A Radio For Hidden Photon Dark Matter

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The Dark Matter Zoo

- What do we know?
  - Astrophysical observations strongly suggest that dark matter exists and some component of it is cold (non-relativistic).
  - Over the last two decades, there has been tremendous progress in probing WIMP dark matter phase space, and WIMP direct detection experiments are now approaching the neutrino background.
  - This motivates broadening our search and running complementary probes for other well-motivated particles.
- Is dark matter heavy (>1 eV) or light (<1 eV)?
- Light dark matter candidates
  - Must be boson: scalar, vector, tensor

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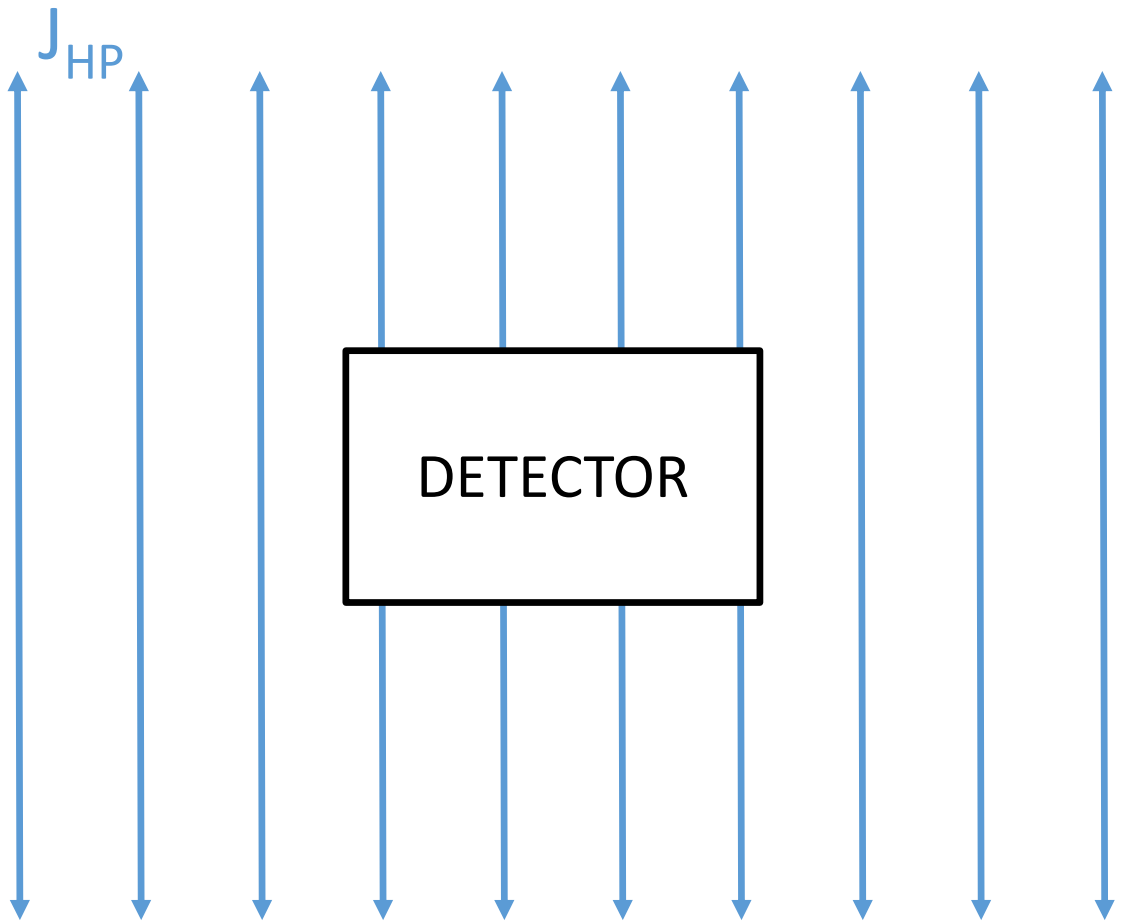
Hidden Photon Dark Matter: A Natural Dark Matter Candidate

