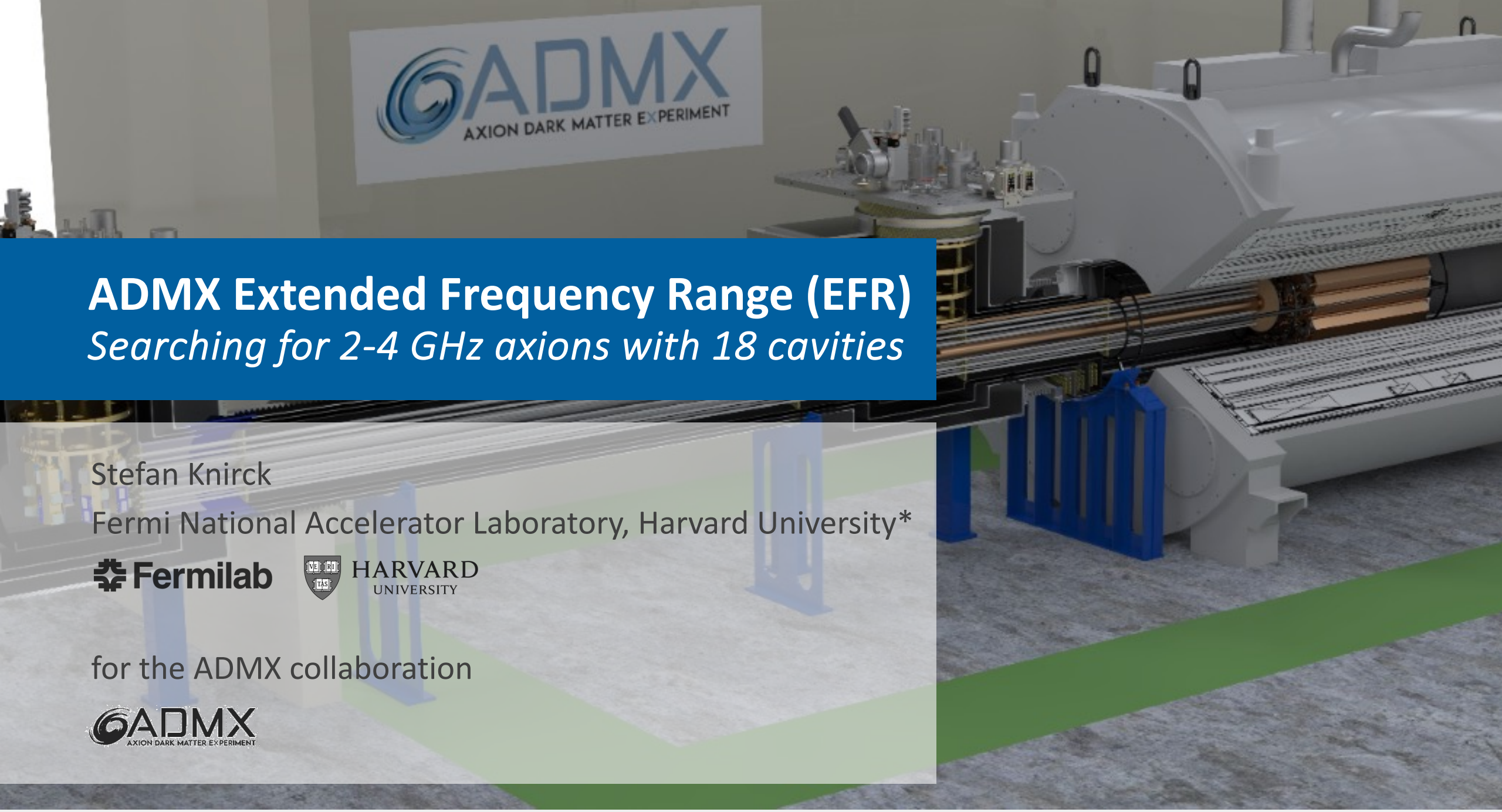


ADMX Extended Frequency Range (EFR)

Searching for 2-4 GHz axions with 18 cavities

Stefan Knirck

Fermi National Accelerator Laboratory, Harvard University*

Fermilab HARVARD UNIVERSITY

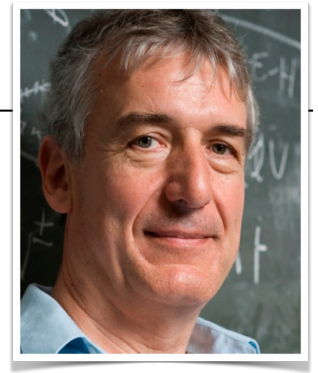
for the ADMX collaboration

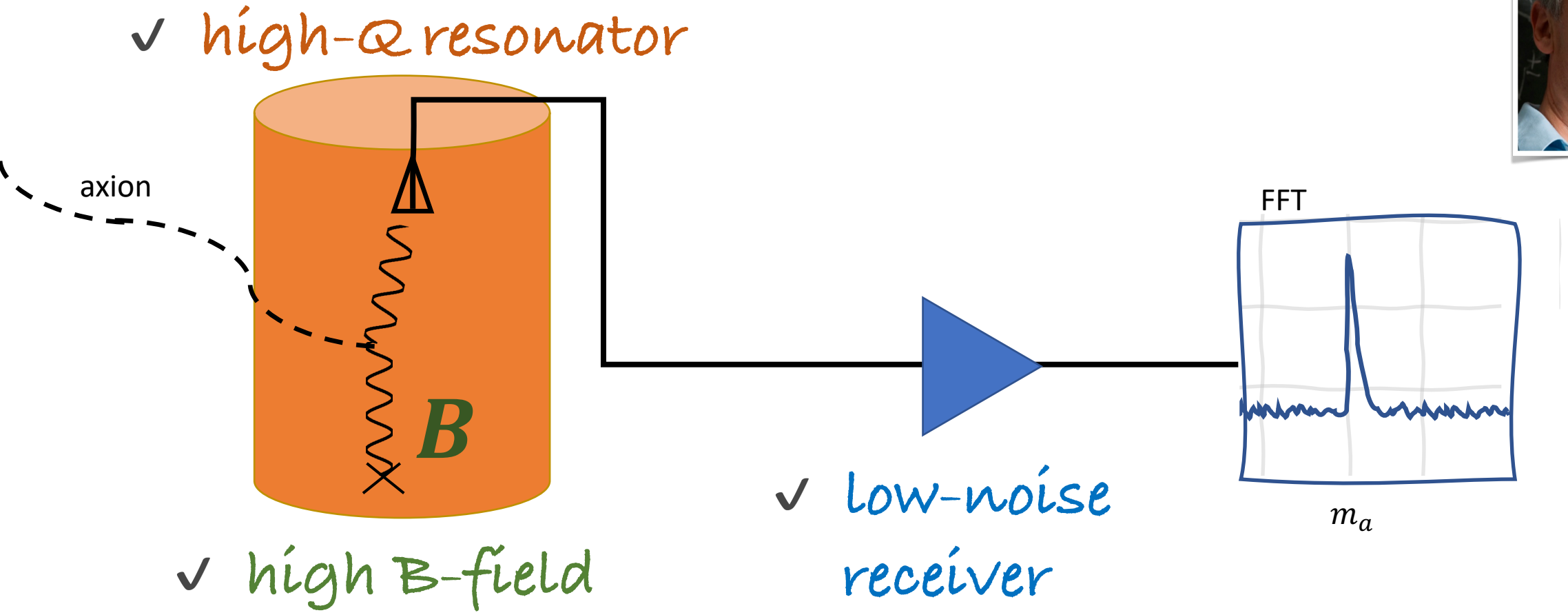
ADMX AXION DARK MATTER EXPERIMENT

* from January 2025

The Resonant Cavity

[P. Sikivie, PRL 51, 1415 (1983)]

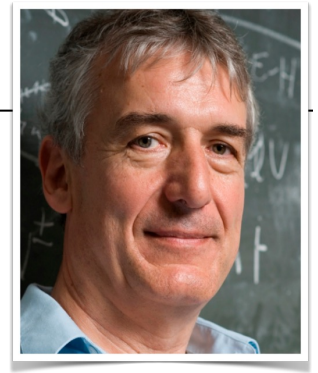




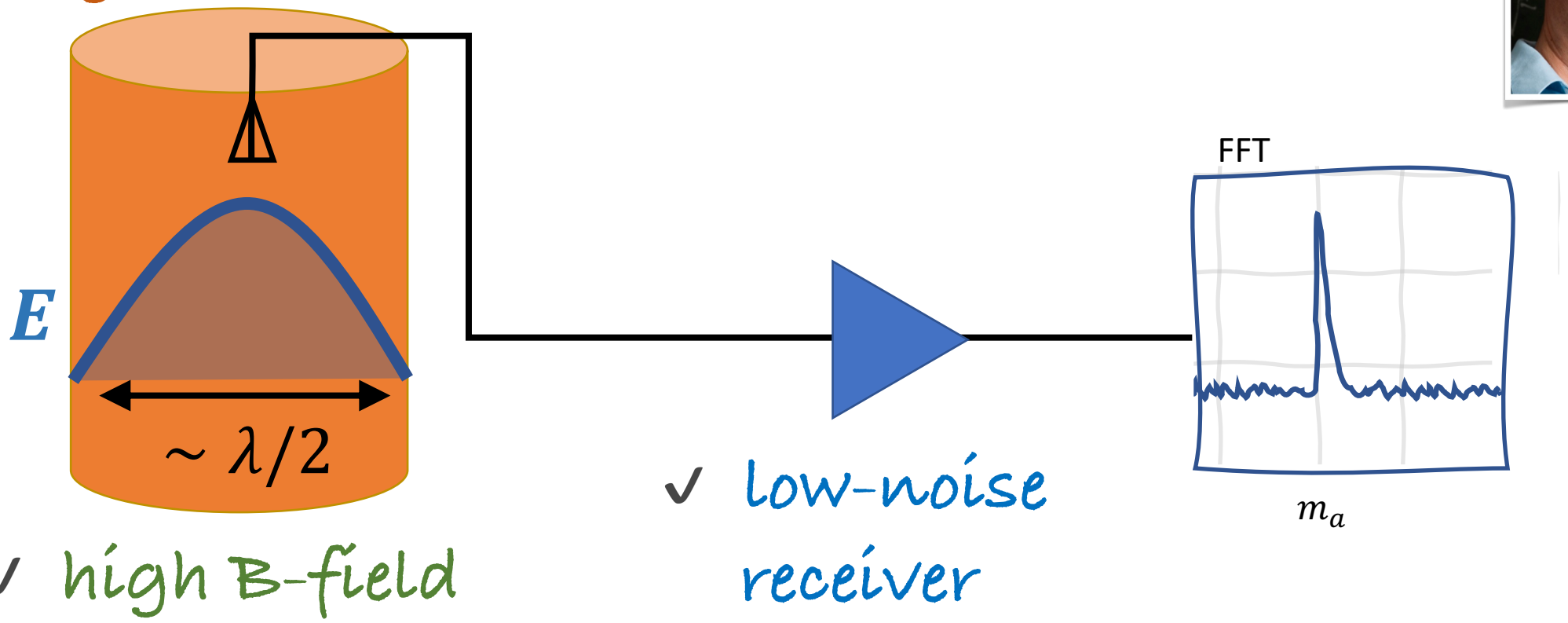
$$P_{\mathrm{sig}} = 2 \cdot 10^{-23}\ \mathrm{W} \cdot \left(\frac{B}{7.6\ \mathrm{T}}\right)^2 \left(\frac{V}{136\ \ell}\right) \left(\frac{C}{0.4}\right) \left(\frac{Q}{30{,}000}\right) \left(\frac{g_\gamma}{0.36}\right)^2 \left(\frac{m_a}{3\ \mu\mathrm{eV}}\right) \left(\frac{\rho_{\mathrm{DM}}}{0.45\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

