

2x2 Modules production and tests in Bern

Module 0 test 1: March 27 - April 12, 2021

Module 0 test 2: June 21-27, 2021

Module 1 test: Feb 3-13, 2022

Module 2 test 1: Nov 13 - 22, 2022

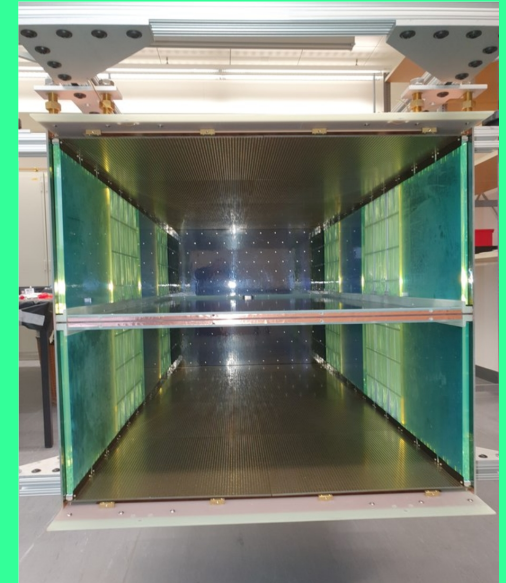
Module 2 test 2: Nov 28- Dec 5, 2022

Module 3 test : expected to start Jan 27, 2023

Module 0 test 1 objectives

1. Confirm ability of the system to reach target LAr purity with vacuum prior to LAr filling
2. Test full readout in 63x64x120 cm 2x2 TPC module
ArCLight/LCM : DAQ throughput, PDE, coordinate, time resolution
LARPIX : DAQ stability, throughput, noise, uniformity
3. Test timing synchronization for LARPIX and LRS (PPS from GPS unit)
4. Validate and quantify charge-light matching between ArCLight/LCM and LARPIX data.
5. Confirm LCM triggering capability for full module
6. Assess drift field uniformity with a set of (straight) muon tracks
7. Basic physics standart candles: dE/dx , (dQ, dL) , MCS, Michel electrons...

Detector assembly



Cryogenic laboratory



Run schedule

27 Mar - 28 Mar evacuation of the detector, leak fixing (4e-5 mbar reached)

29 Mar - 30 Mar cooldown and filling with LAr

30 Mar — 1 Apr start of DAQ, calibrations, debugging of subsystems

1 Apr - first HV @ 0.25 kV/cm. By the end of the day - HV @ 0.5 kV/cm, stable

2 Apr - 6 Apr HV @ 0.5 kV/cm, optimizing CDS-LDS links
optimizing CDS efficiency and noise, taking cosmic data, pedestals

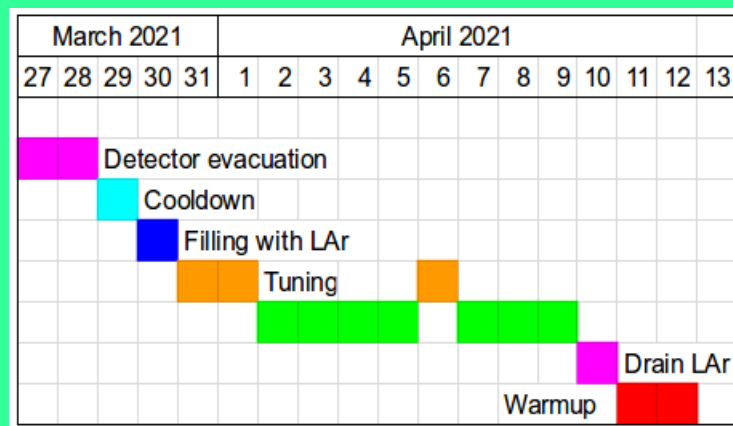
6 - 7 Apr — Special runs at various HV (0 to 1kV/cm)

