1st Accelerators Technology Sector Workshop

Engineering Design Tools and Processes
Project Management Methodologies and Tools

Chair: Mike Lamont

Interconnecting knowledge, experience, methods, people & data to foster learning & collaboration

CERN | ATS
Accelerators and Technology Sector

Defining and executing cryogenic systems for DUNE

Caroline Fabre

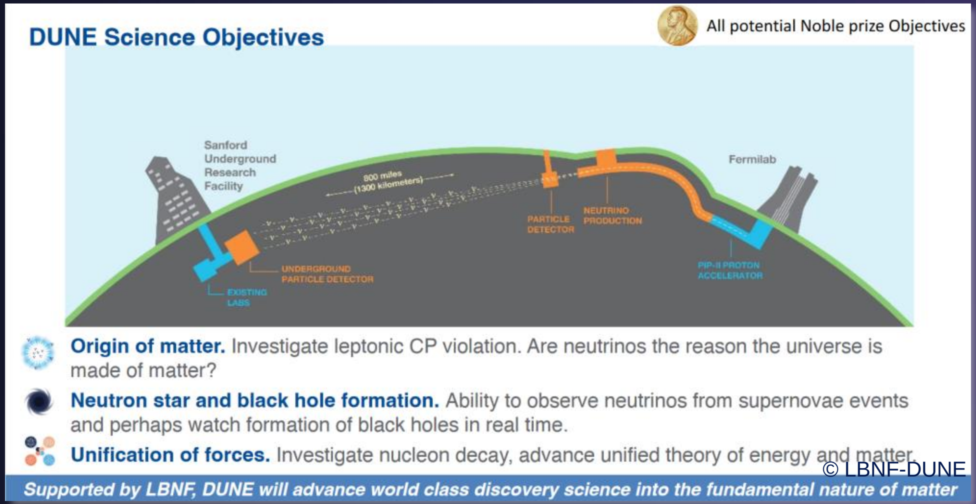
on behalf of the CERN Neutrino Platform and Fermilab partners

CERN | ATS Accelerators and Technology Sector

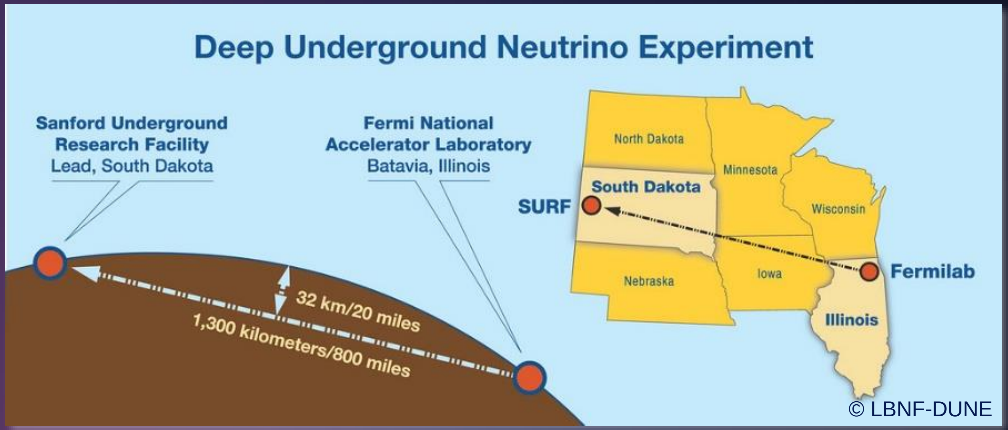
Credits: Johan Bremer; Michel Chalifour; Filippo Resnati

Content

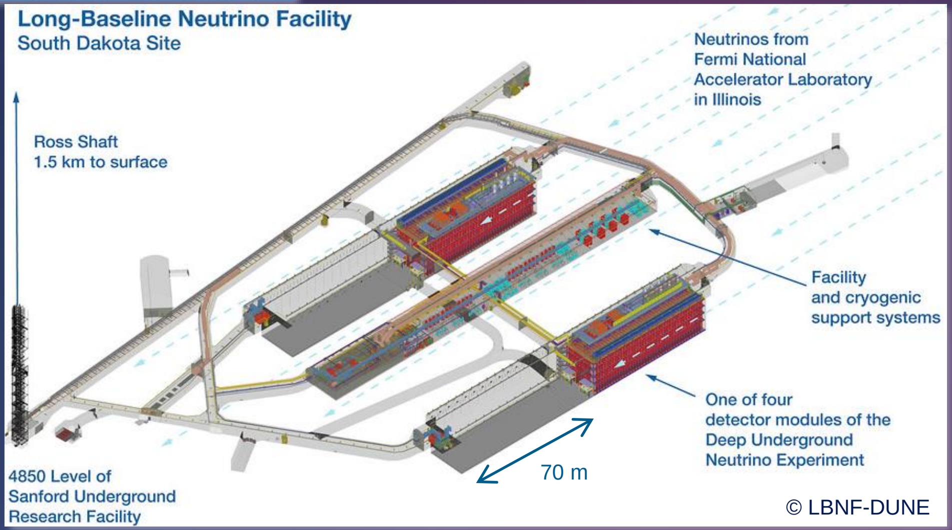
The DUNE project



International collaboration to investigate on neutrino oscillations



Neutrino beam from Fermilab to Sanford lab
- straight through the earth, no tunnel necessary -

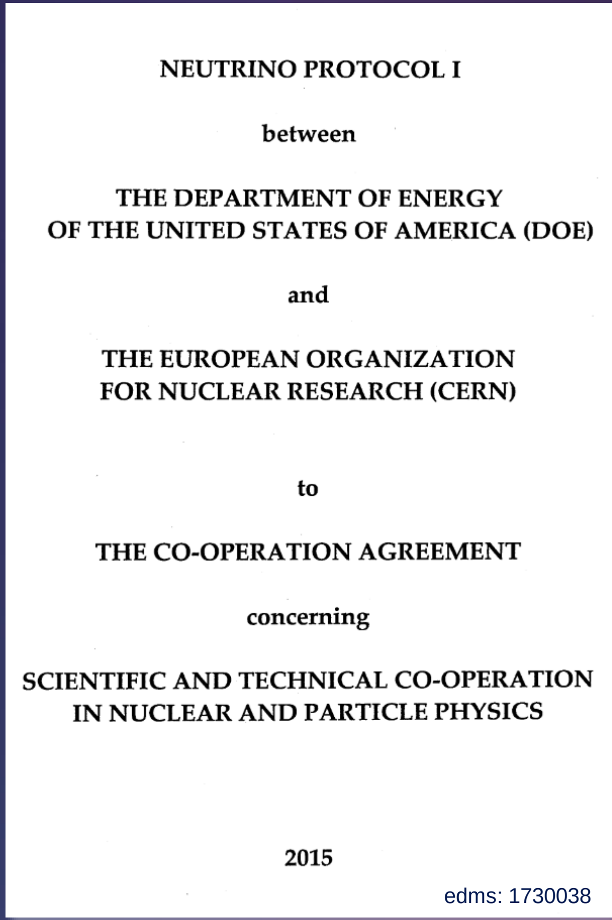


Liquid argon-based detector w 70 kT total argon mass

Co-operation framework between CERN and US-DOE

The CERN Neutrino Platform project:

- To provide a test facility at CERN for large detector prototypes and demonstrators (protoDUNE)
- To support activities related to the construction and operation of the Fermilab SBN program (ICARUS, SBND)
- To contribute to the design, construction and operation of DUNE



NEUTRINO PROTOCOL I

between

THE DEPARTMENT OF ENERGY
OF THE UNITED STATES OF AMERICA (DOE)

and

THE EUROPEAN ORGANIZATION
FOR NUCLEAR RESEARCH (CERN)

