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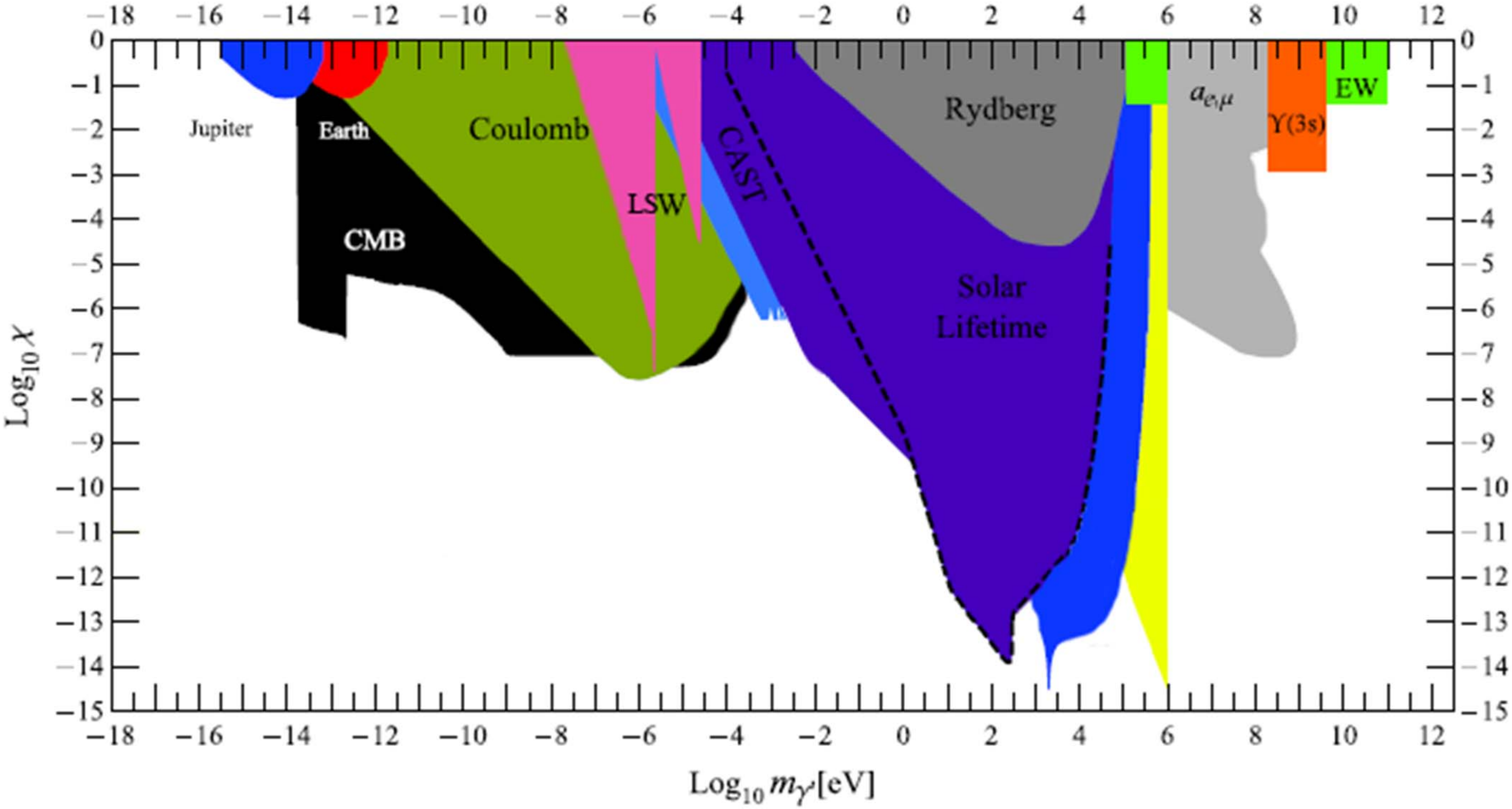
Hidden sector photon

- Hypothetical WISP from extra U(1) predicted by various standard model extensions.
- Interacts very weakly with visible sector via mixing with the photon.
- Possibly massive.

Lagrangian density for EM and HS fields:

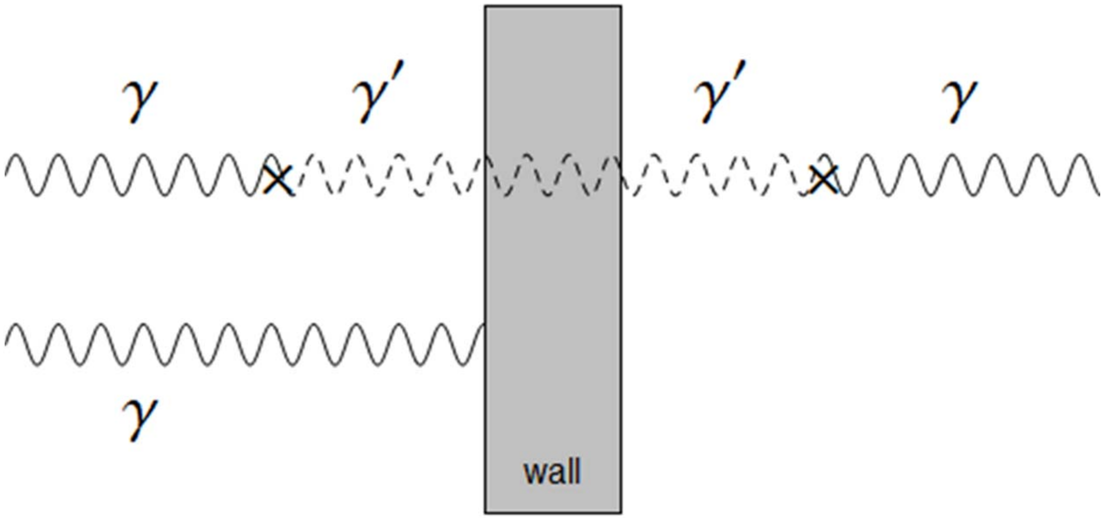
$$\mathcal{L} = -\frac{1}{4}F^{\mu\nu}F_{\mu\nu} - \frac{1}{4}B^{\mu\nu}B_{\mu\nu} - \frac{1}{2}\chi F^{\mu\nu}B_{\mu\nu} + \frac{1}{2}\left(\frac{c}{\hbar}m_{\gamma'}\right)^2 B^{\mu}B_{\mu}$$

Current limits



Light shining through a wall

- Hidden sector photons can't be detected directly.
- Instead look for evidence of γ – γ' mixing.