The Resonant Cavity

[P. Sikivie, PRL 51, 1415 (1983)]



✓ high-Q resonator



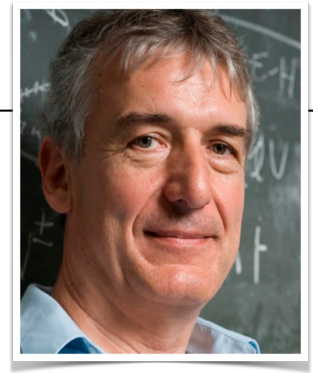
✓ low-noise receiver

✓ high B-field

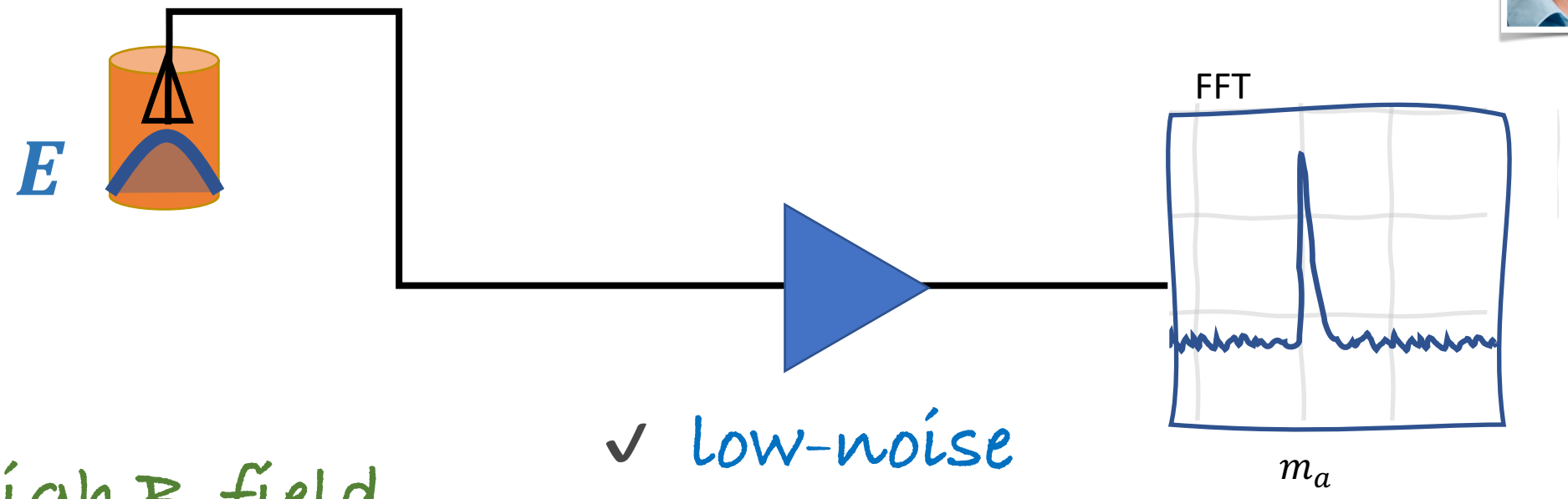
$$P_{\mathrm{sig}} = 2 \cdot 10^{-23}\ \mathrm{W} \cdot \left(\frac{B}{7.6\ \mathrm{T}}\right)^2 \left(\frac{V}{136\ \ell}\right) \left(\frac{C}{0.4}\right) \left(\frac{Q}{30{,}000}\right) \left(\frac{g_\gamma}{0.36}\right)^2 \left(\frac{m_a}{3\ \mu\mathrm{eV}}\right) \left(\frac{\rho_{\mathrm{DM}}}{0.45\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

The Resonant Cavity – Higher Masses

[P. Sikivie, PRL 51, 1415 (1983)]



✓ high-Q resonator



✓ high B-field

✓ low-noise receiver

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

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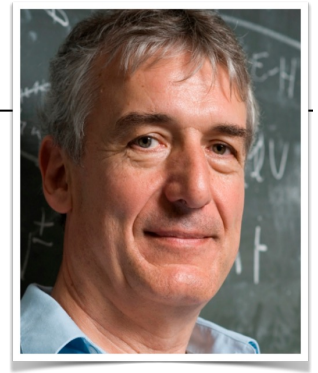
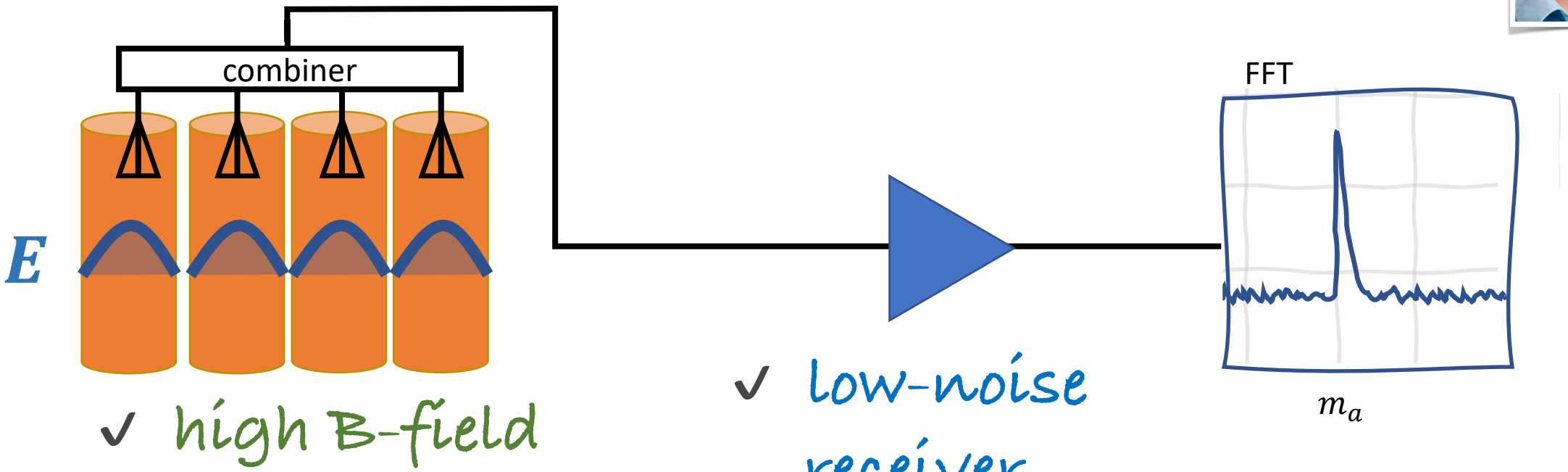


