PROCEEDINGS OF SCIENCE

The Darkside-20k veto readout system: construction and characterization

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Darkside-20k is a global direct dark matter search experiment designed to reach a total exposure of 200 tonne-years free from instrumental backgrounds. The core of the detector is a dual phase Time Projection Chamber (TPC) filled with 50 tonnes of low-radioactivity liquid argon. The entire TPC wall is surrounded by a gadolinium-loaded polymethylmethacrylate, which acts as a neutron veto, immersed in a second low-radioactivity liquid argon bath enclosed in a stainless steel vessel. The neutron veto is equipped with large area Silicon Photomultiplier (SiPM) array detectors, placed on the TPC wall. SiPMs are arranged in a compact design meant to minimize the material used for Printed Circuit Board (PCB), cables and connectors: Veto PhotoDetection Units (vPDUs). A vPDU comprises 16 Tiles, each containing 24 SIPMs, together with front end electronics, and a motherboard, which distributes voltage and control signals, sums tiles channels, and drives the electrical signal transmission. The neutron veto will be equipped with 120 vPDUs. The paper will focus on the production of the first four vPDUs, describing the assembly chain in the UK institutes, in order to underline the rigorous Quality Assurance and Quality Control (QA/QC) procedures, up to the final characterization of the first completed prototypes. Tests have been extensively performed in liquid nitrogen baths either for the single Tiles and for the assembled vPDUs.

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1. Darkside-20k overview

The vast majority of the universe is still unresolved: only the 5% is made of regular matter, the rest is attributed to Dark Energy (68%) and Dark Matter (26%). There are several observations that prove Dark Matter existence, although its nature remains still unknown. The favourite Dark Matter candidate is the Weakly Interacting Massive Particle (WIMP), which lead to the correct density in the universe. The predicting WIMP mass is around MeV - 100 TeV [1]. Several experiments are primary focus in the high-mass WIMPs (> 10 GeV) [2] aiming to search WIMP with cross section down to neutrino "fog" [3].
Darkside-20k aims to reach a high-mass WIMP-nucleon scattering cross section of 7.4×10^{-48}cm^2 for a 1 TeV WIMP mass for a total exposure of 200 ton-year. It aims to operate in an instrumental background free condition for the full exposure, i.e < 0.1 neutron WIMP-like for a total exposure of 200 ton-year. The principal source of background is given by radiogenic neutrons and (α, n) reactions in the detector material, since that mimic the WIMP signal. The WIMP signal is characterized by a single nuclear recoil with Argon nuclei with a recoil energy between 1 and 100 keV [4] . The neutron veto plays a key role in background suppression for dark matter search. The DarkSide-20k neutron veto consists in gadolinium-loaded polymethylmethacrylate (Gd-PMMA) shell, surrounding the entire TPC and immersed in a low-radioactivity liquid argon [5] bath enclosed in a stainless steel vessel. The paper will be focus on neutron veto readout system, which consists in large area Silicon PhotoMultiplier (SIPM) array, called veto Photo Detection Unit (vPDU).

2. Neutron veto readout system

SiPMs have emerged as a compelling photosensor to detect single photons in particle physics and beyond [6]. SiPM consists in an array of Single Photon Avalanche Diodes (SPADs), a p-n junction operating in reverse bias above breakdown voltage [7]. SiPMs have several advantages than PMTs, such as better single photon resolution, higher photo detection unit, low operation voltage, lower cost per area and a radio-purity an order of magnitude lower than PMTs. Darkside-20k SiPM consists in an array of 94.900 SPADs for a total area of 8 x 12 mm^2. DarkSide-20k SiPMs requirements are: breakdown voltage of 28 V, signal to noise ratio higher than 8, dark current rate <0.001 Hz/m^2, cross-talk probability is 33% and after pulsing probability is lower than 10% at operation voltage of 7 V over-voltage (VoV) [8].
The single unit of a vPDU is an array of 24 SiPMs, called tile, for a total area of 24 cm^2. Each tile consists in a single printed circuit (PCB): the front side contains SiPMs array electrically connected trough wire-bonding, the back side contains the electronic front end, which sums together SiPMs response and amplified them with an ASIC device. A vPDU consists in an array of 16 tiles placed in a larger PCB of a total area of 400 cm^2. The PCB is used for control signal, biasing each tile and signal conditioning. Each vPDU has 4 readout channels since four tile are summed together. Figure 1 shows a tile and vPDU.
The neutron veto will be equipped with 120 vPDUs, which correspond to a total of 480 readout channels. The expected light yield is 2.0 pe/keV. A MonteCarlo simulation based on Geant4 [9] of neutron background from different detector components was performed in order to compute neutron detection inefficiency [10]. Neutron capture of Gd produces a high energy gamma cascade

