12 GeV
Cryogenic System Planning

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Cryogenic Systems Group

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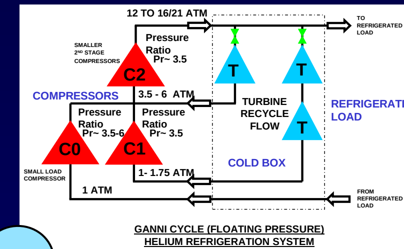
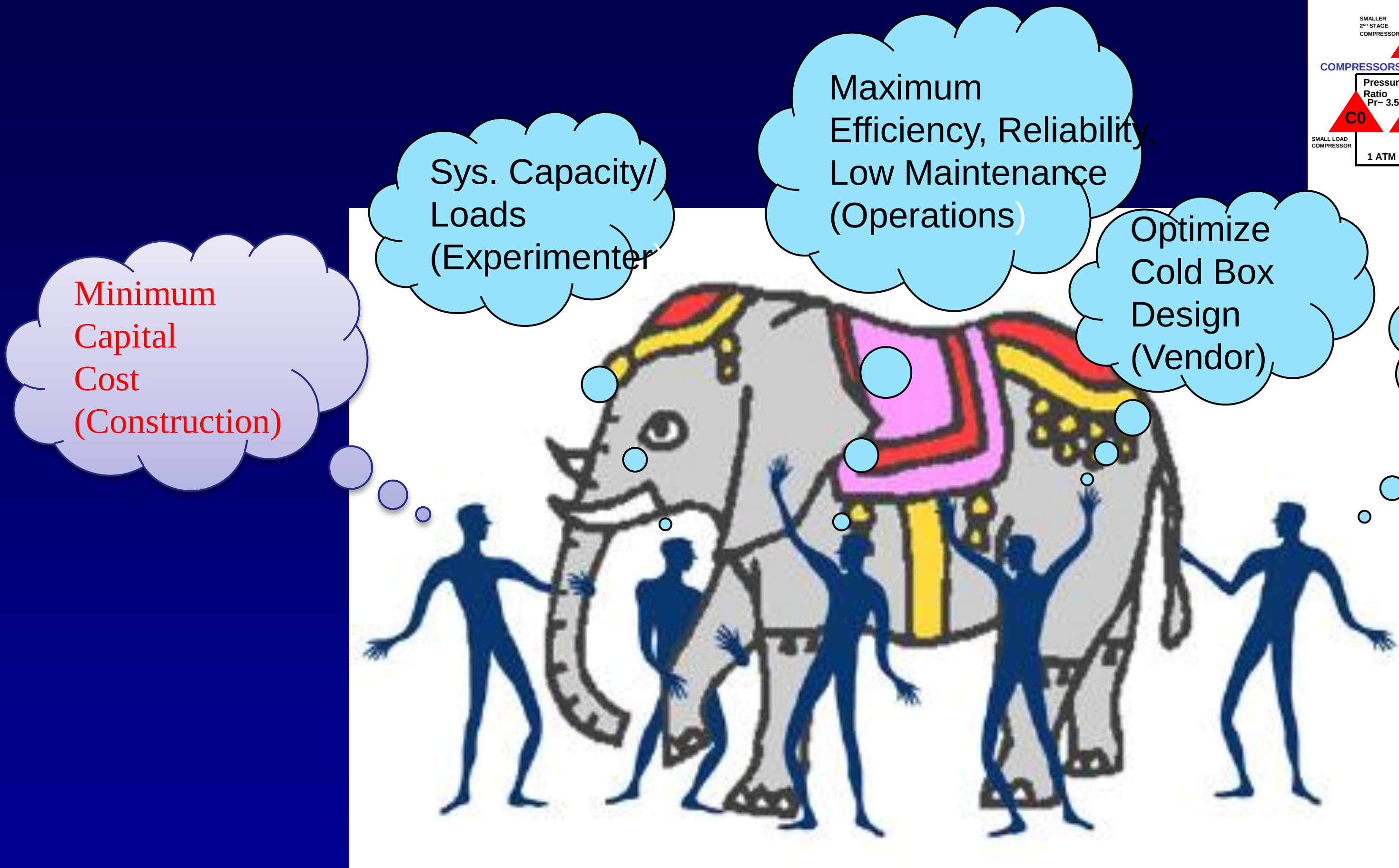
What is an “Optimal” System



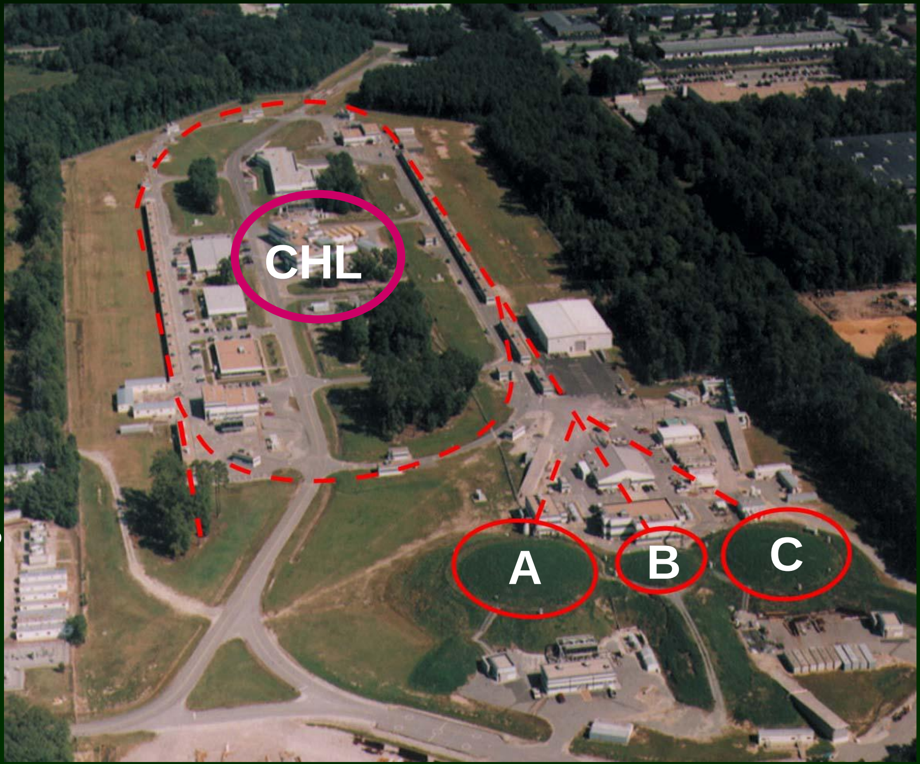


- One’s viewpoint can be based only on their role and focus within a project
- Easy to believe that one’s goals are mutually exclusive of others
- Many believe that maximum system efficiency occurs only at one set of fixed operating conditions

Jefferson Lab Today

2000 member international user community engaged in exploring quark-gluon structure of matter

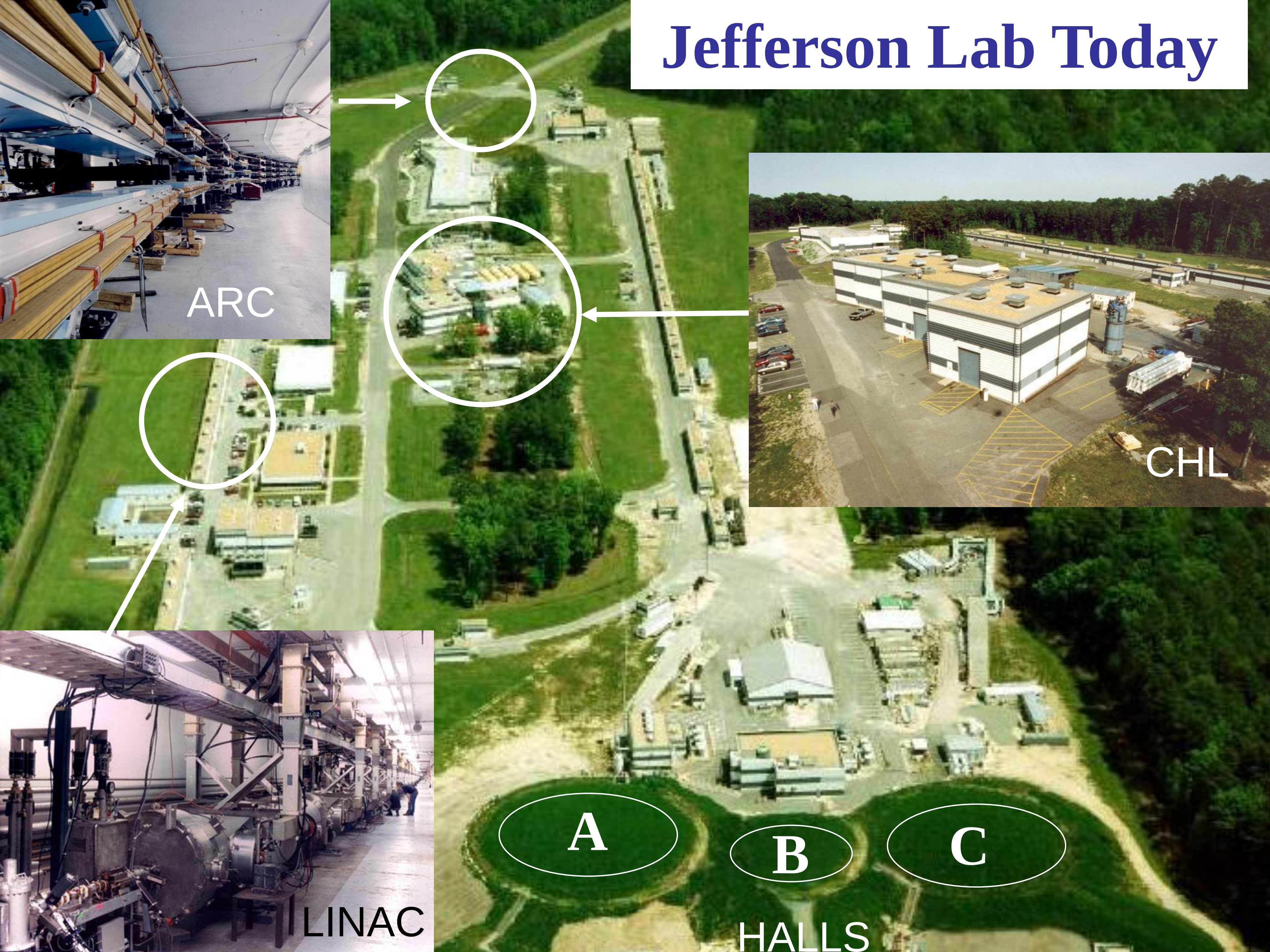
Superconducting accelerator provides 100% duty factor beams of unprecedented quality, with energies up to 6 GeV



