A High Energy Axion Detector for CAST

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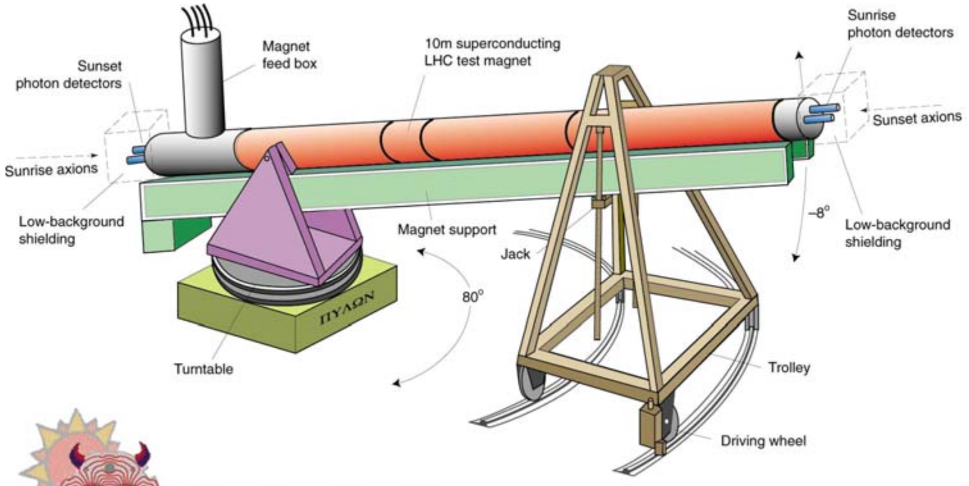
Abstract

We have installed a low background gamma ray detector using a scintillating crystal to perform a search for high energy axions with CAST. The calorimeter will operate at sea level and be sensitive to photon energies 0.3 – 200 MeV. While this is out of the range of thermal axions produced inside the sun, the detector will be sensitive to axions emitted in M1 nuclear transitions or electron-positron annihilation with a branching ratio into axion emission. We will begin taking data in Spring 2004.



Cern Axion Solar Telescope

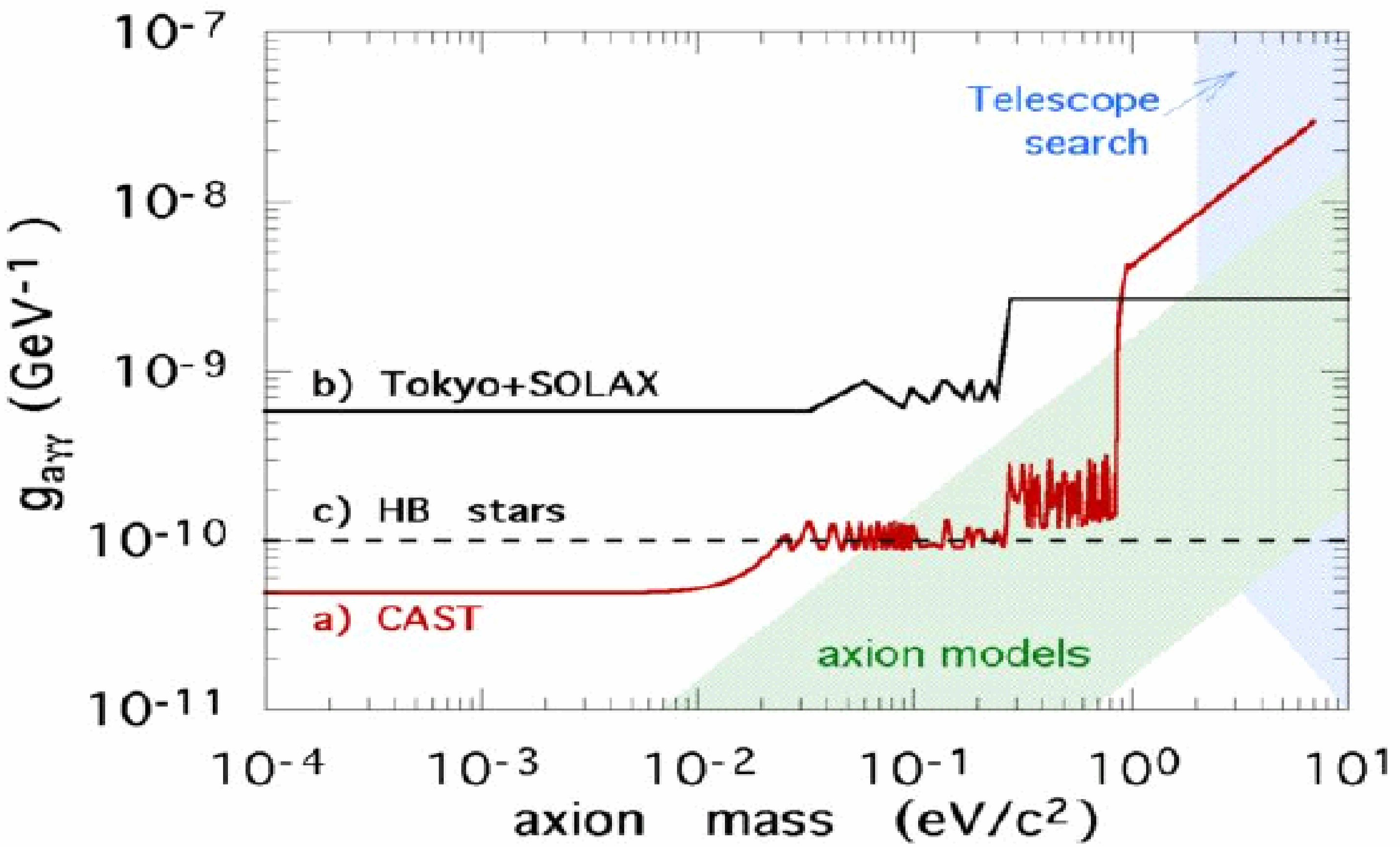
Seeing the Sun with "Invisible" Axions

Axions are hypothetical weakly interacting pseudoscalar bosons first proposed to explain the strong CP problem in QCD [1]. In addition, axions are one of the top particle candidates for galactic dark matter, provided the axion mass lies in the region 10^{-6} eV < m_a < 10^{-3} eV [2]. If axions exist, they would be copiously produced in the core of stars, making our Sun an ideal place to search for them.

