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Status Report of the CAST Experiment

The **CAST** Collaboration

Athens-CERN-Chicago-Darmstadt-Frankfurt-Freiburg-Moscow (INR)-Munich (MPE-MPI)-Patra-Pisa-Saclay-South Carolina-Thessaloniki-Vancouver-Zagreb-Zaragoza

1. Cryogenics and magnet operation

Cryogenics

Following on from the successfully commissioning of the CAST cryogenic system in 2001-2 and the installation of the new 1.8K pumping group during the 2002-3 shut down, the cryogenics system continues to operate well within our normal tolerances of better than 99.5% reliable production.

The initial ramping of the magnet at the start of the 2004 data taking campaign, was only interrupted by a water supply fault and one or two training ramps required to regain full field strength. The thermal stability of the system remains good and the automated control system has been fine tuned to allow fully automated recovery from any quenches, which may occur due to utility "outages".

The ECR cryogenics group is currently helping with the ongoing planning for CAST's 2nd phase operation, contributing to the progress of the experiment.

Magnet operation

In 2003, the operation of the magnet started with two re-training quenches after the cool-down. Magnet operation at 13000A between mid-April to mid-June (~ 400 hours) was frequently perturbed by quenches. Seven quenches occurred, mostly triggered by the quench detection system (QDS) itself and not from inside the magnet. The AT-MTM group made a concerted effort to find the problem but the source was only identified during a lengthy power-down of the magnet to repair a mechanical problem: the QDS continued to trigger itself. The fault was traced to an amplifier card (the only fault of its type so far found in 400 cards made for LHC use).

From the 10 July to 12 August the magnet ran at 13000A, the current was then increased to 13300A for the rest of the running up to the shutdown on 14 November.

The causes of the eight quenches were divided between:

- Perturbations in the electrical network (e.g. thunderstorms, Emergency OFF in PA8 cavern) (4)
- Disconnection of a monitoring PC from the magnet power supply (1)
- Error by a CAST operator in issuing an OFF command during a ramp-down (1)
- Fast ramp down (and resulting quench) triggered by an alarm signal from the Cryogenics. Alarm signal was caused by RF interference due to arc welding (1)
- Real quench of magnet at 12900A during a ramp up (1)

Since the start 2004, the magnet has had one re-training quench at 12190A and soon after another quench due to a water-cooling fault. Since then the magnet has run for ~ 500hrs at 13000A without problems. A second quench in 2004 occured June 28.

Magnet mechanical movement system

After some 50 hrs of magnet movement during sun tracking in 2003, a problem of gripping in the magnet lifting mechanism became apparent. Magnet movement was stopped on the 31 May. Unfortunately, the personnel responsible for the design and assembly of this mechanism had left CERN in 2002, depriving CAST of technical support in this area. However engineers from PH-TA1 and SC-GS were drafted in to help as consultants and provided CAST with excellent technical advice.

The consensus of the expert advice received was that the mechanical movement system was over constrained. These constraints translated into lateral forces on the lifting mechanism. In order to resume data taking in a short time, the engineers proposed to add some mechanical play into the lifting system mechanics, make a factory inspection of the lifting jacks and to improve the lubrication system. Data taking restarted after a stoppage of 6 weeks. Sun tracking runs then continued without incident until data taking ended in mid-November. In view of the problems experienced, it was decided not to mount the 1.2-ton TPC shielding on the magnet in 2003.

In order to provide information for data and engineering analyses, precision angle encoders were installed on the horizontal and vertical pivots of the magnet and load monitoring pins were added to the lifting mechanism. The pointing accuracy of the magnet system was then checked in a full scale ‘GRID’ measurement of 90 points made by the TS/SU survey team. The pointing accuracy was a factor two worse than observed in 2002 (a direct consequence of increasing the mechanical play in the lifting mechanism). However, the measured ~1 arcmin accuracy was nevertheless within the limits required by the X-ray telescope.

In view of the projected ~3 years future running, CAST has commissioned a detailed engineering analysis of the mechanical movement system from the TS-MME group. The analysis has been just been completed and the recommendations for improvements will be studied and where possible implemented in the winter shutdown of 2004.

Winter shutdown 2003-2004

A counterweight was designed and installed to compensate for the additional load on the lifting system caused by the installation of the TPC shielding.

Various improvements to the infrastructure of the SR8 zone were completed. Items included a new extended gas bottle storage facility, removal of portions of internal concrete walls to facilitate movements of the CAST magnet with the new 1.2-ton shielding mounted. Many extra instruments had to be integrated onto the magnet including a new differential pumping system for the TPC, an X-ray finger source to monitor the positional stability of the X-ray telescope and veto counters for both the TPC and Micromegas. All key vacuum gauges used by the safety interlock system have been doubled-up to add redundancy in case of malfunctions or failure.

The vacant space behind the Micromegas detector on the telescope platform has been utilised to install a prototype calorimeter to make first test runs. The X-ray telescope was lifted and cushioned before starting the heavy work on the counterweight and the calorimeter support. Realignment of the X-ray telescope was then necessary and was completed in a complex and lengthy procedure using a special theodolite with a laser attachment positioned at the opposite end of the magnet (without the TPC installed). A new GRID survey was carried out at the end of the shutdown with the magnet and detectors fully installed.

Interlock System - Slow Control

The CAST Interlock System has allowed the safety of operation. The response of the system in all kind of incidences, like magnet quenches or power cuts in the zone, was the expected one, protecting both magnet and detectors. The slow control system over the past year has operated with complete satisfaction and has continued to improve and expand to accommodate new signals. The system continuously monitors all the key experimental parameters as well as parameters necessary for the data analysis, and issues alarms and warnings to CAST personnel in the event of problems. The ramping of the magnet using the system developed for LHC will soon be added to the Slow Control.

2. The TPC detector

The Time Projection Chamber (TPC) of the CAST experiment has been operational during most of the 2003 data taking period. At the end of 2003, the TPC was dismounted in order to proceed with the winter shutdown. Concerning the TPC, the works during that period regarded the building and installation of a differential pumping system and the installation of the shielding. Since May 2004 the TPC is back on the magnet and it is routinely taking data in its full performance, with substantially improved conditions compared with last year.

2003 data taking

At the end of the 2003 CAST data taking phase, the TPC detector had gathered 151 hours of data in “axion-sensitive” conditions (tracking the Sun with the magnet energized) and 4128 hours (172 days) of background data. Approximately half of these tracking data corresponds to the data set 6, taken in especially favorable conditions during the period June-August, and which has been used to derive the 2003 result on the coupling constant $g_{a\gamma\gamma}$ presented below. The main problem the data analysis has faced in 2003 was the position-sensitive background for different magnet orientations. This fact prevented a straightforward subtraction of the total background spectrum from the tracking spectrum. To cope with this, a “weighting method” was designed to obtain an *effective background* from the background data taken only in the magnet positions where tracking is performed, appropriately weighted with the relative tracking exposure time interval. This effective background could be safely compared with the tracking spectrum, but at the expense of an effective reduction of background statistics, as not all the available background material is finally used (Figure 1). The method proved successful, and the subtracted spectrum shown in Figure 2 was obtained.

From that spectrum a limit on the axion-photon coupling of $\mathbf{g_{a\gamma\gamma}<1.42\times10^{-10}\ GeV^{-1}}$ was obtained with 95% CL; the corresponding signal is given by the upper solid line in Figure 2. The limit has been obtained by renormalizing the Bayesian probability in the physically allowed region. The limit has been calculated for different values of the axion mass so the complete contour line in the axion parameter space has been calculated (see Figure 3).

2003 shutdown period & improvements for 2004 operation

In order to improve the data quality during the ongoing 2004 phase of CAST, the TPC work during the 2003 shutdown has been focused on a differential pumping system for the TPC X-ray windows and a detector passive/active shielding.

Differential pumping for the TPC

The leak through the windows of the gaseous detectors towards the magnet is a limiting factor for the proper operation of CAST. In fact, during 2003 we had three weeks of shutdown for the TPC due to slight deterioration of the windows that produced unacceptable leaks towards the magnet. The aim of the differential pumping system, following the successful experience with the Micromegas detector, is to reduce the effective leak towards the magnet, for instance, due to the formation of pinholes in the metallic layer of the detector windows and/or due to diffusion through them. This is accomplished by the continuous pumping of an intermediate volume, separated from the magnet also by a thin window. This intermediate volume is under a relatively poor vacuum (~10^{-5} mbar) but the leak rate through the second window is very small due to the small pressure difference.

Such a system was designed, built and installed during the 2003 shutdown period. After a thorough test the system proved to work satisfactorily. With the TPC back in place, the effective leak towards the magnet is 1.5×10^{-7} mbar·l/sec of Argon, a factor ~240 better than during the 2003 operation. This allows us to have the necessary margin to tolerate small deteriorations of the windows and therefore have a continuous and homogeneous operation during the whole of 2004 without the need of intervention on the TPC.

