The CAST experiment: status and perspectives

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On behalf of the CAST Collaboration

5th Patras Workshop, 13-17 July 2009

University of Durham

AXIONS

Strong CP Violation Problem

QCD predicts violation of CP strong interaction ➔ experimental consequence neutron electric dipole moment prediction $d_n \sim O(10^{-16})$ e·cm but experimental limit $d_n < 2.9\times10^{-26}$ e·cm

Peccei-Quinn: new global symmetry global spontaneously broken at energy scale f_a constructed to exclude CP-violating terms

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

Axion result of the spontaneous breaking of the PQ.
PQ symetry not perfect. Axion has a small mass

Axions properties

Neutral Pseudoscalar

Pratically stable

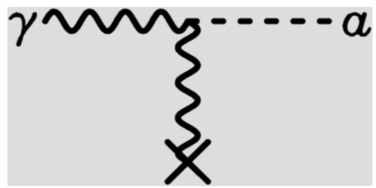
Very low mass

Very low cross-section

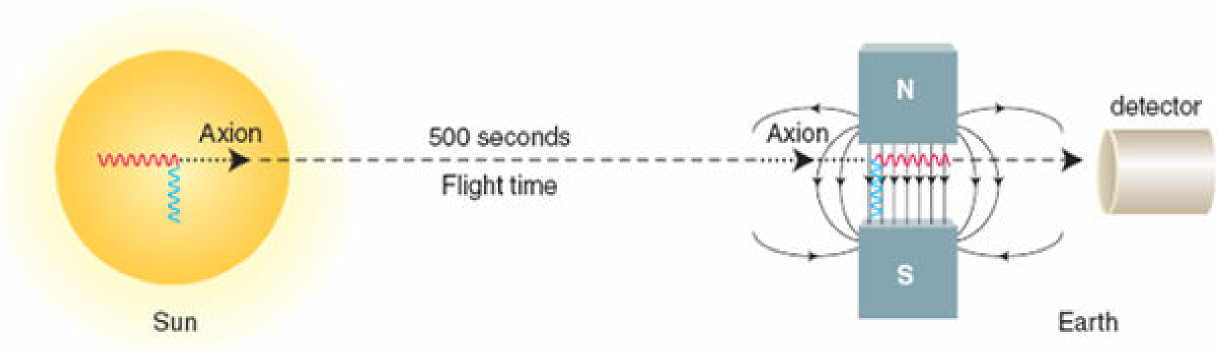
Coupling to photons

Primakoff Effect
Photon conversion into axion (or the inverse reaction)

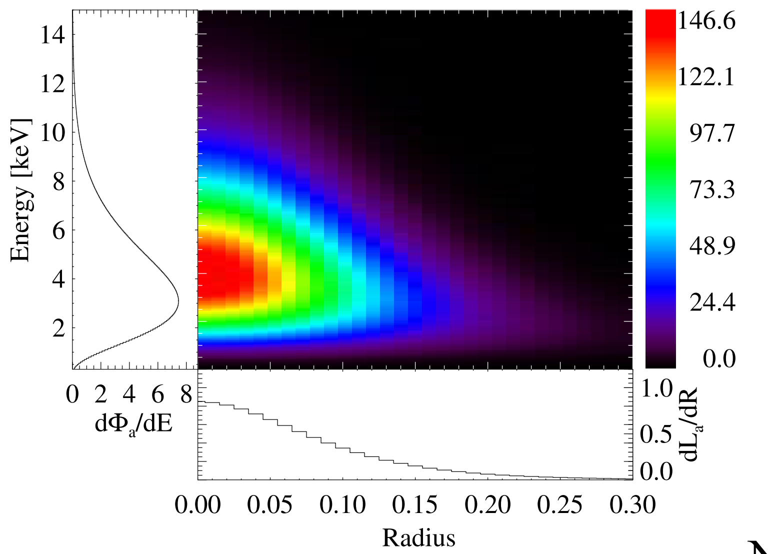
$$L_{a\gamma\gamma} = g_{a\gamma\gamma}(\vec{E}\cdot\vec{B})a$$

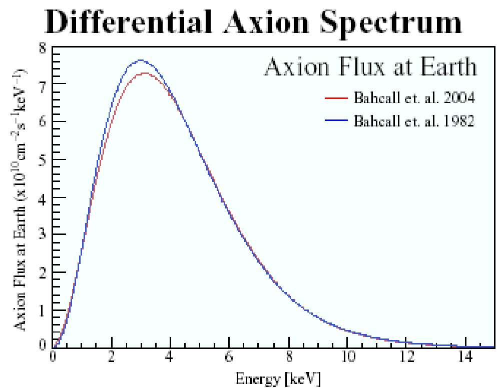


PRINCIPLE OF DETECTION



Helioscope technique





$$\Phi_a \approx 3.67\times10^{11}\,\mathrm{cm^{-2}s^{-1}}\left(\frac{g_{a\gamma\gamma}}{10^{-10}\,\mathrm{GeV^{-1}}}\right)^2$$

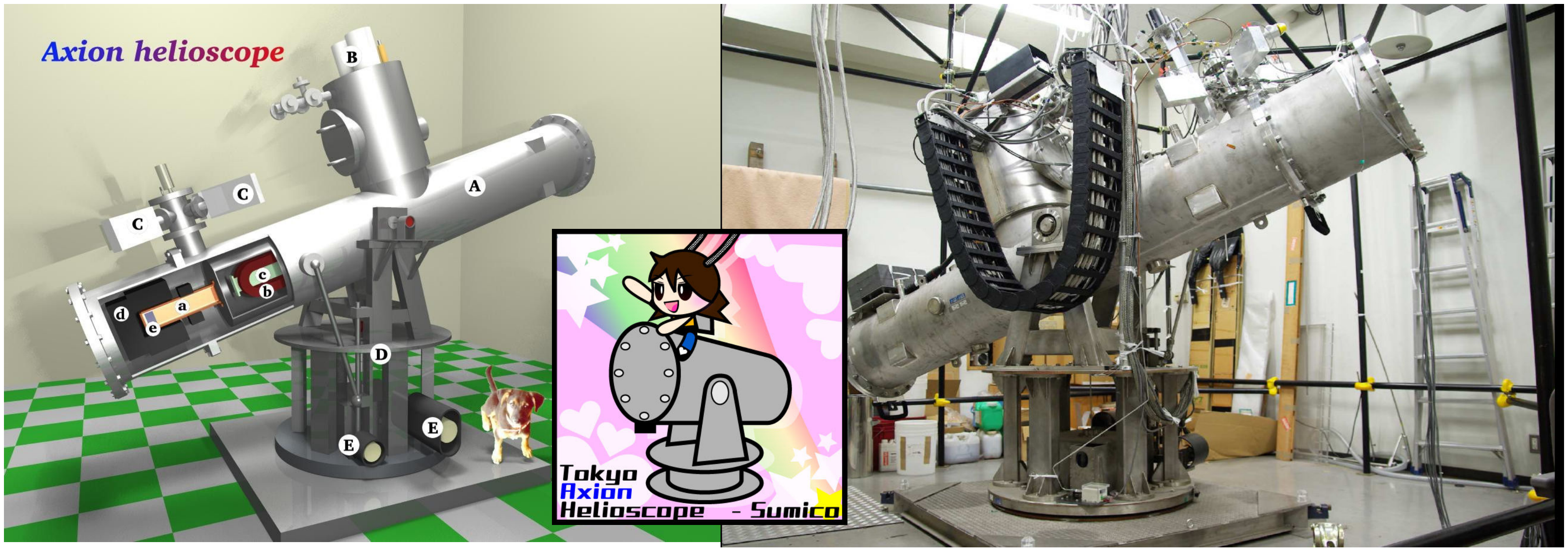
$$N_\gamma = \Phi_a \cdot A \cdot P_{a\to\gamma}$$

$$P_{a\to\gamma} = 1.7\times10^{-17}\left(\frac{B\cdot L}{9.0\mathrm{T}\cdot 9.3\mathrm{m}}\right)^2\left(\frac{g_{a\gamma\gamma}}{10^{-10}\,\mathrm{GeV^{-1}}}\right)^2$$

≈ 7 evts/day with $g_{a\gamma\gamma} = 10^{-10}$ GeV^{-1} and A = 14 cm^2

OTHER HELIOSCOPES

- Brookhaven (a few hours of data): Lazarus et al. PRL 69 (92)
- Tokyo Helioscope (SUMICO): 2.3 m long 4 T magnet



Inoue et al. **Phys.Lett.B668:93-97,2008**.

Talk from R. Ohta this afternoon

CERN AXION SOLAR TELESCOPE
CAST

LHC dipole : L = 9.3 m, B = 9 T

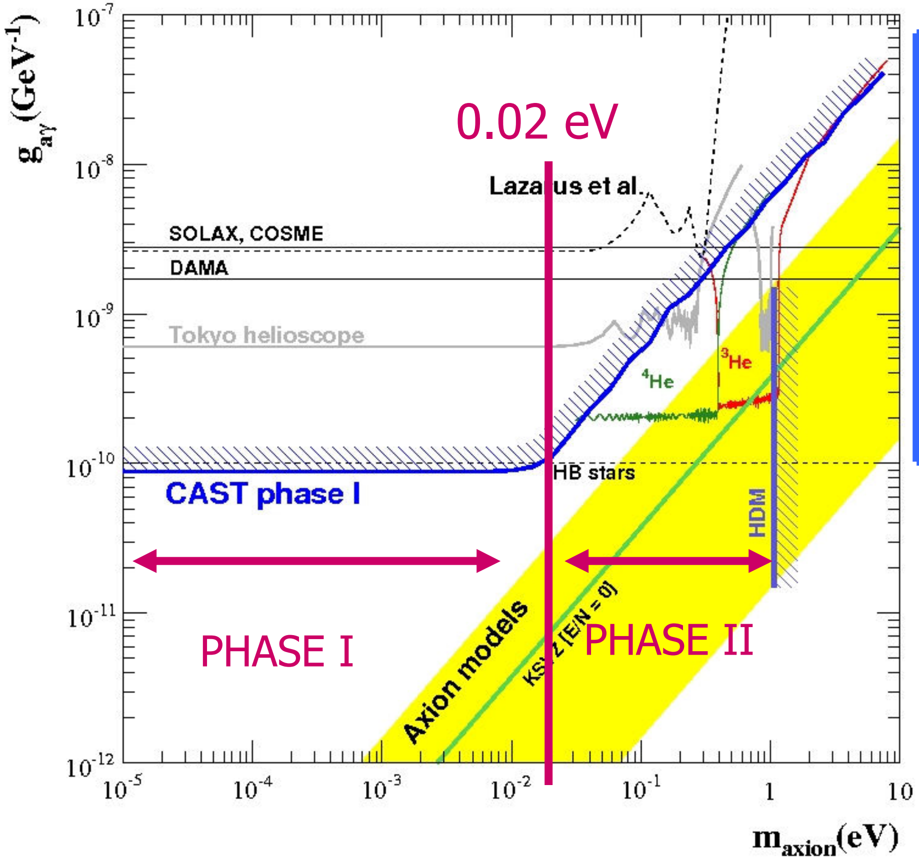
Rotating platform : vertical mouvement 16°
horizontal mouvement 100°

Solar « Tracking » ~3 h/day, background data rest of the day

4 X-rays detectors

Signal: excess of X-rays while pointing the sun

CAST STATUS AND SCHEDULE



2002	Commissioning
2003-2004	**Phase I Data Taking**
2005	**Upgrade phase II (^{4}He)/Data taking**
2006	**Phase II Data taking (^{4}He)**
2007	Upgrade phase (^{3}He), upgrade detectors
2008-2010	**Phase II Data taking (^{3}He)**

CAST Coll, PRL (2005) **94**, 121301
CAST Coll, JCAP (2007) **0704,** 010
CAST Coll, JCAP (2009) **0902**, 008

Parallel searches

High energy axions: Data taking with a HE calorimeter (arXiv:0904.2103) ➔**Talk from K. Jakovčić**