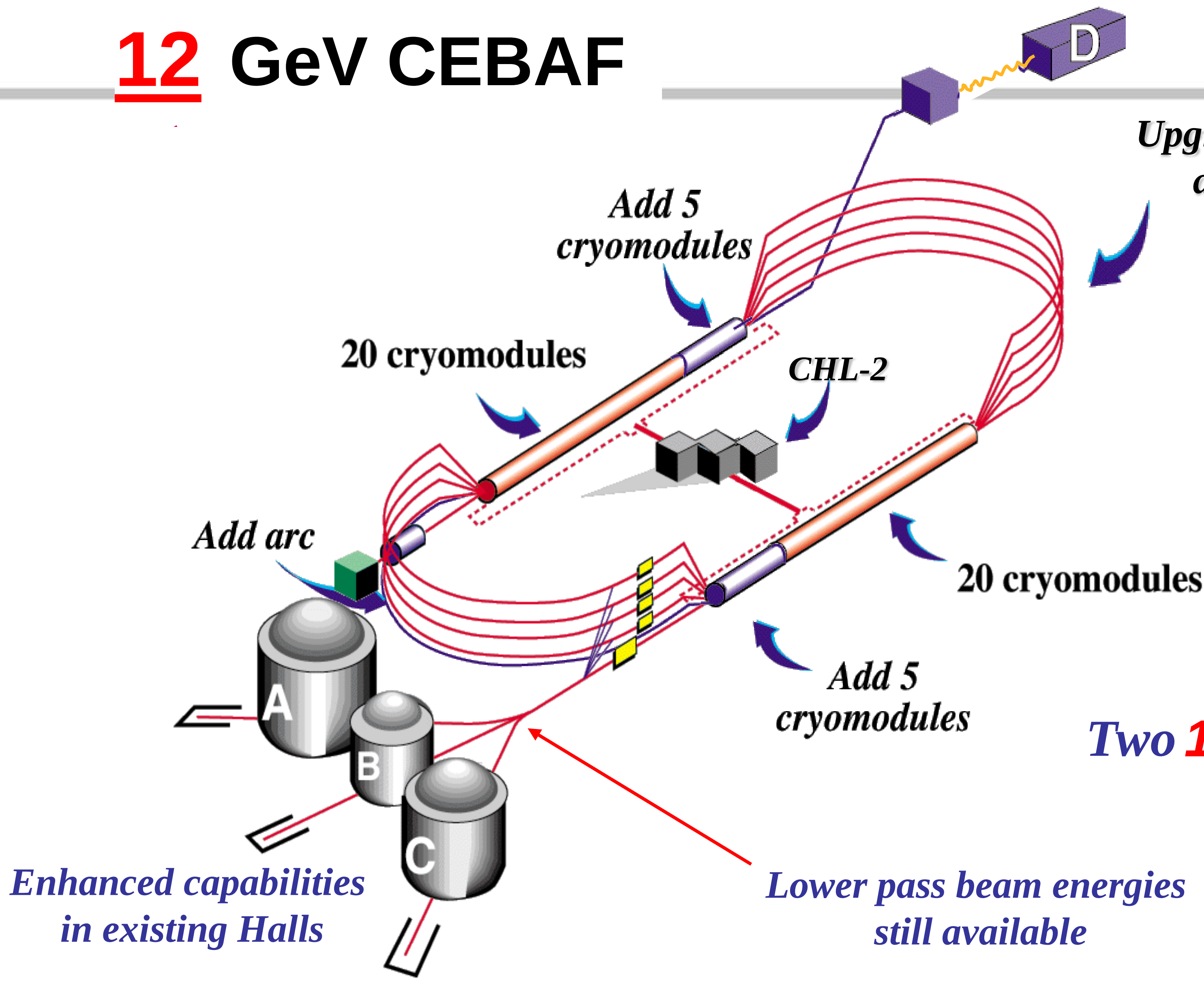
CEBAF's innovative design allows delivery of beam with unique properties to three experimental halls simultaneously

Each of the three halls offers complementary experimental capabilities and allows for large equipment installations to extend scientific reach

Jefferson Lab Today



12 GeV CEBAF



*Two **1.1** GV linacs*

Additional Loads of 12 GeV

- CEBAF Accelerator (Each of 10 new cryomodules)
  - Up to 300 W at 2.1K, Primary Load
  - Up to 300 W at 35 K, Shield Load
- Hall D (inclusive of cryogen distribution system)
  - 100 W at 4.5K refrigeration
  - 0.7 g/s of liquefaction (lead cooling)

CHL#2 Design Goals

System Must Meet Accelerator Refrigeration Requirements

Stable and Reliable Service, 4-5 years at a time

Unattended Operation

Minimal Capital Equipment and Operational Cost

12 GeV Project Stages "Critical Decision"

CD-0

Depicts need of project, R+D to meet technical needs, budgetary estimates of cost and schedule, design criteria and standards, preliminary information concerning supportive systems (ex: Civil requirements)

CD-1

First Phase engineering, "PED", Project Engineering and Design, refinement of cost and schedule, budget review to establish fixed budget and schedule toward end of CD-1 in preparation of CD-2 project stage

CD-2

Completion of engineering, "PED" , Project Engineering and Design

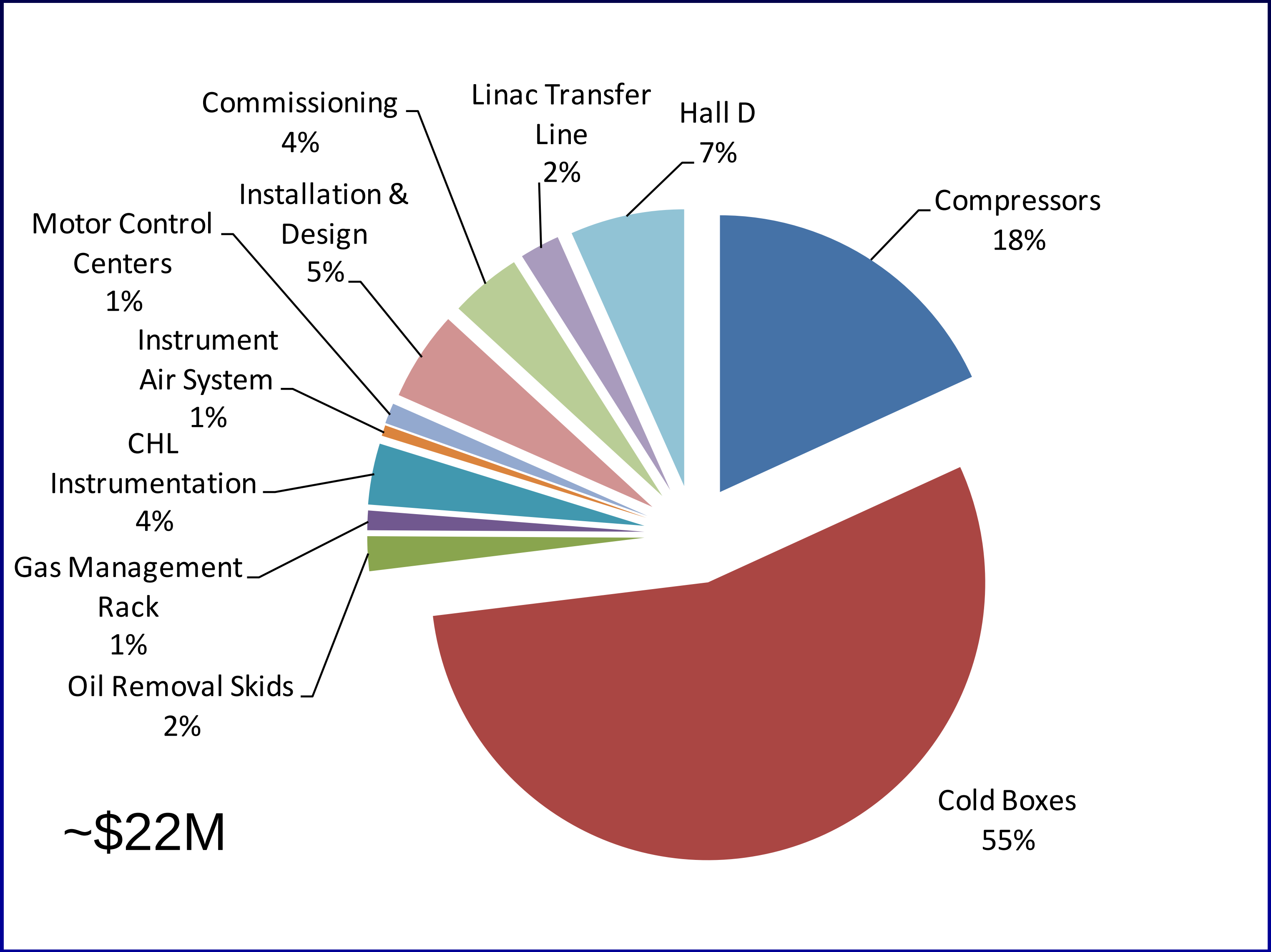
CD-3

Construction and procurements

CD-4

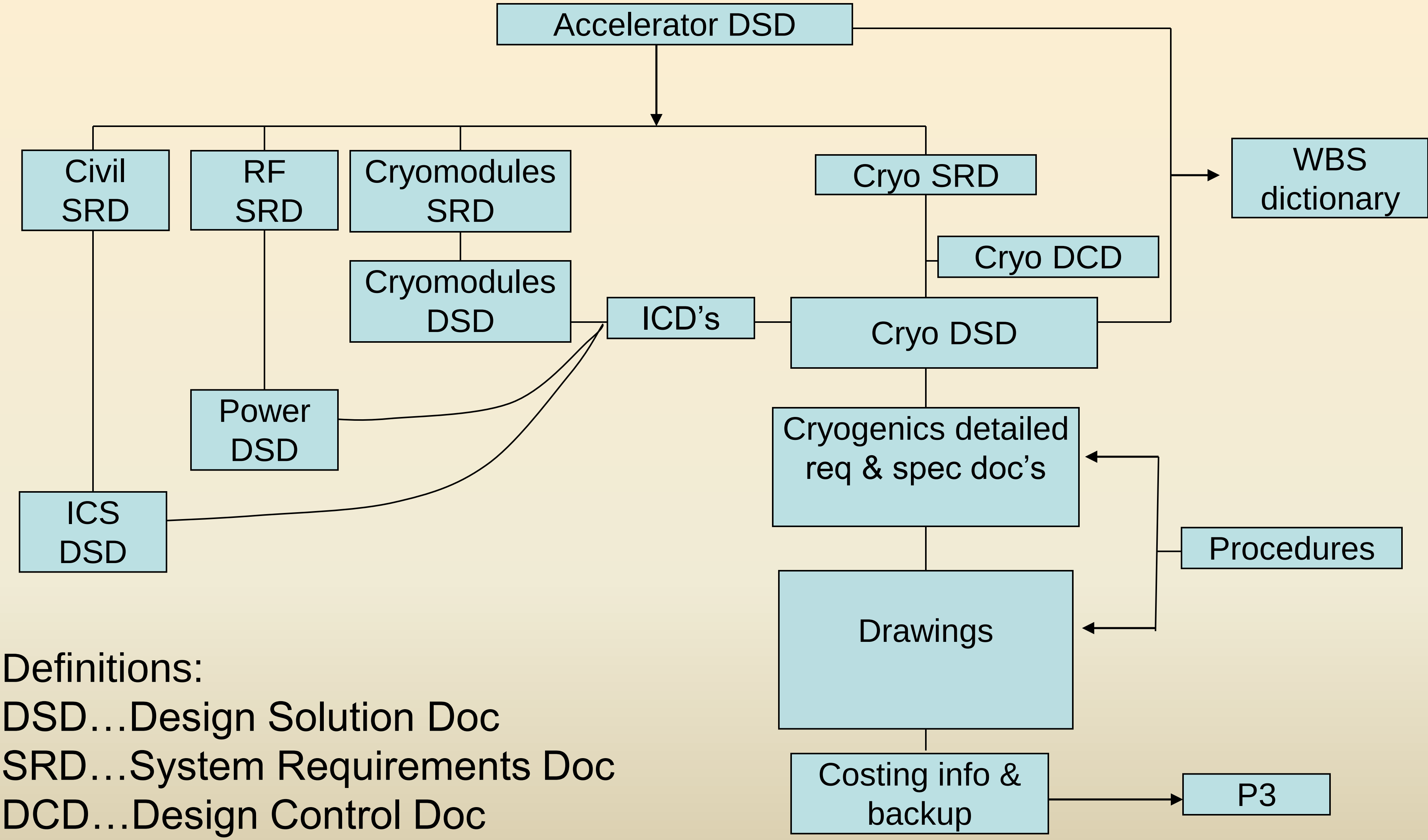
Project commissioning and deliverables

Construction Cost Overview



Cryogenics had extensive existing infrastructure to reduce cost

Cryogenics PED: Documentation



Definitions:

DSD…Design Solution Doc

SRD…System Requirements Doc

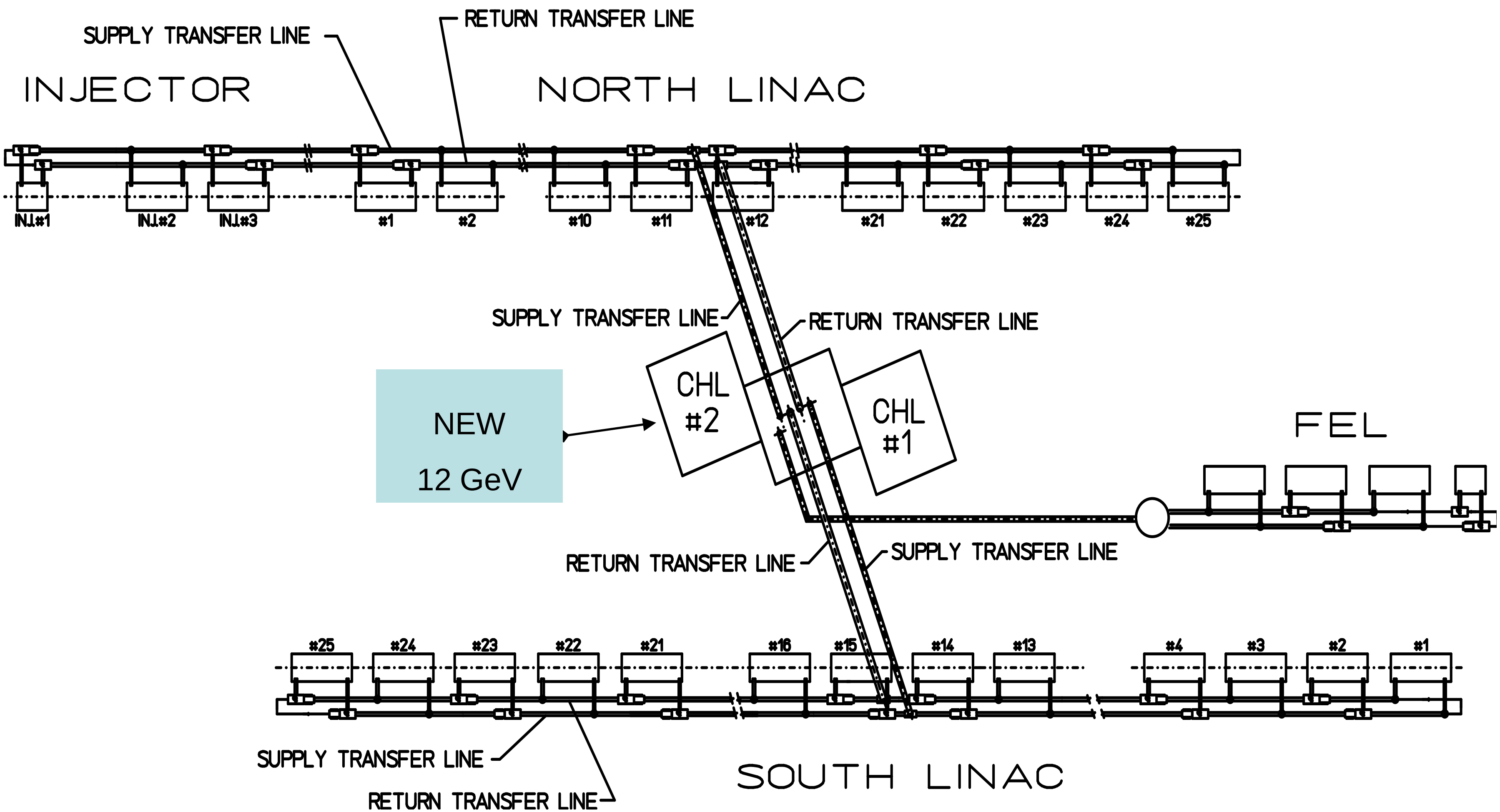
DCD…Design Control Doc

WBS…Work Breakdown Structure

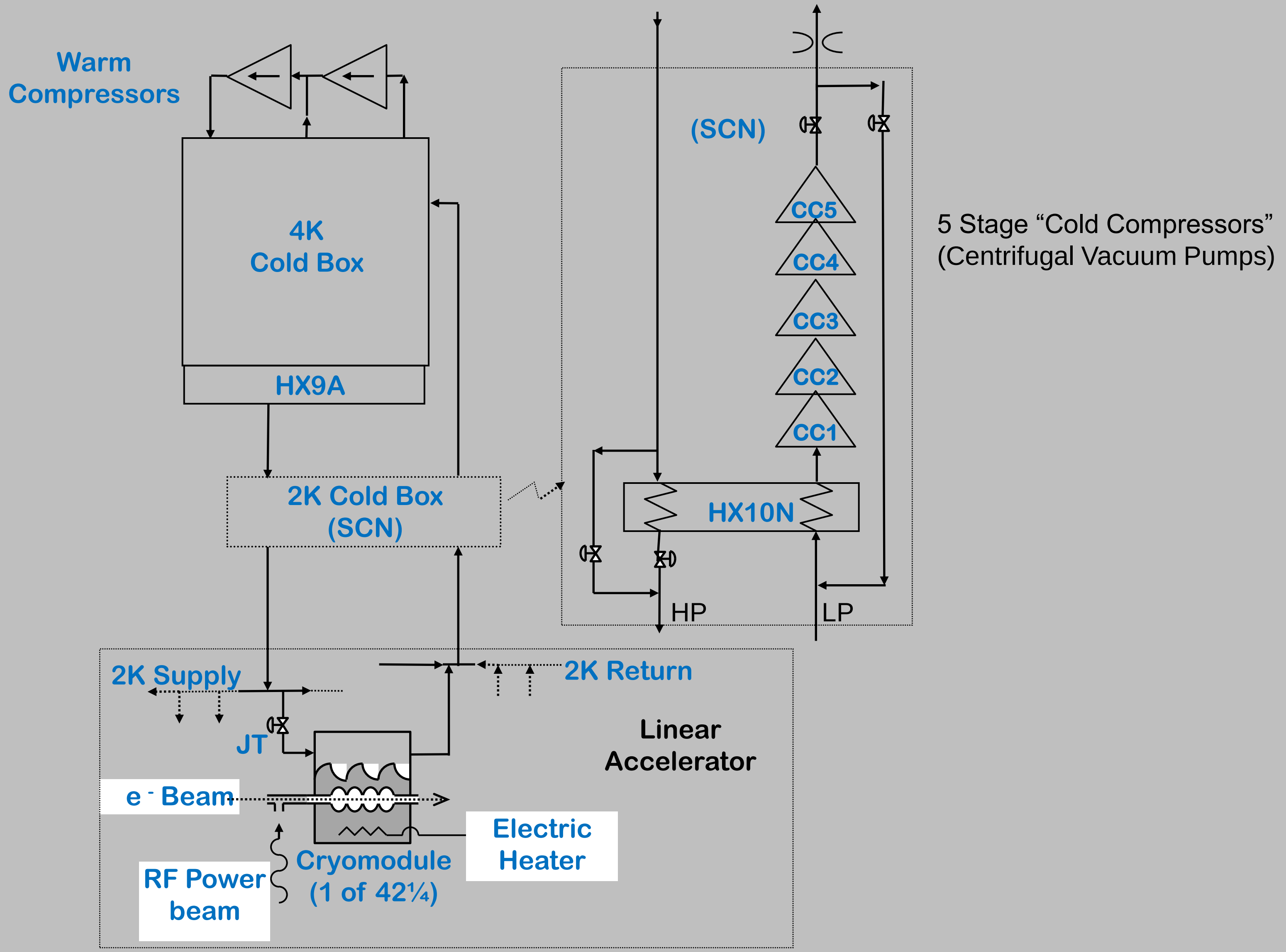
P3…….Master Cost and Schedule Doc

Looking at the CHL

LINAC TRANSFER LINES



CHL Flow Diagram



LINAC TL CONFIGURATION

- CURRENT 6GeV:

  CHL-1 Supplies Injector, N. and S. Linacs, FEL, and 10 g/s to ESR

- NEW 12 GeV:

  CHL-1: Injector, North Linac and ESR (10 g/s)

  CHL-2: South Linac and existing FEL

NOTE: IN CASE OF A CHL-1 OR CHL-2 MAINTANENCE or FAILURE, THE LINACS CAN BE RECONNECTED TOGETHER INTO SINGLE REMAINING CRYO PLANT FOR 6 GeV BEAM OPERATION

CHL Max Capacity Current vs. New

- **Current 6 GeV (CHL #1)**
  - Load: 4.25 kW @ 2.1K, 11.65 kW @ 35K
  - Capacity: 4.6 kW @2.1K, 12 kW @ 35K
  - 10 g/s liquefaction
- **New 12 GeV (CHL #1 + new CHL#2)**
  - Load: 7.25 kW @ 2.1K, 14.65 kW @ 35K
  - Capacity: 9.2 kW @ 2.1K, 24 kW @ 35K
  - 25 g/s liquefaction

Load Distribution for 6/12 GeV

Unit Loads			6 GeV			12 GeV					
						North Linac			South Linac		
	2 K	50 K	#	2 K	35 K	#	2 K	50 K	#	2 K	35 K
Loads (#,W)											
Static											
Transfer Line	530	7000	1	530	7000	0.57	302	3990	0.43	228	3010
Original CM's	16	110	42.25	676	4648	22.25	356	2448	20	320	2200
12 GeV CM's	50	250				5	250	1250	5	250	1250
Dynamic											
Original CM's	72		42.25	3042		22.25	1602		20	1440	
12 GeV CM	250	50				5	1250	250	5	1250	250
TL BAYONETS							75			75	
Totals			42.25	4248	11648	25.25	3835	7938	29.25	3563	6710
TL SECTION											
Capacities (W)											
CHL#1 (W)				4600	12000		4400	12000			
% of Full Load				92%	97%		87%	66%			
CHL#2(W)										4400	12000
% of Full Load										81%	56%

CHL Considerations

- Existing CHL#1 is a "one of a kind" 2K refrigerator
  - Custom engineered and built, not "off the shelf"
  - ~2x as large as any other 2K refrigerator in existence
- New CHL#2 has the following considerations which had to be accounted for…..
  - Commercial custom refrigeration engineering is generally done during the construction project but creates a problem providing detailed information to civil engineering for cost estimation/design that occurs during the previous project phase of engineering. This includes such topics as….

    Building Size, Equipment Floor Loading, Ventilation, Electric and Water Cooling Requirement, Equipment Layout, LN2 usage, Crane requirements, How to get equipment into the building, door sizes, piping/electrical chases, etc. etc.