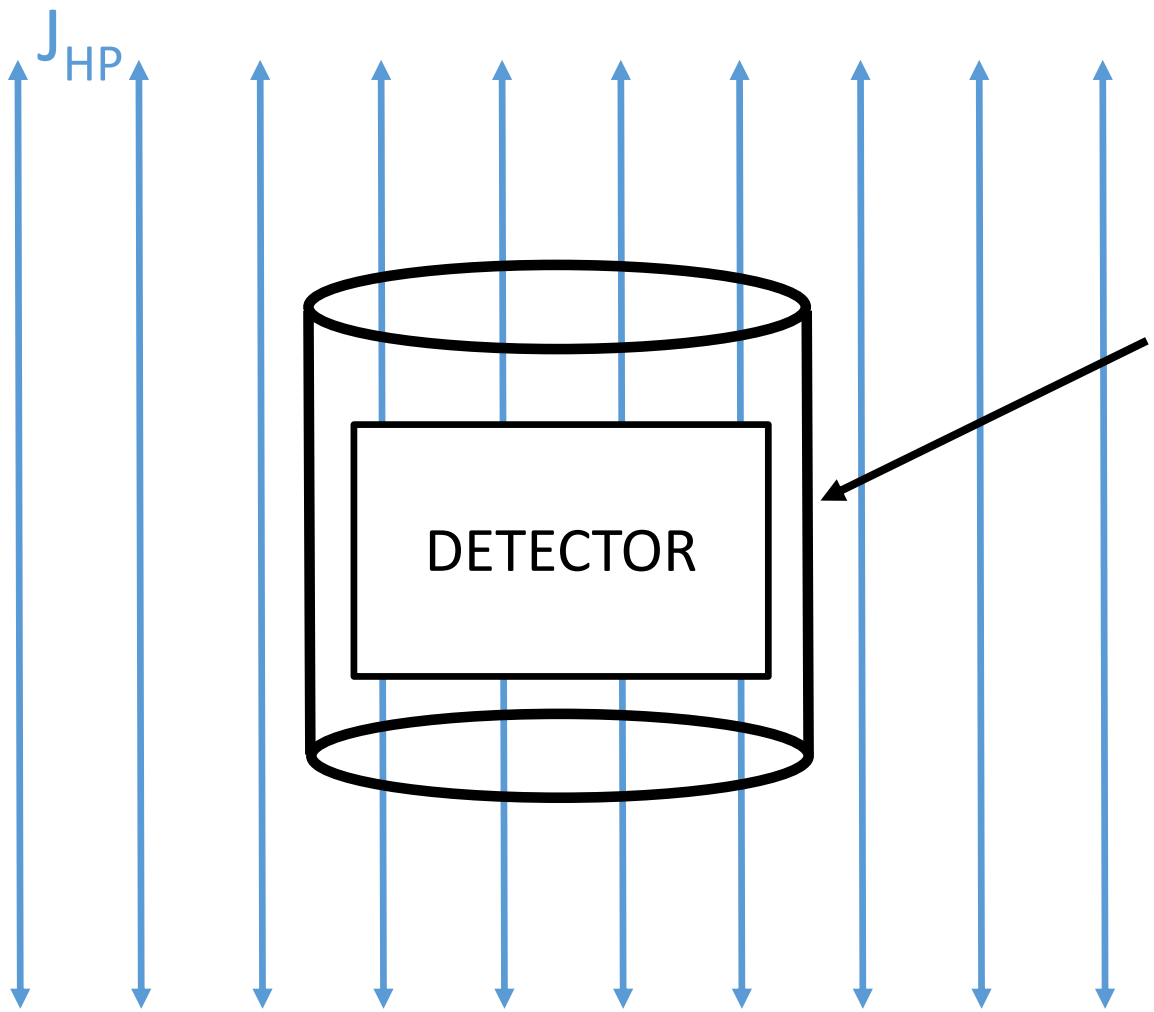
- Massive vector boson
- Couples to regular photon
- Coupling constant: $\varepsilon < 10^{-7}$
- Hidden photon is generic—naturally appears in extensions of Standard Model
- Inflation would produce hidden photons (arXiv: 1504.02102), as would other non-thermal processes
- Largely unexplored phase space – opportunity!

How do we detect hidden photons?



