Status of CAST and Solar Chameleon searches

Theodoros Vafeiadis

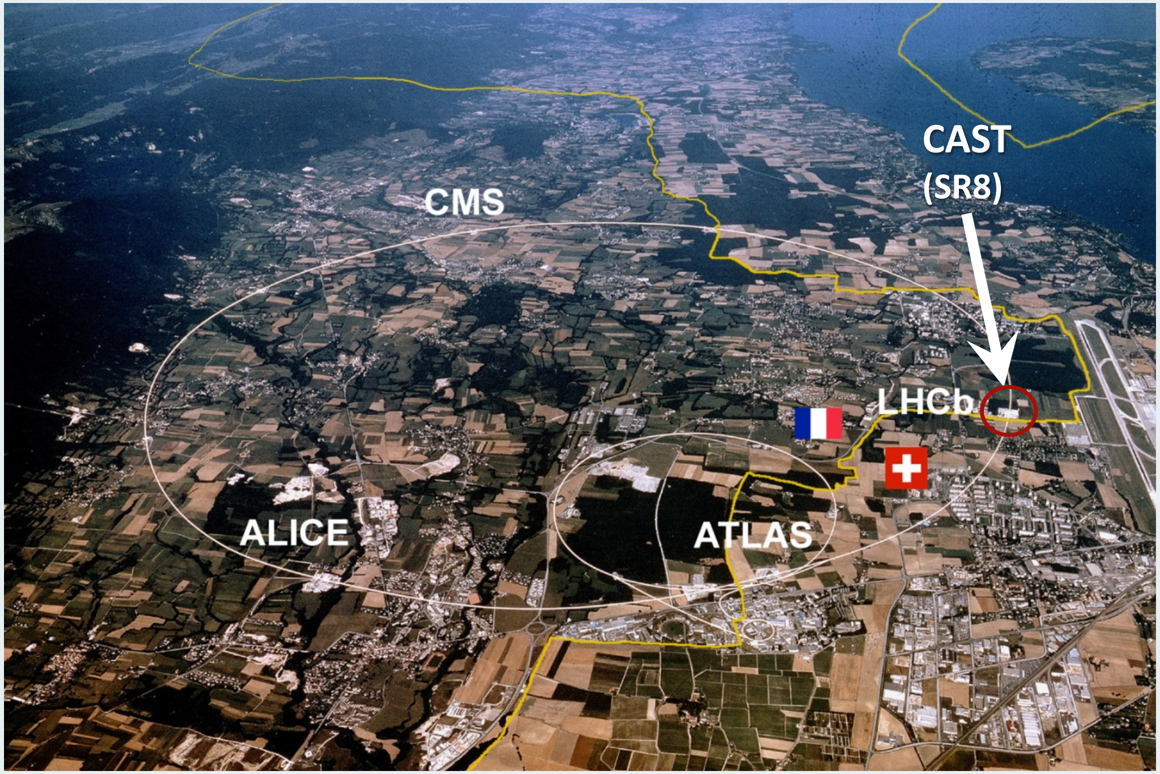
On behalf of the CAST collaboration

10th Patras Workshop on Axions, WIMPs and WISPs

29th June – 4th July 2014, CERN

Contents

- Axions
- CAST
  - Detection principle
  - Scientific program
  - Experimental layout
  - Detectors
- Micromegas evolution
- CAST 2013 - 2015
  - Vacuum run
  - Chameleon searches
- Conclusions



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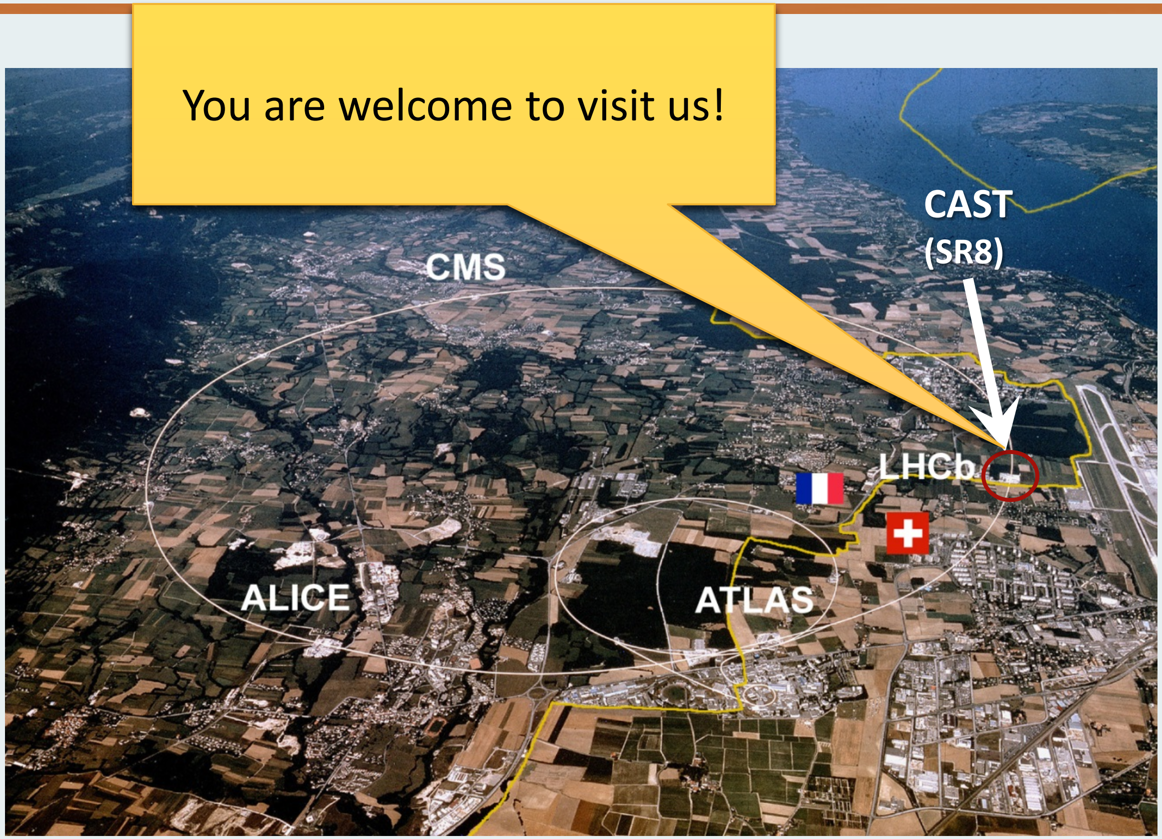

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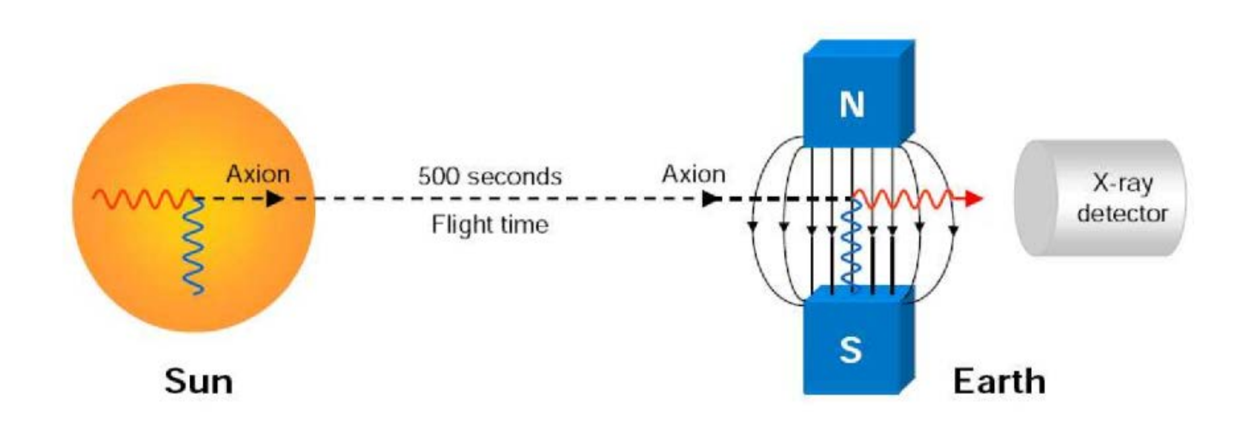
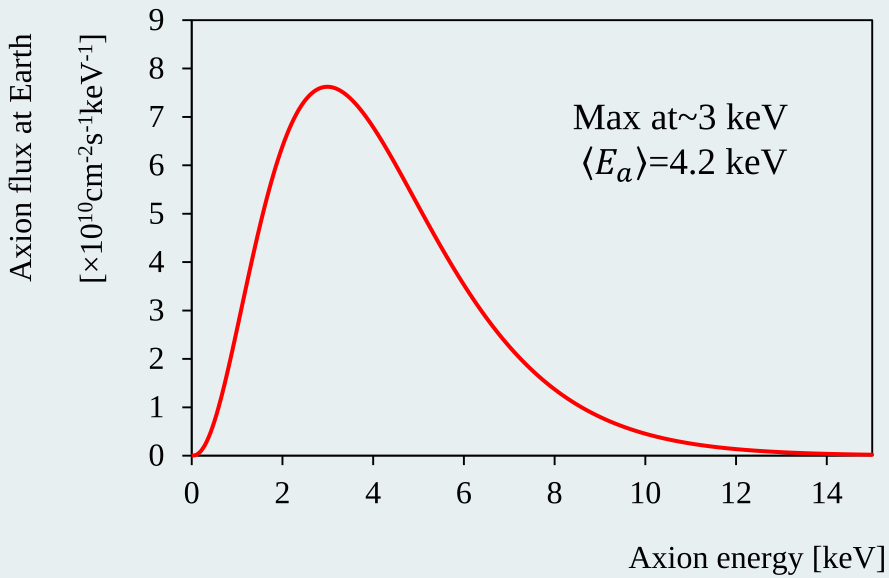
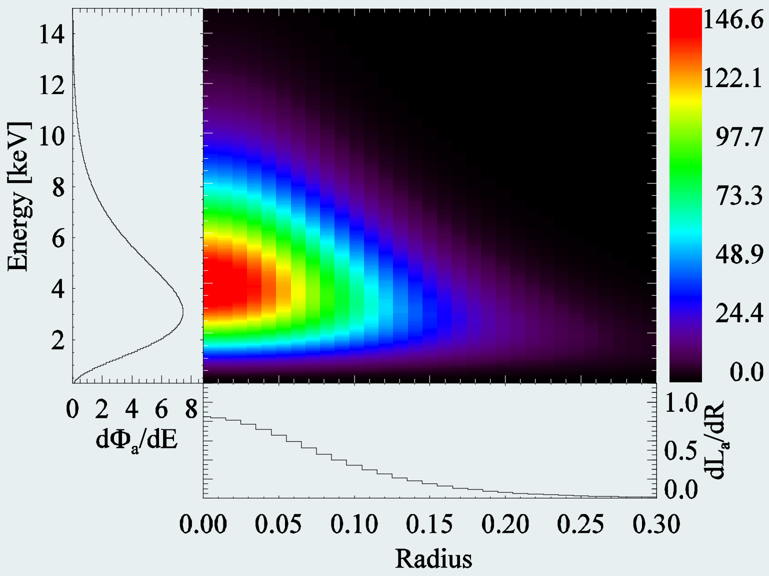
Axions



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





CAST - detection principle

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

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

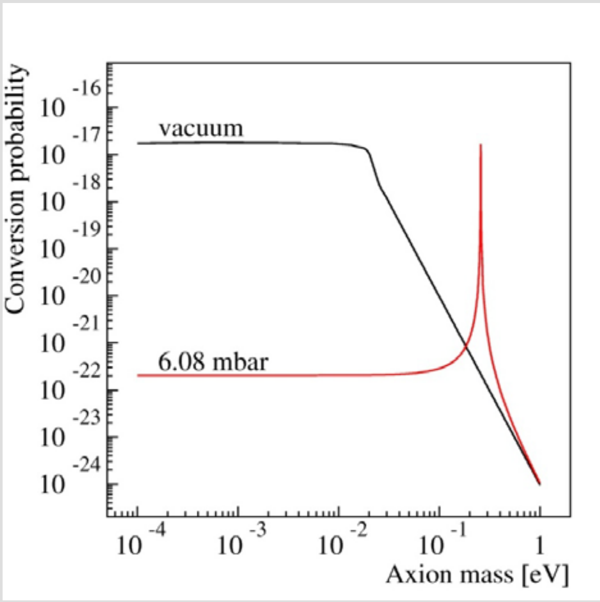
L=magnet length, *Γ*=absorption coeff.

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

Axion-photon momentum transfer

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

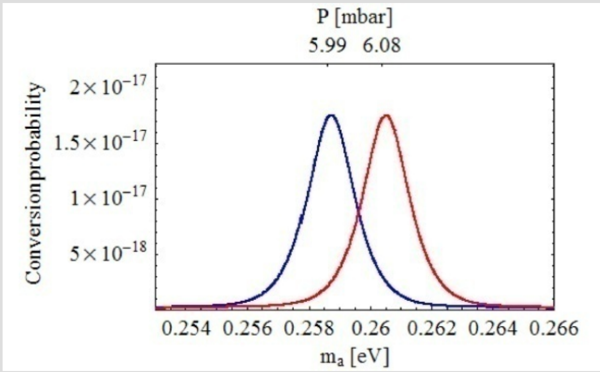
Photon effective mass



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



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CAST Phase I: vacuum operation (2003 - 2004)

m_a <0.02 eV

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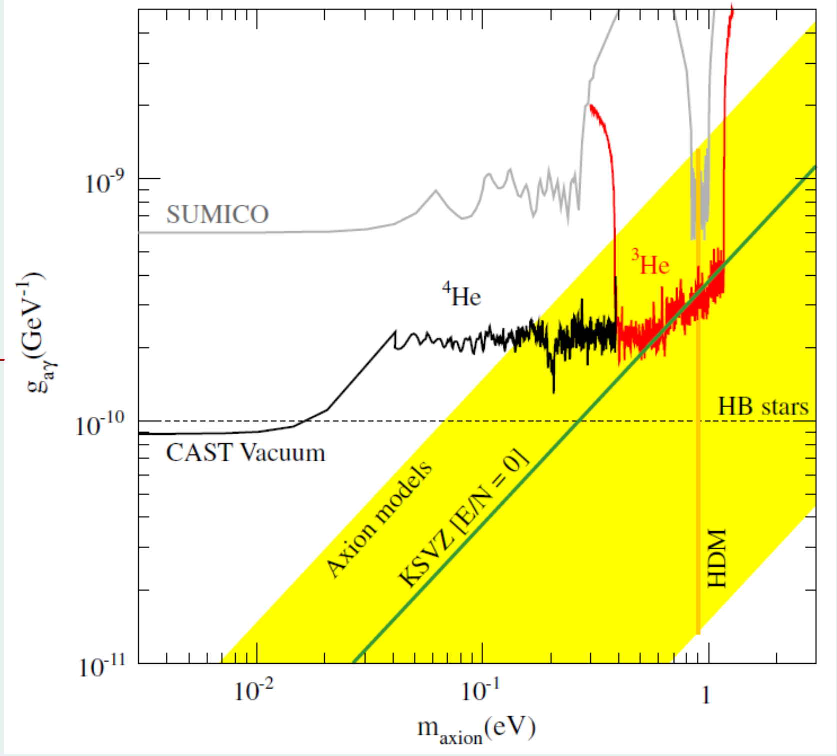

