XLVII Rencontres de Moriond on EW Interactions& Unified Theories

La Thuile, 4rd – 10th March 2012

Results from CAST & other Axion Searches

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Outline

- Axions
  - Physics
  - Motivation
  - The axion to photon coupling
- Axion searches
- Laboratory Experiments: ALPS
- Cold dark matter Axions: ADMX
- Solar Axions: CAST
  - Description
  - Recent Results & prospects
  - The IAXO project
- Conclusions

Axions & the strong CP problem

CP violation is allowed in strong interactions: $\mathcal{L}_{QCD} = \mathcal{L}_{\mathrm{pert}} + \theta \frac{g^2}{32\pi^2} G\widetilde{G}$

Such violation is not observed experimentally!

→ the neutron EDM: $d_n < 3 \times 10^{-26}\ e\ cm$ $\Rightarrow \theta \leq 10^{-10}$

why is θ so small?

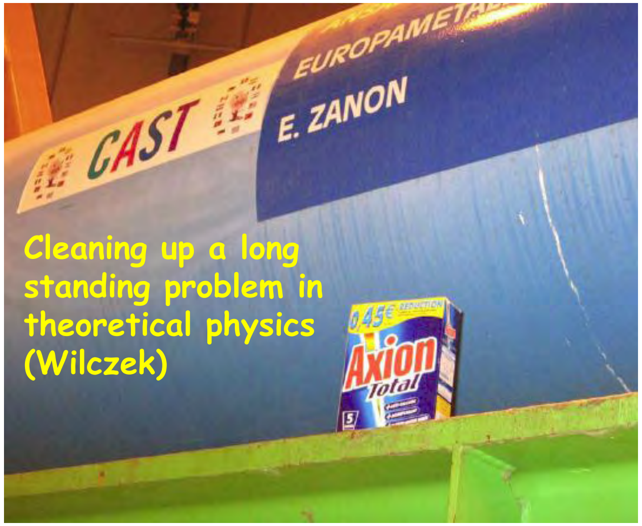
➔ **<u>the strong-CP problem</u>** *the only outstanding flaw in QCD*

The most natural solution: **Peccei-Quinn** global $U(1)_{PQ}$ symmetry broken at a scale f_{PQ},

Appearance of a new field : **Axion field**

$\Rightarrow$ A new pseudoscalar particle the **axion**,

with mass: $m_a = m_\pi \frac{f_\pi}{f_{PQ}} = 6\,\mathrm{eV}\,\frac{10^6\,\mathrm{GeV}}{f_{PQ}}$



All the axion couplings are inversely proportional to f_{PQ}^2 $(\equiv f_a^2)$

Axion summary

Axion properties

- neutral pseudoscalar,
- practically stable,
- very low mass,
- very low interaction cross-sections
  - ➔ Nearly invisible to ordinary matter

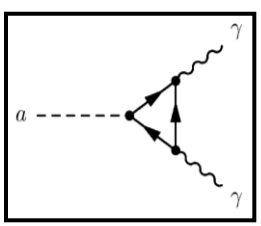
Axion origin

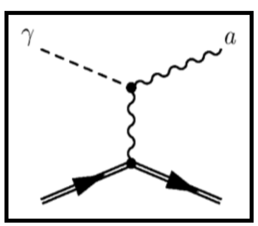
- Cosmological axions (cold dark matter)
- Solar axions

Axions couple to photons

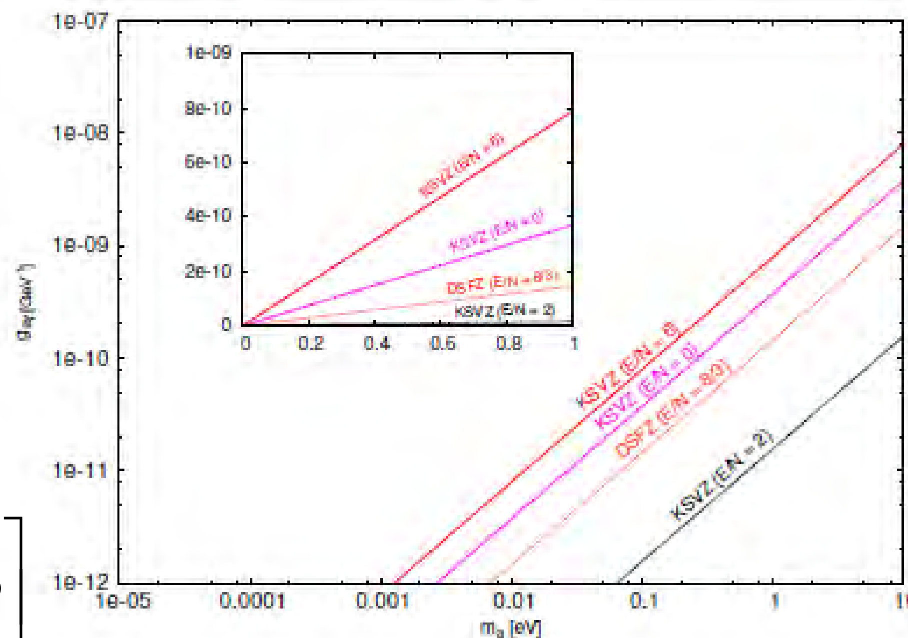
$$L_{a\gamma} = g_{a\gamma}(\boldsymbol{E \bullet B})\, a$$

(PRIMAKOFF EFFECT)



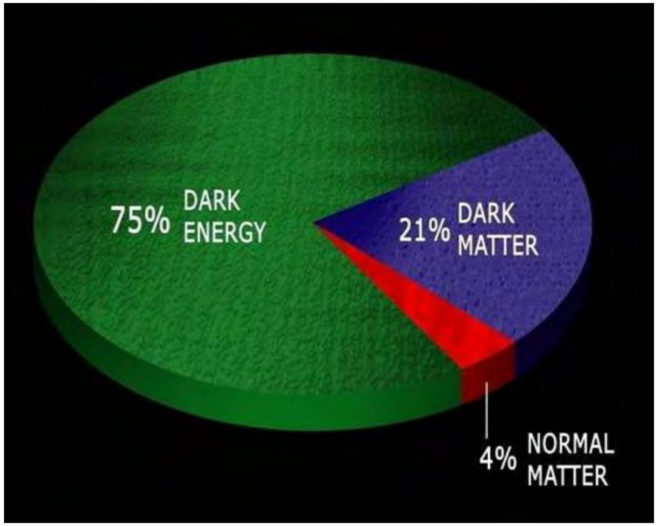


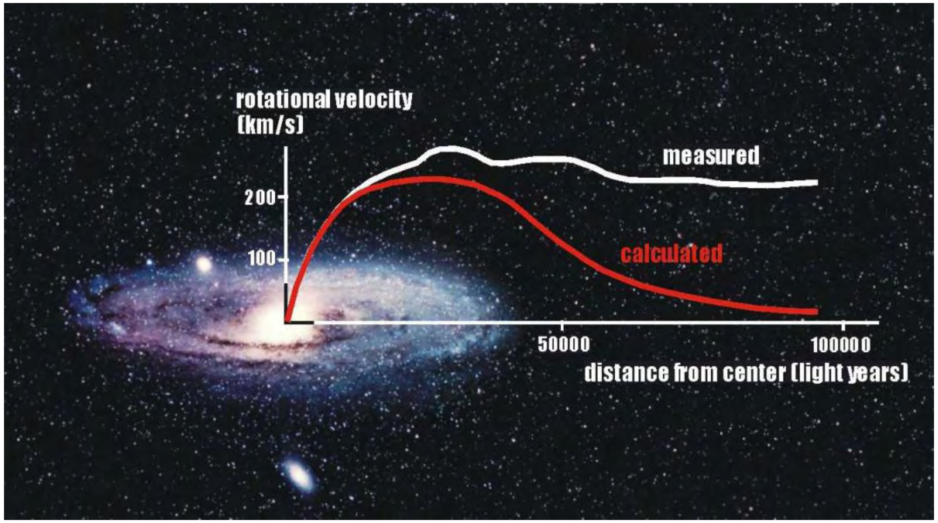
QCD models: $g_{a\gamma} = \frac{\alpha}{2\pi f_a}\left[\frac{E}{N} - 1.92 \pm 0.08\right]$



Open questions: dark matter

- Dark matter seems to consist ~21% of the universe, dominating the dynamics of galaxies and clusters of galaxies.
- The axion (*or ALPs*) is an excellent dark matter candidate

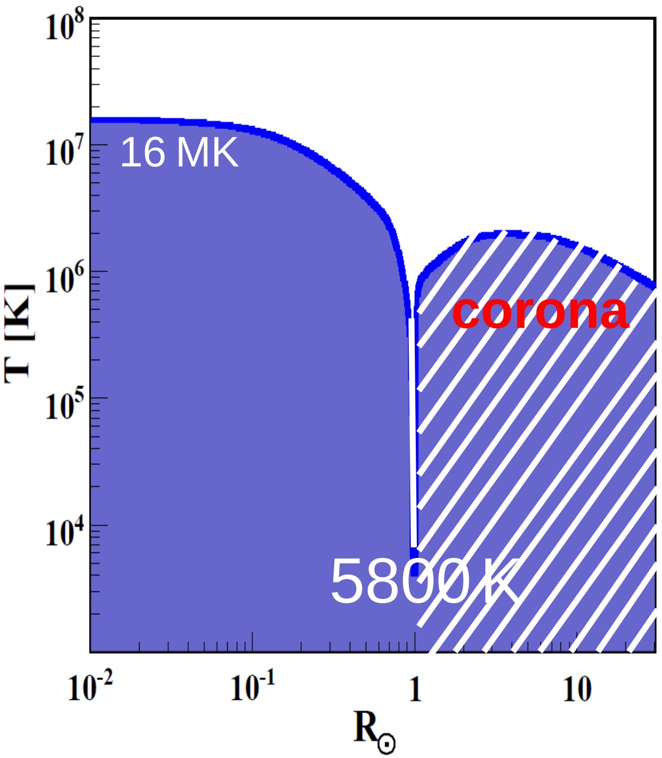


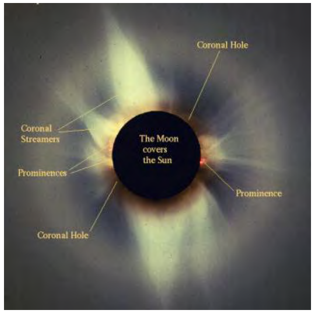


http://cdms.phy.queensu.ca/Public_Docs/Pictures/Rotationcurve_3.jpg

Open questions: the sun

- The solar corona heating

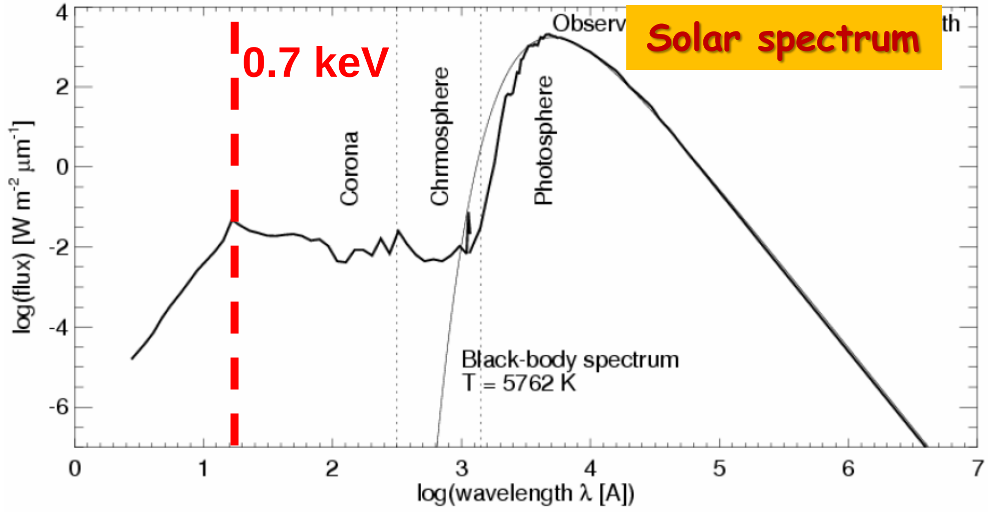




How is energy transferred into the corona?

- The solar spectrum

How can one understand the **X-ray emission**, especially of the **quite sun**?

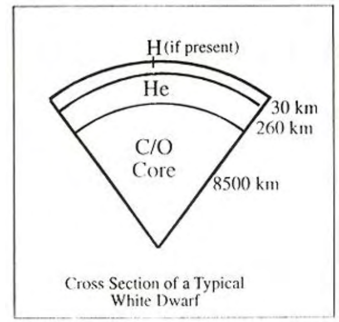


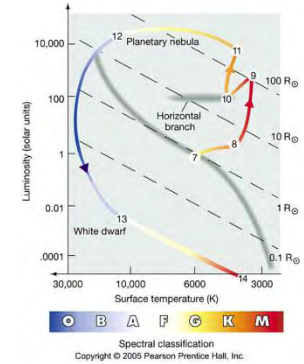
Is there a new mechanism transporting energy from the core to the surface?

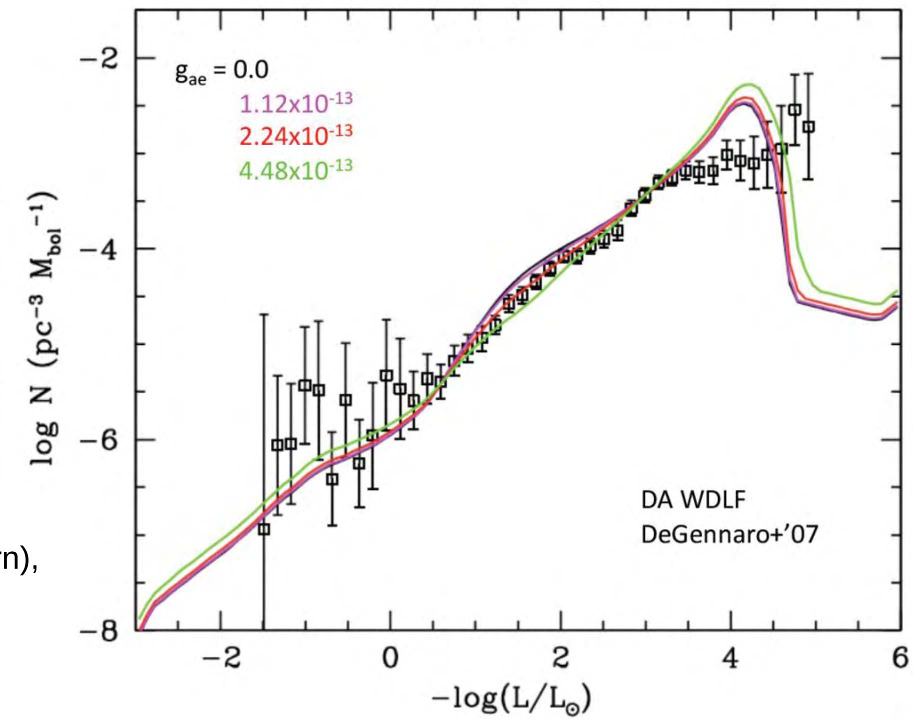
Open questions: white dwarfs

- White dwarfs cool too fast!
  - Observed in individual cases.
  - Seen in samples.

- Is there an unknown energy loss channel at work?
  - *Emission of axions?*







White dwarfs as physical laboratories: the axion case (J. Isern), 7th Patras Workshop on Axions, WIMPs and WISPs, http://axion-wimp.desy.de

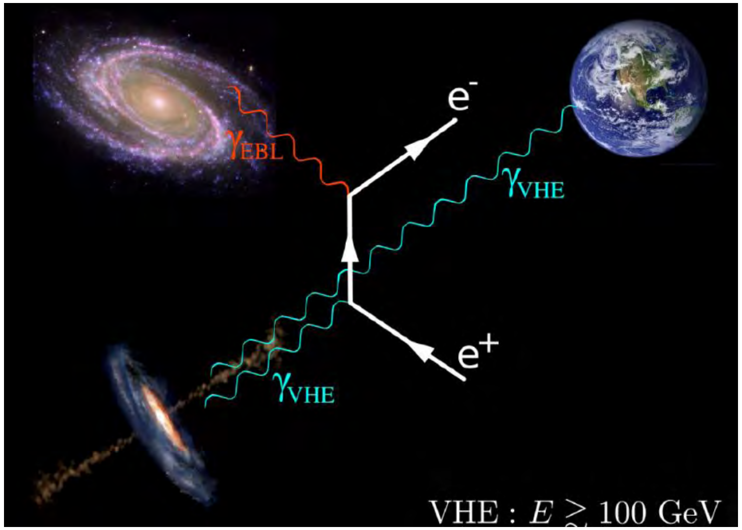
Open questions: TeV γ propagation

TeV photons should be absorbed by e^+e^- pair production due to interaction with the extragalactic background light (EBL):

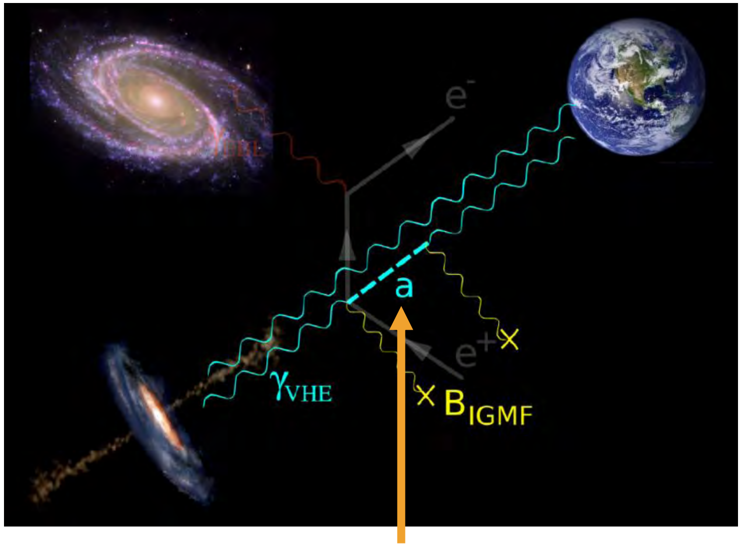
$\gamma_{TeV} + \gamma_{eV} \rightarrow e^+ + e^-$

However, the TeV spectra of distant galaxies extend deep into the optical thick regions.