- Visualize hidden photon field as AC current density J_{HP}
- Frequency of oscillation set by mass, $hf=mc^2$ (~100 Hz- ~1 THz)
- Detection in quasi-dc limit, within coherence length

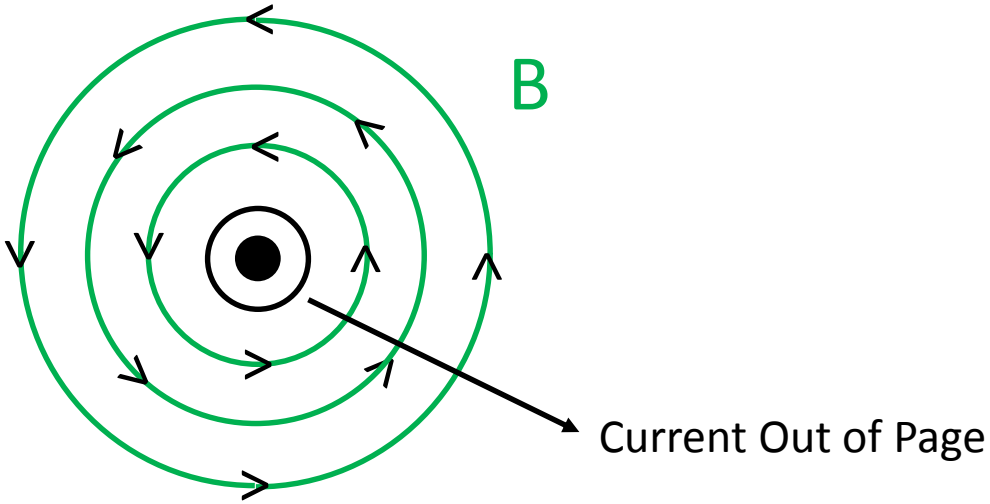
Closed Superconducting Shield Blocks External AC fields



Closed superconducting shield around detector blocks external AC fields, but current density from hidden photons penetrates

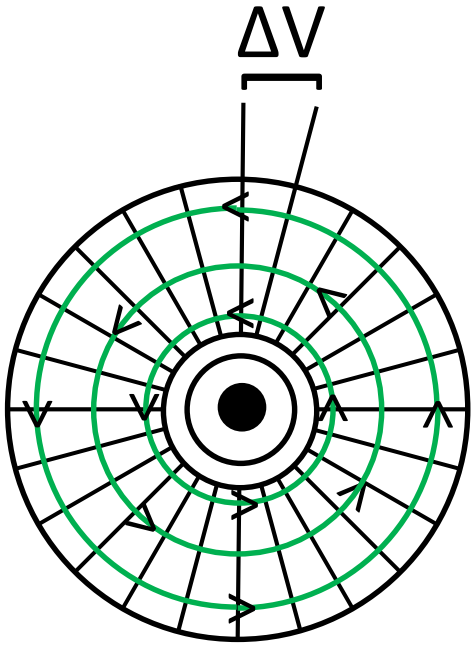
E&M 101: How do we detect quasi-DC current without contact?

- Wire current normal to page gives circumferential quasi-DC B-field
- Question becomes: How do we pick up quasi-DC B-field?

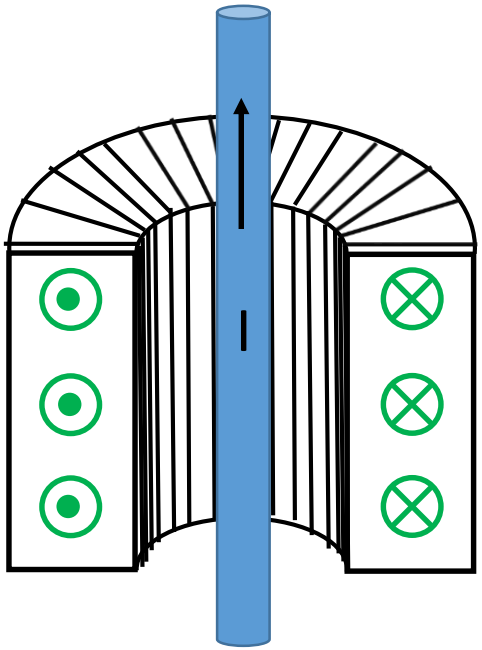


Answer: With toroidal solenoid!

