DUNE Near Detector Conceptual Design

A Concept of a Talk

Overview

- Review agenda?
- Introduction to LBNF/DUNE
  - The experiment and its physics goals
  - Long baseline neutrino experiments and the role of the near detector
    - Past experience and lessons learned
- The overarching requirements
- The PRISM approach
- Hall?
- Introduction to the DUNE Near Detector concept
- Subsystem introductions
  - LAr, MPD, 3DST
- Towards the CDR
  - Filling out the requirements

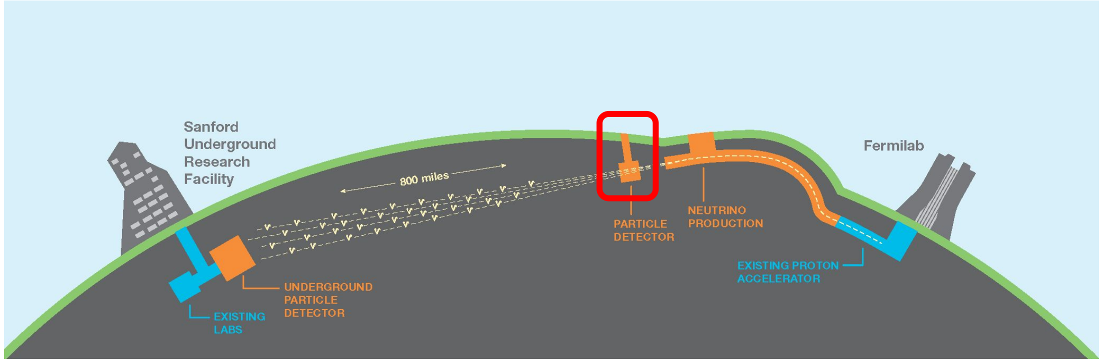
40+20 min talk
Aiming for ~30 slides

Staging stateme

Follow CDR-lite very closely . . what of the discussions over the past few days do we want to include?

Call out LBNC questions, but not necessarily answer them

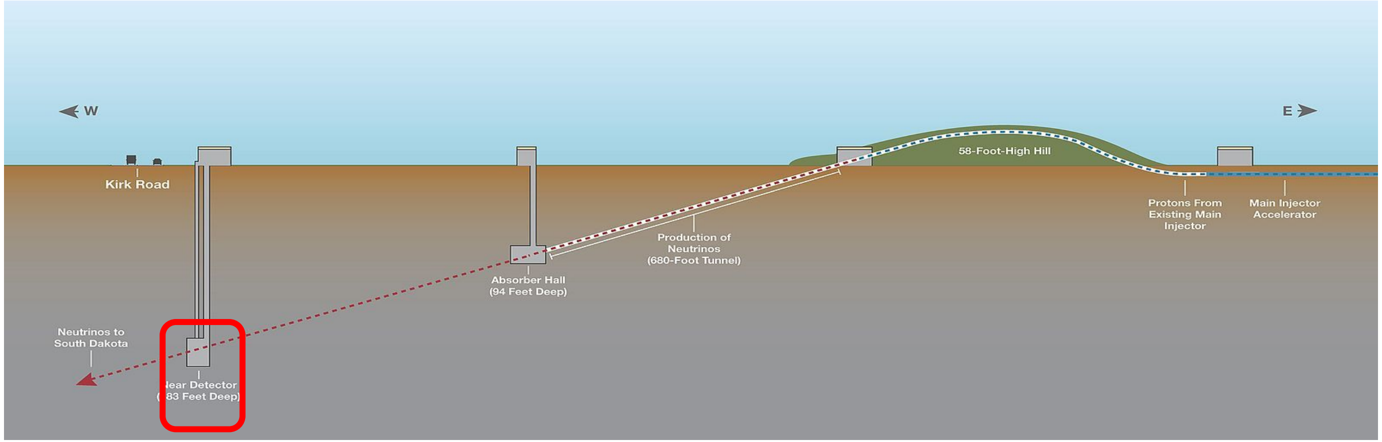
OVERVIEW OF DUNE



Near detector flux, oscillated flux

Beam structure?

Mention event rates/rock muon rates here?



