Low X-ray background measurements at the Underground Canfranc Laboratory

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On behalf of the CAST Micromegas team

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A preview of this talk …

The role of low X-ray background detectors for the axion search **in the CAST experiment.**

Low nominal background **levels achievable** with Micromegas detectors.

Where it does come from the motivation to study and characterize the **influence of different shielding set-ups?**

Set-up preparation and background levels achieved Underground.

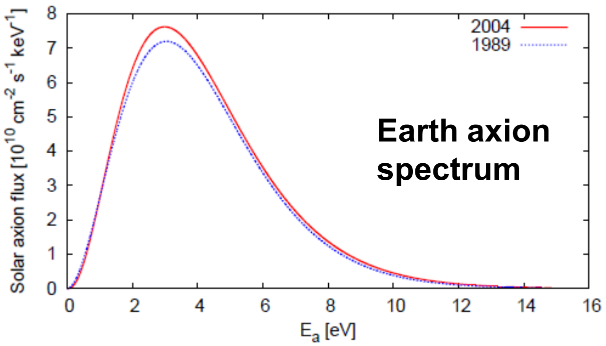
Geant4 simulations to undestand the background nature.

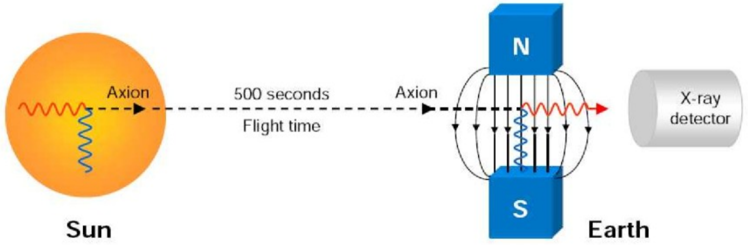
Undergoing **CAST experiment shielding tests.**

The CAST experiment

Helioscope detection principle and CAST experiment description

Idea : Axions would be produced in the Sun's core and re-converted to x-rays inside an intense magnetic field. P. Sikivie, Phys. Rev. Lett. 51, 1415–1417 (1983)





CAST is using a prototype superconducting LHC dipole magnet able to track the Sun for about 1.5 hours during Sunrise and Sunset.
Operation at T=1.8 K, I=13,000A, B=9T, L=9.26m

Expected signal

X-Ray excess during tracking at 1-10 keV region

CAST sensitivity depends on the detector background

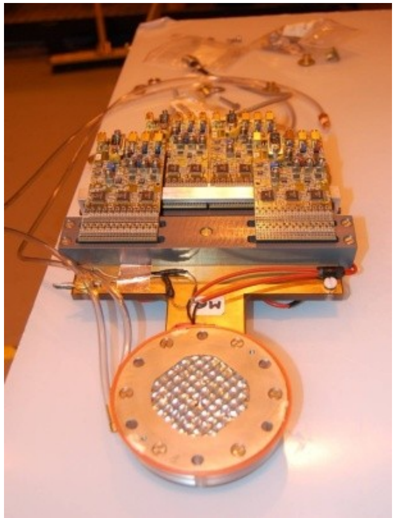
0.3 counts/hour in 14.5 cm^2

$g_{a\gamma\gamma} = 10^{-10}$ GeV^{-1}

The CAST experiment

Micromegas detectors in CAST after 2008

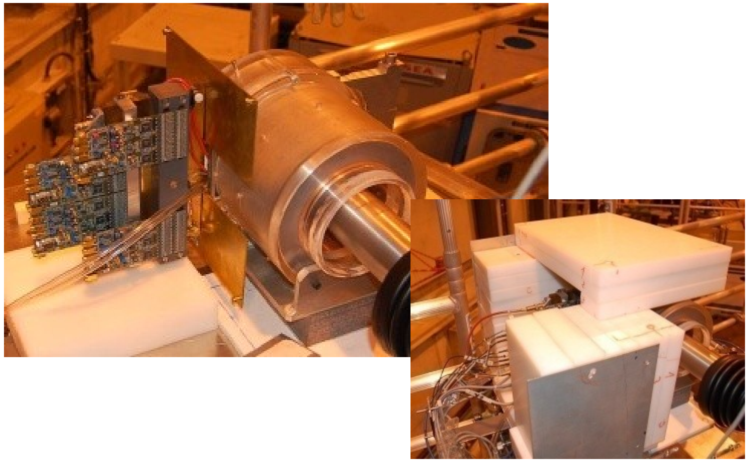
Remarkable improvement of Micromegas detectors inside CAST experiment.



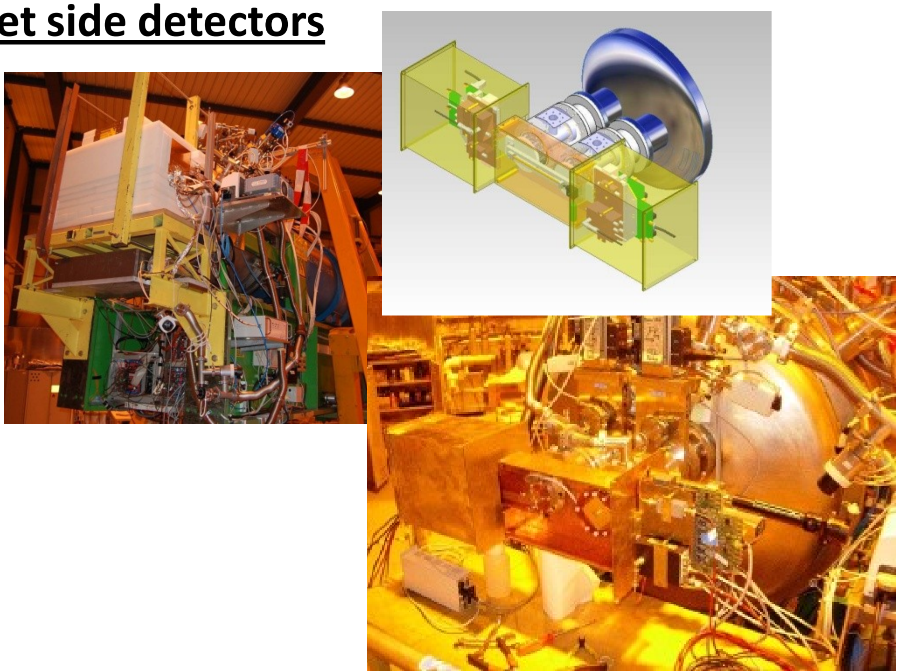
3 Micromegas (Microbulk technology) installed in 3 of the 4 CAST magnet apertures.
Operating with Ar + 2% Isobutane at 1.45 bar
Readout 106x106 strips -> 6x6 cm2
Plus mesh temporal signal

Detectors installation in 2008

Sunrise side detector



Sunset side detectors

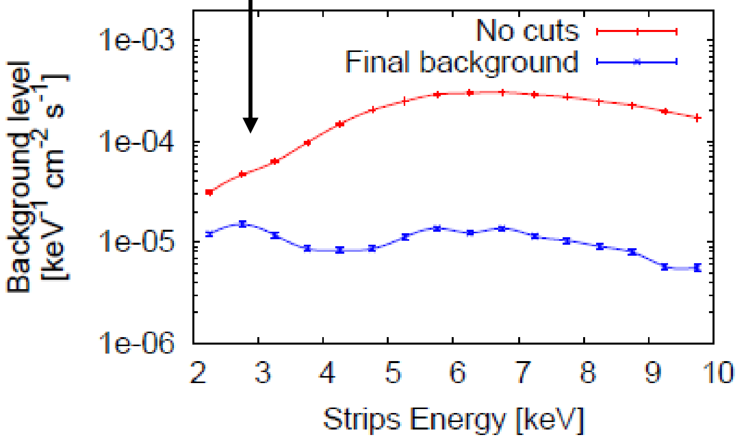


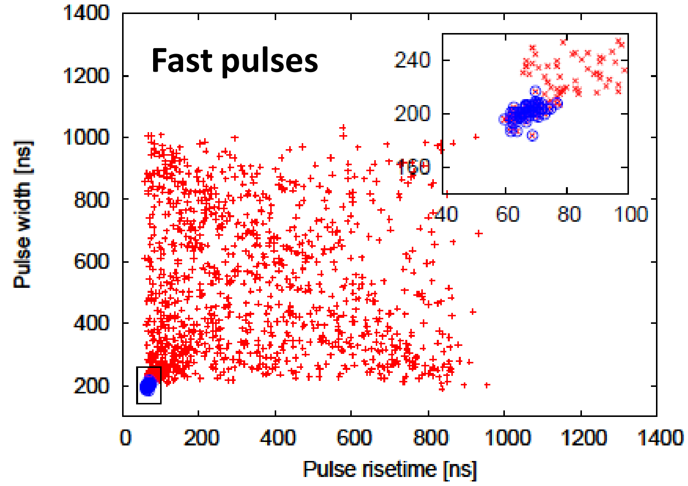
The CAST experiment

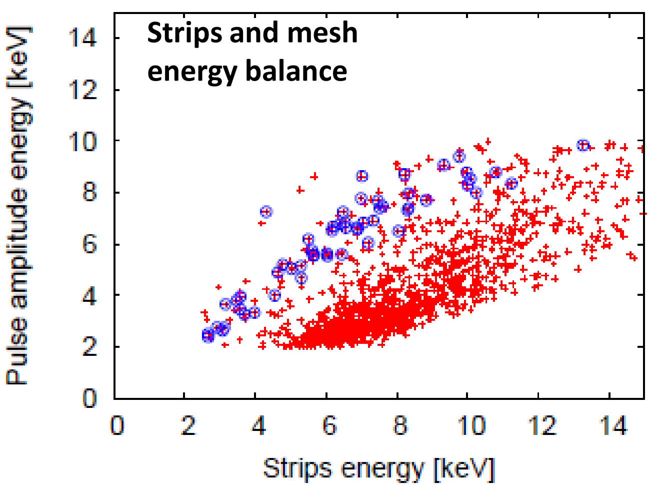
X-ray events selection is obtained from temporal and spatial information

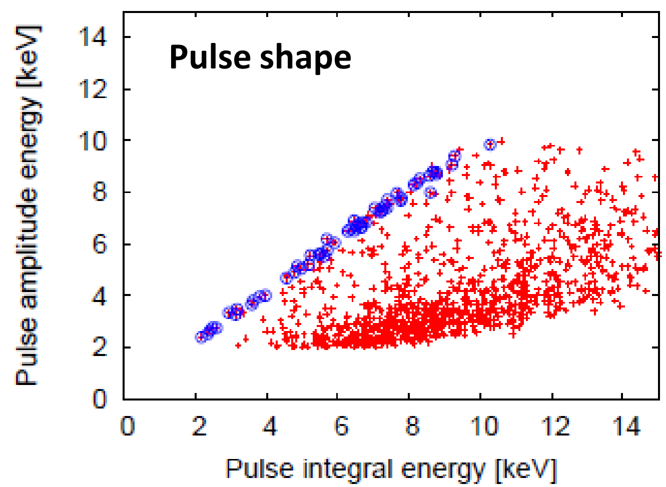
6keV events from an ^{55}Fe source are used for X-ray selection and background discrimination.

