Search for Axions from the Sun

Theopisti Dafni

IKP/Technische Universität-Darmstadt,

for the CAST Collaboration

Les Rencontres de Physique de la Valée d' Aoste 2004,

La Thuile

Outline:

- Axions
- Ideas & Fulfillment
  - CAST : Description
    - Magnet,platform,cryogenics,tracking
    - X-Ray Telescope & X-Ray Detectors
  - Preliminary Results
- Other 'applications'

Axions

α

- *Pseudoscalar particles, similar to π°*
- *Massless (Nambu-Goldstone boson of PQ Symmetry)*

  ***but** can acquire an effective mass interacting with gluons*

- *Therefore the two mix: they **"share"** their mass*

$$m_\alpha f_\pi \approx m_\pi f_a$$

$$m_a \simeq 0.6 \text{ eV} \frac{10^7 \text{GeV}}{f_a}$$

- ***axions'** couplings to photons and nucleons are approximately f_π/f_a times those of π°*

depending on the axion model used

***PQ Symmetry**:*

Peccei & Quinn: CP invariance of the strong interactions expected in QCD, for a non vanishing scalar field that gives mass to a fermion through a Yukawa coupling.

Axions

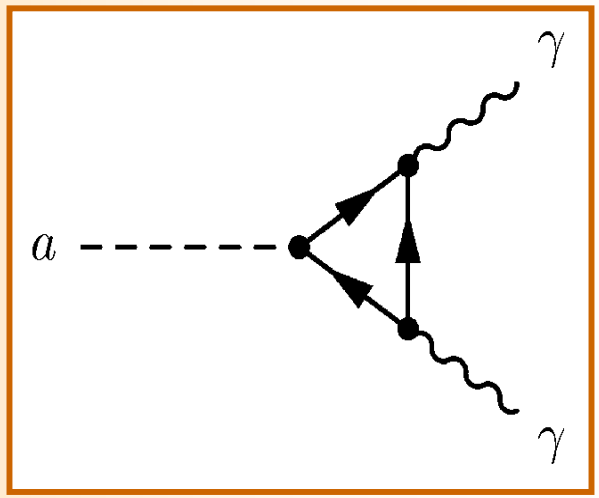
α

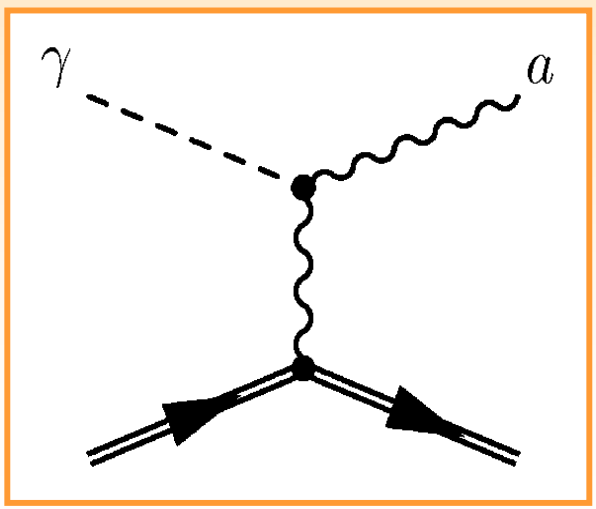
Destiny:

mix with π° $\rightarrow$ Couple with two photons !!

$$L_{\alpha\gamma} = g_{\alpha\gamma}\,(\mathbf{E}\bullet\mathbf{B})\;a$$

Allows $\alpha \leftrightarrow \gamma$ in the presence of E or B





Primakoff (1951) [$\pi^\circ \rightarrow \gamma\gamma$]

PRIMAKOFF EFFECT

Any scalar or pseudoscalar particles:

axion-like particles

Axions

PRIMAKOFF EFFECT

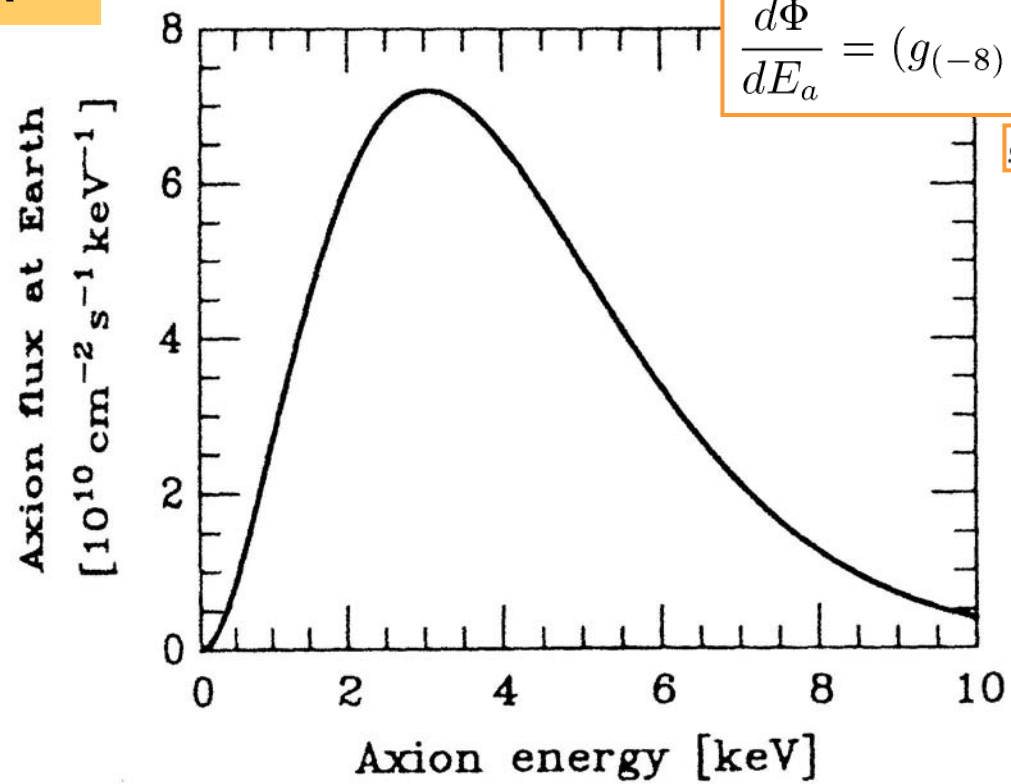
α

Stellar interior → the Sun!! → *Solar Axions*

Flux

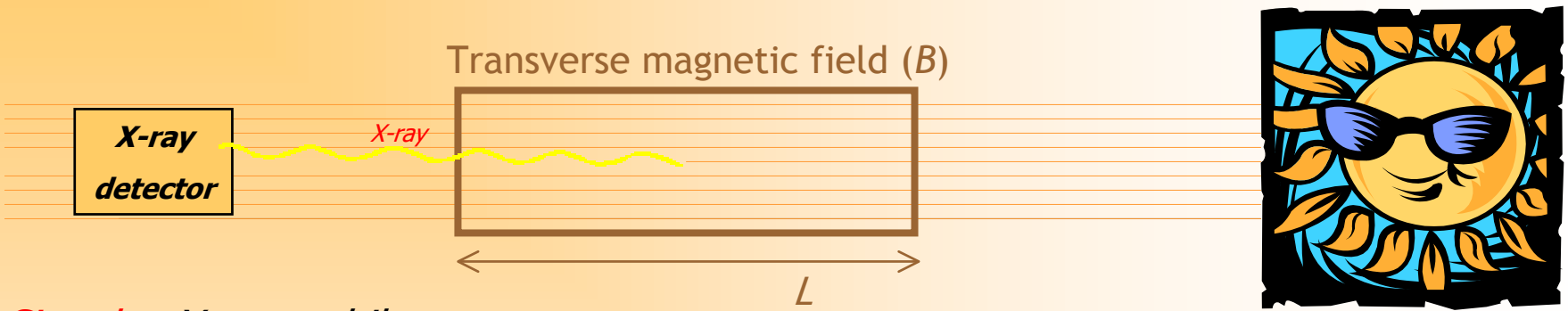
$$\frac{d\Phi}{dE_a} = (g_{(-8)})^2 \frac{\Phi_0}{E_0} \frac{(E_a/E_0)^3}{e^{E/E_0} - 1}$$

$$g_{(-8)} = g_{a\gamma\gamma} \times 10^8/\mathrm{GeV}^{-1}$$

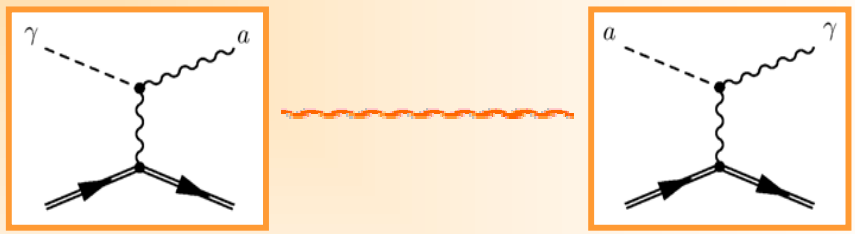


[K.van Bibber et al.,1989]

Axions



Signal: X-rays while tracking (magnet pointing to the Sun) over background



$$P_{a\gamma} = 1.8 \times 10^{-17} \left(\frac{B}{8.4T}\right)^2 \left(\frac{L}{10m}\right)^2 (g_{a\gamma\gamma} \times 10^{10} GeV^{-1})^2 |\mathcal{M}|^2$$

*To preserve **Coherence**: $|M|^2 = 1$*

Lazarus et al., Brookhaven

Tokyo Helioscope:B~4T, L~2m

Axions:

Extending the coherence to higher axion masses...

- *Coherence for higher masses by using buffer gas.*
- *Fill magnetic channels with helium*
- *The photon acquires an effective mass: $m_\gamma > 0$*
- *Momentum transfer is* $|q| = \frac{m_a^2 - m_\gamma^2}{2E}$ *(as opposed to* $|q| = \frac{m_a^2}{2E}$ *)*
- *Coherence condition($qL << 1$) is recovered for a narrow mass range around m_γ*
- *m_γ can be adjusted by changing the gas pressure:*

$$m_\gamma \approx \sqrt{\frac{4\pi\alpha N_e}{m_e}} = 28.9\sqrt{\frac{Z}{A}\rho} \quad \text{eV}$$

- *Thus, changing the pressure of the gas will allow to be sensitive to an extended range of higher axion masses*

Prospects

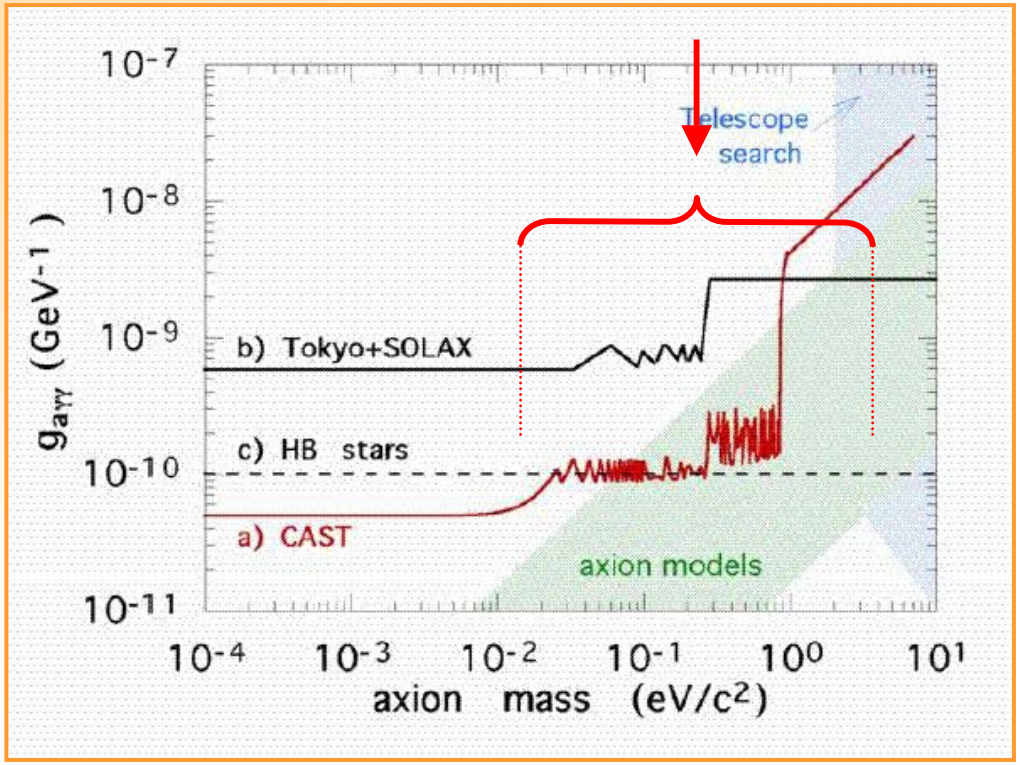
CAST Sensitivity plot

Phase II and up (?)

$$g_{a\gamma\gamma} \leq 1.4 \times 10^{-9} (GeV)^{-1} \frac{b^{\frac{1}{8}}}{t^{\frac{1}{8}} B^{\frac{1}{2}} L^{\frac{1}{2}} A^{\frac{1}{4}}}$$

Filling the magnet bores with helium the photon acquires an effective mass: $m_\gamma > 0$ and by changing the gas pressure we are sensitive to different masses

