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PIP- II Cryogenics

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PIP-II Machine Advisory Committee Meeting

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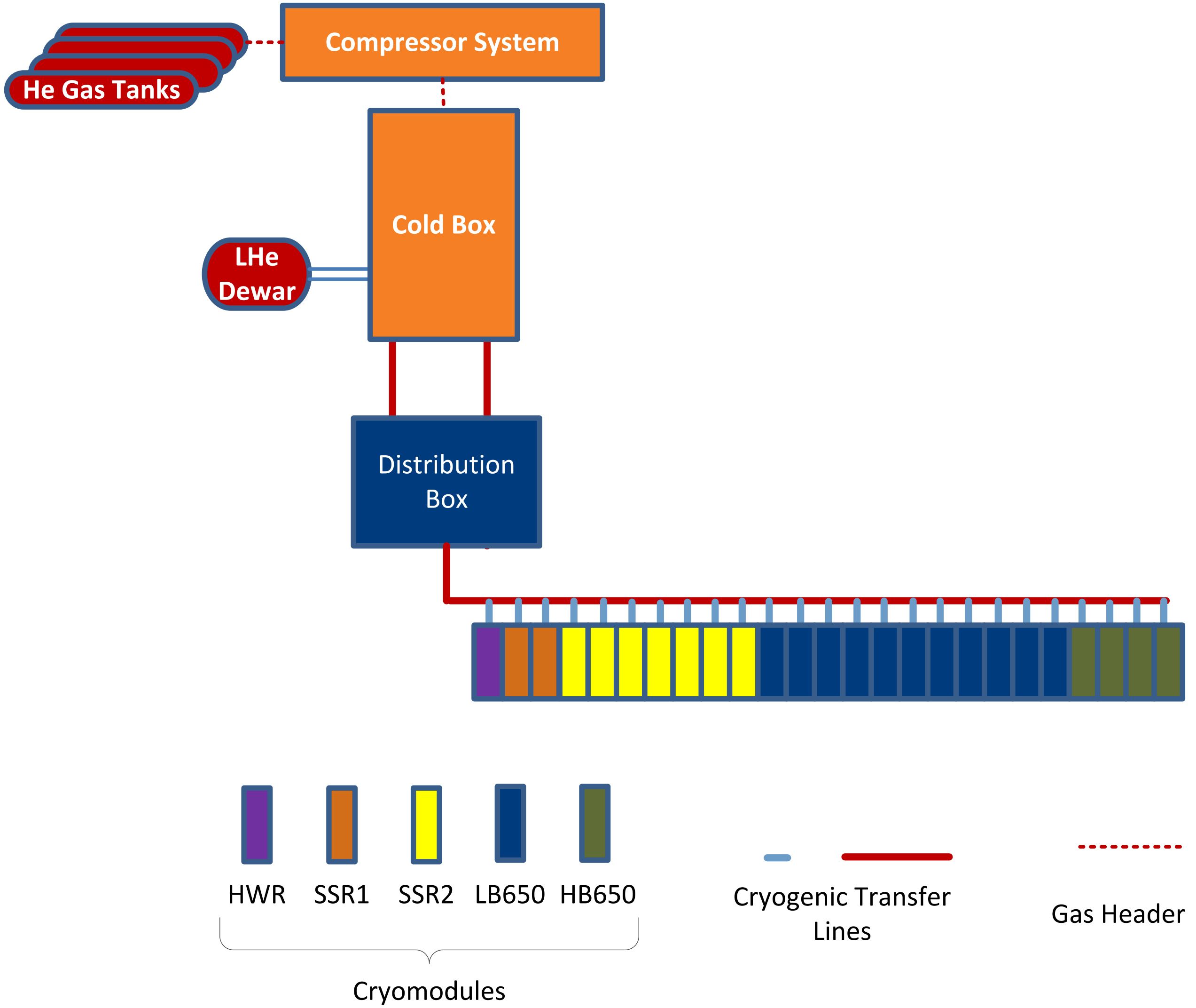
Outline

- System overview
- Scope of work
- Requirements
- Technical choices
- Summary

System overview



Scope

- Cryogenic plant
- Cryogenic distribution system
- Ancillary systems (purification system, cryogenic storage, etc.)

