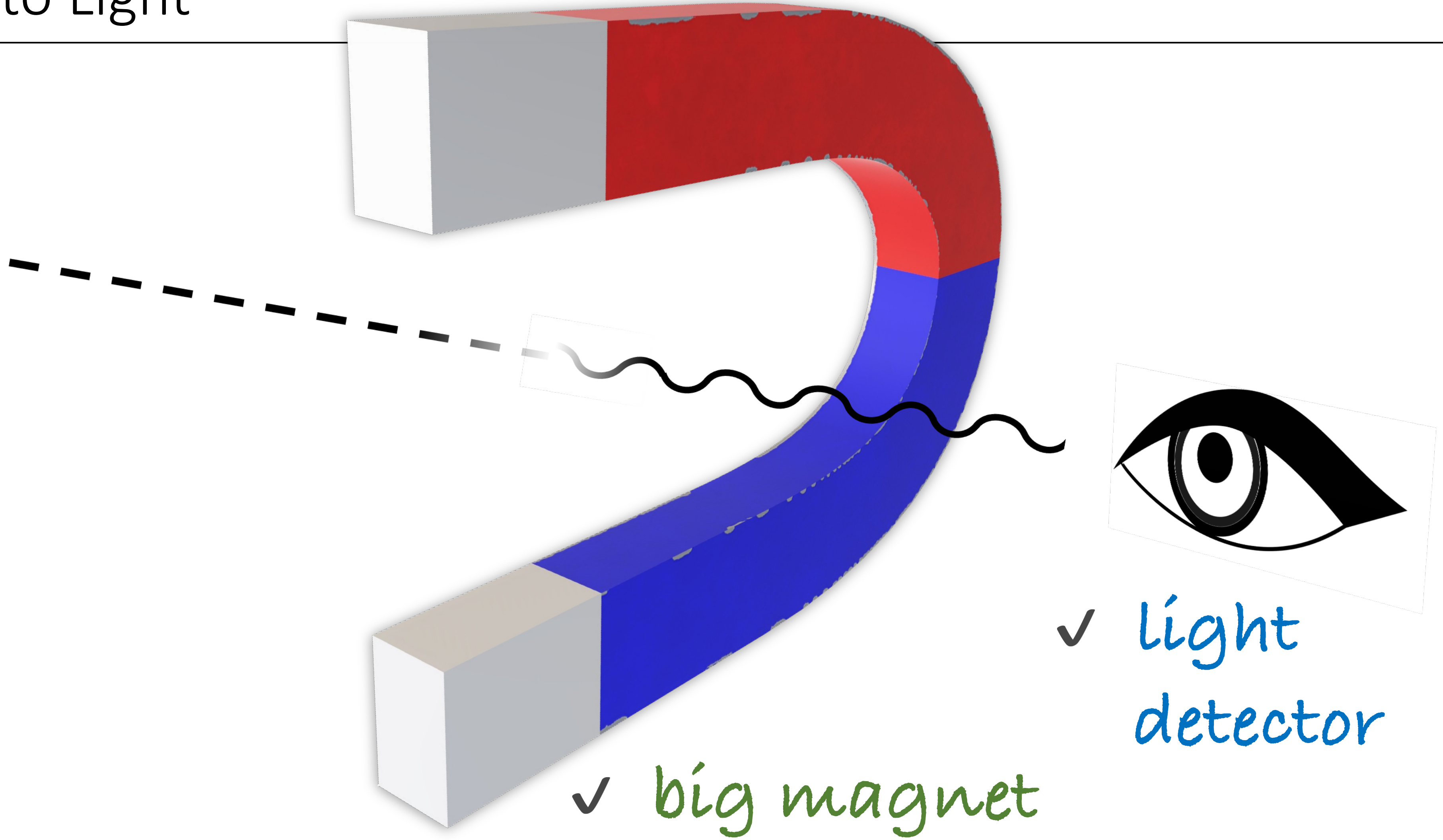
they didn't take note of thes… ls… them. That gave me an oppo… a d… adolescence.

> “A few years before, a supermarket display of brightly colored boxes of a laundry detergent named Axion had caught my eye. It occurred to me that “axion” sounded like the name of a particle and really ought to be one. So when I noticed a new particle that “cleaned up” a problem with an “axial” current, I saw my chance. (I soon learned that Steven Weinberg had also noticed this particle, independently. He had been calling it the ”

Frank Wilczek in Quanta Magazine, January 2016

Axions convert to Light



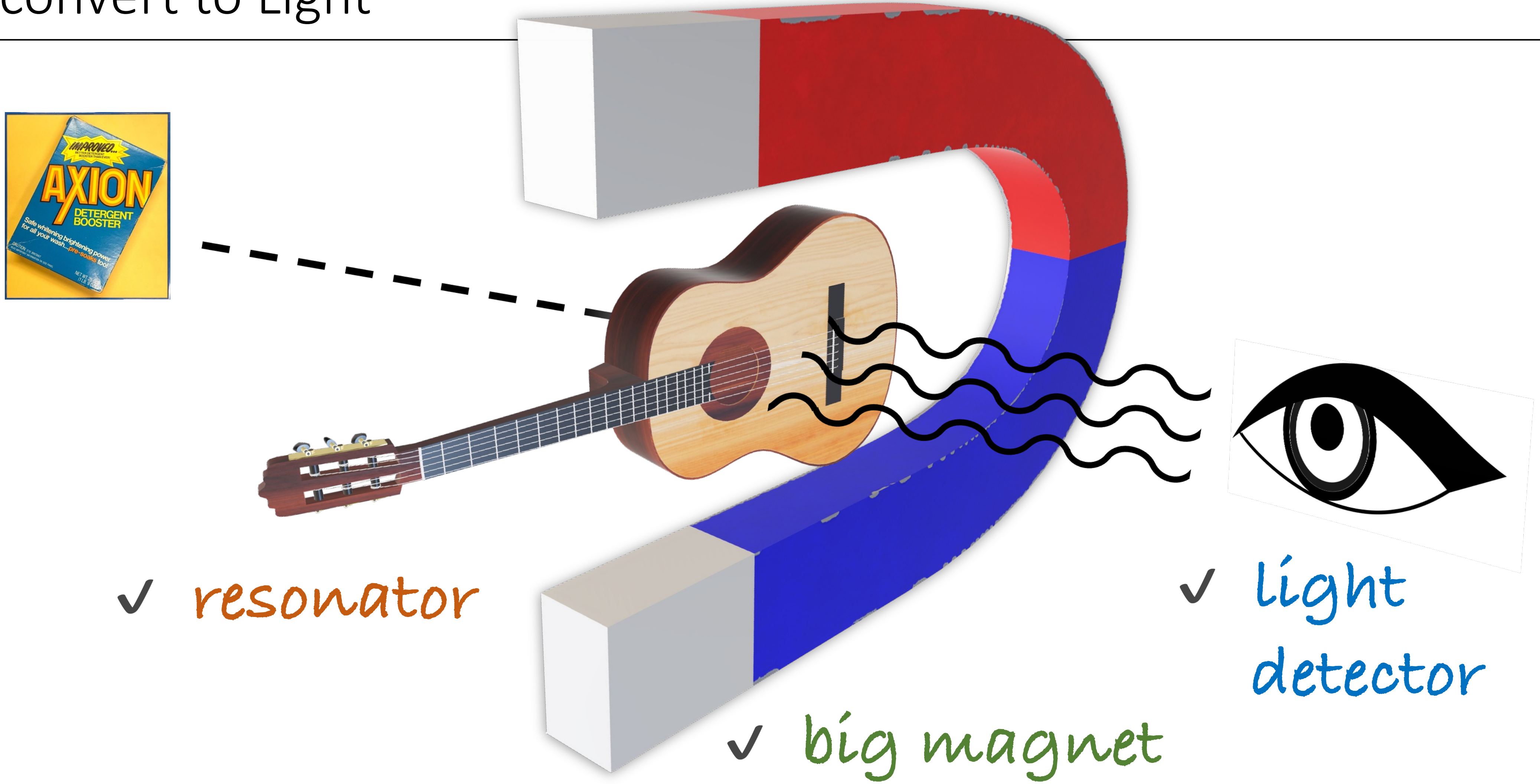


✓ light detector

✓ big magnet

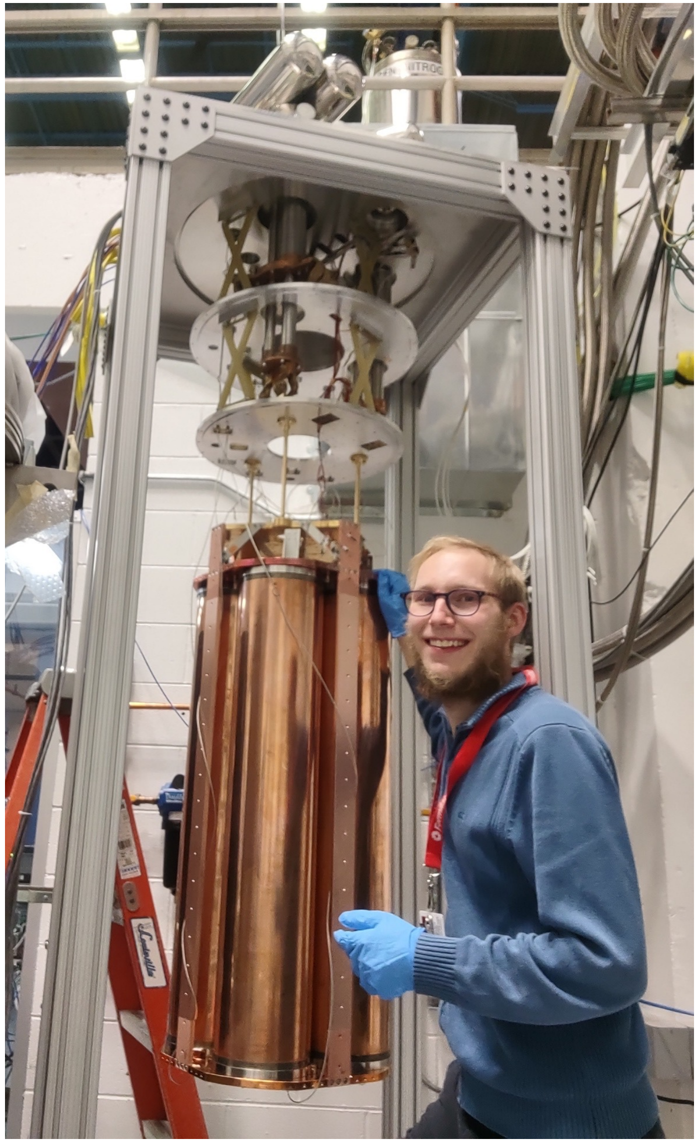
$\boldsymbol{P = 10^{-25}\,\mathrm{W}}$ (@10GHz, 10T, 10m^2 cross-section)

