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Design of the cryogenic systems for the Near and Far LAr-TPC detectors of the Short-Baseline Neutrino program (SBN) at Fermilab

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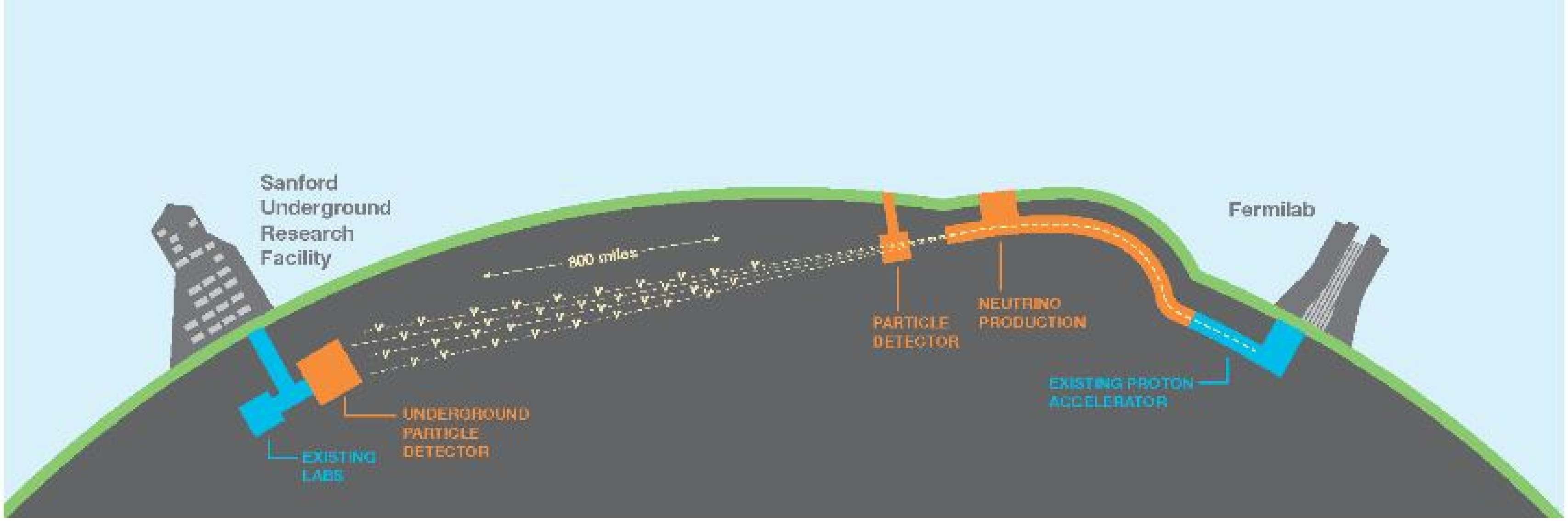
Outline:

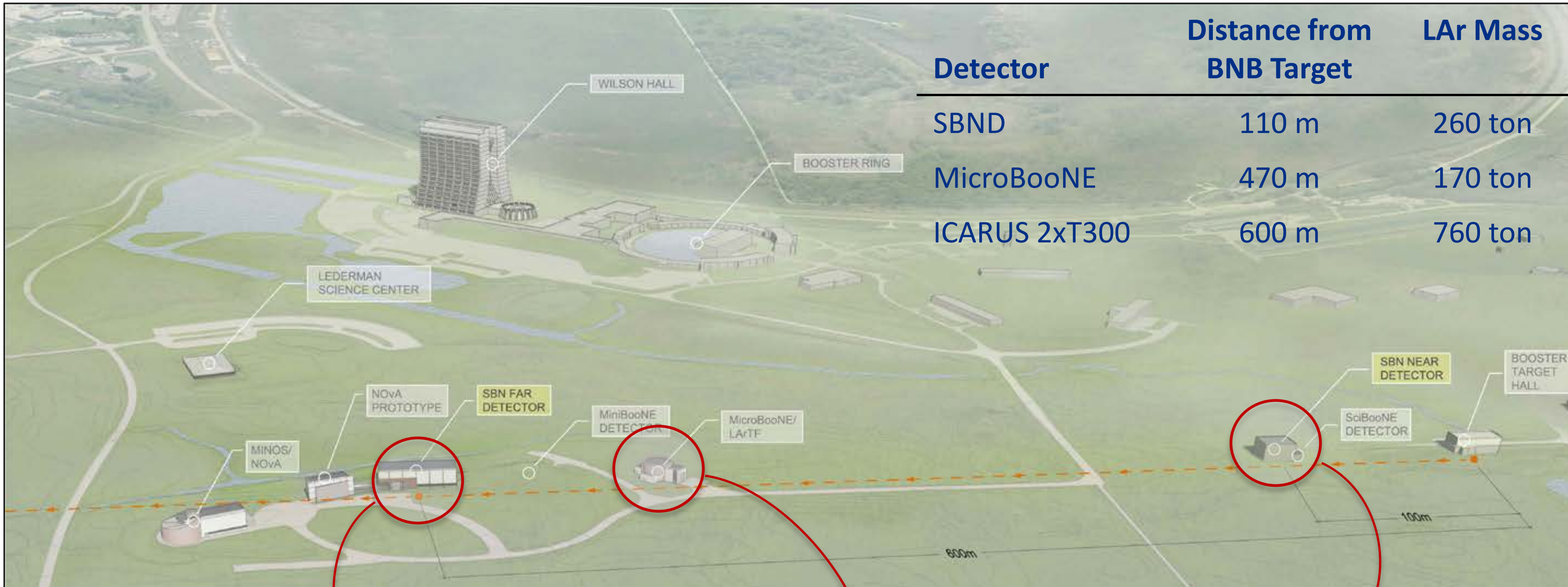
- Introduction
- Design requirements for SBND and SBN-FD cryogenic systems
- Description of cryogenics and design solutions for SBND and SBN-FD
- Present state and conclusion

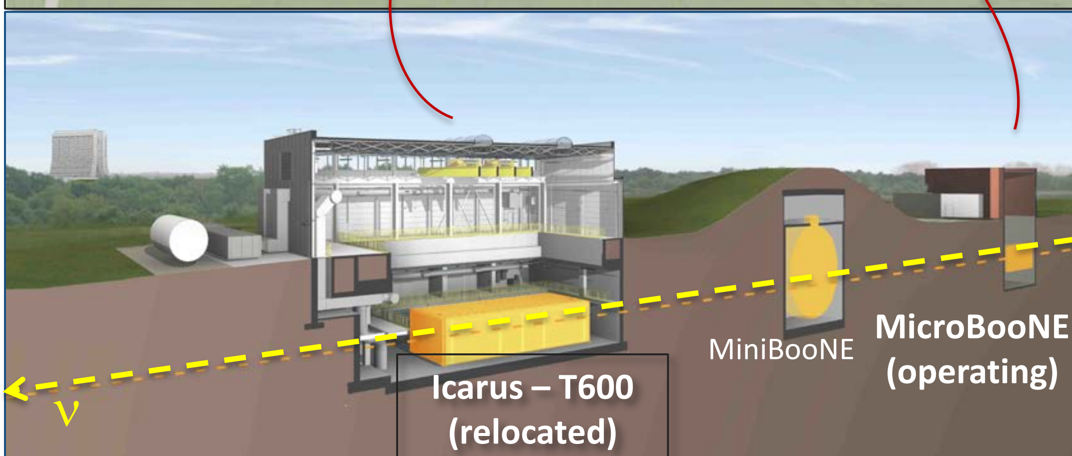
The Short-Baseline Neutrino (SBN) physics program at Fermilab and Neutrino Platform (NP) at CERN are parts of the international Neutrino Program leading to the development of Long-Baseline Neutrino Facility/Deep Underground Neutrino Experiment (LBNF/DUNE) science project. When operated, neutrinos created by the Fermilab beamline will pass the DUNE Near detector at Fermilab and then travel 1300 km to intercept DUNE's TPC based far detector at the Sanford Lab. The detector will be installed in caverns at about 1.5 km below the surface.