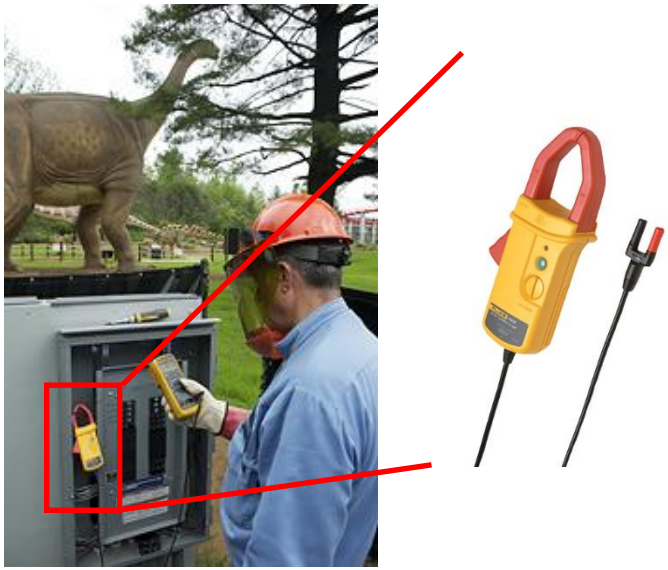
- AC magnetic field induces voltage across toroidal solenoid
- A standard idea…current clamp does the same thing!



