Search for Solar Axions: CAST

Biljana Lakić

IRB Zagreb, TU Darmstadt

for the CAST collaboration

2004 LHC DAYS IN SPLIT, 5 – 9 October

Outline:

- Axions
- The CAST experiment:
  - Physics behind the experiment
  - Description:
    - Magnet, tracking
    - X-ray telescope and X-ray detectors
  - Analysis and preliminary results
  - Prospects

Axions

The strong CP problem:

$$\mathcal{L}_{\text{strong CP}} = \bar{\theta}\frac{\alpha_s}{8\pi} G_a^{\mu\nu}\tilde{G}_{a\mu\nu}$$

$$\bar{\theta} = \theta + \operatorname{Arg}\det M$$

(QCD vacuum + EW quark mixing)

$\Downarrow$

-direct contribution to the electric dipole moment of the neutron d_n

-strong experimental bound on d_n requires $\bar{\theta} \leq 10^{-9}$

Peccei-Quinn solution:

-new global chiral $U(1)_{PQ}$ symmetry spontaneously broken at scale f_a

-associated pseudo Nambu-Goldstone boson: axion !

$$\mathcal{L}_a = \frac{1}{2}\partial_\mu a \partial^\mu a - \frac{\alpha_s}{8\pi f_a} a G_a^{\mu\nu}\tilde{G}_{a\mu\nu}$$

$\Rightarrow \bar{\theta}$ absorbed in the definition of a

-axion mass: $m_a = 6\,\text{eV}\,\frac{10^6\,\text{GeV}}{f_a}$

Axion: pseudoscalar, neutral, practically stable

Axions

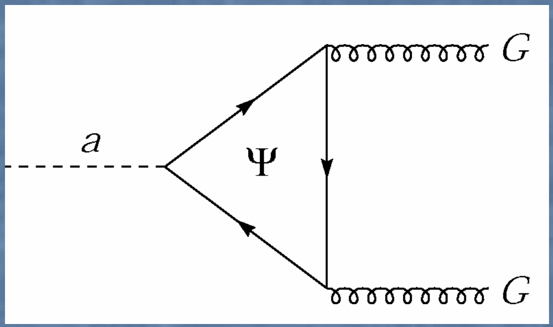
Axion models:

- Standard axion model ($f_a \approx f_{weak}$) excluded experimentaly
- Invisible axion models ($f_a >> f_{weak}$, $g \sim 1/f_a$, $m_a \sim 1/f_a$)
  - KSVZ (Kim, Shifman, Vainshtein, Zakharov)
  - DFSZ (Dine, Fischler, Srednicki, Zhitnitskii)

Axion-photon coupling:

-axion-photon coupling via triangle loop

-axion-pion mixing

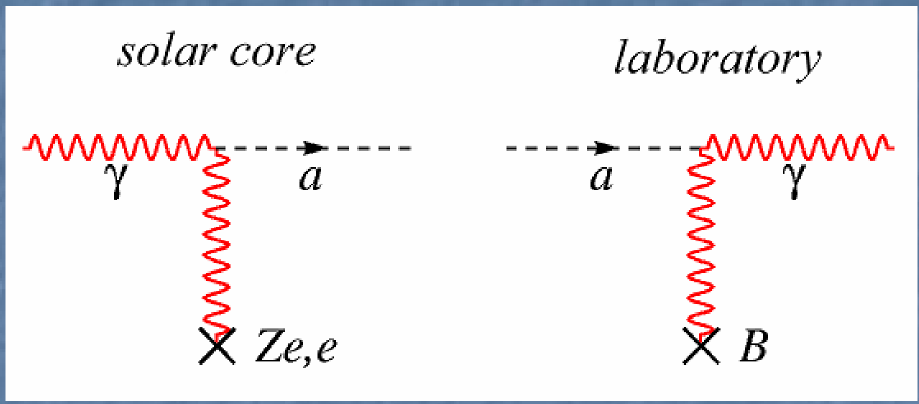


$$g_{a\gamma\gamma} = \frac{\alpha}{2\pi f_a}\left[\frac{E}{N} - \frac{2(4+z+w)}{3(1+z+w)}\right] = \frac{\alpha}{2\pi f_a}\left[\frac{E}{N} - 1.92 \pm 0.08\right]$$

CAST: Physics

Sun: a thermal photon converts into an axion in the Coulomb fields of nuclei and electrons in the solar plasma (Primakoff process)

Earth: an axion converts into a photon in a strong transverse magnetic field



-expected number of photons

$$N_\gamma = \int \frac{d\Phi_a}{dE_a} P_{a\to\gamma} S\, t\, dE_a$$

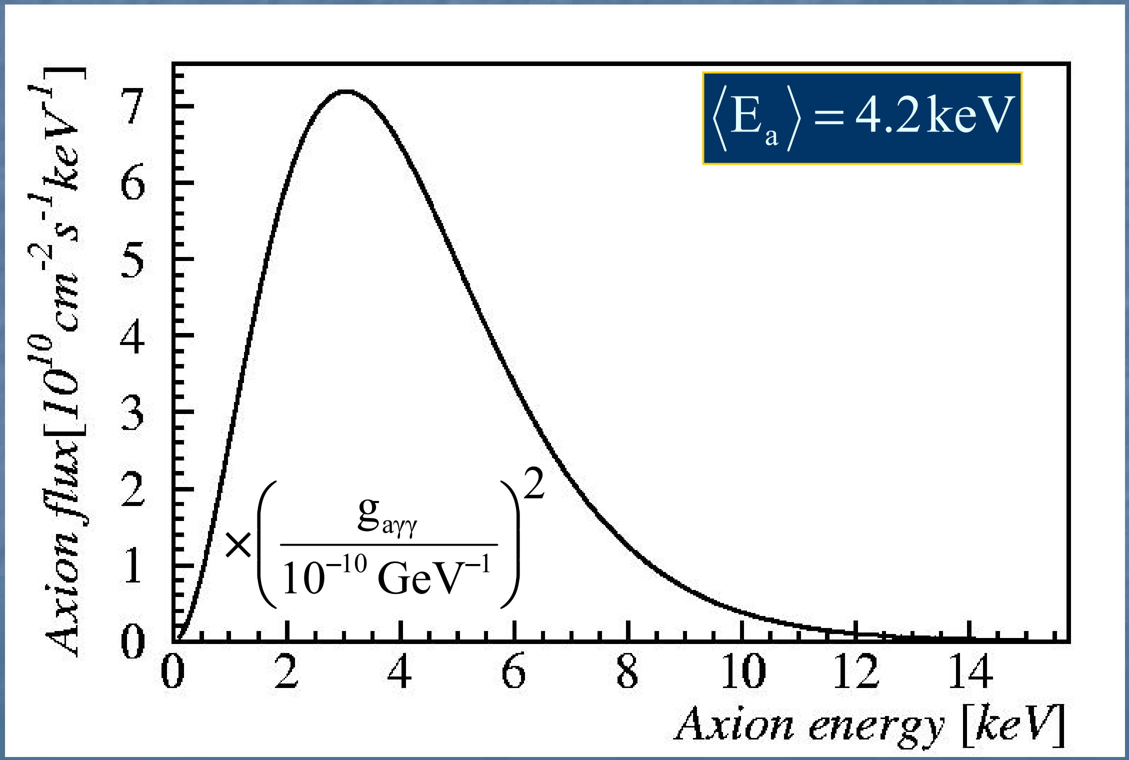
S = detector effective area

t = measurement time

CAST: Physics

- differential axion flux at the Earth:

$$\frac{d\Phi_a}{dE_a} = 4.02\times10^{10}\left(\frac{g_{a\gamma\gamma}}{10^{-10}\ \mathrm{GeV}^{-1}}\right)^2 \frac{(E_a/\mathrm{keV})^3}{e^{E_a/1.08\,\mathrm{keV}}-1} \quad \mathrm{cm^{-2}s^{-1}keV^{-1}}$$



K. van Bibber *et al.*,1989

CAST: Physics

-conversion probability in the gas (in vacuum: $\Gamma = 0$, $m_\gamma = 0$):

$$P_{a\to\gamma} = \left(\frac{Bg_{a\gamma\gamma}}{2}\right)^2 \frac{1}{q^2+\Gamma^2/4}\left[1+e^{-\Gamma L}-2e^{-\Gamma L/2}\cos(qL)\right]$$

L=magnet length, Γ=absorption coeff.

