ProtoDUNE-DP construction and status

D. Duchesneau
on behalf of the ProtoDUNE-DP Collaboration

- Context
- Detector installation highlights
  - Charge Readout Planes and Electronics
  - HV system
  - Photon detection system
- Cryostat instrumentation and cryogenics
- Summary

GDR meeting
LPNHE, June 26th, 2019
Two LAr TPC technology foreseen for DUNE far detector modules

Prototypes to validate:
• Technological characteristics
• Production and installation procedures
• Design and performance
Demonstrate long-term operation stability

The feasibility of both technologies at large scale is being tested with the ProtoDUNE detectors
ProtoDUNE-DP (NP02)

Components and operating conditions

Dual phase:

- **Induction Field:** nominal at 5 kV/cm
- **Amplification Field:** nominal at 30 kV/cm
- **Extraction Field:** nominal at 2 kV/cm in LAr

**Electronics**

**Charge Readout Planes (CRP)**

**Field Cage**

**Cathode**

**Ground grid**

**Photomultipliers**

-300 kV: 6 m drift => drift time = 3.7 μs
Electron lifetime goal at 7 ms (corresponding to 40 ppb of impurities)

-300 kV:

<table>
<thead>
<tr>
<th>Component</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 m drift LIQUID</td>
<td>6 m</td>
</tr>
<tr>
<td>GAS</td>
<td>6 m</td>
</tr>
<tr>
<td>Drift Field</td>
<td>15 mm</td>
</tr>
<tr>
<td>Extraction Grid</td>
<td>5 mm</td>
</tr>
<tr>
<td>Extraction Field</td>
<td>5 mm</td>
</tr>
<tr>
<td>Amplification Field</td>
<td>5 mm</td>
</tr>
<tr>
<td>Induction Field</td>
<td>5 mm</td>
</tr>
</tbody>
</table>

**Electronics**

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Charge Readout Plane (CRP)

Components

- Invar (FeNi36) Frame
- G10 Frame + Extraction Grid (3x3m²)
- Instrumentation: level and distance meters, temperature sensors,
- Detection plane 36 LEM + 36 Anodes (50x50 cm²)

4 CRPs

In NP02 CRYOSTAT

2 instrumented CRPs with LEMs and anodes:
- CRP#1 built in May-June 2018
- CRP#2 built in October 2018

2 CRPs without LEMs:
- CRP#3 built in September 2018
- CRP#4 built in January 2019 (it has 4 anodes (=> single phase like readout)

25/06/2019
**LEM**  
Prod: Jan. to Oct. 2018

1 mm thick LEM layer, standard PCB with 150 holes/cm²

- LEM manufacturing by ELTOS (Italy) – requested specifications met (FR4 and copper thicknesses, hole, rim and LEM size)
- Characterization and tests @ CEA/Irfu

**Anode**  
Prod: Sept. 2017 to Oct. 2018

Micro pattern PCB collection anode designed for equal charge sharing between two views and low inter-strip capacitance 150 pF/m

- Design identical to 3x1x1 prototype
- Manufacturing carried out concurrently by ELTOS
- Visual inspection and electrical continuity test of each strip

- Assembling the 3x3 m² G10 frame and coupling to the Invar structure
- Mounting the anodes and the LEMs
- Cabling and instrumentation
- Weaving and install the grid modules

CRP#1

1 month

9/05/18

36 LEM, 36 anodes

CRP#1

8/06/18

Survey and planarity adjustments

CRP#2

1/11/18

36 LEM and anodes

CRP#3

19/09/18

No LEM, no anode

CRP#4

17/01/19

No LEM, 4 anodes

Transport

- 100 µm diam. wire, 3 m long, 3.125 mm pitch
- combs every meter => Max sag. of 0.1 mm at cold
- Tension at warm: 1.5 N/wire
Cold Box built from Jan 2018 and commissioned in May 2018

Goals: Electrical and mechanical tests of each CRP in nominal thermodynamic conditions.
- Characterisation of HV operation of each LEM
- Characterisation of the HV operation of the extraction grid
- CRP planarity test
- Test the tensioning of the extraction grid wires
- Test of the HV connections (LEM & grid)

- Ar purity < 100 ppm O$_2^{eq}$; GAr @ P$_{atm}$
- LAr evaporation ~0.7 mm/h (< 700 W heat input)
- No boiling nor bubbles, level very quiet
- Liquid level control 250 µm with constant refilling