✓ high-Q resonators

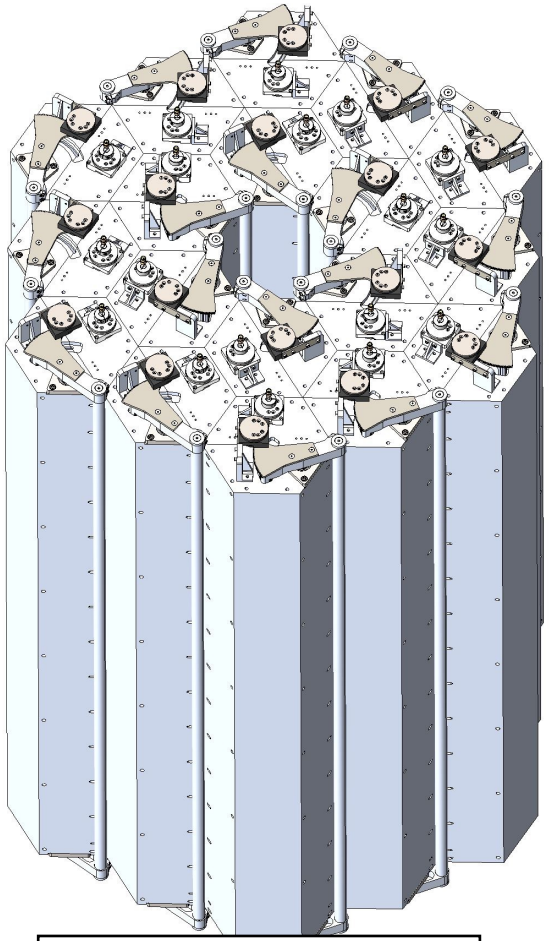


✓ high B-field

✓ low-noise receiver

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

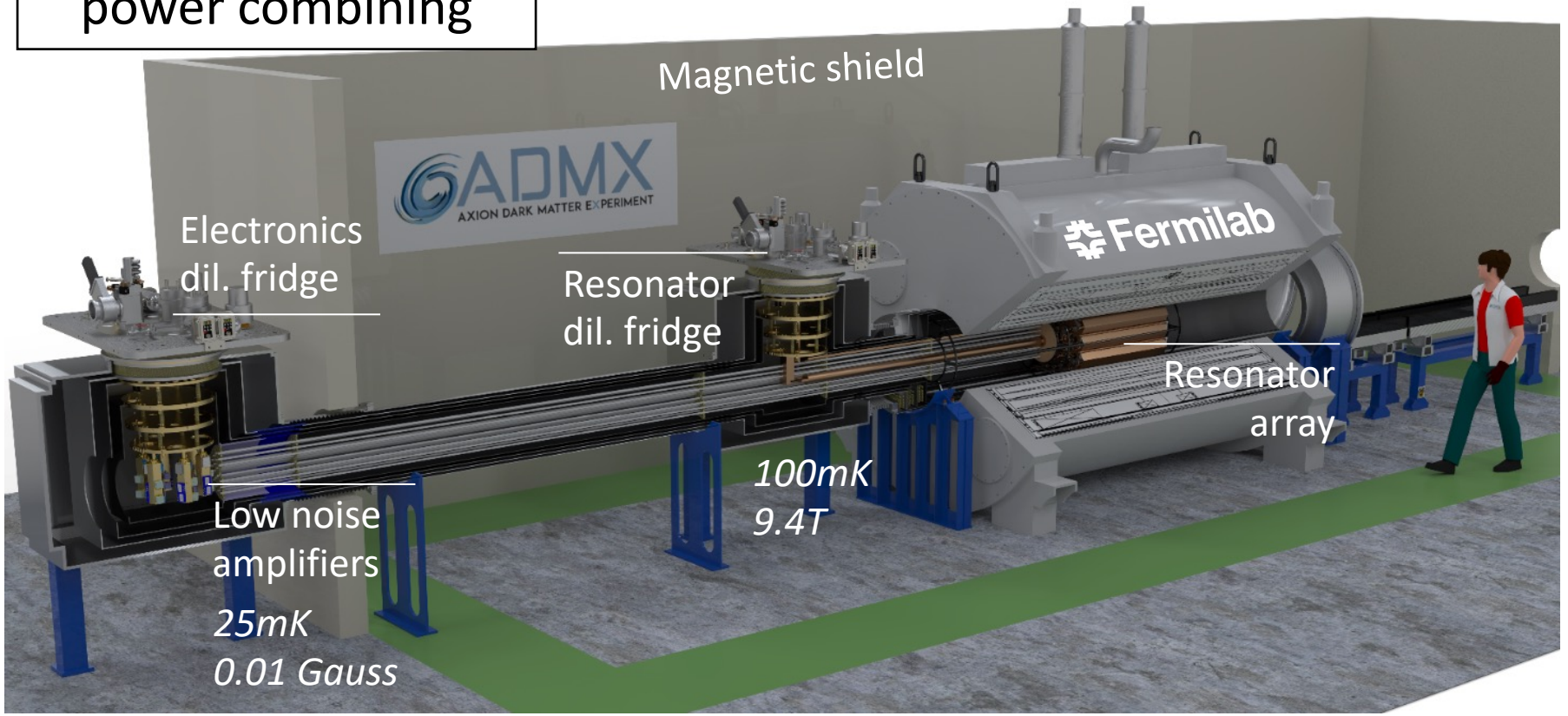
ADMX-EFR (Extended Frequency Range): 2 – 4 GHz (9 – 16 μeV)



18 cavity array

digital power combining

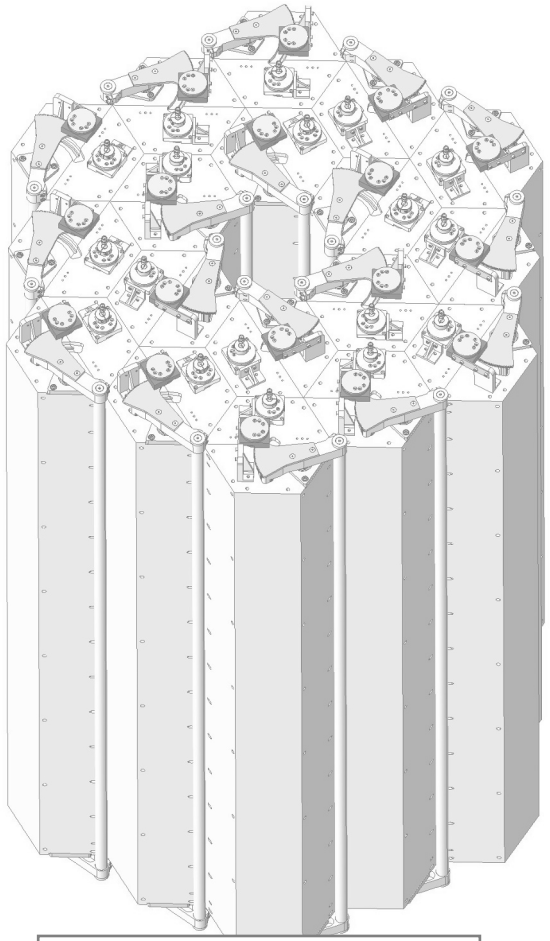
horizontal magnet: 9.4 T, 258 L



Goal: Search 2-4GHz @ DFSZ sensitivity in 3 years scan time

ADMX-EFR (Extended Frequency Range)

✓ high B-field



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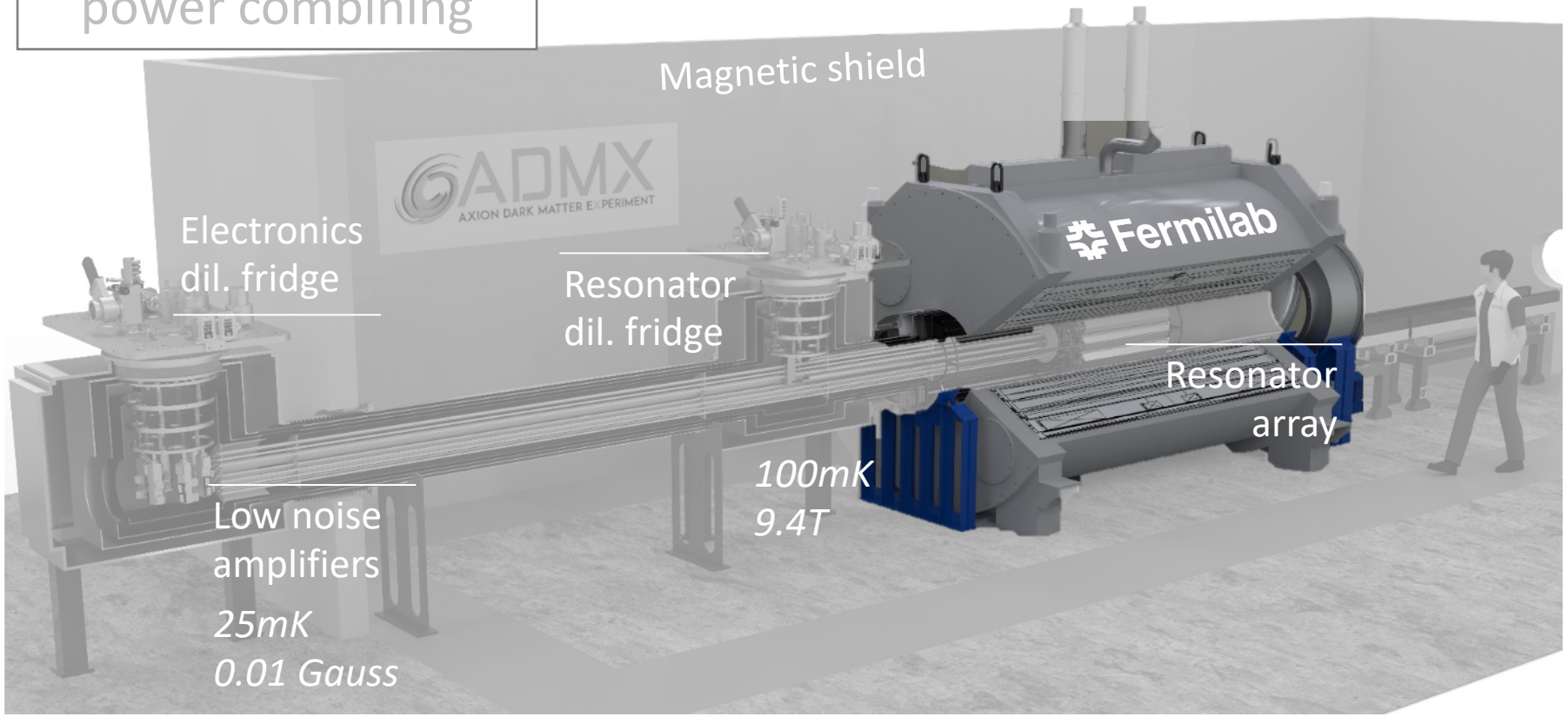


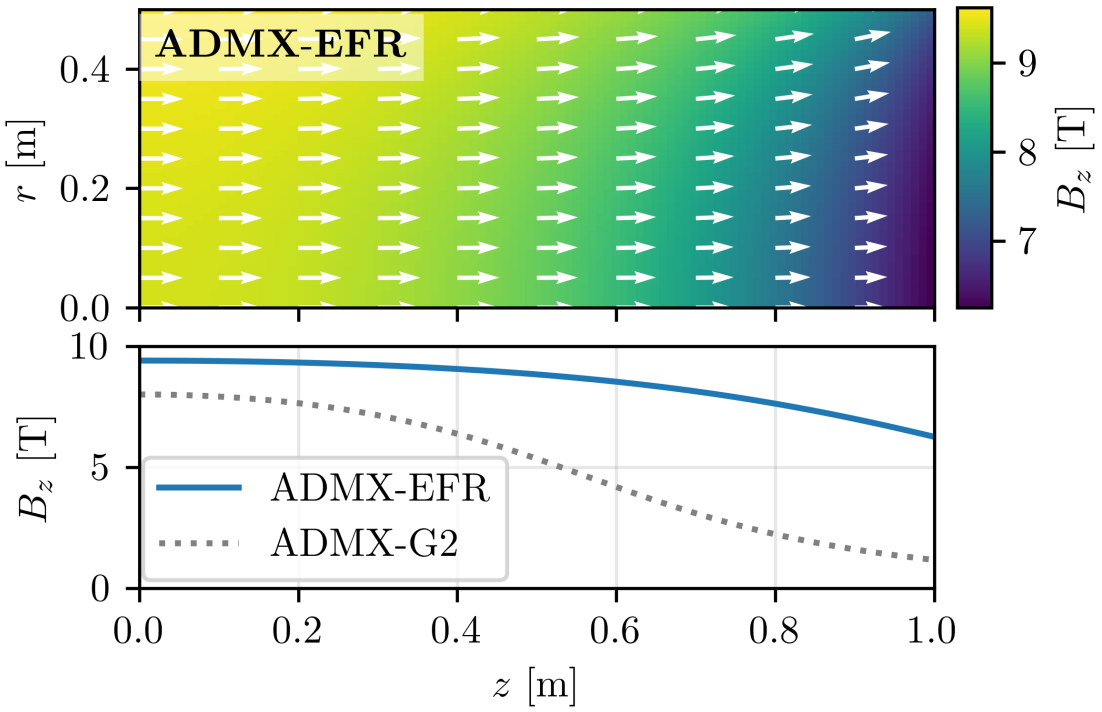
Goal: Search 2-4GHz @ DFSZ sensitivity in 3 years scan time

