Search for Solar Axions: the CAST experiment at CERN

http://cast.web.cern.ch/CAST/

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Dark Side of the Universe

Madrid, June 2006

Outline

- *The physics behind CAST:*
  - ✓ *Axions.*
  - ✓ *Principle of detection.*
- *The CAST experiment.*
- *Data Analysis and results:*
  - ✓ *I phase of CAST: concluded!*
  - ✓ *II Phase of CAST: in progress.*
- *Summary*

Axions : Motivation

- *The Axion is a light pseudoscalar particle resulting from the Peccei-Quinn mechanism to enforce strong-CP conservation*

[Peccei-Quinn(1977),Wilczek (1978), Weinberg(1978)]

- *The are two main sources of axions in the Universe:*
  - ✓ *They may exist as primordial cosmic relics copiously produced in the very early universe. These axions are one of the most interesting non-baryonic cold dark matter candidates.*
  - ✓ *Relativistic axions would also be produced nowadays in the stellar plasma. CAST is sensitive to this kind of particles*

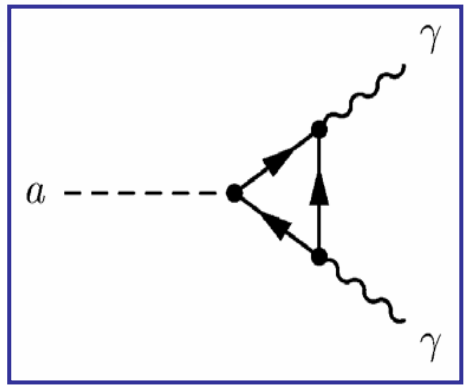
[See the PDG for an interesting review on axions]

Axions : Phenomenology

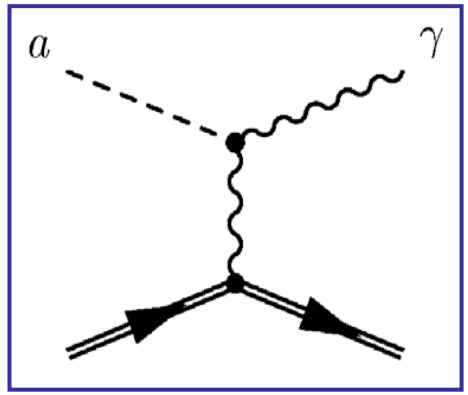
- *The AXION is:*
  - ✓ *weakly interacting*
  - ✓ *pseudoscalar*
  - ✓ *neutral*
  - ✓ *practically stable*
  - ✓ *phenomenology driven by the breaking scale f_a and the specific axion model*
  - ✓ *Axion mass:*

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

Axion-photon coupling present in almost every axion model

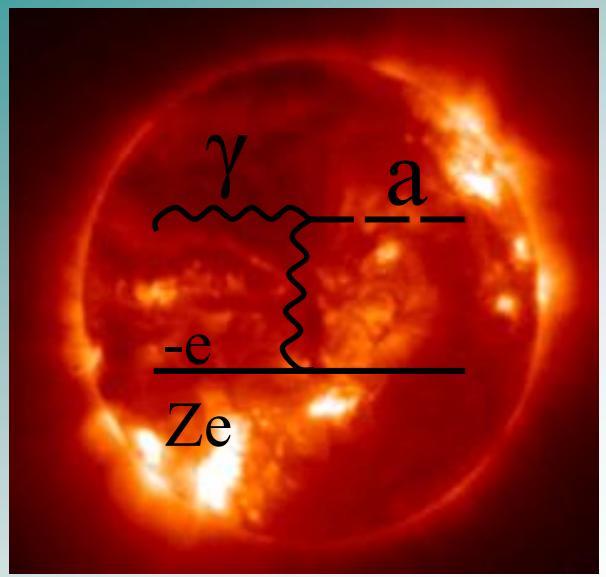


This gives rise to the Primakoff effect: axion-photon conversion (and vice versa) in the presence of electromagnetic fields.