OSCILLATIONS AT DUNE

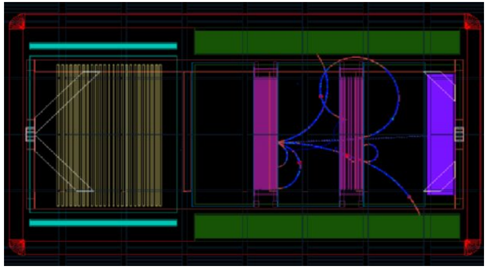
ROLE OF NEAR DETECTOR

Bullet point summary of introduction from CDR-lite.

“BEYOND THE MODEL” SYSTEMATICS

- Neutrino interaction modelling
  - Existing tensions/known issues within neutrino data
- Neutrino flux (monitoring)
  - A priori systematics exist but variations in beam operations, high power operation, etc.
  - Verification of flux model

Past Experience




ND/FD conditions are different (e.g. event rate)

ND capability beyond FD needed to further probe neutrino flux/interactions

ND must inform FD response to neutrino interactions

Needs EB signoff

DRAFT: Overarching Requirements

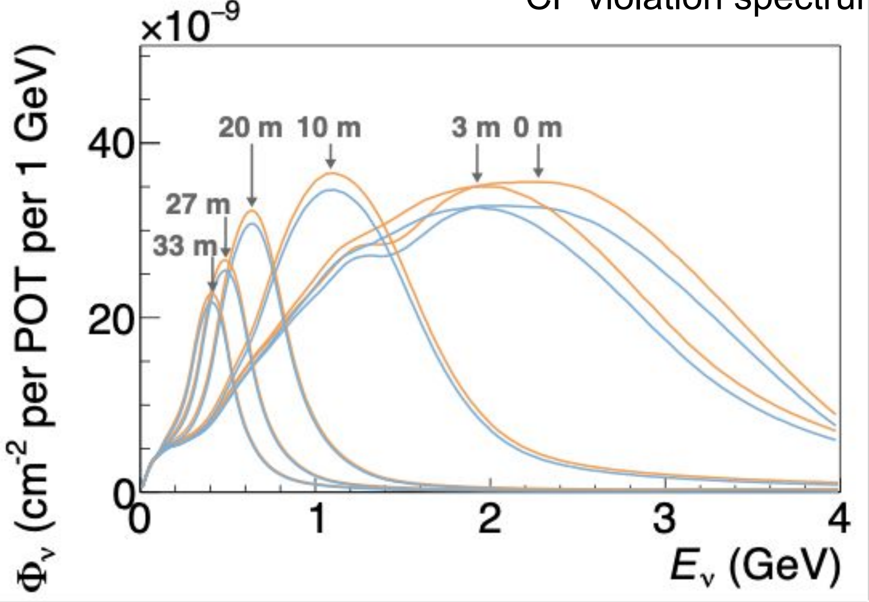
0 **Predict the neutrino spectrum at the FD** The ND must measure neutrino fluxes as a function of flavor and neutrino energy. This allows for neutrino cross-section measurements to be made and constrains the beam model and the extrapolation of neutrino energy spectra from the ND to the FD.		
O0.1	Measure interactions on argon	The ND must measure neutrino interactions on argon to reduce uncertainties due to nuclear modeling. The ND must be able to determine the neutrino flavor and measure the full kinematic range of the interactions that will be seen at the FD.
O0.2	Measure the neutrino energy	The ND must be able to reconstruct the neutrino energy in CC events and control for any biases in energy scale or resolution, keeping them small enough to achieve the required CP coverage. These measurements must also be transferable to the FD
O0.3	Constrain the cross section model	The ND must measure neutrino cross-sections in order to constrain the cross-section model used in the oscillation analysis. In particular, cross-section mis-modeling that causes incorrect FD predictions as a function of neutrino flavor and true or reconstructed energy must be constrained well enough to achieve the required CP coverage.

