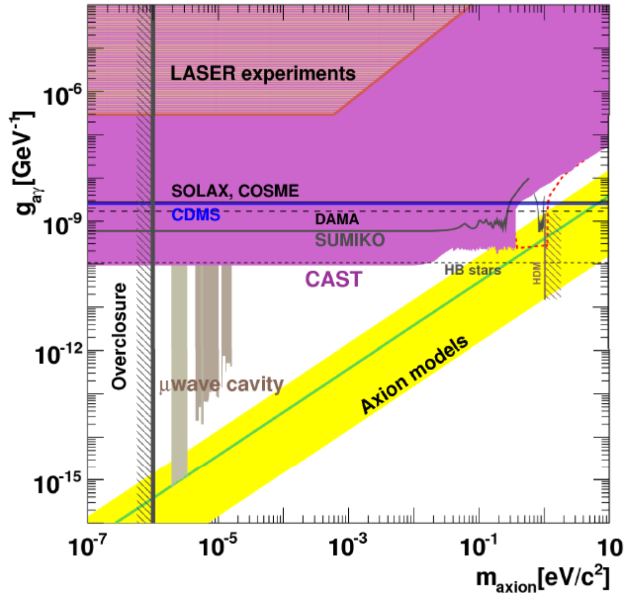
The CAST experiment: status and perspectives



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ICHEP 2010-Palais de Congres (Paris)
24th July 2010

Motivation for Axions

- CP violation is necessary in the SM➔matter-antimatter asymmetry
- CP violation observed in the weak interactions
- QCD predicts violation in the strong interactions

$$\mathcal{L}_\theta = \frac{g^2\bar{\theta}}{32\pi^2} G^\alpha_{\mu\nu} \tilde{G}^{\alpha\mu\nu} \quad with \quad \bar{\theta} = \theta + Arg(\det M)$$

- However no experiment has observed this violation of CP in QCD!

•A possible solution to the strong CP-problem

•Elimination of CP-violating term in QCD Lagrangian by introduction of ne additional global U(1) symmetry

$$\mathcal{L}_a = \left(\bar{\theta} - \frac{a(x)}{f_a}\right)\frac{1}{f_a}\frac{g}{8\pi} G^{\mu\nu}_a \tilde{G}_{a\mu\nu}$$

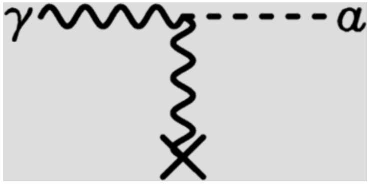
• New pseudo-scalar field : **AXION**

• First proposed by Peccei & Quinn (1977)

• Particle interpretation by Weinberg, Wilczek (1978

Axion properties

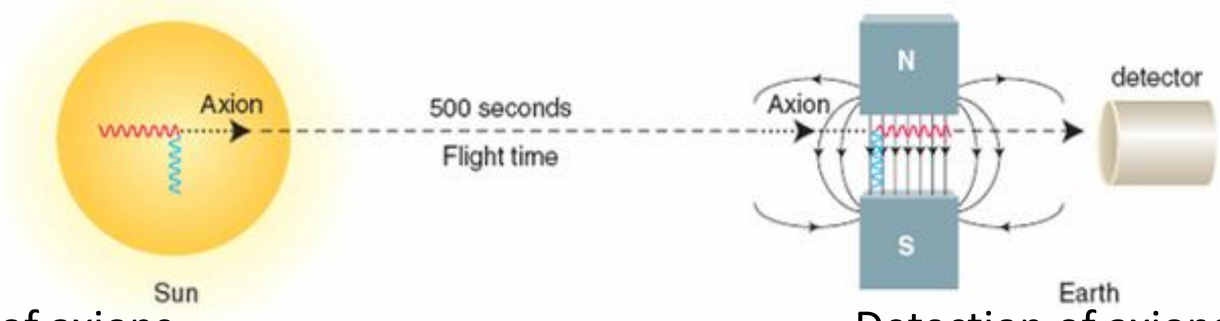
- Neutral Pseudoscalar
- Pratically stable
- Very low mass $$m_a \simeq 0.6\ \mathrm{eV}\frac{10^7\mathrm{GeV}}{f_a}$$
- Very low cross-section
- Coupling to photons



$$L_{a\gamma\gamma} = \mathrm{g}_{a\gamma\gamma}(\vec{\mathrm{E}}\cdot\vec{\mathrm{B}})a$$

- Possible dark matter candidates

Principle of the helioscope

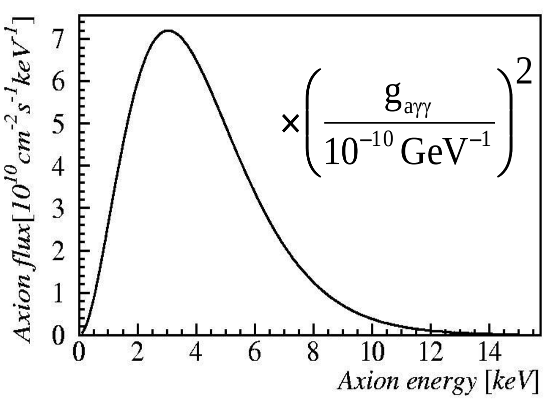


Production of axions

Photons of blackbody radiation (X-rays photons)
→ (strong EM fields in the solar core)
axions

