Low Background X-Ray Micromegas Detectors in CAST

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On behalf of

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Thanks to R. de Oliveira and A. Teixeira, for the microbulk fabrication

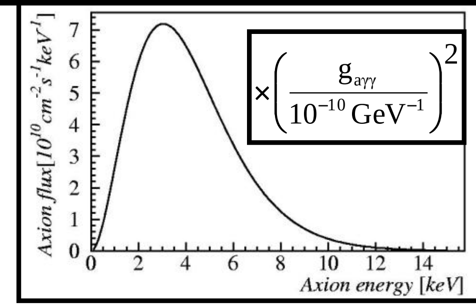
OUTLINE

- The CAST Experiment and IAXO
- Performance and Background of Micromegas in CAST
- CAST-like Micromegas in Canfranc Underground Laboratory
- Prospects
- Summary and Conclusions

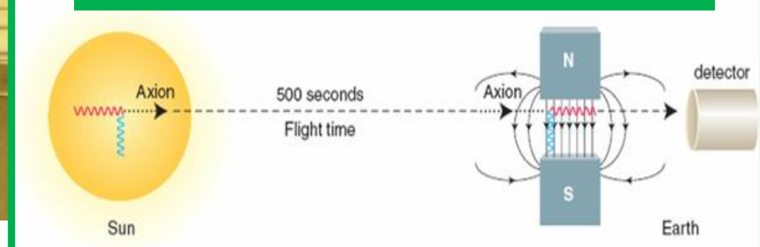
CAST Experiment @ CERN (since 2002)

- Decomissioned LHC test magnet (L = 10 m, B = 9 T)
- 2 Magnet bores to look for X-rays
- Sun tracking (2 x 1.5 h/day). Rest of time defining detectors background

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



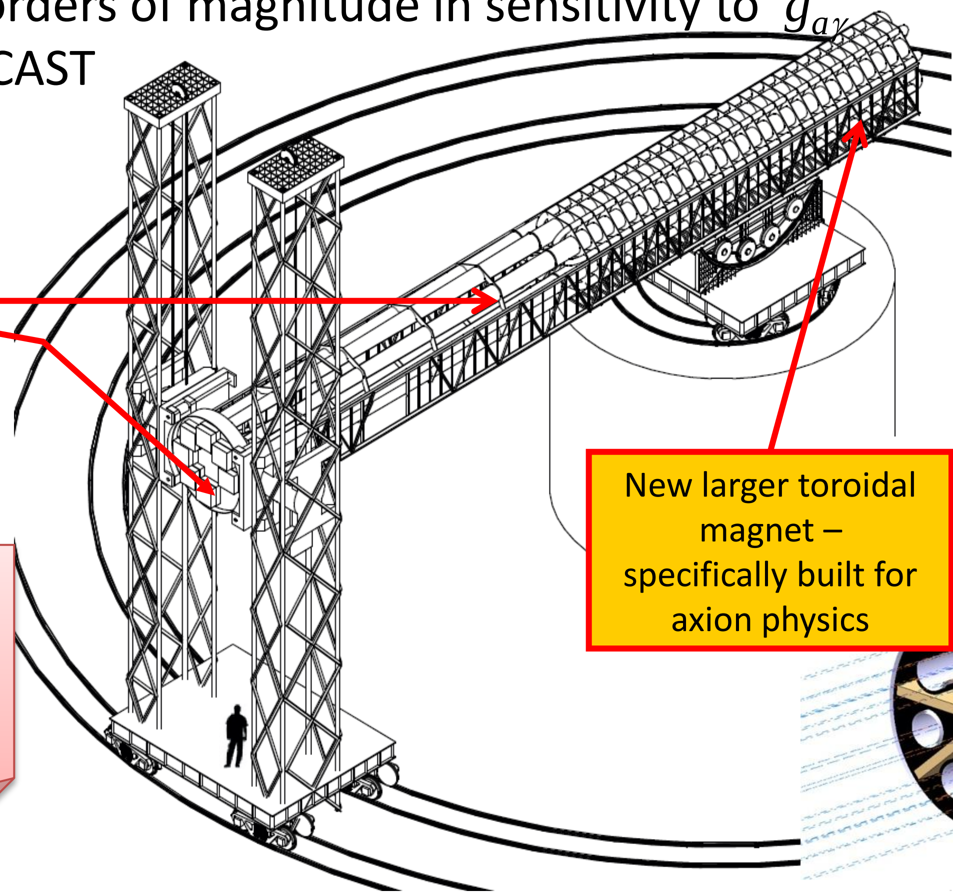
Helioscope principle (Sikivie)
reverse axions into photons



- Solar Axions : detectable via «helioscope concept» . Range of Interest : **[2-7] keV**
- **Low Background of X-Ray detectors**: one of the parameters driving the sensibility → Experimentall challenge
- **CAST** near term program (including pathfinder projects for IAXO) has been recently **approved by CERN SPSC,** explicitly recognizing the Micromegas detectors developments and results.

International Axion Observatory (IAXO)

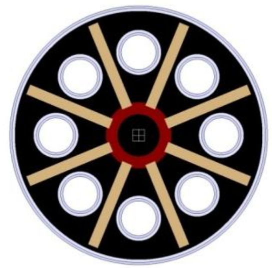
- Towards a new generation axion helioscope
- Conceptual Design Report and **Letter of Intent** to CERN in preparation.
- **Goal**: 1-1.5 orders of magnitude in sensitivity to $g_{a\gamma}$ better than CAST

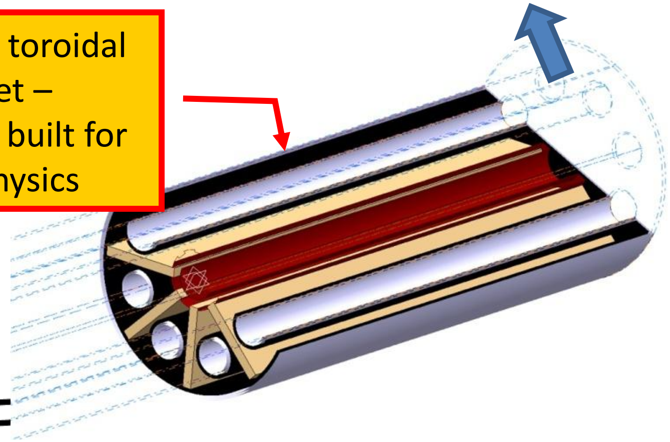


All bores equiped with x-ray focusing and low bkg detectors
-
Fully exploiting innovations of CAST

New larger toroidal magnet – specifically built for axion physics

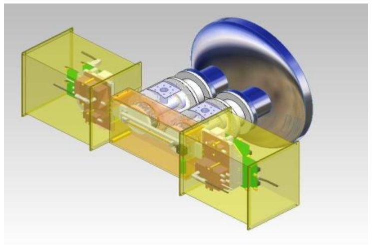
Each conversion bore (between coils) about 0.5-1 m diameter