Requirements

- Provide for full segmentation of the Linac
- Cover all possible operating scenarios
- Support cryogenic loads at various temperature levels
- Cope with the load fluctuations
- Maintain stable pressure to minimize microphonics (100 Pa)
- Reduce system perturbations during fault conditions
- Rapid cool-down and warm-up of cryomodules

Requirements (2)

- Allow installation/removal of a cryomodule under cold conditions
- Commission the cryogenic system independent of cryomodules
- Minimize loss of cryogens
- Provide for some redundancy among its components and sub-systems
- Ensure that the system and its components comply with the Fermilab ES&H manual

Heat Load Range

Three operational scenarios:

1. CW mode, conservative Q_0
2. CW mode, achievable Q_0
3. Pulsed mode

	Total Heat Load		
	Low Temp	LT Shield	HT Intercept
Scenario	[W @ 2K]	[kW @ 5K]	[kW @ 70K]
# 1	1,977	1.1	3.5
# 2	1,665		
# 3	491		

Wide range of the 2 K heat load

Capacity Installed

- Installed cryogenic capacity - $Q_{installed}$

$Q_{installed}$ ➔ (Q_{static}, $Q_{dynamic}$, F_{us}, $F_{overcapacity}$), where

Q_{static} – static heat load

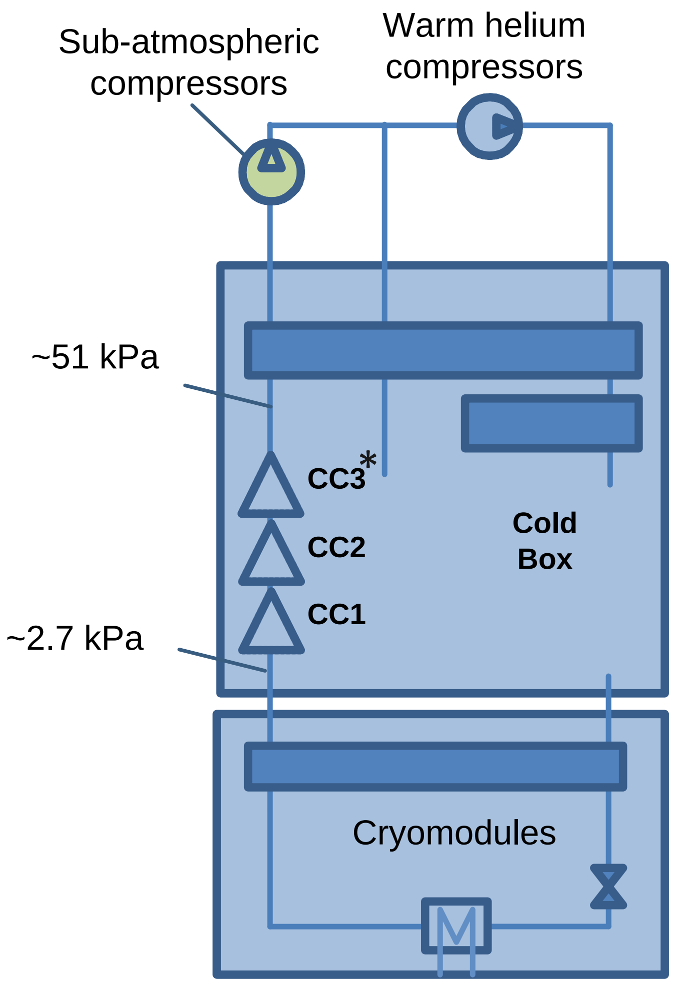
$Q_{dynamic}$ – dynamic heat load

F_{us} – static heat load uncertainty of estimate factor (30%)

$F_{overcapacity}$ – extra capacity for cooldown and system degradation (10%)

