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CERN-SPSC-2006-038
SPSC-M-752

Memorandum to the Chairman of the SPSC Prof. J. B. Dainton
Request for an extension to CAST running time for the years 2008 and 2009

1 Introduction

CAST is presently enjoying a very successful running period with ^{4}He gas fillings in the cold bore. To date, 136 density settings have been measured in the scan; each one over a single day's tracking time of ~100 min. The highest density corresponds to the pressure of 11.3 mbar at the cold bore temperature of 1.8 K.

In the following we shall use the shorthand notation of 11.3 mbar @1.8 K to refer to this point in the buffer gas density scan, in order to highlight the point that small variations in the cold bore temperature make the pressure deviate from the reference value at 1.8 K. In reality the density is controlled by feeding much more precisely metered amounts of buffer gas into the normally closed volume, comprising of the cold bore tubes and lines connecting it to the room temperature parts of the gas system.

The original CAST Phase II strategy was to change to ^{3}He at about 6 mbar @1.8K and then continue to take data at only ~ 50 min tracking time per density setting up to 60 mbar @1.8K in order to cover the ~600 pressure settings by the end of 2007. The changeover to ^{3}He requires a new sophisticated gas system that required a substantial amount of R&D in order to complete the final design. However, during this time CAST has been actively taking data using ^{4}He buffer gas above 6 mbar @1.8K and can continue up to about 14 mbar @1.8K with the present system. The only restriction is that the present gas system permits only one density setting during each100 min tracking run.

The 2005-2006 data taking run has provided essential input for the design of the ^{3}He gas system, which has been conceived and dimensioned to operate up to near the physical limit of ^{3}He at 1.8K (135 mbar). The design of the system, described in the Technical Design Report (TDR) [1], is now completed, and the review of the TDR took place at CERN on 17.10.06 [2]. The Review Recommendations have been compiled [3]. The Addendum No2 to the CAST MOU to cover the ^{3}He gas system and running in 2007 will be signed in the weeks following its endorsement at CAST FRC on 24/11/06.

The installation of the gas system and the commissioning tests should be completed by the end of the 1H2007 and ^{3}He data taking will cover the whole of the 2H2007. Whilst the new system will allow two density settings per tracking, CAST will not be able to achieve the target density equivalent to 60 mbar @ 1.8K by the end of 2007. Nevertheless, CAST should reach a very respectable value of about 35 mbar @ 1.8K.

The 2007 data taking will be enhanced by the addition of a second X-ray optics system (a concentrator) which will be coupled to a new MicroMegas detector on the MicroMegas line. This new optics, made at LLNL with a novel technology, will be an improved version of their original optics which unfortunately failed to meet specifications in tests at PANTER in autumn 2006.

This memorandum contains a request for extra running time, first of all to complete the scan up to the 60 mbar @ 1.8K. CAST is now confident that with steady and careful progress, operation will be possible up to at least 120 mbar@ 1.8K. The second part of the request therefore asks for extra running time to fully exploit the axion mass reach of the system. In this Memorandum we request initially a two year extension, running in 2008 and 2009, but indicate that a further extension may be required to complete the task. In the following sections a physics justification for this request will be presented, followed by some details of the running time, costs and resources required, before ending with concluding remarks.

[1] Technical Design Report of the CAST ^{3}He Gas System
CERN-SPSC-2006-029 SPSC –TDR-001 CAST TDR 1

[2] Minutes of the Technical Design Review for the ^{3}He system of the CAST experiment
CERN-SPSC-2006-036 SPSC-M-750
[3] CAST ^{3}He TDR, Review Committee's Report
CERN-SPSC-2006-037 SPSC-M-751

2 Physics justification

For axions, the ratio between mass and photon-coupling is given, up to model-dependent numerical factors, by the corresponding pion properties. This ratio 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 1.1 eV/c^2 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/c^2. 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.

Axions with eV-range masses would have thermalized in the early universe by their generic pion interactions and thus contribute a hot dark matter component of the universe, similar to neutrinos. The usual structure-formation limits on neutrino masses therefore can be translated into analogous limits on axion masses. Limits of this sort, of course, depend on systematic uncertainties of the cosmological standard model. At the present time, these limits reach approximately down to 1 eV/c^2. Therefore, if CAST II can close the gap to ~1 eV/c^2 from below, and assuming that in future the cosmological limits will reliably reach down to 1 eV/c^2 or even somewhat below, a seamless coverage of all axions masses will be achieved down to the axion-photon coupling limit that is achieved by CAST II. Figure 1 shows the expected contribution that CAST can make in this field.

