Fermilab | U.S. DEPARTMENT OF ENERGY | Office of Science

Dark SRF - Theory

Roni Harnik (Theory Dept.)

to be followed by Anna Grassellino (APSTD)

For the **DarkSRF group:**

APS-TD: Alex Romanenko, Sam Posen, Yuriy Pischalnikov, Roman Pilipenko, Alex Melnitchouk, Damon Bice, Timergali Khabiboulline, Sergey Belomestnykh, Oleg Pronitchev, Valeri Poloubotko

PPD: Aaron Chou (Astrophysics), Zhen Liu (Theory), Joshua Isaacson (Theory).

Opportunities to Explore Dark Sectors

- Fermilab has a unique opportunity to launch a program of exploring dark sectors that couple to EM radiation using SRF technology.

Well motivated theories:
- Dark Photons
- Axions and ALPs

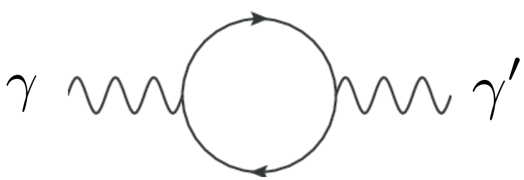
Well motivated searches:
- Light mediators
- Dark matter

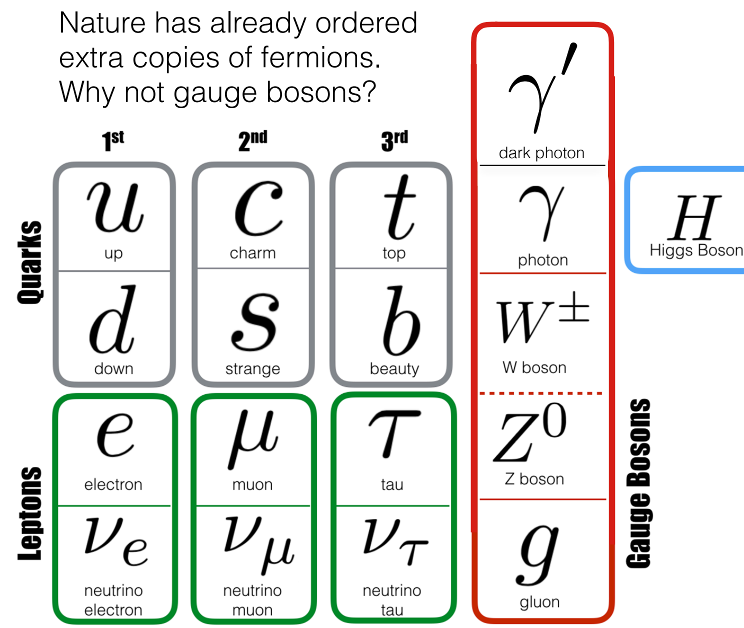
- Leveraging existing Fermilab infrastructure and expertise.

- We are asking the PAC to endorse the physics goals and the effort to use SRF technology for fundamental discovery.

Dark Photons

- Imagine another photon, with a different mass.
- Common in top-down frameworks.
- *Any* heavy particle that is charged both photons will generate mixing.





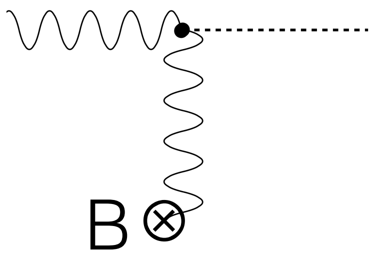
$$\mathcal{L} = -\frac{1}{4}\left(F_{\mu\nu}F^{\mu\nu} + F'_{\mu\nu}F'^{\mu\nu} - 2\epsilon F_{\mu\nu}F'^{\mu\nu}\right) + \ldots \supset \epsilon\left(\vec{E}\cdot\vec{E}' + \vec{B}\cdot\vec{B}'\right)$$

An oscillating EM field is a source of dark photons, and vice versa. (reminiscent of neutrino oscillations)

Axion-like particles

- Imagine an approximate symmetry broken at a high scale f.
  $\rightarrow$ a pseudo-Goldstone Boson $\simeq$ an axion-like particle.
- Common in top-down constructions, the axion is invoked to solve the strong CP problem.
- Loops of heavy charged particles can generate interaction:

$$\mathcal{L} = \frac{\alpha}{f} a F_{\mu\nu} \tilde{F}^{\mu\nu} = g_{a\gamma\gamma} a \vec{E} \cdot \vec{B}$$



Axions and photons mix in a magnetic field.

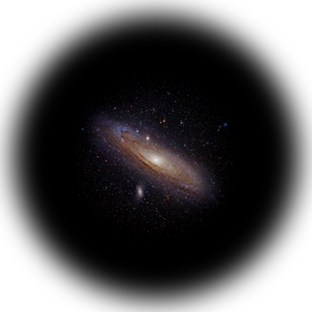
An oscillating E · B is a source of dark photons.