$$q = \left|\frac{m_\gamma^2 - m_a^2}{2E_a}\right|$$

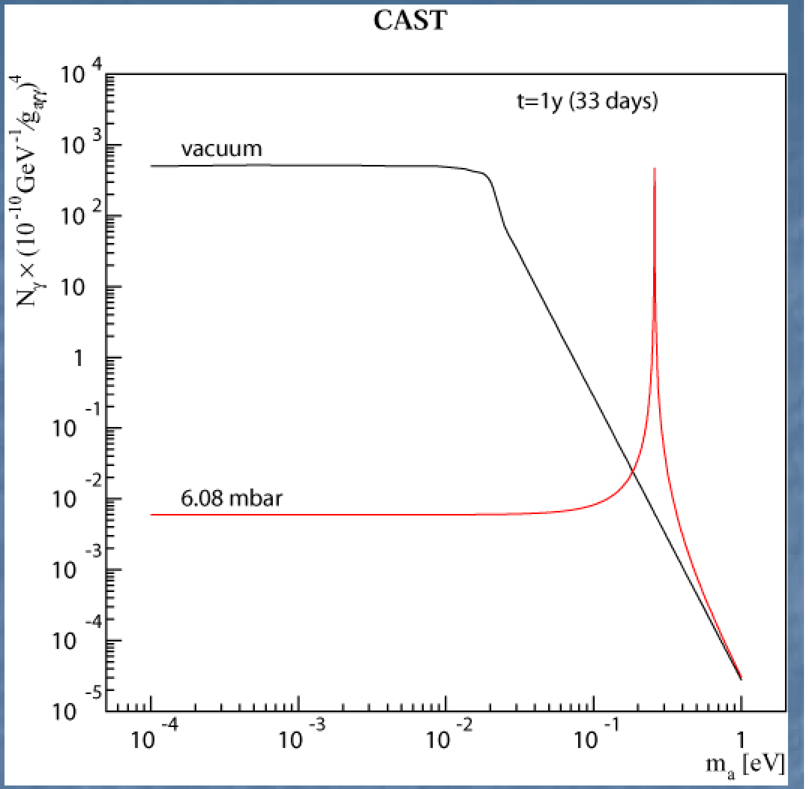
axion-photon momentum transfer

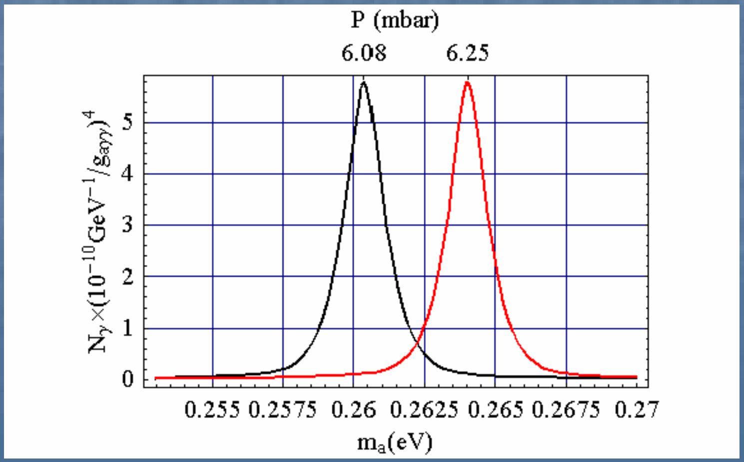
$$m_\gamma(\mathrm{eV}) \approx \sqrt{0.02\frac{P(\mathrm{mbar})}{T(\mathrm{K})}}$$

effective photon mass (T=1.8 K)

-coherence condition:

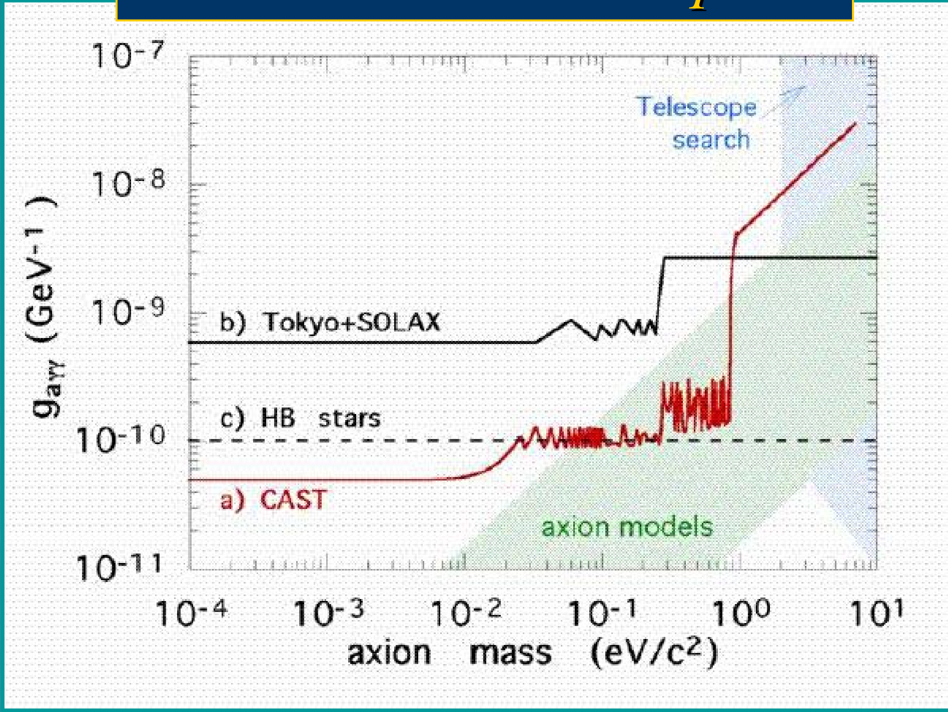
$$qL < \pi \quad\Rightarrow\quad \sqrt{m_\gamma^2 - \frac{2\pi E_a}{L}} < m_a < \sqrt{m_\gamma^2 + \frac{2\pi E_a}{L}}$$





CAST: Physics

Predicted exclusion plot



- 1 year with vacuum in the magnet bores: m < 2.3×10^{-2} eV (during 2003 and 2004)

- 1 year with ^{4}He gas pressure increased from 0 - 6 mbar in 100 increments: m < 0.26 eV

- 1 year with ^{3}He gas pressure increased from 6 - 60 mbar in 365 increments : m < 0.83 eV

