Performance of the micromegas detector in the CAST experiment

Konstantinos Kousouris

Demokritos
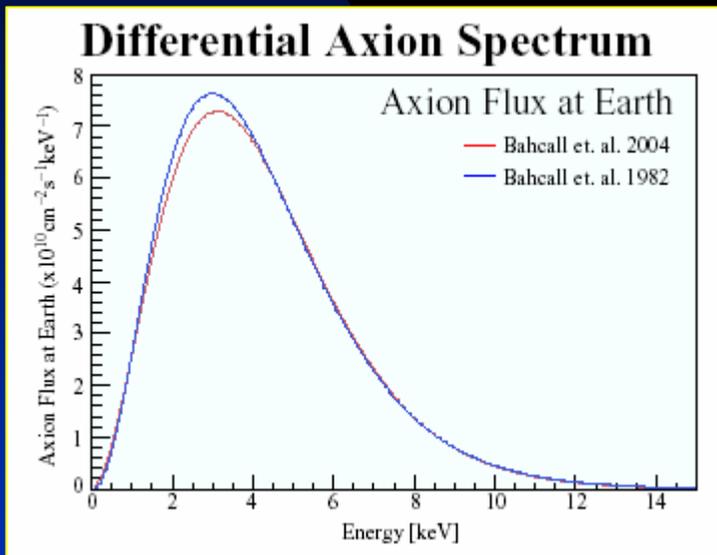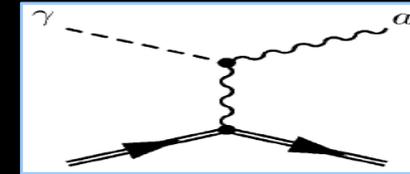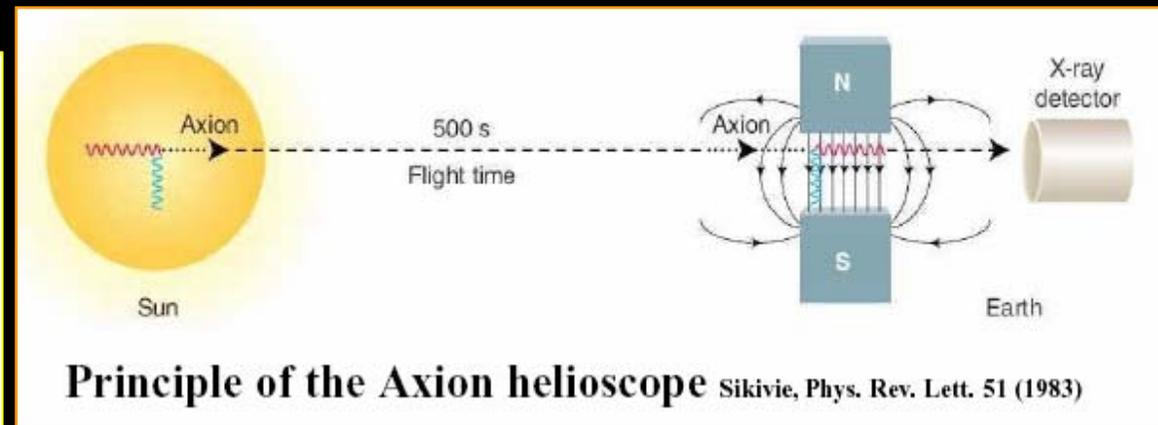National Centre for Scientific Research

Outline

- ✓ **The CAST experiment.**
- ✓ **Micromegas detector.**
- ✓ **Performance during phase-I.**
- ✓ **Developments and prospects.**

Solar axions

Differential Axion Spectrum

Axion flux on Earth

Principle of the Axion helioscope Sikivie, Phys. Rev. Lett. 51 (1983)

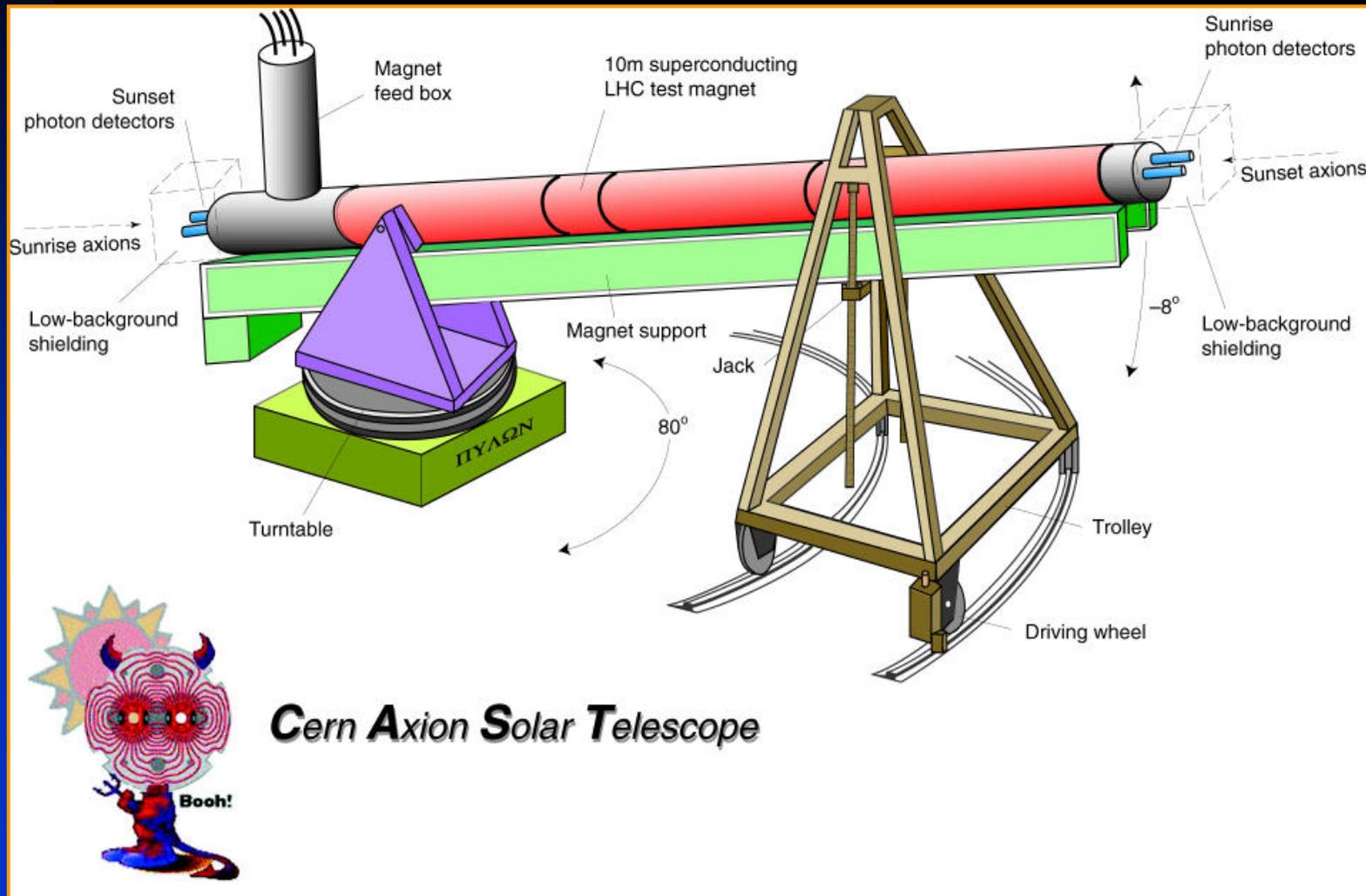**Conversion probability in transverse magnetic field**

