CAST

CERN-Axion-Solar Telescope

Outline:

- Axions: origin and physics
- The CAST experiment:
  - Detecting principle
  - Magnet, Detectors
  - Results
  - Challenges
  - Summary, Outlook, my work

Origin of the Axion

The strong CP problem:

$$\mathcal{L}_{\text{strong CP}} = \bar{\theta}\frac{\alpha_s}{8\pi}G_a^{\mu\nu}\tilde{G}_{a\mu\nu}$$

$$\bar{\theta} = \theta + \text{Arg det } M$$

(QCD vacuum + EW quark mixing)

experimental bound on the neutron electric dipole moment requires $\bar{\theta} \leq 10^{-9}$

Why?

Peccei-Quinn solution:

✓NEW global axial $U(1)_{PQ}$ symmetry spontaneously broken at scale f_a

✓Associated pseudo Nambu-Goldstone boson: axion !

Axion: pseudoscalar, neutral, stable,
candidate for dark matter

Physics of the Axion

QCD Interaction Lagrangian:

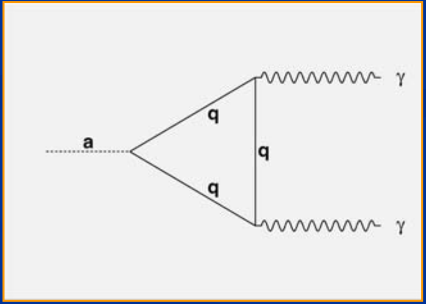
$$\mathcal{L}_a = \frac{1}{2}\partial_\mu a \partial^\mu a - \frac{\alpha_s}{8\pi f_a} a G_a^{\mu\nu} \tilde{G}_{a\mu\nu}$$

✓ $\bar{\theta}$ is absorbed in the definition of the axion field

✓ axion mass inversely proportional to the PQ scale

$$m_a = 6\,\text{eV}\,\frac{10^6\,\text{GeV}}{f_a}$$

Photon interaction: identical to the neutral pion's



Axion-Photon coupling:

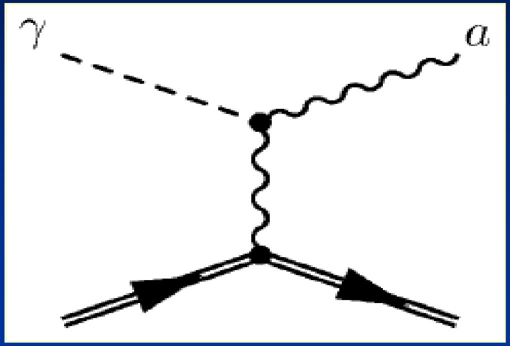
$$g_{a\gamma\gamma} = \frac{\alpha}{2\pi f_a}\left[\frac{E}{N} - 1.92 \pm 0.08\right]$$

MODEL DEPENDENT

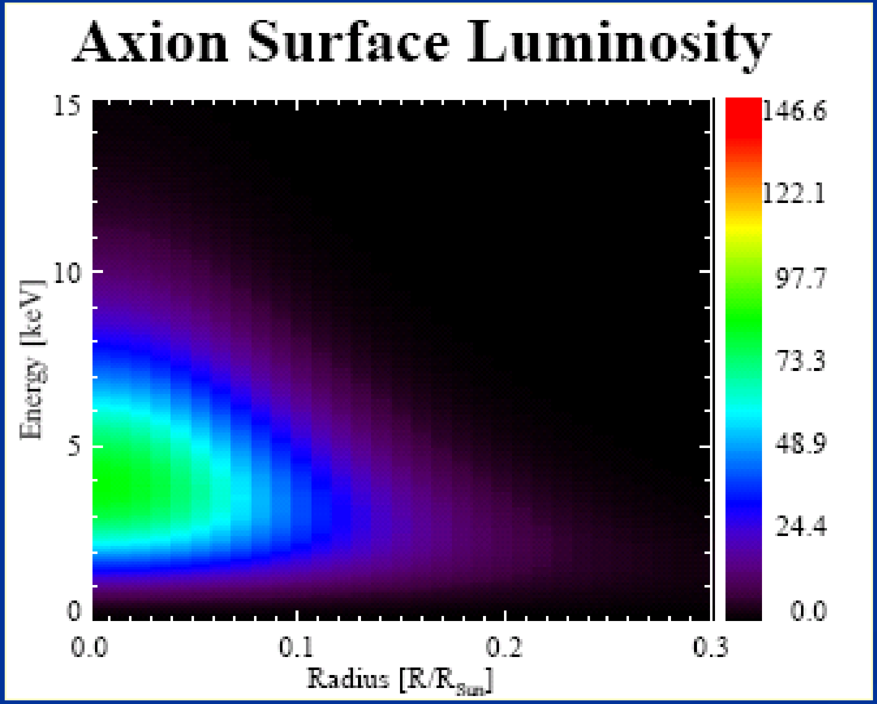
If the PQ scale is large enough: INVISIBLE Axion

