DUNE-PRISM Overview and Facilities Requirements

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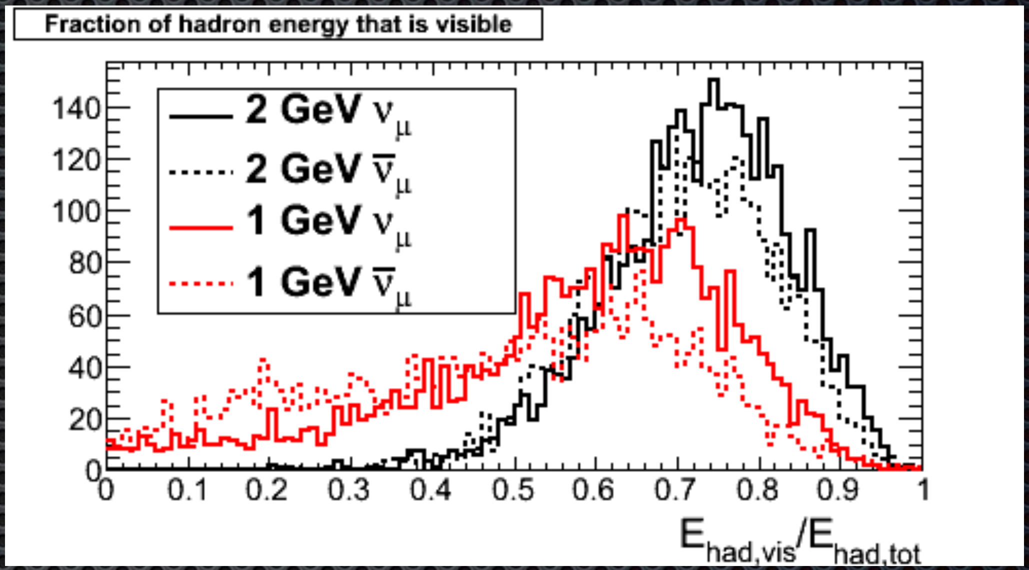
DUNE ND Workshop
November 7th, 2017

Brief Reminder: The E_ν Measurement Problem

(for more details, see previous collaboration meeting and ND workshop talks)

- Currently, our only way to "measure" neutrino energy is from the observed final state
    - Contains **missing energy** (e.g. neutrons) & **nuclear physics** (e.g. MEC, FSI, off-shell effects, …)
    - This causes smearing of E_{rec} relative to E_{true} (typically feed-down)
        - This produces biases in oscillation parameters such as Δm_{32}^2, θ_{23}, & δ_{CP}
- $E_{rec} \rightarrow E_{true}$ translation depends on **poorly understood neutrino interaction models**
    - Nuclear theory is generally trying to "catch up" to neutrino and electron scattering data using effective theories
    - It may be dangerous to assume that the theory will be correct at the percent level, and we will simply have to constrain the remaining unknown parameters with our near detector
        - We should make every effort to **measure $E_{rec} \rightarrow E_{true}$ directly**; however, this is beyond the capability of a standard (even high precision) near detector

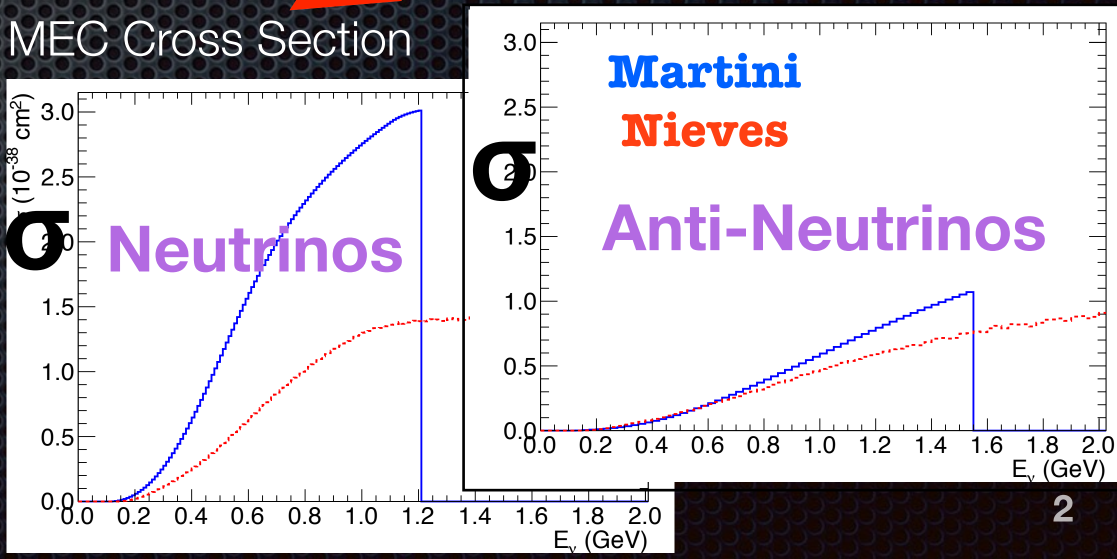
http://public.lanl.gov/friedland/LBNEApril2014/LBNEApril2014talks/McGrew_LANL_Apr2014.pdf



