[C1Or2A-03]
Cold compressor performance and energy consumption improvements at Jefferson Lab's Central Helium Liquefiers

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U.S. DEPARTMENT of ENERGY

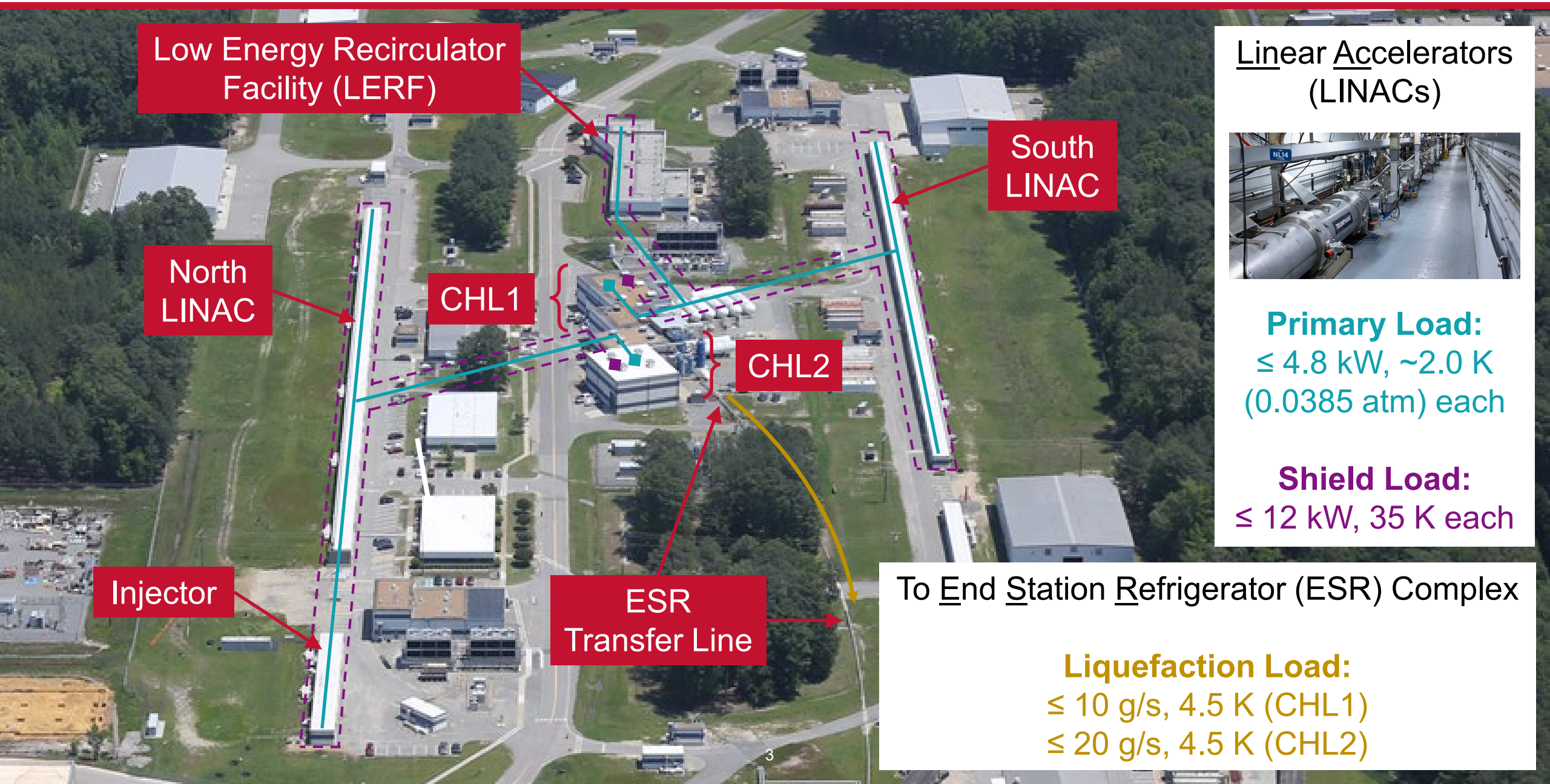
Talk outline

Overview of Jefferson Lab accelerator cryogenic system

CHL1 cold compressor performance and impact on power consumption

CHL2 cold compressor optimization and impact on power consumption

Two Central Helium Liquefiers (CHLs) support cryogenic needs of the Continuous Electron Beam Accelerator Facility (CEBAF)