A Larger Magnet

✓ high B-field

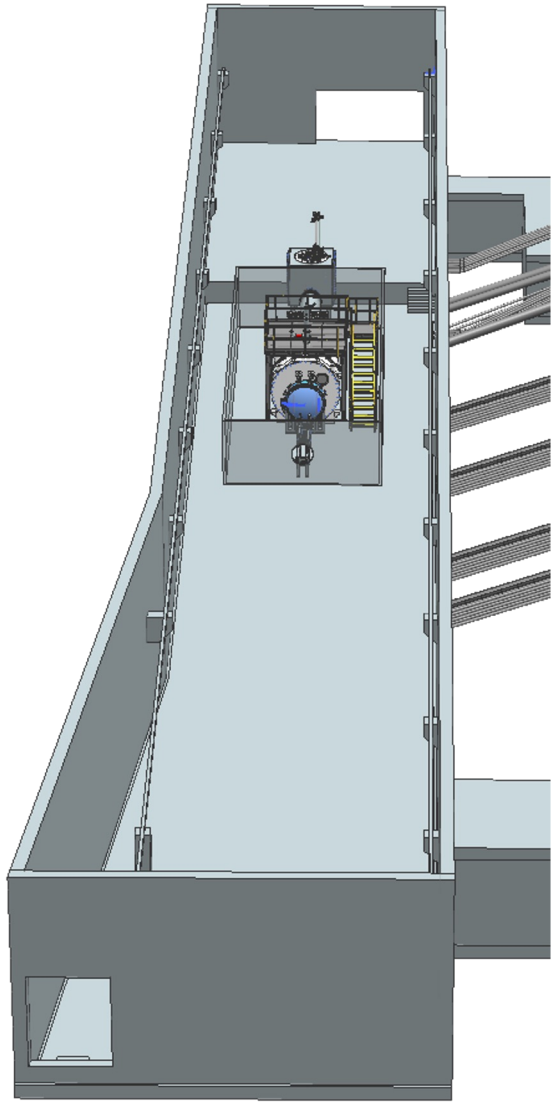
MRI magnet
University of Illinois Chicago (UIC)

Manufactured by GE Healthcare in 2003



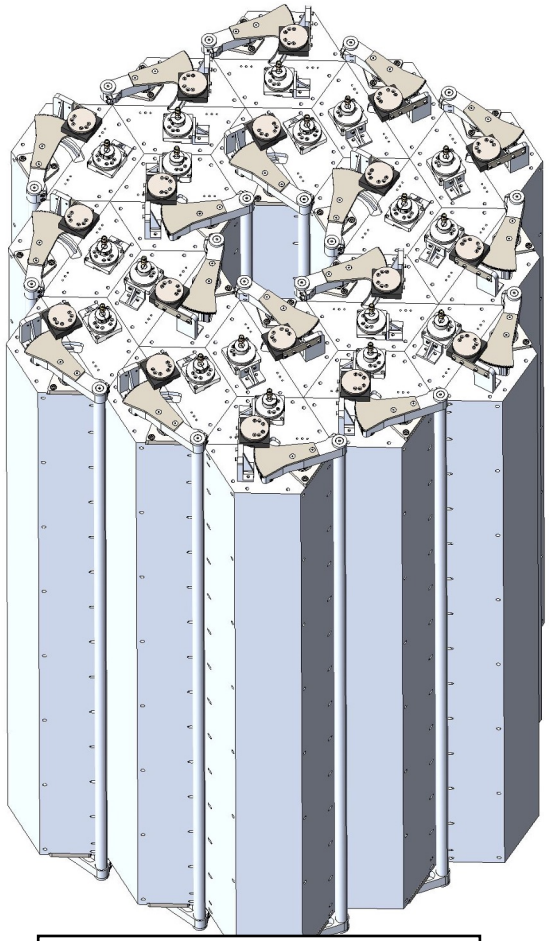
A Larger Magnet – has arrived!

✓ high B-field



ADMX-EFR (Extended Frequency Range)