To Start in 2005



The Collaboration

Canada Vancouver,

University of British Columbia, Department of Physics

Michael HASINOFF

Croatia, Zagreb
Ruder Boskovic Institute

Milica KRCMAR, Biljana LAKIC , Ante LJUBICIC

France, Gif-Sur-Yvette
Centre d'Etudes de Saclay (CEA-Saclay), DAPNIA

Samuel ANDRIAMONJE,Stephan AUNE ,Alain DELBART, Esther FERRER, Ioanis GIOMATARIS, Emile PASQUETTO, Jean Pierre ROBERT

Germany, Darmstadt
Technische Universitat Darmstadt, Institut für Kernphysik
Theopisti DAFNI, Dieter HOFFMANN, Manfred MUTTERER

Germany, Frankfurt
Applied Physics

Vladimir ARSOV, Joachim JACOBY

Germany, Freiburg
Albert-Ludwigs-Universität Freiburg

Horst FISCHER, Juergen FRANZ , Fritz Hertbert HEINSIUS, Donghwa KANG, Kay KÖNIGSMANN, Christian SCHILL

Germany, Garching
Max-Planck-Gesellschaft (MPG), Max-Planck-Institut für Extraterrestrische Physik
Heinrich BRAUNINGER, Jakob ENGLHAUSER , Markus KUSTER

Germany, Muenchen
Max-Planck-Institut für Physik, Werner-Heisenberg-Institut
Rainer KOTTHAUS, Gerhard LUTZ, Georg RAFFELT

Greece, Athens
National Center for Scientific Research "Demokritos" (NRCPS)
George FANOURAKIS, Theodoros GERALIS, Katerina ZACHARIADOU,Kostas KOUSOURIS

Greece, Thessaloniki
Aristotle University of Thessaloníki
Spyridon DEDOUSSIS, Christos ELEFTHERIADIS, Anastasios LIOLIOS, Argyrios NIKOLAIDIS, Ilias SAVVIDIS, Konstantin ZIOUTAS

Italy, Pisa
Scuola Normale Superiore (SNS)
Luigi DI LELLA

Russia, Moskva
Russian Academy of Sciences, Institute for Nuclear Research (INR)
Alexandre BELOV, Sergei GNINENKO, Nikolai GOLOUBEV

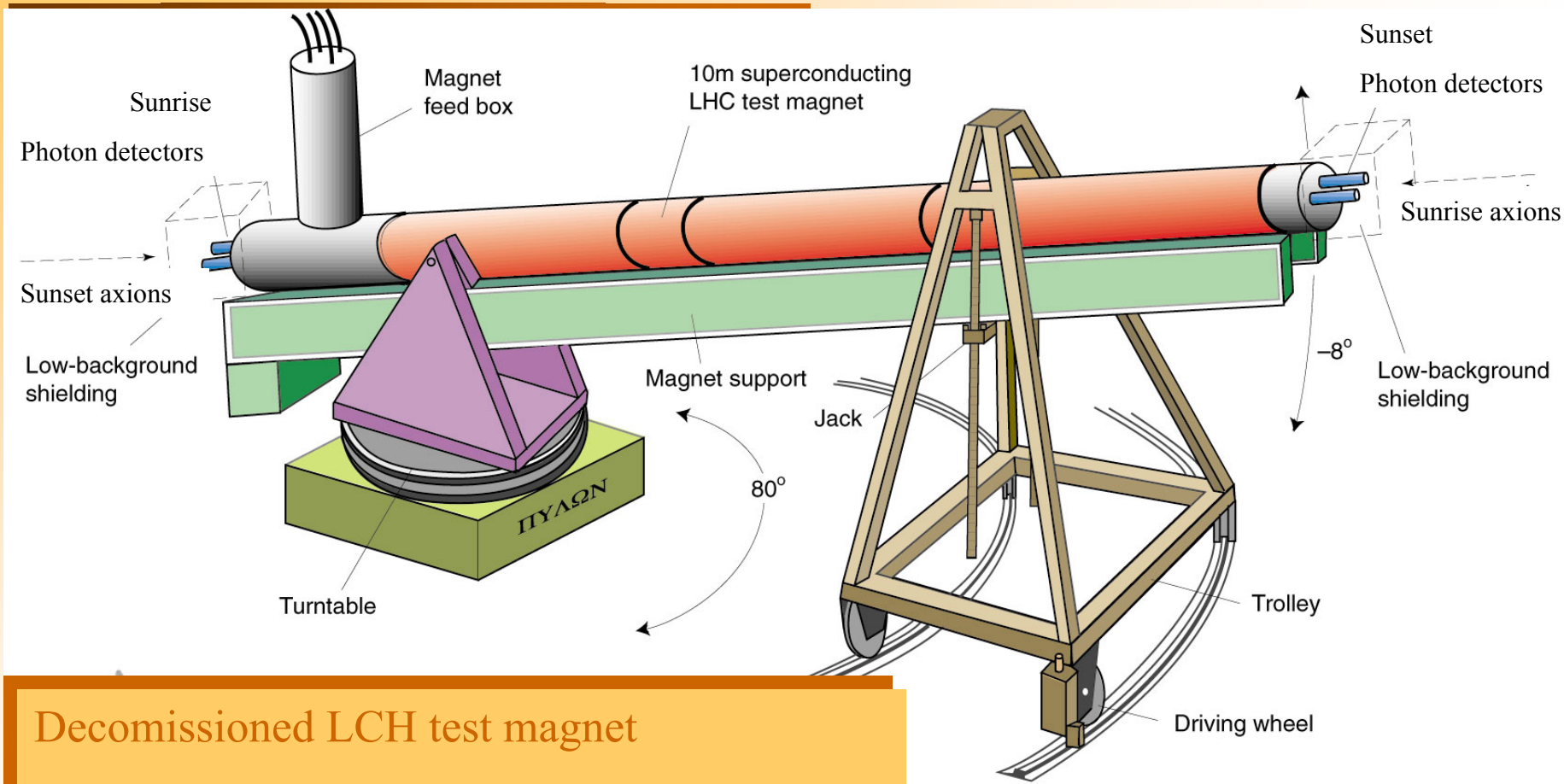
Spain, Zaragoza
Universidad de Zaragoza, Facultad de Ciencias, Instituto de Física Nuclear y Altas Energías
Berta BELTRAN, Jose CARMONA, Susana CEBRIAN, Gloria LUZON, Angel MORALES, Julio MORALES, Alfonso ORTIZ DE SOLORZANO, Jaime RUZ, Maria SARSA, Jose VILLAR

Switzerland, Geneve
European Organization for Nuclear Research (CERN)
Klaus BARTH, Enrico CHESI, Gino CIPOLLA, Martyn DAVENPORT, Michel DELATTRE, Rui DE OLIVEIRA, Fabio FORMENTI, Igor IRASTORZA, Jean-Noel JOUX, Christian LASSEUR, Angelika LIPPITSCH, Thomas PAPAEVANGELOU, Alfredo PLACCI, Laura STEWART, Bruno VULLIERME, Louis WALCKIERS

United States of America, Chicago, Il
University of Chicago, Enrico Fermi Institute
Taylor AUNE, Juan COLLAR, Joaquin VIEIRA

United States of America, Columbia, Sc
University of South Carolina, Department of Physics and Astronomy
Frank AVIGNONE, Richard CRESWICK, Horacio FARACH

Cern Axion Solar Telescope



Decomissioned LCH test magnet

Rotating platform

3 X-ray detectors

X-ray Focusing Device

CAST is here:

LEP Point 8
(former DELPHI point)
Building SR8

Magnet,platform,cryogenics

CAST Experimental area

SR8

L= 10 m

B=9 T

→100 times better than any other !!

Magnet,platform,cryogenics

Magnet,platform,cryogenics

Moving platform:

alignment with the Sun for ~50days per year

Magnet at

-8°

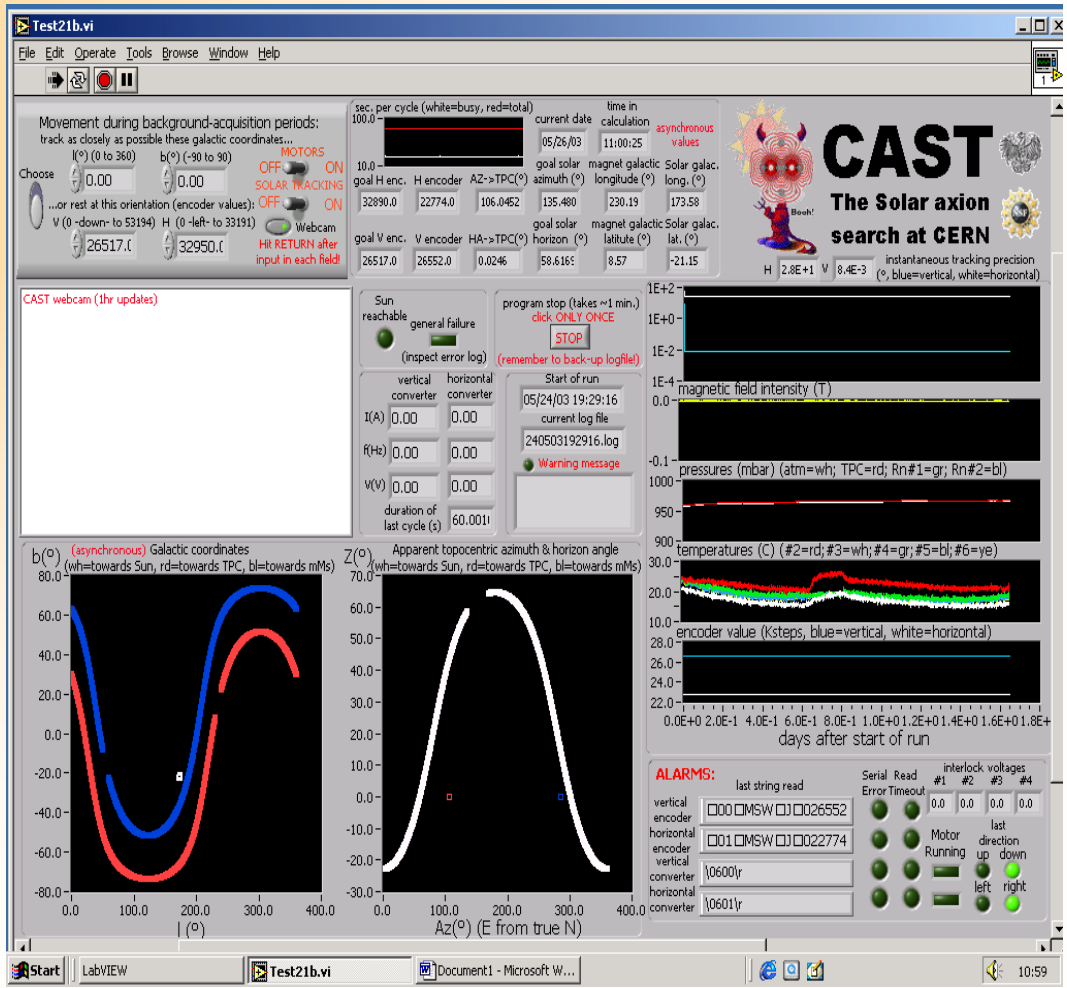
Magnet,platform,cryogenics

Magnet,platform,cryogenics

Tracking system

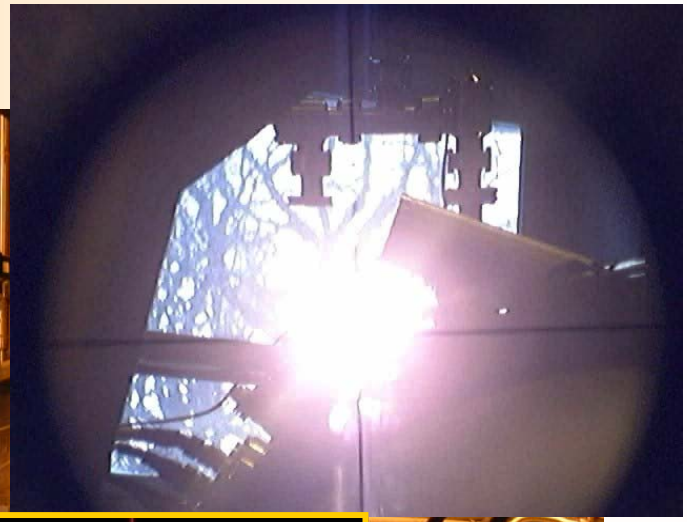
- Motors
- Encoders
- E. Readout→ computer
- Software with astronomical calculations
- Interface to move magnet
- New angle encoders

- Calibrated and correlated with celestial coordinates→ high precision geometer measurement



