TECHNISCHE
UNIVERSITÄT
DARMSTADT

Status and plans of the CAST experiment

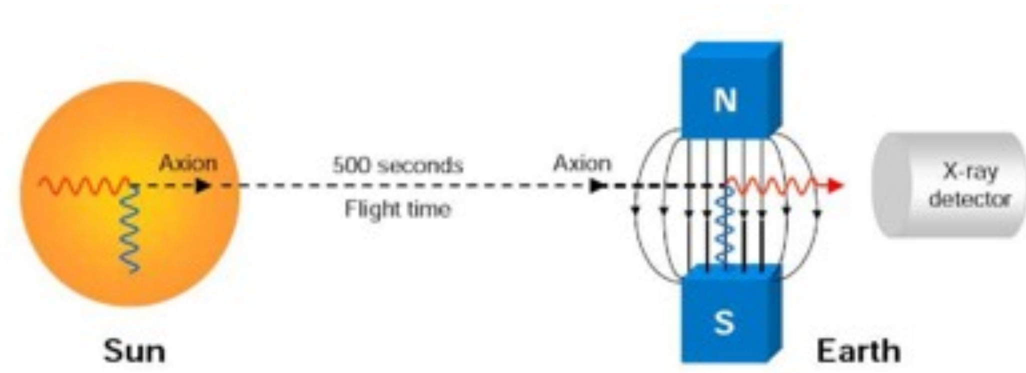
115th Meeting of the SPSC

Stephan Neff
TU Darmstadt

On the behalf of the
CAST Collaboration

Tuesday, 21 October 2014

CAST has been operating since 2003 and still has a great potential for physics discoveries

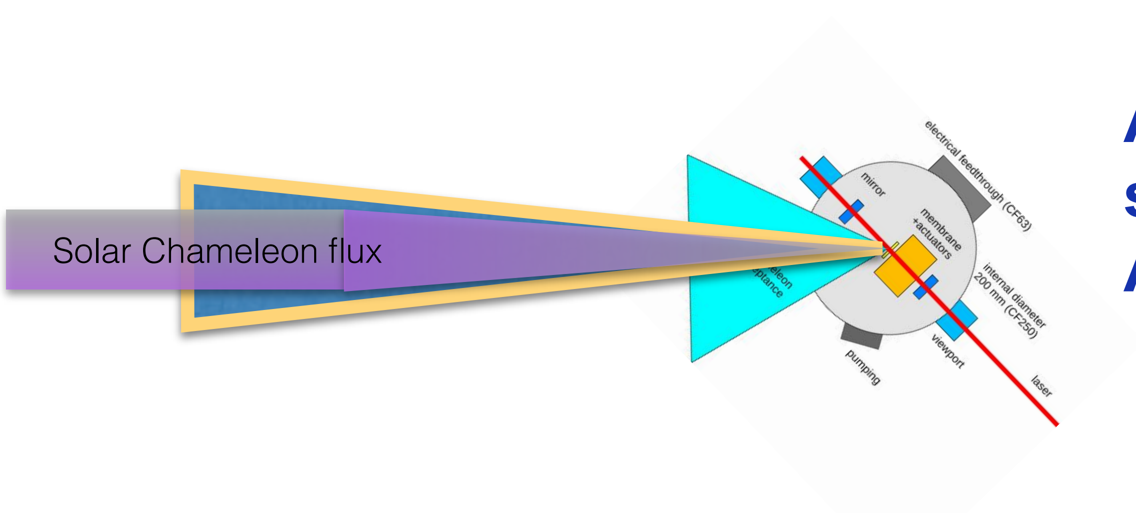


Since 2003: search for solar axions

- CAST has covered axion masses up to 1.18 eV
- New measurements for masses below 0.02 eV with improved detectors started in 2013 and will be finished in 2015

In 2013, the search for solar chameleons has started

- First chameleon helioscope in the world (SDD)
- In 2014, measurements with new detector (InGrid) have started
- In 2015 measurements with an ultra-sensitive force sensor (KWISP) will study coupling to matter

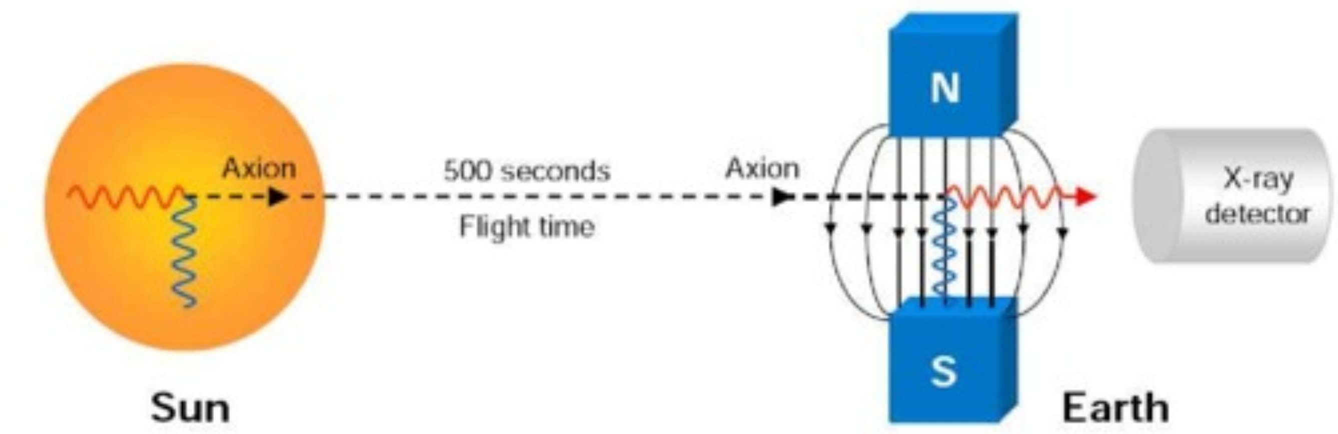


After 2015 CAST will be used to search for solar chameleons (KWISP, InGrid) and relic ALPS

- Dish antenna
- Cavities

Currently in R&D stage

CAST is searching for solar axions using the inverse Primakoff effect



Photons in the sun are converted to axions via the Primakoff effect

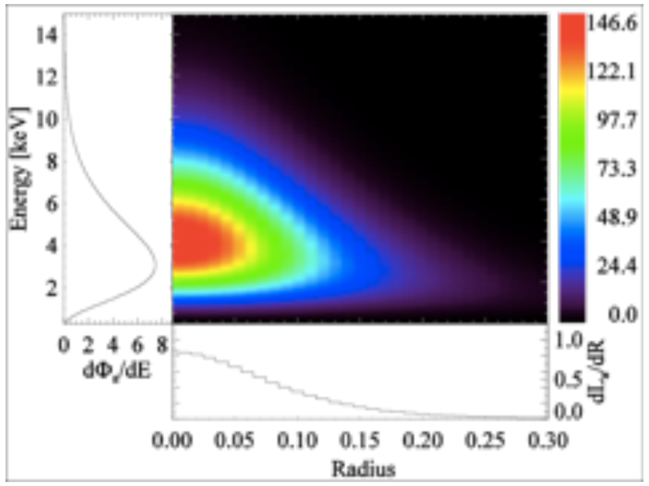
Back-conversion of axions into x-ray photons in a strong magnetic field via the inverse Primakoff effect

P. Sikivie, PRL 51, 1415-1417 (1983)

Expected number of photons

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

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

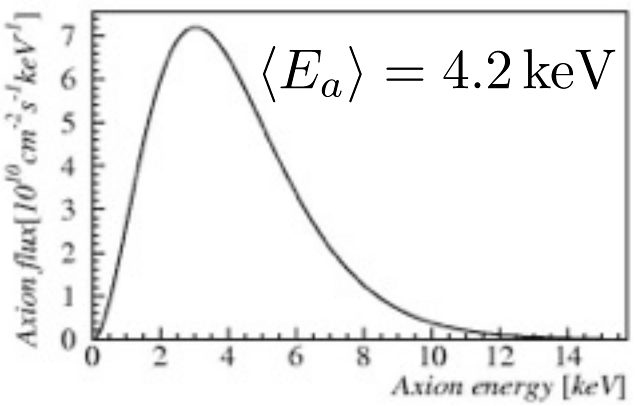


Axion flux on earth

Expected signal (1-10 keV)

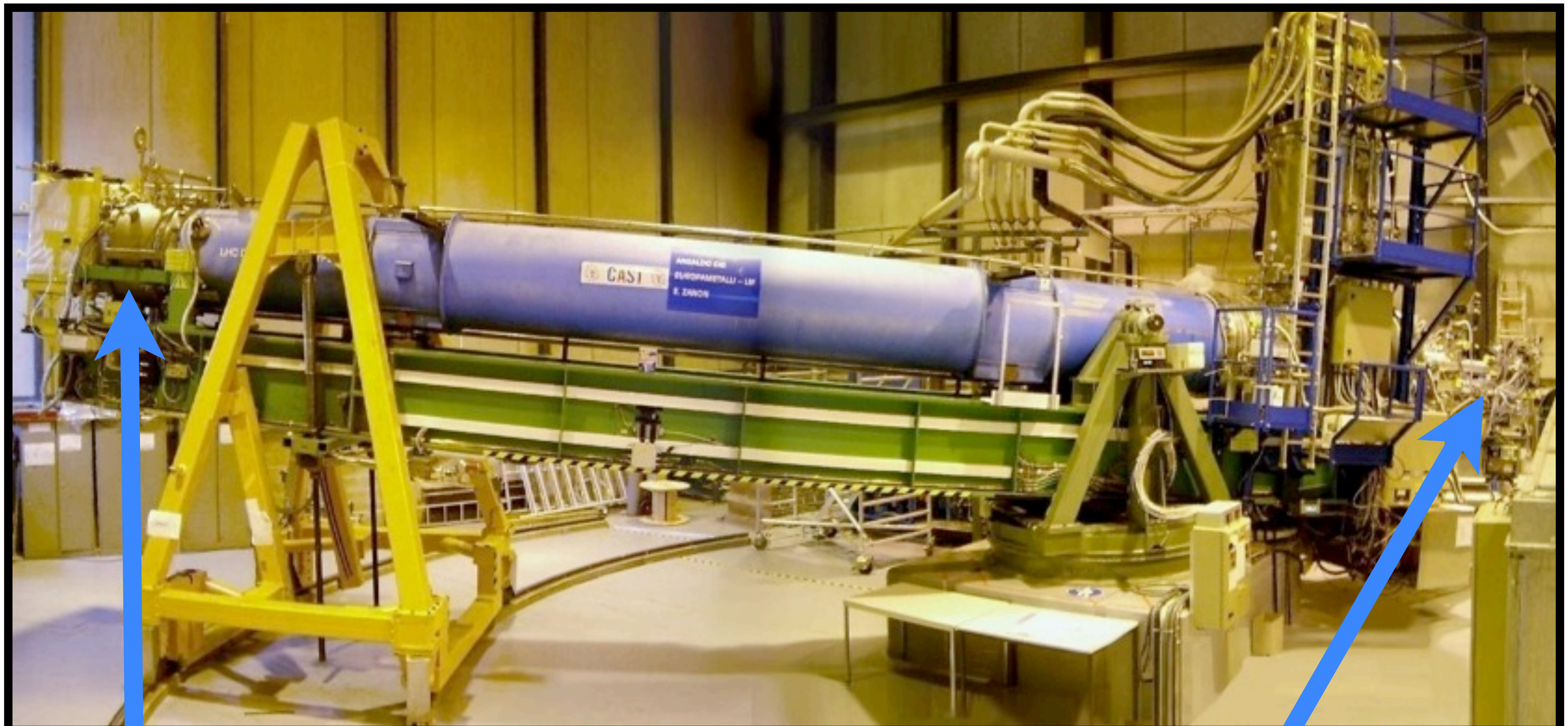
$$0.3 \text{ counts/hour for } g_{a\gamma\gamma} = 10^{-10}\,\mathrm{GeV}^{-1}$$

$$\text{and } A = 14.5\,\mathrm{cm}^2$$



Solar axion luminosity

The CAST helioscope uses a 10 m long dipole magnet to search for solar axions



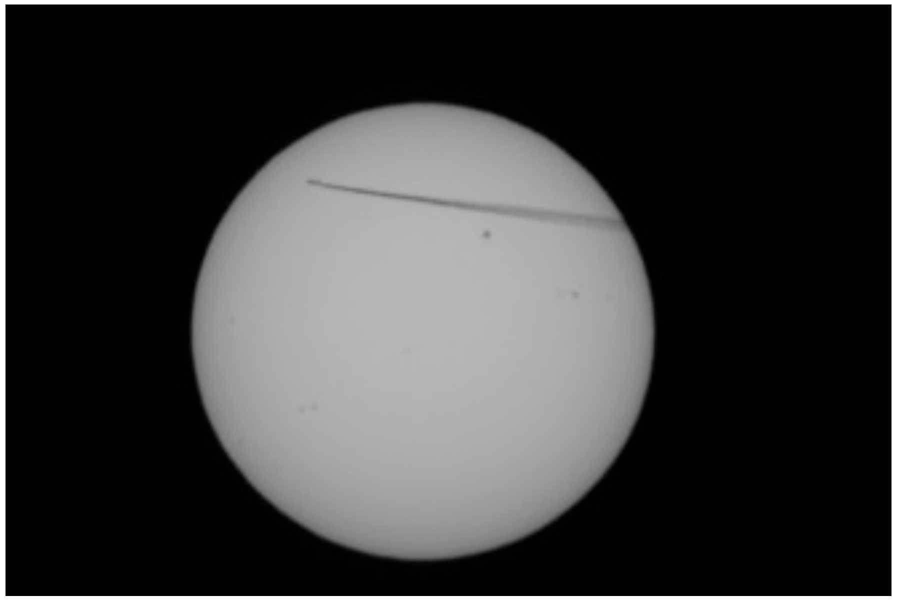
Sunset detectors

2 MicroMegas Detectors

Sunrise detectors

Up to 2013: MicroMegas, CCD & MPE XRT
Since 2014: MicroMegas & LLNL XRT, InGrid & MPE XRT

Sun filming and moon filming were used to check the correct orientation of the magnet to the sun



Improved focusing
Airplane and sunspots visible
Moon with good detail

September 2013 + March 2014

13 days of Sun filming

2 days of Moon filming (November + March) (one with full Moon)

In average we are deviated about

-3.5 mm/10m in horizontal

-2.0 mm/10m in vertical

Always ahead and above the sun

The result does not depend on the grid used.

Discrepancy is below the required precision, so it does not affect our measurements.

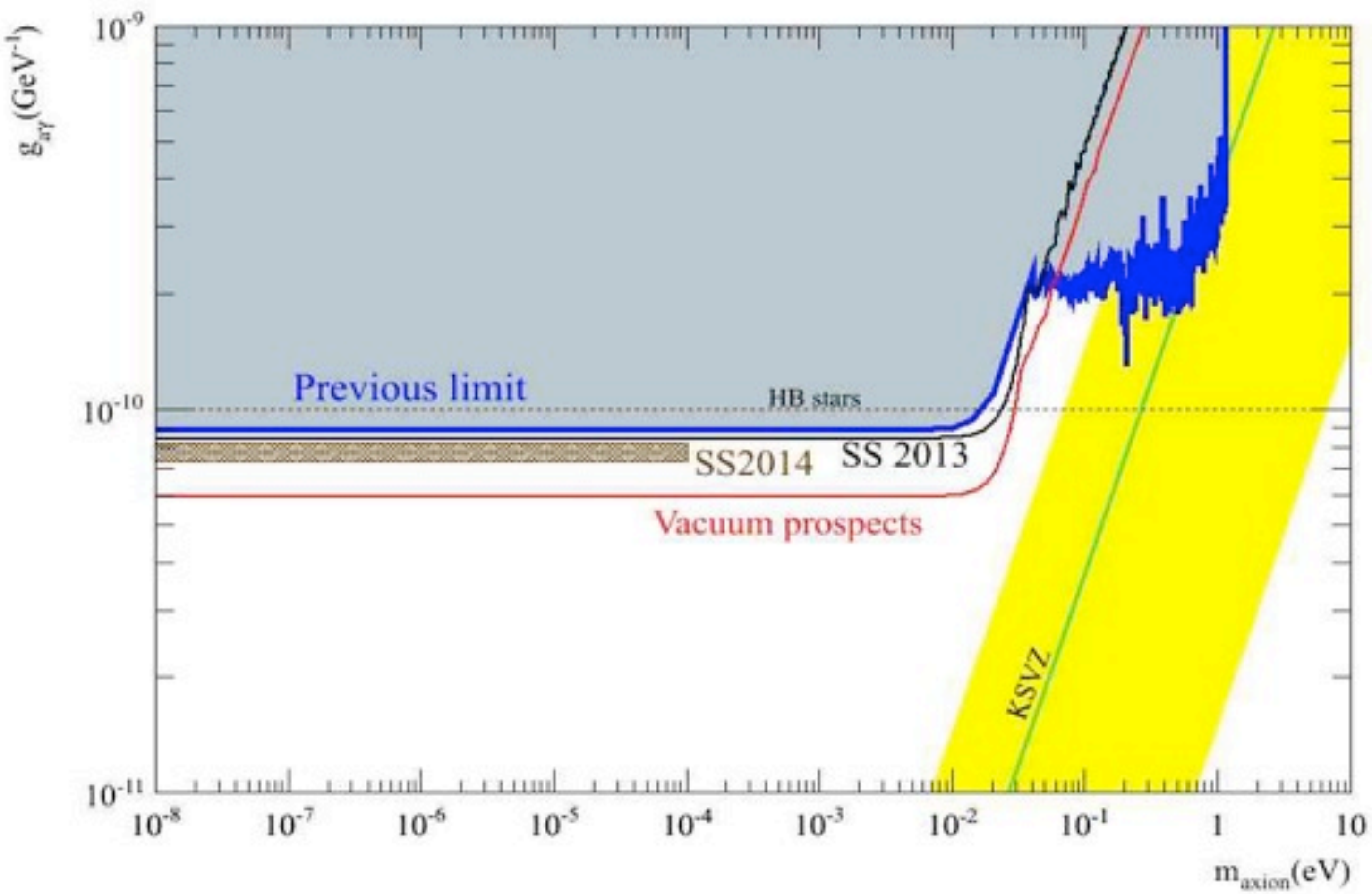
In 2013, data taking in vacuum phase was restarted with improved detectors

2013: 22nd September – 7th December (data taking efficiency 82%)

- 3 Micromegas detectors and a SDD
- Preliminary limit: $g_{a\gamma} < 8.40 \times 10^{-11}$ GeV^{-1} for $m_a < 0.02$ eV at 95% CL

2014: Started 3rd July and will last until the 15th November

- 3rd July – 25th August, only Sunset detectors taking data (94% efficiency)
- From 11th September until now, taking data with the new LLNL XRT + Micromegas system on the Sunrise side
- Beginning of October → All the 4 detectors operative



Analysis of the data from the ^{3}He and ^{4}He runs is progressing and first results are published

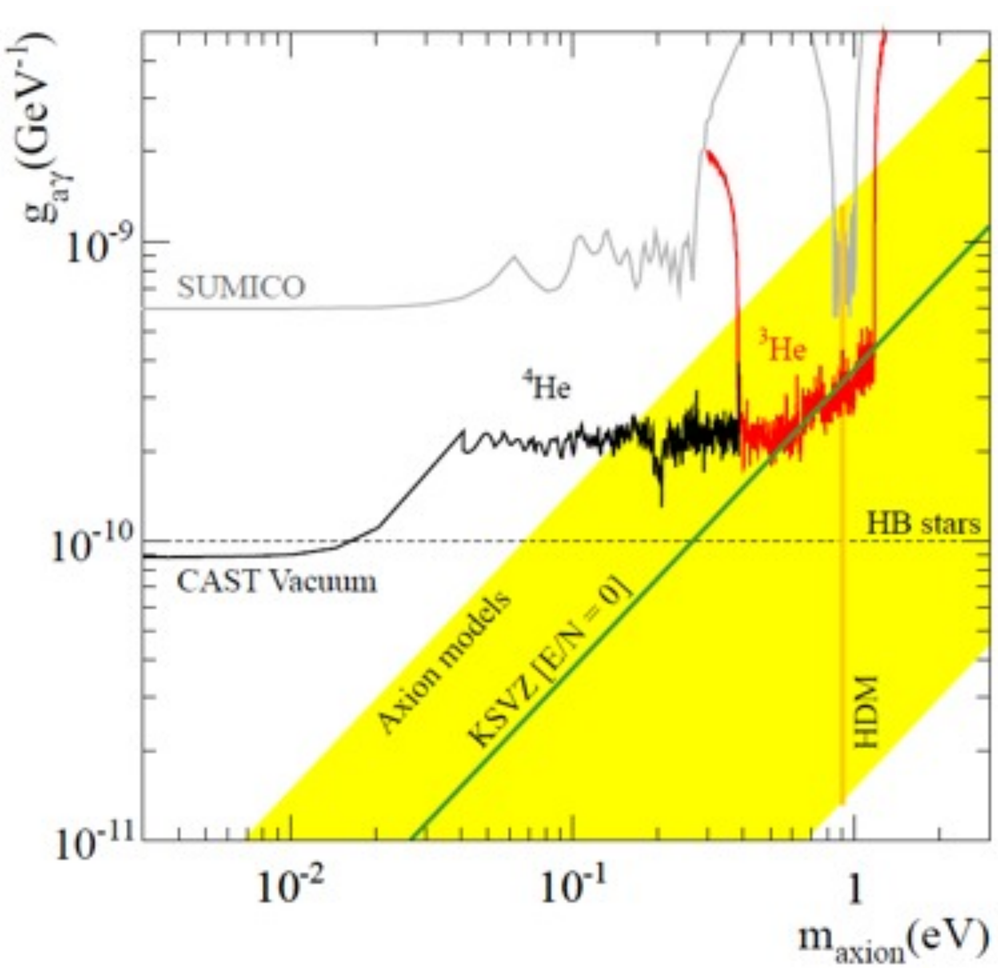
^{3}He data analysis (2009 - 2011 run)

