Toward a List of DUNE-PRISM Requirements

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Requirements Categories

- The goal is to produce a hierarchy tree of requirements
  - Overarching -> Physics -> Capabilities -> Technical

H. Tanaka, 01/29/2020

- We introduced the “overarching” requirements (next slide)
- We discussed a hierarchy of requirements:
  - Physics: Measurements that must be made (independent of specific implementation)
  - Capabilities: Things that are detectors should do and how well they should do it.
  - Technical: dimensions, masses, fields, pressures, etc. that correspond to physical attributes of the detector.
- I think it is important to keep these categories in mind as we move forward
  - Naively, one would go “downwards” in requirements: physics → capabilities → technical
  - Given that we have a reference designs, we can/should proceed from any point and move to the others
    - Why are the detectors the way they are? Why do they do the things they do? Whose detector is this detector?
    - If there are technical parameters, what range is allowable?

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Overarching ND Requirements

O0 Predict the neutrino spectrum at the FD (Far Detector): H. Tanaka, 01/29/2020 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 to reduce uncertainties due to nuclear modeling, 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, keeping them small enough to achieve the required CP coverage and transfer them to the FD.
O0.3	**Constrain the cross section model**	Measure neutrino cross-sections in order to constrain the cross-section model used in the oscillation analysis including potential mismodeling that causes incorrect FD predictions.
O0.4	**Measure neutrino flux**	Measure neutrino fluxes as a function of flavor and neutrino energy to enable neutrino cross-section measurements to be made and constraint the beam model
O0.5	**Obtain data with different neutrino fluxes**	Measure neutrino interactions in different beam fluxes (especially with different mean energies) to disentangle flux and cross-sections, verify the beam model, and guard against systematic uncertainties.
O0.6	**Monitor the neutrino beam**	Monitor the neutrino beam energy spectrum with sufficient statistics to be sensitive to changes in the beam on short timescales.

- Is O0.5 really an overarching requirement, or a physics requirement related to O0.2? (Perhaps broaching this topic is not politically savvy)
  - Primary goal of DUNE-PRISM is to constrain E_{rec} vs E_{true} relationship
    - (i.e. how do we relate what we see in the detector to E_{true}?)

DUNE-PRISM Physics Goals

1. **Identify** cross section mis-modeling that can produce biased osc. parameter measurements
   - By looking off-axis (changing the E_ν spectrum), we can identify mis-modeling problems that are not apparent on-axis
   - **Physics Requirement**: make measurements at a few different off-axis positions over the range of interest (on-axis to 30.5 m = 500 MeV)
2. **Overcome** cross section mis-modeling problems (2 approaches):
   a) **Standard approach**: Develop a cross section model that can describe the near detector data (possibly using more empirical corrections, now that DUNE-PRISM data will make it much more difficult for us to develop a biased model)
      - **Physics Requirement**: make more granular measurements (more stops) of different off-axis positions over the range of interest

   very similar

   b) **Data-driven approach**: Take linear combinations of off-axis measurements to produce a FD prediction composed of ND data
      - Any unknown cross section effects are directly incorporated into the far detector spectrum prediction (immunize ourselves to unknown unknowns)
      - **Physics Requirement (P1.1)**: make continuous measurements over the range of interest
      - **Physics Requirement (P1.2)**: the efficiency in each 50 cm off-axis interval should be as uniform as possible

- Additional **Physics Requirement (P1.3)**: Suite of off-axis measurements should be made within 1 year (anticipated analysis cycle)

Detector Positions

- We need 50% on-axis running for flux measurements (O0.4)
  - Alternating between on-axis and each new off-axis position allows for frequent detector performance verifications (time-dependent effects) and secondary beam monitoring
    - This does not affect the frequency of movement, only the total distance of each movement
- The LAr fiducial volume is 4 m wide, so the minimum number of additional detector positions to span the full off-axis range is 7 (for 30 m) or 8 (for 30.5 m)
- To satisfy P1.2 & P1.3 simultaneously, we would need an additional set of 8 substops
  - (note that the number of substops does not affect the statistics collected in each 50 cm off-axis interval)
- Assuming 70% uptime (which assumption should be used?), this corresponds to 1 week per position, including substops (or 2 weeks per position, excluding substops)
  - To achieve < 5% deadtime, we would require the detector to move between 2 arbitrary positions (and resuming taking high-quality data) within an 8-hour shift
  - This places requirements on LAr & MPD to minimize time for ramp down & ramp up
- Analysis is ongoing to determine minimum statistics needed in each off-axis interval (see last LBL meeting for latest on this)
- Is movement automation needed?
  - With this frequency of movement, is it practical to send a team into the hall ~weekly?
  - Are there safety concerns associated with frequent hall/detector access?

