ProtoDUNE experiments at CERN

Clara Cuesta on behalf of the IFIC, IFAE, and CIEMAT groups
IX CPAN DAYS
October, 23rd 2017
What is the origin of the matter-antimatter asymmetry in the Universe?
What are the fundamental underlying symmetries of the universe?
Is there a Grand Unified Theory of the Universe?
How do supernovae explode? New physics from a neutrino burst?

- New neutrino beam facility at Fermilab
- A highly capable Near Detector at Fermilab to measure the unoscillated neutrino spectrum and flux constraints
- 4 x 10 kton (fiducial) LArTPC modules (single and/or dual-phase) deep underground at SURF (Lead, SD, 1300 km baseline) to measure oscillations, SN burst neutrinos, nucleon decay, atmospheric neutrinos… first data in 2024
Liquid Argon Time Projection Chamber

Charged-particles + LAr → Ionization + Scintillation

- Charges drift thanks to an electric field
- Collection of light and charge
- Single or dual phase
- 3D reconstruction and particle identification
- Cryogenic operation
- Excellent argon purity required
LAr TPC-single and dual phase

**Single Phase**
- Ionization charges are drifted **horizontally** and readout by wires
- No amplification of the signal

**Dual phase**
- Ionization charges are drifted **vertical** and readout by PCB anodes.
- **Amplification** of the signal in LEMs
DUNE Project timeline

- 2017: Far Site Construction Begins
- 2018: ProtoDUNE experiments at CERN
- 2021: Far Detector Installation Begins
- 2024: Physics Data Begins
- 2026: Neutrino Beam and Near Detector Available
ProtoDUNE detectors at CERN

- **Unique setup** to test and compare the performance of both technologies for the DUNE far detector
- 6x6x6 m³ double phase and 6x7x7.2 m³ single phase LAr TPCs at CERN
ProtoDUNE detectors at CERN

- Almost all detector aspects and installation sequence identical to those foreseen for the 10 kton
- Under construction
- Cosmic muons and charge particle test beam data in 2018

*During construction of the cryostats (Spring 2017)*
ProtoDUNE single phase

• Uses a single phase technology in which the anode (APAs) and cathode planes (CPAs) are vertical, and electron drift is horizontal.

• There are two drift volumes of 3.6 meters length separated by a central cathode at -180 kV

• The readout system consists in 3 sets of wires at different angles
Temperature measurements

- Precise (<5 mK) **3D temperature map** to validate fluid dynamic simulations and ensure a good control of the cryogenics system
  - **T-Gradient monitor**: detailed (10-30 cm spacing) vertical profile with 48 sensors cross-calibrated in the lab
  - Complemented with **other sensors** of the same precision at other XY locations to provide a 3D map as detailed as possible
- Standard sensors (~0.1 K) on the **membrane** to monitor cryostat behavior during cool-down and filling
Current calibration setup

2 SUBD-25 connectors to readout

LN2/LAr inlet (not yet there)

5 temperature sensors in teflon bar

Introduce teflon bar through top CF63 port.

pressure sensor

valve to control the pressure

flexible tube to release valve and pressure sensor

release valve (at 3.2 bar)

polystyren insulation
Calibration at pressure

- We have to **cross calibrate** all sensors to better than 5 mK: measure the temperature offset between each sensor and a reference one
- Increase the pressure to get higher temperatures. Aim is to **measure the offsets as a function of temperature**
  - We are trying to understand the calibration system with LN$_2$, which is “cheap”, but the final calibration will be done with LAr, varying slightly the temperature (up with pressure, down by adding some LN$_2$)

Offsets between three sensors: not obvious dependency on pressure
Calibration at CERN

- Final calibration will be done at CERN, using the final readout electronics mounted on the final racks. Those details matter when trying to get precisions below 5 mK.
ProtoDUNE dual phase

- Large monolithic drift cage meter long drift.
- Independent frames (CRPs) at the top performing the Charge extraction, amplification and readout.
- Feedthroughs for signal, high voltage...
- Photomultipliers at the bottom

Drift = 6 m (~300 kV at the cathode)
ProtoDUNE-DP Photon System

Basic configuration:
- 36 8” cryogenic photomultipliers
- Wavelength-shifter: TPB coating on PMT
- Voltage divider base + single HV-signal cable + splitter (external)
- Light calibration system
- DAQ system (external)

Goals of the light detection system:
- Trigger for non-beam events
- $t_0$ for both beam and non-beam events (cosmic background rejection)
- Possibility to perform calorimetric measurements and particle identification

6x6x6 m³ (fid.) DLAr TPC @CERN

TDR: arXiv:1409.4405
3x1x1 m³ DP LAr TPC

- 5 ton demonstrator constructed - being operated at CERN 2015 – 2017
- Same technology as ProtoDUNE-DP 6x6x6 m³
- One of the goals of the 3x1x1 m³ prototype is to validate the system in real conditions
- Taking cosmic ray data!