No cuts: Including only 1 xy-cluster events





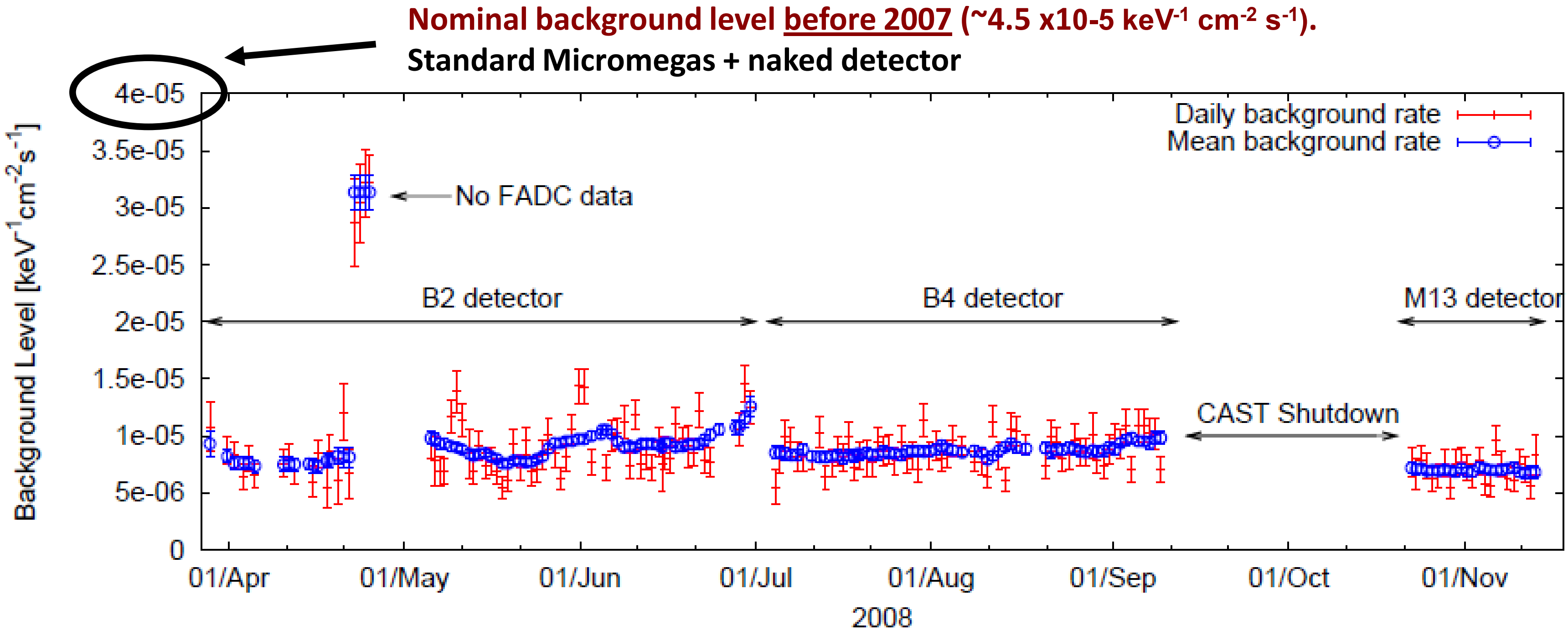




The CAST experiment

Nominal background levels in CAST during last data taking periods.

Mean background evolution during 2008 data taking period for Sunrise side detector.

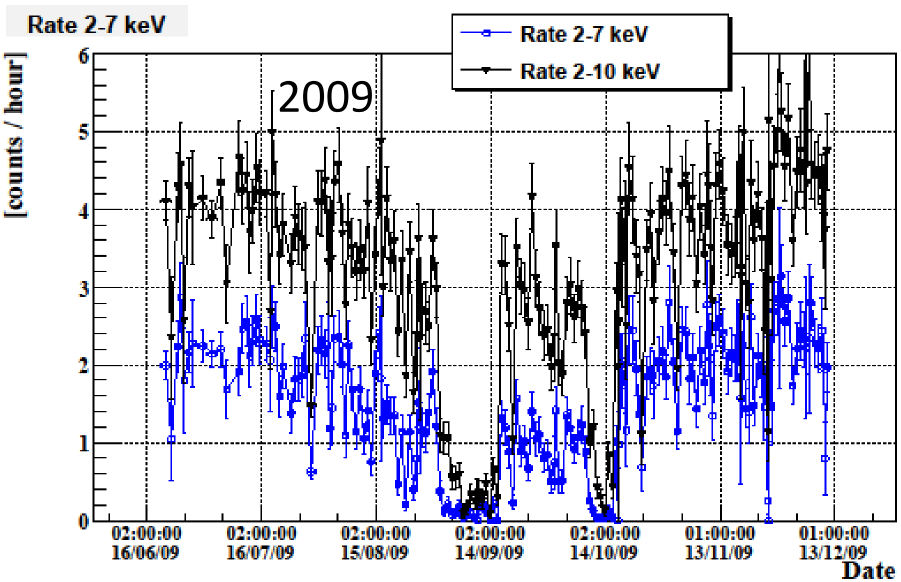


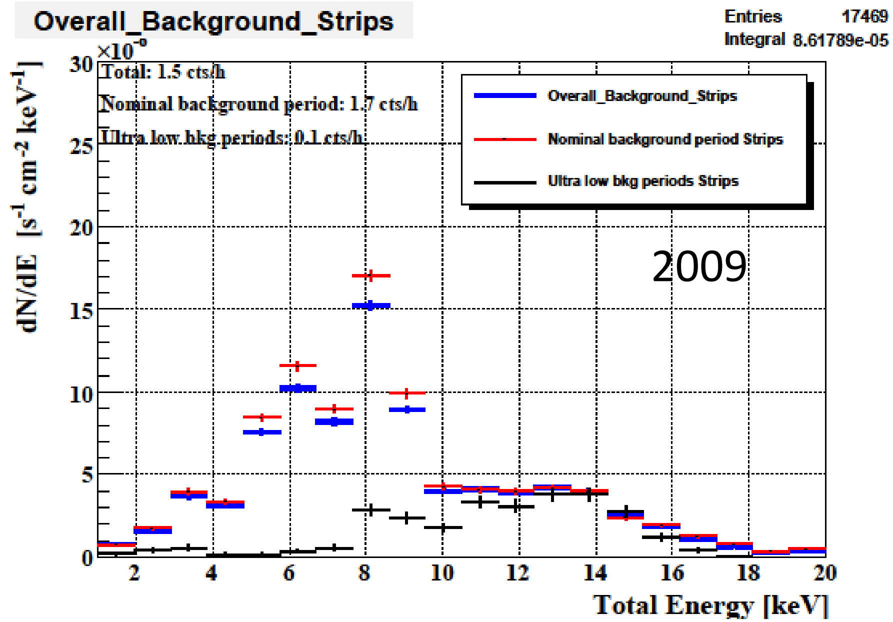
The nominal background during recent data taking phase is below 10^{-5} keV^{-1} cm^{-2} s^{-1}

Meaning around 2.25 counts per hour at the CAST sensitive area and energy.

The CAST experiment

Ultra-low background periods observed in CAST



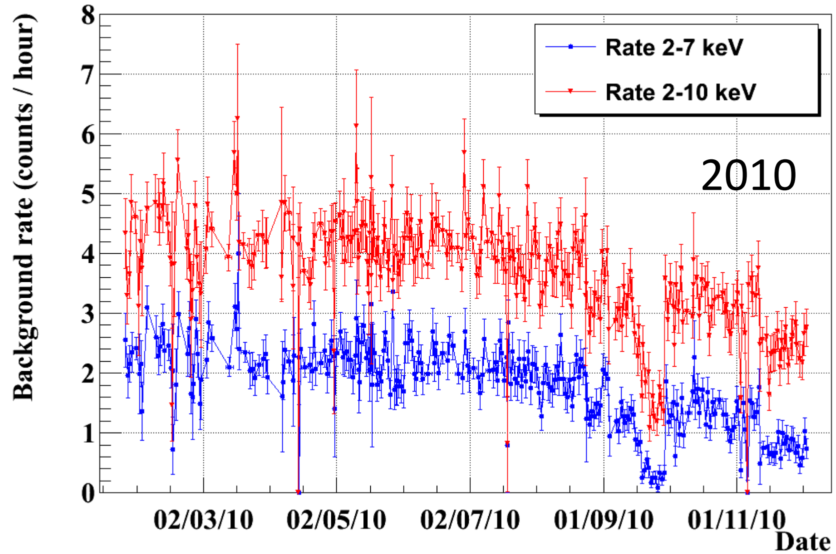


Several ultra-low background periods appeared in 2009 and 2010.

