Status and plans of ProtoDUNE-DP

D. Duchesneau
on behalf of the ProtoDUNE-DP collaboration

- Progress since one year on:
  - Detector construction
  - Installation
- Summary and plans

SPSC meeting
April 2nd, 2019
The feasibility of both technologies at large scale is being tested with the ProtoDUNE detectors.
Components and operating conditions

ProtoDUNE-DP (NP02)

Charge Readout Planes (CRP)

Field Cage

Cathode

Ground grid

Photomultipliers

Electronics

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
- Drift Field, nominal at 0.5 kV/cm

300 kV

5 mm

5 mm

5 mm

15 mm

6 m

ProtoDUNE-DP (NP02)
Invar (FeNi36)

Frame

G10 Frame +
Extraction Grid

(3x3m²)

Instrumentation: level and distance meters, temperature sensors,

Detection plane

36 LEM + 36 Anodes (50x50 cm²)

Components

Charge Readout Plane (CRP)

4 CRPs

Seen from top

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)

02/04/2019

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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)
**LEM production**

Jan. to Oct. 2018

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

=> 74 LEMs produced and validated for 2 CRPs

**Anode production**

Sept. 2017 to Oct. 2018

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

=> 76 anodes validated for CRPs
CRP construction summary

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

CRP#1

1 month

CRP#2

CRP#3

CRP#4

Extraction grid

Grid module (64 wires)

- 36 LEM, 36 anodes
- 36 LEM and anodes
- No LEM, no anode
- No LEM, 4 anodes

G10

Invar

10 mm

100 μm diam. wire, 3 m long, 3.125 mm pitch

Combs

Tension at warm: 1.5 N/wire

- 10 mm diam.
- Combs every meter => Max sag. of 0.1 mm at cold
CRP tests in NP02 Cold box

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

Cold Box built from Jan 2018 and commissioned in May 2018

LAr level ~ 5mm above Grid

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

- New top LEM HV DB and Bottom LEM cabling

- Liquid argon level regulated using coaxial level meter

- Regulation using 1 CRP level meter

- Correct 4 LEMs on CRP1 and replace 1 LEM on CRP2

- Remove bot. LEM HV distrib. box in gas
Ar purity < 100 ppm O$_2^{eq}$

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

- 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).

Results of LEM and grid HV tests in Cold box

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

- Atmospheric pressure variation during the first 5 cold box tests

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

Oct. 2018

0 trip, 17 sparks @ 0.50kV/3.60kV in 13 hrs
### Results of LEM HV tests in Cold box

Liquid level in CB stable to within ~250µm; $T_{\text{LEM}} \sim 91^\circ\text{K}$; $\Delta V_{\text{LEM-GRID}} = 3\text{kV}$

<table>
<thead>
<tr>
<th>CRP1</th>
<th>$V_{\text{TOP}}$ (kV)</th>
<th>$V_{\text{BOT}}$ (kV)</th>
<th>$E_{\text{LEM}}$ (kV/cm)</th>
<th>Time (h)</th>
<th>Spark Rate (h$^{-1}$)</th>
<th>$P_{\text{atm}}$ (mbar)</th>
<th>Estimated $G_{\text{eff}}$ (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>

<table>
<thead>
<tr>
<th>CRP2</th>
<th>$V_{\text{TOP}}$ (kV)</th>
<th>$V_{\text{BOT}}$ (kV)</th>
<th>$E_{\text{LEM}}$ (kV/cm)</th>
<th>Time (h)</th>
<th>Spark Rate (h$^{-1}$)</th>
<th>$P_{\text{atm}}$ (mbar)</th>
<th>Estimated $G_{\text{eff}}$ (no ch. up)</th>
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</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></td>
<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>
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<tr>
<td></td>
<td><strong>0.50</strong></td>
<td><strong>3.555</strong></td>
<td><strong>30.55</strong></td>
<td><strong>42</strong></td>
<td><strong>0.5</strong></td>
<td><strong>962 – 964</strong></td>
<td><strong>25</strong></td>
</tr>
</tbody>
</table>

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

02/04/2019

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Stable operation achieved over a full CRP for several days (with \(\sim 1\) spark/hour per CRP (36 LEMs))

A few LEMs (4 LEMs on CRP1 and 1 LEM on CRP2) suffered suddenly from an uninterrupted series of discharges after several days of stable operation.