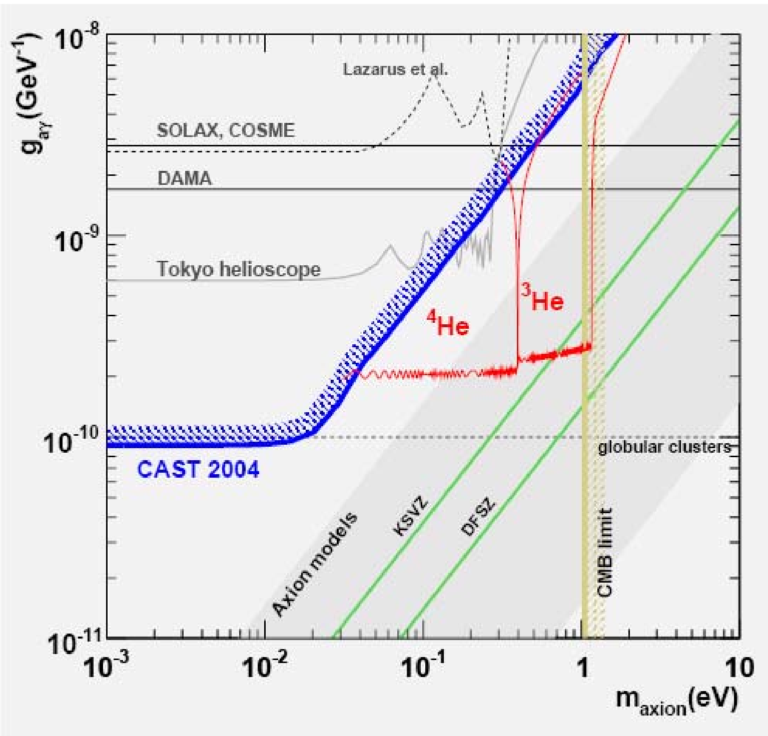

Figure 1: CAST prospects, scan up to 120 mbar @1.8K

There is an ongoing burgeoning interest in the axion and in pseudoscalars beyond Standard Model physics more generally. Indeed it can be said that there has never been so much theoretical and experimental activity in axion physics since its prediction in the late 1970s with the original papers of Peccei and Quinn, Weinberg and Wilczek.

There are several factors contributing to this remarkable renaissance. The Peccei-Quinn mechanism that protects the strong force from CP-violating effects and results in the axion, has endured for thirty years, and is widely regarded as the best and most attractive solution to the strong-CP problem. Additionally, axion is one of the two outstanding candidates to constitute the dark matter of the universe, along with the neutralino or other WIMPs. Furthermore, there is now serious attention being paid to axion by string theorists. The situation may be summarized by saying that axions or axion-like particles are a generic feature of string theories, and it seems that there should be at least two, and possibly of order a hundred, pseudoscalar particles within any particular string theory. In his summary talk at the recent workshop "Axions at the Institute for Advanced Study", Ed Witten mused that axions may even be intrinsic to the very structure of string theories.

The most important factor fuelling this interest, however, is the rapidly growing experimental effort in axion searches: CAST at CERN looking for solar axions, ADMX in the U.S. and CARRACK in Japan looking for dark matter axions, and more than half a dozen photon regeneration projects and proposals in various stages of preparation to check the remarkable claim of magnetically-induced vacuum birefringence and dichroism by the PVLAS collaboration in Italy. These efforts span a large area of mass and coupling space, in part overlapping and in part complementary. The theoretical and phenomenological situation is quite confused, with no clear convergence on the axion parameters. This situation should be viewed as an opportunity rather than discouragement to the experimenter - it tells us that the unknown facts outweigh the known facts and assumptions required by cosmology, astrophysics and underlying theory. In these circumstances the experimentalists should cast the net widely and be open for surprise. We are on the cusp of discovery, perhaps not only of the axion, but an entire sector of pseudoscalars.

In addition, as a tuning experiment planning to explore the axion mass region up to ~1.1 eV/c^2, CAST would also be sensitive to the existence of large extra dimensions, introduced in the world-brane scenarios to solve the hierarchy problem in particle physics. The detection of X-rays at least in two gas-pressures inside the magnetic pipes can be the potential new signature of (two) large extra dimensions with the compactification radius down to around 170 nm.

