Status of WA105 3x1x1m³ prototype

Sebastien Murphy,
protodUNE-DP Project Readiness Review
April 24th 2017 CERN
The WA105 collaboration demonstrate the capabilities of the dual phase technology at the kton scale

21 institutes 138 physicists
Two dual phase liquid argon detectors

same technology, two scales, different goals
Two dual phase liquid argon detectors

Common aspects
✓ LEMs and anode: design, purchase, cleaning and QA
✓ chimneys, FT and slow control sensors
✓ membrane tank technology
✓ Accessible cold front-end electronics and DAQ system
✓ amplification in pure Ar vapour on large areas

3x1x1 m³
✓ First GTT constructed cryostat for LAr
✓ Fully engineered versions of many detector components with pre-production and direct implementation (installation details and ancillary services)
✓ First overview of the complete system integration: set up full chains for Quality Assessment, construction, installation and commissioning
✓ Anticipate legal and practical aspects related to procurement, costs and schedule verification
✓ short term data taking with cosmics

protoDUNE-DP
✓ Large hanging field cage structure
✓ Very high voltage generation and guiding
✓ Large area charge readouts
✓ long drift (e- diffusion, purity, etc..)
✓ test beam data (calibration, reconstruction, fully contained events, x-sections, etc…)
✓ Long term stability of UV scintillation light readout
✓ underground construction method
Construction of the 3x1x1 dual phase LAr TPC at CERN.
First step towards the realisation of 10 kton dual phase LAr TPCs.
3m3 Dual phase LAr TPC

drift cage
muon
photomultiplier tubes

e- γ
3m3 Dual phase LAr TPC

Charge Readout Plane

Charge Readout Plane

- CRP
- Drift cage
- Photomultiplier tubes
- Muon
- $\gamma$
- LEM
- Multilayer PCB anode
- Vapor
- Extraction grid
- Liquid
3x1x1 detector

- Cryogenic cameras
- Signal feedthroughs: front end cards for amplification in cold. Can be removed without accessing main LAr volume
- Charge Readout plane (CRP): extraction of charge readout and amplification in one module adjustable to LAr level
- Drift cage: fixed to top-cap
- GND protection grid
- High voltage feedthrough: this one up to 300 kV.
- 5 coated Photomultiplier tubes
pictures from inside the cryostat
PART 1 DETECTOR INSTALLATION
MARCH-JULY 2016
Detector construction

WA105 3x1x1 prototype

ENTIRE DETECTOR CONSTRUCTED IN 2016

- Jan: LEMs & anode delivered + QA/QC
- Feb: CRP cryogenic bath test
- Mar: top-cap delivered
- Apr: full detector installed under top-cap
- May: full detector lifted in cryostat
- June: successful test and insertion of 300 kV high voltage feedthrough
- July: all control racks, DAQ, + cryogenics installed, cabled and tested. Detector ready for operations
- August: FE electronics inserted + tested

Charge Readout Plane installed under top-cap

50 cm

50 cm
**LEM cleaning**

- Cleaning procedure is rather **simple and straightforward**. ~10 mins per LEM. Doesn’t need specific facility.
- HV testing should be done in **controlled environment** (T,P and RH)
- **no stringent requirements on storage**, should be in a controlled environment that’s about it.

![Cleaning procedure images]

*each LEM has its handling plate*

1) lessive (soap + water 65 °C)  
2) high pressure water DI water

3) rince DI water  
4) ultrasonic bath DI water

6) storage in custom made box designed to hold 20 LEMs with their handling plates.

*Validated for protoDUNE DP*
Assembly of the CRP: example of the $3 \times 1 \, \text{m}^2$ fully active amplification area (here $1 \times 1 \, \text{m}^2$)
Charge Readout Plane

- fully active 3x1 m² amplification and readout adjustable to LAr level.
- All components industrially fabricated with most of the QA/QC performed by the companies.
- mechanical tolerances validated in warm temperature in open cryogenic baths.
- Assembly is straightforward and quick (~2 people, 2 days)
CRP suspension: adjust to LAr level

suspended by 3 ropes coupled to motors on top-cap. Precision of motors 100 um over 4 cm. 8 capacitive level meters readout the LAr level with similar precision.
Slow control: level meters and pulser

- A new NIM design has been done with:
  - 4 Channels
  - improved 0–10 V interface to NI Racks
  - improved filters on voltage rails and output
- 5 Boards NIM size are in production
- The assembly of the entire system will take place in the next 2 weeks, including calibration.
- A test bench for the 6x6x6 Level meter system

In operative condition the LAr level will be in the middle of both level meters, the ones on Drift Cage and the ones on CRP.
Extraction grid mounting and planarity check

**wire spacing.**
wire: SS 100 micron diameter.
spacing between each wire 3.125 mm.
Each wire is precisely positioned on soldering PCBs in 220 um grooves.
Precision obtained on wire spacing: <100 micron.