Impressive result, but yet non well understood background reduction.

Radon? Nitrogen flow? Humidity?
Always around September.

Lower level would increase our sensitivity, so …
Where is the lowest limit of background level?



Measurements at the Canfranc Underground Laboratory

We need to know …

What is the nature of the background reduction in CAST?

Which is the lower limit of background level we can reach?

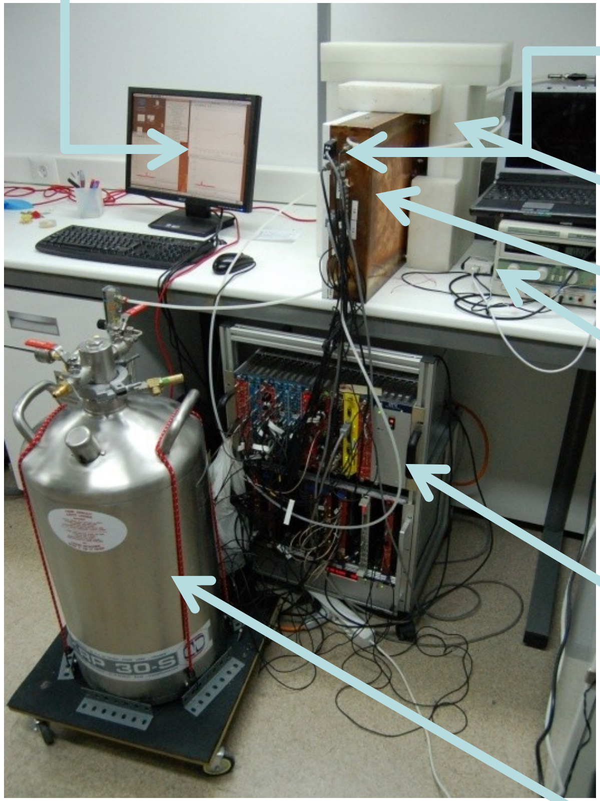
Lower level would increase our sensitivity, so …

It is important to study and to understand the influence of external background in order to improve our set-up on CAST.

Thus, further tests under laboratory controlled conditions are well motivated

Measurements at the Canfranc Underground Laboratory

Set-up at the laboratory in the Universty of Zaragoza



New acquisition software completely based in C++, ROOT, python and GNUPLOT.

Gas, Ar + 2% iso, flowing in open loop with flow and pressure controlled

Shielding reproduces sunrise configuration.

Faraday box prepared for automatic calibrations with ^{55}Fe source.

Slow control: temperature and pressure and detector currents

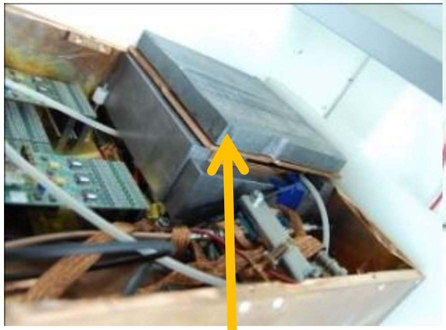
Some modifications in electronics. Fundamental modules are the same.

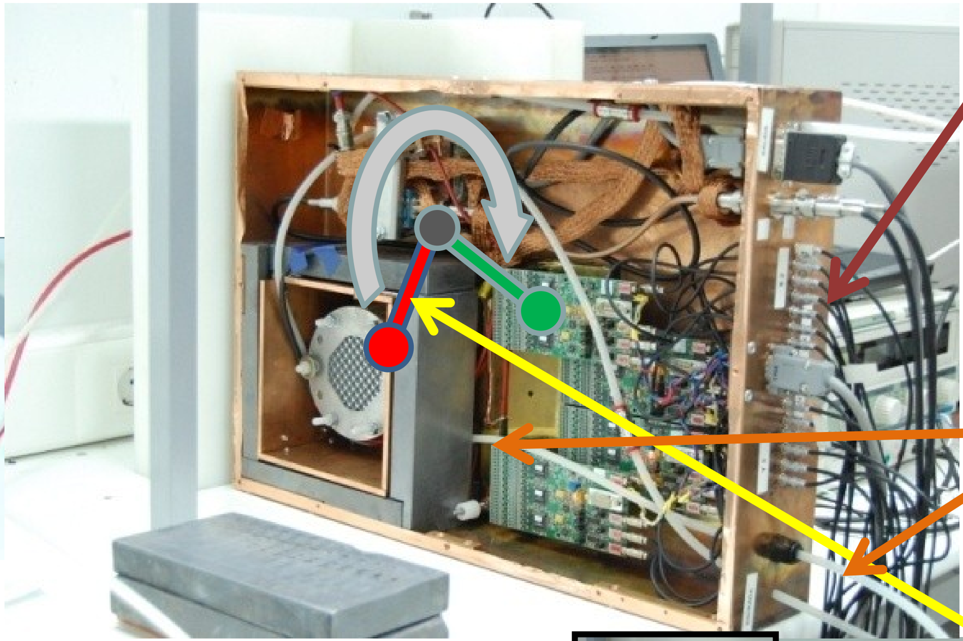
Nitrogen flux = 30 - 50 l/h (for vol < 17 l)
Capacity for more than 2 weeks.

Measurements at the Canfranc Underground Laboratory

The detector Faraday cage set-up

internal configuration: front-end electronics and shielding





All the connections extracted via feedthroughts.

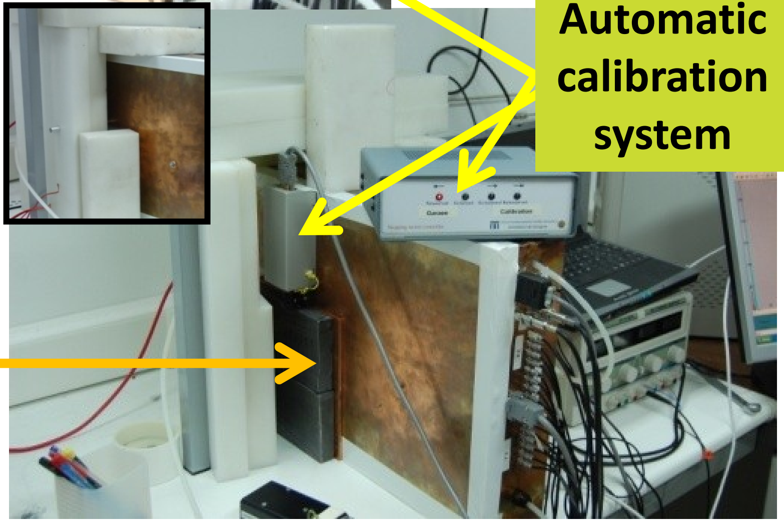
N2 flowing into the inner shielding

Automatic calibration system

4π inner shielding: 5 mm Cu + 25 mm Pb

(With exception of a minimum gap for the calibrator to introduce the source)

+ 8 cm polyethylene external shielding



Measurements at the Canfranc Underground Laboratory

The Micromegas X-ray detector fingerprints (Microbulk M10 detector)

Installation in the Canfranc Underground Lab (LSC) situated inside an old train tunnel under the Tobazo mountain in the spanish Pyrenees at the deep of 2500 m.w.e

- 10^4 reduction factor in cosmic muons
- Stable environmental conditions (T, P, humidity)
- Environmental gamma radiation well known.

M13 microbulk detector, when installed at surface, registered ~1 Hz trigger rate and performed a final background level of:

~$8{\cdot}10^{-6}$ counts keV^{-1} cm^{-2} s^{-1} (2-7 keV)

Independent on several amplifier settings and detector gain. Once underground trigger rate is only ~0.2 Hz and the background:

~$9{\cdot}10^{-6}$ counts keV^{-1} cm^{-2} s^{-1} (2-7 keV)

- Cosmic rays domain the trigger rate at surface but had only a small effect in background after offline analysis, events are easily discriminated.

- In principle the level obtained is comparable to CAST nominal background with a CAST like shielding.

Measurements at the Canfranc Underground Laboratory

Equipping the lab for installing lead and preparing cleaning material

Underground habitants

Final shielding emplacement

Roman Lead bricks
(4 tons)

Cleanning material

Measurements at the Canfranc Underground Laboratory

Lead bricks cleaning process

Cleaning and transporting lead is a **heavy** task.

Cleaning ingredients:

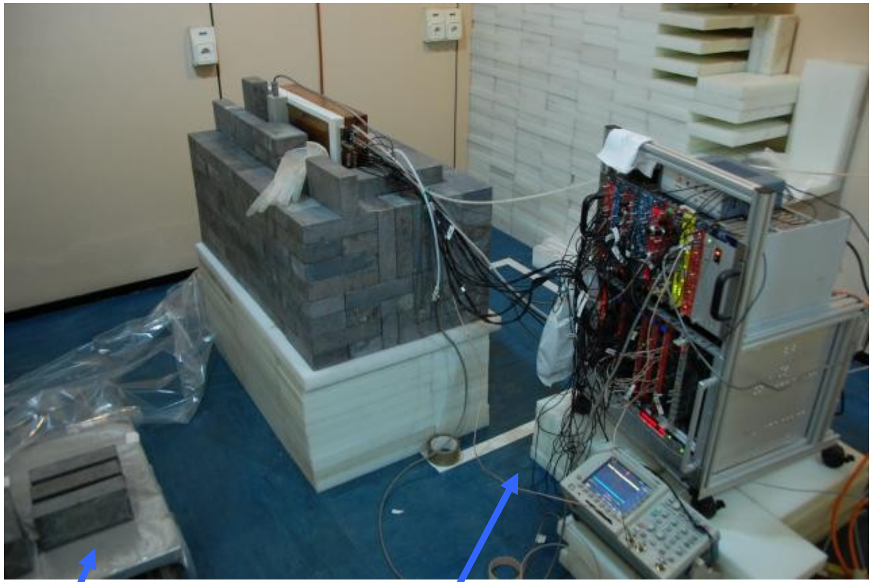
1. Nitric acid (4%). HNO_3
2. Distilled water
3. Alcohol (as much as better)

