Vertical Drift Design and Physics Studies: Introduction

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LBNC Meeting
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Vertical Drift Sim/Reco/Physics

The **Vertical Drift Single Phase FD design** has been well-received within DUNE and in review settings.

At the start of this year, it was recognized that a forum for bringing together the various threads of simulation and physics studies would be helpful.

The Vertical Drift Physics Task Force was formed to facilitate cross-talk and planning across relevant working groups. Meets ~biweekly.

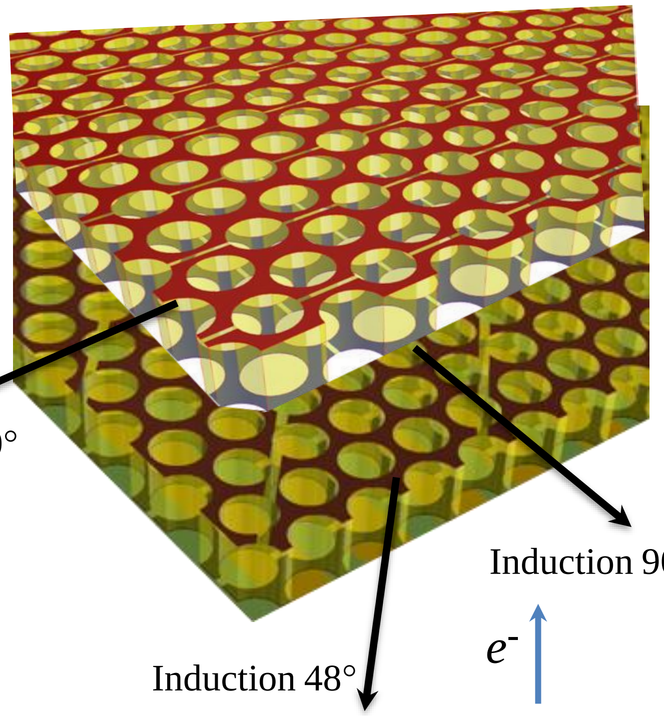
Many attend, but formal members include the following (specific names suppressed, but you'll hear from several today)

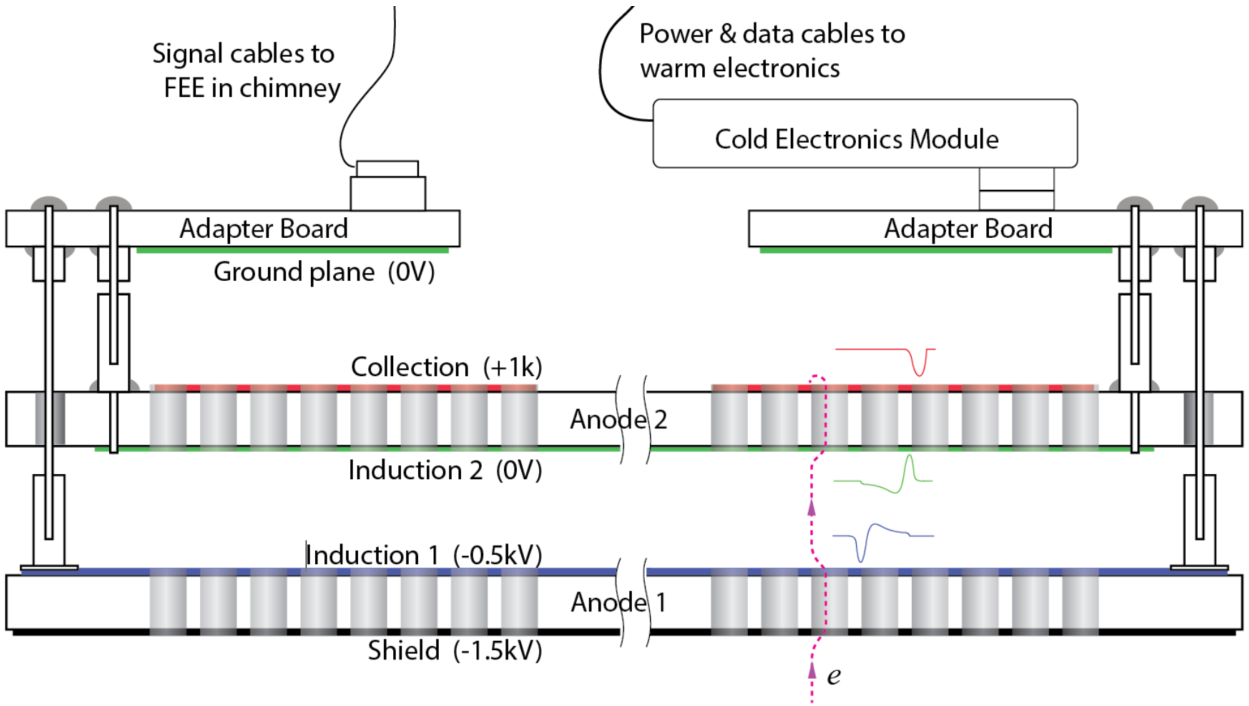
Physics Coordinators (2)
Low *E* Physics Convener
FD Sim/Reco Conveners (2)
VD software experts (2)