$$P_{a\gamma\gamma} = 2.1 \cdot 10^{-17} \left(\frac{B \cdot L}{90T \cdot m} \right)^2 \cdot \left(\frac{g_{a\gamma\gamma}}{10^{-10} GeV^{-1}} \right)^2 \cdot |M|^2$$

$$\frac{d\Phi_a}{dE} = 4.02 \cdot 10^{10} \left(cm^{-2} s^{-1} keV^{-1} \right) \cdot \left(\frac{g_{a\gamma\gamma}}{10^{-10} GeV^{-1}} \right)^2 \cdot \frac{(E/keV)^3}{\exp(E/1.103keV) - 1}$$

$$|M|^2 = \frac{2(1 - \cos qL)}{(qL)^2} \approx 1$$

The CAST experiment (I)
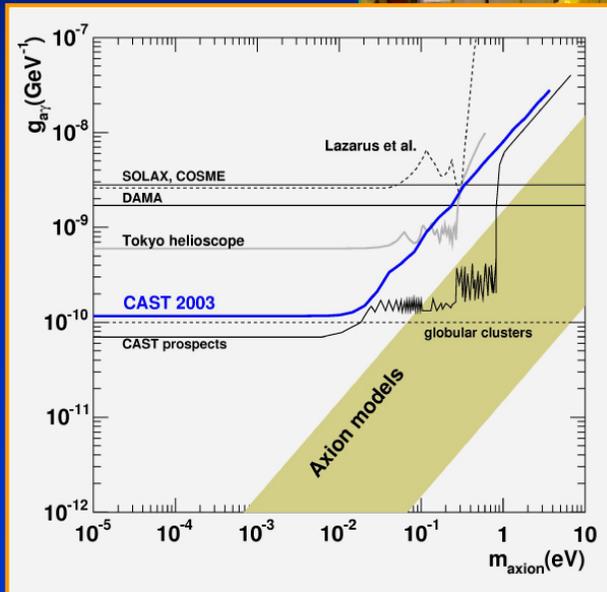

Cern Axion Solar Telescope

The CAST experiment (II)

Magnetic field: B = 9T
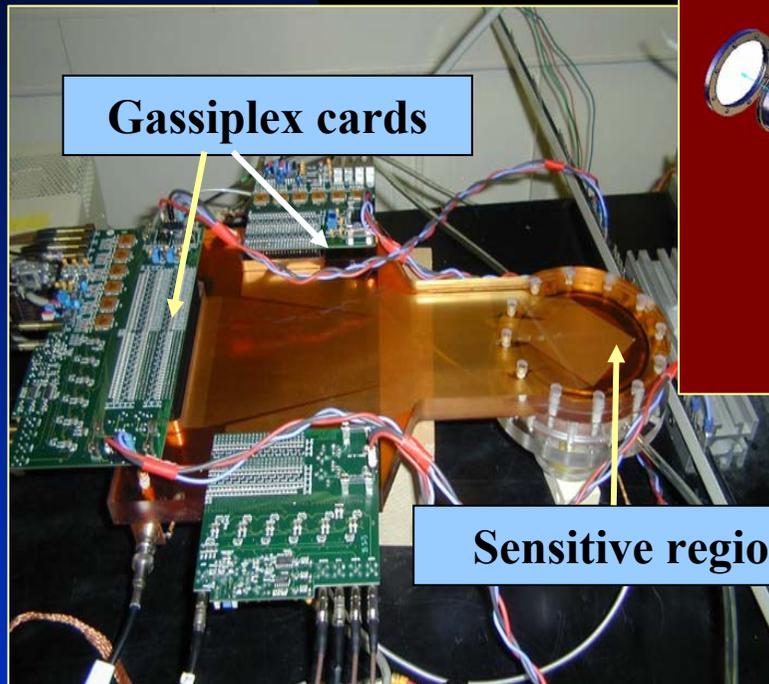
Length: L = 10m

X-ray detector requirements:
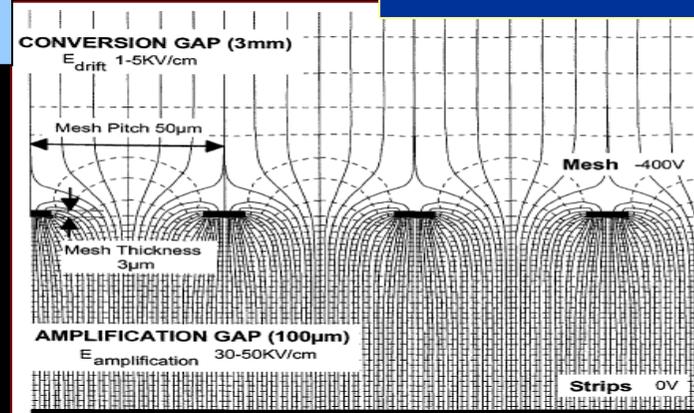
✓ Low background rate.

