LBNF LONG-BASELINE NEUTRINO FACILITY DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT	Standard

Title: **Procedural instructions for CACTUS operators**

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REVISION HISTORY

Version	Description of Change	Author	Effective Date
0	Initial Release	Maritza Delgado	05Apr2024

REFERENCE DOCUMENTS

Document ID Number/URL	Document Title
DUNE-TDR	DUNE – Technical Design Report
QAM 12002	Fermilab Quality Assurance Manual
Dune-doc-120	LBNF/DUNE Quality Assurance Plan
https://www.msha.gov/	Mining Safety and Health Administration (MSHA)
https://www.osha.gov/	Occupational Safety and Health Administration (OSHA)

TABLE OF CONTENTS

1 Introduction

The CACTUS (Cryogenic Apparatus for Control Tests Upon SiPMs) is an experimental apparatus, it was developed to perform the quality assurance (QA) tests to produce the DUNE FD1 SiPMs.

This facility allows for testing important parameters of SiPMs such as the break-down voltage (Vbd) at room temperature and liquid nitrogen temperature (77K), the quenching resistor (Rq) at room temperature and liquid nitrogen temperature, and the dark count rate (DCR) at 77 K.

The operation of CACTUS is performed in shifts by one or two operators per day. CACTUS operators are responsible for performing the tests mentioned above and are responsible for checking the results of the analysis software and they signal the occurrence of anomalies or deviations from tolerance.

2 Purpose

This document contains the procedural instructions used for the execution of single tests of the SiPMs in CACTUS, illustrates the expected results according to the DUNE requirements, concluding with the list of equipment, safety materials and checklist necessary for a CACTUS operator.

3 Scope

The procedural instructions and materials described in this document are applicable to operators at the 5 CACTUS Sites in Europe: Ferrara, Bologna, Granada, Milano Bicocca and Prague.