to

THE CO-OPERATION AGREEMENT

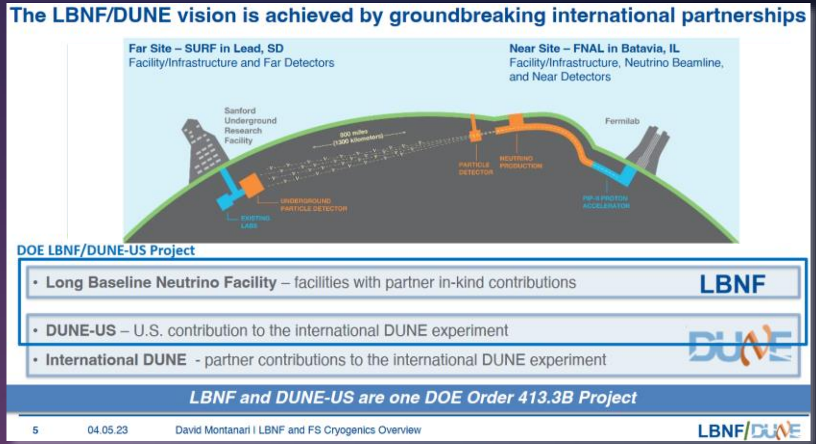
concerning

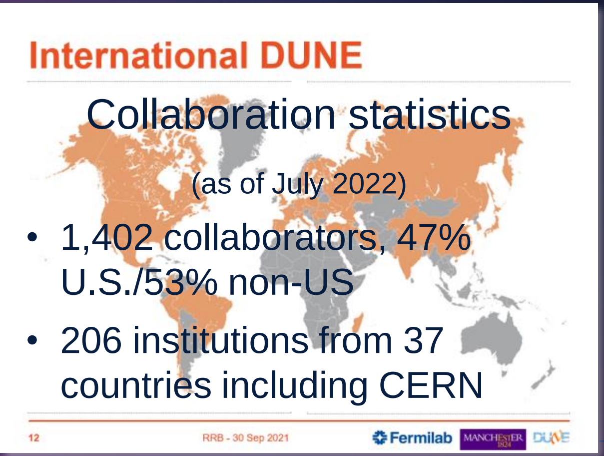
SCIENTIFIC AND TECHNICAL CO-OPERATION
IN NUCLEAR AND PARTICLE PHYSICS

2015

edms: 1730038

as recommended by the 2013 European Strategy for Particle Physics





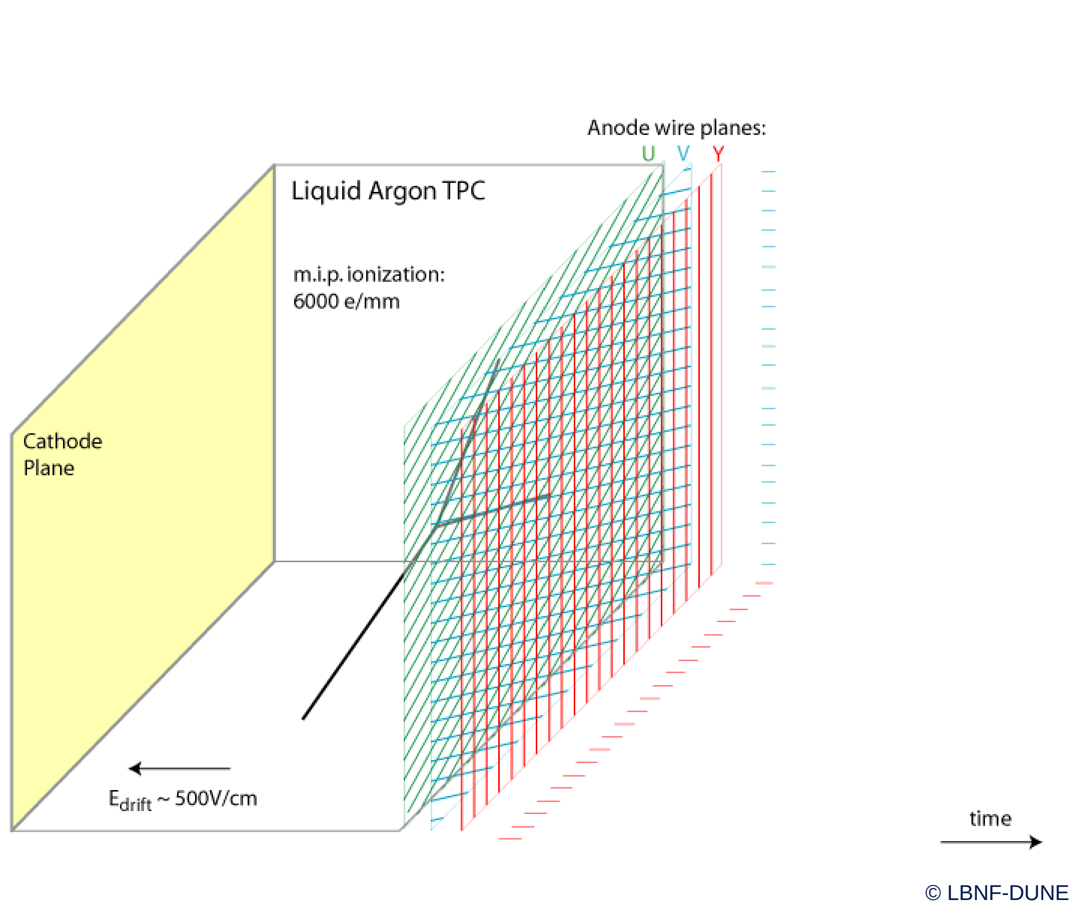
DUNE

Detection principle

Liquid Argon Time Projection Chamber:

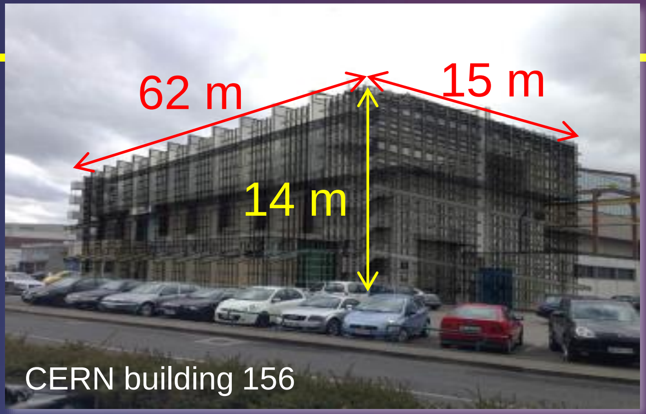
- Neutrino interacts with argon atoms
- Secondary particles liberate valence electrons
- Electrons are collected to the anode wires
- Scintillation light is detected by photo-multipiers

→ Reconstruct 3D image of the interaction



Requirements

1. To guarantee a «long» free electron life-time : > 3 (10) ms → Very pure argon : < 100 (30) ppt O2 equiv. purity)
2. To put a 300 kV HV field → No boiling over the sensitive volume
3. To have a uniform reaction over the sensitive volume → A limited T° difference over the detection volume < 1 K
4. To preserve detector properties → Continuously operated over long periods
5. To guarantee highest safety levels for use in underground caverns → Contain the argon under all circumstances

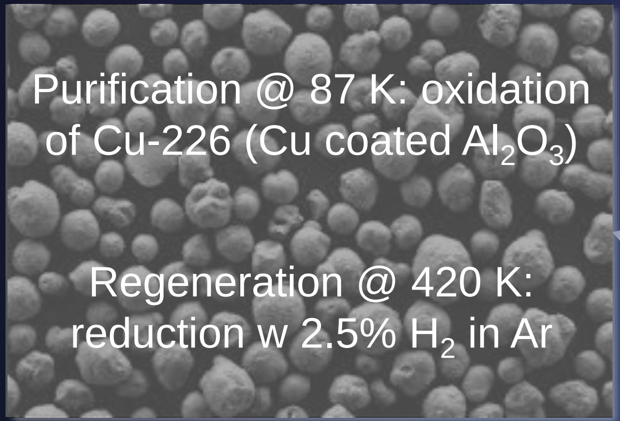


4 cryostats
LAr: 12 500 m^3 – 17 kton
x 500 compared to ATLAS LAr calorimeter

Developments for cryostat and cryogenics

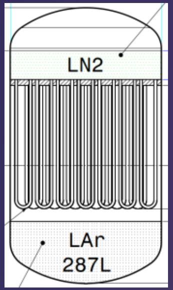
The argon purification principle

circulation
on active copper pellets

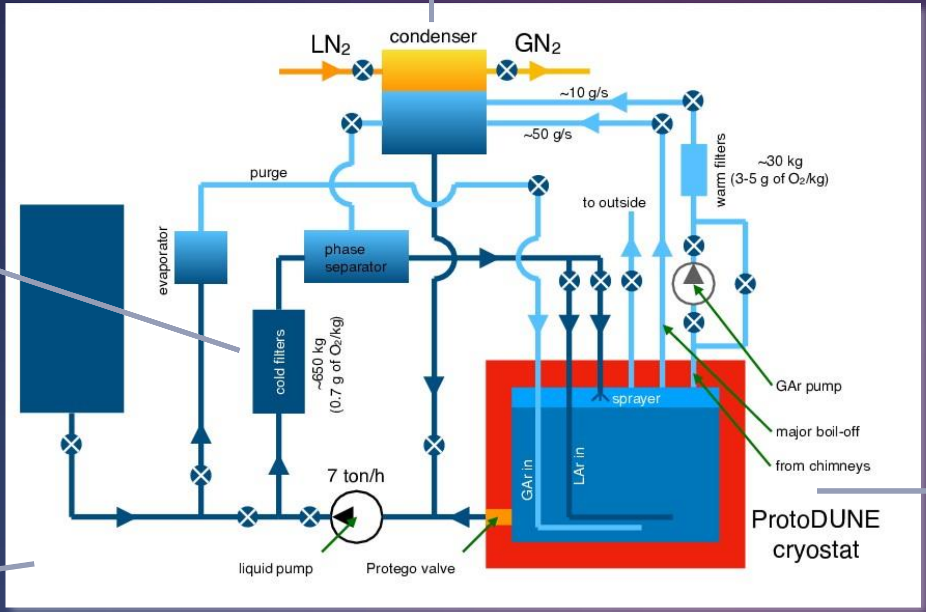


The **pre-ODH alarms**

Principle inherited from NA48



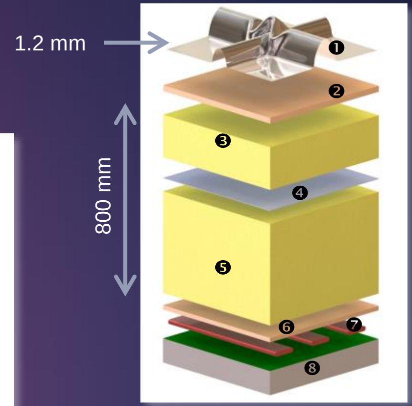
The shell and tube **heat-exchanger:** simple, robust and reliable