That is the only axion phenomenology on which CAST relies…

The Sun as an axion source

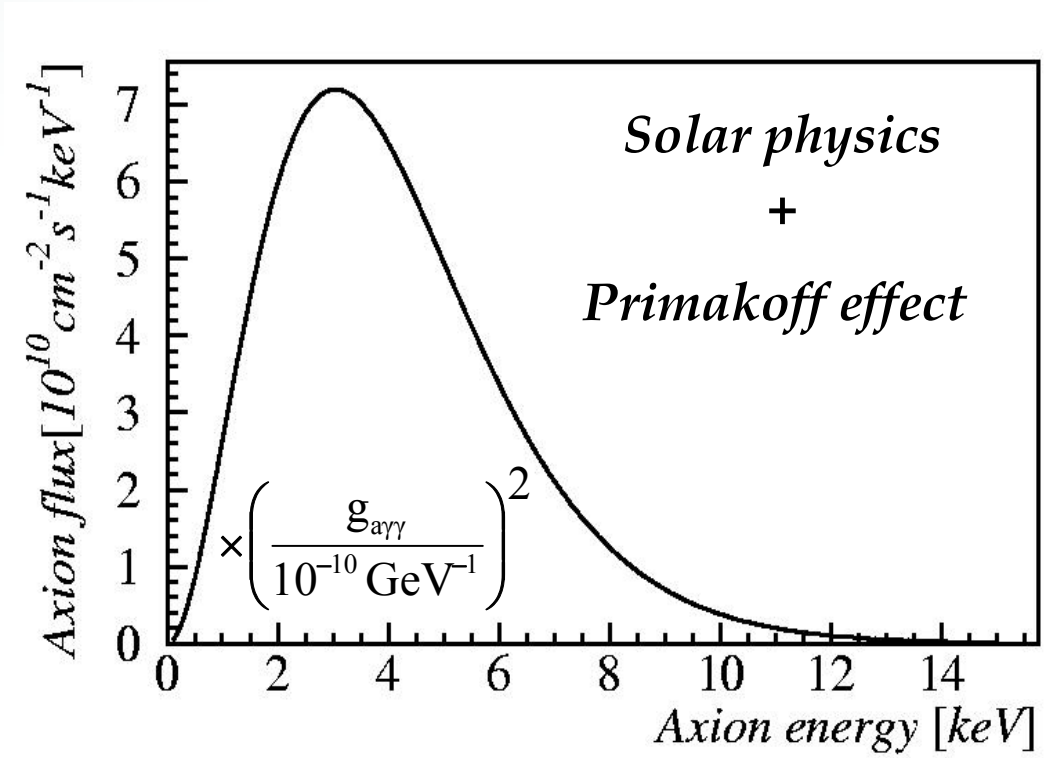


Thermal photons → *Axions*

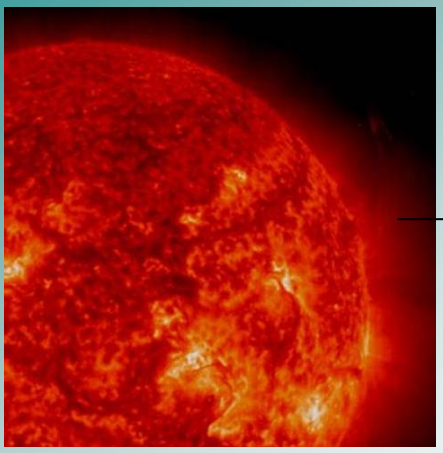
Fluctuating electric fields of the charged particles in the hot stellar plasma

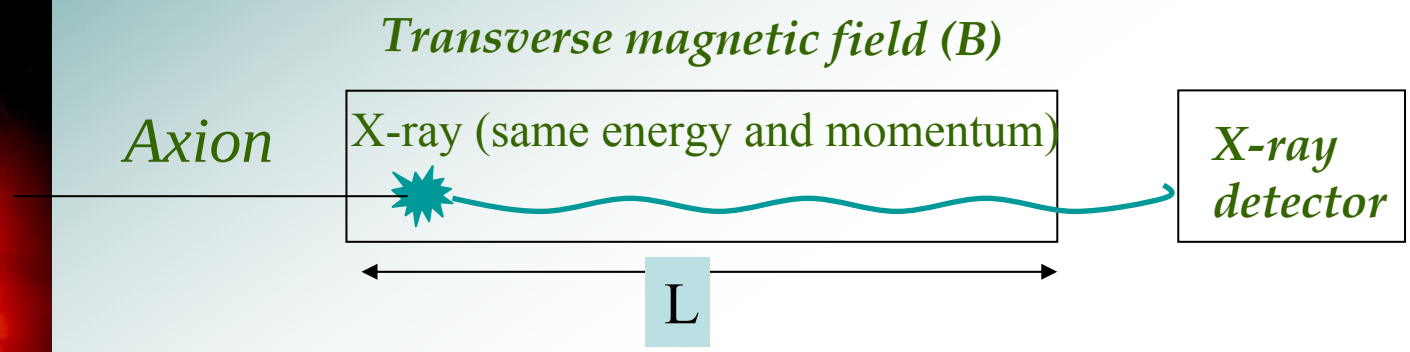
Differential solar axion flux at Earth.

[K. van Bibber *et al*. PRD 39,(1989)]



CAST: Principle of detection





[Sikivie PRL 51 (1983)]