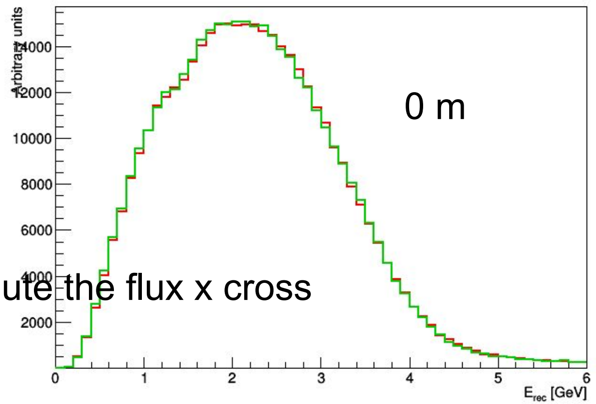
Overarching Requirements 2

O0.4	Measure neutrino flux	The ND must measure neutrino fluxes as a function of flavor and neutrino energy. This allows for neutrino cross-section measurements to be made and constrains the beam model and the extrapolation of neutrino energy spectra from the ND to the FD.
O0.5	Obtain data with different neutrino fluxes	The ND must measure neutrino interactions in different beam fluxes (especially ones with different mean energies) to disentangle flux and cross-sections, verify the beam model, and guard against systematic uncertainties on the neutrino energy reconstruction.
O0.6	Monitor the neutrino beam	The ND must monitor the neutrino beam energy spectrum with sufficient statistics to be sensitive to intentional or accidental changes in the beam on short timescales. The precise requirement will be informed by the run plan as well as experience from previous experiments.

Obtain data with different neutrino fluxes

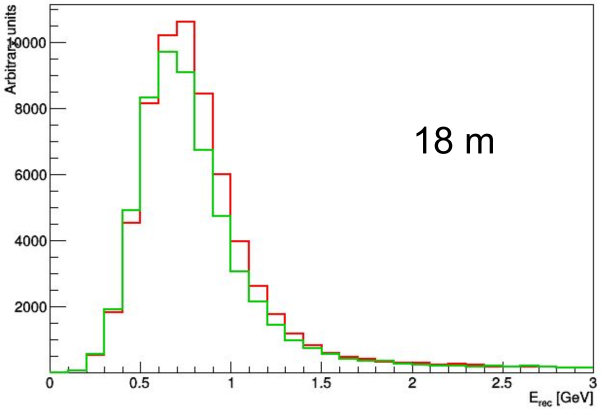
How far off-axis is useful?
Broad band beam
CP violation spectrum bewmak





0 m

Deconvolute the flux x cross section



18 m

Cross check:

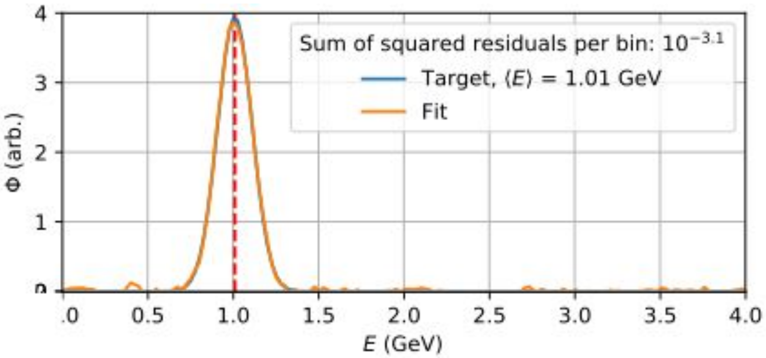
(degeneracies in on-axis tuning resolved by off-axis measurements)

