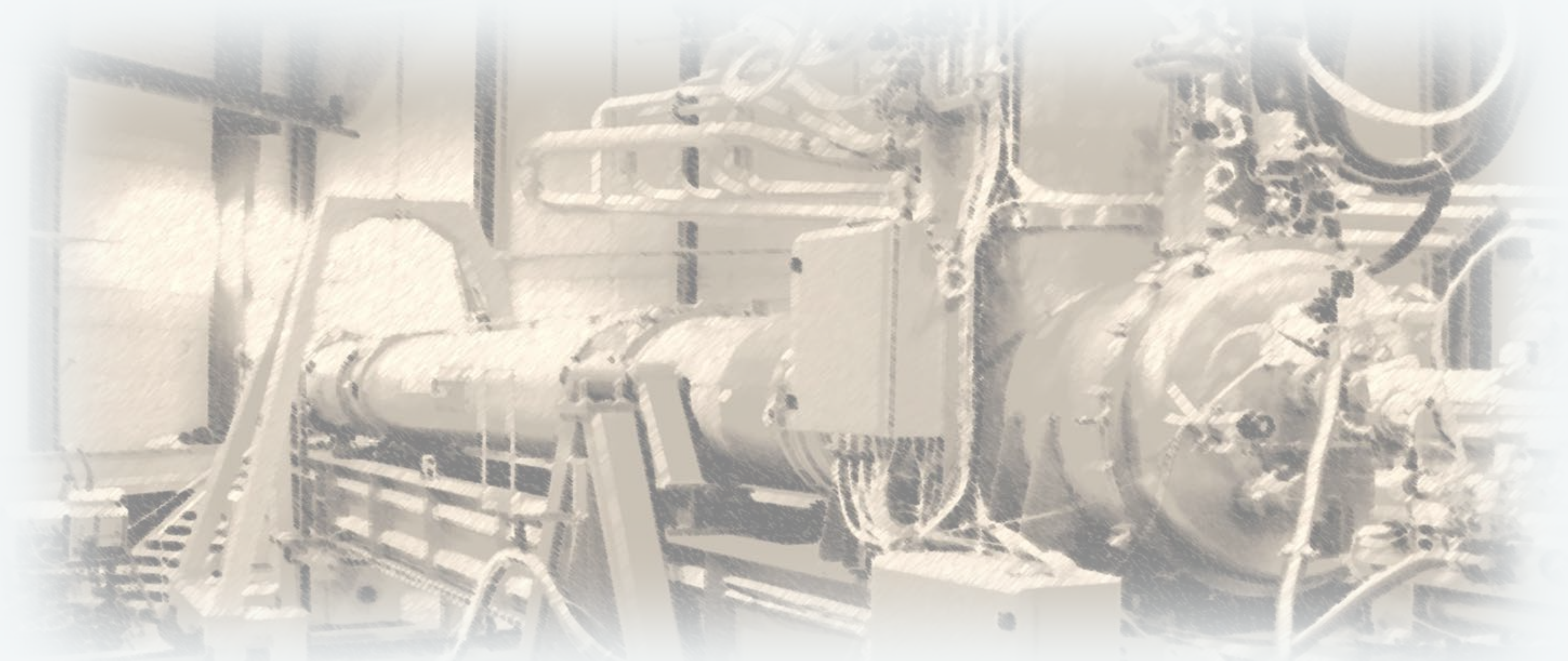
Latest results of CAST and future prospects

Theodoros Vafeiadis

On behalf of the CAST collaboration



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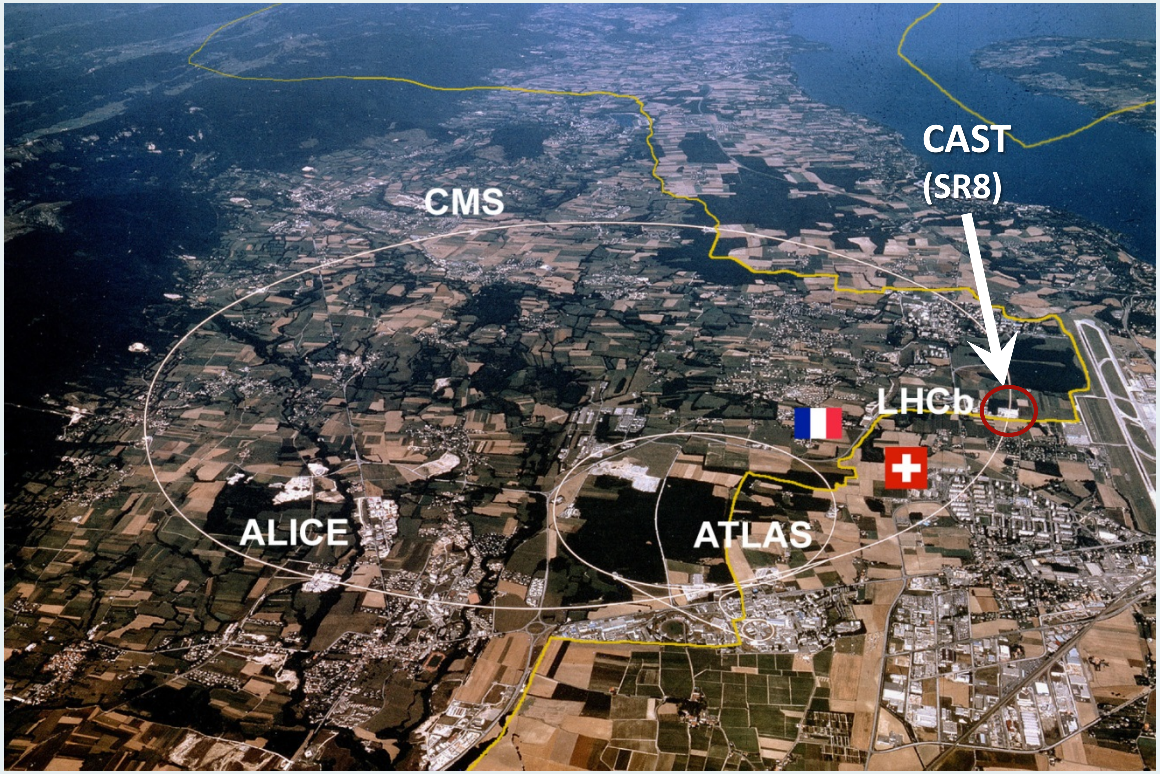
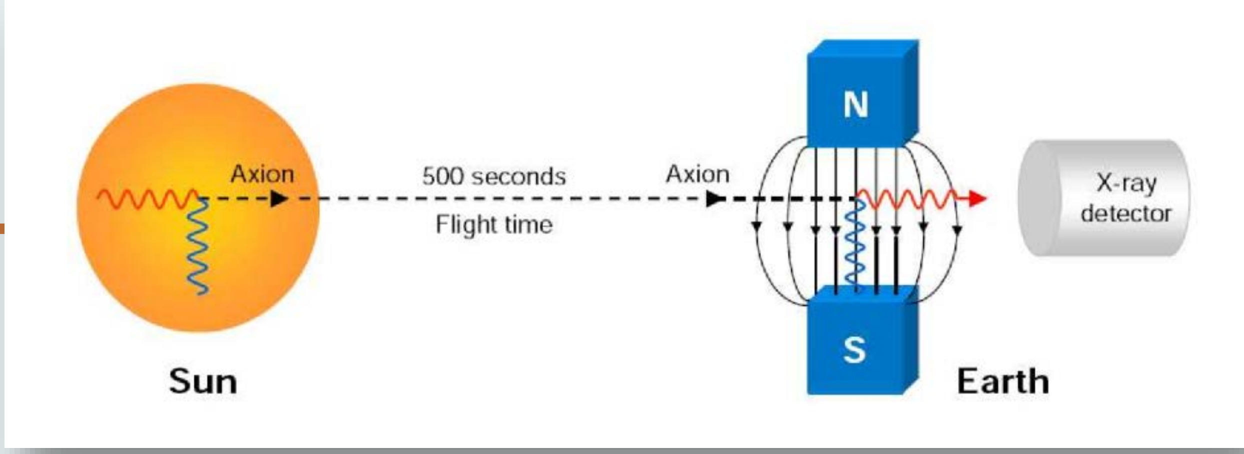


~50 scientists from 20 institutes

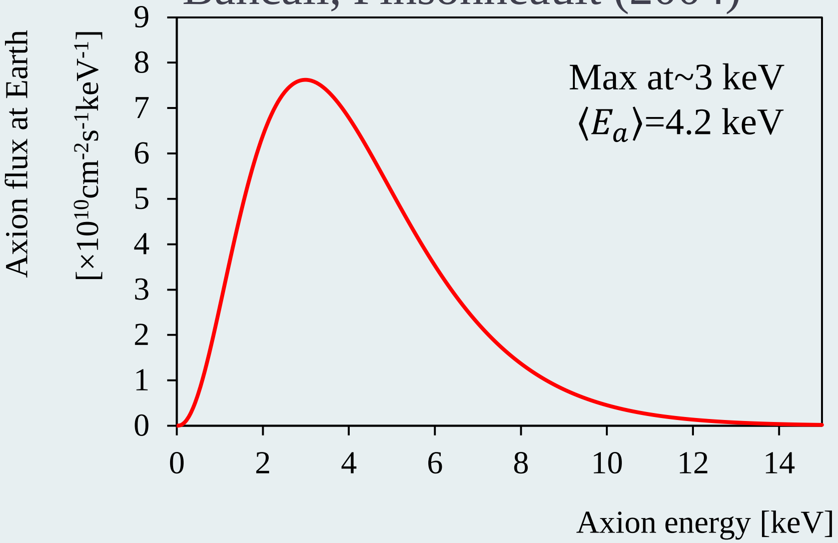
Axions

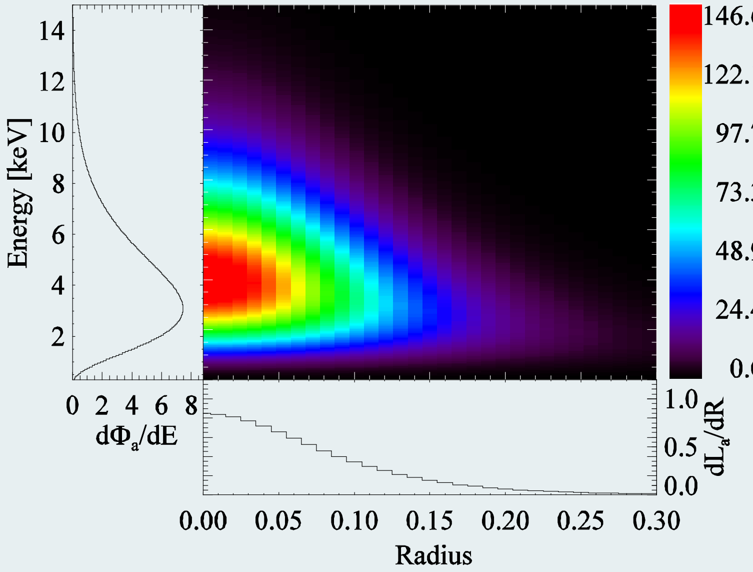


P. Sikivie, Phys. Rev. Lett. 51, 1415–1417 (1983)

- Axions are produced in the Sun via the Primakoff effect
- Re-convert to photons in the presence of strong magnetic field

Bahcall, Pinsonneault (2004)





CAST - detection principle

Conversion probability in gas (vacuum: Γ=0, m_γ =0)

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

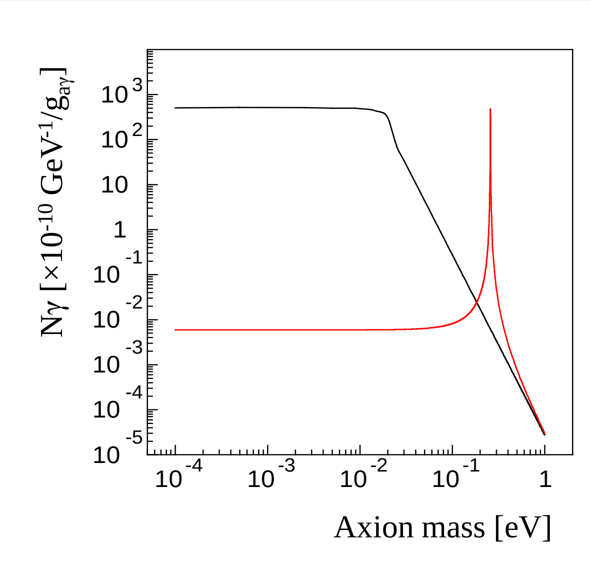
L=magnet length, Γ=absorption coeff.

