Calibration of the DEAP-3600 experiment

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Introduction

The discrepancy between the amount of observable and the amount of gravitating mass in galactic objects such as galaxies and galaxy clusters has evaded explanation for nearly 100 years now. The presence of dark matter is the most promising hypotheses that arose in response. The concept of dark matter has evolved over the years and is now believed to be a form of matter consisting of stable, heavy particles that do not interact through the electromagnetic or the strong nuclear force. Extensions to the standard model of particle physics provide a number of possible dark matter candidates, for example the neutralino, which are predicted to have weak interactions.

The example given in Figure 2 (a) is for the minimal supersymmetric extension of the standard model with non-universal Higgs masses (NUHM) [1].

The DEAP-3600 detector will search for Dark Matter in the form of Weakly Interacting Massive Particles (WIMPs). A 3.6 tonne liquid argon volume is both target for spin-independent WIMP-nucleus interactions and calorimeter, the latter operated in a single-phase or scintillation-only configuration. The liquid argon scintillation light is measured by 255 photo-multiplier tubes, and pulse shape discrimination is used to separate electromagnetic background from the nuclear-recoil interactions.

Overview

The detector is conceptually simple: a large spherical volume of liquid argon contained in a transparent acrylic vessel surrounded by 8-inch Hamamatsu R5912 HQE photomultiplier tubes that detect the scintillation light pulses generated in the argon (see Figure 1). The argon generates 128 nm light, which will be converted to 425 nm by tetraphenyl butadiene (TPB) wavelength shifter. This wavelength shifter is distributed uniformly over the approximately 10 m^2 inside surface of the acrylic vessel. The detector will sit inside an eight meter water shield.

DEAP-3600 will allow a three-year exposure of a one-tonne (fiducial) target of liquid argon in the SNOLAB Cube Hall, which itself has extremely suppressed backgrounds due its 6000 m.w.e. depth. Extreme care has gone into selection of detector materials, including their exposure to radon either during fabrication, or installation at SNOLAB, to ensure background target levels will be met. The acrylic vessel and lightguide acrylic have undergone extensive quality control to ensure radiopurity of the bulk acrylic [2]. The expected sensitivity for DEAP-3600 is shown in Figure 2 (a).