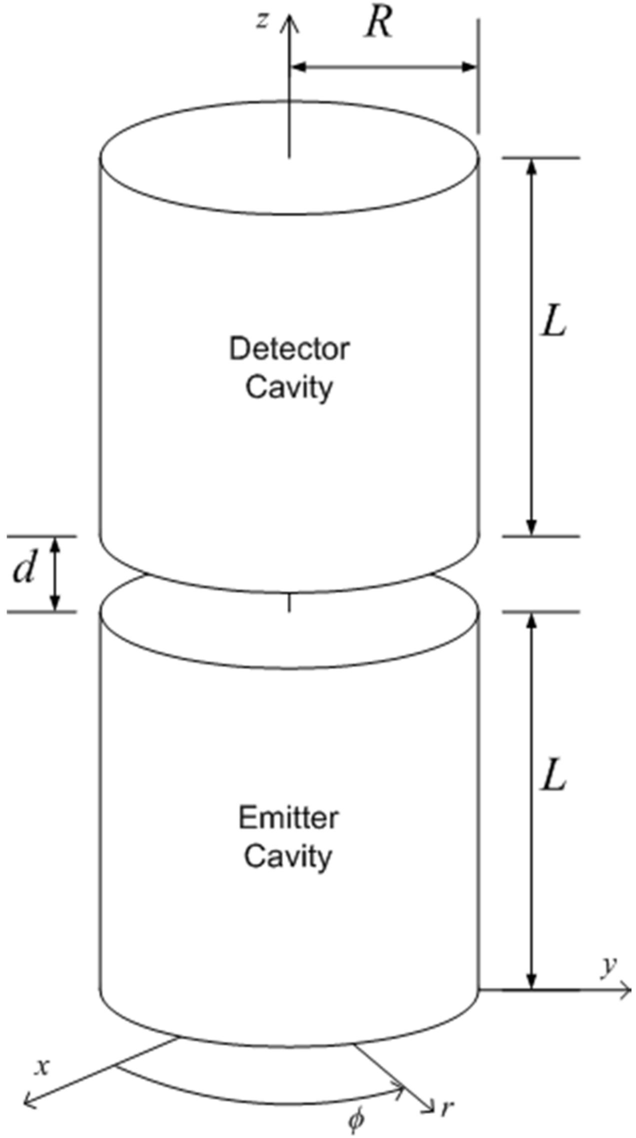


Microwave cavity LSW

- Use resonating cavities either side of the wall.
- Excite one cavity and look for signal in other.
- Liberally apply shielding between.

$$\mathbb{P}_{\rm trans} = \frac{P_{\rm det}}{P_{\rm emit}} = \chi^4 \, Q_{\rm emit} \, Q_{\rm det} \left(\frac{m_{\gamma'} \, c^2}{\hbar \, \omega_\gamma}\right)^8 \, |\mathcal{G}|^2$$

$$\mathcal{G}\left(\frac{k_{\gamma'}}{k_\gamma}\right) = k_\gamma^2 \oint_{V_{\rm emit}} \oint_{V_{\rm det}} \frac{e^{i \, k_{\gamma'} \, |\mathbf{x}-\mathbf{y}|}}{4\pi |\mathbf{x}-\mathbf{y}|} A_{\rm emit}{}^j(\mathbf{y}) \, A_{\rm det}{}^j(\mathbf{x}) \, \mathrm{d}^3\mathbf{x} \, \mathrm{d}^3\mathbf{y}$$

