Light Bosonic Dark Dark Matter Search Using Microwave Kinetic Inductance Detectors (MKIDs)

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Search for Light Bosonic Dark Matter

Vector (Dark Photon)

- Below 1 meV/c^2, easier to probe with LC resonators
- Above 10 eV/c^2, constrained by WIMP expts (liquid nobles, Ge..)

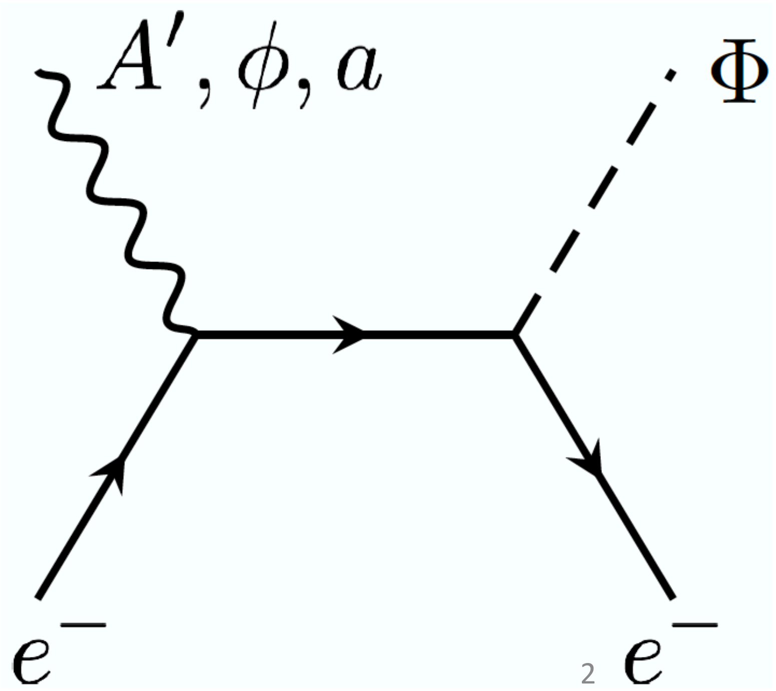
Scalar (e.g. Dilaton-like particles)

- Below 10 meV/c^2, constrained by fifth-force measurements
- Above 10 eV/c^2, constrained by stellar cooling

Pseudoscalar (e.g. Axion-like particles)

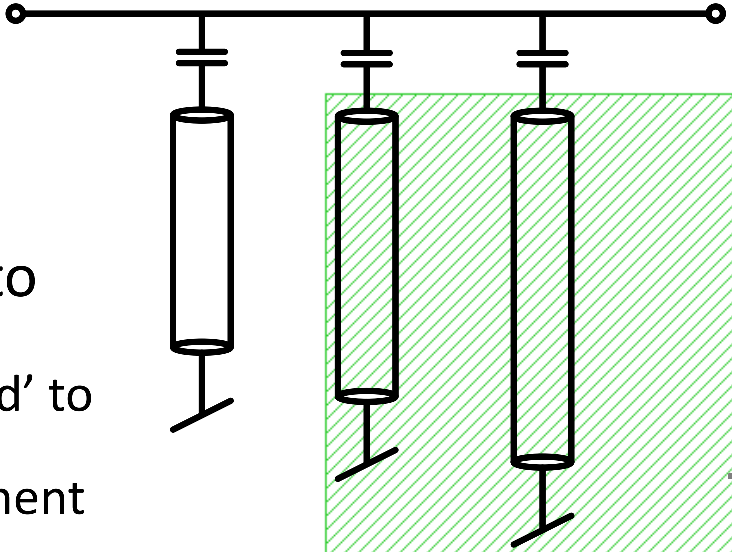
- 1 meV/c^2 – 10 eV/c^2 range, constrained by stellar cooling
- Above 10 eV/c^2constrained by WIMP