Detection of axions

Axions
→ (strong magnetic field in lab.)
X-ray photons

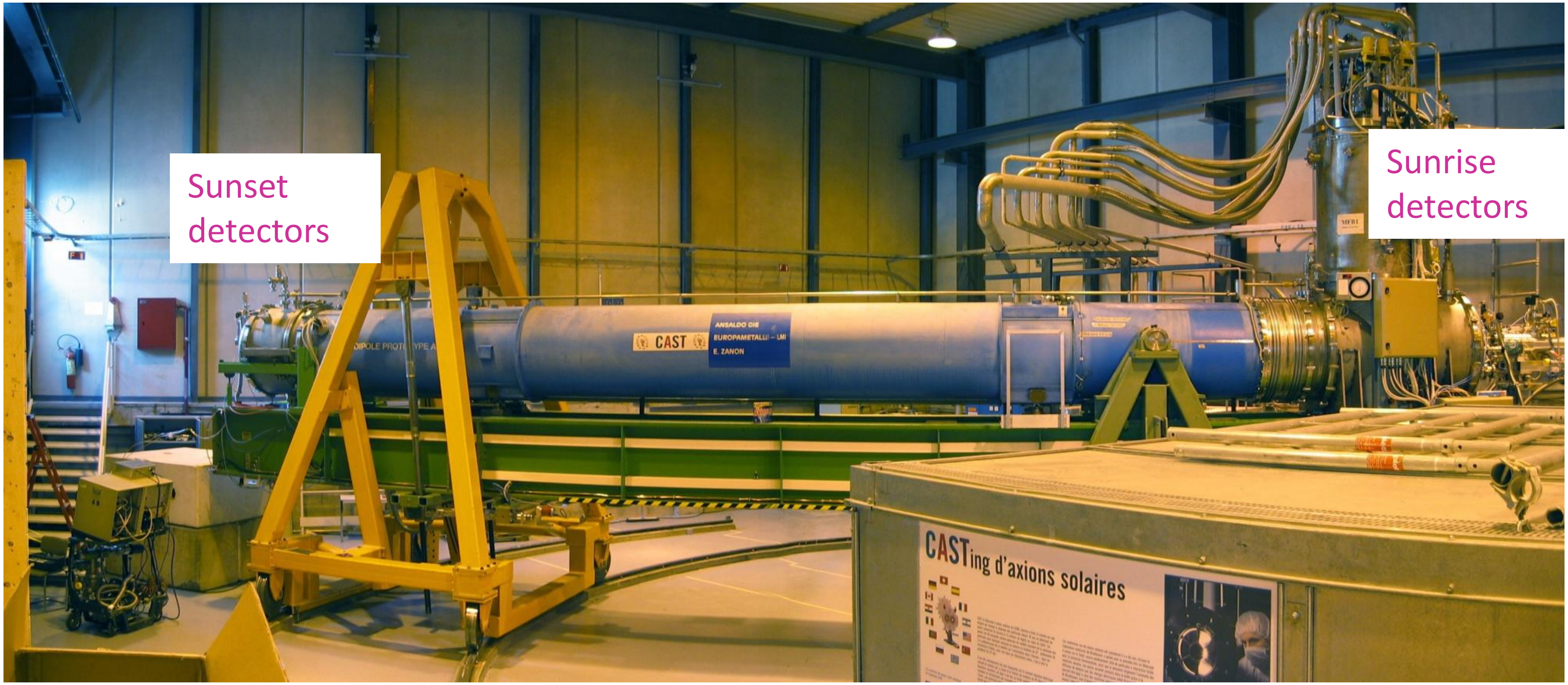


$$N_\gamma = \Phi_a \cdot A \cdot P_{a\to\gamma}$$

$$P_{a\to\gamma} = 1.7\times10^{-17}\left(\frac{B\cdot L}{9.0\mathrm{T}\cdot 9.3\mathrm{m}}\right)^2\left(\frac{g_{a\gamma\gamma}}{10^{-10}\mathrm{GeV}^{-1}}\right)^2$$

≈ 0.3 evts/hour with $g_{a\gamma\gamma} = 10^{-10}$ GeV^{-1} and A = 14 cm^2

CAST: **C**ERN **A**xion **S**olar **T**elescope



LHC dipole : L = 9.3 m, B = 9 T

Rotating platform : vertical mouvement 16°

horizontal mouvement 100°

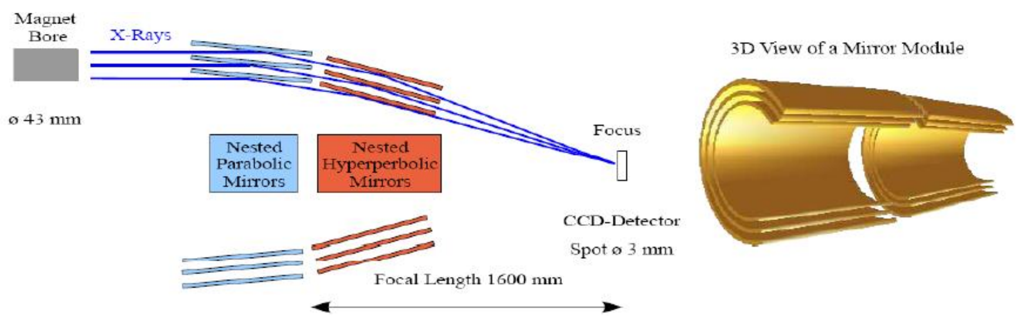
Solar « Tracking » ~3 h/day, background data rest of the day

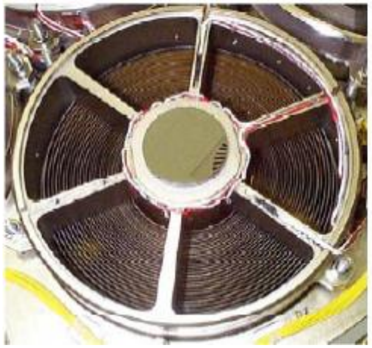
4 X-rays detectors

Signal: excess of X-rays while pointing the sun

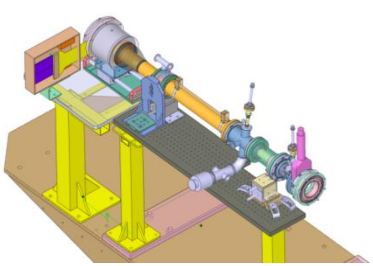
Originalities of CAST

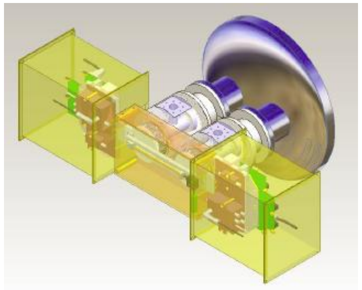
- Use of X-ray telescope ➔ increase S/B noise➔ sensitivity improved by a factor 150 by focusing a ø43 mm x-ray beam to ø3mm

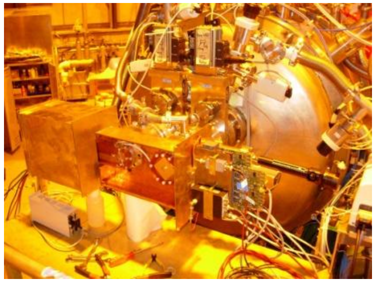




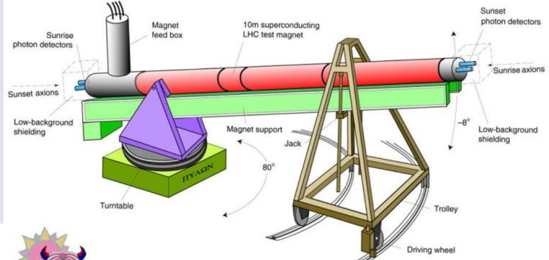
- Low background techniques➔ shieldings, low radioactive materials, simulation and modeling of backgrounds….







