CAST

Searching for Solar Axions

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Outline

- The CAST Experiment
  - Motivation
  - Description
- CAST First Phase
  - Description
  - Results
- CAST Second Phase
- STATUS

Motivation

The Strong CP-Problem

QCD predicts breaking of CP symmetry in strong interactions

BUT: This has never been observed in any experiment so far!

$$L_{CP} = \theta \frac{\alpha_S}{8\pi} G\tilde{G}$$

Two different contributions here: QCD vacuum and EW quark mixing

$$\left[\tilde{G}_{\mu\nu} = \frac{1}{2} \varepsilon_{\mu\nu\rho\sigma} G^{\rho\sigma} \right]$$

CP violation predicts an electric dipole moment for the neutron… $|d_n| = A|\theta| \times 10^{-15} e \times cm$

But experiment says… $|d_n| \leq 0.63 \times 10^{-25}\ e \times cm$

This implies a parameter for the QCD vacuum of $|\theta| \leq 10^{-9}$

Strong CP-Problem: Why is $|\theta|$ so small?

Motivation

R.D.Peccei and H.R Quinn. PRL, 38 (1977) 1440

Axion ⇒

$$L_a = \frac{1}{2}\left(\partial_\mu a\right)^2 - \frac{\alpha_S}{8\pi f_a} a G\tilde{G}$$

axion – gluon vertex

θ absorbed in the definition of a

- a → qq transitions
- a – π^0 mixing
- axion mass > 0

$$m_a \simeq 0.6eV \frac{10^7 GeV}{f_a}$$

Pseudo-Goldstone boson resulting from the spontaneously broken symmetry introduced by Peccei-Quinn global chiral symmetry $U_{PQ}(1)$ to enforce strong CP conservation.

AXION PROPIERTIES:

- ***Neutral pseudo-scalar Goldstone boson***
- ***Very feeble interaction of light axions with matter, practically stable***
  - ***Mass (from a-π_0 mixing):*** $m_a \approx 0.6\,\text{eV}\,\frac{10^7\,\text{GeV}}{f_a}$

    $f_a > 10^7$ GeV ***(Astrophysical Argument, HB)***
  - ***Coupling to photons:*** $L_{a\gamma\gamma} \approx g_{a\gamma\gamma}\left(\vec{E}\cdot\vec{B}\right) a$ ***, where*** $g_{a\gamma\gamma} \approx \frac{\alpha}{2\pi f_a} < 10^{-10}\,\text{GeV}^{-1}$
  - ***Mean life time*** $\tau_a \approx 10^{17}$ yr ***for*** $m_a = 1\text{eV}$ ***i.e.*** $\tau_a > t_{Universe}$

Motivation

Axion

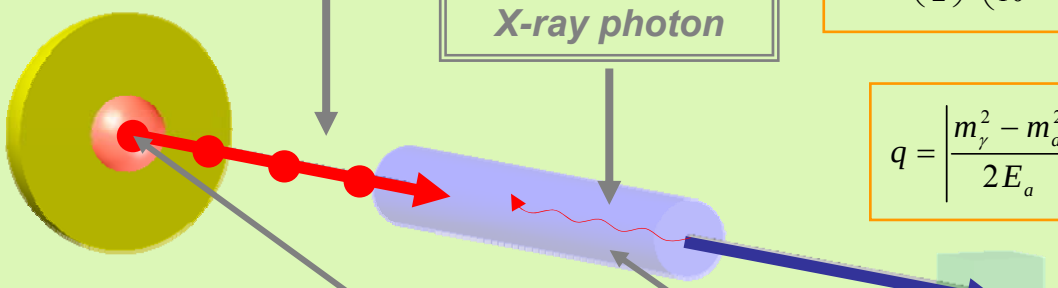
500 sec. flight time

$$\frac{d\Phi(E_a)}{dE_a} = 6.02x10^{10}\left(\frac{g_{a\gamma\gamma}}{10^{-10}GeV^{-1}}\right)^2 cm^{-2}s^{-1}keV^{-1}E_a^{2.481}e^{-E_a/1.205}$$

$$P_{a\to\gamma} = \left(\frac{B}{2}\right)^2\left(\frac{g_{a\gamma\gamma}}{10^{-10}GeV^{-1}}\right)^2\frac{1}{q^2+\Gamma^2/4}\left[1+e^{-\Gamma L}-2e^{-\Gamma L/2}\cos(qL)\right]$$

$$q = \left|\frac{m_\gamma^2 - m_a^2}{2E_a}\right| \qquad m_\gamma[eV] = \sqrt{0.02\frac{P[mbar]}{T[K]}}$$