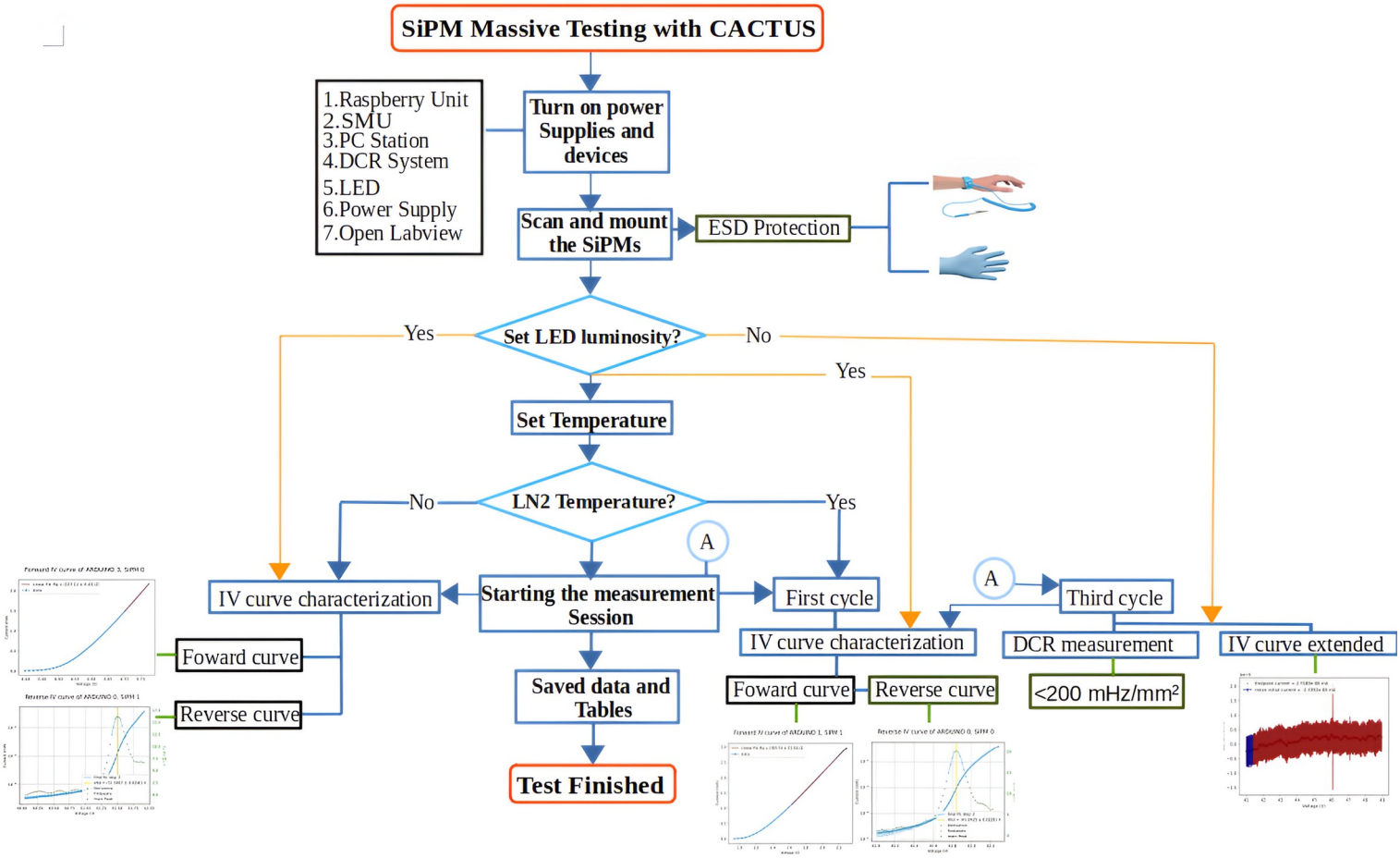
4 Definitions and Acronyms

DocDB	Document Database (DocDB-####)
CACTUS	Cryogenic Apparatus for Control Tests Upon SiPMs.
EDMS	Electronic Data Management System (EDMS #)
Document ID	Alphanumeric document ID or document hyperlink location
Procedure	A fixed, step-by-step sequence of activities or course of action (with definite start and end points) that must be followed in the same order to correctly perform a task. The activities are at a higher level than work instructions.
QA	Quality Assurance
QC	Quality Control

Work Instruction

Work instructions present a sequence of detailed steps to execute a task or activity. The format is typically text, but a visual depiction of the steps can also constitute work instructions. Additionally, hyperlinks are often included. A mix of text, hyperlinks, and pictures are also included in documenting the process steps. Work instructions are much more detailed than procedural steps.

5 Work Instruction Steps



6 Responsibilities

The operator CACTUS shall:

- Perform the measurements:

- Foward and reverse I-V curves at room temperature and LN2 Temperature.
- I-V extend at Vbd+9V of OV, without light.
- DCR measurement with a time window of 120 seconds and the Bias Voltage= Vbd+3V.

- Review the results of the analysis software and they signal the occurrence of anomalies or deviations from tolerance.
- Compare the vendor's data with the data obtained from measurements at room temperature.
- Verify that the data from the first cycle are compatible with those from the third cycle at LN2 temperature.
- Create and upload the tables in the DUNE hardware database.

7 Authorization

It is recommended that the CACTUS operator have:

- Cryogenic Safety Training or training in handling of liquid nitrogen and cryogenic substances.
- Trained to handle the SiPMs boards.

8 Hazards

*** Electrostatic discharges (ESD)**

The handling of SiPMs boards poses a risk of electrostatic discharges (ESD), this is a hazard for the SiPMs board and not for the operator. Consequently, such handling takes place in a static-safe work area known as the “mounting station”, located adjacent to CACTUS. Since SiPMs are not active electronic circuits but are equivalent to an epoxy/silicon packaged p-n junction, the ESD countermeasures implemented at the mounting station align with those established by the packaging companies of the vendors.

The operator who handle the SiPM wears a grounded anti-static wrist strap and safe anti-static gloves. The mounting of SiPMs on the cold boards takes place in a station (mounting station) equipped with an antistatic mat (i.e., a static dissipative tabletop) located near the CACTUS setup.

The operator is trained to handle the boards by the edges, avoiding unnecessary contact with the board pins or the SiPM surface.

After SiPM testing, they are carefully removed from the cold boards using the same precautions and placed back in their original positions in the tray.

