BREAD

Requirements towards a DFSZ-sensitive Experiment

Stefan Knirck

Harvard University, Department of Physics

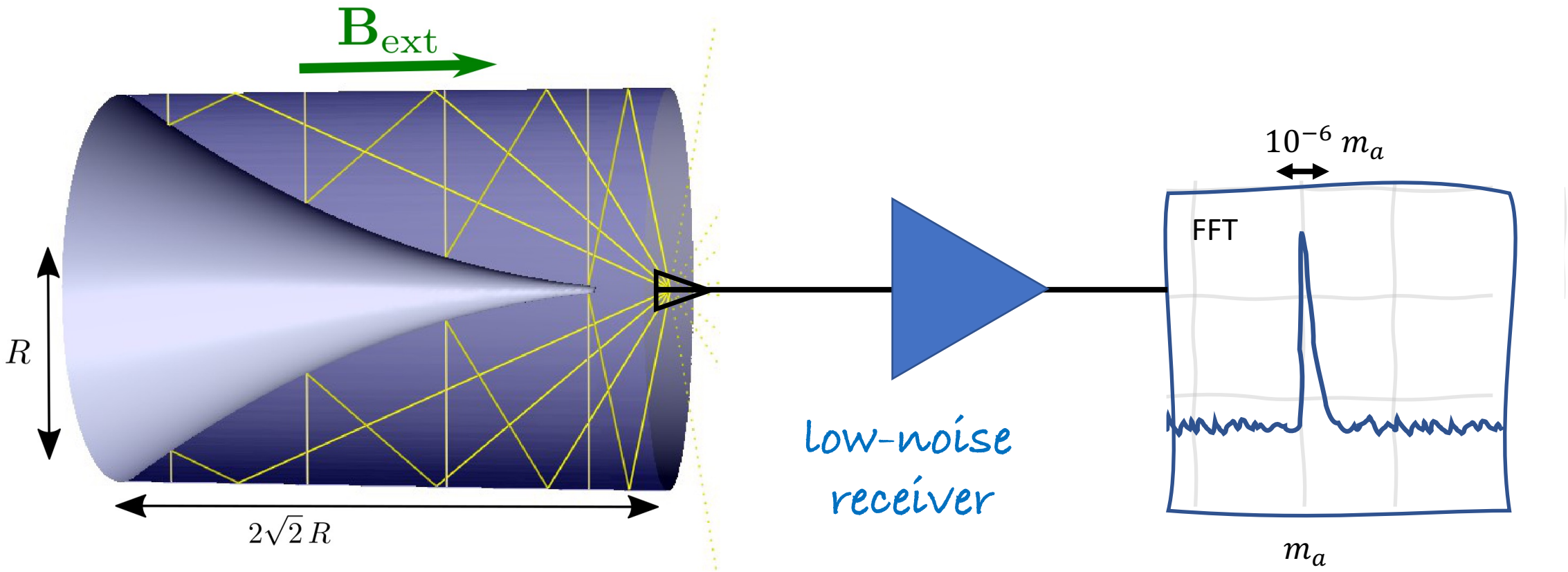
HARVARD UNIVERSITY

for the BREAD collaboration

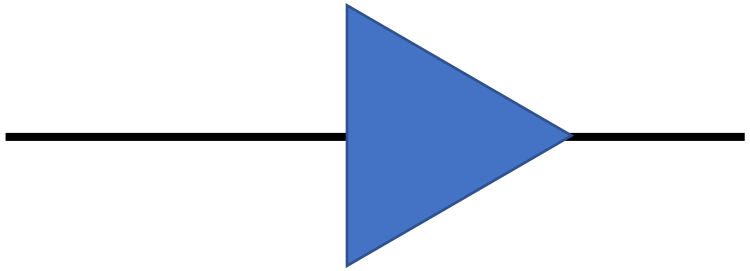
BREAD COLLABORATION

BREAD (Broadband Reflector Experiment for Axion Detection)

$$P_{\mathrm{sig}} = 1.2 \cdot 10^{-25}\ \mathrm{W} \cdot \left(\frac{A}{10\ \mathrm{m}^2}\right)\left(\frac{B_{\parallel}}{10\ \mathrm{T}}\right)^2 \left(\frac{\rho_{\mathrm{DM}}}{0.45\ \mathrm{GeV\ cm}^{-3}}\right)\left(\frac{g_{a\gamma\gamma}}{3.9 \cdot 10^{-16}\ \mathrm{GeV}^{-1}}\right)^2 \left(\frac{1\ \mu\mathrm{eV}}{m_a}\right)^2$$



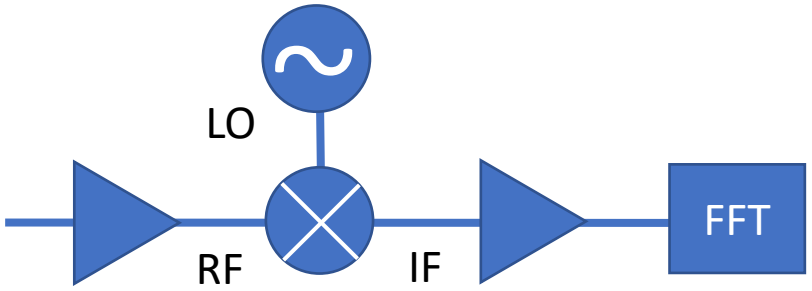
narroband signal, but could be any frequency



Required Sensor?