Linear Accelerators (LINACs)

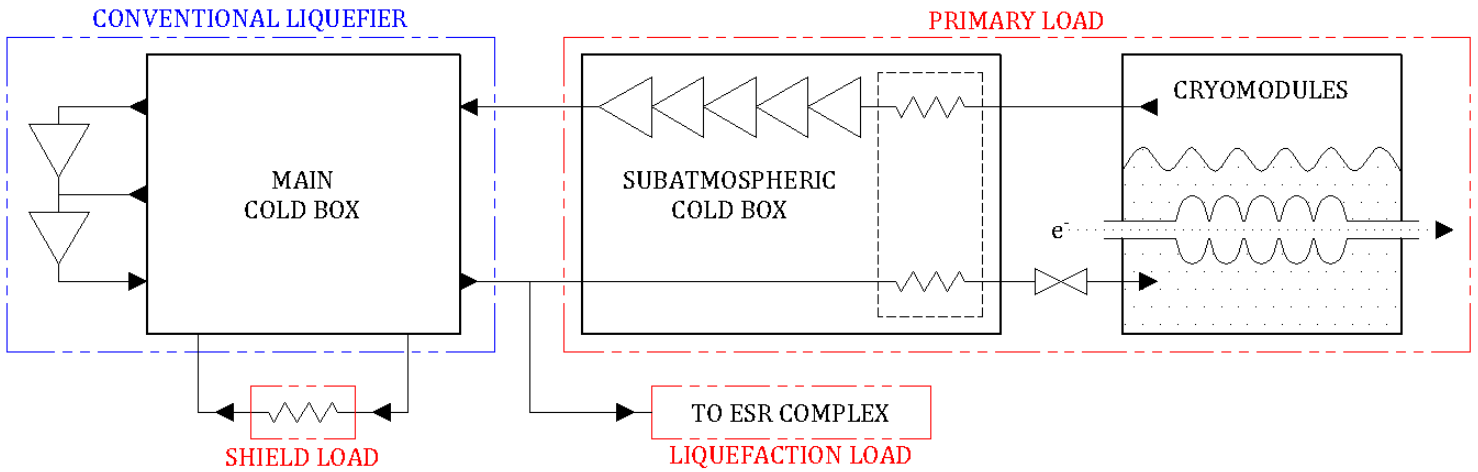
Primary Load:
≤ 4.8 kW, ~2.0 K (0.0385 atm) each

Shield Load:
≤ 12 kW, 35 K each

To End Station Refrigerator (ESR) Complex

Liquefaction Load:
≤ 10 g/s, 4.5 K (CHL1)
≤ 20 g/s, 4.5 K (CHL2)

Cold compressor performance significantly impacts CHL power consumption



Separate cold boxes with 5-stage cold compressor systems maintain subatmospheric LINAC conditions