Low energy axions: Data taking with a PMT/APD (ArXiv:0809.4581) ➔**Talk from M. Karuza**

Coherence

In vacuum:

$$P_{a\to\gamma} = 1.74 \times 10^{-17} \left(\frac{B\cdot L}{9.0\,\mathrm{T}\cdot 9.26\,\mathrm{m}}\right)^2 \left(\frac{g_{a\gamma}}{10^{-10}\,\mathrm{GeV}^{-1}}\right)^2 \cdot |M|^2$$

$$|\vec{q}| = \left|\frac{m_a^2}{2E_a}\right| \qquad |M|^2 = \frac{2(1-\cos(qL))}{(qL)^2} \qquad qL \ll 1 \Longrightarrow |M|^2 = 1$$

For $m_a > 10^{-2}$ eV/c^2 coherence is lost

In a gas:

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

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

Absorption coefficient : Γ

Coherence condition : $qL < \pi$

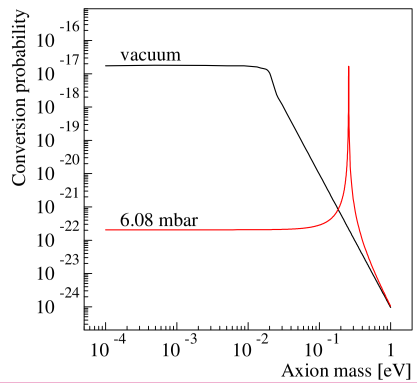
Filling the magnet with a buffer gas provides the photon a mass

$$m_{\gamma,\mathrm{eff}} \approx \sqrt{0.02\frac{P[\mathrm{mbar}]}{T[K]}}\,[\mathrm{eV}/c^2]$$

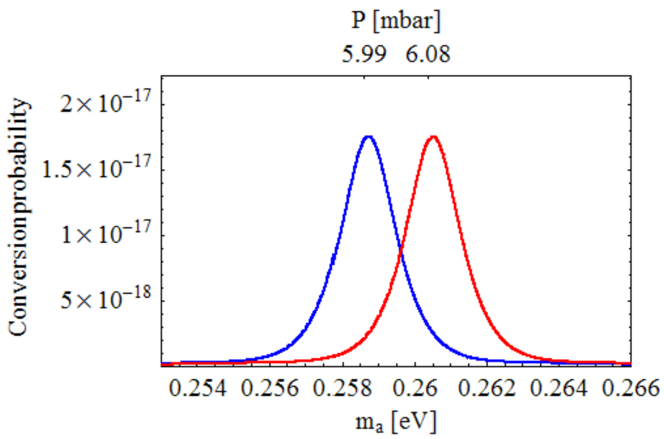
Coherence condition is recovered for a mass interval around m_γ

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

The masses can be adjusted changing the pressure of the gas



Upgrade He system



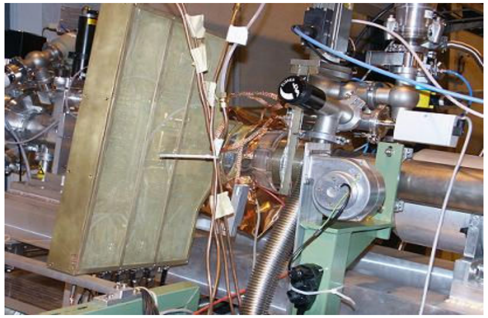
- Every specific pressure of the gas allows the test of a specific axion mass.
- The higher the pressure, the higher the photon effective mass, the higher the axion mass tested.
- For every step there is a new discovery potential

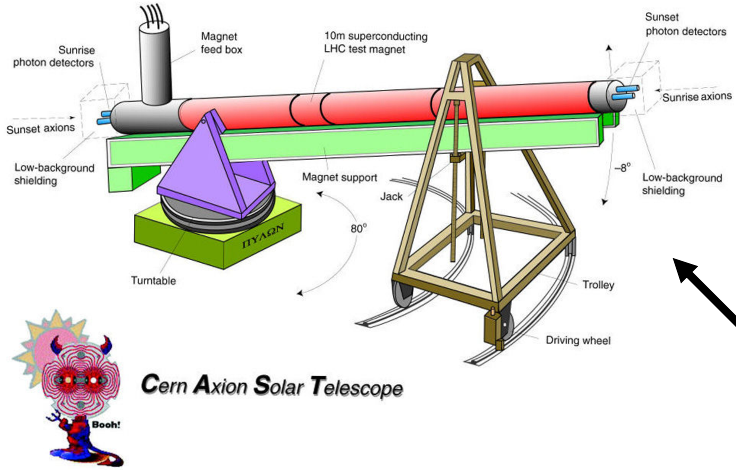
Major upgrade of the experiment : $^4He/^3He$ system

- ^4He gas saturates at ~16 mbar for T=1.8 K, for higher pressures only ^3He remains gas
- Controlled injection of He in the bores
- Precise measurement of gas quantity
- Precise monitoring of gas pressure / temperature
- High reproducibility precision (< 0.01 mbar)
- Extra safety for ^3He loss

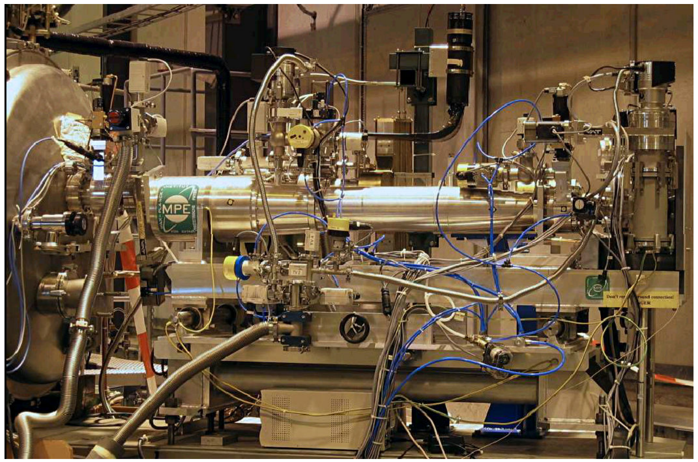
DETECTORS before 2006

SUNRISE SIDE:
unshielded Micromegas

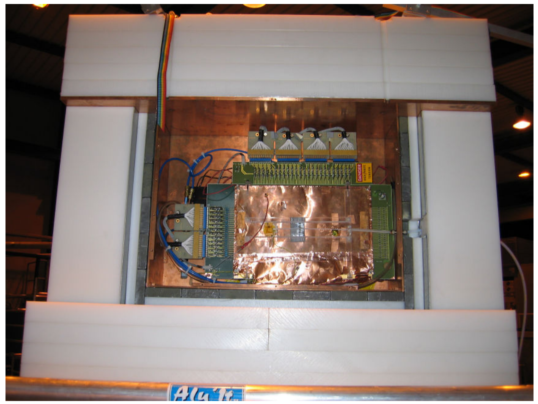




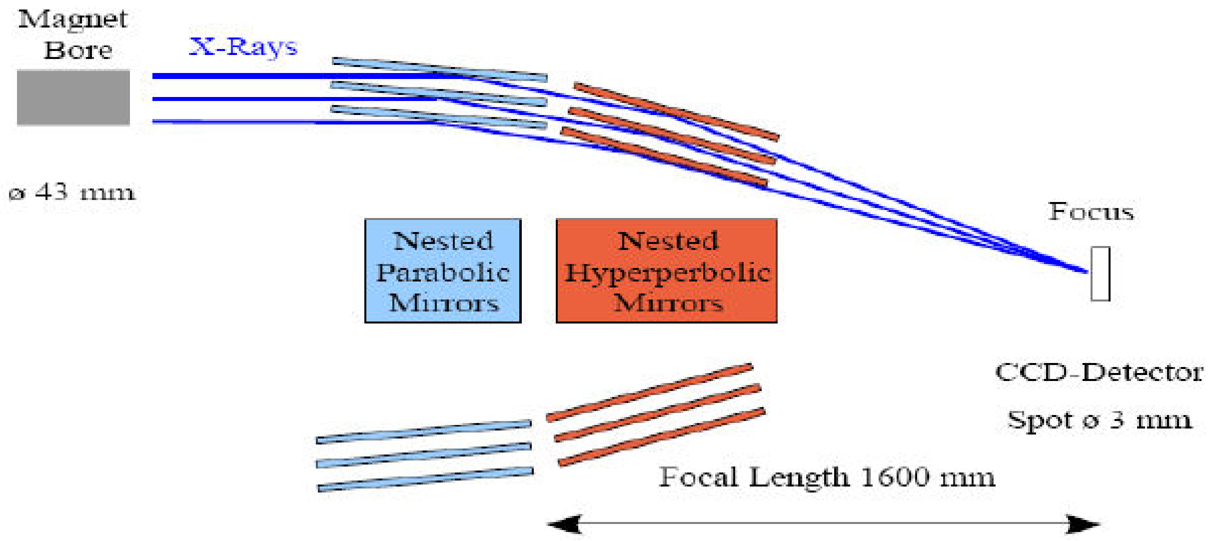
CCD +telescope

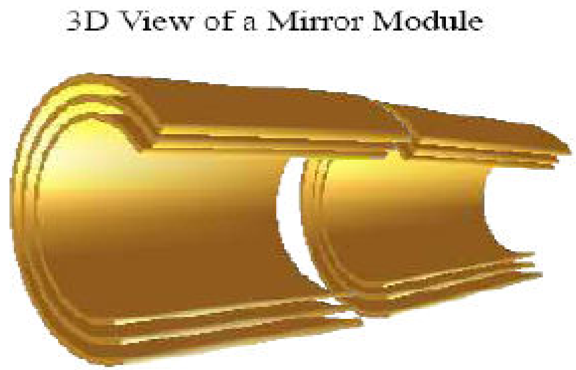


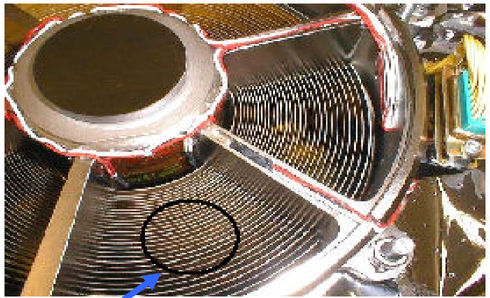
SUNSET SIDE: **shielded TPC**
(looking at two magnet bores)



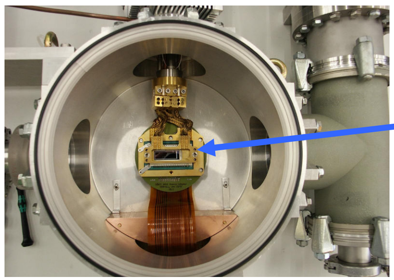
X-ray telescope







Magnet bore size (14.5 cm^2)



CCD Chip
9 mm^2

Wolter I type grazing incident optic (prototype for the ABRIXAS mission)

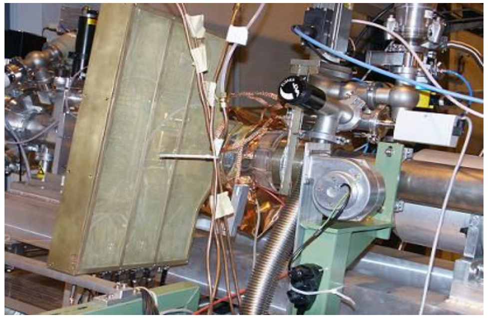
Telescope aperture 16 cm, used for CAST: 43 mm

