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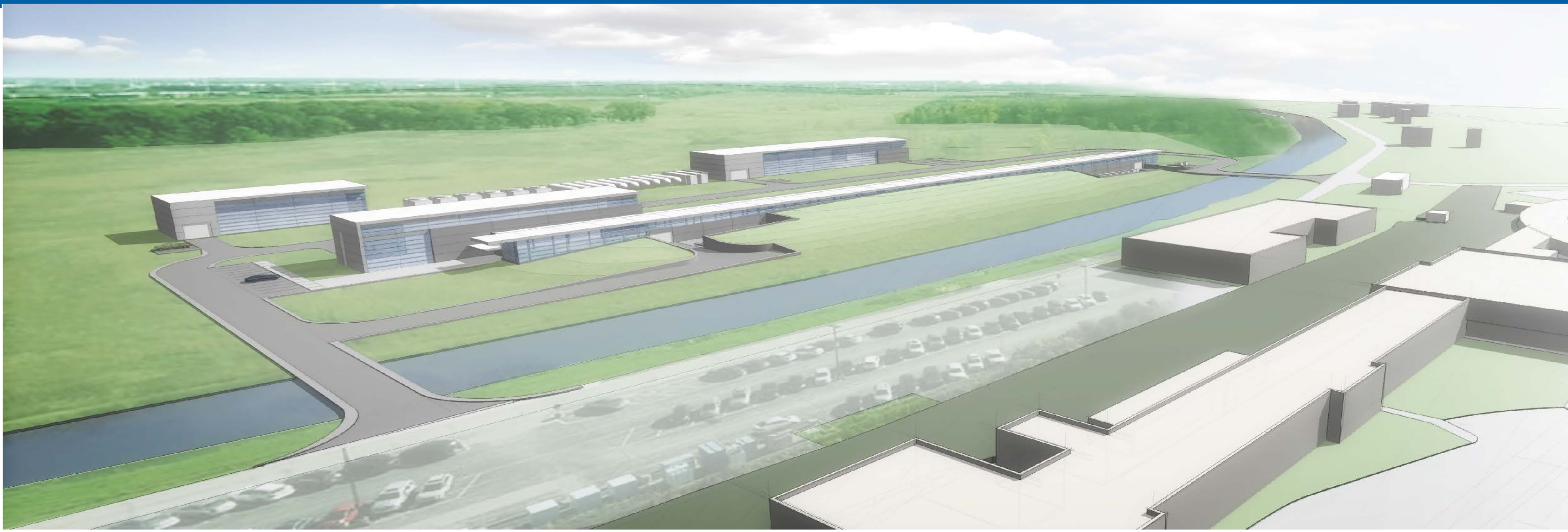


WBS 121.3.11 Cryogenics

SC Acceleration Modules and Cryogenics

Anindya Chakravarty and Arkadiy Klebaner

PIP-II Director's Review

10-12 October 2017

In partnership with:
India Institutes Fermilab Collaboration
Istituto Nazionale di Fisica Nucleare
Science and Technology Facilities Council

Outline

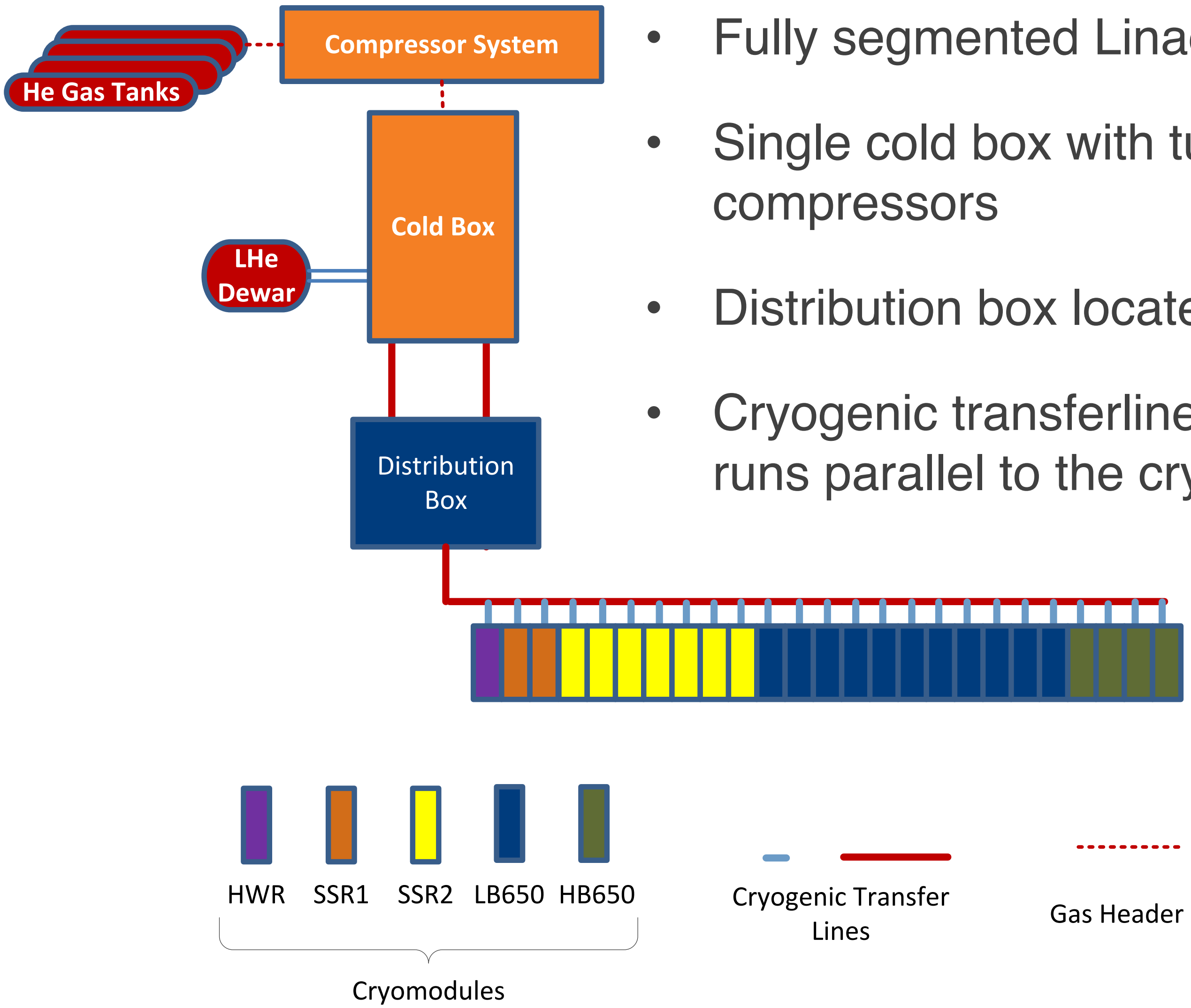
- System overview
- About Me
- Performance Requirements
- Conceptual Design, Maturity
- Scope/Deliverables
- Interfaces
- Organization
- Technical Progress to Date/Design Review Plan
- ESH&Q
- Cost
- Risk
- Schedule
- Summary

About Me:

- Role in PIP-II: Scientist
  - Superfluid Helium Cryogenic Plant and associated systems

- Relevant experience:
  - SO-G, CrTD, BARC (current position)
  - Group Leader, CrTD, BARC
  - Development of helium liquefaction and refrigeration systems at BARC
  - Development of cryogenic turboexpanders at BARC
  - Ph. D. in Cryogenic Engineering

System Overview



- Fully segmented Linac
- Single cold box with turbines and cold compressors
- Distribution box located in the refrigerator room
- Cryogenic transferline with bayonet cans that runs parallel to the cryomodules

WBS 121.11.3 Requirements flow down

PIP-II Conceptual Design Report

PIP-II Conceptual Design Report

- ➔Engineering Manual, Fermilab ESH&Q Manual
- ➔Cryomodules requirement documents

TC#ED0001313, TC#ED0001316, TC#ED0001829, TC#ED0001830, TC#ED0001322

- ➔Cryogenic System

*Functional Requirements Specifications (*TC#ED0003531*)*
*Engineering Specifications (*TC#ED0005493,5587, etc.*)*
*Design Criteria Documents (*TC#ED0004748, 6895, etc.*)*
*Engineering Notes (*TC#ED0003531,6860, 6901, etc.*)*
*Interface Control Documents (*TC#ED0006893*)*