Credits: F. Resnati

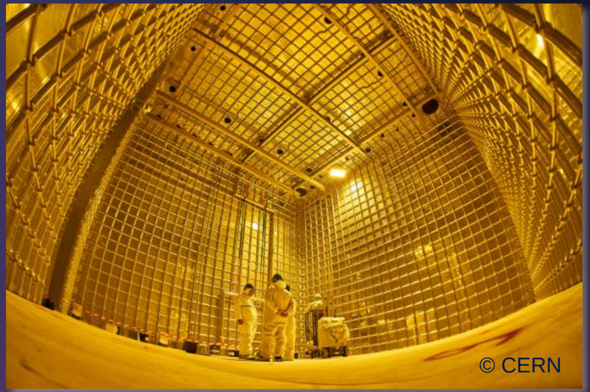
The cryogenic system principle

The **membrane cryostat** principle developed from a qualified technique for LNG tankers



1. Stainless steel primary membrane
2. Plywood board
3. Reinforced polyurethane foam
4. Secondary barrier
5. Reinforced polyurethane foam
6. Plywood board
7. Bearing mastic
8. Steel structure with moisture barrier

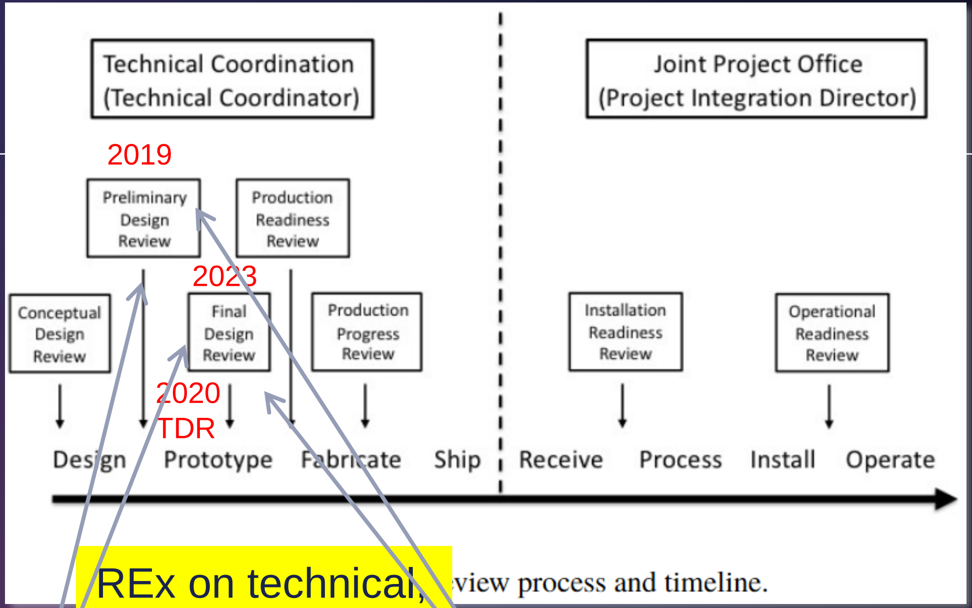
Mark III concept
GTT intellectual property



NP04 cryostat before detector integration

Prototyping

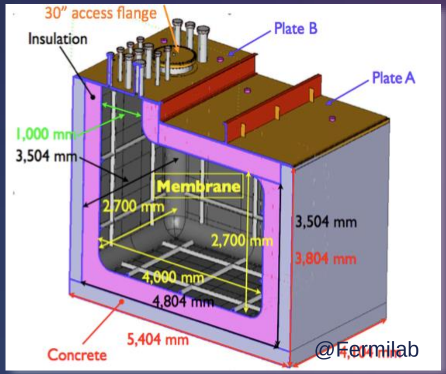
- LBNF cryogenics design developed by Fermilab
- based on the principles developed at ProtoDUNE by NP
- including the Return of Experience
- through **continuous interactions** of the NP and LBNF teams
- and formal participation to reviews



REx on technical, organizational & safety aspects

Sour... iop.org/article/10.1088/1748-0221/15/08/T08009/pdf

26 T
Program finished
(CERN)



35 T
Program finished
(Fermilab)

ProtoDUNE-HD

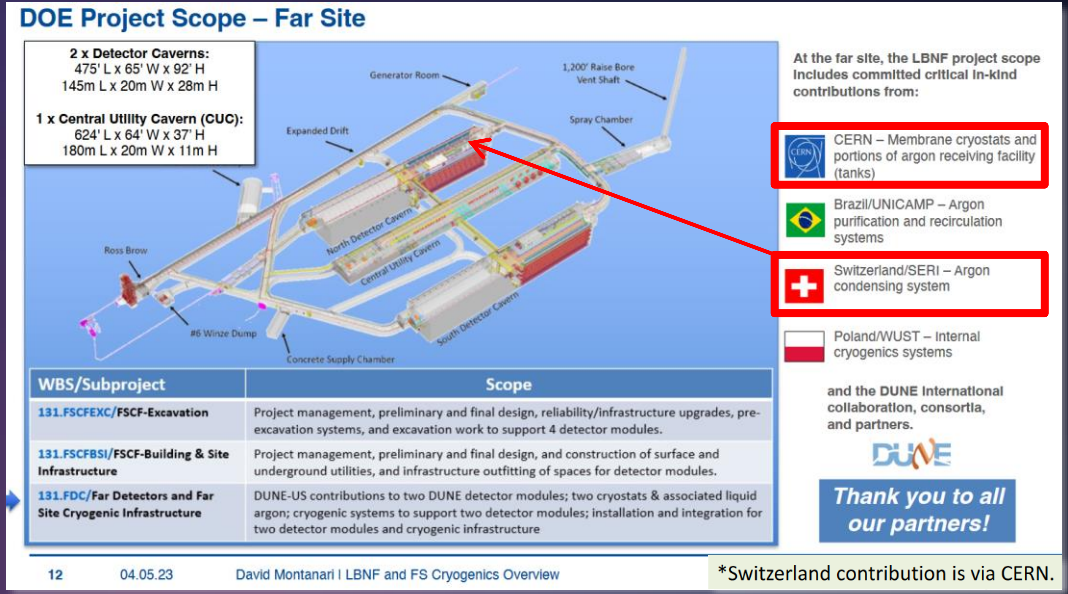
740 T
Cool-down in June 2018
(NP04, CERN)

ProtoDUNE-VD

740 T
Cool-down in Dec. 2018
(NP02, CERN)

Working in a collaboration

- 1st time large scale delivery to a host lab outside CERN via in-kind contribution
- Share of expertise started 2013
- Responsibility
- What is needed for the equipment to be accepted in a US-lab ? (see next slides)
- How do we integrate into the project organization?