Could an axion or a Weakly Interacting Slim Particle, (WISP) be involved?



M. Meyer, 7th Patras Workshop on Axions, WIMPs and WISPs, 2011



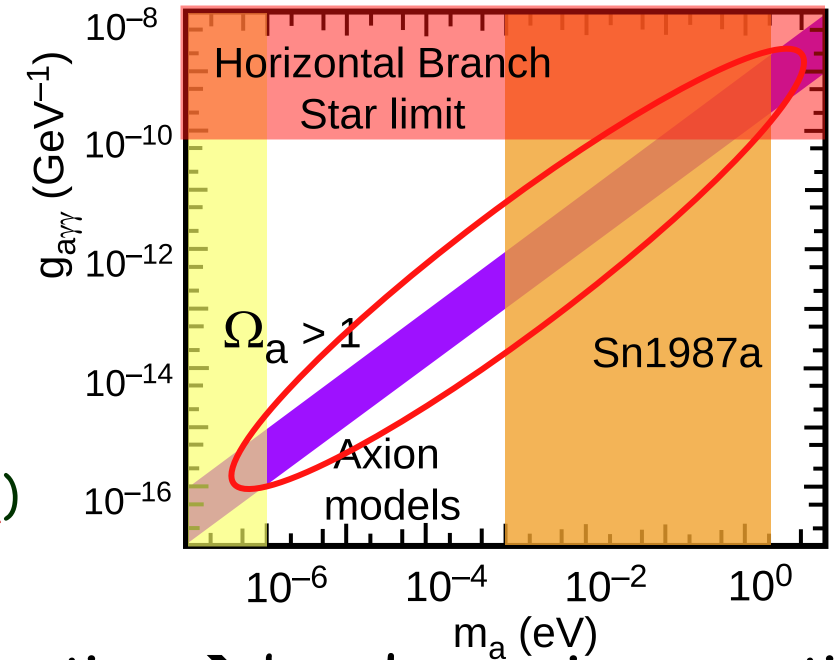
TeV photons may "hide"

Axion searches

Search for **axion couplings**, most commonly the **axion to photon**

Parameter space:

(coupling constant $g_{a\gamma}$ & axion mass m_a)

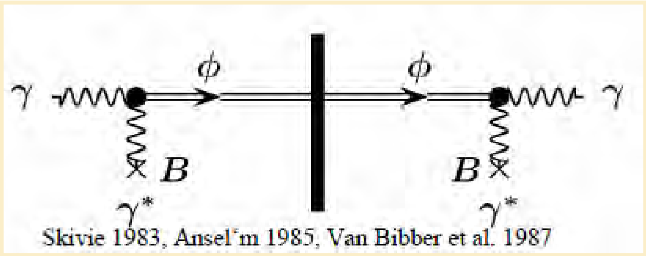


Cosmological & Astrophysical observations ➔ bounds on axion properties

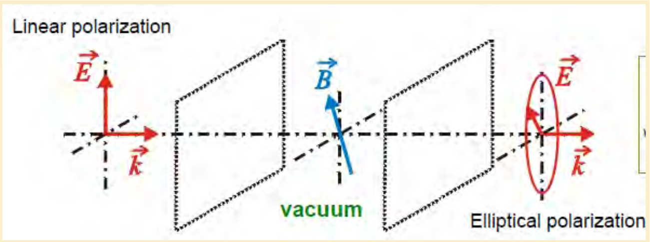
1. **Sun lifetime.** $g_{a\gamma} \approx 2 - 5 \cdot 10^{-6}\,\mathrm{GeV}^{-1} \longrightarrow$ 1000 years
2. **Stellar evolution. Globular clusters.** $g_{a\gamma} \leq 10^{-10} GeV^{-1}$
3. **White dwarf cooling.** Axion would affect rotation frequency evolution.
4. **Supernova Sn1987a.** ν pulse precludes NN→NNa for $m_a \sim 10^{-(3-0)}$ eV.
5. **Overclosure.** $\Omega_a \propto fa^{\frac{7}{6}} \rightarrow m_a \geq 1\mu eV/c^2$

Experimental axion searches

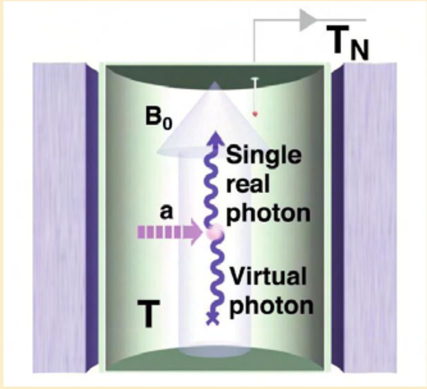
- **Laser experiments (*laboratory*):**
  - Photon regeneration – "invisible light shining through wall" (ALPS,OSCAR,LIPSS,GammeV...)



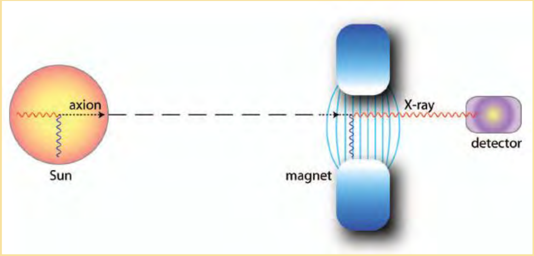
  - Polarization experiments (PVLAS)



- **Search for dark matter axions:**
  - Microwave cavity experiments (ADMX)



- **Search for solar axions:**
  - Bragg + crystal (SOLAX, COSME, DAMA)
  - Helioscopes (SUMIKO, ***CAST***)



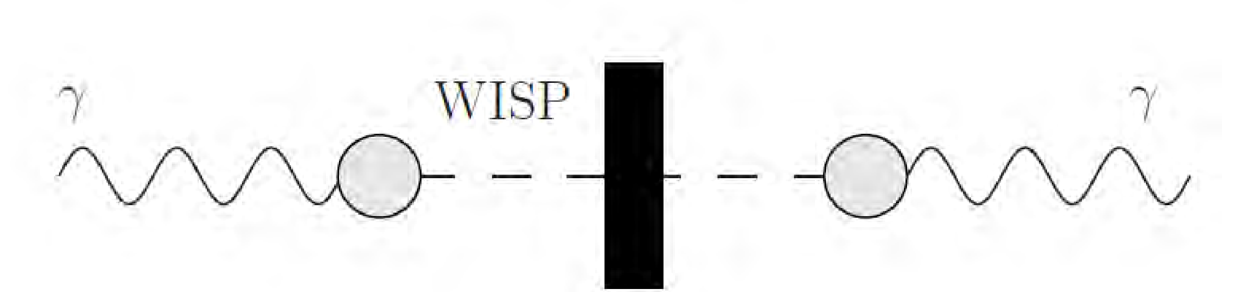
The ALPS Experiment

Any **L**ight **P**article **S**earch @ DESY: ALPS-I concluded in 2010

Courtesy of **Axel Lindner, DESY**

The ALPS Experiment

Any **L**ight **P**article **S**earch @ DESY: ALPS-I concluded in 2010

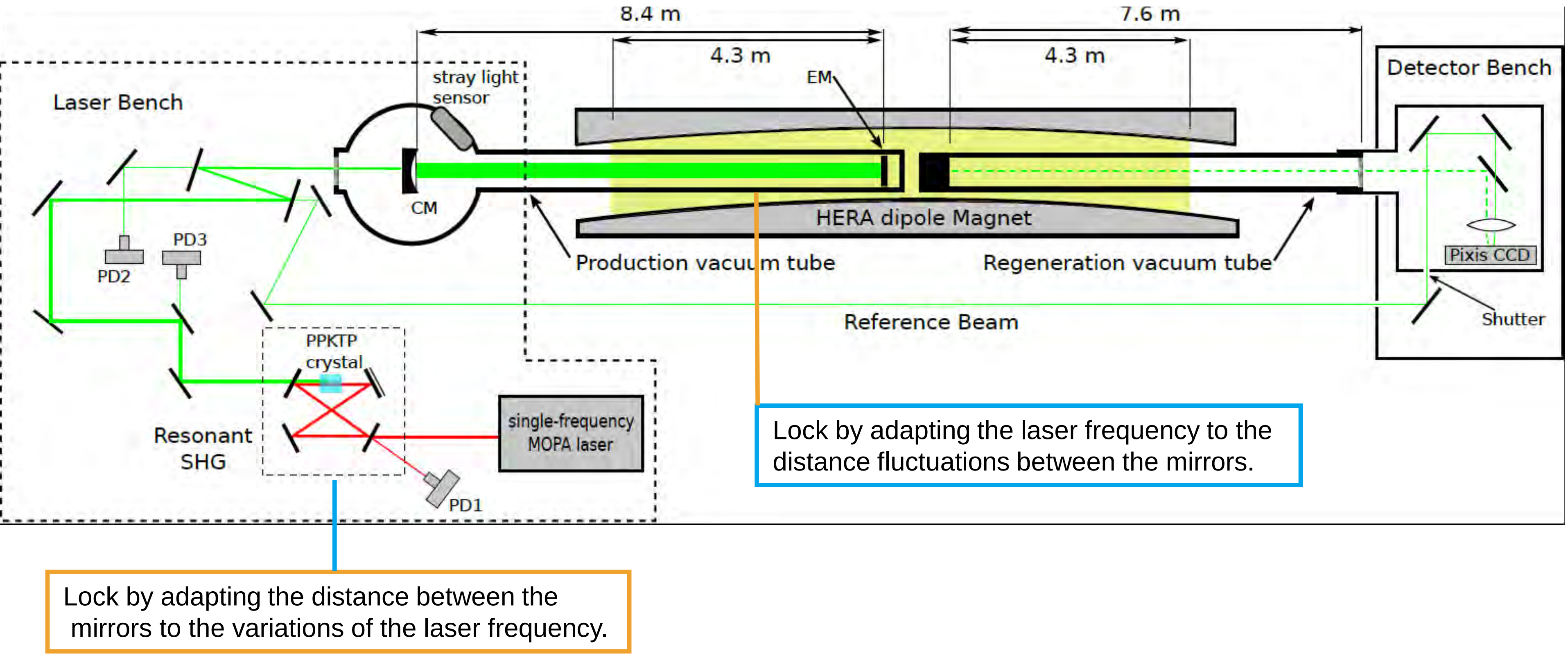


"Light-shining-through-a-wall" (LSW)

Courtesy of **Axel Lindner, DESY**

The ALPS-I experiment

New: realize an optical resonator inside the HERA dipole!



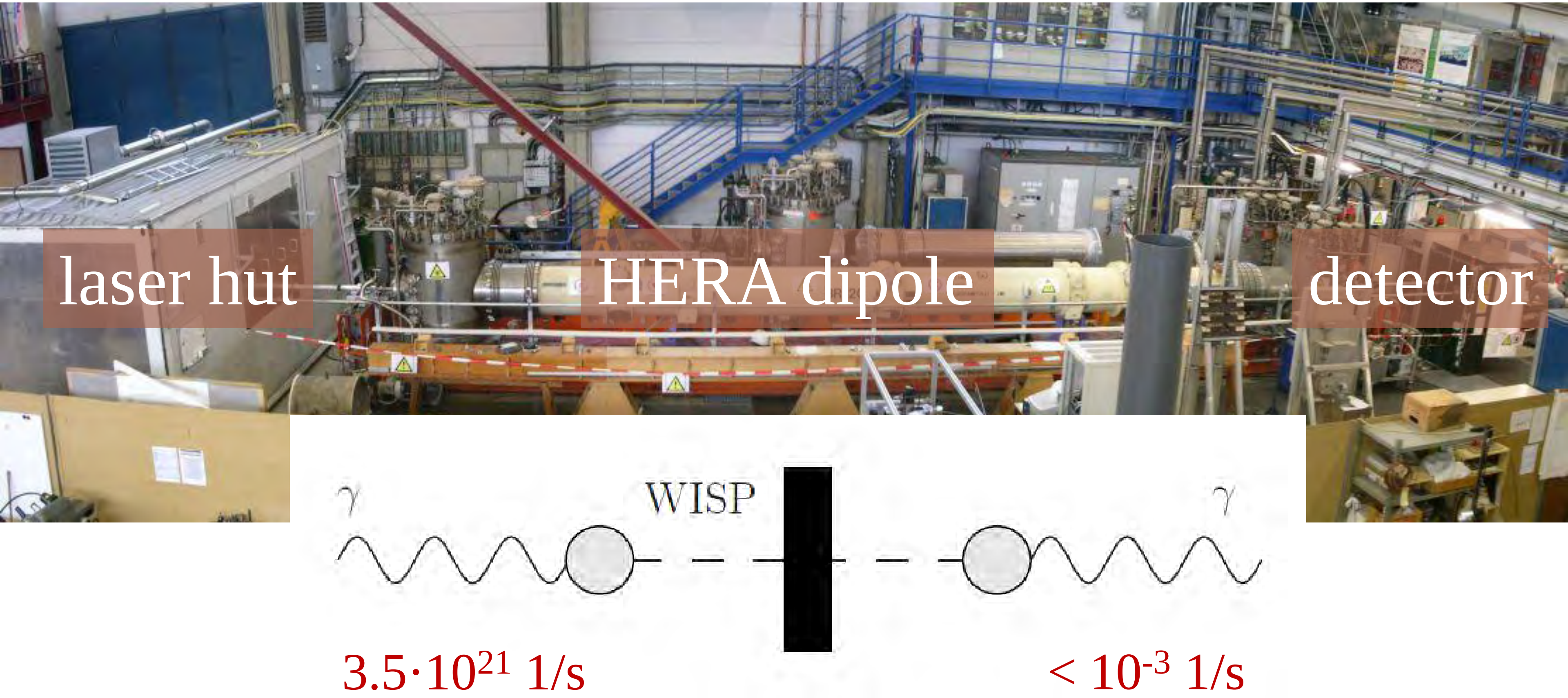
Limitation: power density on the mirrors of ≈ 50 kW/cm² (532 nm).