Key Requirements

Details are in TC#ED0003531

- ***Project Key Performance Parameters*** and ***Physics Requirements*** shall be met
- Linac operating modes:
  - CW or pulsed mode
  - 2.0 K in the standby mode
  - 4.5 K in standby mode
  - Cool-down and warm-up
- Cavity helium pressure – 31 mbar
- Cavity helium pressure stability → ± 0.1 mbar
- Expected availability during scheduled beam operation – 98%
- Support cool-down or warm-up of the Linac in < 20 days

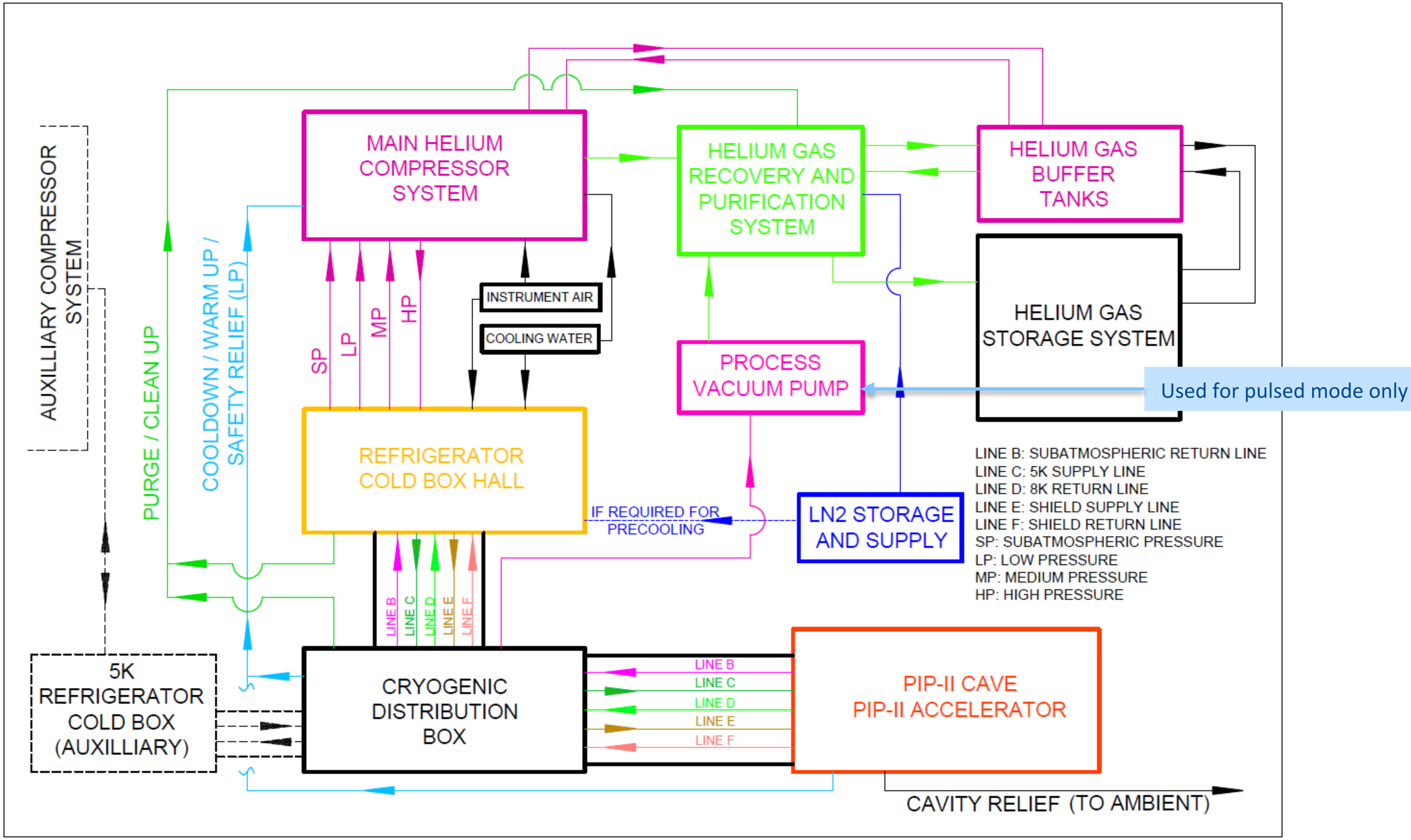
Key Requirements

Cryomodule Static and Dynamic Heat loads

CM	No. of CM	2K CW mode, (W)	2K Pulsed mode, (W)	5K Intercept, (W)	70 K Shield, (W)
HWR	1	61	61	60	250
SSR1	2	70	26	176	332
SSR2	7	429	83	434	882
650 MHz Lowβ	11	633	54	176	528
650 MHz Highβ	4	535	43	128	344
TOTAL		1728	267	974	2336

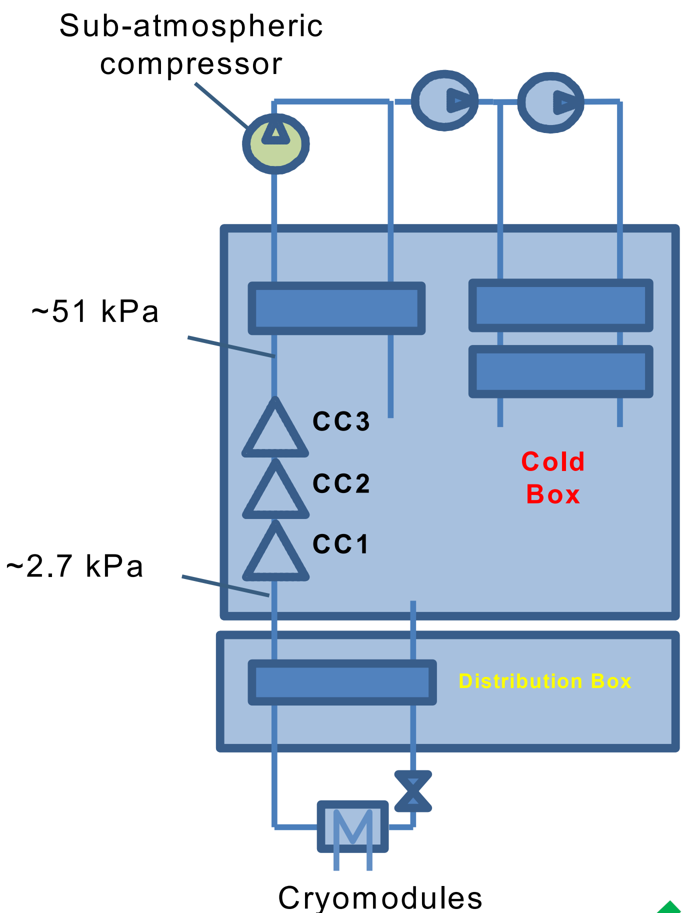
Requirements are defined and traceable

Cryogenic System Design – Conceptual Design



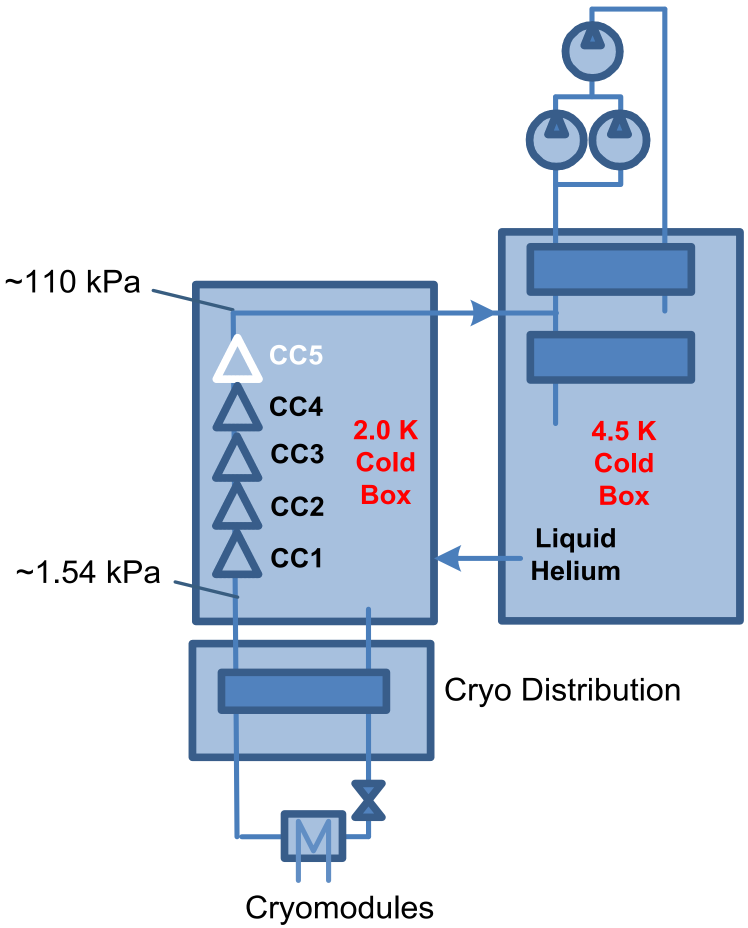
Cryogenic Plant Design – Conceptual Design