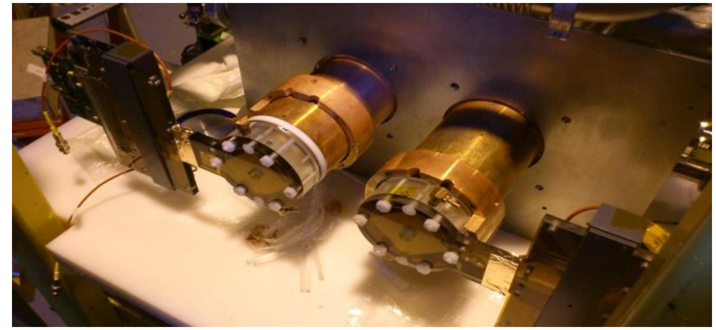




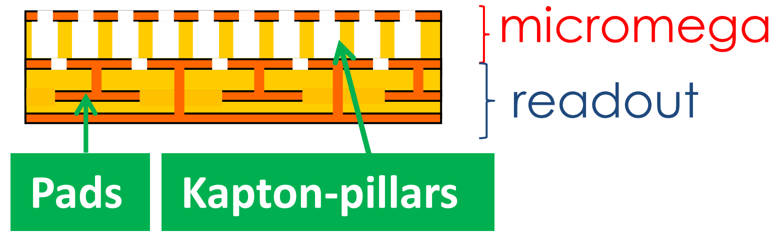
First feasibility results and sensitivity prospects recently published:
JCAP 1106:013,2011
(arxiv:1103.5334)

Micromegas detectors in CAST: 2003-2012





Latest Microbulk since 2008



- Since 2008: 3/4 of CAST detectors Microbulk Micromegas (2 in Sunset side, 1 in Surise side)
- Readout: 6 x 6 cm (106 x 106 strips) , 550 µm pitch
- Gas: Ar – 2.3 % Isobutane at 1.4 bar
- Shielding: radiopure copper and Lead

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

Special thanks to R. de Oliveira and A. Teixeira, for the microbulk fabrication

Low Background Strategies

These strategies are being actively developed under the **T-REX R&D project** (UNIZAR) funded by a ERC Starting Grant

Technology
- Classic → Bulk & Microbulk. Better performance and rejection capabilities
- Further develpments: segmented mesh, less complexity in the manufacturing process

TPC properties:
- R&D on gas mixtures and improvement on chamber drift field.

Shielding:
- Increase in Cu & Pb shielding thickness yields lower background levels (environmental gamma radiation)
- *Active* (cosmic veto): cosmics are the dominant contribution to CAST background at current levels.

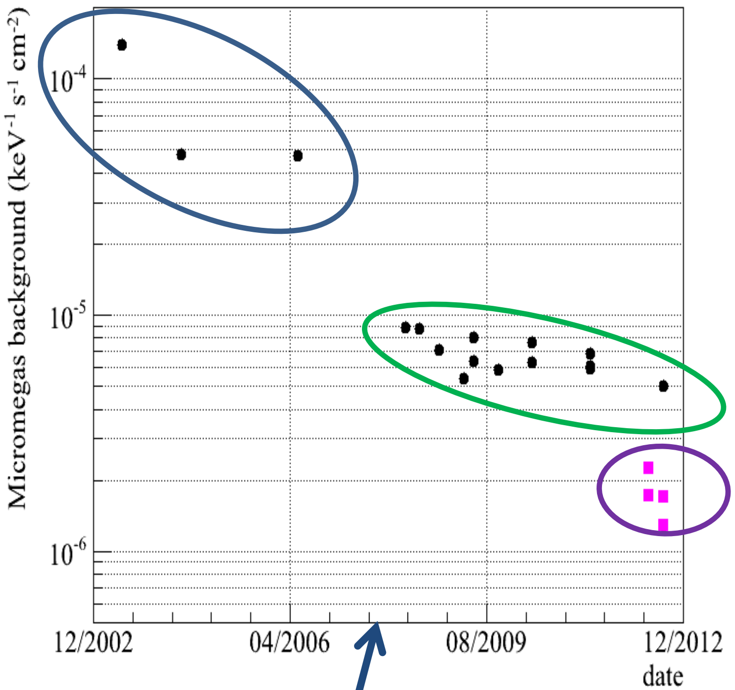
Radiopurity:
- Is intrinsic radioactivity of detector components relevant? Tests and simulations going on … → Replacement of non radiopure components.

Front End Electronics:
- Gassiplex electronics replacement by AFTER electronics: more information available, probably increasing rejection factor.

Optics: improvement of signal/noise ratio

History of Micromegas in CAST (I)

Nominal values during data taking campaigns



TPC at sunset replaced by 2 new micromegas. 3/4 of detectors in CAST are Micromegas since then !!

The history of CAST Micromegas closely related with Micromegas development evolutions

CAST as a test-bench for Micromegas and profitting from its evolution

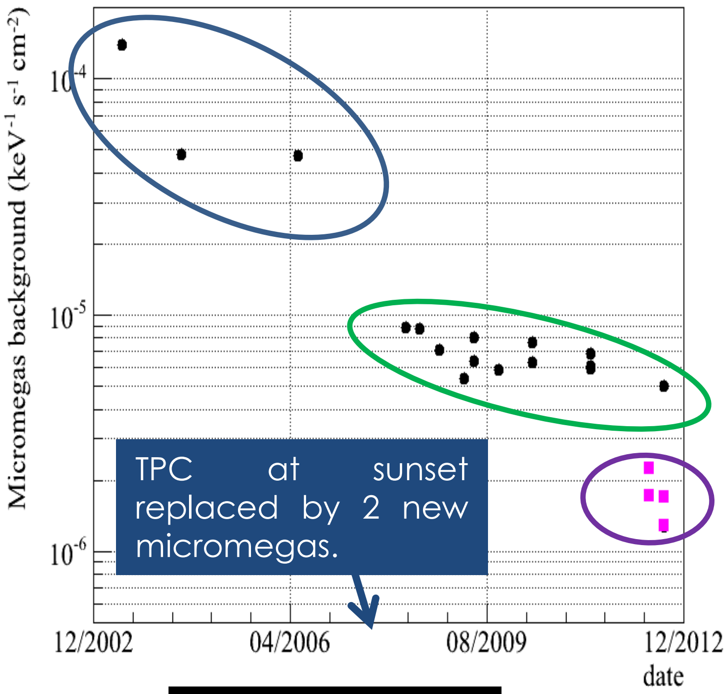
Stability and reliability are major requirements

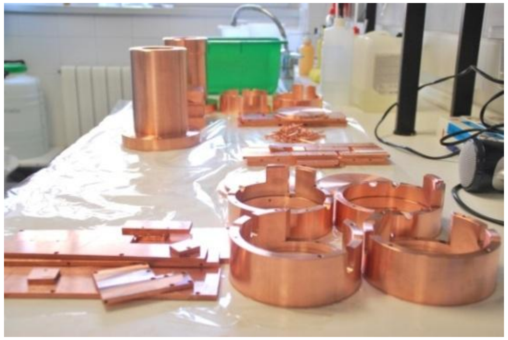
2003-2006:Unshielded classic Micromegas. At the beginnig etching techniques not fully mastered → cross-talk problems, bad energy resolution in strips …

2008-2012: Shielded Bulk and Microbulk Micromegas. Readout pattern re-desinged to fullfill CAST discrimination requirements. Gain in robustness, performance and rejection capabilities.