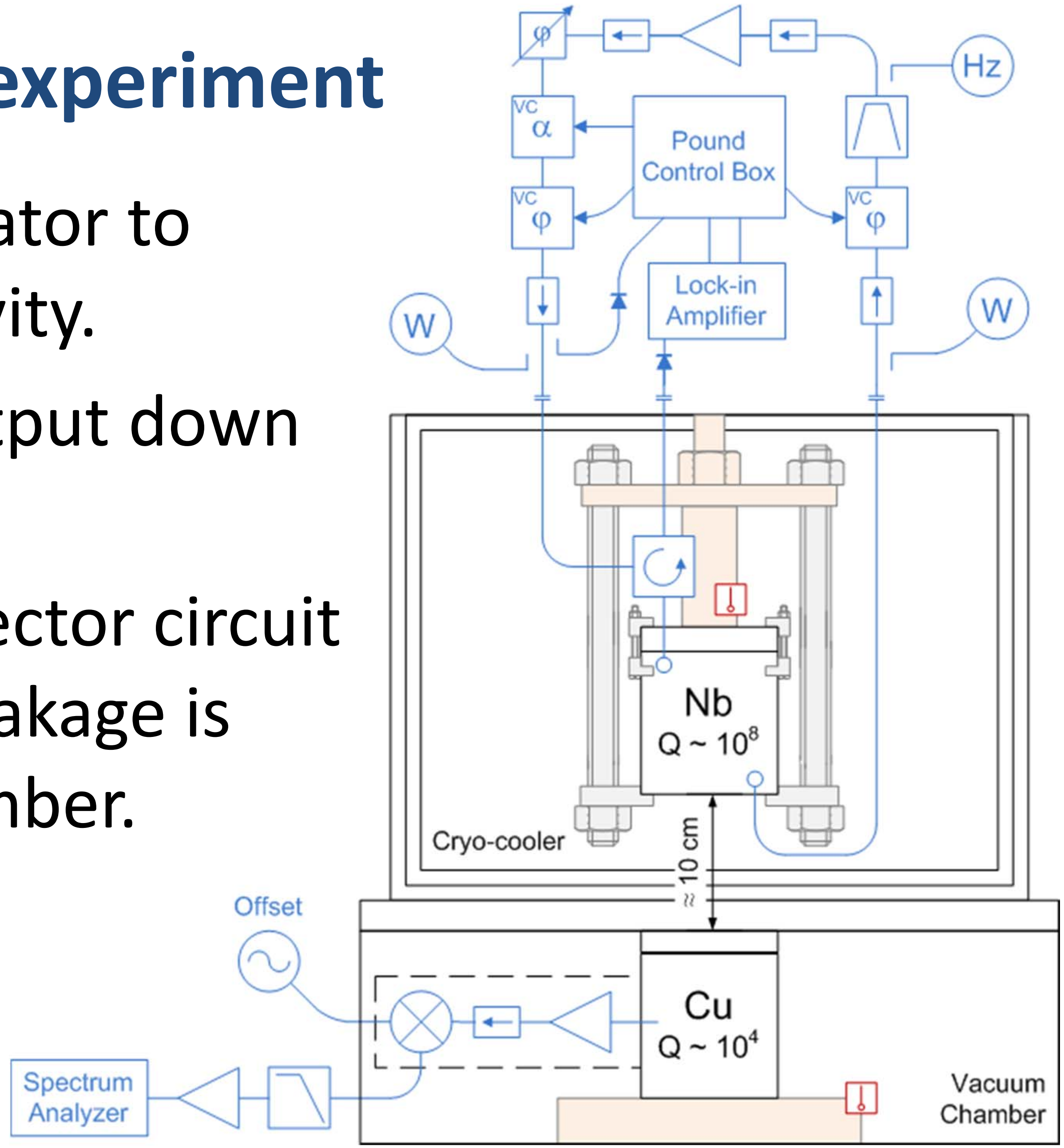


New UWA LSW experiment

- Using superconducting niobium cavity in a cryo-cooler as emitter cavity, Q ~ 10^8.
- Using room temperature copper cavity in a separate chamber as detector cavity, Q ~ 10^4.
- Lower Q detector allows for easier resonance frequency matching.
- Separate vacuum chambers reduces microwave leakage.

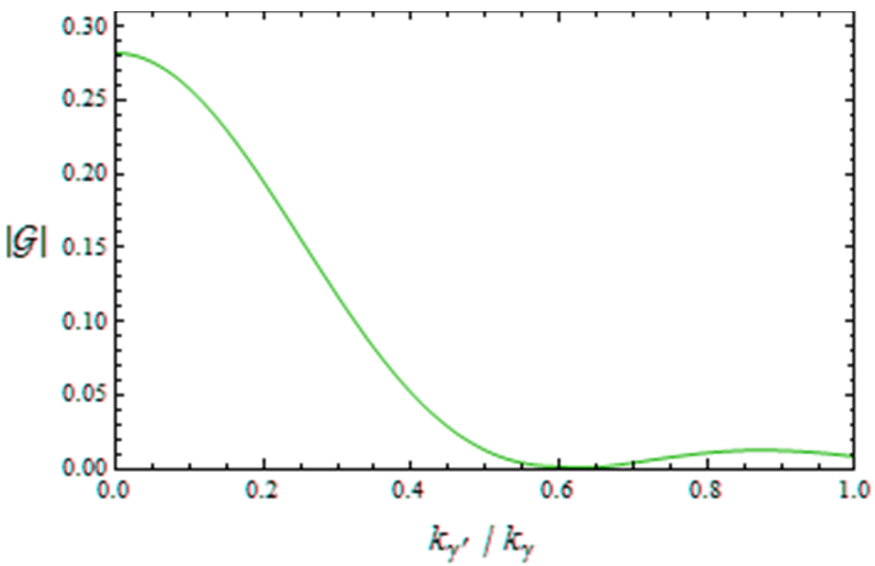
New UWA LSW experiment

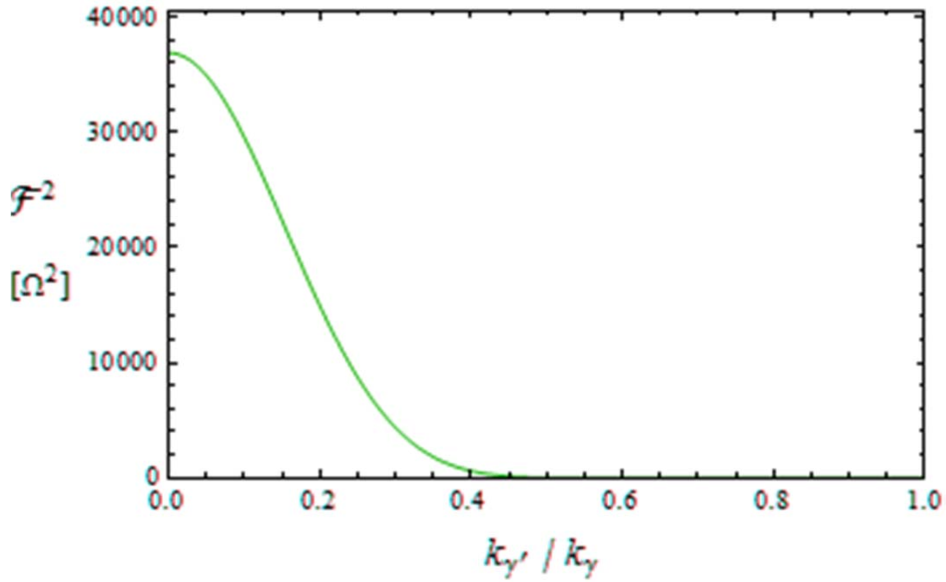
- Use a loop oscillator to drive emitter cavity.
- Mix detector output down to base-band.
- Only part of detector circuit susceptible to leakage is enclosed in chamber.