Test procedure
- Inject dry air during > 1 day and test the LEM HV
- Purge and flush with Gas argon for 1 day
- Cool down and fill LAr : 10 hours

CRP tests in NP02 Cold box

7 sessions of cold test: CRP1, CRP2, CRP3 and CRP4
Cold box tests of the 4 CRP from June 2018 to January 2019

- **Initial HV LEM DB design + Grid**
- **Grid corrections**
- **Modifications of HV distributions**
- **Liquid argon level regulated using coaxial level meter**
- **Regulation using 1 CRP level meter**
- **Liquid level in CB stable to within ~250µm; \( T_{\text{LEM}} \sim 91^\circ\text{K}; \Delta V_{\text{LEM-GRID}} = 3\text{kV} \)**

CRP1

22/06, 09/07, 27/07, 17/08

CRP1

03/10, 15/10, 10/10, 30/10, 12/11, 27/11, 11/12, 20/12, 18/01, 24/01

CRP3

CRP1

CRP2

CRP1

CRP4

Remove bot. LEM HV distrib. box in gas

New top LEM HV DB and Bottom LEM cabling

Correct 4 LEMs on CRP1 and replace 1 LEM on CRP2
Ar purity < 100 ppm $O_2^{eq}$

- Large GAr density variations due to $P_{atm}$ rapid changes.

**Extraction grid set to values ranging from 6 to 7 kV to keep always an extraction field of 3 kV/cm**

- CRP1 and CRP2 operated for « long » periods of time at different HV settings with all 36 LEMs and extraction grid powered.

- Stable operation conditions reached with ~1 spark/hour per CRP (9m$^2$ for 36 LEMs).

- Effective Gain before charging up > 20 reached for HV configuration with $V_{TOP} \sim 0.5kV$.

Results of LEM and grid HV tests in Cold box

- Atmospheric pressure variation during the first 5 cold box tests

Example: CRP1 : $V_{TOP} = 0.50kV$ and $V_{BOT} = 3.60kV$

Oct. 2018

- 0 trip, 17 sparks @ 0.50kV/3.60kV in 13 hrs
CRP transport, Installation and metrology in Cryostat:

Inserted in the cryostat following a delicate manipulation procedure to avoid any shaking of the structure and very little space tolerances.

- Entering clean room buffer
- In cryostat
- Opening of the transport box
- Suspend and remove box

CRP3: October 2018
CRP2: December 2018
CRP1: January 2019
CRP4: February 2019
CRP installation and cabling in cryostat (February 2019)

The procedures are similar to the ones foreseen for DUNE far detector DP module => very important experience
Planarity and metrology in cryostat

**The planarity of the CRP:** measured and adjusted on 50 points and 2-3 iterations. There were 2 campaigns: 1 before the cold box and 1 when inserted in NP02 cryostat.

- CRP3 before: Measured Vertical deformation 5mm
- After 1st iteration: Measured Vertical deformation 1.5mm

**Planarity of each CRP is within 1 mm.**

<table>
<thead>
<tr>
<th>Values in mm</th>
<th>Initial max diff</th>
<th>Initial std dev</th>
<th>Final max diff (mm)</th>
<th>Final Std dev (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRP1</td>
<td>3,71</td>
<td>1,03</td>
<td>0,97</td>
<td>0,240</td>
</tr>
<tr>
<td>CRP2</td>
<td>5,95</td>
<td>1,55</td>
<td>0,94</td>
<td>0,200</td>
</tr>
<tr>
<td>CRP3</td>
<td>4,22</td>
<td>1,192</td>
<td>0,73</td>
<td>0,170</td>
</tr>
<tr>
<td>CRP4</td>
<td>5,02</td>
<td>1,21</td>
<td>0,90</td>
<td>0,240</td>
</tr>
</tbody>
</table>

**Vertical alignment and horizontality of the CRPs**

- Performed with 3 laser targets/CRP positioned along the CRP external periphery.
- Adjusted by moving the 3 suspension vertically from the cryostat roof.