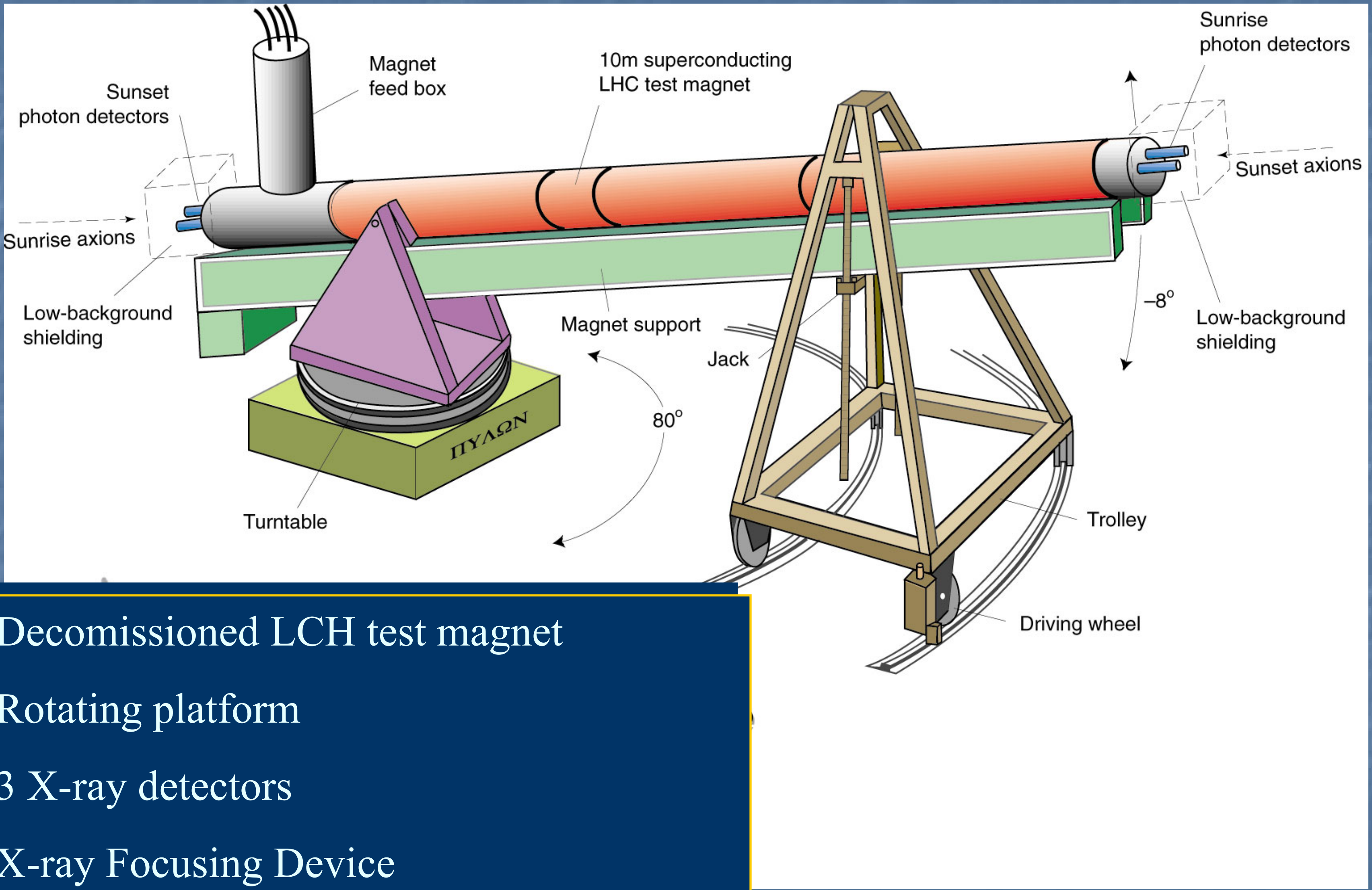
To start in 2005

CAST: Collaboration

Canada, Vancouver, Bc, University of British Columbia
Department of Physics *(1 participant(s)) Team Leader:* ***Michael HASINOFF***
Michael HASINOFF
Croatia, Zagreb
Ruder Boskovic Institute *(3 participant(s)) Team Leader:* ***Milica KRCMAR***
Milica KRCMAR, Biljana LAKIC, Ante LJUBICIC
France, Gif-Sur-Yvette, Centre d'Etudes de Saclay (CEA-Saclay)
DAPNIA *(6 participant(s)) Team Leader:* ***Ioanis GIOMATARIS***
Samuel ANDRIAMONJE, Alain DELBART, Esther FERRER RIBAS, Ioanis GIOMATARIS, Emile PASQUETTO, Jean Pierre ROBERT
Germany, Darmstadt, Technische Universitat Darmstadt
Institut für Kernphysik *(6 participant(s)) Team Leader:* ***Konstantin ZIOUTAS***
Horst BALONIER, Theopisti DAFNI, Dieter HOFFMANN, Joachim JACOBY, Manfred MUTTERER, Hans RIEGE
Germany, Frankfurt Am Main, Johann-Wolfgang-Goethe Universität Frankfurt
Institut für Kernphysik *Team Leader:* ***Konstantin ZIOUTAS***
Germany, Freiburg
Albert-Ludwigs-Universität Freiburg *(6 participant(s)) Team Leader:* ***Kay KONIGSMANN***
Horst FISCHER, Jurgen FRANZ, Igor GARCIA IRASTORZA, Fritz-Herbert HEINSIUS, Donghwa KANG, Kay KONIGSMANN
Germany, Garching, Max-Planck-Gesellschaft (MPG)
Max-Planck-Institut für Extraterrestrische Physik *(2 participant(s)) Team Leader:* ***Markus KUSTER***
Heinrich BRAEUNINGER, Markus KUSTER
Germany, Muenchen
Max-Planck-Institut för Physik *(3 participant(s)) Team Leader:* ***Gerhard LUTZ***
Rainer KOTTHAUS, Gerhard LUTZ, Georg RAFFELT
Greece, Athens
National Center for Scientific Research "Demokritos" (NRCPS) *(4 participant(s)) Team Leader:* ***George FANOURAKIS***
George FANOURAKIS, Theodoros GERALIS, Konstantinos KOUSOURIS, Aikaterini ZACHARIADOU
Greece, Thessaloniki
Aristotle University of Thessaloníki *(6 participant(s)) Team Leader:* ***Christos ELEFTHERIADIS***
Spyridon DEDOUSIS, Christos ELEFTHERIADIS, Anastasios LIOLIOS, Argyrios NIKOLAIDIS, Ilias SAVVIDIS, Konstantin ZIOUTAS
Italy, Pisa
Scuola Normale Superiore (SNS) *(1 participant(s)) Team Leader:* ***Luigi DI LELLA***
Luigi DI LELLA
Russia, Moskva, Russian Academy of Sciences
Institute for Nuclear Research (INR) *(3 participant(s)) Team Leader:* ***Sergei GNINENKO***
Alexandre BELOV, Sergei GNINENKO, Nikolai GOLUBEV
Spain, Zaragoza, Universidad de Zaragoza Facultad de Ciencias
Instituto de Física Nuclear y Altas Energías *(7 participant(s)) Team Leader:* ***Angel MORALES***
Berta BELTRAN LIZARRAGA, Jose CARMONA MARTINEZ, Gloria LUZON MARCO, Julio MORALES, Jaime RUZ ARMENDARIZ, Maria SARSA, Jose VILLAR
Switzerland, Geneve
European Organization for Nuclear Research (CERN) *(12 participant(s)) Team Leader:* ***Martyn DAVENPORT***
Klaus BARTH, Gino CIPOLLA, Martyn DAVENPORT, Rui DE OLIVEIRA, Fabio FORMENTI, Jean-Noel JOUX, Christian LASSEUR, Angelika LIPPITSCH, Thomas PAPAEVANGELOU, Alfredo PLACCI, Bruno VULLIERME, Louis WALCKIERS
United States of America, Chicago Il, University of Chicago
Enrico Fermi Institute *(3 participant(s)) Team Leader:* ***Juan COLLAR***
Juan COLLAR, David MILLER, Joaquin VIEIRA
United States of America, Columbia Sc, University of South Carolina
Department of Physics and Astronomy *(2 participant(s)) Team Leader:* ***Frank AVIGNONE***
Richard CRESWICK, Horacio FARACH

The total number of participants: 65

CAST: CERN Axion Solar Telescope



- Decomissioned LCH test magnet
- Rotating platform
- 3 X-ray detectors
- X-ray Focusing Device

CAST: Magnet, tracking

CAST Experimental area SR8

L= 9.26 m

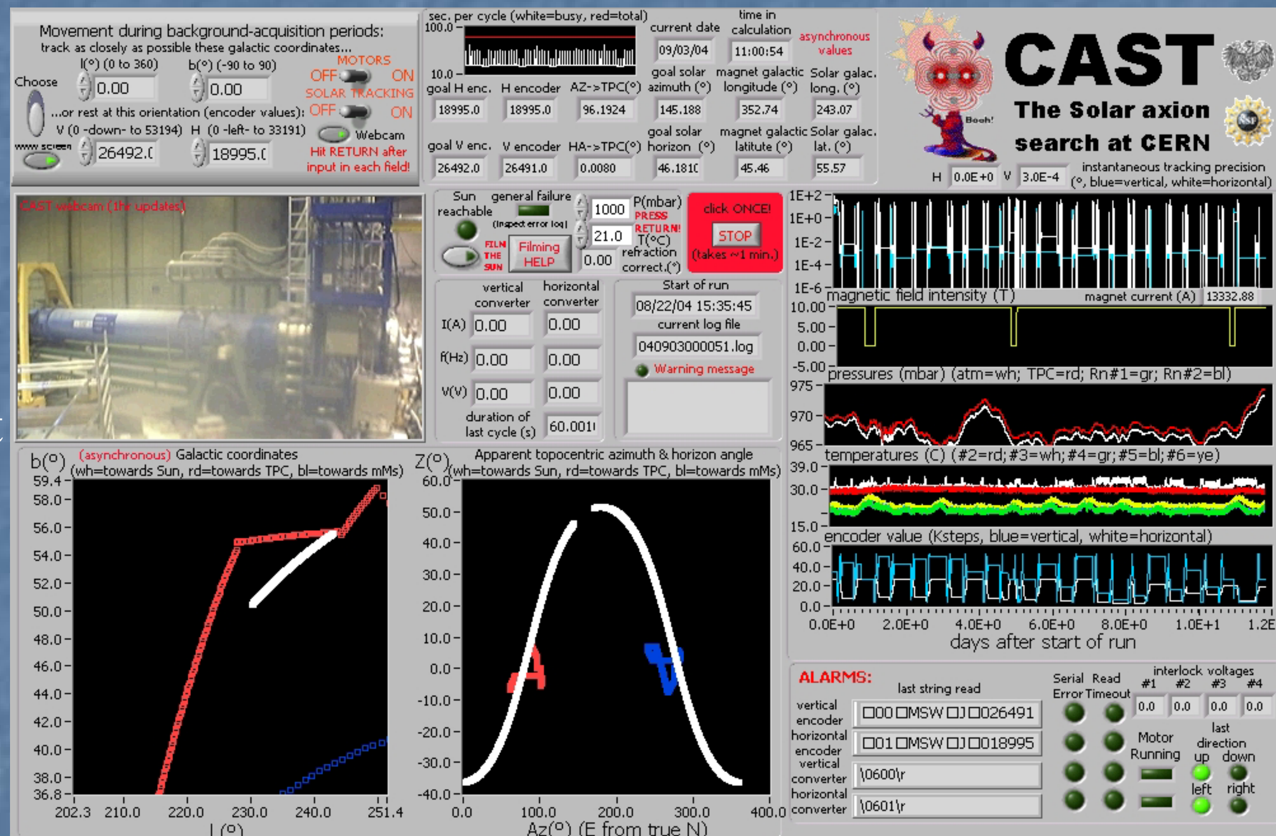
B=9 T

→100 times better than any other !!

