STAX

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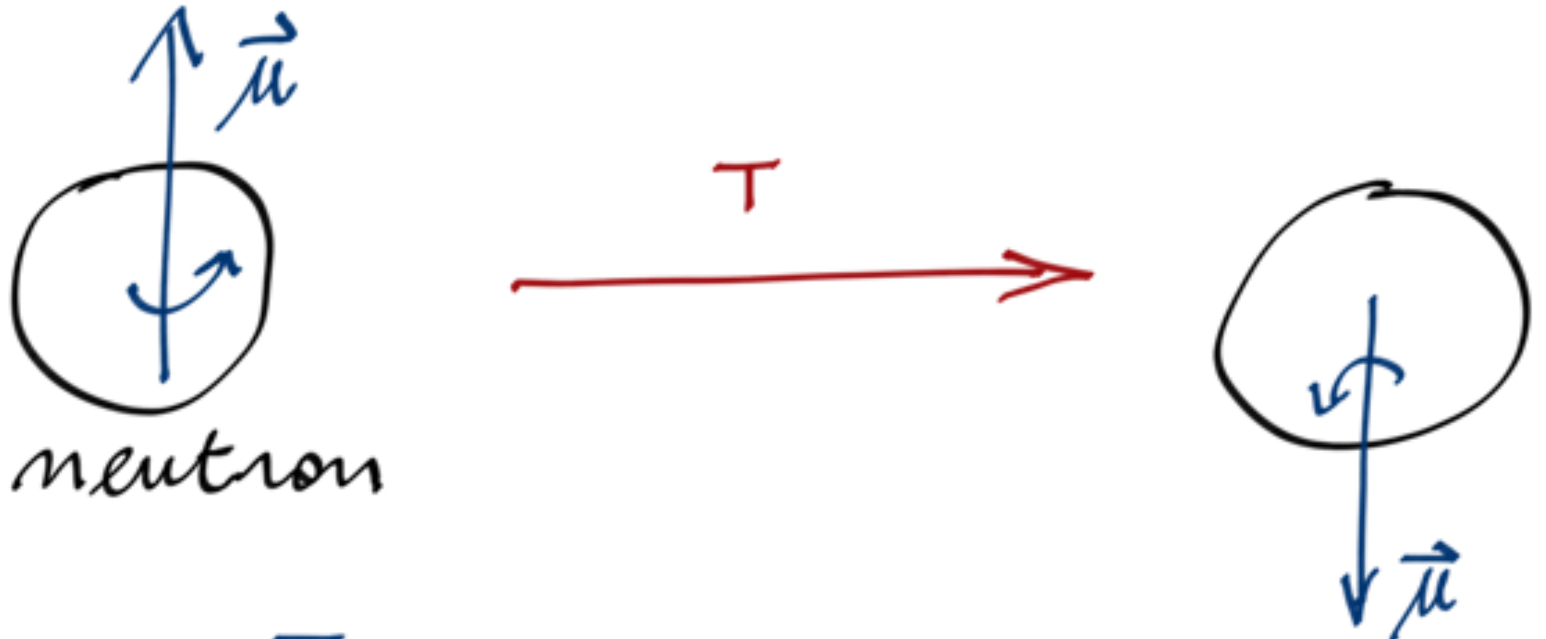
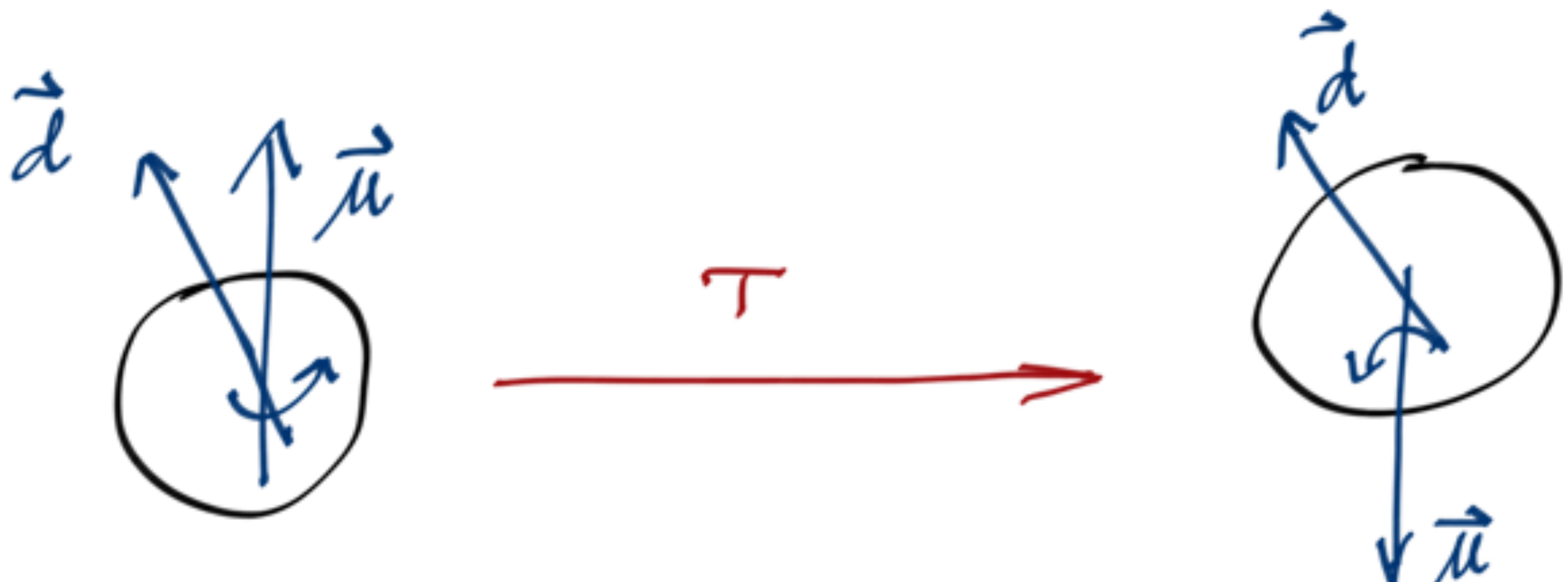


$\bar{\psi}\sigma^{ij}\psi \cdot F_{ij}$ CP-even coupling.