The axion can couple to two photons via the Primakoff effect. This allows for the experimental detection of the axion by setting up a conversion EM field to provide a virtual photon for this interaction to take place (Fig. 1). In this scenario, the axion is converted in the magnet into a real and detectable photon with the same energy as the incident axion. The probability of this coherent conversion process , while small, goes as $P \sim (B\ L)^2$ where B is the intensity of the magnetic field and L is the length of the magnet.

While many methods have been employed to search for axions [3], this experiment will search primarily for solar axions using an axion helioscope (Fig. 2) which tracks the Sun at sunrise and sunset. The CERN Axion Solar Telescope (CAST) uses a 10 m, 9.5 T LHC dipole magnet (Fig.3) [4] with projected sensitivity two orders of magnitude more powerful than previous experiments, allowing experimental limits to surpass astrophysical constraints for the first time (Fig. 4).

The energy spectrum of solar axions peaks ~4.4 keV and tapers off beyond 10 keV. For this reason, the three detectors currently mounted on CAST are x-ray detectors, transparent to photon energies greater than a few tens of keV. The Chicago detector is designed to be placed behind one of the x-ray detectors to search for high energy axions. These higher energy axions may be produced, for instance, in M1 nuclear transitions in the Sun (Fig. 5) or positron-electron annihilations with a branching ratio to axions [5].



a) Attainable 99.7% c.l. limits on the coupling strength of axions to two photons as a function of axion rest mass in CAST (CERN Axion Solar Telescope).

b) Present experimental limits (Tokyo axion helioscope + SOLAX).

c) Astrophysical constraints (HB stars, theoretical).

Fig. 4 Expected axion limits attainable at CAST

•**Motivation for high energy axion detector**: If new boson couples to nucleons, it can substitute for a γ in plasma and nuclear processes. Solar luminosity via axion emission can be as high as few % of total. Search with helioscope has not been performed before.

→ Weak experimental limits already exist from observed solar γ flux below 5.5 MeV ($a \rightarrow \gamma\gamma$ following $p + d \rightarrow He + a$).

→ Other reactions of interest exist (e.g., 2.2 MeV from $p + n \rightarrow d + a$, 511 keV from $e^+ + e^- \rightarrow a + \gamma$, 477 keV from $^7Be + e^- \rightarrow {}^7Li^* + \nu_e$, etc.)

→ A generic search should not be limited to M1 transitions. Should surpass sensitivity of searches for anomalous production of single γ's in accelerators. May surpass sensitivity to small branching ratios (~<10^{-5}-10^{-6}) in laboratory searches. (calculation of expected sensitivity in progress)

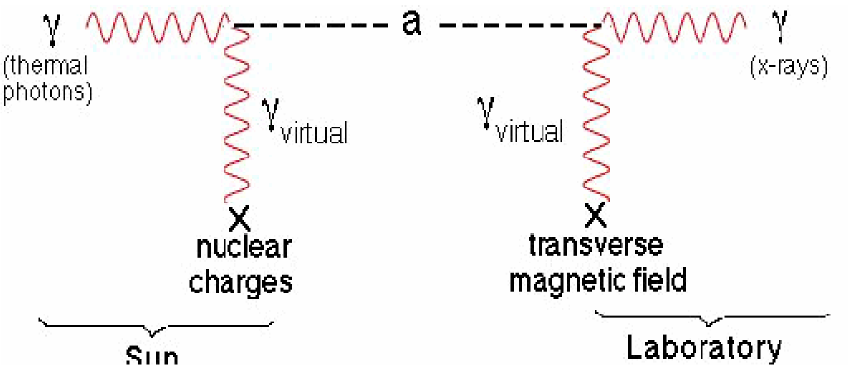


Fig. 1 Axion production in the Sun and detection in the laboratory via the Primakoff Effect.