CAST: Magnet, tracking

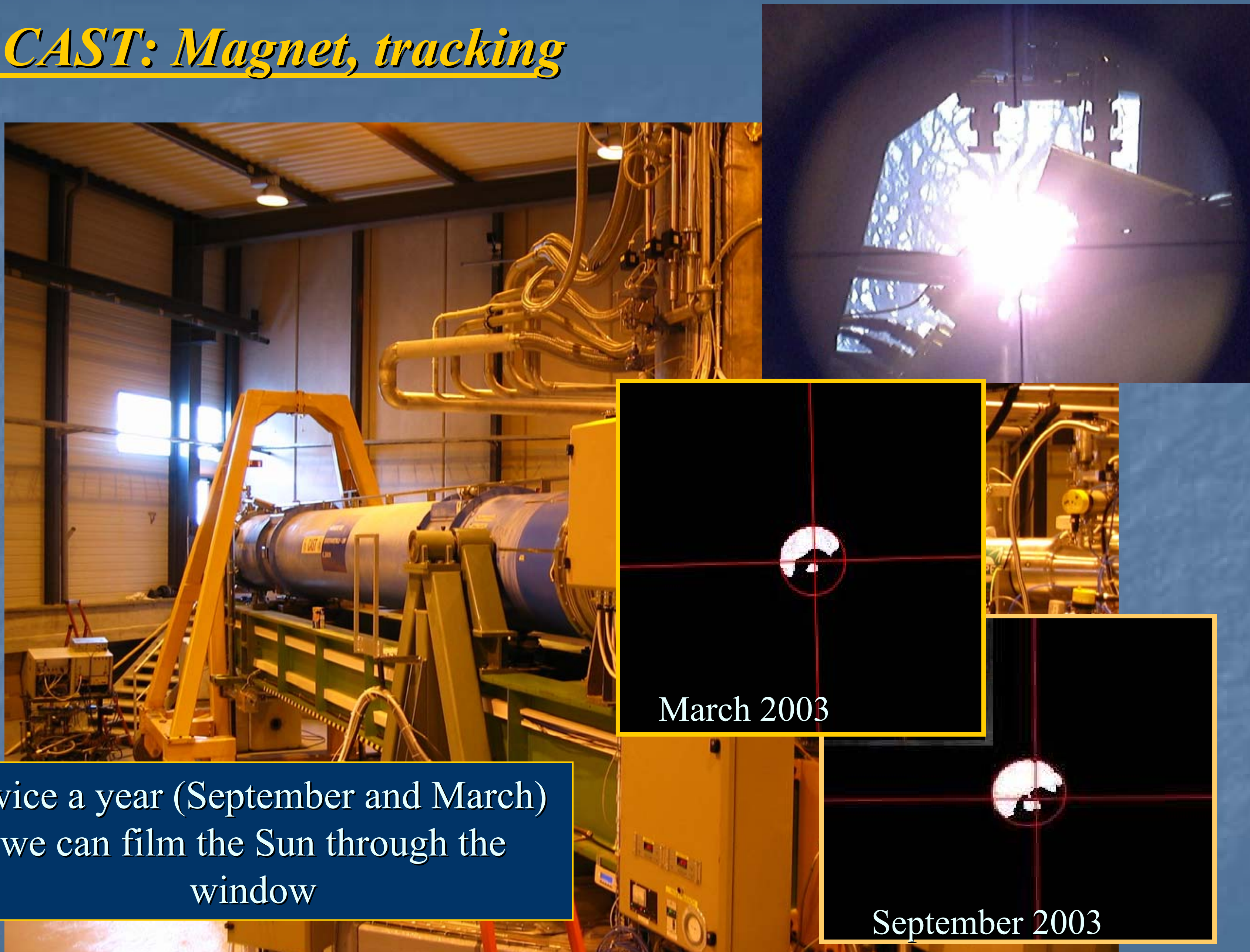
- Motors
- Encoders
- E. Readout→ computer
- Software with astronomical calculations
- Interface to move magnet
- New angle encoders

Snapshot of the tracking program



Calibrated and correlated with celestial coordinates → high precision geometer measurements (precision 0.01°)

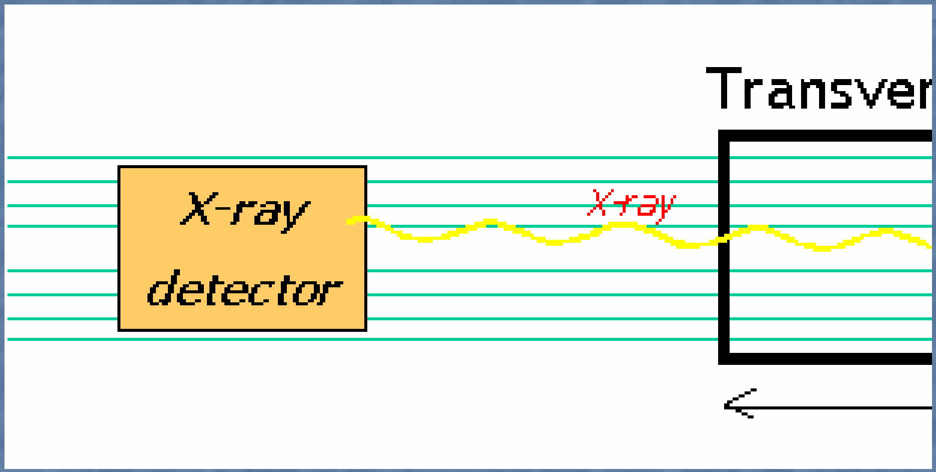
CAST: Magnet, tracking



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

CAST: Telescope, detectors

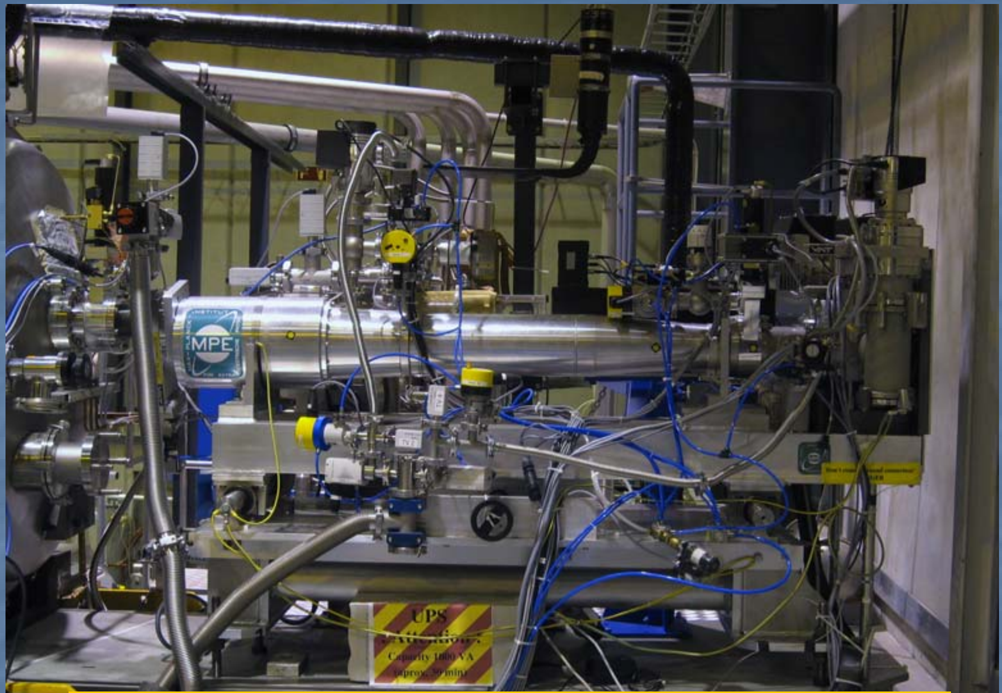
- X-Ray Telescope
  (Focusing Device)
- Detectors
  - CCD
  - Micromegas
  - TPC



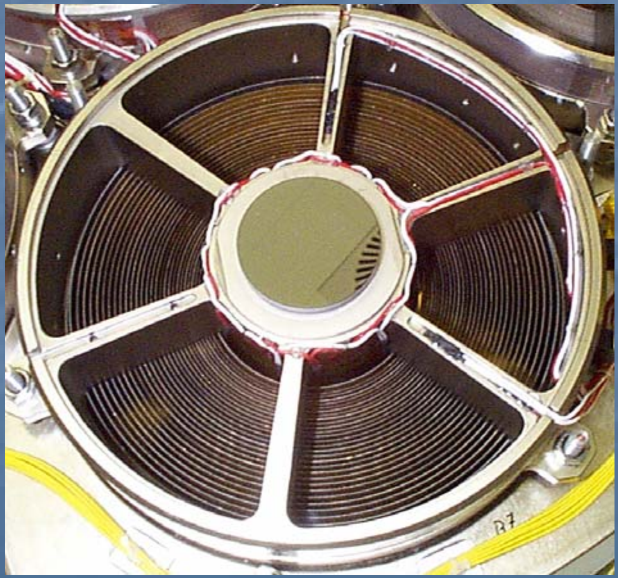
CAST: X-ray telescope

Space technology:

prototype for the satellite ABRIXAS



X-ray telescope with the CCD in place

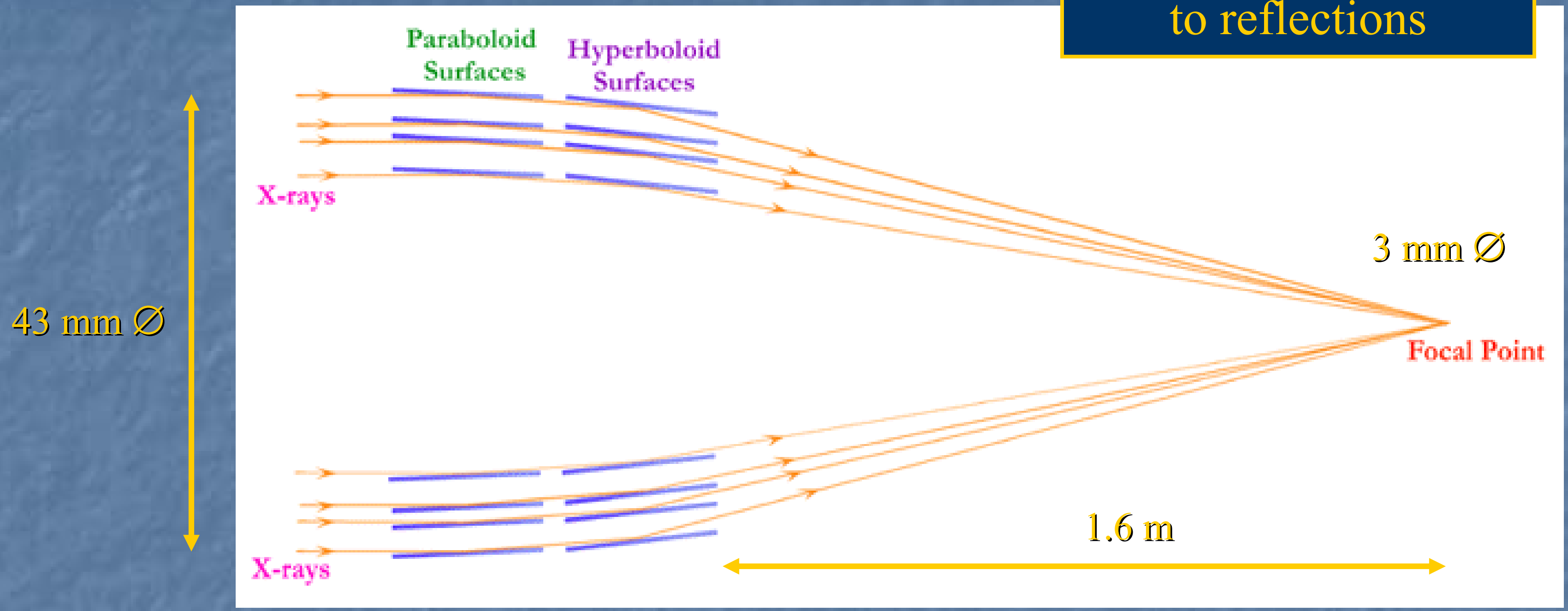


⇨ 27 concentrically nested mirror shells:

- focal length 1.6 m
- diameter 164 mm

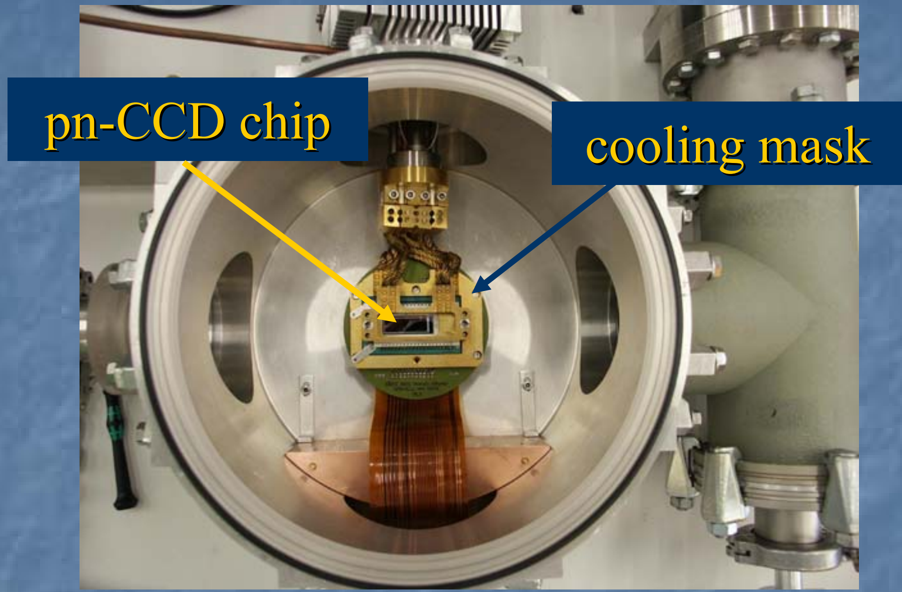
CAST: X-ray telescope

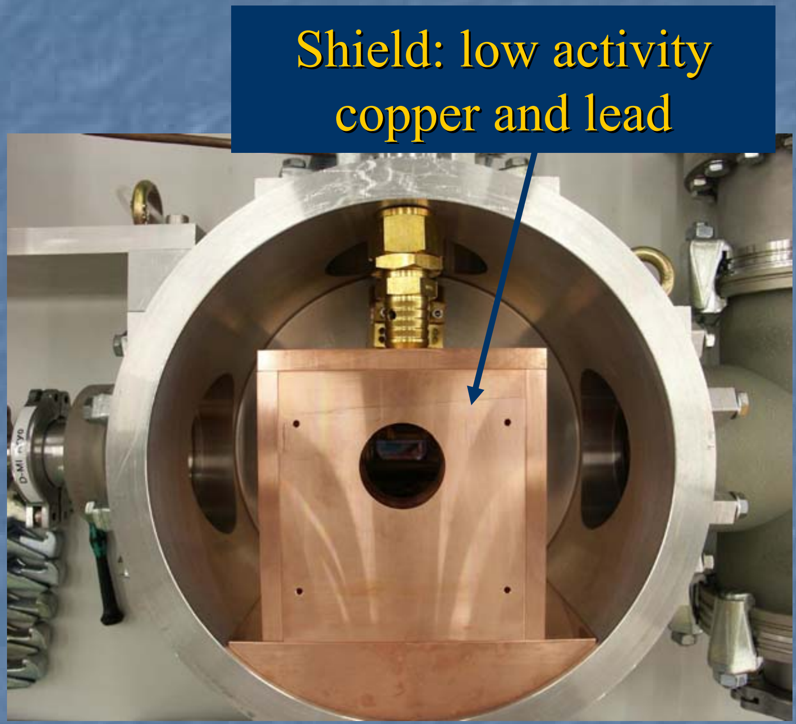
~35% efficiency due to reflections



- from 43 mm ∅ (LHC magnet aperture) to ~3 mm ∅
- signal-to-noise improvement (up to 200!!!)

CAST: CCD





Geometry: 200×64 pixels (1×3 cm^2)