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

Axion-photon momentum transfer

$$m_\gamma\left[\frac{\text{eV}}{\text{c}^2}\right] = 28.77\sqrt{\frac{Z}{A}\rho\,\left[\frac{\text{g}}{\text{cm}^3}\right]}$$

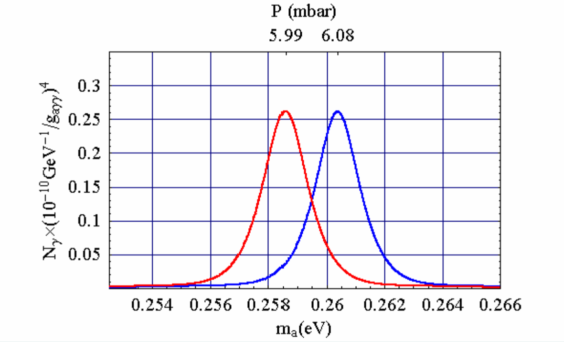
Photon effective mass



Coherence condition : qL<π

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

Higher ρ → higher m_γ → restoration of coherence for higher m_a



CAST – scientific program

PhysRevLett.112.091302

CAST Phase I: vacuum operation (2003–2004)

$m_a < 0.02$ eV

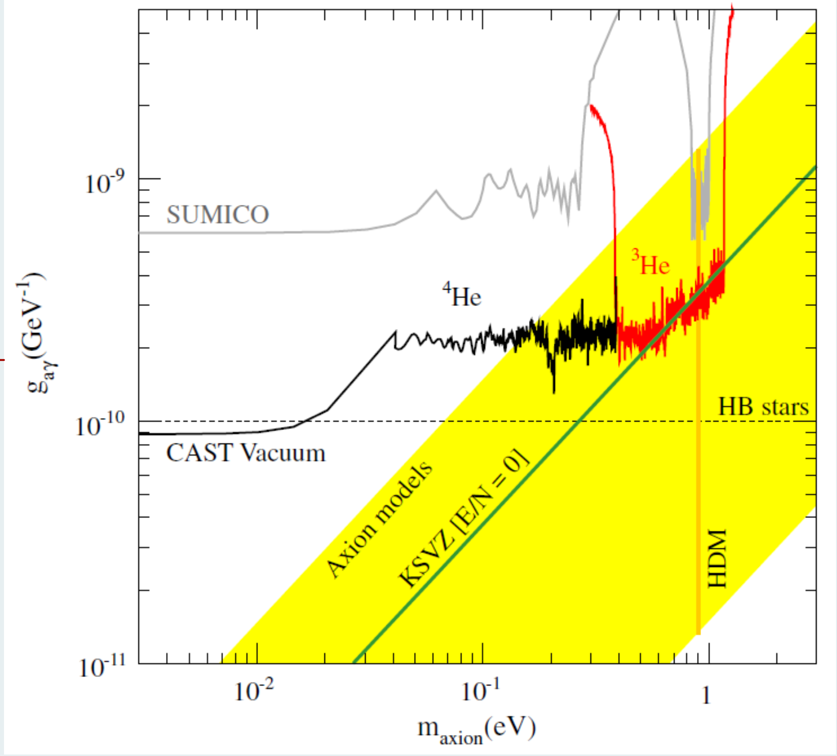
CAST Phase II: (2005–2011)

^{4}He run, (2005–2006)

$0.02 \text{ eV} < m_a < 0.39 \text{ eV}$

^{3}He run (2008–2011)

$0.39 \text{ eV} < m_a < 1.15 \text{ eV}$

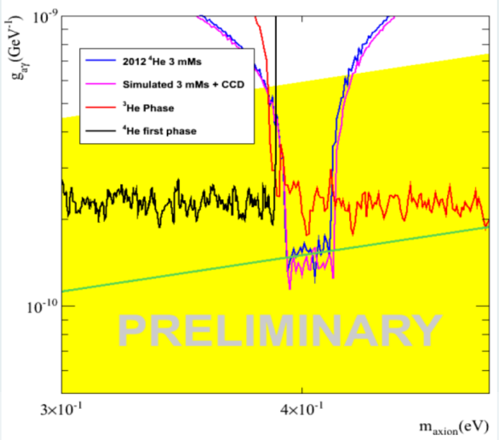


CAST ^{4}He run (2012)

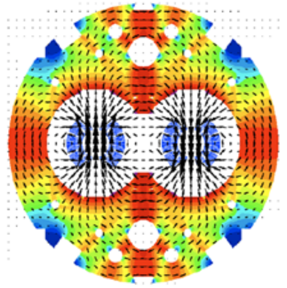
$0.39 \text{ eV} < m_a < 0.42 \text{ eV}$

Vacuum run (2013–2015) – improved sensitivity

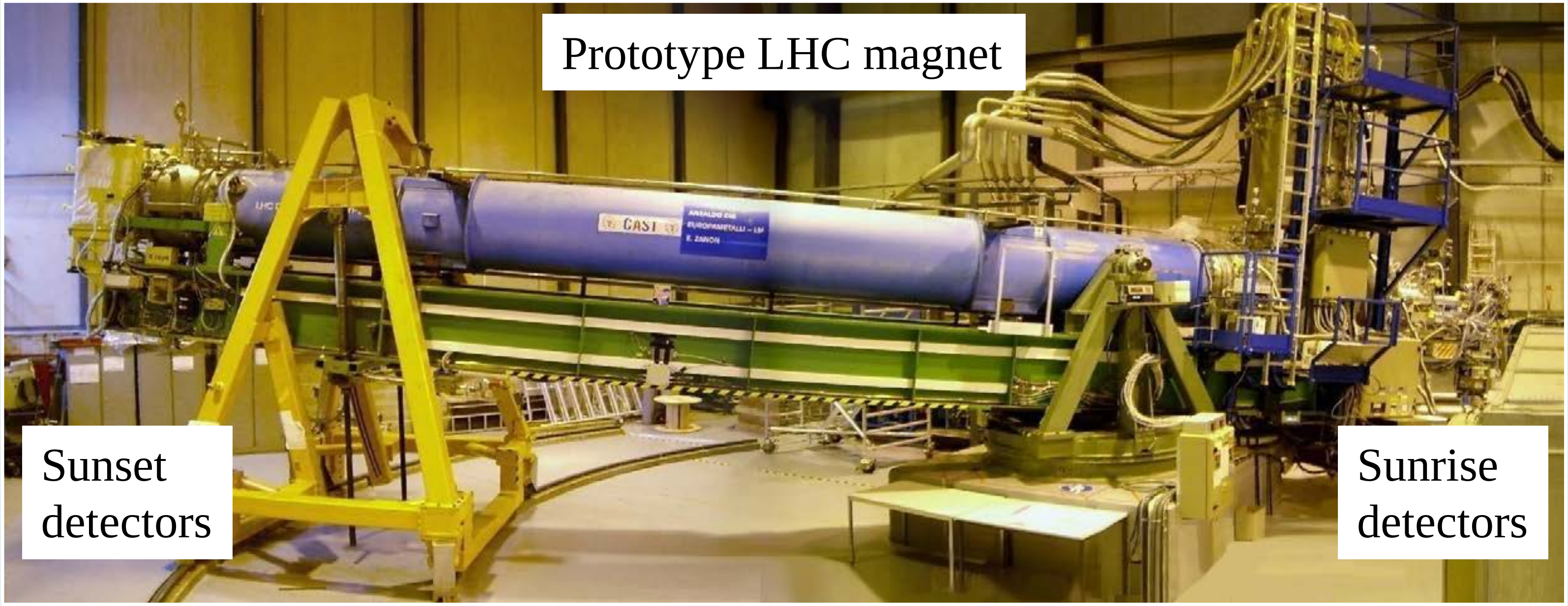
$m_a < 0.02$ eV



CAST – experimental layout



- 10 m decommissioned LHC prototype magnet (B ≈ 9 T, T≈ 1.8K)
- Two cold bores of 43 mm aperture.
- 4 low-background X-ray detectors (3 Micromegas & 1 pn-CCD) - 1 focusing device
- Rotating platform : H= ±40°, V ±8°.
- 2 x 1.5 hours of tracking / day



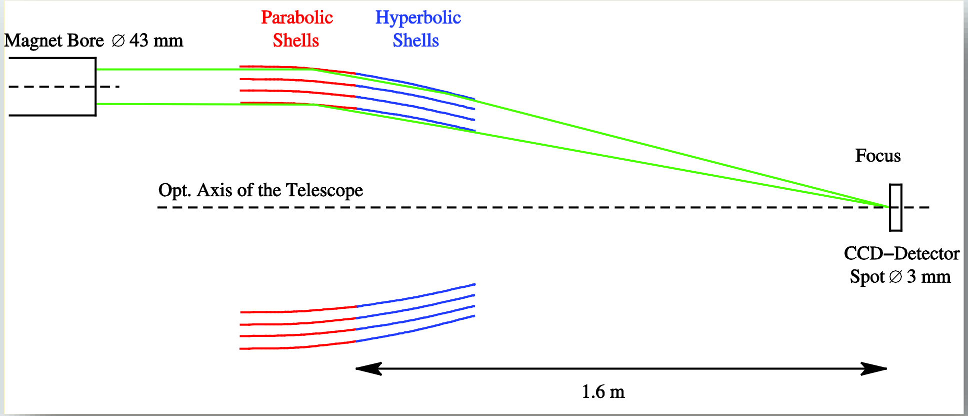
CAST detectors - CCD

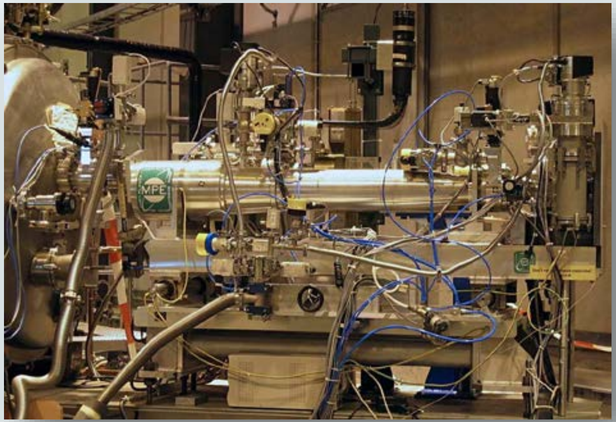
X-ray telescope

- Focal length 1600 mm
- 27 gold coated parabolic & hyperbolic mirror shells
- 14.5 cm^2 focused to ~6 mm^2

