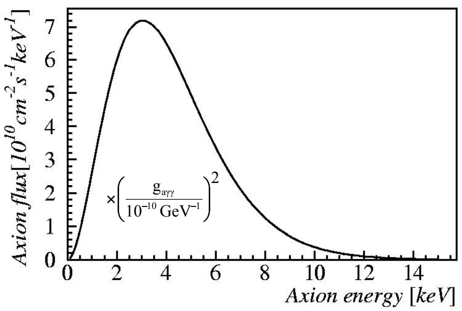
6th Patras Workshop on Axion, WIMPs and WISPs

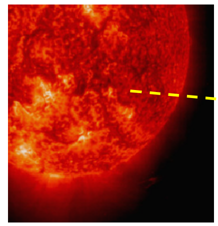
Zurich 2010

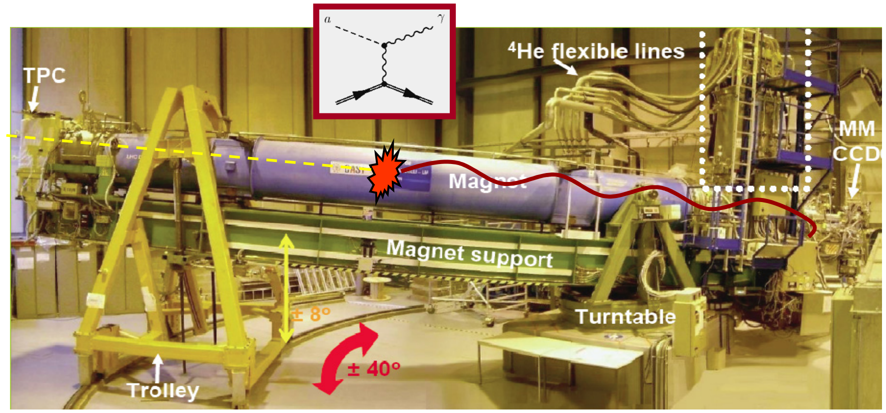
CAST: Recent Results & Future Outlook

Thomas Papaevangelou
for the
CAST Collaboration

The 10 years of CAST!!!







CAST is using a decommissioned prototype superconducting LHC dipole magnet to detect solar axions:

Operation at T=1.8 K, I=13,000A.

B=9T, L=9.26m.

➢ Solar tracking: ~3 hours/day

- Signal: X-Ray excess during tracking at **1-10 keV** region
- ***CAST phase II → different pressure setting(s) in every tracking***. Each setting is a new experiment!

  ➢ expect **0.3 events/hour** for $g_{a\gamma\gamma}$= 10^{-10} GeV^{-1} and A = 14.5 cm^2

CAST, Physics program

1) ***CAST Phase I:*** vacuum operation, ***completed*** (2003 - 2004)

2) ***CAST Phase II:*** ^{4}He run, ***completed*** (2005–2006)
   0.02 eV < m_a < 0.39 eV

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

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

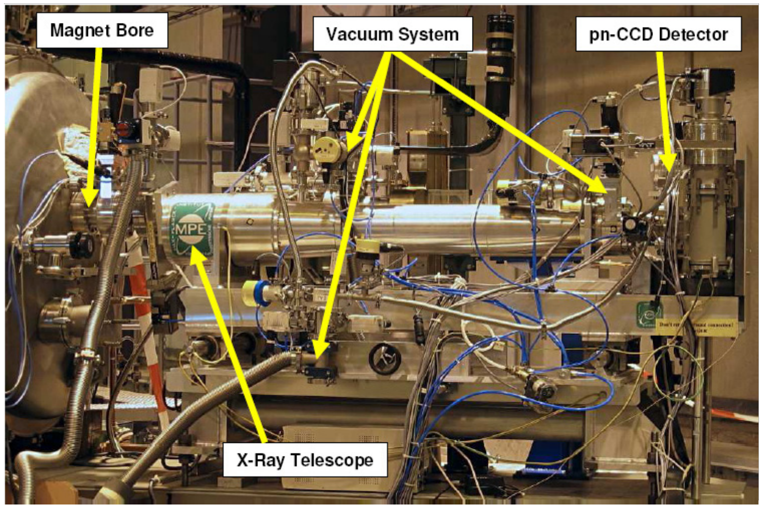
13th April 2010: CAST 10th anniversary

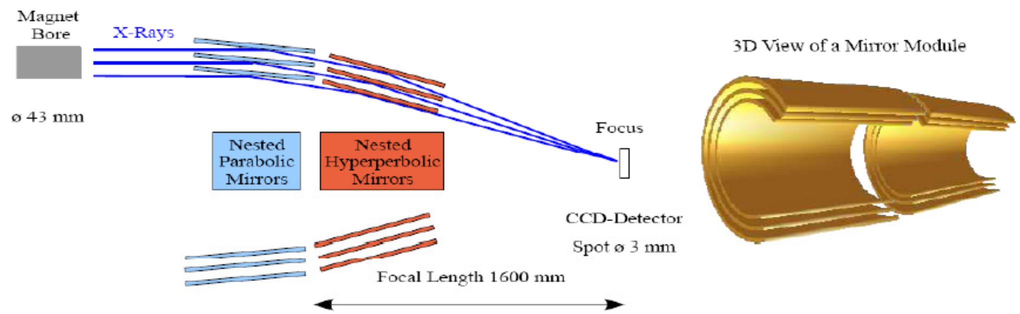
CAST detectors *(phase I & phase II-^{4}He)*

