Near Site Cryogenics Overview

David Montanari (on behalf of Near Site Cryogenics Team)
DUNE Conceptual Design Review: Near Detector
7-9 July 2020

DM: Slides have been edited on Jul 8, 2020 (5, 19, 20, 22).

Outline

- Scope/Overview
- Organization
- Layout.
- LAr Cryogenics.
- LHe Cryogenics.
- Process Controls.
- Next Items
- Schedule.
- Summary.

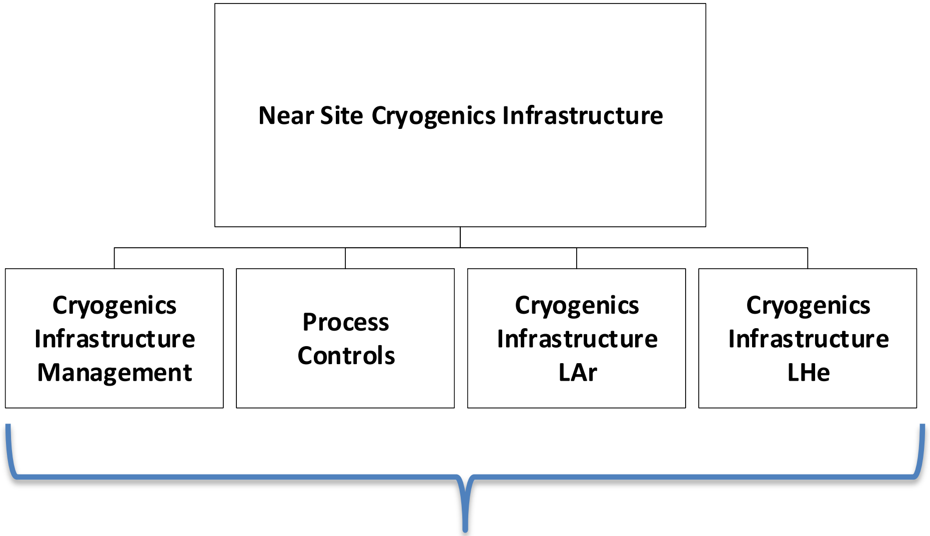
Cryogenics Infrastructure Scope

- **Cryogenics Infrastructure** planned to support LAr Detector and SAND with capability to support future additional detector with SC magnet (MPD).
- **LAr Cryogenic Systems** includes design, procurement of materials, installation and testing of cryogenic systems for LAr detector (LAr/LN2).
  - Includes Cryogen Receiving, transport underground, liquefaction and purification sub-systems, associated instrumentation and monitoring equipment.
- **LHe Cryogenics** includes design, procurement of materials, installation and testing of cryogenic systems for magnets (SAND + capability to support future SC magnet).
  - Includes He transport underground, liquefaction cryoplant, distribution, associated instrumentation and monitoring equipment.
- **Process Controls** includes design, procurement of materials, installation and testing of process controls infrastructure supporting LAr/LHe cryogenics.
  - Includes readout modules, PLC architecture, HMI/SCADA.

Created in Dec-2019, previously part of Near Detector Integration.

Near Site Cryogenics Infrastructure Organization

- Project Manager:
  - David Montanari (LBNF).
- Lead Cryogenics Systems Engineer:
  - Mark Adamowski (LBNF).
- Engineers:
  - Joaquim Creus (Fermilab/APS-TD) → NS LAr cryogenics.
  - Li Wang (LBL) → NS LHe Cryogenics.
  - Trevor Nichols (Fermilab/ND) → NS Process Controls.
  - Ian Young (Fermilab/PPD) → NS Process Controls.
  - Erik Voirin (Fermilab/PPD) → CFD modeling (as needed).
- Design and Drafting support:
  - Mike Delaney (LBNF).
  - Justin Tillman (Fermilab/ND, until early Jun-2020).
  - Andrew Lawrence (LBL).



Near Site Cryogenics Infrastructure

Cryogenics Infrastructure Management

Process Controls

Cryogenics Infrastructure LAr

Cryogenics Infrastructure LHe

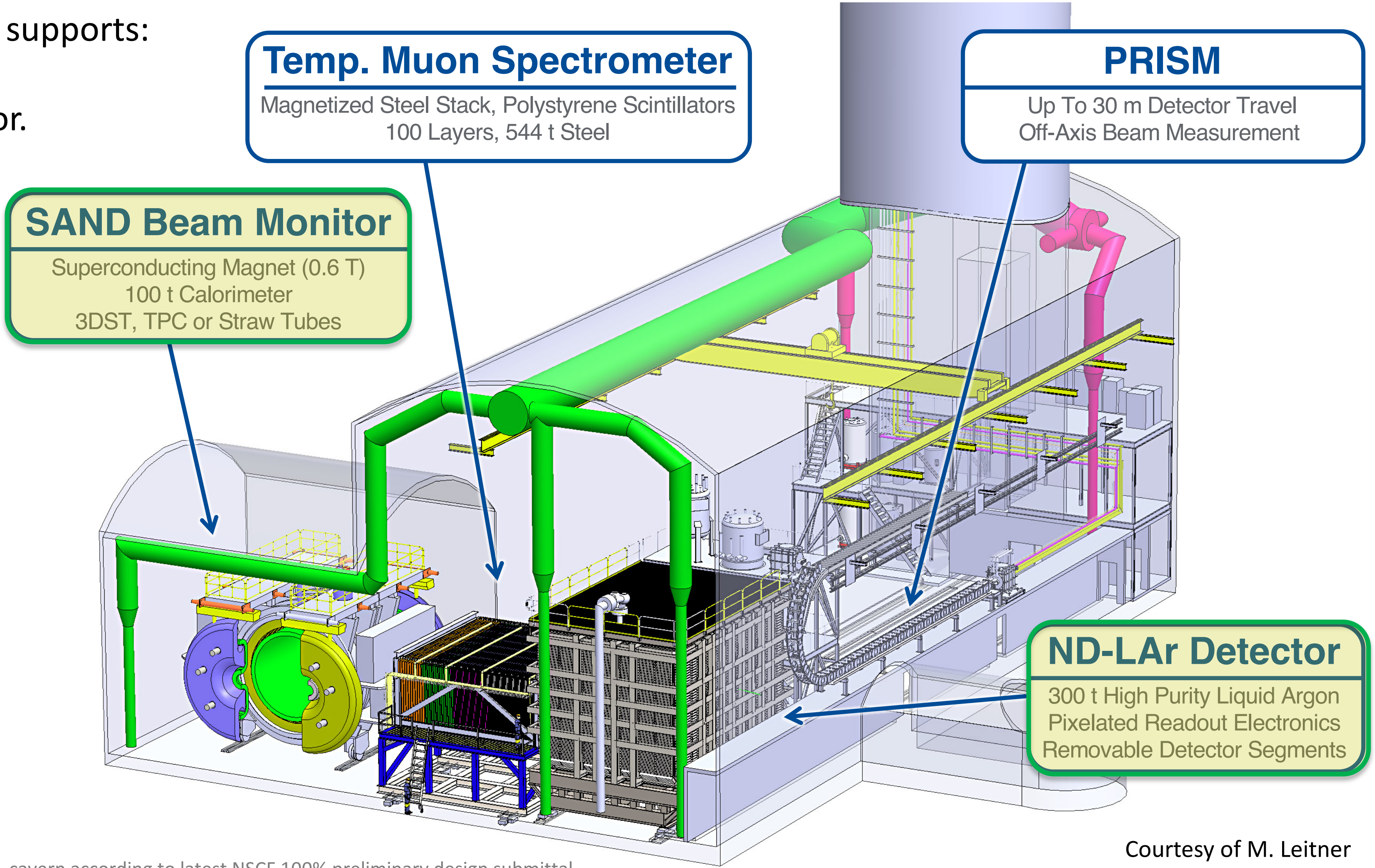
LBNF, APS-TD, ND, PPD labor and LBL.

- Support from Project:
  - Matthaeus Leitner (LBL) → Installation & Integration
  - Jack Fowler (Duke University) → Systems Engineering.
  - Mike Andrews (LBNF/DUNE) → ES&H.
  - Kevin Fahey (LBNF/DUNE) → QA.

DM: This slide has been edited.

Near Detector (ND): Project Scope And Baseline Design (Day-one configuration)

NS Cryogenics supports:
- SAND
- LAr Detector.



Temp. Muon Spectrometer

Magnetized Steel Stack, Polystyrene Scintillators
100 Layers, 544 t Steel

PRISM

Up To 30 m Detector Travel
Off-Axis Beam Measurement

SAND Beam Monitor

Superconducting Magnet (0.6 T)
100 t Calorimeter
3DST, TPC or Straw Tubes

ND-LAr Detector

300 t High Purity Liquid Argon
Pixelated Readout Electronics
Removable Detector Segments

Courtesy of M. Leitner

cavern according to latest NSCF 100% preliminary design submittal

High level Requirements (more later)

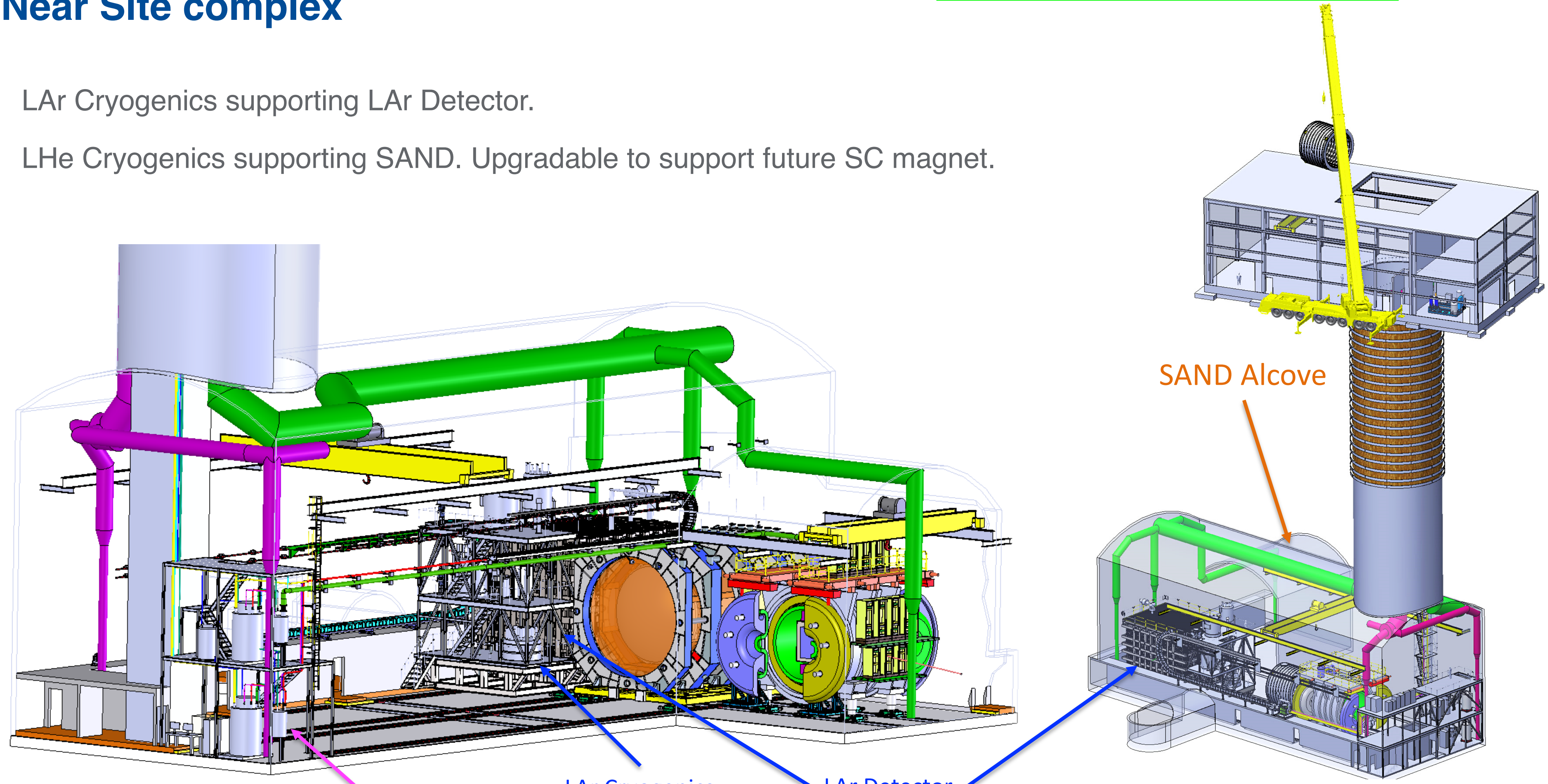
- **SAND**
  - Thermosiphon cooling requirements:
    - 55W at 4K.
    - 530W at 70K shield.
  - Cooldown with mixing chamber in the magnet top insert.
  - Total LHe volume of 200 liters.
  - Cold mass 10 Tons.
- https://edms.cern.ch/document/2387229

- **LAr Detector**
  - Electron lifetime of 3 ms.
  - System volume 318 Tons of LAr.
  - Membrane cryostat technology.
  - Detector moves 30 meters once a month at 1 cm/minute.
  - Liquid distribution to 7-off rows with five ArgonCube modules each.
  - Centralized LAr purification system.
- https://edms.cern.ch/document/2391482

Near Site complex

Cryo surface facilities not shown.

- LAr Cryogenics supporting LAr Detector.
- LHe Cryogenics supporting SAND. Upgradable to support future SC magnet.