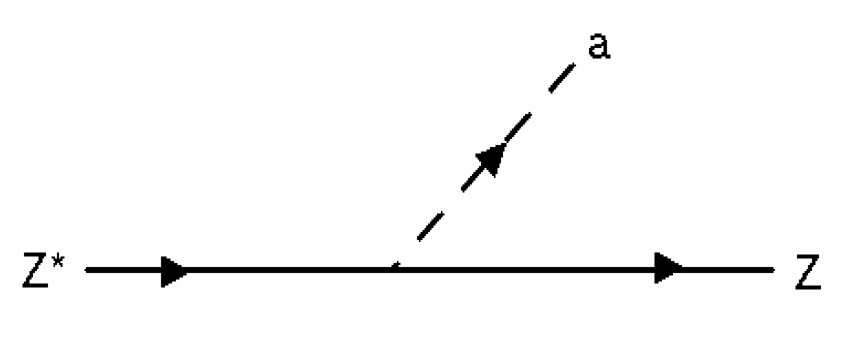
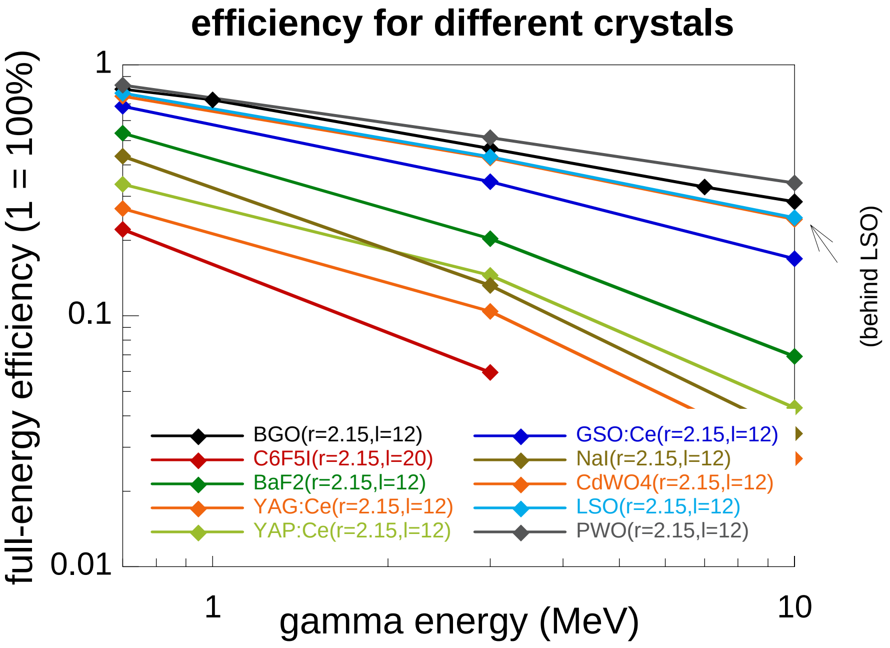


Fig. 5 An excited nucleus emits an axion in an M1 transition

Calorimeter Properties

- Large low-background CWO inorganic crystal scintillator (0.6 kg)
- 200 keV threshold
- 200 MeV dynamic range (can increase this but efficiency becomes very low)
- 12.8% resolution at 835 keV measured in CAST area
- Muon veto efficiency > 97% (not yet optimized → 99.5% efficiency was achieved previously in Chicago)
- > 90% livetime (measured with LED pulser)
- Background still not optimized (radon displacement and pulse shape discrimination cuts not yet implemented).
- ~ 5 Hz raw counting rate measured in CAST experimental area in February 2004

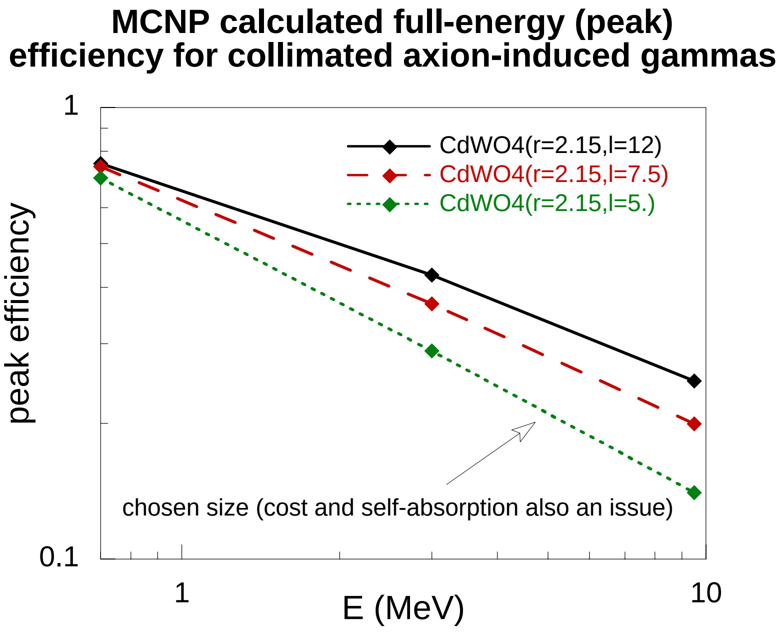


efficiency for different crystals

Decisions, decisions:

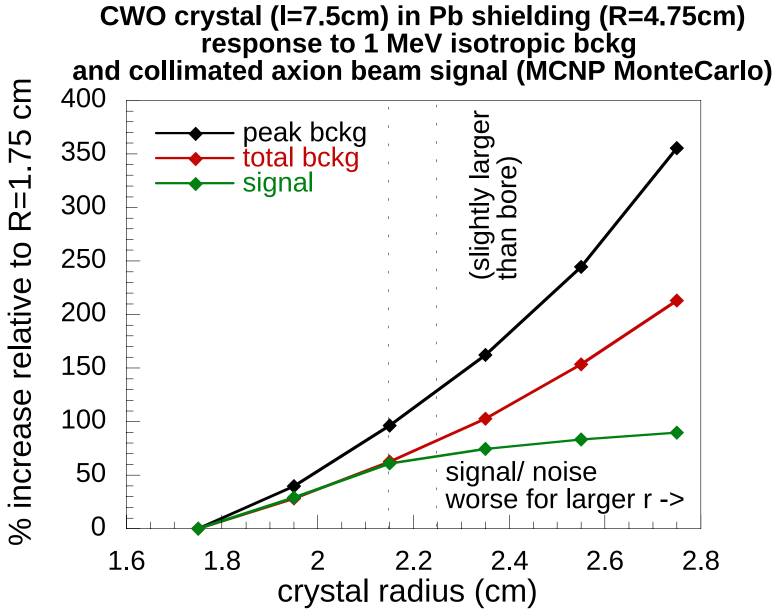
Monte Carlo of inorganic crystal response reduced best choices to BGO or CWO (PWO has too low a light yield)

Choice of optimal crystal length and radius via Monte Carlo of collimated signal and isotropic backgrounds. Crystal must be well-aligned with magnet bore (only slightly larger than it).



