TRIUMF

Canada's national laboratory for particle and nuclear physics and accelerator-based science

ARIEL e-linac 2K Cryogenic System: First Operational Experience

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Workshop on Cryogenic Operations - 2016

Fermilab

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TRIUMF: A National Science Laboratory

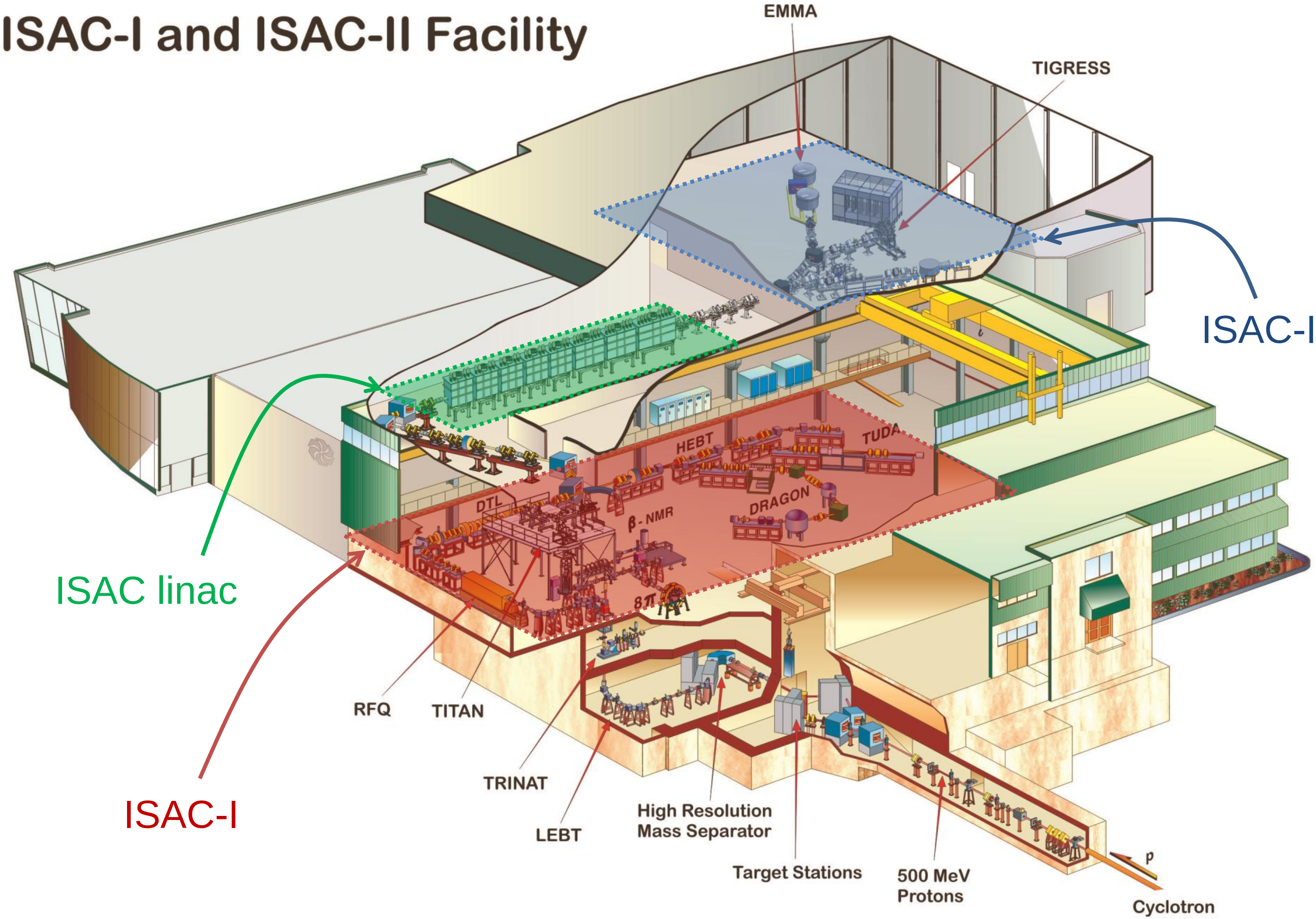
TRIUMF Laboratory

- founded 45 years ago
- owned and operated by consortium of 18 universities
- ~450 scientists and staff on campus
- research focus on rare isotopes & structure of matter