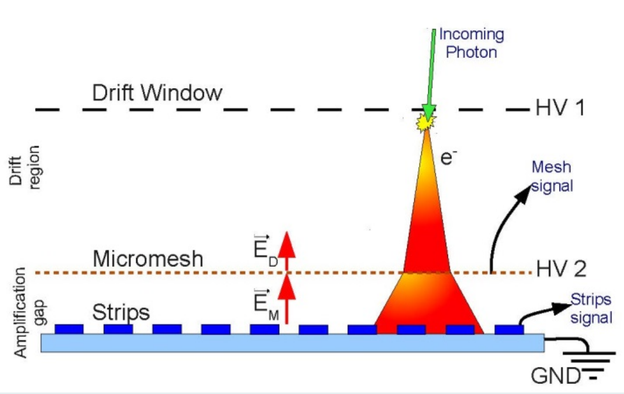
pn-CCD

- Sensitive area 2.88 cm^2
- Axion signal diameter : 19 pixels or 2.83 mm
- 0.2 counts/h (1-7 keV)



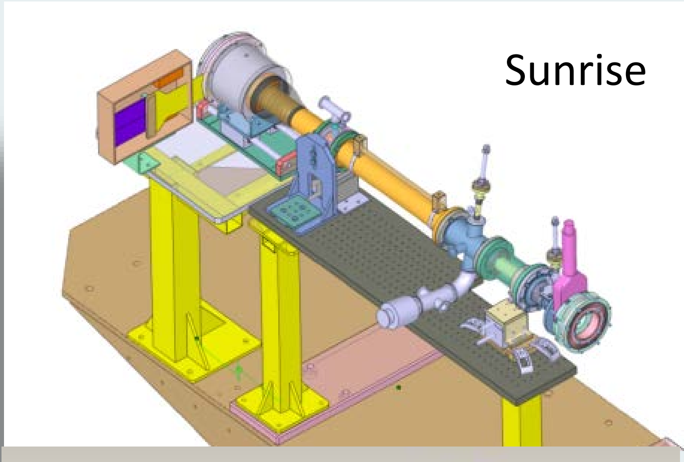


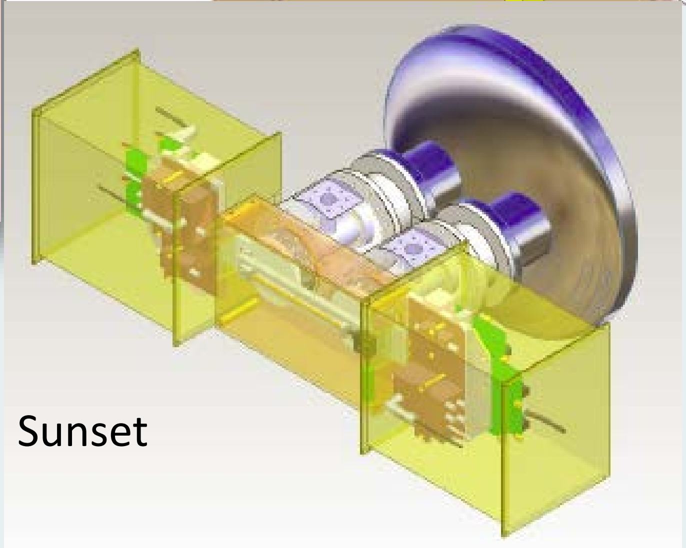
CAST detectors - Micromegas



Microbulk – technology specially designed for CAST

3 out of 4 detectors are Micromegas

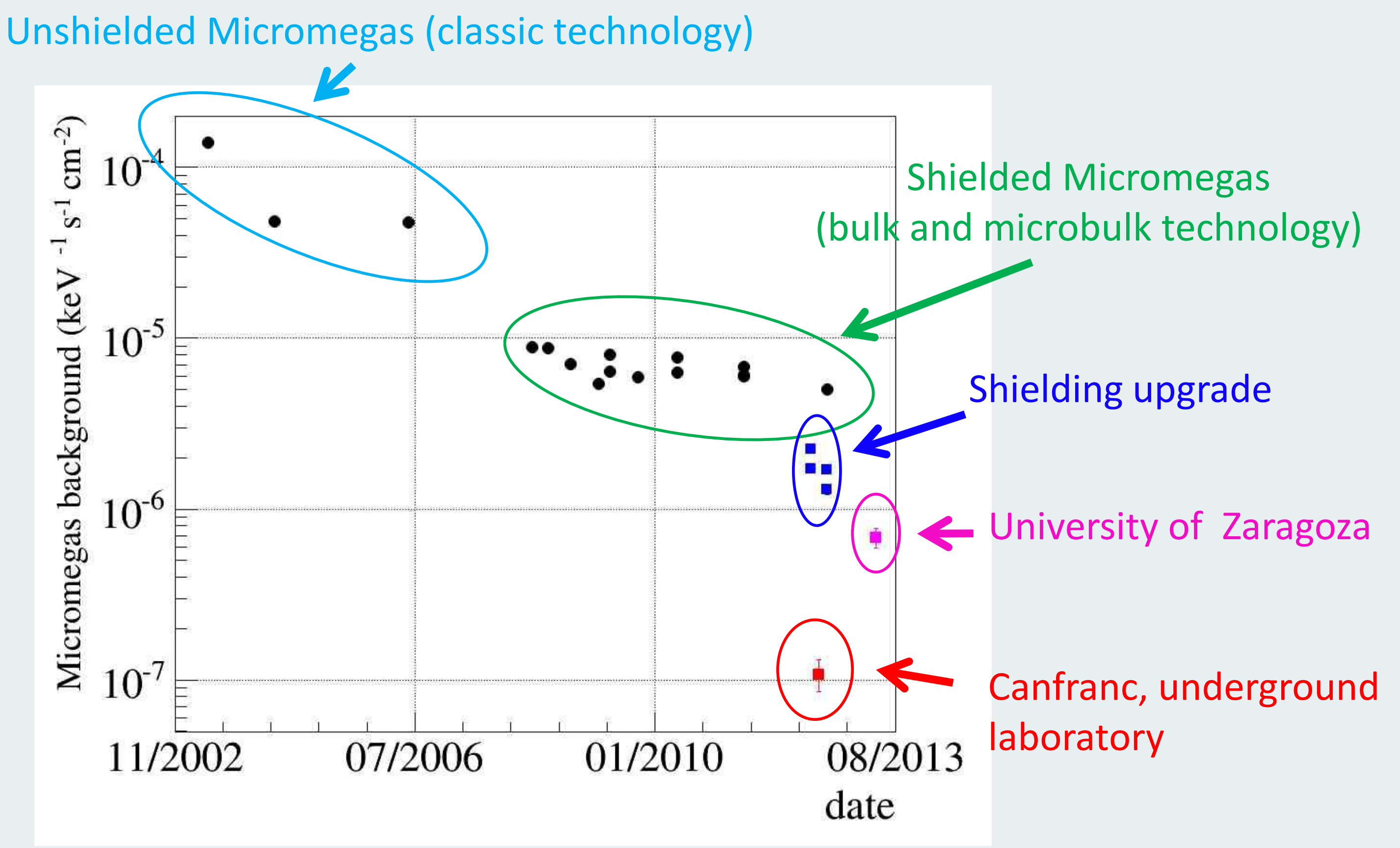




- Uniformity
- Clean materials
- Energy resolution (<13% FWHM @ 6 keV)
- Low background
- ~1 count/hour (2-10 keV)

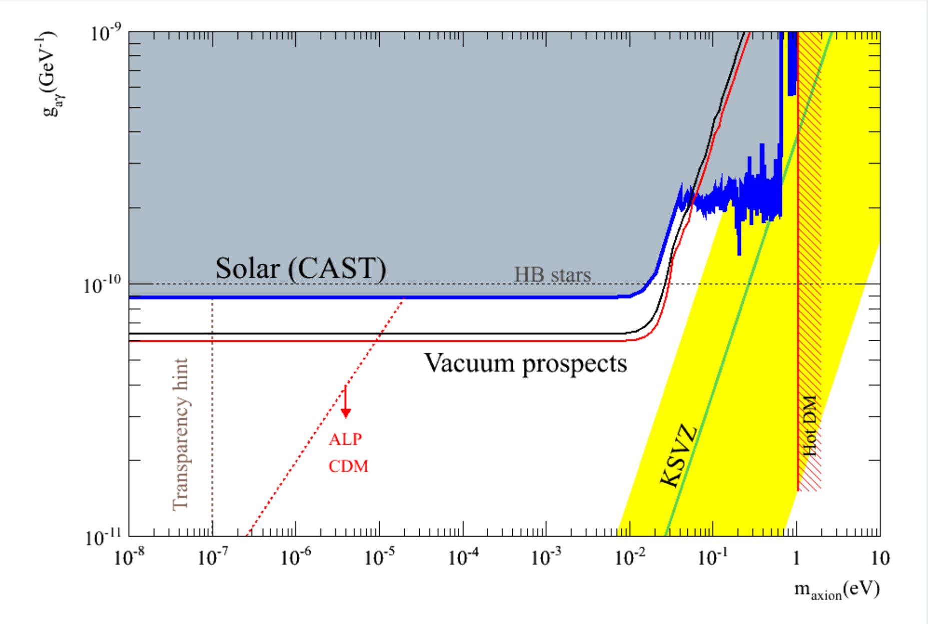
Micromegas evolution

Improvement of two orders of magnitude in background since 2002



CAST 2013 & 2014

CAST has started in 2013 and will continue in 2014 the vacuum phase to search for axion-like particles (ALPs) with improved detectors.

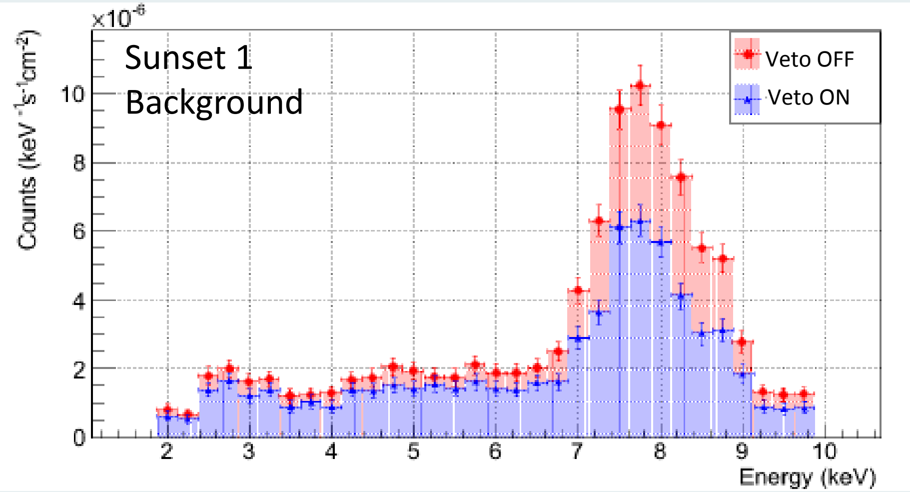


Why?

- ALPs appear in extensions of the standard model, in string theories, as dark matter candidates, as a possible solution to some unexplained astrophysical observations

How?

- Very low background (~ 1×10^{-6} s^{-1} cm^{-2} keV^{-1}) Micromegas detectors & additional new X-ray optics for the sunrise Micromegas



CAST 2013

Micromegas low background techniques:

- New AFTER based electronics provide more information (pulse shape analysis extended to every strip)
- Cosmic veto with 75% coverage (sunset line)
- New shielding design

New detector design (sunrise line)

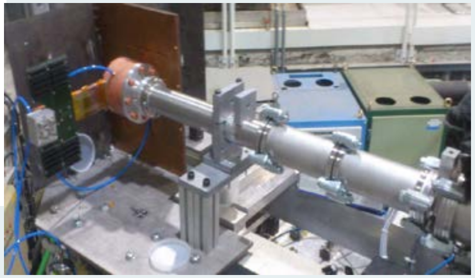
Main novelties: field shaper, body and support made of copper, 16% energy resolution before selection criteria!