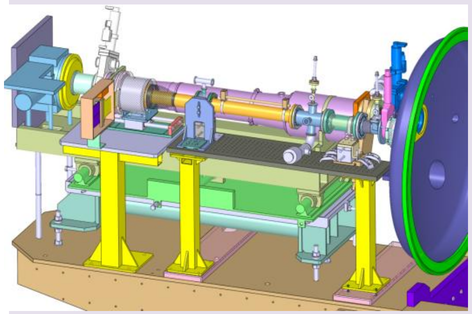
Present detectors

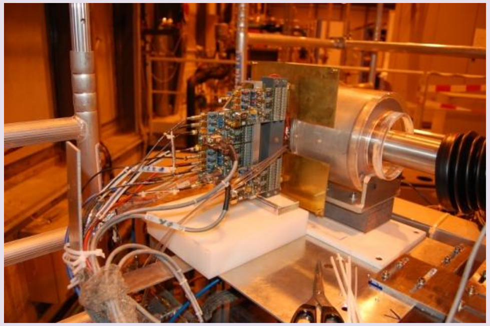


Cern Axion Solar Telescope

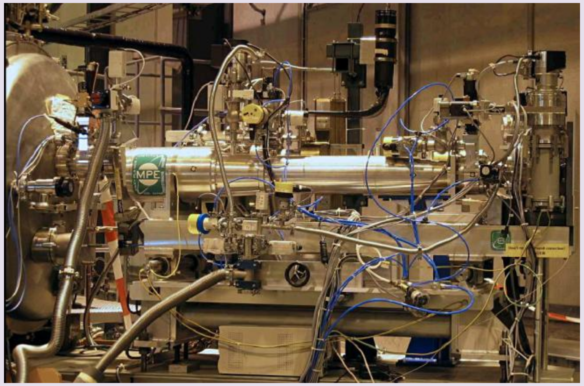
	Typical Rates
MM	2 counts/h (2-10 keV)
CCD+telescope	0.18 counts/h (1-7 keV)

SUNRISE SIDE
Shielded Micromegas last generation-Microbulk type

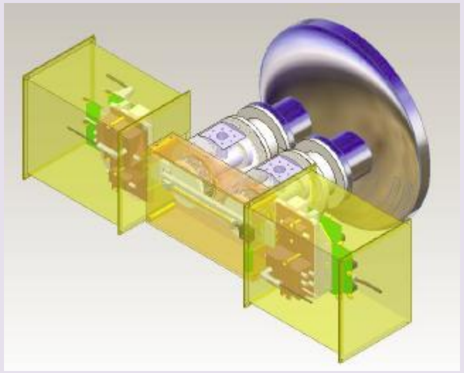


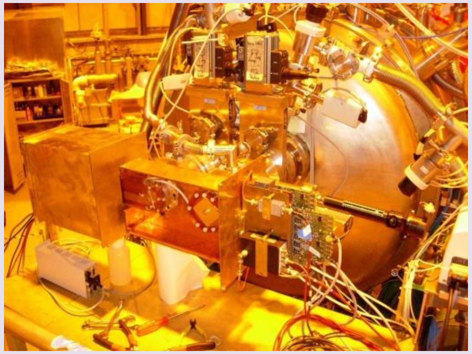


CCD +telescope

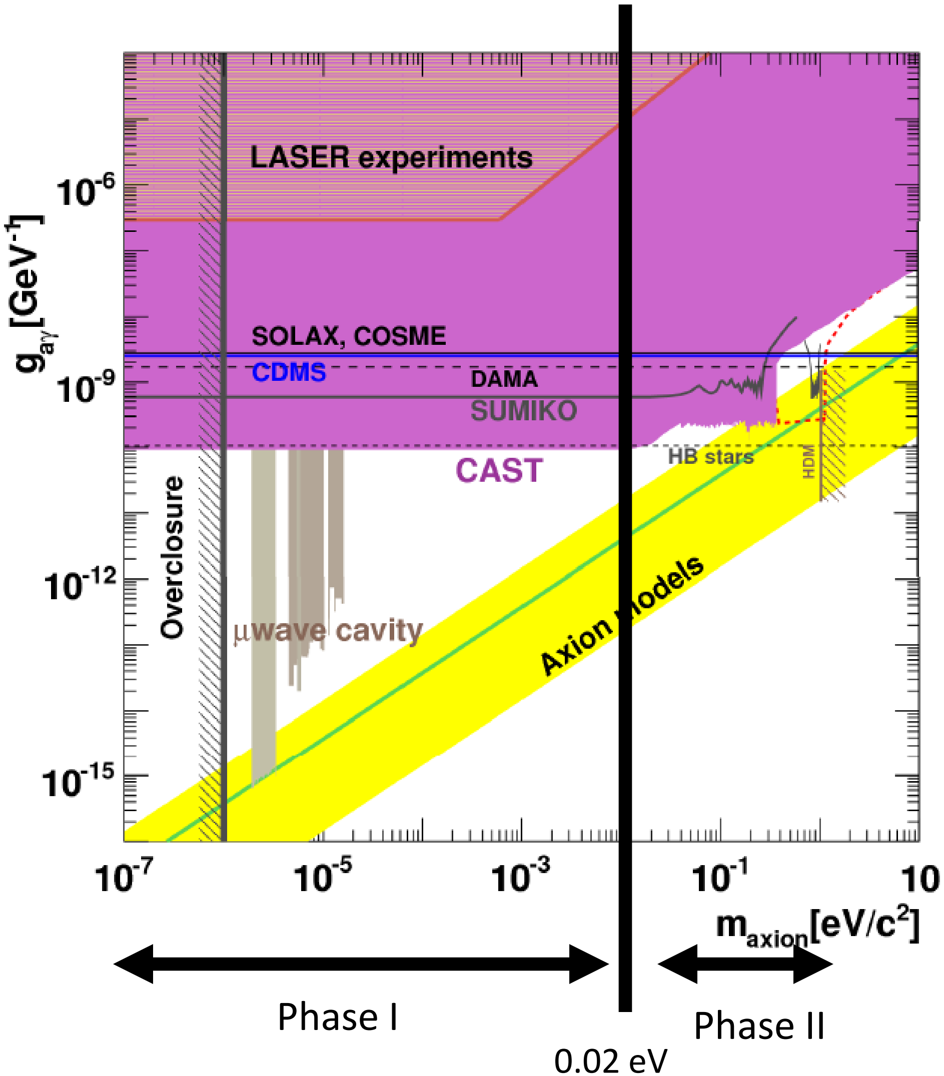


SUNSET SIDE: two shielded Micromegas last generation-Microbulk type





CAST SENSITIVITY



1) CAST Phase I: (vacuum operation)
completed (2003 - 2004)
$m_a < 0.02$ eV

2) CAST Phase II: (buffer gas operation)
^4He completed (2005 -2006)
$0.02 \text{ eV} < m_a < 0.39 \text{ eV}$

