Low Background MICROMEGAS in CAST

J. G. Garza[1]
On behalf of CAST/IAXO-Micromegas group.

7th Symposium on Large TPCs for Low-Energy Rare Event Detection.
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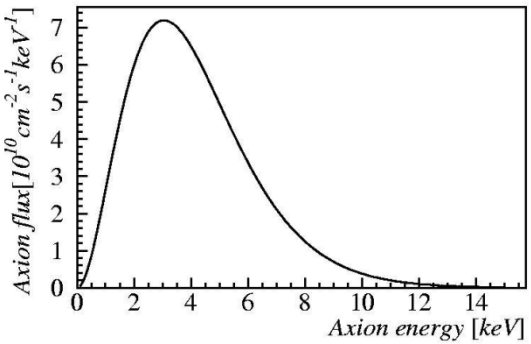
[1] jgraciag@unizar.es, Universidad de Zaragoza

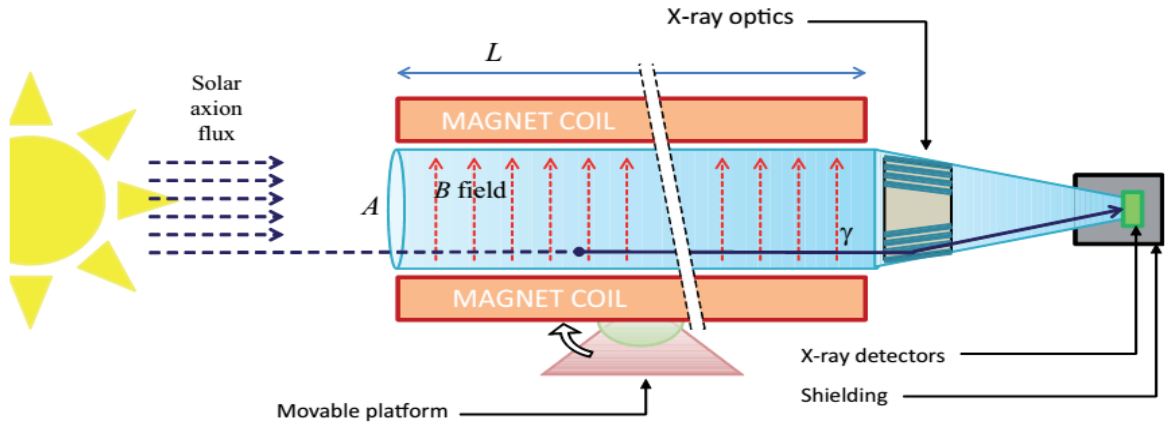
Outline

- Axion helioscopes: CAST & IAXO.
- Micromegas in CAST.
- Background level and background model.
- Prospects for:
  - ❑ background reduction
  - ❑ lowering the enegy threshold
- Conclusions.

Axion detection by an helioscope



Serpico & Raffelt, JCAP04 (2007) 010



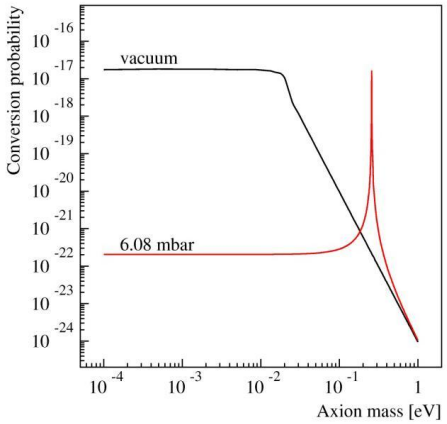
Production: *Primakoff effect.* Thermal photons interacting with solar nuclei produce axions.

Detection: *inverse Primakoff* Axions in a magnetic field convert to photons.

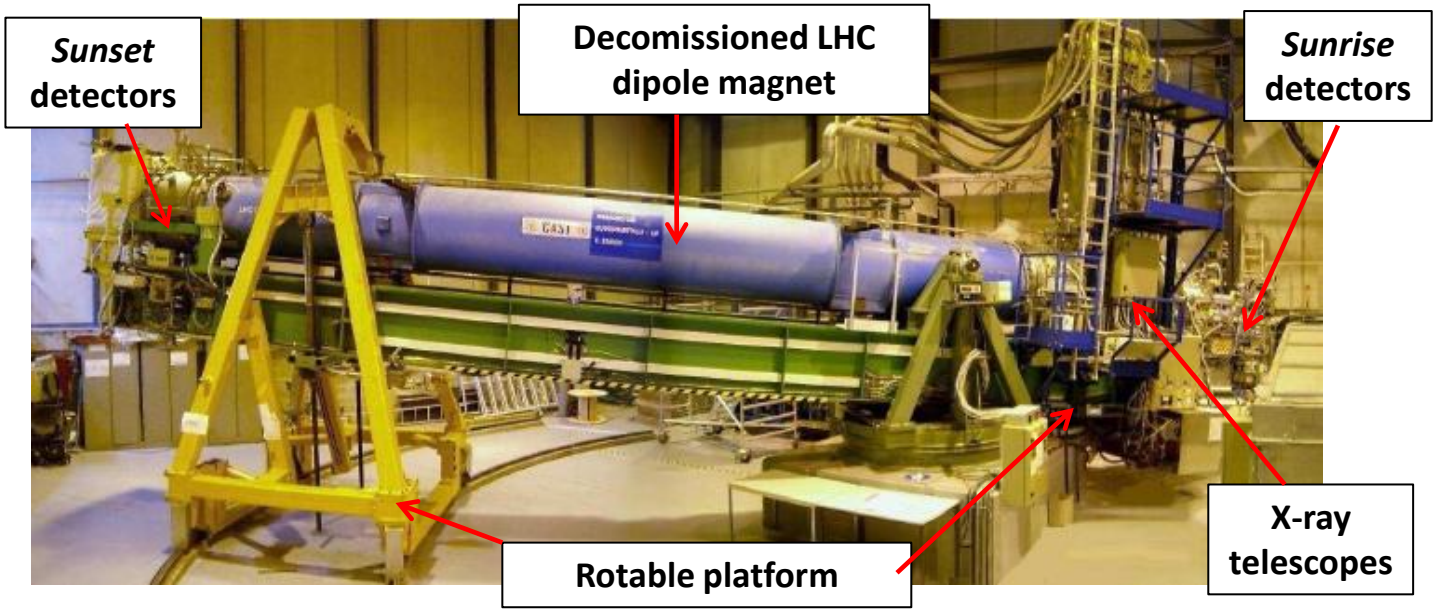
(Sikivie 1983, *PRL 51 1415-1417*)

Axion Signal: x-ray excess when the magnet points to the Sun.
→ need of low background x-ray detectors.

- Conversion probability depends on medium.
- In vacuum coherence is lost for $m_a > 0.02$ eV.
- In the presence of a buffer gas, the coherence can be restored for a narrow mass range.



CAST: CERN Axion Solar Telescope



MAGNET:

- Length: 9.3 m. Field: 9 T. Apperture: 14.5 cm^2 (x2).
- Range of movement: 80º horizontally and ± 8º vertically.
- Solar tracking possible during sunrise and sunset (2 x 1.5 hours per day).

- CAST is operating at CERN since 2003, most sensitive helioscope so far.
- An important improve in sensitivity to axions and ALPs is only expected with a fully new helioscope as proposed by IAXO (4 orders of magnitude better in S/N wrt CAST, i.e. 1-2 orders in $g_{a\gamma}$). ***See Esther Ferrer-Ribas talk, «The IAXO helioscope».***

CAST Physics program

1) CAST Phase I, Vacuum

- m_a < 0.02 eV; $\mathbf{g_{a\gamma\gamma} < 0.88 \cdot 10^{-10}\ GeV^{-1}}$.

PRL94 (2005) 121301 & JCAP04(2007)020.

2) CAST Phase II, ^{4}He

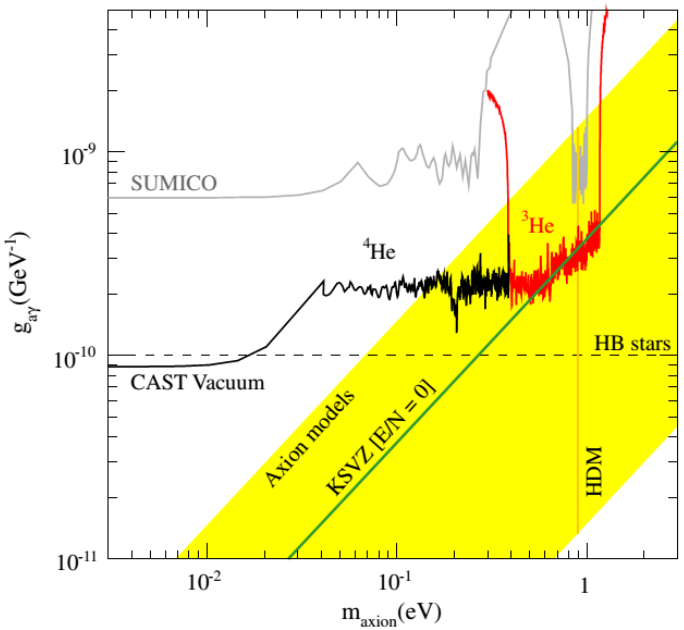
- P < 13.4 mbar (1.8K), 160 steps
- 0.02 < m_a< 0.39 eV; $\mathbf{g_{a\gamma\gamma} < 2.2 \cdot 10^{-10}\ GeV^{-1}}$

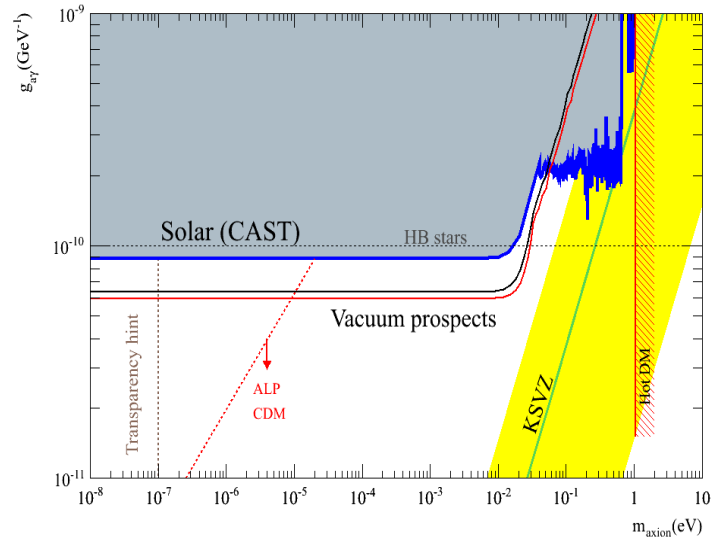
JCAP02 (2009) 008

3) CAST Phase II, ^{3}He

- P < 120 mbar (1.8K), 160 steps
- 0.39 < m_a< 1.17 eV; $\mathbf{g_{a\gamma\gamma} < 3.3 \cdot 10^{-10}\ GeV^{-1}}$

PRL 107 (2011) 261302 & PRL 112 (2014) 091302

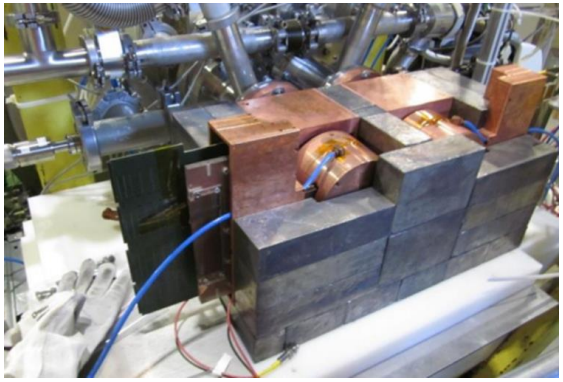




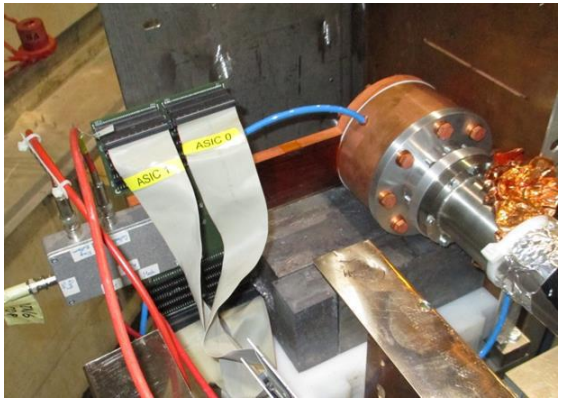
Current activities

- Revisiting the vacuum phase (2013-2015) with more sensitive detectors.
- Looking for non-hadronic axions and other WISPs (chamaleons, paraphotons, etc.)

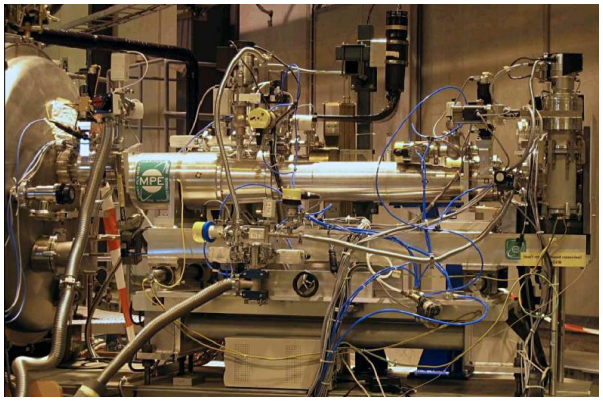
CAST X-ray Detectors



CAST-Micromegas at Sunset



CAST-Micromegas at Sunrise



X-ray optics + CCD at Sunrise

JINST 9 (2014) P01001

New J. Phys. 9 (2007) 169.