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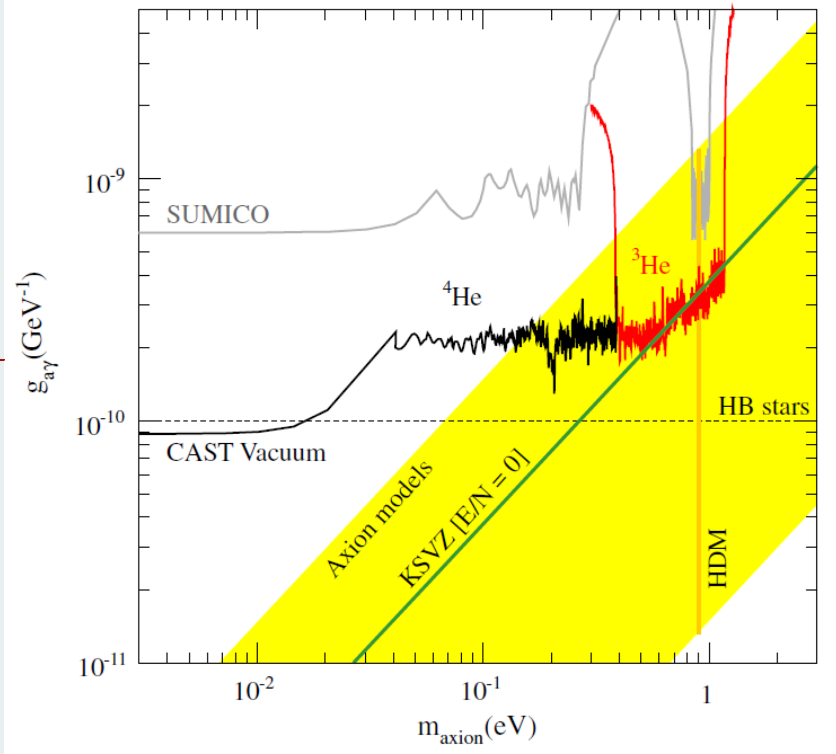

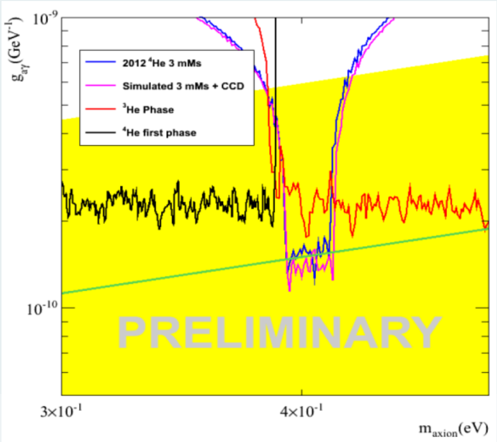

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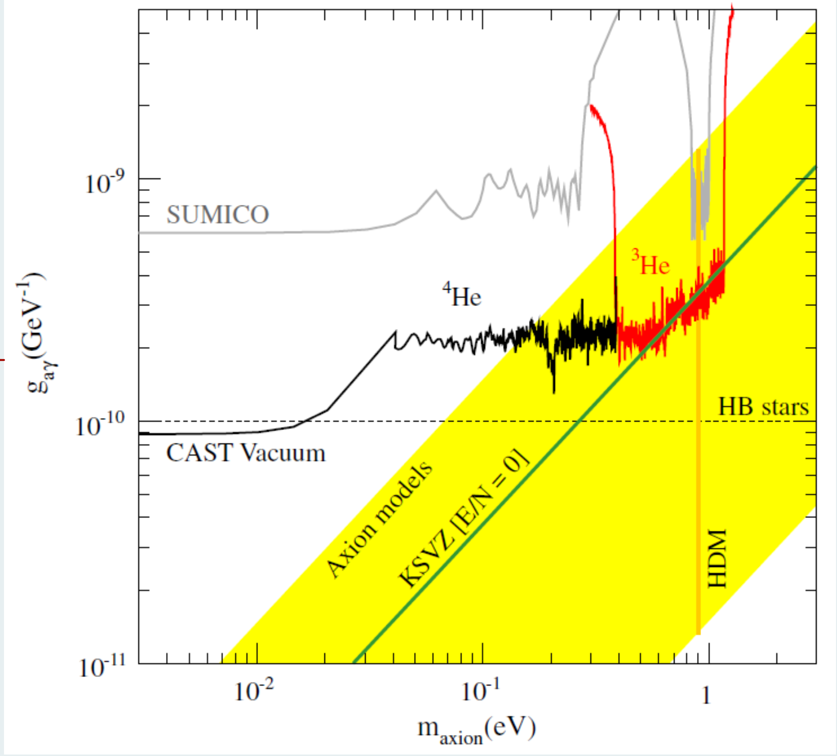

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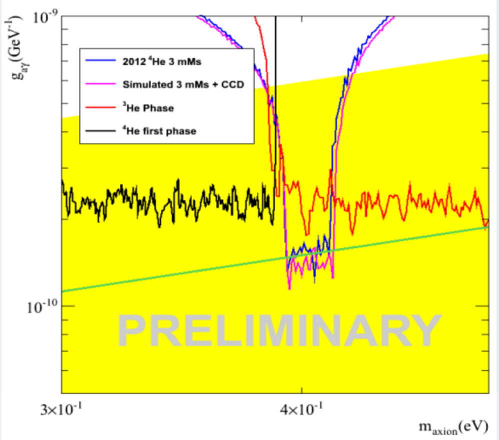
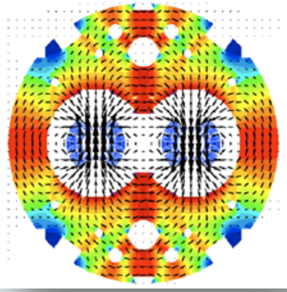
Vacuum run (2013-2015) – improved sensitivity

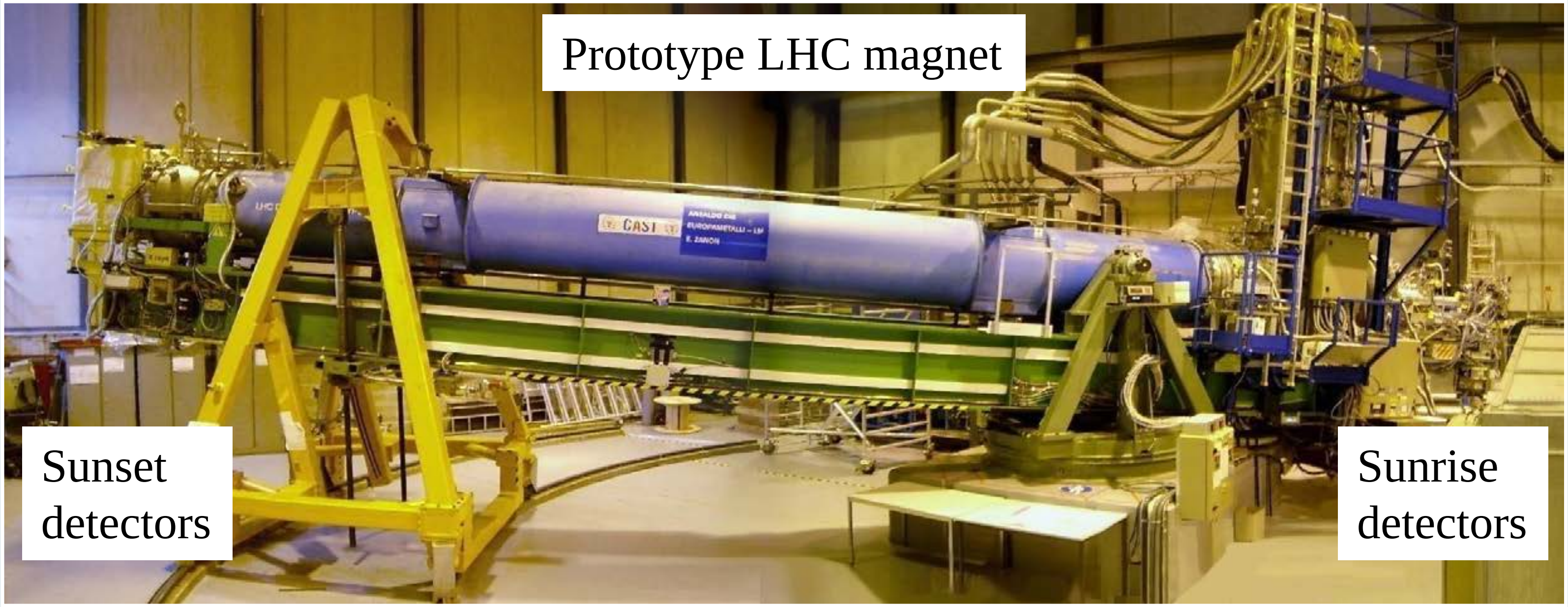
$m_a < 0.02$ eV



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 × 1.5 hours of tracking / day.



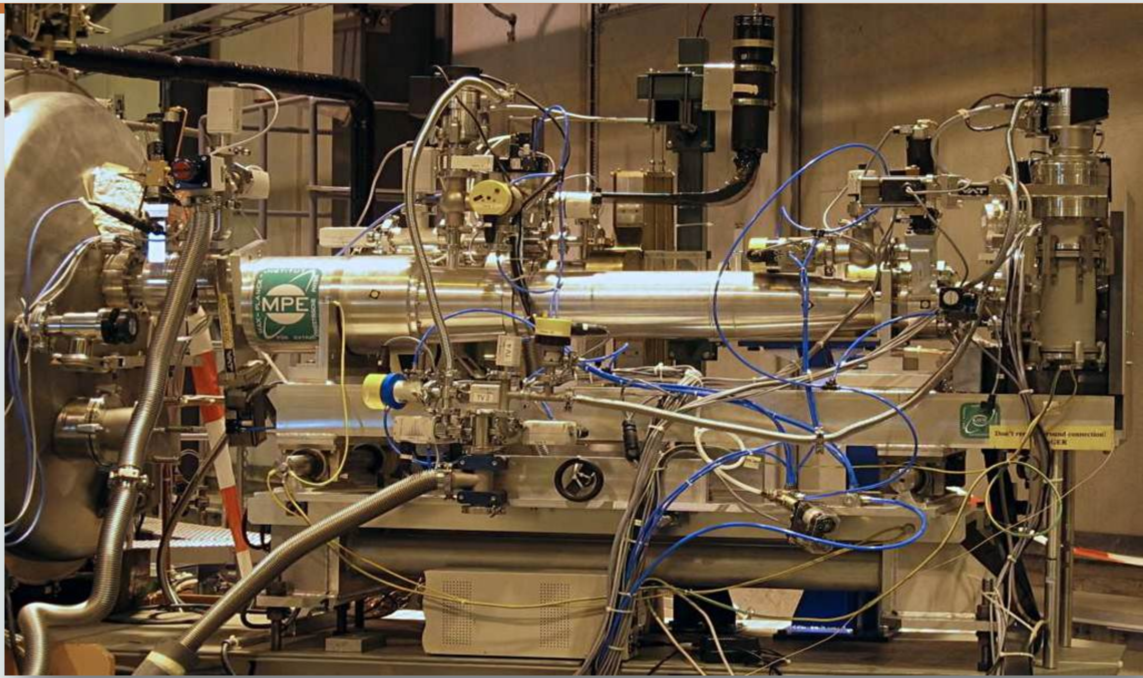
CAST detectors - CCD

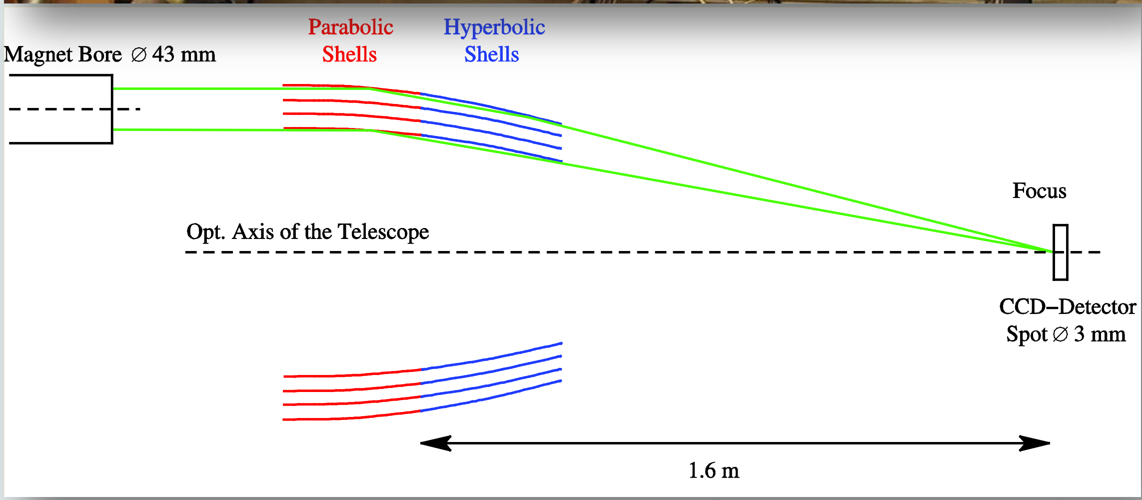
X-ray telescope

- Focal length 1600 mm
- 14.5 cm^2 focused to ~6 mm^2

pn-CCD

- 0.2 counts/h (1-7 keV)

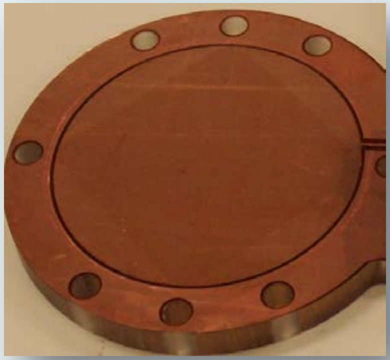




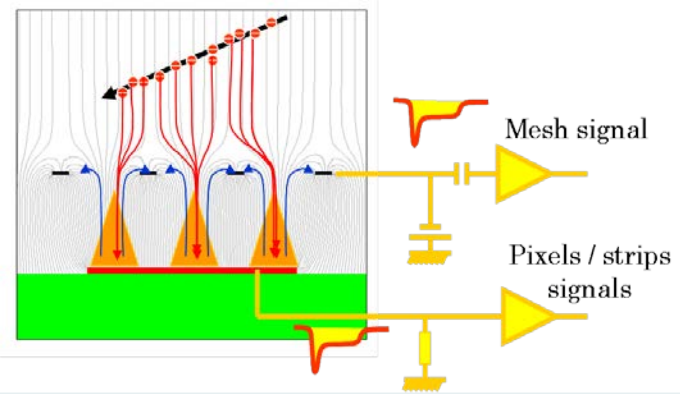
CAST detectors - Micromegas

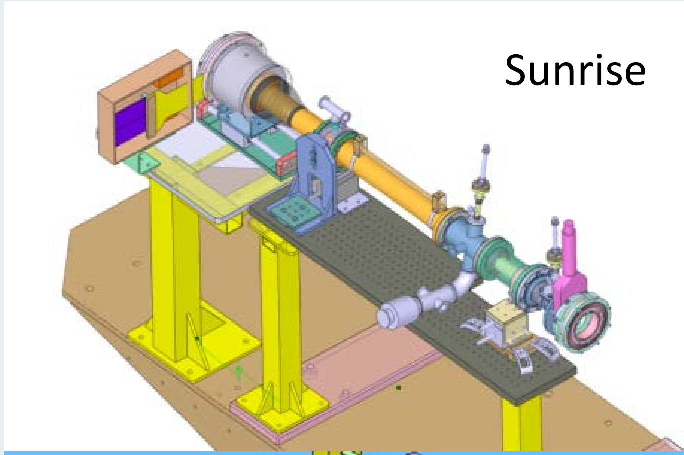
Microbulk – technology specially designed for CAST