Scenario	Required Capacity
	[kW @ 2K]
# 1	2.3
# 2	2.0
# 3	0.7

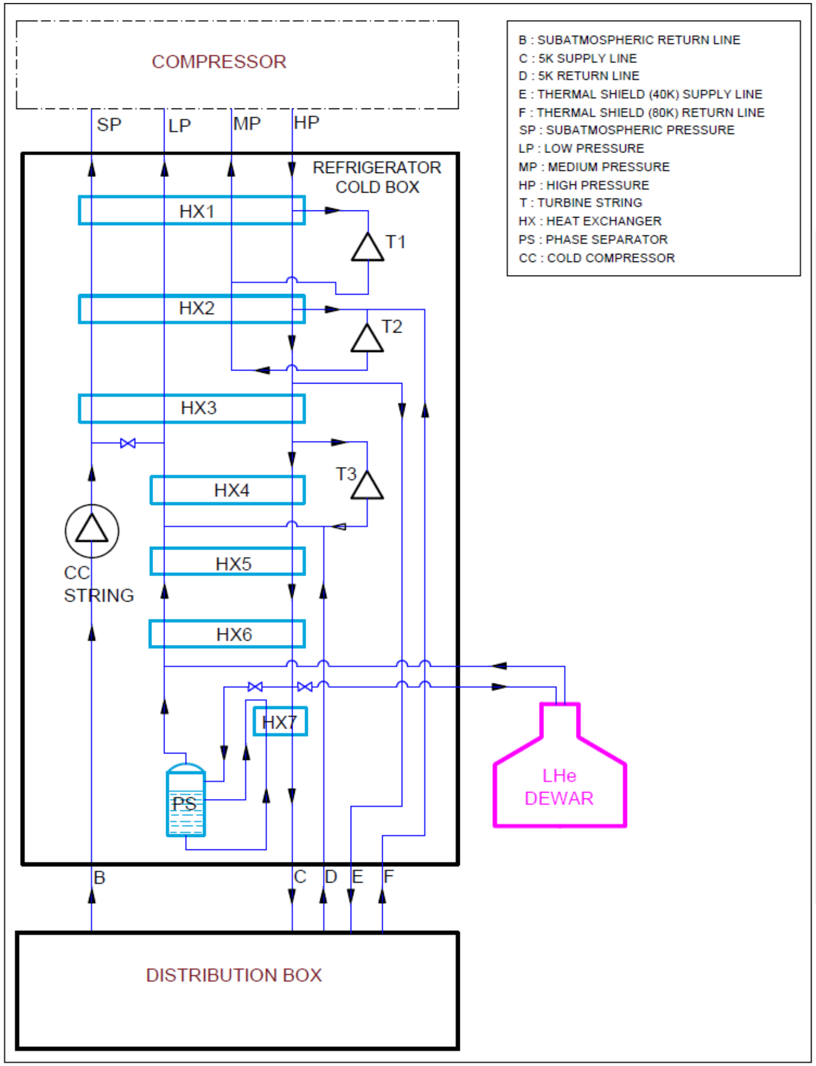
Technical choice - hybrid pumping

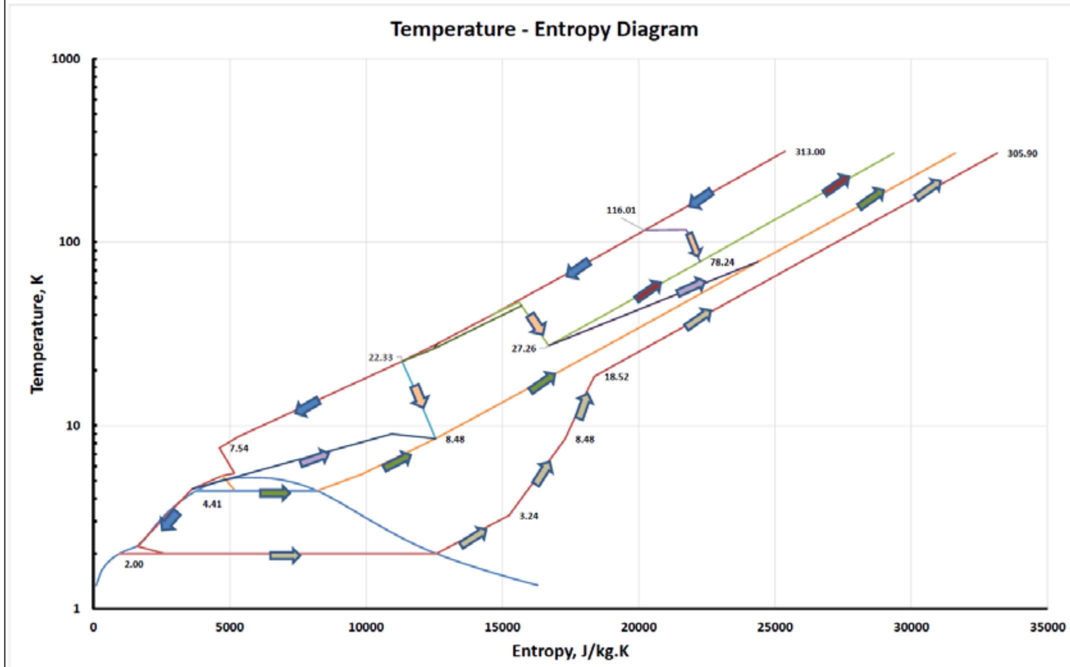


* - may require more than 3 stages of cold compression

- 2 kW @ 2K Refrigerator with three (+) stages of cold compressors and warm sub atmospheric helium compressors system connected in series (LHC like)
- Decrease of the warm vacuum pumps suction pressure enables to linearly reduce the cold compressors mass flow. This in turn allows the cold compressors to stay within their respective working hydrodynamic fields away from surge or stall areas
- Up to 50% turn down range
- Will require operation in a liquefier mode to support Linac's pulsed operation

Reference Cycle





Plant Configuration A

Refrigeration	2K (W)	5 – 9K (W)	35 – 75K (W)
Nominal Capacity*	2,500 (Max: 2,624)	900 (Max: 944)	➢ 13,000 ➢ (Max: 13,650)
Supply Pressure	3 bar	3 bar	< 23 bar
Return Pressure	27 mbar	> 1.3 bar	> 14 bar
Supply Temp	4.5 K	4.5 K	< 35 K
Return Temp	≈ 3.3 K	< 9 K	< 75 K