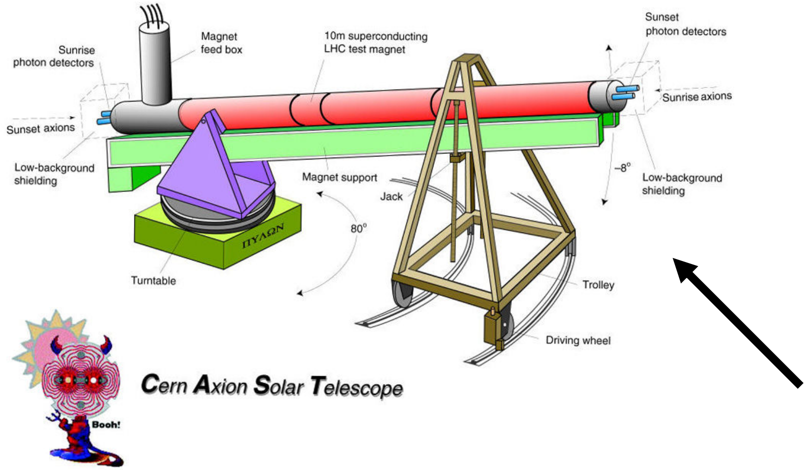
Only one sector is used in CAST

S/B improved by a factor ≈ 160

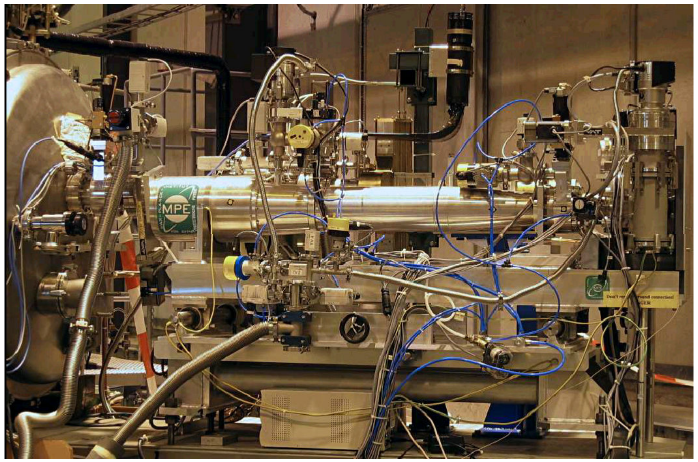
DETECTORS before 2006

SUNRISE SIDE:
unshielded Micromegas



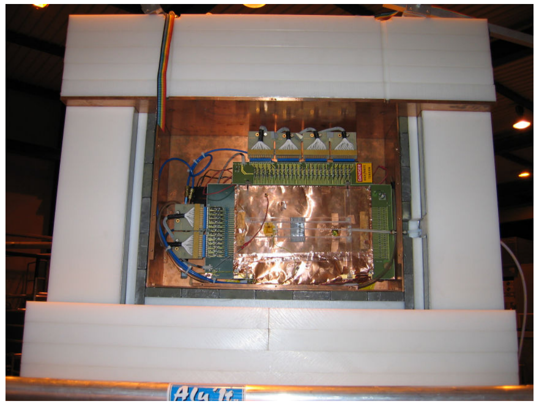


CCD +telescope



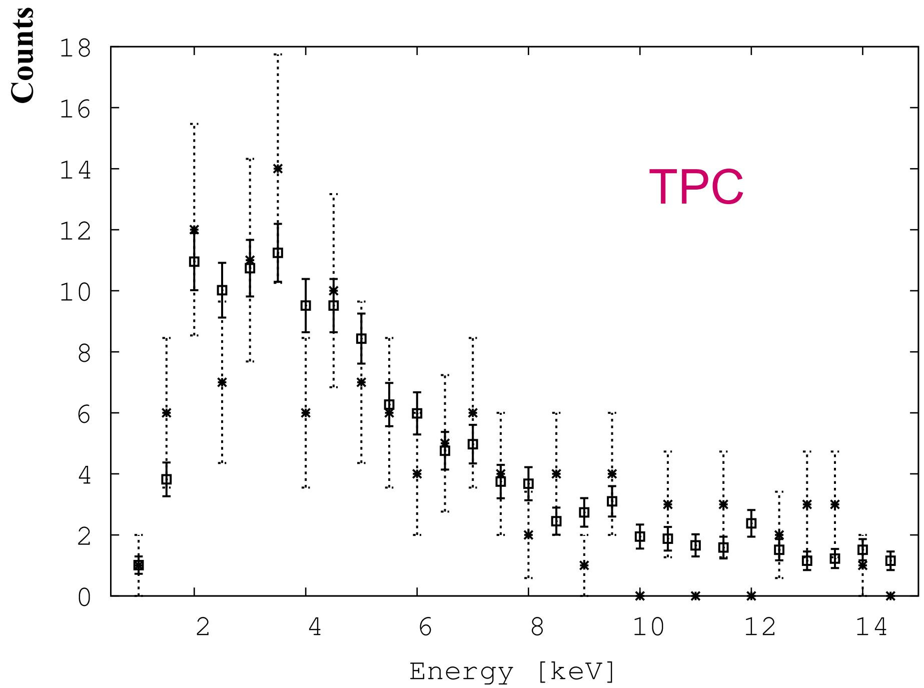
	Typical Rates
TPC	85 counts/h (2-12 keV)
MM	25 counts/h (2-10 keV)
CCD	0.18 counts/h (1-7 keV)

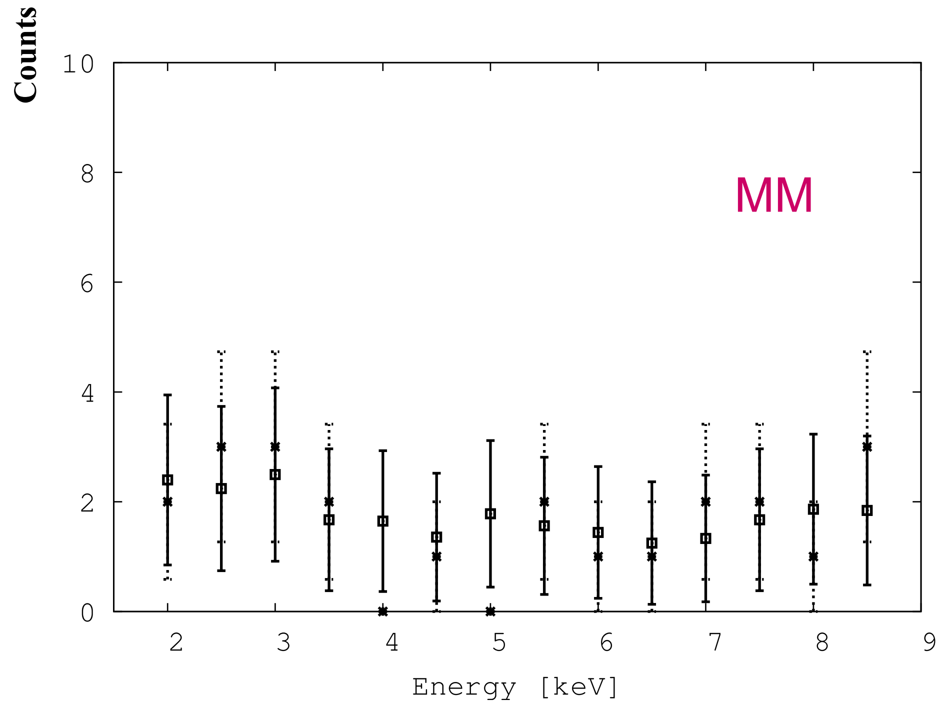
SUNSET SIDE: **shielded TPC**
(looking at two magnet bores)



RESULTS TPC & MM ^{4}He data

An example of the spectra obtained for a given pressure (P=8.909 mbar)