TPC Shielding

A passive shielding for the TPC had been designed and built; due to mechanical problems of the CAST moving platform, it had not been installed during 2003 but for testing purposes. Those problems have been solved during the last shutdown (see Section 1), and the shielding has been finally installed for the 2004 run. It consists of an innermost copper cage of 5 mm of thickness, surrounded by a lead layer of 2.5 cm, 1 mm of cadmium and finally a wall of 20 cm of polyethylene. The full set is closed by a plastic bag, which is slightly pressurized by injection of clean N_2. This reduces the radon concentration from the air in the space close to the detector, further reducing the detector background.

The first data taking in 2004 is giving a quite satisfactory hint of the effect of the shielding on the TPC data (Figure 4). Regarding the average background level, it is compatible with the expectations drawn from 2003 tests with the temporally installed shielding. Preliminarily, the TPC background between 1 and 10 keV is 4.13×10^{-5} counts/keV/sec/cm^2, i.e., a factor of 4.2 below the level reached by the TPC without any shielding. It represents a factor of 2.2 improvement compared with the 2003 operation (the TPC was then shielded by only a copper box and N_2 flux). The background reduction is better in the high energy part of the TPC-spectrum (see Figure 4).

But more importantly, the shielding was supposed to reduce the worrisome dependence of the background on the magnet position. The preliminary result concerning this issue, and taking into account the small statistics gathered so far in different magnet positions, shows no dependence so far. Provided this is definitely confirmed with much more statistics, it may eventually allow us to use the full background data in the analysis, reducing the statistical errors and therefore increasing the CAST-sensitivity.

In addition to the passive shielding, a muon veto has been installed on top of the shielding. Though muons interacting directly in the TPC are very clearly identified and rejected, there may be secondary particles (photons, neutrons, etc.) which are produced by muons traversing the shielding material, which may mimic X-ray interactions in the TPC. The background reduction capability of the veto is still under study.

Prospects for 2004 operation

The TPC is installed on the magnet and taking data routinely with its full performance. The improvements described above allow us to expect a further improvement of the sensitivity, mainly, due to a more homogeneous data taking during the 2004 phase thanks to the detector shielding. At the moment, 32.5 hours of tracking data were taken during 2004. The preliminary 2004 background and tracking spectra are shown in Figure 5.

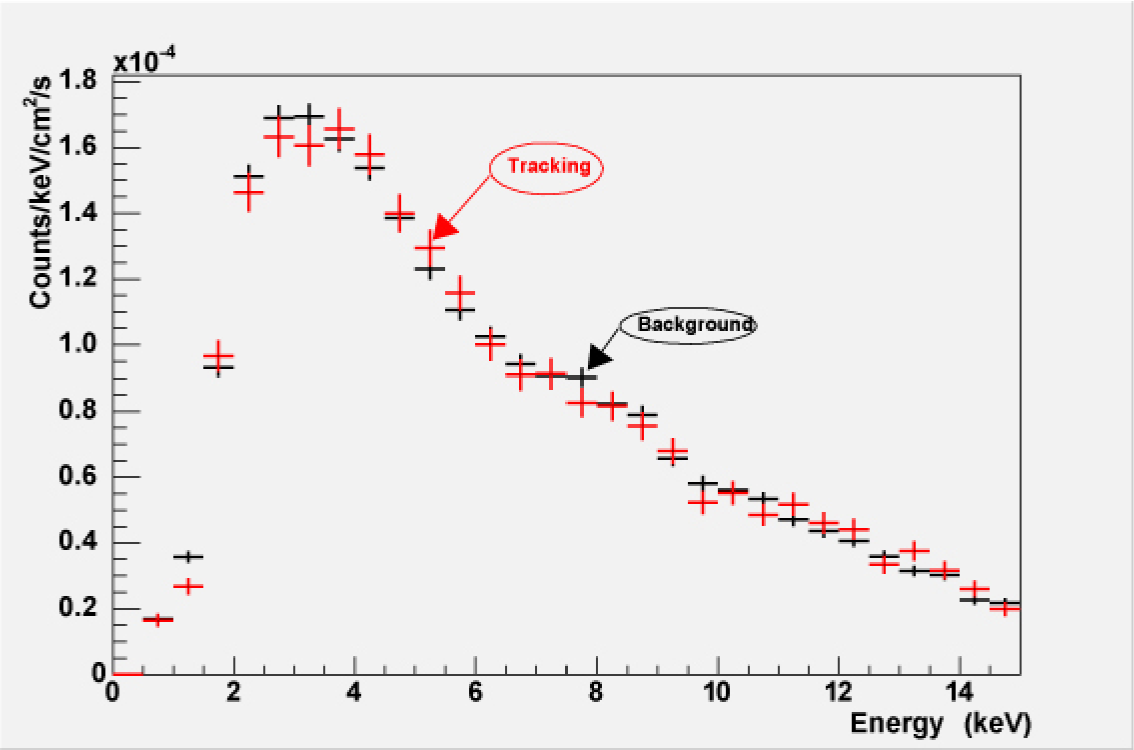

Figure 1. Comparison of TPC-spectra taken in 2003 during sun tracking (***red***) and background periods (***black***).

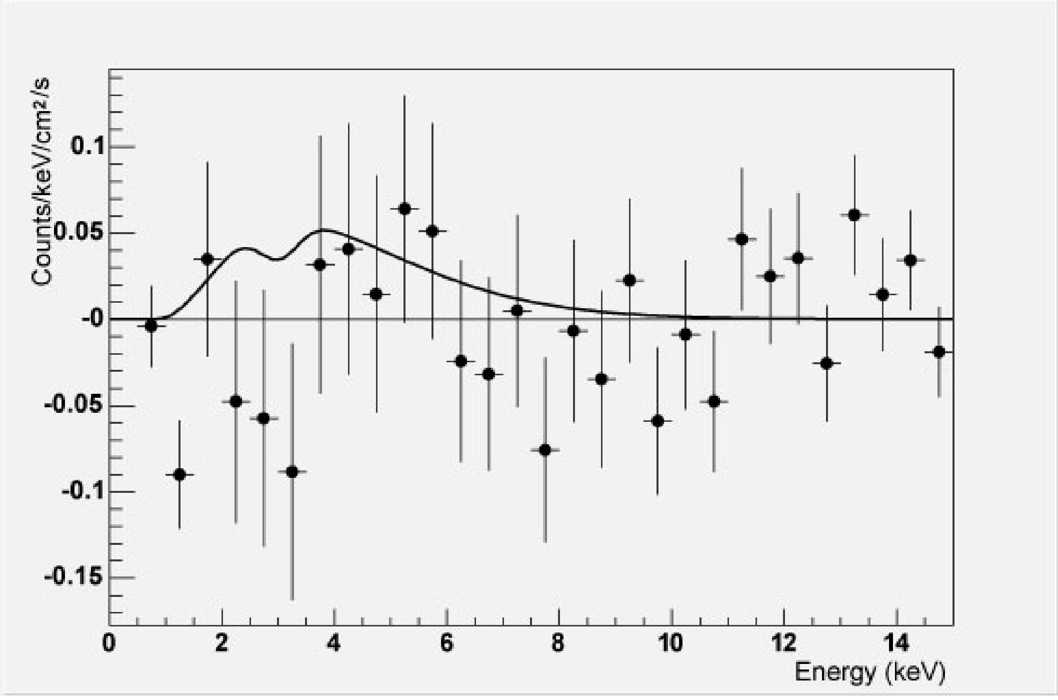

Figure 2. Subtracted TPC-spectrum (sun tracking minus background) with the corresponding solar axion signal at the 95% CL.

