The ND Conceptual Design Report Status

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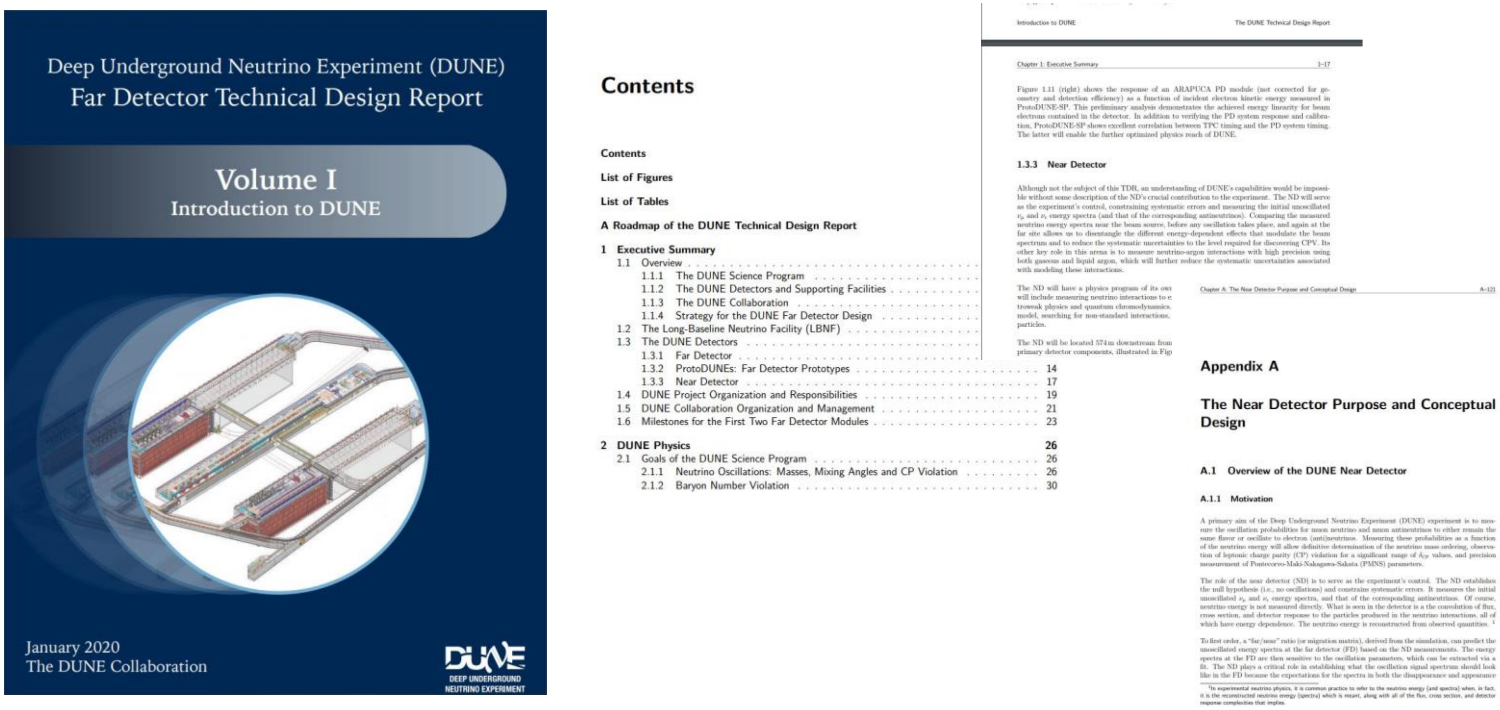
DUNE LBNC Meeting

March 5, 2020

ND documentation …

- ND executive summary in Volume I of FD TDR
- CDR-lite → Appendix A of Volume I of FD TDR



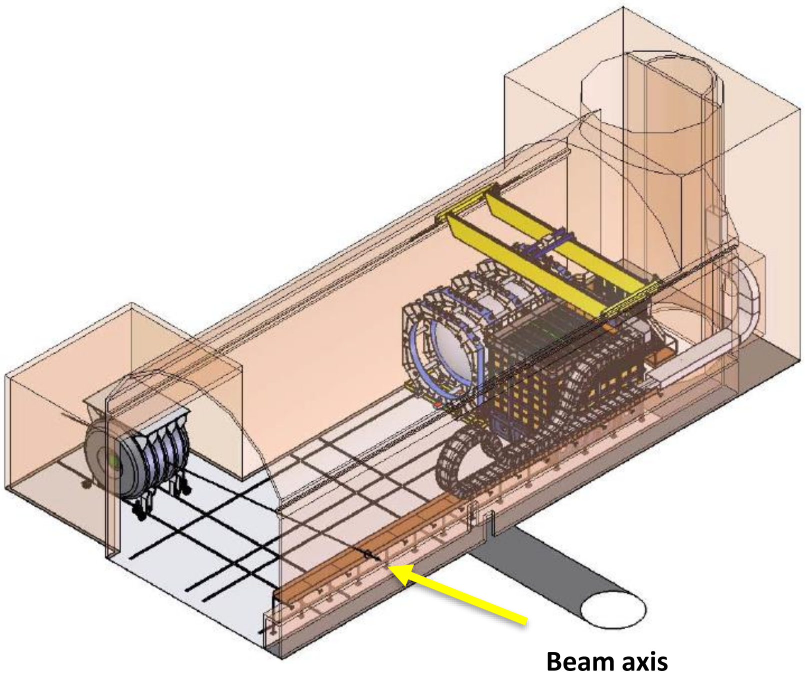
- Now evolving into ND Conceptual Design Report (CDR)

Some expected changes in the CDR relative to the appendices of the TDR

New chapter structure
Hall/facilities update/chapter
DAQ chapter
Computing chapter
Flux chapter, including some on beam model
BSM to include dune ND relevant stuff
SM cross sections chapter
LAr – mostly design updates
SAND – 3DST in KLOE
SAND – acceptance, resolutions
SAND – beam monitoring update
SAND – neutron study update
MPD – neutron study update
MPD – muon tagging study
MPD – ECAL and muon tagger design
MPD – pileup simulation and mitigation
MPD – magnet design
MPD – pion multiplicity study (bias on oscillations)
MPD – photon and NueCC study
MPD – Ks and lambda reconstruction (energy scale)
Requirements update

- List incomplete
- Maybe not everything shows up in final draft

- At this time, the CDR goals are
  - present the reference design
  - present the physics case for the reference design (at least to degree supported by studies to date, ongoing)
  - discuss alternatives being considered in the context of the reference design
- To the extent there is discussion about staging scenarios, that is not part of the CDR.



CDR structure

- Chapter 1 – introduction (currently 14 pages)
- Chapter 2 – Liquid argon TPC (currently 31 pages)
- Chapter 3 – HP gas argon TPC/muon spectrometer (currently 33 pages)
- Chapter 4 – SAND (beam monitor) (currently 30 pages)
- Chapter 5 – PRISM concept (currently 22 pages)
- Chapter 6 – ND hall and facilities (currently ***15*** pages)
- Chapter 7 – ND data acquisition (currently 4 pages)
- Chapter 8 – ND computing (currently 7 pages)
- Chapter 9 – Neutrino beam modeling and flux (currently 6 pages)
- Chapter 10 – Neutrino cross section measurements (currently 22 pages)
- Chapter 11 – BSM physics with the ND (currently 14 pages)
- Chapter 12 – Summary of requirements

About 200 pages

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May be combined

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Probably full table here and partial requirements sections in major subdetector chapters

Schedule shown in early December

- December 2019, new input from groups/studies
- January 2020, major editing push, begin internal reviews
- February 2020, revise and edit using internal review feedback
- March 2020, version ready for LBNC

Schedule now

- December 2019, new input from groups/studies
- January 2020, new input from groups/studies, editing
- February 2020, new input from groups/studies, editing
- March 2020, still waiting for some important input, editing, need to do some internal reviewing
- Goal is still to deliver at end of month
- Frustrating reality: CDR co-editors invited to participate in significant, distracting activities by DOE this month. Likely to affect CDR schedule.