^3He run, commissioning in Nov 2007
^3He run, data taking started in Mar 2008
approved until Dec 2010
$0.39 \text{ eV} < m_a < 1.20 \text{ eV}$

3) Low energy axions (2007 – 2010)
in parallel with the main program
~ few eV range and 5 eV – 1 keV range

Extending sensitivity with a buffer gas

In vacuum:

$$P_{a\to\gamma} = 1.74\times 10^{-17}\left(\frac{B\cdot L}{9.0\,\mathrm{T}\cdot 9.26\,\mathrm{m}}\right)^2\left(\frac{g_{a\gamma}}{10^{-10}\,\mathrm{GeV}^{-1}}\right)^2\cdot|M|^2$$

$$|\vec{q}| = \left|\frac{m_a^2}{2E_a}\right| \qquad |M|^2 = \frac{2(1-\cos(qL))}{(qL)^2} \qquad qL \ll 1 \Longrightarrow |M|^2 = 1$$

For $m_a > 10^{-2}$ eV/c^2 coherence is lost

In a gas:

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

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

Absorption coefficient : Γ

Coherence condition : $qL < \pi$

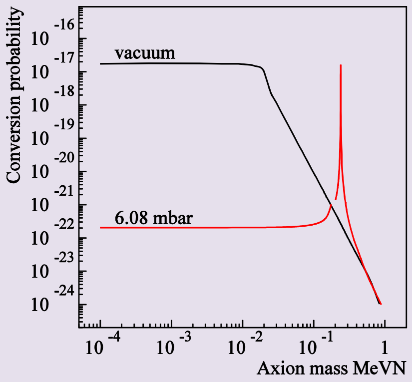
Filling the magnet with a buffer gas provides the photon a mass

$$m_{\gamma,\mathrm{eff}} \approx \sqrt{0.02\frac{P[\mathrm{mbar}]}{T[K]}}\,[\mathrm{eV}/c^2]$$

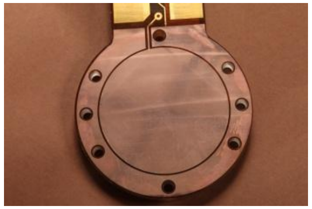
Coherence condition is recovered for a mass interval around m_γ

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

The masses can be adjusted changing the pressure of the gas

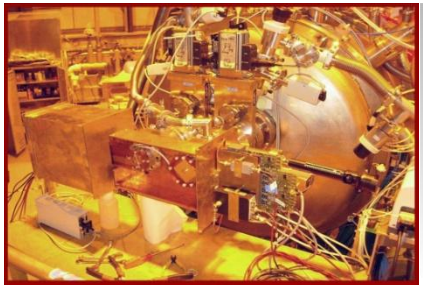


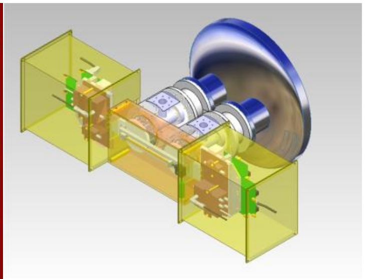
Relevant CAST upgrades

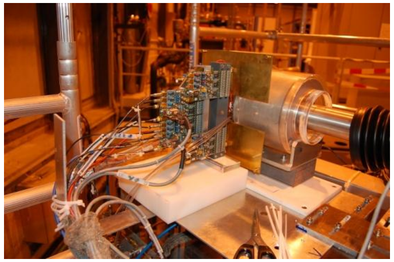


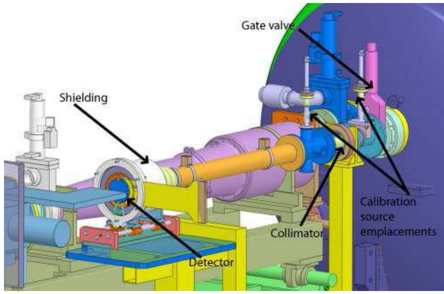
Installation of 3 last generation Micromegas detectors- Microbulk type with full shielding:

High radio-purity materials (Kapton, copper, plexiglass).
Potential for ultra-low background rates.







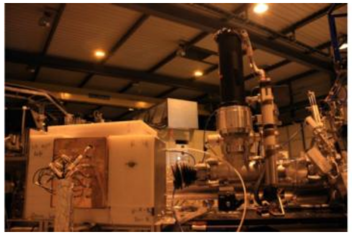


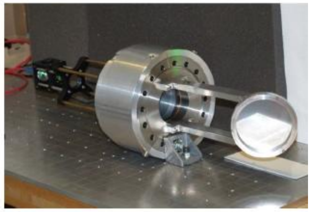
New ^3He system:

Automated gas filling and recovery.

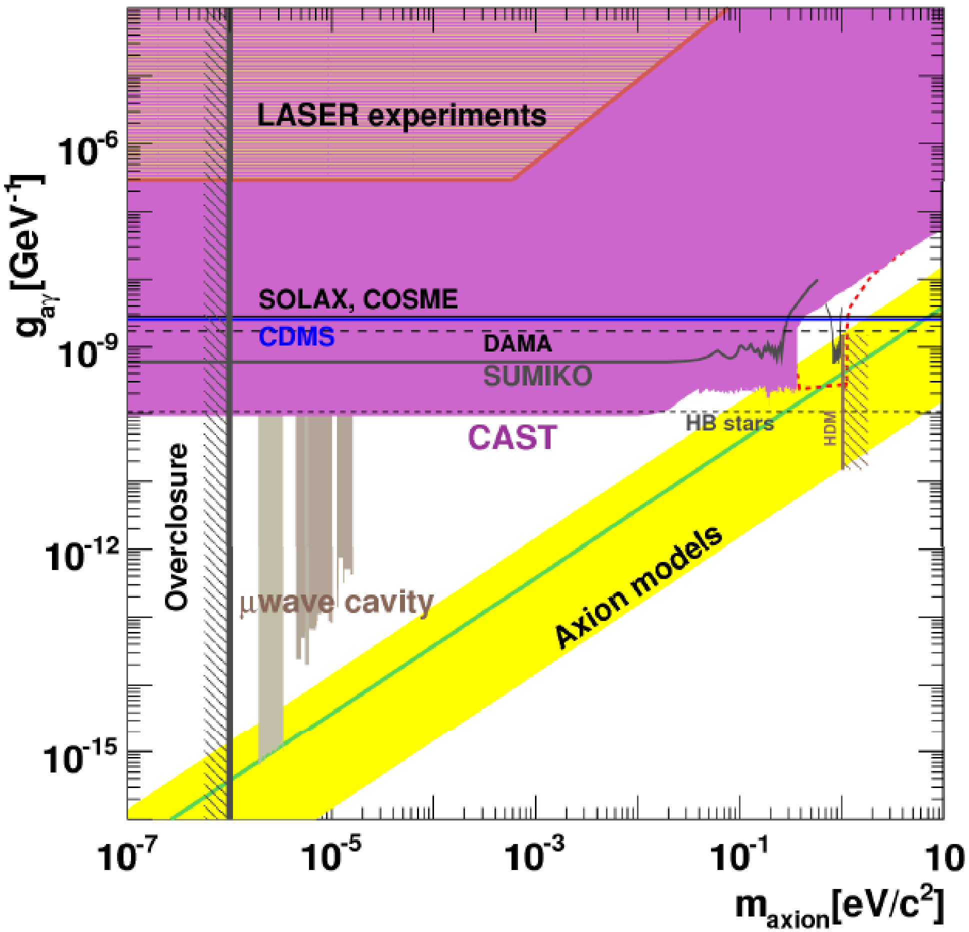
A 5th line for visible photons connected to the sunrise MM line:

A 3.5 μm aluminized Mylar foil (transparent to X-rays) deflects visible photons on an angle 90º, towards the PMT/APD (2010)





CAST published results



CAST search gives the most restrictive experimental limit in most of the favored (cosmology/astrophysics) parameter space

For m_a < 0.02 eV:
$g_{a\gamma\gamma}$ < 0.88 × 10^{-10} GeV^{-1}

JCAP04(2007)010, CAST Collaboration
PRL (2005) 94, 121301, CAST Collaboration

For m_a < 0.39 eV:
$g_{a\gamma\gamma}$ < 2 2 × 10^{-10} GeV^{-1}
JCAP 0902:008,2009, CAST Collaboration

CAST byproducts:

High Energy Axions: Data taking with a HE calorimeter
JCAP 1003:032,2010

14.4 keV Axions: TPC data (before 2006)
JCAP 0912:002,2009

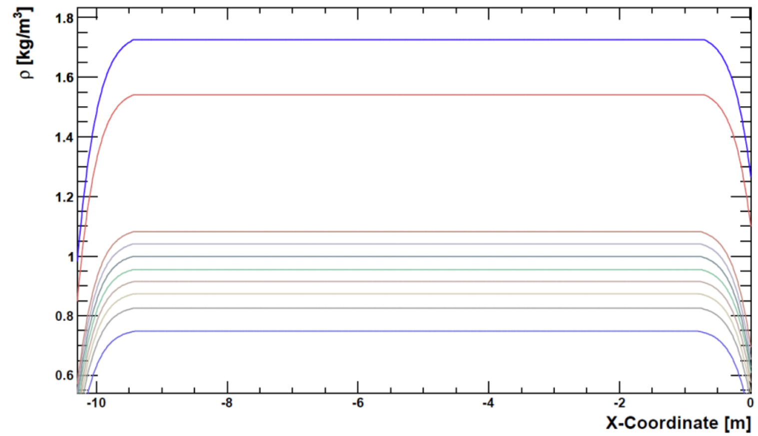
Low Energy (visible) Axions: Data taking with a PMT/APD.
arXiv:0809.4581

Analysis of the ^{3}He data

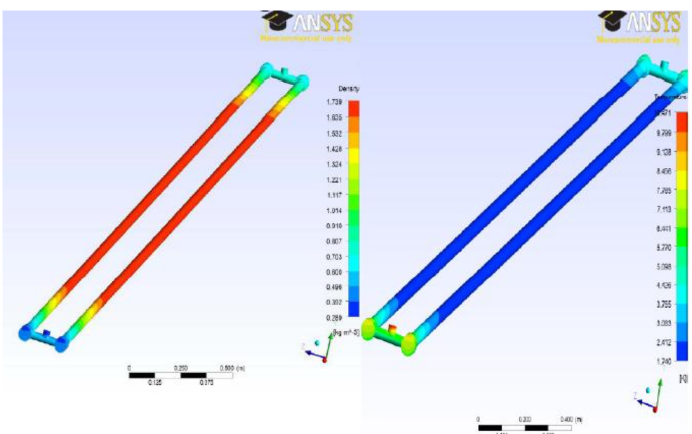
High precision filling and reproducibility is mandatory for each pressure setting.

Gas homogeneity is guaranted by the surrounding superfluid ^{4}He along the magnet region.

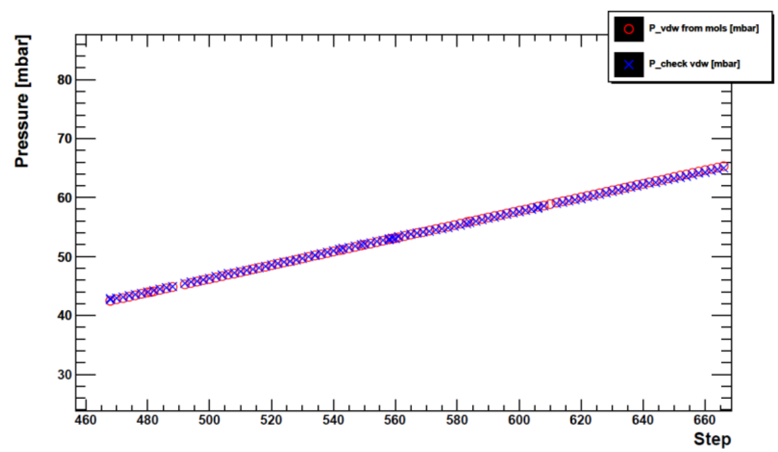
However at higher densities, ^{3}He Phase data-taking period, window temperature cannot be kept as much stable. It can vary during tracking and may depend on the buffer gas density.→ SIMULATION EFFORTS + installation of temperature sensors along the magnet



Magnet pipe density distribution at different pressure settings and boundary conditions.



