Micromegas as low background x-ray detectors for axion experiments

  

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on behalf of

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MPGD2013, Zaragoza (Spain), July 2013

OUTLINE

- **Axion helioscopes: CAST and IAXO**
- **Low background techniques with Micromegas**
- **Background levels at CAST**
- **Prospects**
- **Summary and conclusions**

CAST (CERN Axion Solar Telescope) looking for ALP since 2002

Originalities of CAST:

Use of X-ray telescope:
Increase in signal-to-background ratio.

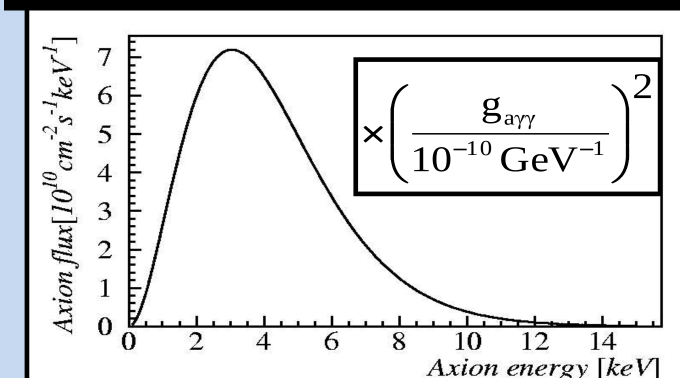
Low background techniques: shielding, low radioactive material, muon veto, …

Helioscope principle (Sikivie) reverse axions into photons

Production in the Sun
Conversion of thermal photons into axions via Primakoff effect in the solar plasma

Detection @ CAST
Conversion of axions into photons via the Inverse Primakoff in a strong magnetic field

Axion energy spectrum:
Serpico & Raffelt - JCAP04 (2007) 01

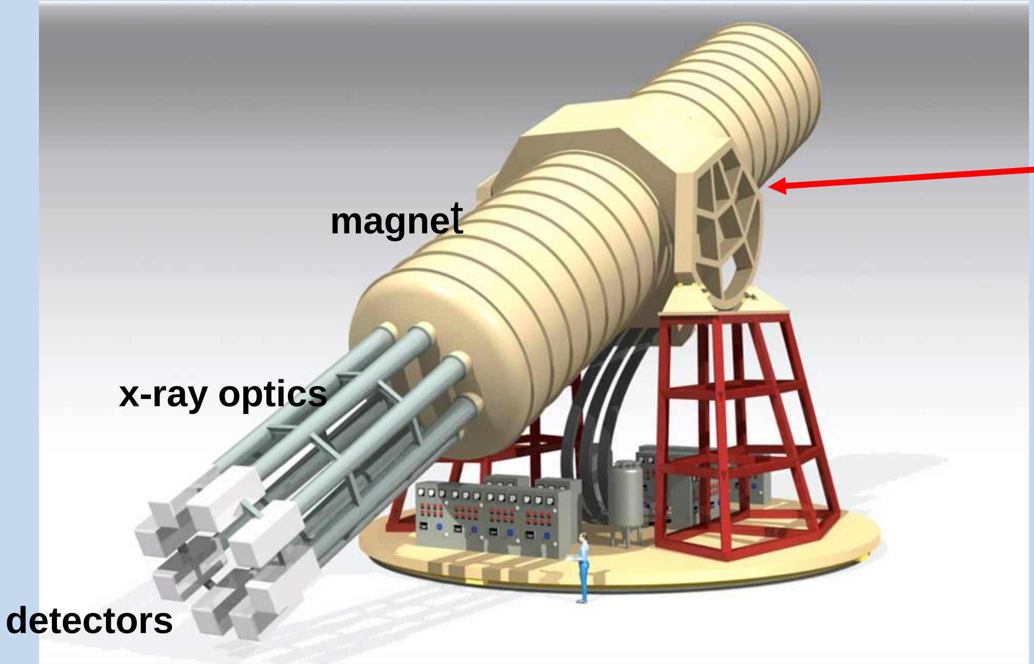


- **Low background x-ray detectors**: one of the parameters driving the sensibility.
- **SPSC** explicitly recognizes the Micromegas detectors improvements and results.
- **CAST** near-term program (including pathfinder projects for IAXO) has been recently **approved by CERN.**

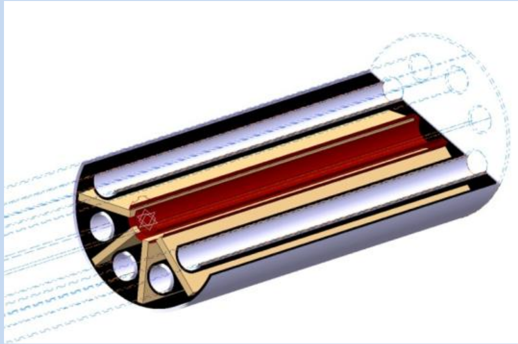
Axion helioscopes: CAST & IAXO

IAXO (The International AXion Observatory)

First feasibility results and sensitivity prospects recently published:
JCAP 1106:013,2011 (arxiv:1103.5334)



New larger toroidal magnet specifically built for axion physics



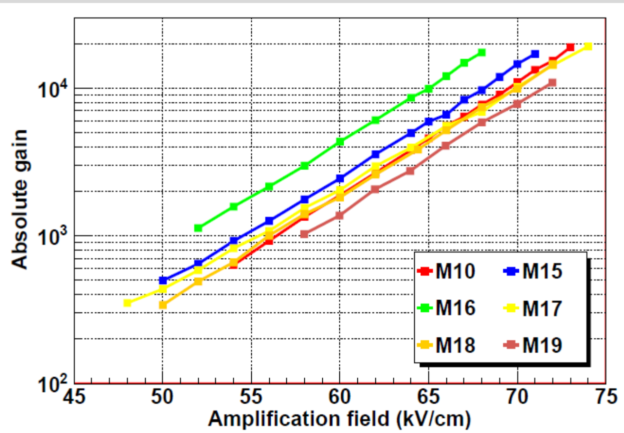
Each conversion bore about 0.5-1 m diameter

- Fully exploiting innovations of CAST.
- All bores equipped with x-ray focusing devices and low background detectors.
- **IAXO** will improve CAST sensitivity by 1-2 orders of magnitude, exploring astrophysically motivated regions in space parameters.
- CDR and LoI are in preparation.

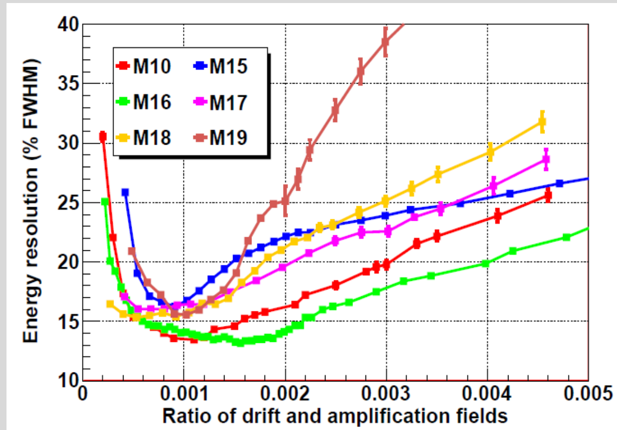
Why use microbulk Micromegas in Axion searches?