**planarity.**
LEM-LAr 5 mm distance.
Check that the mounted frame is within tolerance (planarity ±1 mm)
Resistance to thermal shock

The horizontal geometry of the $3\times\$ m$ CRP allows to perform cryogenic test in open bath. Already demonstrated for the $3\times1\times1$. What we checked:

- monitor expected shrinkage with photogrammetric measurements.
- extraction grid robustness.
The installation of the detector under the top-cap essentially started in May. By end of June it was complete and most parts were tested. Thanks to the large collaboration effort during those 2 months
Detector installation

- CRP assembly
- CRP test in cold
- Signal continuity check
Detector installation
Drift cage
Feedthroughs

All feedthroughs operational and tested over the past year. Same to be installed in pDUNE-DP

- 4 signal chimneys
- 3 slow control and medium voltage
- 3 CRP suspension
- 1 High voltage tested at 300 kV, operated at ~50 kV
Very high voltage

Design successfully tested in dedicated setup up to the end of the scale of the Heinzinger PSU. About 295 kV.

JINST 12 P03021 arXiv:1611.02085
The insertion of the detector was fast about 2 hours and no problems were encountered. This was thanks to CERN support and professionalism.
Inspection and measurements inside cryostat

- entering through the manhole
- view from the bottom of the manhole

drift cage and LEMs

PMTs
Experimental layout in final configuration

top-cap during cabling

all racks installed

signal feedthrough
Slow control: cameras

5 cameras placed in different strategic areas of the detector. Main purpose to have visual check of the LAr level.

cameras tested in LAr for many days without degradation of image.
Cryogenic installation and commissioning

- Cold piping (LAr+ LN2 lines, valve boxes, liquid purification, ..) Sept 19th- Oct 13th
- Warm piping (gas argon purification system, chimney purges, ..) Oct-Nov
- Control system Sept-Nov
- Start of gas argon piston purge Jan 24th
- Start of cool down Feb 27th
difficulties encountered during commissioning

- longer than anticipated installation of warm piping
- broken bellow at the middle of pump tower
- manhole sealing
- some leaks on pump tower flanges
- difficulties in regulating LN2 flow in condenser.
  - leak searched and identified in warm piping
Purging and cooling down

Piston purge
4 warm gas lines each with 3 openings of 12 mm ø.
total flow rate during piston purge ~4 l/s

Cool down: 4 sprays
mixture of LAr and GAr
for slow and uniform cool down. Nominal flows:
300 K GAr 500 l/m
87 K LAr 21 l/h
Piston purge & evolution of impurities

- ~80 volume changes
- Purge in open loop
- Purge in close loop
- Upgrade LN₂ piping
- Tank cooling down

Impurity (ppm)

01-25 02-01 02-08 02-15 02-22 03-01

Time [M-D]

- Oxygen
- Nitrogen
- Moisture

~80 volume changes

10^2

10^1 1 1

10^2
All sensors operational - some data during cool down

- Chain of temperature probes along drift cage
- 45 temperature probes inside insulation
- GN2
- First insulation layer (40cm from membrane)
- Second insulation layer (70cm from membrane)
- Outermost temperature (cryostat outer structure)
- Minimum temperature in cryostat
- The insulation space is constantly flushed with N2 gas. A bubbler at the output guarantees a few mbar overpressure w/respect to the atmosphere
All sensors operational - monitoring over the past months

Detector monitoring:
- >150 temperature probes
- 20 pressure probes
- 30 HV channels
- 1 300 kV HV channel
- Purity monitors (Gas + liquid)
- 15 level meters
- 5 cryogenic cameras