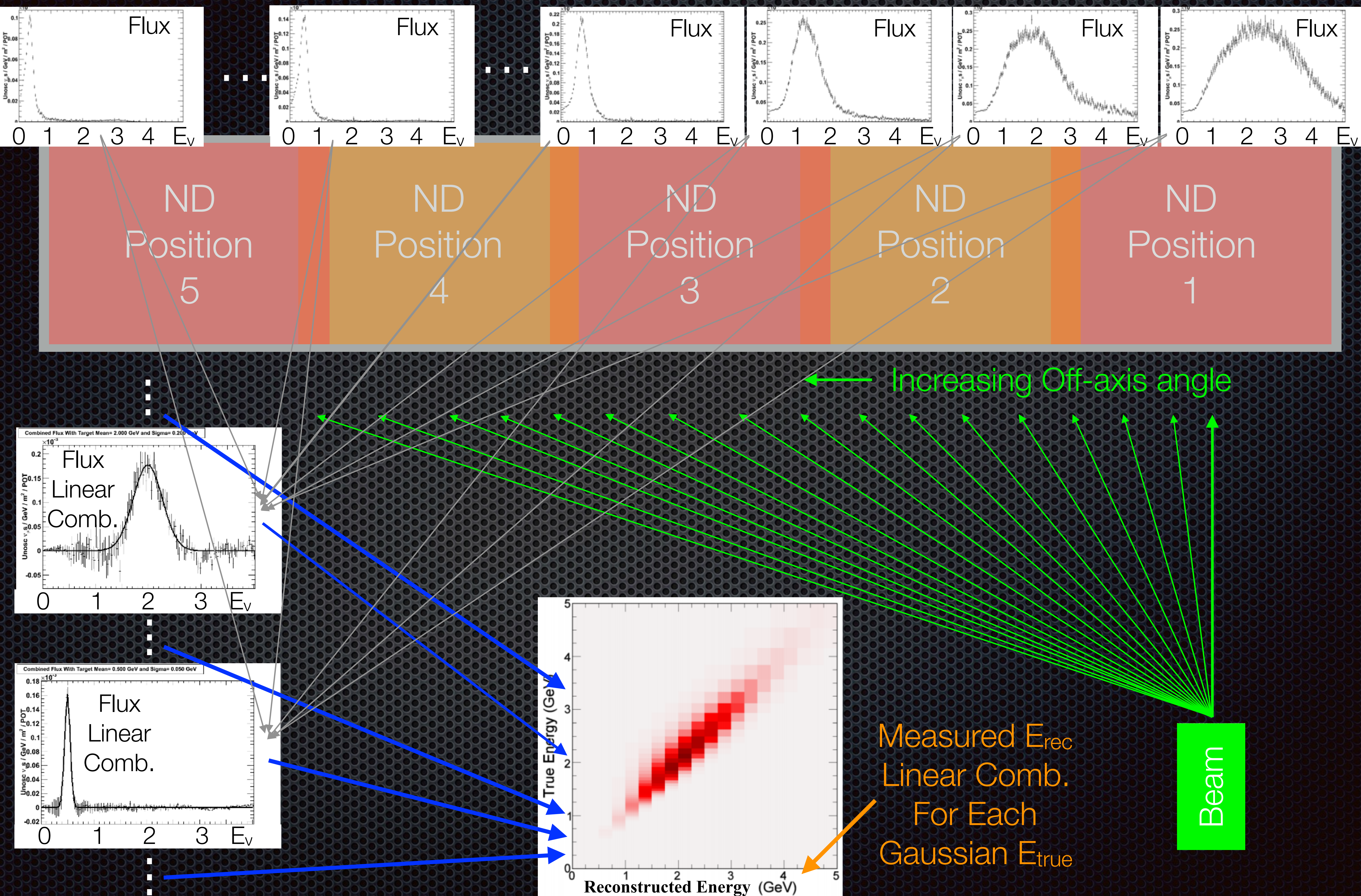
GEANT4 Simulation of a large LAr volume

(True deposited hadronic energy)/
(True initial hadronic energy)