Performances and capabilities

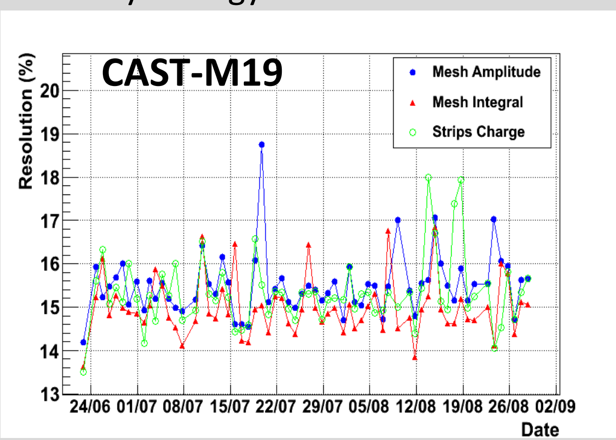
Absolute Gain



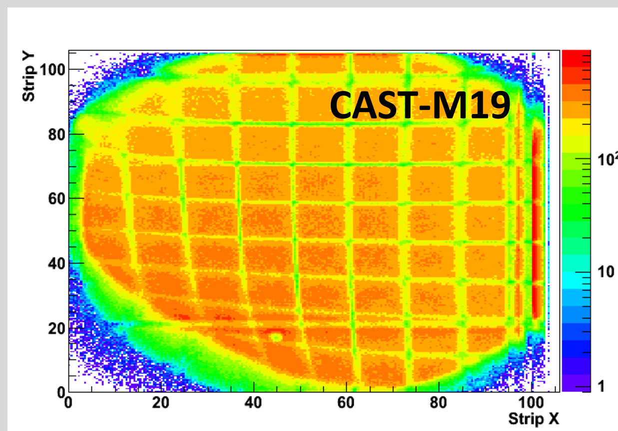
Energy resolution



Stability: Energy resolution in 2012



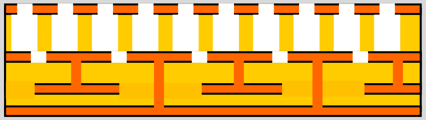
Hitmap distribution



Requirements:

- High gain.
- Good energy resolution (~15% FWHM @ 6 keV
- Stability in long term runs.
- Uniformity, no dead regions.
- Intrinsically radiopure.
- High background rejection capabilities (pattern recognition).

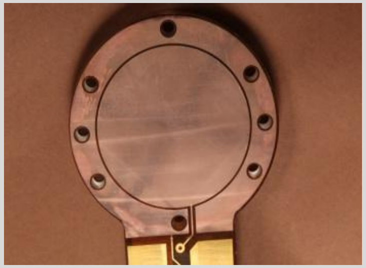
Low background techniques with Micromegas

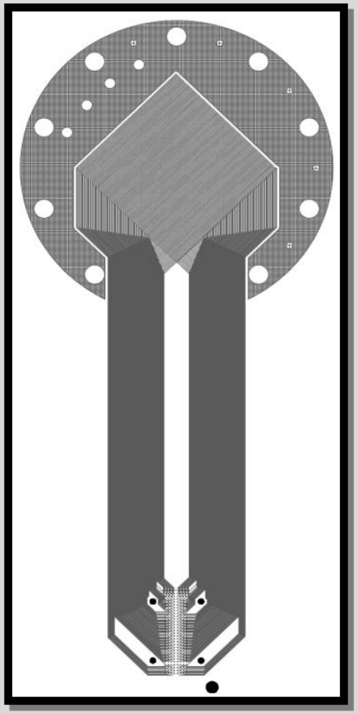


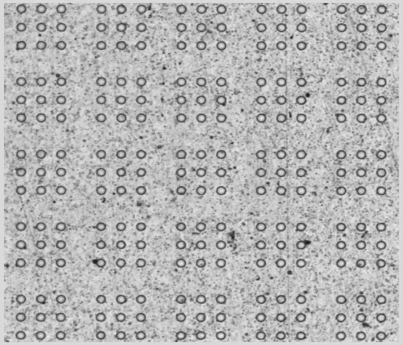
Since 2008: 3/4 of CAST detectors are microbulk Micromegas.

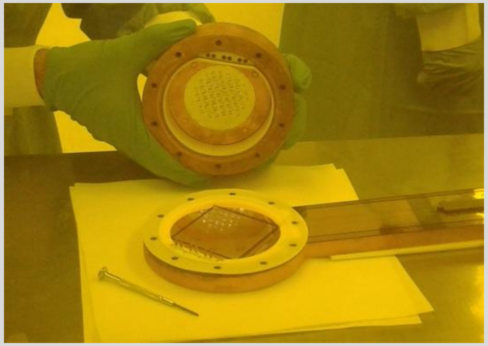
CAST: a test-bench for Micromegas, profitting from its evolution.

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









Latest Microbulk for CAST manufactured last week.

High voltage for the amplification and drift field also embedded in the PCB.

Readout glued to a clean copper support.

Special thanks to R. de Oliveira, A. Teixeira and S. Ferry, for the microbulk fabrication through the years

CAST microbulk MICROMEGAS exploit different low background strategies:

> *"Radiopurity of Micromegas readout planes"*
> **Astroparticle Physics (2011) 354-359**

1. Low intrinsic radioactivity

Low mass, clean materials (copper, teflon, kapton ...)

2. Shielding

External lead shielding, inner Cu shielding.

Active shielding: muon veto.

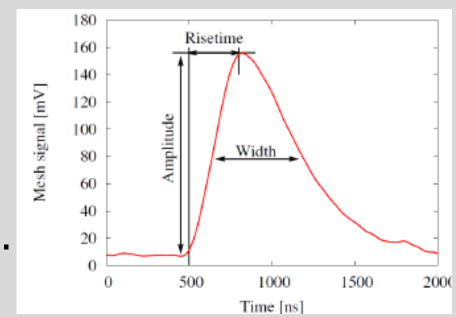
3. Offline analysis

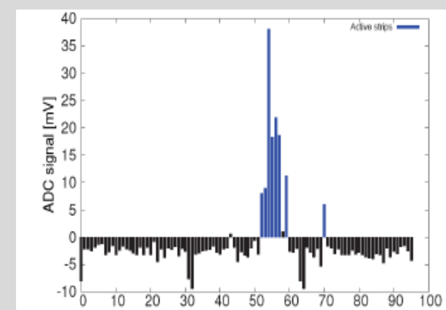
Mesh: pulse shape analysis.

temporal evolution of the event.

Strips: Topology, 2D pattern reconstruction.

3D information with AFTER electronics.





4. TPC properties

R&D on gas mixtures.

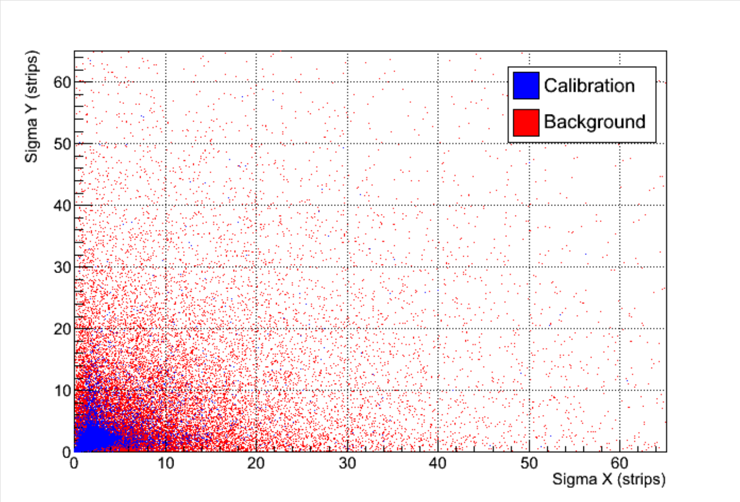
Improvement on chamber drift field.