All operational

over-pressure in insulation space

Pressure in signal FT

Stable since 50 days, no leaks

All operational

cryo-cameras
First results from commissioning - light and trigger

Scintillation time in GAr (1000 mBar, 215 K)

\[
\begin{align*}
  t_0 & : 539.41 \pm 0.96 \text{ ns} \\
  \sigma & : 10.40 \pm 0.63 \text{ ns} \\
  A & : 1051 \pm 139 \\
  \tau_1 & : 6.00 \pm 0.00 \text{ ns (fix)} \\
  B & : 115.4 \pm 22.7 \\
  \tau_2 & : 60 \pm 9 \text{ ns} \\
  C & : 19 \pm 1 \\
  \tau_3 & : 3616 \pm 305 \text{ ns} \\
  \chi^2/dof & : 453/866
\end{align*}
\]

Muon flux, from NW

Muon flux, from SE

DEEP UNDERGROUND NEUTRINO EXPERIMENT
First results from commissioning - Charge readout

DAQ and computing farm fully commissioned

noise at room temperature stable at about 1'500~ electrons

accessible cold amplifiers at 110 K. Sealed in chimney separate from main argon volume
Cryostat- issues during cool down

- Since Feb. 28th two attempts at cooling down the cryostat have been made. Both have been interrupted due to the presence of multiple cold spots (some <-40°C) on the outer structure.
- The exact source of the cold spots as well as the solution to fix the issue is currently under investigation by CERN and GTT. So far the following has been understood:
  - A cold leak from the inner membrane has been excluded.
  - In some locations the outer structure was drilled and missing layers of fibreglass sheets were found. Those holes have been filled with expandable foam which cures the problem locally.
  - Next week a GTT team is coming to CERN and should be in position to solve the general issue based on results from a full simulation of the gas convection arising from the free spaces between the insulation blocks.
Conclusion

• Most of what has been shown in the slides has been designed to match the scale of protoDUNE. From that perspective, the installation and commissioning steps of the 3x1x1 has provided many valuable inputs.

• The complete assembly of the 3x1x1 detector including cabling and DAQ commissioning took about 6 months.

• Some delay on the operation has been accumulated during cryogenic installation and commissioning phase and more recently due to the defect in the insulation which resulted in an abort of the cool down. The reason seems now understood and repaired. We are currently filling the cryostat.

• Although cosmic tracks have not yet been acquired, large experience has been gained for protoDUNE-DP design, installation and commissioning.
THANK YOU
Signal feedthrough

2 view readout 3 chimneys for the 1 m strips. 1 chimney for the 3m long view.
Signal feedthrough

Amplifiers accessible during operations

Amplifiers inside closed volume. Close to anodes, ~110 K

4 ASICs per board

Signal to digitisers
Signal chimneys

Independent volumes (to allow replacement of preamps). Pumped to remove air and sealed under GN2 with ~20 mbar overpressure W/ respect to Patm.

Differential pressure to atm in Signal Feedthrough chimneys & atmospheric pressure

- Stable since 50 days, no leaks

\[ \text{Delta}_P(\text{SGFTxx-atm}) \]
Charge Readout

1. Charge signal multiplied and collected on low capacitance anode strips

2. Signal guided to cold amplifiers by group of 32 channels

3. Signal amplified by ASICS in cold

4. Signal brought outside by vacuum tight custom designs PCB flanges

5. Signal digitised by 12it in AMC arms in uTCA crates

inside detector (not accessible)
signal feedthrough (accessible)
Top of cryostat

6. Event building & triggering

- Top of cryostat
  - Fiber connection:
    - 2 x 10Gb rate: link aggregation in between 2 optical switches
  - Designed for number of channels and data flow of pDUNE-DP

7. Computing farm: buffer storage, display and online analysis in control room

8. Send via 10 Gb CERN Network to computing center (EOS, etc..)
**Grounding**

- **ground floor racks**
- **on top of racks 1st floor**
- **cable tray fixed on the side of Dimitar's beam**
- **connection platform-cryostat**
- **ground pillar (approx location)**

**signal feedthroughs**

(1,2,3,4)

**termination near SGFT:** a clip with about 4 holes that will be screwed on the flange.

- **copper cable 95 mm²**
- **copper cable smaller section**
- **copper foil**
Status part 2 November-December

Moved from “Construction” to “Operations” mode (conveners Laura M.B, Laura M.)