Pixel size: 150×150 μm^2

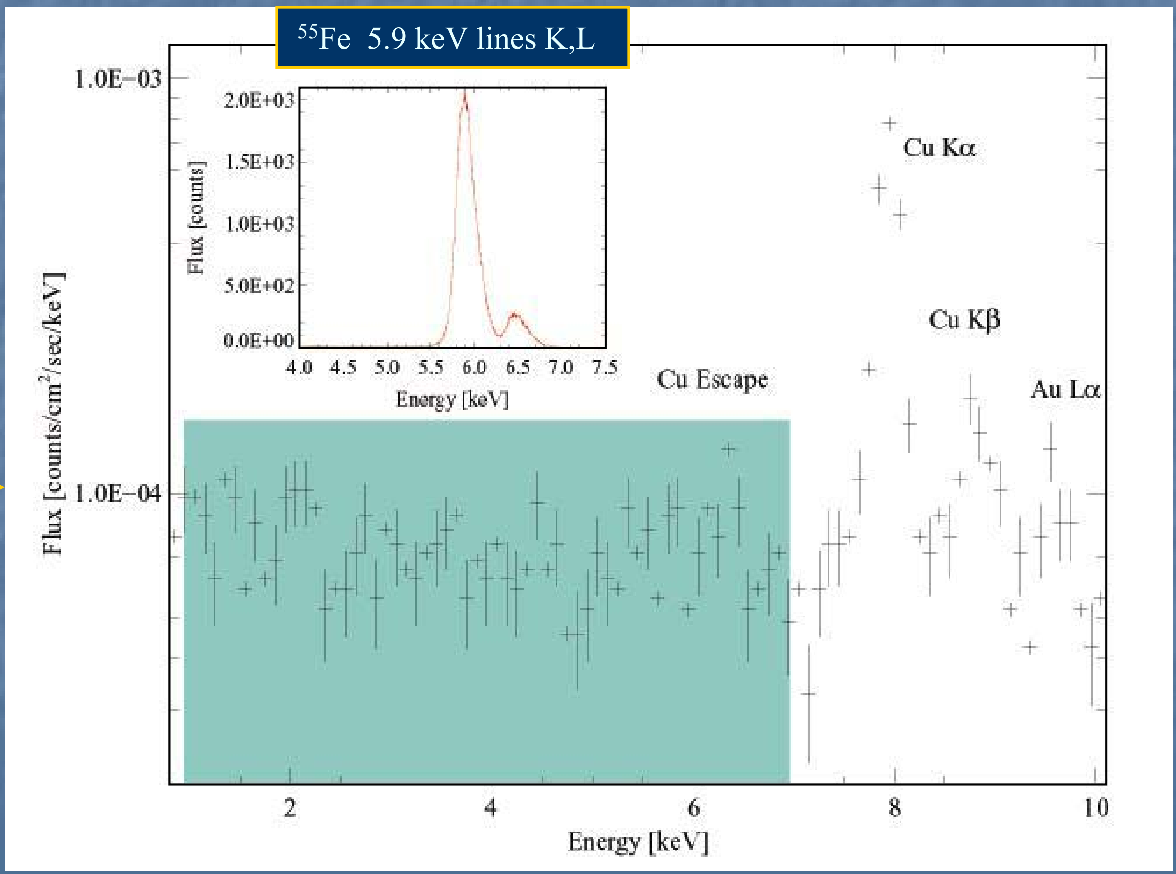
CCD temperature: -130° C

} excellent space resolution

CAST: CCD

Efficiency (1-7 keV): > 95 % → constrained only by telescope

FWHM: 160 eV @ 6 keV → excellent energy resolution

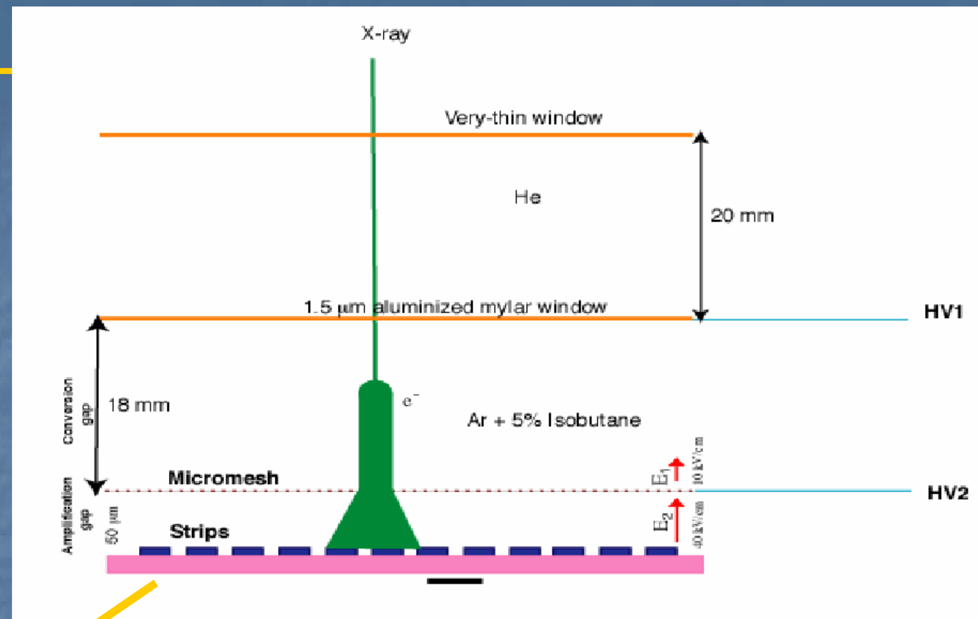


Background spectrum

~ 10^{-4} counts keV^{-1} s^{-1} cm^{-2}

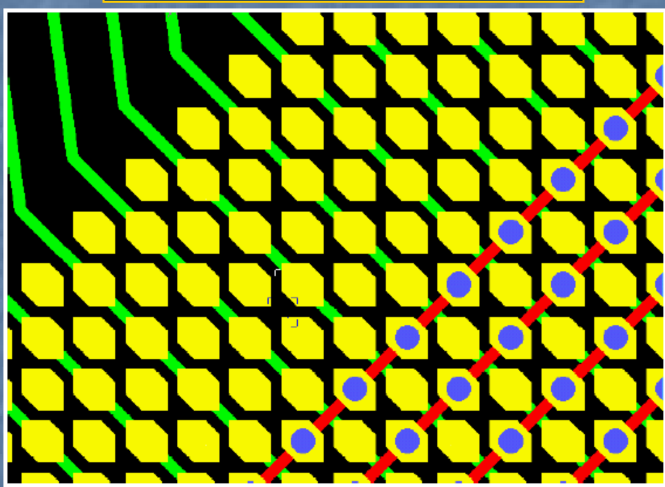
(Cu and Au lines from the cooling mask)

CAST: Micromegas



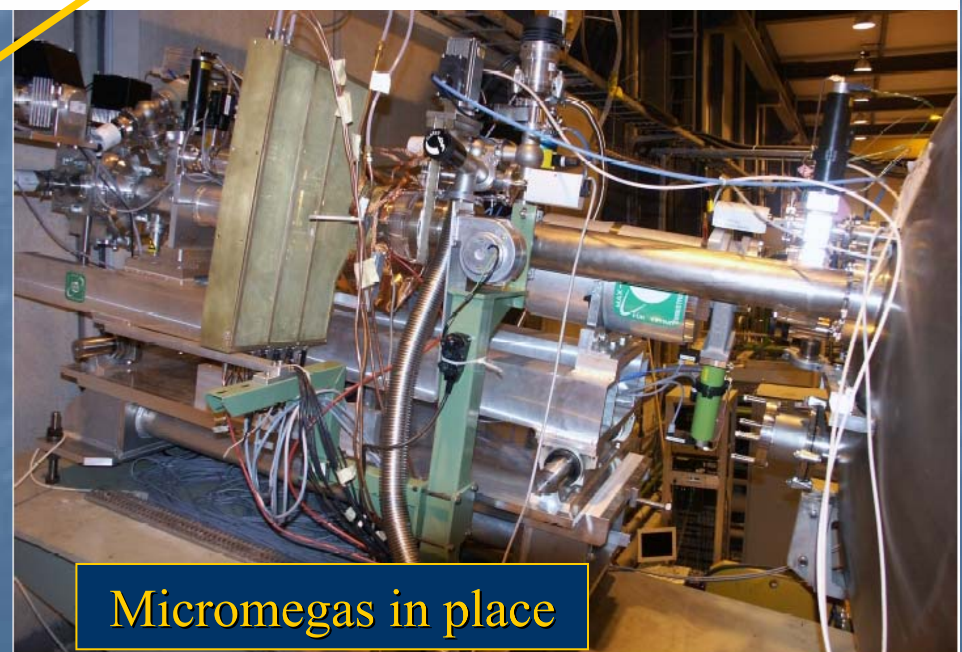
Gas: Ar 95%, Isobutane 5%

CAST prototype



192 charge collection strips for x

192 charge collection strips for y

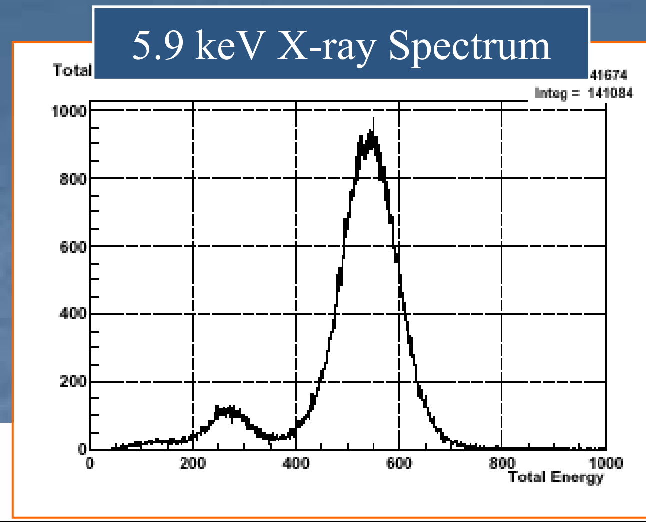


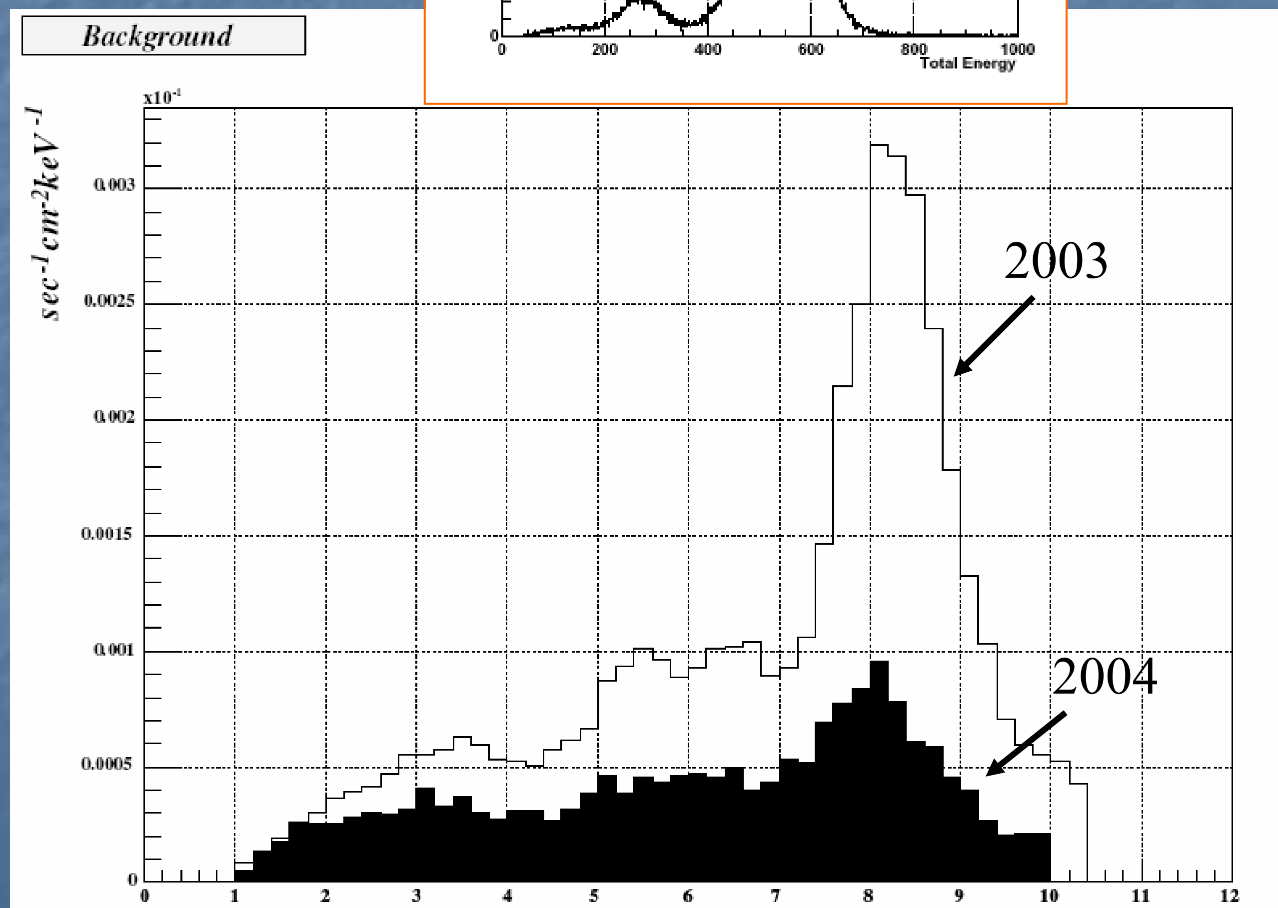
Micromegas in place

CAST: Micromegas

Background rate:

10^{-4}-10^{-5} counts s^{-1} cm^{-2} keV^{-1}



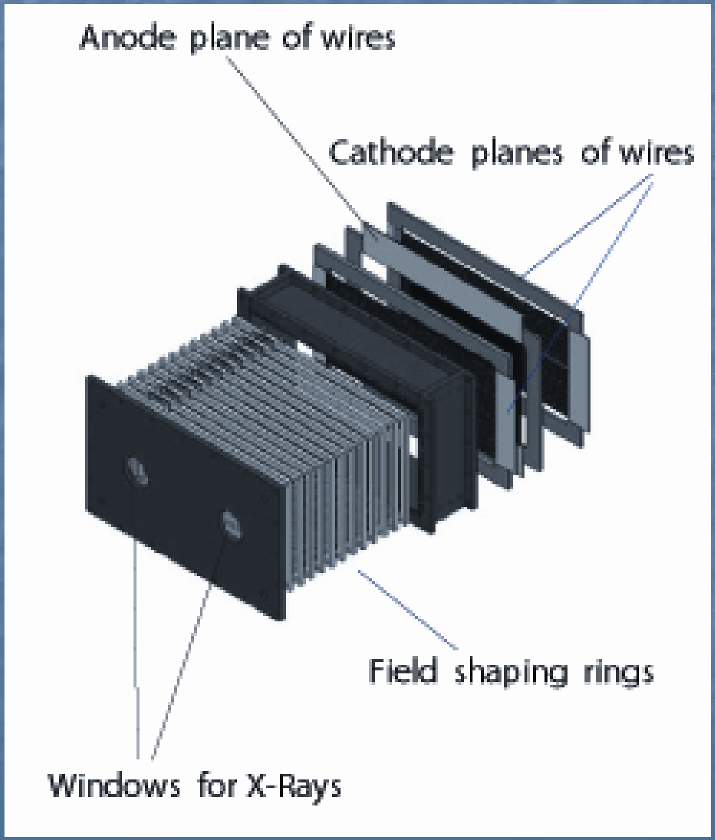


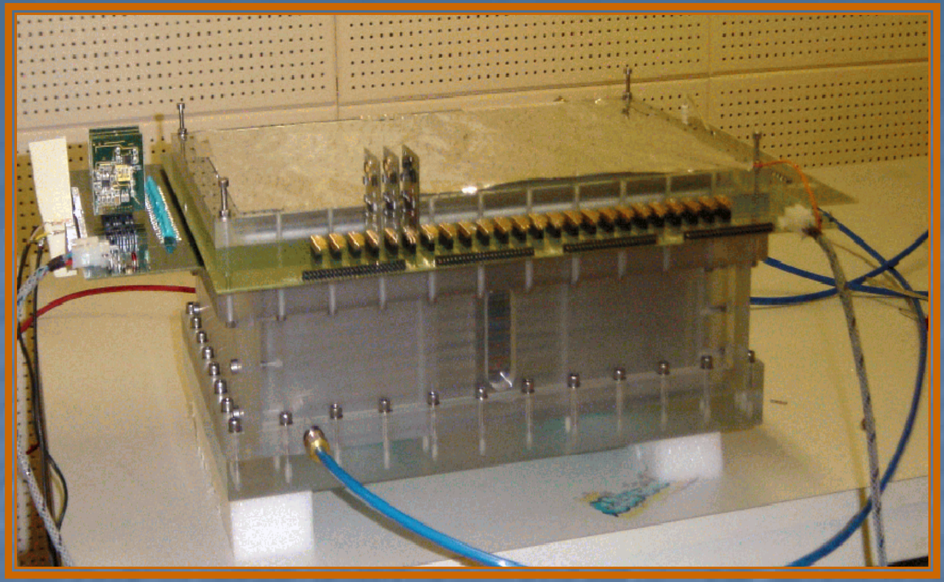
Biljana Lakić

CAST: TPC

Geometry: 30 cm × 15 cm × 10 cm

Gas: Ar 95%, CH_4 5%

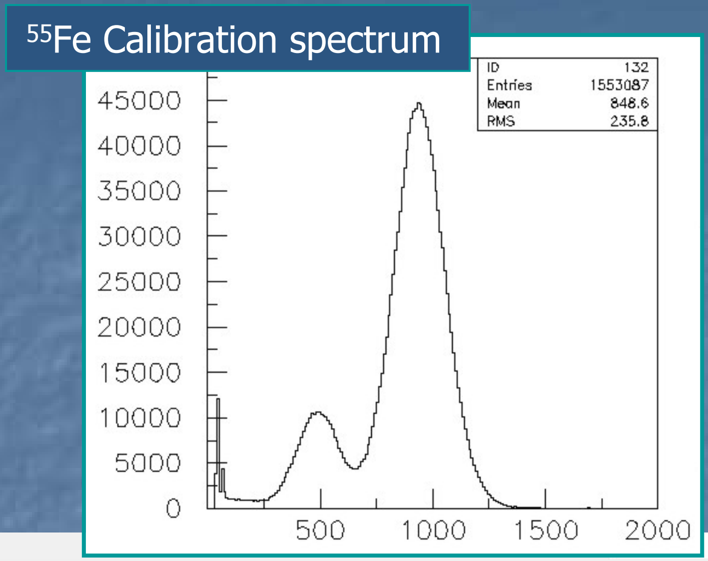




- Position sensitive (3 mm spacing)
  - 48 anode wires (x)
  - 96 cathode wires (y)

CAST: TPC

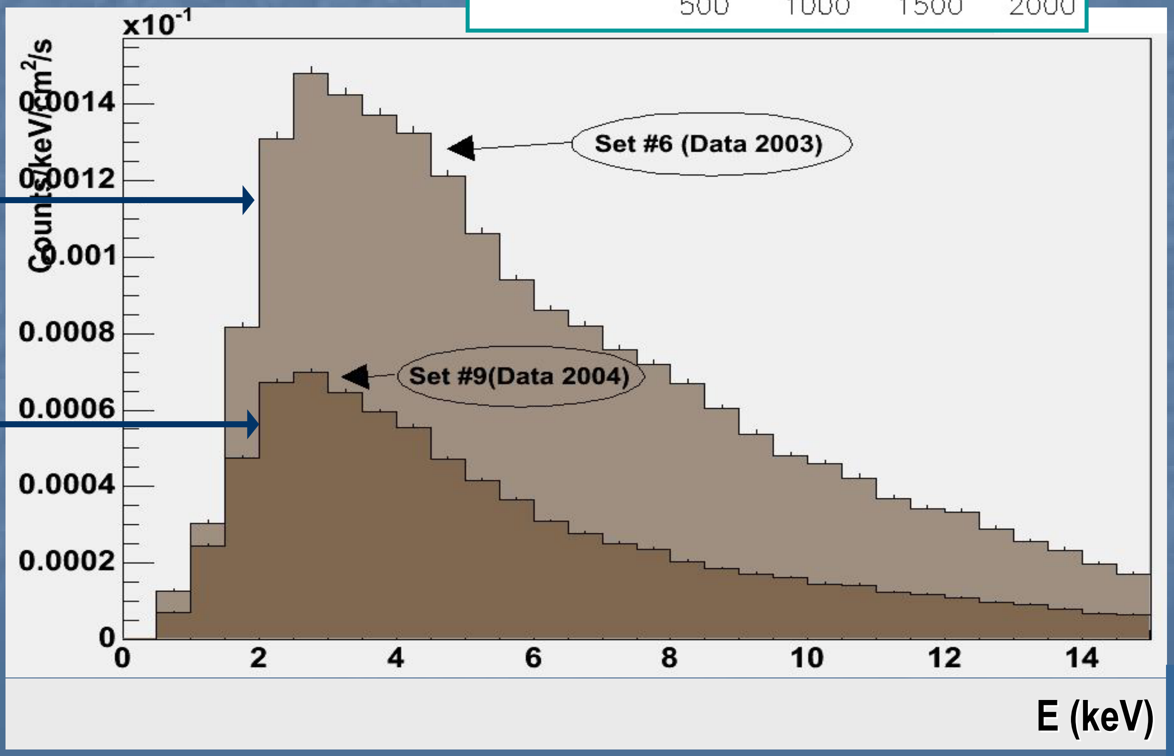
Clean materials + shielding
(polyethylene + copper + ancient lead)



Integrated spectrum from 1-10 keV:

9.3×10^{-5} cts/keV/s/cm^2

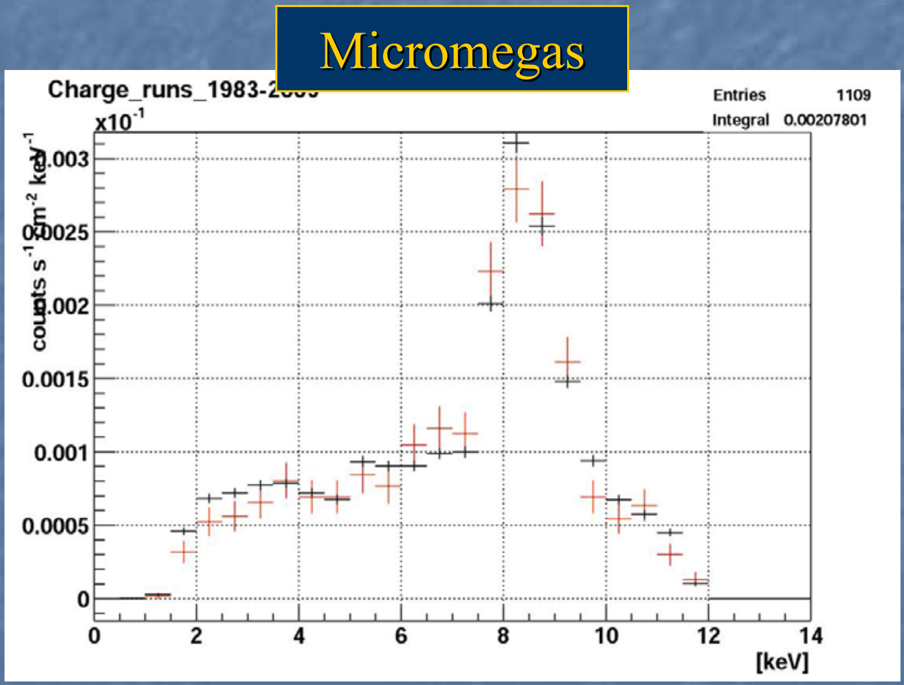
3.8×10^{-5} cts/keV/s/cm^2

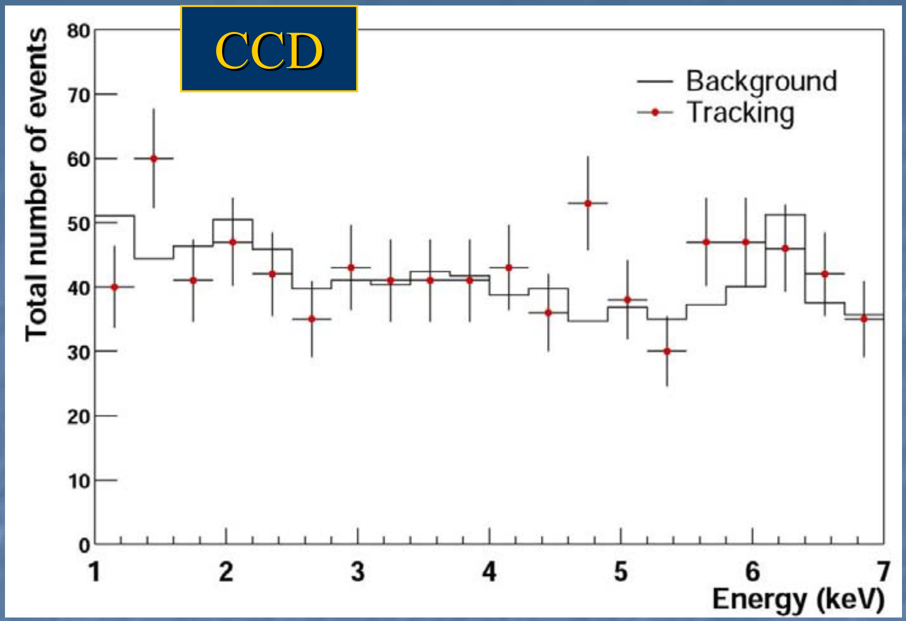


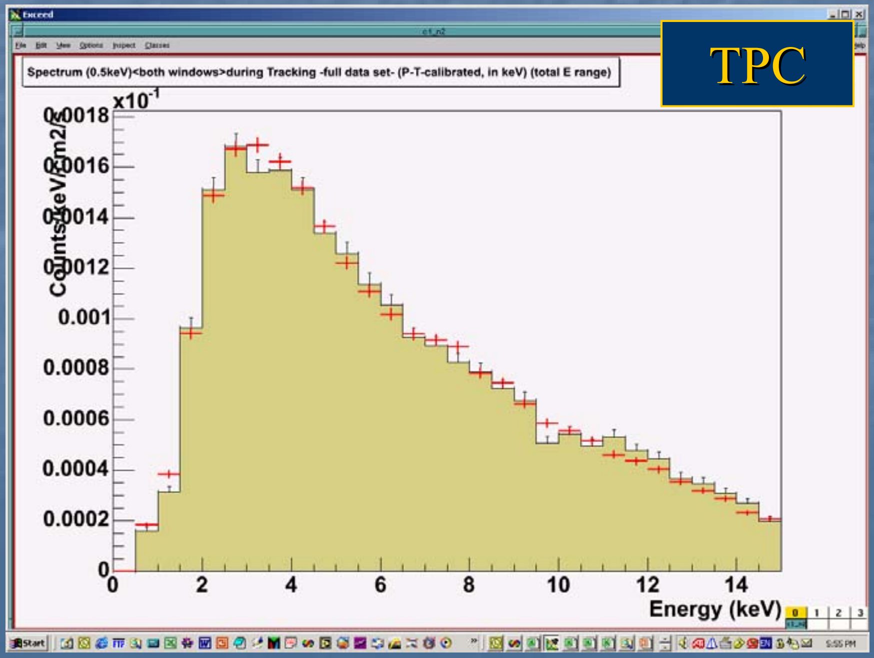
There is an improvement by a factor of 2.4!!

CAST: Analysis 2003

-no signal observed so far





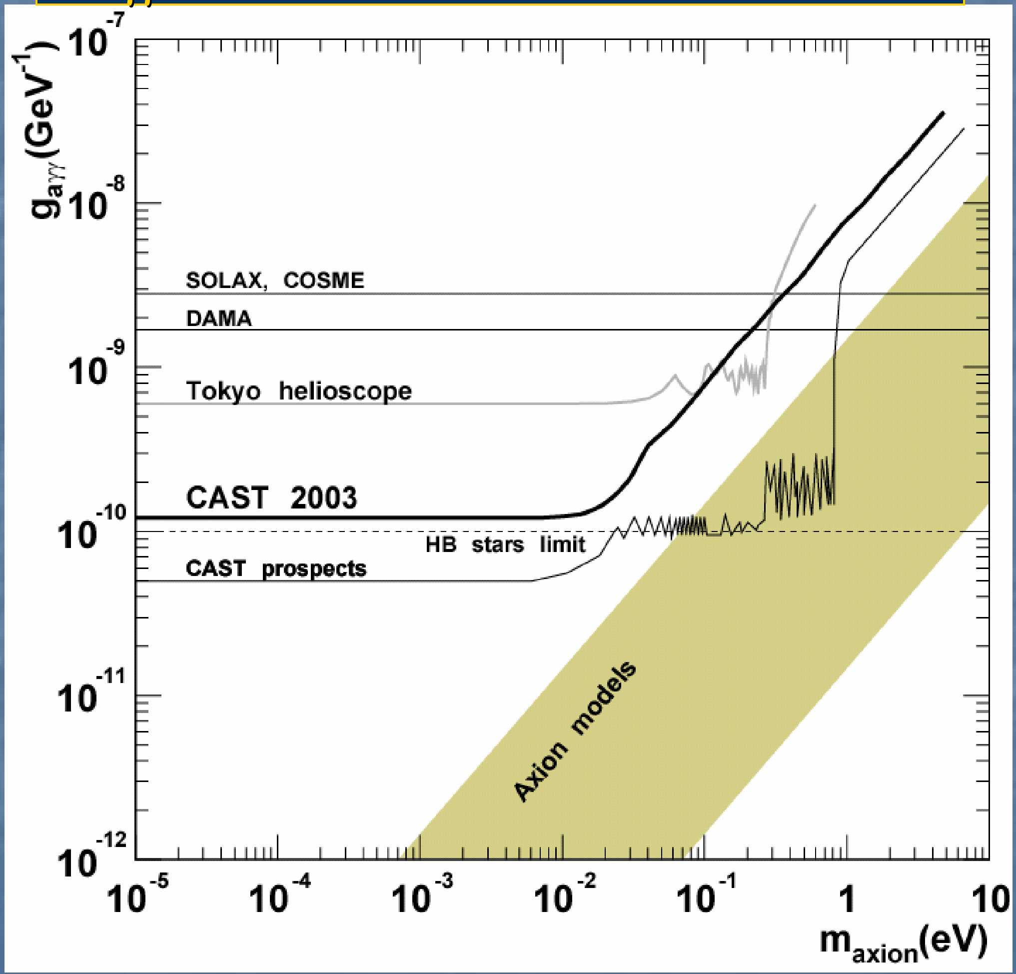


Biljana Lakić

CAST: Analysis 2003

➢ Combined upper limit (preliminary !)

$g_{a\gamma\gamma}$ (95% C.L.) < 1.2×10^{-10} GeV^{-1}



Russian Academy of Sciences

Institute for Nuclear Research (INR) (3 participant(s)) Team Leader: Sergei GNINENKO

Alexandre BELOV, Sergei GNINENKO, Nikolai

CAST: Prospects

- Vacuum in the magnet bores: 2003 & 2004
- PHASE 2: ^{4}He & ^{3}He in the magnet bores → to start in 2005 !

…. and also …

- High energy axions: High energy calorimeter installed during 2004
- Axion astronomy
- 14.4 keV solar nuclear axion line
- Kaluza-Klein axions

Switzerland, Geneve

European Organization for Nuclear Research (CERN) (12 participant(s)) Team Leader: Martyn DAVENPORT

Klaus BARTH, Gino CIPOLLA, Martyn DAVENPORT, Rui DE OLIVEIRA, Fabio FORMENTI, Jean-Noel JOUX, Christian LASSEUR