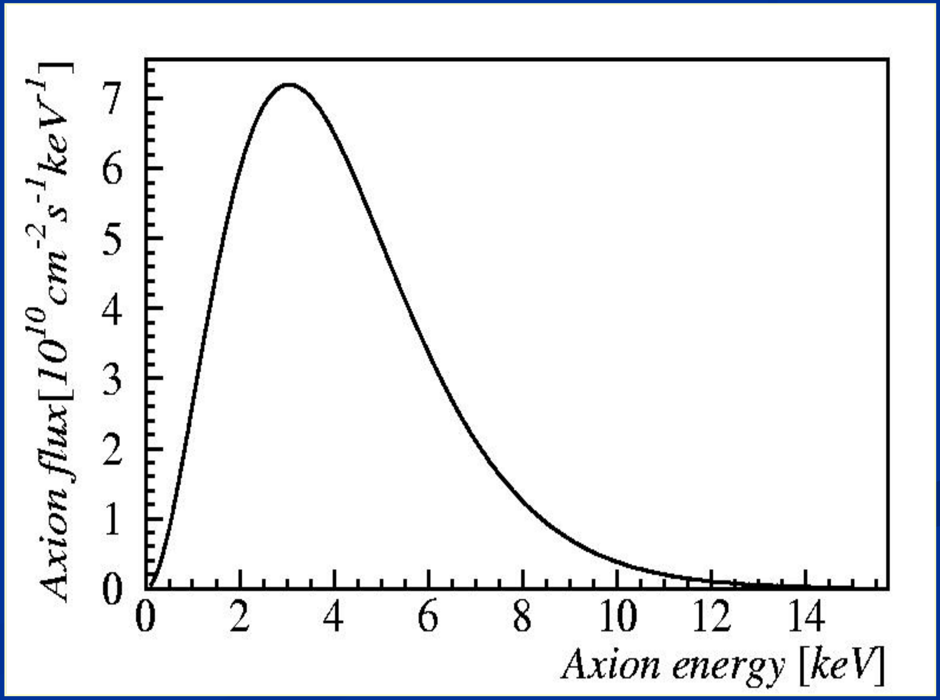
Solar Axions

Primakoff effect: a photon is converted into an axion in the presence of an electric or magnetic field and vice versa.



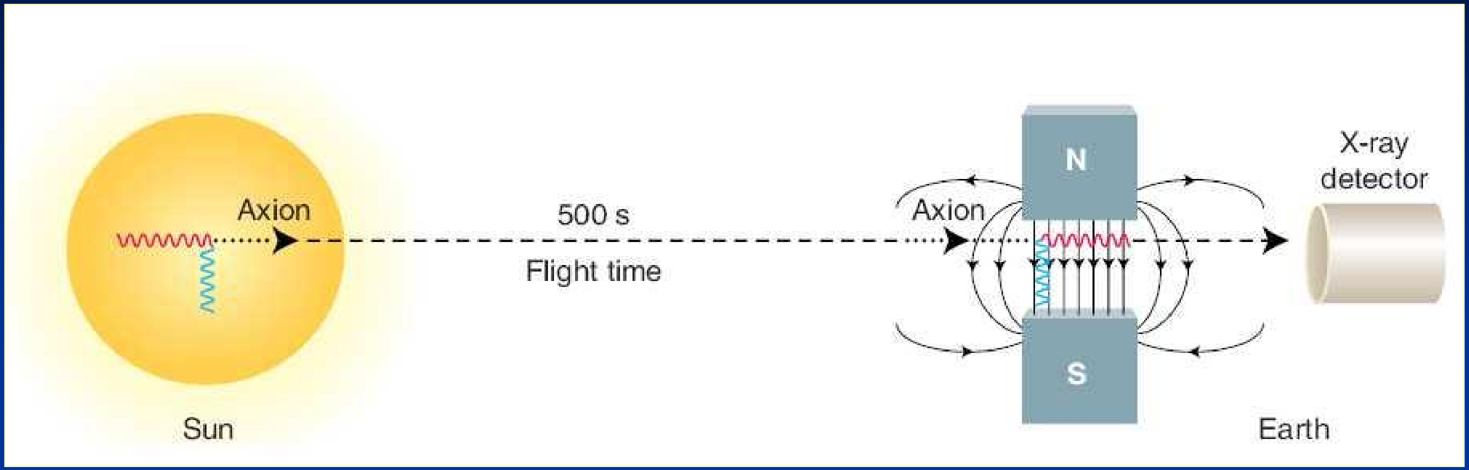
Sun: primakoff cross section + charge screening effects in plasma + solar density and temperature profile + invisible axion = differential flux.





differential axion flux at the Earth

CAST: Detection principle



Principle of the Axion helioscope Sikivie, Phys. Rev. Lett 51 (1983)

conversion probability in the gas
(in vacuum: m_γ=0, abs.coeff. Γ= 0):

$$P_{a\to\gamma} = \left(\frac{g_{a\gamma\gamma} B}{q}\right)^2 \sin^2\left(\frac{qL}{2}\right)$$

