CERN Axion Solar Telescope (CAST)

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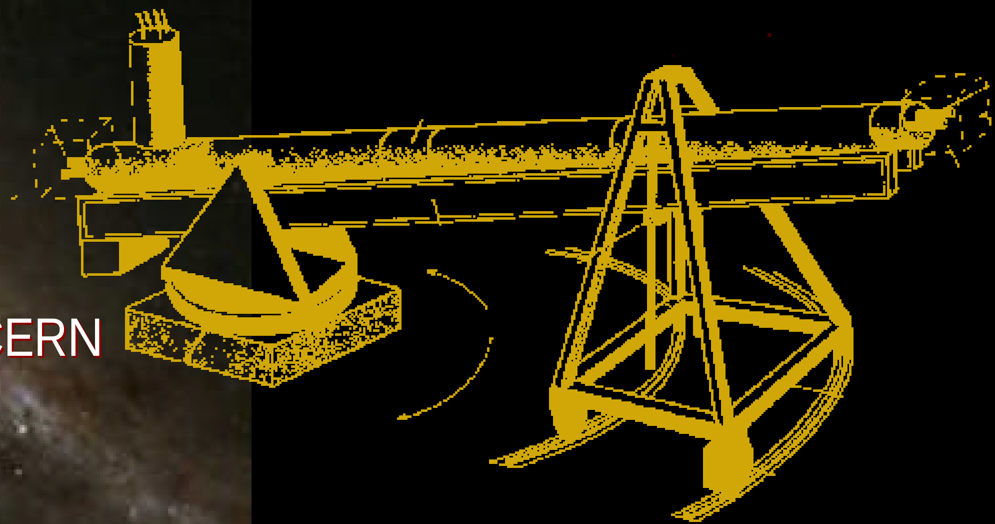
(for the CAST collaboration)

Symposium on Detector Developments for Particle, Astroparticle and Synchrotron Radiation Experiments
SLAC, Stanford, California, US, 6-10 April 2006

Summary:

- Motivation for the axion
- Solar axions
- The CAST experiment at CERN
- Future prospects
- Conclusions



AXION theory motivation

- Axion: introduced to solve the **strong CP problem**

Possible CP-violating term in QCD lagrangian:

$$\mathcal{L}_{CP} = \theta \frac{\alpha_s}{8\pi} G\tilde{G}$$

($\tilde{G}_{\mu\nu} = \frac{1}{2}\epsilon_{\mu\nu\rho\sigma}G^{\rho\sigma}$)

Two different contributions here: QCD vacuum and EW quark mixing

Experimental consecuence: prediction of electric dipole moment for the neutron:

$$|d_n| = A|\theta| \times 10^{-15} e \times cm$$ (A = 0.04 – 2.0)

AXION theory motivation

- But experiment says...

$$|d_n| < 0.63 \times 10^{-25} e \times cm$$

So,

$$|\theta| < 10^{-9}$$

•Why so small?

•Hight fine-tunning of two different contributions required

Peccei-Quinn (1977) propose an elegant solution to this problem.
θ not anymore a constant, but a field → the axion a(x).
Fine-tunning reached naturally, dinamically.

AXION theory motivation

- **Peccei-Quinn solution** to the strong CP problem

•New U(1) symmetry introduced in the SM:
Peccei Quinn symmetry of scale f_a
•The AXION appears as the Nambu-Goldstone boson of the spontaneous breaking of the PQ symmetry

$$\mathcal{L}_a = \frac{1}{2}(\partial_\mu a)^2 - \frac{\alpha_s}{8\pi f_a} a G\tilde{G}$$

θ absorbed in the definition of a

axion – gluon vertex

•a → qq transitions
•a – π^0 mixing
•axion mass > 0

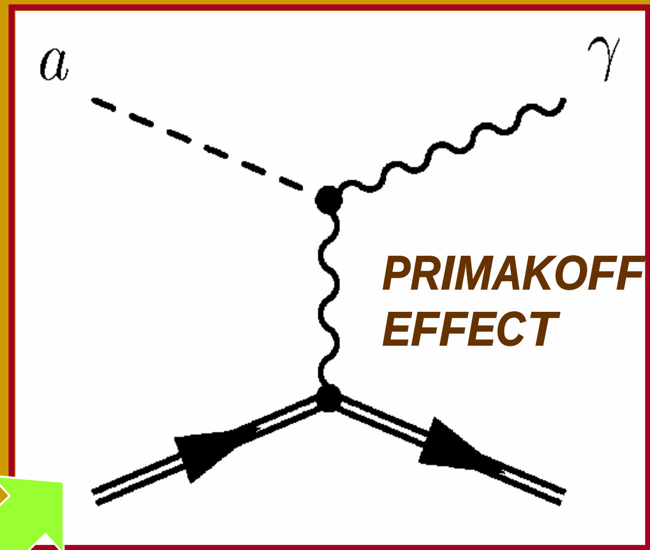
$$m_a \simeq 0.6 \text{ eV} \frac{10^7 \text{GeV}}{f_a}$$

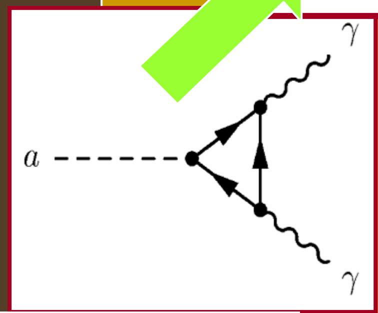
AXION phenomenology

- The axion is...
  - ✓pseudoscalar
  - ✓neutral
  - ✓practically stable
  - ✓phenomenology driven by the breaking scale f_a and the specific axion model
  - ✓Couples to photon:

$$\mathcal{L}_{a\gamma} = g_{a\gamma\gamma}(\mathbf{E}\cdot\mathbf{B})a$$

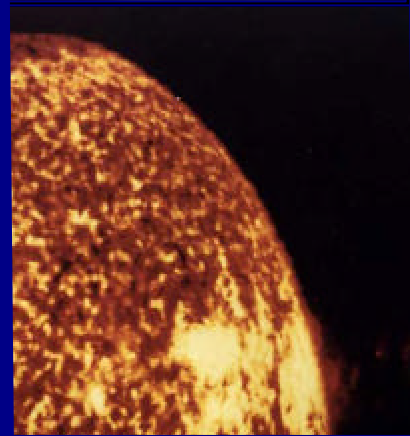
$$g_{a\gamma\gamma} = \frac{\alpha_s}{2\pi f_a}\left(\frac{E}{N} - 1.92\right)$$

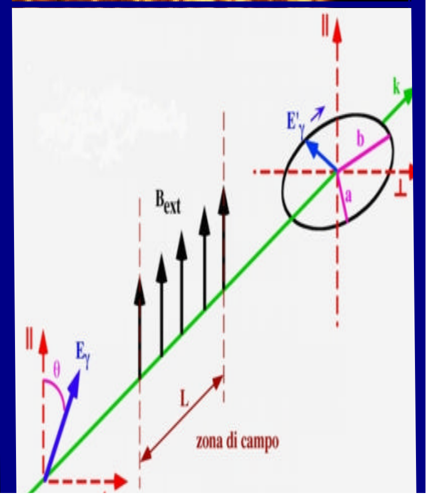




axion-photon coupling present in almost every axion model

Axion Searches

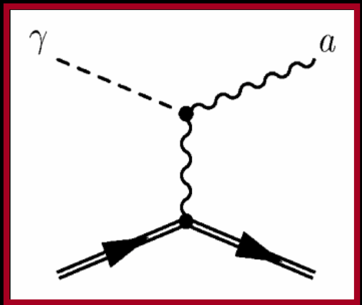


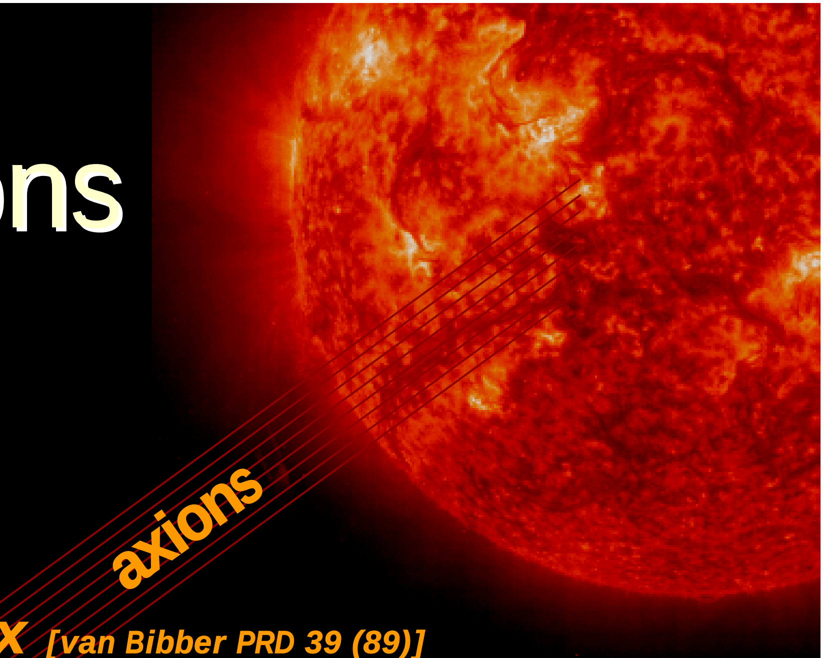


- Axions are searched for in 3 different contexts (different sources of axions):
  - Dark matter axions (as relics of Big Bang):
    - Axion Haloscopes (**ADMX**, CARRACK)
  - Axions produced in the Sun:
    - Axion Helioscopes (Tokyo, **CAST**)
    - Crystal detectors (SOLAX, COSME, DAMA)
  - Axions produced in the laboratory
    - "Light shinning through wall" experiments
    - Vacuum birrefringence experiments (**PVLAS** positive signal!)