MEC Cross Section



DUNE-PRISM Concept



ND Decision Roadmap

4) PRISM Concept

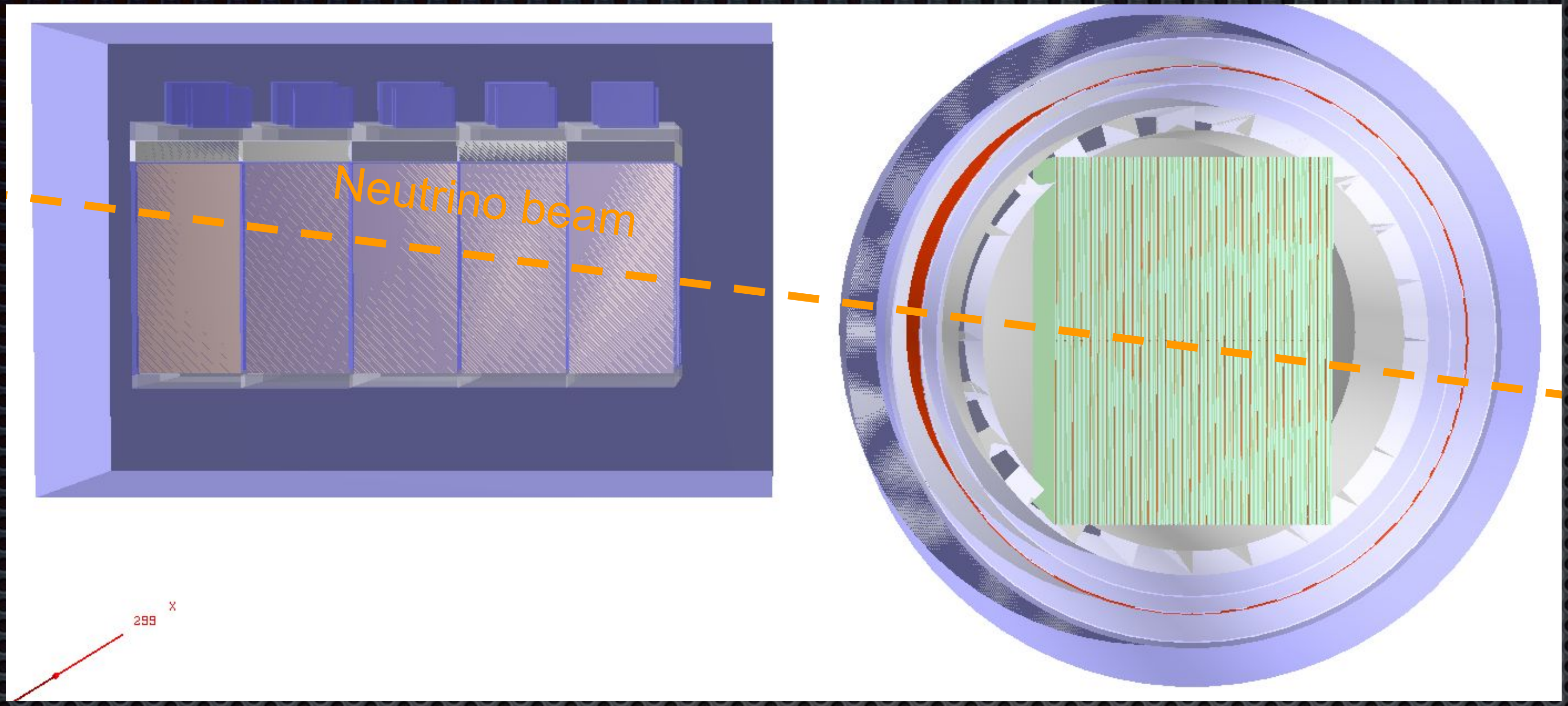
- At this point in time, the scientific benefits of a movable detector (PRISM concept) have not been quantified. The Near Detector Concept Study is asked to demonstrate the document the benefits
  - **November workshop:** The ND Concept study is asked to define and document a program of studies to demonstrate quantitatively the physics case for the PRISM concept. In addition, the ND Concept study should agree the layout and footprint of the PRISM concept for further study.
  - **December:** the Co-Spokespersons will work with LBNF to understand the cost implications.
  - **January:** the ND Concept Study leaders will draft a short report describing the proposed layout and results from any initial studies.
  - **January workshop:** the ND Concept Study is asked to make a recommendation on whether to continue to pursue the PRISM concept. This recommendation should take account of the physics case and the cost implications for the Near Site facilities. The recommendation will be considered by the EC.
- The following steps are contingent on a positive recommendation:
  - **March 2018:** draft a report giving quantitative results elucidating the benefits of PRISM concept, assuming the previously agreed layout.
  - **March workshop:** the ND Concept Study is asked to make a recommendation on the PRISM concept, based on the scientific merits as documented in the report. The report, including any recommendations, will be delivered to the EC.
  - **April 2018:** the EC will consider the recommendations of ND Concept Study.

- At this workshop, we must determine:
  - ND hall requirements for DUNE-PRISM for engineering cost estimations
  - Feasible physics studies needed to demonstrate physics capabilities

DUNE ND Decisions that Impact DUNE-PRISM

- **Detector length in the beam direction**
  - To move the detector transverse to the beam direction,
  - This is well defined for the KLOE magnet geometry
  - The final length of the dipole magnet impacts required hall size and dictates the options available for a DUNE-PRISM measurement
- **Integration of the LAr detector and MPT**
  - It may be difficult to effectively integrate the LAr detector with the MPT due to dead material / scattering between the detectors
    - In this case, it may be more useful to use a muon range detector (magnetized or not) to determine the momentum of exiting muons
    - This solution would make DUNE-PRISM much simpler / cheaper