- First results:
  Phys.Rev.Lett. 107 (2011) 261302
- Mass interval 0.64 eV ≤m_a ≤ 1.16 eV fully analyzed with Micromegas detectors, results published in
  Phys.Rev.Lett. 112 (2014) 091302
- Publication with CCD data in 2015

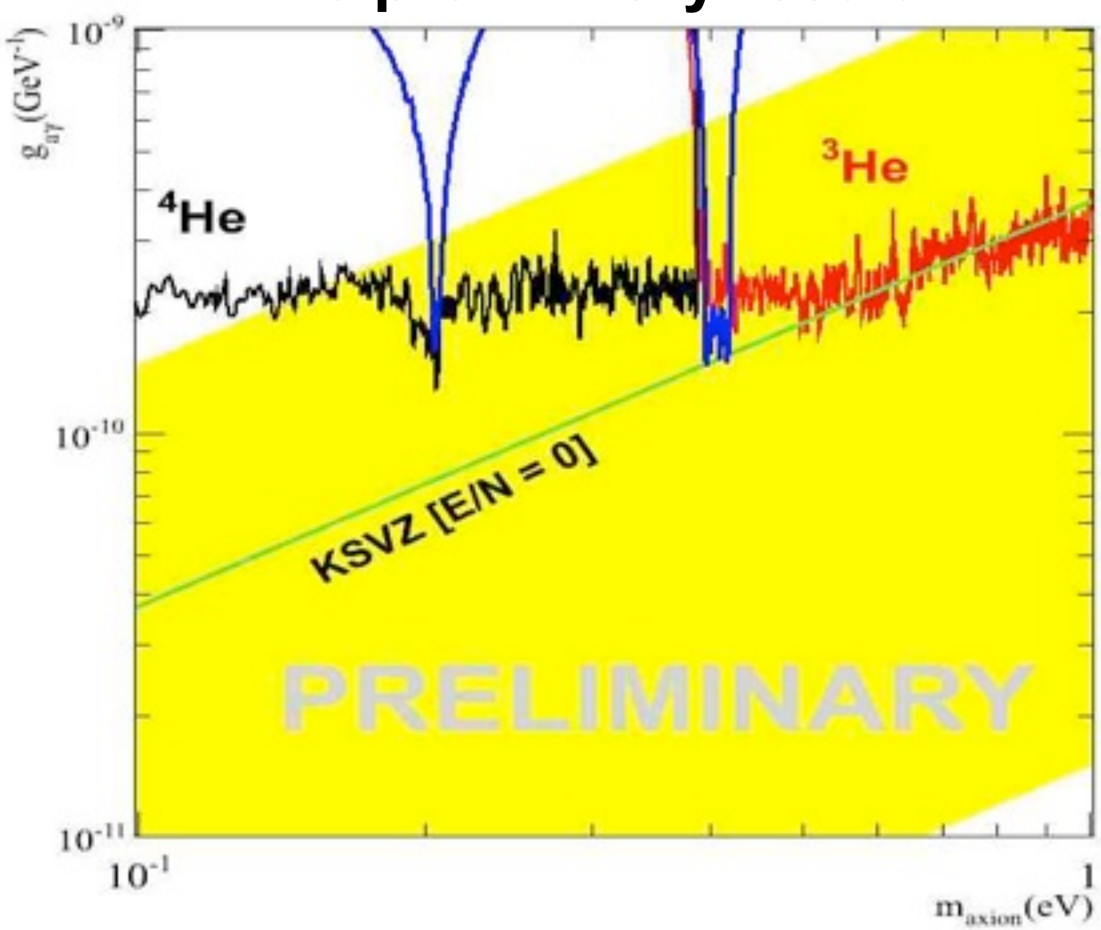
^{4}He data analysis (2012 run)

- Scanned two narrow regions at m_a~0.2 eV and m_a~0.4 eV
- Publication under preparation using the Micromegas data.

^{3}He limit

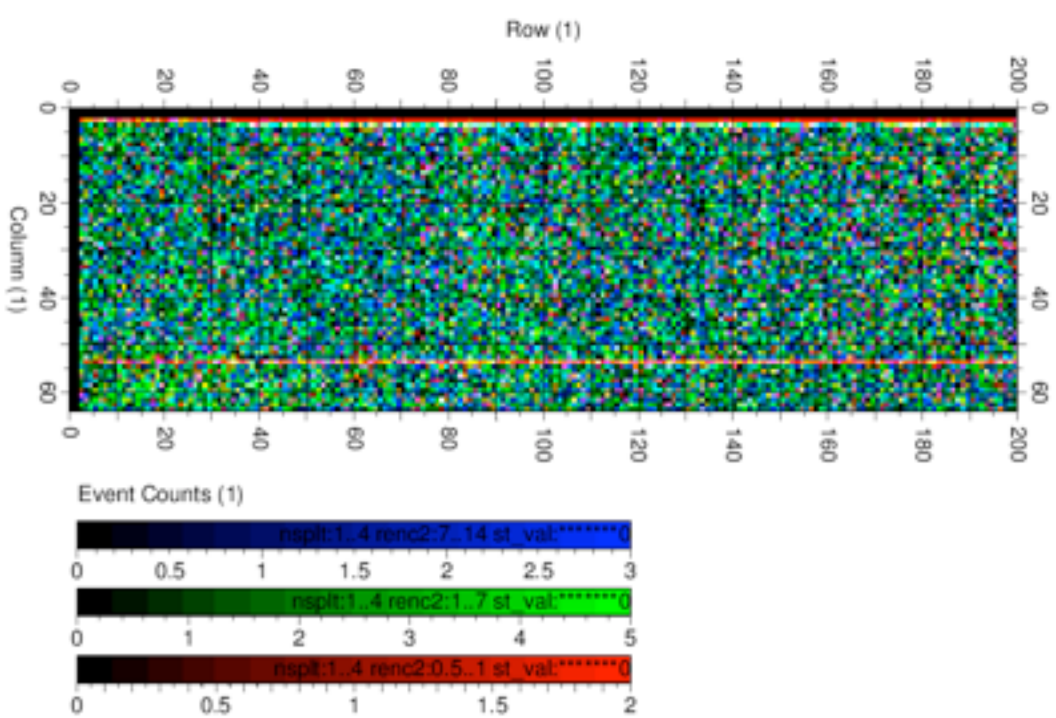


^{4}He preliminary result

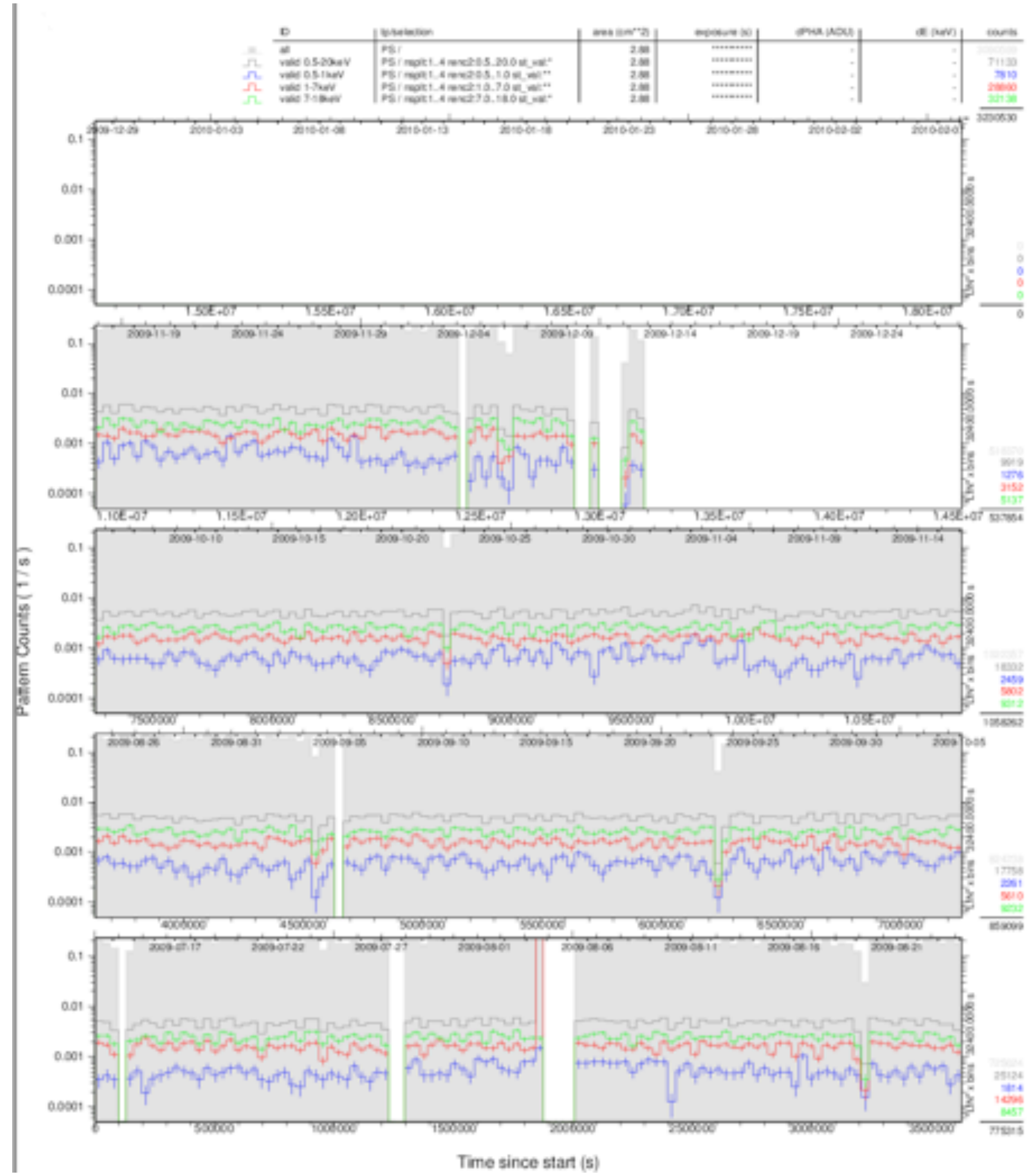


Analysis of the X-ray CCD data for the ^{3}He run will be finished by the end of 2014

- Event lists have been created from the data of the ^{3}He run (2009-2011)
- Currently the analysis is being cross-checked
- The resulting data will be merged with existing data to improve the limit on the axion-photon coupling constant



Signal on CCD integrated for 2009
(21 weeks of data taking)
red: 0.5-1 keV; green: 1-7 keV; blue: 7-14 keV

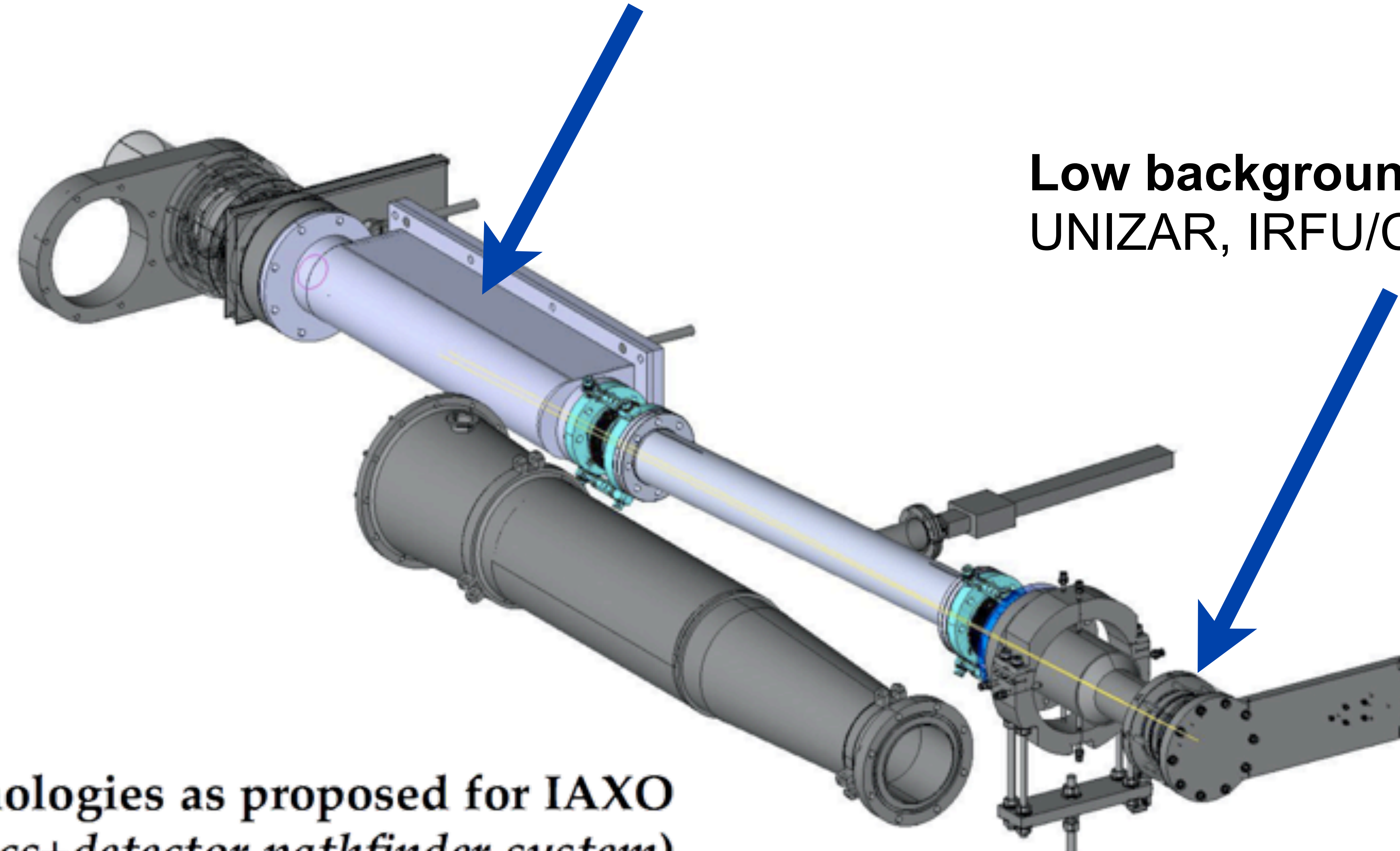


Light curves for 2009 (0.5 day binning)

A 2nd X-ray telescope and an upgraded Sunrise Micromegas detector increase our sensitivity

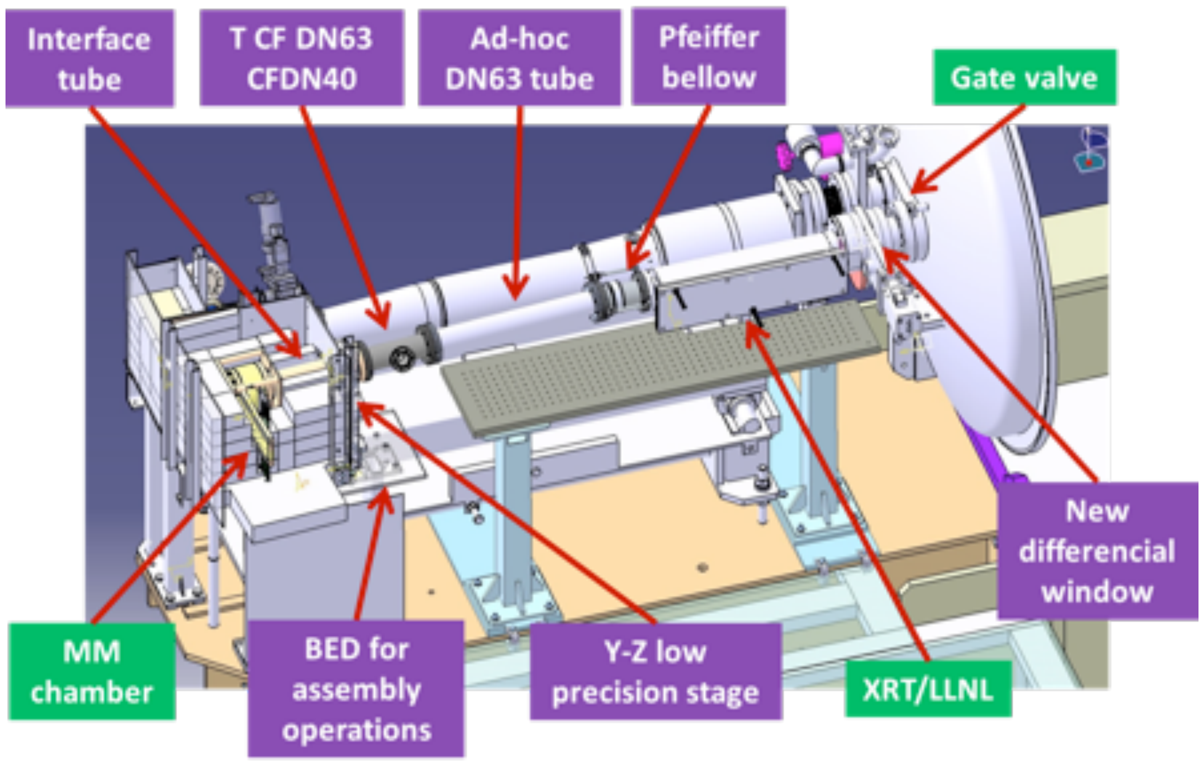
New X-ray telescope
specifically designed and built for CAST
LLNL, DTU, and UC

Low background Micromegas
UNIZAR, IRFU/CEA



- **Same technologies as proposed for IAXO (*IAXO optics+detector pathfinder system*)**
- Successfully installed + commissioned end August
- **Big milestone for CAST → best SNR ratio**

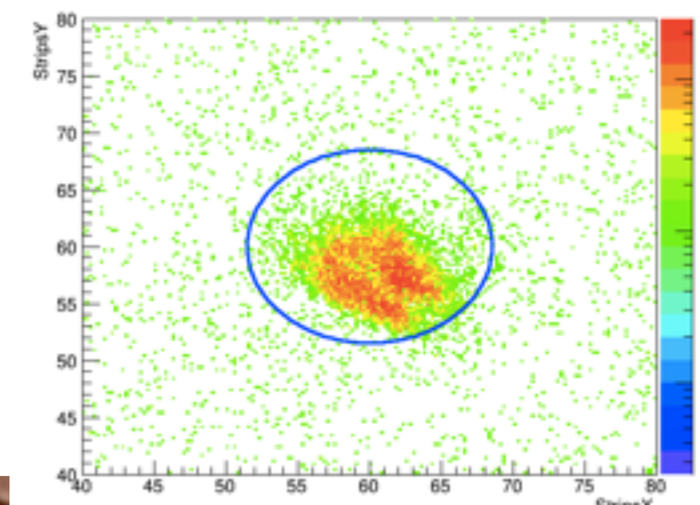
The installation of the telescope in 2014 required a redesigned vacuum line and detector window

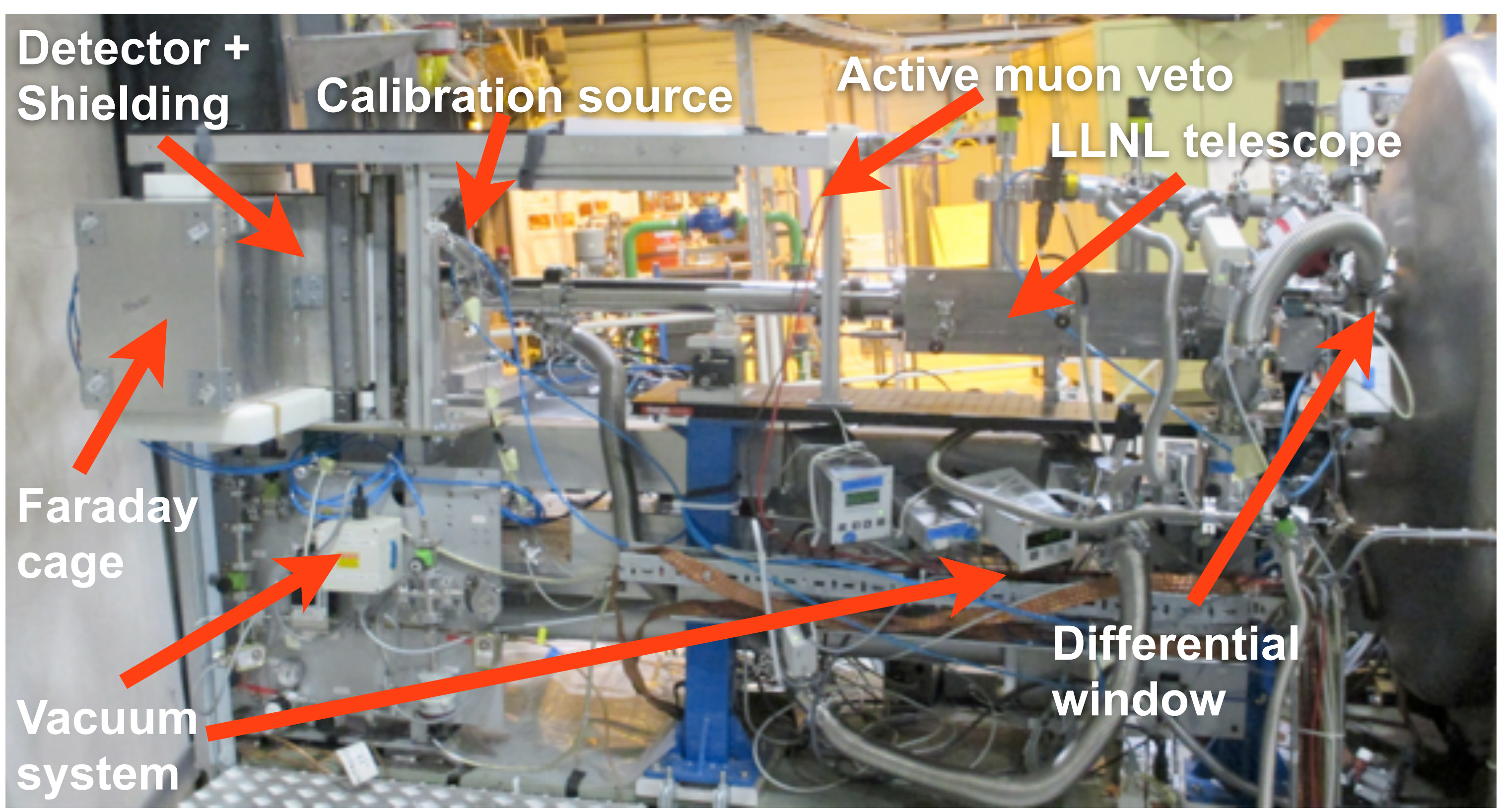


Completely new vacuum line adapted to XRT

Muon veto installed
(formerly used at Sunset MicroMegas in 2012)