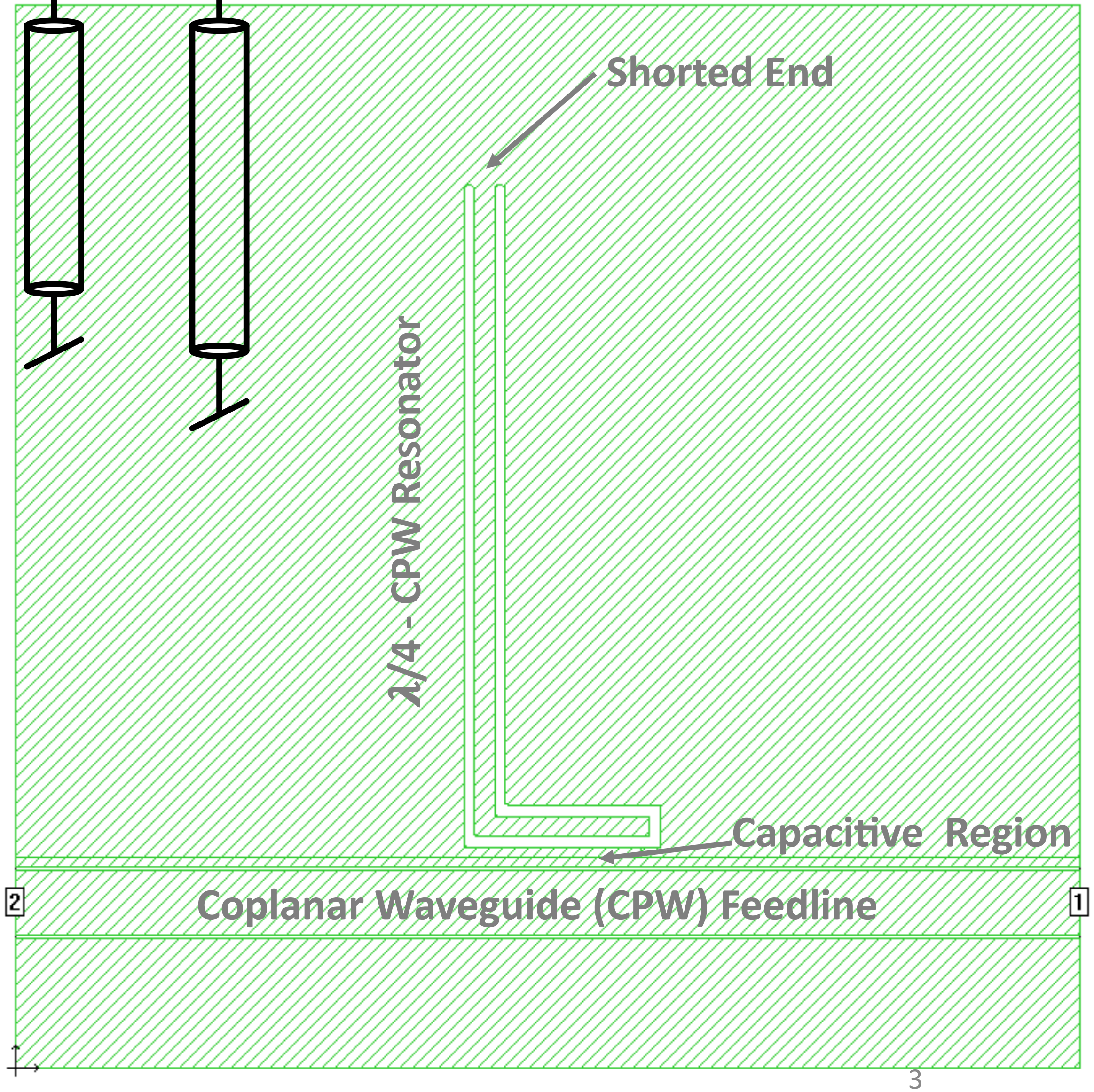
Absorption on Electrons



MKID Overview

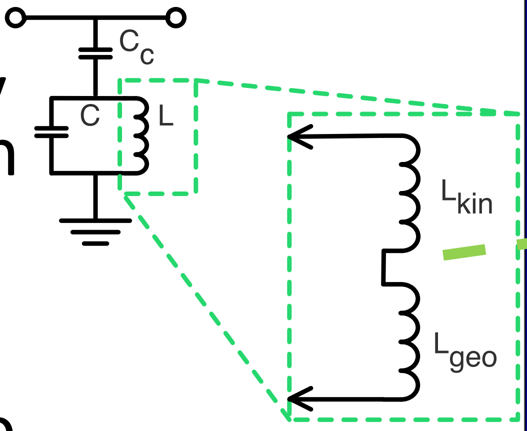
- Pattern superconducting film into resonant circuit
  - Usually capacitively ‘shunt-coupled’ to ‘feedline’
  - Transmission Line or Lumped Element resonator geometries possible
- Resonant frequency controlled by geometry
- Simple to multiplex in frequency domain
  - Each resonator has unique resonant frequency in GHz range
  - +20k pixel demonstrated for optical





MKID Operation Principles

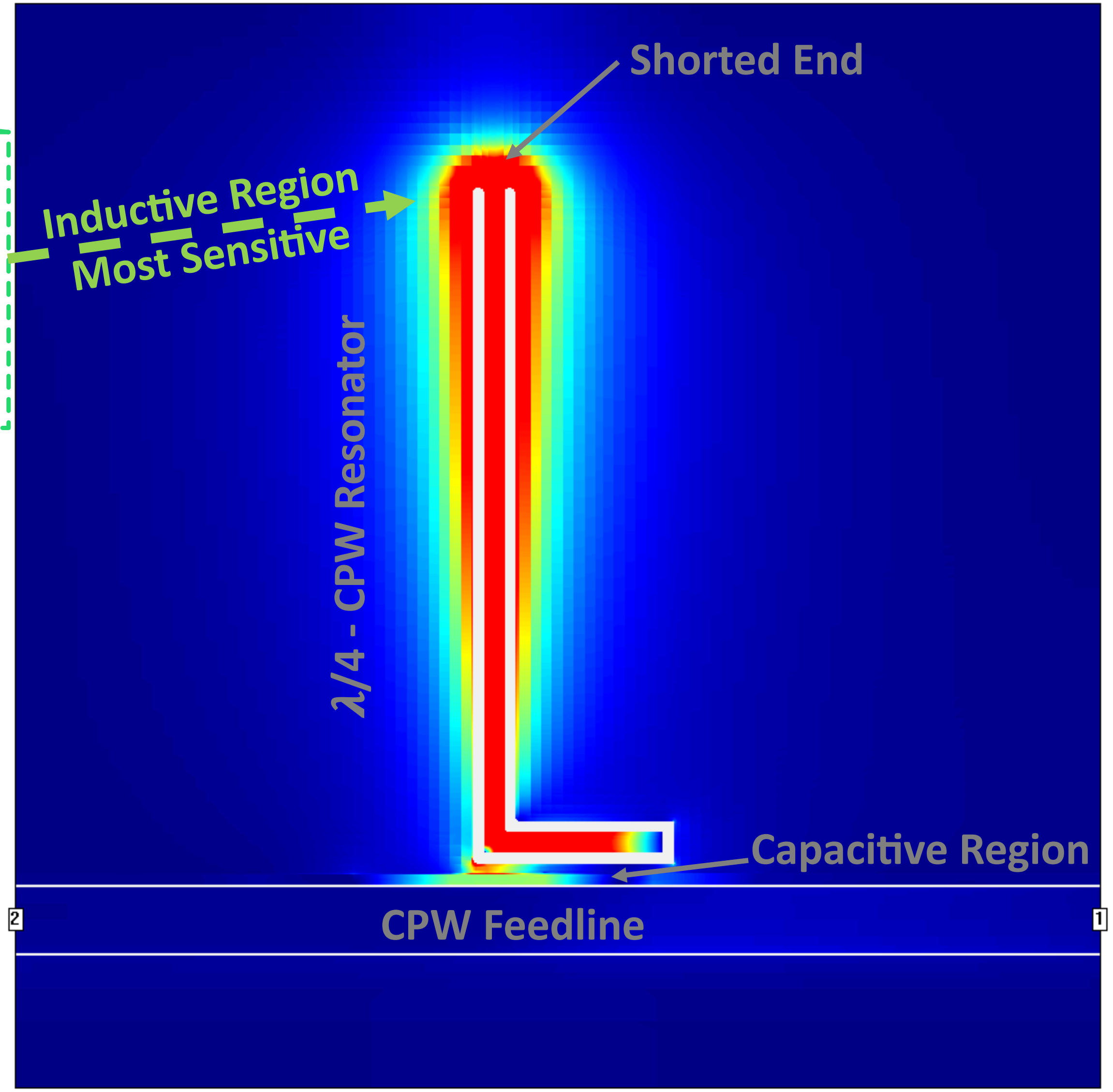
- Drive each resonator at its unique resonant frequency and look for tiny changes in transmitted amplitude and phase (f_0 & Q)
- Inductive component of surface impedance has two parts
  - Geometric – momentum of the fields
  - Kinetic –momentum of the 'Cooper-pairs'
- Pair-breaking energy ⇒ Creates 'Quasi-Particles'⇒ increases L_{kin} surface impedance