- *Expected number of photons in the x-ray detector:*

$$N_\gamma = \int \frac{d\Phi_a}{dE_a} P_{a\to\gamma}\, S\, t\, dE_a$$

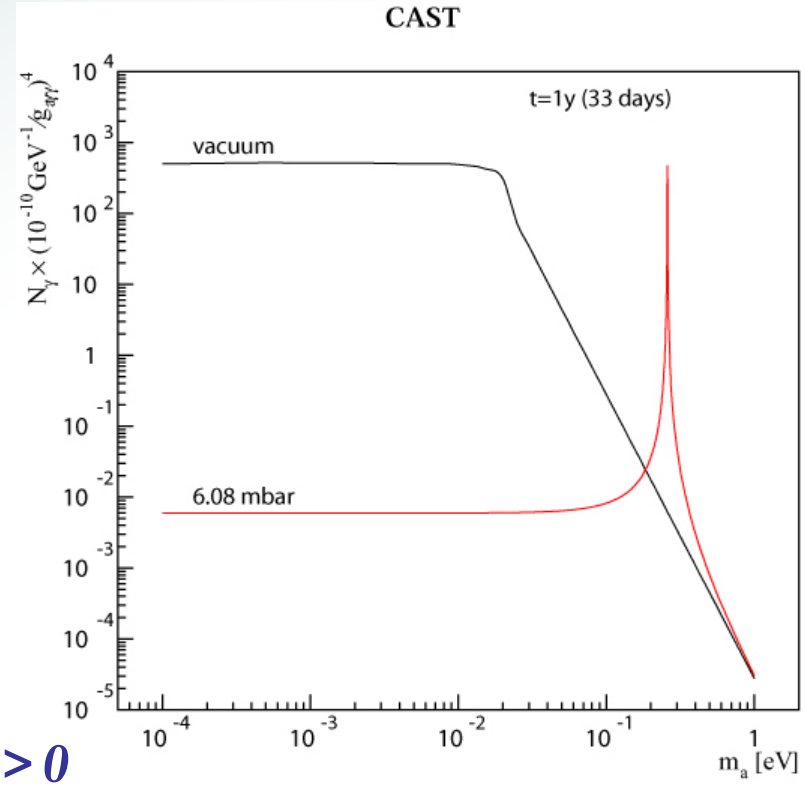
For $g_{a\gamma\gamma} = 1\times 1O^{-10}\ GeV^{-1}$
$t = 100\ h$, $S = 15\ cm^2$
$N_\gamma \approx$ 30 events

- $\frac{d\Phi_a}{dE_a}$ → *Differential axion flux at the Earth ($cm^{-2}\ s^{-1}\ keV^{-1}$)*
- $P_{a\to\gamma}$ → *Conversion probability of an axion into photon ($\propto (B\times L)^2$)*
- S → *Magnet bore area (cm^2)*
- t → *Measurement time (s)*

- *But* $P_{a\to\gamma}$ *is a coherent process only when the axion and photon fields remain in phase over L*

Coherence condition states that $qL < 1$

with $$q = \left| \frac{m_\gamma^2 - m_a^2}{2E_a} \right|$$ *(axion-photon momentum transfer)*



- *Vacuum inside the magnet:*

We are sensitive to axion masses $\leq 2.3\times10^{-2}$ *eV (CAST phase I)*

- *Buffer gas (He) inside the magnet:* $m_{\gamma,eff} > 0$

The coherence is restored

$$m_\gamma(eV) \approx \sqrt{0.02\,\frac{P(mbar)}{T(K)}}$$

Different gas pressures P will make us sensitive to different axion masses up to 1 eV (CAST phase II)