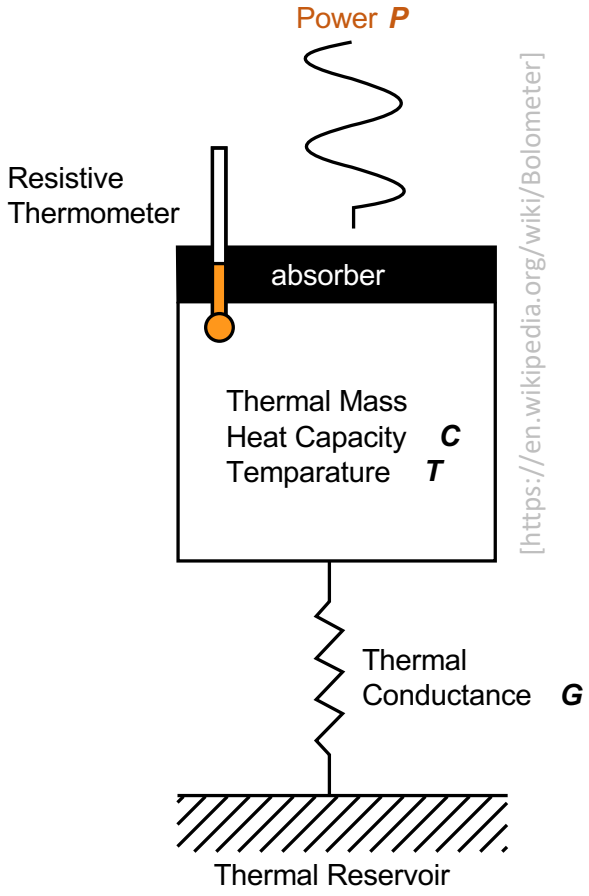
Sensors

Heterodyne



- high resolution
- **Standard Quantum Limit (SQL):**
  $k_B\, T_{noise} = hf$

Bolometer



NEP ~ $10^{-20}\, W/\sqrt{Hz}$

Single Photon Counting

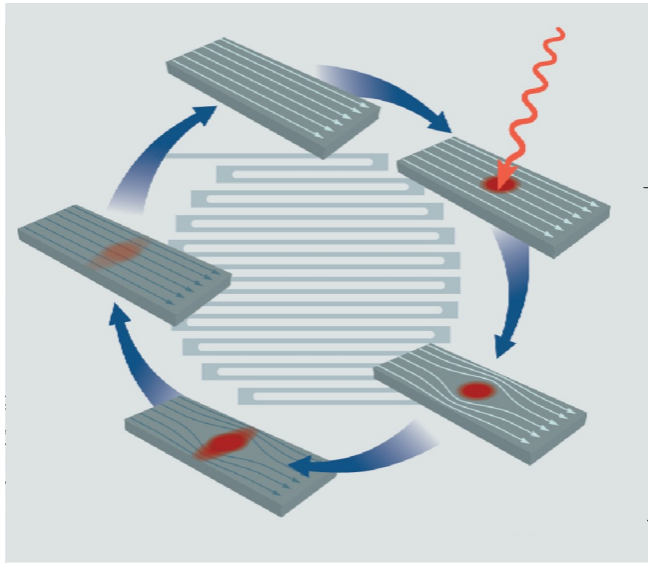


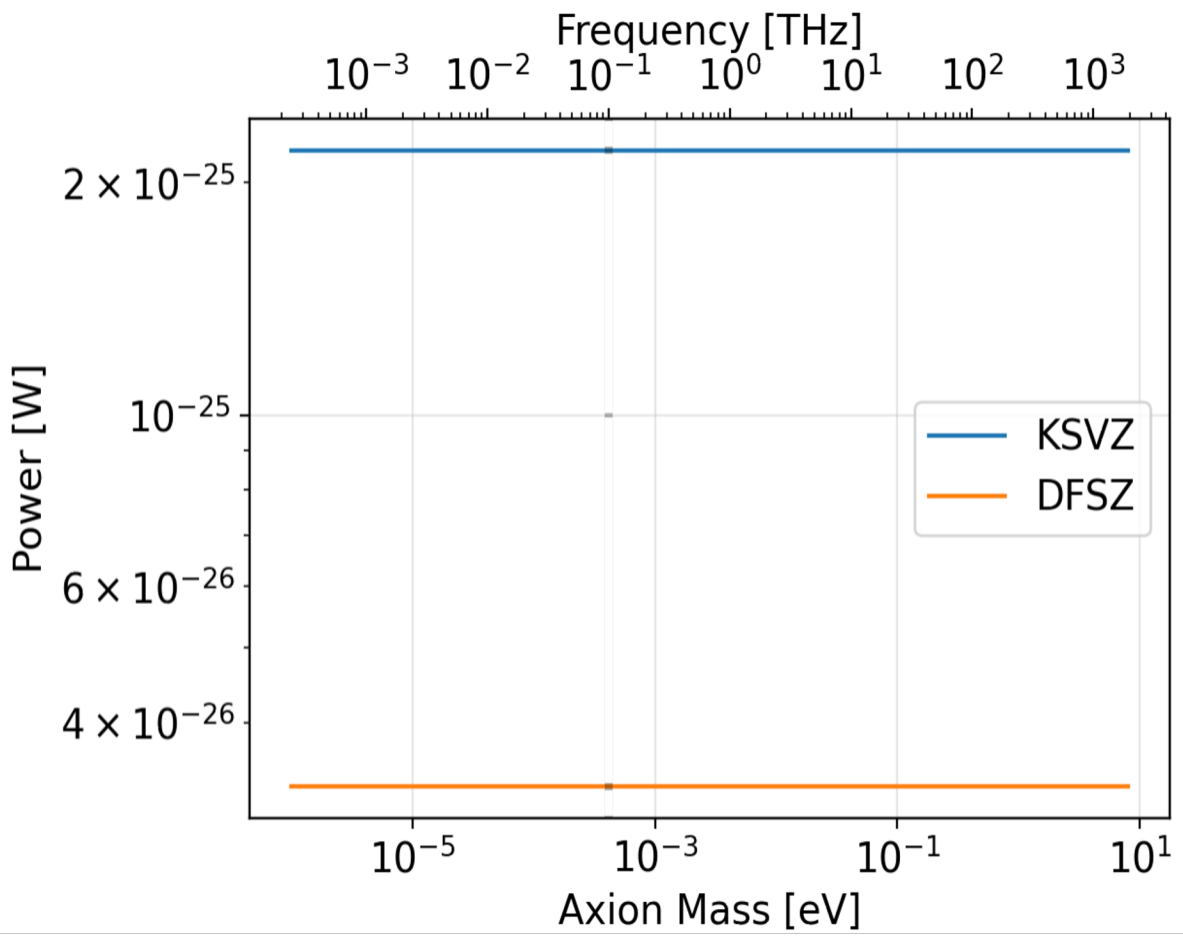
Fig.: Sae Woo Nam (NIST)