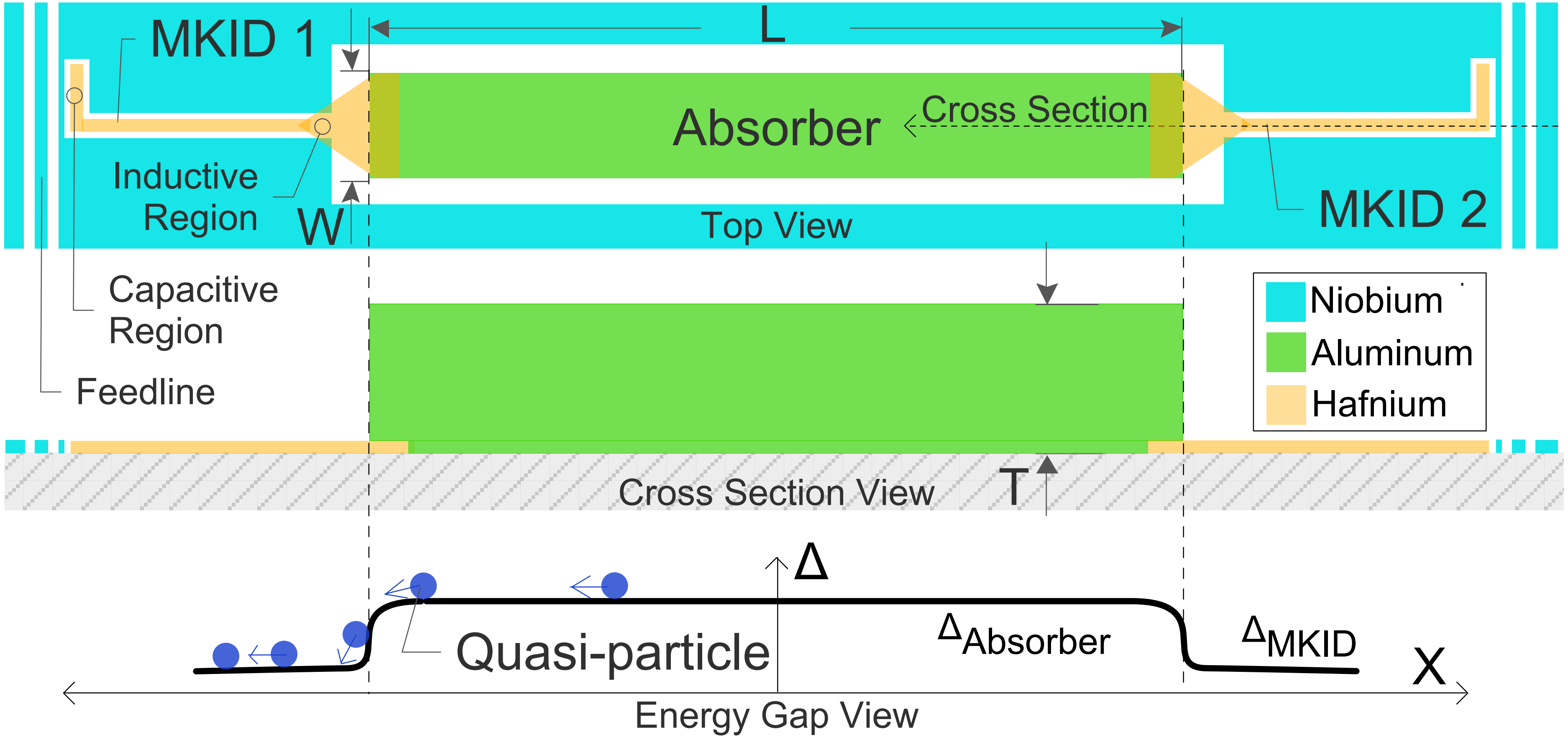
$$f_0 \approx \frac{1}{\sqrt{(L_{\rm kin} + L_{\rm geo})C}}$$

$$L_{\rm kin} \propto \frac{1}{n_{\rm pairs}}$$

Current Density on Resonance

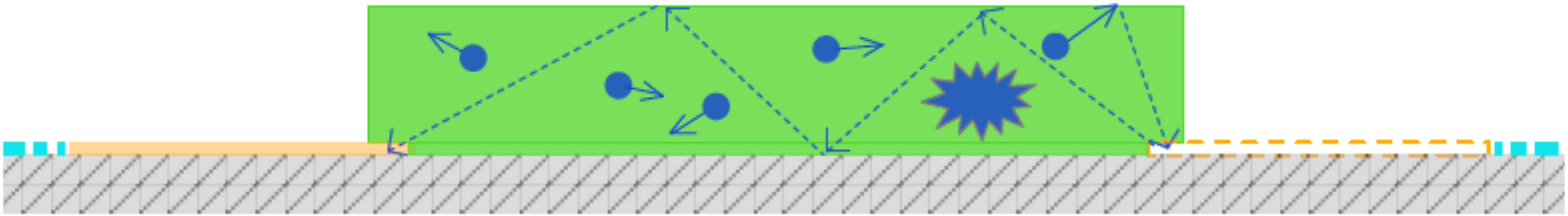


MKID Strip Detector Concept



Absorber Dimensions: 2000 μm x 200 μm x 5 μm :: L x W x T

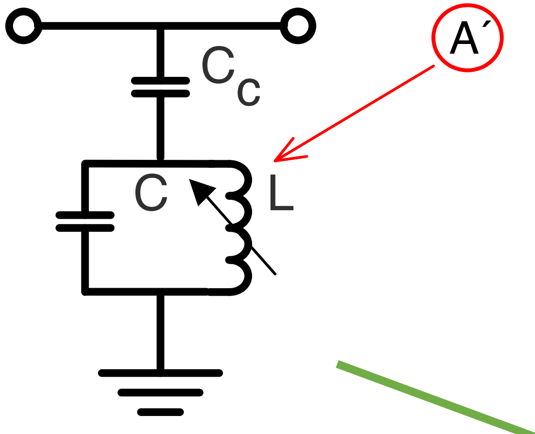
Why use strip detector?



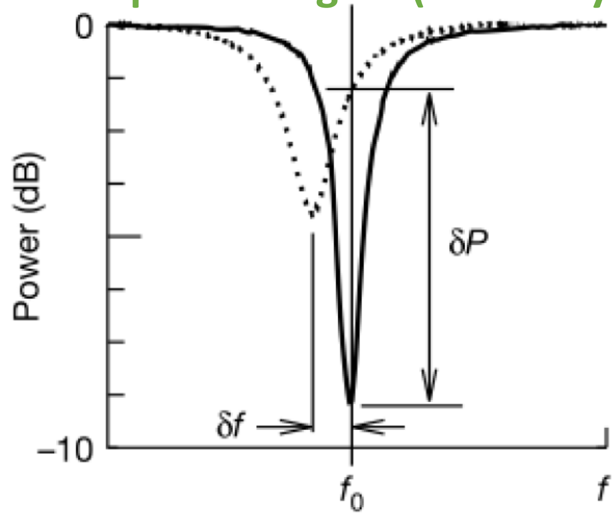
Using two or more MKIDs to collect quasi-particles

