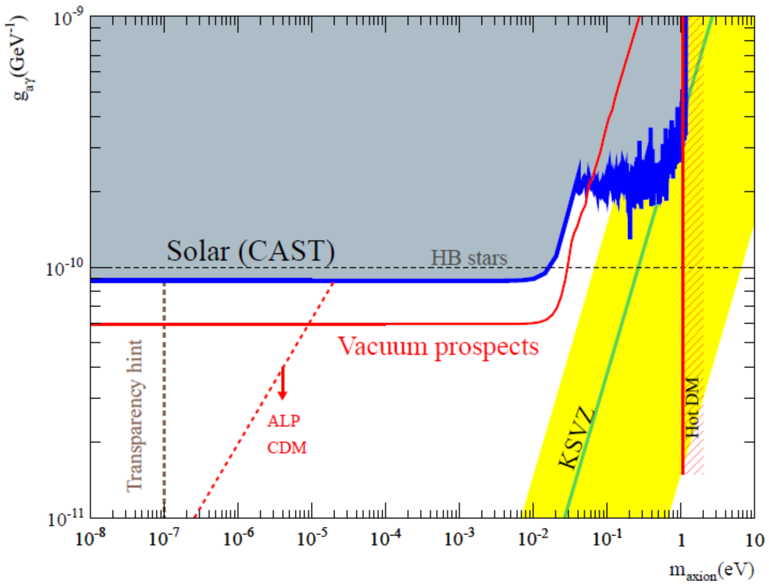
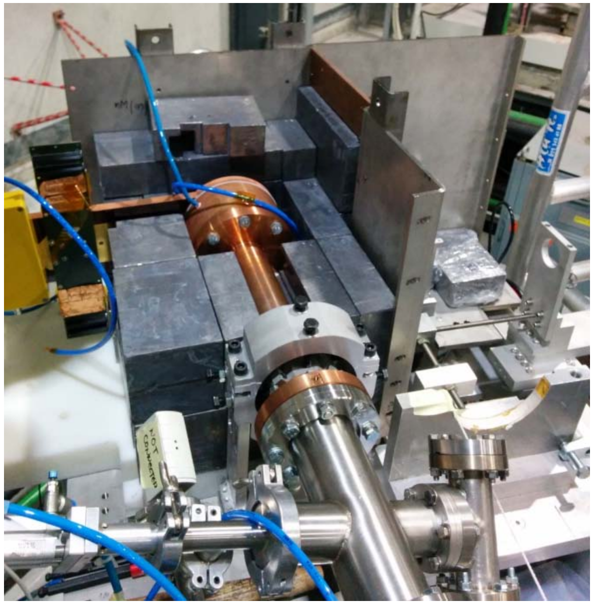
Axion search and research with low background Micromegas





JuanAn García[1] on behalf of CAST & IAXO Collaborations

11th Patras Workshop on Axions, WIMPs and WISPs
Zaragoza, June 2015

[1]Universidad de Zaragoza
e-mail: jagarpas@unizar.es

OUTLINE

- Axions and Axion Like Particles
- The CAST experiment
- Low background techniques
- Future prospects
- Summary and conclusions

AXIONS AND ALPS

Axion arises as a solution of the strong CP problem.

Peccei-Quinn → Introduction of new global and chiral symmetry that is spontaneously broken at the energy scale of the symmetry f_a

It implies the existence of a new particle → **The axion**

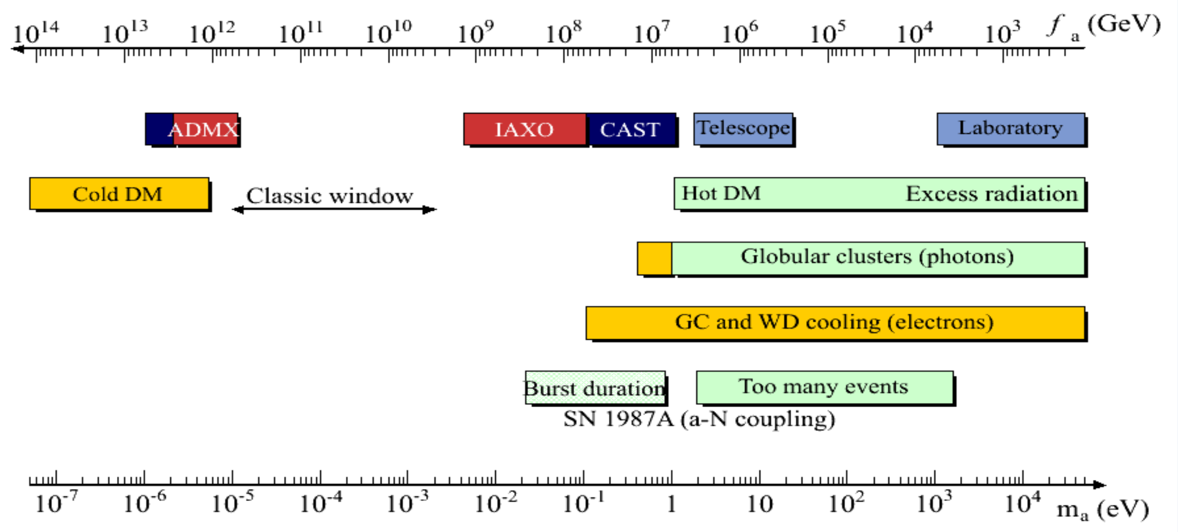
Axion properties:

$$m_a \propto \frac{1}{f_a}, \qquad g_{ai} \propto \frac{1}{f_a}$$

Axion generically couples to photons and gluons. It could also interact with fermions.

Axion masses are constrained due to astrophysical and cosmological considerations.

See Raffelt's and Straniero's talks



AXIONS AND ALPS

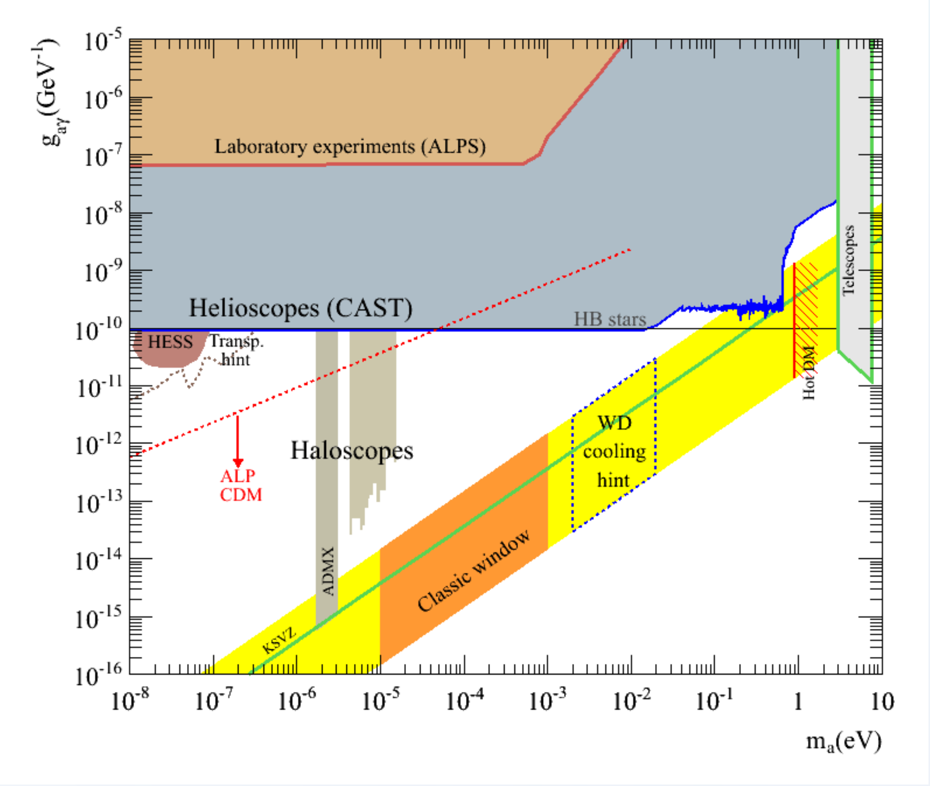
Axion Like Particles (ALPs) or more generic WISPs, share the same phenomenology as the axions. But in this case m_a and $g_{a\gamma}$ are not correlated

ALPs arise from extensions of the SM as pseudo NG bosons of new symmetries that are broken at a high energy scale. Also, they appear in string theory.

Axions and ALPs could provide the right amount of Dark Matter, in a wide range of the parameter space.

Axions and ALPs hints:
- VHE transparency
- Stellar evolution

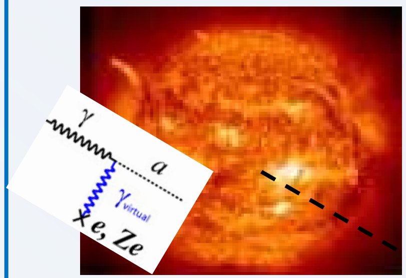
Troitsky, Roncadelli and Giannotti talks