5 PMTs: Different configurations being tested

Charge data (no noise filtering)  Light data

cosmic muon

S1  S2
3x1x1 Preliminary Results

• Commissioning preliminary results:
  o LAr purity studies: The slow scintillation component can be monitored run by run on every PMT
  o S1 and S2 studies: determination of best operating conditions

- Light analysis signals on-going:
  o Response to muon interactions
  o Light & charge correlation
  o Data to simulations comparison (adding photon detection system)

- Run 1618: CRT trigger, Cathode 56 kV, Grid 0 V, LEM Down 200 V, LEM Up 0 V

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PMT testing at CIEMAT

1. **Validation** of PMT base and detailed charact. of PMT response at warm and cold

2. **Characterization** of the 40 PMTs before their installation in the 6x6x6 m³ detector

**PMT base design:**
1 cable base (+HV) + ext. splitter

- GND
- +HV
- Pos. power supply
- Splitter
- Decoupling capacitor & power supply filter
- Front-end
PMT characterization - setup

Designed to test PMTs immersed in LN₂ with a configurable amount of light

- Laser (405 nm)
- Optical fiber
- Filters box
- LED & Laser controller
- QDC
- LabView
- PMT under test R5912-02
- Diffuser (to provide homogeneous illumination)

Clara Cuesta | ProtoDUNE experiments at CERN
Room temperature results

- **Gain:**

  Blue solid line: CIEMAT voltages are 80 V above the Hamamatsu values, expected by splitter configuration.

- **Dark current:** expected rates, some PMTs under investigation.
Cryogenic temperature results

- **Gain:** The voltages for the nominal gain ($10^9$ e⁻) at cryogenic temperature are 388 V higher (22% higher on average) than the values obtained at room temperature.

  Blue solid line: 388 V above the RT voltage

- **Dark Current:** For a given gain, DC is typically higher at CT than at RT.

  On-going data taking
  - Light frequency linearity
  - Light linearity
TPB coating

- Need to convert UV LAr scintillation at 128 nm to visible light where PMTs are sensible
- Reuse the setup available at CERN for the PMTs of the ICARUS experiment
- Evaporator + vacuum pumps + quality assessment of coating
**Light Calibration System**

**Goal:**
- Determine PMT gain (SPE)
- Study PMT stability

**Components:**
- Black box with light source (Kaputschinsky LEDs) outside of cryostat
- 6 fibers going to cryostat
- 2 CF40, each with 3 optical feedthroughs
- Inside the cryostat (6x):
  - 22.5 m fiber
  - 3 m 1-to-7 bundle
Conclusions

• The construction of ProtoDUNE 6x6x6 m3 detectors is in progress and it is expected to start taking data with cosmic rays and the charged-particle beam before CERN LS2.

• ProtoDUNE-SP cryostat is ready and detector installation will start in two weeks. The first set of temperature sensors will be installed in November, while the T-gradient monitor will be installed once everything else is in place, hopefully in May 2018.

• The first WA105 results (from the 3x1x1 m³ detector) with cosmic muons are available: the performance of the first prototype is being successful and we are obtaining valuable experience for the upcoming projects.

• The 40 PMTs characterization for ProtoDUNE-DP is almost finished and the final configuration for the light calibration system is being tested.

• We will learn a lot about neutrinos in the next decades and DUNE will be a crucial experiment as well as an enormous challenge.
In memoriam of José Ángel Villar
Thanks!

Fig: Symmetry Magazine
Backup
Experimental contribution from Spanish groups to DUNE and ProtoDUNEs

- **ProtoDUNE-SP: IFIC**
  - Slow Controls and Cryogenics Instrumentation: WG coordination, 3D temperature mapping of the cryostat, sensor and cable procurement and calibration, mechanics, installation
  - On-site work: cryostat cleaning, leak checks, help with cold-box and APA installation, sensors installation, etc
  - Data analysis: development of the analysis framework and kaon selection
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- **ProtoDUNE-DP: IFAE, CIEMAT**
  - Photon Detection System: 40 PMT procurement, PMT bases, PMT mechanics, PMT characterizations at room and cryogenic temperature, calibration system, HV splitters, PMT TPB coating
  - 3x1x1 m³ photon detection system commissioning, operation and data analysis
  - Data analysis: light signal analysis and comparison to simulations
Experimental contribution from Spanish groups to DUNE and ProtoDUNE

• DUNE:
  - Supernova and Low Energy Neutrino Physics WG: CIEMAT (I. Gil convener)
  - Nucleon Decay Physics WG: IFIC (M. Sorel convener)
  - Far Detector Dual Phase Photon Detection Consortium: IFAE, IFIC, CIEMAT (I. Gil leader), others as WG conveners
  - Slow Controls and Cryo. Instrum. Consortium: IFIC (A. Cervera technical lead), CIEMAT

Personnel
  - IFIC: 3 staff, 2 postdocs, 1 PhD, 2 engineers, 2 tech.
  - IFAE: 2 staff, 1 postdoc, 1 engineer
  - CIEMAT: 2 staff, 2 postdocs, 3 PhD, 4 engineers, 1 tech.
PMT base circuit

- Design: 1 cable base (positive HV) + ext. Splitter

The splitter decreases the effective voltage by a small per cent, but reduces the number of cables.

- All the PMT bases have already been mounted, cleaned and tested at CIEMAT
- The PMT bases have been soldered to the PMTs
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**SOURCE**
- Blue LED of 470 nm
- Kapuschinski circuit as LED driver
- 1 LED connected to 1 fiber going to one optical feedthrough
- 6 LEDs in total placed in an hexagonal geometry
- Direct light to fiber, stray light to reference sensor
- 1 reference sensor in center: Sensl SiPM
Goal:

• Determine PMT gain (SPE)
• Study PMT stability

Components:

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INNER FIBERS

• Selected to minimize light loss (0.2% light transmission, losses dominated by surface reduction)
• Full system tested at CT to study mechanical performance and light output.
• Input power measured with a power meter compared to PMT response.