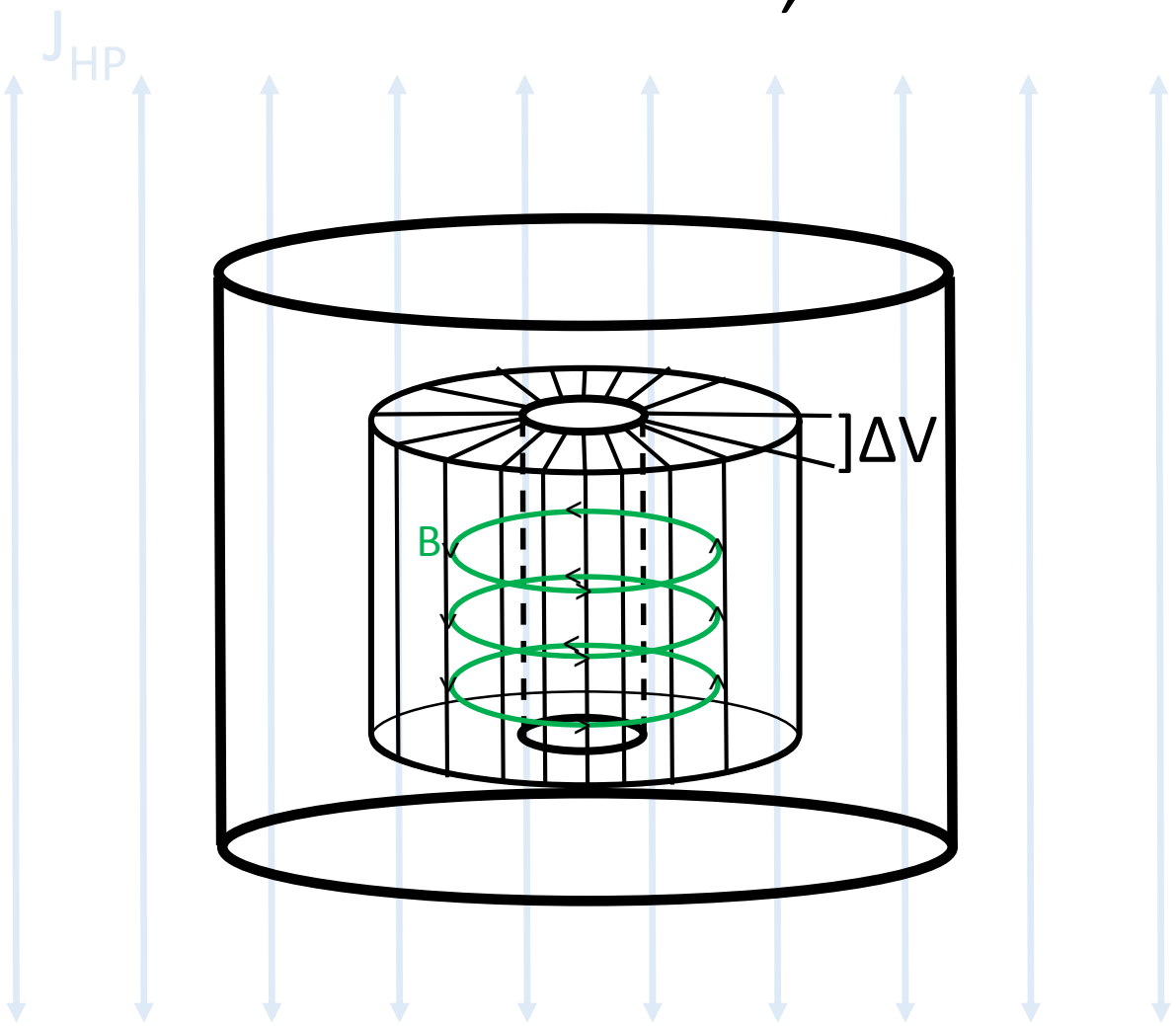
Top View



Cross-Sectional View



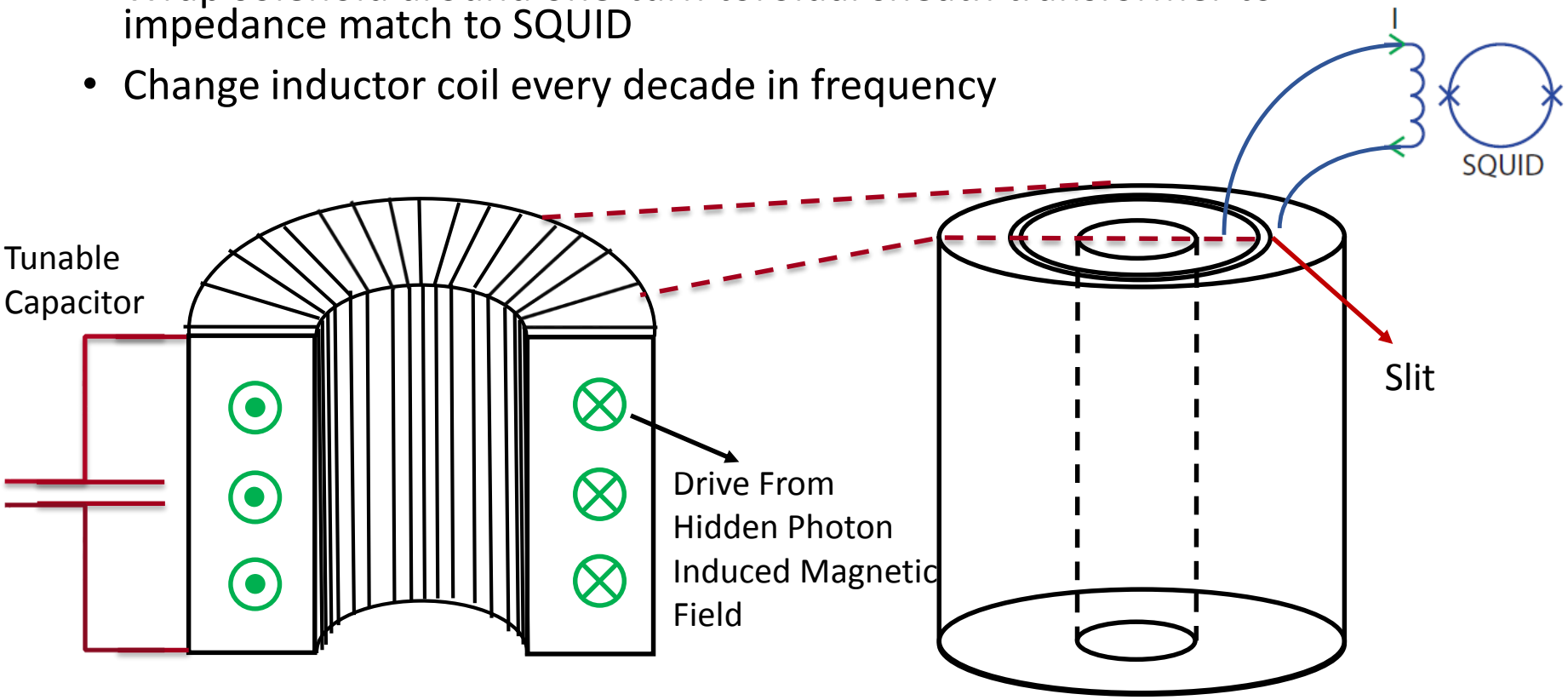
Toroidal Solenoid Detects Hidden Photons, But Low SNR



- Current J_{HP} creates circumferential quasi-dc magnetic field inside shield
- Use toroidal geometry to pick up magnetic field
- Read out voltage with amplifier, e.g. SQUID
- Inherently broadband, but would need to integrate forever!