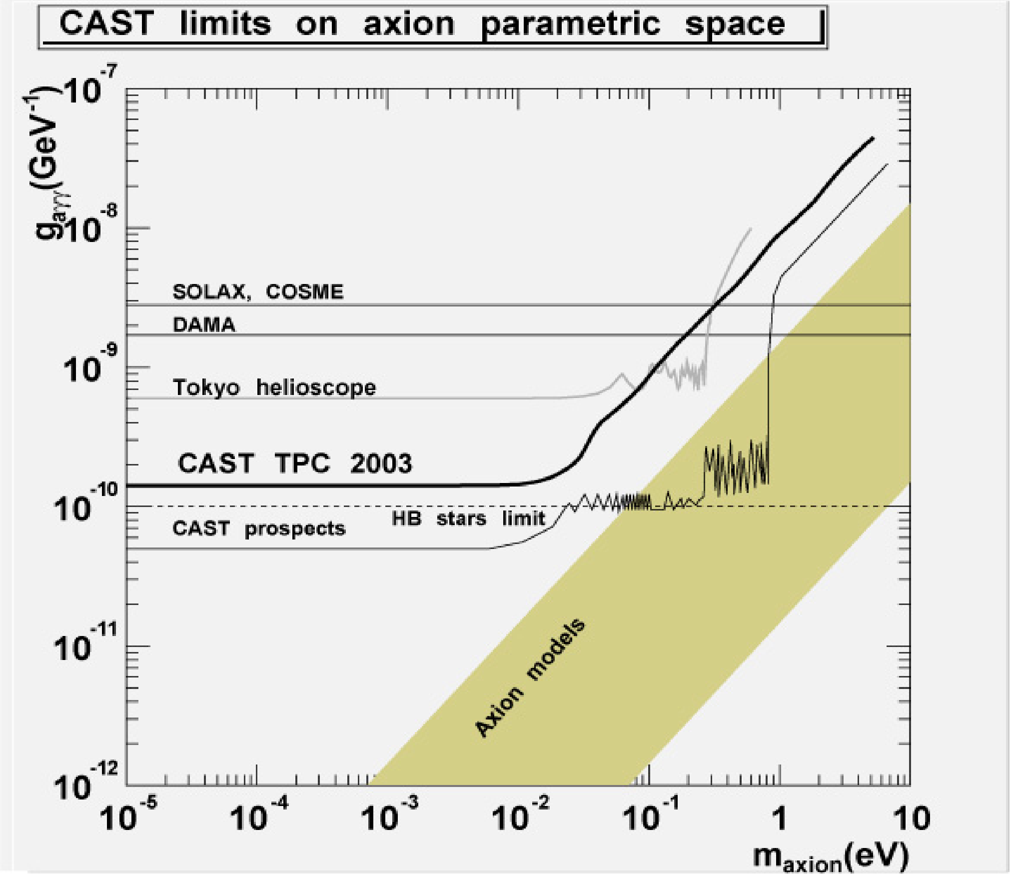

Figure 3. Exclusion plot reached with the TPC in 2003 including also other results.

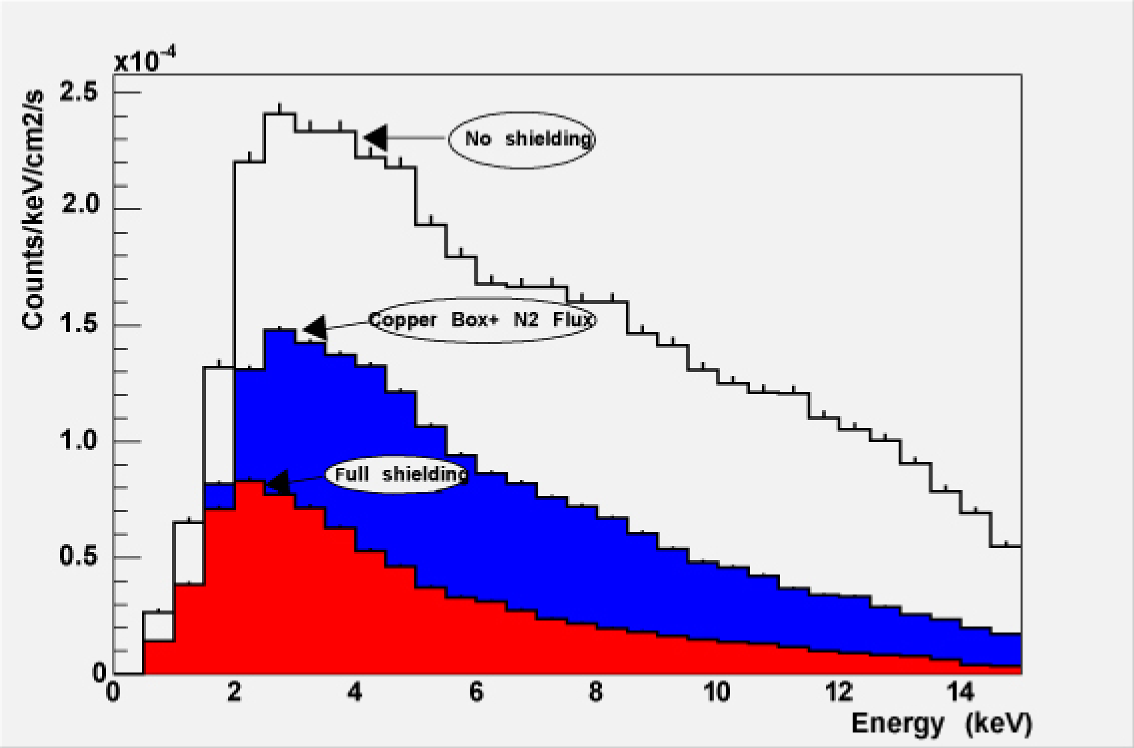

Figure 4. TPC-spectra from 2003 and 2004 for different shielding conditions.

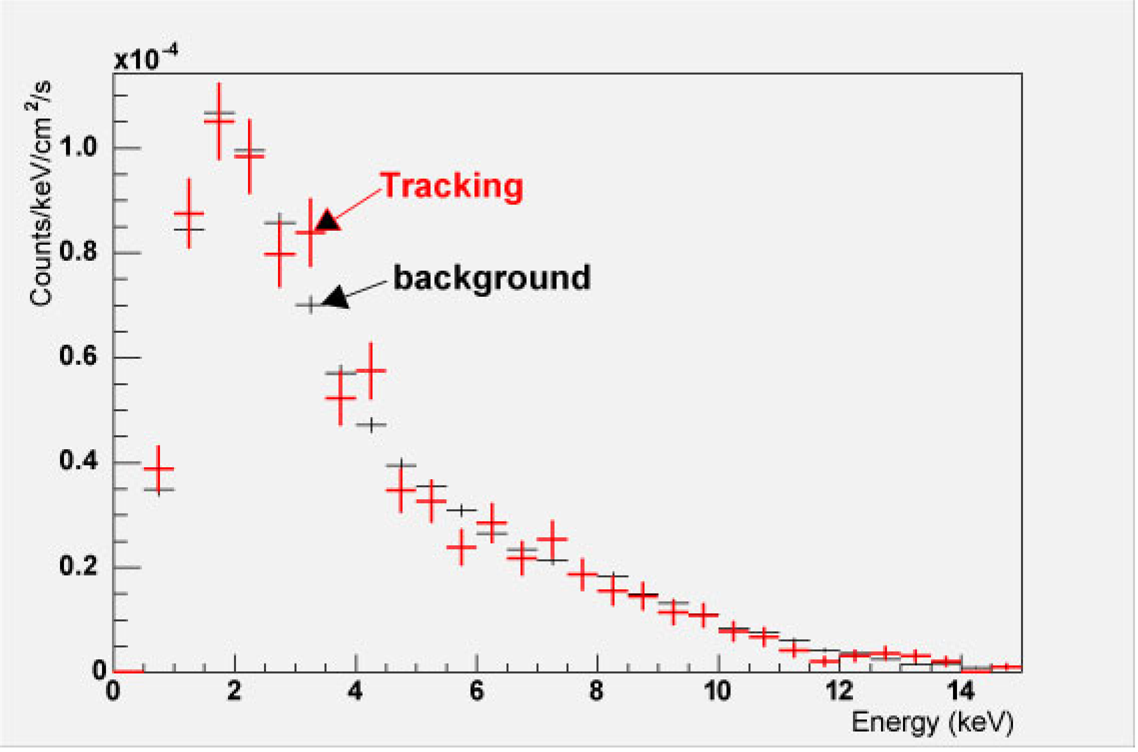

Figure 5. Preliminary 2004 TPC-spectra: sun tracking (***red***) and background (***black***).

3. The MICROMEGAS Detector

From May 2003 until November 2003, the Micromegas detector had been taking data, showing good stability in its performance. A first result of the analysis resulted in deriving an upper limit for the coupling constant of the axion to two photons. Since the beginning of 2004 data taking, a new Micromegas has been installed with superior performance along with a better and more automated system.

2003 period

By the end of July 2003 it was already realized that the information from the strips was affected by an apparent 'cross-talk' among them, making it hard to profit from their information. The implementation (August 2003) of a high sampling VME Digitizing Board (MATACQ Board) in order to read and record the time structure of the pulse coming from the mesh, paid off giving a significant advantage for the analysis. The detector's performance was held quite stable (±2%) as Figure 7 reveals. In total, 810 h of background data and 77 h of tracking data were accumulated. Figure 6 shows a background and a tracking energy spectra representing almost one third of the data, giving a limit on the axion photon coupling of $g_{a\gamma\gamma}<1.6\times10^{-10}$ GeV^{-1} at 95% CL, following the same procedure as described in section 2 for the TPC. The limit obtained for the axion-photon coupling from the complete set of data is $\mathbf{g_{a\gamma\gamma}<1.39\times10^{-10}}$ **GeV^{-1}** at 95% CL.