✓ Positional sensitivity.

✓ Fiducial area ~14cm².

✓ Moderate energy resolution.

✓ Stability.

Micromesh gaseous detector
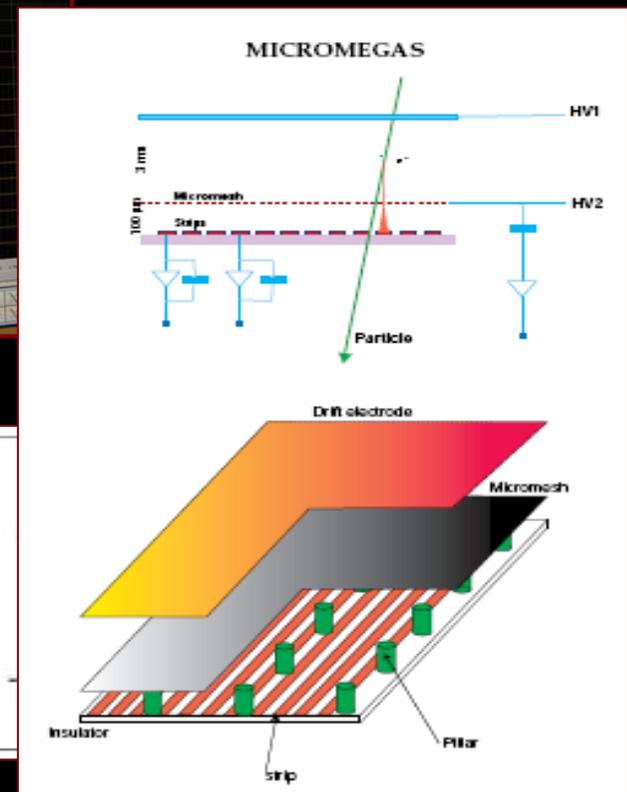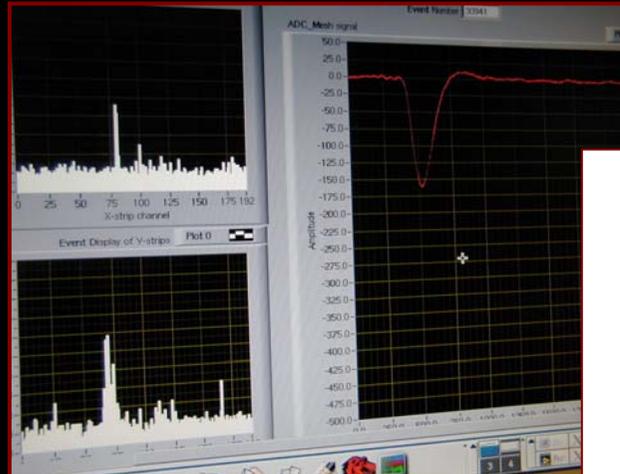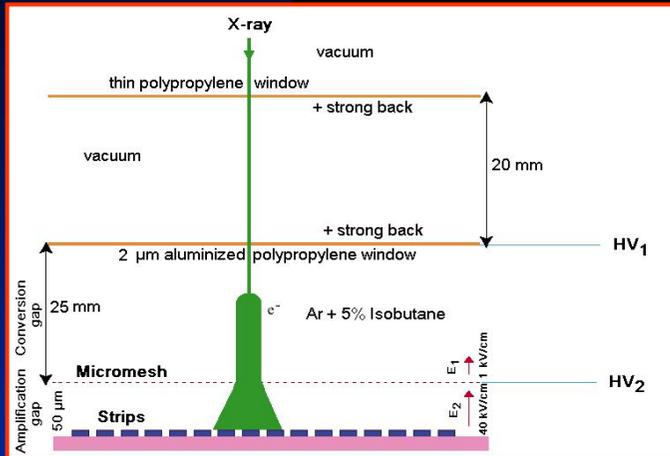
Gassiplex cards

Sensitive region

✓ **The operating gas is at atmospheric pressure.**

✓ **10^4 amplification is easily achievable.**

✓ **High field ratio: 100% electron transparency.**

✓ **No space charge effects due to fast collection of positive ions.**

CONVERSION GAP (3mm)
E_{drift} 1-5KV/cm

Mesh Pitch 50μm

Mesh −400V

Mesh Thickness 3μm

AMPLIFICATION GAP (100μm)
$E_{amplification}$ 30-50KV/cm

Strips 0V
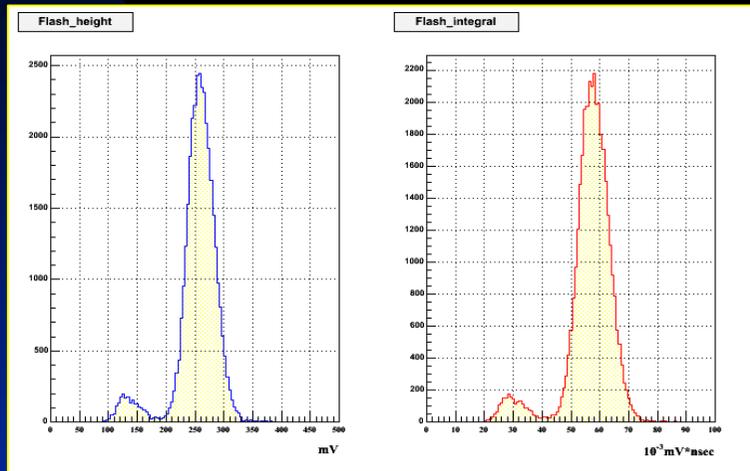
The detector is built and tested in Saclay.
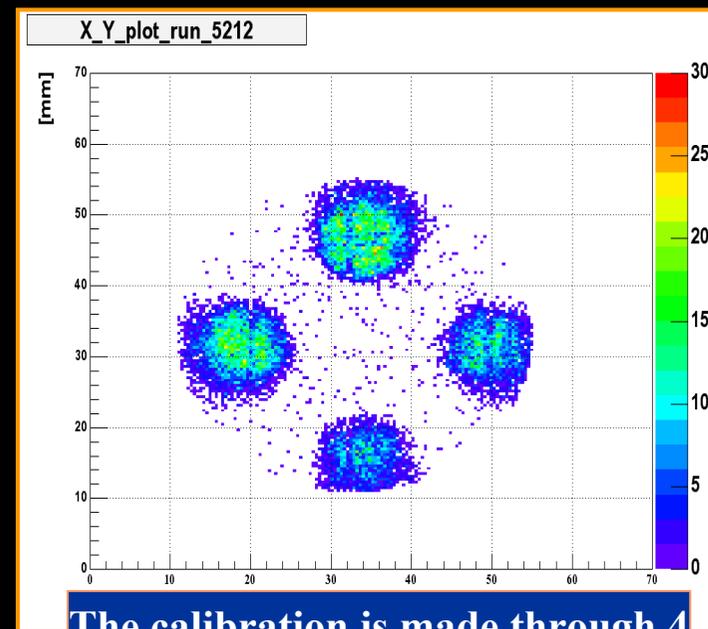
Detection principle

