Status report of the CAST experiment, planning and requests for 2013-2014

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on behalf of
the **CAST Collaboration**

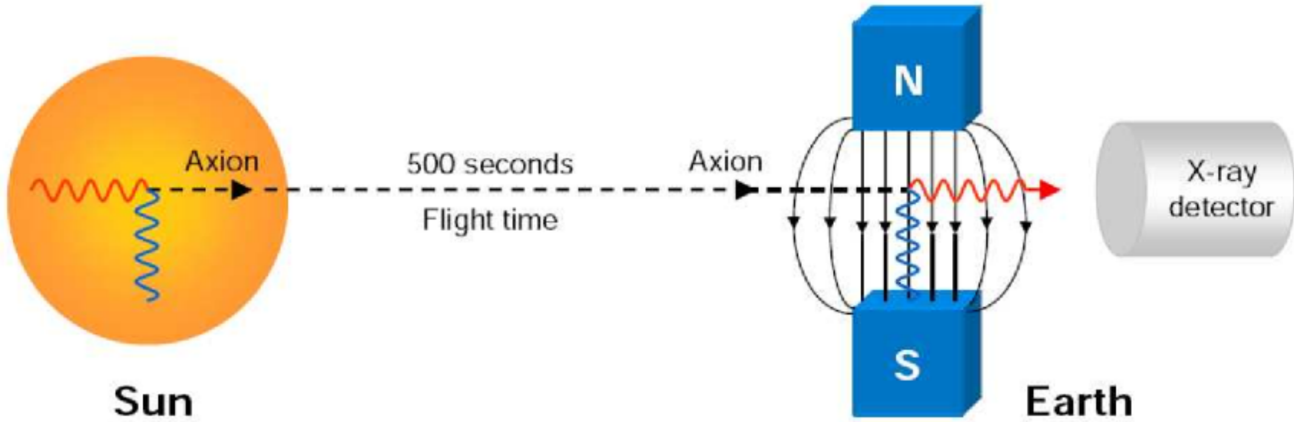
111th meeting of the SPSC - Oct. 22nd 2013

Summary

- Introduction
- Status report
  - On-site activities
  - Detector upgrades, status and performance
  - CFD simulations
  - Data taking, analysis and publications
  - Paraphotons
  - Sun filming and GRID measurements
- Proposal for 2013-2014
  - Upgrades, planning and requests
  - Physics motivation for Axions, Chameleons and other WISPs
- Conclusions

CAST basic physics

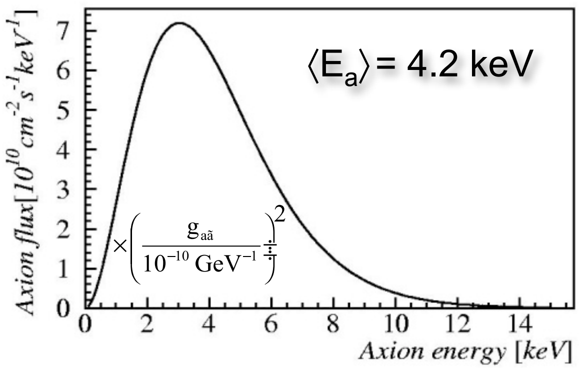
- Magnetic helioscope principle (*P. Sikivie, Phys. Rev. Lett. 51, 1415–1417 (1983)*)
  - Axions would be produced in the core of the Sun core and re-converted to X-rays inside an intense magnetic field

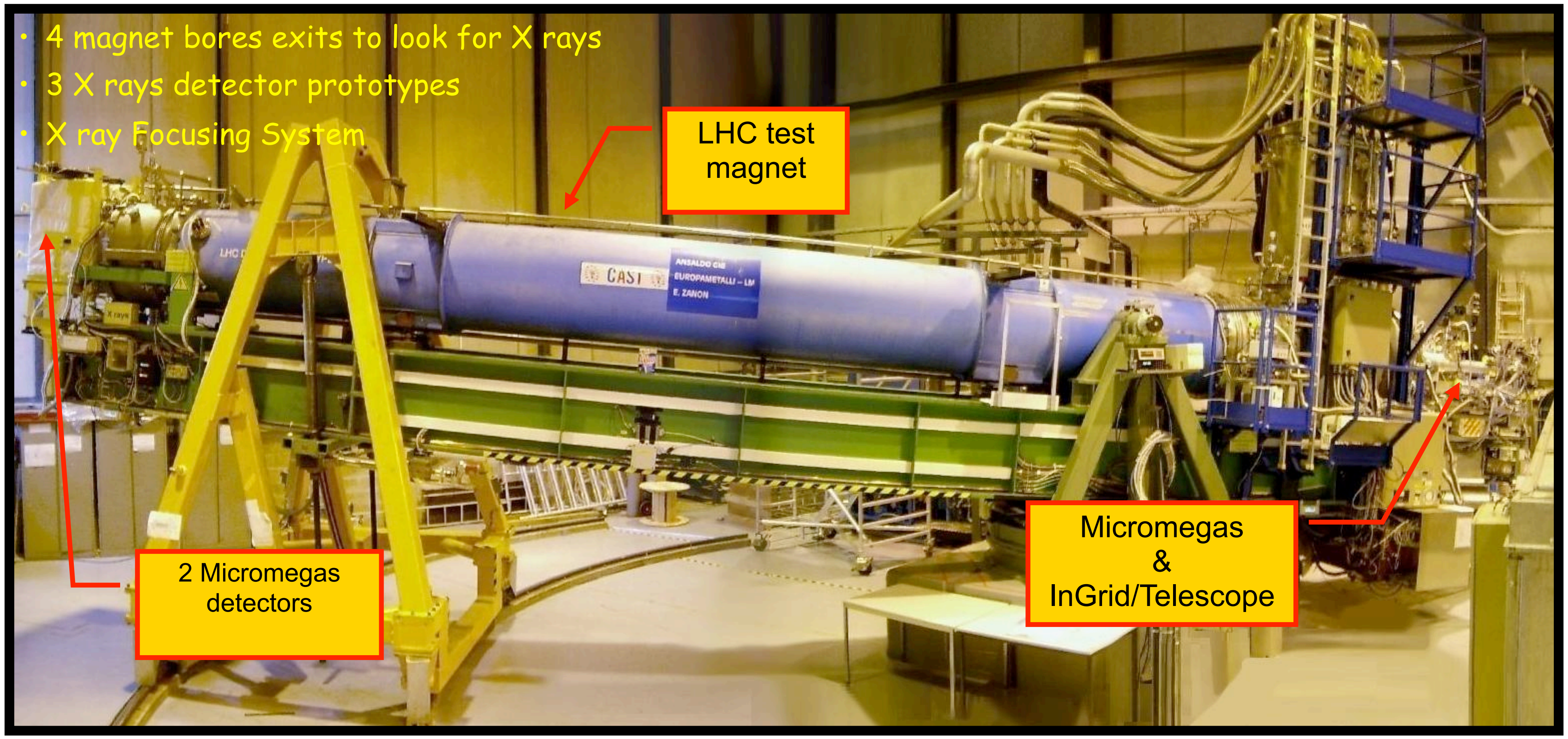


Expected number of photons:

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

Axion flux on earth





Expected signal

X-Ray excess during solar alignment in the 1-10 keV region

CAST sensitivity per detector

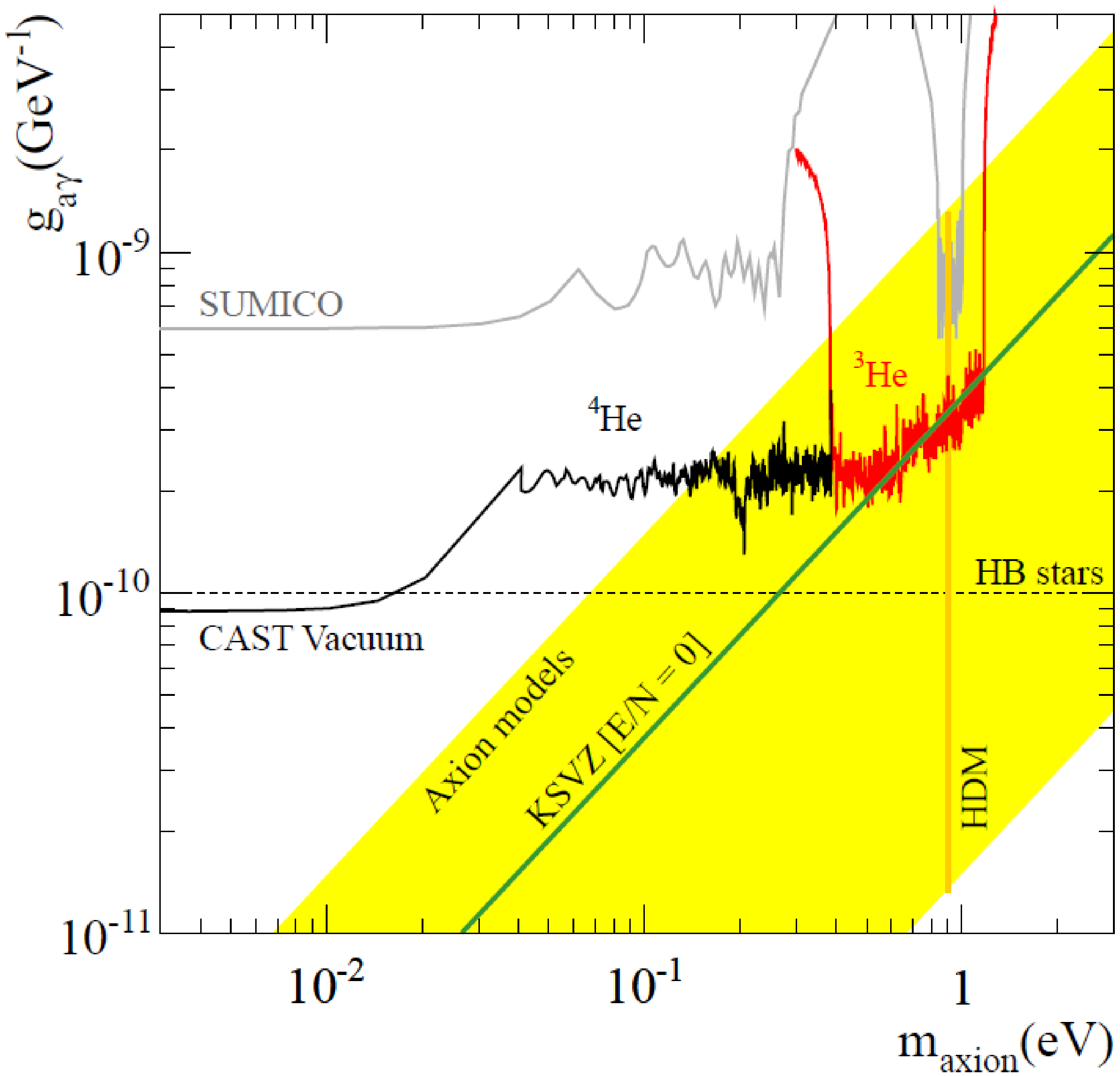
0.3 counts/hour (100% eff.) for $g_{a\gamma\gamma} = 10^{-10}$ GeV^{-1} and A = 14.5 cm^2

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 = 13,000 A, B ≈ 9T, L = 9.26 m

CAST at glance

CAST has been taking data since 2003, establishing the most restrictive wideband experimental limit on Axion-photon coupling - Axion mass coverage up to 1.18 eV

- Vacuum phase (2003-2004)
  JCAP 04010 (2007), PRL 94 121301 (2005)
- Gas phase (2007-2012) - 4He and 3He (analysis being completed)
  JCAP 0902:008 (2009), PRL 107 261302 (2011)
- Other CAST results
  - High Energy axions (*JCAP 1003:032 (2010)*)
  - 14.4 keV axions (*JCAP 0912:002 (2009)*)
  - Low Energy axions (*arXiv:0809.4581*)



CAST Detectors - active and planned

- Micromegas (active) and new generation MM (commissioning) - few keV range
- Low-threshold detectors
  - SDD (active) - > 400 eV range
  - InGrid (commissioning) - 280 eV and above
  - BaRBE (commissioning) - eV range
- Detectors for expanding sensitivity
  - KWISP Radiation Pressure force sensor (prototype)

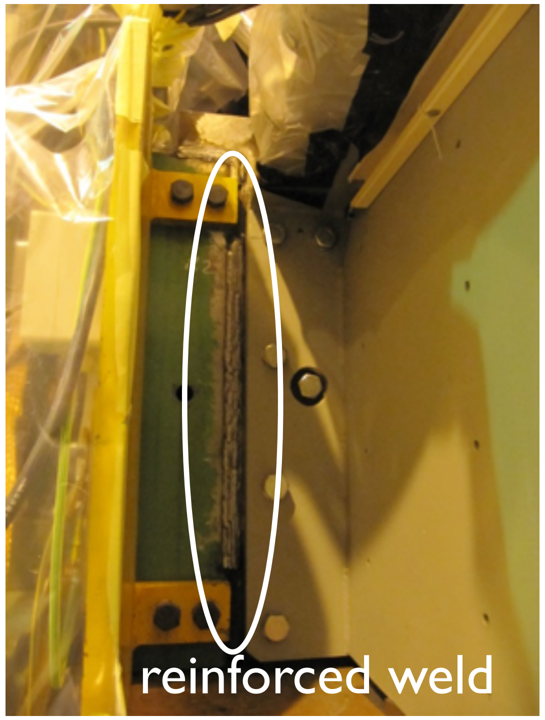
  - dish antenna tracking haloscope (feas. study phase)

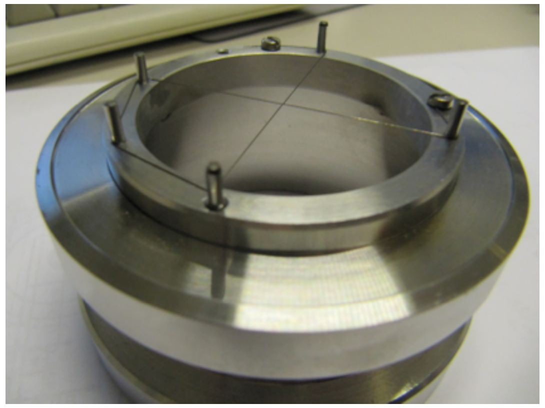
CAST detectors summary table

Detector	Type	γ energy range	Main target WISP	Status
Micromegas	gas based	few keV	solar axions	active
NG Micromegas	gas based	few keV	solar axions	commissioning
SDD	Si drift	> 400 eV	solar chameleons	active
InGrid	gas based	280 eV ⇒ few keV	solar axions	commissioning
BaRBE	PMT/APD	2-4 eV	LE solar axions, paraphotons	commissioning
KWISP	radiation pressure force sensor	N/A	solar chameleons	planned
Dish antenna	cryogenic?	> 10^{-4} eV	relics	feasibility study phase

On-site activities

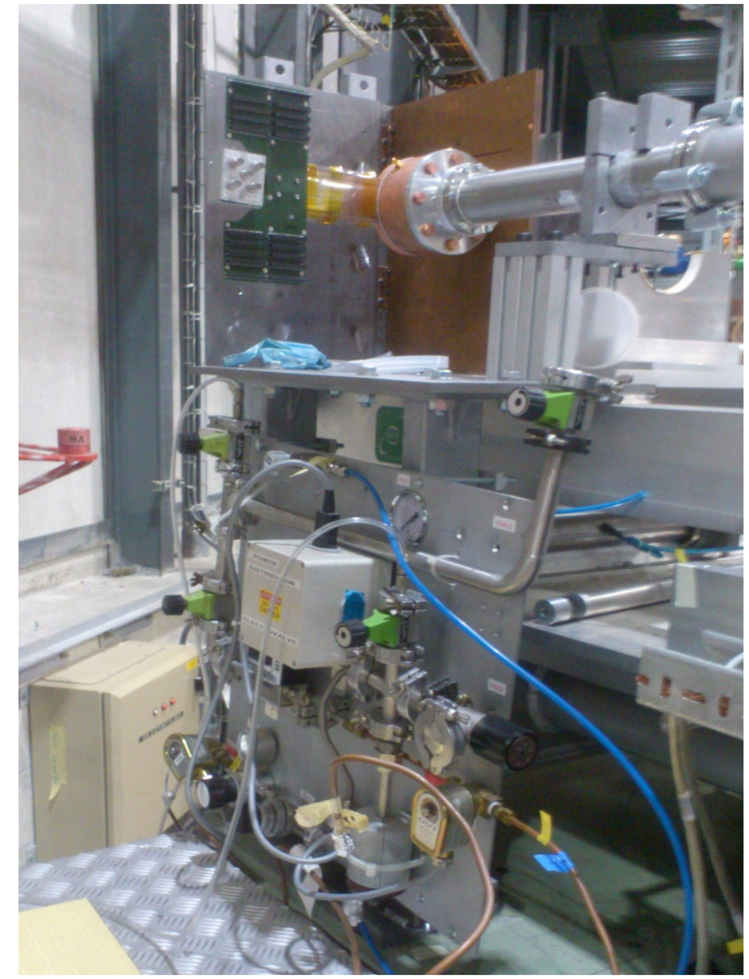
- **2012-2013 shutdown**
  - SSMM detectors removed, cold-magnet alignment check of the XRT-CCD
  - 4He fillings to understand gas dynamics
  - Magnet force-warmed (Dec. 2012)
  - Changed a cryogenic system bellows valve on the MFB end (3 months of work)
  - MRB end of cryostat opened, survey of the positions of all temperature sensors (see CFD simulations)
  - Studies on load-bearing properties of MFB XRT platform ⇒ reinforcement welding
  - internal 3He gas system decoupled from cold bore vacuum circuit
  - X-ray cold windows replaced with original open flanges with cross-wires
  - added new temperature sensors
  - maintenance and repair on a main compressor of the cryogenic system
- **Cooldown (started 26/7/2013)**
  - tests of magnet temperature systematics following different tilts
  - quench training
  - XRT removed
  - SSMM detector installation
  - welding of SRMM and InGrid support platforms, InGrid and SRMM installation started, small SDD detector installed
  - GRID survey
  - sun filming (in parallel with data taking)
- **Data taking started on 22/9/2013**

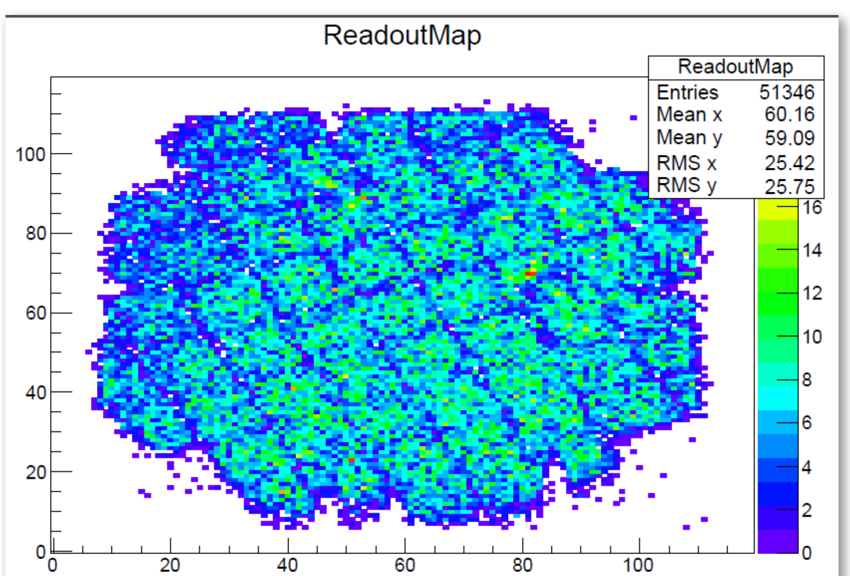


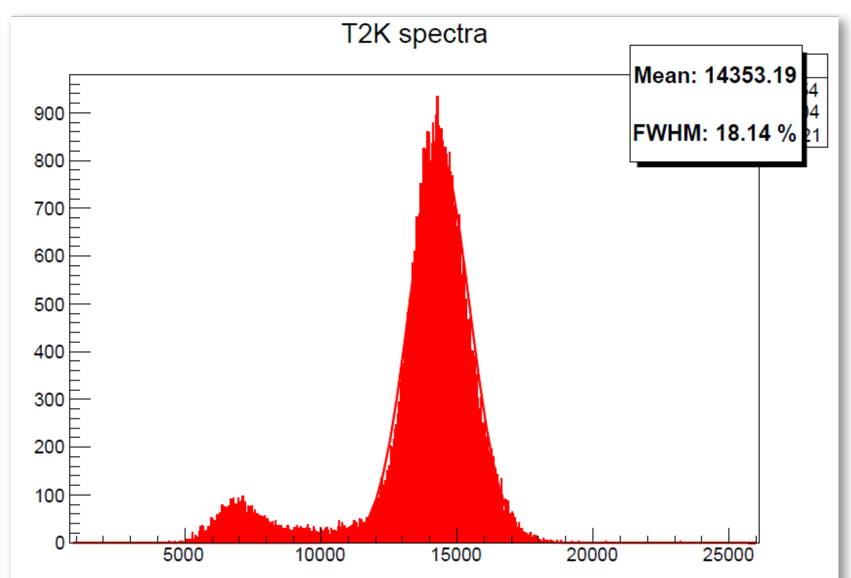


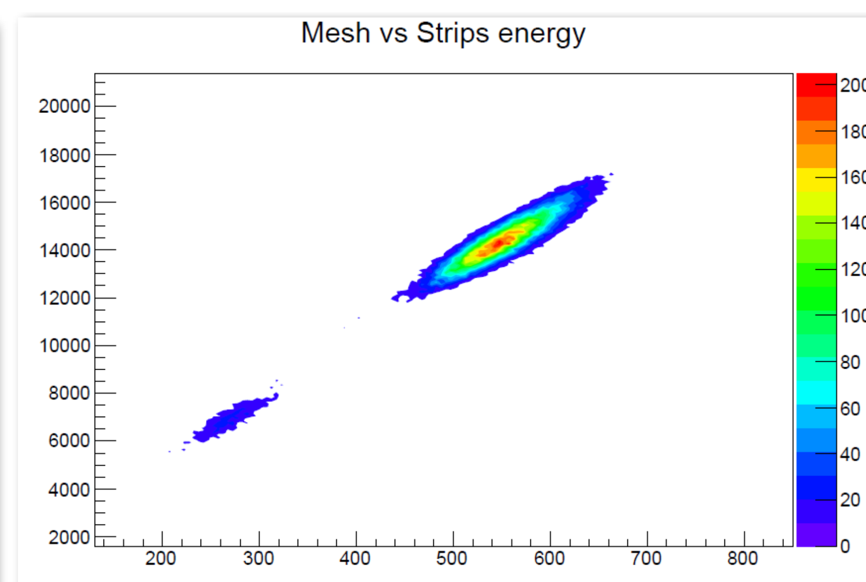
SunRise MicroMegas novelties

- New detector
- New platform and shielding
- Detector problems due to noise fixed
- Power cut at SR8 resulted in current in the detector
  - Replacement detector being presently installed



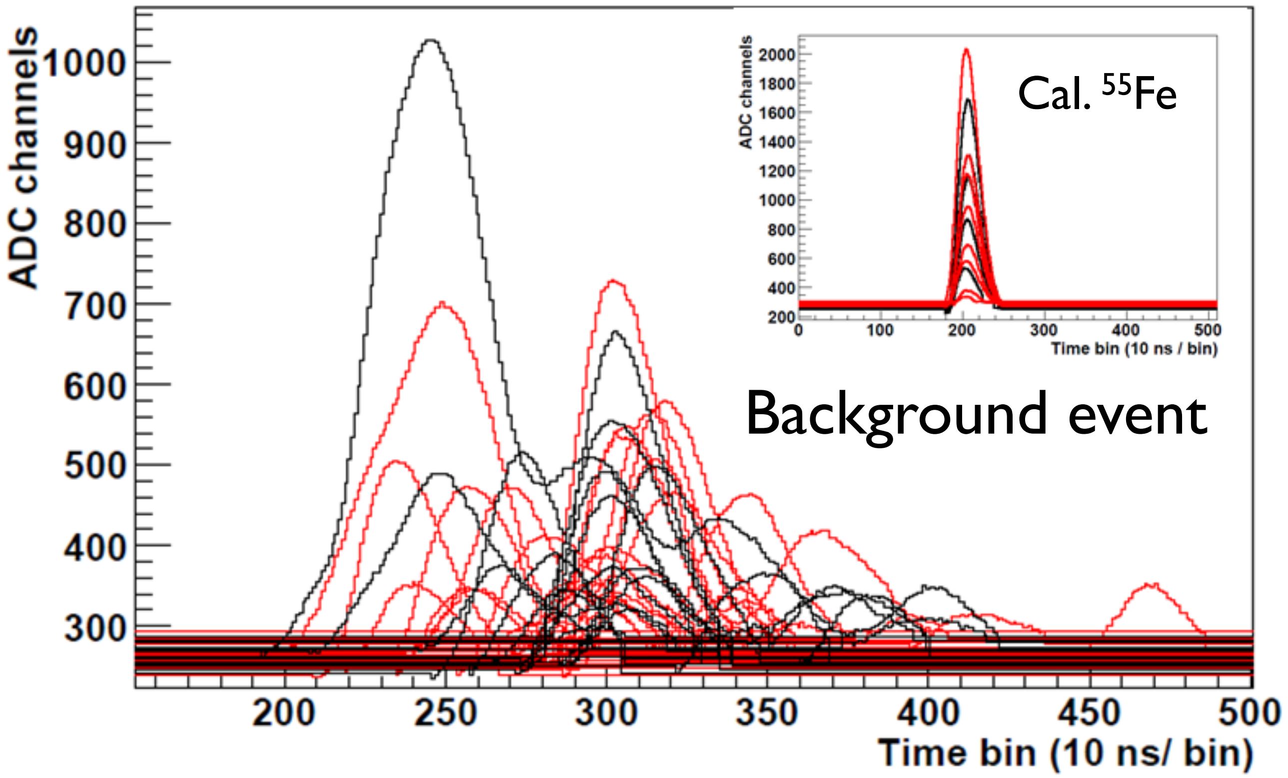


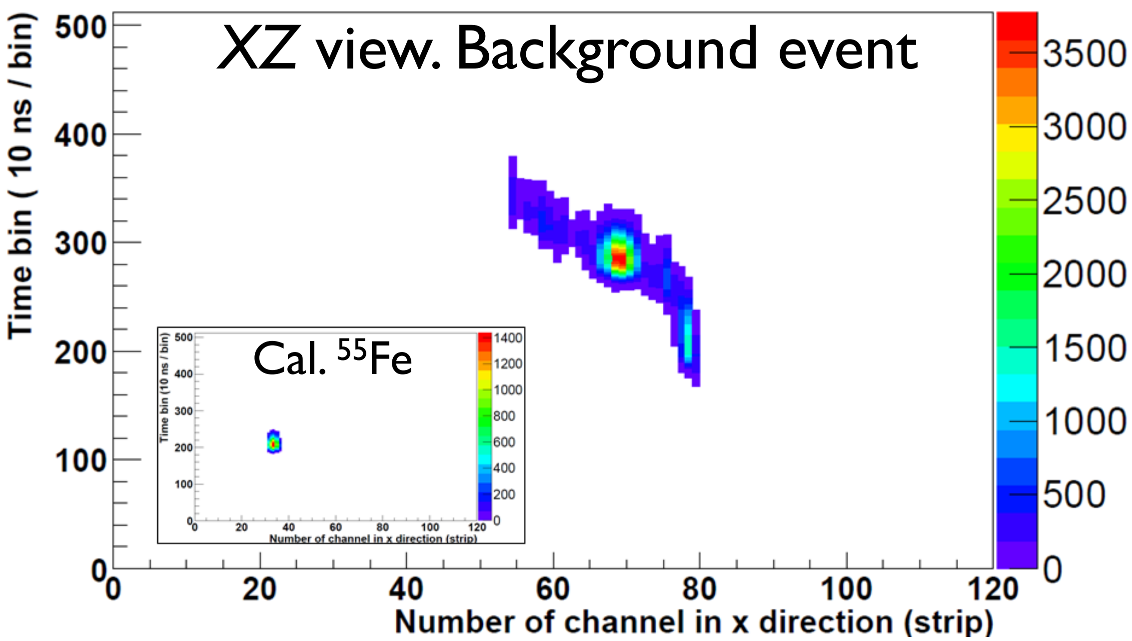




New FEE & DAQ for MM

More handles for better background discrimination.