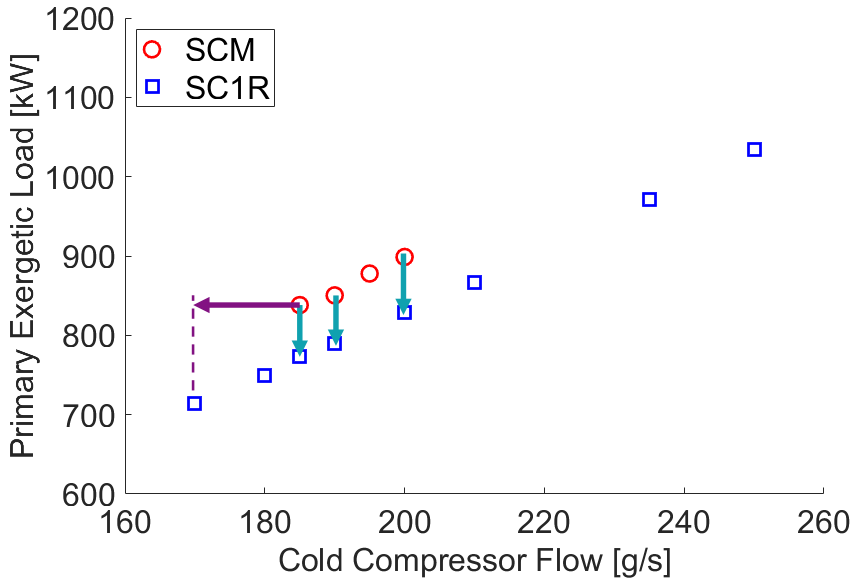
Primary load on conventional refrigeration system includes LINACs and subatmospheric (2 K) cold box

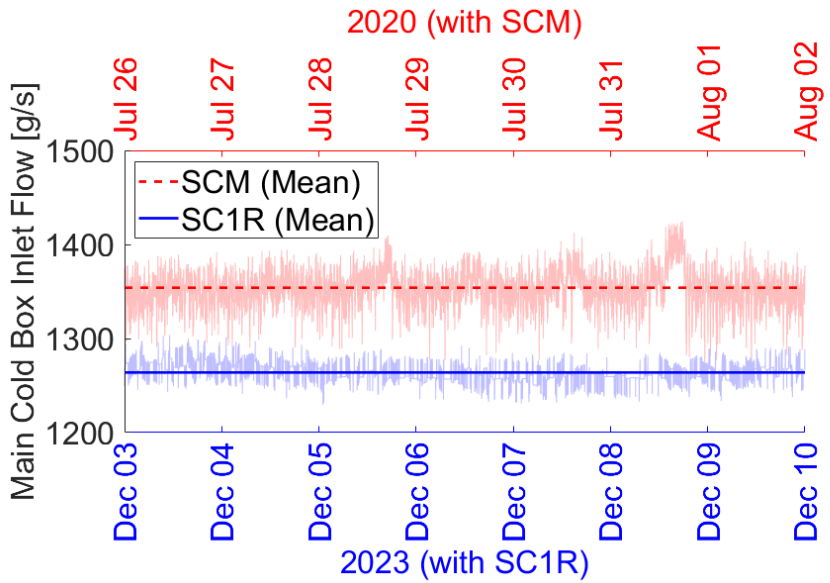
Load	CHL1		CHL2	
	Heat/Flow	Exergy	Heat/Flow	Exergy
Primary	4.8 kW	1,071 kW	4.8 kW	1,071 kW
Shield	12.0 kW	89 kW	12.0 kW	89 kW
Liquefaction	10 g/s	68 kW	20 g/s	136 kW
NBP Equivalent	17.6 kW	1,228 kW	18.6 kW	1,296 kW

Combined primary load accounts for over 80% of total load exergy usage

Lower cold compressor flow rates and **higher efficiencies** will **reduce input power** for main refrigerator

New CHL1 cold compressors offer better efficiency and turndown than the original technology that they replace





CHL1 2 K cold box (formerly SCM) was recently replaced (now SC1R)