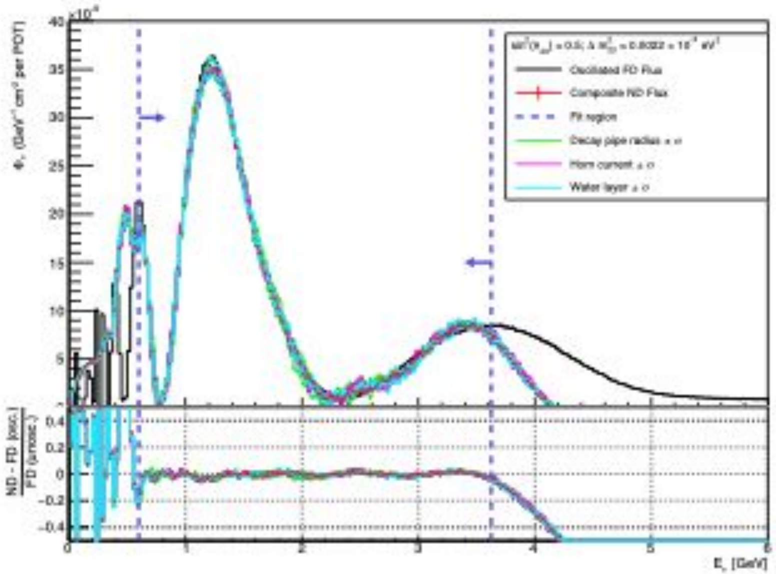
MODELLING NEUTRINO SPECTRA

Examples of how to use the PRISM data to “fix” things

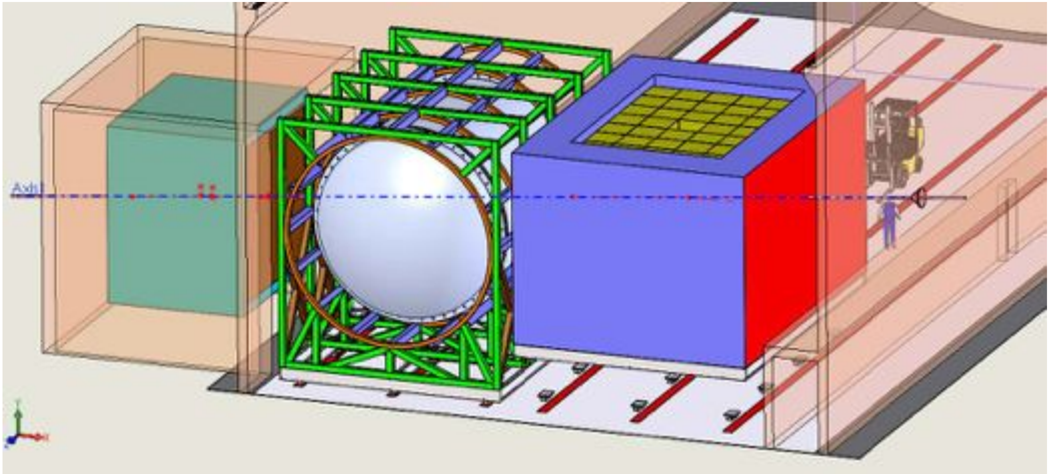
“Pseudo-Monoenergetic” beams

Matching oscillated spectra.