LBL Physics Convener
High *E* Physics Convener
VD hardware experts (2)

CRP Reference Design: Reminder

- **Three views**, two perforated PCB anodes, includes shield plane.
- Views at 0º, 90º, 48º.
- Design validated in 50L test in April.
- **First full-size CRP under construction** for cold box test in October.





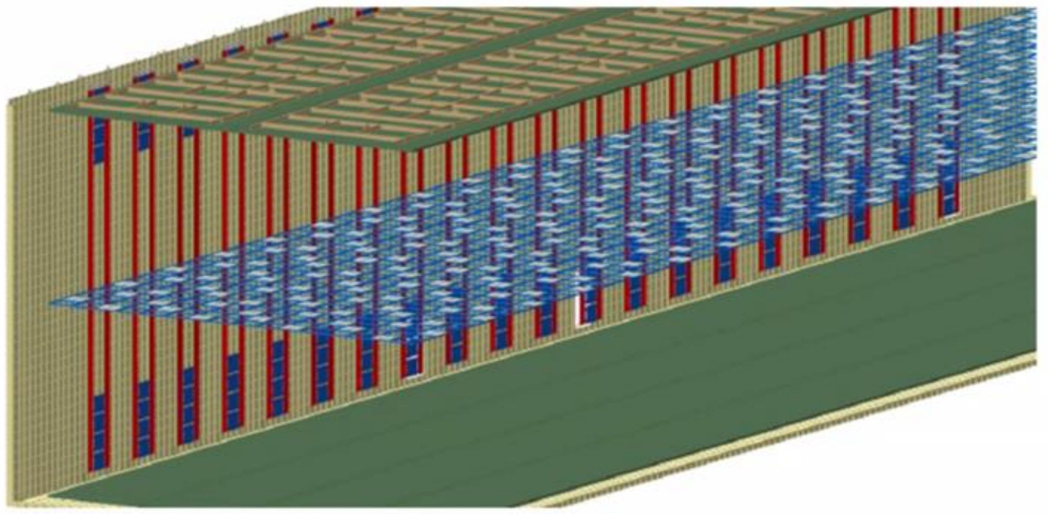
- 2.6 mm holes
- Collection strips transverse to beam (5.2 mm)
- Induction strips along beam (5.2 mm) and at 48º (8.7 mm)
- **Will have more flexibility on strip width in future designs**

Channel count per CRU:
1st view: 384, 2nd view: 640, 3rd view: 576

PDS Reference Design: Reminder

- **Cathode + cryostat membrane instrumented**
- Reference design provides **increased performance with a cost no greater** than membrane-only backup

Reference Design (Cathode & Membrane mounted PDS ⊕ Xe doping)