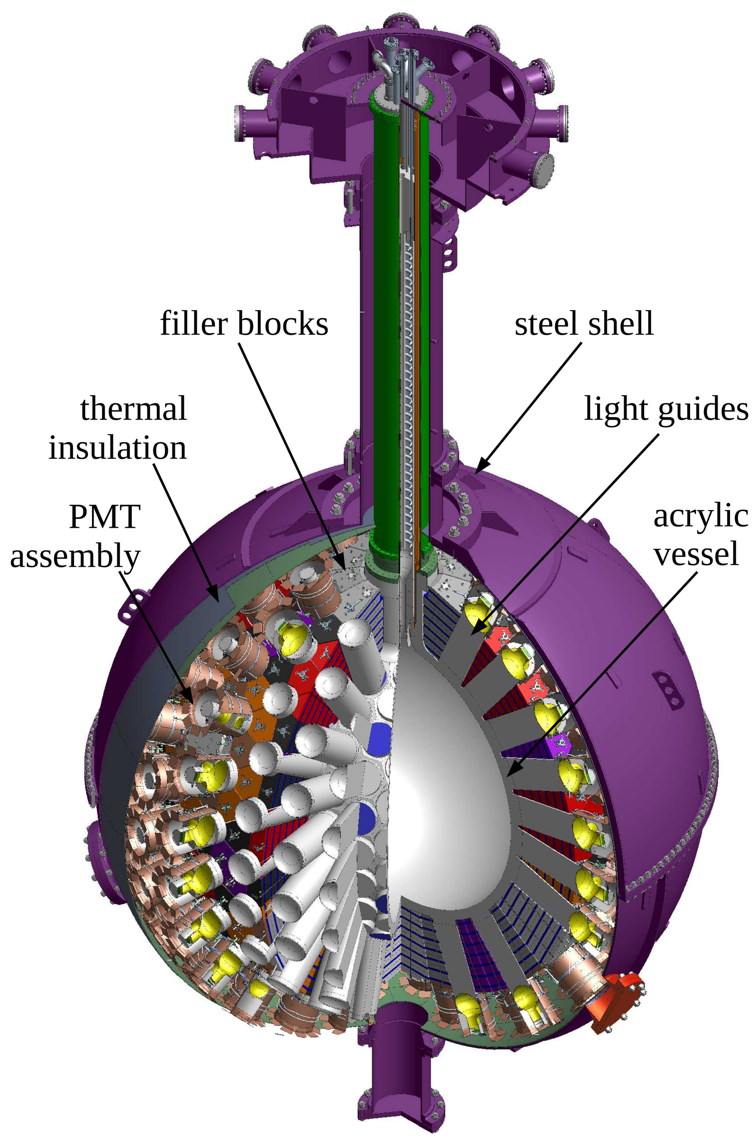
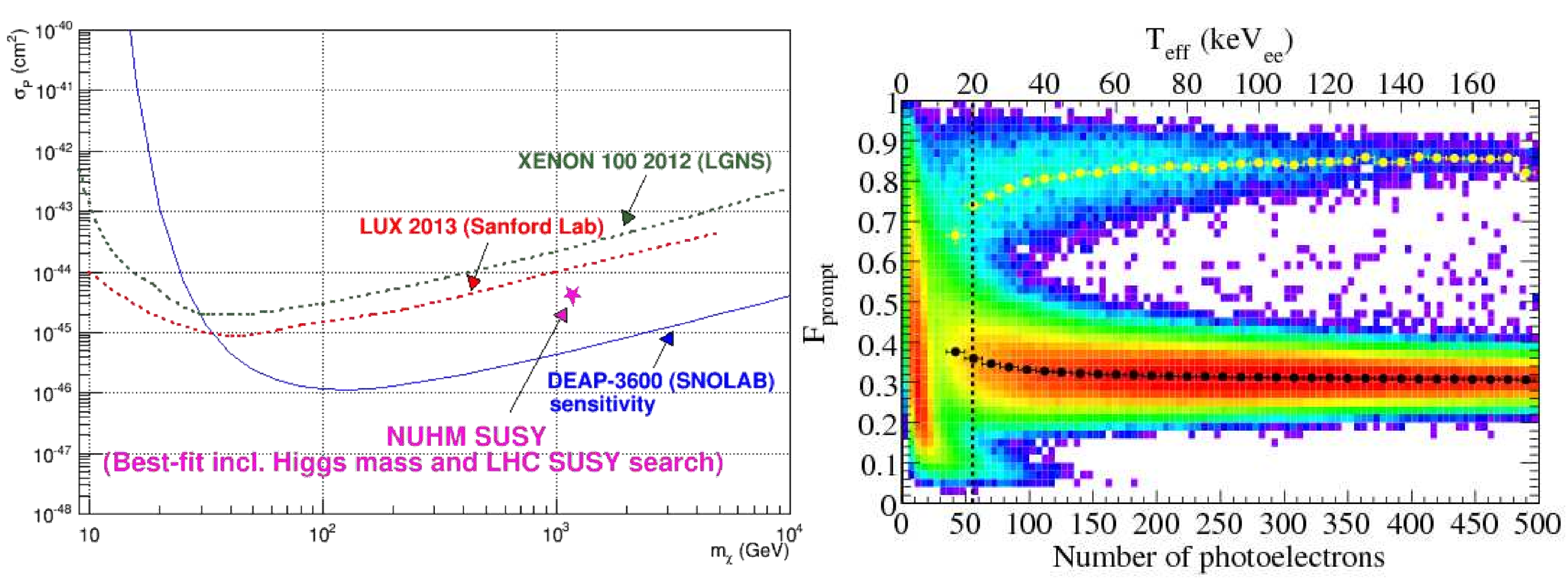


Figure 1: *Overview of the DEAP-3600 experiment.*



(a) (b)

Figure 2: *(a) Sensitivity of DEAP-3600 (3 tonne-years). (b) Pulse shape discrimination in DEAP-1 [3].*

Pulse-Shape Discrimination

When a WIMP interacts with an atom in liquid argon (LAr), excitation and ionisation leads to the production of Ar_2^*. Light with a wavelength of 128 nm is produced in the dissociation of Ar_2^*. There are two molecular states of Ar_2^*; singlet and triplet, with very different lifetimes: 7 ns vs. 1.5 μs.