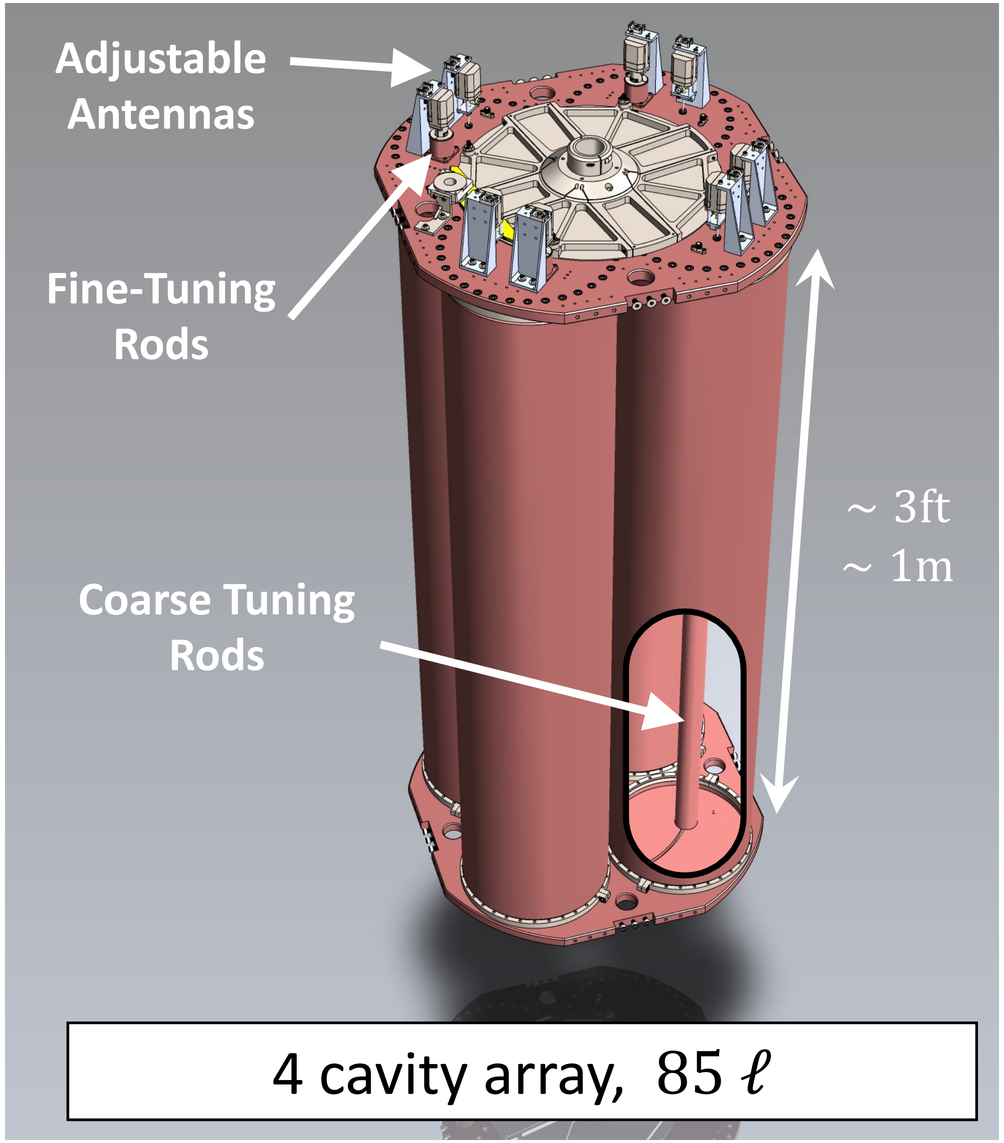
Axions convert to Light



$$\boldsymbol{P = \ Q \times 10^{-25}\ \mathrm{W}}$$ (@10GHz, 10T, 10m^2 cross-section)

ADMX (Axion Dark Matter eXperiment):1.4 – 2.1 GHz (6 – 9 μeV)

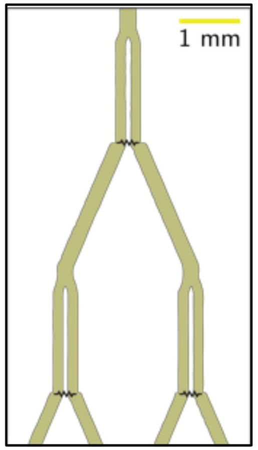


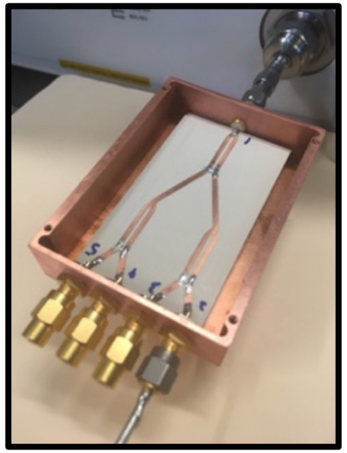


4 cavity array, 85 ℓ

currently testing & upgrading at FNAL

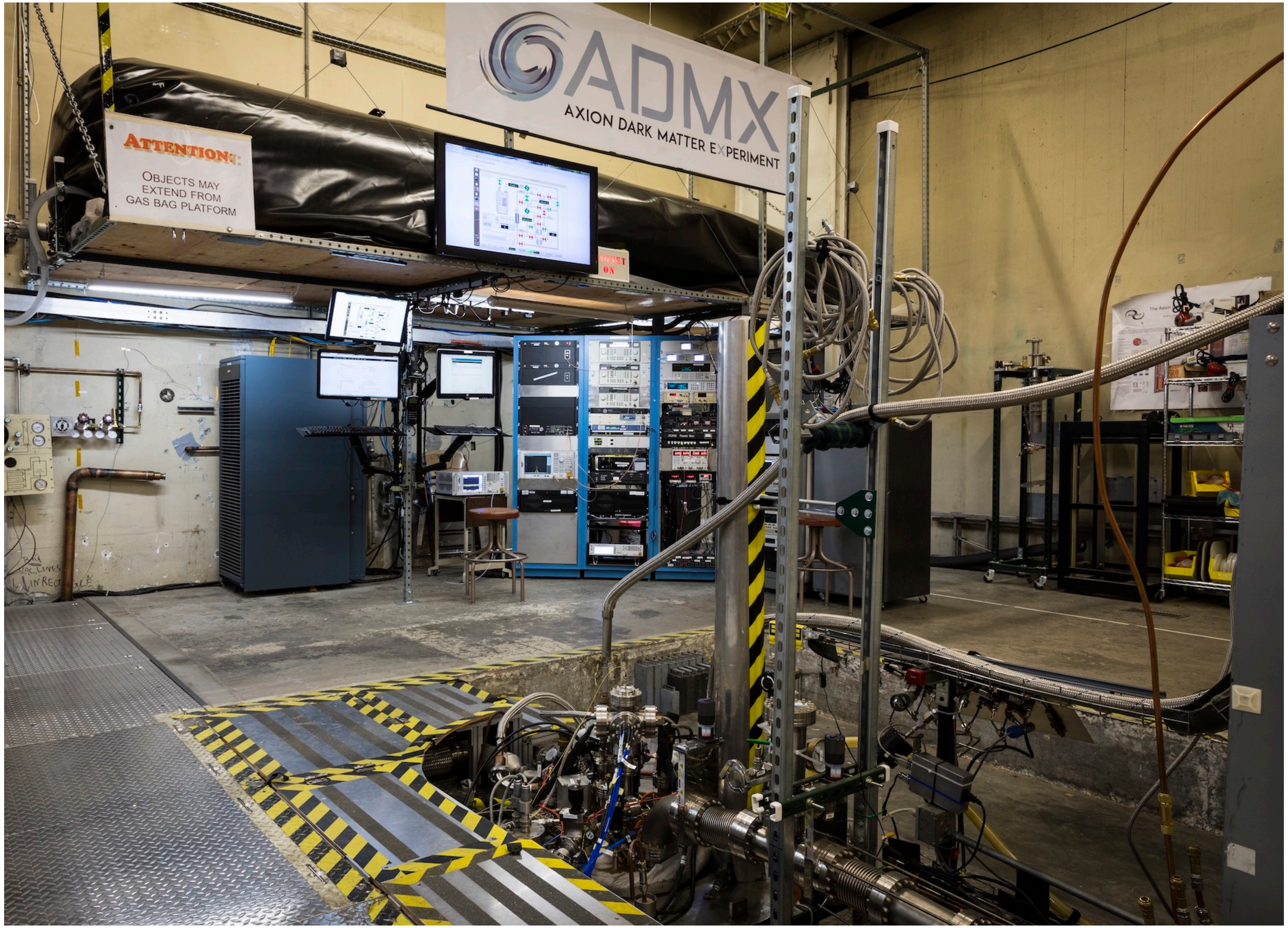
Analog Power Combining:





Data Taking:
at Univ. Washington
from 2023/24

Current ADMX (University of Washington)

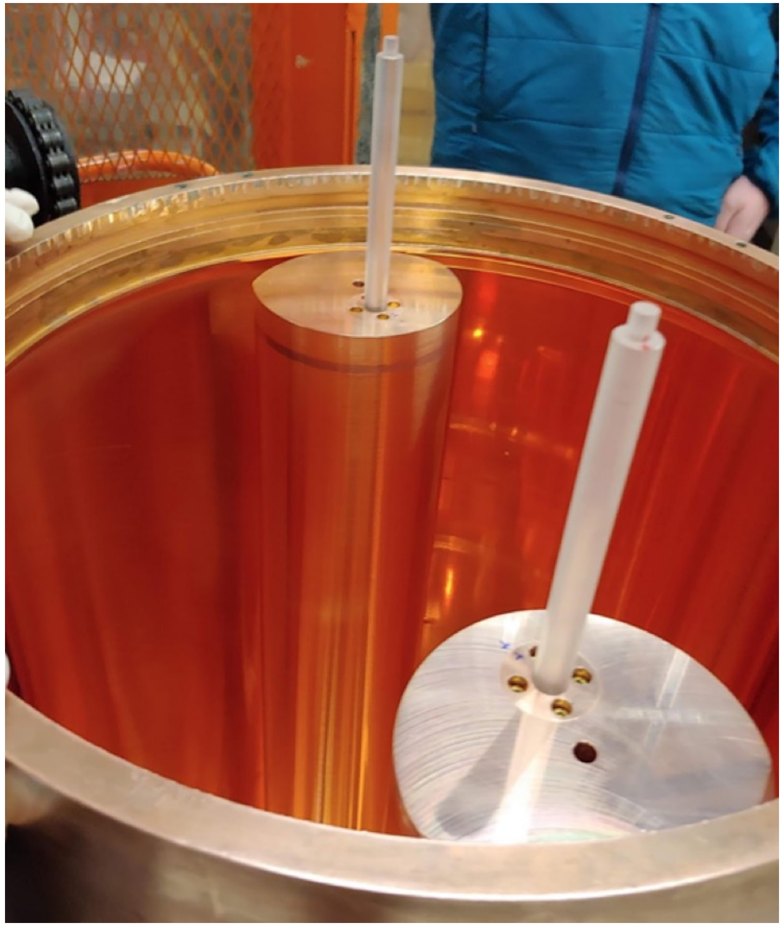


Current ADMX (University of Washington)

✓ high B-field

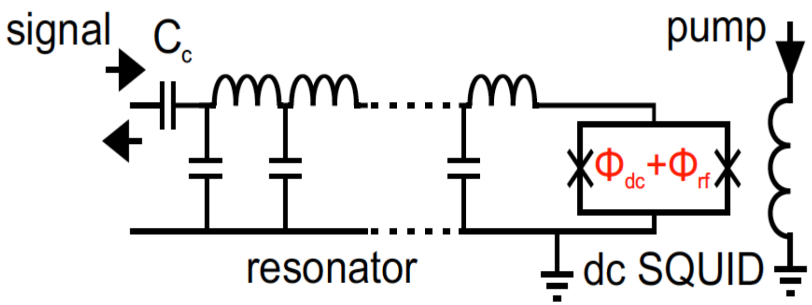
$B \approx 7.6T$ | ~ 50 cm bore

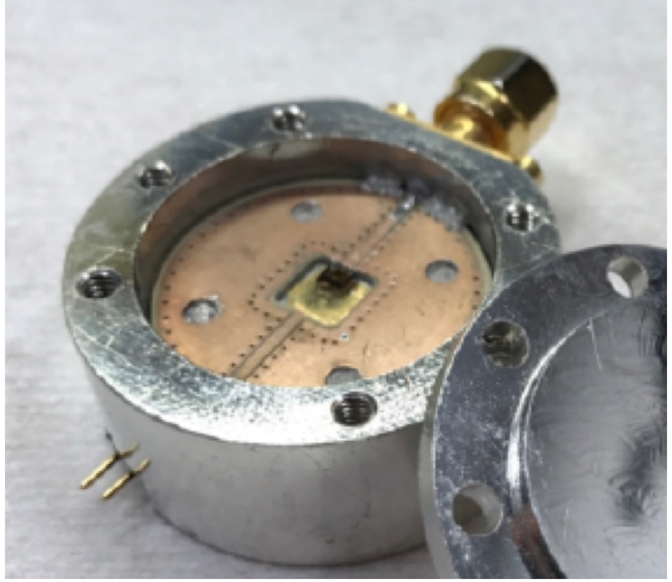
✓ high-Q resonator



$V \sim 136\,\ell$ | $Q_L \sim 80{,}000$ (cryo)