The spot is clearly visible after ~7 h of run



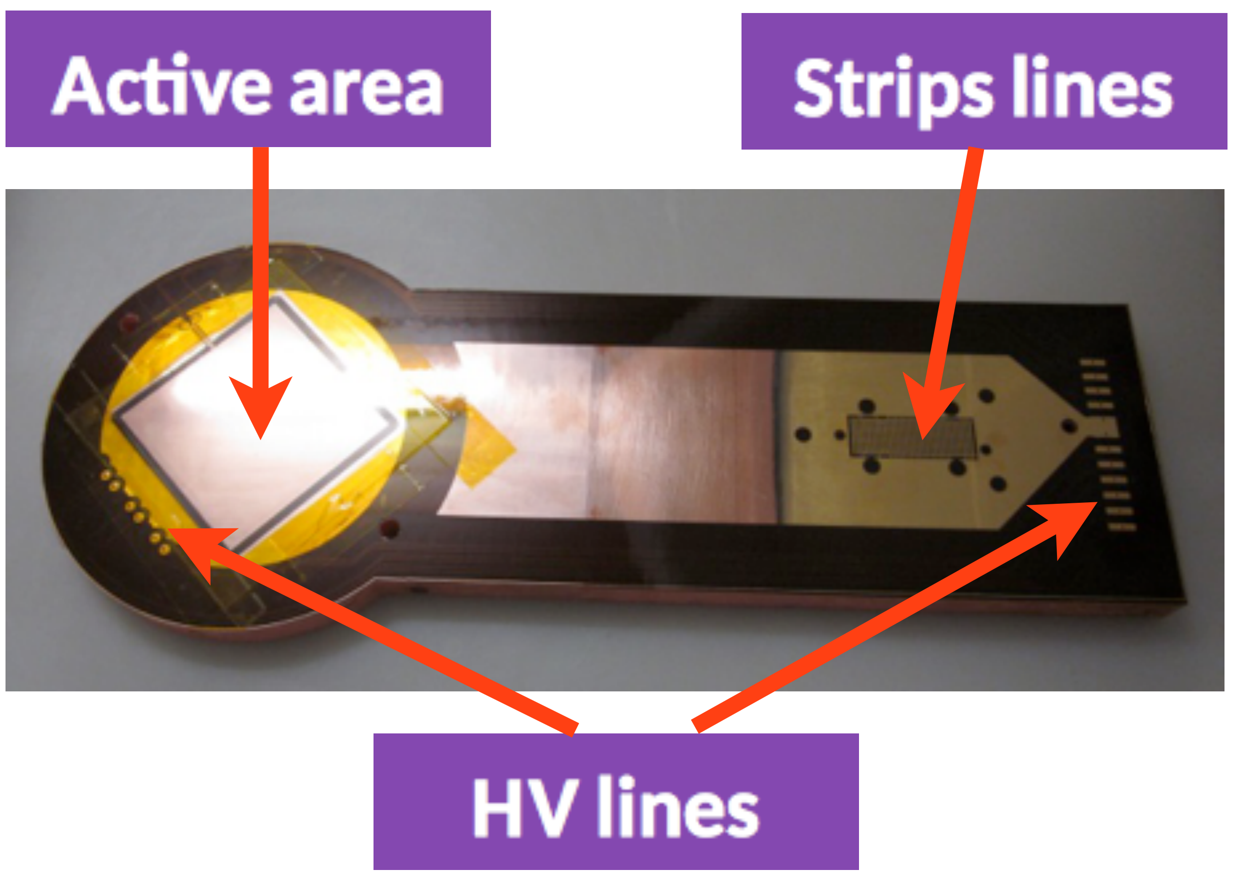


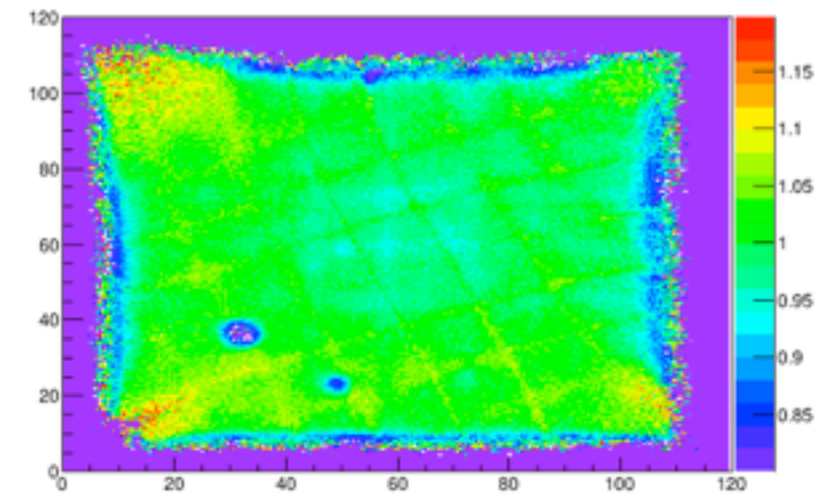
Strongback cathode
Ø 8.5 mm
in the center

A new design of the Sunrise Micromegas was introduced in 2014 to improve its performance

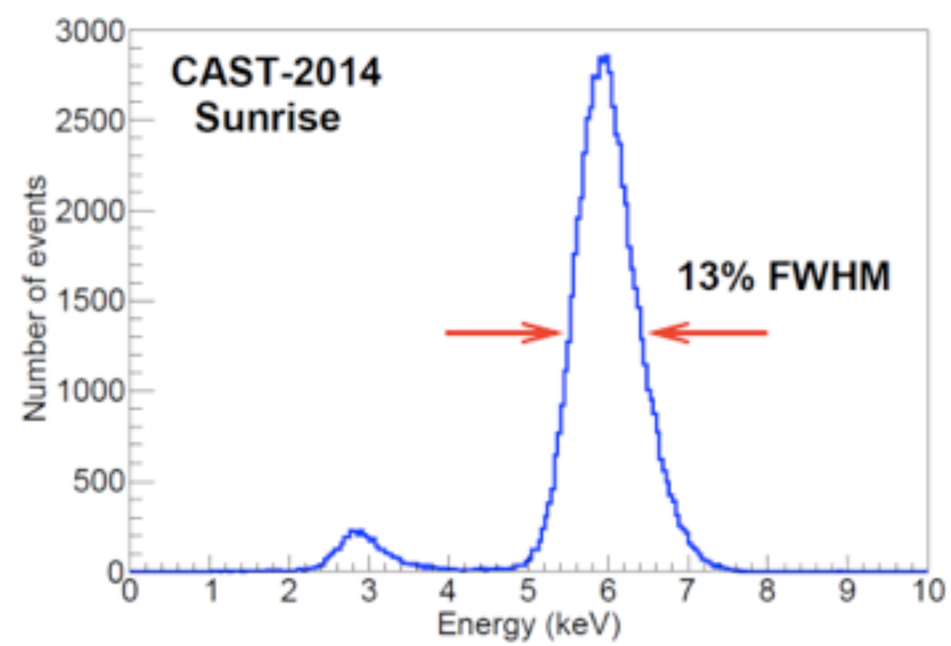
Three new detectors built with the isolation problem fixed.

Characterized at Zaragoza: good gain uniformity in the active area & excellent energy resolution (13% FWHM at 5.9 keV).





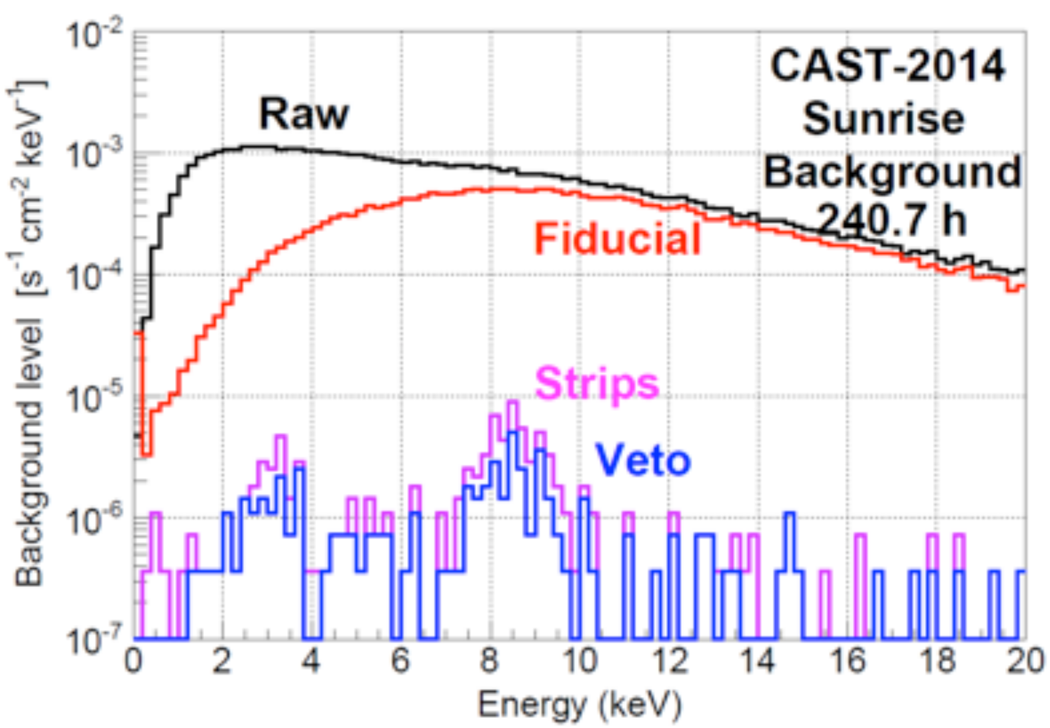
Gain for the new detector



Energy spectrum from ^{55}Fe source

The performance of all Micromegas detectors has been improved

Sunrise Micromegas



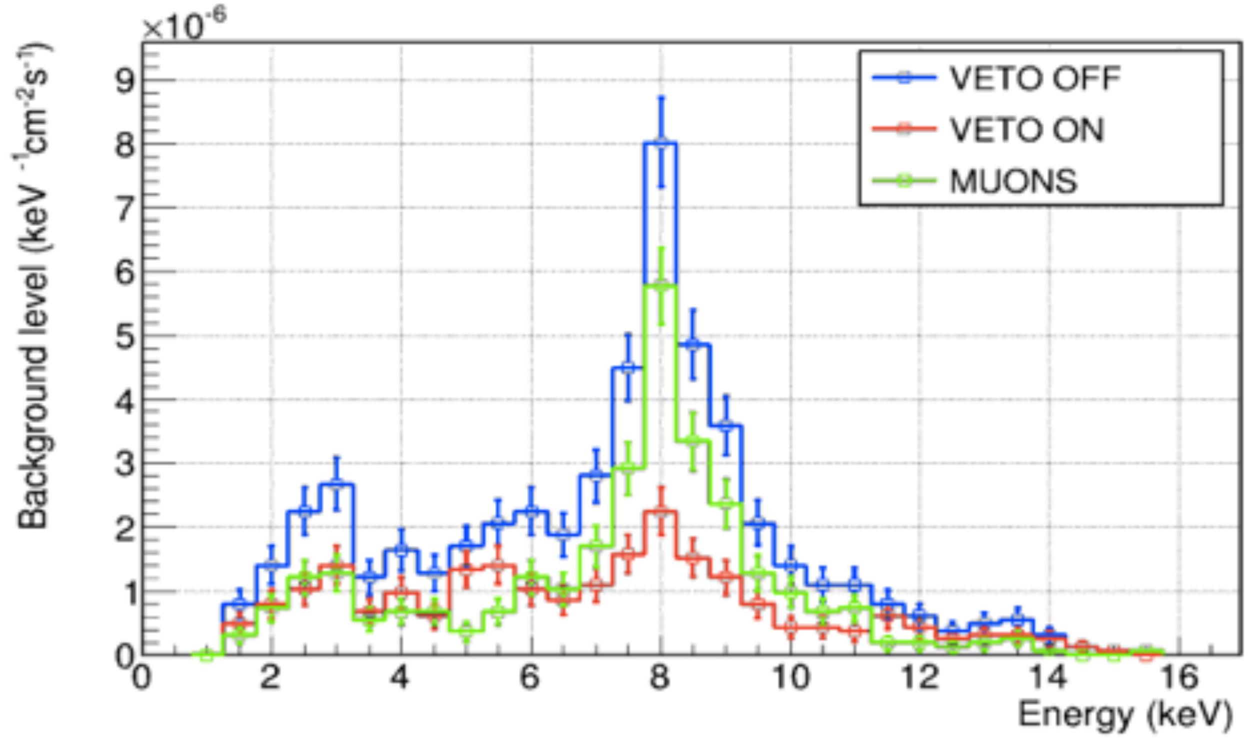
Taking data since 4th September

Gain & energy resolution stable

Preliminary analysis of the first 240 hours in a wide active area gives a background level compatible with Sunset values:

$(0.8 \pm 0.2) \times 10^{-6}$ keV^{-1} cm^{-2} s^{-1}

Sunset Micromegas



Newly-designed scintillator veto system installed in September 2013
Better than 90% efficiency
New veto system reduced background by 50%

Accumulated background data during 2013 and 2014
Data taking resulted in an unprecedented level of

$(1.00 \pm 0.05) \times 10^{-6}$ $keV^{-1}cm^{-2}s^{-1}$

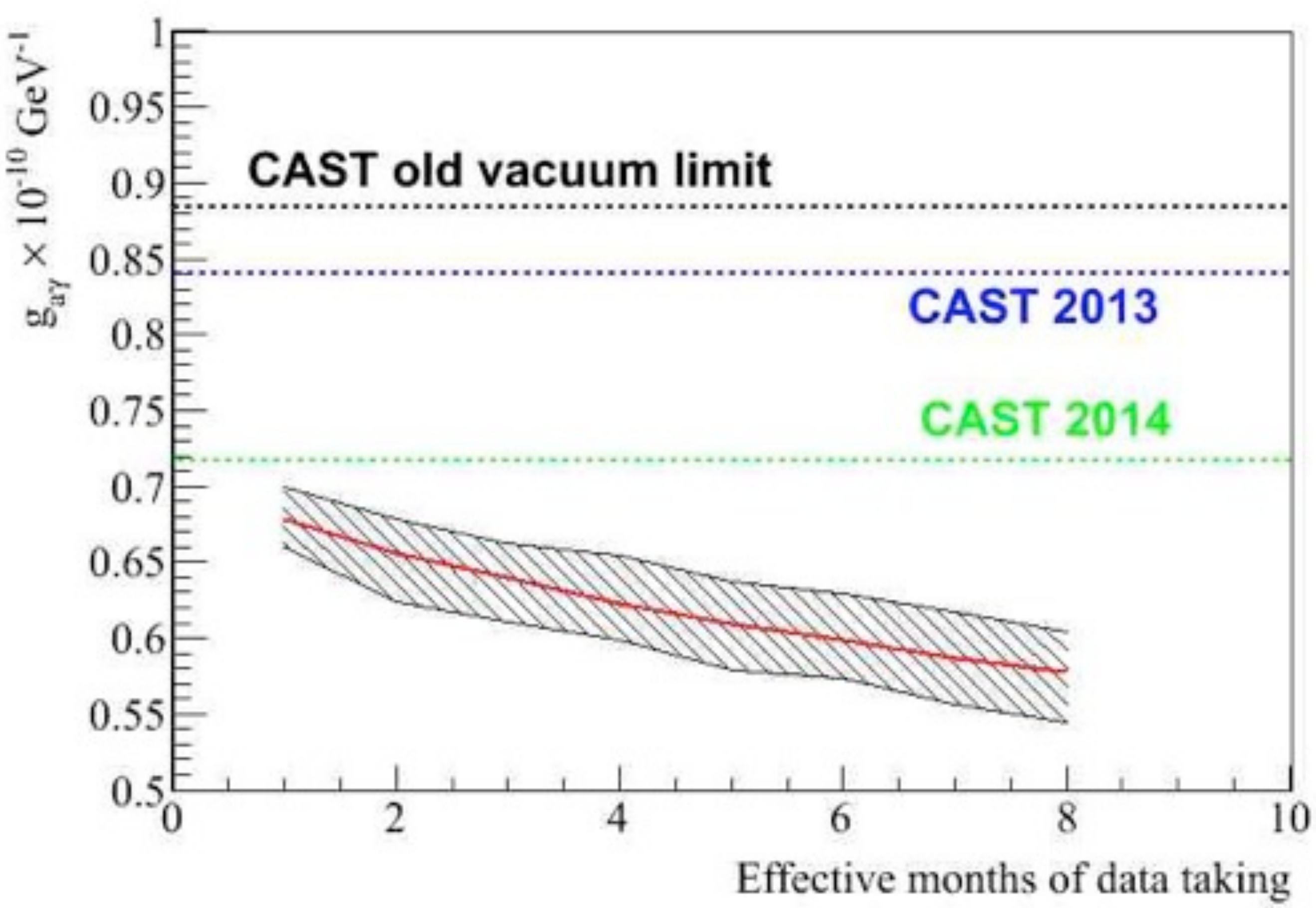
in the [2-7] keV range (75% signal efficiency)

Vacuum run 2013-2015 will search for solar ALPS with increased sensitivity

- **CAST Phase I (vacuum) limit on the axion-to-photon coupling $g_{a\gamma} < 8.8 \times 10^{-11}$ GeV^{-1} (for $m_a < 0.02$ eV) is now widely known and referenced in the Axion (WISP) field.**
- **The improved technology now available in CAST guarantees increased sensitivity with respect to Phase I**
- **Motivation for pushing the CAST vacuum limit to lower $g_{a\gamma}$ values:**

a) access to a new region of ALP parameter space (theoretically motivated e.g., in string theory)
b) access to a portion of the parameter space where ALP models give a valid Cold Dark Matter density
c) access to the "VHE transparency region" of the ALP parameter space

- **The ongoing vacuum run in CAST will test technological options proposed for IAXO, tokamak field configurations and other options.**



Expected sensitivity of the ongoing CAST vacuum phase with all the detectors in operation, versus the exposure time. Also shown are the CAST Phase I limit, and preliminary limits obtained from the 2013 and 2014 data.

In 2013, CAST started to look for Chameleons, dark energy particle candidates

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.

