



Search for Solar Axions: CAST

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for the CAST collaboration

2004 LHC DAYS IN SPLIT, 5 – 9 October

Outline:

- Axions
- The CAST experiment:
 - Physics behind the experiment
 - Description:
 - Magnet, tracking
 - X-ray telescope and X-ray detectors
 - Analysis and preliminary results
 - Prospects

Axions

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)

- direct contribution to the electric dipole moment of the neutron d_n
- strong experimental bound on d_n requires $\bar{\theta} \leq 10^{-9}$

Peccei-Quinn solution:

- new global chiral $U(1)_{\text{PQ}}$ symmetry spontaneously broken at scale f_a
- associated pseudo Nambu-Goldstone boson: **axion !**

$$\mathcal{L}_a = \frac{1}{2} \partial_\mu a \partial^\mu a - \frac{\alpha_s}{8\pi f_a} a G_a^{\mu\nu} \tilde{G}_{a\mu\nu} \quad \Rightarrow \quad \bar{\theta} \text{ absorbed in the definition of } a$$

-axion mass: $m_a = 6 \text{ eV} \frac{10^6 \text{ GeV}}{f_a}$

**Axion: pseudoscalar, neutral,
practically stable**

Axions

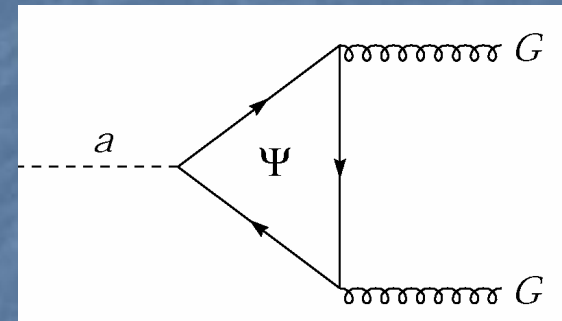
Axion models:

- Standard axion model ($f_a \approx f_{\text{weak}}$) excluded experimentally
- Invisible axion models ($f_a \gg f_{\text{weak}}$, $g \sim 1/f_a$, $m_a \sim 1/f_a$)
 - **KSVZ** (Kim, Shifman, Vainshtein, Zakharov)
 - **DFSZ** (Dine, Fischler, Srednicki, Zhitnitskii)

Axion-photon coupling:

-axion-photon coupling via triangle loop

-axion-pion mixing

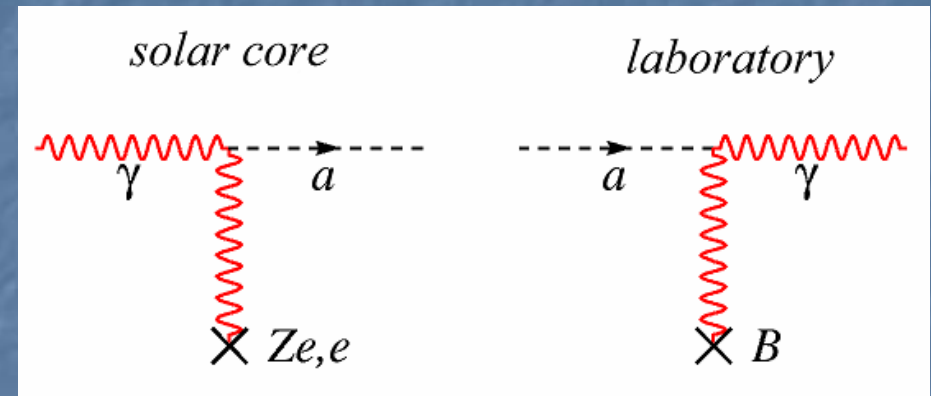


$$g_{a\gamma\gamma} = \frac{\alpha}{2\pi f_a} \left[\frac{E}{N} - \frac{2(4+z+w)}{3(1+z+w)} \right] = \frac{\alpha}{2\pi f_a} \left[\frac{E}{N} - 1.92 \pm 0.08 \right]$$

CAST: Physics

Sun: a thermal photon converts into an axion in the Coulomb fields of nuclei and electrons in the solar plasma
(Primakoff process)

Earth: an axion converts into a photon in a strong transverse magnetic field



-expected number of photons

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

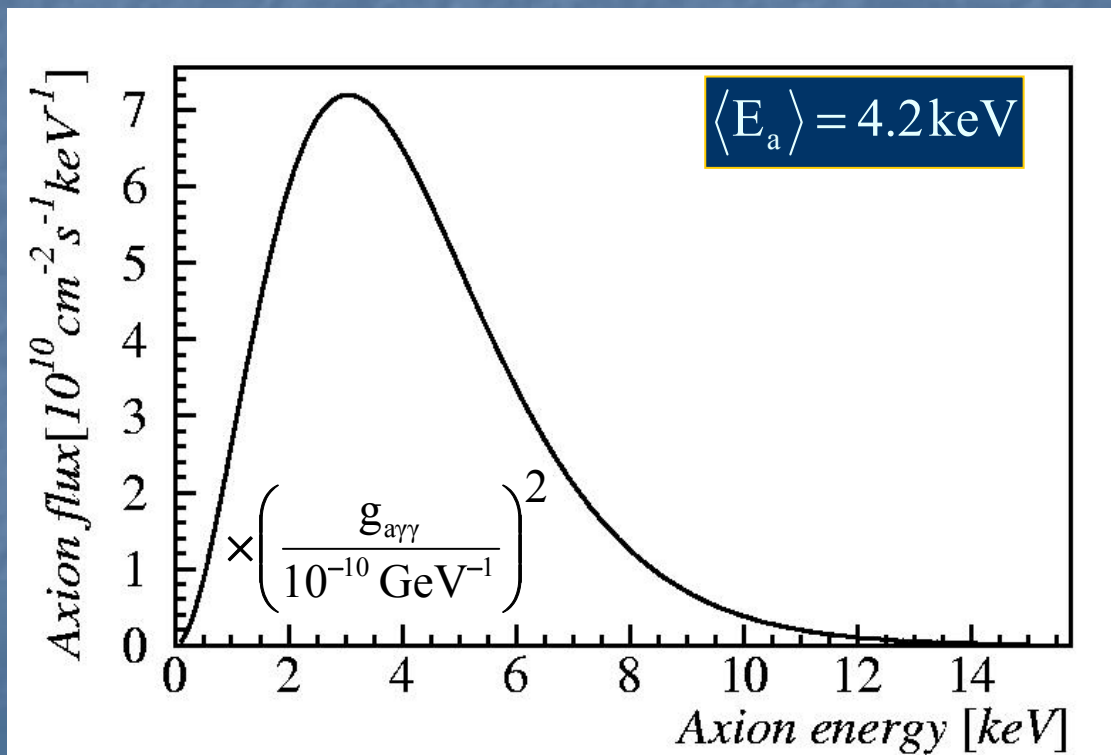
S = detector effective area

t = measurement time

CAST: Physics

- differential axion flux at the Earth:

$$\frac{d\Phi_a}{dE_a} = 4.02 \times 10^{10} \left(\frac{g_{a\gamma\gamma}}{10^{-10} \text{ GeV}^{-1}} \right)^2 \frac{(E_a/\text{keV})^3}{e^{E_a/1.08\text{keV}} - 1} \text{ cm}^{-2}\text{s}^{-1}\text{keV}^{-1}$$



K. van Bibber *et al.*, 1989

CAST: Physics

-conversion probability in the gas (in vacuum: $\Gamma=0$, $m_\gamma=0$):

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

L =magnet length, Γ =absorption coeff.