CHL Considerations

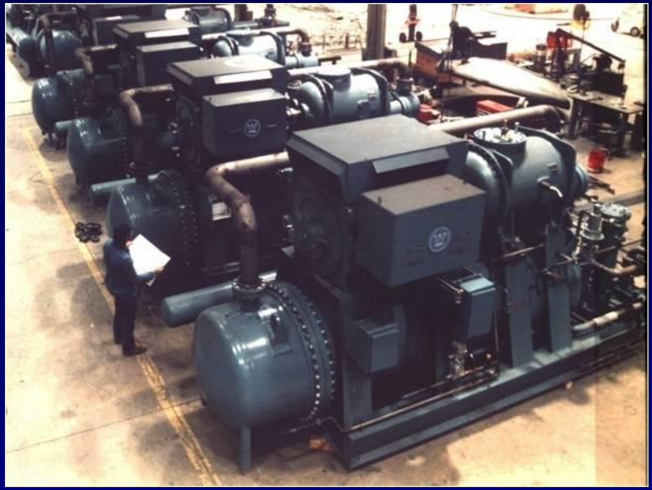
- Very large fluctuations in the foreign exchange rates during the refrigerator project (1.29 to 1.65 exchange variations) Large refrigerators of this type are of foreign origin.
- Large increases in raw materials used in the construction of the refrigerator plant inclusive of copper, carbon steel, and stainless steel.
- Ether CHL#1 or #2 could be used to support beam operations at 6GeV should one of the refrigerators go down.

Original CHL-1 Installation

Less than ideal installation conditions: Through the roof (heavy/high crane pick, pit required, stripped of end vacuum shells to save weight, complicated reassembly

Existing Equipment (CHL#1)

4600W @ 2.1K Refrigerator & 1st set of Cold Compressor (2K Cold Box), 245 g/s

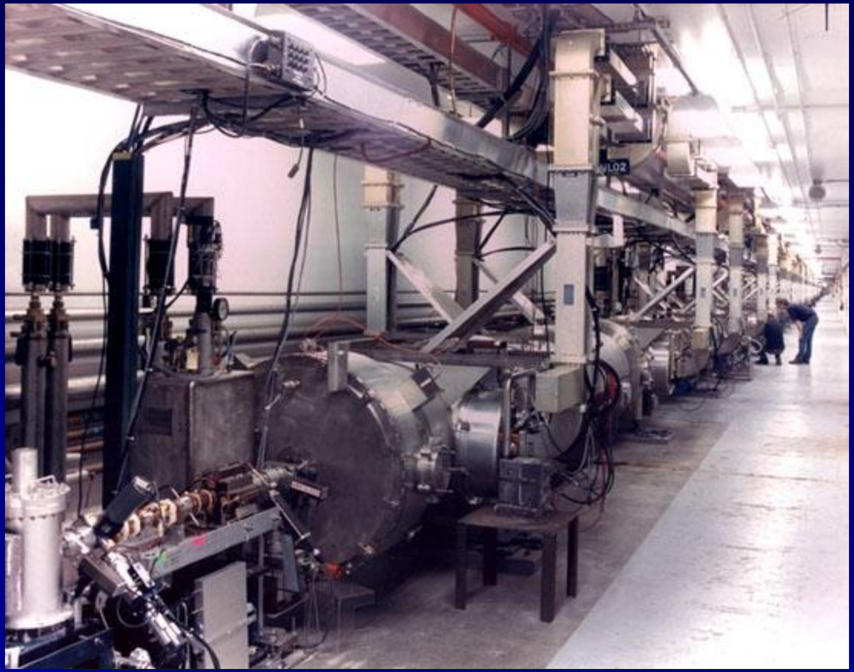


Warm Helium Compressors, ~5.2 MW
Qty 3, 600 HP ; Qty 3, 2250 HP

2nd set of Cold Compressor (2K Cold Box)
245 g/s

Typical 2K Cold Box Internal Piping

Existing Transfer Line Components



Existing 42 Cryomodues,1600 liters ea.

TL Already Has 10 Connection
Bayonet Locations for the
12 GeV Expansion
300 liters ea

Other CHL Operational Modes

- Although meeting the “steady state” operational mode is important…there are many other modes which the refrigerator must practically meet

  Examples….
  - Filling the cryomodules with liquid (liquefaction rate)
  - Maintaining the cryomodules at 4.5K instead of 2K
  - Translating from 4.5 to 2.1K operations (very low refrigeration requirement)
- So these “other” modes must be mapped out to make sure that the refrigerator can cover them…(part of the procurement specification)

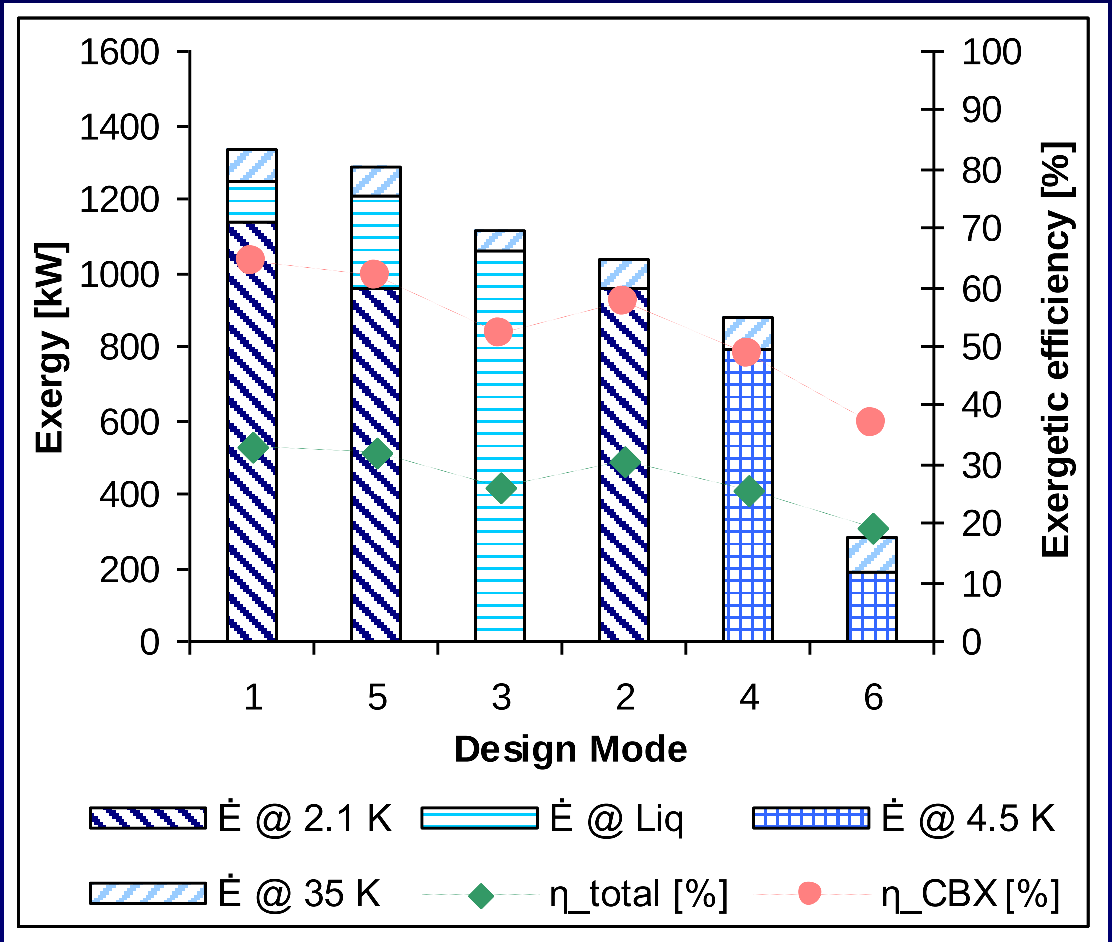
CHL-2 Design Modes of Operation

#	Design Mode	Load @ 2 K [g/s] *	Load @ 4.5 K [kW]	Liquefaction [g/s]	Load @ 35 K-55K [kW]
1	Maximum capacity (CBX supporting maximum cold compressor operation)	>238	0	>15	>12
2	Nominal capacity (CBX supporting nominal cold compressor operation)	>200	0	0	>7.5
3	Maximum 4.5-K liquefaction	0	0	>150	>7.5
4	Maximum 4.5-K refrigeration	0	>10.5	0	>12
5	Maximum fill (of Linac cryomodules)	>200	0	>35	>12
6	Stand-by 4.5-K refrigeration**	0	>2.5	0	>12

- Load at 2.1 K means supply flow at 3.2 bar 4.5 K, with return flow at 1.2 bar 30 K

** Mode 6 requires a minimum amount of rotating equipment while supporting the LINAC loads at 4.5-K.

CHL-2 4.5K System Projected Efficiencies



Operational high efficiencies remain fairly constant no matter the operational mode

Old Vs. New @ Maximum Capacity CHL Plant Comparison

CHL#1 (Old)	**CHL#2 (New)**
• Electric Power, 6 MW	• Electric Power, 4 MW
• Liquid Nitrogen Use, 300 gal/hr	• Liquid Nitrogen Use, 200 gal/hr
• Number of compressors, 6	• Number of compressors, 5
• Cooling Water, same as electric	• Cooling Water, same as electric

Key cryogenic technologies developed at JLab (Ganni Cycle, LN2 precooling efficiency, etc.) has enabled reduction of utilities used by the refrigeration systems coupled with reduced capital equipment costs

JLab CHL#1 facility
had many supportive subsystems
already in place needed by CHL#2
which reduced system cost
substantially

Existing CHL Infrastructure

- ✓ Gaseous Helium Storage Tanks
- ✓ LN_2 Storage Dewars (twin 80,000 liter)
- ✓ Cold Compressor Sets (twin 245 g/s @ 2.1K)
- ✓ Helium Gas Purification and Contamination Monitors
- ✓ Guard Vacuum Subsystem (2.1K operations)
- ✓ Building for lower 60-4.5 K Cold Box
- ✓ Outdoor Foundation for upper 300-60 K Cold Box
- ✓ Linac Cryogen Distribution Piping (ok for double flow but cuts down on maximum refrigeration due to need for lower 2K operating pressure by 5 mbar, ie. compensation for additional piping pressure drop due to increased flow)

Needed New Equipment for CHL#2

- 4.5 K cold box and warm helium compressors
  - Two sectional 4.5K cold box, (300-60K, 60K-4.5K)
  - Design baseline is JLab’s Ganni Helium Process Cycle
  - Capacity, 4600 W @ 2.1 K and 12 kW at 35 K plus 25 g/s
- Compressor oil removal system
- Gas Management System
- Computer distributive control system
- 10 kL helium dewar

New Facilities and Utilities

- Cooling Water System (twin 15,200 l/min)
- Electrical Power (twin 5 MW, 4160V)
- 4800 ft^2 compressor building

Existing CHL#1 Building

New CHL #2 Compressor Building

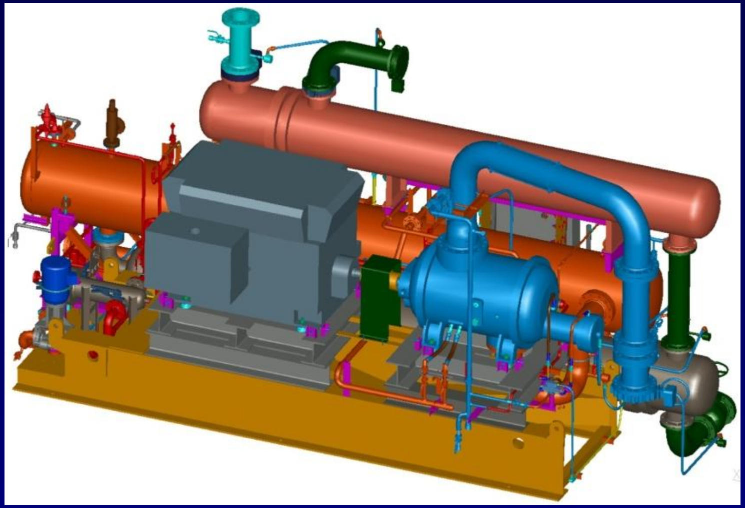
CHL #2 Building
(August 09)