with CERN-NP personnel

FD-1 = HD
FD-2 = VD

FD-1 = HD
2018

Trading of scope in progress 2024

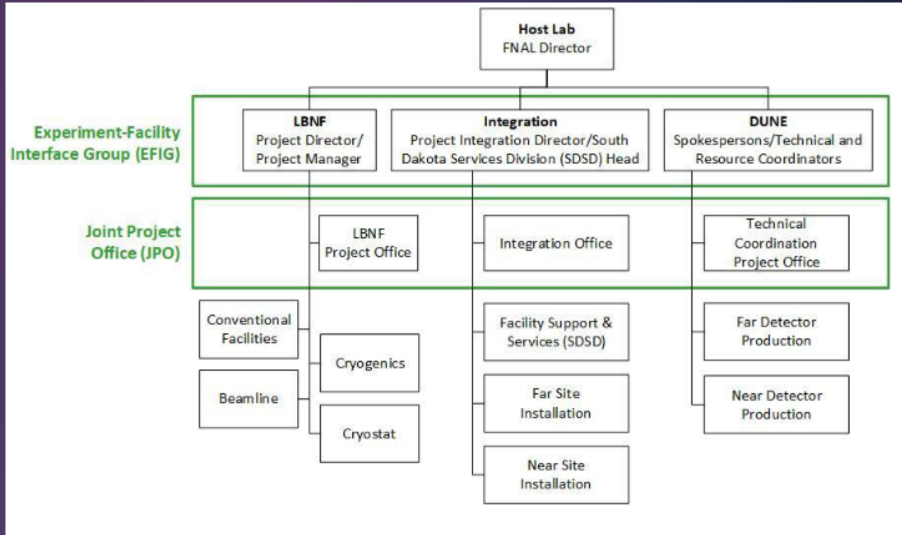
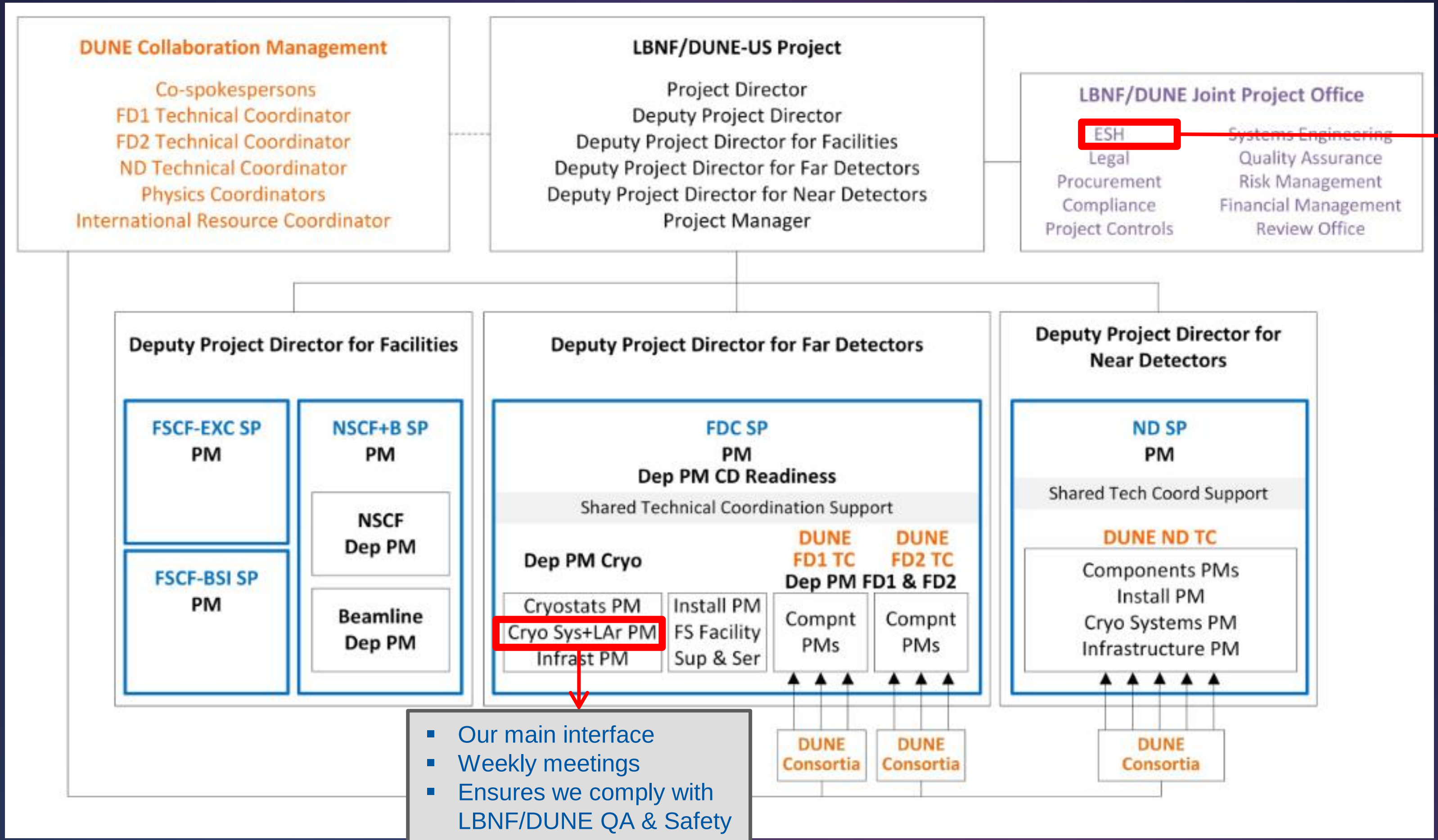


Figure 2.1. LBNF/DUNE organization.

Source: DUNE TDR

CERN/NP in the LBNF-DUNE-US Project



Codes/standards equivalencies

- Our main interface
- Weekly meetings
- Ensures we comply with LBNF/DUNE QA & Safety
- Participates to reviews

Source:
edms 2795431

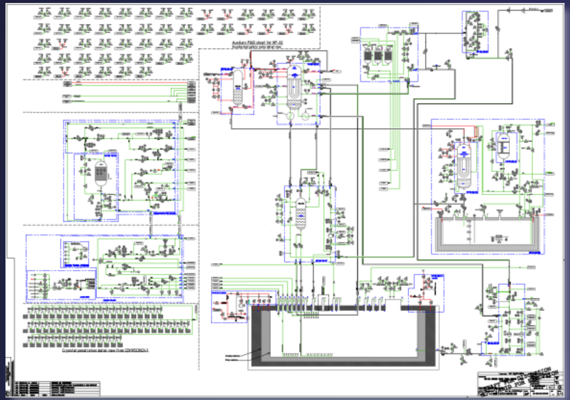
Cryogenic systems

- a set of vacuum insulated valve-boxes and interconnecting transfer-lines
- including instrumentation, filters, pumps, heat exchangers …
- for liquid argon and liquid nitrogen @ temperatures ranging from 80 K to 420 K

From concept

To functional equipment

ProtoDUNE cryogenics @ CERN

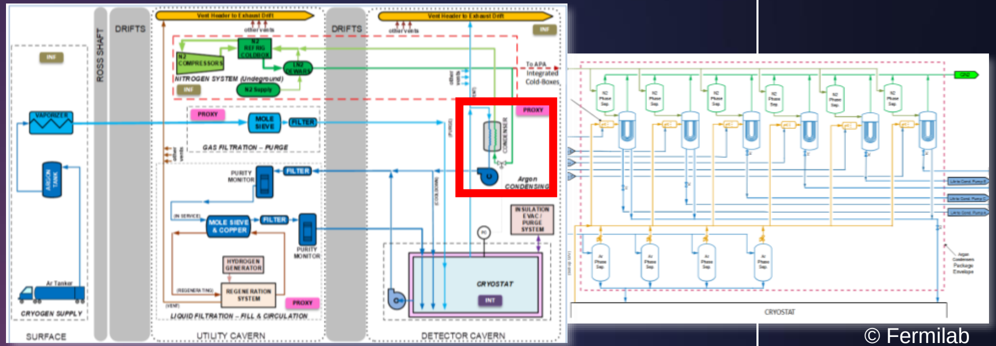


The installed cryogenic system @ EHN1

Scaling up

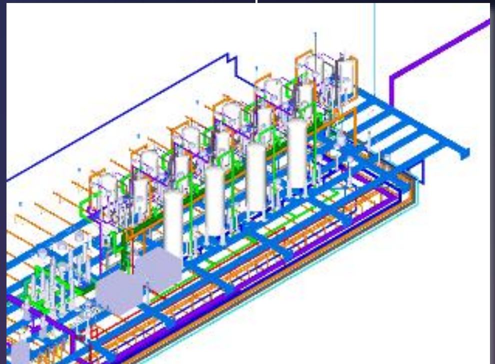
in size and complexity

DUNE cryogenics @ SURF



several similar units working in parallel

- 22 valve boxes
- ~700 m transfer-lines
  w diam. up to DN250
- ~ 135 cryogenic valves
  ranging DN40 to DN150



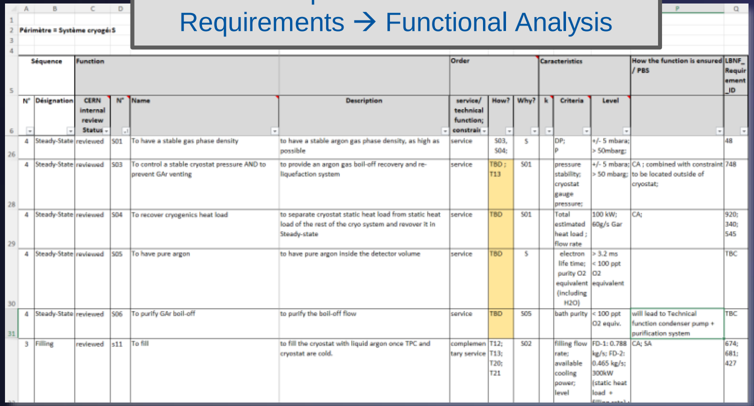
Condensers system 3D on cryostat mezzanine

From the definition to the execution

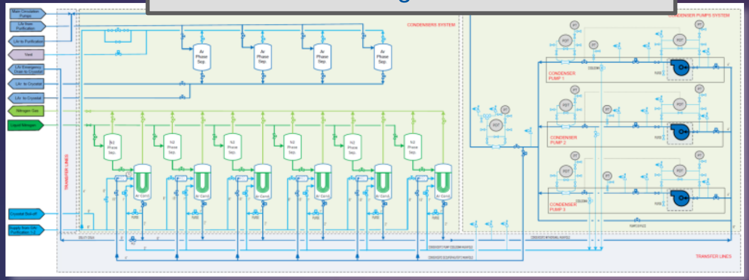
- Freedom to structure our sub-project
- Management and development plan based on standard practices
- Builds on the team past experience on similar cryo projects
- Approach: adopt a methodology and a level of formalism appropriate to efficiently deliver the cryogenic system, with the allocated resources