* - Nominal Capacity; max – expected values

Plant Configuration B

Refrigeration	2K (W)	5 – 9K (W)	35 – 75K (W)
Nominal Capacity*	2,000 (Max: 2,153)	1,900 (Max: 2,099)	➢ 13,000 ➢ (Max: 13,650)
Supply Pressure	3 bar	3 bar	< 23 bar
Return Pressure	27 mbar	> 1.3 bar	> 14 bar
Supply Temp	4.5 K	4.5 K	< 35 K
Return Temp	≈ 3.3 K	< 9 K	< 75 K

* - Nominal Capacity; max – expected values

Plant Configuration C

Refrigeration**	2K (W)	5 – 9K (W)	35 – 75K (W)
Nominal Capacity*	~ 700	1,900 (Max: 2,099)	➢ 13,000 ➢ (Max: 13,650)
Supply Pressure	3 bar	3 bar	< 23 bar
Return Pressure	27 mbar	> 1.3 bar	> 14 bar
Supply Temp	4.5 K	4.5 K	< 35 K
Return Temp	≈ 3.3 K	< 9 K	< 75 K

* - Nominal Capacity; max – expected values

** - Liquefier mode operation; requires 60% of the main compressor flow

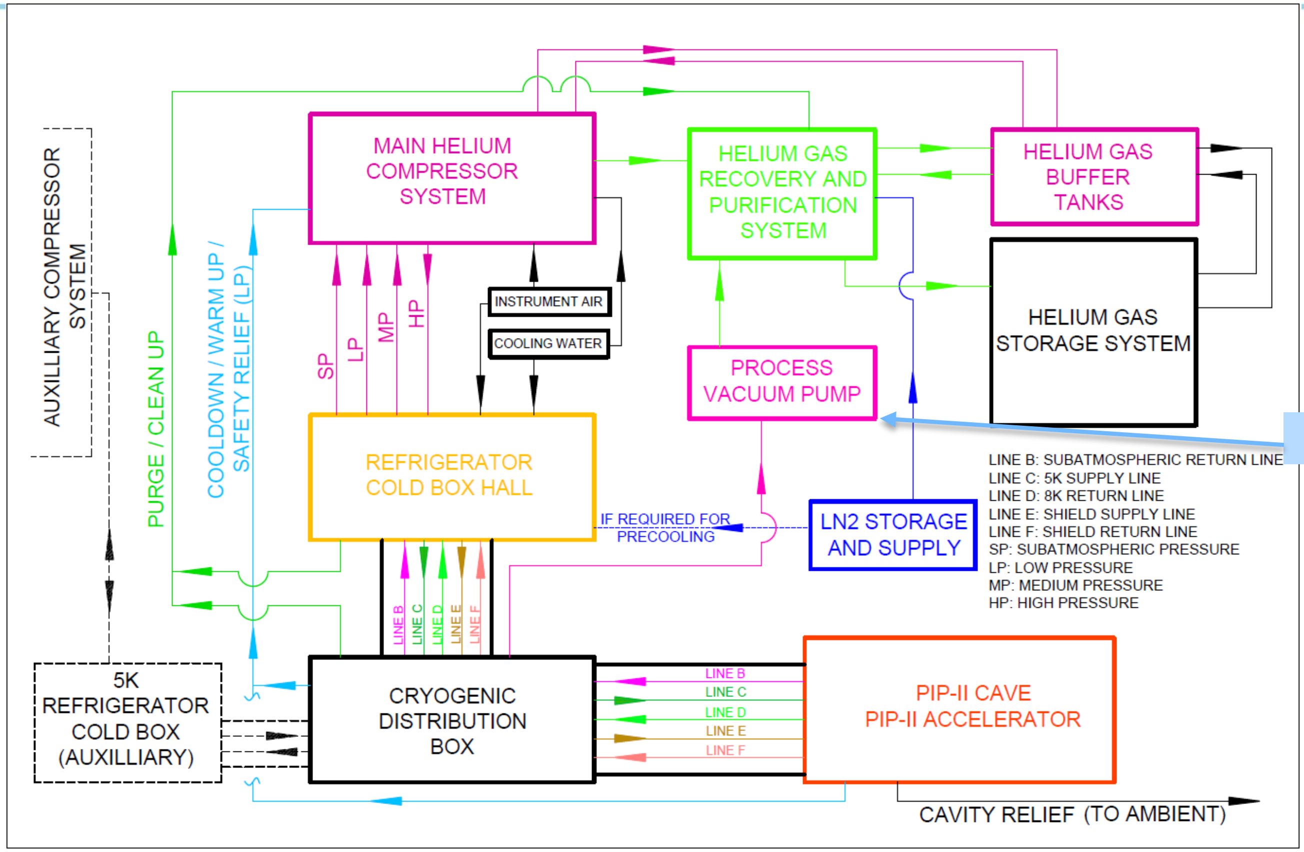
2 kW @ 2K CBx

Scenario	Configuration
# 1	A*
# 2	B
# 3	C

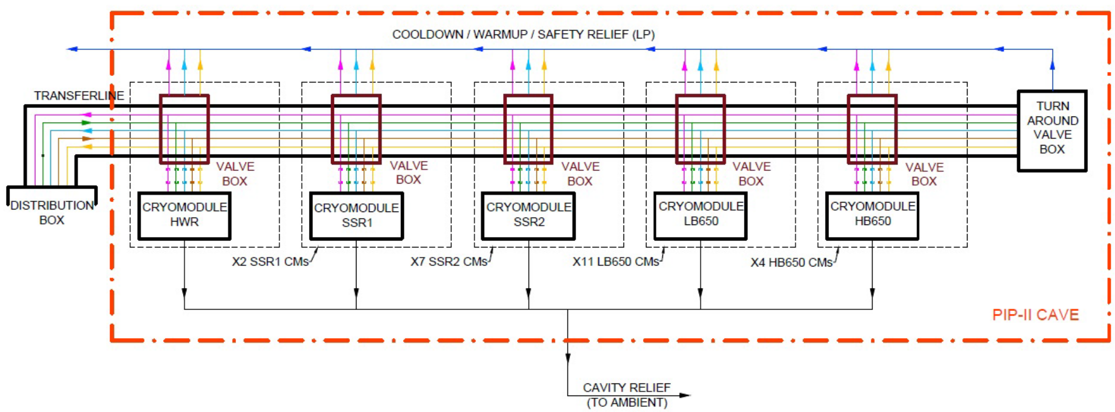
* - Will require additional 5 K CBx to meet LTS requirements