$\bar{\psi}\sigma^{ij}\psi \cdot \tilde{F}_{ij}$ CP-odd

$(\vec{\sigma}\cdot\vec{E})$

QCD action contains a CP odd term (euclidean)

$$i\,\theta\, q[A]$$

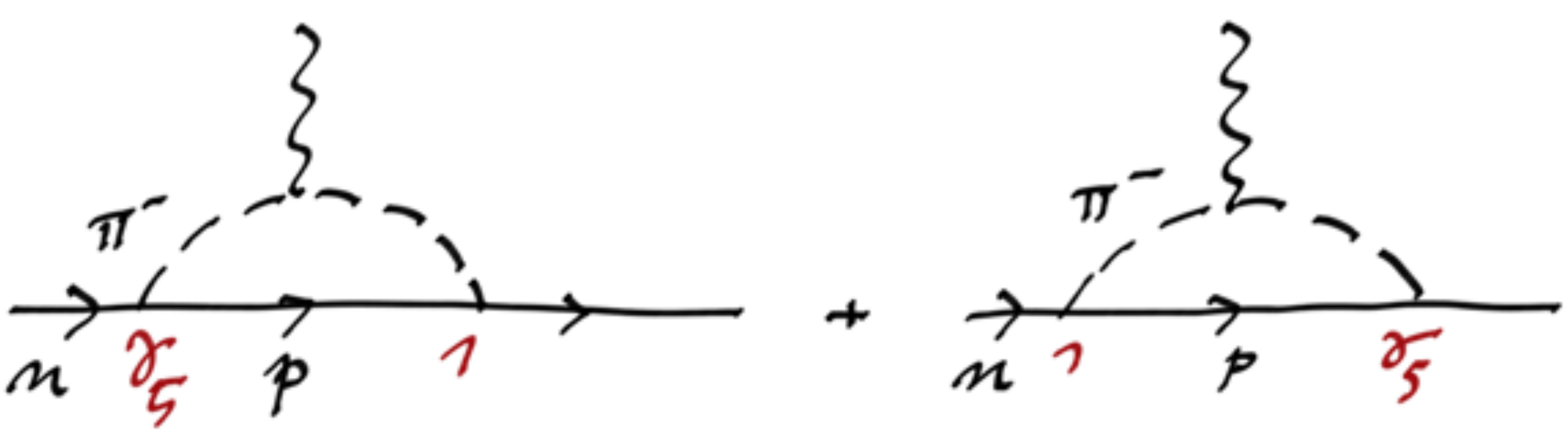
where

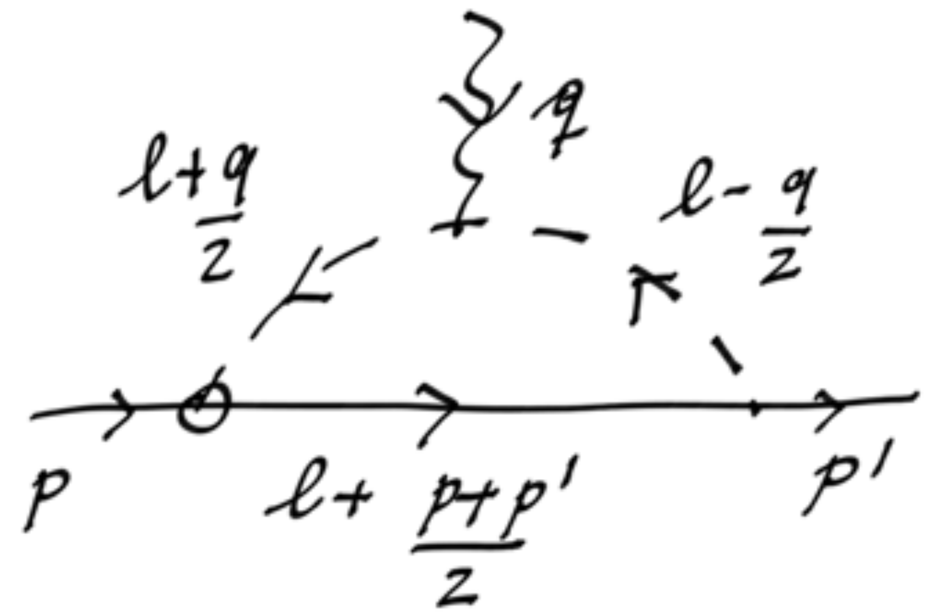
$$q[A] = \frac{g_0^2}{32\pi^2}\int F\cdot\tilde{F}\, d^4x$$

which induces a CP-odd term in the low energy theory

$$\mathcal{L}_{\pi NN} = g_{\pi NN}\,\bar{\Psi}\gamma_5\vec{\sigma}\psi\cdot\vec{\pi} + g'_{\pi NN}\,\bar{\Psi}\vec{\sigma}\psi\cdot\vec{\pi}$$

Consider a gg' amplitude





↕ separation of charge

$$\sim \left(\bar{u}(\vec{p}\,')\, i\sigma^{\mu\nu} q_\nu \gamma_5\, u(\vec{p}\,')\right) \epsilon_\mu(q)$$

$$\sim \tilde{F}_{\mu\nu}\, \bar{\psi}\, \sigma^{\mu\nu} \psi$$

$\gamma - \pi$ coupling ensures a $\ln \frac{\Lambda^2}{m_\pi^2}$ enhancement where $\Lambda = 4\pi f_\pi$