- ***Sunset*:** 2 Microbulk Micromegas detectors.
- ***Sunrise*:**
  - X-ray focusing device + CCD (2003-2013). CCD was replaced by InGrid detector in 2014 ***(see Klaus Desch talk, «Ingrid detector in CAST»).***
  - Microbulk Micromegas detector (with x-ray optics since 2014).
- X-ray optics produce an increase in S/N of around 150.

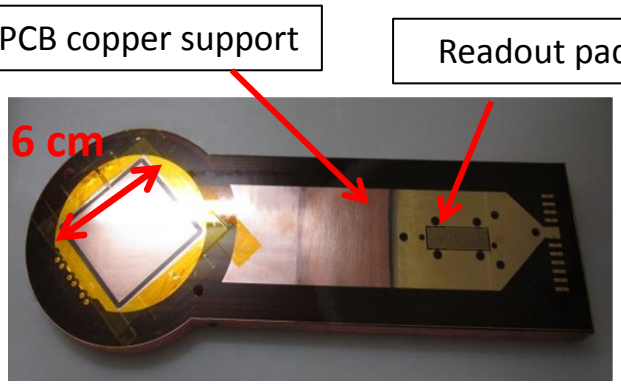
Detectors & optics figure of merit:

$$f_{DO} = \frac{\varepsilon_d \varepsilon_o}{\sqrt{ba}}$$

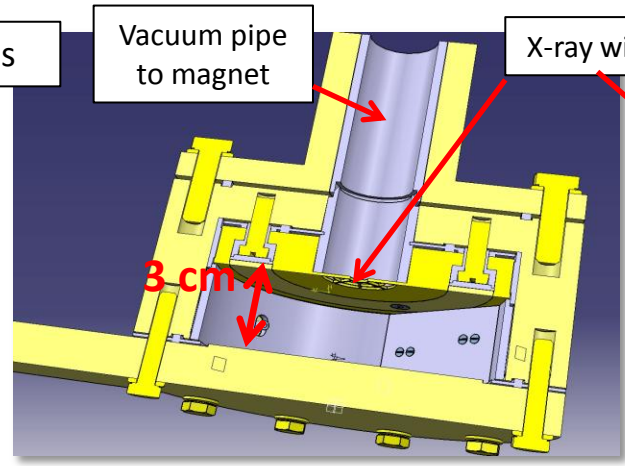
To increase sensitivity:

- increase efficiency of detector & optics (ε).
- Reduce detector backgrounds (b) and focusing area (a).

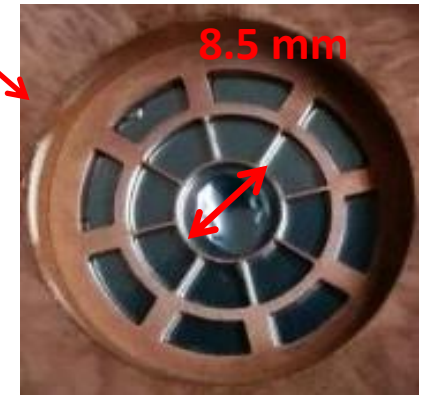
Micromegas in CAST



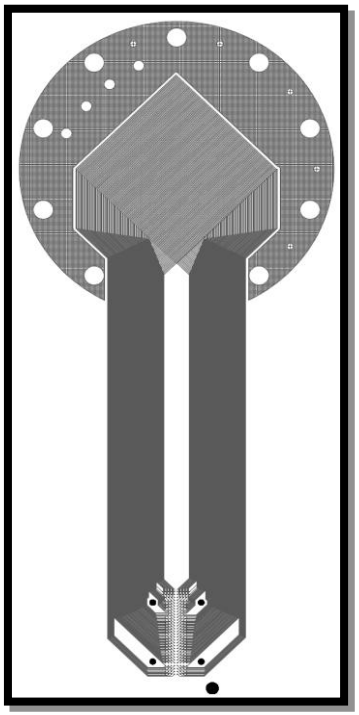
Readout plane

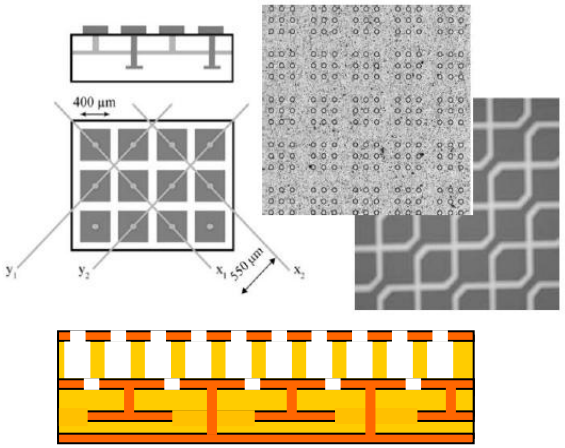


TPC schematics



X-ray window + strongback cathode.





Mesh 5 µm of copper
Holes 30 µm diameter
Pitch 100 µm
Pads of 400 µm
Thickness 80 µm

CAST-MMFeatures

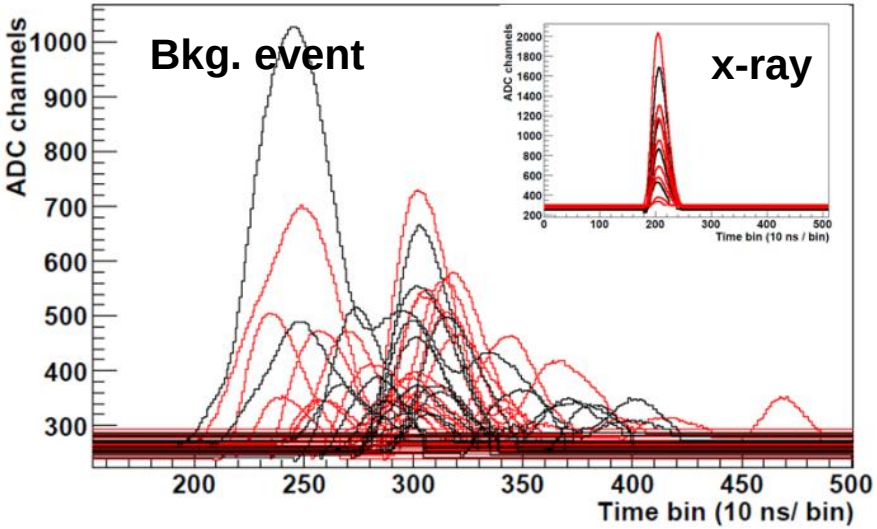
- Active area: 6x6 cm^2 (120x120 strips) microbulk produced at CERN workshop.
- Gas: Ar + 2%iC_2H_4 at 1.4 bar.
- Conversion region: 3 cm (100 V/cm).
- Amplification gap: 50 µm (10^4 V/cm).
- X-ray window: 4 µm aluminized mylar.
- AFTER-based readout electronics.

Why Micromegas for axion helioscopes?

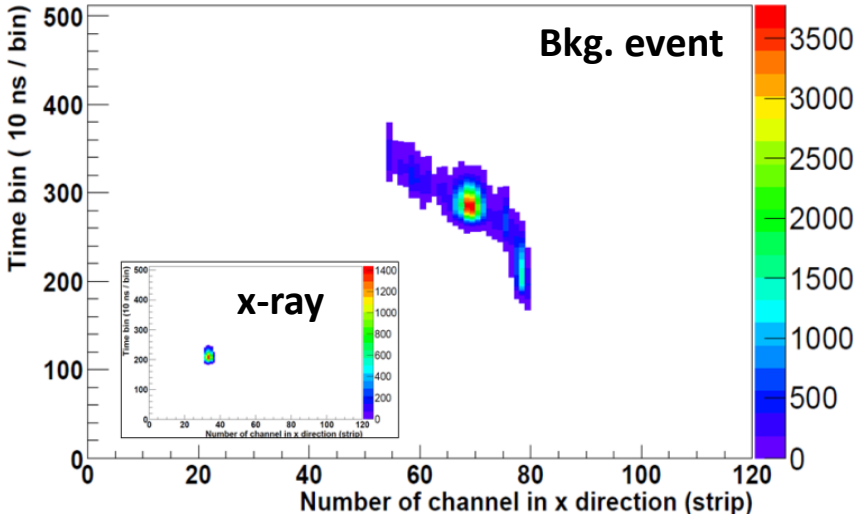
1) Hihgly granular readout allows strong background suppression based on signal topology and cluster analysis. (*JINST 9 (2014) P01001*)

- We look for x-rays, i.e. punctual energy depositions in a gas.
- High granular Micromegas have high power to discriminate x-rays from backgrounds, which usually present more extended, non-symmetric tracks.
- Daily ^{55}Fe calibrations define reference data set for signal/background discrimination.

Comparison of a typical x-ray and background event:



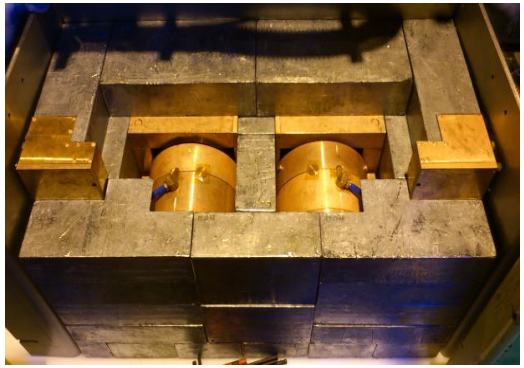
Pulses in x and y strips



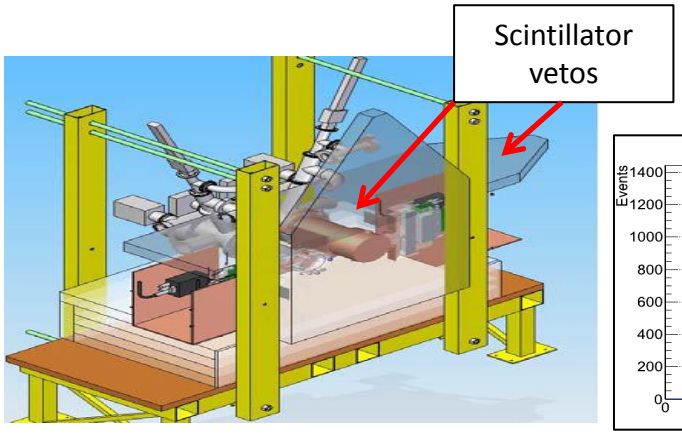
Events in XZ plane

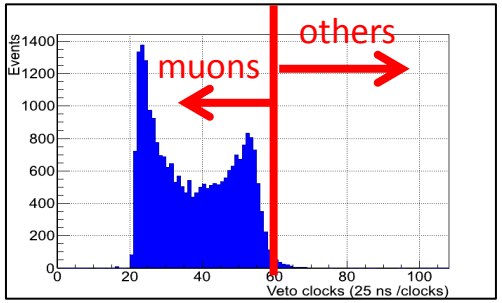
Why Micromegas for axion helioscopes?

2) Shielding techniques (passive and active) from low background experiments are also applied.



Passive shielding: copper and lead around the detector to block gamma rays + N2 flush to avoid radon progeny arond the detector.





Active shielding: scintillators as muon vetos registering the time difference between the Micromegas and scintillator triggers.

Time difference between veto and Micromegas mesh.

3) Intrinsically radiopure, very low radioactivity budget

Astr. Part. 34 (2011) 354.

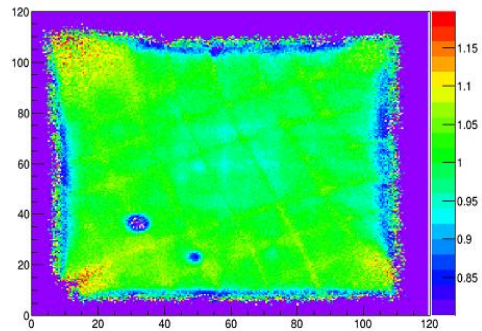
Why Micromegas for axion helioscopes?

- Gain up to 10^4, and highly uniform.
- Consolidated fabrication

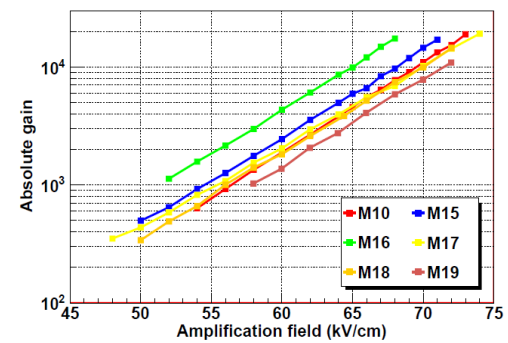
JINST 5 (2010) P02001,
JINST 7 (2012) P04007

- Good energy resolution
- (12% FWHM at 5.9 keV).
- Stable over long running periods.