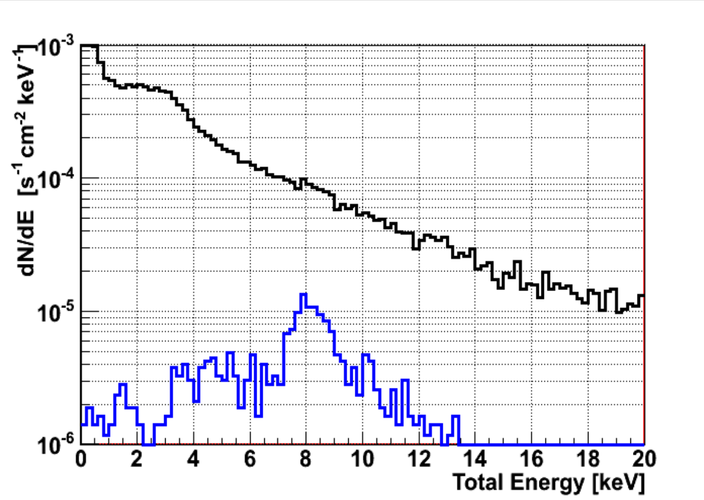
> **Strategies actively developed under the T-REX R&D project (Universidad de Zaragoza) funded by an ERC Starting Grant.**

Data analysis and discrimination:

Mesh pulse: Digitized by MATACQ card in 2500 samples at 1GHz (12-bit dynamic range)
→ Pulse-shape analysis (event time evolution)

Strips: strips charge integrated by Front End Gassiplex cards (10-bit value for each strip),
→ Cluster analysis (event topology)



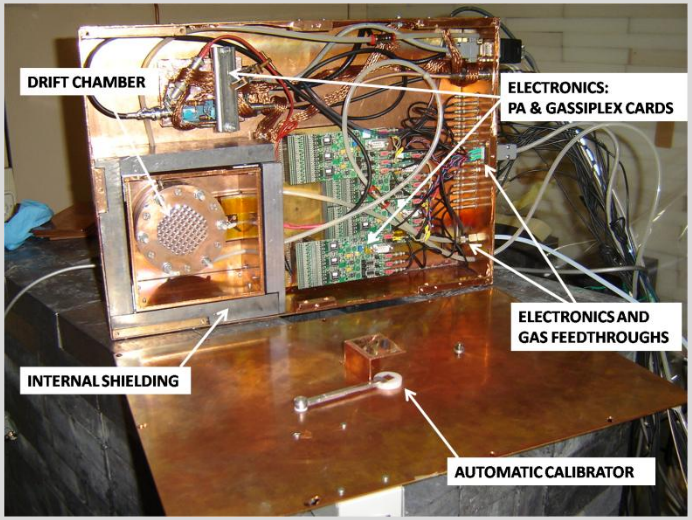


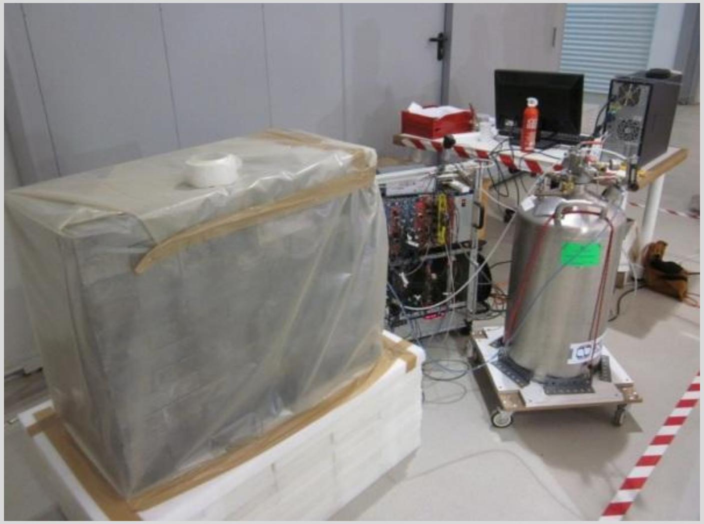
- Axion signature: X-ray event [1-10] keV → Point-like events.
- Daily ^{55}Fe calibrations define the characteristic parameters of X-ray like events.

Excellent discrimination capabilities. To be improved upgrading to AFTER Front End electronics.

Canfranc Underground Laboratory (LSC) measurements:

Situated in the spanish Pyrenees (under 2500 m.w.e.) → muon flux reduced by ≈ 10^4





Shielding: 4π x 10 cm Pb + 2.5 inner Cu

N_2 flux to avoid Radon

Internal components are radiopure

The main goal is to evaluate the contribution and background nature of CAST-MM:

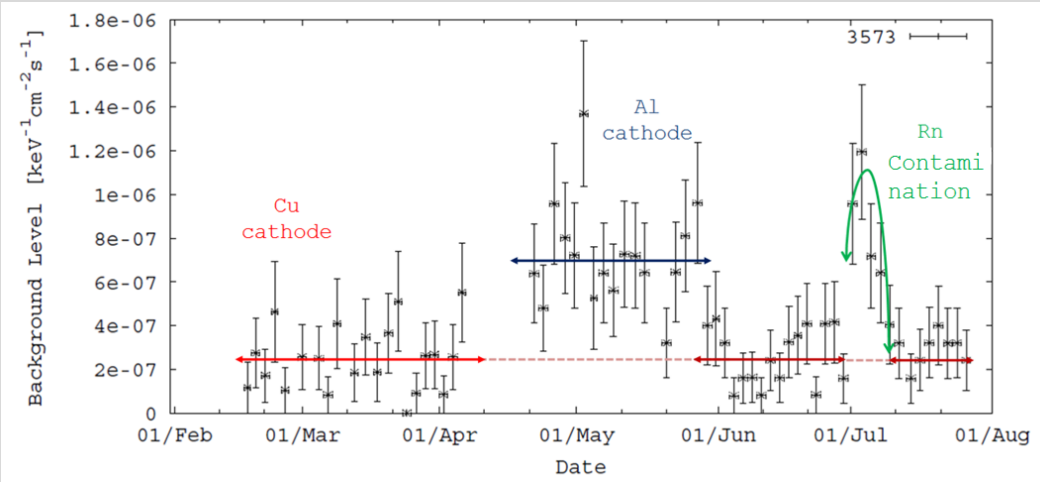
- Lead against external gammas.
- Polyethylene against neutrons.
- A nitrogen atmosphere against Radon emanations.