✓ "quantum" sensor

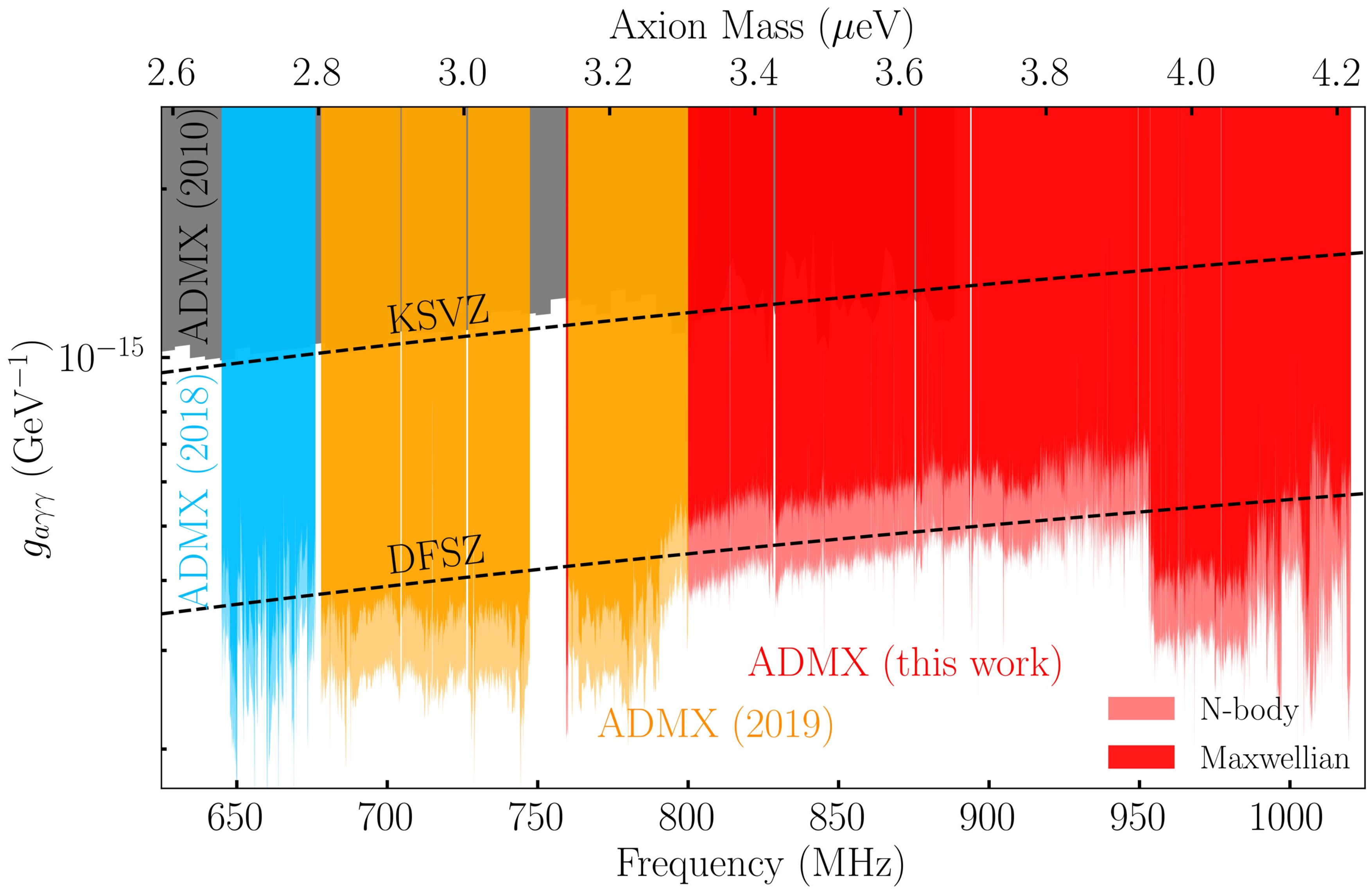




$T_{\mathrm{JPA}} \sim 100\mathrm{mK} \sim 2 \times$ quantum limit

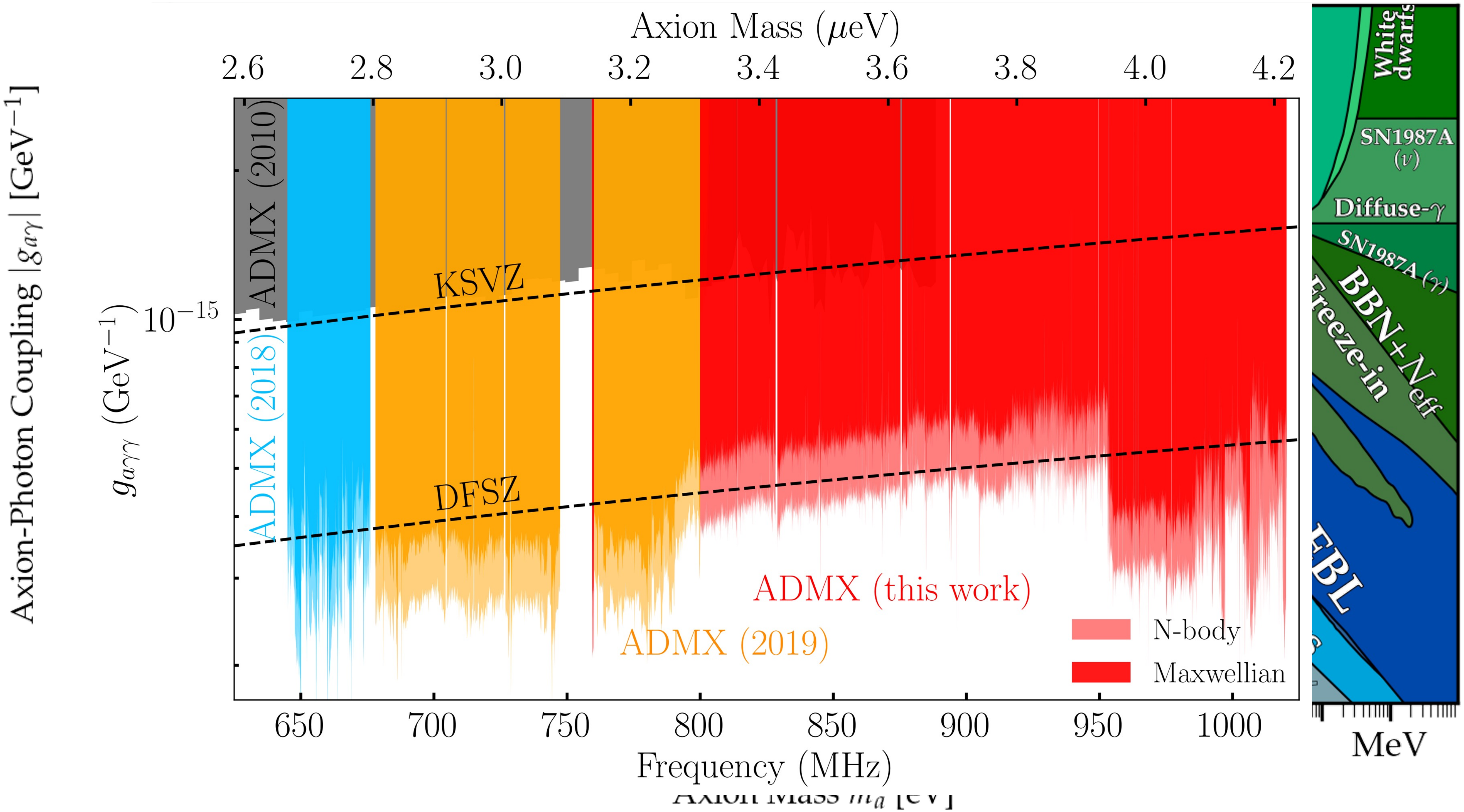
ADMX Results

[PRL 127, 261803 (2021)]



… zoom out a bit…

[adapted from cajohare.github.io/axionlimits]



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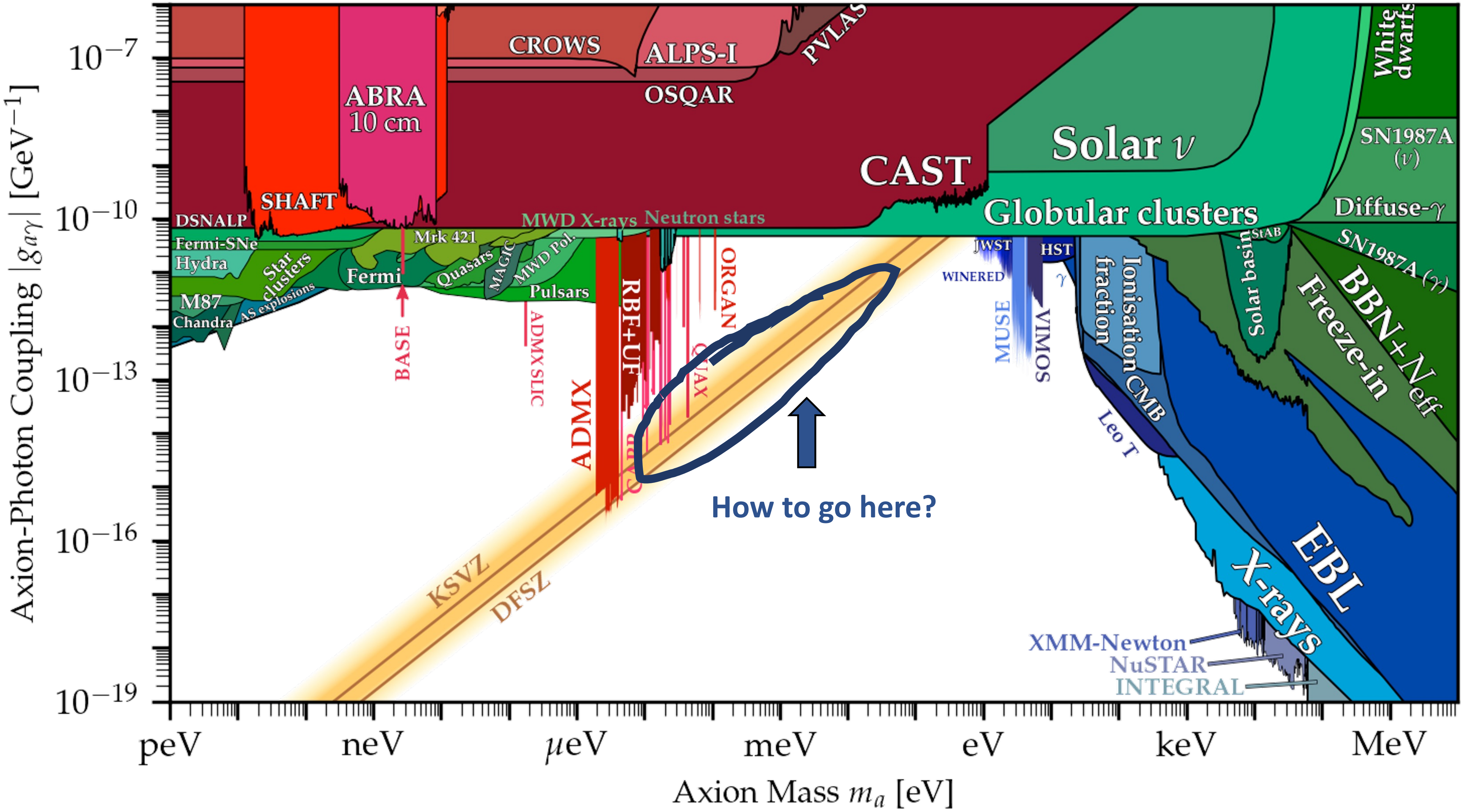
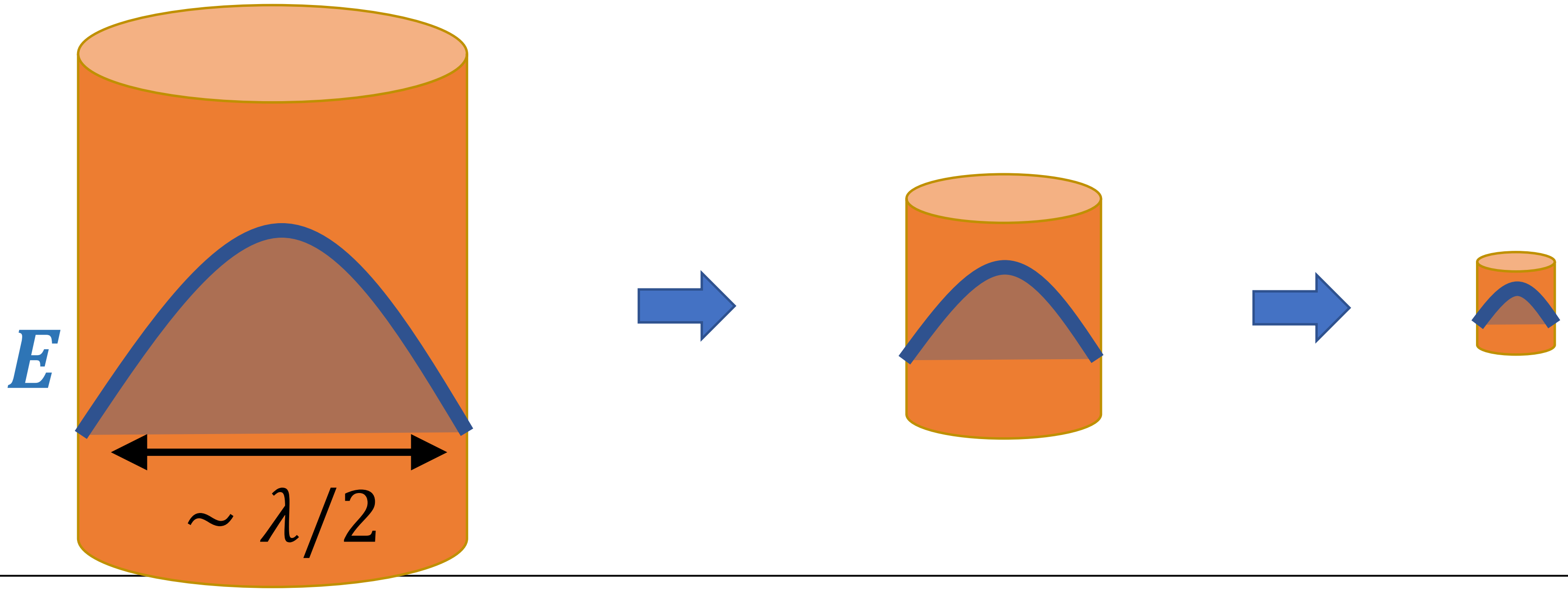


High Mass = Heigh Frequency = Small Cavity!

