Low Background Micromegas

for CAST and IAXO

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Outline

- Micromegas technologies
- Micromegas in CAST
- Towards lower background levels
  - Simulations
  - Tests at surface
  - Tests underground
  - Radiopurity
  - New designs
- Low threshold possibilities
- Summary

Micromegas principle of operation

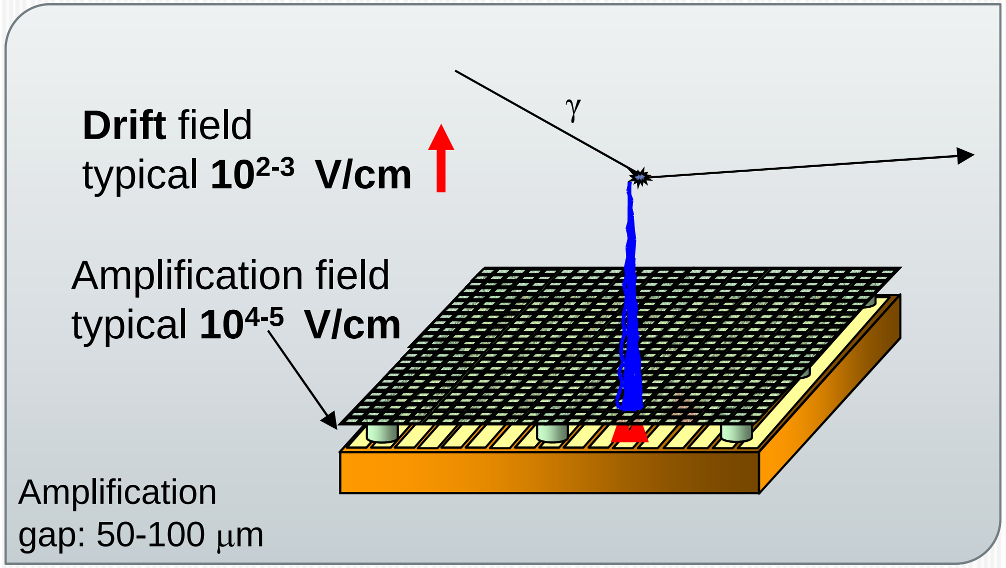
Two-region gaseous detector:

Conversion region

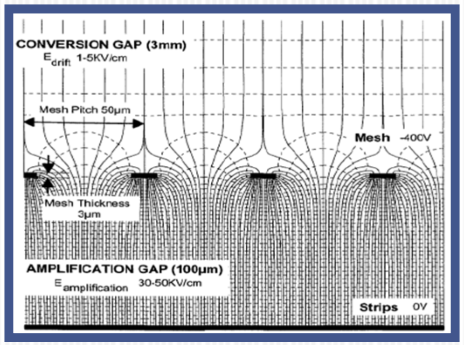
- Primary ionization
- Charge drift

Amplification region

- Charge multiplication
- Readout layout
  - Strips (1or 2 D)
  - Pixels



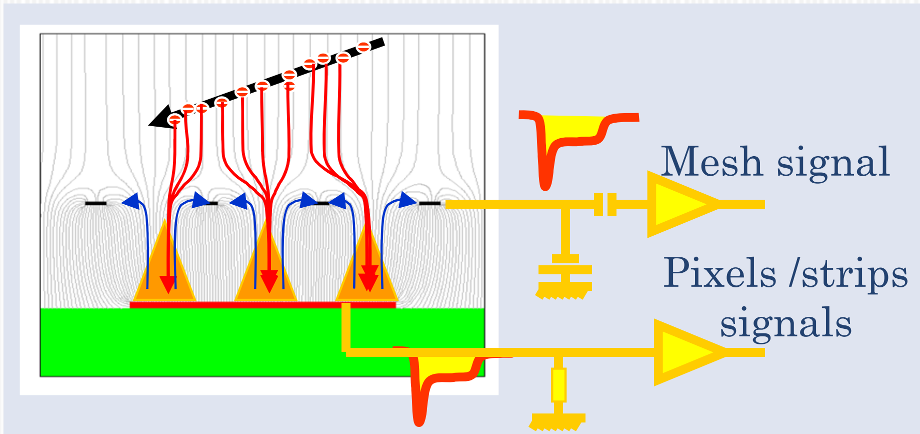
Separated by a Micromesh:
Very strong and uniform electric field



Giomataris et al. (1996)

Advantages:

- Simplicity
- Granularity
- Homogeneity
- Large areas
- …



Micromegas technologies

Bulk & microbulk techniques developed for all-in-one fabrication

- Ease of operation
- Large areas

See also NIM A 604: 15-19, 2009

BULK
Robust
Mature
Very large areas available (2 m^2)

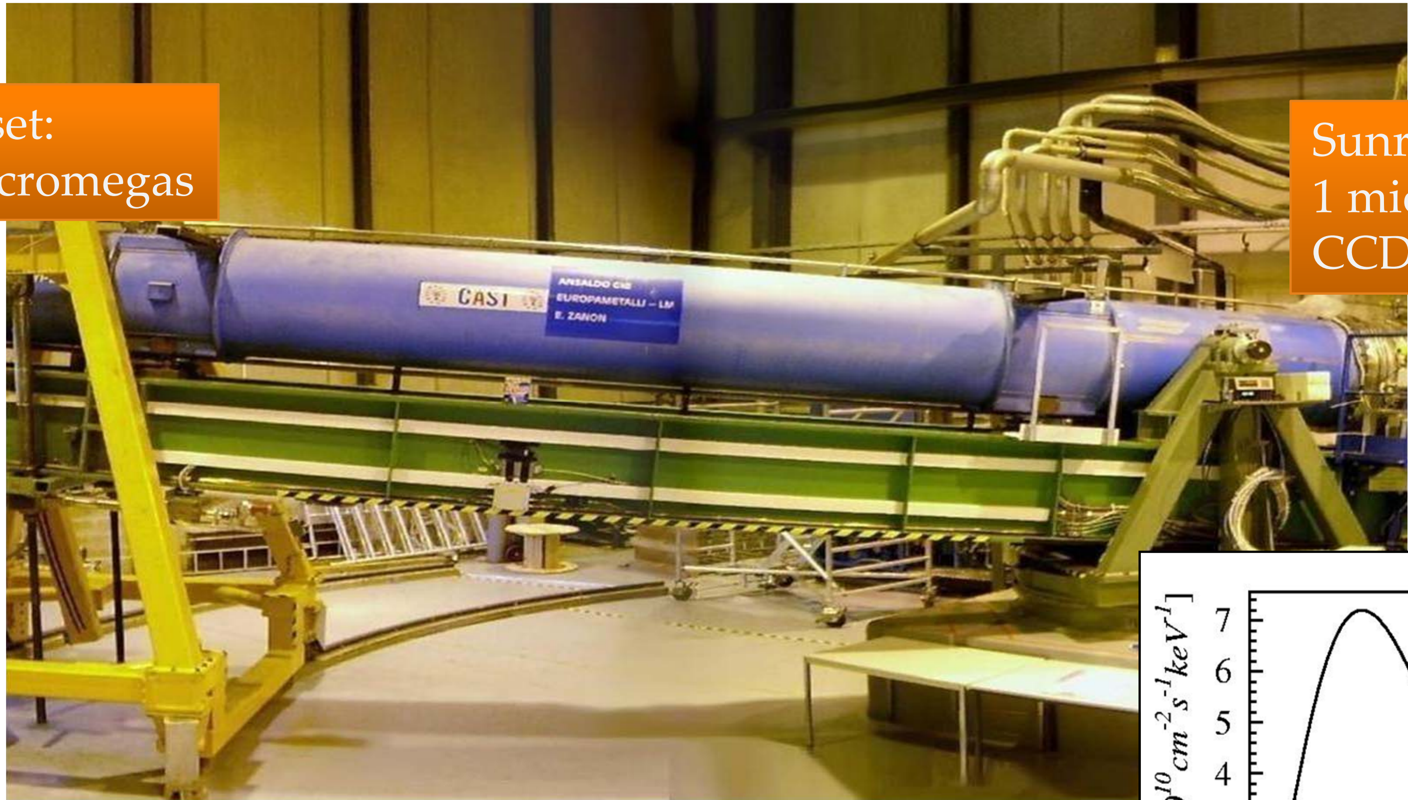
MICROBULK
Higher homogeneity
Light weight, radiopure