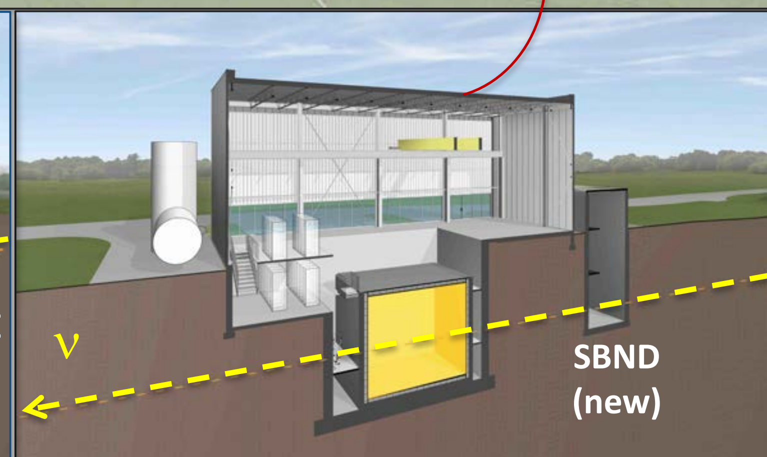


SBN: Three LAr-TPC detectors positioned along BNB at Fermilab

Detector	Distance from BNB Target	LAr Mass
SBND	110 m	260 ton
MicroBooNE	470 m	170 ton
ICARUS 2xT300	600 m	760 ton







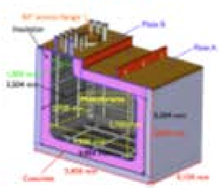
Highlights:

- Different design of cryostats => specific requirements for the SBN building facilities and SBN cryogenic systems
- Collaboration CERN <–> INFN <–> Fermilab while using different approaches for deliverables

CERN
1 x 1 x 3

26 T
Cool down

Fermilab
35 T

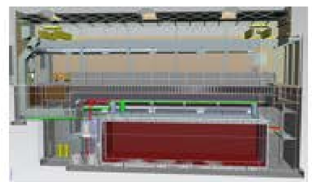


35 T
operational

Fermilab-CERN
SBN Near

270 T
2019

Fermilab-CERN-INFN
SBN Far

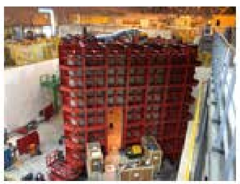


760 T
2018

CERN
Proto
Dune SP

676 T
2018

CERN
6 x 6 x 6



676 T
2018

DUNE

4 x 17100 T
First cryostat 2024

The main design requirement -> electron lifetimes in argon in excess of 3 milliseconds:

$$\tau\,[ms] \approx \frac{300\,[ms \cdot ppt\ Oxygen\ Equivalent]}{\rho\,[ppt\ Oxygen\ Equivalent]}$$ > 3 ms => ρ < 100 ppt (10-10 parts)

Problem: Commercial argon ~ 1 ppm, plus outgassing and back-diffusion
Solution: Filtration of O_2 and H_2O while transfer of LAr from storage to cryostat, plus continuous recirculation of LAr volume of cryostat with cryostat volume change every 5-8 days

Additional main requirements:

- Argon losses to atmosphere should be minimized to reduce re-filling
- Temperature difference over the detection volume shall be limited to have a uniform reaction over the sensitive volume
- Operating pressure should be tightly controlled

Design requirements for SBN cryogenic systems

Requirements and Specification: SBND	Value
Cryostat type and size	Membrane (GTT) with self-supported steel structure 5.202 m x 5.423 m x 7.027 m, ~270 tons (~2% ullage) Gas purge for insulation space
Verifiable contamination for LAr delivery	O_2 < 1 ppm, H_2O < 1 ppm, N_2 < 2 ppm
LAr purity in cryostat	> 3 ms electron lifetime (<100 ppt O_2 equivalent)
Nitrogen contamination	< 2 ppm
Design Pressure	Internal 345 mbarg (~5 psig), external 50 mbar
Operating gas pressure	70 mbar (~1 psig) with +/- 5%
Initial purification technique	GAr Piston purge with rate of rise 1.2 m/hr
Cooldown technique	LAr spray with GAr and GAr momentum (< 10-15 K/hr)
TPCs cool-down rate restriction	< 40 K/hr, < 10 K/m (vertically)
LAr recirculation rate	2.5 – 8.0 m^3/hr (10 – 35 gpm)
Number of side/bottom penetrations	1 (use of Protego© internal valve or external safety valves)
Included subsystems	LAr and LN2 storage and transport, O_2-N_2-H_2O contamination monitoring, LAr and GAr recirculation and filtration, GAr condensing and recovery, safety and controls
Grounding and noise requirement or external equipment	Electrical isolation of noise from cryostat and its electronics

Design requirements for SBN cryogenic systems

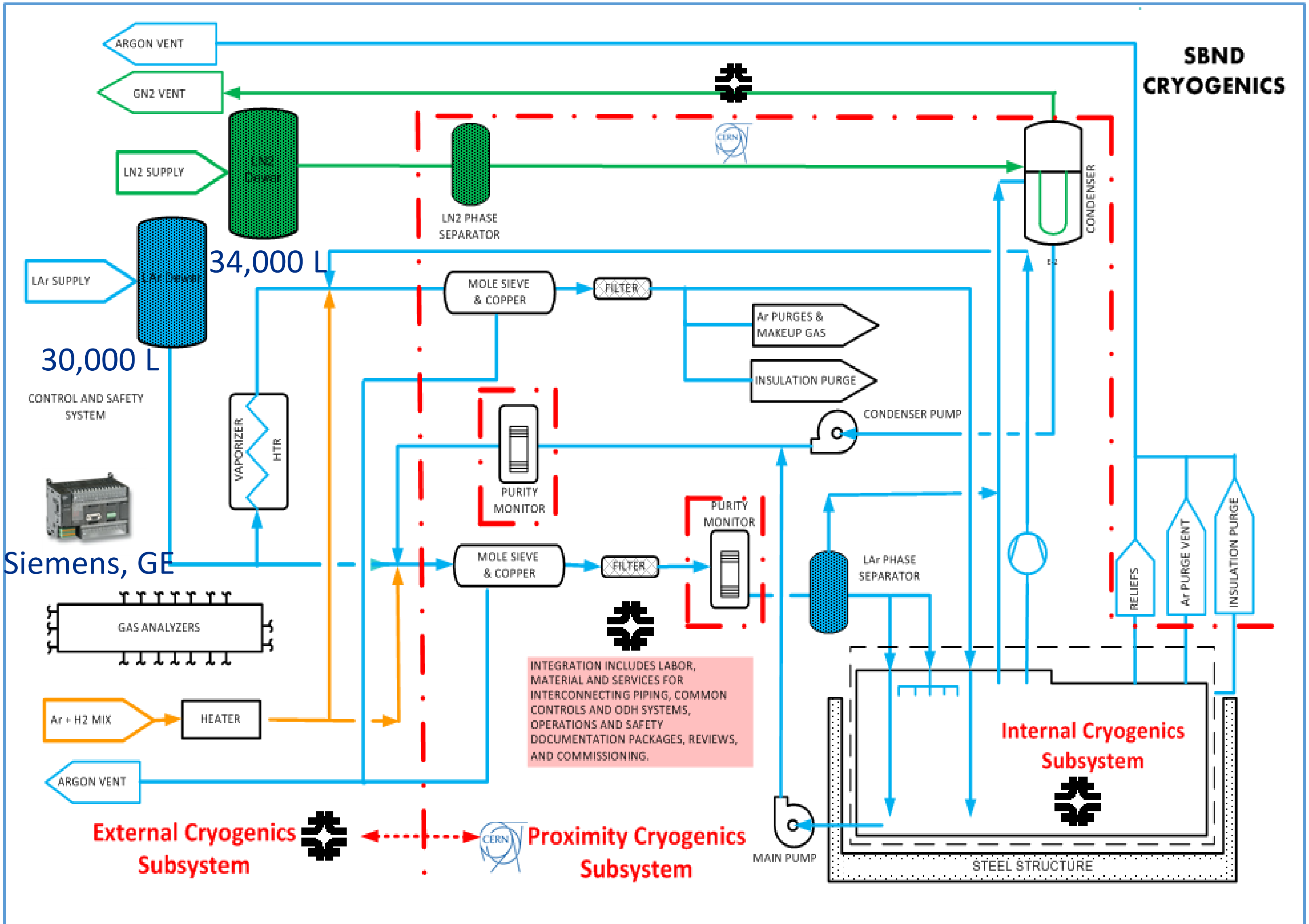
Requirements and Specification: SBN-FD	Value
Cryostat type and size	Dual aluminum vessels with common LN_2 shields within a warm self-standing steel structure with GTT-style insulation 3.600 m x 19.600 m x 3.900 m, ~380 tons each (~2% ullage) Gas purge for insulation space
Verifiable contamination for LAr delivery	O_2 < 1 ppm, H_2O < 1 ppm, N_2 < 2 ppm
LAr purity in cryostat	> 3 ms electron lifetime (<100 ppt O_2 equivalent)
Nitrogen contamination	< 2 ppm
Design Pressure	Internal 345 mbarg (~5 psig), external up to 1 barg
Operating gas pressure	150 mbar (~2 psig) with +/- 5%
Initial purification technique	Pump down to full vacuum
Cooldown technique	Initial with LN_2 shield, final with LAr fill at 2 K/hr
TPCs cool-down rate restriction	< 70 K/hr, < 50 K/m (vertically)
LAr recirculation rate	2.5 – 8.0 m^3/hr (10 – 35 gpm)
Number of side/bottom penetrations	1 side and 1 bottom (per cryostat) (use of external safety valves)
Included subsystems	LAr and LN2 storage and transport, O_2-N_2-H_2O contamination monitoring, LAr and GAr recirculation and filtration, GAr condensing and recovery, safety and controls
Grounding and noise requirement or external equipment	Electrical isolation of noise from cryostat and its electronics