DETECTOR OVERVIEW

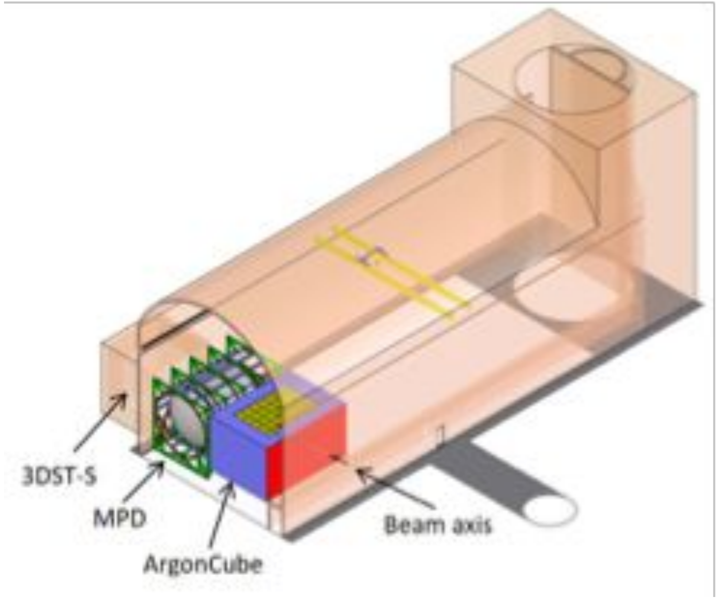


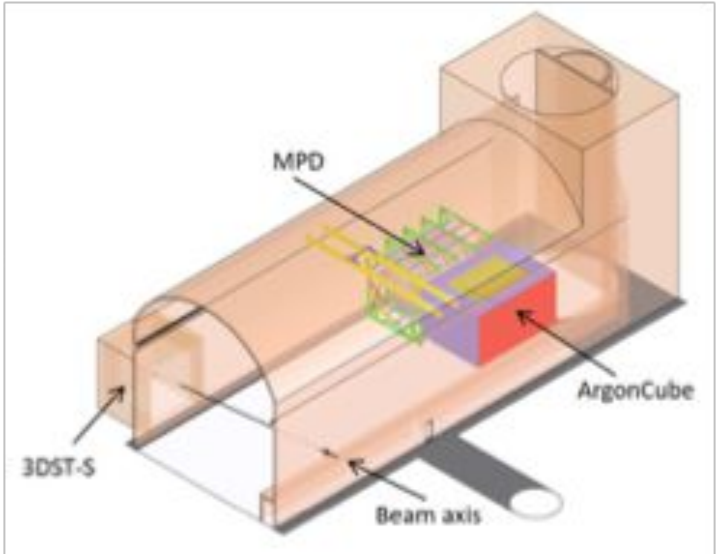
LAr

MPD

3DST

PRISM IN THE DUNE ND HALL





Add off-axis position rates

Event class	HPgTPC	LArTPC	3DST
$\nu_\mu + e^-$ elastic ($E_e > 500$ MeV)	1.3×10^2	3.3×10^3	1.1×10^3
ν_μ low-ν ($\nu < 250$ MeV)	2.1×10^5	5.3×10^6	1.48×10^6
ν_μ charged current (CC) coherent	8.8×10^3	2.2×10^5	
$\bar{\nu}_\mu$ CC coherent	8.4×10^2	2.1×10^4	