- Baseline



Hybrid cycle design

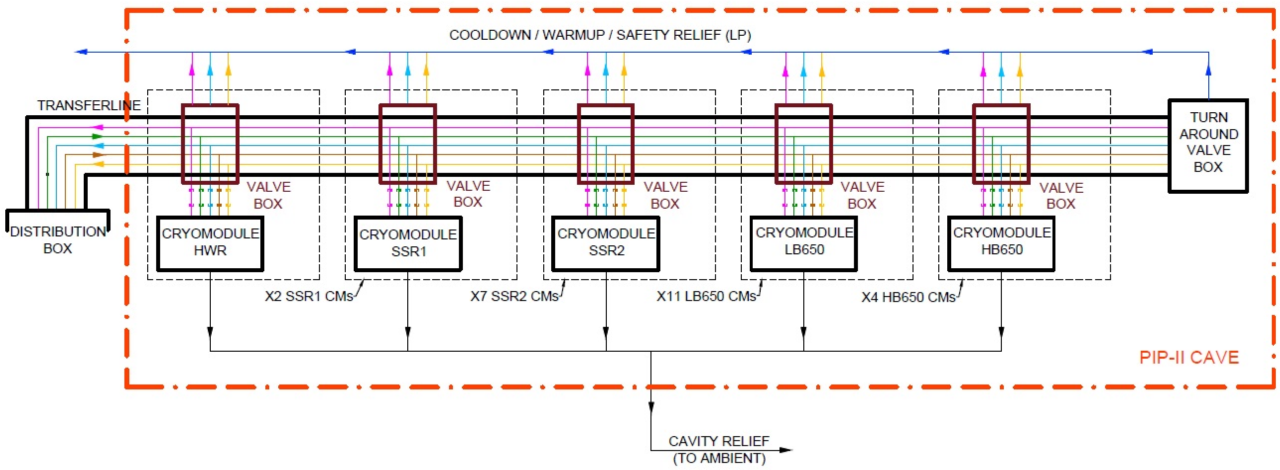
- Alternative



Cold compression design

PIP-II Cryogenic Distribution System (CDS) – Conceptual Design

- Fully segmented Linac
- Distribution box located in the refrigerator room
- Cryogenic transferline with bayonet cans that runs parallel to the cryomodules



Auxiliary Systems – Conceptual Design

- Warm and cold interconnect piping
- Warm helium storage tanks
- Liquid helium Dewar
- Helium recovery system
- Initial system purification equipment

Reuse from the Tevatron

Charge #1

Conceptual design is supporting key design requirements

Scope

- PIP-II Cryogenic Plant (121.3.11.2)
- PIP-II Cryogenic Distribution System (121.3.11.3)
- PIP2IT Cryogenic Distribution System (121.3.11.1)

Scope – Cryogenic Plant

- **2kW at 2.0 K Cryogenic plant**
  - Warm recirculation compressors with associated cooling, oil-removal systems and dryers, gas management system, refrigerator cold box(s) with heat exchangers, turbines, cold compressors, plant controls and instrumentation, acceptance test cryostat, and commissioning services ➔ **DAE/BARC Deliverables**
- **Ancillary support equipment**
  - Warm and cold interconnect piping, helium purification system, helium gas and liquid storage, liquid nitrogen storage – **FNAL**
- **Plant equipment installation services**
  - Rigging, welding, cabling, leak checking, pressure testing - **FNAL**

Scope – Cryogenic Distribution System (CDS)

- Design and fabricate components needed to feed and return the cryogens to the Linac components in accordance with functional requirements and other applicable specifications including:
  - Distribution Box
  - Tunnel cryogenic transferlines
  - Cryomodule bayonet can(s)
  - Vacuum insulated jumpers
  - Helium recovery headers
  - Turn around box
  - Pressure safety systems

Scope – PIP2IT Cryogenic Distribution System

- Design, fabricate, install, and commission components needed to feed and return the cryogens to the PIP2IT cryogenic system in accordance with functional requirements and other applicable specifications including:
  - External transferline
  - Cave transferline and turn around box
  - Vacuum insulated jumpers (u-tubes)
  - Cryogenic instrumentation and controls
  - Warm recovery headers
  - Installation and commissioning services
  - Transfer to operation services

Charge #2

Cryogenic system technical scope is defined for FNAL and BARC

Interfaces

Cryogenic System interfaces with the following sub systems:

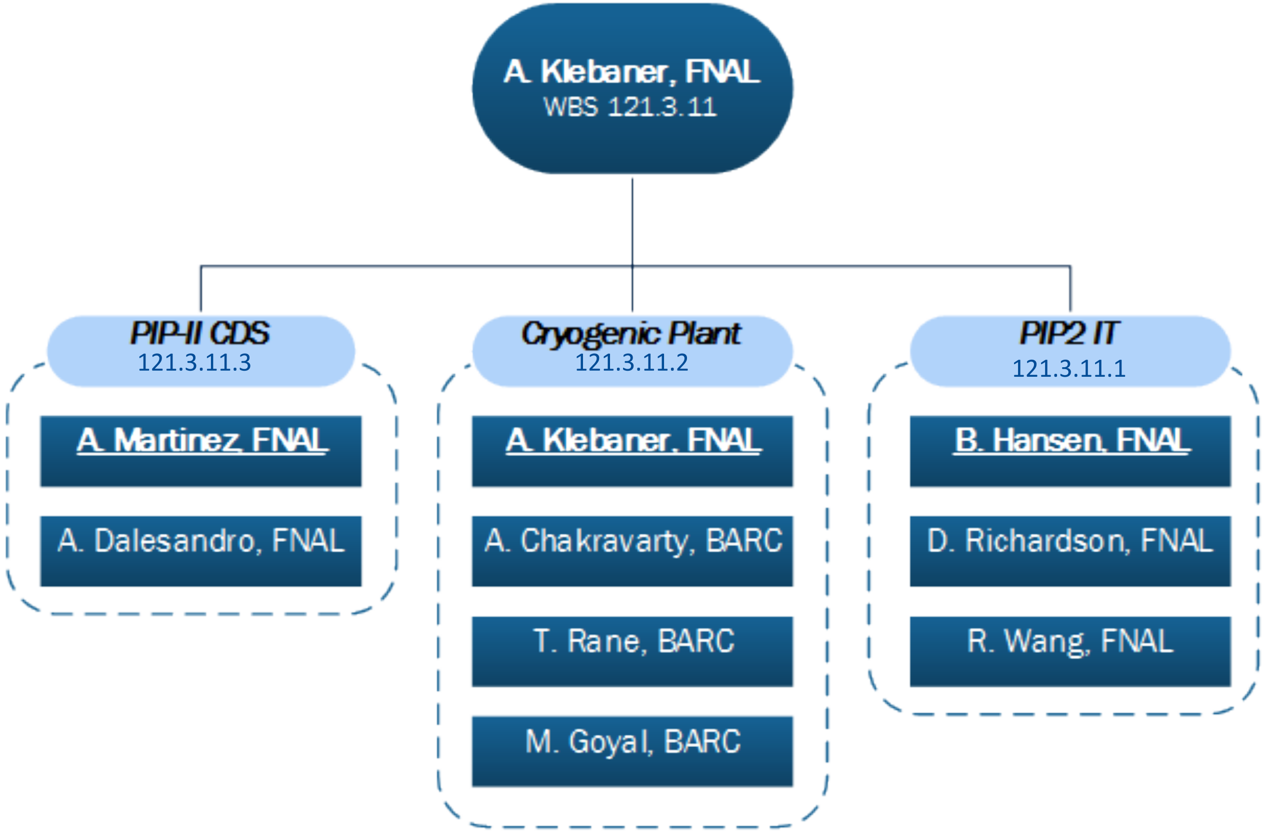
- Conventional Facilities (WBS 121.5)
- Control System (WBS 121.3.17)
- HWR (WBS 121.3.4)
- HB650 (WBS 121.3.8)
- Installation, Integration, Commmisioning (WBS 121.3.22)
- LB650 (WBS 121.3.7)
- Safety Systems (WBS 121.3.20)
- SSR1 (WBS 121.3.5)
- SSR2 (WBS 121.3.6)
- Vacuum System (WBS 121.3.18)