X-ray photon



Solar Core

Magnet

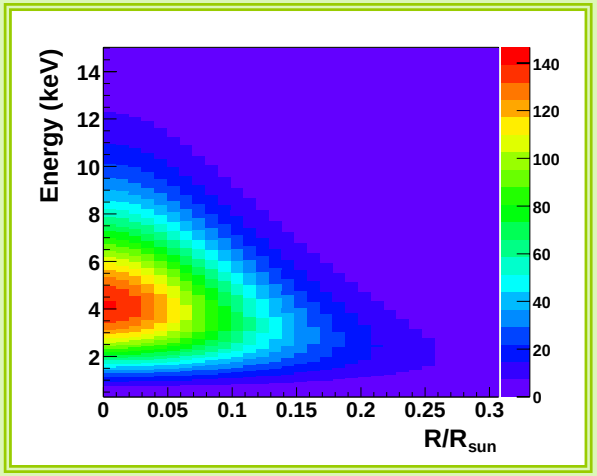
X-ray Detector

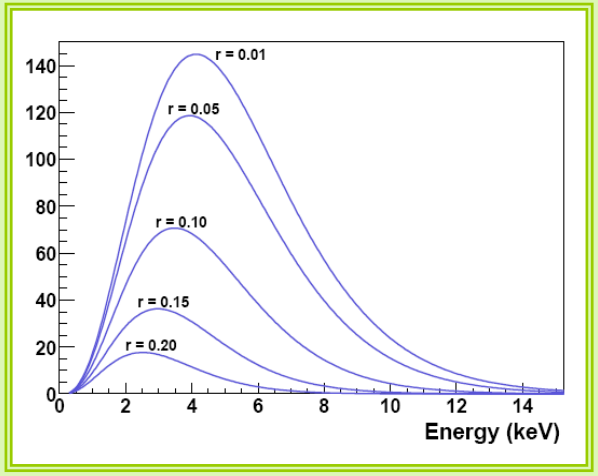
K. Van Bibber et al. Phys. Rev. D 39 (1989)

H. Primakoff. Phys. Rev. 81 (1951) → $L_{a\gamma} = g_{a\gamma}(E.B)a$

Motivation

SOLAR AXION SURFACE LUMINOSITY





$$r = \frac{R}{R_{SUN}}$$

$$units[cm^{-2}s^{-1}keV^{-1}]$$

AXION FLUX AT THE EARTH SURFACE

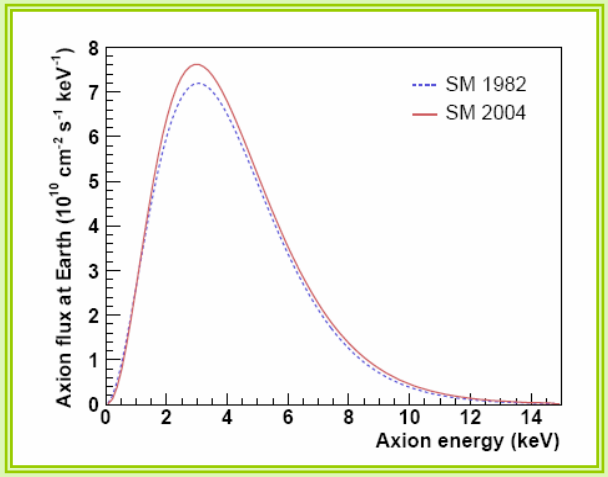
J.N. Bahcall and M.H. Pisonneault PRL 92 (2004) 121301