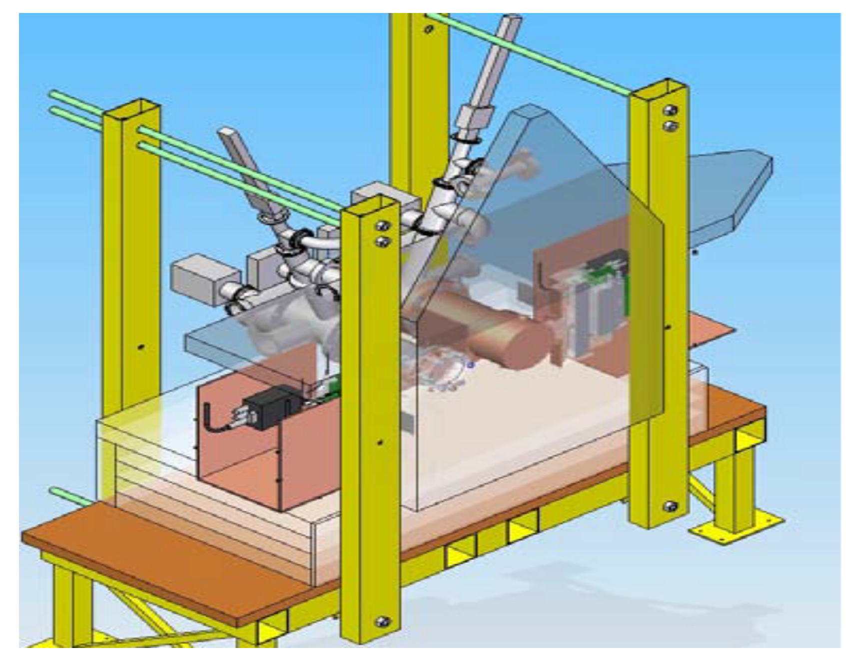
Setup	Analysis type	Run time (hours)	Bkg. ([2-7] keV)
CAST-M10	Gassiplex	303.1	2.07 ± 0.19
CAST-M10	AFTER	303.1	1.60 ± 0.12
CAST2012-M18	Gassiplex	2265.5	1.66 ± 0.55
CAST2013-M18*	AFTER	445.9	1.23 ± 0.10

Indication of improvement in data when comparing the two systems (units of 10^{-6} $keV^{-1}cm^{-2}s^{-1}$).

SunSet MicroMegas: the new veto

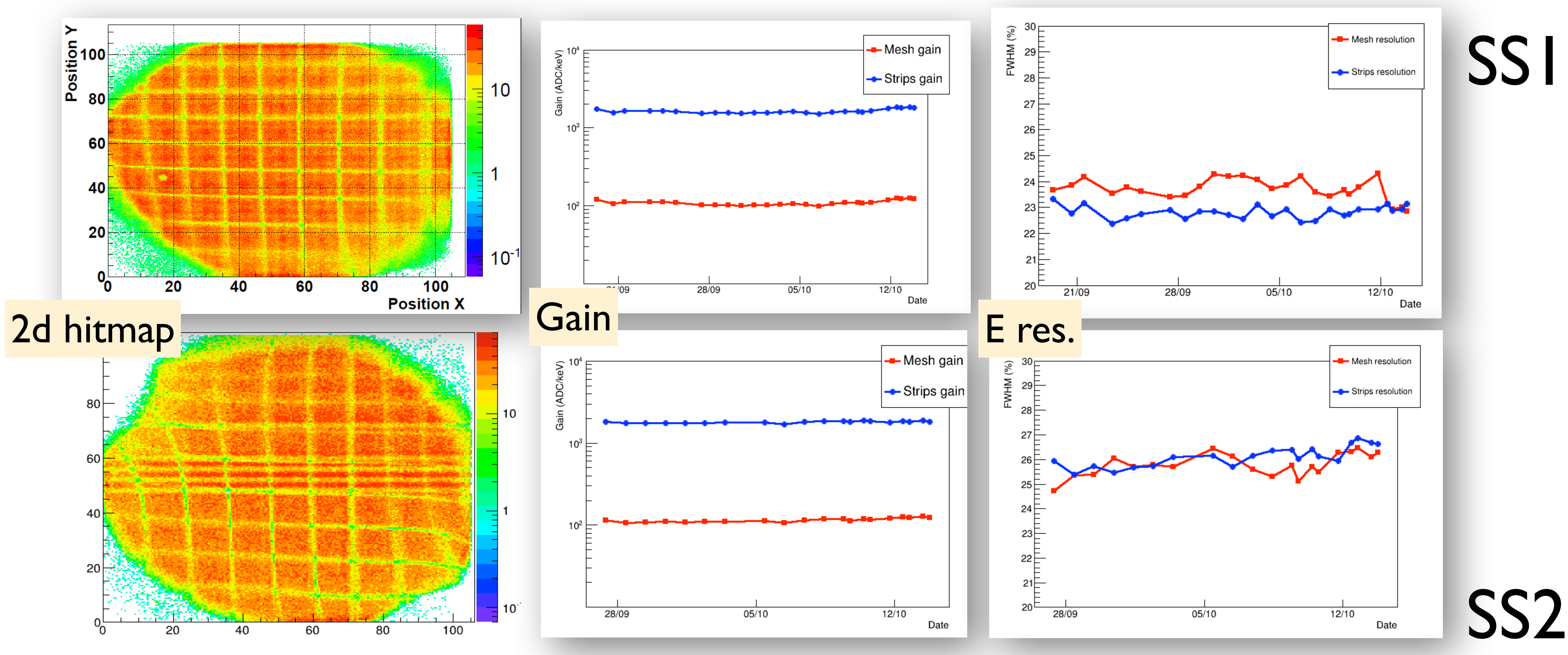
- 2012: veto scintillator geometrical coverage of ~44%
  - Reduction of 25% of SSMM background level with respect to 2011

- 2013: custom-made veto scintillator, coverage ~95%
  - Made in CERN workshop
  - Some vacuum pieces modified



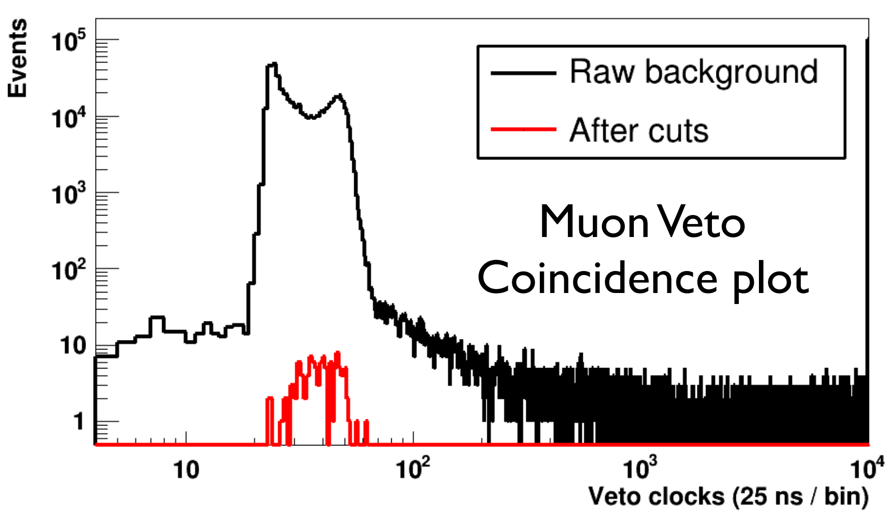
SS detectors performance

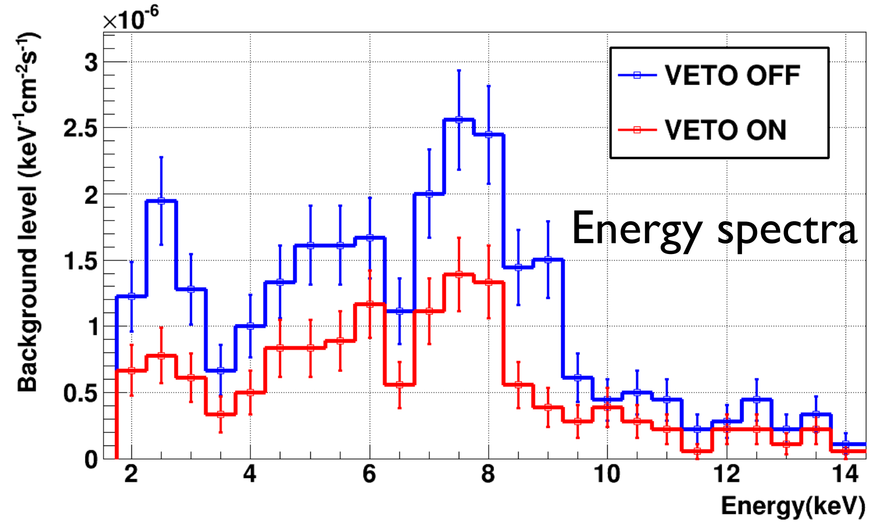
- Detectors M18 (SS1) and M19 (SS2) installed.
  - Now M19 substituted by M15 because of poor performance (high current)
- Some problems with the cathode-windows: glued unsatisfactorily, were leaky
  - Substituted by Al ones – room for improvement: the intended Cu ones will be used next



SSMM quick look

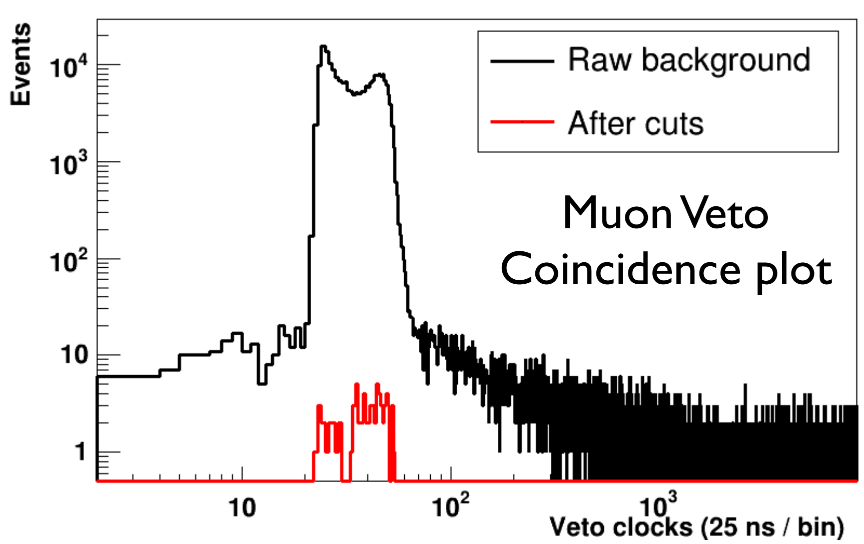
- **SS1**
  - Preliminary analysis (first ~687 h SS1, only strips, same efficiency as for 2012) $(1.28 \pm 0.08)\times10^{-6}$ keV^{-1}cm^{-2}s^{-1} to $(6.8 \pm 0.6)\times10^{-7}$keV^{-1}cm^{-2}s^{-1} in 2-7 keV
  - **For the first time for a detector in CAST, Bkg < 10^{-6} – *meeting expectations.***

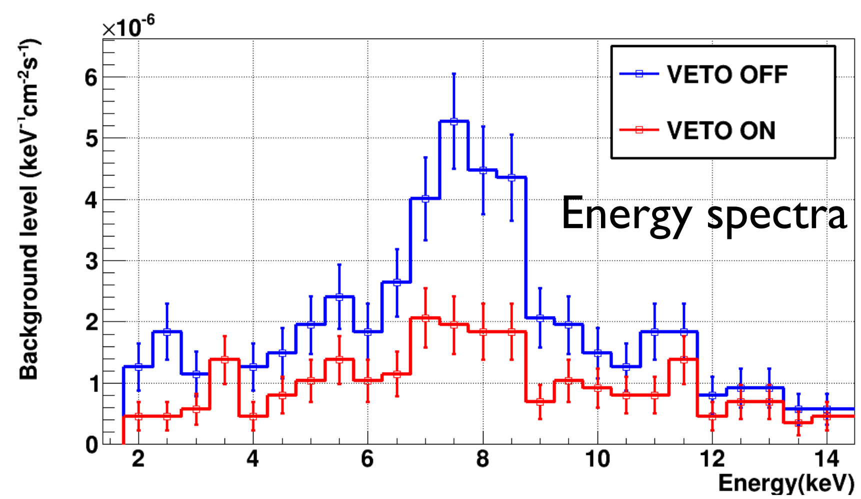




SS1
47 % background reduction in [2-7] keV due to veto

- **SS2**
  - Preliminary analysis (first ~333 h SS2, only strips, same efficiency as for 2012) $(1.68 \pm 0.14)\times10^{-6}$ keV^{-1}cm^{-2}s^{-1} to $(8.7 \pm 1.0)\times10^{-7}$keV^{-1}cm^{-2}s^{-1} in 2-7 keV
  - **For the first time for a detector in CAST, Bkg < 10^{-6} – *meeting expectations.***



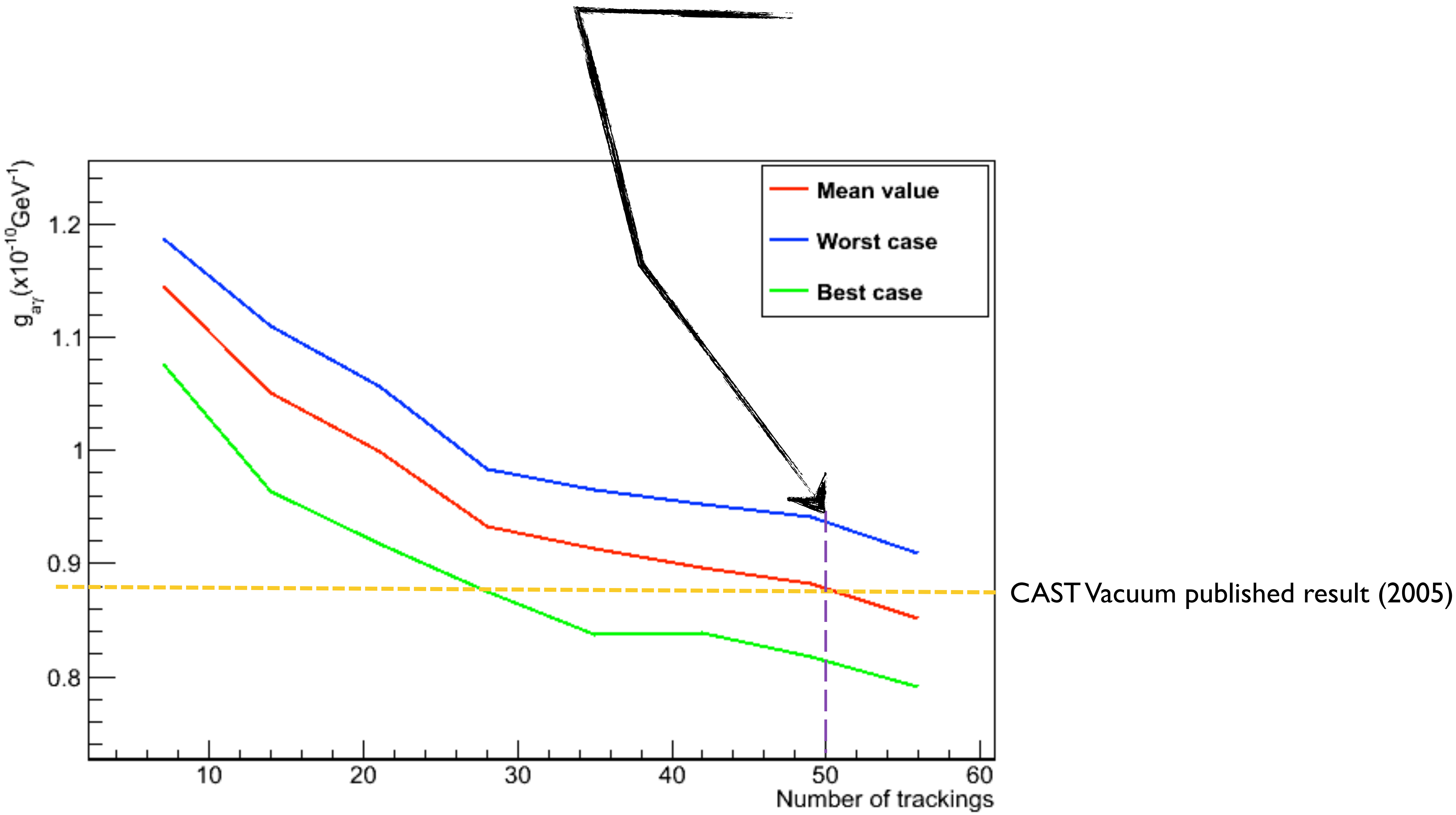


SS2
48 % background reduction in [2-7] keV due to veto

Note: data with Al cathode. Level could go down by ~5×10^{-7} keV^{-1}cm^{-2}s^{-1} when changed to Cu (Canfranc data)

Sensitivity reminder

- For a level of 1×10^{-6} $\mathrm{kev^{-1}cm^{-2}s^{-1}}$ for both **SSMM**, we would reach the CAST vacuum result in ~2 months

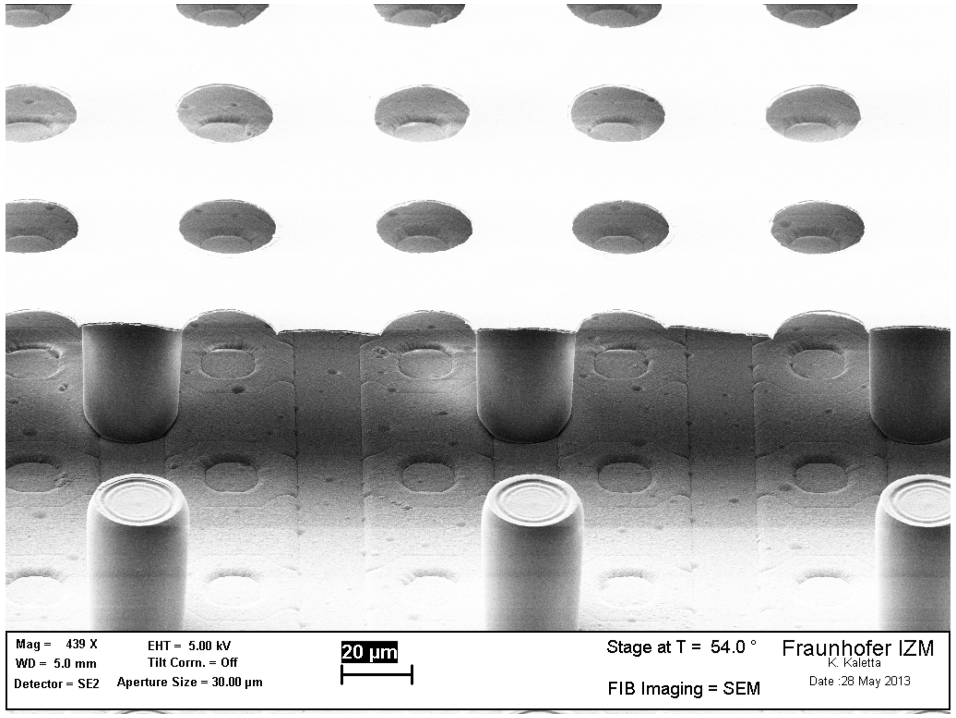


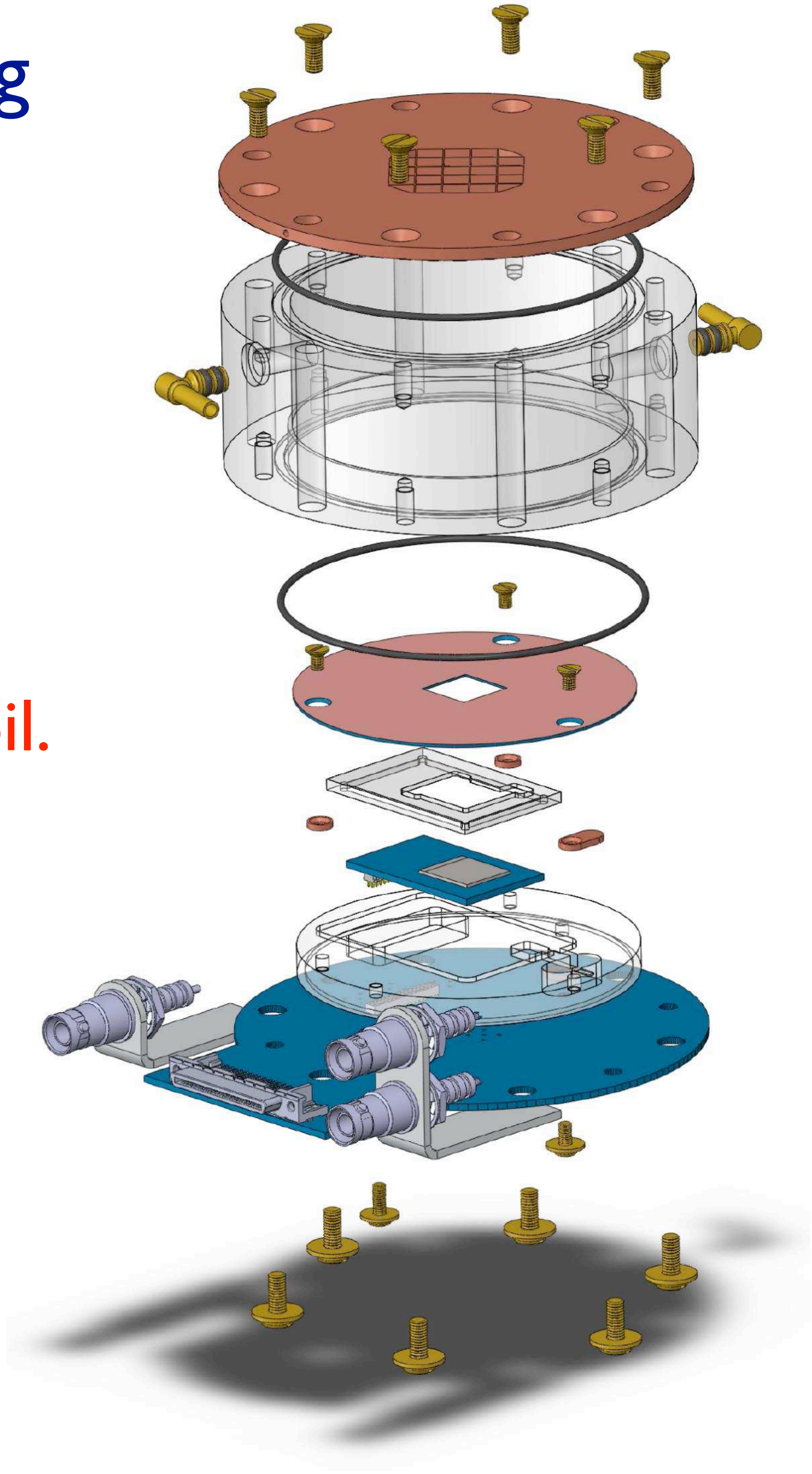
Summary of MicroMegas status

- **Several novelties**:
  - Detector design
  - Change of FEE: more information, better opportunities for background rejection and possibly lower threshold.
  - New DAQ system: automated sequence for SR as well
  - New setup and shielding for the SR
  - New veto scintillators for the SS
- Detector **tests in the lab** with the X-ray tube have assessed the software tools efficiencies
- The SR setup is being re-installed now after power cut issues.
- At SS, the two detectors work satisfactorily: preliminary analysis shows background levels of **$\sim 6\times10^{-7}$ kev^{-1}cm^{-2}s^{-1}** an improvement of factor 2 with respect to the 2012 level, as foreseen.

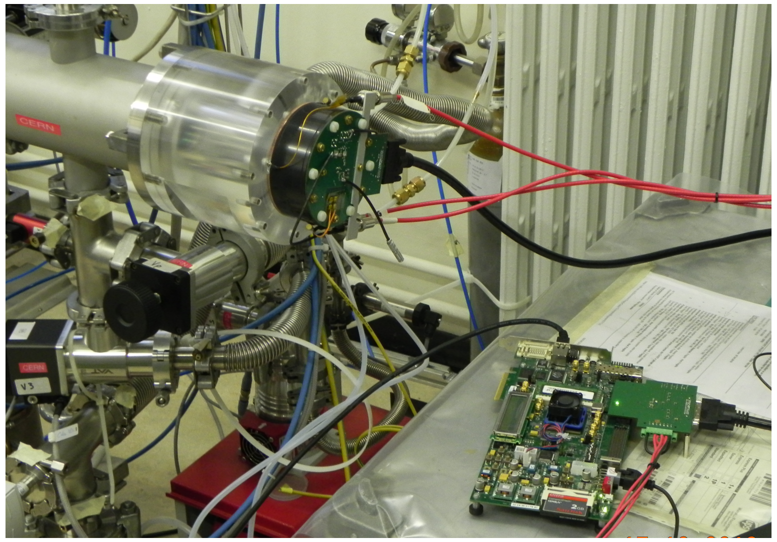
InGrid Detector

- Detector for Q4 was developed starting from Micromegas detectors.
- InGrid based on Timepix
  - Drift distance 3 cm
  - Gas mixture Ar:iC_4H_{10} 97.7:2.3
  - Entrance window 2 μm aluminized Mylar foil.