The role of the ND

- The ND provides the control samples for the oscillation analysis
- Measures the neutrino energy spectrum before oscillations occur
- The measured rate is a convolution of three ingredients:

$$\text{ND Rate} = \int [\text{Flux}] \times [\text{CrossSection}] \times [\text{Det.Response}]$$

- The ND must allow the experiment to predict the FD spectrum:

$$\text{FD Rate} = \int [\text{OscProb}] \times [\text{Flux}] \times [\text{CrossSection}] \times [\text{Det.Response}]$$

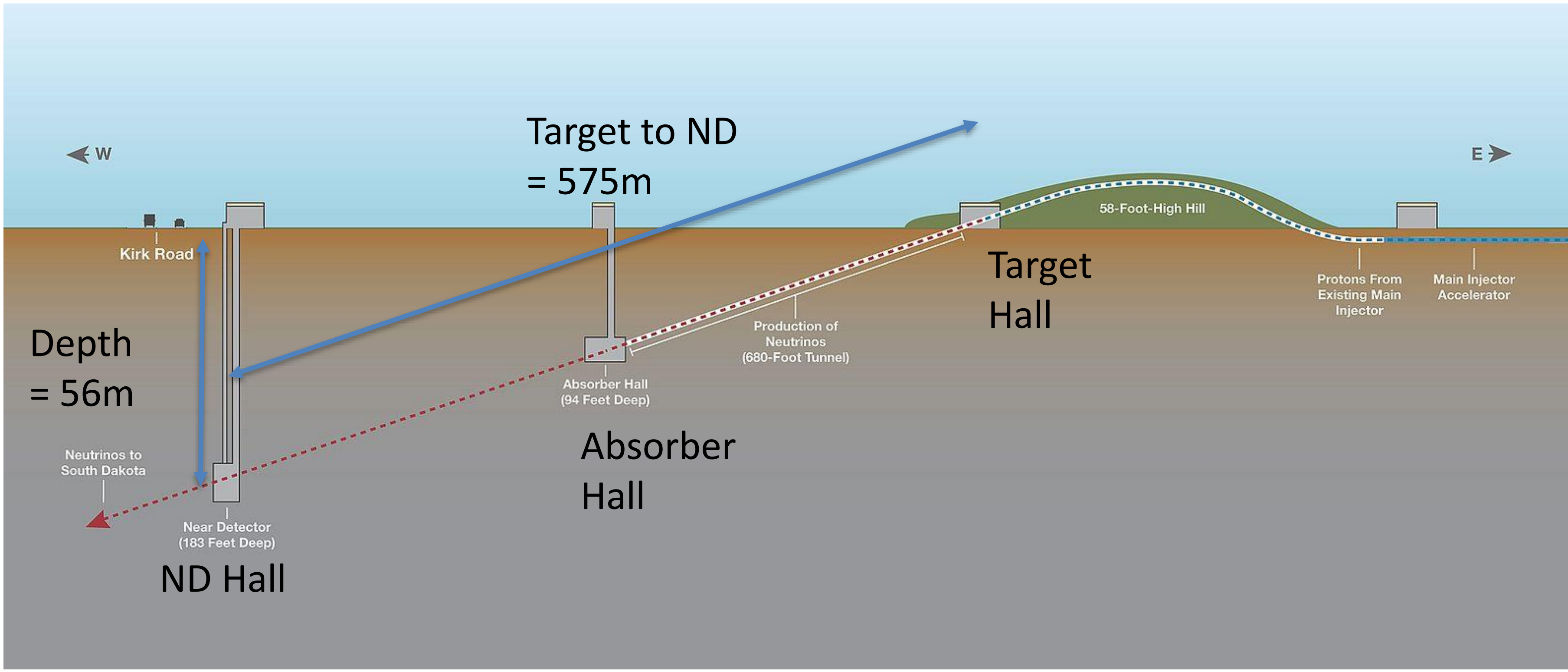
- The ingredients are not necessarily well known. The ND must have the ability to deconvolve them to make the FD prediction and to set systematic errors confidently.

Overarching ND Requirements

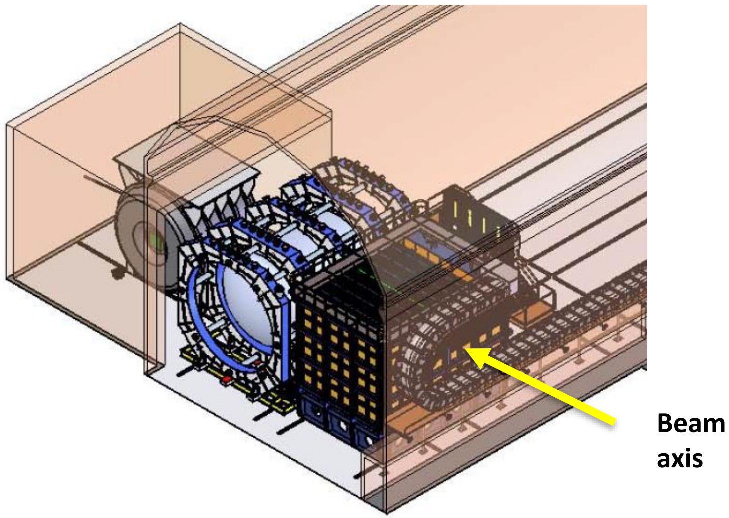
O0: Predict the neutrino spectrum at the FD: The Near Detector (ND) must measure neutrino events as a function of flavor and neutrino energy. This allows for neutrino cross-section measurements to be made and constrains the beam model and the extrapolation of neutrino energy event spectra from the ND to the FD.

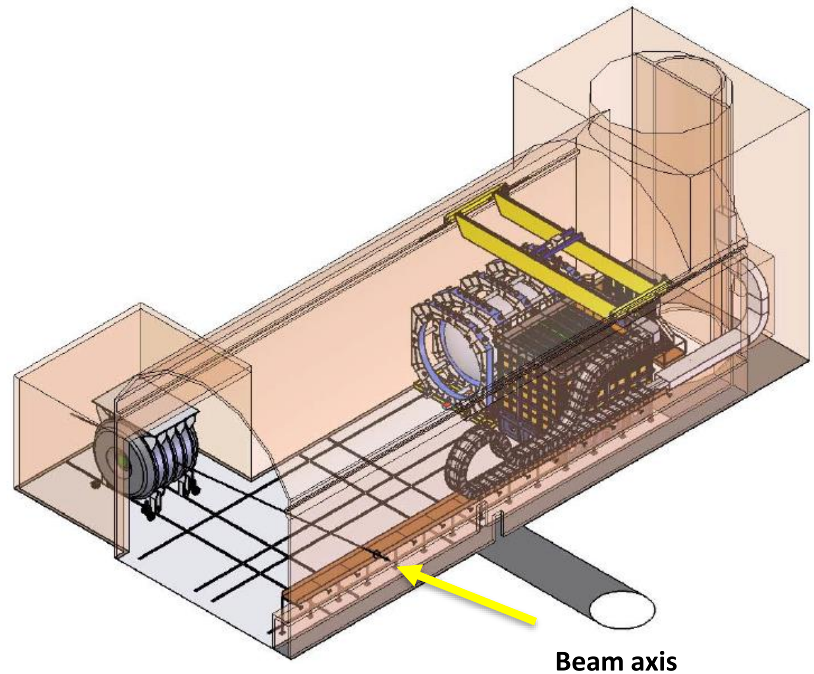
O0.1	**Measure interactions on argon**	Measure neutrino interactions on argon, determine the neutrino flavor, and measure the full kinematic range of the interactions that will be seen at the FD.
O0.2	**Measure the neutrino energy**	Reconstruct the neutrino energy in CC events and control for any biases in energy scale or resolution.
O0.3	**Constrain the xsec model**	Measure neutrino cross-sections in order to constrain the cross section model used in the oscillation analysis.
O0.4	**Measure neutrino flux**	Measure neutrino fluxes as a function of flavor and neutrino energy.
O0.5	**Obtain data with different neutrino fluxes**	Measure neutrino interactions in different beam fluxes in order to disentangle flux and cross sections and verify the beam model. **(PRISM)**
O0.6	**Monitor the neutrino beam**	Monitor the neutrino beam energy spectrum with sufficient statistics to be sensitive to intentional or accidental changes in the beam on short timescales.