- Background reduction is equally attributable to shielding techniques and Micromegas developments (around a factor 3 due to each)

Background Levels of Micromegas in CAST (II)

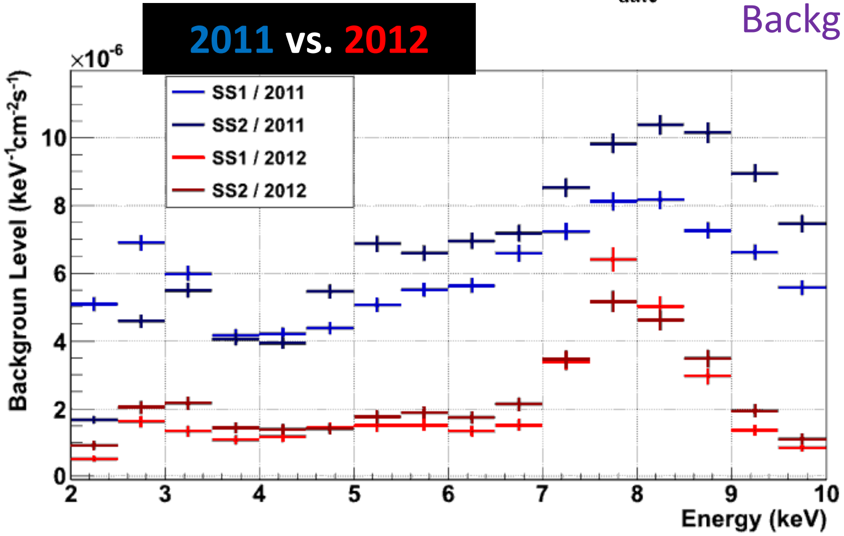




2012 Upgrade: new Microbulk detectors and new radiopure shielding (thicker and better solid angle closure)

All stainless steel pieces were replaced by copper to prevent [5-7] keV fluorescences.

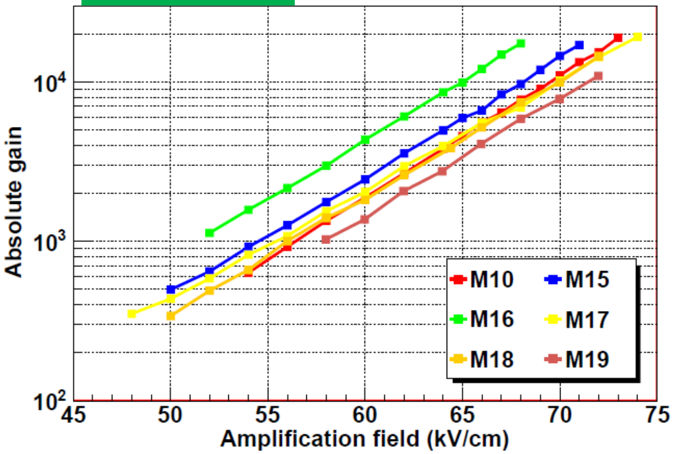
Background level around 4.5 times lower than previous SSMM



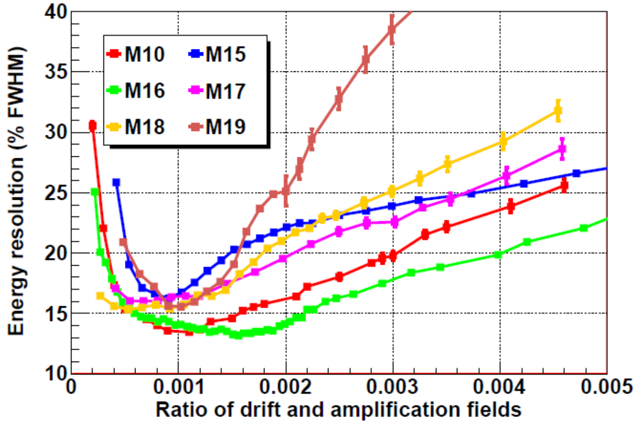
- Moving to latest Micromegas technology and Shielding upgrades have consistently yield to better background levels over the years in CAST Experiment
- Further improvements are expected in the coming years (see Prospects)

Microbulk Micromegas peformance

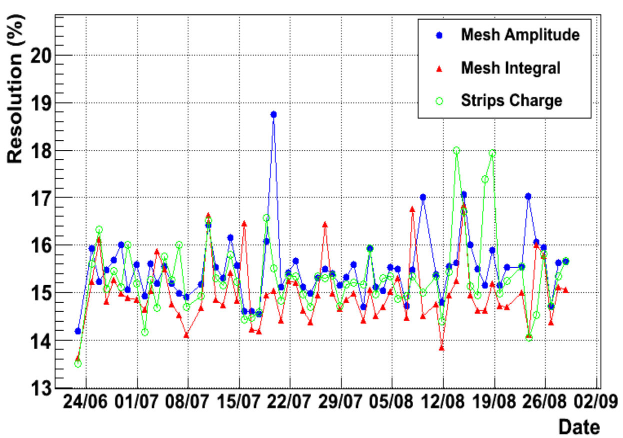
High Gain



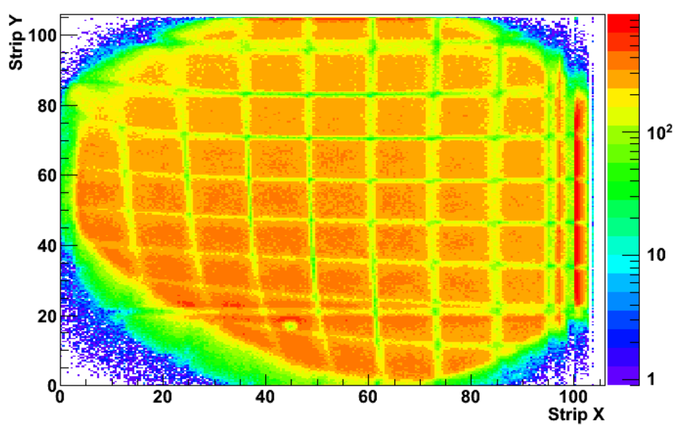
Good energy resolution



Feasability:
Sunrise Energy resolution in 2012



Unfiformity, no death regions



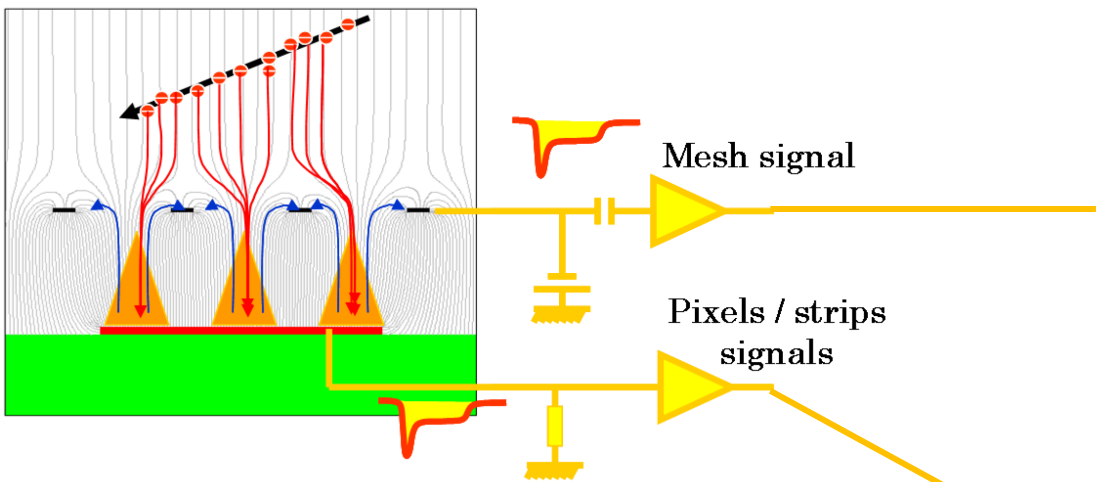
Advantages:

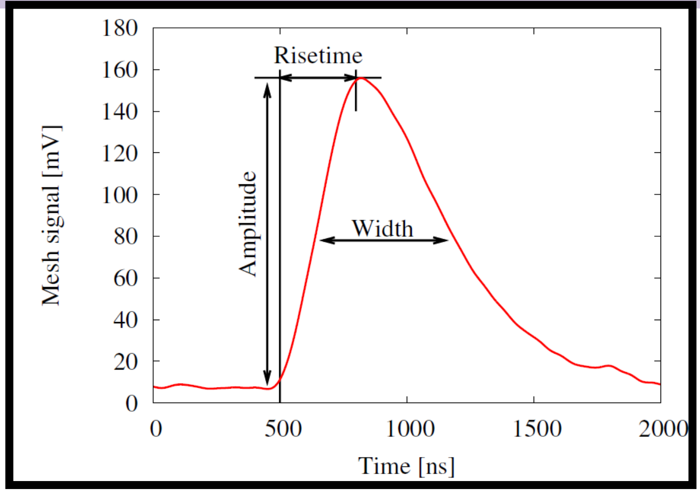
- Uniformity,
- high gain,
- good energy resolution (13% FWHM @ 6 keV),
- feasability at long term runs,
- intrinsically radiopure,
- higher background rejection capabilities

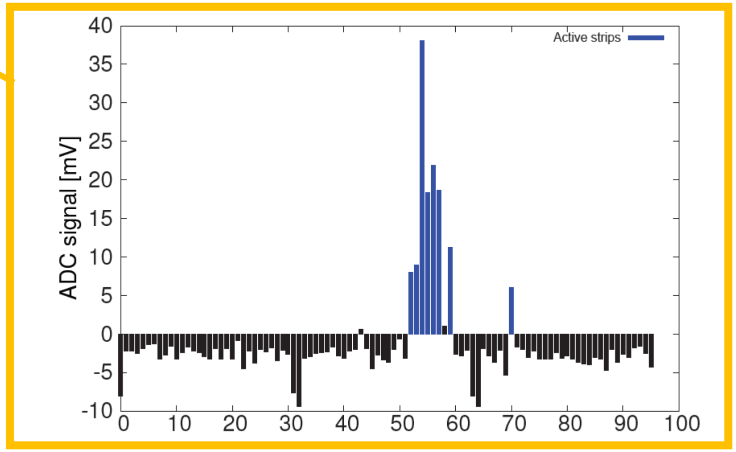
Disadvantages:

- Complexity of manufacturing process (possibly alleviated by new segmented mesh developments)
- fragility

Signal and Background rejection in CAST (I)





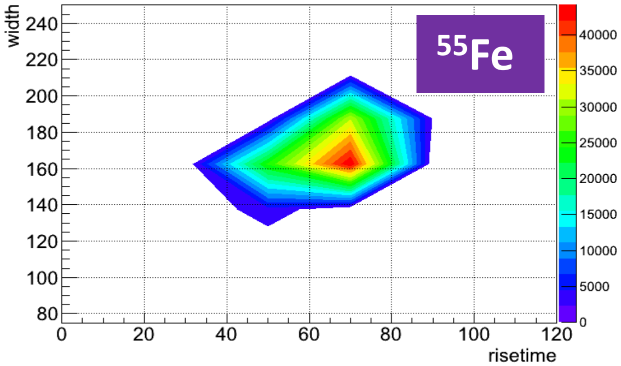


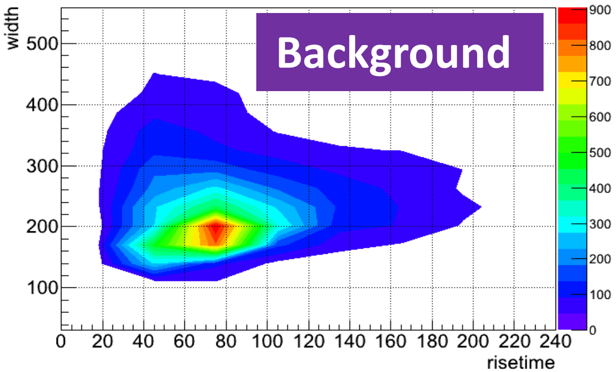
2D Spatial information
+
Time information

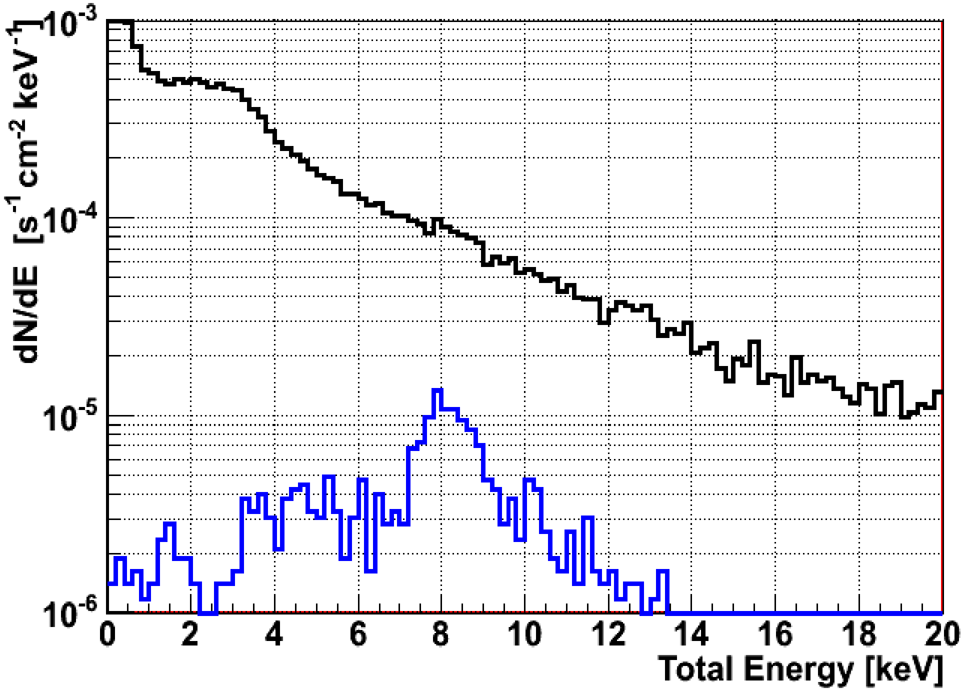
Mesh: pulse induced by slow ions from the avalanche. Digitized by MATACQ card in 2500 samples at 1GHz (12-bit dynamic range) → Preamp + Fast timing Amplifier →Pulse shape analysis

Strips: strips charge integrated by Front End Gassiplex cards (10-bit value for each strip), controlled by a CAEN Sequencer and 2 C-RAMS modules → Cluster analysis (topology)

Signal and Background rejection in CAST (II)





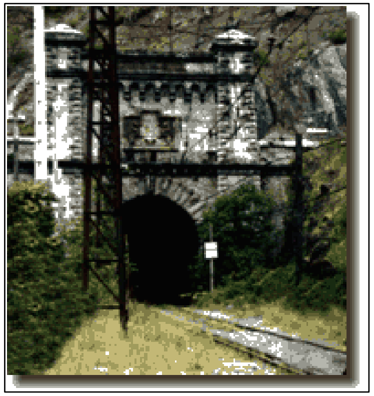


- Axion signature: X-ray event → Point-like events
- Daily ^{55}Fe calibrations define the characteristic parameters of X-ray like events
- **Mesh cuts:** risetime, width, amplitude vs. Integral …
- **Strips cuts:** cluster size, multiplicity, asimetry, X-Y energy balance …