↓

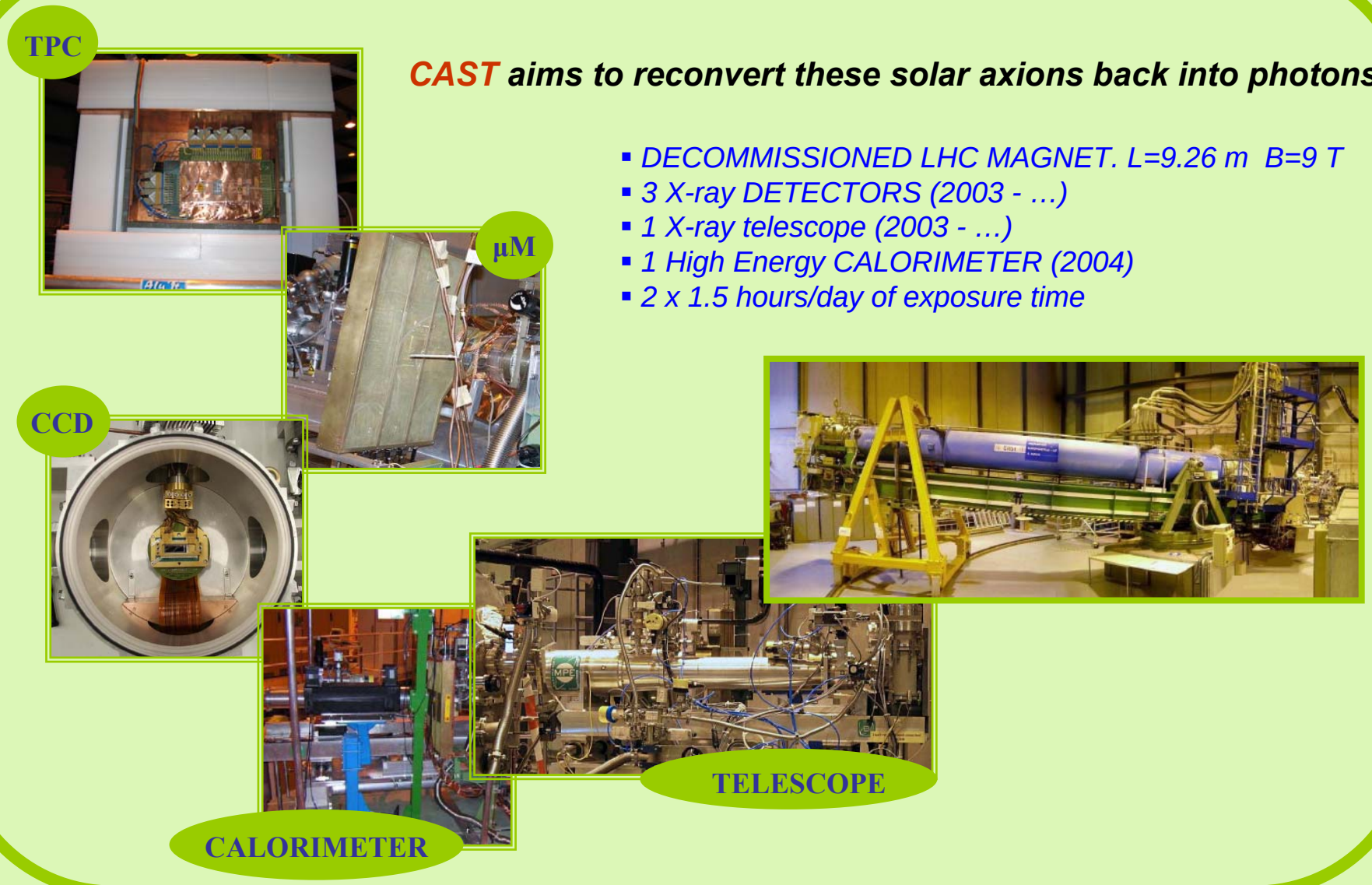
P.D.Serpico and G.G. Raffelt. CAST Internal Report (2005)

↓

$$\frac{d\Phi(E_a)}{dE_a} = 6.02x10^{10}\left(\frac{g_{a\gamma\gamma}}{10^{-10}GeV^{-1}}\right)^2 cm^{-2}s^{-1}keV^{-1}E_a^{2.481}e^{-E_a/1.205}$$



