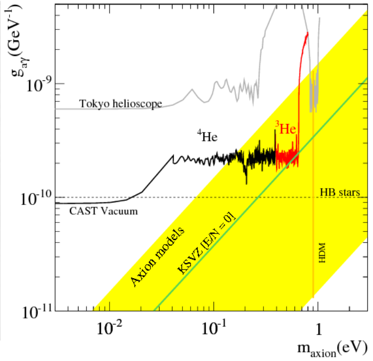
Solar axion detection with the CAST experiment





Esther Ferrer Ribas
IRFU/CEA-Saclay
For the **CAST Collaboration**

IRFU MPGD
7th December 2011

PLAN

CAST physics

Micromegas developments within CAST

Perspectives

Motivation for Axions

- CP violation is necessary in the SM➔matter-antimatter asymmetry
- CP violation observed in the weak interactions
- QCD predicts violation in the strong interactions

$$\mathcal{L}_\theta = \frac{g^2\bar{\theta}}{32\pi^2} G^{\alpha}_{\mu\nu}\tilde{G}^{\alpha\mu\nu} \quad \textit{with} \quad \bar{\theta} = \theta + Arg(\det M)$$

- However no experiment has observed this violation of CP in QCD!

•A possible solution to the strong CP-problem

•Elimination of CP-violating term in QCD Lagrangian by introduction of ne additional global U(1) symmetry

$$\mathcal{L}_a = \left(\bar{\theta} - \frac{a(x)}{f_a}\right)\frac{1}{f_a}\frac{g}{8\pi} G^{\mu\nu}_a \tilde{G}_{a\mu\nu}$$

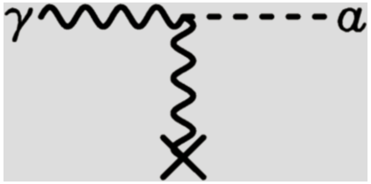
• New pseudo-scalar field : **AXION**

• First proposed by Peccei & Quinn (1977)

• Particle interpretation by Weinberg, Wilczek (1978

Axion properties

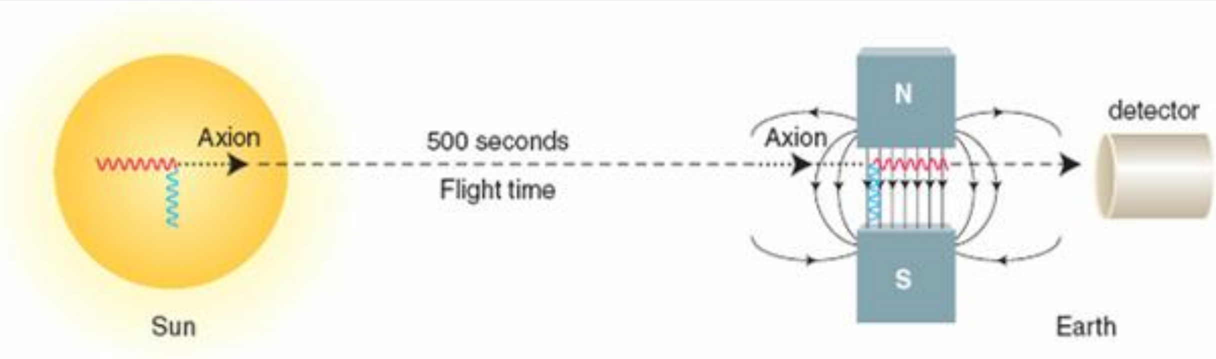
- Neutral Pseudoscalar
- Pratically stable
- Very low mass $m_a \simeq 0.6 \text{ eV} \frac{10^7 \text{GeV}}{f_a}$
- Very low cross-section
- Coupling to photons



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

- Possible dark matter candidates

CAST Physics

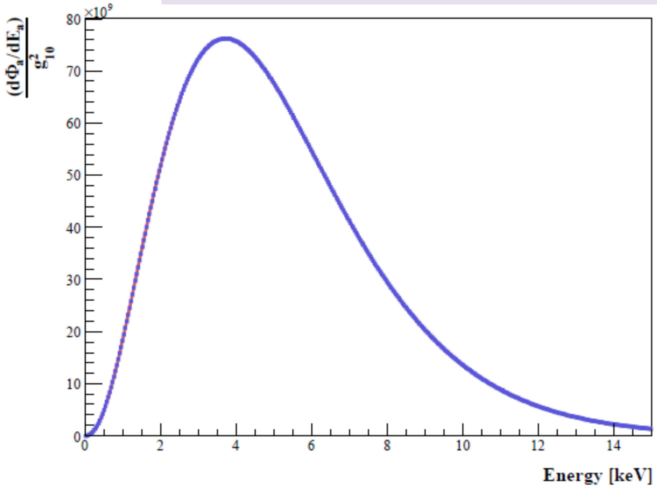


Production in the Sun

Conversion of thermal photons into axions via Primakoff effect in the solar core

Detection inCAST

Conversion of axions into photons via the inverse Primakoff effect in a strong magnetic field

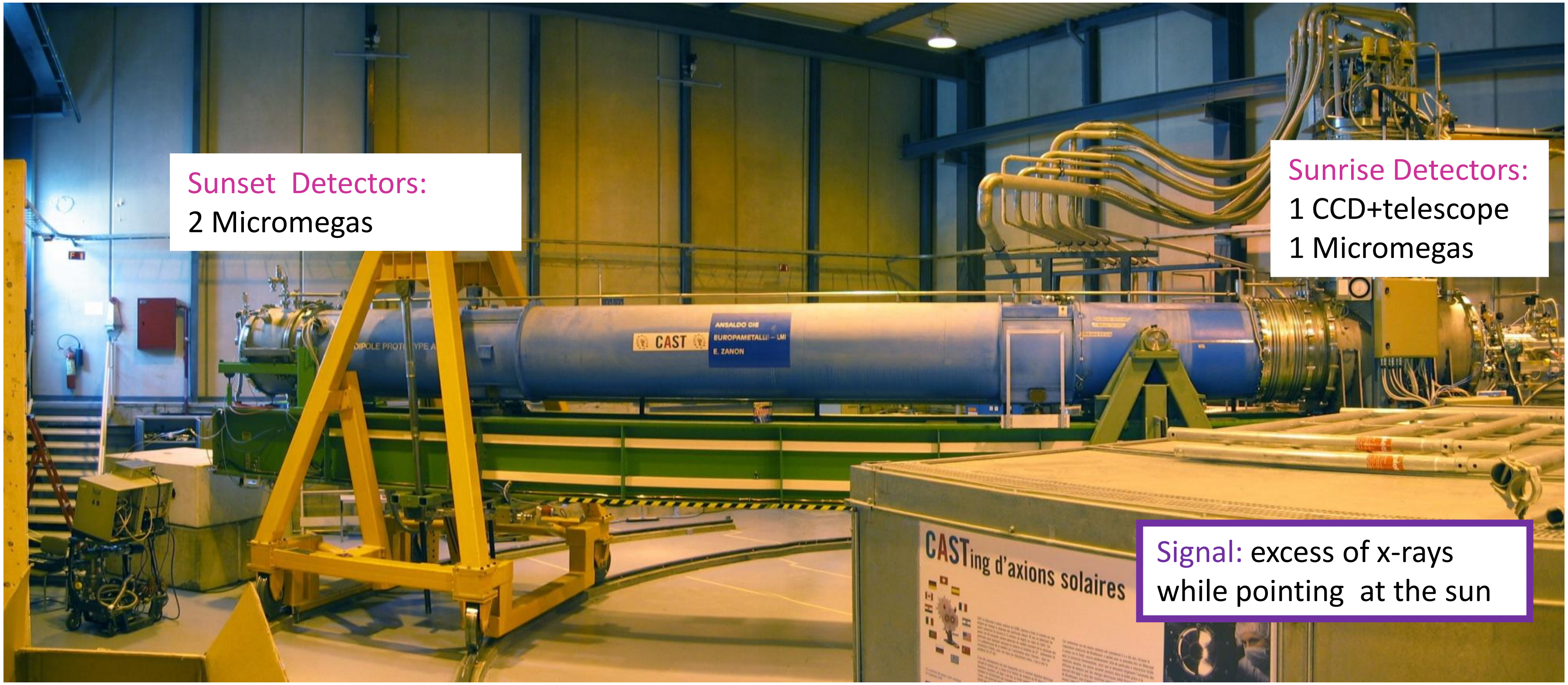


Expected number of photons:

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

$\approx$ 0.3 evts/hour with $g_{a\gamma}$= 10^{-10} GeV^{-1} and A = 14 cm^2

CAST: CERN Axion Solar Telescope



Sunset Detectors:
2 Micromegas

Sunrise Detectors:
1 CCD+telescope
1 Micromegas

Signal: excess of x-rays while pointing at the sun

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

Rotating platform : vertical mouvement 16°

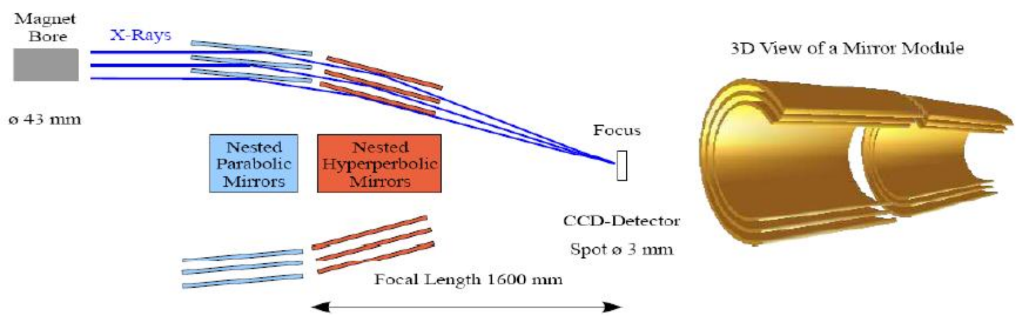
horizontal mouvement 100°

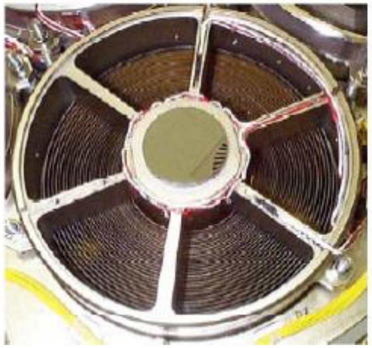
Solar « Tracking » ~3 h/day, background data rest of the day

4 X-rays detectors

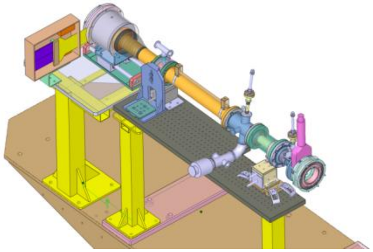
Originalities of CAST

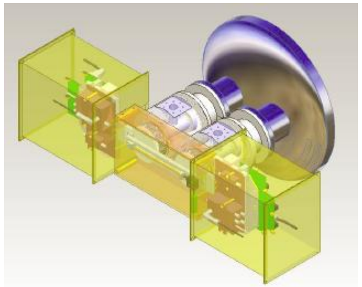
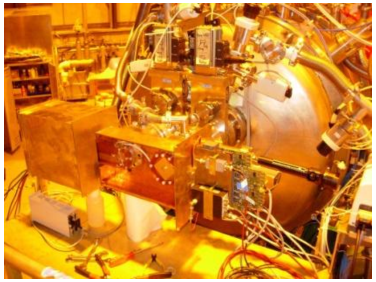
- Use of X-ray telescope ➔ increase S/B noise➔ sensitivity improved by a factor 150 by focusing a ø43 mm x-ray beam to ø3mm



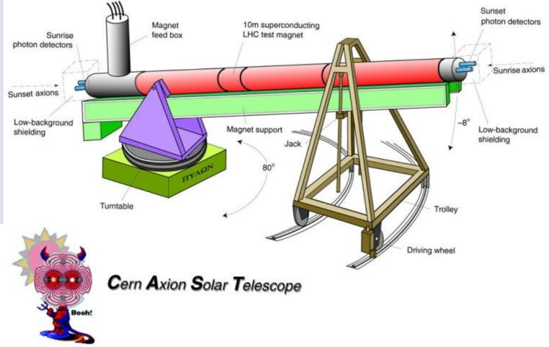


- Low background techniques➔ shieldings, low radioactive materials, simulation and modeling of backgrounds….