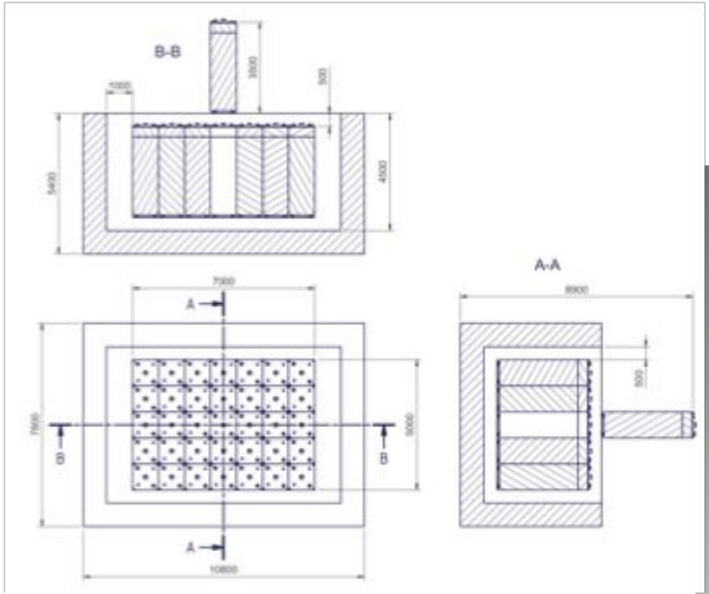
SUBCOMPONENT ROLES

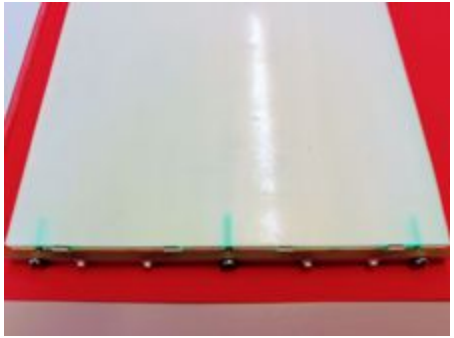
Restructure table, pull out PRISM

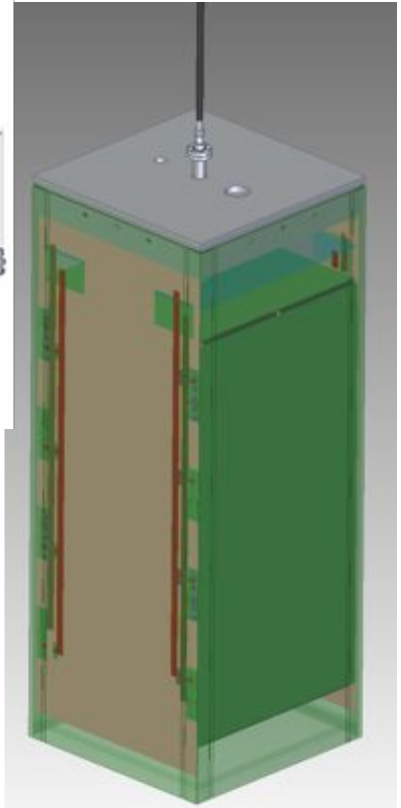
Component	Essential Characteristics	Primary function	Select physics aims
LArTPC (ArgonCube)	Mass	Experimental control for the Far Detector	$\nu_\mu(\overline{\nu}_\mu)$ CC
	Target nucleus Ar	Measure unoscillated E_ν spectra	ν-e$^-$ scattering
	Technology FD-like	Flux determination	ν_e+$\overline{\nu}_e$ CC Interaction model
Multipurpose detector (MPD)	Magnetic field	Experimental control for the LArTPCs	$\nu_\mu(\overline{\nu}_\mu)$ CC
	Target nucleus Ar	Momentum analyze liquid Ar μ	ν_e CC, $\overline{\nu}_e$
	Low density	Measure exclusive final states with low momentum threshold	Interaction model
DUNE-PRISM	LArTPC+MPD move off-axis	Change flux spectrum	Deconvolve xsec*flux
			Energy reponse Provide FD-like energy spectrum at ND ID mismodeling
3D scintillator tracker spectrometer (3DST-S)	On-axis	Beam flux monitor	On-axis flux stability
	Mass Magnetic field CH target	Neutrons	Interaction model A dependence ν-e$^-$ scattering

LAr

- 1 x 1 x 3 m3 volume
- Two-sided drift with pixel readout
  - Direct 3D representation of ionization
- Optically isolated
  - A priori localization of scintillation signal
- 7 (width) x 5 (depth) array
  - ~150 tons of LAr active







DESIGN DRIVING CONSIDERATIONS

- HIgh rate:
  - Pixelization:
    - Overcome occupancy/disambugation issues in wire readout detectors
  - Modularization
    - Faster drift, localization of scintillation signal
- Number/size of overall detector
  - Muon momentum reconstruction and hadron containment
- Primary/most direct view into how events look at FD
- Flux measurements via ν-e elastic scattering, low-ν