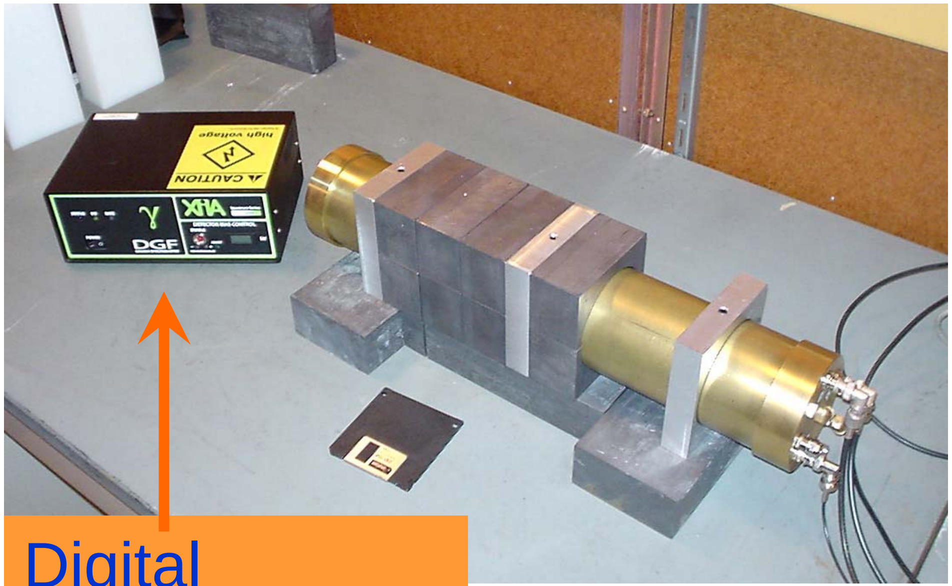
MCNP calculated full-energy (peak) efficiency for collimated axion-induced gammas

chosen size (cost and self-absorption also an issue)



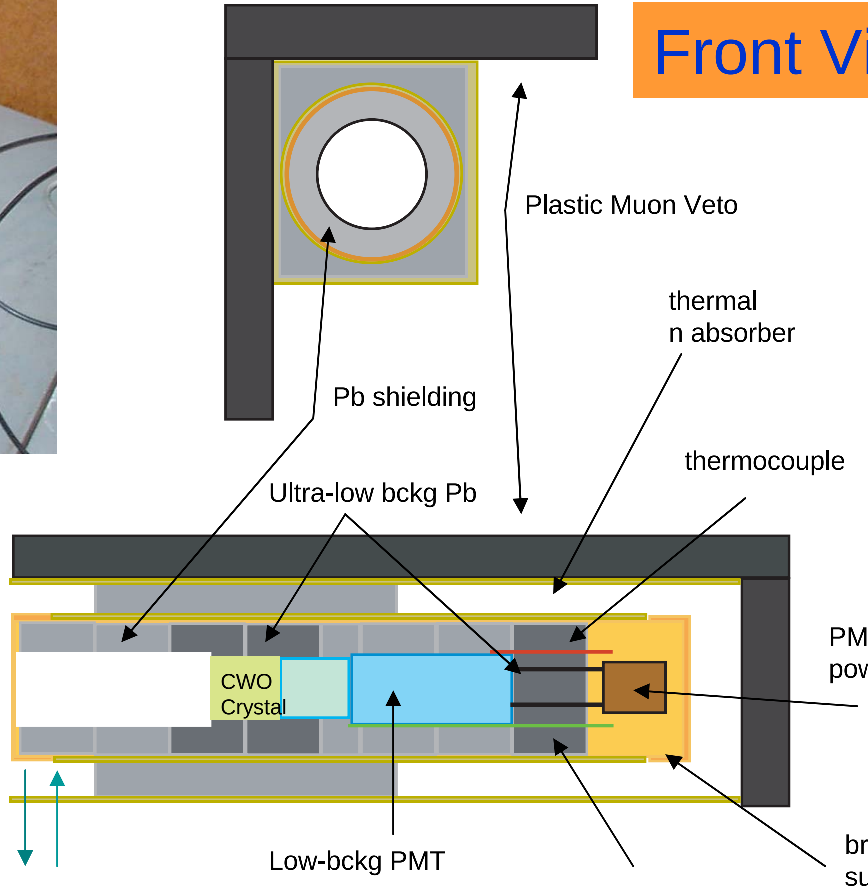
CWO crystal (l=7.5cm) in Pb shielding (R=4.75cm) response to 1 MeV isotropic bckg and collimated axion beam signal (MCNP MonteCarlo)

signal/ noise worse for larger r ->



Digital spectrometer + DAQ

Front View



Plastic Muon Veto

thermal n absorber

Pb shielding

thermocouple

Ultra-low bckg Pb

Thin brass end cap and window

CWO Crystal

PMT power base

Incoming gammas (magnet bore)

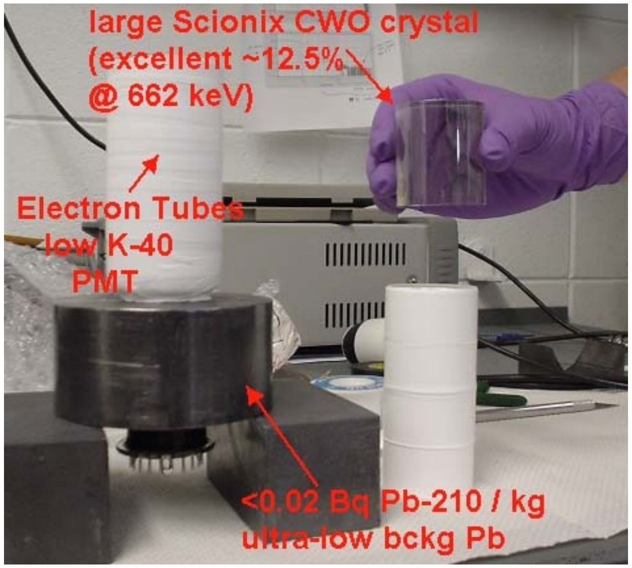
Low-bckg PMT

(< 20 ^{40}K gamma / day)