The 2 KW @ 2 K cold box can be reconfigured for the key operation scenarios and Q_0 assumptions

PIP-II Cryogenic System Diagram



Used for pulsed mode only



Fermilab PIP-II

Safety

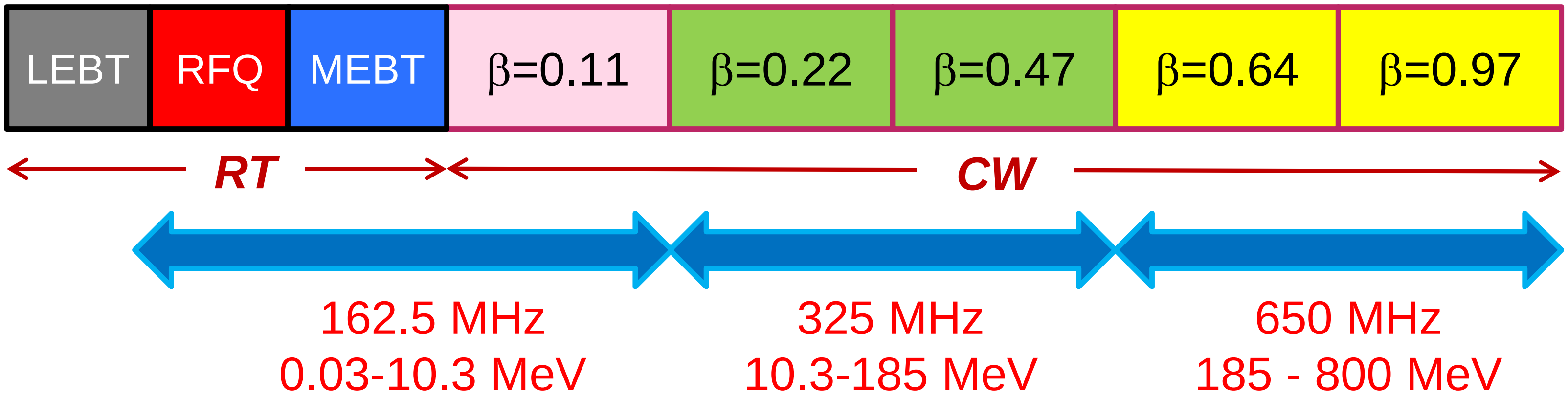
- PIP-II Cryogenic system will use compressed and liquefied Helium
- This presents potential following hazards:
  - Extreme cold hazard
  - Oxygen Deficiency Hazard (ODH)
  - Oxygen enriched hazard
  - Over pressurization or explosion due to rapid expansion
  - High noise levels
- The approach to protection from hazards by minimizing potential hazards at levels as low as is reasonable will be incorporated in a design for the PIP-II Cryogenic system
  - Utilizing National and International Codes and Standards for pressure systems design
  - Segment insulating vacuum (reduces release rate)
  - Move relief valves out of the tunnel wherever possible
  - Pipe all relief valves outside (whenever possible)
  - Reduce heat flux by adding insulation
  - Provide barriers to minimize external effects/damages