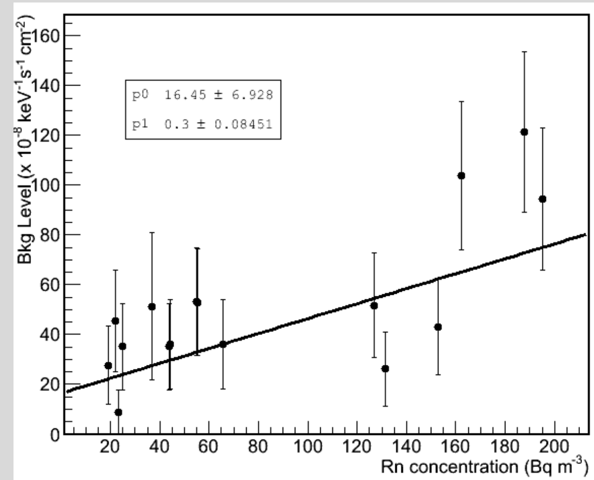
"CAST Microbulk Micromegas in the Canfranc Underground Laboratory"
Physics Procedia (2012) 478-482

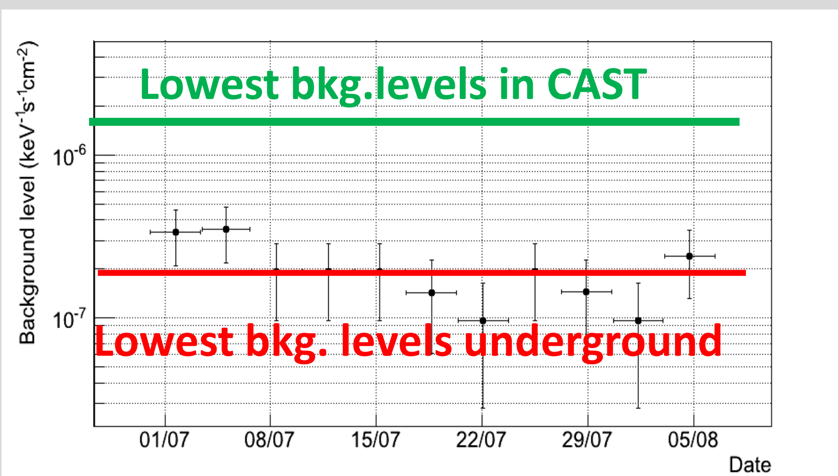
Muons contribution can be extracted from comparison with surface results.

Limits for the background related with the intrinsic radioactivity of the set-up can be obtained.

Canfranc Underground Laboratory (LSC) measurements:





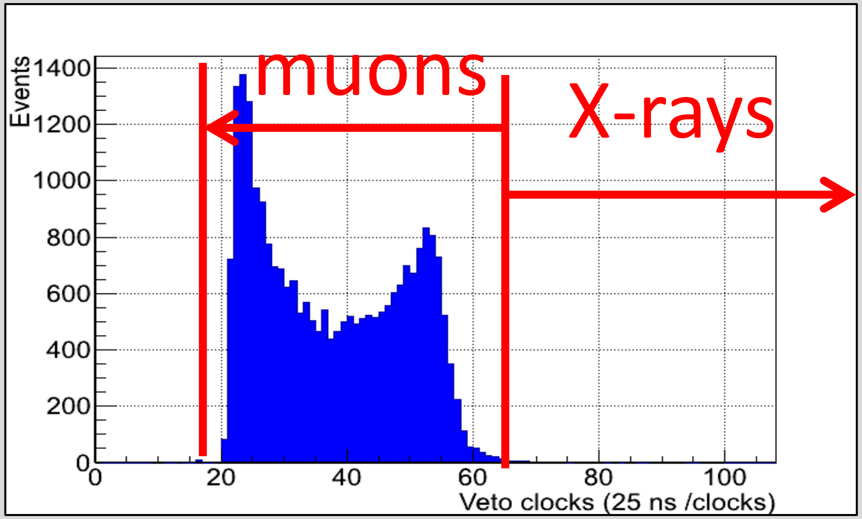


Different sources of background have been evaluated and quantified:

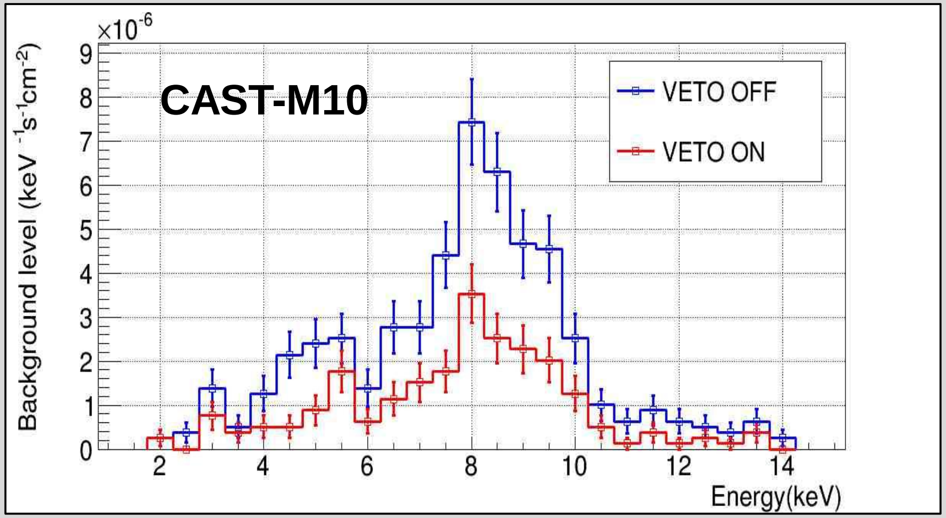
- **Aluminum cathode: ~ 5×10^{-7} keV^{-1} cm^{-2}s^{-1}. → need to use clean radiopure material close to the detector.**
- **Radon intrusion: ~ 3×10^{-9} keV^{-1} cm^{-2}s^{-1} /(Bq/m^3)**

Lowest background level achieved underground is ~10^{-7} keV^{-1} cm^{-2}s^{-1}. Around 10 times lower than nominal CAST level in similar shielding configuration. This deviation is a sign of a limiting factor present is surface.

Active shielding against cosmic muons:



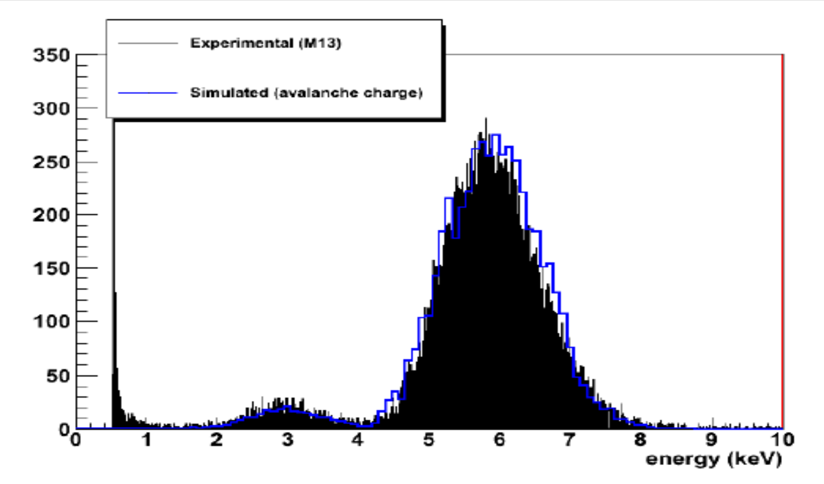
Time difference distribution between veto and mesh



Background spectrum

- The time difference between the veto signal and the Micromegas trigger is recorded → used in off-line analysis.
- Veto effect: reduce the fluorescence events induced by muons at 8 keV and 5 keV.
- 50% of background reduction with a non optimum veto (75% coverage) in CAST RoI.