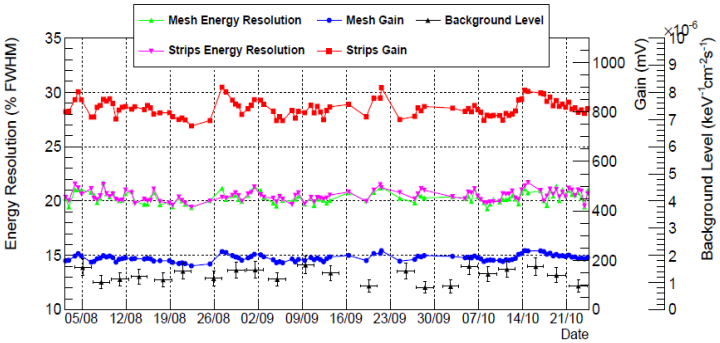
Uniformity of gain



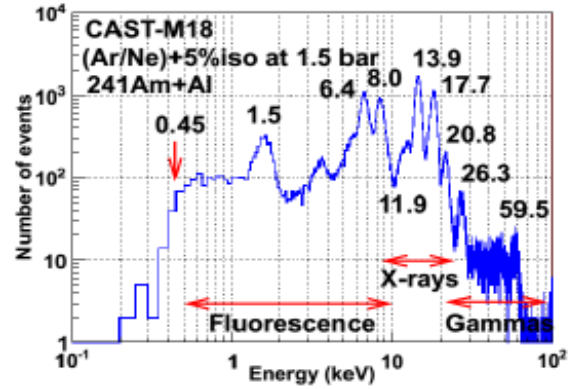
Absolute gain



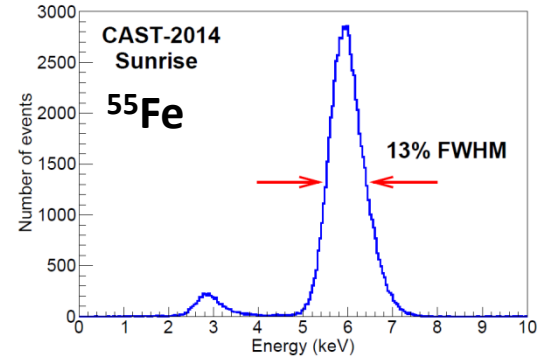
Long term stability



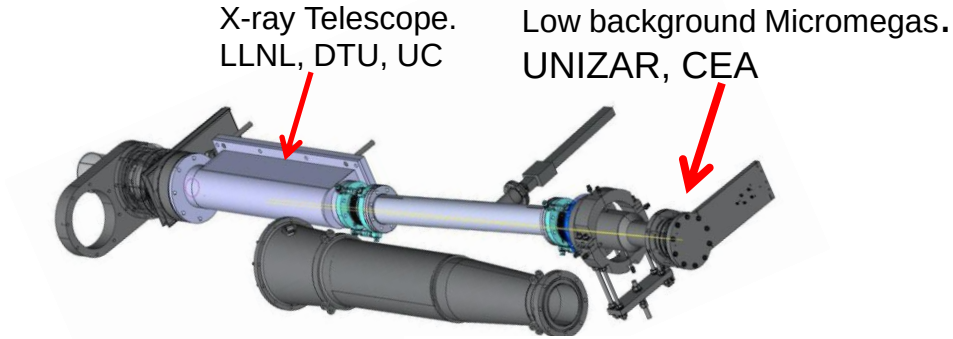
Energy threshold



Enegy resolution

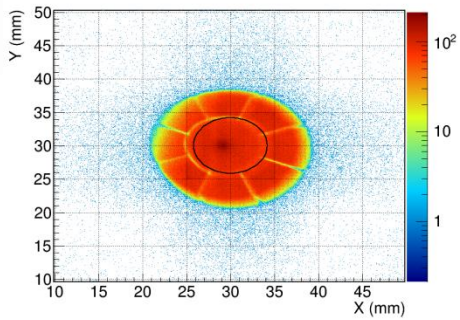


Micromegas + X-ray Optics at CAST 2014



- X-ray optics specifically designed and built for CAST.
- XRT installed + commissioned in August 2014.
- Big milestone for CAST → ~150 improve in S/N .
- Pathfinder system for IAXO.

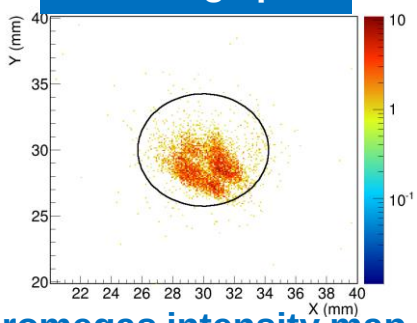
Window + strongback



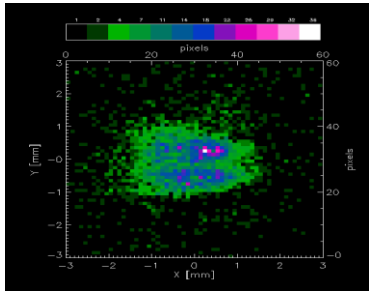
Micromegas Intensity map: ^{55}Fe calibration.

- X-ray source placed in the other side of magnet (13 m away), focused by the x-ray Optics to the Micromegas detector.

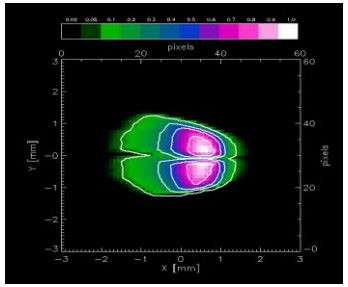
Focusing spot



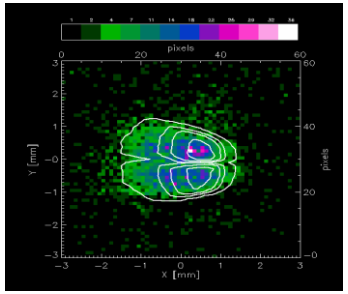
Micromegas intensity map of x-ray source through the optics.



Micromegas



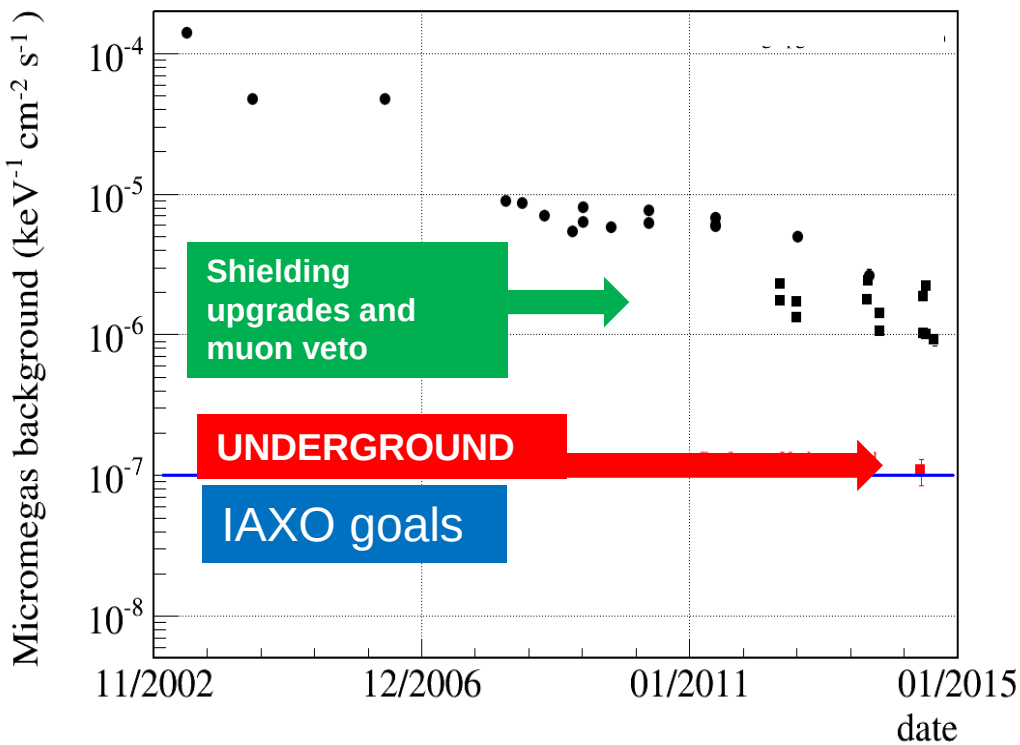
Simulation



Simulation & Micromegas data over-plotted

Micromegas in CAST , J. G. Garza et. al, 7th LTPC-2014 Meeting (16 Dec. 2014, Paris)

Micromegas Background evolution at CAST



JINST 8 (2013) C12042
X-ray detection with Micromegas with background levels below 10^{-6} keV^{-1}cm^{-2}s^{-1}

JINST 9 (2014) P01001:
Low background x-ray detection with Micromegas for axion research

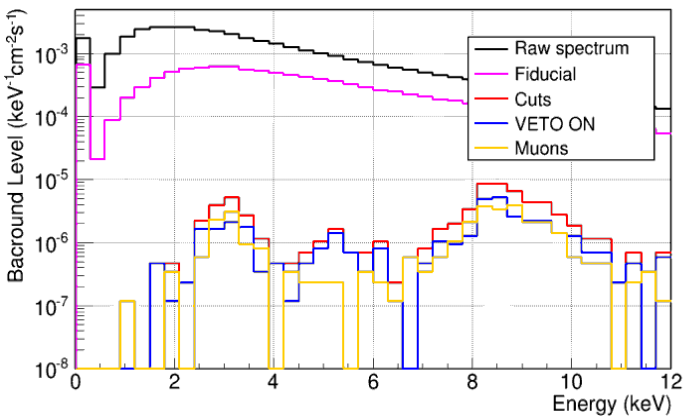
- Application of low background techniques: more than 2 orders of magnitude improvement in background over the years.
- **Underground level**: 10^{-7} keV^{-2}cm^{-2} s^{-1}, almost at required IAXO levels.
- XRT+MM in CAST-2014 for the first time below 10^{-6} keV^{-2}cm^{-2} s^{-1} (< 6 counts per day !!).

Background level at CAST in 2014

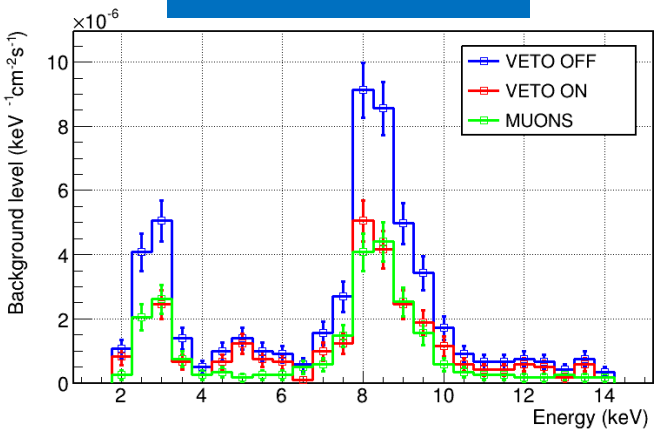
XRT/MM Line: below 10^{-6} $keV^{-2}cm^{-2}s^{-1}$: $(8,7 \pm 0.6)\cdot 10^{-7}$ in 670 hours.

SUNSET Detectors CAST-2014 $\left\{ \begin{array}{l} (1,00 \pm 0,06)\cdot 10^{-6} \\ (0,99 \pm 0,06)\cdot 10^{-6} \end{array} \right\}$ in 1317 hours.

CAST-SR 2014



CAST-SR 2014



- CAST RoI: [2-7] keV.
- Background spectrum characteristic of an 8 keV x-ray (Cu, K_α) + escape peak (5 keV) + 3 keV (Ar, K_α).
- Further background reduction requires indentifying the origin of these events.

Background Model based on:

- In-situ measurements at CAST.
- Surface tests at Zaragoza.
- Canfranc Underground Laboratory (LSC): Upgrade CAST-MM replica.
- Geant4 Montecarlo simulations of CAST-MM.

Contribution	Background Level ($c/keV^{-1}/cm^2/s^{-1}$)	Technique	FINAL Background Level ($c/keV^{-1}/cm^2/s^{-1}$)
Gamma flux	~ 7×10^{-5}	Lead/copper shield	**Negligible**
Radon	~ 8×10^{-7}	N_2 flux	**Negligible**
Muons	~ 2×10^{-6}	Active veto	**~ 7×10^{-7}**

Underground (CAST-LSC) lower limit:

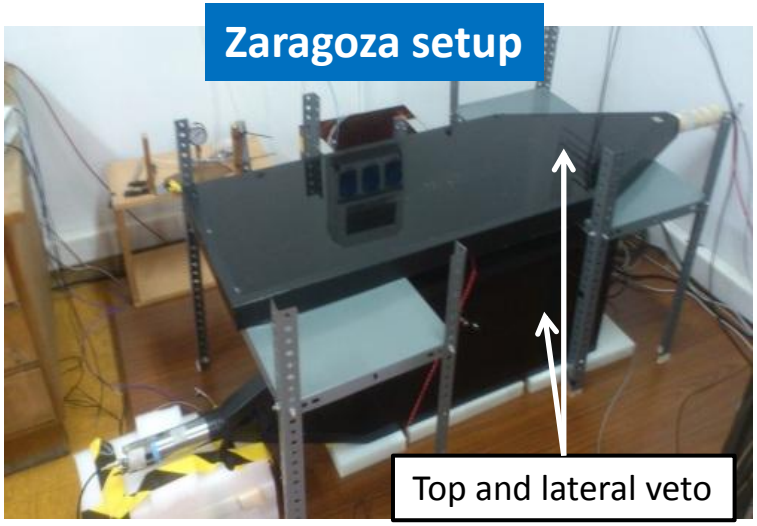
- ❑ Background: ~ 1×10^{-7} $c/keV^{-1}/cm^2/s^{-1}$.
- ❑ Origin: **^{39}Ar radio-activity? Neutrons ? Cosmic ativation ??**

- R&D activity to reduce the dominant contributions to background (main IAXO-Micromegas TDR activity).