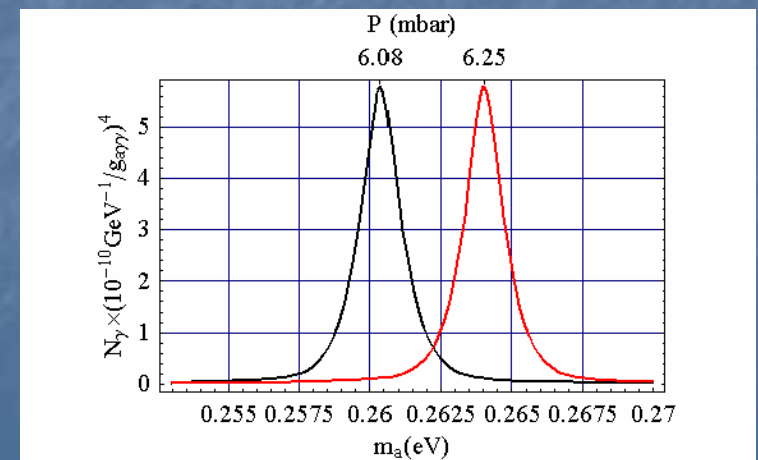
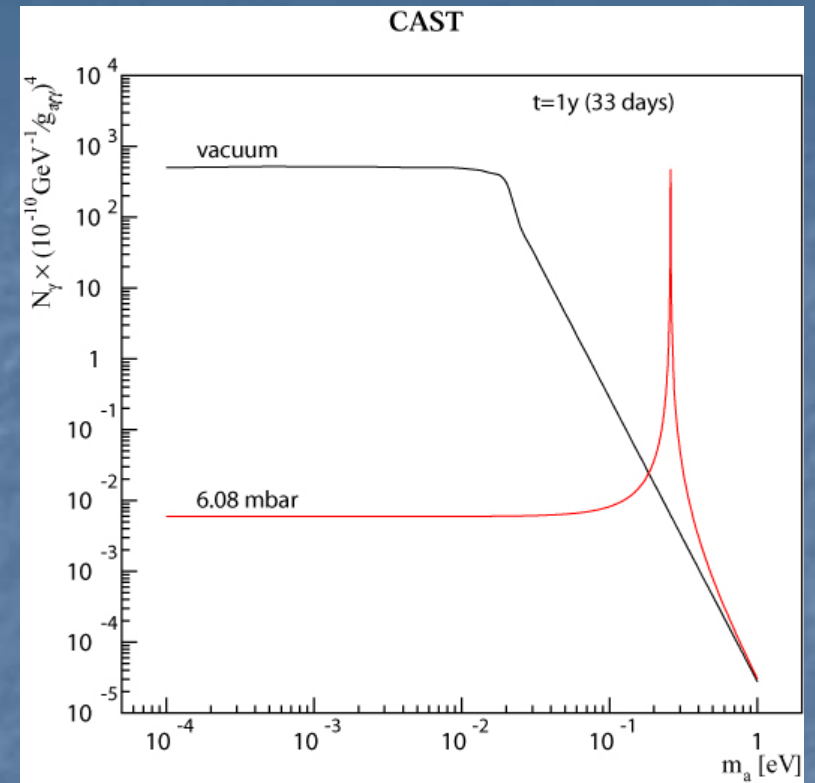
$$q = \left| \frac{m_\gamma^2 - m_a^2}{2 E_a} \right| \quad \text{axion-photon momentum transfer}$$

$$m_\gamma \text{ (eV)} \approx \sqrt{0.02 \frac{P \text{ (mbar)}}{T \text{ (K)}}} \quad \text{effective photon mass} \quad (T=1.8 \text{ K})$$

-coherence condition:

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

Biljana Lakić

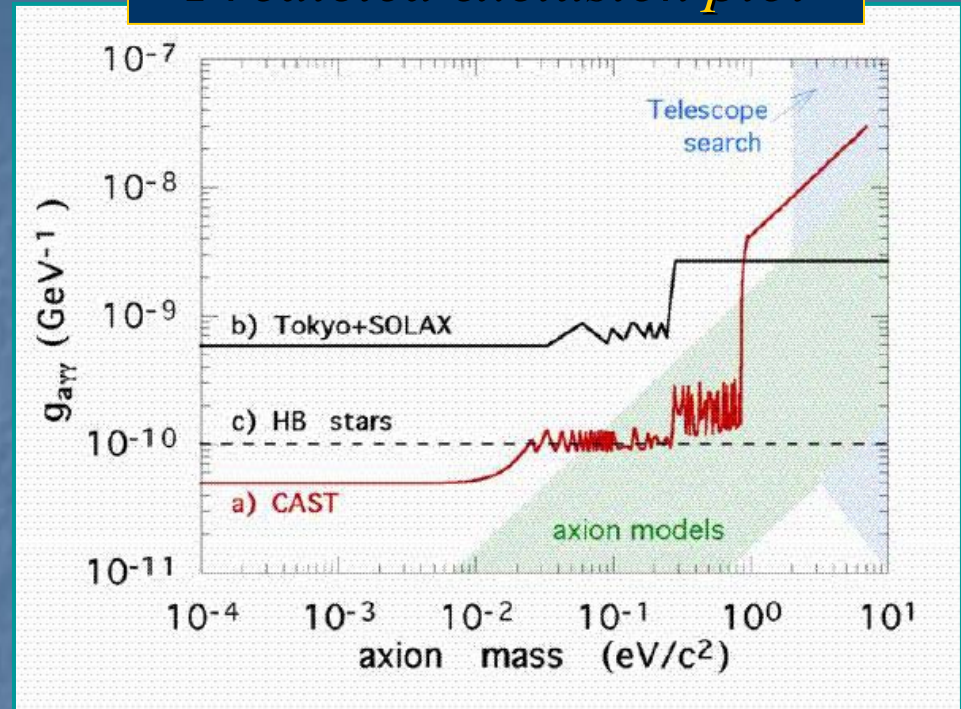


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CAST: Physics

- 1 year with vacuum in the magnet bores: $m < 2.3 \times 10^{-2} \text{ eV}$ (during 2003 and 2004)
- 1 year with ^4He gas pressure increased from 0 - 6 mbar in 100 increments: $m < 0.26 \text{ eV}$
- 1 year with ^3He gas pressure increased from 6 - 60 mbar in 365 increments : $m < 0.83 \text{ eV}$

Predicted exclusion plot



To start in 2005

CAST: Collaboration

Canada, Vancouver, Bc, University of British Columbia

[Department of Physics](#) (1 participant(s)) Team Leader: **Michael HASINOFF**
Michael HASINOFF

Croatia, Zagreb

[Ruder Boskovic Institute](#) (3 participant(s)) Team Leader: **Milica KRCMAR**
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Luigi DI LELLA

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[Instituto de Física Nuclear y Altas Energías](#) (7 participant(s)) Team Leader: **Angel MORALES**
Berta BELTRAN LIZARRAGA, Jose CARMONA MARTINEZ, Gloria LUZON MARCO, Julio MORALES, Jaime RUZ ARMENDARIZ, Maria SARSA, Jose VILLAR

Switzerland, Geneve

[European Organization for Nuclear Research \(CERN\)](#) (12 participant(s)) Team Leader: **Martyn DAVENPORT**
Klaus BARTH, Gino CIPOLLA, Martyn DAVENPORT, Rui DE OLIVEIRA, Fabio FORMENTI, Jean-Noel JOUX, Christian LASSEUR, Angelika LIPPITSCH, Thomas PAPADEVANGELOU, Alfredo PLACCI, Bruno VULLIERME, Louis WALCKIERS

United States of America, Chicago II, University of Chicago

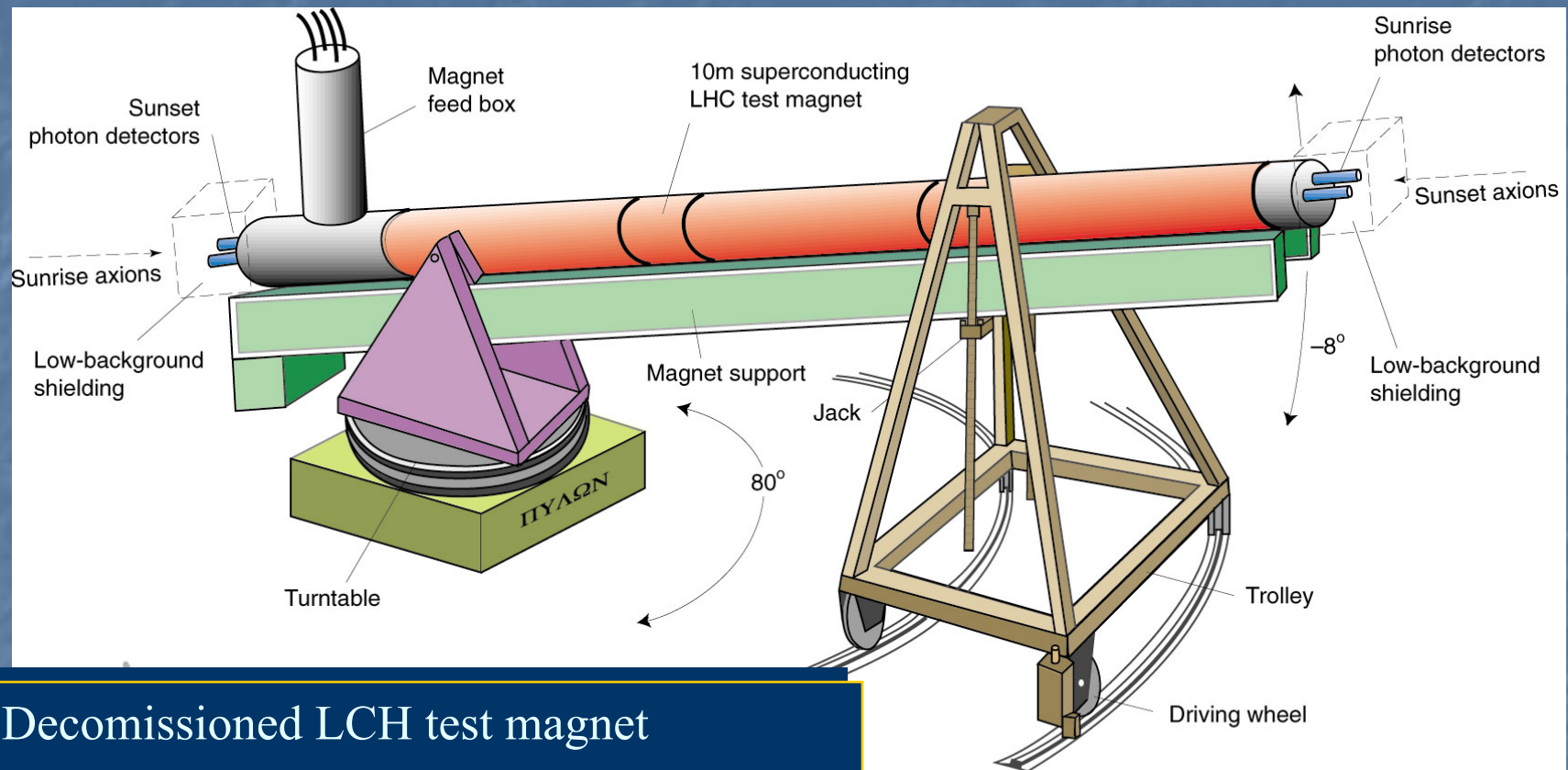
[Enrico Fermi Institute](#) (3 participant(s)) Team Leader: **Juan COLLAR**
Juan COLLAR, David MILLER, Joaquin VIEIRA