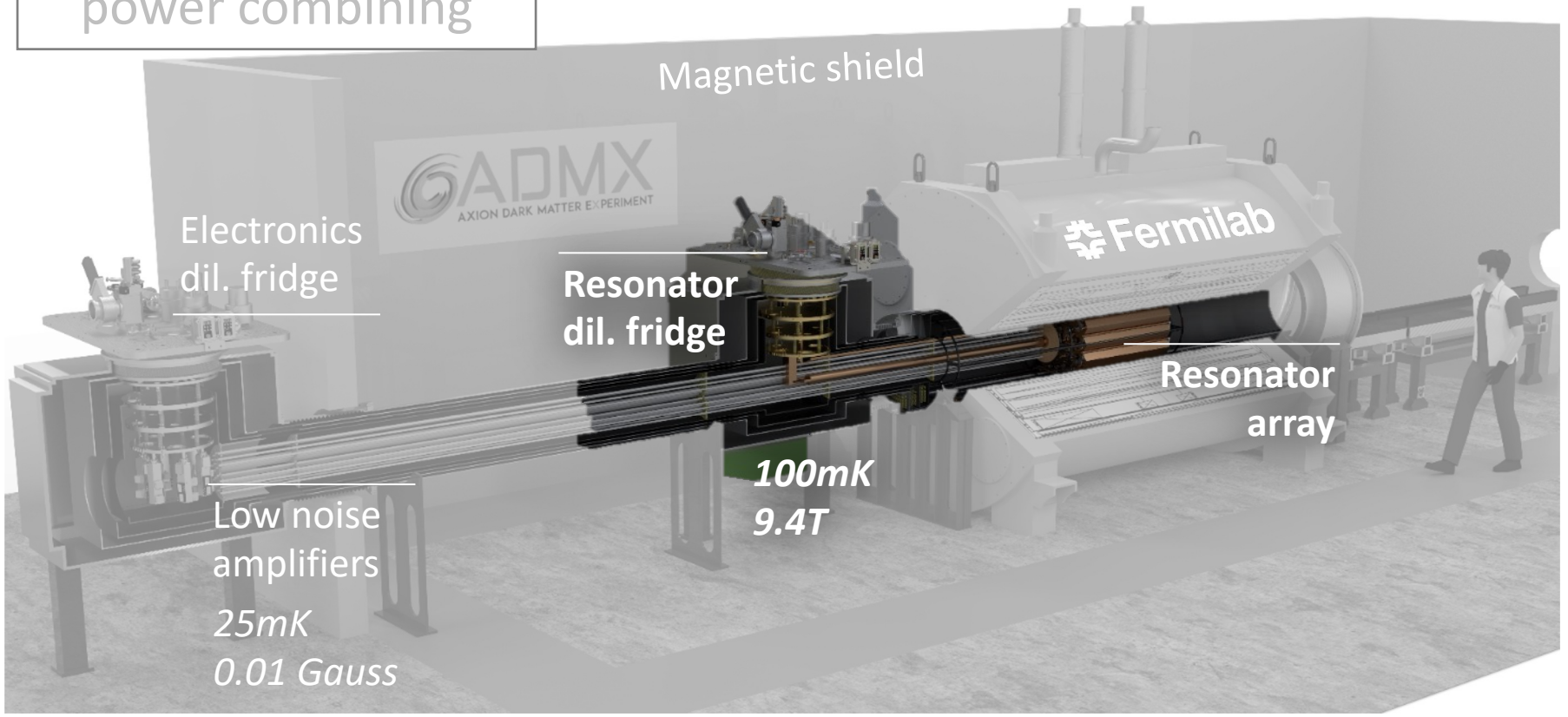
✓ resonator



18 cavity array

digital power combining

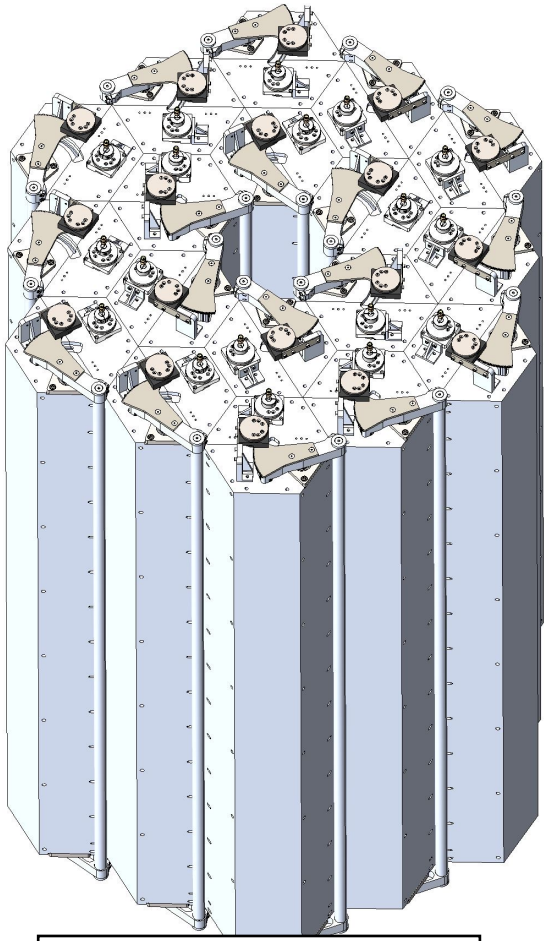
horizontal magnet: 9.4 T, 258 L



Goal: Search 2-4GHz @ DFSZ sensitivity in 3 years scan time

Resonator Modelling

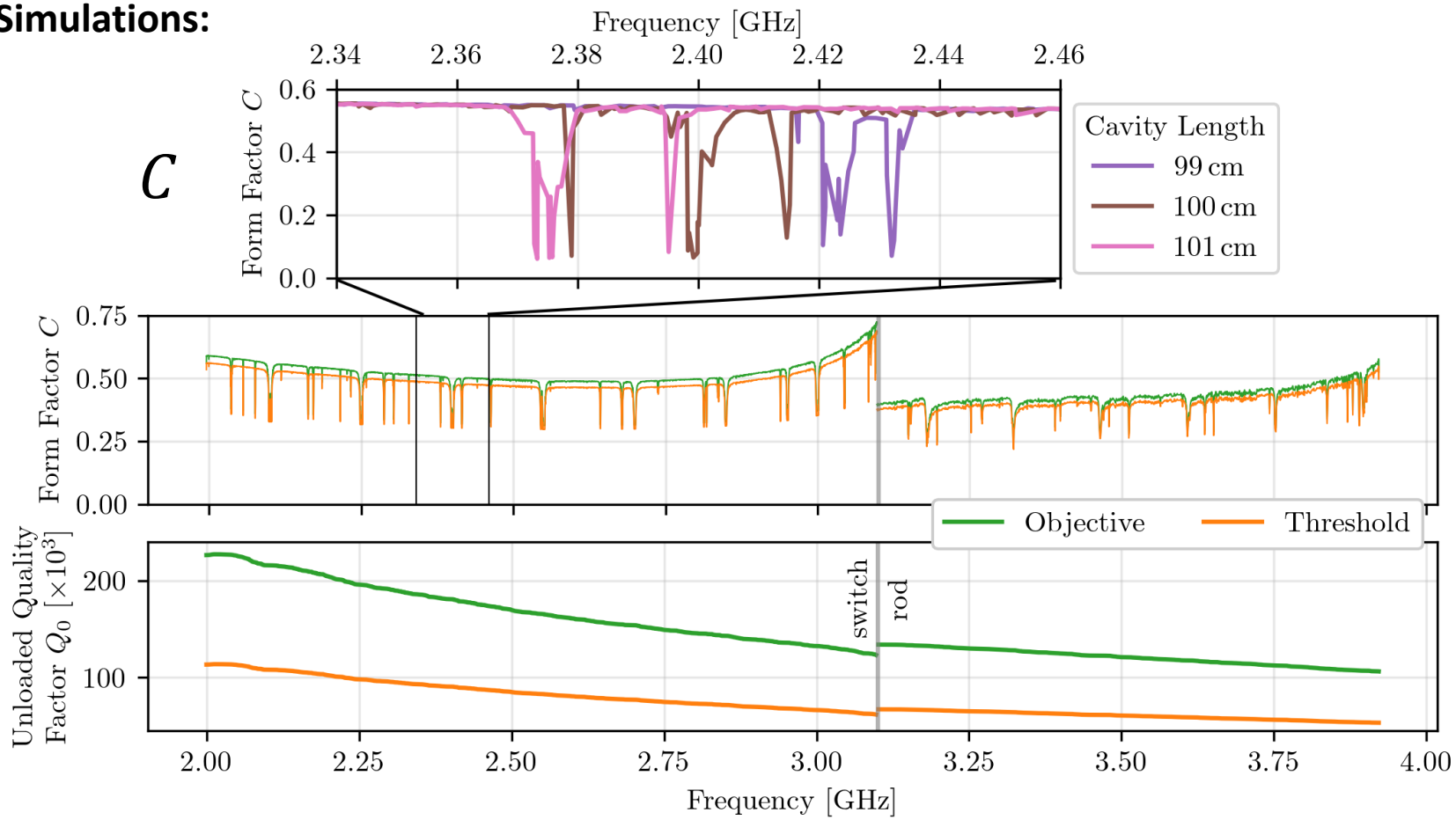
✓ resonator



18 cavity array

Simulations:

C

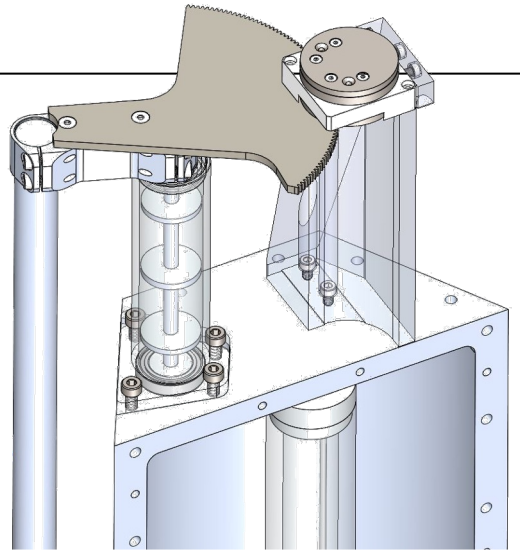


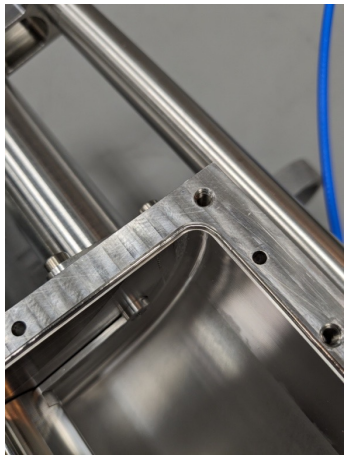
$V \sim 250\ \ell$

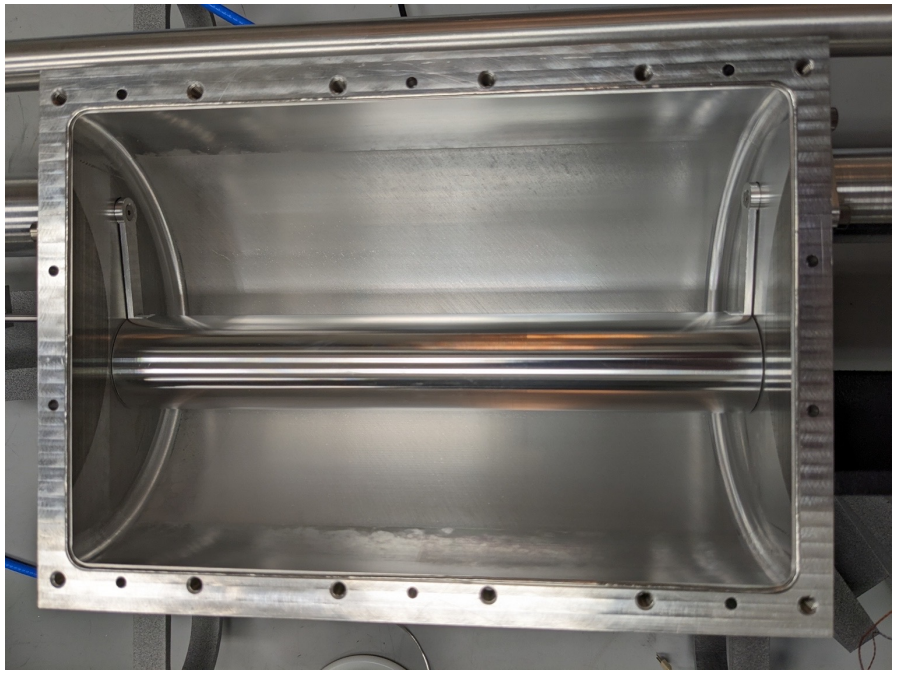
$Q_0 \sim 60{,}000$ (predicted, cryogenic)

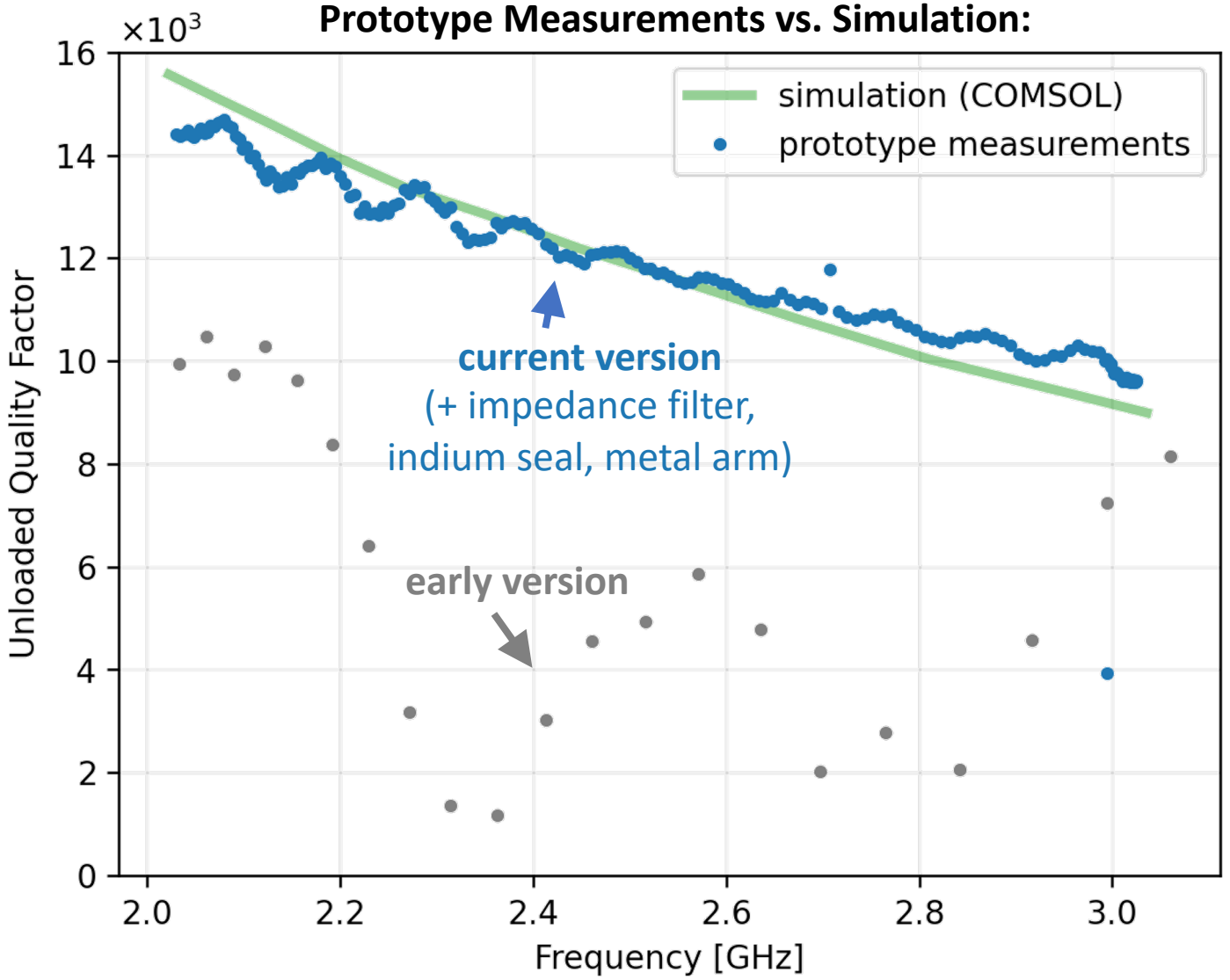
Prototype Resonator Tests

✓ resonator



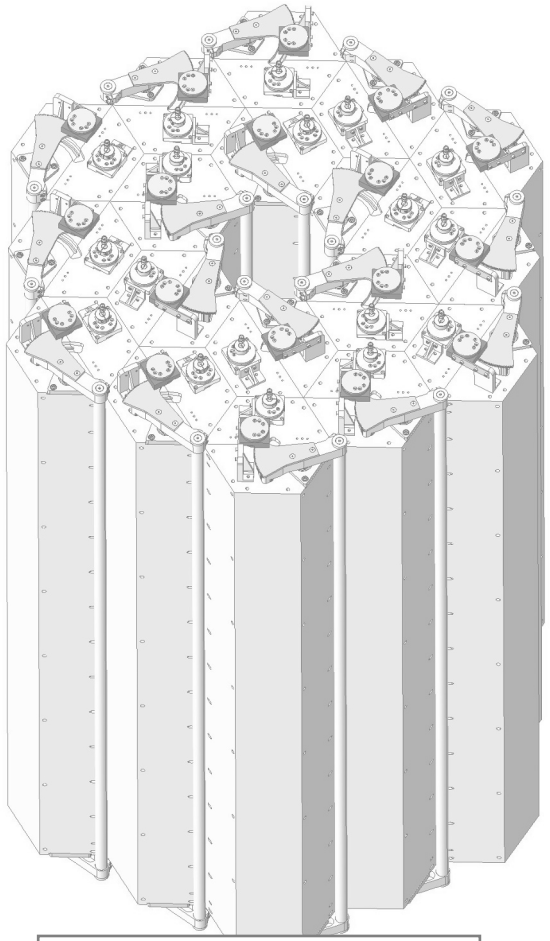






ADMX-EFR (Extended Frequency Range)