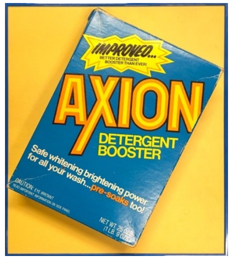
$3\mu\text{eV}$ $10\mu\text{eV}$ $30\mu\text{eV}$

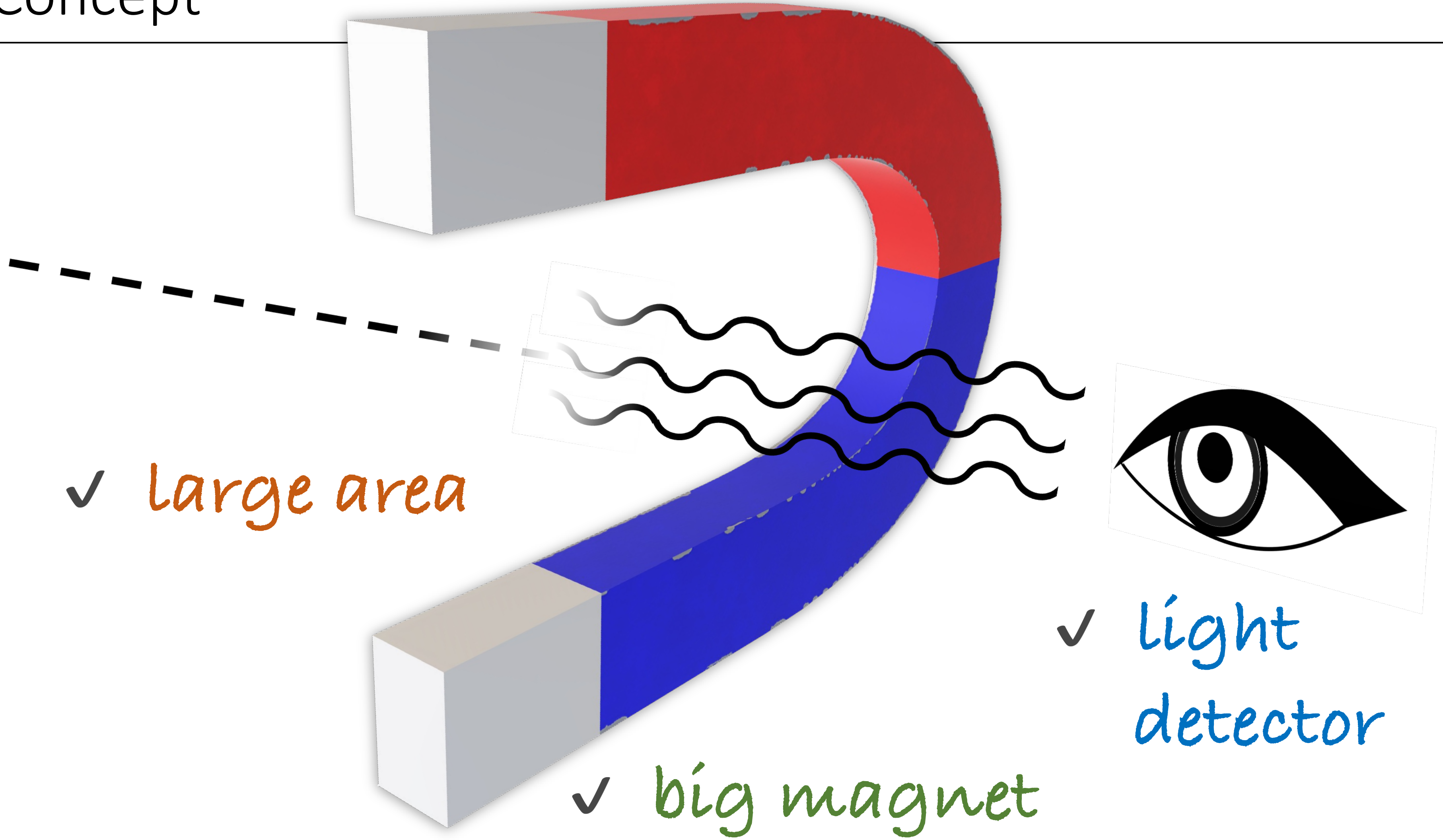


V	100ℓ	3ℓ	0.1ℓ
$Q \propto V/\delta V$	30,000	10,000	3,000

$$P_{\text{sig}} = 2 \cdot 10^{-23}\,\text{W} \cdot \left(\frac{B}{7.6\,\text{T}}\right)^2 \left(\frac{V}{136\,\ell}\right)\left(\frac{C}{0.4}\right)\left(\frac{Q}{30{,}000}\right)\left(\frac{g_\gamma}{0.36}\right)^2 \left(\frac{m_a}{3\,\mu\text{eV}}\right)\left(\frac{\rho_{\text{DM}}}{0.45\,\text{GeV cm}^{-3}}\right)$$

