A LArTPC with Vertical Drift for the DUNE Far Detector

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NuFACT - 08/09/2021
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The Far Detector of the DUNE experiment will consist of four gigantic, 17-kiloton Liquid Argon modules*.

The first module is a **Single Phase, Horizontal Drift** LArTPC

- ProtoDUNE-SP: first operation of LArTPC at the kiloton scale

The **Vertical Drift** concept is proposed for the second module

- Evolved from experience with ProtoDUNE Single- and **Dual-Phase** prototypes operation at CERN *See Wenjie’s talk!
- Proved high LAr purity achievable
  → electron lifetimes of tens of ms enable longer drift lengths

*See Monday’s plenary or the many DUNE physics and ProtoDUNE talks for more!
The Vertical Drift TPC concept

The LAr Time Projection Chamber technology:
- detectors with large fiducial volumes
- high imaging capabilities → excellent kinematic reconstruction with a mm-scale spatial resolution.

VD-TPC summarized:
- Cathode hanging at mid-height bias voltage: -300kV
- Field cage ensures Efield uniformity, 500 V/cm
- Electrons drift vertically over 6.5m
- Anodes: perforated PCB, on the top and bottom of the detector
- Photon-sensors on cathode
The Vertical Drift Far Detector

- Maximization of the active volume, with only cathode structure within fiducial volume
- Perforated PCB anodes can be hanged horizontally without deformations
  - simplified fabrication
  - no risk of broken wires
- Independent field-cage structure
  → modular concept, easier installation
- Top electronics located in chimneys are accessible:
  - possible to repair or upgrade electronics throughout detector’s lifetime
  - reduced risk of dead channels
Anode structures

Top Anodes:
- Stainless-steel frame hanging from 64 suspension chimneys
- Adjustable position (motors, kevlar wires)
- Main requirements:
  - planarity 10mm over 3m
  - >15% transparency for LAr flow.

Bottom Anodes:
- Supported by adjustable feet
- no stainless steel structure → lighter, more transparent
- bottom electronics underneath
Anode Plane Design

Optimization:
- hole diameter
- Strip pitch and direction

Electrons drift through holes in $1^{st}$ and $2^{nd}$ induction layers before being absorbed by the collection plane.

Expected electric field simulated (with Wire-Cell).

Studies on going: 2 vs 3 views, angular disposition of strips...
TPC readout electronics

Top Electronics
- Cryogenic FE analog boards in chimneys based on LARZIC amplifier ASIC
- uTCA crate with AMC for warm digitization

Bottom Electronics
- FE LArASIC amplification and shaping
- Digitization with ColdADC
- 30-year operation in cold certification required
  - Developed since 2006, successfully tested in ProtoDUNE DP and SP
  - Total system noise $< 1000e^-$
  - FE-shaping $\sim 1\mu s$
  - Digitization: 12 bit ADC $\rightarrow$ no noise contribution, sampling at $\sim 2MHz$ to match shaping
  - White Rabbit based local timing distribution
The Photon-Detection System

- The photons of LAr scintillation are detected to provide:
  - the trigger and
  - time-stamp of the event

- Given the opaque structure of the anode, the photon-sensors need to be mounted elsewhere:
  - the cryostat wall behind the field cage → increased FC transparency
  - the high-voltage surfaces (cathode)

- Sensors on HV surface:
  - enhanced coverage enables physics goals (low trigger threshold for SN)
  - power supply and signal must be transmitted over non-conducting materials
PDS implementation

x-ARAPUCA sensors

- concept developed for FD1
- double- or single-sided square tiles
- VUV-light trap enhances SiPM signal collection
- Xe doping (10ppm) increases photon scattering length

**Digitization in cold**: FPGA, digital transmitter and receiver. Each FPGA should readout several sensors to limit power consumption.

**Power over Fiber**

- Successful test of SiPM bias units

**Signal over Fiber**

cryogenic analog transmitter
Very intense campaign to develop and test the different VD-TPC systems:

- **Anode plane test** in a 50l setup
  - small scale proof of concept
  - 2 or 3 views, strip direction, hole diameter
  - S/N and transparency evaluation
  - HV connectors

- **Stand-alone test of HV components** in the NP02 cryostat at CERN (full size)

- **Test of full-sized components** in 4x4x1m³ cryostat at CERN:
  - mechanical testing of anode planes and cathode,
  - performance of anode planes and full top and bottom electronics chain,
  - proof of concept of baseline PDS
  - starting October 2021

Crossing muons produce clear and sharp signals.
DUNE has a long and rich list of physics goals:

- long-baseline neutrino beam
- deep underground → atmospheric, solar and SN $\nu$
- super-massive detector → proton decay

DUNE physics sensitivity estimations are based on a 40kton Far Detector, assuming an FD performance based on a horizontal drift LArTPC.

The VDTPC requirements are motivated by the achievement of an equivalent - or improved - performance with respect to this reference.

- An equivalent TPC signal quality requires longer $e^-$ lifetime ($>6\text{ms}$ - LAr purity $<50\text{ppt}$) and relatively shorter strips (higher intrinsic noise)
- The pitch and orientation of the collection view is similar, whereas the induction view differs. Preliminary studies show similar performance.

On-going exploration of how photon detector calorimetry can expand DUNE’s low-energy physics reach. Preliminary results show:

- improved energy and spatial resolution at low energies (i.e. 700 keV and $<1\text{m}$ for at 10 MeV deposited energy)
- timing resolution $>10\text{ns}$
- 100% trigger efficiency $>5\text{MeV}$ up to 4m from the cathode
Conclusions

- The Vertical Drift LArTPC concept was introduced end of 2020 as an option for the 2\textsuperscript{nd} DUNE Far Detector Module
- The project took shape rapidly, and currently counts with reasonably mature designs for most components
- A time-aggressive and intensive R&D campaign has been put in place, aiming to prove the concept’s feasibility
- The main identified risk factors are being addressed:
  - Cathode HV: the need to connect -300 kV over 6.5m is a major technical challenge. A full-scale prototype test will being at CERN this October.
  - The PDS: having an enhanced light collection system is conditioned to the success of PoF and SoF transmission. Alternatively the sensors can be mounted on the cryostat wall, posing no risk.
- A Conceptual Design Report has been written and is under review. Stay tuned for its publication!

Thanks for your attention!
Back Up
**Liquid Argon Time Projection Chamber**: technology capable of measuring with sub-centimeter precision ionization tracks. First time implemented at this scale.
LAr Time Projection Chamber

- Incoming neutrino interacts with Argon nucleons via weak interaction

- Charged particles from interaction generate ionization electrons and photons

- Electrons drift towards anode plane and photons detected to photo-detectors

- Signal generated in wires are reconstructed as 2D projections called views
Anode 50l test result

Signal to noise ratio with 5mm horizontal tracks of MIPs = MPV / noise RMS

- Agrees with expectations from COMSOL simulation
- First extrapolation to 1.7m long strips reduces S/N to \(~\)half these values
- Results for 2-view PCB. On-going test of latest design (3-views at -48°, 0° and 90°)