Capabilities

- Physics: Measurements that must be made (independent of specific implementation)
- Capabilities: Things that are detectors should do and how well they should do it.
- Technical: dimensions, masses, fields, pressures, etc. that correspond to physical attributes of the detector.

- P1.1,P1.2,P1.3->Capability (C2.1): 8 hour timeframe for taking data at a new position
- Capability (C2.2): Placement precision to within 1 cm
- Capability (C2.3): “Gentile” accelerations (incl. minimizing vibrations)
- Capability (C2.4): Monitoring of speed, position (to within 1 mm), acceleration, …

Technical Requirements

- Physics: Measurements that must be made (independent of specific implementation)
- Capabilities: Things that are detectors should do and how well they should do it.
- Technical: dimensions, masses, fields, pressures, etc. that correspond to physical attributes of the detector.

- C2.1 -> T3.1: Can achieve movement speeds of at least 10 cm/min
- C2.1 -> T3.2: Placement precision to within 1 cm, actual achieved position known to within 1 mm
- C2.2 -> T3.3: Smoothness of rollers/beams; brushes for beams?
- …

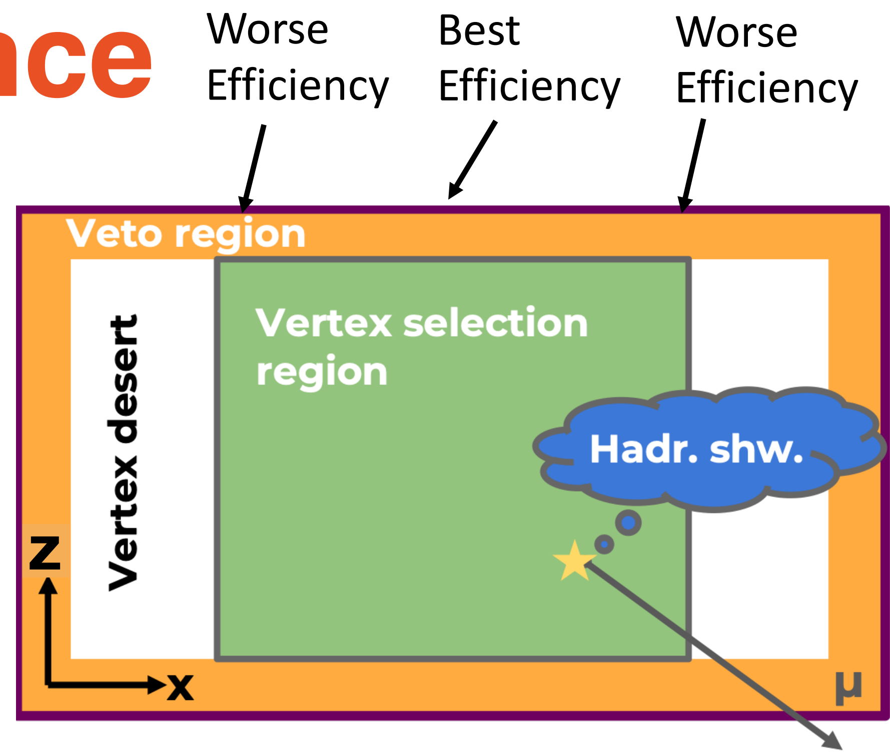
Backup

DUNE-PRISM “Wishlist” Summary

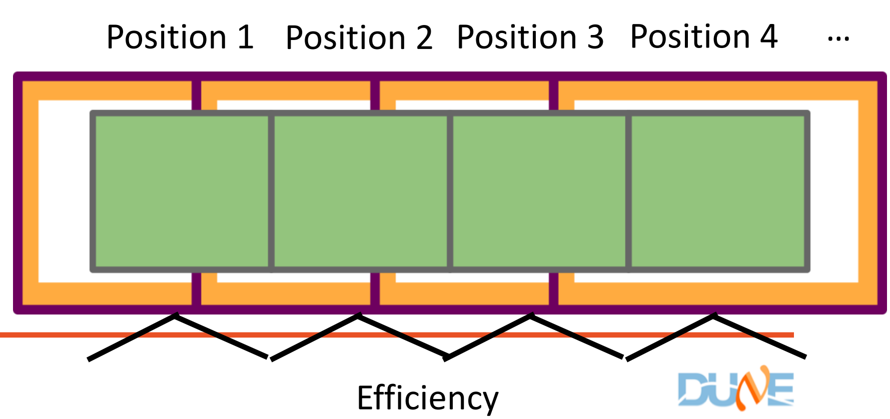
- Max speed: ~10 cm/min (30 m in 5 hours); depends on movement preparation time
  - Min speed? 1 cm/min? 1 mm/min?
- Acceleration: gentle ramp up, reaching top speed over several minutes
  - No “jerking” behavior
- Vibrations: “minimized”; minimal disruption to detector systems during movement
  - Must minimize downtime due to detector “ramp down”, and in getting detectors ready to take physics-quality data at a new location (depends on detector operation details)
  - e.g. possibly implement “brushes” to clean the rails as the detector moves
- Positioning: placement to within 1 cm; position determination to within 1 mm
  - We will almost certainly want a laser positioning system
  - Both platforms (LAr + MPD) must stay synchronized to ~1 mm
- Movement frequency: at least weekly
  - Fully automated (no person present; can be moved from the external control room)