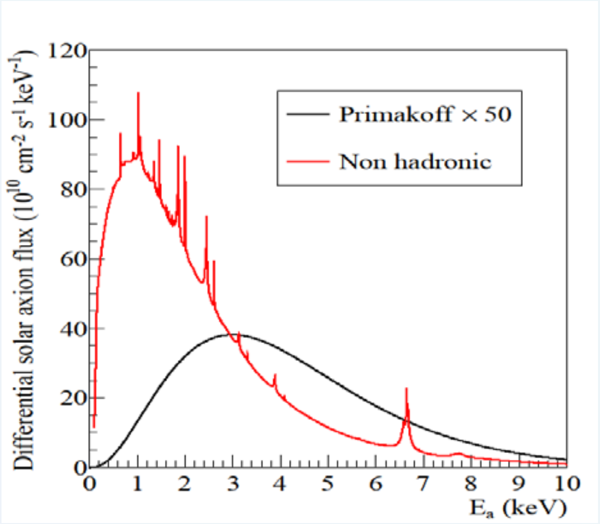
AXIONS AND ALPS

Helioscope technique

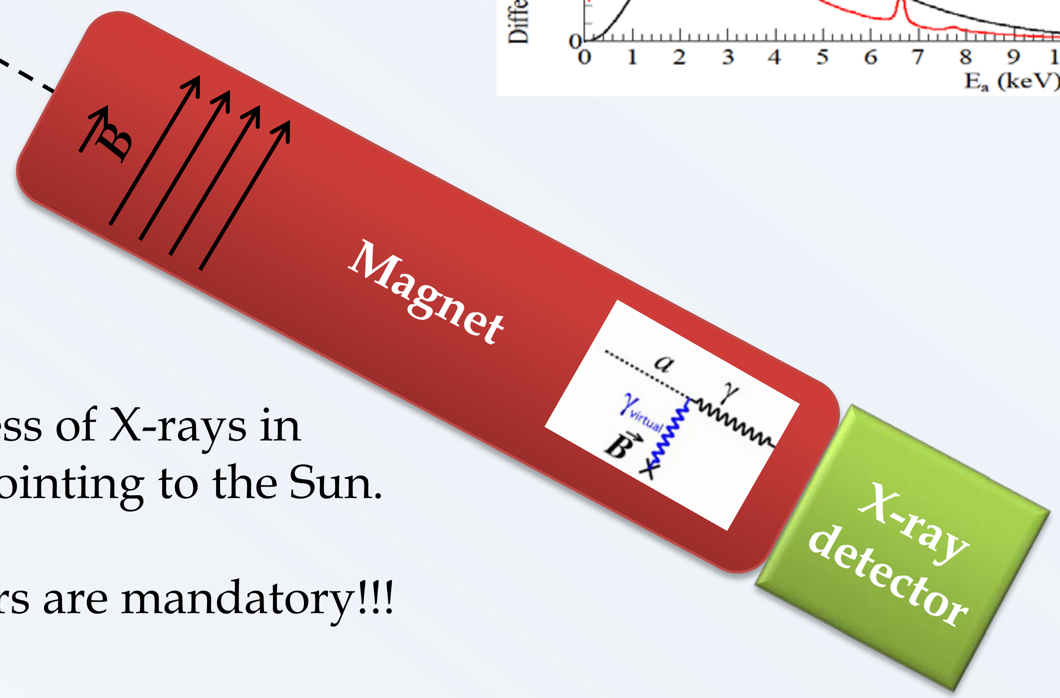
Proposed by *P. Sikivie* in 1983 **PRL 51, 1415**



Thermal photons inside the strong electric fields of the charged particles in the solar plasma could be converted into axions.



Solar axions could be reconverted into photons inside strong magnetic fields via "inverse Primakoff" effect.



The axion signal will be an excess of X-rays in detectors while the magnet is pointing to the Sun.

Low background X-ray detectors are mandatory!!!

AXIONS AND ALPS

Probability of the axion-photon conversion:

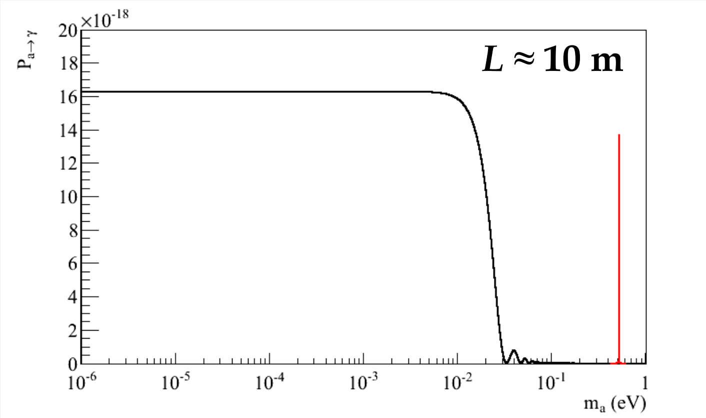
$$P_{a\to\gamma} = \left(\frac{g_{a\gamma}}{2}\right)^2 B^2 \frac{1}{q^2+\Gamma^2/4}\left[1+e^{-\Gamma L}-2e^{-\Gamma L/2}\cos(qL)\right]$$ where $$q = \left|\frac{m_\gamma^2 - m_a^2}{2E_a}\right|$$

Vacuum case:

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

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

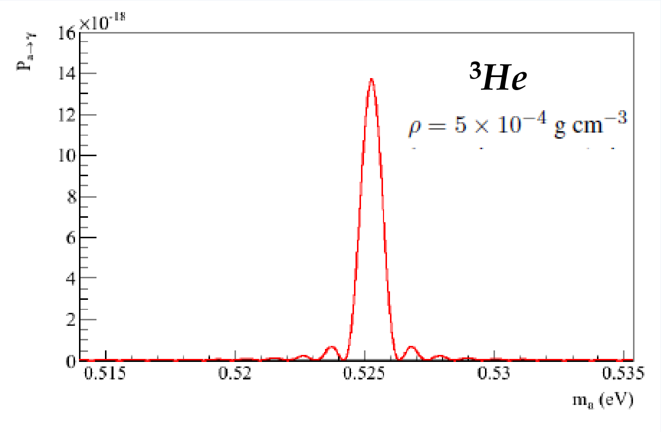
Coherence condition → $m_a < \sqrt{\frac{4\pi E_a}{L}}$



Buffer gas case:

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

The coherence can be restored for higher axion masses.