Longer Range Interactions and Wave-like Dark Matter

- Both axion-like particles and dark photons are well motivated as mediators of long range interactions that can be searched for.

$$\mathcal{L} \supset \quad \text{dark photons?} \quad \text{axions?}$$

- Both axion-like particles and dark photons are dark matter candidates with nice production mechanisms.
- In the Wave-like DM category. Oscillating at $\omega = m_{\rm DM}$.

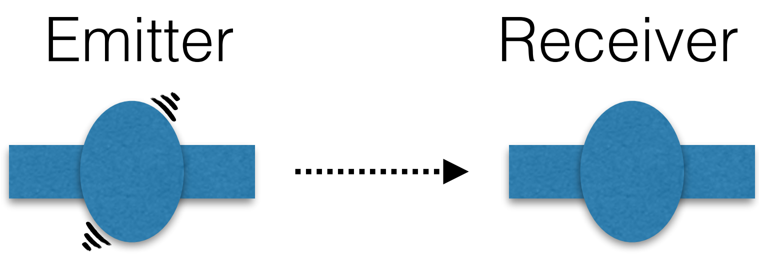


$\supset$ dark photons? axions?

Searches with SRF Cavities

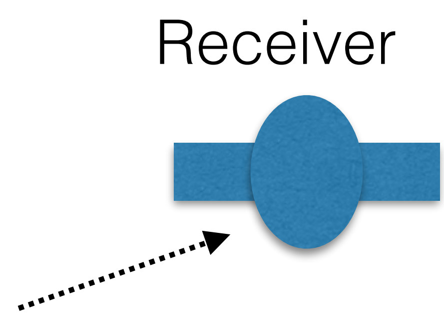
- **Fermilab's SRF Cavities are world's highest quality photon resonators, with Q as high as 10^{11}:**
  - Large coherent fields when excited → source dark fields.
  - Resonant response → amplify coherent feeble signals.

Light Shining through wall:



a search for a mediator.

A dark matter search:



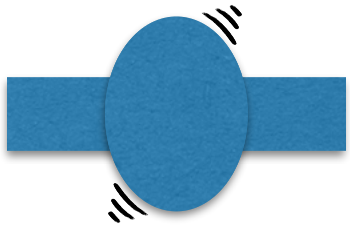
the DM filled Universe
is the emitter

Dark Photon Search

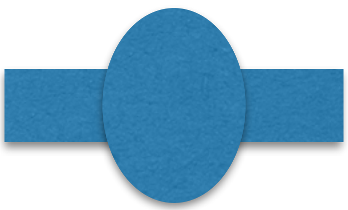
The first simple setup:

Dark Photon Search

The first simple setup:



Emitter Cavity

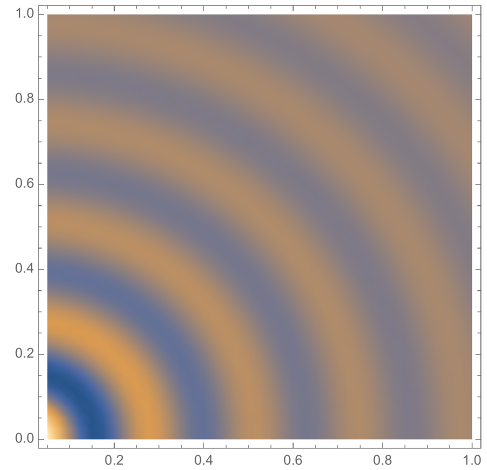


Receiver Cavity

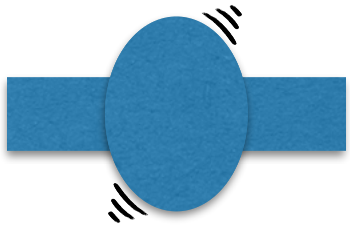
Frequency of 1.3 GHz, excited to ~ 35 MV/m. Thats ~ 10^{25} Photons!

Dark Photon Search

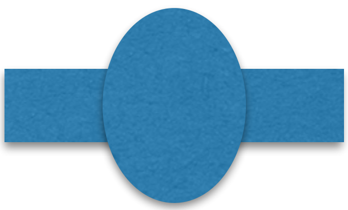
The first simple setup:



a dark photon field is radiated at 1.3 GHz.



Emitter Cavity

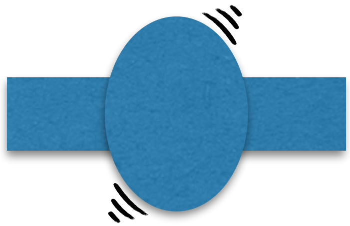


Receiver Cavity

Frequency of 1.3 GHz, excited to ~ 35 MV/m. Thats ~ 10^{25} Photons!