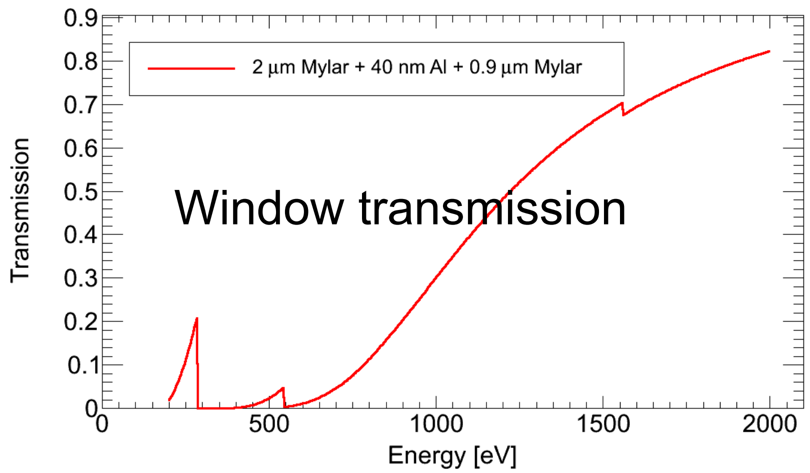


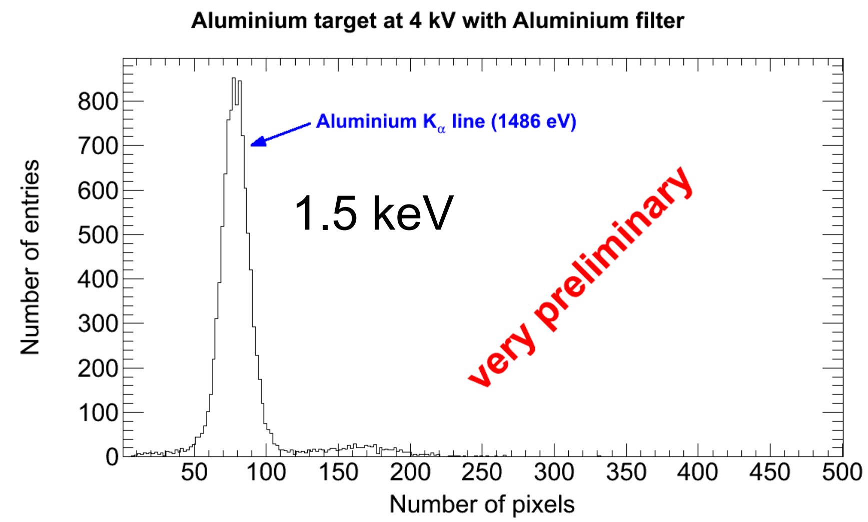


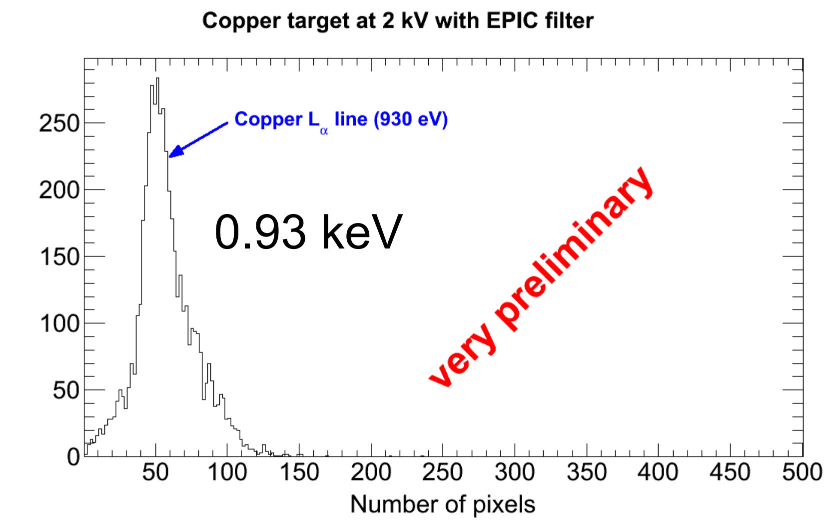
Tests in detector lab at CERN

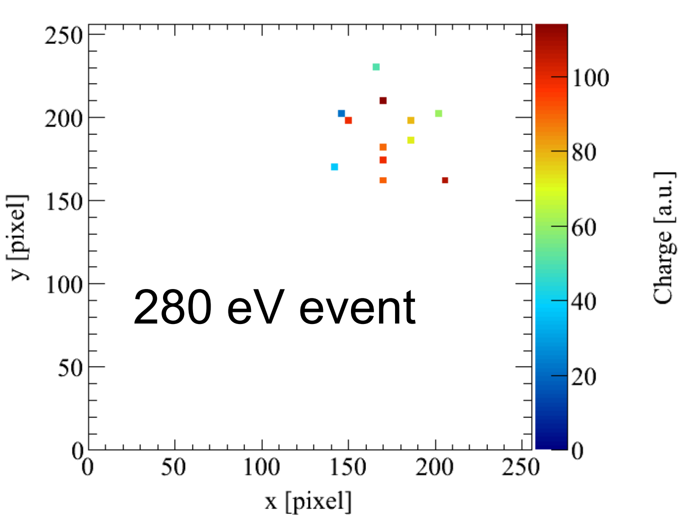


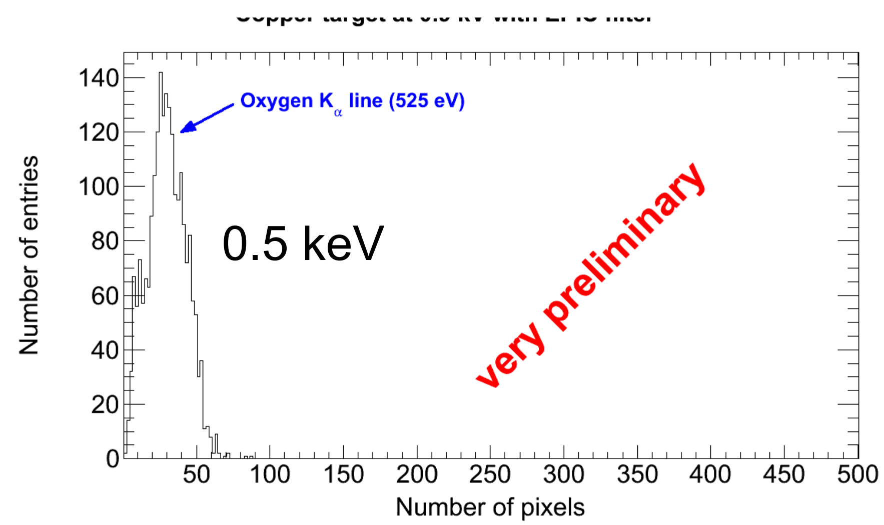
- The InGrid-based detector was tested in the detector lab at CERN.
- There photons with an energy between 280 eV and 8 keV are available from an X-ray tube.
- Detected photons down to 280 eV.

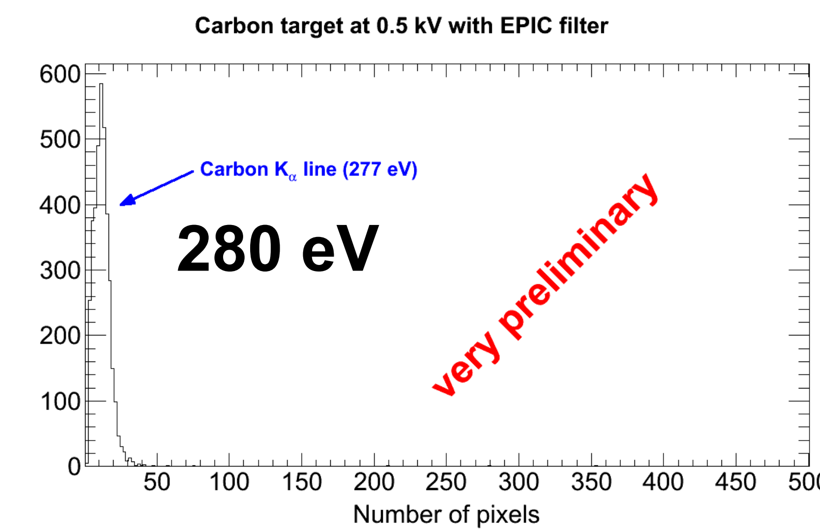






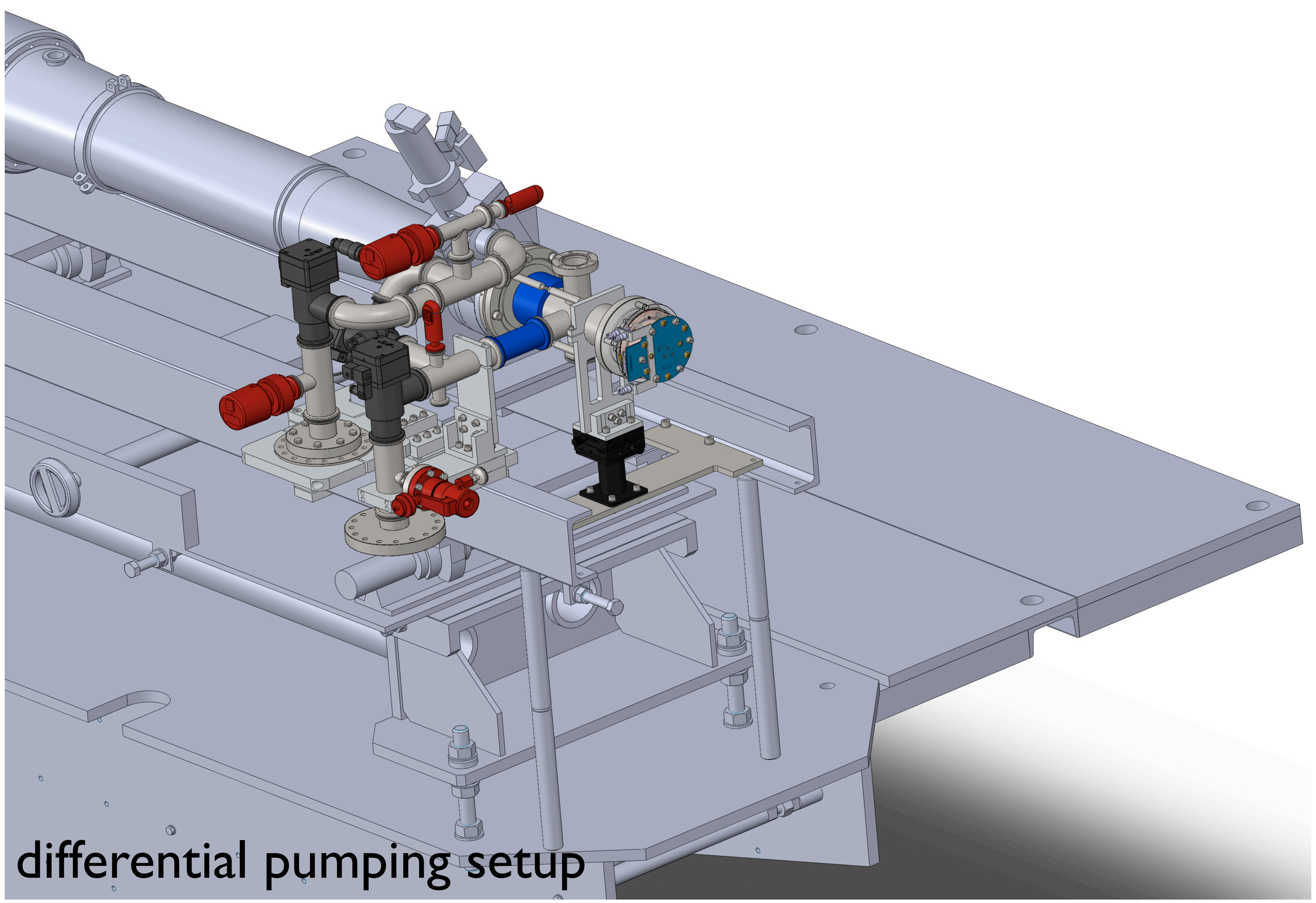




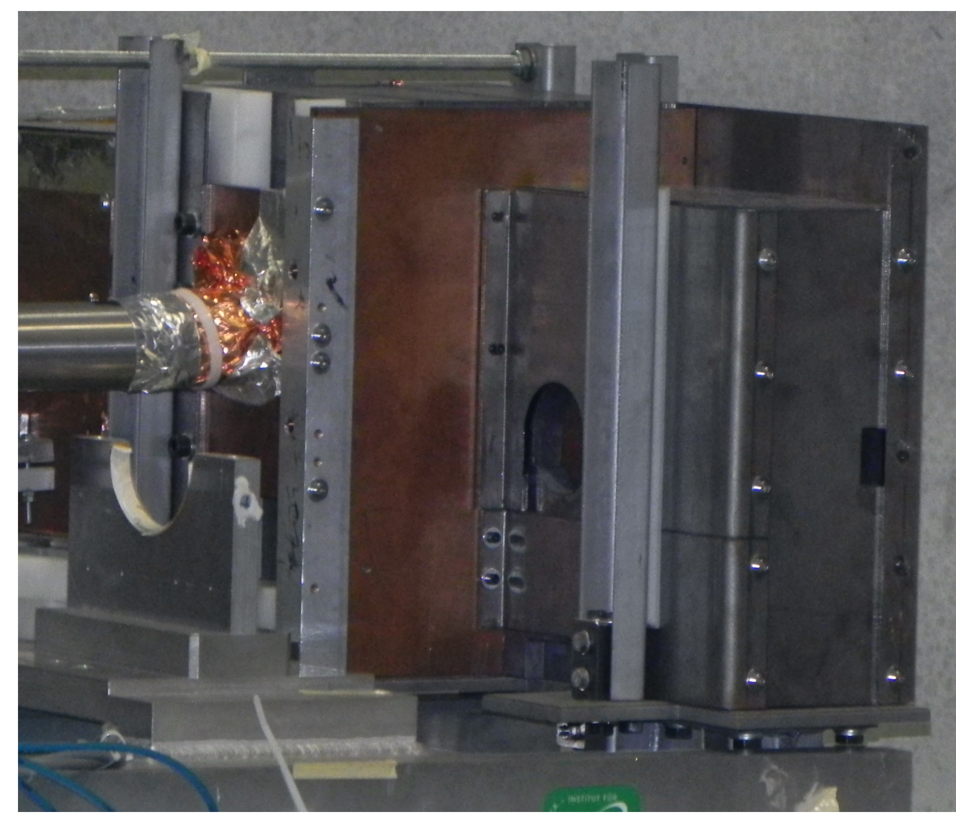


Setup at CAST

- To reach a vacuum of 10^{-7} mbar in the X-ray telescope, differential pumping has to be implemented.
- All parts have been produced/purchased. System has been tested as far as possible.
- Lead shielding has been manufactured and is already mounted on platform.



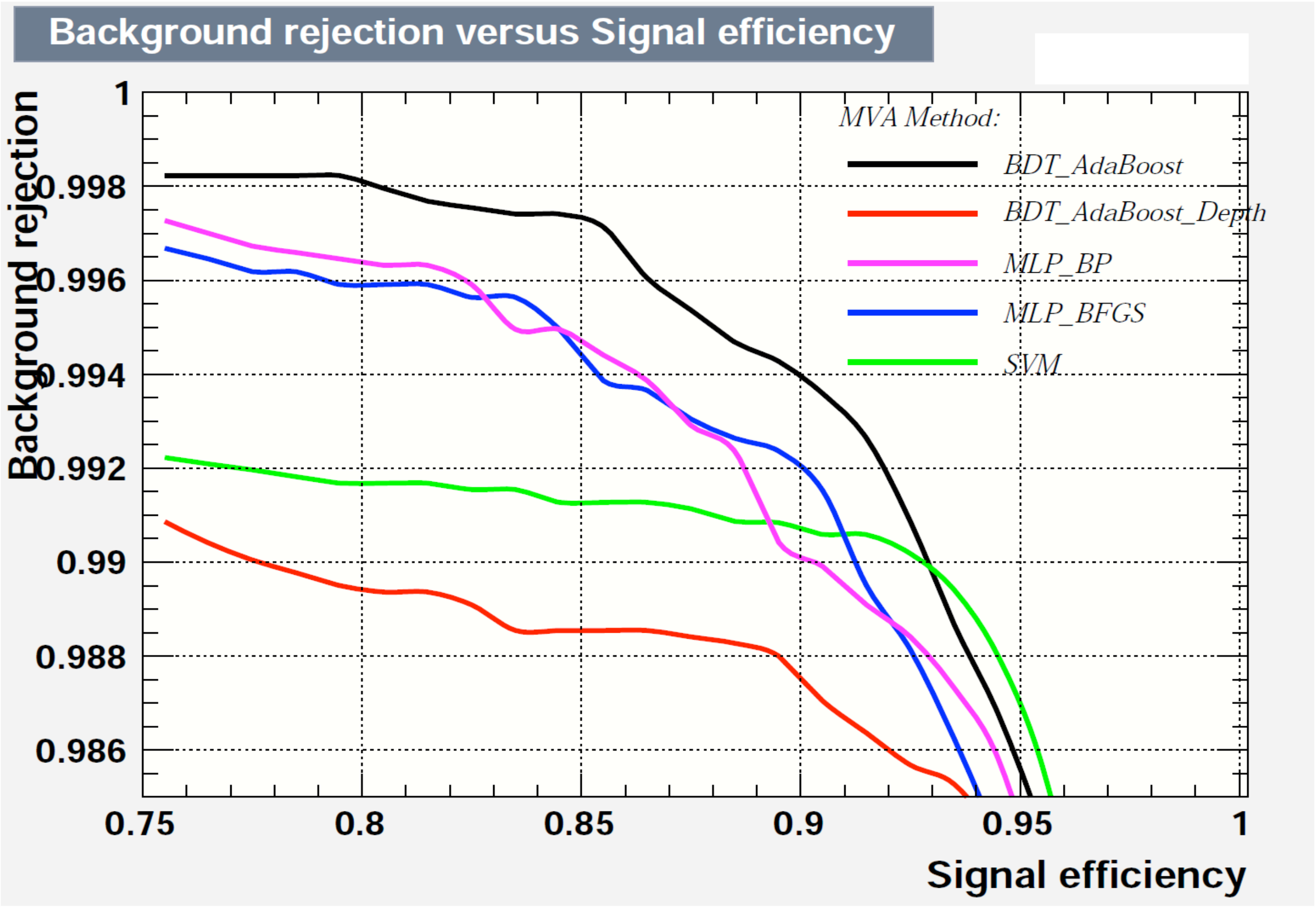
differential pumping setup



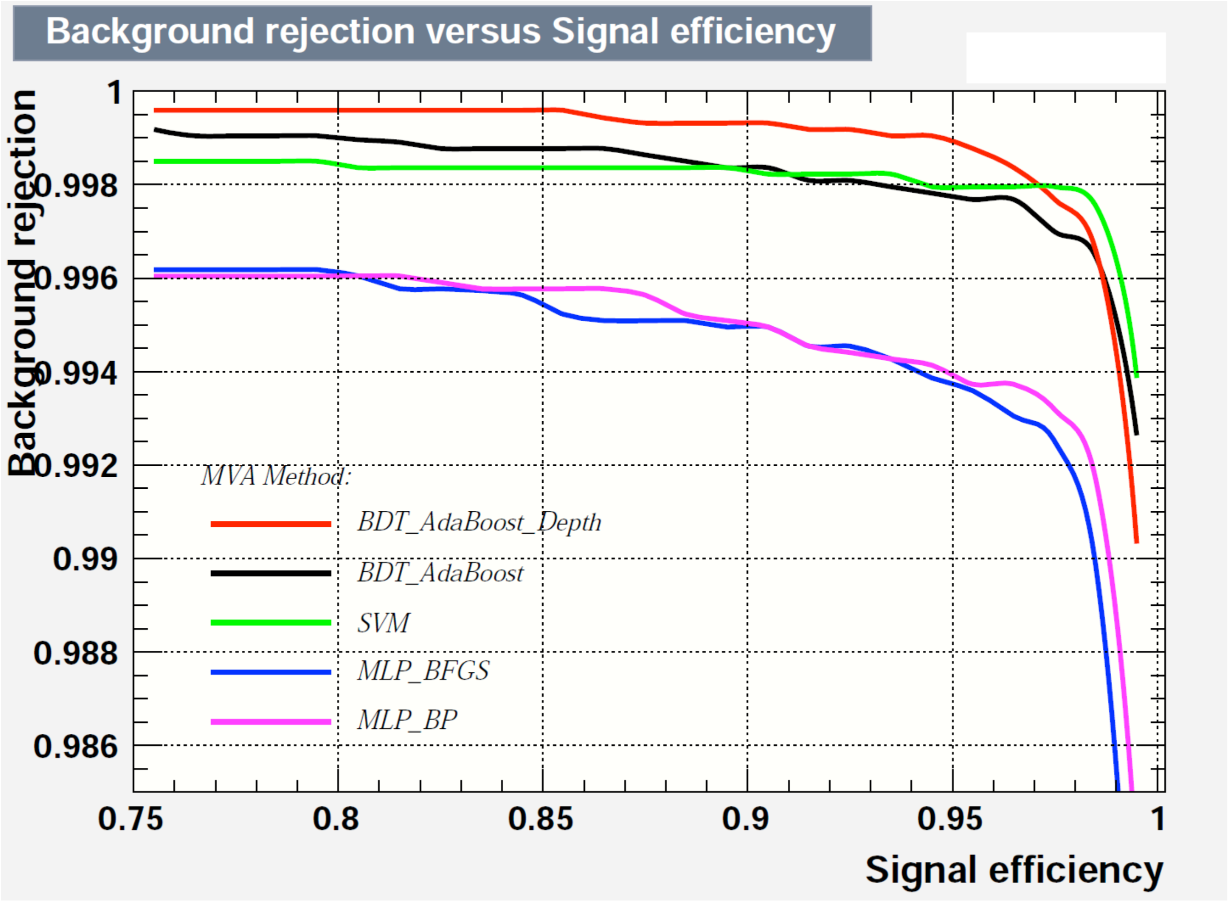
lead shielding

Software improvements

- New algorithms from the TMVA/ROOT package were tested for separating tracks from photons: neural nets, boosted decision trees etc.
- These algorithms show an even better performance than the likelihood ratio.

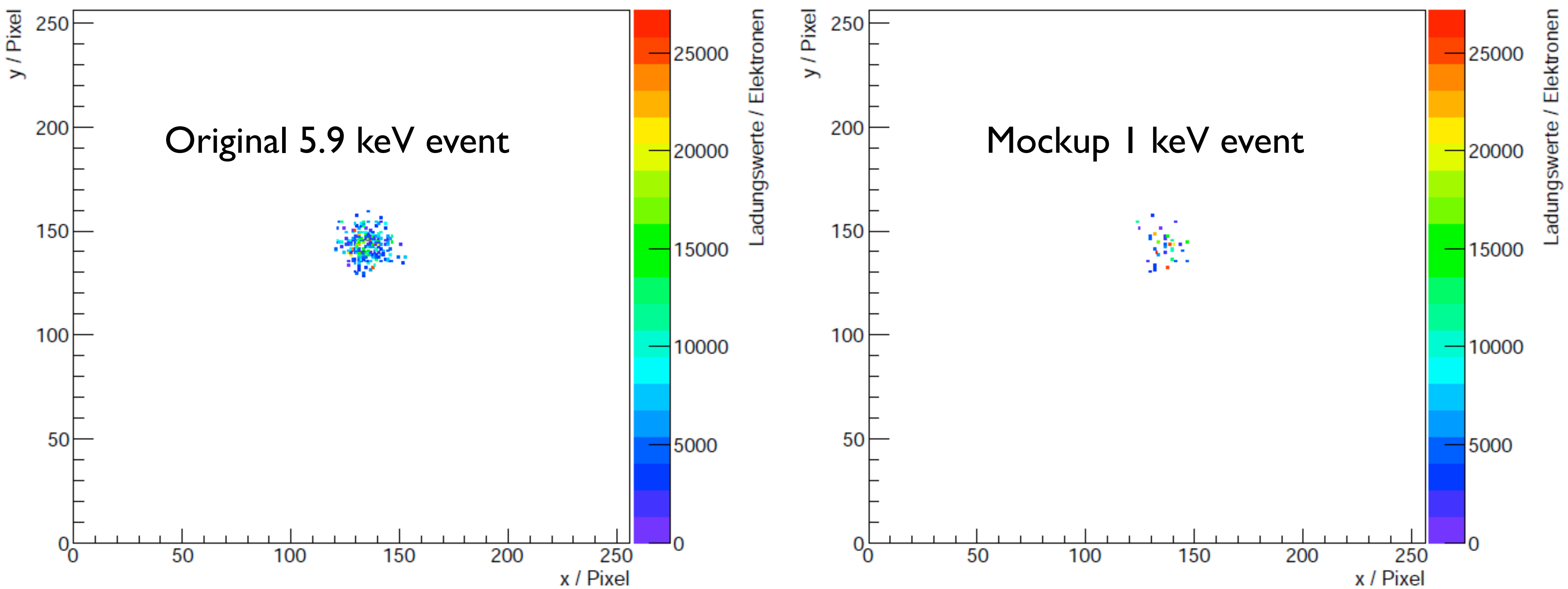


Background rejection vs. signal efficiency, when the photon data set contains both ^{55}Fe lines (3 keV and 5.9 keV)



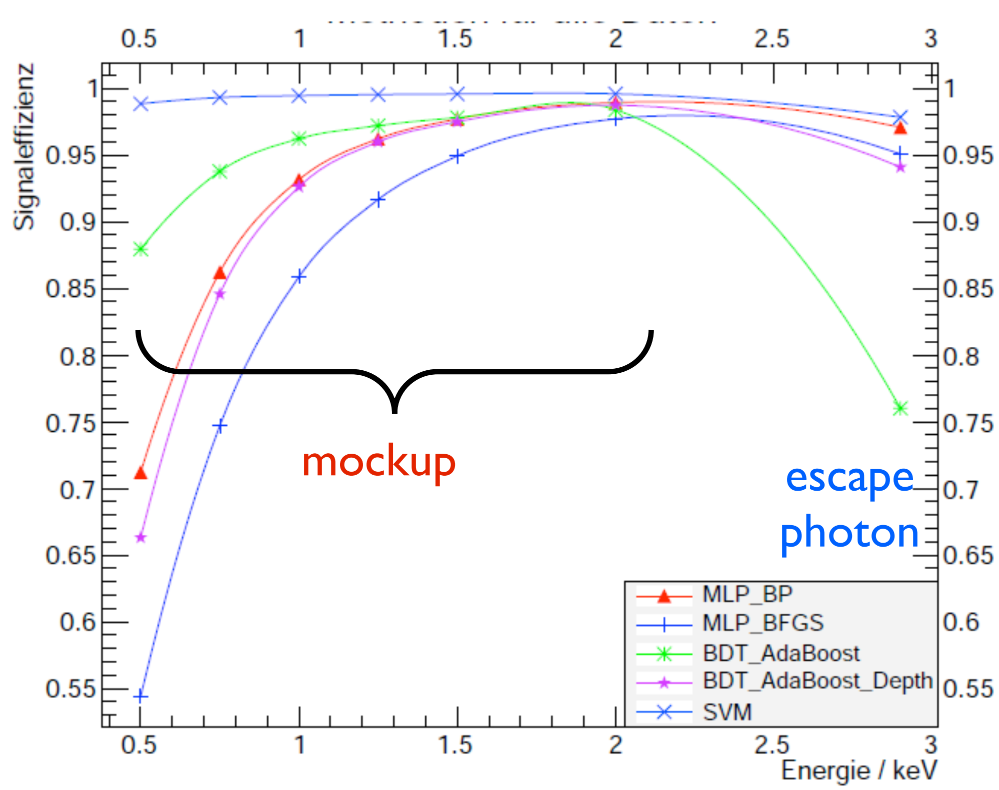
Background rejection vs. signal efficiency, when the photon data set contains only one ^{55}Fe line (5.9 keV)

Software efficiency test for low energy signals



(a) (b)

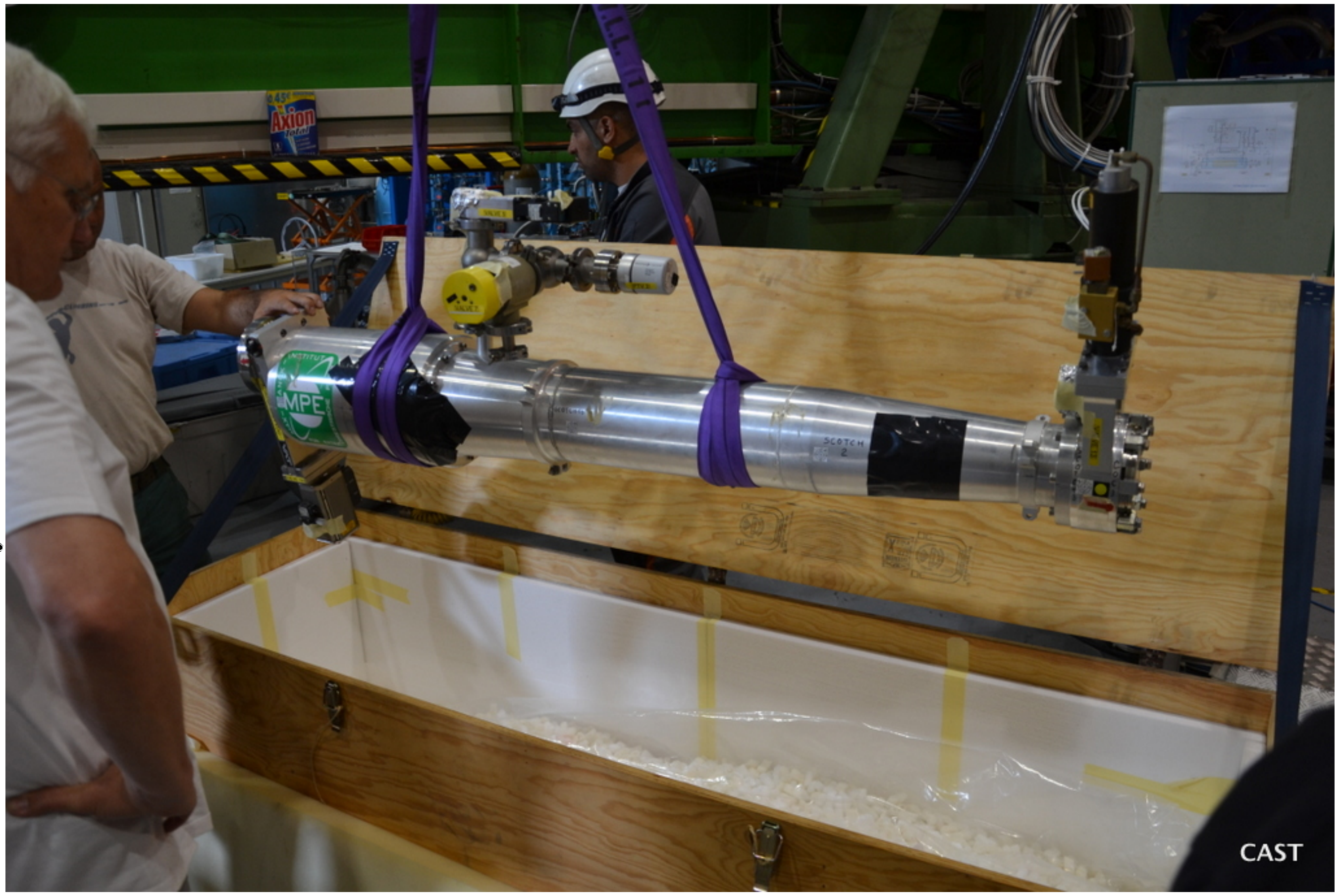
To test the software efficiency for low energy events, a test sample of mockup events was generated from ^{55}Fe events by randomly eliminating hits.