Courtesy of **Axel Lindner, DESY**

ALPS-I results

(PLB Vol. 689 (2010), 149, or http://arxiv.org/abs/1004.1313)

- *Unfortunately, no light was shining through the wall!*

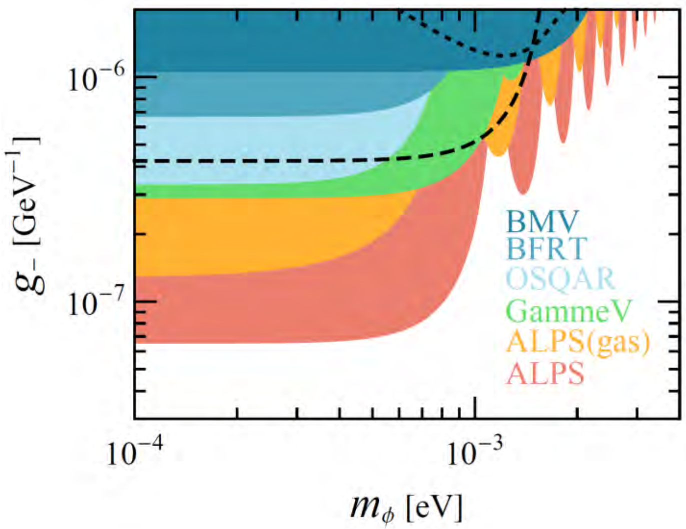


Courtesy of **Axel Lindner, DESY**

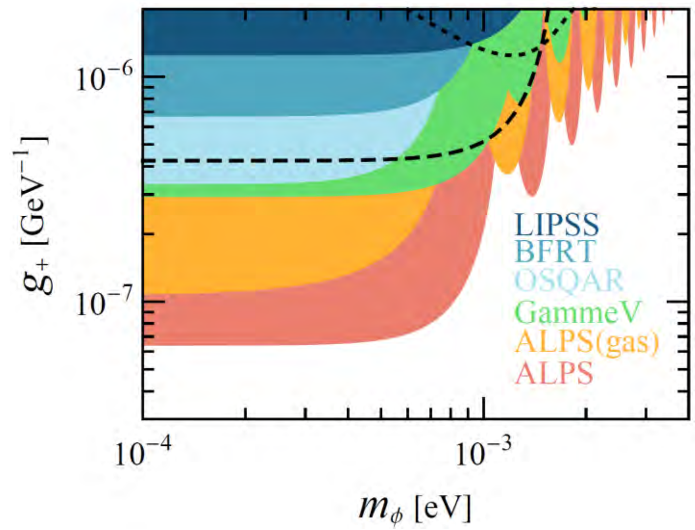
ALPS-I results

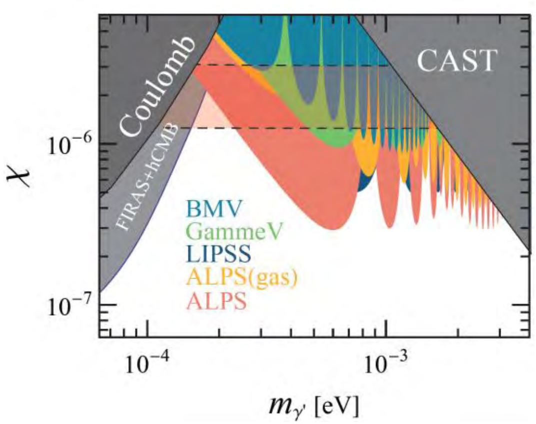
(PLB Vol. 689 (2010), 149, or http://arxiv.org/abs/1004.1313)

- ALPS is the most sensitive experiment for WISP searches in the laboratory.



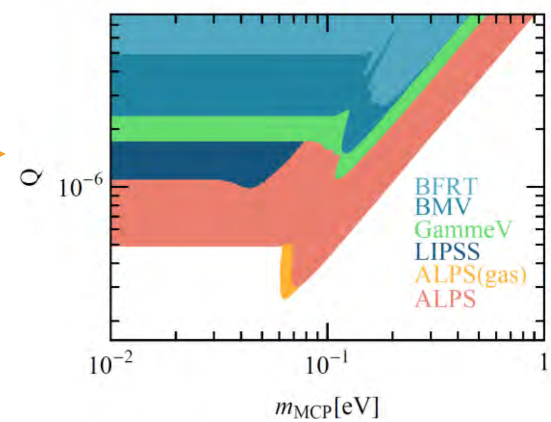
pseudoscalar
and
scalar
axion-like particles





hidden sector photons
and
minicharged particles

Filling a gap remaining from astrophysics and other experiments!

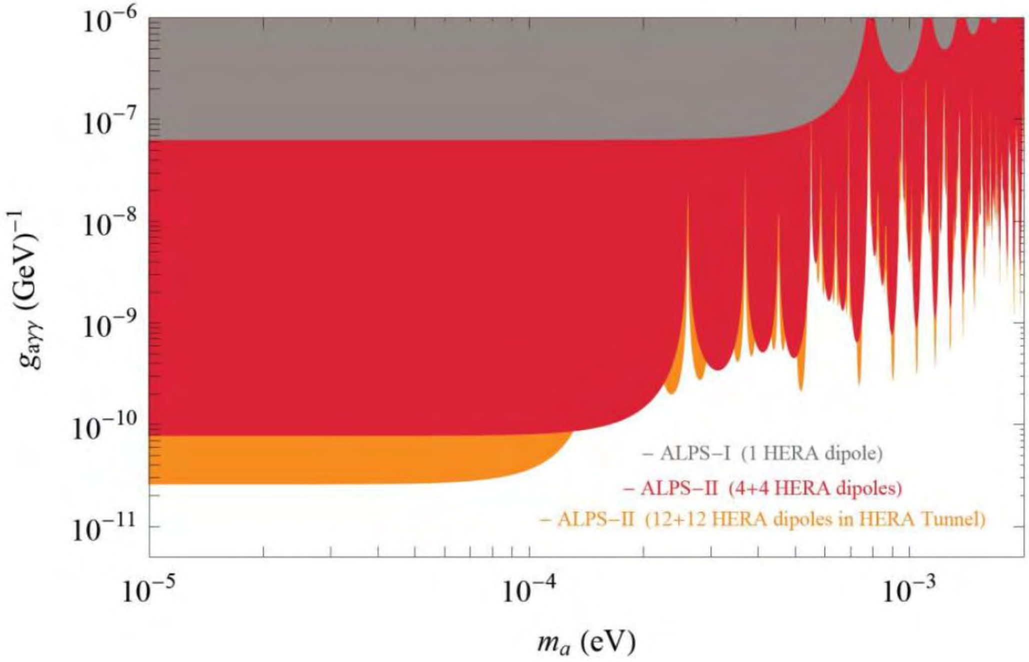


Courtesy of **Axel Lindner, DESY**

The ALPS-II potential and summary

Goal: reaching the region close to 10^{-11} GeV^{-1} in 2017 to probe astrophysical phenomena.

- Laser with optical cavity to recycle laser power, switch from 532 nm to 1064 nm, increase effective power from 1 to 150 kW.
- Magnet: upgrade to 12+12 straightened HERA dipoles instead of $\frac{1}{2}+\frac{1}{2}$ used for ALPS-I.
- Regeneration cavity to increase WISP-photon conversions, single photon counter (*superconducting transition edge sensor?*)



Main challenges:

Getting the optical system running (at present no show stopper found)

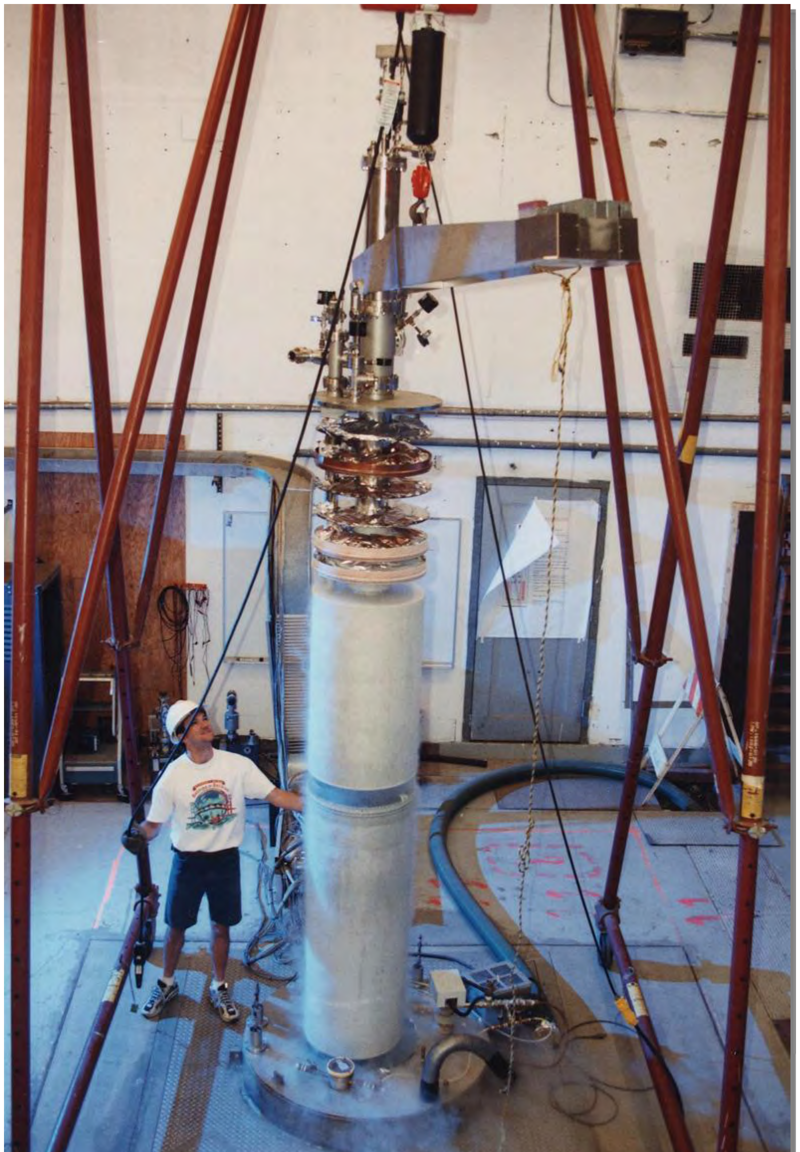
Getting the HERA dipoles straight (at present no show stopper found)

Getting a TES detector running (first success)

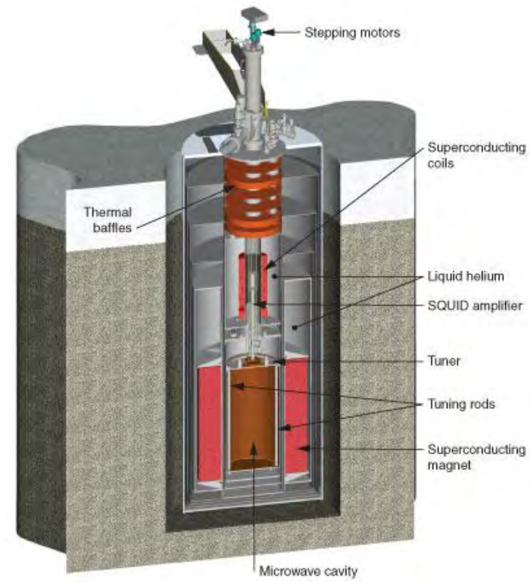
Setting up a 260 m long system (surveys under way, decision expected for 2015)

Courtesy of **Axel Lindner, DESY**

The Axion Dark Matter eXperiment



ADMX: Existing experiment at Washington university.



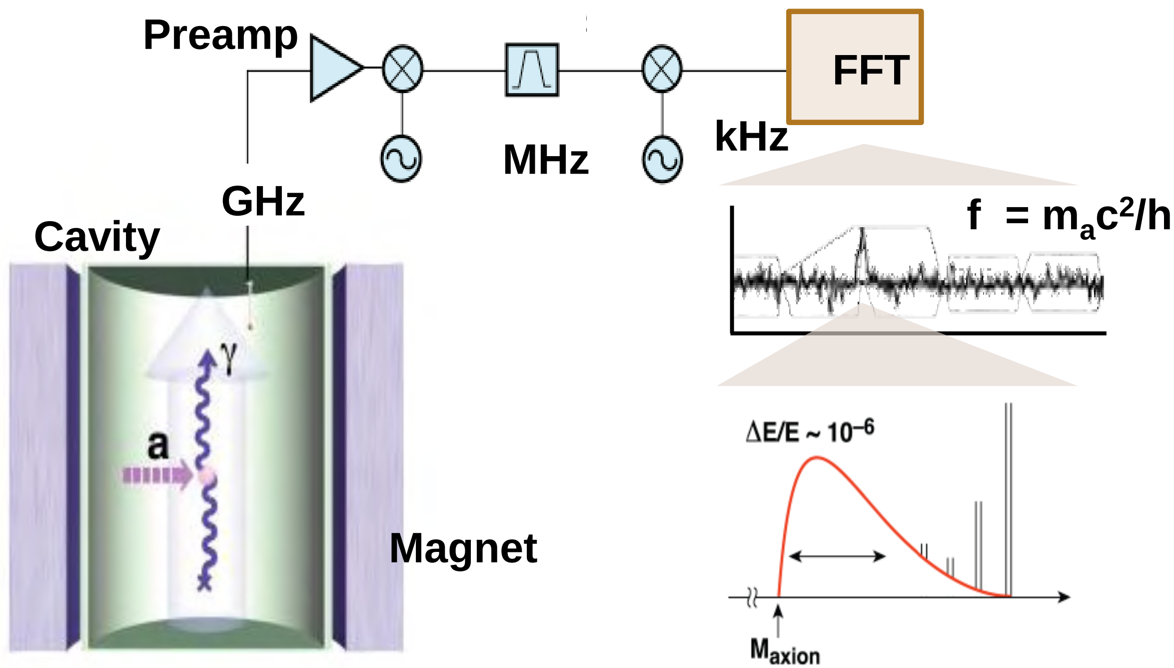
ADMX-HF in preparation at Yale.

- Both experiments could probe a large part
  of the parameter space for dark matter axions!

Courtesy of **Karl van Bibber UC Berkeley**

ADMX: search for cold dark matter axions

- Due to the low axion mass, cold dark matter can not be detected by recoil techniques.
- Dark matter axions (*or WISPs*) have to convert into photons in a thoroughly shielded environment.
- The mass of the dark matter particle determines the energy to be detected. For axions it is in the **microwave range**.



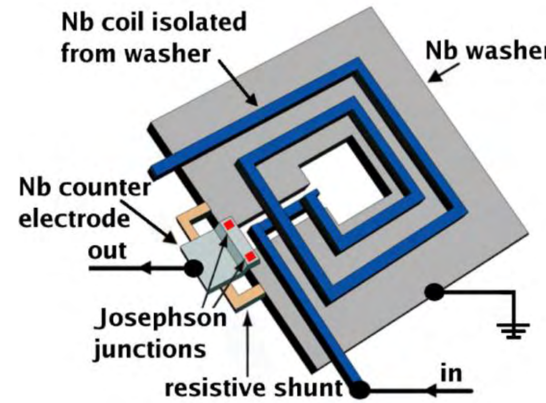
$$P_{sig} \propto (B^2 V Q_{cav})(g^2 m_a \rho_a) \sim 10^{-23}\ W \qquad s/n = \frac{P_{sig}}{kT_{sys}}\sqrt{\frac{t}{\Delta\nu}}$$

Courtesy of **Karl van Bibber UC Berkeley**

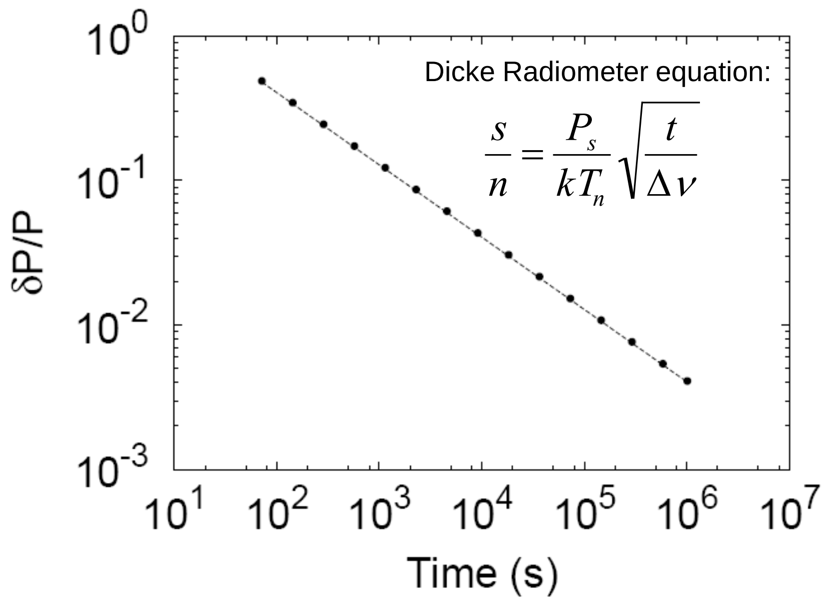
ADMX sensitivity

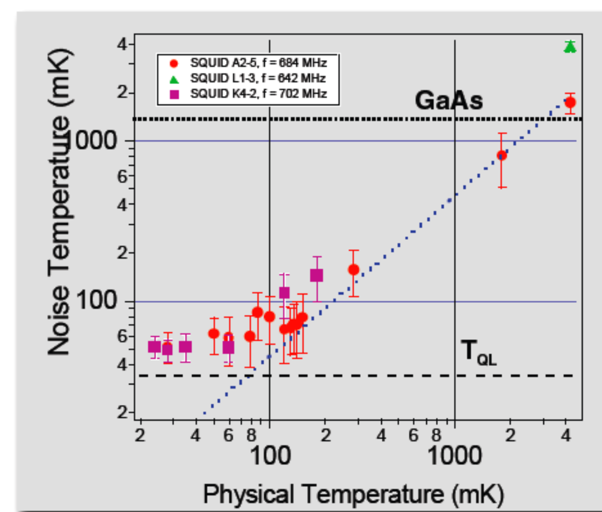
Microstrip SQUID amplifiers (John Clarke, UCB Physics)

Operation at ~1 K



ADMX is the world's quietest spectral receiver:
Sensitive to **one RF photon every two weeks**