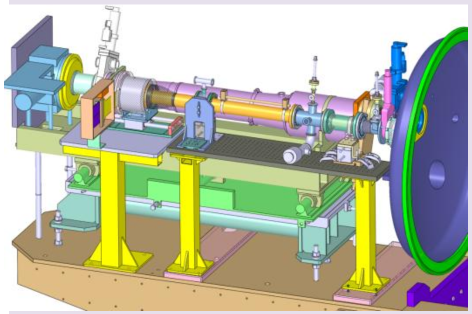



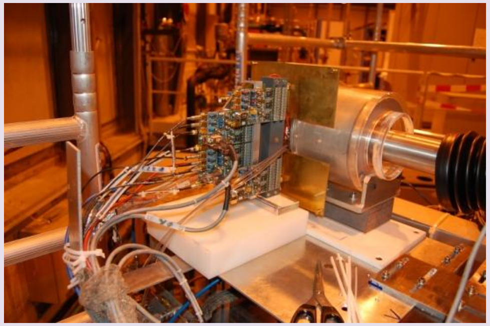
Present detectors



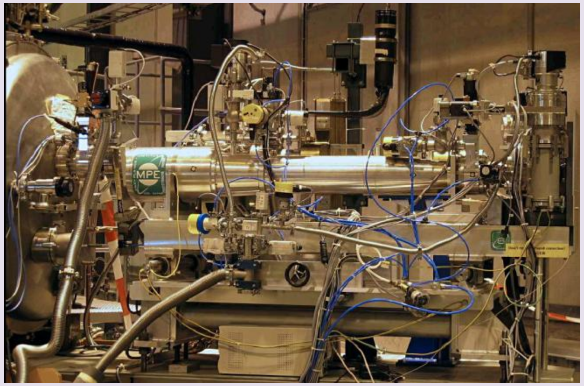
	Typical Rates
MM	2 counts/h (2-10 keV)
CCD+telescope	0.18 counts/h (1-7 keV)

SUNRISE SIDE
Shielded Micromegas last generation-Microbulk type

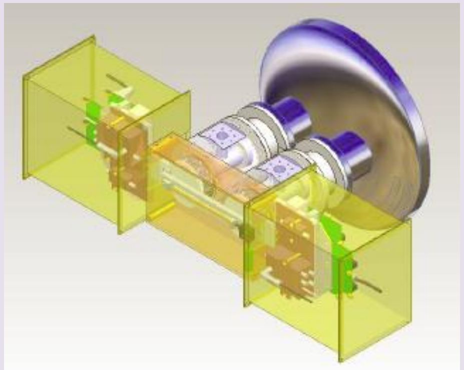


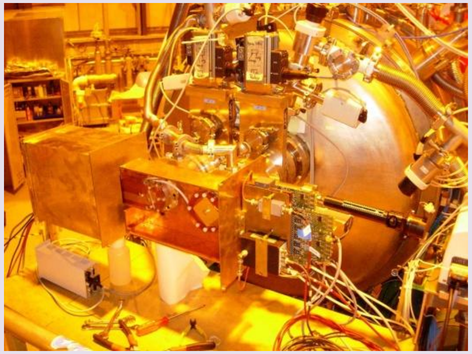


CCD +telescope

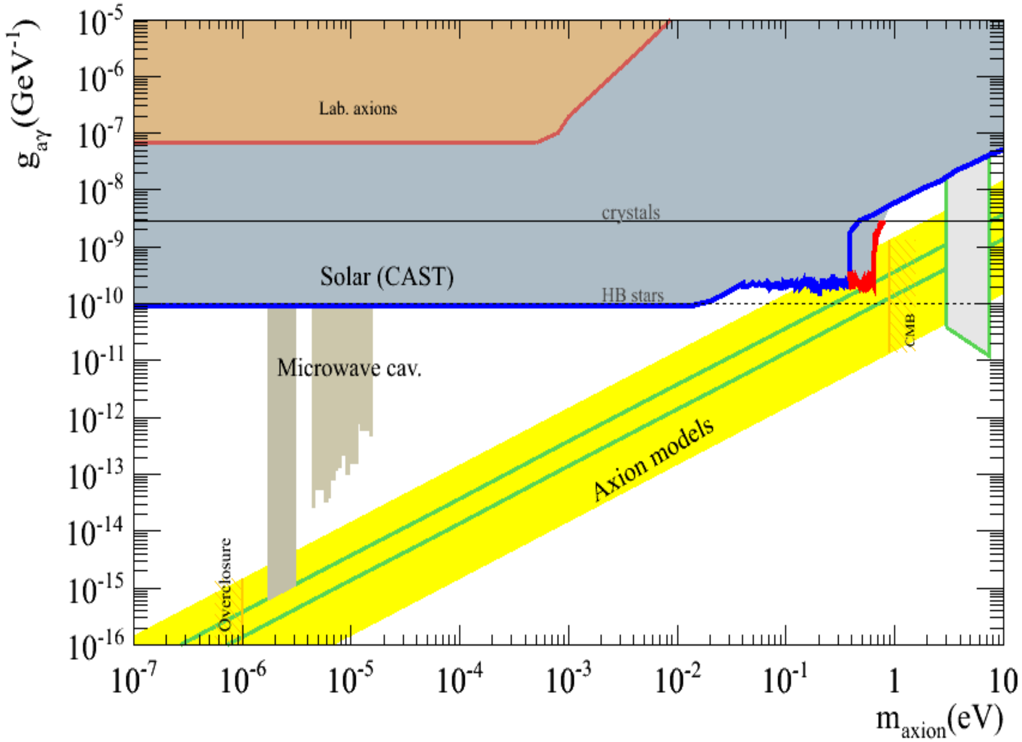


SUNSET SIDE: two shielded Micromegas last generation-Microbulk type





CAST PROGRAM AND SENSITIVITY



CAST Phase I: (vacuum operation 2003-2004)

completed (2003 - 2004), $m_a < 0.02$ eV

JCAP 0704(2007) 010, CAST Coll.

PRL (2005) 94, 121301, CAST Coll.

CAST Phase II: (buffer gas operation 2005-2011)

^{4}He completed (2005 -2006) , 0.02 eV < m_a < 0.39 eV

JCAP 0902 (2009) 008, CAST Coll.

^{3}He run completed (2007-2011),0.39 eV < m_a < 1.18 eV

First part ^{3}He run analysis accepted in PRL, Preprint:1106.39119

Original aims of CAST reached!

Short term plans for 2012-2015 later in this talk

Long terms plans→ see Juanan' s talk

CAST byproducts:

High Energy Axions: Data taking with a HE calorimeter JCAP 1003:032,2010

14.4 keV Axions: TPC data (before 2006) JCAP 0912:002,2009

Low Energy (visible) Axions: Data taking with a PMT/APD arXiv:0809.4581

Micromegas developments within CAST

S. Aune[2], T. Dafni[1], G. Fanourakis[3], E. Ferrer-Ribas[2], A. Gardikiotis[4], T.Geralis[3], I. Giomataris[2], H. Gómez[1], J. Gracia[1], D. C. Herrera[1] ,F. J. Iguaz[2], I. G. Irastorza[1], G. Luzón[1], T. Papaevangelou[2], A. Rodríguez[1], J. Ruz[1,5], L. Seguí[1], A. Tomas[1], T. Vafeiadis[6] and S. C. Yildiz[7]

[1] Grupo de Física Nuclear y Astropartículas, Zaragoza

[2] IRFU/SEDI, CEA

[3] Institute of Nuclear Physics, NCSR Demokritos, Athens

[4] University of Patras, Patras

[5] CERN

[6] Aristotle University of Thessaloniki, Thessaloniki

[7] Doğuş University, Istanbul

Sensitivity and background

$$g_{\alpha\gamma\gamma} \propto \underbrace{(BL)^{1/2} \times A^{1/4}}_{magnet} \times \underbrace{b^{1/8}}_{Detector} \times \underbrace{t^{1/8}}_{\substack{tracking\\ system}}$$

Fixed by the experiment

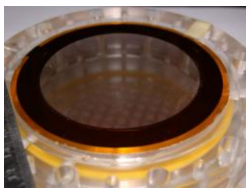
Low background. How?

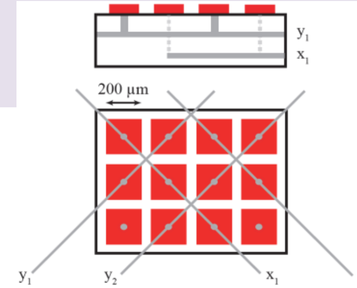
-Intrinsic radiopure materials (plexiglas, kapton, copper)

-Protection against external radiations by using shielding (Lead, Copper, Polyethylene, Cadmium)

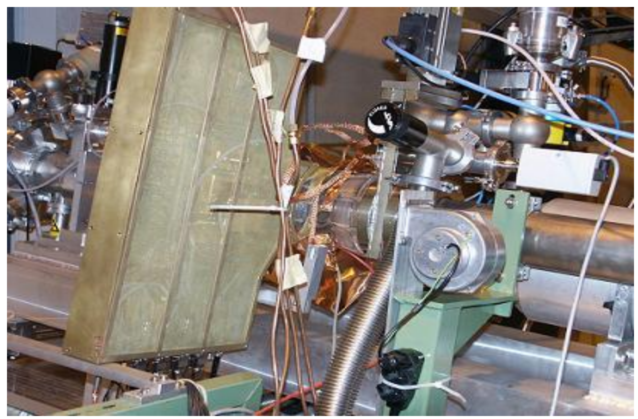
-Discrimination capabilities exploiting event topology and Statistical offline analysis for optimized discrimination