New UWA experiment

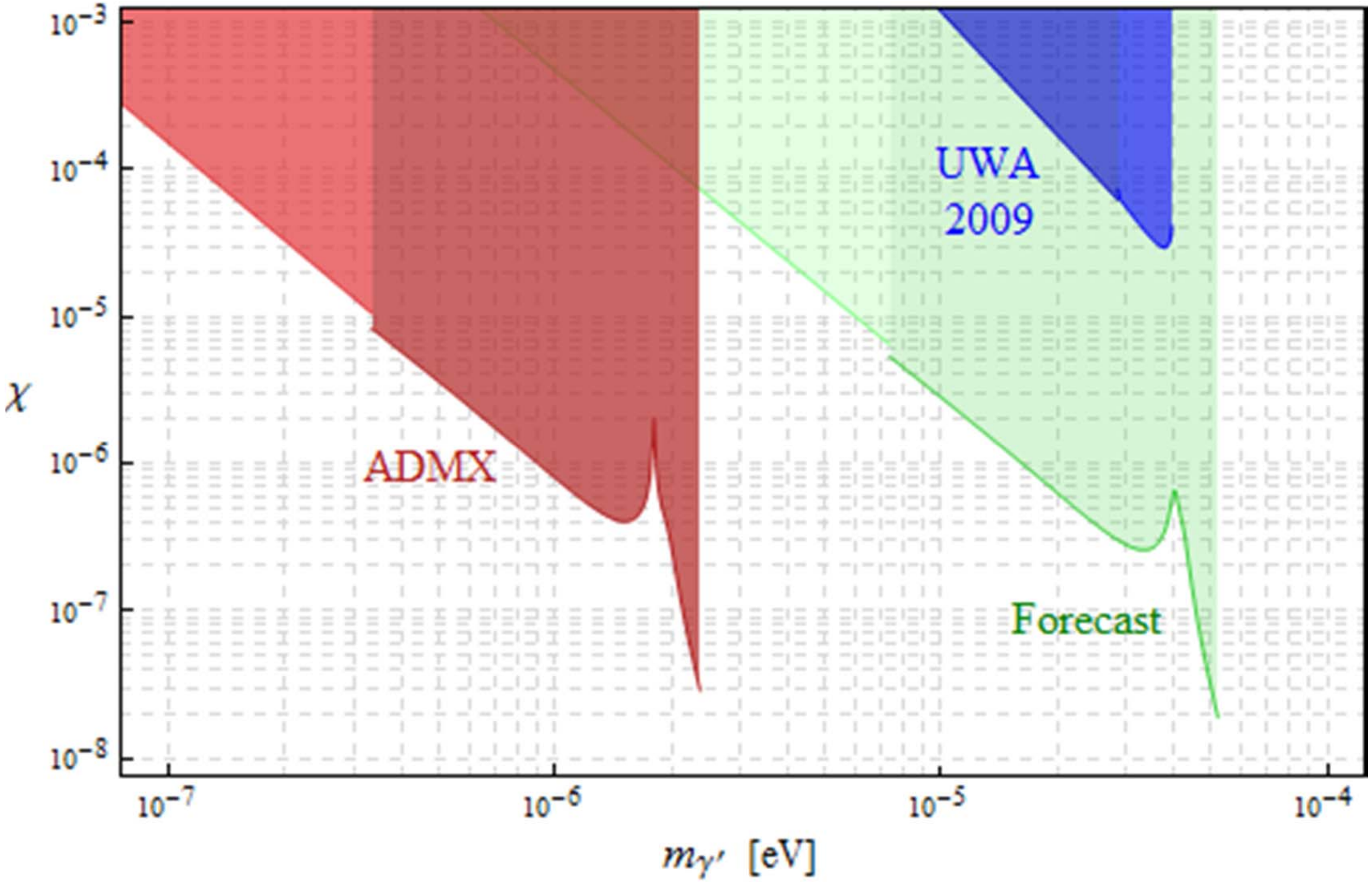
- Emitter cavity R = 20.91 mm, L = 39.65 mm.
- Will operate the $TM_{0\,2\,0}$ mode at 12.596 GHz.





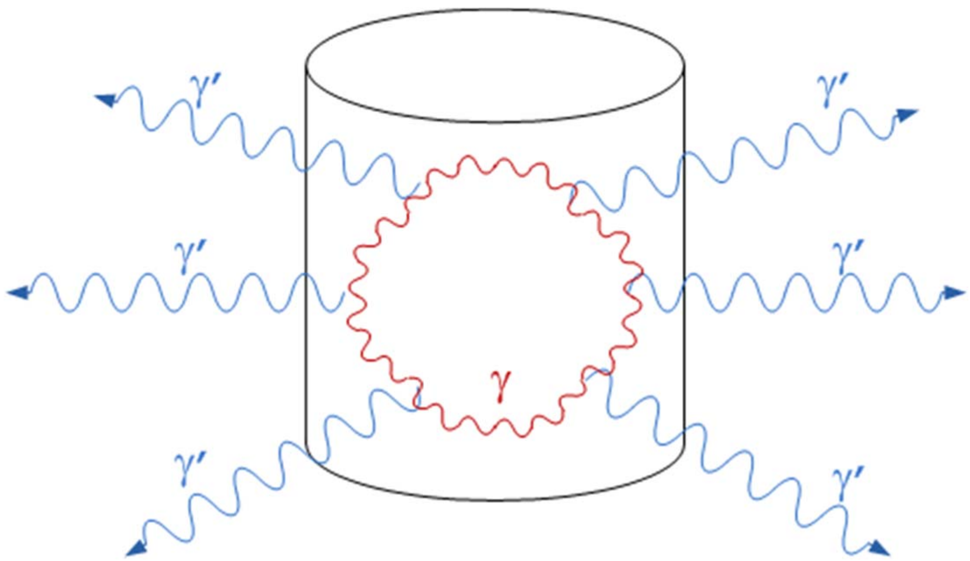
Projected sensitivity

- $\chi < 1.8 \times 10^{-8}$ at $m_{\gamma'} c^2 = 52.1\ \mu\,eV$



Hidden sector photon threshold crossing

- New experimental method using one cavity.
- No photon regeneration. Hence no microwave leakage and no resonance matching.
- Narrow γ' mass search range.



Hidden sector photon threshold

- For $\gamma - \gamma'$ mixing the photon must have an energy greater than the rest mass of the hidden sector photon.

$$hf_\gamma > m_{\gamma'} c^2$$

- Expect a drop in circulating power as the resonance frequency is tuned over the threshold frequency due to the sudden creation of hidden sector photons.

Threshold crossing model

- Define a hidden sector photon quality factor.

$$\frac{1}{Q_{\gamma'}} = \frac{1}{\omega_\gamma} \frac{P_{\gamma'}}{U}$$

$$\frac{1}{Q_0} = \frac{1}{Q_\gamma} + \frac{1}{Q_{\gamma'}}$$

Stress-energy-momentum tensor

$$\langle T^{\mu\,\nu}\rangle = \frac{1}{2}\,\Re\Bigg(-F^{\mu\lambda}\,{F^{\nu}}_{\lambda}{}^{*} - B^{\mu\lambda}\,{B^{\nu}}_{\lambda}{}^{*} - \chi\,F^{\mu\lambda}\,{B^{\nu}}_{\lambda}{}^{*}$$

$$- \chi\,B^{\mu\lambda}\,{F^{\nu}}_{\lambda}{}^{*} + \left(\frac{c}{\hbar}\,m_{\gamma\prime}\right)^{2} B^{\mu}\,B^{\nu *} - \eta^{\mu\nu}\Bigg(-\frac{1}{4}F^{\alpha\beta}\,{F_{\alpha\beta}}^{*}$$

$$- \frac{1}{4}B^{\alpha\beta}\,{B_{\alpha\beta}}^{*} - \frac{1}{2}\chi\,F^{\alpha\beta}\,{B_{\alpha\beta}}^{*} + \frac{1}{2}\left(\frac{c}{\hbar}\,m_{\gamma\prime}\right)^{2} B^{\alpha}\,{B_{\alpha}}^{*}\Bigg)\Bigg)$$