8 Apr - HV scan for charge-light anticorrelation study

9 Apr - More cosmics at 0.5kV/cm mainly for stopping muons analysis (captures+Michels)

10 Apr - 8:00 last data run, simulation of «loss of cooling» event, start emptying detector

13 Apr - Detector is at room T, 24-h shifts are finished.



Reference documents : https://wiki.dunescience.org/wiki/ND_LAr_Test_Runs

Data collection summary

~550 **20'**-long runs in total

~ **250 «good for analysis»** - both light and charge data present, full overlap

~60'000'000 events

@ 0.5 kV/cm

182 runs

@ 1 kV/cm - 0kV/cm in steps of 50V/cm (HV scan)

24 runs

@ 1.0 kV/cm

12 runs

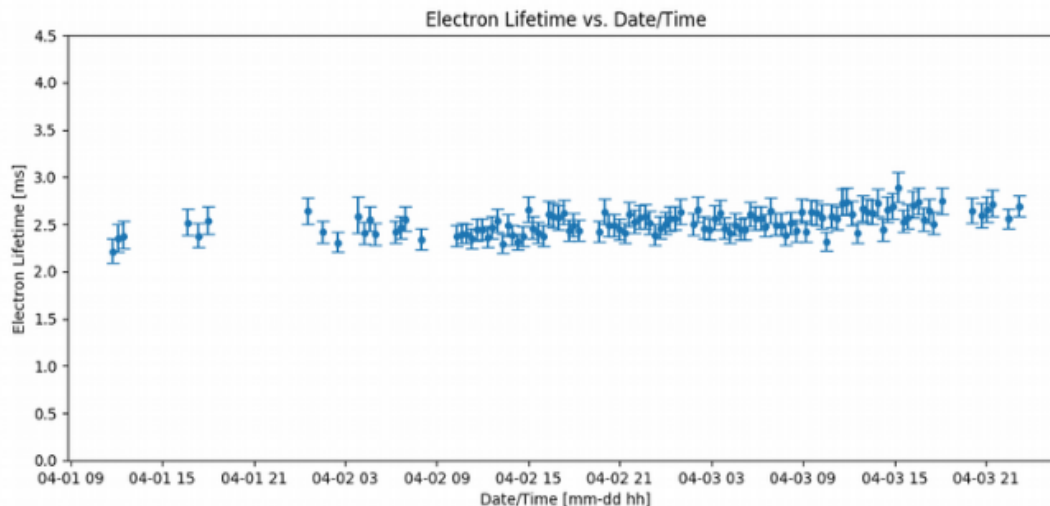
Charge run size: varies from 0.6 to 6 GB

Light run size: 7GB (256 samples), 22GB (1024 samples)

Total data **9.2 TB**

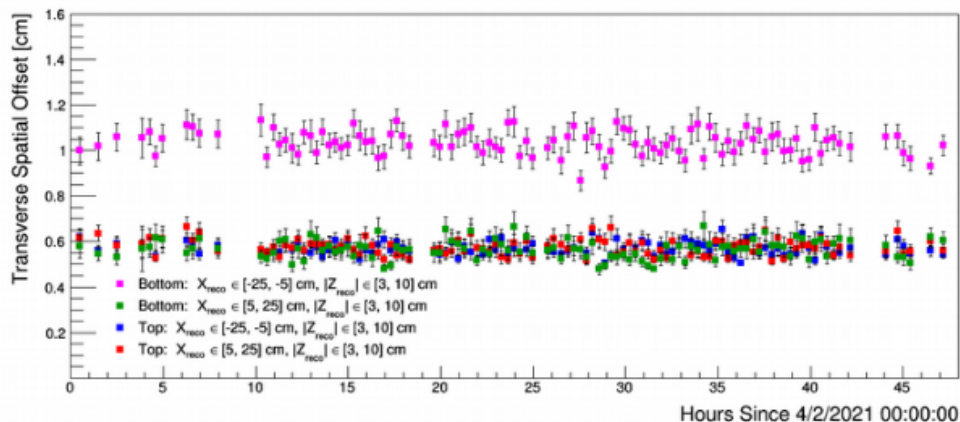


Electron Lifetime Studies



- ◆ Select anode-cathode-crossing tracks for electron lifetime studies: track Z values span entire drift distance
- ◆ Electron lifetime stable at **~2.5 ms** (and slowly rising?)
- ◆ Next step: measure across entire Module 0 run, provide results to analyzers