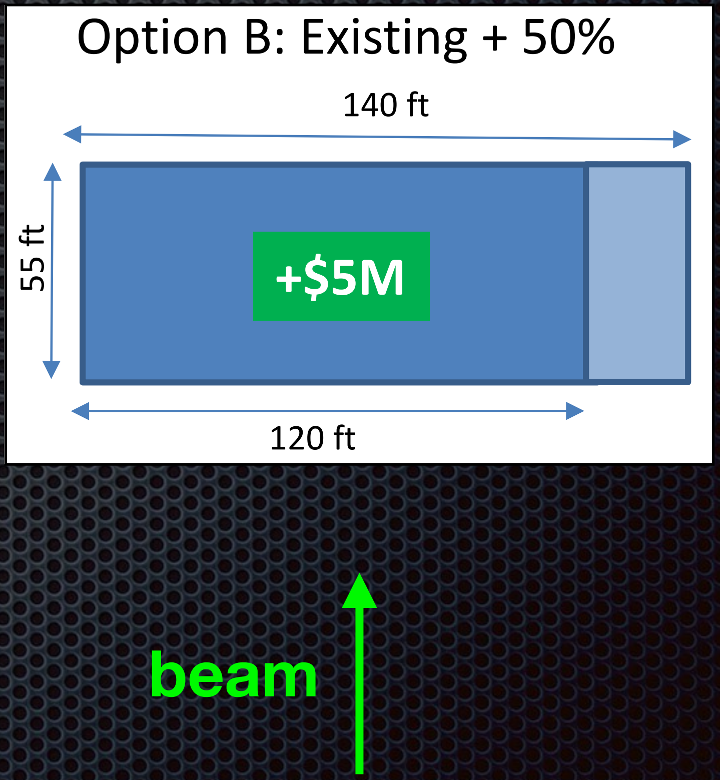
Basic ND Hall Parameters



- Currently planned ND consists of a LAr cryostat with an “integrated” magnet / low density tracker
  - Cryostat is currently 7 m long in the beam direction
  - KLOE magnet option has a 5.7 m diameter along the beam direction
    - (Length of dipole magnet option is currently unspecified; is 6 m enough?)
- This implies a ~13 m long apparatus along the beam direction (but could get larger)
  - Additional muon range detectors, etc. may also need to be added

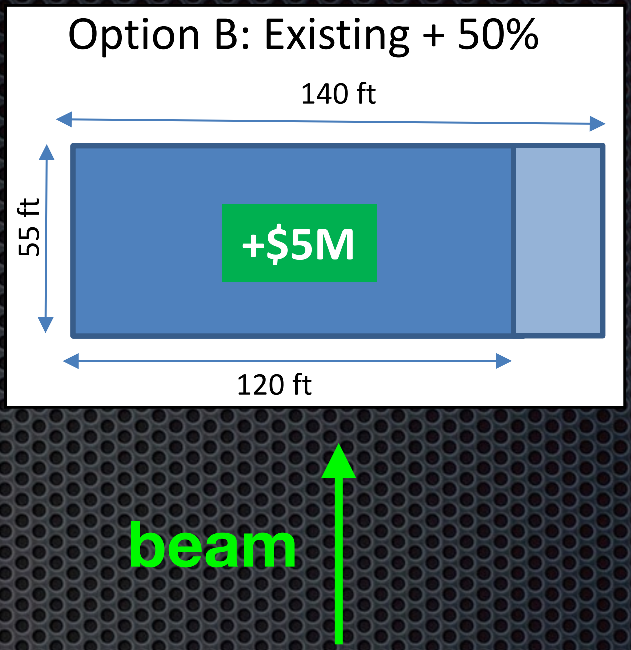
Basic ND Hall Parameters

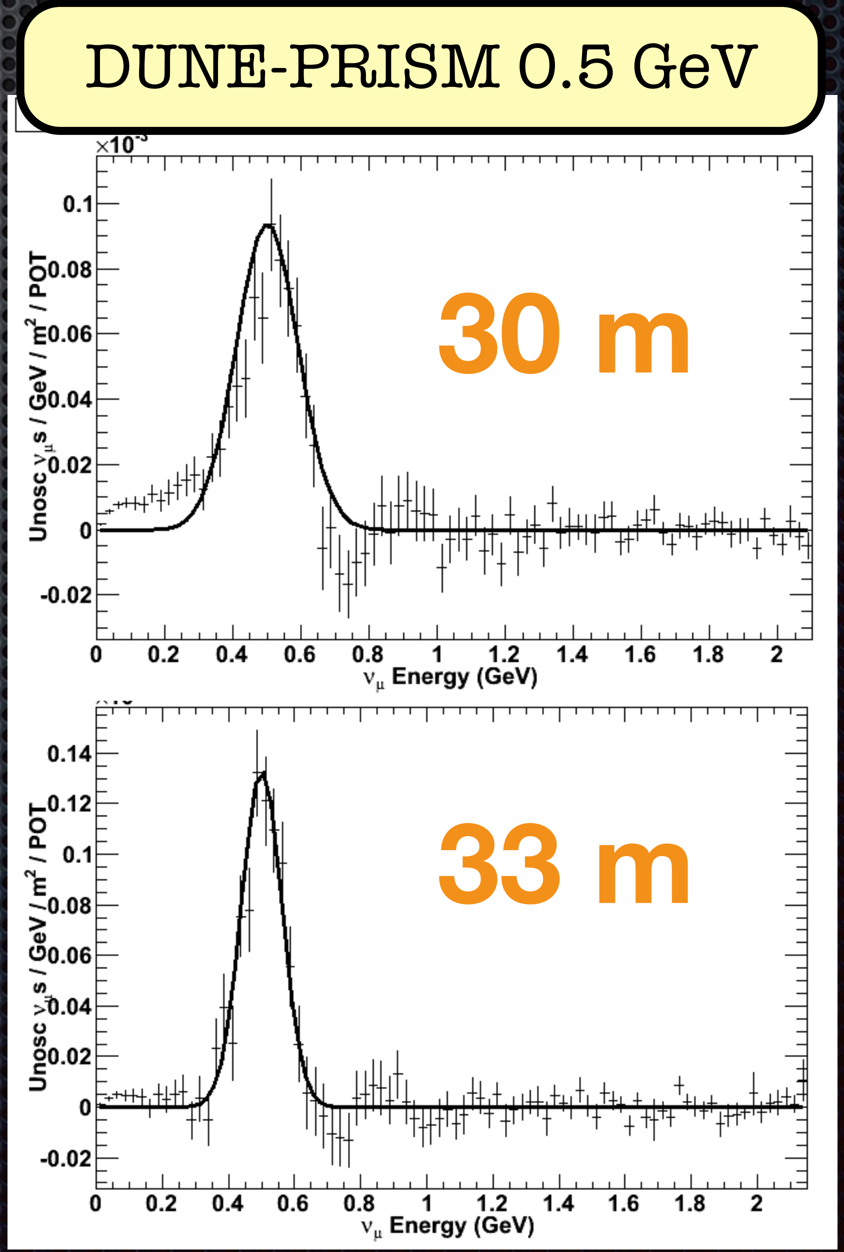
- The currently planned hall (option B) is 140/120 ft x 55 ft   (= 42.7/36.6 m x 16.8 m)
  - 5 ft of the 55 ft dimension is reserved for an access hallway (safety)
    - This leaves 15.2 m in the beam direction for the detector, if the entire detector is made moveable
  - Wider halls have been discussed (e.g. 65 ft / 19.8 m), but the exact width of the hall will depend on the quality of the rock (geological survey required)
    - The width is (roughly) limited to the height of good-quality bedrock above the ceiling of the cavern
    - Beyond this width, more reinforcement is needed, which can have a significant impact on cost