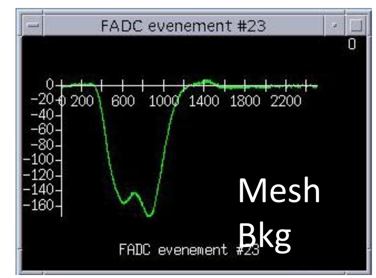
From 2002-2006

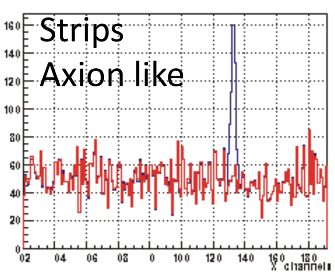


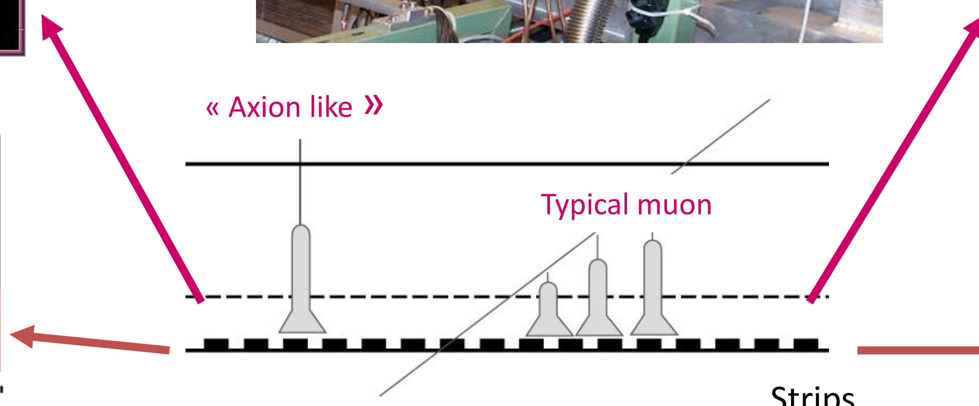


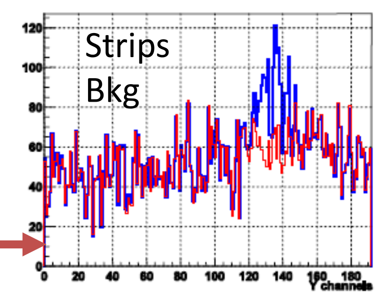
1 detector installed in the experiment
conventional Micromegas (2D)
Low background materials: kapton, plexiglass
Electronics for both for the strips (gassiplex) and the mesh (matacq)
Trigger with the mesh
No shielding









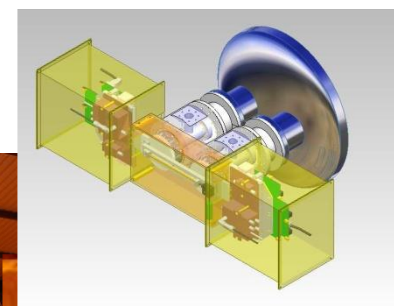


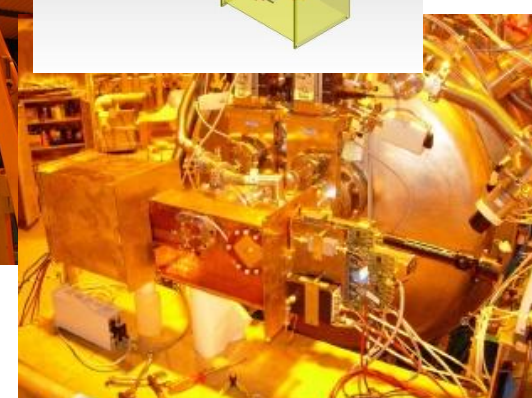
From 2006-2011

- 3 Micromegas detectors installed in the experiment
- New generation of Microbulk Micromegas (very radiopure materials→see Juanan’s talk)
- Shielding

Sunrise side detector

Sunset side detectors

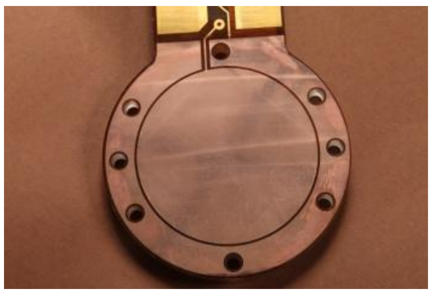


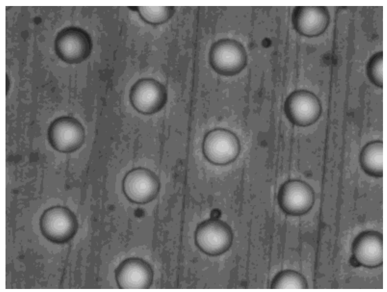


Microbulk

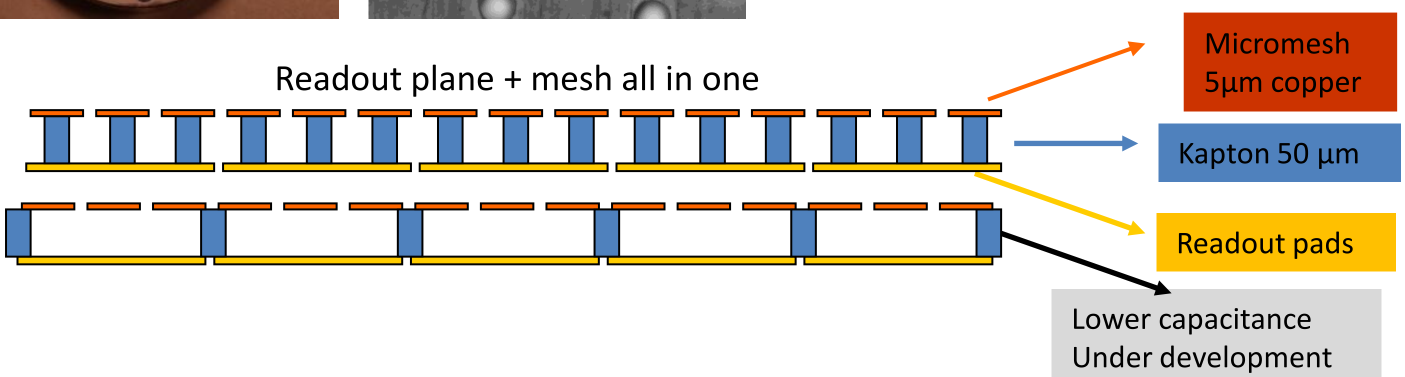
3 Micromegas detectors installed in the experiment
Microbulk Micromegas (very radiopure materials→see Juanan's talk)
Shielding

New generation of Micromegas: Microbulk



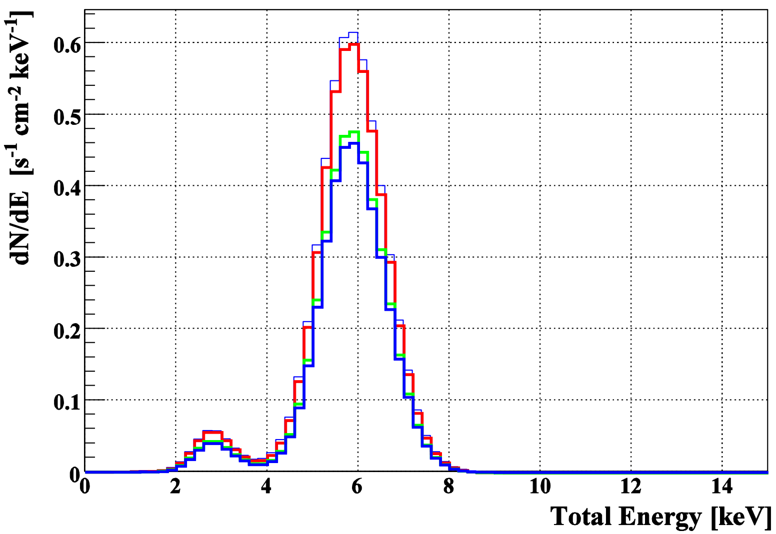


- **Energy resolution** (down to 10% FWHM @ 6 keV)
- **Low intrinsic background**
- **Low mass detector**
- **Very flexible structure**

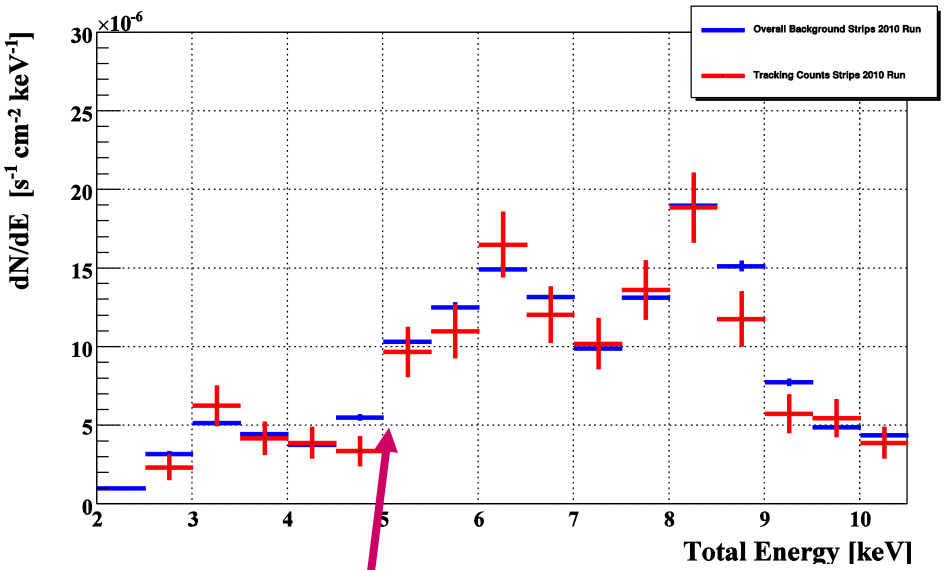


What do we measure?