Cryogenic Systems

- SC Solenoid: Sulzer TCF200 Helium Refrigerator (off)
- Cyclotron Cryopumping: Linde 1630 Helium Refrigerator
- Helium Recovery Facility: Linde 1610 Helium Liquefier
- ISAC-II SC Linac: two Linde TCF50 Helium Refrigerator
- ARIEL SC Linac: Air Liquide HELIAL LL Helium Liquefier

Rare Isotope Beam Facilities: ISAC-I and ISAC-II



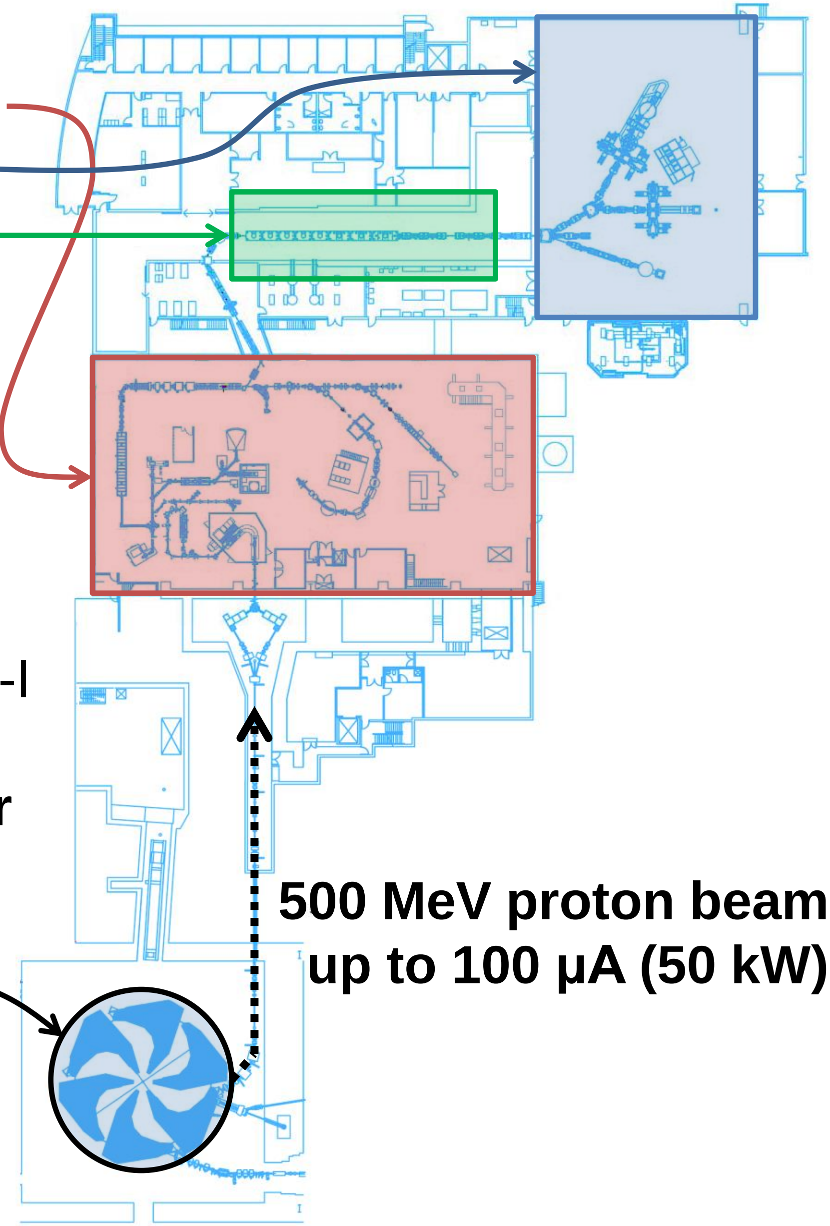
TRIUMF's Rare Isotope Beam facilities:

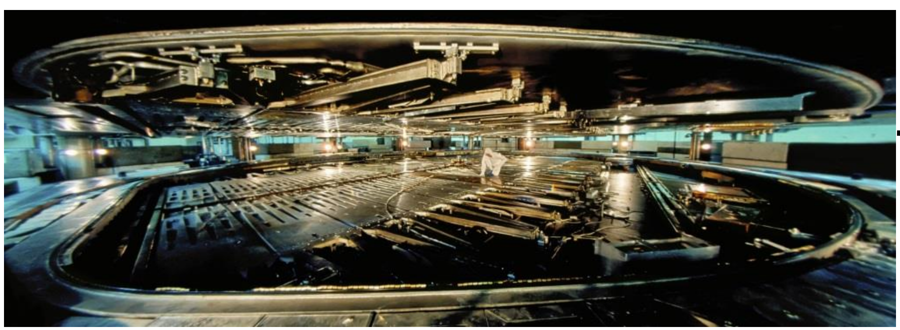
- ISAC-I (low and medium energy facilities)
- ISAC-II (high energy accelerated beams)
- ISAC heavy ion SRF linear accelerator

Science program:

- Nuclear Structure and Reactions
- Nuclear Astrophysics
- Materials Science
- Fundamental Symmetries

With many world class experiments in ISAC-I and ISAC-II areas, TRIUMF is only able to support a single user **due to a single driver**