CHL #2 Building
(March 10)

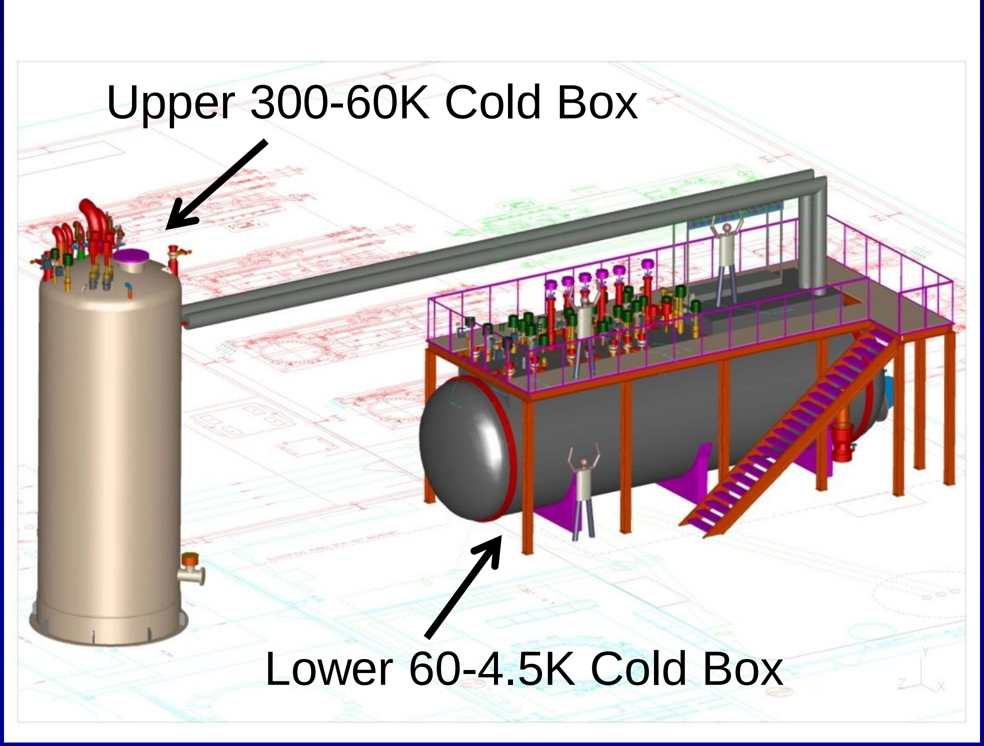
CHL #2 Compressor Building Foundation and Electrical Conduits

(before the compressors were purchased)

CHL Major Equipment Procurements



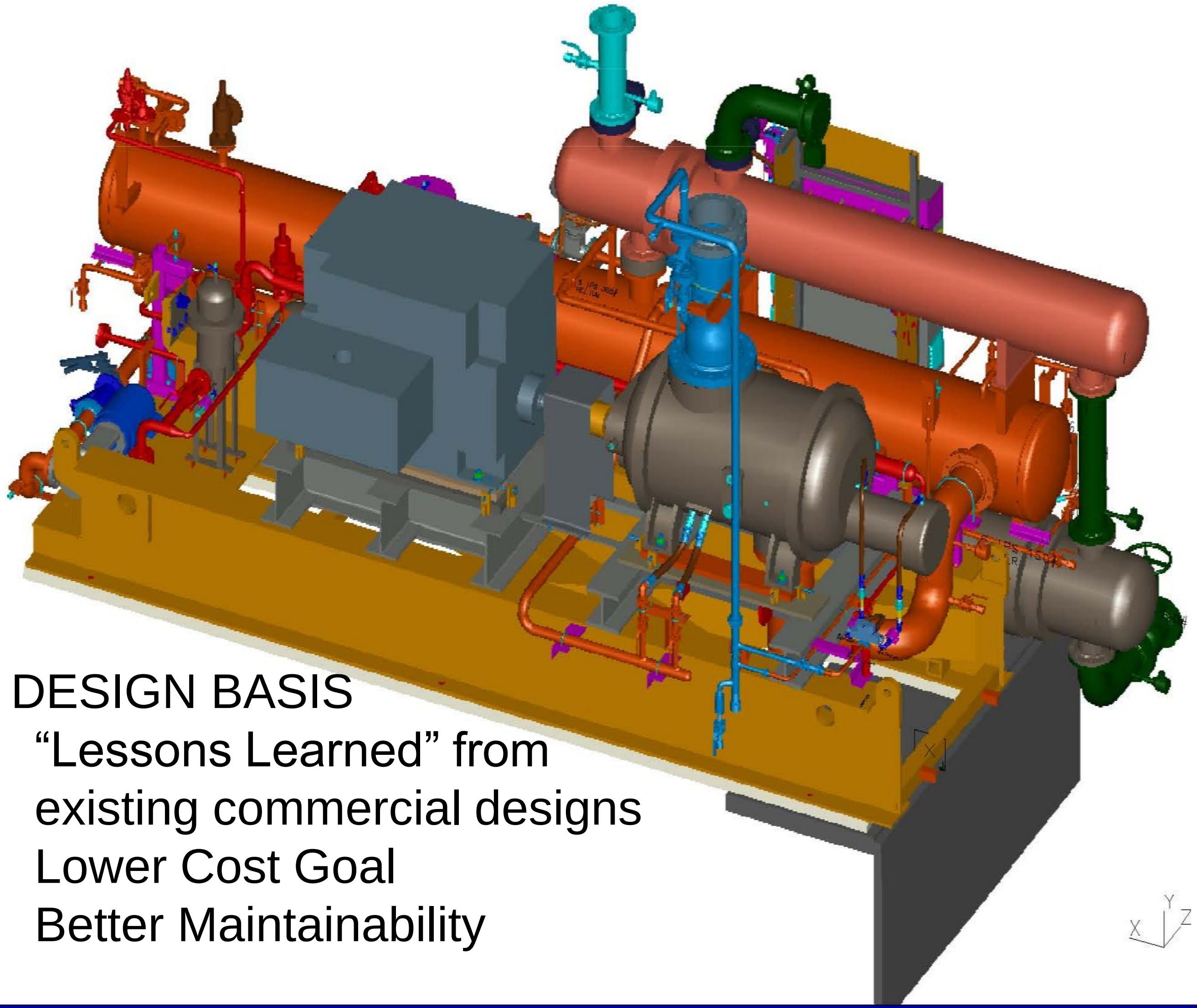
CHL Warm Helium Compressors (5)



CHL 4.5K Cold Box

Compressors & 4.5K Cold Box ~73% of the cost

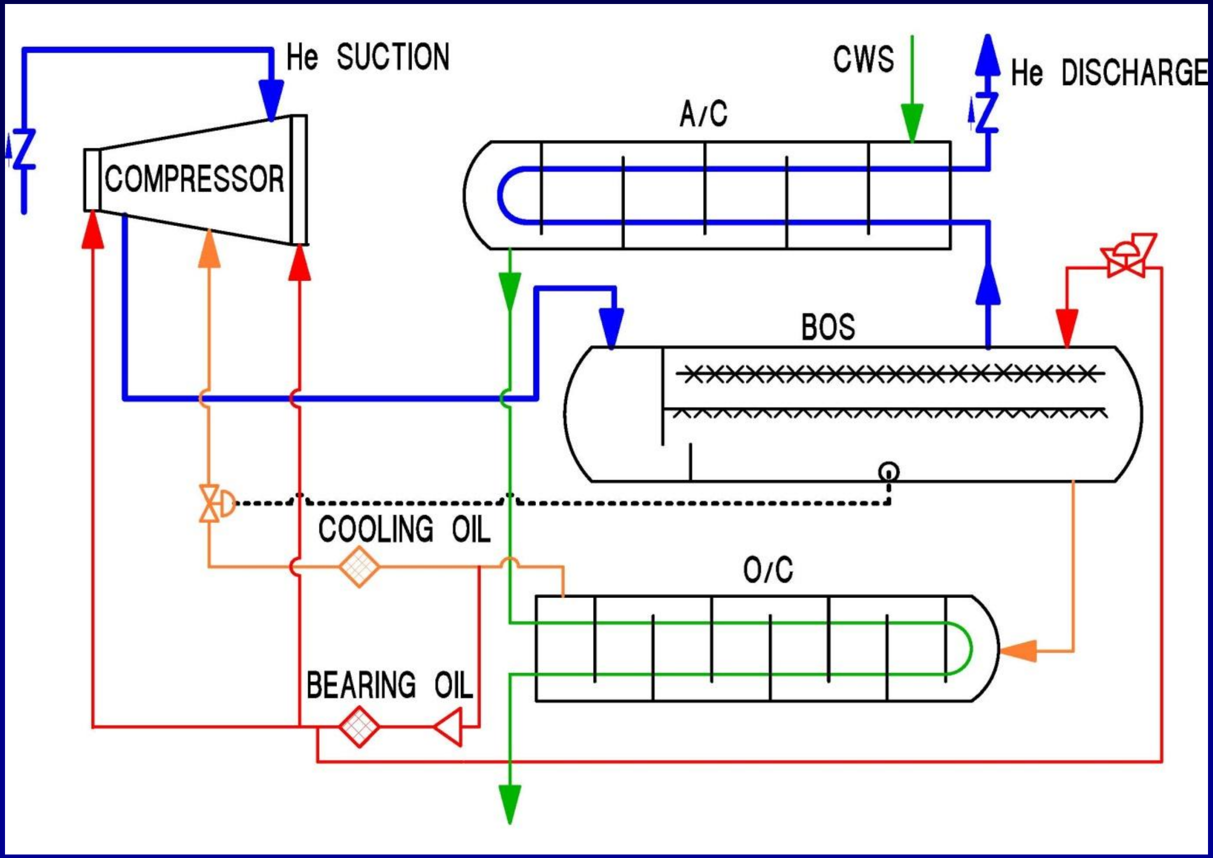
Typical CHL#2 Compressor Assembly



JLab DESIGN BASIS

- "Lessons Learned" from existing commercial designs
- Lower Cost Goal
- Better Maintainability