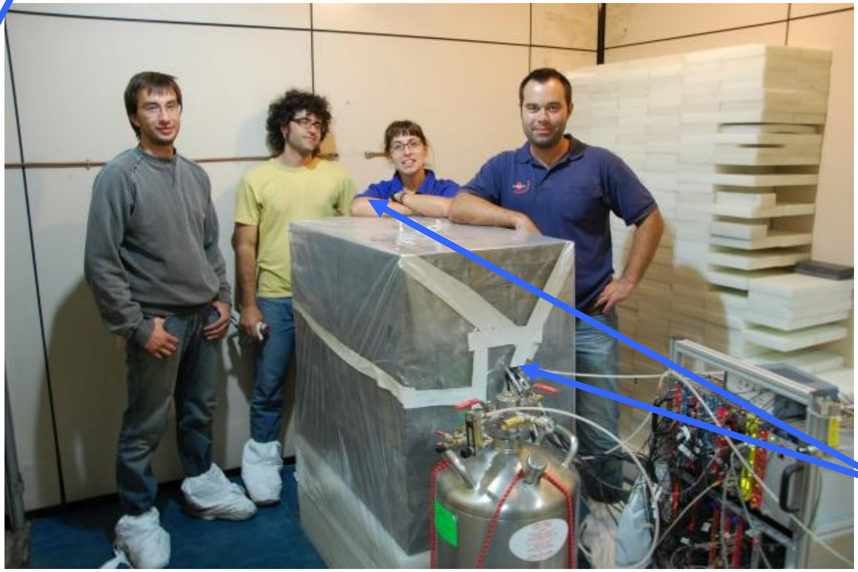
Cleaning process

Lead transportation device

Measurements at the Canfranc Underground Laboratory

Final shieding installation





Bricks ready to be mounted.

Crosschecking electronic noise and acquisition tuning

Small cabling passthrough hole

Some members of the crew proud of the new heavy gift just installed.

Measurements at the Canfranc Underground Laboratory

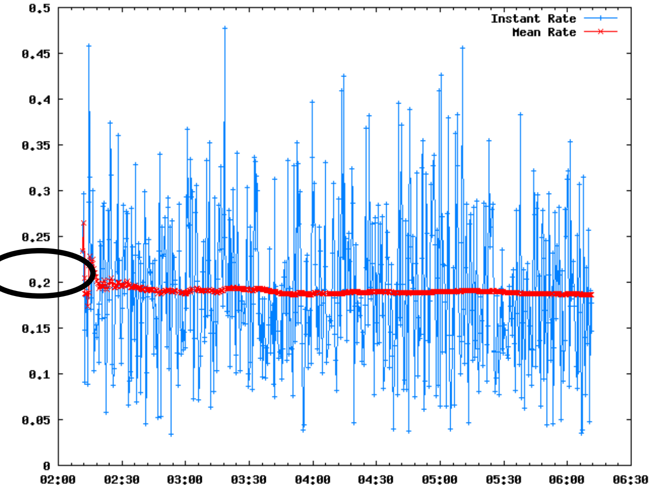
Effect on the overall trigger rate

CAST-like shielding

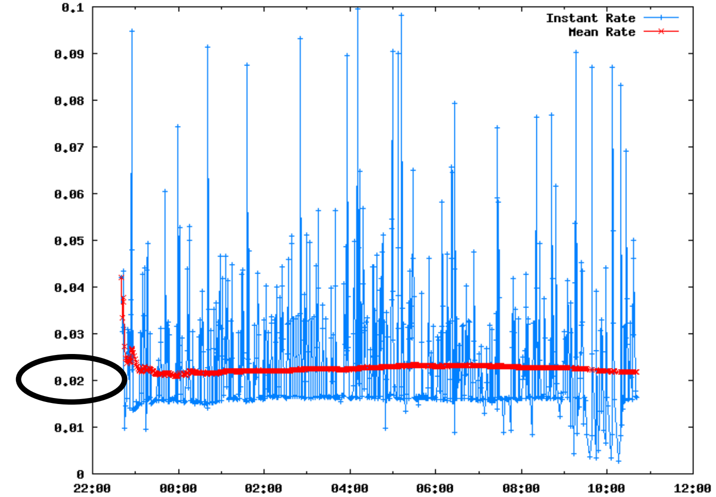
Shielding upgrade

Trigger rate before cuts

0.2Hz



0.02Hz

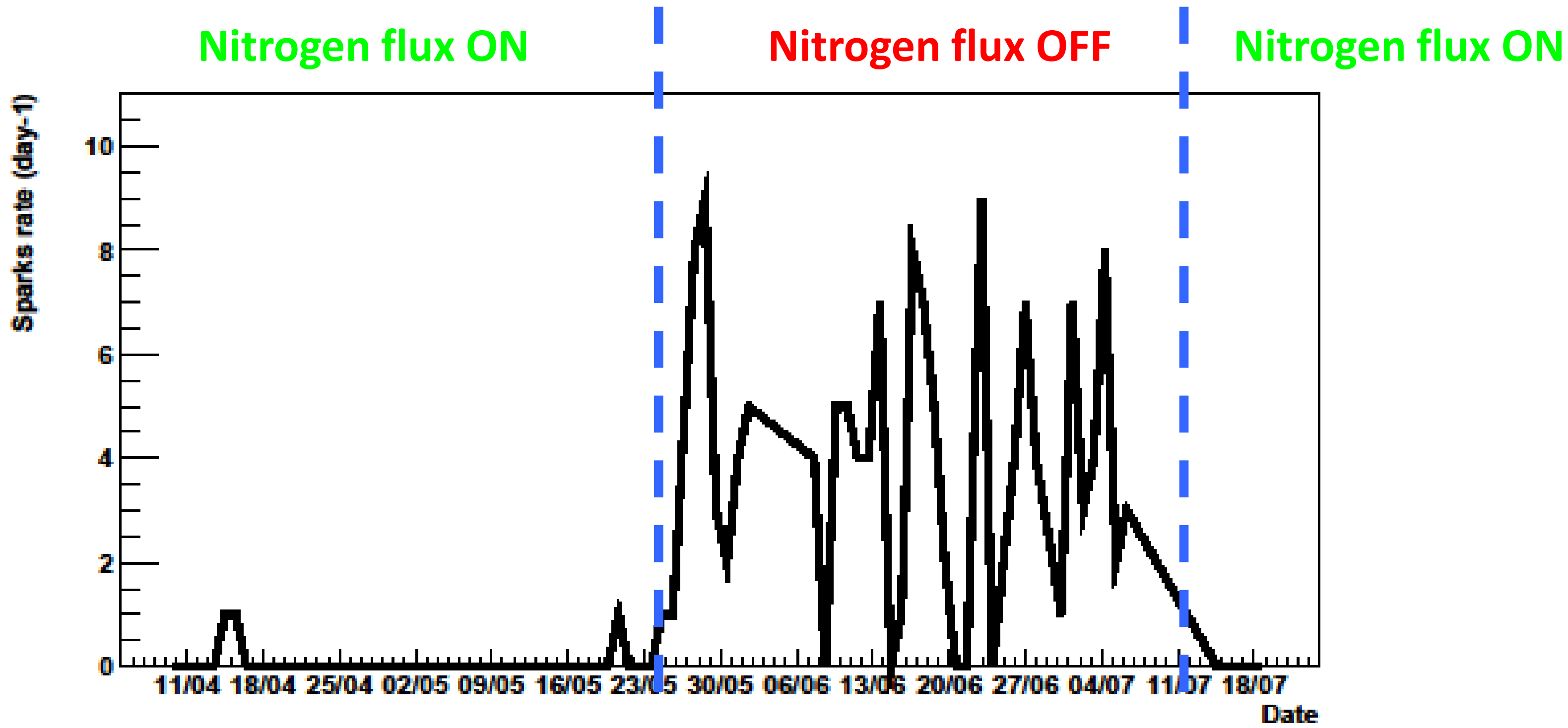


Measurements at the Canfranc Underground Laboratory

Nitrogen flux effect on the spark rate

Spark rate as measured by the power supply current increases when the Nitrogen flux is disconnected.

Since the sparks were not observed on surface, they are probably due to the higher radon abundance underground (4.8 MeV αs).



Measurements at the Canfranc Underground Laboratory

3 different shielding configurations

CAST-like:
No external Pb
(but still 4π)