e.g., nanowire detectors

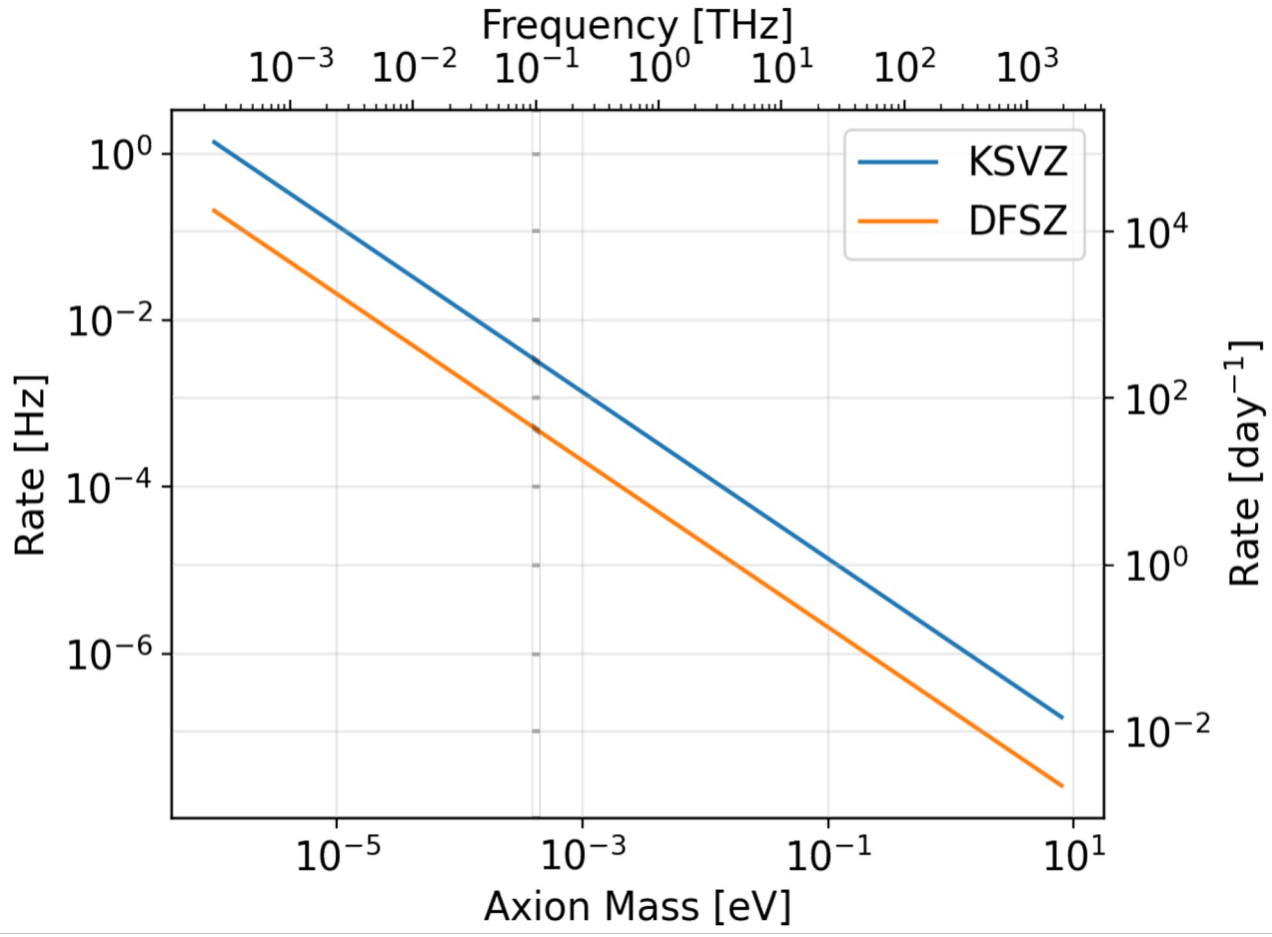
down to ~ 1 photon/day

Signal Rate – 10m^2 dish in 10T field

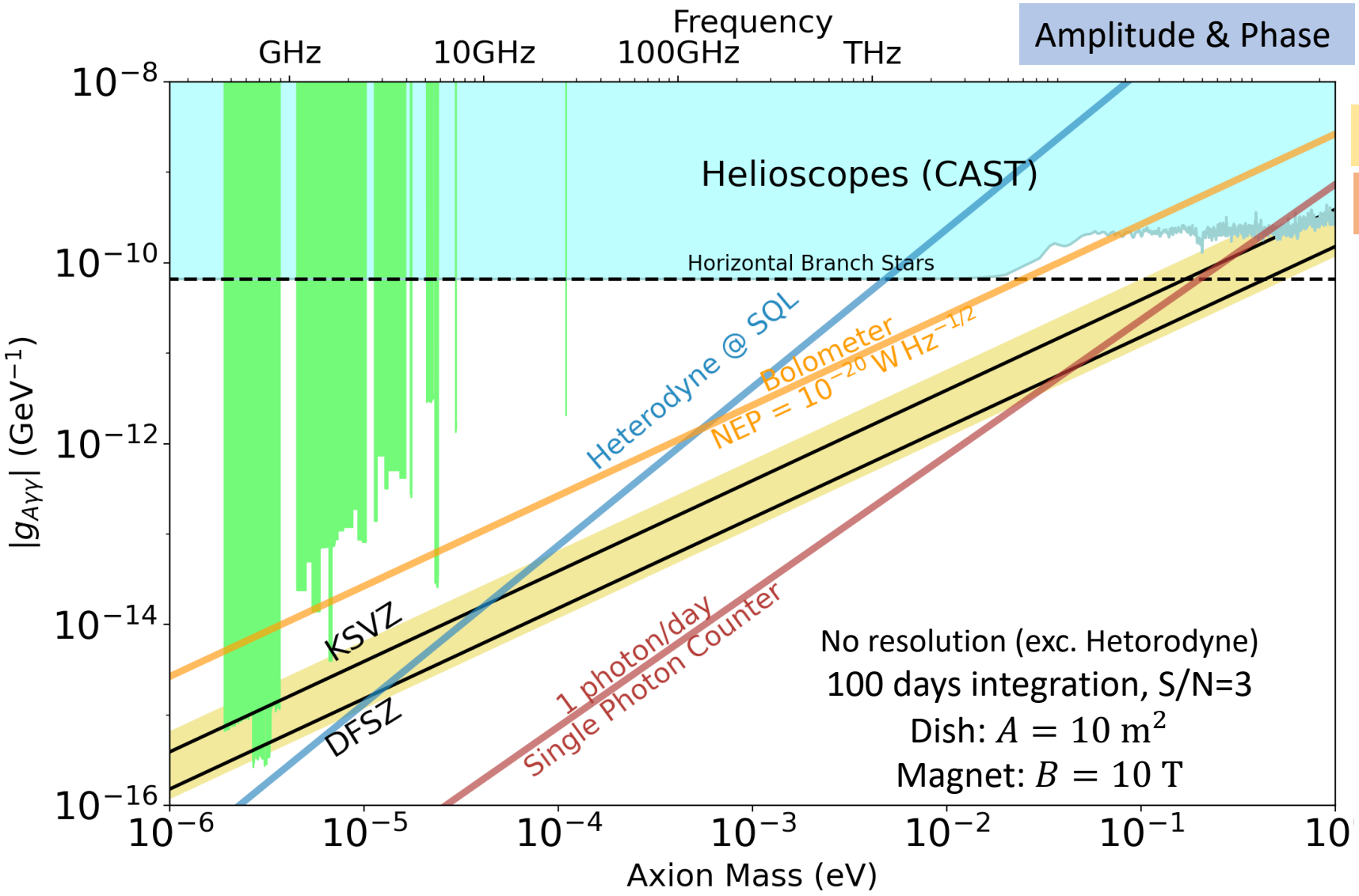
Power



Single Photons

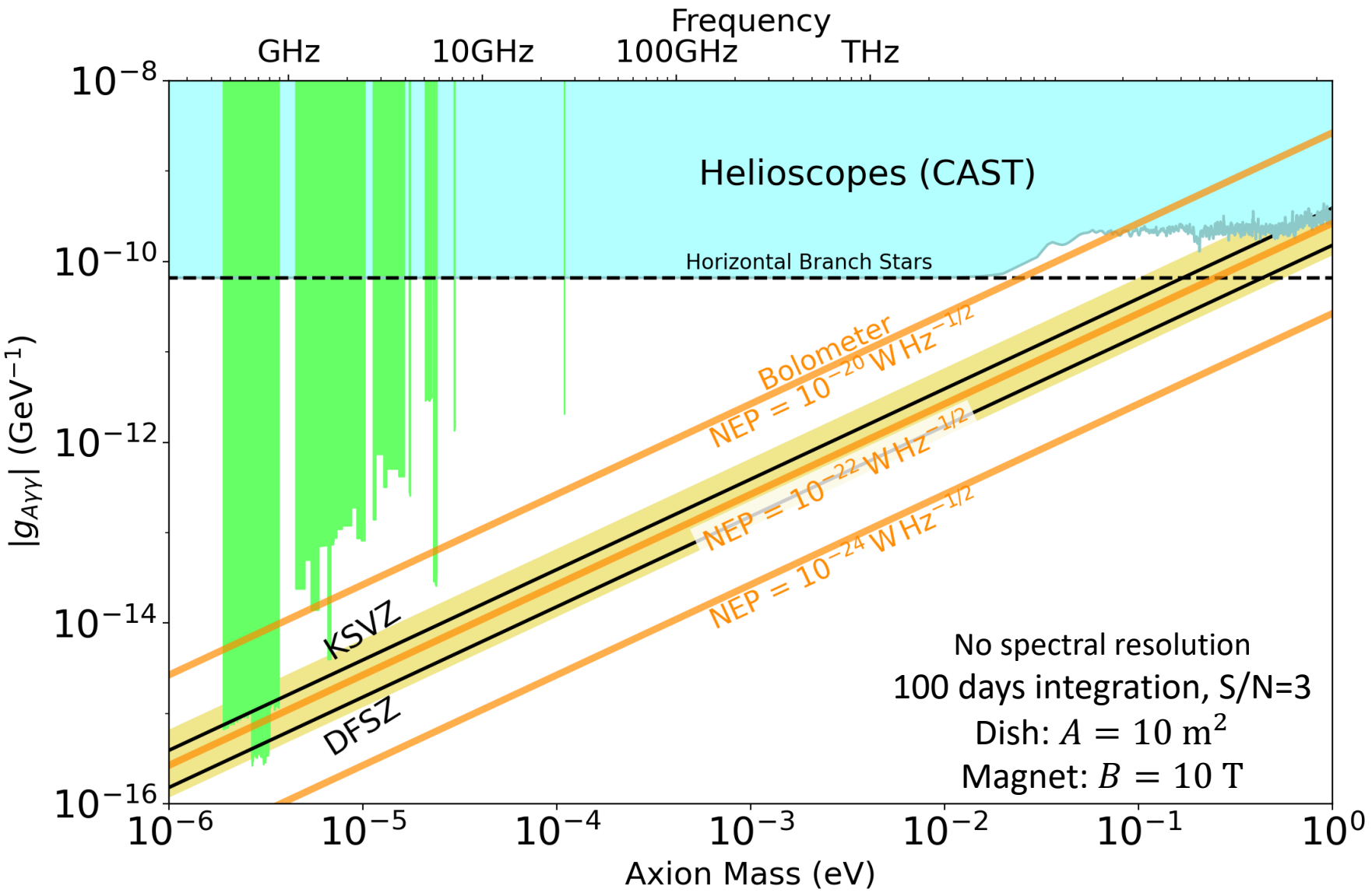


Sensitivity – Conceptual



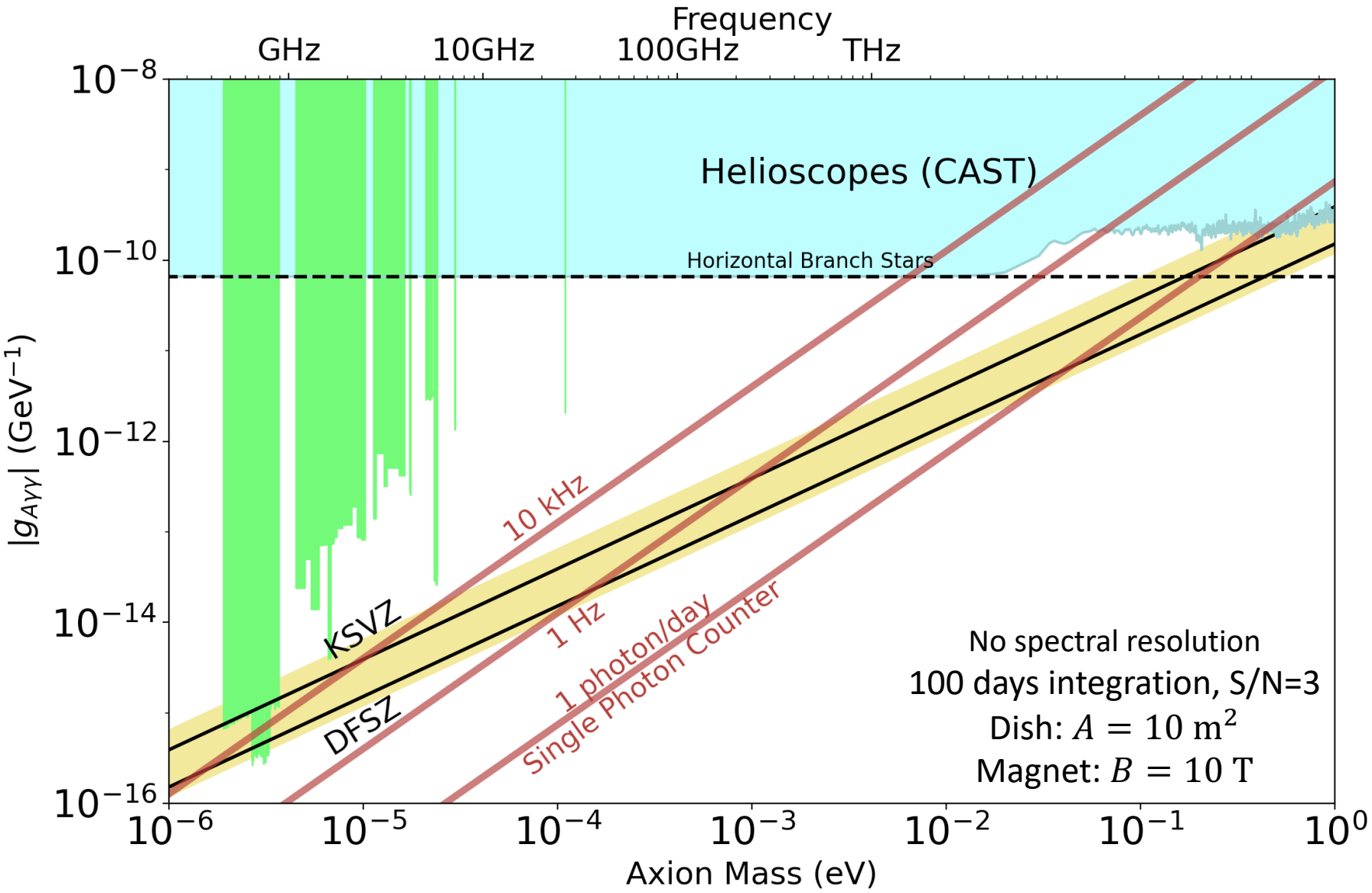
Adapted from
[Rybka et al, PDG2019]