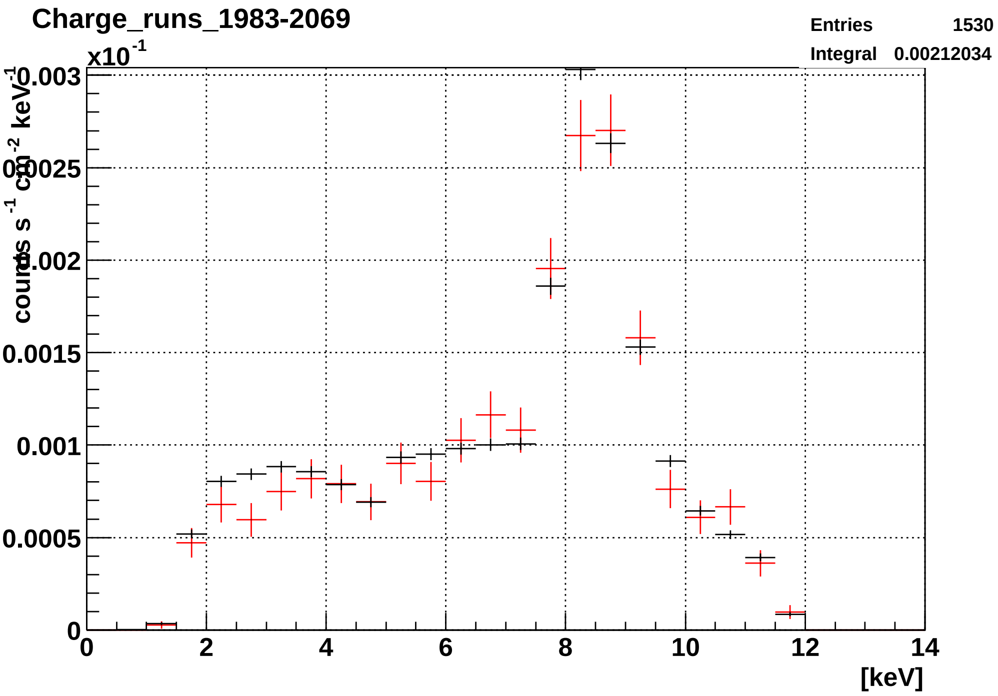

Figure 6. The superposition of the Tracking (***red***) and Background spectra (***black***) for Set C

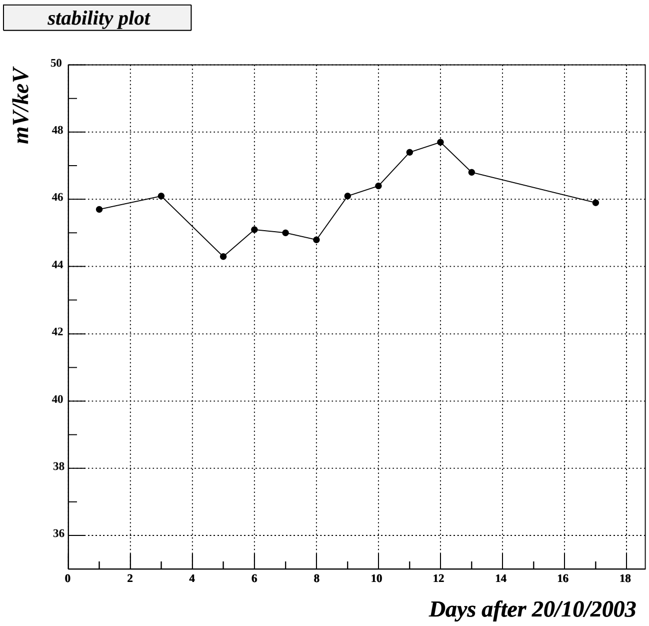

Figure 7. Pulse amplitude calibration during data set C

Improvements for 2004 during the shutdown period and present status

The forementioned 'cross-talk' of the strips, led to the replacement of the 2003 detector (V3) by another one, V4, in 2004, free of such a problem. This detector has in addition a much better set of strips (less than 5 dead, as opposed to around 10 of V3). Already the level of background achieved with this detector is ameliorated by a factor of 2.4 (Figure 9), the resolution on the strips is much better, resulting in higher quality of the data (Figure 8) .

Extra information that could be valuable for the analysis is expected by the installation of a muon veto above the chamber. The hoped-for result has not yet been ascertained. Another thicker veto scintillator, covering a larger solid angle, is planned to be built, in order to replace the existing one.

A faster VME Digitizing Board has improved the data transfer, reducing even more the DAQ dead time, and an automatic source controller for calibrations, along with more information on display, allow for an easier and more direct control of the DAQ system.

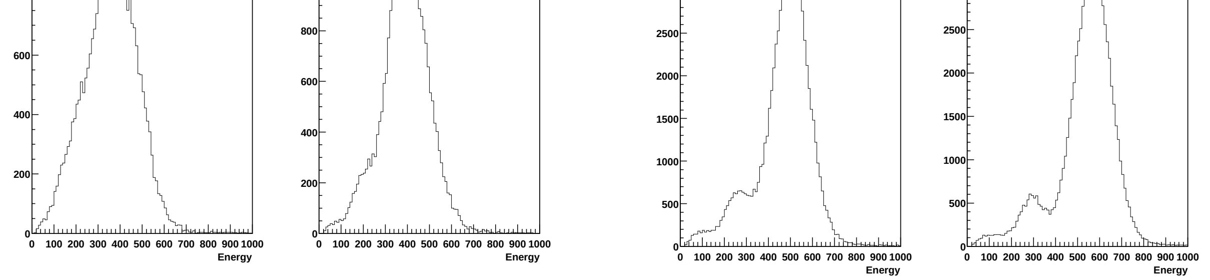

Figure 8. The strip energy resolution: the 2004 detector (right) vs the 2003 module (left).

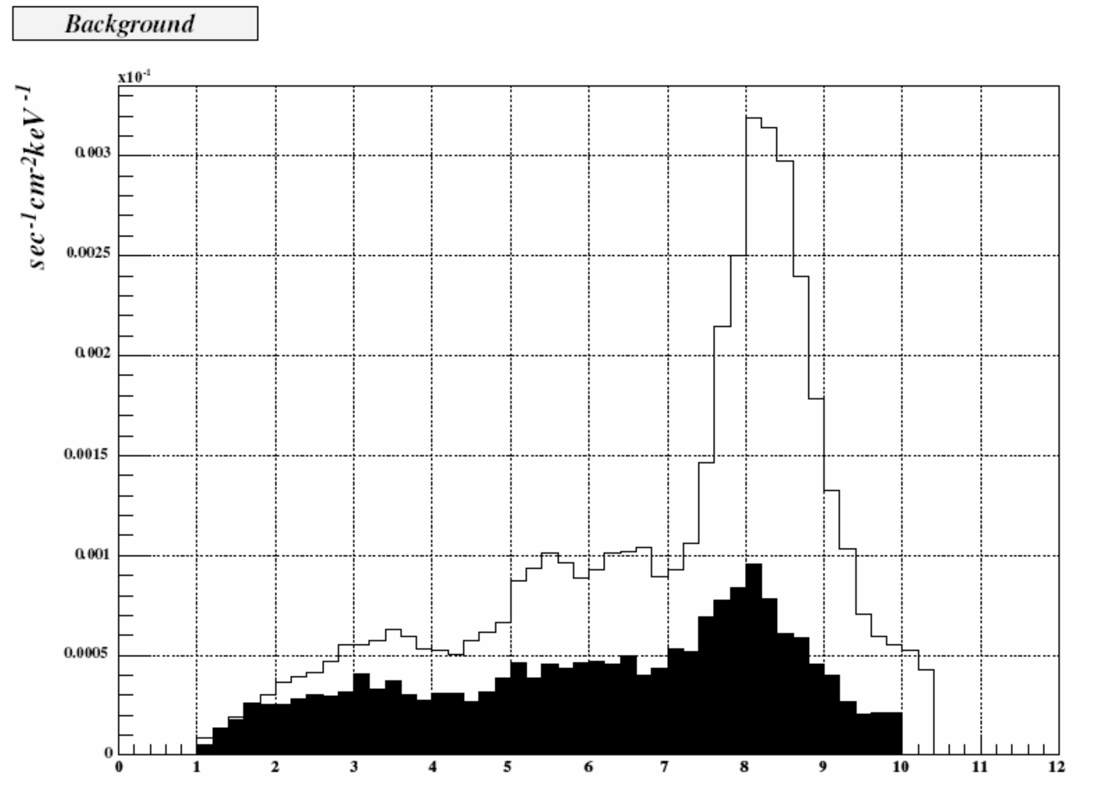

Figure 9. Micromegas background in 2004 (V4, ***black***) and in 2003 (V3, ***open***).