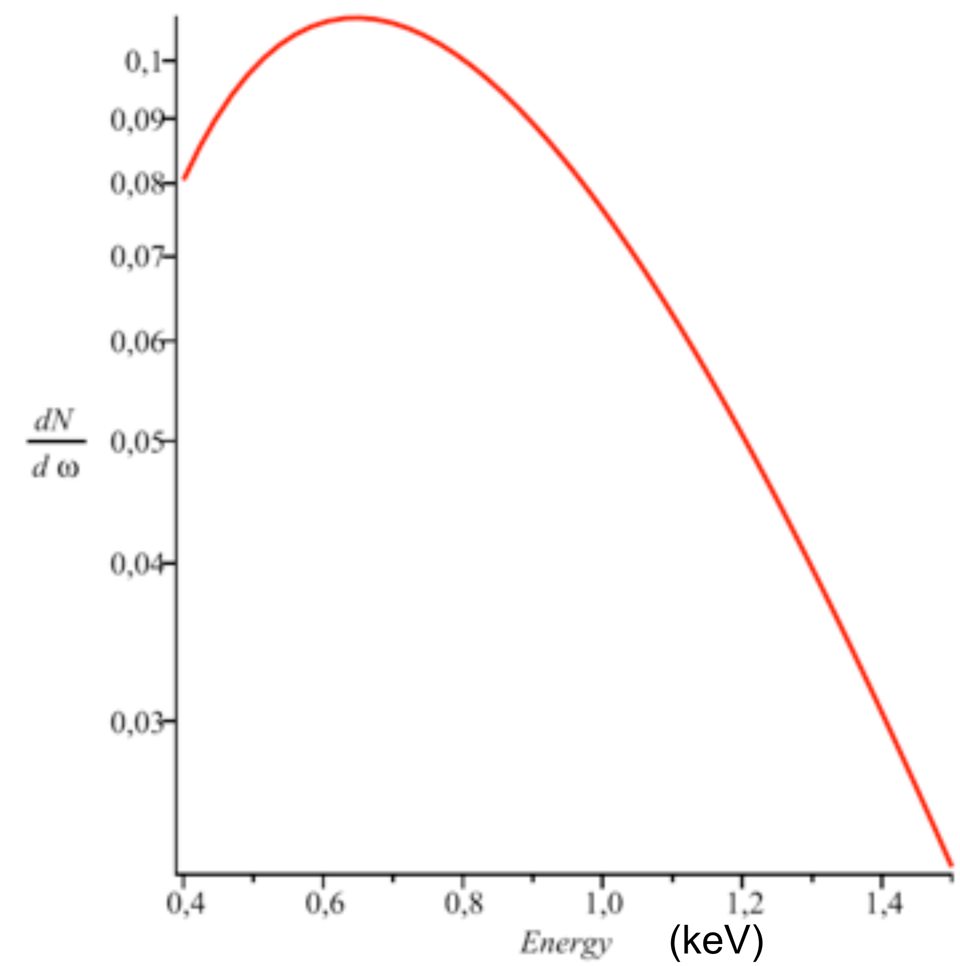
Solar Chameleons

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

Detector requirements:

- Low energy threshold
- Low background
- Good energy resolution

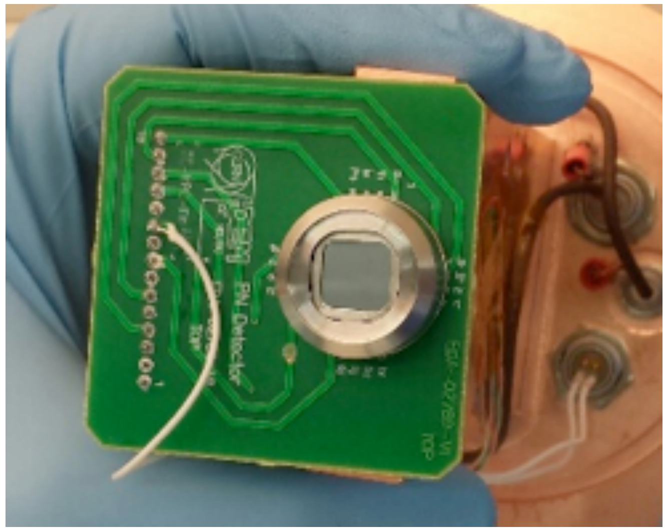
Spectrum of back-converted photons in the CAST magnet inside 16mm²
for B_{tacho} =10T, n=1



P. Brax, K. Zioutas, Phys. Rev. D82 (2010) 043007
P. Brax, A. Lindner, K. Zioutas, Phys. Rev. D85 (2012) 043014

Measurements with a SDD started in 2013, making CAST the first chameleon helioscope

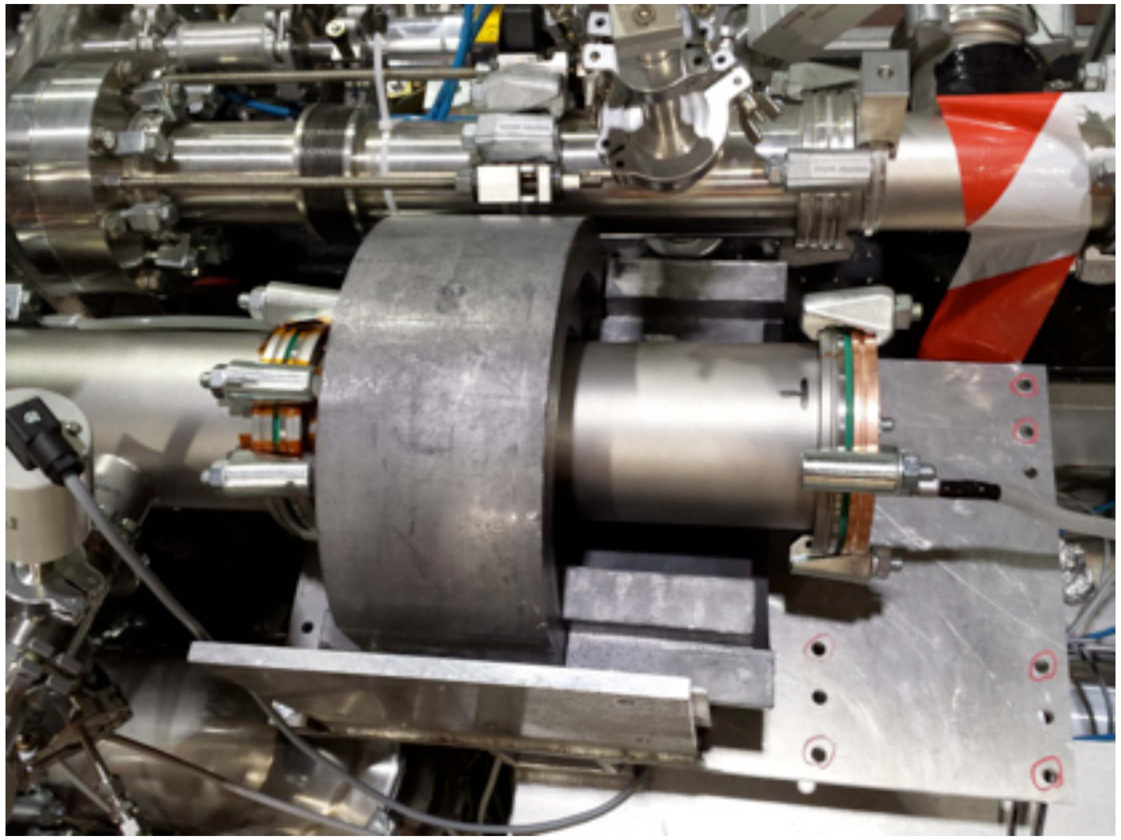
Took advantage of the available port due to MPE-XRT recalibration

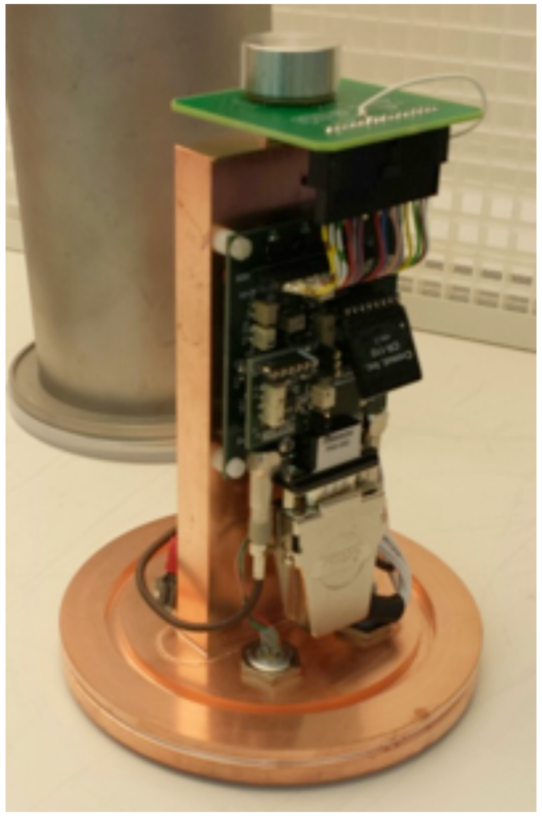


SDD (from PNdetector)

- Detector system assembled from commercial parts
- SDD ~ 100 mm^2 surface area

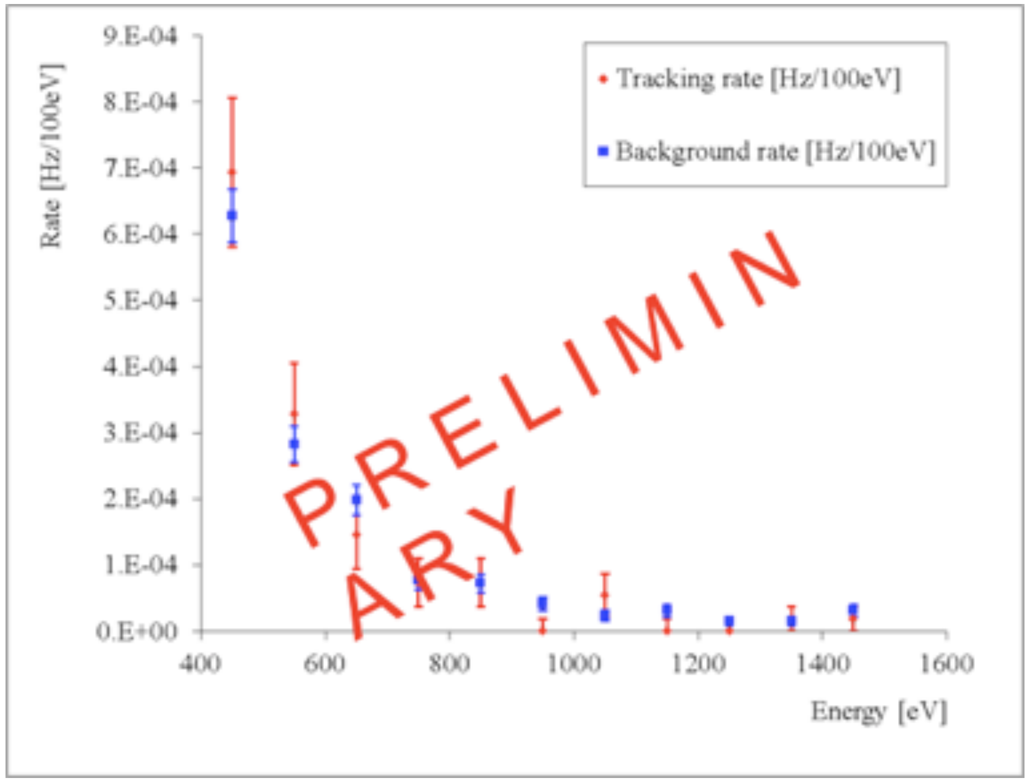
No window
Q.E. > 70% above 400 eV

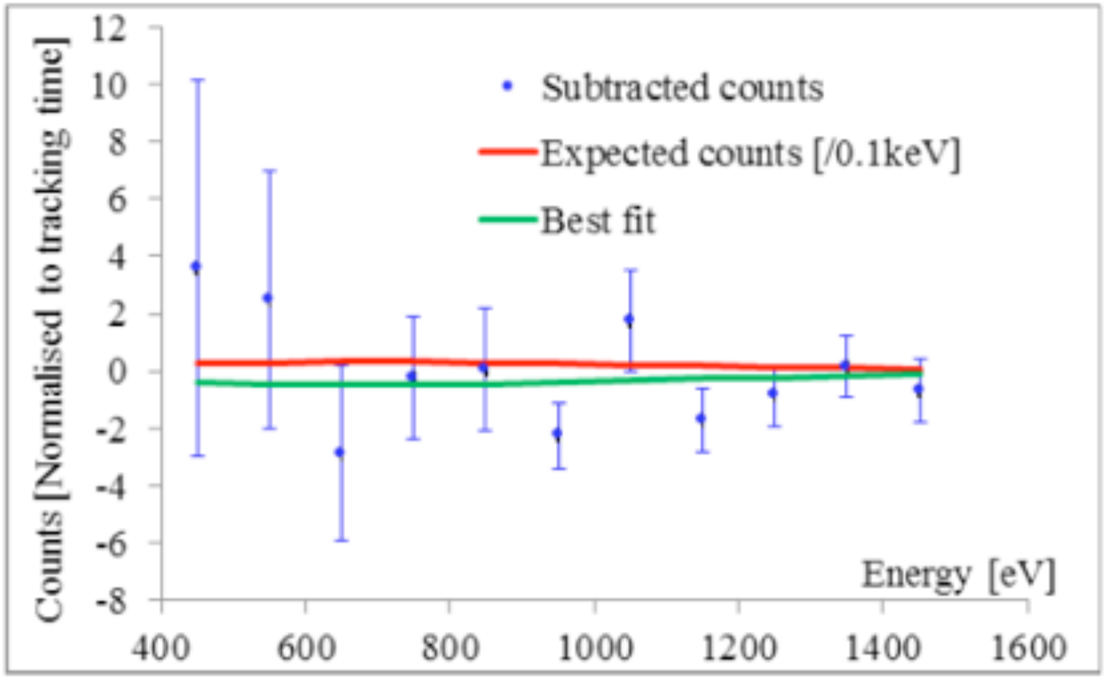




First results from SDD measurements are being prepared for publication

Data tracking strategy
Detector at room temperature → tracking (detector cold)
Detector at room temperature → background (detector cold)



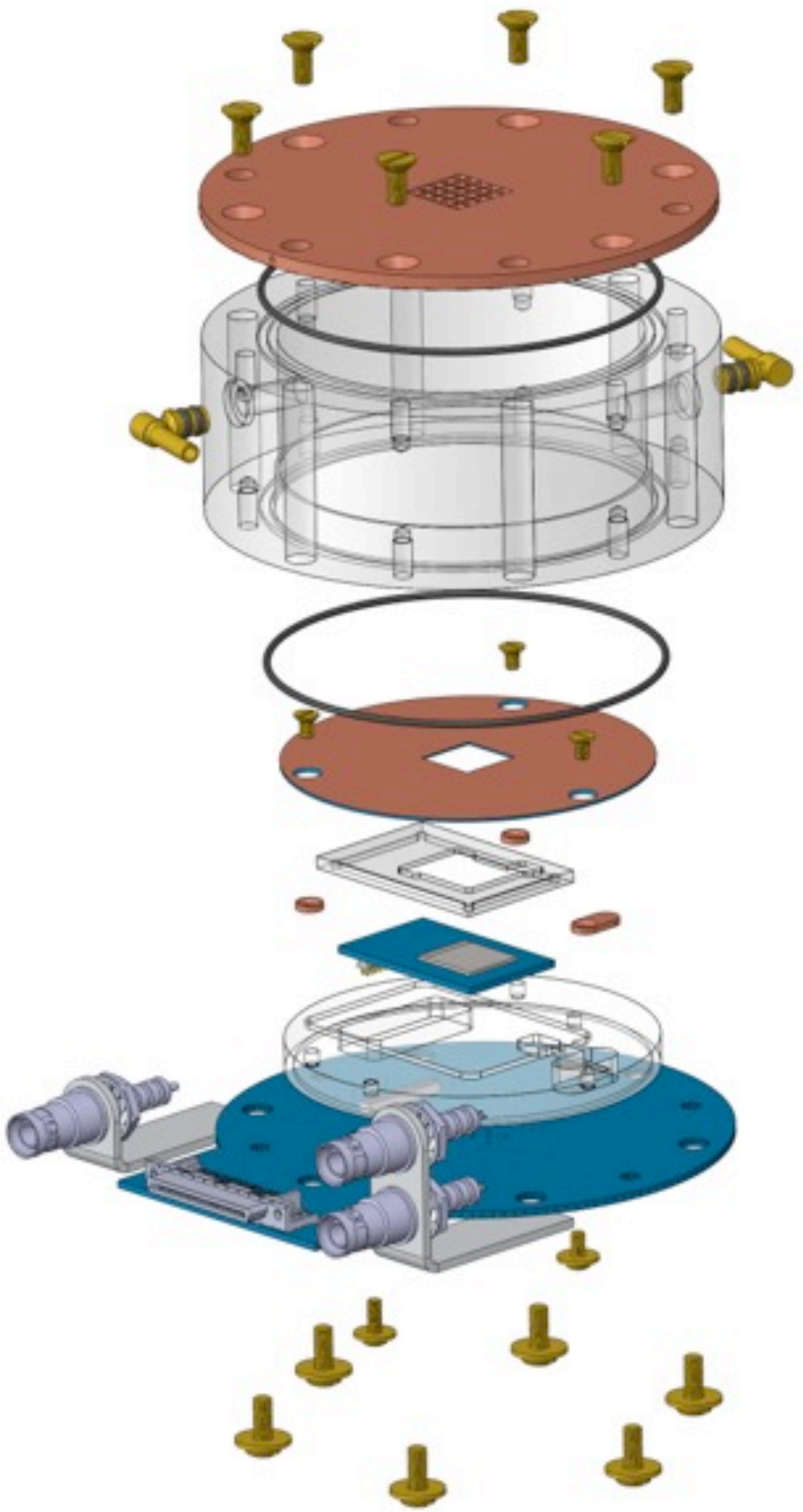


15.2 h of tracking time
108 h of background time

Results of SDD compatible with null hypothesis
Limit to **$\beta_\gamma \leq 9.2 \cdot 10^{10}$ at 95% C.L.**
Valid for $1 \leq \beta_m \leq 10^6$

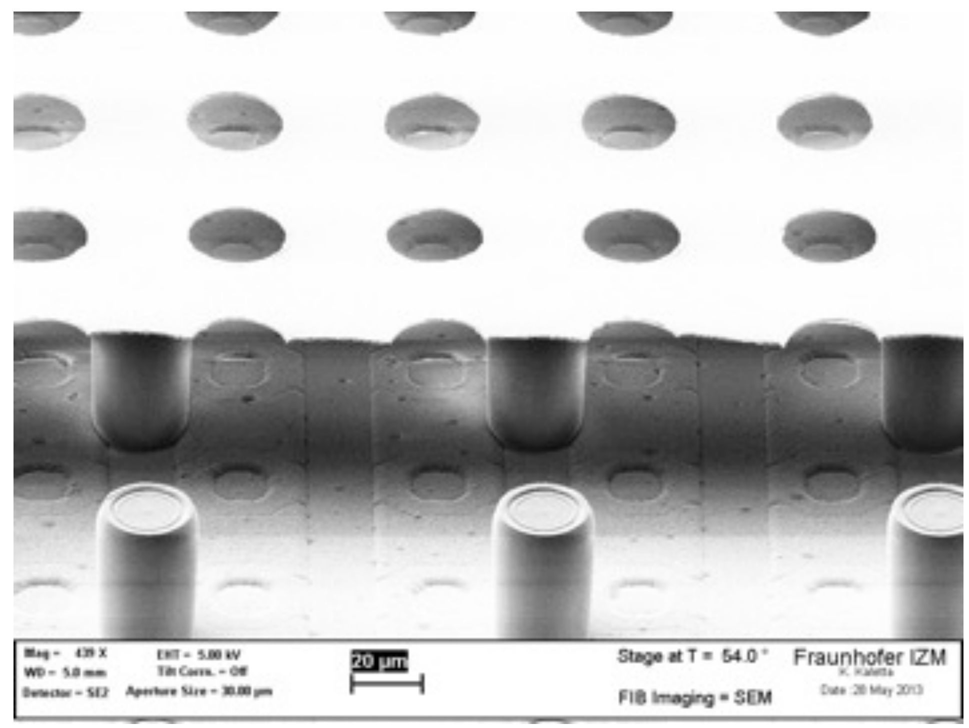
Publication under preparation

The new InGrid detector replaces the CCD detector behind the MPE X-ray telescope



Detector for Q4 was developed based on the Micromegas detectors

InGrid on top of Timepix ASIC



Drift distance 3 cm

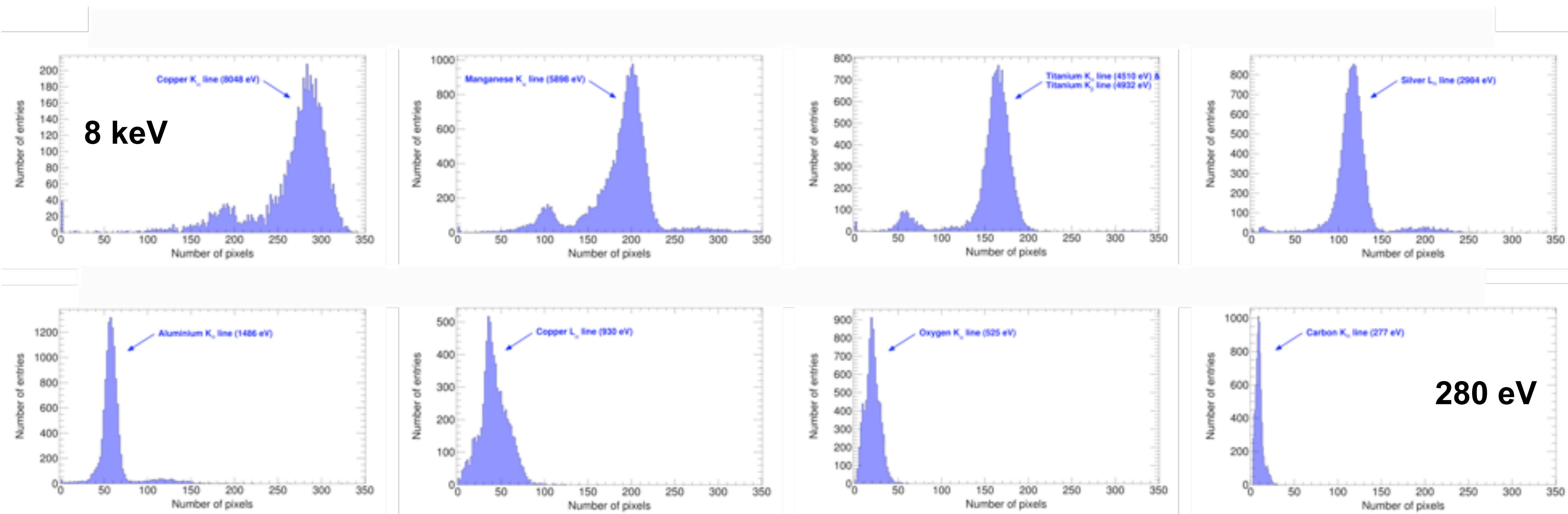
Gas mixture: Ar:iC_4H_{10} 97.7:2.3

Entrance window 2 µm aluminized mylar foil

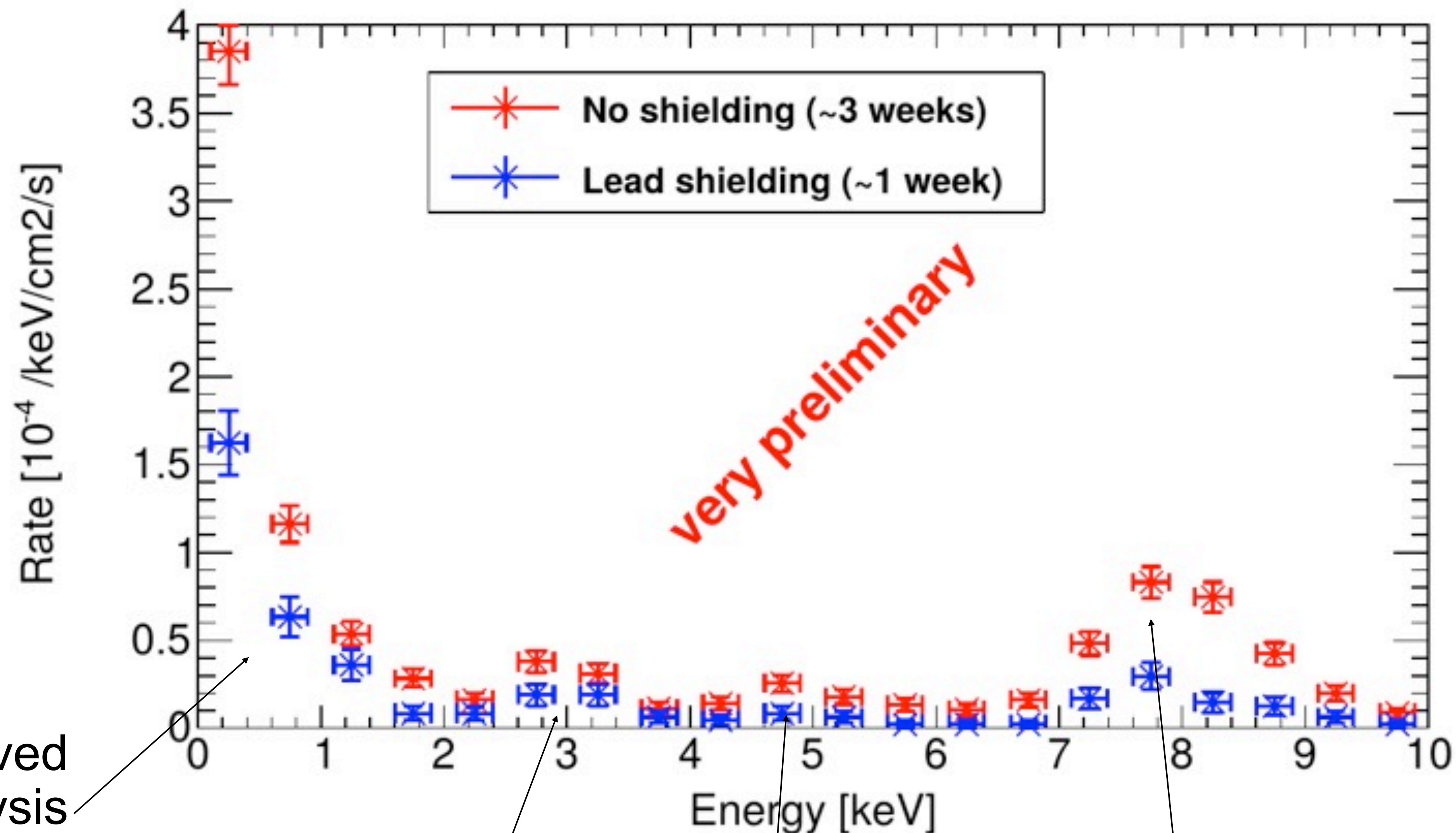
The InGrid has been tested at the detector lab at CERN down to 280 eV

Photon energies between 280 eV and 8 keV are available from an X-ray tube.