Sensitivities (naïve) – Noise Equivalent Power



$$P_{sens} \sim \frac{NEP}{\sqrt{\Delta t}} \sim NEP\sqrt{\Delta \nu_{det}}$$

Sensitivities (naïve) – Single Photon Counting



$$P_{sens} \sim \sqrt{DCR\ \Delta t}\ \frac{h\,\nu}{\Delta t}$$

<u>Comparison to Heterodyne SQL:</u>

$$P_{N,SQL} = h\,\nu\,\Delta\nu$$

$$\#\gamma_{N,SQL} = \Delta\nu$$

<u>For Axion DM:</u>

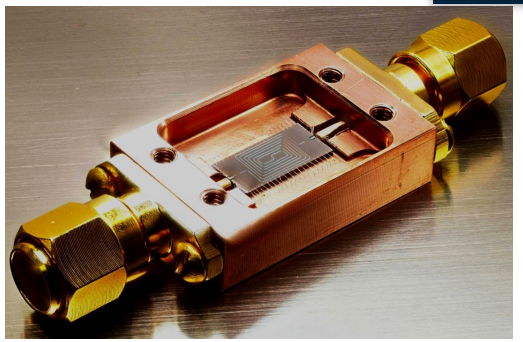
$$\Delta\nu = 10^{-6}\,\nu$$

Sensors (Selection)

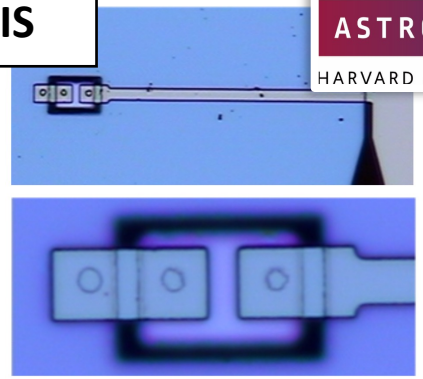
multiple talks today & tomorrow

Heterodyne

TWPA

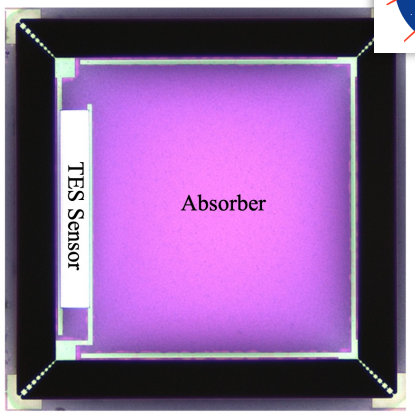


SIS

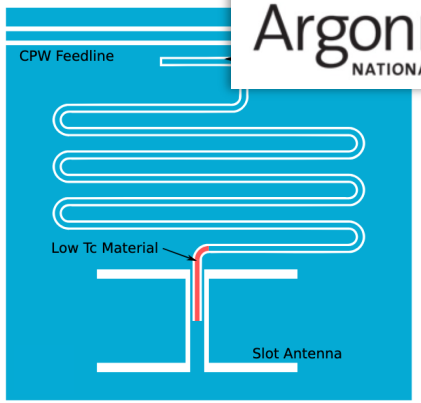


Bolometer

TES

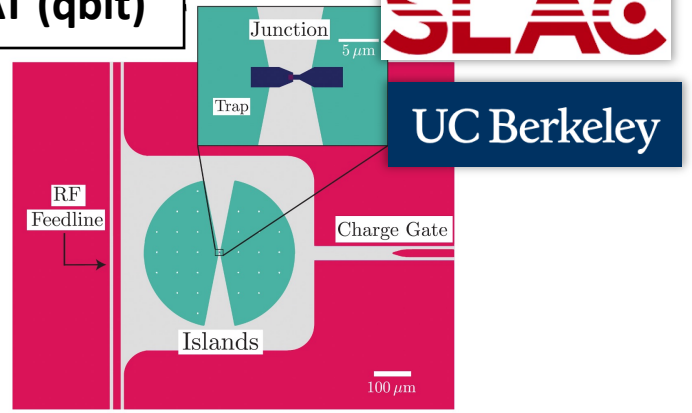


MKID

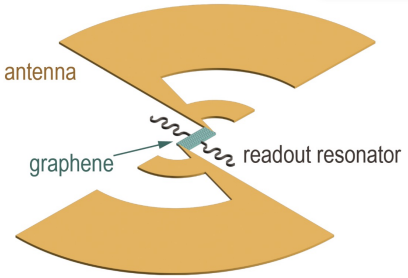


Single Photon Counting

SQUAT (qbit)



WIXARD (Graphene)



& more!

Sensors (Selection)

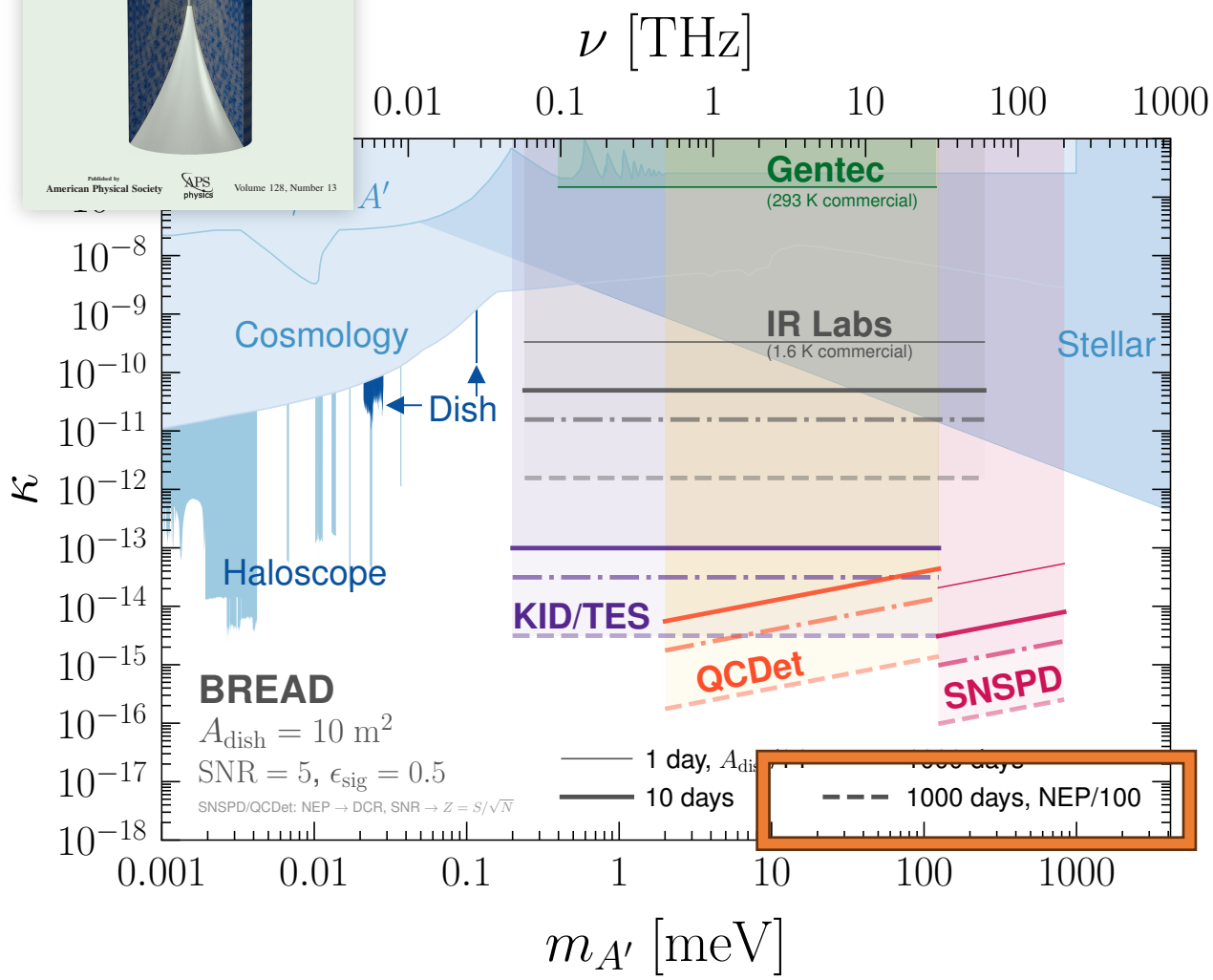
[Liu *et al*, BREAD collab., arXiv:2111.12103, PRL 128 (2022) 131801]