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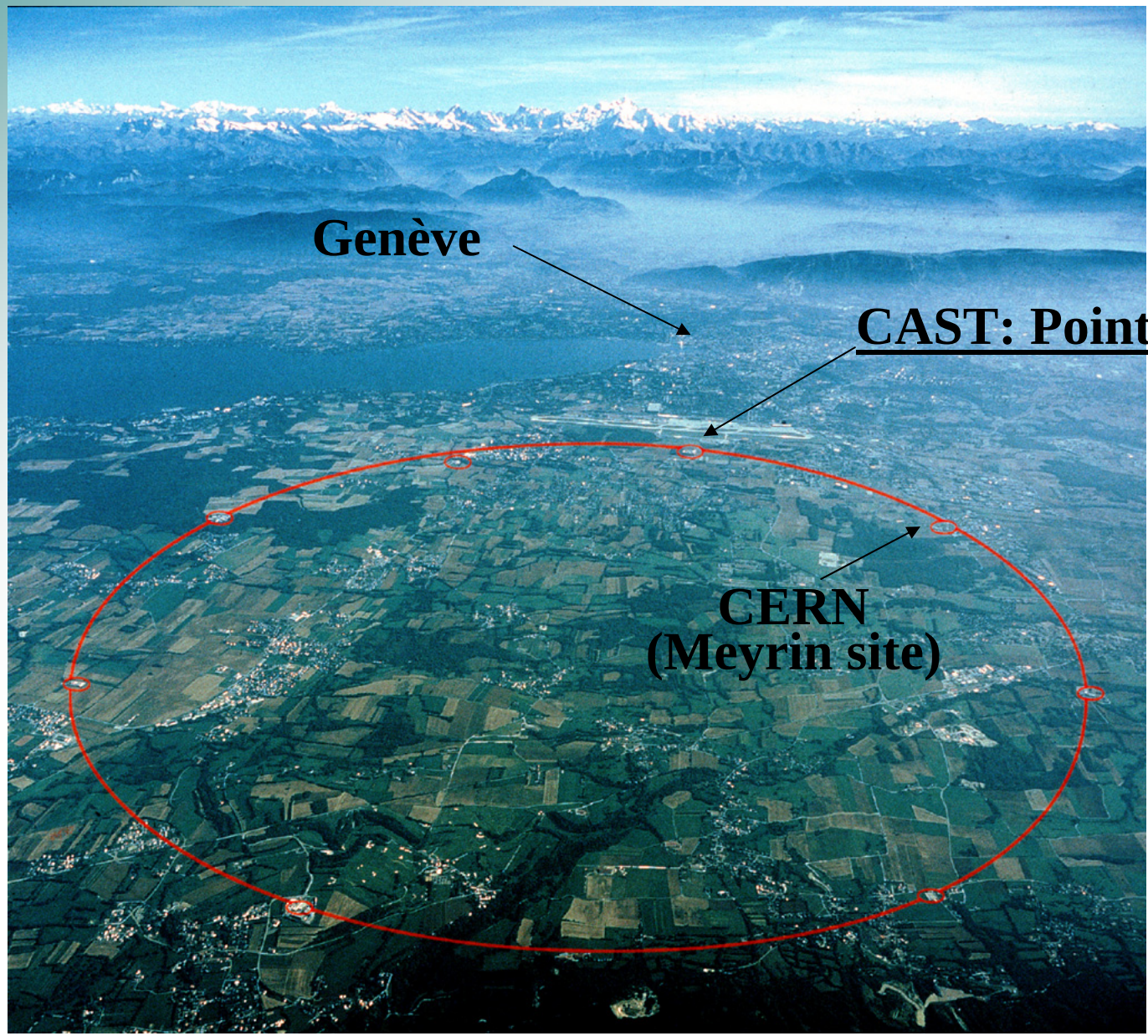
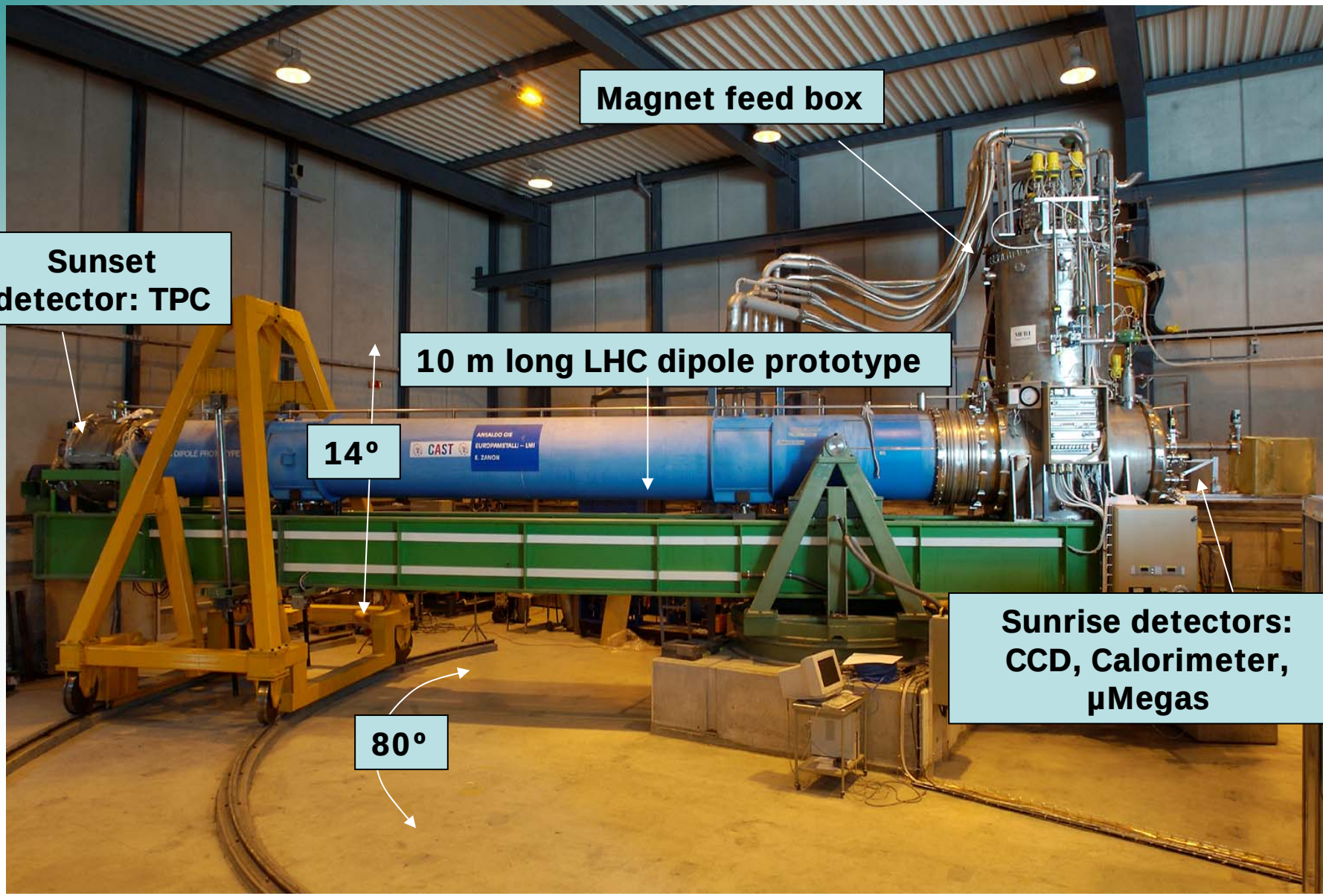
CAST at CERN:



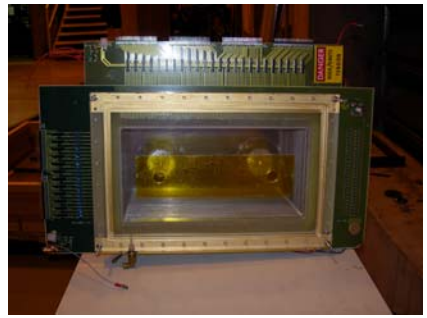
CAST: Axion helioscope experimental setting



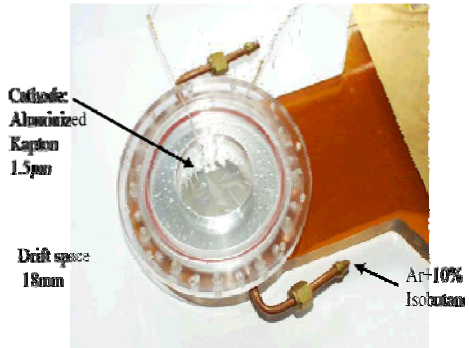
CAST following the Sun

CAST X-ray detectors

- *3 detectors using different technologies: reduction of systematic effects.*



- *TPC: conventional technology, robust and stable. Uses a passive shielding to reduce the environmental radiation.*



- *MICROMEGAS: novel technology. Very good spatial resolution (~100 μm). Innovative two dimensional strip read-out.*

- *CCD+ X-ray focusing device: Space technology. Signal to noise ratio increased by a factor ~200.*

CAST experiment: status

- *I Phase of CAST: concluded!*
  - ✓ *2003 data taking: First CAST results (K.Zioutas et. al. PRL 2005).*
  - ✓ *2004 data taking:*
    - *Improved conditions in the three detectors (shiledings,….) and in the experiment.*
    - *Add of a fourth detector to search for High Energy axions.*
- *II Phase of CAST: in progress...*
  - ✓ *Experiment setup updated during 2005.*
  - ✓ *Started commissioning data taking at the end of 2005.*
  - ✓ *2006: continuous data taking running each day with a different pressure inside the magnet.*

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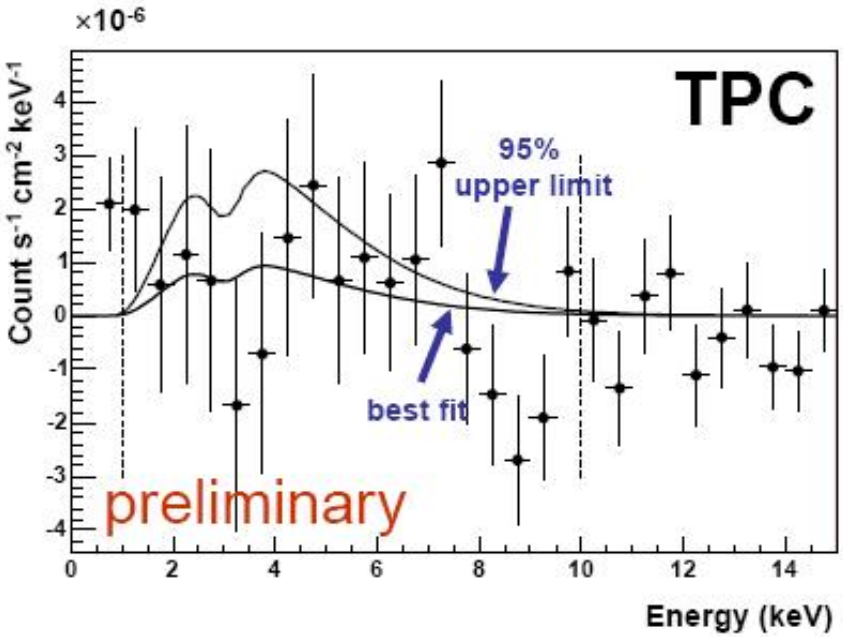
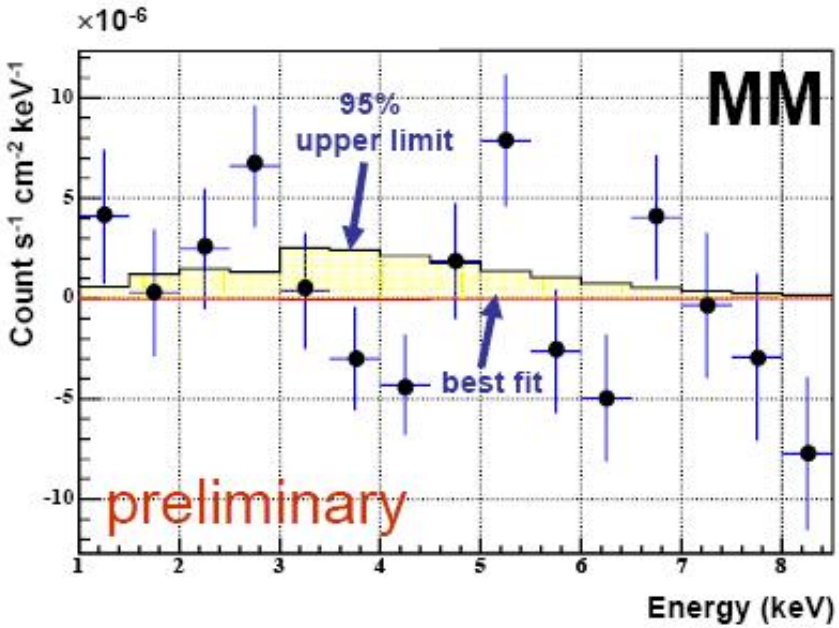
The 2004 data taking results