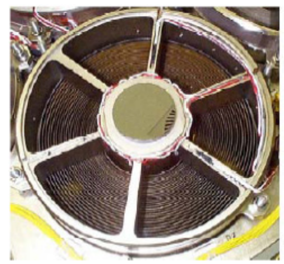
Sunrise side

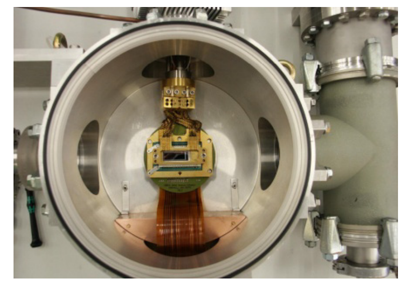
CCD + X-Ray Telescope

(prototype for the ABRIXAS Space mission)

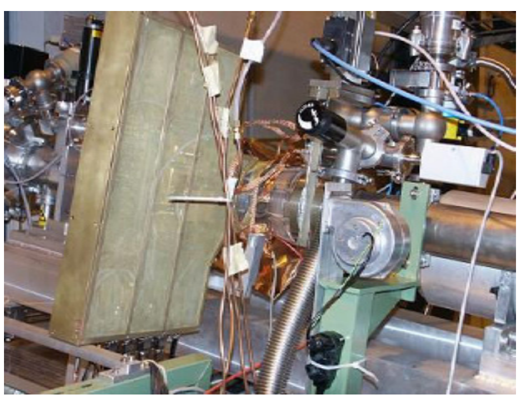








Unshielded Micromegas

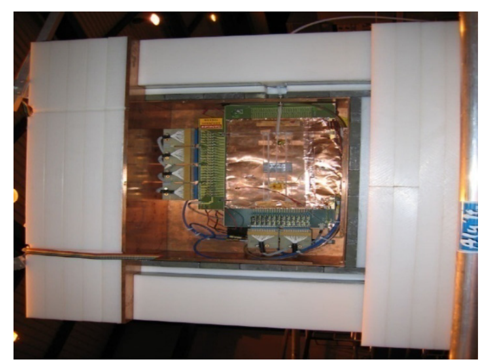


The X-Ray Telescope is focusing a ∅43 mm x-ray beam to ∅3mm
S/B improvement by ~150

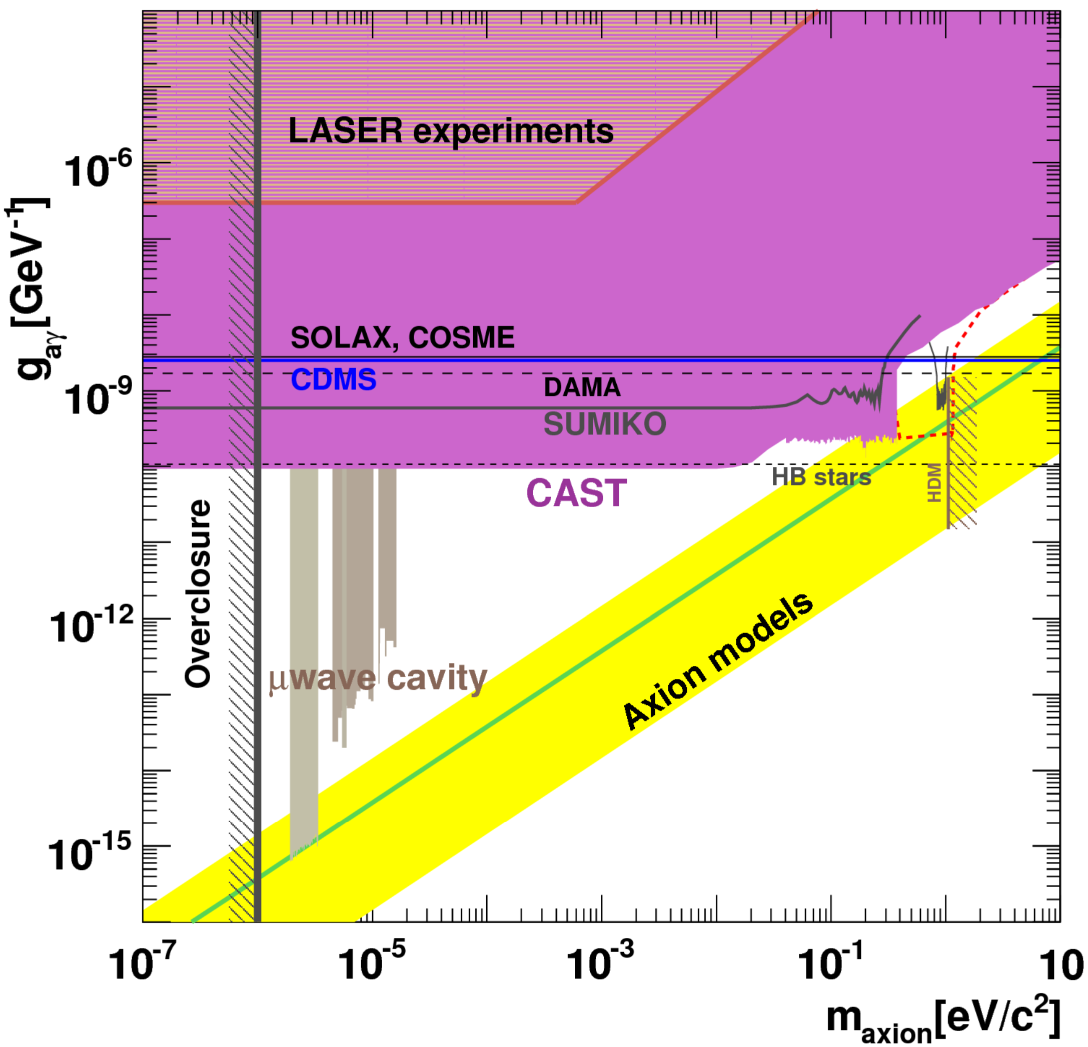
	Typical rates
TPC	85 counts/h (2-12 keV)
MM	25 counts/h (2-10 keV)
CCD	0.18 counts/h (1-7 keV)