**The 12 points measured (3/CRP) are in the same (6mx6m) plane within +0.9 mm and -0.6 mm.**
Analog cryogenic FE:
- 64 channels FE cards with 4 cryogenic ASIC amplifiers DP-V3, 0.35um CMOS
- First batch of 20 cards (1280 channels) operational on the 3x1x1 since the fall 2016
- Production or remaining FE cards for 6x6x6 completed => 120 cards for 4 CRPs fully tested

AMC digitization cards:
- uTCA 64 channels AMC digitization cards (2.5 MHz, 12 bits output, 10 GbE connectivity)
  - 20 cards operational on the 3x1x1 since the fall 2016
  - Production or remaining 100 AMC cards for 6x6x6 completed => 120 cards for 4 CRPs fully tested

White Rabbit timing/trigger distribution system:
- Components produced in 2016 for the entire 6x6x6, full system operational on the 3x1x1 since the fall 2016

DAQ backend, online storage and computing facility commissioned in the fall 2018
- High bandwidth (20GBytes/s) distributed EOS file system for the online storage facility
  - 20 Storage servers (1.44 PB total disk space, 10 Gbit/s connectivity /server)
- DAQ back-end.online storage and processing facility network architecture:
  - Network infrastructure: 40 Gbit/s DAQ switch + router completed in January 2018
  - 9 DAQ service machines installed in May 2018
  - DAQ back-end: 2 LV1 event builders + 4 LV2 event builders Installed in August 2018
- Online computing farm:
  - ~1k cores installed in June 2017
  - Additional 40 servers installed in fall 2018 doubling the computing power of the online farm
Charge Readout Electronics and DAQ

installation at EHN1:
February-March 2019:
- Optical fibers backbone infrastructure in between the cryostat roof and the DAQ room
- Installation of uTCA crates, cabling and commissioning
- Installation and commissioning of White Rabbit timing and trigger system (GPS, WR Grand Master, Trigger server)
- Installation and commissioning of dedicated trigger network among trigger server and event builders

- Installation and commissioning of low voltage power supply and control and of the low voltage distribution system for cryogenic electronics, and its cabling to chimneys

- Successful operation tests of the full DAQ chain from the uTCA crates to event builder to EOS storage system
Charge Readout Electronics and DAQ

- In the double phase argon TPC all the active electronics is accessible from outside, still being at cold.
- The electronics cards are inserted in a vacuum tight chimney that crosses the cryostat insulation.

April 2019

Installation of cryogenic FE cards mounted on the supporting blades in the signal chimneys (SGFT)

Assembly of the 64 channels cryogenic FE cards on the insertion blades

Systematic test of the charge readout signals by using the pulsing system injecting signals in the anode strips

CRP cabling (anodes) to the cold flange done in February

Cold flange inside cryostat

Warm Signal FT (1480 contacts)

Cold FE Analog Acquisition card (32 ch. each)

Cold Signal FT (1360 contacts)
HV system:
• Field cage
• Cathode and ground grid
• Power supply, extender and cable
**Field Cage**

- The whole FC was completed by spring 2018:
  - 8 vertical modules of 6310 x 3010 mm² (2 modules per detector face: 3 sub-module/module);
  - Voltage Divider Board mounted on two modules

- Long term HV test stability test successfully performed in June/July 2018:
  - 150 kV on FC ring at 3 m drift
  - Nominal E-field between rings of 500 V/cm
  - No discharge recorded
  - Current from PS higher than expected but correlated with humidity in the air in the cryostat => layer of water on FRP I-Beam
  - From FRP I-beam test in LAr => current down to few pA

- Last field shaper board control:
  - Installed and tested in March 2019
Cathode

- Cathode will be powered at -300 kV.
- Composed by 4 identical sections mechanically assembled together during installation.
- Electrically the 4 parts are connected via damping resistors.
- 6 m x 6 m cathode is held only at the edges (scalable concept).

The 4 ground grid modules were inserted in the cryostat at the same time and attached below the cathode modules waiting for final activities.
Field cage and cathode installation completion

Feb 24, 2019

The 2 remaining modules in place

Last cathode module installed after FC completion

22/02/2019

23/02/2019
Heinzinger 300 kV Power Supply:
- 300 kV HV Cable (Silicon based insulator).
- Installed on cryostat roof in March 2019

VHV feed-through:
- tested in purified LAr at CERN for 5 hours with success in January 2019
- Connected to the HV extender end of March

No discharge recorded at nominal voltage (300 kV) provided that the LAr surface is quiet and no gas bubbles are formed along the feed-through
HV extender:
• to connect feed-through to cathode;
• inner conductor (at max HV) surrounded by an insulator;
• metallic degrader rings installed on the insulator, electrically connected to the field shaping ring at the same height