Summary

- Cryogenic system technical scope is defined
- Functional performance requirements and key interfaces are identified
- Heat load sources are identified and documented
- Strategy and technical solutions to support wide range of cryogenic load is developed
- CDS and Cryoplant are being designed as a single system with safety considerations in the design phase

Back-up

System overview



Parameter	Requirement	Units
RF pulse length	pulsed-to-CW	
Average beam current in SC Linac	2	mA

CM type	Cavities per CM	Number of CMs	CM configuration	CM length (m)
HWR	8	1	8 × (sc)	5.93
SSR1	8	2	4 × (csc)	5.2
SSR2	5	7	sccsccsc	6.5♦
LB650	3	11	ccc	3.9♦
HB650	6	4	cccccc	9.5♦

Heat Load: Scenario #1 → CW Mode, Conservative Q_0

#	Cryomodule Type	Static	Dynamic	Total	LT Shield	HT Intercept
		[W @ 2K]	[W @ 2K]	[W @ 2K]	[W @ 5K]	[W @ 70K]
1	HWR	37	24	61	60	250
2	SSR1	13	23	36	80	166
3	SSR1	13	23	36	80	166
4	SSR2	8.8	52	61	50	126
5	SSR2	8.8	52	61	50	126
6	SSR2	8.8	52	61	50	126
7	SSR2	8.8	52	61	50	126
8	SSR2	8.8	52	61	50	126
9	SSR2	8.8	52	61	50	126
10	SSR2	8.8	52	61	50	126
11	650MHz LB	2	56	58	16	48
12	650MHz LB	2	56	58	16	48
13	650MHz LB	2	56	58	16	48
14	650MHz LB	2	56	58	16	48
15	650MHz LB	2	56	58	16	48
16	650MHz LB	2	56	58	16	48
17	650MHz LB	2	56	58	16	48
18	650MHz LB	2	56	58	16	48
19	650MHz LB	2	56	58	16	48
20	650MHz LB	2	56	58	16	48
21	650MHz LB	2	56	58	16	48
22	650MHz HB	4	130	134	32	86
23	650MHz HB	4	130	134	32	86
24	650MHz HB	4	130	134	32	86
25	650MHz HB	4	130	134	32	86
26	CDS	249		249	137	670
	TOTAL	**411**	**1566**	**1977**	**1011**	**3006**

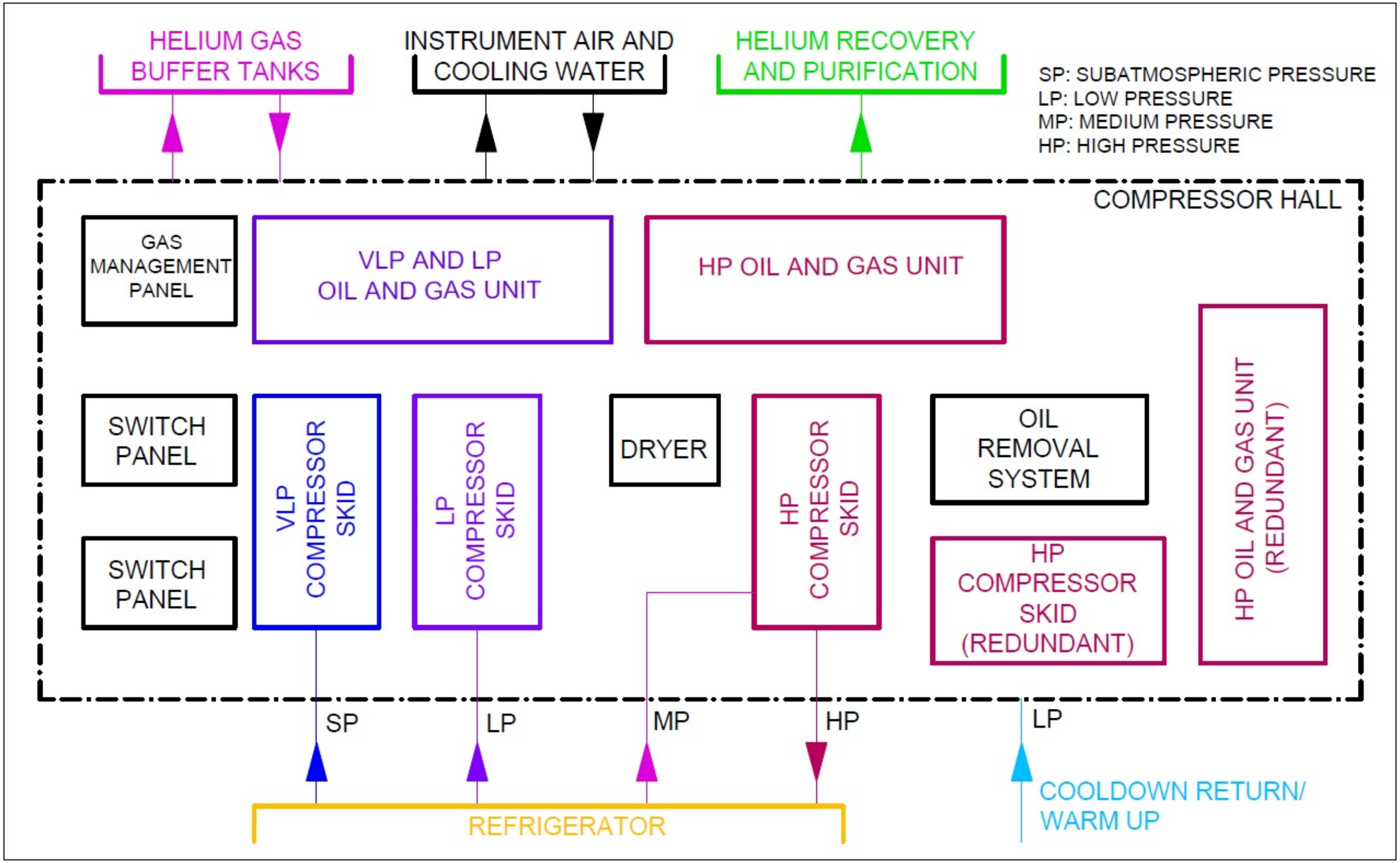
Heat Load: Scenario #1 → CW Mode, Achievable Q_0