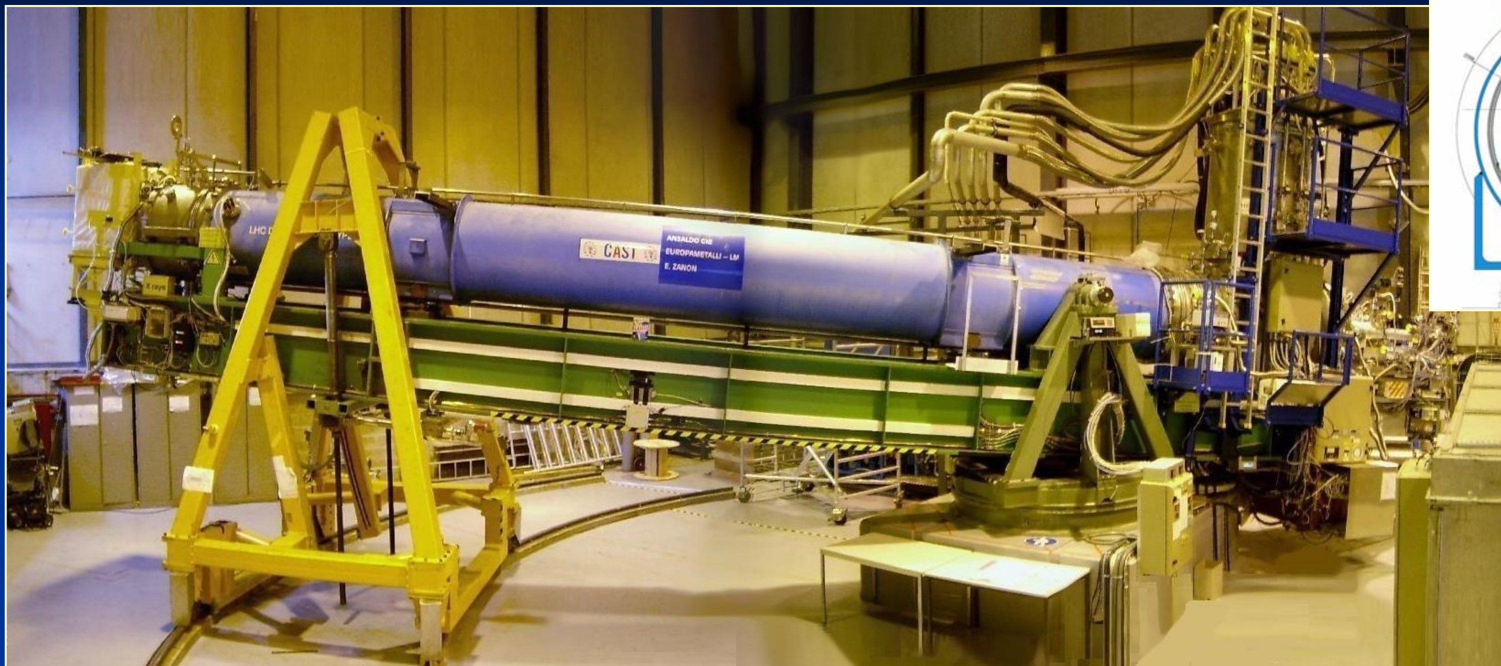
coherence condition:

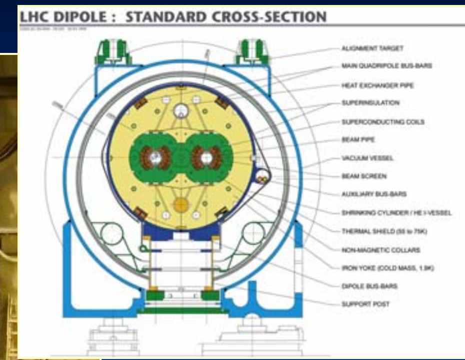
$$qL < \pi \quad \Rightarrow \quad \sqrt{m_\gamma^2 - \frac{2\pi E_a}{L}} < m_a < \sqrt{m_\gamma^2 + \frac{2\pi E_a}{L}}$$

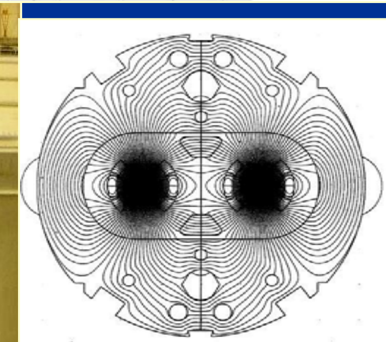
momentum transfer:

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

CAST: Magnet & Infrastructure







- ✓ De-commissioned LHC test dipole magnet
- ✓ Superconducting, operation at T=1.8 K
- ✓ Magnetic field: B=9T
- ✓ Electric current: 13000 A
- ✓ Length of the magnet: L=9.26m

Rotating platform :