The algorithms (NN, SVN and BDT) were trained with 5.9 keV photons and the signal detection efficiency of low energy mockup photons (0.5-2 keV) and of photons from the escape peak (2.9 keV) was tested.
Good efficiency was found for most algorithms.

Progress with the X-ray telescope

- Measurements at PANTER (MPE, Garching) will determine X-ray reflectivity
- Measurements will check whether performance has degraded since the last measurements in 2009
- Telescope has been removed from the setup and is being prepared for shipping
- Due to delays at PANTER, it cannot be measured before November 19, 2013
- Will be put back at the beginning of 2014 and be ready for measurement run starting middle of 2014

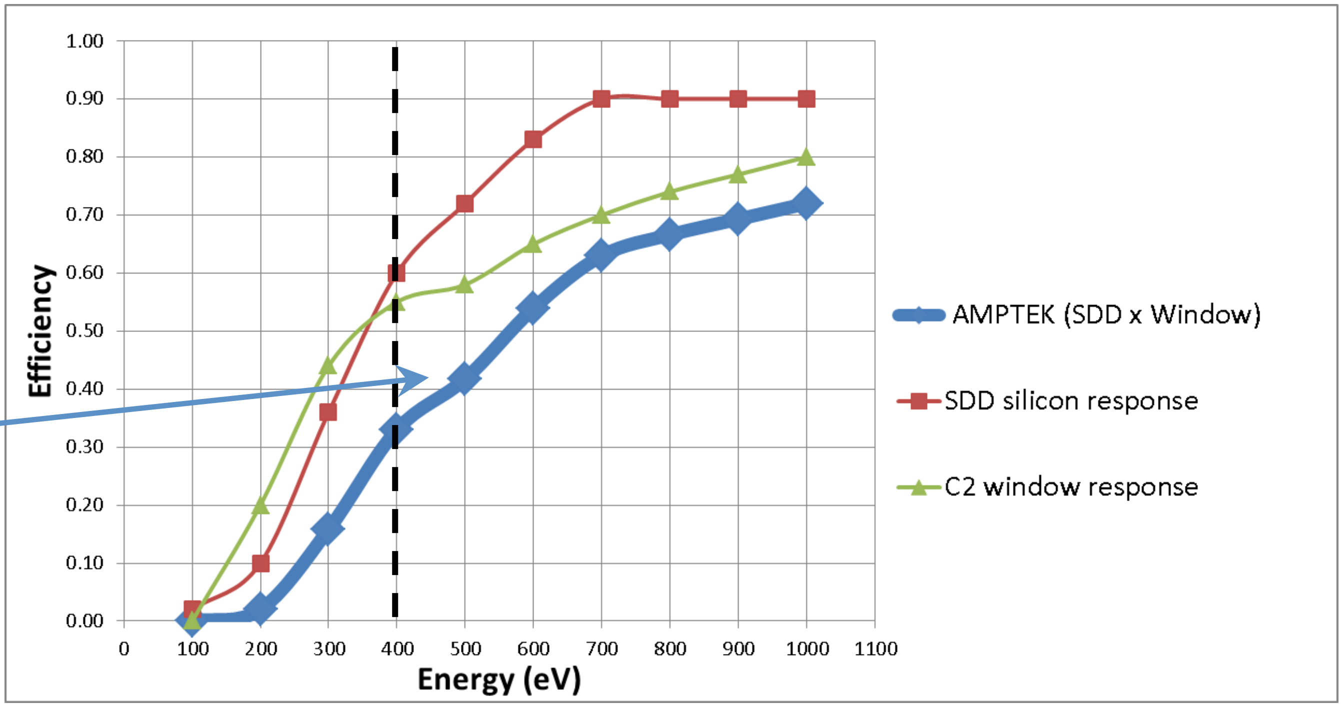


CCD detector Data analysis status

- pn-CCD Data from 3He run have been preprocessed
- currently signals are being cross-checked for consistency)
- data will be ready for analysis at the beginning of 2014

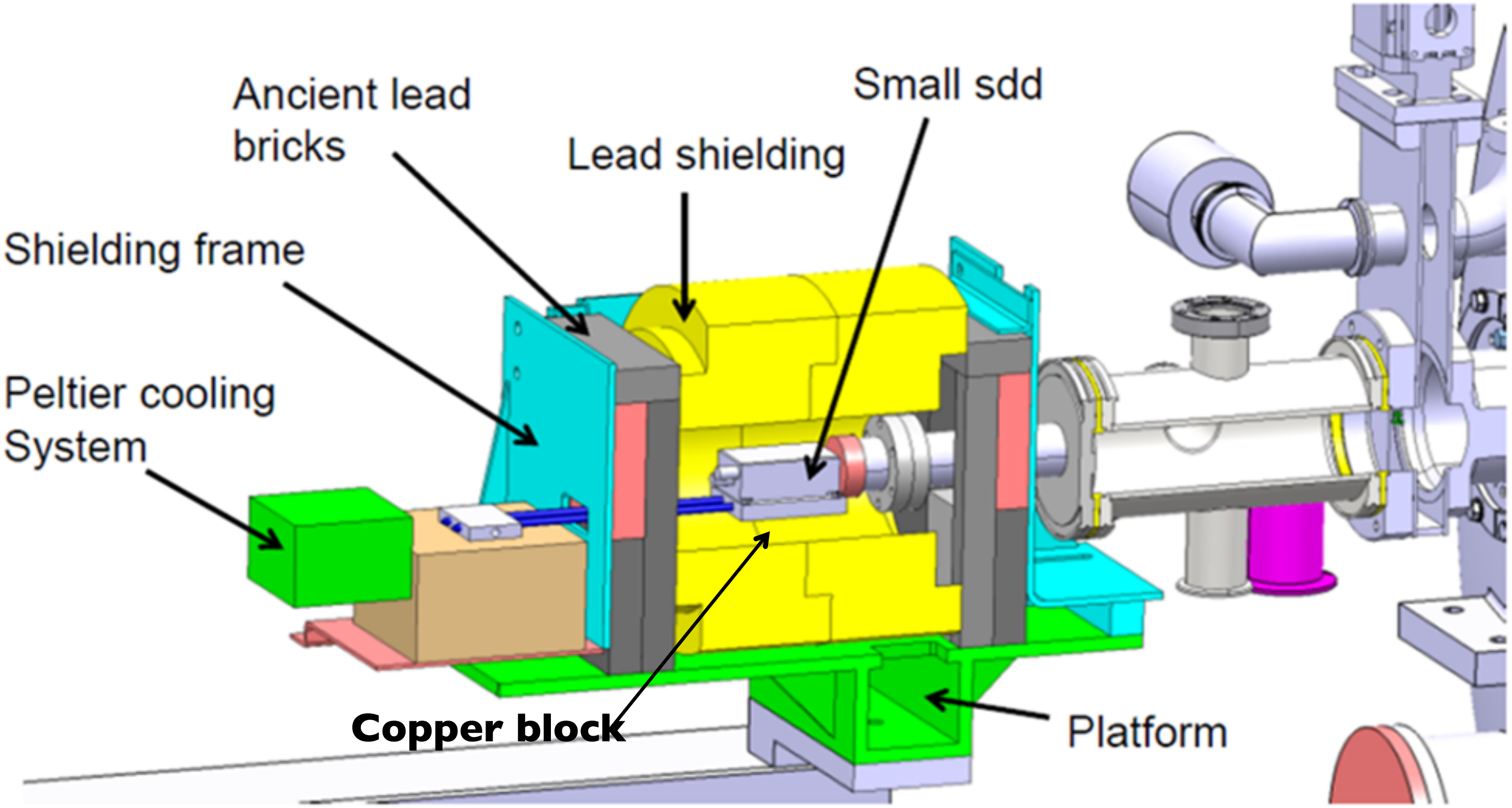
Simple Low Energy detector for a first look at sub-keV

- Sub-keV energy range is so far unexplored in a helioscope
- XRT at PANTER
  - beamline available for 1 – 2 months
- No X-ray Optics; detector requirements:
  - Well understood
  - Good energy resolution
  - Low threshold and with sensitivity down to < 300 eV
    - No window or special low-E window
  - Non-imaging acceptable
    - Signal from ~ whole solar disc
  - Ultra low background not necessary
    - Moderate - Low bgkd sufficient (bkgd $^{1/8}$)
  - Ideal area 15 cm^2
    - Smaller area still OK for a first look (flux$^{-1/4}$)
- Available detector
  - X-ray test lab ref detector
  - 16 mm^2 AMPTEK SDD
    - C2 Vacuum window
    - Operates at 220 K
    - 65 eV FWHM @ 500 eV
    - Threshold of < 400 eV in CAST conditions?
      - Cooling necessary



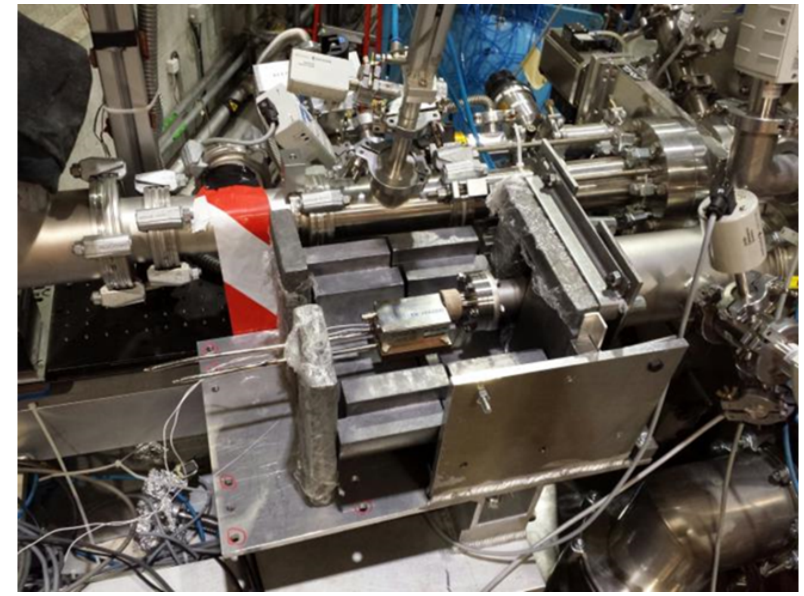
Installation on CAST

- Cold bore Area ~ 14.5 cm^2
- SDD Active area ~ 16 mm^2
- SDD 'sees' via 9.26 m , 9 T field
  - 15% surface of solar disc (32% of tachocline 'disc')
- Pb shielding 3-6 cm thick
- Cooling of SDD electronics box by external Peltier cooler
  - Via heat pipes + copper block fixed to SDD
  - Sandwiched between (SDD box and copper block) is 0.5 mm AlN electrical insulator sheet
- Data Acquisition via commercial Digital Pulse Processor (PX5)
- Data
  - Timestamp + energy channel

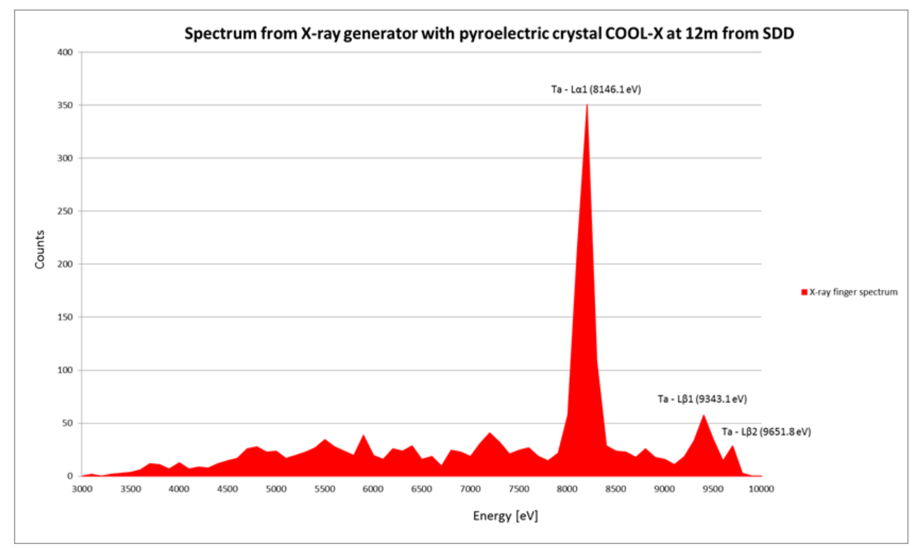


Performance in CAST

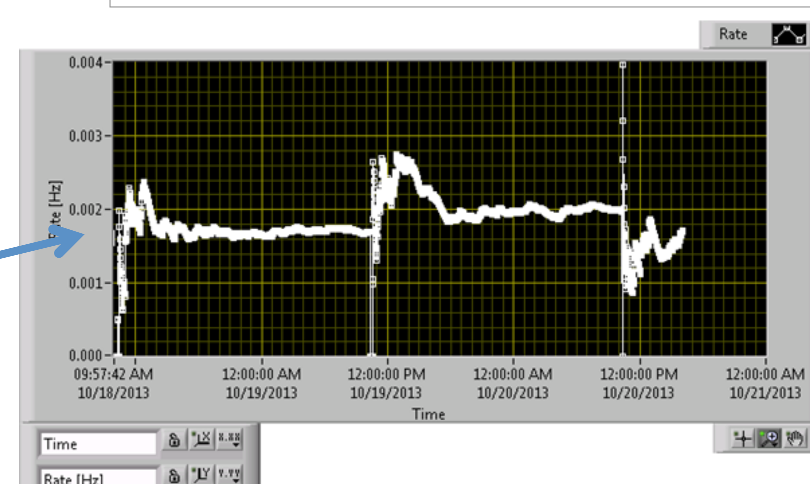
- Commissioning/data talking since 22 October
- – 1 week (No shielding + Peltier cooling) 217 K
- – 1 week (No shielding + No cooling) 221 K
- – 2 weeks (Pb Shielding + Peltier cooling+AlN) 217 K
  - First week has been analysed



- Tracking and Background data systematics
- – Noise studies in progress



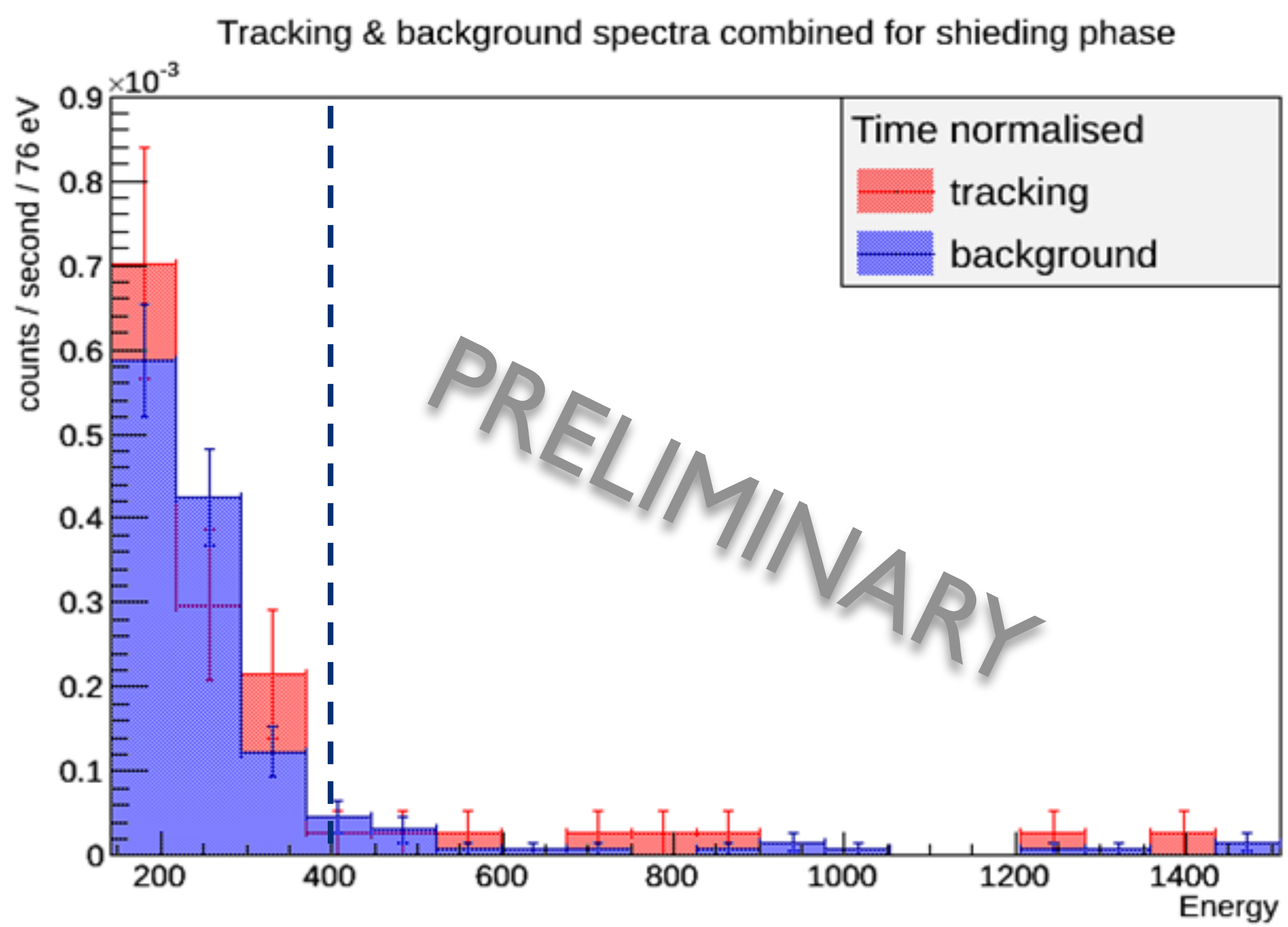
- Calibration check (8 hrs)
- – Field ON
- – Pyro-electric source (8 keV)
- – Source at opposite end of magnet



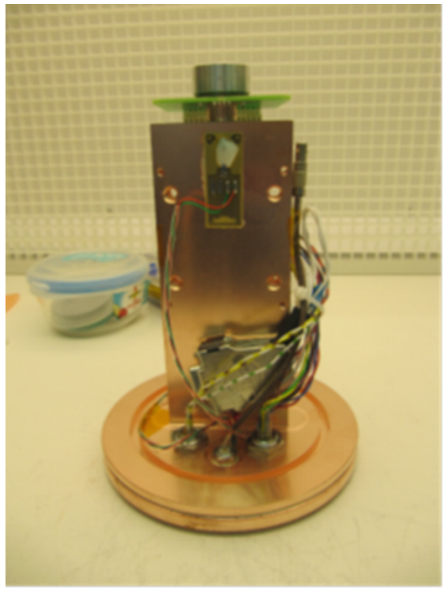
- Detector stability (217 K)
- – Latest online plot 2 x24 hrs runs
- – Stable rates
- – Rate 150 - 9000 eV
  - **~ $2\cdot10^{-3}$ Hz**

Preliminary Analysis Shielding + Cooling

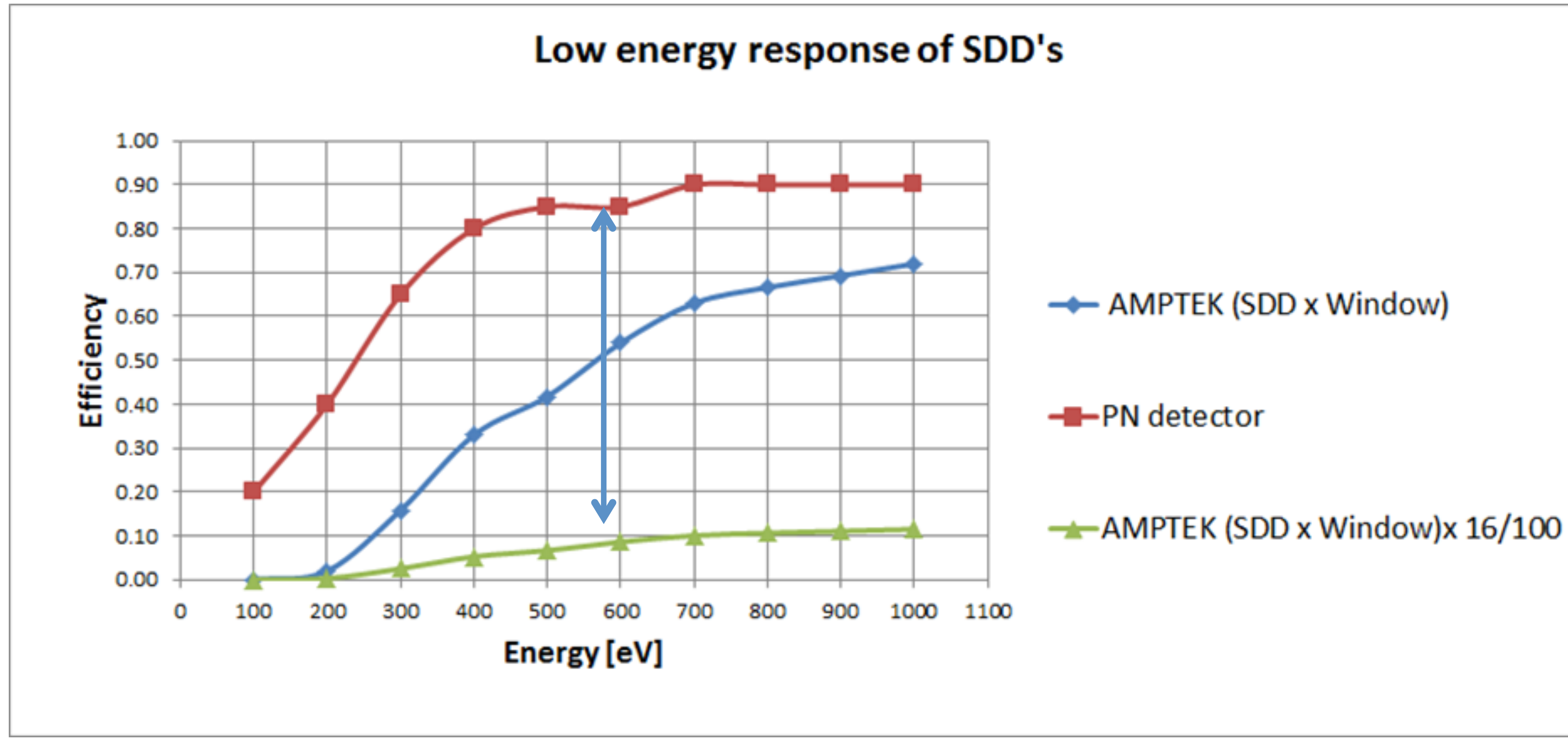
- First data from final configuration
  - Shielding and Cooling
- Background 6 hrs each night (field ON)
- Solar tracking data ~ 100 mins each morning
- Tracking (red) and background (blue) rates 400 – 1500 eV
  - Typically < $4 \cdot 10^{-5}$ Hz (per 76 eV bin)

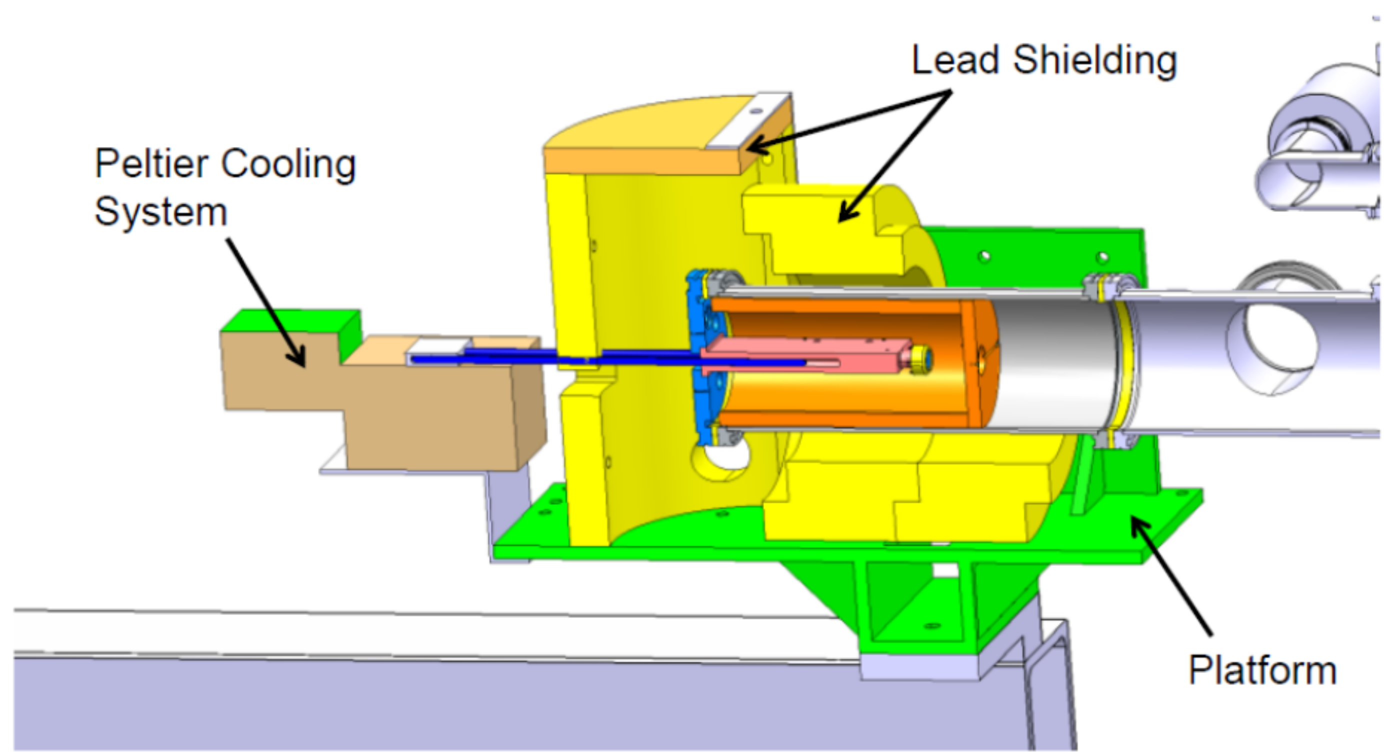


100 mm^2 SDD status



- Large windowless SDD
  - From PNDetector
  - Operates at 240 K in vacuum
  - Needs cooling
    - Vacuum operation
  - Uses same PX5 DAQ as small
  - Gain
    - 7-15 times flux of small SDD
  - Background?
    - To be measured this week in lab
    - Noise threshold ?
  - Next weeks x-ray beam line
    - 1-2 weeks tests
    - Calibrations
    - Optimizing parameters
    - Final internal shielding
  - Install on CAST
    - When performance satisfactory
    - Week 45
    - 4 weeks data taking then remain

