Micromegas detectors in the CAST experiment

(CERN Axion Solar Telescope)

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Outline

The CAST Experiment and the need for low background detectors.

Evolution of micromegas detectors in CAST.

Background discrimination

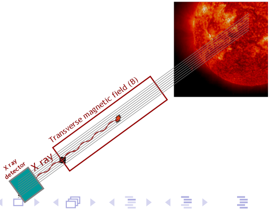
Detectors characterization

Ultra low background periods

The CERN Axion Solar Telescope Experiment. And intense magnetic field tracking the Sun.

- CAST uses an LHC prototype (dipole) superconducting magnet mounted on a rotating platform.
- The magnet can follow the Sun's center during sunset and sunrise during more than 1.5 hours.
- The magnet operates at a temperature around $1.8K$.
- Transverse magnetic field $B = 9.0T$ inside the two magnet bores with $L = 9.26m$.
- 4 x-ray detectors : x-ray telescope (mirror optics and CCD) + 3 μM detectors.

The axion is a pseudo scalar Nambu-Goldstone boson that can be produced via Primakoff effect in stellar plasmas (e.g. Sun)



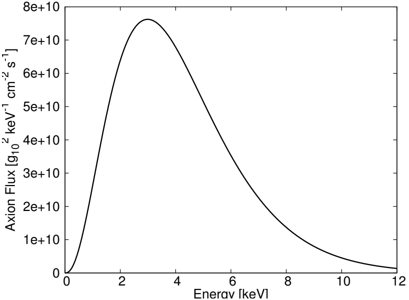
- Phase I (Vacuum) : $m_a < 0.02eV$ (2003-2004)
- Phase II (He4) : $m_a < 0.38eV$ (2005-2006)
- Phase II (He3) : $m_a < 1.15eV$ (2008-2010?)

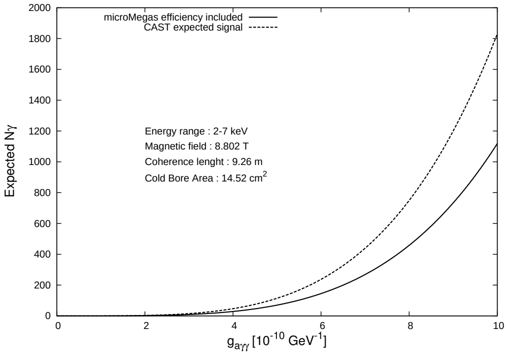
The need for low rate background detectors.

Solar Axion Flux and conversion probability in the CAST magnetic field depends directly in the axion-photon coupling constant.

Coupling constant sensitivity.

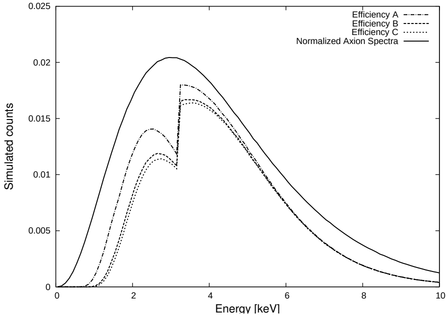
$$g_{a\gamma}^4 \propto \frac{b^{1/8}}{t^{1/8}\varepsilon^{1/4}}$$





The sensitivity of CAST depends strongly in the low background rate of the detectors.

The micromegas detectors efficiency.



Overal efficiency (2-7 keV)		
A	mM detector	75.97 %
B	mM + CW	62.45 %
C	mM + CW + DW	61.49 %

- Detector pressure 1.5 bar for increased efficiency.
- Polipropilene and Drift windows are designed to assure good vacuum levels between detector and magnetic field.
- Good vacuum level assures minimal deposition of gas in the cold windows of the magnet.

Detector efficiency loss contributions

- Intrinsic detector efficiency (Argon).
- 5 μm Aluminised-mylar drift window + 5% Strongback
- 4 μm polypropylene differential window
- 15 μm polypropylene cold window + 17.5% Strongback

Evolution of Micromegas detectors in the CAST Experiment.

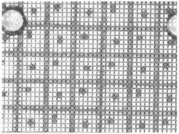
- The latest generation of Micromegas detectors are in production for CAST.
- Detectors are built with low radiation materials (Plexiglass, Kapton, ...)