Non-Resonant Concept





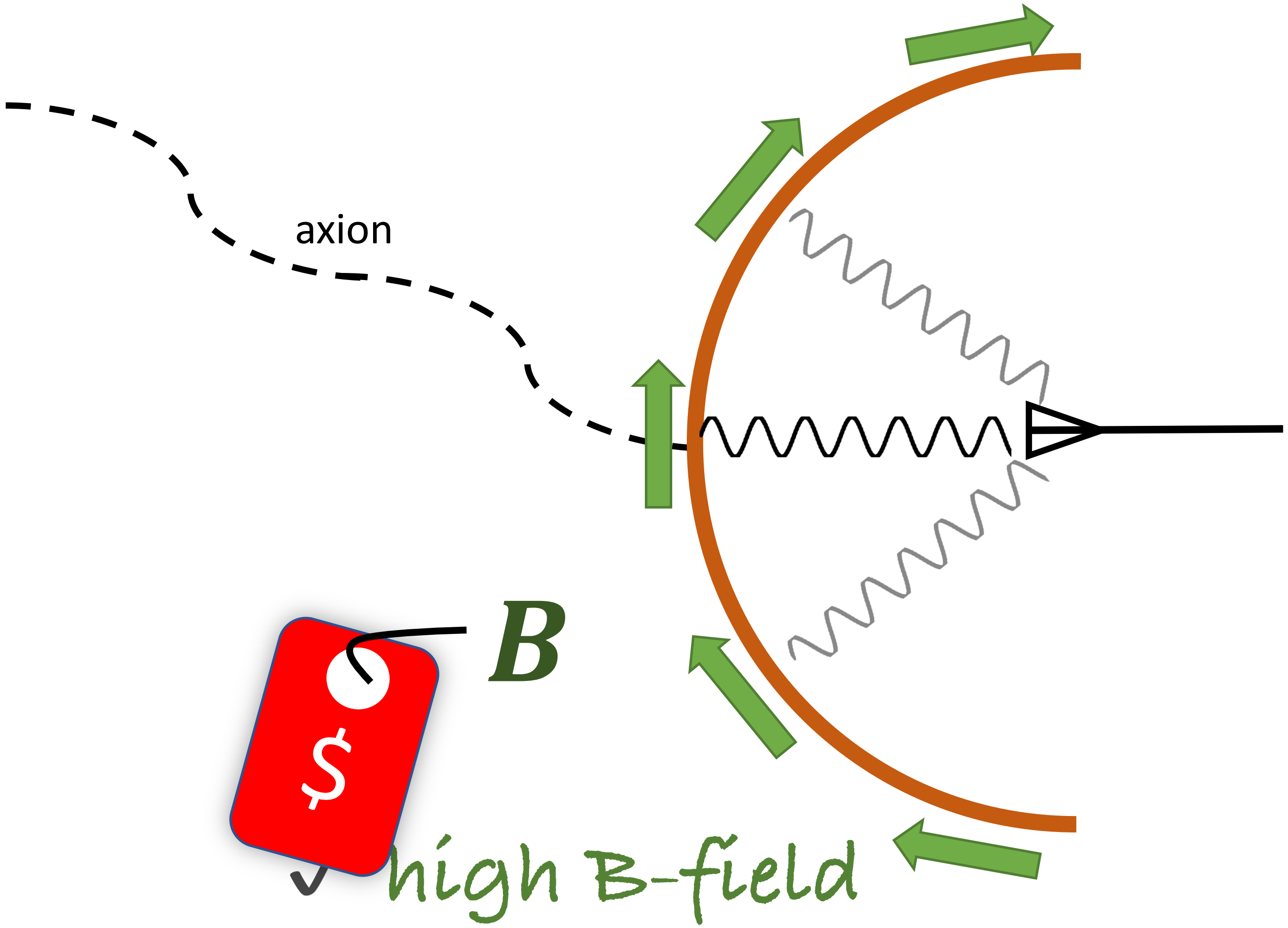
✓ large area

✓ big magnet

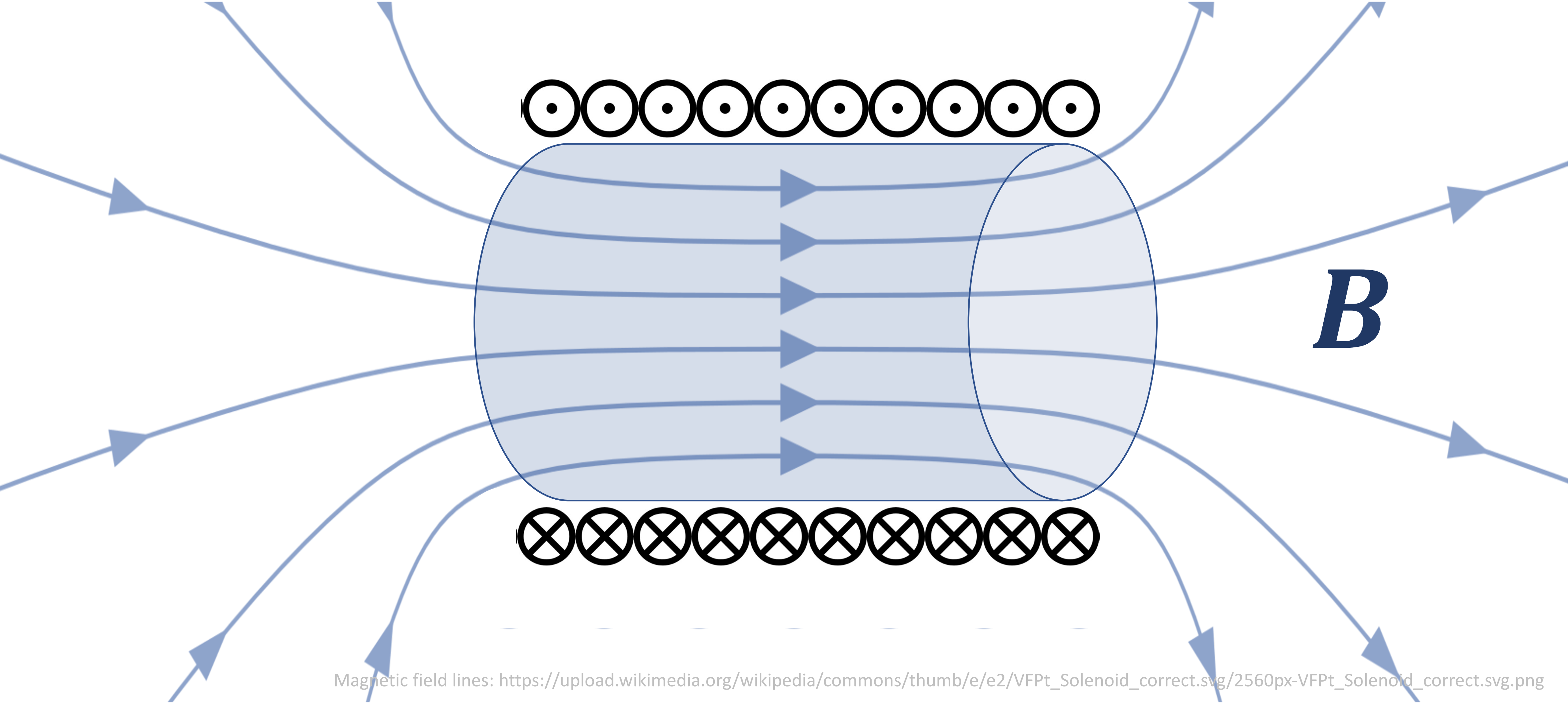
✓ light detector

no resonance → no length scale set by λ → make as large as possible

Dish Antenna

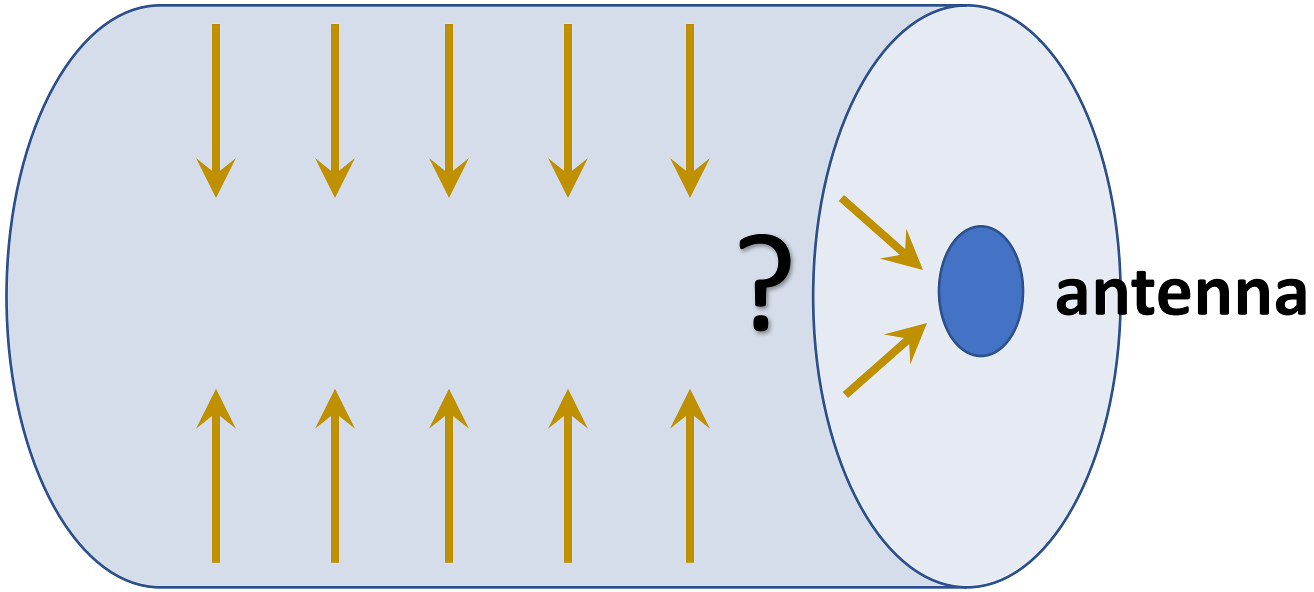


Available Magnets: Solenoid Magnets

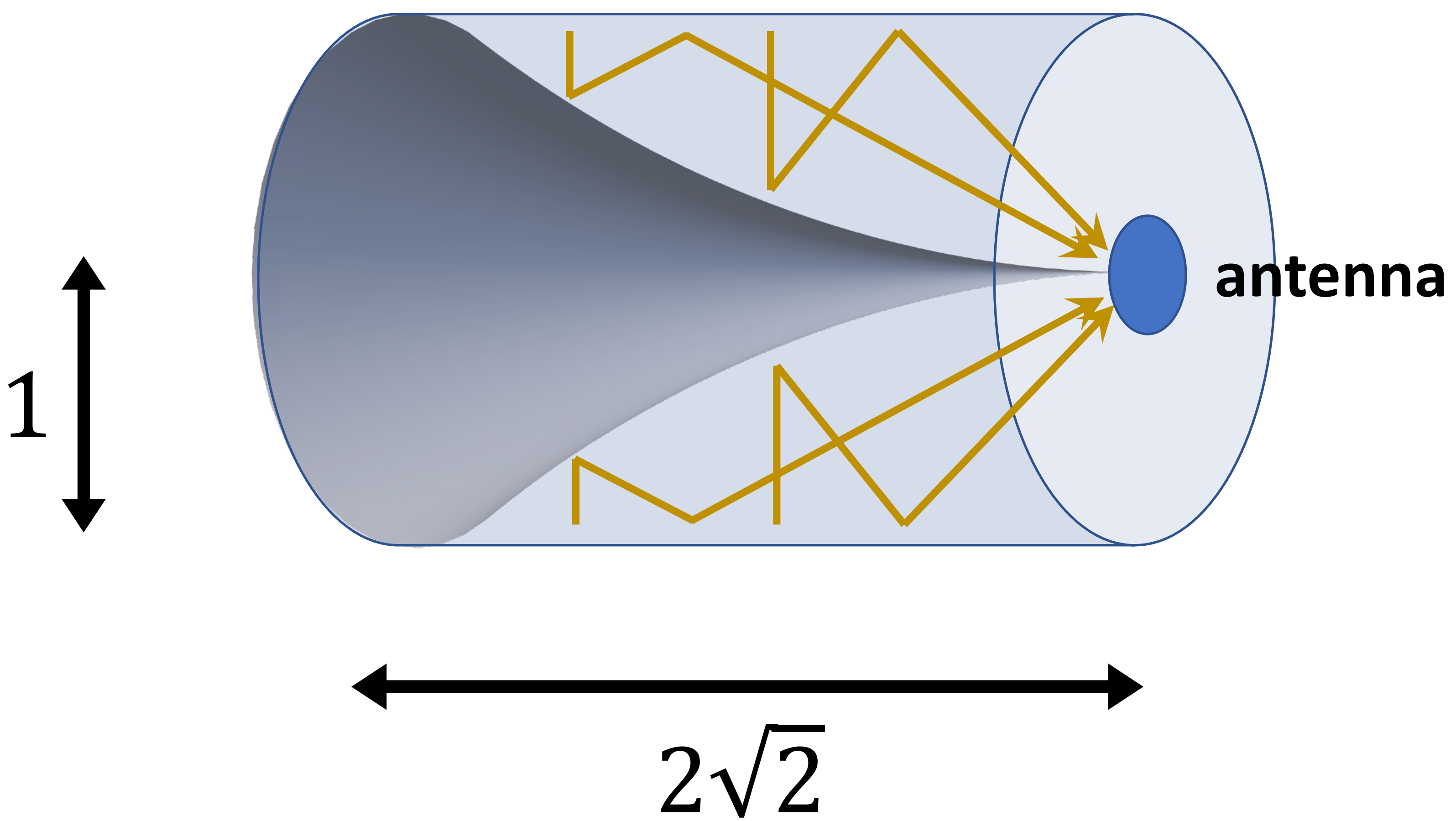


Magnetic field lines: https://upload.wikimedia.org/wikipedia/commons/thumb/e/e2/VFPt_Solenoid_correct.svg/2560px-VFPt_Solenoid_correct.svg.png