Sunset side

Shielded TPC,
covering both magnet bores



CAST published results



CAST <u>experimental</u> limit dominates in most of the favored (cosmology/astrophysics) parameter space

For $m_a < 0.02$ eV:

$g_{a\gamma\gamma} < 0.88 \times 10^{-10}$ GeV^{-1}

JCAP04(2007)010, CAST Collaboration

PRL (2005) 94, 121301, CAST Collaboration

For $m_a < 0.39$ eV typical upper limit:

$g_{a\gamma\gamma} < 2.2 \times 10^{-10}$ 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 (JCAP 0912:002,2009)

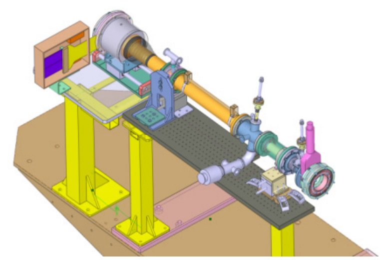
Low Energy (visible) Axions: Data taking with a PMT/APD. (arXiv:0809.4581)

CAST Upgrades

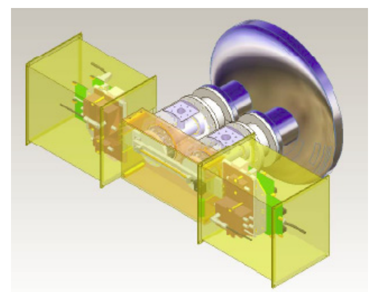
- More sophisticated gas system - ^{3}**He** (2007 – improvements on 2008-2010)
- Replacement of TPC and sunrise Micromegas by **new technology Micromegas** (2008-2010)
- Establishment of a **"5th line"**: a 3.5 μm aluminized Mylar foil (transparent to X-rays) is placed on the sunrise micromegas line to deflect **visible photons** on an angle of 90°, towards the **PMT/APD** (2010)

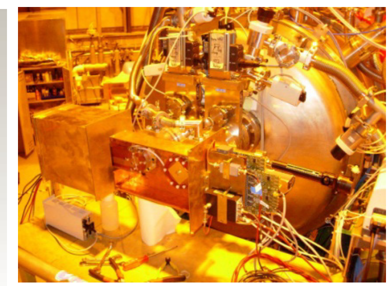
New manufacturing technique: **Microbulk Micromegas**.
- High radio-purity materials (kapton, Cu & Plexiglas)
- *Potential for ultra-low background rates.*

Sunrise side



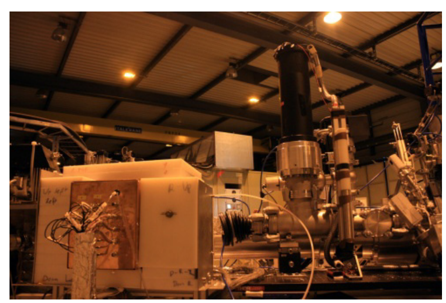
Sunset side

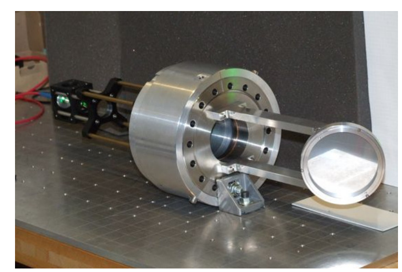




Typical new MM rate: ~2 c/h

The 5th line





Extending sensitivity to higher axion masses…

Axion to photon conversion probability:

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

Vacuum:
Γ=0, m_γ=0

Coherence condition: $qL < \pi$, $|q| = \frac{m_a^2}{2E}$

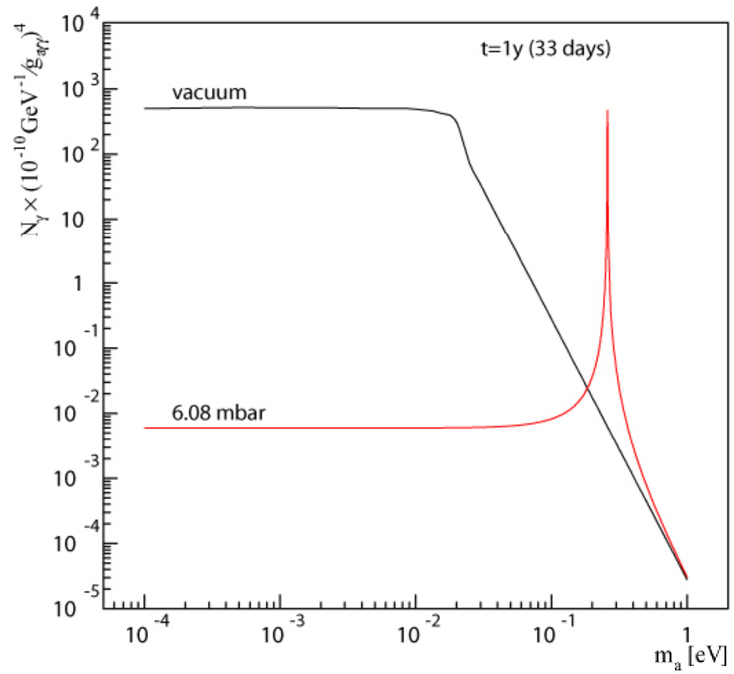
For CAST phase I conditions (vacuum), **coherence is lost for m_a > 0.02 eV**.

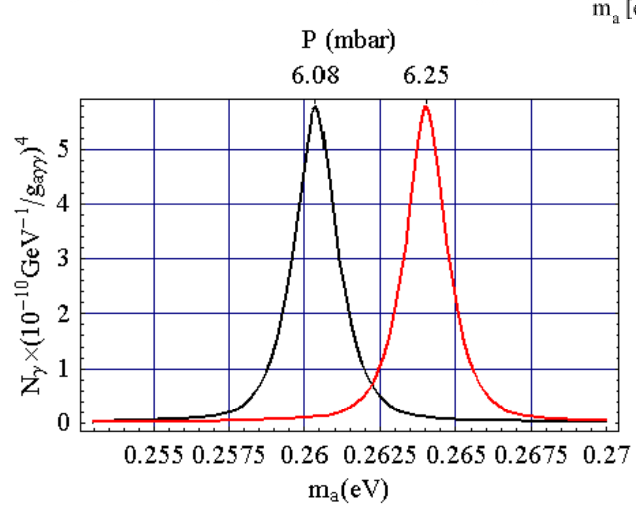
With the presence of a **buffer gas** it can be **restored** for a narrow mass range:

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

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

➢ New discovery potential for each density (pressure) setting





For P~50 mbar $\Delta m_a \sim 10^{-4}$ eV !!!

Working with a buffer gas…

- Precise knowledge and/or **reproducibility** of each pressure setting is essential
- Gas **density homogeneity** along the magnet bore during tracking is critical
  - ✓ **Supperfluid** ^{4}He @ 1.8 K guaranties **temperature stability** along the cold bore
  - ✓ Hydrostatic pressure effects are not critical

However:

- × There are parts of the magnet bores, outside the magnetic field region, that are in higher temperatures. These temperatures **can vary during tracking** and may **depend on the buffer gas density**
- × There is also a volume of pipe work in high temperature directly connected with the cold bores

To face that situation we:

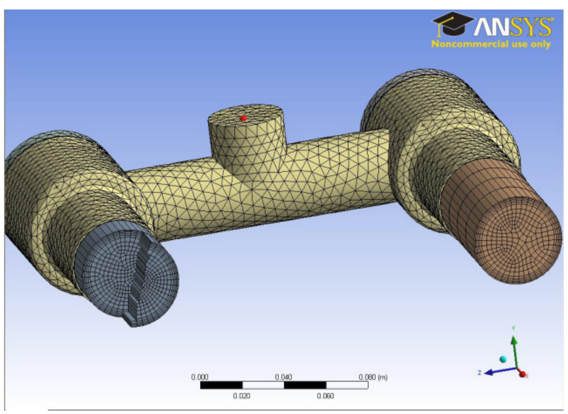
- Measure precisely the amount of **gas ejected** into the magnet with a **metering volume** kept at stable temperature (typically 36 °C)
- During ^{4}He phase we kept the **cold windows** that confine the gas **at T=120K**, making the effective "dead volume" **negligible**
- × However at higher densities (^{3}He phase) heat conduction towards the magnet does not allow high window temperatures. Dead volumes become **significant** and more effects appear (**gas convection**) . Comprehending the gas behavior is critical for the data analysis!

Understanding ^{3}He behavior

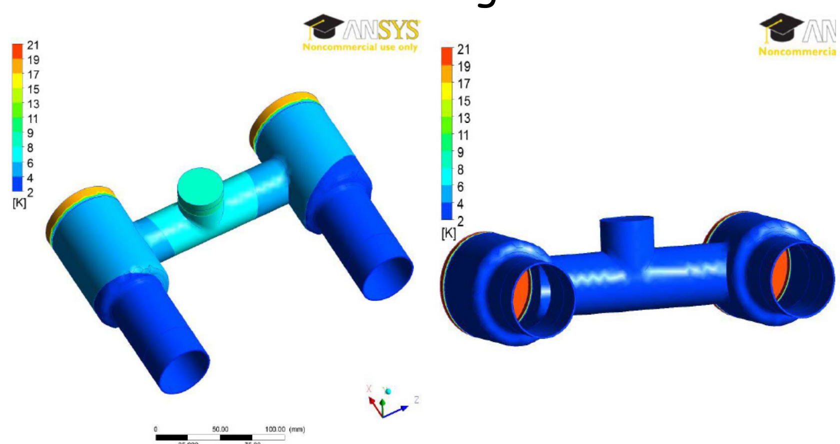
A number of **temperature and pressure sensors** have been placed in several points of the magnet and the gas system