X-rays can be detected down to 277 eV.



Background of new InGrid detector is by a factor of 2-4 lower than that of the X-ray CCD



Improved analysis necessary

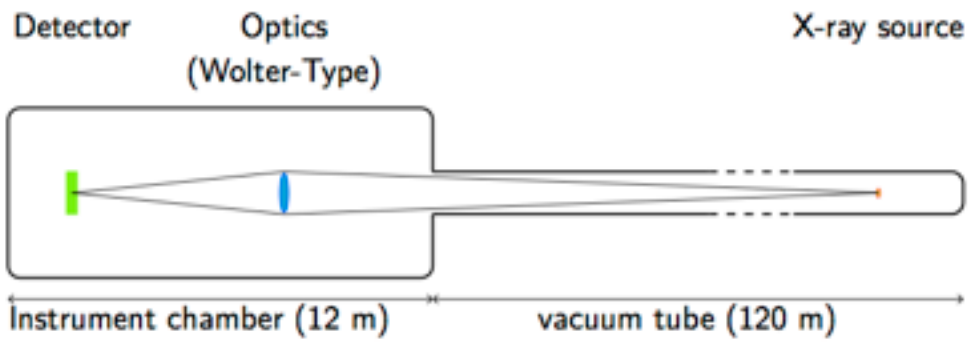
Ar-K_a fluorescence line

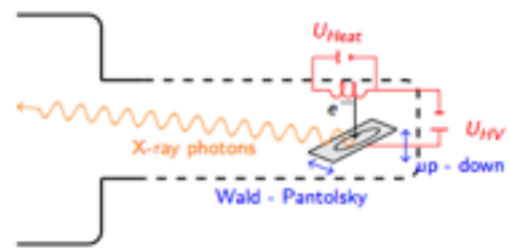
Cu-K_a fluorescence line
+ perpendicular cosmic rays

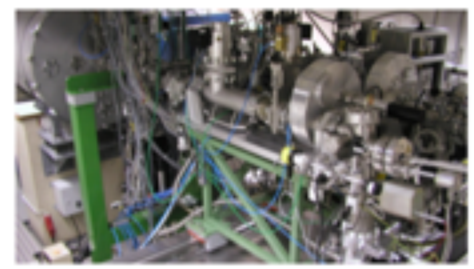
Ar escape peak of Cu-K_a fluorescence line

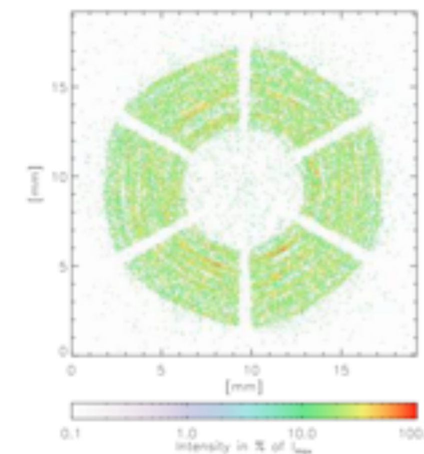
For comparison:
X-ray CCD $5 \cdot 10^{-5}$ keV^{-1} cm^{-2} s^{-1}

X-ray reflectivity measurements at PANTER verified the good condition of the MPE telescope

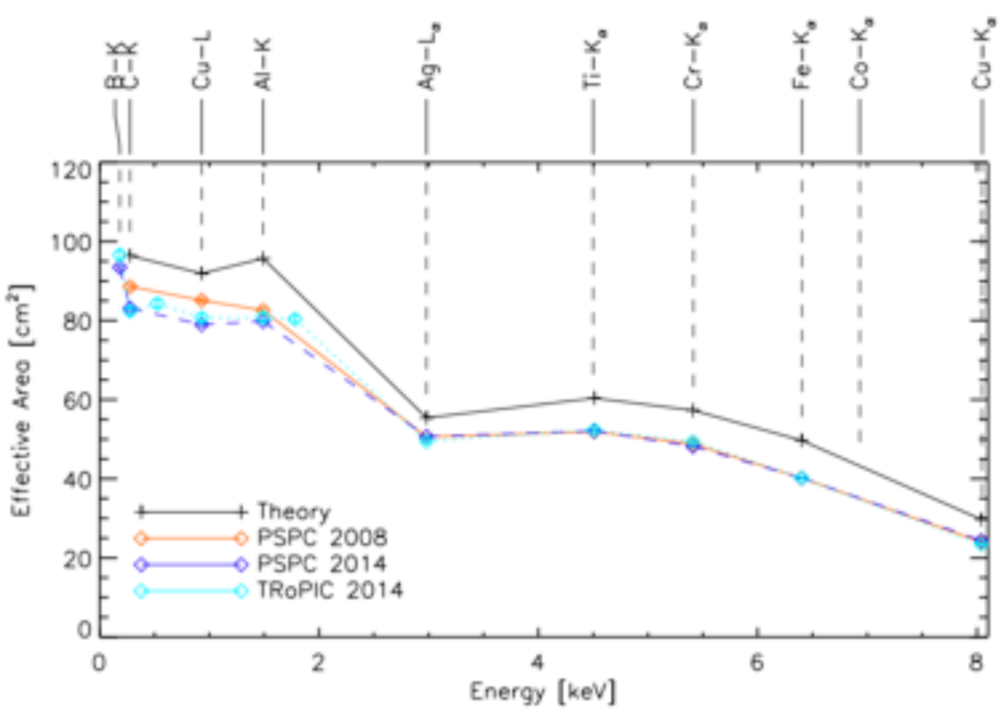


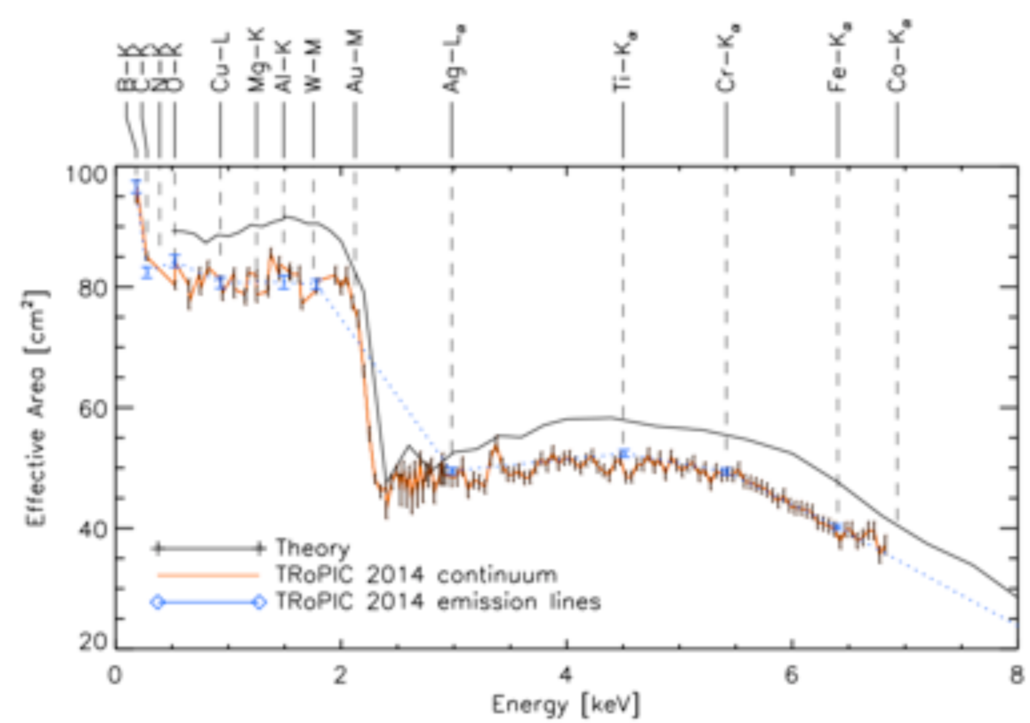






- Third measurement (after 2000 and 2008) to check reflectivity of the telescope
- Reflectivity checked in the energy range from 180 eV to 8 keV
- For energies above 2 keV: no significant change compared to 2008
- For energies below 2 keV: reflectivity reduced by 5%





A contamination of the InGrid detector happened, but MPE telescope was not contaminated

By mistake vacuum grease was used for the assembly of the InGrid vacuum system. A contamination with hydrocarbons would reduce the reflectivity of the telescope.

To avoid this, the system had been taken apart and parts have either been cleaned or replaced.

X-ray telescope telescope was shipped to MPE in Garching to test for contamination with hydrocarbons

Swipe tests inside the telescope housing showed that telescope had not been contaminated

MPE X-ray telescope has been installed back into the setup (-> M. Rosu)

Detection of solar chameleons via matter coupling with KWISP: sensitive force sensor

The hypothetical flux of solar Chameleons has been recently estimated in arXiv:1409.3852v1 (submitted to PLB) with a special emphasis on the direct coupling to matter

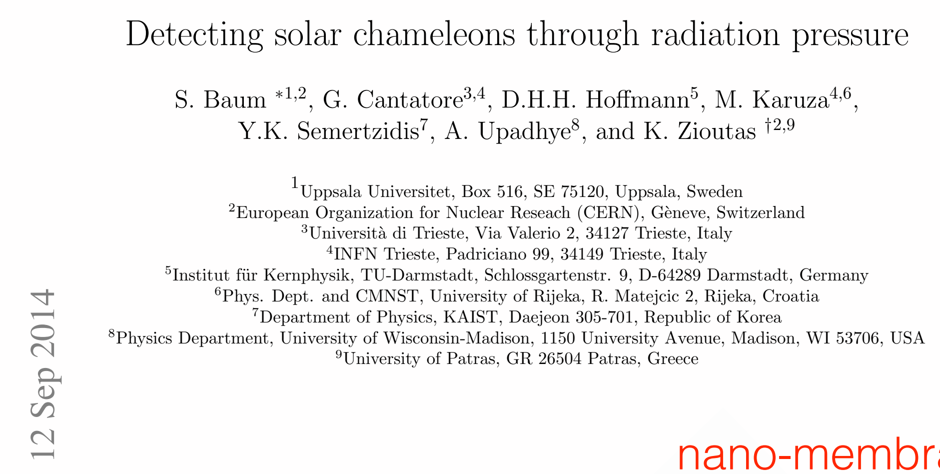
- estimate of the expected spectrum of solar Chameleons and parameter space coverage
- perspectives at CAST

KWISP measurement program

- sensor complete characterization (Trieste)
- preliminary commissioning:
- off-beam prototype test in the CAST area (CERN)
- design of sensor coupling to the CAST beamline (CERN)
- assembly and commissioning (CERN)
- live data taking (CERN)

Projected KWISP time schedule

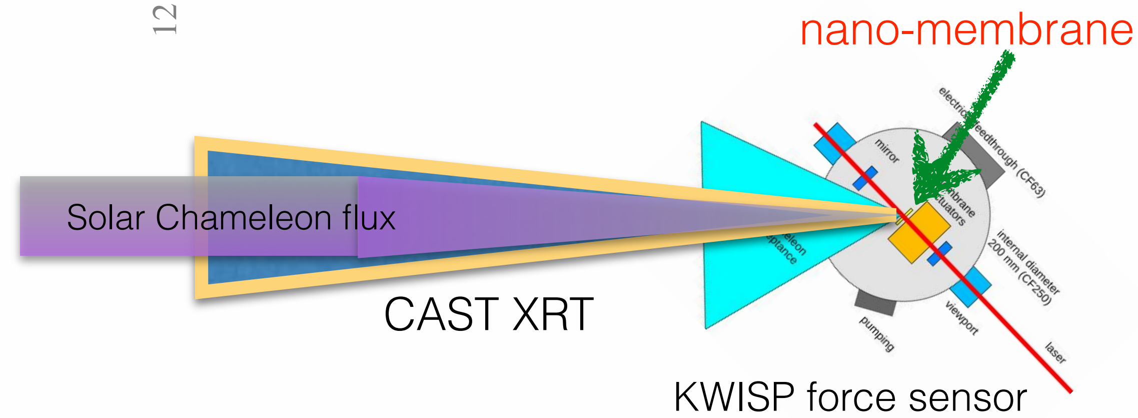
- October-December 2014:
  off-beam preliminary commissioning at CAST
- 2015 (first half)design of coupling to CAST beam-line in-beam assembly
- 2015 (second half)
  commissioning live data taking
- 2016 ⇒ live data taking


Detecting solar chameleons through radiation pressure

S. Baum *1,2, G. Cantatore3,4, D.H.H. Hoffmann5, M. Karuza4,6, Y.K. Semertzidis7, A. Upadhye8, and K. Zioutas †2,9

1Uppsala Universitet, Box 516, SE 75120, Uppsala, Sweden
2European Organization for Nuclear Reseach (CERN), Gèneve, Switzerland
3Università di Trieste, Via Valerio 2, 34127 Trieste, Italy
4INFN Trieste, Padriciano 99, 34149 Trieste, Italy
5Institut für Kernphysik, TU-Darmstadt, Schlossgartenstr. 9, D-64289 Darmstadt, Germany
6Phys. Dept. and CMNST, University of Rijeka, R. Matejcic 2, Rijeka, Croatia
7Department of Physics, KAIST, Daejeon 305-701, Republic of Korea
8Physics Department, University of Wisconsin-Madison, 1150 University Avenue, Madison, WI 53706, USA
9University of Patras, GR 26504 Patras, Greece

12 Sep 2014



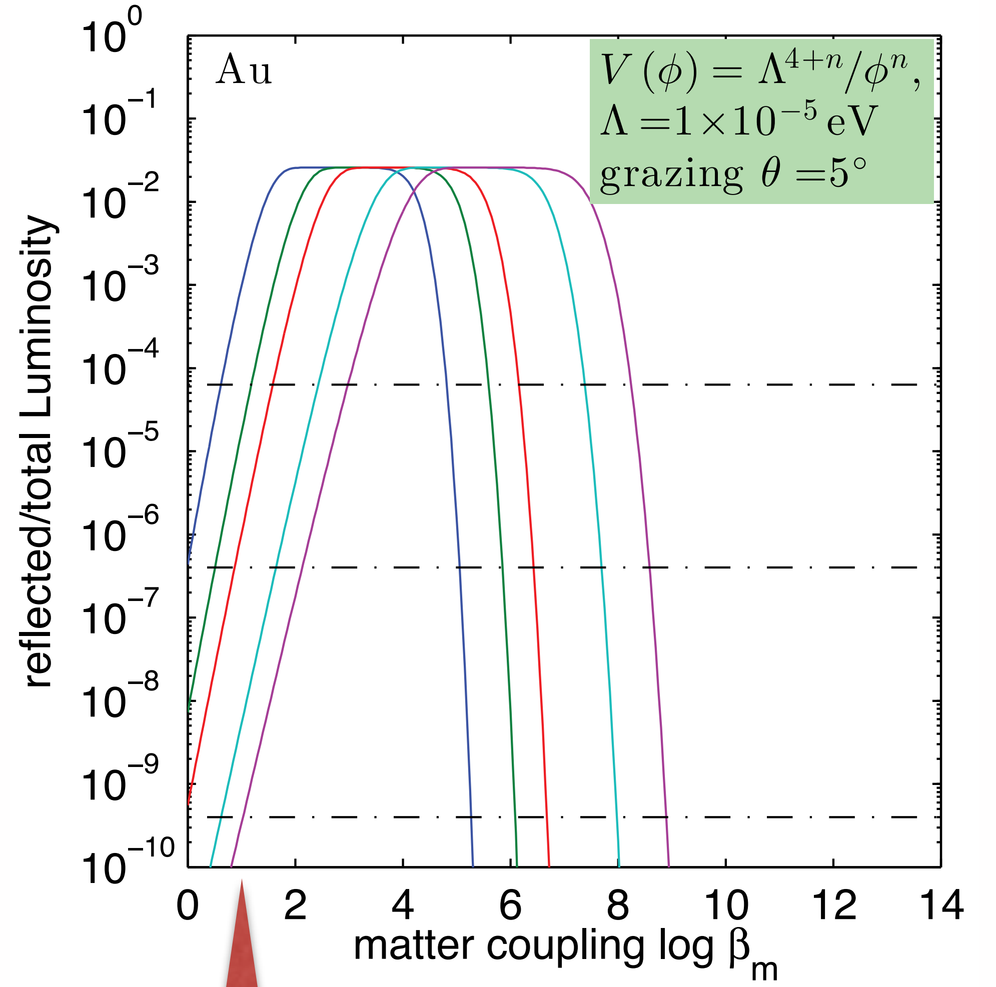
CAST advantages
- solar tracking
- XRT focusing

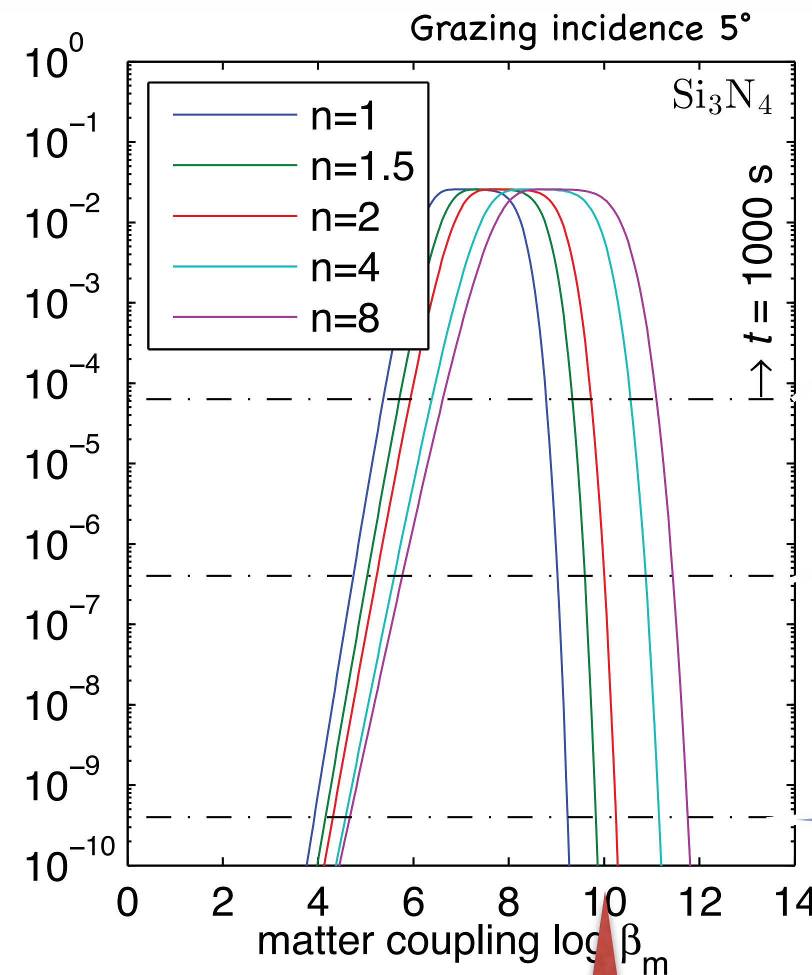
G. Cantatore (University and INFN Trieste) and M. Karuza (University of Rijeka) and INFN Trieste) collaboration with S. Baum (CERN), D. Hoffmann (TU Darmstadt), A. Lindner (DESY), Y. Semertzidis (KAIST- CAPP Seoul), A. Upadye (ANL) and K. Zioutas (U Patras & CERN)