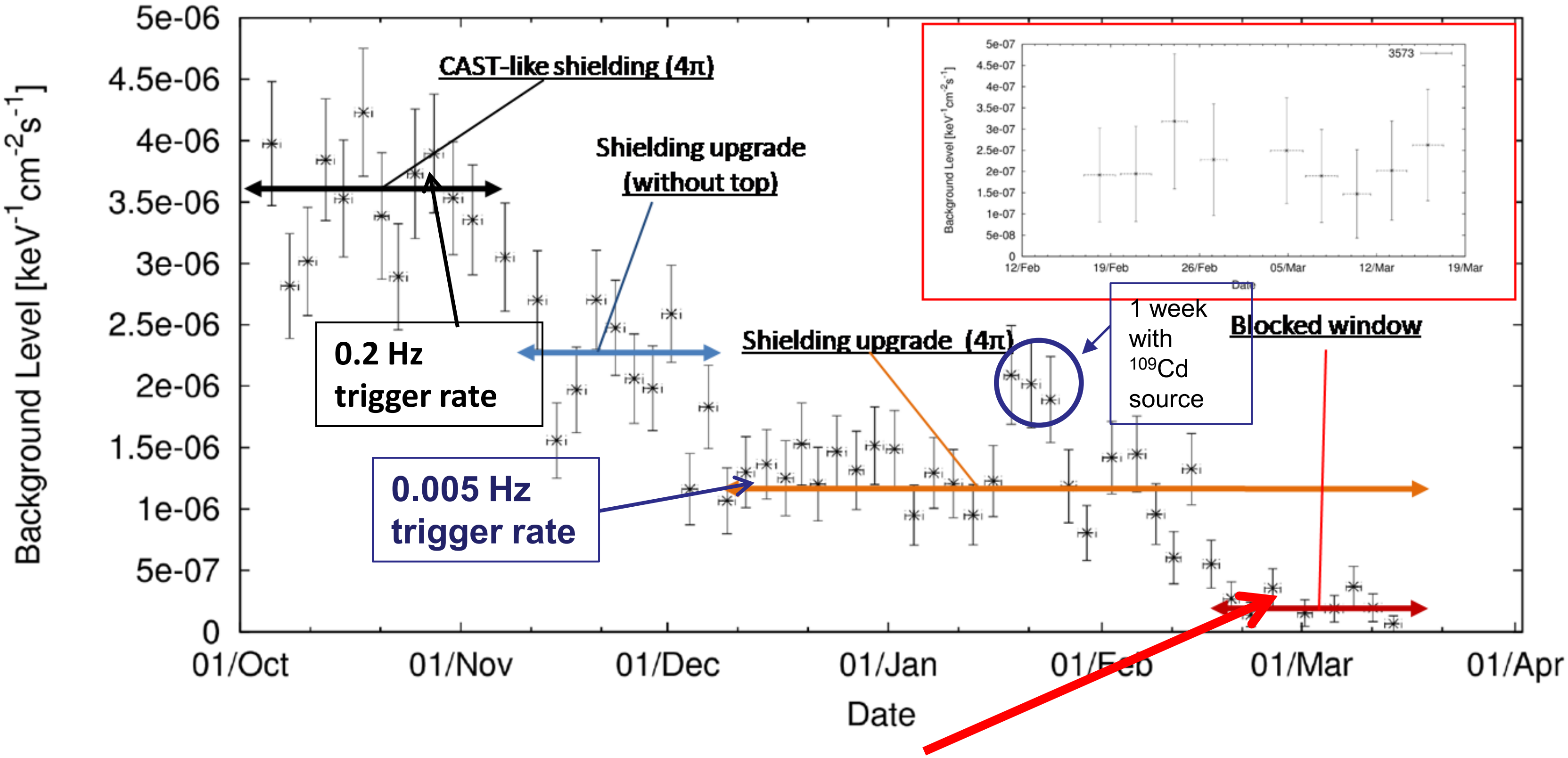
"Half" closed:
5π/6 20 cm external Pb

Complete:
20 cm
external Pb

0,5 cm Cu + 2,5 cm Pb
+ Nitrogen flux to avoid Rn

Measurements at the Canfranc Underground Laboratory

3 different configurations underground



First approach to final background limited only by intrinsic radioactivity (from microbulk, chamber materials, inner shielding):

< $2\cdot10^{-7}$ counts keV^{-1} cm^{-2} s^{-1} [2-7 keV] (~1 count/day)

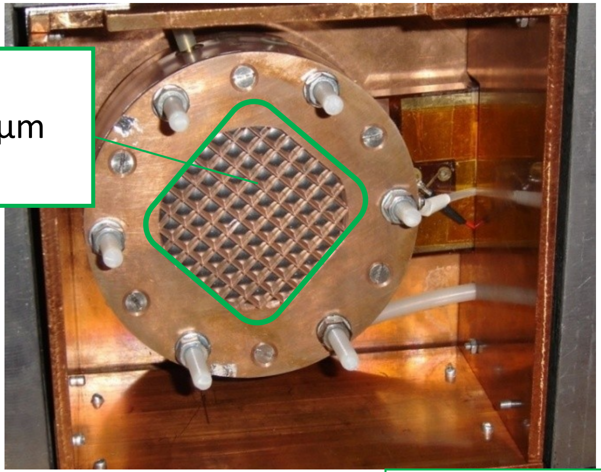
This result proves that background levels >20 times lower that current CAST MM nominal background are possible via shielding improvement.

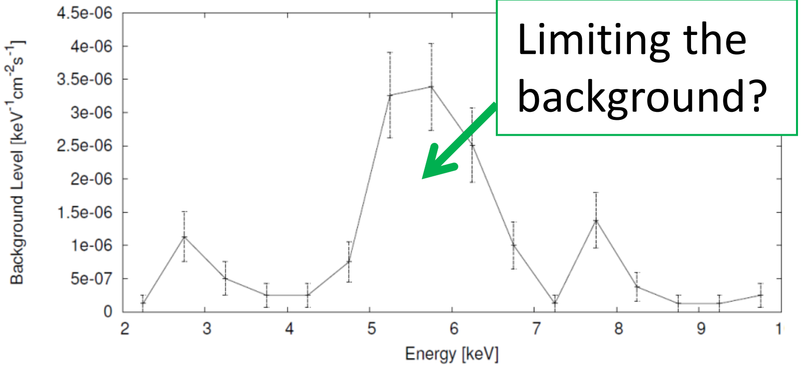
Measurements at the Canfranc Underground Laboratory

Contamination coming from the drift window side

The most internal part of the shielding is based in copper, including the cathode with the calibration window in Canfranc's set-up.
An excess of counts around 5-6 keV made us think about the presence of a soft X-rays source in the environment of the detector (maybe ^{55}Fe contamination) and we proceeded to block the calibration window with a thin layer of copper.

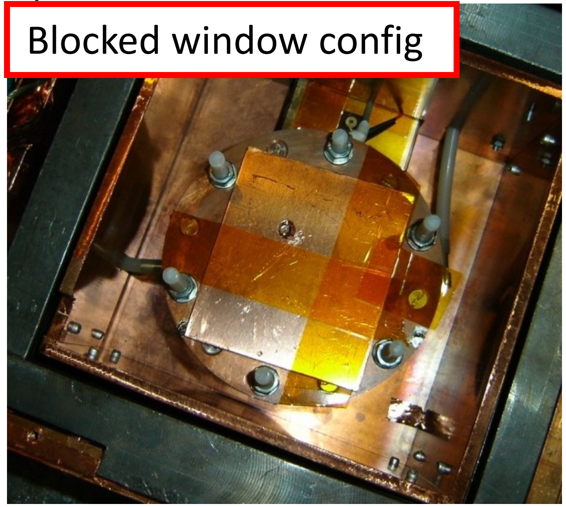
Calibration window (4 μm thickness)

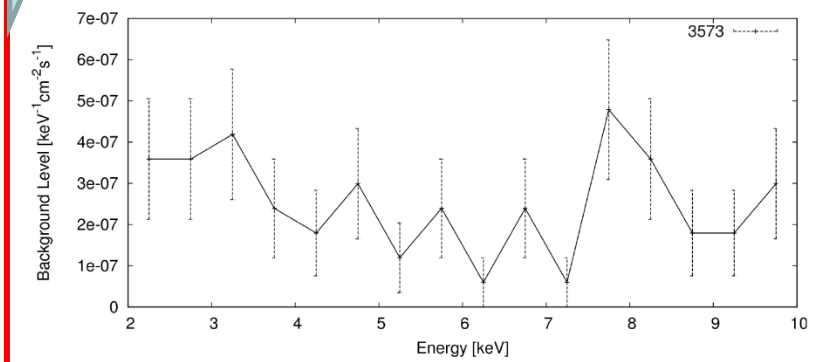




Limiting the background?

Blocked window config



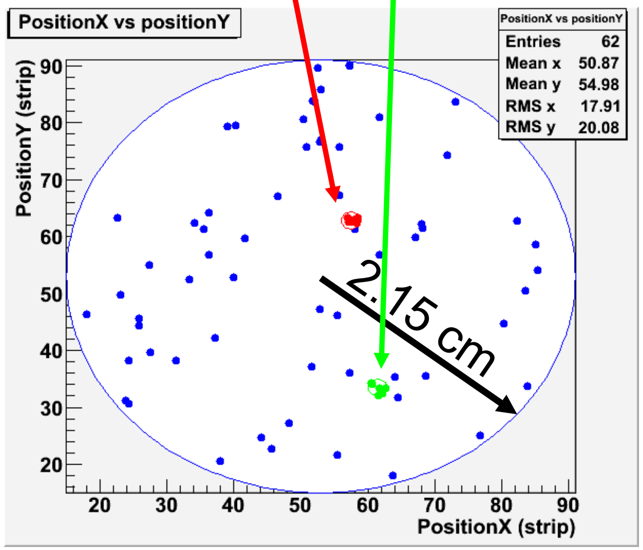


Measurements at the Canfranc Underground Laboratory

The lowest background level reached

2 Hotspots are found in the background hitmap during these days.

A total of 21 events from 62! concentrated in 2 spots of $2.2mm^2$: 9 and 12 events

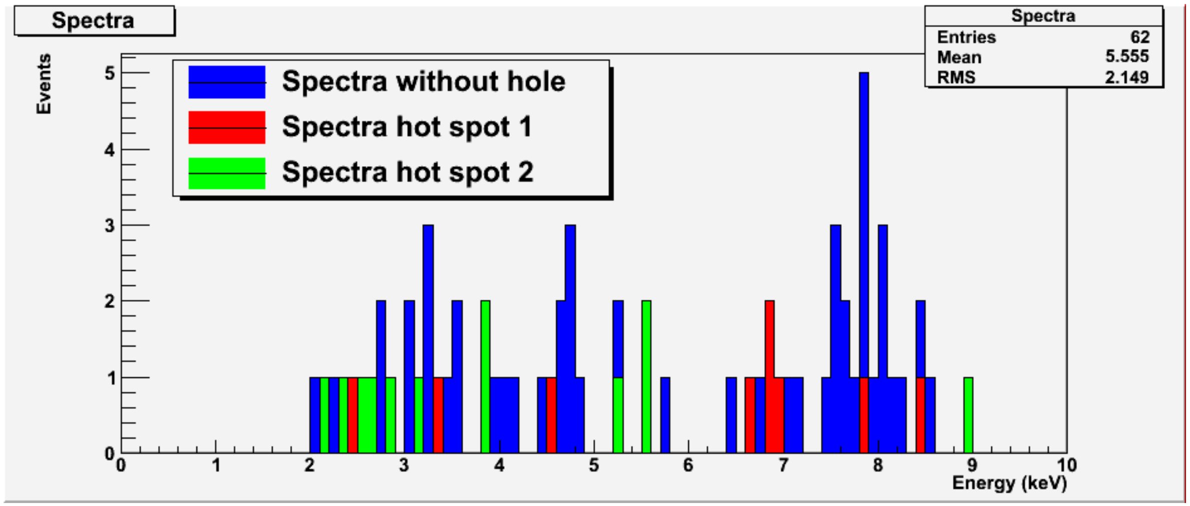


Removing the hotspots from the data we obtain the following background lower limit