DUNE near site



DUNE near detector





System for on-Axis Neutrino Detection (SAND)

Beam monitor (O0.6)

Neutrons and xsec model

Multi-purpose Detector (MPD)

Momentum analyze CC event in LAr

Low threshold + detailed Ar xsec, minimal secondaries

LAr Detector (ArgonCube)

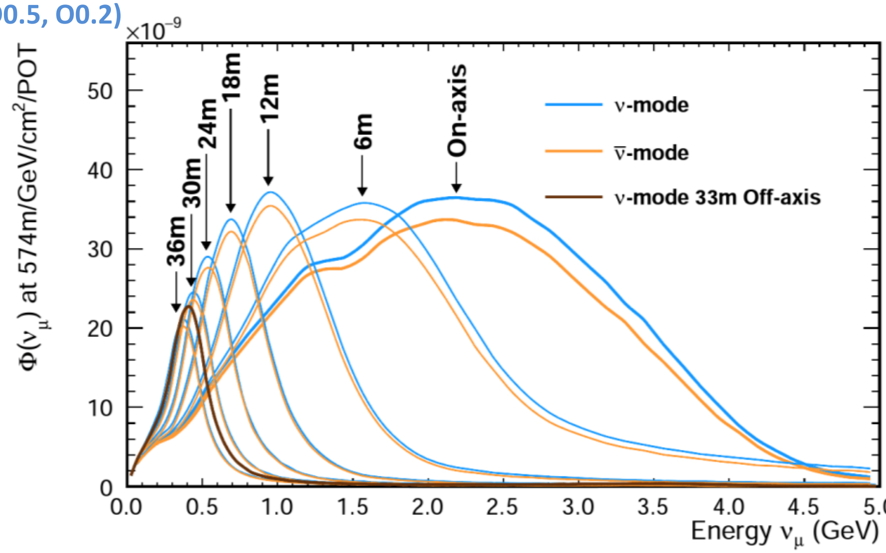
Meas. ND flux on argon

(O0, O0.1)

LAr response

(O0.3, O0.4, O0.5)

(O0.5, O0.2)

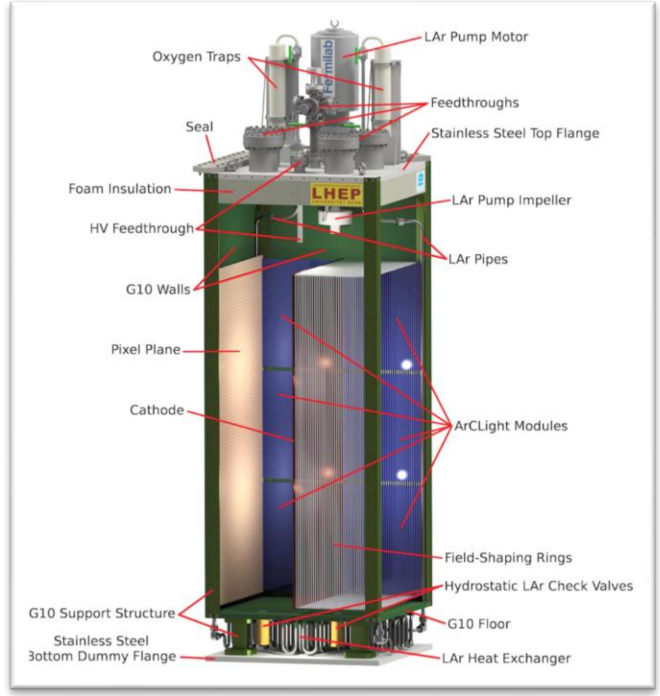


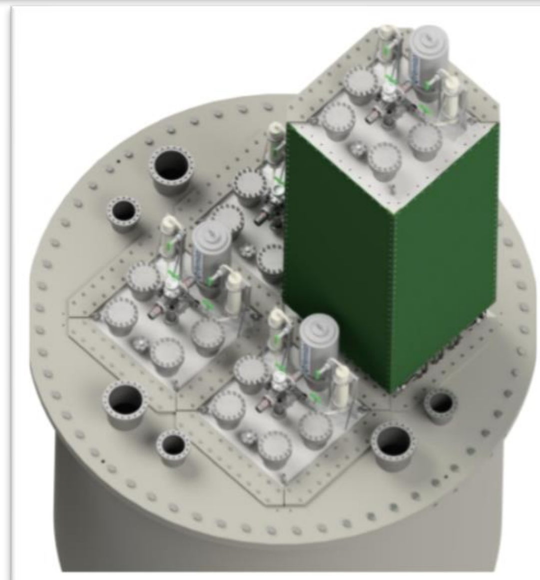
The LArTPC

- As similar as feasible to the FD to allow a Near<->Far translation approach to oscillation analysis.

  [O0 Predict the neutrino spectrum at the FD]
  [O0.1 Measure interactions on argon]

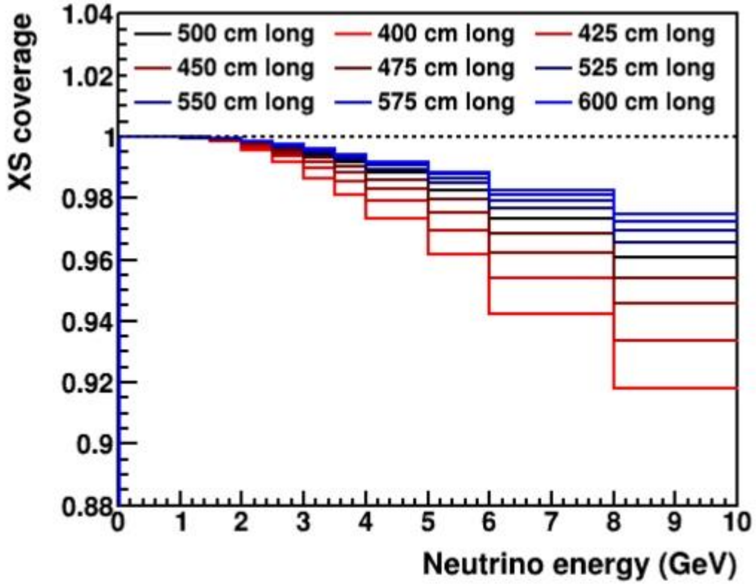
- Segmented into 1x1x3m modules with thin walls (1cm G10) that have similar density to LAr.
- Pixelized readout to deal with pileup.
- Optical readout via dielectric light traps (ArcLight) provides t0 determination.
- A 2x2 module prototype will run in NuMI next summer

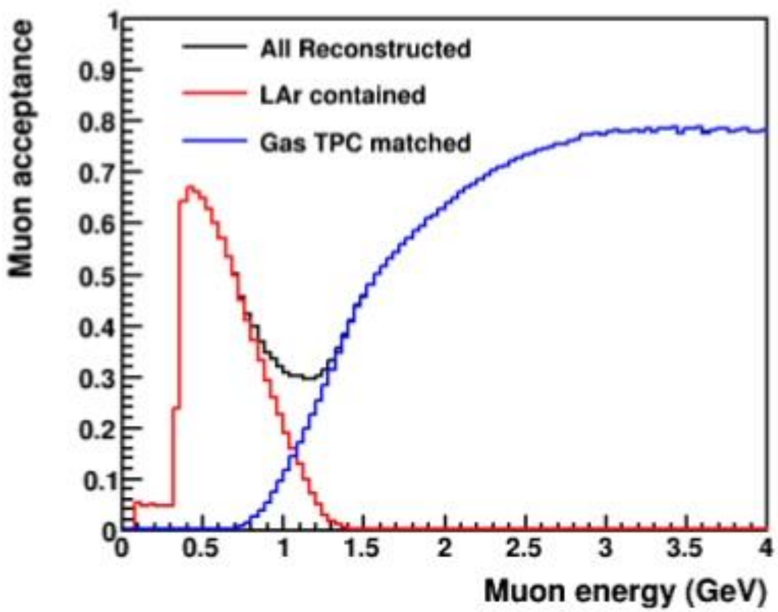




The LArTPC

- 3m height is set by hall height and crane.
- 5m depth set by hadronic shower containment.
- 7m width:
  - 5m for shower containment
  - +1m on each side to contain side exiting muons
    - Cost effective solution
    - Increases fiducial volume by 50%
- Muons with energy > 1GeV are not contained well so a spectrometer is needed downstream.