Solar Axions

- Solar axions produced by photon-to-axion conversion of the solar plasma photons

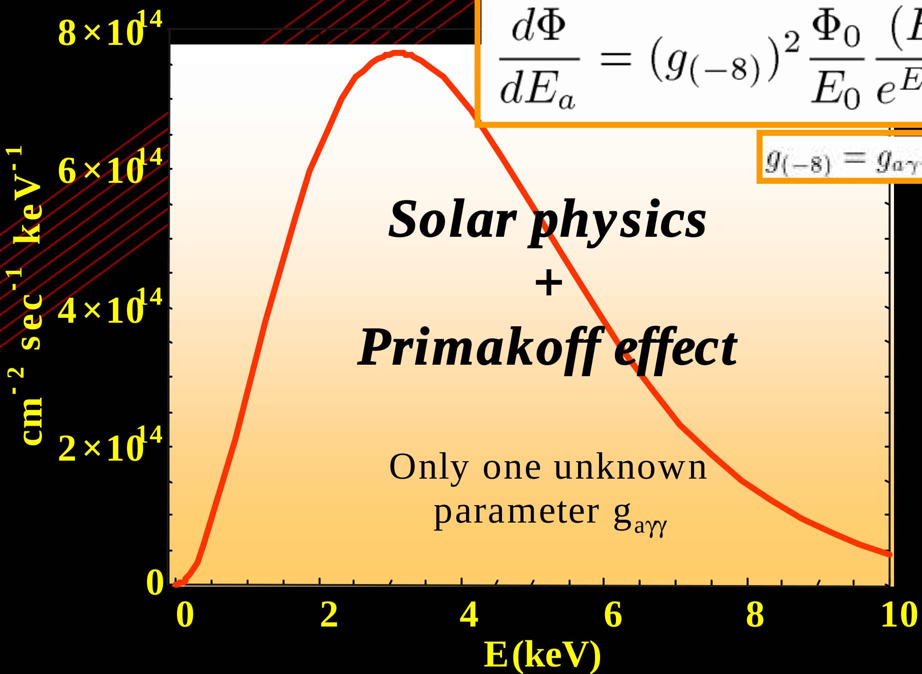




- ***Solar axion flux*** *[van Bibber PRD 39 (89)]*

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

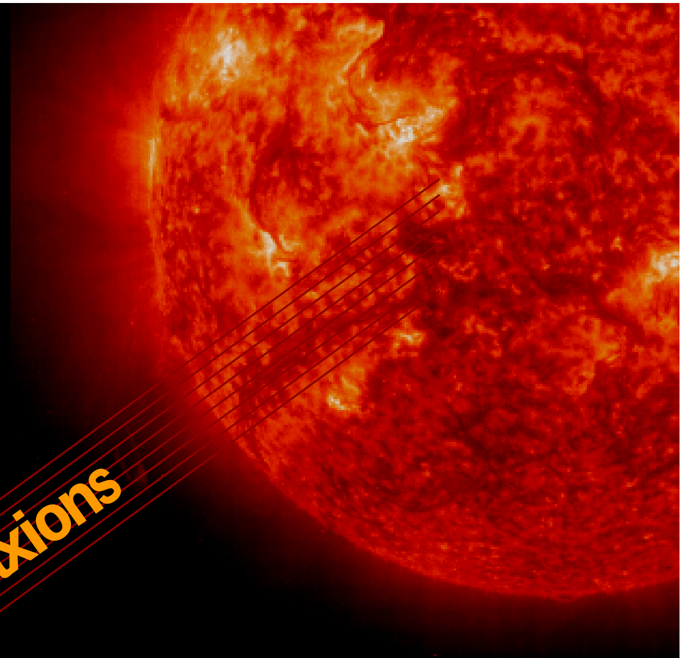
$$g_{(-8)} = g_{a\gamma\gamma} \times 10^8/\mathrm{GeV}^{-1}$$

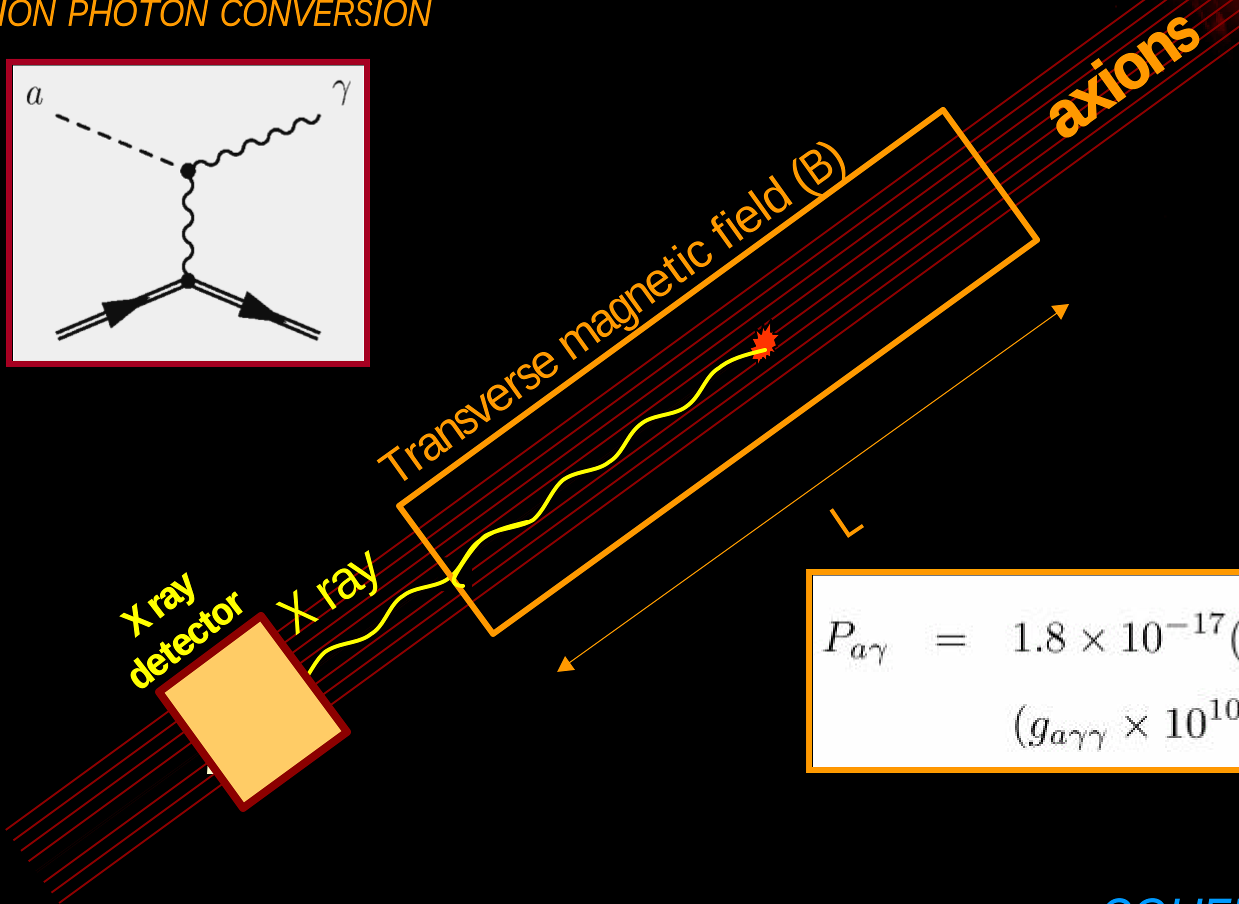


Solar Axions

- Principle of detection (**axion helioscope**)
  [Sikivie, PRL 51 (87)]

AXION PHOTON CONVERSION



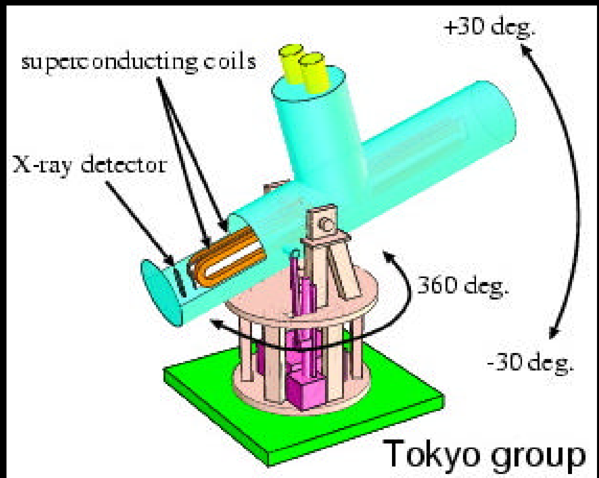


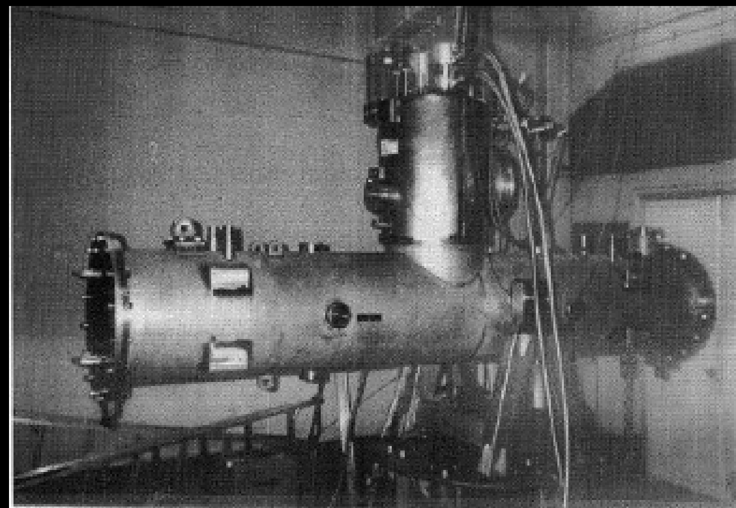
$$P_{a\gamma} = 1.8 \times 10^{-17} \left(\frac{B}{8.4T}\right)^2 \left(\frac{L}{10m}\right)^2 (g_{a\gamma\gamma} \times 10^{10} GeV^{-1})^2 |\mathcal{M}|^2,$$