Effective exposure time 993.825 hours

Rate (2-7keV)	1.46e-07 $keV^{-1}\cdot cm^{-2}\cdot s^{-1}$
Rate (2-9 keV)	1.71e-07 $keV^{-1}\cdot cm^{-2}\cdot s^{-1}$

Effect from 8keV peak



Measurements at the Canfranc Underground Laboratory

The lowest background level reached

2 Hotspots are found i… background hitmap d… these days.

A total of 21 events fr… concentrated in 2 spo… $2.2 mm^2$: 9 and 12 ev…

Removing the hotspots from the data we obtain the … …ver limit

….825 hours

…$keV^{-1} \cdot cm^{-2} \cdot s^{-1}$

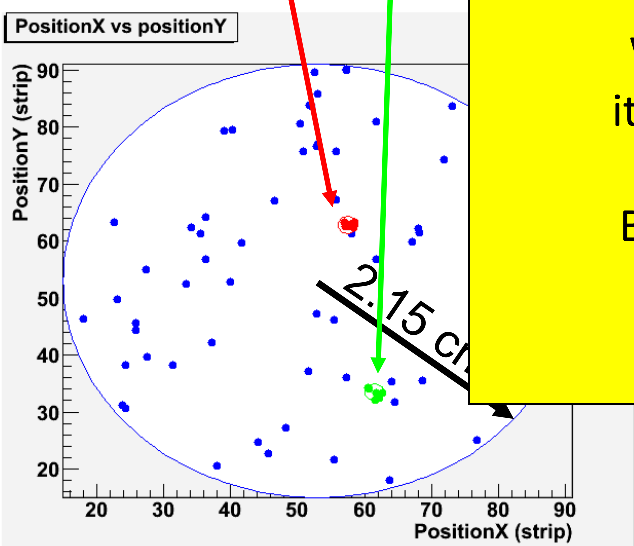
…$keV^{-1} \cdot cm^{-2} \cdot s^{-1}$

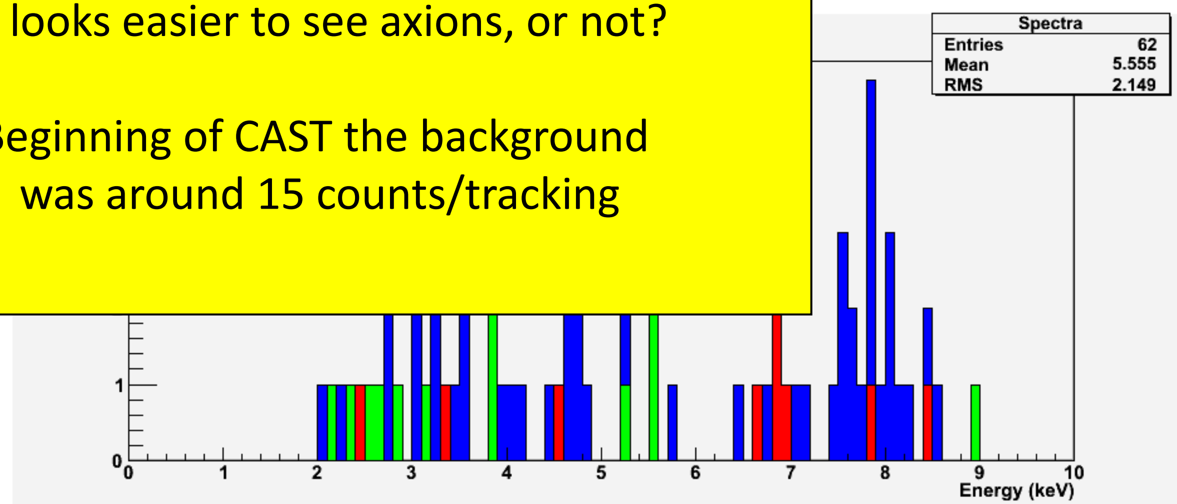
Effective exposure is 41 days.
If we do not consider the events in the spot it means **1 count/day**!
(In the actual CAST detection area)

On average, 1 background count every 16 trackings!

With a background level like that, it looks easier to see axions, or not?

Beginning of CAST the background was around 15 counts/tracking

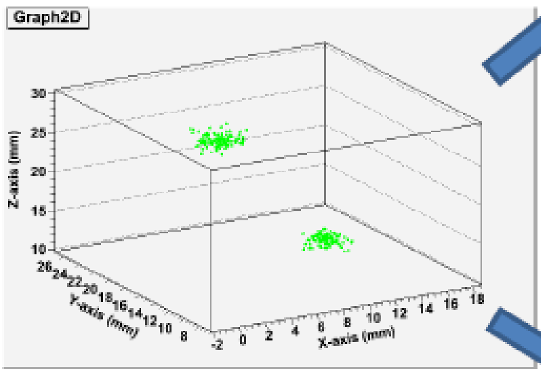


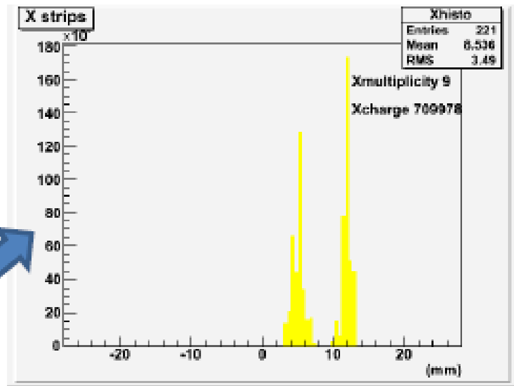


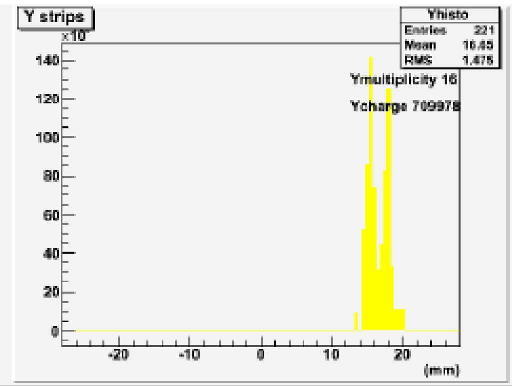
Geant4 Simulations

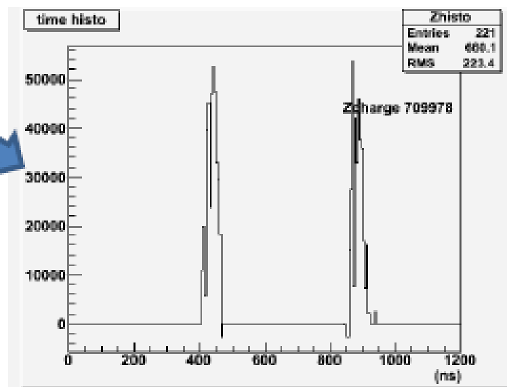
Strips and mesh readout generation from Geant4 simulation.

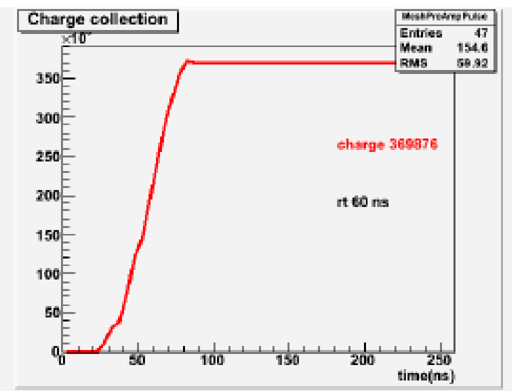
Simulations include a detailed geometry and readout electronics, including temporal and spatial signal, in order to apply the corresponding discrimination cuts afterwards.