Engineering activities & methodology (1/2)

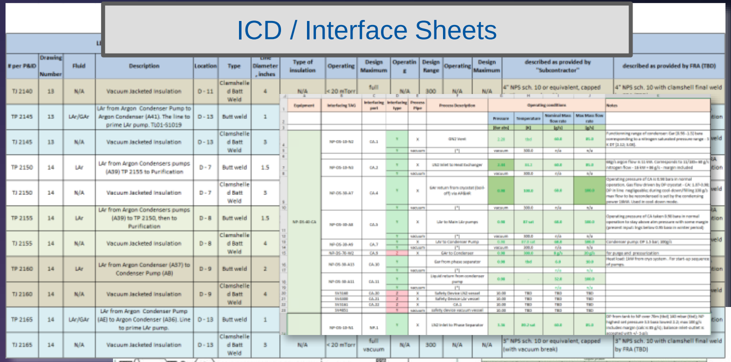
Expression of need:
Requirements → Functional Analysis



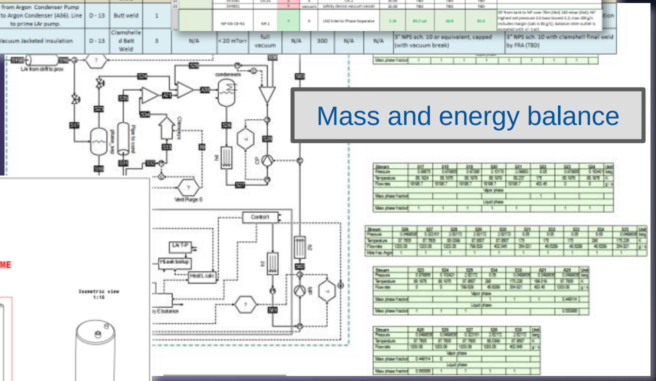
Block diagram / PFD



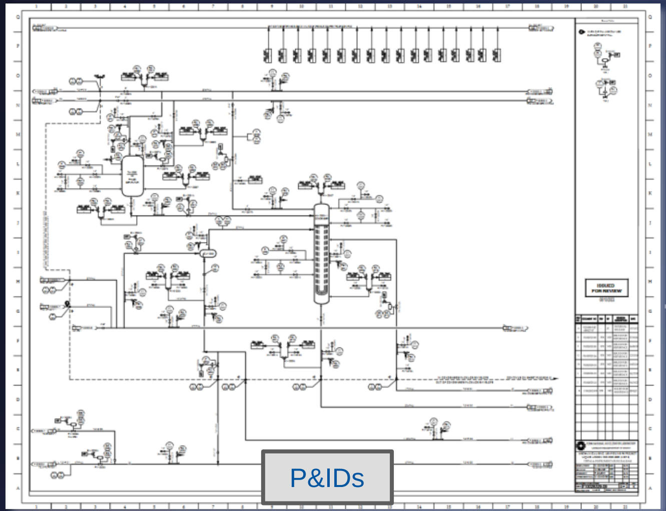
ICD / Interface Sheets



Mass and energy balance

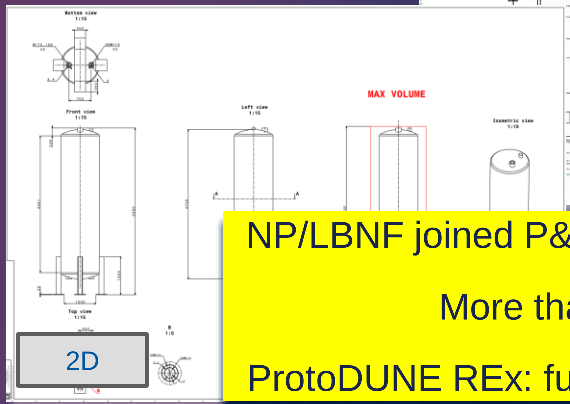


© Fermilab



P&IDs

3D



2D

NP/LBNF joined P&ID review; HAZOP / FMECA

More than just a concept

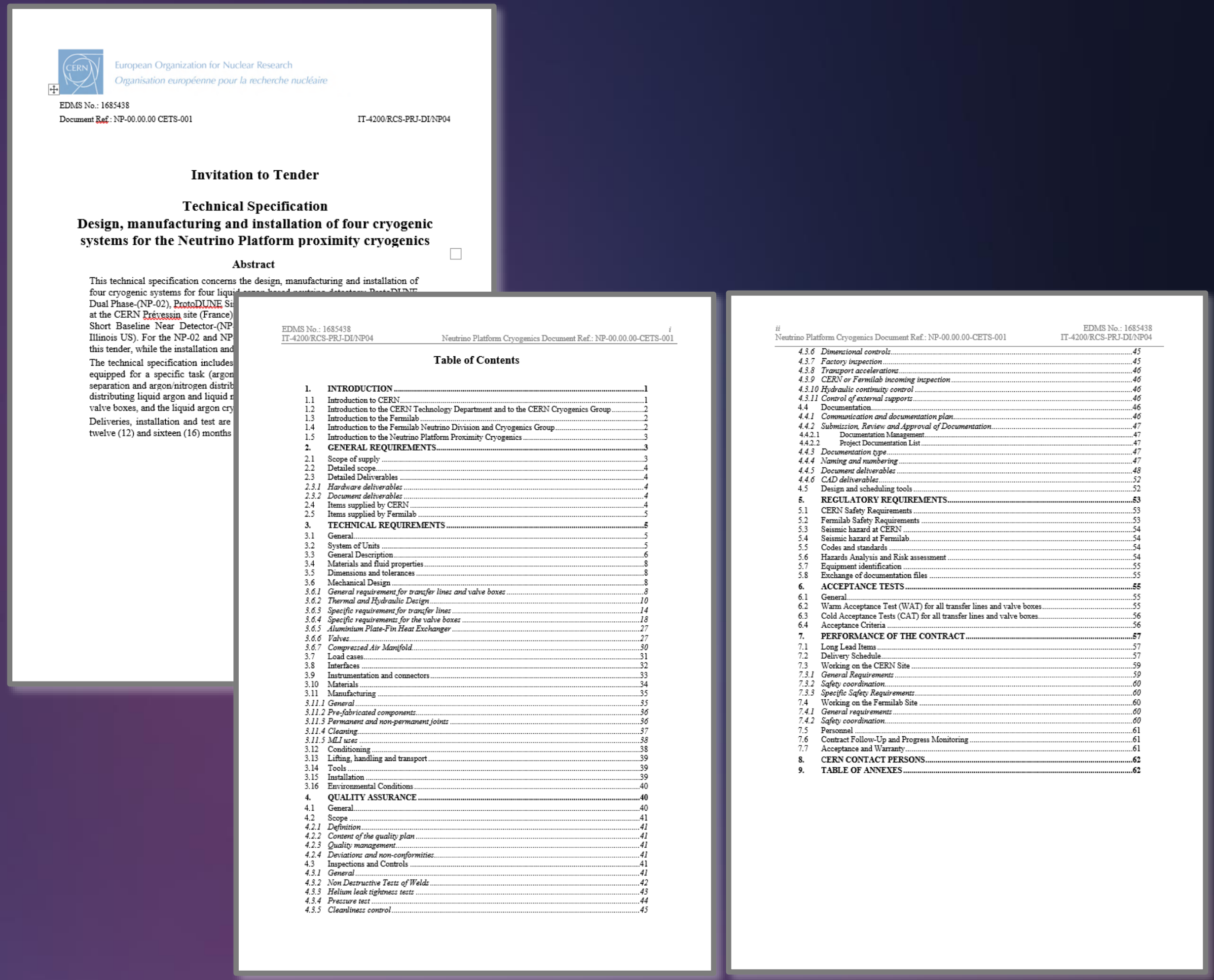
ProtoDUNE REx: functional vs **technical specs**

Engineering activities & methodology (2/2)

Technical specification

- NP responsibility
- PRR / spec committee
- w participation of LBNF partners
- Validate requirements
- Sets the ground for acceptance by LBNF

→ Ready for industrial consultation



European Organization for Nuclear Research
Organisation européenne pour la recherche nucléaire

EDMS No.: 1685438
Document Ref.: NP-00.00.00 CETS-001 IT-4200/RCS-PRJ-DI/NP04

Invitation to Tender

Technical Specification
Design, manufacturing and installation of four cryogenic systems for the Neutrino Platform proximity cryogenics

Abstract

Table of Contents

Management activities

Management Plan

Neutrino Platform

Management Plan for the Neutrino Platform Proximity Cryogenics

Management Plan for the

Neutrino Platform Proximity Cryogenics

Abstract

This document describes the management plan for the Neutrino Platform Proximity Cryogenics