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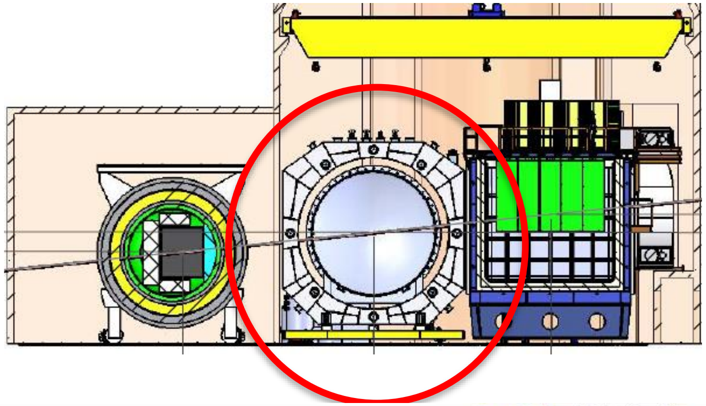
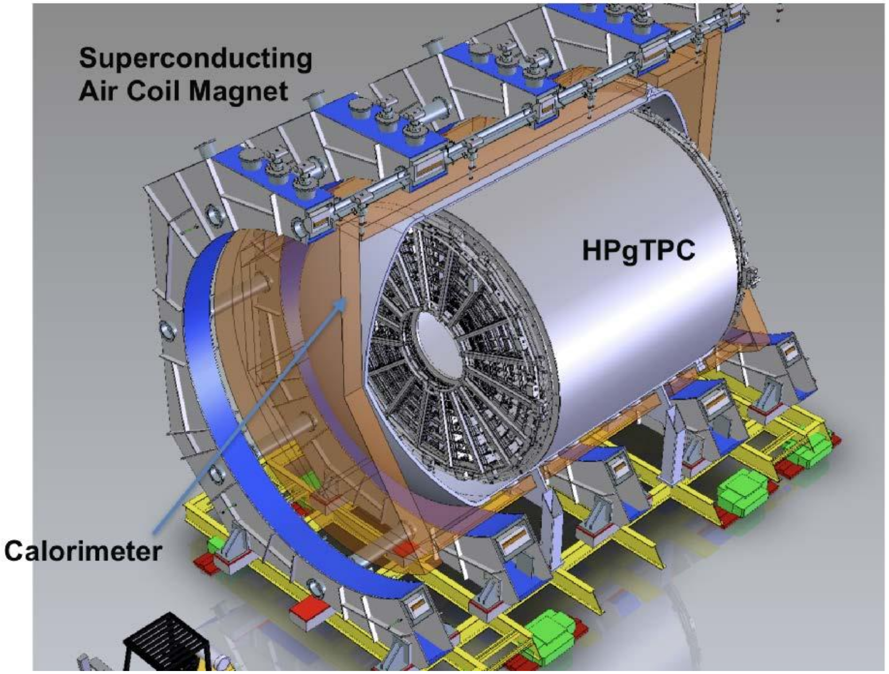
Under construction

Drilling down in requirements one level for the LArTPC

- The ND must take data on argon (already an overarching requirement, needed so nuclear effect systematics cancel to some extent)
- The ND must have a technology that is as similar to the FD as practically possible (needed so that detector systematics cancel to some extent).
- The ND must be able make a statistically significant measurement of numu and numubar CC event rates/fluxes in a short period (needed for the oscillation constraint)
- The ND must be able to make a good constraint on the flux via neutrino-electron scattering (need to constrain flux with technique largely independent of interaction model).
- The ND must be able to measure many different neutrino interaction morphologies (constrain neutrino interaction model used in oscillation analysis).
- Derived requirements: must handle rate, must have big mass, must have sufficient containment of events, must have good resolution, must be able to move off-axis

Multi-Purpose Detector Overview





- High pressure (10bar) gas TPC + ECAL + SC magnet + μ tag
- Provides muon spectrometry for muons leaving LAr [O0.2 Measure the Neutrino Energy]
  - LAr event containment
- Provides an independent, statistically significant event sample on Ar gas

  [O0.1] On Ar [O0.3] cross sections
  - Sign selection
  - Full 4π coverage
  - Very-low tracking threshold
  - Relatively few secondary interactions
- Can move off axis

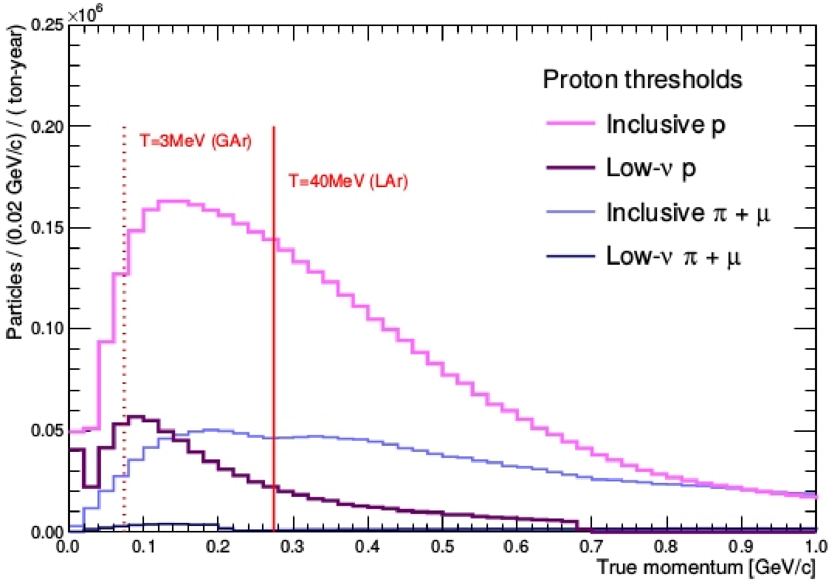
Multi Purpose Detector

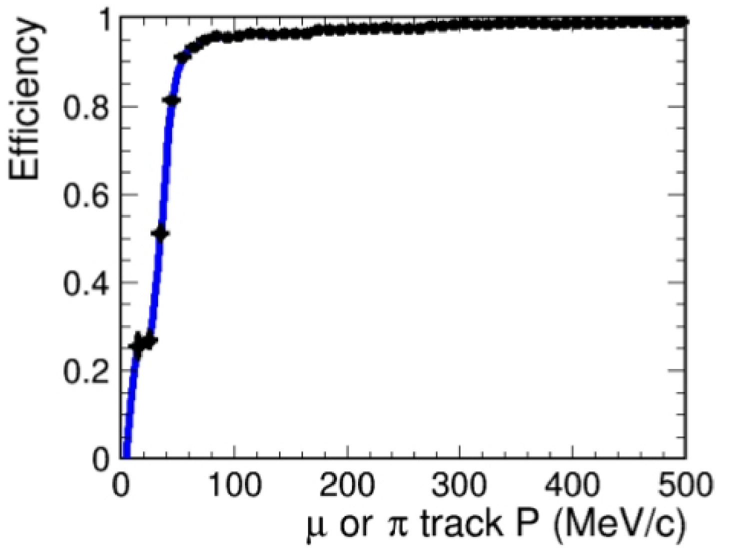
Serves as a control for the LArTPC.

- Very low thresholds and high efficiency. Can see what the LArTPC is missing.
- Kinematic acceptance nearly 4π like the far detector
- Measures hadron energies using a more accurate & precise technique than the LArTPC.
- Measures the composition of the hadronic system.