Solution: Use LC resonator to get High SNR

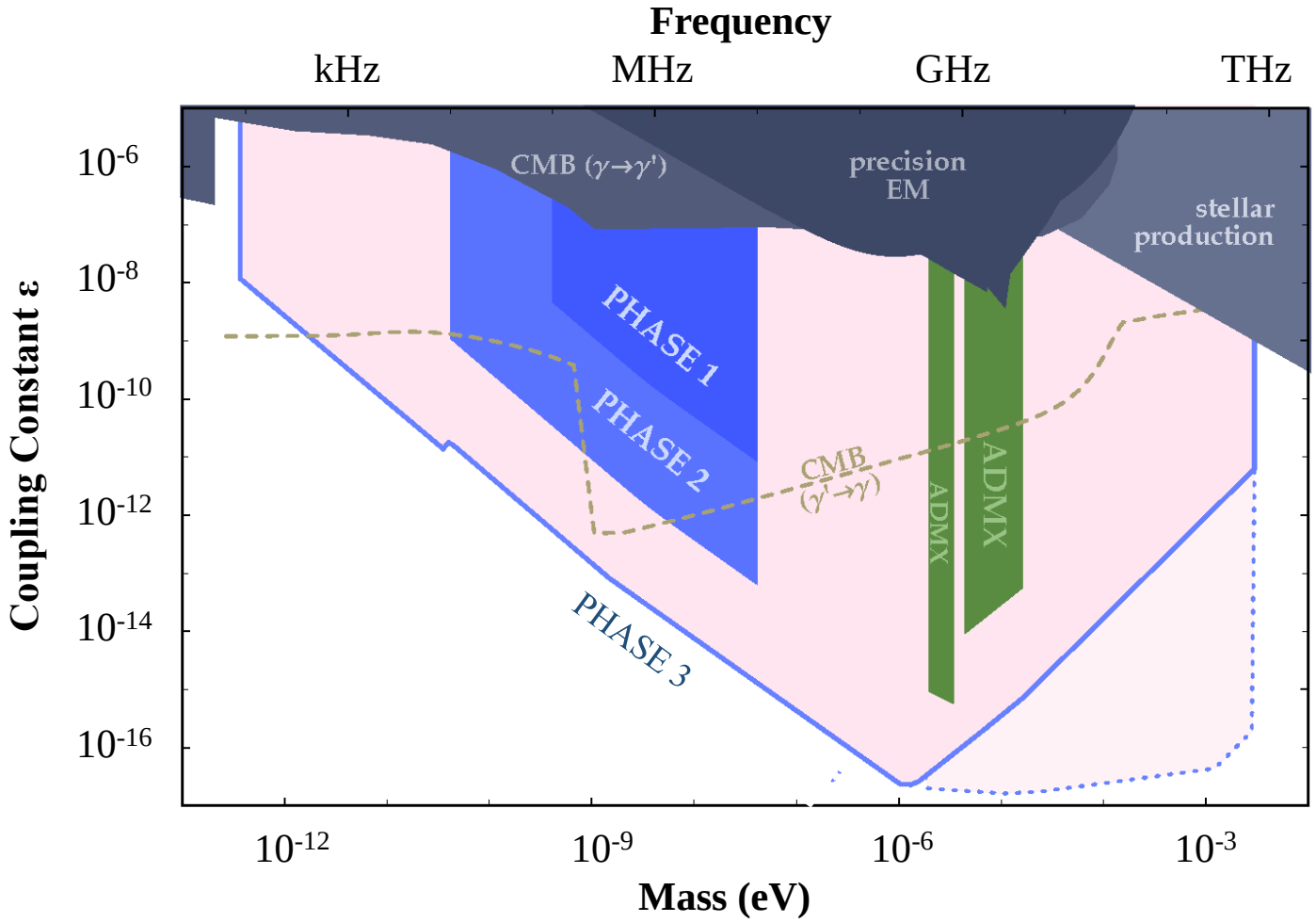
- Attach tunable capacitor to solenoid to make tunable LC resonator
- Narrowband, but high signal-to-noise
- Wrap solenoid around one-turn toroidal sheath transformer to impedance match to SQUID
- Change inductor coil every decade in frequency