3 / 15

$$g' \simeq \frac{\theta \zeta}{f_\pi} \quad \text{where } \zeta \simeq \frac{m_u m_d}{m_u + m_d}$$

$$g \simeq \frac{g_A m_N}{f_\pi} \quad \text{where } g_A = 1.27$$

FROM THE MEASUREMENT OF d_n ($\lesssim 6\times 10^{-26}\, e\cdot cm$)

$$|\theta| < 10^{-10}$$

Either $m_u \equiv 0$ or there is a dynamical reason setting $\theta \to 0$.

$$\theta F\tilde{F} \longrightarrow (\theta + a/f)\, F\tilde{F}$$

where a is a new pseudoscalar field with a potential $V(a)$.

The minimum is at

$$a = -f\theta + \tilde{a}$$

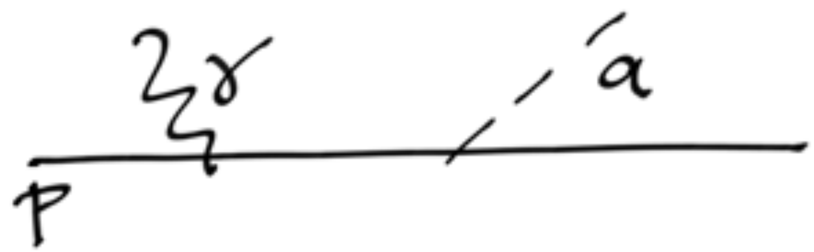
From the $\tilde{a}^2$ term one gets

$$m_a^2 = \frac{m_\pi^2 f_\pi^2}{f^2}\, \frac{m_u m_d}{(m_u+m_d)^2}$$

All axion couplings are $1/f$ suppressed (Goldstone)

- AXIONS CAN BE COPIOUSLY PRODUCED IN THE EARLY UNIVERSE — if a certain upper bound is saturated ($f \lesssim 10^{11}$ GeV), they can constitute DM.

- A lower bound ($f \gtrsim 10^{10}$ GeV) from astrophysics.



$$\text{Rate} \sim \frac{\alpha}{f^2} \cdot n_\gamma \sim \frac{\alpha}{f^2} T^3 \qquad (T_{SUN} \sim 1\,\text{MeV})$$

$$R = \text{Rate}/V \sim n_p \frac{\alpha}{f^2} T^3 \qquad \left(n_{e,p} = \frac{\#e}{R^3_{SUN}} \simeq 3 \times 10^{17}\,\text{GeV}^3 \right)$$

hydrogen

$$R = \frac{2.2 \times 10^{-28}}{f^2}\,\text{GeV}^4$$

$$R_\nu = (G_F^2 E^2)\, n_e^2 = 1.2 \times 10^{-49}\,\text{GeV}^4$$

Require $R_\nu \sim R \rightarrow f \sim 10^{10}$ GeV. $m_a \simeq 2$ meV.

AXION–γ COUPLING

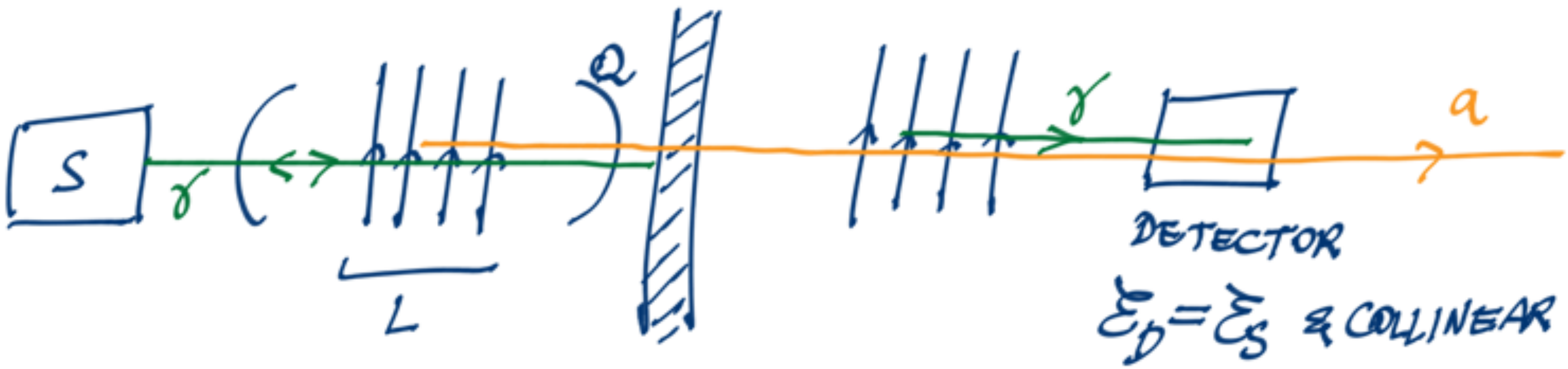
$$G_{a\gamma\gamma} = G\,\frac{\alpha}{2\pi} \simeq \frac{m_a}{m_\pi f_\pi}\,\frac{\alpha}{2\pi}$$