	$\frac{E}{\mathrm{meV}}$	$\frac{T_{\mathrm{op}}}{\mathrm{K}}$	$\frac{\mathrm{NEP}}{\mathrm{W}/\sqrt{\mathrm{Hz}}}$	$\frac{A_{\mathrm{sens}}}{\mathrm{mm}^2}$	
Bolometers					
GENTEC	[0.4, 120]	293	$1 \cdot 10^{-8}$	$\pi 2.5^2$	[https://www.gentec-eo.com/]
IR LABS	[0.24, 248]	1.6	$5 \cdot 10^{-14}$	1.5^2	[https://www.irlabs.com/products/bolometers/]
KID/TES	[0.2, 125]	0.3	$2 \cdot 10^{-19}$	0.2^2	[Ridder *et al*, J. Low Temp. Phys. 184, 60–65 (2016)], [Baselmans *et al,* Astro. Astroph. 601, A89 (2017)]
Single Photon Counters					
QCDet	[2, 125]	0.015	$\frac{\mathrm{DCR}}{\mathrm{Hz}} = 4$	0.06^2	[Echternach *et al.*, Nat. Astron. 2, 90–97 (2018)], [Echternach *et al.*, J. Astron. Telesc. Instrum. Syst. 7, 1–8 (2021)]
SNSPD	[124, 830]	0.3	$\frac{\mathrm{DCR}}{\mathrm{Hz}} = 10^{-4}$	0.4^2	[Hochberg, et al., Phys. Rev. Lett. 123, 151802 (2019)] [Verma, *et al.*, arXiv:2012.09979 [physics.ins-det] (2020)]

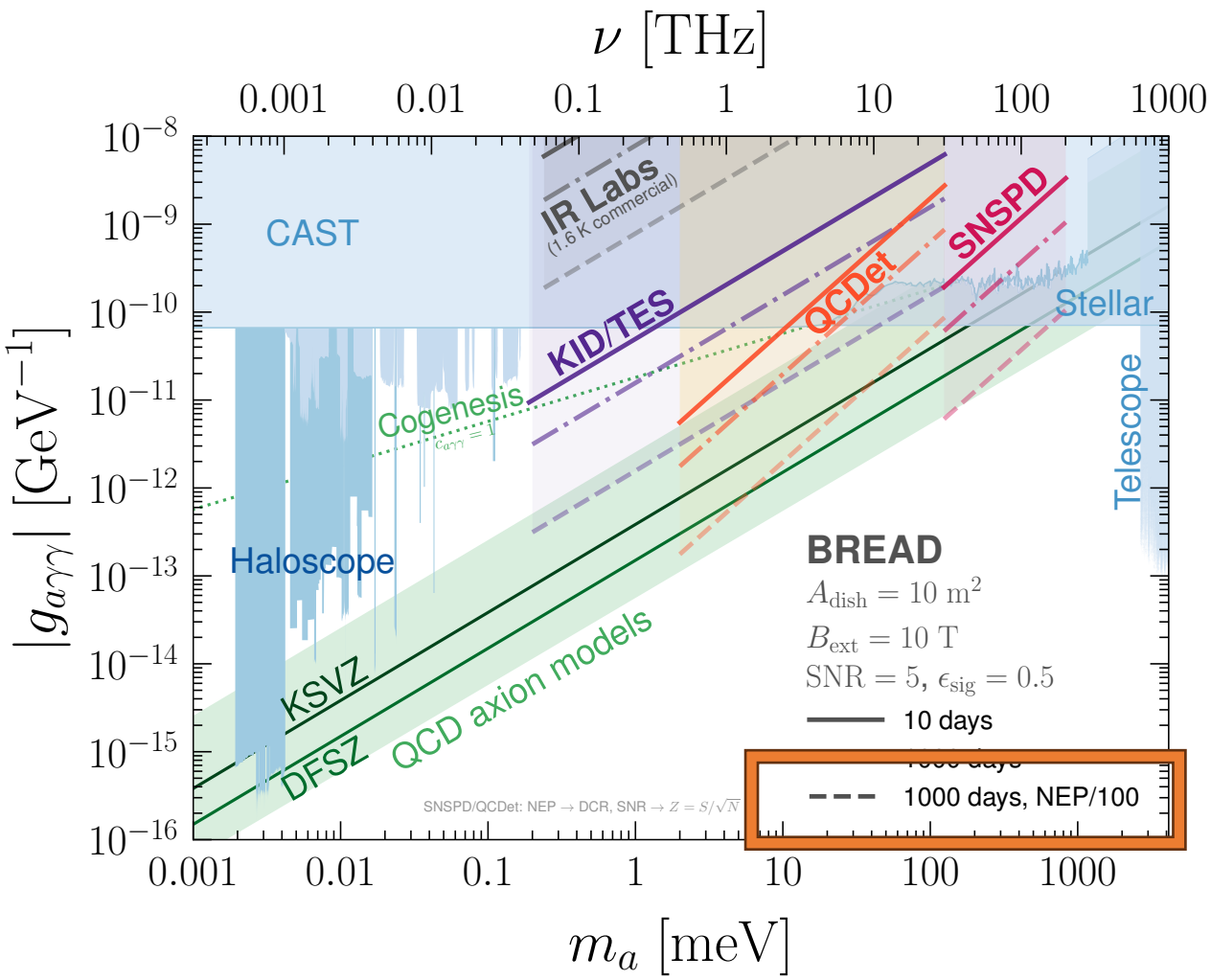
Sensitivities with Literature Sensors

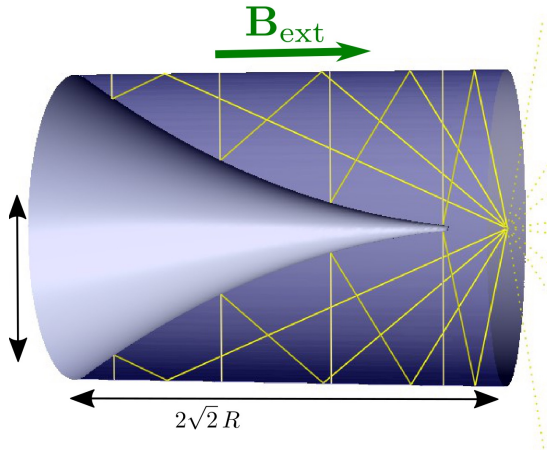
[Liu *et al*, BREAD collab., arXiv:2111.12103, PRL 128 (2022) 131801]