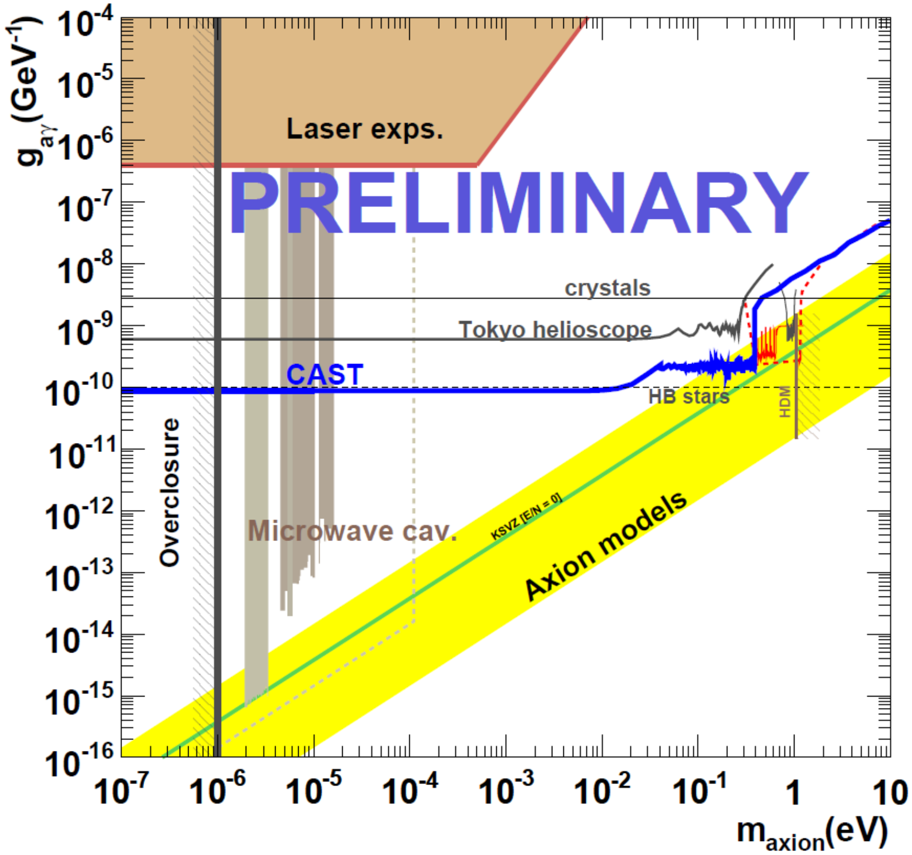
Temperature and density studies for several magnet angles.

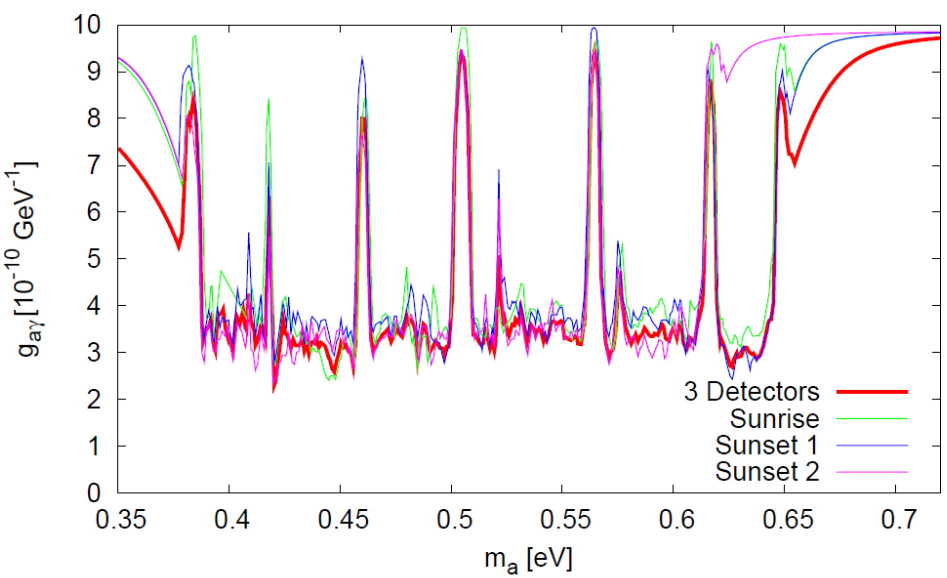


Agreement between simulated and measured pressure.

A first preliminary exclusion plot with ^{3}He data

$$Log\left(L_{m_a}(g_{a\gamma})\right) = \underbrace{-g_{a\gamma}^4 \int_E \int_{t_k} \frac{d^2 n_\gamma}{dE \cdot dt_k} dE \cdot dt_k}_{\text{Zero counts detected contribution}} + \sum_{k_{n_i}=1} \underbrace{Log\left(b_{ik} + g_{a\gamma}^4 \int_{E_i}^{E_i+\Delta E} \frac{dn_\gamma^k}{dE}\right) dE}_{\text{One count detected contribution}}$$





Next generation of helioscopes

$$g_{\alpha\gamma\gamma} \propto \underbrace{(BL)^{1/2} \times A^{1/4}}_{magnet} \times \underbrace{b^{1/8}}_{Detector} \times \underbrace{t^{1/8}}_{tracking\ system}$$

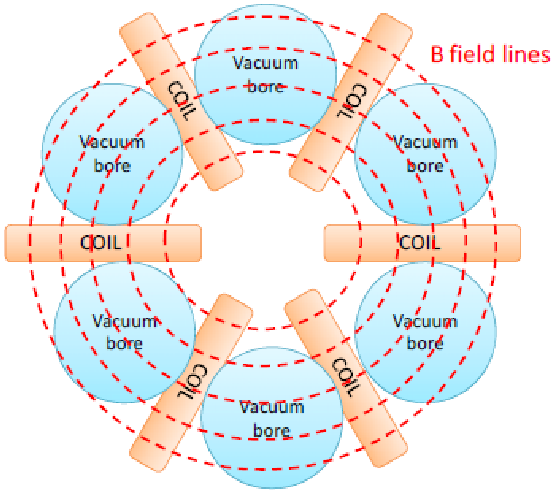
Magnet possible upgrades

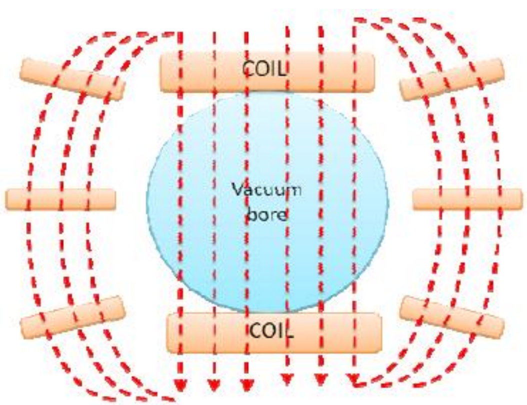
Strong dependence with B,L but small improvement margins for next decade