In nuclear recoils, the long lifetime is less likely to survive and thus produce light. Hence, the pulse shape can discriminate between nuclear and electronic recoils by measuring the fraction of light that is prompt compared to the total amount of light observed (F_{prompt}, see Figure 2 (b)).

Calibration overview

Calibration sources inserted to the detector are a contamination risk: no sources are to be placed into the liquid-argon volume before and during data taking once the detector is filled with liquid argon.

Source calibrations

During physics data-taking, calibrations will use the internal ^{39}Ar decays, a dedicated laser and LED systems injecting light into the detector from outside, as well as external neutron and gamma sources.

A tagged ^{22}Na will be deployed via source tube going around the detector (see Figure 3 (a)), allowing to map the detector with well understood gamma spectrum and provide an energy calibration. This calibration will be aided by the uniform internal ^{39}Ar.

A tagged $AmBe$ can be deployed in a number of different source tubes around the detector (see Figure 3 (b)). This will populate detector with WIMP-like recoil events.

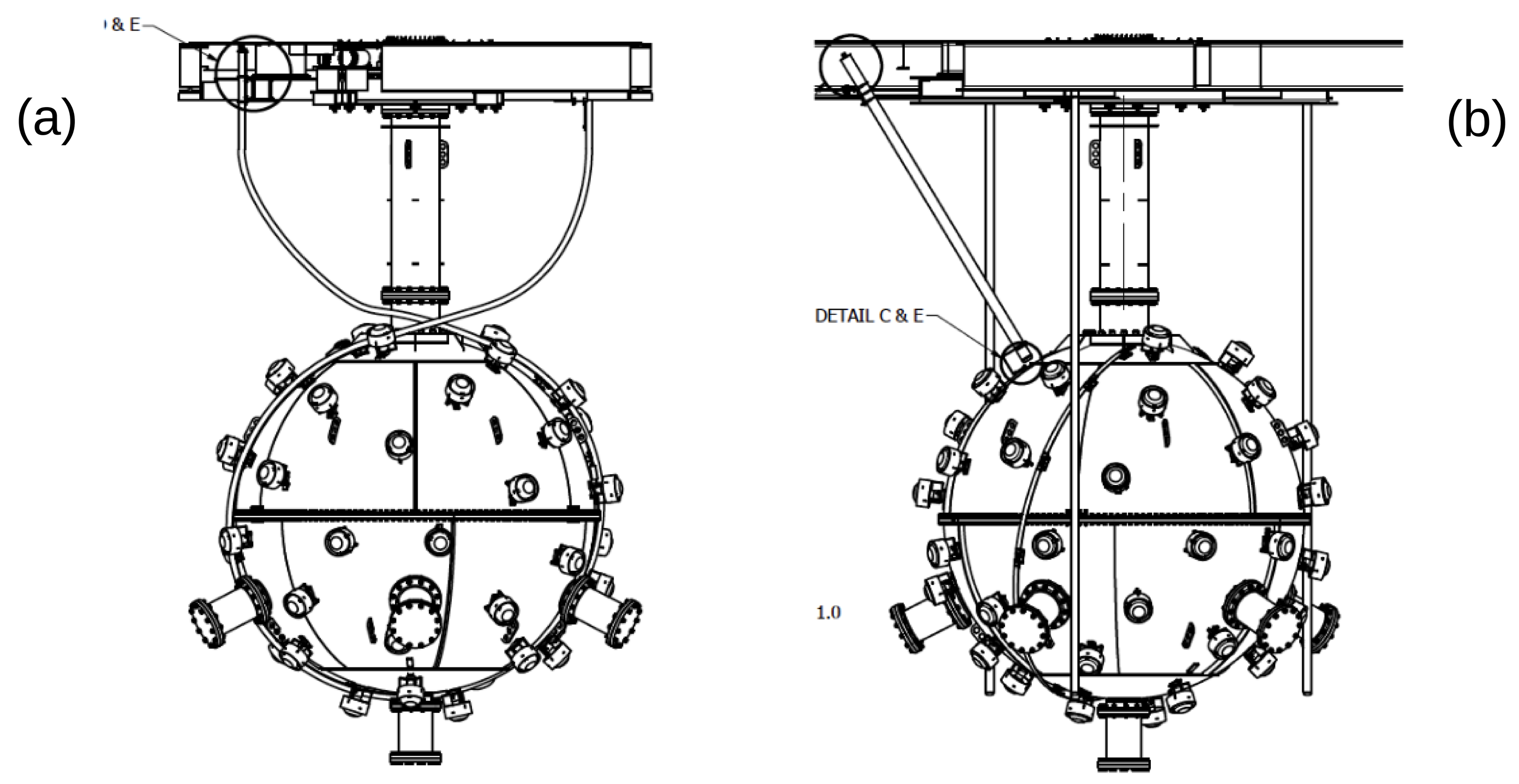


Figure 3: *The calibration tubes for the gamma source deployment(a) and the neutron source deployment.*

Optical calibration

Optical calibration will be done by four different optical systems.

During the data taking, the primary instrument to monitor the optical performance of the detector is a fibre-based light injection system that will run continiously during data taking (see Figure 4). This system will produced ultra-fast LED pulses and will be able to monitor the optical properties of the acrylic, effective gain and the timing offset of the PMTs.

This system will be complimented with a laser that can shine 244 nm VUV light pulses from the outside through the detector neck at the bottom. The wavelength shifter TPB will convert the laser pulses into blue light that can be observed through the entire detector.

Before and after the TPB deposition, when the volume is still under vacuum, the PMT array will be calibrated with tow different deployable optical sources.

The first source is a laser ball: 405 nm light pulses from a laser diode will be diffused through a spherical diffuser. This will be lowered into the vessel when vacuum, before the removal of the surface layer of the acrylic. This will allow the the commissioning of the data-acquisition system and at the same time provide a calibration of the optical properties of the light guides.

The second source is a VUV led ball: 11 wide-angle VUV LEDs uniformly arranged on a small sphere. The LEDs are driven by the same ultra-fast pulse drivers as the optical fibre system. This system will be deployed in a vacuum after the TPB has been applied to the inside of the acrylic vessel. It will provide a complete initial calibration of the detector system.

