PDR to FDR task force report

Status: Draft 1
TODO:

- Hook height crane MINOS hall

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Executive summary

The task force discussed and defined scenarios to be worked out as alternatives to be decided on. The 2x2 program is assumed to proceed unchanged. For the FSD the following alternatives are considered:

A. Bern and SLAC FSD (default consortium planning)
B. Only Bern FSD 2023 + MATF 2024 (N2, LAr maybe if re-using Bern equipment).
C. No FSD pre-FDR
   Full Size modules warm tested only pre-FDR (FDR is early 2024), location TBD.

The task force considers Option B a minimal realistic scenario that offers a compromise that satisfies the risk mitigation while minimizing costs.

Overall the strategy that could be followed is to advise the ND-LAr consortium to default to Scenario B if no decision can be taken on a very short timeline to enact Scenario B.

Scenario C was a nice exercise, but no way could be found to make it remotely viable. It would leave significant risks that require major mitigation efforts requiring significant time and funding.

Even if one defaults to Scenario B, it is critical that management immediately transfers the engineering effort at SLAC to other aspects of ND-LAr, ND or DUNE. It is necessary that SLAC support from SLAC physics and engineering staff will remain to help supplement the remaining FSD and MATF efforts. The possibility of having some of the module construction at SLAC using the existing well equipped clean room facilities should also very seriously be considered.

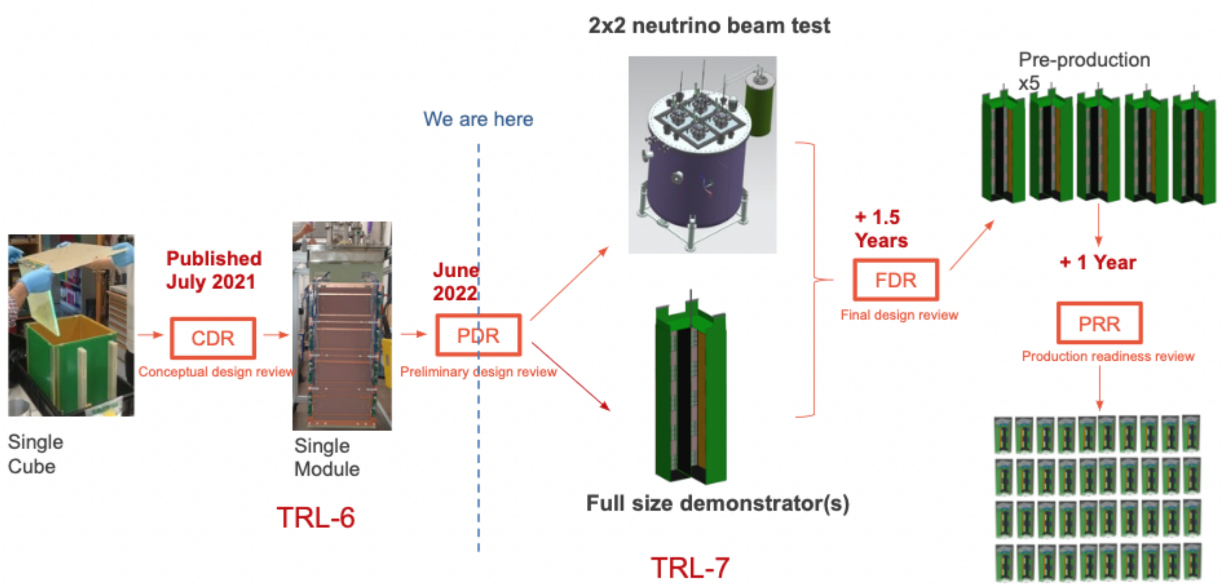
Scenario A remains the preference of the task force. Scenario B still shows weaknesses and risks. The Bern is not designed for long term runs from the technical and personnel point of view. Also the MATF facility might not be brought up to speed on time to continuously have a testing facility available.

In comparison with Scenario B, the main advantage of Scenario A is the sharing of expertise and building up US groups for full module construction, handling and testing. This is a considerable aspect for the overall construction phase. Further advantages include the possibility for long term testing and the possibility to add scope based on unforeseeable challenges.

To enable Scenario A a clear statement needs to be made in October 2022 that delineates funding, schedule and scope. The cost required are estimated to be $3.28M by end of September 2022 (unspent costs). A fraction would be maintained to maintain support from SLAC to other facilities.

Introduction

The ND-LAr consortium will execute two demonstrator programs after the PDR, the 2x2 physics demonstrator in the NuMI neutrino beam at Fermilab, and the Full-scale demonstrator program to construct and test a 1:1 size module. The intended timeline is 2023.



The DUNE/LBNF review process includes several general categories of reviews:

- Conceptual Design Review (CDR)
- Preliminary Design Review (PDR)
- Procurement Readiness Review
- Final Design Review (FDR)
- Production Readiness Review (PPR)
- Installation Readiness Review (IRR)

- Operations Readiness Review (ORR)

See EDMS https://edms.cern.ch/document/2173197/2 for more details.

For Final Design Review (FDR), the deliverables include among other items, the final designs, evaluation of prototypes and design modifications with including lessons learned, the final quality assurance plan and quality control plan and equipment design, and installation plans, schedules, procedures as understood at the time, to assess the adequacy of design related to installation.

While a validation of a “module-0” is actually expected as input to a PRR, the goal of the consortium is to have a full demonstration of a module (TRL-7) ahead of the FDR, similar to what was done for the far detector ProtoDUNEs.

It is important to note that the DUNE technical readiness is not the only requirement for the detector construction to proceed. Requirements, need and availability resources from the participating institutions need to be considered as well as providing the necessary material for funding agency critical decisions. For the ND-LAr, in particular, these include DoE as well as the Swiss and JINR funding cycles and conditions. The timely evaluation of prototypes and module-0 production are critical items in these.

One additional item the task force considered, is longevity tests. The FSD and demonstrator tests above include in their scope reaching the next technical readiness level. There is at this time no scope to perform longer term tests (many months years) to mitigate risks from long-term operation. Timely and efficient operation of the 2x2 and FSD (especially with multiple sites) and anticipating the MATF construction would open the possibility for such tests.

The PRD report from the review states *“We recommend that the Consortium, within the real-world constraints, resolve promptly, ideally within 3 months, possibly through a task force or standing committee, the estimates of the appropriate scope of work for remaining development and future testing for the SLAC and FNAL sites.”*.