Hall Length (Off-axis)

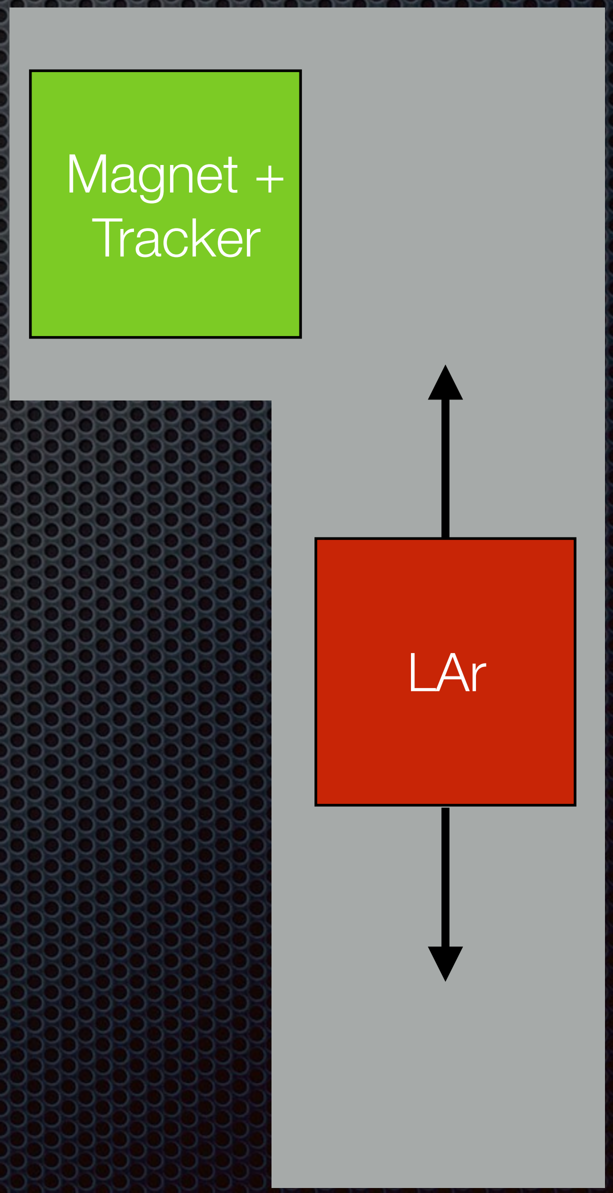
- An off-axis spanning detector is able to constrain neutrino interactions down to 500 MeV (i.e. below the 2nd oscillation maximum) with a range of around 30 m
- In principle, the hall cost is proportional to the hall length
  - Significant extra reinforcement is not needed to make the hall longer, since the width (i.e. the cost-limiting dimension) remains fixed
- There is likely not much motivation, even for DUNE-PRISM, to extend the hall beyond the currently planned 42.7/36.6 m