Prospects: background reduction.

SURFACE → achieve underground lower limits.

- Build a first prototype of a Micromegas detection line as would be in IAXO.
- Better (thicker) lead shielding with less openings.
- 4π muon veto.
- Where? Zaragoza. When? 2014-2016.



UNDERGROUND → pushing lower limits

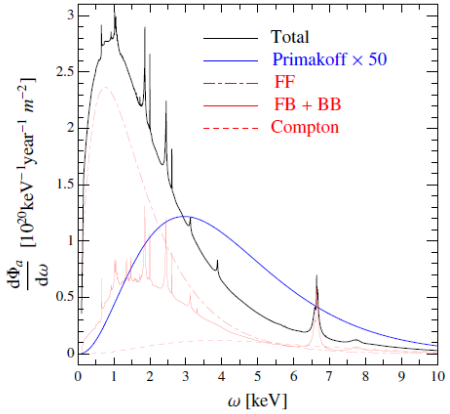
- **Gas change**: Argon → Xenon/Neon? **No ^{39}Ar radioactivity**. No fluorescences at 5 & 3 keV.
- **Detectors size**: larger detector → use it as active veto.
- **Neutron shielding:** polyethylene.

Prospects: Lowering the enegy threshold

Motivation:

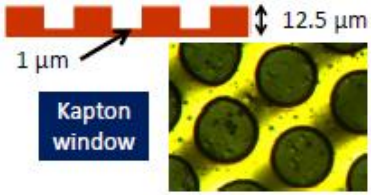
- With the XRT efficiency, big part of the axion flux is expected below 2 keV.
- In non-hadronic axion models, the solar axion flux peaks at sub-keV energies.
- Other searches also peak at lower energies: paraphotons, chamaleons, etc.

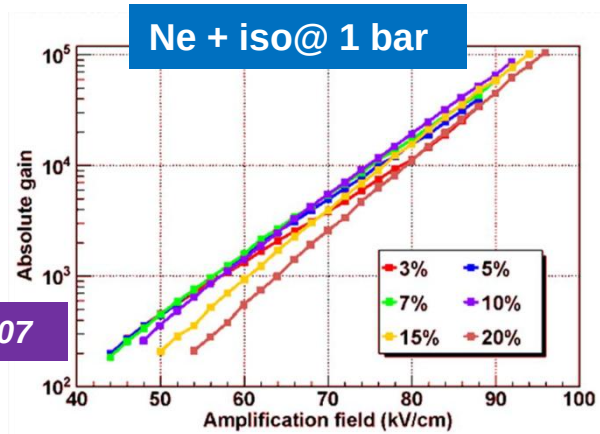
J. Redondo, JCAP 12 (2013) 008
K. Barth et. al., JCAP 05 (2013) 010



R&D in this direction:

- More transparent x-ray windows.
- New gas mixtures with higher gain (Neon?).
- Auto-trigger electronics (AGET)
- Resistive microbulk (higher gain?)
- Calibration and analysis at lower energies.





JINST 7 (2012) P04007

CONCLUSIONS

- In the last 12 years, the CAST Experiment has put the strictest limit on axion couplings for a wide range of axion masses.
- **Micromegas**: mature technology for Rare Event Searches: axions, 0ν2β-decay (NEXT-MM), WIMPs (TREX-DM, see F.J. Iguaz talk).
- The implementation of an Optics + MM system increases CAST sensitivity, and serves as demonstrator of a IAXO subsystem.
- On the low background side:
  - In CAST, 2 orders of magnitude of background reduction over the years
    - ✓ Currently in CAST: ~ 10^{-6} $keV^{-2}cm^{-2}s^{-1}$.
    - ✓ Underground: ~ 10^{-7} $keV^{-2}cm^{-2}s^{-1}$.
    - ✓ IAXO goals: < 10^{-7}-10^{-8} $keV^{-2}cm^{-2}s^{-1}$.
  - Clear strategy for background reduction both in surface and underground.
- On the low threshold side:
  - Sub-kev physics at CAST motivates R&D activities to lower the energy threshold: x-ray transparent windows, appropriate gas mixtures, better readout electronices, etc.

Thank you

Axions

- Axions are the most elegant solution to the Strong CP problem (why QCD does not seem to break the CP symmetry):
  - Pseudoscalar particles, neutral, practically stable.
- Candidates for both cold and hot dark matter.
- Axion-like particles (ALPs) are predicted by many extensions of the Standard Model
- Relevant axion/Axion-Like Particles parameter space at reach of current and near-future experiments
- New theory scenarios: string theory predicts axions/ALPs with detectable parameters
- Astrophysical hints for axion/ALPs?
  - transparency of the Universe to UHE gammas$\rightarrow$ very light ALPs
  - white dwarf cooling anomaly $\rightarrow$ few meV axions

What is the motivation of axions?

- Most compelling solution to the Strong CP problem of the SM.
- Axion-like particles (ALPs) predicted by many extensions of the Standard Model (like the string theory)
- Axions, like WIMPs, may solve the Dark Matter (DM) problem for free. (i.e. not an ad hoc solution to DM).
- Astrophysical hints for axion/ALPs?
  - Transparency of the Universe to UHE gammas.
  - White dwarfs anomalous cooling point to few meV axions
- Relevant axion/ALP parameter space at reach of current and near-future experiments
- Still too little experimental efforts devoted to axions when compared to WIMPs.

Axion as Dark Matter candidate

- Axions are produced in the early Universe by a number of processes:
  - Axion realignment
  - Decay of axion strings
  - Decay of axion walls

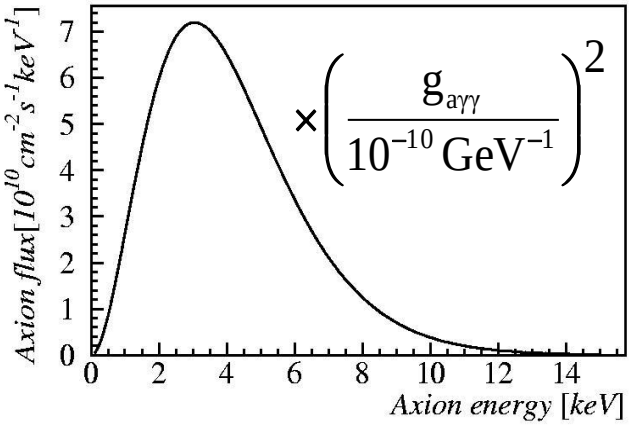
  → **Non relativistic COLD AXIONS**
- Axion mass giving the right CDM density? Depends on cosmological assumptions:
  - "classical window": around 10^{-5}-10^{-3} eV
  - "anthropic window" ~ much lower masses possible
  - Other subdominant CDM / non standard scenarios

- Thermal production
  - Axion masses **ma > ~0.9 eV** gives densities too much in excess to be compatible with latest CMB.

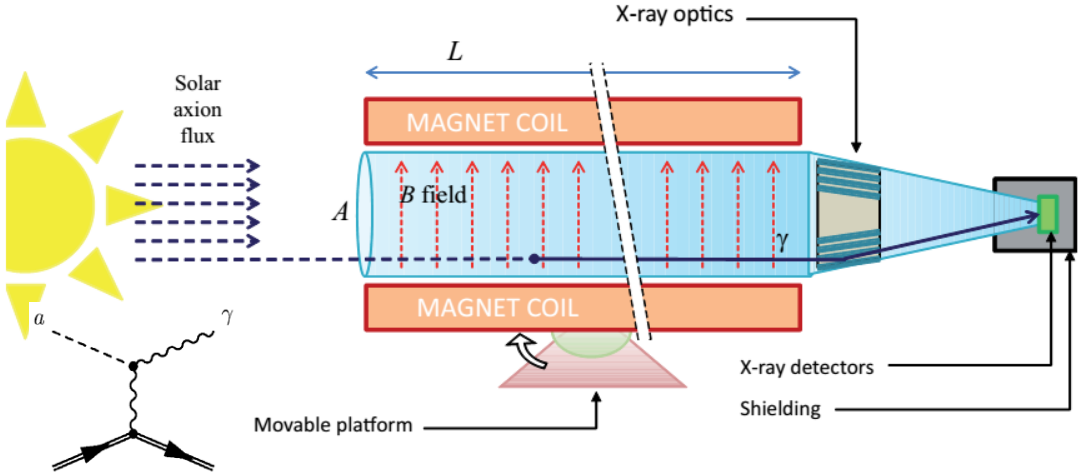
Hannestad et al, JCAP 08 (2010) 001

→ **Relativistic HOT AXIONS**

Axion detection by an helioscope



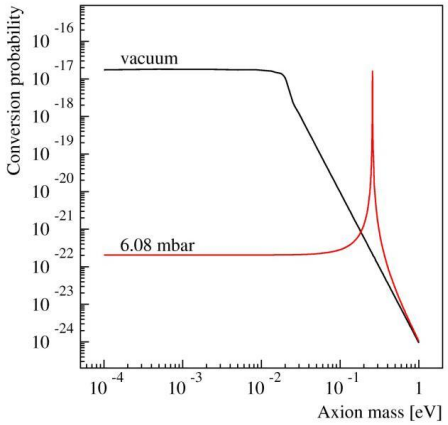
Serpico & Raffelt, JCAP04 (2007) 010



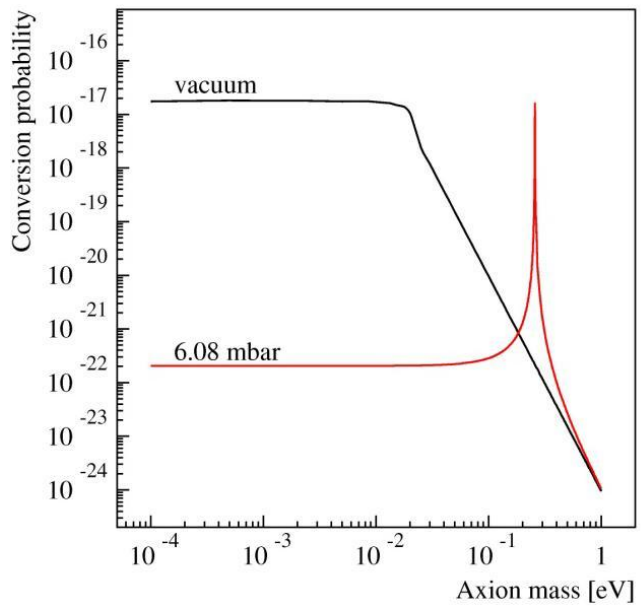
Production: *Primakoff effect.*
Thermal photons interacting with solar nuclei produce axions.

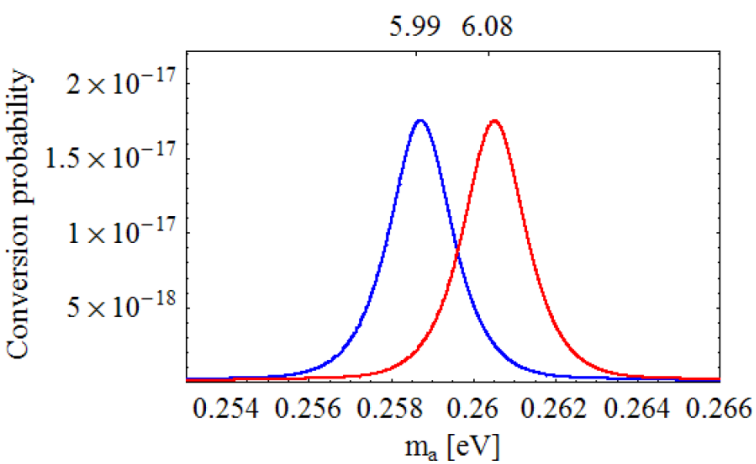
Detection: *inverse Primakoff* (Sikivie 1983)
Axions in a magnetic field convert to photons.
Expected x-ray excess when the magnet points to the Sun.

- Conversion probability depends on medium.
- In vacuum coherence is lost for $m_a > 0.02$ eV.
- In the presence of a buffer gas, the coherence can be restored for a narrow mass range.