United States of America, Columbia Sc, University of South Carolina

[Department of Physics and Astronomy](#) (2 participant(s)) Team Leader: **Frank AVIGNONE**
Richard CRESWICK, Horacio FARACH

The total number of participants: 65

CAST: CERN Axion Solar Telescope



Decommissioned LHC test magnet

Rotating platform

3 X-ray detectors

X-ray Focusing Device

Biljana Lakić

2004 LHC DAYS IN SPLIT

CAST: Magnet, tracking

CAST Experimental area SR8

$L = 9.26 \text{ m}$

$B = 9 \text{ T}$

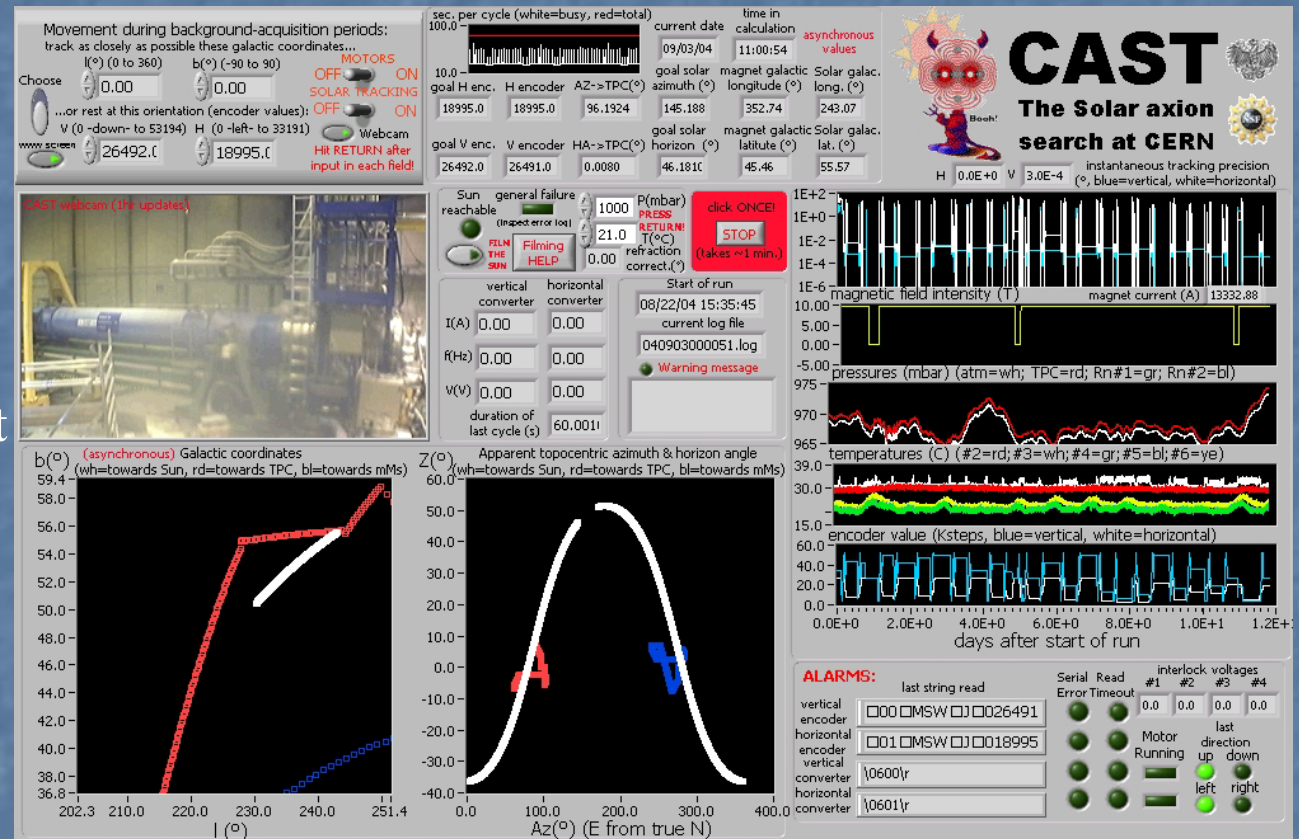
→ *100 times better than any other !!*



CAST: Magnet, tracking

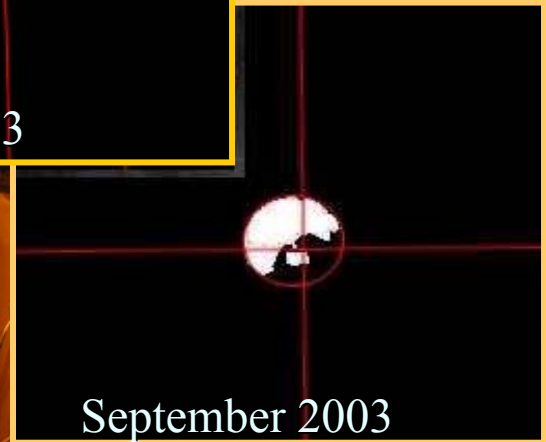
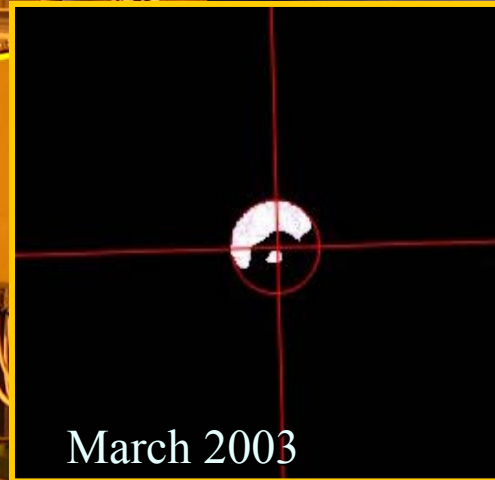
Snapshot of the tracking program

- Motors
- Encoders
- E. Readout → computer
- Software with astronomical calculations
- Interface to move magnet
- New angle encoders



Calibrated and correlated with celestial coordinates → high precision goniometer measurements (precision 0.01°)