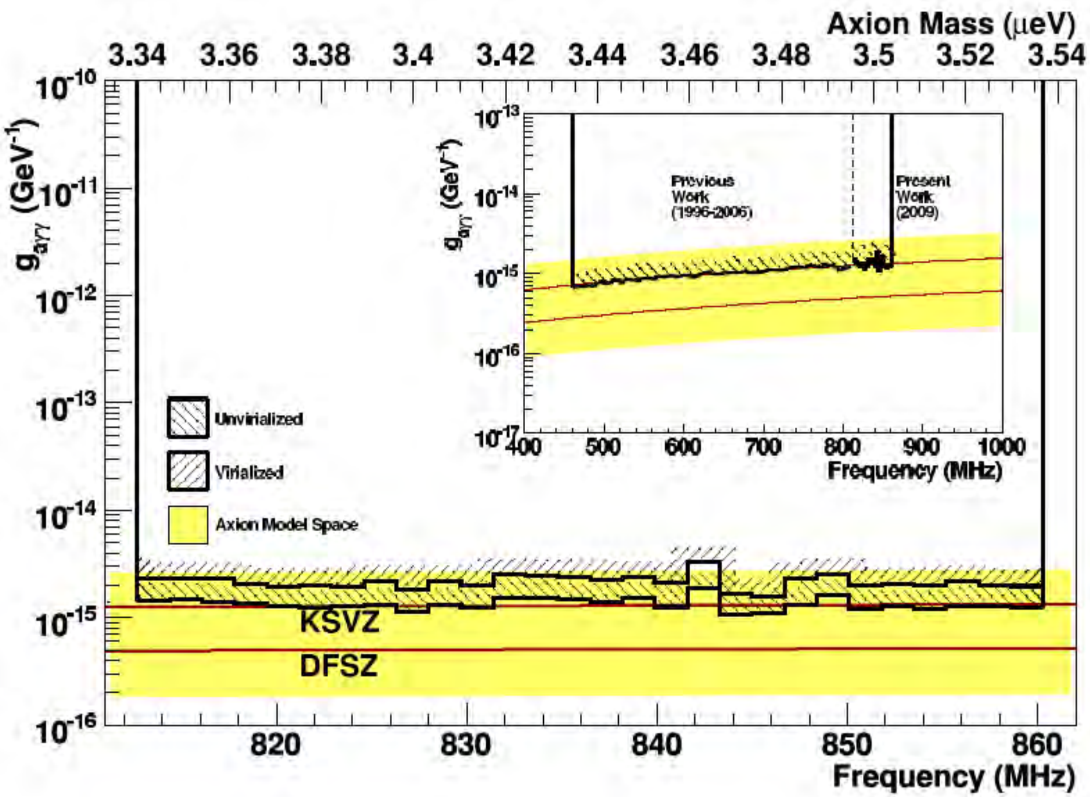


More than an order of magnitude quieter than current GaAs HFET amplifier

Courtesy of **Karl van Bibber UC Berkeley**

ADMX results

So far, no axion over an octave in mass! (1.9 - 3.6 μeV)



Need to push the experiment on two fronts:

Reduce System Temperature

ADMX Phase II: add Dilution Refrigerator

Go up (& down) in Frequency

ADMX-HF (High Frequency): smaller microwave cavities

PRL 80 (1998) 2043
PRD 64 (2001) 092003
ApJ Lett 571 (2002) 27
PRD 69 (2004) 011101(R)
PRL 95 (9) 091304 (2005)
PRD 74 (2006) 012006
PRL 104 (2010) 041301

$$T_{Sys} = T + T_N \quad , \quad T_N^{Squid} \propto T$$

Courtesy of **Karl van Bibber UC Berkeley**

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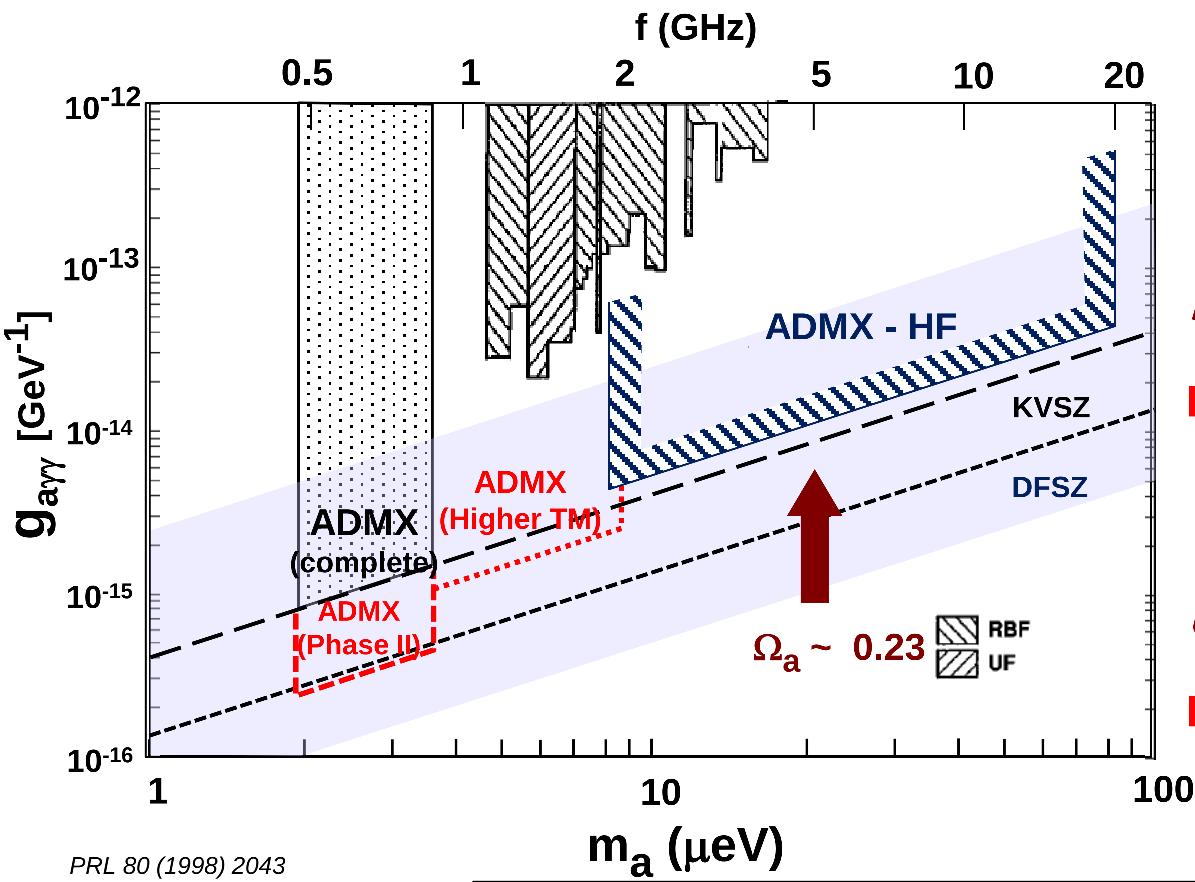

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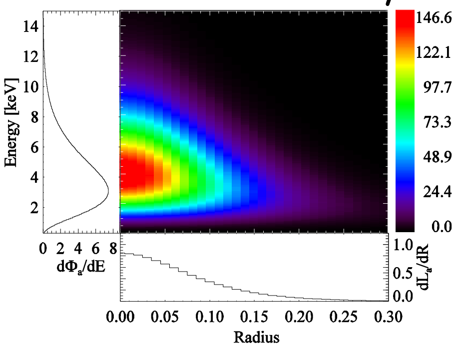
$$T_{Sys} = T + T_N \quad , \quad T_N^{Squid} \propto T$$

Courtesy of **Karl van Bibber UC Berkeley**

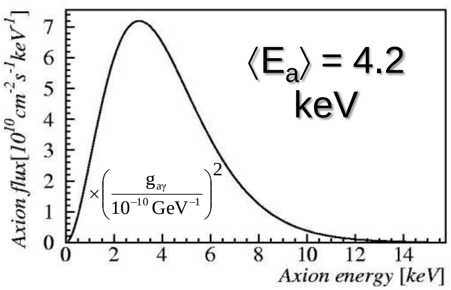
CAST: a helioscope "a la Sikivie"

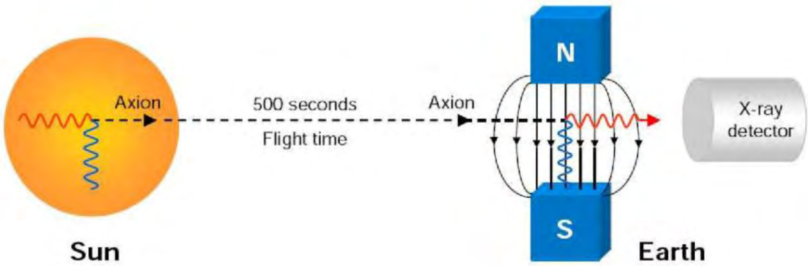
Axions would be **produced in the Sun's core** and re-converted **to x-rays** inside an **intense magnetic field**. *P. Sikivie, Phys. Rev. Lett. 51, 1415-1417 (1983)*

Solar axion luminosity



Axion flux on earth





CAST is using a prototype superconducting LHC dipole magnet able to track the Sun for about 1.5 hours during Sunrise and Sunset.
Operation at T=1.8 K, I=13,000A, B=9T, L=9.26m

Expected signal

X-Ray excess during tracking
at 1-10 keV region

CAST sensitivity per detector

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

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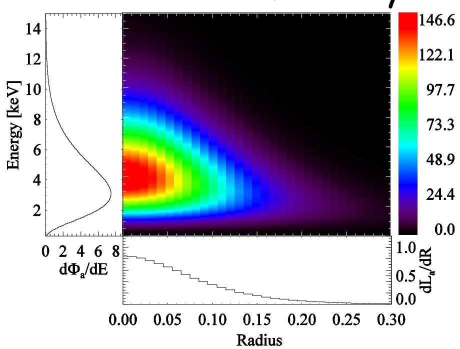
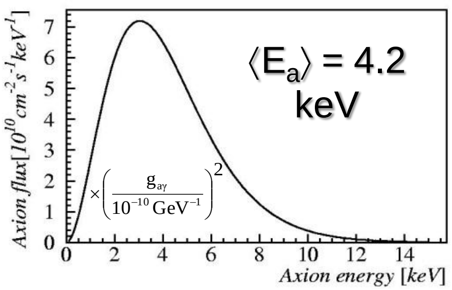
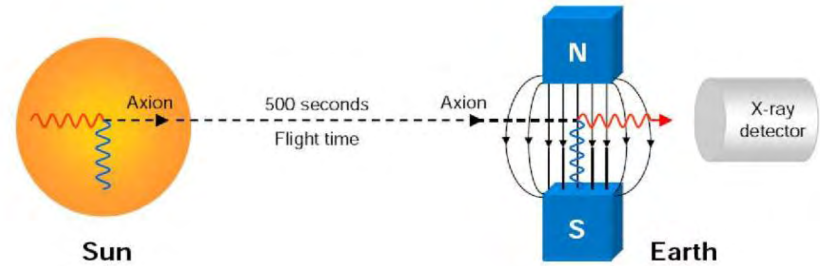


Axion flux on earth





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Operation at T=1.8 K, I=13,000A, B=9T, L=9.26m

Low X-ray background detectors required to observe a signal.

CAST sensitivity per detector

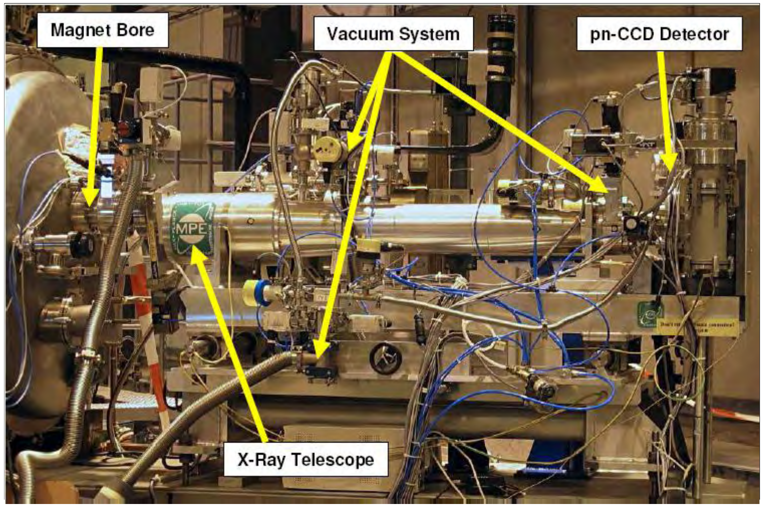
0.3 counts/hour for
$g_{a\gamma\gamma} = 10^{-10}$ GeV^{-1} and $A = 14.5$ cm^2

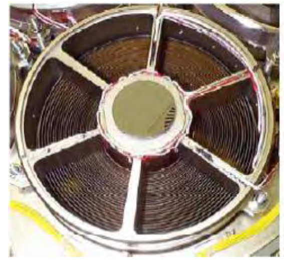
CAST detectors

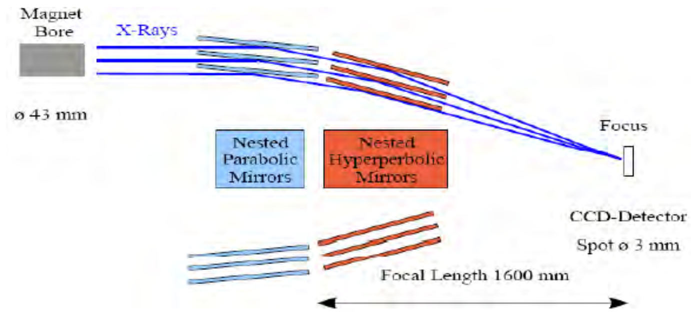
Sunrise side

CCD + X-Ray Telescope

(prototype for the ABRIXAS Space mission)



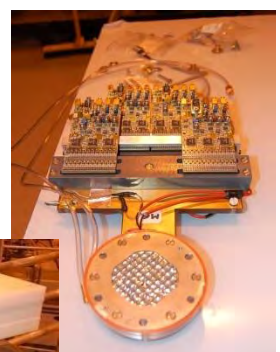


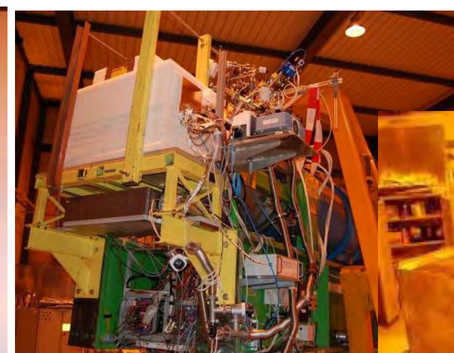


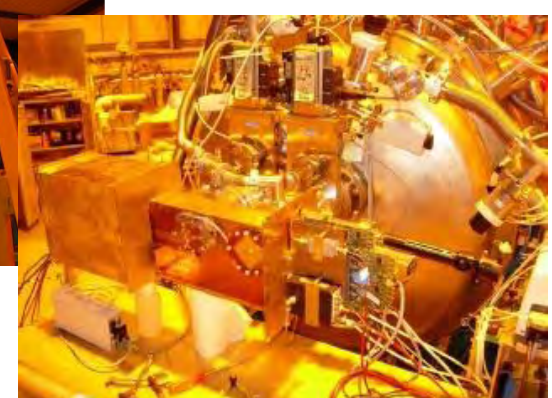
	Typical rates
TPC	*85 counts/h (2-12 keV)*
MM	*25 counts/h (2-10 keV)*
CCD	**0.18 counts/h (1-7 keV)**
New MM	**1-2 counts/h (1-7) keV**

Sunrise side Micromegsas detector

Sunset side Micromegas detectors







CAST physics program & main results

Proposal approved by CERN (13th April 2000)

Commissioning (2002)

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

CAST Phase II: (2005–2011)

^{4}He run, (2005–2006) *completed*

0.02 eV < m_a < 0.39 eV

^{3}He run (2007-2011) *completed*
ongoing analysis

0.39 eV < m_a <~1.20 eV

Low energy axions (2007 - 2011) in parallel with the main program

~ few eV range

April 2011: Proposal to SPSC for 2012-2014
Start of 3rd CAST phase,
solar axions & chameleons

For m_a < 0.02 eV:

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

JCAP04(**2007**)010, CAST Collaboration

PRL (**2005**) 94, 121301, CAST Collaboration

For m_a < 0.39 eV typical upper limit:

$$g_{a\gamma} < 2.2 \times 10^{-10}\ GeV^{-1}$$

JCAP 0902:008,**2009**, CAST Collaboration

For 0.39 < m_a < 0.64 eV typical limit:

$$g_{a\gamma} < 2.1 \times 10^{-10}\ GeV^{-1}$$

PRL (**2011**) 107, 261302, 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)

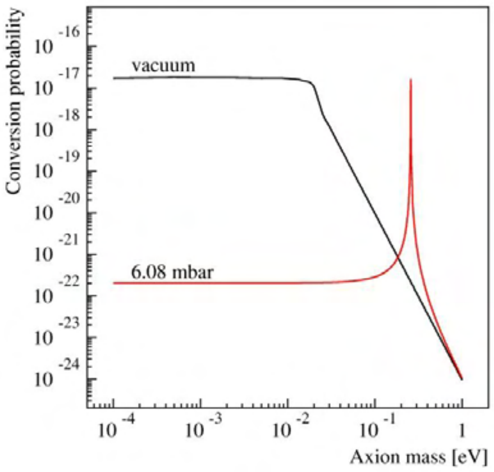
Low Energy (visible) Axions: Data taking with a PMT/APD. (arXiv:0809.4581)

CAST sensitivity

Axion to photon conversion probability:

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

Vacuum:
Γ=0, m_γ=0



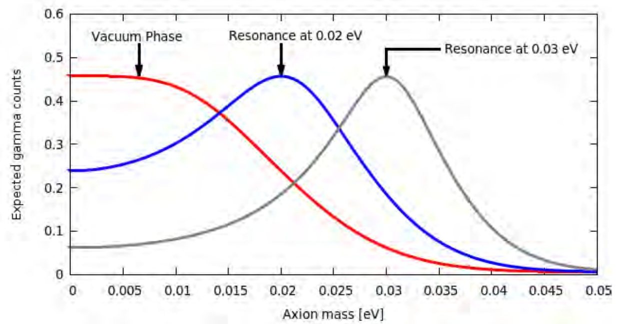
Coherence condition: $qL < \pi$, $|q| = \frac{m_a^2}{2E}$

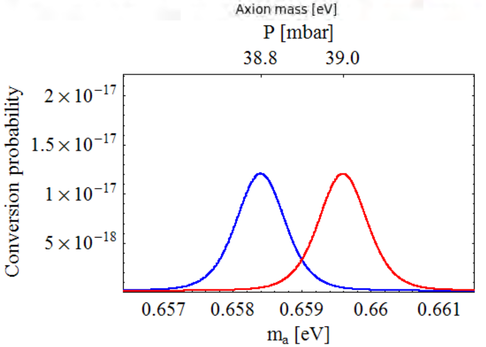
For CAST phase I conditions (vacuum), **coherence is lost for m_a > 0.02 eV**.