The KWISP force sensor can cover a wide range of β_m

- Curves below represent, for different *n* and Λ parameters in the Chameleon potential the fraction of the total incident flux reflected by the Si_3N_4 membrane ("Au" plot refers to a gold coated membrane)
- Dashed lines indicate, for different measurement conditions, the minimum fraction detectable by KWISP with the current expected force sensitivity of $5 \cdot 10_{-14}$ N/√Hz (assuming L_{ch}/L_{sol} = 0.1)

curves from arXiv:1409.3852v1





- T_{mis} = 1000 s
- No XRT

- T_{mis} = 100 s
- sensor in the CAST XRT focus

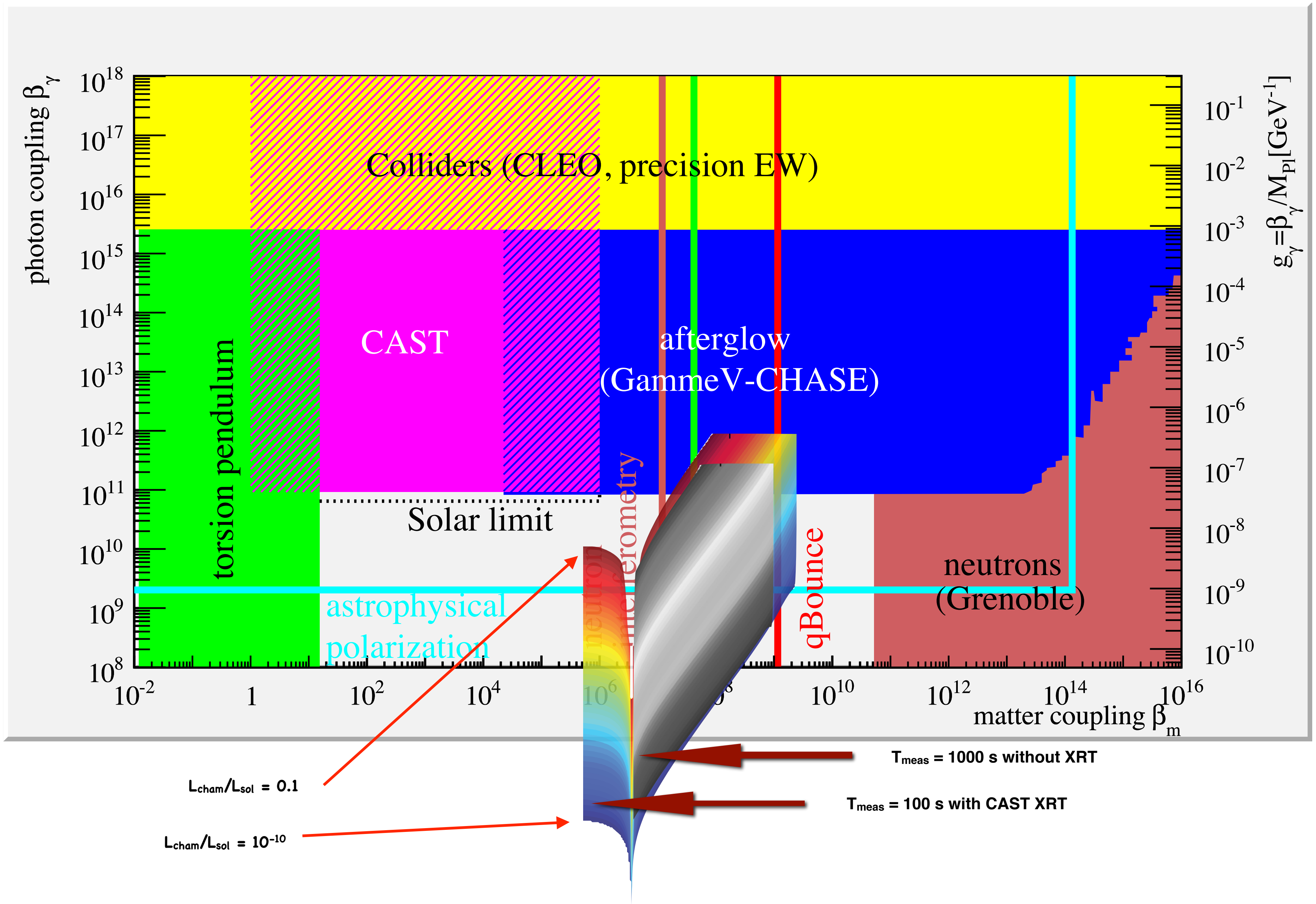
- T_{mis} = 100 s
- sensor in the CAST XRT focus
- membrane at < 1 K
- chopper

Wide β_m reach from ~10 to ~10^{10}

Expected KWISP coverage in the β_m-β_γ plane

Expected coverage of the KWISP sensor in the β_m-β_γ plane with the current sensitivity of $5 \cdot 10^{-14}$ N/√Hz

- The greyscale band corresponds to a solar tracking measurement done without the CAST X-ray telescope
- The coloured band corresponds to a solar tracking measurement carried out with the sensor in the focal plane of the CAST X-ray telescope



After 2015: CAST could also be used to search for relic dark matter

CAST after 2015? → Axion DM detection?

- Highly motivated if competitive & complementary (with ADMX)
- Recent cosmology progress → increased interest for higher mass ranges (10 μeV– 1meV)
- How to go here is not clear. New ideas being proposed recently, but R&D is necessary

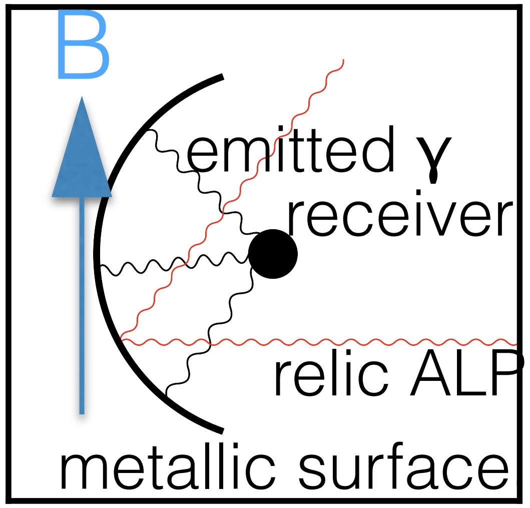
Different detector concepts under discussion:

1. Dish antenna
2. Dielectric resonator
3. Long thin cavities

Dish antenna could be used to search for relic ALPS and Hidden sector Photons at CAST

- **Novel concept to extend the mass range of relic axion searches**
  (see arXiv:1212.2970 and 1308.1103)

- **Captivating idea: the promise of entering uncharted territory in the Axion (ALP) parameter space**



  - Advantages at CAST
    - cold environment (1.8 K)
    - large B
    - moving magnet to intercept relic streams (if any…)
  - **Gravitational lensing** on streaming Dark Matter could give factor 10-100 increase in sensitivity
    ⇒ **unique CAST capability**

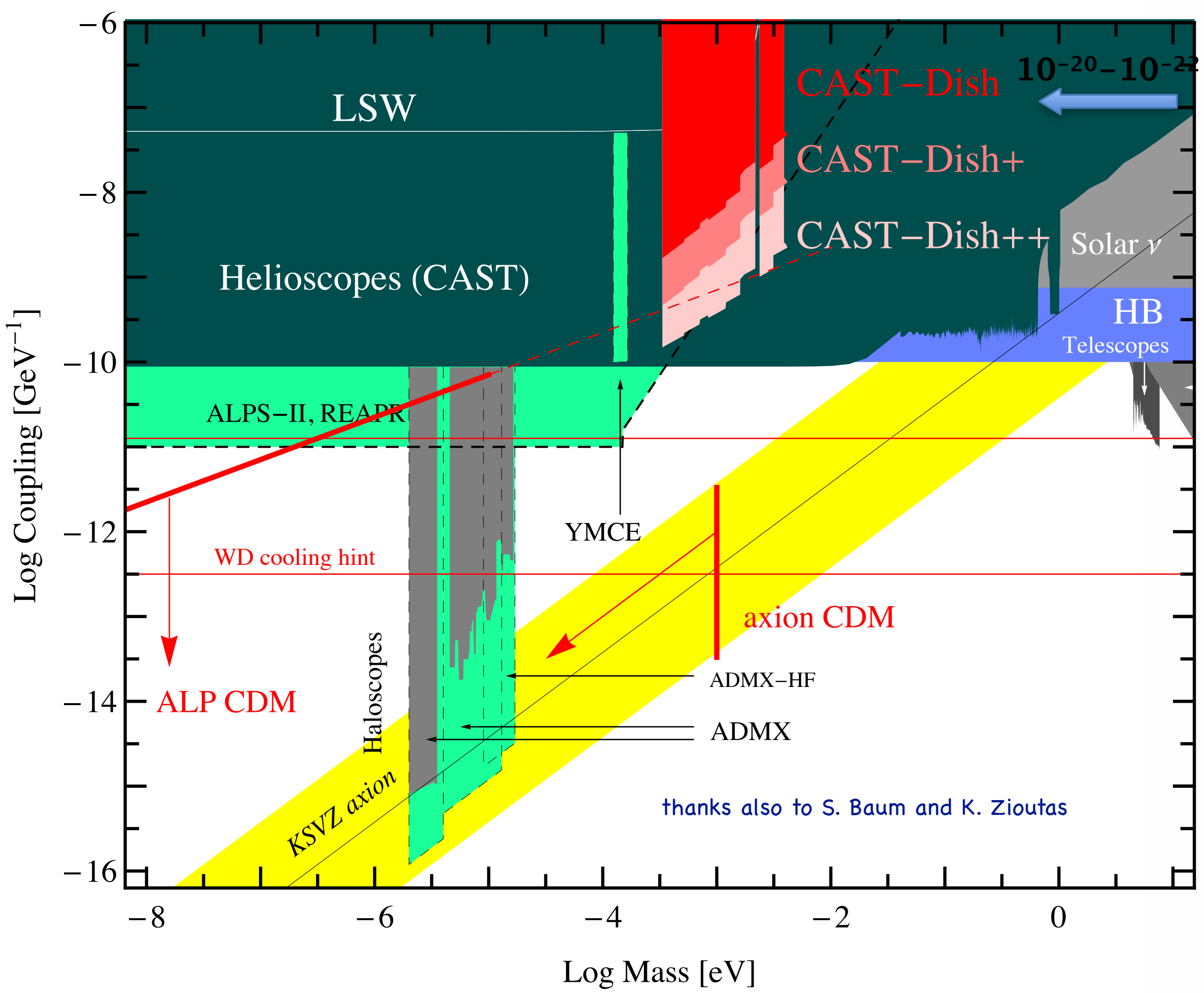
- Technique suitable also for other WISP searches such as

- **Detector technology** must however be pushed hard with expert help (radio-astronomy community?)

- **CAST can become a precursor "multi-technique lab" having a shot at discovery and paving the way for future efforts**

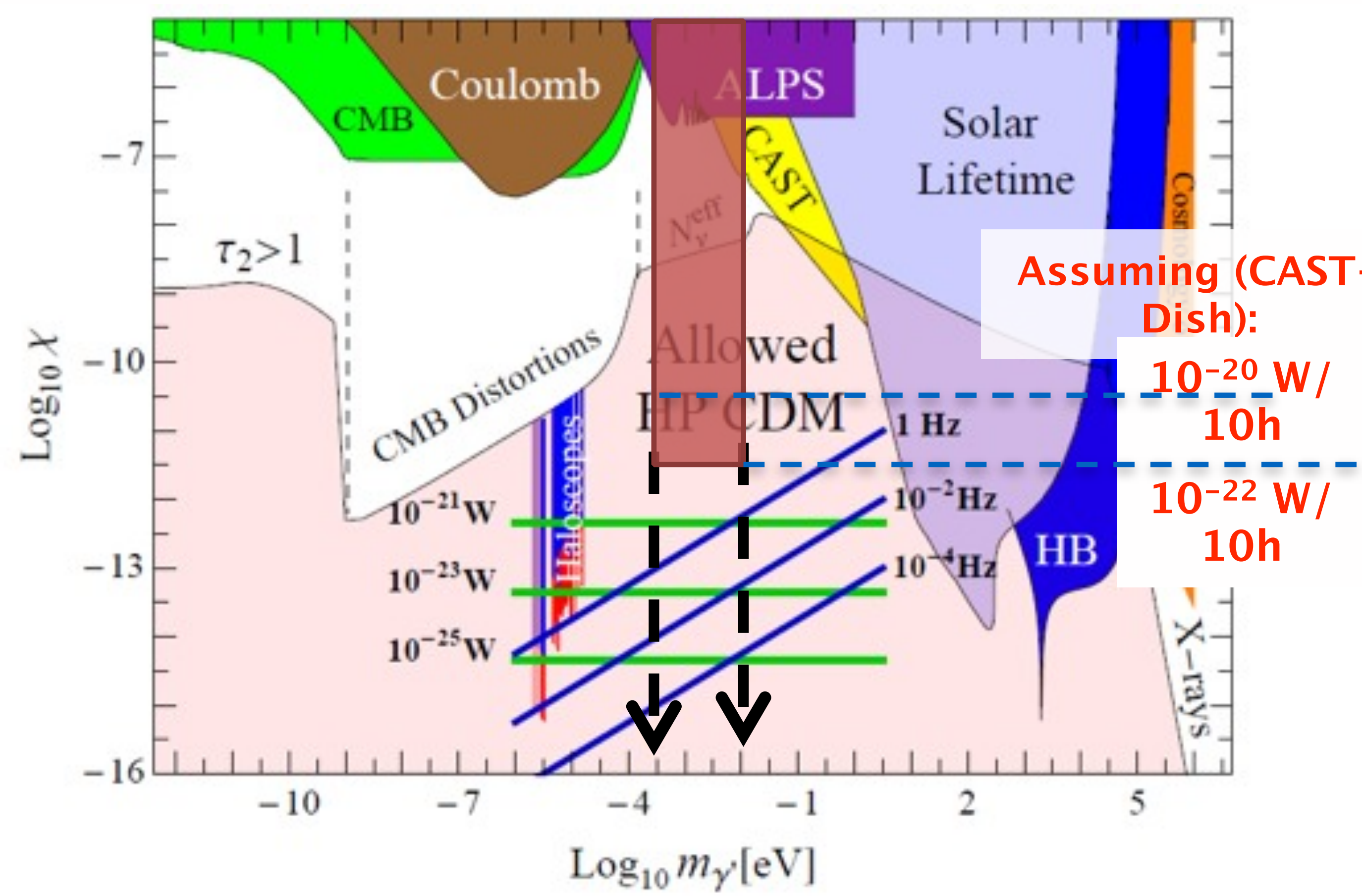
Dish antenna ALP and HP sensitivity estimate

- **With currently available detector technology** (ALMA telescope receivers) - courtesy of A. Lobanov (MPIfR Bonn)



ALP sensitivity

CAST-Dish - current technology
CAST-Dish+ - better electronics
CAST-Dish++ - add cryogenic environment



From ArXiv: 1212.2970v1 D. Horns et al.

Hidden Photon sensitivity

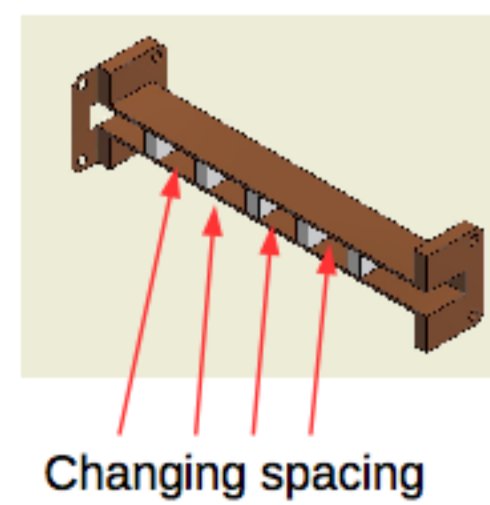
CAST-Dish - current technology
CAST-Dish+ - better electronics
CAST-Dish++ - add cryogenic environment

<u>Pursuing the concept at CAST</u>: G. Cantatore (Trieste), D. Hoffmann (TU Darmstadt), M. Karuza (Rijeka and Trieste), A. Lindner (DESY), Y. Semertzidis (KAIST- CAPP Seoul), and K. Zioutas (U Patras & CERN) also interested K. Desch (U Bonn)

Dielectric-loaded waveguides for relic ALP detection at CAST (*)

- A waveguide can be used inside a dipole magnet (CAST for instance) to maximise coupling between the magnetic field and the electric field from relic ALP conversion (see O.K. Baker et al., PRD 85, 035018 (2012))
    - mode crossing limits length to ~1.5 m (possible solution: multiple cavities)
    - tuning frequency up to a few GHz ⇒ ALP mass ~10^{-5} eV
    - form factor (coupling between **B** and **E**) ~0.66 (best case)
- Dielectric inserts periodically spaced in a waveguide can still enhance **E**-**B** coupling and overcome length limitations (see G. Rybka in Patras 2014 workshop)
    - tuning (potentially up to tens of GHz, corresponding to the 10^{-4} eV range in ALP mass) can be achieved by changing the spacing between dielectrics
- Difficulties
    - tolerances in dielectric thicknesses and spacings
    - moving the dielectrics to tune the structure
- **Possible first step at CAST**
    - **build a fixed-frequency prototype, test its properties and carry out a test run inside the magnetic field**

Gray Rybka - PATRAS 2014, CERN July 2014



(*) Proposed to CAST by Y.K. Semertzidis

Long thin cavities could be used to search for relic ALPS with CAST

Assumptions (at first sight realistic):

- Q=3000
- Noise = 5K
- T = 12 h /step
- 15% tuning span (450 steps)
- B=9T
- Black 1 m length
- Red 10 m length