If the CAST data taking period is extended, this might allow CAST to also search solar axions at lower energies during short periods (e.g. a few times 1-3 days run). It is worth noticing that solar axions below the range (0.5 – 1) keV has not been considered before, neither theoretically nor experimentally. This might be a new territory, which CAST can cover for the first time. Solar observations may favour the search for low energy axions, if part of the otherwise not-understood quiet sun soft X-rays is due to solar axion conversion in the ubiquitous solar surface magnetic fields. The same could happen also in CAST, provided the detector threshold can be lowered accordingly. Moreover, the quiet sun soft X-ray spectrum increases rapidly at lower energies, which makes this region even more attractive, in case the aforementioned axion scenario is valid. The first rough estimates presented in the SPSC meeting, in VILLARS in 2004, seem now to be rather conservative. Taking into account the large efforts under way in JefLAB and DESY to directly confirm the PVLAS claim, such measurements with CAST require far less resources, without affecting actually the CAST base program [see Villars meeting of the SPSC, 22-28 September 2004, CAST presentation (K. Zioutas). http://indico.cern.ch/conferenceDisplay.py?confId=a043551 .

3 Details of running time, costs and resources required

3.1 Running time

The intervention to install the ^{3}He gas system will take place in the 1Q2007, there will then be the cool-down followed by a commissioning phase in the 2Q2007 (see the TDR pages 25-27 for a detailed planning). The commissioning phase will include tests of the several different gas metering modes implemented in the system (see TDR pages 10-11and 31-39). The gas density can simply be increased before the sunset tracking to change the setting by one step each day for each detector or, the density changed by one step in the middle of a solar tracking run or, the density can be uniformly ramped across a range equivalent to about one step during the tracking. After thorough testing, the optimal metering mode will be identified and adopted for the data taking phase which should then occupy the whole of the 2H2007. It is expected that at the end of 2007 the scan will reach about 35 mbar @ 1.8K (axion rest mass of 0.62 eV/c^2).

In 2008 and 2009, we assume that at the start of each year there will be a medium-sized intervention to either change cold X-ray windows or to make additions or repairs inside the cryostat. In parallel, the annual maintenance will be scheduled for CAST experiment. Additional overheads come from pumping and cooling down of the magnet. There a number of other tasks to schedule, namely alignment of the X-ray telescopes and general alignment of the CAST magnet (GRID). Finally, CAST operation must coexist with the LHC machine installation and commissioning work at PA8. Machine-induced changes to the PA8 infrastructure shutdowns have disrupted the CAST schedule in 2006. Whilst CAST will align its schedule with the machine schedule where possible, the effect on the CAST operating efficiency during the forthcoming LHC commissioning and operation cannot be evaluated at the moment.

The estimated number of calendar days for data taking runs in 2007-2009 is shown in Table 1. The number of tracking days with two 100 min tracking data sets and background data records is assumed to be 80%[1] of the available calendar days. This 80% data taking efficiency takes into account quenches, window bake-outs, sun–filming, X-ray alignment runs and the condition that at least two out of the three X-ray detectors are functioning correctly during the tracking.

Year	Calendar days	Tracking days (80%)	Pressure range covered with: One step mid tracking or Ramp of ~0.2 mbar (mbar @ 1.8K)	Pressure range covered if also include a search protocol (mbar @ 1.8K)
2007	160	128	12 - 35 (0.37 - 0.62 eV/c^2)	12-32 (0.37 - 0.59 eV/c^2)
2008	220	176	35 - 70 (0.62 - 0.88 eV/c^2)	32-61 (0.59 - 0.82 eV/c^2)
2009	220	176	70- 107 (0.88 - 1.09 eV/c^2)	61- 93 (0.82 - 1.01 eV/c^2)

Table 1: 2007 to 2009, running time available in calendar days, tracking days (after normal losses), and pressure ranges (with corresponding axion rest mass ranges) achievable each year.

The number of pressure settings was optimised to maximise discovery potential; the optimal density step corresponding to a pressure difference of ~ 0.1 mbar @ 1.8 K or about one FWHM of the mass distribution at a given density (TDR pages 3 & 10).

In the ~ 480 tracking days in 2007-2009, it is essential to cover at least 0.2 mbar @ 1.8K each day by either introducing a metering step mid-tracking or making a smooth ramp over a metering step during the tracking. With the assumption of ~0.1mbar @ 1.8K per step, a maximum pressure of about 107 mbar can be achieved by the end of 2009. To search for small signals amongst background fluctuations, a simple real-time protocol can be triggered using the results of a fast CCD/telescope analysis for hits in the CCD fiducial area. This protocol would then entail remaining at the same density setting until a 'signal' hypothesis is rejected. Such a protocol with the existing CCD-telescope requires an additional 15% running time and the reduced pressure coverage that would result is shown in the last column of Table 1. With the

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[1] The 80% efficiency figure is derived from experience gained from taking run in 2005-2006.
Quenches (~10 per year, 1 day each), window bake outs (~ 8 per year, 3 days each), infrastructure failures, sun–filming, survey GRID and X-ray alignment runs. This efficiency decreases from 80% to 70% if the CCD data is required to be present at all pressure settings.

addition of a second X-ray optics (MicroMegas Line) on the sunrise side, this additional time would be slightly reduced or the same time could be spent on extending the search to smaller signal levels.