Could not work at desired voltage afterwards. => Dark spots (FR4 carbonization) were observed in some of the corners of the LEMs after CRP removal from Cold Box.

Such discharges can be quickly detected and stopped with an « intelligent » HV monitoring program. Implementation in progress for ProtoDUNE-DP.

Faulty CRP1 LEMs reconditioned: LEMs removed, cleaned and successfully tested in Ar @ 3.3 bar at CEA/Irfu.

CRP2 LEM replaced by a spare one.

FR4 carbonization successfully treated with potassium permanganate.
**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
Planarity adjustment in cryostat

The planarity of the CRP is measured and adjusted on 50 points and 2-3 iterations.

This is performed in one day for a CRP.

There were 2 campaigns of tuning: 1 before the cold box and 1 when inserted in EHN1 cryostat.

Tuning of planarity of CRPs

23/01/2019

Test of the distance meter sensors

24/01/2019

Example: Planarity distribution for CRP3:

Planarity over a whole CRP is better than 1 mm.

<table>
<thead>
<tr>
<th>CRP</th>
<th>Initial max diff (mm)</th>
<th>Initial std dev (mm)</th>
<th>Bdg 185 Max diff (mm)</th>
<th>Bdg 185 std dev (mm)</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>1.53</td>
<td>0.309</td>
<td>0.97</td>
<td>0.240</td>
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<tr>
<td>CRP2</td>
<td>5.95</td>
<td>1.55</td>
<td>1.54</td>
<td>0.363</td>
<td>0.94</td>
<td>0.200</td>
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<tr>
<td>CRP3</td>
<td>4.22</td>
<td>1.192</td>
<td>1.57</td>
<td>0.357</td>
<td>0.73</td>
<td>0.170</td>
</tr>
<tr>
<td>CRP4</td>
<td>5.02</td>
<td>1.21</td>
<td>1.16</td>
<td>0.280</td>
<td>0.90</td>
<td>0.240</td>
</tr>
</tbody>
</table>

Measured Vertical deformation

5mm before

1.5mm after 1st iteration

In clean room
CRP installation and cabling in cryostat

5/02/19 CRP1
6/02/19 CRP4

CRP1
CRP2
CRP3
CRP4
CRP after metrology and final positioning
HV system:
- Field cage
- Cathode and ground grid
- Extender and cable
- Power supply
Cathode assembly in cryostat

• 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.
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

Another commissioning test in air of the entire VHV system is foreseen before and after the closure of the TCO.
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

26/02/2019

02/04/2019
NP02 HV distribution

- **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
  - 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
  - Arrived in February and was positioned in cryostat on 07/03/19
  - Connected to the field cage last week (29/03/19)
Photon Detection System

Activities since spring 2018

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


→ 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)
- PMT base resistance checked: all ok

- 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
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 completed
- 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
Electronics and DAQ

Installation

• Optical fibers infrastructure installed and tested

• uTCA racks installed with data optical fibers connections cabled and tested to the event builders

• **Complete White Rabbit timing and trigger system** installed and commissioned: slave nodes in uTCA crates, WR optical fibers network, central timing system (WR Grand Master and GPSDO), trigger timestamping server and trigger network to event builders
Electronics and DAQ

Installation

March 2019:

- Installation and commissioning of uTCA digitization cards for all chimneys
- Full commissioning of digital front-end system and trigger timing system
- 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

Next step:
Installation and commissioning of cryogenic FE cards mounted on the supporting blades in the chimneys
**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

**Cryogenic cameras**
- Twelve 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.

**Purity monitors**
- Two are foreseen: 15 cm drift measurement device
  - They will be installed after the TCO closure at 15 cm and 250 cm from the membrane floor
Cable trays are laid and grounded.
Most of the detector feedthroughs are installed.
The building and detector ground monitor is running.