COHERENCE 1

Helioscopes

- Previous helioscopes:
  - First implementation at Brookhaven (just few hours of data) [Lazarus et at. PRL 69 (92)]
  - TOKYO Helioscope: 2.3 m long 4 T magnet





- Presently running:
  - CERN Axion Solar Telescope (**CAST**)

CERN Axion Solar Telescope (CAST)

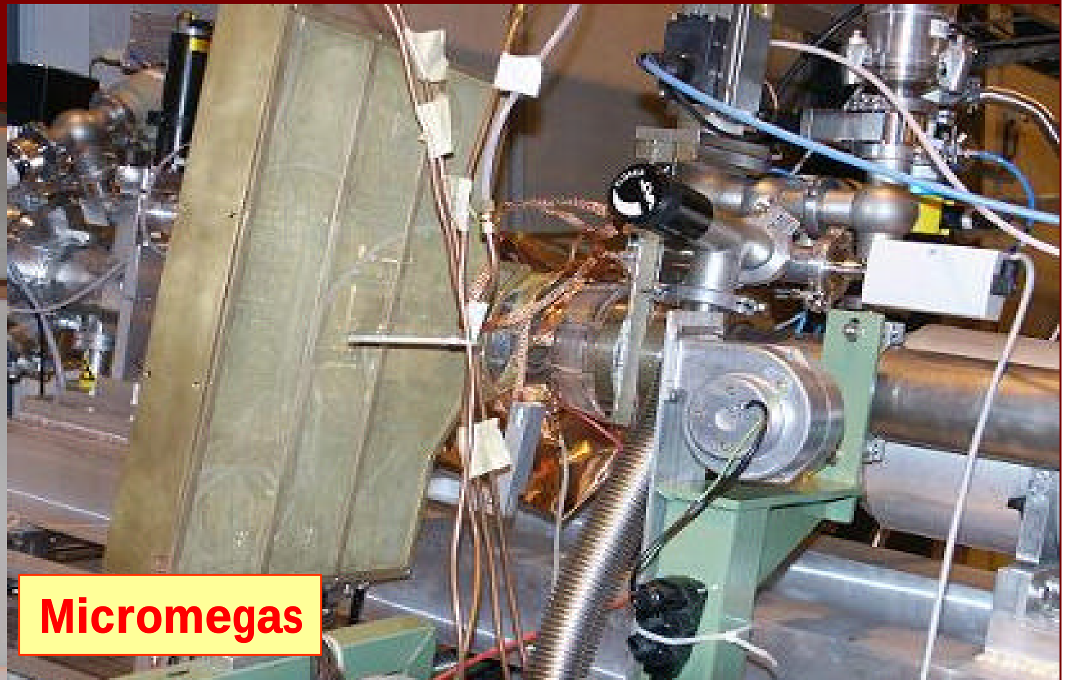
- **Decommissioned LHC test magnet (L=10m, B=9 T)**
- **Moving platform ±8°V ±40°H (to allow up to 50 days / year of alignment)**
- **4 magnet bores to look for X rays**
- **3 X rays detector prototypes being used.**
- **X ray Focusing System to increase signal/noise ratio.**