Architecture Constraints

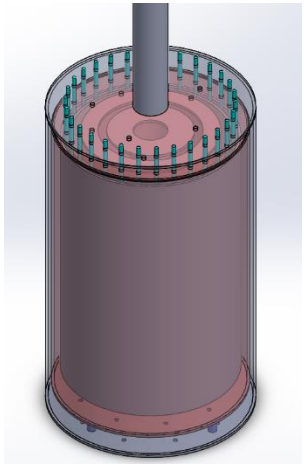
- Constraints:
  - Optimal Q of 10^6 set by virial velocity
  - Coupling to amplifier architecture strong enough to be resonator thermal-noise limited (low f) or quantum-noise limited (high f), but …
  - Weak enough to make Q degradation due to amplifier backaction negligible
- Solutions:
  - Use superconducting materials (niobium, NbTi wire)
  - f<10 MHz: dc SQUID
  - 10 MHz<f<1 GHz: microwave SQUID
  - f>1 GHz: quantum-limited parametric amplifiers (similar to ADMX), future- bolometers or single-photon counting

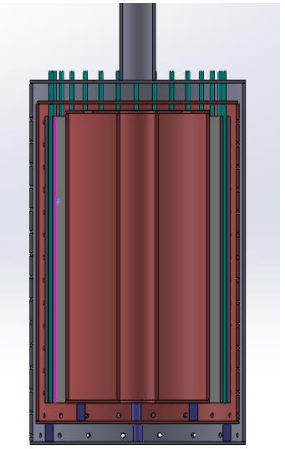
Reach- 10 Orders of Magnitude in Mass, ~16 in Cross Section!



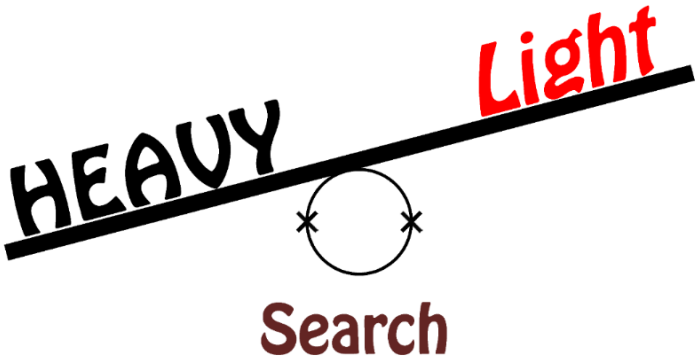
- Phase 1: 1.5 L at 4K - dip probe. Now!
- Phase 2: 30 L at 4K
- Phase 3: 1000 L at 100 mK
  - Multiplexed extension
- 1 month per decade

Phase 1 Experiment Now Funded!





- Phase 1 funded by Kavli Foundation through Kavli Institute for Particle Astrophysics and Cosmology
- Design now underway; construction to begin in September
- Proposed name:



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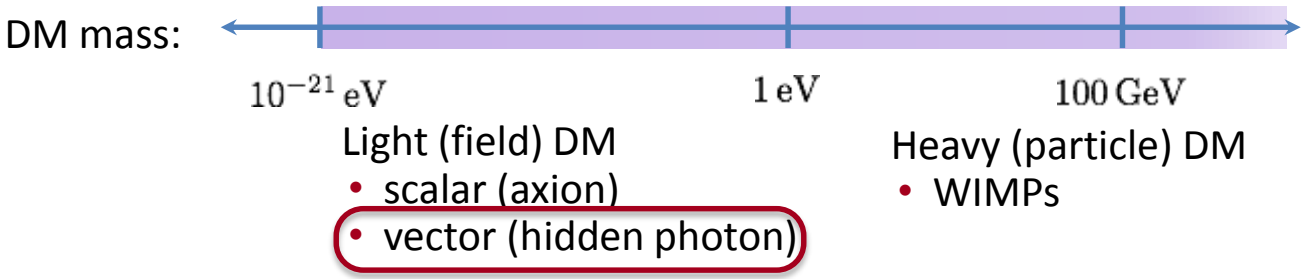
CAD by Max Silva-Feaver