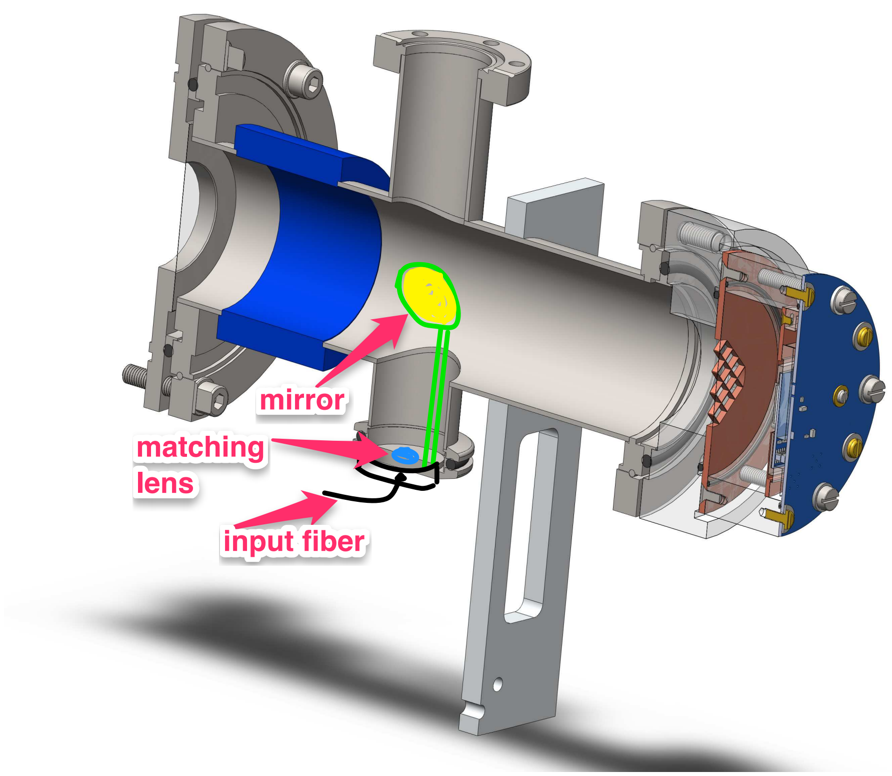




BaRBE status

- BaRBE original light collection optics have been removed from the SRMM line to free space for the new optics from LLNL.
- The **BaRBE optics will be redesigned and moved** to a position in front of the InGrid detector through an available 40 mm dia. vacuum port.
- Thanks to the XRT the expected beam diameter in the new BaRBE position is 16 mm, and the mirror dia. can be reduced down to 25.4 mm
- To avoid interference with InGrid, the mirror will be mounted on a motorized foldable mount (mechanical parts are being designed and manufactured in the INFN Trieste machine shop)
- Light will be extracted, as in the previous BaRBE optical system, through a matching lens and optical fiber up to an optical switch alternating between two outputs.
- A single detector can then look alternatively either at the beam or at the background, while two detectors can share beam time.
- The single-detector scheme has already been implemented previously using a PMT (provided by Y. Semertzidis and D. Lazarus, BNL) ⇒ paraphoton results
- **The two-detector scheme will be set up in the new BaRBE setup,** keeping the PMT as the "benchmark" detector and using a cooled Avalanche PhotoDiode (APD) as the second detector.

Interface flange with InGrid detector



CFD Simulations I

- Carried out in collaboration with the CFD team of EN/CV
- Necessary to understand the density distribution of the 3He in the magnet bores during tracking ⇒ Coherence length
- Several turbulence models tested ⇒ Gas distribution and coherence length are model dependent.

Inputs

Pressure while magnet is horizontal

Temperature of the cold bore

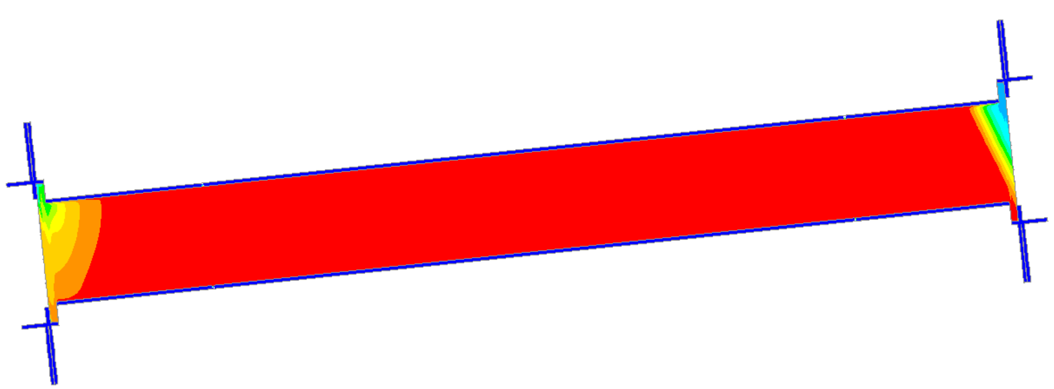
Temperature of the link volumes

Outputs

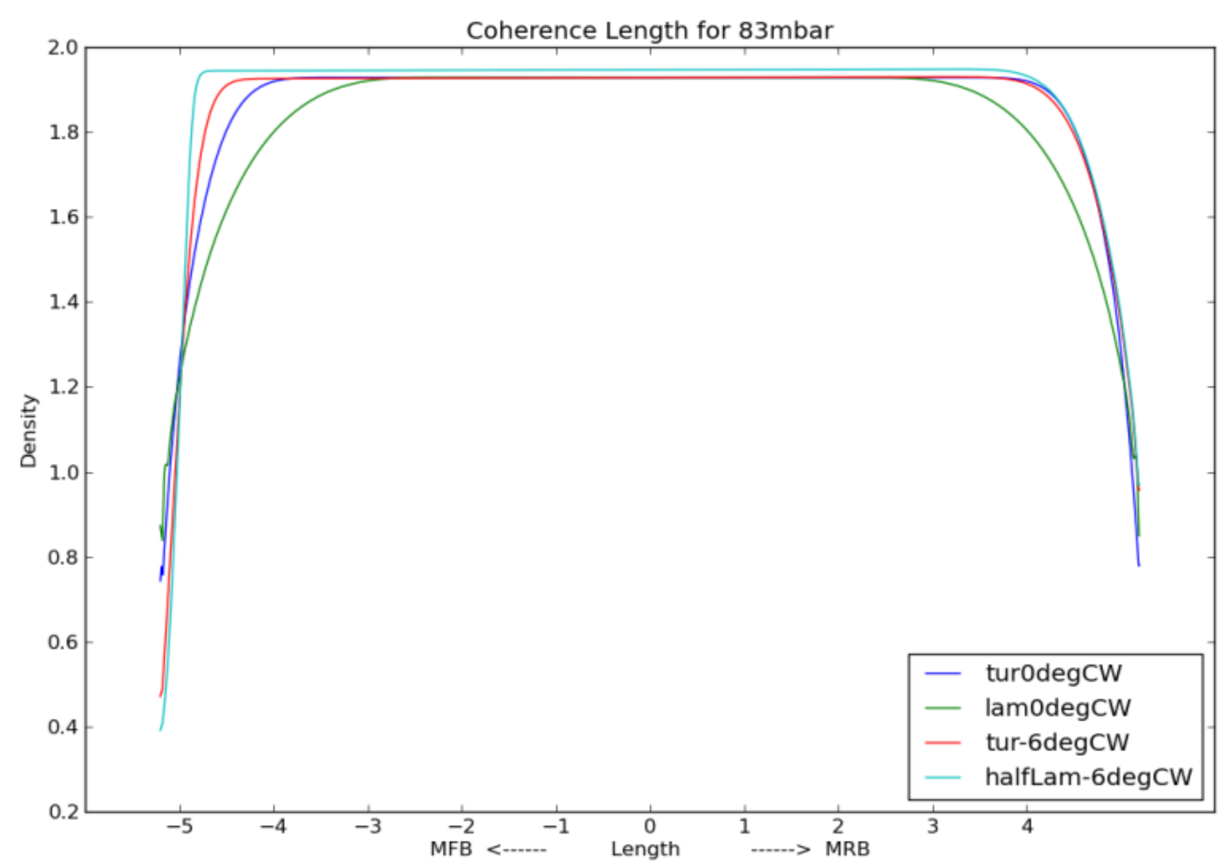
Number of Moles

Density distribution

Pressure when magnet is tilted

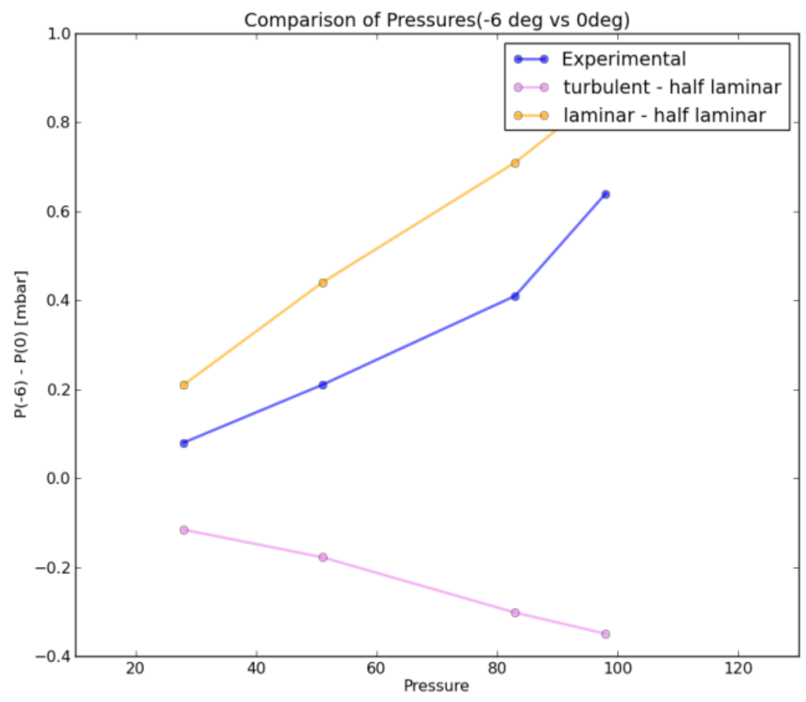


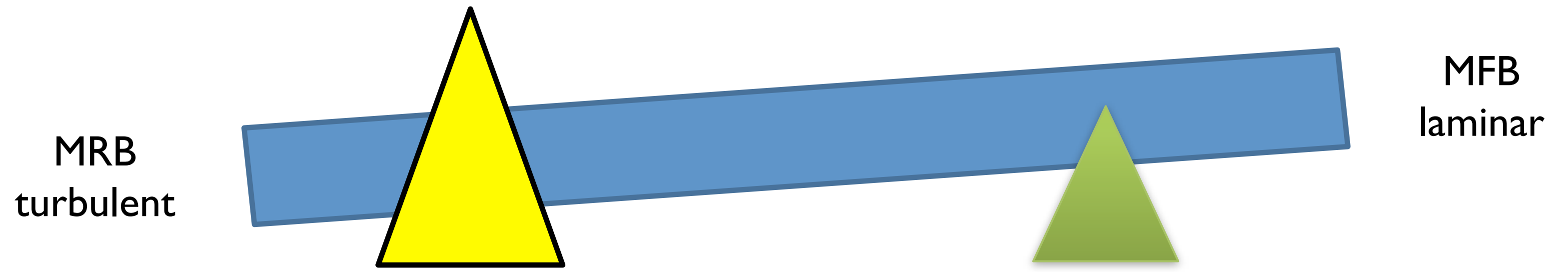
Density profile over the magnet for half-laminar tilted simulation, 83mbar.



CFD Simulations II

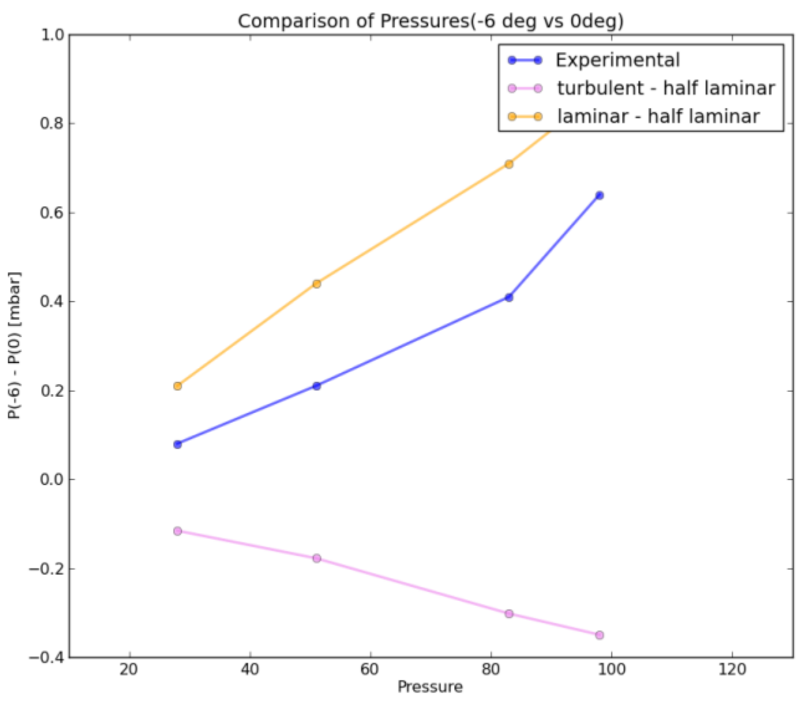
- Simulating CAST conditions: very challenging for CFD models.
- Reproducing the experimental pressure change while tilting is a indication that the CFD model is realistic.
- For non-heated windows (high pressure running)
  - Horizontal: Laminar flow model
  - Tilted:
    - Laminar flow on the top part
    - Turbulent flow on the bottom part

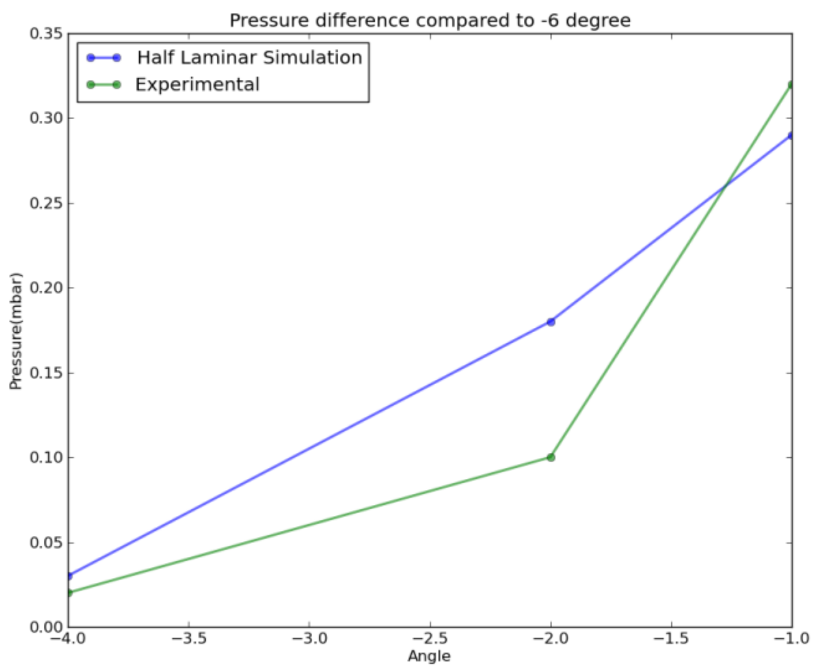




CFD Simulations III

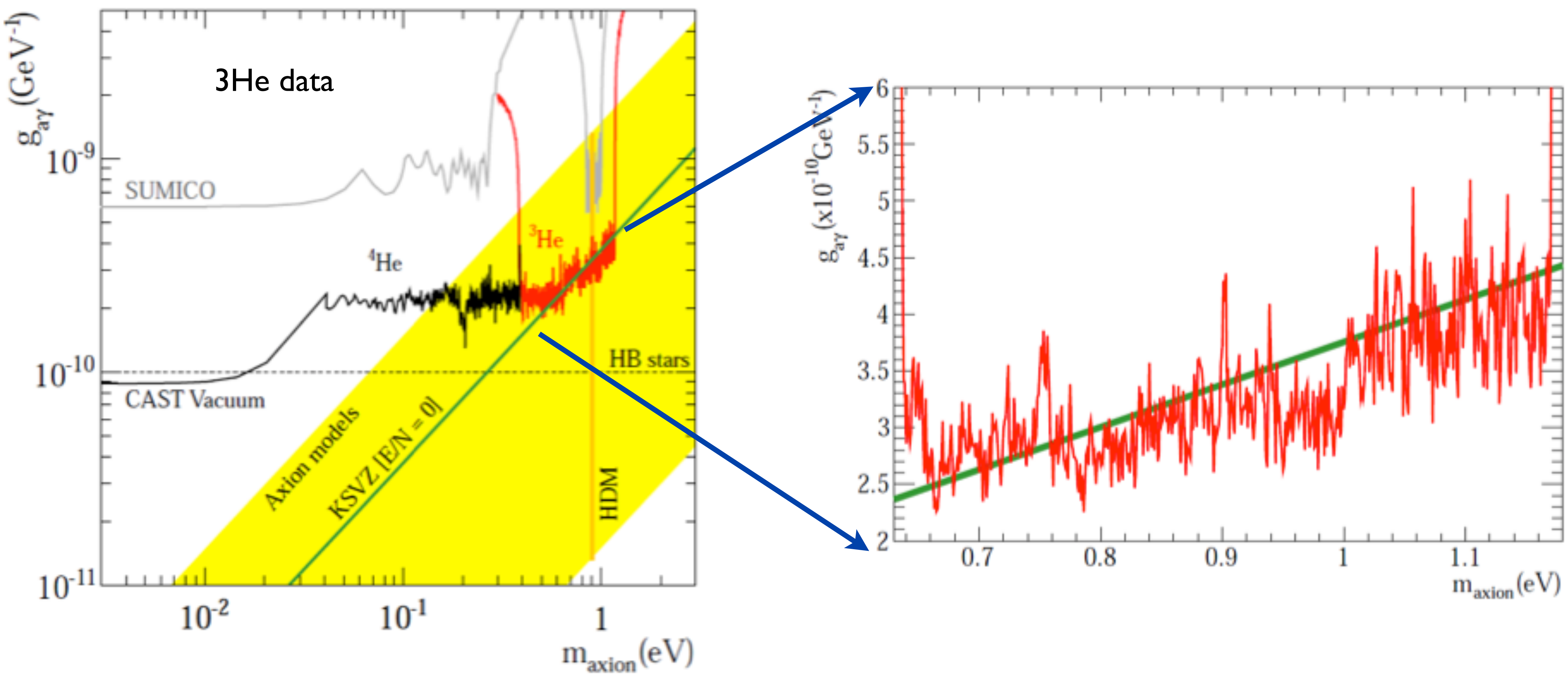
- Tilted simulations are tuned to have the same number of moles produced by horizontal simulation (total gas mass is constant during tilting)
- Horizontal simulation (laminar) is less realistic than the tilted simulation (half-laminar).
- The perfect horizontal model would produce the correct number of moles ⇒ Correct pressure change during tilting.





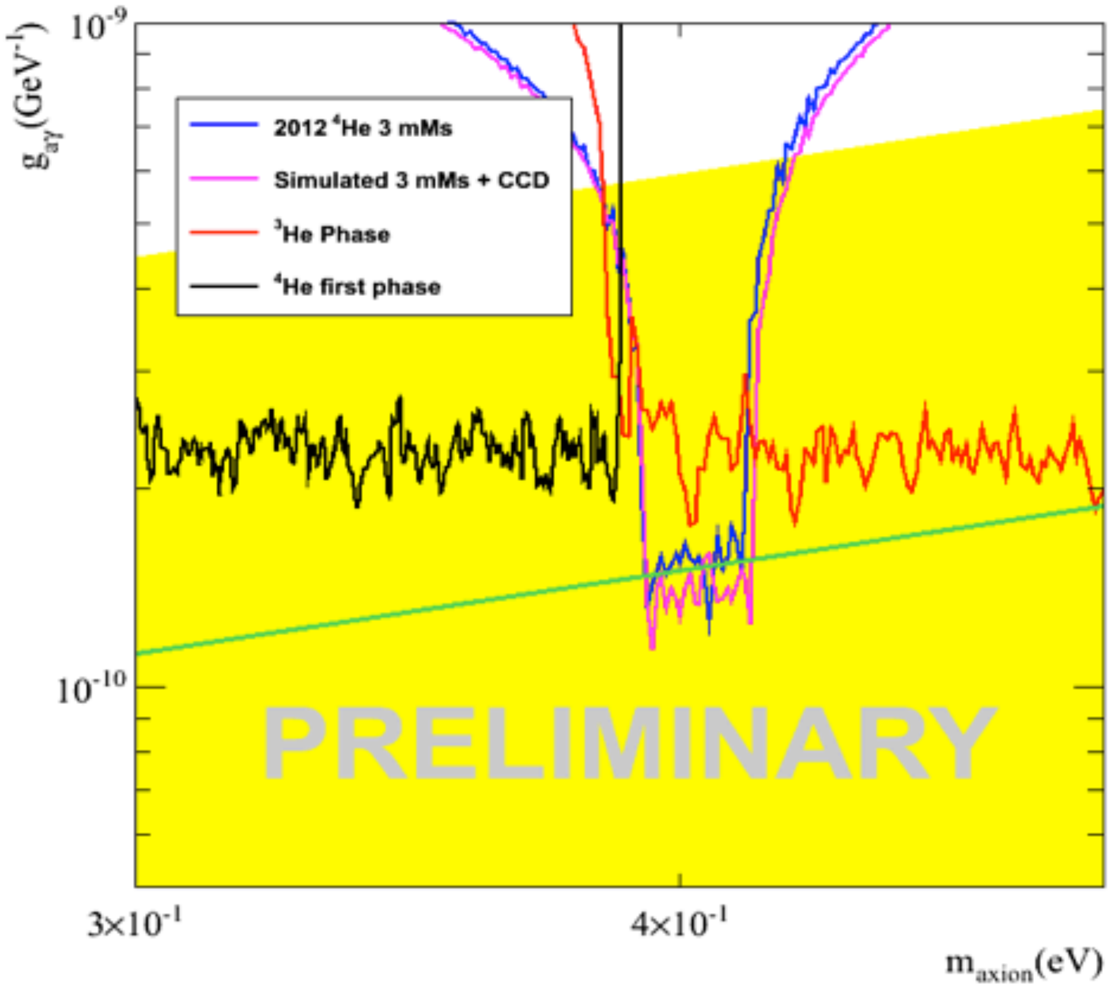
Data taking, analysis and publications I

- Data Taking 2013
  - The data taking started on 22nd September and will last until 10th December repeating vacuum measurements with significantly improved sensitivity
  - Detectors: three Micromegas detectors (two on the sunset side and one on the sunrise side) and a new SDD detector on the sunrise side.
  - The data taking efficiency, in terms of solar trackings covered, is 90% (for the period 22nd September to 21st October).
- ^{3}He data analysis (data taking period 2009-2011)
  - The mass interval $0.64\ \text{eV} \leq m_a \leq 1.16\ \text{eV}$ been almost fully analyzed. No excess of counts on MM detectors: $g_{a\gamma\gamma} \leq 3.3\times10^{-10}\ \text{GeV}^{-1}$ at 95% CL - Submitted to PRL, now in the review process

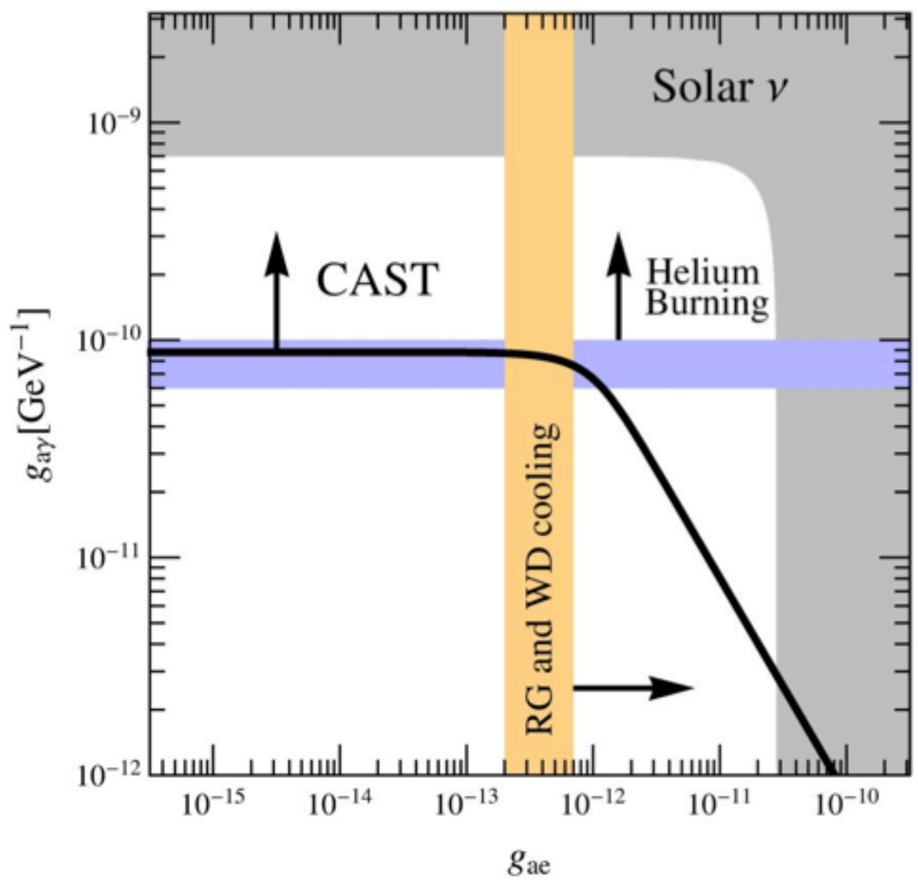


Data taking, analysis and publications II

- ^{4}He data analysis (data taking period 2012)
  - Revisiting with better sensitivity the mass range around 0.4 eV. No excess of counts on MM detectors: $g_{a\gamma\gamma} \leq 1.5\times10^{-10}$ GeV^{-1} at 95% CL - Starting the publication process.
- Axion-electron coupling bound
  - As a by-product, the CAST Phase I data (vacuum) were used to publish a bound on the product $g_{a\gamma\gamma^*}\, g_{ae}$ - (*JCAP 1305 (2013) 010*)