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

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

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



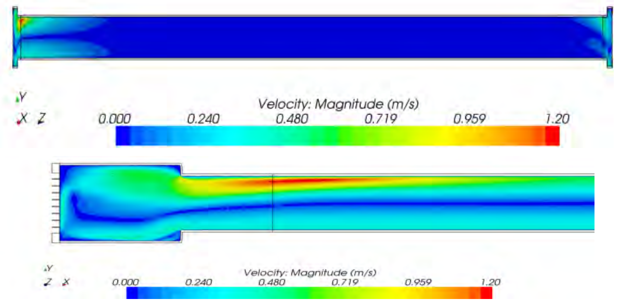


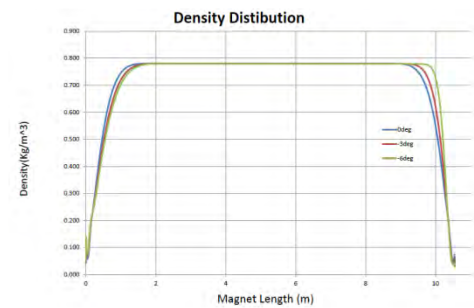
For P~50 mbar Δm_a ~ 10^{-3} eV

- New discovery potential for each density (pressure) setting

Using a buffer gas…

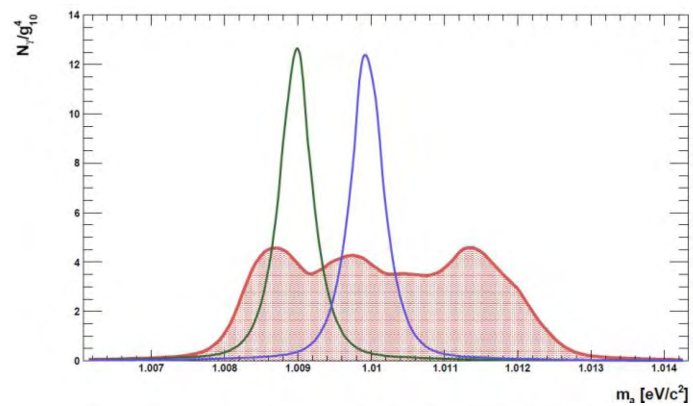
- Precise knowledge and/or **reproducibility** of each pressure setting is essential
- Gas **density homogeneity** along the magnet bore during tracking is critical
  - ✓ **Supperfluid** ^{4}He @ 1.8 ➔ **temperature stability** along the cold bore
  - ✓ Hydrostatic pressure effects are not critical
  - × parts of the magnet bores, outside the magnetic field region, in higher temperatures. **Variations during tracking, depended on the buffer gas density**





To face that situation we:

- Precise **measurement of the amount of gas** ejected into the cold bores
- Installed **temperature and pressure sensors** at several points
- **Computational Fluid Dynamics Simulation** with the **sensors' data as bounding conditions**

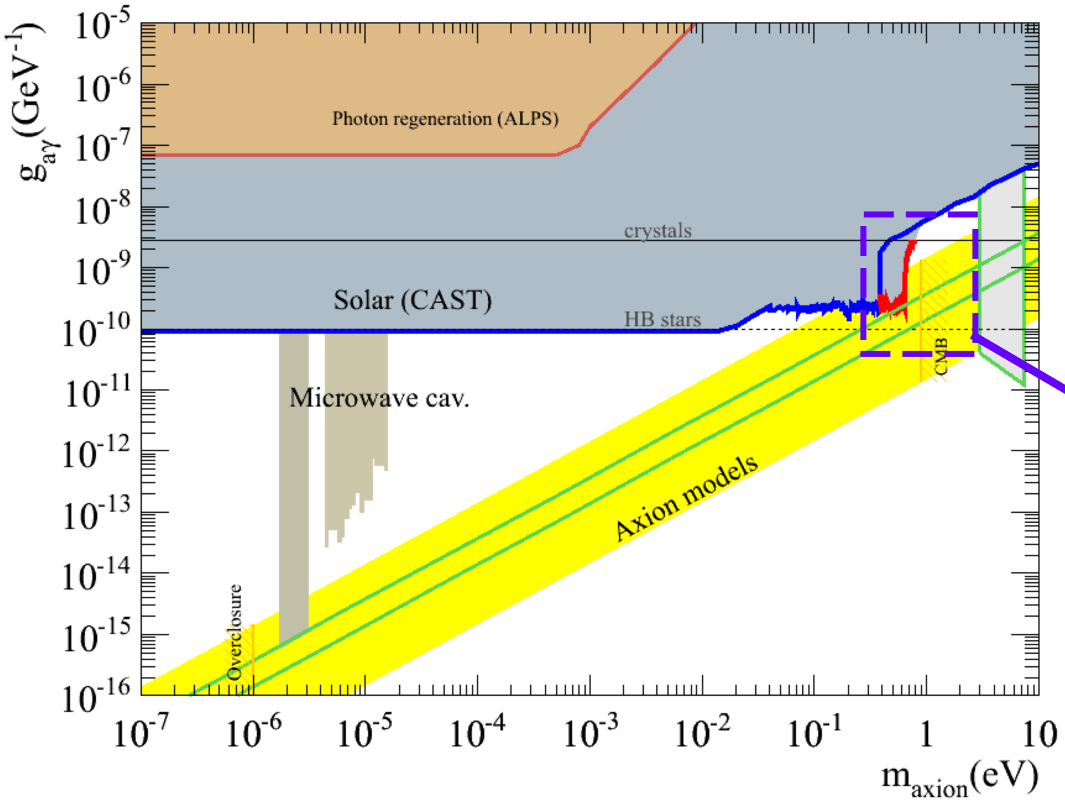


Variation of gas density during tracking ➔ m_a scanning!

new formulation of the binned likelihood:

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

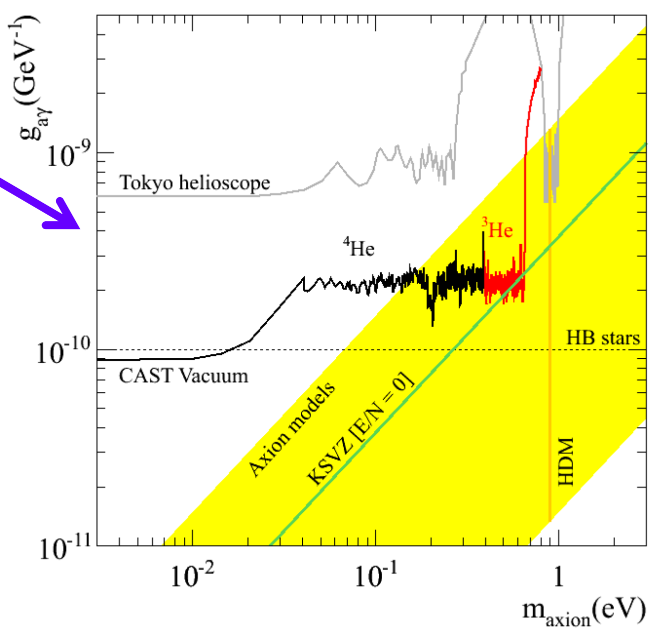
CAST latest results (published)



For 0.39 <m_a < 0.64 eV typical limit:

$$g_{a\gamma} < 2.1 \times 10^{-10}\ GeV^{-1}$$

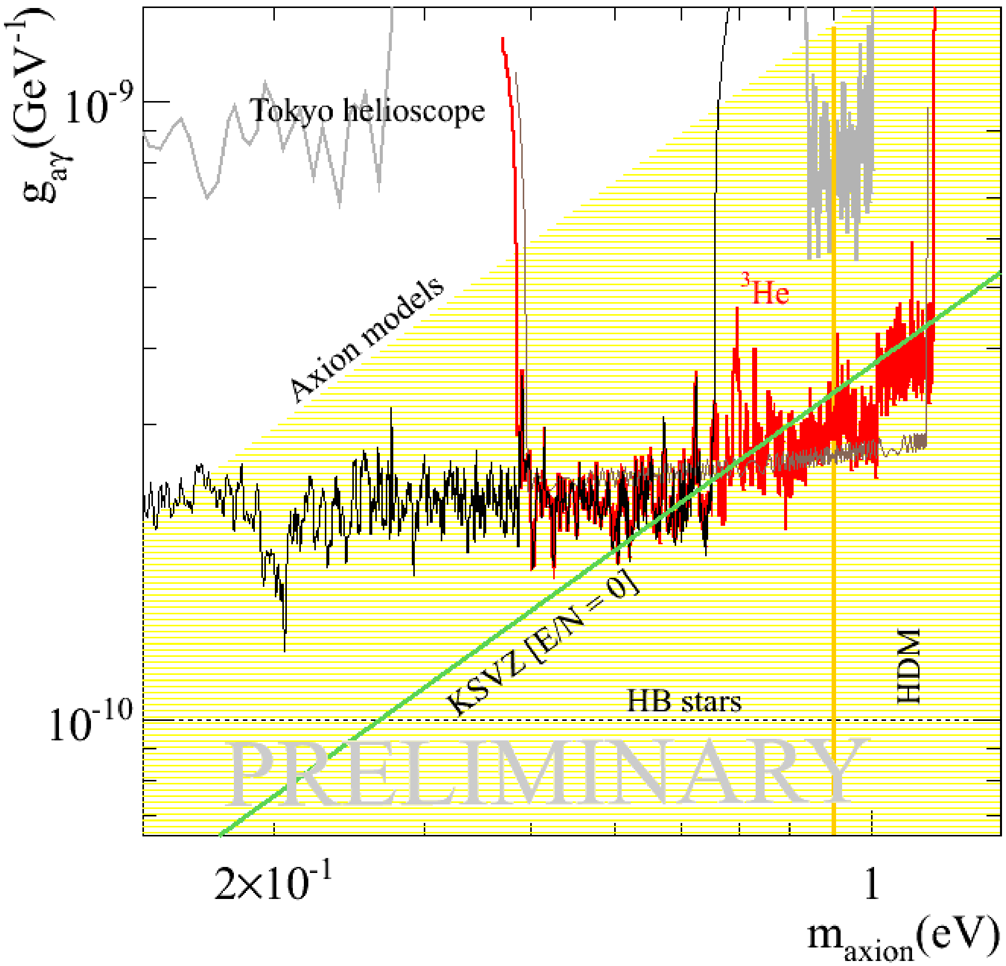
Data taken at 2008 with ^{3}He buffer gas
Published Dec 2011: PRL (**2011**) 107, 261302



^{3}He limit exceeds expectations!

☞ ***Detector improvements***

CAST preliminary results for $m_a > 0.64\ eV/c^2$

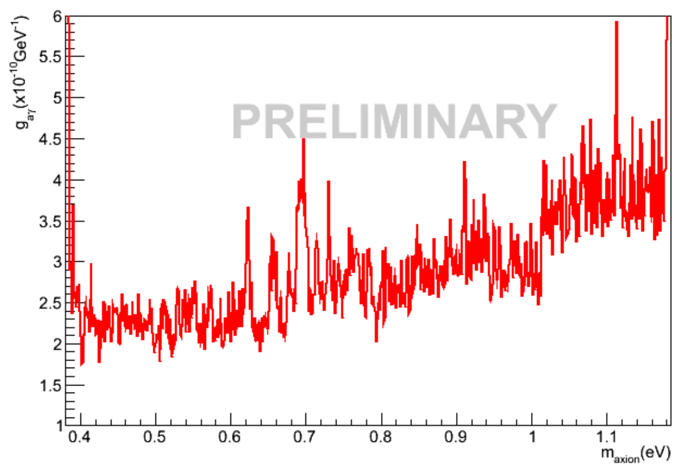


Data taken during 2009 – 2010

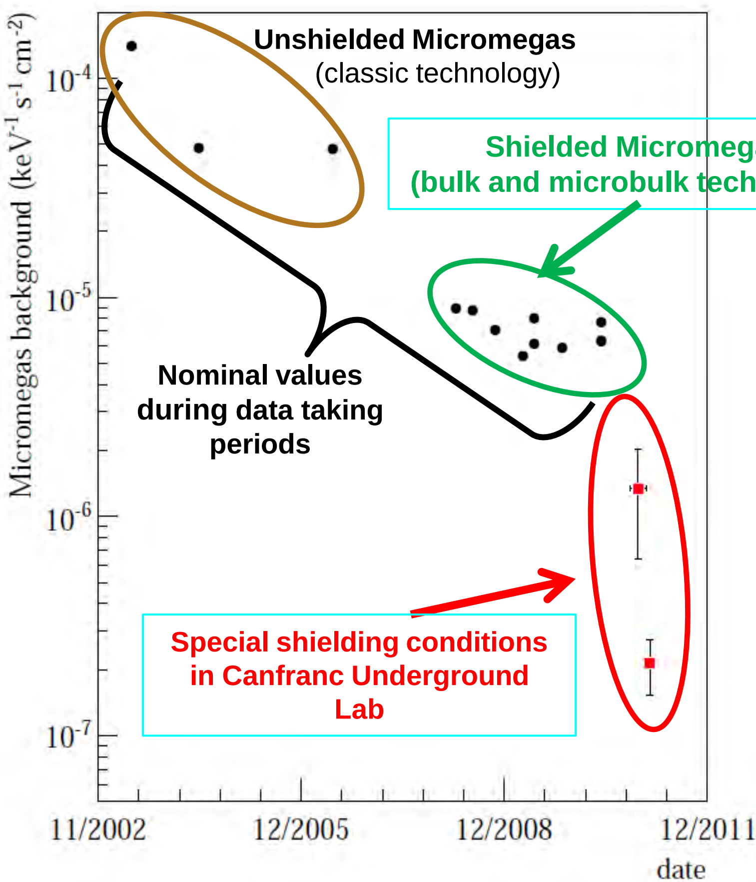
3 additional months in 2011 to fill gaps and cover axion masses up to 1.15 eV/c²

Exclusion plot includes:

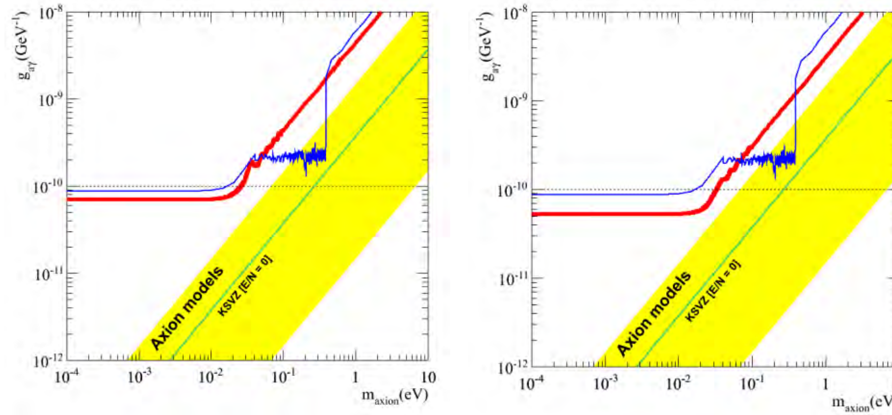
- ✓ Sunrise MM 2010(gaps), 2011
- ✓ Sunset MM *2009, 2010*, 2011
- ✓ X-Ray telescope 2010 (gaps)
- ➢ Analysis to be completed
- ➢ Finalize CFSs for a moving magnet, to exclude signal excess