SAND Alcove

LHe Cryogenics

LAr Cryogenics

LAr Detector

Courtesy of M. Leitner

LAr Cryogenics

Relevant Requirements (partial list)

EDMS 2390106

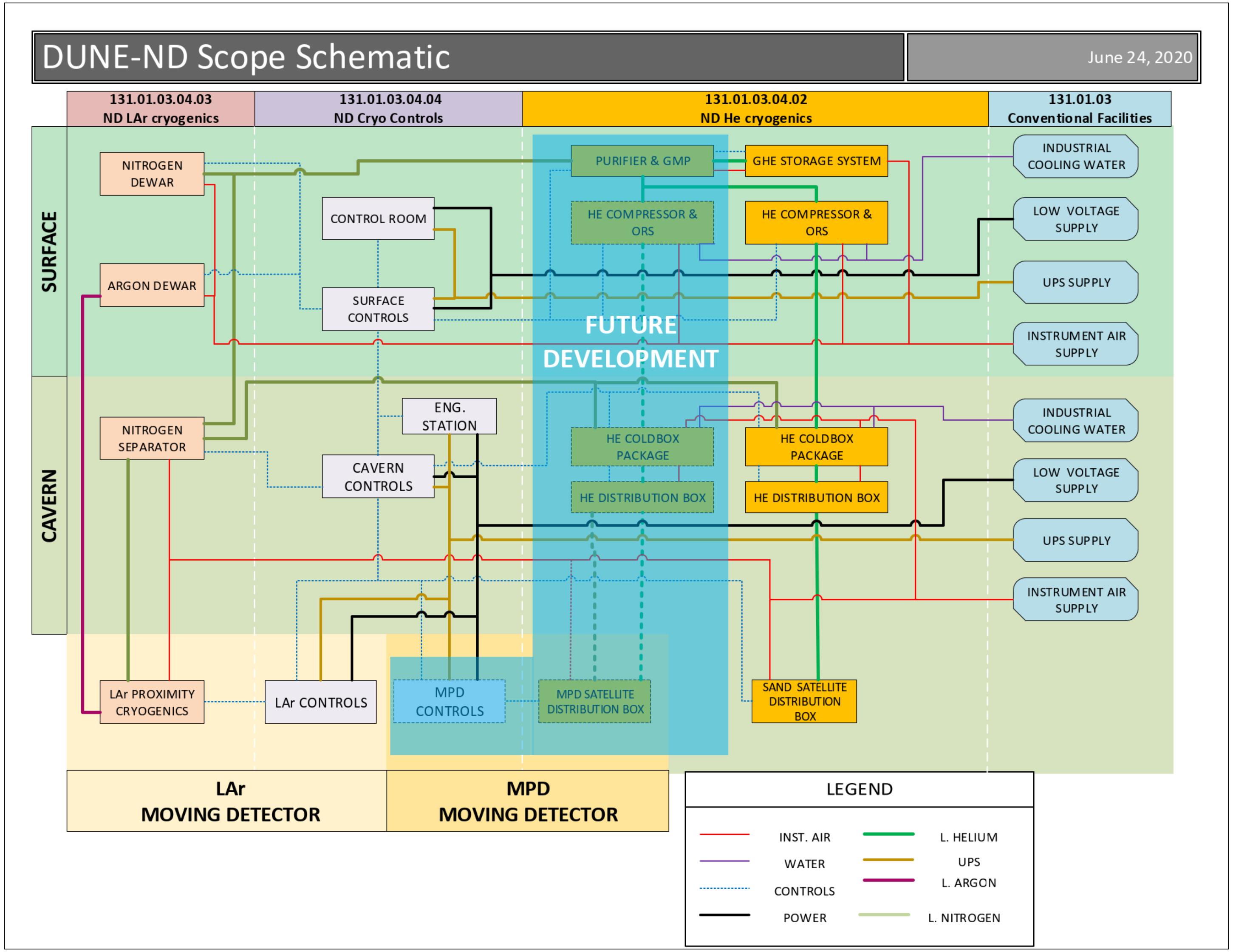
Requirements from DOORS requirements management:

- Electron lifetime of 3 ms required for experiment.
- Each row of 5 ArgonCUBE detector elements receives its own LAr stream from a common LAr distribution/purification. There are 7-off rows.
- The estimated heat loads are:
  - From the cryostat 3 kW;
  - From the detector electronics within the cryostat 12 kW;
  - From the LAr pumps 0.5 kW (assuming 1 pump in operation);
  - From the piping and purification vessels 1.0 kW.
- Vessel internal size of L x W x H = 9.0 m x 6.0 m x 4.5 m (318 ton LAr).
- Detector moves 30 meters once a month at 1 cm/minute.

Interfaces

LINK: EDMS 2339685

- NS Conventional Facilities **ICD**
  - Industrial utilities (LV, IA).
  - HVAC (+ ODH mitigation).
  - External layout.
  - Cavern layout.
- NS Integration **ICD**
  - Energy chain.
  - Moving platform.
  - Cryostat integration.
    - Internal cryogenics.
    - ArgonCube modules.
- NS He cryogenics **ICD**
- NS Cryo Controls (CF ICD + Spec).



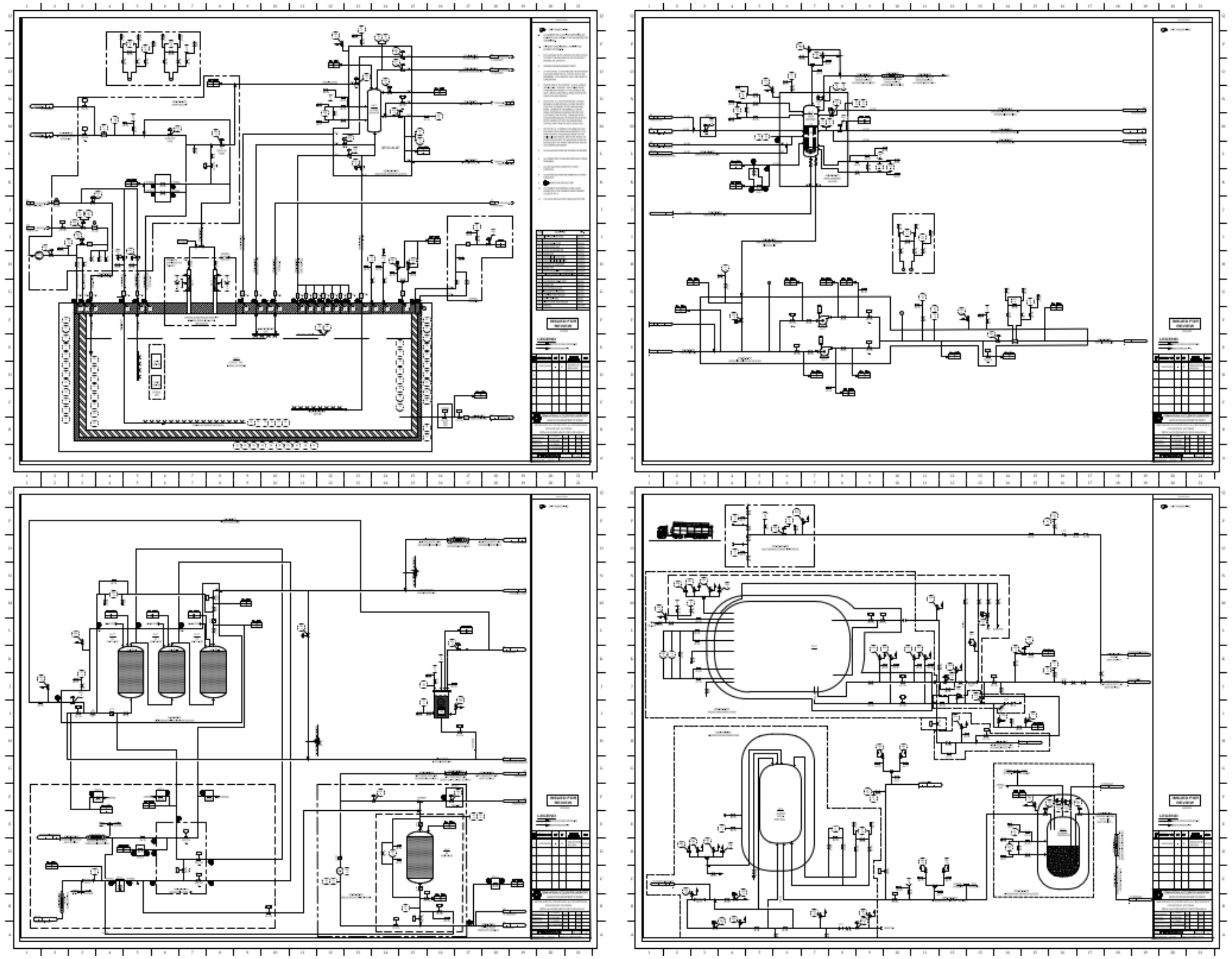
Modes of Operation

1. **Piston Purge:** Vessel purged of Air contaminants with GAr flowing from a gas manifold at membrane vessel base. Expected to involve 10 volume changes and last two days.
    1. **1.1 Water desorption**: Since ArgonCube modules have a lot of G10 surface, warm dry gas will be flown to help dry G10 surface. Process parameters and details being worked out at Bern, Switzerland. Cold trap might be used as well.
2. **Cooldown:** Vessel and detector are cooled down with LAr sprayers fed from a Tube-shell 24kW condenser cooled by LN2. Location of sprayers being discussed.
3. **Cryostat Fill**: Liquid argon deliveries are tested for quality. Argon flows on-pass to purification system, is treated in phase separator and enters the cryostat in a liquid distribution manifold.
4. **Purification Mode**: The detector is expected to work in this mode for years. The circulation pump valve box suction receives argon from a side penetration in cryostat. Discharge flows to purification valve box, then phase separator and back in the cryostat distributed in the 7-off ArgonCube modules. Condenser collects cryostat boil-off and phase separator flashing diverted into circulation pump suction.
5. **Activation/Regeneration:** Purification system is based on Copper Oxide and Molecular Sieve. Copper Oxide is activated and regenerated by flowing a non-flammable mix of Argon/Hydrogen heated to 500 K. Molecular Sieve bed regenerated with a flow of gas at 500 K.
6. **Empty:** ND-LAr is 215-ft deep underground. In order to empty it, heaters with a total power of 45 kW will be placed in different parts of the vessel to boil the argon off in two weeks.

Design

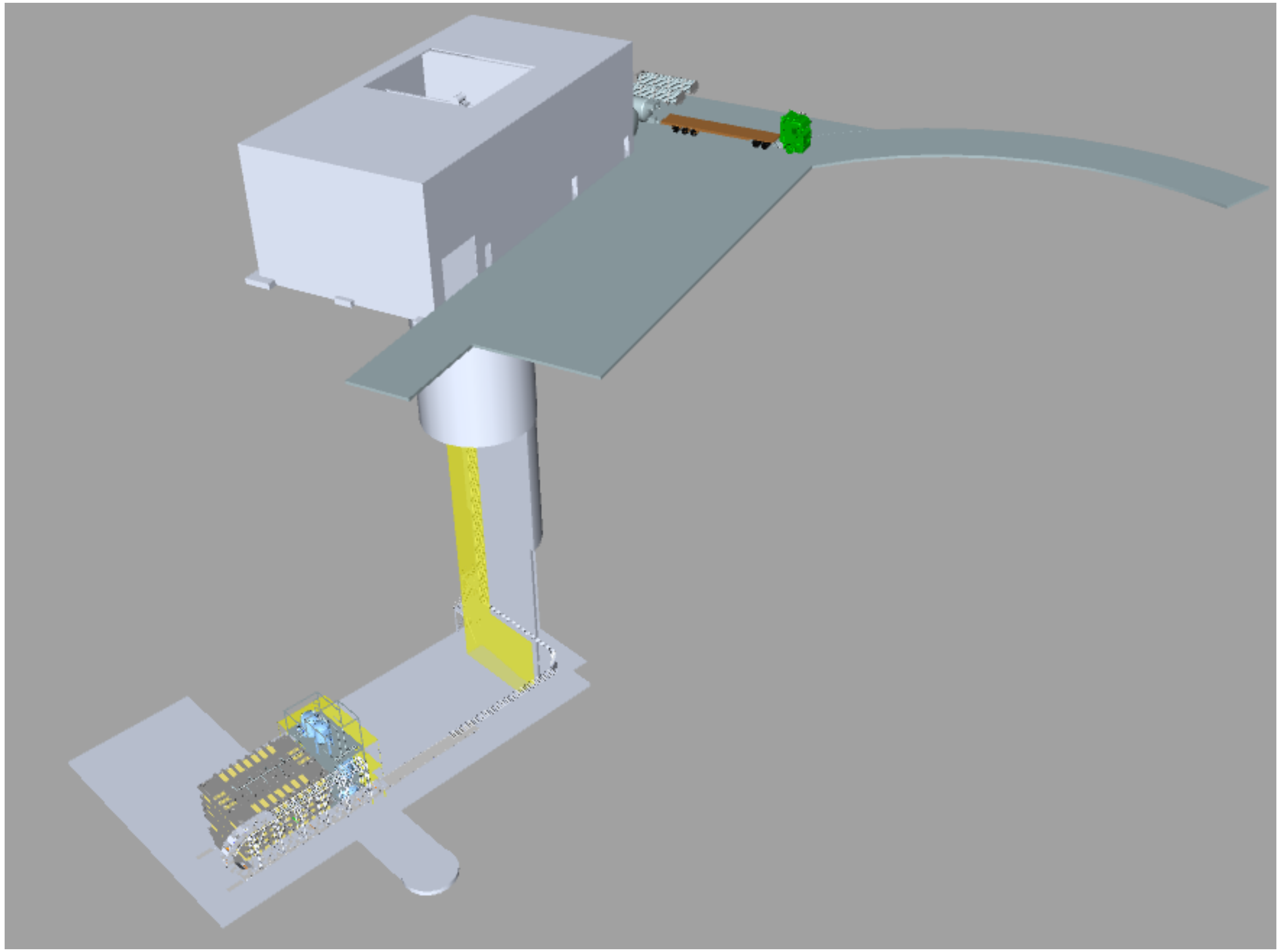
LINK: [EDMS 2370342]

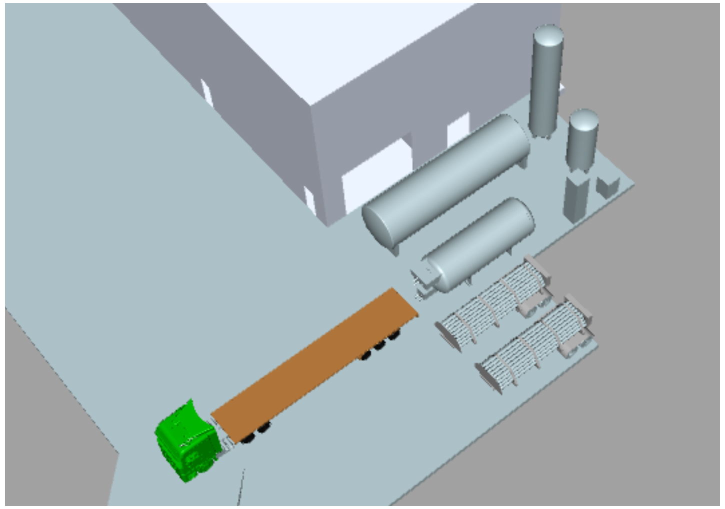
- P&IDs and functions very similar to SBN-ND.
- Supply of liquid argon to 7-off ArgonCube strings. Agreed on simplified Argon distribution.
- Details of Internal Cryogenics to be worked out.
- Supply of LN2 to He services to surface and cavern.
- Integrated design and VIE with AutoCAD Plant.
- Use of PBS to define equipment naming in documentation, P&ID, 3D and interfaces.
- Possibility to reuse existing equipment from Fermilab and CERN.