The task force started work in the middle of September by collecting input material from the PDR documentation. A set of tasks were assigned to members and the task force met 5 times in the week of Sept 26th. The task force continued to meet several times per week until this report was completed mid October.

Information on the work of the Module Assembly and Testing Facility testing strategy task force (2021)

The MATF was originally planned to test all 35+spare modules using two LAr filled cryostats with full redundancy in their infrastructure (filters, pumps extra) to enable good uptime. It was suggested that the facility is descoped to remove LAr operation due to the cost of the facility. 2021 a task force weighed the impact of testing in liquid Ar, in liquid N2, or gasses N2.
The task force

- Collected input from all ND LAr subsystems leads to access risk and what, if any, modifications would be needed to the current testing strategy.
- assumed that the testing strategy would include the 2x2 and at least one full-scale demonstrator, plus smaller systems for individual component tests.
    - Due to 2x2 not using the final design version of all components, it was not considered adequate to replace the FSD.

A quick summary of the finding is:

- CRS and LRS: Individual components checks in LAr, in combination with assembled module N2 checks, were classified as low risk.
- Calibration: Newly designed system will not be tested in 2x2. A demonstration in LAr is therefore required at the FSD, and potentially additional check out at the I&I stage. At MATF, simple connectivity checks suffice. In any case a proof of concept needs to be made prior to the FSD via SingleCube Test Stand or equivalent.
- Field shell: the FSD will test at full size and final design in LAr. Testing must be thorough enough to mitigate the risk of possible failures which could not be probed in N2 at the MATF. The possibility for needed redesign and retest at FSD is relevant for FSD running times. The task force suggest
    - Longer test of single module (longevity test)
    - Repeated cryogenic cycling of single module (stress test)
    - Shorter tests of O(5) modules (small-statistics test)
- Spreadsheet with a summary of sub system risks https://docs.google.com/spreadsheets/d/1ioFc20iH43lOwRCyostzSe7Q9-vi11JlBaAb5Wymvil/edit?usp=sharing

Conclusion: while no formal report from this task force was prepared, the findings above point to the fact that a thorough FSD program is the mitigation for a descoped MATF not operating with LAr.

Risk Management

Risk Introduction

ND-LAr risks fall into three categories: 1) technical design risks, 2) production process development risks, and 3) production, assembly, and installation risks. Technical design risks are related to meeting the science requirements of the Near Detector Liquid Argon TPC (electric field uniformity, charge resolution, photon capture, pileup separation) as well as the operational requirements (cryo-hardness/longevity, thermal management, structural integrity) both with respect to a signal full size module and with respect to the modular design. Production process risks are related to development of adequate quality assurance plans and quality control procedures prior to production phase, accurate production labor estimates, inefficient production management. Production, assembly, and installation risks are related to the actual build, test, and installation of the TPC modules from the component receipt at the Module Assembly and Test Facility to cool-down and commissioning of the fully TPC array and the Near Site are cover various scenarios such as damage to a TPC module, stop work orders, damaged components, etc.

Risk Retirement

The table below summarizes the number of the ND-LAr risks retired at each prototyping stage, progressing from component level testing to the 2x2 Demonstrator and capped with the Full-scale Demonstrator (FSD). The FSD is the final design validation of the ND-LAr technical and operational requirements, as well as the execution of the required quality control, assembly, handling, and lifting procedures required for later module production, assembly and test. As such the FSD serves as a key step to retiring remaining technical design and production process development risks.

Table: ND-LAr Risk Summary; risks are progressively retired through prototyping and design development. The colors are somewhat arbitrary, red indicating that no risk has been retired, yellow that some risks are retired and green indicates that after this step all risks are retired. The numbers are the risk items retired at that step.

		Prototyping			Production				
		Component Prototyping	2x2 Demonstrator	Full-scale Demonstrator	Component QC Testing	Assembled Module Testing (at MATF)			Module Row Testing (at Near Site)
	Test Temp	RT/LN	RT/HP-LAr	RT/HP-LAr	RT/LN	RT	LN	HP-LAr	RT
Risk Category	Initial Risk Level	Number of Risks Retired at Each Stage							
Technical Design Risks e.g. - TPC design fails to meet physics performance requirements (fidelity, efficiency) - Subsystem interference degrades performance (noise, field distortion, purity, heat) - Component aging degrades performance	High	16	27	10	0	0	0	0	0
Production Process Development Risks e.g. - Inadequate procurement and assembly processes and procedures - Underdeveloped QA/QC processes - Underestimate of production labor needs - Poor managment structure/coordination of production team	High	5	0	11	0	0	0	0	0
Production/Assembly/Installation Risks e.g. - Inconsistent/sub-standard performance of production components - Errors (electrical, mechanical, etc) in assembly of TPC modules - Errors (electrical, mechanical, etc) in integration of TPC modules to cryostat lid	High	0	0	0	3	0	26	0	24

Risks retired by the 2x2:

In the table below are the risk retired at the 2x2 Demonstrator stage of the prototyping process. This demonstrator addresses any risks that have not yet been retired through component prototyping. Each 2x2 TPC module is cold-tested in high-purity LAr prior to final integration into the 2x2 TPC array.

Table: Risks retired by the 2x2 Demonstrator

Risk ID:	Risk Title:
MOD-004	HV breakdown in volume above TPCs
MOD-019	Pressure drop accross LAr difussers is too high
MOD-016	Feedthrough Noise
HV-03	Change of filter requirements on Fcut
HV-04	Change of filter requirements on Vmax
HV-07	HV Instabilities
HV-08	HV Breakdown (Non-Recoverable)
LRO-005	Incompatibility of TPB coating
LRO-006	Incompatibility of cold electronic components for LAr conditions
LRO-007	Pollution of the liquid argon by using existing materials in construction of LCM
LRO-008	Incompability of materials of LCM construction for LAr conditions
LRO-009	Possible ripples from charge readout
LRO-010	Spatial Resolution - LCM
LRO-011	Photon detection efficiency - Arclight
LRO-018	Arclight tile failures
ChRO-018	ASIC does not meet noise requirement
ChRO-019	ASIC Power
ChRO-020	Warm Electronics
ChRO-023	Noise pickup
ChRO-025	Full-tile Triggering Instability
ChRO-029	Tile Optimization for Physics Requirements
ChRO-034	Edge Pixel Coupling
ChRO-035	Charge Readout Data Cable Incompatible with Liquid Argon
ChRO-037	Loss/limitation to produce prototype ASICs
FS-016	Electric field uniformity
FS-017	Contamination
FS-019	Voltage Breakdown

The technical risks retired by the 2x2 primarily relate to retiring key technical design risks at the component level for each of the TPC module subsystems (HV Breakdown, ASIC Power, Material Incompatibility with LAr) as well as some system level risks where there are not substantial differences between a 2x2 and ND-LAr module (noise pickup).
The primary purpose of the 2x2 program is to retire risks associated with neutrino physics measurement performance of the modular detector design.