Hidden Photons



Axions

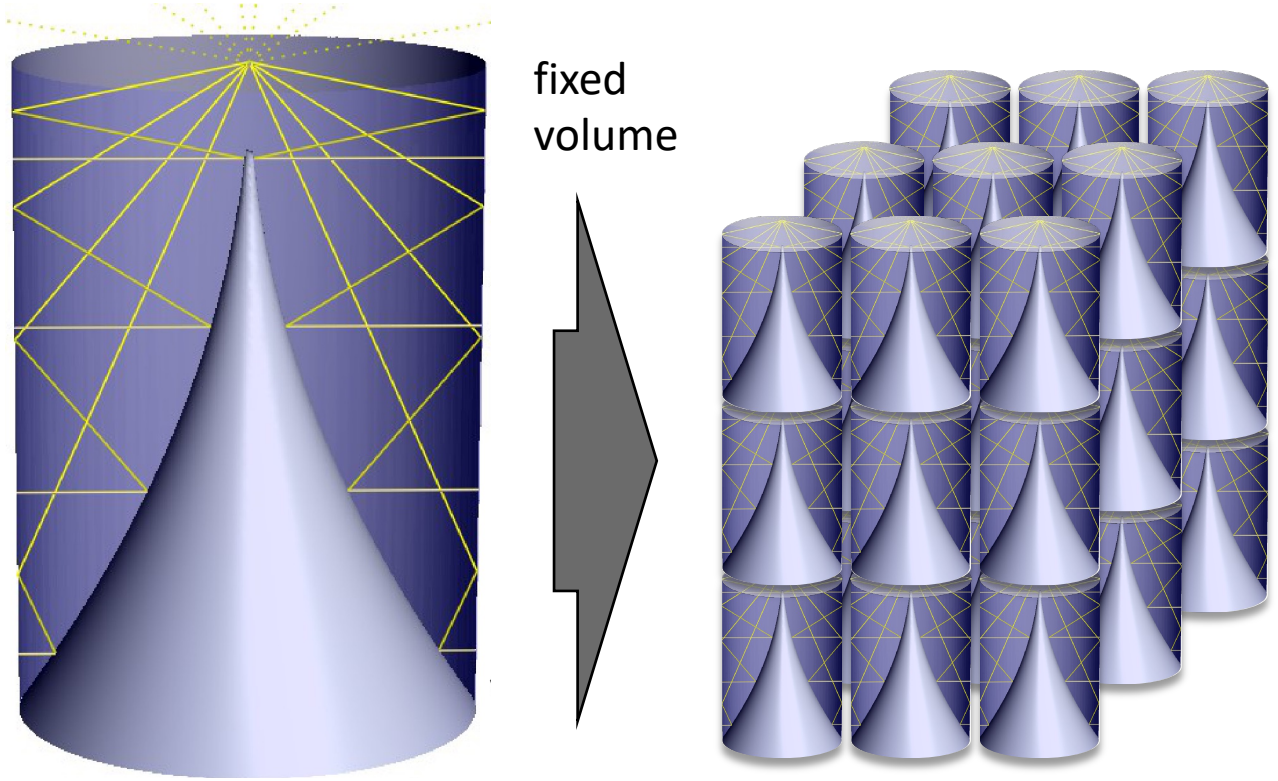




More Signal?

StackedBREAD – Increase Area

$$P_{sig} \propto A$$

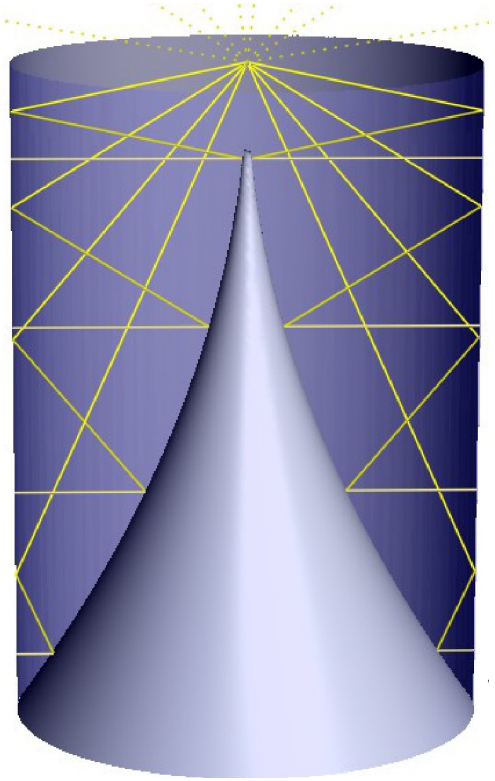


StackedBREAD – Increase Area

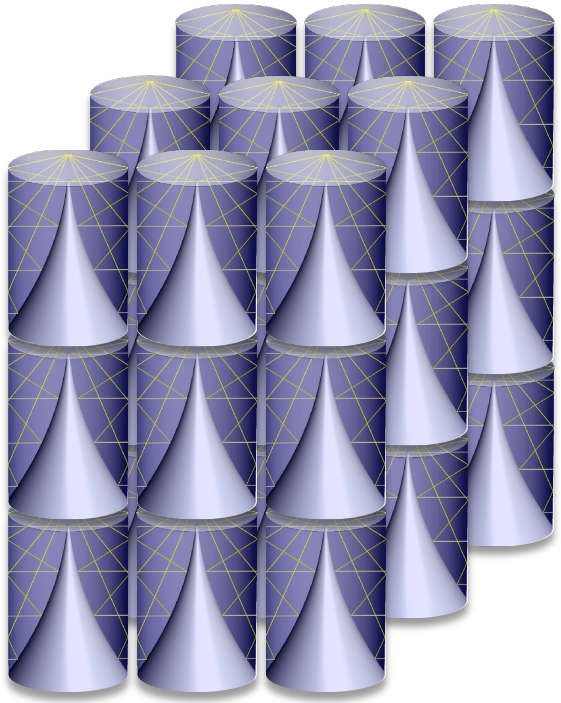
1 BREAD

$N \times N \times N = N^3$ BREAD

$P_{sig} \propto A$



fixed volume



$N = 3$

$A_{\text{single}} \propto 1/N^2$

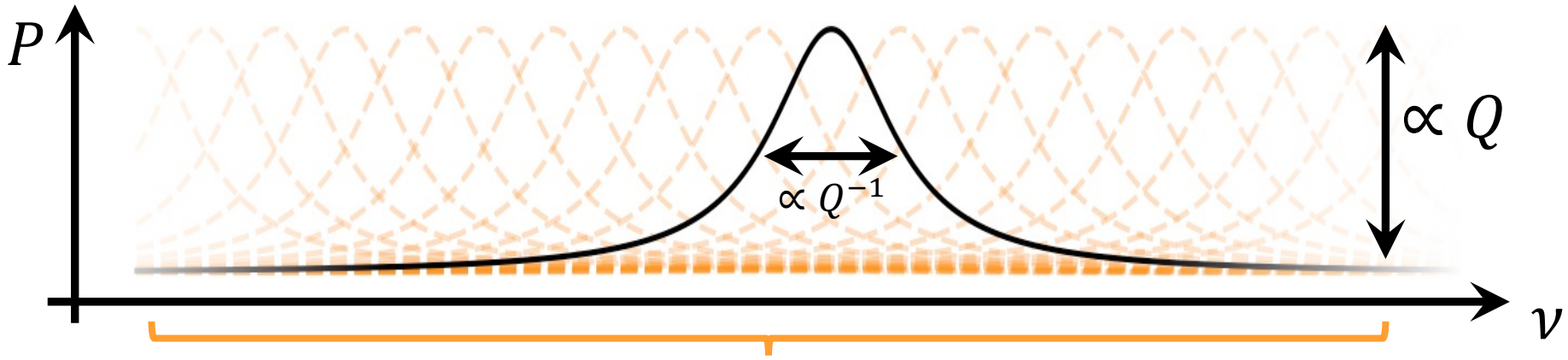
$A_{\text{tot}} = N^3 A_{single} \propto N$

$P_{\text{tot}} \propto N$

Limited gain / complexity

Resonant vs. Broadband Experiment

Scanning Experiment:

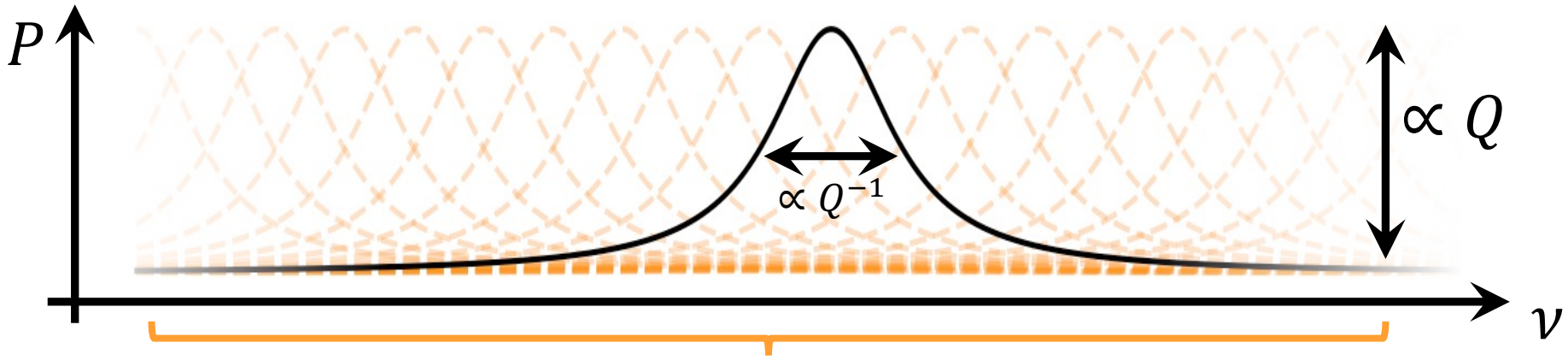


$\sim Q$ steps, each for Δt

	Background Limited:	**Background Free:**
Signal-to-Noise:	$\frac{S}{N} = \frac{Q \cdot P_0}{kT_{sys}} \sqrt{\frac{\Delta t}{\Delta \nu_a}}$	$\frac{S}{N} = \frac{Q \cdot P_0 \, \Delta t}{\sqrt{Q \cdot P_0 \, \Delta t}} = \sqrt{Q \cdot P_0 \, \Delta t}$
Total Scan Time (Q):	$T_{tot} \sim Q \, \Delta t \propto Q \, Q^{-2} \propto Q^{-1}$	$T_{tot} \sim Q \, \Delta t \propto Q \, Q^{-1} \propto 1$