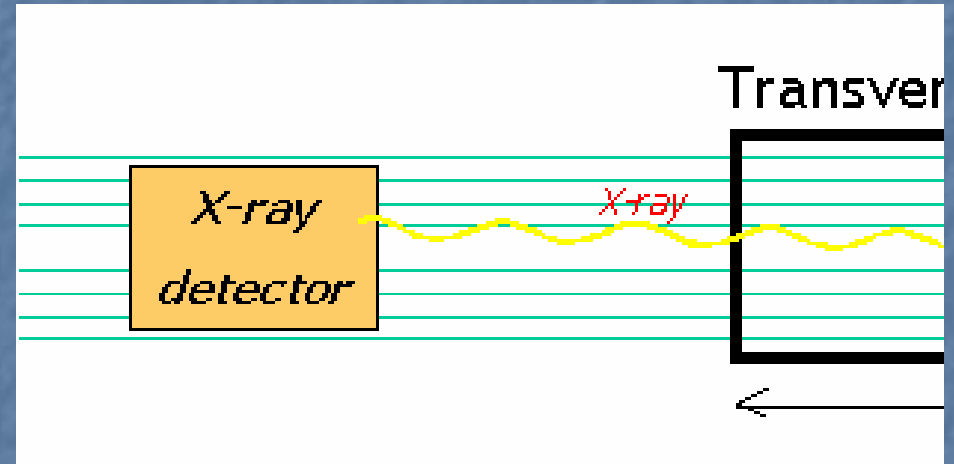
CAST: Magnet, tracking



Twice a year (September and March)
we can film the Sun through the
window

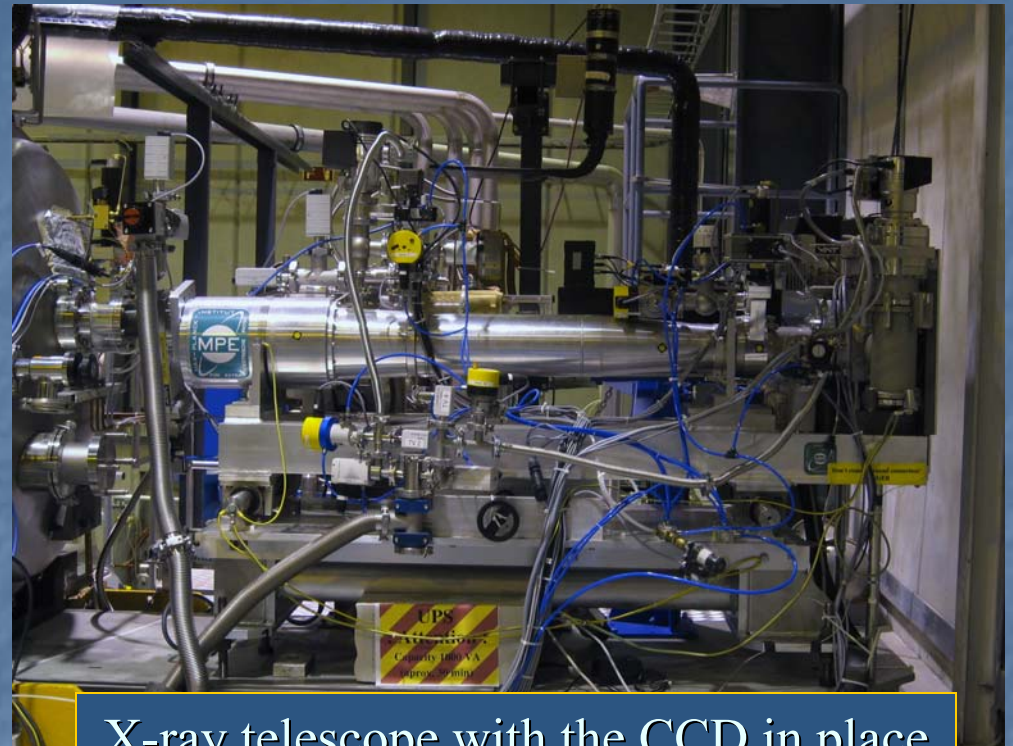
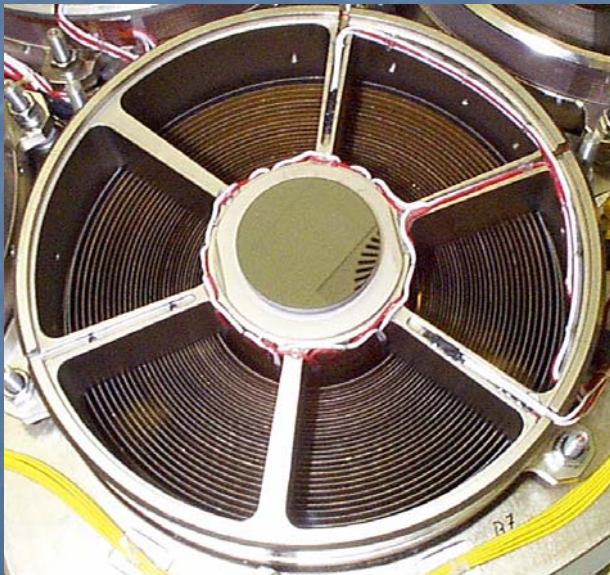
CAST: Telescope, detectors

- X-Ray Telescope
(Focusing Device)
- Detectors
 - CCD
 - Micromegas
 - TPC



CAST: X-ray telescope

Space technology:
prototype for the satellite ABRIXAS

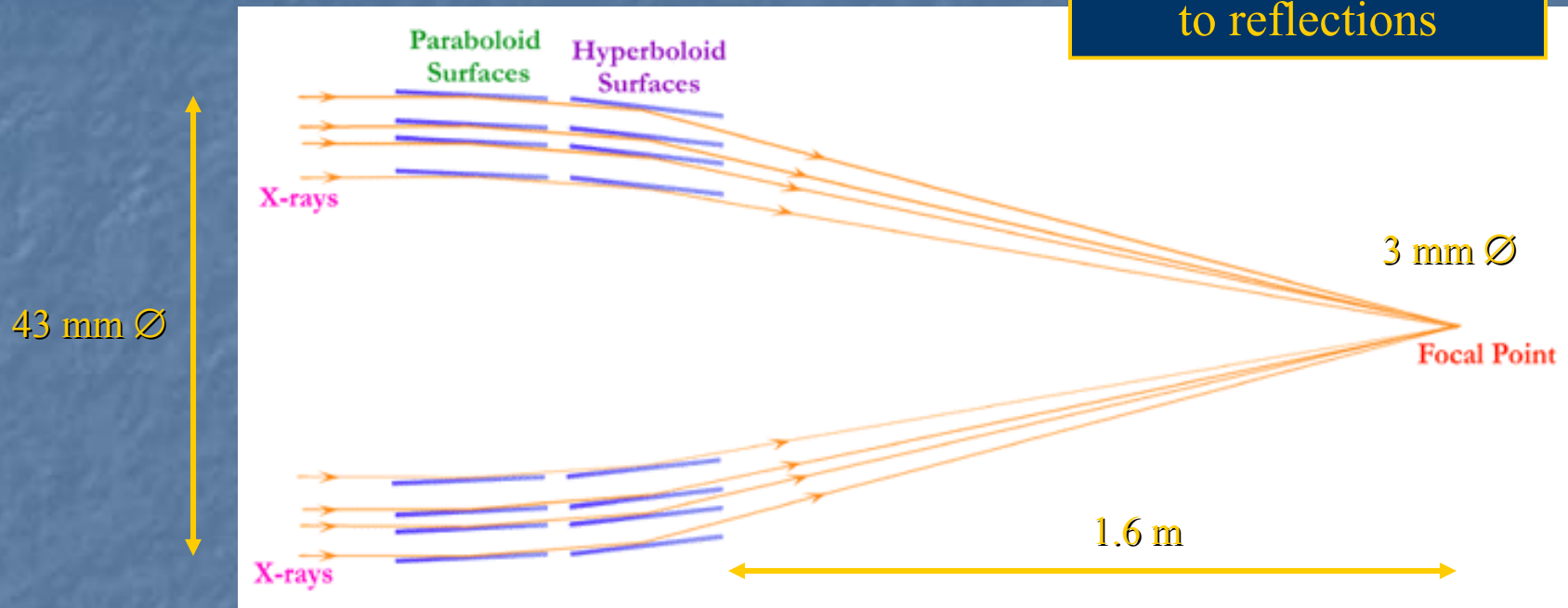


X-ray telescope with the CCD in place

- ⇒ 27 concentrically nested mirror shells:
- focal length 1.6 m
 - diameter 164 mm