^{4}He preliminary analysis



axion-electron coupling from CAST phase I vacuum data

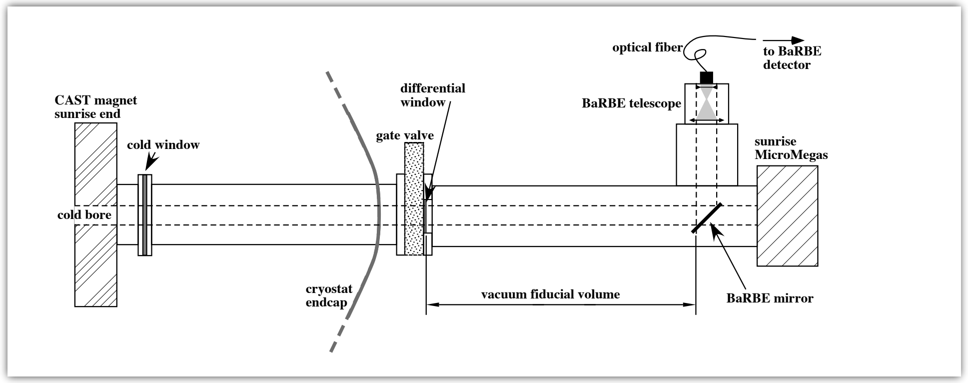
Solar paraphotons with BaRBE

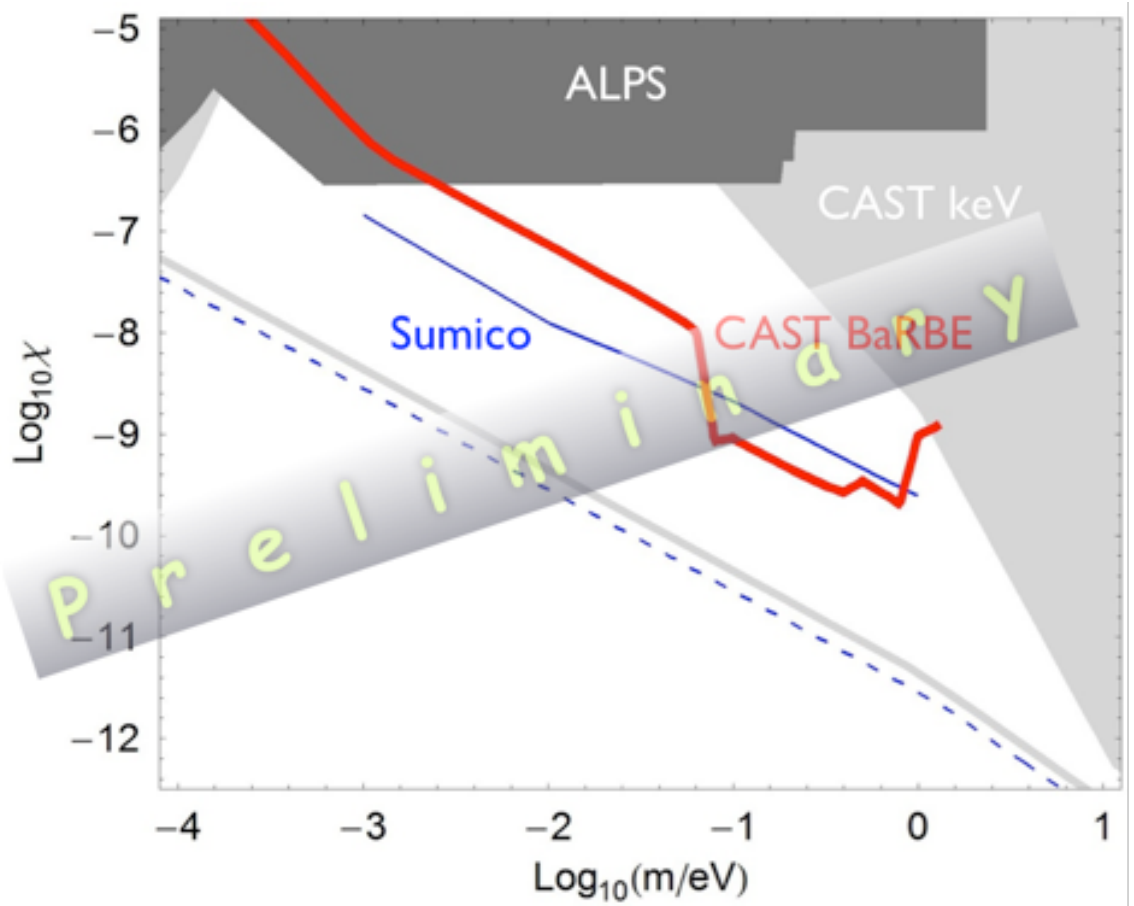
- The Dark Count Rate (DCR) from sun-tracking and background data collected by BaRBE in 2010, 2011 and in 2012 has been used to obtain an experimental bound on the production of solar paraphotons in a vacuum section of the beampipe in front of the BaRBE detector.

- Thanks to an optical switch, the PMT (peak sensitivity at 3.5 eV) looks alternatively at the fiducial volume and at a shutter (switching frequency = 1 Hz). The common background can then be rejected.

- Data were acquired each day during CAST sun-tracking runs for 5500 s, followed by 72000 s of background data with the magnet in parking position.

- The results summarized in the table have been used by to obtain the **preliminary exclusion plot for the kinetic mixing of paraphotons with ordinary photons**(*). A publication on this topic is in preparation at the moment.



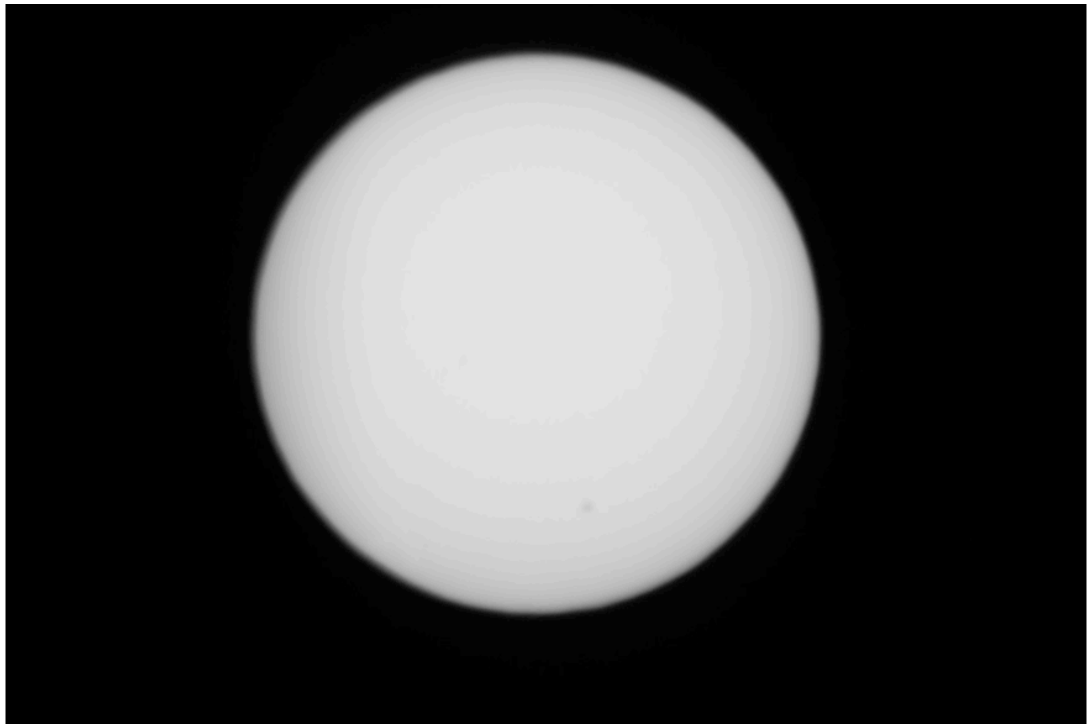


BaRBE Data	T_{bckgrd} [s] / T_{track} [s]	FOV [mrad]	DCR [mHz]
2010-2011	$1.17 \cdot 10^7$	1.0	1.4
	$8.7 \cdot 10^5$		
2012	$1.9 \cdot 10^6$	7.5	3.5
	$1.5 \cdot 10^5$		

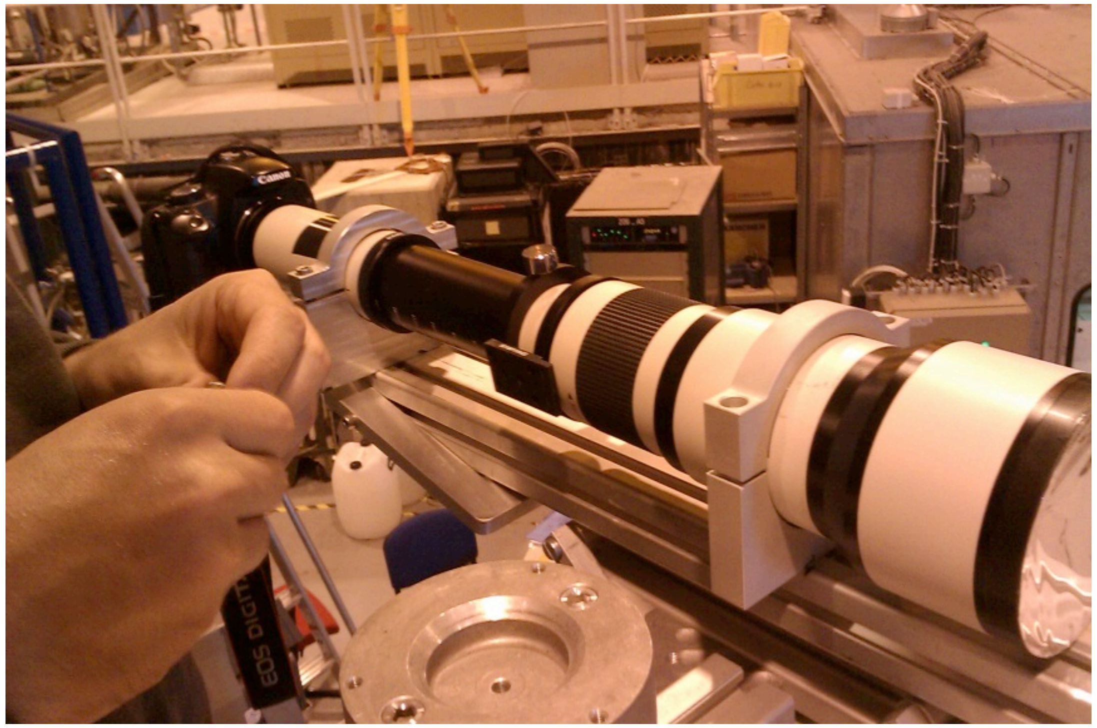
(*) S. Troitsky (INR Moscow)

Sun filming of September 2013

- Six days of excellent weather and filming. We have modified the camera support to improve precision.
- The first half of the campaign was carried out with the 2011 grid into the tracking program. The second half was completed with the new September 2013 grid: it shows a correction of 0.5 mm in 10 m horizontal
- Sun filming results:
    - magnet leading the sun by 3.4 mm in 10 m horizontal, and above the sun by 1.2 mm in 10 m vertical.
    - magnet within the 10% of the sun.
- We consider this alignment adequate for the present 2013 run.



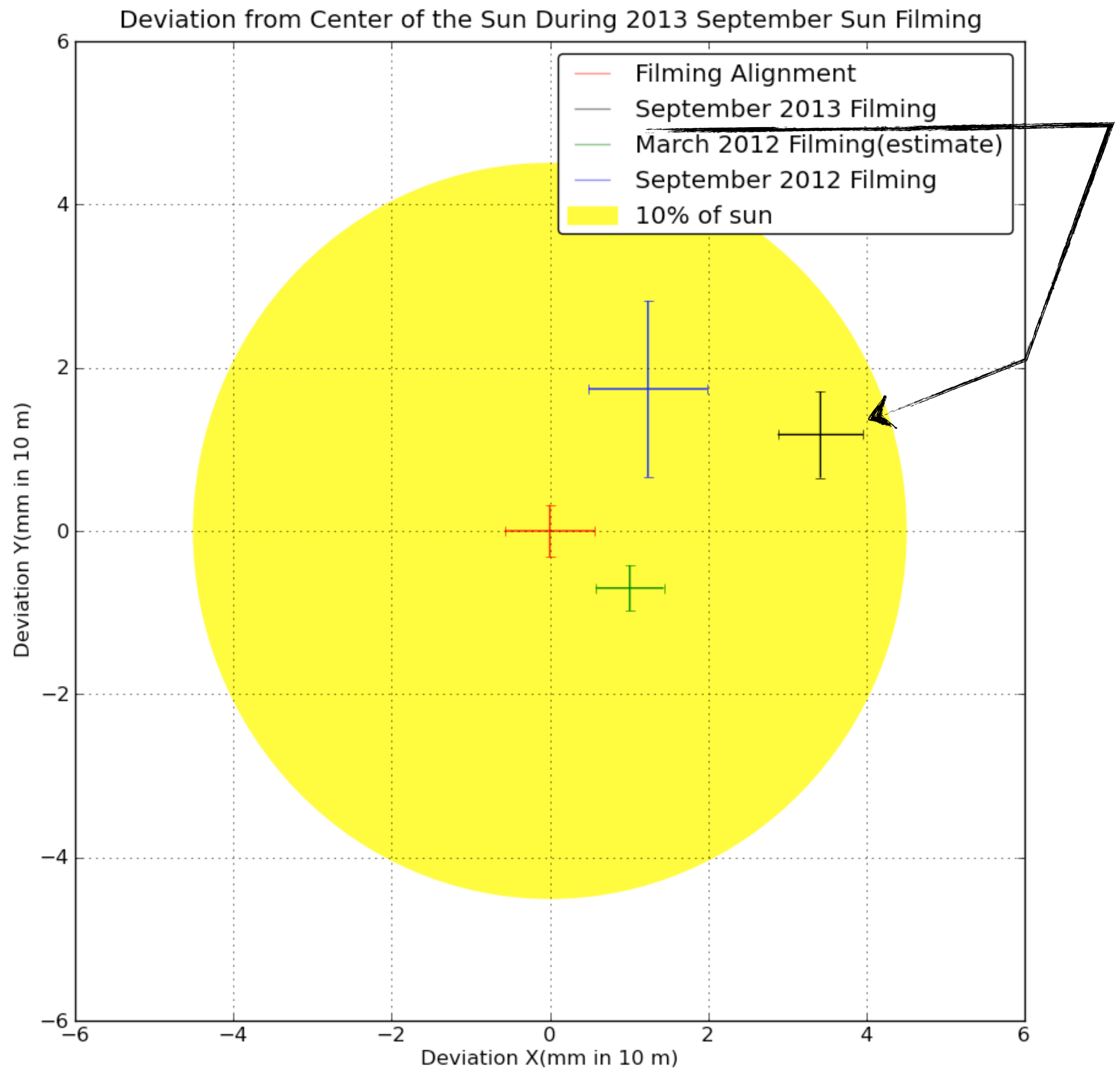
Photograph of the sun taken with the sun filming camera



Sun filming camera and lens

Sun filming results

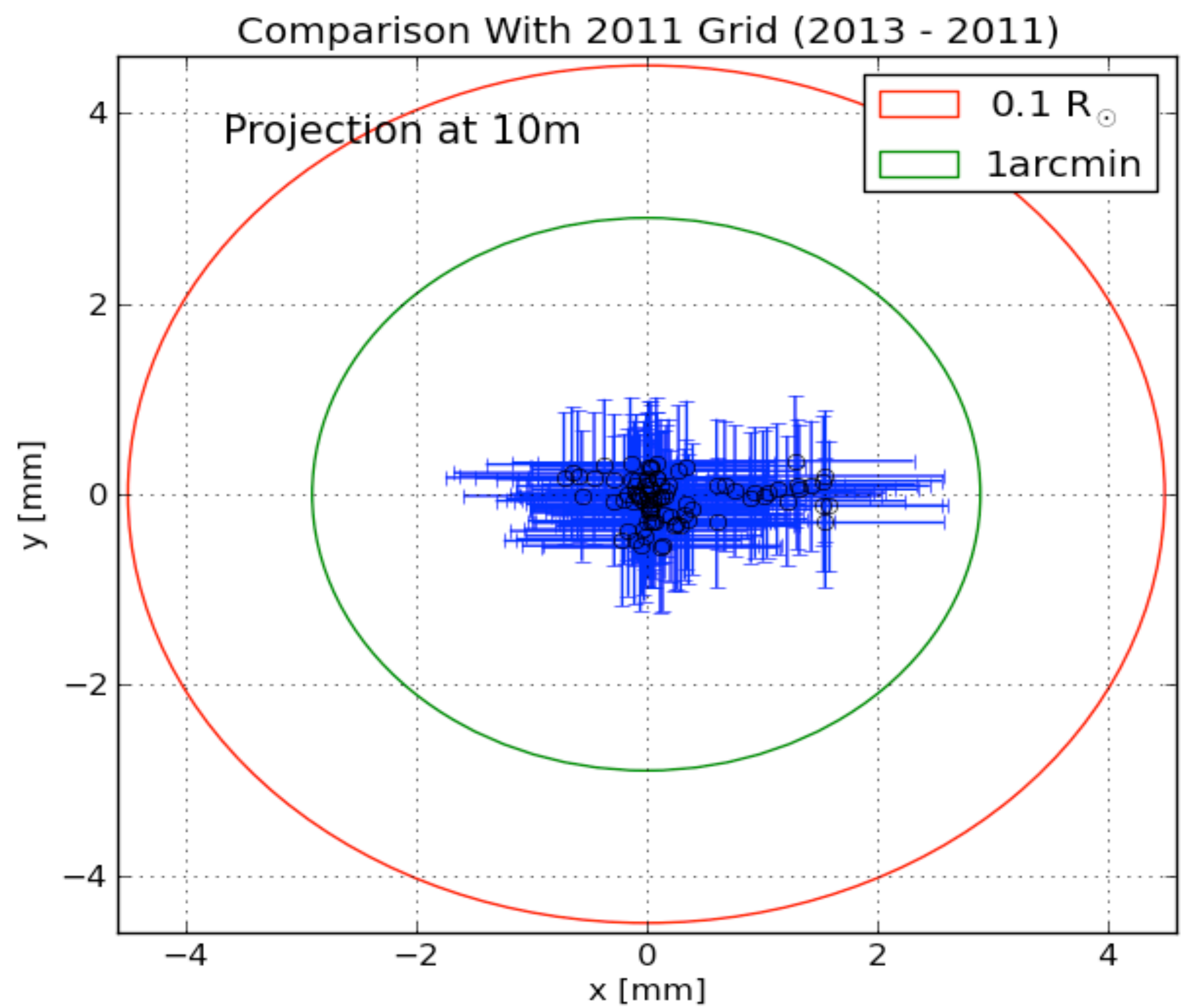
- We observe a small shift away from the centre compared to the September 2012 filming.
- The most plausible explanation for this deviation is an error in the alignment of the camera with respect to the V1 bore. Studies will continue to understand this discrepancy.
- Unfortunately March 2013 sun filming could not be done due to ongoing work on the magnet.
- Lunar filming is being considered as it presents more opportunities to film during the year.



2013 GRID measurements

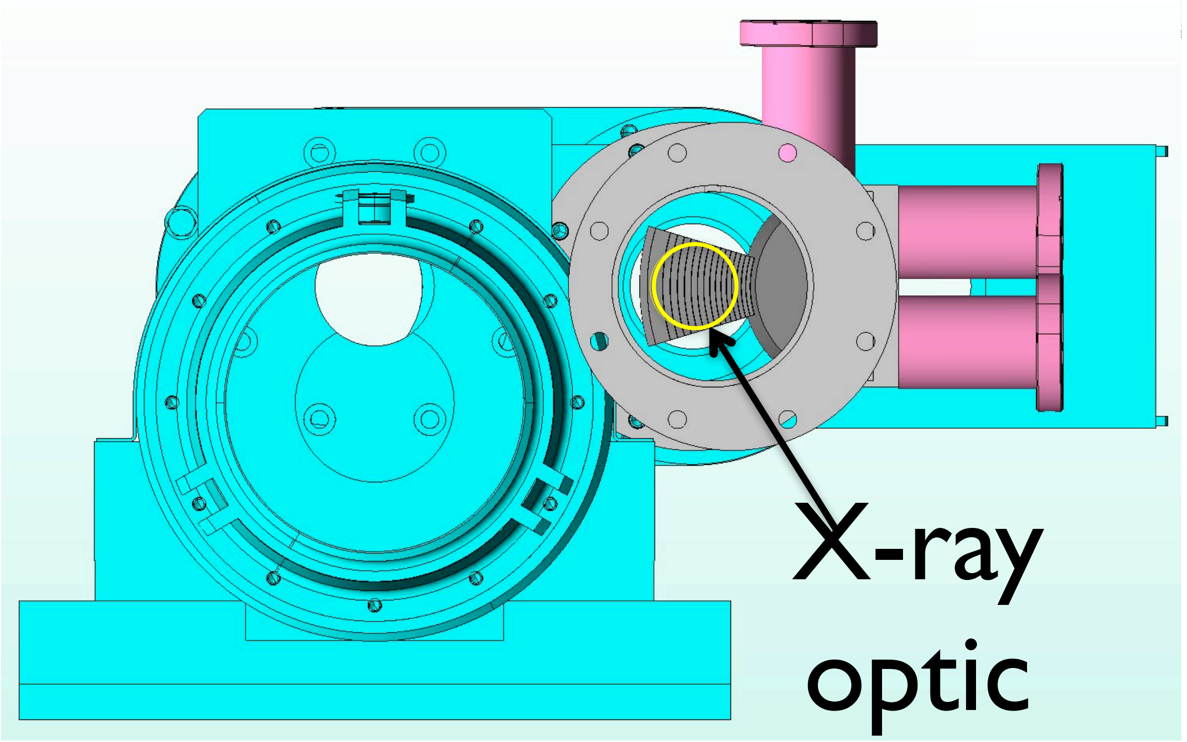
- The 2013 GRID was performed at the same 90 points that were originally used in the 2011 grid.

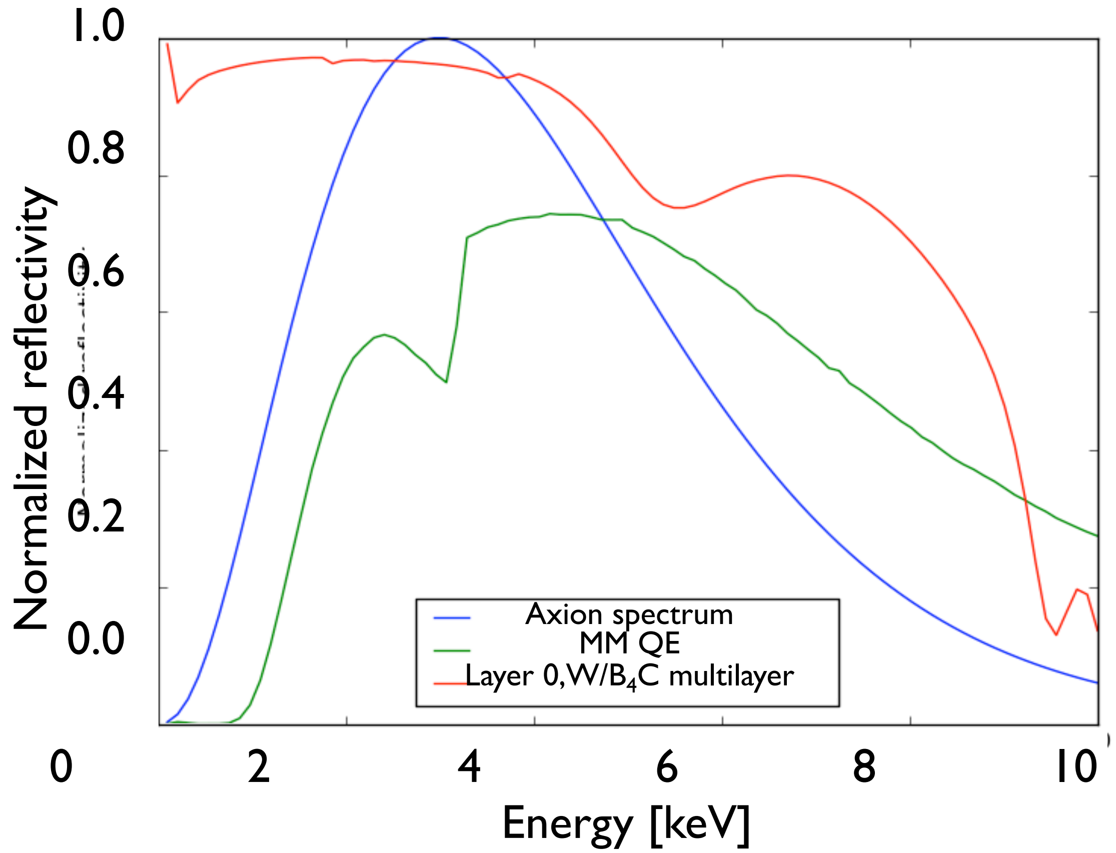
- The differences between the 2013 and 2011 grids are calculated at each point:
    - in vertical angle, differences are within ±0.5 mm, whilst in horizontal, the 2013 grid differ by a maximum of +1.58 mm in 10 m, and a minimum of -0.72 mm in 10 m.