4. The X-ray Telescope and the pn-CCD Detector

Modification of the tracking system of CAST

The tracking system of CAST allows following the sun with the magnet for 1.5 h during sunset and sunrise every day. Thereby the pointing accuracy of the magnet relative to the center of the sun has to better than ±1 arcmin at any time. To measure the absolute pointing direction angular encoders are installed close to the tracking motors, but far away from the vertical and horizontal rotation axis of the magnet. Therefore, changes of the magnet structure can not be measured during tracking. For this reason, we improved the system by installing two additional angular encoders directly on the vertical and horizontal rotation axis of the magnet. These new devices allow us to measure the non-linearity in the tracking system, which can be taken into account, and partially are corrected by the tracking software. To do so, a correction matrix has to be derived from a systematic survey at different magnet positions (see section 5).

Alignment of the X-ray telescope and pn-CCD detector

The most critical parameter with respect the efficiency of the X-ray telescope/pn-CCD system is the alignment of the optical axis of the telescope system relative to the optical axis of the magnet bore. To reduce the uncertainty of the effective area below 5 %, the optical axis of the whole telescope/pn-CCD system has to be parallel to the optical axis of the magnet with an accuracy better than 1.4 arcmin (= 0.023^{o} see vertical lines in Figure 10). We used a parallel laser beam to align the X-ray telescope relative to the magnet (Figure 11).

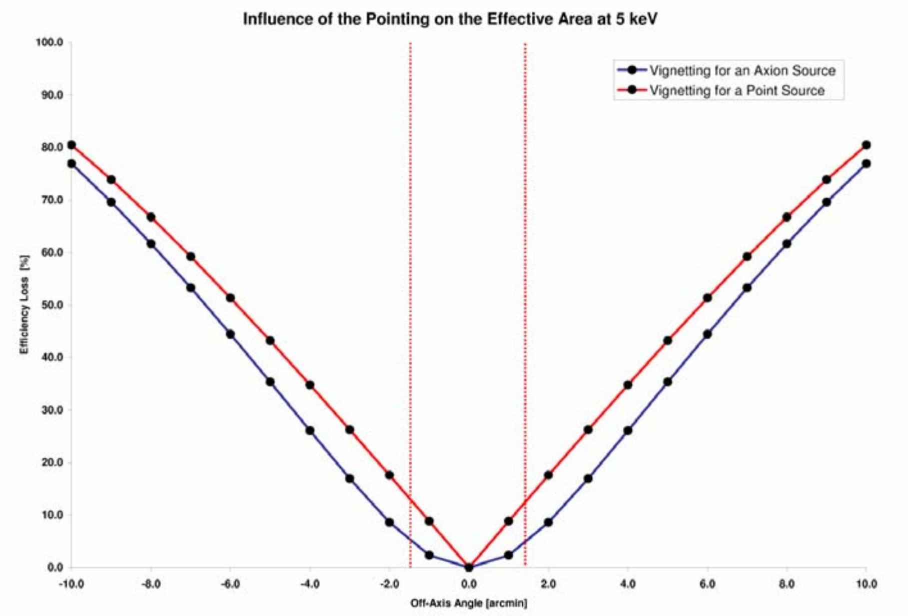

Figure 10. Effective area of the X-ray telescope for different off-axis angles. The relative efficiency is shown for a realistic extended axion source and for a point source.

With the laser, the telescope system was aligned relative to the magnet bore and subsequently the pn-CCD detector relative to the X-ray telescope. After and during the alignment procedure the positions of all components were verified by the aid of the surveyors using reference points on the magnet, telescope, and pn-CCD detector housing to cross check the results derived from the laser measurements and to get a reference data set. In addition,

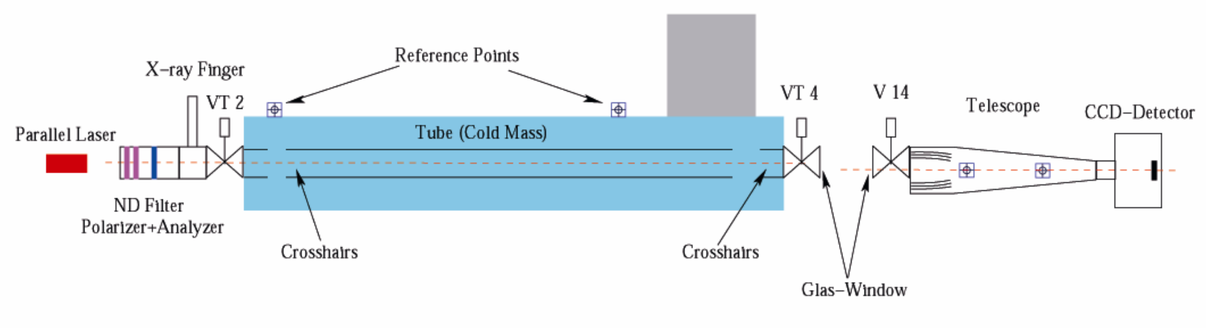

Figure 11. Experimental setup for the alignment of the X-ray telescope and pn-CCD relative to the optical axis of the CAST magnet.

this setup was and will be used in future to determine the expected position of the image of the sun on the pn-CCD chip with an accuracy close to the spatial resolution of the CCD (pixel size 150 μm = 20 arcsec). Figure 12 shows the resulting laser spot centered on the CCD chip after the alignment. As a verification of the final alignment we measured the off axis behavior of the focal spot for different off-axis angles in vertical and horizontal direction. The results are shown in Figure 13 and demonstrate an almost perfect linear dependency between the off-axis angle of the laser and the position of the laser spot on the pn-CCD chip.

Improvements to the detector during the winter shutdown 2003/2004

We made intensive tests to reduce the abnormal electronic noise of the pn-CCD detector. Unfortunately, up to now the source for the electronic noise or a correlation to electronic equipment or the other detectors in use in the CAST experimental area could not be found, nor could the high noise level be reproduced in our laboratory in Munich. Due to this problem the energy range of the pn-CCD is restricted to energies above 0.75 keV compared to 250 eV when the detector is being operated in Munich. The pn-CCD detector was calibrated in the range of 0.5-9 keV using an X-ray tube. The linear energy response is shown in Figure 14, with an energy resolution of 160 eV at 6 keV.

The detector shielding was enhanced by adding a 17 to 25 mm thick layer of low-activity ancient Pb free of ^{210}Pb on the outside of the Cu shielding used during the data taking period in 2003. The additional shielding has reduced the background level by a factor of 1.5 to a mean flux of $(7.5 \pm 0.2) \times 10^{-5}$ counts/cm^2/keV/sec in the energy range of 1-7 keV (Figure 15), which is consistent with background measurements in Munich.

The ^{55}Fe calibration source installed on a manipulator close to the pn-CCD detector was modified to reduce the count rate of the source by adding an Al filter. Thus, the emergent Al fluorescent emission line can also be used for calibration. A miniature X-ray generator is mounted on the TPC side to monitor the telescope performance. It provides a near-parallel X-ray beam through the magnet bore which illuminates the X-ray telescope aperture. Figure 16 shows the X-ray image and the energy spectrum of the calibration beam observed with the pn-CCD. The spot size is larger than the expected size in the focal plane of the telescope, since the X-ray beam is slightly divergent. The X-ray beam allows to monitor the temporal stability of the focus and to study a possible dependence on the orientation of the CAST magnet during data taking.

From the data taken in 2003 the derived preliminary limit is $\mathbf{g_{a\gamma\gamma}<2.0 x 10^{-10} GeV^{-1}}$. Note that this limit does take into account the focusing cabability of the X-ray telescope, and therefore it can only be used to check the consistency of the results from all 3 CAST detectors. A more detailed analysis including the full telescope efficiency is more complicated and is in progress.