The detection probability





Axion to photon conversion probability

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

L = magnet lenght,
Γ = absorption coefficient

Coherence condition: q L < π, $|q| = \frac{m_a^2}{2E}$

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

With the presence of a buffer gas, the coherence can be restored for a narrow mass range

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

Probability of the axion-photon conversion:

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

where

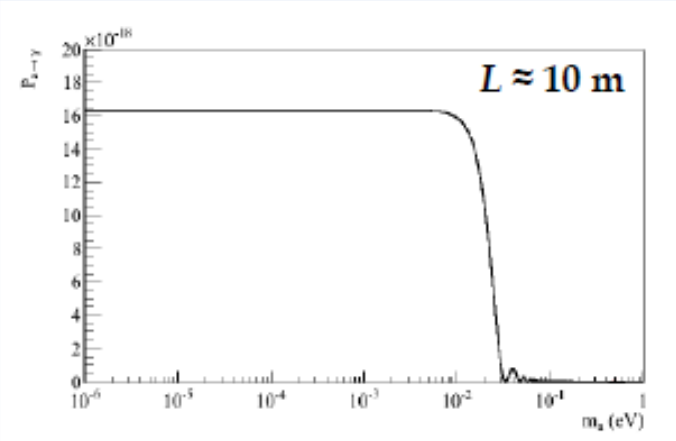
$$q = \left|\frac{m_\gamma^2 - m_a^2}{2E_a}\right|$$

Vacuum case:

$$q = \frac{m_a^2}{2E_a} \qquad \Gamma \simeq 0$$

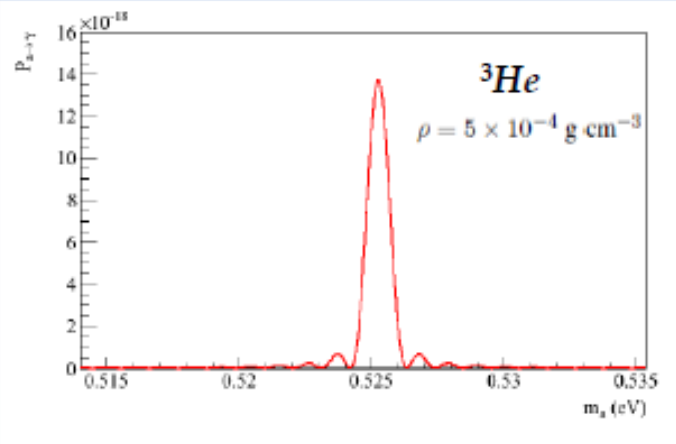
$$\Rightarrow \quad P_{a\to\gamma} = \left(\frac{g_{a\gamma}BL}{2}\right)^2 \left(\frac{\sin\left(\frac{qL}{2}\right)}{\frac{qL}{2}}\right)^2$$

Coherence condition $\Rightarrow$ $m_a < \sqrt{\frac{4\pi E_a}{L}}$



Buffer gas case:

$$m_\gamma = \omega_p = \sqrt{\frac{4\pi\alpha n_e}{m_e}} \qquad n_e = \frac{Z}{W}\rho$$



The coherence can be restored to higher axion masses

CAST Physics Program

1) CAST Phase I, Vacuum

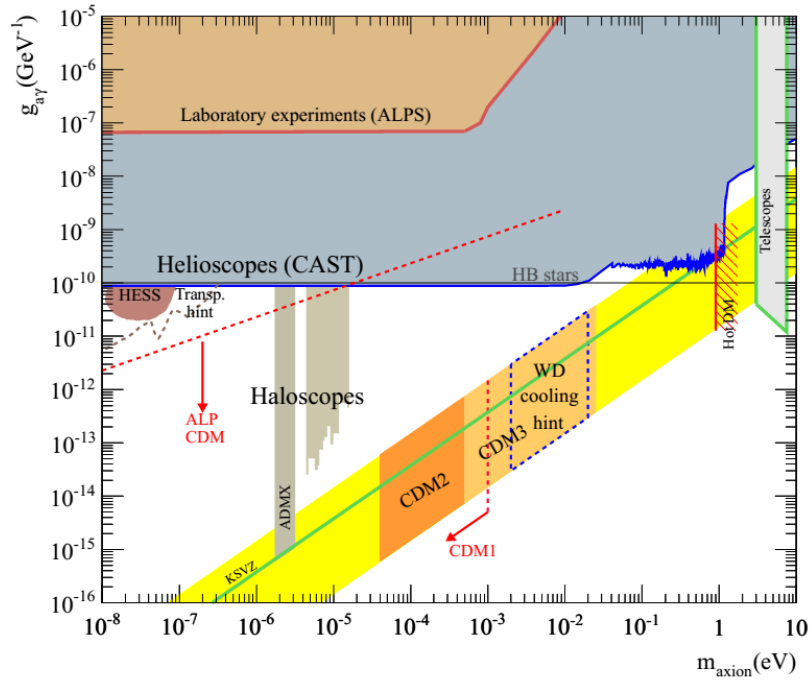
- $m_a < 0.02$ eV
- $g_{a\gamma\gamma} \lesssim 0.88 \times 10^{-10}$ GeV^{-1}
- **PRL94 (2005) 121301** & **JCAP04(2007)020.**

2) CAST Phase II, ^{4}He

- P < 13.4 mbar (1.8K), 160 steps
- 0.02 eV < m_a < 0.39 eV
- $g_{a\gamma\gamma} \lesssim 2.2 \times 10^{-10}$ GeV^{-1}
- **JCAP02 (2009) 008**.

3) CAST Phase II, ^{3}He

- P < 120 mbar (1.8K), 160 steps
- 0.39 eV < m_a < 1.17 eV
- $g_{a\gamma\gamma} \lesssim 3.3 \times 10^{-10}$ GeV^{-1}
- **PRL 107 (2011) 261302** & **PRL 112 (2014) 091302**



Parallel searches:

- HE axions: **JCAP 1003 (2010) 032**.
- 11.4 keV axions from M1 transitions: **JCAP 0912 (2009) 002**.
- LE (visible) axions: **arXiv:0809.4581**.
- Constrains on axion-electron coupling: **JCAP 1305 (2013) 010**

CAST: latest results & current activites

Latest results:

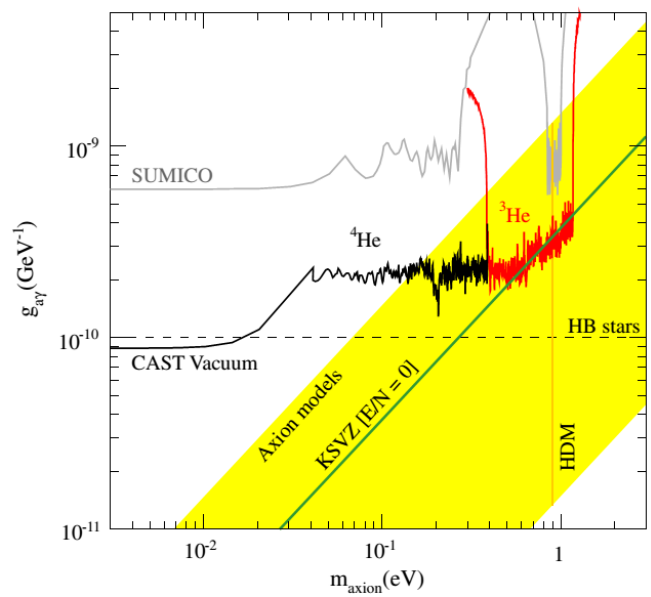
- ^{3}He phase results recently published: PRL 112 (2014) 091302 (only mM).
- Axion mass 0.64 – 1.17 eV excluded down to **~3.3 × 10^{-10} GeV^{-1}**.
- Paper on the simulation of gas dynamics inside the magnet in preparation.

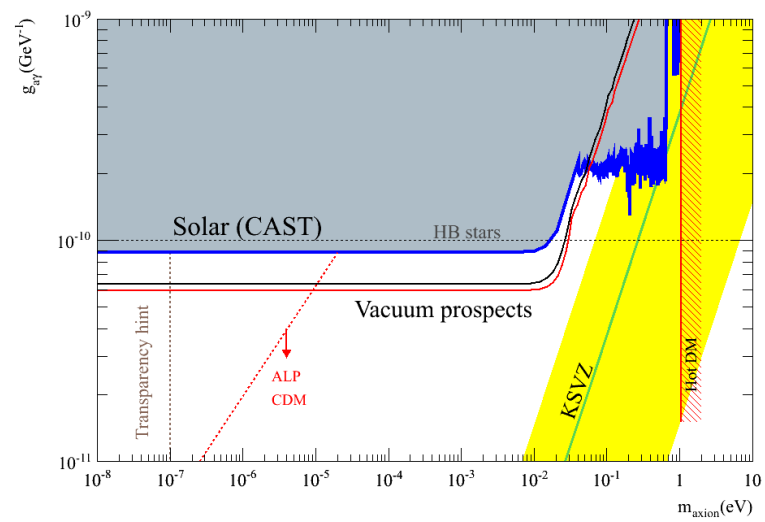
Current activities:

- Revisiting the vacuum phase with three high performance microbulk detectors.
- Seach of exotic physics (chameleons, paraphotons, low energy axions).

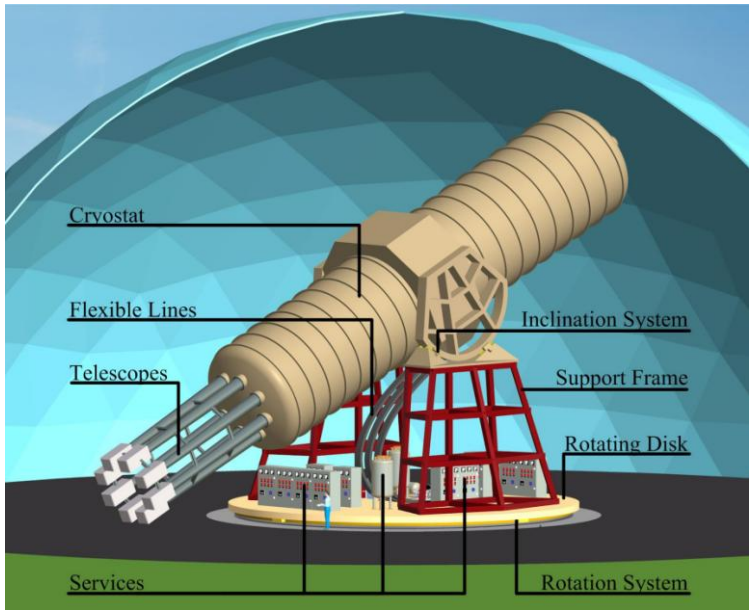
Detector updates:

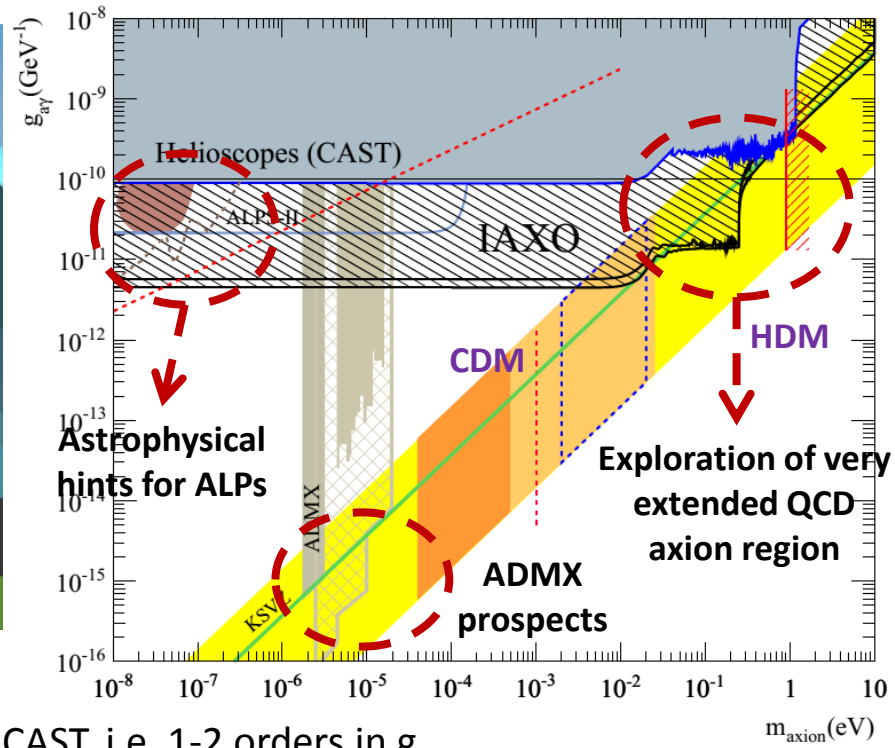
- An x-ray optics will increase the sensitivity of Sunrise detector.
- InGrid micromegas and Silicon Drift Detectors (SDD) are tested.





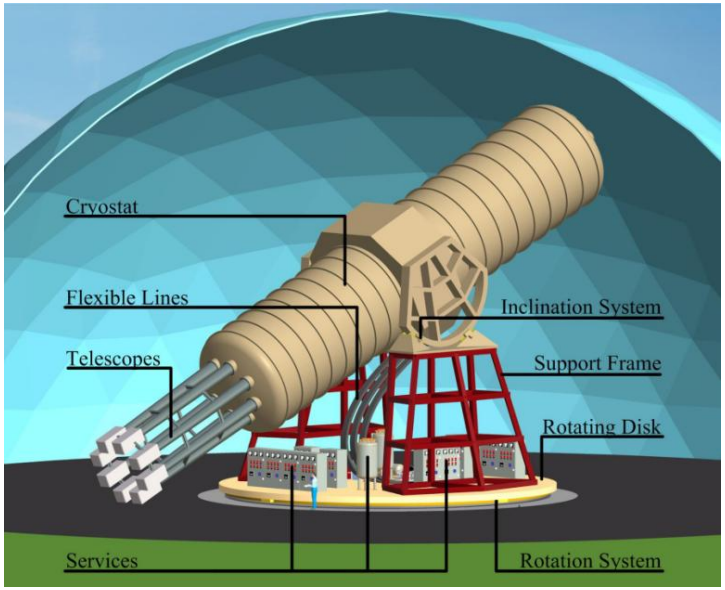
IAXO: International AXion Observatory





- New generation of axion helioscope.
- 4 orders of magnitude better in S/N wrt CAST, i.e. 1-2 orders in $g_{a\gamma}$.
- New features: toroidal magnet, dedicated optics, low background detectors.
- CAST & ADMX can explore a big part of the axion model region in next decade.
- Potential for new physics: white dwarfs, ALPs, low energy axions…
- Ideas under discussion to explore meV axions (resonant cavities, antenna dishes).
- More details: IAXO-CDR (**2014 JINST 9 T05002**) & NGAH (**JCAP 06 (2011) 013**).