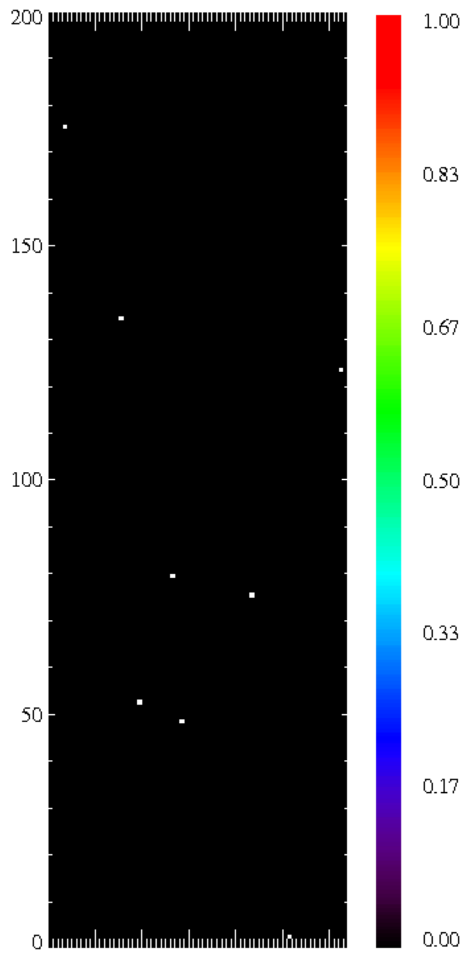




Good agreement between tracking and data
➔ No Axion signal

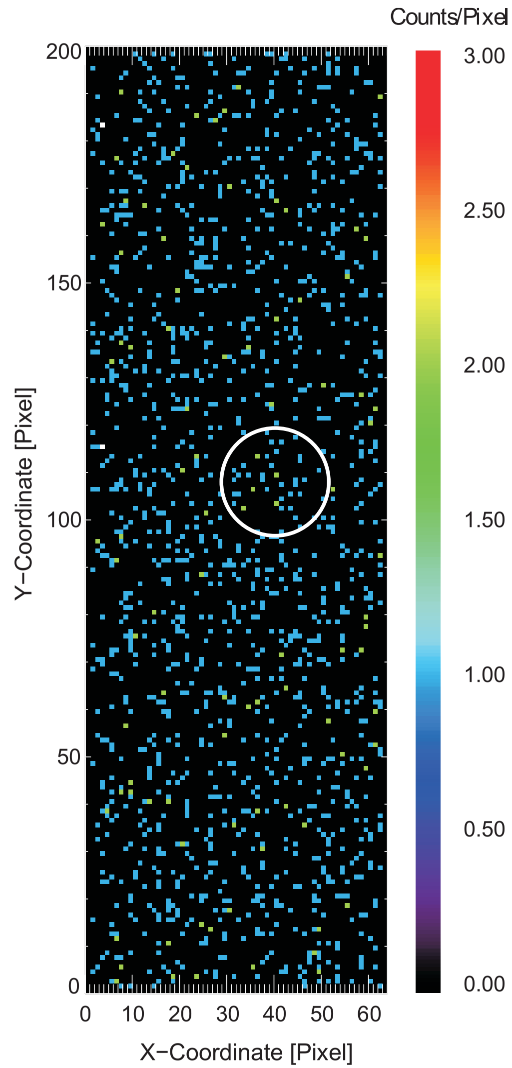
RESULTS CCD ^{4}He data

One single tracking

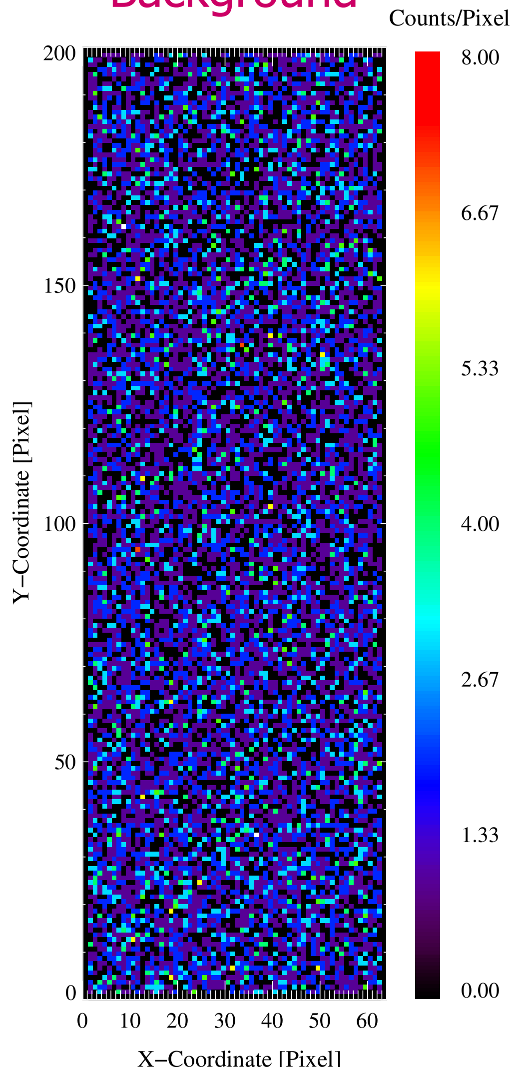


Intensity Image

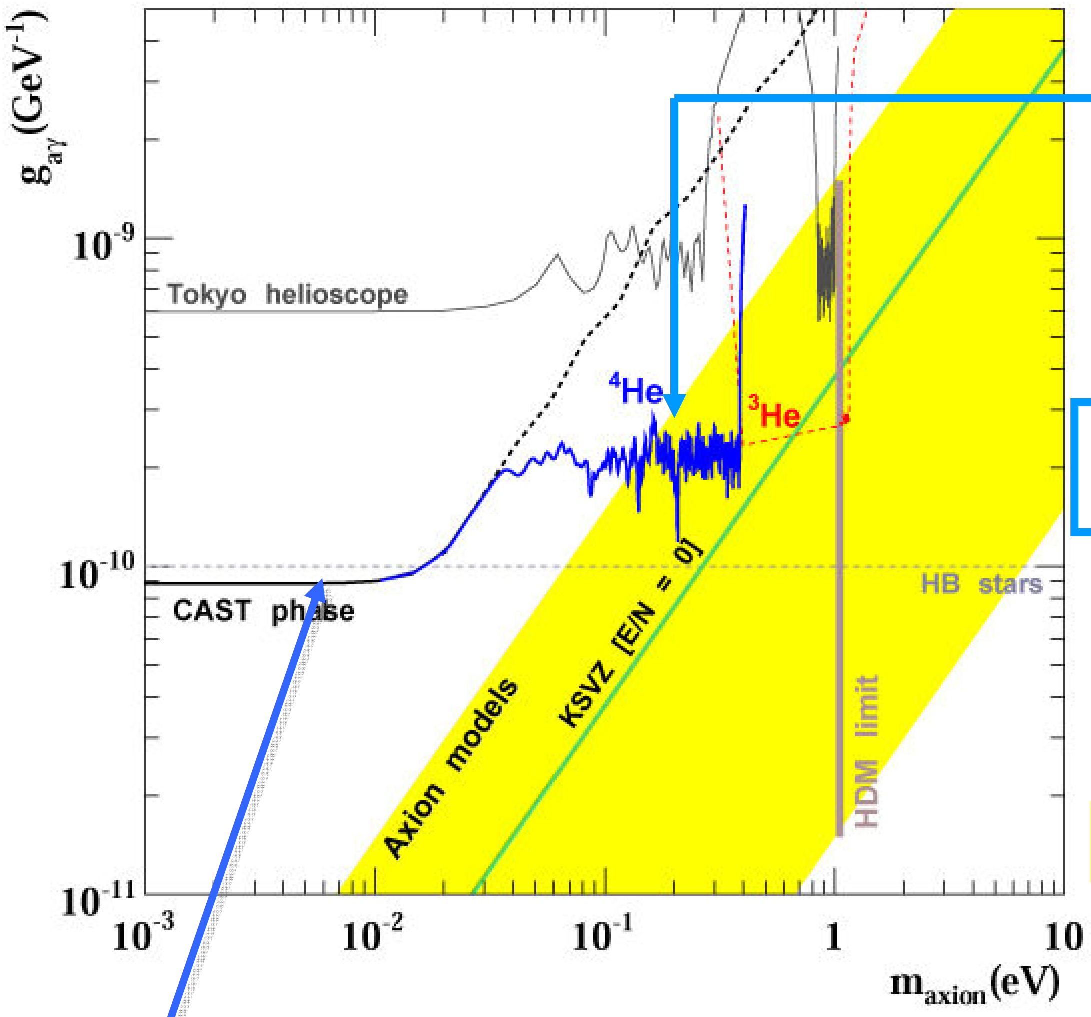
Integrated trackings



Background



Combined results on the ^{4}He data



He^4 @ T = 1.8 K,
p < 13.6 mbar $0.02 < m_a < 0.26$ eV

≈160 pressure settings

$g_{a\gamma\gamma} \leq 2.17 \times 10^{-10}$ GeV^{-1} (95% C.L) for $0.02 < m_a < 0.39$ eV

$g_{a\gamma\gamma} \leq 8.8 \times 10^{-11}$ GeV^{-1} (95% C.L) for $m_a < 0.02$ eV

CAST Coll, JCAP (2009) **0902**, 008

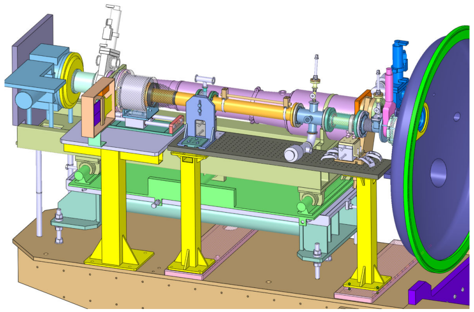
DETECTORS in 2008

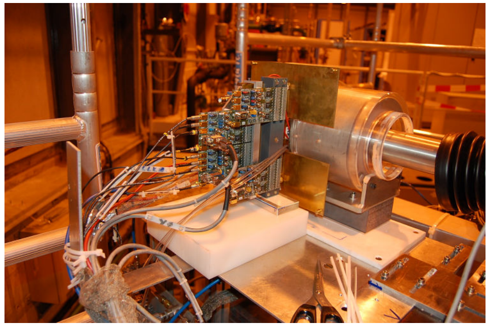
	Typical Rates
MM	3 counts/h (2-10 keV)
CCD	0.18 count/h (1-7 keV)

(TPC 85 counts/h 2-12 keV)
(old MM 25 counts/h 2-10 keV)

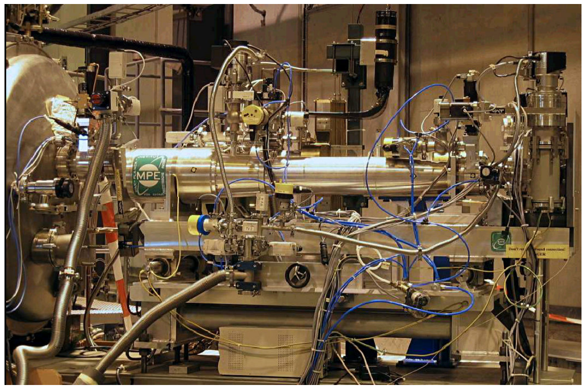
SUNRISE SIDE:

shielded Micromegas (2nd generation)

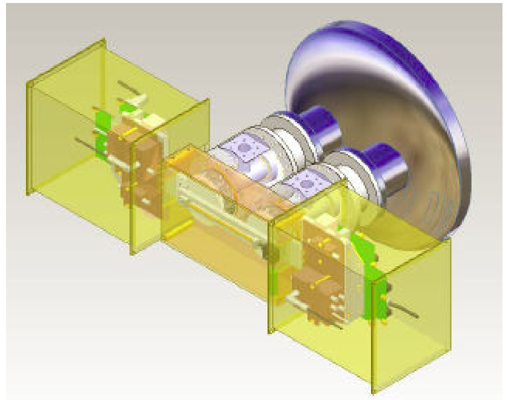


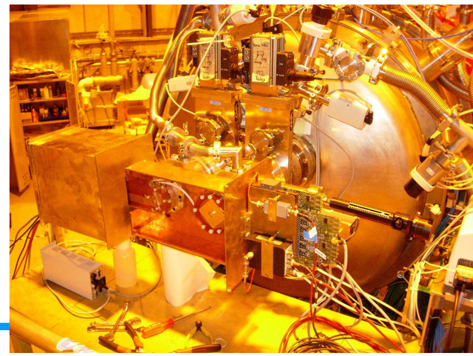


CCD +telescope

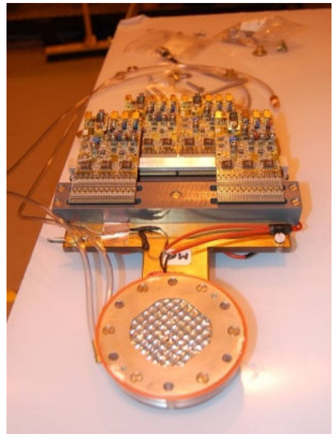


SUNSET SIDE: shielded MM (2nd generation)





Improved Micromegas detectors (2008 onwards)



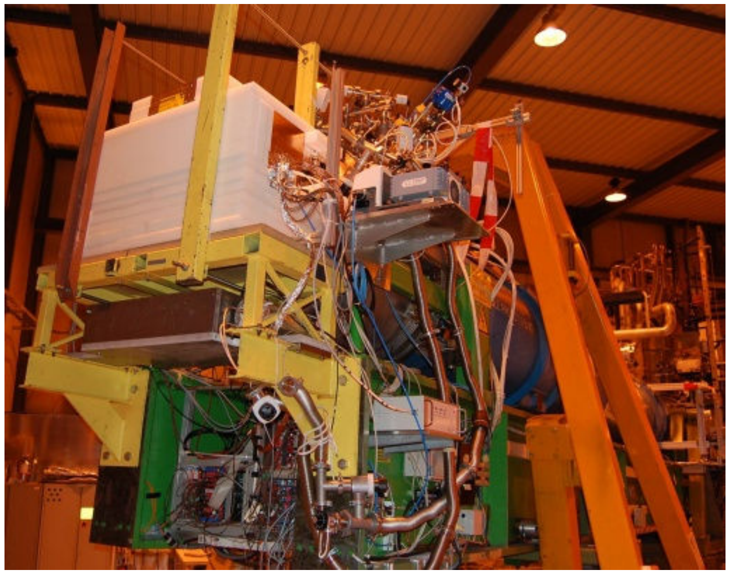
2nd generation Micromegas: Microbulk manufacturing technique