- Triggering scheme, cosmic ray trackers operational
- Cryogenic warm piping finished. Cryostat ready for purge.
- DAQ + pulsing system operational.
- First data, cross check of all channels (continuity, noise and cross-talk) with DAQ
- All sensors ready and monitored
- Sealing of Manhole
- Start of GAr piston purge
Ready for detector operation

Detector monitoring:

- >150 temperature probes
- 20 pressure probes
- 30 HV channels
- 1 300 kV HV channel
- Purity monitors (Gas + liquid)
- 15 level meters
- 5 cryogenic cameras

ALL ONLINE

Y.Rigaud (ETHZ) pDUNE-DP parallel session
Monitoring

- Cryo cameras
- Level meters
- Anode pulsing
- Temperature

**ALL RUNNING**

**3x1x1 Slow Control DB**

<table>
<thead>
<tr>
<th>Group: Pressure(16)</th>
<th>Selected</th>
</tr>
</thead>
<tbody>
<tr>
<td>PE0000</td>
<td>PE0000</td>
</tr>
<tr>
<td>PE0002</td>
<td></td>
</tr>
<tr>
<td>PE0003</td>
<td></td>
</tr>
<tr>
<td>PE0004</td>
<td></td>
</tr>
<tr>
<td>PE0005</td>
<td></td>
</tr>
<tr>
<td>PE0006</td>
<td></td>
</tr>
<tr>
<td>PE0007</td>
<td></td>
</tr>
<tr>
<td>PE0009</td>
<td></td>
</tr>
<tr>
<td>PE0101</td>
<td></td>
</tr>
<tr>
<td>PE0102</td>
<td></td>
</tr>
<tr>
<td>PE0103</td>
<td></td>
</tr>
<tr>
<td>PE0104</td>
<td></td>
</tr>
<tr>
<td>PE0105</td>
<td></td>
</tr>
<tr>
<td>PE0106</td>
<td></td>
</tr>
<tr>
<td>PE0107</td>
<td></td>
</tr>
<tr>
<td>PE0108</td>
<td></td>
</tr>
<tr>
<td>PE0110</td>
<td></td>
</tr>
<tr>
<td>PE0111</td>
<td></td>
</tr>
<tr>
<td>PE0112</td>
<td></td>
</tr>
<tr>
<td>PE0113</td>
<td></td>
</tr>
<tr>
<td>PE0114</td>
<td></td>
</tr>
<tr>
<td>PE0115</td>
<td></td>
</tr>
<tr>
<td>PE0116</td>
<td></td>
</tr>
</tbody>
</table>

Graph: START: 2017-01-01 08:05:08  STOP: 2017-01-20 08:05:08

Y. Onischchuk (UKiev)  T. Viant (ETHZ)

C. Cantini (ETHZ)
Control room

Control desk:
- Linux screen: DAQ/Data management
- Windows screen: Slow control

Slow control screens:
- 2 x 55" monitors
- Windows computer screen

Farm rack:
- 10 CPU computers
- 4 storage servers
- Switches

Conference equipment:
- Computer
- 2 x 55" monitors

EventDisplay:
- Working with Qscan
- Connected to wa105cpu0000
- Managed from the control desk
Cosmic Ray Trigger & Purity monitor

Purity monitor Installed

Glued with Stycast to membrane

L. Manenti (UCL)

CRT installed and running

- 4 scintillating modules
- 2 modules at each short side of the cryostat

- provides an external trigger using crossing muons
- muon tracking reconstruction

I. Kreslo D. Iorca (LHEP, Bern)
pulsing and noise data
December-ready for purge

Remove contaminants by flushing gas argon and recirculating and filtering in closed loop.

- Nitrogen: 100 ppb precision
- Oxygen: 100 ppb precision
- Water: 100 ppb precision

All pre-tested and operated beforehand.
pressurisation of tank

On December 19th the Manhole was sealed and GAr was flushed to pressurise the tank...
Large leaks we found on both flanges of the pump tower
about 30 flanges on top-cap (+ piping)
pump tower
Looking back 2016

WA105 3x1x1 prototype

**ENTIRE DETECTOR CONSTRUCTED IN 2016**

- Jan: LEMs & anode delivered + QA/QC
- Feb: CRP cryogenic bath test
- Mar: Top-cap delivered
- Apr: Full detector installed under top-cap
- May: Full detector lifted in cryostat
- Jun: Success test and insertion of 300 kV high voltage feedthrough
- Jul: All control racks, DAQ, + cryogenics installed, cabled and tested. Detector ready for operations
- Aug: FE electronics inserted + tested
- Sept: Nov: Dec:

Charge Readout Plane installed under top-cap

CRP LEM active area seen from below
The “3x1x1” in February 2016

6 months later.
chan_pedrms

Pedestal RMS (ADC)

Ch in View 0

Ch in View 1
Cryostats in construction. 11/01/2017

AND THE SAME FOR PROTODUNE-DP!