- ➢ These sensors revealed a **diversion** from the gas behavior expected by the initial **simple model**.
- ✓ A series of Finite Element Analysis (ANSYS) with the sensors' data as bounding conditions was performed and is still going on
  - ➢ Static case
  - ➢ Dynamic case (magnet movement)

Geometry parameterization



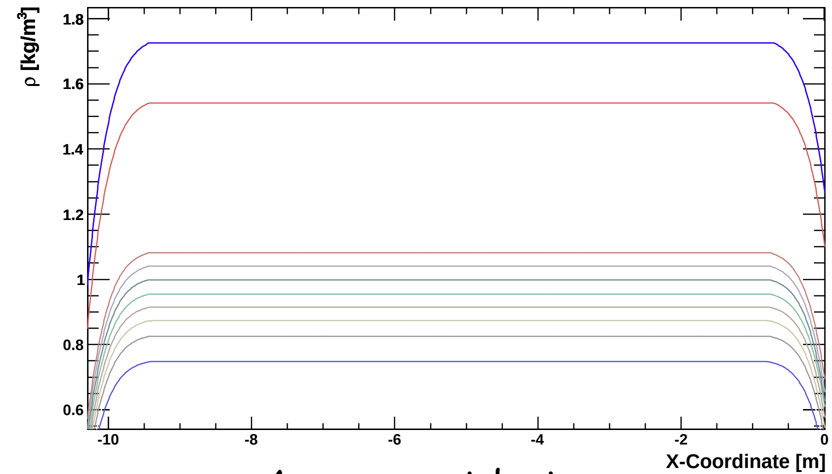
Temperature distribution in the cold window region



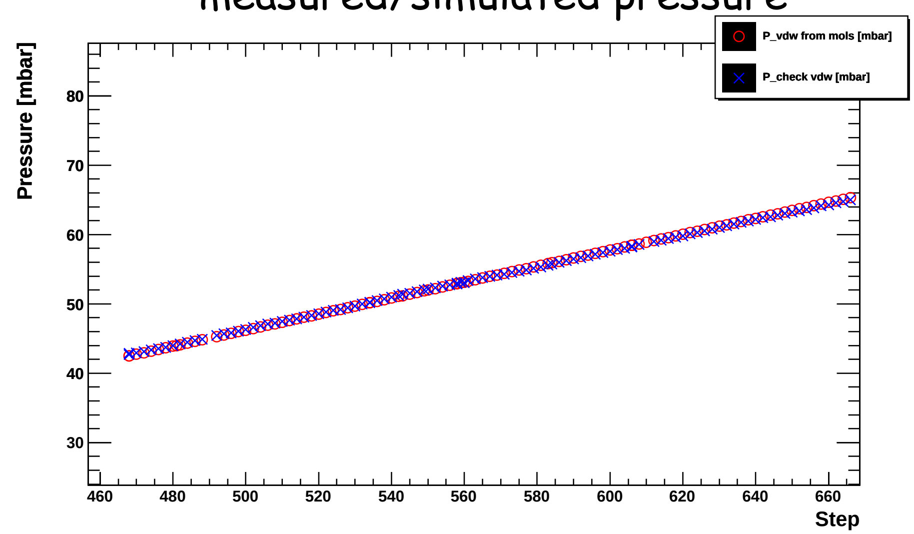
Simulation results

- An analytic calculation approach showed similar results
- A key point in the convergence of the simulation results to measured data: ^{3}He-3 above some density is not an ideal gas (Van der Waals forces)
- ✓ Knowledge of gas density / setting reproducibility possible
- ✓ Variation During tracking, **but gas density still homogeneous**