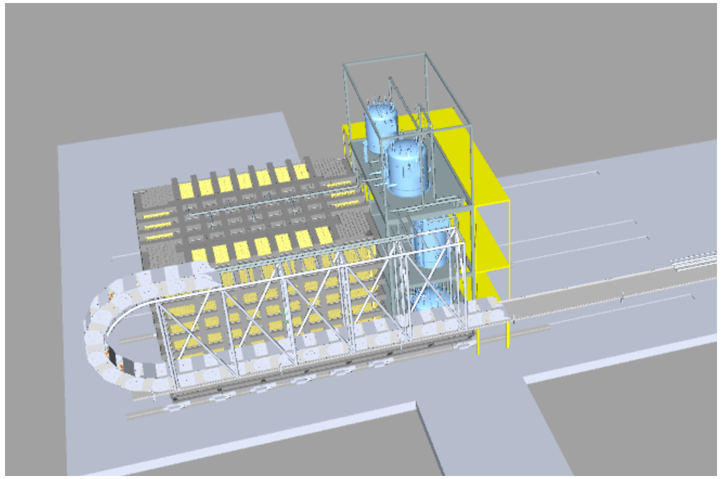


Layout

LINK: EDMS 2339713







LHe Cryogenics

https://edms.cern.ch/document/2387229/1

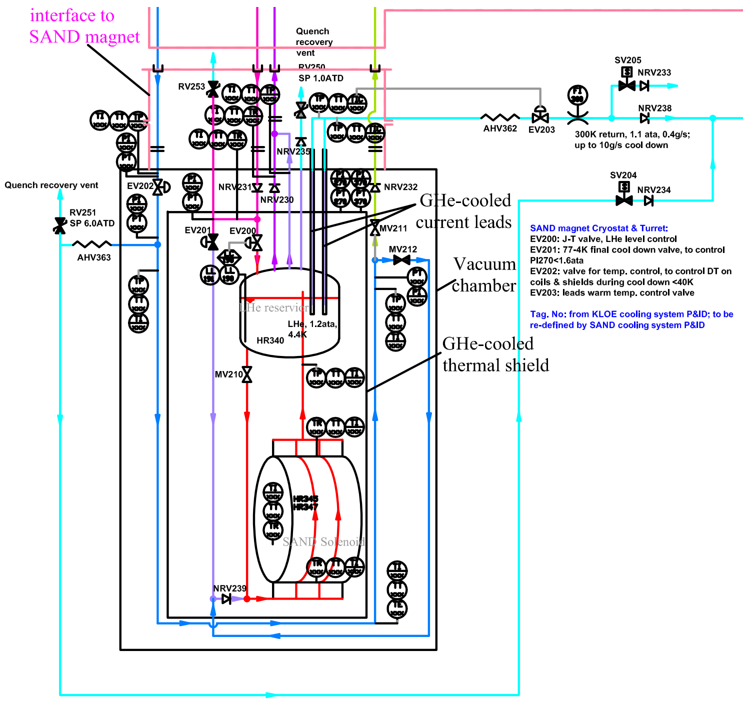
SAND Cooling Requirements (1/2)

Coil assembly	**Parameter**
Central Field (T)	0.6
Layers	2
Turns/layer	368
Ampere-turns	2.14 MA-T
Operating Current (A)	2902
Design Current (A)	3000
Inductance at full field (H)	3.4
Stored energy (MJ)	14.32
Discharge voltage (V)	250
Peak Quench Temperature (K)	80
Conductor	10 mm x 5 mm Al stabilized NbTi Rutherford cable, Rutherford cable co-extruded with high purity aluminium, wrapped with two half lapped layers of 0.125 mm glass tape.
Coil winding method	internally wound coil; a two layer coil wound on flat with a full vacuum impregnated insulation system
Coil support bobbin	5083 aluminum cylinder
Coil shell inner diameter (m)	5.19
Coil Cold mass (ton)	10 (~8.5)
Radiation shield	two 5 mm thick solid aluminum cylinders with cooling pipes attached to the outside of each
Vacuum Case	
Vacuum jacket	12 mm thick externally rolled and welded machined cylinder with external strengthening ribs
	12 mm thick internal rolled and welded machined cylinder with internal strengthening ribs - calorimeter support
	Two 40 mm thick end plates with double o-ring machined grooves
Vacuum case length (m)	4.32
Vacuum case inner diameter (m)	4.86
Vacuum case outer diameter (m)	5.76
Vacuum case mass (ton)	26
Iron return yoke mass (ton)	475
Service Turret	supply and control of LHe including JT valve; supply and control of 70 K helium for radiation shields; gas cooled 3,000 A current leads; Instrumentation connections to the coil and radiation screens; LHe reservoir: 150 liter

https://edms.cern.ch/document/2387229/1

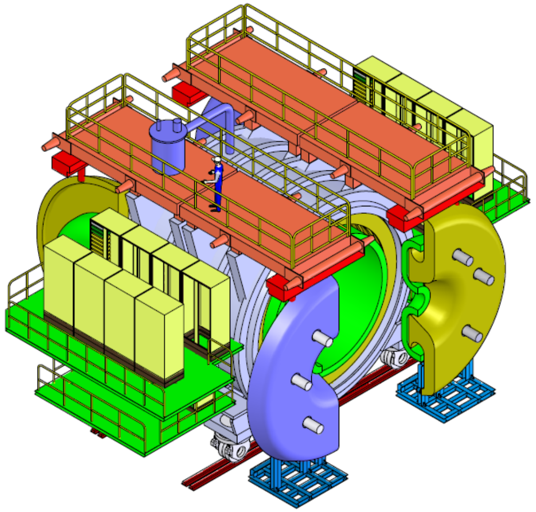
SAND Cooling Requirements (2/2)

Coil cooling scheme	indirectly cooled through a LHe thermosiphon cycle
He supply from cold box	3 bara/ 5K with expansion from 3 to 1.2 bara/4.4K inside the magnet
Thermal shield cooling method	70K forced cold GHe flow
Current leads	a pair of GHe cooled 3kA leads, cooled by helium vaporized from LHe reservoir in the Turret, 0.4g/s
4 K radiation and conduction (W)	55
Current leads' cooling flow (g/s)	0.4
70 K radiation and conduction (W)	530
Operating temperature (K)	4.42
Operating pressure (bara)	1.2
LHe in magnet w/Turret (liter)	~200
LHe reservoir in Service Turret (liter)	~150
300-70K cool down scheme	300K and 70K GHe mixing forced flow, 4~5 bara
70-4K magnet cool down scheme	3 bara/5K GHe forced flow
Coil cold mass (ton)	~10



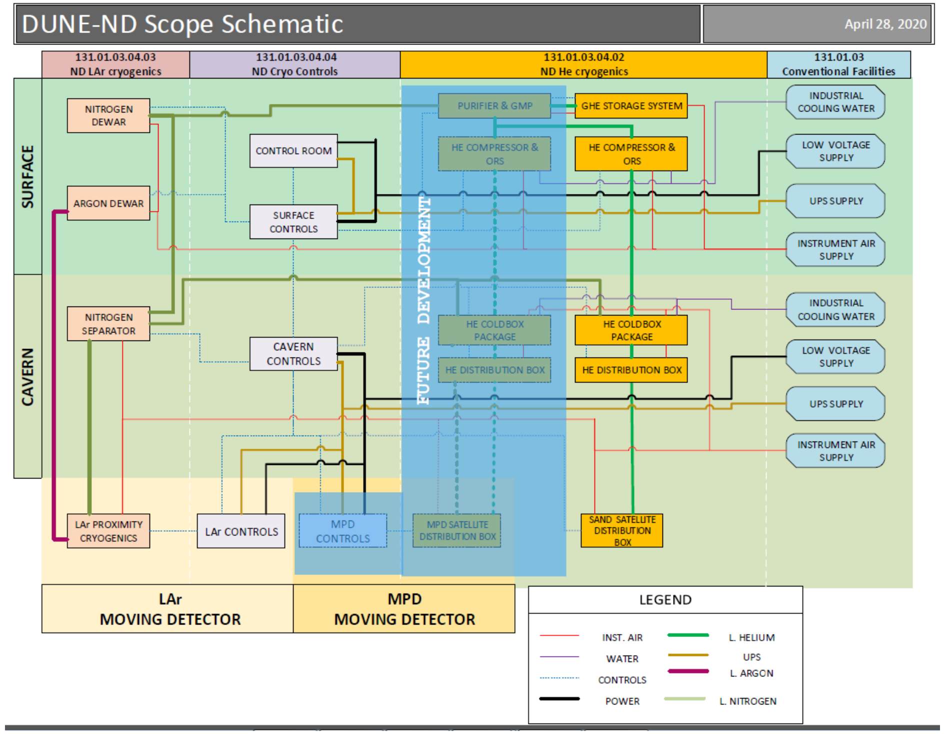
SAND magnet Cryostat & Turret:
EV200: J-T valve, LHe level control
EV201: 77-4K final cool down valve, to control PI270<1.6ata
EV202: valve for temp. control, to control DT on coils & shields during cool down <40K
EV203: leads warm temp. control valve

Tag. No: from KLOE cooling system P&ID; to be re-defined by SAND cooling system P&ID



Interfaces

- LAr system:
  - LN2 phase separator.
  - LN2/GN2 transfer lines.
- SAND magnet:
  - Service turret.
- Integration & Installation:
  - Energy Chain.
  - Platform.
- Near Site Cryo Controls.



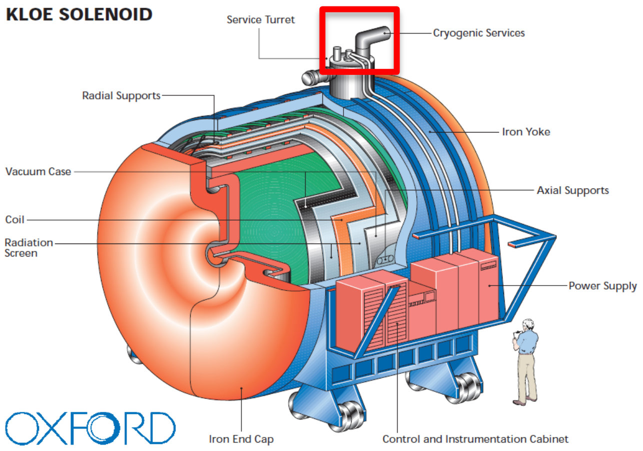
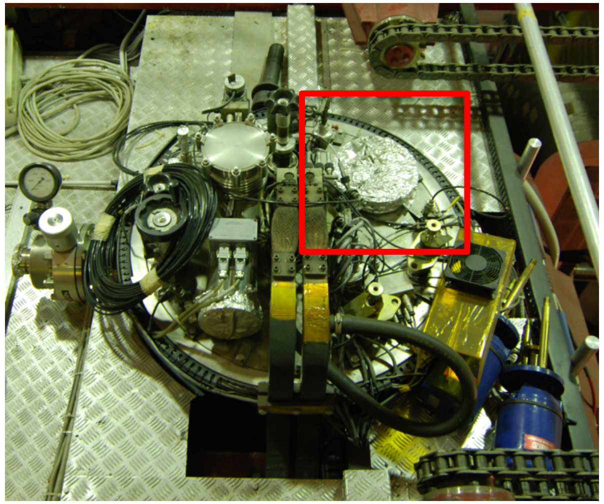


Figure 1 - KLOE schematic



Modes of Operation

Based on old SAND magnet cooling system:

- Cool down processes.
  - ✓ 300-77 K cool down: SAND magnet and thermal shields.
  - ✓ 77-4 K cool down: SAND magnet and current leads w/ thermal shields at 70-80K.
- Normal operation.
- Quench process.
- Cool down after quench.
- Warm-up.
- Failure modes (vacuum loss, power outage, etc.).

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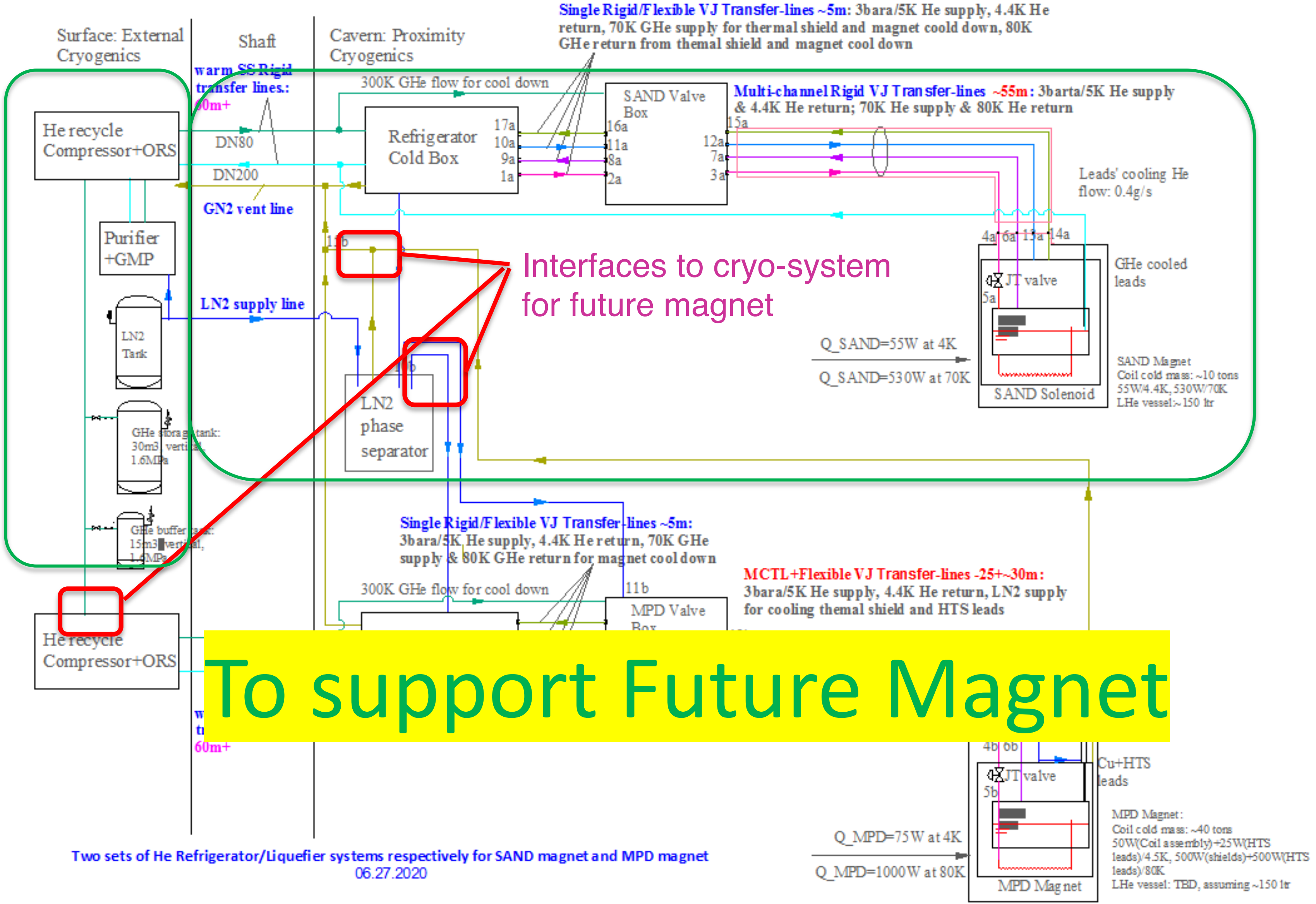
Design Schemes

- Preliminary design supports SAND magnet, with upgrade capabilities to also support a future magnet.
- Two Schemes are considered (both under design) and will be determined based on available installation space and bottoms-up cost estimates:
  - Scheme I: One smaller He refrigerator with LN2 precool (~200 W at 4.5 K). Will require another smaller refrigerator and another LN2 precool for future magnet.
  - Scheme II: One larger He refrigerator without LN2 precool to support SAND magnet (4-500 W at 4.5 K). Will require LN2 precool for future magnet.
- Scheme I being pursued. However recent design developments (increased heat load) may lead to reconsider Scheme II.

DM: This slide has been edited. https://edms.cern.ch/document/2387228/1

Process Flow Diagram (Scheme I)

- One 200 W / 4.5 K order of magnitude He Refrigerator system with LN2 precooled cold box is under design to **only** serve the SAND magnet.
- LN2 phase separator shared with LAr system.
- Includes interfaces to be able to connect to future magnet cooling system.
- Another 200W/4.5K order of magnitude He Refrigerator system with LN2 precooled cold box will be added to serve a future magnet later.