See D. Autiero plenary + parallel session Wednesday
Detector installation

- CRP assembly
- CRP test in cold
- Signal continuity check
Detector installation
CRP 3x1 m2 -> 3x3 m2

same design for the protoDUNE DP

See talk from Dario A.

1 50x50 cm² LEM-anode sandwich

CRP LEM active area seen from below

extraction grid
Charge Readout Plane

CRP resting on optical table - for flatness measurements
CRP: adjustable to LAr level

suspended by 3 ropes coupled to motors on top-cap. Precision of motors 100 um over 4 cm. 8 capacitive level meters readout the LAr level with similar precision.
Inspection and measurements inside cryostat

- entering through the manhole
- view from the bottom of the manhole
- drift cage and LEMs
- PMTs
Experimental layout in final configuration

Heinzinger 300 kV

proximity slow control racks
DAQ and computing farm

Fiber connection: 2 x 10Gb rate: link aggregation between 2 optical switches

digitised signal from uTCA on signal feedthroughs
proximity DAQ rack

~10 m

~30 m

10 Gb CERN Network for computing center (EOS, etc..)
**DAQ and computing farm**

**Proximity rack composed of:**
- event-builder (46 TB storage server)
- 1 switch HP Procurve 6600 24xg → 2x10Gb
- White rabbit unit
- Cosmic counters crate/computer
- 4 x microTCA crate linked by fibber channel

**Farm rack composed of:**
- 16 cpu modules with 16 cores inside
- 4 storages servers: total space 192TB
- 1 switch HP Procurve 6600 24xg → 2 x 10 Gb
- 1 switch HP Procurve 6600 48g 4 xg

10 Gb CERN Network for computing center (EOS, etc.)

~30 m

Fibber connection:
- 2 x 10Gb rate: link aggregation in between optical switches

~10 m

digitised signal from uTCA on signal feedthroughs

proximity DAQ rack

Fibber connection from uCTA to proximity rack

computing farm
Getting prepared for data taking. Data base is setup, recording values of e.g. temperatures and high voltages. Important measurements taken during assembly (such as LEM thicknesses) in the process of being incorporated in DB.
Slow control: level meters and pulser

- A new NIM design has been done with:
  - 4 Channels
  - improved 0–10 V interface to NI Racks
  - improved filters on voltage rails and output
- 5 Boards NIM size are in production
- The assembly of the entire system will take place in the next 2 weeks, including calibration.
- *Aso be a test bench for the 6x6x6 Level meter system*

In operative condition the LAr level will be in the middle of both level meters, the ones on Drift Cage and the ones on CRP.
Cryogenics-internal piping

filling line (Gar+LAr)

Gar piston purge

Gar momentum nozzle

LAr and Gar mixing nozzle

LAr

Gar
successful test of the entire pump tower was performed by a company. The pump tower is now installed in the cryostat.
Purity monitor

1. Purity Monitor built, tested HV at room temperature
2. Tested PHC for no peeling in LAr
3. Charge amplifier tested
4. PrM successfully installed in WA105

- Still to install optical fibre (1st week of October)
- Test planned when filling starts
The cryostat - leak checking

\[ P_{\text{top-cap}} = P_{\text{ins}} \]

\[ P_{\text{tank}} = 1000 \text{ mbar} \]

\[ P_{\text{ins}} = P_{\text{atm}} + 5 \text{ mbar} \]

Want to keep \( P_{\text{tank}} \) constant at 1000 mbar independent from atmospheric pressure variations. Important to check tightness of the entire cryostat:

1. No leak from insulation space to inner tank above 1e-9 mbar l/s (to guaranty Ar purity)
2. leak-rate from atm to insulation space low enough to keep \( P_{\text{ins}} = P_{\text{atm}} + 5 \text{ mbar} \)