CAST First Phase. Description



***CAST** aims to reconvert these solar axions back into photons*

- *DECOMMISSIONED LHC MAGNET. L=9.26 m B=9 T*
- *3 X-ray DETECTORS (2003 - …)*
- *1 X-ray telescope (2003 - …)*
- *1 High Energy CALORIMETER (2004)*
- *2 x 1.5 hours/day of exposure time*

CAST First Phase. Description

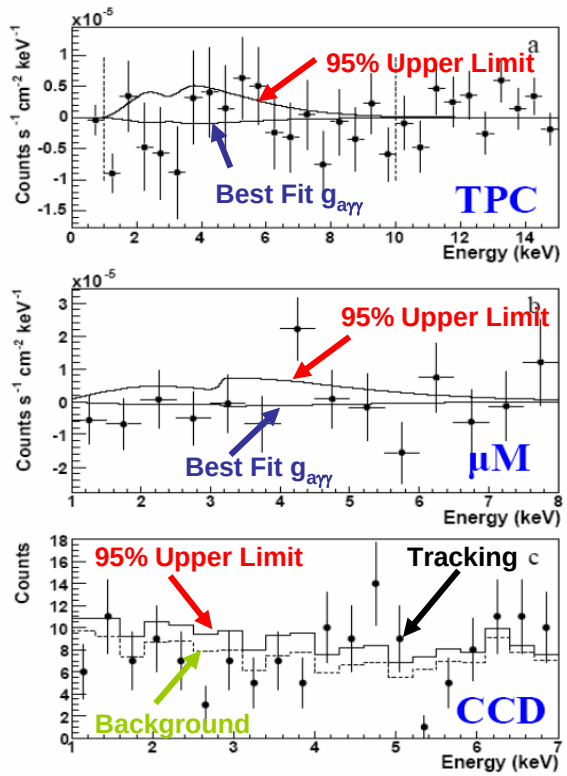
SIGNAL

⇩

Excess of X-ray in TRACKING over BACKGROUND

⇩

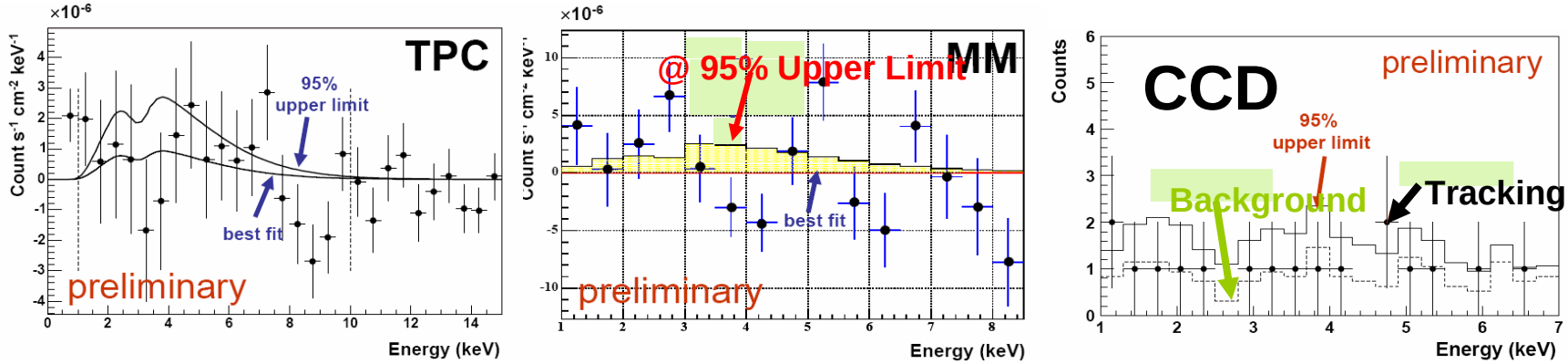
$$N_\gamma = \int \frac{d\Phi(E_a)}{dE_a} P_{a\to\gamma}(E_a) St\varepsilon dE_a$$