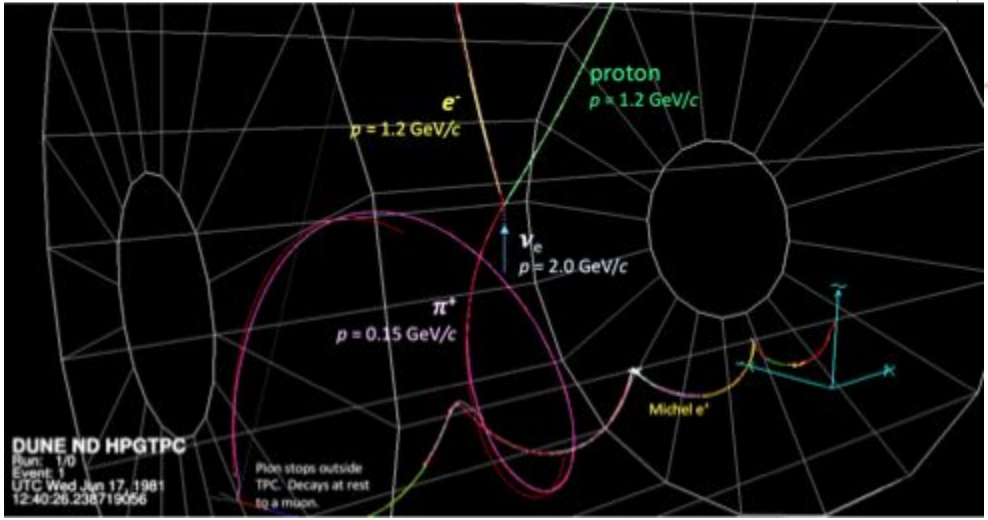
Pileup and ND/FD “mismatch” issues

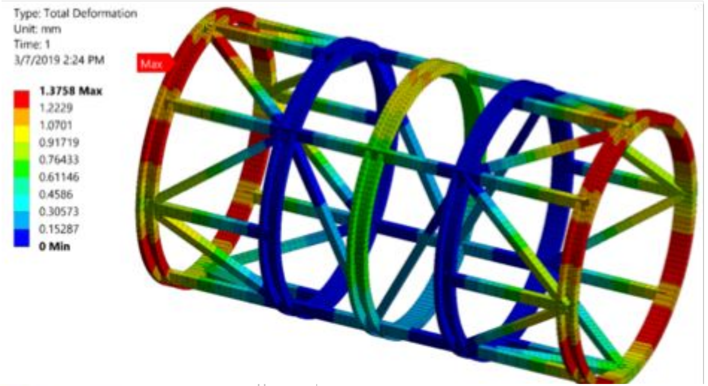
MPD

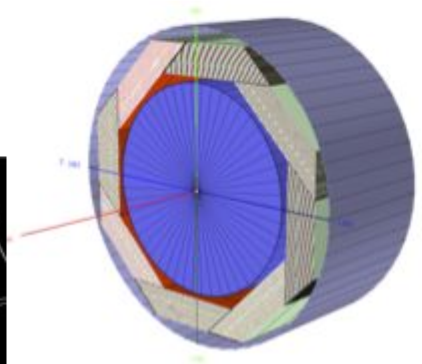
Magnetized: 0.5 T field

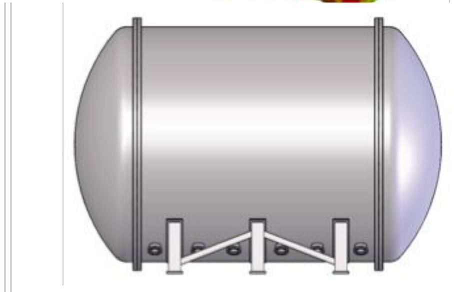
High Pressure (10 Atm) gaseous argon TPC

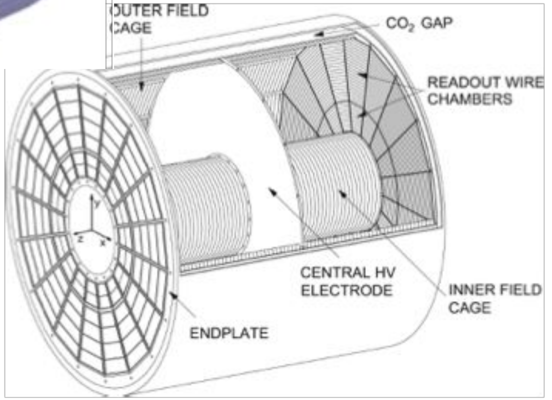
Calorimetry surrounding tracking











DESIGN DRIVERS

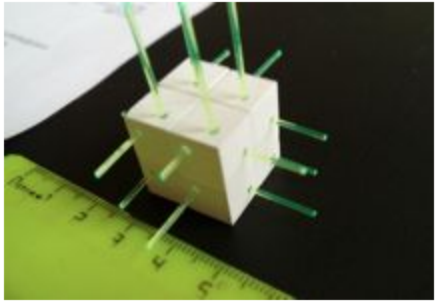
- Downstream muon spectrometer for LAr
- ν-Ar events with:
    - Sign-selection, momentum spectrometry
    - Very low tracking thresholds
    - Minimal secondary interactions

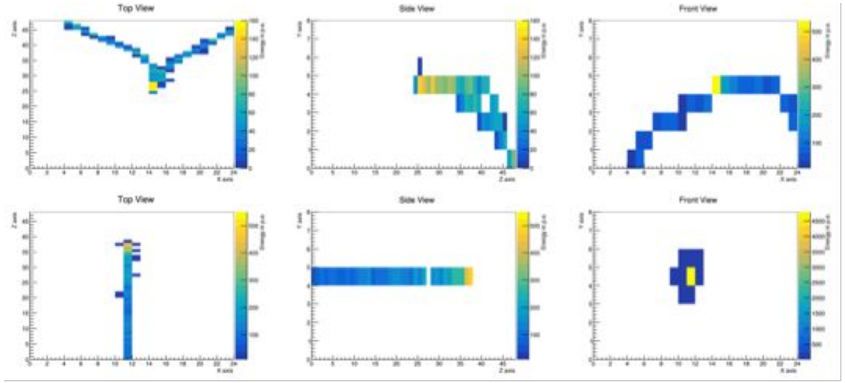
- Flavor specific measurements by tagging lepton/sign
- Fully observe “bare” ν-Ar interactions:
    - disentangle: ν-Ar from secondary interactions from detector response
    - powerful tool in transferring ND measurements to FD