See also 2010 JINST 5 P02001

Micromegas detectors in CAST

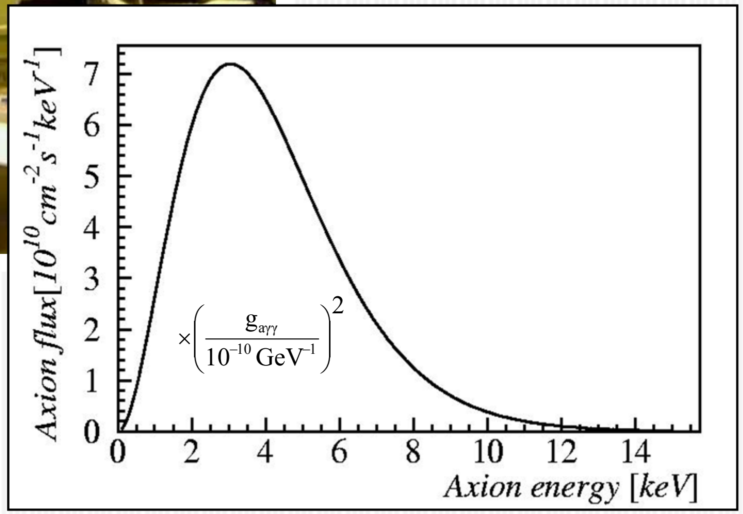
History
Latest performance

CAST



Sunset:
2 micromegas

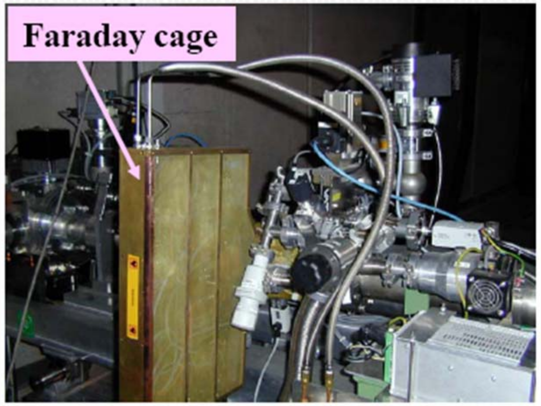
Sunrise:
1 micromegas
CCD + X-ray



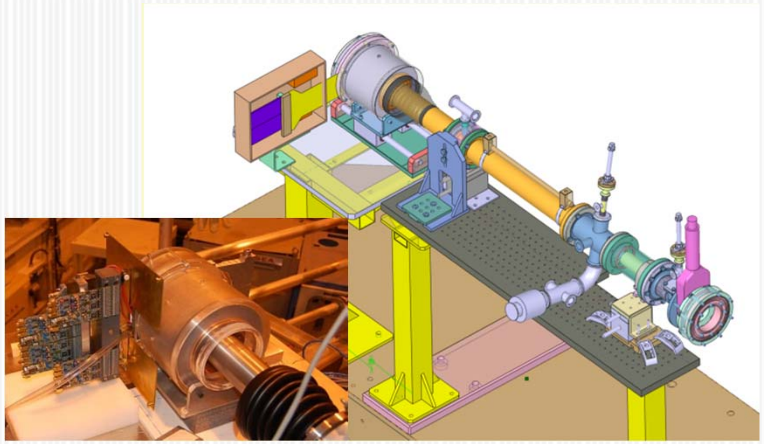
The CAST Magnet featuring
3 microbulk micromegas
a CCD-X-ray focusing device system

Micromegas in CAST (i)

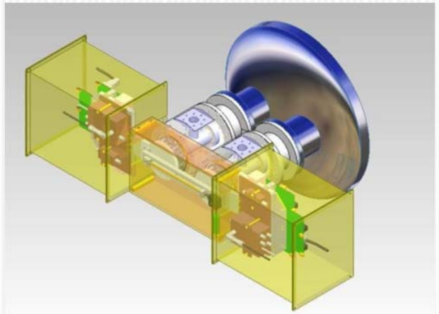
2002-2005: a *conventional* and *unshielded* Micromegas

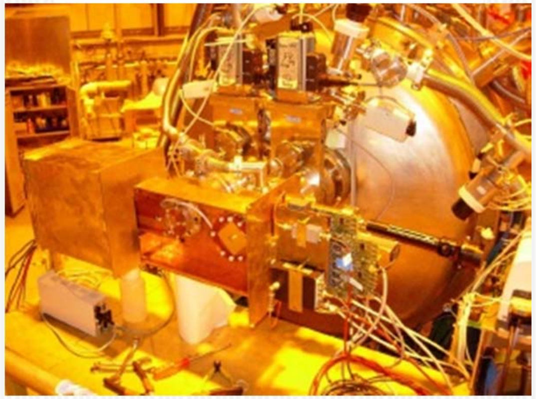


2008: Moved to a *microbulk* after the design of the new sunrise line (shielding, X-ray optics)



2008: two *microbulks* replaced the TPC at sunset



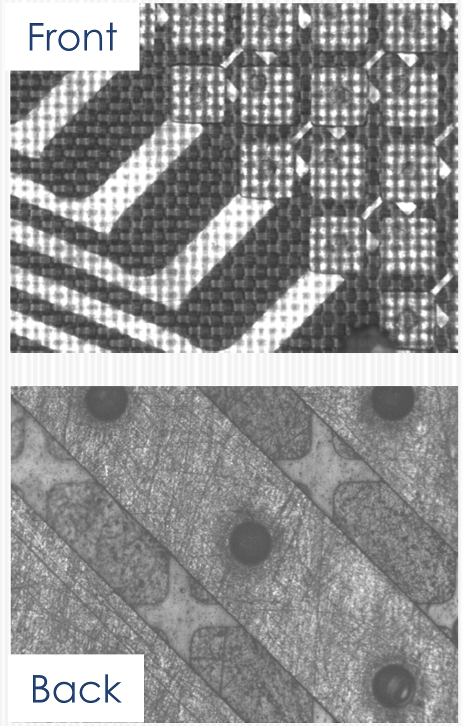


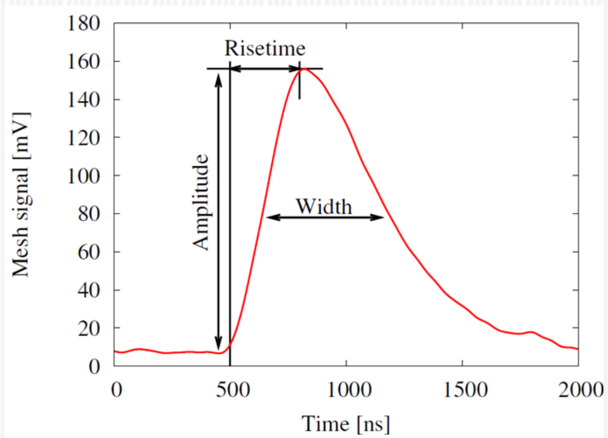
Since 2010 all the micromegas at CAST are of the *microbulk* type

Micromegas in CAST (ii)

- CAST microbulk Micromegas exploit 3 strategies:
  - o Low intrinsic radioactivity:
    - Light mass
    - Clean materials (copper, plexiglass,…)
  - o Signal topology : offline discrimination
    - 2D readout pattern
    - information from mesh pulse
  - o Shielding
    - 2.5 cm archaeological lead
    - 0.5 cm inner copper
    - Clean inner atmosphere by N_2 flushing.