PIP-II DocDB doc#1160-v3 «PIP-II Interface Matrix »

Cryogenic System Interface Control Document (ICD) TC#ED0006893

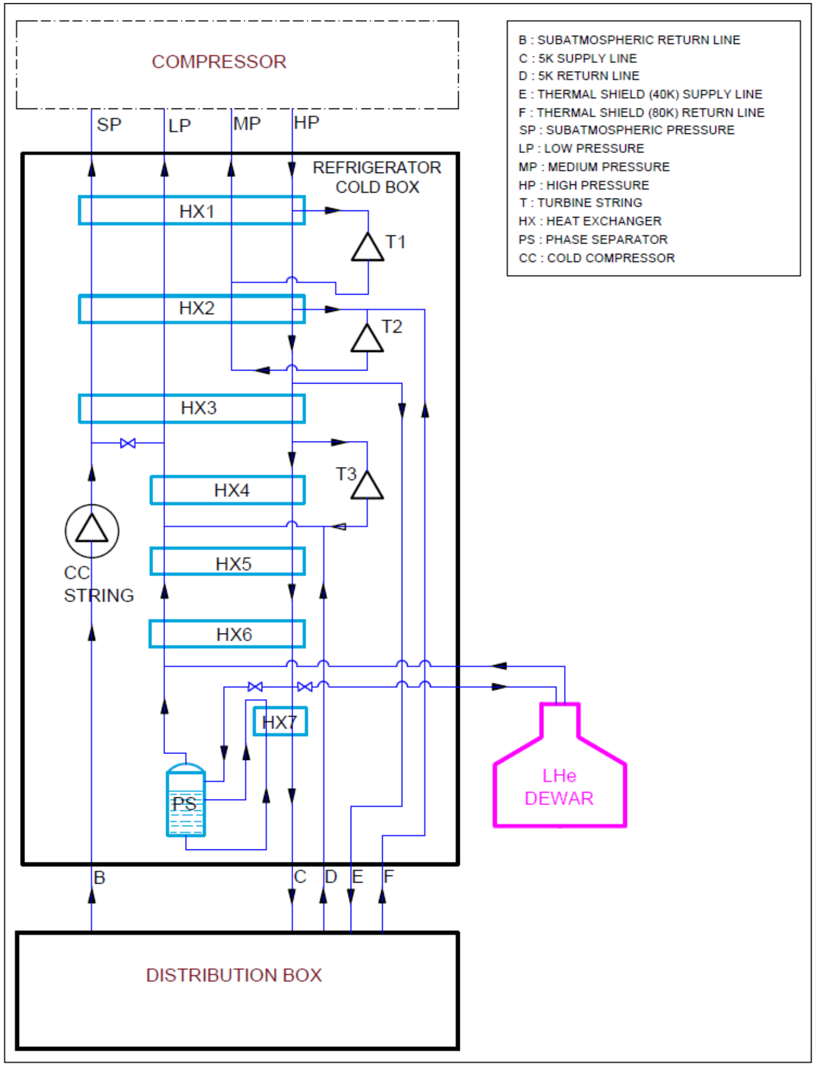
- **Interfaces are defined and documented**
- **The level of interface details is commensurate for the current project stage**

Organization

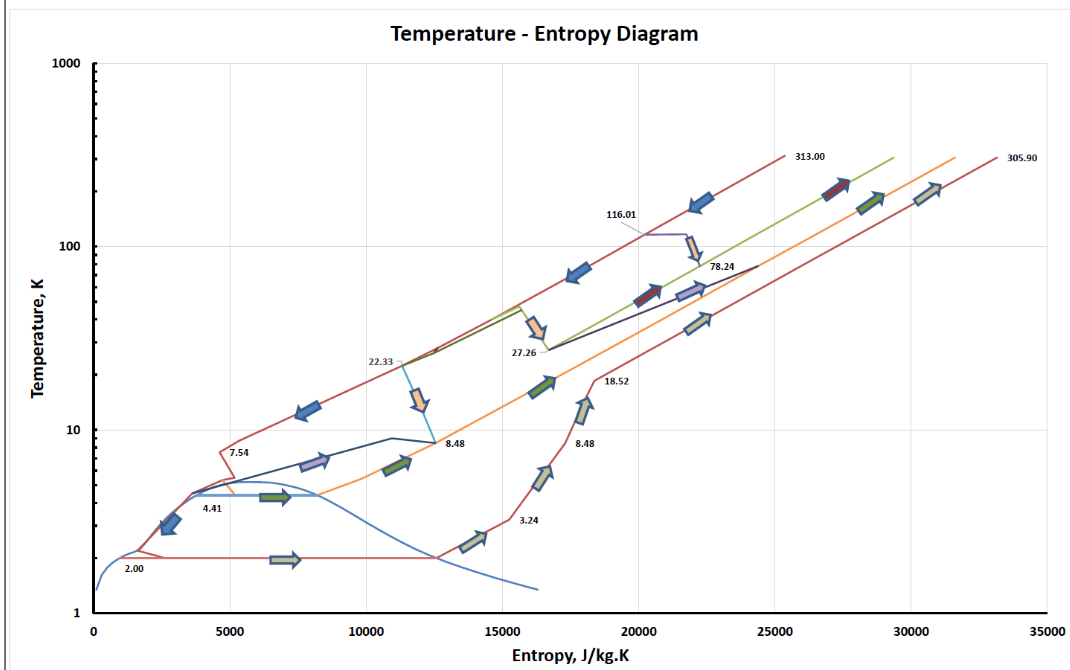


Qualified project personnel are in place at Fermilab and BARC

Technical Progress to Date - Cryogenic Plant



Hybrid compression cycle



Baseline Cryoplant Specifications

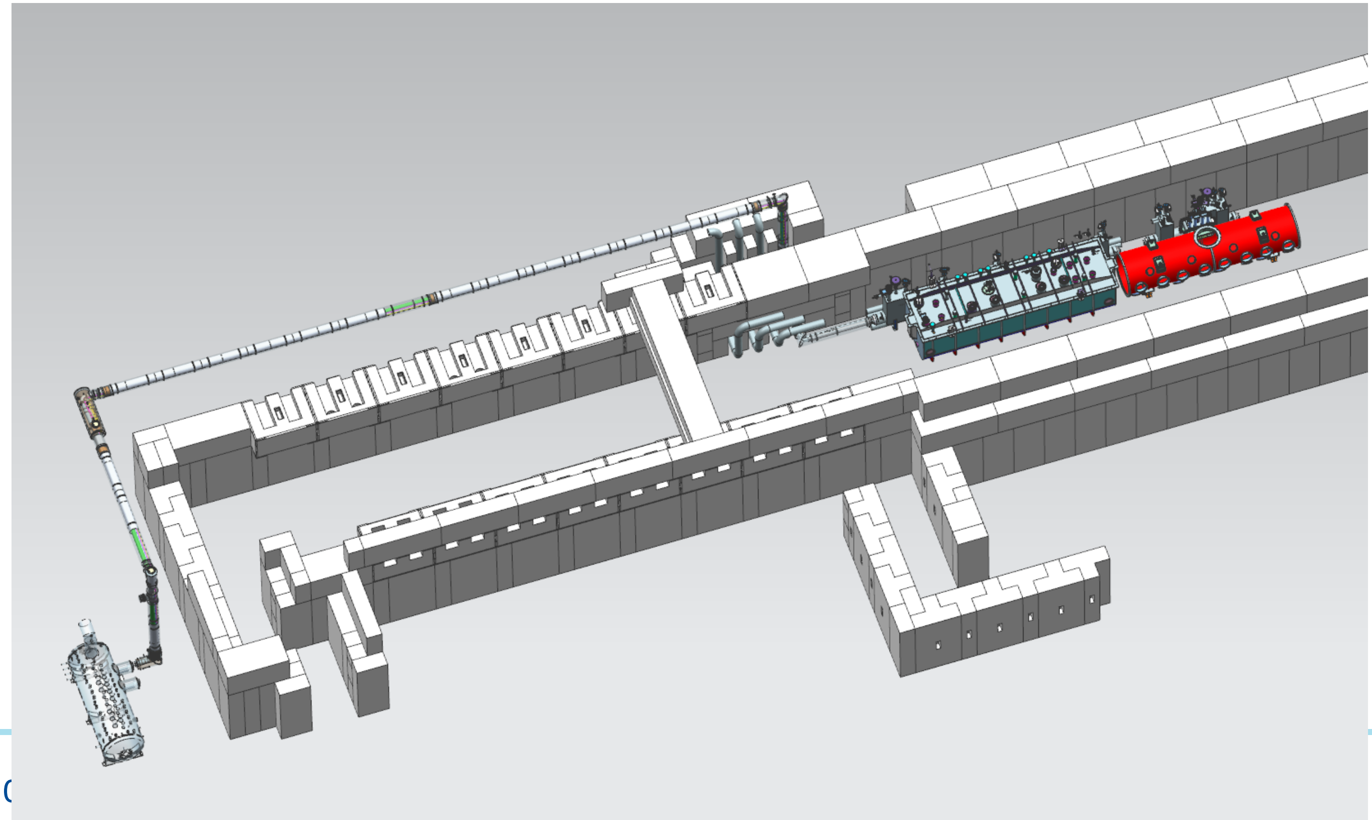
Refrigeration	2K (W)	5 – 9K (W)	35 – 75K (W)
Capacity	1,900	1,500	9,100
Supply Pressure	2.2 ≤ P ≤ 4 bar	2.2 ≤ P ≤ 4 bar	3 ≤ P ≤ 18 bar
Return Pressure	27 mbar	2.2 ≤ P ≤ 4 bar	3 ≤ P ≤ 18 bar
Supply Temp	≤ 4.5 K	≤ 4.5 K	35 – 40 K
Return Temp	≤ 3.8 K	≤ 9 K	≤ 80 K