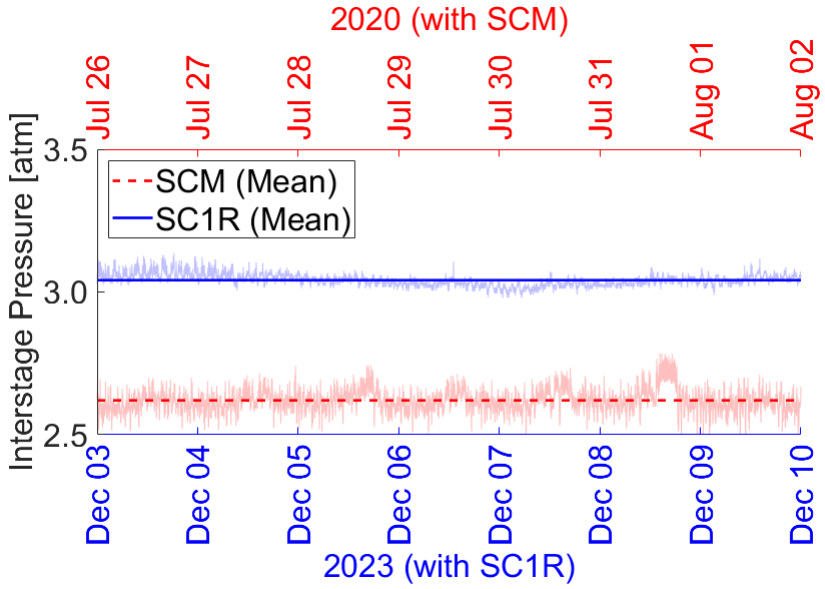
New cold box is built around new cold compressor technology

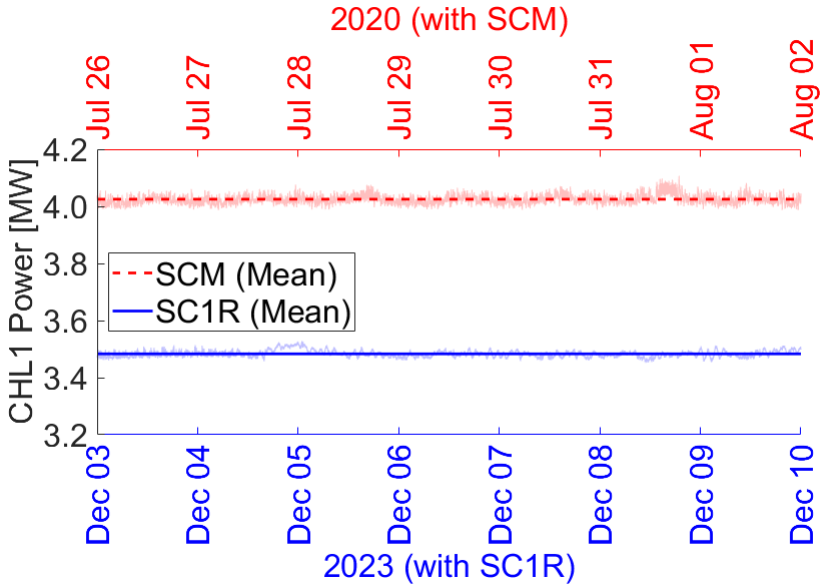
- **8% lower primary load exergy usage rate**
- **15 g/s better turndown**

Availability required at main cold box high pressure inlet is reduced

- Pressure is fixed by turbine static gas bearing requirements
- Temperature is fixed by compressor cooling water system
- **Main compressor flow is reduced**

Superior performance of SC1R has reduced the number of second stage main compressors required to sustain 2 K operations





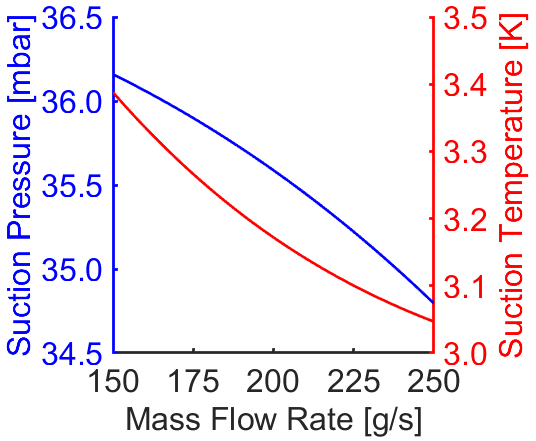
Two and a half second stage main compressors with ~ 2.6 atm interstage pressure produce ~ 1,350 g/s to satisfy SCM demand