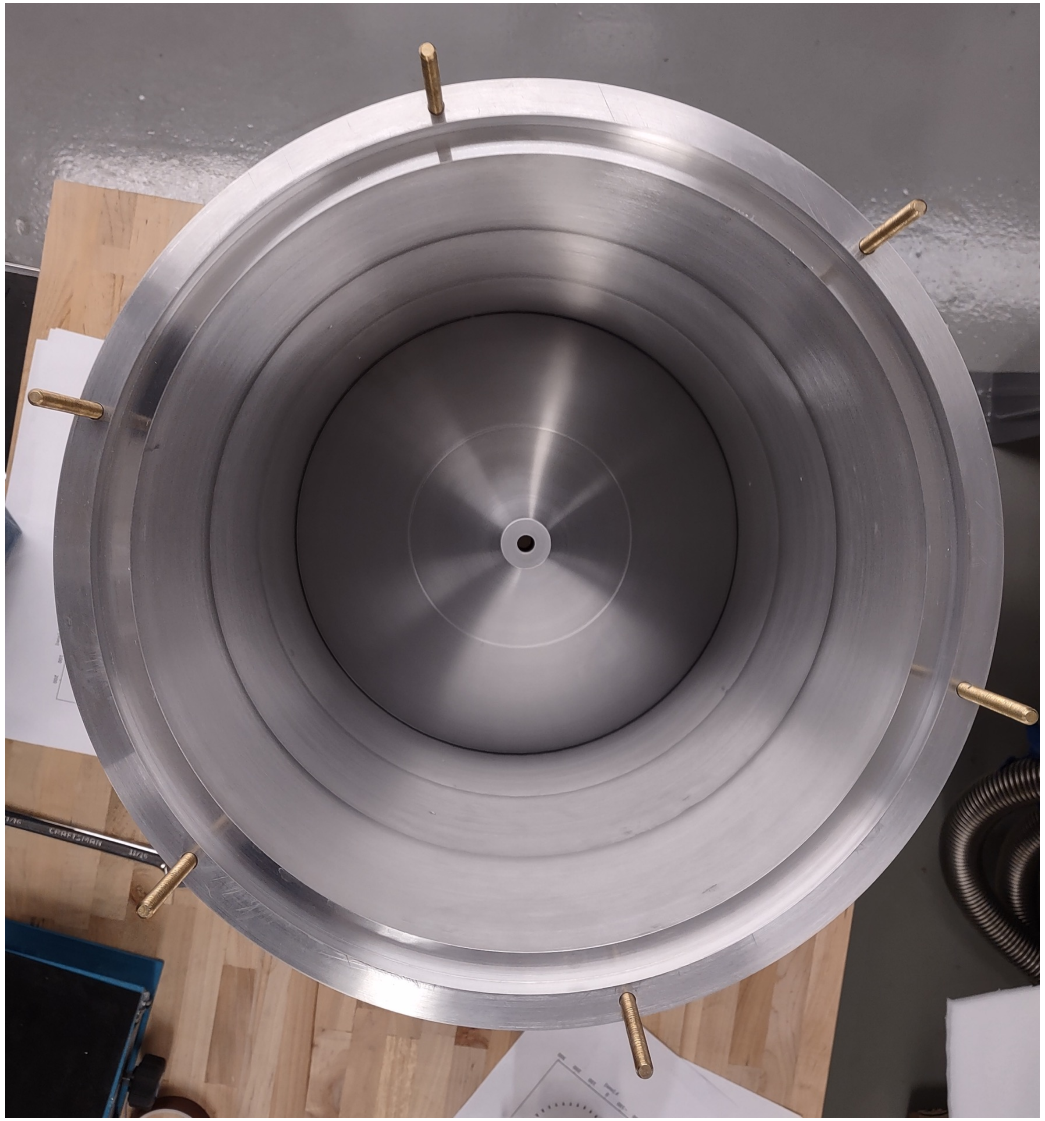
The Magnet: Solenoid



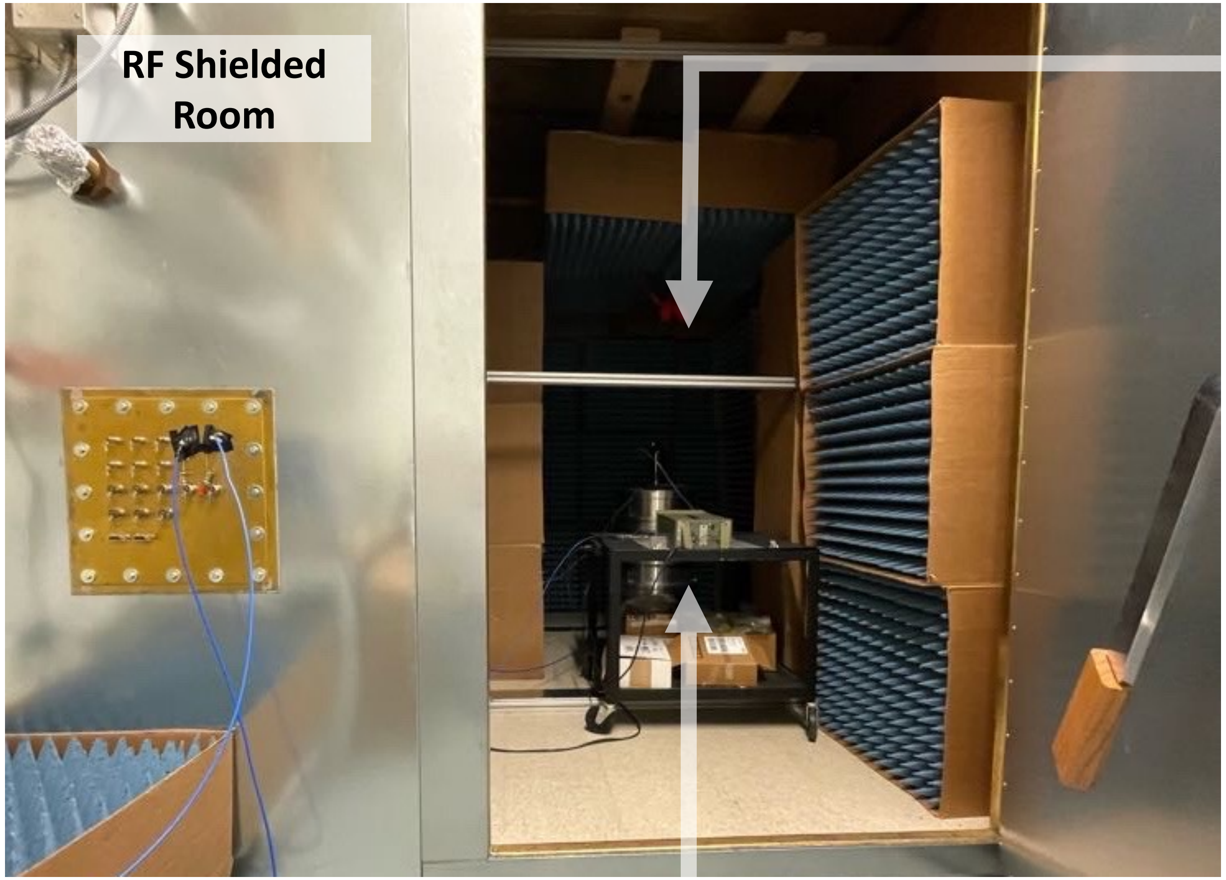
Coaxial Dish Concept

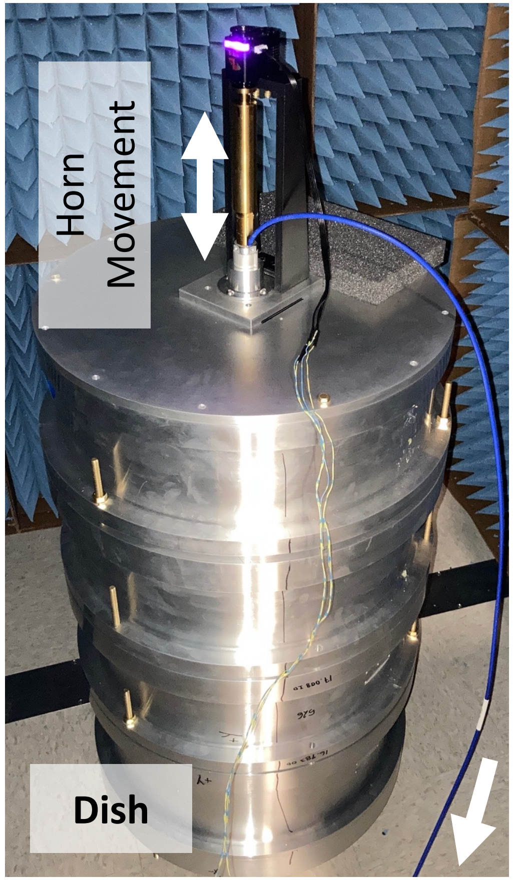


GigaBREAD: First 10-14 GHz (50μeV) BREAD pilot

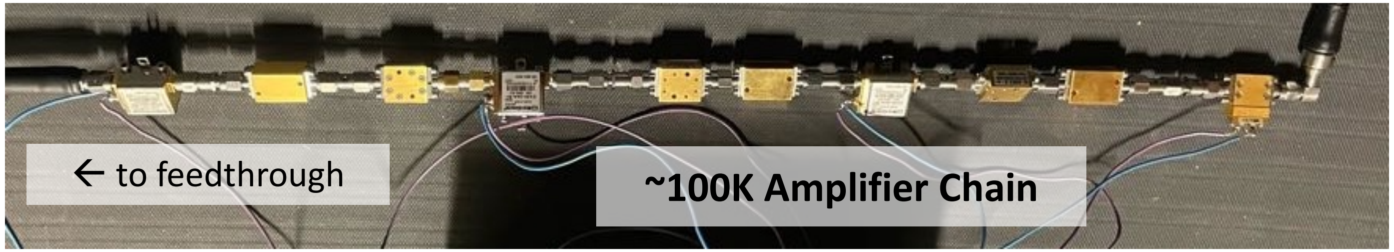


First Data Taking Run





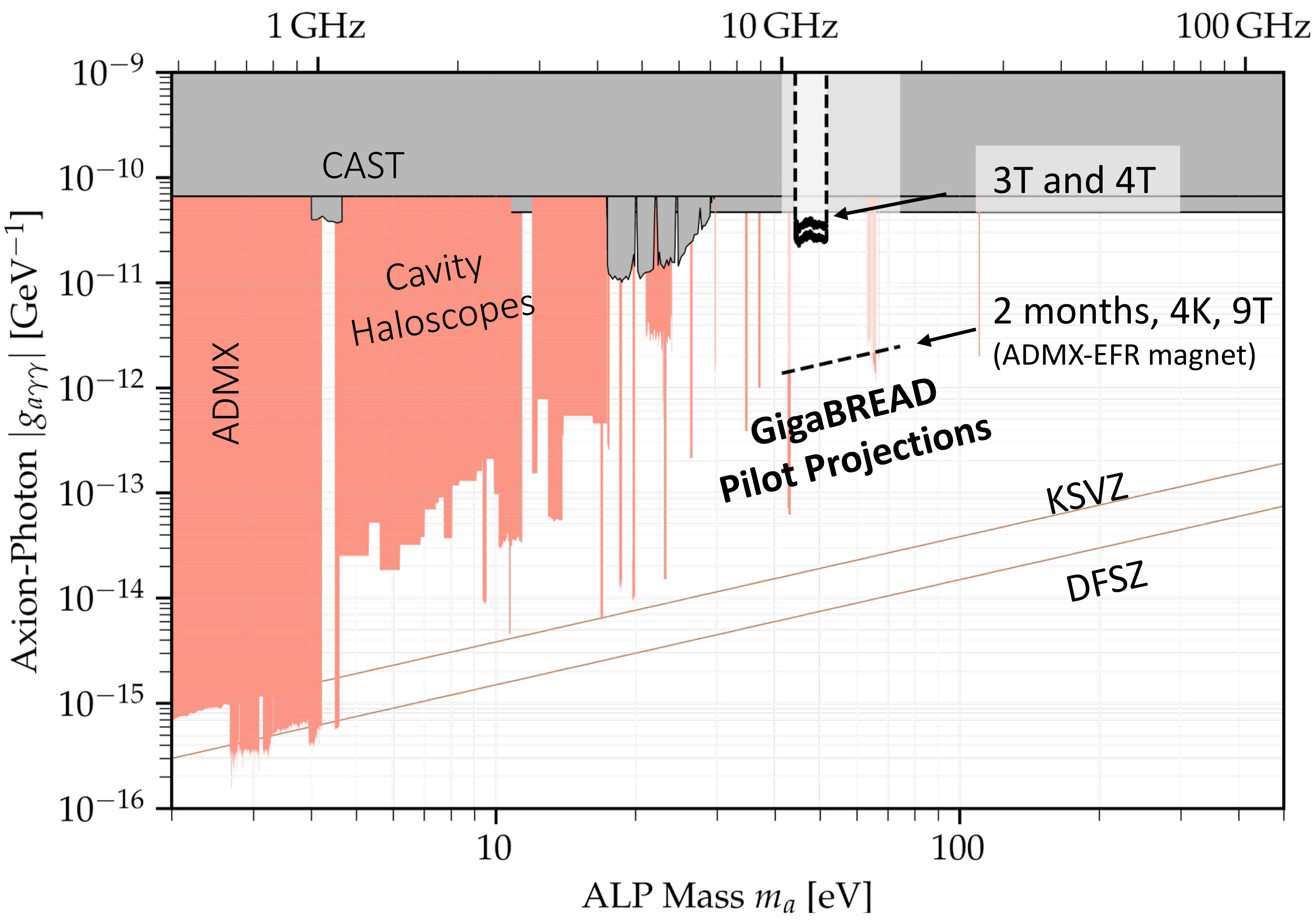
← to DAQ



- **24 days science data, June 16 – July 17**
- University of Chicago 41° 47' 31.6098", -87° 36' 6.141"
- sensitive to vertical dark photon polarization
- horn antenna focal spot sweep over every ~ 4hrs
- *RFI shielded Faraday cage:* dish, all RF amplifiers
- *in basement:* down-conversion, DAQ, slow control