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

A Micromegas CAST-like detector Underground

LSC
Laboratorio Subterráneo de Canfranc



Canfranc Underground Laboratory

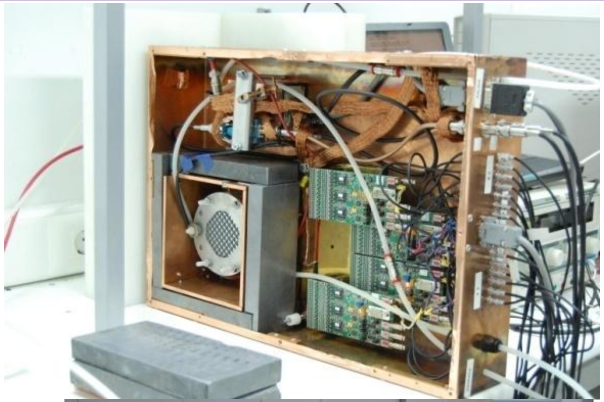
- A Microbulk CAST-like detector is installed and running underground
- 2500 m.w.e deep → **Muon flux reduced a factor 10^4**
- Stable environmental conditions (T, humidity) → avoid systematic effects

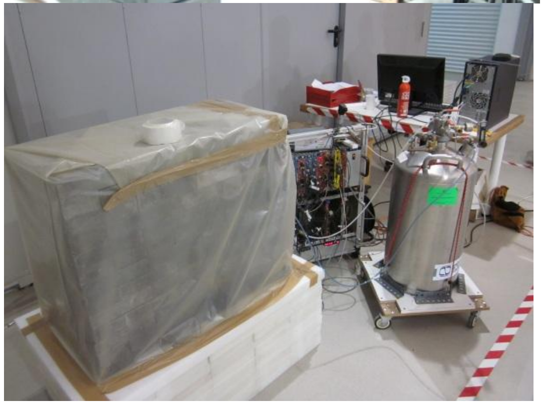
GOALS

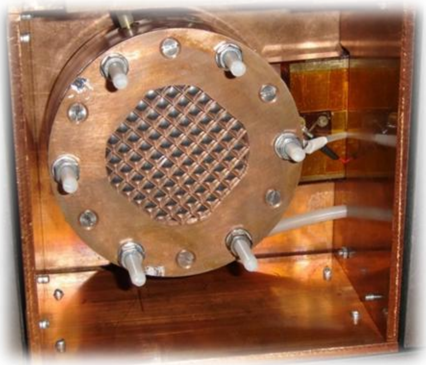
- Estimate microbulk micromegas reliability for an ultra-low background experiment (underground).

- Study CAST background nature. Itemize different contributions:
    - Cosmic rays
    - External gamma flux (natural radioactivity)
    - Internal contamination (detector/readout)
    - Radon

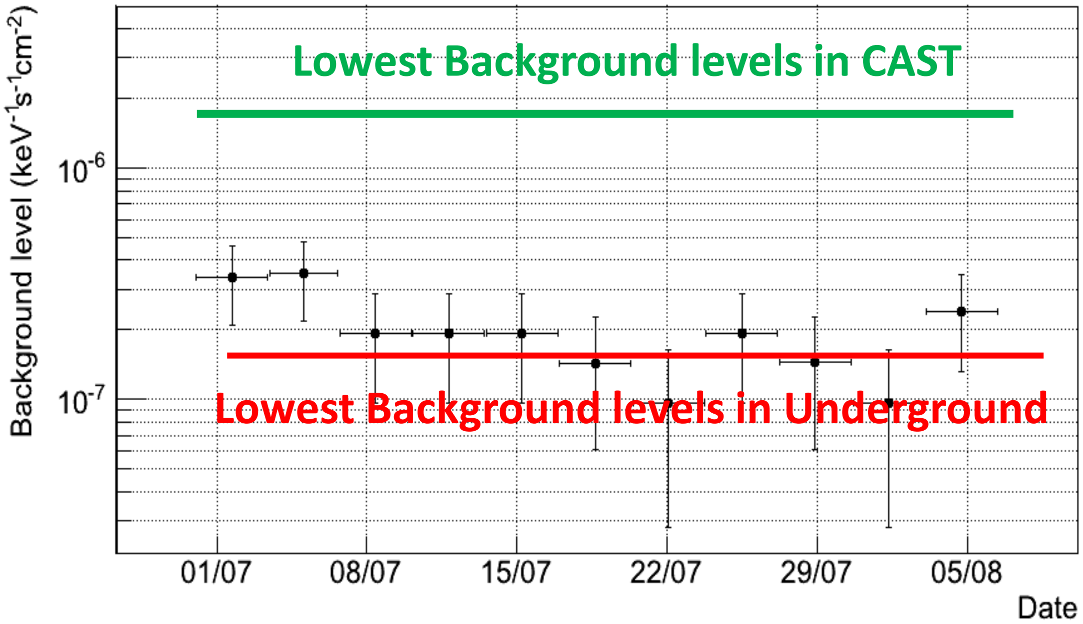
A Micromegas CAST-like detector Underground