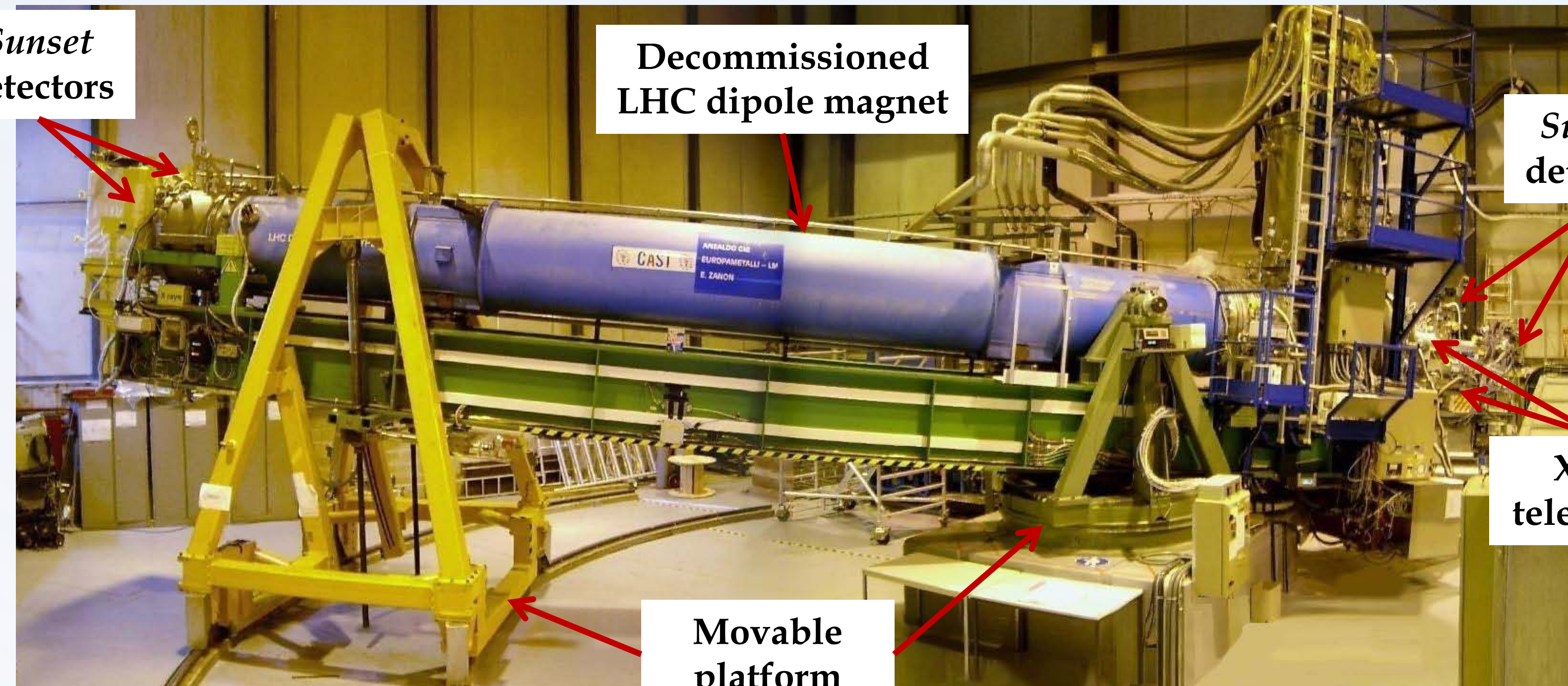


THE CAST EXPERIMENT

The CERN Axion Solar Telescope

http://cast.web.cern.ch/CAST/

Operating at CERN since 2003, being the most sensitive helioscope, so far…



Magnet length: 9.26 m
Magnet aperture: 2 x 14.5 cm^2
Magnetic field: 8.8 T

Solar trackings:
~1.5 h during Sunset
~1.5 h during Sunrise

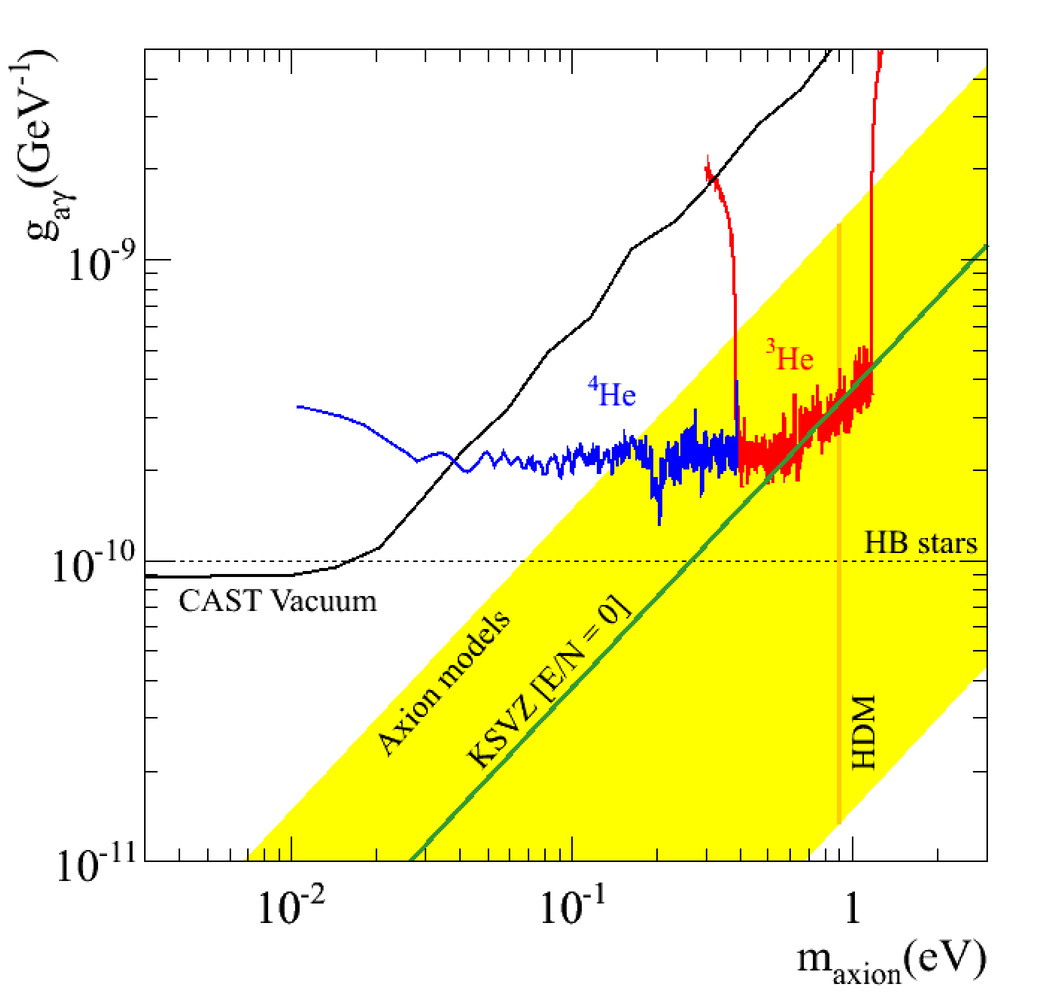
X-ray detectors:
- 3 Micromegas
- 1 Ingrid detector

Iguaz talk

Desch talk

THE CAST EXPERIMENT

CAST research program:



Phase I: JCAP2007(04):010

Vacuum 2003-2004

$m_a < 0.02$ eV

$g_{a\gamma} < 8.8 \cdot 10^{-11}$ GeV^{-1}

Phase II: Buffer gas

^{4}He 2005-2006 JCAP2009(02):008

$0.02 < m_a < 0.39$ eV

$g_{a\gamma} < 2.17 \cdot 10^{-10}$ GeV^{-1}

^{3}He 2008-2011 PRL 107, 261302

$0.39 < m_a < 0.64$ eV

$g_{a\gamma} < 2.30 \cdot 10^{-10}$ GeV^{-1}

PRL 112, 091302

$0.64 < m_a < 1.17$ eV

$g_{a\gamma} < 3.30 \cdot 10^{-10}$ GeV^{-1}

LOW BACKGROUND TECHNIQUES

CAST microbulk Micromegas exploit different low background strategies, developed under the T-REX project:

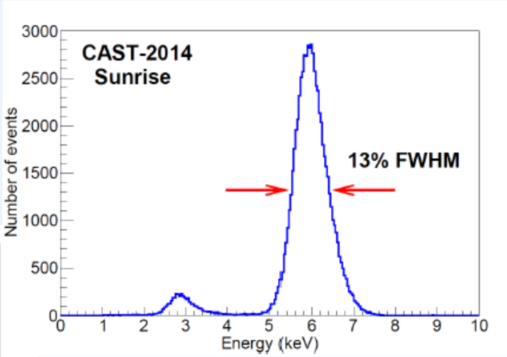
JINST 9 P01001

Radiopurity:

Low mass

Clean materials (copper, plexiglass, kapton,..)

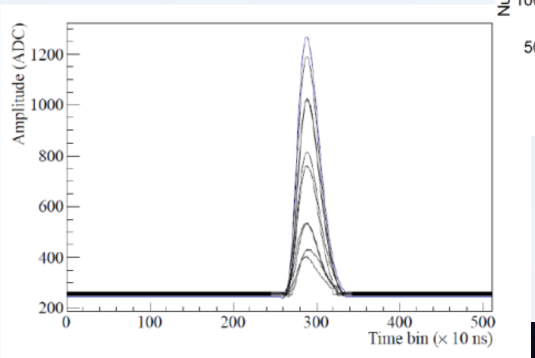
"Radiopurity of Micromegas readout planes"
Astroparticle Physics 354 (2011)



Manufacturing technology:

Improvements on the detectors performance

Better discrimination capabilities



Event discrimination:

2D readout pattern via strips

Time information from mesh pulse

New AFTER front-end electronics

Shielding

Inner Cu shielding

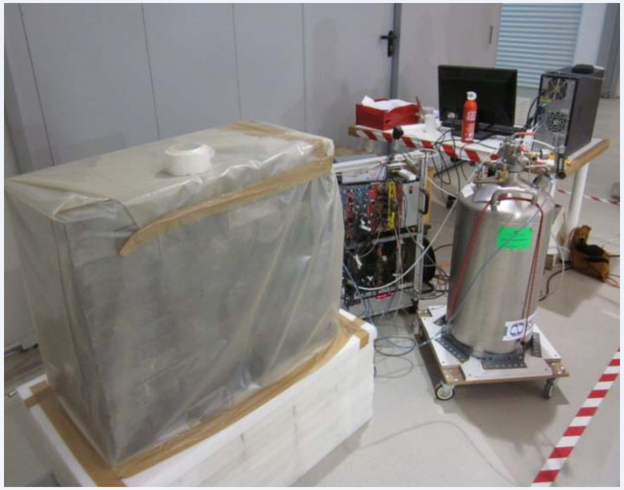
External lead shielding

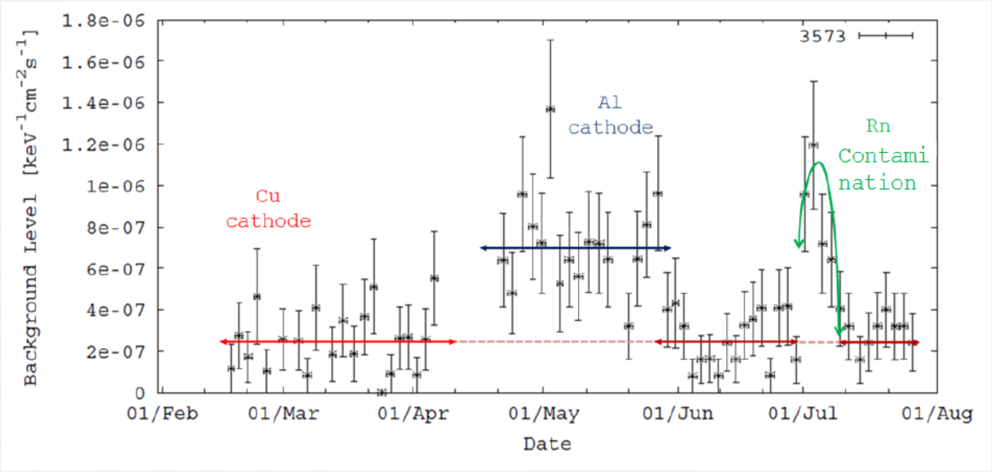
Active muon veto

LOW BACKGROUND TECHNIQUES

Canfranc Underground Laboratory (LSC) measurements:

LSC situated at Canfranc (Huesca) in the Spanish Pyrenees under Tobazo mountain, with a depth of 2500 m.w.e. → muon flux reduced by a factor 10^4





Shielding: 10 cm Pb + 2.5 cm inner Cu

N_2 flux to avoid ^{222}Rn

Internal components are radiopure

Al cathode contribution:
~5 x 10^{-7} c keV^{-1}cm^{-2}s^{-1}

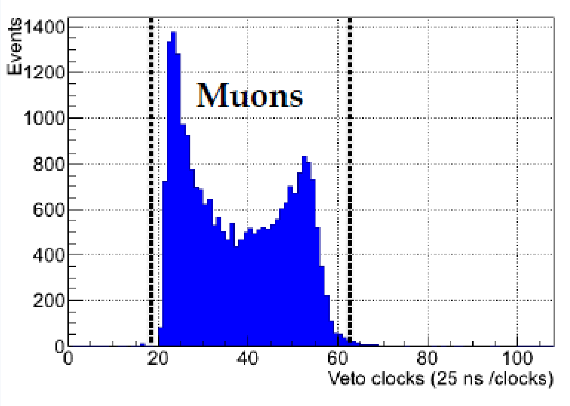
^{222}Rn contribution:
~3 x 10^{-8} c keV^{-1}cm^{-2}s^{-1} per Bq m^{-3} of ^{222}Rn

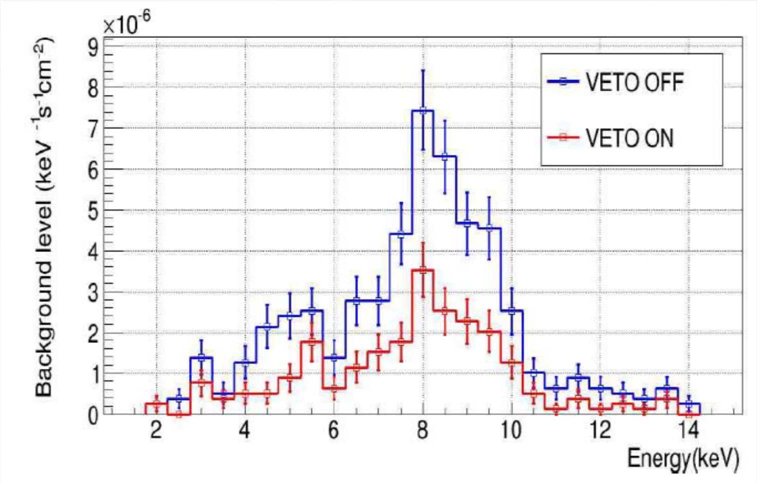
Final background level ~10^{-7} c keV^{-1}cm^{-2}s^{-1}

LOW BACKGROUND TECHNIQUES

Measurements at surface level:

The contribution of the cosmic muons to the background has been measured.