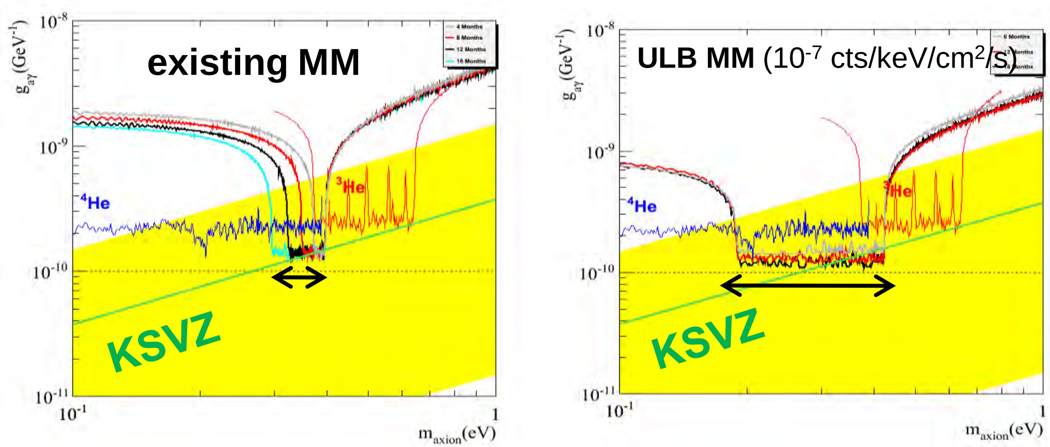
CAST prospects for axion searches



12 months data taking in vacuum with the new detectors ➔ CAST sensitivity well below astrophysical limits (~5×10^{-11} GeV^{-1})



2012: ^{4}He run: 3.2 - 16 mbar: 6, 12 & 18 calendar months
(1.5, 3 and 4.5 trackings/step)



Very low background Micromegas is critical for the 2012-2014 CAST physics program

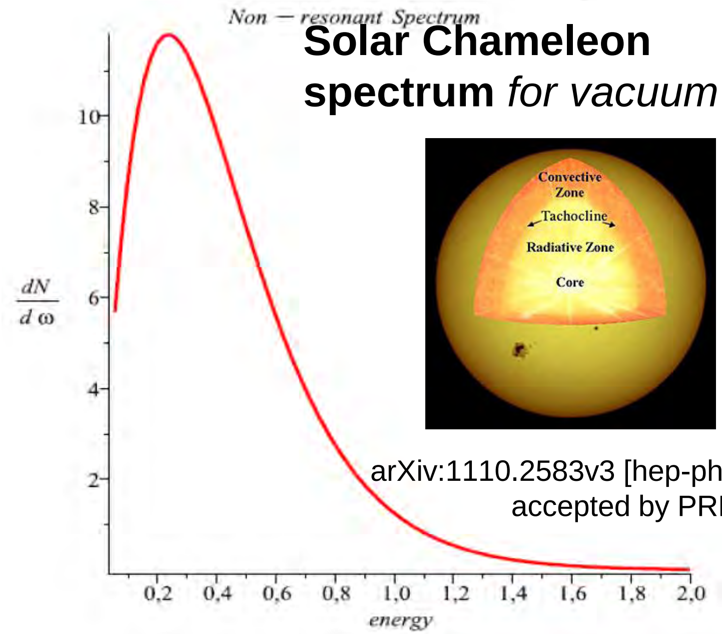
CAST new physics 2012-2014

$$\phi_{\min}(\rho_m) = \Lambda \left(\frac{n M_{Pl} \Lambda^3}{\beta_m \rho_m}\right)^{\frac{1}{n+1}}$$

$$m(\phi)^2 = V''_{\text{eff}}(\phi) = \frac{n(n+1)\Lambda^{n+4}}{\phi^{n+2}}$$

Solar Chameleons

- Chameleons are **DE** candidates to explain the acceleration of the Universe
- Chameleon **mass depends on the energy density** of its environment
- Chameleon particles can be created by the **Primakoff effect** in a strong magnetic field. This can happen in the tachocline of the Sun.
- The chameleons created inside the sun eventually reach earth where they are energetic enough to penetrate the CAST experiment. **Like axions**, they can then be back-converted to X-ray photons.
- In vacuum, CAST observations lead to stronger constraints on the chameleon coupling to photons than previous experiments.



Solar Chameleon spectrum *for vacuum*

arXiv:1110.2583v3 [hep-ph], accepted by PRD

axion helioscope = chameleon helioscope @ LE!!

Sub-keV detector threshold + vacuum

Detection Prospects for Solar and Terrestrial Chameleons

Philippe Brax,[1,*] Axel Lindner,[2] and Konstantin Zioutas[3]

Solar Paraphotons: Hidden Sector particles (Theoretically motivated)

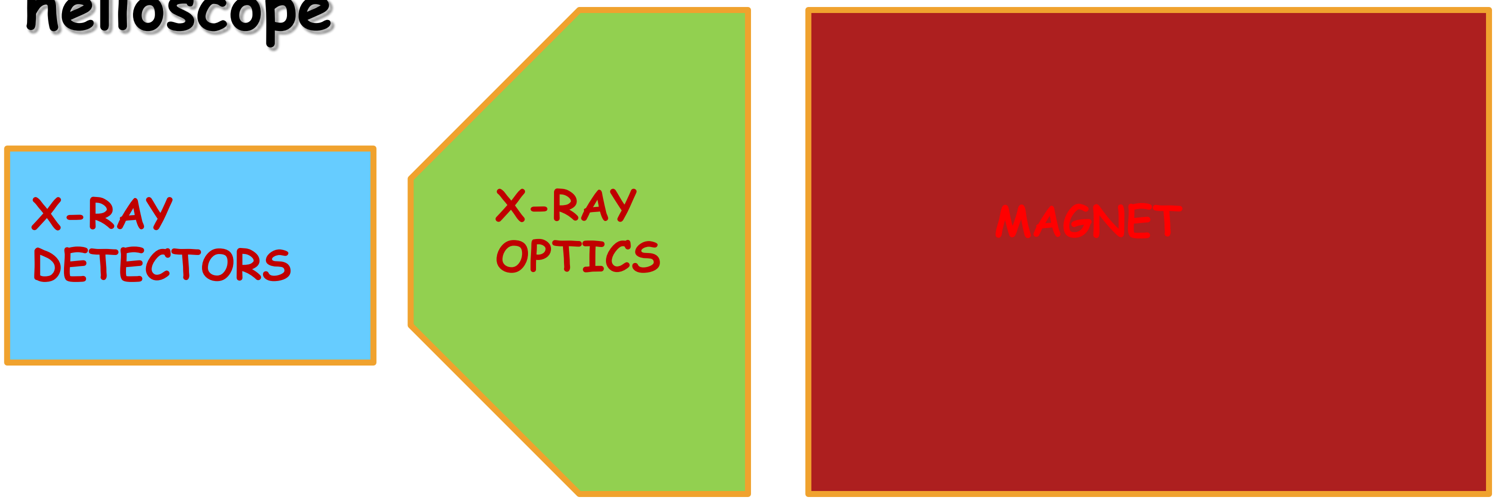
kinetic mixing with thermal photons:

γ ↔ γ' oscillations

→ **NO magnetic field!** → NO cold bores needed

Axion helioscope's FOM

- **3 parts drive the sensitivity of an axion helioscope**

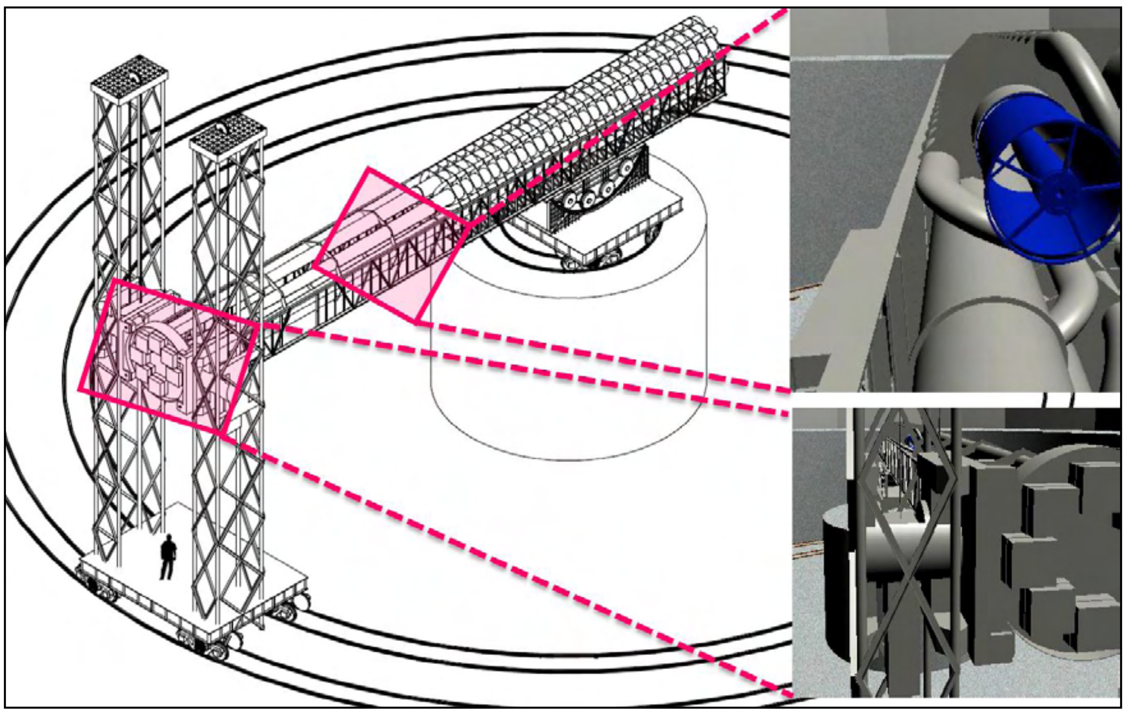


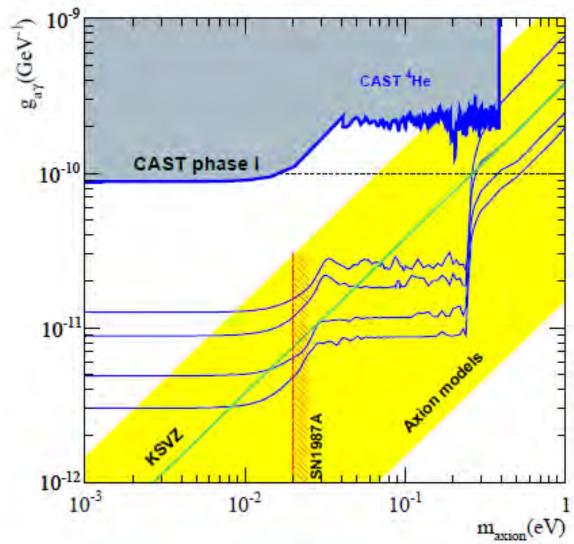
$$\frac{1}{\mathrm{FOM}} \propto g_{a\gamma}^4 \propto \underbrace{b^{1/2}\epsilon^{-1}}_{\text{detectors}} \times \underbrace{a^{1/2}\epsilon_o^{-1}}_{\text{optics}} \times \underbrace{(BL)^{-2}A^{-1}}_{\text{magnet}} \times \underbrace{t^{-1/2}}_{\text{exposure}}$$

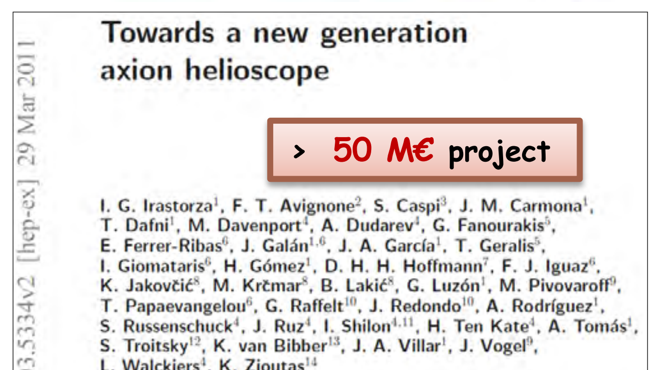
where b is the time- and area-normalized background of the detector, ϵ_d its efficiency; a is the focal spot area of the optics, ϵ_o its througput, B is the magnet field strength, L its length, and A its cross sectional area; t is the exposure time.

*Helioscopes' future(?): the **IAXO** proposal*

- The **I**nternational **Ax**ion **O**bservatory
  - CAST principle with dramatically enlarging the aperture
  - Use of toroid magnet similar to ATLAS?
  - X-ray optics similar to satellite experiments.







Towards a new generation axion helioscope

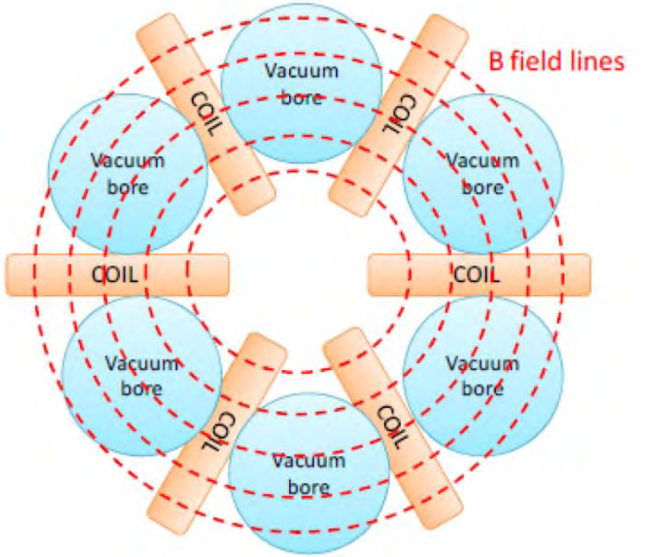
I. G. Irastorza[1], F. T. Avignone[2], S. Caspi[3], J. M. Carmona[1], T. Dafni[1], M. Davenport[4], A. Dudarev[4], G. Fanourakis[5], E. Ferrer-Ribas[6], J. Galán[1,6], J. A. García[1], T. Geralis[5], I. Giomataris[6], H. Gómez[1], D. H. H. Hoffmann[7], F. J. Iguaz[6], K. Jakovčić[8], M. Krčmar[8], B. Lakić[8], G. Luzón[1], M. Pivovaroff[9], T. Papaevangelou[6], G. Raffelt[10], J. Redondo[10], A. Rodríguez[1], S. Russenschuck[4], J. Ruz[4], I. Shilon[4,11], H. Ten Kate[4], A. Tomás[1], S. Troitsky[12], K. van Bibber[13], J. A. Villar[1], J. Vogel[9], L. Walckiers[4], K. Zioutas[14]

> 50 M€ project

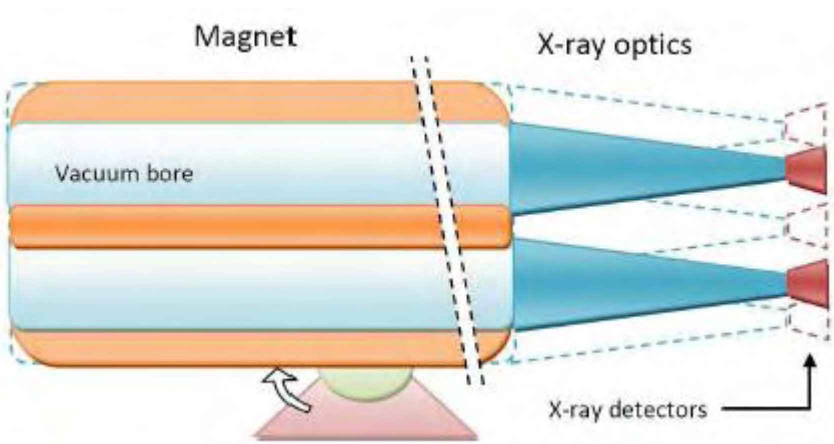
New magnet "a la ATLAS"