IAXO: International AXion Observatory



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- New features: toroidal magnet, dedicated optics, low background detectors.
- CAST can explore a big part of the axion model region in next decade.
- Positive recommendations from SPSC.
- More details: IAXO-CDR (**2014 JINST 9 T05002**) & NGAH (**JCAP 06 (2011) 013**).

Several preparatory activities in parallel for the Technical Design Report (TDR):

- **IAXO-T0**: a demonstration coil.
- **IAXO-X0**: a prototype x-ray optics.
- **IAXO-DO**: a low background detector.
- **Pathfinder**: a small optics & detector at CAST. The same techniques as for IAXO.

Status of IAXO

- 90 signatures. 38 institutions. Enlarged community interested in IAXO physics.
- In International roadmaps of Europe (**ASPERA/APPEC, ESPP**) & US (**Snowmass**).
- Conceptual Design: **2014 JINST 9 T05002**.
- Letter of Intent presented at CERN-SPSC on 22th Oct 2013: **SPSC-2013-022**.
- Positive recommendations from SPSC.
- Preparation of a MoU to carry out TDR work. Search for new interested partners.
- Several preparatory activities in parallel for the Technical Design Report (TDR):
  - **IAXO-T0**: a demonstration coil.
  - **IAXO-X0**: a prototype x-ray optics.
  - **IAXO-DO**: a low background detector.
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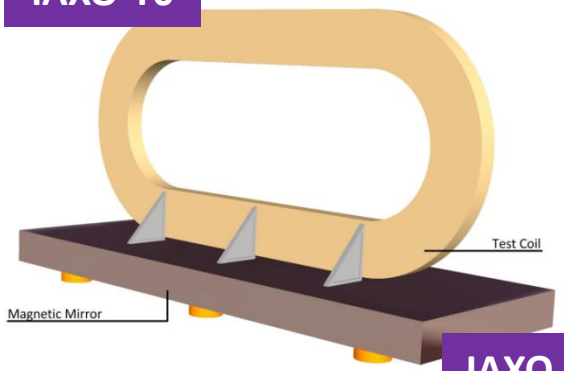
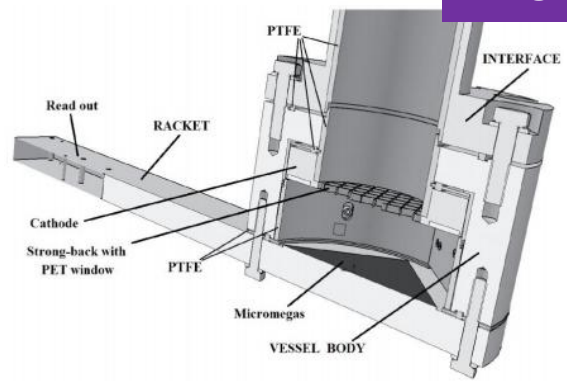
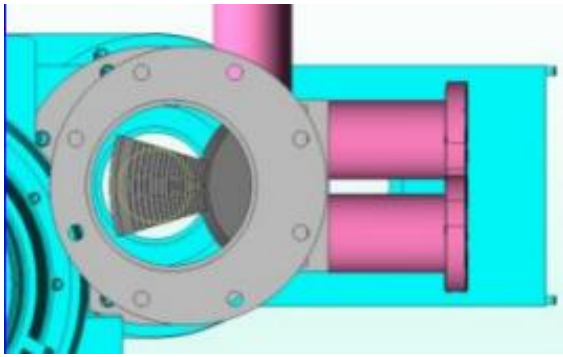
IAXO-T0



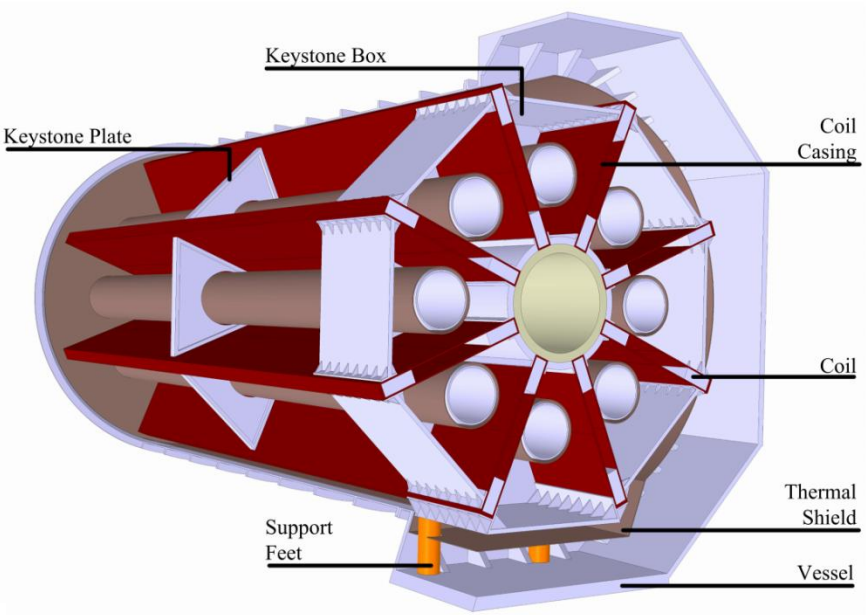
IAXO-XD

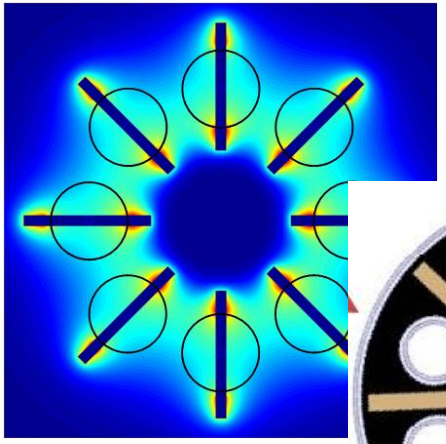


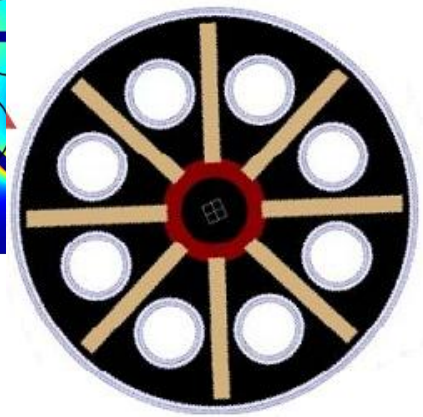


IAXO Magnet

- Large toroidal 8-coil magnet specifically built for axion physics.
- Many technical aspects studied and defined in the CDR.
- Magnetic length: 20 m.
- Bore diameter: 0.6 m.
- IAXO-T0 project to build a test coil.





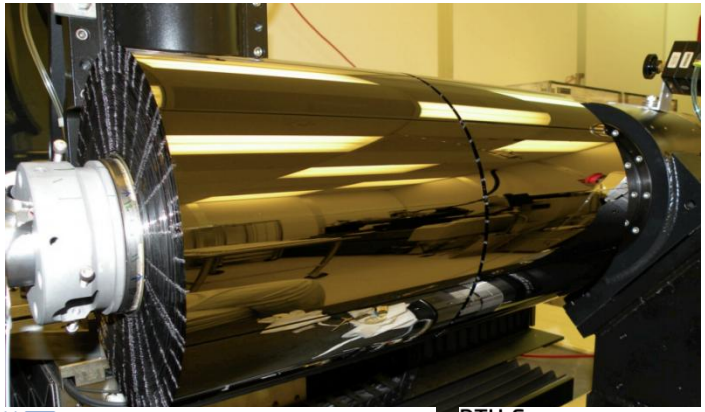


IAXO magnet concept presented in:

- IEEE Trans. Appl. Supercond. 23 (ASC 2012)
- Adv . Cryo. Eng. (CEC/ICMC 2013)
- IEEE Trans. Appl. Supercond. (MT 23)

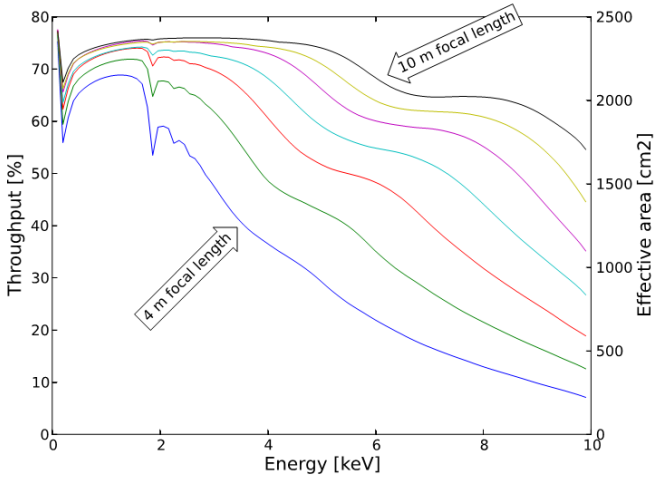
IAXO Optics

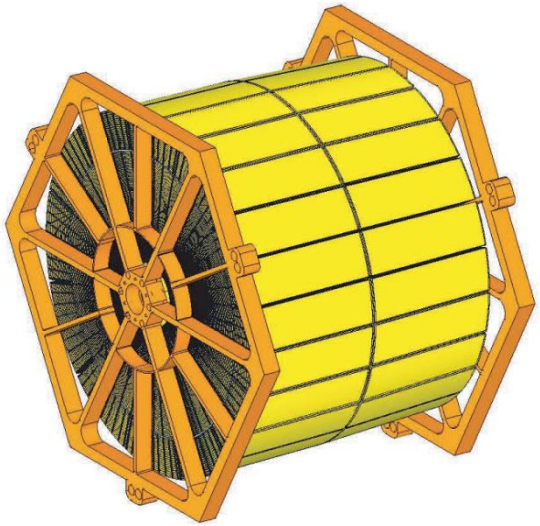
- Technique of choice: optics made of thin glass substrates coated to enhance reflectivity in the energy regions for axions. Used in NuSTAR/HEFT project.
- Optimization study to maximize the efficiency in the focussing power:
- Diameter: 600 mm. Focal length: 10 m.
- First realistic drawings made.
- New telescope for CAST in construction.



Lawrence Livermore National Laboratory

DTU Space
National Space Institute





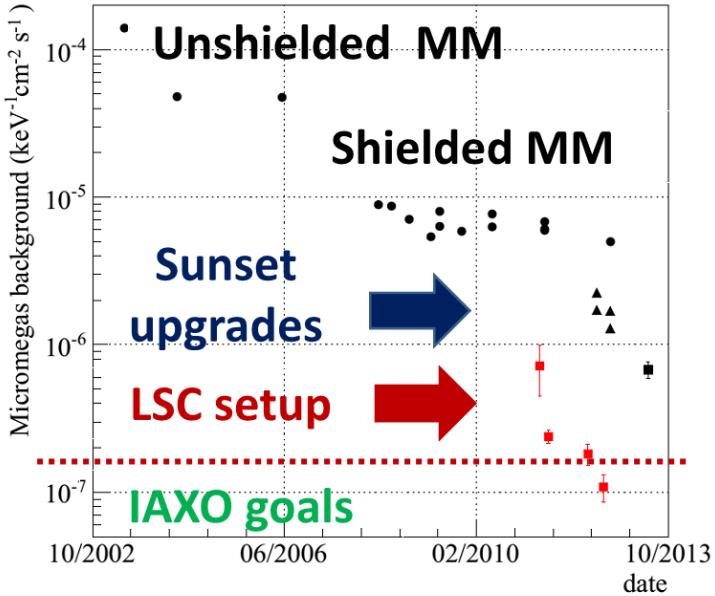
IAXO detector: Microbulk Micromegas

Why are they used in axion searches?

- High power to discriminate x-rays signals from other type of events.
- Intrinsic radiopure (*Astr . Part. 34 (2011) 354*).
- Consolidated manufacture (**JINST 5 (2010) P02001, JINST 7 (2012) P04007**).
- Shielding techniques from low background experiments can be also applied.