Fiber optic and LED

brass support tube

Rn displacement (N2 purge gas)

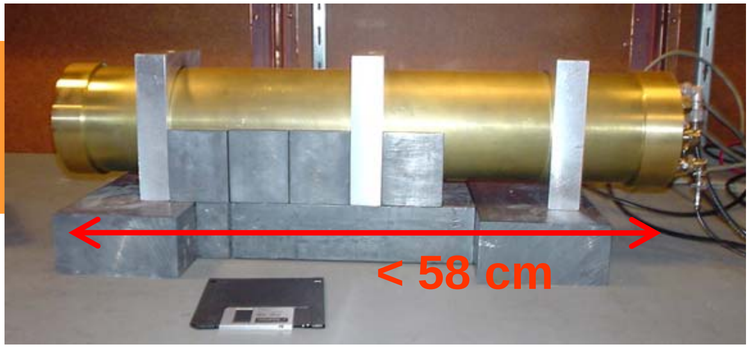


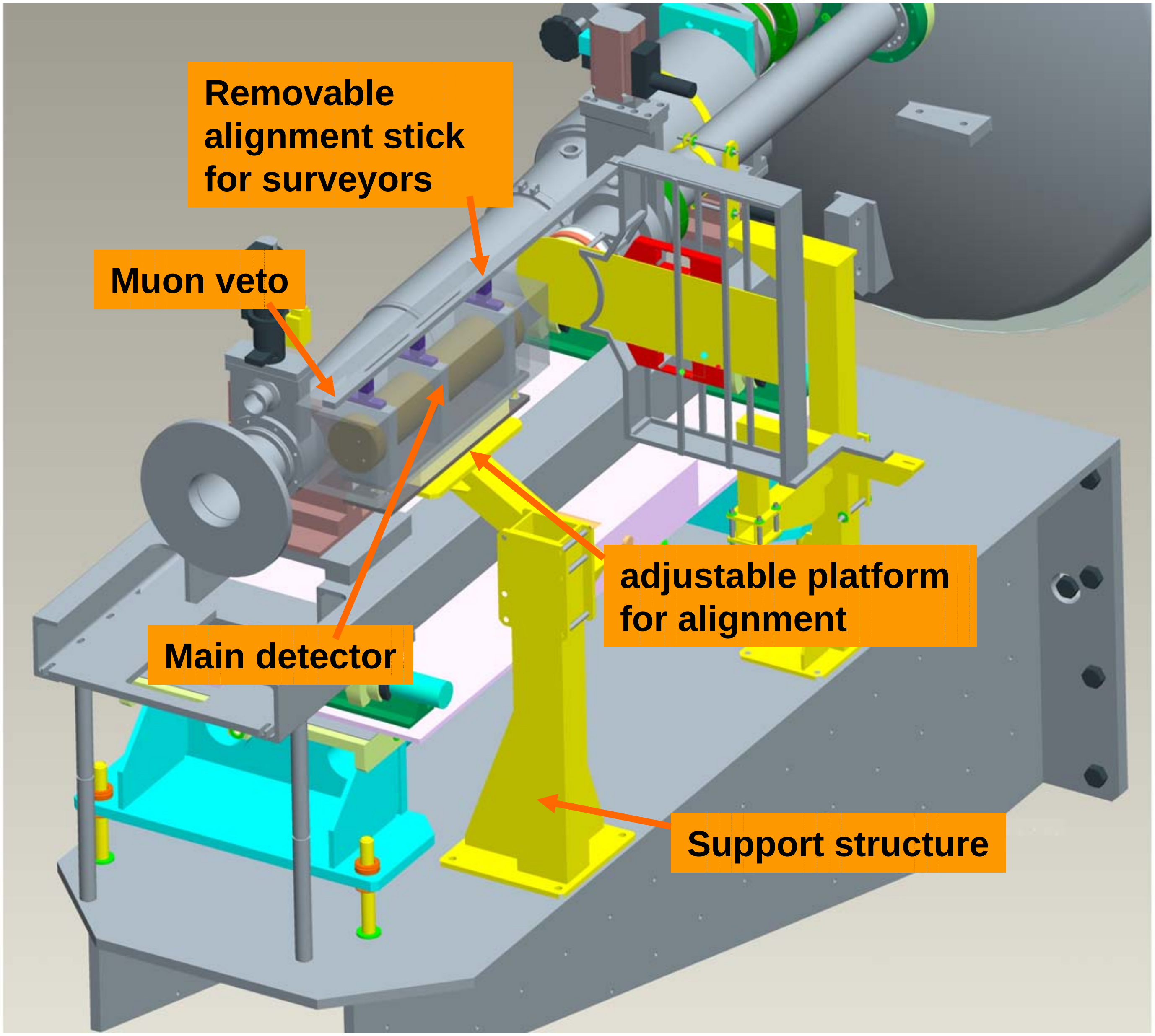
large Scionix CWO crystal (excellent ~12.5% @ 662 keV)