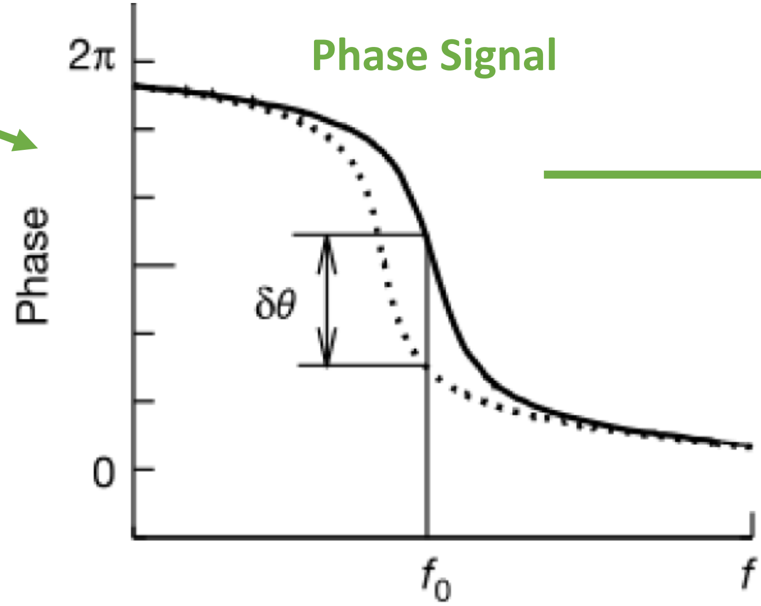
- allows for larger absorber
- increases energy collection efficiency
- enables position sensitivity

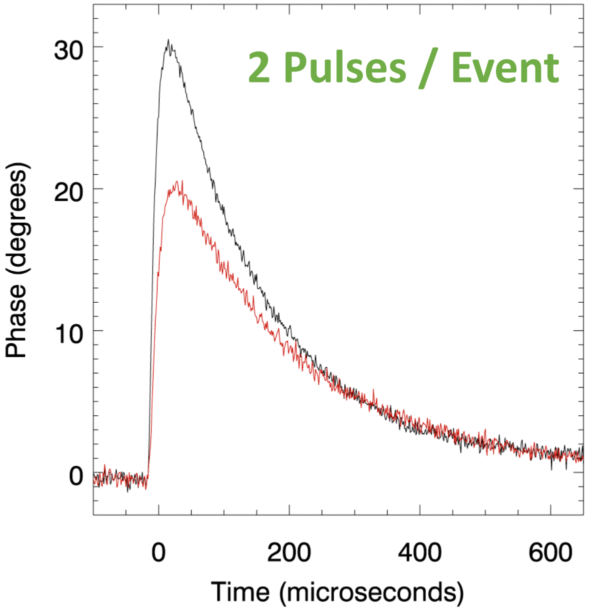
We readout phase response…

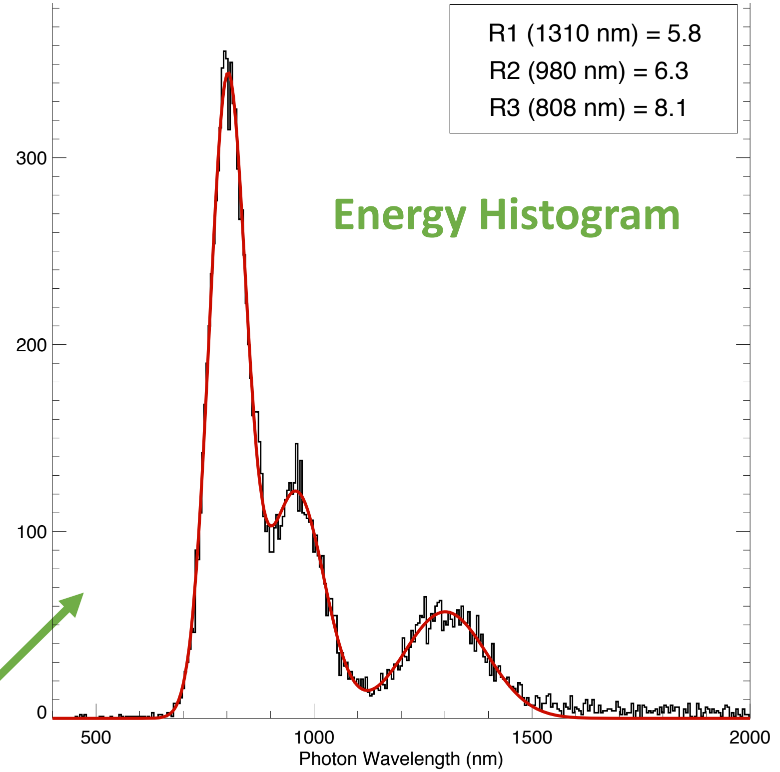


Amplitude Signal (Currently Not Used)









Pulse shapes tell us
- Energy
- Position
- Timing

Why Use Aluminum Absorber?

- Long quasi-particle lifetime
  - $\sim$ 3 msec (J. Baselmans et al, *AIP Conf. Proc.,* 2009.)
- Long diffusion length
  - $\sim$ 2 mm (M. Loidl, et al. *NIMA*, Jun. 2001.)
- Easy to obtain in high purity
- Dark matter event rate $\propto$ normal conductivity, σ_1
  - Rate (Y. Hochberg et al, PR D, 2017):
  - κ_{eff} = effective kinetic mixing parameter (coupling to normal matter)

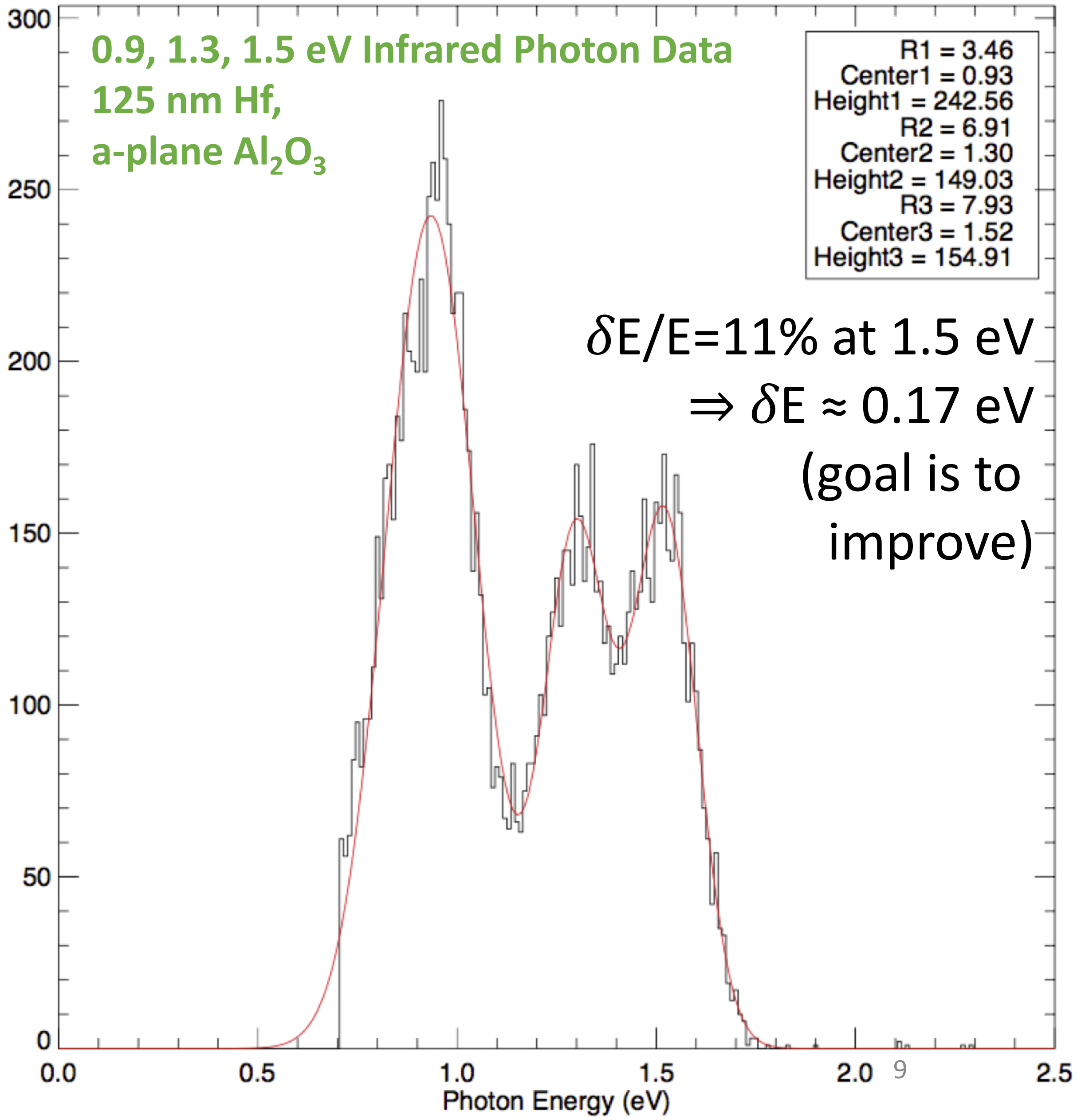
$$R = \frac{1}{\rho_{\mathrm{absorber}}} \frac{\rho_{\mathrm{DM}}}{m_{\mathrm{A'}}} \kappa_{\mathrm{eff}}^2 \sigma_1$$