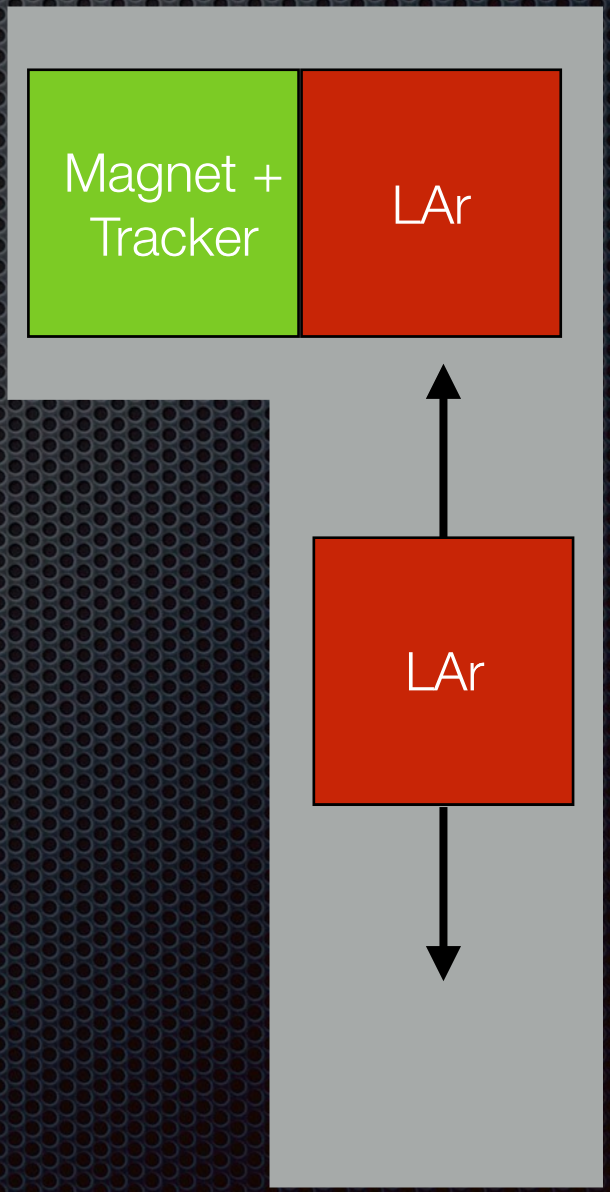
"Integrated" LAr + Tracker

- The ND group is currently pursuing a integrated LAr + tracker system
  - However, given the cryostat wall, magnet yoke, and possibly pressure vessel between the 2 detectors, it may be difficult to achieve integration in an effective manner
  - If so, it may be necessary to include (magnetized?) muon range detectors directly downstream of the LAr
- In such a case, the LAr could be decoupled from the downstream tracker, and only the LAr component would need to move to make effective DUNE-PRISM measurements
  - In this scenario, the width of the hall could be made even smaller (<10 m?) than the current design