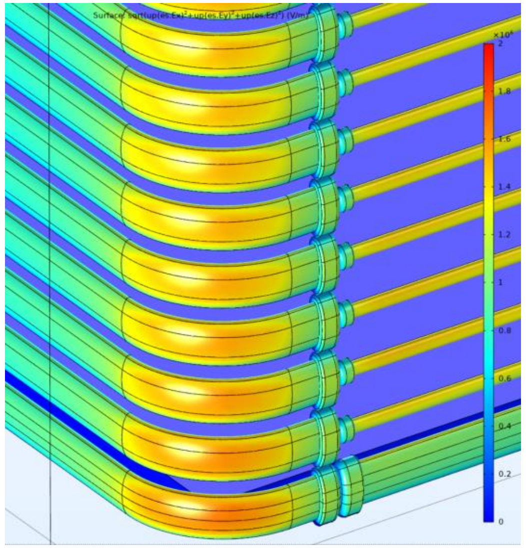


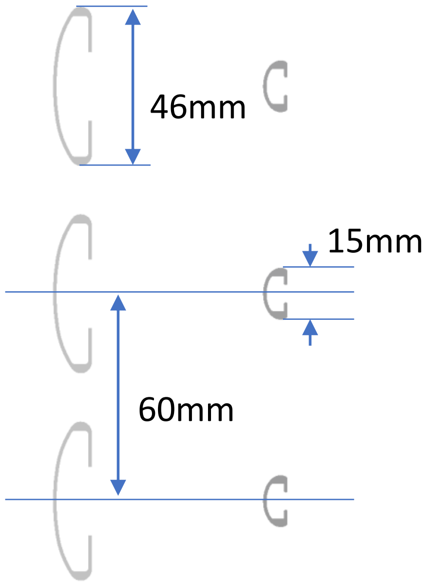
4 pi layout :

- Full trigger capabilities down to 10 MeV
- Energy, Position and T0
- xArapucas 60x60 on the cathode, 115 mq, analog readout
- xArapucas 60x60 on the cryo membrane, ~3m from Cathode

- 320 xARAPUCA on cathode
- 320 xARAPUCA on cryostat membrane near anodes
- Xe doping
- 70% transparent field cage
- Robust 2021-23 R&D program for power/readout over fiber
- *Backup solution*: 720 xARAPUCA on membrane → comparable cost, lower performance

70% transparent field cage design





Relationship between the Horiz and Vert drift designs

While the detectors are technically sophisticated, **relatively few aspects of their designs** directly contact the physics

While the HD and VD designs choose different technical solutions to achieve the detector requirements, they are **still largely the “same” detector**.

This allows many of the HD studies carried out over the past years to be brought to bear.

- Ultimately, the detectors are imaging the same ionization and scintillation, just with differently built “cameras”.

- If the “cameras” meet the same specs, many conclusions can carry over.

High-level DUNE FD detector specifications

The table at the right contains the primary physics requirements as outlined in the HDSP TDR.

Table 1.4: High-level DUNE single-phase far detector design parameters and specifications

Parameter	Specification	Goal
Drift field	$> 250\,\mathrm{V/cm}$	500 V/cm
Electron lifetime	$> 3\,\mathrm{ms}$	10 ms
System noise	< 1000 enc	—
Light yield (at cathode)	$> 0.5\,\mathrm{pe/MeV}$	$> 5\,\mathrm{pe/MeV}$
Time resolution	$< 1\,\mu\mathrm{s}$	100 ns

Together, these characterize the overall function of a DUNE LAr TPC modules.

The first three work together to ensure adequate signal is recorded by the TPC wires/strips. These three are actually technical proxies for ensuring ***adequate signal and signal/noise for ionization events anywhere in the drift volume.***

The last two ensure that sufficient scintillation information is gathered for establishing event times (and thus positions in the drift direction) for all of DUNE's physics.

…But, this table has a few HD-specific assumptions baked in

Unpacking HD and VD differences

1. *Drift distance, electron lifetime, electronics gain, field strength*

   These are potentially all different between HD and VD, but they are all **proxies for obtaining adequate ionization signal**.

   If the VD signal strengths meet or exceed the HD signal strengths, then the particular values of the above proximate parameters can freely vary as needed for technical requirements.

   VD signal strengths and SNR are estimated to meet or exceed HD performance. This will continue to be studied with simulation and direct hardware tests.

2. *Readout pitch and angles*

   Some variations in pitch and angle were explored as part of a "Far Detector Optimization Task Force" in prior years.

(next page…)