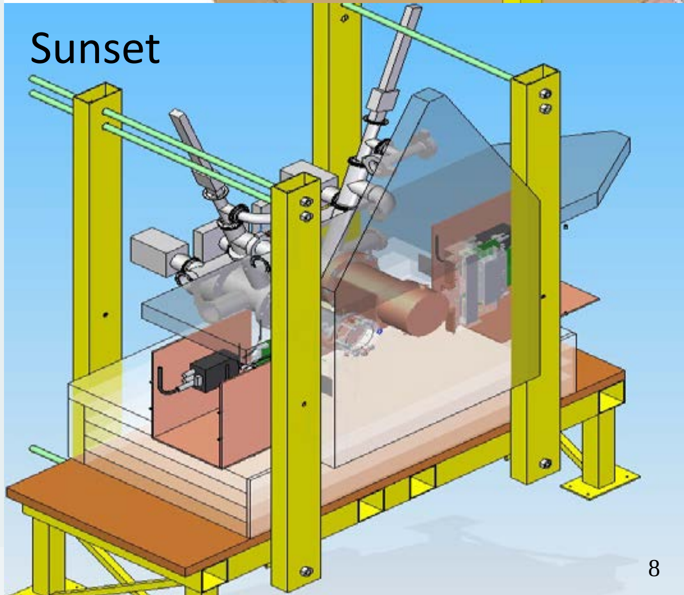
3 out of 4 detectors are Micromegas



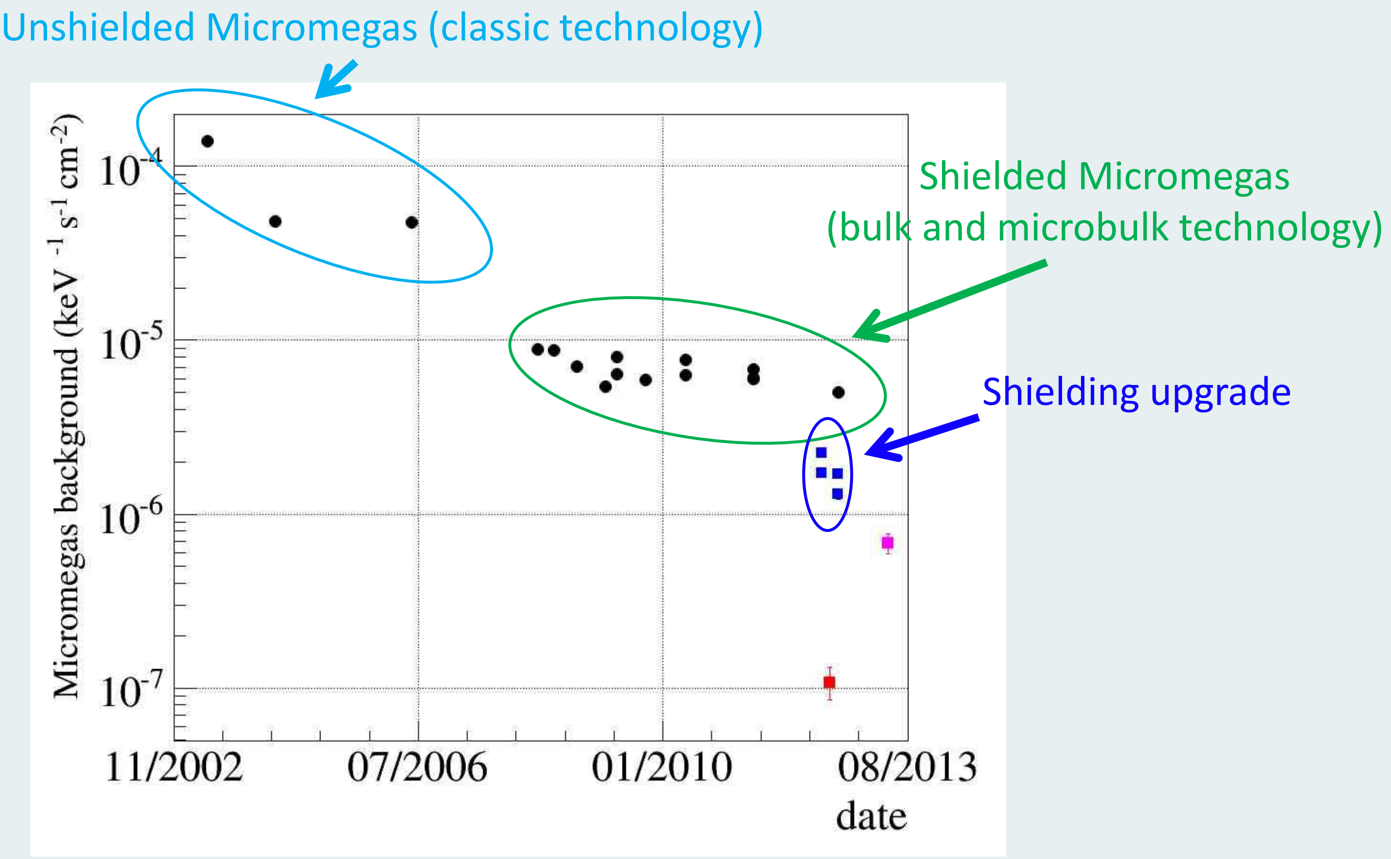
- Uniformity
- Clean materials
- Energy resolution (<18% FWHM @ 6 keV)
- Low background
- ~1 count/hour (2-10 keV)







Micromegas evolution



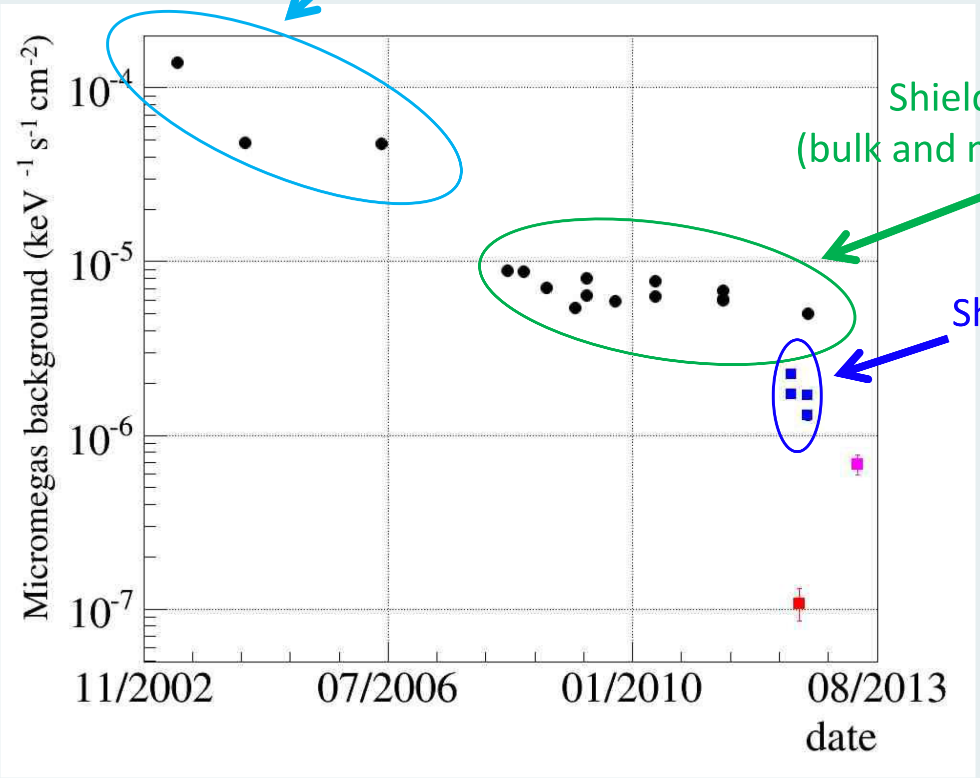
Micromegas evolution

Improvement of two orders of magnitude in background over the years

Unshielded Micromegas (classic technology)

Shielded Micromegas (bulk and microbulk technology)

Shielding upgrade



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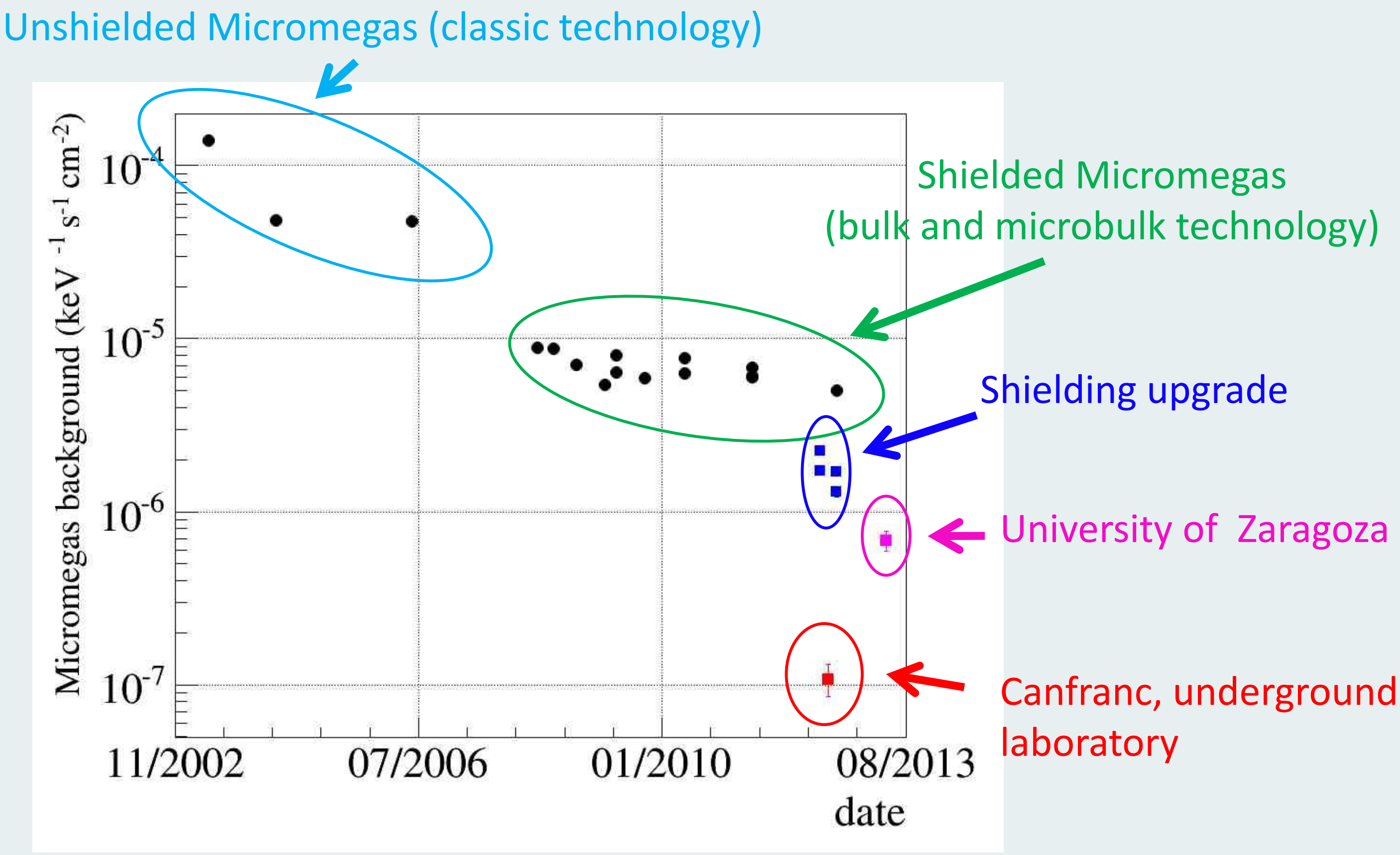

CAST 2013 - 2015

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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
- New X-ray optics for the sunrise Micromegas
- InGRID + X-ray telescope (MPE)

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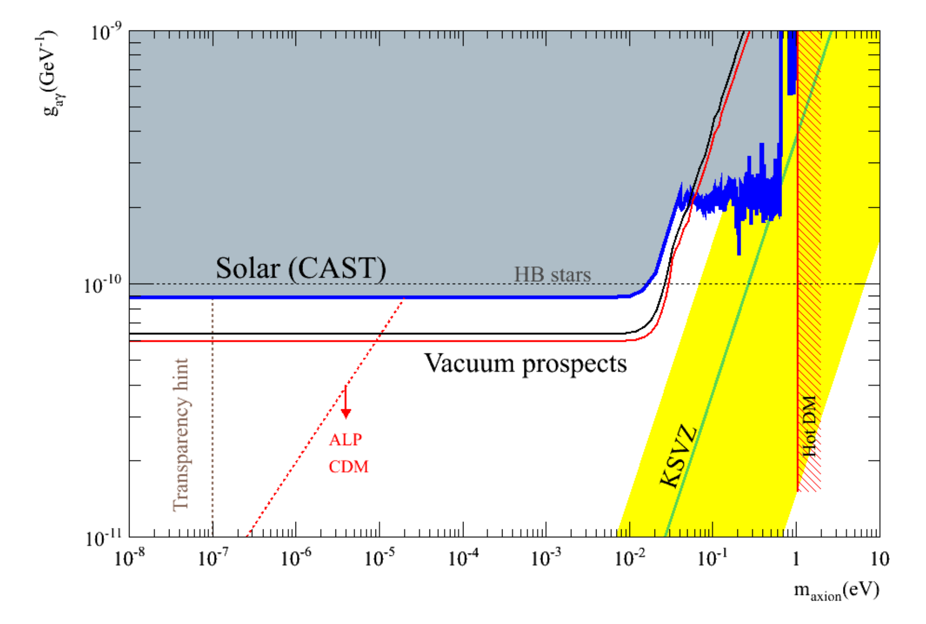

CAST 2013

Micromegas low background techniques:

- New electronics
- Cosmic veto
- New shielding design

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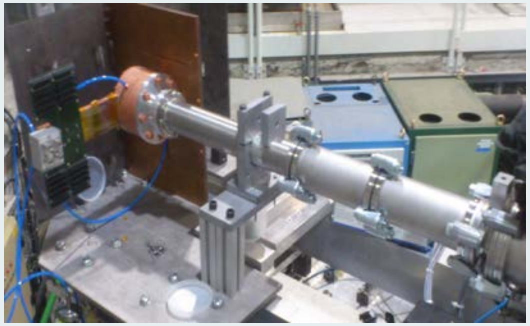
New detector design (sunrise line)

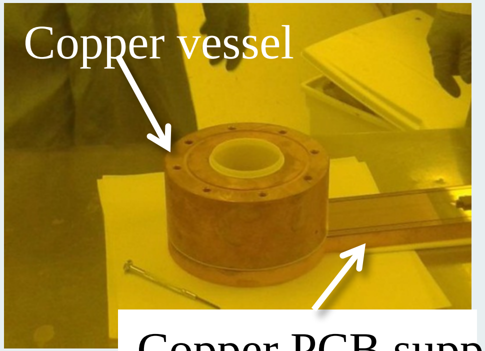
Main novelties: field shaper, body and support made of copper

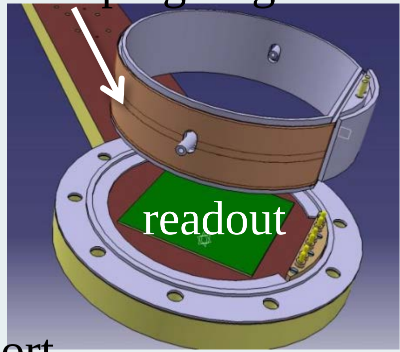
Teething problems :

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

Sunrise line







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New searches in vacuum : **Chameleons**

- Chameleons are Dark Energy candidates to explain the acceleration of the expansion of the Universe.
- Their mass depends on the energy density of the environment

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Solar Chameleons

- Can be created by the Primakoff effect in the tachocline region of the Sun ($R \sim 0.7 R_{\odot}$).
- They can be converted to X-ray photons in CAST via the inverse Primakoff effect (like axions)

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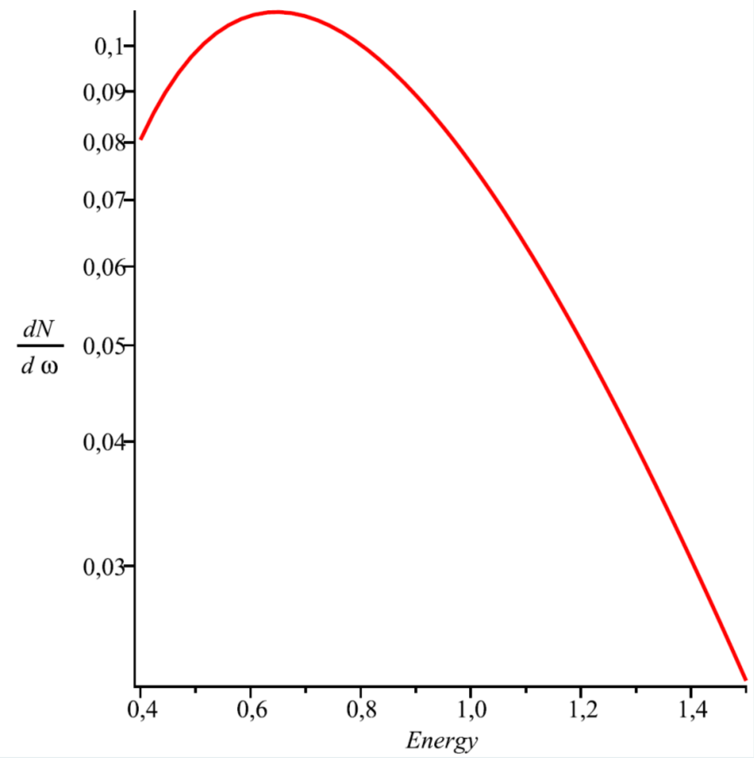
Spectrum of back-converted photons in the CAST magnet inside $16mm^2$
for B_{tacho} =10T, n=1



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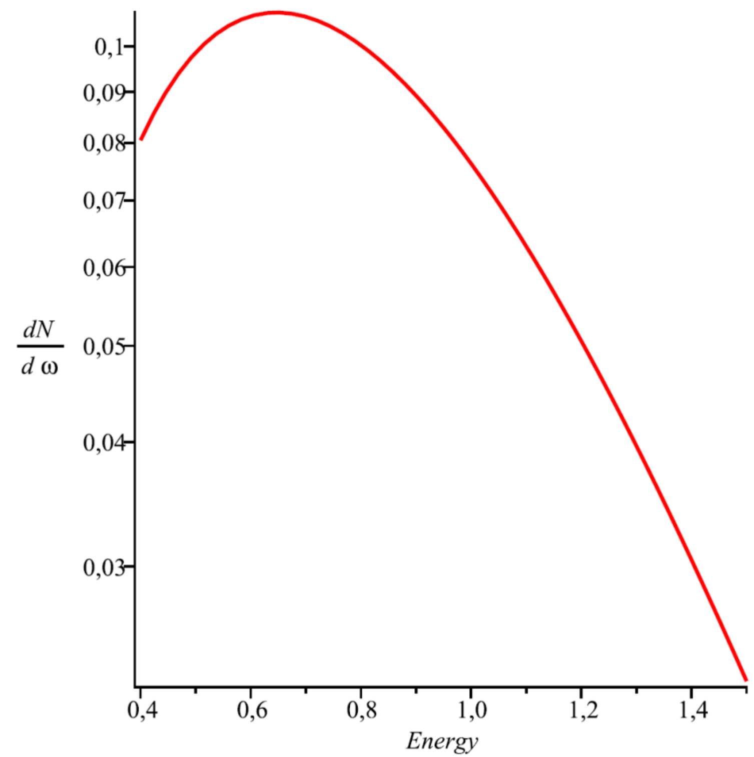

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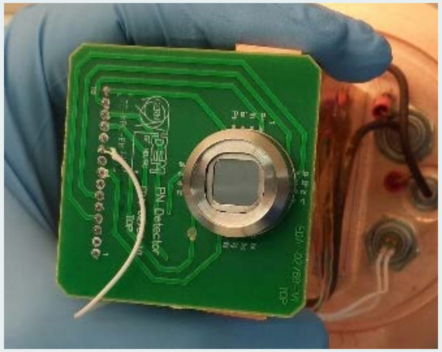
Detector requirements:

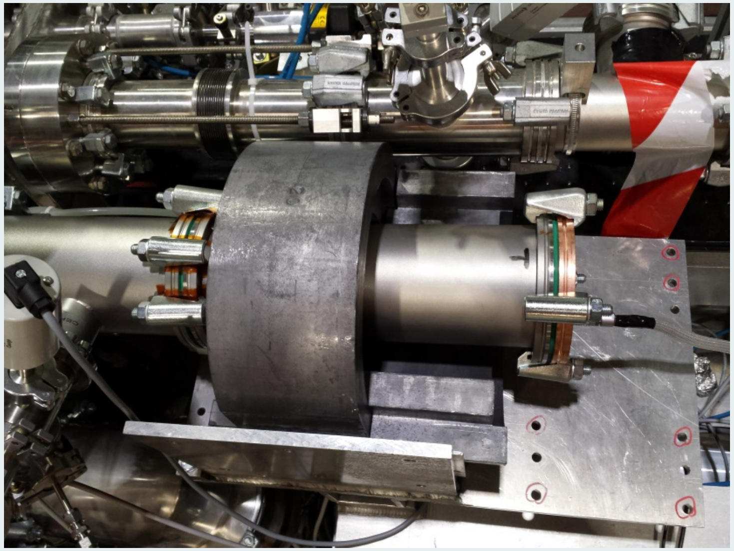
- **Low energy threshold**
- **Low background**
- **Good energy resolution**

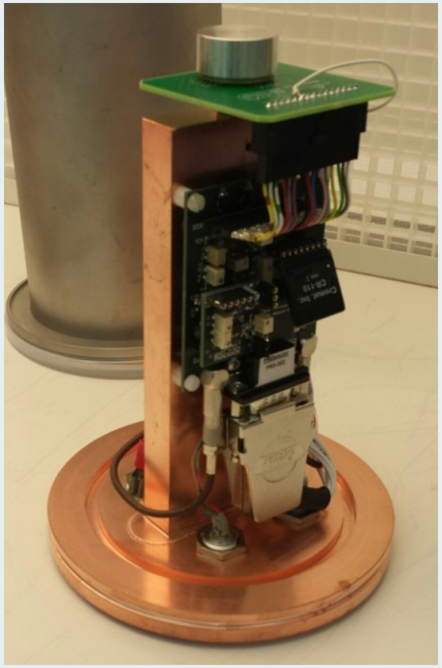
CAST 2013

- Took advantage of the available port due to MPE-XRT recalibration



- SDD (from PNdetector)
  - Detector system assembled from commercial parts
  - SDD ~100 mm^2 surface





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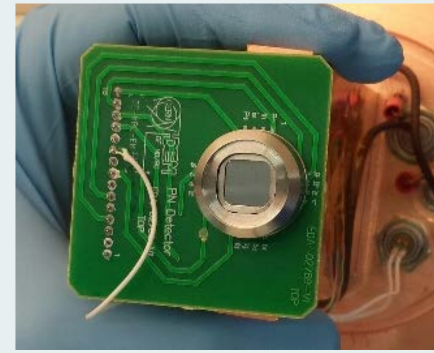

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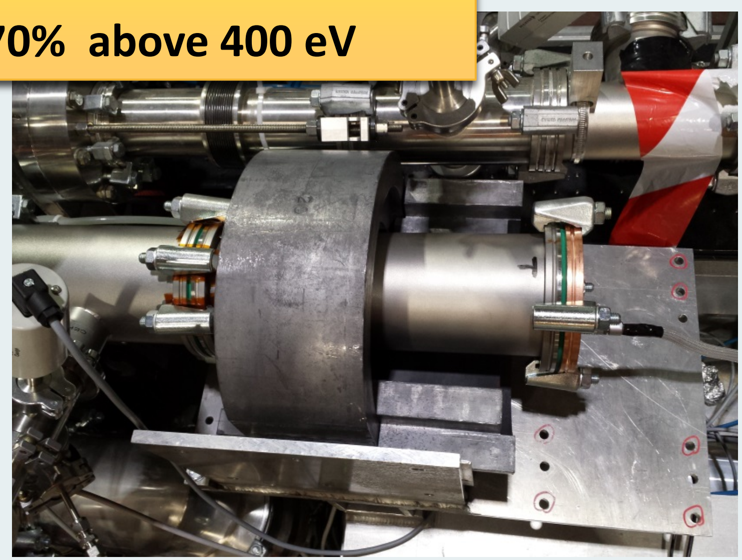
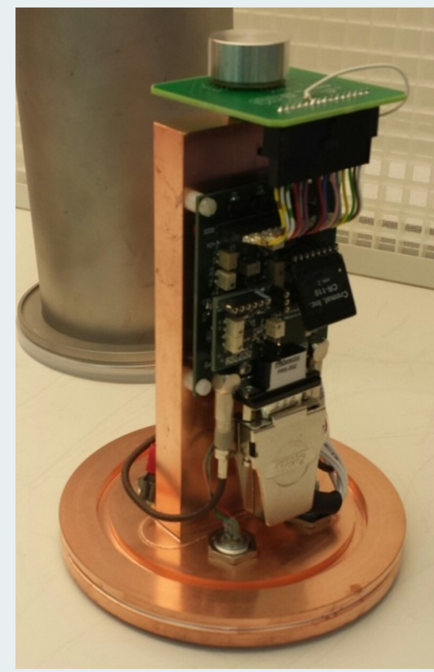
No window
- **Q.E > 70% above 400 eV**





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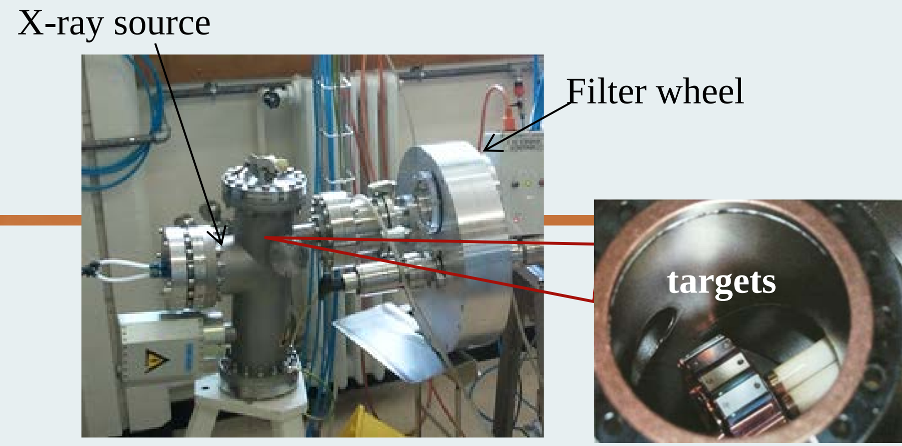

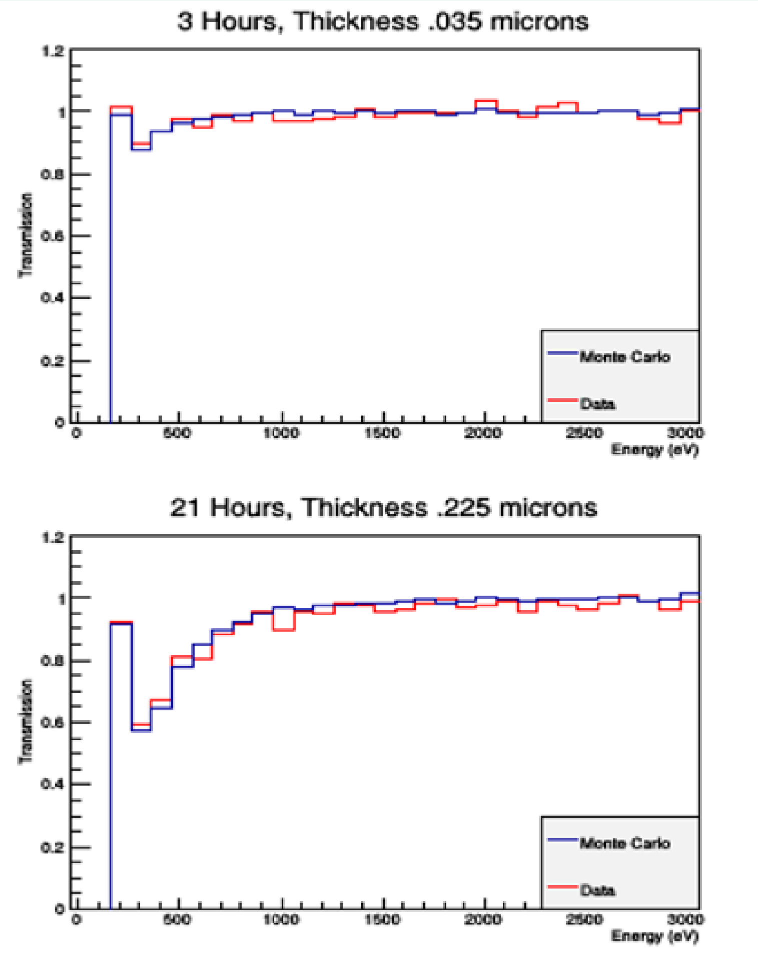

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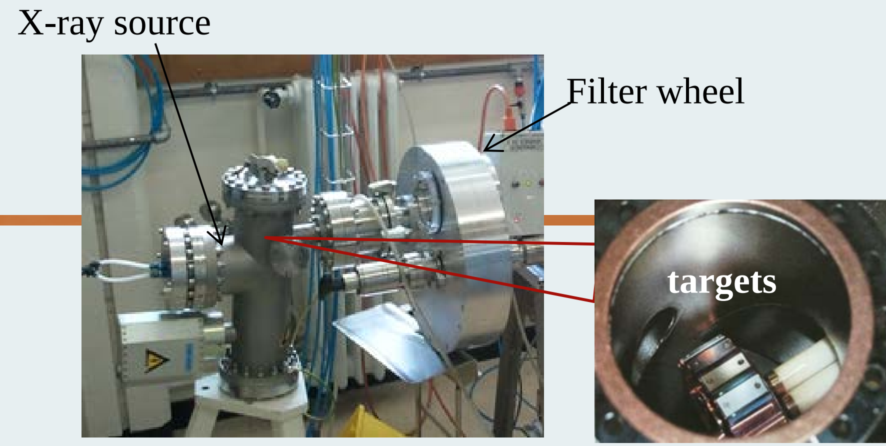