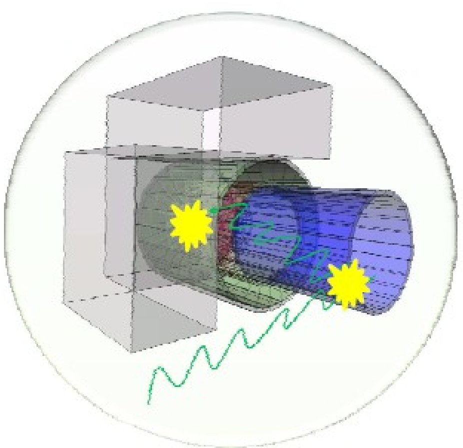








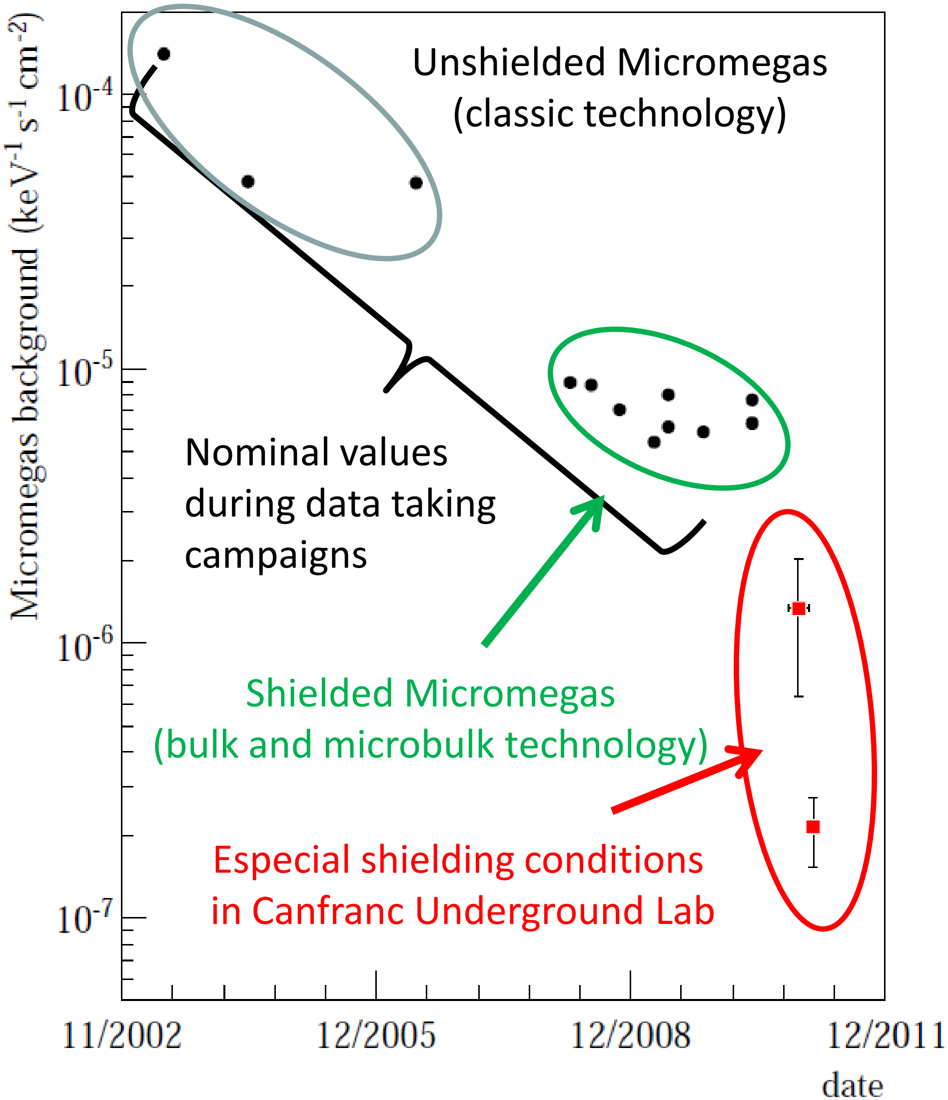




Comparison between experimental results and outcome of simulations will allow **to determine the nature of the background**, and **to optimize future shielding set-ups**.

Shielding improvement at the CAST experiment

Final conclusions



The improvement of the shielding design.

+

The fact that microbulk technology is built from low radiactivity materials.

+

The improved discrimination capabilities of the microbulk detector given by a better energy resolution.

=

An improvement in the lower background level reached during last years.

Backup Slides

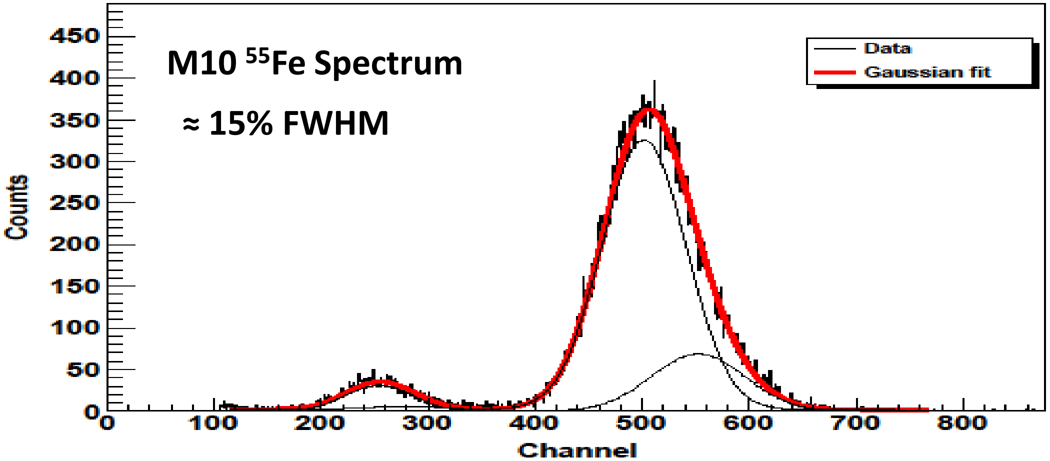
Measurements at the Canfranc Underground Laboratory

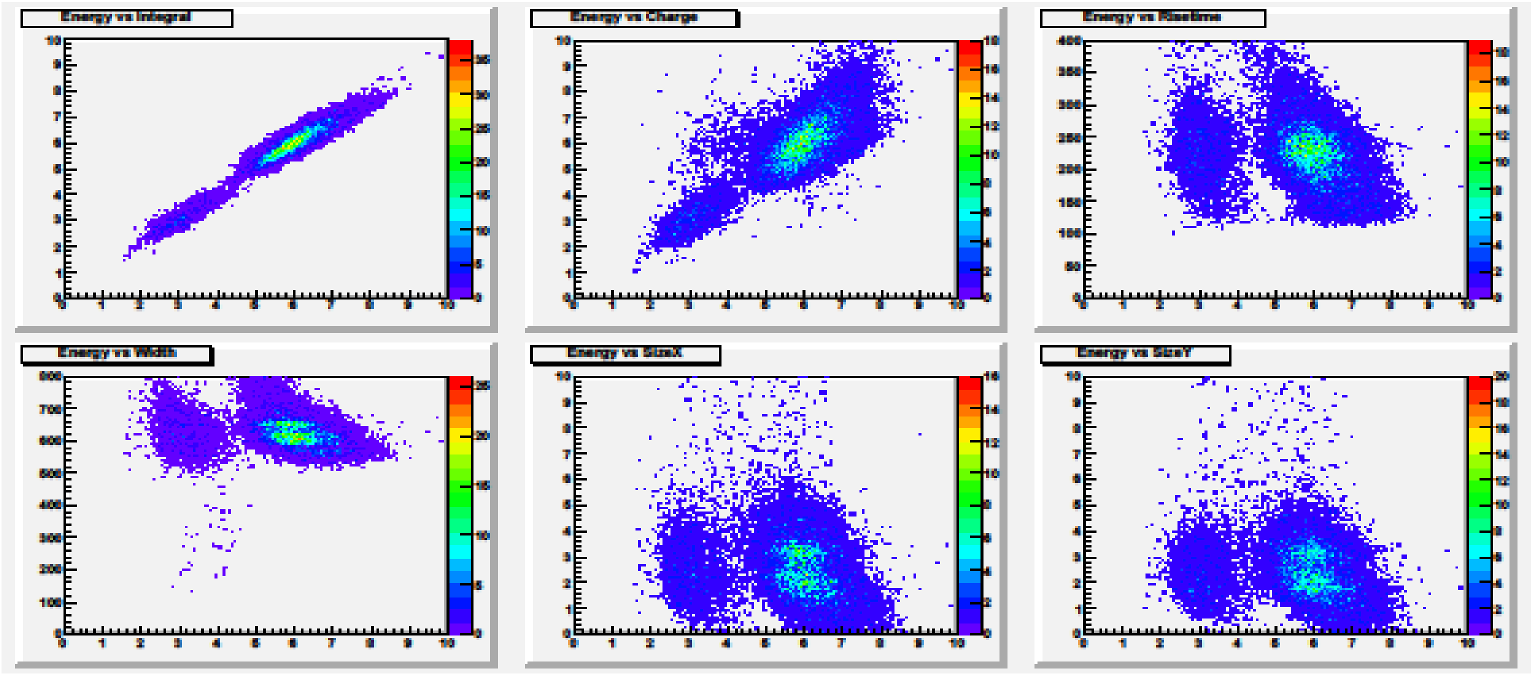
The Micromegas X-ray detector fingerprints (Microbulk M10 detector)

- Similar CAST operating conditions.

- Ar+2% Iso at 1.4 bar.

- Good energy resolution irradiating the entire surface of the detector.





Measurements at the Canfranc Underground Laboratory

Many different settings for understanding influence on background

Each 1-2 weeks a new setting/modification is applied in order to see the influence on the background level.

Main changes concern to Timing Settings and Drift window materials.