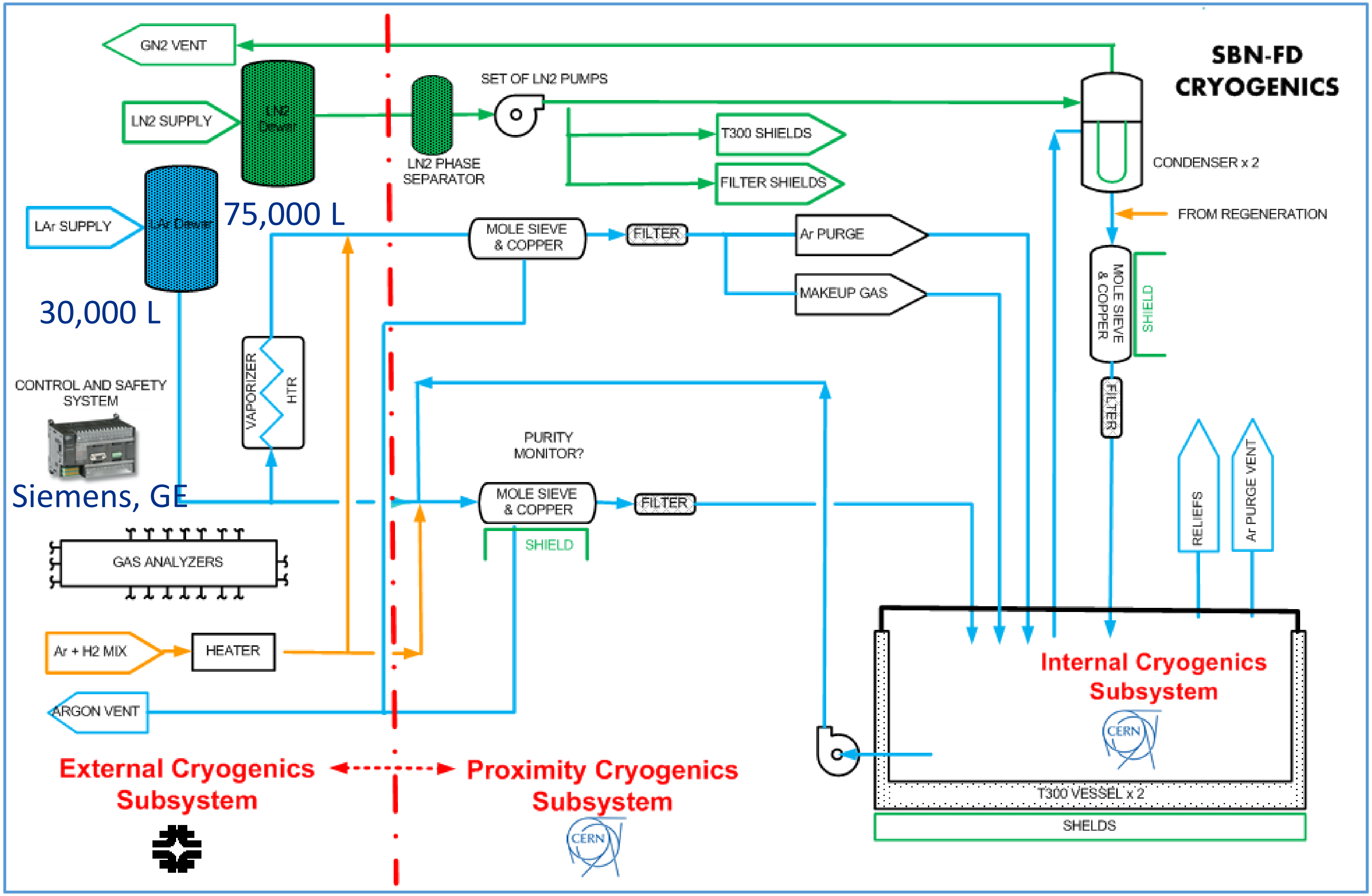
As Fermilab and CERN engage in SBN partnership, an agreement has been established for naming cryogenic sub-systems, some of which are deliverables of Fermilab and some are deliverables of CERN.