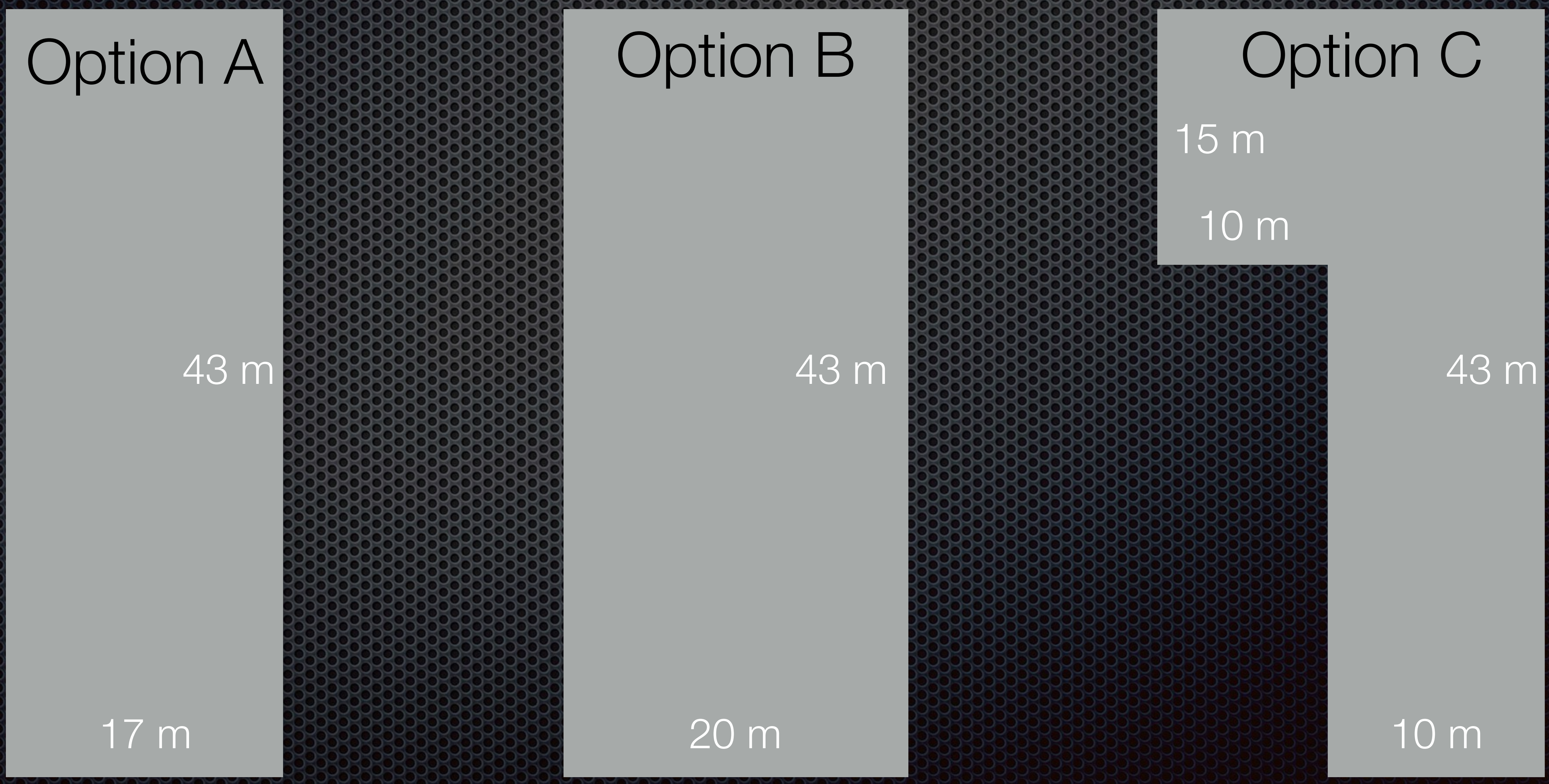
2 Detector Solution

- If LAr/MPT integration is still desired, it may be possible to construct a separate LAr detector with an integrated muon range detector that moves
    - Need to understand the relative benefits of:
        1. a (magnetized) muon range detector, integrated into the LAr
        2. a downstream tracker with significant material between the detectors
- This would allow for simultaneous traditional + DUNE-PRISM measurements (with added ND fiducial volume)



DUNE-PRISM ND Hall

- Choice of hall layout depends main on integration of LAr/MPT and detector length along the beam direction
  - **Option A (existing hall size)**: best choice for the KLOE magnet or a dipole that is not too much longer
  - **Option B**: may be necessary for longer dipole magnets if the LAr/MPT remain integrated
  - **Option C**: (cheaper?) option if LAr is decoupled from MPT or if a 2nd, movable LAr detector is available



Physics Studies Overview

- Goal is to demonstrate the ability of a moving near detector to **reduce** the risk of **biases** in measured **oscillation parameters** due to incorrect neutrino interaction modeling:

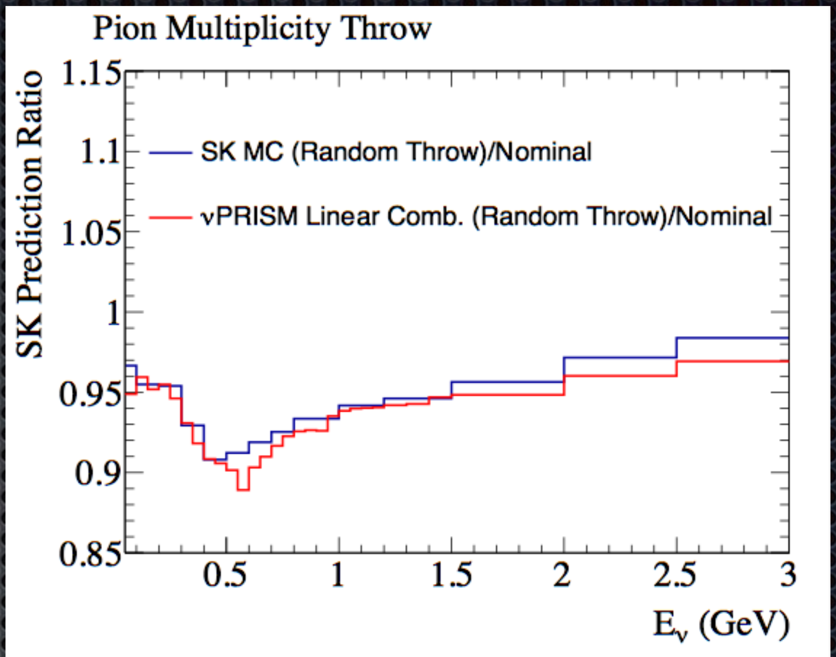
1. Show that DUNE-PRISM can **identify** modeling problems that cannot be seen by a traditional near detector
    - This may be possible with just a few off-axis locations
    - First results today from Guang Yang using fake data studies with CAFAna
2. Show that DUNE-PRISM can **correct/overcome** modeling problems that would exist in a traditional near detector
    - This will likely require more comprehensive off-axis angle coverage
    - Detailed flux-fitting studies today from Cris Vilela, and potential run plans from Luke Pickering