- ✓ **X-ray entering the conversion gap.**
- ✓ **Photoelectric effect: primary electron.**
- ✓ **Secondary ionisations.**
- ✓ **Drift through the mesh.**
- ✓ **Amplification.**
- ✓ **Signal (charge on the strips read by the Gassiplex chips & mesh pulse read by a MATACQ digitizing board).**
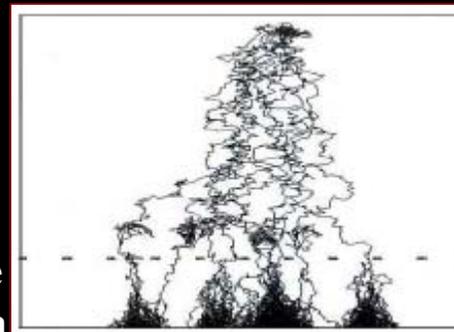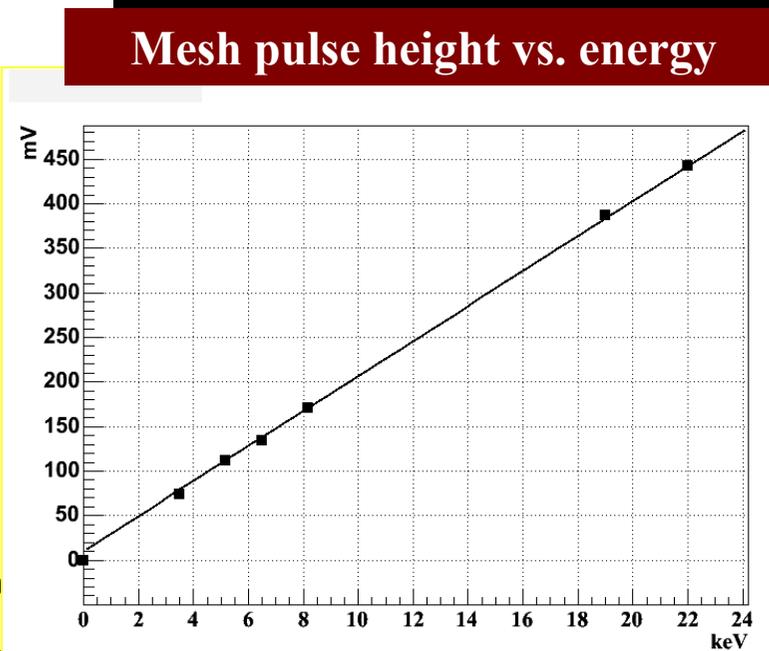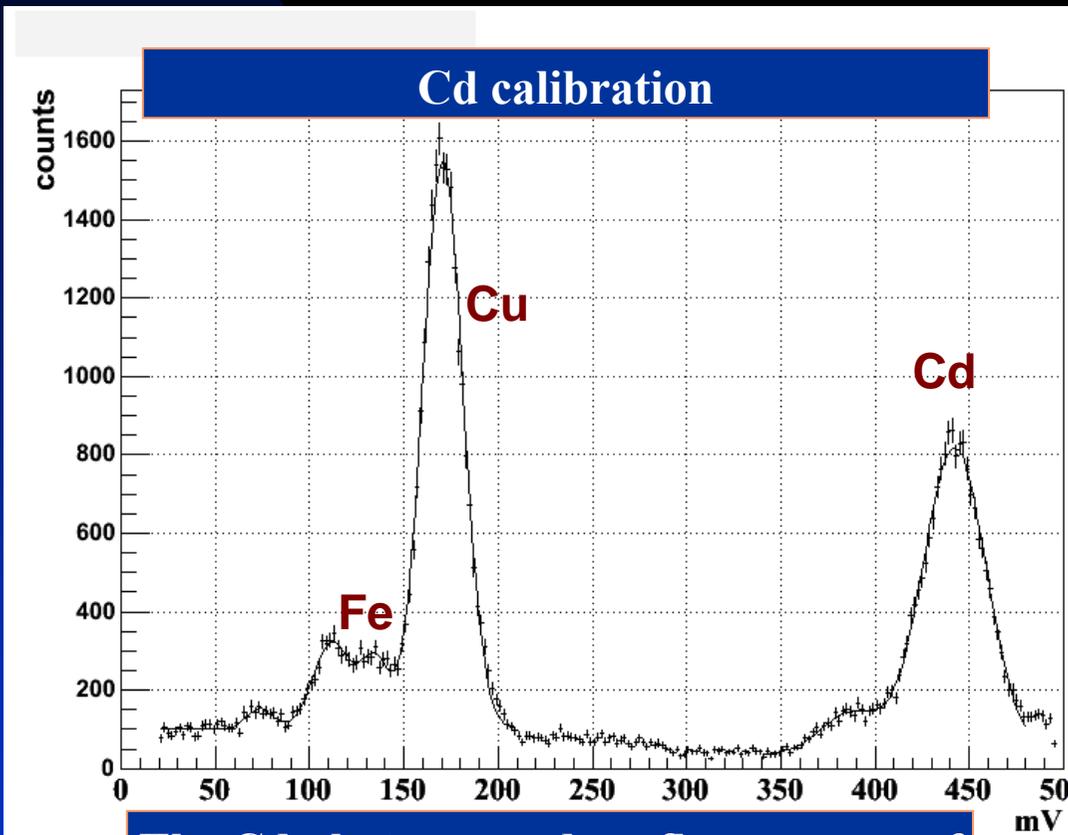
^{55}Fe Calibration