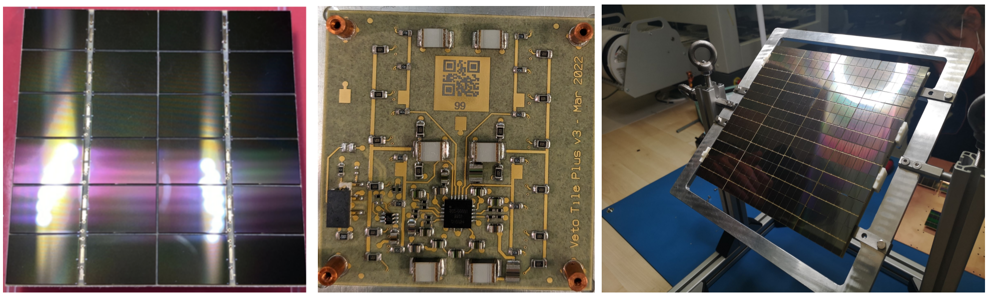

Figure 1: Left: Front and back side of a veto tile. Right: a vPDU

	From summing [Bq]	From assay [Bq]
Uup	2.2E+00	2.3E+00
Umid	1.2E+00	1.3E+00
Ulow	5.8E+01	**8.4E+01**
Th232	1.3E+00	1.1E+00
Ur-235	1.6E-01	1.1E-01
K40	1.4E+01	1.3E+01

Figure 2: Radioactive budget comparison between summed components and direct measurement.

(8 MeV), which can be detected in the neutron veto or in the TPC itself. Events with an energy deposit higher than 50 keVee in the TPC or 200 keVee in the veto, in a coincidence time window of 800 μs with a WIMP-like event, are tagged as neutron-induced. The total neutron detection inefficiency is 1.6×10^{-5}, evaluated as the fraction of simulated events (250×10^8) which survive the veto cuts and it is reduced by 20% including electronics response, SiPM noise and pile-up. The neutron background events expected are less than 0.1 in a full exposure of 200 ton-year.

3. veto PhotoDetectionUnits: production and testing

vPDUs production line is developed along different UKs institutions. The first step is front-end electronic PCB production at University of Birmigham. The second step is die attach and wire-bonding at University of Liverpool and at STFC interconnect. The final step is the vPDU integration at University of Manchester. All these steps are performed in class ISO5-ISO7 clean rooms, with a radon control system in order to minimize any possible recontamination. The radon level in each clean room is lower than 5 Bq/m^3. Each vPDU components was assayed trough ICPMS [11] and BeGe [12] in order to quantify radioactive budget and select the most radio-pure material. A full populated board were also assay in order to check production line, comparison between summed components and direct measurement is reported in figure 2. This outstanding results shows negligible differences, there is no additional contamination during manufacturing process.