Magnet,platform,cryogenics

Looking at the sunrise…

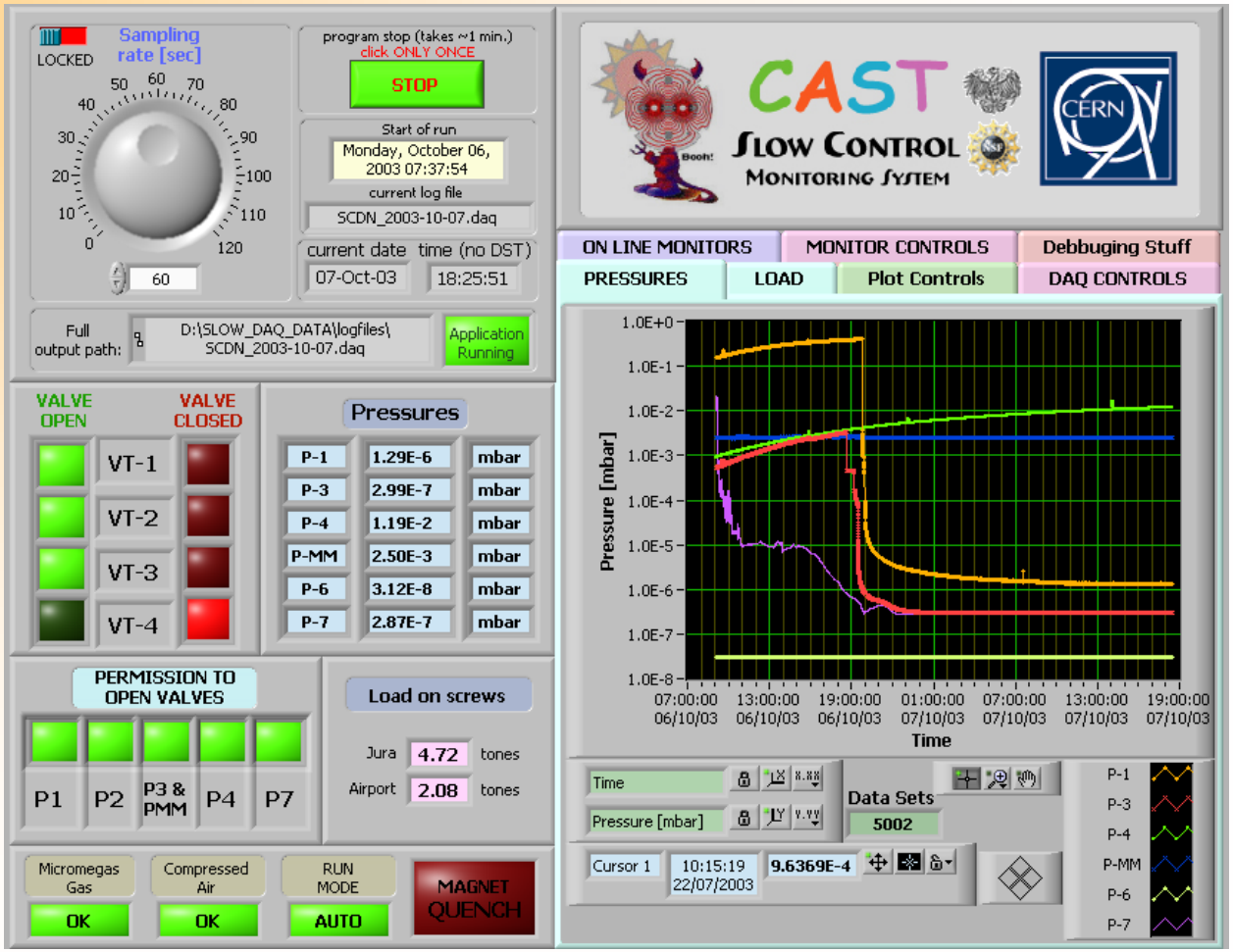


Twice a year (September&March) we can film the Sun through the window

Magnet,platform,cryogenics

Slow Control system

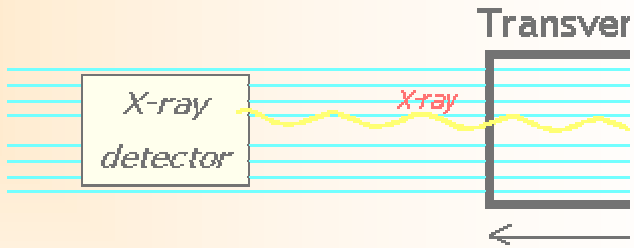
- **Pressure & load logging**
- **Continuous status monitoring (valves, detector gas, various alarms**
- **Mail and GSM notification**
- **On-line plots & history recall utilities.**



X-Ray Telescope

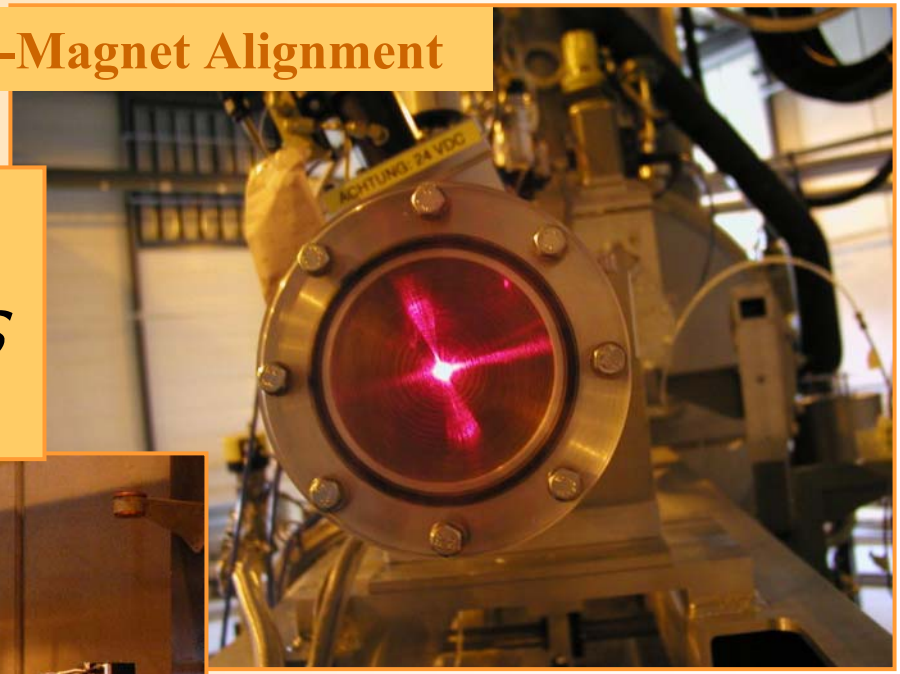
& X-Ray Detectors:

- X-Ray Telescope
  (Focusing Device)
- Detectors
  - CCD
  - TPC
  - Micromegas



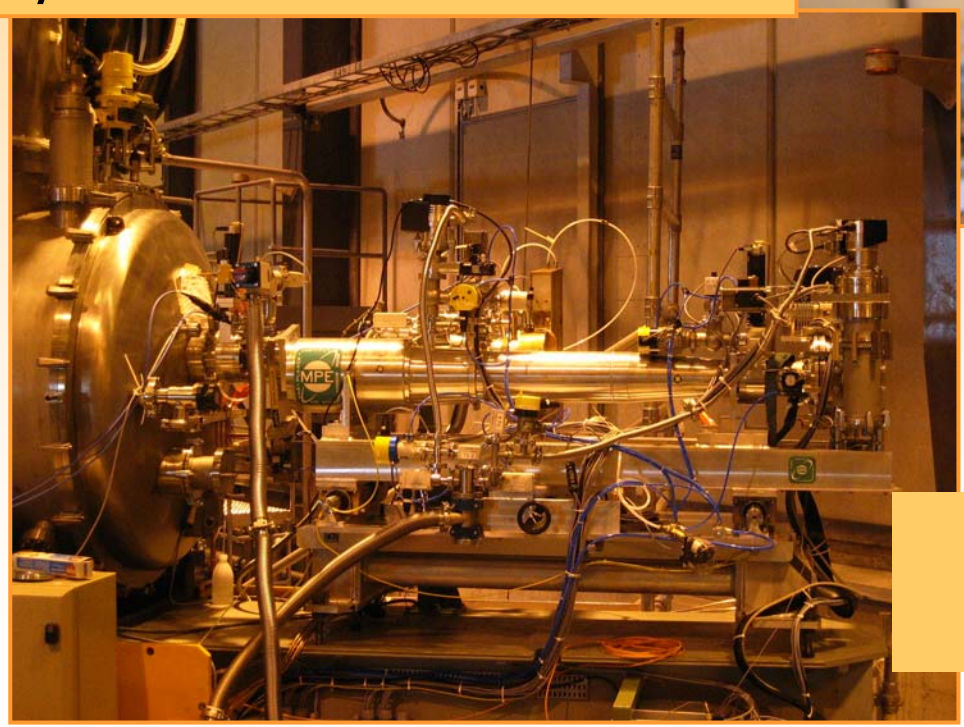
The X-Ray Telescope

Telescope-Magnet Alignment



Space technology:

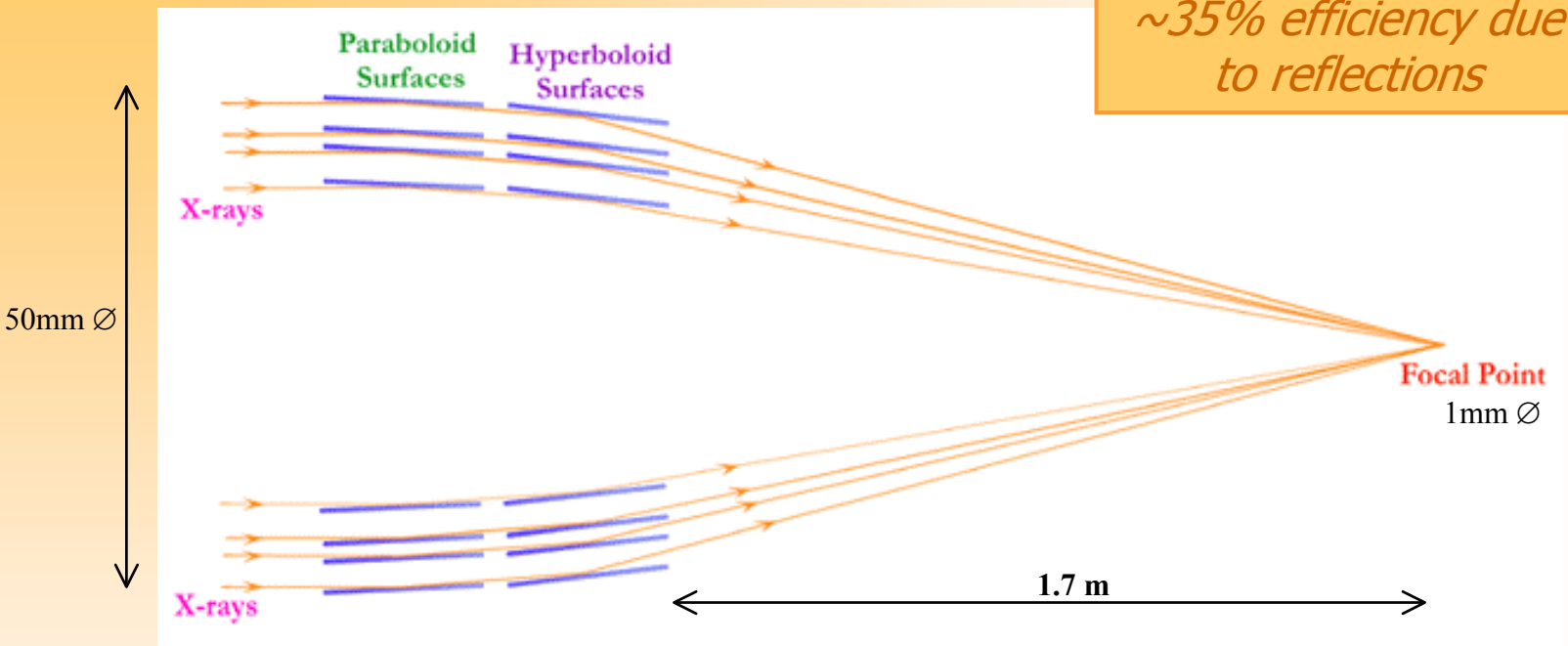
Spare part of the ABRIXAS Space mission



Telescope on the Magnet with the CCD in place

The X-Ray Telescope

~35% efficiency due to reflections



- 27 nested pairs of mirrors
- From 50mm∅(LHC magnet aperture) to ~1mm∅

signal-to-noise improvement

(up to 200!!!)