Simulation to understand background sources:

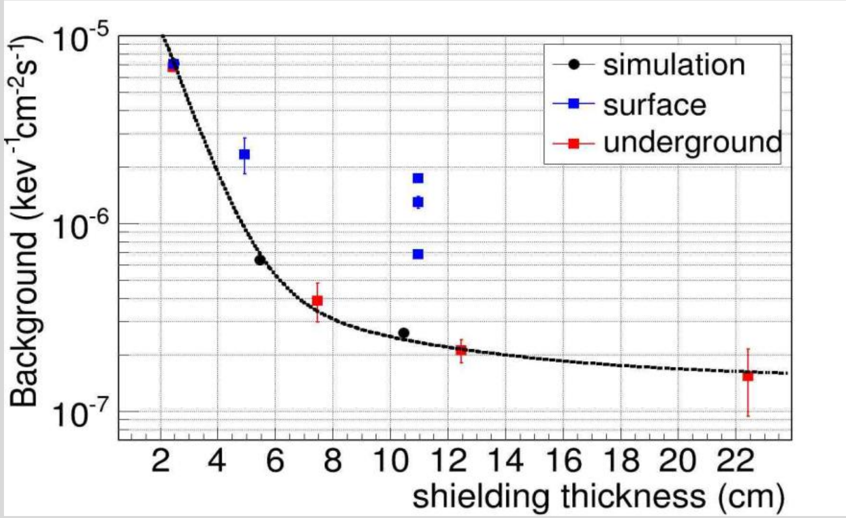


Experimental vs. simulation

Geant4 → ^{55}Fe γ and environmental γ

RESTSoft (Zaragoza)→ 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.



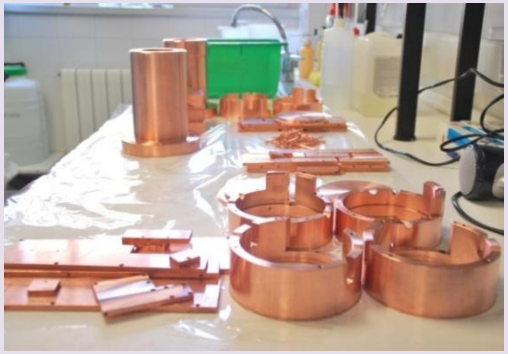
Background level vs. Shielding thickness

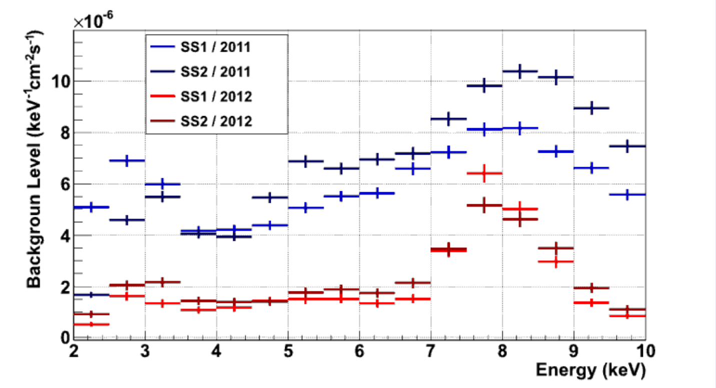
Underground vs surface: The background level at surface has an important contribution of cosmic muons.

This hypothesis has been confirmed by MonteCarlo simulations: The dependence of the background with the shielding thickness has been reproduced.

Background levels at CAST

2012 upgrade was the result of all the experience acquired in low background techniques:





Background level 2011 vs 2012

1. Low intrinsic radioactivity

- Low mass, radiopure materials (copper, teflon, kapton ...), carefully cleaned.
- All steel pieces replaced by copper to prevent [5-7] keV fluorescences.

2. Shielding

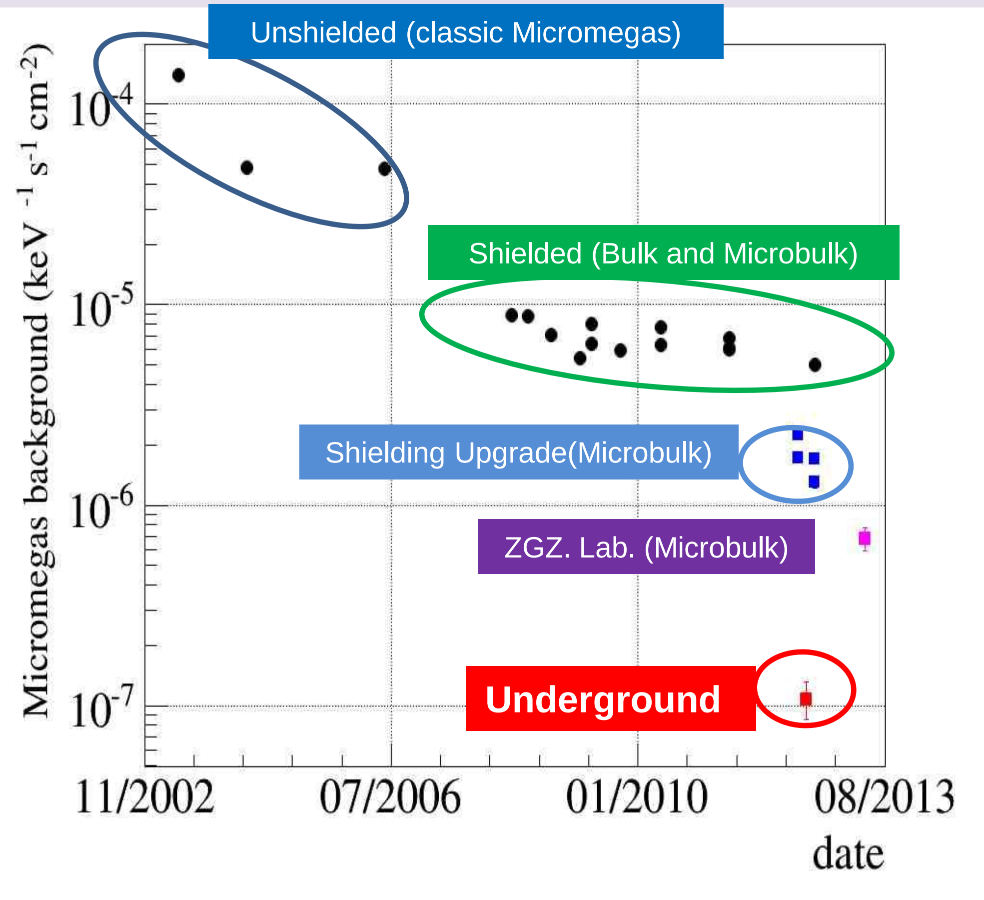
- More compact shielding and better solid angle closure.
- First attempt with a cosmic veto (40% coverage yield to ~ 25 % reduction in background level)

3. Detectors

- New microbulk detectors with improved performance and better discrimination power.