Why Use Hafnium Resonators?

- Generally want low T_c materials because
  - Higher sensitivity (Smaller Tc, $\Delta \approx 1.72\, T_c k_B$)
  - Finer Energy Resolution

$$\frac{\delta E}{E} = 2.355\sqrt{\frac{F_{\mathrm{Fano}}\Delta}{\eta E_{\mathrm{DM}}}}$$

- Hafnium happens to work:
  - Produces high Q resonators (~ 500K)
  - Elemental material (easy to deposit & good uniformity)
  - Film Tc ≈ 450 mK @ 125 nm thickness $\Rightarrow$ High L_{kin} ~ 20 pH/□
  - High normal state resistivity $\Longrightarrow$ high L
  - measured τ_{qp} ~ 30 μsec



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Experience with Strip Detectors

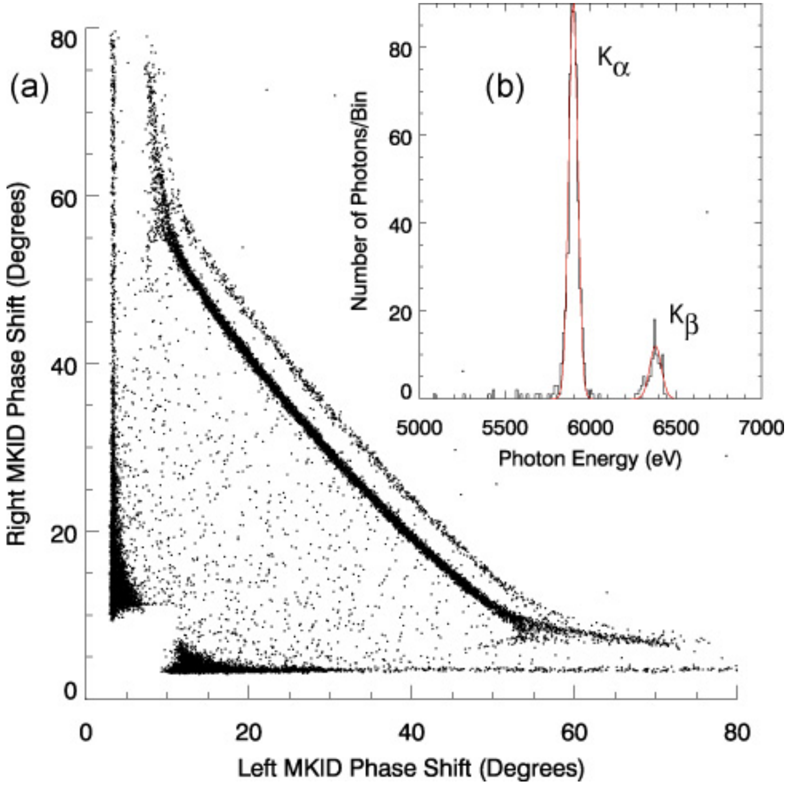
Position sensitive x-ray spectrophotometer using microwave kinetic inductance detectors

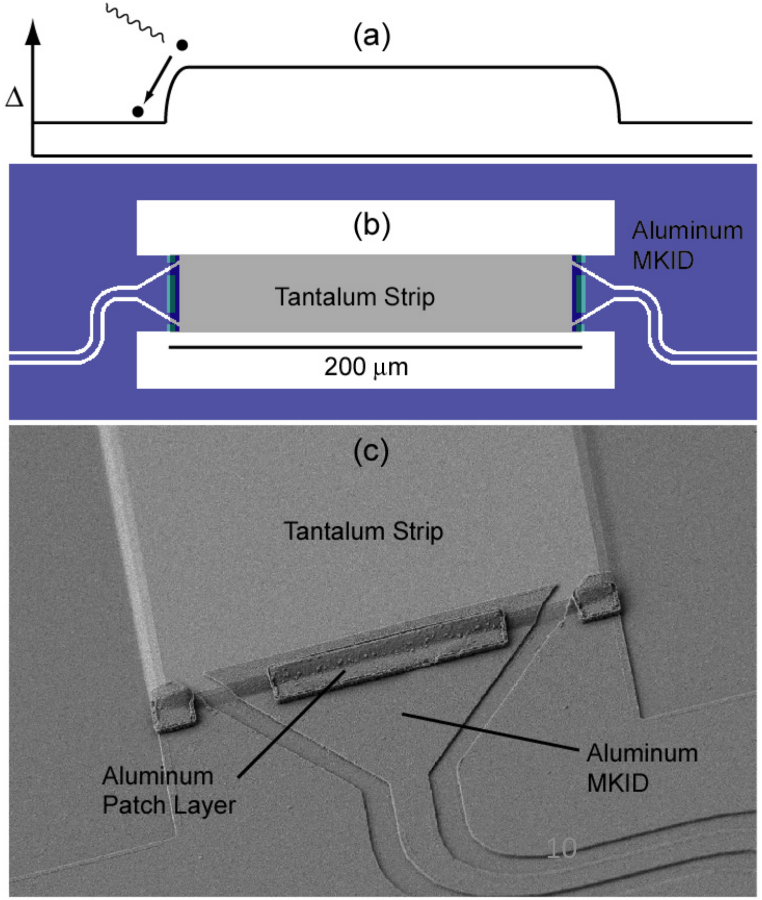
Benjamin A. Mazin,[a)] Bruce Bumble, and Peter K. Day
Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, MS 169-506, Pasadena, California 91109-8099