Resonant vs. Broadband Experiment

Scanning Experiment:



$\sim Q$ steps, each for Δt

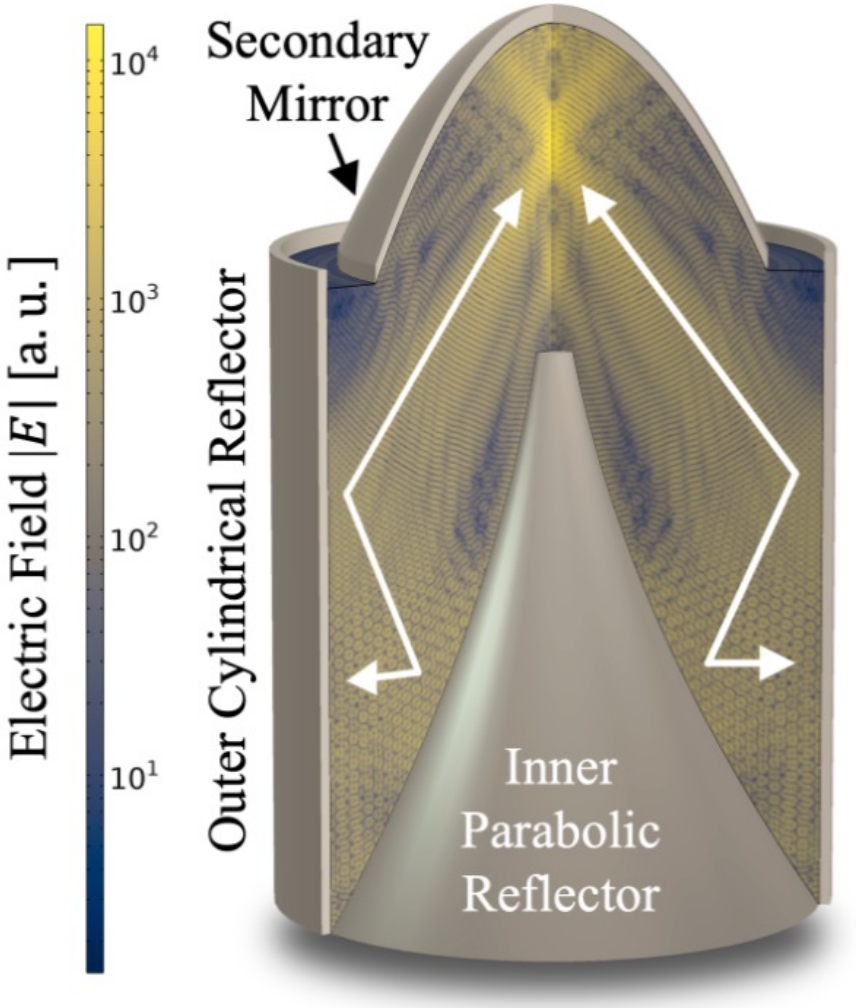
Scan Speed Cavity:

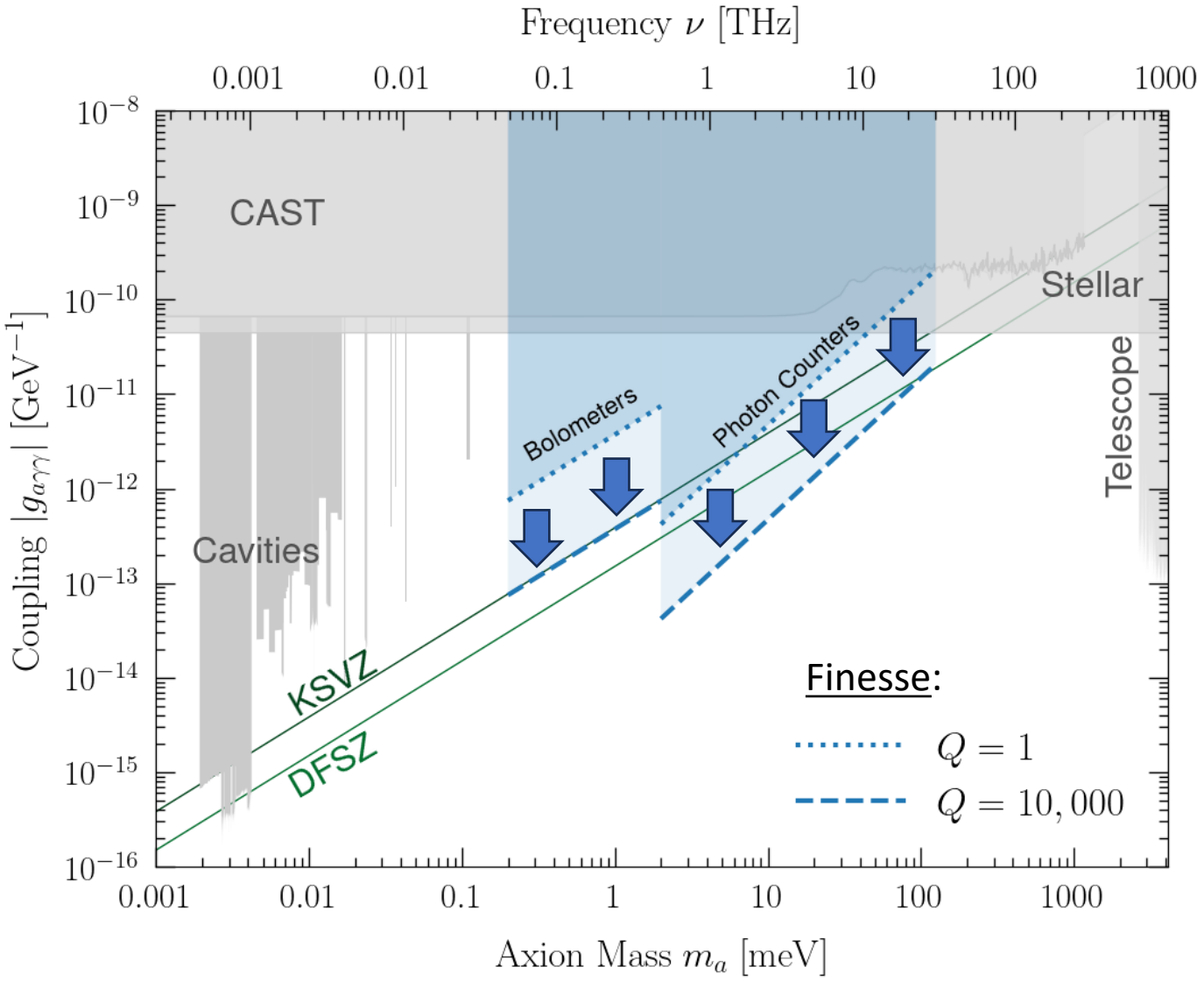
$$\frac{df}{dt} \approx 543 \frac{\text{MHz}}{\text{yr}} \left(\frac{\beta}{1+\beta}\right)^2 \left(\frac{g_\gamma}{0.36}\right)^4 \left(\frac{f}{740\ \text{MHz}}\right)^2 \left(\frac{\rho}{0.45\ \text{GeV/cm}^3}\right)^2 \left(\frac{3.5}{\text{SNR}}\right)^2 \left(\frac{B}{7.6\ \text{T}}\right)^4 \left(\frac{V}{136\ell}\right)^2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

[PRD 103, 032002 (2021)]