$G \leftarrow \frac{1}{f}$

$$T(\pi^0 \to 2\gamma) = -\frac{1}{f_\pi}\,\frac{\alpha}{2\pi}\langle k_1 e_1 \; k_2 e_2 | F \cdot \tilde{F} | \pi^0 \rangle$$

$$T(a \to 2\gamma) = \frac{f_\pi}{f}\; T(\pi^0 \to 2\gamma)$$

LIGHT-SHINING-THROUGH-WALL



$$\dot{N}_e \propto \dot{N}_\gamma \, P_{\gamma \to a} \, P_{a \to \gamma}$$

$$\propto \dot{N}_\gamma (G \cdot H \cdot L)^4 \quad \text{where } G \sim 1/f$$

with $G \lesssim 10^{-10}\,\text{GeV}^{-1}$

$$(GHL)^4 \lesssim 10^{-35}$$

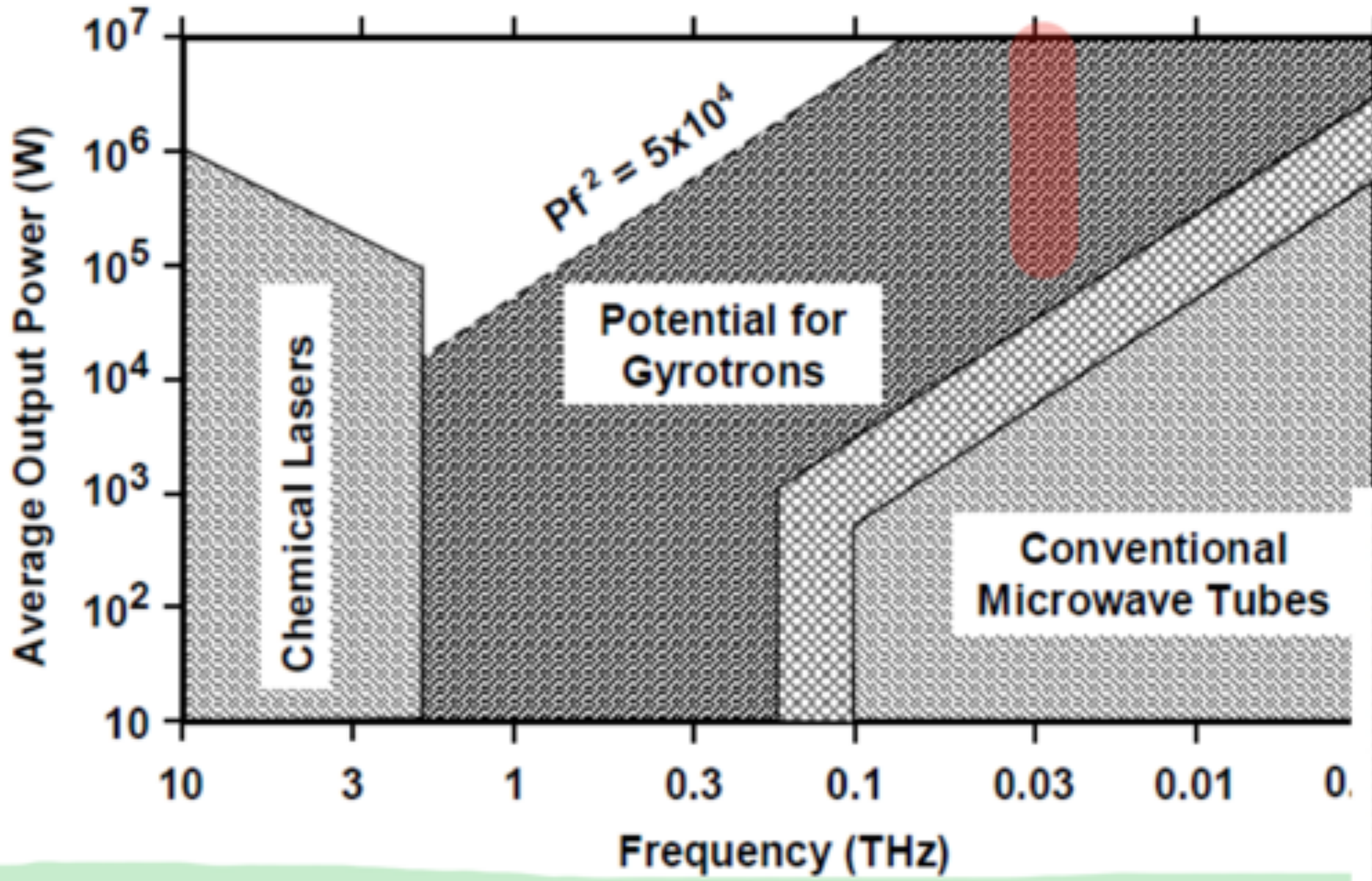
MEGAWATT GYROTRON SOURCES can produce (@30GHz)