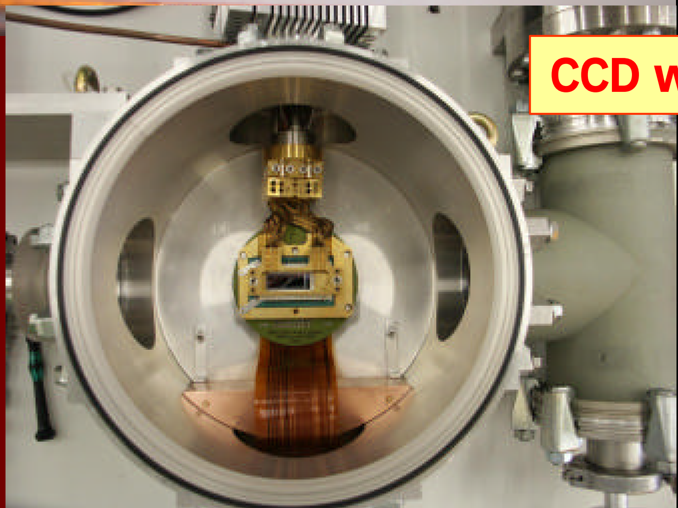
Platform & magnet

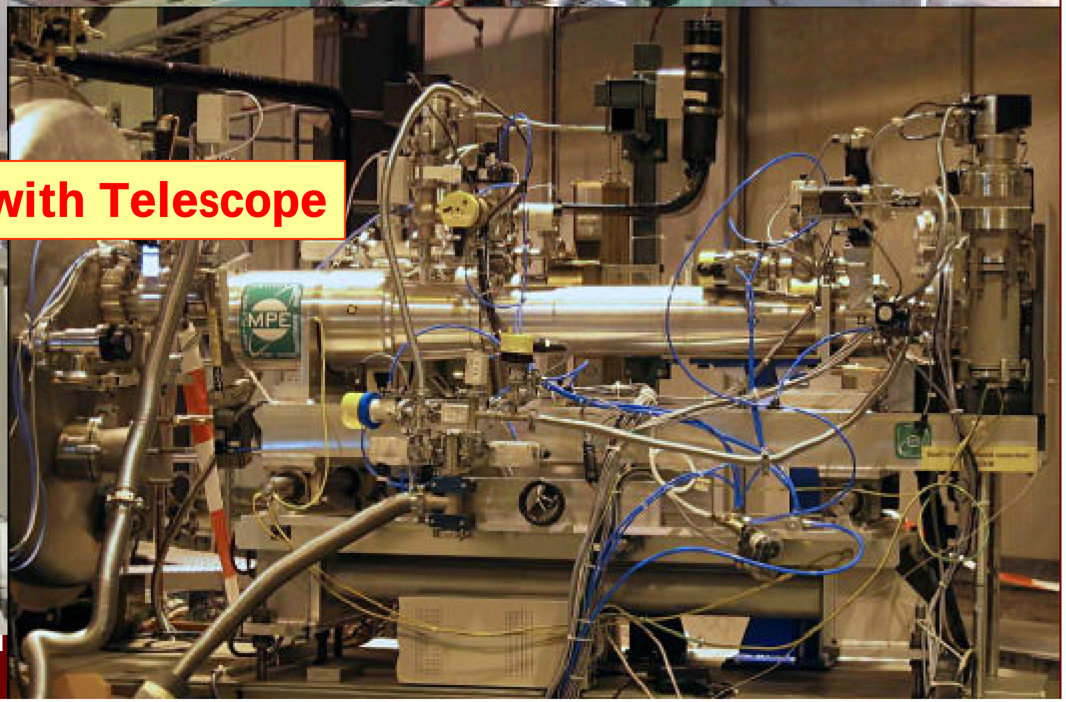
- *Solar tracking*

cast2.avi

X-ray detectors





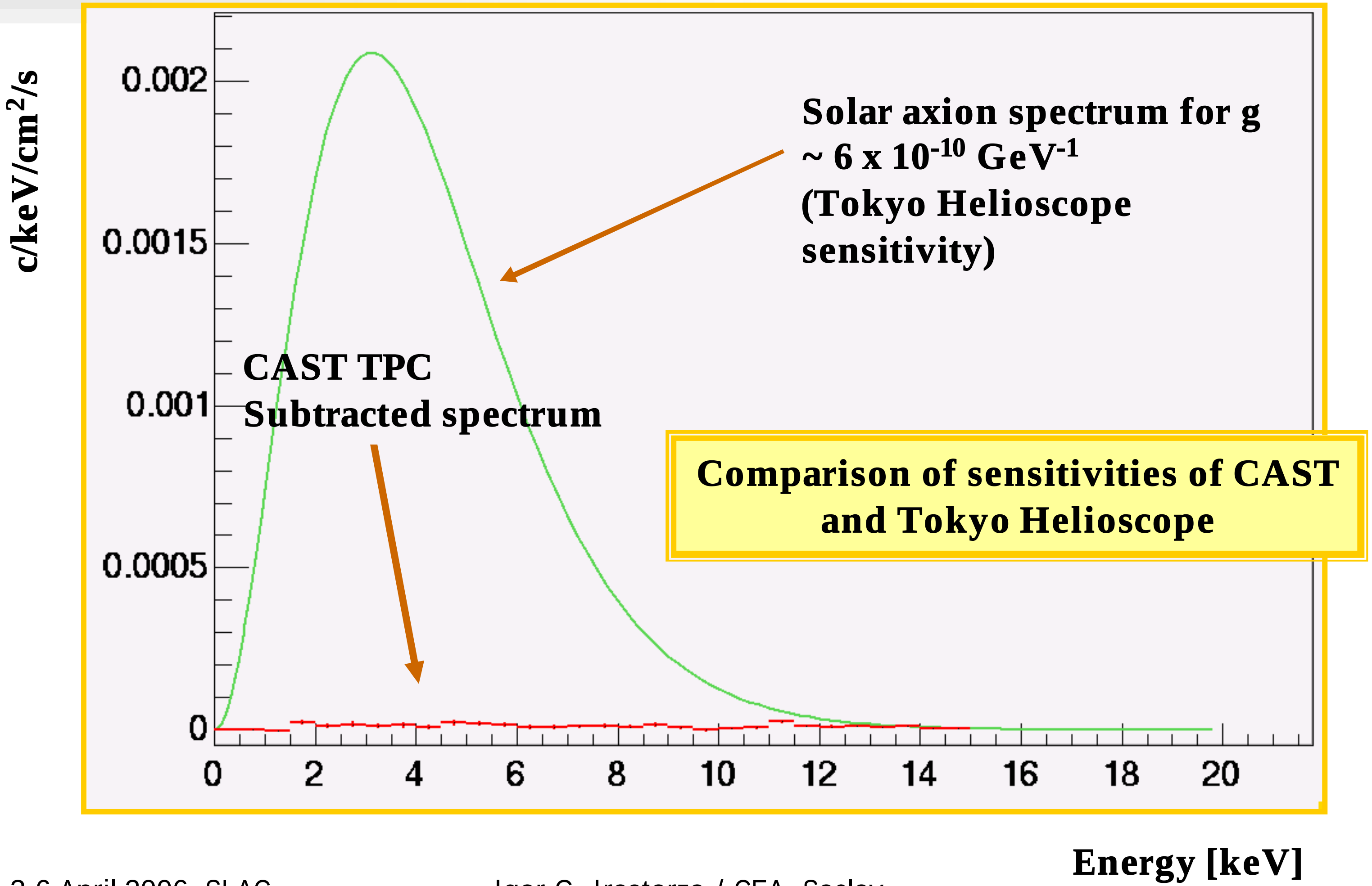


CAST experiment : STATUS

- ✓**2003 data taking**
  - ✓CAST running for about 6 months
  - ✓Data analyzed --> first result published in **Physical Review Letters 94 (2005) 121301**
- ✓**2004 data taking**
  - ✓Improved conditions on all detectors (shieldings,...), tracking system and magnet (more reliability, homogeneity of data taking)
  - ✓Fourth detector for HE axions
  - ✓CAST ran from May to November
  - ✓Data analysis almost finished → **preliminary result just released**
- ✓**2005**
  - ✓Work on upgrading experimental setup for phase II
- ✓**CAST phase II just started**
  - ✓He4 gas inside magnet, pressure changed daily
  - ✓Data being taken since last November...

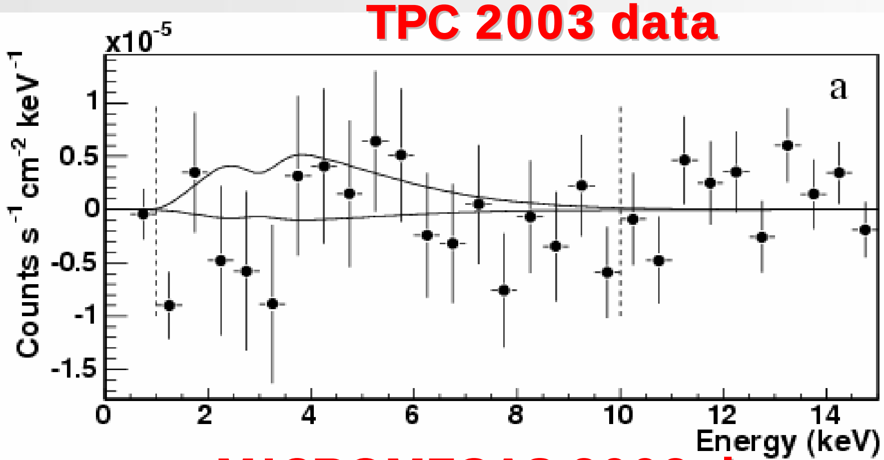
CAST sensitivity

- ✓ Subtracted spectrum → “expected“axion spectrum

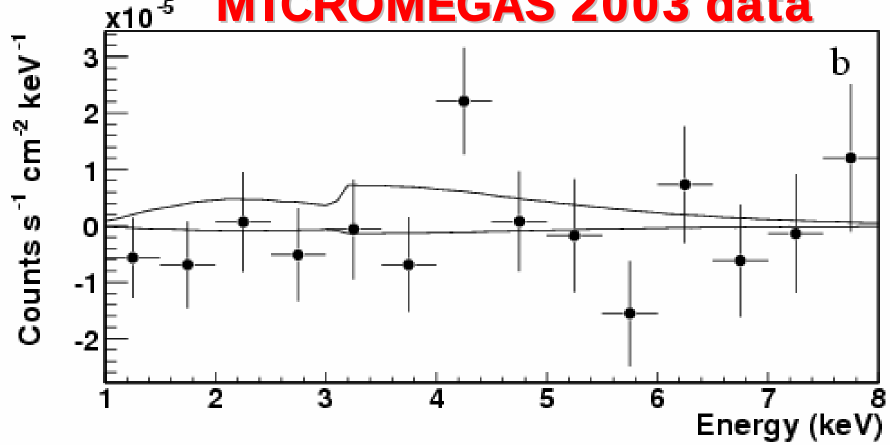


CAST first results: 2003 data

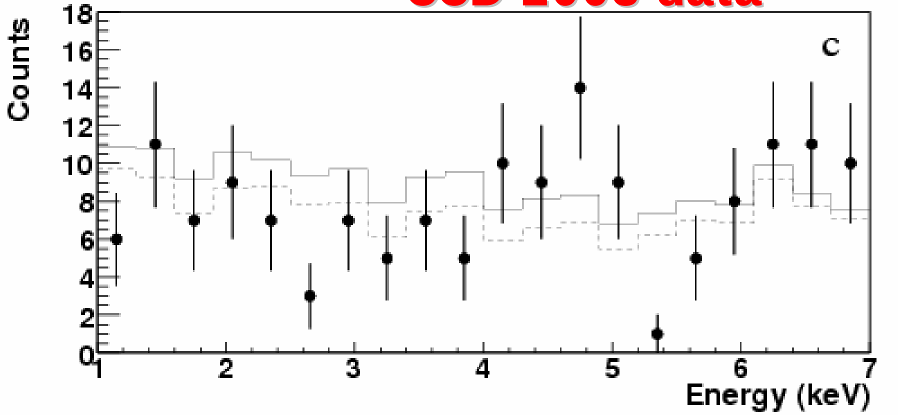
TPC 2003 data



MICROMEGAS 2003 data



CCD 2003 data



No signal over background in any of the three detectors

combined limit obtained (95%):