Electron Tubes low K-40 PMT

<0.02 Bq Pb-210 / kg ultra-low bckg Pb

Side View





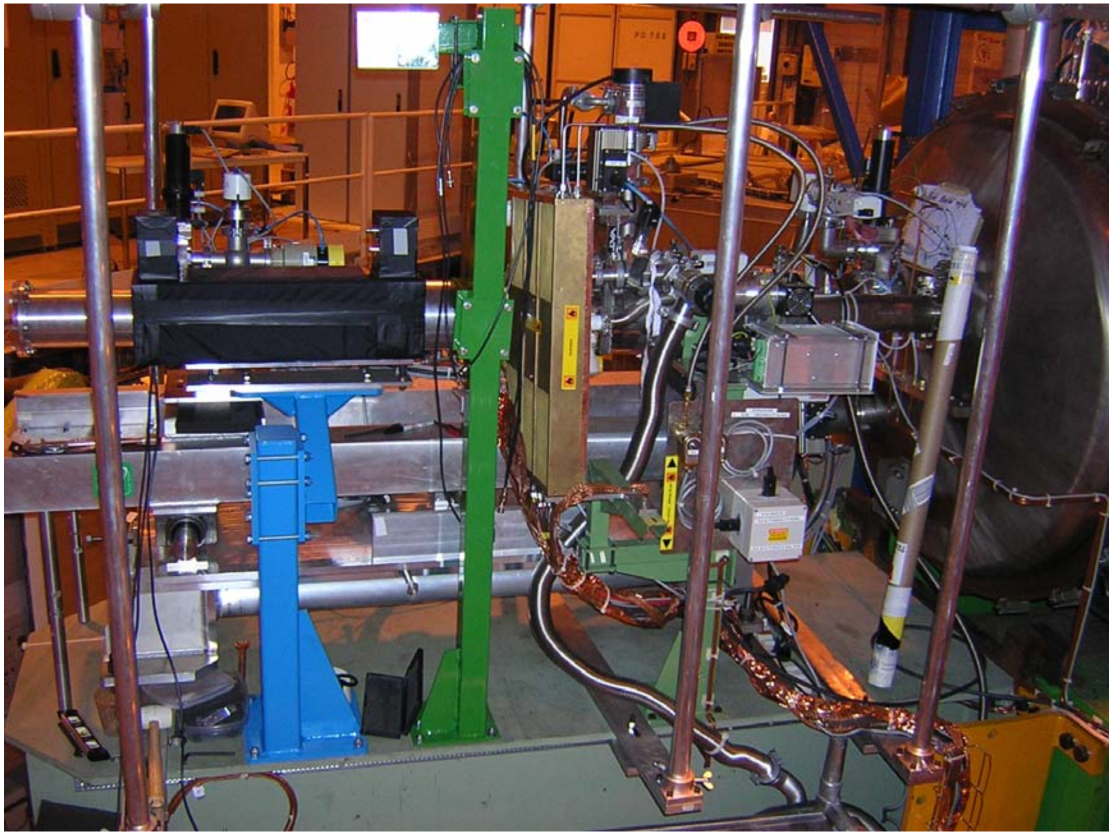
Removable alignment stick for surveyors

Muon veto

Main detector

adjustable platform for alignment

Support structure

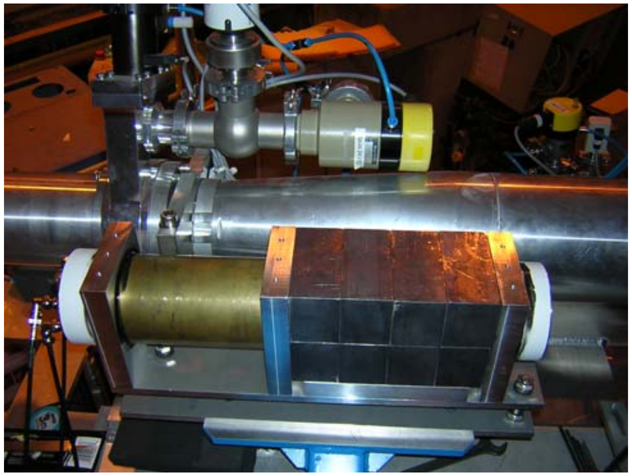


The Calorimeter is INSTALLED and OPERATIONAL.

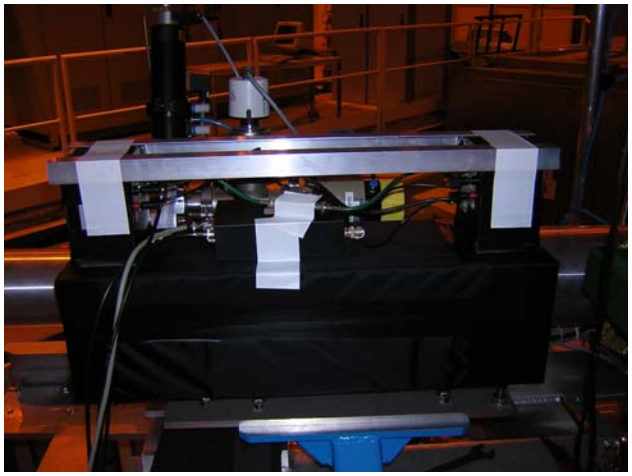
These pictures show the detector and the back end of the decommissioned LHC magnet immediately after installation