QualityBREAD

see Gabe

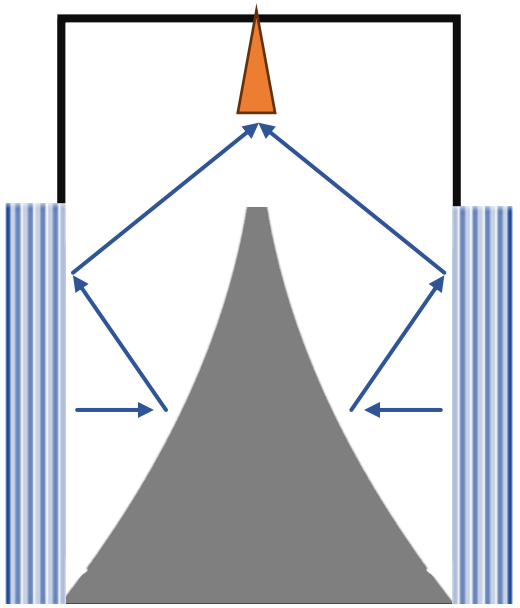




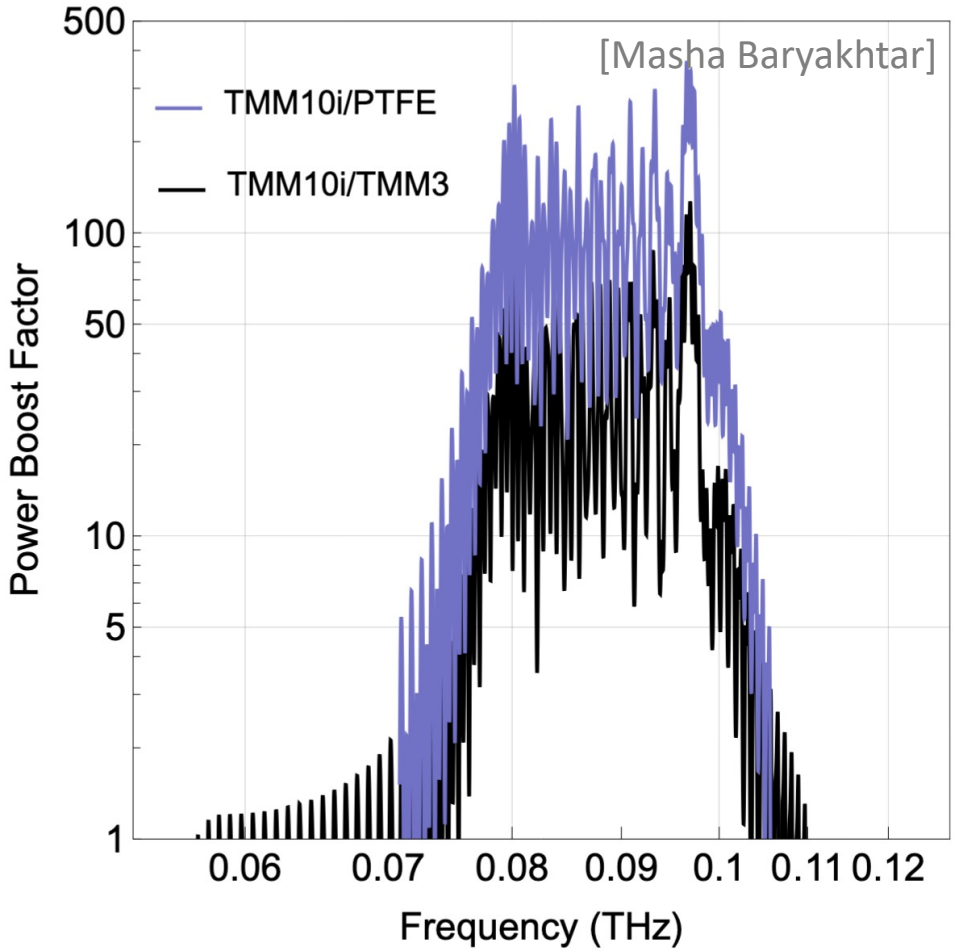
SlicedBREAD – Dielectric Stacks

same idea as MADMAX

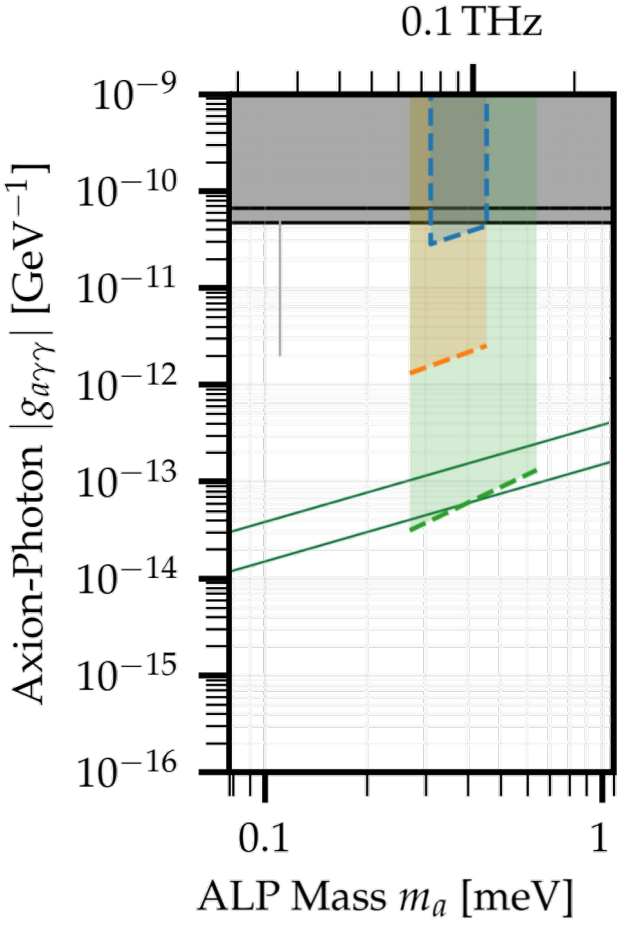
see I-See, Grant



<u>resonant</u> & <u>volume</u> enhancement (adjustable)



Boost $\beta^2 \sim$ # layers
100 – 1,000 realistic

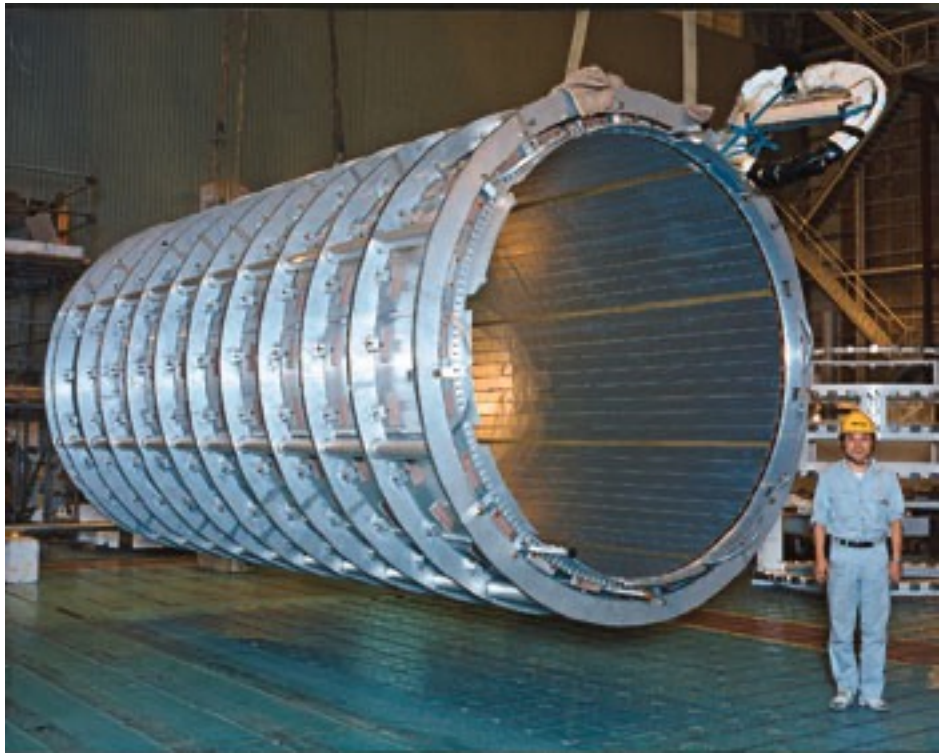


$\beta^2 \sim 20$
small scale

$\beta^2 \sim 100$
DWL

$\beta^2 \sim 1{,}000$
$20T, 7m^2$

$g_{a\gamma\gamma} \propto \sqrt{\beta^2}$



How about a huge magnet?

→ Andrew

[https://cerncourier.com/a/atlas-solenoid-coiling-is-complete/]

Conclusion

Thank you very much!