Vertical: ±8°, Horizontal: ±40°

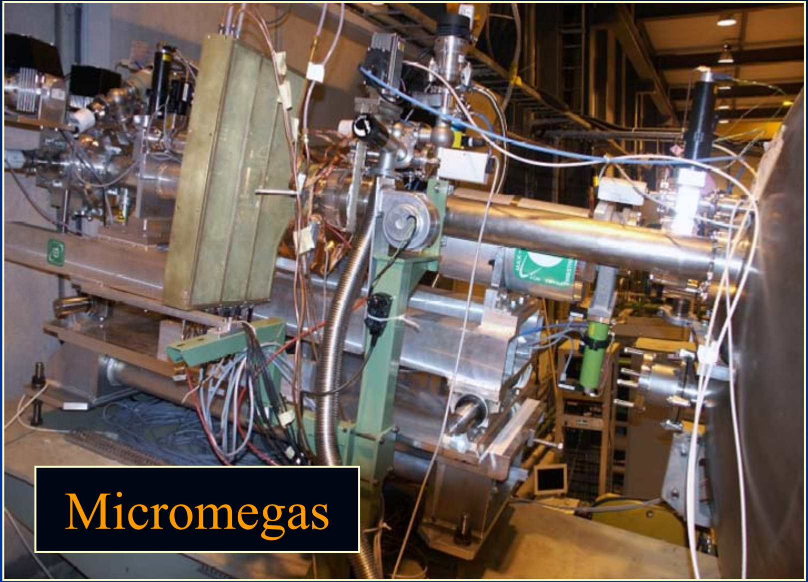
Pointing precision better than: 0.01°

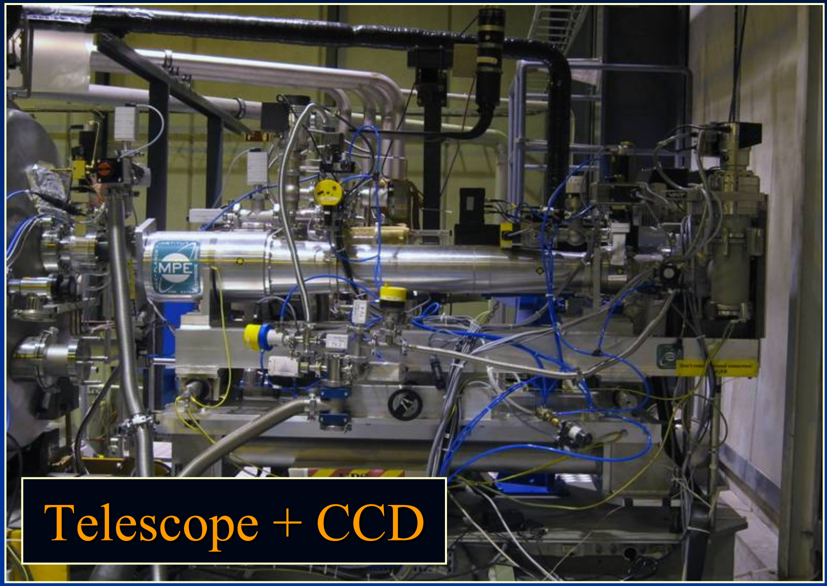
3 X-ray detectors

X-ray Focusing Device

Exposure time: 2×1.5h per day

CAST: Detectors



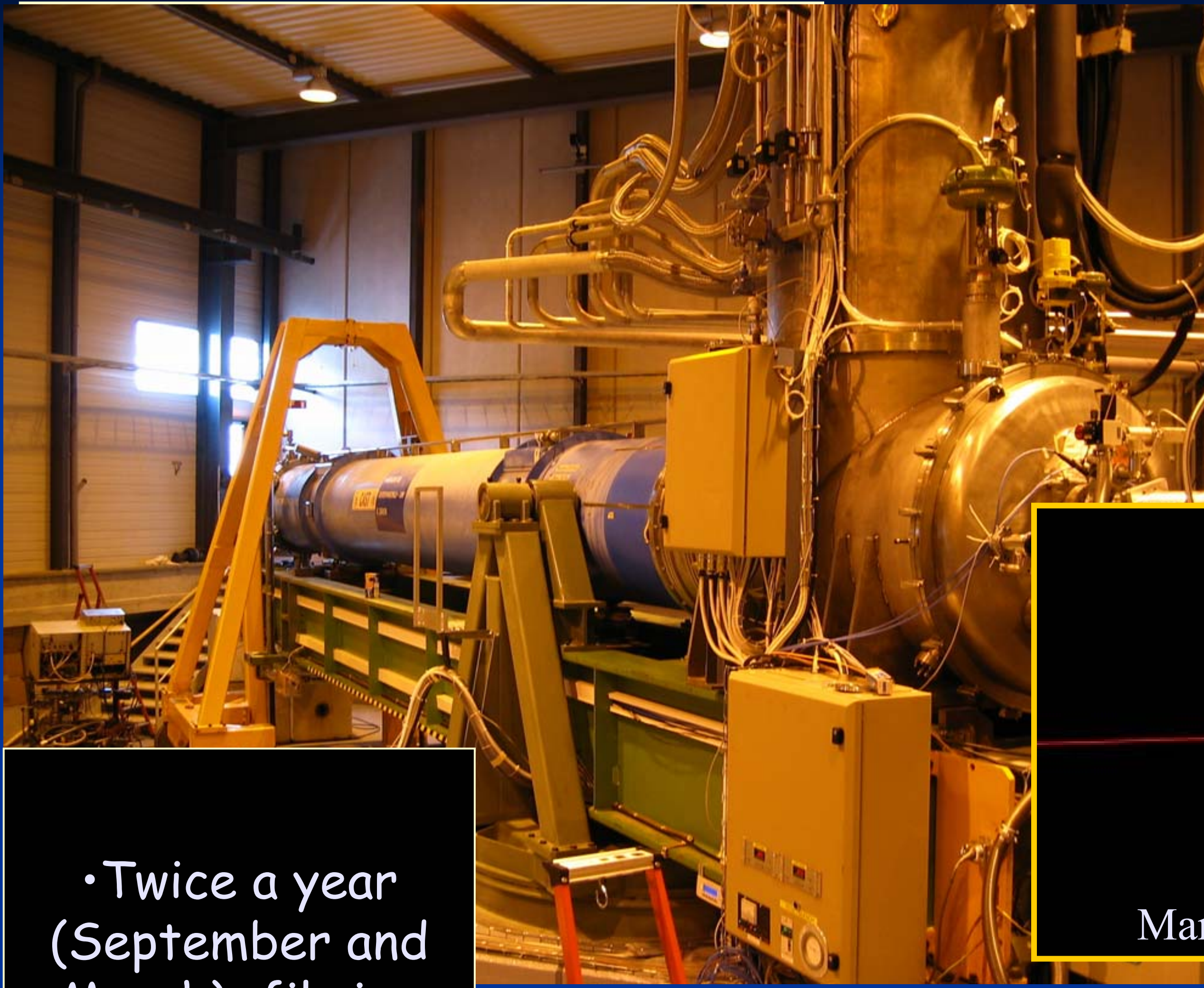


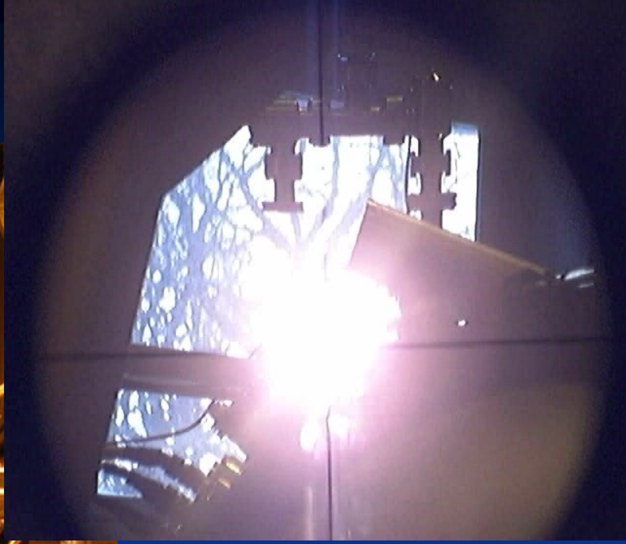
✓ X-ray mirror Telescope: prototype of the German X-ray satellite mission ABRIXAS (focal length: 1600mm)
✓ improving the signal-to-noise ratio by a factor of ~100

✓ pn-CCD detector (Charged Coupled Device): prototype developed for the European XMM-Newton X-ray observatory

✓ Micromegas (Micromesh Gaseous structure): very good space and energy resolution

CAST: Sun tracking





- Twice a year (September and March): filming the Sun through the window

CAST: Results

PHASE I

vacuum in the magnet bores:

$m < 2.3\times10^{-2}$ eV (during 2003 and 2004)