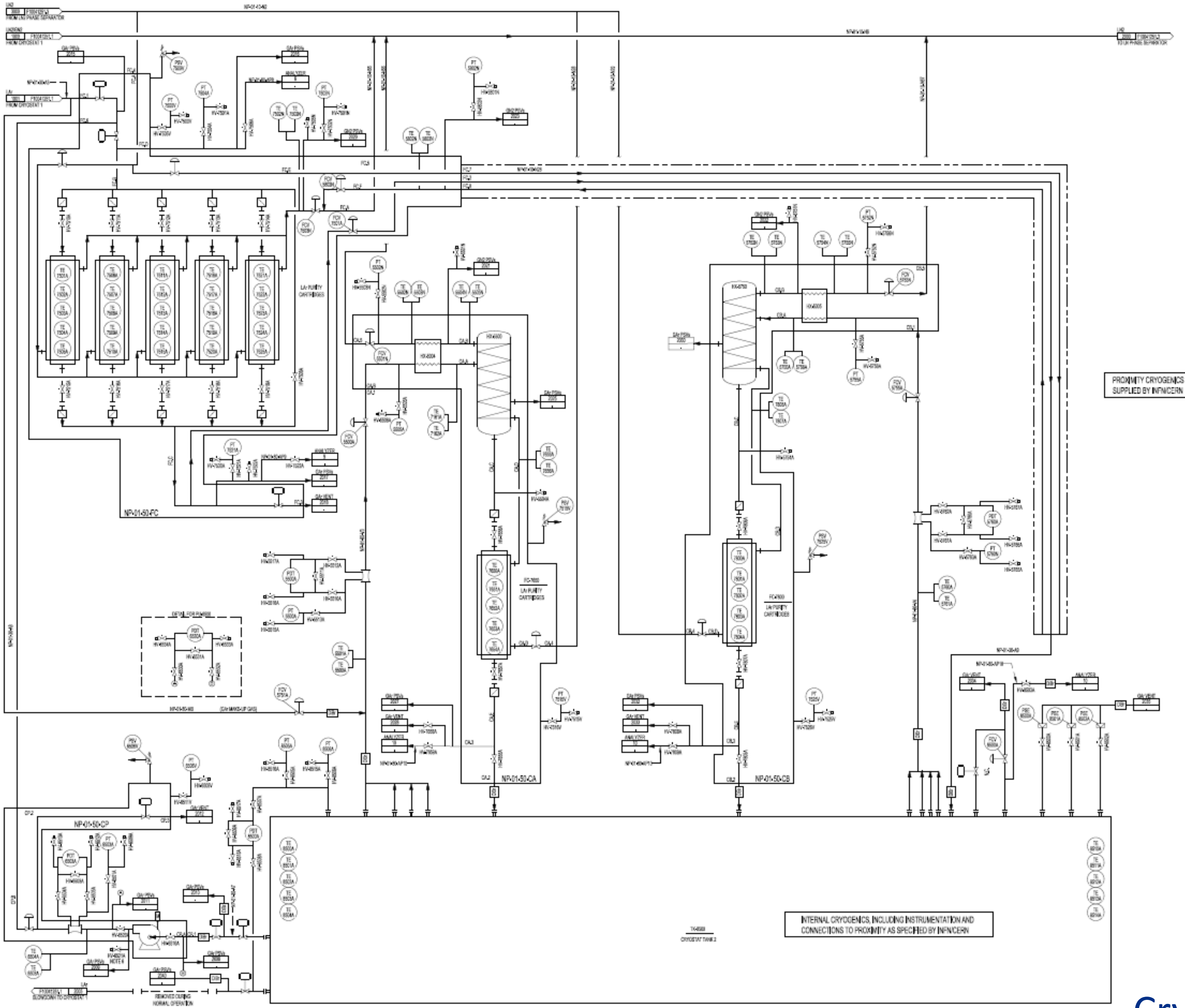
Deliverables / Institutions	SBND				SBN-FD			
	Internal Cryo	Proximity Cryo	External Cryo	Cryogenic Controls	Internal Cryo	Proximity Cryo	External Cryo	Cryogenic Controls
CERN		X				X		
Fermilab	X		X	X			X	X
INFN					X			

To satisfy design requirements, the following modes of operations are implemented:

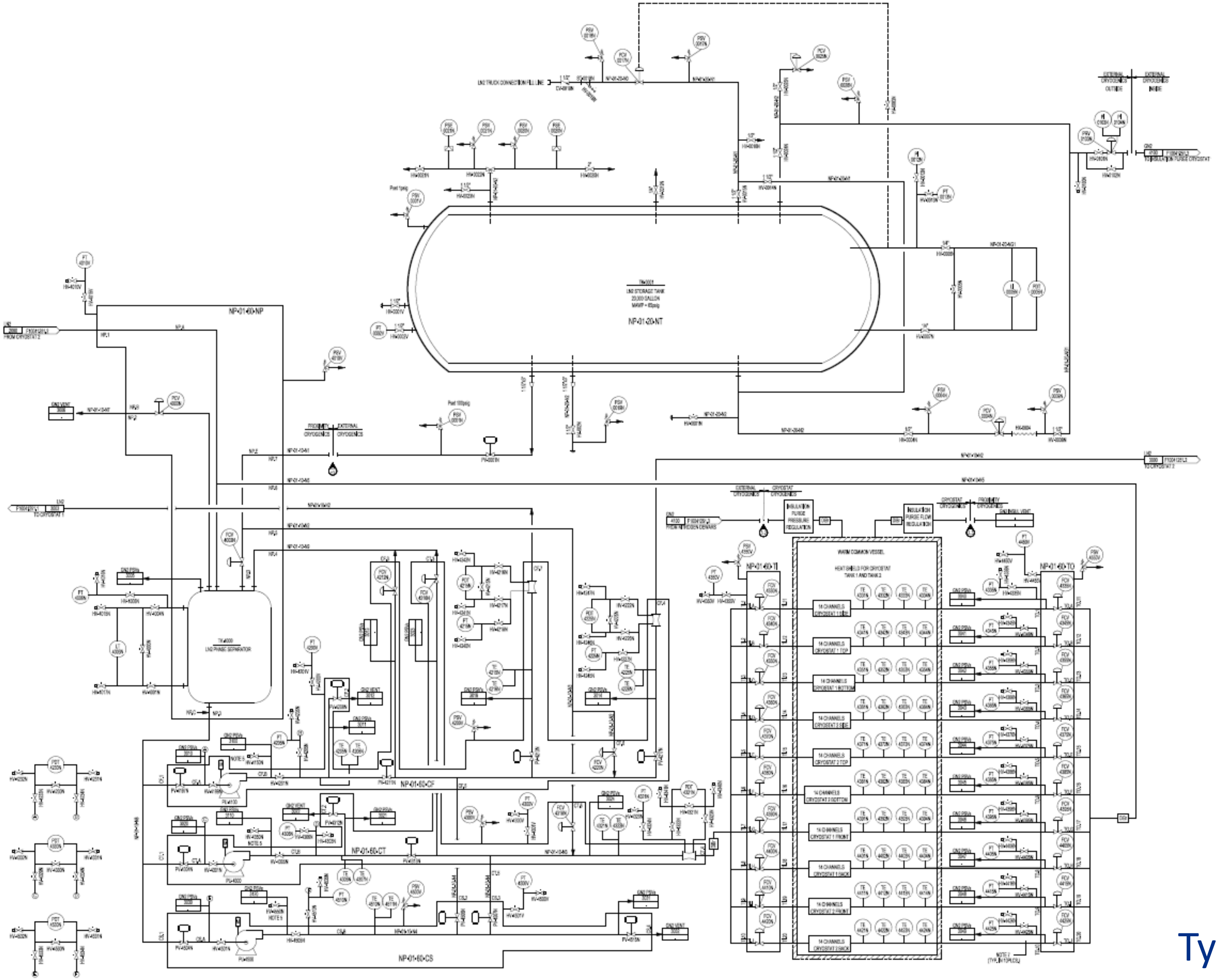
Mode of Operation	SBND (membrane cryostat)	SBN-FD (aluminum vessels)
Initial cleanup	Piston purge with gaseous argon to remove the initially present air	Pump down to full vacuum for up to 90 days
Final cleanup	Internal circulation via a membrane pump through a commercial room temperature purification system	None
Cooldown	Spray with commercial grade argon through spray nozzles with GAr and GAr momentum (< 10-15 K/hr)	Initial with LN2 shield, final with LAr fill at 2 K/hr
Fill	From LAr storage dewar with commercial grade argon and re-condensing with LN_2	From LAr storage dewar with commercial grade argon and re-condensing with LN_2
Purification	Circulation by LAr pumps through specially developed externally located purifiers consisting of volumes filled with molecular sieve, which will adsorb the eventual water traces present in the argon flow, and active copper pellets which will chemically react with the diminish the oxygen equivalent contamination from the low parts per million to the parts per trillion level.	Circulation by LAr pumps through specially developed inline purifiers consisting of removable cartridges filled with molecular sieve, which will adsorb the eventual water traces present in the argon flow, and active copper pellets which will chemically react with the diminish the oxygen equivalent contamination from the low parts per million to the parts per trillion level.
Normal operation	• Maintaining level by adding condensed GAr • Maintaining pressure by rate of condensing GAr boiloff • Maintaining purity by recirculating and filtering LAr	• Maintaining level by adding condensed GAr • Maintaining pressure by rate of condensing GAr boiloff • Maintaining purity by recirculating and filtering LAr
Regeneration of filters	Regeneration filters in place with heated GAr / 2.5% H_2 mix	Regeneration removed cartridges with heated GAr / 2.5% H_2 mix