Background levels at CAST

Micromegas detectors at CAST have experimented a background reduction of ≈2 order of magnitude from the beginning of the experiment



Upgrades:

2007 installation of the first shielding:
5 mm of Cu + 2.5 cm of Pb
Improving the background 4-5 times

2012 shielding upgrade:
1cm of Cu + 10 cm of Pb + muon veto
Achieving a reduction of the background in a factor 4-5

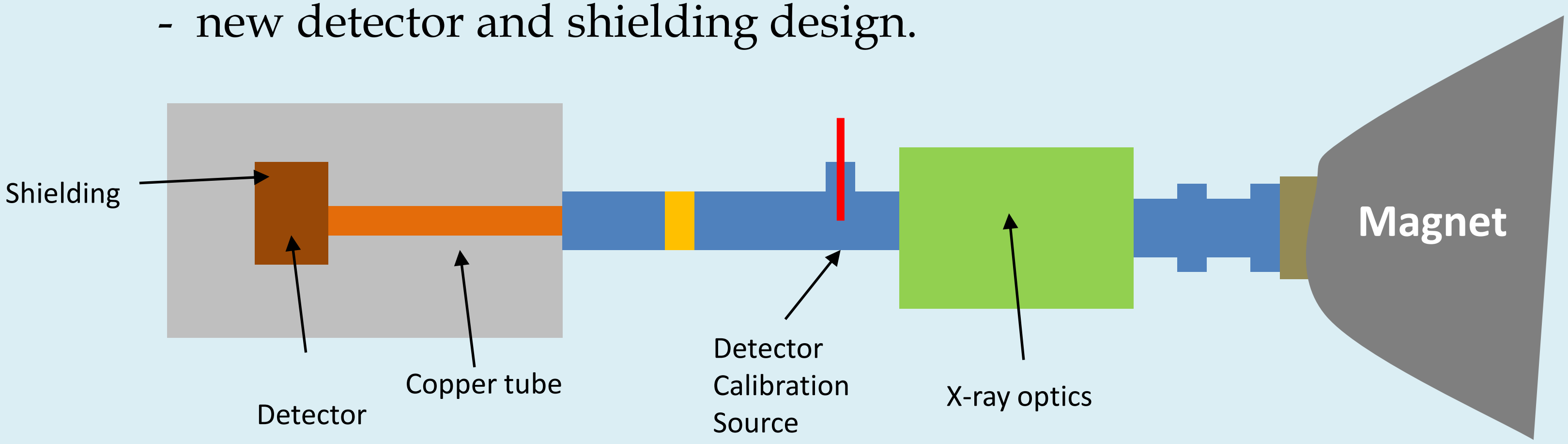
Latest Micromegas technology and shielding upgrades have consistently yielded better background levels over the years.

Further improvements are expected in the coming campaigns.

A paper summarizing all this R&D towards background supression is in preparation.

CAST will revisit vacuum phase in 2013/14:

- new x-ray optics will be installed in the Sunrise Micromegas line +
- new detector and shielding design.



Summary of improvements:

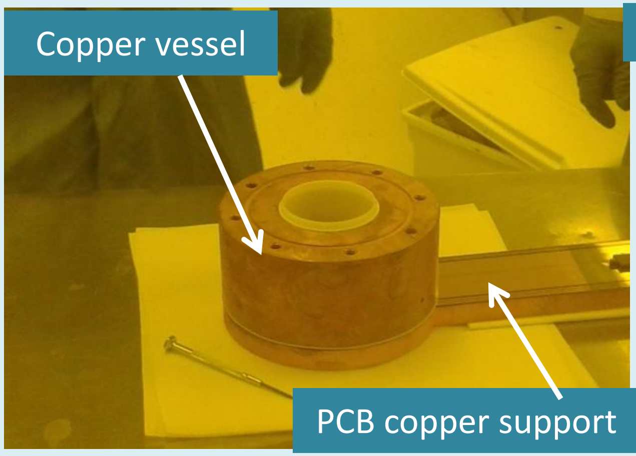
- New X-Ray telescope → Best signal-to-noise ratio, increase of sensibility

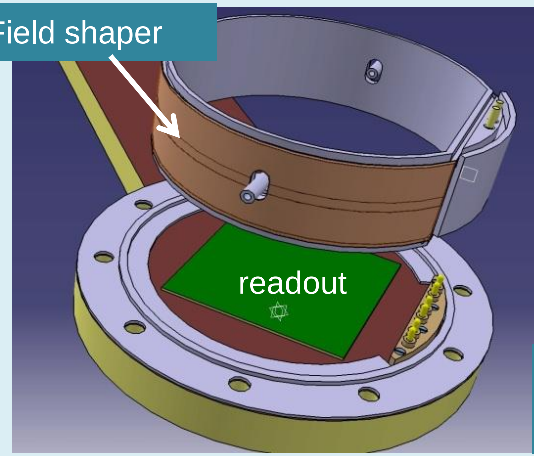
- New shielding design:
    - lead thickness (~ 10 cm) and use of radiopure materials.
    - Custom made cosmic scintillator with ~100% coverage to be installed.

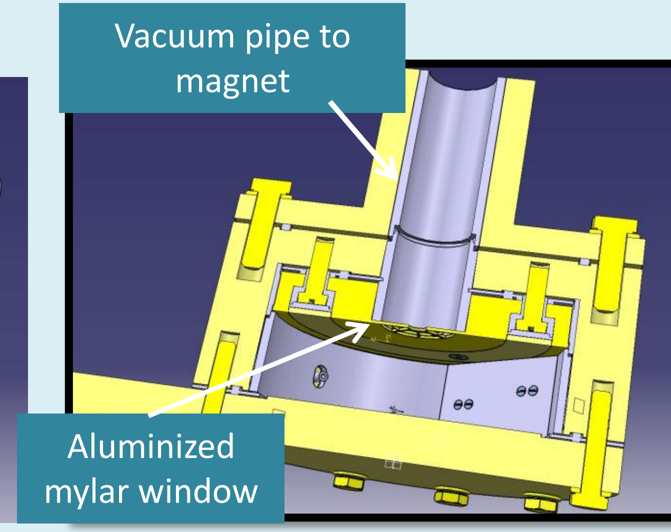
- New *microbulk* detector and AFTER electronics.