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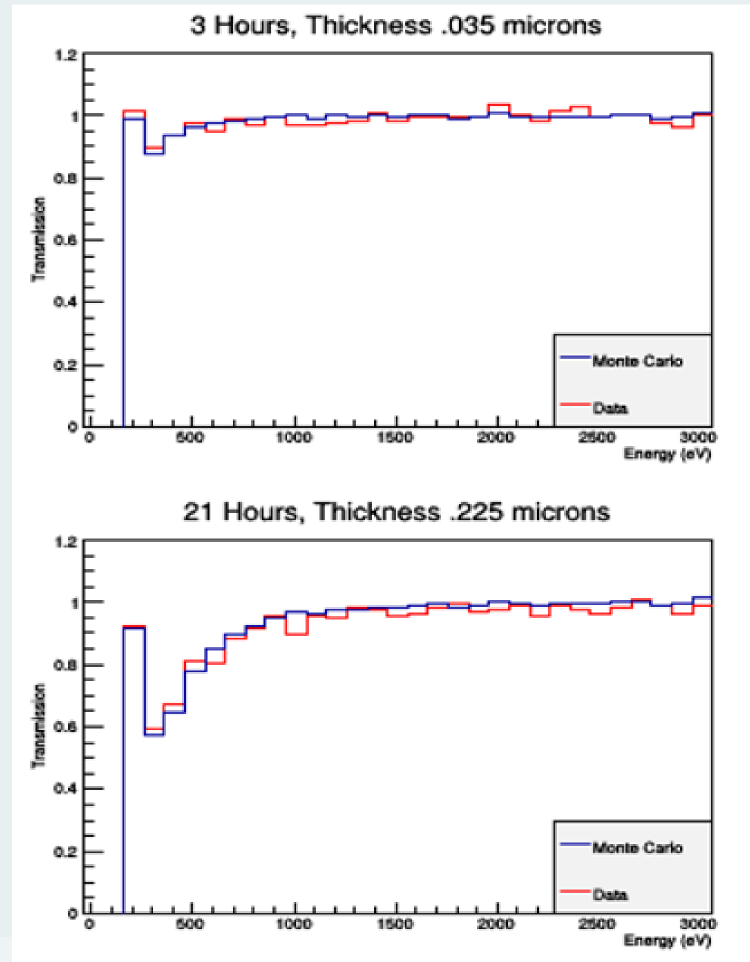

Deposition window:
Better transmission than any commercial entrance window!

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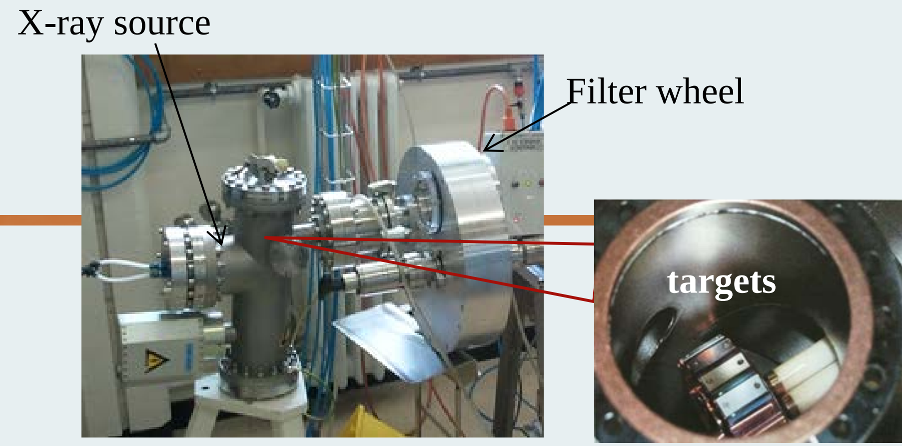

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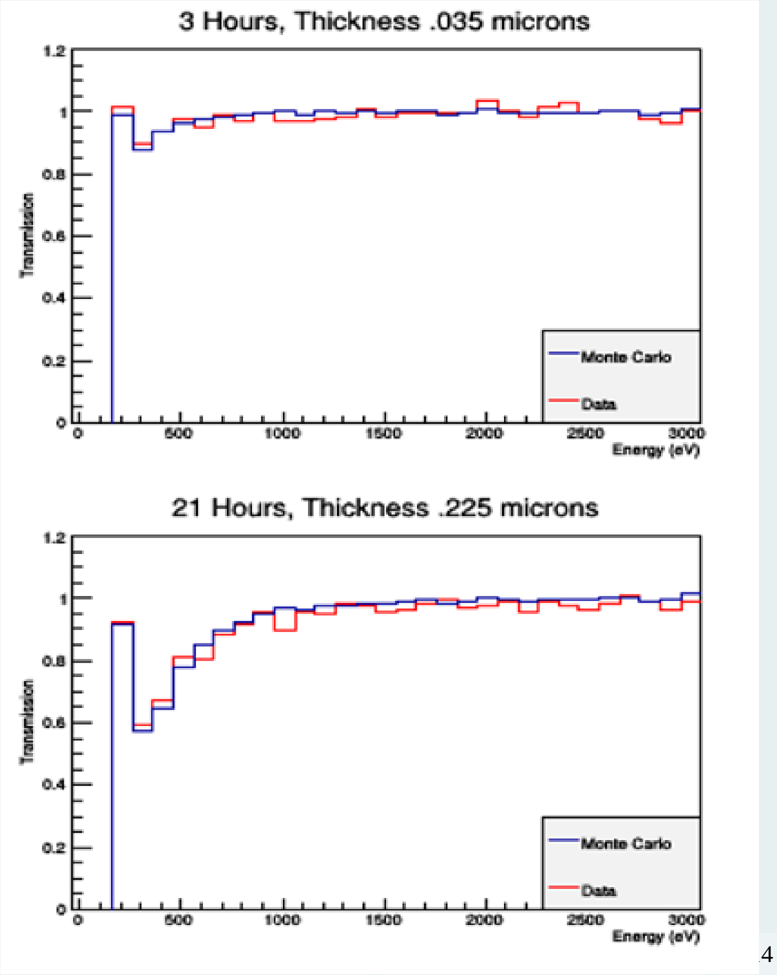

Deposition window:
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Efficiency recovered after 1 h at room temperature

CAST 2013

Consequence : Data taking strategy:

- Detector at room temperature → tracking (detector cold)
- Detector at room temperature → background (detector cold)

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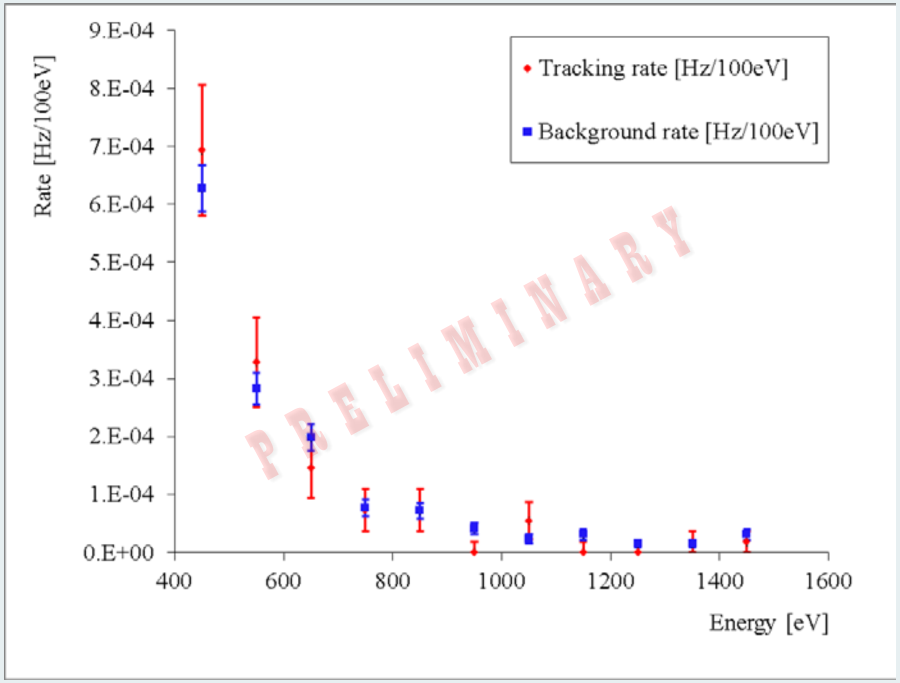
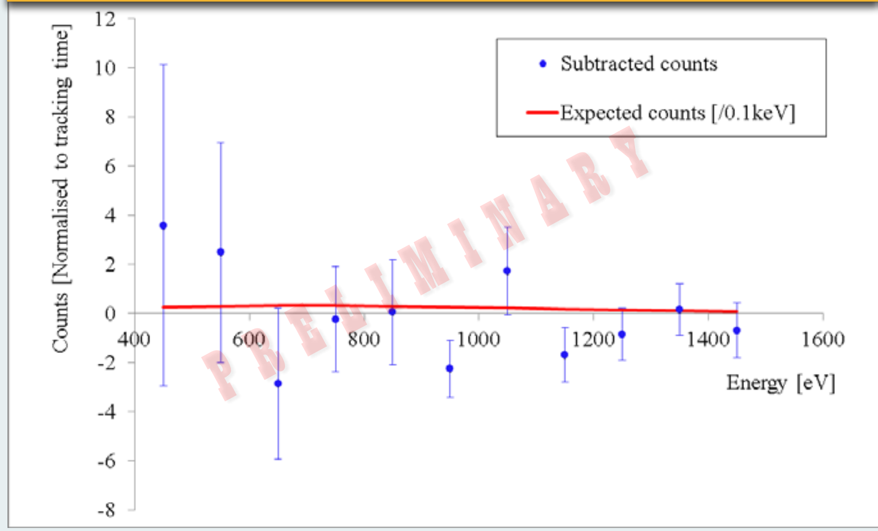


15.2 h of tracking time
108 h of background time

CAST 2013

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



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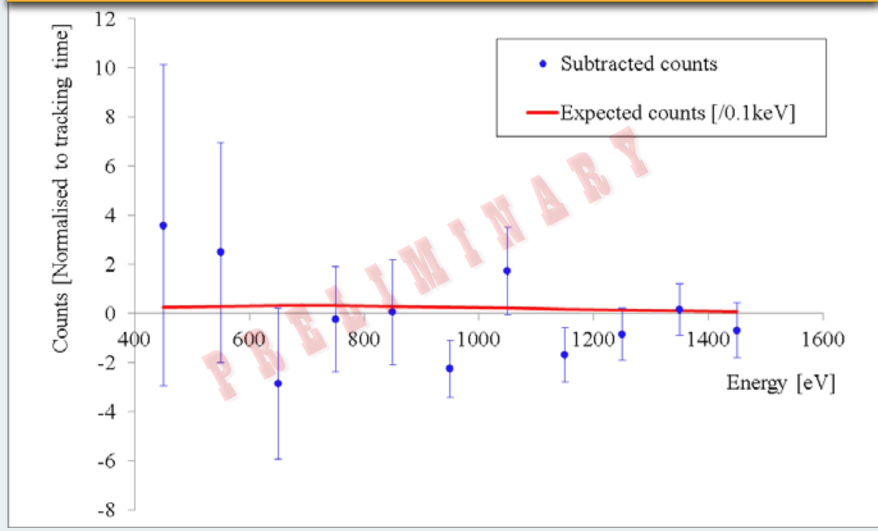
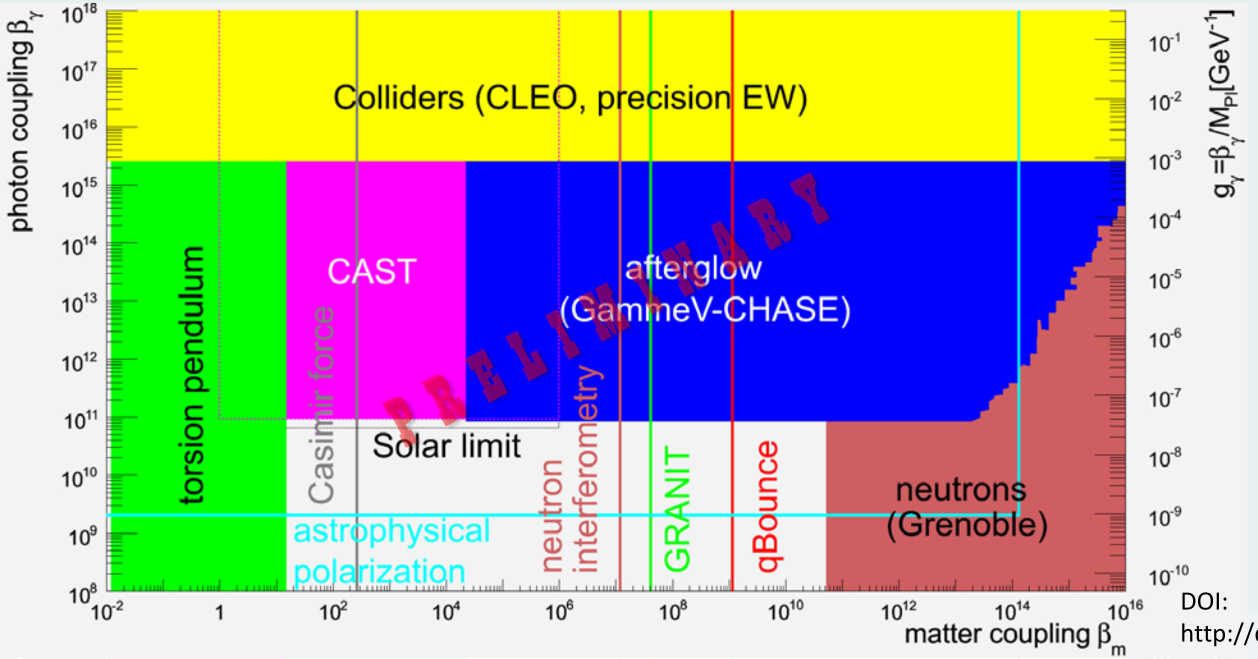
Results of bSDD compatible with the null hypothesis

- Limit to $\beta_\gamma \leq 9.18 \times 10^{10}$ at 95% C.L.