Megan E. Eckart, Sunil Golwala, Jonas Zmuidzinas, and Fiona A. Harrison
Physics Department, California Institute of Technology, 1200 E. California Blvd., Pasadena, California 91125

Data From:

- 200 nm thick Al
- 600 nm thick Ta
- ^{55}Fe source
- δE = 62 eV at 5.9 keV





- Objective is to combine sensitivity and E-resolution of our optical detectors with volume of strip detectors to reach

$\delta E \leq$ 100 meV down to **100 meV sensitivity**

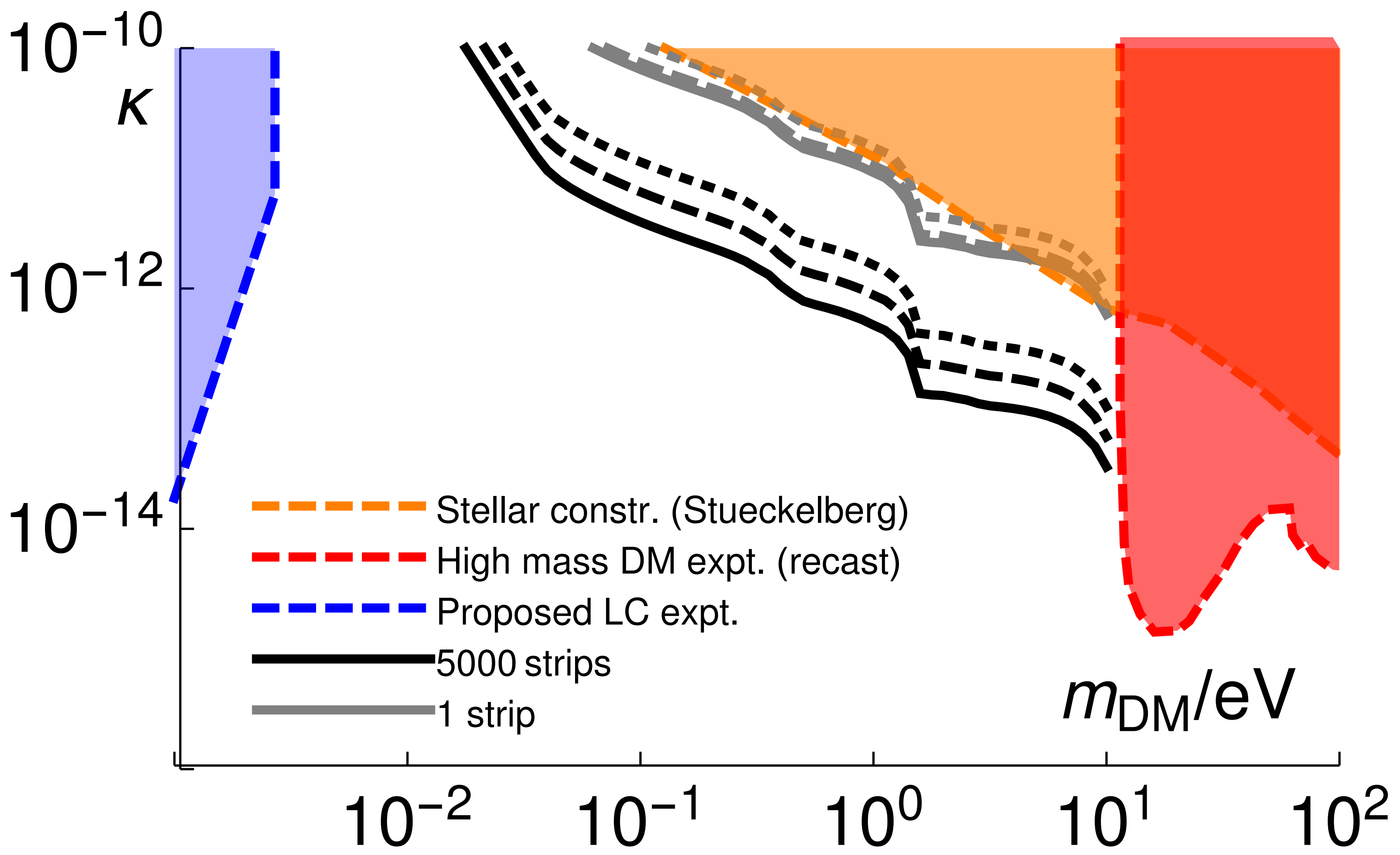
- Use MKIDs as opposed to TESs to get high multiplex factor

Estimated Dark Photon Sensitivity

- Proposing 5000 MKID Strip Detectors
  = 10,000 MKIDs
  = 10 mm^3 Al
  = 2 x 4" wafers