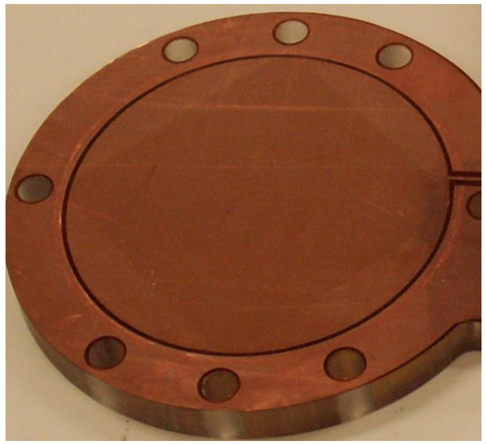
Lower intrinsic radioactive material

Better shielding

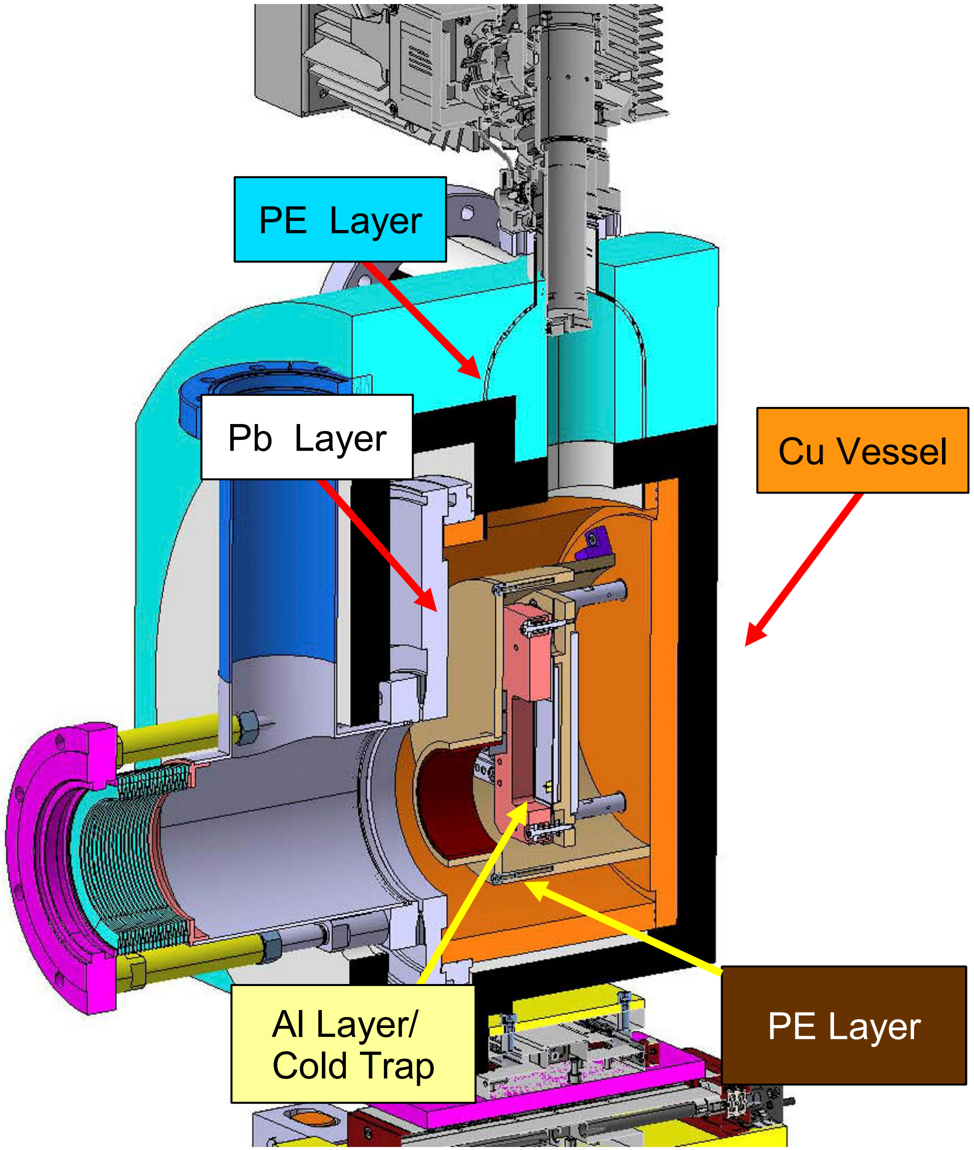
Potential for ultra-low background rates

See talks from J. Galan Lacarra and T. Papaevangelou at MPGD 2009
http://candia.inp.demokritos.gr/mpgd2009/





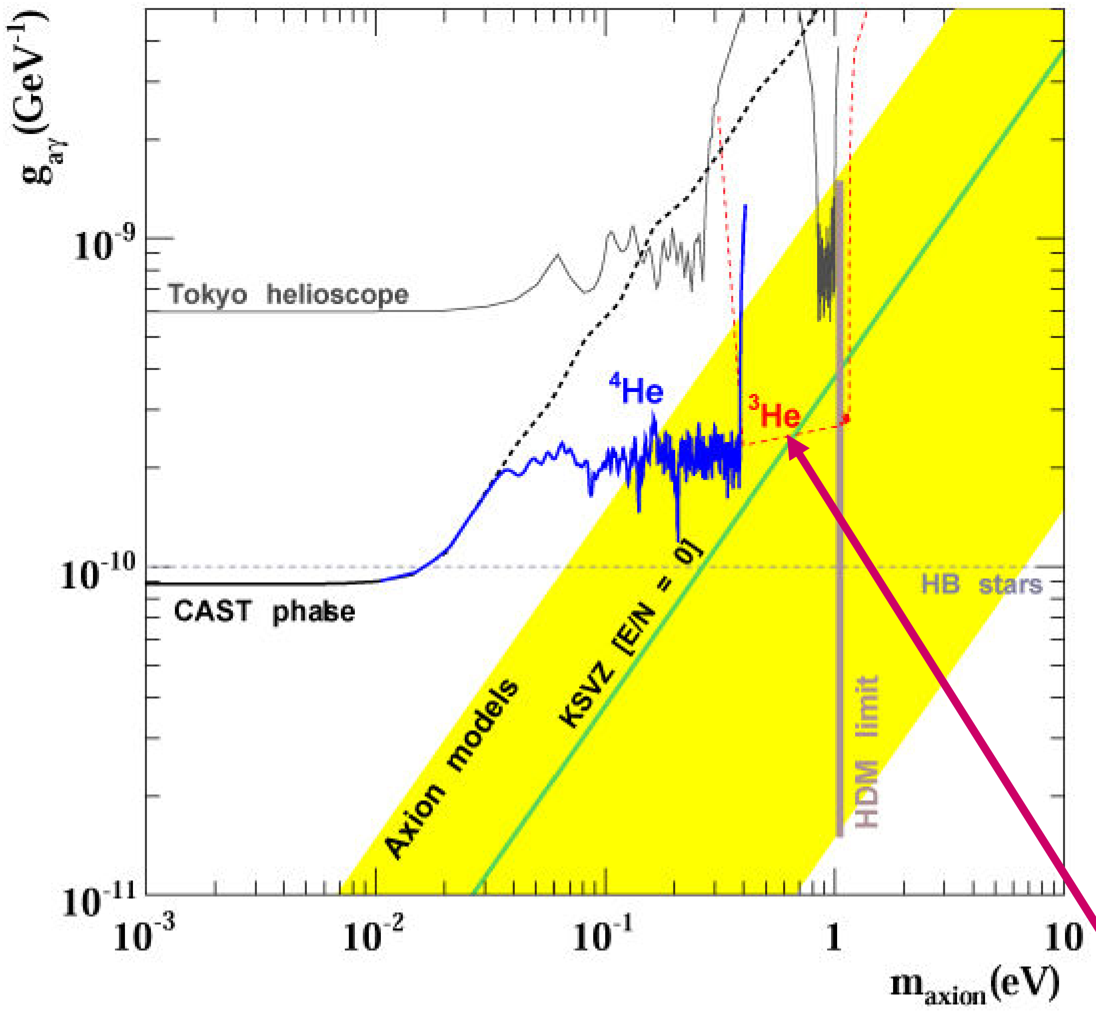
CAST FRAME-STORE CCD (fall 2009)



Improvements

- Better low energy response: 0.2 keV < E < 1 keV
- Lower background (radio-pure material+shield)
- Less out-of-time event 8 % of measured flux
- State-of-the-art technology
- Decoupling of telescope and detector→ simplifies alignment

CAST on the sun track again since yesterday 13/07/09 !



Continuing the ^{3}He data taking started in 2008 where a sensitivity of 0.65 eV was reached

Expectations

End of 2009 ➔ $m_a \approx 0.8$ eV/c^2

End of 2010 ➔ $m_a \approx 1.1$ eV/c^2

^{3}He @ T = 1.8 K,
p < 120 mbar, $m_a < 1.1$ eV

On going now!

PERSPECTIVES : sensitivity considerations

- Since the beginning of CAST a lot of expertise on the helioscope technique has been gained
- Thinking of the after CAST
- See T. Papaevangelou's talk at New opportunitues in the Physics Landscape at CERN Workshop where different scenarios are presented

Magnet
More intense, longer and bigger surfaces

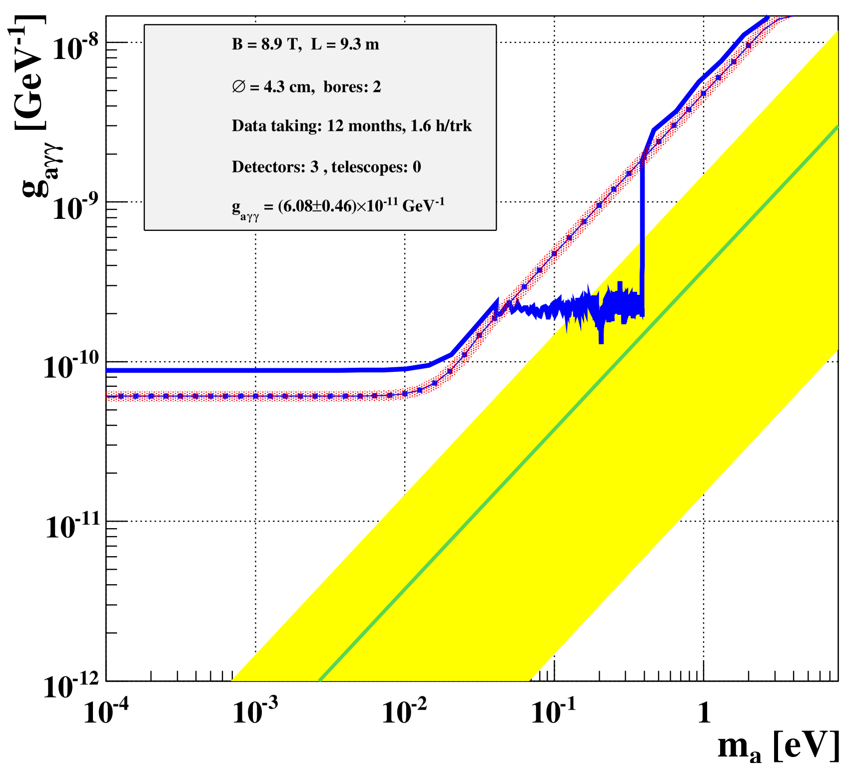
Detectors
Low background and/or telescopes

$$g_{a\gamma\gamma} \;\alpha\; (B\,L)^{-1/2}\,(1 / A^{1/4})\,(b^{1/8} / t^{1/8})$$

Platform
Observation time

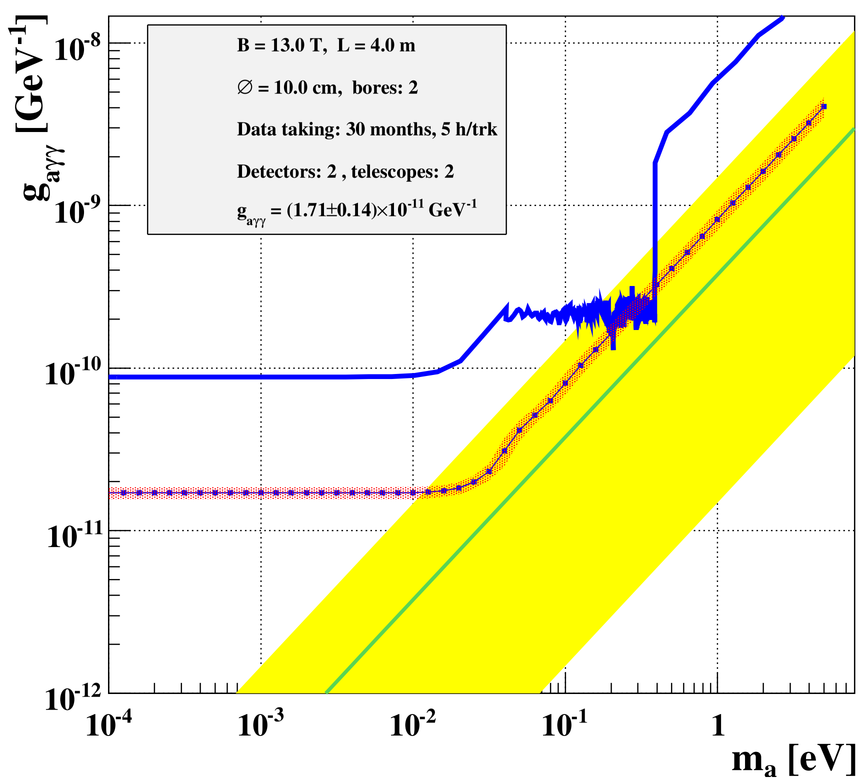
SHORT AND MID TERM PERSPECTIVES

2011-2012



Existing detectors +
same magnet + same platform

2013 (B=13 T, L=4 m, ϕ=10 cm)