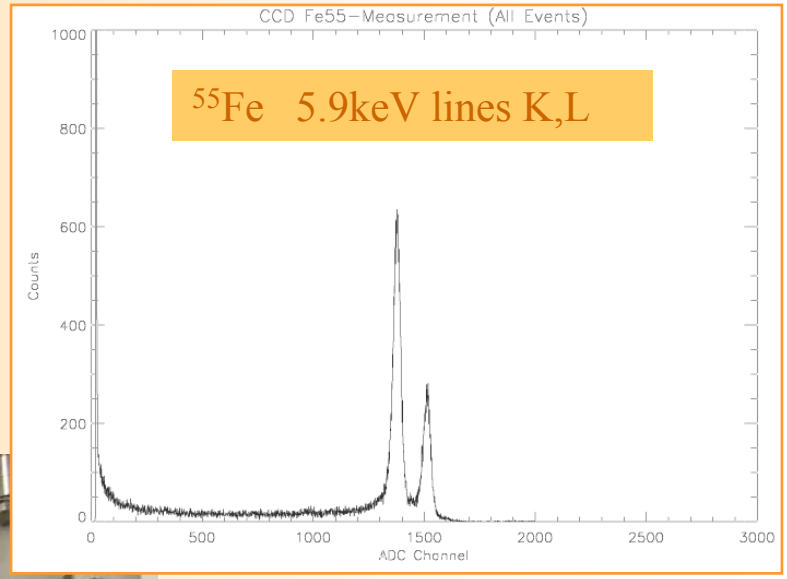
CCD

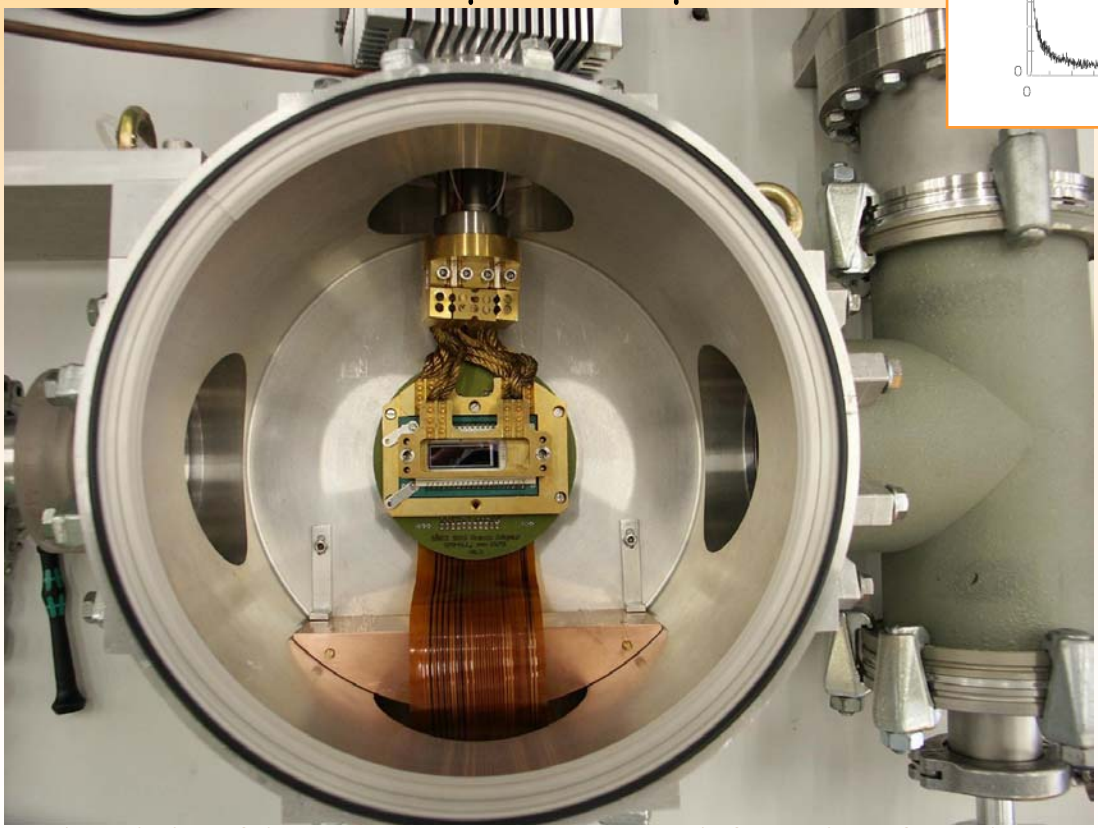
- Excellent Energy Resolution

  < 0.5 keV

- Excellent Space Resolution

  Pixel size: 150μm x 150μm





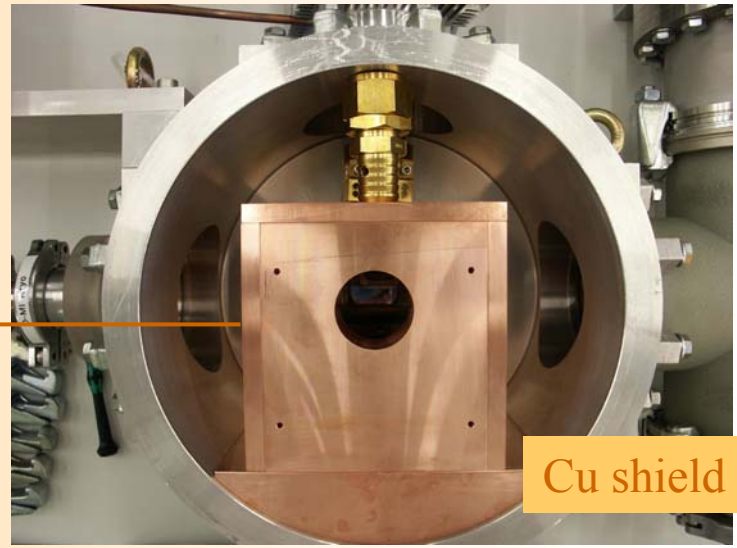
Surface : ***1x3 cm²***

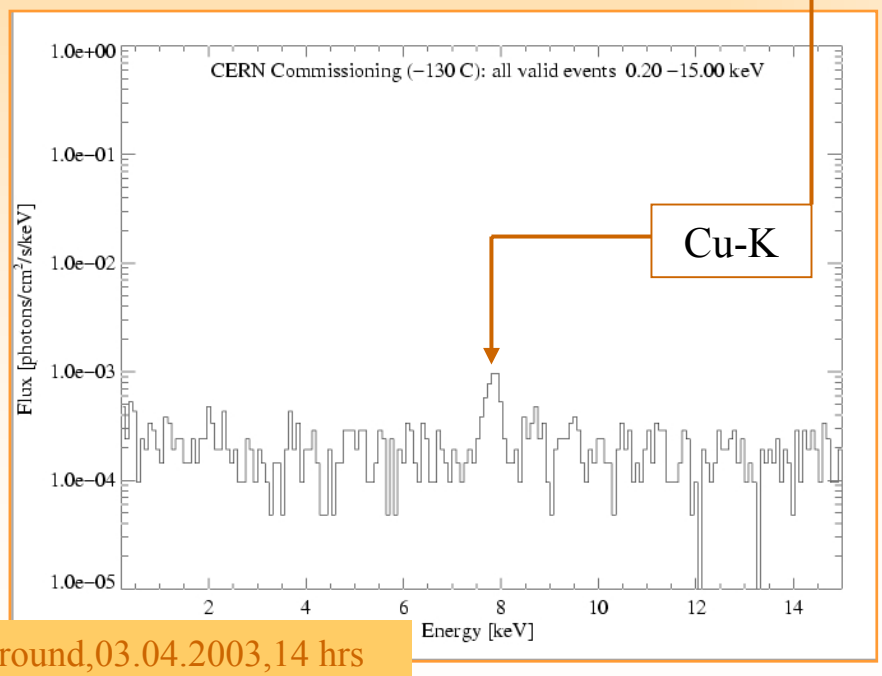
Optimum working temperature:***-130°C***

CCD

- Background:

$\sim 10^{-4}$ events keV^{-1} s^{-1}cm^{-2}



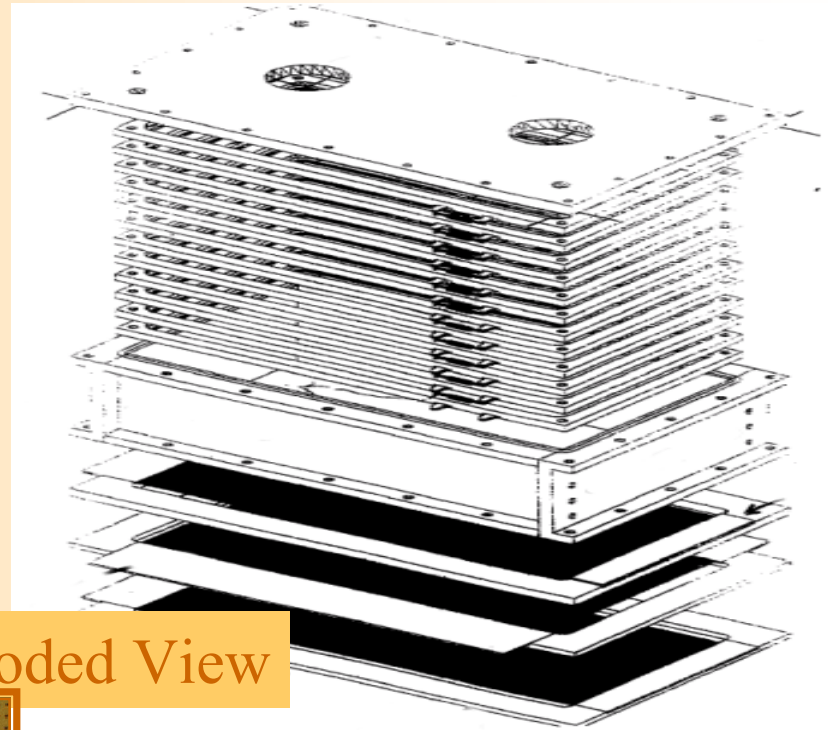


Background,03.04.2003,14 hrs

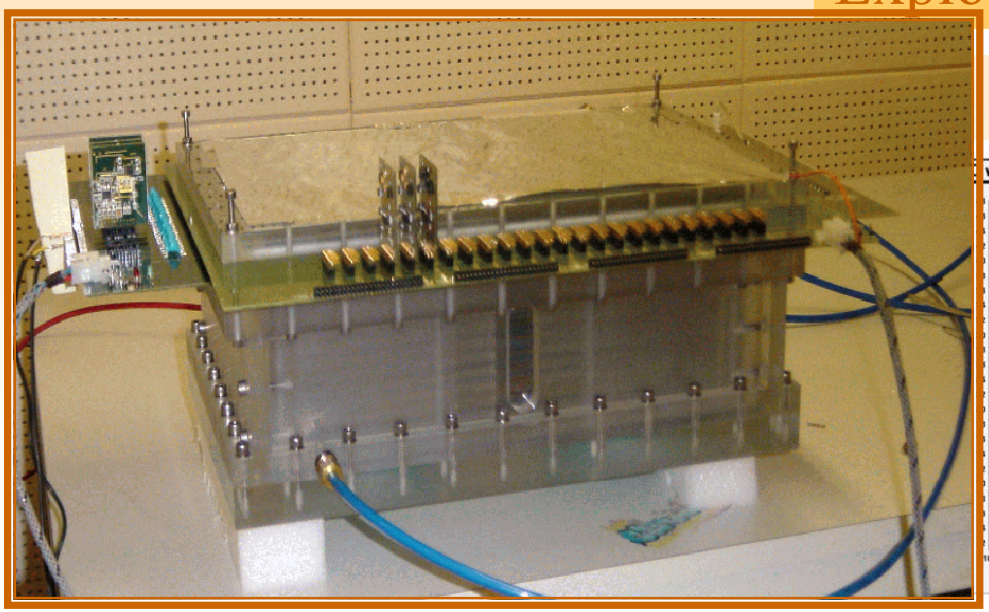
- Efficiency close to 100% over the full energy range (*works in vacuum without window*)
- Constrained only by the telescope

TPC

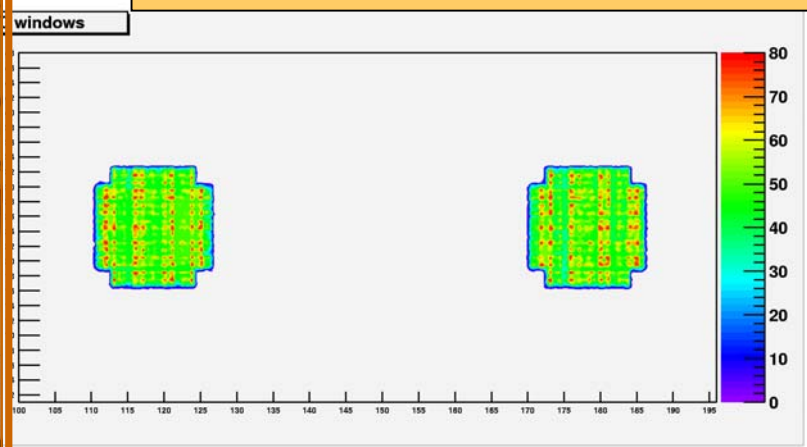
- ***Conventional*** *therefore* **robust** and **stable**
- ***Position sensitive*** *(3mm spacing)*
  - *48 anode wires(x)*
  - *96 cathode wires(y)*
  - ***time (!)***