$g_{a\gamma\gamma} < 1.16 \times 10^{-10}$ GeV^{-10}

CAST first results: 2003 data

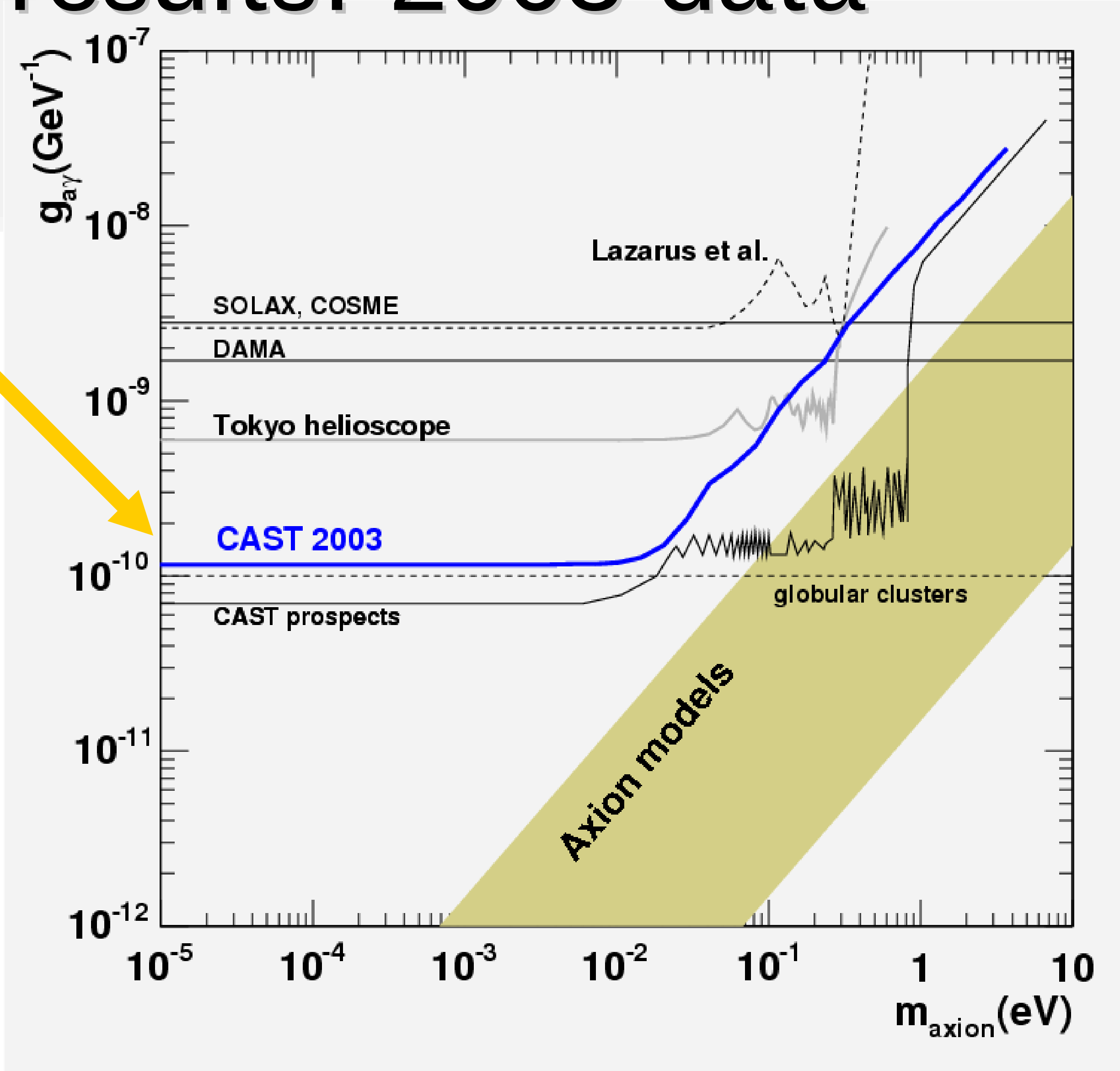
Axion exclusion plot

$g_{a\gamma\gamma} < 1.16 \times 10^{-10}$ GeV^{-1}

In the coherence region

- 2003 result recently published in PRL

- More to come…
- analysis of 2004 data ongoing
- phase II with buffer gas



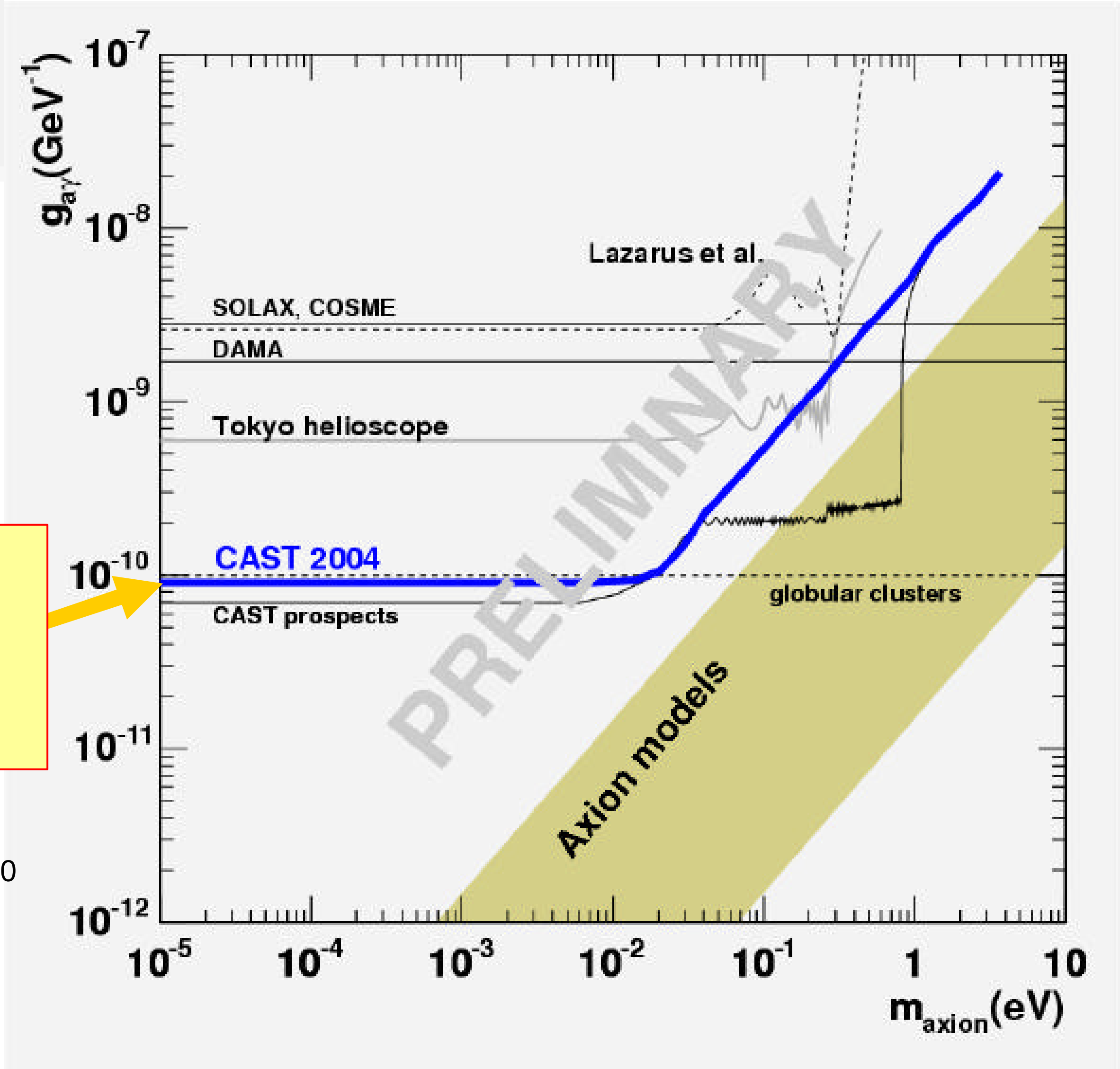
CAST 2004 result: preliminary

Preliminary result very recently released

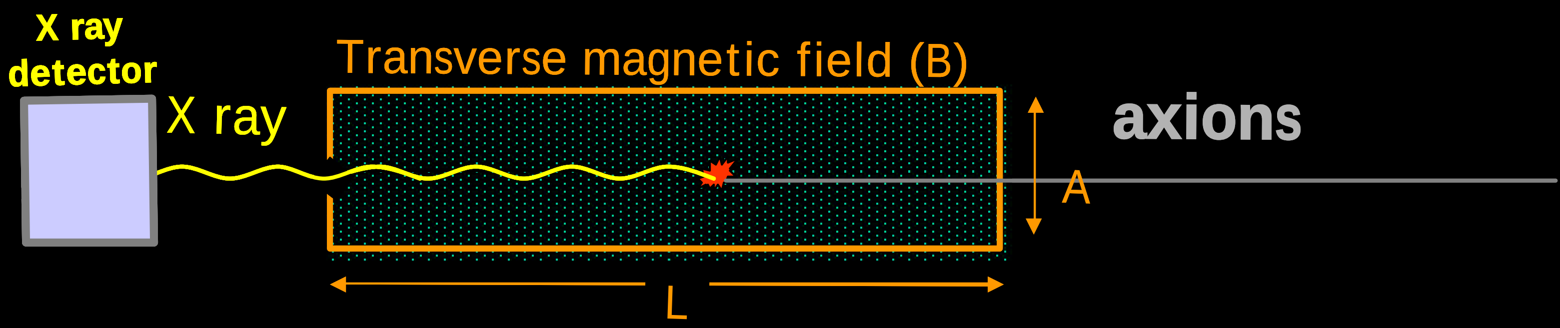
$g_{a\gamma}$ < 9 x 10^{-11} GeV^{-1} (Preliminary)

In the coherence region

For the 1st time beyond 10^{-10}



CAST phase II – principle of detection



Extending the coherence to higher axion masses…

- Fill magnetic channels with helium
- The photon adquires an effective mass: $m_\gamma > 0$
- Momentum transfer is

$$|q| = \frac{m_a^2 - m_\gamma^2}{2E}$$

- Coherence condition (qL << 1) is recovered for a narrow mass range around m_γ
- m_γ can be adjusted by changing the gas pressure:

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

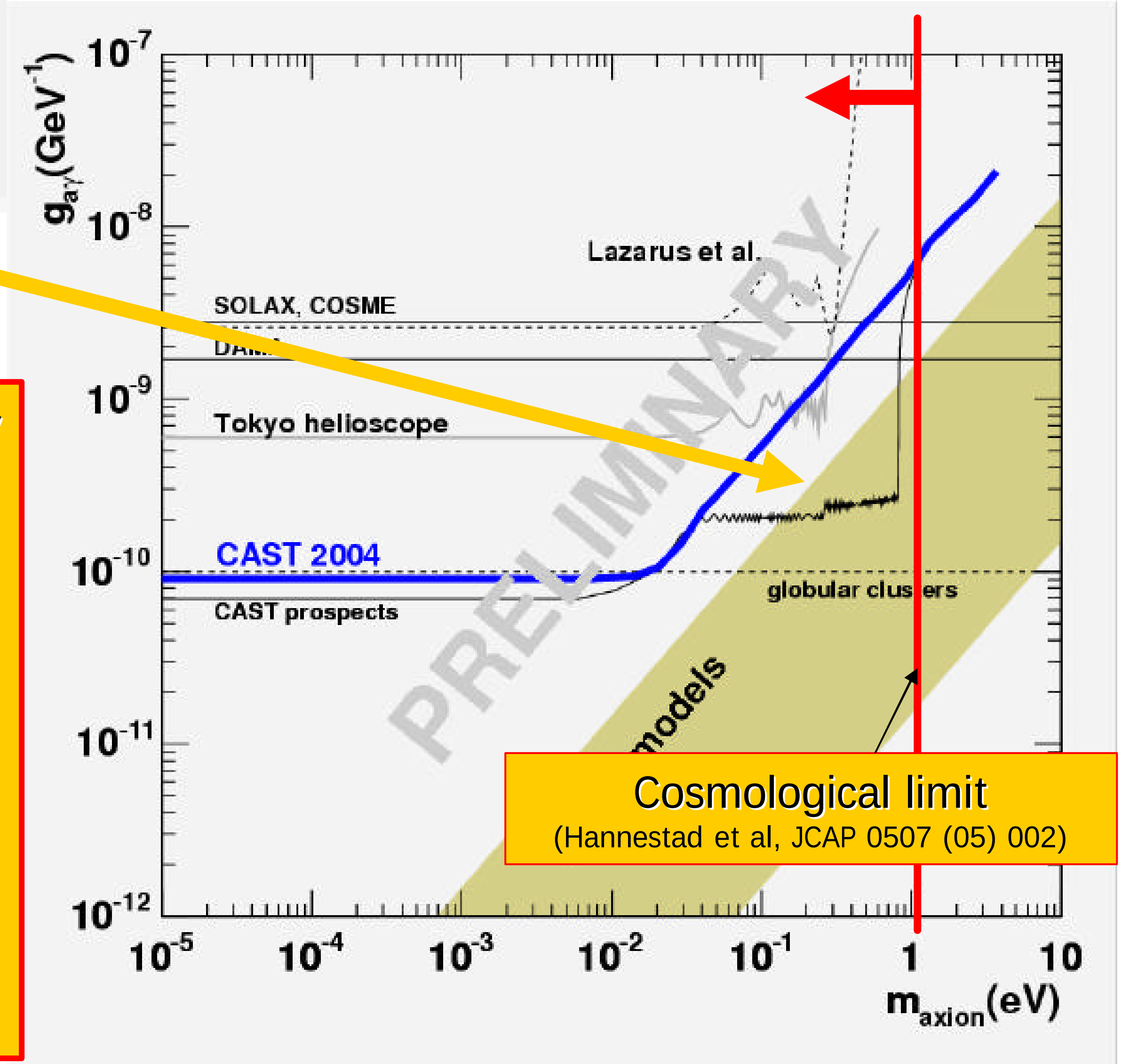
N_e: number of electrons/cm^3

r : gas density (g/cm^3)