- 6 months

- 1, 10, 100 Background events

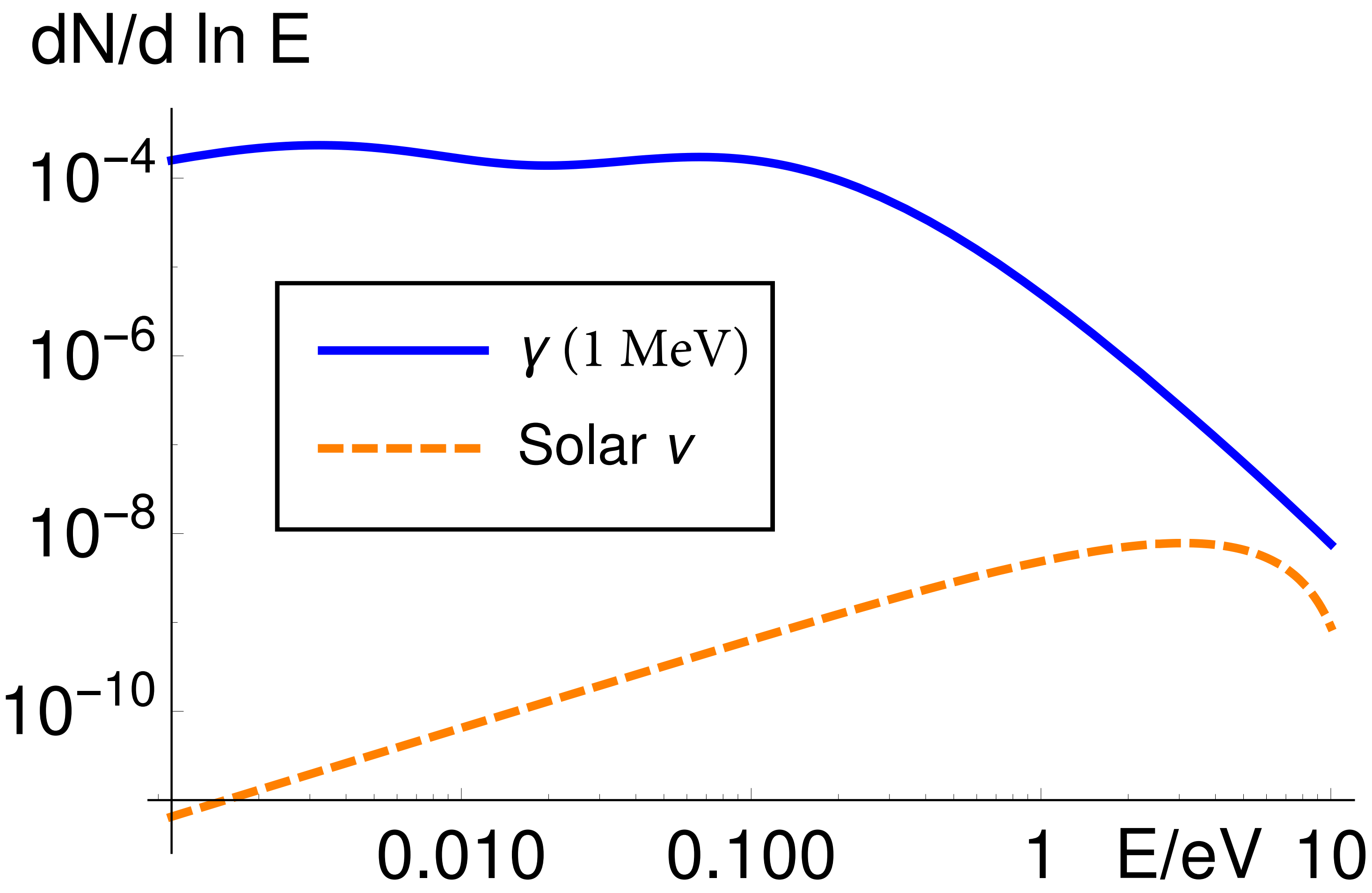


Backgrounds

We are estimating backgrounds from:

- Radioactivity
- Cosmic Rays (expt above ground)
- Coherent Photon Scattering off Atoms
- Stray Light
- Vibrations
- [pp – Neutrinos]