Technical Progress to Date - PIP-II Cryogenic Distribution System

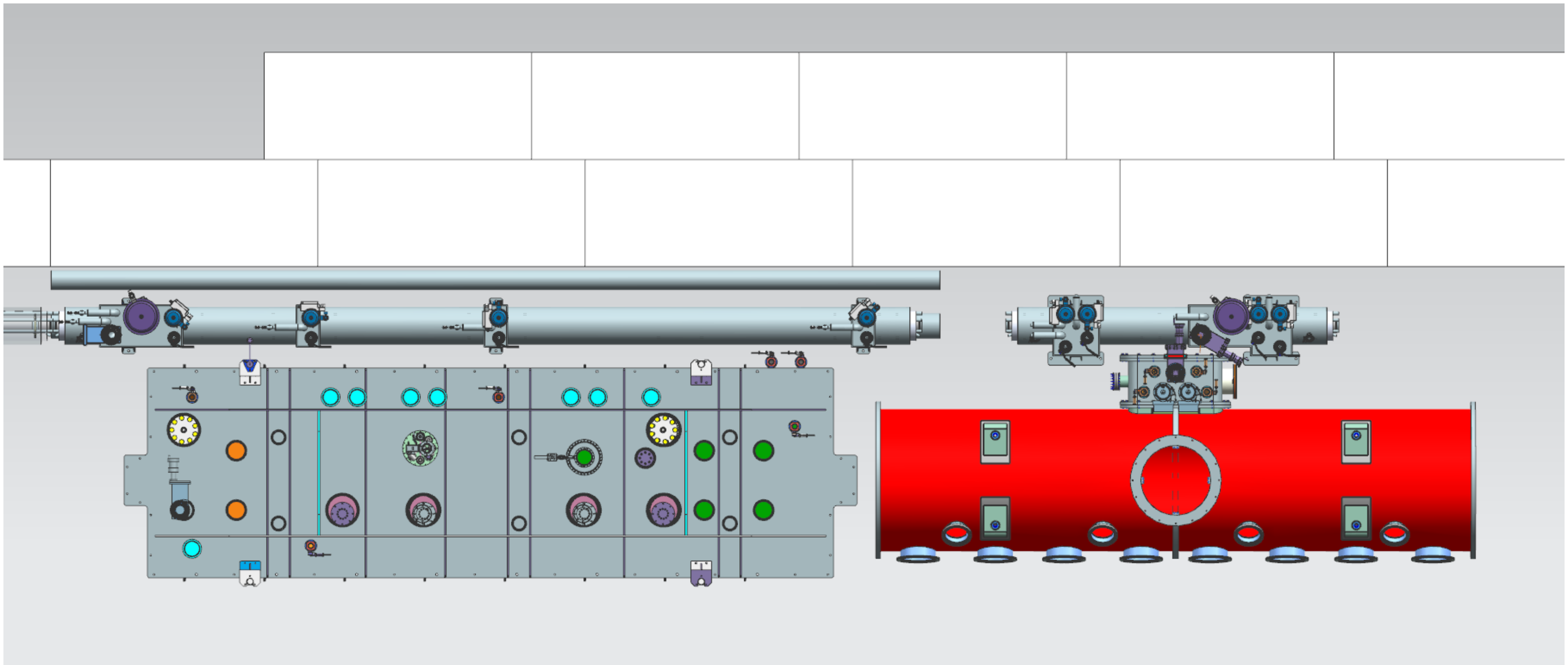
- Developed preliminary detailed list of requirements
- Defined preliminary loads, steady-state and transient modes – TC#ED0003531
- Defined preliminary interfaces and boundaries – TC#ED0006893
- Surveyed similar designs
- Refined heat load estimates – TC#ED0003531
- Interface Control Document – TC#ED0006893
- Valve and Instrument List – TC#ED0006894
- CDS Functional Analysis – TC#ED0006895
- Bayonet Box Functional Analysis – TC#ED0006896
- Cryomodule Bayonet Boxes P&ID - TC#ED0006897
- Site Layout of Cryogenic Distribution Lines – TC#ED0006898
- Pressure drop calculations – TC#ED0006899
- Preliminary relief valves calculations – TC#ED0006900
- Preliminary piping layout – TC#ED0006901

Technical Progress to Date - PIP2IT

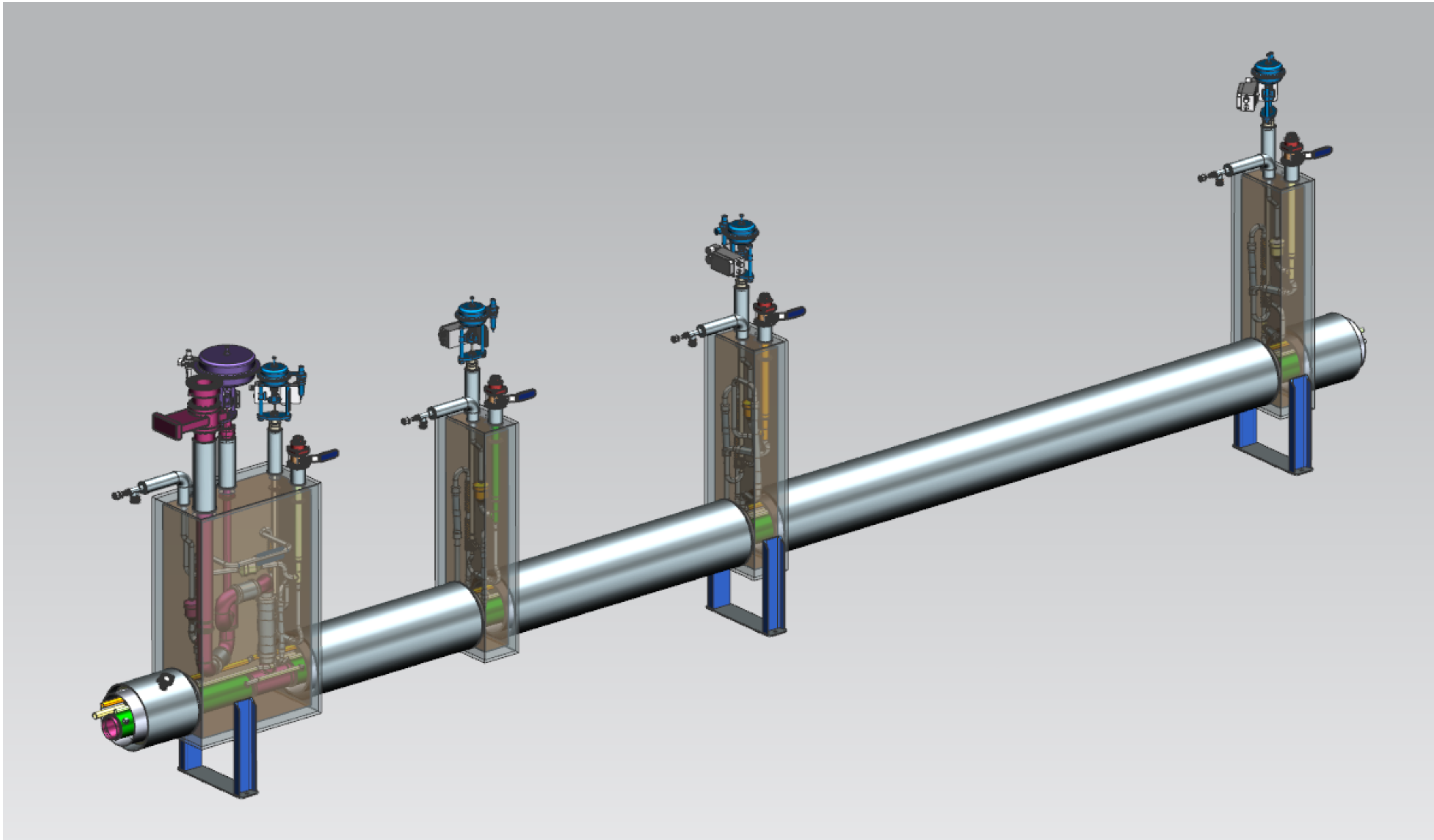
- External transferline is under fabrication at Fermilab
- Cave transferline design-built contract was awarded to Demaco B.V. Holland
- Integration and installation plans are being developed