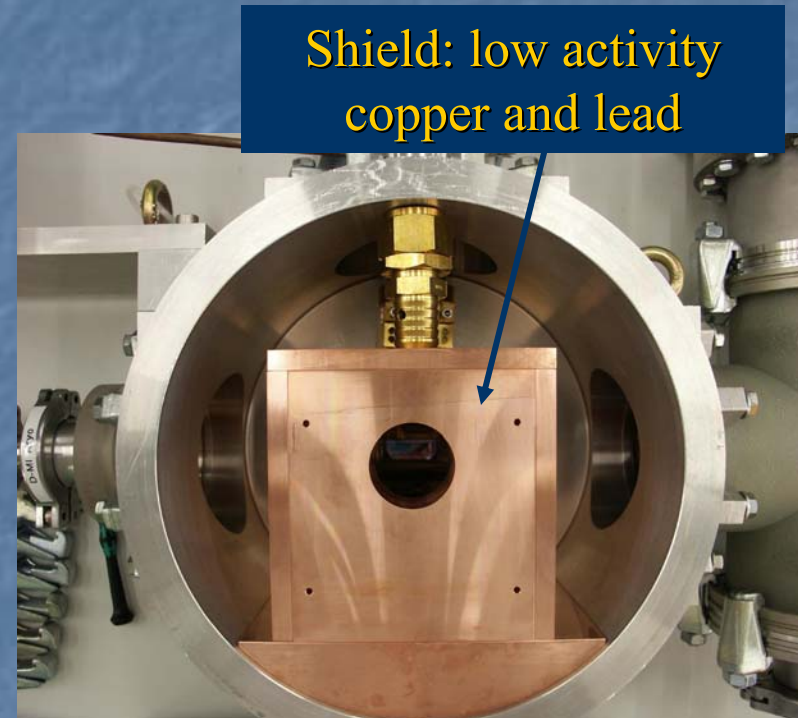
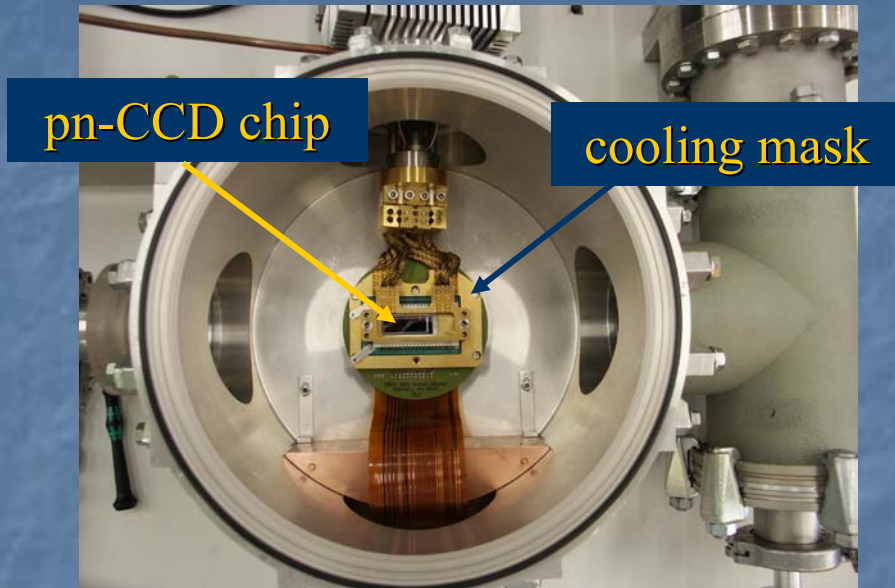
CAST: X-ray telescope

~35% efficiency due to reflections



- from 43 mm Ø (LHC magnet aperture) to ~3 mm Ø
- signal-to-noise improvement (up to 200!!!)

CAST: CCD



Geometry: 200×64 pixels (1×3 cm²)

Pixel size: 150×150 μm^2

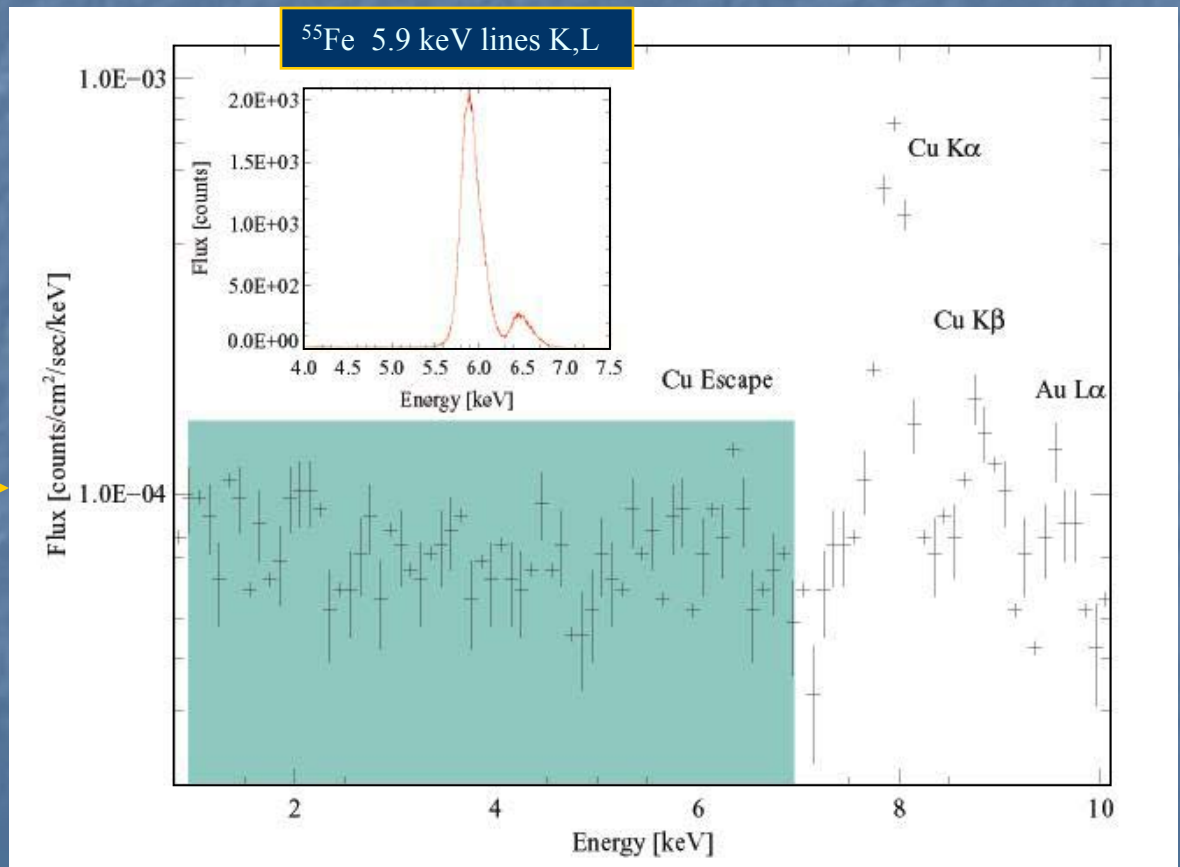
CCD temperature: -130° C

excellent space resolution

CAST: CCD

Efficiency (1-7 keV): $> 95\%$ → constrained only by telescope

FWHM: 160 eV @ 6 keV → excellent energy resolution



Background spectrum →

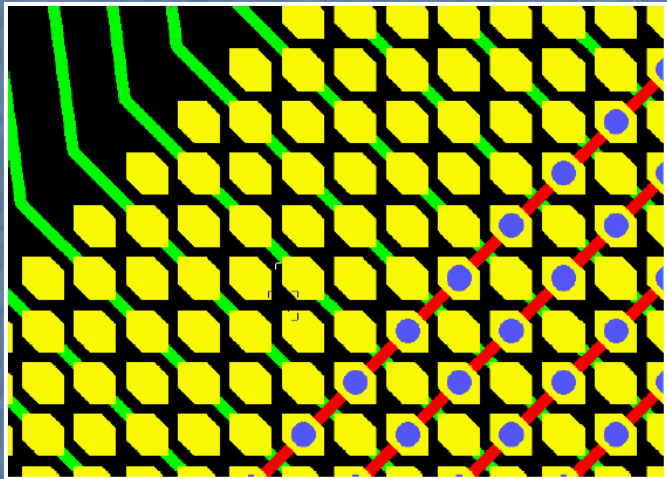
$\sim 10^{-4}$ counts keV⁻¹ s⁻¹ cm⁻²

(Cu and Au lines from the cooling mask)