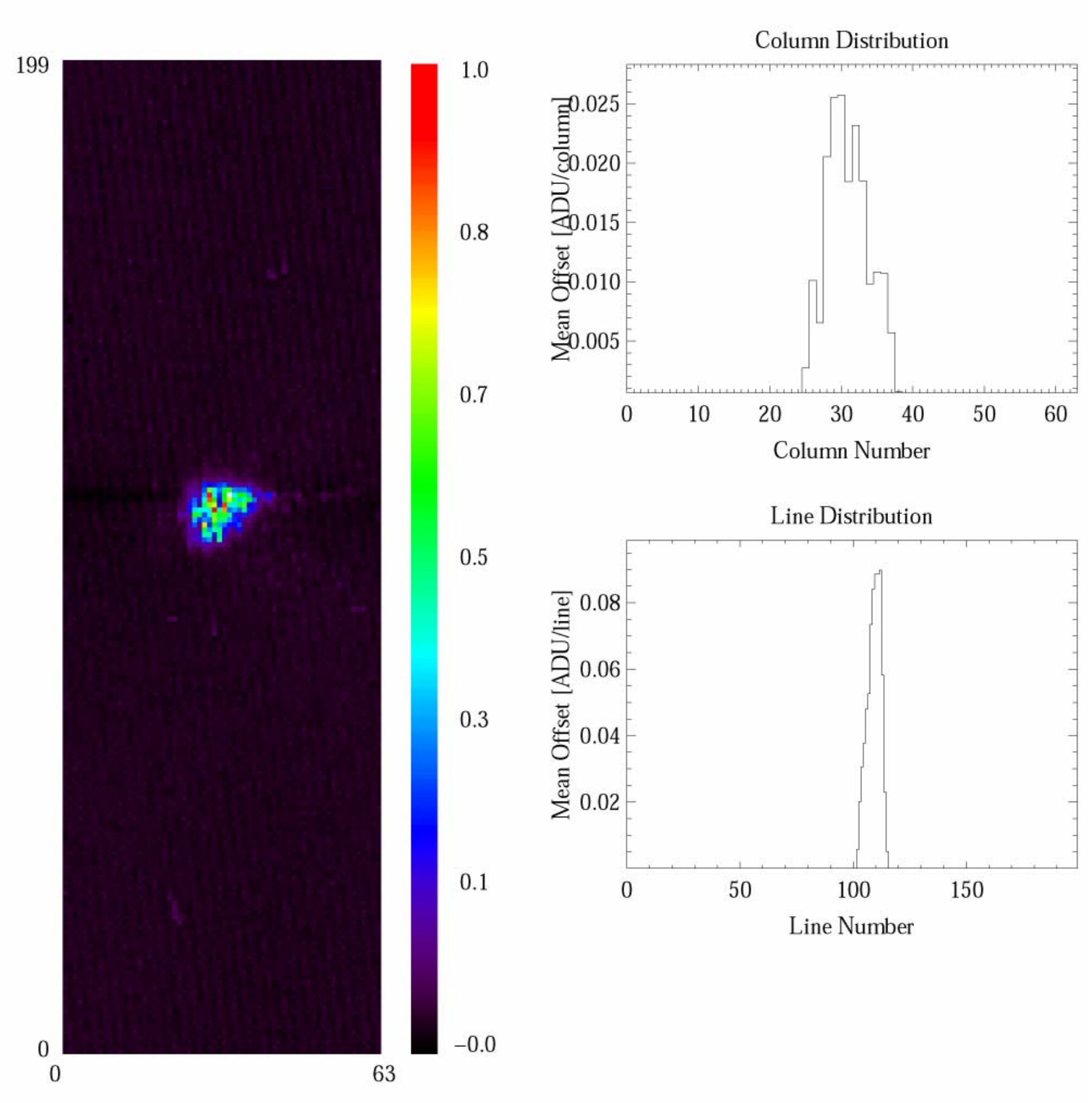

Figure 12. Spot of the parallel laser beam observed with the pn-CCD detector. The position and size of the spot correspond to the expected axion image of the sun.

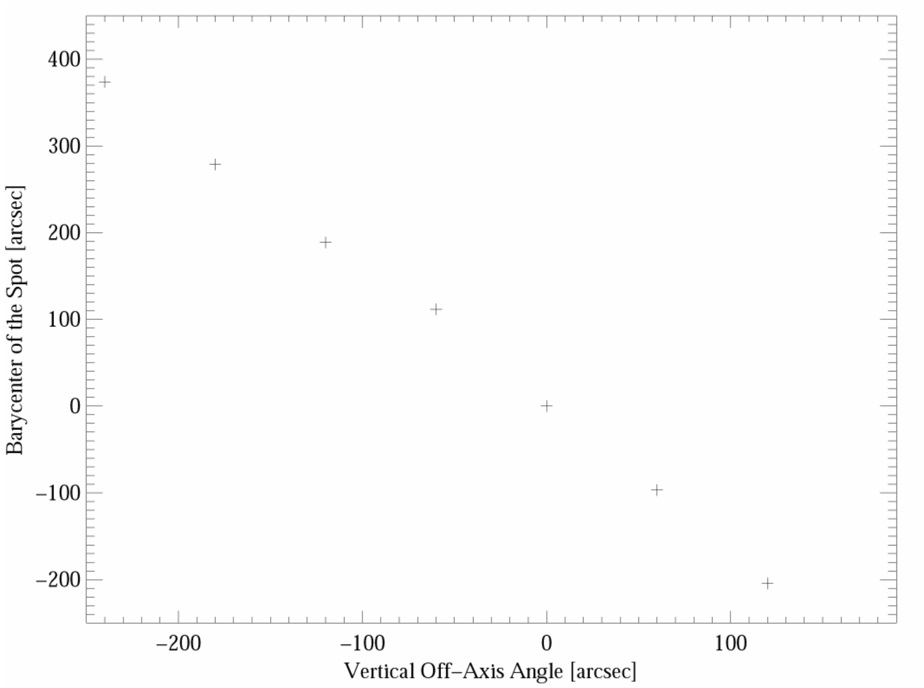

Figure 13. Off-axis position of the laser spot as observed with the pn-CCD detector depending on the off-axis angle of the parallel laser beam.

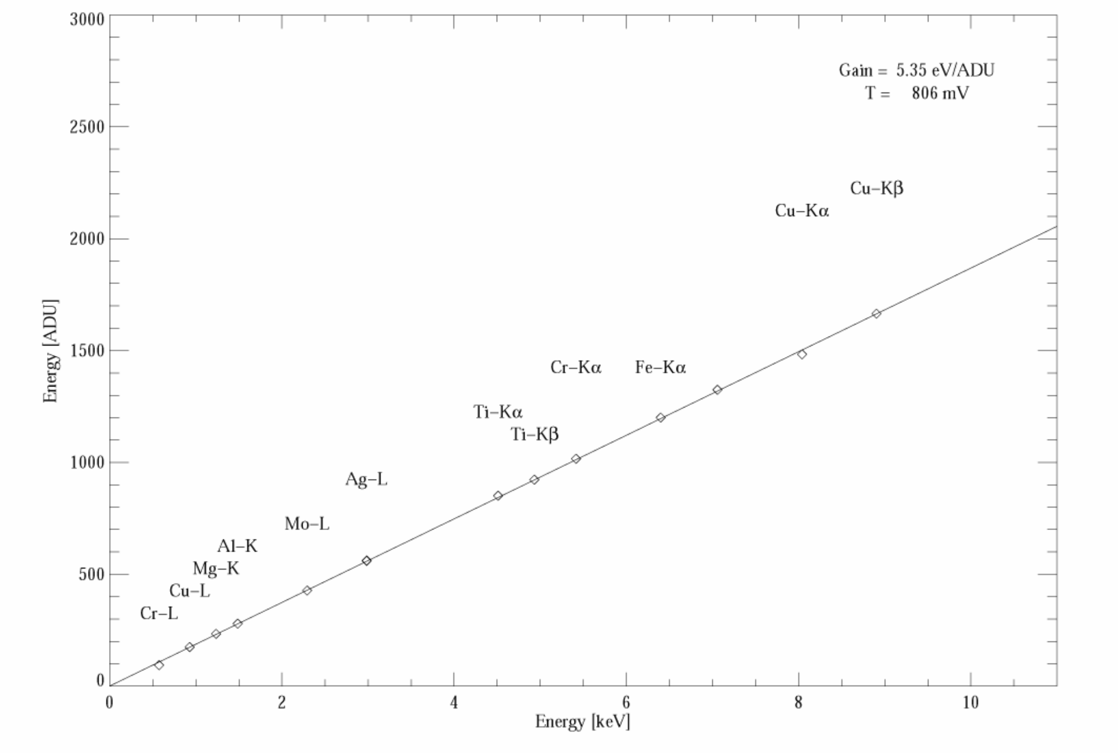

Figure 14. Energy calibration of the pn-CCD. The measurements were performed in the CAST experimental area with an X-ray tube connected to the dismounted detector chamber.