Two second stage main compressors with just over 3 atm interstage pressure produce ~ 1,260 g/s to satisfy SC1R demand

Shutting off the third machine **reduces power consumption at CHL1 by 540 kW**

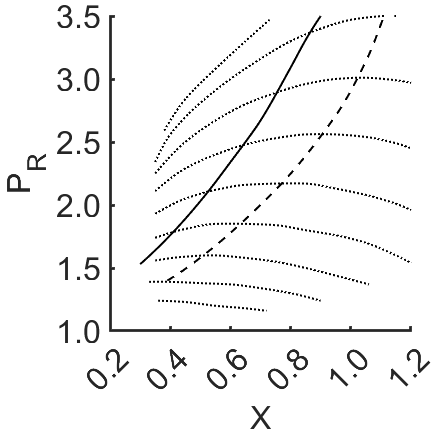
Third machine is still required for periods of increased loading (e.g., use of ESR transfer line)

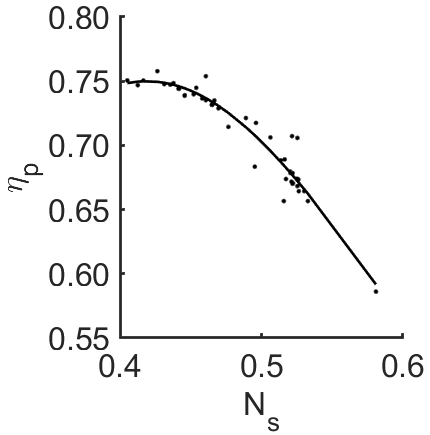
CHL2 2 K cold box commissioning data can be used to fully characterize the cold compressor system operating point



first stage suction conditions for P_{sat} = 0.0385 atm

pressure ratio given reduced flow and reduced speed





polytropic efficiency given specific speed

Originally built as a redundant 2 K cold box for CHL1 using older cold compressor technology (SCN)

Given LINAC pressure and mass flow rate:

- First stage suction pressure and temperature from empirical cryogenic distribution system data

Given cold compressor suction pressure, suction temperature, mass flow rate, and rotational speed:

- Discharge pressure from vendor's performance law
- Discharge temperature from measured efficiency

Cold compressor system operating point obtained given only **mass flow rate** and **rotational speeds**

Cold compressor performance can be optimized by choosing the "best" among many potential operating points

Choose a mass flow rate of interest and a range of speeds for each stage

Compute pressures and temperatures for each speed combination - typically results in 0.5-2M operating points

Assign a value to each operating point using a cost function

Rotational speed combination with the lowest cost is considered optimal for the flow rate setpoint under investigation

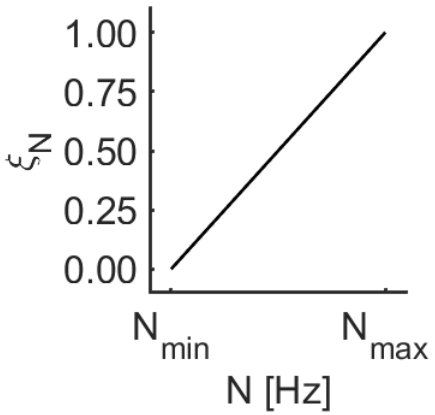
Main Cost Function

$$\Xi = \underbrace{\sum_{i=1}^{5} W_{N,i}\xi_{N,i}}_{\text{5 terms: rotational speed}} + \underbrace{\sum_{i=1}^{5} W_{M,i}\xi_{M,i}}_{\text{5 terms: surge margin}} + \underbrace{W_T\xi_T}_{\text{final outlet temp}} + \underbrace{W_\sigma\xi_\sigma}_{\text{surge margin std dev}}$$