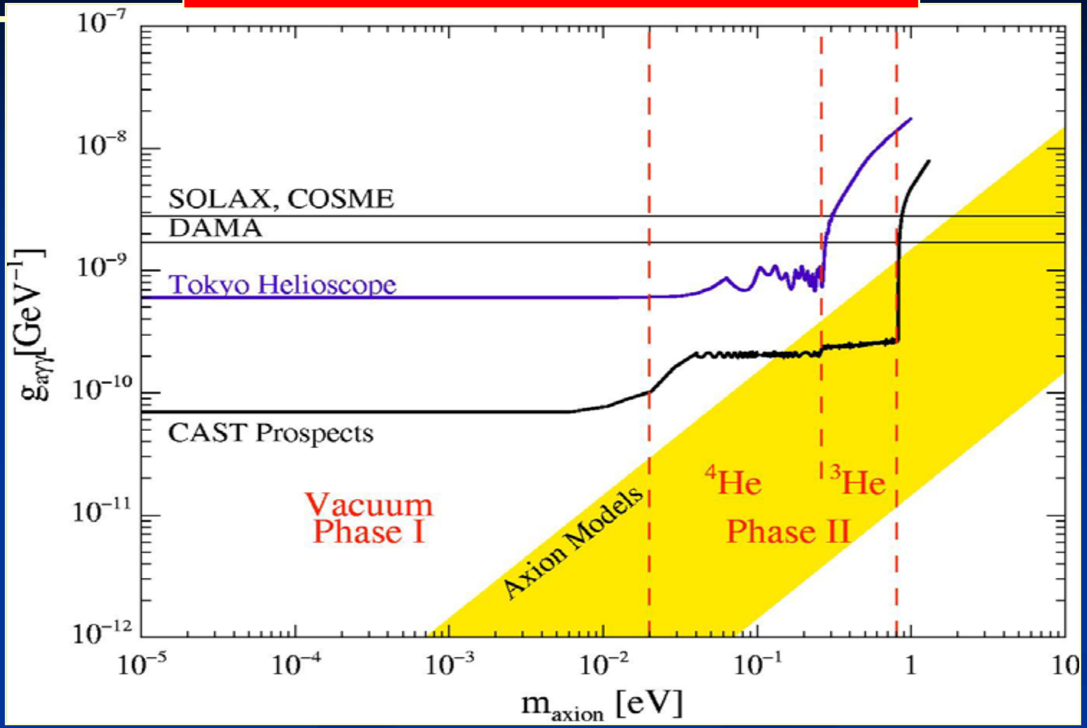
PHASE II

- ^{4}He gas pressure increased from 0 - 10 mbar: m < 0.26 eV
- ^{3}He gas pressure increased from 6 - 60 mbar: m < 0.83 eV

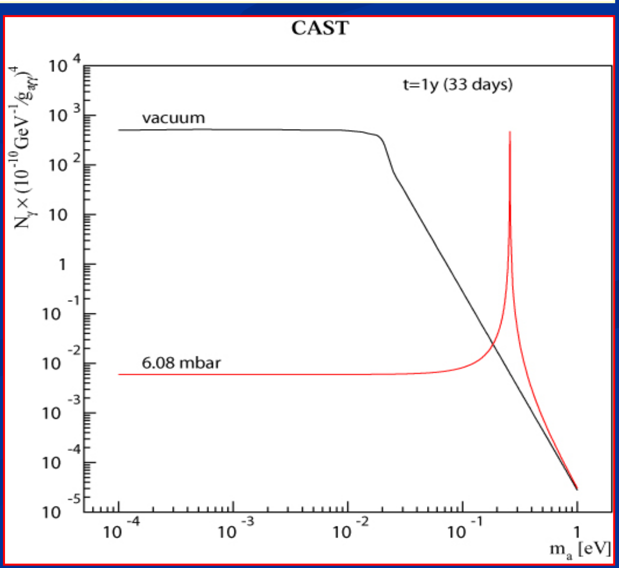
Started in November 2005

Only He can remain in the gas state at 1.8K

Predicted exclusion plot



CAST sensitivity



CAST: Results

- 2003 data: Phys. Rev. Lett. **94**, 121301 (2005) Our limit:

1. is comparable to the limit from stellar energy-loss arguments
2. improves the best previous laboratory result by a factor 5

- 2004 data:

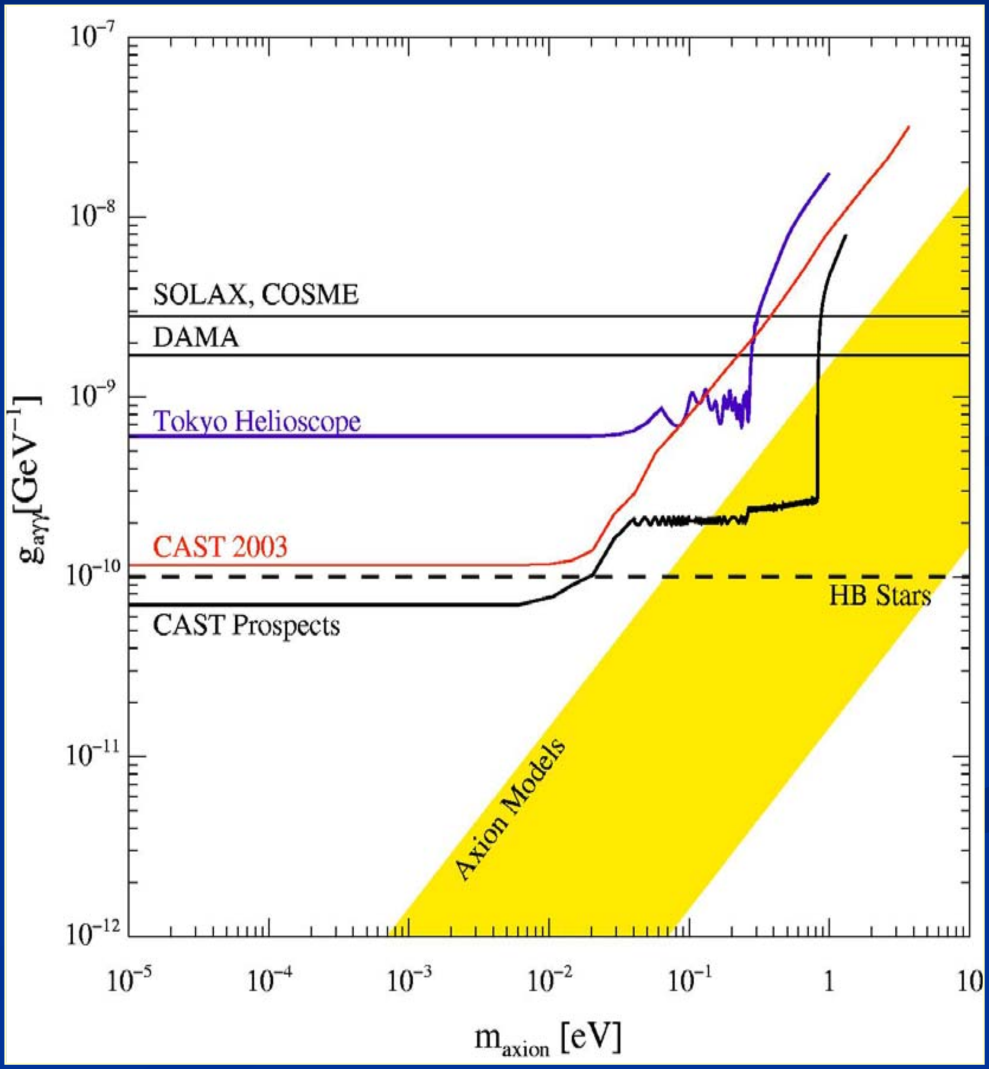
1. higher quality (optimal performances of the detectors, lower background)
2. no signal over background observed yet, approaching predicted limit