Energy resolution at 5.9 keV
(mesh signal):
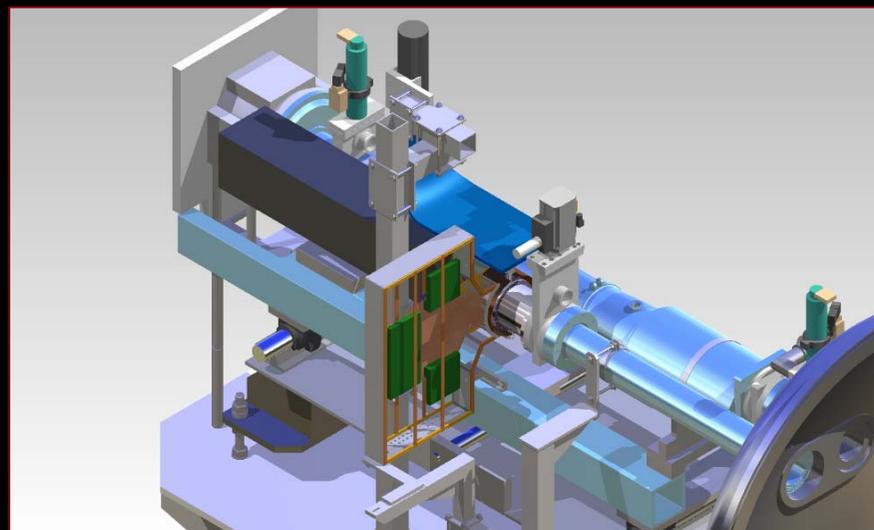16% (2003), 20% (2004)
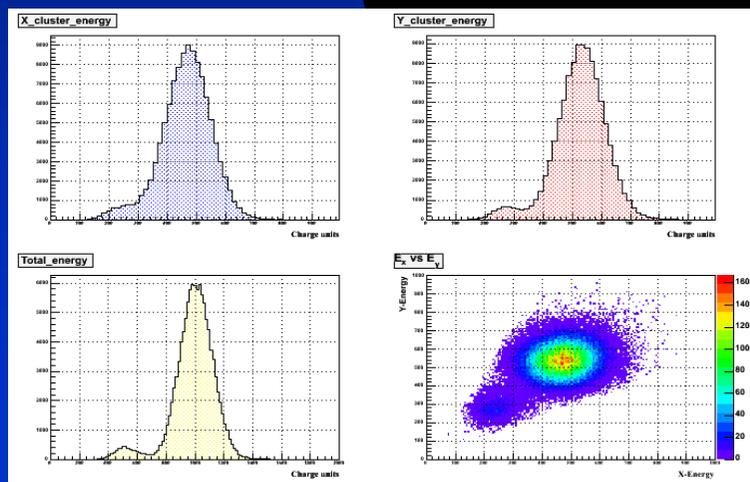
The calibration is made through 4 holes at the back of the detector

Linearity check

Cd calibration

Cu

Cd

Fe

The Cd photons produce fluorescence of the detector's materials

Mesh pulse height vs. energy

The micromegas in CAST

Faraday cage

Hardware efficiency, d=1.64 mg/cm^3
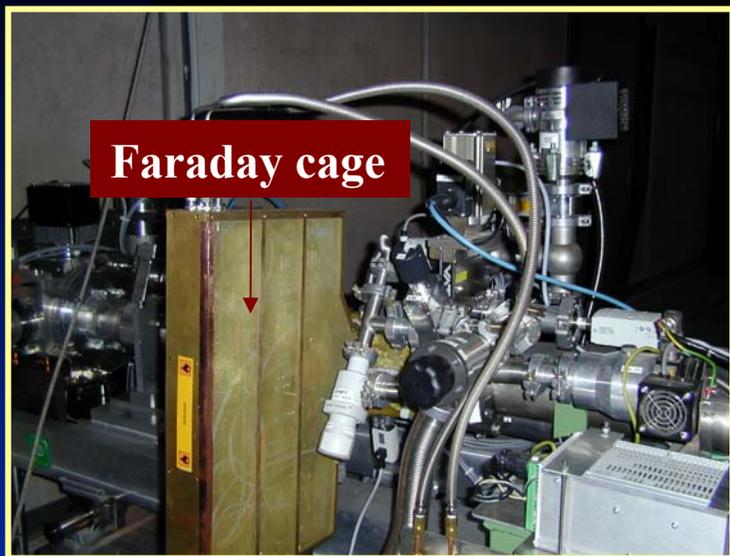
Run	Model	Conv. gap (mm)	Ampl. gap (µm)	Gas mixture
2003	V3*	25	50	Ar/Isobutane (95%-5%)
2004	V4	30	100	Ar/Isobutane (95%-5%)

192 X and 192 Y strips (4 Gassiplex cards of 96 channels each) with 350µm pitch.

Dead time: 14msec (due to the slow data acquisition system), 1.4% of the raw data rate (~1Hz).
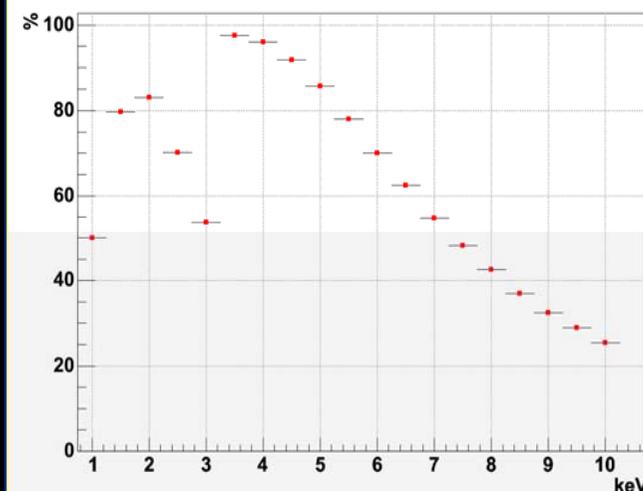
Offline analysis