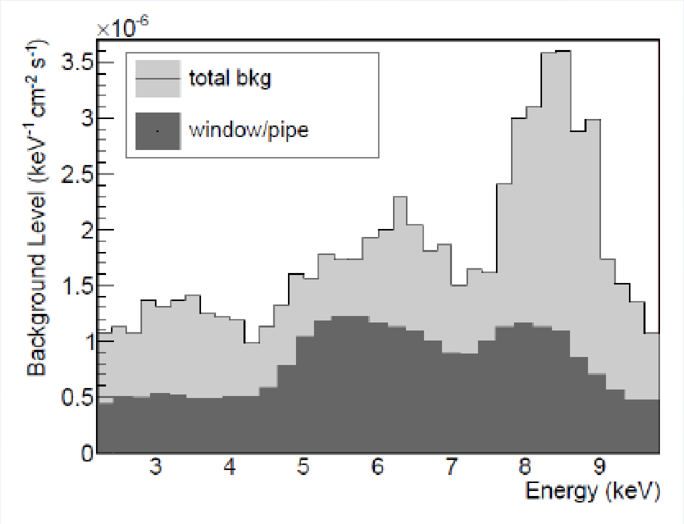
Two plastic scintillators have been installed and the time difference between the Micromegas and the veto triggers is stored.

Background level after veto cut:

~10^{-6} c $keV^{-1}cm^{-2}s^{-1}$ →50% of reduction

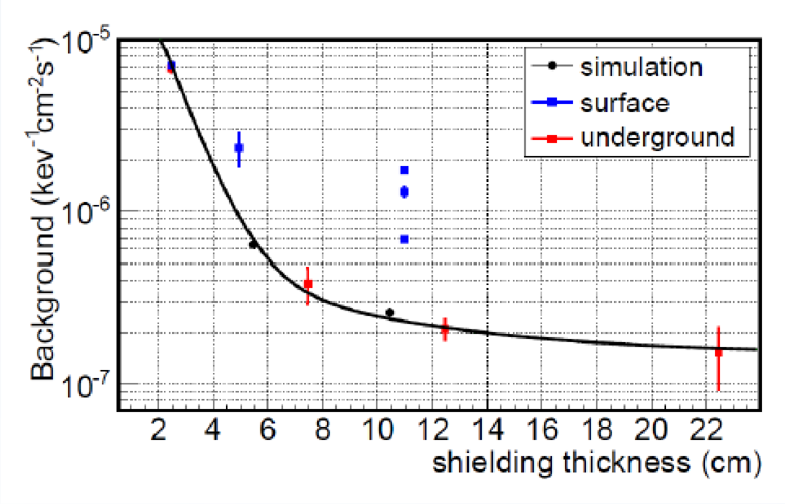
LOW BACKGROUND TECHNIQUES

Simulations are an important input to understand the experimental results.



RESTSoft (Zaragoza):
GEANT4→ Drift and diffusion in the chamber (Magboltz for drift and diffusion parameters) → Electronic response.

Simulated environmental γ at CAST →Flux characterized experimentally in the CAST area.



Proposed upgrades at CAST:

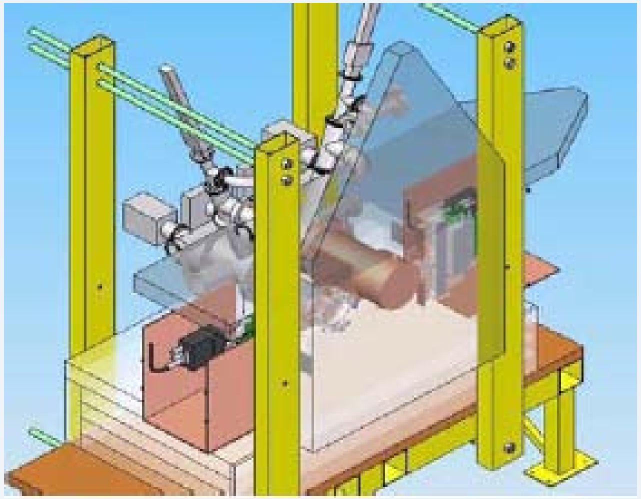
- Increase the lead shielding along the pipe to the magnet.

- Replace the steel pipe by a copper one.

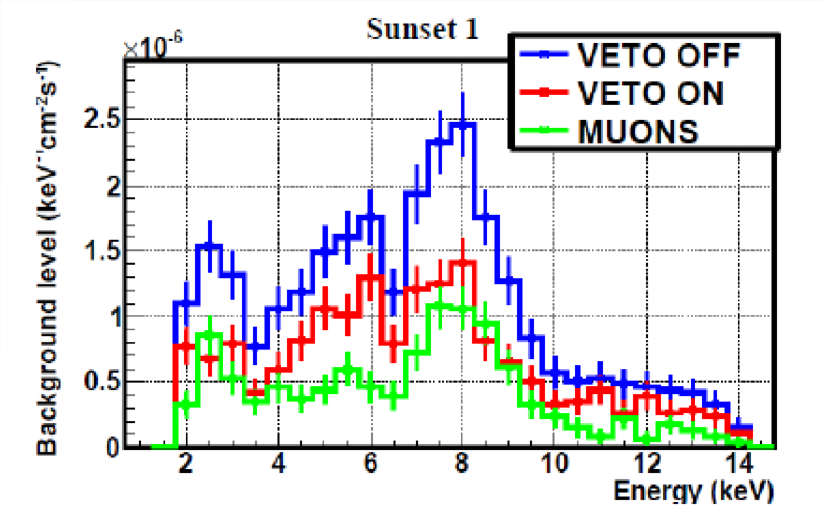
- Use of an active muon veto.

LOW BACKGROUND TECHNIQUES

Sunset Micromegas upgrade:



- New Micromegas detectors have been manufactured.
- New shielding design, extending the lead shielding along the pipes to the magnet bores.
- 10 mm of Cu shielding.
- 100 mm external Pb.
- Cu strongback.
- Plastic scintillators for muon rejection.
- AFTER front-end electronics.



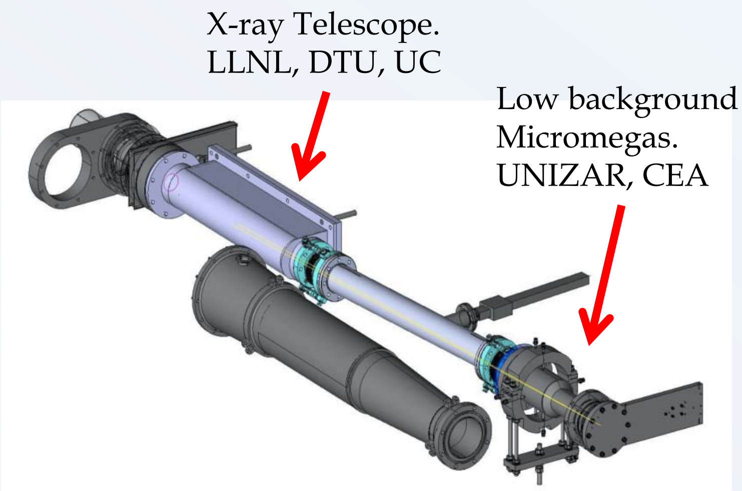
After the upgrade the background level diminished to:

$\sim 10^{-6}$ c keV^{-1}cm^{-2}s^{-1} → A factor ~6 of reduction.

The scintillators account for ~50% of the background events.

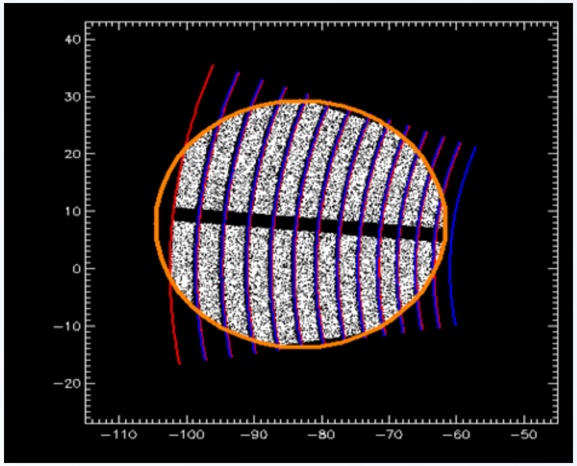
LOW BACKGROUND TECHNIQUES

New Sunrise XRT + Micromegas line

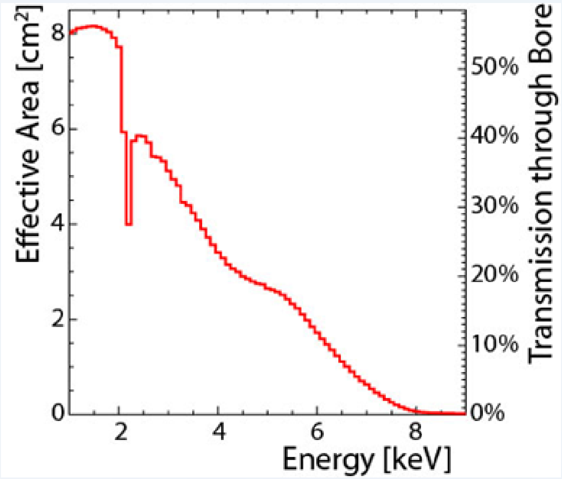


- X-ray optics specifically designed and built for CAST.
- Focal length 1.5 m
- Focusing spot 1-5 mm^2
-Big milestone for CAST → ~100 improve in S/B .
- Pathfinder system for IAXO.