Risks retired by the FSD:

The following table identifies the remaining risks that are retired by the Full-Scale Demonstrator TPC.

Table: Risks retired by the Full-Scale Demonstrator TPC

Risk ID:	Risk Title:
MOD-003	Thermal Management - Fluid Flow across the module
MOD-002	Interfaces
HV-06	HV Breakdown (Recoverable)
LRO-001	Restrictions of JINR fellows presence onsite
LRO-002	Restrictions of JINR fellows presence onsite
LRO-014	Time Syncronization
CAL-001	Grounding
ChRO-027	DAQ Interface
FS-008	Interfaces
FS-026	Alternative Field Structure Concept does not meet performance
FS-002	G10 - large
FS-003	Large Copper Clad and etching availability
ChRO-003	Insufficient Quality Control of Off-Shore Produced PCBs
ChRO-007	Production ASIC design flaw
ChRO-009	ASIC slow cryo-failure
ChRO-013	ASIC lifetime / bad channels
ChRO-014	Charge system production cost risk
ChRO-006	ASIC foundry access
ChRO-022	ASIC foundry access for engineering runs
ChRO-030	Vendor is unable to meet Pixel Tile PCB flatness specification
ChRO-033	ESD related failure/damage

In the FSD a 1:1-size module is built for the first time. The risks retired by the FSD are related to system integration and performance issues (interfaces, thermal management, HV breakdown, grounding, time synchronization) as well as production process related issues (G10 - large panel availability, etching, PCB flatness, ASIC lifetime / bad channels). Quality control measures in view of the production phase can be exercised. The majority of the technical design risks at the component level and technology choice are retired by the testing during R&D and modular operation is retired by the 2x2 program (4x TPCs at 0.7m x 0.7m x 1.4m each), remaining technical risks are retired at FSD such that once the production stage is reached all technical risks are retired.

For comparison, without the FSD the number of remaining risks at the production stage is shown in

Table: ND-LAr Risk Summary with FSD; some technical design and production process oriented risks remain into production and the Near Site without sufficient testing of a FSD module.

		Prototyping			Production				
		Component Prototyping	2x2 Demonstrator	Full-scale Demonstrator	Component QC Testing	Assembled Module Testing (at MATF)			Module Row Testing (at Near Site)
	Test Temp	RT/LN	RT/HP-LAr	RT/HP-LAr	RT/LN	RT	LN	HP-LAr	RT
Risk Category	Initial Risk Level	Number of Risks Retired at Each Stage							
Technical Design Risks e.g. - TPC design fails to meet physics performance requirements (fidelity, efficiency) - Subsystem interference degrades performance (noise, field distortion, purity, heat) - Component aging degrades performance	High	16	27	0	0	0	5	0	5
Production Process Development Risks e.g. - Inadequate procurement and assembly processes and procedures - Underdeveloped QA/QC processes - Underestimate of production labor needs - Poor managment structure/coordination of production team	High	5	0	0	0	0	10	0	1
Production/Assembly/Installation Risks e.g. - Inconsistent/sub-standard performance of production components - Errors (electrical, mechanical, etc) in assembly of TPC modules - Errors (electrical, mechanical, etc) in integration of TPC modules to cryostat lid	High	0	0	0	3	0	26	0	24

As the table shows, without an FSD module test several technical design and production process development risks persist into the module production phase and into the Near Site installation and operations. This illustrates the utility of the FSD module to help retire the final technical and production process risks prior to modules being constructed and delivered to the Near Site; this is especially important given the long time-scales to service the ND-LAr detector (dominated by cryostat emptyping, warm-up, cool-down, and fill).

Risk Summary

In essence the FSD shall demonstrate TRL7 (DOE G 413.3-4): production of components for a full-scale ND-LAr module (1.0m x 1.0m x 3.0m), integration of these components into a coherent TPC module, and verification in relevant operation (LAr) that the performance requirements for the Near Detector are achieved. In this process system level design and production process related risks are retired.

Facilities

The task force concludes that all TPC test requirements are independent of the test facility and that initial Full Size module demonstration tests could be done equally well at SLAC or at BERN. Also the MATF facility (in case of operation with LAr) is functionally equivalent, optimized for a higher repetition and total tests during production.

The facility at SLAC

The SLAC facility offers

- 10T and 50T crane access with 10.2m hook height
- An 8.4m x 23.6m cleanroom with 5T crane and ~7m hook height

    - This facility is large enough for production assembly and warm-testing of TPC modules and could be considered an alternative or backup to the MATF facility if supplemented with the planned liquid argon purification system.

Comments on the SLAC facility

- There is no permanent external cryo facility. The plan is to lease a 3000 gallon argon tank truck for the expected 6-month period of FSD testing
    - If long-term testing was required this plan could be possibly be changed
    - We plan to flush Argon after each test; there is no facility for pumping the argon to a storage vessel.
- The proximity cryo system will be completely new.
    - Unexpected design or performance issues cannot be excluded
- The quality of vendor supplied argon in large quantities is unknown
    - Airgas COC quotes <5ppm O2 and <15ppm N2 in bulk (not research) quantities
    - Praxair COC quotes <4ppm O2 and does not specify N2 for bulk delivery
- The overall system will be completely new
    - Unexpected issues with grounding may occur before they are solved
    - The control system will be new. At this time it has not been decided whether the FSD control system should be an extension of the existing IGNITION system or a prototype for that of the ND

While design drawings of the dewar, service lid and physics lid exist, the current procurement hold means that nothing has been ordered and the design could change, if desired the diameter could be enlarged to allow some system to simulate the heat effects of adjacent modules

The current P&ID

- Allows for variable flow through the diffusers. There are several bypasses in the system which will allow the pump to operate at design flow (currently 20 LPM) and send only 1 LPM through the diffusers to satisfy requirement MOD-008.
- Does not include a devoted purity monitor. The plan is to infer O2 contamination levels by measuring the e- lifetime in the TPC. This is relevant to requirement FSD-020 and FSD-021 (e- lifetime and contamination levels). There will be a RGA.