The strategy for the CAST data taking will be based on a continuous ascending pressure scan. Operating with a buffer gas-filled cold bore is unexplored territory for CAST and there is a learning curve to understand convectional heat loads and possible thermo-acoustic oscillations as the density continues to rise. The window cooling, due to their coupling to the cold bore by the convection of the buffer gas, must also be understood and controlled. Successive small steps are the best way to maximize the discovery potential (e.g. as opposed to missing every second step and returning later). CAST also prefers not to leave large gaps at lower density in order to target the maximum density region first.

A scan at pressures above ~ 100 mbar @ 18.K most probably goes beyond 2009. CAST is interested to run to the limit of the capabilities of the ^{3}He system (at least 120 mbar @1.8K). CAST will also make a feasibility study on how to make a significant increase in the sensitivity of the experiment (augmenting the X-ray optics and improving the X-ray detection efficiency). The exploration of the region above 100mbar @ 1.8K will be the subject of another request at an appropriate time in the future.

3.2 Costs and resources for CERN

The costs for CERN of this extension in 2008 and 2009 are the usual electricity costs for the cryogenics and magnet power converter and the M&O costs of the cryogenic support team as shown in Table 2.

Item	**Dept**	**Units**	**2008**	**2009**
Cryogenics M&O (incl gases)	AT	(kCHF)	180	180
Cryogenics power		(hours)	6250	6250
	TS	(kCHF)[2]	172	172
Magnet Power Converter		(hours)	3500	3500
	TS	(kCHF)[2]	25	25
PS Field Support	AB	(kCHF)	10	10
Annual Total		(kCHF)	387	387
Integrated Total		(kCHF)	387	774

Table 2: Estimates of the costs to CERN for the operation of the CAST magnet in 2008 and 2009.

The figures for manpower have been estimated and are already mentioned in the Work-packages being prepared for the CAST MOU covering the ^{3}He system and the running in 2007.

3.3 Costs to CAST and a Future Addendum No 3 to the CAST MOU

The funding of the extension for 2008-2009 will be detailed in an Addendum No 3 to the CAST MOU to be prepared during 2007. The first estimate of the costs of running CAST with the present set of detectors and making only moderate interventions (e.g. changing X-ray windows) requires a sum of about 500 kCHF for 2008-2009, which corresponds to ~10kCHF per member (post-doc and above) of the present Collaboration of CAST Phase II. The interest in the extension for 2008-2009 from the CAST Phase II Collaboration is nearly unanimous (see Table 3).

[2] Calculated assuming 55 CHF/MW

3.4 Conclusions

In view of the growing interest in axion physics, and in order to fully exploit the discovery potential of the Phase II gas system, CAST plans to extend the operation of the experiment at CERN beyond its present approval to cover the years 2008 and 2009. The Collaboration is requesting this extension to be recommended by the SPSC for the approval of the Research Board. This extension would enable to take significant amount of data in the most interesting range of axion mass reach between 0.59 eV/c^2 and 1.01 eV/c^2.

We are also contemplating further improvements for even higher sensitivity and mass reach, and for a lower energy of the solar axion spectrum. Such development work requires tests to be made with the present apparatus, and can take place in parallel with the operation of the experiment without compromising the data taking efficiency. These further extensions will the subject of another motivated request at an appropriate time in the future.

3.5 List of interested Institutes

Institute	**Team leader**	**Interest 2008 & 2009**
CERN	M. Davenport	Yes
SED-Saclay, France	I. Giomataris	Yes
UP, UTH,NCSR,HOU, Greece	K. Zioutas	Yes (UP,UTH,NCSR)
UC, USA	J. Collar	Yes
TUD,MPE,WHI, Germany	M. Kuster	Yes
UFRA, Germany	J. Jacoby	Yes
UFREI, Germany	K. Königsmann	Yes
UD, Turkey	S. Cetin	Yes
INR, Russia	S. Gninenko	Yes
LLNL, USA	M. Pivovaroff	Yes
UBC, Canada	M. Hasinoff	Yes
RBI, Croatia	M. Krcmar	Yes
UZ, Spain	J. Morales	Yes

Table 3: List of interested Institutes from the present CAST Collaboration