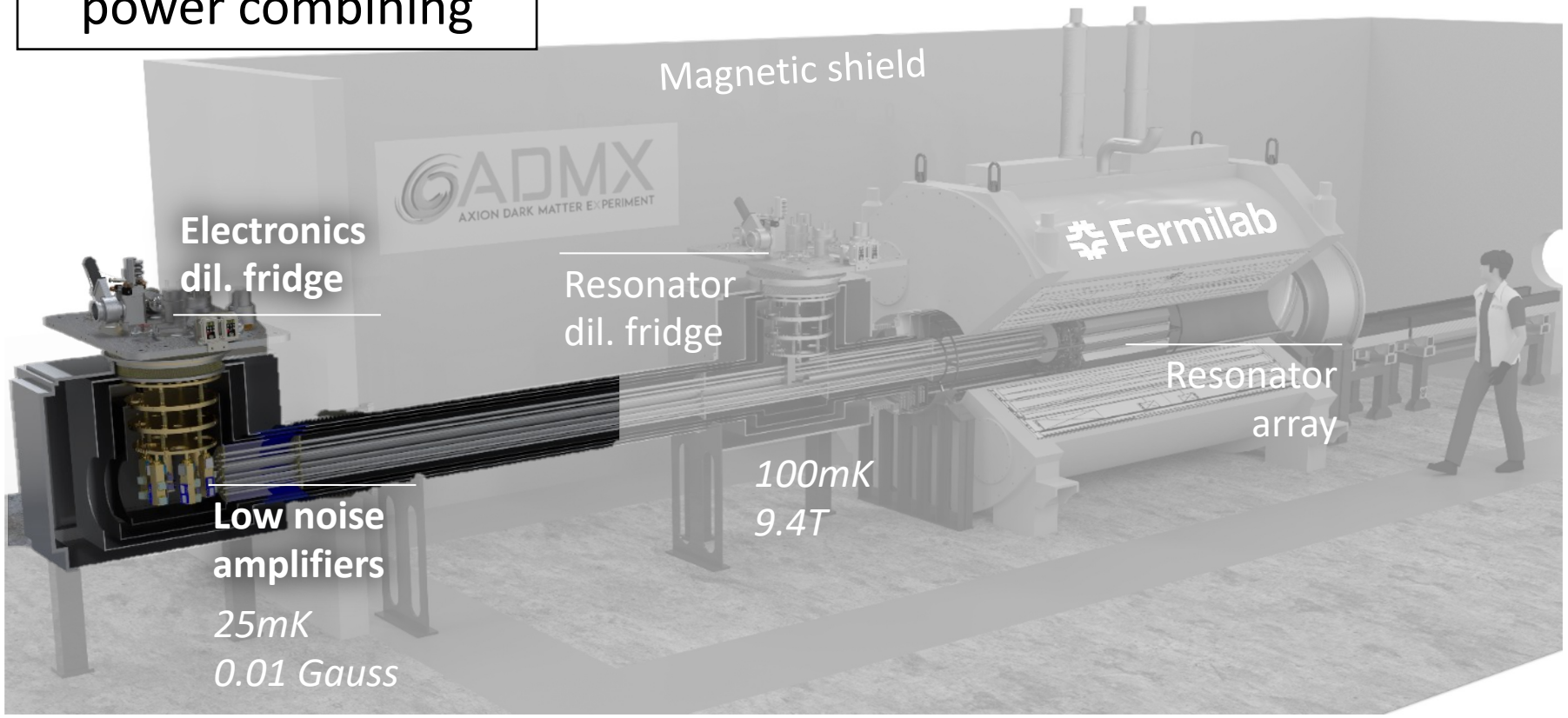
✓ receiver



18 cavity array

digital power combining

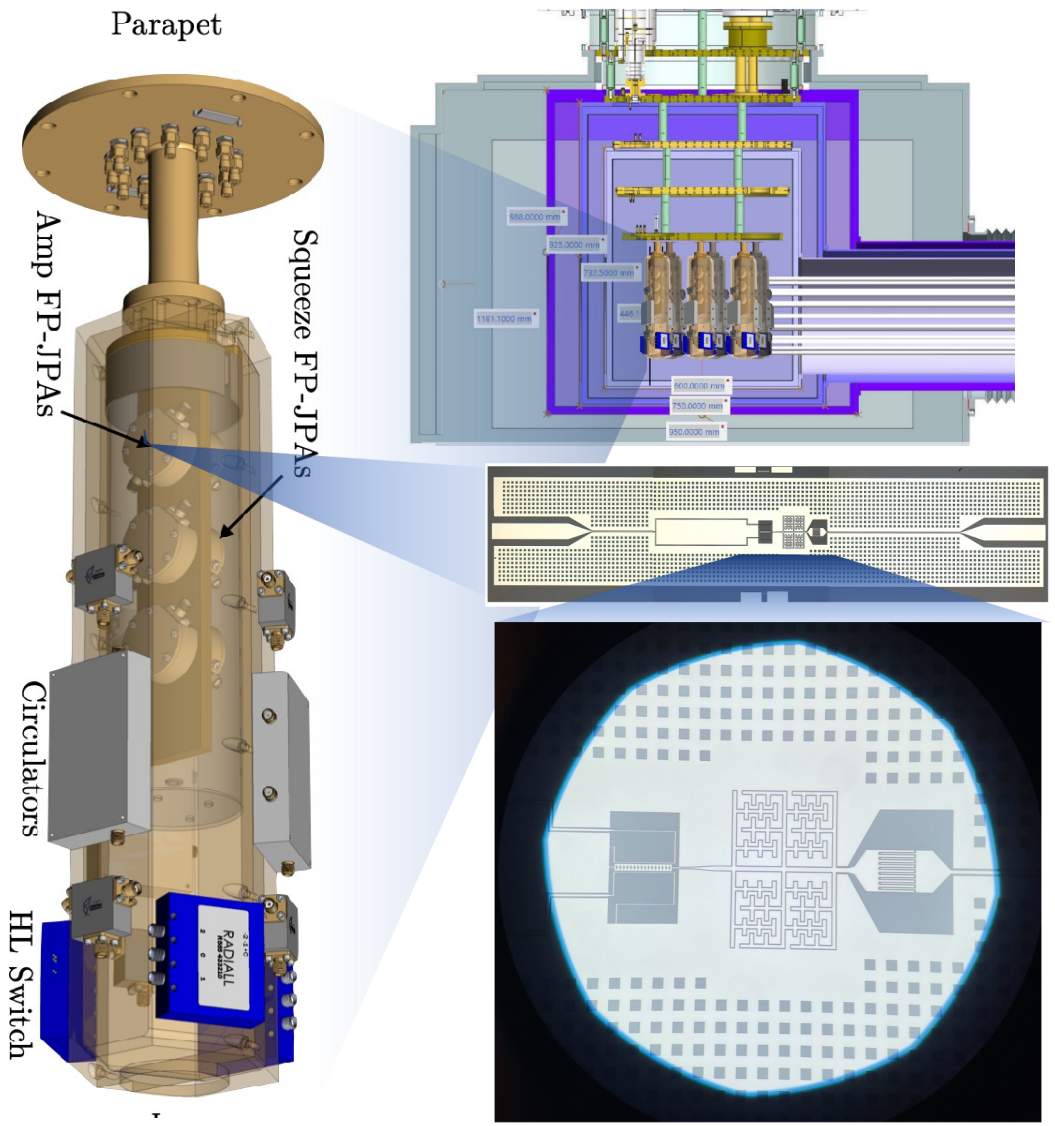
horizontal magnet: 9.4 T, 258 L

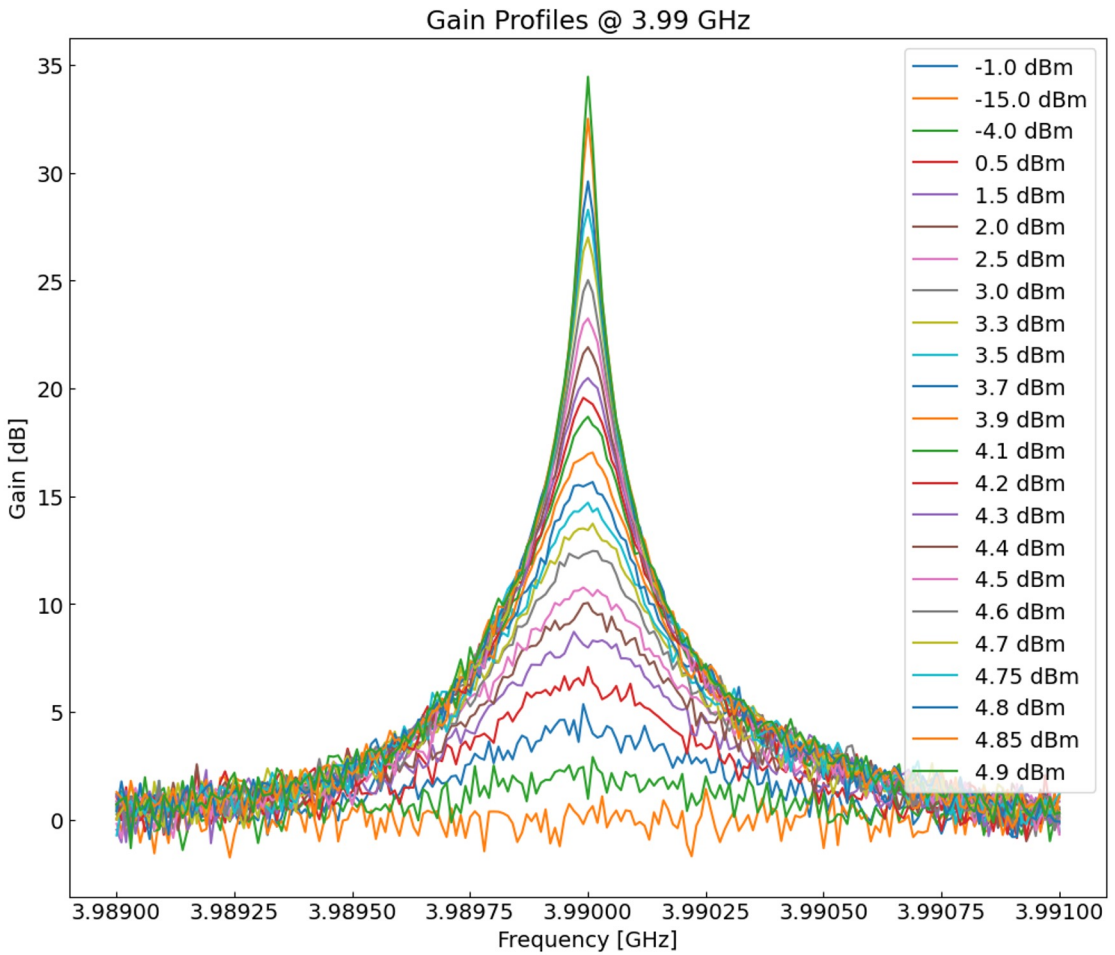


Goal: Search 2-4GHz @ DFSZ sensitivity in 3 years scan time

Cold Electronics: Flux-pumped JPAs

✓ receiver