Under Study

- Neutron performance
- Potential to set the absolute energy scale via Ks and Lambda decays



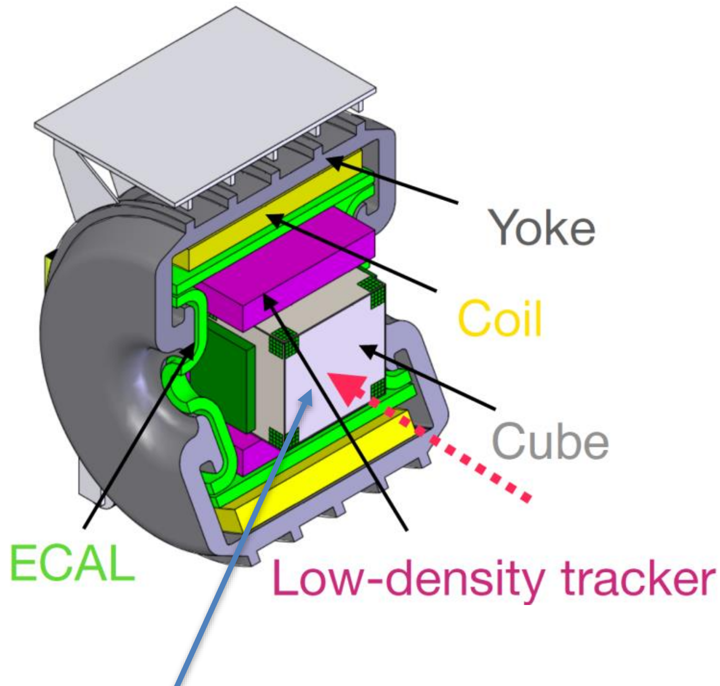


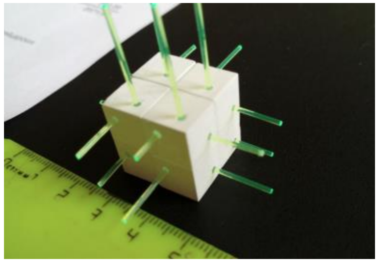
Under construction

Drilling down in requirements one level for the MPD

- The ND must track, tag charge-sign, and momentum analyze muons exiting from the LArTPC. (To measure the energy spectrum of numu and numubar CC interactions occurring in the LArTPC.)
- The ND must measure neutrino interactions on argon with a kinematic acceptance that equals or exceeds the FD across the energy range relevant to oscillations. (To constrain neutrino interaction uncertainties in regions of phase space not accessible to the LArTPC.)
- The ND must have the ability to clarify the relationship between true and reconstructed energy by studying neutrino interactions on argon with low energy thresholds, good kinematic resolutions, and good particle ID. The ND should be sensitive to particles that are not observed or may be misidentified in the LArTPC.

SAND – System for on-Axis Neutrino Detection





- 10.9 tons of 1cm x 1cm x 1cm scintillator cubes inside a B field.
- Projective readout with SiPMs
- Surrounding trackers and ECAL
- 14 million CC events per year
- Remains on beam axis
- Functionality:
  - **Beam monitoring** (of particular importance when MPD and LArTPC are off-axis)

    [O0.6 Monitor the Neutrino Beam]
  - Sensitive to neutrons

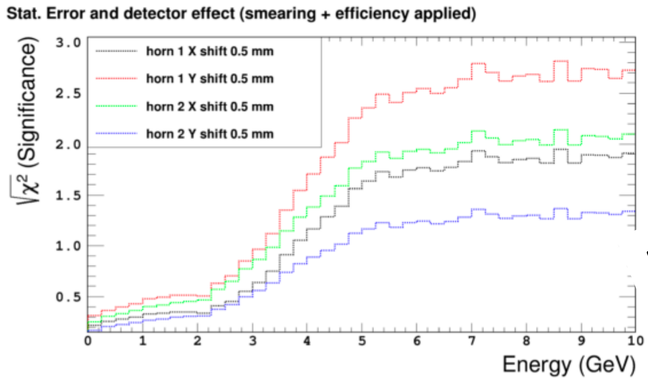
    [O0.2 Measure the Neutrino Energy]

    [O0.3 Constrain the xsec model]
  - Nuclear dependence with C and H

    [O0.3 Constrain the xsec model]

SAND – System for on-Axis Neutrino Detection

Muon spectra in 3DST in 0.6T B field. Shift seen relative to nominal in one day

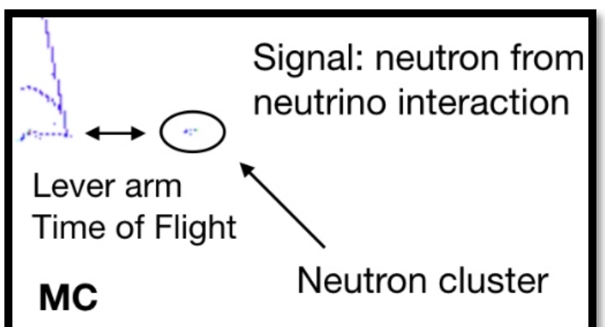


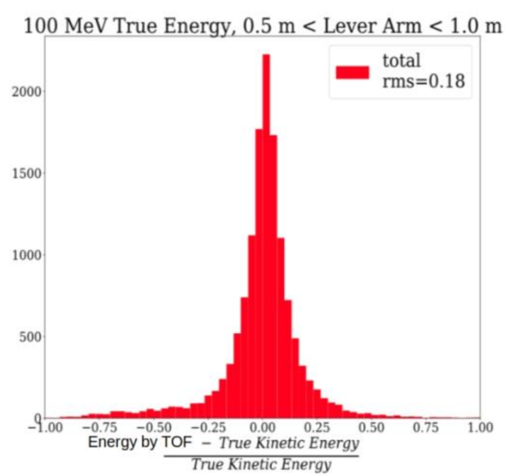
Preliminary

Muon spectra in 3DST in 0.6T B field (one day) *versus* rate only detector (4 7-ton modules at 0,1,2,3 m) over one week

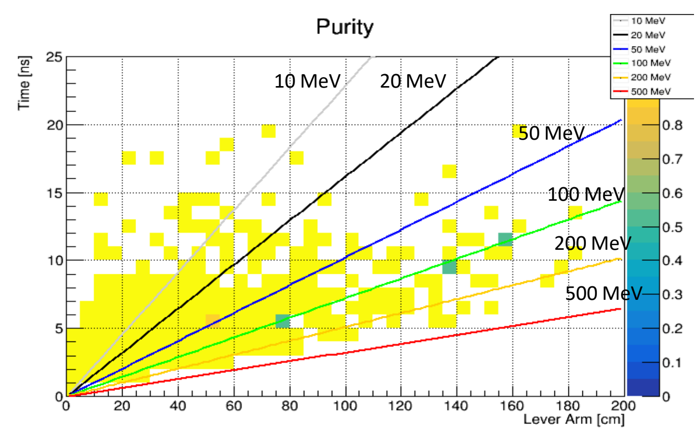
	Significance, $\sqrt{\chi^2}$	
Changed beam parameter	Rate-only monitor	3DST-S
proton target density	1.9	7.8
proton beam width	3.0	6.6
proton beam offset x	0.7	20.0
roton beam theta phi	0.2	12.5
horn 1 along x	1.9	8.8
horn 2 along x	0.7	12.8
horn 1 along y	0.2	9.9
horn 2 along y	0.4	6.3

Neutron detection with energy determination via time-of-flight





Only out of fiducial background considered. Secondaries under study.