#	Cryomodule Type	Static	Dynamic	Total	LT Shield	HT Intercept
		[W @ 2K]	[W @ 2K]	[W @ 2K]	[W @ 5K]	[W @ 70K]
1	HWR	37	24	61	60	250
2	SSR1	13	23	36	80	166
3	SSR1	13	23	36	80	166
4	SSR2	8.8	52	61	50	126
5	SSR2	8.8	52	61	50	126
6	SSR2	8.8	52	61	50	126
7	SSR2	8.8	52	61	50	126
8	SSR2	8.8	52	61	50	126
9	SSR2	8.8	52	61	50	126
10	SSR2	8.8	52	61	50	126
11	650MHz LB	2	38	40	16	48
12	650MHz LB	2	38	40	16	48
13	650MHz LB	2	38	40	16	48
14	650MHz LB	2	38	40	16	48
15	650MHz LB	2	38	40	16	48
16	650MHz LB	2	38	40	16	48
17	650MHz LB	2	38	40	16	48
18	650MHz LB	2	38	40	16	48
19	650MHz LB	2	38	40	16	48
20	650MHz LB	2	38	40	16	48
21	650MHz LB	2	38	40	16	48
22	650MHz HB	4	100	104	32	86
23	650MHz HB	4	100	104	32	86
24	650MHz HB	4	100	104	32	86
25	650MHz HB	4	100	104	32	86
26	CDS	249		249	137	670
	TOTAL	**411**	**1254**	**1665**	**1011**	**3006**