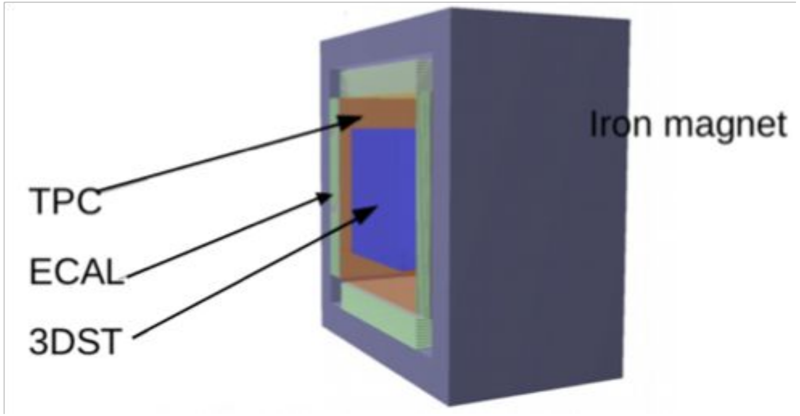
I can’t talk to you now . . .
my LAr detector needs me!

Pileup and external photon backgrounds

3DST-S




Top View
Side View
Front View
Top View
Side View
Front View


Iron magnet
TPC
ECAL
3DST

DESIGN DRIVERS

- On-axis flux monitor
  - Rate, spectrum, transverse profile
- Neutron detection
  - New capability in neutrino detectors
  - Nascent capabilities in MINERvA show potential
- ν-CH sample
  - Cross check ν-A modelling across A
  - Connect to “historic” data sets

I'd like to hold off judgment on a thing like that until all the facts are in . ..

Suitability as a beam monitor

OVERARCHING REQUIREMENTS:

Review how detectors fulfill these requirements

REQUIREMENTS

- Propose a hierarchy of requirements:
  - **Overarching (O):**
    - State the role/purpose of ND in the experiment
    - No reference to individual subsystems or particular implementations
  - **Capabilities (C):**
    - Measurements that the ND must make to deliver overarching requirements (e.g. ν-e flux measurement)
    - Refers to subsystems that perform these measurements but not particular implementation
  - **Performance (P):**
    - Detector performance (efficiencies, resolutions, etc.) that are needed to deliver the capabilities.
    - Refers to specific subsystems and refers to particular implementation as needed
  - **Technical (T):**
    - Parameters/other properties (pixel pitch, granularity, magnetic field, etc.) specific to detectors needed to deliver required performance.

CASE STUDY/EXAMPLE

- **O0.6: Monitor the neutrino beam:** The ND must monitor the neutrino beam energy spectrum with sufficient statistics to be sensitive to intentional or accidental changes in the beam on short timescales. The precise requirement will be informed by the run plan as well as experience from previous experiments.
- Capabilities:
    - The neutrino event rate must be measured to X% in Y days
    - The neutrino beam center must be measured to X cm in Y days
    - The neutrino beam spectrum must be sensitive to distortions induced by . . .
- Performance
    - The near detector must accumulate X events/day to measure the rate
    - The near detector must have XXX cm position resolution to map out the beam profile
    - The near detector must . .. .

ANOTHER CASE STUDY?

- **O0.4: Measure the neutrino energy:** The ND must measure neutrino fluxes as a function of flavor and neutrino energy. This allows for neutrino cross-section measurements to be made and constrains the beam model and the extrapolation of neutrino energy spectra from the ND to the FD.
- Capabilities: . . ..
- Performance: . . ..
- Technical: . . . .

CONCLUSIONS