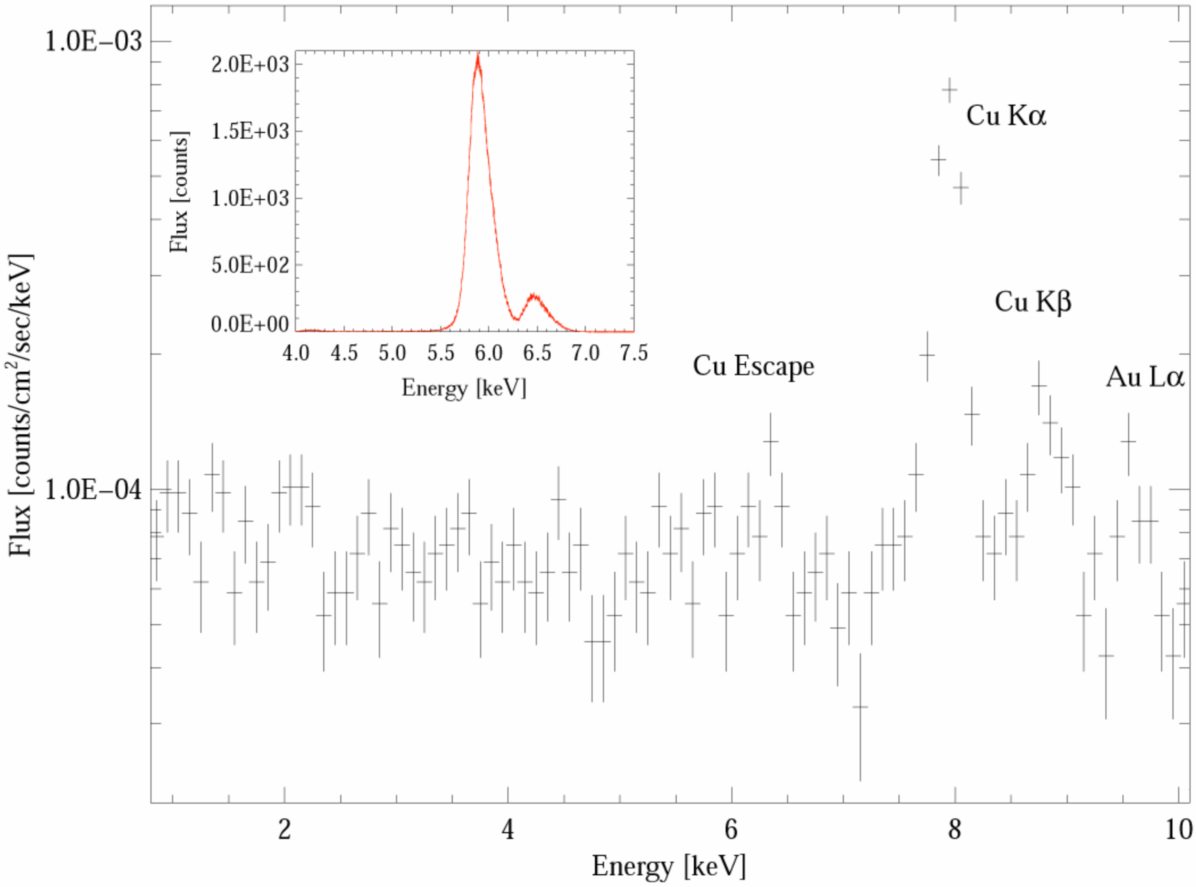

Figure 15. Background spectrum measured with the pn-CCD detector. The extra Pb shield added in 2004 has reduced the background level by a factor of 1.5 to a mean differential flux of $(7.5 \pm 0.2)\text{x}10^{-5}$ counts/cm^2/sec/keV in the energy range of 1-7 keV. Inlay: Calibration spectrum of an ^{55}Fe source.

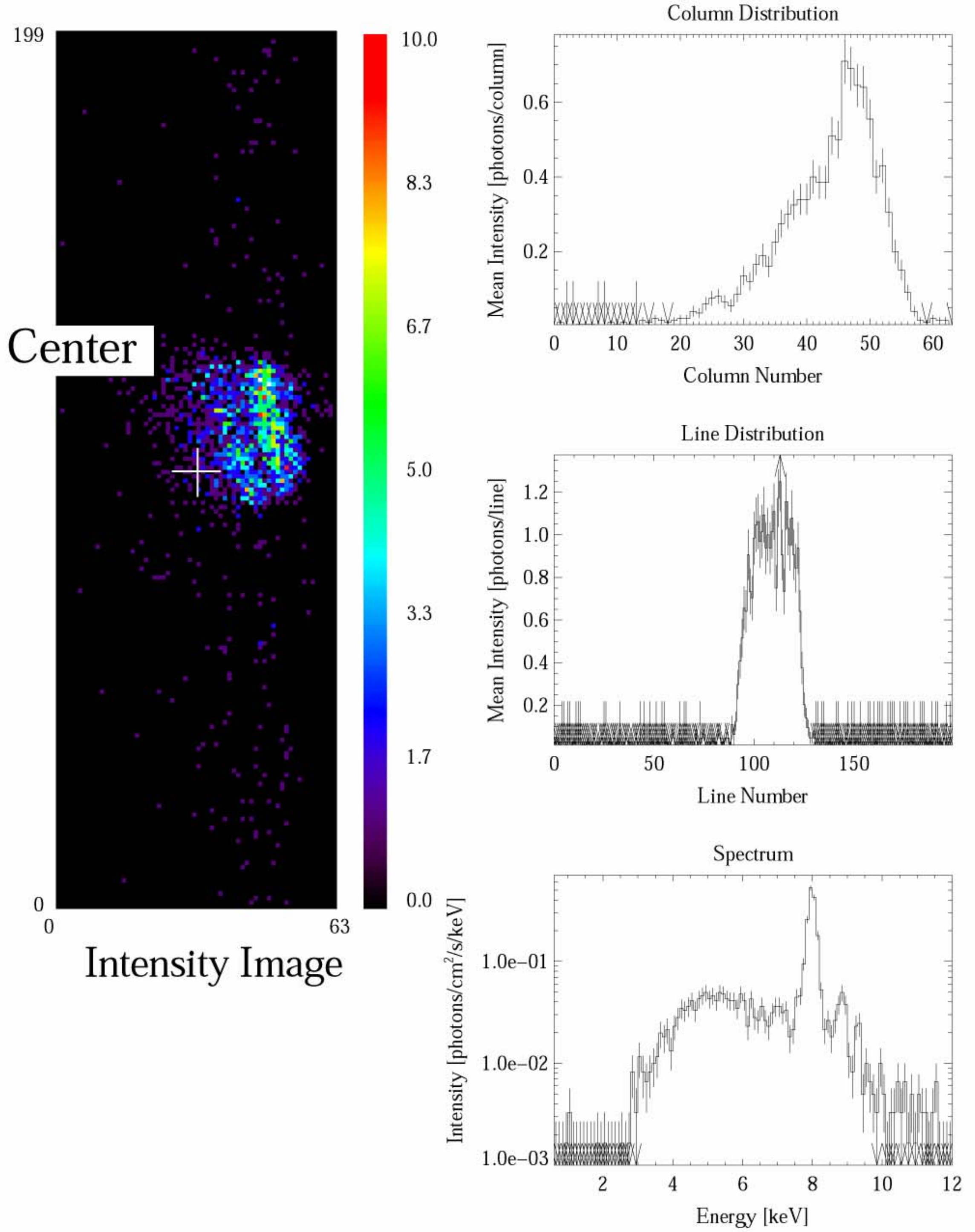

Figure 16. X-ray image and energy spectrum of a near parallel X-ray beam through the CAST magnet. The beam is produced by a ~100 MBq pyroelectric source emitting mostly in the Cu-K fluorescent line.

5. Grid measurements

The CAST magnet is pointed to the sun with the support of an azimutal mounting. The pointing accuracy for the tracking system is specified to be below ± 1 arcmin.

Caused by the constructive constraints (cryogenic system) it was not possible to move the centre of gravity of the magnet to the crossing point of the 2 rotation axis. Therefore the mounting has resulted in some imperfection of positioning the magnet to the sun due to an overestimation in the mechanical mounting. These imperfections of the pointing system can be overcome by using an adapted pointing software. The basic elements for the software is the so called grid measurement. The basic idea of the correction is, that the adjustment of the magnet for several pointings is correlated to an astronimical coordinate system. This matrix of correction has been determined in 2002. We also have verified by observation of the sun with a telescope in the visible, that the system works very well.

During the last observation period we have found some malfunctions of the moving system, and we had to modify some components; during the last shut-down phase we have increased the weight of the movable part by ~10%. Therefore, we had again to verify the used matrix of correction. Before we started our observations we again performed a grid measurement. This time we have found some imperfection: a slip of the motor encoder and some shift and drift in the horizontal rotation. In the meantime we have solved these malfunctions of the moving system. Based on the results of a little grid measurement performed in June 2004, we can use the matrix of correction from 2002 and the available software. The deviations of adjustment for the grid measurement 2002 and the little grid measurement 2004 is < 0,01° and this is within our error box.