The facility in Bern

The ACTF facility at LHEP, Bern offers:

- Cryogenic laboratory 11m x 9m x 8m
- In the middle of the floor - cryostat pit 3m x 3m, 7m deep
- Crane (4T) hook height ~5.3m above the lab floor
- Assembly lab ~10m x 7m with clean tent area ~3m x7m
- External LAr storage cryostat 4.6 m3 (may be upgraded to 10 m3 in 2023)
- External LN2 storage cryostat 10 m3
- Established supply of LN2 and LAr with guaranteed purity <1 ppm H2O and O2

- LAr recirculation system used in 2x2 single module test: piping, LAr filter with ~10 kg of active material, LN2-LAr heat exchanger for argon cooling, process control PLC.
- Both the filter and the heat exchanger are housed in the same LN2 cryostat maintained at ~2.25 bar, which controls the cooling and temperature as well as filtering at the same time.
- Compressed air supply 8 bar
- Vacuum pumping system (<10-6 mbar)
- Clean power motor-generator
- Ventilation system with ODH sensors and automatic shutoff of cryogens supply
- Access to loading/unloading ramp (truck access)
- Gas chromatograph (0-50 ppm O2, N2, H2, H2O, CH4)
- Two cryostats ~1.54m inner DIA x 4 m straight wall height (4.3m total) - ordered, delivery Feb 2023. One to be used as "detector" cryostat (with physics flange) and one to be used as "storage".

Comments on the ACTF (risk registry items in brackets):
- Possibility to pump LAr between two cryostats in either direction
- Purification of LAr in either of the two cryostats (allows quick turnaround between tests, minimal pure argon loss)
- Purity monitor in "storage" cryostat (optionally also in "detector" cryostat).
- LAr flow can be throttled from max 2000 l/h to zero with bypass lines (MOD-003, MOD-019, SYS-013)
- Filter can be bypassed to study no cooling and no purification scenaria
- Vertical heaters to address thermal/purity management risks (SYS-001)
- Cryo-camera to observe boiling (SYS-008)

Drawbacks of the ACTF-Bern:
- Extended tests (> 2 weeks long) are not possible because of lack of manpower (could be mitigated by collaborators) and filter regeneration (downtime)
- No change in cryostat design is possible (SYS-015 = change of cryostat design)
- Cooling power is provided by LN2 cooling the filter, meaning cooling power is lost on filter regeneration.

Integrated Engineering Research Center at the Helen Edwards building

A new building next to Wilson Hall was constructed for which beneficial occupancy is expected in spring 2023. It includes minimal lab outfitting i.e along the lines of tables, desks. It does not include any cryo. The IERC was planned so that the available funds maximized building size, with full outfitting coming through additional funds later. Two DUNE labs will be available: a Warm DUNE lab, and Cold DUNE lab. The latter being the home of MATF.
Warm planned for gaseous DUNE ND construction. As this is no longer part of phase-1 this should also be available as additional space for warm testing/assembly for ND-LAr. This has

not been officially confirmed but has been unofficially been stated but will depend on other space requirements at the lab.

Initially, the plan was that MATF would move into the cold lab immediately with cryo system costs split between DUNE and Fermilab. Now, as MATF is starting later, there is a delay between external systems and internal cryo systems.
Fermilab is currently installing external N2 and Ar dewars, transfer lines, safety controls, process controls, ODH mitigation. This is moving ahead as planned to be ready in 2023 (but a later-than-beneficial occupancy).
The cold lab space is to be used for FD VD component testing in the short term, so the space is not sitting empty, but they only need a simple setup.
The cold lab was specifically designed for MATF. It also contains 5’ pit for cryo stats (to enable enough crane hight), 15 ton crane.