SBND
CRYOGENICS
ARGON VENT
GN2 VENT
LN2 SUPPLY
LN2 Dewar
LN2 PHASE SEPARATOR
CONDENSER
34,000 L
LAr SUPPLY
LAr Dewar
30,000 L
CONTROL AND SAFETY SYSTEM
Siemens, GE
MOLE SIEVE & COPPER
FILTER
Ar PURGES & MAKEUP GAS
INSULATION PURGE
CONDENSER PUMP
VAPORIZER
HTR
PURITY MONITOR
PURITY MONITOR
MOLE SIEVE & COPPER
FILTER
LAr PHASE SEPARATOR
RELIEFS
Ar PURGE VENT
INSULATION PURGE
GAS ANALYZERS
INTEGRATION INCLUDES LABOR, MATERIAL AND SERVICES FOR INTERCONNECTING PIPING, COMMON CONTROLS AND ODH SYSTEMS, OPERATIONS AND SAFETY DOCUMENTATION PACKAGES, REVIEWS, AND COMMISSIONING.
Ar + H2 MIX
HEATER
ARGON VENT
Internal Cryogenics Subsystem
External Cryogenics Subsystem
Proximity Cryogenics Subsystem
MAIN PUMP
STEEL STRUCTURE

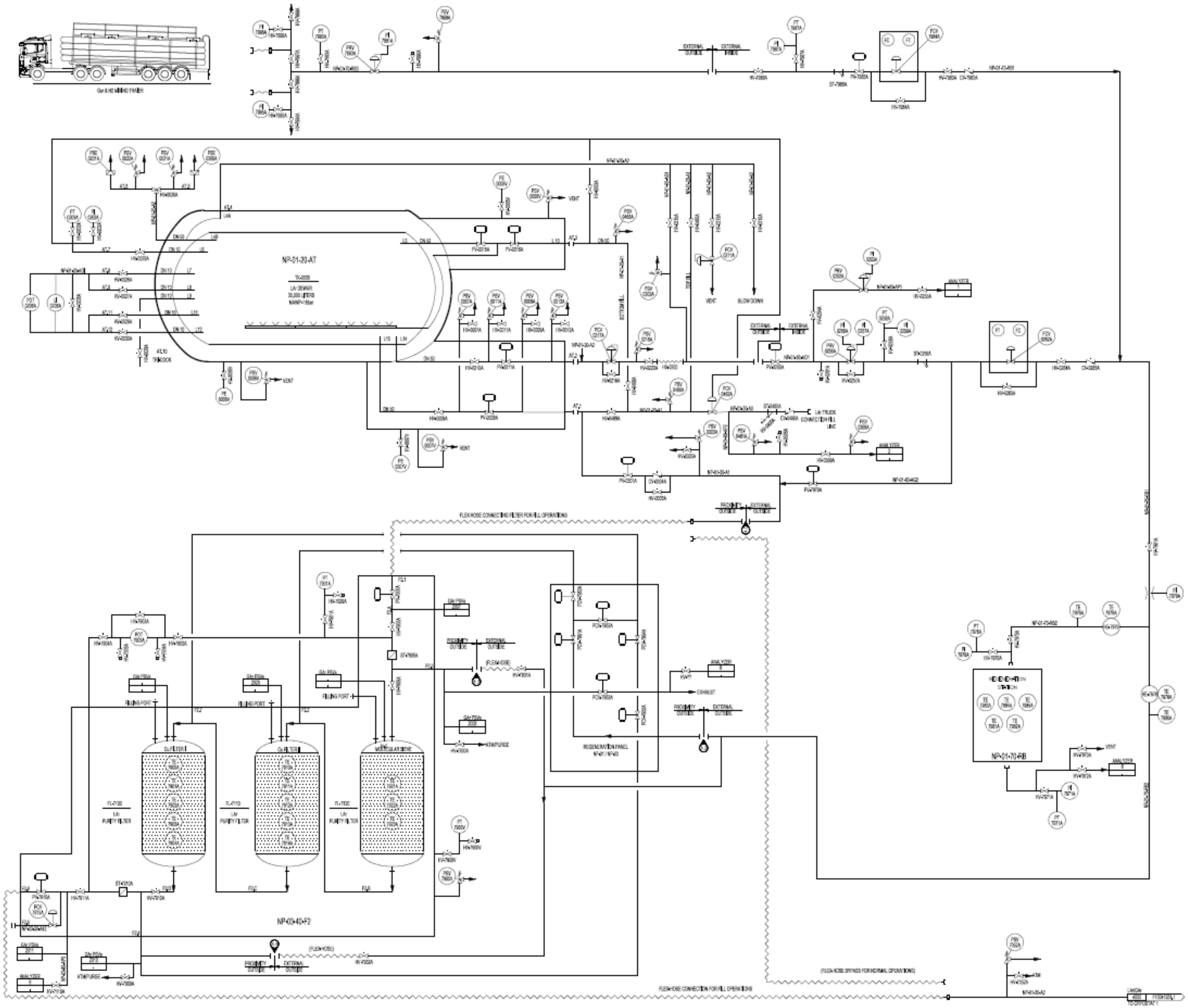

SBN-FD CRYOGENICS
GN2 VENT
LN2 SUPPLY
LN2 Dewar
75,000 L
LAr SUPPLY
LAr Dewar
30,000 L
SET OF LN2 PUMPS
LN2 PHASE SEPARATOR
T300 SHIELDS
FILTER SHIELDS
CONDENSER x 2
FROM REGENERATION
MOLE SIEVE & COPPER
FILTER
Ar PURGE
MAKEUP GAS
SHIELD
CONTROL AND SAFETY SYSTEM
Siemens, GE
VAPORIZER
HTR
PURITY MONITOR?
RELIEFS
Ar PURGE VENT
GAS ANALYZERS
Ar + H2 MIX
HEATER
ARGON VENT
Internal Cryogenics Subsystem
T300 VESSEL x 2
SHELDS
External Cryogenics Subsystem
Proximity Cryogenics Subsystem