  Valid for $1 \leq \beta_m \leq 10^6$





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

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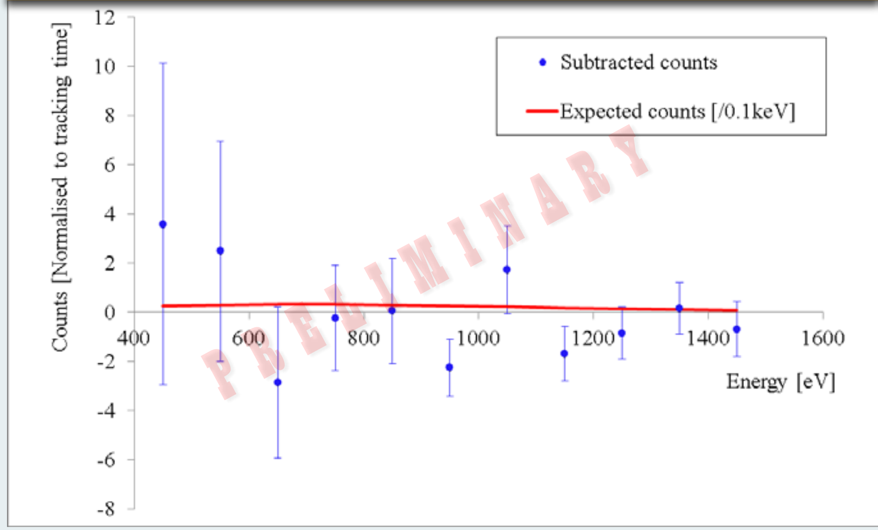

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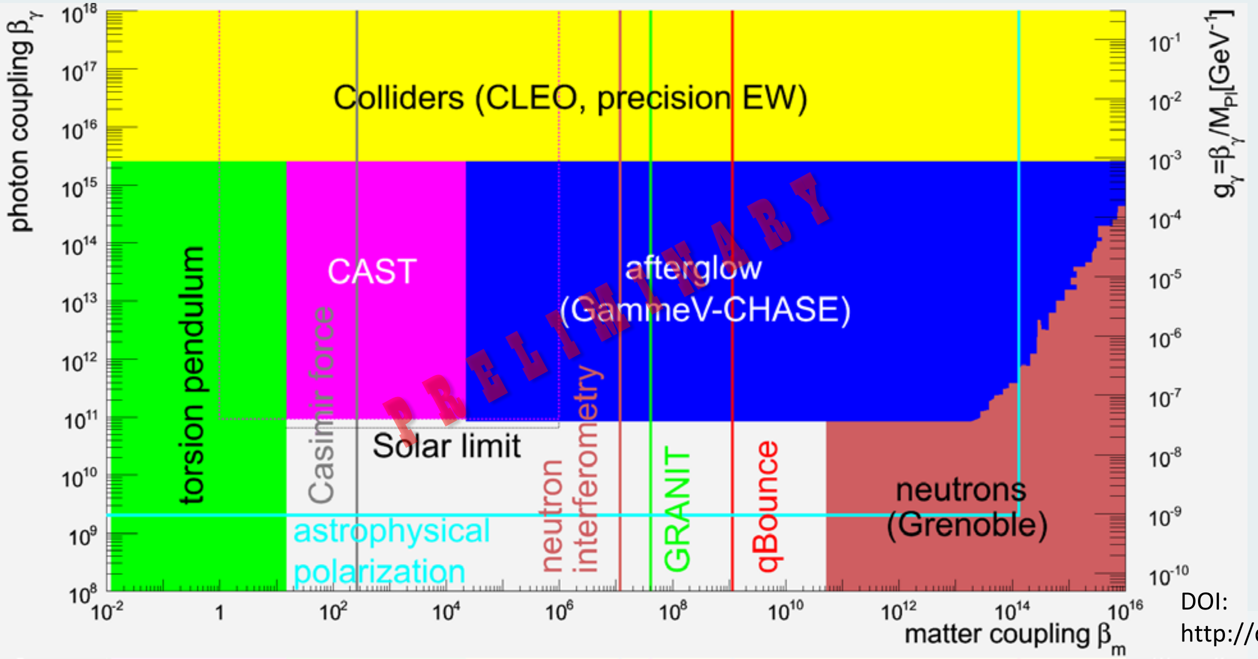
Publication under preparation



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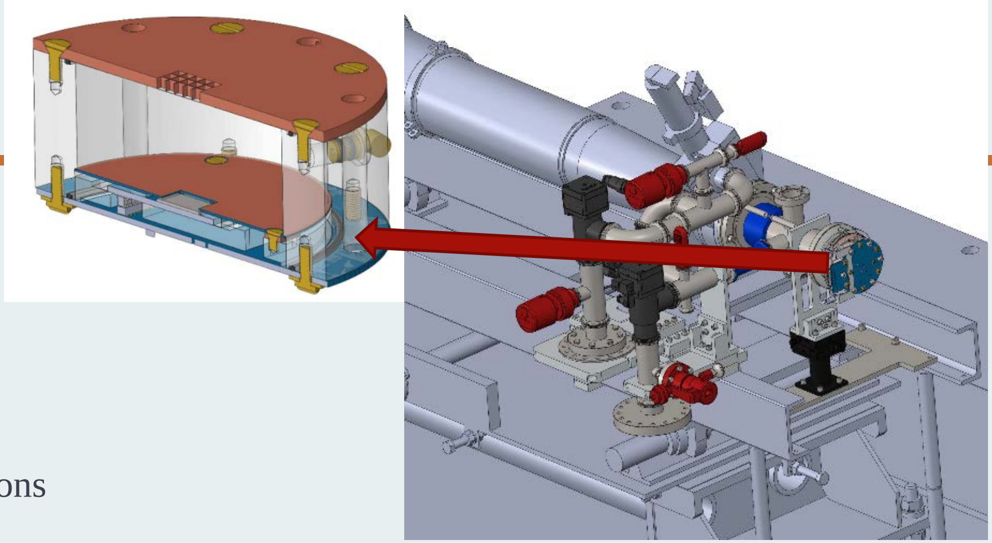
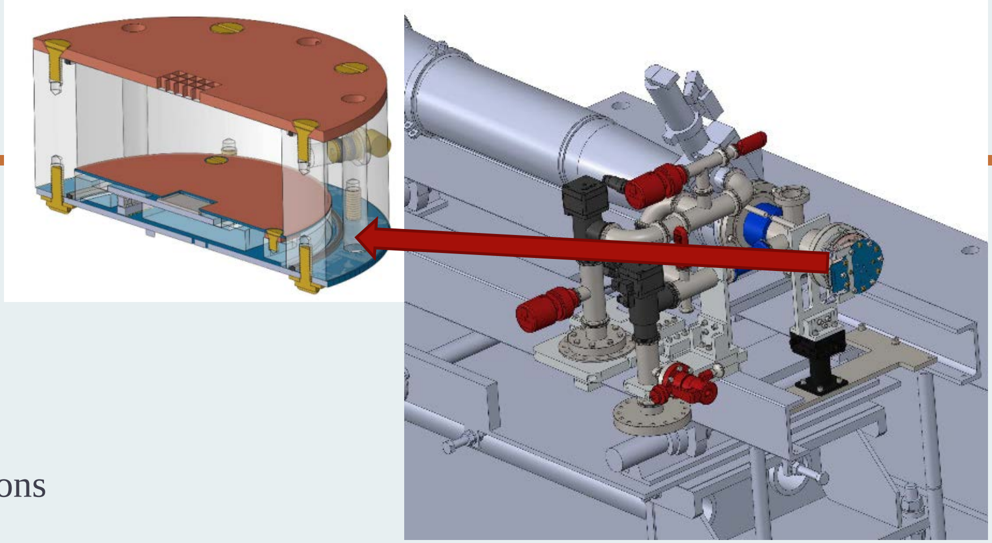
CAST 2014 & 2015



- **InGrid Micromegas detector (replaced CCD)**
  - Timepix chip
  - Threshold well below 1 keV
  - Simultaneous search for solar axions and chameleons
  - (talk of Christoph Krieger)

CAST 2014 & 2015



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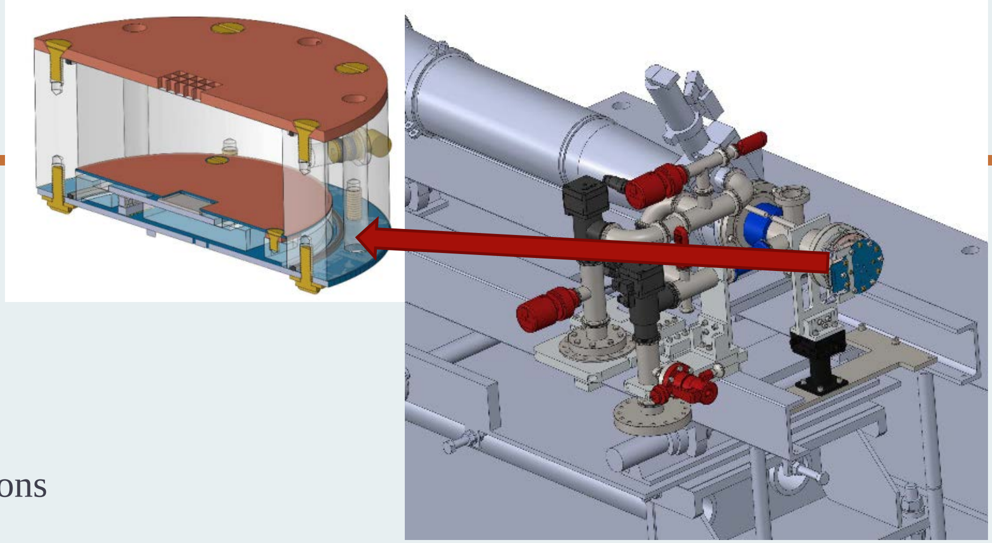
- **Second iteration of new Micromegas design**

CAST 2014 & 2015



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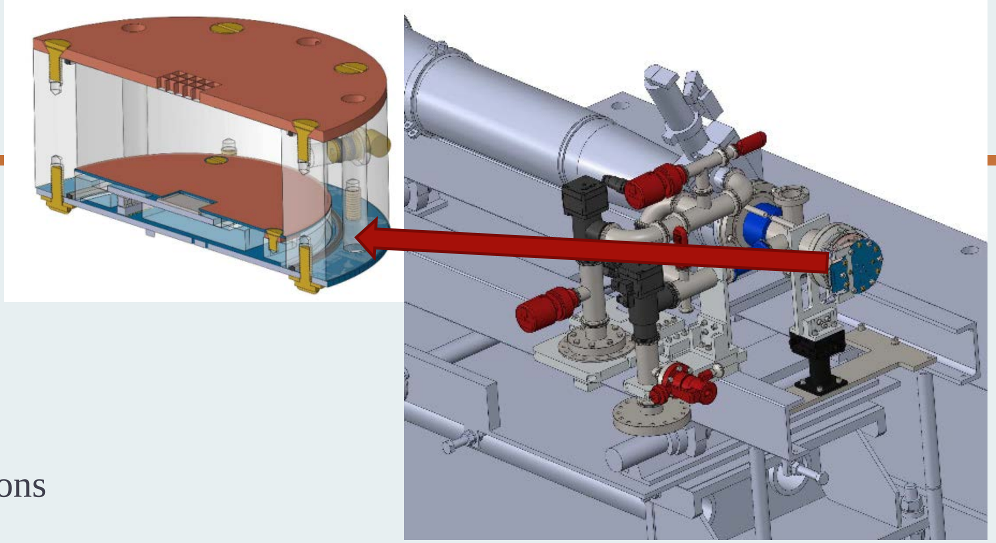
- **X-ray telescopes for both sunrise detectors (one new, one existing)**

CAST 2014 & 2015



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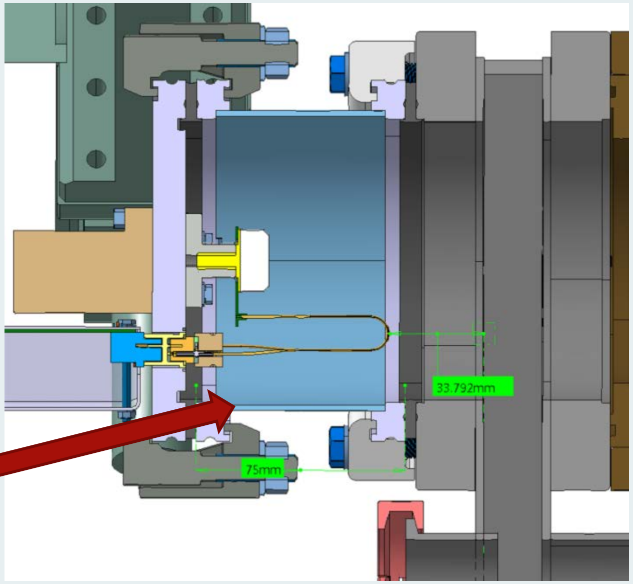
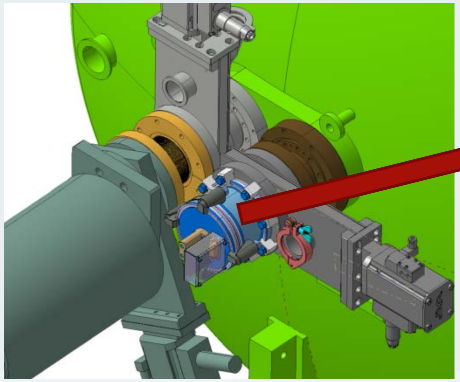
- **X-ray telescopes for both sunrise detectors (one new, one existing)**