Interfaces to cryo-system for future magnet

To support Future Magnet

Two sets of He Refrigerator/Liquefier systems respectively for SAND magnet and MPD magnet
06.27.2020

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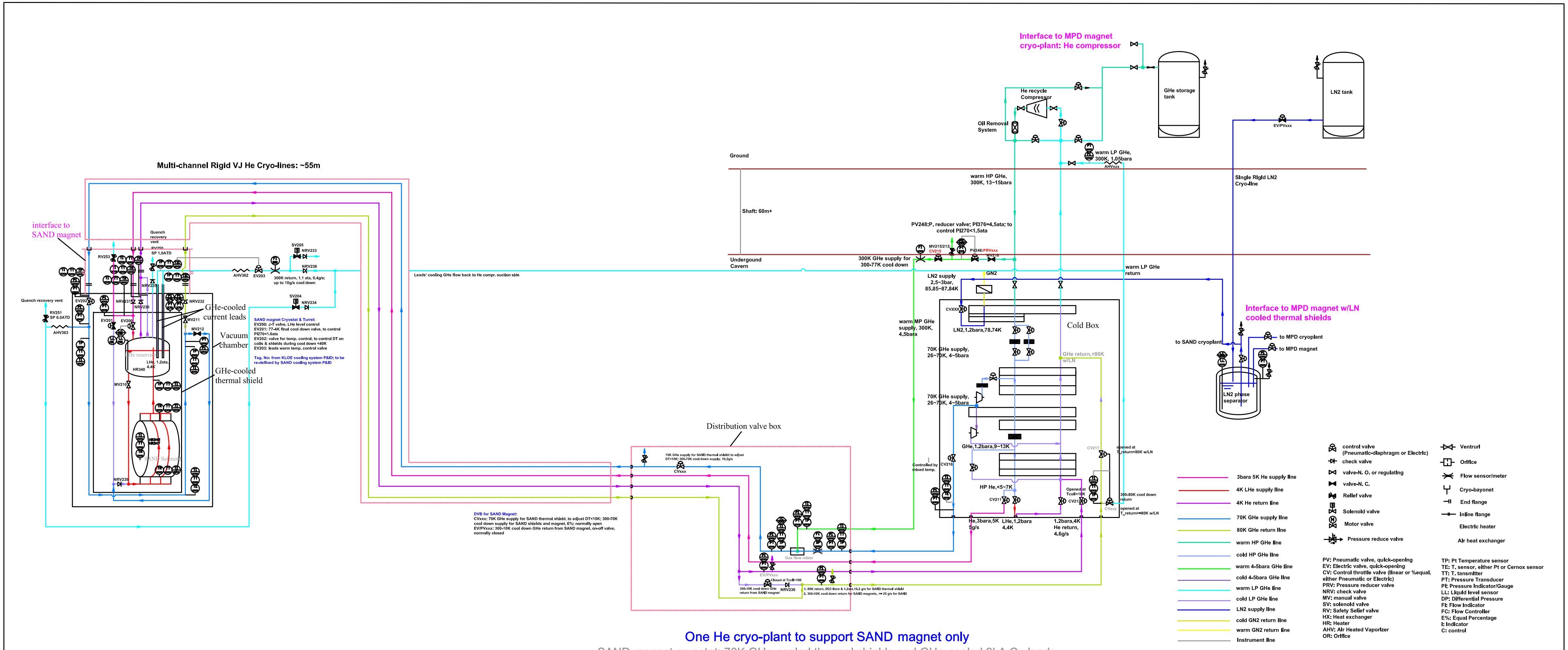
Preliminary P&ID for SAND magnet cooling system



SAND magnet Cryostat & Turret:
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EV203: leads warm temp. control valve

Tag. No: from KLOE cooling system P&ID; to be re-defined by SAND cooling system P&ID

DVB for SAND Magnet:
CVxxx: 70K GHe supply for SAND thermal shield, to adjust DT<10K; 300-70K cool down supply for SAND shields and magnet, E%; normally open
EV/PVxxx: 300-10K cool down GHe return from SAND magnet, on-off valve, normally closed

PV: Pneumatic valve, quick-opening
EV: Electric valve, quick-opening
CV: Control throttle valve (linear or %equal, either Pneumatic or Electric)
PRV: Pressure reducer valve
NRV: check valve
MV: manual valve
SV: solenoid valve
RV: Safety Selief valve
HX: Heat exchanger
HR: Heater
AHV: Air Heated Vaporizer
OR: Orifice

TP: Pt Temperature sensor
TE: T. sensor, either Pt or Cernox sensor
TT: T. tansmitter
PT: Pressure Transducer
PI: Pressure Indicator/Gauge
LL: Liquid level sensor
DP: Differential Pressure
FI: Flow Indicator
FC: Flow Controller
E%: Equal Percentage
I: Indicator
C: control

One He cryo-plant to support SAND magnet only

SAND magnet cryostat: 70K GHe cooled thermal shields and GHe-cooled 3kA Cu leads

One customized refrigerator w/ LN precool: 200W/4.5K order of magnitude

06.27.2020

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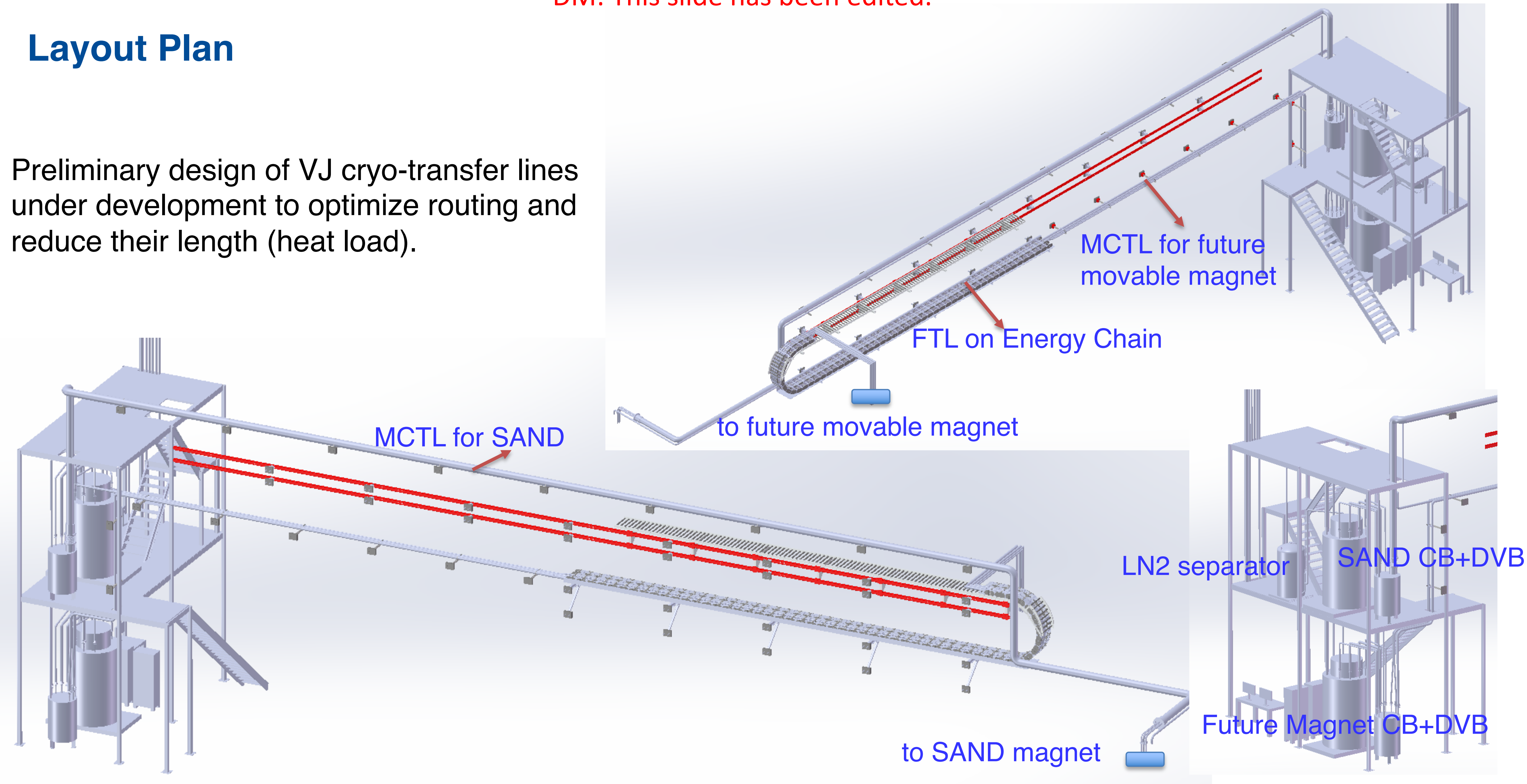
Layout Plan

Preliminary design of VJ cryo-transfer lines under development to optimize routing and reduce their length (heat load).

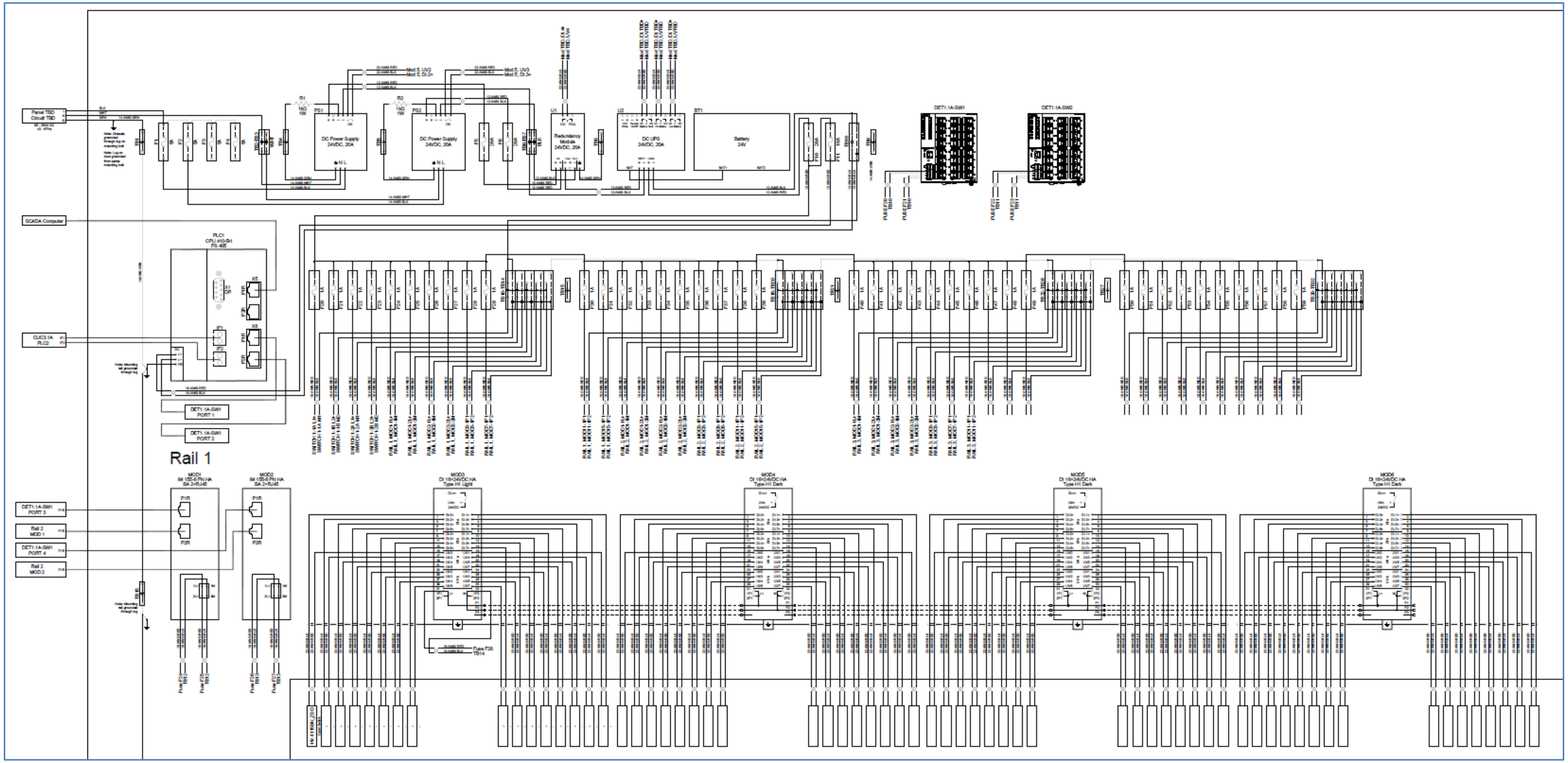


Process Controls

Process Controls

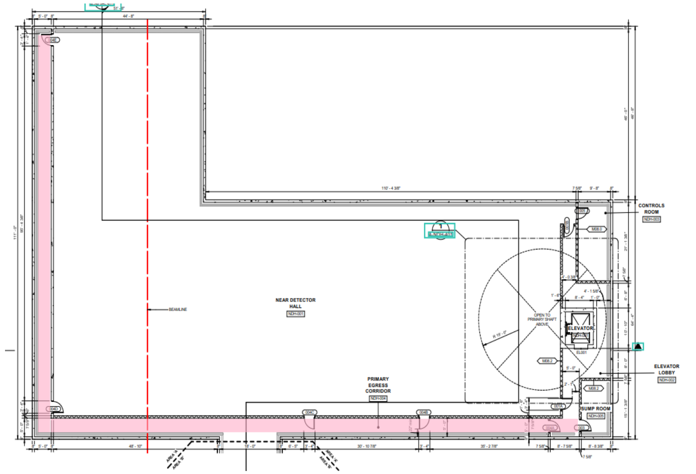
- Main Cryo controls system:
  - Designed for autonomous operations. Under normal conditions does not require human operators.
  - With redundancy to reduce system downtime.
  - Exhibit control over all cryo equipment at Near Site (either directly or indirectly).
- Safety Integrated System:
  - Provides ODH protection.
  - Provides cryostat overpressure protection.
  - Decoupled from main to allow for main system updates without interfering with safety safety system.
- Developed:
  - System architecture.
  - PLC Controls strategy.
  - HMI/SCADA Strategy.
  - I/O counts and I/O maps.
  - Preliminary Drawings (Main and safety PLC and control cabinets mechanical and electrical drawings).