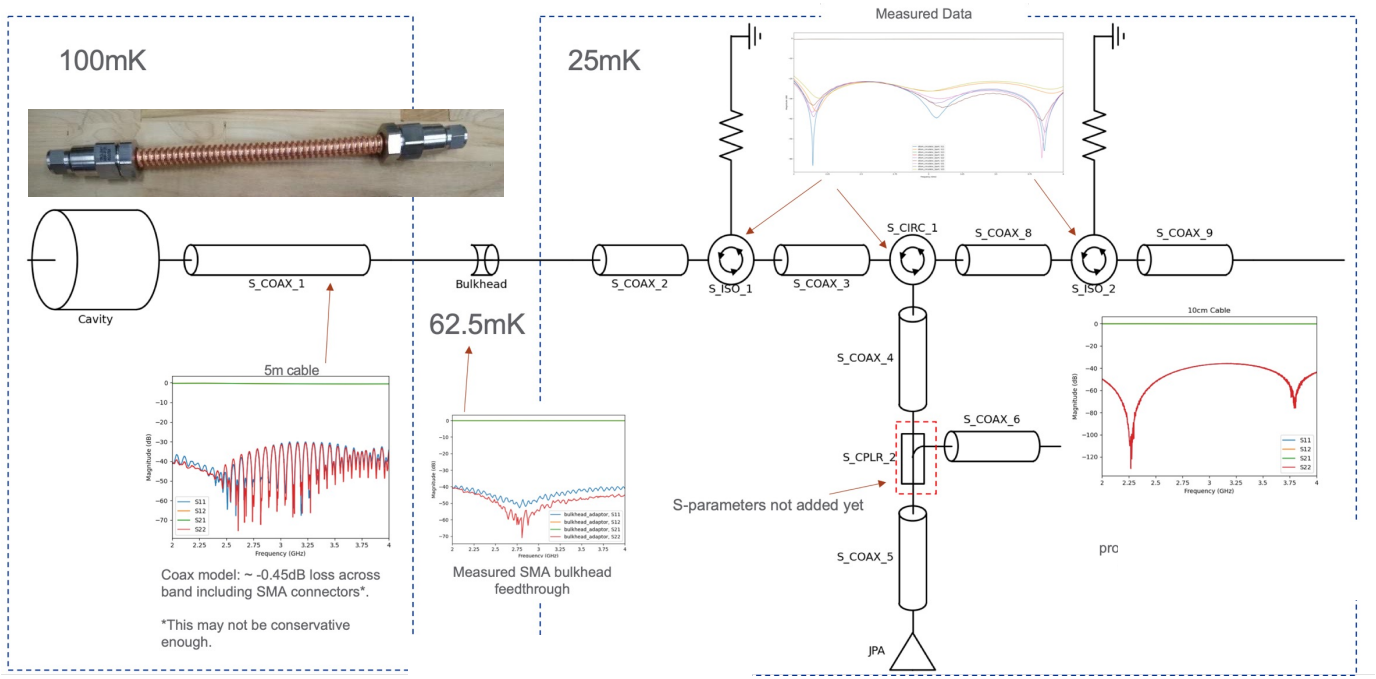


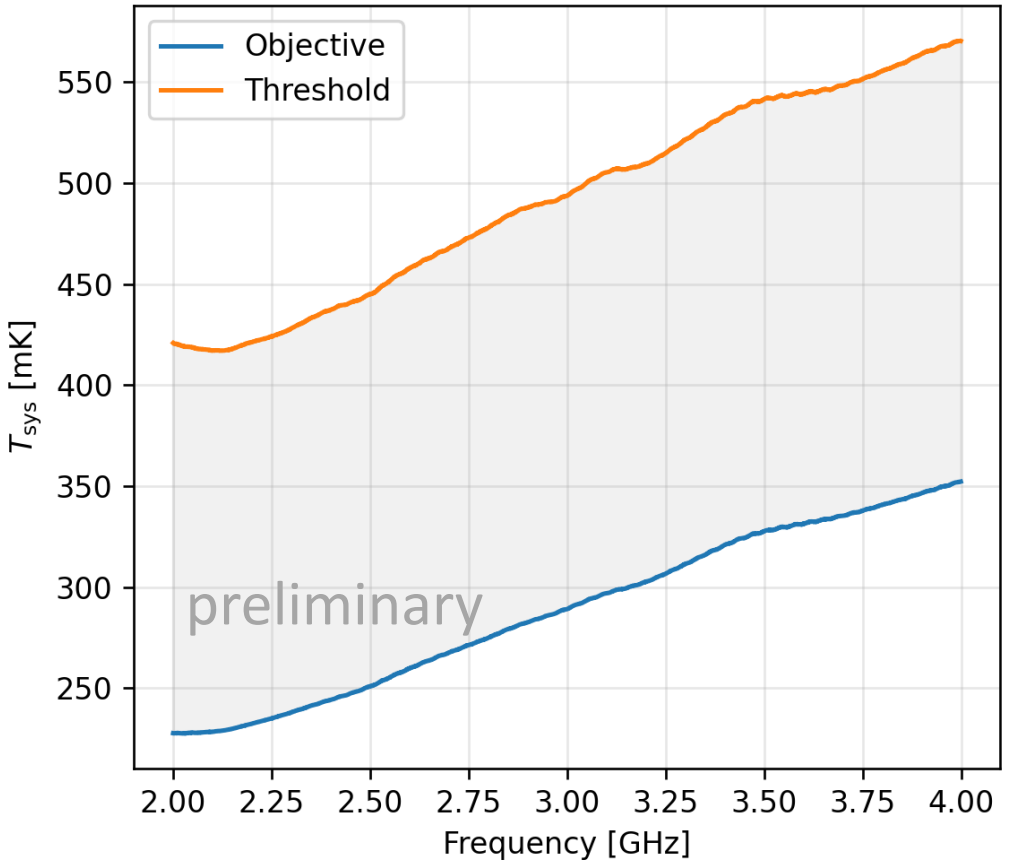
Demonstrated
3-4 GHz tunability

Preliminary result:
~ ½ photon added noise

Full Electronics Noise Model w/ scikit-rf

✓ receiver





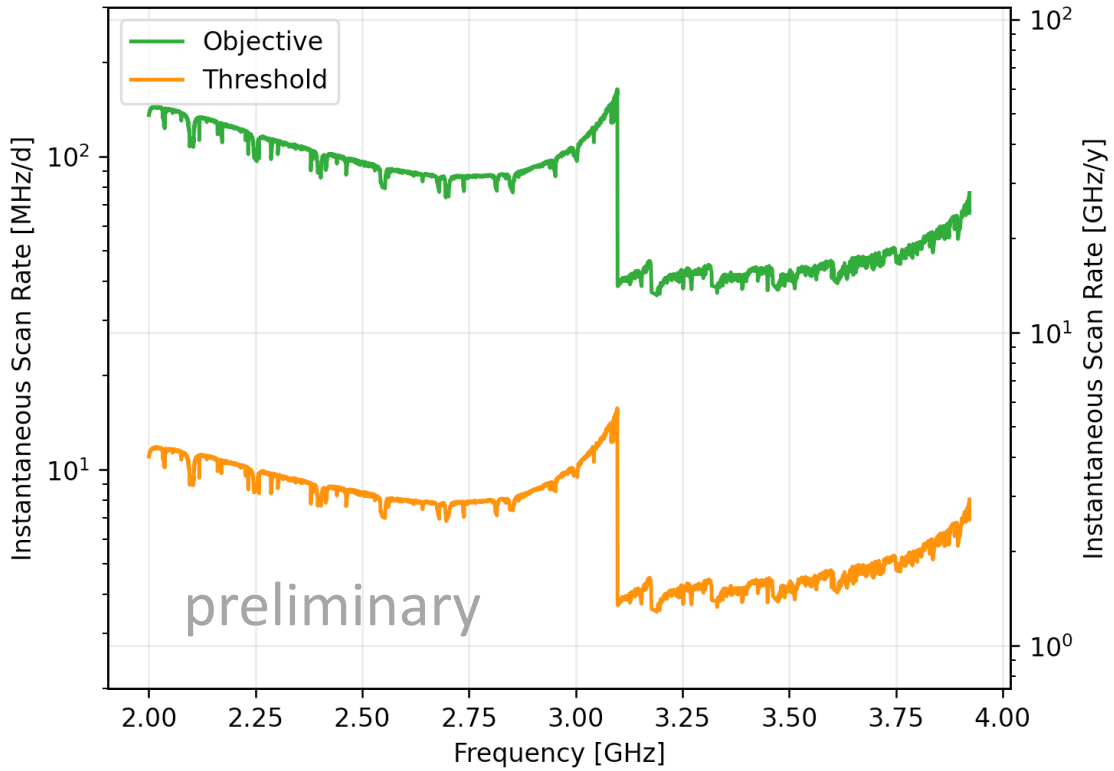
Total system noise at 4GHz: 350mK (objective), 600mK (threshold)