New X-Ray optics for CAST

- **Build single multilayer X-ray optic and couple it to a Micromegas detector on the existing SR MM line** (Columbia U., LLNL & DTU-Space)
- Optic will leverage team's expertise and NuSTAR infrastructure to build optic with properties similar to those of current ABRIXAS X-ray optic
- Significantly easier to build than NuSTAR
  - 15 nested shells (cp to NuSTAR: 133 shells)
  - Only 1 of 6 sectors needed due to small magnet aperture (1/6th of a full X-ray optic)
- Focal length ~1.5 m, 80% encircled energy in 4' radius



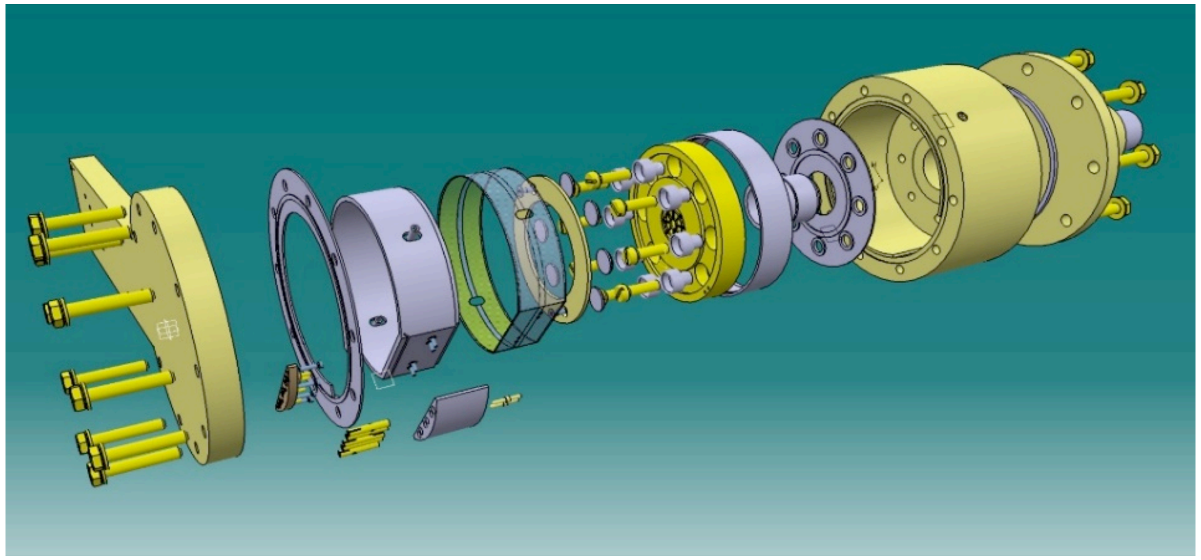
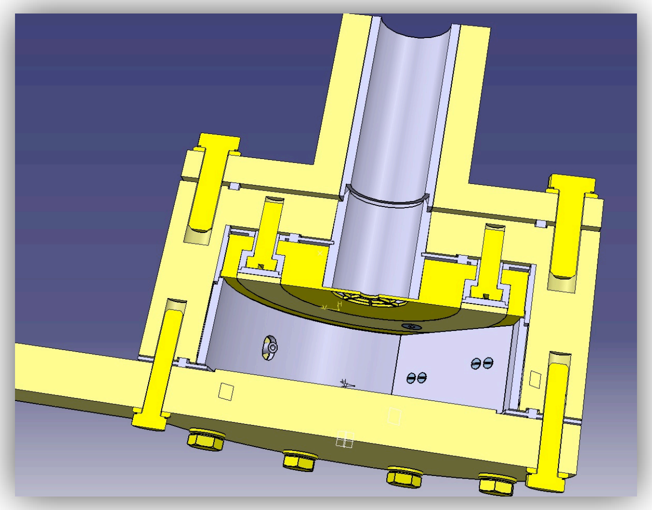
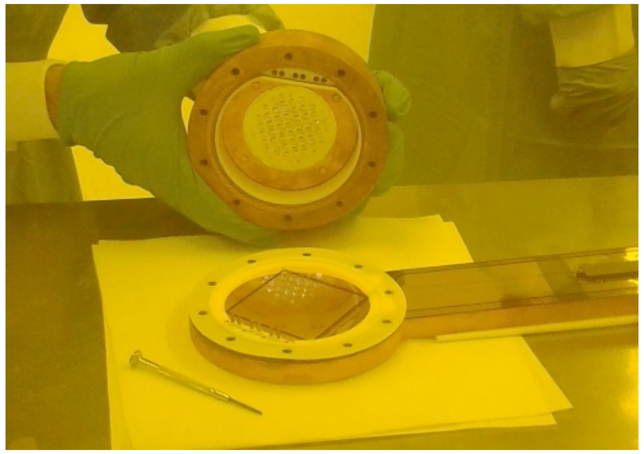
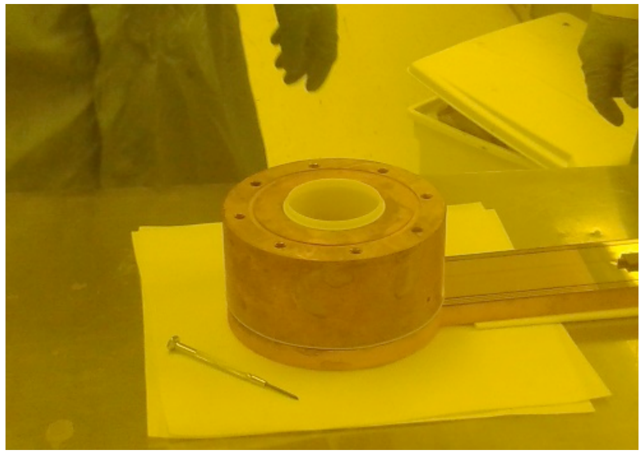


Schedule

- ✓ Set up of support structure and completion of the coating process by end of Q4 2013
- ✓ Optics assembly and testing in Q1 2014
- ✓ Ready for science at CAST in Q2 of 2014

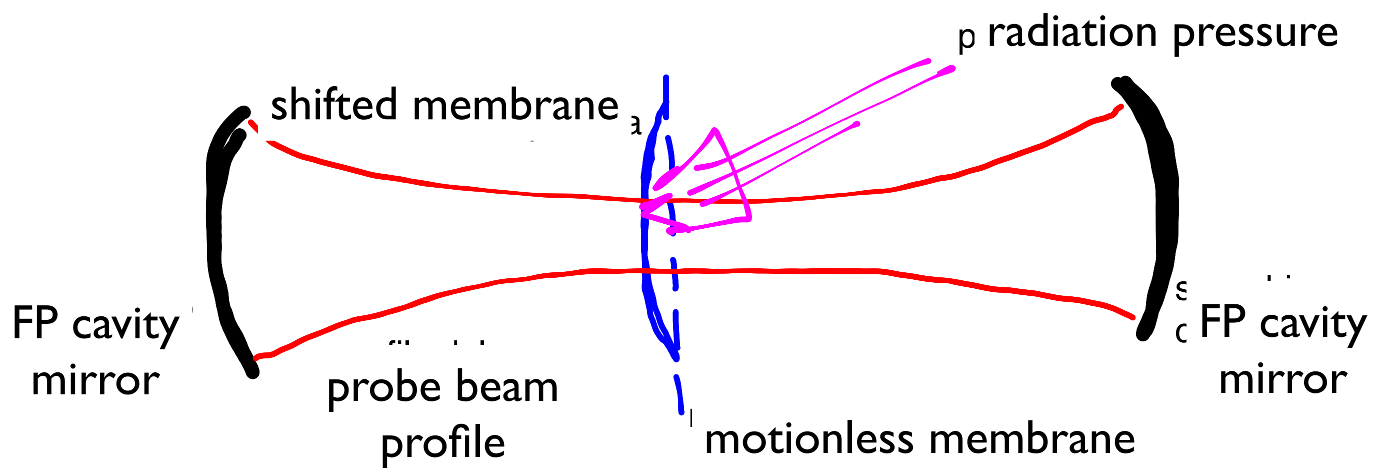
New Generation MM

- New detector design requirements:
  - Radiopurity of materials. Allowed: Cu, PTFE, Kapton
  - Shielding: Cu, Pb, PTFE, specific dimensions due to lack of space
  - Field configuration improvements
  - General: easy to mount, modular, common interface with pipe
- Resulted in an all-in-one design
- Installed last summer on the SR line
- The new X-ray focussing optic combined with NG MM are technogical options proposed for IAXO

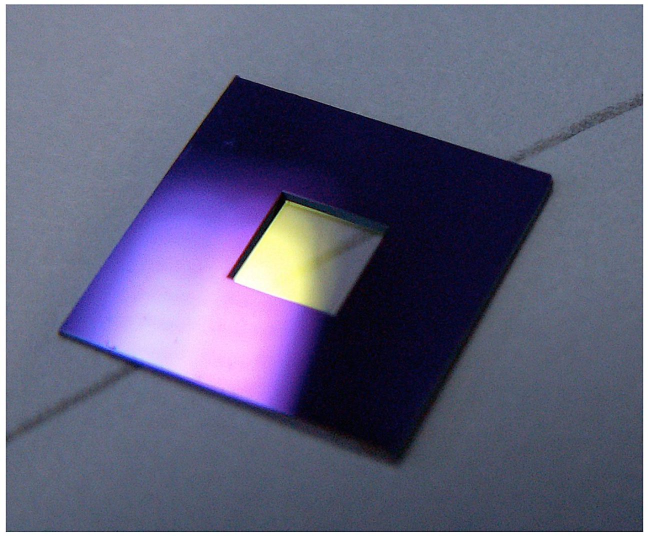





Radiation pressure from solar Chameleons

- A thin micromembrane having a suitable density absorbs momentum from a flux of chameleons coming from the sun and reflecting off it: the resulting radiation pressure causes a collettive motion (shift) of the membrane (arXiv:1206.0614)
- Membrane motion can be detected with high sensitivity by exploiting the multiplication factor afforded by the finesse (resonator Q in practice) of a Fabry-Perot (FP) interferometer
- During operation the FP is kept at resonance with a probe laser beam by means of a feedback loop: the control signal of this loop contains the information on membrane motion and hence on chameleon properties



(1 mm)x(1 mm), 50 nm thick Si_3N_4 micromembrane mounted on a 200 μm thick Si substrate

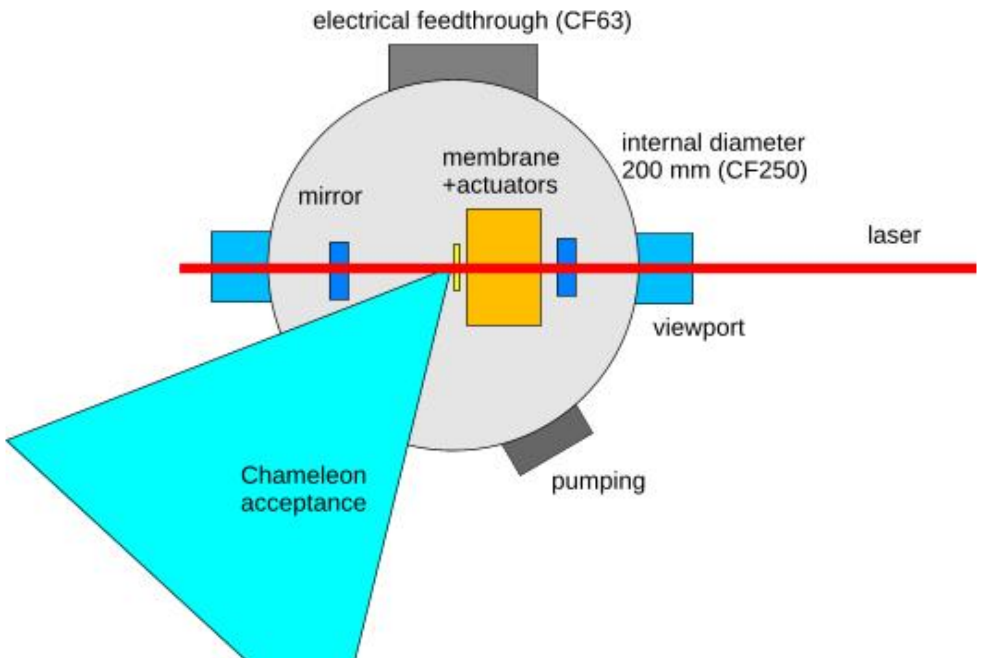


Goals for radiation pressure

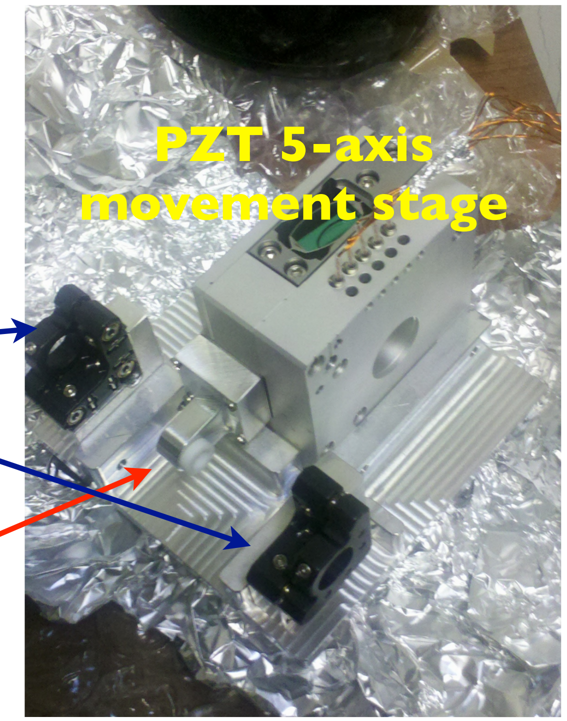
- Short tem
  - build a bench-top prototype force sensor and measure force sensitivity
    - started so far in the Trieste lab, estimate ~3-4 weeks to complete
  - Prepare setup for initial test beam at CAST
    - participation of several CAST groups and of external collaborators
- Long term
  - Place setup in the focal plane of an XRT to increase the chameleon flux by ~100
  - Study increase force sensitivity by membrane cooling down to ~K (factor 100 possible)
  - Other possible upgrades
    - chopped probe beam ⇒ common mode rejection

KWISP detector prototype for Radiation Pressure

- A prototype sensor with a micromembrane set inside a Fabry-Perot cavity has already been built in the Trieste lab
- Stoichiometric Si nitride membrane, 0.5x0.5 mm^2, 30 nm thickness inside a 95 mm long FP cavity
- INFN funding for the project, under the name KWISP, has been requested for 2014

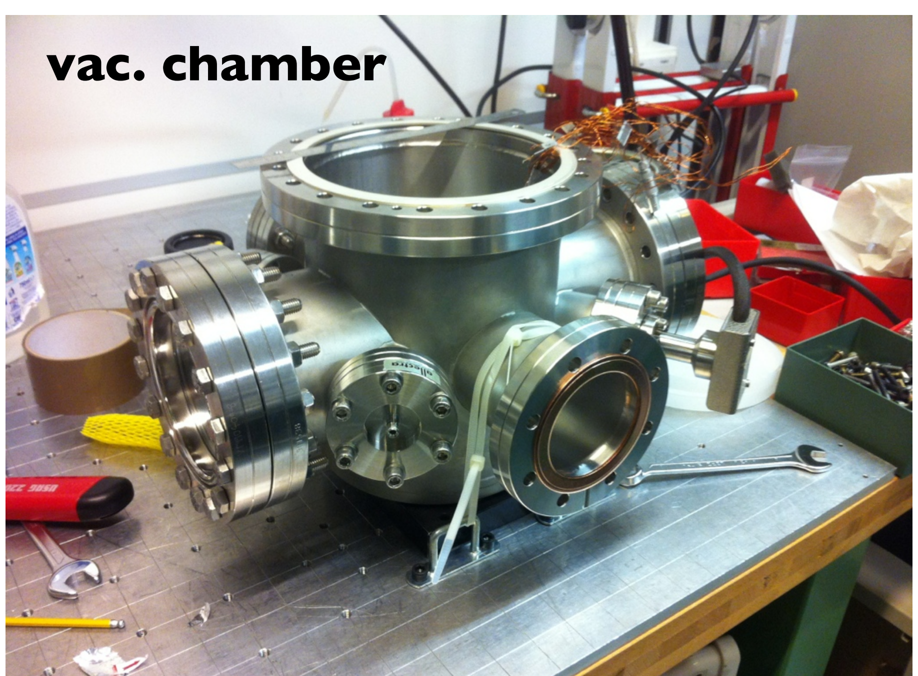


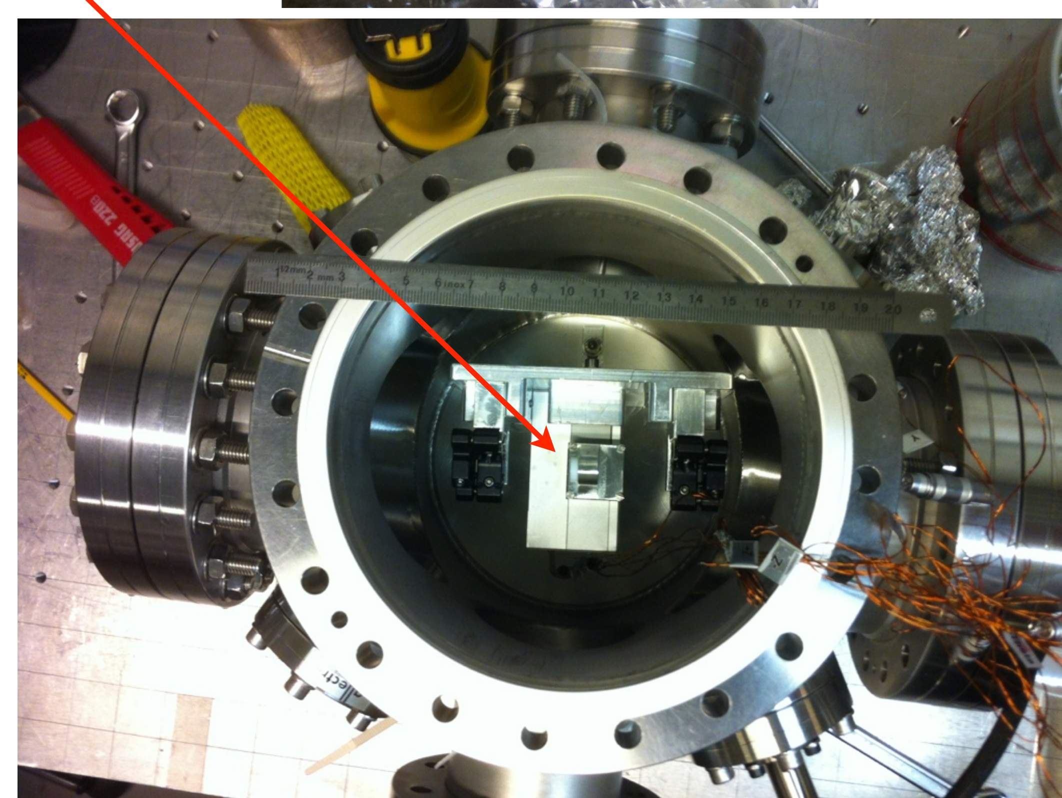
setup schematic



cavity mirrors

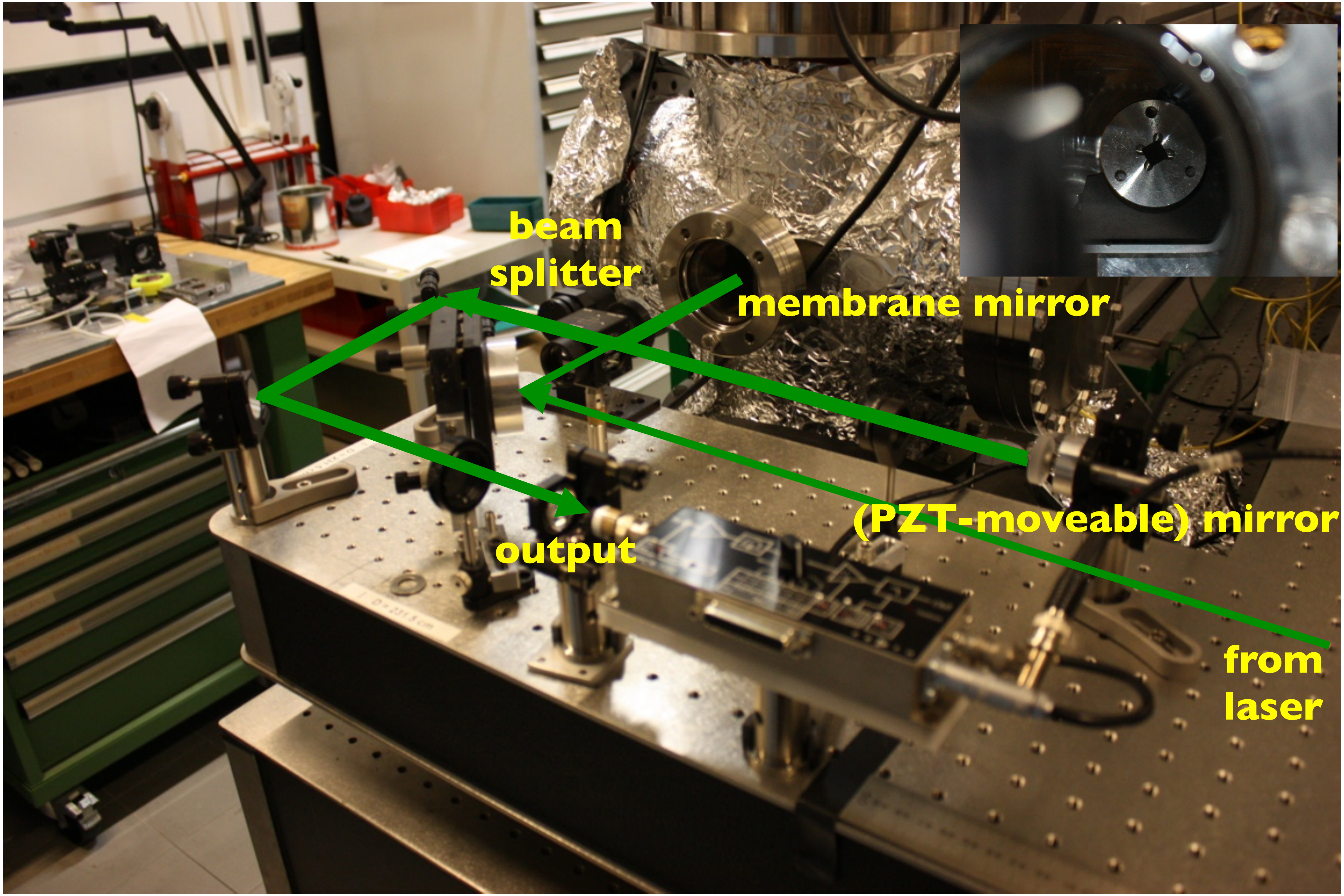
membrane holder





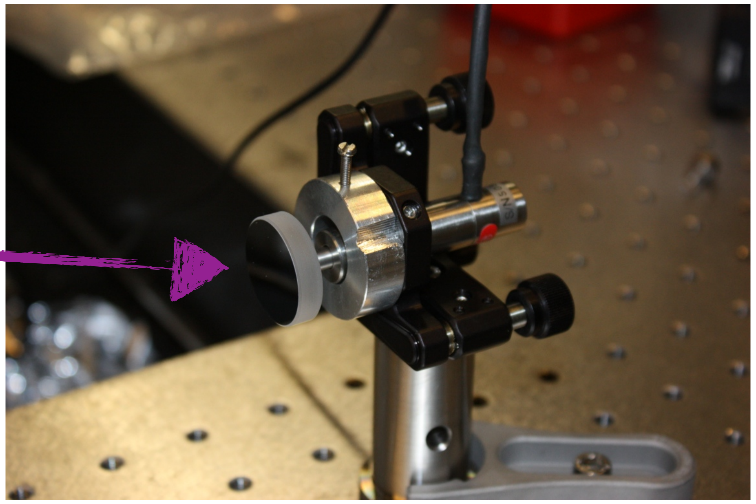
Test Michelson interferometer

- The test Michelson interferometer uses a 0.5x0.5 mm^2, 30 nm thick stoichiometric Si nitride membrane as one of the mirrors, and is excited with 532 nm laser light
- The membrane is in vacuum to avoid noise from air pressure variations



Sensitivity estimate with PZT-moveable mirror

- Interfererometer characteristic cross check: membrane is kept stationary and the other PZT-mounted mirror is moved using a controlled signal



- With a 100 Hz, 600 mV sine wave excitation the output shifts by one bright fringe to the next (= λ), therefore the PZT transduction characteristic is

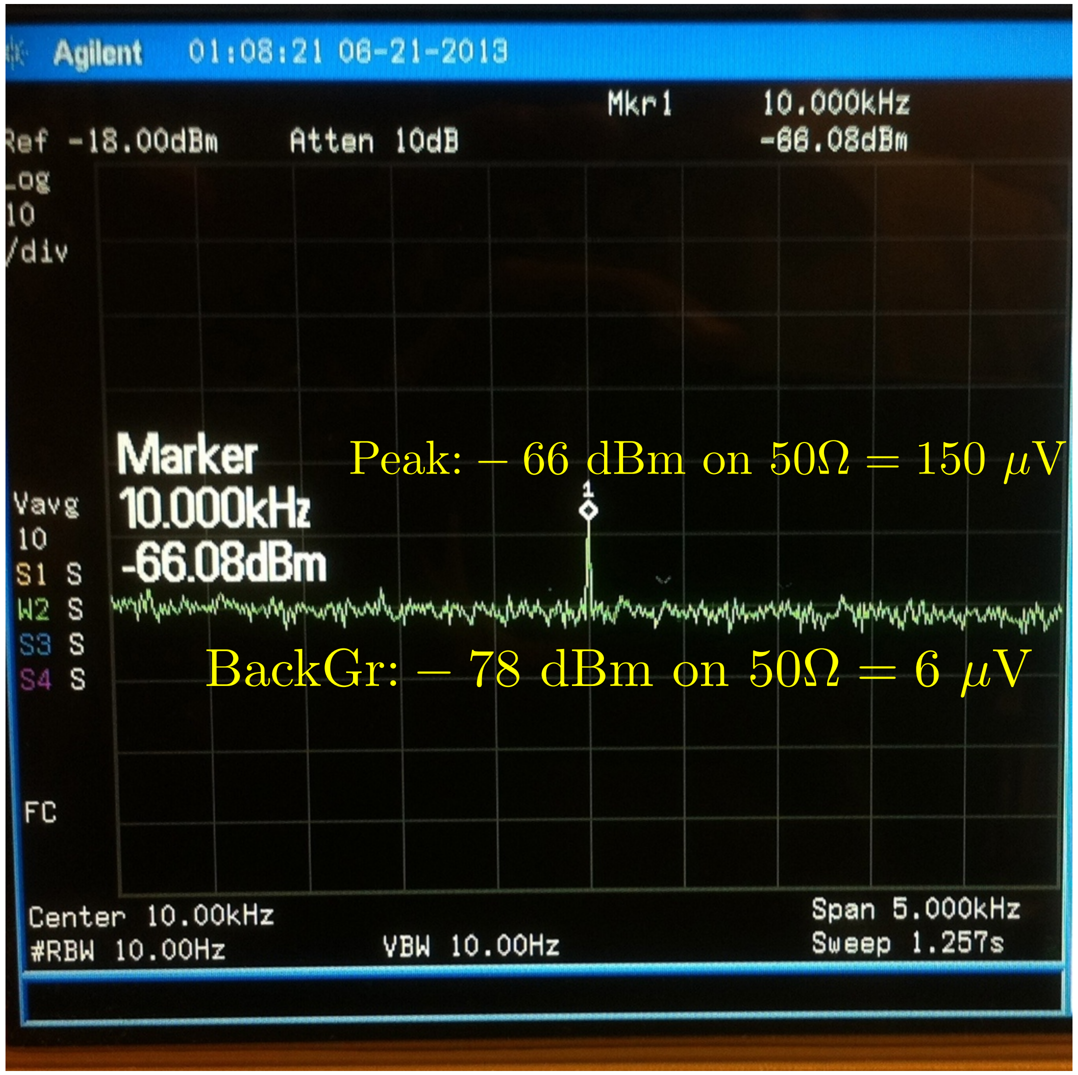
$$C = \frac{600\ \mu V}{532\ nm} = 1.1\ \frac{\mu V}{nm}$$

- To estimate sensitivity at frequencies as near as possible, given the PZT actuator input BW, the mechanical resonance frequency of the membrane (~800 kHz) we ecite the PZT with a 10 kHz, 13 mV sine wave and observe the corresponding peak in the Fourier spectrum of the interferometer output

$$@\ 10\ \text{kHz}\ 13\ \text{mV}\ \ \text{on}\ \ \text{the}\ \ \text{PZT} = 14.6\ \text{nm}\ \ \text{mirror displacement}$$

$$@\ \text{output peak}\ 150\ \mu\text{V} \Rightarrow \frac{150\ \mu\text{V}}{14.6\ \text{nm}} = 10.3\ \frac{\mu\text{V}}{\text{nm}}$$

$$\text{Background level corresponds to a displacement of}\ \frac{6\ \mu\text{V}}{10.3\ \mu\text{V/nm}} = 0.58\text{nm}$$



Force sensitivity estimate

- Since the resolution bandwidth of the Fourier spectrum used to estimate the background was 10 Hz, the **instantaneous displacement sensitivity** of the test Michelson interferometer is

$$S_{disp} = (0.58\ \mathrm{nm})\left(\sqrt{0.1\ \mathrm{s}}\right) = 0.18\ \frac{nm}{\sqrt{\mathrm{Hz}}}$$