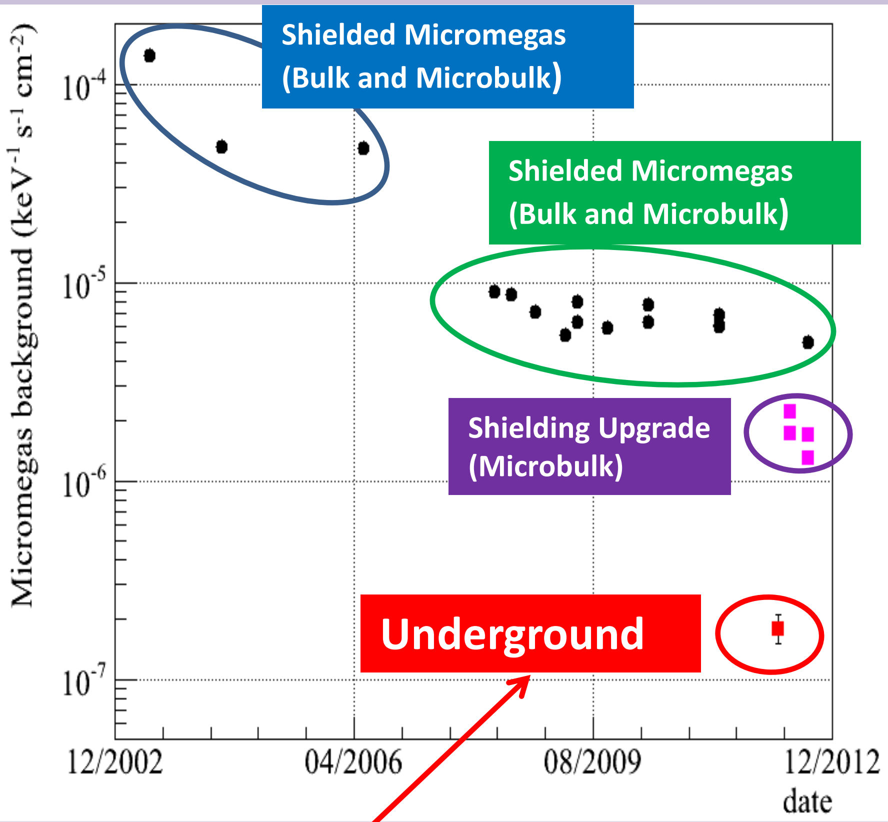


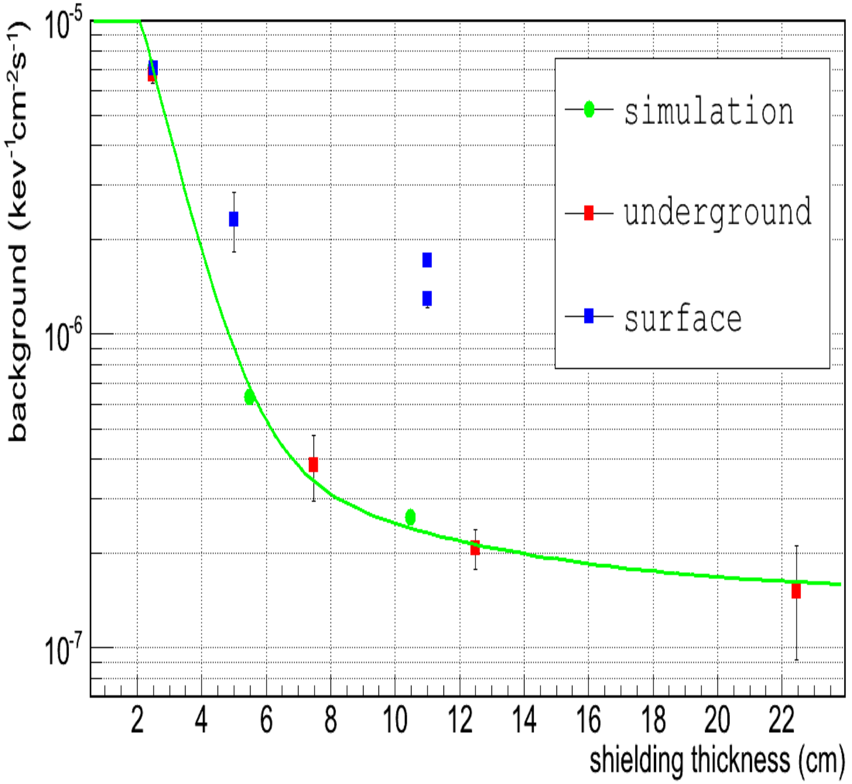
- All the connections extracted via feedthroughs , 4π ~ 10 cm lead shielding
- N_2 flowing into the inner shielding to avoid Radon intrusion
- Use of radiopure materials



Around 10 times lower background Underground than in CAST detectors, in similar shielding conditions

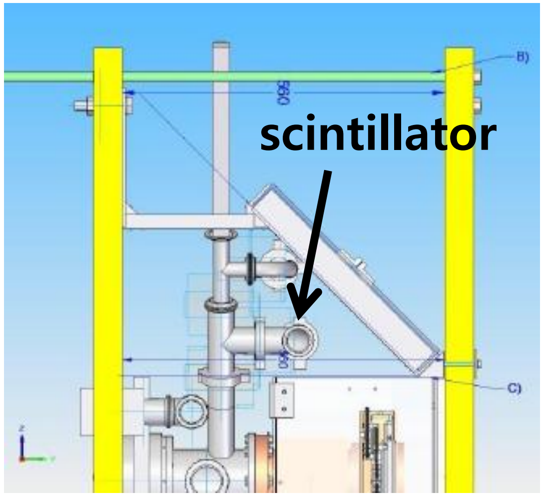
Underground and surface tests: confrontation



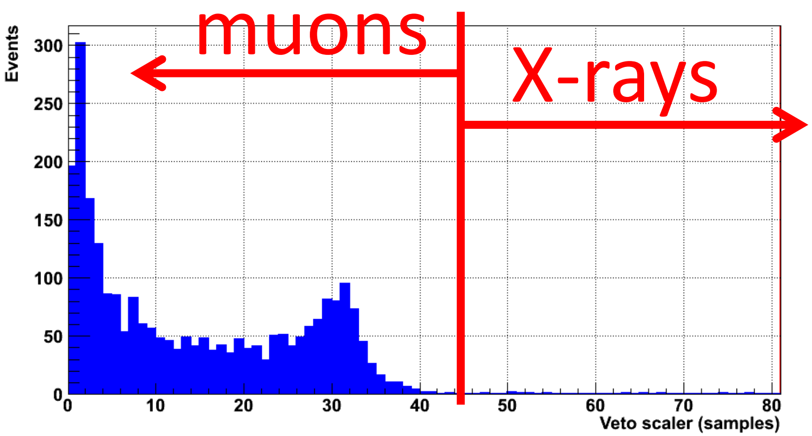


- First ***upper* boundary** to the contribution to the background by the **DETECTOR** (*microbulk* + plexiglass structure + Cu cathode, etc …) **INTRINSIC RADIOPURITY→** experimental program to indentify and replace dirtiest components
- Underground vs. surface tests: at current CAST background levels, the **dominant contribution to background is cosmics muons**.
- This hypothesis is **confirmed by MonteCarlo** simulations: simulation of gamma radiation reproduces the drop in background level achieved underground via thicknes increase.

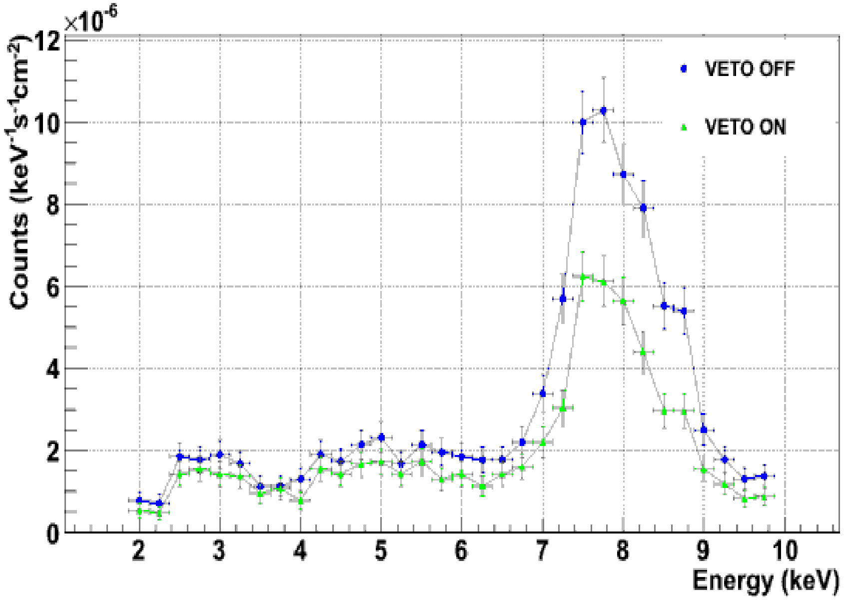
Cosmic Veto installation in CAST



- Underground and surface tests motivated the installation of a scintillator veto for cosmic rays in 2012.
- The time difference between the veto signal and the Micromegas trigger is recorded and used to reject cosmic coincident events in off-line analysis