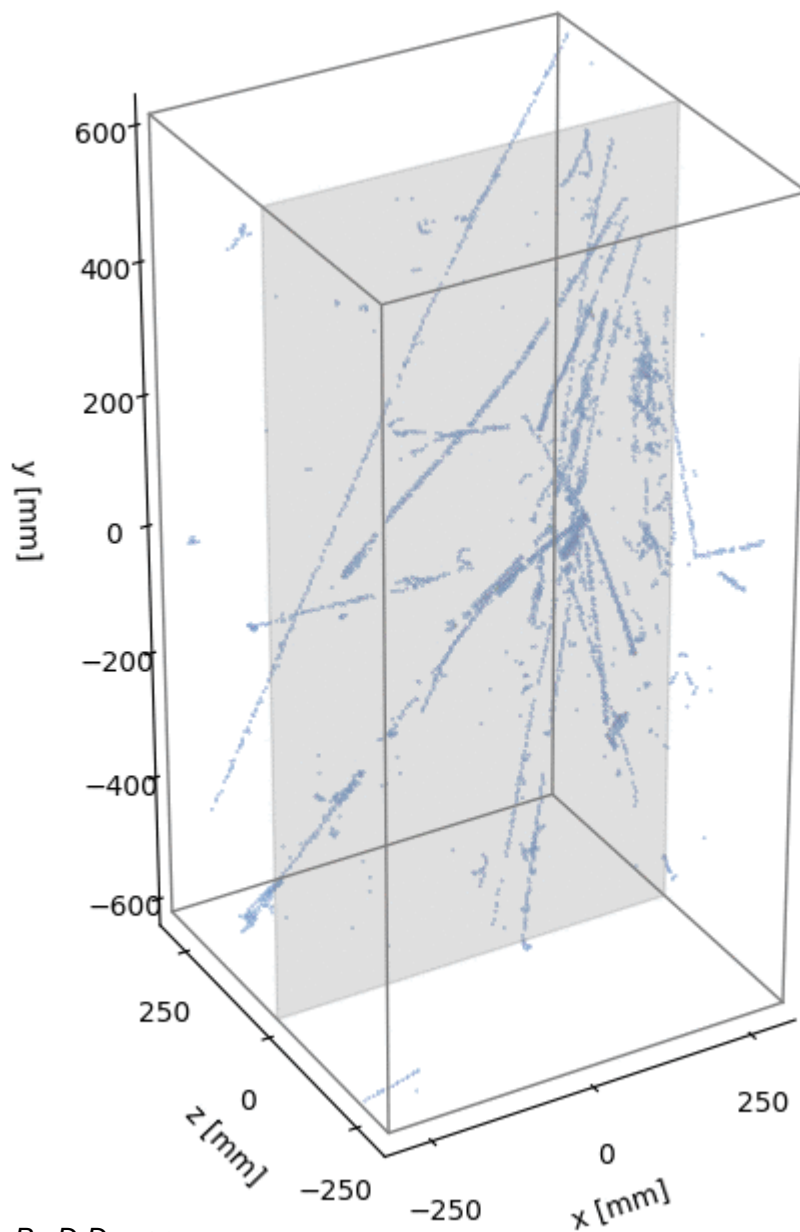
$Z < 0$



- ◆ Max (average) transverse spatial offset 3.5 (2.0) cm
 - Accounts for additional offsets from edges of pixel planes to light detectors (sides), field cage (top/bottom)
 - Translates to max (average) transverse E field of 60 (30) V/cm, and max (average) E field magnitude shift of **0.7%** (0.2%), which is smaller than 1% physics requirement
- ◆ Very little time dependence (< 0.2 cm) → can calibrate out!