Prepared by:	Checked by:	Approved by:
M. Chalifour TE-CRG-CI	J. Bremer TE-CRG-CI,	M. Nessi RCS-PRJ-DI

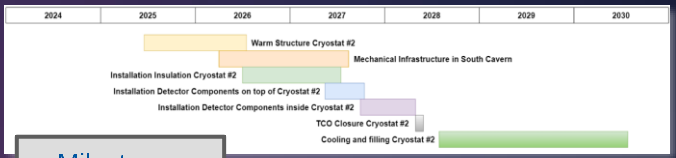
Distribution List

Team members of the Neutrino Platform Proximity Cryogenics

PBS

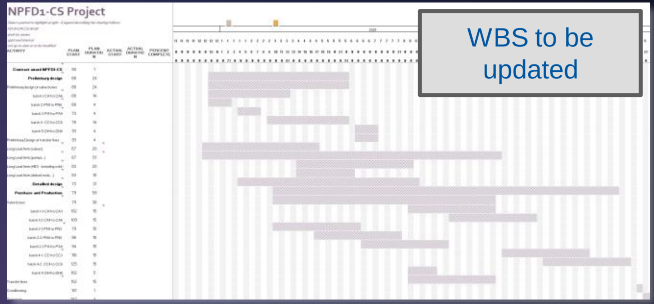
LBNF Proximity Cryogenics Condensation System

PBS proposal							#
Level 0	Level 1	Level 2	Level 3	Level 4	Level 5	product name	Comments
project level	sub-project level	system level	sub system	family	Product		
FD	01	00	00	00	00	Common	common components to the **Far Detector 1**
FD	01	**CR**	00	00	00	Common	common components to the **proximity CRyogenic system**
FD	01	CR	**CS**	00	00	Common	common components to the **Condensation System**
FD	01	CR	CS	**LN**	00	Common	common components to the **Nitrogen transfer Lines**
FD	01	CR	CS	**LA**	00	Common	common components to the **Argon transfer Lines**
FD	01	CR	CS	**SN**	00	Common	common components to the **N2 phase Separator**
FD	01	CR	CS	PN	01	N2 phase separator 1	N2 phase separator system 1
FD	01	CR	CS	PN	02	N2 phase separator 2	N2 phase separator system 2
FD	01	CR	CS	PN	03	N2 phase separator 3	N2 phase separator system 3
FD	01	CR	CS	PN	04	N2 phase separator 4	N2 phase separator system 4
FD	01	CR	CS	PN	05	N2 phase separator 5	N2 phase separator system 5
FD	01	CR	CS	PN	06	N2 phase separator 6	N2 phase separator system 6
FD	01	CR	CS	**SA**	00	Common	common components to the **Ar phase Separator**
FD	01	CR	CS	**DH**	00	Common	common componenents to the **De-superHeater**
FD	01	CR	CS	**CA**	00	Common	common components to the **Argon Condensers**
FD	01	CR	CS	CA	01	Condenser 1	Condenser 1
FD	01	CR	CS	CA	02	Condenser 2	Condenser 2
FD	01	CR	CS	CA	03	Condenser 3	Condenser 3
FD	01	CR	CS	CA	04	Condenser 4	Condenser 4
FD	01	CR	CS	CA	05	Condenser 5	Condenser 5
FD	01	CR	CS	CA	06	Condenser 6	Condenser 6
FD	01	CR	AC	00	00		Liquid argon circulation
FD	01	CR	AC	MC	00		Main circulation box
FD	01	CR	AC	CC	00	Common	common components to the **Condenser Circulation boxes**



Milestones

Tender out : 01-02-2025
Contract signed: 01-06-2025
Shipment: 01-02-2027
Delivery: 01-04-2027



WBS to be updated

OBS

Organisation of the Neutrino ... rk package (WP):

NPPC

WP	name	NP01	NP02	NP03	NP04	WA105
1	Contracts	MCR-JBR				
2	Quality	MCR-JBR				
3	Project Management	JBR-MCR				
4	Process	CFE-Fermilab	CFE	CFE-Fermilab	CFE	
5	Instrumentation	NVR-CFE				
6	Control, Electrical-Cabling cabinets	Fermilab	MPI-ROI	Fermilab	MPI-ROI	
7a	Assembly, Integration and tests EHN1		JCS-PCT		JCS-PCT	
7b	Assembly, Integration and tests Fermilab	MCR-PCT		MCR-PCT		
8	Risks and Availability Analysis	MCR-JBR				
9	Operation	Fermilab	CERN	Fermilab	CERN	
10	Safety	MCR-PCT				
11	Mechanical	MCR-PCT				

WP Leader Roles and Responsibilities

2.4.4 WP 4: Process

The "Process" WP Leader is

She will be Responsible for the following activities:

- Review all Process Calculation notes:
  i.e: Thermodynamic, Hydraulic (Valves, Pipes, PSV…), Thermal (Heat Leaks…)
- Review Equipment Data Sheet and ensure that they comply with process calculation.
- Review PFD and PID and ensure that they comply with CERN requirements.
- Review PFD and ensure that they comply with process calculation.
- Review Equipment Part List.
- Organize the HAZOP and SIL Study Reviews.
- Maintain the Process IS up-to-date based on Contractor Data.
- Perform Functional Analysis (Basis for PLC Program).
- Ensure that the Performances as per Calculation Notes meet Tech Spec requirements
- Ensure that Technical Specification WP4 requirements are respected.
- Ensure that relevant version of CERN Applicable Process Doc. are Transmitted to Contractor via RO and that associated requirements are respected.
- Alert the RO if the Contractor Process Definition comes with Risks

She will provide support to the following activities:

- WP5: Provide support to review strategy with main control loops.
- WP9: Provide support to Operation for Process Diagnostic and Optimisation.

Cost estimate

COST ESTIMATE for LBNF Proximity Cryogenics Condensation Sys

Organization: CERN
Date: Feb. 2024

Scope description:
DUNE Far Detector 1 PROXimity cryogenic system - argon CondenSers sub-system
To re-condense GAr boil-off of FD-1 in Cool-down, Filling and steady state operation and send it to the LAr purification
Design and fabrication
Installation NOT included

Basis of estimate:
Study estimate (factored estimate)
Equipment costs (CEQ) based on past purchase records of cryo equipment in CERN cryo group, with cost indexes assumed 1.0 between 2010 and 2020 (ref. edms: 2391637)
benchmarked against DarkSide 20k Bid Assessment

Assumptions:
Based on equipment from P&ID and 3D model by Fermilab ref: F10028329 rev K
Batches of identical equipment reduces the design cost of duplicates by a factor 2
Cost index 2020 to 2024: 1.25

Range:
Class of estimate: 3, with an expected accuracy range of +30% -10%.

Equipment costs:

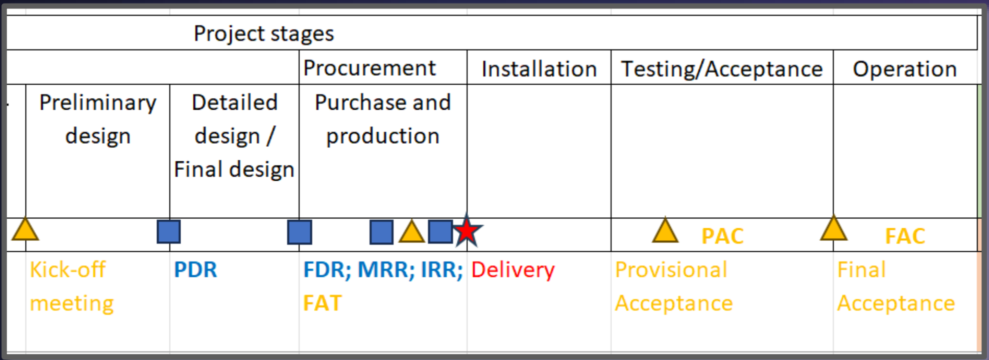
PBS						Product name	Comments	Cost [kCHF]2024
FD	01	CR	CS	LN	00	N2 Transfer-Lines	common components to the **Nitrogen transfer Lines**	
FD	01	CR	CS	LA	00	Ar Transfer-Lines	common components to the **Argon transfer Lines**	
FD	01	CR	CS	SN	00	N2 Phase Separators	6 identical **N2 phase Separators**	
FD	01	CR	CS	SA	00	Ar Phase separators	4 identical **Ar phase Separators**	
FD	01	CR	CS	CA	00	Ar condensers	6 identical tube-in-shell **Argon Condensers**	
FD	01	CR	AC	CC	00	Condensers Circulation boxes	6 identical **Condenser Circulation boxes** (pumps outside of scope)	
						Cold valves	x141	
						Safety valves	x32	
						Orifice Flow Elements	x6	
						Pressure sensors	x56	
						Vacuum gauges	x94	