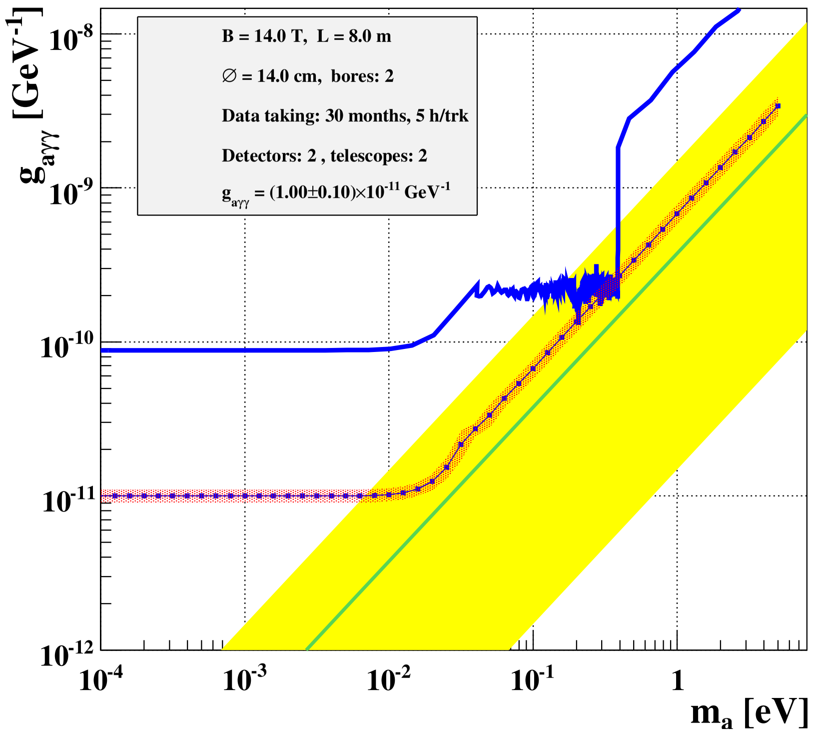


Detectors coupled to x-ray optics with
High efficiency +new magnet + new platform

Sensitivities of 2×10^{-11} GeV^{-1} atteinable and can probe QCD favored model for $m_a \geq 0.2$ eV well below astrophysical limits

LONG TERM PERSPECTIVES

2016

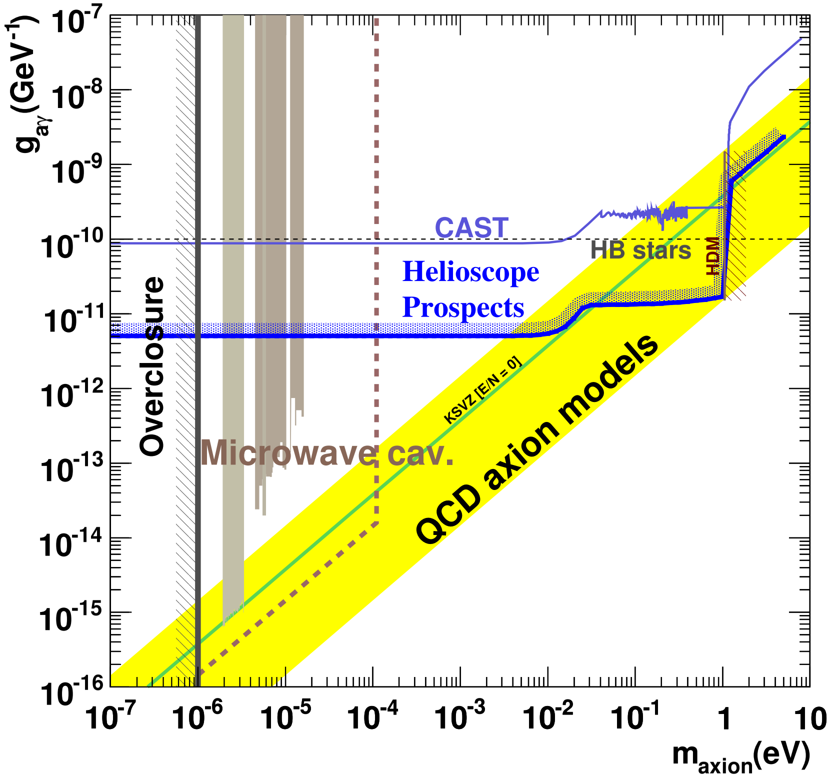


B=14 T, L= 8 m, $\phi = 14$ cm

High efficieny X-ray optics

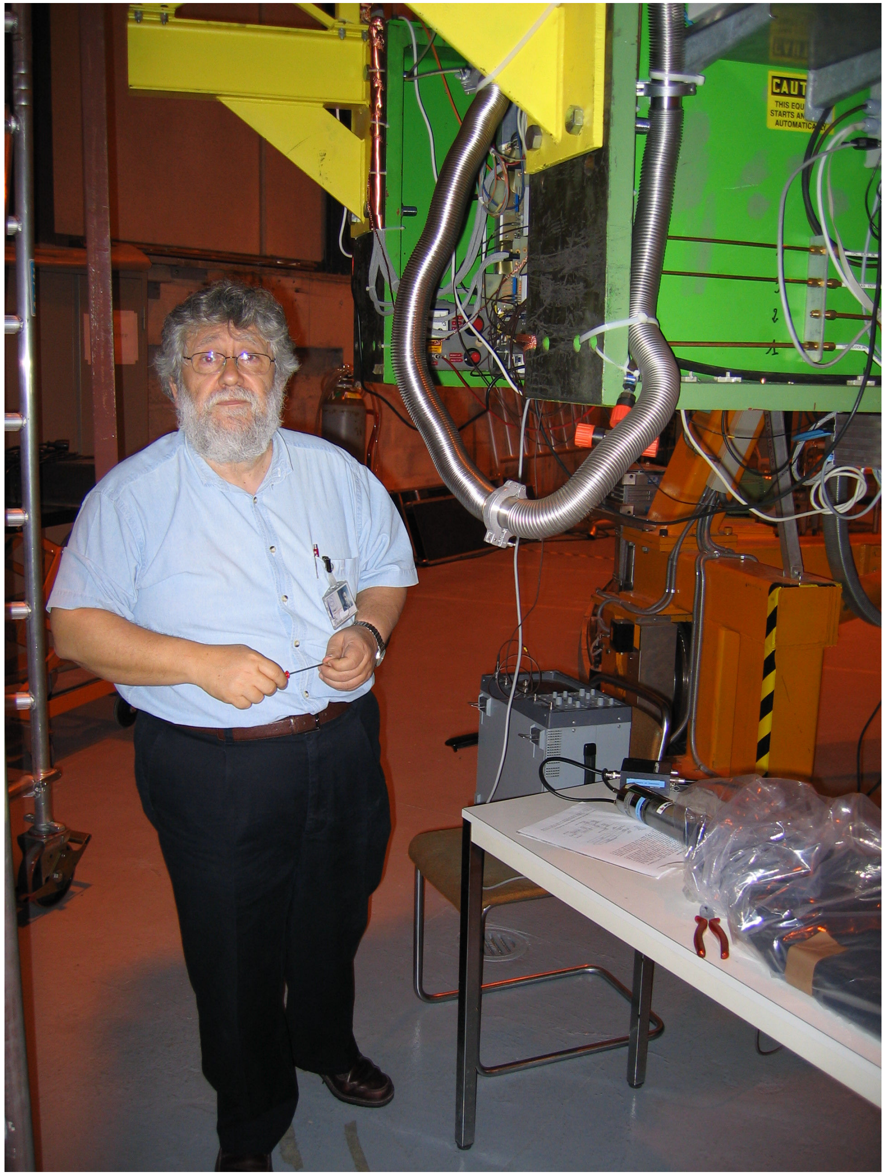
Can reach sensitivity of the order of 10^{-11} GeV^{-1} and probe a wide range of QCD favored model region

AFTER 2020



In combination with Microwave Cavity experiments (ADMX) a big part of the QCD favored model region can be swept up to 2020

Julio Morales



Julio Morales left us on 3/07/09

He was involved and active in CAST since the very beggining

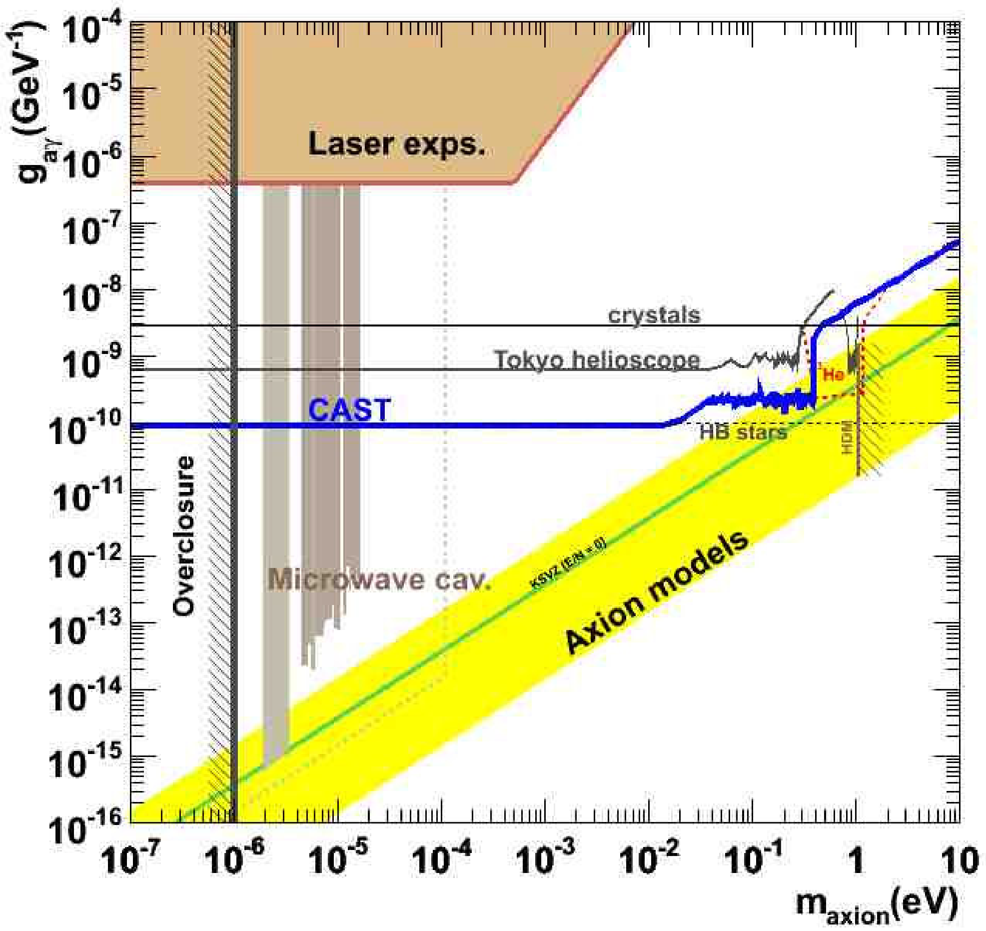
A great loss for CAST and for underground laboratories physics in general

CONCLUSIONS

- Exclusion limits up to now
  - Compatible with best astrophysical limits
  - Entering realistic QCD axion model band for the first time
  - Over a wide range of masses

- The hunt for the axion continues. We are exploring a very exciting region. Everyday place for discovery!

- Thinking of the next generation of Helioscopes which could be complementary with dark matter axion seraches (ADMX) a big part of model region could be explored in the next decade




CAST
EUROPAMETA
E. ZANON
0,45€ REDUCTION
Axion
Total
5
Thank you!