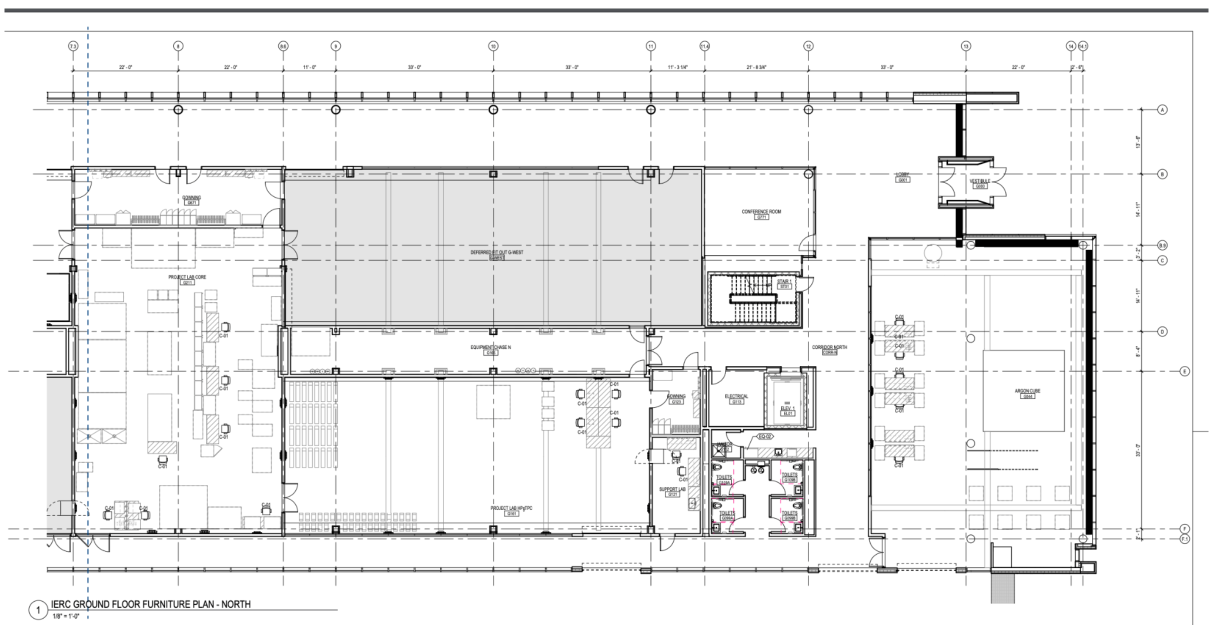
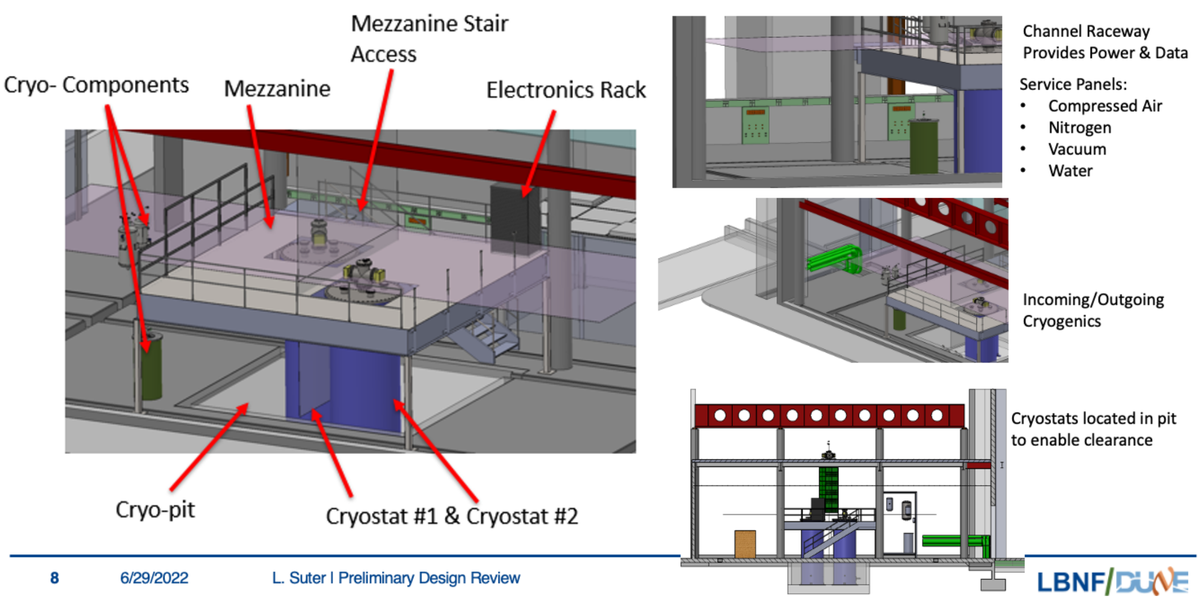


Image of the Helen Edwards building:
Bottom/middle - Warm lab.
Right - Cold lab, showing the location of pit for cryostats.

The purpose of the MATF space in the Helen Edwards building it to host the assembly and test of 35+spares modules in liquid N2, over a time of about 2 years. There is a long term plan plan for the facility being used as ND-LAr MATF to become a future/additional PAB-like facility.



Features of MATF:

- Two cryostats planned, to allow quicker module turn over time, more redundancy or to send longer bugging if needed.
- Cryo-pit enables enough hight to get modules in and out of crypstatos.
- Standard cryostats planned to be used, which could also be used LAr, with a refit.
- Lab comes outfitted with LAr, which could be used for same components tests if needed.
- Most of the cost savings when descoping from LAr to LN2 cames through not needing a recirculation system for the LAr. Original plan have a fully redundant (two of everything system).

General summary of space

- High-bay sufficient for cleanroom for ~4m-tall module assembly, and storage for subsystem components, with a mezzanine structure for cryostat(s).
- Crane with ~4m clearance above cryostat for module installation/removal.

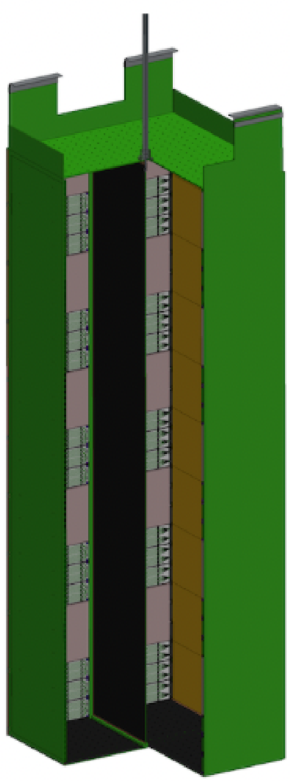
- External system for LN2 storage & delivery of liquid and gaseous nitrogen and venting of gaseous cryogens
- ODH safety system for the MATF hall
- Cryostats capable of hosting ~4m x 1m x 1m module. Two cryostats to parallelize assembly and testing.
- Internal system for LN2 distribution, cooldown and warmup of 2 x 7000 L cryostats
- Common process control system required for providing I/O management through PLCs-based controls and computers-based HMI.
- Two assembly clean spaces planned of ISO8 of 12' x 18' x 8
- Two component check areas of 12' x 18' x 8

Summary table on facilities

	Location			
Capacity	2x2 @ NuMI	BERN FSD	SLAC FSD	MATF@FNAL
Neutrino beam	YES	No	No	No
Cryogenic volume	6000 l	2x6300 liter LAr + 4600l liter in ext. tank	7440 liter LAr in 8700 liter dewar	Same as Bern if cryostat re-used
Recirculation	Yes, submerged pump	Yes, submerged pump	Yes, external pump	LN2 only as baseline (upgradable to LAr)
Crane Hook Height	?	5.3m to floor, 7m pit for cryostats	10.2m	8.76m, 1.52m pit for cryostats
Crane capacity (tons)	15 ton	4 ton	50 ton/10 ton 5 ton in clean room	10 ton
Cryogenic Temperature achievable	By cryo-cooler and LAr evaporation	LN2 cooled LAr	LN2 cooled LAr	LN2 If LAr, LN2 cooled
Fill from the top/Bottom	Flexible flow (both top and bottom in adjustable ratio)	Flexible flow (both top and bottom in adjustable ratio)	From Top when circulating From bottom when filling	From Top when circulating From bottom when filling