The detector sits behind the MicroMegas detector and beside the CCD telescope

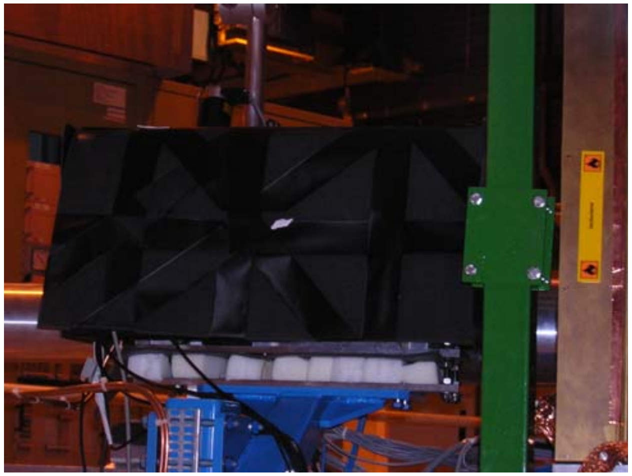
Detector + Pb shielding

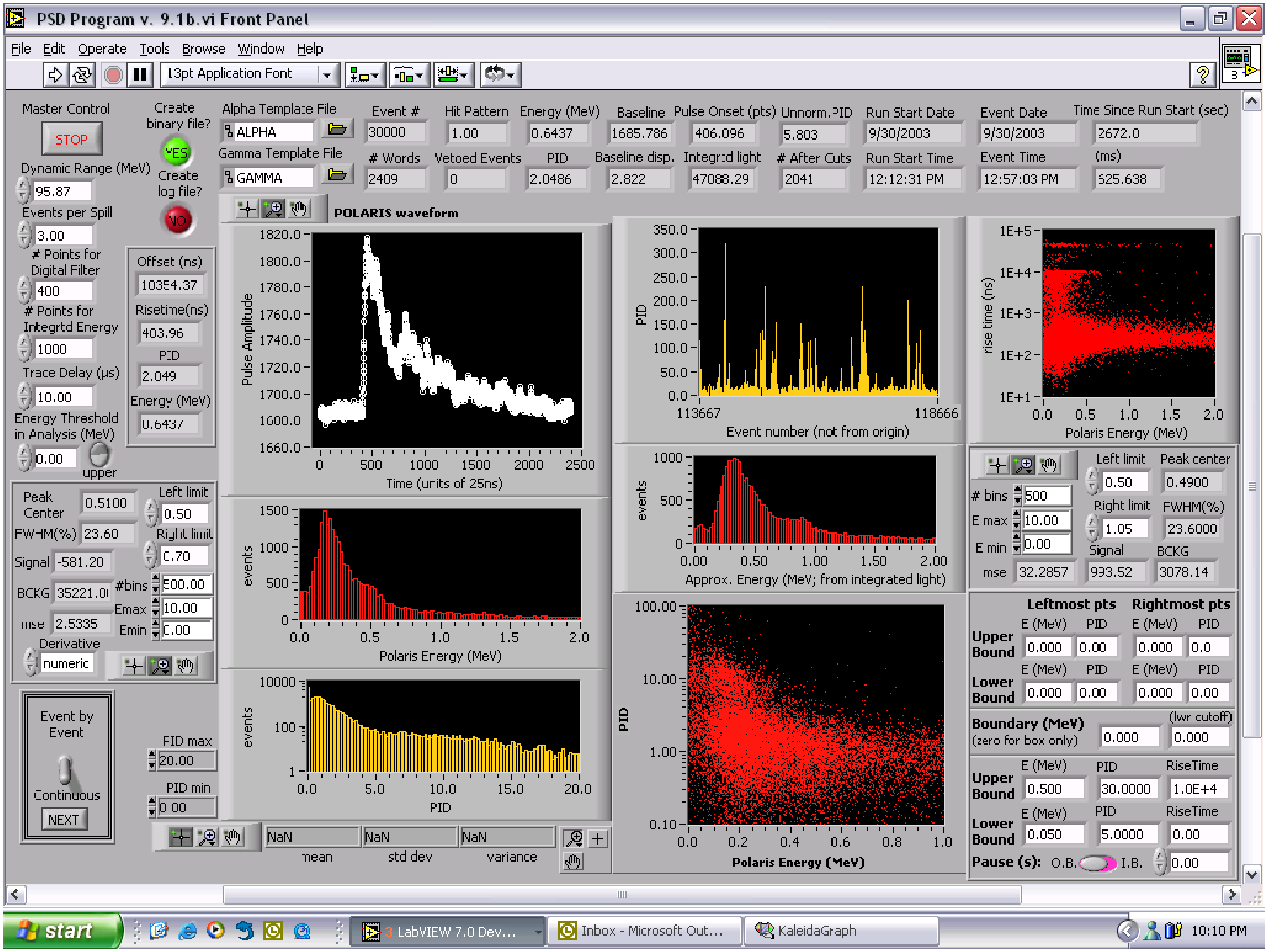


+ Muon Veto



+ thermal neutron absorber





Master Control: STOP

Create binary file? YES

Create log file? NO

Dynamic Range (MeV) 95.87

Events per Spill 3.00

Points for Digital Filter 400

Points for Integrtd Energy 1000

Trace Delay (µs) 10.00

Energy Threshold in Analysis (MeV) 0.00 upper

Offset (ns) 10354.37

Risetime(ns) 403.96

PID 2.049

Energy (MeV) 0.6437

Alpha Template File ALPHA

Gamma Template File GAMMA

Event # 30000

Words 2409

Hit Pattern 1.00

Vetoed Events 0

Energy (MeV) 0.6437

PID 2.0486

Baseline 1685.786

Baseline disp. 2.822

Pulse Onset (pts) 406.096

Integrtd light 47088.29

Unnorm.PID 5.803

After Cuts 2041

Run Start Date 9/30/2003

Run Start Time 12:12:31 PM

Event Date 9/30/2003

Event Time 12:57:03 PM

Time Since Run Start (sec) 2672.0

(ms) 625.638

Peak Center 0.5100

FWHM(%) 23.60

Signal -581.20

BCKG 35221.0

mse 2.5335

Derivative numeric

Left limit 0.50

Right limit 0.70

#bins 500.00

Emax 10.00

Emin 0.00

Event by Event / Continuous

NEXT

PID max 20.00

PID min 0.00

NaN mean

NaN std dev.