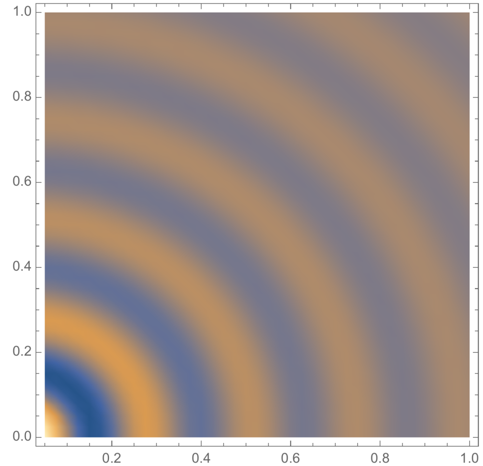
Dark Photon Search

The first simple setup:

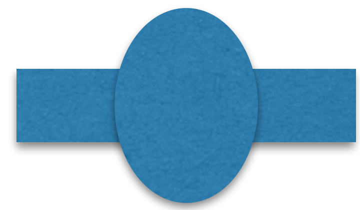


Emitter Cavity

Frequency of 1.3 GHz, excited to ~ 35 MV/m. Thats ~ 10^{25} Photons!



a dark photon field is radiated at 1.3 GHz.



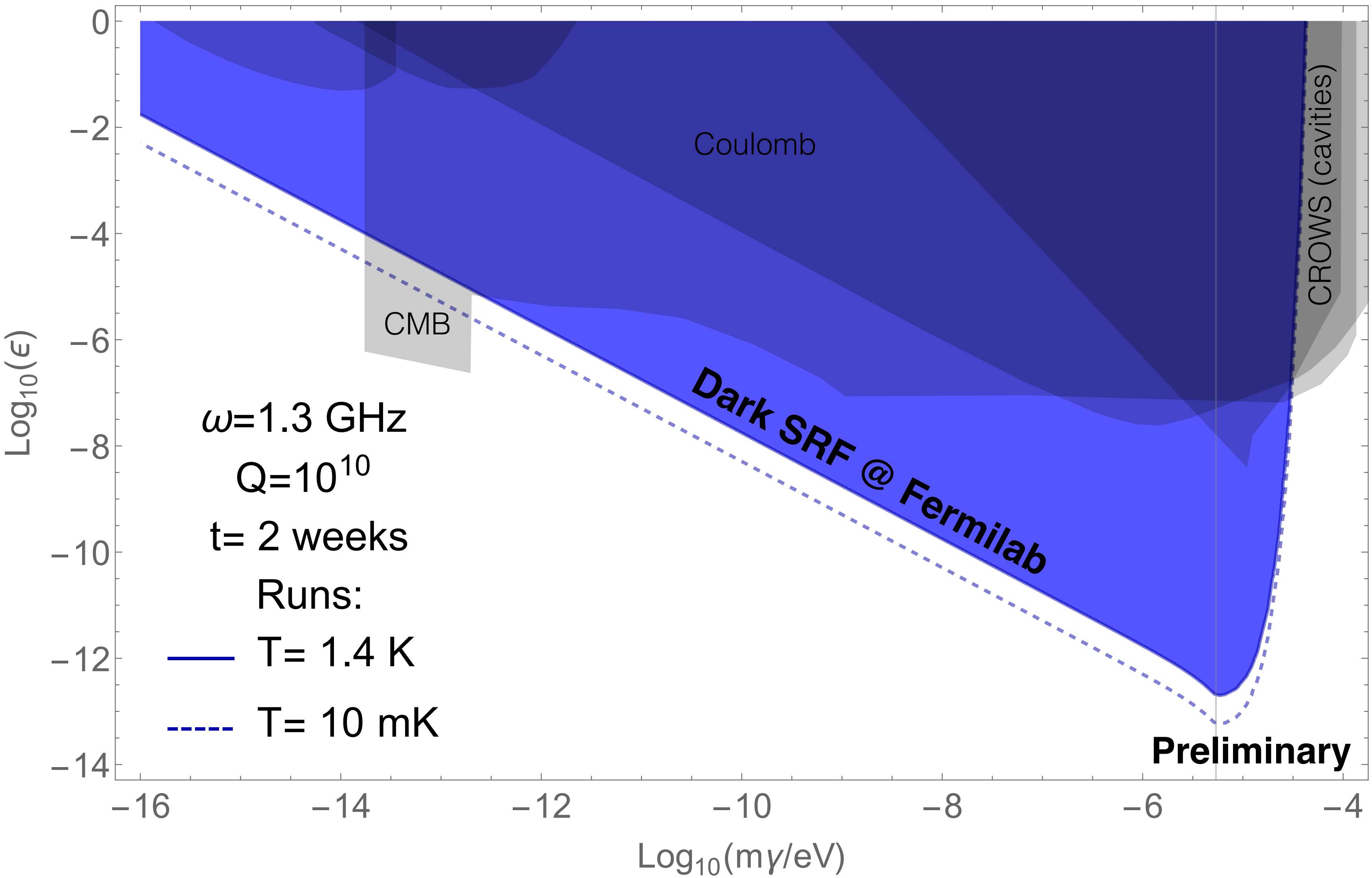
Receiver Cavity

Tuned to 1.3 GHz. Responds to dark field. Contains only thermal noise (T=1.4 K).