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

CAST phase II

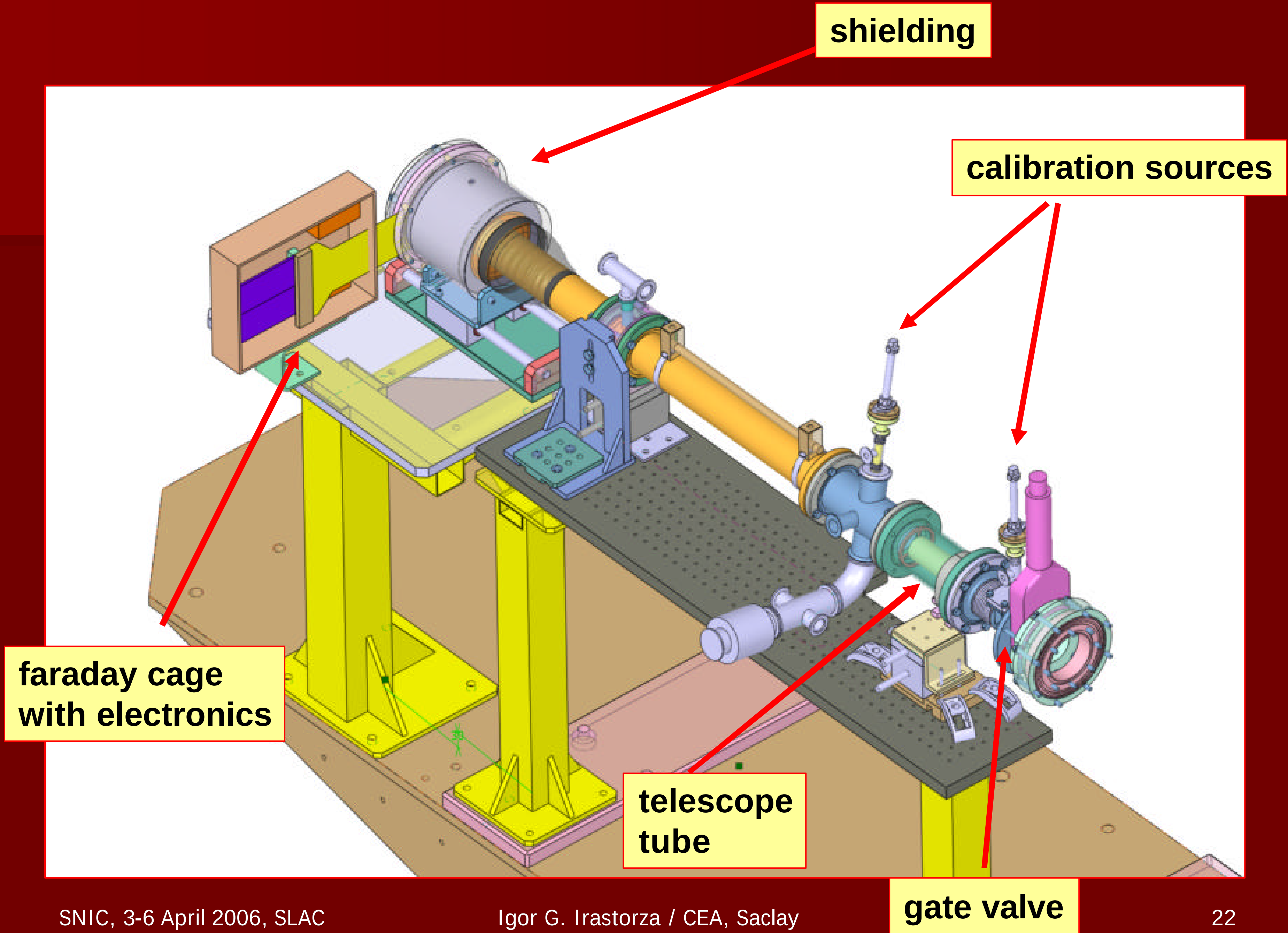
CAST phase II sensitivity



- CAST phase II approved by CERN Researh Board on Dec 2004
- **Data taking with He4 started last November**
- New institutions joining CAST, in partitular, **Lawrence Livermore National Lab** (second x-ray telescope, He-3 for gas-filling)

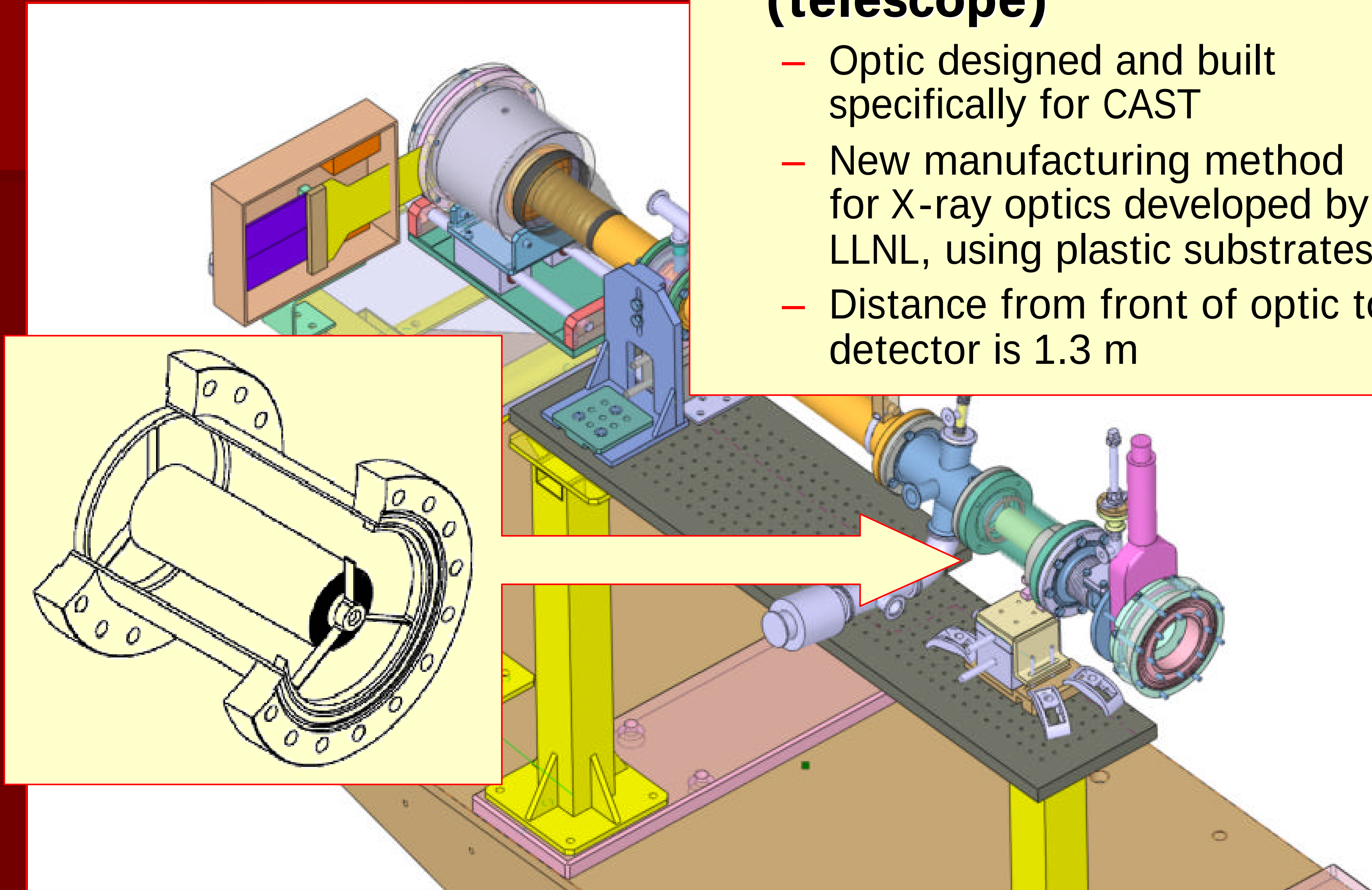
Detector Improvement

- Important upgrades on the MICROMEGAS line:
  - New X-ray focusing optics (telescope) beind made by Livermore for CAST.
  - New MICROMEGAS adapted to the telescope
  - New shielding
  - New conversion gas (Xenon-based mixture)
  - Semi-sealed mode of operation


shielding
calibration sources
faraday cage with electronics
telescope tube
gate valve