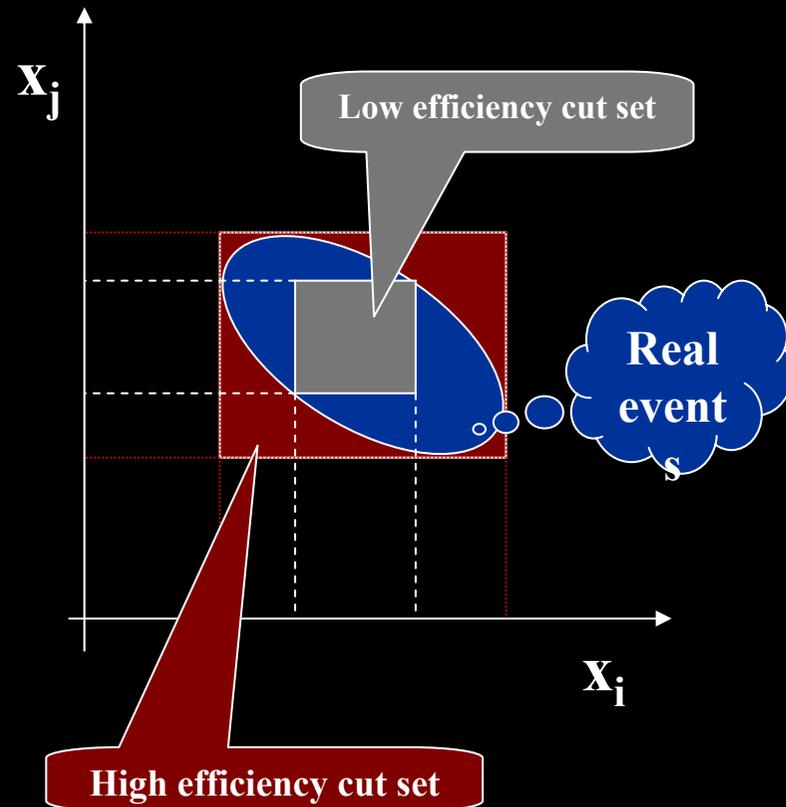- The sequential cut method does not meet the experimental requirements for high background rejection capability and purity of the selected events.

- A multivariate Fisher discriminant method was developed based on six observables combining information from the two dimensional readout and the time structure of the mesh pulse:

I. Mesh pulse risetime (x_1).
II. Mesh pulse width (x_2).
III. Mesh height vs. integral correlation (x_3).
IV. X cluster vs. Y cluster energy balance (x_4).
V. X vs. Y strip multiplicity balance (x_5).
VI. Mesh pulse integral vs. total strip energy correlation (x_6).

x_j

Low efficiency cut set

Real events

High efficiency cut set

x_i

The multivariate method (I)

event

Observables:

x_i i=1,…,N

$$q = \left(\frac{E}{5.9}\right)^{\frac{1}{2}} (X - \bar{X})^T \cdot V^{-1} \cdot (X - \bar{X})$$