For correct cavity positioning $P_{\rm rec} \sim G^2\, \epsilon^4 \left(\frac{m_{\gamma'}}{\omega}\right)^4 Q_{\rm rec} Q_{\rm em} P_{\rm em}$

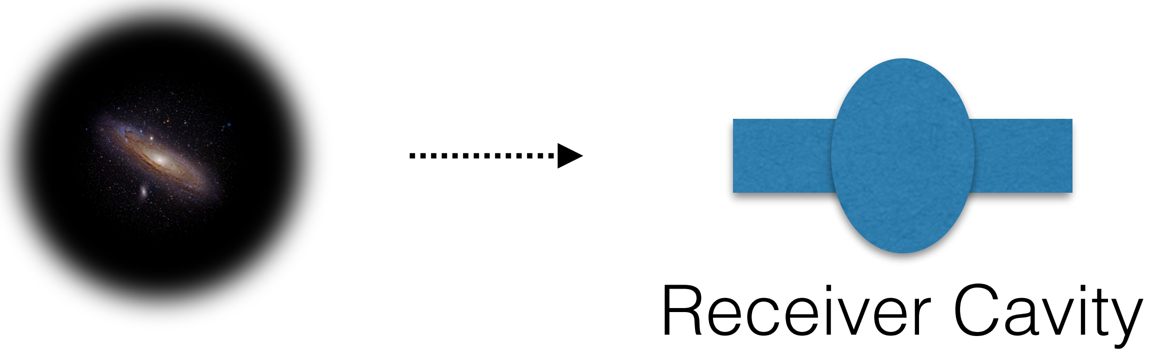
[see Graham, Mardon, Rajendran, Zhao 2014]

Dark Photon Search

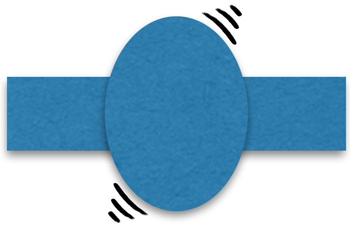


Dark Photon Search

A further search for dark photon DM can follow using a tunable receiver cavity.

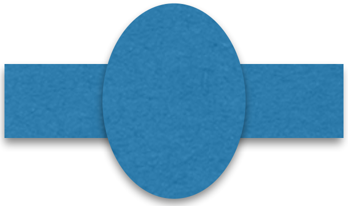


Axion Searches (future directions)



Emitter Cavity

an axion field is radiated at $(f_1 \pm f_2)$.



Receiver Cavity

Excite *two* modes, with a non-zero (oscillating) $E_1 \cdot B_2$

or

search for cosmic DM.

Several possibilities to explore:

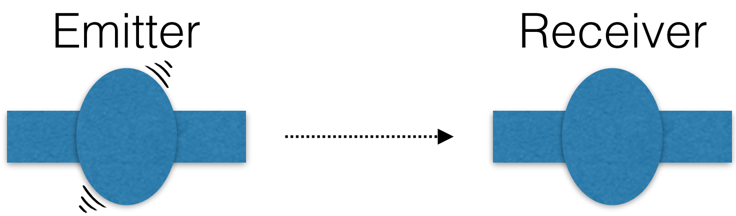
- One excited and one quiet mode.
- Inserting a region of static B field.
- .... R&D is required

Fermilab

On to Anna…

Deleted Scenes

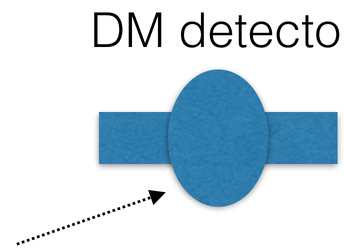
Light Shining through Wall versus a DM Search



Independent of whether the A' or axion are the DM.

No need to scan.

Need to tune cavities to one another.



Assumes the A' or axion are the DM, but is often more sensitive.

Need to scan.

No need to tune.

Some References LSTW

Graham et al, Phys.Rev. D90 (2014) no.7, 075017
S. R. Parker et al, Phys. Rev. D 88, 112004 (2013)
J. Hartnett et al, Phys. Lett. B 698 (2011) 346
J. Jaeckel and A. Ringwald, Phys. Lett. B 659, 509 (2008)