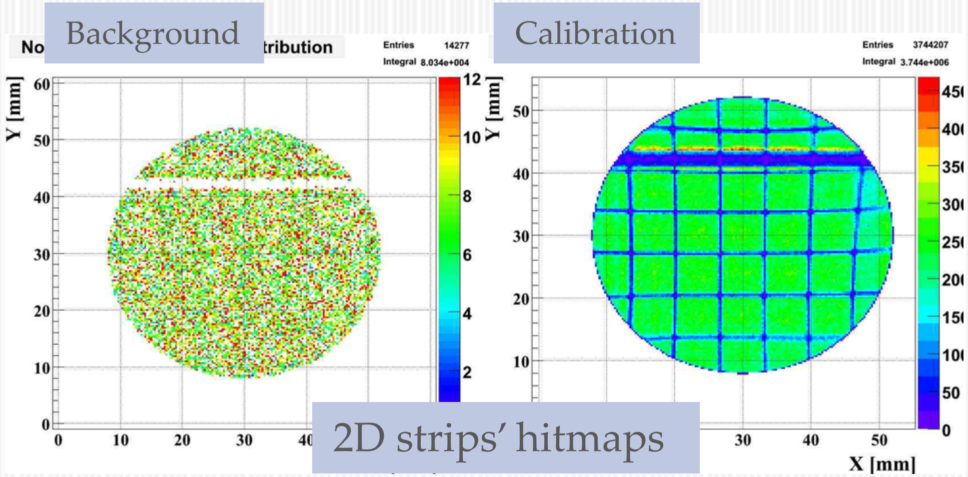
Readout 2d design:

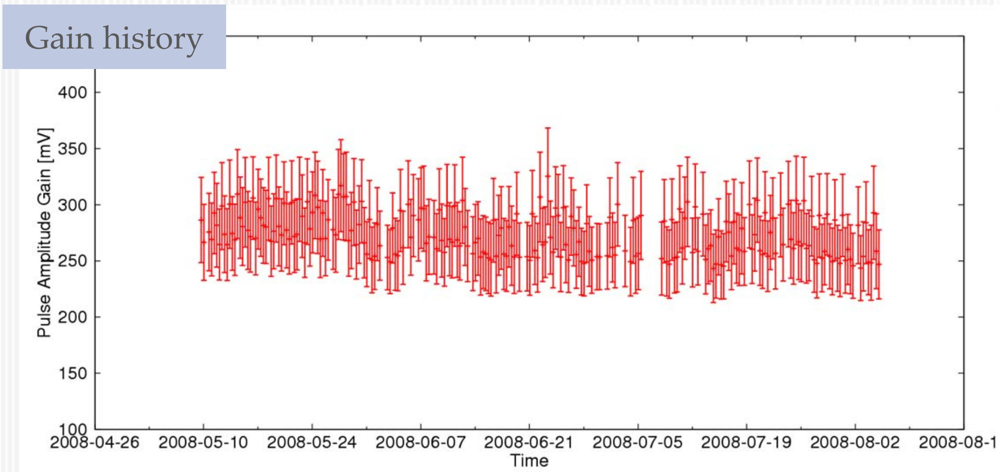


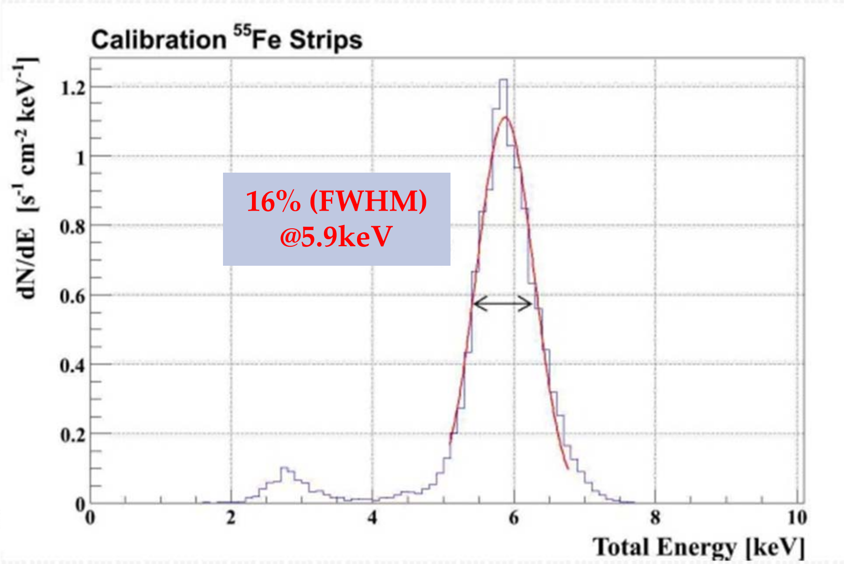


Micromegas in CAST (iii)

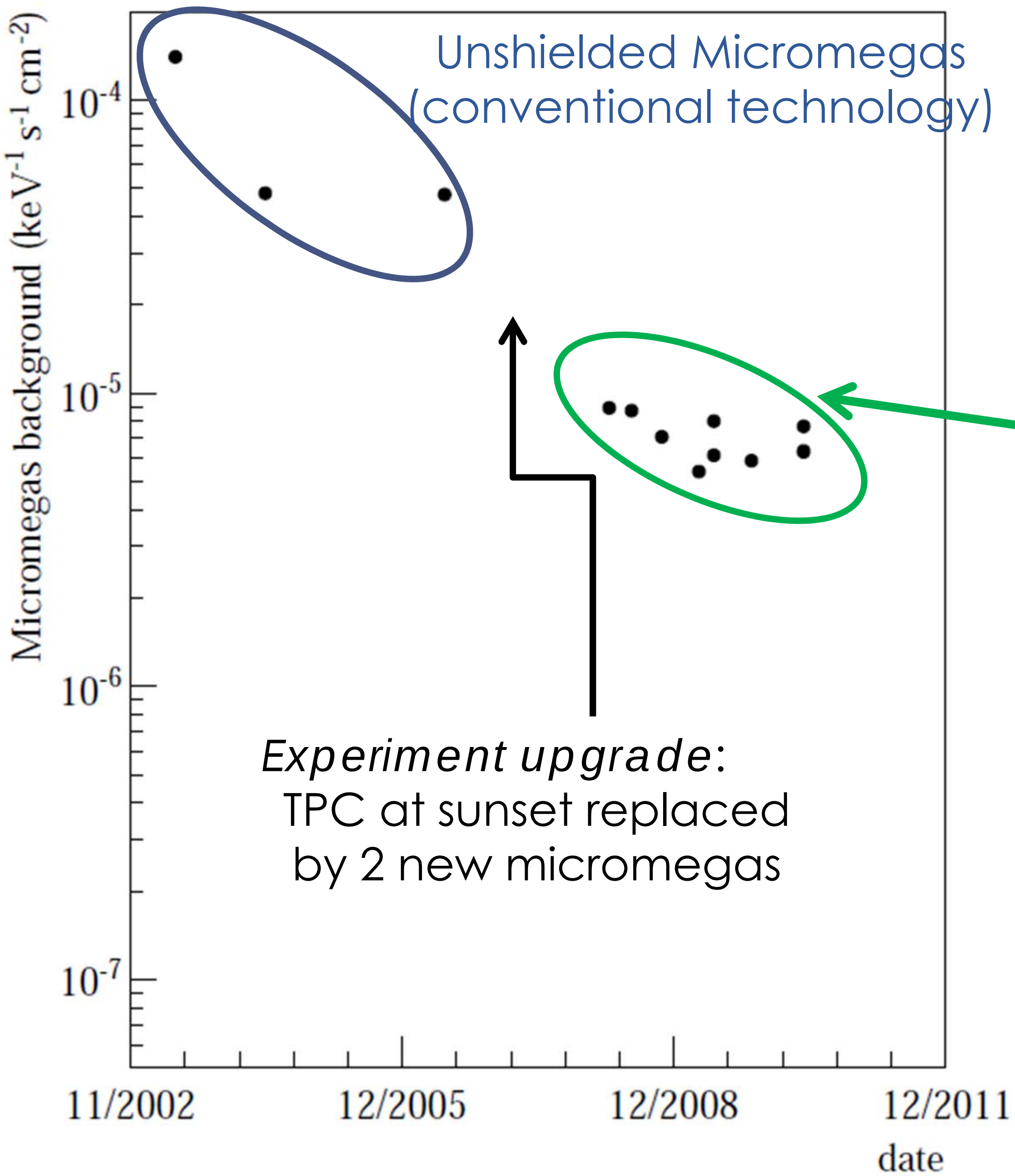
- Space resolution
- Time resolution
- Spatial homogeneity of gain
- Gain very stable in time
- Very good energy resolution
- High granularity