➔ Concentrate effort on magnet bore's aperture

➔ Work with magnet expert's to design a dedicated magnet for a helioscope

- ✓ The constraints are different from accelerator magnets, i.e homogeneity is not as important as in accelerators
- ✓ An "ATLAS – like" configuration proposed by L. Walckiers is the most promising
  - ➢ Big aperture (~1 m) / multiple bores seem possible
  - ➢ Big magnetic field possible (new superconductive material)
  - ➢ Lighter construction than a dipole





Next generation of helioscopes

Detector upgrades

- Ongoing simulations
- Ongoing background measurements

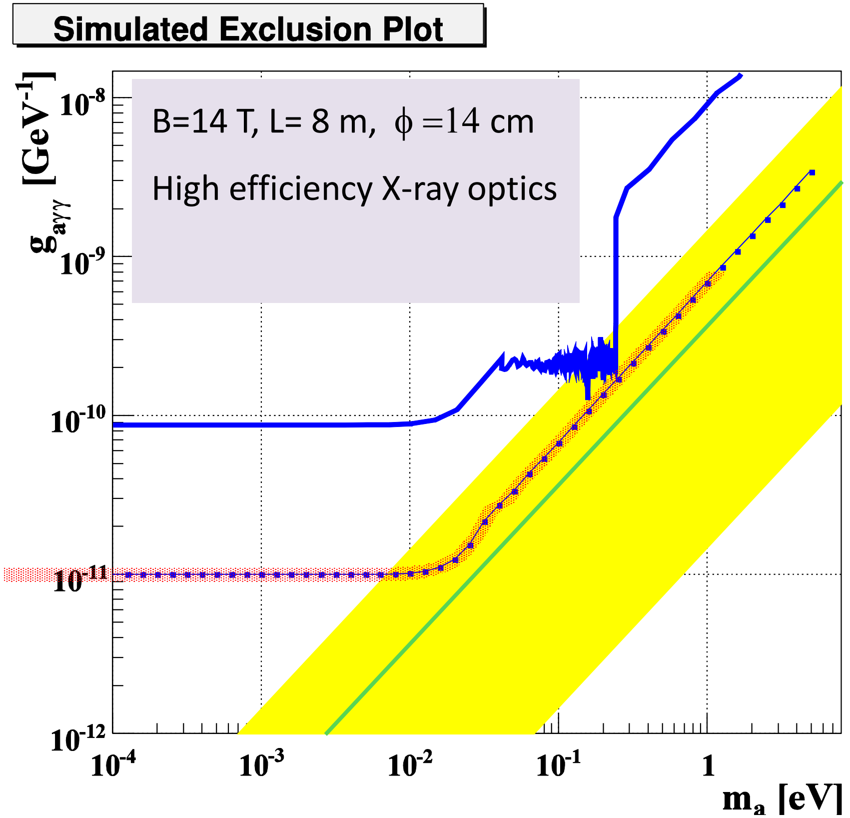
in a controlled environment (underground laboratory Canfranc)

- Optimized detector design

X-ray optics upgrades

- Cover big aperture
- High efficiency (>50%)

Can reach sensitivity of the order of 10^{-11} GeV^{-1} and probe a wide range of QCD favored model region



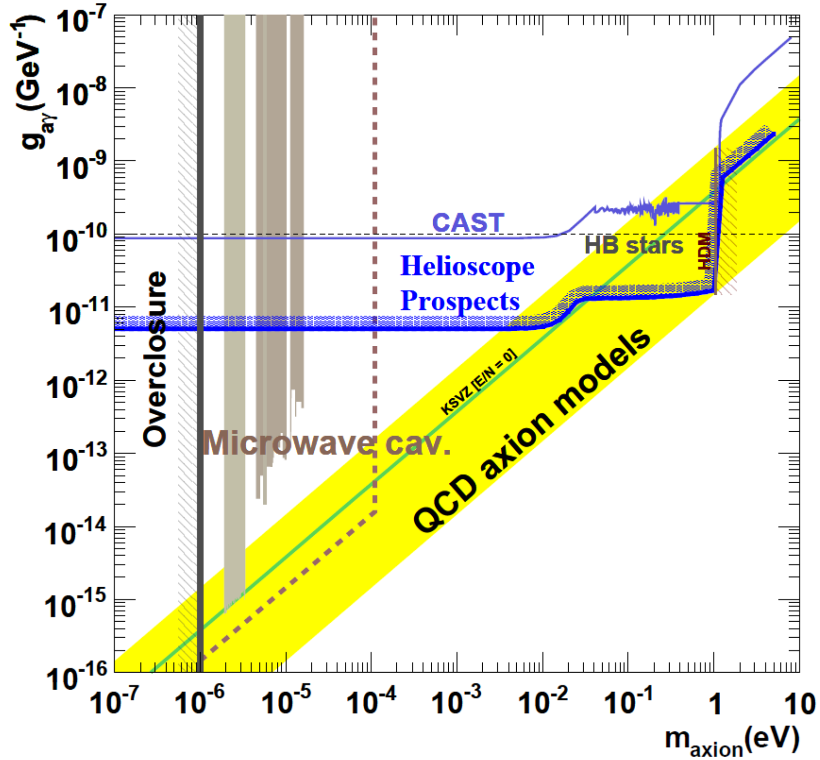
See T. Papaevangelou's talk at New opportunities in the Physics Landscape at CERN Workshop (May 2009) where different scenarios were presented

Conclusions & perspectives

- During the 10 years of existence of CAST the exclusion limits up to now
    - Compatible with best astrophysical limits
    - Entering realistic QCD axion model band for the first time over a wide range of masses

- The hunt for the axion continues. We are exploring a very exciting region. Everyday place for discovery!

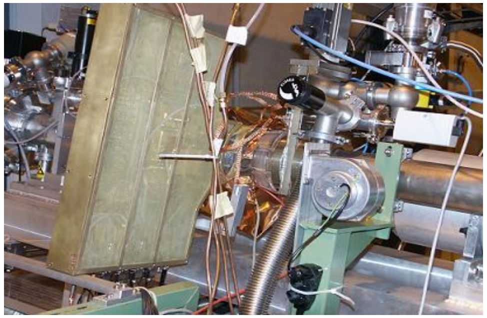
- Thinking of the next generation of Helioscopes which could be complementary with dark matter axion seraches (ADMX) a big part of model region could be explored in the next decade
    - Dedicated magnet development
    - R & D on detectors and X-ray optics