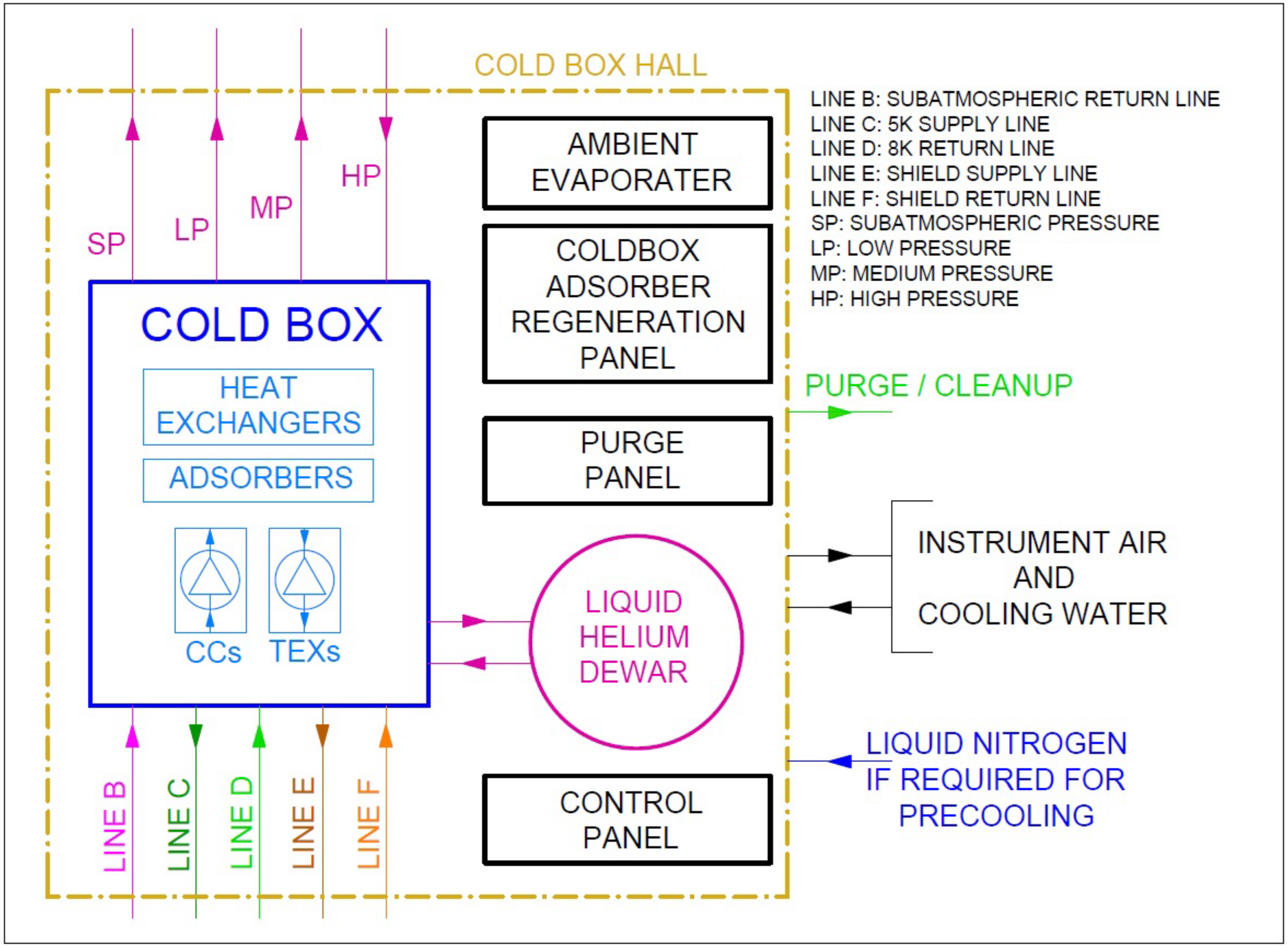
Heat Load: Scenario #3 ➔ Pulsed, Acc Cavity Discharge

#	Cryomodule Type	Static	Dynamic	Total	LT Shield	HT Intercept
		[W @ 2K]	[W @ 2K]	[W @ 2K]	[W @ 5K]	[W @ 70K]
1	HWR	37	0	37	60	250
2	SSR1	12	1	13	80	166
3	SSR1	12	1	13	80	166
4	SSR2	9	3	12	50	126
5	SSR2	9	3	12	50	126
6	SSR2	9	3	12	50	126
7	SSR2	9	3	12	50	126
8	SSR2	9	3	12	50	126
9	SSR2	9	3	12	50	126
10	SSR2	9	3	12	50	126
11	650MHz LB	2	3	5	16	48
12	650MHz LB	2	3	5	16	48
13	650MHz LB	2	3	5	16	48
14	650MHz LB	2	3	5	16	48
15	650MHz LB	2	3	5	16	48
16	650MHz LB	2	3	5	16	48
17	650MHz LB	2	3	5	16	48
18	650MHz LB	2	3	5	16	48
19	650MHz LB	2	3	5	16	48
20	650MHz LB	2	3	5	16	48
21	650MHz LB	2	3	5	16	48
22	650MHz HB	4	7	11	32	86
23	650MHz HB	4	7	11	32	86
24	650MHz HB	4	7	11	32	86
25	650MHz HB	4	7	11	32	86
26	CDS	249		249	137	670
	TOTAL	**411**	**80**	**491**	**1011**	**3006**

PIP-II Cryogenic System Diagram - Compressor Hall



PIP-II Cryogenic System Diagram - CBx Area



Risks

- Cryogenic system specification changes
- Cryoplant Design Requirements
- Cryoplant delivery delay
- Qualified vendors availability and capacities
  - Competition for cryogenic components fabrication
  - Limited number of vendors with cryogenic engineering and design capabilities
  - Multiple parallel procurements within limited market

Safety (2)

Cryogenic System Design, Fabrication and Installation will comply with Fermilab ESH&Q Manuals including the following national standards:

- ASME Boiler and Pressure Vessel Code Section VIII
- ASME/ANSI B31.3 Process Piping
- Expansion Joint Manufacturers Association
- Compressed Gas Association Pressure Relief Standards
- Independent review