2003 DATA

$$\left\{ \begin{array}{l} g_{a\gamma\gamma}(TPC\_2003\_95\%C.L.) \le 1.55x10^{-10} GeV^{-1} \\ g_{a\gamma\gamma}(mM\_2003\_95\%C.L.) \le 1.50x10^{-10} GeV^{-1} \\ g_{a\gamma\gamma}(CCD\_2003\_95\%C.L.) \le 1.23x10^{-10} GeV^{-1} \end{array} \right\}$$

CAST First Phase. Description



PRELIMINARY

2004 DATA

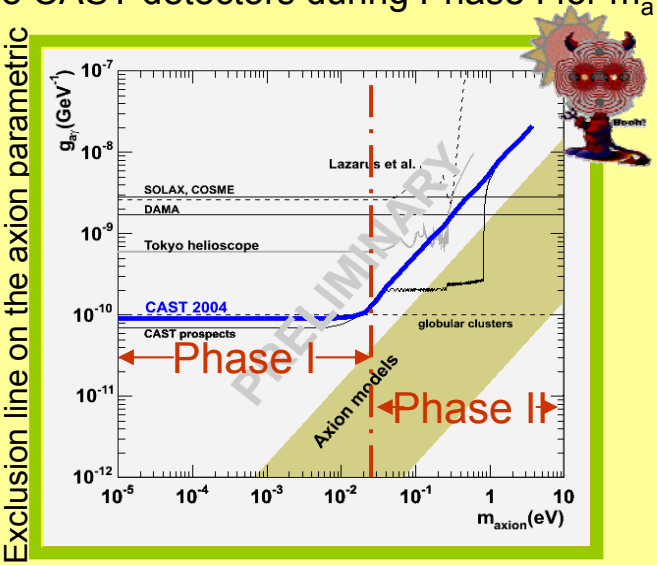
$$\left\{\begin{array}{l} g_{a\gamma\gamma}(TPC\_PRELIMINARY\_2004\_95\%C.L.) \le 1.24x10^{-10}GeV^{-1} \\ g_{a\gamma\gamma}(mM\_PRELIMINARY\_2004\_95\%C.L.) \le 1.25x10^{-10}GeV^{-1} \\ g_{a\gamma\gamma}(CCD\_PRELIMINARY\_2004\_95\%C.L.) \le 9.00x10^{-11}GeV^{-1} \end{array}\right\}$$

CAST First Phase. Results

PRELIMINARY EXPERIMENT RESULTS

No axion signal above background has been observed in any of the CAST detectors during Phase I for m_a<0.02 eV

Exclusion line on the axion parametric



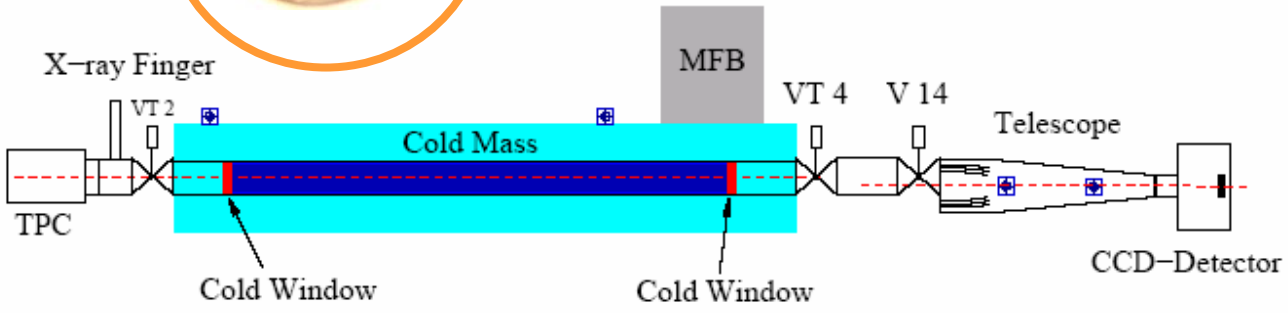
$$g_{a\gamma\gamma}(CAST\_2003\_95\%C.L) \leq 1.16x10^{-10} GeV^{-1}$$

$$g_{a\gamma\gamma}(PRELIMINARY\_CAST\_2004\_95\%C.L) \leq 9.00x10^{-11} GeV^{-1}$$