Continuity of the whole HV chain (power supply, HV feed-through, extender, cathode, field cage and HV termination boards) was successfully tested in air up to 20 kV.
Photon Detection System

Photomultipliers (PMT)

- **Full characterization** of 36 (+4 spares) 8” Hamamatsu PMTs at room and cryogenic temperature
- **Dedicated cryogenic test facility final system assembled and validated in LN2**
- **TPB coating** performed at CERN during Jul-Aug 2018

→ **Installation of the 36 PMTs in NP02 cryostat in Feb 2019**

PMT calibration system

- Design: black box with 6 LEDs (+1 SiPM) outside the cryostat + 6 fibers into the cryostat divided at the end in 7 fibers arriving to each PMT
- All final fibers, bundles and optical feedthroughs **procured and tested in LN2**
- Light source components **assembled**
  → D. Belver et al. JINST 14 (2019) T04001

→ **Full light calibration system tested in May 2018 and installed in Feb 2019**
Photon Detection System

PMT and calibration system installation and cabling in the cryostat on Feb. 25-28th

- 36 PMTs mounted on their bases & oriented (1st dynode to the north)
- Fiber inspected with a microscope and cleaned before connecting
- Power output of all the fibers measured (LED + powermeter): uniform response
- Fibers positioned parallel to the 1st dynode (optimal angle)
- Fibers and cables routed along the pipes
Slow control and instrumentation

Temperature monitors

- 58 High-precision Pt1000 installed at two corners of the cryostat:
  - about 15 cm from each other; more denser close to nominal level
  - follow the filling of the liquid argon and monitor its temperature (that depends on the pressure) to better than 0.05 K
- => operational interlocks for the power of the CRPs and the VHV system

Purity monitors

- Two with 15cm drift space installed at the bottom and one at 250 cm from the membrane floor
- A third purity monitor with a longer drift has been added:
  => sensitive to lifetime larger than 7ms

Pt1000 above the CRP to measure temp gradient in gas and on Invar

20 cm
Slow control and instrumentation

Cryogenic cameras  11 cryogenic Ethernet cameras

Installed in strategic points to monitor:
- the CRP planarity, the interface between two CRPs
- the liquid argon level
- liquid argon sprayers and input
- cathode, VHV extender and the feedthrough.

Serial connection : Ethernet port + power supply camera and Heater

- Casing in transparent plexiglas
- Vacuum inside to minimize cold convection
- Heater and camera are supplied from a RaspBerry

Except the wide angles, the focus had to be readjusted to compensate in order to get a good focus at cold
**General cryostat monitoring**

- Stress sensors and the position sensors on the cryostat are installed.
- Temperature and pressure sensors installed to monitor the insulation space together with several valves to control the pressure in the insulation membrane.

**Liquid argon level monitoring:**

- 2x 4m coaxial capacitive level meter used during filling.
- 16 parallel plate capacitive level meters: 14 around the CRP frame and 2 in cryostat with precision of 250 µm and 600 µm respectively to adjust to the nominal level.
Cryogenics

**Proximity cryogenics of ProtoDUNE-DP (NP02)**
- Installation completed during summer 2018.
- Successfully followed by the pressure and leak tests.
- Control system installation started in September and ended in January 2019.

**External cryogenics**
(consisting of the liquid argon and liquid nitrogen storage tanks, the system to manage the hydrogen for the purification filter regeneration, the related dispatch circuits and all the controls) common to NP04:
- Was finalised and commissioned in summer 2018

- Start of the commissioning phase with the purge in open loop of the NP02 tank on June 14th 2019
Gabadi company entered the cryostat just after to install the insulation layers, the secondary membrane and to weld the cryostat membrane.

**Work inside finished on May 22\textsuperscript{nd} 2019**
Following steps:

Finalise the activity inside the cryostat

The access inside the cryostat was done through the manhole after Tuesday May 21st:

The activities done in 3 weeks:

- Dismount the SAS
- Clean up at height with the scaffoldings (on false floor)
- Install the remaining instrumentation:
  - cameras,
  - purity monitors,
  - LED ribbons
  - Level meters
- Clean up the floor
- Remove the protection on top of PMTs
- Install the ground grid frames
- Remove the scaffolding
Pressure test at 200 mbar was done to verify the cryostat deformation => in the expected range.

The extraction of one of the last 2 persons from the cryostat.