Exploded View

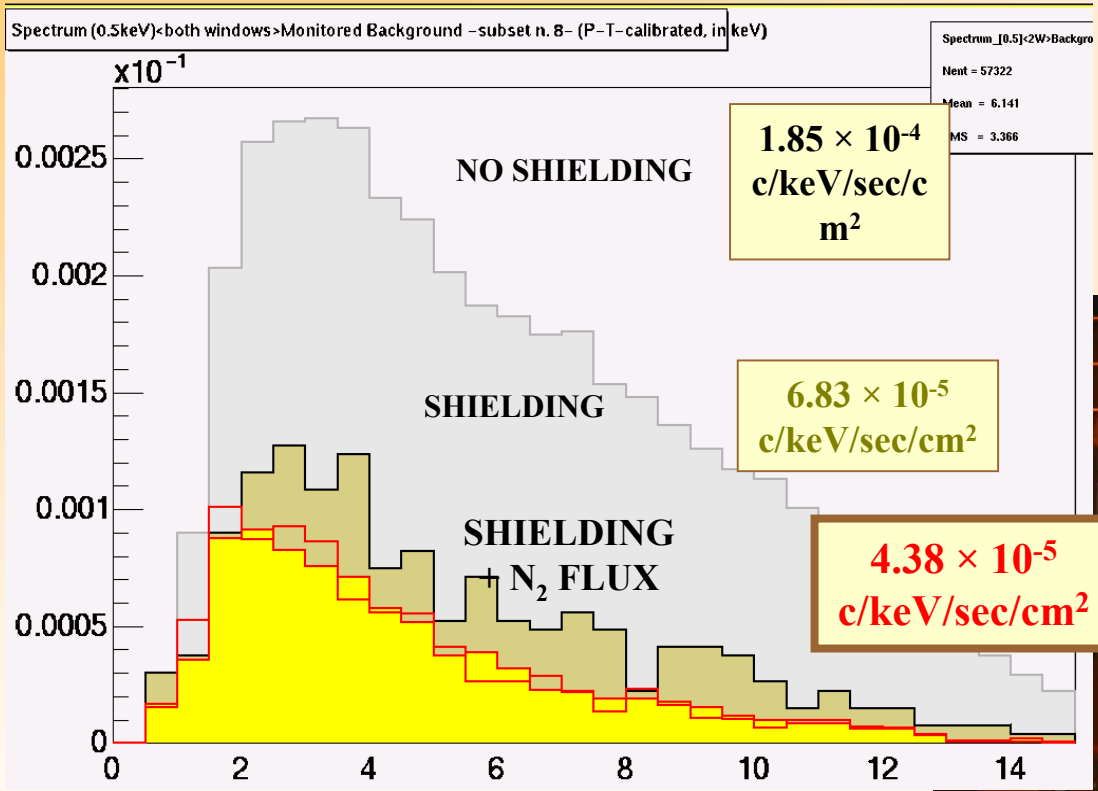


Both windows with data from PANTER

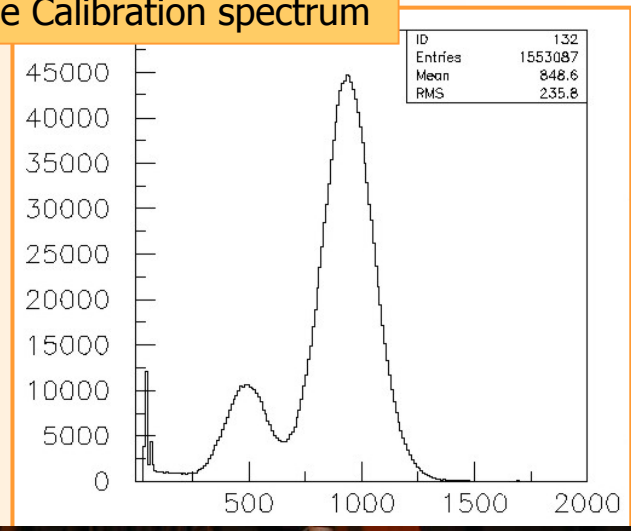


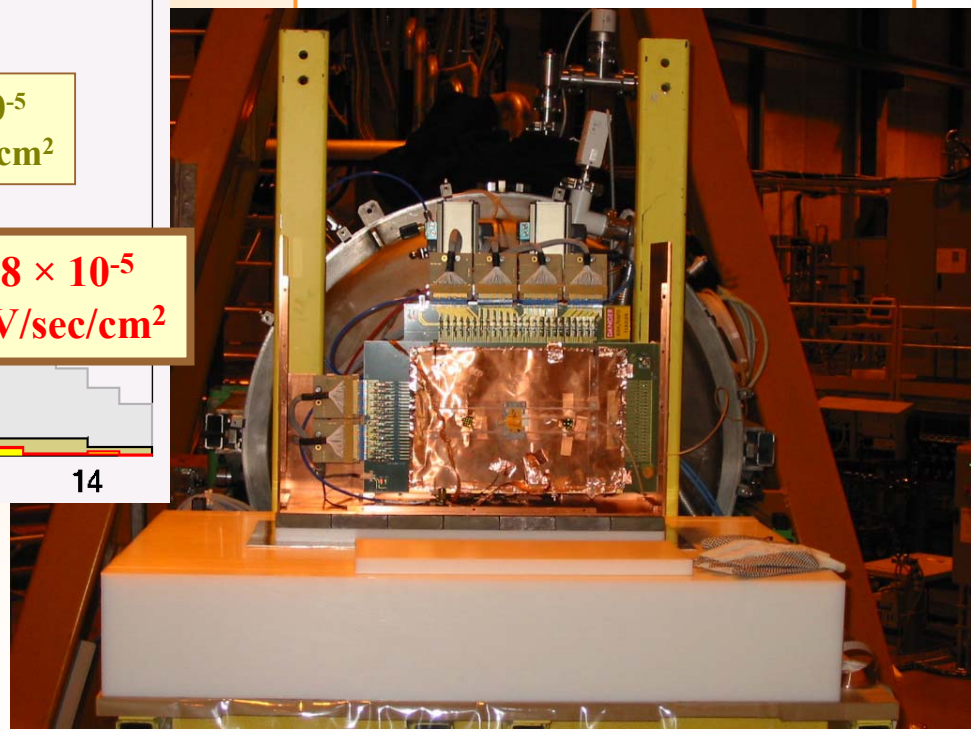
TPC

Clean materials + shielding
(polyethylene+copper+*ancient* lead)



^{55}Fe Calibration spectrum





Low Background:

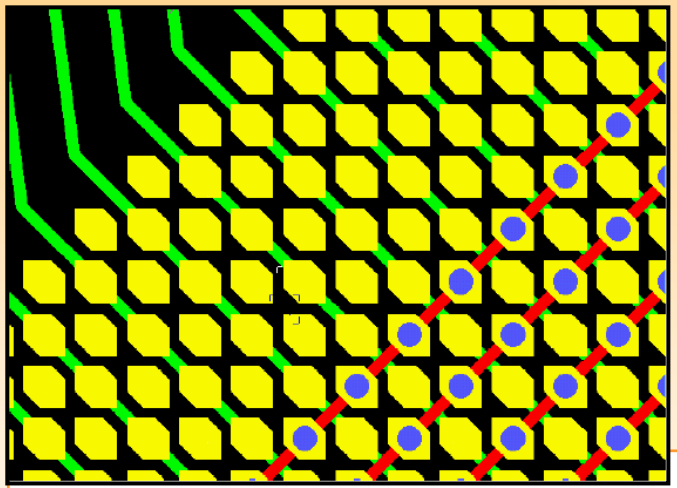
$<10^{-5}$ counts keV^{-1}cm^{-2}s^{-1}

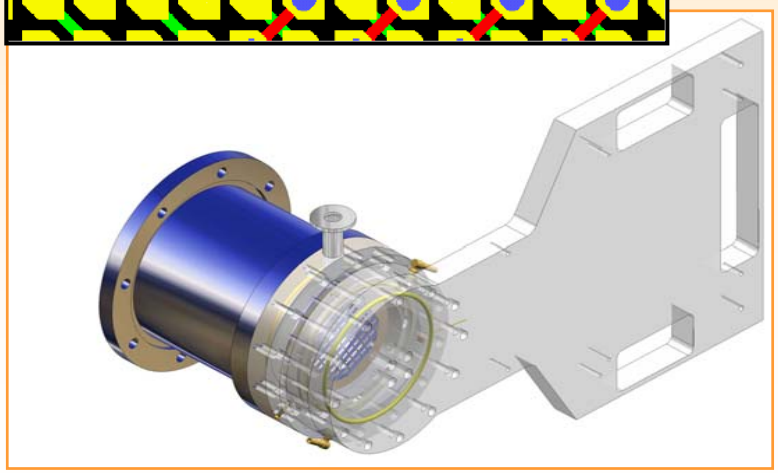
Micromegas

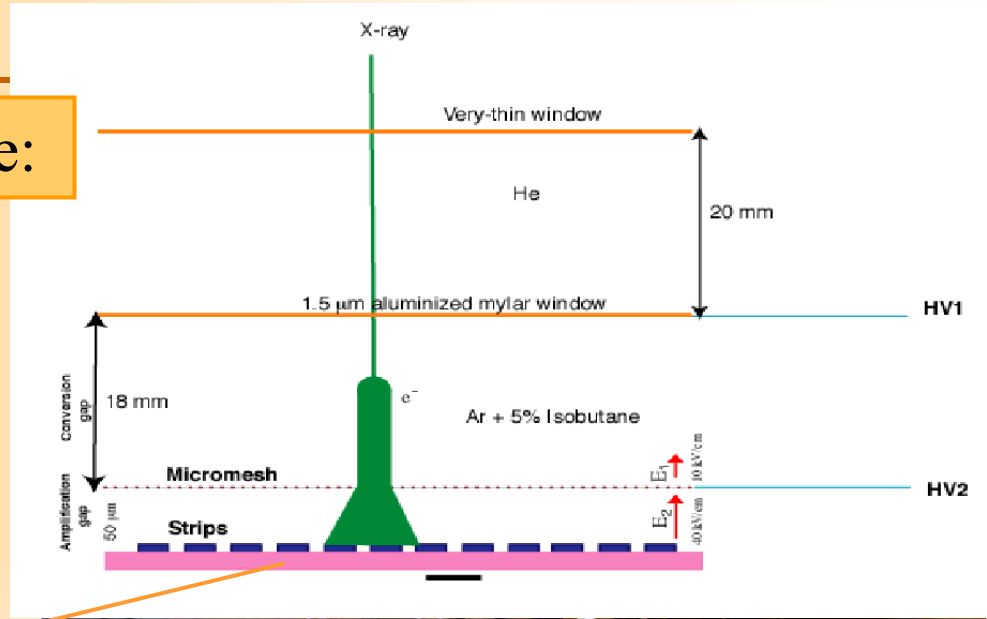
CAST Prototype: x-y structure:

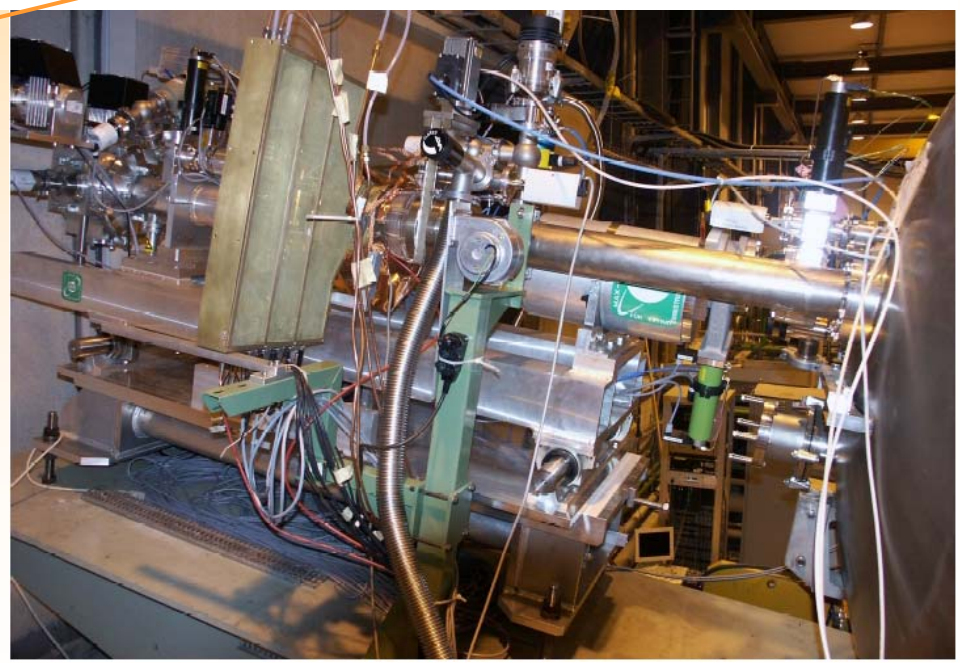
192 charge collection strips for x

192 charge collection strips for y



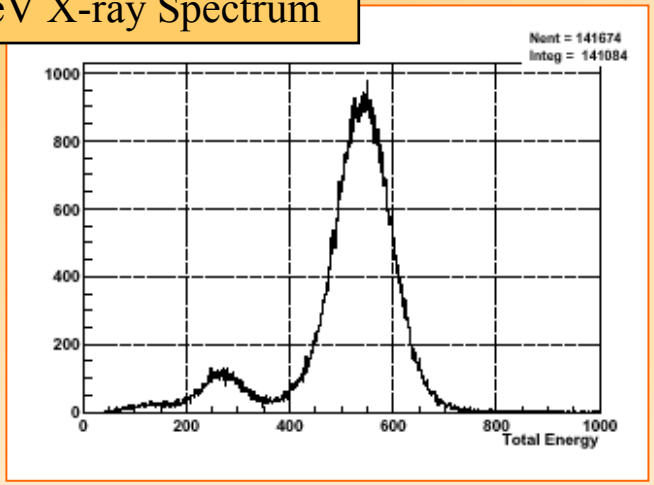


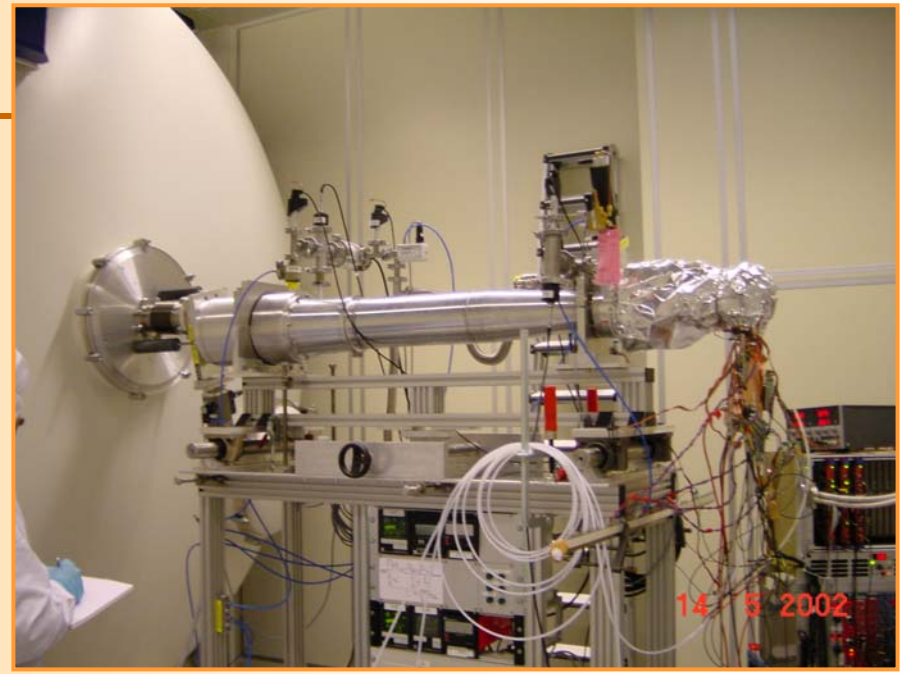




Micromegas

6.4 keV X-ray Spectrum



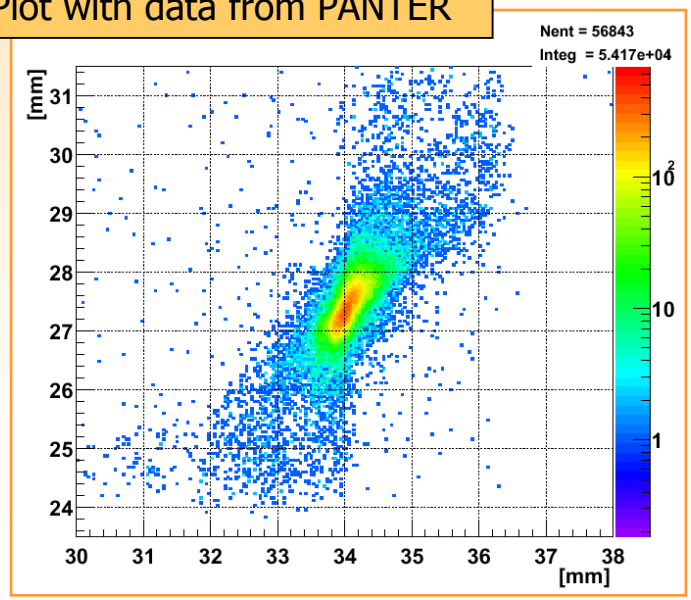


- *X-Ray detection Threshold:*
  ~0.6KeV

  (95%Ar+5%Isobutane)
- *Background rate:*

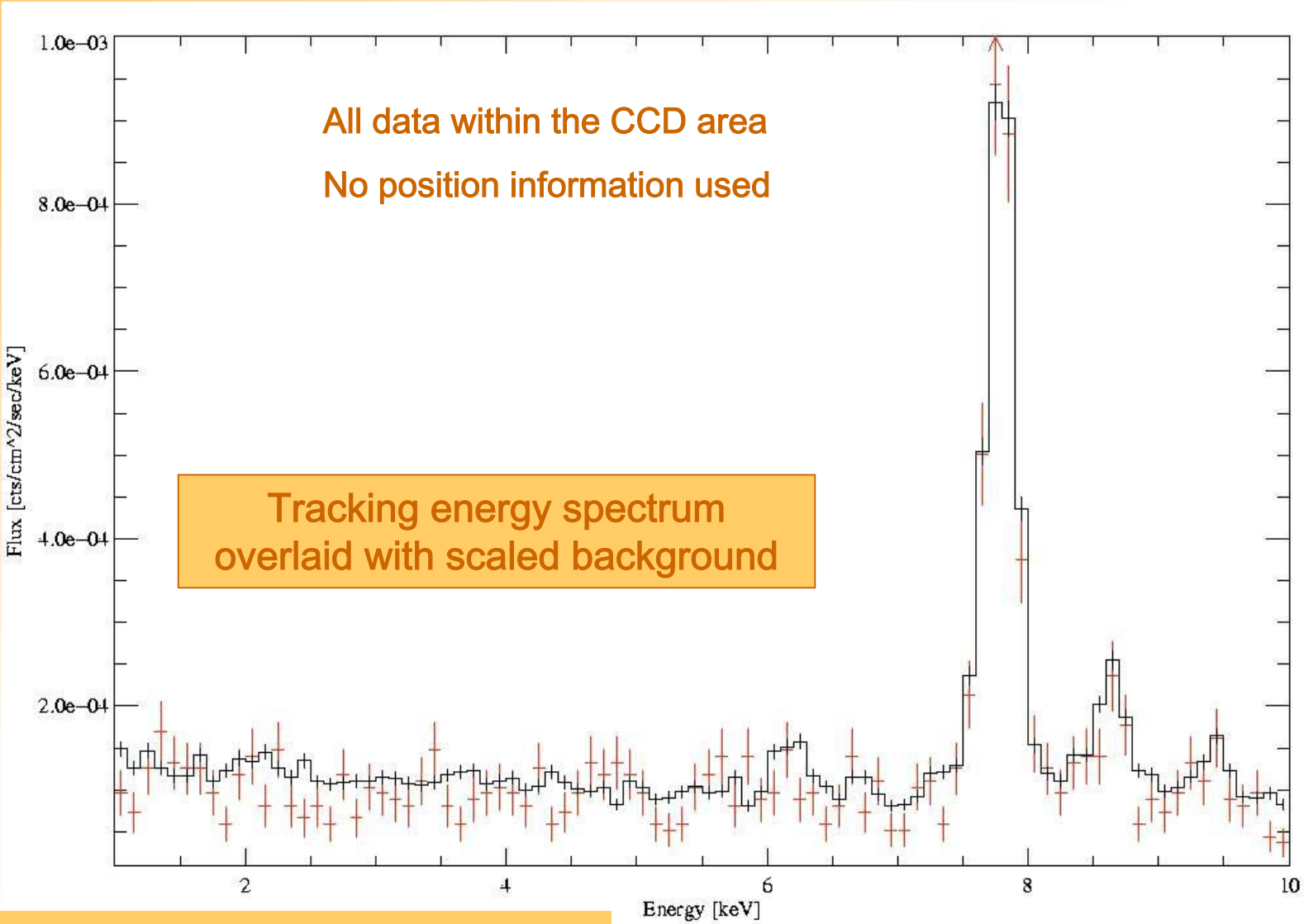
  10^{-4}-10^{-5} *events* $keV^{-1}s^{-1}cm^{-2}$

Plot with data from PANTER



Analysis: CCD

PRELIMINARY

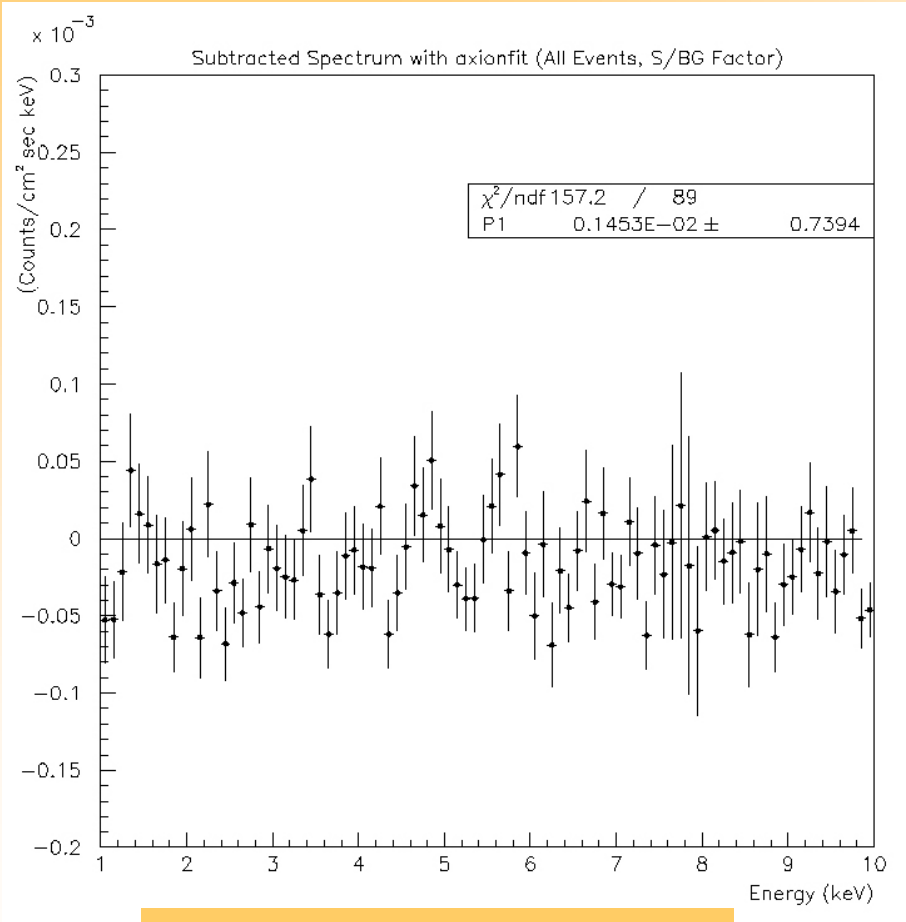


Prominent CuK_a and CuK_b fluorescence lines

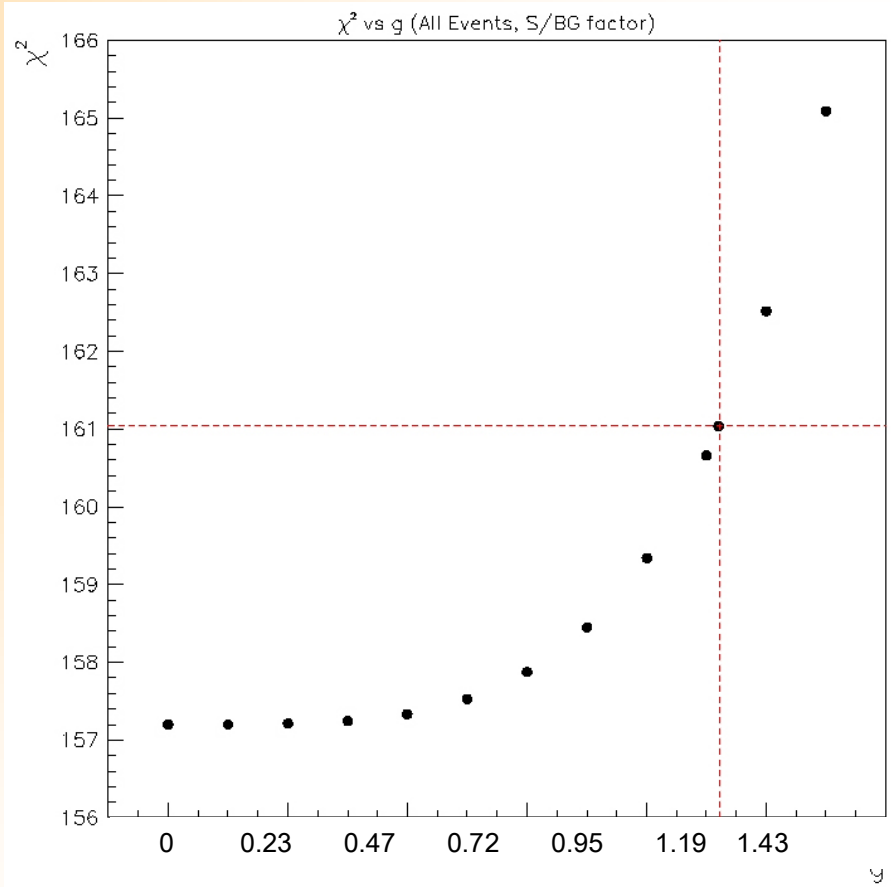
Analysis: CCD

PRELIMINARY

CCD upper Limit $g_{a\gamma\gamma}$ from fit to background subtracted data



Subtracted Spectrum

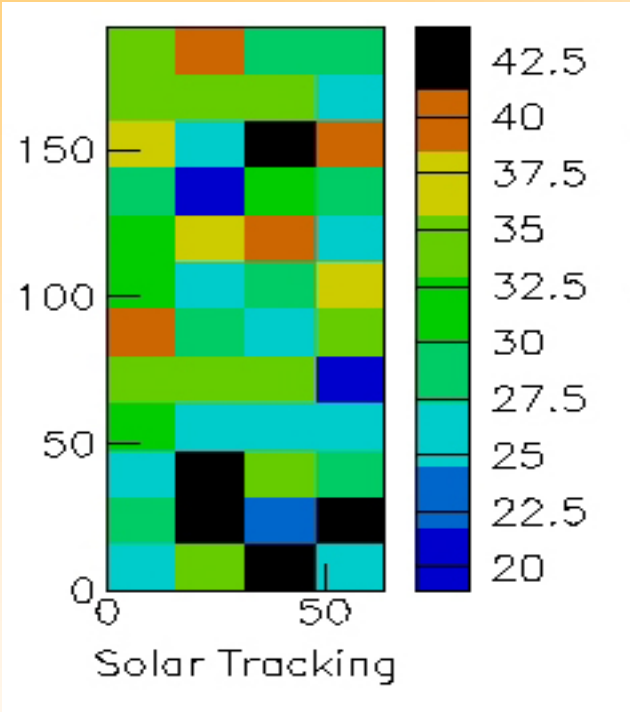


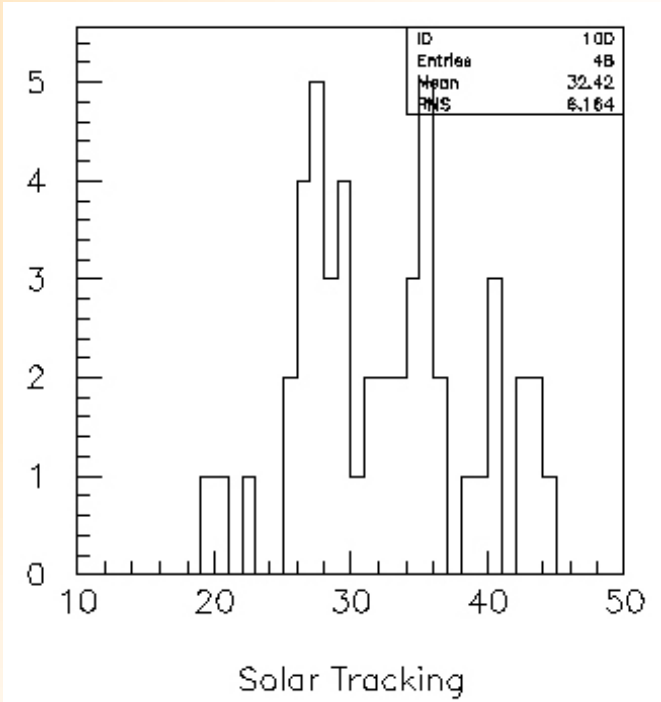
$g_{a\gamma\gamma}$ (95%)< 1.1×10^{-10} GeV^{-1}