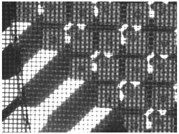
Bulk

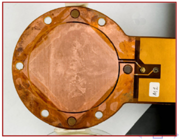
- 30μm inox mesh.
- 128μm pilars.
- 3-4 years of experience : well established technique.
- Reachable energy resolution (18%$FWHM$).
- Spatial uniformity and very robust.
- Limit on the energy resolution due to the thickness of the mesh.

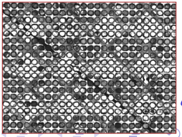
Microbulk

- 5μm copper mesh.
- 30μm mesh holes.
- pilars are replaced by attached Kapton substrate.
- 1-2 years of experience : technology almost complete.
- Reachable energy resolution ($<$ 13%$FWHM$).
- Good behaviour against sparks.



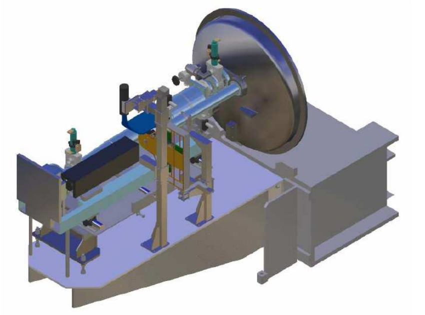


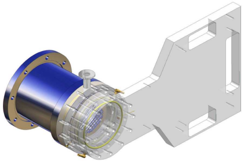




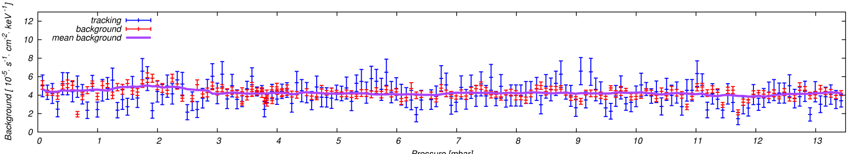
Evolution of Micromegas detectors in the CAST Experiment.

- The CAST Experiment takes data with one micromegas detector till the end of 2007.
- A conventional technology Micromegas detector covers the Sunrise side of the Magnet.
- Simple vacuum system and no shielding protecting the detector.



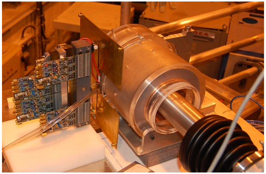


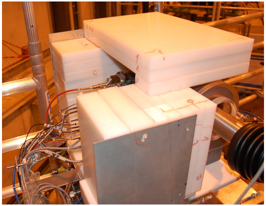
2005-2006 Data Taking

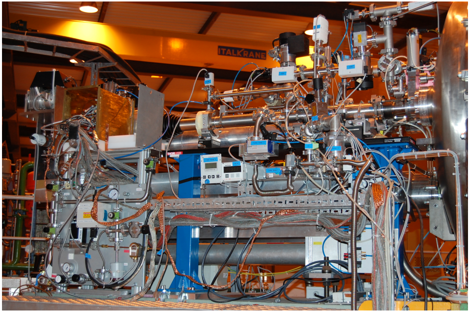


CAST Sunrise Micromegas Detection Line (Status in 2008)

- New vacuum line + detector pressure and flow control
- Designed a new lead + cadmium + copper shielding for the new line.
- Polythylene shielding designed to optimize space and weight limitation.
- Inner shielding flooded with nitrogen (Radon contamination and water vapor reduction).

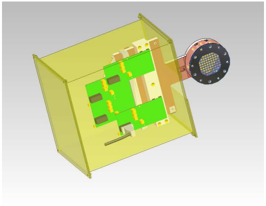


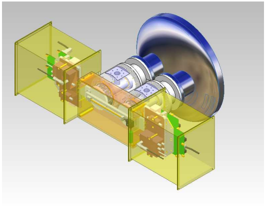


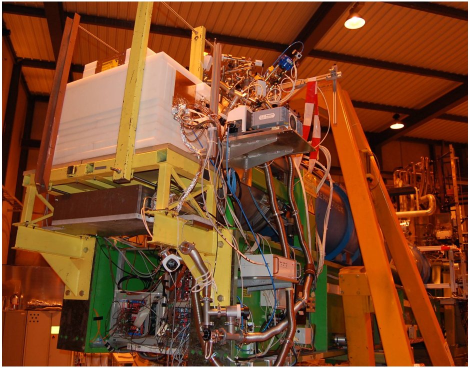


Installation of two new Micromegas detectors in the Sunset side.