Compressor Flow Schematic



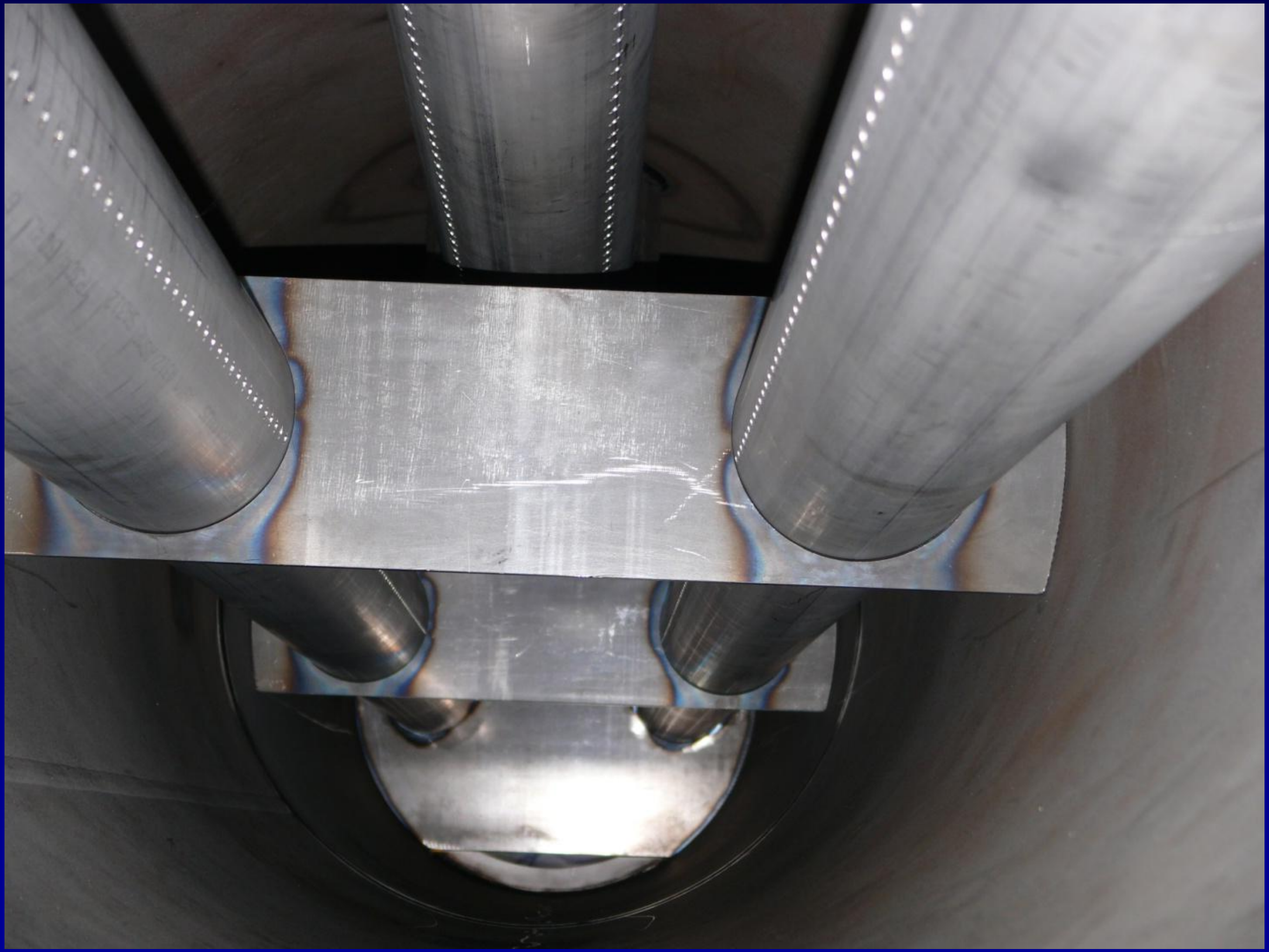
A/C….Gas Discharge After-cooler Heat Exchanger
BOS…Bulk Oil Separator Vessel
O/C….Oil Cooler Heat Exchanger

Compressor Skid Assembly Underway At Vendor's Facility

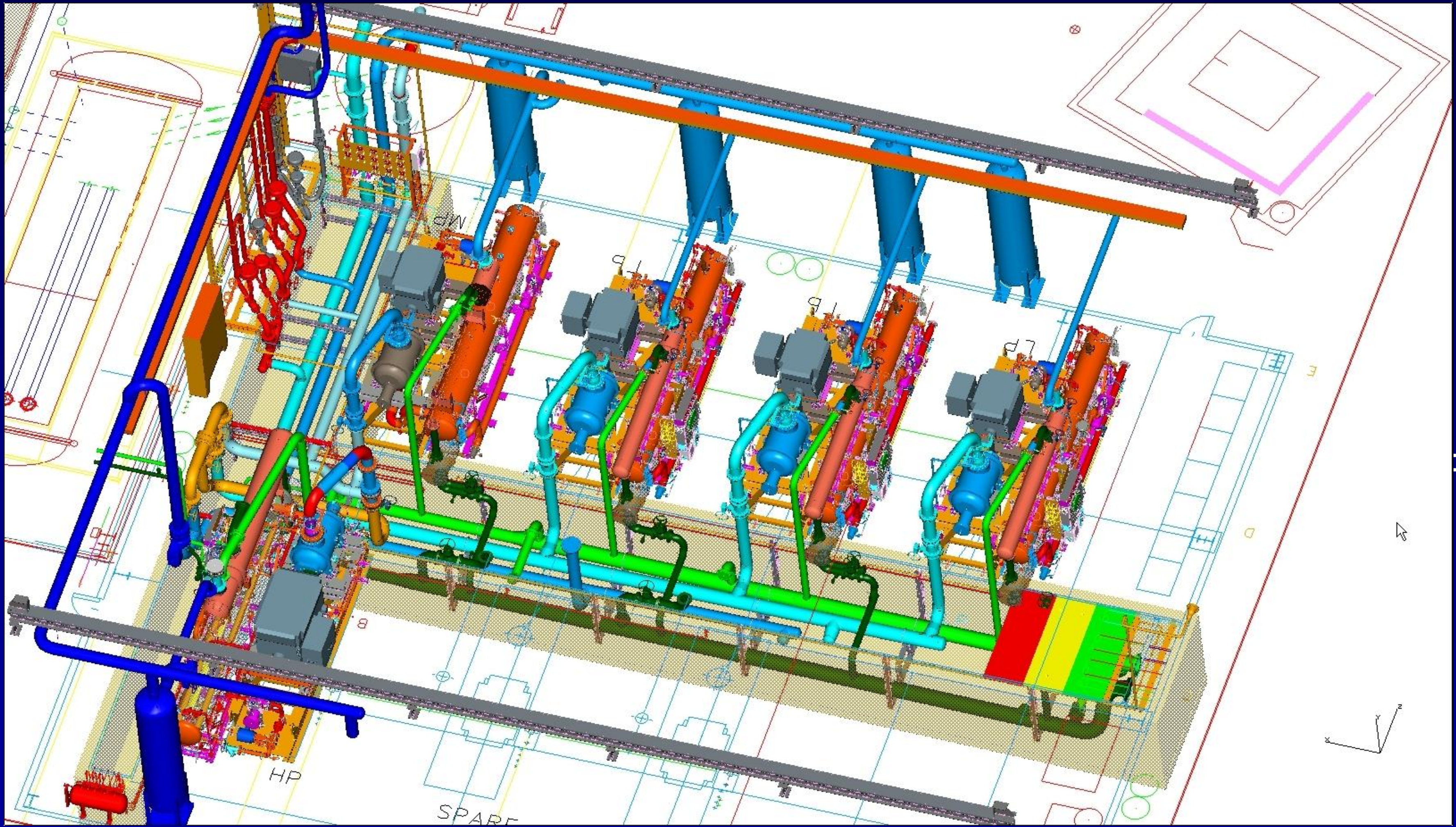
JLab Designed BOS

3x more effective oil separation

JLab Bulk Oil Separator Internals



CHL#2 Compressor Building Layout

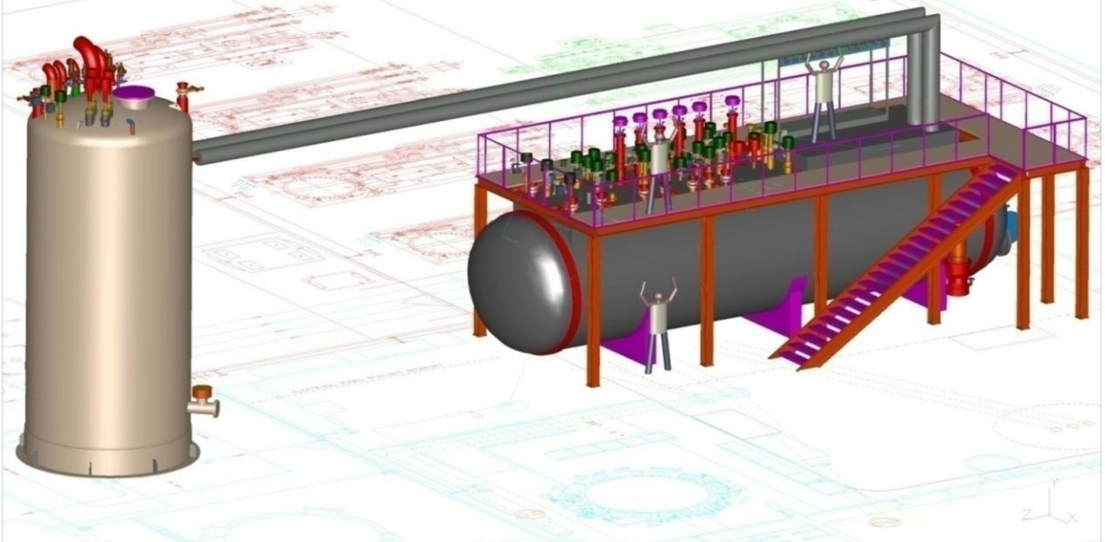


CHL#2 He and Cooling Water Trench Piping Installatin Underway

CHL#2 Final Oil Removal Vessels

New CHL#2 4.5K Cold Box Design Considerations

Uses JLab Ganni Helium Cycle In “Split Cold Box Design” as basis



•Moves large upper temperature section (>60K) out-of-doors for smaller indoor system foot print and easier field construction and facility cost reduction, eliminates special building feature requirements such as large building access doors and cold box insulating vacuum floor pits, enabled use of existing JLab building without modifications

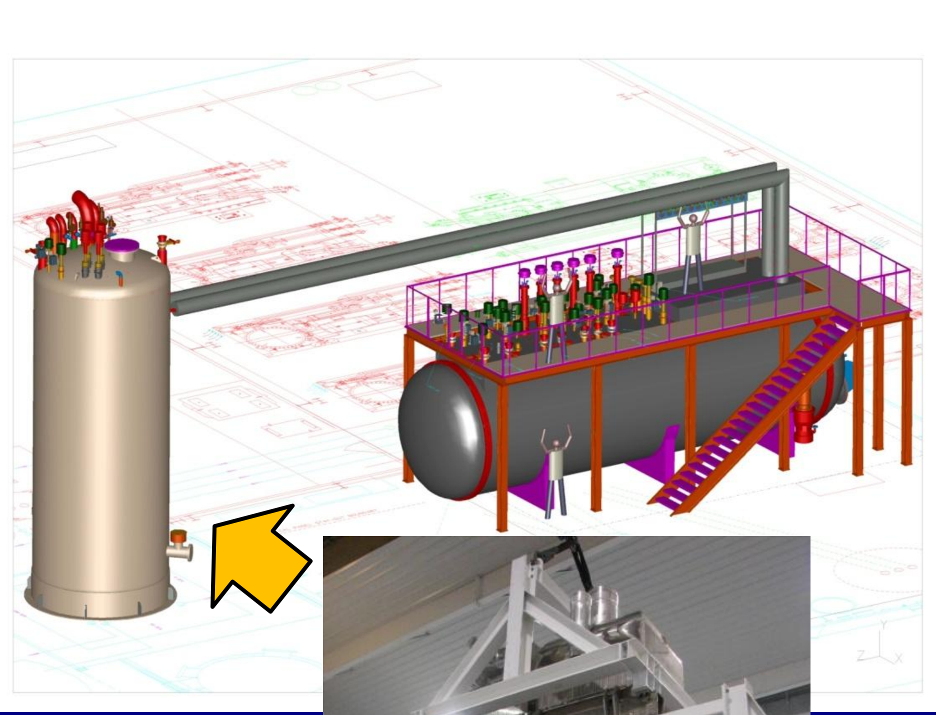
•Has lower temperature (<60K) section indoors which contains turbines, valves, etc. which require personnel access and controlled work environment