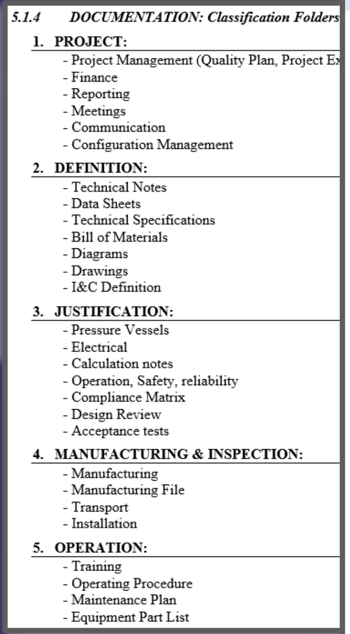
Total costs:

$(C_{EQ})_{FOB}$	Total Equipment cost Free ON Board (delivered to CERN)
Delivery cost	Cost of transport CERN to US
$(C_{EQ})_{DEL}$	Total Equipment cost Delivered to site
	Expected accuracy range -10%<(CEQ)DEL<+30%

Simple tools, sufficient to handle sub-project of this scale

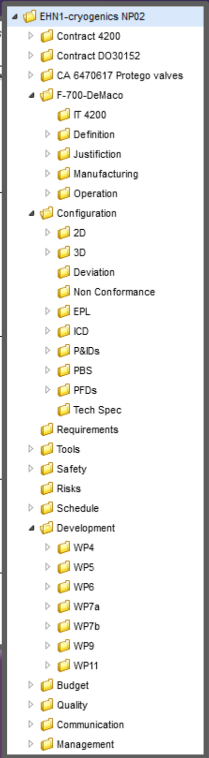
QA activities in contract execution

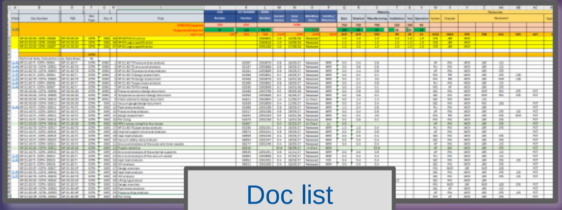




5.1.4 DOCUMENTATION: Classification Folders

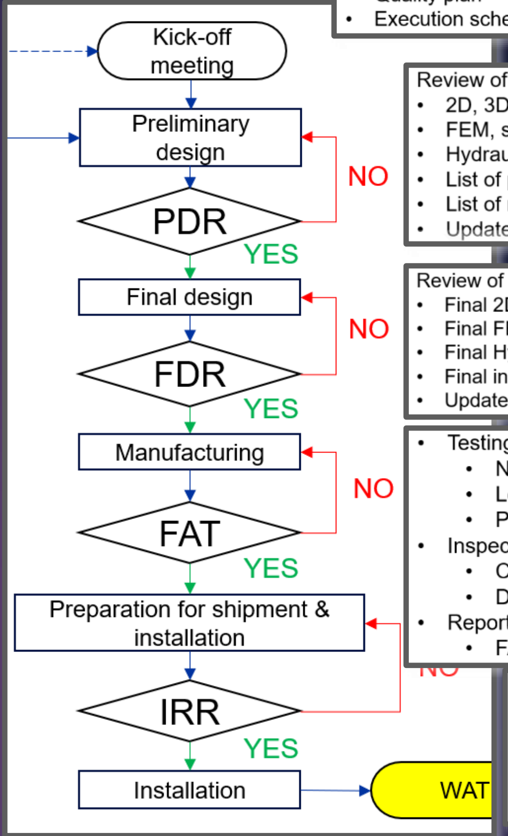
1. PROJECT:
   - Project Management (Quality Plan, Project Ex
   - Finance
   - Reporting
   - Meetings
   - Communication
   - Configuration Management
2. DEFINITION:
   - Technical Notes
   - Data Sheets
   - Technical Specifications
   - Bill of Materials
   - Diagrams
   - Drawings
   - I&C Definition
3. JUSTIFICATION:
   - Pressure Vessels
   - Electrical
   - Calculation notes
   - Operation, Safety, reliability
   - Compliance Matrix
   - Design Review
   - Acceptance tests
4. MANUFACTURING & INSPECTION:
   - Manufacturing
   - Manufacturing File
   - Transport
   - Installation
5. OPERATION:
   - Training
   - Operating Procedure
   - Maintenance Plan
   - Equipment Part List





Doc list

- Documentation deliverable at each Milestone defined in specs
- Deviations requests: joined examination by NP/LBNF
- Reviews and acceptance tests are Hold Points → **verification of compliance w requirements**



- Risk plan
- Quality plan
- Execution schedule

Review of all PDR deliverables:
- 2D, 3D CAD files
- FEM, structural reports
- Hydraulic, thermal, safety calculations
- List of procedures, tests
- List of materials, standards, etc.
- Updated execution schedule

Review of all FDR deliverables:
- Final 2D, 3D CAD files
- Final FEM, structural reports
- Final Hydraulic, thermal, safety calculations
- Final instrument/part list
- Updated execution schedule

- Testing
  - NDE of welds
  - Leak testing
  - Pressure testing
- Inspection & control
  - Cleanliness control
  - Dimensional control
- Reporting
  - FAT report

Witnessed by NP/LBNF

- As built 3D model
- Installation, inspection, control procedures
- Cleanliness work plan
- MIP for installation
- Welding plan for installation

Credits: T. Baroncelli

- Helium leak test (from atm. to vacuum)
- Purge/flushing of pipes
- Helium leak test + pressure test (from process side to vacuum @ MAWP, T_{amb})

Conclusion

Run medium size sub-project with:

- standard PM practices;
- methodology and level of formalism appropriate to efficiently deliver the cryogenic system, with the allocated resources;
- **simple tools**;
- continuous interactions within a **collaboration** framework (both for including REx and for acceptance by LBNF)

Methodology is a tool; People make it happen !

The metal structure of the first cryostat in the harbour (Spain)

Photo: Matthew Kapust, Sanford Underground Research Facility

https://news.fnal.gov/2024/02/excavation-of-colossal-caverns-for-fermilabs-dune-experiment-completed/

First cryostat filling is foreseen to begin in Q2 2028…

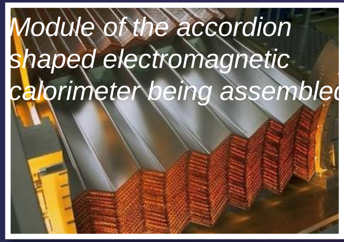
and complete 1 year later, after argon delivery by 1000 road trucks !

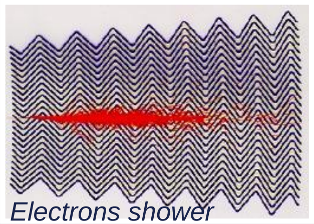
BACK-UP SLIDES

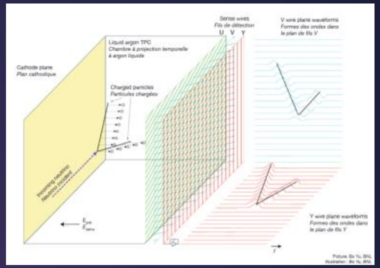
ATS
Accelerators and
Technology Sector

Cryogenics expertise for liquefied rare gases detectors

Cryogenics as active "medium" of detectors
for particles energy measurements
like Liquid Ionization Chambers


Module of the accordion shaped electromagnetic calorimeter being assembled


Electrons shower


Reconstructed 3D image of the neutrino interaction

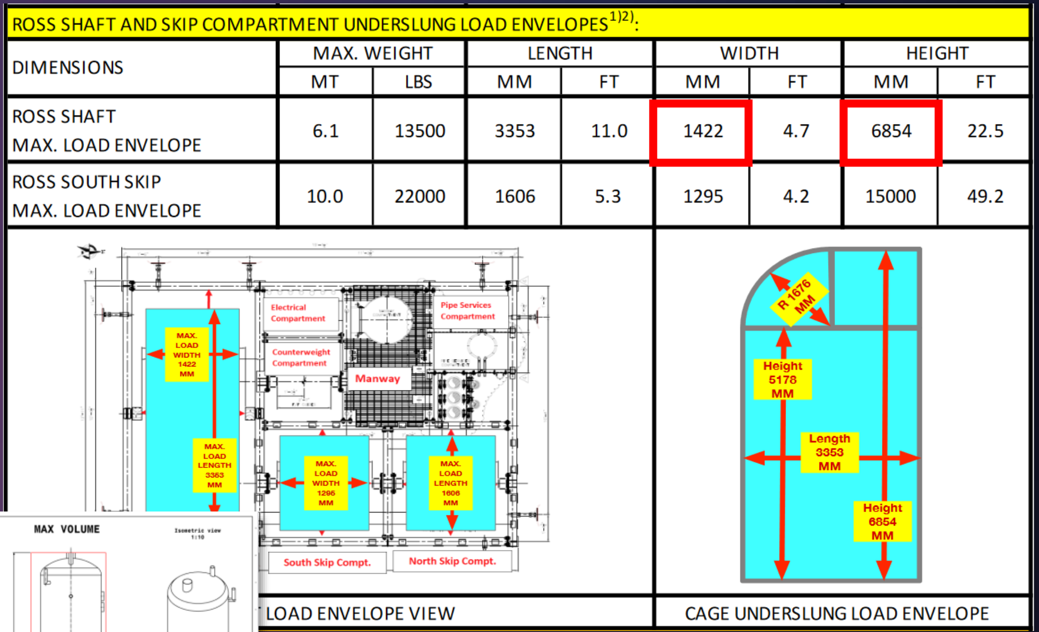
Calorimeters | **Time Projection Chambers**