Manhole plug installation

Last checks before closing

Camera view
NP02 Cryogenic activities:

The activities programmed after pressure test are:

- Purge => 2 weeks (until June 27th)
- Cool down => 1 week
- Filling => 5 weeks
- Purification => 3 weeks

According to these expectations, the filling should be completed by the beginning of August => Start of detector commissioning when the liquid level reaches the extraction grid

ProtoDUNE-DP Detector setup:

Preliminary activities that can be foreseen with part of the detector sub systems:

- Turn on the photon detection system as soon as possible after the final closure to acquire some data
- Turn on LEM high voltage to low values as soon as the detector is cold

The whole commissioning process of the detector is being organised

Quite exciting moments in front of us!
Summary: In nearly 1 year time: From an empty cryostat to a fully integrated detector
Thank You
ProtoDUNE-DP (NP02) construction status

Assembly in the cryostat

All detector components are installed since March 2019
Charge Readout Plane (CRP)

ProtoDUNE-DP configuration

2 instrumented CRPs with 36 LEMs and anodes (50x50 cm²):
- CRP#1 and CRP#2

2 CRPs without LEMs:
- CRP#3 no anode, CRP#4 has 4 anodes (single phase like readout)

Dual Phase principle:
Results of LEM HV tests in Cold box

Oct. – Nov./2018

Liquid level in CB stable to within \( \sim 250 \mu m \); \( T_{LEM} \sim 91^\circ K \); \( \Delta V_{LEM-GRID} = 3kV \)

<table>
<thead>
<tr>
<th>CRP1</th>
<th>( V_{TOP} ) (kV)</th>
<th>( V_{BOT} ) (kV)</th>
<th>( E_{LEM} ) (kV/cm)</th>
<th>Time (h)</th>
<th>Spark Rate (h(^{-1}))</th>
<th>( P_{atm} ) (mbar)</th>
<th>Estimated ( G_{eff} ) (no ch. up)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.25</td>
<td>3.35</td>
<td>31.0</td>
<td>12</td>
<td>1.3</td>
<td>968 - 972</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td><strong>0.50</strong></td>
<td><strong>3.55-3.60</strong></td>
<td><strong>30.5-31.0</strong></td>
<td><strong>13</strong></td>
<td><strong>1.3</strong></td>
<td><strong>962 - 966</strong></td>
<td><strong>24 - 31</strong></td>
</tr>
<tr>
<td></td>
<td>0.75</td>
<td>3.70</td>
<td>29.5</td>
<td>42</td>
<td>0.6</td>
<td>943 - 953</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>1.00</td>
<td>3.80</td>
<td>28.0</td>
<td>18</td>
<td>2 trips*</td>
<td>970 - 976</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>1.00</td>
<td>3.85</td>
<td>28.5</td>
<td>12</td>
<td>3 trips</td>
<td>936 - 947</td>
<td>15</td>
</tr>
</tbody>
</table>

* PS TRIP time set too short

<table>
<thead>
<tr>
<th>CRP2</th>
<th>( V_{TOP} ) (kV)</th>
<th>( V_{BOT} ) (kV)</th>
<th>( E_{LEM} ) (kV/cm)</th>
<th>Time (h)</th>
<th>Spark Rate (h(^{-1}))</th>
<th>( P_{atm} ) (mbar)</th>
<th>Estimated ( G_{eff} ) (no ch. up)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.10</td>
<td>3.15 – 3.20</td>
<td>30.5 – 31.0</td>
<td>17</td>
<td>0.8</td>
<td>969 - 973</td>
<td>9 - 11</td>
</tr>
<tr>
<td></td>
<td>0.25</td>
<td>3.34</td>
<td>30.9</td>
<td>16</td>
<td>1.3</td>
<td>968 – 970</td>
<td>19</td>
</tr>
<tr>
<td><strong>0.50</strong></td>
<td><strong>3.55</strong></td>
<td><strong>30.5</strong></td>
<td><strong>11</strong></td>
<td><strong>0.9</strong></td>
<td><strong>957 – 965</strong></td>
<td><strong>24</strong></td>
<td><strong>25</strong></td>
</tr>
</tbody>
</table>

- Effective Gain before charging up \( > 20 \) reached for HV configuration with \( V_{TOP} \sim 0.5kV \).
- For larger \( V_{TOP} \) values, need to decrease \( \Delta V_{LEM} \) to achieve stable operation.