γ‘ energy flow

$$\langle {S_{\gamma\prime}}^{j}\rangle = \langle T^{j\,0}\rangle c\,|_{A^{\mu}=0} = \frac{c}{2}\,\Re\left(-B^{j\lambda}\,{B^{0}}_{\lambda}{}^{*}\right) \qquad P_{\gamma\prime} = \oiint_{|\mathbf{b}|=s} \langle \mathbf{S}_{\gamma\prime}(\mathbf{b})\rangle\cdot \mathrm{d}^{2}\mathbf{b}$$

γ energy density

$$u = \langle T^{0\,0}\rangle|_{B^{\mu}=0} = \frac{1}{2}\,\Re\left(-F^{0\,\lambda}\,{F^{0}}_{\lambda}{}^{*} + \frac{1}{4}F^{\alpha\beta}\,{F_{\alpha\beta}}^{*}\right) \qquad U = \oint_{V} u(\mathbf{a})\,\mathrm{d}^{3}\mathbf{a}$$

Hidden sector photon field

- We assume a purely standard photon field is excited within the cavity and this then produces a hidden sector photon field.

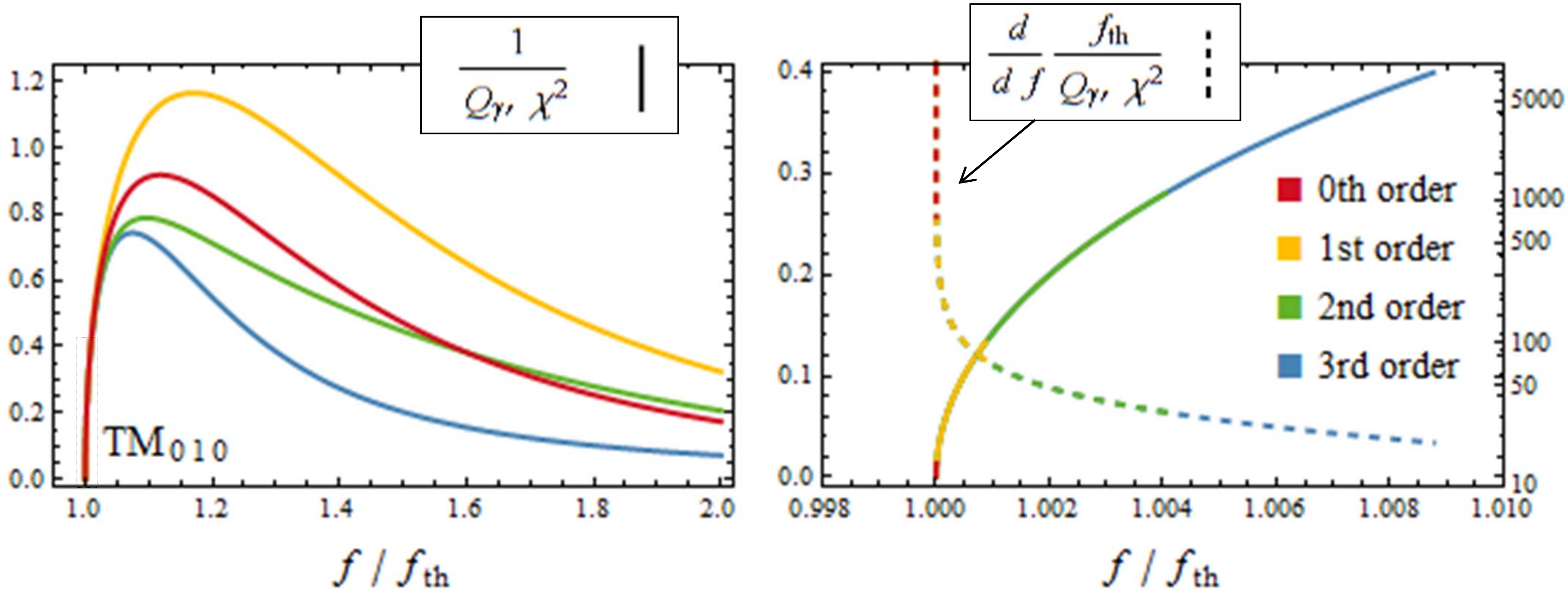
$$\tilde{B}^j(\boldsymbol{b},t) = \chi \left(\frac{c}{\hbar}\, m_{\gamma'}\right)^2 \oint_V \frac{e^{i\,k_{\gamma'}|\boldsymbol{b}-\mathbf{a}|}}{4\pi\,|\boldsymbol{b}-\mathbf{a}|} A^j(\mathbf{a},t)\,\mathrm{d}^3\mathbf{a}$$

- Taylor series expansion about |**a**|= 0.