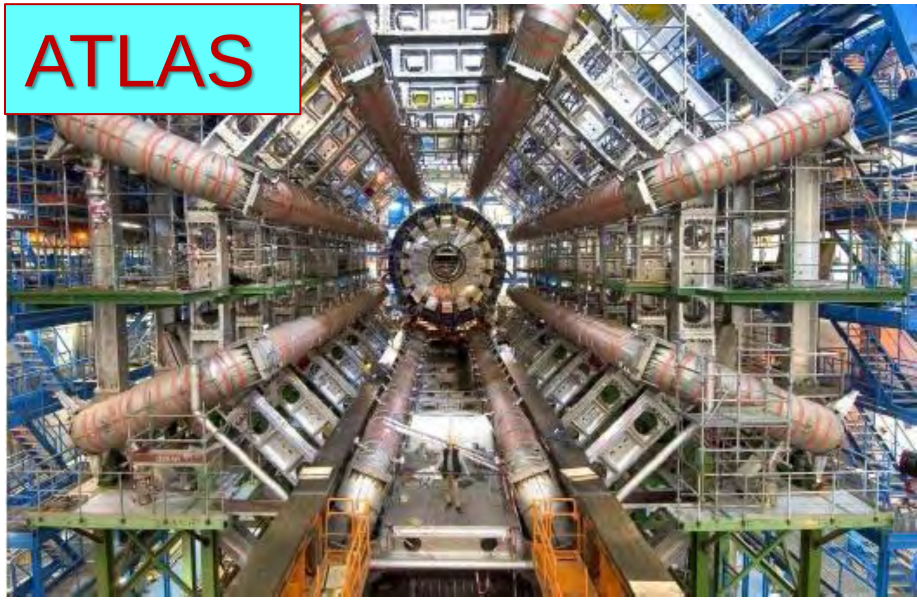
L. Walckiers'/CERN suggestion

- CAST enjoys one of the best existing magnets than one can "recycle" for axion physics
  - LHC test magnet
- Only way to make a step further is to built a **new magnet**, specially conceived for this.
- Work ongoing, but best option up to know is a **toroidal configuration:**
  - Much bigger aperture than CAST: ~0.5-1 m / bore
  - Lighter than a dipole (no iron yoke)
  - Bores at room temperature



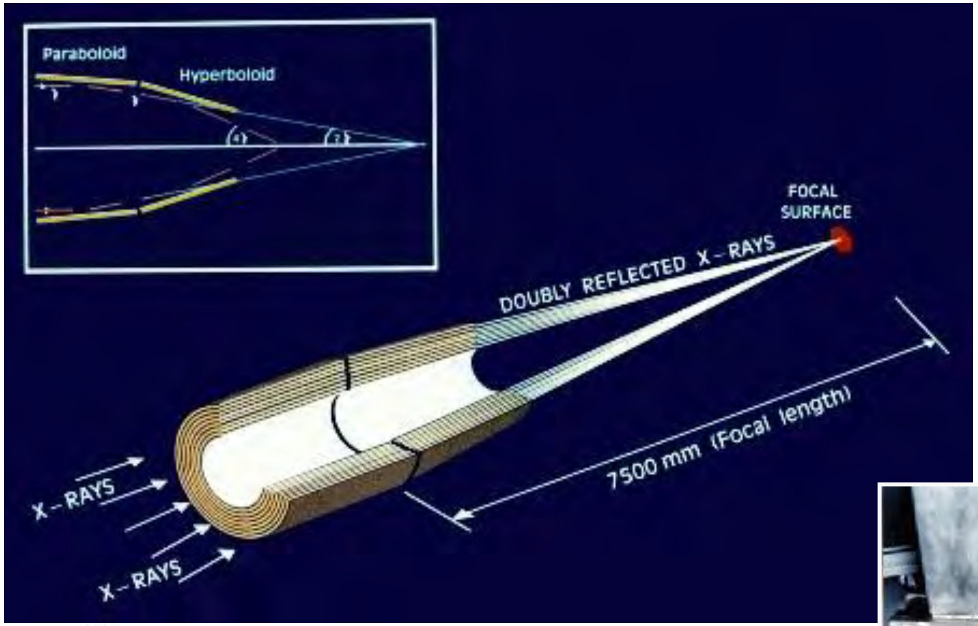
Cross section of the magnet





X-Ray optics

Light Path in XMM-Newton Telescope

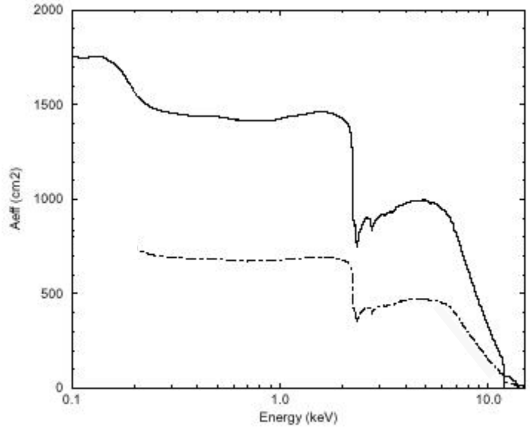


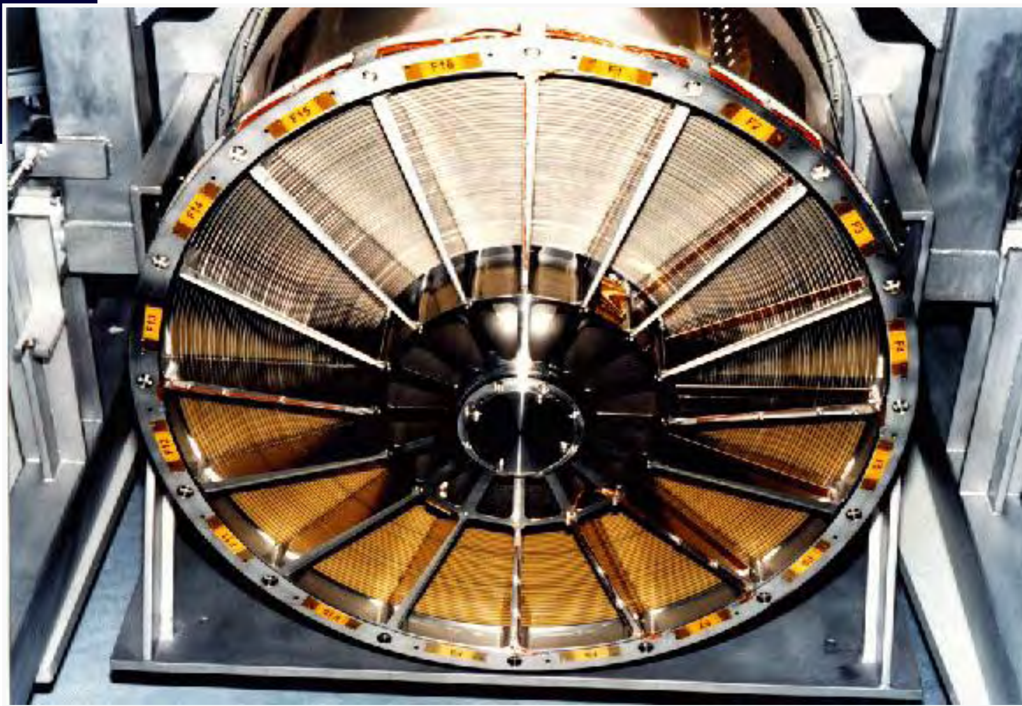
Large magnet aperture

➔ **X-ray focusing device**

- Background reduction
- Detector simplification

XMM mirror module





Collecting area:

~1900cm^2 (<150 eV), ~1500cm^2 (@ 2 keV), ~900cm^2 (@ 7keV), ~350 cm^2 (@ 10 keV).

Conclusions

CAST, has completed Phase II by the end of 2011. During its 12 years of existence:

- has put the strictest experimental limit on axion searches for a wide m_a range
- has tested axion masses inside the region favored by QCD models (analysis of all data close to finish)

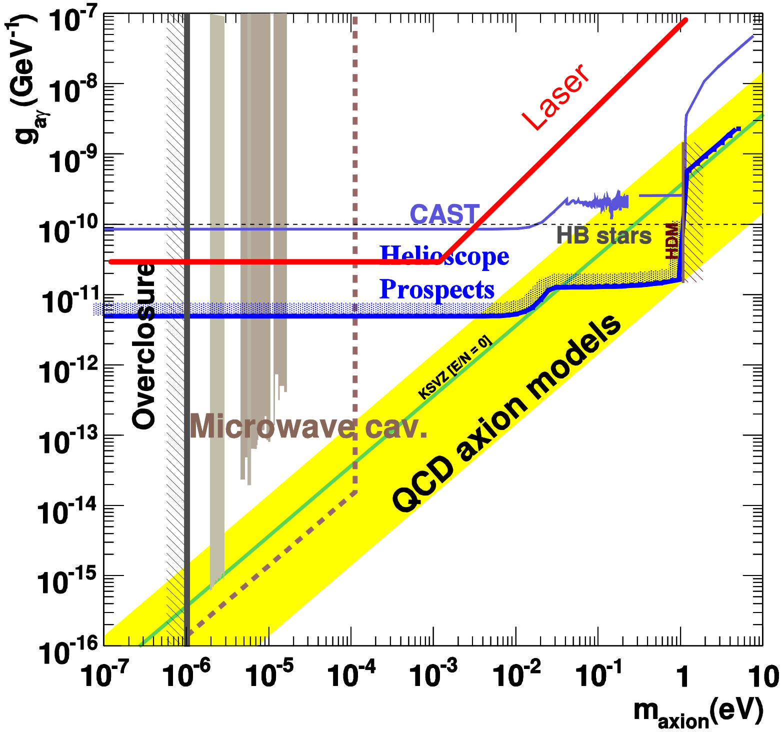
New searches for axions/WISPs will start in mid 2012

Different type axion searches are going on:

- ADMX is scanning the m_a-$g_{a\gamma}$ parameter space deep inside the QCD model region for dark matter axions. ADMX-II and ADMX-HF will widen this search in the near future
- ALPS has reached the strictest laboratory bounds on axion to photon coupling. Future upgrades will allow the search for ALPs beyond the limit of the HB stars

With the ongoing upgrades on laboratory experiments, helioscopes & haloscopes, a big part of QCD favored model region can be swept up to 2020

Prospects of axion searches in the next decade

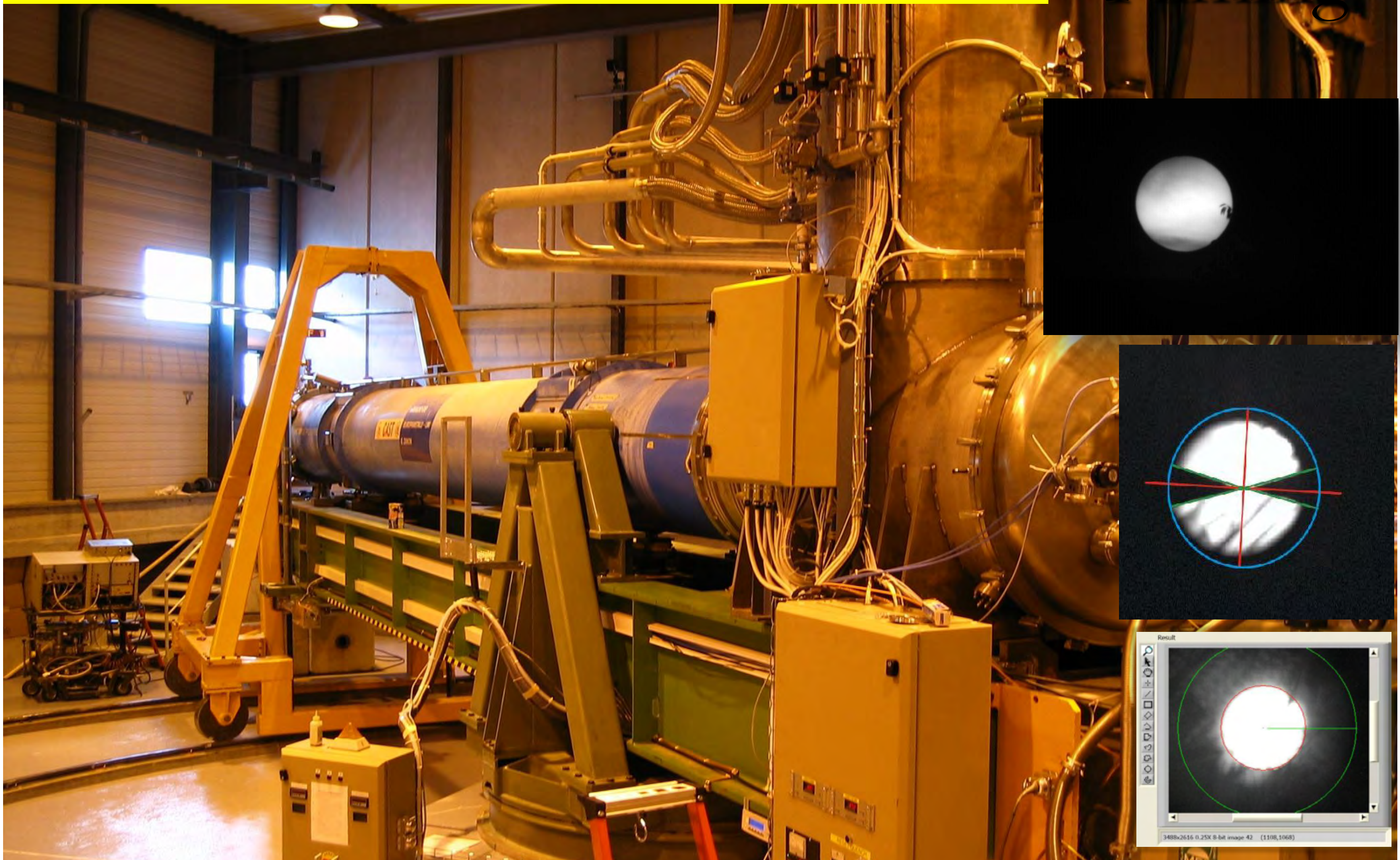


Thank you!!!

End - Backup slides

Twice per year (March/September) direct optical check
A camera on top of the magnet aligned with the bore axis
Corrections for visible light refraction are taken into account

Filming



The Magnet Pointing precision is well within our requirements (0.5 mrad)

Tracking system precision

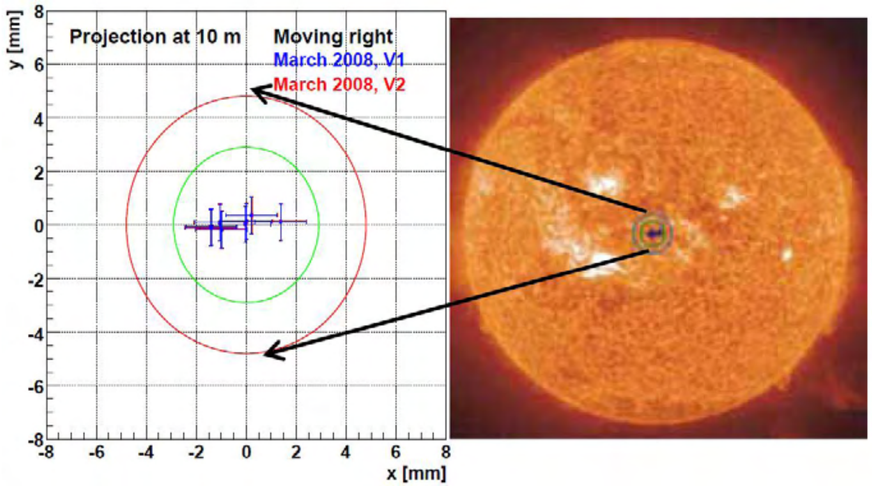
Several yearly checks cross-check that the magnet is following the Sun with the required precision