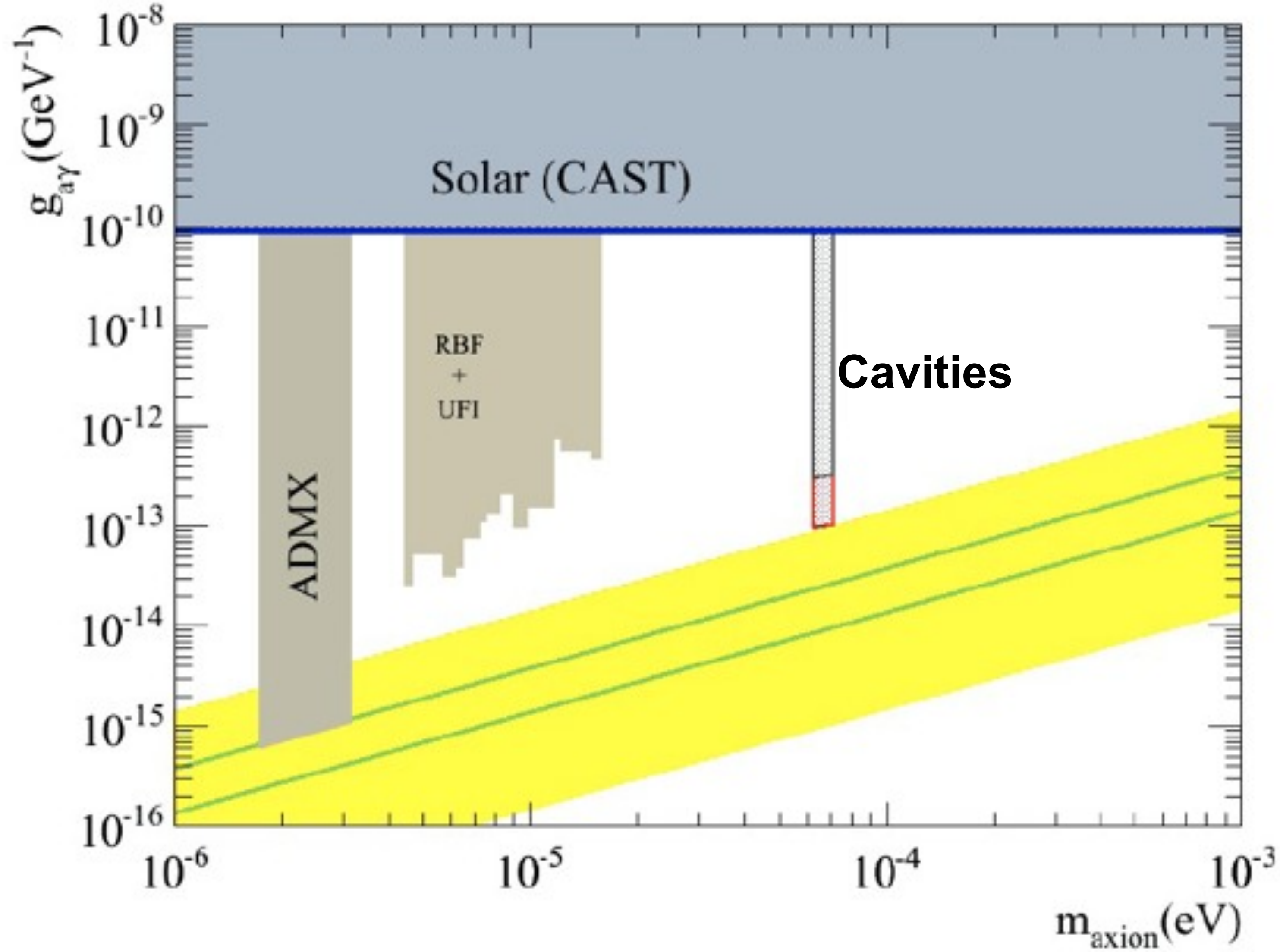


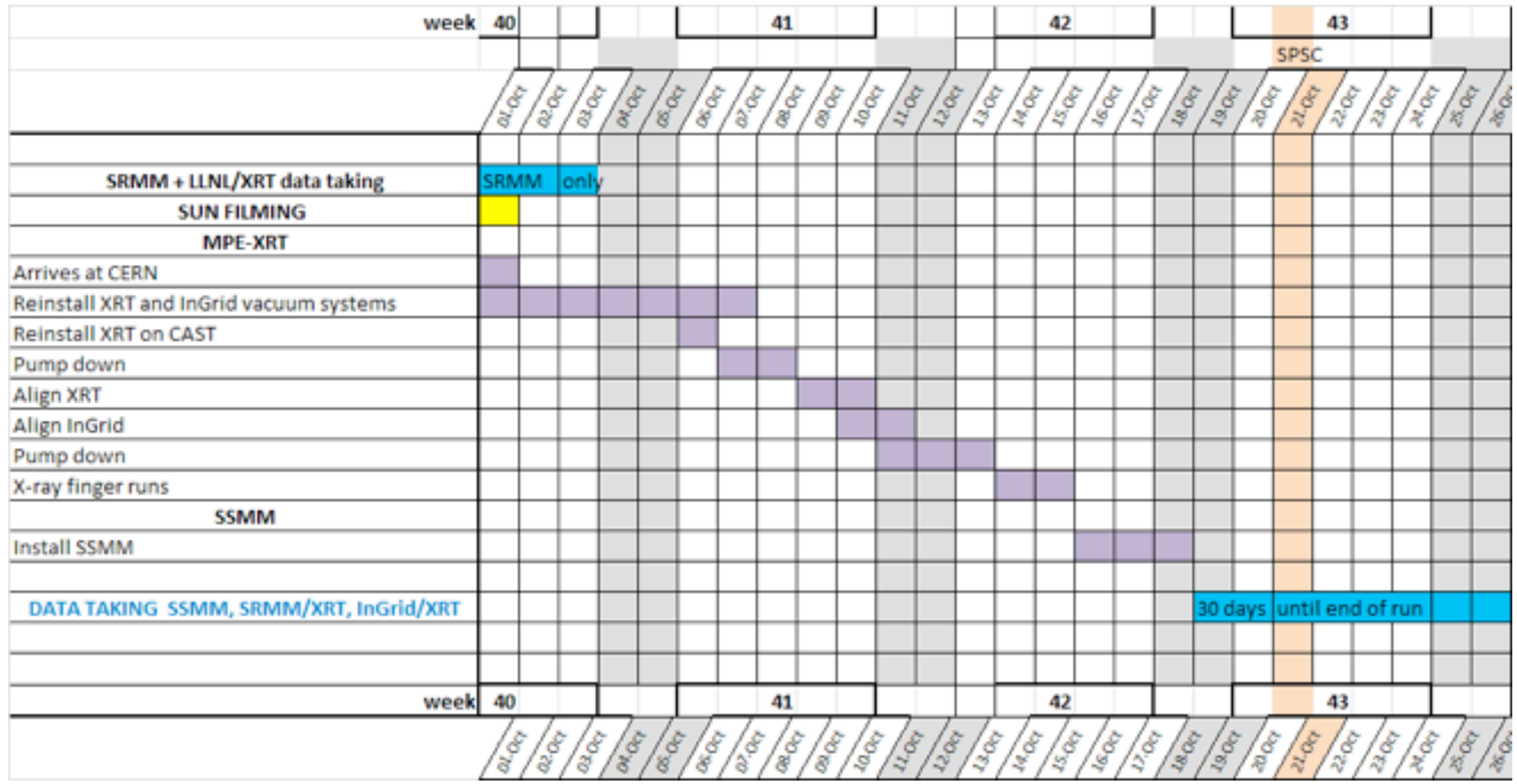
FIG. 1: Left: 1m-long 1×2cm cavity being built for a first test of the RADES setup at the U. Politécnica de Valencia. Right: sensitivity prospects obtained for such a cavity (resonant at ∼ 60 μeV axion mass), assuming a quality factor $Q = 3000$, in the CAST magnetic field ($B = 9$ T), with a detection system noise of 5 K, assuming that a tuning system is implemented with a frequency span of 15%, and a data taking time of 12h for each of the 450 frequency steps (∼225 days total effective exposure). The red line represents the same for a 10m long cavity. Note that the sensitivity is already very close to the axion band even if some of the parameter values are relatively conservative (Q). It seems thus possible to imagine sensitivity to real QCD axion models for more aggressive assumptions, e.g. access to lower detection noise levels. Plot by Juan A. García.

Schedules for data taking in 2014 and operation in 2015

Schedule for data taking in 2014

Data taking with all four detectors started on Monday, October 20

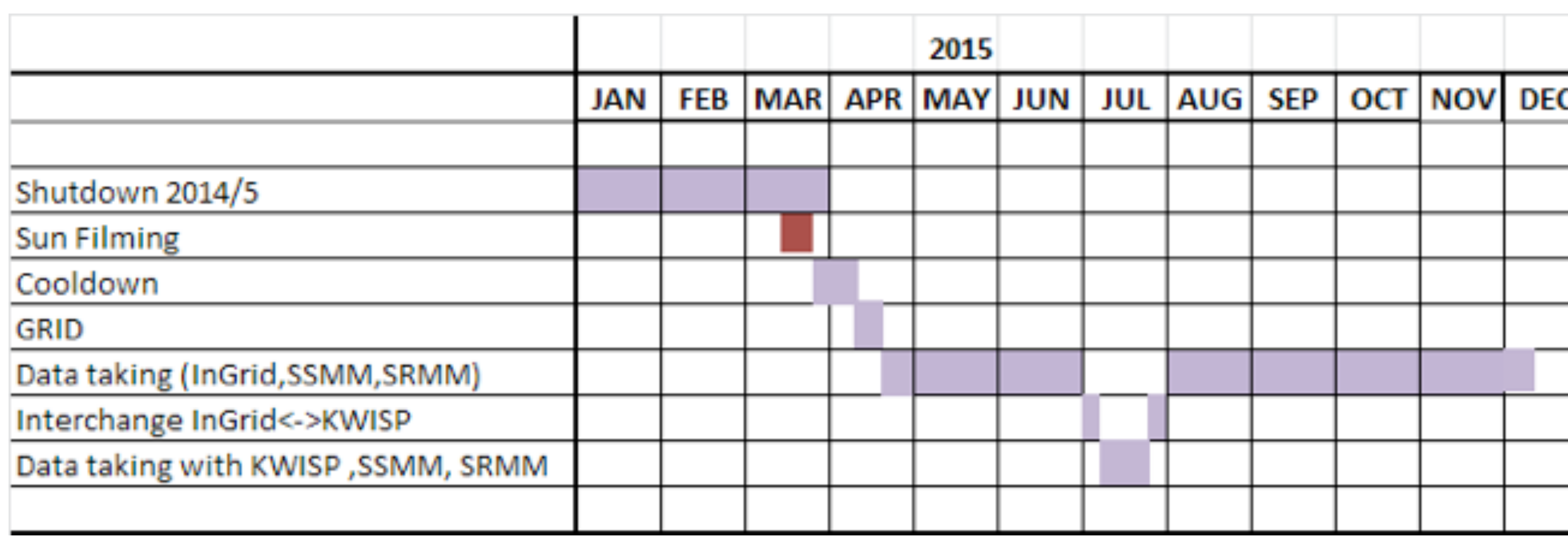
We will commission the KWISP detector in parallel



Tentative schedule for 2015

We will complete the data taking for solar ALPS in 2015 (5-6 months of measurements)

First radiation pressure measurements with CAST start in 2015



Plans after 2015: We will use CAST to search for chameleons and relic ALPS

Depending on the outcome of the measurements in 2015, we will make a proposal for 2016 in the next SPSC meeting in 2015.

Funding
As usual except for cryo upgrade (250 kCHF)

Personnel support needed from CERN
Fellow / Scientific Associate

Budget profile
To be defined after the experience from next year.

Conclusions

CAST is finishing its solar axion measurements in 2015

- CAST has been upgraded with a 2nd X-ray telescope and improved detectors
- CAST measurements will be the most sensitive ones

First sub-keV measurements have been carried out to search for chameleons

- CAST is the **first chameleon helioscope** in the world (using SDD)
- Measurement with improved sensitivity (InGrid detector) have started

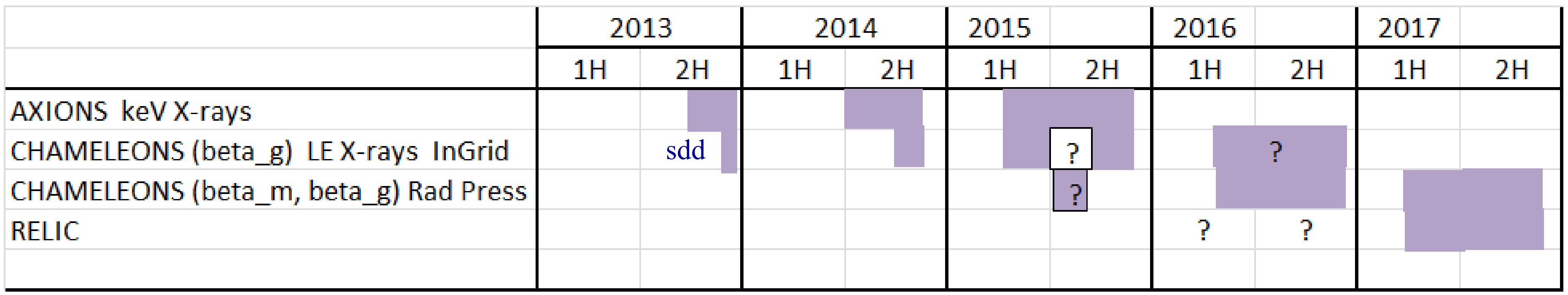
An ultra-sensitive force detector (KWISP) will probe for the matter coupling of chameleons starting in 2015

After 2015, we want to use CAST to search for chameleons and relic ALPS

Backup slides

Experimental Program: Slide presented at FRC on Sept. 25, 2014

Experimental Program - Phase IV and Long Term Outlook



- 2014
  - Axions (SSMM,SRMM/**XRT**, InGrid/XRT)
  - Chameleon (InGrid/XRT)
- 2015
  - Early cryo start up requested. Aim for 6-7 months data taking
  - Axions (SSMM,SRMM/XRT, InGrid/XRT)
  - Chameleon (InGrid/XRT)
  - First run Chameleon (Radiation Pressure/XRT) ⟷ (InGrid)
- 2016
  - Will depend on the evolution and performances of :
    - InGrid (mesh signal, optimised X-ray windows) …. 2016 move to other beam line?
    - Radiation Pressure device
    - Developments and Integration studies for Relic Axion devices (installation on Sunset side)
- 2017
  - Full exploitation of Radiation pressure and Relic devices

Long term outlook: Slide presented at FRC on September 25, 2014

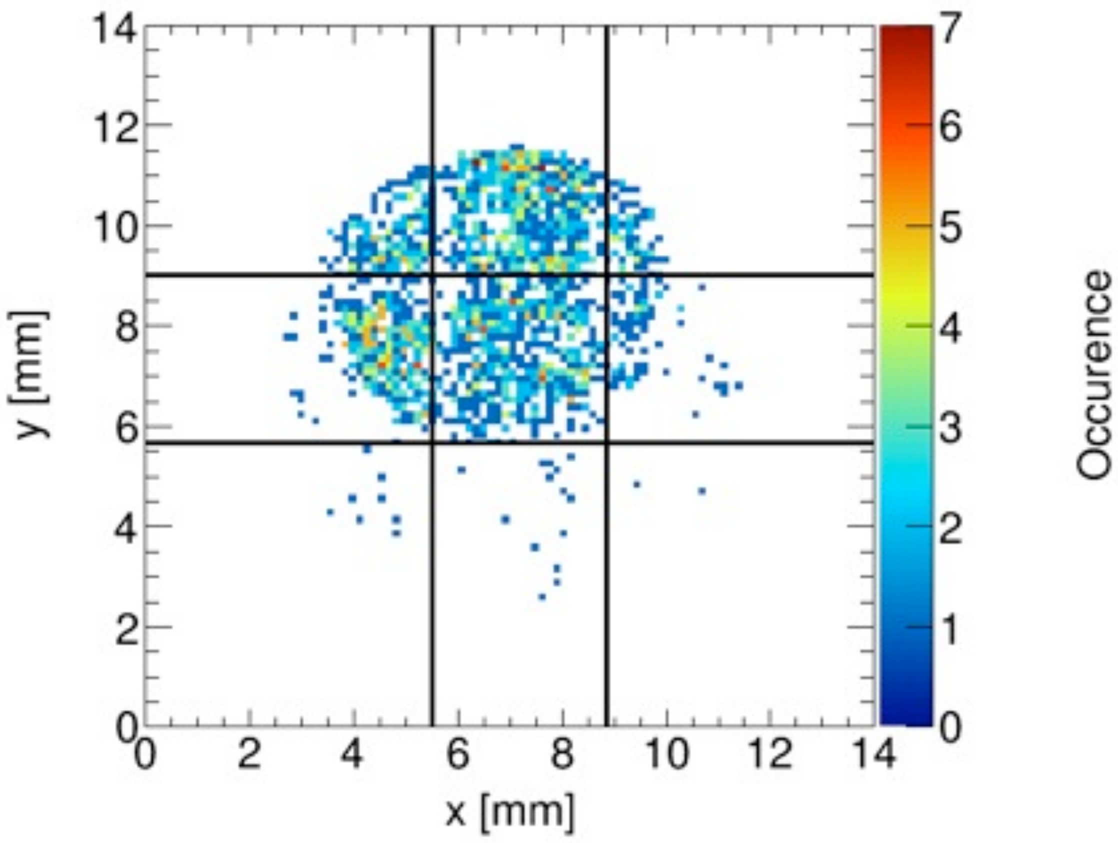
Long Term Outlook

- Program of measurements → 2017 →2020?
- Need safe and efficient magnet & cryo operation over 3-6 years …
  - Cryogenics Control and Supervision system relies on >20 y.o ABB PLC system
    - No longer 48hr response from ABB
    - 2 week response on best effort (retirees from ABB)
  - TE-CRG have strongly advised CAST to undertake a migration to a standardised CERN system
- TE-CRG have requested in 2013 & 2014 funds for the migration
  - Accelerator Consolidation Workshop 12.09.2013 (L Tavian)
    - Not authorised
  - IEFC, 08.08.2014, TE-CRG Consolidations (D Delikaris)
    - Response in October ?
- Cost of migration 250kCHF
  - 200kCHF control racks
  - 50kCHF PJAS to oversee the project
- Search for funding
  - CERN Consolidation funds
  - CAST Institutes contribution ?
  - CAST M&O A budget (PJAS) ?
- Two smaller upgrades under study:
  - Solar tracking system (not expensive but very delicate)
  - Roots primary pump shaft seals upgrade 10kCHF (to be done 1Q2015)

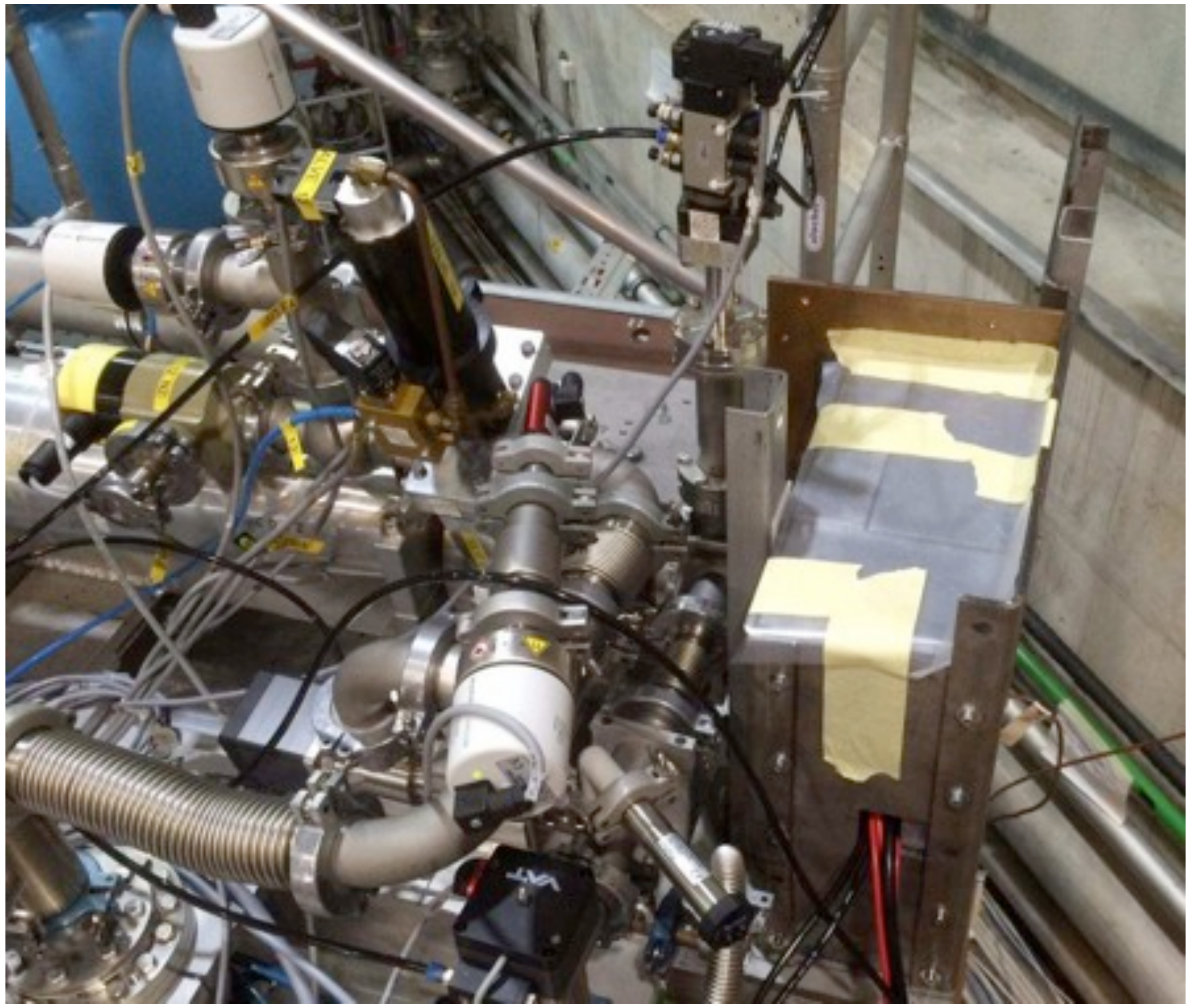
Financial estimates for cryogenics

			Actual values			Projected values	
Item	**Dept**		**2011**	**2012**	**2013**	**2014**	**2015**
		Units					
Cryogenics M&O	**EN**	(kCHF)	**180**	**180**	**180**	**180**	**180**
Cryogenics power	**EN**	*(hours)* **(kCHF)**	*2951* **81**	*4877* **134**	*3400* **94**	*5040* **139**	*6768* **186**
Power Converter power	**EN**	*(hours)* **(kCHF)**	*797* **6**	*1576* **11**	*1032* **7**	*806* **6**	*3091* **22**
FSU maintenance (TE)	**CAST**	(kCHF)	5	5	5	5	5
Yearly TOTAL	**CER N**	**(kCHF)**	**267**	**325**	**281**	**324**	**388**

The InGrid detector has taken several weeks of background data



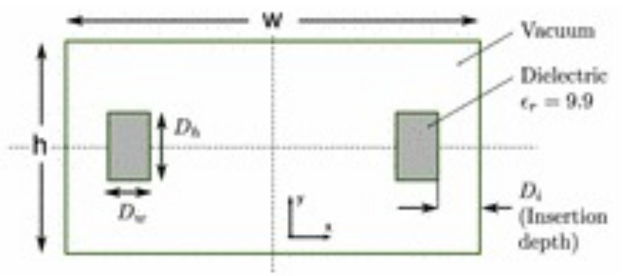
During an 8 hour run, the detector alignment was verified by using the pyroelectric X-ray source at the other end of the dipole magnet.
Then for 3 weeks background data was taken.

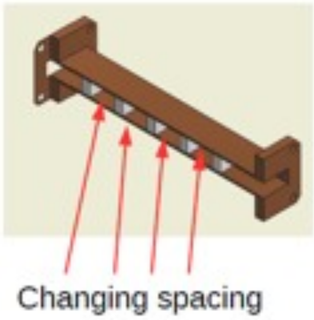


Finally the lead shielding produced by the University of Zaragoza was installed. One more week of background data was taken.

Relic axions- Long thin cavities

- First proposed and studied in PRD 85 (2012) 035018
- Directionality in JCAP 1210 (2012) 022
- Main motivation with respect standard cavities: allow for higher frequency “without” losing in detection volume
- But:
  - Mode crossing?
  - Mode localization?
  - How to tune?





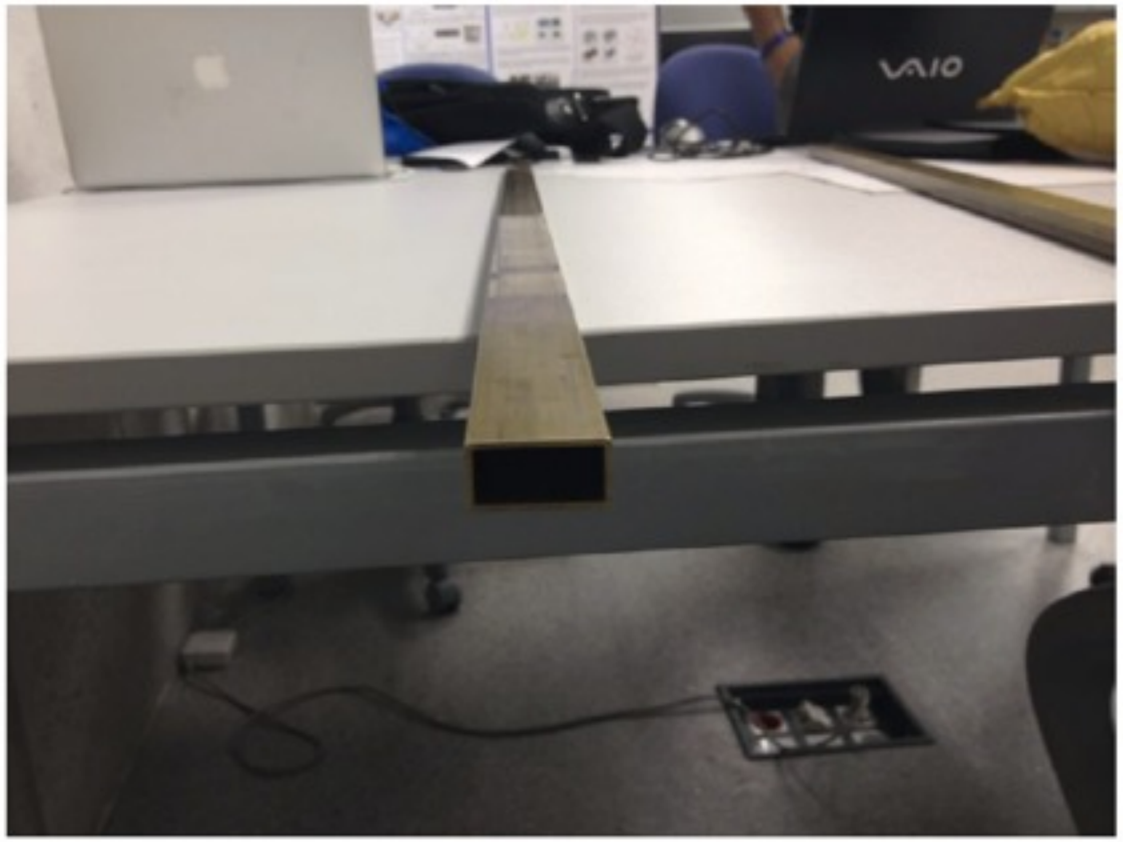
•Bars
•Dielectric spacers (Rybka)
•Movable wall
•Crazy idea?: tune with gas/liquid cocktail

  - After first considerations these “buts” seem surmountable, more work needed to prove feasibility.