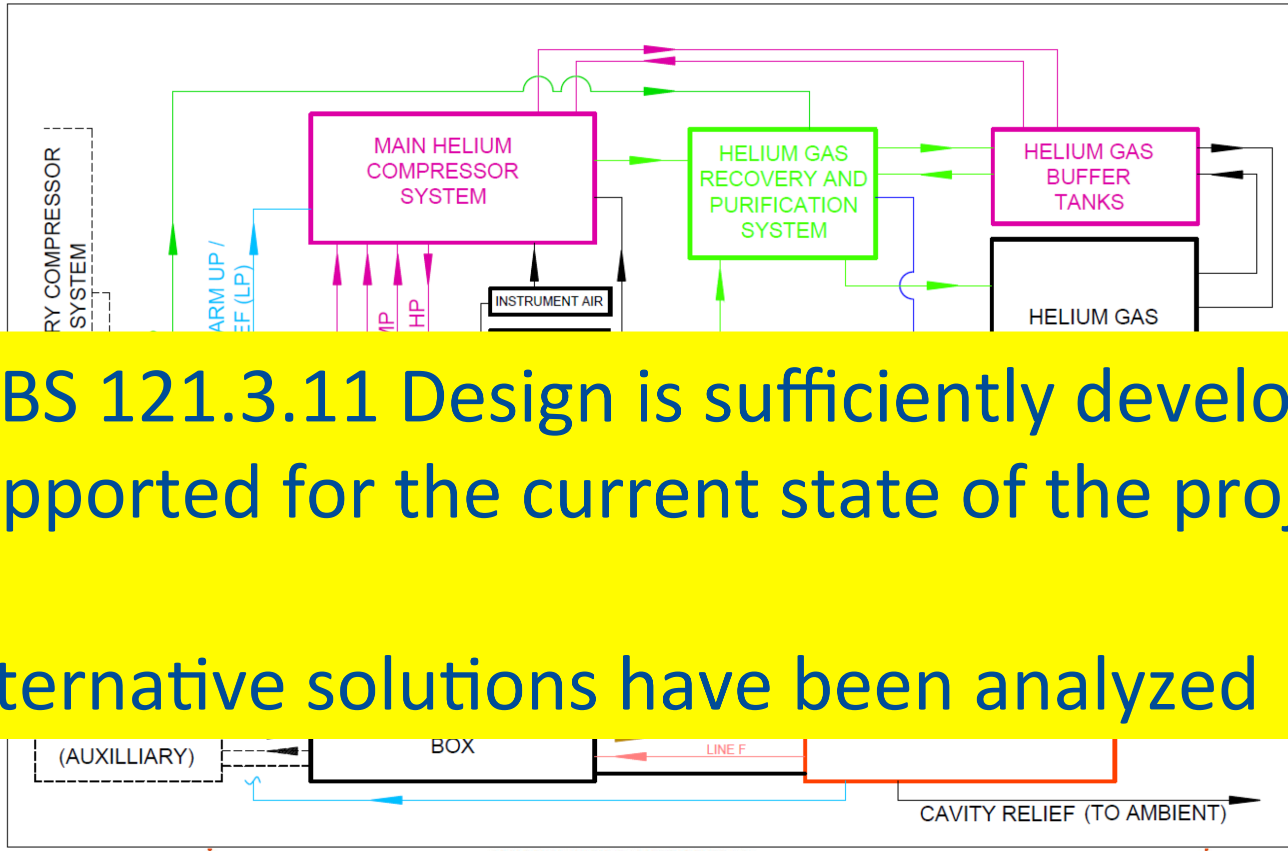
Technical Progress to Date - Cave transferline



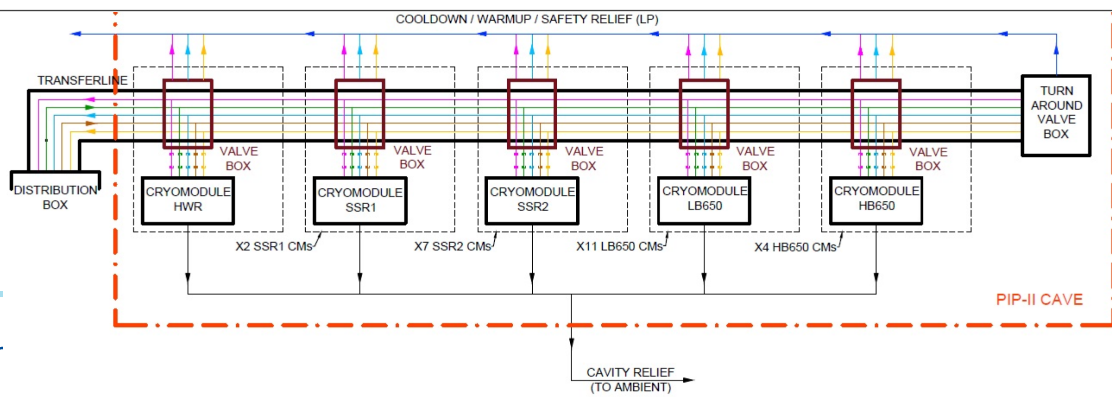
Technical Progress to Date - CM bayonet boxes



Cryogenic System Design



- WBS 121.3.11 Design is sufficiently developed and supported for the current state of the project
- Alternative solutions have been analyzed



Design Review Plan

- Cryogenic System is subject to Project Reviews
- Divi/Dept review procedures based on the Fermilab Engineering Manual
- Technical reviews (PDR, FDR, PRR whenever appropriate)
- PIP2IT CDS Internal Review – April 2017
  - all recommendations are closed
- PIP2IT Cave TL
  - Preliminary Design Review – October 2017
  - Final Design Review – November 2017
  - Production Readiness Review – January 2018
- Cryogenic Plant
  - ESD review – April 2016
  - BARC committee review – May 2016
  - All recommendations are closed, RFP was issued December 2016
  - PO likely to be released by mid 2018

Appropriate number of engineering and project reviews have been completed or planned

ESH&Q

- PIP-II Cryogenic system will use compressed and liquefied Helium
- This presents following potential 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 (wherever possible)
  - Reduce heat flux by adding insulation
  - Provide barriers to minimize external effects/damages
- Project ISM and QA plans (docdb #141 and 142)

Cryogenic System is designed to be safe and to minimize impact on the environment

BOE Summary

WBS Number	Title	Docdb #
121.3.11.1	PIP2IT CDS	297-v4
121.3.11.2	PIP-II Cryoplant	300-v3
121.3.11.3	PIP-II CDS	309-v4