Typical P&ID Cryostat, Proximity

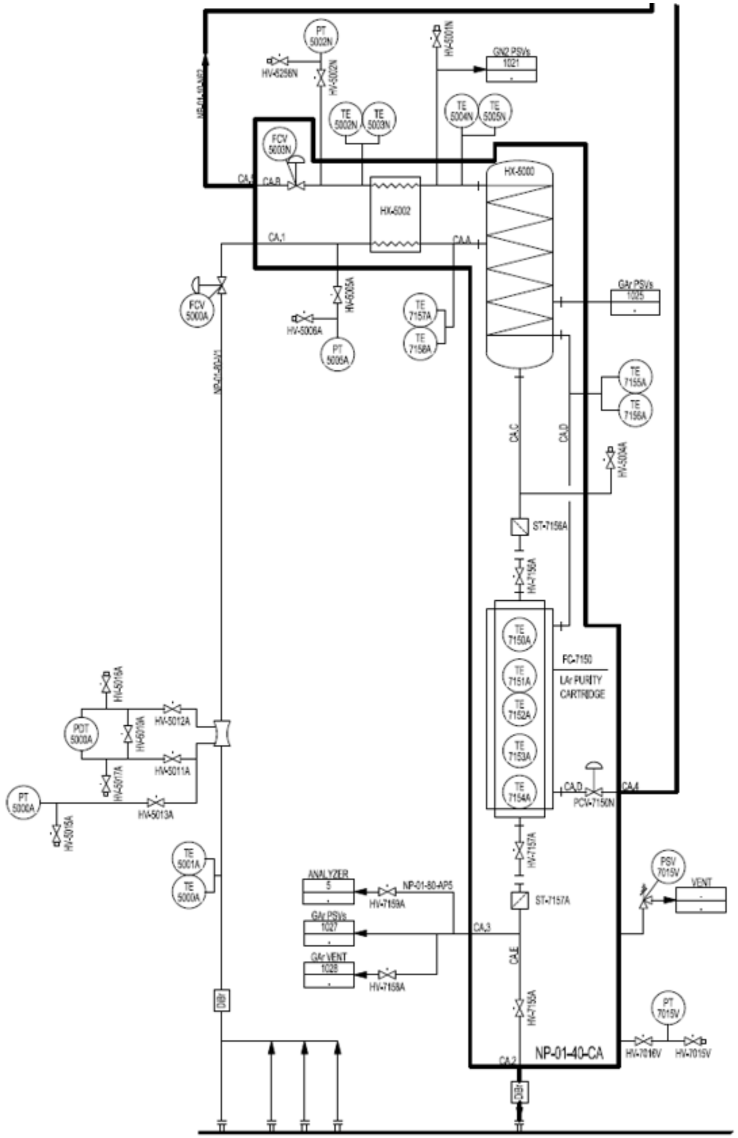


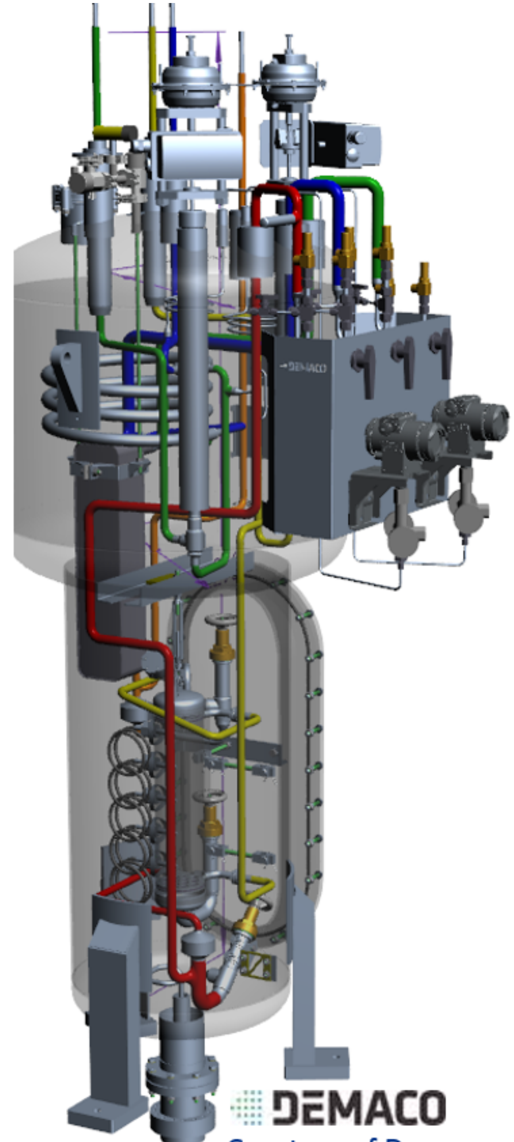
Typical P&ID
Proximity, External



Typical P&ID
Proximity, External

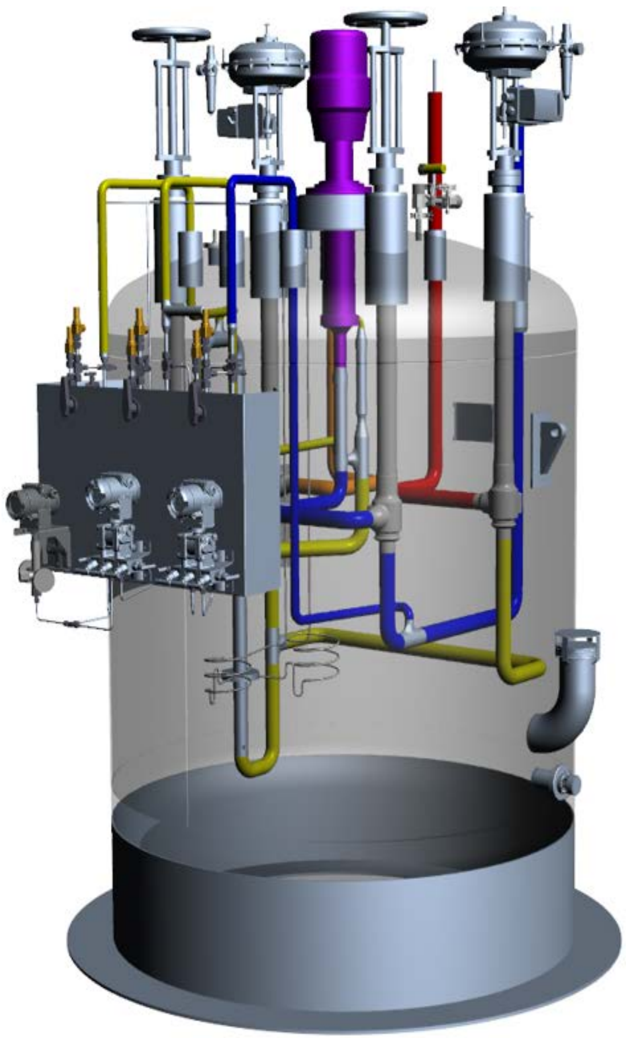
Typical Design: Condenser-Filter



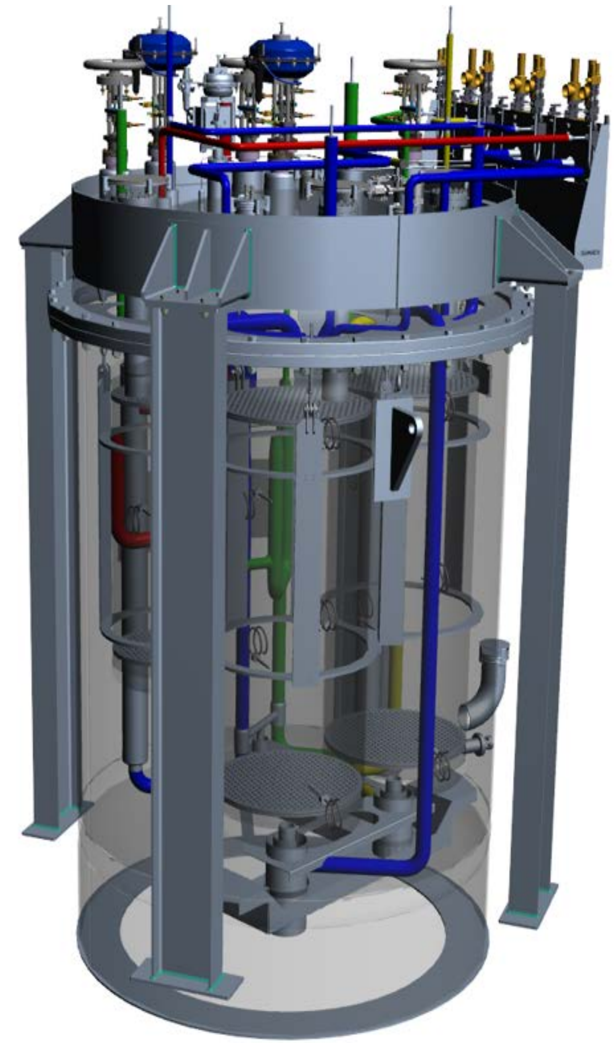


Courtesy of Demaco

Typical Design: LAr pump, External filter

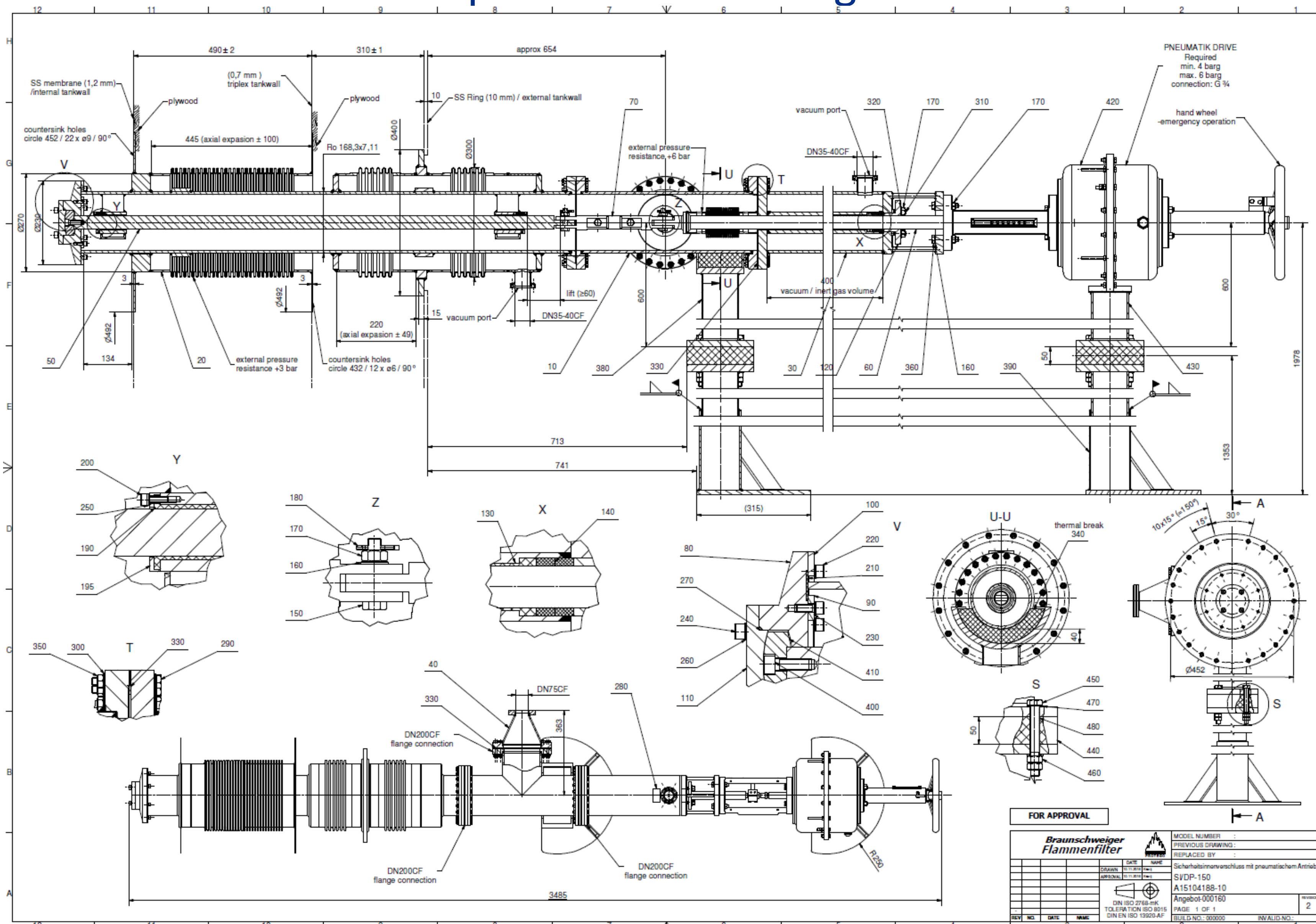


DEMACO
Courtesy of Demaco



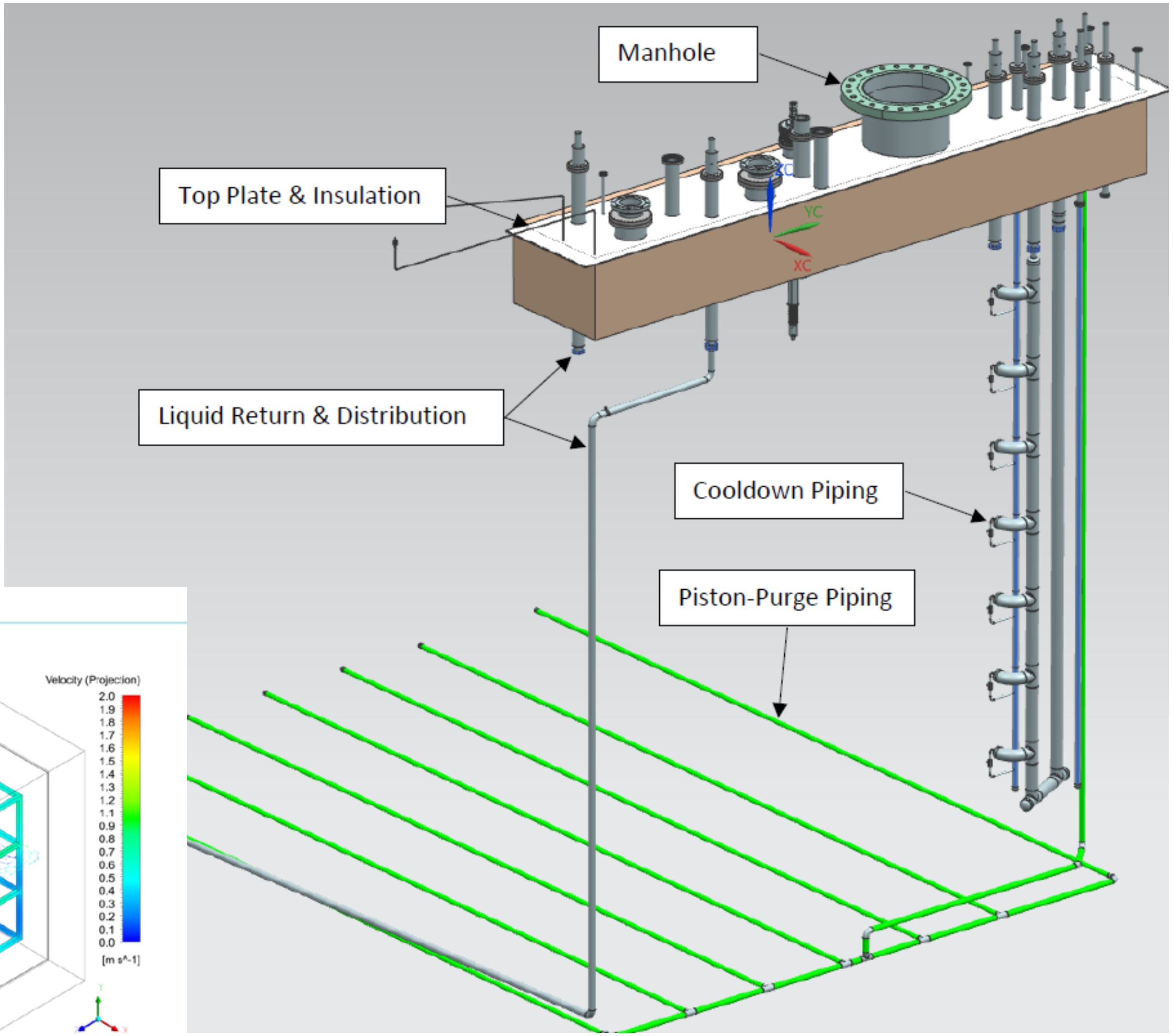
DEMACO
Courtesy of Demaco

Side penetration: Protego®