Teething problems :

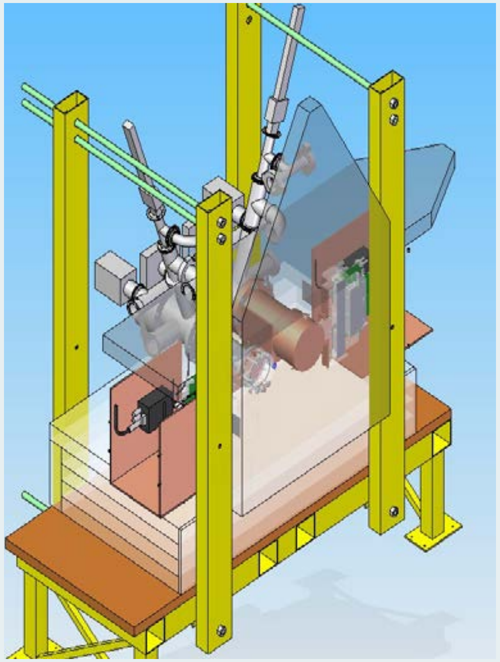
Electronic noise / Design issues / Interface to vacuum line -All solved with the new generation

Took data for 4 days.

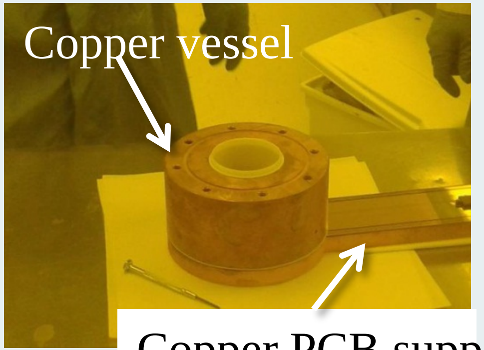
Sunrise line

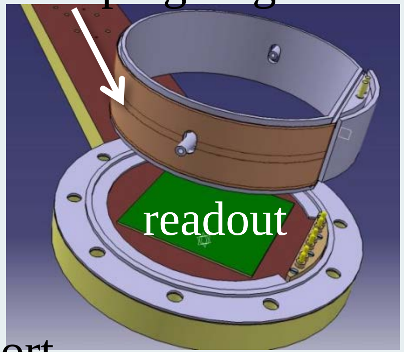


Sunset line



Field shaping rings





Copper PCB support

CAST 2013

New searches in vacuum : **Chameleons**

- Chameleons are Dark Energy candidates to explain the accelerated expansion of the Universe.
- Their effective mass depends on the energy density of the environment (ambient mass energy density)

Solar Chameleons

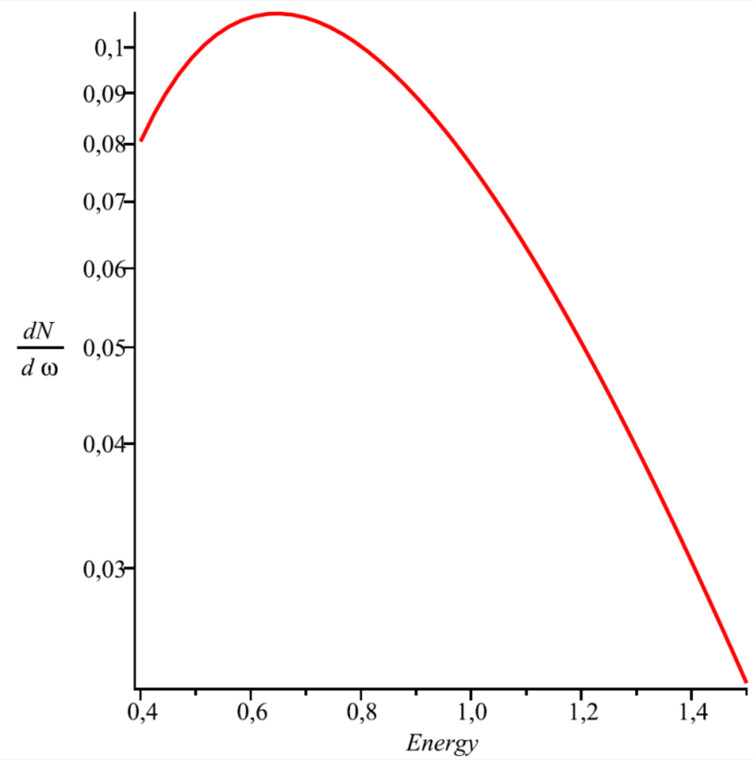
- Can be created by the Primakoff effect in the tachocline @ ~0.7 $R_\odot$
- They can be converted to X-ray photons in CAST via the inverse Primakoff effect (like axions)

Requirements:

- **Low background and low threshold detectors**

Philippe Brax

Analog spectrum of back-converted photons in the CAST magnet.
for B_{tacho} ***=10T, n=1 ,*** A_{det}**=17 mm**^{2}

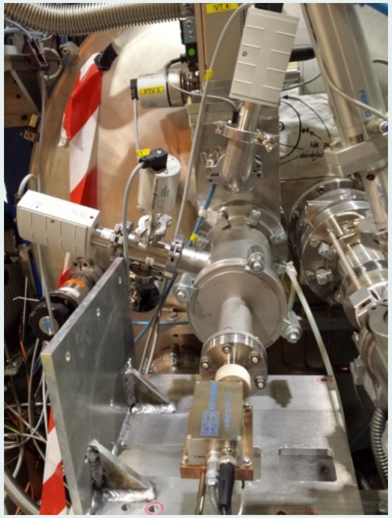


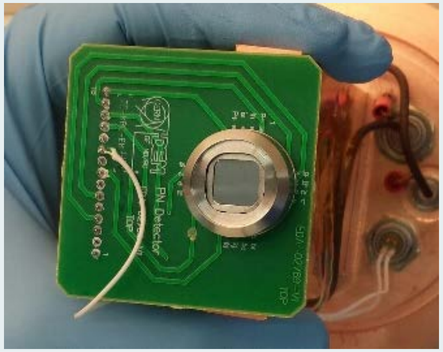
CAST 2013 - Silicon Drift Detectors

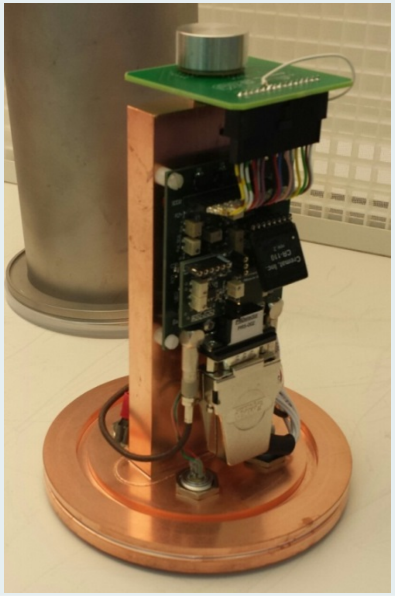
Two SDDs (Silicon Drift Detectors)

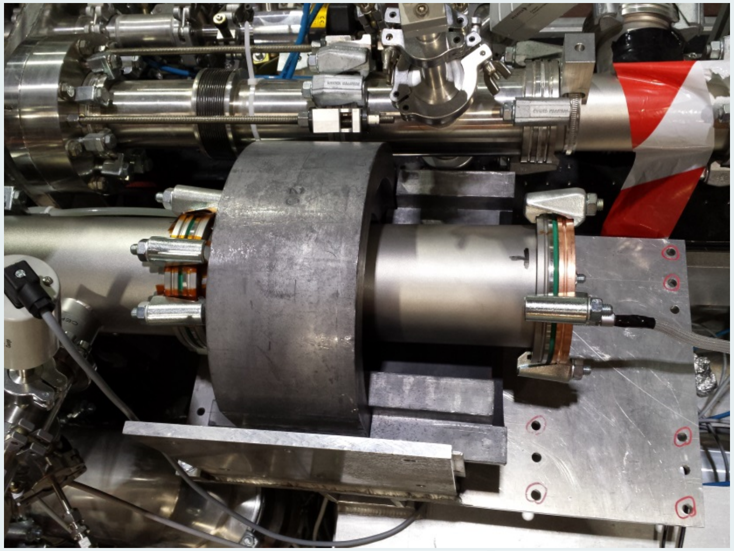
Energy range : 400-1500eV

- Amptek XR-100SDD (small SDD – sSDD)
  - Very thin window: Si_3N_4 coated with Al
  - Active surface 17 mm^2
  - 125 eV FWHM Resolution @ 5.9 keV
- PN Detector SDD (Big SDD – BSDD)
  - No window
  - Custom-built
  - ~100 mm^2 surface









CAST 2013

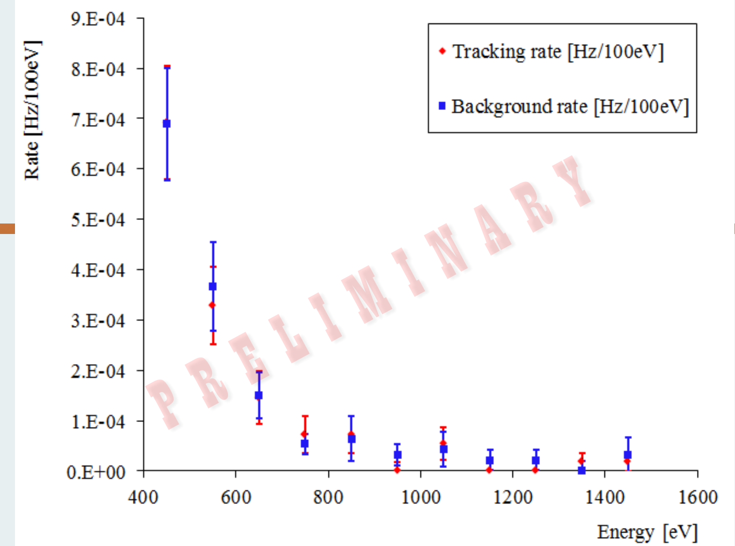
Results of sSDD – still under evaluation

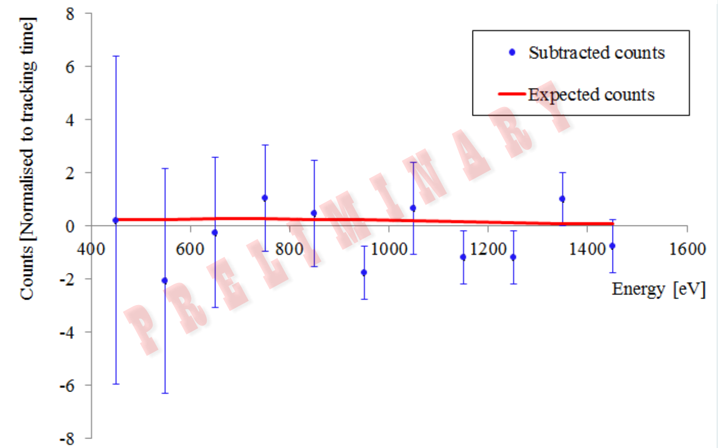
Results of BSDD:

- 15.2 h of tracking time
- 25.8 h of background time

Compatible with the null hypothesis

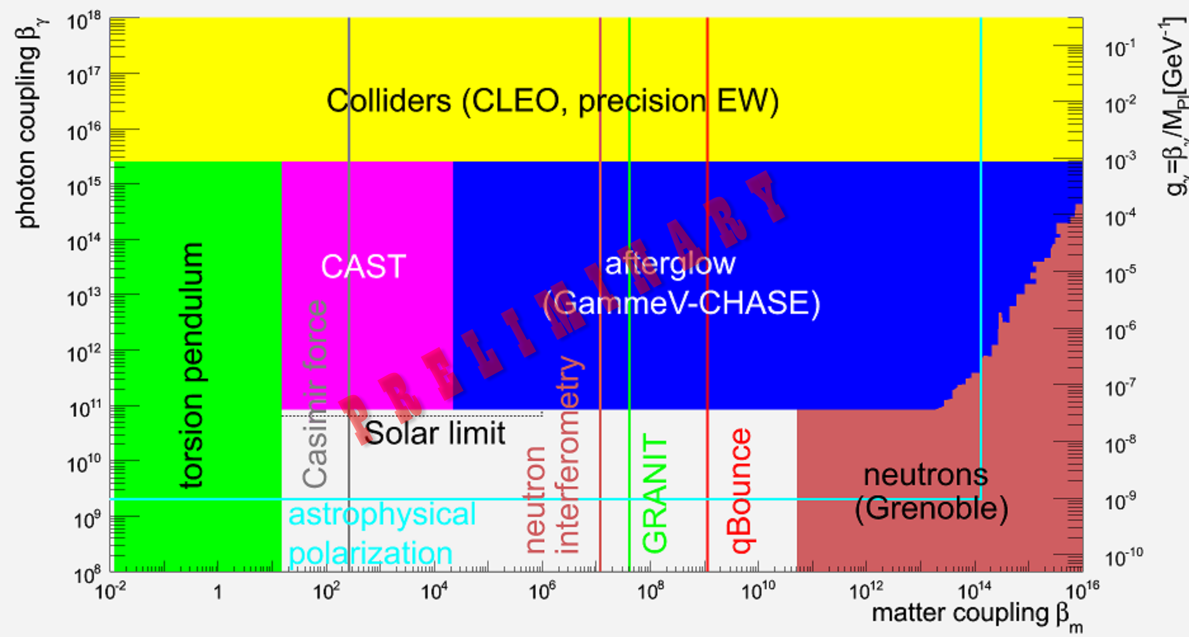
- Limit to $\beta_\gamma \leq 8.39 \cdot 10^{10}$ at 95% C.L.





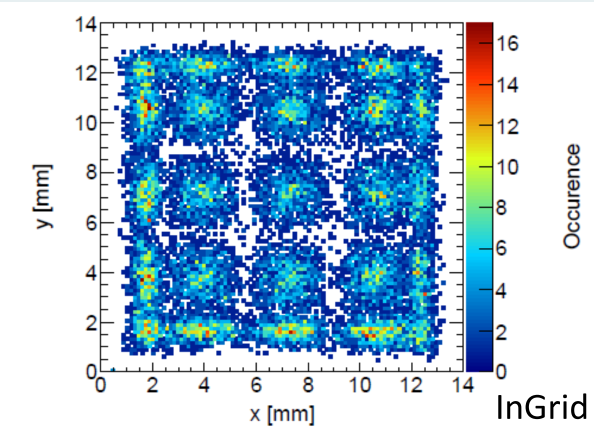
Expected counts calculated taking into account:

- Time of tracking the Sun
- Area and Q. E. of detector
- Length that chameleons travel inside magnet
- Absorption effects due to windowless detector

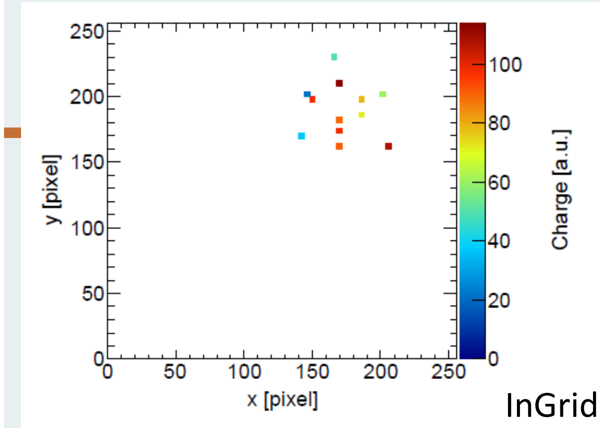


DOI:
http://dx.doi.org/10.3204/DESY-PROC-2013-04/weltman_amanda

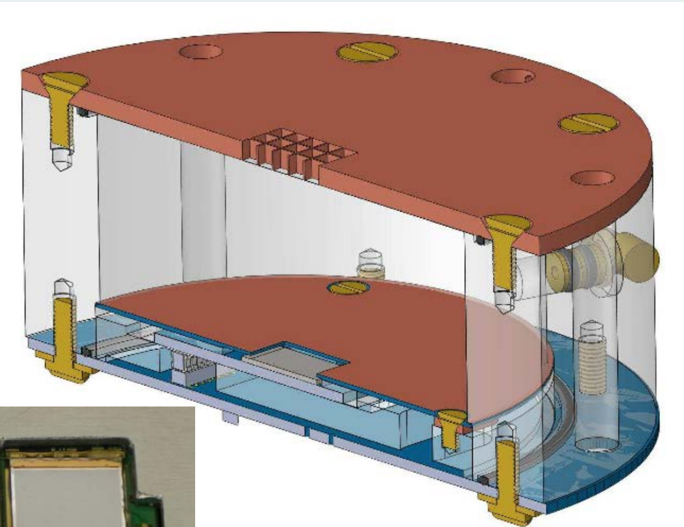
image of the window strongback

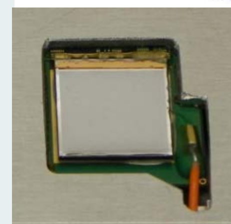


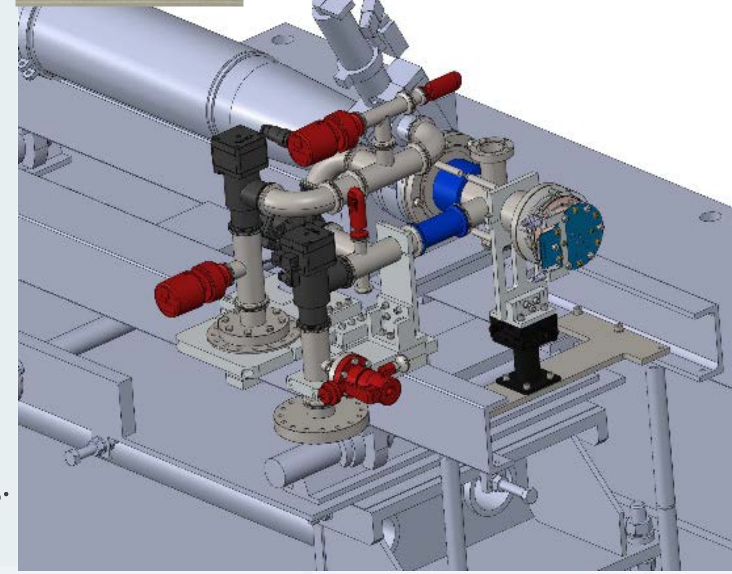
Sample Carbon event (X-ray generator)



CAST 2014







- **Second iteration of new Micromegas design -**

  Will address all the issues of the previous design

- **X-ray telescopes in front of both sunrise detectors (one new, one existing)**
- **Possibility to re-install a redesigned BSDD**
- **New detector** behind the MPE X-ray telescope : InGrid Micromegas detector
  - Timepix chip, 256 × 256 pixels, 1.4 × 1.4 cm^2 , 55×55 μm^2 pitch
  - Threshold well below 1 keV
  - Can detect the primary electrons from X-rays with high single-electron efficiency
  - Simultaneous search for solar axions and lower energy particles, e.g. chameleons

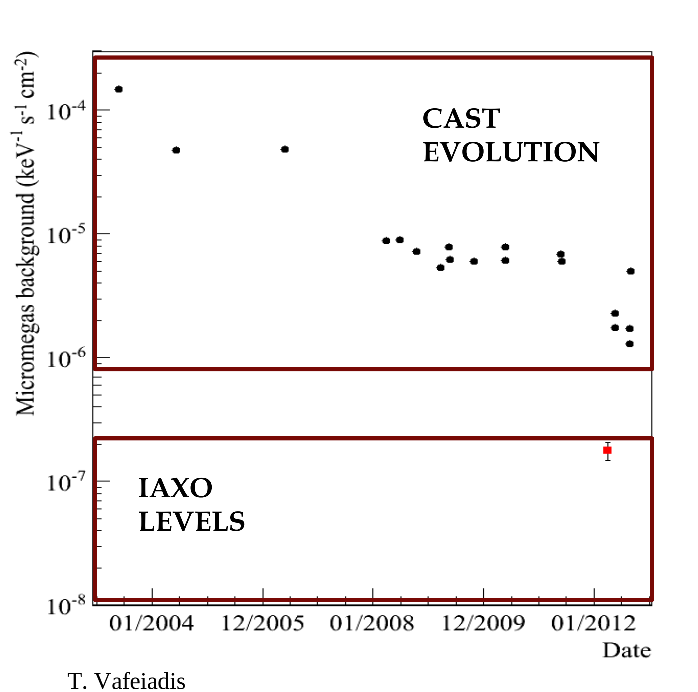
The next step- IAXO

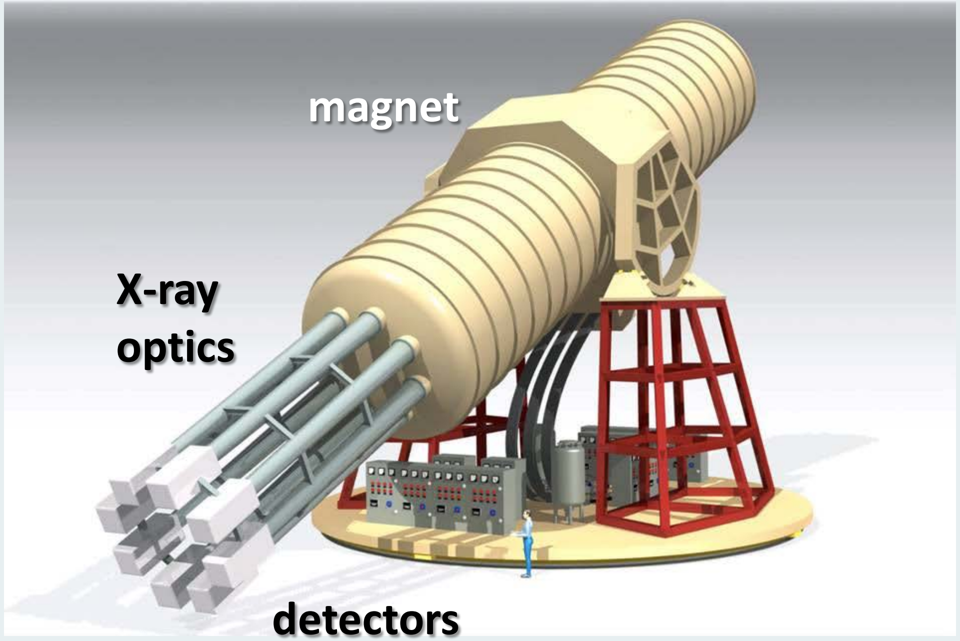
International AXion Observatory

JCAP 1106 (2011) 013

The accumulated experience from CAST put to practice

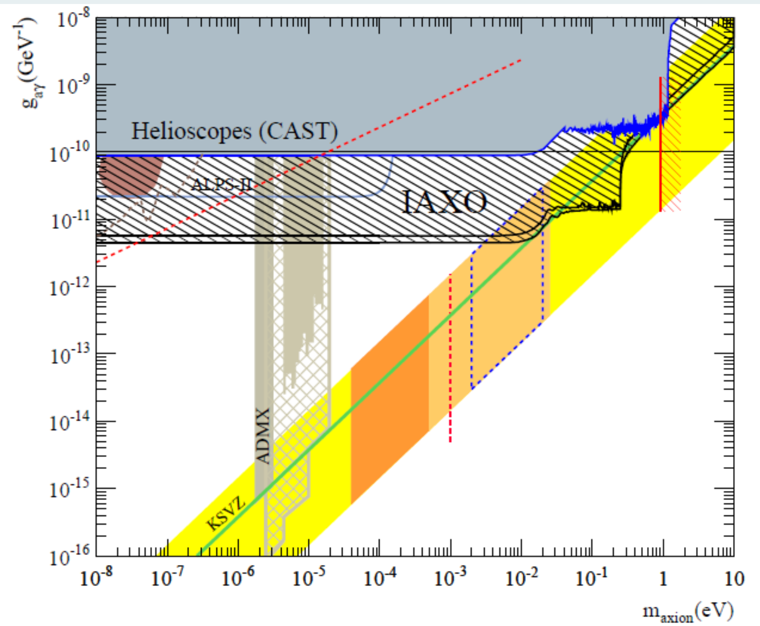
- All bores equipped with x-ray focusing devices and low background detectors. Will improve the CAST limits by 1-2 orders of magnitude
- LoI submitted to CERN (CERN-SPSC-2013-022)
- SPSC recommended that IAXO proceeds to a TDR