Extra Slides

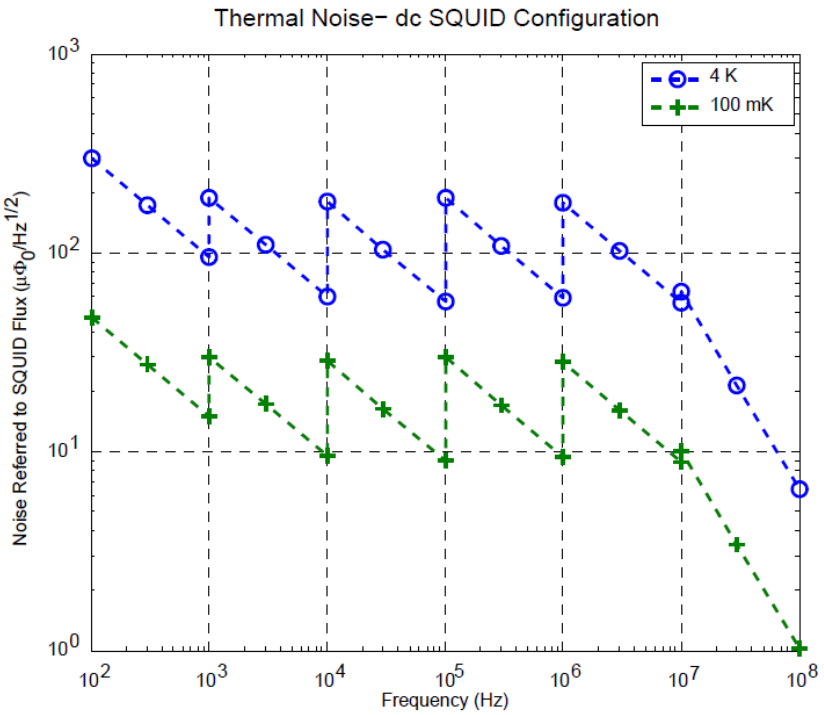
The Dark Matter Zoo



- Many well-motivated candidates out there!
- Split into two classes
- Heavy DM detection: particle scattering, energy deposition into target
- Light DM detection: look for collective interactions of the field

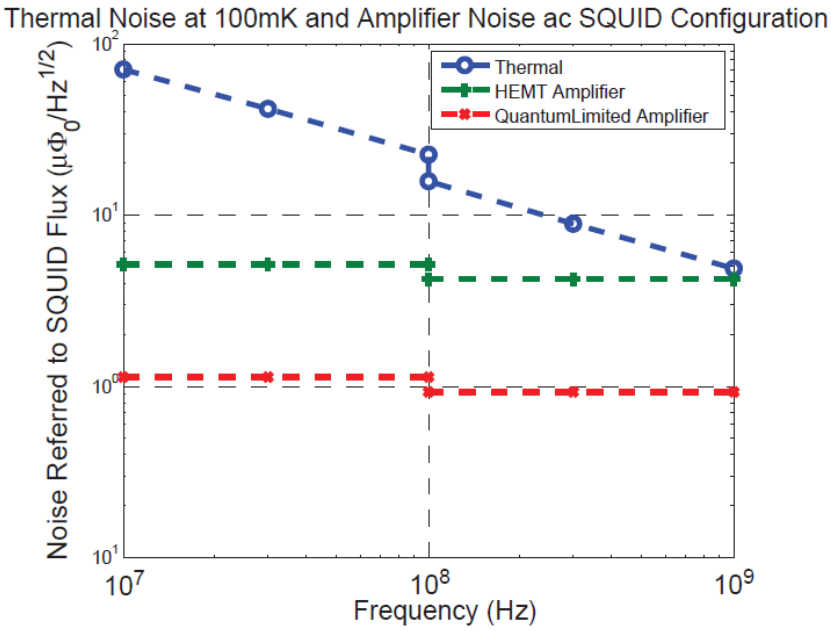
f<10 MHz: dc SQUID

- Amplifier backaction from resistive shunts
- Upper limit set by noise degradation, also potentially parasitic capacitance between SQUID washer and inpu coil



10 MHz<f<1 GHz: Microwave SQUID

- Dissipationless rf SQUID coupled to a microwave resonator
- rf SQUID acts as flux-dependent inductor- read out flux change as change in resonance frequency
- Sub-gap loss in junction instead of resistive shunts
- Largest readout noise contribution from microwave amplifier, e.g. HEMT or quantum-limited paramp
- >1 GHz and operating temperature ~100 mK: Quantum noise > thermal noise



Acknowledgments

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