- The micromembrane used in the previous measurements can be approximated by a simple spring having a spring constant of about 16.6 N/m *(finite element simulation by A. Gardikiotis)*, giving for the **force sensitivity**

$$S_{force} = (16.6\ N/m) \cdot S_{disp} = 3.0 \cdot 10^{-9}\ \mathrm{N}/\sqrt{\mathrm{Hz}}$$

- Improvement factor with FP sensor is proportional to finesse ~10^4, then the **projected prototype force sensitivity @RT** is

$$S_{force,\ proj.} = 5.0 \cdot 10^{-14}\ \mathrm{N}/\sqrt{\mathrm{Hz}}$$

Final remarks on KWISP

- Prototype optomechanical sensor for radiation pressure detection of solar chameleons is ready in the Trieste optics lab
  - Now optimizing optical FP resonator
- **Preliminary force sensitivity** of micromembrane measured with test Michelson interferometer is

$$S_{force} = (16.6\ N/m) \cdot S_{disp} = 3.0 \cdot 10^{-9}\ \mathrm{N}/\sqrt{\mathrm{Hz}}$$

- **Projected force sensitivity** with Fabry-Perot setup (Q~60000)

$$S_{force,\ proj.} = 5.0 \cdot 10^{-14}\ \mathrm{N}/\sqrt{\mathrm{Hz}}$$

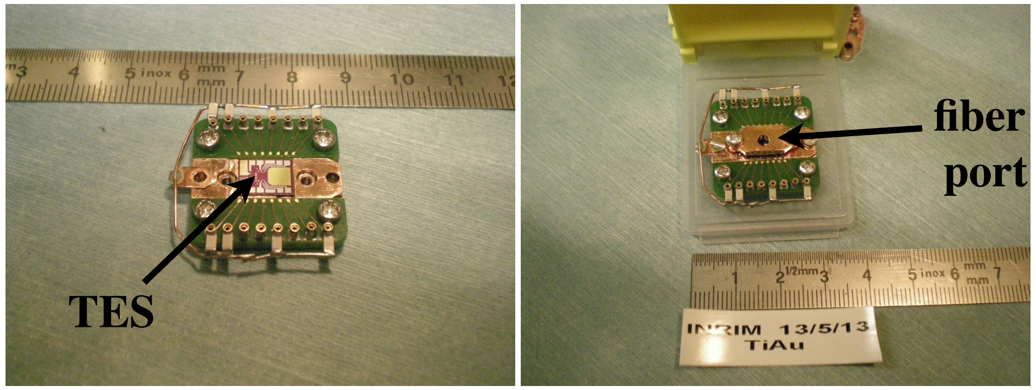
Sensitive to $10^{-6} \cdot L_{\odot}$ in 10^{4} s

- Timeline
  - 2-3 weeks to complete FP setup and measure sensitivity
  - next step: adapt prototype to CAST beamline(*)

(*) with A. Lindner (DESY), Y. Semertzidis (BNL), A. Upadye (ANL)

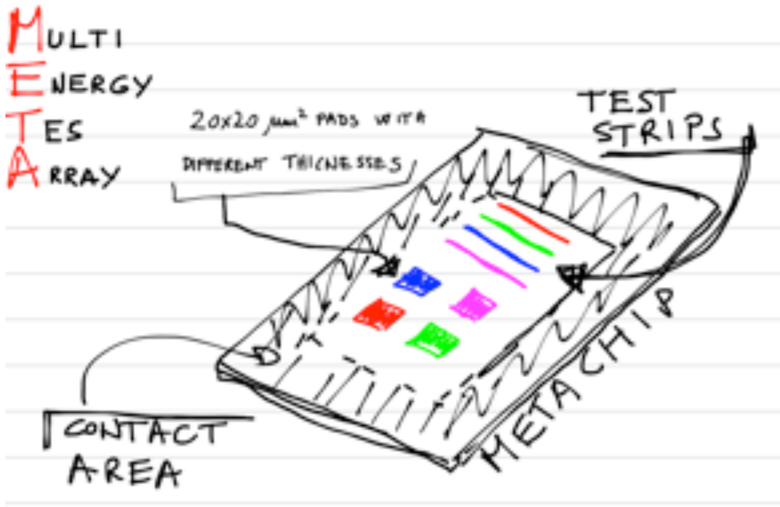
TES-based detectors for searches in the ~meV⇔keV range

- **Current tests**
  - New TES chip (INRIM, Torino) fixed and bonded in Trieste on a copper base having also a support for mounting the tip of an optical fiber.
  - First tests (spring of 2013 at the University of Camerino lab.) were unsuccessful.
  - Internal oscillations of the electro-thermal feedback giving an excessive amplitude noise in response to photon hits. Possible cause: non-optimal impedance matching.
  - Cure: change inductance of the TES readout chain. A second series of tests is foreseen for the end of 2013 – beginning of 2014.



Ti-Au double layer INRIM TES, 20x20 μm^2 pads, transition temperature 290 mK, mounted and bonded on copper base (at left). Assembly completed with fiber holder port (at right)

- **Future developments**
  - Multi Energy TES Array (META) prototype concept: integrate on the same chip several sensor pads optimized for different photon energies, and organize the pads in an array to be read in parallel to maximize active area
  - Start with proven technology by INRIM (Ti-Au double-layer TES), and vary energy sensitivity by simply changing Au thickness.
  - Potential problem: phonon cross-talk between pads when working simultaneously on a "wideband beam".
  - The Trieste BaRBE group has received seed funding from INFN to start design and production of a prototype META chip in 2014.



META chip concept

Solar Axions with the 2014 vacuum run

- The CAST Phase I (vacuum) limit on the axion-to-photon coupling $g_{a\gamma\gamma} < 8.8\times10^{-11}$ GeV^{-1} (for $m_a < 0.02$ eV), is the first experimental bound surpassing the stringent $g_{a\gamma\gamma} < 10^{-10}$ GeV^{-1} derived from arguments on Helium Burning stars, and 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 $g_{a\gamma\gamma}$ values

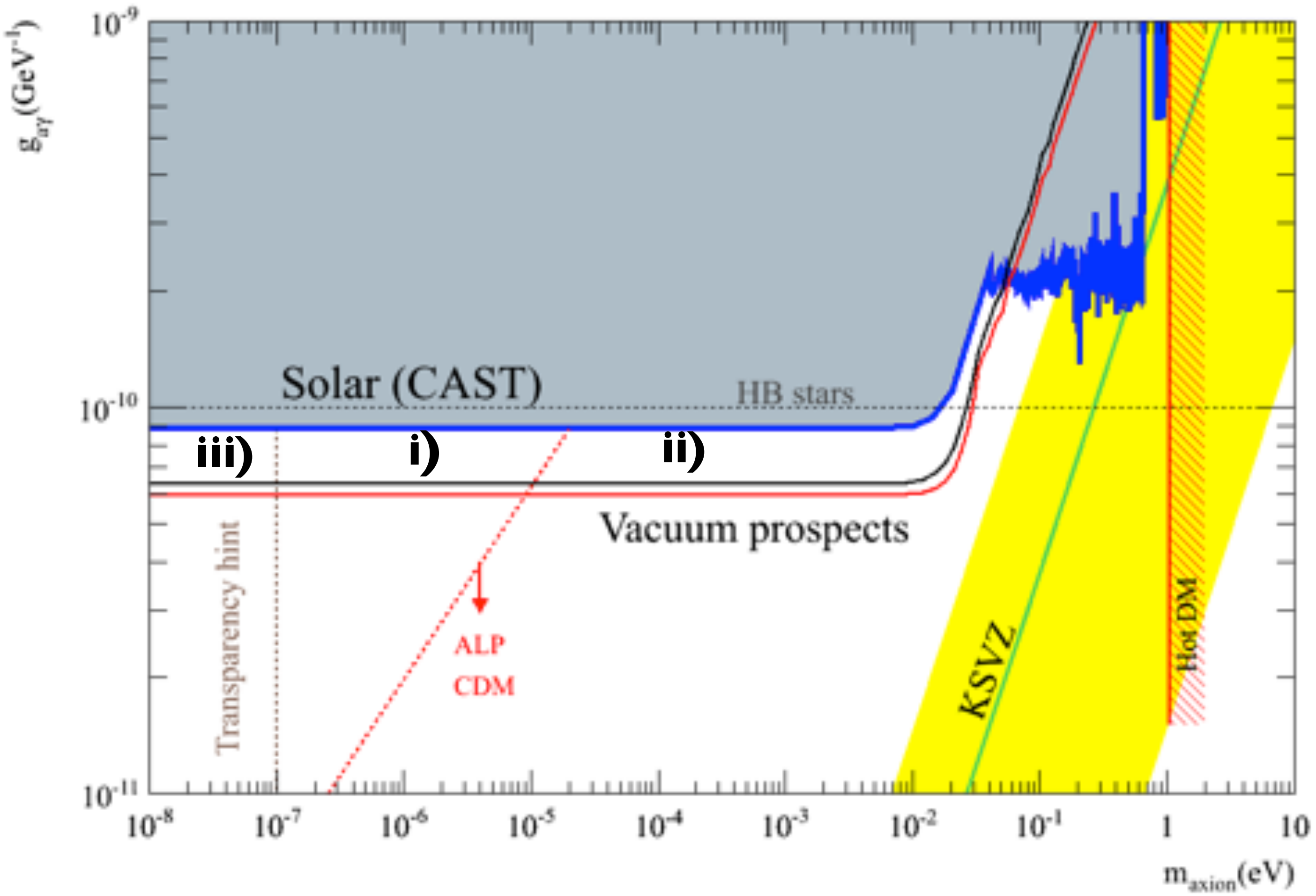
  i) access to a new region of ALP parameter space

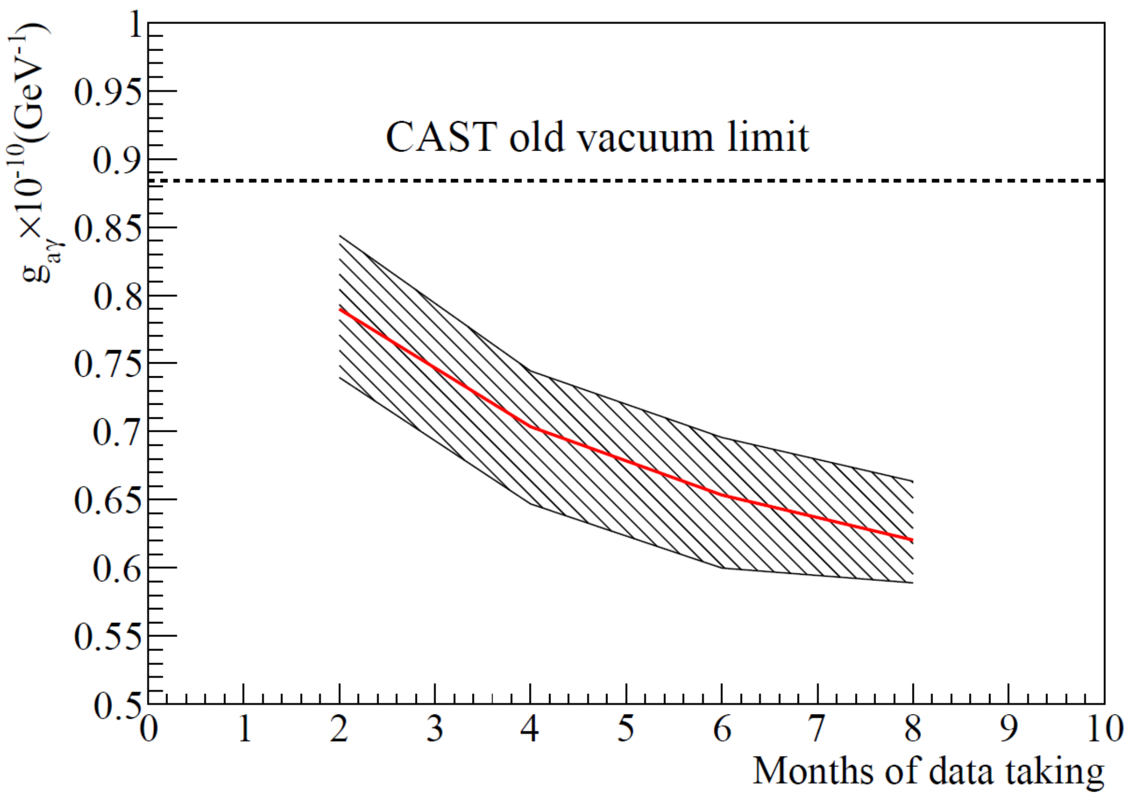
  ii) access to a portion of the parameter space where ALP models give a valid Cold Dark Matter density

  iii) access to the "VHE transparency region" of the ALP parameter space where 10^{-10} eV $< m_a < 10^{-7}$ eV

- The 2014 vacuum run will combine in a single beamline a new X-ray focussing optic and an NG MM (technogical options proposed for IAXO)

Expected vacuum sensitivity to ALPs





Expected sensitivity to $g_{a\gamma\gamma}$ of the new CAST vacuum phase vs. exposure time

Expected sensitivity in vacuum, 9 calendar months running with 75% data taking efficiency.

Black line: Micromegas background 1.5×10^{-6} counts · keV^{-1}cm^{-2}s^{-1} ⇒ $g_{a\gamma\gamma} < 6.34\times10^{-11}$ GeV^{-1}

Red line: Micromegas background 8×10^{-7} counts · keV^{-1}cm^{-2}s^{-1} ⇒ $g_{a\gamma\gamma} < 5.94\times10^{-11}$ GeV^{-1}

Solar Chameleons

- CAST offers a **window of opportunity also for Dark Energy particle identification** at the elementary level. **Chameleons** are Dark Energy candidates and CAST sensitivity to solar Chamelons has been estimated in the previous report to SPSC [CERN-SPSC-2012-028]

- For 2014 CAST plans to a **low threshold InGRID detector** attached in the focal plane of the X-ray telescope (XRT) with **the larger surface SDD** as backup. In addition, the X-ray detector in the focal plane of the CAST-XRT can be replaced by a **radiation pressure sensor (KWISP)**. Two approaches in CAST for solar Chameleon detection:

  a) **Primakoff production ⇒ sub-keV photon detectors**

  b) **Radiation pressure (coupling to matter) ⇒ high sensitivity opto-mechanical sensor**

- **CAST** is presently the only helioscope searching for solar axions, chameleons or other ALPS. With data taking already started in the sub-keV range, and the novel and interdisciplinary concept of the opto-mechanical force sensor **we enter into an unexplored domain**.

- Although competitive experiments may appear at any time CAST has therefore the **potential to remain in the forefront**.

New perspective: CAST as a *tracking haloscope* for relics

- **Helioscope** (axion/chameleon/paraphoton)

?

The "Dish Antenna" concept
(arXiv:1212.2970, arXiv:1307.7181)

- **Haloscope**(*) for (streaming) axions/ALPS/paraphotons

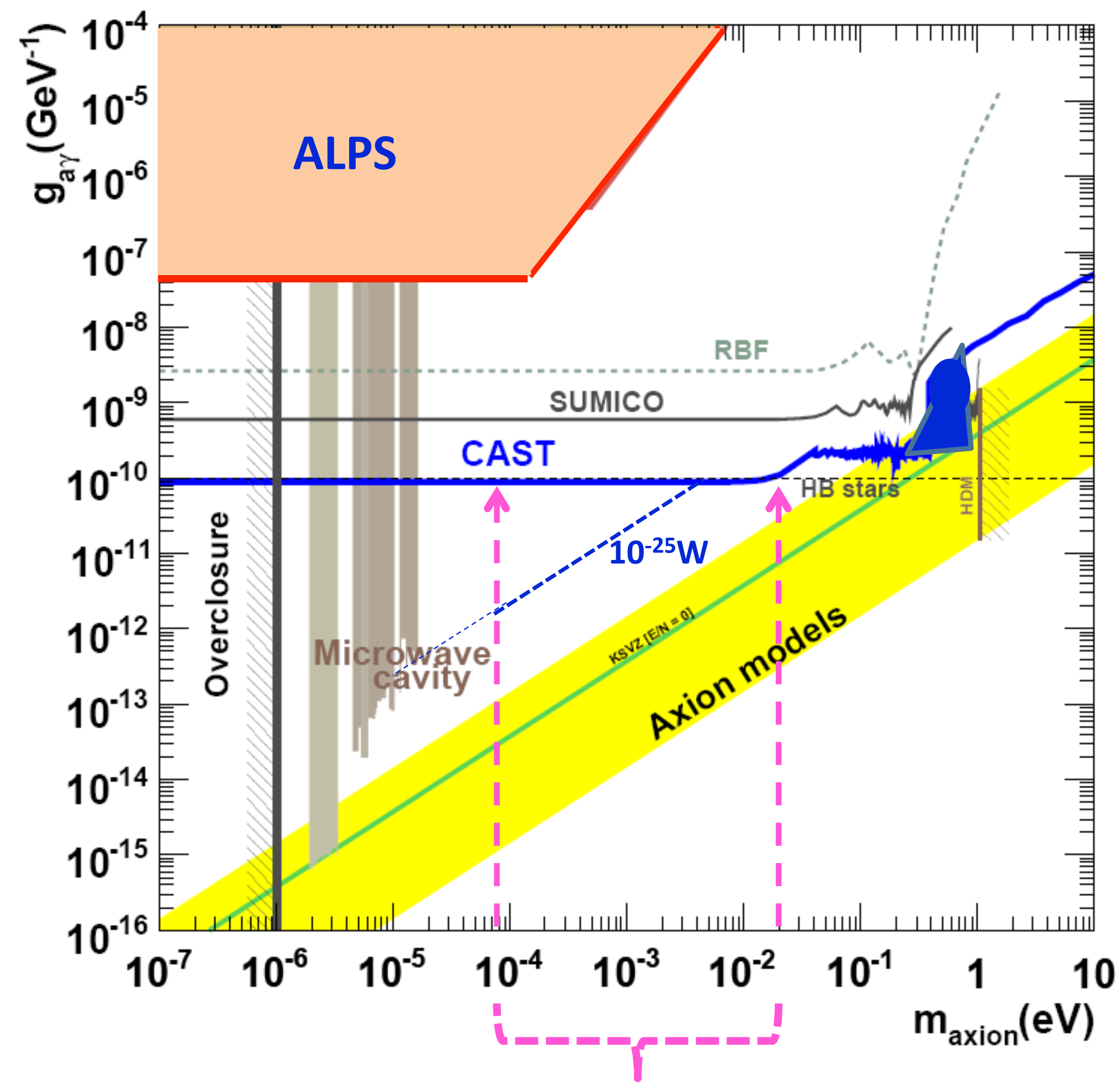
$m \gtrsim 10^{-4}$ eV/c^2 ($\lambda \lesssim 1$ cm)
Single photon detection!
⇒ recover existing detectors!?

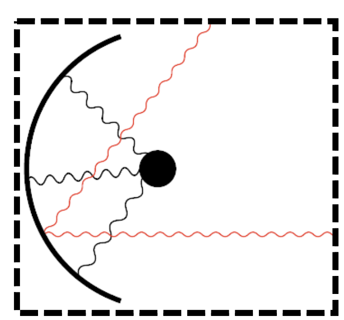
⇒ *search in progress*

CAST plusses: large **B**, moveable, T~1.8K

⇒ $m \lesssim 10^{-4}$ eV/c^2 ? ⇒ cavity? … ADMX

CAST: past + pioneering future!?





"Dish Antenna"

(*) Feasibility study in progress with A. Lindner (DESY) [see ref. 20 in the report]

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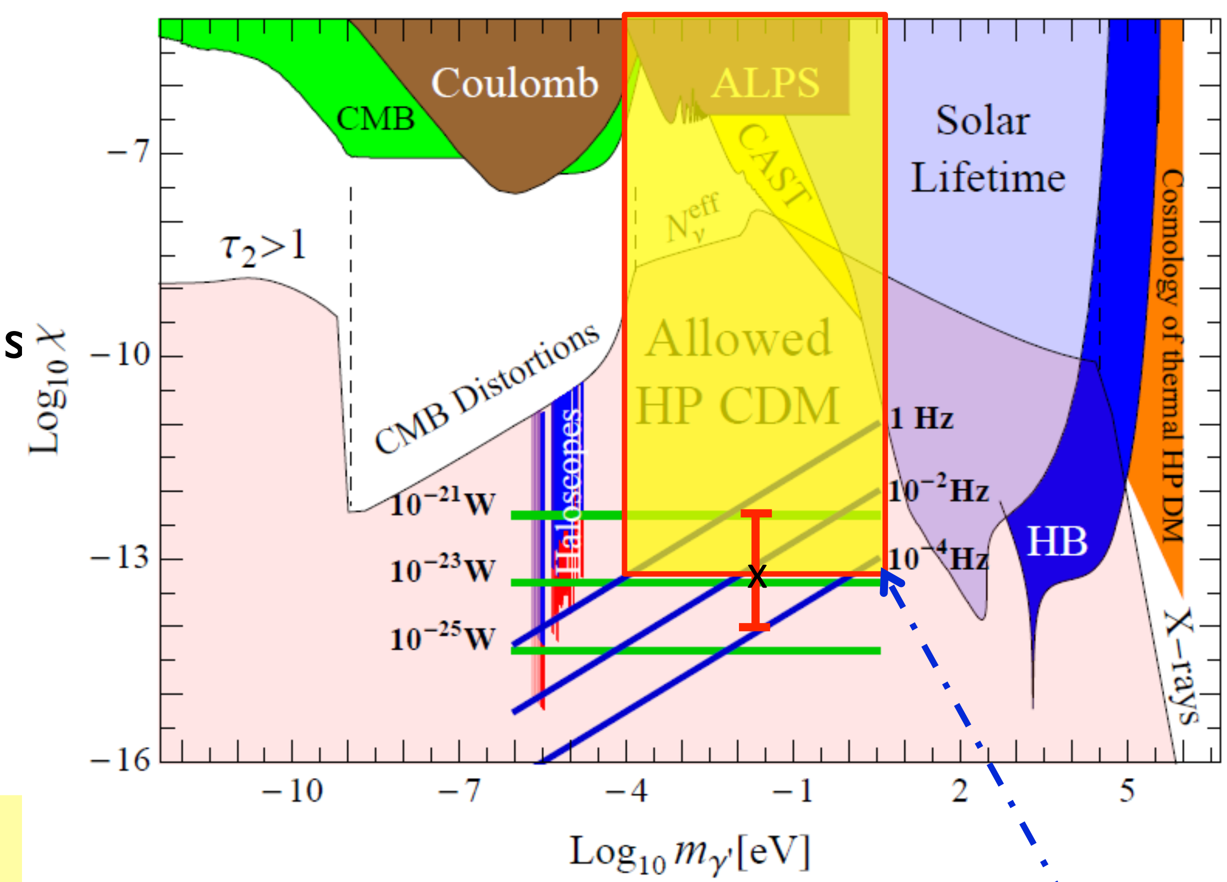
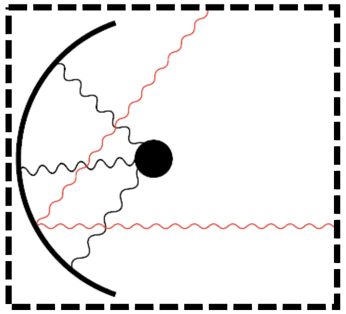
Search for Hidden sector DM



CAST sensitivity to relic γ' with *"dish antenna"*.



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Conclusions

- **CAST has, as planned:**
  - **started taking vacuum data with enhanced sensitivity detectors reaching 10^{-6} cts · keV^{-1} · cm^{-2} · s^{-1}**
  - **Installed low threshold detctors and started data taking**
- The **vacuum measurements** with lower detector background have the potential, in case of no signature, to **improve CAST own world best limit for solar ALPS below ~20 meV/c^2**.
- With the already started **sub-keV range** solar chameleon searches **CAST** became **one of the very few laboratory experiments worldwide investigating the dark energy sector**.
  - Low energy threshold detectors are the key in making CAST the first and best performing solar helioscope for particles like Chameleons.
- In addition, a novel interdisciplinary radiation pressure detector concept was implemented in a prototype opto-mechanical force sensor. This entirely in-house-made, state-of-the-art, force sensitive device can be installed in CAST by replacing alternatively the sub-keV X-ray detector at the focal plane of the XRT.
- **Then, CAST may not end with its present basic program on solar ALPS, Chameleons and Paraphotons.**

Additional slides

CAST schedule to the end of 2013

CAST 2013 SCHEDULE		OCT					NOV				DEC				JAN 14	
	39	40	41	42	43	44	45	46	47	48	49	50	51	52	1	2
13.10.2013			CM		SPSC											
Sun Filming																
Data taking SSMM & SRMM																
Data taking small sdd no shielding with cooling																
Data taking no cooling no shielding																
Data taking with sdd + shielding (with cooling)																
tests on big SDD in lab																
Test InGrid in Lab on beam line																
Add big SDD and commission on CAST																
Add Shielding								X								
Data taking big SDD + Shielding								XXXX								
Stop cooling of magnet												X				
Maintenance of cooling & ventilation (8 weeks)															until	end feb
Electricity power cuts (2 full days)																

Present CAST schedule for 2014

Present Schedule 2014												
2014	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Remove SSMM	XX											
InGrid (Barbe)												
Install InGrid infrastructure												
Install XRT		X										
Align XRT(magnet warm)		XX										
Install Ingrid (")		X										
Align InGrid (")			X									
Align Barbe ? (")			XX									
Magnet & Sun filming												
Cool Down magnet *(depends on LHC infrastructure- could be later)*			X	X								
SUN FILMING ? Not Possible if magnet inbetween 300 & 1.8K			?									
Magnet cold				X								
Magnet tests (quench)				X								
SR Line												
CALIBRATE LLNL-XRT												
Dismount SR line												
Install LLNL XRT				XX								
Align LLNL XRT				X	X							
Check alignment of MPE-XRT					X							
Install SRMM					X							
Install SSMM					X							
GRID						X						
DATA TAKING						XXX						X

Estimated magnet support costs for 2013-2014

			Actual values		Projected values	
Item	**Dept**		**2011**	**2012**	**2013**	**2014**
		Units				
CryogenicsM&O	**EN**	(kCHF)	**180**	**180**	**180**	**180**
Cryogenics power		*(hours)*	*2951*	*4877*	3696	*6570*
	EN	**(kCHF)**	**81**	**134**	**102**	**181**
Power Converter power		*(hours)*	*797*	*1576*	1232	*2168*
	EN	**(kCHF)**	**6**	**11**	**9**	**16**
FSU maintenance (TE)	**CAST**	(kCHF)	5	5	5	5
Yearly TOTAL	**CERN**	**(kCHF)**	**267**	**325**	**290**	**376**

Present requests for CERN support

PH-DT	Consultant Mechanical engineer. Mechanical technician - support for the experimental apparatus including movement system. Electrical technician - support for Slow Control and interlocks and electrical support for SDD. Applied Fellow - Completion of the 3He CFD project, liaison with EN-CV, X-ray test lab and SDD.
TE-VSC	Consultant vacuum physicist/technician. Aid with the interventions on magnet and detector vacuum systems and in X-ray lab.
TE-EPC	Support for the Power Converter (PC) operation and maintenance.
TE-CRG	Cryolab support for measures to place and maintain 3He system on Standby during vacuum running. Help with dismounting and re-mounting and all manipulation of cryo sensors. Support for the maintenance the 3He system PLC for at least one year after end of 4He run. Support for the operation of the magnet cryogenics and its ABB control system Support for opening and closing the cryostat to change cold windows
TE-MPE	Support for the Quench Protection rack
EN-ICE	Support for the Power Converter controls system
BE-ABP	General Survey work and support for the alignment of two X-ray telescopes
EN-MME	Coordination of integration of detectors and telescopes on XRT platform
TE-CV	Support for demineralized water cooling system for 13 kA cables and Power Converter. Support for completion of 3He CFD simulations