$$\dot{N}_\gamma \simeq 10^{28}/\text{sec}$$

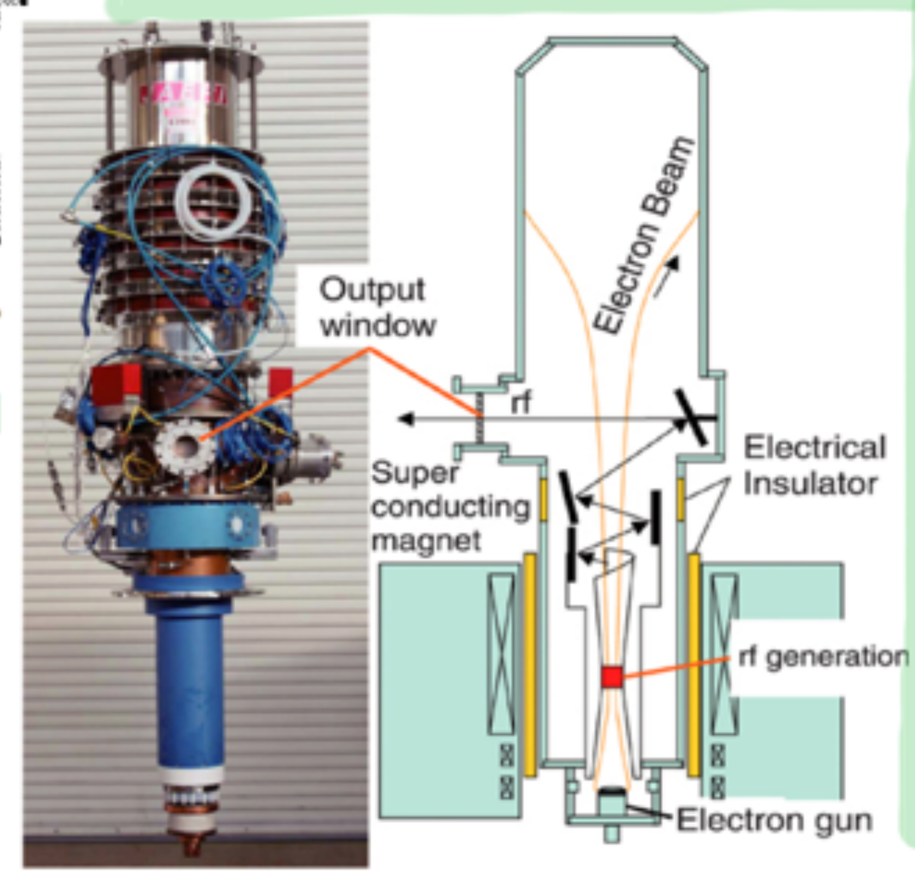
w/ continuous emission.

(10 LSW events/yr) × Q

Gyrotrons



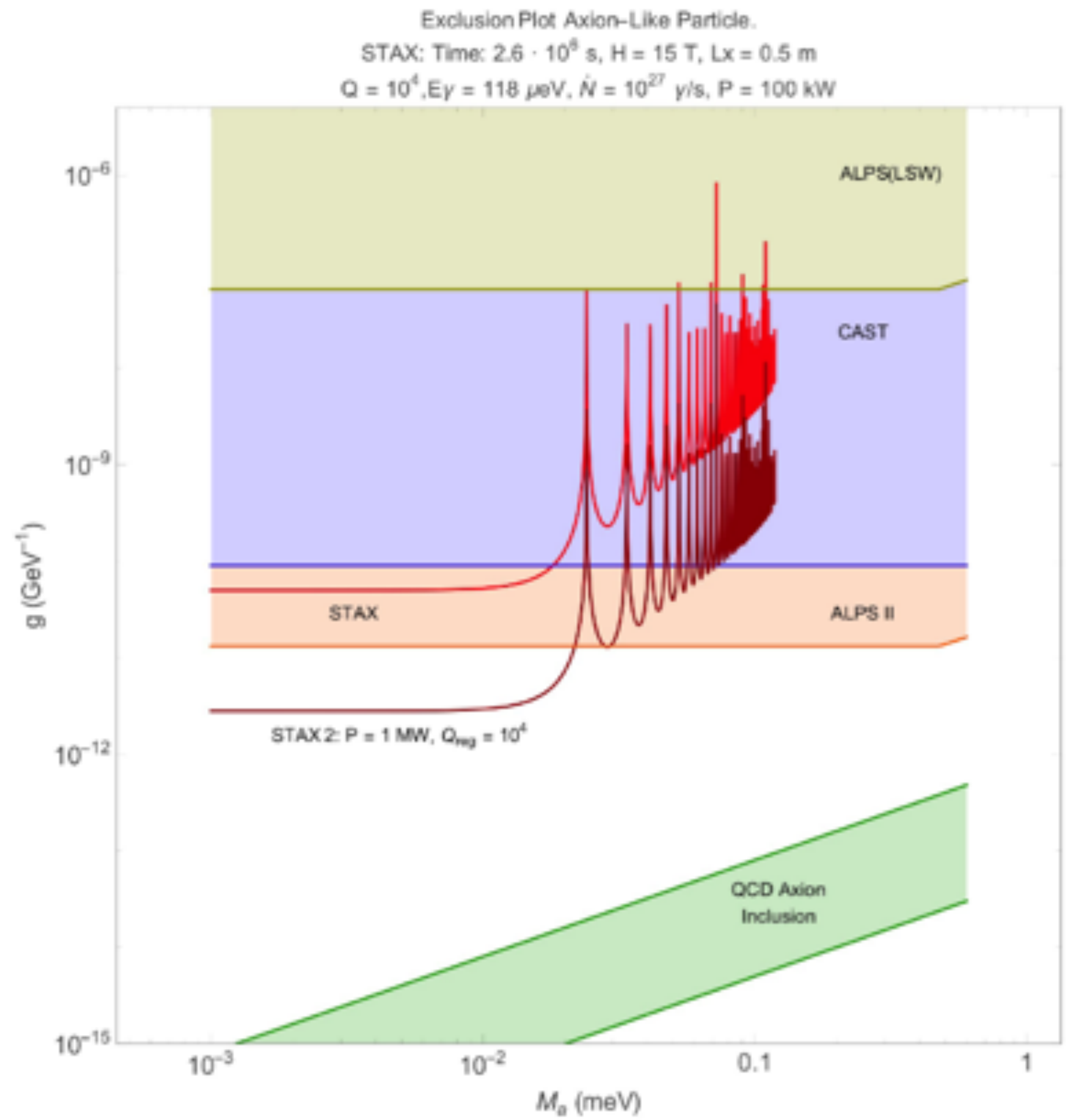
CW highly desired.



POTENTIAL REACH

$$P = G^2 H^2 \frac{\sin^2(qL/2)}{q^2} \frac{E_\gamma}{1/L + \sqrt{E_\gamma^2 - m_a^2}}$$

$$q = E_\gamma - \sqrt{E_\gamma^2 - m_a^2} - 1/2L$$



EXCLUSION @ 90% CL

IN CASE OF A NULL RESULT FOR AXIONS

$m_a \lesssim 0.02$ meV

ONE MONTH EXPOSURE AND ZERO DARK COUNTS

STAX @ 100 kW

STAX2 @ 1 MW + REG. Q.