Prospects

New detector design and first tests

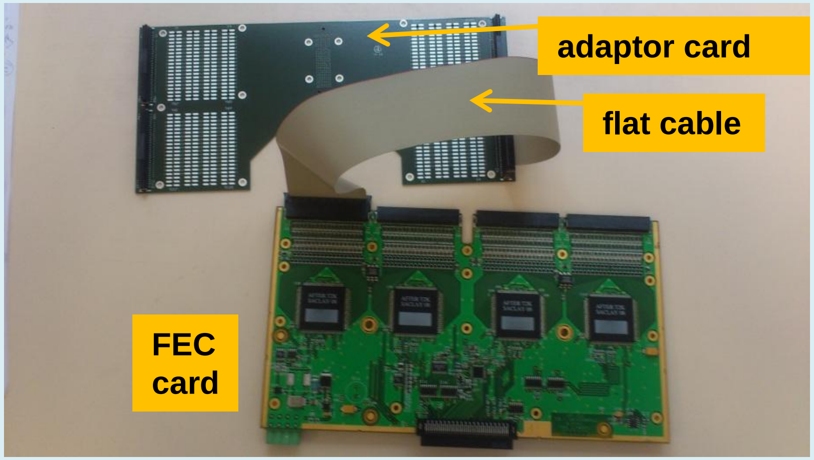


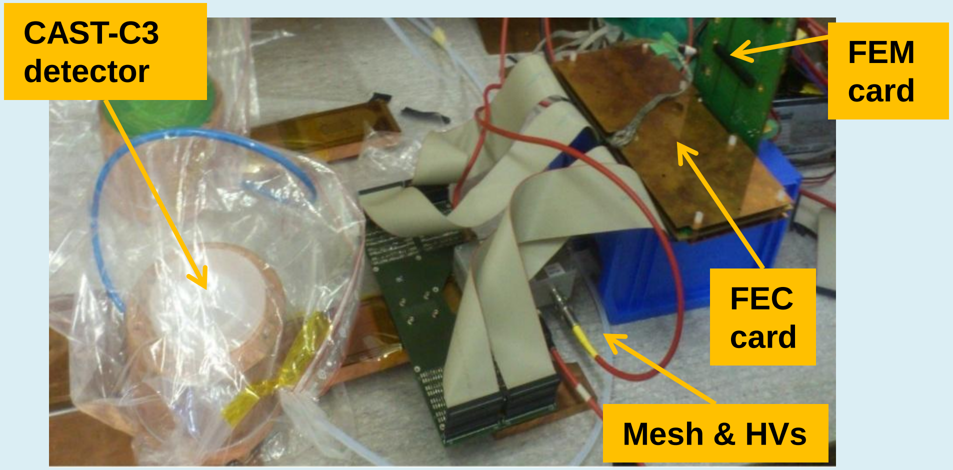




- First new type *Microbulks* and body chambers already manufactured and assembled.
- **Main novelties**: printed rings on kapton field shaper, body and support completely made out of copper.
- Smaller window for x-rays → better shielding closure.
- No single strip connected to mesh. A couple of strips in short-circuit.
- All readout surface is active: 6x6 cm^2 (120x120 strips)
- Mesh transparency much better than previous CAST-MM (big plateau)
- The energy resolution at 5.9 keV is around 16% FWHM in mesh and strips without any selection criteria applied.

New electronics: AFTER based electronics (Saclay)

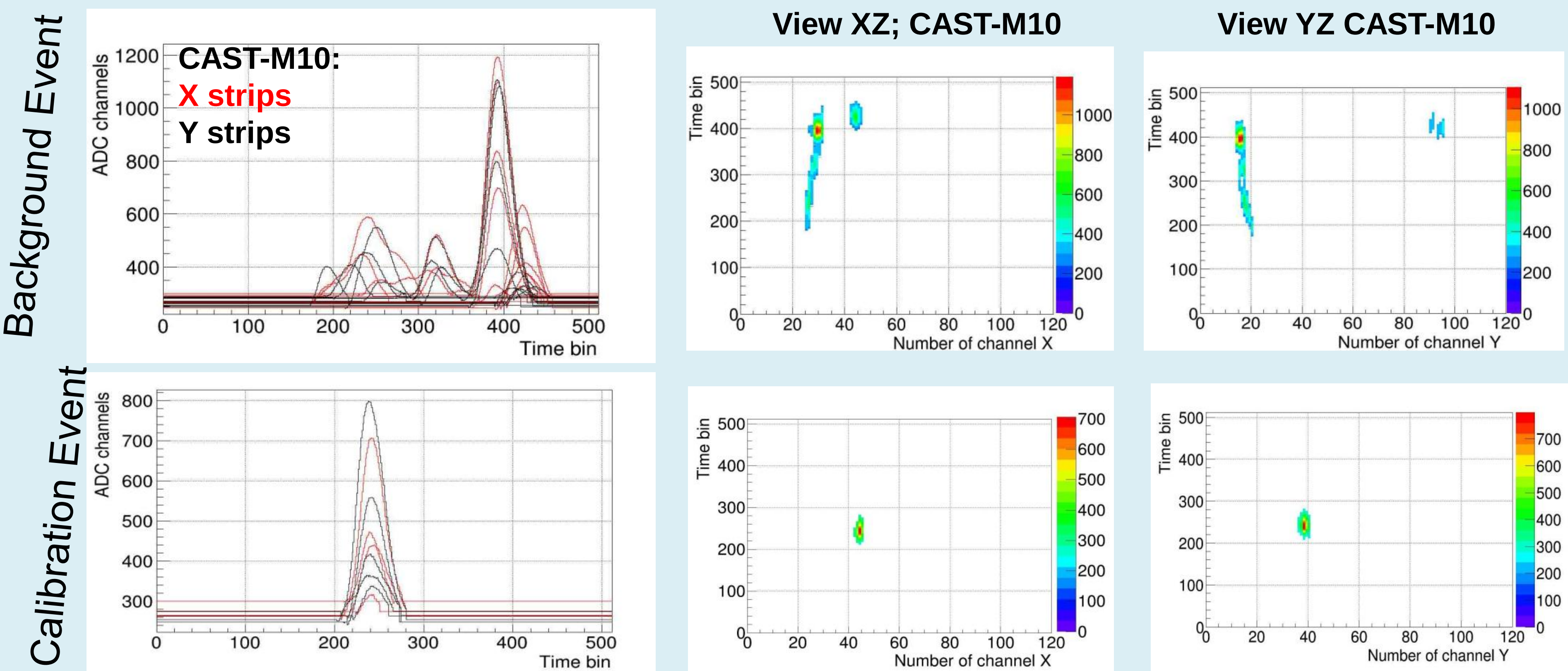




- Modular, fast electronics which amplifies and digitizes signals.
- Sampling time: 100 MHz (10 ns). Shaping time: 100-1000 ns.
- Number of samples: 512. Input capacity (gain): 120-360 pF.
- Basic component is a FEC card, which contains 4 ASIC chips. Each ASIC digitizes 72 channels (288 channels each card).
- A transition card was designed to take the 120x120 strips to 4 ERNI connectors.
- 4 flat cables take signals to one FEC card.
- An external trigger is created from the mesh pulse.

Thanks to D. Calvet, F. Druillole and A. Le Coguie for helping with the electronics

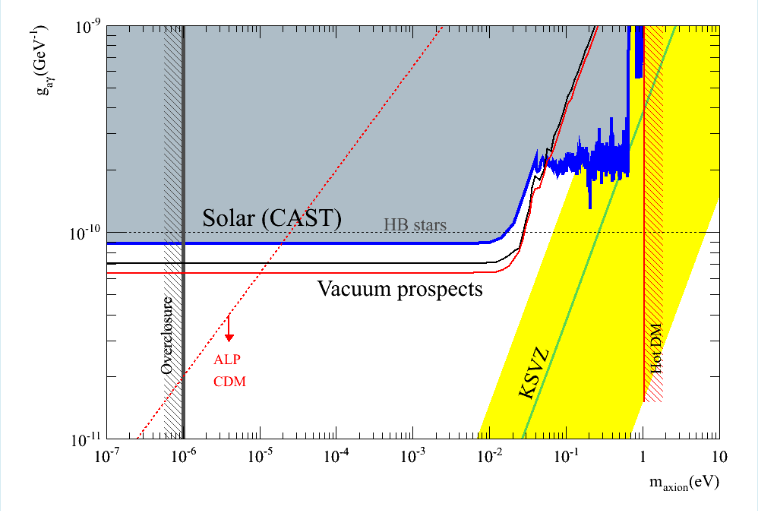
New electronics: AFTER based electronics (Saclay)



- Strips pulses are digitized: **Pulse-shape analysis** extended to every strip.
- XZ and YZ projections are reconstructed using the signal induced in each strip and the detector decoding.
- The charge in a time bin (or z-position) is the pulse height.
- We can now extend the Cluster / Topological analysis also to the z-direction.
- Increase in discrimination power is expected. To be installed in CAST in august 2013.