- Replacement of the sunset TPC by two microbulk micromegas detectors.
- Great background reduction, at least one order of magnitude : Better events discrimination and new TPC shielding design.

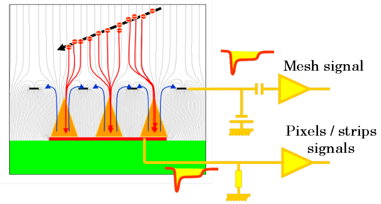




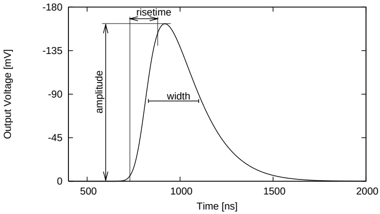


Micromegas readout

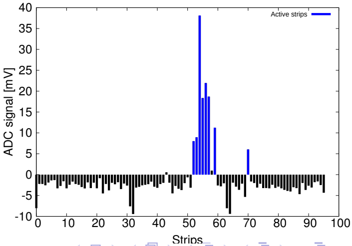
- Mesh signal comes from ions produced in the amplification gap.
- Electron avalanches created in the amplification gap give a signal in the strips.
- The temporal mesh pulse and the spatial strips provide good information for event discrimination.



Pulse Signal

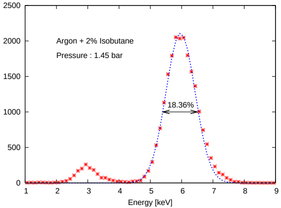


Strips Signal

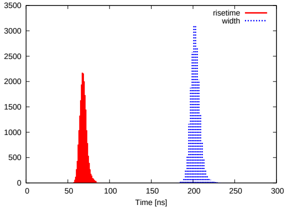


X-ray photon finger prints.

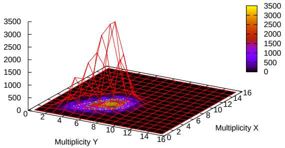
A daily calibration checks for stability and fixes cuts to be applied to the background data.



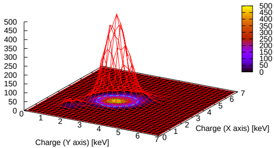
- x-ray are characterized by :
  - low and narrow pulse parameters distribution.
  - Good energy balance.
  - Localiced charge deposition (mono-cluster events).



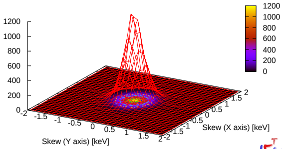
Strips Cluster Size



Charge Balance



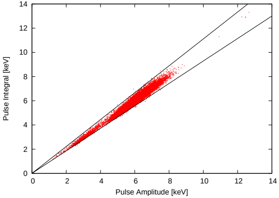
Cluster Assymmetry



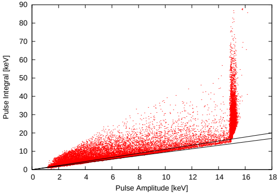
Background discrimination methods.

Several statistical methods have been implemented for background discrimination.

Sequential Analysis

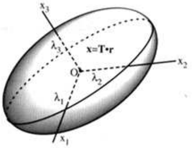


- Cuts are applied in the parameters space one after the other.



Multivariate Analysis

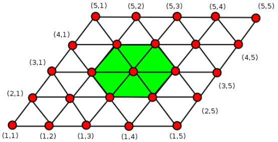
- The method takes into account the correlation between the choosen discrimination parameters.



- A covariance matrix defines the volume of an hyper-ellipsoid where a controlled percentage of calibration events are inside.

SOFM Analysis (Neural Networks)

- A neural network is trainned with background data.
- Each cell gets specialized in recognizing a set of events.

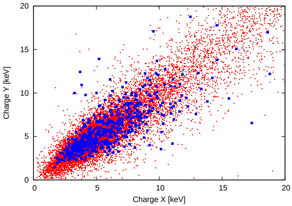


- An Fe55 run determines the cells that recognize photons.

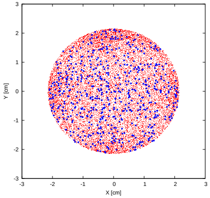
Background rejection distributions.