L. CAPPARELLI et al.
PHYS. DARK. UNIV. 12 (2016) 37

FABRY-PEROT CAVITIES

$$P \sim (GH)^4 \cdot L^2 \cdot L^2$$

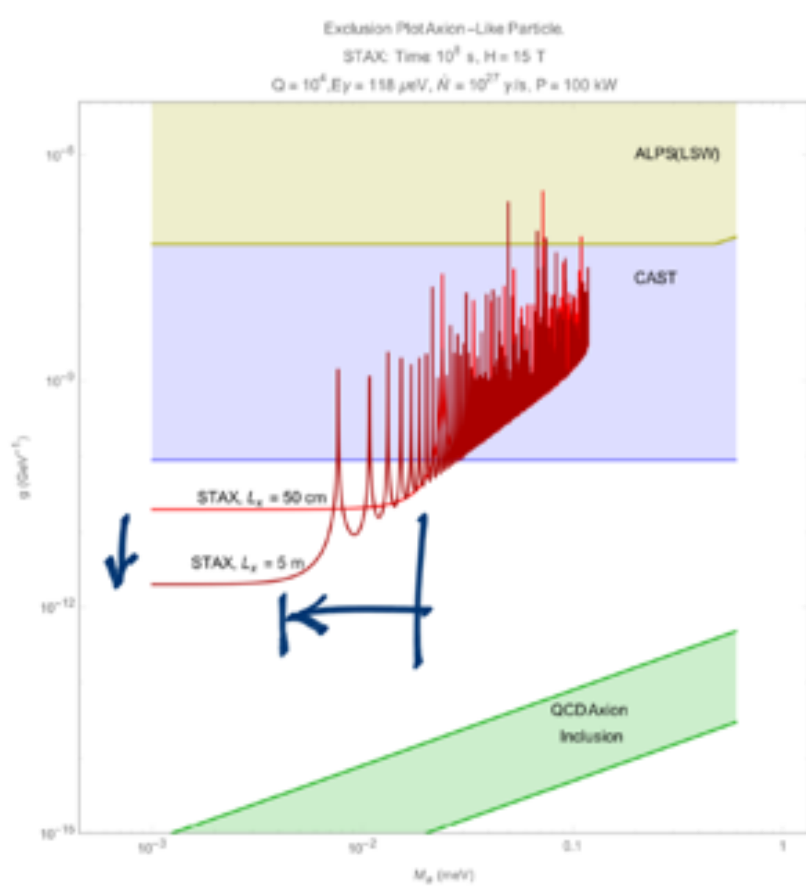
$$\downarrow$$

$$Q L^2 \quad (Q \sim 10^5 \text{ in MW})$$

THIS ALLOWS TO EXPLORE G VALUES SMALLER BY $Q^{-1/4}$

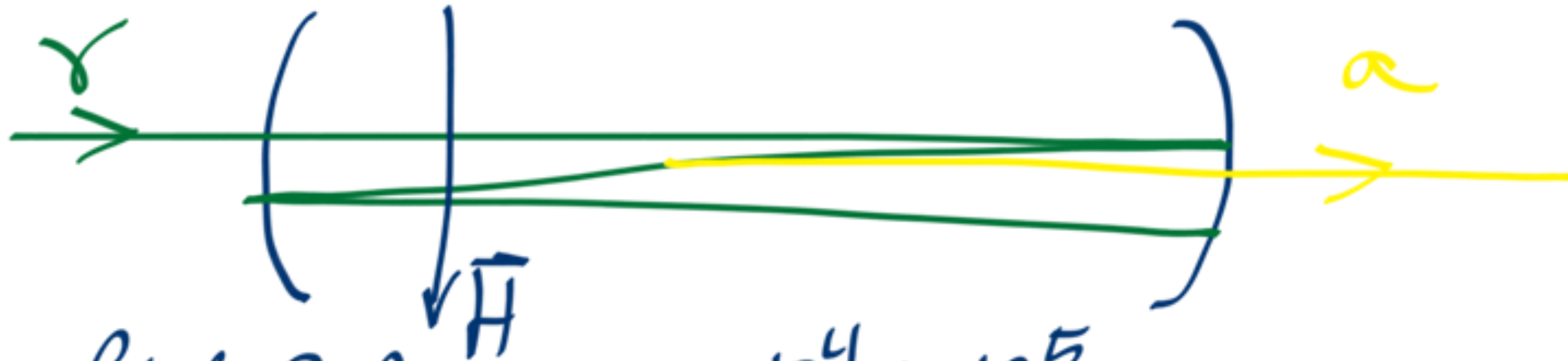
Someone suggests $Q^{-1/2}$ by setting a 'regeneration' cavity.