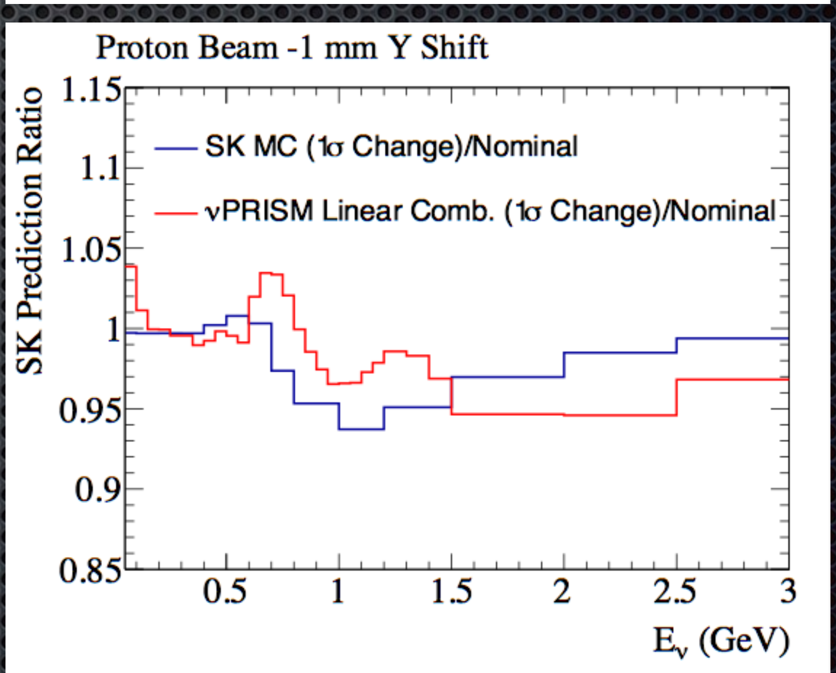
DUNE-PRISM Questions

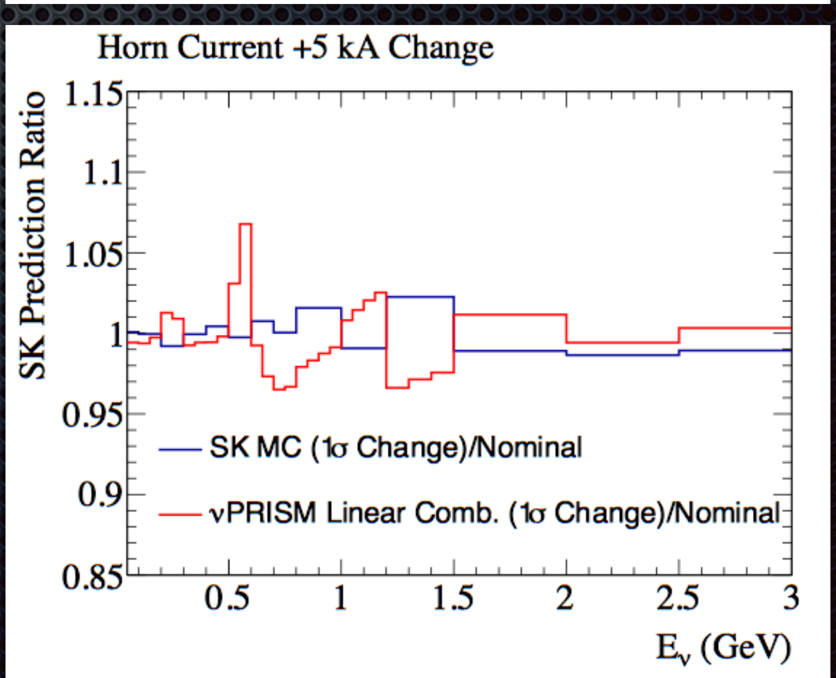
1. **Can DUNE-PRISM help constrain the focusing errors at the FD?**
   - Related question: what is the impact of focusing errors (such as the NuMI ME focusing effect)
   - More on the next slide
2. **To what extent can DUNE-PRISM with realistic hall size deconvolute xsec and flux errors?**
   - First steps and a sample run plan will be shown today
   - For January, we will try to form far detector predictions from near detector linear combinations (i.e. a full DUNE-PRISM analysis) to demonstrate robustness to xsec modeling inadequacies
3. **What is the FOM/study for this?**
   - Future DUNE-PRISM plans will be discussed in a few slides that will hopefully address the necessary remaining studies

Beam Uncertainties

- A powerful aspect of the DUNE-PRISM technique is that many flux variations will cancel in the near/far comparisons
    - Plots show effect of flux systematics on the FD spectrum and the ND linear combination measurement
- **Normalization uncertainties will cancel** in the DUNE-PRISM analysis
    - Cancelations persist, even for the linear combinations
    - **T2K without PRISM**: hadron prod. errors dominate; **T2K with NuPRISM**: hadron prod. errors are negligible
- Variations that affect off-axis angle shape are most important
    - Horn current, beam direction, alignment, etc.
- However, for T2K, even these beam uncertainties **do not dominate** the oscillation analysis sensitivity (<1% overall effect)
    - We hope to demonstrate a similar result for DUNE-PRISM, provided these flux uncertainties can be made available







Next Steps

- Update all studies with most recent fluxes with higher statistics
- Finish some additional fake data studies (e.g. proton energy -> neutron energy)
- Produce a full DUNE-PRISM analysis with FD predictions from ND linear combinations
    - Ideally subject these to some additional beam focusing uncertainties if these can be obtained

Supplement

Ceiling Height

- Current height of LAr fiducial volume is limited by hall ceiling height
  - Need to place ArgonCubes into the top of the cryostat
  - floor 546, crane 586, springline 593, crown over 600
- If the LAr is on a moveable platform, it may be possible to load ArgonCubes into the cryostat within the access shaft
  - ~22 ft diameter currently planned, although ~half is needed for elevator
- As ceiling height shrinks, hall width can be expanded
  - Combined optimization is needed