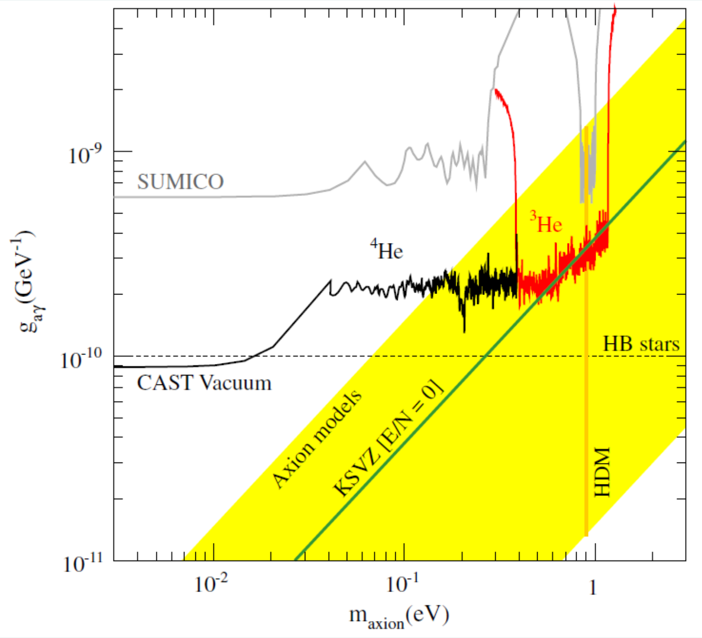
- **We will have the chance to continue the chameleon searches with the SDD for ~6 weeks with design improvements**





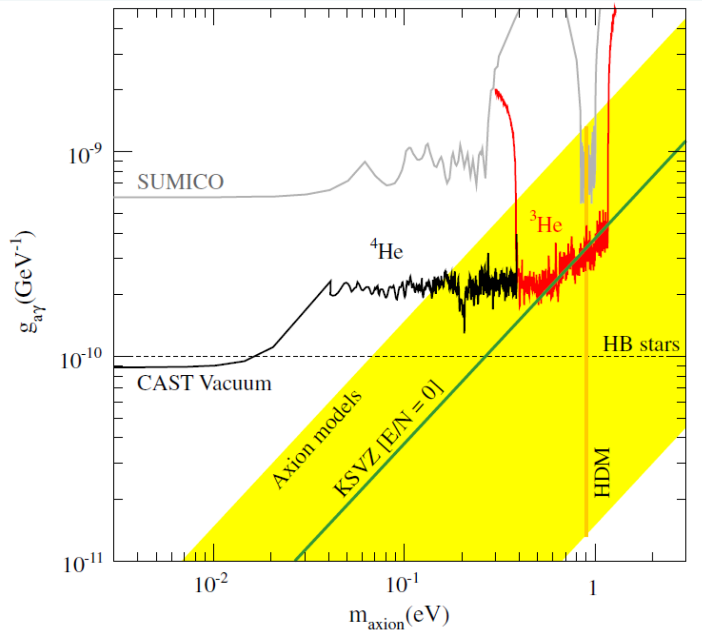
Conclusions

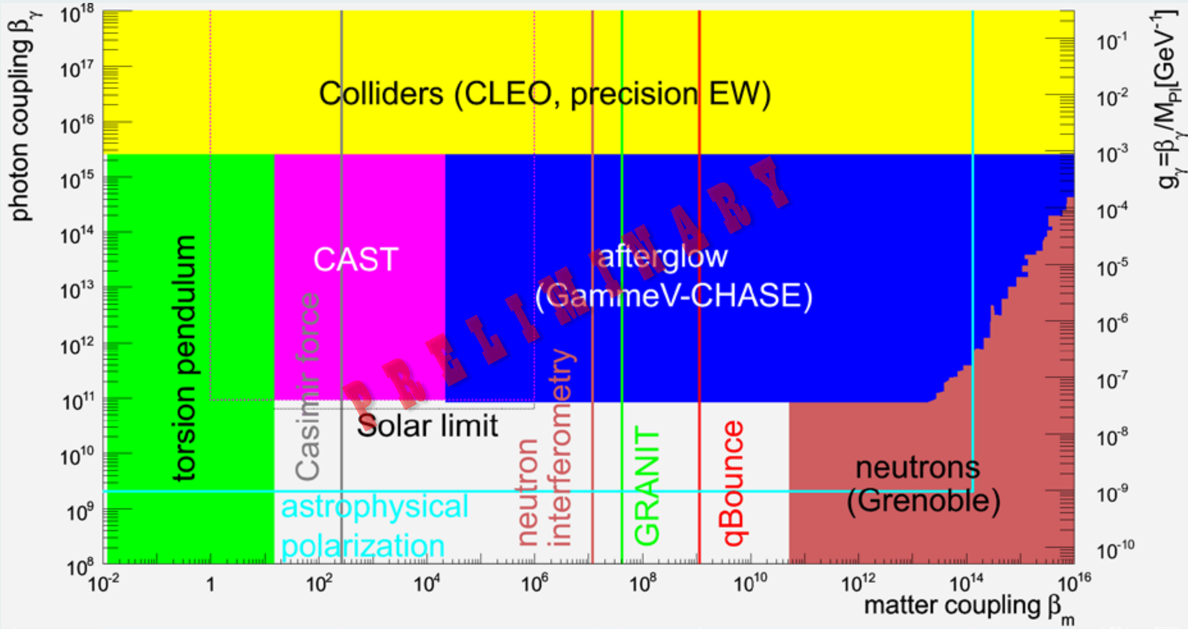
- CAST provides the best experimental limit on axion-photon coupling constant over a broad range of axion masses.
- After having completed its original program, CAST is going to improve the vacuum results and study other exotica with improved detectors.



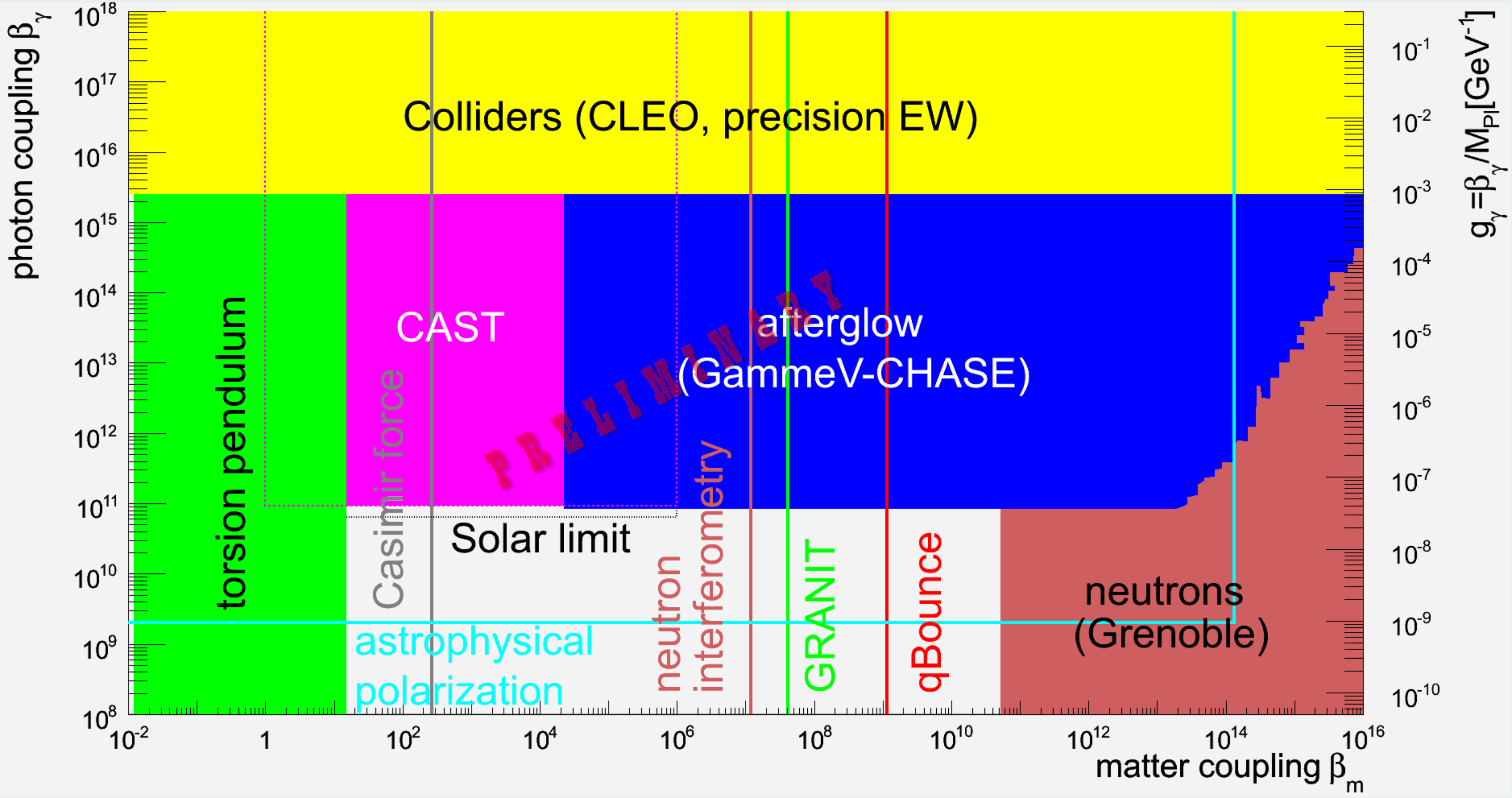
Conclusions

- 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 (see talk by I. Irastorza)**

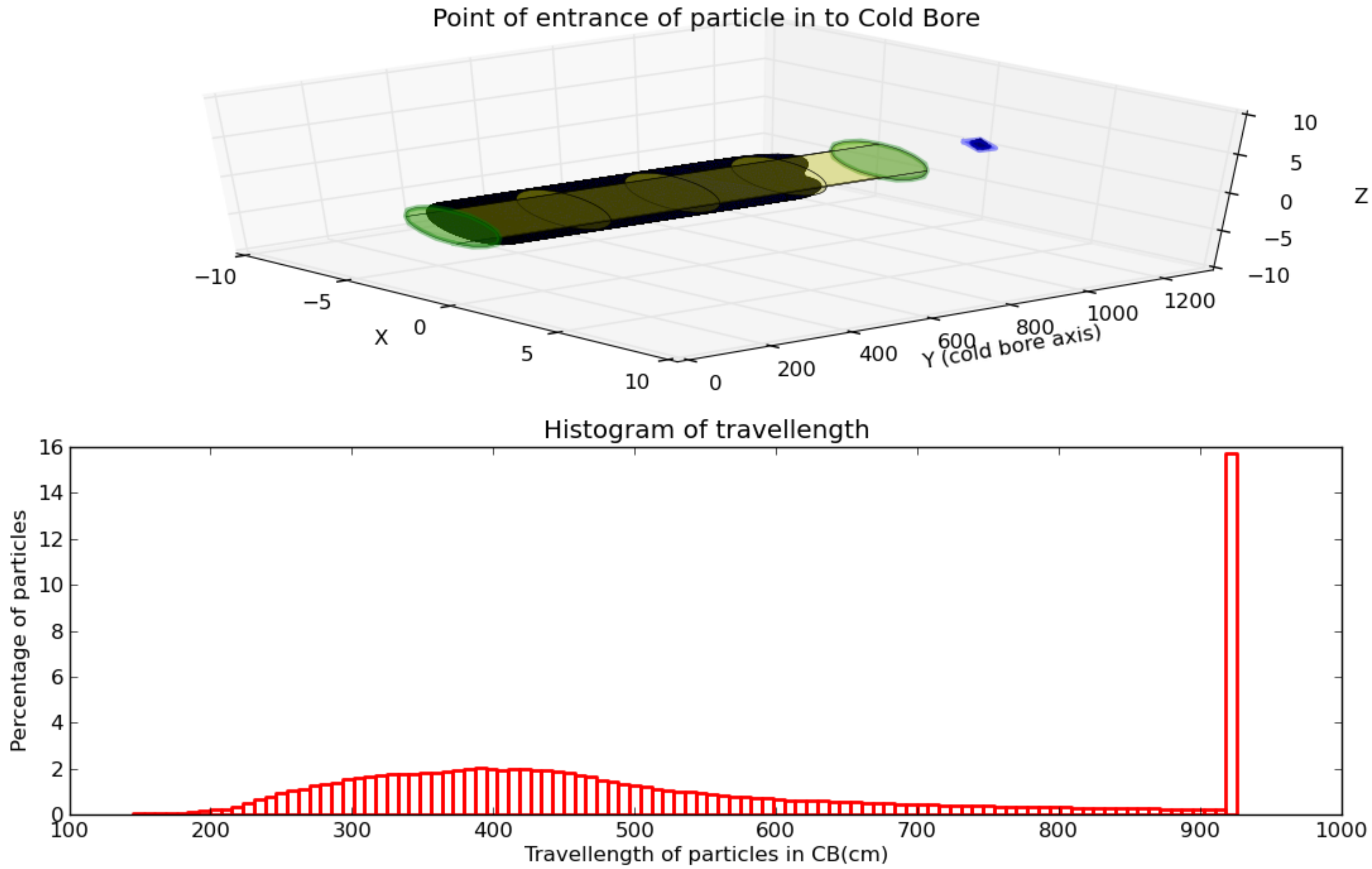




Thank you



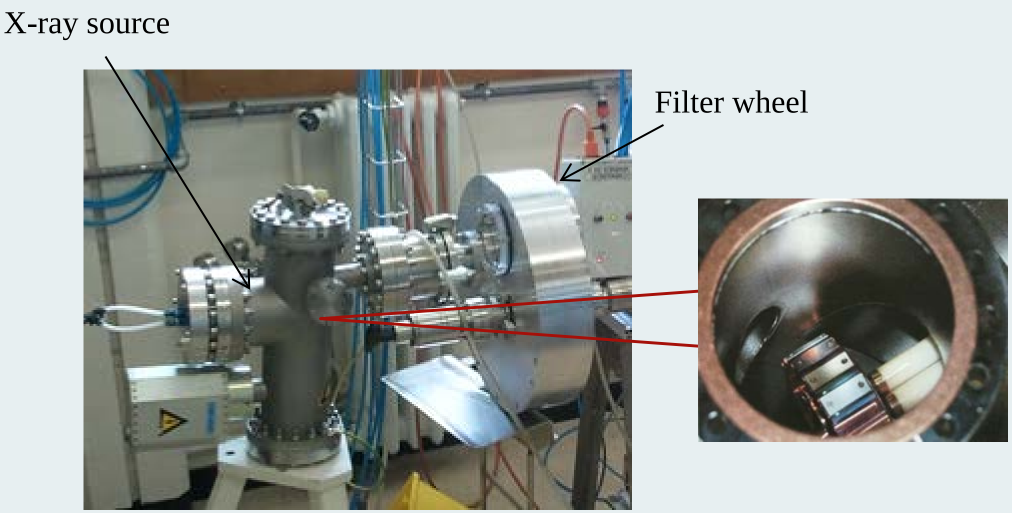
photon coupling β_γ
$g_\gamma = \beta_\gamma / M_{Pl}$ [GeV^{-1}]
Colliders (CLEO, precision EW)
torsion pendulum
CAST
Casimir force
afterglow
(GammeV-CHASE)
PRELIMINARY
Solar limit
neutron
interferometry
GRANIT
qBounce
neutrons
(Grenoble)
astrophysical
polarization
matter coupling β_m


Point of entrance of particle in to Cold Bore
X
Y (cold bore axis)
Z
Histogram of travellength
Percentage of particles
Travellength of particles in CB(cm)