- 2005/2006 data:

1. First data are analysed
2. No signal over bg observed yet

For mass range m<0.02eV:

$g_{a\gamma\gamma}$ (95% C.L.) < 1.16×10^{-10} GeV^{-1}



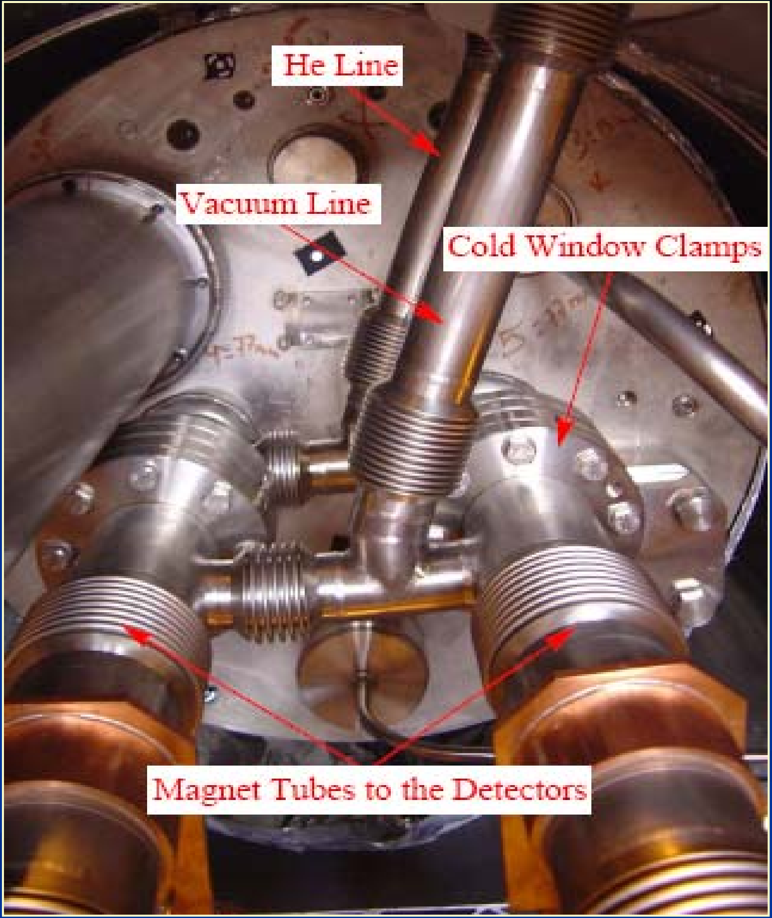
CAST Challenges: cold windows

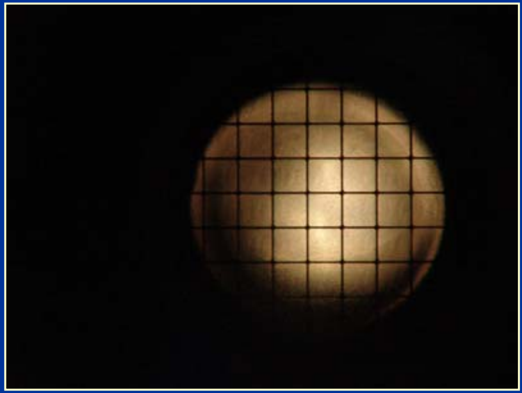
✓ High transmissivity to X-rays.