Calibration: Fe source



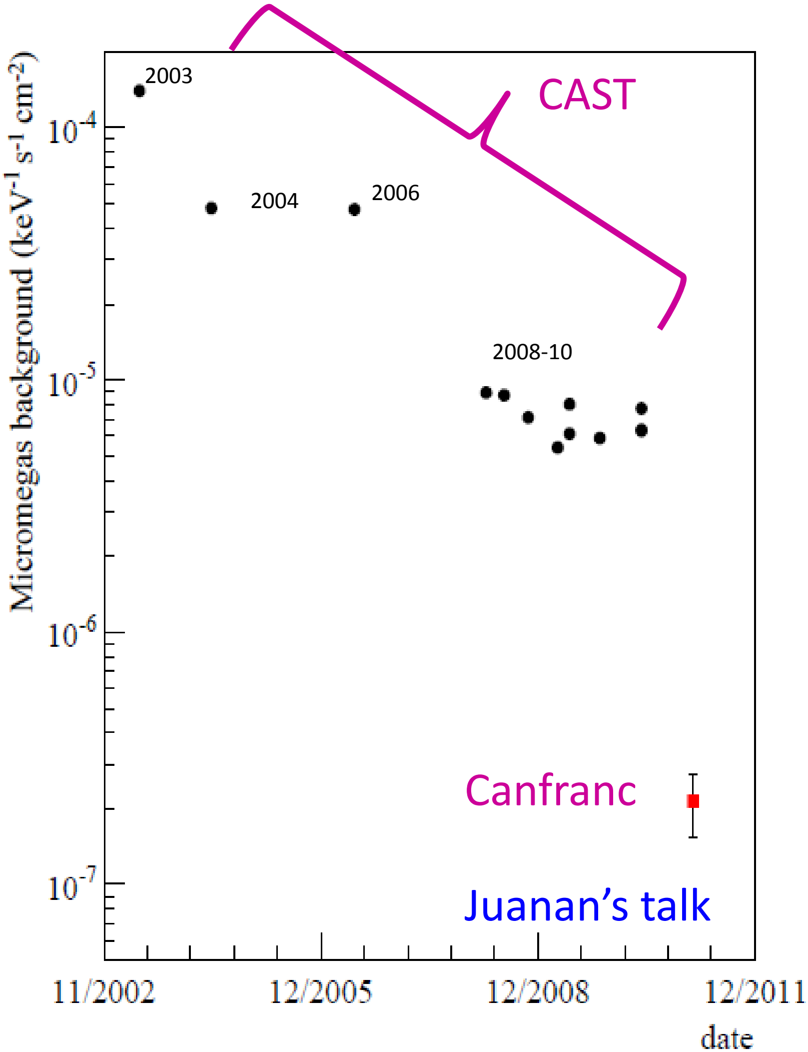
Background and tracking



Understanding background: big effort on simulation and Canfranc studies

Juanan's talk

History of Micromegas background in CAST



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

Thanks to:

Shielding +Microbulk technology

Potential for very low background rates

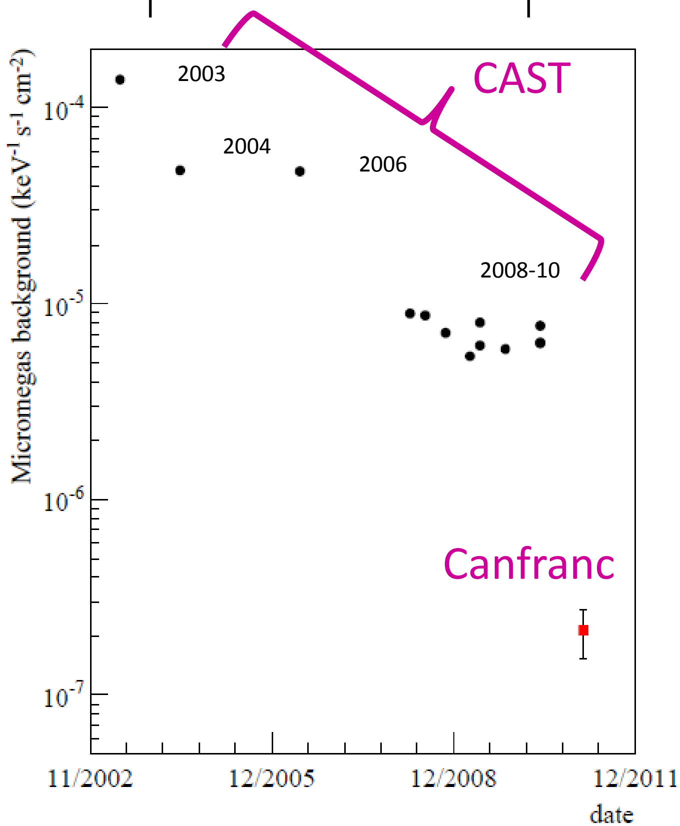
2010 JINST 5 P01009
2010 JINST 5 P02001

Perspectives

Plans for the future: Micromegas detectors performance have motivated an extension of the program

SHORT TERM

2012	Revisit ^4He R&D for vacuum phase	Focus on restricted axion mass range cross KSVZ axion models with present detectors
2013-2014	Revisit vacuum phase	Improve CAST phase I sensitivity thanks to improved detectors + new optics



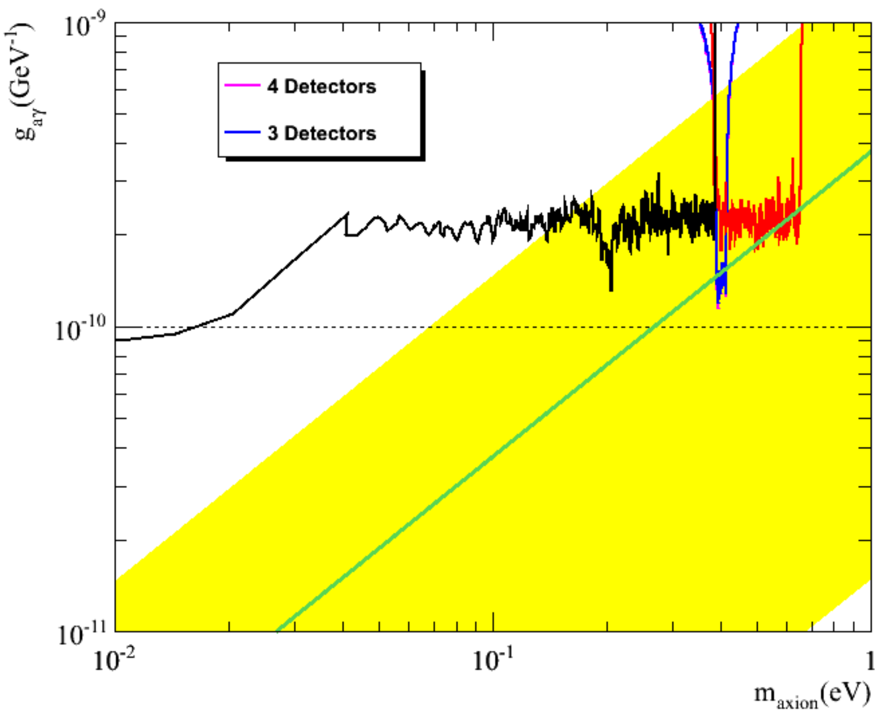
LONG TERM: IAXO

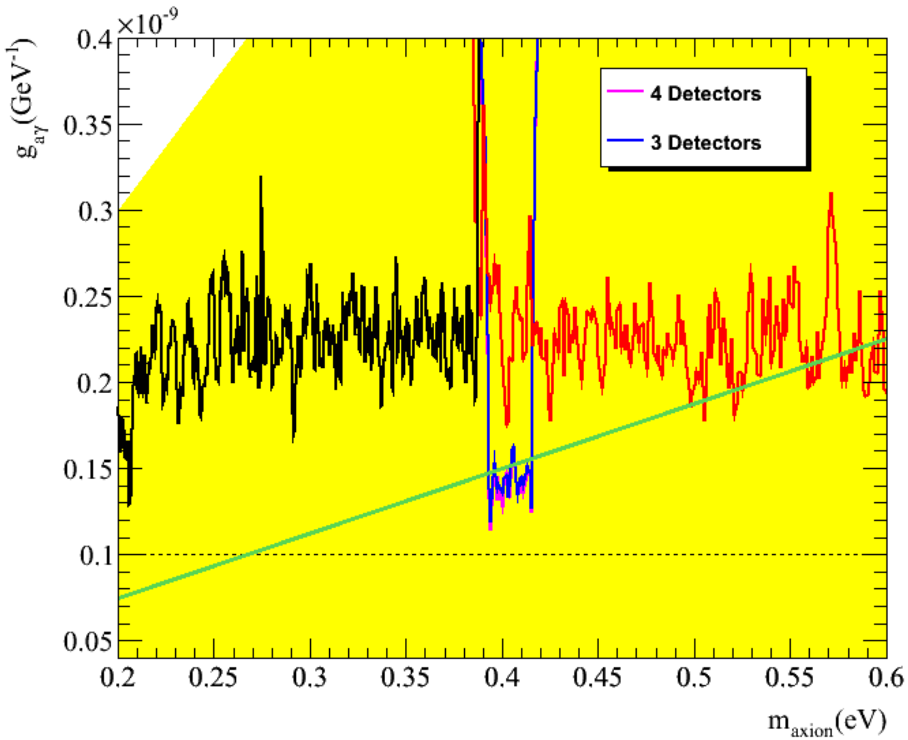
New Generation of Axion Helioscope

JCAP 06 (2011) 013

Juanan's talk

2012: short ^{4}He run and R&D for vacuum phase





10 trackings per density step during 3.5 months starting @ 0.415 eV (≈15.5 mbar)

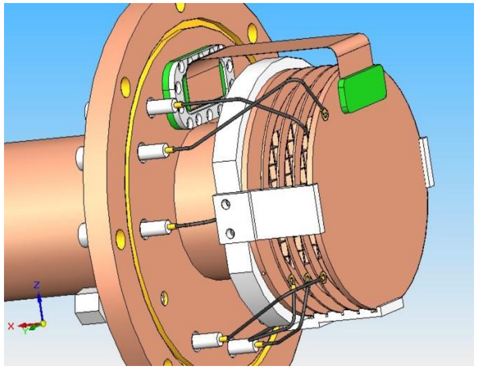
1) Improvements in detectors background ➔ improvement in sensitivity wrt our published results

2) At this mass improvement so that the KSVZ axion model benchmark is crossed

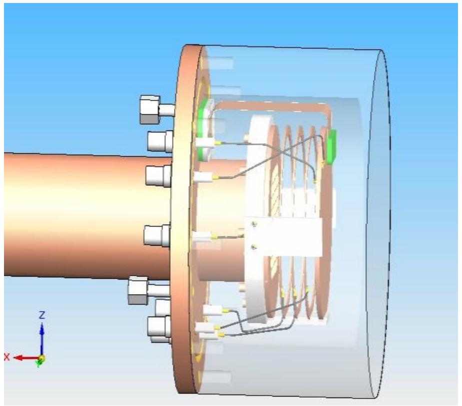
R&D in parallel: going further with Micribulk detectors

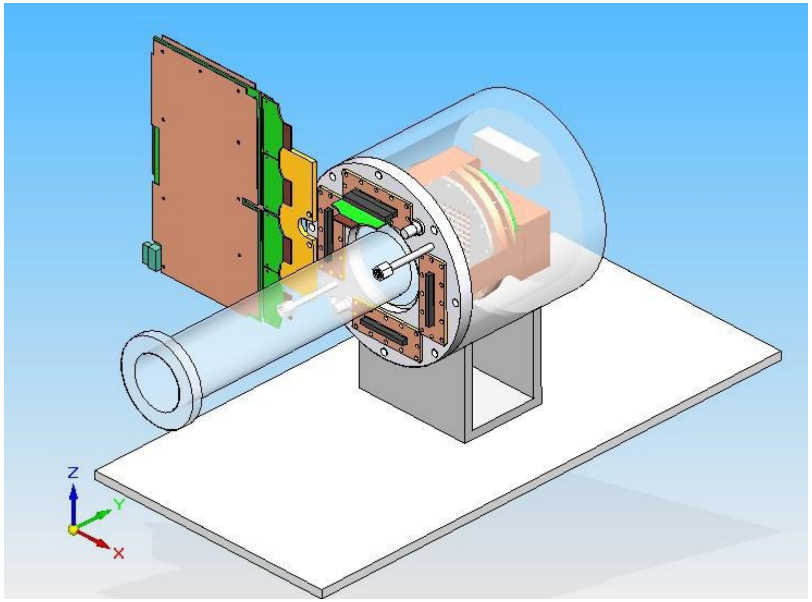
Finalise new design of Micromegas detectors ➔lower background and lower energy threshold