mM Background history in CAST



Nominal values during data taking campaigns

Shielded Micromegas
(bulk and microbulk technology)

~5x10^{-6} c/keV/s/cm^2

Micromegas for long time operation: **reliability** and **stability**

Towards lower background levels

Simulations

Tests underground

Points to be addressed

- Current MM background in CAST: **~5x10^{-6}** c/keV/cm^2/s (2-7keV)
- Goal for IAXO: **10^{-7}** c/keV/cm^2/s to **10^{-8}** c/keV/cm^2/s if possible

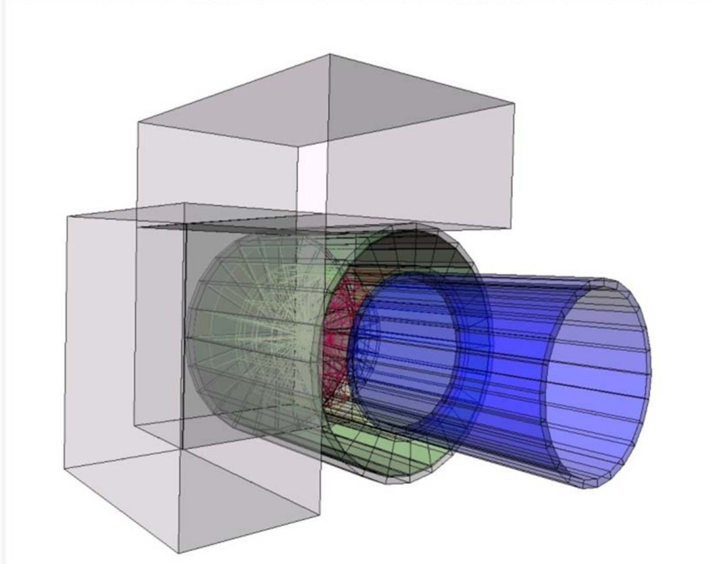
- Points to be addressed to assure lower level of backgrounds

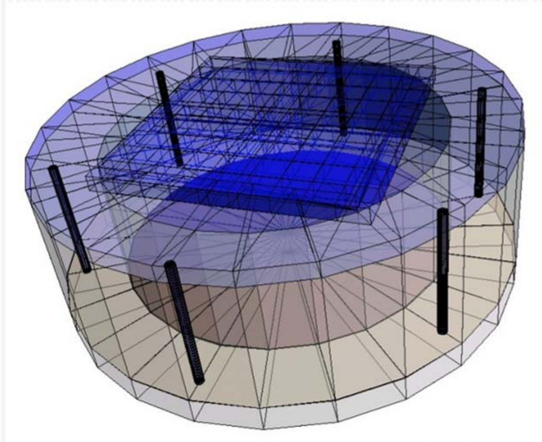
  - Simulations: Construct a background model
  - Tests with different shielding configurations
    - At surface
    - Underground
  - Radiopurity Issues: intrinsic radioactivity

- Study the possibility of a focusing device

A. Simulation tools

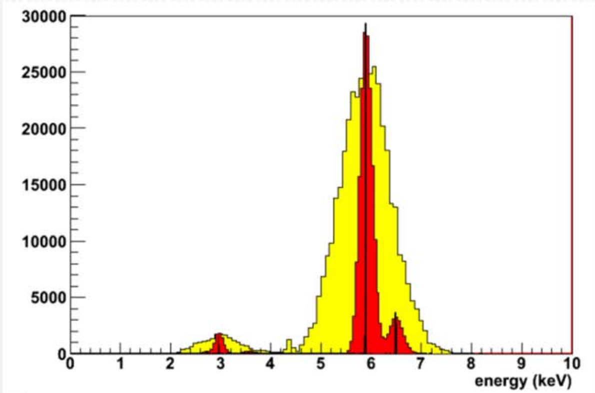
- To obtain a background model describing the setup:
  - Accurate description of the geometry
  - Implementation of the Physics
  - Addition of the electronics' chain response
  - Identification of the background sources



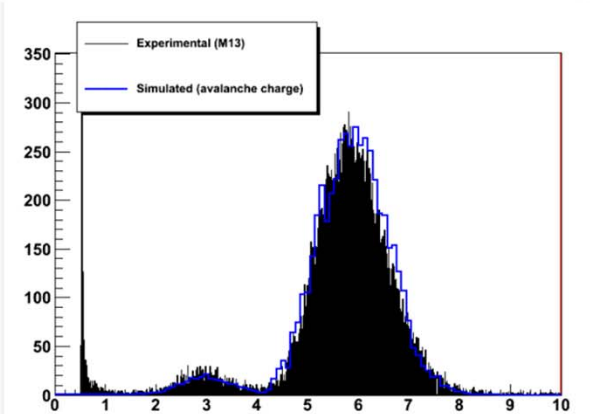


Simulations

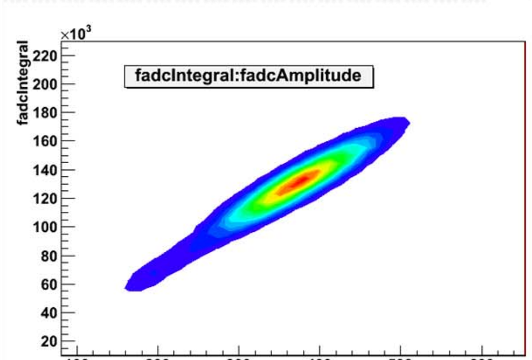
- Particle transport, Energy deposition
- Primary charge generation, Diffusion
- Drift, charge amplification, charge collection in strips



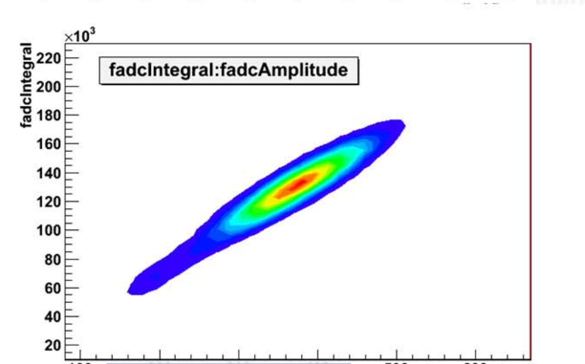
- Remarkable agreement between the simulated spectrum with experimental data taken with a ^{55}Fe source in Ar + 2% Iso



- Adding the electronic chain response we obtain the observables in the analysis and can
  - **apply the analysis routines**
  - **make a direct comparison with data**