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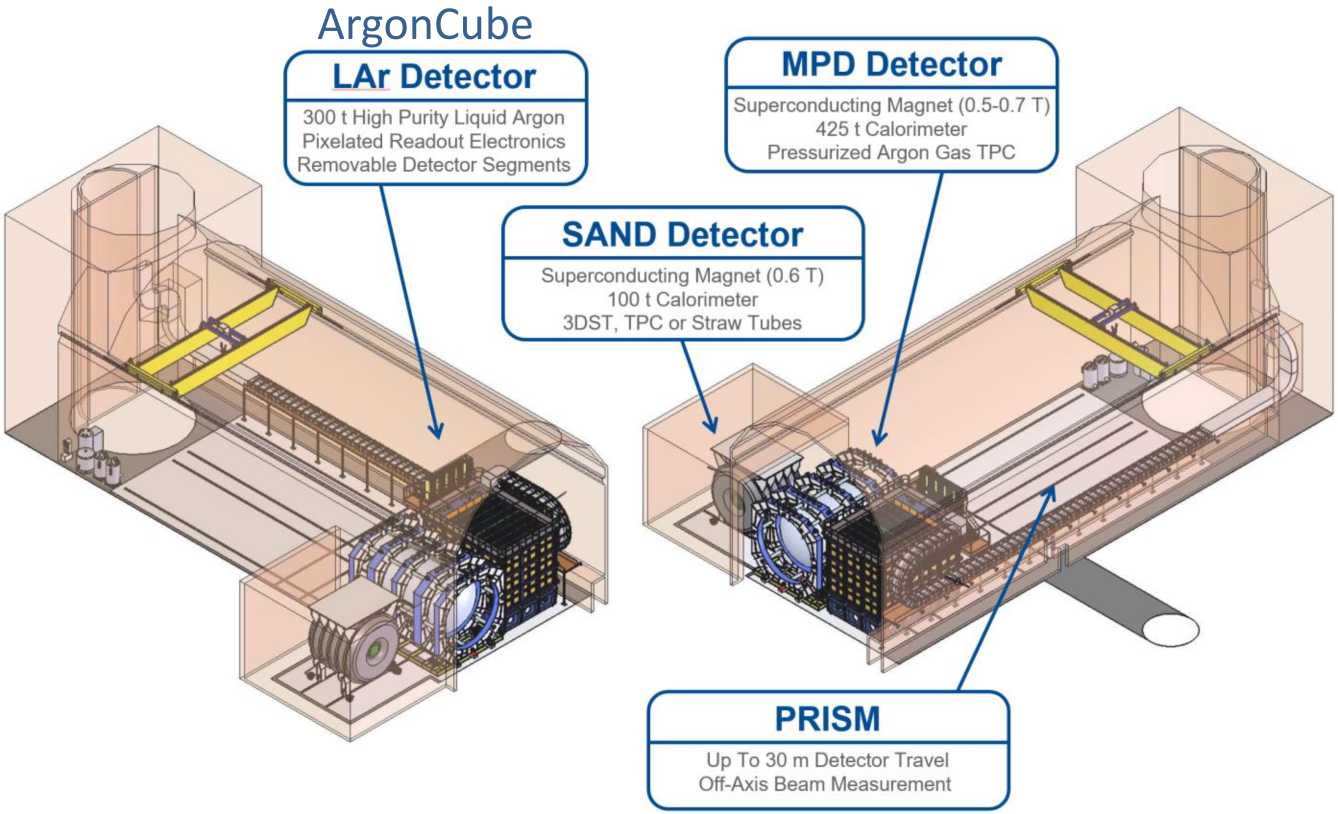
Drilling down in requirements one level for SAND

- Primary: The ND must be able to detect spectral distortions in the on-axis beam corresponding to 1 shifts in beam parameters in O(1 week).
- Secondary: SAND must make measurements of the flux that are complementary to those made by argon detectors.
- Secondary: SAND must make measurements that contribute in complementary fashion to improving the neutrino interaction models used in the oscillation program

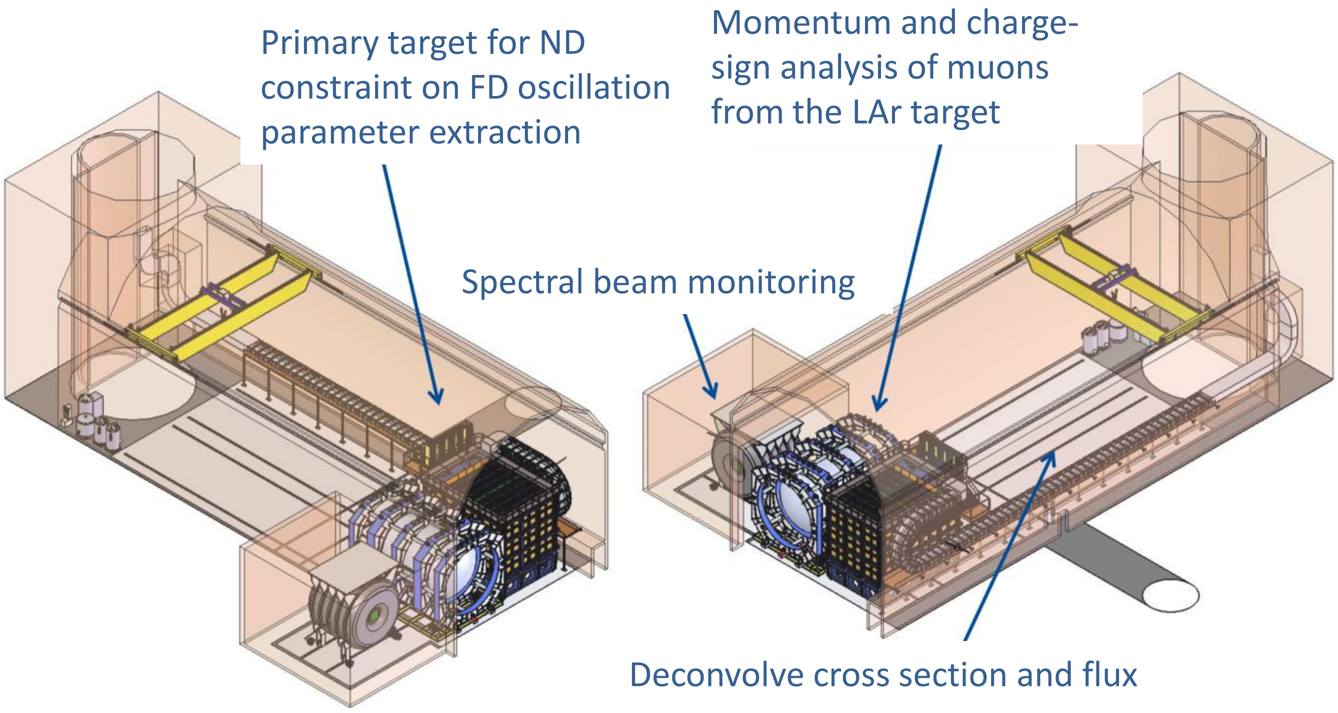
What's in a name?

- Easy to see as three, independent detectors.
- One might ask if only one can do the job.



What's in a name?

- Each element plays a critical role in the basic oscillation analysis.



What’s in a name?

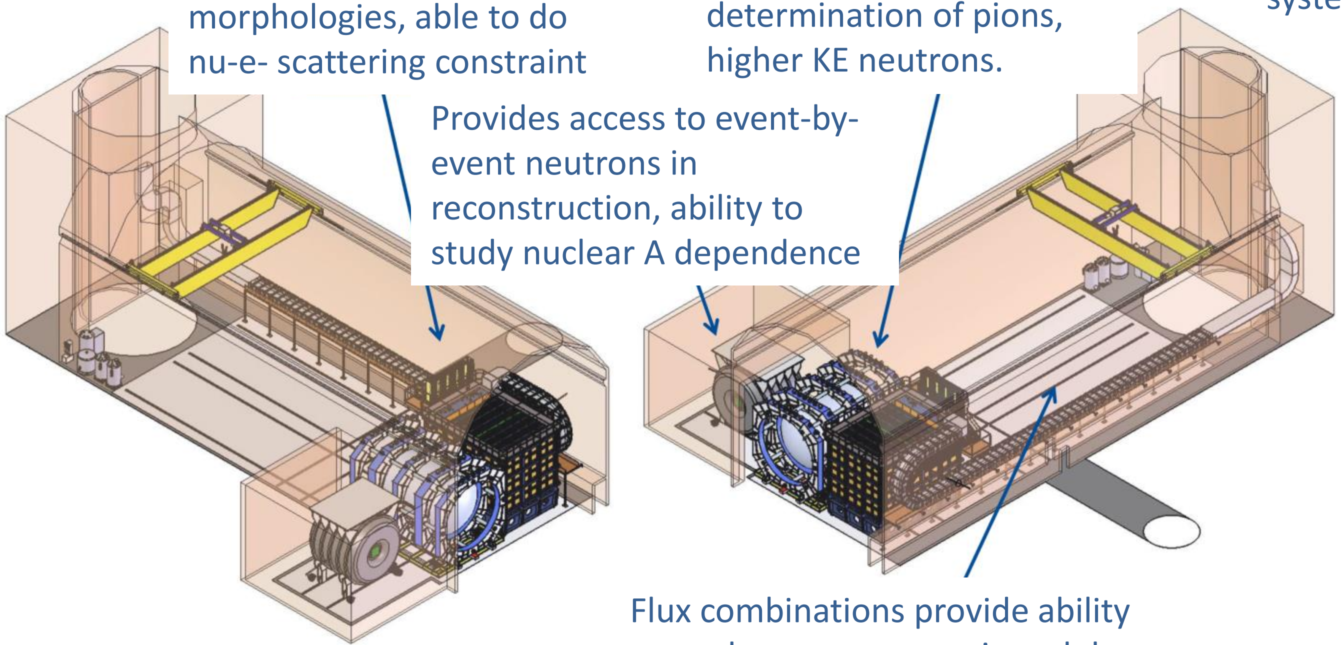
- Each element plays largely unique roles in helping to reduce the overall systematic error budget.