Sample Cabinet Electrical Diagram PLC – Sample drawing

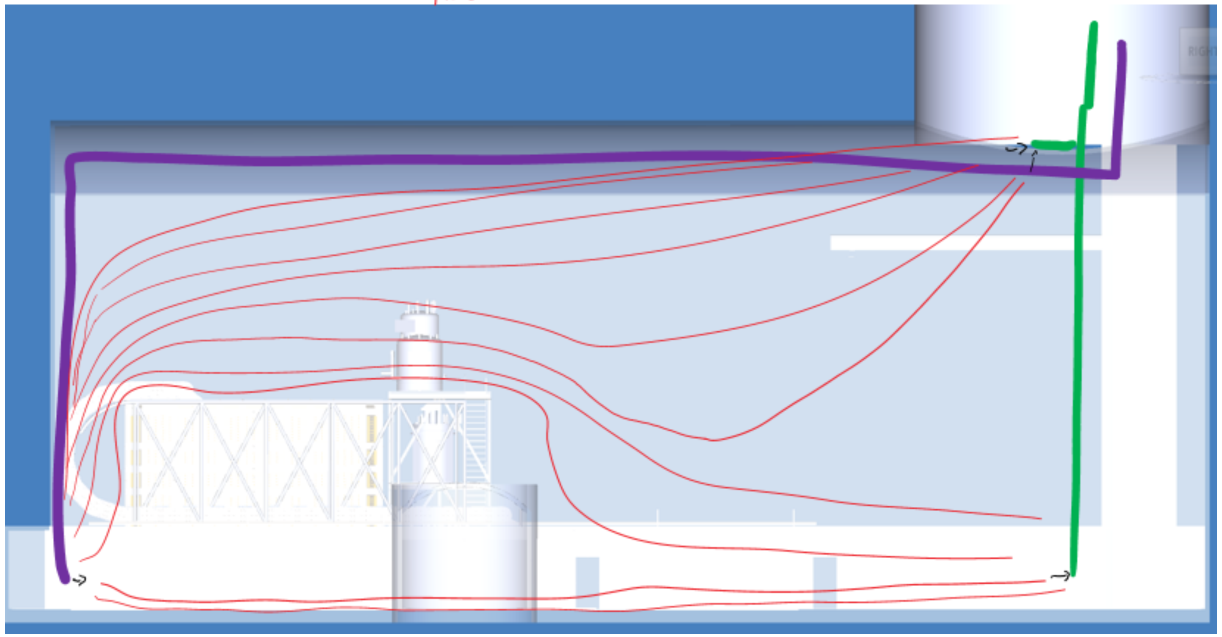


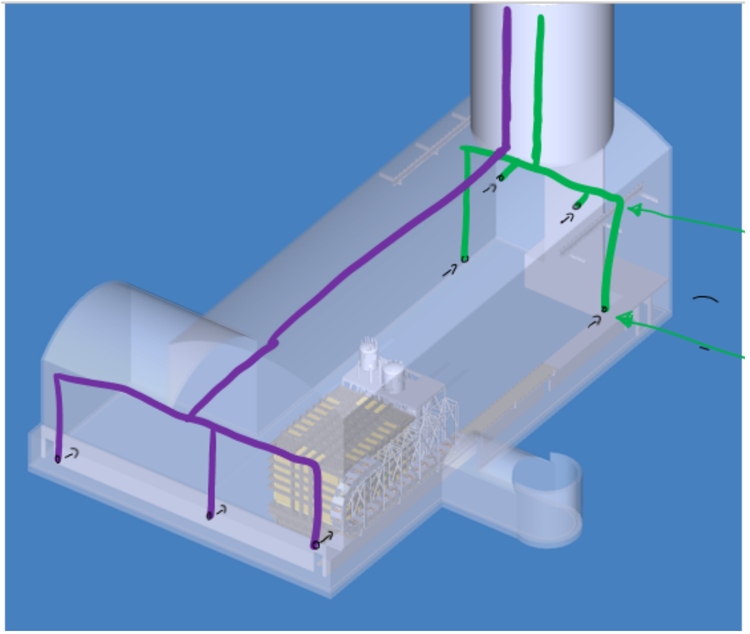
ES&H

- ODH 1 + escape pack with OA 7500 CFM.
- Shared ODH mitigation with HVAC.
- Escape corridor at the cavern level.
- LBNF cryo safety panel engaged with concept.



— flow lines





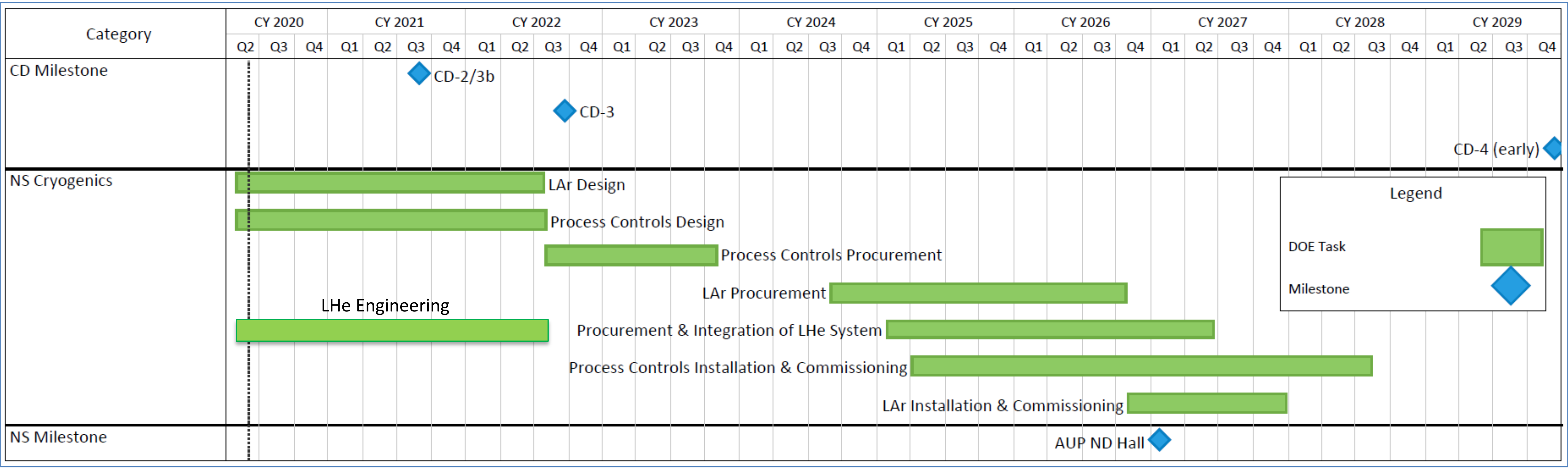
Design Status

- Design work started in Dec-2019 and proceeding with high priority.
- Tremendous progress to date:
  - Preliminary Design (pipe and equipment sizing, process parameters, etc.).
  - 3D layouts.
  - P&IDs.
  - Main cryo controls and safety controls strategy and cabinet drawings.
  - ODH strategy socialized with LBNF Cryo safety review panel.
- Preliminary Design Reviews (PDRs) on Jul 1-2, 2020.
- Process Controls WBS fully implemented in P6. Ian Young is Manager and CAM.
- LAr Cryogenics WBS fully implemented in P6. Joaquim Creus is Manager and CAM.
- LHe Cryogenics WBS being developed. Conceptual-level estimates being updated with detailed bottoms-up estimates. Values expected to be inline with current estimates. Li Wang is Manager. Will become CAM once bottoms-up completed.

Next Steps

- LAr Cryogenics:
  - Finalize LAr Cryogenics Detector requirements.
  - Finalize Interfaces between cryogenics and LAr Detector.
  - Possibility to reuse valve boxes from Fermilab/SBN (**??**) and CERN/ProtoDUNEs (✓).
- LHe Cryogenics:
  - Confirm SAND Detector requirements.
  - Finalize Interfaces between cryogenics and SAND.
  - Obtain design and manufacturing documentation for SAND magnet and its operation at LNF.
- Process Controls:
  - Update design and plan as LAr Cryogenics and LHe Cryogenics advance.
  - Complete drawings.
- ODH:
  - Complete definition of requirements for NSCF.

NS Cryo Summary Schedule



Summary

- Management and Engineering structure in place and functioning.
- Highly qualified and motivated team.
- Design of all items proceeding at fast pace and with high priority.
- Working with Integration and Near Detector to address requirements and interfaces.

Thanks

Backup

Reuse valve boxes from DUNE related experiments

As presented in Value Engineering request VE-3 Cryo, the following valve boxes from SBN or ProtoDUNE are proposed to be reused:

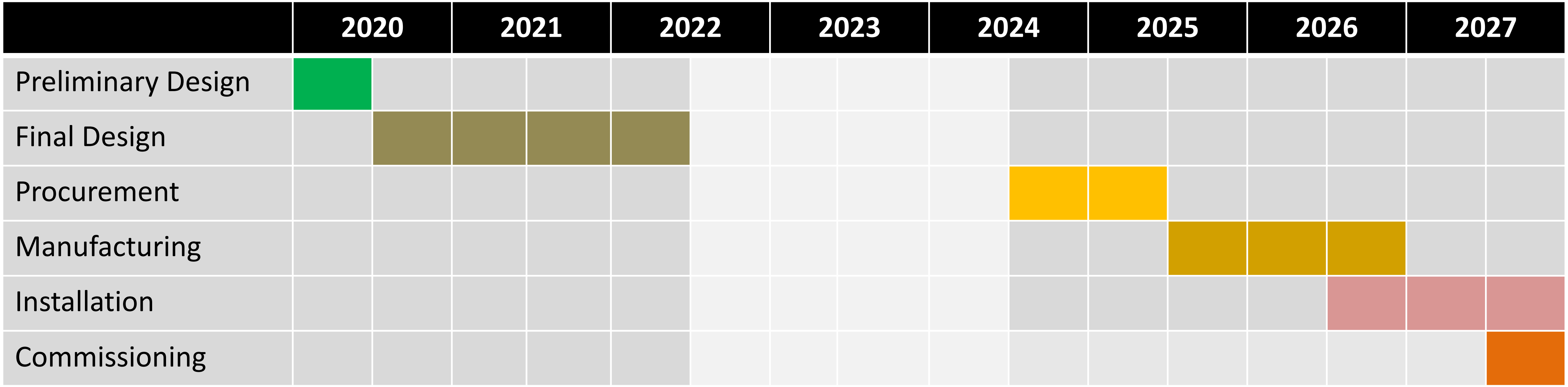
- **GAr purification vessel:** The vessel purification capacity is oversized for ProtoDUNE, fully capable.
- **LAr condenser**: The tube shell 24kW condenser design is capable to handle the cool-down and normal operation loads. Also the nitrogen vessel works well as a secondary phase separator.
- **LAr circulation valve box:** The valve box has all the functions enabled. If the valve box with B&N 1.63 kg/s was donated, they would have to be replaced by smaller capacity specified to fit in the current pump casing.

Valve boxes that can't be reused

- **LAr purification vessel:** The vessel is oversized for 1.63 kg/s and almost does not fit in the ND-LAr platform.
- **Argon Phase Separator**: Additional LAr outlets required for ArgonCube.
- **Nitrogen Phase Separator**: Larger vessel and vent valve required, multiple outlets

LAr Cryogenics Schedule

LINK: [EDMS 2339685]()



	2020		2021		2022		2023		2024		2025		2026		2027	
Preliminary Design	■															
Final Design		■	■	■	■											
Procurement										■	■					
Manufacturing												■	■	■		
Installation														■	■	■
Commissioning																■

Previous LAr TPC experiences with similar systems

The following experiences have helped establish the LAr purification and membrane cryostat technologies, operating procedures, best practices and lessons learned that try to be implemented in this system:

- **FNAL LAPD** -> LAr purification
- **FNAL 35-Ton Prototype** -> LAr purification, membrane cryostat
- **FNAL MicroBooNE** -> LAr purification
- **CERN WA105-182** -> LAr purification, membrane cryostat
- **CERN ProtoDUNE Single Phase** -> LAr purification, membrane cryostat
- **CERN ProtoDUNE Dual Phase** -> LAr purification, membrane cryostat
- **SBN – FD** -> LAr purification
- **SBN – ND** (under construction) -> LAr purification, membrane cryostat

CHARGE QUESTION 5

ES&H and Quality Assurance/Quality Control (QA/QC)

- ES&H:
  - Team is involved with LBNF Cryo Safety panel for ODH considerations.
- QA/QC:
  - Following LBNF/DUNE QA plan.
  - LBNF QA Manager will assist in the development of QA Plans, as needed, and review Manufacturer's QC Plans.
  - Equipment manufacturers will follow their facility's QA/QC Program.
  - Subcontractors will be responsible for QC of installation.
  - Cryogenic team will perform oversight of fabrication and installation.
  - Fabrication and Installation QA/QC documentation will be maintained.

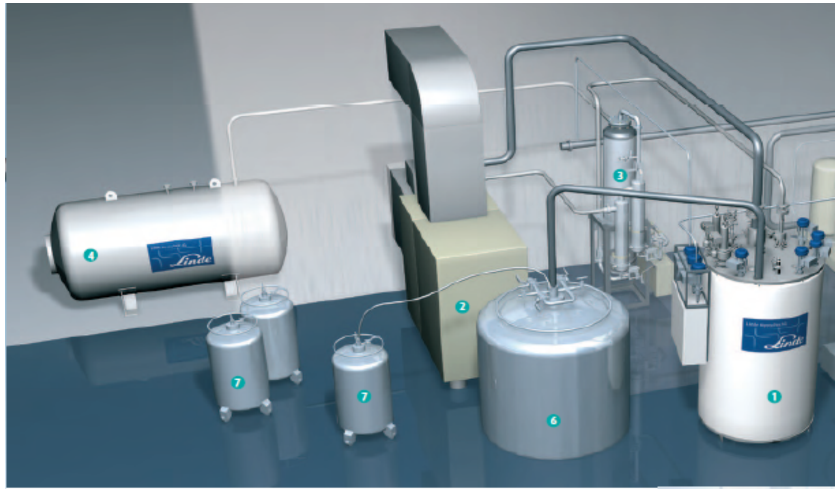
LAr Cryogenics Doc list

Document	Item	Cat.	ID	Rev	Title	Date	Class	Author	Status
EDMS 2385443	000	DOC		Rev 1	DOC List	5/29/2020	PM	J Creus	APPROVED
EDMS 2385428	001	DOC		Rev 1	PDR Presentation - 15 min	6/16/2020	PM	J Creus	APPROVED
EDMS 2370356	002	DOC		Rev 1	Basis of Estimates	5/12/2020	PM	J Creus	APPROVED
EDMS 2381764	003	DOC		Rev 1	Risk register	6/4/2020	PM	J Creus	APPROVED
DOCDB 19258	004	DOC		Rev 1	Value Engineering Request CRYO-3	6/9/2020	PM	J Creus	APPROVED
EDMS 2339749	005	DOC		Rev 1	ICD: LA cryo - CF	3/3/2020	ICD	J Creus	APPROVED
EDMS 2385478	006	DOC		Rev 1	ICD: LAr cryo - ND I&I: Energy Chain, Cryostat.	6/12/2020	ICD	J Creus	APPROVED
EDMS 2385477	007	DOC		Rev 1	ICD: LAr cryo - He for shared Nitrogen supply	6/4/2020	ICD	J Creus	APPROVED
EDMS 2339713	008	DRW	F10135040	Rev 1	3D model	4/28/2020	ENG	J Tillman	APPROVED
EDMS 2370889	009	DRW	F10135040	Rev 1	2D drawings	5/12/2020	ENG	J Tillman	APPROVED
EDMS 2370342	010	DRW		Rev 1	P&ID drawing	6/2/2020	ENG	M Delaney	APPROVED
EDMS 2380142	011	DOC		Rev 1	PBS: Product Breakdown Structure	5/29/2020	ENG	J Creus	APPROVED
EDMS 2376034	012	DOC		Rev 1	Preliminary ODH analysis	10/3/2019	ENG	M Adamowski	APPROVED
EDMS 2380152	013	DOC		Rev 1	Purification system sizing	4/9/2020	ENG	J Creus	APPROVED
EDMS 2385846	014	DOC		Rev 1	VI&E List	6/17/2020	ENG	J Creus	APPROVED
EDMS 2390106	015	DOC		Rev 1	ND-LAr detector requirements documentation	6/25/2020	ENG	J Creus	APPROVED
EDMS 2390126	016	DOC		Rev 1	ND-LAr process parameters for RFI application notes	5/4/2020	ENG	J Creus	APPROVED