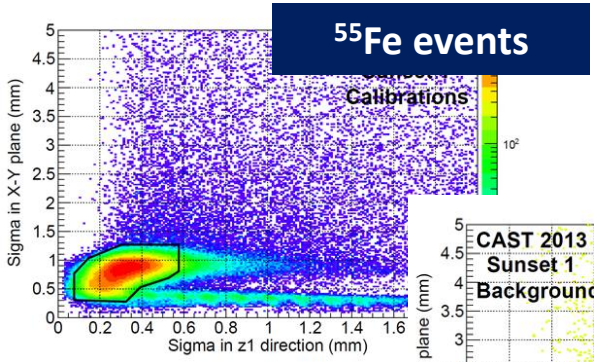
Status of Micromegas for IAXO

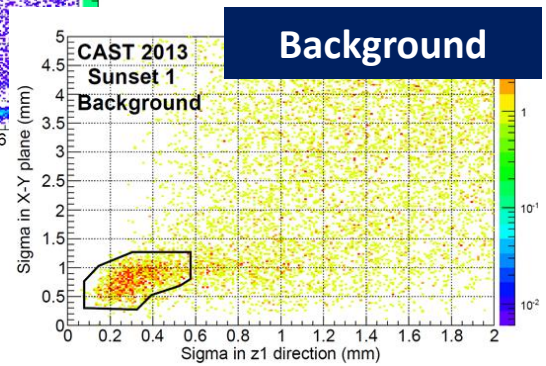
- Background levels below **10^{-6} $s^{-1}keV^{-1}cm^{-2}$** obtained **in CAST** for the first time (2013).
- Levels at **10^{-7} $s^{-1}keV^{-1}cm^{-2}$ at LSC**.
- Roadmap to reach IAXO levels, based on
  - In-situ measurements at CAST.
  - Replica at Canfranc Laboratory (LSC).
  - Geant4 simulations of CAST-MM.



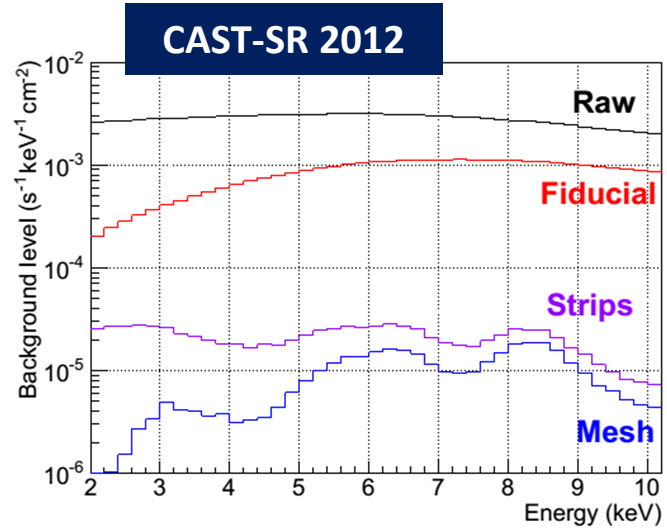
Contribution	Background level in 2-7 keV (counts s^{-1} keV^{-1} cm^{-2})	Technique
Gamma flux	~7 x 10^{-5}	Lead shielding
Muons	2 x 10^{-6} - > 6 x 10^{-7}	Active veto
Al cathode	(5.2 ± 1.2) x 10^{-7}	Cu cathode
Radon	~8 x 10^{-7}	N_2 flux
CAST-LSC lower limit	1.1 x 10^{-7}	Neutrons? Gas purity?

Micromegas for axion searches



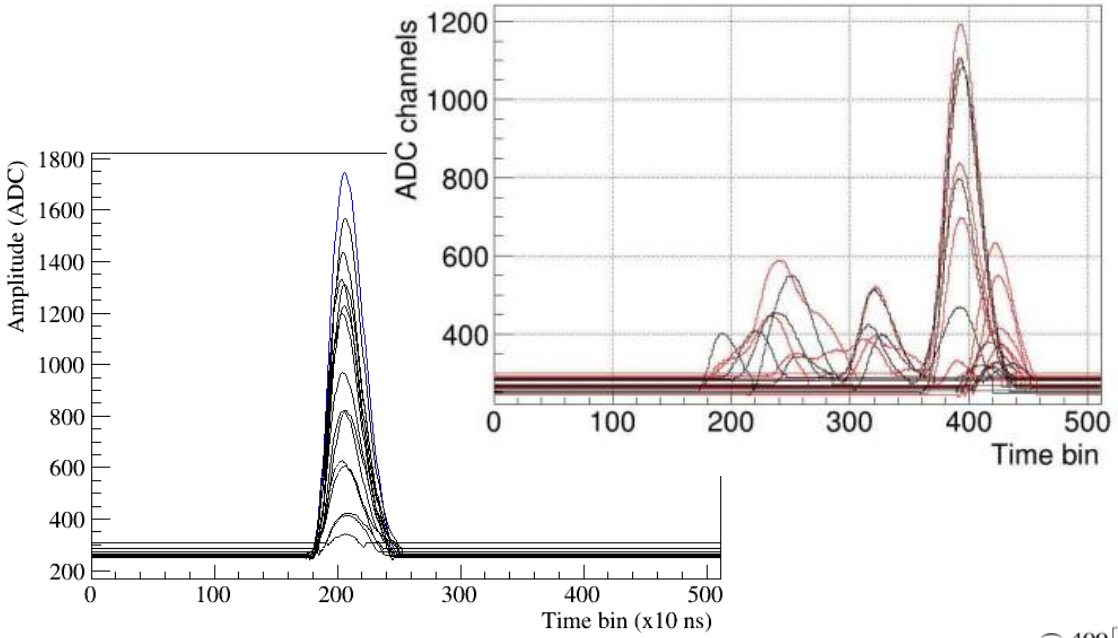


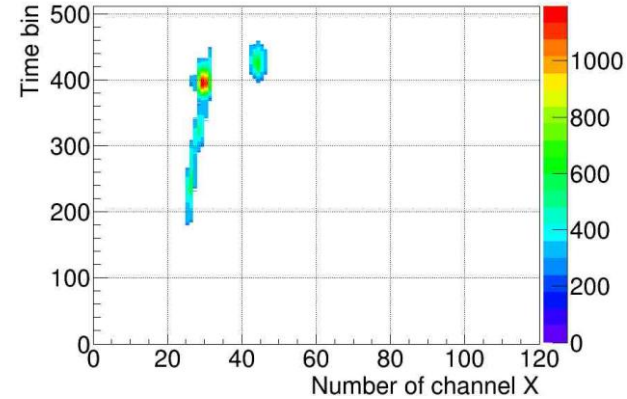
Width in XY vs width in Z



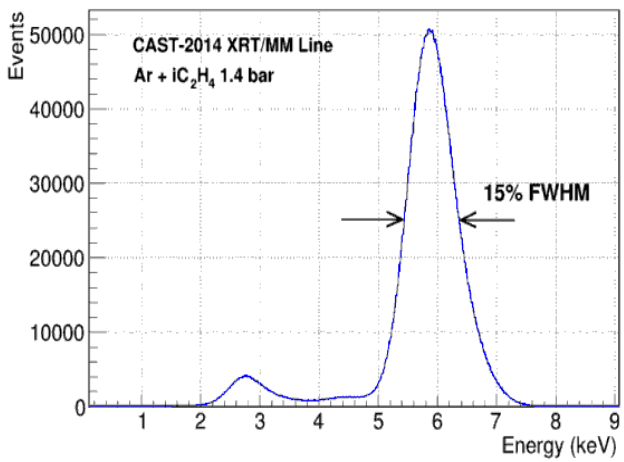
It is an amplification structure used as readout in a Time Projection Chamber (**Y. Giomataris, NIMA 376 (1996) 29**).

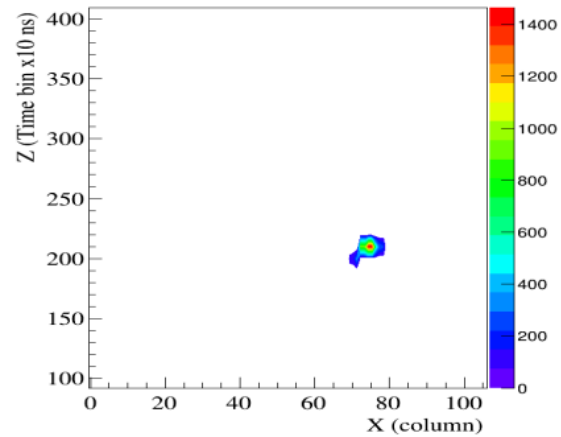
- Excellent energy resolution (**12% FWHM at 5.9 keV**).
- High power to discriminate x-rays signals from other type of events.
- Intrinsic radioupure (**S. Cebrian et al, Astr. Part. 34 (2011) 354**).
- Consolidated manufacture (**microbulk technique**) & stable in time (**S. Adriamonje et al., JINST 5 (2010) P02001**).


Amplitude (ADC)
Time bin (x10 ns)
ADC channels
Time bin


Time bin
Number of channel X

XZ view

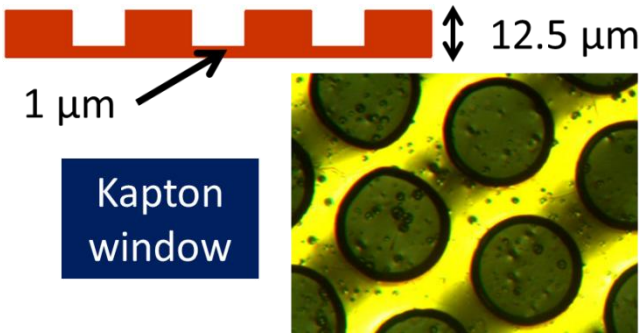

CAST-2014 XRT/MM Line
Ar + iC2H4 1.4 bar
15% FWHM
Events
Energy (keV)


Z (Time bin x10 ns)
X (column)

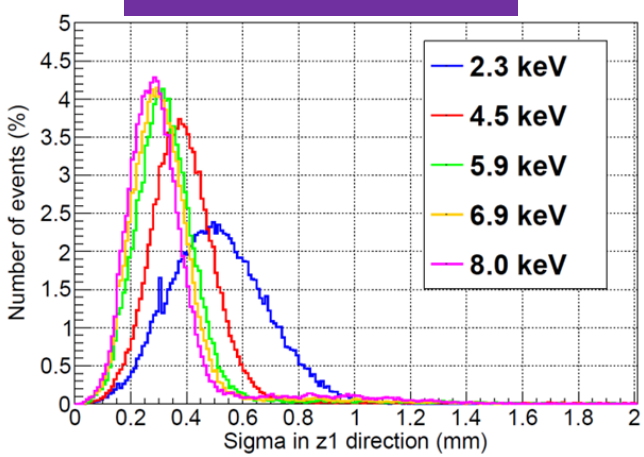
Lowering the energy threshold of CAST

R&D on this direction for Micromegas:

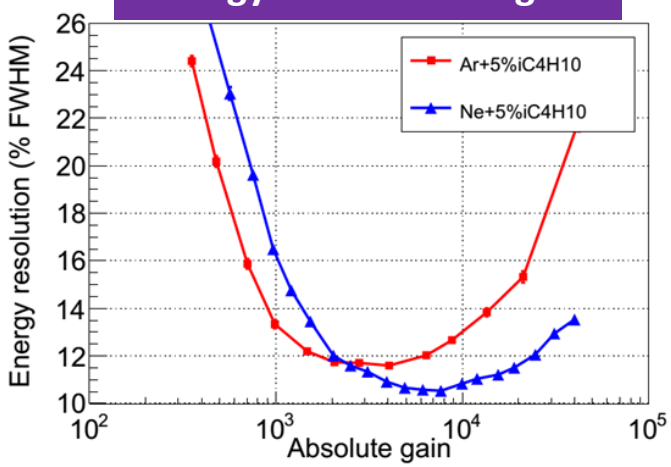
- New thin windows for CAST detectors.
- Autotrigger electronics **AGET.**
  (S. Anvar et al, NSS/MIC/RTSD IEEE 2011)
- New analysis based on x-rays calibrations.
- Neon-based mixture: higher gain
  (**F.J. Iguaz et al, JINST 7 (2012) P04007**).



Cluster width in z



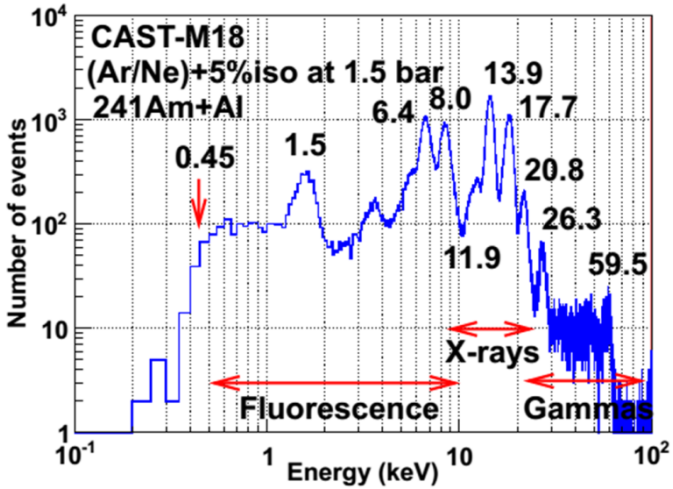
Energy resolution vs gain



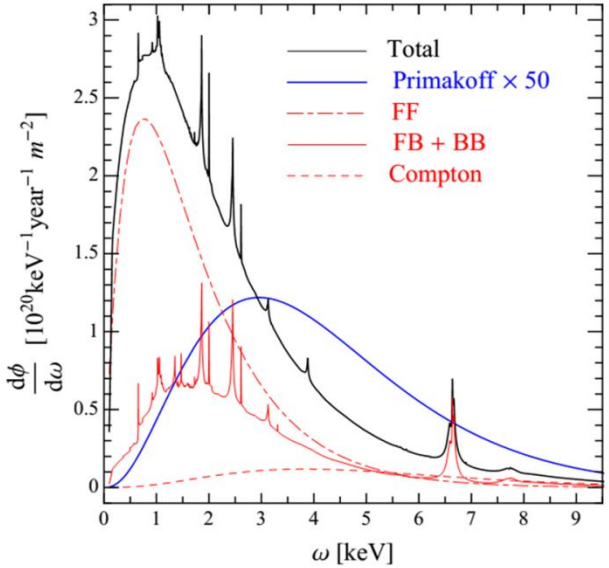
Lowering the energy threshold of CAST

Physics motivation:

- In non-hadronic axion models, the Sun produces axions by BCA processes.
- The expected axion flux peaks at sub-keV energies.