q ~ chi2 with N d.o.f

Energy dependent covariance matrix

$$V_{ij} = \overline{(x_i - \bar{x}_i) \cdot (x_j - \bar{x}_j)}$$
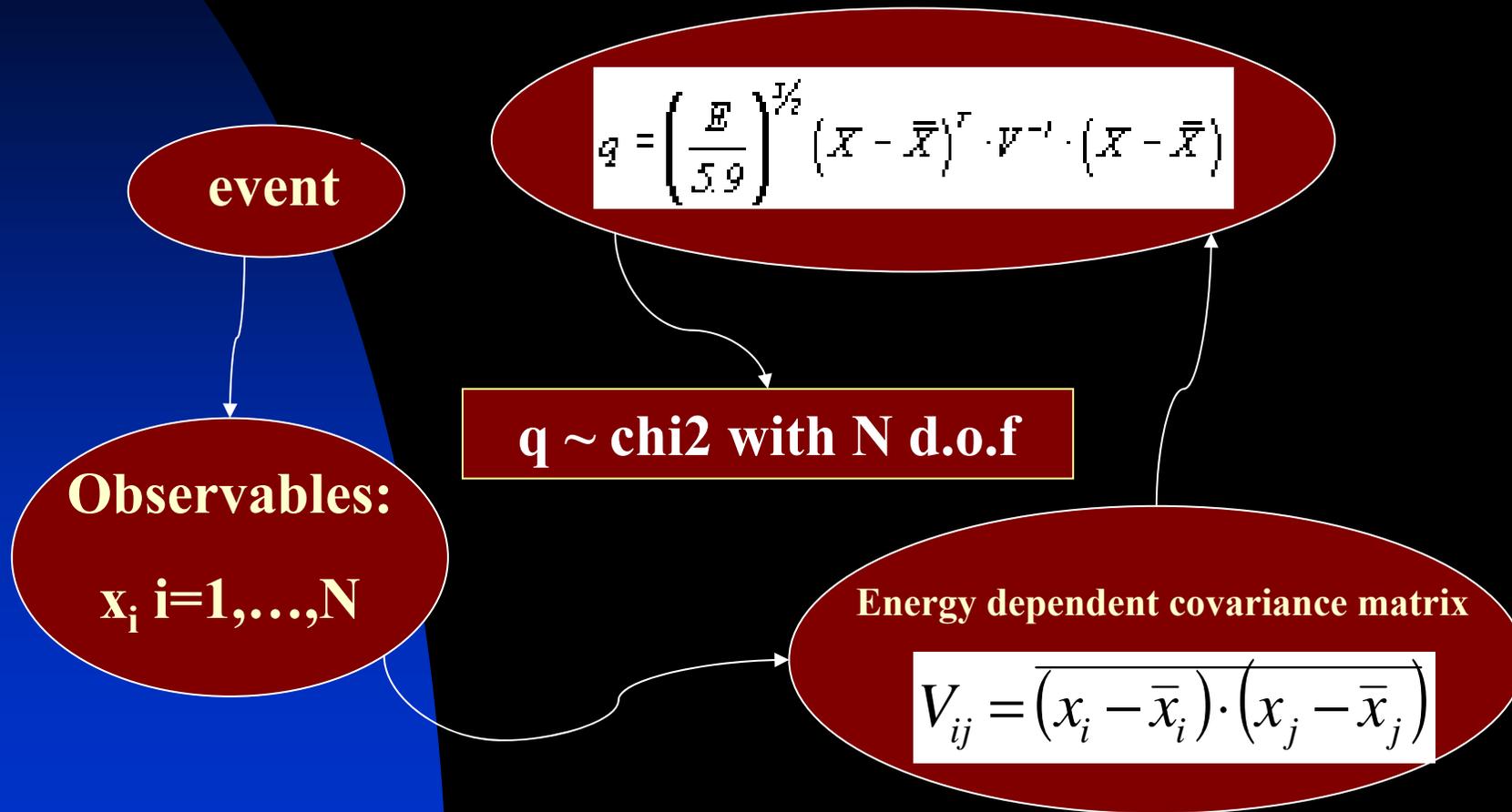
The multivariate method (II)
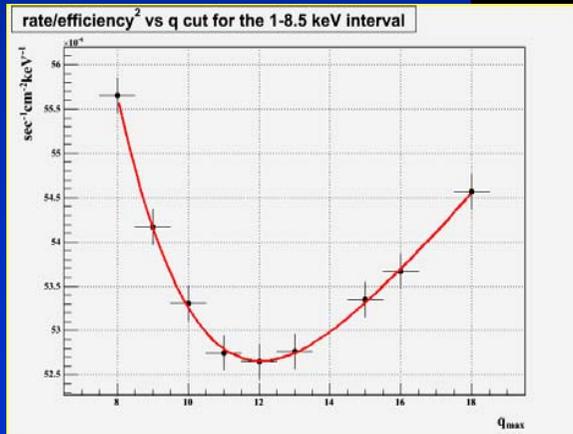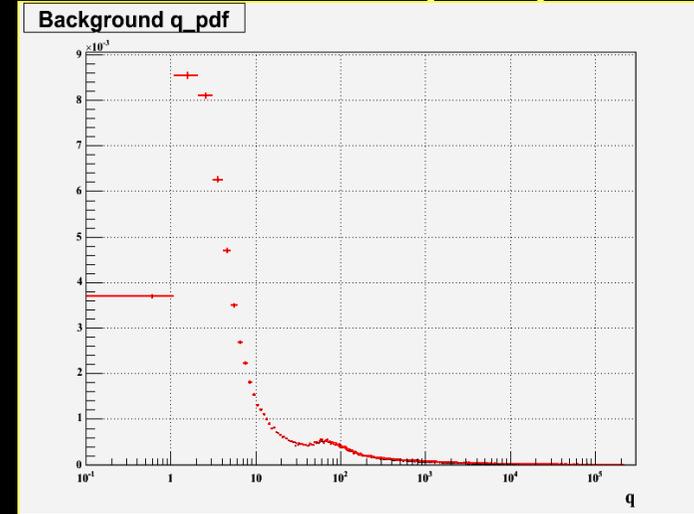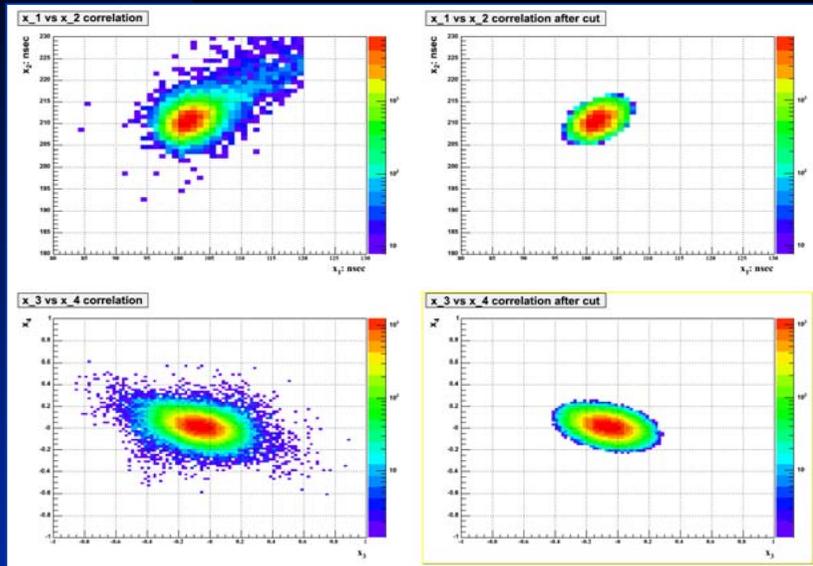
✓ **Energy invariant q pdf.**

✓ **Uniform cut.**

✓ **Optimization is possible.**

✓ **Efficiency given by the qumulative q-pdf up to a given cut.**
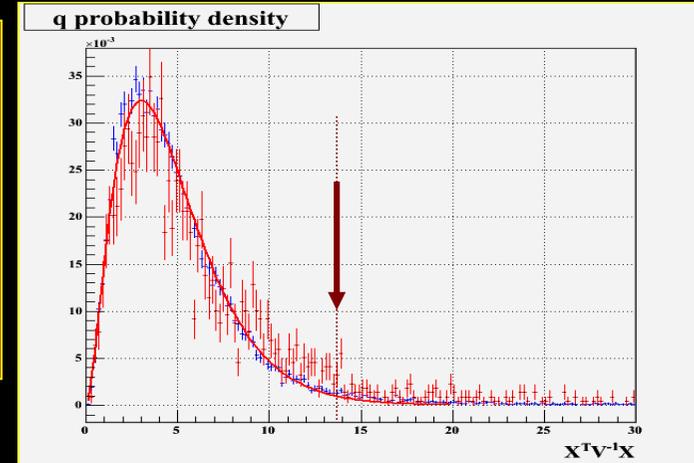
Stability (2004)

Variation of the relevant observables during the 2004 run (~ 6 months)

	mean	sigma	%
x_1	101.6	0.5	0.5
x_2	211.8	1.6	0.7
x_3	-0.0673	0.0014	2.1
x_4	0.0119	0.0007	5.8
x_5	0.222	0.003	1.3
x_6	0.064	0.07	10.7

Gain variation ~ 10% on a week scale, probably due to sensitivity of electronics to the environmental conditions.