Hidden sector photon quality factor

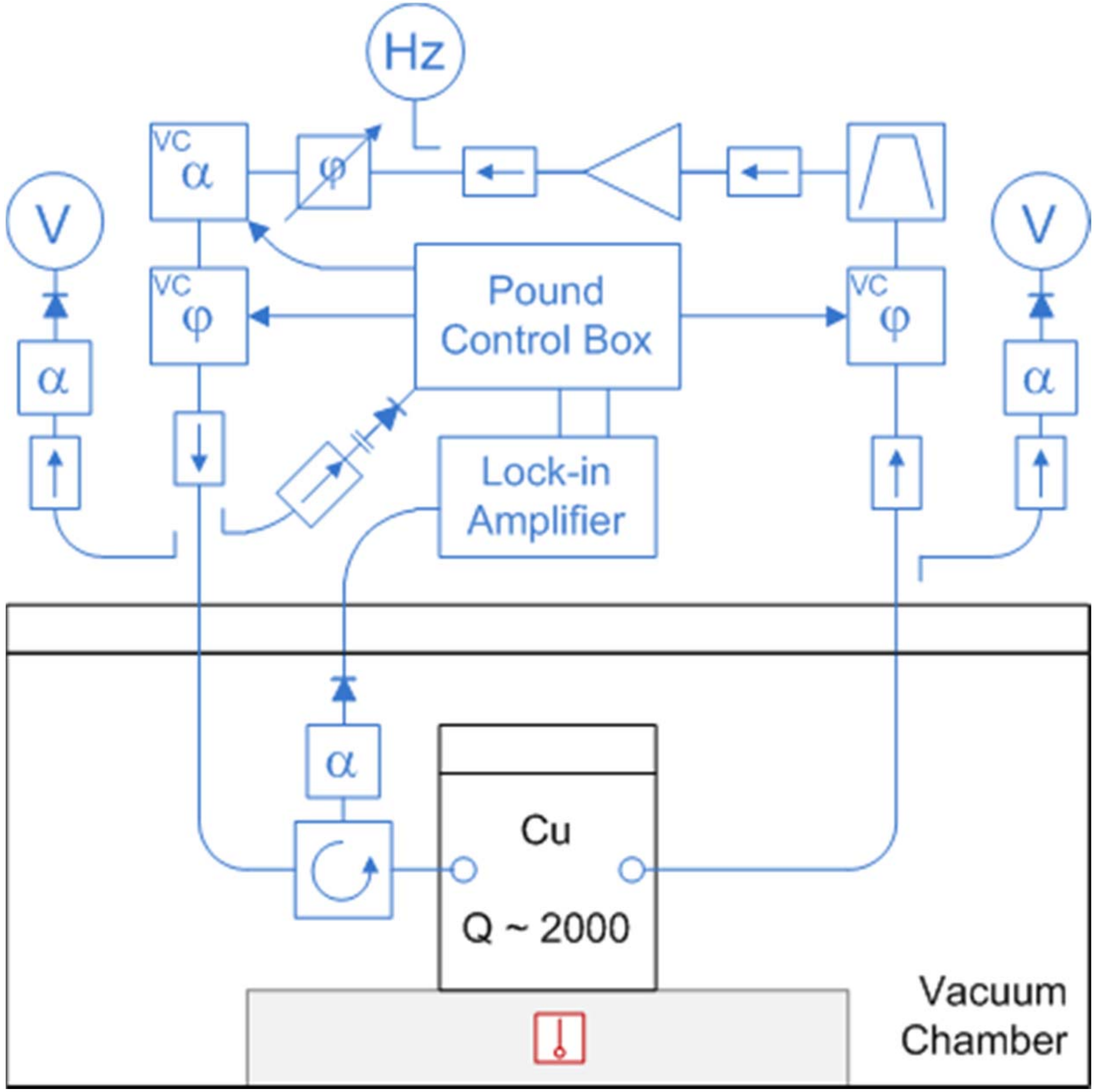
- $Q_{\gamma'}$ minimized by $TM_{0\,1\,0}$ mode in a cylindrical cavity.

$$\frac{1}{Q_{\gamma'}} \overset{0}{=} \frac{2\,\chi^2 L}{3}\left(\frac{c}{\omega_\gamma}\right)^4 \left(\frac{c}{\hbar} m_{\gamma'}\right)^4 \sqrt{\left(\frac{\omega_\gamma}{c}\right)^2 - \left(\frac{c}{\hbar} m_{\gamma'}\right)^2}$$

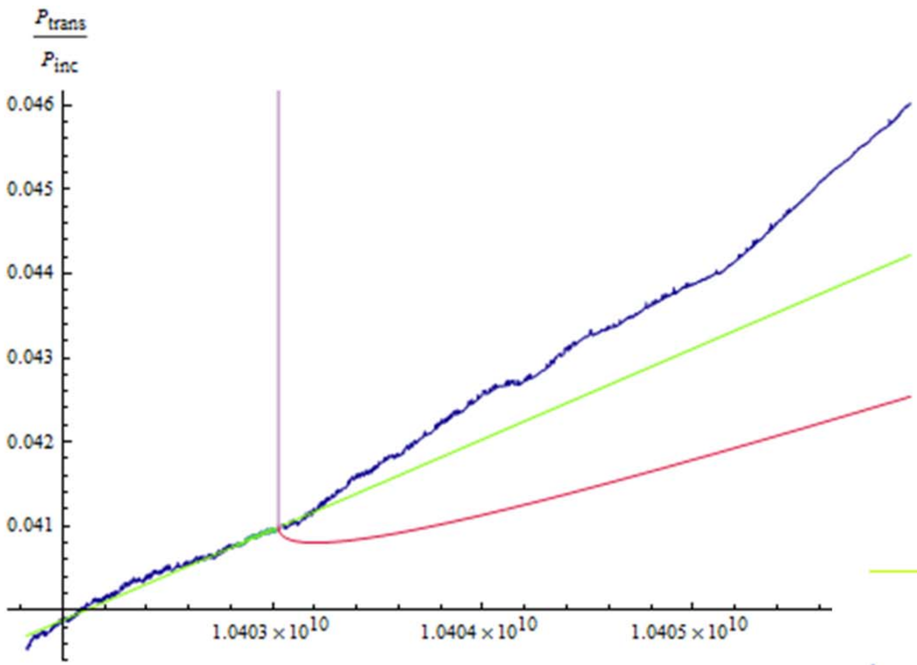


A prototype threshold crossing experiment

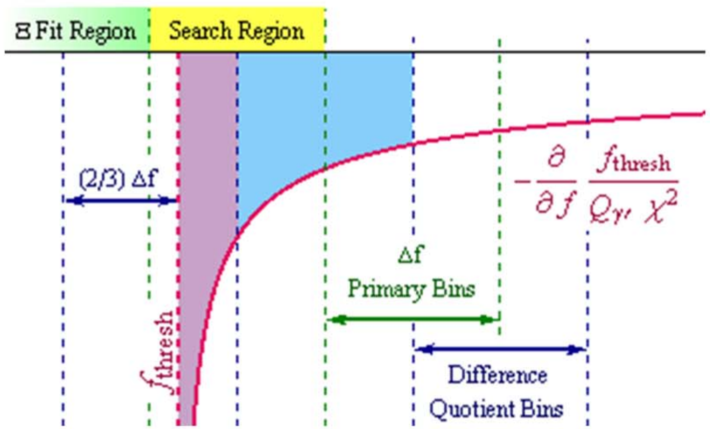
- TM_{010} mode around 10.4 GHz.
- Loop oscillator.
- Tune with temperature, 300K – 324K.
- Frequency range of 4 MHz.