BACK UP SLIDES

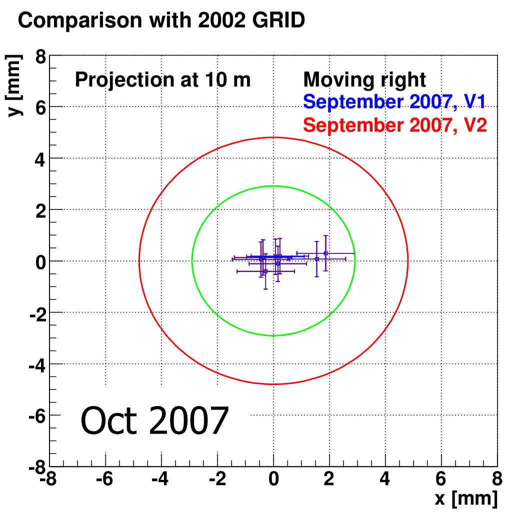
TRACKING PRECISION

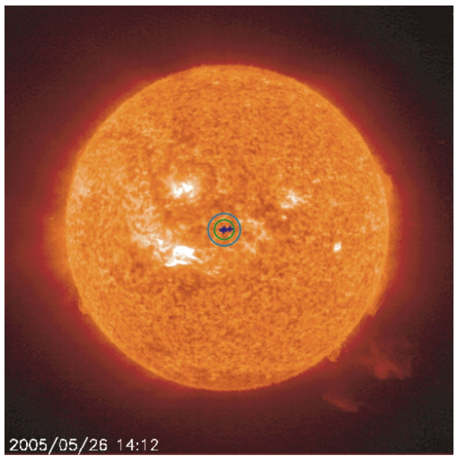
GRID measurements (CERN surveyors)

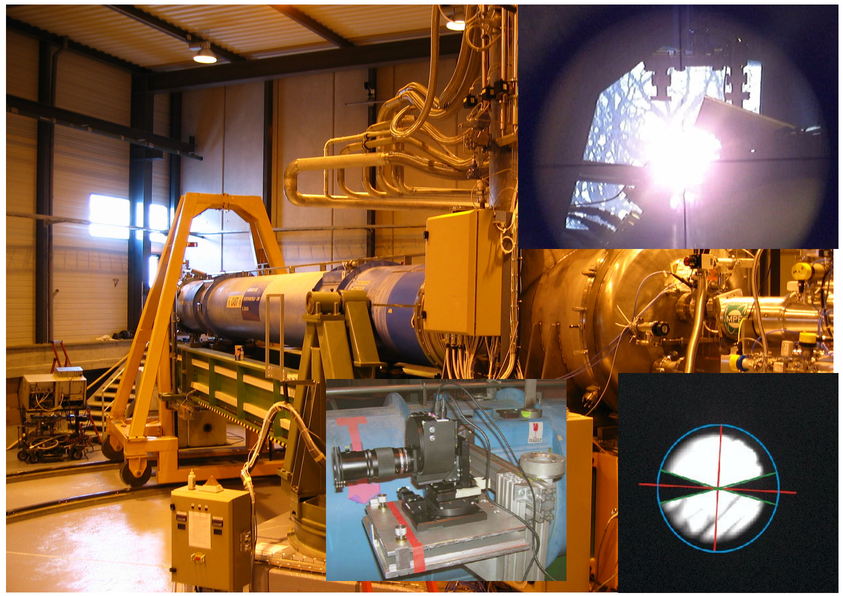
- The orientation of the magnet is determined with the use of stepping encoders (horizontal/vertical)
- Correlation between encoder value – magnet orientation has been established for a number of points (GRID)
- The correlation is checked periodically for a number of points

Sun filming

- Twice per year (September/March) tracking is passing trough a window
- A camera is placed on top of the magnet and is aligned with the bore axis
- Corrections for visible light refraction are taken into account

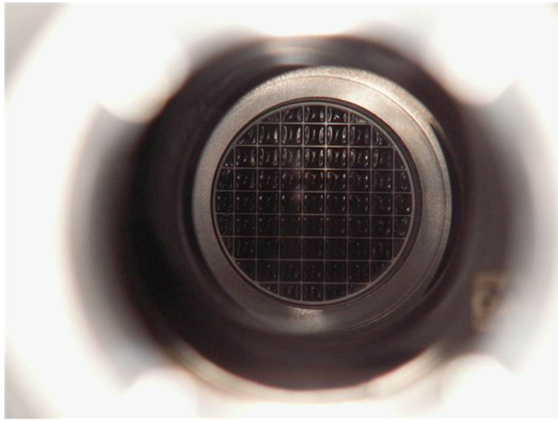






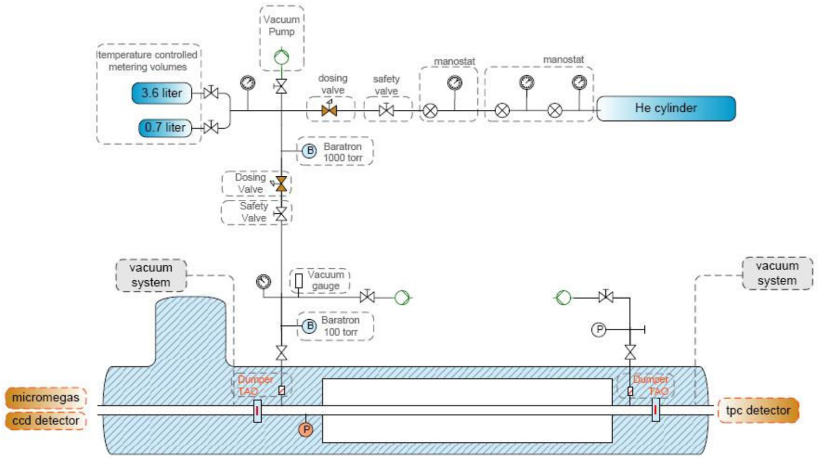
Tracking overall precision ≈ 0.01°

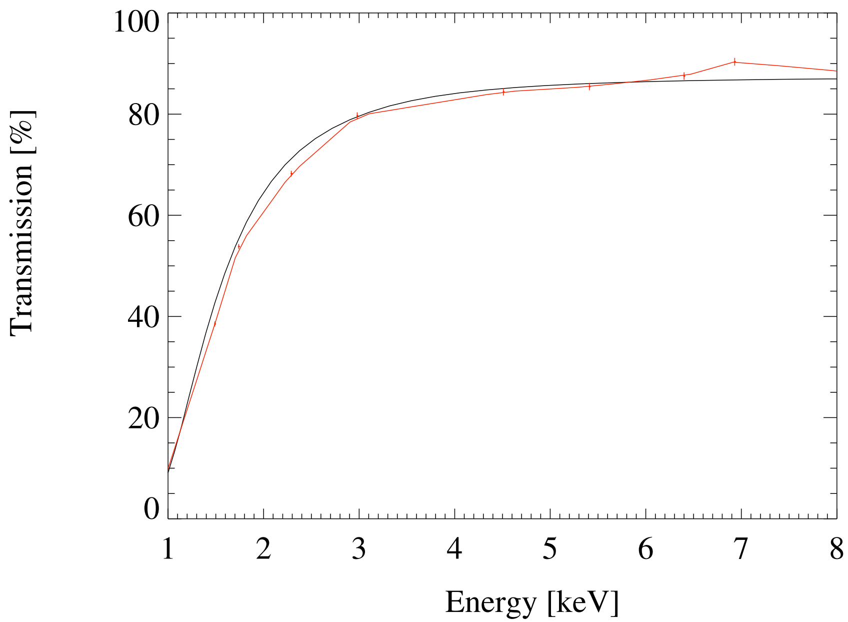
Cold windows



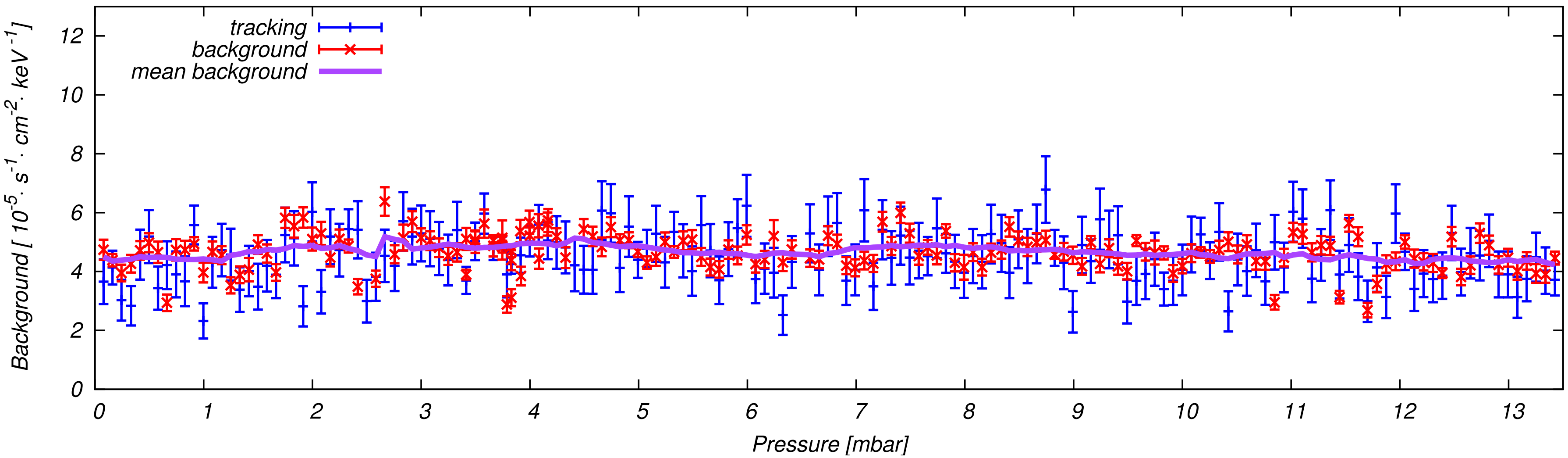
Confine the gas + high X-ray transmission

Resistance to magnet quenches
15 µm polypropylene supported by electroeroded grid to withstand pressure difference