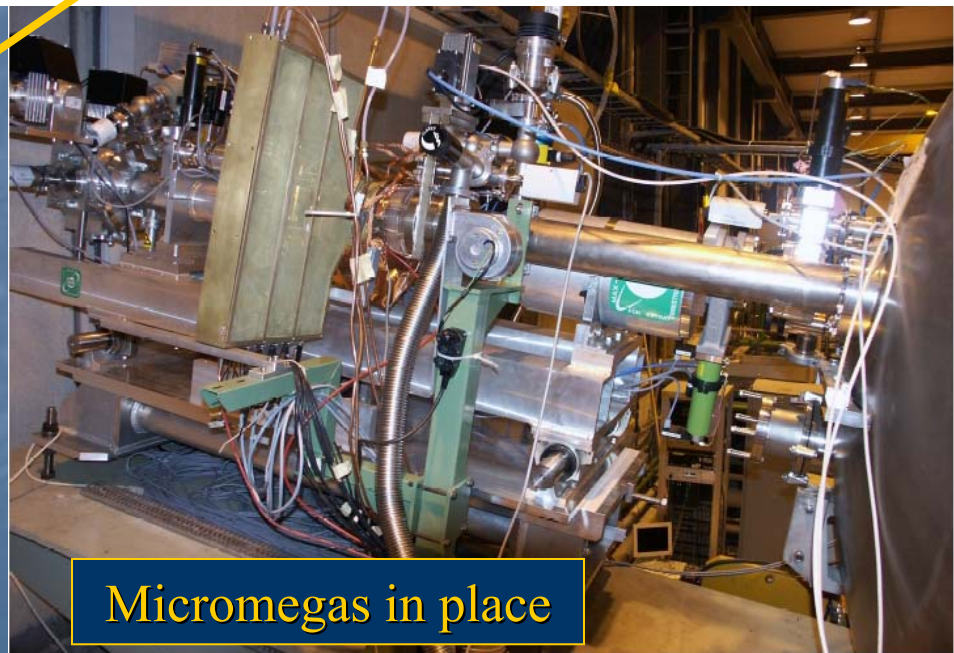
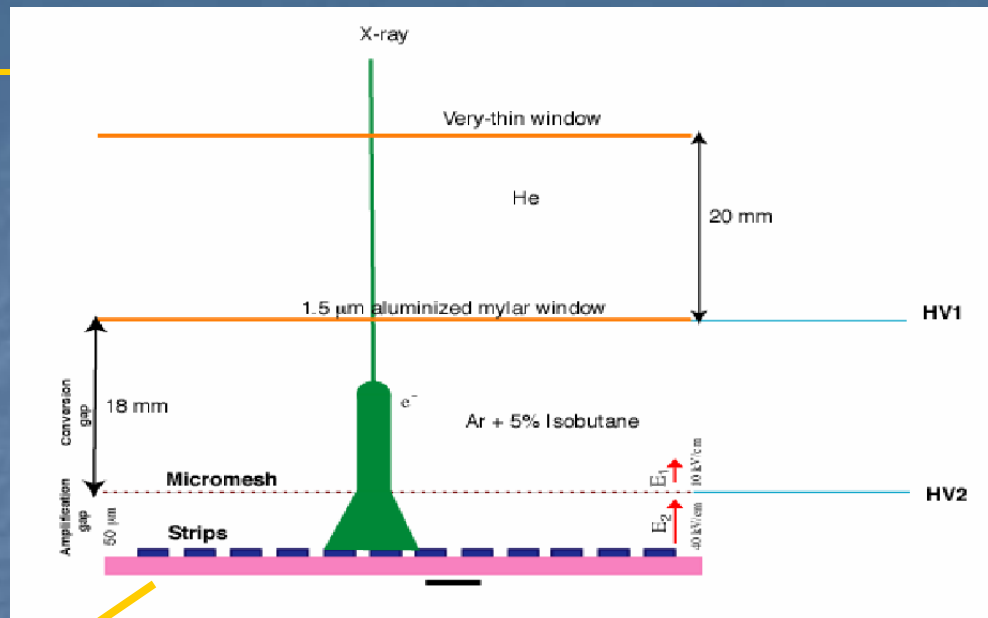
CAST: Micromegas

Gas: Ar 95%, Isobutane 5%

CAST prototype



192 charge collection strips for x
192 charge collection strips for y

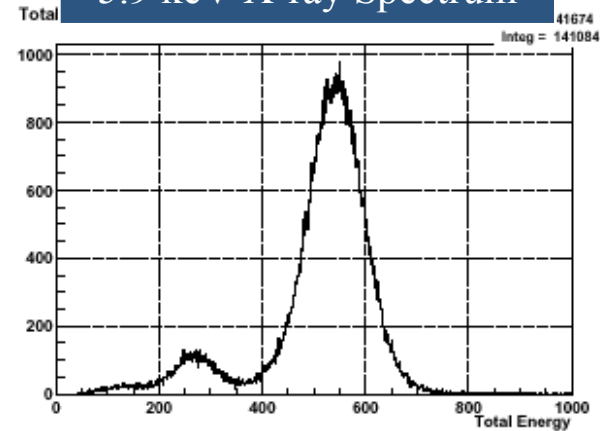


CAST: Micromegas

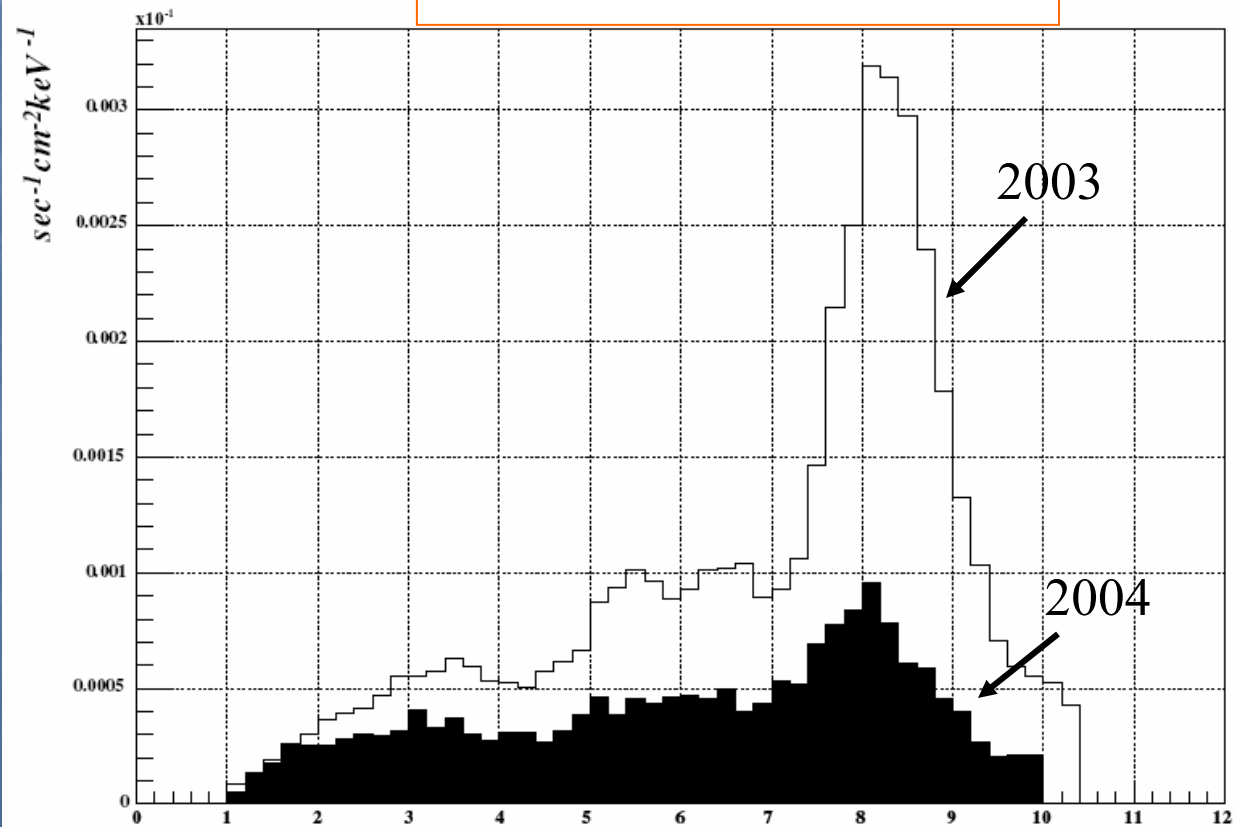
Background rate:

10^{-4} - 10^{-5} counts $s^{-1} cm^{-2} keV^{-1}$

5.9 keV X-ray Spectrum



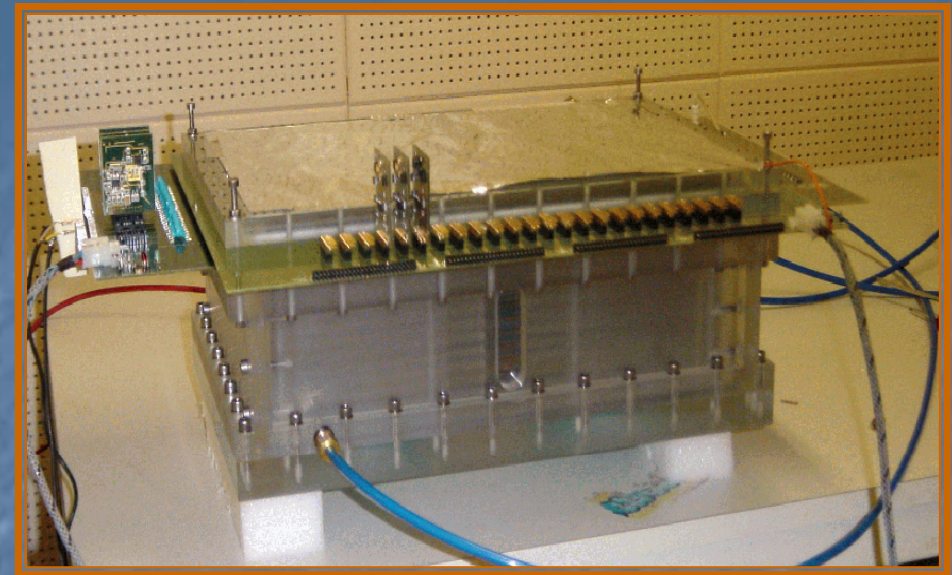
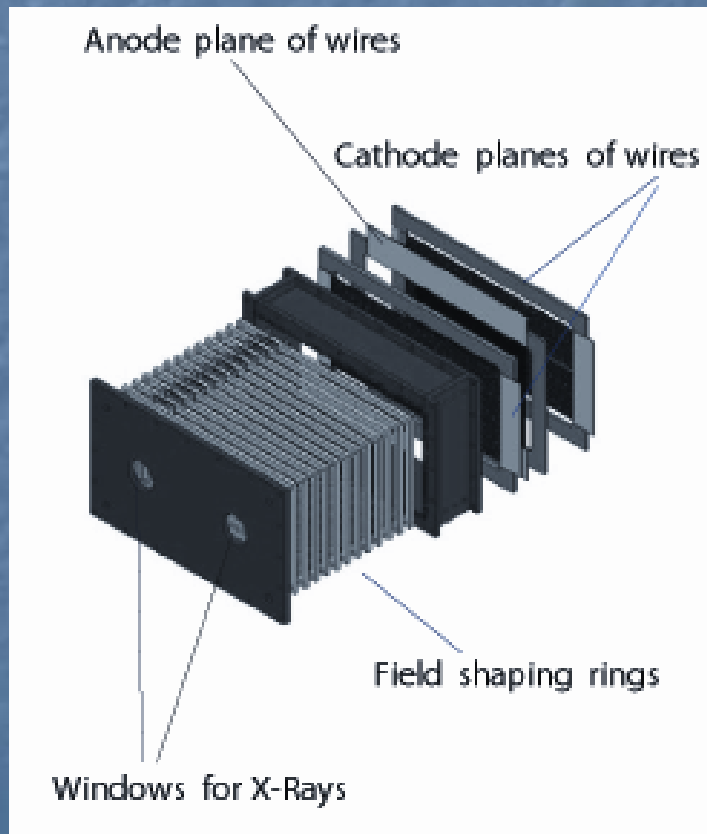
Background



CAST: TPC

Geometry: 30 cm × 15 cm × 10 cm

Gas: Ar 95%, CH₄ 5%



- Position sensitive (3 mm spacing)
- 48 anode wires (x)
- 96 cathode wires (y)

CAST: TPC

Clean materials + shielding
(polyethylene + copper + ancient lead)

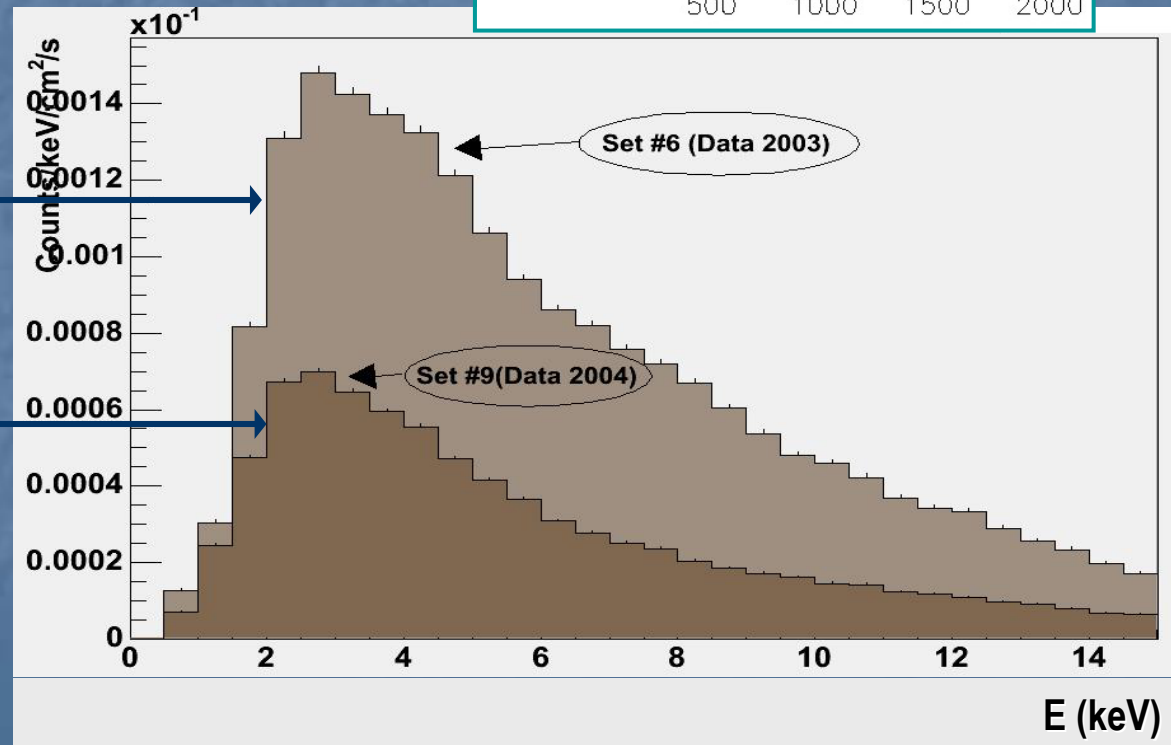
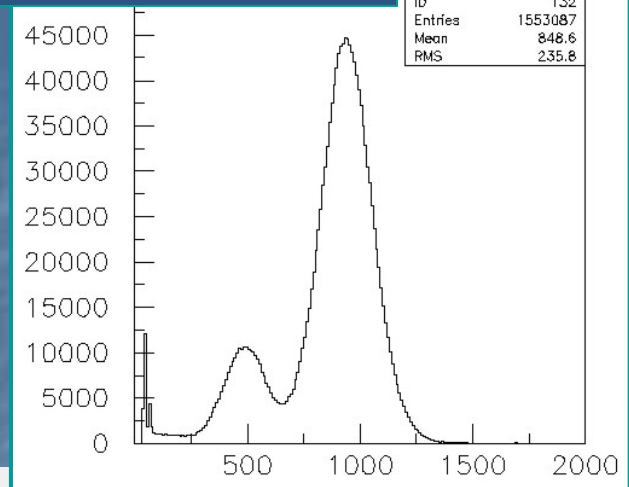
Integrated spectrum
from 1-10 keV:

$$9.3 \times 10^{-5} \text{ cts/keV/s/cm}^2$$

$$3.8 \times 10^{-5} \text{ cts/keV/s/cm}^2$$

There is an
improvement by a
factor of 2.4!!