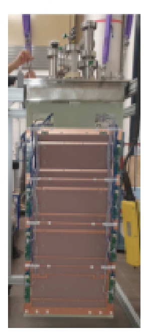
Run period	2022-2023	2023	2024–	2024–
Runtime for tests	During NuMI neutrino beam	weeks (personnel and filter lifetime)	months	Defined by module construction rate
Funding	secured	Secured	Cost cap limited	Planned, cost cap limited, objective scope
Funding source for facility (not detectors)	Bern + FNAL	Switzerland	US DOE + SLAC	US DOE + FNAL + re-use of Bern items

Comparison between 2x2 and FSD modules



Full Size module
100cm x 100cm x 300cm

2x2 module
70cm x 70cm x 120cm



	2x2	Full Size
Charge tile or light module size	30 cm x 30 cm	30 cm x 50 cm

Channels (asics) per charge tile	6400 (100)	10240 (160)
Number of charge tiles or light mod. per module	16 (2 drift regions x 2 lateral x 4 in height)	40 (2 drift regions x 2 lateral x 10 in height)
SiPMs per LCM/ArcLight	6	6
Module dimension	70 cm x 70 cm x 120 cm	100 cm x 100 cm x 300 cm
Active mass per module	~600 kg	~4200 kg
HV	up to 50 kV (1.3 kV/cm)	up to 50 kV (1 kV/cm)
Calibration system	Not implemented	yes

Scenarios

The task force discussed and defined scenarios as alternative options. The 2x2 program is assumed to proceed unchanged. The MATF is assumed to proceed with its timing and scope potentially affected by the scenarios. A larger set of scenarios was considered and trimmed or combined to the three A, B and C. The choice included deliberately a scenario along the preferred plan from ND-LAR (A) and a scenario which eliminated the demonstrator testing (C). The latter was not intended as viable alternative from the start, but rather as an academic study to explore an extreme option and find arguments why it is not viable. The third scenario (B) was developed to fulfill charge question 3 of finding an updated plan. The task force understood that it is not its scope to make a decision on the scenarios, but to lay these out and compare them.

Scenario A: Bern and SLAC FSD

Overview

Scenario A is the current planning of the consortium, involving two FSD sites at Bern and SLAC which complete the full size module demonstration for the FDR and the SLAC facility remains for additional tests while activities ramp up at MATF. This scenario has not been realized yet because of funding limitations.

Risks

The main benefit of having multiple facilities in terms of risk mitigation for the facilities themselves, especially in the case of uncorrelated risks.
The FSD project in Bern is fully funded. The cryostats are ordered and in production. However, in view of the present geo-economical situation one could expect certain shortages in raw materials supply. We mitigate this risk with expedited design and procurement of critical items: Cryostat lids, TPC physics flange, cryo-piping and cryo-valves. As of October 2022 we estimate the probability of realization for this risk to be low but not negligible.
The funding for the FSD facility at SLAC is not secured. Even though the procurement documents are ready, they have not been released and the offers are expiring. Waiting beyond October 2022 poses a serious risk to the timeline and overall

Further risks mitigated by multiple FSDs:

- Two FSDs enable skills to be built at two hubs in the US and EU, building a large set of experts in multiple locations.
- Building and testing two full-sized modules further reduces risk in design - (see risk mitigation above)
- Building and testing two full-sized modules further reduces risk in assembly and testing procedures
- Building and testing two full-sized modules further reduce risk in all logistical aspects of the large-scale production of modules
- If limited resources and personnel having them spread those across two FSDs, instead of focusing on one, might result in delays and needed expertise not being available.

Comments and status

SLAC:

- The P6 budget for a SLAC FSD Facility reviewed at the May 2022 ND Cost Review was ~$3.7M US. SLAC has been on a hardware procurement hold since DOE announced its cost cap in early 2022. This amount, less that spent for ongoing engineering, would be available to the project if the SLAC FSD was canceled.
- If a SLAC FSDTF is funded by November 2022, 12-18 months would be required for hardware acquisition, assembly and commissioning, meaning TPC testing could begin ~ July 2024.
- One needs to decide whether the TPC, assembly fixturing and readout electronics will be transferred from BERN to SLAC or that the Consortium will find the means to produce two sets of everything.
- Beneficial occupancy of the LSST Clean Room in May-June 2023.
- SLAC has lab wide skill sets on cryogenics and controls (LZ, EXO, LSCLS, LSST) and the staff has the expertise to build and operate the FSD. An FSD at SLAC would provide a scientific platform for developing the current and future

generations of experimental physicists at SLAC for working on low temperature detectors.
- CSU, LBL and SLAC could more easily & cheaply contribute effort to a SLAC FSD.
- SLAC is not providing a permanent external cryo system. Current plans call for tank truck rental for 6-months at ~$200/day. If the scope of a SLAC FSD changes, this plan could be revisited.
- The SLAC FSD does offer the possibility for extended and long-term testing of modules

Bern:

- Expertise for building modules already exists at Bern, high success rate for building modules with minimal issues. Experienced team using some new and some existing equipment means high probability that commissioning could begin without major hiccups by the end of CY 2023.
- Much of the cryo infrastructure and that required for building and assembling modules is already in place at BERN. The remaining hardware needed is fully funded by Switzerland.
- Experts can be trained in a well-developed setting and bring that back to SLAC, MATF
- New dewars are scheduled to arrive February 2023. The current TPC timeline shows FSD TPC construction beginning June 2023 with completion October 2024
- Reasonable chance that Swiss FDR review early 2024 milestone can be met
- Risk further mitigated if TPC is assembled at BERN, as per 2x2 modules

A related issue with two FSD facilities that needs to be addressed is that additional modules would need to be produced for testing. Currently the consortium has plans for 1 or 2 modules (depending on the success of the tests). Extended testing would require more TPCs, including module structure, top flange, field cage, charge & light readout, LV, HV, DAQ.

Conclusion

Despite the resources and effort, this scenario remains the preferred one overall by the consortium and the task force reaffirms the preference.
This scenario has several advantages, including the possibility for long term testing and the possibility to add scope based on unforeseeable challenges. It offers, on the other hand, no significant advantage with respect to scenario B within the minimal scope of successfully testing a 1:1-size module for the FDR.
A main advantage of this scenario is the sharing and building up expertise among US groups for the construction, assembly and testing of modules. This is a considerable aspect for the overall construction phase. Another aspect is related to the own risks associated with the facilities themselves (listed above). In scenario A, these risks on both ends - Bern and SLAC - have smaller impact if uncorrelated.
The reason why the scenario is not realized yet is the cost on the side of the DUNE US project. The task force points out that the offers and procurement for the SLAC facilities expired. At this point scenario A can only be realized if immediate action is taken and a clear statement is made in October 2022 that delineates funding, schedule and scope.