CAST Second Phase. Description

Extending coherence for higher axion masses …

FILL MAGNET BORE WITH HELIUM



The photon adquires an effective mass $m_\gamma > 0$

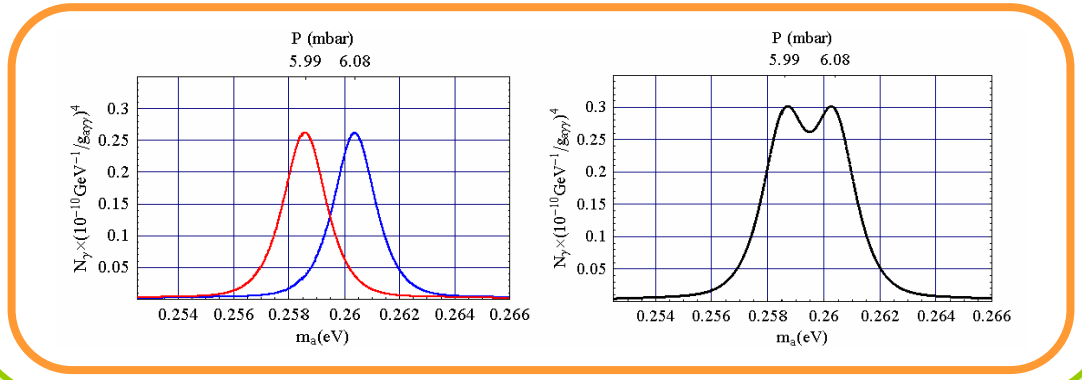
Momentum transfer ⇒

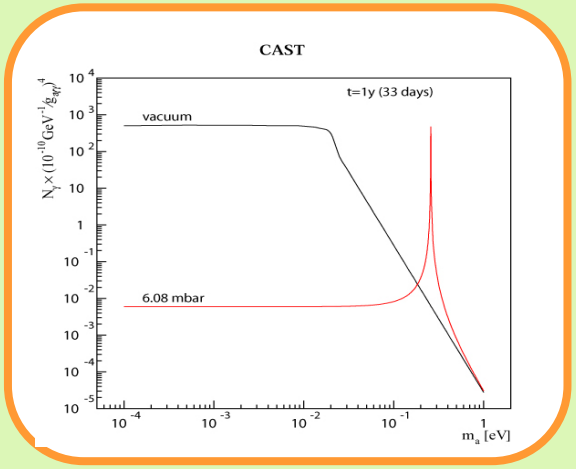
$$q = \left| \frac{m_\gamma^2 - m_a^2}{2E_a} \right|$$

CAST Second Phase. Description

m_γ can be adjusted by changing the gas pressure

$$m_\gamma\,[eV] = \sqrt{0.02\,\frac{P\,[mbar]}{T\,[K]}}$$





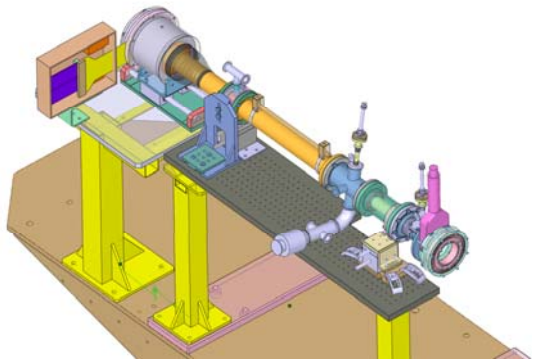
Coherence condition (qL << 1) restored for a narrow mass range around m_γ

CAST Second Phase. Description

- *1.5 hours of exposure time per pressure setting and detector*
- *3 X-ray DETECTORS*
- *1 X-ray telescope for CCD*
- *New X-ray focalizator for the μM detector*
- *2005-2006 ^{4}He to restore coherence up to $m_a < 0.26$ eV*
- *2007-… ^{3}He to restore coherence up to $m_a < 0.83$ eV*

SO FAR…

80 PRESSURE SETTING HAVE BEEN TAKEN



STATUS

No axions yet, CONTINUE DATA TAKING

STATUS

No axions yet?

Not exactly