Commercial Refrigerator/Liquefier

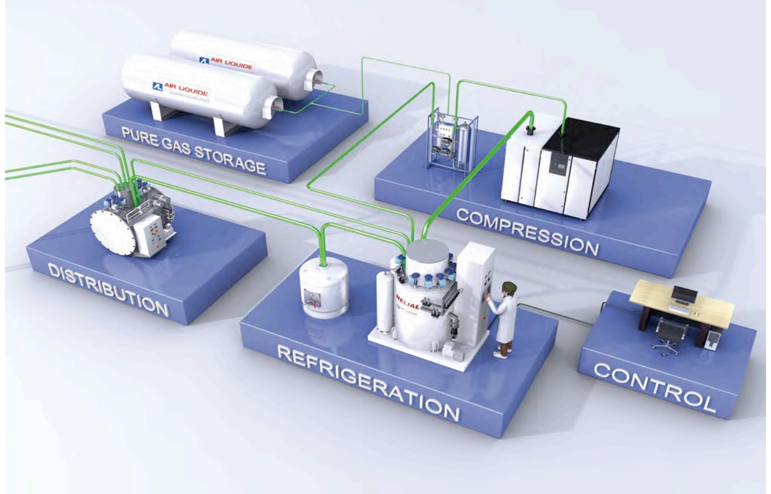
Linde-He Refrigerator/Liquefier: Dynamic gas-bearing turbine technology

Series No.	Liquefaction rate at 4.5K (L/hr)		Refrigeration at 4.5K (W)		Power Rating (kW)
	w/LN precooling	w/o LN precooling	w/LN precooling	w/o LN precooling	
L70	40-70	20-35			45~75
LR70			130-190	100-145	
L140	90-140	45-70			90~132
LR140			255-400	210-290	
L280	200-290	100-145			160~250
LR280			560-900	445-640	



Air Liquide-He Liquefier: Static gas-bearing turbine technology

	Liquefaction rate at 4.5K (L/hr)		Refrigeration at 4.5K (W)		ELECTRIC POWER (kW)	MAXIMUM EFFICIENCY (kW/(L/hr))
	w/LN precooling	w/o LN precooling	w/LN precooling	w/o LN precooling		
HELIAL SL	30 to 50	15 to 25			45 to 55	1.0
HELIAL SF			100-300		45 to 132	
HELIAL ML	75 to 150	35 to 70			75 to 132	0.9
HELIAL MF			300-600		132 to 210	
HELIAL LL	215 to 330	110 to 145			160 to 250	0.75
HELIAL LF			600-1000		210 to 315	



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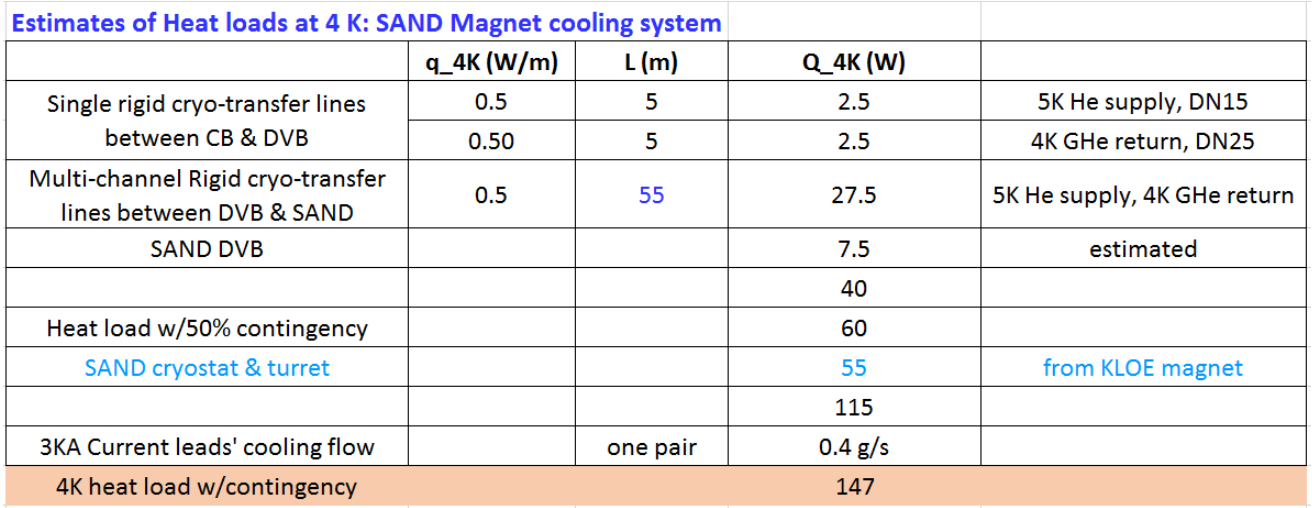
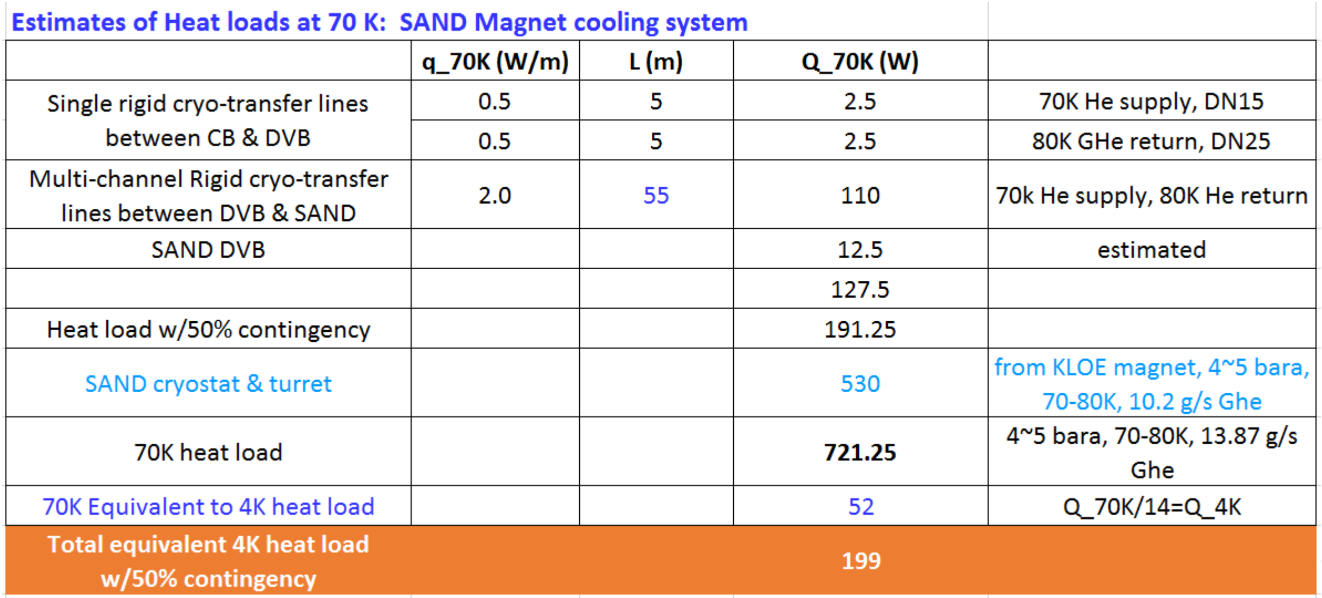
Estimates of Heat Loads: SAND cooling system



Estimates of Heat loads at 4 K: SAND Magnet cooling system

	q_4K (W/m)	L (m)	Q_4K (W)	
Single rigid cryo-transfer lines between CB & DVB	0.5	5	2.5	5K He supply, DN15
	0.50	5	2.5	4K GHe return, DN25
Multi-channel Rigid cryo-transfer lines between DVB & SAND	0.5	55	27.5	5K He supply, 4K GHe return
SAND DVB			7.5	estimated
			40	
Heat load w/50% contingency			60	
SAND cryostat & turret			55	from KLOE magnet
			115	
3KA Current leads' cooling flow		one pair	0.4 g/s	
4K heat load w/contingency			147	



Estimates of Heat loads at 70 K: SAND Magnet cooling system

	q_70K (W/m)	L (m)	Q_70K (W)	
Single rigid cryo-transfer lines between CB & DVB	0.5	5	2.5	70K He supply, DN15
	0.5	5	2.5	80K GHe return, DN25
Multi-channel Rigid cryo-transfer lines between DVB & SAND	2.0	55	110	70k He supply, 80K He return
SAND DVB			12.5	estimated
			127.5	
Heat load w/50% contingency			191.25	
SAND cryostat & turret			530	from KLOE magnet, 4~5 bara, 70-80K, 10.2 g/s Ghe
70K heat load			**721.25**	4~5 bara, 70-80K, 13.87 g/s Ghe
70K Equivalent to 4K heat load			52	Q_70K/14=Q_4K
Total equivalent 4K heat load w/50% contingency			199	

Assuming:
Q_SAND include contingency, only add 50% contingency to Q_lines and Q_DVBs.

Cooling capacity: at least 200W at 4.4K w/ 70K Ghe supply

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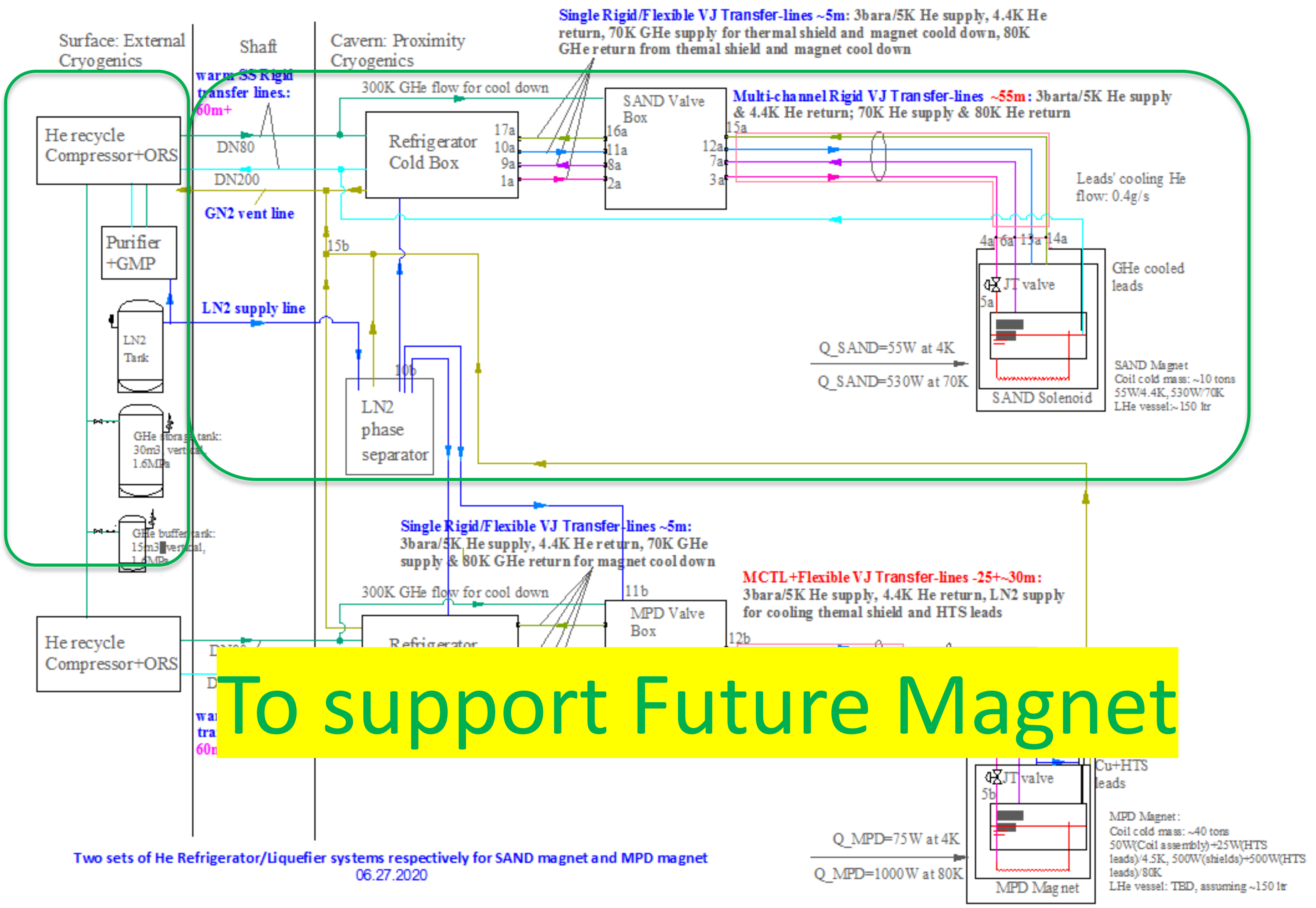
Main Components

Surface:
- He recycle compressor + ORS + GMP + He Purifier
- GHe storage/buffer tanks
- Warm piping/valve system
- LN2 tank

Shaft:
- Warm Ghe transfer lines (HP/LP)
- LN2 supply cryo-lines
- GN2 vent lines

Cavern:
- He Refrigerator cold box & its control system
- Distribution valve box
- Vacuum-jacketed cryogen transfer lines
- LN2 phase separator



To support Future Magnet

Two sets of He Refrigerator/Liquefier systems respectively for SAND magnet and MPD magnet
06.27.2020

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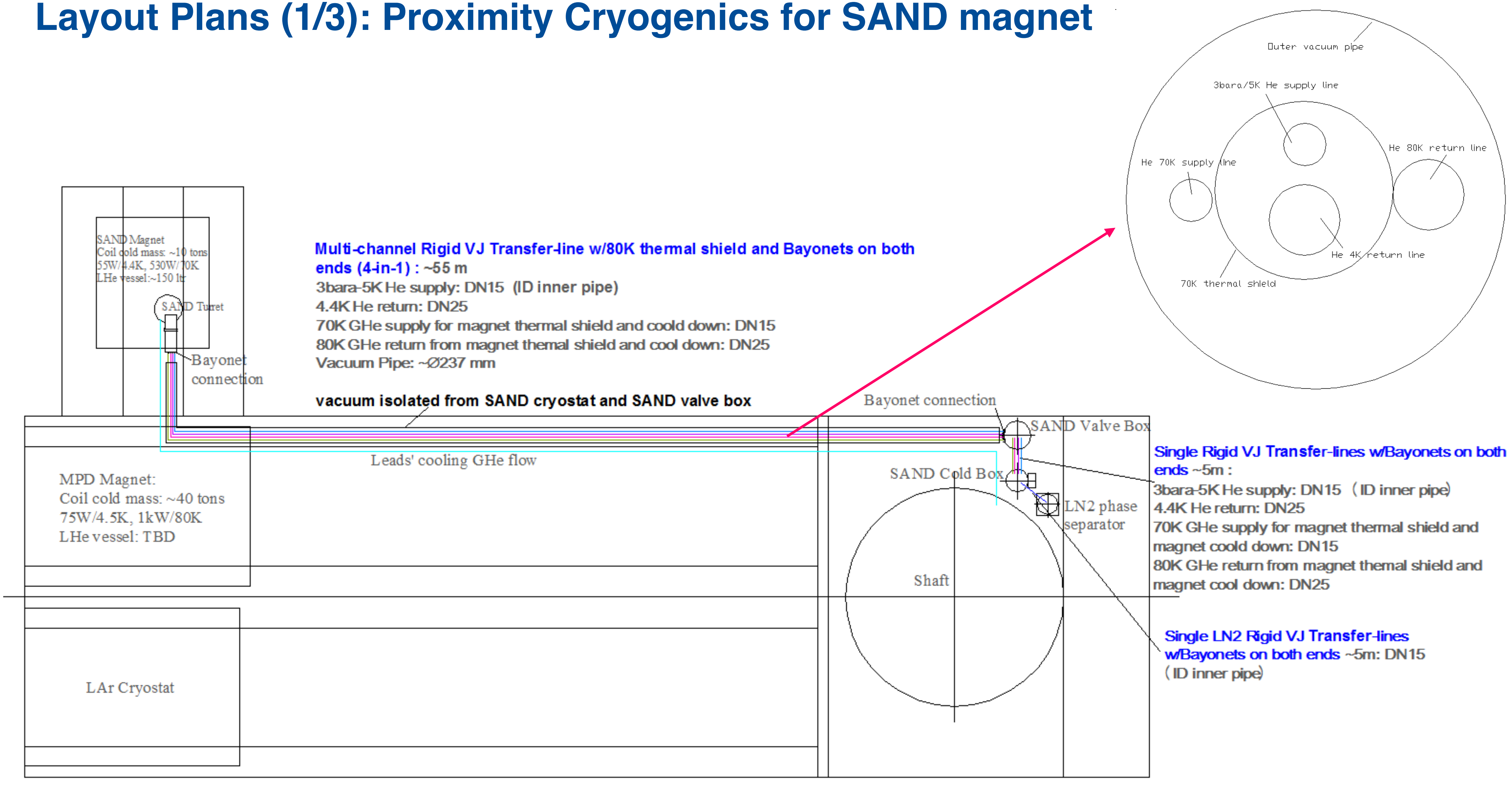
Layout Plans (1/3): Proximity Cryogenics for SAND magnet