Axion-Like Particles – Magnetic Field

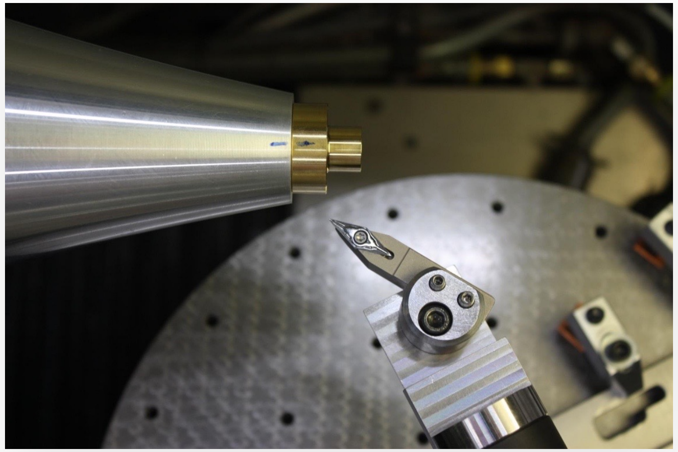
4 T MRI magnet at Argonne

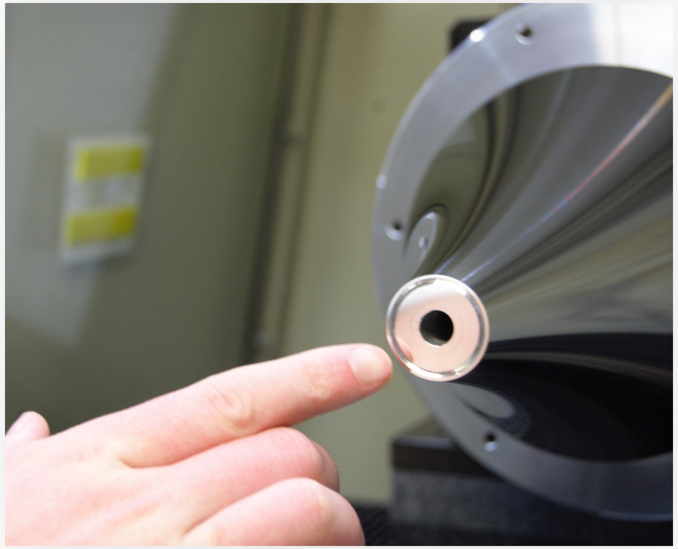


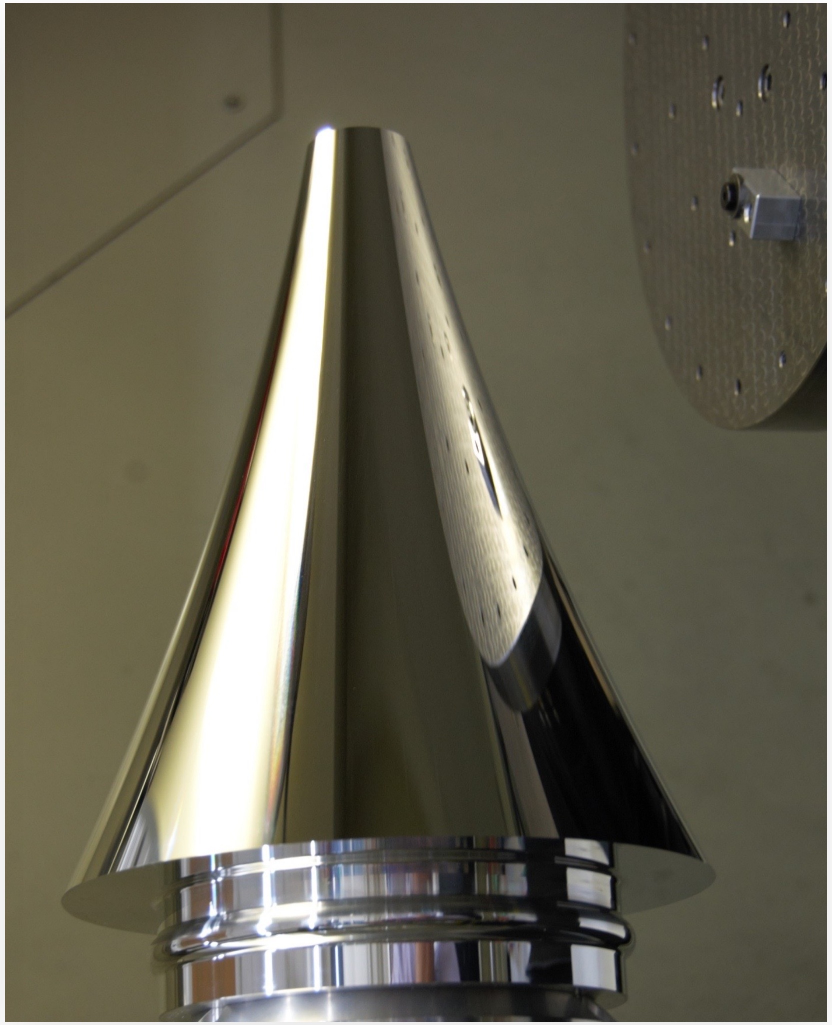
[limit plot adapted from cajohare.github.io/axionlimits]

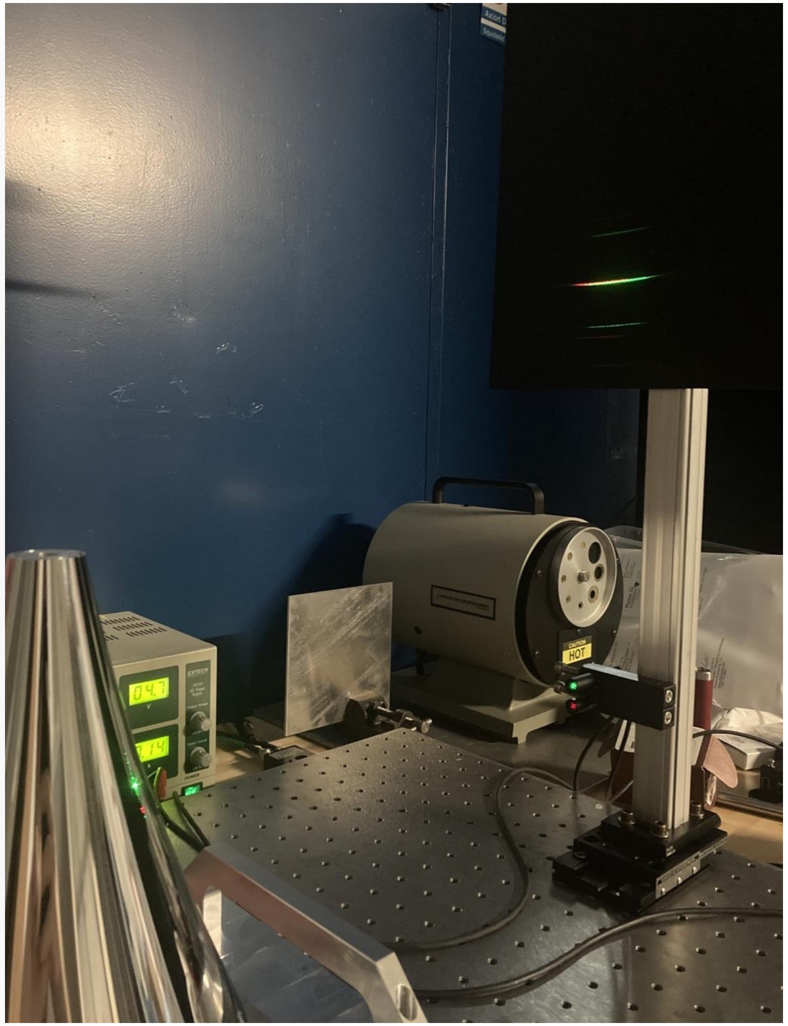
Pictured: Derrick Rodriguez, Gabe Hoshino, Andrew Sonnenschein, SK, Ben Knepper, Mira Littmann

Optical-Grade Reflector from LLNL → InfraBREAD







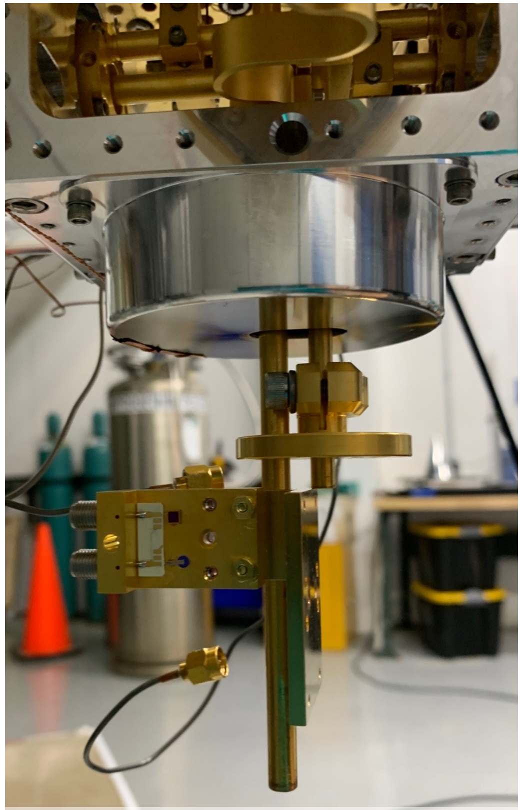


mirror-like finish, expected focal properties

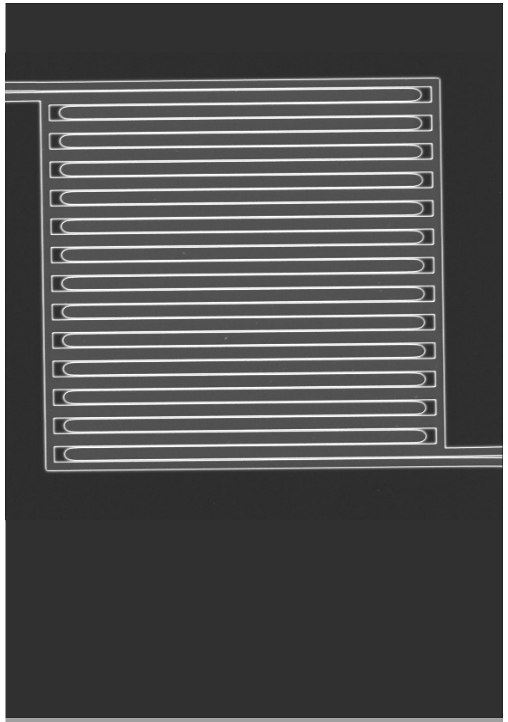
Allows to search for infrared (eV) axions

→ Ethan

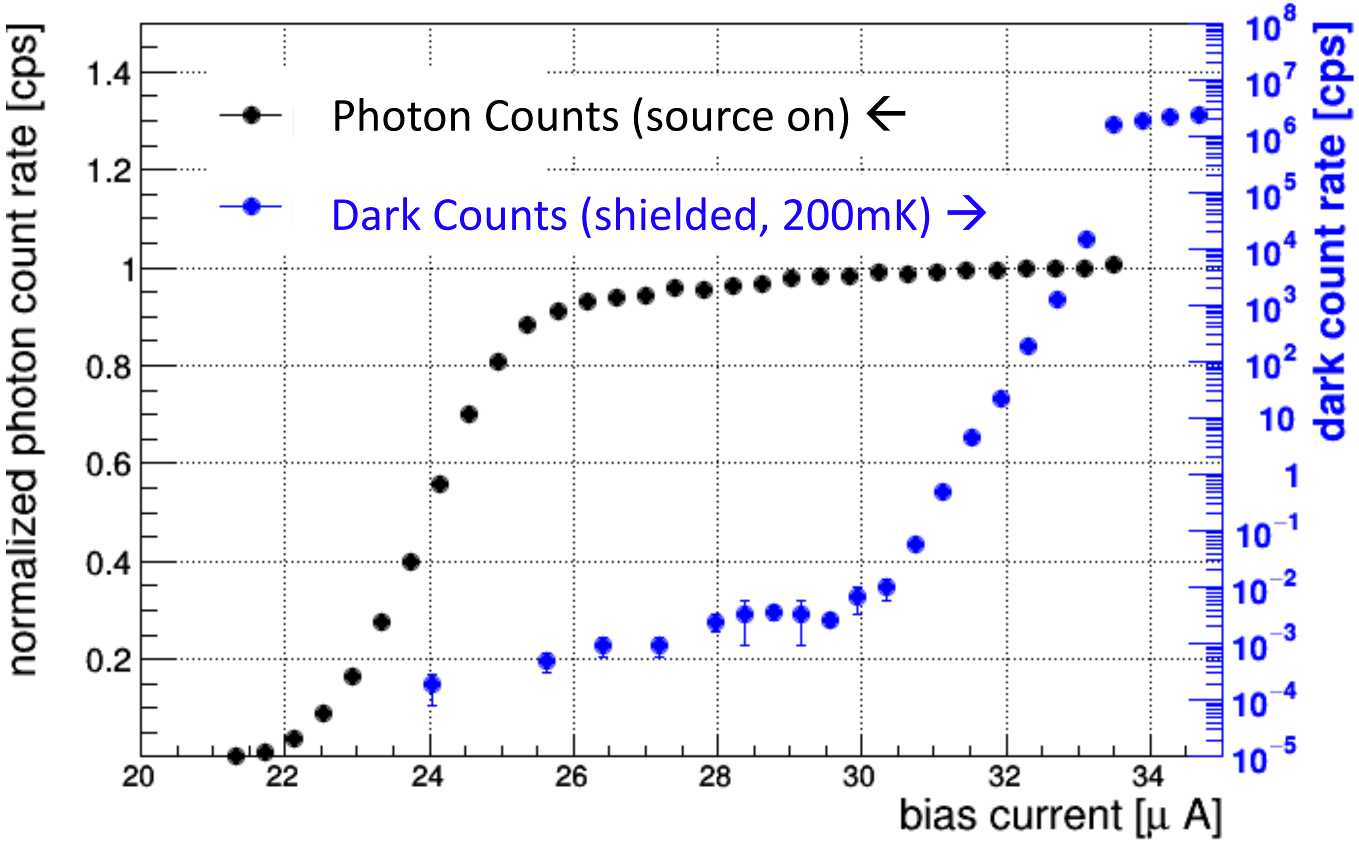
Infrared Sensors: Superconducting Nanowire Single Photon Detector (SNSPD)