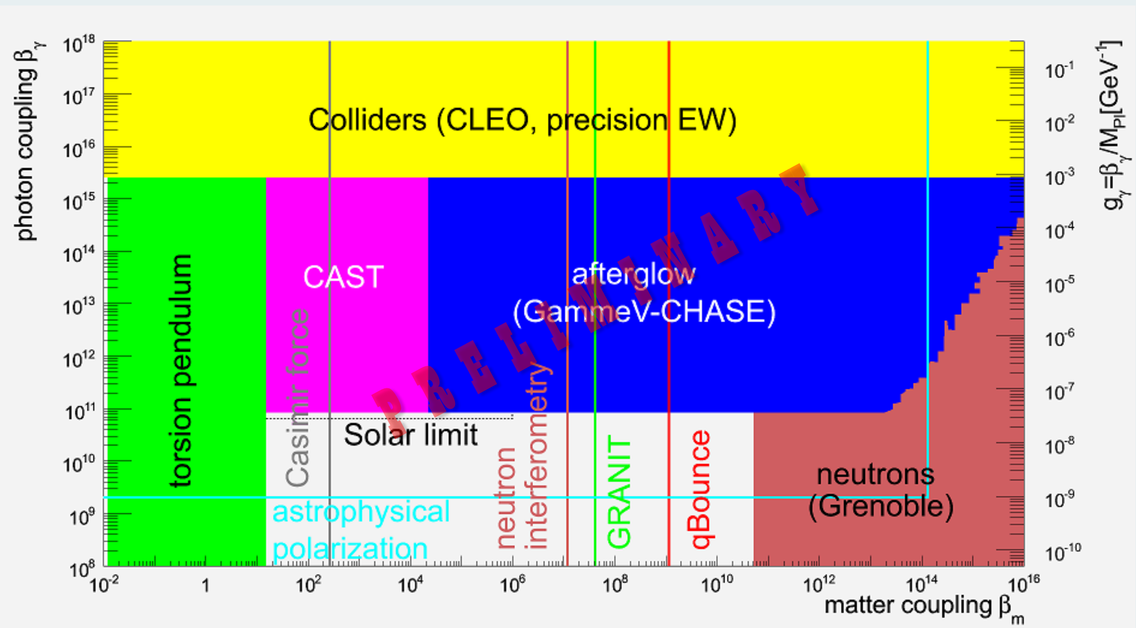




Conclusions

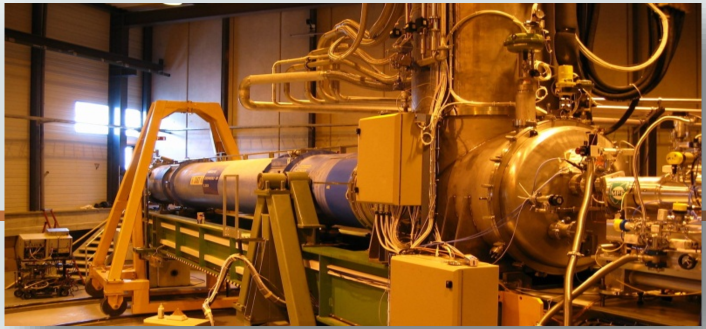
- CAST provides the best experimental limit on axion-photon coupling constant over a broad range of axion masses.
- After having completed its original program, CAST is going to improve the vacuum results and study other exotica with improved detectors.
- In 2013 CAST has provided the first limit for the chameleon to photon coupling constant with a helioscope.
- The CAST Collaboration has gained a lot of experience in detector R&D and axion helioscope searches which will be put into practice in the next generation experiment, IAXO.





Thank you

Position measurements

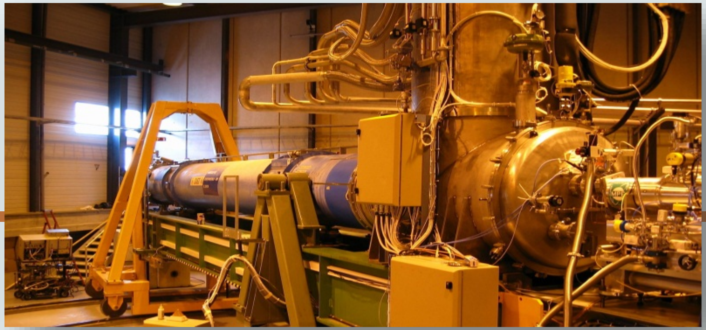


Sun filming

- March & September
- Sun visible through window in the east-facing wall
- SLR camera + optics aligned (Survey team)
- Precision (R_{sun} = 1139±2 pixels, alignment ±25 pixels)

Not always easy…

Position measurements



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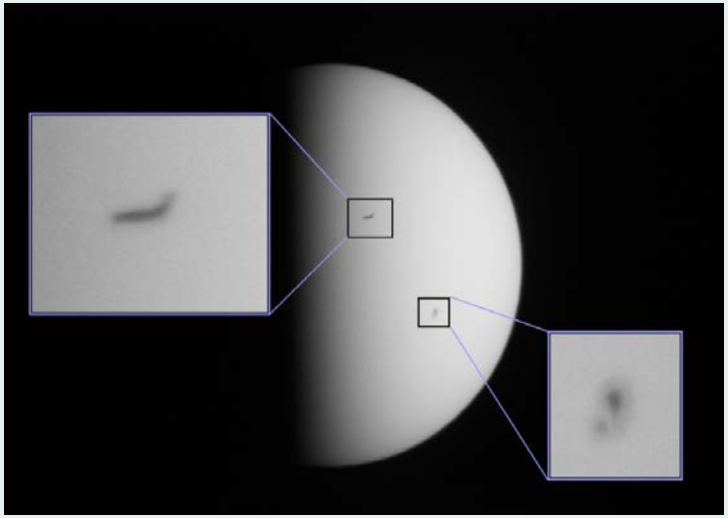
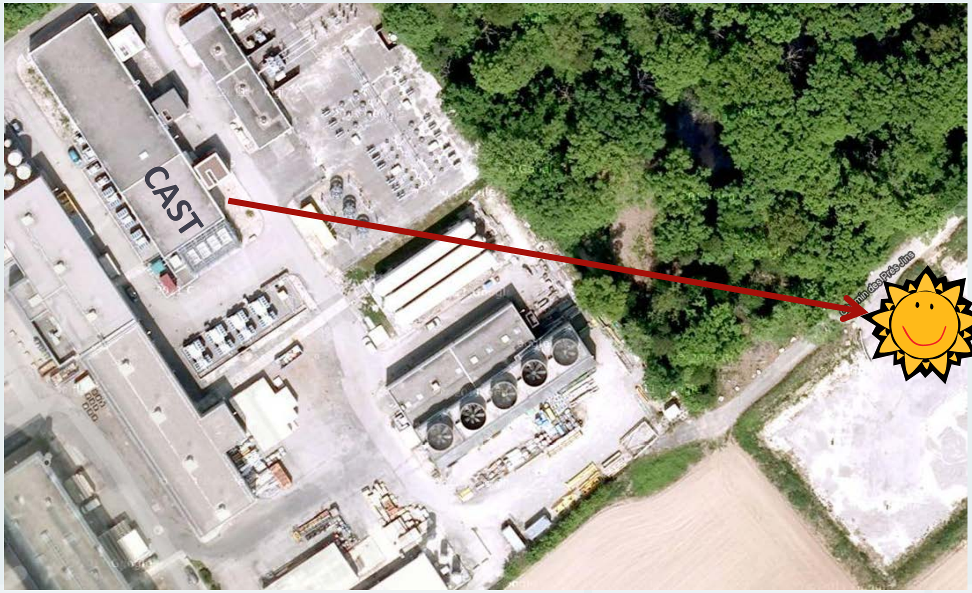
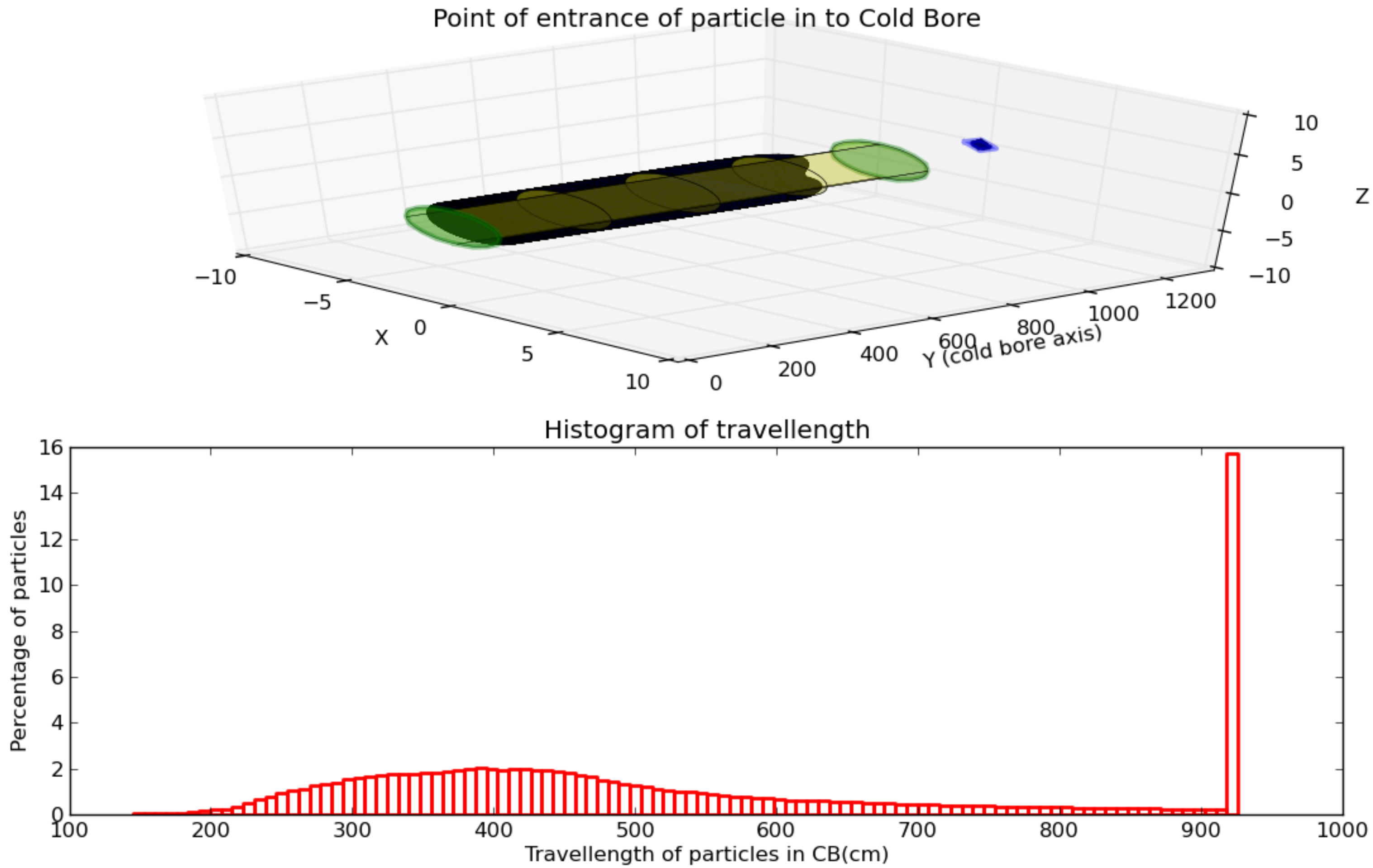




Moon filming!