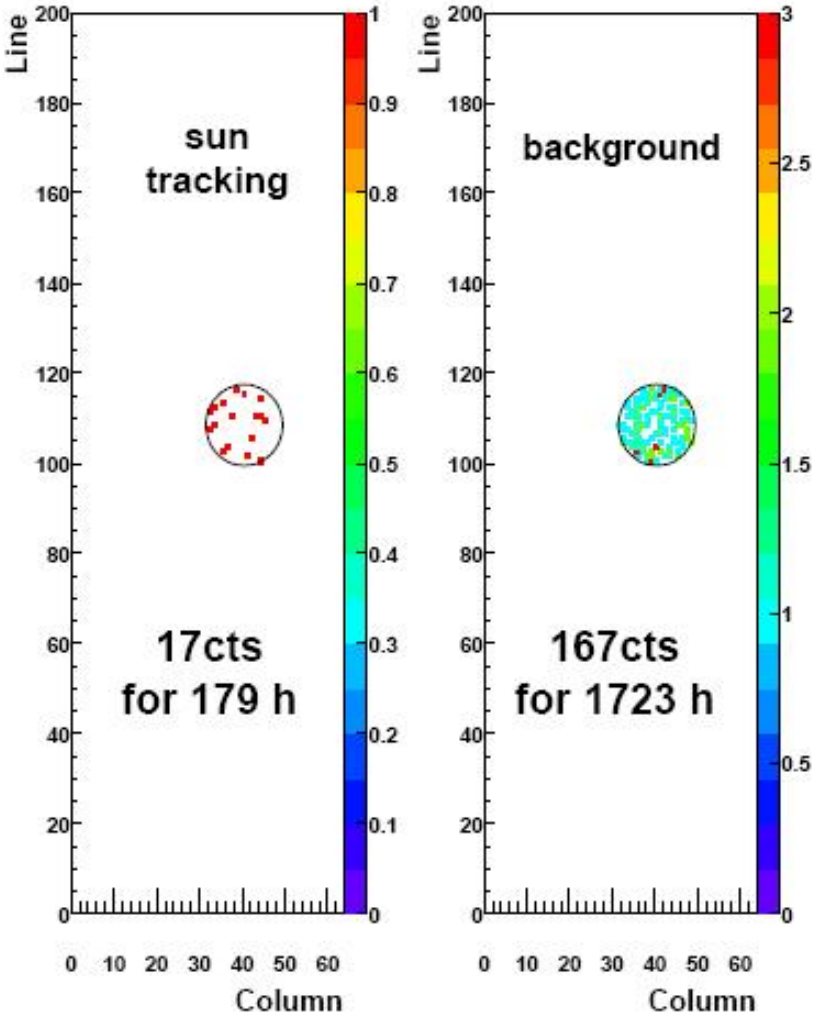


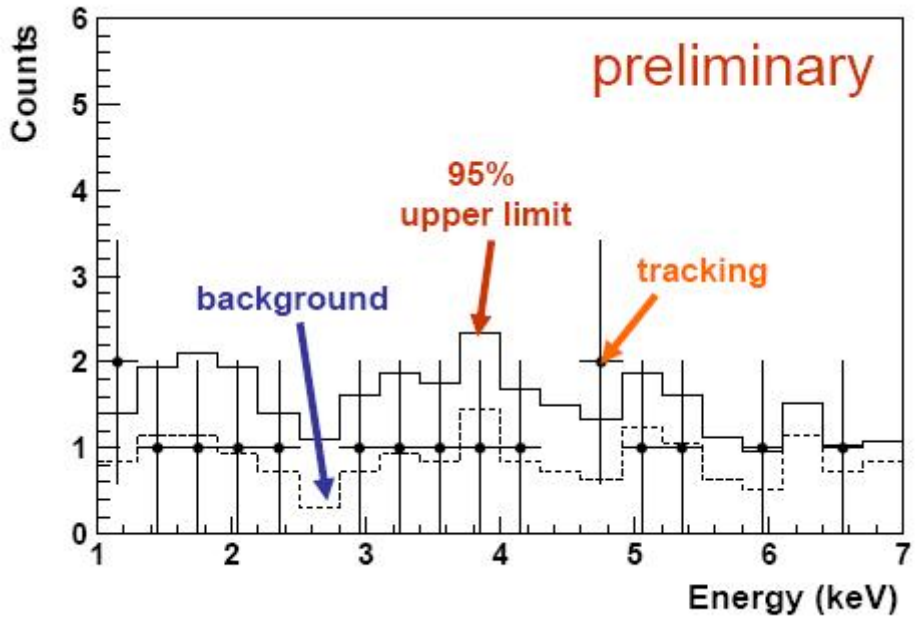


- *Tracking: 203h & Background: 2617h*
- *Fitting by χ^2*
- *Fit energy range: 1-10 keV*
- *$g_{a\gamma\gamma}$ (95 C.L) < 1.24×10^{-10} GeV $^{-1}$*

- *Tracking: 196h & Background: 1390h*
- *Fitting by χ^2*