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

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

- Complete system is ready to first activate the purification filters, purge the argon circuit
- Start of the commissioning phase with the purge in open loop of the NP02 tank is scheduled beginning of June 2019
ProtoDUNE-DP (NP02) construction Summary

Component status as of today 2/04/19

- **Charge Readout Planes (CRP)**: Installed and cabled
- **Field Cage**: Fully completed
- **Cathode**: Assembled and installed
- **Ground grid**: Constructed and inserted
- **Photomultipliers**: Installed and cabled
- **Electronics and DAQ**: Installed cabled and commissioned
- **Slow control and instrumentation**: Remaining Instrumentation under completion/ready to be installed
- **Cryogenics**: Complete system ready
- 300 kV HV system finalised to be ready for tests in air

02/04/2019

D. Duchesneau / SPSC meeting
Plan of the NP02 detector installation

Schedule starts on Jan 7th with the CRP installation
- Before TCO closure: 45 days were foreseen
  => for installing CRP, Cathode, ground grid, HV feedthrough and PMT
- TCO closure: 5 weeks
- After the TCO closure: 15 days
  => to install remaining instrumentation, HV extender, ground grid small modules, clean up and remove scaffolding, false floor part etc...

Company will come to CERN on April 23rd
=> 4 weeks later than originally foreseen
- To minimise impact, work initially planned after the TCO closure is done before.
- More extensive test of the HV system can be performed

Filling completed end of July
=> Start of commissioning
Beam for NP02

extension of the existing H2 beam line in the CERN North Area was designed and commissioned end of 2018

**Commissioning:** Dec 2018 with negative charged particles

trigger rates measured in H2-VLE. For momenta < 3 GeV/c the tungsten target was used, while for the momenta > 4 GeV/c the copper target was employed.

Reasonable agreement between the data and the expected rated

**Beam Instrumentation:**
- profile monitors
- trigger counters
- two threshold Cherenkov counters,
Thank You
Additional slides
Faulty LEM inspections

in the vicinity of boundary regions, like the edges or the corners where the hole density is no longer uniform, holes are more likely to be surrounded by decentered rims (40 µm) with residual copper present inside.

Related to the micro etching process used by the company
=> Different technique under study
Cryostat commissioning

- Several qualification and certification of vital components of the detector, the cryogenic and the cryostat already done
- Commission of the cryogenic controls is done during the purging period

Before cryo operation is allowed the following is needed:
- Helium leak tests on all the penetrations
- Helium leak check of the TCO weldings
- 200 mbar overpressure test monitored with strain gauges
- Purge and monitor the insulation space
- Formal CERN approval to start the cryogenic operation
Purging, cooling, filling (8 weeks) & purifying (few weeks)

From the experience of NP04:

• After 20 volumes exchange water content will still be 100 ppm or more. The cryo team is developing a cold trap for water to be installed through two penetrations and being operated during the purge phase (two weeks).
• Improved sprayers will simplify the cool down of the cryostat+detector. Cool-down will take 1 week.
• Regeneration of the purification cartridges is needed before start the filling.
• Filling: constantly monitor the quality of the LAr delivered filling at an increasing speed up to nominal 2x 20 ton/day. Filling will take 5 weeks.
• One regeneration of the cartridges may be needed during filling. This would add four days on the filling schedule.
• Two volume recirculation through the purification cartridge may be done when the detector is partially full. This would add about 5 days to the filling schedule and may save time during the purification phase.
• From O10 ppb to several ms need several weeks of purification.