Experiment



Simulation

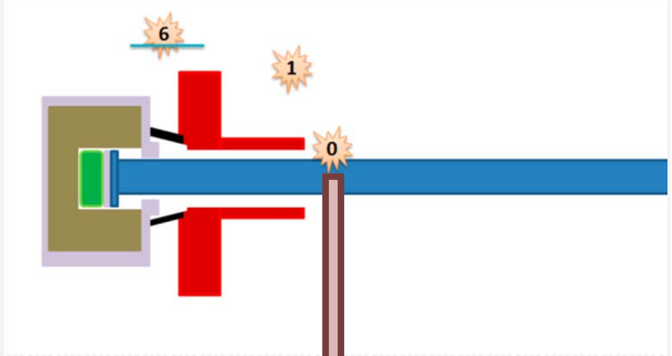
Simulations

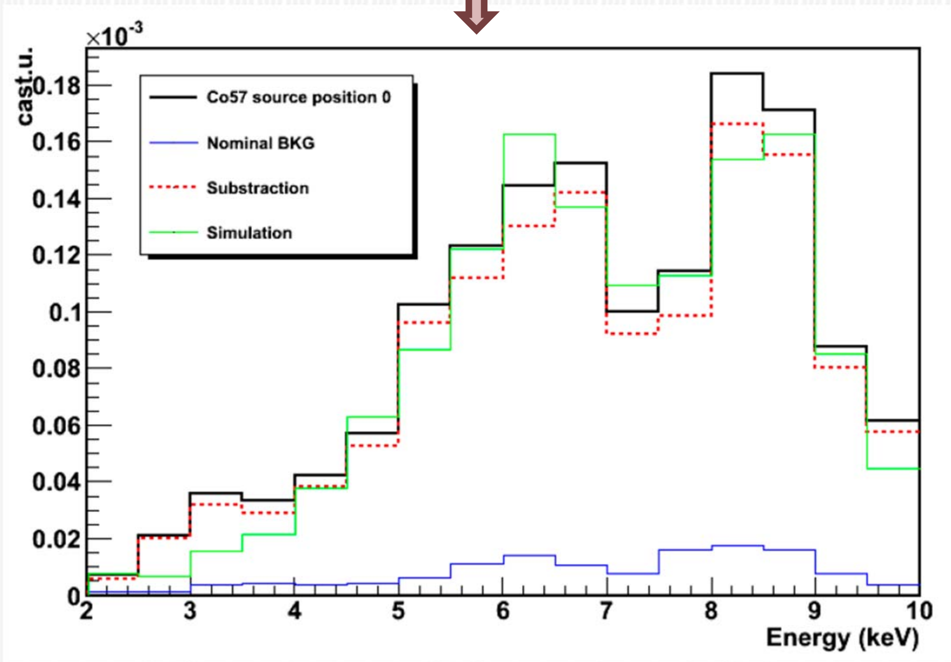
- Important test:
  - o Simulations of an *external gamma* background reproduce experimental data.
  - o Tests in situ at CAST with an intense ^{57}Co source at different positions

- Confirmation: agreement between the expected from simulations and the observed spectra

- To implement:
  - o Internal radioactivity
  - o Effect of cosmics (maybe)

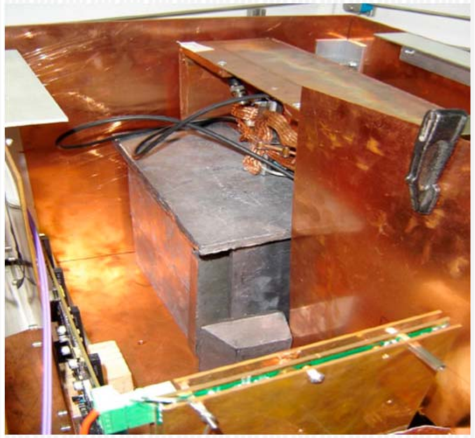
Example of source positions around the SRMM at CAST



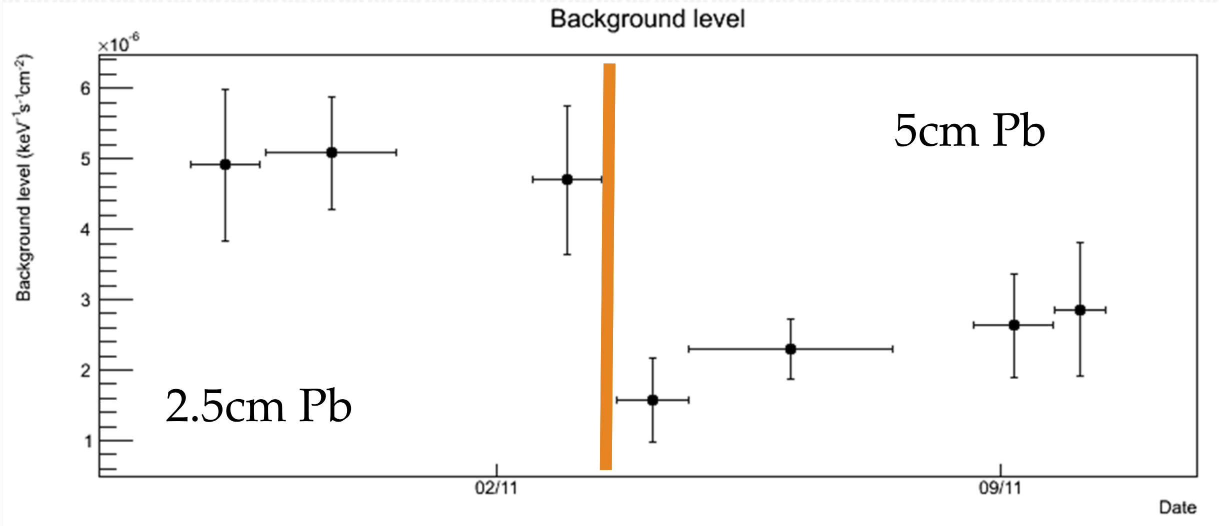


B1.Tests at surface

- An old CAST micromegas while at CAST in 2008:
  - o 2.5cm Pb, 1.4 bar
  - o Levels of 6 x10^{-6}c/keV/cm^2/s
- First thought: check at lab a replica of the setup with a 4π shielding of 2.5cm and 5cm Pb
  - o two years and several interventions later, at 1bar



$5x10^{-6}$c/keV/cm^2/s $2.3x10^{-6}$c/keV/cm^2/s



B2.Tests Underground

Going underground means:

- A 10^4 reduction factor for muons
- Stable environmental conditions regarding T, P and humidity
- Well-known environmental gamma radiation