Four pre-production vPDUs were assembled in order to test and to optimize the full production line and define Quality Assurance and Quality Control (QA/QC) criteria in each step of the production. The performed tests includes charge injection on the populated readout unit of the tile before die attach, single tile and vPDU in a liquid nitrogen cold test stand. A single tile testing, able to test 4 tilles per time, is developed at STFC interconnect. The main facilities of vPDU cold test is developed at University of Liverpool, which aims to test 20 tiles per time. There are also

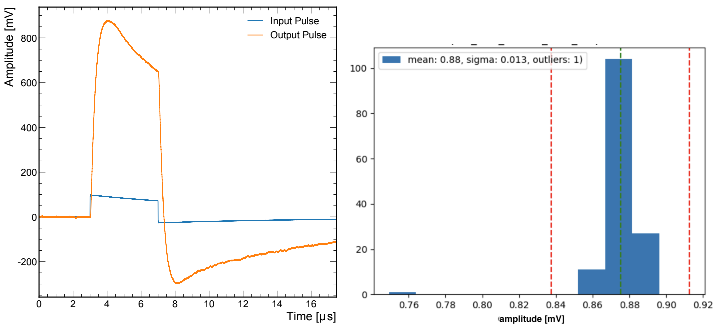

Figure 3: Left: charge injection pulse in blue and output pulse in orange. Right: distribution of pulse amplitude

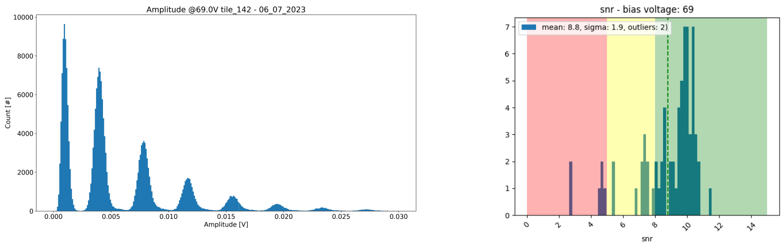

Figure 4: Single tile amplitude spectra of a single tile and SNR distribution from pre-production tile testing.

other 3 smaller facilities for vPDU cold tests: at the University of Edinburgh and the University of Lancaster (which aim at testing 4 units per batch), and at AstroCeNT/NCAC PAS in Warsaw (capable of testing 10 units per batch).

The first performed test is charge injection to test tile front end electronics before die attach of SiPMs. During this test, a 100 mV, 4us, 1kHz input pulse to measure rise time and amplitude of the ASIC response. In figure 3 is reported an example of ASIC response during charge injection test on the left and the amplitude distribution on the right. QA/QC current criteria are a rise time between 380 and 583 ns and an amplitude between 837 and 913 mV.

Each tile, after die attach, is tested at liquid nitrogen temperature to establish whether a tile has single PE detection performance good enough to integrate into a vPDU. The same happen for the vPDU to establish whether a vPDU has single PE performance good enough to integrate into DarkiSide-20k neutron veto. QA/QC are defined for both, tile and vPDU at the operation voltage of 7 VoV trough a laser calibration. In figure 4 is reported an example of amplitude spectra of a single tile on the right and signal to noise ratio (SNR) distribution on the left. SNR is defined as the ratio between 1 PE amplitude and the RMS of baseline, estimated in the pre-trigger region. QA/QC acceptance criteria required a 1 PE amplitude between 3.7 and 4.3 mV and SNR higher than 8. SNR higher than 8 corresponds to an SNR higher than 10 for the tile integrated into MB. The relative improvement is due additional filtering to optimize noise on the vPDU. The QA/QC criteria for the vPDU is not defined yet due lack of statistics, only 3 vPDU have been tested. An example of PE distributions per quadrant is reported in figure 5. One quadrant correspond to the sum of four tiles, i.e. 10×10 cm area and the 1PE is around 14 mV.

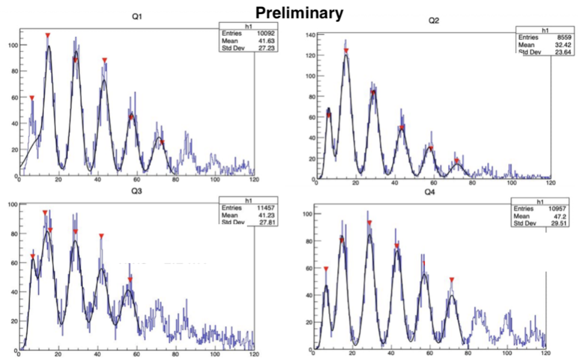

Figure 5: Amplitude spectra for each quadrant of the vPDU.

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