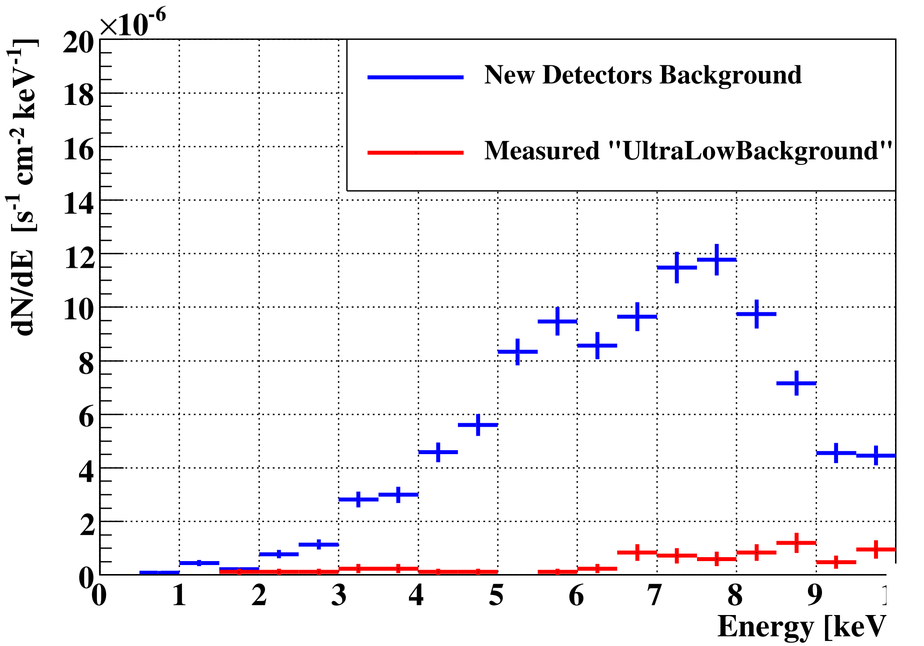


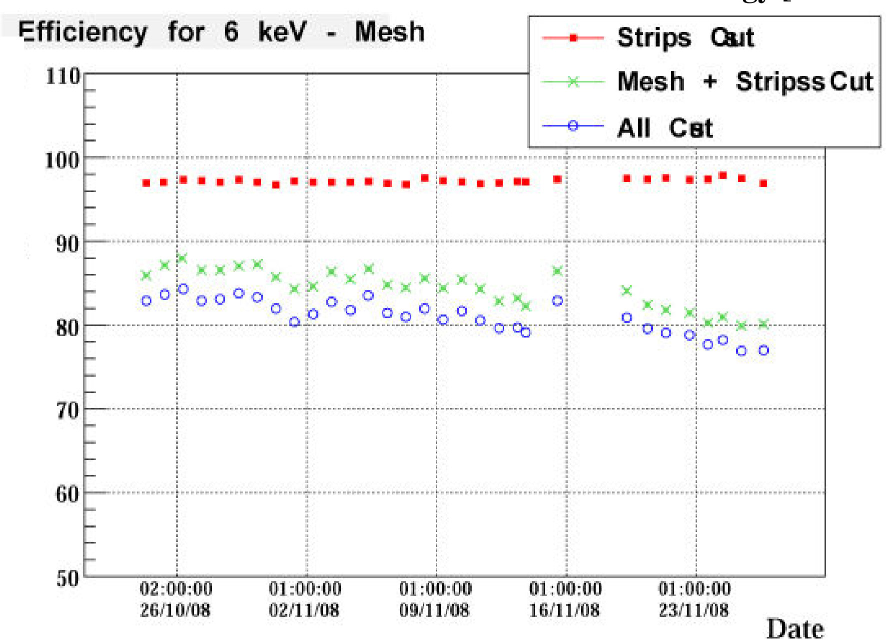


STABILITY OF BACKGROUND VS PRESSURE

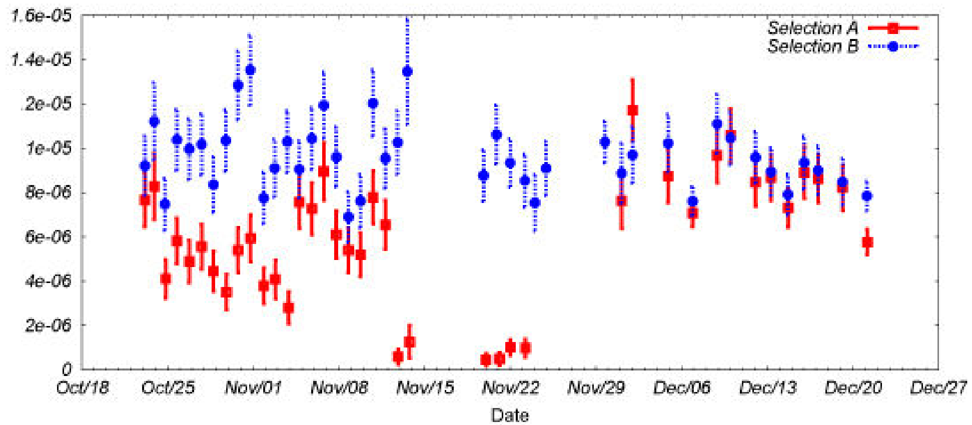


New detectors performance



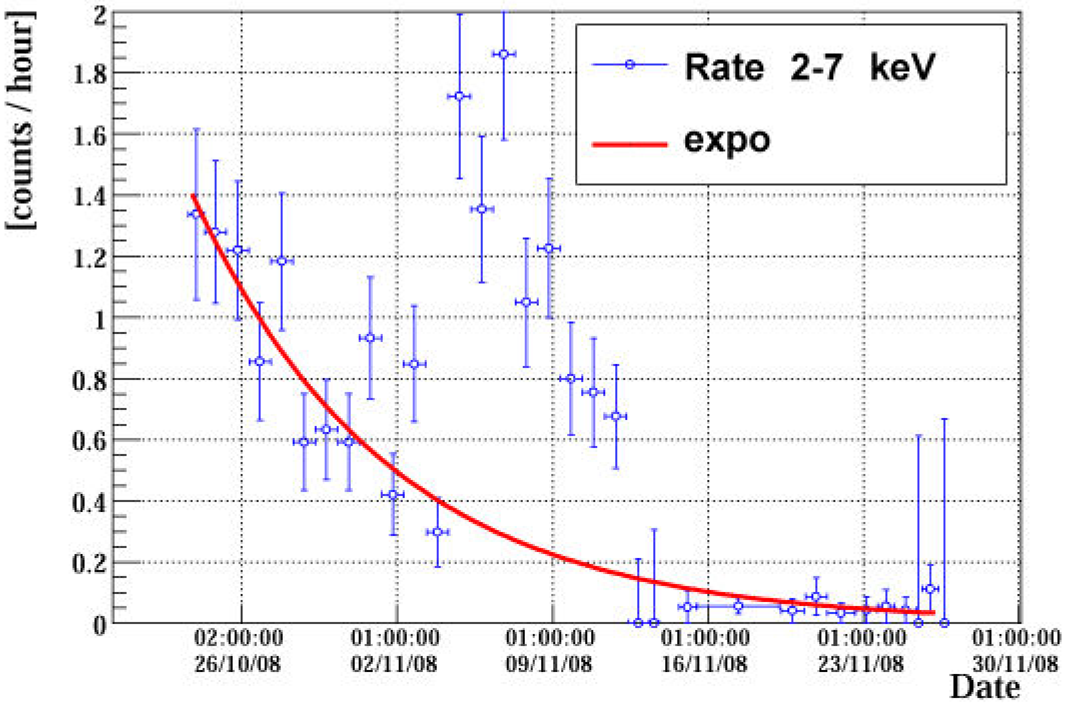


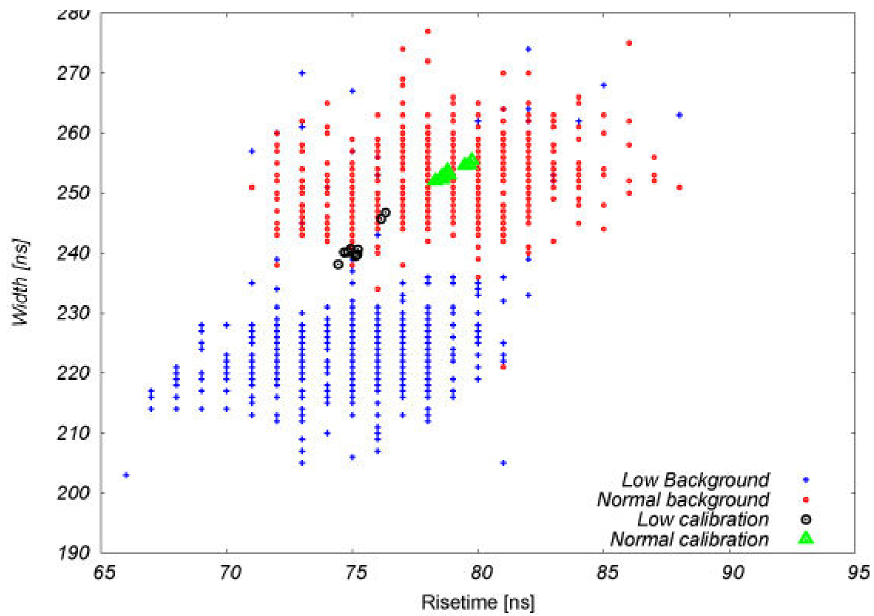
- •Exceptionally low background
- •Correlated to radon flow



Need to reproduce these results systematically

Measurements at the underground Canfran Lab.


[counts / hour]
Rate 2-7 keV
expo
02:00:00
26/10/08
01:00:00
02/11/08
01:00:00
09/11/08
01:00:00
16/11/08
01:00:00
23/11/08
01:00:00
30/11/08
Date


Width [ns]
Risetime [ns]
Low Background
Normal background
Low calibration
Normal calibration

Micromegas readout

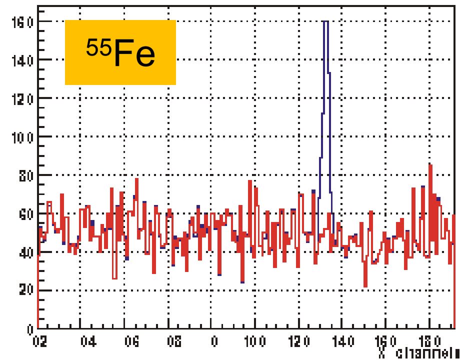
- Mesh: 1 GHz FADC, 2.5 µsec (MATACQ)
- Strips: Integrated charge at each strip in groups of 96 (Gasiplex)

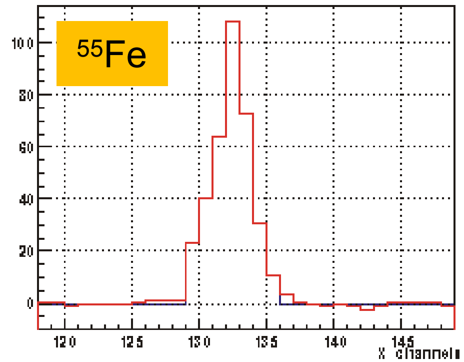
1 – 10 keV X-Rays: Localized energy deposition (<1 mm) ➔

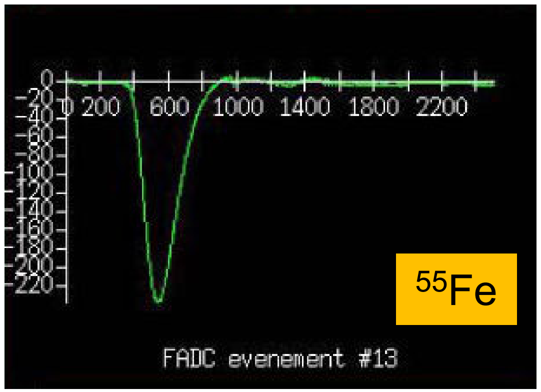
➢Short risetime and pulse width for the analogue signal

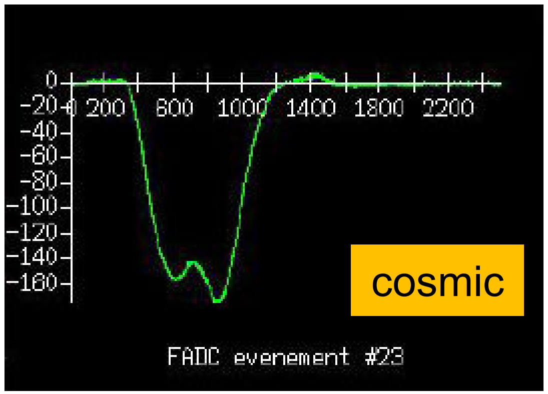
➢Charge in one cluster of few strips per axis

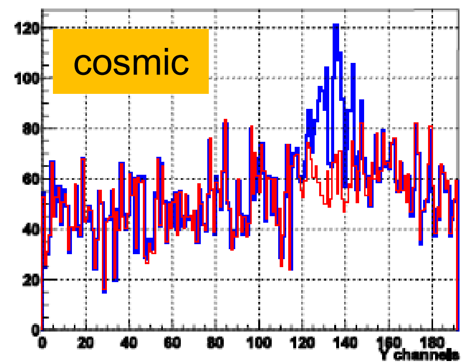
Pattern recognition algorithm can be applied to reduce background











Pattern recognition

- Define signal characteristics for ^{55}Fe X-Rays (daily calibration runs)
  - Strips: multiplicity, width, topology of clusters
  - Mesh: risetime, width, amplitude, integral of signals
- Examine distributions
- Define cuts from bins with content above a relative value
- Apply cuts in data runs
  - Sequential
  - Multivariate analysis
  - Neural networks
- Optimize between efficiency and rejection

Data reduction >10^3