Scenario B: Only Bern FSD (2023) and MATF (2024)

Overview

In this scenario only the Bern Full-Scale Demonstrator (FSD) Facility is operated. While the SLAC FSD is de-scoped from the prototyping plan, it is envisaged that SLAC support from SLAC physics and engineering staff will remain to help supplement the remaining FSD and MATF efforts. As the Bern facility is not planned for long-term and extended testing, a follow up facility needs to be in place as soon as a FSD module is successfully tested (the Bern facility has fulfilled its scope). Therefore, this scenario assumes that a Bern FSD will operate in the calendar year 2023 with a subsequent MATF being outfitted and commissioned in CY 2024. The MATF baseline is to operate with LN2, but the option to upgrade to LAr must be maintained in this scenario. If UBern has no plans for long-term tests it makes sense to transfer equipment (dewars in particular) to MATF, reducing cost and perhaps allowing MATF to be configured as a LAr system.

Risks

Risks that are retired by the Bern FSD are described in the “Risk Management” section earlier in this document. This section lays out risks related to the FSD facility itself and how they relate to this specific scenario. Risks associated with the FSD Facility at Bern are as follows:

- Delays in cryogenic component availability
- Failure to reach required LAr purity
- Delays in commissioning system
- Staffing limitations in Bern
- Safety or technical stand-down
- Energy shortage

With only a single FSD facility there are some additional risks that should be considered, as there will not be a back-up site:

- Inability of partner institutions to travel to Bern to support facility commissioning and operations due to
    - Funding
    - COVID-19
    - War in Ukraine
- Funding cuts due to economic geopolitical deterioration in Switzerland/Europe
    - Due to War in Ukraine
    - Due to Interest Rates
- Loss of key staff/personnel at host site
- Increased export control limitations that negatively impact ability to ship components to Bern from partner institutions/countries

- Shortages in raw materials supply. We mitigate this risk with expedited design and procurement of critical items: Cryostat lids, TPC physics flange, cryo-piping and cryo-valves. As of October 2022 we estimate the probability of realization for this risk as **low**.

Table for Scenario B Pros and Cons

	Only Bern FSD (2023)	**Early MATF (2024)**
Pros:	- The BERN FSD cryo system is funded. - New dewars scheduled to arrive February 2023 - Experienced team using some new and some existing equipment means high probability that commissioning could begin without major hiccups by the end of CY 2023. - Reasonably small risk that Swiss FDR review early 2024 milestone can not be met - Risk further mitigated if TPC is assembled at BERN, as per 2x2 modules	- IERC has beneficial occupancy early 2023 as well. Given the need for some production testing it makes sense to start assembly and operation of the MATF cryo facility as soon as possible - If BERN has no plans for long-term tests it makes sense to transfer equipment (dewars in particular) to MATF, reducing cost and perhaps allowing MATF to be configured as a LAr system. - Testing the FSD TPC at MATF for a long duration would reduce risk if operated with LAr. - Need to build expertise at FNAL for a successful MATF. The testing module at MATF from 2024 would develop well-trained team and optimal facility functionality - All post-assembly production procedures can be fully vetted in the facility they will be performed in, QA/QC procedures (warm and cold), critical lift procedure, transport, etc. - Module could be run for extended period > 6 months for further risk mitigation if production schedule is delayed
Cons:	- Susceptible to some geopolitical risks that are outside the control of the ND-LAr Consortium and the DUNE Collaboration as a whole	- Requires advancement of plan on US-side of the project, would need to be implemented prior to CD-2

Cost and Resources

Descoping the SLAC FSD would alleviate ~ $3.28M in US costs through reduction in M&S and labor (about half each) associated with outfitting and operation of the facility; considering the US cost cap on the Near Detector these savings are not insignificant. A fraction of the labor would be maintained to continue SLAC engineering support of the Bern FSD and travel to assist during FSD testing in Bern.

Timeline

Scenario B envisages a Full-Scale Demonstrator in operation at Bern in late calendar year 2023, with outfitting and commissioning of the MATF in 2024 (early compared to various timelines).

The Bern facility will receive the dewars in February 2023. The 2x2 module production and testing is expected to be completed by the end of 2022, with contingency time extending into January 2023. One additional 2x2-size module will be built and tested with a new version of the field shell. This is planned for January/February 2023 and should complete by March 2023, when the Bern FSD facility installation can start. It is expected to take about 6 months to complete (not technically limited).

The MATF timeline for 2024 should be worked out and agreed including the interfaces to FD-VD. At the MATF the external LN2 (and potentially LAr system) are installed 2023. The proximity and the internal system can be started as soon as funds are available, and ready for 2024.

The current TPC timeline shows FSD TPC final components assembly and integration beginning June 2023.

Conclusion

Scenario B proposes relying on the Bern FSD and not proceeding with the SLAC FSD. It is a compromise that the task force studied carefully and concluded that is a viable, though not preferred, scenario.

This scenario shows some risks associated with a single facility being a single point of failure. The task force judges the risks to be acceptable.

In this option the engineering effort at SLAC should be transferred immediately to other aspects of ND-LAr, ND or DUNE. Management should seriously also consider the possibility of having some of the module construction at SLAC using the existing well equipped clean room facilities.

As the Bern facility is not planned for long-term and extended testing, the MATF should be outfitted and commissioned in CY 2024, immediately after the Bern tests are successfully completed. There is a risk associated with bringing up the MATF on time and on scope as well as bringing up expertise. In this scenario the MATF does gain in relevance and the flexibility, as commented by the PDR review report, should be maintained: *“The experience from the suite of prototypes will help inform and “right size” the MATF testing program. The subsystem should keep “working the plan” to adapt to the prototype experiences; modifications in scope of MATF might be necessary or desirable.”, “One aspect of the MATF is possible rework/repair of modules. Again, the planning of this possible activity should be informed by the experience with the suite of prototypes.”.* Furthermore the knowledge transfer to US scientists should be actively supported, as also noted by the PRD report: *“A vigorous program visits of US scientists and engineers to the Bern facility are essential to integrate the experiences at Bern into the MATF planning.”.*

The cost savings in terms of M&S are limited, and are estimated to be $XXXX.