S. Aune et al, JINST *9* (2014) P01001



J. Redondo, *JCAP 12* (2013) 008
K. Barth et al, *JCAP* 05 (2013) 010

Is it feasible for x-ray detectors?

- Evident for CCD & SDD.
- To be verified by MM & Ingrid.

Summary

In the last 12 years, the **CAST experiment**

- has put the strictest limit on axion coupling for a wide range of masses and has gained extensive experience on Helioscope Axion Searches.
- has just published the first results of 3He phase (**PRL 112 (2014) 091302**): $\mathbf{g_{a\gamma\gamma} \lesssim 3.3 \times 10^{-10}\ GeV^{-1}}$ (95% CL) for $\mathbf{0.64\ eV < m_a < 1.17\ eV}$.
- is revisiting the vacuum phase to increase the sensitivity and explore other exotica like solar chamaleons, paraphotons, improve the LE setup.

The future is the **International Axion Observatory (IAXO)** which

- will improve on CAST results more than one order of magnitude.
- will use a dedicated magnet, large area optics and low background detectors.
- can explore a big part of axion models in next decade together with ADMX.
- has published its LoI (**SPSC-2013-022**) & CDR (**2014 JINST 9 T05002**).
- develops several activities for the TDR: test coil, optics, detectors,…

CERN SPSC recommendations (Jan 2014)

*The Committee **recognizes the physics motivation** of an International Axion Observatory as described in the Letter of Intent SPSC-I-242, and considers that the proposed setup makes appropriate use of state-of-the-art technologies i.e. magnets, x-ray optics and low-background detectors.*

*The Committee **encourage**s the collaboration to take the next steps towards a **Technical Design Report**.*

*The Committee **recommends** that, in the process of preparing the TDR, the possibility to **extend the physics reach** with additional detectors compared to the baseline goal should be investigated. The collaboration should be further strengthened.*

*Considering the required funding, the SPSC r**ecommends** that the R&D for the TDR should be pursuit within **an MOU** involving all interested parties.*

IAXO in astroparticle roadmaps

- **ASPERA/APPEC Roadmap** acknowledges axion physics, CAST, and **recommends** progress towards IAXO.

> "...A CAST follow-up is discussed as part of CERN's physics landscape (new magnets, new cryogenic and X-ray devices). The Science Advisory Committee **supports** R&D on this follow up, as well as smaller ongoing activities on the search for axions and axion-like particles."

C. Spiering, ESPP Krakow

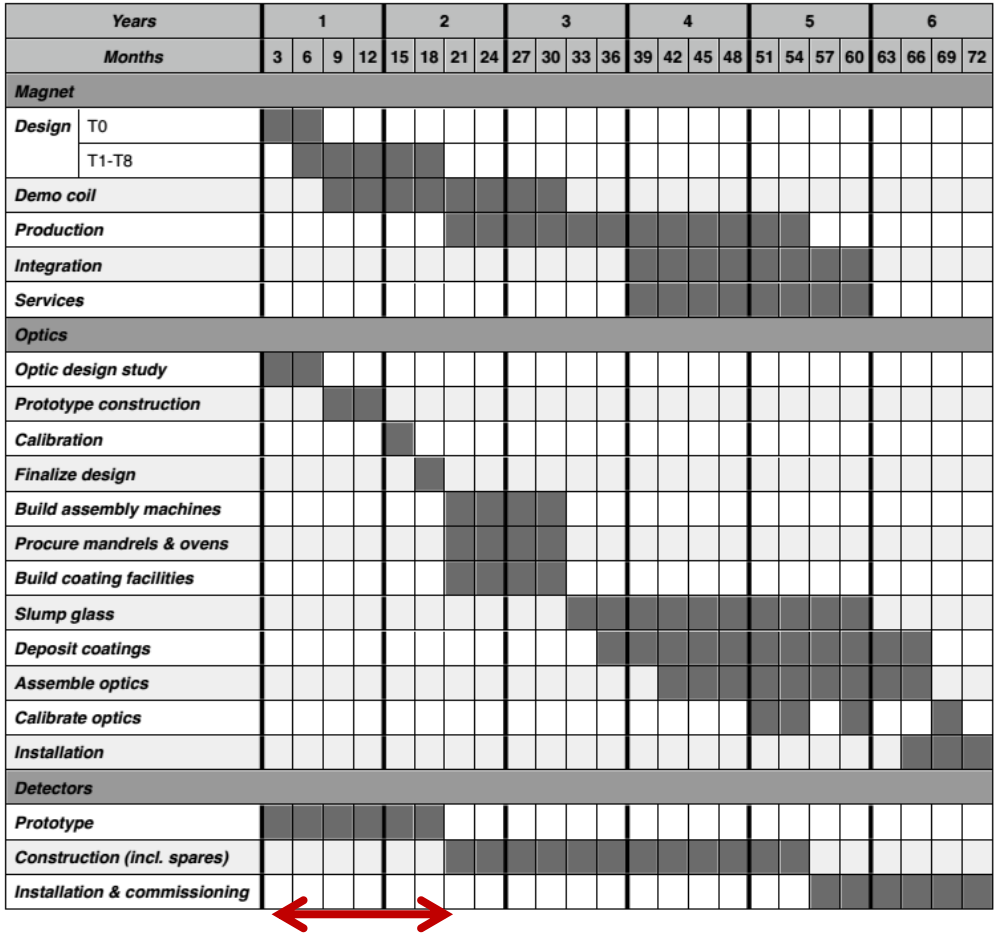
- Important community input in the **European Strategy for Particle Physics**
- Presence in the Briefing Book of the ESPP, which reflects also APPEC roadmap recommendations.
- **ESPP recommends CERN to follow APPEC recommendations.**
- Important effort in relation with US roadmapping (Snowmass, and P5 process). **Snowmass reports speak very favorably of axion physics and IAXO.**

Signal-to-noise ratio of IAXO

Parameter	Units	CAST-I	IAXO Nominal	IAXO Enhanced
B	T	9	2.5	2.5
L	m	9.26	20	20
A	m^2	2×0.0015	2.3	2.3
f^*_M		1	300	300
b	$\frac{10^{-5}\,\mathrm{c}}{\mathrm{keV\,cm^2\,s}}$	~ 4	5×10^{-3}	10^{-3}
ϵ_d		0.5 – 0.9	0.7	0.8
ϵ_o		0.3	0.5	0.7
a	cm^2	0.15	8×0.2	8×0.15
f^*_{DO}		1	17	60
ϵ_t		0.12	0.5	0.5
t	year	~ 1	3	3
f^*_T		1	3.5	3.5
f^*		1	2×10^4	6×10^4

Table 3: Values of the relevant experimental parameters representative of IAXO, both the *nominal* and *enhanced* ones, based on the considerations explained in section 4. They are compared to the ones representing the CAST vacuum phase result (CAST-I) [59]. Numbers shown for the figures of merit (equation 11) are relative to CAST-I, i. e. $f^* = f/f_{\mathrm{CAST}}$, and are approximate.

IAXO timeline



- TDR + preparatory activites: 1.5 years.
- Construction: 3.5 years.
- Integration & comissioning: 2.5 years.
- Total: **6 years**.

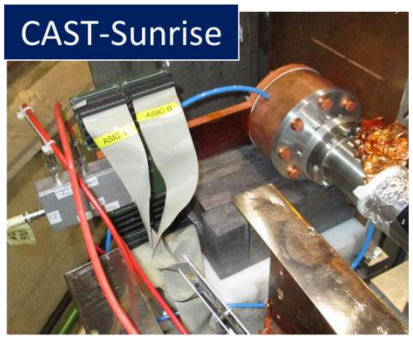
IAXO costs

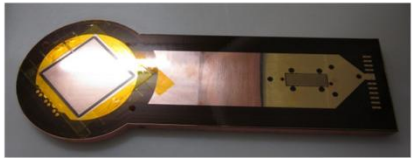
Item	Cost (MCHF)	Subtotals (MCHF)
Magnet		31.3
Eight coils based assembled toroid	28	
Magnet services	3.3	
Optics		16.0
Prototype Optic: Design, Fabrication, Calibration, Analysis	1.0	
IAXO telescopes (8 + 1 spare)	8.0	
Calibration	2.0	
Integration and alignment	5.0	
Detectors		5.8
Shielding & mechanics	2.1	
Readouts, DAQ electronics & computing	0.8	
Calibration systems	1.5	
Gas & vacuum	1.4	
Dome, base, services building and integration		3.7
Sum		**56.8**

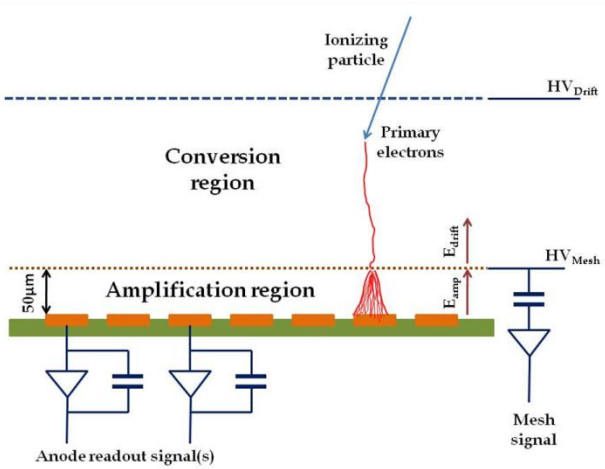
Table 5: Estimated costs of the IAXO setup: magnet, optics and detectors. It does not include laboratory engineering, as well as maintenance & operation and physics exploitation of the experiment.

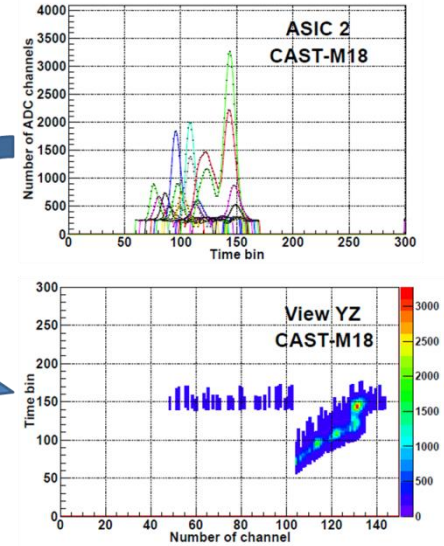
Laboratory engineering, maintenance & operation and physics exploitation not included

Micromegas for axion searches









It is an amplification structure used as readout in a Time Projection Chamber (**Y. Giomataris, NIMA 376 (1996) 29**).

- Excellent energy resolution (**12% FWHM at 5.9 keV**).
- High power to discriminate x-rays signals from other type of events.
- Intrinsic radioupure (**S. Cebrian et al, Astr. Part. 34 (2011) 354**).
- Consolidated manufacture (**microbulk technique**) & stable in time (**S. Adriamonje et al., JINST 5 (2010) P02001**).

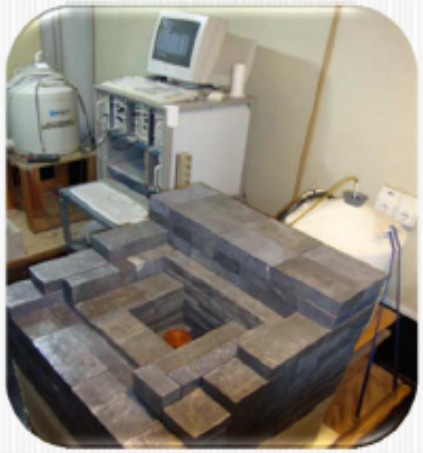
C. Radiopurity issues: measurements

Microbulks are mostly Cu & Kapton

potentially very radiopure

Several samples measured with HPGe at LSC

- 2 samples of raw material (double clad kapton foil)
- 2 samples detached from old CAST detectors



HPGe detector in Canfranc

S. Cebrian et al., Astropart. Phys 34 (2011) 354-359

Results (in μBq/cm^2)	^{232}Th	^{235}U	^{238}U	^{40}K	^{60}Co
Microbulk mM	<9.3	<13.9	26.3±13.9	57.3±24.8	<3.1*
Kapton-Cu foil	<4.6*	<3.1*	<10.8	<7.7*	<1.6*
Cu-Kapton-Cu foil	<4.6*	<3.1*	<10.8	<7.7*	<1.6*

*Level obtained from the Minimum Detectable Activity of the detector

- Very low levels of radioactivity, compatible with the sensitivity of the measurement
- Contamination probably comes from the treatment of the materials used