Systematic variation: gain dependence

Cut efficiency

Cumulative Q_q
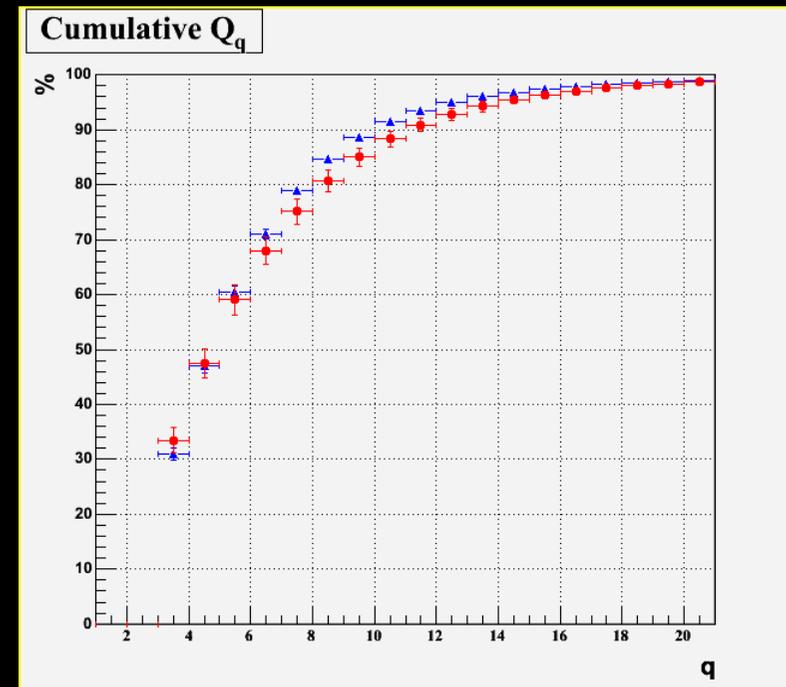
Monte Carlo

- ✓ **The GEANT4 is used to simulate the detector's materials and geometry.**

- ✓ **Only the energy deposition is simulated and NOT the full detector response.**

- ✓ **The goal is to understand qualitative the origin of the measured background.**

- ✓ **The energy resolution is implemented "by hand" according to the experimental results.**

- ✓ **The normalization is done according to the Cu peak.**

Background sources:

Gamma rays from environmental radioactivity.

X-rays from fluorescence of the surrounding materials.

Neutrons.
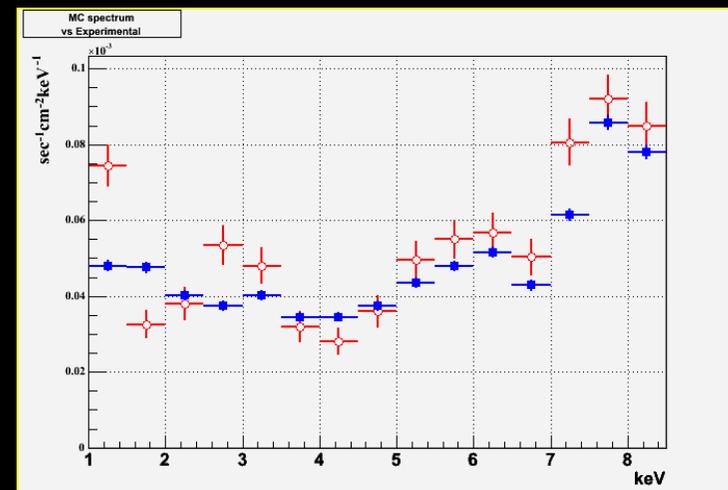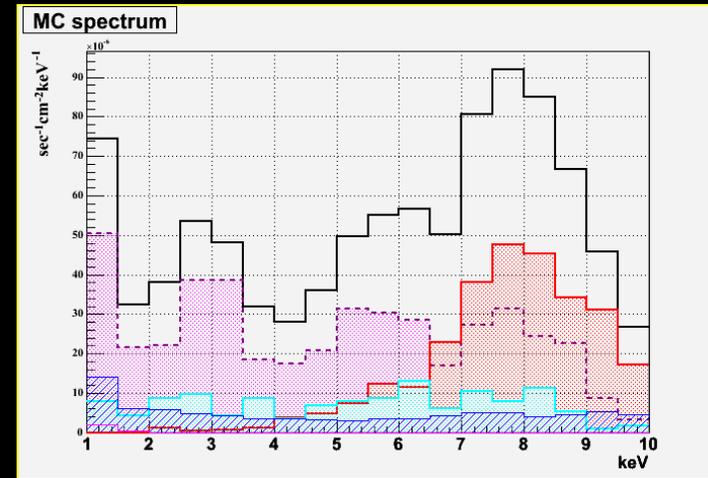
Summary & Conclusions

✓ The micromegas detector of CAST was optimized to detect X-rays in the 1-10 keV interval.

✓ The 2003 model (V3) had very good spectroscopic properties with good positional sensitivity but contained a few damaged strips and suffered from "cross-talk" effects.

✓ The upgraded model (V4) operated successfully during the 6 months run of 2004.

✓ The stability of the detector's performance and the advanced offline analysis allowed for an average background of 5×10^{-5} counts/sec/cm^2/keV with 94% cut efficiency.

✓ Through the MC investigation, the origin of the background is clarified.

✓ A more detailed MC is under way to optimize the detector's shielding for the next phase of the experiment.

✓ A new model is being developed to work with a focusing devise during CAST phase-II.