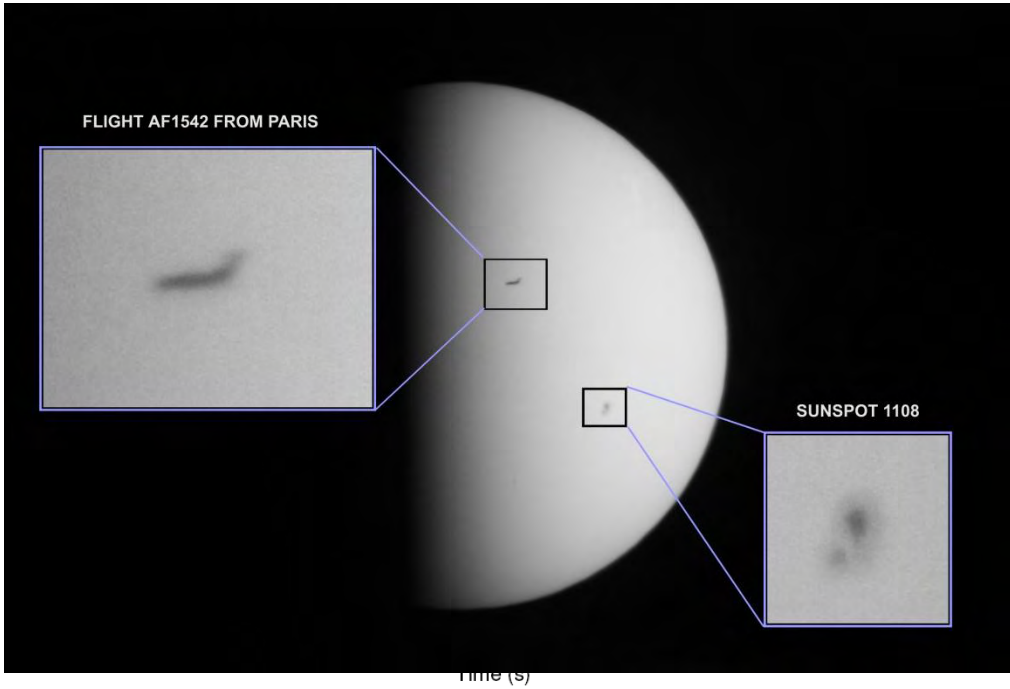
GRID Measurements

- 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 within our aceptance

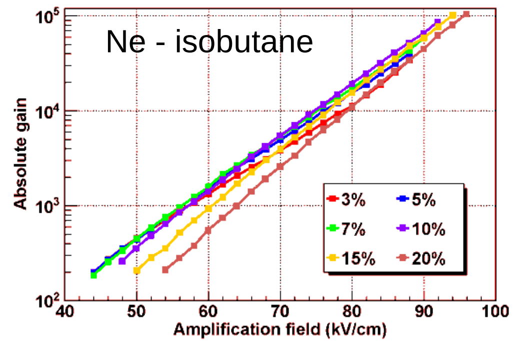


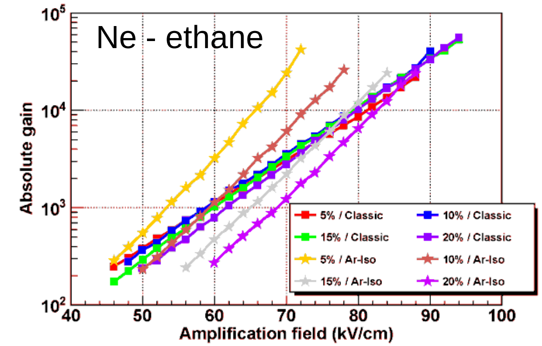


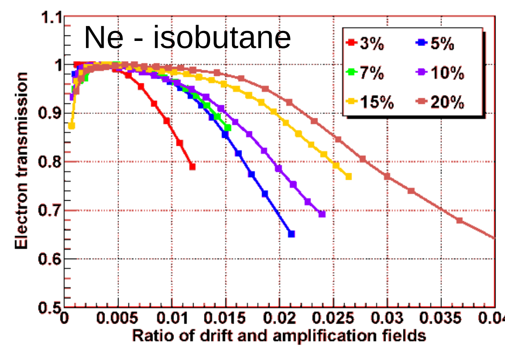
Operating in the sub-kev range

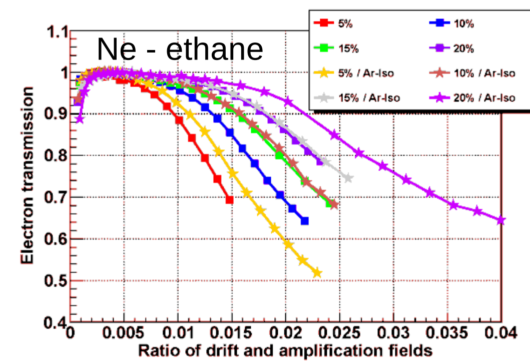
Low threshold

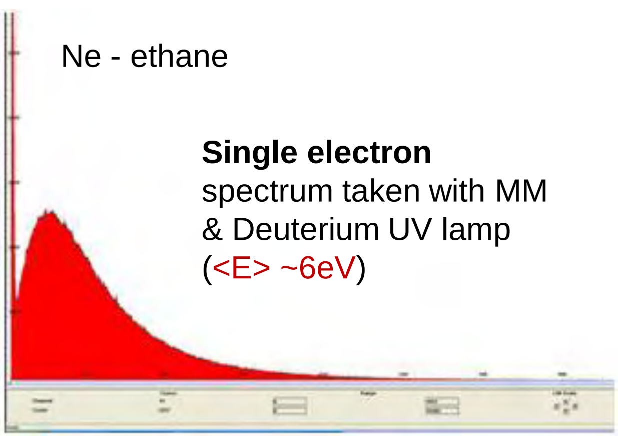
- Argon: good absorption efficiency in the energy range 1-7 keV
- Neon: higher gain (> factor 10)
  ➔ *Single electron detection!!!*
- Good absorption up to 3 keV
- Mixture of Ar-Ne can be used to cover all range **0.1-10 keV**
- Study several Ne –ethane / isobutane mixtures
- Ongoing studies for Ar-He and *Ar-cyclohexane* mixtures

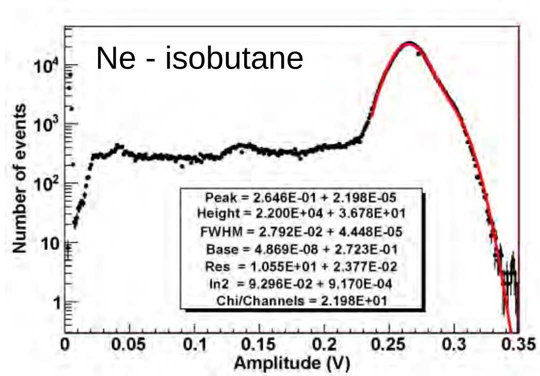


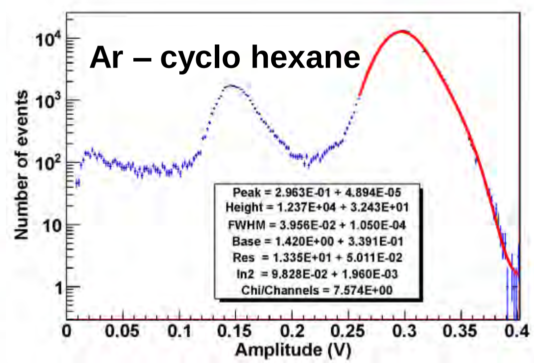






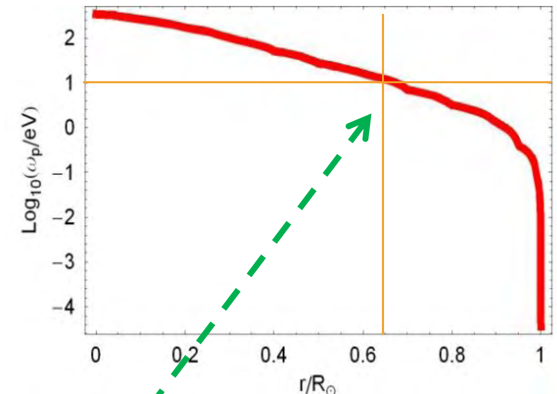


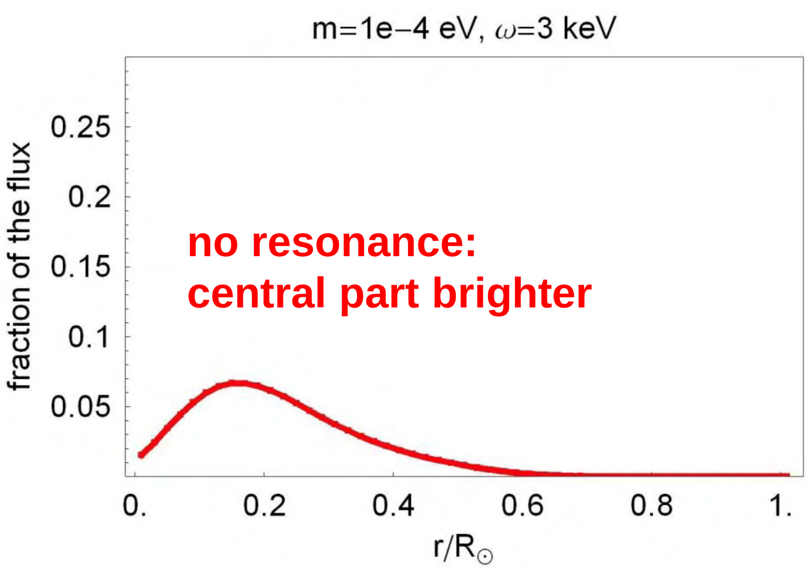


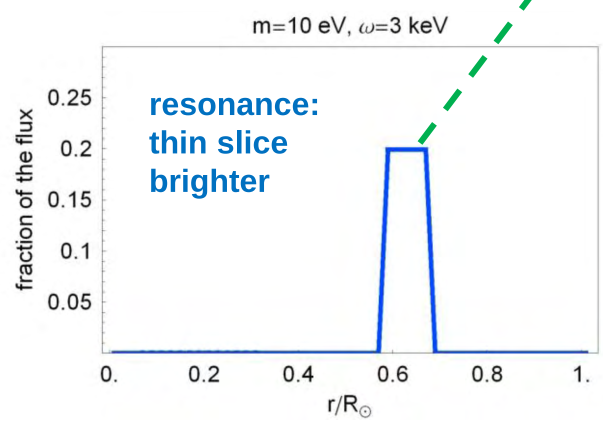


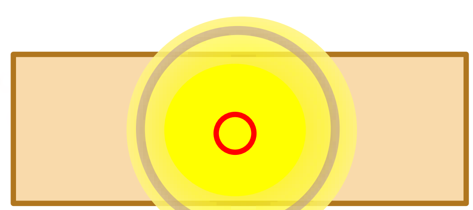
Solar Paraphotons

- Converted from thermal photons inside the Sun due to kinetic mixing
- Region of interest for CAST **$10^{-3} < m < 10$ eV**
- **Resonant production** in a shell inside sun for $m > 10^{-2}$ eV
- Clear signature .... **ring images** **$r/R_o > 0.7$**
- CAST **XRT/CCD** - our solar imaging system

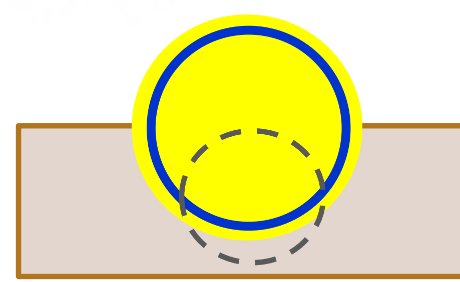








Normal solar tracking



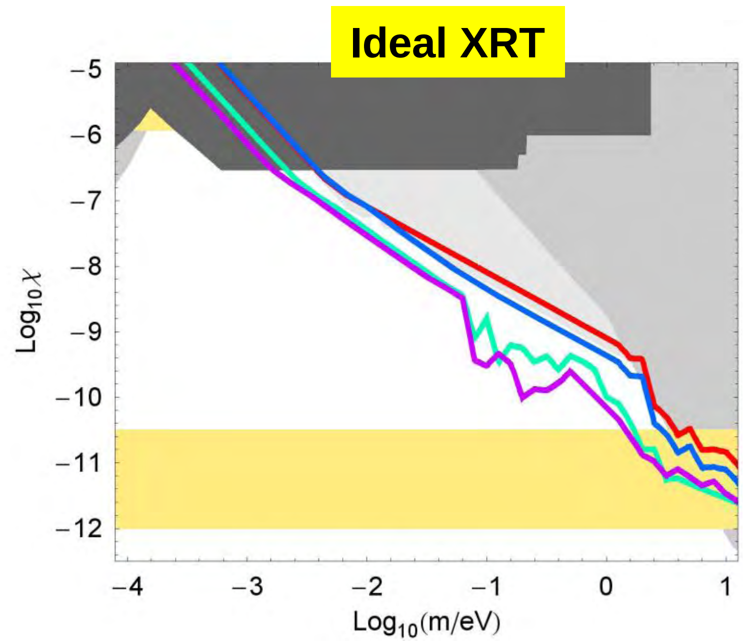
Off-pointing solar tracking

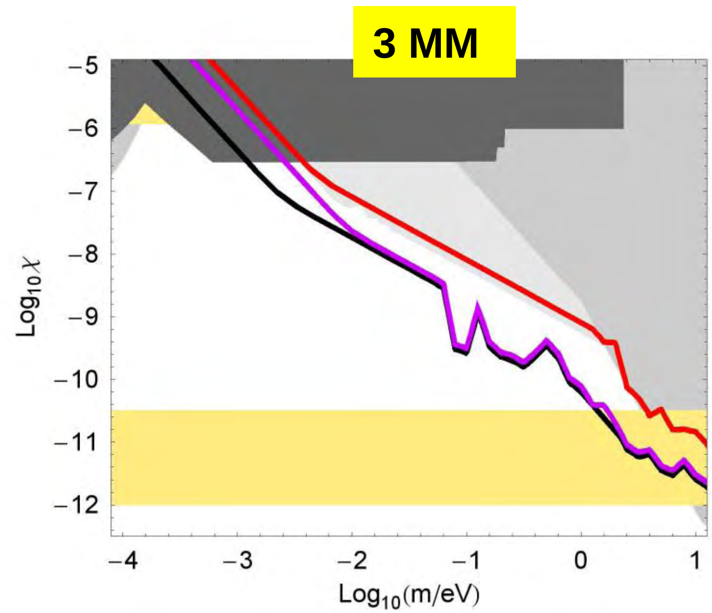
Cast Paraphoton sensitivity

New Vacuum Run (2x10^{6}sec):

normal tracking, XRT FOV strongly limits sensitivity. → **Off-pointing**

➔ Could be used to look for structure with good ε over reduced region





More realistic estimate of XRT/CCD

(assume only 60% of sun visible via XRT)

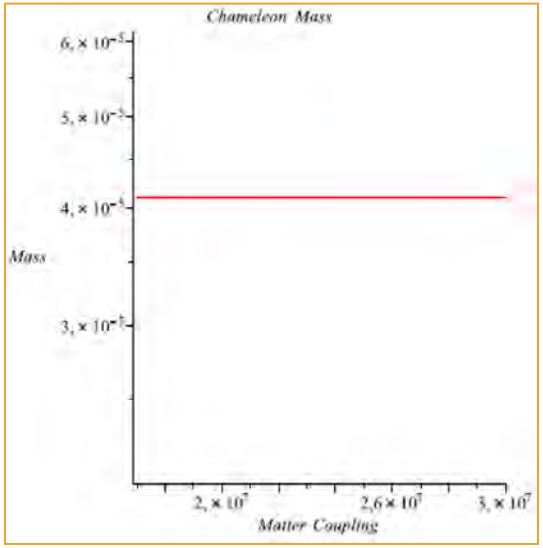
1.0 – 7 keV 2years, 0.3 – 7 keV, 0.1 – 7 keV

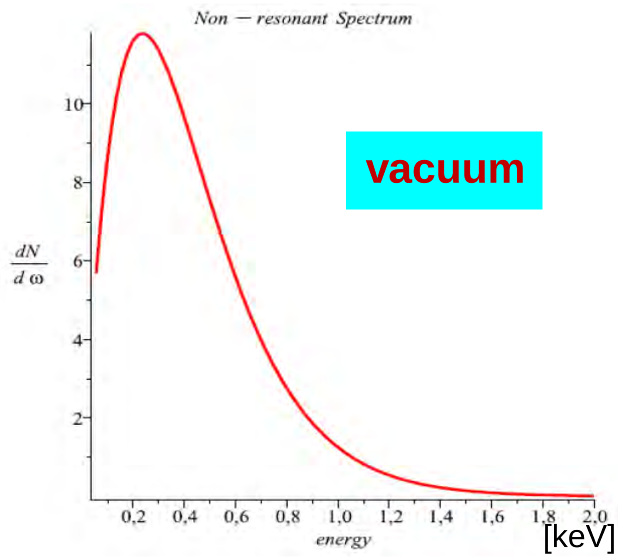
ULB & LET MM (0.2 - 2 keV)

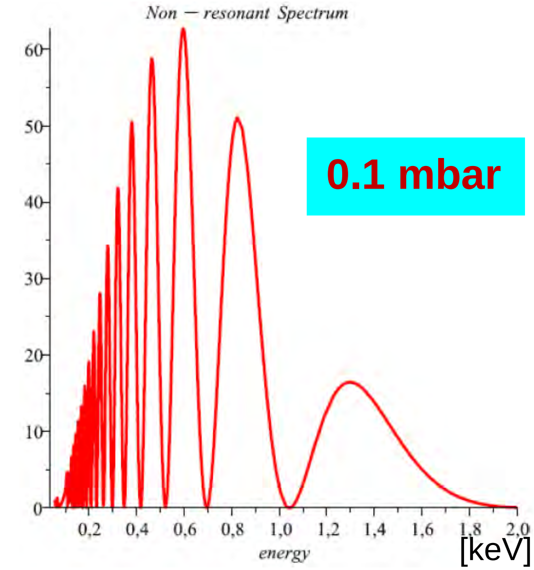
ε = 15%

14m (black) & 1m (purple)

CAST sensitivity to Chameleons







The mass of the chameleon in the CAST pipe with vacuum is: $m_{ch} = 40\ \mu eV$

The analogue spectrum [$h^{-1}\ keV^{-1}$] of regenerated photons as predicted to be seen by CAST: *matter coupling = 10^6, B=30T in a shell of width $0.1R_{solar}$ around the tachocline (~$0.7R_{solar}$).*