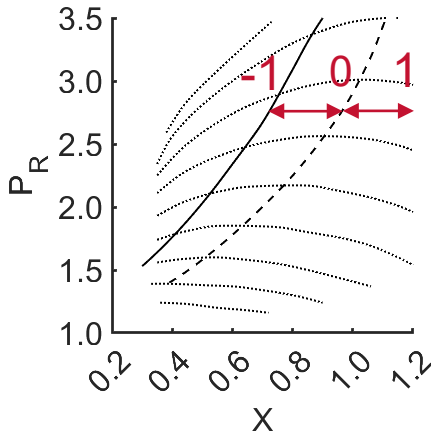
ξ: Function assigning a cost to each cold compressor operating parameter of interest (range must be 0-1)

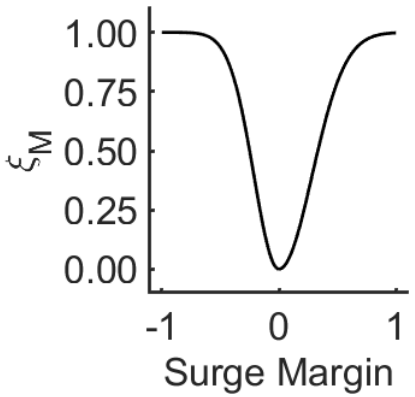
W: Weighting factor to set the importance of each parameter cost function

Parameter cost functions are selected to prioritize stability and reliability of the cold compressor system

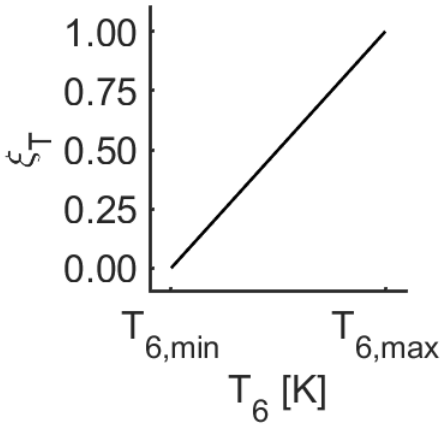


Lower speeds are preferred to minimize stress on the analog active magnetic bearing system





Deviations from peak efficiency to surge line are more aggressively penalized than deviations toward choke line