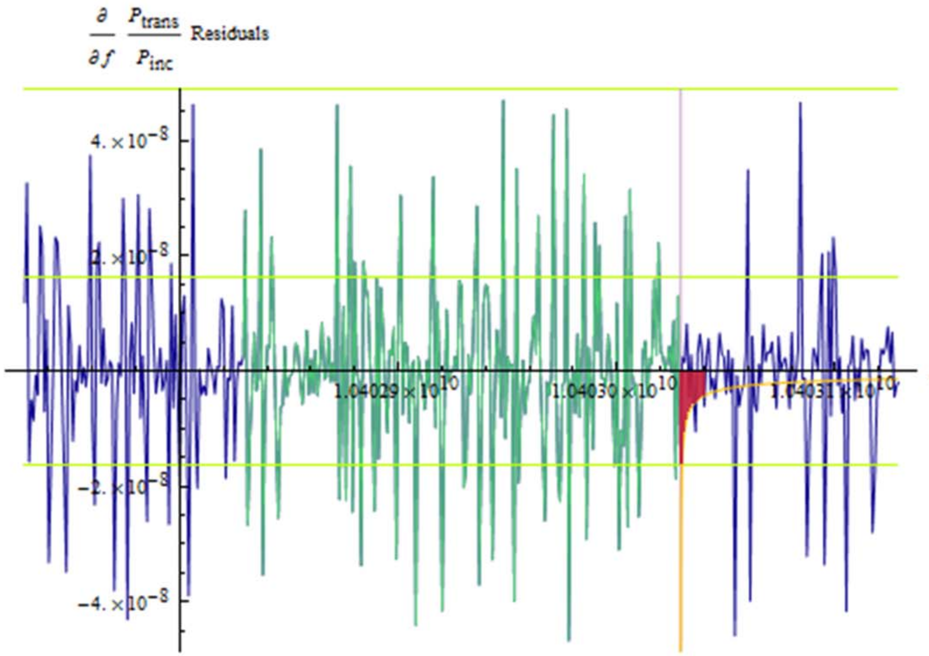


Threshold cross checking



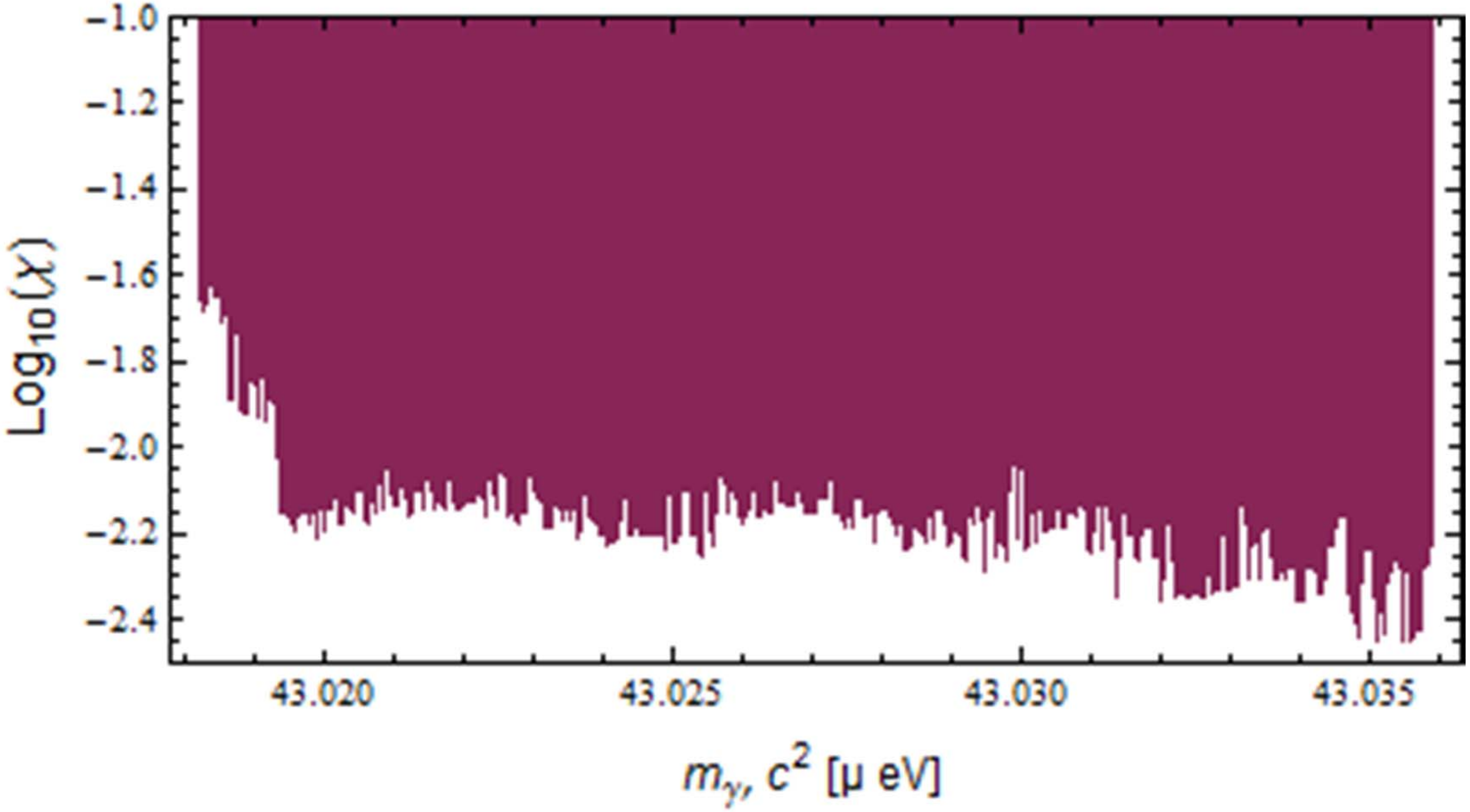
- Check each point for threshold crossing.
- Look at derivative.