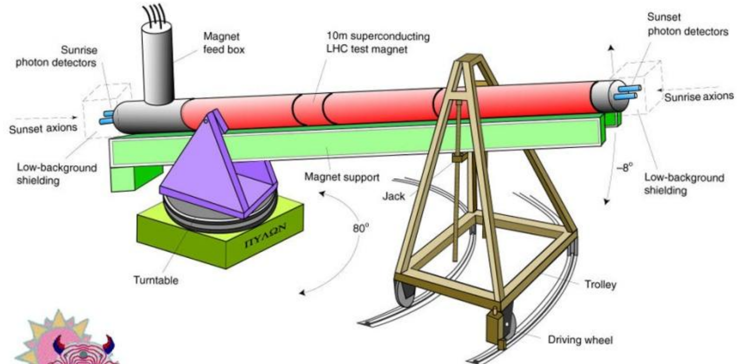


BACK UP

Detectors before 2006

SUNRISE SIDE:
unshielded Micromegas

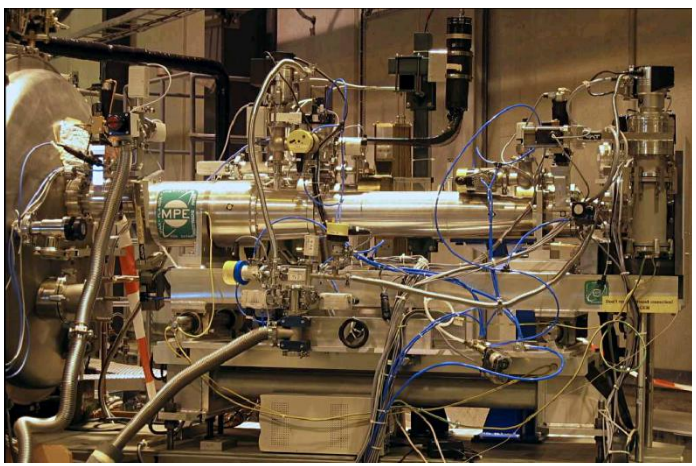




Cern Axion Solar Telescope

CCD +telescope (prototype for the ABRIXAS Space mission):
enhanced sensitivity by improving S/B

SUNSET SIDE: **shielded TPC**
(looking at two magnet bores)



	Typical Rates
TPC	85 counts/h (2-12 keV)
MM	25 counts/h (2-10 keV)
CCD	0.18 counts/h (1-7 keV)

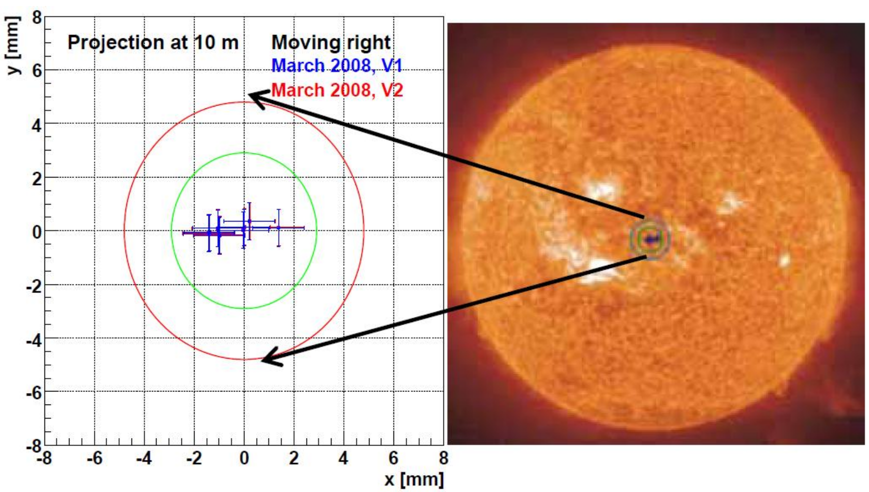
Φ 43 mm (LHC magnet aperture)
==> Φ 3 mm (spot of the sun)

Tracking system precision

Several yearly checks cross-check that the magnet is following the Sun with the required precision

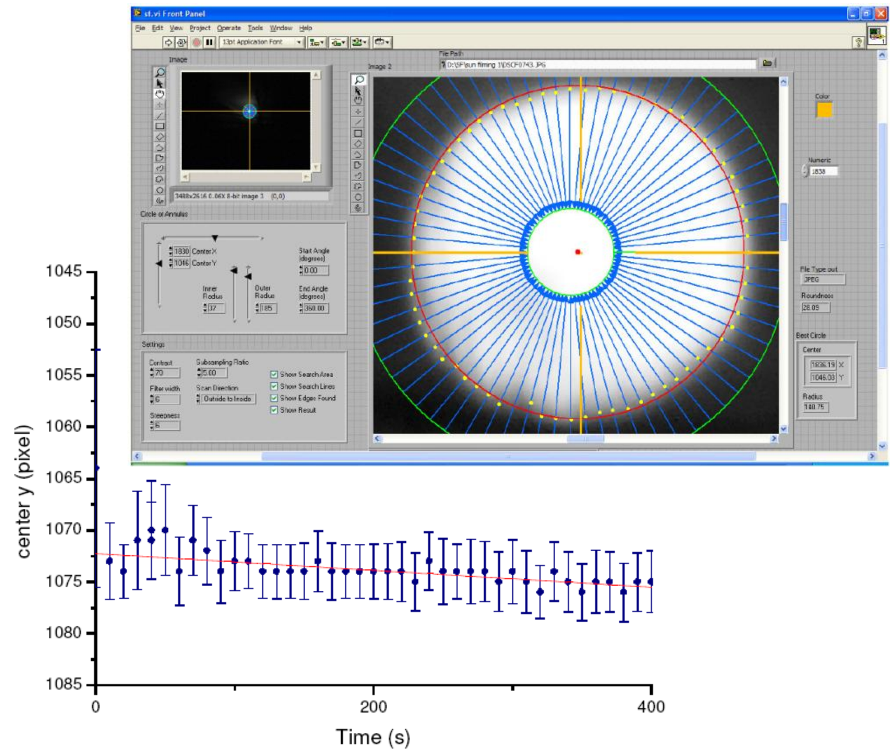
GRID Measurements

- Horizontal and Vertical encoders define the magnet orientation
- Correlation between H/V encoders has been established for a number of points (GRID points)
- Periodically checked with geometer measurements



Sun Filming

- Twice a year (March – September) Direct optical check. Corrected for optical refraction
- Verify that the dynamic Magnet Pointing precision (~ 1 arcmin) is with our aceptance



New Micromegas detectors and potential for ultra low background

•Very low background: Without loss of efficiency
•Not really understood yet

Nominal background : 1.6 counts/hour
Ultra-low background : 0.1 counts/hour

•Ultra background reduction could be related with clean atmosphere (Nitrogen) surrounding the detector

Studies going on to reproduce conditions of stable ultra-low background detectors.

Extremely detailed Geant4 Simulations (A. Tomas)
+
Stable Underground measurements

2010 JINST 5 P01009
2010 JINST 5 P02001