Requirements	ATLAS	ProtoDUNE	DarkSide-20k	DUNE
to maximize the number of events → **a large volume of a dense noble liquid**	100 m^3 LAr	560 m^3 LAr	500 m^3 LAr	4 x 12 000 m^3 LAr
to have a uniform reaction over the sensitive volume → **a limited T° difference over the detection volume**	88.3 K DT < 700 mK	87.5 K DT < 500 mK	87.5 K	87.5 K DT < 1 K
to put a HV field over the sensitive argon volume → **a subcooled bath to prevent bubbles**	2 kV field 2 mm drift gap	18 kV 3.6 m drift gap	-	300 kV 6 m drift gap
to guarantee a sufficiently long free electron lifetime → **a pure liquid** (oxygen equiv. purity)	> 0,15 ns < 2 ppm	> 3 ms < 100 ppt	> 3 ns < 100 ppb	> 10 ms < 30 ppt
to reduce the noise level (cosmic particles) → **in underground areas**	-100 m @ CERN	-10 m @ CERN	- 1.4 km @ LNGS	- 1.5 km @ Sandford Lab
to preserve detector properties → **continuously operated over long periods**	Since 2005 17 years	2019 1 year	2024 years	beg 2028 years

Commonalities | **Scaling in size and complexity**

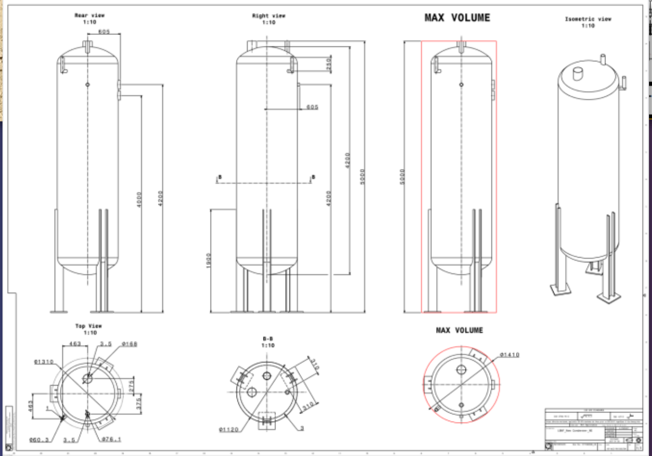
Perspectives towards DUNE proximity cryogenic system

This is how everything has to go down: personnel and material !

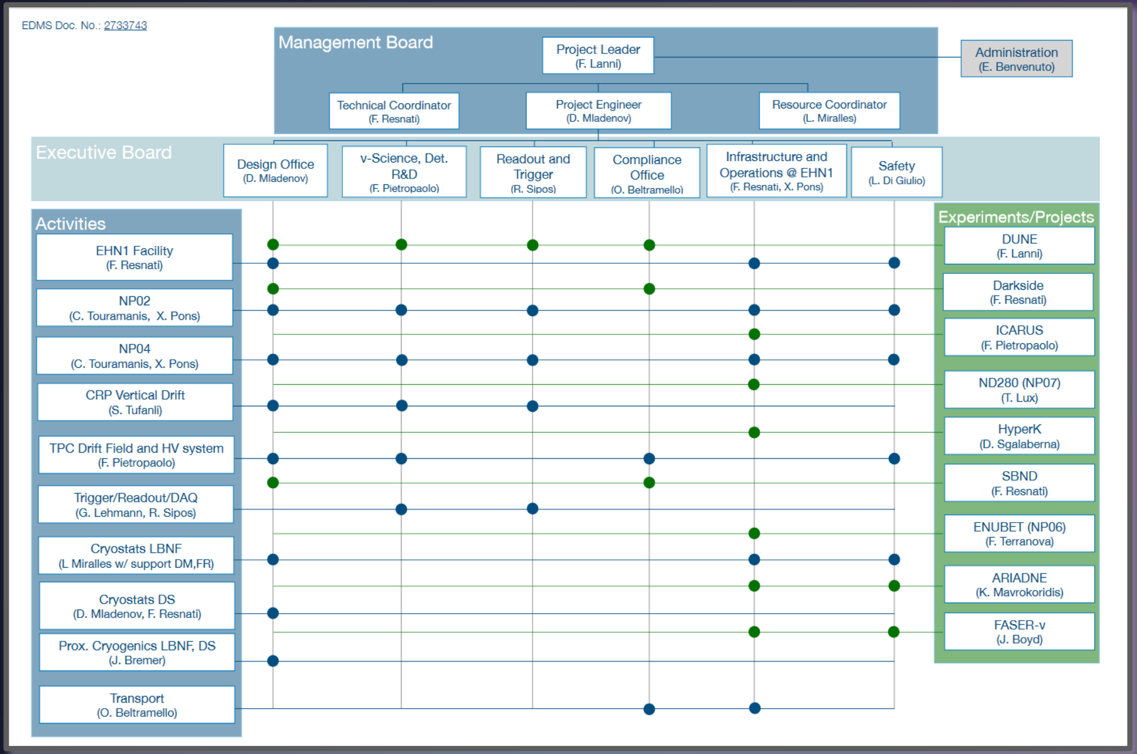


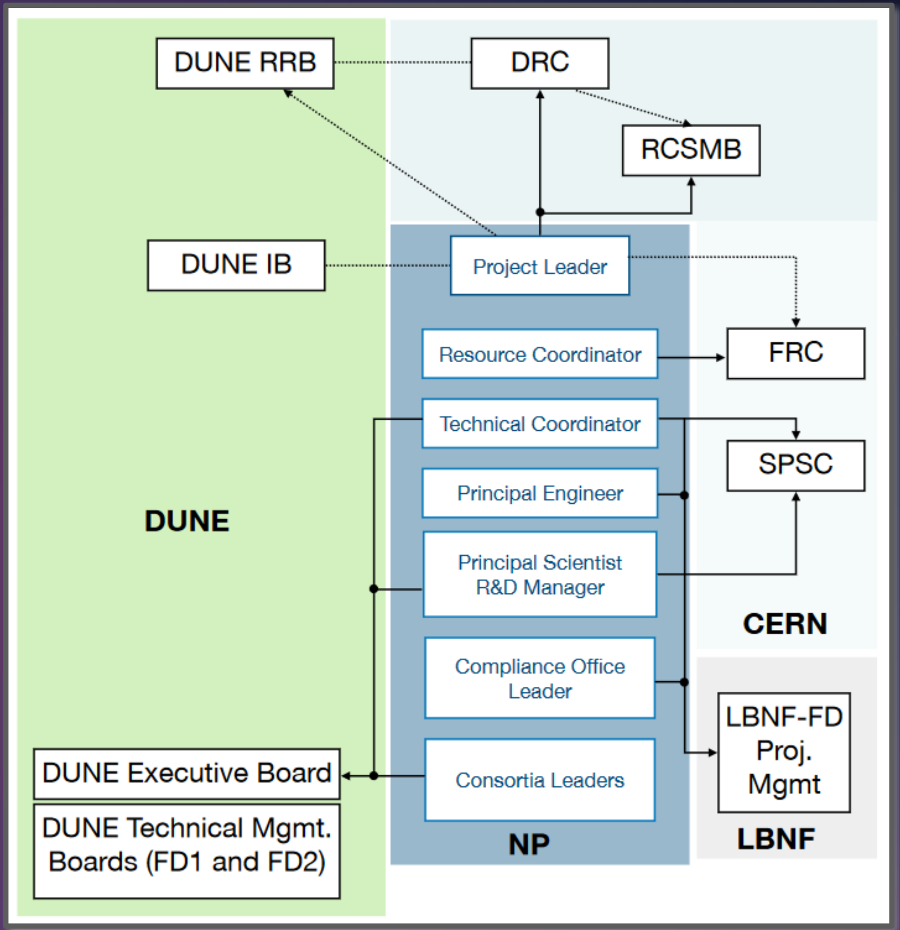
ROSS SHAFT AND SKIP COMPARTMENT UNDERSLUNG LOAD ENVELOPES[1)2)]:

DIMENSIONS	MAX. WEIGHT		LENGTH		WIDTH		HEIGHT	
	MT	LBS	MM	FT	MM	FT	MM	FT
ROSS SHAFT MAX. LOAD ENVELOPE	6.1	13500	3353	11.0	1422	4.7	6854	22.5
ROSS SOUTH SKIP MAX. LOAD ENVELOPE	10.0	22000	1606	5.3	1295	4.2	15000	49.2



Neutrino Platform Organization





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