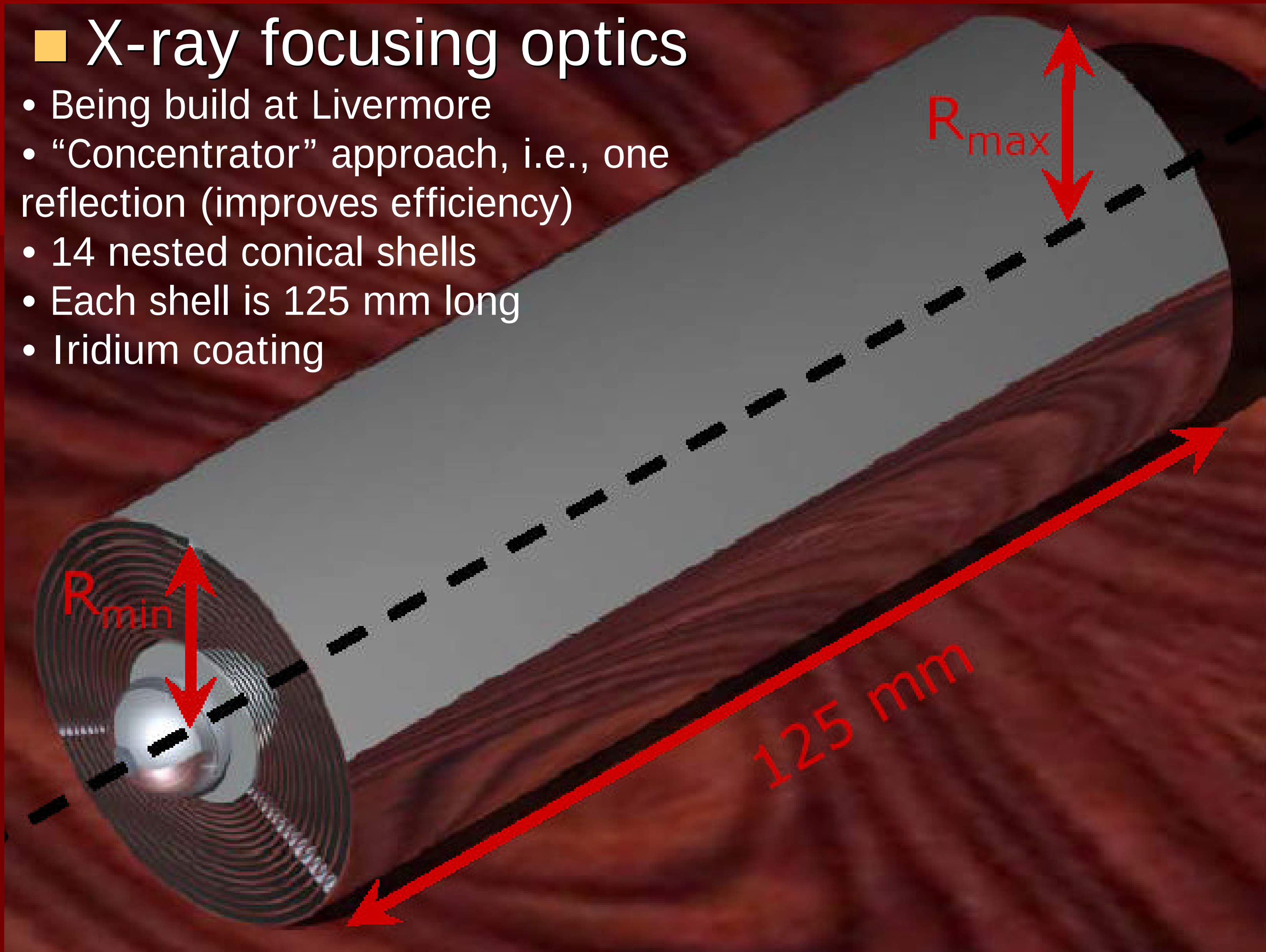
X-ray focusing optics (telescope)

- Optic designed and built specifically for CAST
- New manufacturing method for X-ray optics developed by LLNL, using plastic substrates.
- Distance from front of optic to detector is 1.3 m

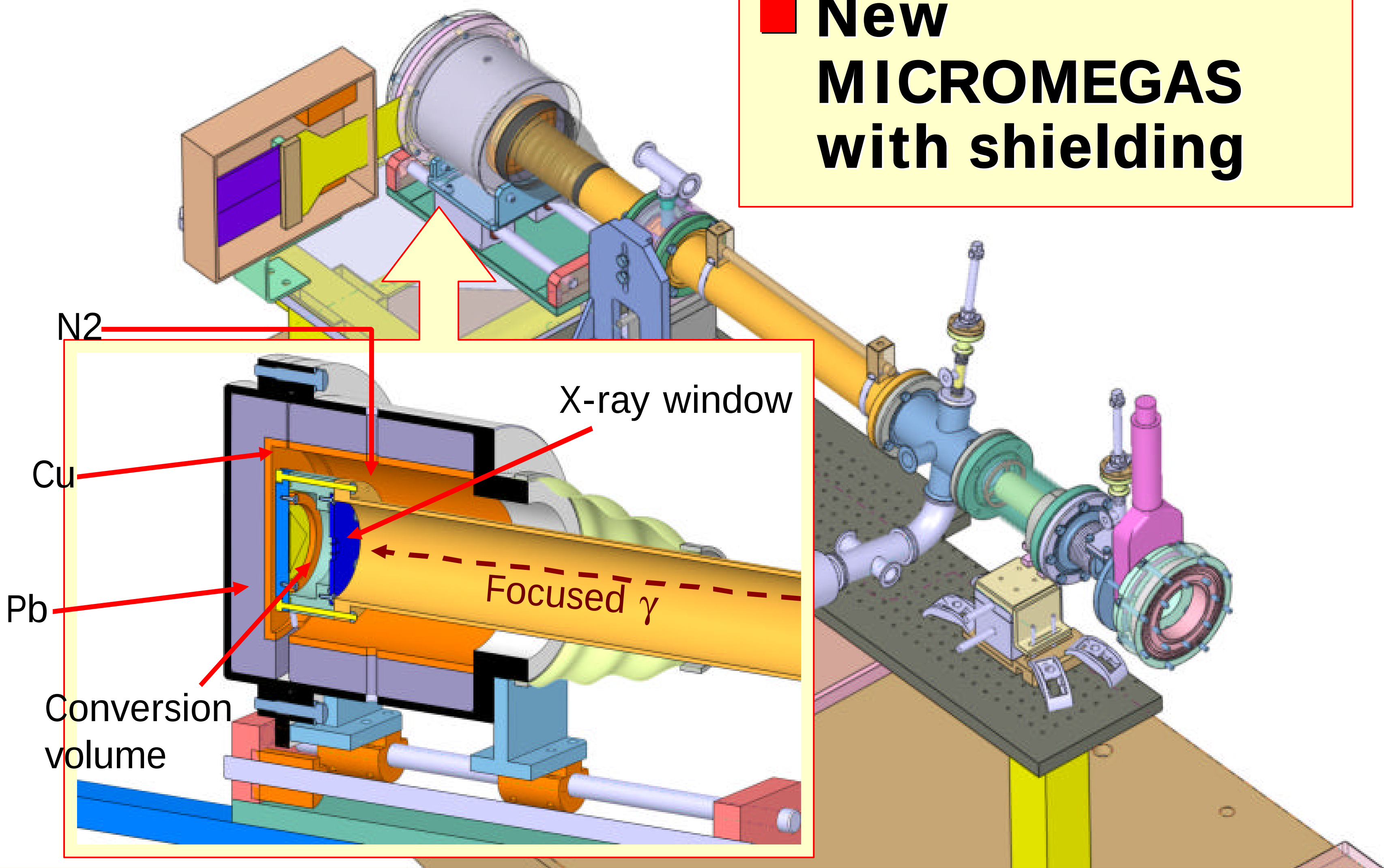


X-ray focusing optics

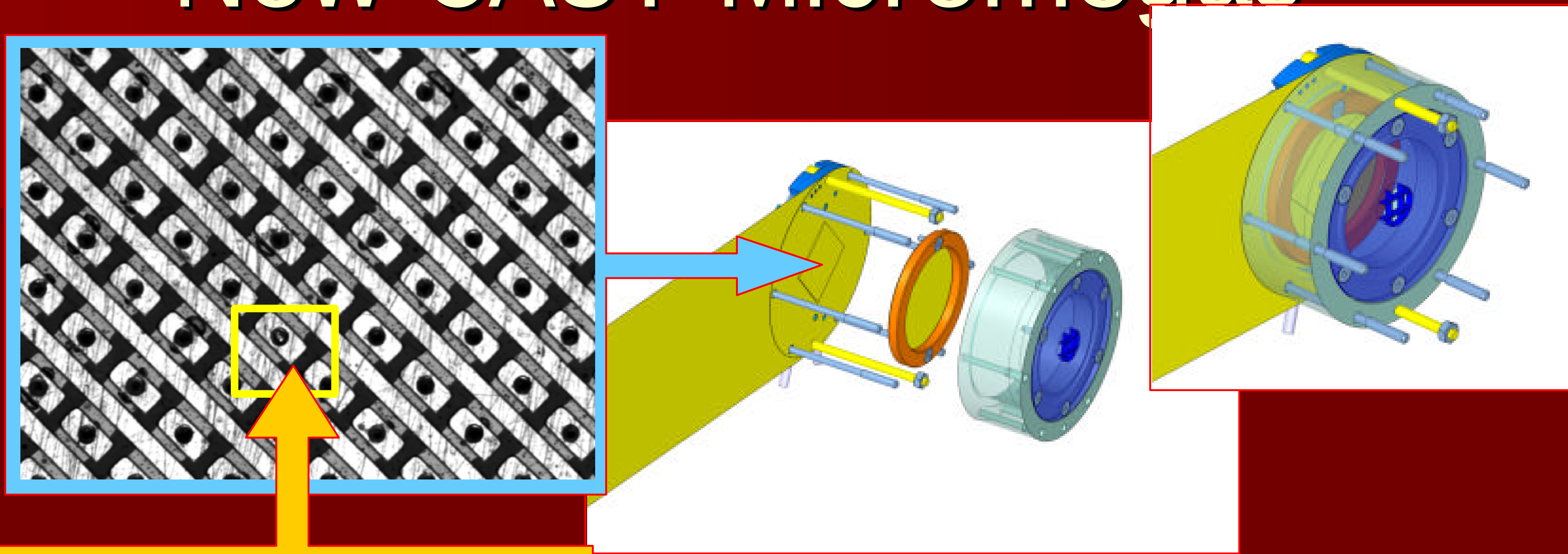
- Being build at Livermore
- “Concentrator” approach, i.e., one reflection (improves efficiency)
- 14 nested conical shells
- Each shell is 125 mm long
- Iridium coating