Cold Box Under Construction

Upper Cold Box Heat Exchangers

Lower Cold Box Heat Frame and Vacuum Shell Top Assembly

CHL 4.5K Cold Box Assembly

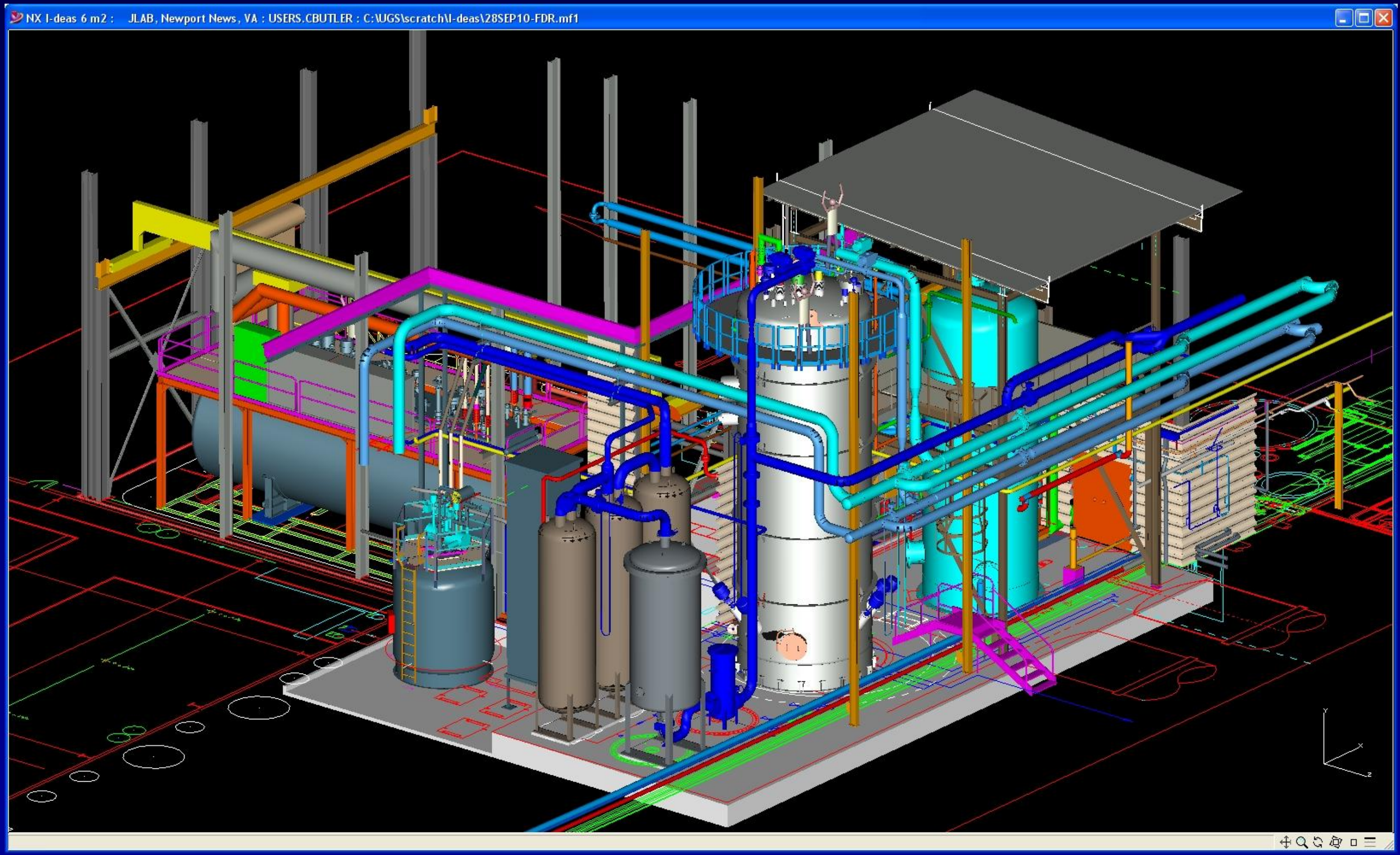


"Top Hat" and Cold Box Frame

Internal Heat Exchangers

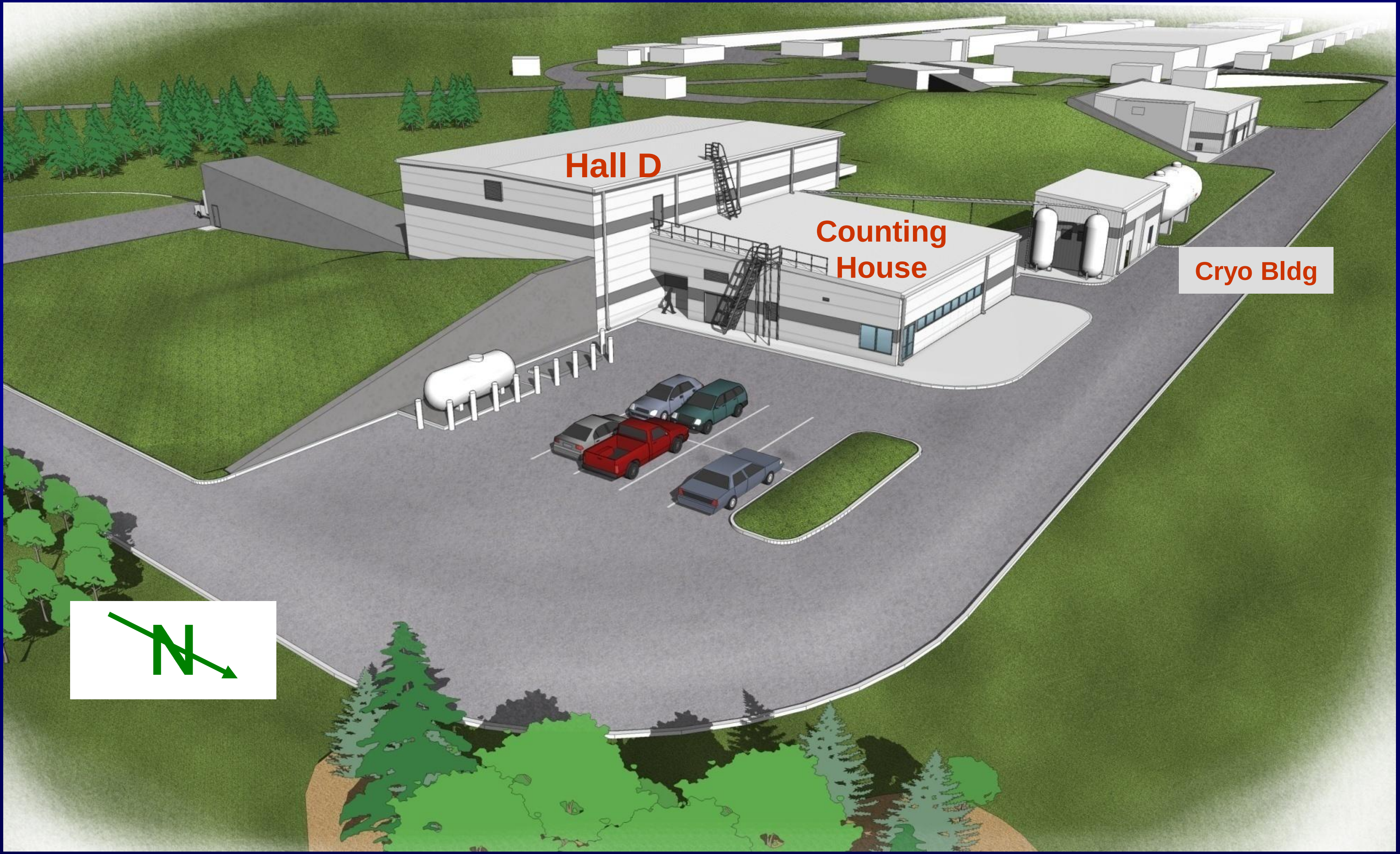
Existing 2K Cold Compressor Box (to be used with CHL#2)

CHL #2 Installation Plans



CHL 4.5K Cold Boxes Installed
In Existing Building

Hall D Rendering



A Look at the Hall D Refrigerator

HALL-D Cryogenic System

Hall D 4.5K Refrigerator (Built 1980)

200W @ 4K Refrigeration or 2 g/s Liquefaction Capacity

Hall-D Mixed Load…0.7 g/s liquefaction + 100W Refrigeration

(includes transfer line load)

Hall D Refrigerator Equipment “On Hand”

- ✓Two CTI Cryogenics Helium RS Compressors
- ✓CTI M2800 200W 4.5 K Helium Refrigerator
- ✓LHe Subcooler Dewar
- ✓Motor Starters, 480V

Other Hall D Cryogenic Equipment Requirements

- Gas Management Valve Control Rack
- LN2 storage, 10,000 liter dewar
- One 4000 cf Helium Gas Storage Vessel
- Integrated Refrigerator Computer Controls
- Instrument Air System, 15 scfm
- Purification Loop Piping to the CHL via N. Linac
- 640 ft^2 building
- Compressor/Turbine Cooling Water
- 480V, 300 kW compressor power

Hall D Refrigerator Building Under Construction

Hall D 4,000 Cuft Gas Storage Tank

12 GeV Cryogenic Schedule

October 2006 – October 2008	CD-2, Project Engineering and Design Status
October 2008	CD-3, Project Construction Status
April-Sept 2009	CHL#2 Major Component Purchase
December 2009	CHL#2 Building Construction Complete
October 2010	CHL#2 Utilities Construction Complete
October 2010-July 2011	CHL#2 Major Equip Delivery/Installation
Oct 2011-March 2012	Hall D Refrigerator Installation
Oct 2011 -June 2012	CHL#2 Commissioning
March-April 2012	Hall D Refrigerator Commissioning

Current Cryogenic Status

- Construction Phase, CD-3, Sept 2008
- CHL Civil Design ~100% Complete
- Hall D Cryogenic Civil Design ~100% Complete
- Major Cryogenic Specifications Developed
- CHL 4.5K Refrigerator Fabrication Underway
- CHL Compressor Skid Fabrication Underway
- All Major Procurements have been placed
- CHL Field Installation Piping and Controls On-going
- On Schedule and Budget

Thank You for Your Kind Attention

May We Answer Your Questions ?