- Labor and M&S estimate cover the entire scope of work defined in the WBS
- Cost Estimating procedure #12.PM-005
- TC#ED0003758 "Assumptions for Cryogenic Components Estimate"
- Historical data and recent vendor quotes are used
- No contingency is included
- P6 contains raw hours and dollars

Cost Estimate is documented using consistent assumptions and is traceable

Cost Summary

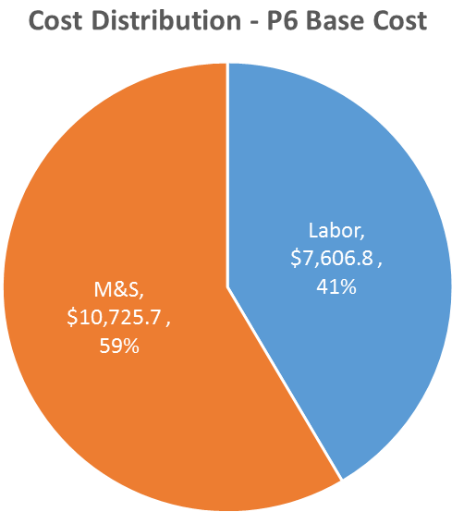
Charge #2

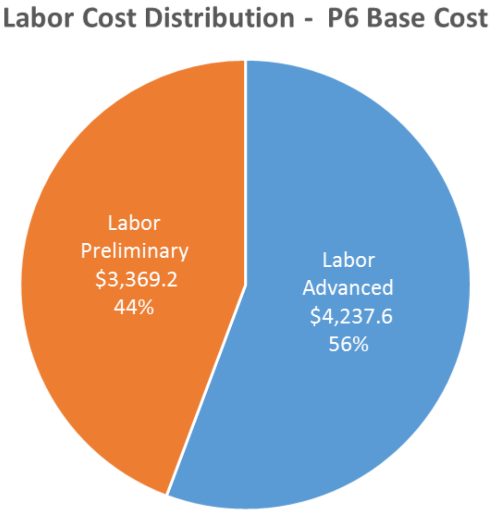
WBS Element	Hours	Labor ($000)	M&S ($000)	Est. Uncertainty ($000)		Total Cost Incl. Uncrty.
121.3.11 - Linac - CRYOgenics (CRYO)	**P6 Hours**	**P6 Base Cost**	**P6 Base Cost**	**Total**	**% of Base**	
121.3.11.1 - Linac - CRYO - PIP2IT Cryo Distribution System (CDS)	4,983	$ 579.2	$ 696.7	$ 255.2	20.0%	$ 1,531.1
121.3.11.2 - Linac - CRYO - PIP-II CryoPlant	27,444	$ 4,210.6	$ 5,781.9	$ 2,935.7	29.4%	$ 12,928.1
121.3.11.3 - Linac - CRYO - PIP-II Cryo Distribution System (CDS)	25,174	$ 2,994.6	$ 4,247.1	$ 1,873.0	25.9%	$ 9,114.7
Grand Total	**57,601**	**$ 7,784.4**	**$ 10,725.7**	**$ 5,063.9**	**27.4%**	**$ 23,573.9**
Note: P6 base cost = BOE + overheads and escalation						

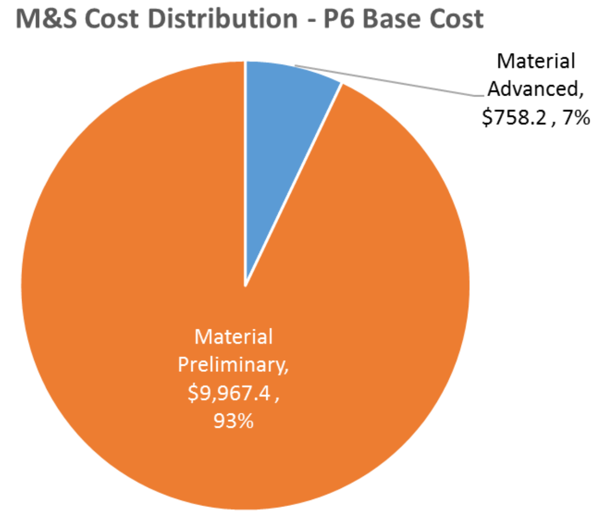
- Oversee delivery of all scope of WBS 121.11.3
- Costs generated from resource loaded schedule
- Estimate developed by people experienced with cryogenics. Estimate Uncertainty follows project guidelines
- Collaborative methods used while developing cost estimate assumptions
- Assumptions are realistic and used consistently

Cost Drivers and Estimate Maturity

Charge #2



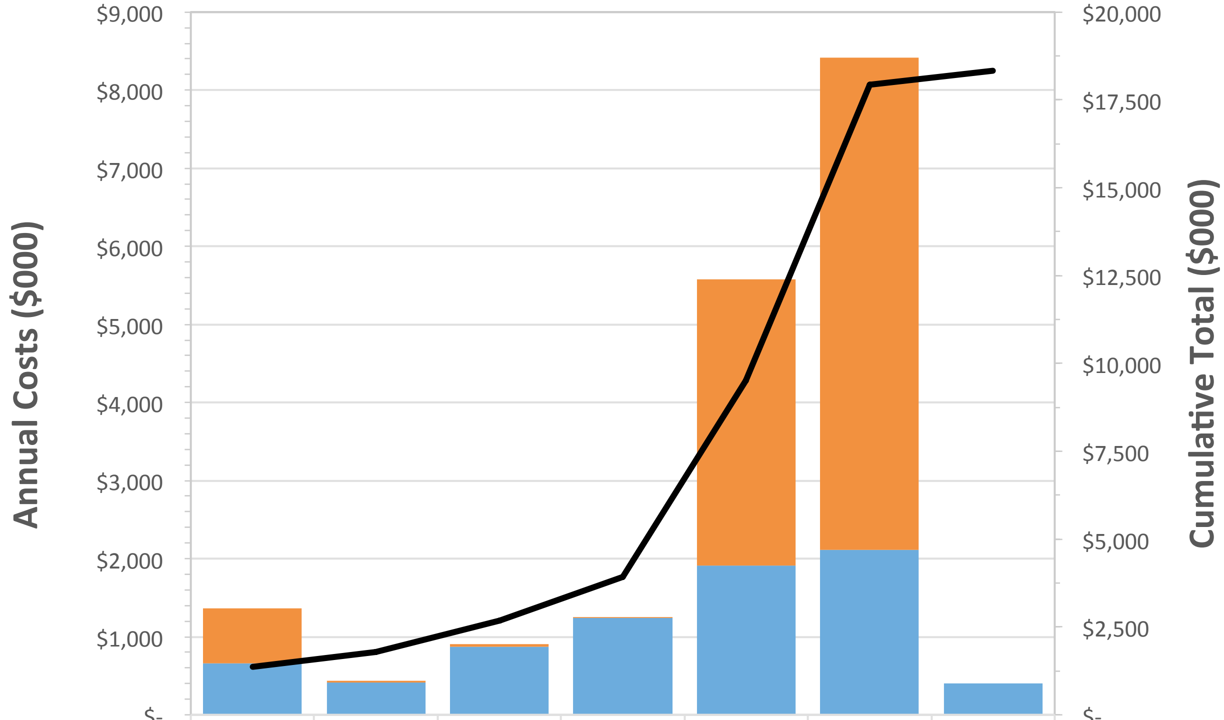




- Design, fabricate, procure, and install PIP2IT CDS components
- Cryogenic plant contract oversight, cryogenic plant and associated auxiliary systems installation and commissioning
- Design, fabricate, procure, and install PIP-II CDS components
- Cost drivers identified

Cost Profile

Charge #2



	FY18	FY19	FY20	FY21	FY22	FY23	FY24
Material	$696.7	$22.9	$32.3	$6.3	$3,667.9	$6,299.5	$-
Labor	$664.3	$408.5	$868.5	$1,236.4	$1,911.8	$2,113.1	$404.2
Cumulative Tot.	$1,361.1	$1,792.5	$2,693.3	$3,936.0	$9,515.7	$17,928.3	$18,332.5