Multi-channel Rigid VJ Transfer-line w/80K thermal shield and Bayonets on both ends (4-in-1) : ~55 m

3bara-5K He supply: DN15 (ID inner pipe)
4.4K He return: DN25
70K GHe supply for magnet thermal shield and coold down: DN15
80K GHe return from magnet themal shield and cool down: DN25
Vacuum Pipe: ~Ø237 mm

vacuum isolated from SAND cryostat and SAND valve box

Single Rigid VJ Transfer-lines w/Bayonets on both ends ~5m :

3bara-5K He supply: DN15 (ID inner pipe)
4.4K He return: DN25
70K GHe supply for magnet thermal shield and magnet coold down: DN15
80K GHe return from magnet themal shield and magnet cool down: DN25

Single LN2 Rigid VJ Transfer-lines w/Bayonets on both ends ~5m: DN15 (ID inner pipe)

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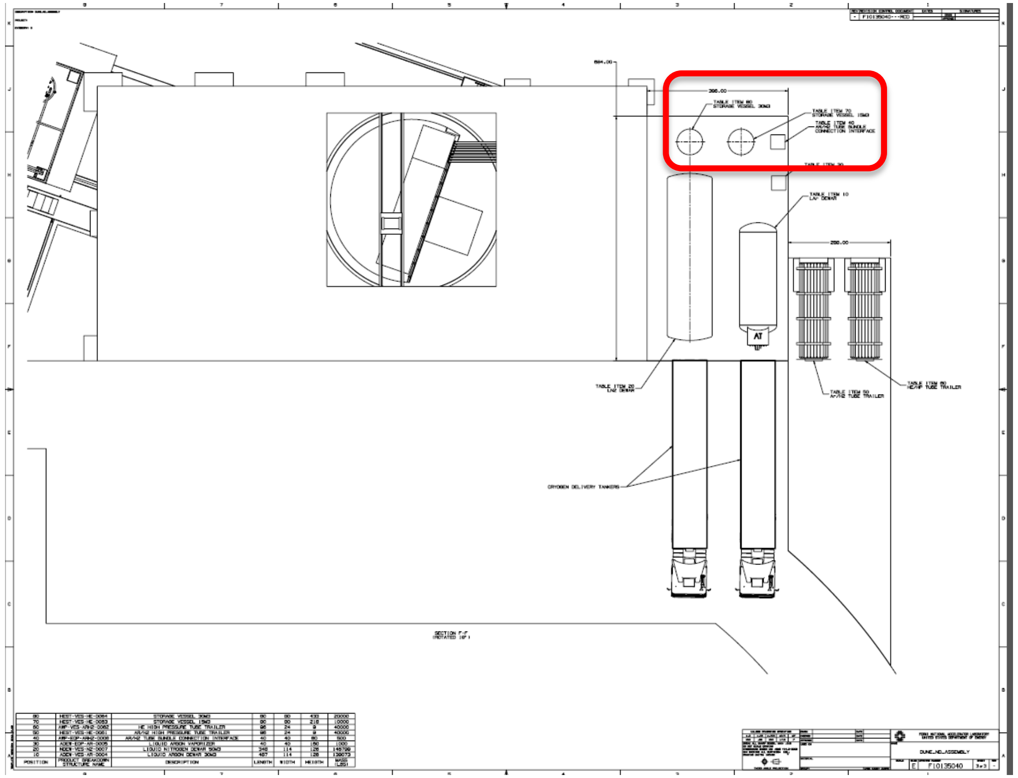
GHe storage/buffer tanks

Position	Product Breakdown Structure name	Description	Length	Width	Height	Mass
			in	in	in	lbs
70	HEST-VES-HE-0063	Storage Vessel 15m3, vertical, 1.6MPa	80	80	218	10,000
80	HEST-VES-HE-0064	Storage Vessel 30m3, vertical, 1.6MPa	80	80	433	20000



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Process Parameters & System Sizing (1/2)

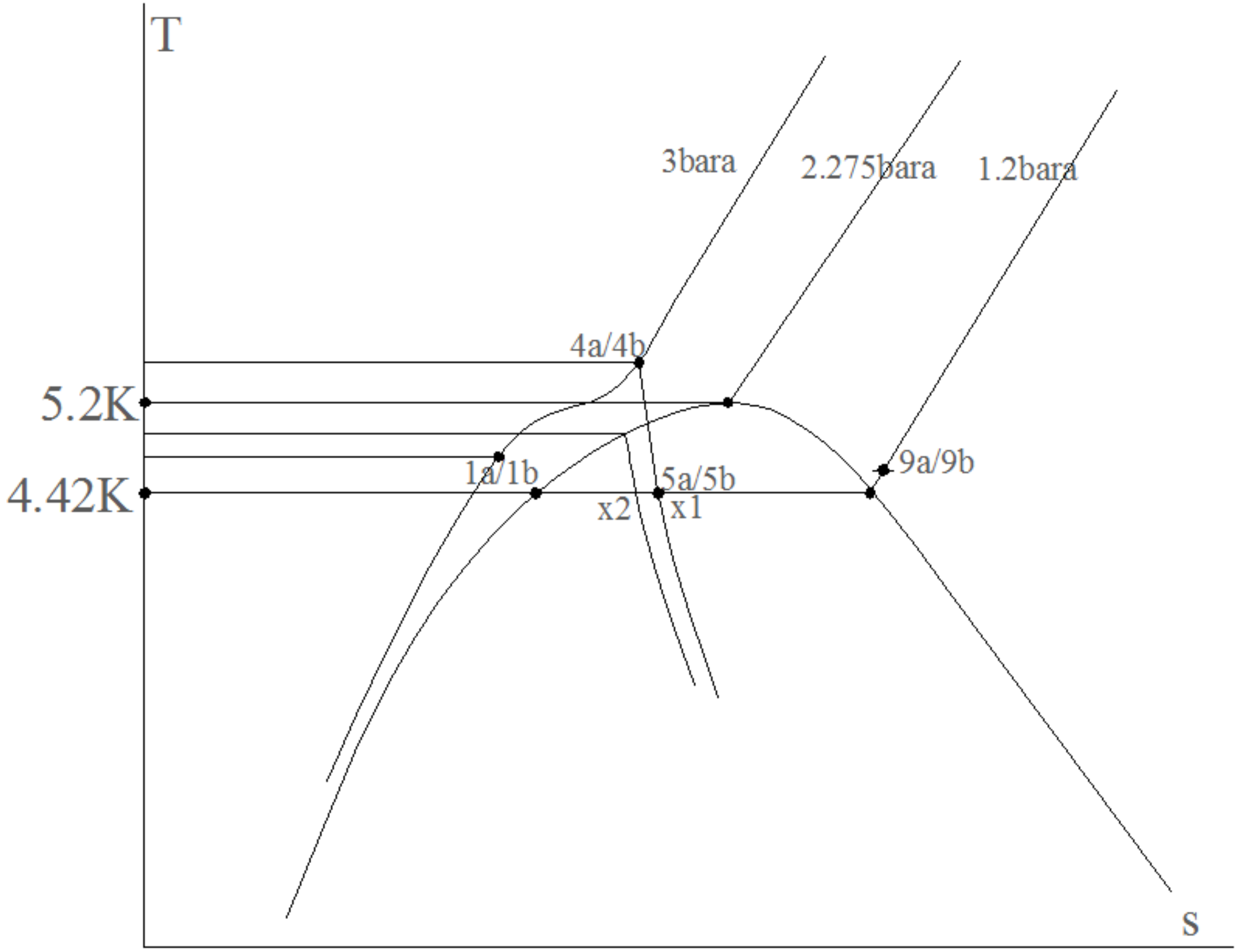
SAND Cooling System					
	Work point	**P (bara)**	**T (K)**	**Mass flow rate (g/s)**	**Inner Din - VJ Cryo-lines**
3bara/5K He suspply	1a	3.0, negligible pressure drop	4.94	5.038	DN15 (15~18mm)
	2a		5		
	3a		5.06		
	4a (before JT valve)		5.38		
	5a (after JT valve)	1.2	4.42, x=0.363		
4K He return	6a	1.2, negligible pressure drop	4.42, x=1	4.638	DN25 (25~30mm)
	7a		4.78		
	8a		4.91		
	9a		4.98		
70K Ghe supply	10a	5.0, negligible pressure drop	68.8	10.2	DN15 (15~18mm)
	11a		68.85		
	12a		68.96		
	13a		70.00		
80K Ghe return	14a	1.2~1.5, neligible pressure drop	80.00	10.2	DN25 (25~30mm)
	15a		81.04		
	16a		81.16		
	17a		81.21		

Process Parameters & System Sizing (2/2): T-s Diagram

- T at P=3bara before JT valve will be in the range of 4.42~5.876K. If T is higher than 5.876K, there will be no liquid helium generated after JT throttle.

- For SAND magnet cooling, the mass flow rate supplied from cold box at 3 bara will be > 5.0 g/s and its temperature lower than 5 K.

- In order to lower down the temperature before JT valve, heat loads resulting from VJ cryo-transfer lines need to be reduced as much as possible, or a LHe subcooler may be adopted.



SAND magnet cooling: T-s diagram

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Specifications of Utilities

Liquid Nitrogen

Condition:

Supply pressure	barg	> 2 (3 max)
Purity	mol %	> 99.5
State	-	saturated liquid

Instrument Air

Condition:

Supply pressure	barg	≥ 6 and < 10
Dew point	°C	≤ -20
Oil content	mg/m^3	< 1

Helium Gas

Quality:

He purity	for purging	vol% He	> 99.995	(4.5)
He purity (at storage tank)	for filling and performance test	vol% He	> 99.999* *) or feeding 99.995 via the make-up purifier available optionally	(5.0*)

Cooling water temperatures and pressures (Kaeser compressors) / *Kühlwassertemperaturen- und Drücke (Kaeserkompressoren)*

	Unit	Limits
Inlet pressure / *Druck am Eintritt*	[barg]	3 to 10
Pressure drop / *Druckabfall*	[bar]	1 (standard design / *Standardauslegung*)
Inlet temperature / *Eintrittstemperatur*	[°C]	5 to 40
Temperature rise / *Temperaturanstieg*	[°C]	15 (standard design / *Standardauslegung*)

Temperatures and pressures for turbine cooling water / *Temperaturen und Drücke für Turbinenkühlwasser*

	Unit	Limits
Inlet pressure / *Vordruck*	[barg]	3 to 10
Pressure drop / *Druckabfall*	[bar]	≤ 1
Inlet temperature / *Eintrittstemperatur*	[°C]	20 to 30
Temperature rise / *Temperaturanstieg*	[°C]	≤ 10

* Data from Linde Kryogenik AG.

LHe Cryogenics Doc list

DUNE Near Site: LHe Cryogenics for Magnets						
Folder	**EDMS ID**	**Title**	**File Name**	**Upload Date**	**Author**	**Note**
P&ID for LHe Cryogenics	2387228 (v.1)	DUNE ND LHe Cryogenics Preliminary P&ID	DUNE_ND_LHe_Cryoplant_Preliminary_PID_LW_06182020.dwg	2020-6-21	L. Wang	
			DUNE_ND_LHe_Cryoplant_Preliminary_PID_Only_SAND.pdf	2020-6-25	L. Wang	
			DUNE_ND_LHe_Cryoplant_Preliminary_PID_Scheme_I.pdf	2020-6-25	L. Wang	
			DUNE_ND_LHe_Cryoplant_Preliminary_PID_Scheme_II.pdf	2020-6-25	L. Wang	
			DUNE_ND_LHe_Cryoplant_Preliminary_PID_Only_SAND_Update.pdf	2020-6-28	L. Wang	
			DUNE_ND_LHe_Cryoplant_Preliminary_PID_Scheme_I_Update.pdf	2020-6-28	L. Wang	
			DUNE_ND_LHe_Cryoplant_Preliminary_PID_Scheme_II_Update.pdf	2020-6-28	L. Wang	
Layout Plans	2390133 (v.1)	LHe cryogenics Preliminary layout plans in Cavern	DUNE_ND_LHe_Cryoplant_Preliminary_Layout_MPD_magnet_cooling.pdf	2020-6-25	L. Wang	
			DUNE_ND_LHe_Cryoplant_Preliminary_Layout_SAND_magnet_cooling.pdf	2020-6-25	L. Wang	
			DUNE_ND_LHe_Cryoplant_Preliminary_Layout_SAND_magnet_cooling_Update.pdf	2020-6-28	L. Wang	
			DUNE_ND_LHe_Cryoplant_Preliminary_Layout_MPD_magnet_cooling_Update.pdf	2020-6-28	L. Wang	
Cost Estimates	2387232 (v.1)	BOE of DUNE ND LHe Cryogenics	LBNF_NearSite_LHeCryogenics_CostEstimate_LW_20200621update.pdf	2020-6-22	L. Wang	
	2387233		LBNF_NearSite_LHeCryogenics_CostEstimate_LW_20200621update.xlsx	2020-6-25	L. Wang	
Design Documents	2387227 (v.1)	DUNE ND LHe Cryogenics Design	DUNE_ND_LHe_Cryogenics_Preliminary_Design_LW_20200618.xlsx	2020-6-25	L. Wang	
			DUNE_ND_LHe_Cryogenics_Preliminary_Design_LW_20200627update.xls	2020-6-28	L. Wang	
			DUNE_ND_LHe_Cryoplant_Calculation_Model.pdf	2020-6-25	L. Wang	
			DUNE_ND_LHe_Cryoplant_Calculation_Model_Update.pdf	2020-6-28	L. Wang	
			DUNE_ND_LHe_Cryogenics-PDR-July2020_V1.pptx	2020-6-25	L. Wang	
			DUNE_ND_LHe_Cryogenics-PDR-July2020_V2.pptx	2020-6-28	L. Wang	
	2387229		kloe-Cryo-PID.pdf	2020-6-21	L. Wang	Publication or Engineering reports regarding KLOE magnet & its cooling
			The_DAONE_Cryogenic_System.pdf	2020-6-21	L. Wang	
			3DST-SAND_Assy_2020-03-04.PDF	2020-6-21	L. Wang	
			00614583.pdf	2020-6-21	L. Wang	
			P00022550_The_KLOE_Detector_Techinical_Proposal_1993.pdf	2020-6-28	L. Wang	
			Status_of_DAONE_and_KLOE_1999.pdf	2020-6-28	L. Wang	