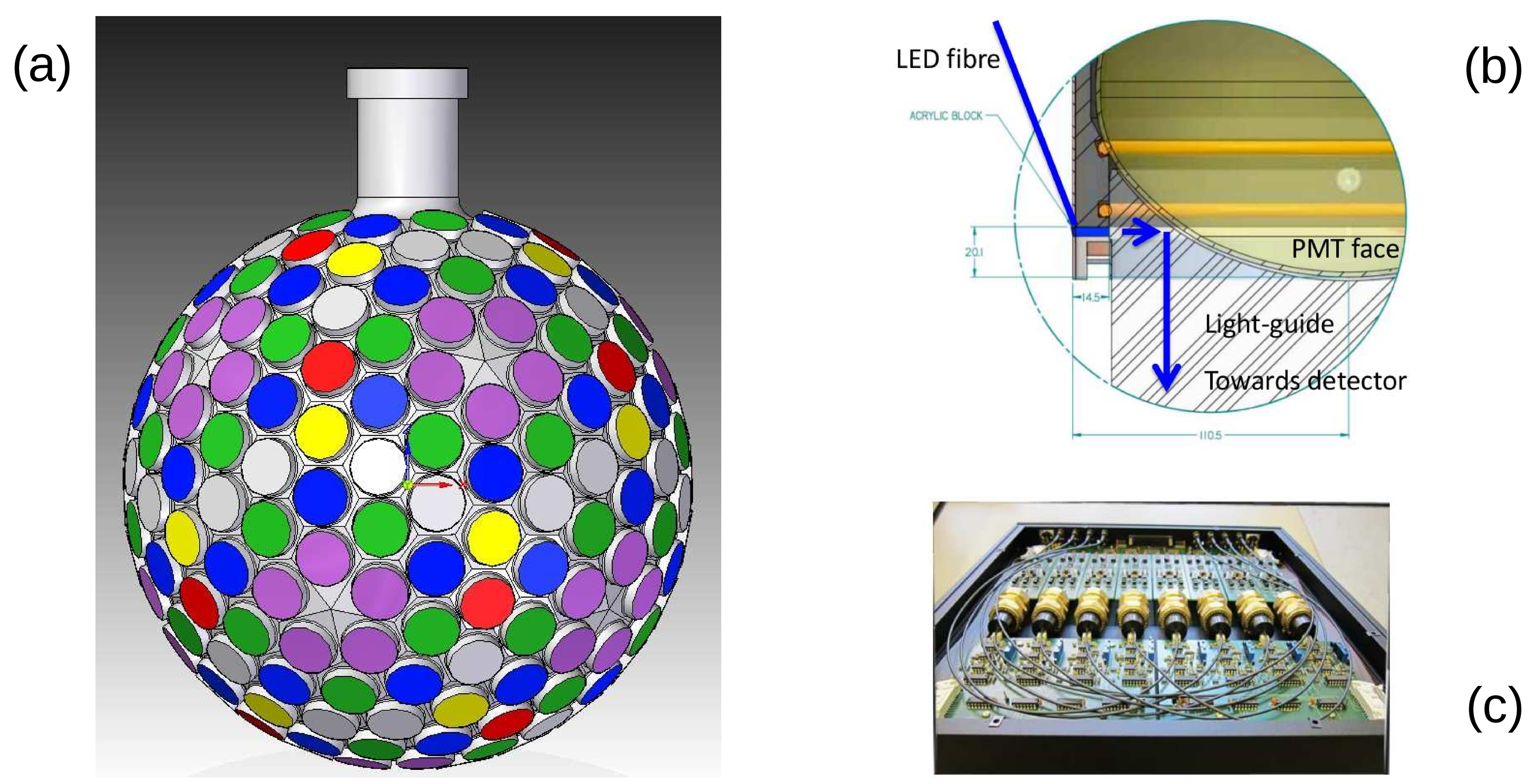


Figure 4: *LED light pulses, generated outside and guided into the detector via optical fibres, will be injected into 20 light guides evenly distributed around the detector. The injection postions are indicated in red in Figure (a). The optical pulses will be aimed at a PMT, which acts boht as a trigger and as reflector, to guide the light across the detector volume (b). The LED drivers are a much enhanced version of the Kapustinksy driver [4] (c).*

Conclusions

The first calibration data is expected during this summer. First physics data is expected this year!

DEAP-3600 is expected to have a leading sensitivity after 2 months of operation. After three tonne-year exposure, the peak sensitivity will be 10^{-46} cm^{-2} for a 100 GeV WIMP.

References

[1] *Implications of non-universality of soft terms in supersymmetric grand unified theories*, D. Matalliotakis, H.P. Nilles, Nucl.Phys. B435 (1995) 115-128.

[2] *Control of Radon-Induced Contamination in the DEAP-3600 Acrylic Vessel*, C.J. Jillings, LRT2013.

[3] *Measurement of the scintillation time spectra and pulse-shape discrimination of low-energy beta and nuclear recoils in liquid argon with DEAP-1* M.G. Boulay et al., arXiv.org:0904.2930.

[4] *A fast timing light pulser for scintillation detectors* J. Kapustinsky et al., NIM A 241 (1985) 612-613.