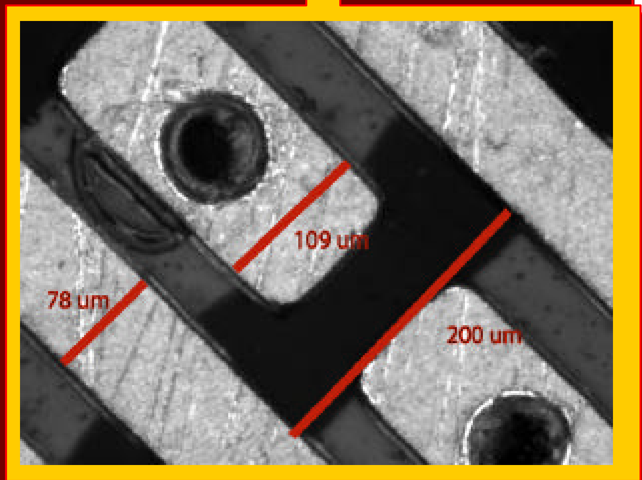


- **New MICROMEGAS with shielding**



New CAST Micromegas



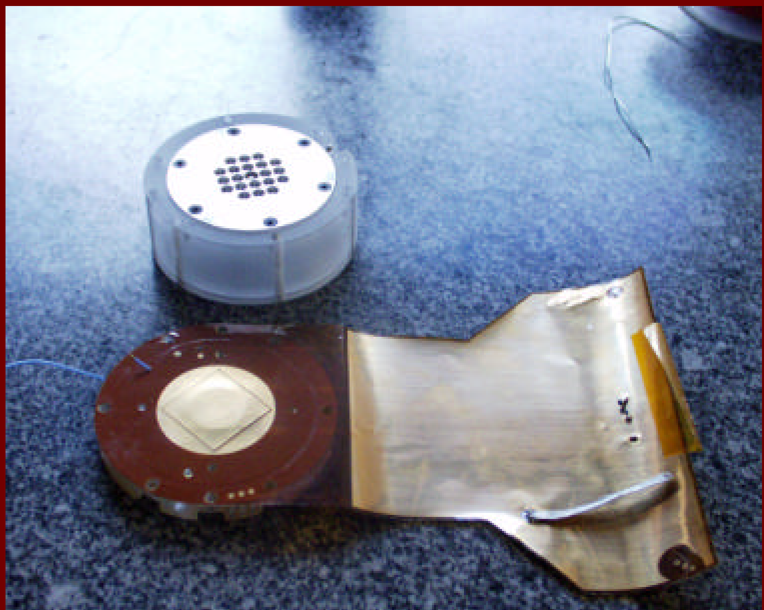


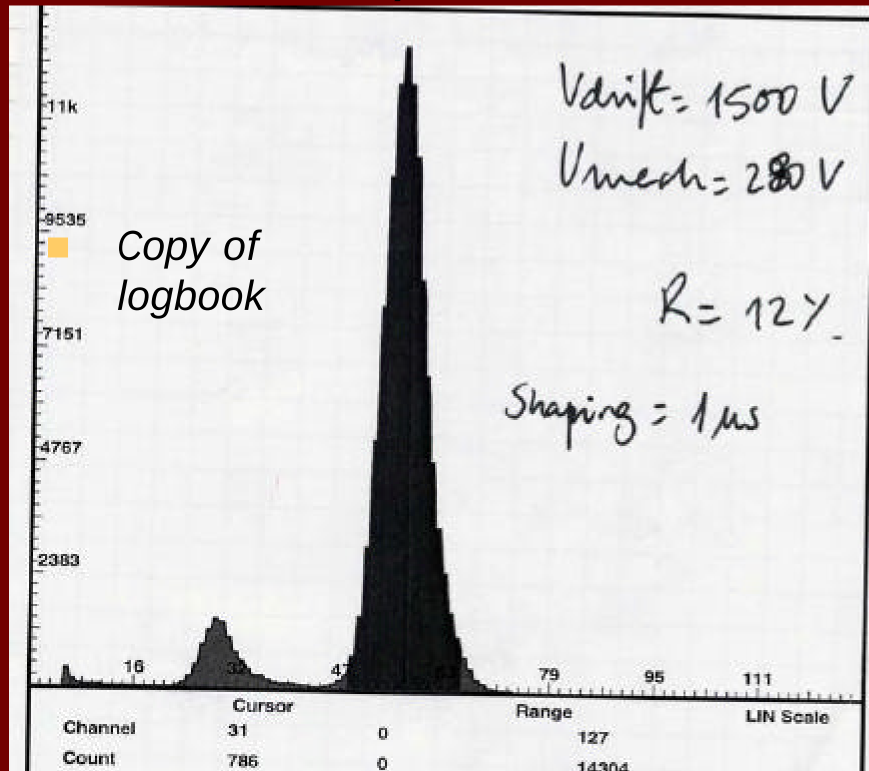
Same 2-D pattern as in phase I

- Higher efficiency:
  - X-ray window more transparent
  - Heavier gas (Xe-based mixture)
- Lower background:
  - Smaller: easier to shield, spot.
  - Cleaner materials
  - Less fluorescence (golden mesh)
- Better resolution:
  - Better mechanical solution

New CAST Micromegas

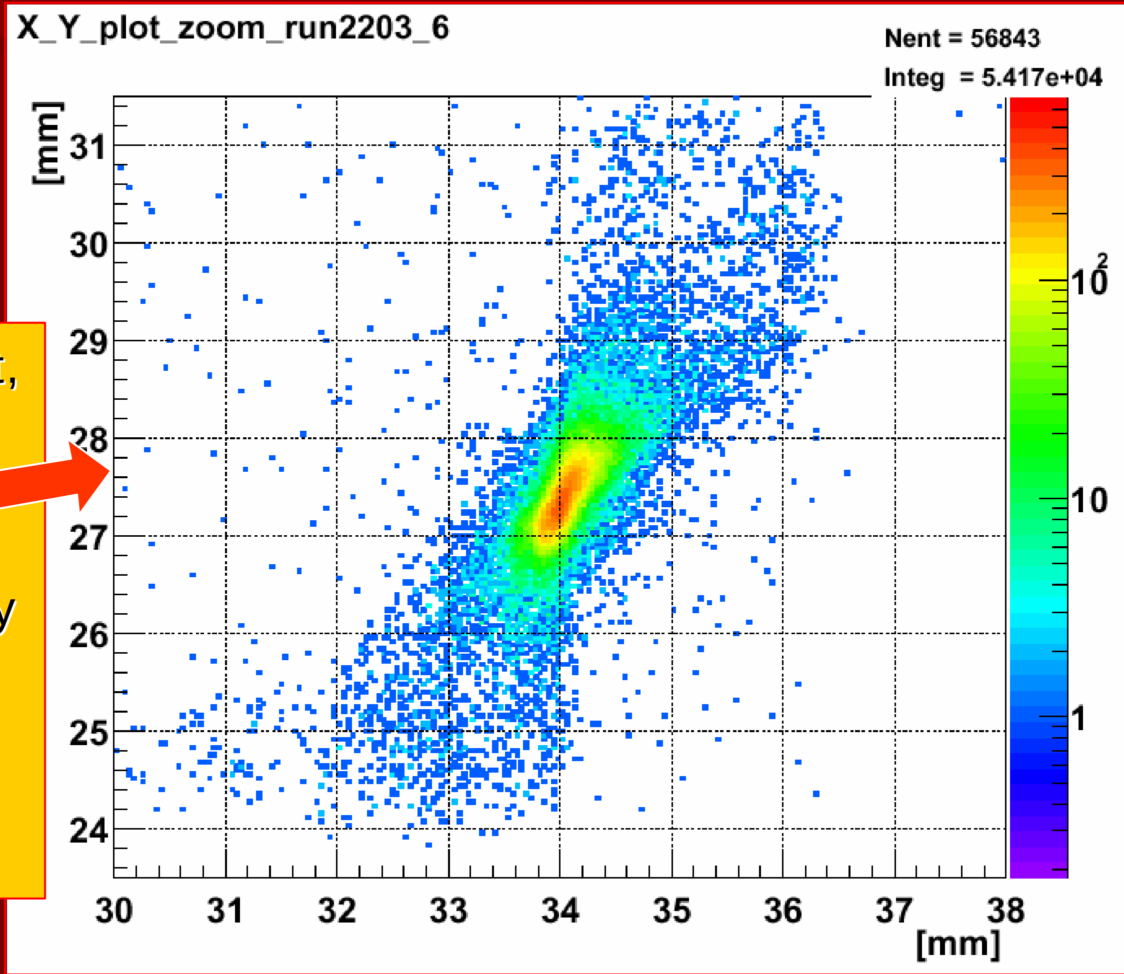
- First test ongoing at Saclay → satisfactory
  - Gain test
  - Stability test
  - Semi-sealed mode test
  - Gas tests (Xe mixtures)
  - Improved resolution demonstrated (~12% FWHM at 5.9 keV peak achieved)





- Calibration test with both the MICROMEGAS and the telescope scheduled for this summer, in the PANTER X-ray facility in Munich.

- The ABRIXAS telescope spot, as seen by the current CAST Micromegas (test done in PANTER in 2002)
- Logarithmic scale in intensity
- Expected structure of the spot.
- Spatial resolution of the CAST Micromegas < 160 μm



Conclusions

- The status of CAST, a unique kind of telescope, looking for solar axions, has been presented
- Phase I has been finished. Limits to axions properties, for the first time beyond some astrophysical limits, have been achieved.
- After an important effort, during 2005, to upgrade the experiment to hold a buffer gas inside the magnet, phase II of data taking has just started (November 2005)
- Important detector improvements are foreseen this year, in particular, a new X-ray focusing system coupled to a new MICROMEGAS detector.


CAST
EUROPAMETAL
E. ZANON
0,45€ REDUCTION
Axion
Total