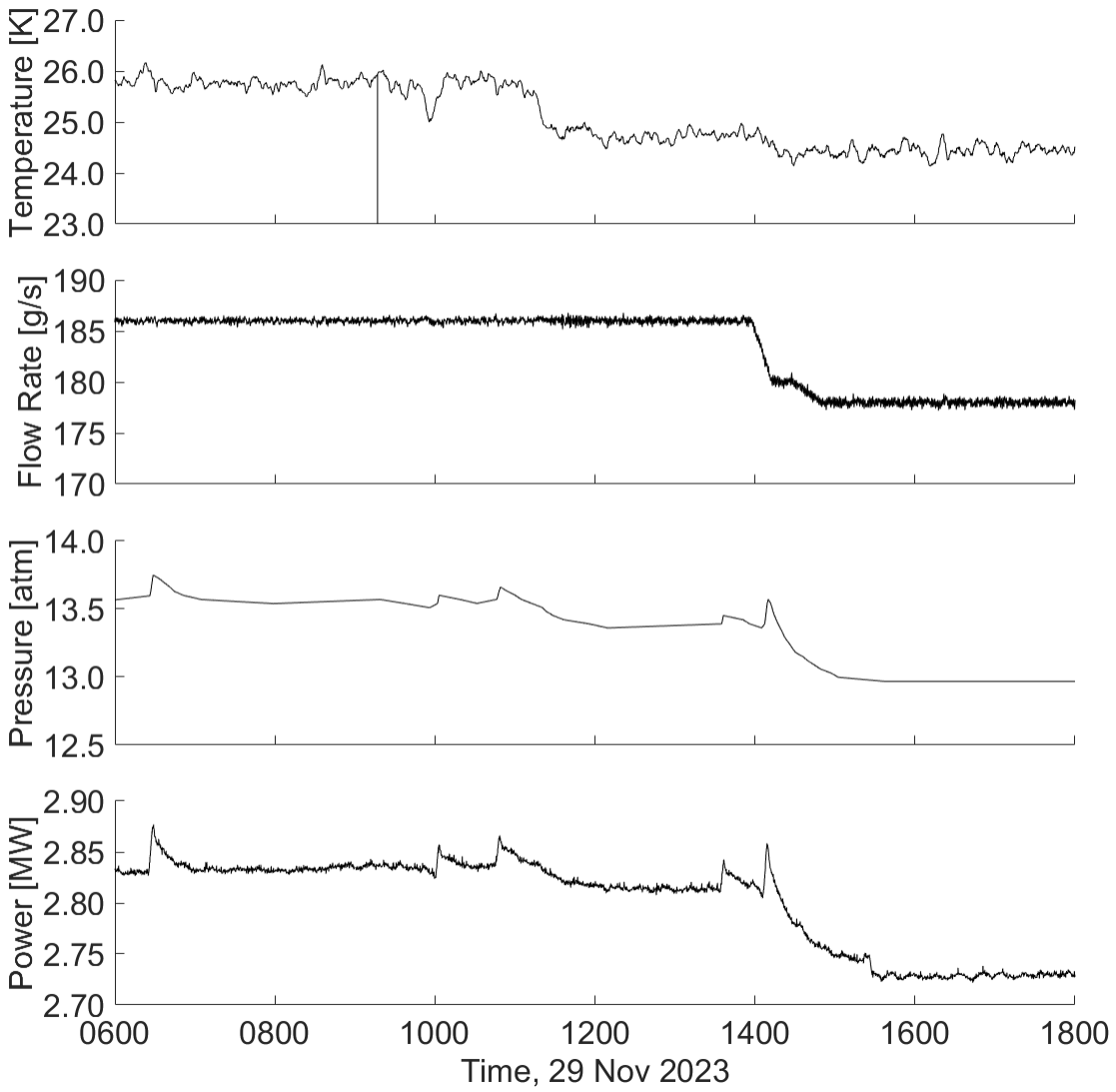
Lower fifth stage discharge temp. (T_6) indicates higher overall system efficiency

$$\xi_\sigma = \sigma_M$$

Lower surge margin standard deviation means no compressor is “sacrificed” to achieve very low costs for the other four

Range is 0-1 due to surge margin definition

Optimization has identified a stable operating point for the CHL2 cold compressors with lower mass flow and better efficiency



Former minimum flow setpoint was 186 g/s

178 g/s is the lowest flow rate for which speed ratios could be found that keep surge margin above -30% for all five stages

Final discharge temperature fell from 25.8 K to 24.4 K upon implementation of new speed ratios

Floating Pressure – Ganni Cycle technology lowers main compressor pressure in response to the decreased load, **reducing CHL2 power consumption by 110 kW**

Cold compressor performance improvements at Jefferson Lab have reduced combined CHL power consumption by nearly 10%

Turndown and efficiency of SC1R cold compressors allows CHL1 to operate at 2 K with one less second stage main compressor, **reducing CHL1 power consumption by 540 kW (over 13%)**

Optimization of SCN cold compressor speed ratios improves CHL2 primary load turndown range, **reducing CHL2 power consumption by 110 kW (about 4%)**

Total power consumed by the CEBAF cryogenic system has been **reduced by 650 kW, nearly 10% of the former combined CHL energy usage rate**