Since we have not solved fundamentally the mechanical problems in the tracking system, we have to improve the concept for the second phase of CAST. To do this task we have to study the dynamical behaviour of the moving system and structure of the magnet.

6. High Energy Calorimeter

A high-energy calorimeter dedicated to parasitic searches for cosmological axion-like particles has been installed during May-June of 2004 behind the Micromegas chamber (which is transparent to photon energies above few tens of keV). While a mapping of the sky in galactic coordinates looking for an excess signal along the galactic plane or center might be of some interest, a more realistic high-energy boson search should continue to rely on the Sun as a source. Weak experimental limits already exist from the observed flux of solar gamma-rays below 5.5 MeV, to which axion decay ($a \rightarrow \gamma\gamma$) following ($p + d \rightarrow {}^3He + a$) might contribute. Other unexplored interesting channels exist and a generic search should not be limited to pseudoscalar particles, leaving room for surprises. Astrophysical constraints still allow axions to partake a fraction (few %) of the solar luminosity. This type of higher-energy search has not been performed with a helioscope before. In particular, the absence of a 511 keV excess signal (from $e^+ + e^- \rightarrow \gamma + a$) in this CAST calorimeter at times of solar alignment may impose tighter bounds than similar searches for anomalous production of single photons in accelerator experiments.

The calorimeter is a 644g $CdWO_4$ (CWO). Low-background techniques were implemented in the design (ancient lead, photomultiplier with low ${}^{40}K$ content, radon displacement, active muon veto, etc.). Challenges involved achieving the highest possible background rejection and stopping power for high-energy gammas (>20% peak efficiency below 10 MeV for the crystal selected) within the smallest possible shielding due to space limitations. A powerful pulse shape discrimination (PSD) system was developed, able to efficiently separate internal alpha decays, spurious PMT pulses and cosmic neutron recoils from gamma-induced events (Figure 17). The achieved raw counting rate prior to radon displacement is already ~1.5 Hz (300 keV - 150 MeV), which is excellent for a crystal of this mass operated at the surface in the absence of a heavy shielding. Data-taking has started only a few days before the time of this writing: the data shown in Figure 17 should be considered very preliminary. The calorimeter has been aligned in its final position, coaxially with the magnet bore.

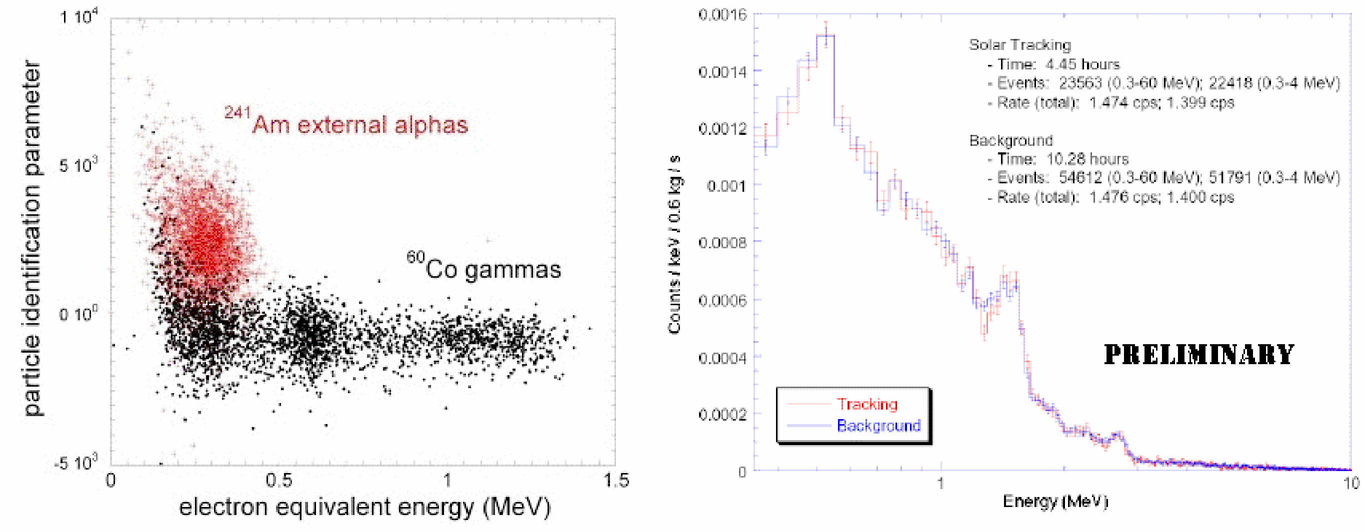

Figure 17. Left: Example of pulse shape discrimination with the CAST 0.6 kg CWO calorimeter. The achieved ability to discriminate γ-events from internal α-emissions is comparable to that from dedicated CWO crystals used in double-beta decay experiments. Right: Preliminary data obtained with the calorimeter during its first week of operation (June 2004).

7. Second phase of CAST

Introduction

For axions, the ratio between mass and photon-coupling is given, up to model-dependent numerical factors, by the corresponding pion properties. This defines the "axion line" in the parameter plane of mass and photon coupling strength. The gas-filling phase of CAST will allow us to extend our sensitivity up to masses of about 1 eV and thus to "cross the axion line". This will be the first laboratory experiment to reach a sensitivity where the existence of "invisible axions" is tested, albeit only in a narrow range of masses around 1 eV. All previous experiments, including the CAST vacuum phase, were only able to search for generic axion-like particles with masses much smaller than would be expected if they are indeed responsible for solving the strong CP problem.

Experimental aspects

CAST plans to operate with low-pressure helium gas in the magnet cold bore from 2005 onwards. This requires the installation inside the cryostat of thin windows to contain the helium in the isothermal region of the cold bores, so that good vacuum in the beam pipe extensions leading to the detectors can be preserved and a low heat leak along maintained. The cold windows need to be helium gas-tight, capable of operating at 1.8K and able to withstand rapid temperature and pressure fluctuations in the event of a quench. Finally, the windows must transmit efficiently low energy X-rays above ~ 1keV.

The density of the cold bore gas filling will be varied in order to tune the magnet to different axion rest masses. In order to operate safely at 1.8˚K (avoiding condensation), He-4 can be used up to a maximum pressure of ~ 6 mbar and He-3 up to ~ 60 mbar. Initially, low pressure He-4 will be used together with a relatively simple gas system where the risks due to the effects of quenches are small. With the experience gained and after in situ tests - the final gas system can be completely specified and built - ready for the more challenging higher-pressure He-3 running starting about a year later.

Schedule

In an extended winter shutdown, the preparations and modifications will be made for the start of the second phase. He-4 running is planned in the second half of 2005 and will then consist of about 150 sun-tracking runs divided into 30 discrete pressure settings between 0 and 6 mbar (extending the Axion mass coverage up to ~ 0.3 eV/c^2). The subsequent He-3 running will consist of about 300 sun-tracking runs divided into discrete pressure settings between 6 to 60 mbar (extending the Axion mass coverage up to ~ 0.8 eV/c^2).

Modifications to CAST for the second phase

Mechanical intervention on the magnet movement system

In the extended shutdown leading to the second phase, modifications to the mechanical lifting system should be made following the recommendations of the study made by TS-MME group.

Installation of cold windows

The cold windows are a crucial element in the success of the second phase. No such windows exist in commerce and a collaborative R&D project together with METOREX (FI) has been has been launched to develop such windows. A small 8mm diameter prototype has been successfully tested at 1.8˚K at CERN (Cryolab Note 03-04). The final window will have a diameter of ~ 50 mm (cold bore diameter 43mm), METOREX is now fabricating two 50 mm diameter prototype windows, which will be tested by early autumn 2004.

Helium gas system

The gas system must be able to maintain a precise and constant pressure during data taking and also be able to respond rapidly in the event of a quench in order to protect the integrity of the cold windows.

One key parameter involved in the system design is the transient temperature response of the gas filling of the cold bore in the event of a quench. This crucial parameter has never been measured in an LHC magnet. A test will be made to fill the cold bore with low pressure He-4, provoke a quench and monitor the pressure rise in the gas. The passive and active safety systems for He-3 running will be designed to cope with the measured response time and the pressure limitations of the cold windows. The He-3 system must necessarily be a high-purity and completely leak-tight recirculation system in view of the high cost of He-3.

The vacuum lines between cold windows and detectors can no longer be assured by the cryo-pumping of the cold bore after the installation of the cold windows. Active pumping of the external pipe work will be necessary. The vacuum pumping system must be interlocked and integrated with the gas system and be interlocked to a He-3 leak detector in case of leaks developing on cold windows. A doctorial student supervised by experts from AT-ACR, AT-ECR and AT-VAC will make the final design.