M. Mooney @ LAr Analysis Workshop this week. 8

Cosmic event gallery



By D.Dwyer

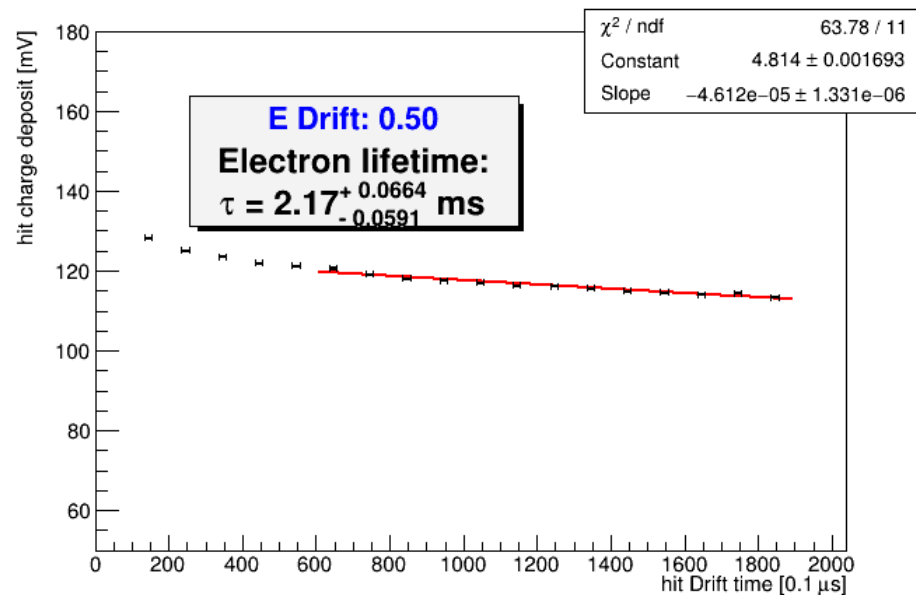
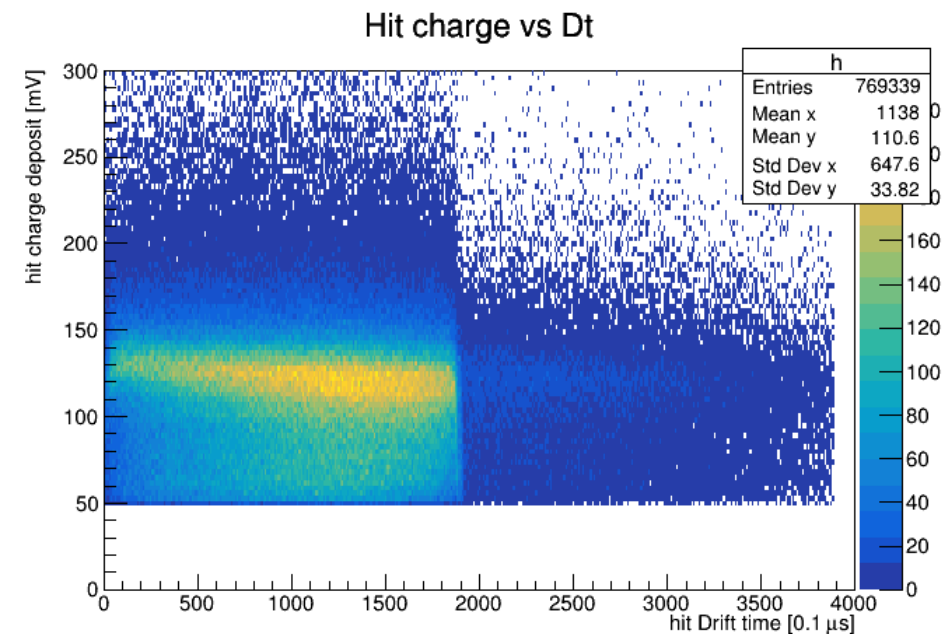
Module 0 Test 2 objectives

1. Reach the purity with piston purge.
2. Take some more LED pulse data for pulse shape analysis for LDS
3. Measure noise spectrum on the field shell shunt.
4. Gradually lower cooling flow till we have boiling at the ASICs - define the limit
5. Measure noise spectrum on PACMAN analog monitor
6. Take data with trigger from 1 to 4 pixels via analog monitor (& signal from LDS) to study far-field induction effects on the pixels

Purity Mod 0 test 2

1. Reach the purity with piston purge.

After ~200 gas volume exchanges, the H₂O level dropped below 1 ppm and after filling and recirculation for 1 day we are at **2.2 ms life time**.