MAKING L LONGER MEANS THAT THE ONSET OF OSCILLATIONS SHIFTS TO SMALLER VALUES BY $1/\sqrt{x}$ IF $L \to xL$



Some Numbers

Improvements are possible w/ FP cavities



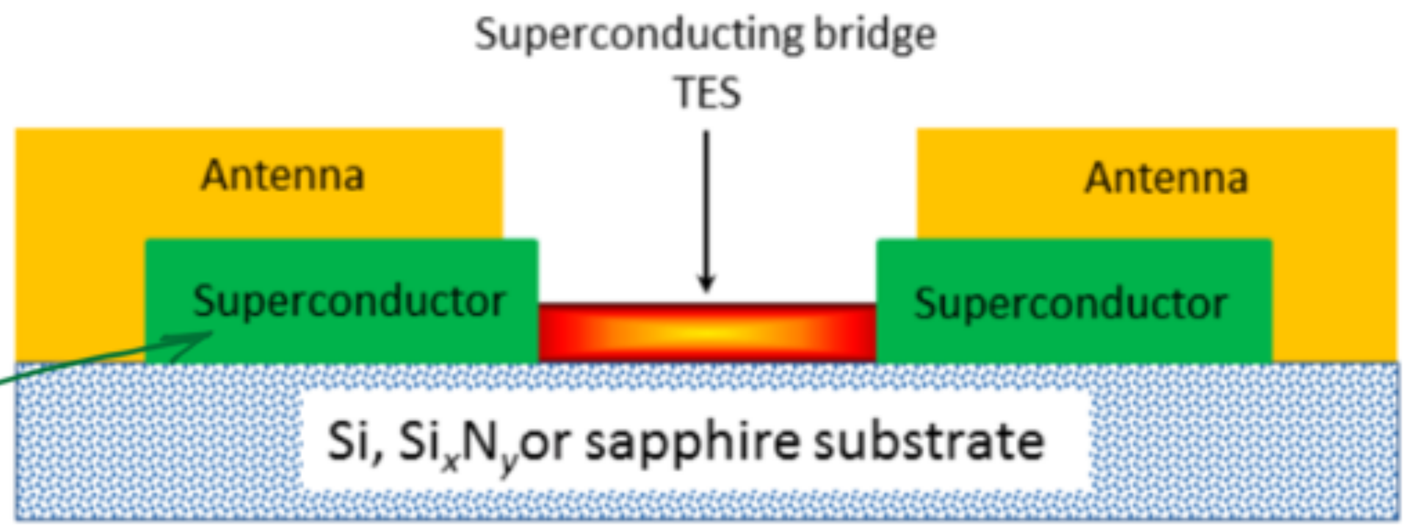
very high Q for mw. ~ $10^4 \div 10^5$

Parameter	ALPS	STAX	g_{ALPS} / g_{STAX}	STAX II	g_{ALPS} / g_{STAXII}
Laser Power	0.8 W	100 kW	18.8	1 MW	188
Photon Energy	2.327 eV	124 μeV	11.7	124 μeV	11.7
Cavity Q-factor	55.0	10^4	3.7	10^8	37
$H * L_x$	22 T m	7.5 T m	0.3	7.5 T m	0.3
Detection Efficiency	0.9	1.0	1.0	1.0	1.0
Detector Noise	$1.8\ 10^{-3}\ sec^{-1}$	$10^{-9}\ sec^{-1}$	34.0	$10^{-9}\ sec^{-1}$	34
Combined Improvement			~ 10^4		~ $8x10^5$

30 GHz γ-DETECTION

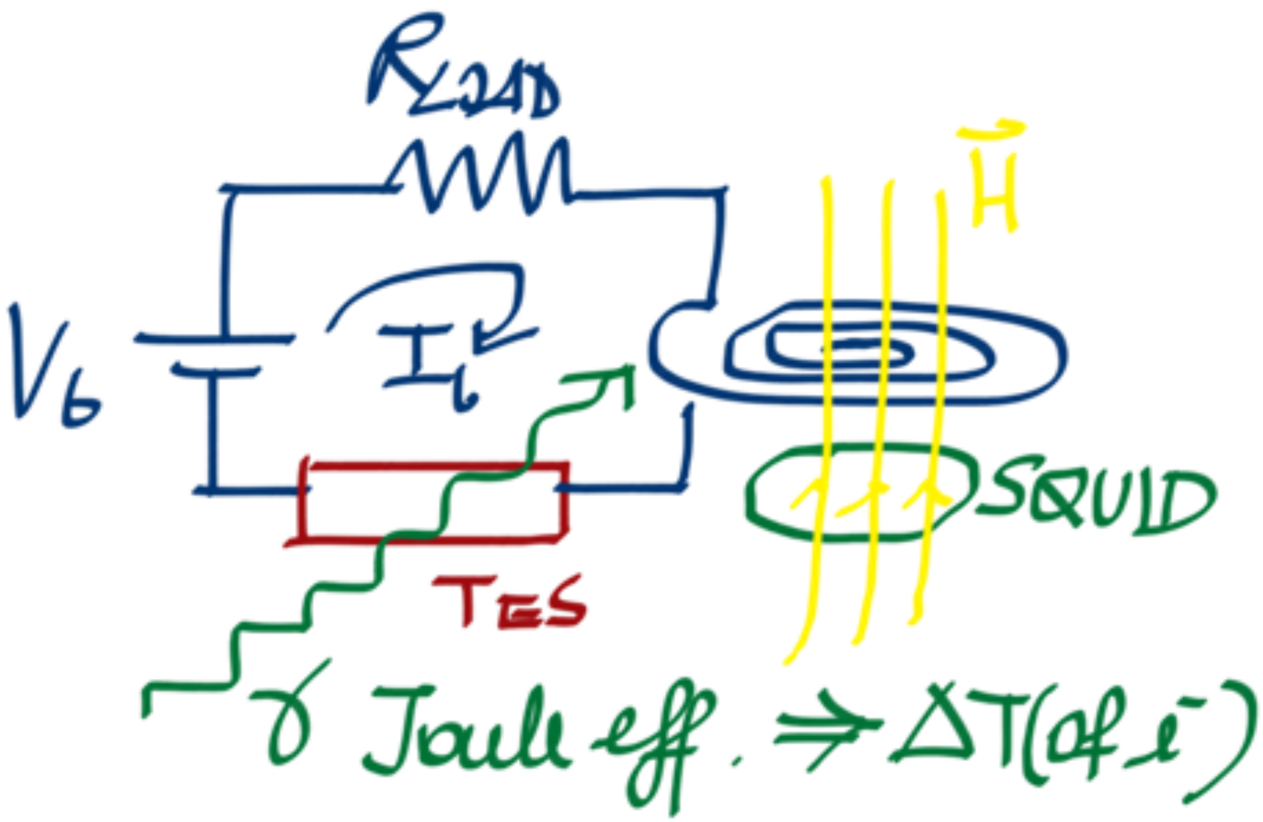
1. SINGLE-γ detection ← CRYOGENIC (10 mK)
2. MW screening
3. ...