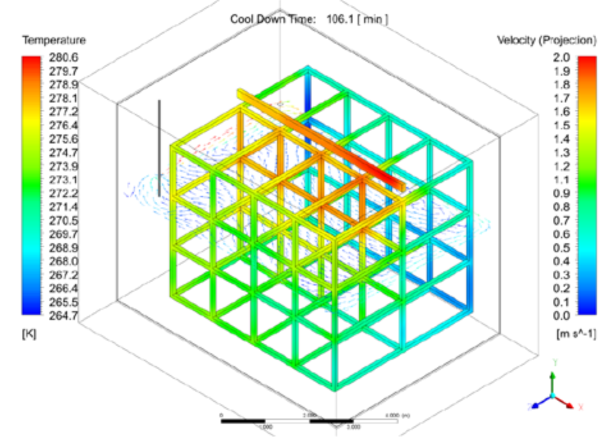


Internal cryogenic system for SBND

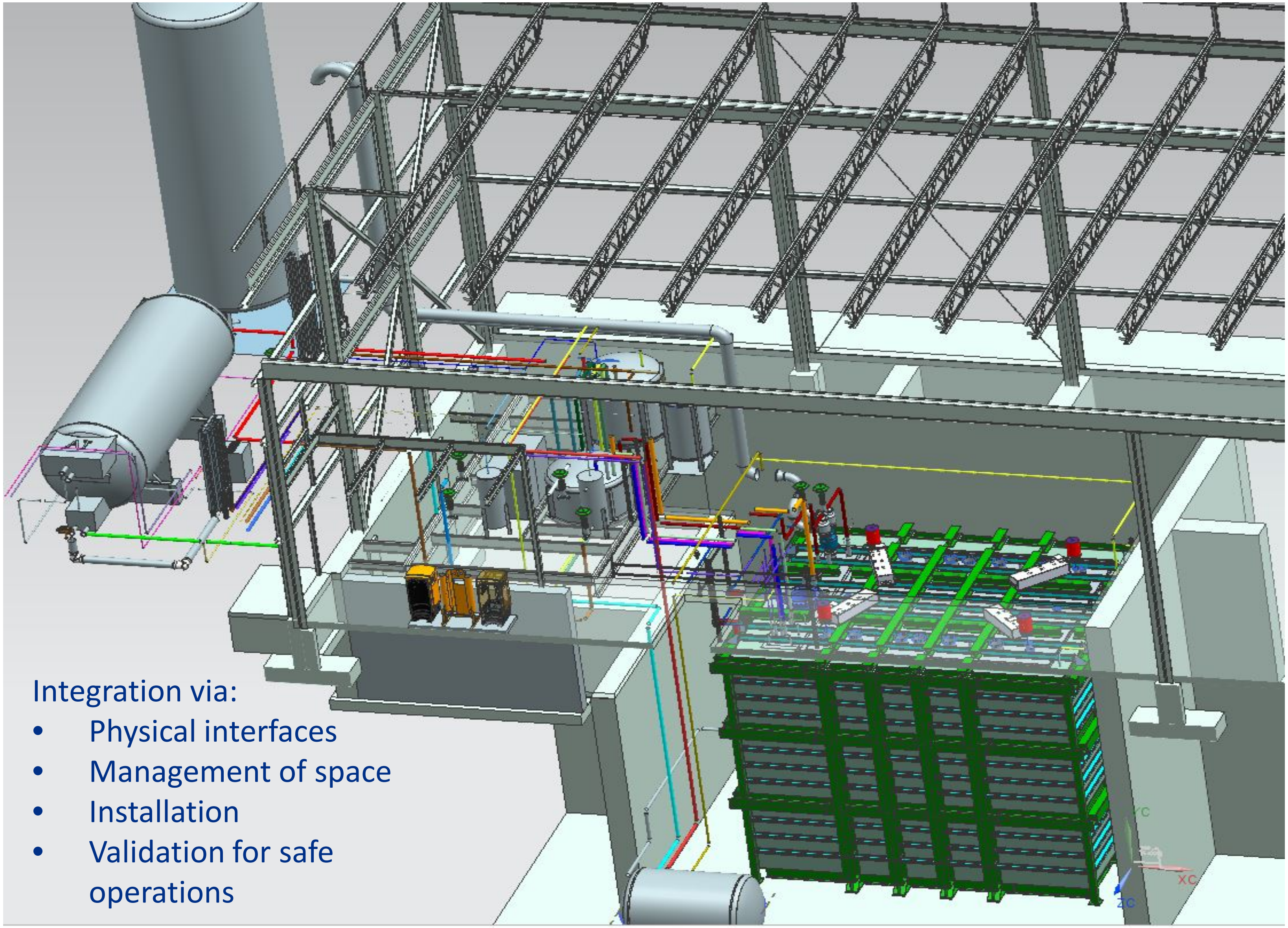
- Connecting interfaces
- Support of internal piping
- Design based on modeling
- SBN Cooldown - CFD Simulation



Frame Temperature @ 106 minutes

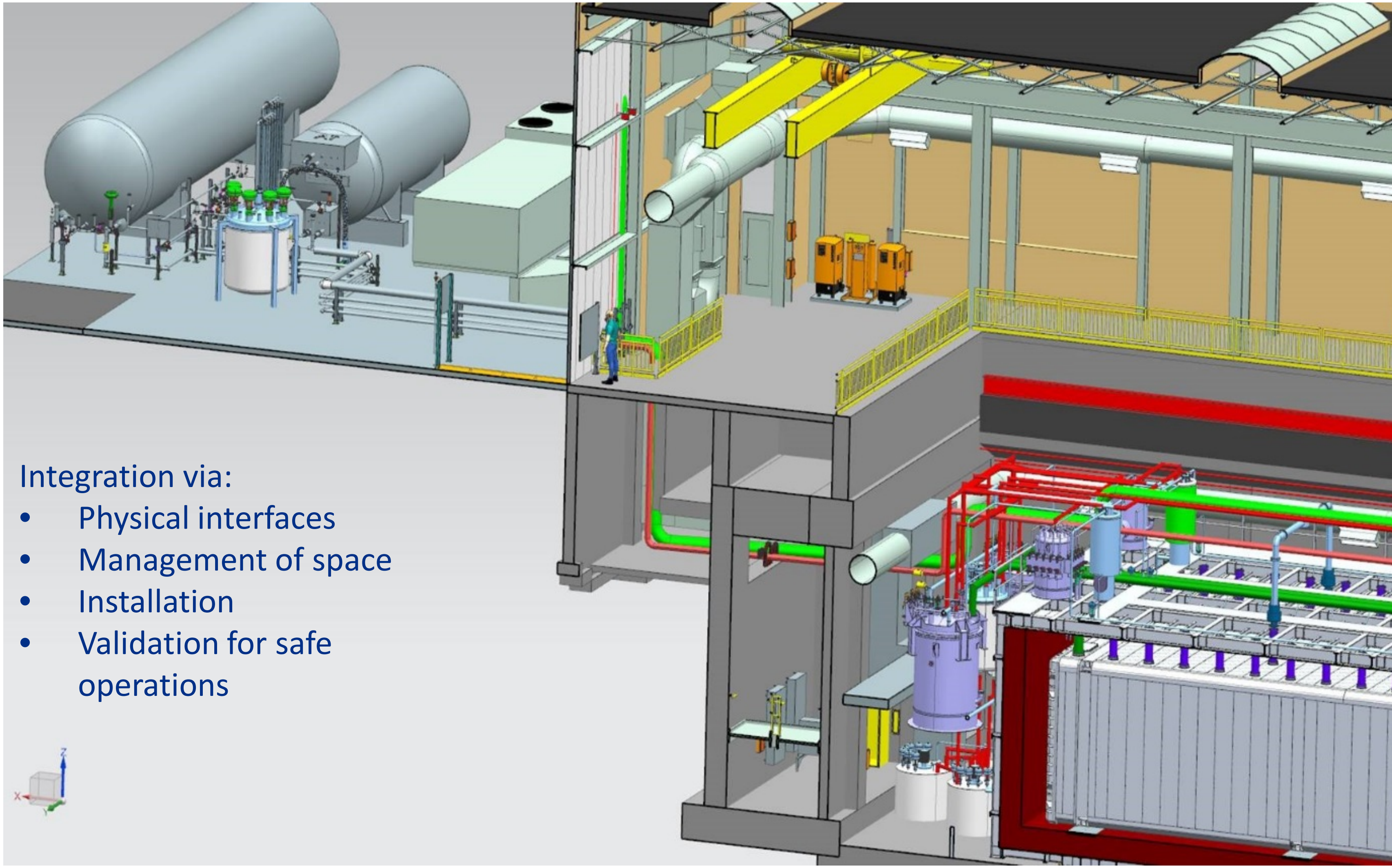


Integration: SBND



Integration via:
- Physical interfaces
- Management of space
- Installation
- Validation for safe operations

Integration: SBN-FD



Integration via:
- Physical interfaces
- Management of space
- Installation
- Validation for safe operations

Conclusions:

- Fermilab has already added two new neutrino detector buildings to the Neutrino Campus at Fermilab.
- Equipment for External cryogenics is beginning to populate SBND and SBNFD (in-house designed and constructed)
- The Proximity cryogenics are being designed and constructed in Europe.
- The commissioning of the cryogenic systems is scheduled for 2018 (SBN-FD) with SBND following.
- Many of the design solutions will be tested for SBN cryogenics to validate design of the cryogenic system for the LBNF/DUNE project.