- Monitoring: must ensure no relative displacement of detector components before/after movement

Detector Acceptance

- We have to reject events with hadronic energy in outer ~30 cm
  - Otherwise, we can't guarantee that we've contained all of the energy
- This means that events near the edge of the detector have worse efficiency
  - This is not desirable, since our ability to correct for this effect depends on the same poor models we are trying to avoid
- This means we don't want to repeatedly put the detector in the same off-axis positions
- The requirement is be able to place the detector in an arbitrary position to within 1 cm, and to be able to measure the detector position to within 1 mm



Configuration with the Least Number of Detector Stop Positions



Example Run Plan

- The DUNE-PRISM run plan has not yet been optimized
  - Working assumption of 50% running on-axis (e.g. for sufficient statistics for nu-e elastic scattering flux constraint)
  - 50% off-axis, split between off-axis positions
- Low backgrounds and high statistics in each off-axis position

		Liquid				Gas
		All int.	Selected			All int.
Stop	Run duration	$N\nu_\mu CC$	NSel	WSB	NC	$N\nu_\mu CC$
0 m	1/2 yr.	22.2M	9.8M	0.2%	1.6%	590,000
4 m	1/16 yr.	2.4M	1.2M	0.3%	1.2%	63,000
8 m	1/16 yr.	1.4M	690,000	0.4%	1.1%	37,000
12 m	1/16 yr.	680,000	340,000	0.8%	0.9%	18,000
16 m	1/16 yr.	370,000	190,000	1.0%	0.8%	10,000
20 m	1/16 yr.	220,000	110,000	1.3%	0.9%	6,000
24 m	1/16 yr.	140,000	68,000	1.8%	0.8%	4,000
28 m	1/16 yr.	95,000	44,000	2.2%	0.9%	3,000
32 m	1/16 yr.	68,000	30,000	2.5%	0.9%	2,000

NSel = Number of Selected events

WSB = wrong-sign background

NC = neutral current

Geometrical Efficiency Correction

- Model dependence can be further reduced by empirically determining the efficiency of each event
- Every observed event can be rotated about the neutrino direction, and translated within a logical off-axis slice
  - "Efficiency correction" = probability to detect the event
- A model-based correction is needed for events that would never be seen in the ND
  - (applies to all near/far analyses)