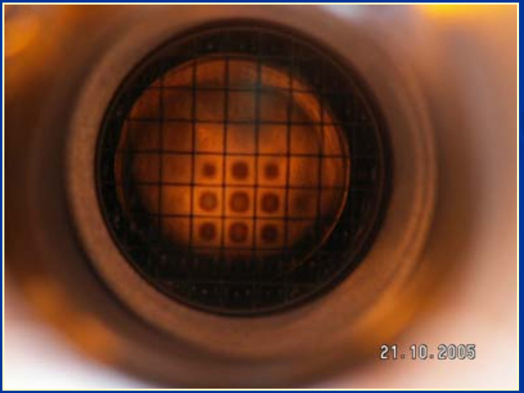
✓ Minimum He leakage.

✓ Mechanical endurance to sudden rise of pressure during a QUENCH.

✓ Robustness during normal operation at 1.8K.



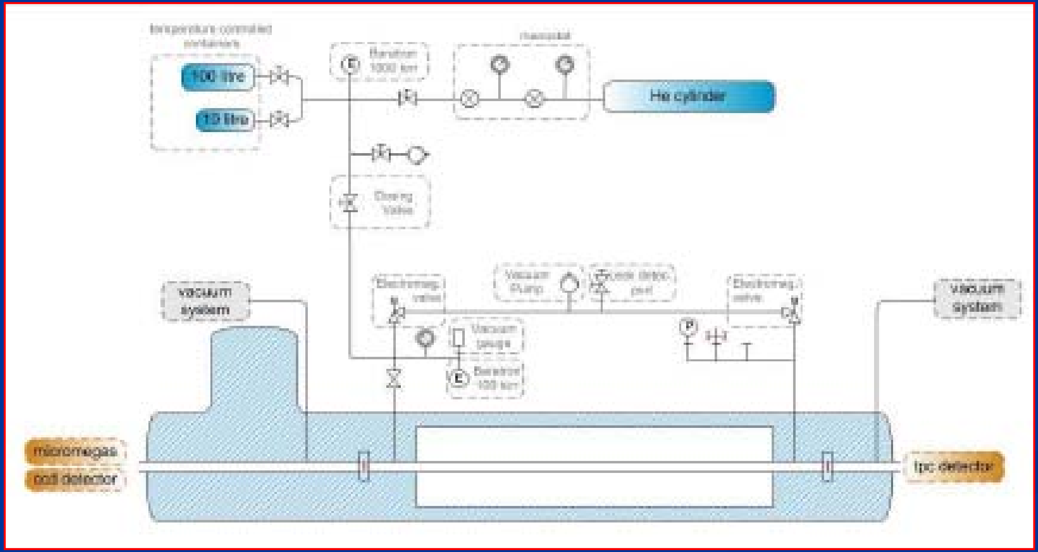


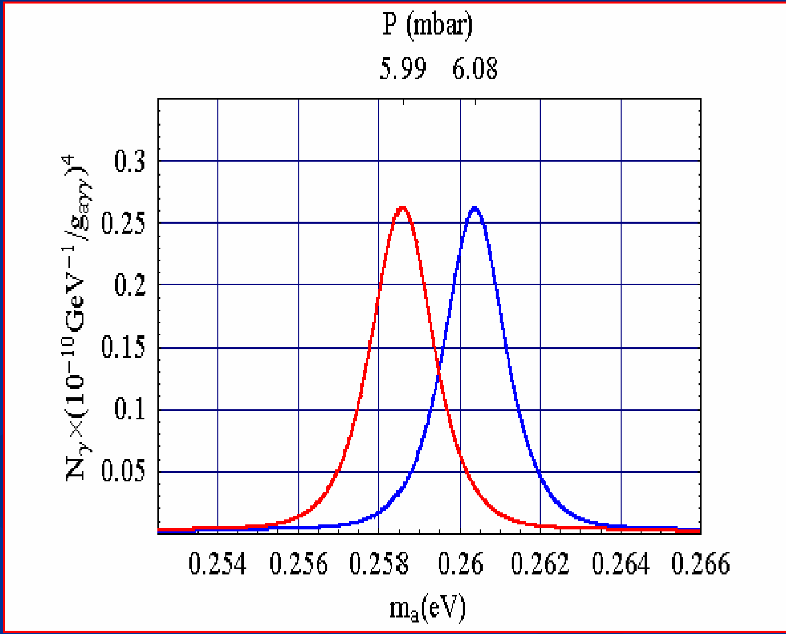


Polypropylene 15μm thick with strongback

CAST Challenges: Density steps during PHASE II

- ✓ Precise knowledge of the amount of He in the magnet.
- ✓ Restore of previous settings.
- ✓ Recover the ^{3}He after a QUENCH and protect the cold windows.
- ✓ Precise control of the gas conditions during input and output in order to achieve homogeneous density and avoid thermoacoustic oscillations.





Summary and Outlook

1. No signal over background observed during Phase I and first part of Phase II (prel.!!!)
2. In April/May 2007 the second part of PhaseII starts
3. Hopefully we can take data until the end 2008/09 to have enough time to find the Axion!!!

My work :

1. Analysing the daily CCD Data of Phase II in general (done)
2. Scanning the CCD chip for event-clusters (done)
3. Include densitiy data into the analysis (to do)
4. Include a new principle to define the correct confidence level (based on an ordering principle of likelihood-ratios- this method was used for neutrino oszillations) (to do)