Full System Simulation: Instantaneous Scan Rate

Parameter	Unit	Threshold	Objective
Cavity system full tuning range	GHz	2-4	2-4
Magnetic Field Average	Tesla	9.1	9.4
N Cavities		16	18
Volume per cavity	Liters	12.1/10.4	
Cavity Q_0 at 4 GHz *		53,000	106,000
Cavity TM010 form factor *		-5%	0.4-0.5
Maximum Cavity Physical Temperature	mK	100	100
Maximum Electronics Physical Temperature	mK	25	25
JPA Noise Temperature at 4 GHz *	mK	125	200
JPA Gain	dB	15	21
JPA Tuning range/ Circulator Bandwidth	GHz	0.5	1
Insertion loss (cavity to JPA, max)	dB	2	2
System Noise Temperature at 4 GHz *	mK	500	440
Amplifier squeezing speed up factor		1	1.4
Cavity locking error	% BW	15	5
Power combining efficiency	%	95%	99%

* Frequency dependency taken into account.

$$\frac{df}{dt} \approx 543 \frac{\text{MHz}}{\text{yr}} \left(\frac{g_\gamma}{0.36}\right)^4 \left(\frac{f}{740\ \text{MHz}}\right)^2 \left(\frac{\rho}{0.45\ \text{GeV/cm}^3}\right)^2 \left(\frac{3.5}{\text{SNR}}\right)^2 \times \left(\frac{B}{7.6\ \text{T}}\right)^4 \left(\frac{V}{136\ \ell}\right)^2 \left(\frac{\beta}{1+\beta}\right)^2 \left(\frac{Q_\text{L}}{30{,}000}\right) \left(\frac{C}{0.4}\right)^2 \left(\frac{0.2\ \text{K}}{T_\text{sys}}\right)^2$$



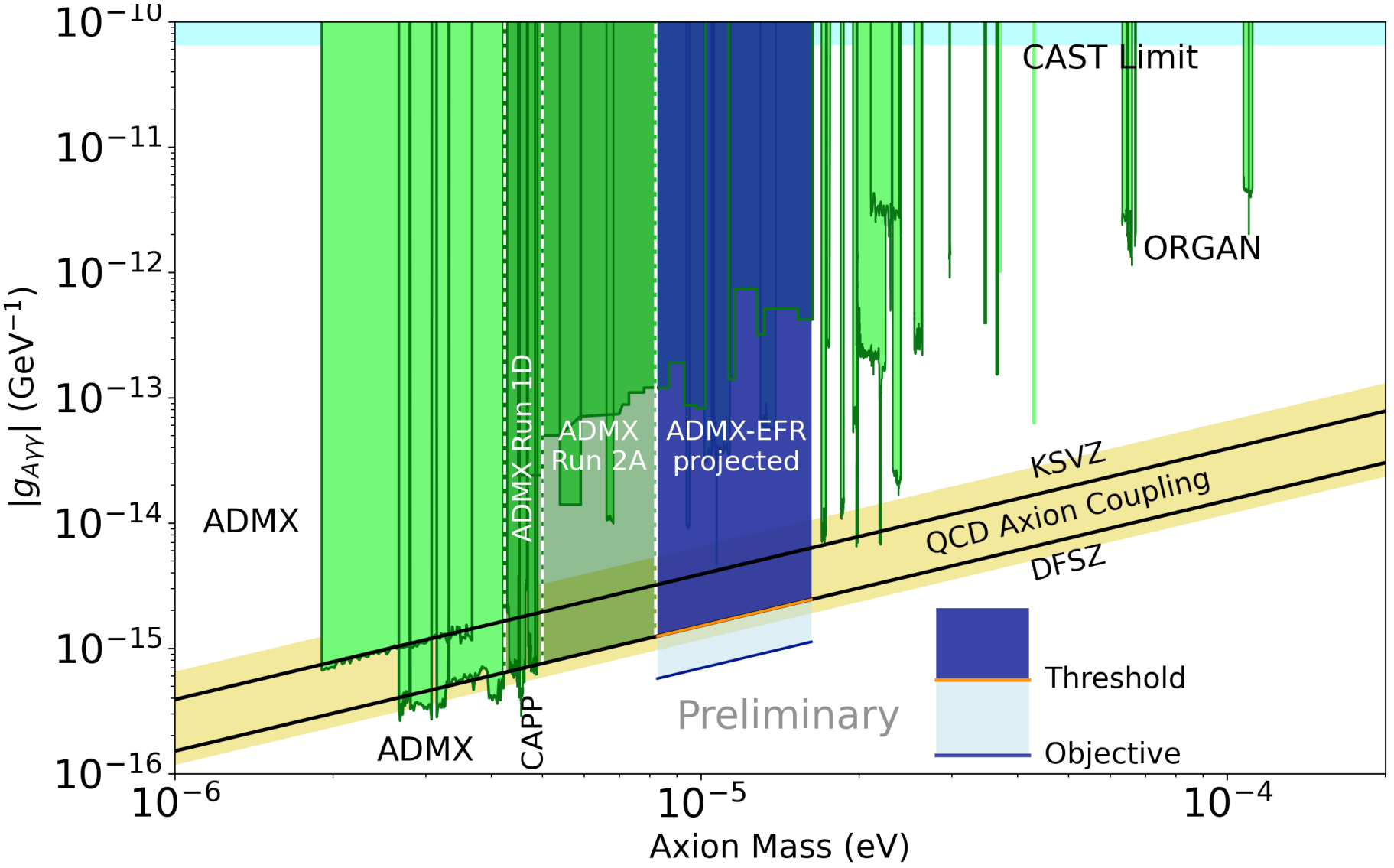
Full System Simulation: Sensitivity

Incl. Downtime:

- Tuning, Locking, Recoupling
- JPA rebiasing
- Rescans

- Operations (insert, extract, error fixing)
- …

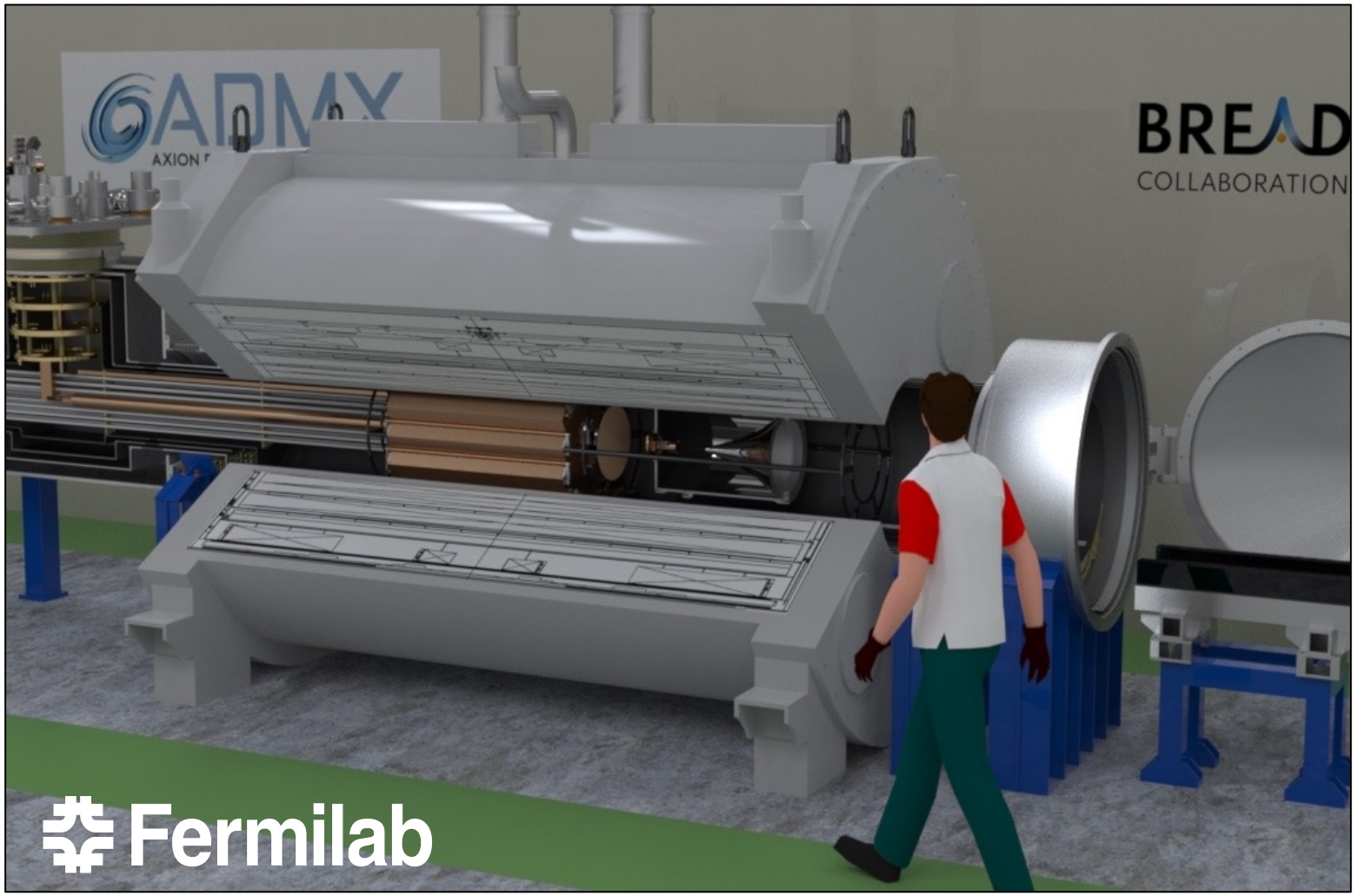
3 year total runtime



ADMX Collaboration

This work was supported by the U.S. Department of Energy through Grants No DE-SC0009800, No. DE-SC0009723, No. DE-SC0010296, No. DE-SC0010280, No. DE-SC0011665, No. DEFG02-97ER41029, No. DE-FG02-96ER40956, No. DEAC52-07NA27344, No. DE-C03-76SF00098 and No. DE-SC0017987. Fermilab is a U.S. Department of Energy, Office of Science, HEP User Facility. Fermilab is managed by Fermi Research Alliance, LLC (FRA), acting under Contract No. DE-AC02-07CH11359. Additional support was provided by the Heising-Simons Foundation and by the Lawrence Livermore National Laboratory and Pacific Northwest National Laboratory LDRD offices.

The Dark Wave Laboratory – U.S. Axion Facility



Workshop, April 2024,
https://indico.fnal.gov/event/63051/

Broad Interest, e.g.:

ADMX: SLIC, VERA, ORPHEUS; BREAD, ORGAN; SC Cavities; MADMAX; Yours?, …

Propose Your Experiment!

Work on these experiments!

HARVARD
UNIVERSITY

postdoc search

https://academicpositions.harvard.edu/postings/13773

Conclusions

Σας ευχαριστώ πολύ!