Point of entrance of particle in to Cold Bore
X
Y (cold bore axis)
Z
−10
−5
0
5
10
200
400
600
800
1000
1200
Histogram of travellength
Percentage of particles
Travellength of particles in CB(cm)
16
14
12
10
8
6
4
2
100
300
500
700
900

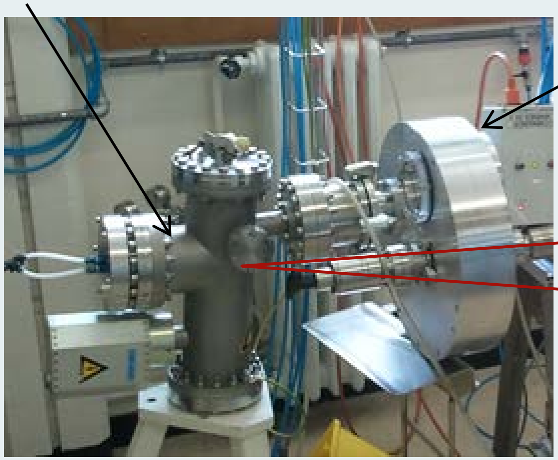
CAST 2013

Detector lab at CERN

- Variable energy X-ray generator built at MPE
  - Energies from 0.18-9 keV

X-ray source

Filter wheel



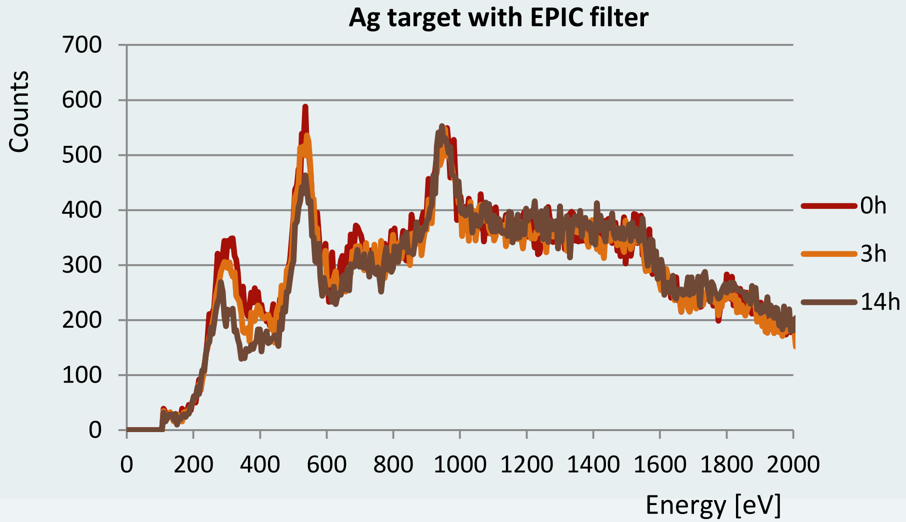
Purpose

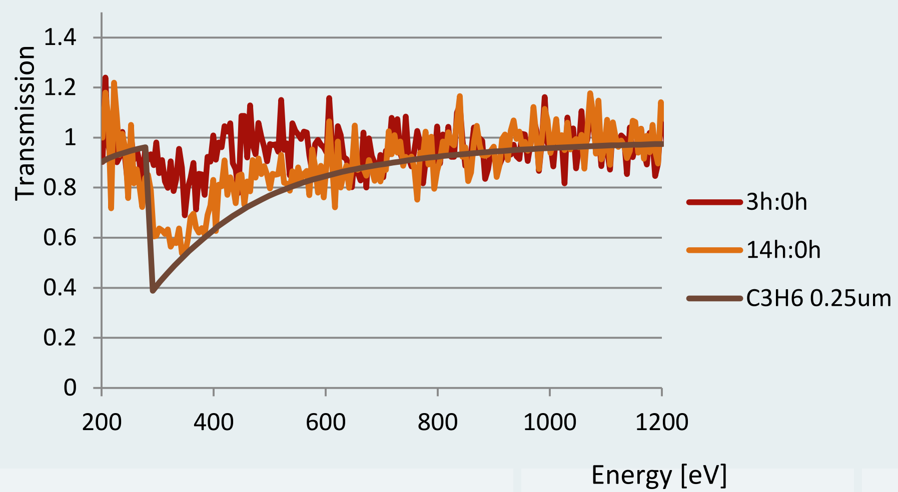
- New X-ray identification techniques.
- Calculation of the data analysis efficiency.

Transmission of BSDD

Verdict:

- There is definitely a hydrocarbon microfilm cryopumped on the cold surface of the BSDD.
- Monte Carlo to simulate the deposition rate from the spectra, taking into account the resolution of the detector.
- Extreme scenario : 17 nm/h of C_3H_6 deposition.
- In any case >75-80% transmission above 400 eV for the first 3 hours.





Micromegas detectors

Y. Giomataris *et al.*, NIM A 376 (1996) 29

Gaseous detector with two regions

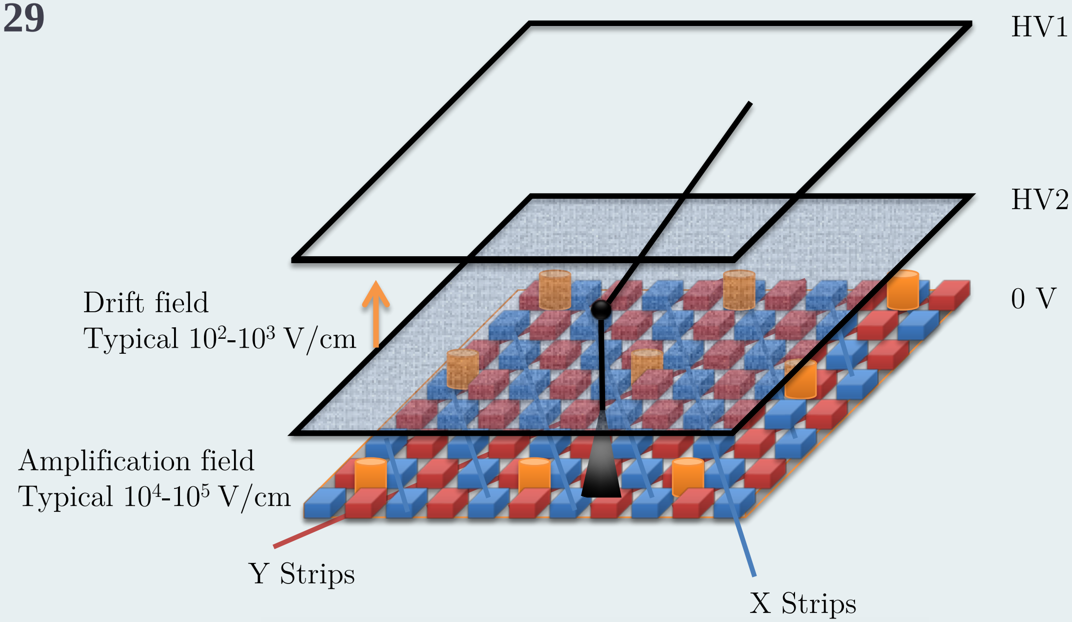
- Conversion region
- Primary ionization
- Charge drift

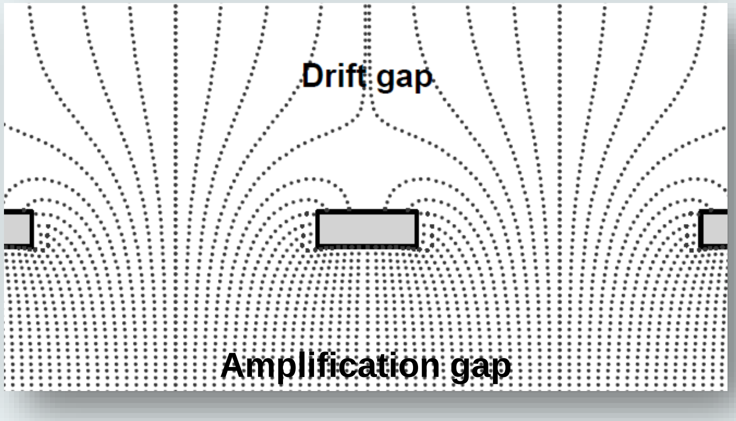
Amplification region

- Charge multiplication
- Readout layout

Separated by a Micromesh

- Very strong and uniform electric field

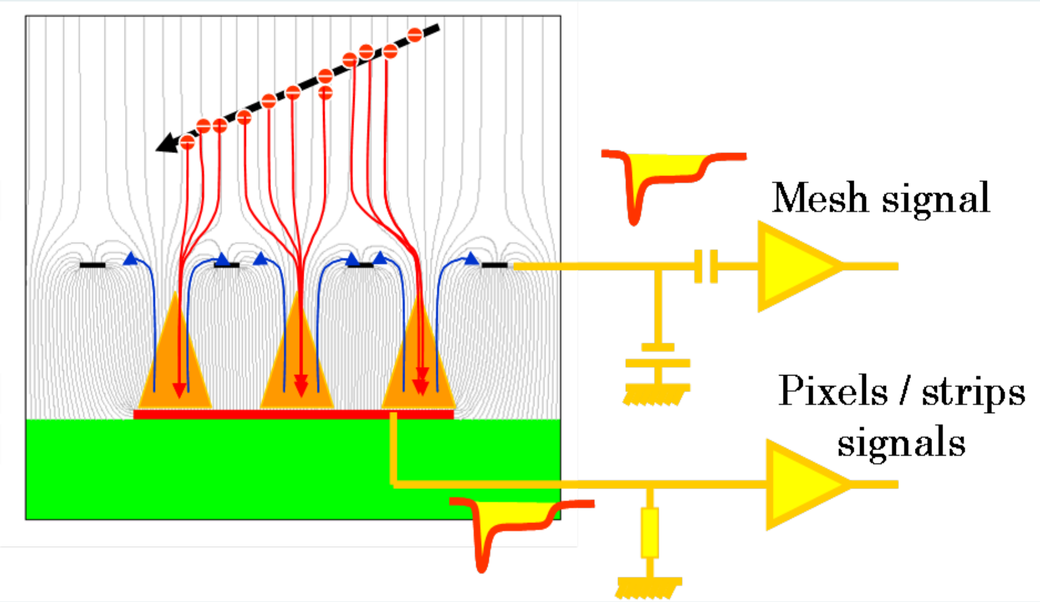


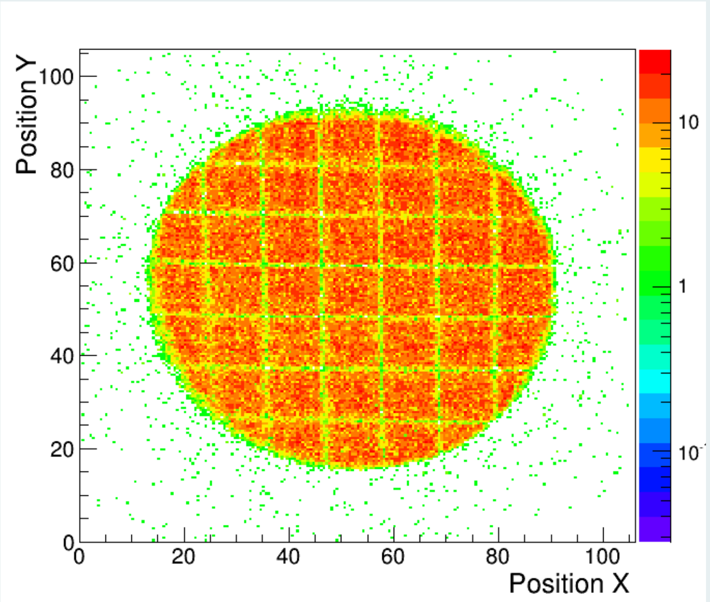


Micromegas detectors

Mesh
- Collection of the ions generated in the avalanche → Energy and time information.