- Improve radiopurity of construction materials
- Inclusion of new electronics providing 3D information (T2K)
- More compact and full coverage shielding
- Study different gas mixtures to increase the gain



By J.P. Mols

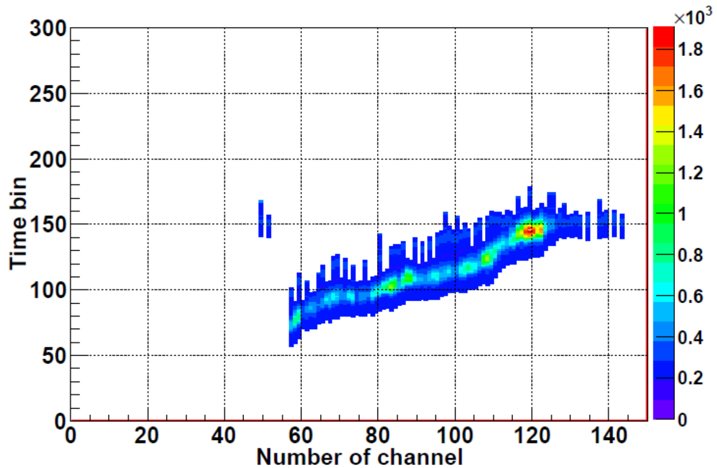




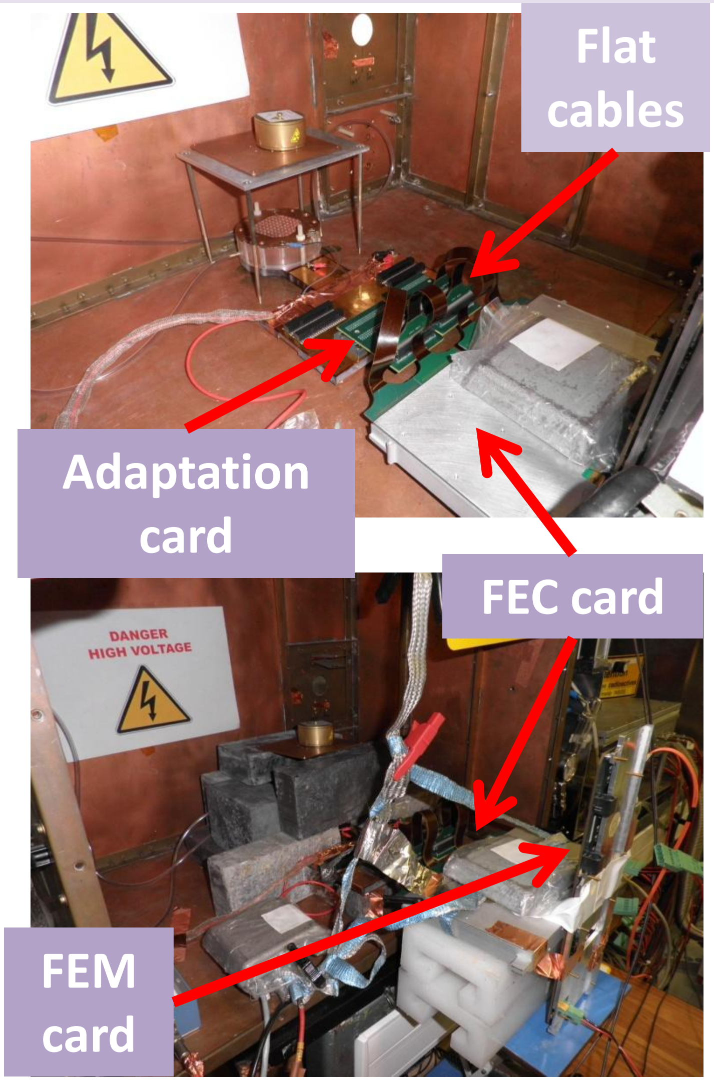
Using T2K electronics : first tests in the lab

- A new program has been created to reconstruct the two 2D view of each event

- The CAST analysis to discriminate low energy x-rays from background has been expanded to the temporal axis.



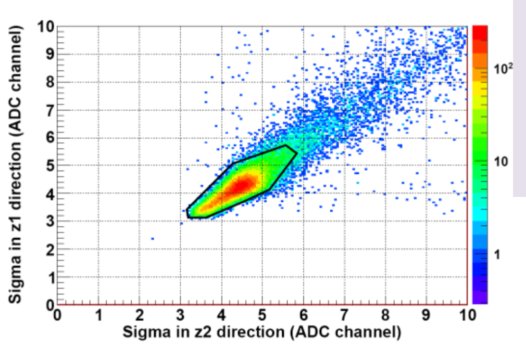
A low-energy electron viewed by a CAST detector



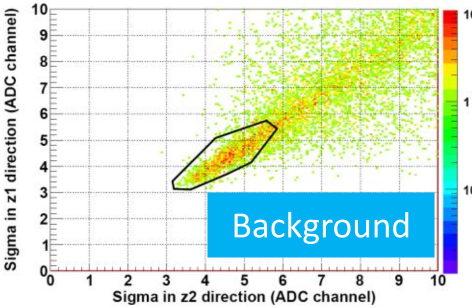
The CAST-M18 detector shielded with 5 cm of lead

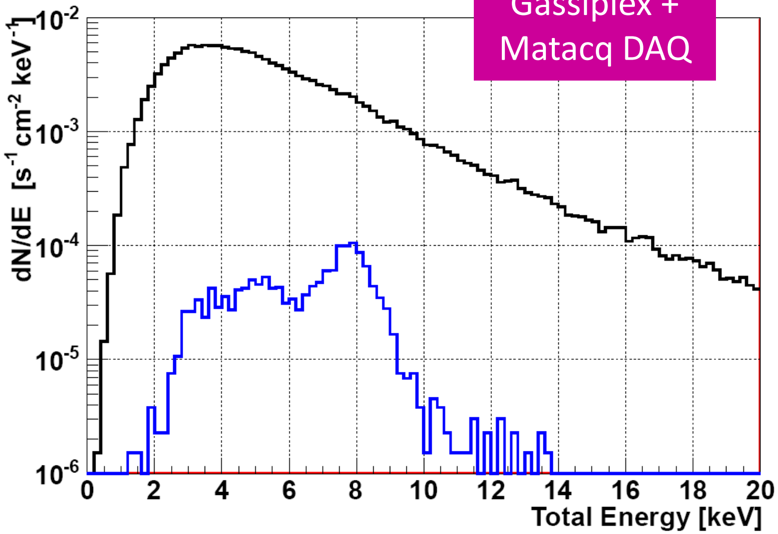
Using T2K electronics:
first « fresh preliminary » results

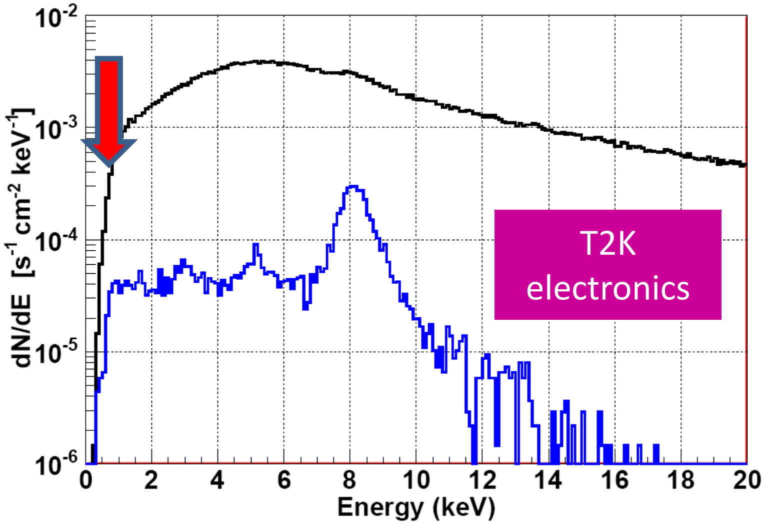
- Strip energy resolution as good as **12% FWHM**, (**15.4% FWHM** obtained with the gassiplex charge)
- Preliminary results with both electronics equivalent
- However, the energy threshold is as low as **700 eV**!
- Ne+10%Iso will also be tested



Cluster widths in temporal directions







- The CAST experiment has achieved its original goal of scanning axion masses up to 1.16 eV (**1.18 eV)**

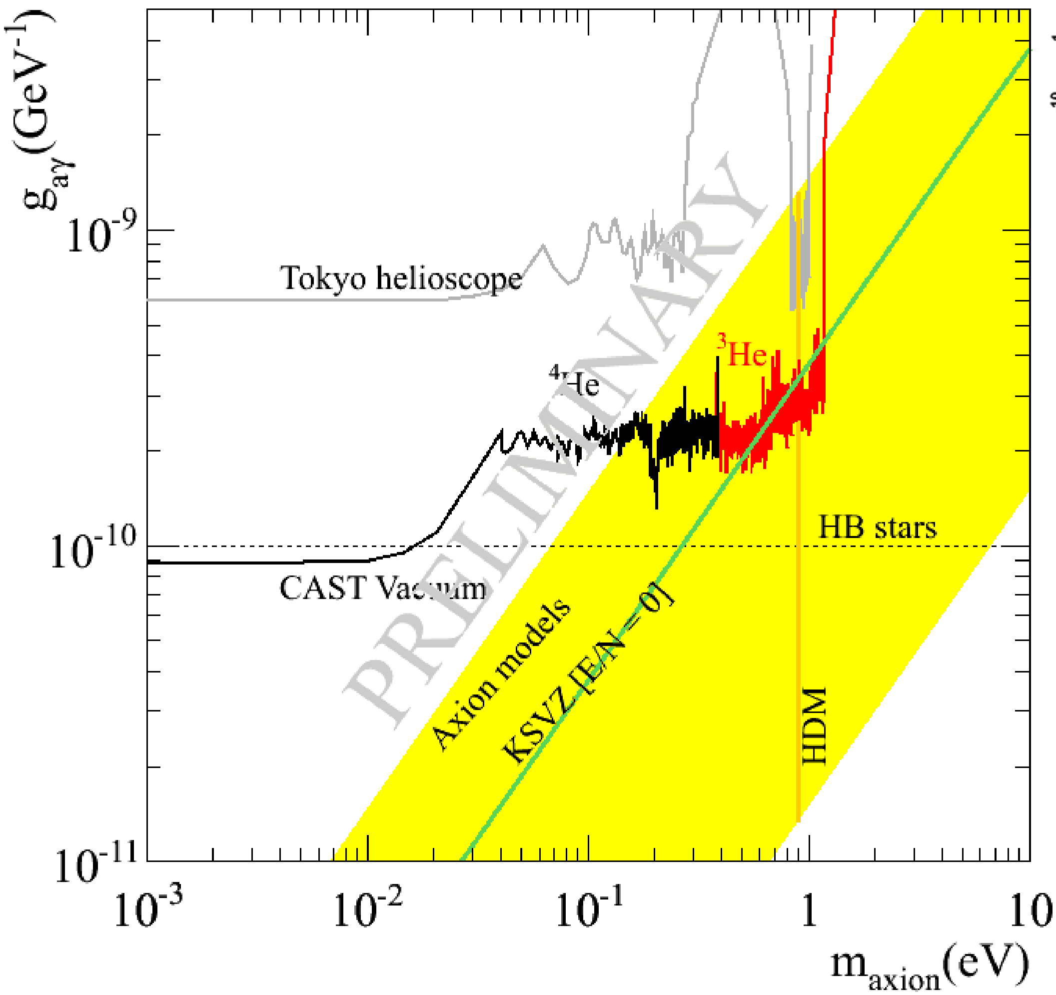
- Strictest experimental limit on axion searches for a wide m_a range entering the region most favoured by QCD models