- *Fit energy range: 1-8.5 keV*
- *$g_{a\gamma\gamma}$ (95 C.L) < 1.25×10^{-10} GeV $^{-1}$*

The 2004 data taking results



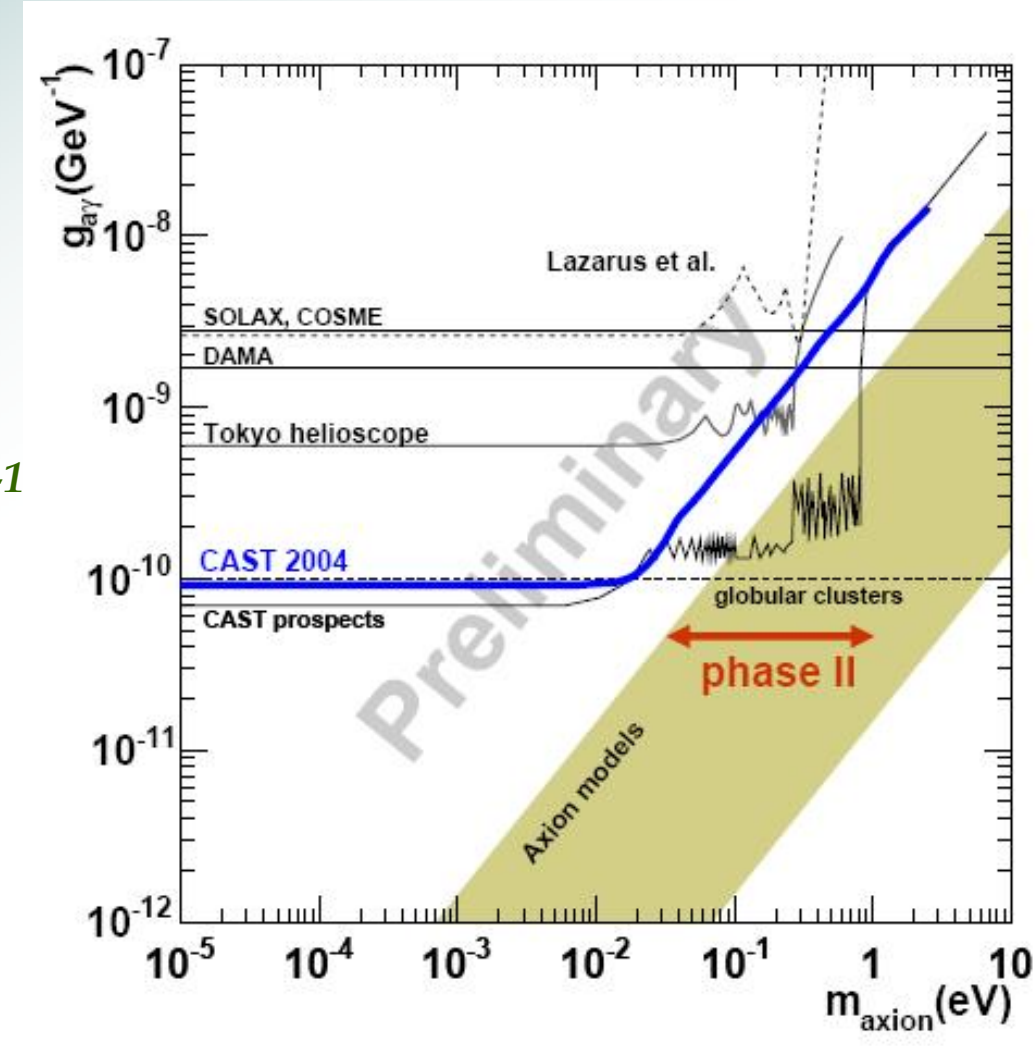


- *Spot with 9 pixels radius.*
- *Maximum likelihood fit.*
- *Fit energy range: 1-7 keV*
- $g_{a\gamma\gamma}$ *(95 C.L) < 0.9×10^{-10} GeV^{-1}*