Exclusion results

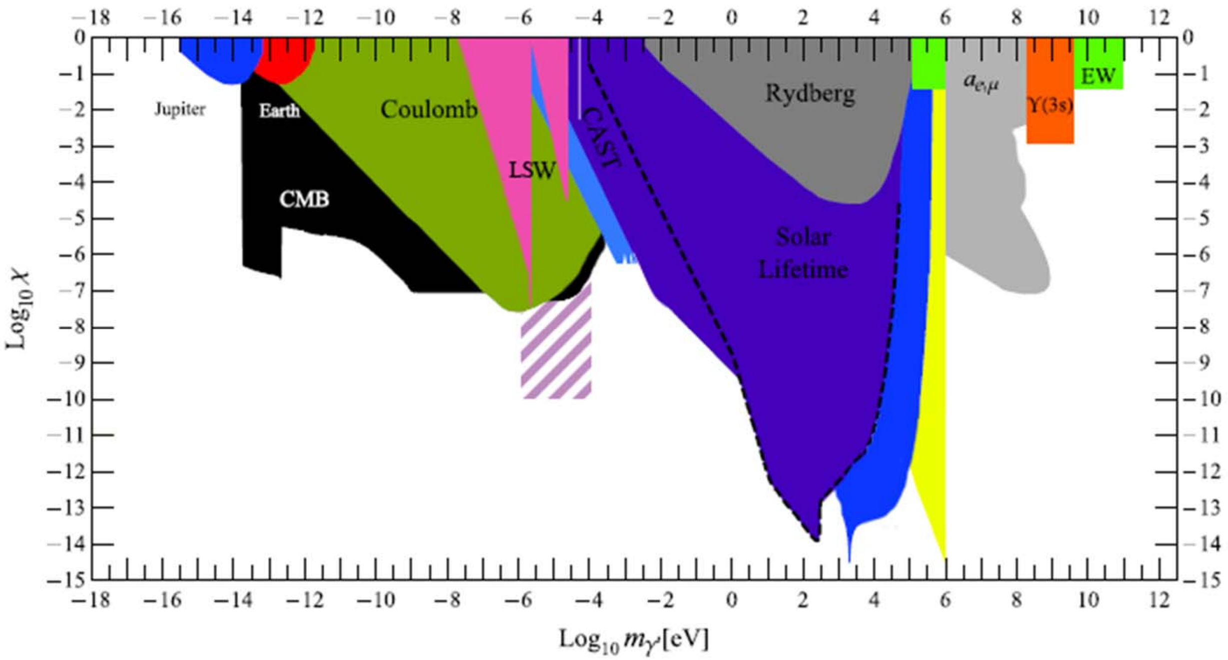
- Very narrow mass range.



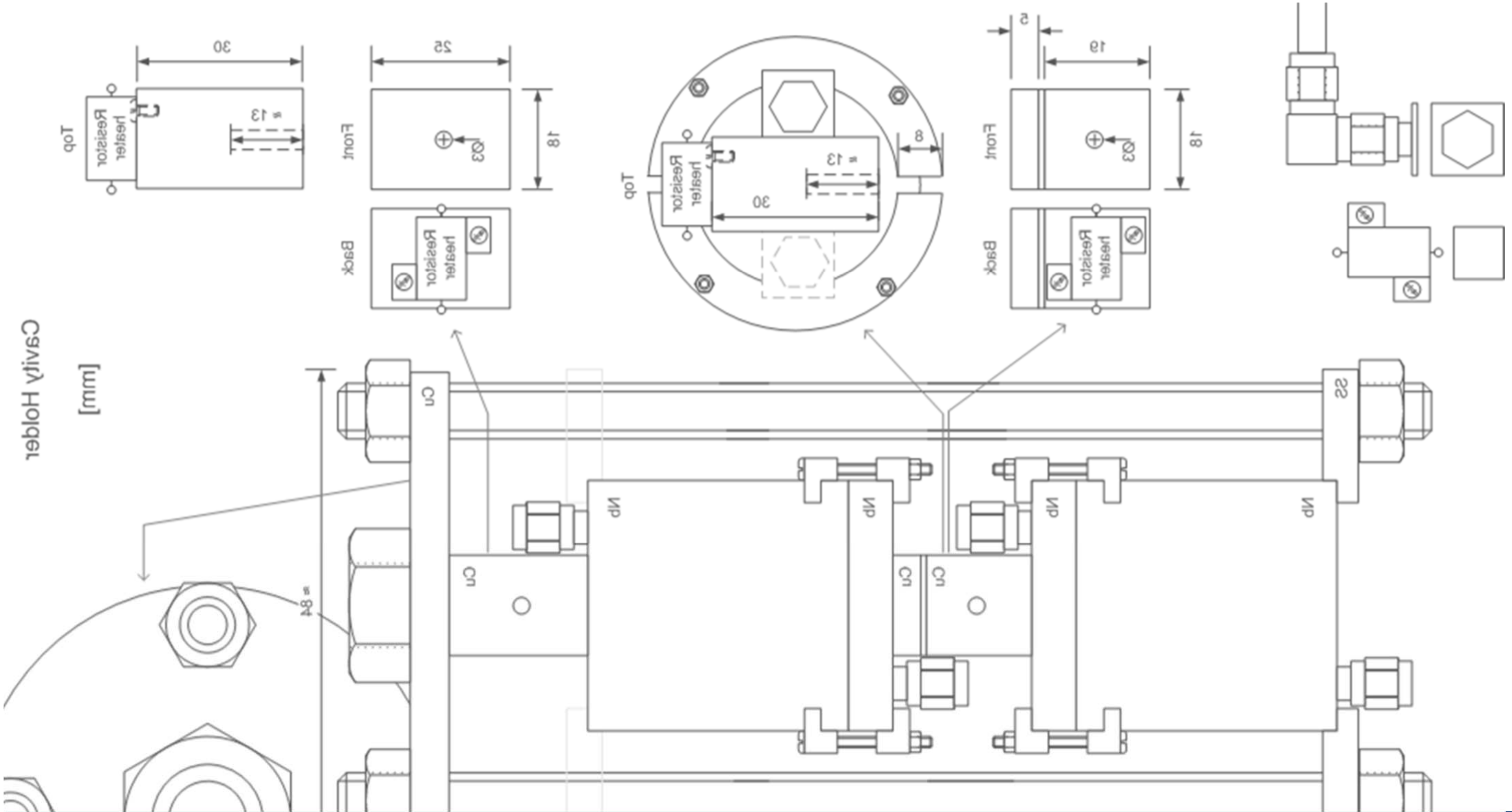
Possible threshold crossing results

- Using a higher Q cavity, stepped tuning and longer measurements.

$$\chi \propto \sqrt{\sigma}\,\sqrt{1/Q_\gamma}\,\sqrt[4]{\Delta f}\,\sqrt[4]{f_{\text{th}}}$$



End


Cavity Holder
[mm]
Top
Resistor heater
≈ 13
30
Front
Back
25
18
Ø3
8
19
5
Cu
Nb
SS
≈ 84