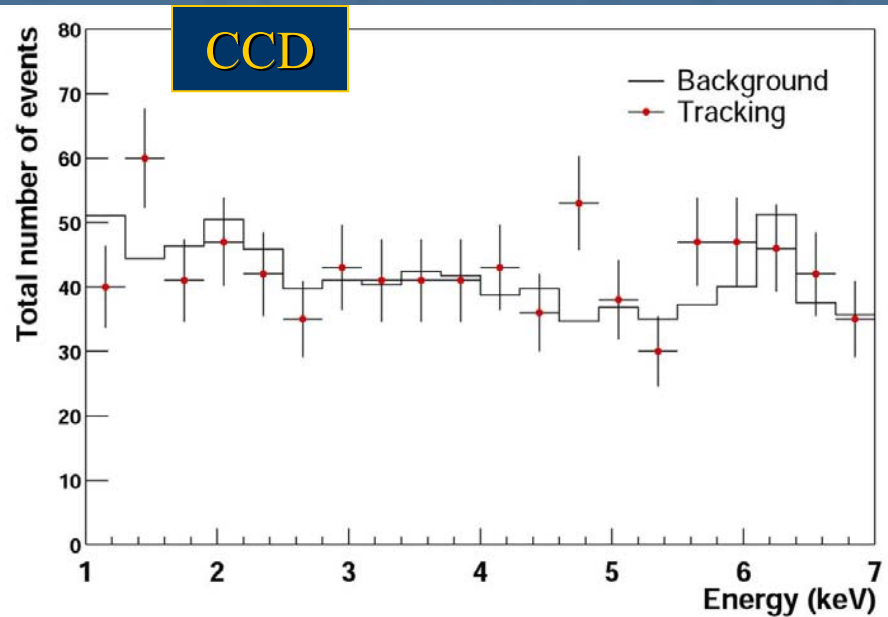
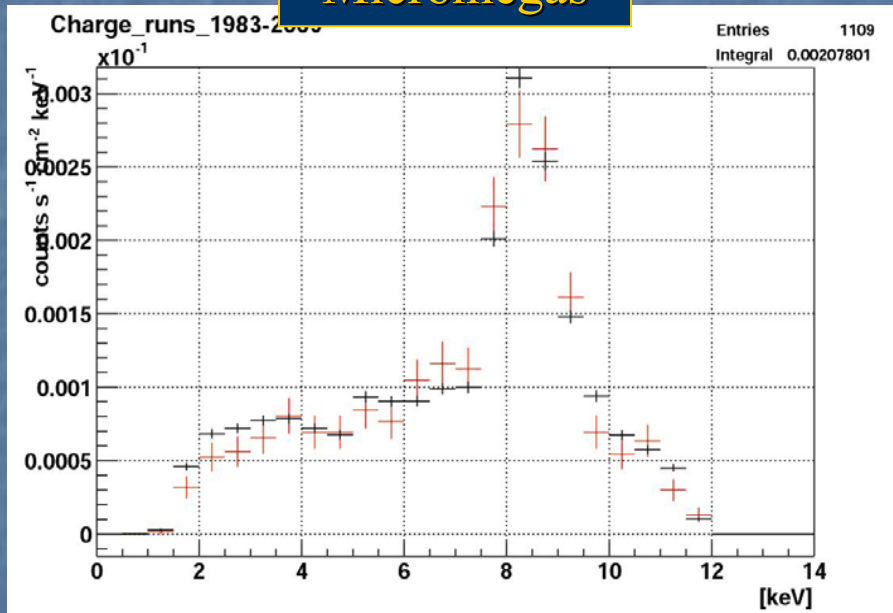
⁵⁵Fe Calibration spectrum



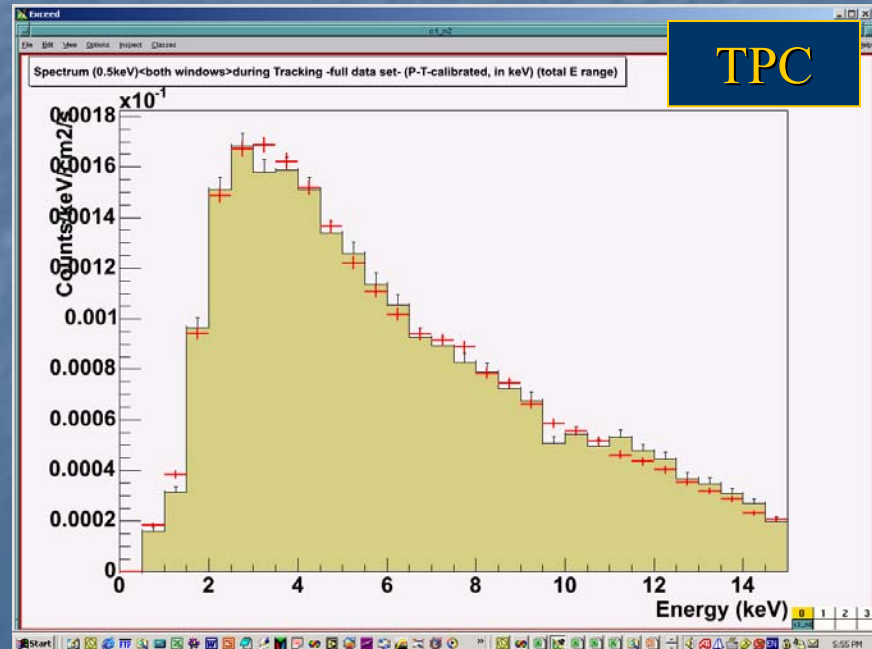
CAST: Analysis 2003

-no signal observed so far

Micromegas

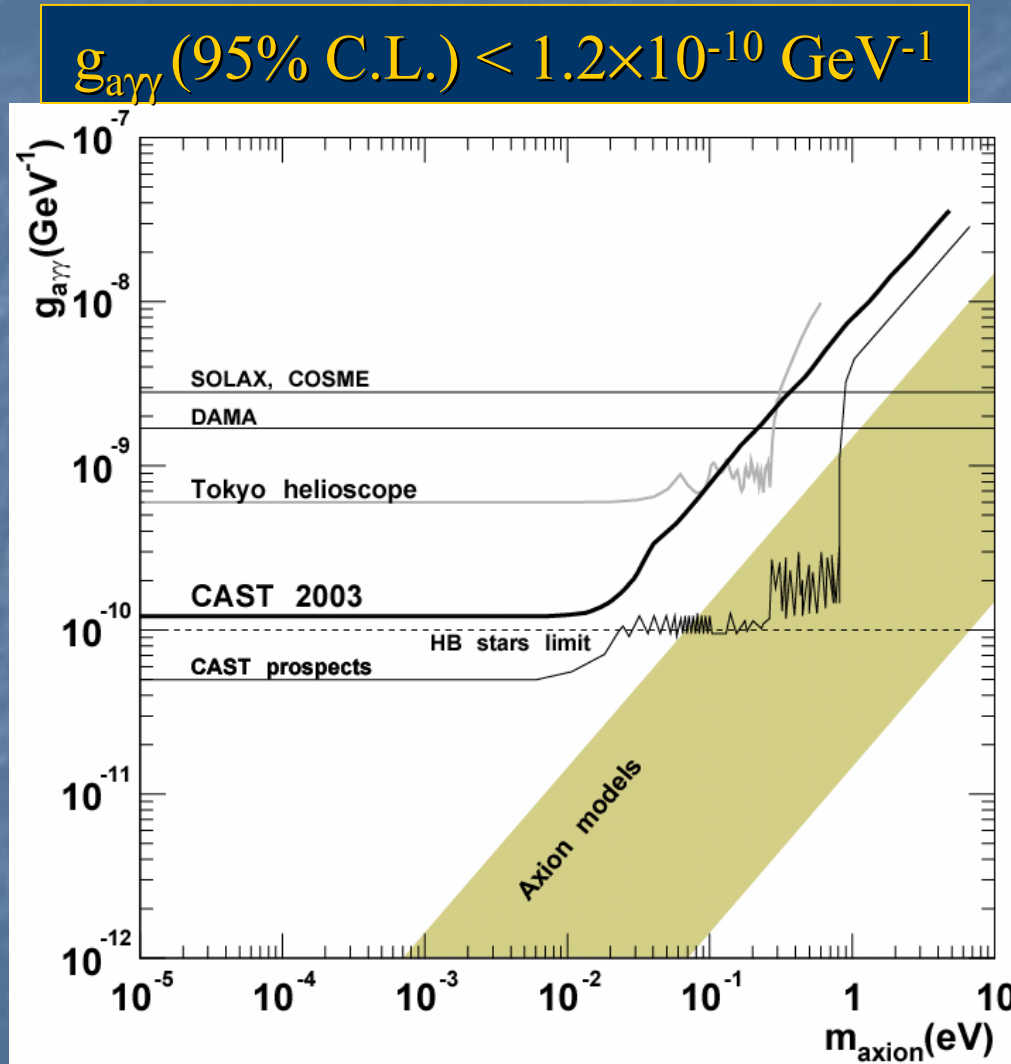


TPC



CAST: Analysis 2003

➤ Combined upper limit (preliminary !)



CAST: Prospects

Institute for Nuclear Research (INR) (3 participant(s)) Team Leader: Sergei GNINENKO

Alexandre BELOV, Sergei GNINENKO, Nikolai

- Vacuum in the magnet bores: **2003 & 2004**
- **PHASE 2:** ^4He & ^3He in the magnet bores \rightarrow to start in **2005 !**
- and also ...
- High energy axions: High energy calorimeter installed during 2004
- Axion astronomy
- 14.4 keV solar nuclear axion line
- Kaluza-Klein axions

European Organization for Nuclear Research
(CERN) (12 participant(s)) Team Leader: Martyn
DAVENPORT

Biljana Lakić

Klaus BARTH, Gino CIPOLLA, Martyn
DAVENPORT, Rui DE OLIVEIRA, Fabio
FORMENTIL, Jean-Noël JOLIX, Christian LASSEUR

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