13 multilayers W/B_4C

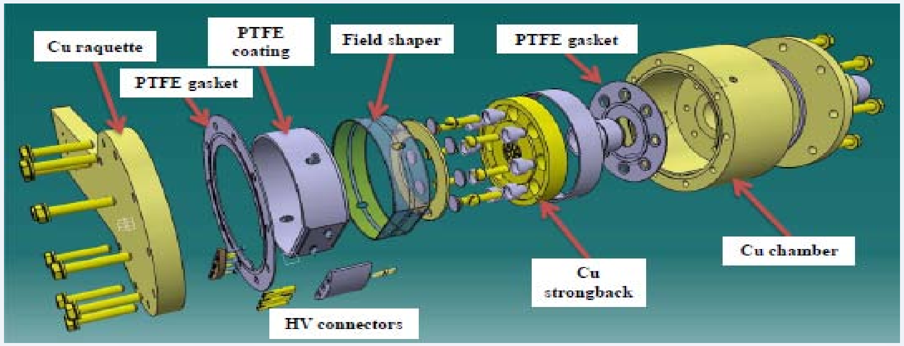


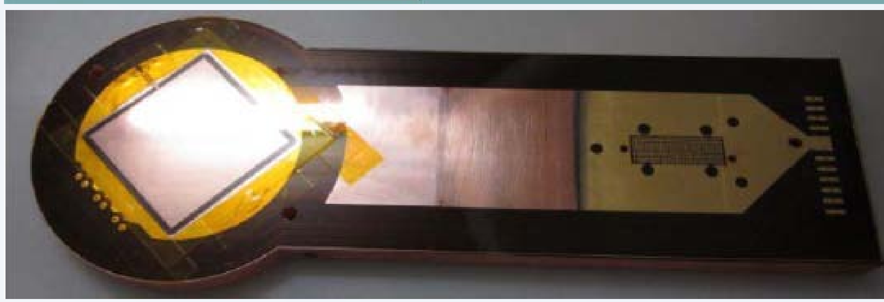
XRT efficiency



LOW BACKGROUND TECHNIQUES

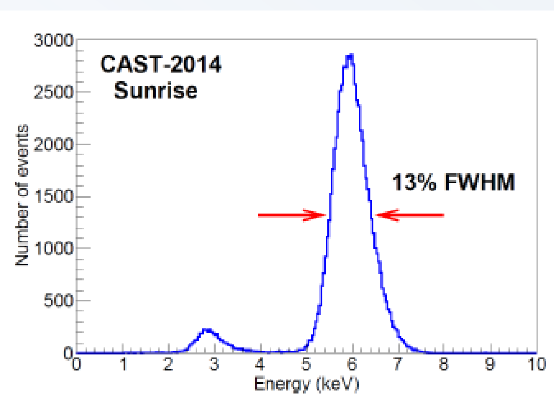
A low-background Micromegas is placed in its focal plane

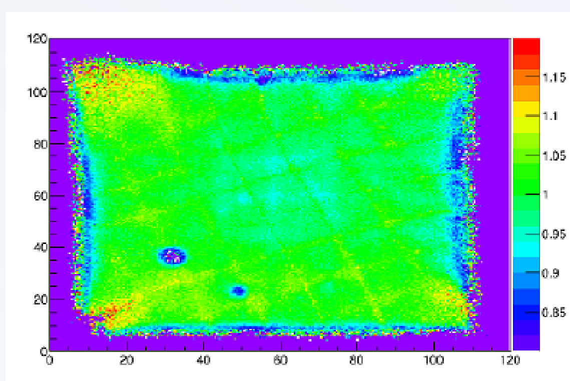




- New detector design: Cu raquette and Cu chamber.
- Radiopure materials: Cu and PTFE.
- Field shaper.
- New shielding design: 20 mm Cu and 100 mm Pb.
- Plastic scintillator.
- AFTER front-end electronics.

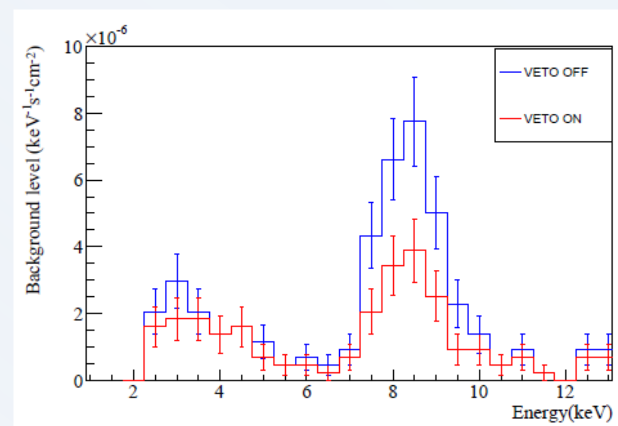
Excellent spatial and energy resolution.





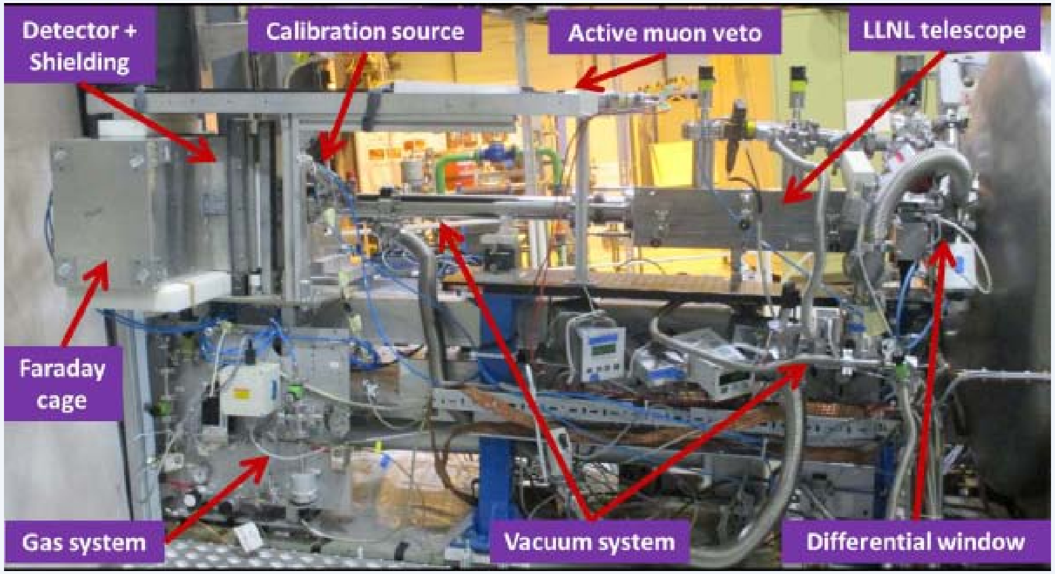
Background

~8 x 10^{-7} c $keV^{-1}cm^{-2}s^{-1}$



LOW BACKGROUND TECHNIQUES

Operating at CAST since September 2014.



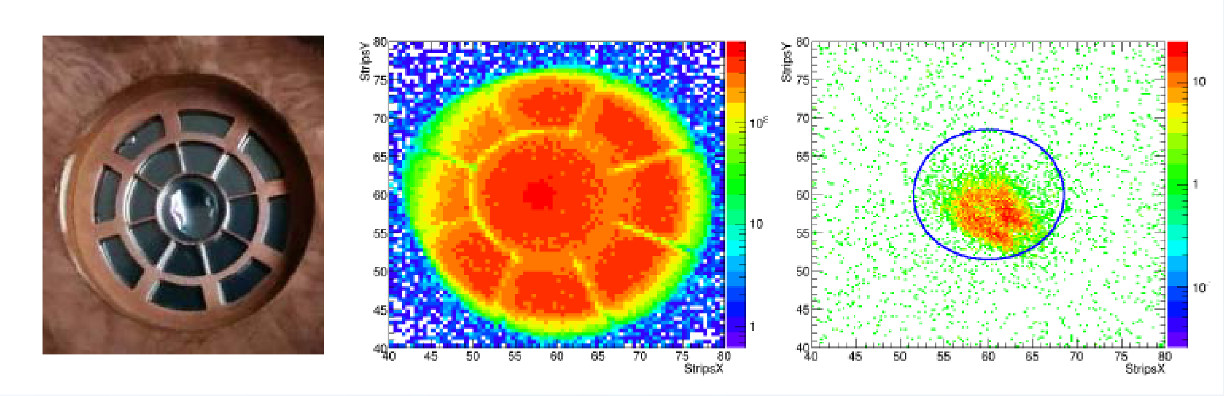
XRT + Micromegas were installed and aligned in August 2014.

First time that an X-ray focusing device has been constructed for axion research with a low-background Micromegas in its focal plane

Alignment procedure

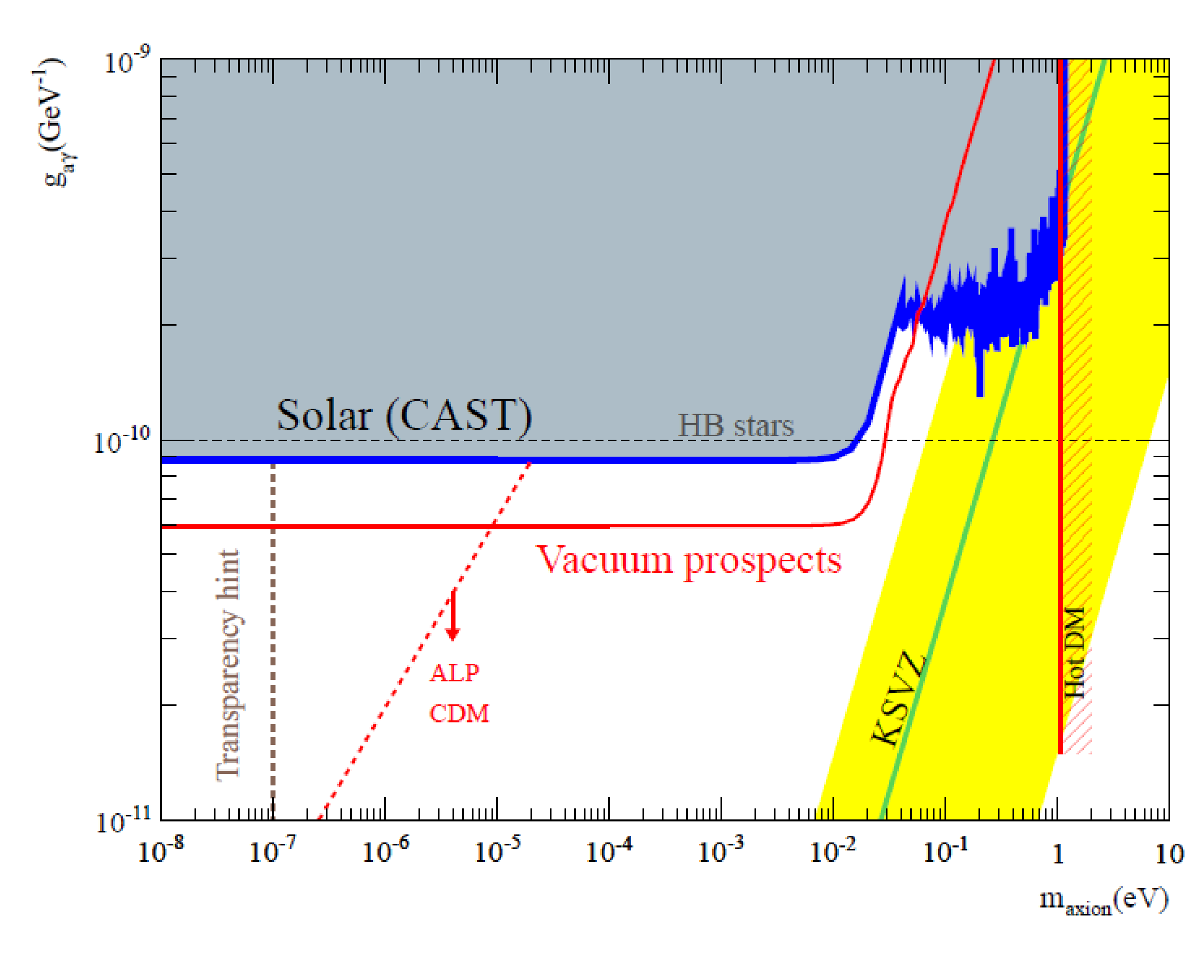
"Spider web" cathode

X-ray finger run



LOW BACKGROUND TECHNIQUES

A revisited vacuum phase started in 2013.