The tray is then repacked in antistatic bags and returned inside the original box. Shipping from the

CACTUS site takes place once an entire box has been tested.

* **Cyrogenic liquids**

There are three groups of health hazards associated with cyrogenic liquids: extreme cold, asphyxiation, and toxicity.

The 5 CACTUS Sites in Europe have well-ventilated location, and CACTUS operators have the necessary training and safety materials such as cryogenic gloves to avoid the aforementioned dangers.

It is important to highlight that the hosting university or laboratory has reviewed safety issues and has given clearance for operation.

9 Required Safety Equipment

The operator in each CACTUS installation has the following safety materials available:

List of Cautionary, Warning, Danger and misc. icons to be used for applicable work instructions:

☐ Cryogenic Gloves	☐ ESD Protection	☐ Gloves & Hand Protection	☐ ESD Caution	☐ Gloves & Hand Protection	☐ Cryogenic Danger
					

10 Prestart Requirements

The CACTUS operator, before starting the SiPMs tests, shall:

- Check the level of liquid nitrogen in the Dewar.
- Verify that the cold boards and connector cables are free of moisture.

11 Measurement Equipment Required

✓MotherBoards DC power supplies

✓Sourcemeter

✓Power supply for the DCR system

✓MS bias (actuator and controller)

✓Dual channel DC bias for LED system and heating system

12 DUNE requirements

During the analysis and approval of the data obtained from CACTUS, the operator must check that the values obtained in each measurement are within the DUNE Physics Requirements and are summarized below:

Requirements	Range	Description
Breakdown voltage (V_{bd}) spread.	< 200 mV (max-min)	Mean spread for a group of 180 SiPMs (one PDS module)
Maximum V_{bd} voltage spread	< 2 V (max-min)	Maximum spread without grouping.
Dark Count rate	< 200 mHz/mm^2 at Vop	At LN_2 temperature per SiPM.
Thermal cycles	> 20	Tested at 77 K

Table 1: DUNE requirements

13 Check list procedural Steps

This procedure will be used by the operators of each of the CACTUS facilities when testing 20 SiPM Boards “One Tray”.

The procedure is the following:

☐ Turn on power Supplies and devices.
- ☐ Raspberry Unit
- ☐ SMU
- ☐ PC Station
- ☐ DCR System
- ☐ LED
- ☐ Power Supply

☐ Launch the Raspberry daemon scripts.
- ☐ DAQiv.py
- ☐ Temp_meas.py

☐ Open The LabVIEW interface.

☐ Check in LabVIEW the setup, IV parameters and set the tray number to be tested.

☐ Take an ESD safe tray of 20 SiPM boards.

- ☐ Wearing ESD safe gloves and an ESD wrist strap
- ☐ Roll the plastic holder over the ESD mat to ensure it is discharged.

☐ Scan QR code reported on the back of each SiPM Board.

☐ Install the SiPMs boards in one of the cold boards.

☐ Move the cold boards to the CACTUS test system.

☐ Set and control of the LED luminosity at room temperature.

☐ Start with IV curve measurements, at room temperature: Forward and Reverse.

☐ Verify analysis and save data locally.

- ☐ Is the measured Vbd at room temperature consistent with vendor data within the CACTUS precision? ☐ Yes ☐ No
- ☐ Is the measured current at Rq at room temperature consistent with the set range for CACTUS (HPK:115.4±21.9Ω)?☐ Yes ☐ No
  - ☐ If the answer is no to the previous questions, it should be reported in the data table.

☐ LN2 refill only if necessary.

☐ Immerse the cold boards in the LN2 and close the Dewar.

☐ Set and control of the LED luminosity at LN2 temperature.

☐ Start with IV curve measurements, at LN2 temperature: first cycle.

☐ Verify analysis and save data locally.

☐ Start thermal cycles: Two full immersion.

☐ Perform the IV curve measurements, at LN2 temperature: third cycle.

☐ Verify analysis and save data locally.

- ☐ Are the I-V curve forward and reverse consistent before and after three thermal cycles within the CACTUS precision? ☐ Yes ☐ No
- ☐ Is Vbd at 77 K within 200 mV from the mean Tray value after 3 thermal cycles? ☐ Yes ☐ No
  - ☐ If the answer is no to the previous question, it should be reported in the data table.
- ☐ Is the measured current at Rq at room temperature consistent with the set range for CACTUS (HPK:386,6±26,5Ω)?☐ Yes ☐ No

☐ Turn off the LED.