In combination with the simulations can get a

↳New detector design

At Canfranc

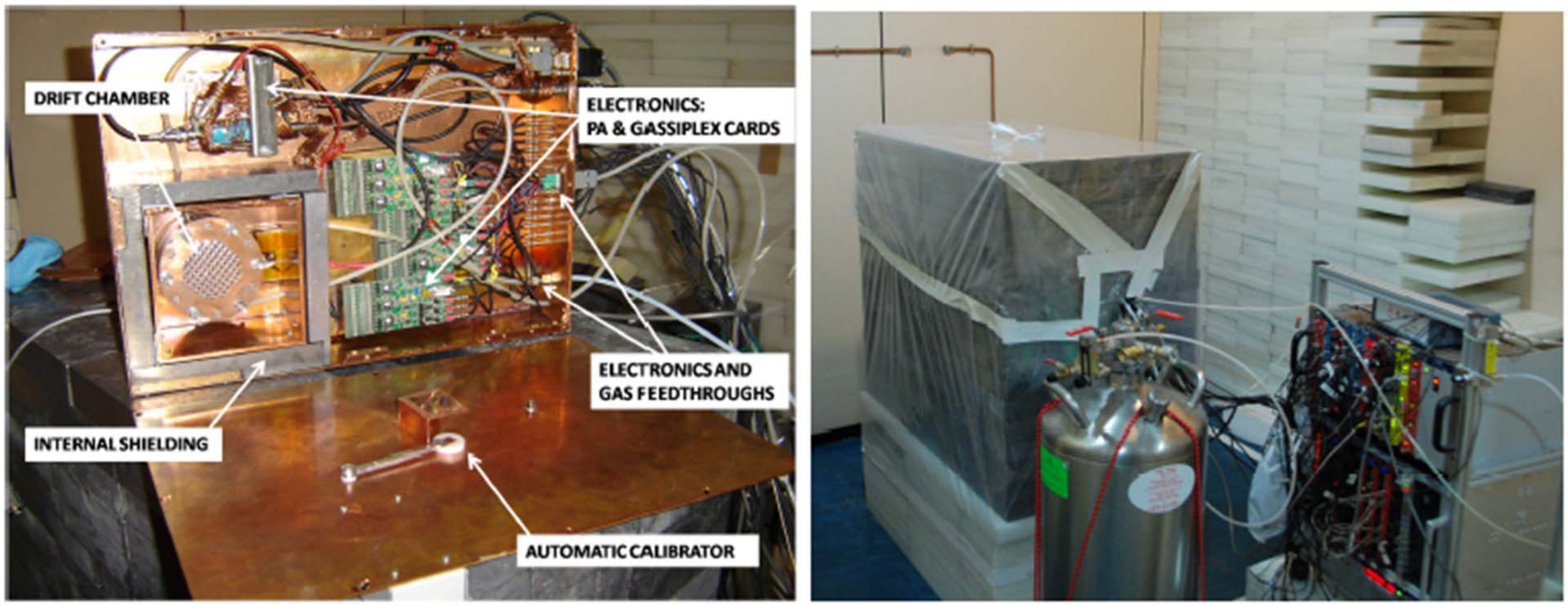
Tobazo Peak at the Spanish Pyrenees.

Depth: 2500 m.w.e.

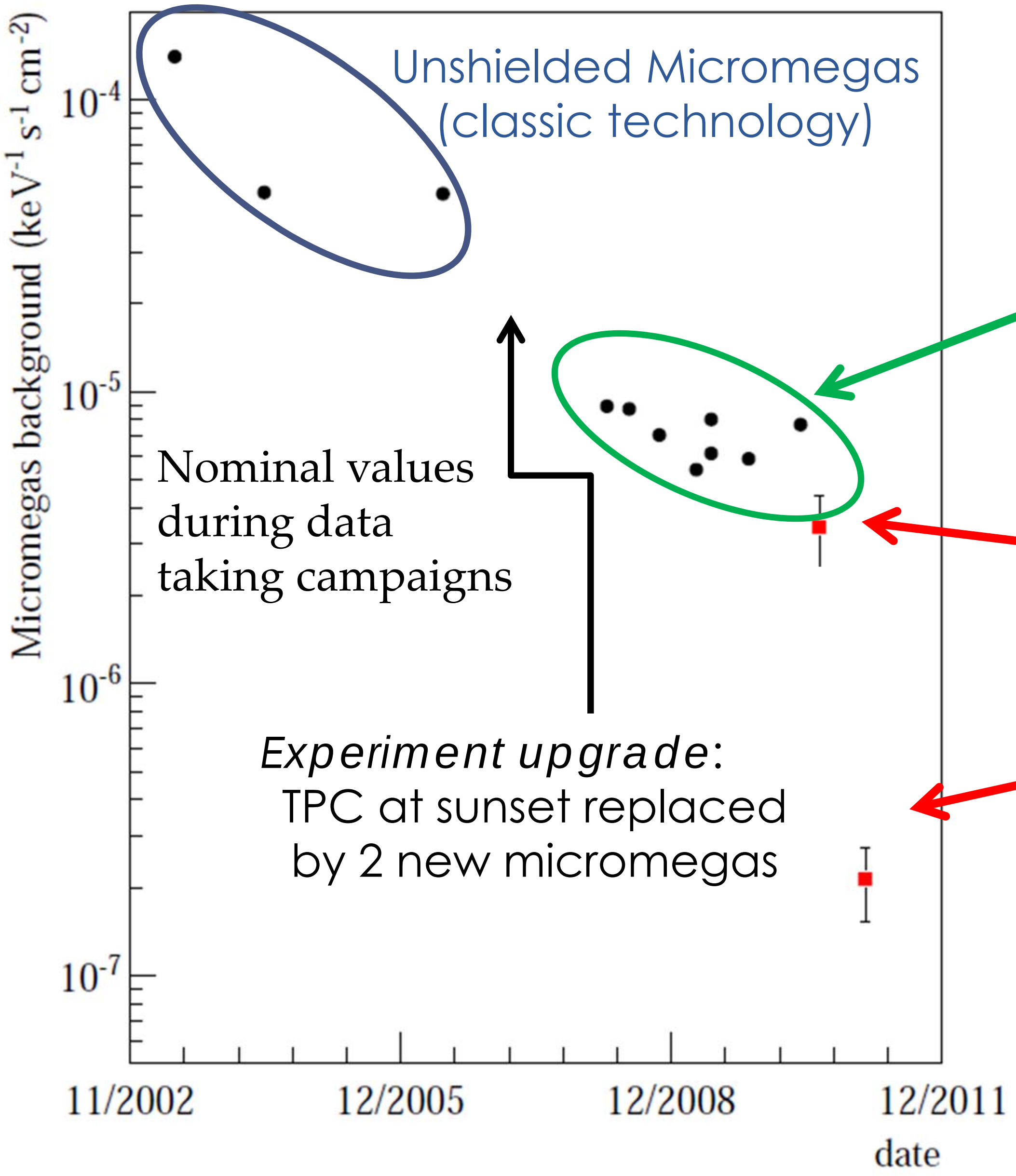
Research at LSC has been carried out by the group of the University of Zaragoza since 1985 on dark matter and double beta decay.

mM at Canfranc

CAST setup reproduced
Moved to Canfranc:
better and thicker shielding coverage



mM Background history improvement



Shielded Micromegas
(bulk and microbulk technology)

~5x10^{-6} c/keV/s/cm^2

2,5cm Pb shielding
in **Canfranc**

≥ 10cm Pb shielding
in **Canfranc**

Reduction of a factor ~20
wrt CAST results

2x10^{-7}c/keV/s/cm^2

Intrinsic background of the
detectors

C. Radiopurity issues: measurements

Microbulks are mostly Cu & Kapton

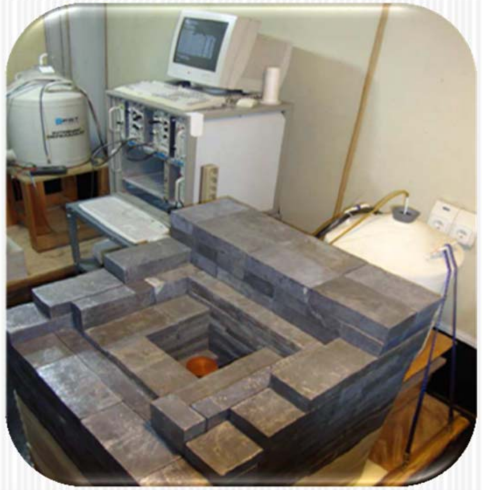
potentially very radiopure

Several samples measured with HPGe at LSC

2 samples of raw material (double clad kapton foil)

2 samples detached from old CAST detectors

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



HPGe detector in Canfranc

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

Radiopurity issues: to be done

- Study and reduce intrinsic radioactivity:
  - Identify
    - limiting components: chamber and surroundings
    - Possible additions in the treatment of the materials

  and replace them
  - Use current setup at Canfranc (already at 10^{-7} level)