CAST 2013

Detector lab at CERN

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



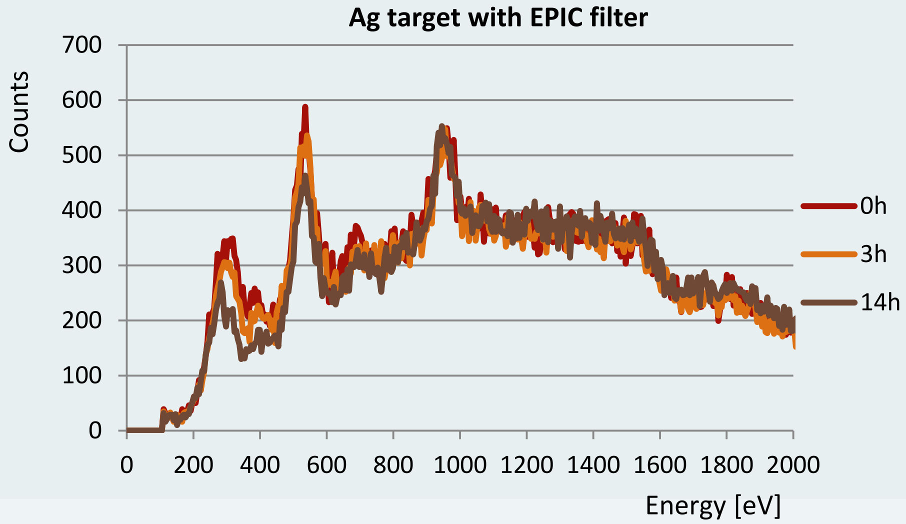
Purpose

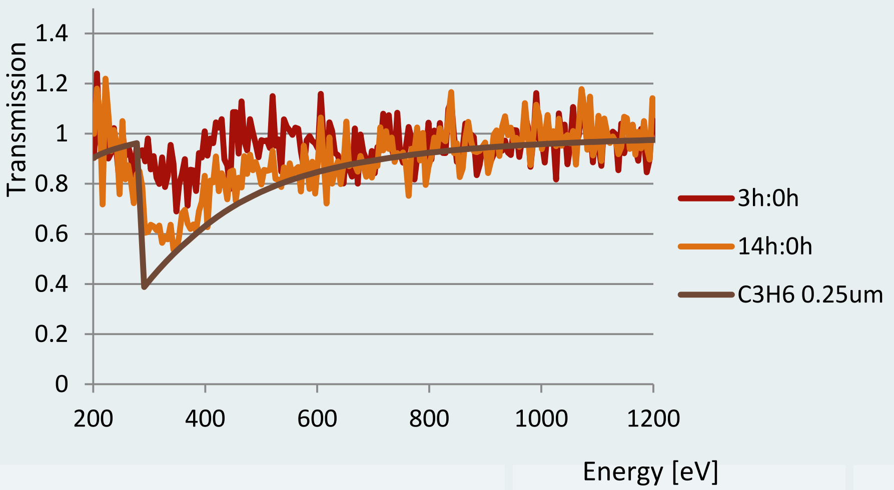
- New X-ray identification techniques.
- Calculation of the data analysis efficiency.

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

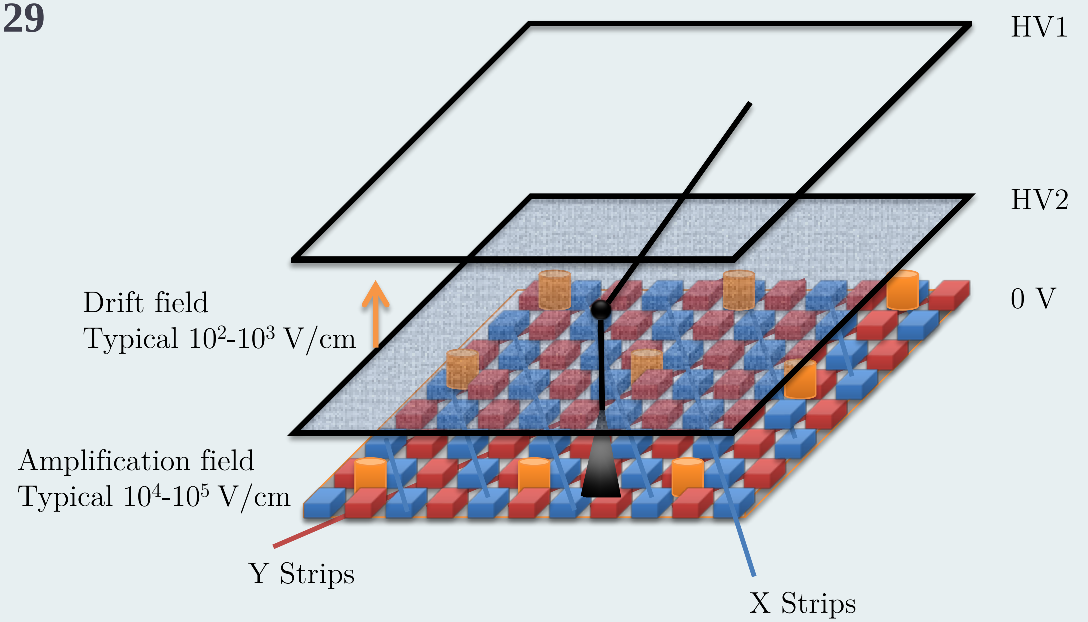
- Conversion region
- Primary ionization
- Charge drift

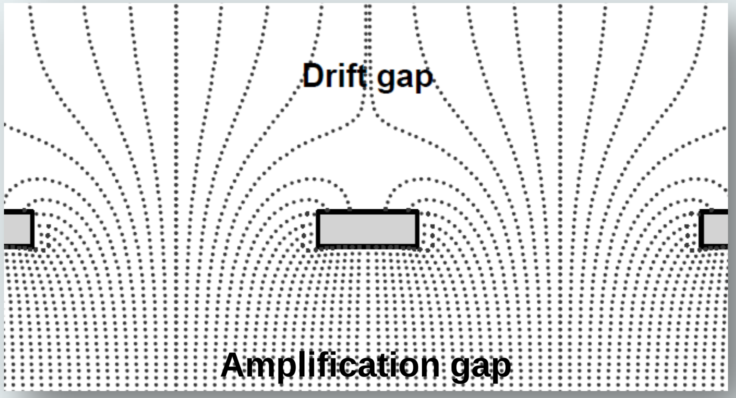
Amplification region

- Charge multiplication
- Readout layout

Separated by a Micromesh

- Very strong and uniform electric field





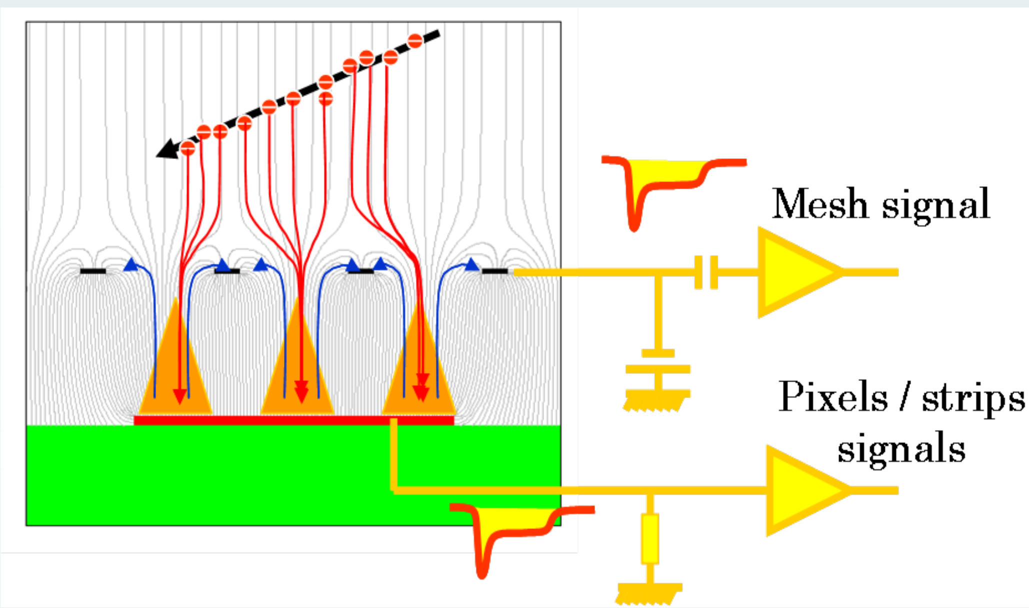
Micromegas detectors

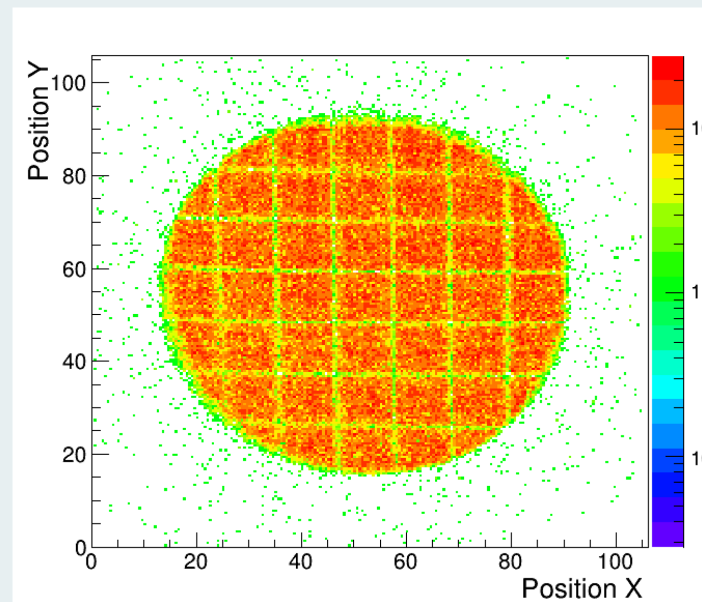
Mesh

- 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.





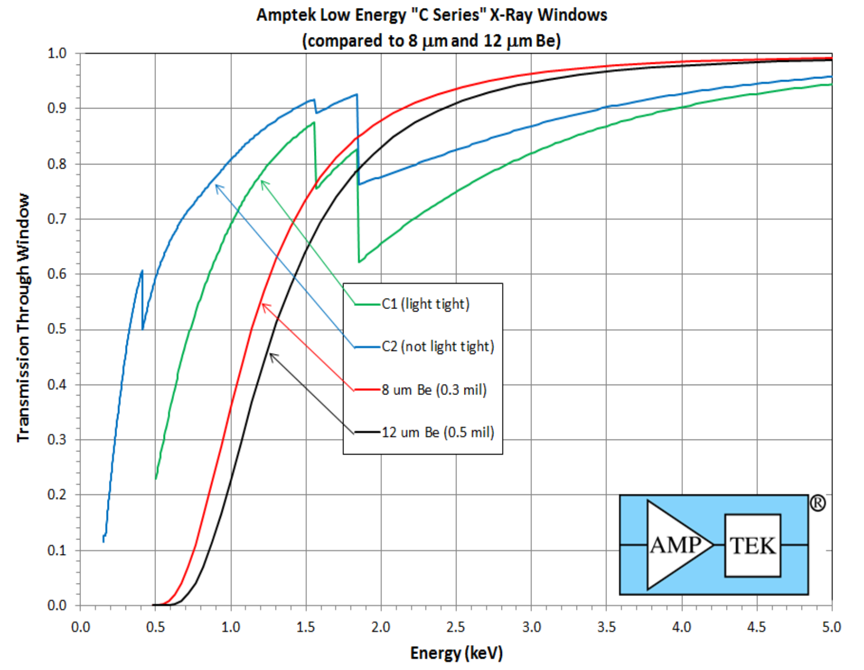
backup

Sub-keV energy range:

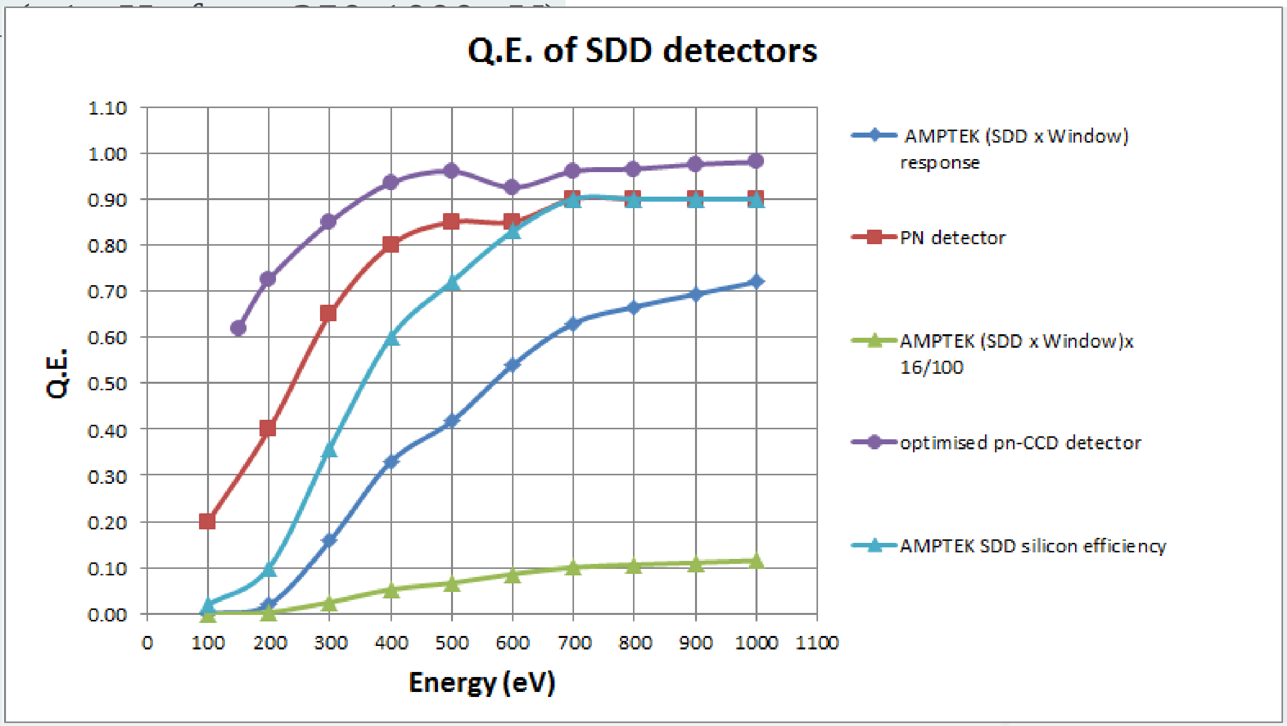
- Unexplored in a helioscope

The "small" SDD:

- Plug and play (..and program and analyse)
- Non imaging
- Low background
- 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)

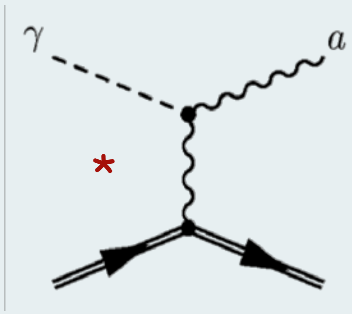
Elegant solution:

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**)