☐ Perform the extended IV curve characterization.

☐ Verify analysis and save data locally.

☐ Perform the DCR measurement.

☐ Verify analysis and save data locally.

- ☐ Is the DCR at 45% PDE taken after 3 thermal cycles within the allowed range (< 200 mHz/mm2) ? ☐ Yes ☐ No
- ☐ Is there a Noisy SiPM with high Dark Count Rate and shows anomalous reverse IV curve in an extended Vbias range? ☐Yes ☐No
  - ☐ If the answer is yes to the previous question, it should be reported in the data table.

☐ Save all the data,create and upload the data tables into DUNE database.

☐ Dry and disassemble the cold boards and SiPMs.

☐ Repackage the tray in antistatic bags and return inside the original box (Wearing ESD safe gloves and an ESD wrist strap).

14 APPENDIX I : Issues

During the analysis and approval of the data obtained from CACTUS, the operator may find some anomalous data or plots, which will indicate some issues with the software, hardware or an noisy SiPM. The most frequent issues are:

1. **Anomalous forward I-V curve**

If during the analysis, a forward curve is observed as illustrated in figure 1, the analysis will need to be performed again. But first, verify that there is no presence of moisture in the Bias connector, or that the bias connector is making good contact with the cold board. If the previous plot is only observed in some channels, the problem may be in the warm amplification stage (Daughter boards connected to a Mother warm board).

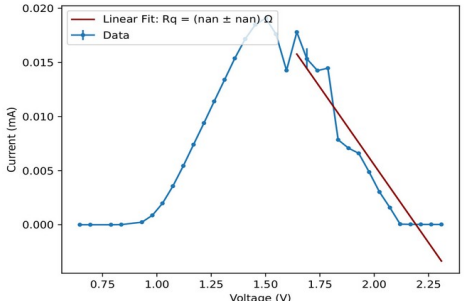


Figure 1: Anomalous forward IV curve

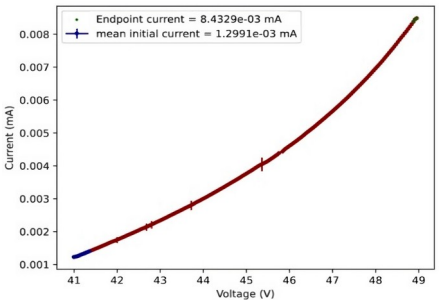


Figure 2: Anomalous extended reverse IV curve

2. **Anomalous extended reverse IV curve**

Anomalous extend reverse IV curve refers to currents are defined as currents above 10 nA at 1.7 V in reverse polarization and has a behavior as seen in figure 2.

If the SiPM was not exposed to any light source, it should be verified whether it is a noisy SiPM by corroborating the DCR data.

3. **High DCR**

Noisy SiPM has been detected, when samples with high Dark Count Rate (> 200 mHz/mm2) show anomalous reverse IV curve in an extended Vbias range.

If an anomalous curve is not obtained, fake events can be obtained in the DCR due to the detection

of environmental noise, electronic noise or poor light isolation. This can be verified by running the DCR script with a bias voltage set to 1V.

4. **Anomalous reverse IV curve**

When the luminosity of the LEDs is not homogeneous for all SiPMs, unusual results such as the one in figure 3 can be observed. It is important that the CACTUS operator sets the proper illumination conditions to improve the analysis. This may vary with orientation and sun exposure at each CACTUS site.

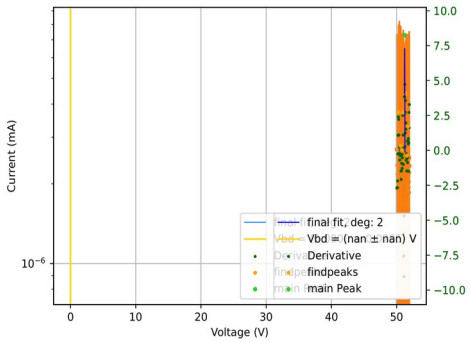


Figure 3: Anomalous reverse IV curve