ND STAGING DISCUSSION

U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

INTRODUCTION:

- Staging:
  - In what order would we build/deploy detectors?
  - All paths lead to a full detector system at the end
- Guidelines:
  - First, scientific and technical considerations
    - What are the most immediate needs of the LBL analysis?
    - What makes sense technically?
    - What is the time scale of each stage?
  - How to factor socio-financial issues of where resources for detectors come from?
  - The hall cannot be “staged”
    - The hall you start with is the hall you have for the rest of time.
    - Assume we have the full reference hall from the beginning.

“STRICT” AND “EFFICIENT” STAGING

- “Strict” staging
  - Avoid temporary detectors that are not part of our baseline subsystems
  - e.g. resources going to detectors that will eventually be removed
  - Deviations should require minimal resources:
    - Reusing existing detectors, etc.
  - We discuss having LAr without MPD
    - Can LAr sufficiently alone?
    - Are there suitable existing detectors that can serve as muon momentum detector?
    - Can it be reused within the complex
      - e.g. temporary muon detector for LAr becomes muon detector for 3DST?
- “Efficient” staging: avoid temporary resources that will be replaced.
  - Can DUNE-PRISM infrastructure (e.g. to allow LAr/MPD movement) be staged?
  - Or would we have to effectively replace the

BEAM MONITORING

- **O0.4: Measure neutrino fluxes** 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.
- **O0.6: 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.

"NEUTRINO BEAM MONITOR"

- There has been some discussion of the necessity of a beam monitor on day 1.
- We should be clear what we mean by "beam monitor"
- Detects **variations** in the neutrino flux **using neutrinos (e.g. a "neutrino beam monitor")**
  - May arise from primary beam optics, target alignment/degradation, horn current/alignment, etc.
  - Use **rate, spectrum, latera**l profile of the neutrino interactions
  - Complements other beam monitors in the beam line (muon, primary optics, etc.).
  - We have just started to define requirements:
    - With what frequency do we want measurements, at what precision?
- Neutrino beam monitoring:
  - Is not a flux measurement (e.g. ν-e elastic scattering)
  - Is not flavor-specific (e.g. wrong-sign) unless we demonstrate it is essential to monitoring
  - Does not have to use a Ar detector
  - Does not need to be fully diagnostic . . . other detectors can be used once a variation is detected
- A beam monitor can provide these other functions but they are beyond the role of "beam monitor"
  - Functionality may be split between different detectors in some cases.

BEAM MONITOR ON DAY 1

In my opinion:

- A neutrino beam monitor is necessary for day 1 operations
- A neutrino beam monitor may suffice to start operations, but it is insufficient for neutrino oscillation results.
- In other words, it is plausible to start operations with “just” a beam monitor, but one cannot produce oscillation results until other parts of the overarching requirements are fulfilled.

STANDALONE/DESCOPED CAPABILITIES

	Capabilities/Deficits
LAr	Provides large statistics sample of LAr interactions Sufficient for neutrino beam monitoring if on-axis, except for maybe spectrum measurement. No muon sign and limited muon momentum information from range and MCS
Temporary muon detector (TMD= stand in for MPD)	What is needed here? Do we need sign selection? → magnetized (MIND, MINOS-ND, SeaQuest magnet + tracker)? Or not? → range stack? If we are doing PRISM with this detector, it must cover the full width of LAr
Magnet + HPgPTC	Only proper subset of the full MPD that makes sense (e.g. Magnet + ECAL doesn't make sense) Provides full muon spectrometry for LAr Limited studies of ν-GAr interactions with low-threshold/precise tracking
3DST	"S" without 3DST doesn't make sense Provides on-axis neutrino monitoring. Limited study of ν-CH interactions with neutron detection.
NO DUNE-PRISM	Full reliance on neutrino interaction modelling. May not be able to beat currently achieved (e.g. T2K/NOvA) systematic uncertainty levels. Infrastructure likely in place any case . . it then become whether to move the detectors or not.

ORDERING 1:

	LAR	MPD	3DST-S	PRISM	Comments
0	Full LAr	TMD		Infrastructure in place, but not used	Initial configuration is just the LAr detector that stays on-axis. Additional beam monitor not needed
1	Full LAr	TMD	Minimal 3DST	In effect	Minimal 3DST in place to enable DUNE-PRISM
2	Full LAr	Magnet + MPD	Minimal 3DST	In effect	Minimal MPD with tracking capabilities
3	Full LAr	Magnet + MPD + ECAL	Minimal 3DST	In effect	Full MPD
4	Full LAr	Magnet + MPD + ECAL	Full 3DST	In effect	Complete the full complement of detectors

- Comments:
  - **Multiple stages in principle could happen at once if resources available**
  - While 3DST eventually is a dedicated beam monitor, can profit from large LAr mass by deploying it first.
  - When do we need a dedicated beam monitor with spectrometry?
    - Can we get by with rate measurements and bring LAr+muon detector on-axis as needed?

ORDERING 2:

	LAR	MPD	3DST-S	DUNE-PRISM	Comments
0	Full LAr detector	TMD		Infrastructure in place, not used	Initial configuration is just the LAr detector that stays on-axis. Additional beam monitor not needed
1	Full LAr detector	Magnet + MPD		Not used	Replace temporary muon detector with MPD + Magnet
2	Full LAr detector	Magnet + MPD + ECAL		Not used	Complete the MPD
3	Full LAr detector	Magnet + MPD + ECAL	Minimal 3DST	In effect	Now that LAr+MPD is moving, we need a dedicated off-axis monitor
4	Full LAr detector	Magnet + MPD + ECAL	Full 3DST	In effect	Complete the full complement of detectors

- Comments:
  - Relative to Scenario 1, this delays DUNE-PRISM until MPD is fully constructed
  - Which is needed first?: MPD measurements or DUNE-PRISM (with limited muon detector)
  - Can DUNE-PRISM start from day one in any case if beam monitoring can be carried out with LAr+"MPD" detector by bringing it back on axis regularly?

STAGING SCENARIOS

Stage	LAR	MPD	3DST-S	DUNE-PRISM	Comments
Baseline	Full LAr detector	TMD		In effect	
Stage 1	Full LAr detector	Magnet + MPD +ECAL	(TMD?)	In effect	Assumes we can sufficiently monitor the beam while DUNE-PRISM Is in effect
Stage 2	Full LAr detector	Magnet + MPD +ECAL	3DST-S	In effect	Beam monitoring may become more stringent as beam intensity increases

Stage	LAR	MPD	3DST-S	DUNE-PRISM	Comments
Baseline	Full LAr detector	Magnet + MPD		In effect	Provides DUNE-PRISM with full mu sign selection/spectrometry, some level of GAr interactions
Full	Full LAr detector	Magnet + MPD + ECAL	3DST	In effect	Add dedicated on-axis monitoring

STAGING SCENARIOS

Stage	LAR	MPD	3DST-S	DUNE-PRISM	Comments
Baseline	Full LAr detector	TMD	3DST (S)	In effect	DUNE-PRISM with LAr + TMD, assumes dedicated beam monitor needed from day 1
Stage 1	Full LAr detector	Magnet + MPD +ECAL	3DST (S)	In effect	