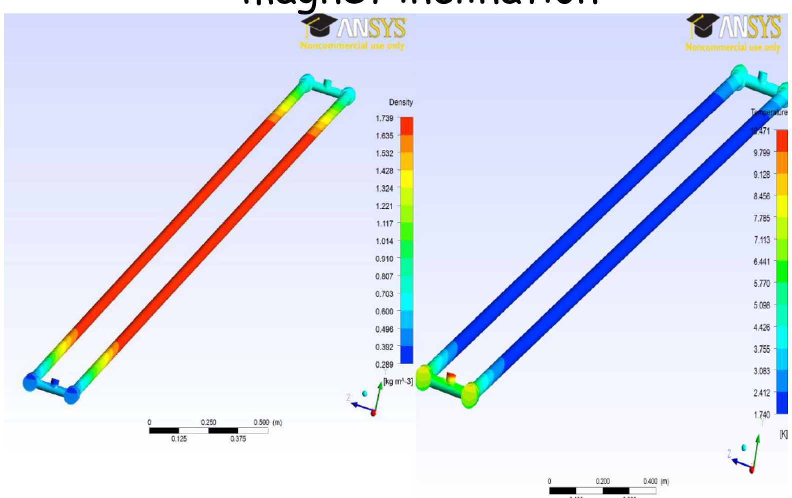
Gas density along the magnet bore



Agreement between measured/simulated pressure



Density and temperature variation for magnet inclination



First - preliminary - 3He result

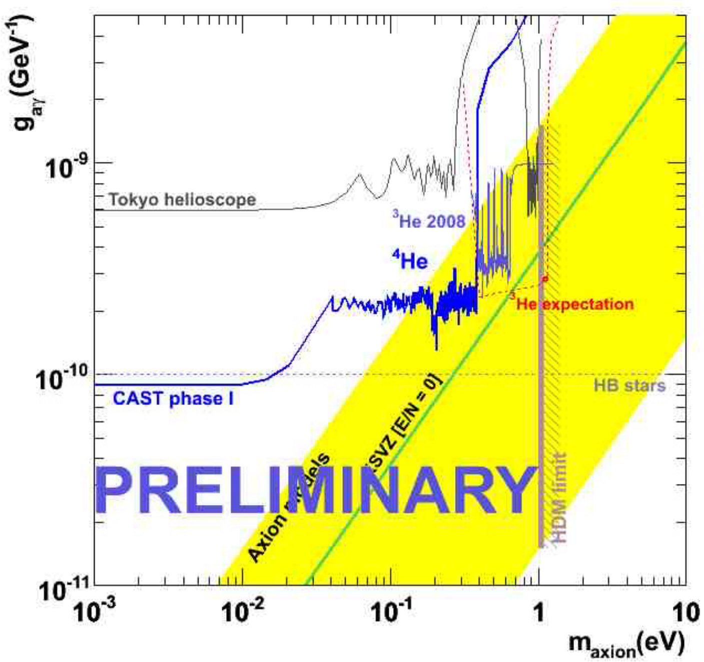
Density variation during a tracking ➔ 4He phase limit method not easy to be used.

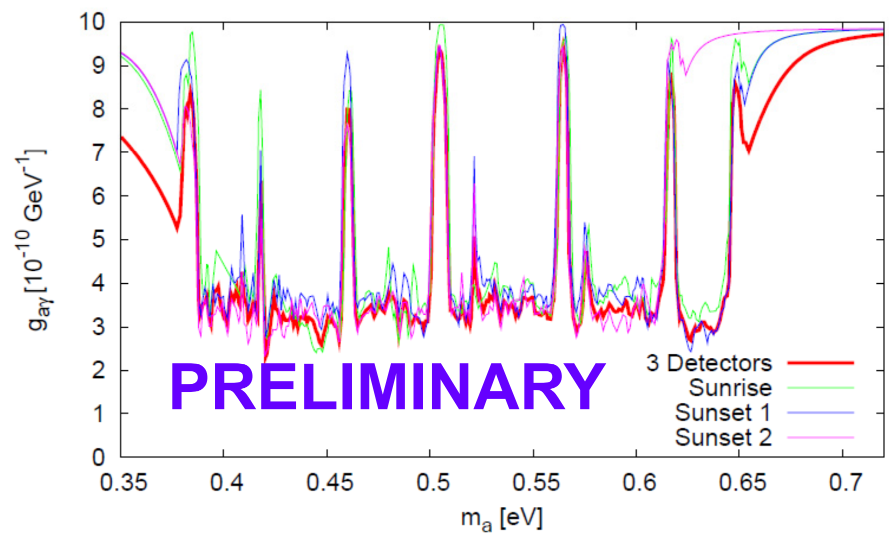
- new formulation of the binned likelihood:

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

1st term: expected number of axions. Depended on exposure time

2nd term: contribution of each detected count



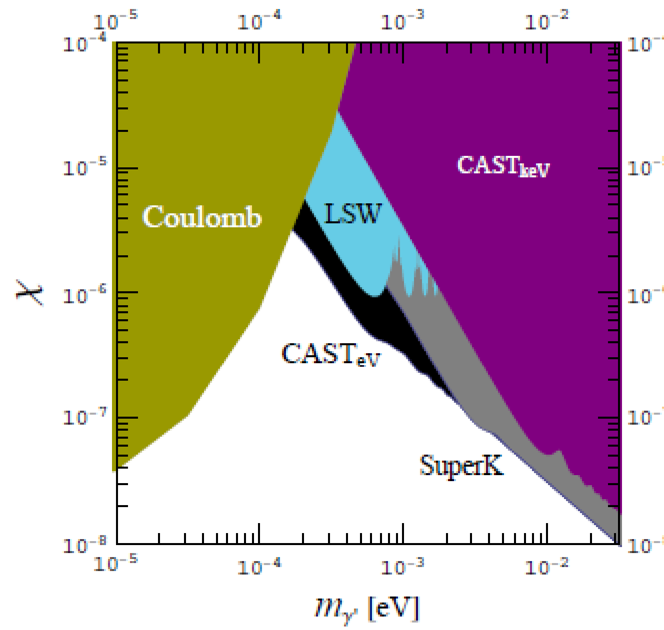


J. Galan PhD Thesis

X-Ray telescope data not included yet

Future outlook 2011-2012

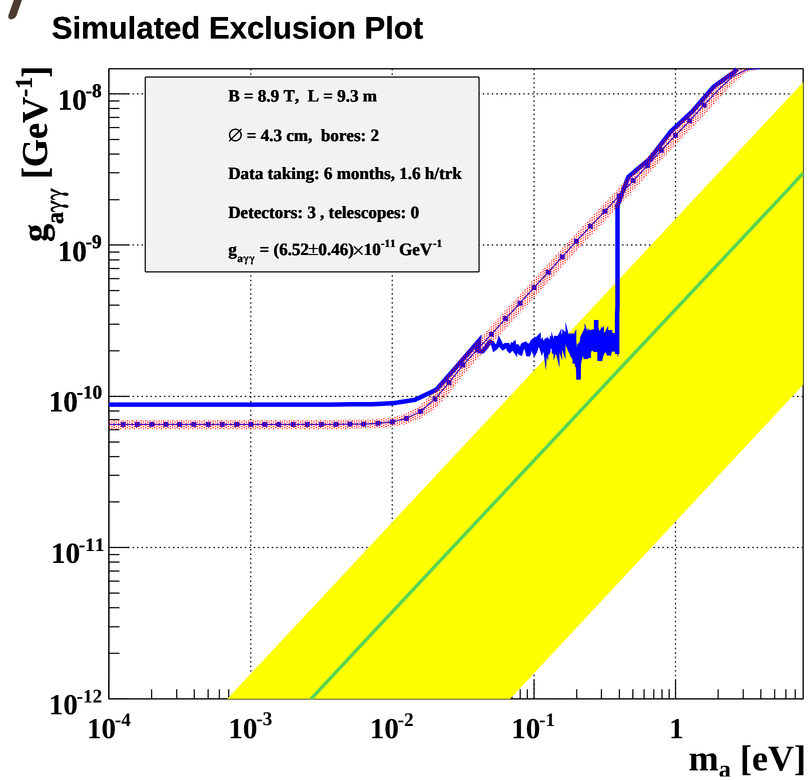
- CAST Phase II has been accepted by CERN up to the end of 2010. However we are encouraged to continue ➔ *new physics program*
- Complete He-3 Run
  - ✓ Scan up to m_a~1.05 eV
  - ✓ Revisit suspicious settings
- Search for other ALPs:
  - ✓ Paraphotons (see talk by K. Zioutas)
  - ✓ Chamelions (see talk by P. Brax)
- Low Energy axions (see talk by G. Cantatore)
- Revisit vacuum phase



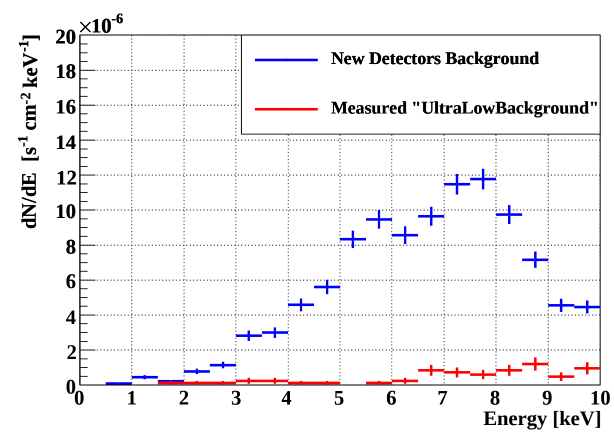
Phys.Lett.B664:180-184,2008, S. Gninenko, J. Redondo

Revisit CAST vacuum phase

- CAST phase I limit determined by X-Ray telescope
- Micromegas developments ➔ 3 additional high performance detectors
- *Measurements of very low background level (~2×10^{-7} s^{-1} cm^{-2} keV^{-1}) ➔ additional sensitivity*



6 months of data taking in Phase I conditions (vacuum) with the new detectors could extend CAST sensitivity well below astrophysical limits (~6.5×10^{-11} GeV^{-1})



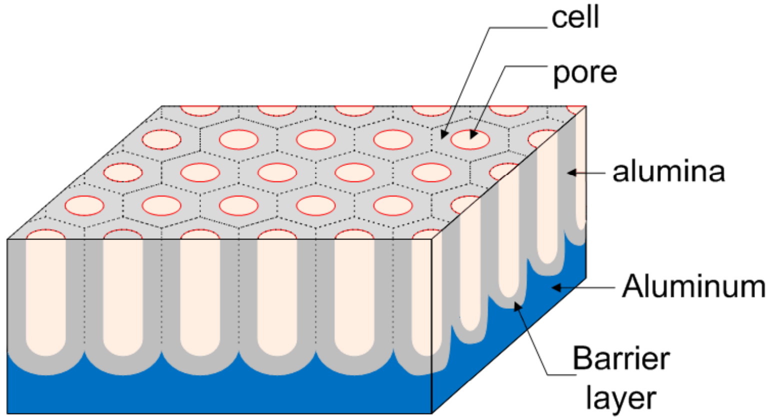
Improvement not so big, but:

- Preparation of new detectors for a future experiment
- Cosmological photon survival puzzle (see F. Avignone's talk)

Low energy axions

- Uniform transverse magnetic field ➔ enhance sensitivity by measuring the photon's linear polarization
- Cover UV range:
  - ✓ micromegas detectors with CsI photocathodes are already under development
- Cover all sub-keV range
  - ✓ Lower detector's threshold
  - ✓ For gaseous detectors it is possible down to eV range, but transparent windows are needed
  - ☞ *Nanotube materials:*
    - ✓ Partially transparent to all photon energies
    - ✓ Small gas conduction

D Anastassopoulos, N. Spiliopoulos, A. Vradis, "Thalis" proposal



A schematic representation of a close-packed array of columnar alumina units. The barrier layer as well as the Aluminum substrate can be removed in a post procedure following the anodization.