Ar target, similar technology to FD, able to measure many morphologies, able to do nu-e- scattering constraint

Ar target, explores final state in more detail with low threshold detection of charged particles, sign determination of pions, higher KE neutrons.

Three detector subsystems all can do low-nu with different systematic errors

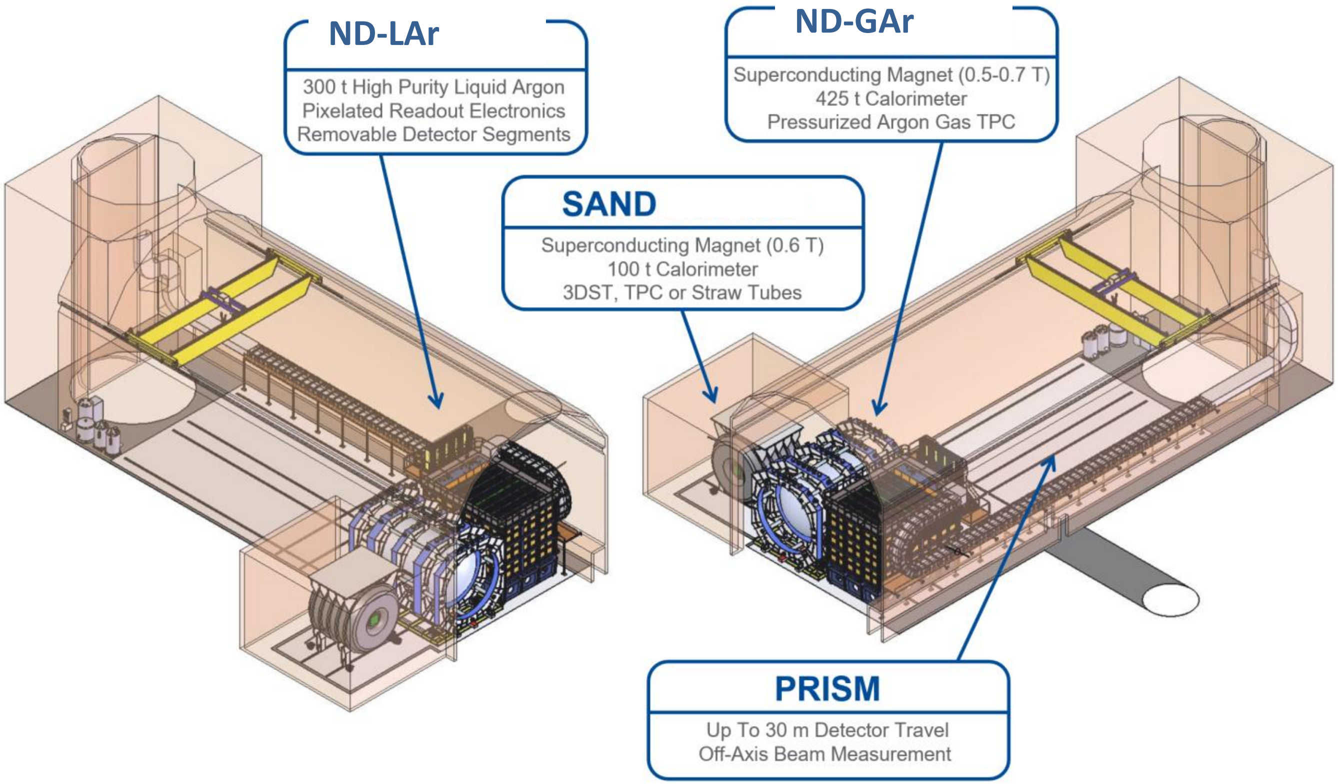
Provides access to event-by-event neutrons in reconstruction, ability to study nuclear A dependence



Flux combinations provide ability to study response matrix and do analysis with “ND flux” similar to FD oscillated flux

What's in a name?

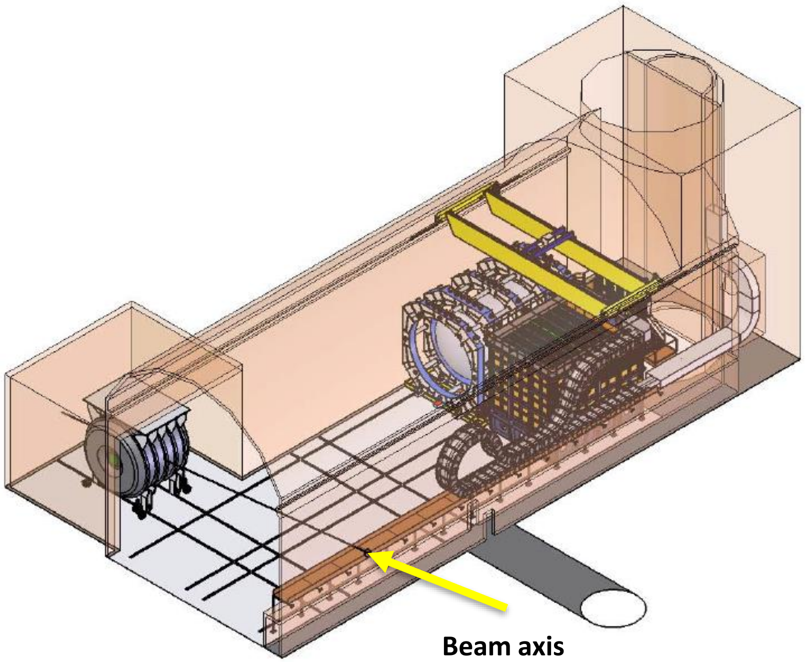
- CDR attempts to paint the holistic picture of the DUNE near detector and its different components.