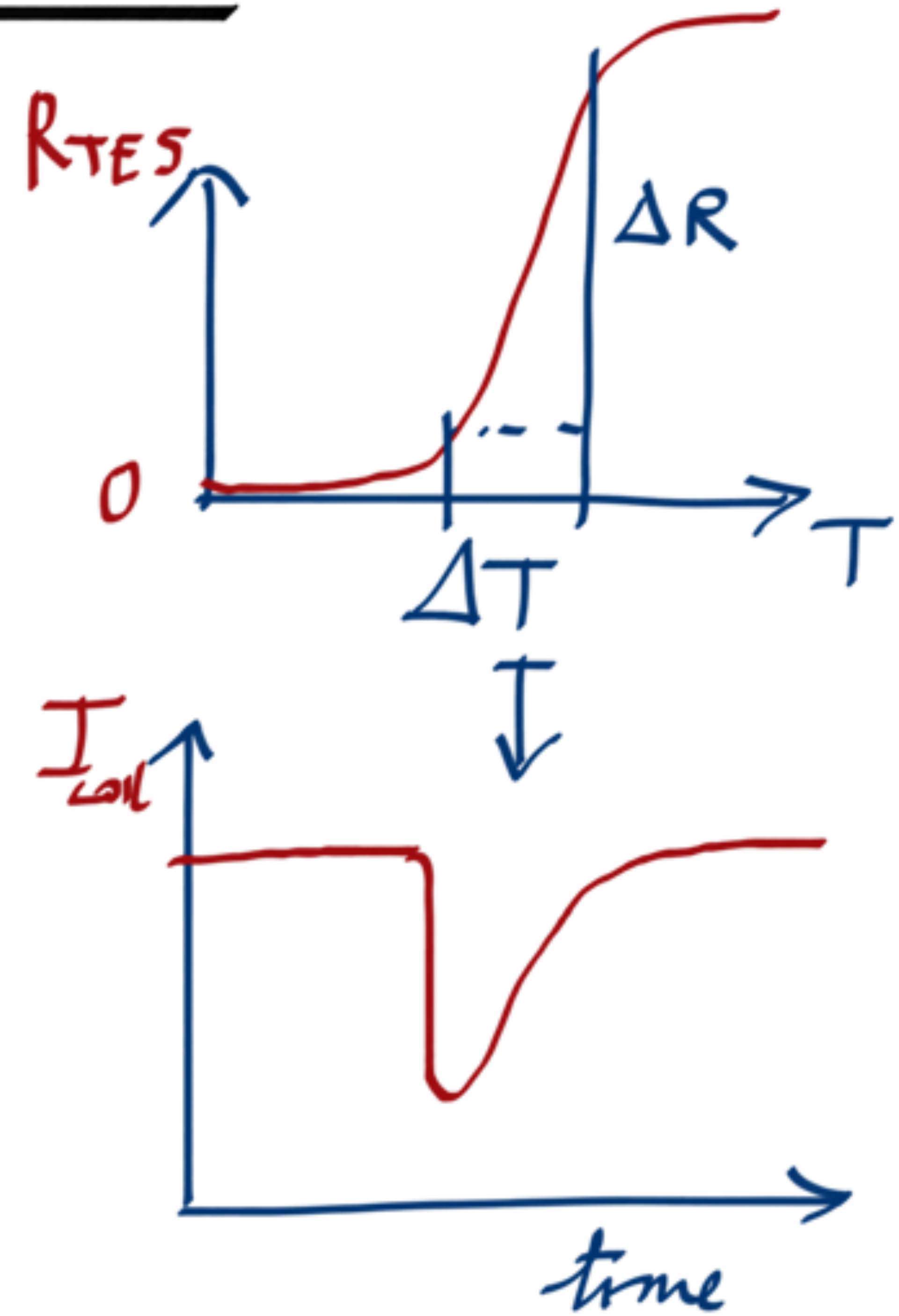
⋮



- $T_c < 20$ mK
- α-W, Ti-Au, Ti-Cu
- $V \sim 10^{-3} \div 10^{-4}\ \mu m^3$
- low noise SQUID readout.

EYE SCHEME





$\tau(e^- - \phi \,@\, 10\,mK) \gtrsim 0.1\,sec$

Read a voltage on SQUID

R&D on $\Delta T, \Delta R, \Delta V_{SQUID}$ @ 30 GHz & 10 mK.

TES

TES work @ T slightly below T_c.

$V_{TES} \simeq 2 \times 10^{-22}\, m^3$ @ 10 mK

$1\gamma(30\,GHz) \to \Delta T_e \simeq 40\, mK$

Estimate & engineer ΔI _

__ SQUID SPECTRAL NOISE DENSITY

$$\frac{1\,pA}{\sqrt{Hz}}$$

__ to be multiplied by the det. passband$^{1/2}$

$$\approx \sqrt{100\,Hz}$$

Oscillations

Occur when $qL \ll 1$ fails.

$$q \simeq \frac{m_a^2}{2E_\gamma} \longrightarrow \frac{(m_a - m_\gamma^*)^2}{2E_\gamma}$$

Shifts the onset of oscillations to higher m_a values.

Example (CAST)

Introduce He gas in the cavity, γ will have an effective velocity $c/n(\omega) = |\vec{k}|/E_\gamma$

$\Rightarrow m^* > 0$. N.B. CAST uses X-rays.