Scenario C: No FSD pre-FDR

Overview

This scenario was prepared as a study case to elaborate arguments for having an FSD at all.
It was not intended to develop the scenario as a viable alternative.
Number of challenges arise in this scenario, as there is no FSD facility prior to the Final Design Review. ND-LAr would have to rely on other planned or new tests and prototypes. The task force explores ways to reach technical maturity in this case and estimate the residual risks. Scope for test shifts in this scenario, with the MATF taking up scope to include LAr operation and Bern would abort the already planned FSD. Additional costs certainly arise, which are not studied in detail.
In scenario C no appropriate level of integrated testing (QA), crucial to validate design of full-scale module components ahead of production, is carried out. The 2x2 becomes the primary integrated test for ND-LAr, though strictly including tests of reduced-scale components, and lacking tests of the calibration system altogether. The design validation of full-scale components via integrated testing would need to be done in reduced-scale tests (e.g. “SingleCube”, but with full-scale components).

Risks

The next table shows that without an FSD module tests several technical design and production process development risks persist into the module production phase and into the Near Site installation and operations. These risks must instead be mitigated during the module production phase through planned LN testing. Some risks that are only resolvable via LAr testing will not be retired until final operation in the LAr Cryostat at the Near Site. This illustrates the utility of the FSD module to help retire the final technical and production process risks prior to modules being constructed and delivered to the Near Site; this is especially important given the long time-scales to service the ND-LAr detector (dominated by cryostat emptying, warm-up, cool-down, and fill).

Table: ND-LAr Risk Summary with FSD; some technical design and production process oriented risks remain into production and the Near Site without sufficient testing of a FSD module.

		Prototyping			Production				
		Component Prototyping	2x2 Demonstrator	Full-scale Demonstrator	Component QC Testing	Assembled Module Testing (at MATF)			Module Row Testing (at Near Site)
	Test Temp	RT/LN	RT/HP-LAr	RT/HP-LAr	RT/LN	RT	LN	HP-LAr	RT
Risk Category	Initial Risk Level	Number of Risks Retired at Each Stage							
Technical Design Risks e.g. - TPC design fails to meet physics performance requirements (fidelity, efficiency) - Subsystem interference degrades performance (noise, field distortion, purity, heat) - Component aging degrades performance	**High**	**16**	**27**	**0**	**0**	**0**	**5**	**0**	**5**
Production Process Development Risks e.g. - Inadequate procurement and assembly processes and procedures - Underdeveloped QA/QC processes - Underestimate of production labor needs - Poor managment structure/coordination of production team	**High**	**5**	**0**	**0**	**0**	**0**	**10**	**0**	**1**
Production/Assembly/Installation Risks e.g. - Inconsistent/sub-standard performance of production components - Errors (electrical, mechanical, etc) in assembly of TPC modules - Errors (electrical, mechanical, etc) in integration of TPC modules to cryostat lid	**High**	**0**	**0**	**0**	**3**	**0**	**26**	**0**	**24**

Pro and cons, cost and resources

The study of this scenario is interesting from the point of view of exploring the risks of a technical issue causing delays to the Bern facility in scenario B. In this case risk mitigation could be recovered via early testing at MATF in LAr.

There are cost savings early during the demonstration and technical maturation phase, but the recovery through risk mitigation later is expected to use these savings up (a detailed study was not done).

In any case the risks are unacceptable before production starts and this scenario is not viable.

Conclusion

Doing integrated tests only during construction does not fully retire risks during ND-LAr operations and is thus unacceptable and not viable. The exercise performed for Scenario C shows clearly that an FSD is necessary to reduce the risks on costs and timeline to an affordable level.

It was studied how the design validation via integrated testing could happen at the MATF if upgraded to operate with LAr. The 2021 taskforce conclusion was to descope MATF while at the same time extending the FSD scope. Scena for design validation also interferes with the production of modules and retires risks very late, with serious consequences if design modifications are necessary. It would cause substantial delays in the schedule.

The task force explored the option to construct at least one full size module but not testing it in LAr (mechanical prototype) before going into the FDR and construction. Given the recommendations from the PDR on the thermodynamics of the LAr and its impact on the module operation this was not considered as sufficient to mitigate the risks. The HV testing and risk mitigation would also not be retired. As well as the performance demonstration could not be done.

A further option considered is a full-size-cube test (one element of 0.5m x 0.5m x 0.3 m or 1m x 0.5m x 0.3m) in LAr to mitigate technical maturation risk. Most of the risks remaining after the 2x2 step are related to the vertical size and cryogenic flows that can only be retired in a full size test with LAr. While interesting, such a cube test would also not be appropriate to mitigate the risks.
The political damage of aborting an already funded and planned facility in Bern should be considered.

CHARGE:

1. Review and, if needed, update the technical maturation plan ("the plan").
   a. Review and update the technical risks in the risk registry, considering the outcomes of the PDRev.
   b. Define an operation and test plan that addresses these risks on the path to the final design.
2. Summarize constraints/opportunities at the facilities relevant for the plan including:
   a. Physical and other practical constraints that may limit its scope
   b. Existing infrastructure that can be reused and scope constraints that may result.
   c. Schedule and availability
3. Propose an updated execution of the plan considering the proposed facilities (LAr@Bern, 2x2@FNAL, MATF@FNAL, FSDTF@ SLAC):
   a. Assume LAr@Bern is the primary site and assess its ability to execute parts (if not all) of the maturation plan and retire risks on the path to final design
   b. If any aspect of the plan cannot be fulfilled at LAr@Bern, propose how they can be executed by either :
      i. Specific modifications to the currently planned LAr@Bern facility
      ii. Adapting other facilities (including possibly other than those mentioned here) to specifically address them
   c. Estimate the cost differential for the updated plan
   d. Evaluate its impact on the QA/QC plan for module production

DUNE Technical Coordination would like to work to this timeline:

- 26 September: Initial report on the findings on the first two charge points regarding the technical maturation plan and the facility constraints and opportunities.
- 17 October: Initial findings regarding the third charge element regarding execution of the plan
- 1 November: Final report from the task force.