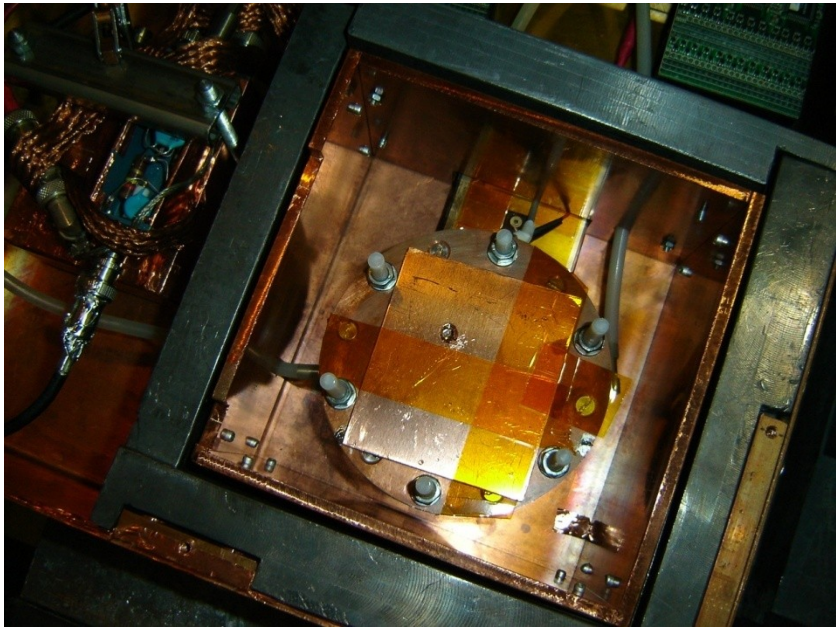
RunSeries	Starting date	Shielding	Others	Observations	Mean rate (keV^{-1} cm^{-2} s^{-1})
5600-5623	27/10/2010	Just CAST	1st Cu drift	(round holes drift)	~$4 \cdot 10^{-6}$
5624…	03/11/2010	Pb castle, half closed	1st Cu drift		~$3 \cdot 10^{-6}$
5700	18/11/2010	Pb castle, half closed	2nd Cu drift, (from now on)	(cast-like strongback)	~$2 \cdot 10^{-6}$
5800	26/11/2010	Pb castle, half closed	No 55Fe source	Only background runs	~$2 \cdot 10^{-6}$
5900	03/12/2010	Complete Pb castle	55Fe inside. Calibrator not working.	First Run is a calibration. Rest are only bkg.	~$1 \cdot 10^{-6}$
6000	14/12/2010	Complete Pb castle	Everything working		~$1 \cdot 10^{-6}$
7000	28/12/2010	Complete Pb castle	55Fe source attenuated	(factor 5 attenuation)	~$1 \cdot 10^{-6}$
7100	20/01/2011	Complete Pb castle	109Cd source replacing 55Fe	Calibrator stucks Run#7115 Ar bottle changed	~$1 \cdot 10^{-6}$
7200	02/02/2011	Complete Pb castle	55Fe source replacing 109Cd		~$1 \cdot 10^{-6}$
7300	10/02/2011	Complete Pb castle	T.A. Settings changed 100/100 → **50/50**	Peak degeneration	~$1 \cdot 10^{-6}$
7400	16/02/2011	Complete Pb castle	Copper piece installed in the strongback with a *small* hole for calibrations	Noise appear Ultra low background reached	~$2 \cdot 10^{-7}$
7500	03/03/2011	Complete Pb castle	Fine gain reduced	Minimization of noise	~$2 \cdot 10^{-7}$
7600	09/03/2011	Complete Pb castle	Feedthrough replaced	Noise disappear	~$2 \cdot 10^{-7}$
7700-7725	17/03/2011	Complete Pb castle	Copper piece in the strongback upgraded big hole and few cm to the strongback		~$2 \cdot 10^{-7}$
7725-???	24/03/2011	Complete Pb castle	T.A. Settings changed 50/50 → **100/100**		

Measurements at the Canfranc Underground Laboratory

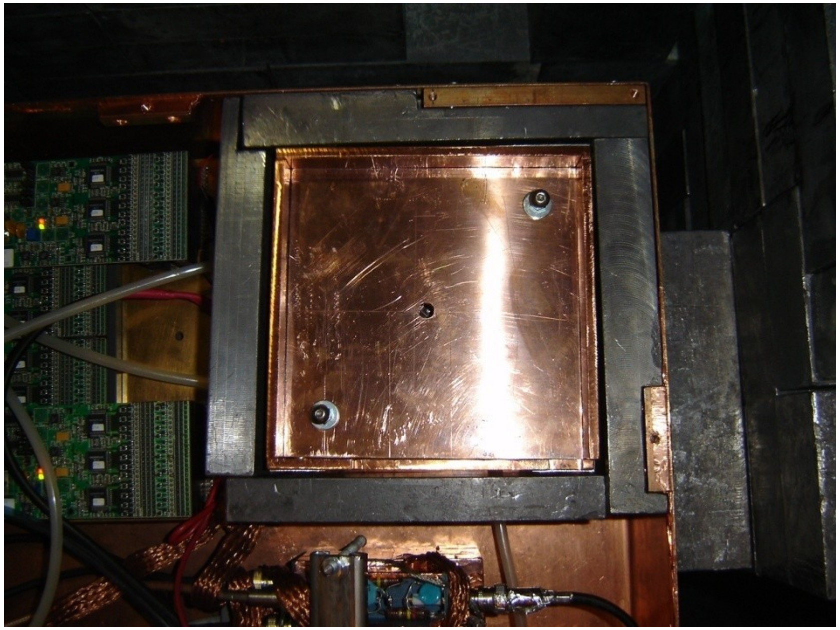
Many different settings for understanding influence on background

An example, 2 comparable different settings with blocked window.

Background Level
1.32e-07 $keV^{-1} \cdot cm^{-2} \cdot s^{-1}$



Background Level
1.63e-07 $keV^{-1} \cdot cm^{-2} \cdot s^{-1}$



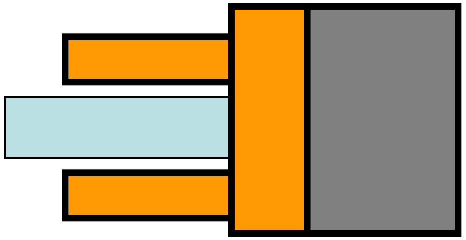
Shielding improvement at the CAST experiment

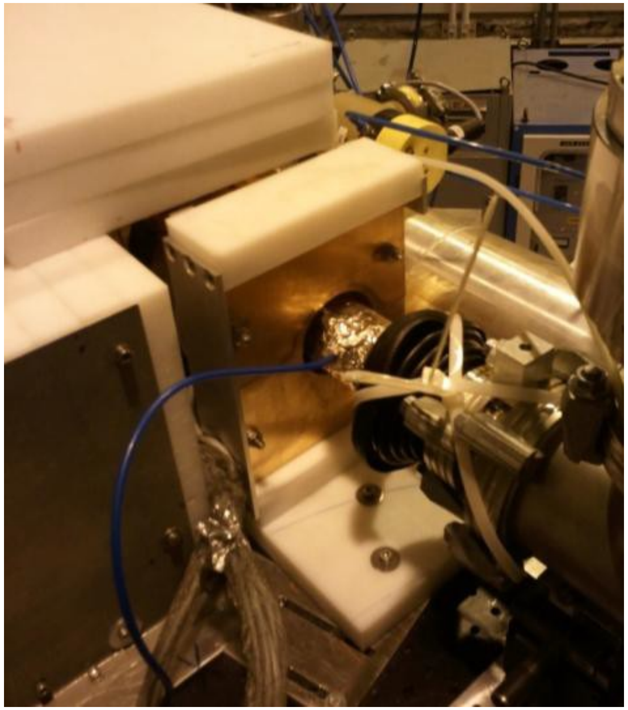
CAST Sunrise detector shielding upgrade

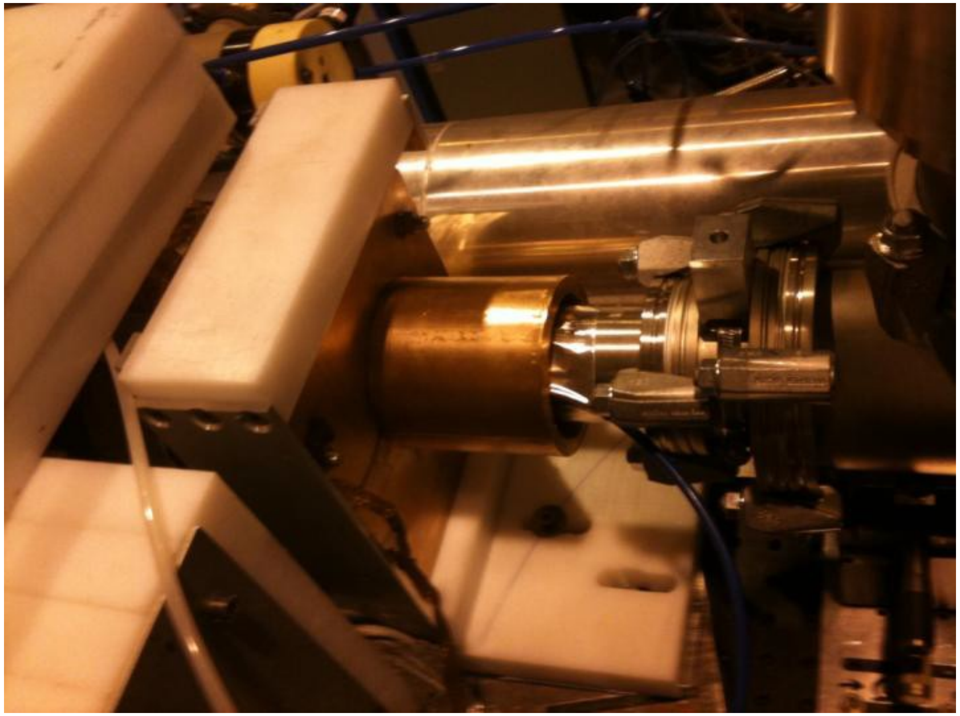
Additional tests are actually going on at CAST experiment in order to improve the background level.

The idea is to reduce the background by shielding the iron stainlessteel pipe which could produce additional fluorescence.

Background analysis is going on already, a considerable reduction has been observed, but it is early to give a final value.



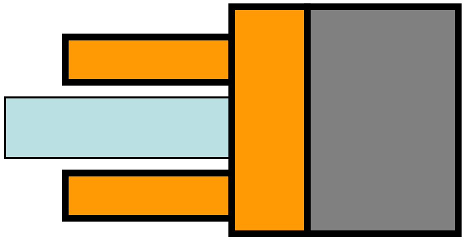




Shielding improvement at the CAST experiment

CAST Sunrise detector shielding upgrade

Additional tests are actually going on at CAST experiment in order to improve the background level.



The idea is to reduce the background by shielding the iron stainlessteel pipe which could produce additional fluorescence.

Background analysis is going on already, a considerable reduction has been observed, but it is early to give a final value.