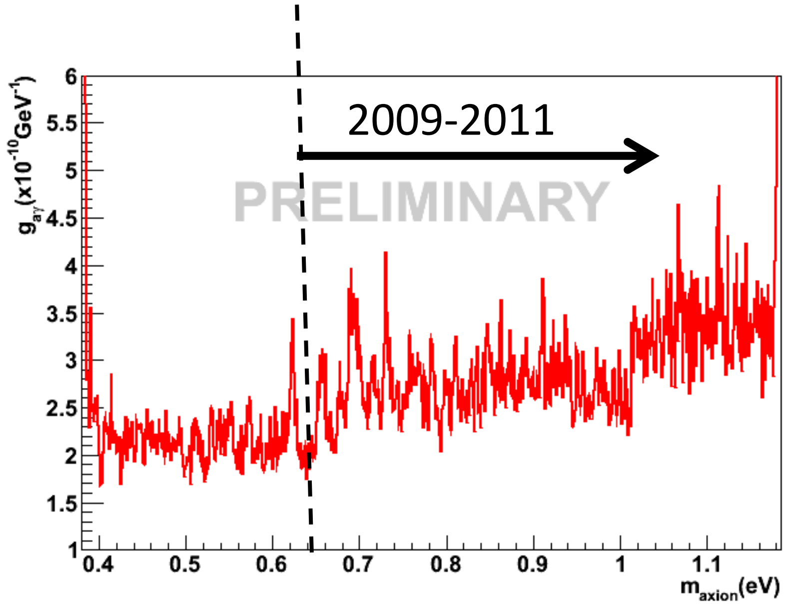
- The performance of Micromegas detectors have motivated the extension of CAST and New generation of Helioscope: IAXO

- Very exciting work in the short and long term for Micromegas in this field

BACK UP

VERY! Preliminary analysis plot (2009-2011)

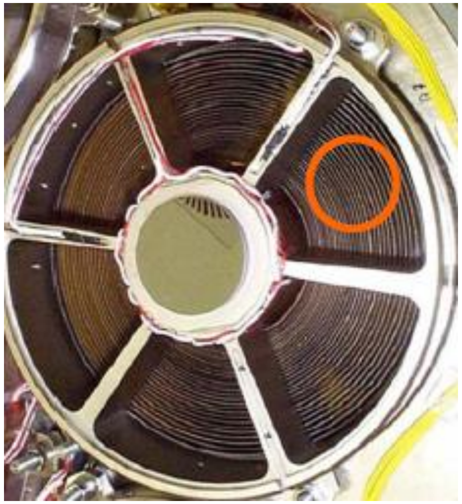




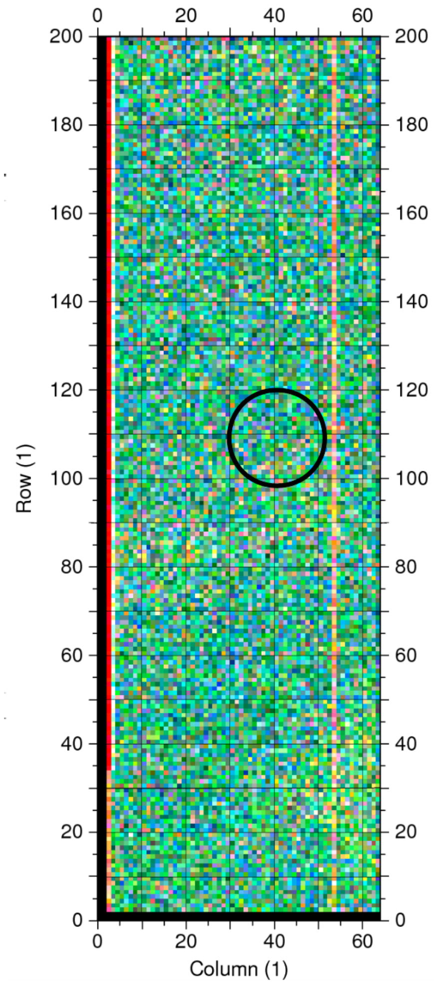
Data analysis 2009-2011

- ❑Analysis in progress
- ❑Goal: produce a preliminary analysis to identify possible candidates before ^{3}He is returned to LLNL

DETECTORS: CCD+telescope



Tracking rate≈ 1.3×10^{-7} events per second per pixel
Tracking rate in the spot ≈ of 1.4×10^{-7} events per second per pixel



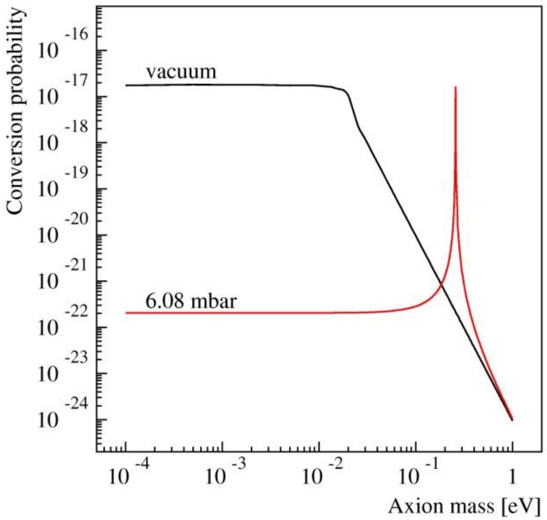
Year	Dates considered	Days of detector operation	Covered trackings from possible ones	Total Detector live time	Total Axion sensitive time
2010	30-08 -> 17-11	73	37/50 (74%)	4235 hours	131 hours
2011	21-03 -> 07-08	121	50/55 (91%)	176.5 days	5.45 days

Extending sensitivity to higher masses

Axion to photon conversion probability:

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

Vacuum:
Γ=0, m_γ=0



with $$q = \left|\frac{m_\gamma^2 - m_a^2}{2E_a}\right| \qquad m_\gamma(\text{eV}) = \sqrt{\frac{4\pi\alpha N_e}{m_e}} \approx 28.9\sqrt{\frac{Z}{A}\rho\left(\frac{\text{kg}}{\text{m}^3}\right)}$$

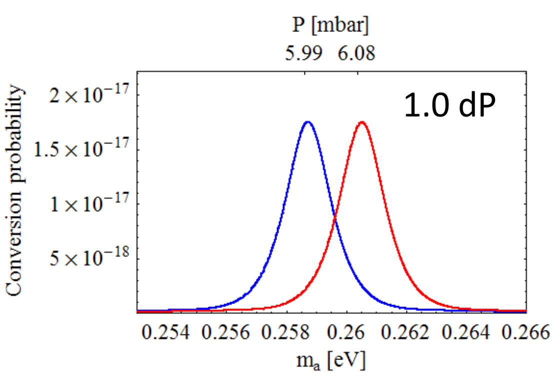
Coherence condition: $qL < \pi$

For CAST phase I conditions (vacuum), **coherence is lost for m_a > 0.02 eV**

With the presence of a **buffer gas** it can be **restored** for a narrow mass range:

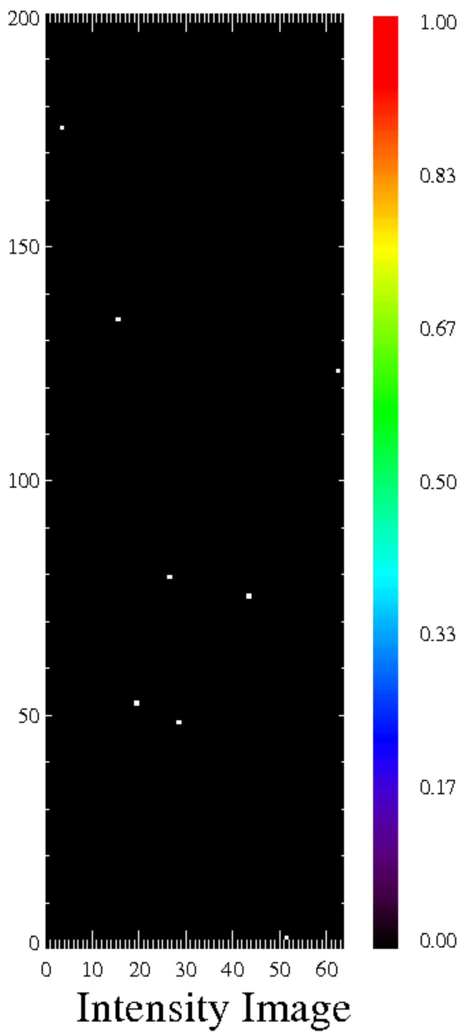
$$\boxed{qL < \pi \Rightarrow \sqrt{m_\gamma^2 - \frac{2\pi E_a}{L}} < m_a < \sqrt{m_\gamma^2 + \frac{2\pi E_a}{L}}}$$