- The acquisition registers many cosmic events and high energy events that are rejected.
- Noise at low energies is easily rejected too.
- The range of main interest is 2-7 keV

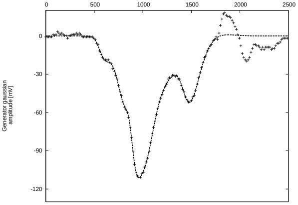
Charge Balance



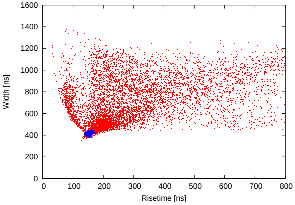
Background Hitmap



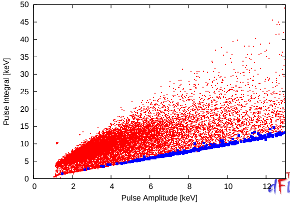
Cosmic Event Pulse Shape



Risetime and Width

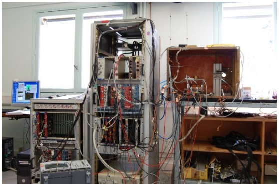


Pulse Energy (Integral vs Amplitude)

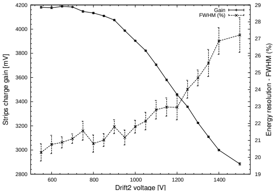


Micromegas under different gas conditions

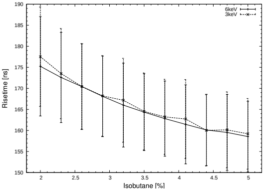
Bulk detector characterised in CEA Saclay Institute.

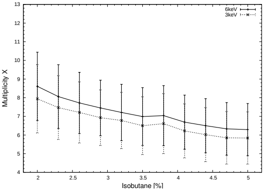


Drift Voltage

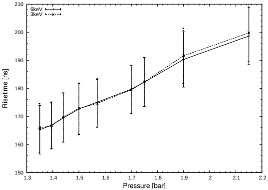


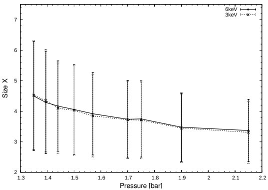
Isobutane concentration





Detector Pressure

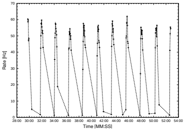




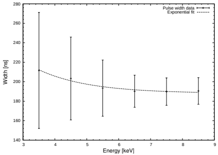
Micromegas detectors characterisation

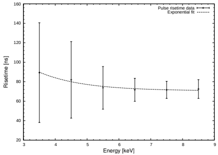
Energy characterization in CAST

- An x-ray generator installed in the sunset side is used to crosscheck the alignment of the x-ray telescope.
- The sunset Microbulk detector is able to detect scattering from the walls.
- The x-ray energies cover the full energy range of the detector.
- Future measurements with x-ray tube scheduled.

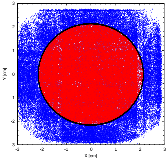


Pulse parameters and cluster size are found to be slightly dependent with the x-ray energy.



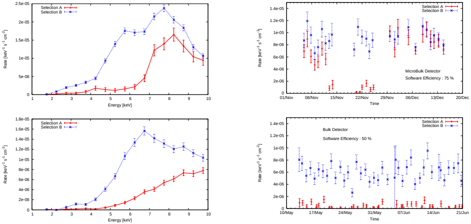


Frontal characterization of the detector *in situ*.



Ultra low background periods

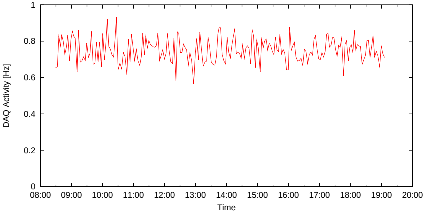
- Two Periods during CAST Data Taking show a very low background.
- Reduction is observed in the low energy range.