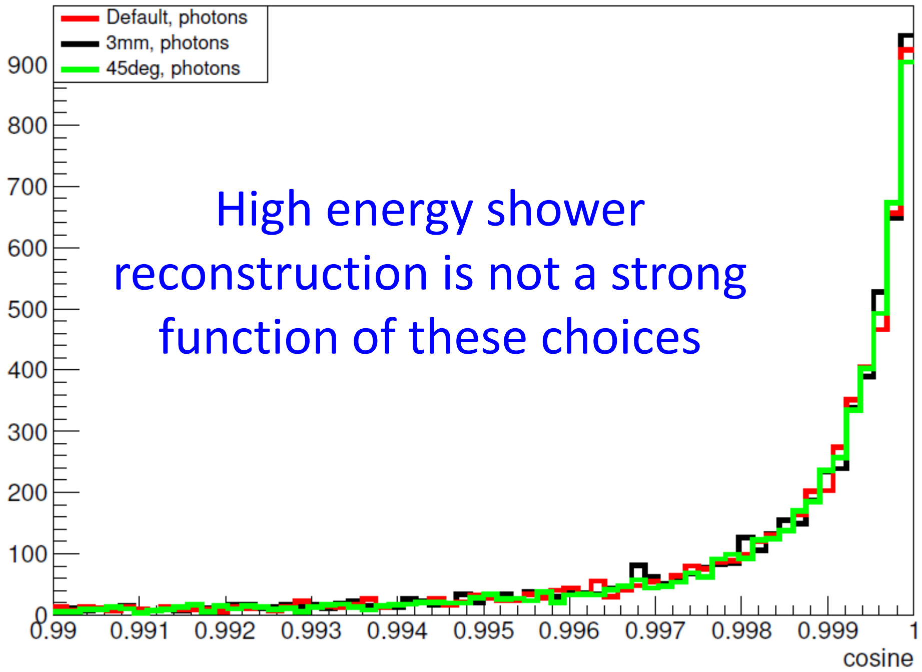
Unpacking HD and VD differences (cont'd)

<u>Examples from that Task Force's report:</u>

comparing 5 mm vs. 3 mm pitch

comparing 35.7° vs. 45° angles

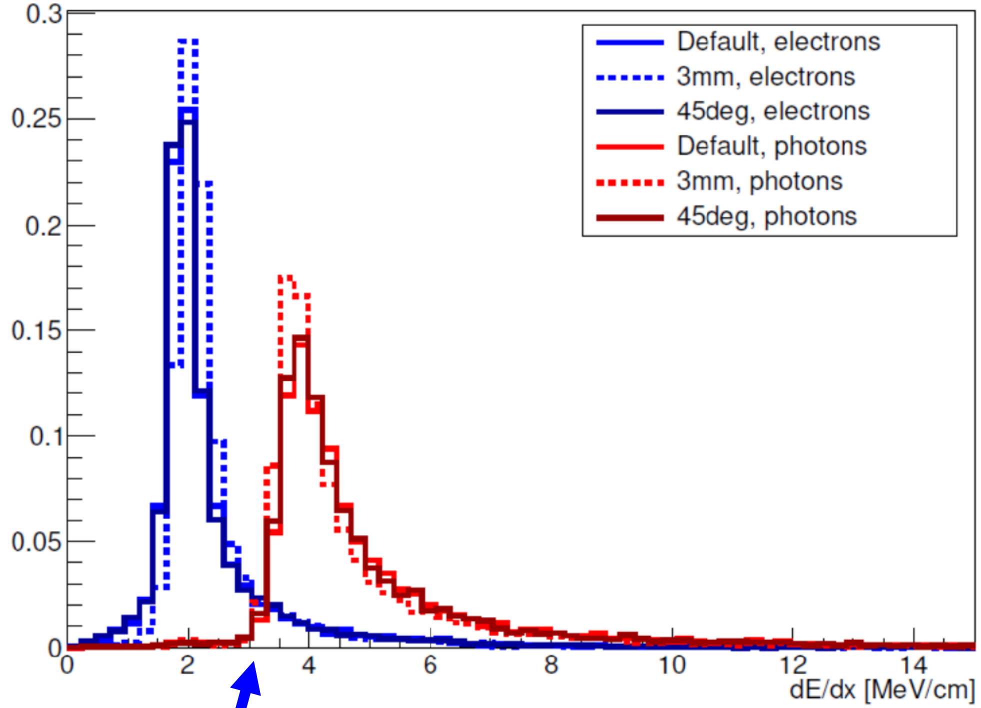
High-energy photon angular resolution



High energy shower reconstruction is not a strong function of these choices

$$\cos\theta_{\text{deviation}} = \mathbf{u}_{\text{true}} \cdot \mathbf{u}_{\text{reco}}$$

Shower-start *dE/dx* for electrons and photons



e/γ separation is not a strong function of these choices

Unpacking HD and VD differences (cont'd)

2. *Readout pitch and angles (cont'd)*

Notes:

- The **relative strip angles are comparable in VD**
- The **strip pitches are nearly the same** (5.2 mm vs. 5.0 mm) in two of the views, and a little larger in the third view (8.7 mm).

With these comparable specs and the earlier Task Force work, such variations are expected to be **negligible for high energy physics channels**.

Physics that relies on tracking over a small number of strips could, in principle, be affected by the slightly larger pitch on the third view.

Tracking efficiency for low-energy protons and kaons will be studied to ensure performance is maintained.