…Pulse shape/timing/energy spectrum discrimination

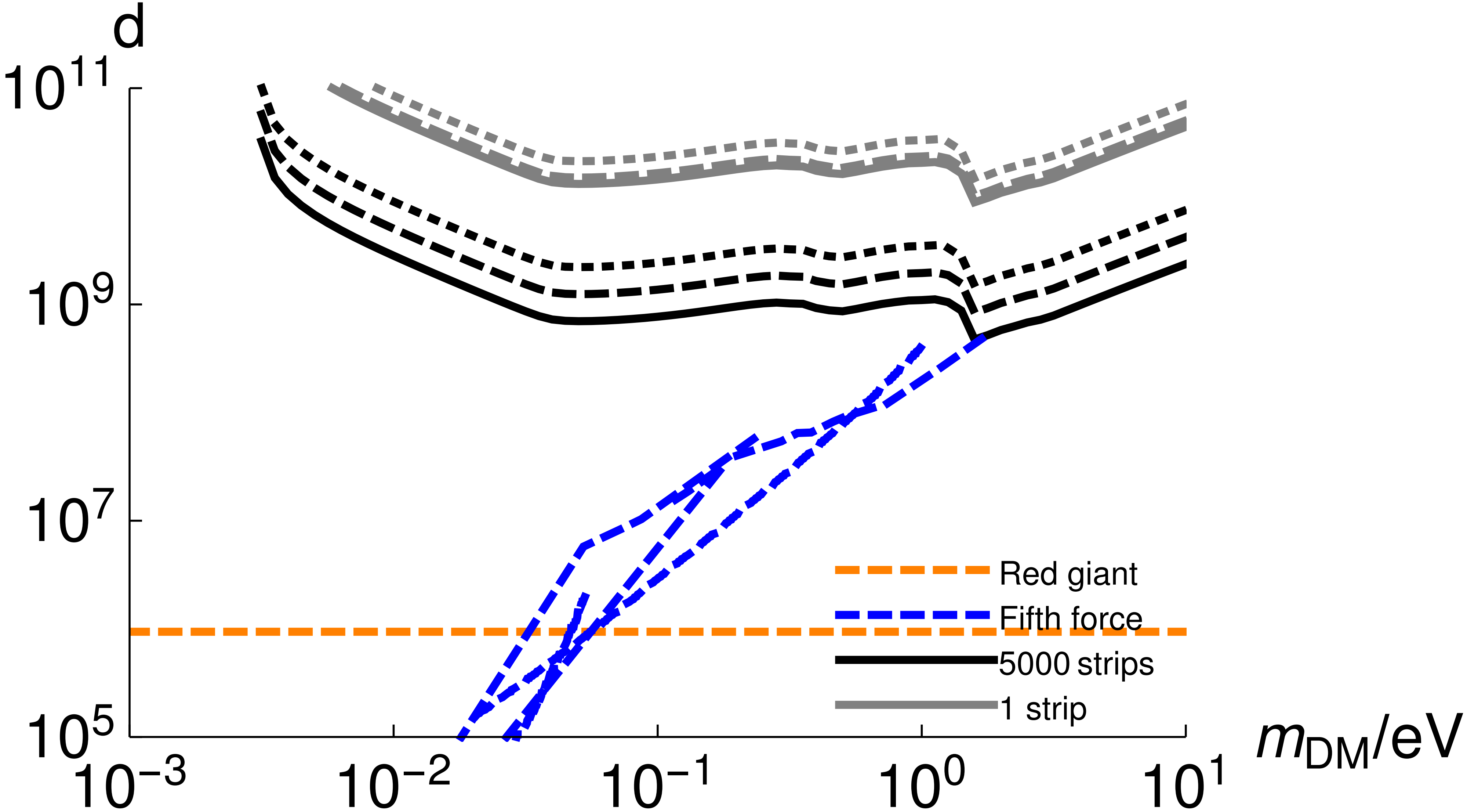


Conclusions…

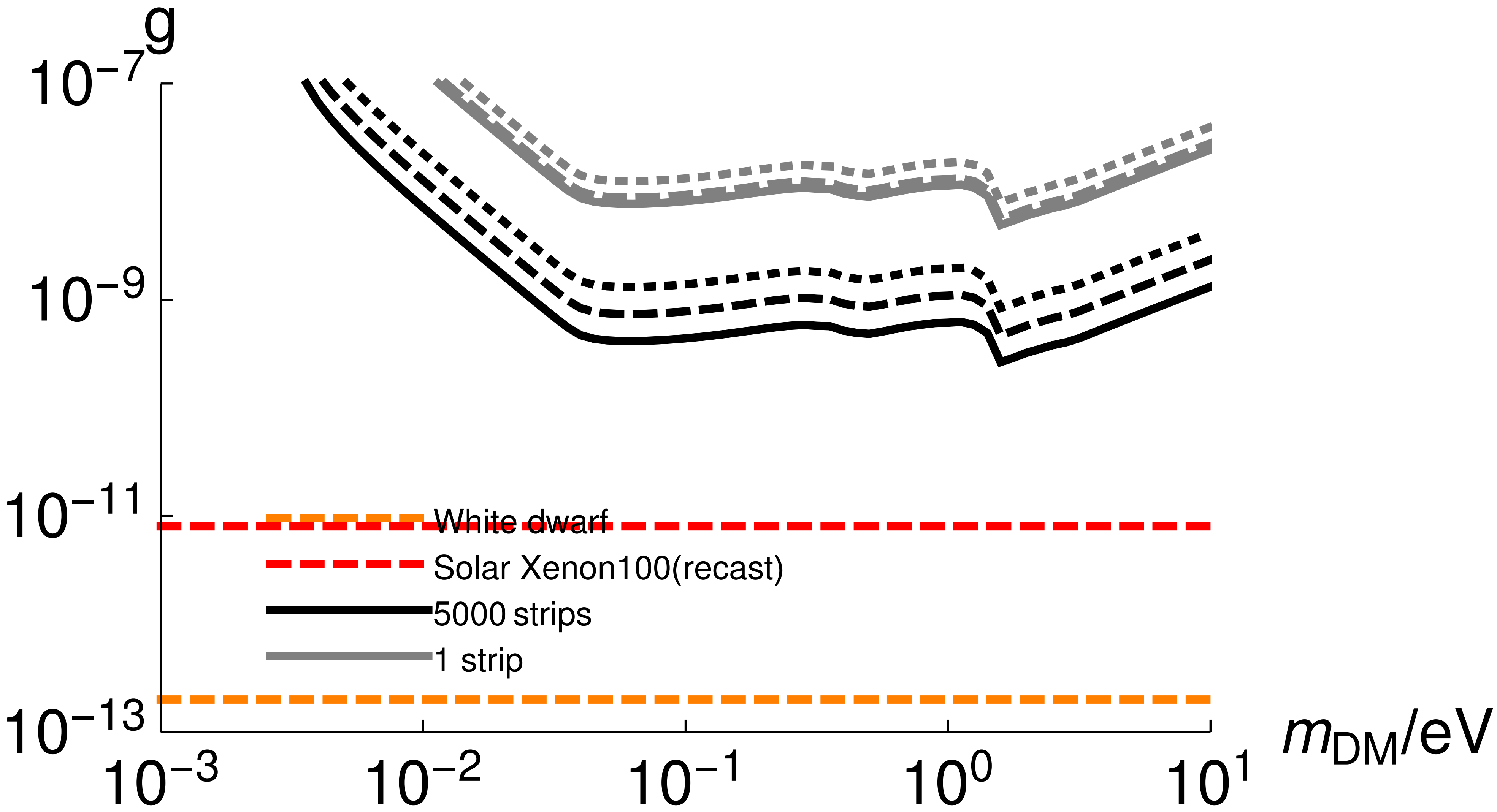
- Look for dark photons absorption onto e^-'s of superconducting Al
- Use MKIDs to read out ‘large’ number of strip detectors $\sim$ 10k
- Possibility of competitive limit using small absorber and minimal shielding $\sim 10mm^3$ Al
- Background discrimination possible using pulse shape/energy and timing

- End-

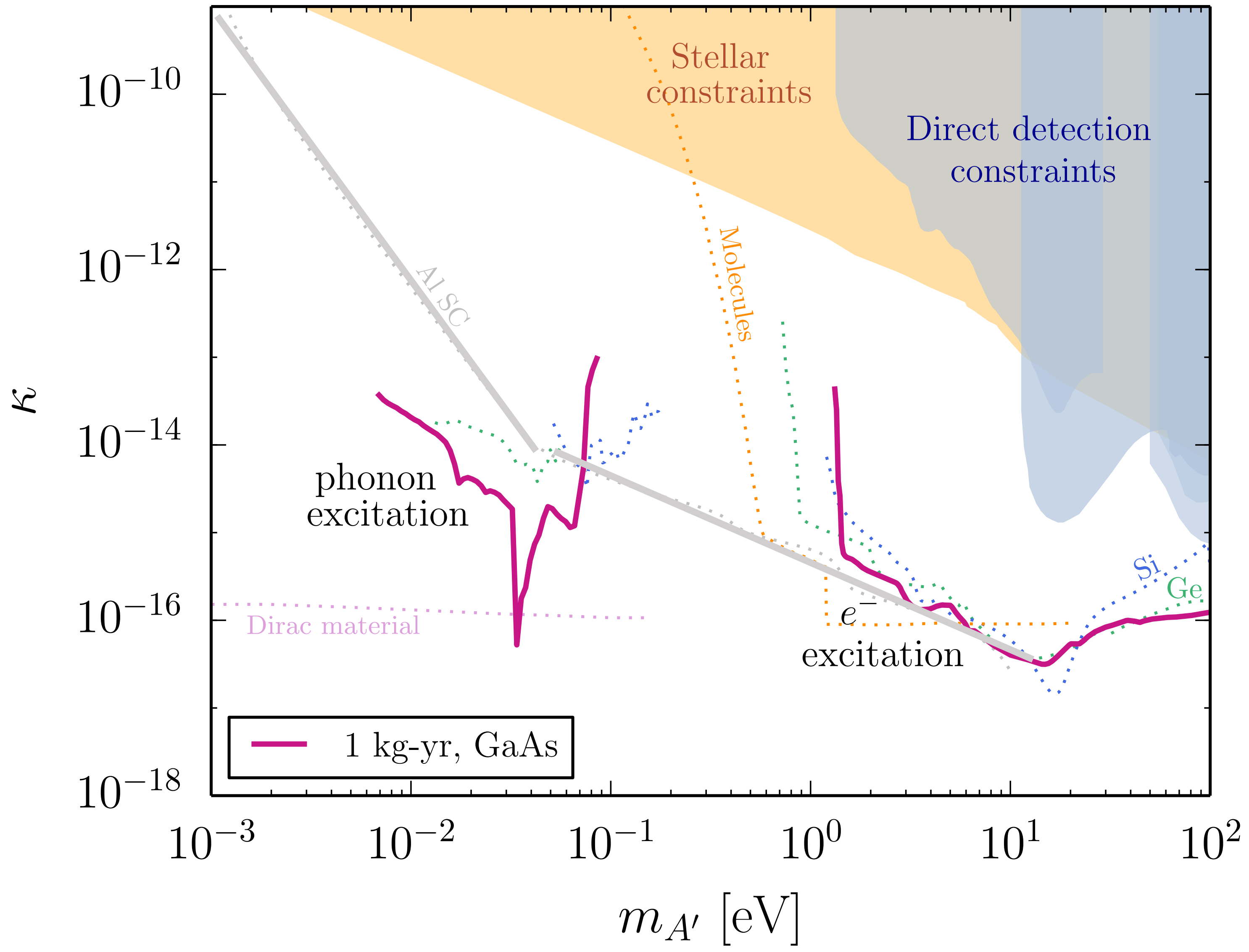
Estimated Scalar Boson Sensitivity



Estimated Pseudoscalar Boson Sensitivity



GaAs, Si, Ge (From arXiv:1712.06598)



Lumped Element Strip Detectors