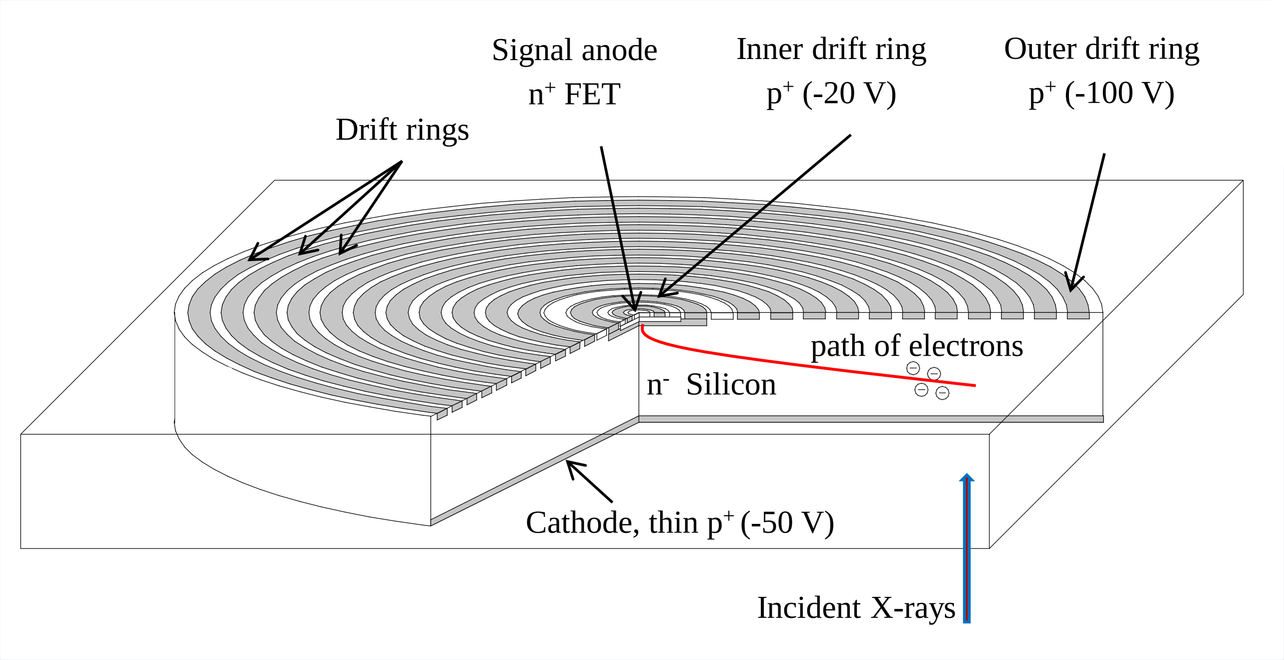
Strips
- Collection of the electrons from the avalanche in the strips →Energy and topological information of the event.





backup


PX5
DIGITAL PULSE PROCESSOR
AMP IN
XR-100 POWER
ON
OFF
XR-100CR
X-RAY DETECTOR


Signal anode
n+ FET
Inner drift ring
p+ (-20 V)
Outer drift ring
p+ (-100 V)
Drift rings
path of electrons
n- Silicon
Cathode, thin p+ (-50 V)
Incident X-rays

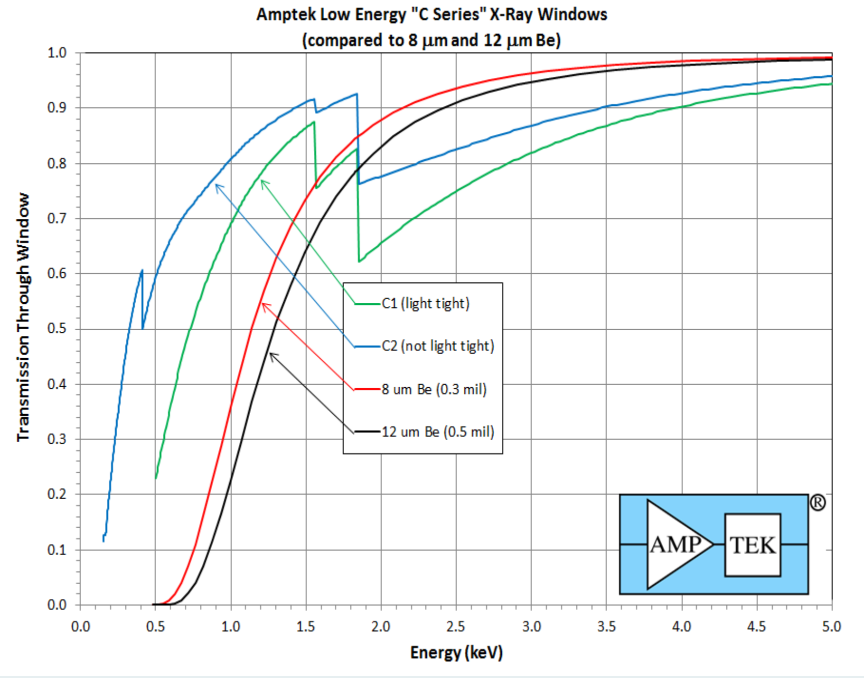
backup

Sub-keV energy range:

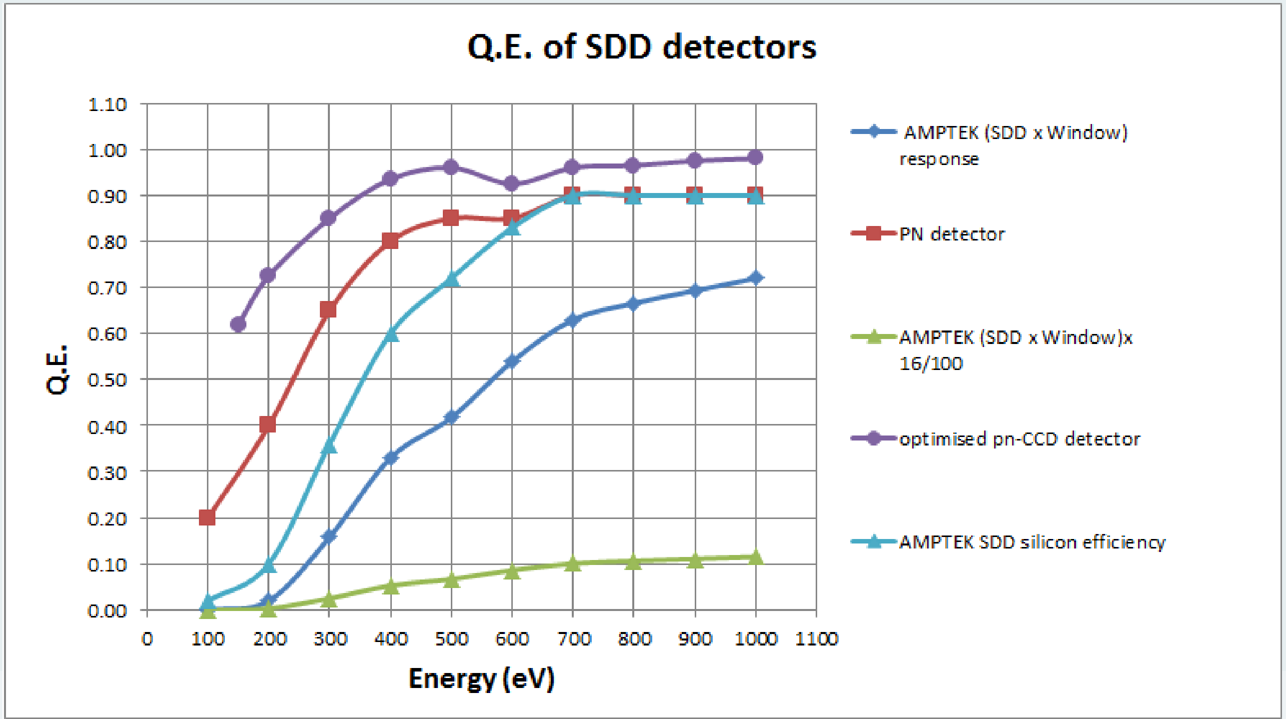
- Unexplored in a helioscope

The "small" SDD:

- Plug and play (..and program and analyse)
- Non imaging
- Low background (<1mHz from 250-1000 eV)
- C2 Window



- Amptek vs PN SDD



Backup - The trigger for axions

"I named them after a laundry detergent, since they clean up a long standing problem in theoretical physics." Wilczek

Standard Model

- Strong interactions do NOT violate CP symmetry

Experimental limit to neutron electric dipole moment $|d_n| \leq 2.9 \times 10^{-26}\, e \times cm$ (90% CL)

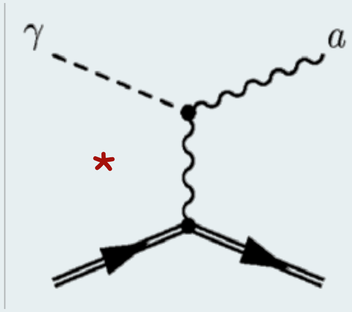
Elegant solution:

Peccei & Quinn (1977) proposed a spontaneously broken global symmetry (PQ)

AXION : pseudo Nambu-Goldstone boson of spontaneous breaking of PQ symmetry (Weinberg and Wilczek , 1978)

Backup - Axion properties

Primakoff



* magnetic field
from the plasma of the center of the sun

Axion properties

- Pseudoscalar boson
- Color and charge neutral
- Light
- Long lived
- Couples to photons
- Weakly interacting
- Dark matter candidate

Backup - Axion experiments

Axion : WANTED

Search strategy by Sikivie (axion couplings)

Most common : axion to photon coupling (Primakoff effect – exists in all models)

Haloscopes

- Galactic halo axions produced in early universe
- Electromagnetic cavities in strong magnetic fields (ADMX, CARRACK)

Laser experiments

- Interaction of polarized photon beams with virtual photons of a magnetic field (PVLAS, OSQAR, Alps, etc)

Helioscopes

- Solar axions
- Powerful magnet → transverse magnetic field
- Primakoff effect (Tokyo, **CAST**)