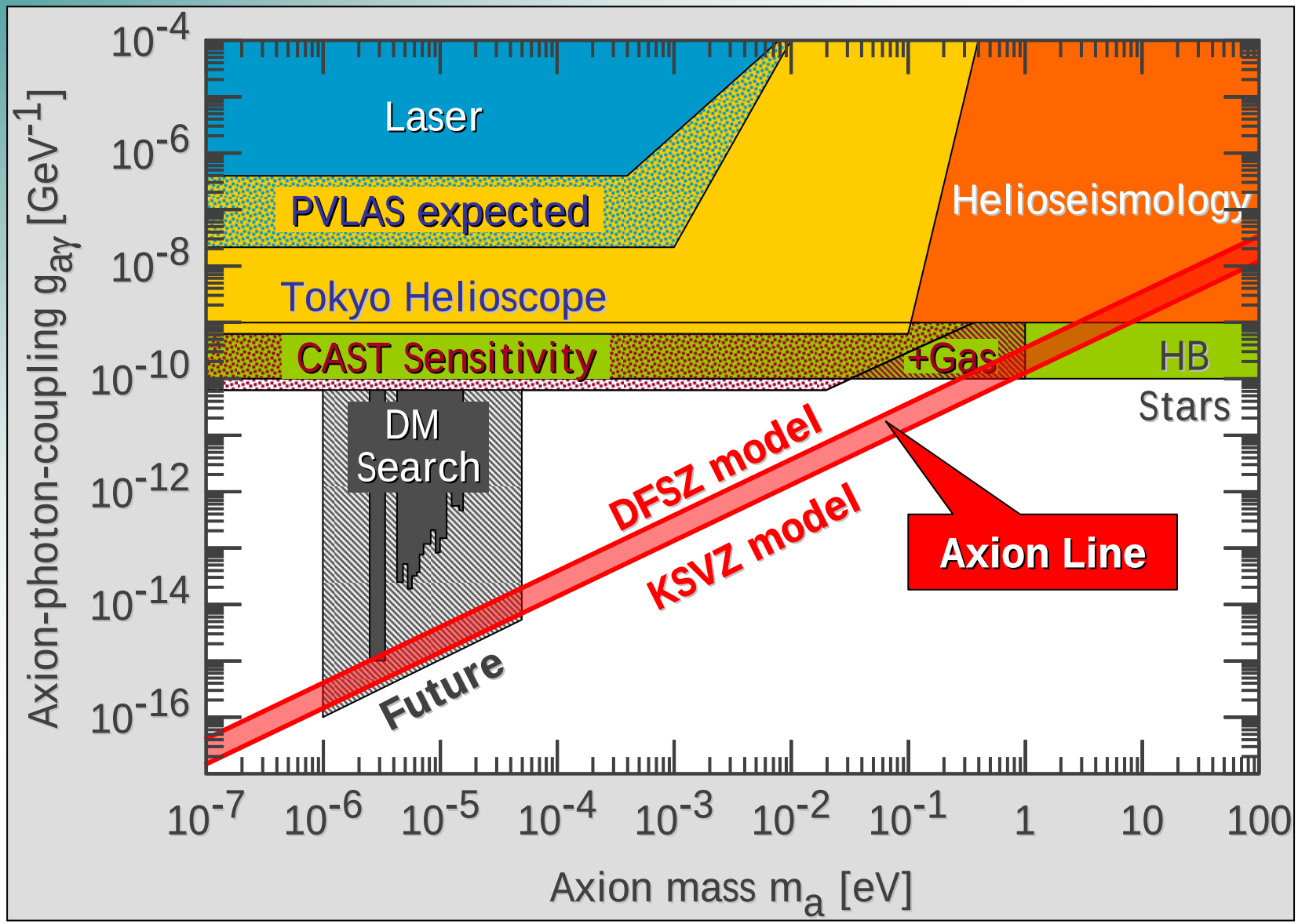
The 2004 data taking results

- *Combined result for 2004 data:*

$g_{a\gamma\gamma}$ *(95 C.L) < 0.9×10^{-10} GeV^{-1} for* m_a *< 0.028 eV*



CAST 2004 result into a wider exclusion plot…



Summary and prospects…

- *I Phase of CAST: concluded!*
  - ✓ *First CAST results paper already published (2003 data analysis).*
  - ✓ *2004 data already analyzed:*
    - *Second paper on preparation.*
    - *Best result obtained ever with an axion helioscope.*
    - *Better result than the astrophysical limits from globular clusters.*
- *II Phase of CAST: in progress, stay tuned!!*