Should allow to achieve the step from 10^{-7} to 10^{-8}

D. New designs

- Several configurations have been tried:
  - Pb Shielding thicknesses : 2,5cm, 5cm, 10cm, 20cm
  - Different CAST spare detectors: M10, M13, M17
  - Different cathode windows: Cu, SS
  - Tests underground
  - Tests at surface

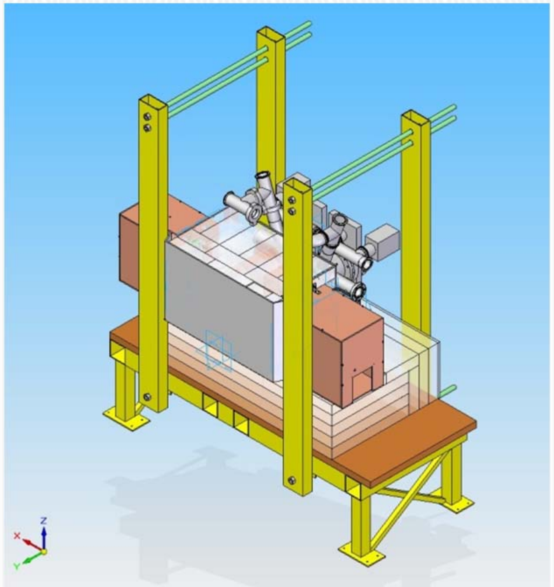
- In combination with the simulation estimations:
  - Background mainly due to external gammas
  - Vulnerable point the front entrance
  - If cosmics: possibility to use a veto in anti-coincidence

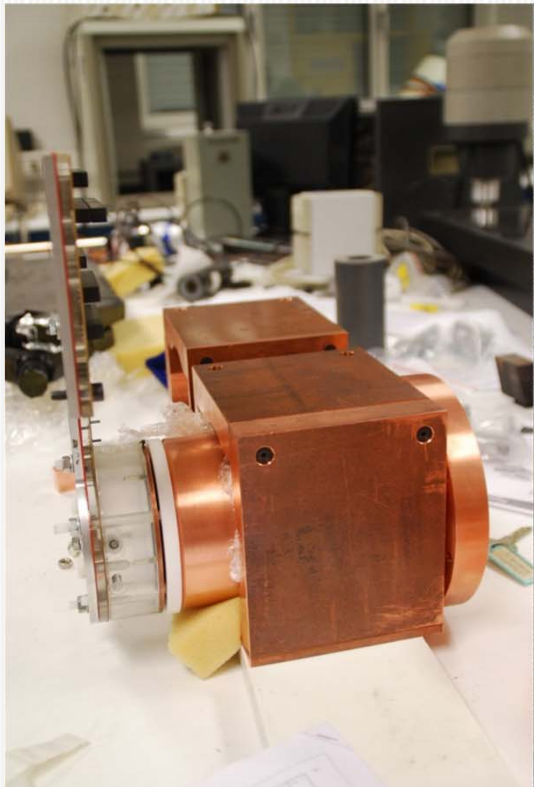
have shown that an upgrade of the shielding (design, thickness) will result in an important background reduction

New designs: shielding

- The new design of the Sunset detectors foresees a coverage of 10cm.
- Being installed these days in CAST: 2012 run, 4months of data-taking
- Results expected soon.
- Possible upgrade: Installation of a Veto system in anti-coincidence.

Already being tested in Zgz.





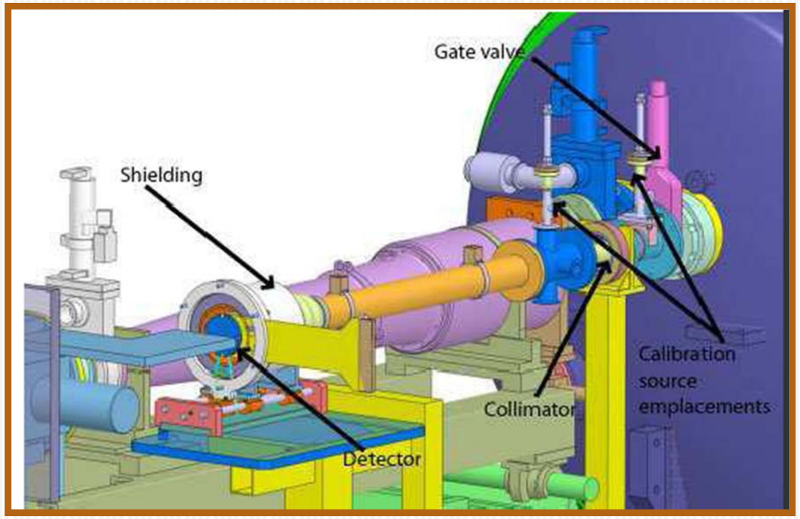
New designs: new detector

New detector design for the 2013 CAST run

- Take advantage of the experience in all fronts
- Improve shielding in all stations
- Even less radioactive design
- New readout electronics

Construct small optics using thermally formed glass substrates. (LLNL, U. Columbia, DTU)

- Operational experience in real data-taking conditions in CAST in 2013



Low threshold possibilities

…

Increase Gain

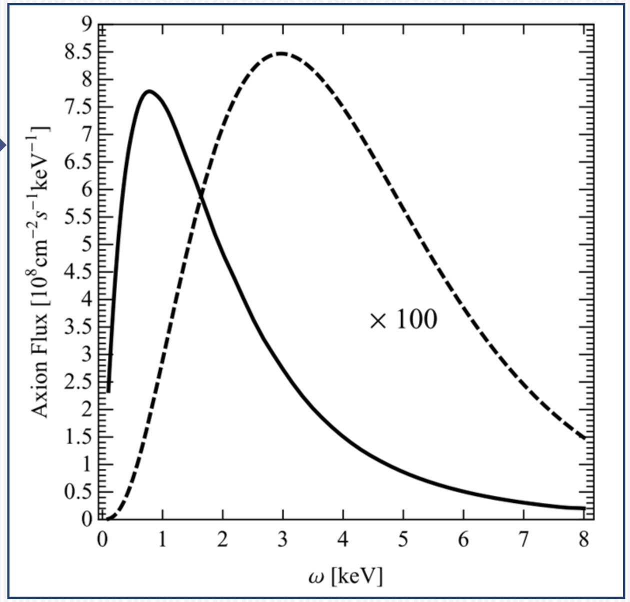
Employ transparent windows

Low threshold

Application for IAXO:

Study of the anomaly because of the cooling of the white dwarfs

Other ALP searches such as chameleons



Which peak at <1keV

- Use transparent windows
- Increase gain:
  - optimize the gas mixture and the operating pressure
  - reduce electronic noise

To keep in mind
- avoid operating at extreme values of gain
- acceptable background reduction
- acceptable efficiency

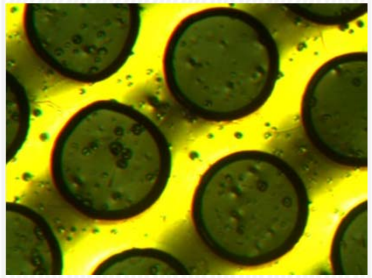
Transparent windows: sub-keV ideas

- Classical technique:

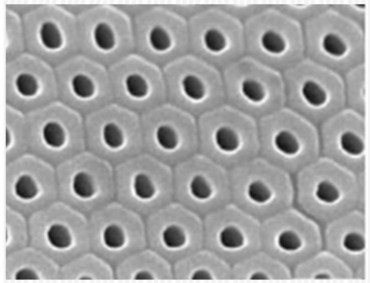
stretched foils with appropriate strongback support (i.e 0.9 μm aluminized mylar, 0.5 μm aluminized polypropylene…)