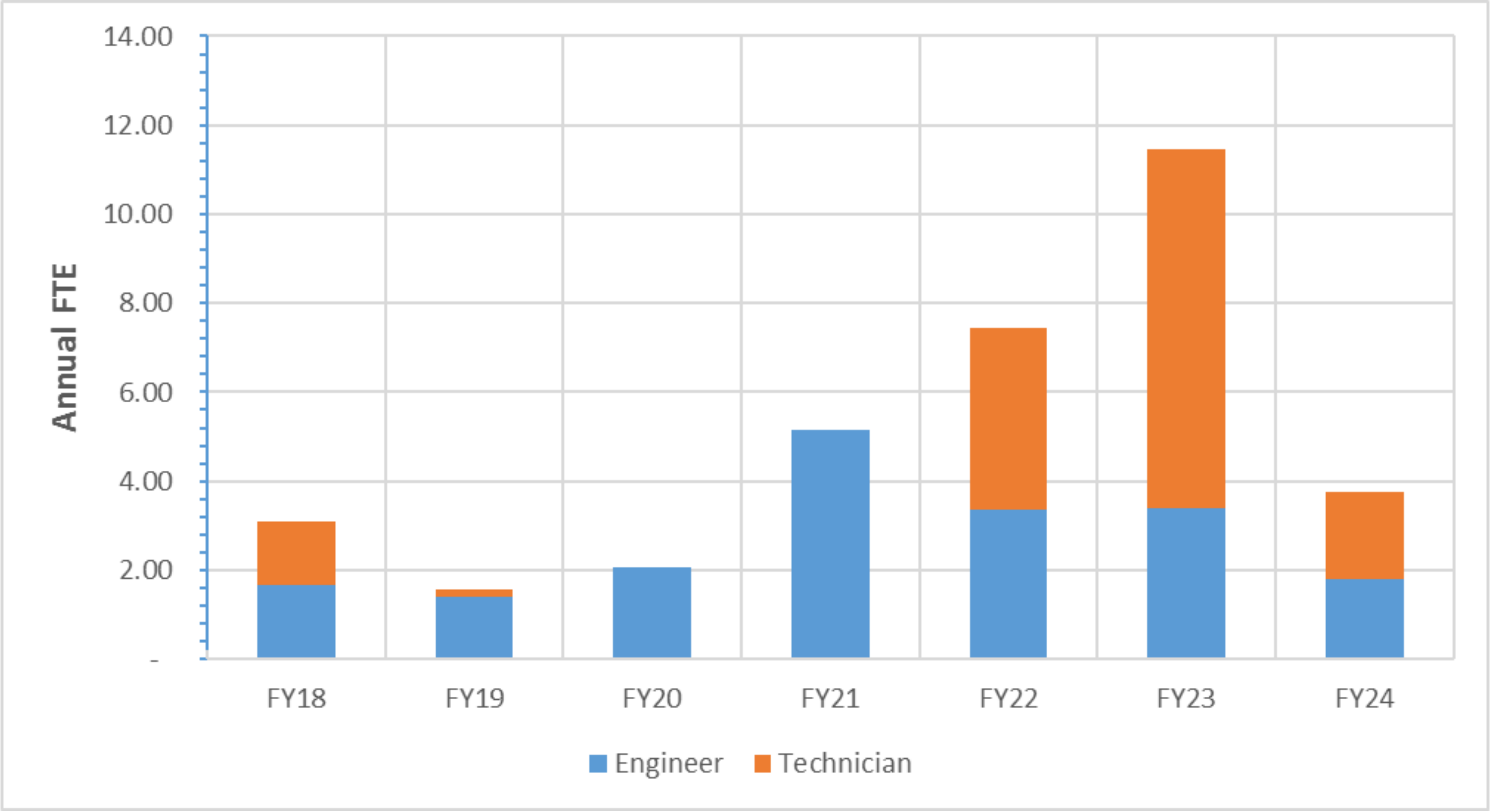
P6 Base Costs = BOE + Overheads + Escalation

We understand our funding demands

PIP-II

Labor Profile

Charge #2



Labor profile is consistent with WBS121.11.3 scope needs and can be supported

Risk

Two high risks associated with Cryogenic System are documented in the Risk Register

1. Pulsed and CW cryomodule operating modes cause cryogenic or mechanical instabilities
2. Insufficient Cryogenic system vendor manufacturing capacity and priority

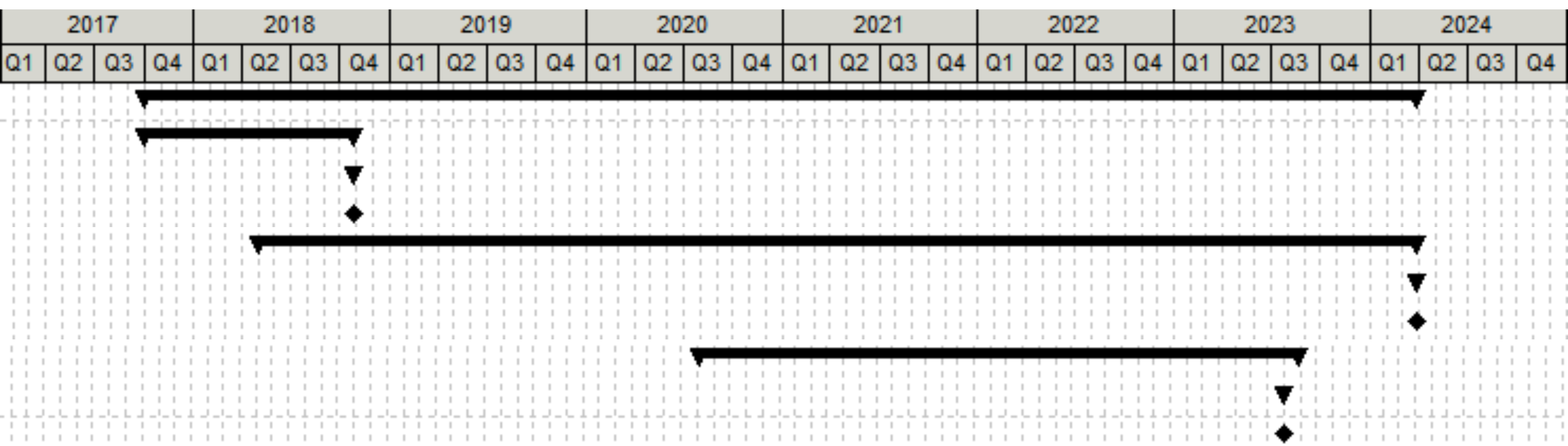
Title	Probability	Probability Score	P * Impact (k$)	P * Impact (months)	Impact Score - Cost	Impact Score - Schedule	Risk Rank
Pulsed and CW cryomodule operating modes cause cryogenic or mechanical instabilities	50.00%	4 (H)	688	3.3	2 (M)	3 (H)	3 (High)
Insufficient Cryogenic system vendor manufacturing capacity and priority	50.00%	4 (H)	500	3.5	2 (M)	3 (H)	3 (High)

Risks associated with delay of the Cryogenic Plant delivery is included in **the PIP-II Project Risk** section of the Risk Register – see presentation by S. Mishra

Schedule

Charge #2

Activity ID	Activity Name
121.3.11 Linac - CRYOgenics (CRYO)	
121.3.11.1 Linac - CRYO - PIP2IT Cryo Distribution System (CDS)	
121.3.11.1.1 Linac - CRYO - PIP2ITCDS: T4 Milestones	
A17294140	Linac - CRYO - PIP2ITCDS - CavTL - R&DPh: T4 MS - CDS installation completed in PIP2IT
121.3.11.2 Linac - CRYO - PIP-II CryoPlant	
121.3.11.2.1 Linac - CRYO - PIP-IICryoP: T4 Milestones	
A17294170	Linac - CRYO - PIP-IICryoP - ConstrPh: T4 MS - CryoPlant commissioned
121.3.11.3 Linac - CRYO - PIP-II Cryo Distribution System (CDS)	
121.3.11.3.1 Linac - CRYO - PIP-IICDS: T4 Milestones	
A17294200	Linac - CRYO - PIP-IICDS - ConstrPh: T4 MS - PIP-II CDS Ready For Installation in PIP-II Tunnel



PIP-II

Summary

- Cryogenic system technical scope is defined
- Functional performance requirements and key interfaces are identified
- Strategy and technical solutions to support wide range of cryogenic load is developed
- WBS 121.3.11 design is sufficiently developed and is supported for the current state of the project
- CDS and Cryoplant are being designed as a single system with safety considerations in the design phase
- Cost and schedule are understood
- Detailed budget and schedule, in P6, are structured to achieve the technical scope
- Qualified project team is in place both at FNAL and BARC

We are ready for CD-1

Thank you!