We will also examine low energy electrons, but **none of the DUNE physics sensitivities** presented in the HDSP TDR rely on the detailed tracking of low-energy EM showers, only total calorimetric energy.

Unpacking HD and VD differences (cont'd)

3. *Readout orientation relative to beam direction*

The **reference design** has one induction strip aligned with the beam.
An **alternative design** uses rotated views like the HDSP.

Non-beam physics will not be sensitive to this choice. Beam physics could be.
A worst-case scenario is estimated by using only two or one views in the HDSP.
See later talk.

Will test particle tracking and lepton ID efficiencies for simulated beam events in the beam-aligned (reference) geometry.

If any significant losses are seen, alternative design is available.

Unpacking HD and VD differences (cont'd)

4. *Photon detection system*

   Photons are collected using a very different scheme in VD vs. HD.

   However, **no physics sensitivities in the HDSP TDR use anything more than t_0 information** from the PDS. VD's PDS is designed to meet or exceed the light yields and timing resolutions of HD for events throughout the active volume.

   In both the HD and VD designs, we are actively exploring new capabilities through the incorporation of more PDS information (*e.g.*, calorimetry, positional information). See later slides.

5. *Calibration systems*

   The VD design will need a **comparably performant calibration system**. The technical development of the calibration subsystems for VDSP is underway.

Summarizing the connections / metrics

Design choices that make contact with physics	VD reference design same/better than HD?
TPC signal strength	Yes
TPC noise	Yes
PDS light yield	Yes
PDS timing resolution	Yes
Readout pitch	Yes + caveat 1
Readout angles	Yes
Readout beam alignment	Maybe
Calibration systems	Design underway

Will study/document no loss of **relevant low-*E* tracking** given the wider pitch of third view.

Beam-aligned view could affect particle tracking and ID in beam events. Must study with geometry-specific sim/reco. **Lepton tracking and PID efficiencies vs. energy** (for fixed background efficiency) are key metrics. Tracking of other particles in beam events not used in current sensitivity estimates.

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Elevating these items to "Yes" is what's required to know that the design will achieve the physics goals.

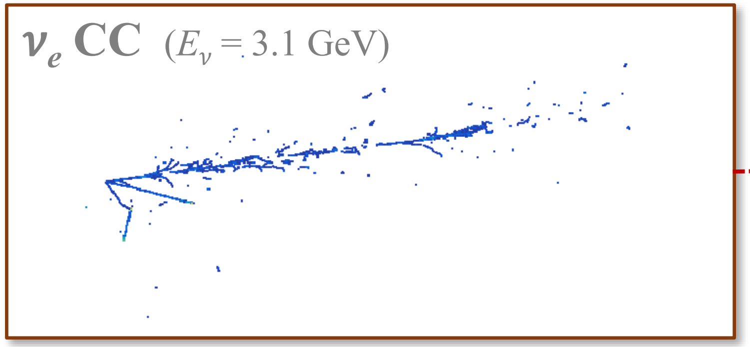
Analysis flow

VD = HD

Flux simulation
Event generation (*e.g*, GENIE, MARLEY)

Different for VD, so requires new implementation. **Status shown in subsequent talks.**

Propagation / E depositions
Ionization and scintillation yields
Field response, PDS acceptances
Signal processing
Hit finding



Data "boundary" here. ~Equivalent information continues downstream for VD and HD.

Event reconstruction
Tracking, PID

Implementation details are detector-specific, but approach and performance on equivalent data already demonstrated, save for previous caveats. **Status shown in subsequent talks.**

High-level analysis
- ND/FD integration
- systematics
- parameter fitting
- sensitivities
- …

VD ≈ HD

Timeline

Done

- Flux simulation
- Event generation (*e.g*, GENIE, MARLEY)

To be in complete and documented in CDR

- Propagation / *E* depositions
- Ionization and scintillation yields
- Field response, PDS acceptances
- Signal processing
- Hit finding

To be complete and documented in CDR

Data "boundary" here. ~Equivalent information continues downstream for VD and HD.

Progress will be reported in CDR. Ready by January 2022, in ample time for either (a) locking in the reference design or (b) recommending an alternative choice.

(Alternative designs, including 2-view, are being carried forward in parallel with reference. 3-view demonstration is early priority.)

- Event reconstruction
- Tracking, PID

Done, though calibration system design is needed

- High-level analysis
  - ND/FD integration
  - systematics
  - parameter fitting
  - sensitivities
  - …