Module 1: What's new compared to Mod-0?

LRS:

- Novel DAQ and signal processing
- SiPMs with higher PDE
- Better EMI shielding on E-boards

CRS:

- Novel tile PCBs
- Novel tile setup and configuration software
- Improved grounding on TPC1

SC:

- Monitoring of tile voltages & currents
- Improved data representation

Module -1 Collected events and conducted studies

Normal conditions

109 Runs ~ 20 min each (150 Hz trigger rate) : ~19e6 events

Special runs:

Threshold scan on CRS

PACMAN clock study (reduced Sync frequency)

CRS analog pixel response study (waveforms recorded)

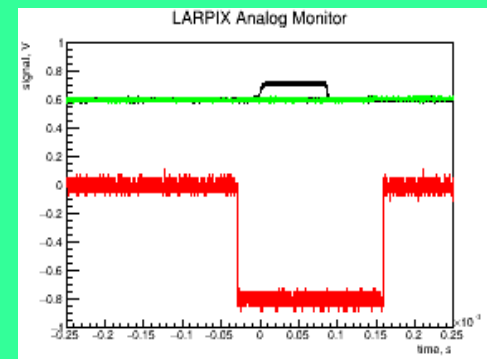
Threshold scan on LRS

Double-pulse LRS LED test

LRS time resolution test with calibration system (Blue & UV LEDs)

Cryogenic flow scan

No-flow detector stability test



Module - 2 highlights

LArPix V2B ASIC:

improved signalling

lower noise/pickup

higher number of channels / ASIC (64 vs 49)

higher number of pixel on tiles (6400 vs 4900)

smaller pixel pitch (3.8 vs 4.4)

In the first test run a problem with sleeve identified ...

Sleeve difference in Module-2 compared to 0 and 1



Suspected «ringing» of the sleeve

Fixed sleeve



Nov 22 - started to drain LAr

Warmed up the detector

Extracted from the sleeve

Glued the corners with 2 layers
of glass fabric & epoxy

Re-inserted to the sleeve

Cooled down and filled again...

Filling started Nov 28 Monday
with vacuum level $\sim 3e-3$ mbar

Recool-refill-restart

The noise is suppressed !
(see details from CRS team)

Module 2 Run - 2

Measurements program:

- CRS qualification Nov 29 - end of run
- LRS qualification Nov 30
- HV ramp program for field shell charging studies Dec 2
- HV scan program for recombination studies (charge-light anticorrelation) Dec 2
- Cosmics data taking Dec 3 - Dec 4

Run - 2 data summary

In both runs we have aquired :

LRS data - 23.5 TB

CRS data - 4.4 TB

approx 10h of cosmic data @ 450 Hz of trigger rate

~ 50 runs (10 mins) for field shell charging studies

~ 50 runs for recombination studes

much more for the CRS qualification

Modules performance summary

	Module 0	Module 1	Module 2	Module 3
LArPix ver.	v2A	v2A	v2B	v2A
Pixel pitch,mm	4.434	4.434	3.8	4.434
CDS Threshold	5.8 ke, ~1/4 MIP	4.5 ke, ~1/5 MIP	7.5 ke, ~2/5 MIP	?
Inactive channels	7.8%	2.4%	tbd	?
LDS PDE: LCM	0.6 %	0.6 %	0.6 %	?
LDS PDE: ACL	0.06%	0.2 %	0.2 %	?
LDS threshold	~ 5 MeV	~ 1.6 MeV	< 1.6 MeV	?
LDS timing	< 2 ns	1.2 ns	1.2 ns	?
Field shell	DR8	DR8	DR8	DR8
Purity reached	> 2 ms	> 2 ms	> 2 ms	?
Field tested	1 kV/cm	0.5 kV/cm	0.8 kV/cm	goal 1 kV/cm

Where they are now?

Module 0 : FNAL since October 6, 2022

Module 1 : FNAL since June, 2022

Module 2 : FNAL since Jan 16, 2023

Module 3 : Bern, expected to go to FNAL mid - Feb, 2023 if tests are successful