- R&D on Kapton etching:

reduce thickness to ~1 μm, with hexagonal support structure of ~12.5 μm (Rui de Oliveira, CERN)



- Parallel effort in Patras by V. Athanassopoulos et al. with Nanotube Porous aluminum membrane

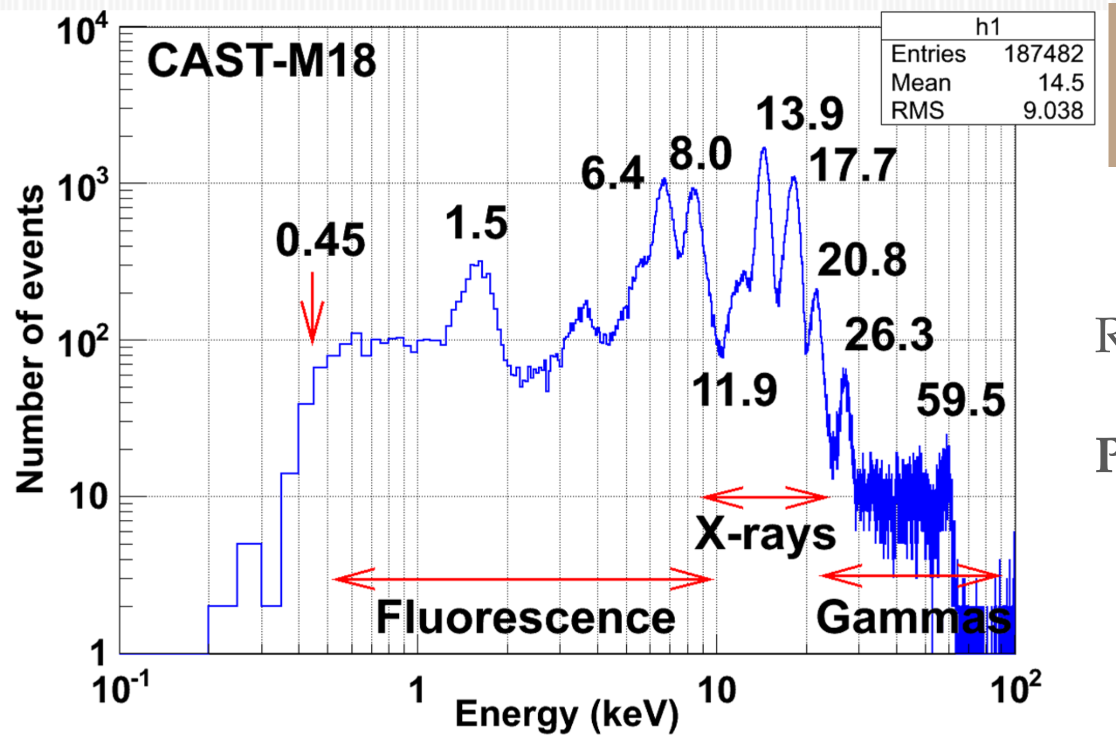


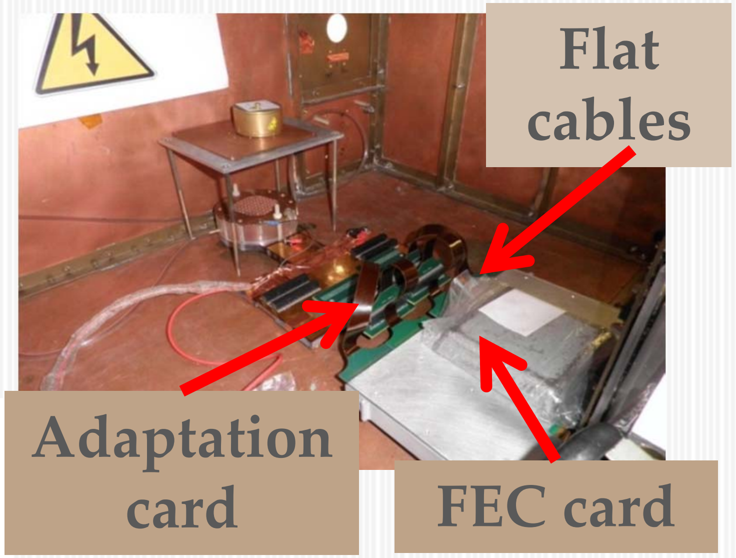
Readout electronics example

Decision to upgrade the electronics chain from the Gassiplex chip to the T2K ones.

Tests with a CAST spare detector

Al foil in front of an ^{241}Am α source

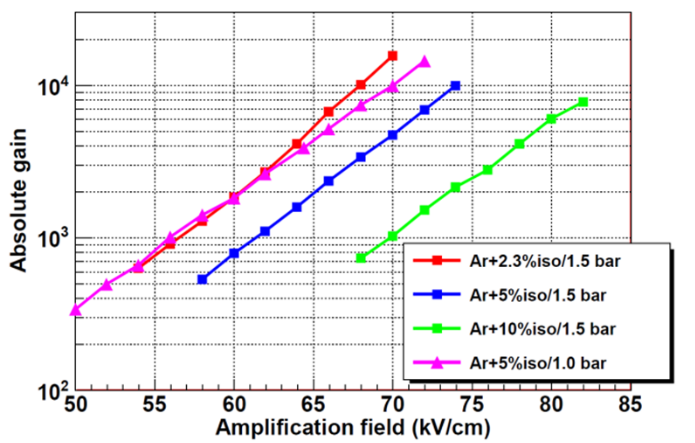




Reachable threshold **< 500eV**

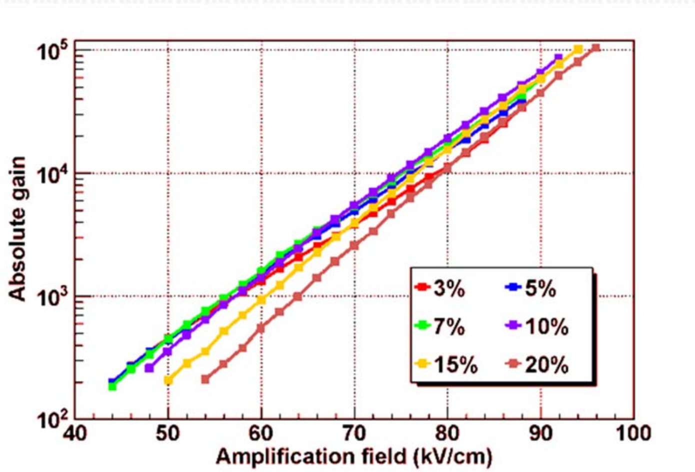
Promising results for
better thresholds
improved offline analysis

Gas studies example



Operating conditions in CAST:
Ar-2.3% Isobutane at 1.5bar

Max gain: 10^4
Operating gain: few x 10^3
Thresholds at CAST (without windows



Tests in Ne + Isobutane at 1 bar

Max gain: 10^5

Iguaz et al. , 2012 JINST 7 P04007

Summary

- Micromegas detectors: a *mature* technology that shows good prospects for further background improvement.
- On the low background side:
  - Nominal background levels achieved in CAST
    ~5 x10^{-6} c/s/keV/cm^2 potentially lower
  - Backgrounds in R&D setups already reached levels of
    ~2 x10^{-7} c/s/keV/cm^2
  - Good possibilities to reach the IAXO requirements of
    ~10^{-7}-10^{-8} c/s/keV/cm^2

  By means of completing the background models, intrinsic radioactivity
- On the low threshold side
  - R&D on transparent windows at sub-keV and appropriate gas-mixtures
  - Actual detectors with better readout electronics reach down to 0.5keV
- The implementation of an optics
  - Will increase the FOM of IAXO
  - An opportunity to acquire experience with a micromegas+optics system in real data-taking conditions in CAST (2013)