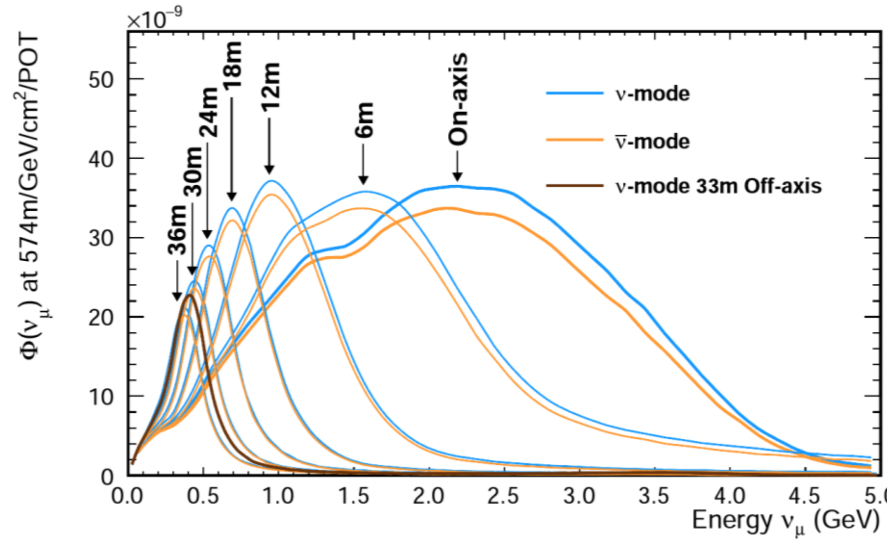


Backups

Some clarification on DUNE-PRISM

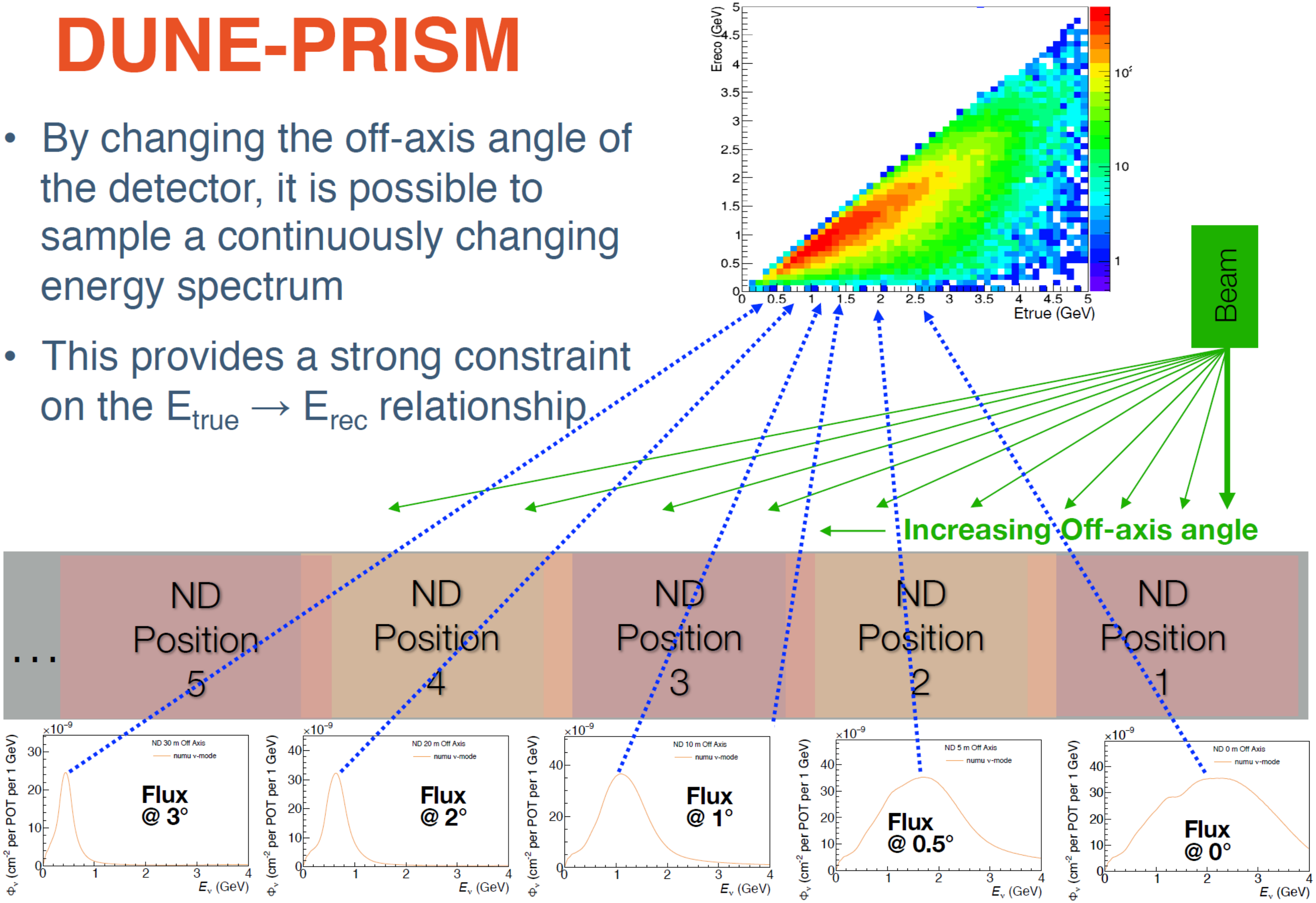
Responding to several questions/comments in the September feedback
Will try to improve presentation in the CDR as well





DUNE-PRISM

- By changing the off-axis angle of the detector, it is possible to sample a continuously changing energy spectrum
- This provides a strong constraint on the $E_{true} \rightarrow E_{rec}$ relationship

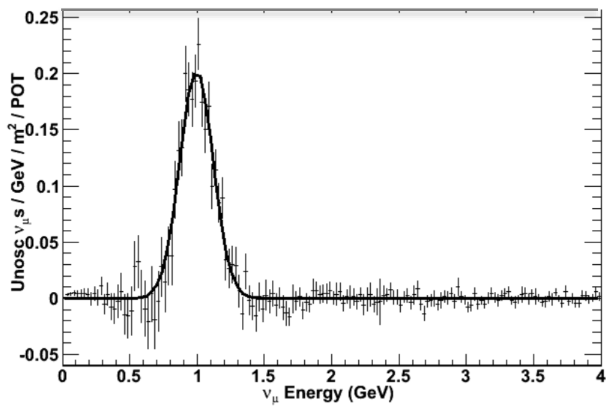


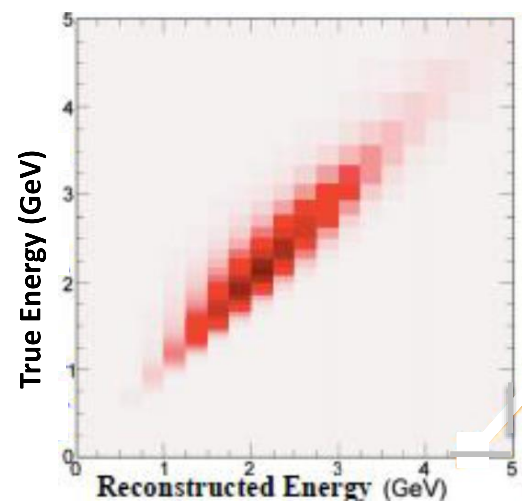
Slide from M. Wilking

Calibrating ND response with DUNE-PRISM

- Can create Gaussian distributions at given true E_ν from linear combinations of the expected true fluxes
- Map out the response at that E_ν by comparing to the data for the same linear combination
- Repeat for different E_ν

- Ability to do this well suffers at low Ev as you limit the transverse travel (that pulls the spectrum low) and you run out of statistics

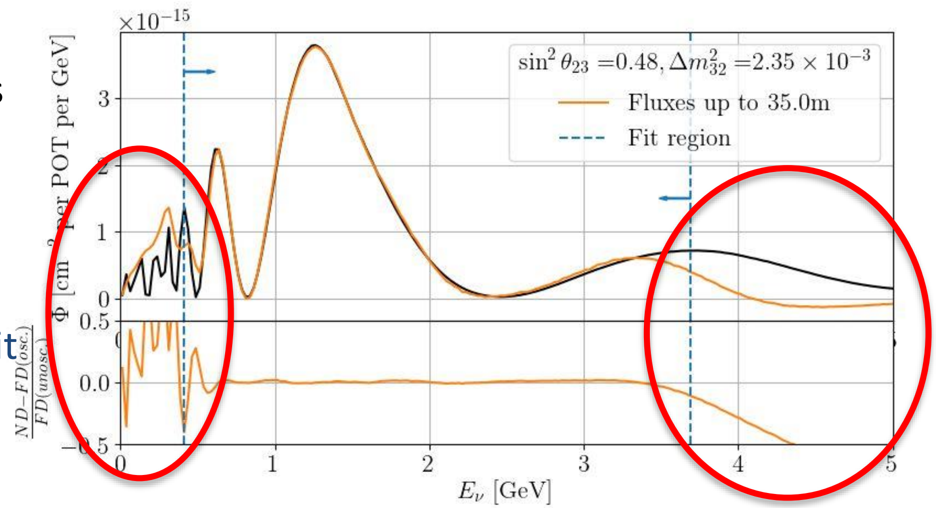




Modeling FD spectrum using DUNE-PRISM

- Use linear combination of off-axis fluxes to generate an ND flux that looks like the oscillated FD flux, i.e., minimize ND and FD flux difference and associated systematics
  - Make oscillated FD flux prediction with given parameters (modeled fluxes)
  - Use linear combination of near detector flux slices to build FD flux prediction
  - Use coefficients of this fit to build linear sum of any ND efficiency-corrected observable
  - Apply FD efficiency
  - Gives data-driven FD prediction in this observable (minimal model dependence)

- Limits of energy range of input spectra (and stats at low end) means ability to model FD flux breaks down at high and low energy regions
- Correct those regions with model as necessary
- Those regions relatively unimportant for oscillations
- In limit that the modeled fluxes are perfect, the fit is perfect, and systematic variations are same for FD and fit model, this is a model independent measurement



- All this not quite true. Reduces but does not eliminate model dependence for FD prediction and systematic error determination