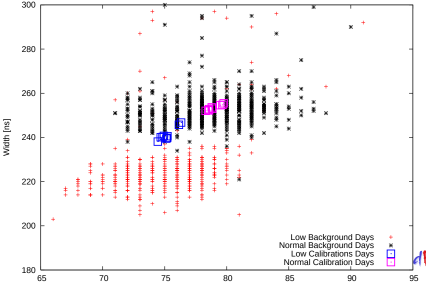


Mean background in $keV^{-1}s^{-1}cm^{-2}$

Width Parameter	YES	NO
Bulk (50%)	$5.01 \cdot 10^{-7}$	$6.01 \cdot 10^{-6}$
Microbulk (75%)	$8.23 \cdot 10^{-7}$	$8.99 \cdot 10^{-6}$

Acquisition rate

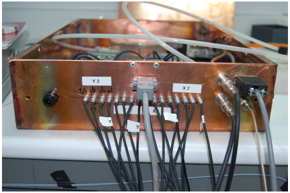


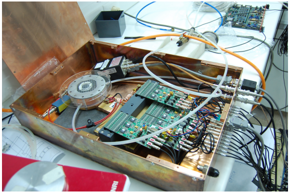


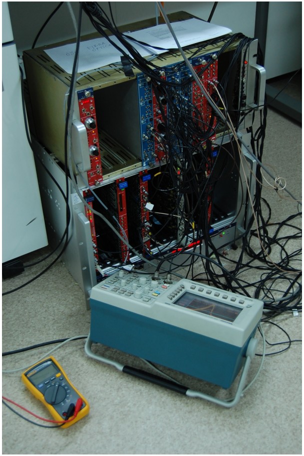
Near future tests related to ultra low background

Laboratory of University of Zaragoza

- Efforts are concentrated in obtaining same good reduction in laboratory conditions.
- Nitrogen flow around detector seems to be correlated with the good reduction achieved.
- A Faraday Cage leak tide was prepared for flood the detector surrounding with Nitrogen.
- System will be placed at *The Canfranc Underground Laboratory* to perform stable measurements.



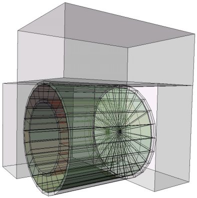


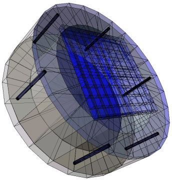


Background Geant4 Simulations

- Efforts are also being focusing in Geant4 simulations implementing the geometry of detector and shielding in CAST.
- Radiopurity levels from materials from the detector are being measured in *The Undergraund Laboratory of Canfranc* using a low background germanium detector.

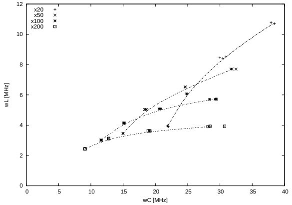
- Simulations will help to understand the origin of the background measured by the detector.
- ... and to estimate the background level produced by the external background and the internal radioactive contaminations and compare it with the real background measured by the detector.
- Work is going on events drift and readout to produce rawdata in the same format as the real detector readout.





Model for pulse shape analysis

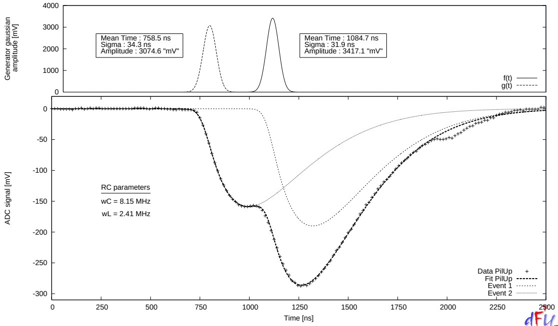
- Pulse Shaping Parameters have some influence in background rejection.
- A Timing model allows to quantify the timing parameters for the electronics.
- Represents a step towards the implementation of readout in Geant4 simulations.



w_C and w_L are the two timing parameters that define the pulse shape.

$$\frac{1}{w_C}\frac{d^2V(t)}{dt^2}+\frac{dV(t)}{dt}+w_L V(t)=\frac{d\left(R\cdot i_g(t)\right)}{dt} \qquad (1)$$

di_g is defined as a gaussian shape which preserves the energy of the events.



Summary conclusions

- Many improvements in detectors and detectors systems during CAST running years.
- CAST Micromegas detectors have shown good stability during the long data taking periods of CAST.
- Micromegas detectors development for CAST experiment inspires confidence and reliability.
- Micromegas detectors readout fullfills the requirements for rare events search.
- Last ultra low background results are motivating and justifying efforts in this topic.
- Controlled ultra low background would provide an increased sensitivity if reached in the three micromegas detectors