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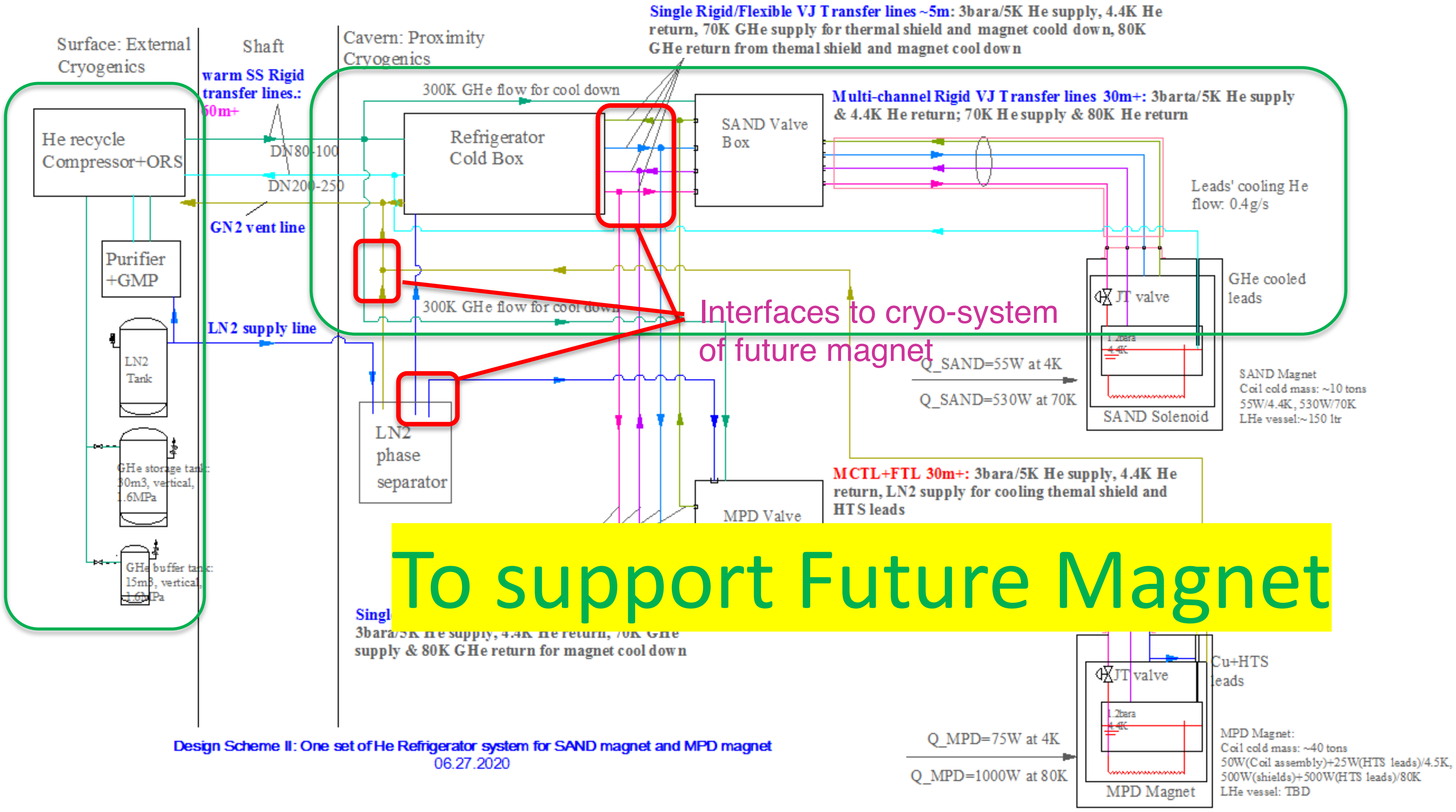
Process Flow Diagram (2/2): Design Scheme II

- One 400~500 W / 4.5K He Refrigerator system without LN2 precool is used to serve the SAND magnet.
- No LN2 is needed for SAND cooling system.
- Interfaces upgradable to support future magnet cooling system.
- The 400~500W/4.5K He Refrigerator system with LN2 precool will be used to cool both SAND and MPD magnet later.



Interfaces to cryo-system of future magnet

To support Future Magnet

Design Scheme II: One set of He Refrigerator system for SAND magnet and MPD magnet
06.27.2020

Cooling Requirements for SAND Magnet and MPD Magnet

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	SAND magnet	MPD magnet
Coil cooling scheme	thermosiphon circulation LHe flow system through cooling channels welded to the outside of the coil support cylinder, a solenoid magnet indirectly cooled through a Lhe thermosiphon cycle	Thermosiphon
He supply from cold box	5.2 K and 3 bara with expansion from 3 to 1.2 bara inside the magnet	
Thermal shield cooling method	70K forced cold GHe flow: 50 K gas for thermal shields removed at the 1st turbine output	cooled by force LN2 flow
Current leads	a pair of GHe cooled 3kA leads, cooled by helium vaporized from Lhe reservoir in the Turret	a pair of conduction-cooled 10kA HTS leads; cooling approach to cold ends of Cu leads/warm ends of HTS leads at 80K : conduction-cooled using LN2 circuit; cooling approach to cold ends of HTS leads: conduction-cooled by Lhe
4 K radiation and conduction (W)	55	50 at 4.7K
HTS power lead pair 4.7 K heat load (W)	N/A	25
Current leads' cooling flow	0.4 g/s Ghe	N/A
70 K radiation and conduction (W)	530	500 at 80K
HTS power lead pair 80 K heat load (W)	N/A	500
Operating temperature (K)	4.42	4.7
Operating pressure (bar)	1.2	
Lhe in magnet w/Turret (ltr)	~200	
Lhe reservior in Service Turret (ltr)	~150	
300-70K cool down scheme	300K and 70K Ghe mixing foced flow, 4~5 bara	Ghe forced flow
70-4K cool down scheme	5K 3bara Ghe forced flow	Ghe forced flow

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Design Schemes: Comparison

	Scheme I	Scheme II
	SAND+MPD: two refrigerator systems	SAND and MPD later: one refrigerator system
Customized Refrigerator capacity	2 x ~200W/4.5K	SAND: ~200W/4.5K; SAND+MPD: 400~500W/4.5K
	Two ~200W refrigerators w/LN precool	SAND: one 400~500W refrigerator w/o LN precool; SAND+MPD: one 400~500W w/LN precool
External Cryogenic Facilities	2 x~200W refrigerators He recycle compressor + ORS & GMP control cabinet	1 x 400~500W refrigerator He recycle compressor + ORS & GMP control cabinet
	shared Ghe storage/buffer tank	
	LN2 tank & 2xHe purifiers	LN2 tank & 1x He purifier
	2x (Warm piping/valve system+ LN2 supply cryo-line)	1x (Warm piping/valve system+ LN2 supply cryo-line)
Cavern Shaft	2 sets of warm HP (DN80) / LP (DN200) He piping, LN2 supply cryo-line/GN2 vent line	One set of warm HP (DN80) / LP (DN200) He piping, LN2 supply cryo-line/GN2 vent line
Cavern	2 x ~200W refrigerators Cold Boxes + 2x DVBs	one 400~500W refrigerator Cold Box + 2x DVBs
	shared LN2 phase separator	

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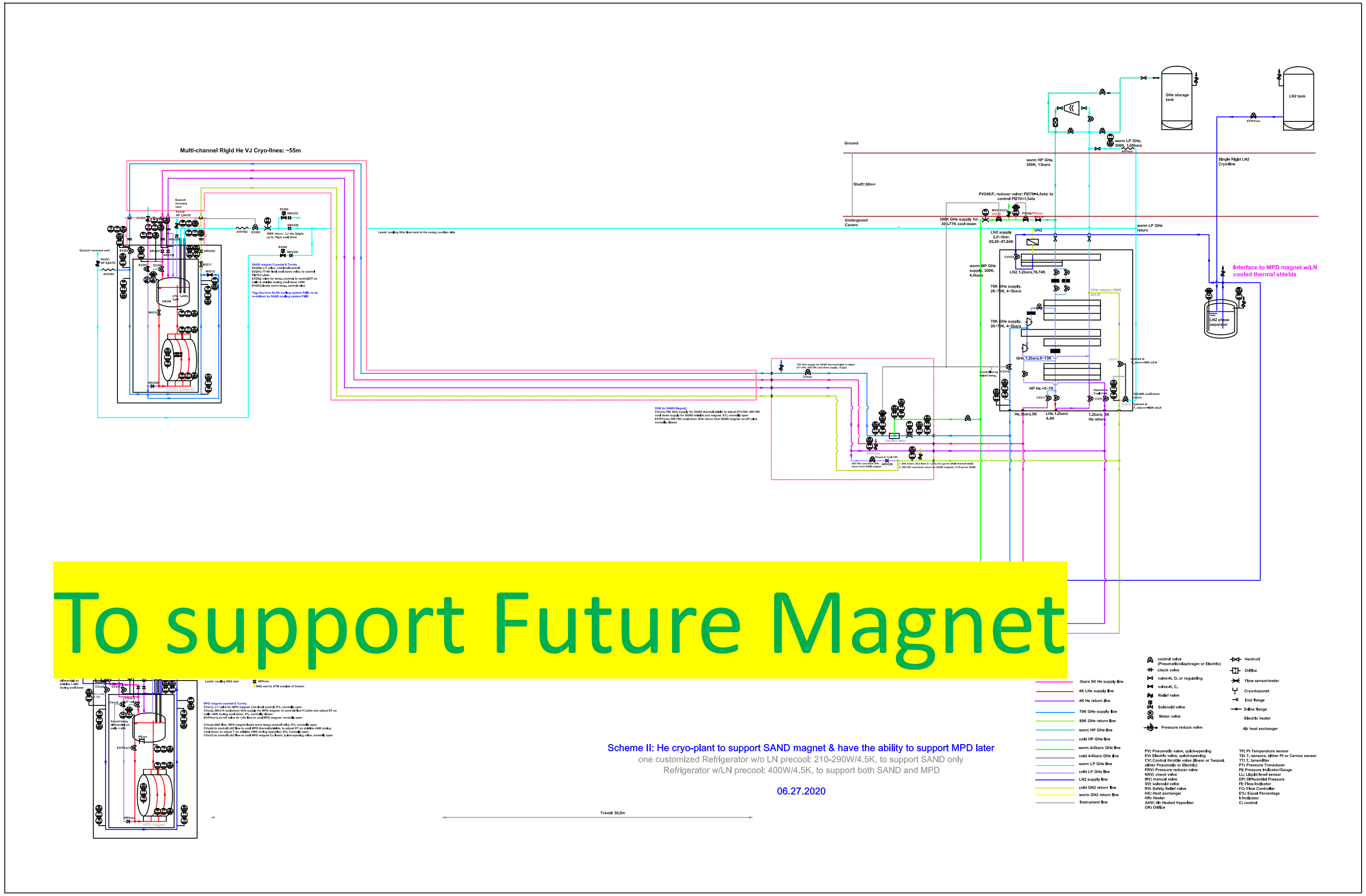
Preliminary P&ID for Scheme II



To support Future Magnet

Scheme II: He cryo-plant to support SAND magnet & have the ability to support MPD later
one customized Refrigerator w/o LN precool: 210-290W/4.5K, to support SAND only
Refrigerator w/LN precool: 400W/4.5K, to support both SAND and MPD

06.27.2020

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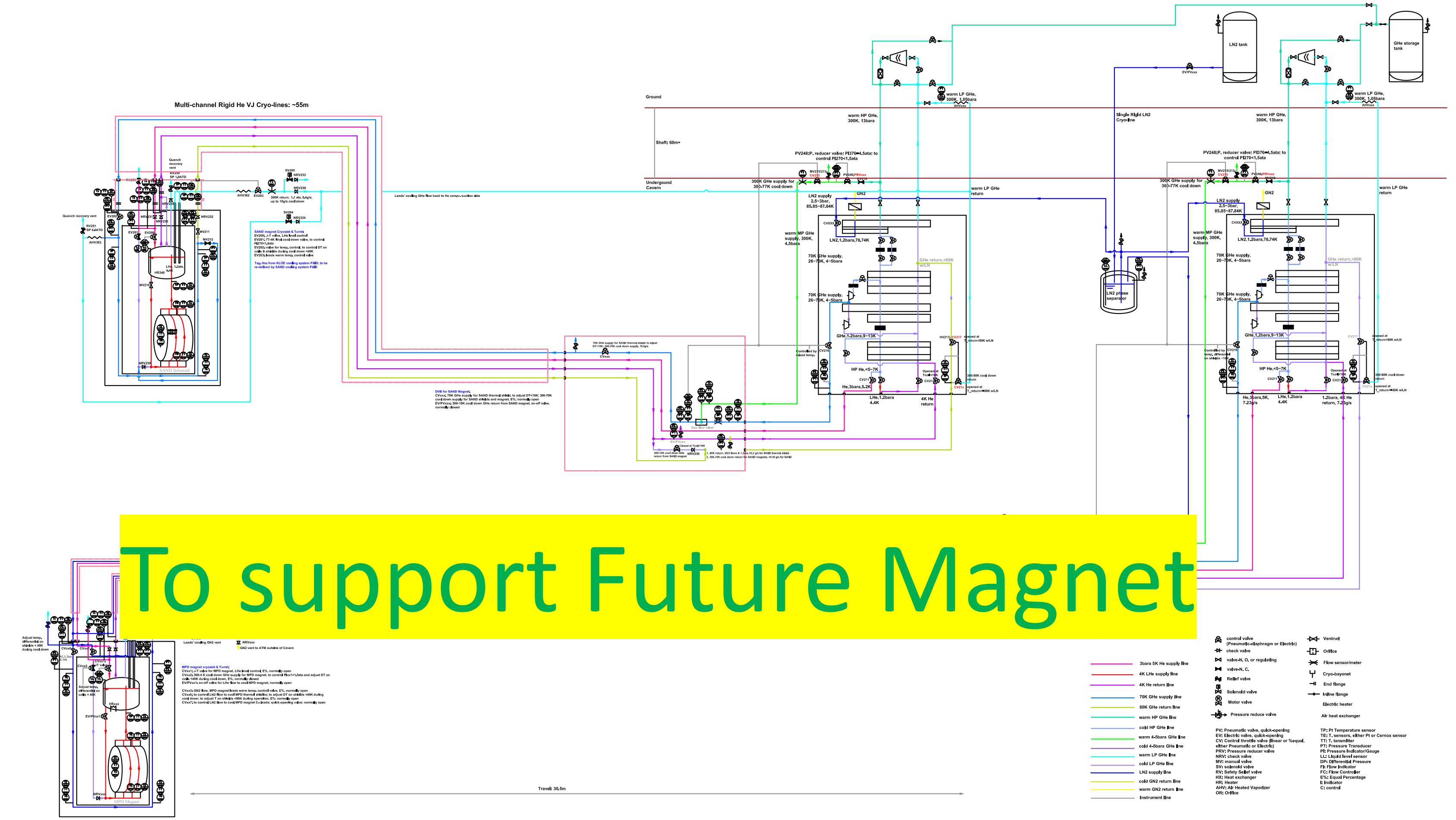
Preliminary P&ID (Scheme I)



To support Future Magnet

Scheme I: cooling SAND magnet and MPD magnet using individual He cryo-plants
SAND magnet cryostat: 70K GHe cooled thermal shields and GHe-cooled 3kA Cu leads
MDP magnet cryostat: LN2 cooled thermal shields and LN2 conduction-cooled 10kA HTS leads
Two customized refrigerator w/LN precool: 2 x 200W/4.5K order of magnitude

06.27.2020