e.g. for 50 mbar $\Delta m_a \sim 10^{-3}$ eV

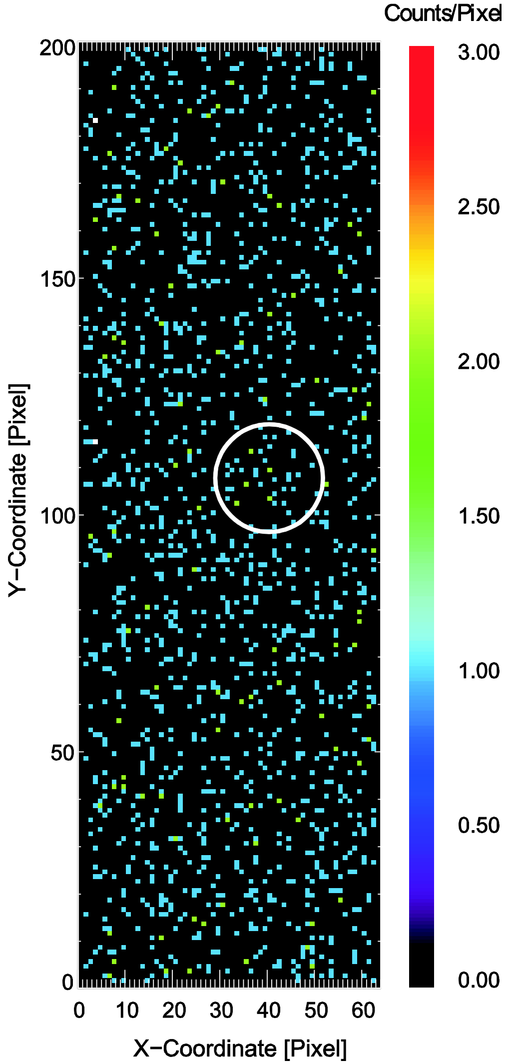


RESULTS CCD ^{4}He data

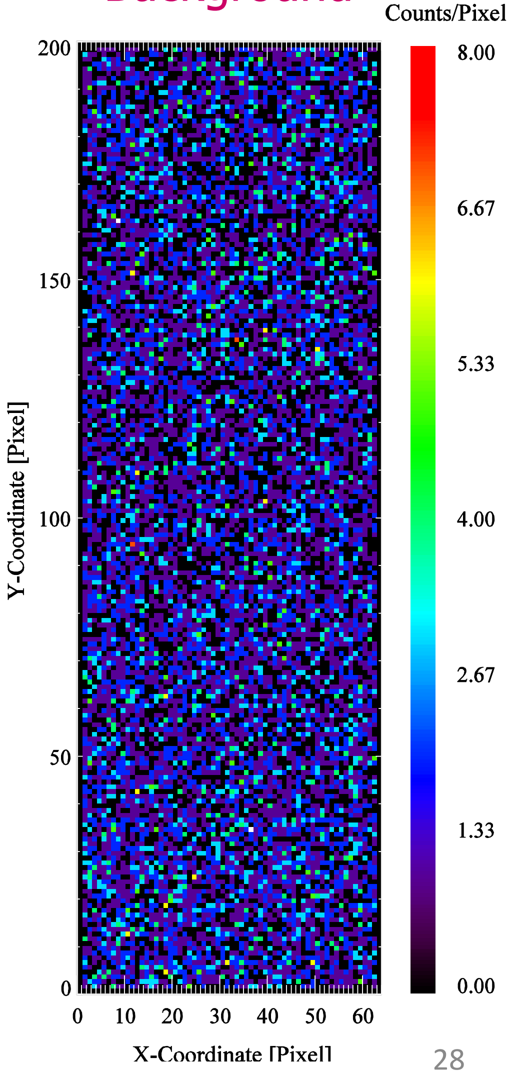
One single tracking



Integrated trackings

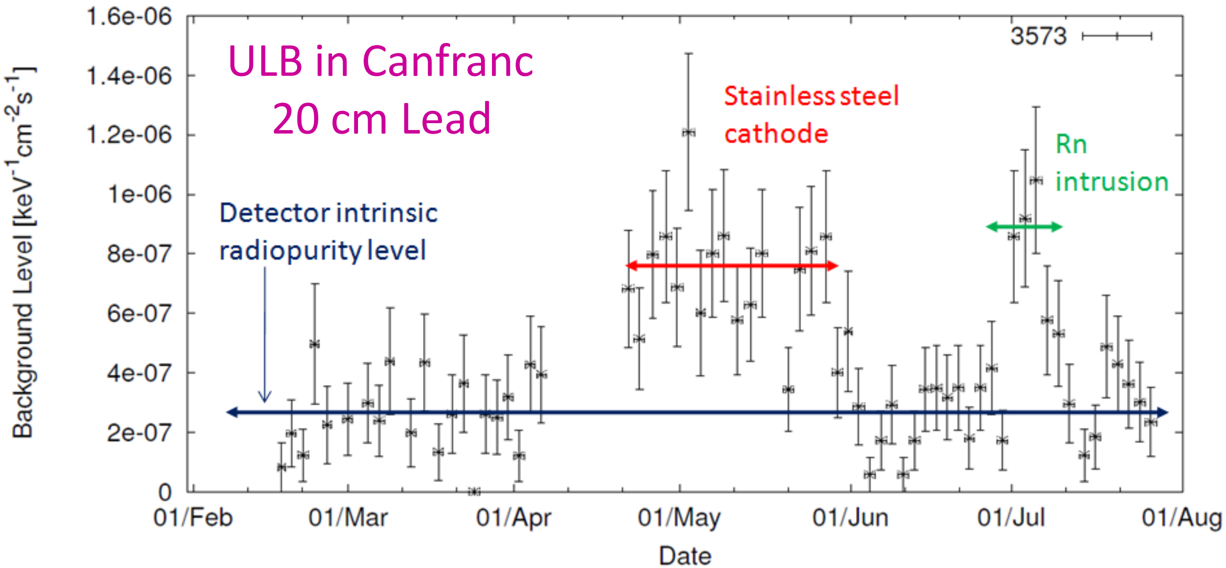


Background



Status of ULB (1)

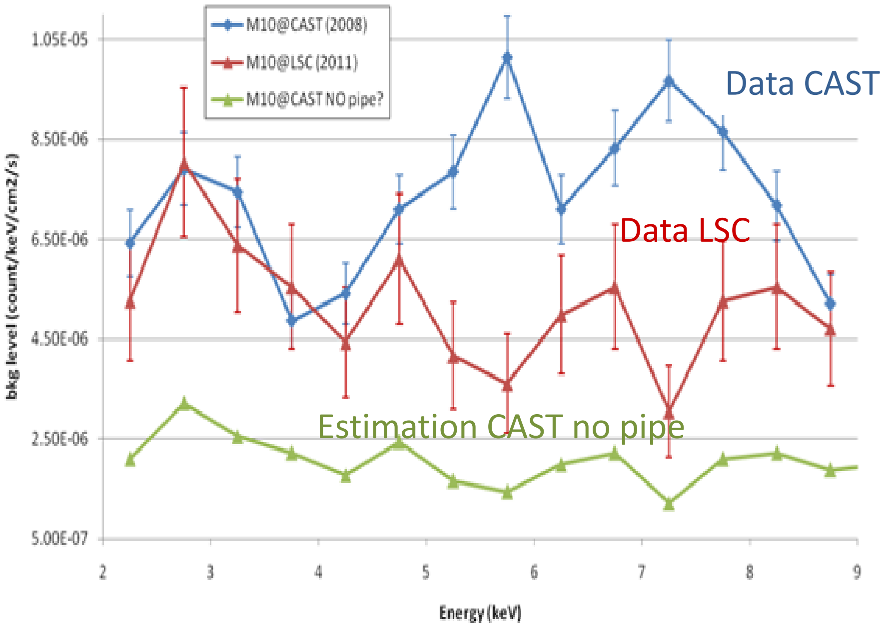
- Strategy to understand this effect
  - Shielding tests at ground in CERN and Saclay
  - Shielding tests in the Underground Laboratory of Canfranc
  - Simulations of the detector

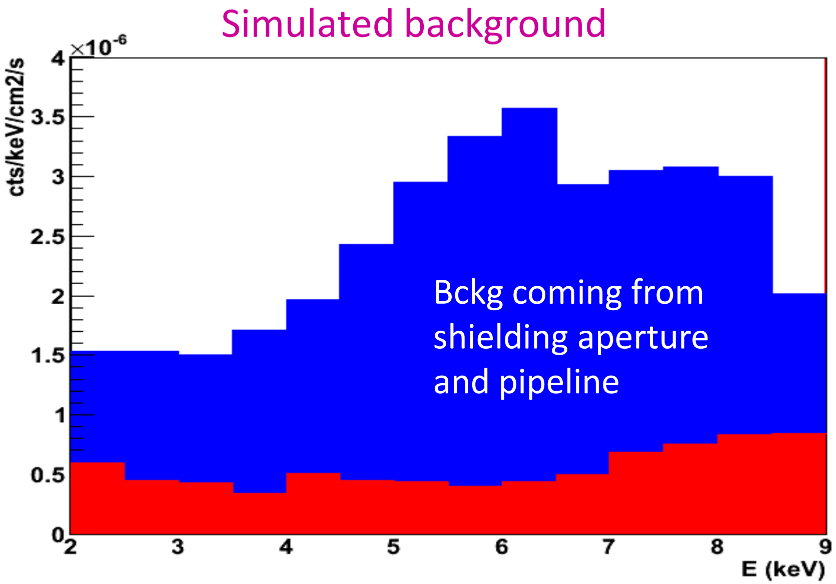


Intrinsic radioactivity level determined

≈ $2x10^{-7}$counts keV^{-1} s^{-1} cm^{-2}

Status of ULB (2)



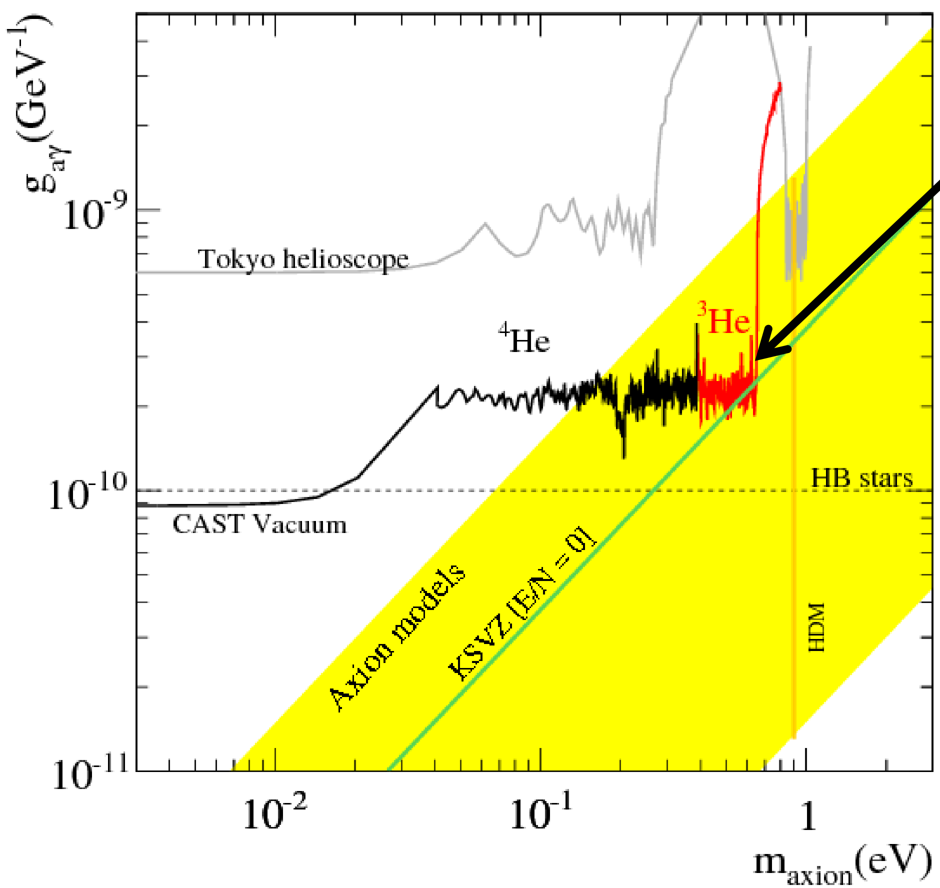


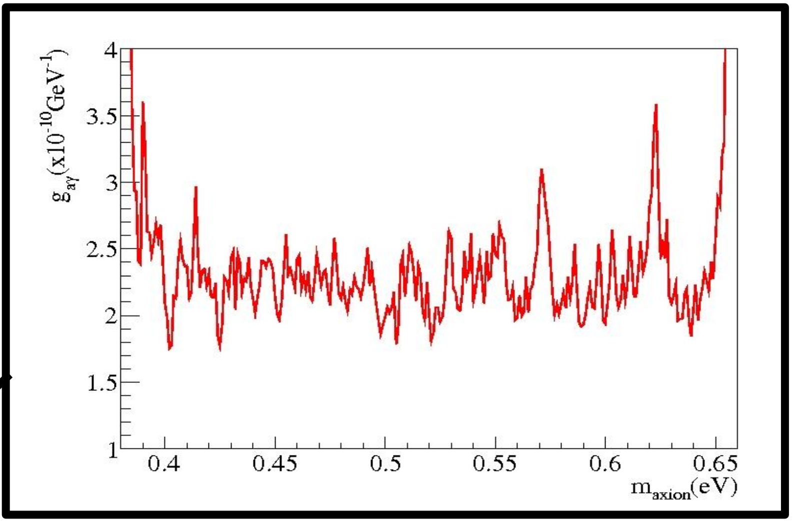
- ❑Dominant contribution of gammas coming from the aperture of the shielding
- ❑Increasing the shielding, especially on the pipe=> reduction of the background
- ❑ULB not yet understood
- ❑ Significant research is underway
- ❑ Promising results to continually reduce the backgrounds in future detectors
- ❑Roadmap of tests/development to explore ideas and consolidate lower backgrounds