Prospects

CAST could improve the vacuum result down to $g_{a\gamma} < (5.9 – 6.3)\text{x}10^{-11}$ GeV^{-1}

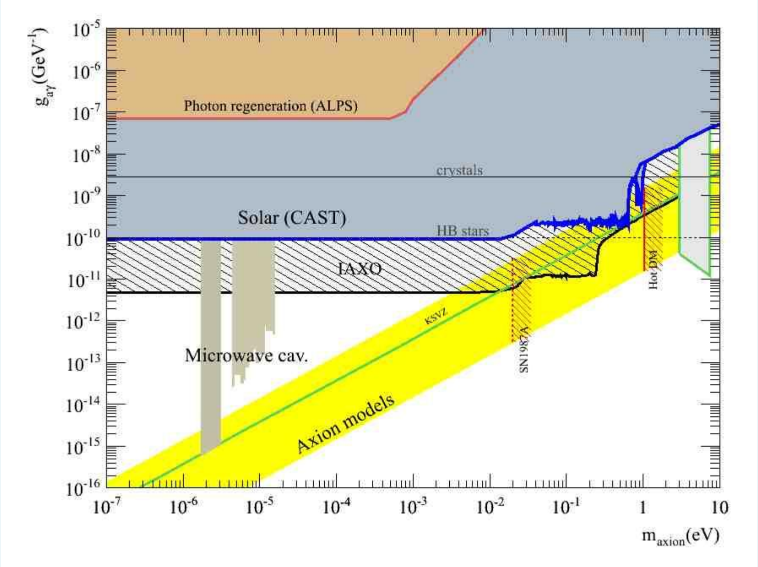


Two assumptions of background have been computed:

- Pessimistic (current levels):
  1.5· 10^{-6} c/keV/cm^2/s (solid black line)

- Optimistic:
  8· 10^{-7} c/keV/cm^2/s (solid red line)

Long term prospects: IAXO



An ultra-low background Micromegas is required for IAXO

Goal: at least 10^{-7}, down to 10^{-8} c/keV/cm^2/s

Factor ~18 better in $g_{a\gamma}$

A big part of the QCD axion model region could be explored in the next decade.

Summary and conclusions

- Acquired experience in low background techniques and applied to Axion physics in CAST Experiment.
- Intensive R&D towards background suppression in Micromegas detectors still on-going.
- Underground and surface tests + simulations → deep understanding of background origins and develop strategies to mitigate it.
- 2013 CAST Micromegas upgrade will contain all the lessons extracted from this research program.
- These results encourage the use of Micromegas readouts for IAXO, that aims to improve CAST sensitivity by more than one order of magnitude.

Thank you

New detectors characterization in Ar+2.3% iC_4H_{10} at 1 bar

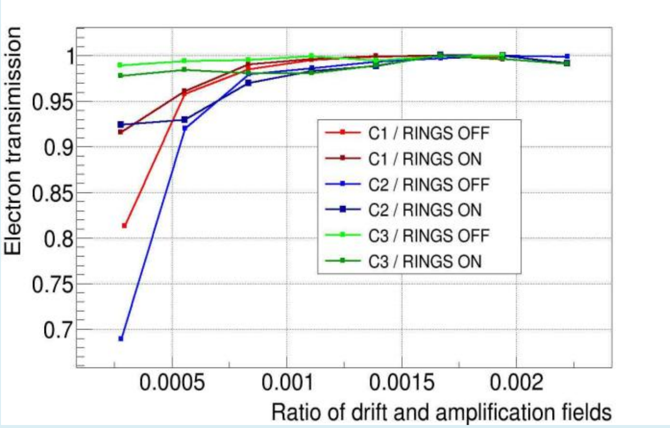
- No single strip connected to mesh. A couple of strips in shortcut among them.

- All readout surface is active: 6x6 cm^2 in 120x120 strips.

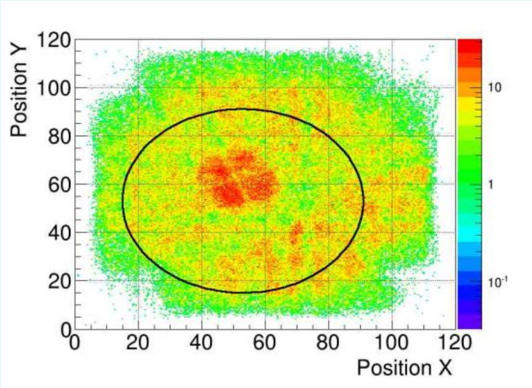
- Mesh transparency much better than previous CAST detectors (big plateau).

- A gain of $2x10^3$ is reached before the spark limit.

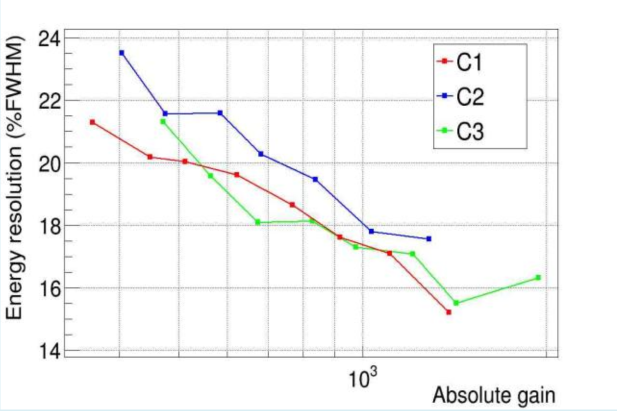
- The energy resolution at 5.9 keV is around16 %, both for the strips charge and mesh pulse amplitude, without having applied any selection criteria.



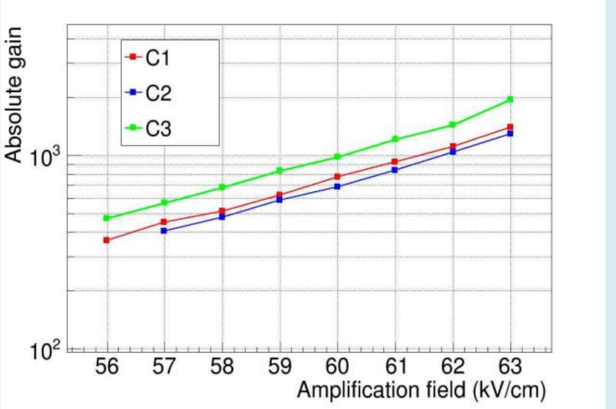
Electron transmission vs. fields ratio



CAST-C2 detector hitmap

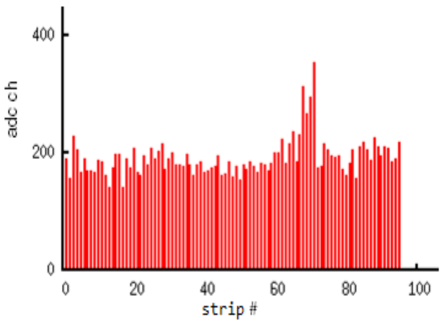


Energy resolution vs. gain



Gain vs. amplification field

Gassiplex electronics
(currently at CAST)



Only 1 value for every strip

AFTER electronics
(CAST upgrade 2013)