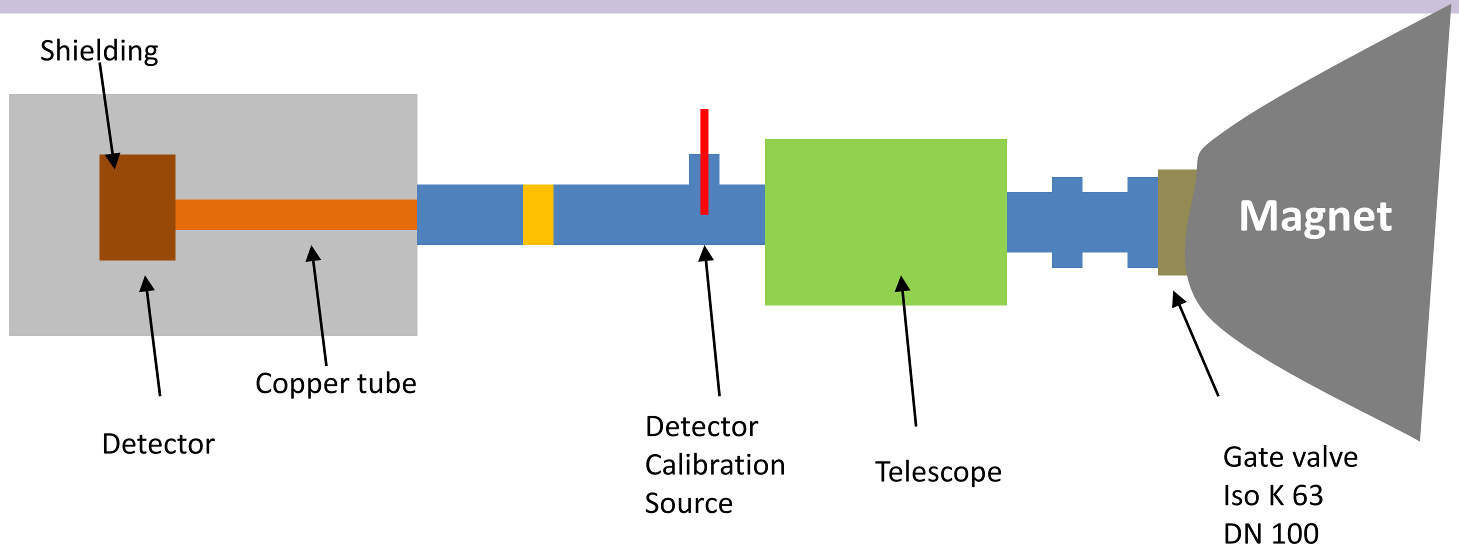


Background spectra without and with veto cut



- Background reduction: ~ 25 %
- Results motivate a special veto design with higher geometrical efficency

PROSPECTS (I): new Sunrise line for 2013



A complete upgrade of CAST Sunrise line is expected for 2013. It includes:

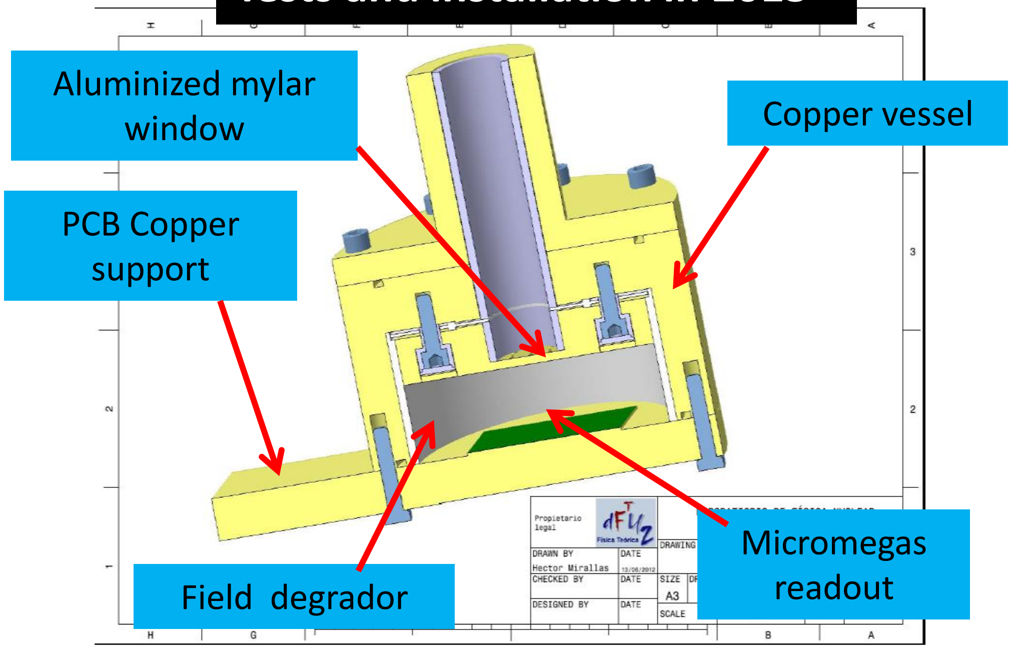
- New X-Ray telescope → best signal-to-noise ratio, increase of sensibility
- New passive shielding design: increase in Lead thicknes (~ 10 cm) and use of radiopure materials
- In view of R&D tests, a cosmic scintillator veto to be installed.
- New detector design and electronics (see next slide)

PROSPECTS (II): new *Microbulk* detector and electronics

New detector design

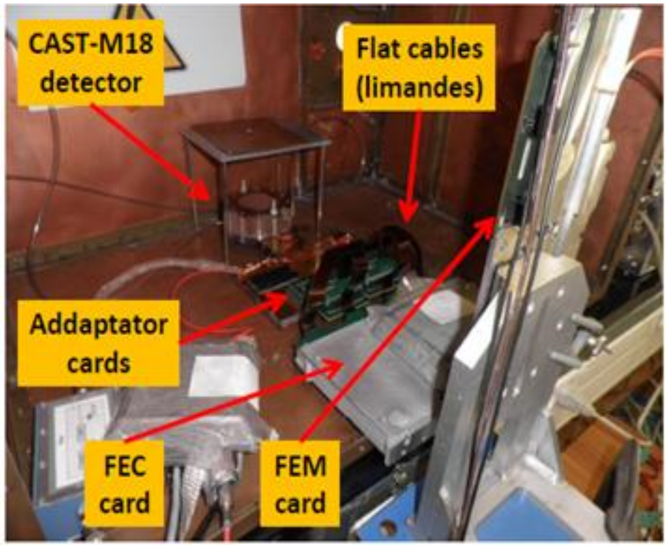
- **Body and support made out completely of copper**, also working as shielding
- Smaller window → better closure
- Kapton field degrador to uniformize the drift field, and absorb fluorescences
- **All signals** (including mesh pulse for logic trigger) extracted **through the PCB**

Tests and installation in 2013



AFTER based Electroncis (Saclay)

- Strips pulses are digitized: **Pulse shape analysisis extended to every strip** → further background reduction is expected (more information available)
- **Ready to be used**: accumulated comissioning experience under the T-REX R&D project on long term reliability tests
- To be installed in CAST in mid-2013