First science results from ^3He

Accepted for publication in PRL

Preprint:1106.39119



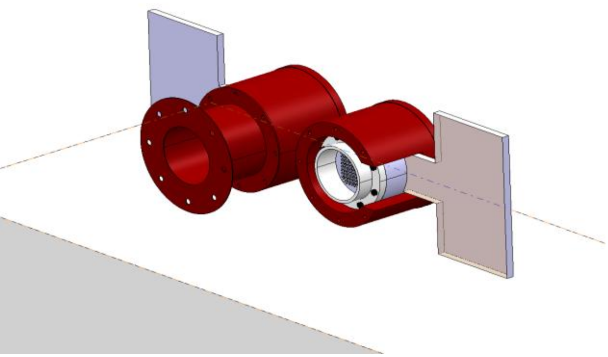


- First ^3He data (2008) shown in red
- Masses 0.39-0.65 eV excluded down to 2-2.5×10^{-10} GeV^{-1}
- Touching KSVZ benchmark models for the first time

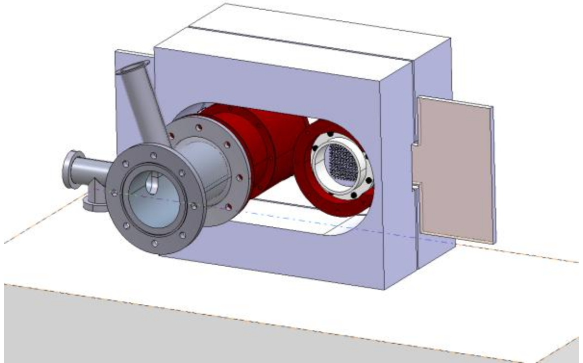
2012: detectors

SUNRISE	SUNSET	
CCD +Telescope (unchanged)	Micromegas 1 (replaced)	Shielding upgrade
Micromegas (unchanged)	Micromegas 2 (replaced)	
BARBE (increase field of view)		

Sunset shielding upgrade design:



reduction factor 4 possible



Micromegas tasks during shutdown

- ❑Background tests
- ❑Calibrate detectors with the X-ray gun in the CAST detector laboratory
- ❑Build and install the shielding

2012: R&D in parallel (1)

1) Develop thin transparent windows to search in parallel for other WISPs (chameleons and hidden sector paraphotons)

2) A next-generation framestore pn-CCD detector is being tested

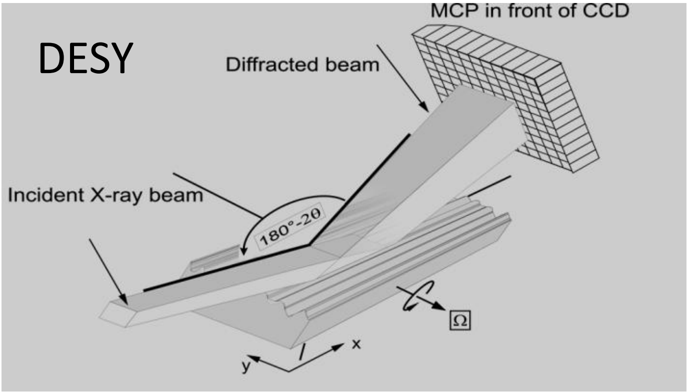
3) Finalise new design of Micromegas detectors in order to reach levels approaching 2×10^{-7} counts keV^{-1} s^{-1} cm^{-2} with lower energy threshold

4) Develop new optics to be coupled to Sunrise Micromegas

5) TES based detector tests on the BaRBE line?

1) Thin transparent windows

- Nanotubes materials :
  - base material Al_2O_3
  - fraction of incident photons can be transmitted directly or channeled through pores
  - test of windows at DESY
- Feasability for Kapton based using Microbulk techniques→ honeycomb



CAST Microbulk manufacturing

Kapton foil (50μm), both sides Cu-coated (5μm)

Construction of readout (strips/pads)

Added a single-side Cu-coated kapton foil (25/5)

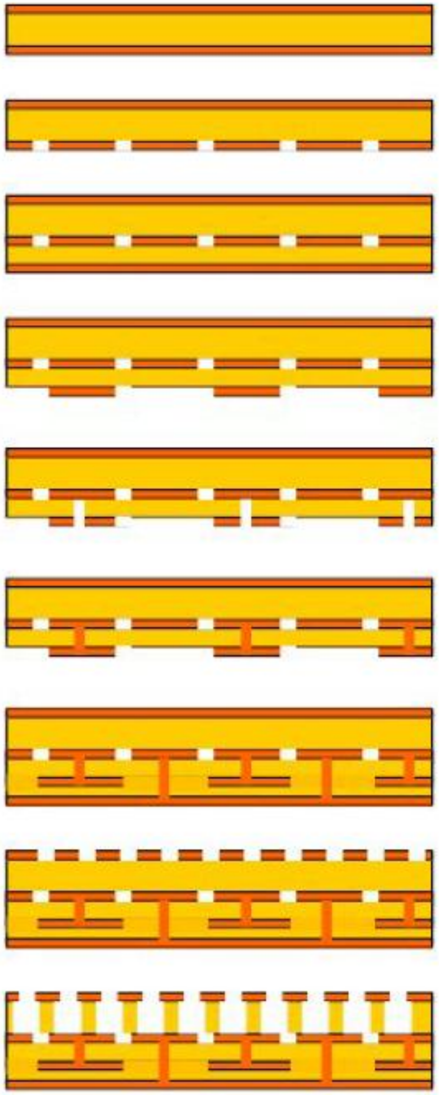
Construction of one direction readout lines

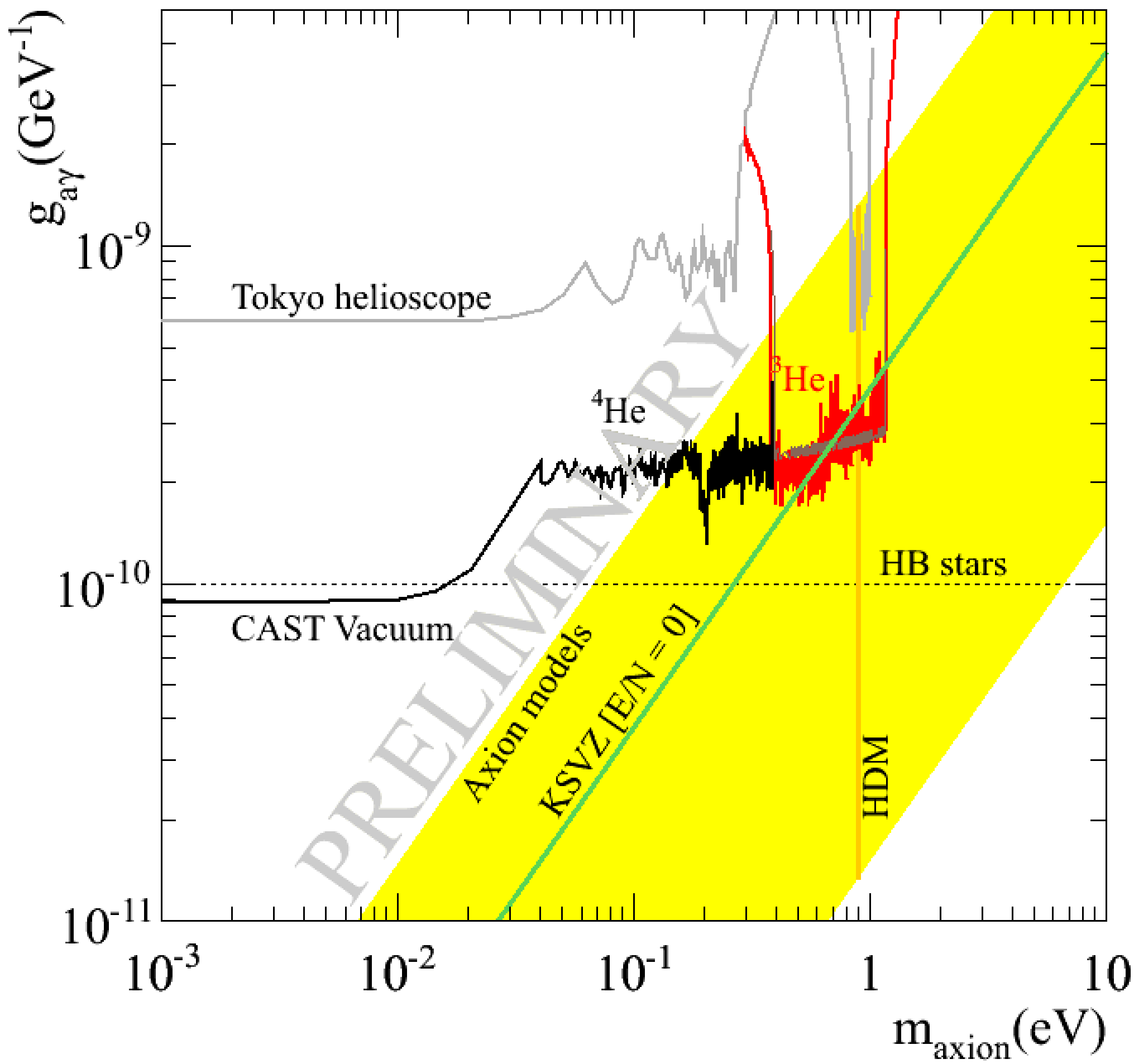
Vias construction by etching the kapton

Construction of the second direct readout lines and vias

Photochemical production of mesh holes

Kapton etching and cleaning





$g_{a\gamma}(\mathrm{GeV}^{-1})$
10^{-9}
10^{-10}
10^{-11}
10^{-3}
10^{-2}
10^{-1}
1
10
$m_{axion}(\mathrm{eV})$
Tokyo helioscope
^{4}He
^{3}He
HB stars
CAST Vacuum
PRELIMINARY
Axion models
KSVZ [E/N = 0]
HDM