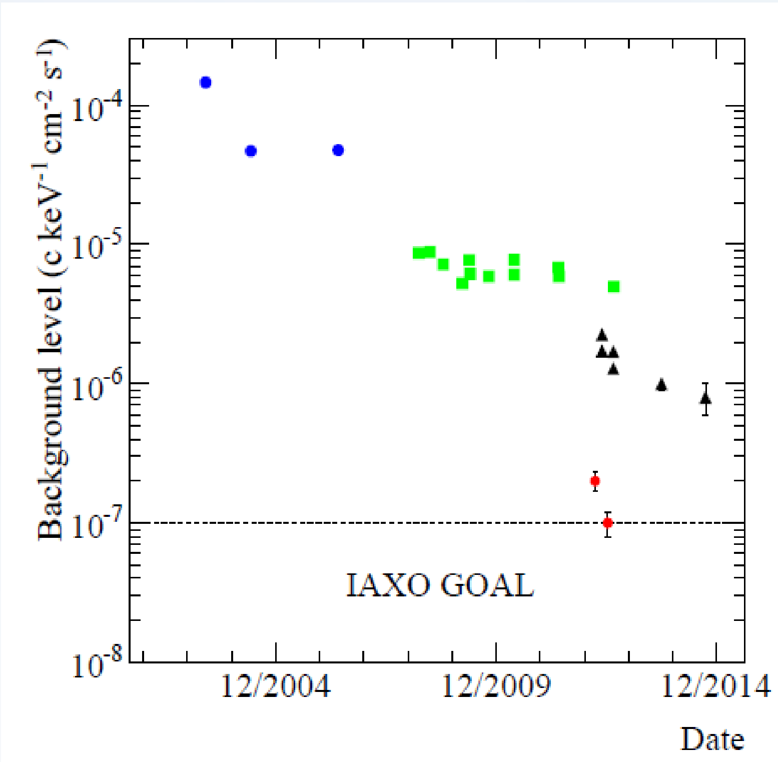
Due to the new XRT and the reduction of the background level in the Micromegas detectors, CAST will improve its previous limit down to:

$g_{a\gamma} < \sim 6 \cdot 10^{-11}$ GeV^{-1} for $m_a < 0.02$ eV

FUTURE PROSPECTS

Ultra-low background detectors are required for IAXO.

Redondo talk

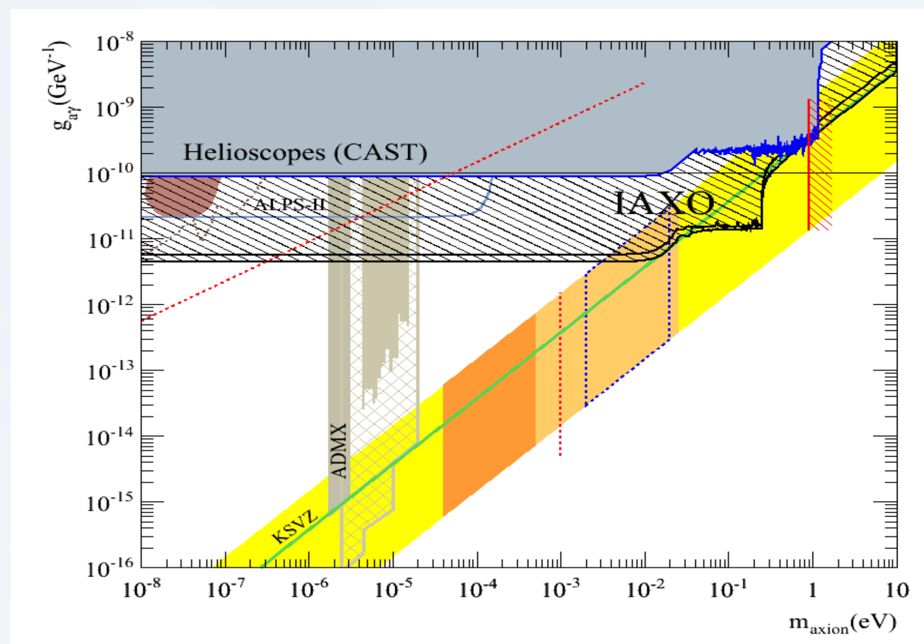


Baseline technology → Micromegas

New R&D lines:

-Veto coverage: Extend the surface area as much as possible.

- New gas mixtures: Remove the ^{39}Ar isotope. New base gas (Xe, depleted Ar).



Goal: 10^{-8} - 10^{-7} c keV^{-1}cm^{-2}s^{-1}

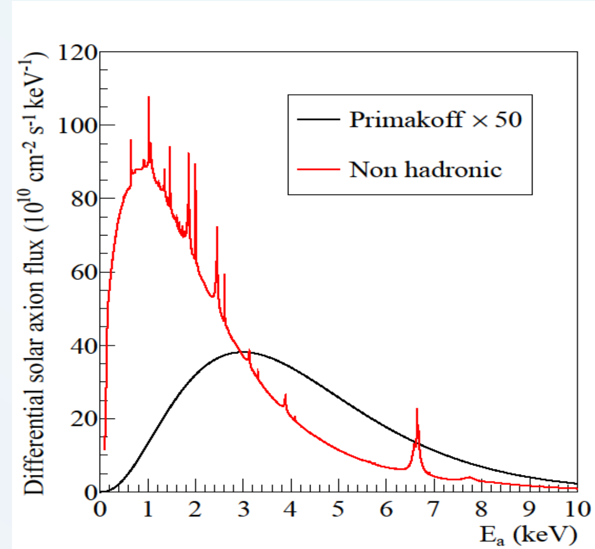
FUTURE PROSPECTS

Lowering the energy threshold:

New physics could be explored:

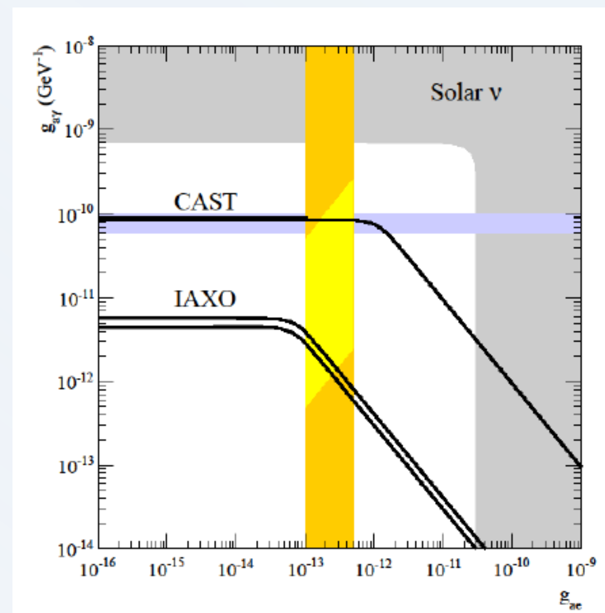
- Non-hadronic solar axions, which flux could be larger than the Primakoff emission.

- More exotic particles: paraphotons, chameleons, hidden photons…



R&D lines:

- New thin windows: Increase the efficiency at low energies.
- AGET front-end electronics: Reduce the low energy threshold.
- Resistive Micromegas: Higher intrinsic gain.



SUMMARY AND CONCLUSIONS

❖The CAST experiment has been looking for axions since 2003 being the most sensitive helioscope so far.

❖Low background techniques for Micromegas detectors have led to a reduction of a factor ~100 in the CAST experiment.

❖ The new XRT + Micromegas system at CAST will improve the sensitivity of the experiment and could be considered as a pathfinder for IAXO.

❖ IAXO would require ultra-low background detectors and new R&D lines have been proposed.

❖ The reduction of the low energy threshold of the Micromegas will open new physics for IAXO.

The End

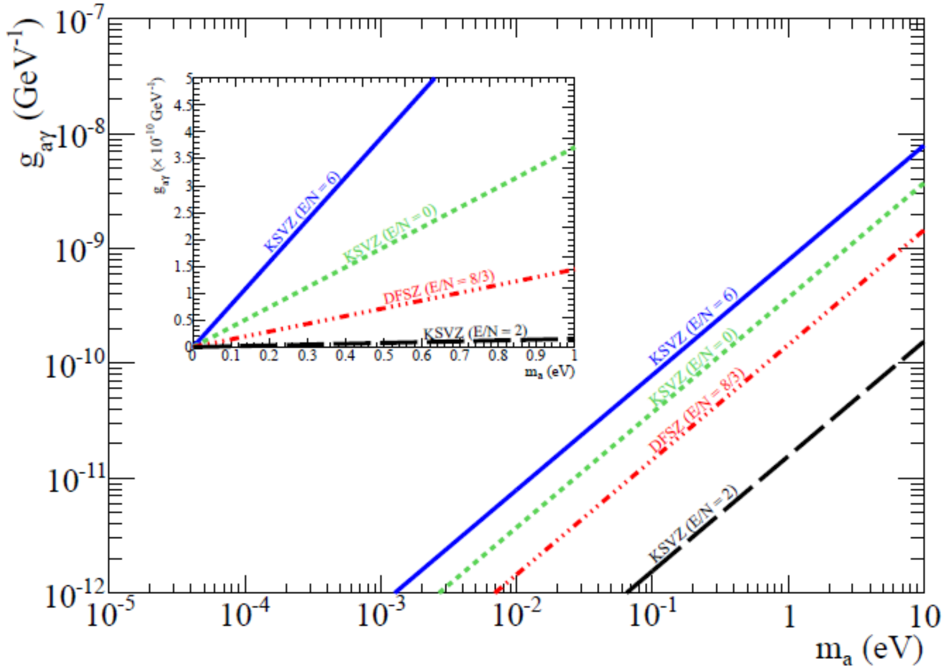
BACK UP

Invisible axion models:

KSVZ

$$\frac{E}{N} = 6Q_{heavy}^2$$

$$Q_{heavy} = 2/3, -1/3, 1, 0$$



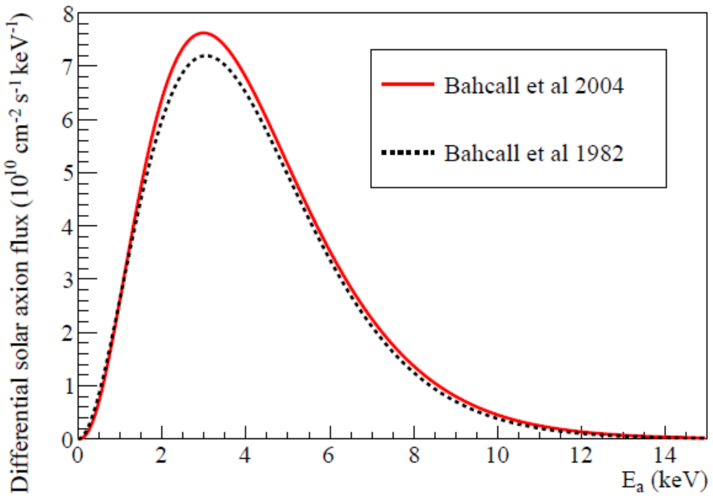
DSFZ

$$E/N = 8/3$$

BACK UP

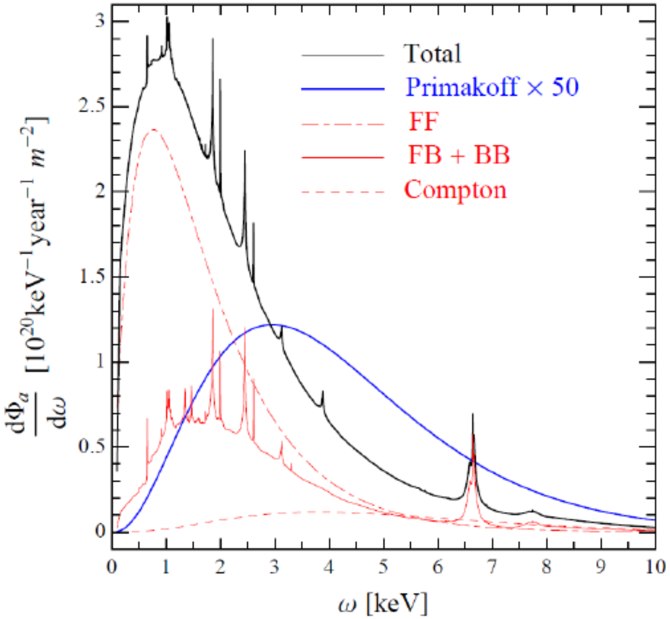
Solar axion emission:

Hadronic (Primakoff):



$$\frac{d\Phi_a}{dE_a} = 6.02 \times 10^{10} \left(\frac{g_{a\gamma}}{10^{-10}\ \mathrm{GeV}^{-1}} \right)^2 (E_a/\mathrm{keV})^{2.481}\, e^{-E_a/1.205\mathrm{keV}}$$

Non-hadronic:

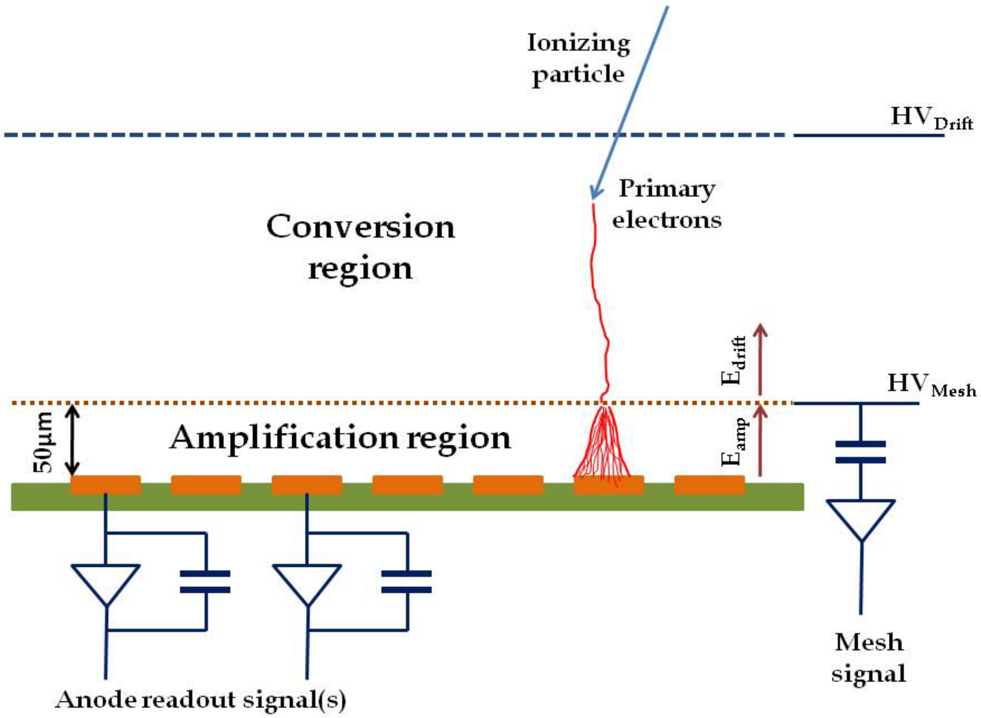


- Bremsstrahlung
- Axio-recombination
- Axio-desexcitation
- Compton

BACK UP

MICRO Mesh Gaseous Structure, developed by *I. Giomataris* NIM A 376, 29

MICROMEGAS are gaseous ionization detectors in the frame of the novel MPGD technology.



Conversion region:

- Generation of primary ion-electron pairs.
- Drift and diffusion of the primary electrons.

Amplification region:

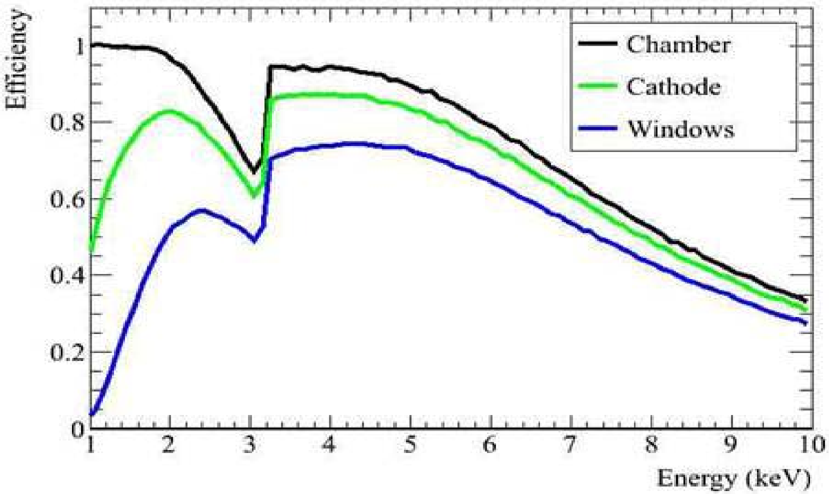
- Avalanche of electrons.
- Mesh signal.
- Strips/pixel signals from the anode readout.

Different manufacturing techniques: *classical*, *bulk* and *microbulk*.

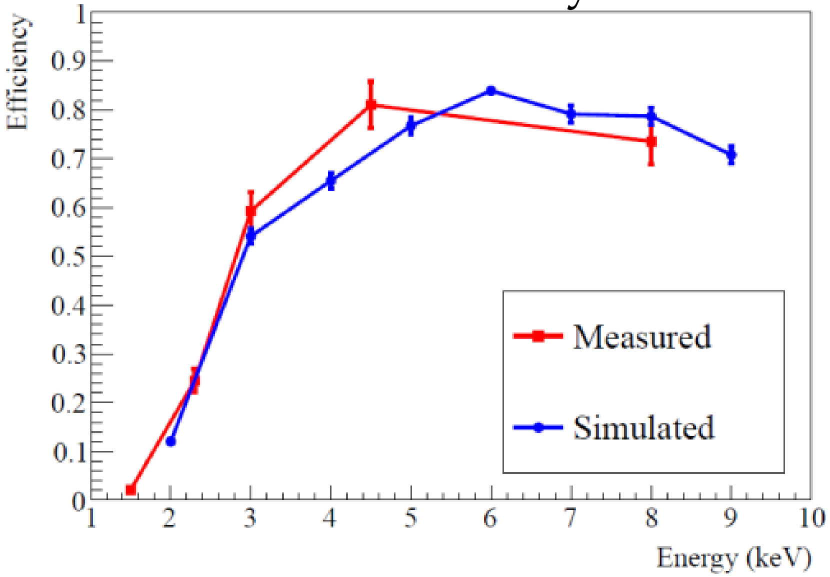
BACK UP

Micromegas efficiency:

Quantum efficiency

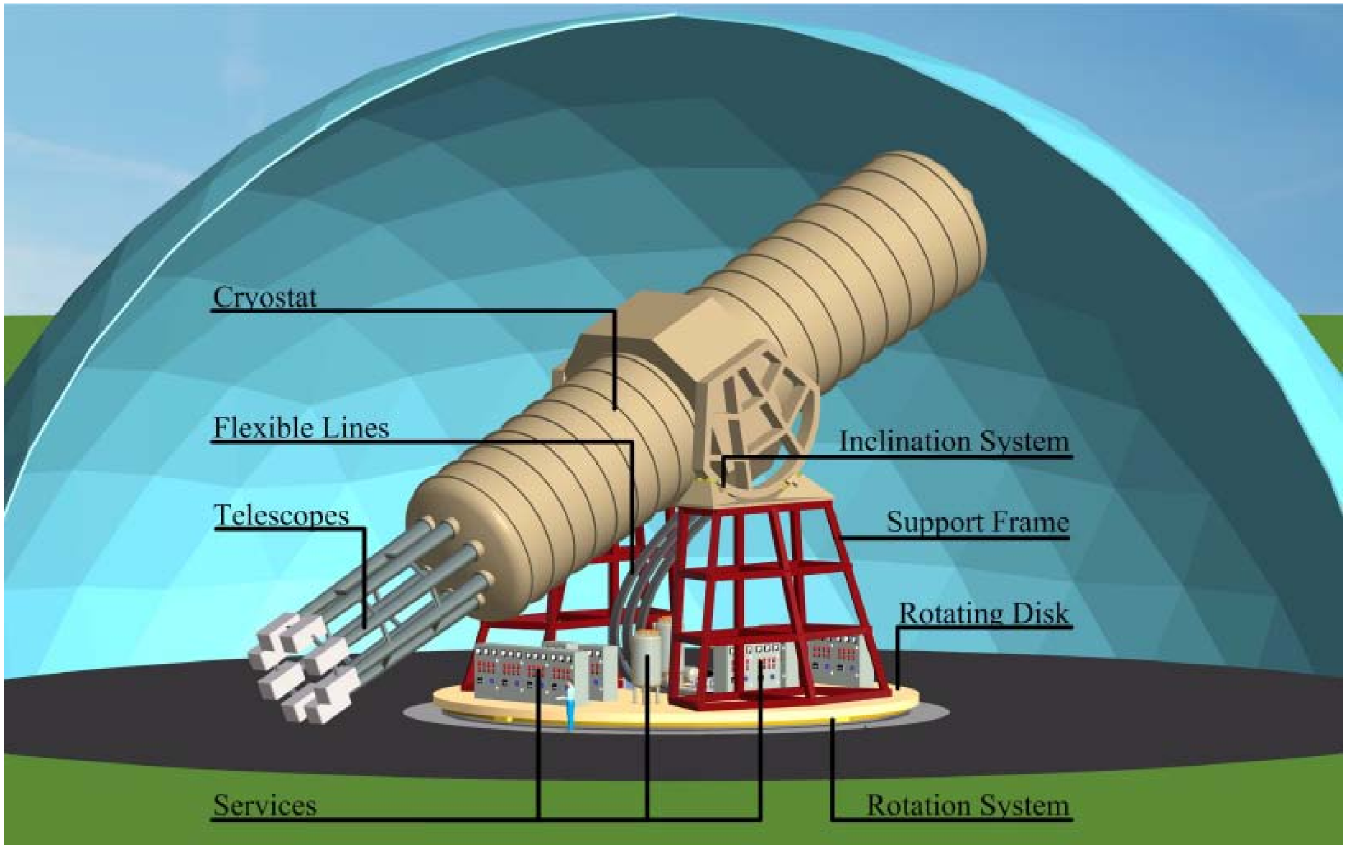


Software efficiency



BACK UP

The International AXion Observatory http://iaxo.web.cern.ch/iaxo/



Letter of Intent submitted to CERN received positive recommendation

SPSC-2013-0022

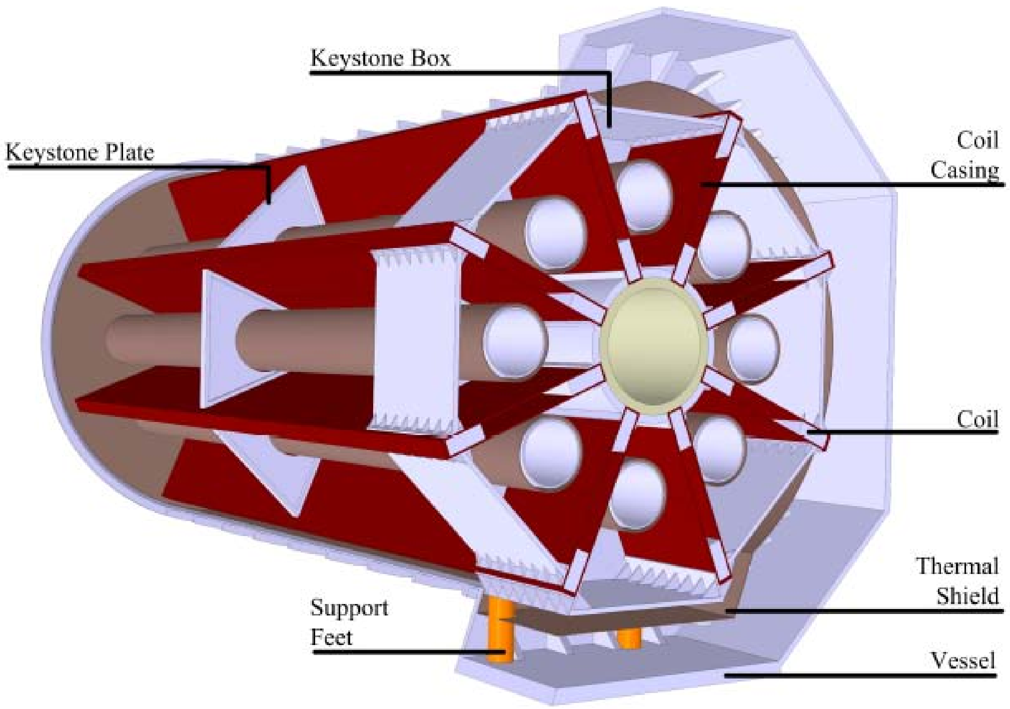
Conceptual Design Review already published

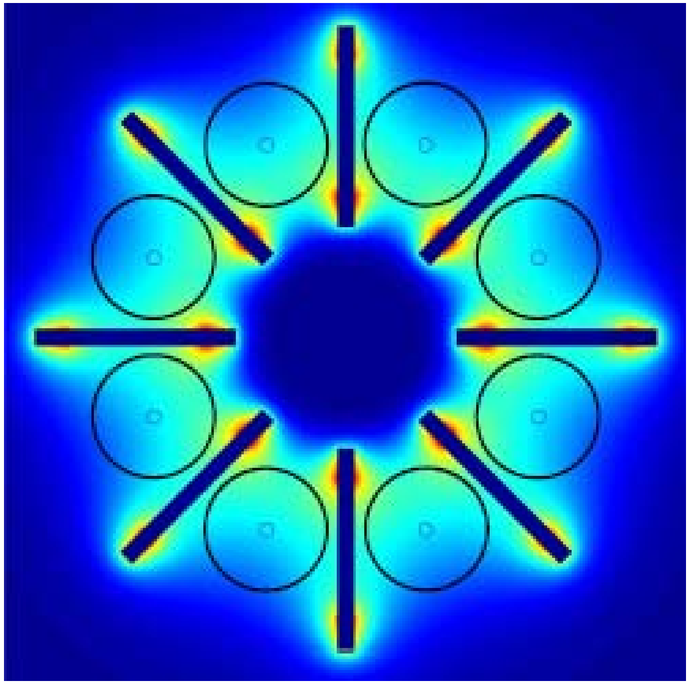
JINST 9 T05002

IAXO will enhance the helioscope technique by exploiting all the singularities of CAST.

BACK UP

A dedicated toroidal magnet is planned for IAXO:



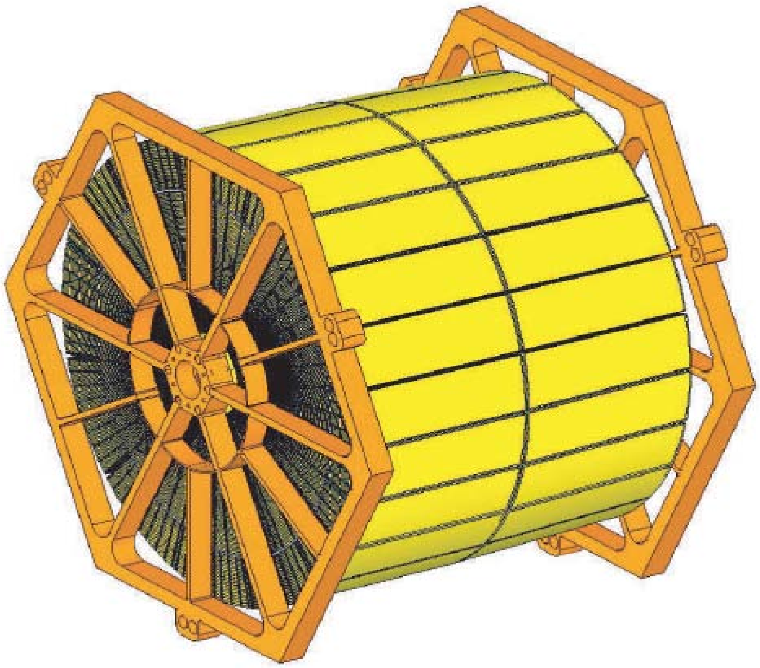


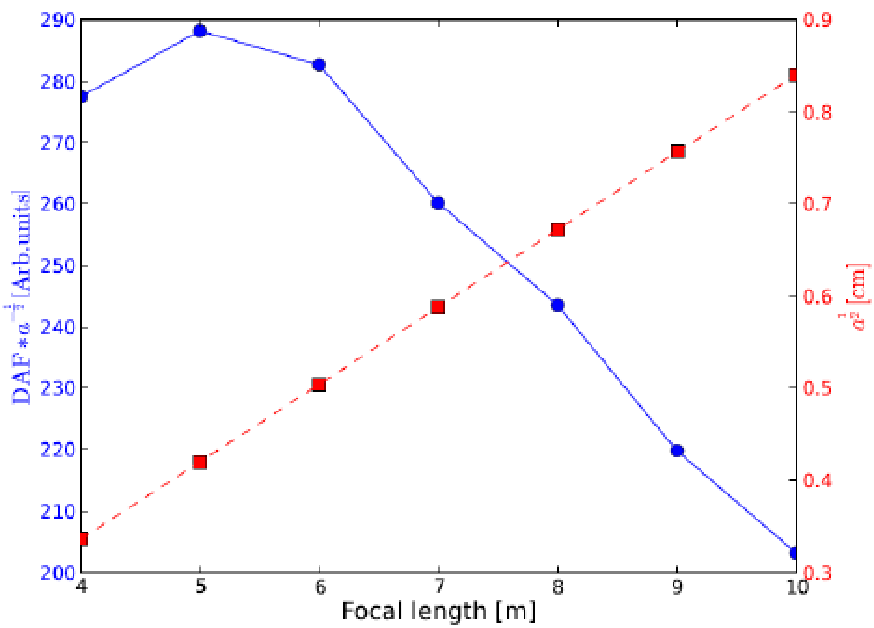
Magnet length: 21 m
Magnet aperture: 2.3 m^2
Magnetic field peak: 5.4 T

The support structure of the magnet allows solar trackings of ~12 h/day

BACK UP

X-rays telescopes at IAXO will be installed





Signal to background ratio increased by a factor 10^4 !!!

Focal length: ~5 m
Focusing spot: ~0.2 cm^2