Backup Slides of Ganni Cycle Description

Compressor Characteristics

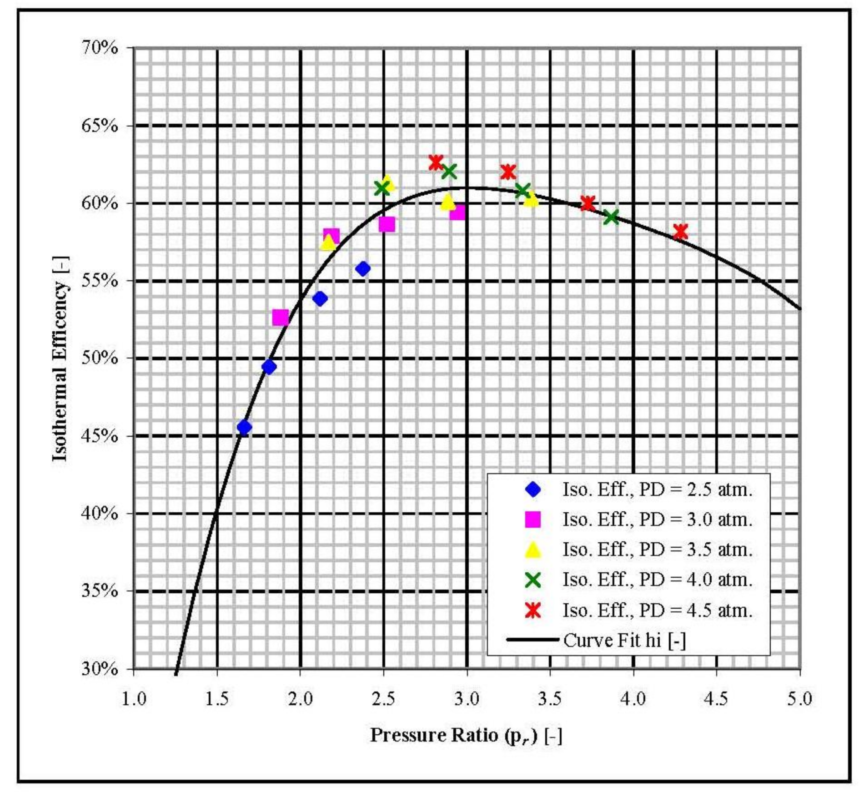


FIGURE 1.3 BRV=2.2 1st Stage

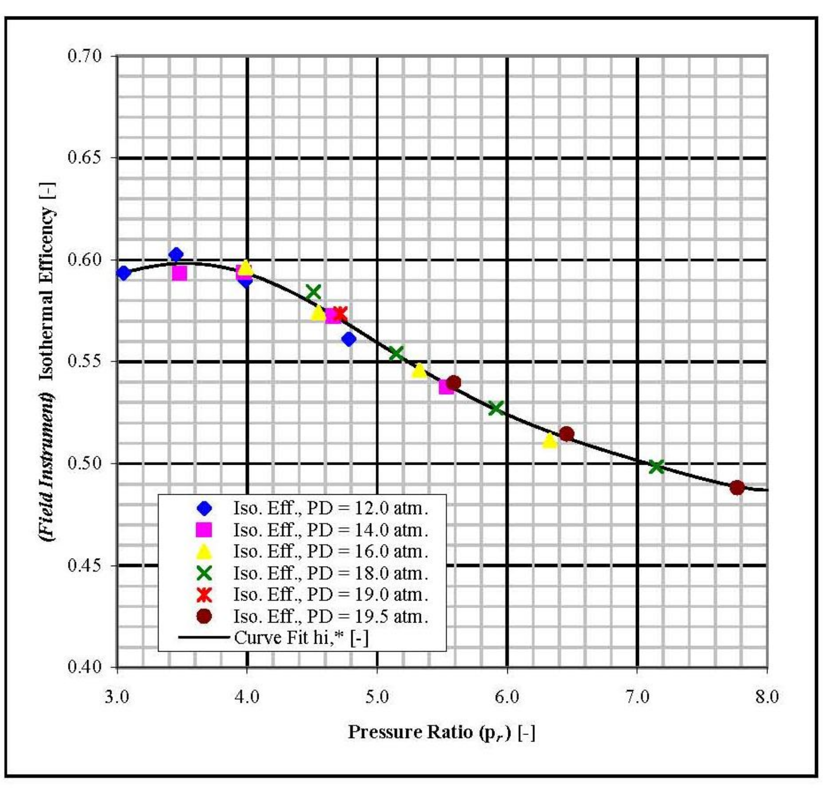
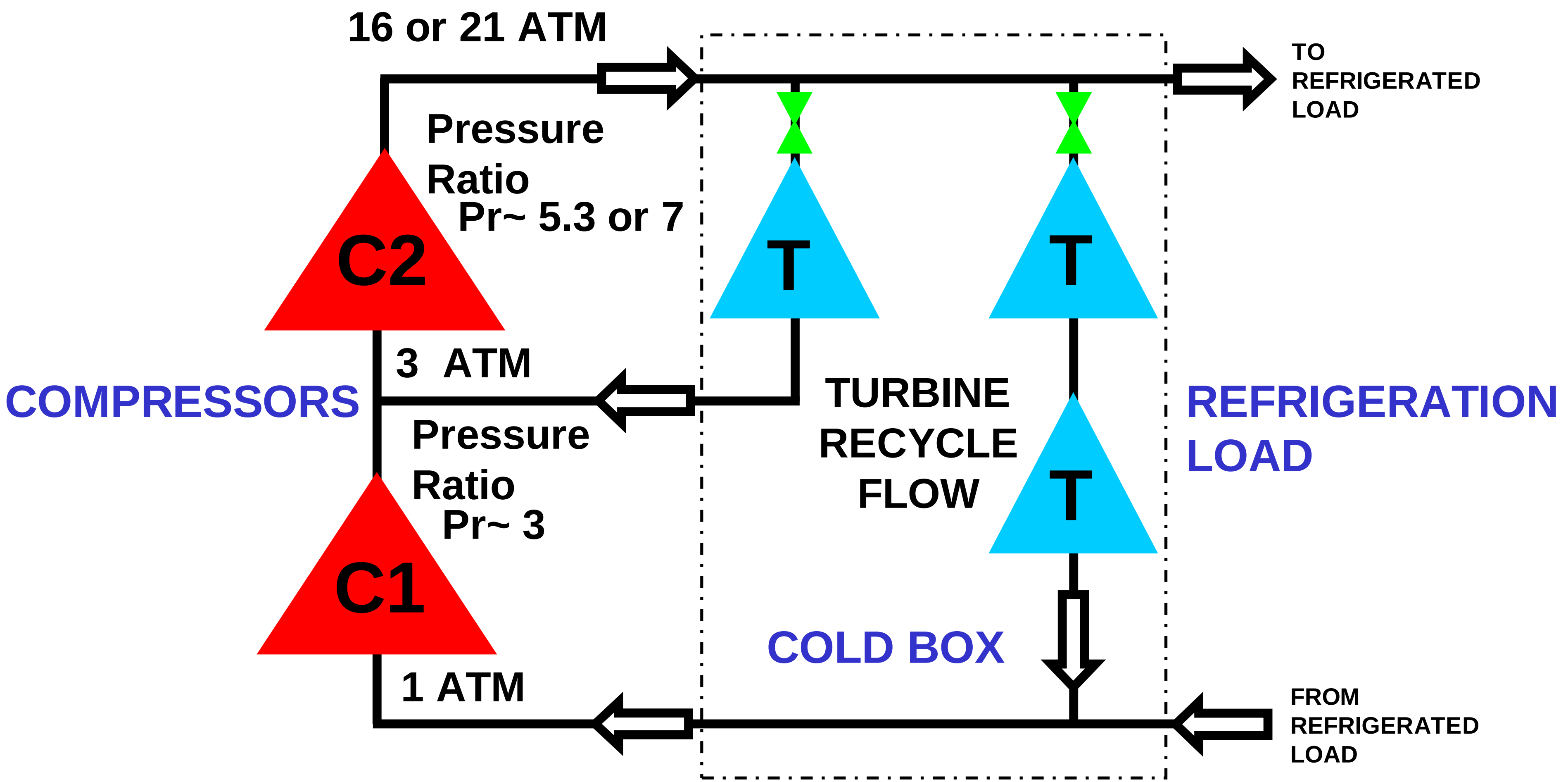


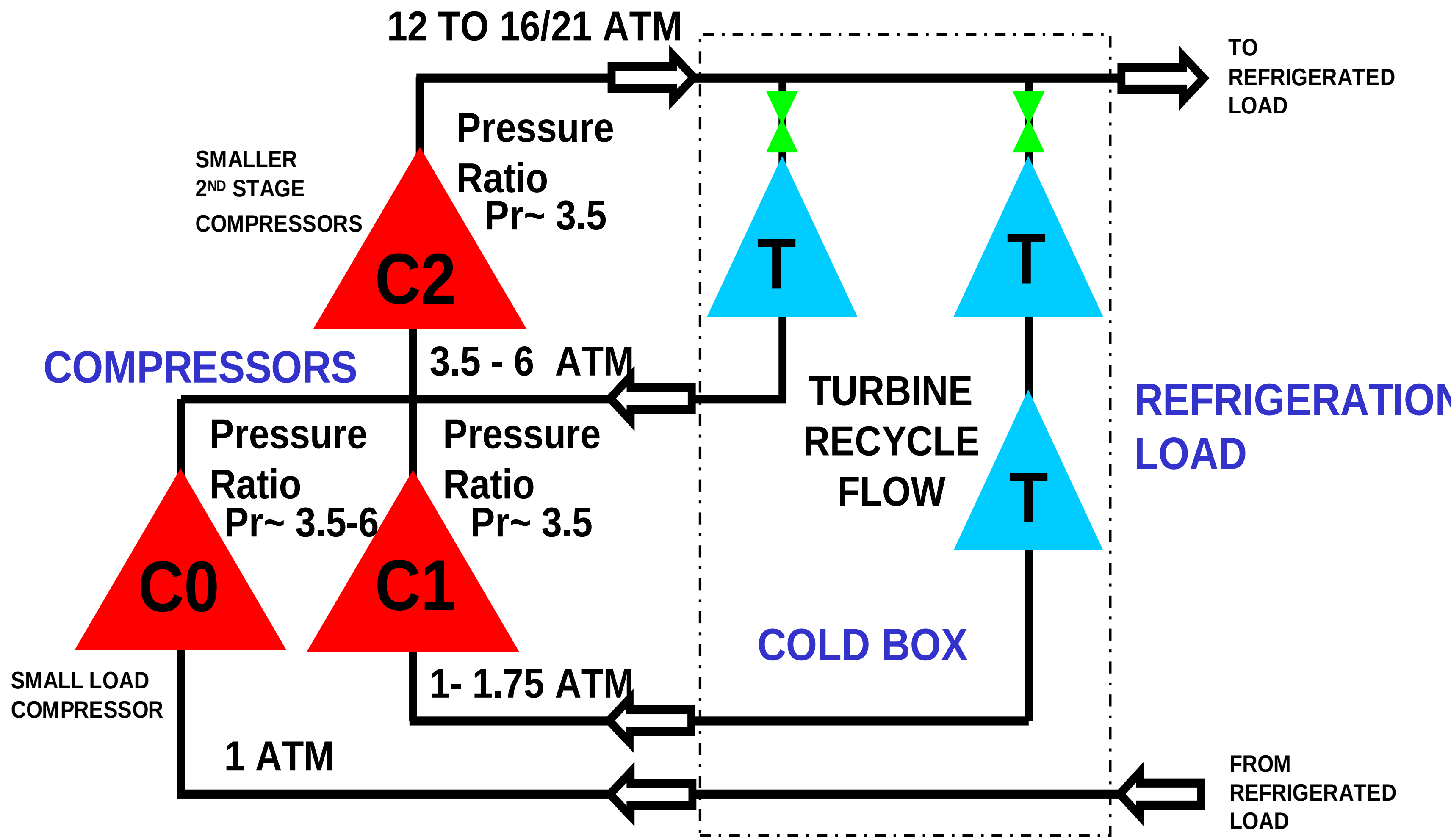
FIGURE 1.4 BRV=2.6 2nd Stage

Standard Cycle



STANDARD INDUSTRIAL
HELIUM REFRIGERATION SYSTEM

Ganni Cycle



GANNI CYCLE (FLOATING PRESSURE)
HELIUM REFRIGERATION SYSTEM