Possible thin waveguide detector for relic axions

- 1x2 cm crosssection → ~60 μeV axion mass (very nice value!)

- To look into:
  - Thermal load to magnet?
  - Tuning mechanism?
  - Sensor & DAQ system
  - Atract and/or build needed expertise
  - Funding



- Short term plans with Valencia
  - Do some tests (Q and f measurements)
  - Understand the system and get some experience

Detector table

Energy [eV]	Wavelength [mm] (Freq[GHz])	Coupler	Detector	Cryogenics (minimum requirements)	Notes
10^{-5}	124 (2.4)	Cup Dipole, Spiral-, Helix-, Fractal-Ant. (Resonant Case: Magnetic loop)	HEMT's SQUID's Rydberg atoms	≤15K (closed cycle) ≤4K (LHe/closed cycle) ≤1K (pumped LHe/dilution fridge)	Radioastronomy, "standard„ heterodyne ADMX CARRACK, single photon det. possible
10^{-4}	12.4 (24)	Horn (Res. Case: Magnetic loop / E-field probe / Hole coupler)	HEMT's up to ~100GHz	≤15K (closed cycle)	Radioastronomy, "standard" heterodyne
10^{-3}	1.24 (240)	Horn	SIS + IF-HEMT 100GHz≤ f ≤ 1.5THz	≤4K (LHe/closed cycle)	Radioastronomy, heterodyne
10^{-2}	0.124 (2400)	Horn / Planar (quasi-optics)	HEB + IF-HEMT (IF-bw ≤ 3GHz)	≤4K (LHe/closed cycle)	Radioastronomy, THz heterodyne

Courtesy of F. Schäfer, E.Kreysa (MPIfR, Bonn)

Solar Chameleon production

- Chameleons are a type of scalar WISPs have an effective mass depending on the local matter density
- This makes them candidate constituents for the Dark Energy and allows evading constraints on short range interactions fixed by “fifth-force” measurements.
- Chameleons couple
  - to two photons (Primakoff effect inside a magnetic field)
  - directly to matter (no magnetic field needed)
- To estimate the spectrum of the Chameleon flux emitted by the sun one can assume that production takes place in the solar tachocline region, with a 30 T magnetic field inside it, then linearly decreasing outside.
- In short:
  - Chameleons are produced in the solar magnetic field from the conversion of photons (coupling β_γ)
  - they propagate unhindered to Earth
  - under specific conditions Chameleons interact directly with matter (coupling β_m), in particular by reflecting off a suitable surface

matter coupling

photon coupling

$$V_{\rm eff}(\phi) = \frac{\Lambda^{4+n}}{\phi^n} + e^{\frac{\beta_m}{M_{\rm Pl}}\phi}\rho_m + e^{\frac{\beta_\gamma}{M_{\rm Pl}}\phi}\rho_\gamma,$$

Effective potential

matter coupling

local matter density

$$m_{\rm eff}^2 = (n+1)\frac{\beta_m \rho_m}{M_{\rm Pl}}\frac{1}{\phi_{\rm min}}.$$

Effective mass

solar magnetic field

photon coupling

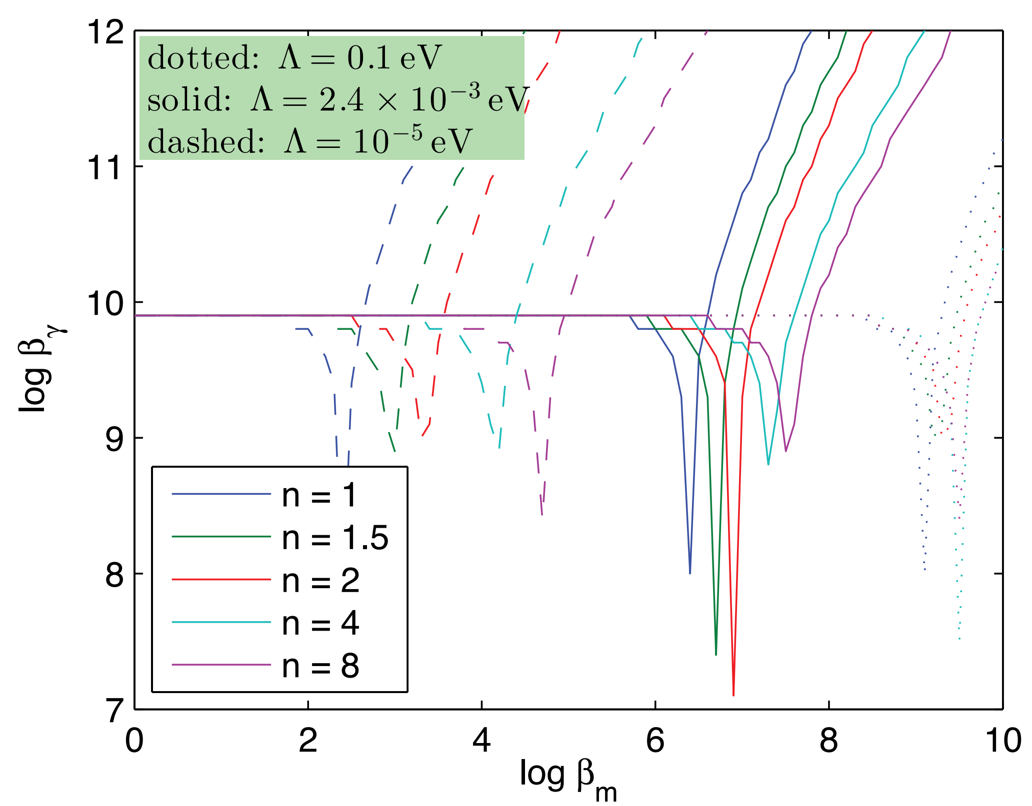
$$P_{\rm chameleon}(\omega) = 2\theta^2 = 2\left(\frac{\omega B \beta_\gamma}{M_{\rm Pl}\left(m_{\rm eff}^2 - \omega_{\rm pl}^2\right)}\right)^2.$$

Photon-chameleon conversion probability assuming production in the solar tachocline

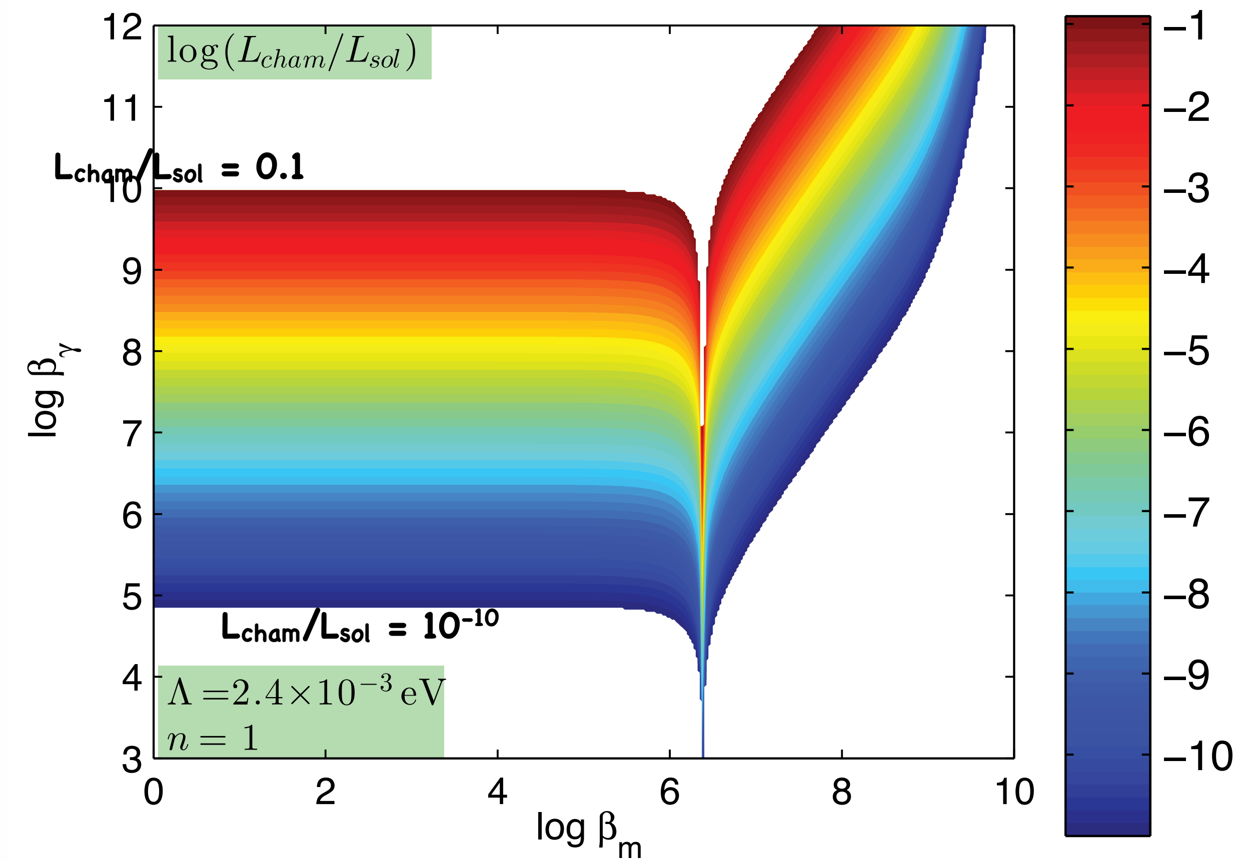
Relationship between β_γ and β_m

- The two couplings β_γ and β_m are not independent. Their particular numerical relationship is dictated by the fraction of the total solar luminosity which is emitted as Chameleons

- This fraction can be at most 10% in order to preserve observations on solar age and evolution

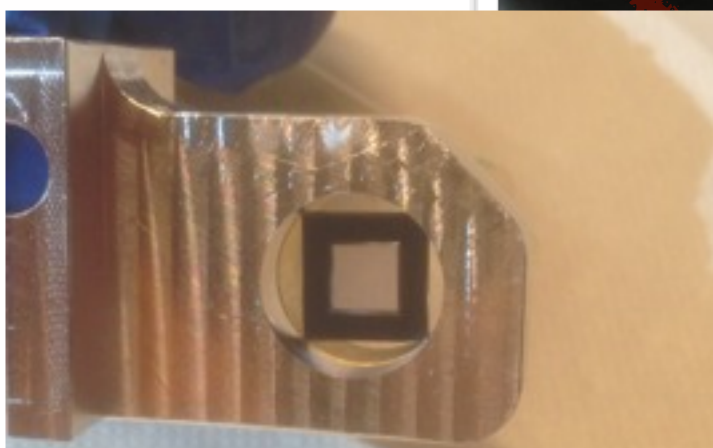


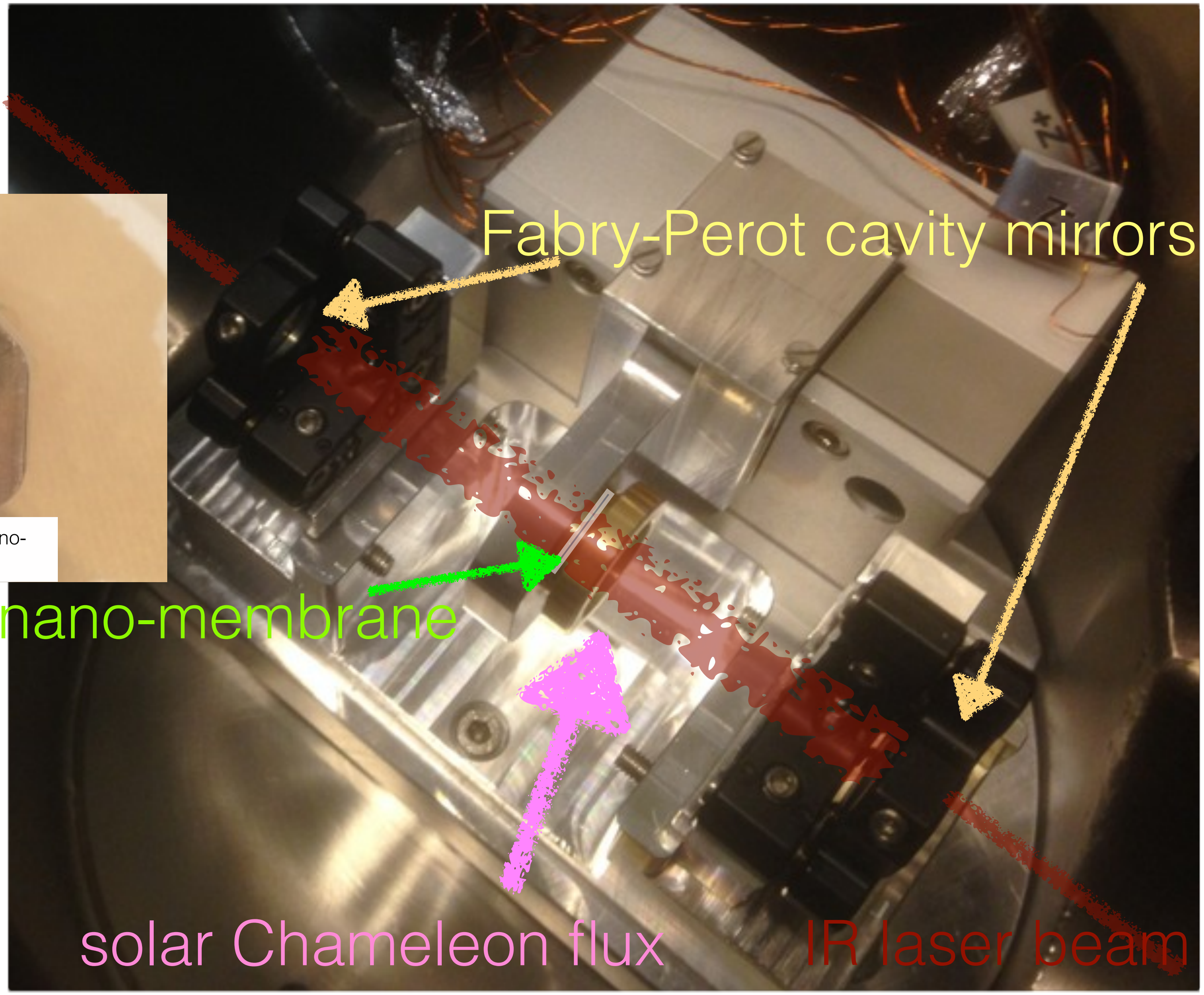
β_γ as a function of β_m for L_{cham}/L_{sol} = 0.1 and for different choices of the potential parameters. The resonance appears when $m_{eff} \sim \omega_{plasma}$



β_γ as a function of β_m for several values of L_{cham}/L_{sol}. n = 1 and Λ = 2.4x10^{-3} eV (dark energy scale) have been set in the potential. The resonance appears when $m_{eff} \sim \omega_{plasma}$

Trieste force sensor prototype

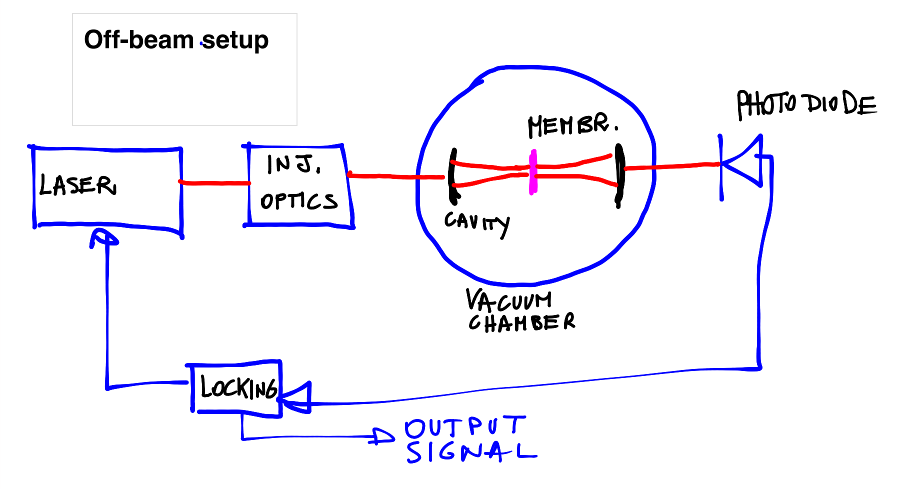

(5 mm)x(5 mm) 100 nm thick SiN_4 nano-membrane set inside its holder



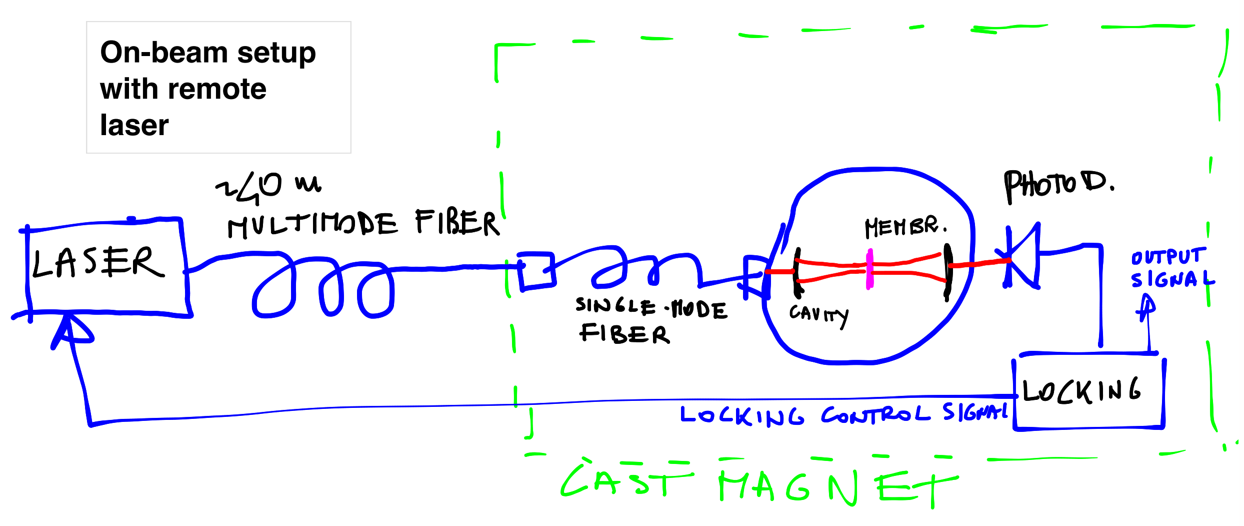
- Force sensitivity estimate for the Trieste prototype
  - measured base force sensitivity (“single pass” FP): $3 \cdot 10^{-9}$ N/√Hz
  - projected sensitivity with 60000 finesse FP: $5 \cdot 10^{-14}$ N/√Hz

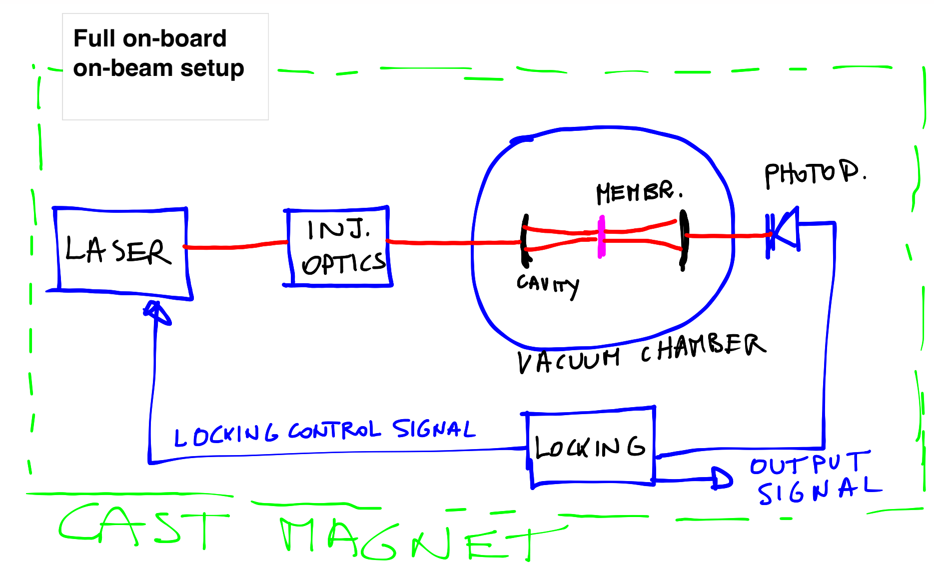
Concepts for installation at CAST

- Off-beam setup



- On-beam setup





Increasing the sensitivity

- Membrane cooling down to 1 K and below (cryogenic infrastructure already present at CAST) ⇒ factor 10
- “Chameleon chopper”⇒ detection noise scales to first approximation as 1/f, with f = chopper frequency
  - Optimistic case:

    (cooling)*(chopper at 100 Hz) = factor 10^3 increase in sensitivity!!
  - Sensible message: there is much room for improvement