Next generation Helioscope

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

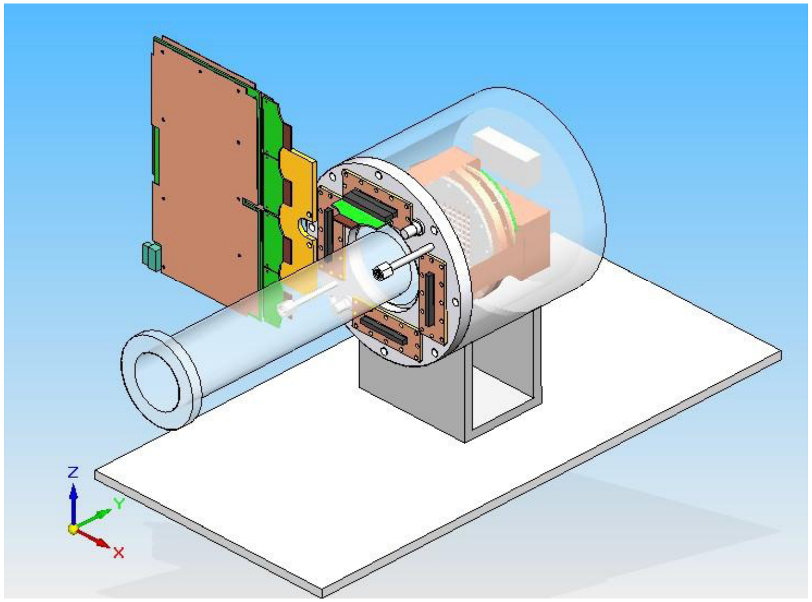
Detector improvements

Dependence $\propto$ 8th root but big margins:

✓ Ultra-Low-Background periods (>1 week each) have been observed with 4 different detectors

Not fully understood yet but:

- Ongoing simulations by Zaragoza group
- Ongoing background measurements in a controlled environment (Canfranc)
- Optimized detector design



✓ New X-ray optics feasible

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

Next generation Helioscope

Coupling constant dependence: $$g_{a\gamma\gamma} \propto \underbrace{(BL)^{1/2} \times A^{1/4}}_{magnet} \times \underbrace{b^{1/8}}_{Detector} \times \underbrace{t^{1/8}}_{\substack{tracking \\ system}}$$

Magnet improvements

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

Increase of tracking time helps but big technical difficulties

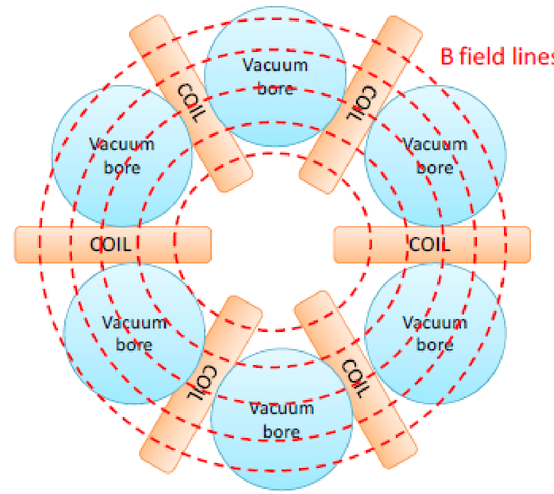
Magnet bore's aperture!

Meetings with CERN magnet experts ➔ alternative configurations

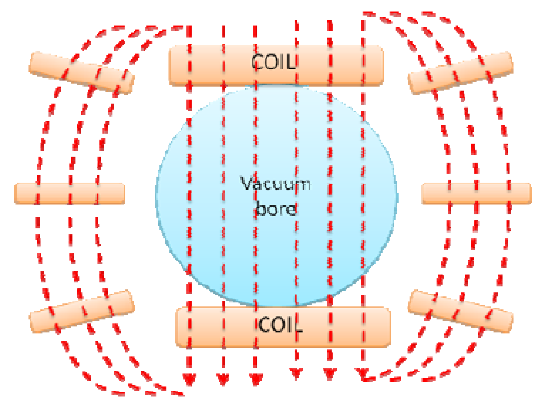
✓ In an axion Helioscope field homogeneity is not as important as in accelerators

✓ An "ATLAS – like" configuration proposed by S. Russenschuck and 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



Feasibility studies have started



Conclusions

CAST, during its 10 years of existence:

- has put the strictest experimental limit on axion searches for a wide m_a range
- is currently testing axion masses inside the region favored by QCD models

New searches for ALPs can start by 2011

CAST Collaboration has gained much experience on Helioscope Axion Searches

Detector development and research on superconducting magnets can lead to more sensitive helioscopes

In combination with Microwave Cavity experiments (ADMX), a big part of QCD favored model region can be swept up to 2020