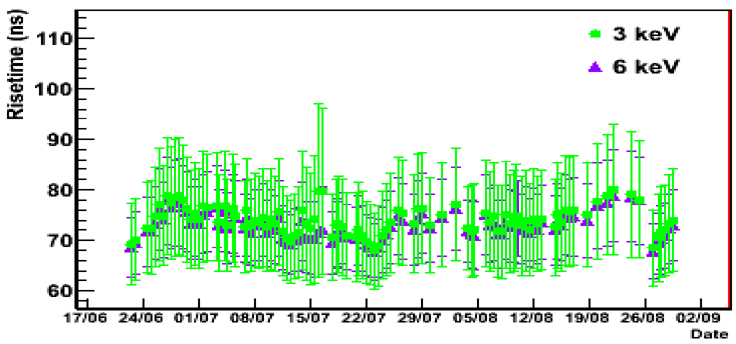


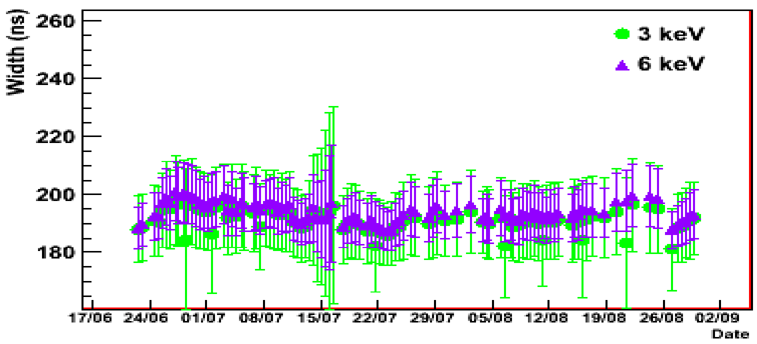
SUMMARY AND CONCLUSIONS

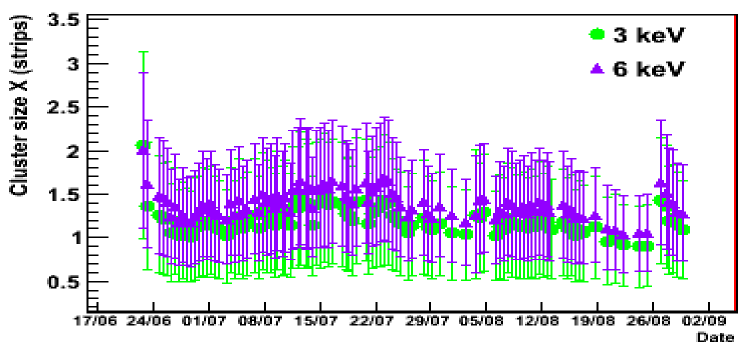
- **10 years of Micromegas** in CAST Experiment consolidate their realiability on long term runs. Continuous improvement in performance was based on:
  - **State of the art technology** (upgrading to bulk – microbulk)
  - **Shielding**
  - **Analysis**
- These principles are not exhausted. Significative new improvements are expected in the near future based on CAST Micromegas active development in:
  - **Technology** (detector chamber design, new materials, new electronics, X-ray focusing optics…)
  - **Shielding** (active shielding too [cosmic scintillator])
  - **Analysis** (AFTER → more information available, best background comprehension …)

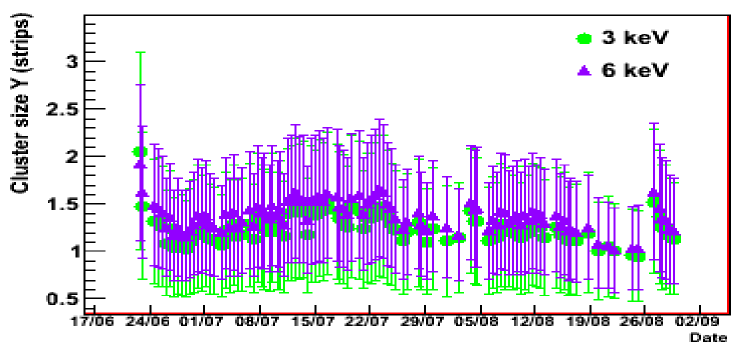
Back-up Slides

Microbulk Micromegas peformance



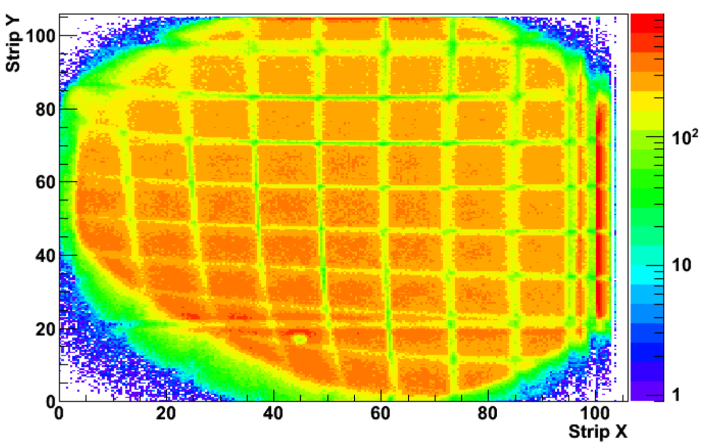




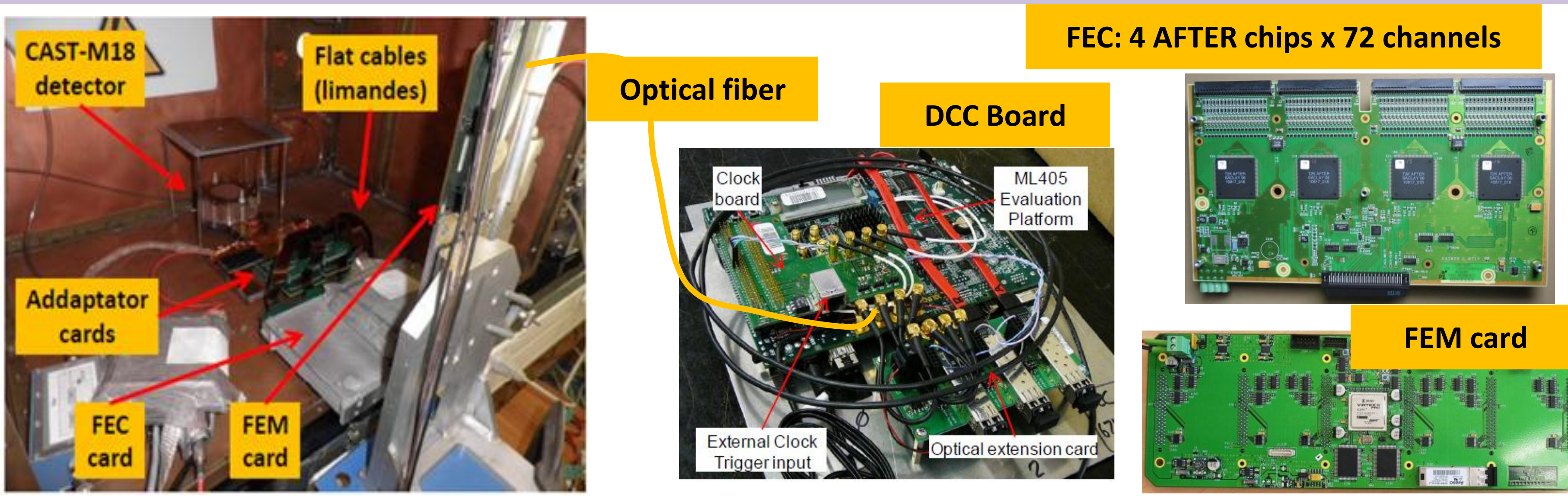


Advantages:
Uniformity, high gain, good energy resolution (13% FWHM @ 6 keV), feasability at long term runs, intrinsically radiopure, higher background rejection capabilities

Disadvantages:
Complexity of manufacturing process, fragility



PROSPECTS (III): The AFTER based Electronics



- Designed in Saclay for T2K TPC in 2006, prototyped in 2007, produced in 2008
- Strips pulses are digitized: **Pulse shape analysisis extended to every strip** → further background reduction is expected (more information available)
- Lower energy thresholds < 1 keV reachable
- Ready to be used: accumulated comissioning experience under the T-REX R&D project on long term reliability tests
- To be installed in CAST in mid-2013

- **DCC (Data Concentration Card) :**
  - Configures the Front End electronics, gets and sends the external trigger from the mesh pulse to the Electronics and receives the data through the same optical fiber.

- **FEC based on AFTER chip (ASIC For TPC Electronics Readout):**
  - The SCAs of each channel are frozen when the trigger is received. 512 samples at variable sampling frequency [10-100] MHz are digitized and stored for each strip.