SNSPDs from JPL

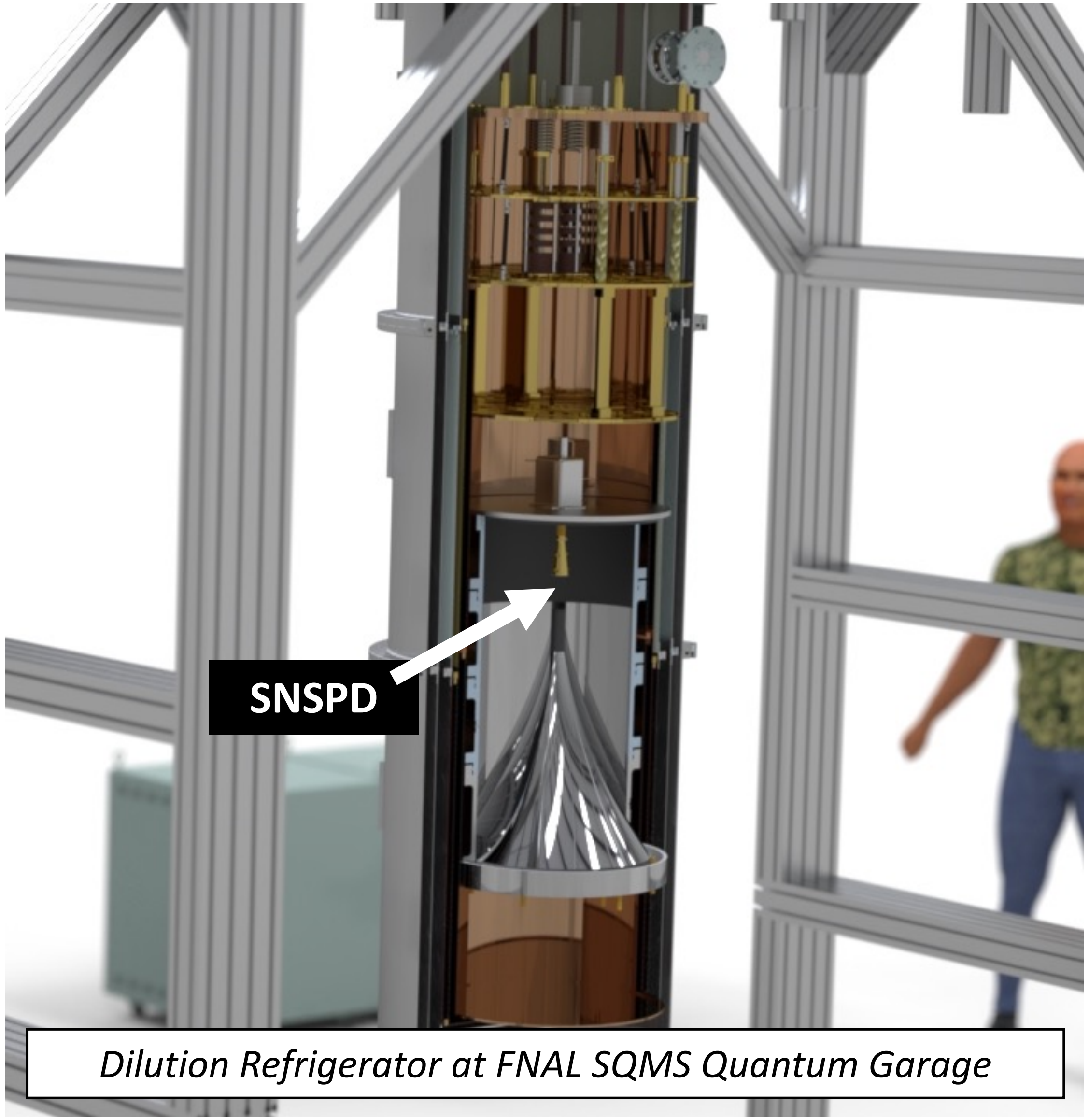


100nm wide nanowires in 15x15μm SNSPD from MIT



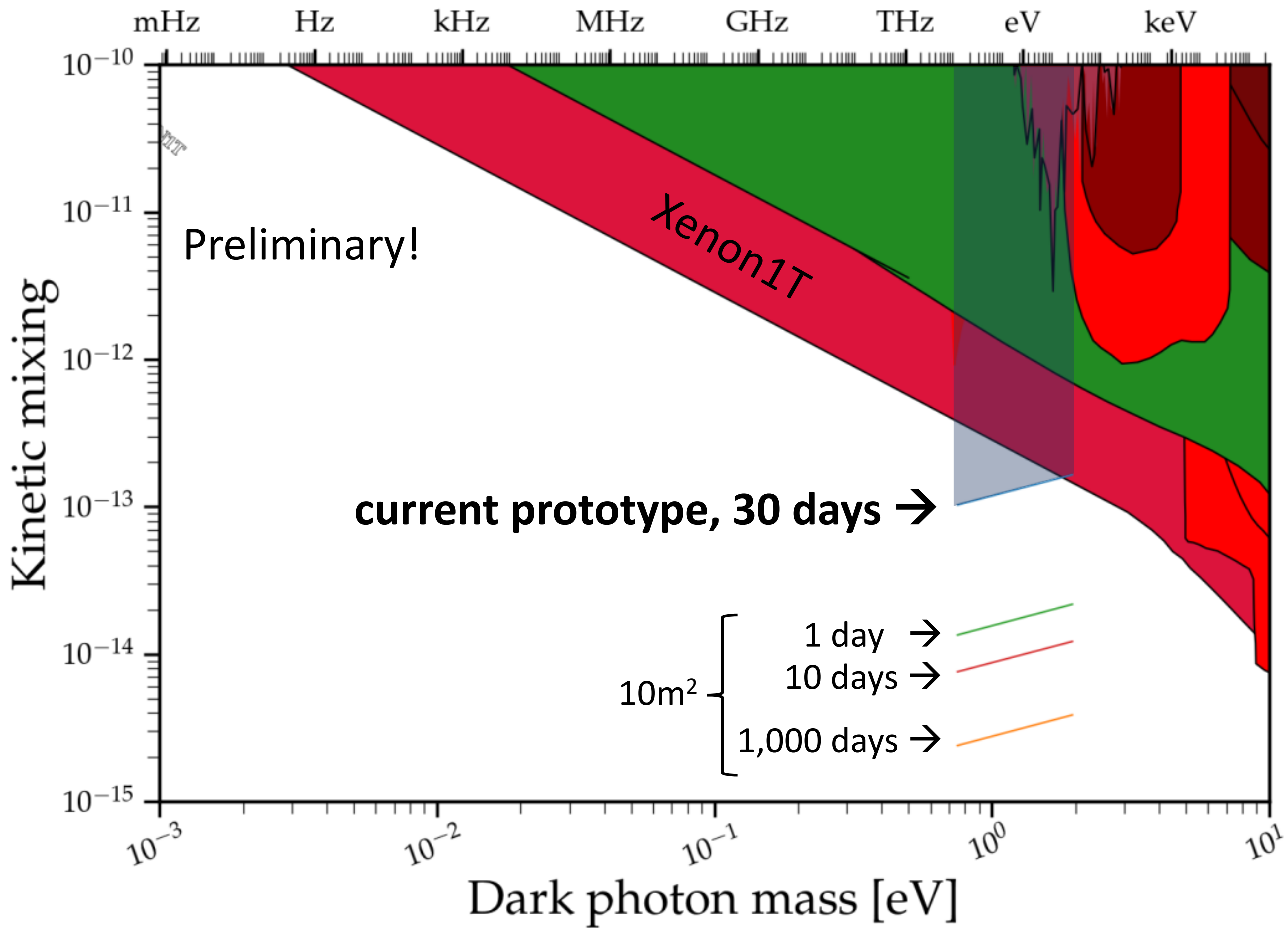
will enable cryogenic dark photon search at infrared (eV)

InfraBREAD Pilot Sensitivity

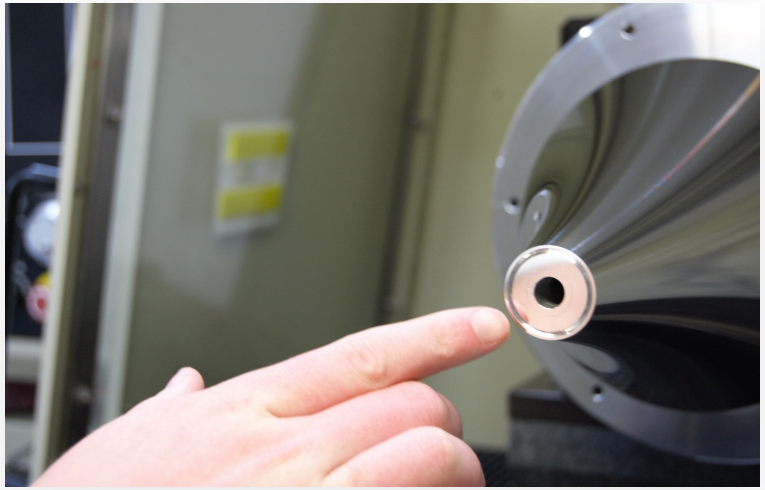


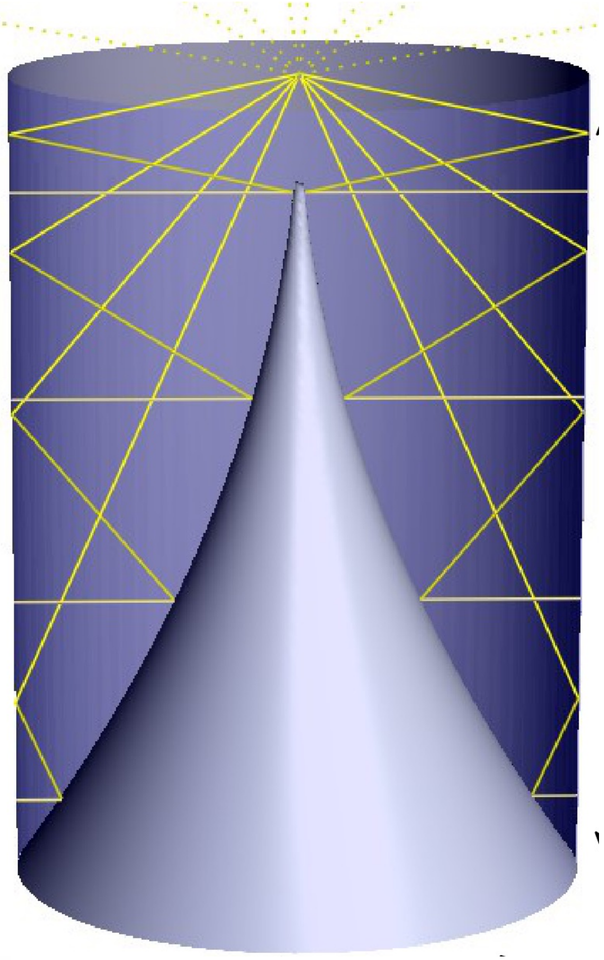
Dilution Refrigerator at FNAL SQMS Quantum Garage

Hidden Photon Sensitivity Projection

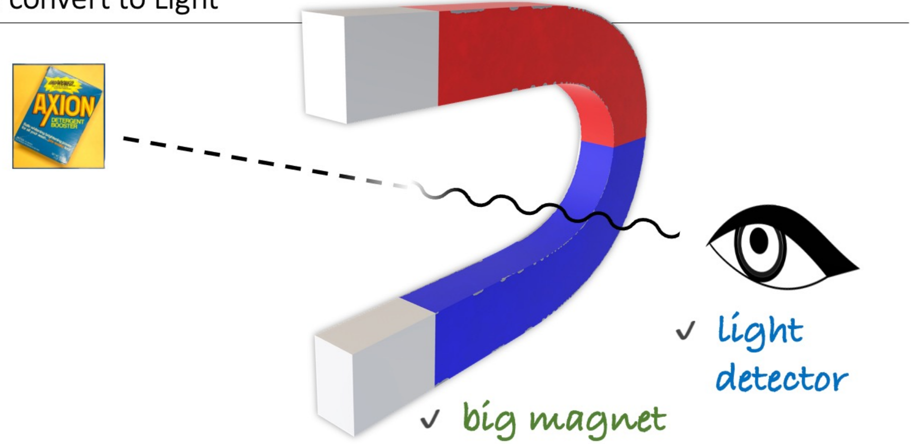


Conclusion





Axions convert to Light



$P = 10^{-25}$ W (@10GHz, 10T, 10m^2 cross-section)