Analysis: CCD

CCD position information
to be used in refined analysis
will reduce background by ~1/50

Number of hits in color code





Frequency of hits in cells

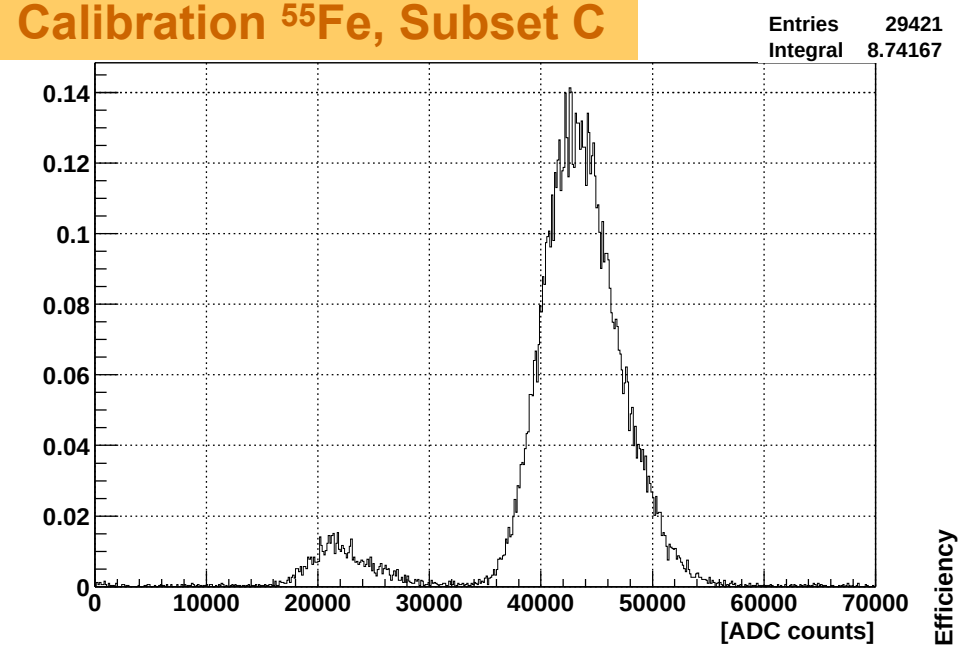
- **CCD area divided into cells of 16×16 Pixels ≈ 7mm² corresponding to image size of axion source of the sun**

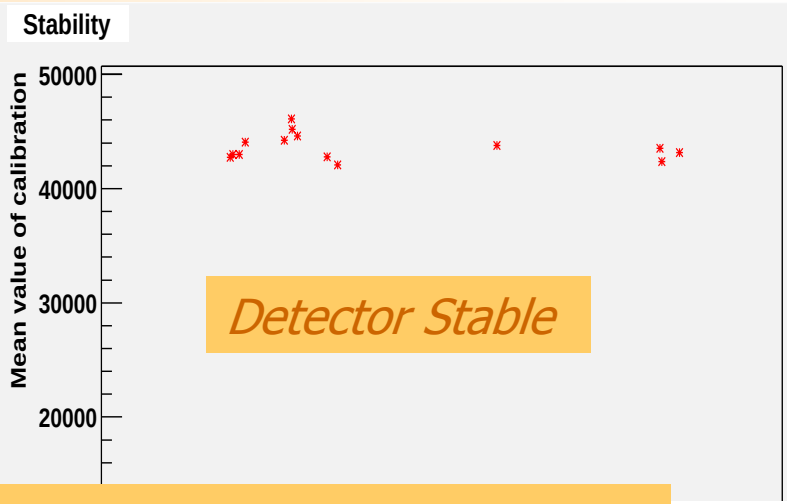
Measuring at the same time background and tracking!!!!

Analysis: Micromegas

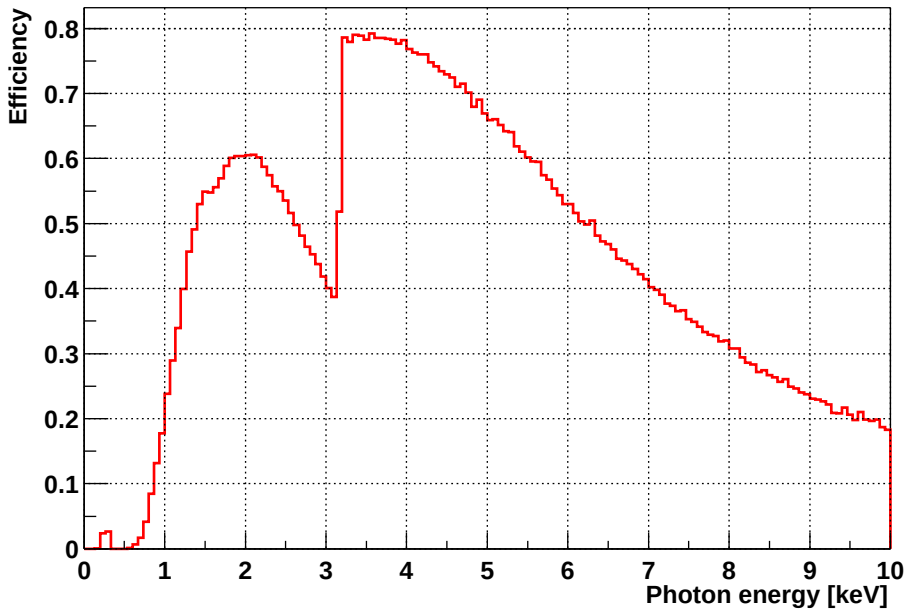
PRELIMINARY

Calibration ^{55}Fe, Subset C





X-ray conversion efficiency



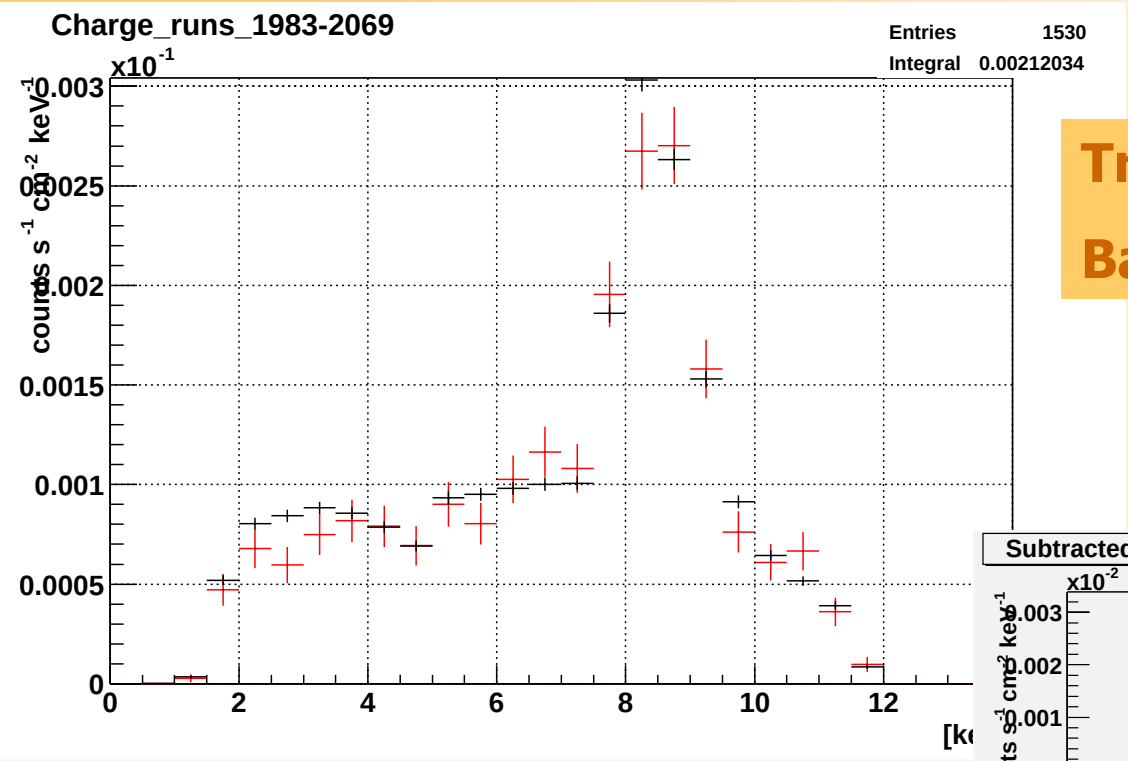
Dead time :~5%

Software efficiency:

Subset C 3keV: 77% 6keV: 87%

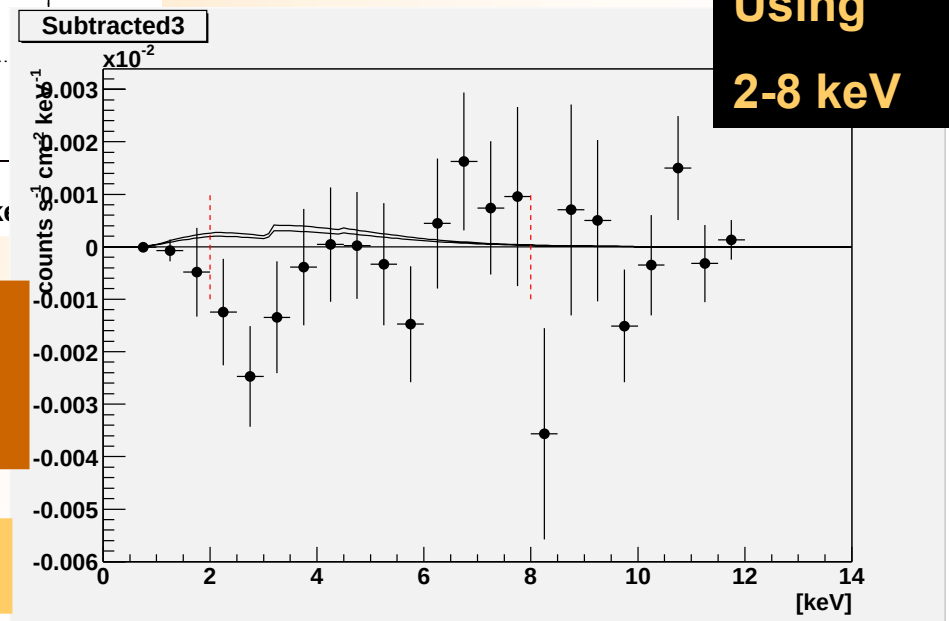
Analysis: Micromegas

PRELIMINARY



Tracking (red): 20.4h

Background (black): 253h



Using 2-8 keV

$g_{a\gamma\gamma}$ (95%CL)< 1.41x 10^{-10} GeV^{-1}

X^2_{min}/dof = 14/10

Constrained to the physical region

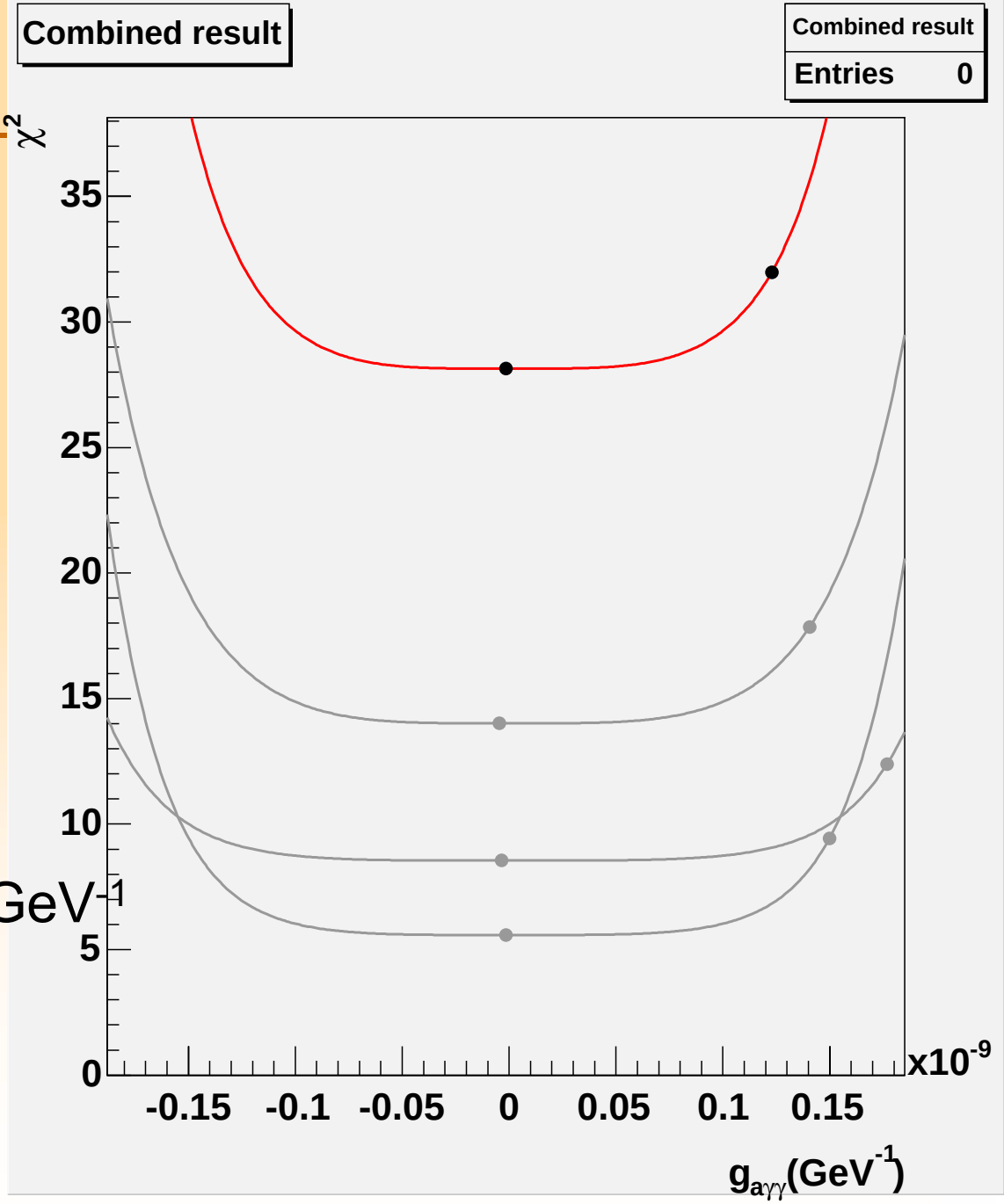
Analysis: Micromegas

Micromegas Data:
Combined result
of 3 Subsets

PRELIMINARY

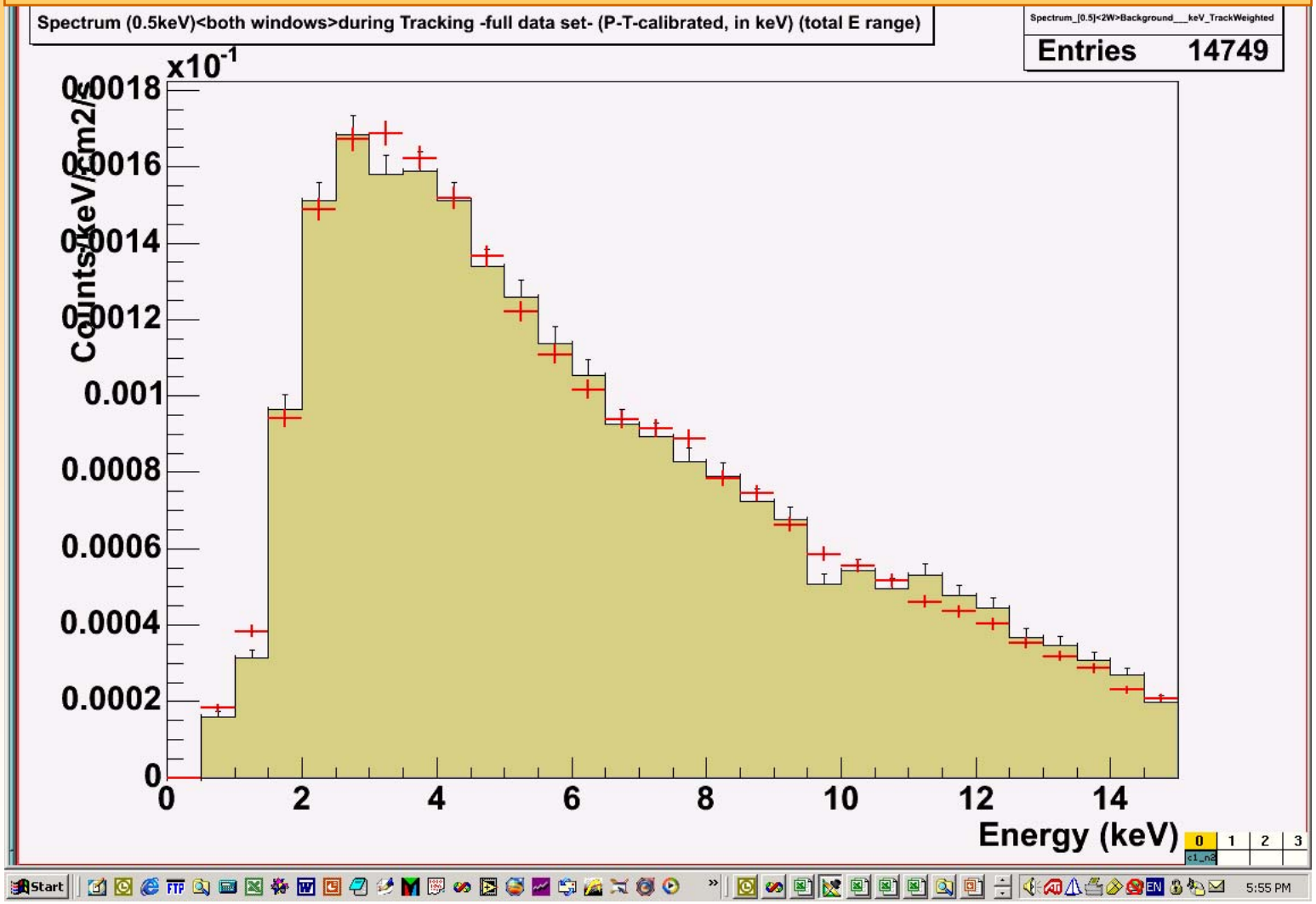
$g_{a\gamma\gamma}$ (95%CL)<1.23x 10^{-10}GeV^{-1}

χ^2_{min}/dof = 28 /30



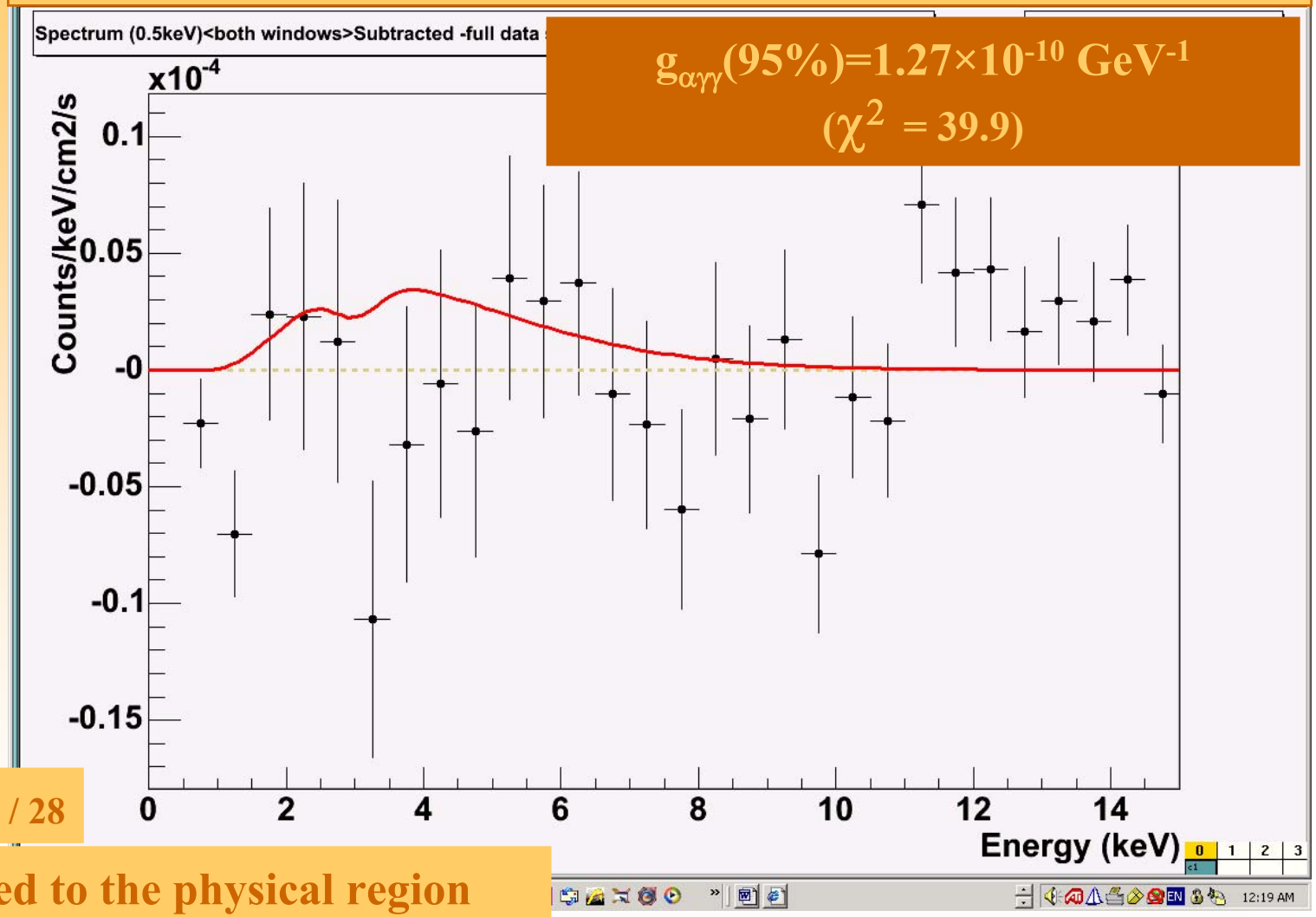
Analysis: TPC

Tracking & background spectra combined



Analysis: TPC

chi2 minimization – 95% C.L. exclusion.



$g_{a\gamma\gamma}(95\%)=1.27\times10^{-10}$ GeV^{-1}

(χ^2 = 39.9)

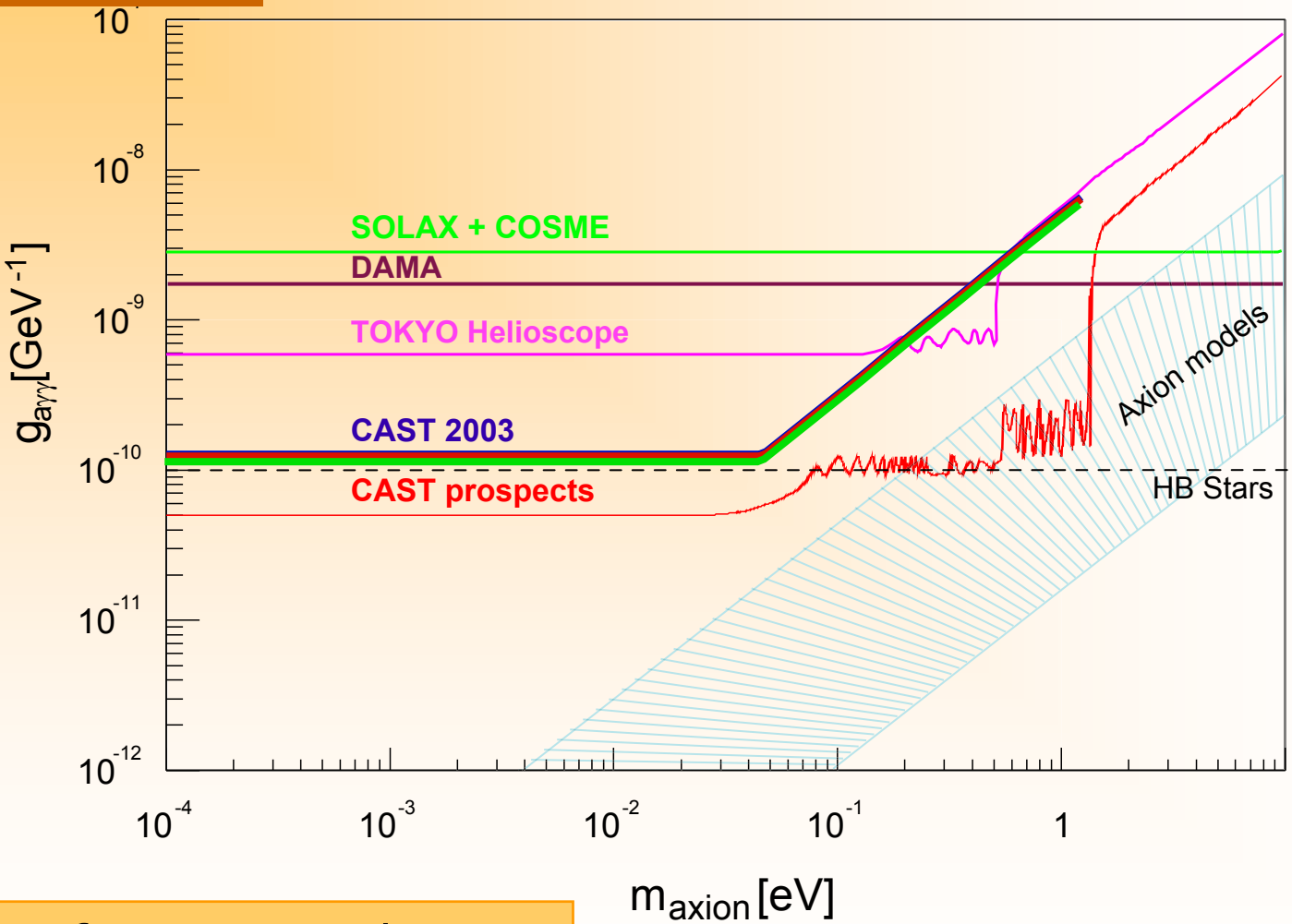
χ^2_{min}/dof = 36.0 / 28

Constrained to the physical region

PRELIMINARY ANALYSIS RESULTS

To be combined

CAST Sensitivity



CAST data from 2002 and 2003

And yet…