NaN variance

Left limit 0.50

Peak center 0.4900

bins 500

E max 10.00

E min 0.00

Right limit 1.05

FWHM(%) 23.6000

Signal 993.52

BCKG 3078.14

mse 32.2857

	Leftmost pts		Rightmost pts	
	E (MeV)	PID	E (MeV)	PID
Upper Bound	0.000	0.00	0.000	0.0
Lower Bound	0.000	0.00	0.000	0.00

Boundary (MeV) (zero for box only) 0.000

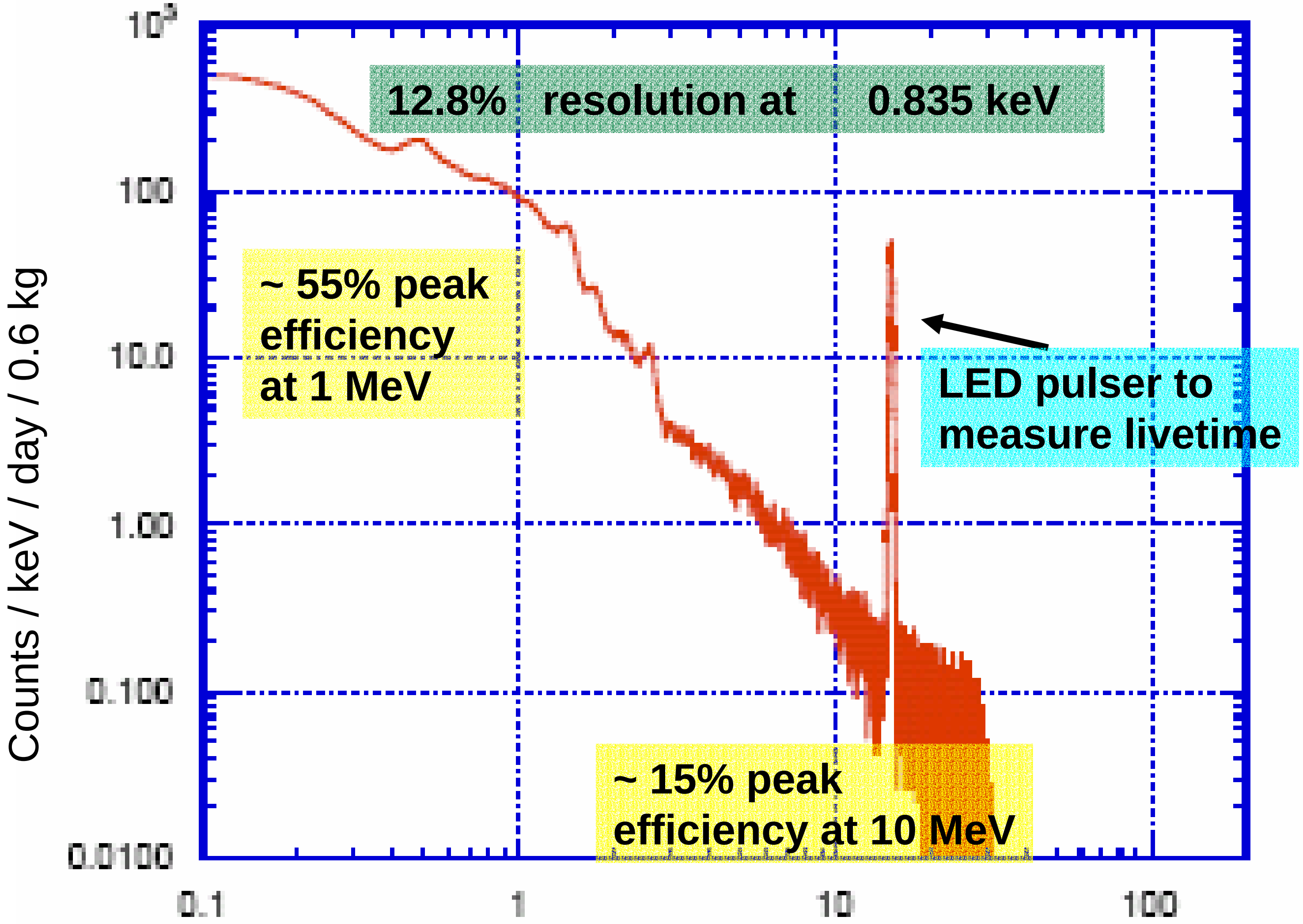
(lwr cutoff) 0.000

	E (MeV)	PID	RiseTime
Upper Bound	0.500	30.0000	1.0E+4
Lower Bound	0.050	5.0000	0.00

Pause (s): O.B. I.B. 0.00

analysis program for pulse shape discrimination

Calorimeter Background Spectrum taken in CAST Experimental Area February 2004



12.8% resolution at 0.835 keV

~ 55% peak efficiency at 1 MeV

LED pulser to measure livetime

~ 15% peak efficiency at 10 MeV

Important! For this plot:
→ Muon veto was running!
→ NO PSD cuts were made!
→ No N2 flow (ie no Radon displacement).

Conclusion:

The detector is installed at CERN and we are now waiting for the CAST magnet to turn on to begin taking data.

References:

[1] H. Murayama. (Particle Data Group), Phys. Rev. D (2002)

[2] M. Turner. Phys. Rev. D 33. (1986) 889

[3] C. Hagmann, K. van Bibber, L. Rosenberg. (Particle Data Group), Physics Review D. (2002)

L. Rosenberg, K. van Bibber. “Searches for Invisible Axions”. Physics Reports. 325. (2000) 1

[4] K. Zioutas, et al. NIM A 425 (1999) 480

[5] G. Raffelt. Stars as Laboratories for Fundamental Physics. (1996) University of Chicago Press