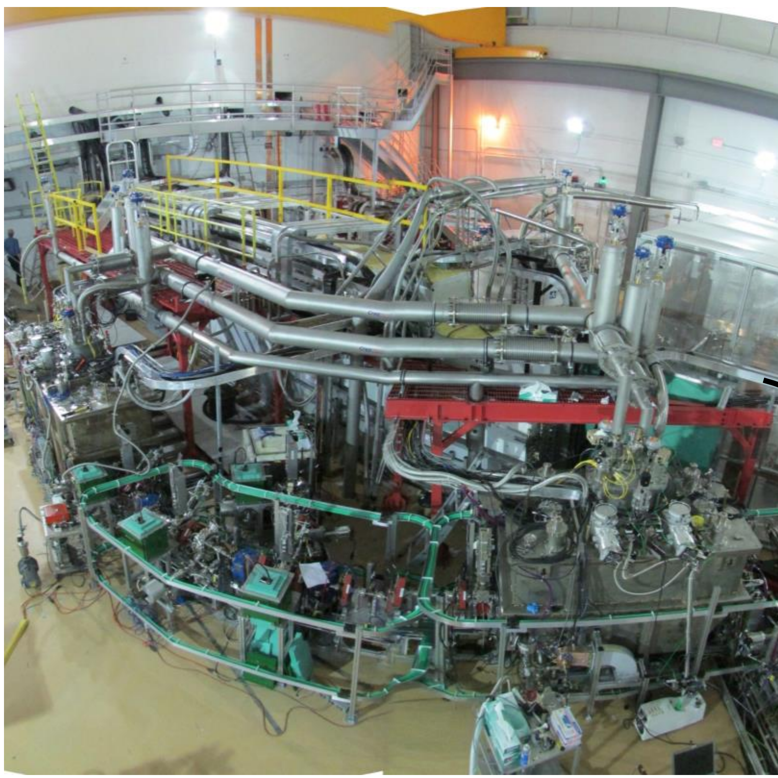




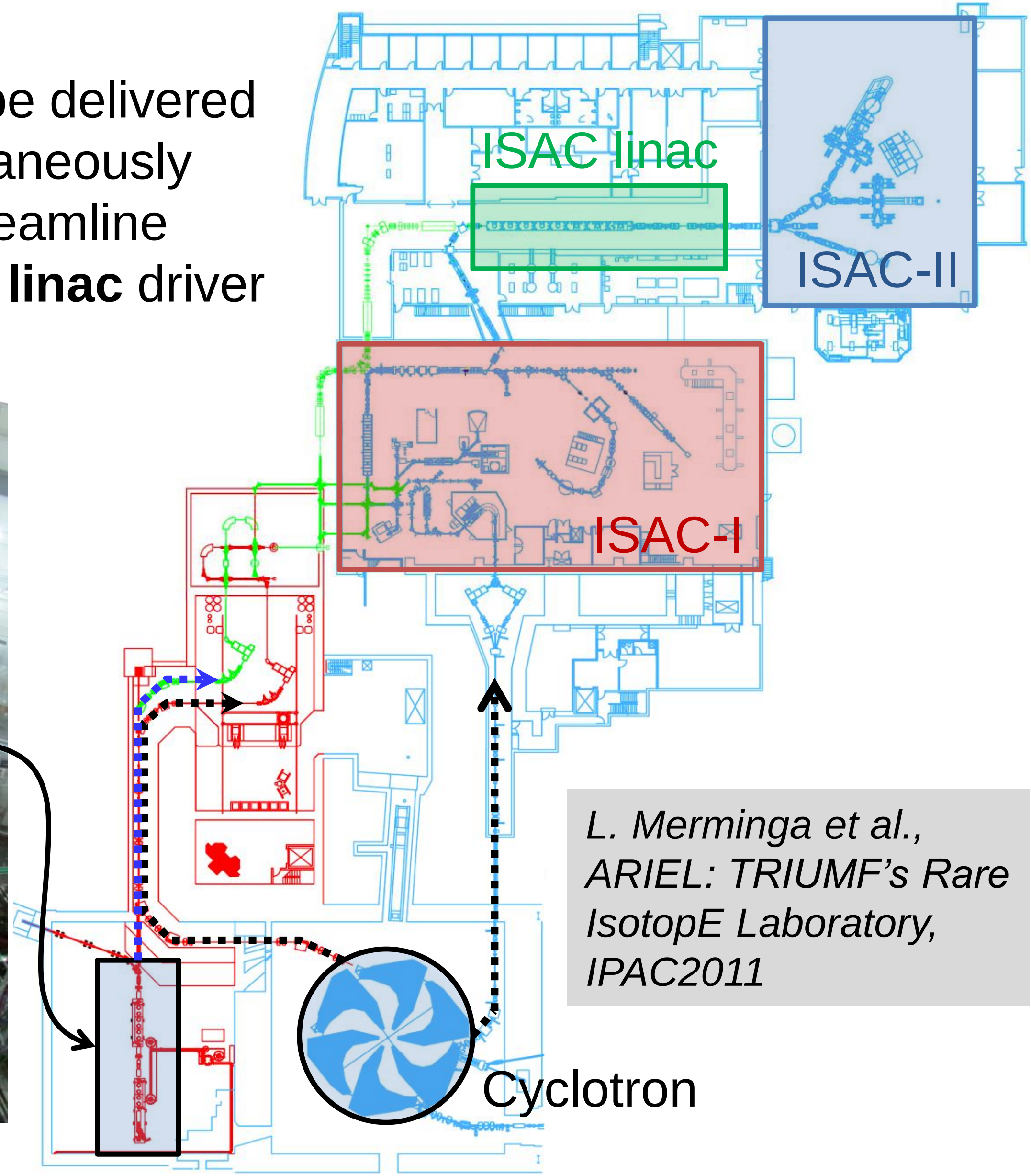
TRIUMF Cyclotron (built in 1972)

TRIUMF's ARIEL Project:

- allows rare isotope beams to be delivered to multiple experiments simultaneously
- extra proton cyclotron driver beamline
- complementary **electron SRF linac** driver 30 MeV, 10 mA (300 kW)



electron SRF linac



L. Merminga et al., ARIEL: TRIUMF's Rare IsotopE Laboratory, IPAC2011

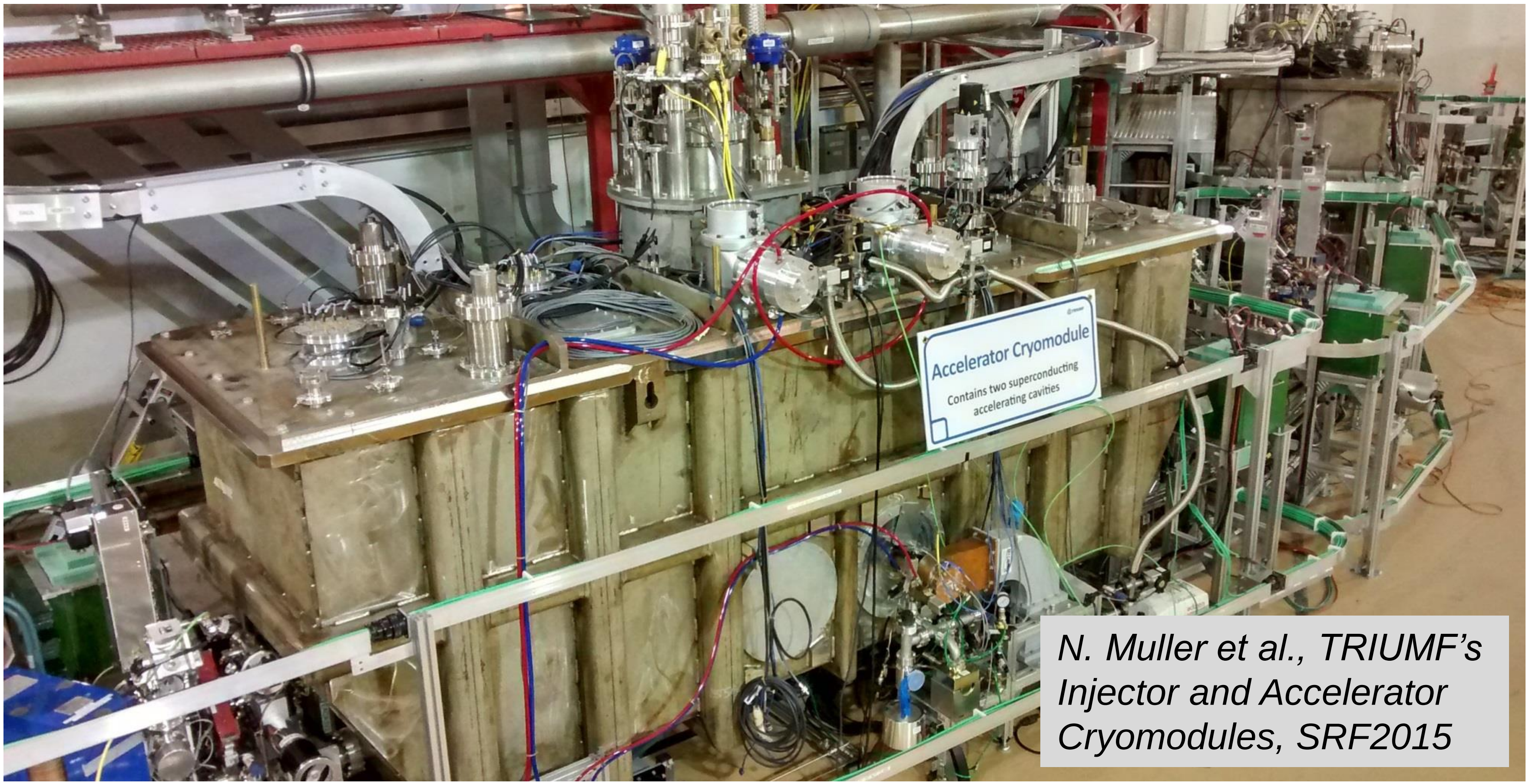
ARIEL Project: SRF Specification

Electron SRF linac specification:

- 30 MeV @ 10 mA (300 kW beam)
- 5 elliptical 1.3 GHz SRF cavities
- 1 injector and 1 accelerator cryomodules (1 + 2 cavities)

Cryogenic requirements:

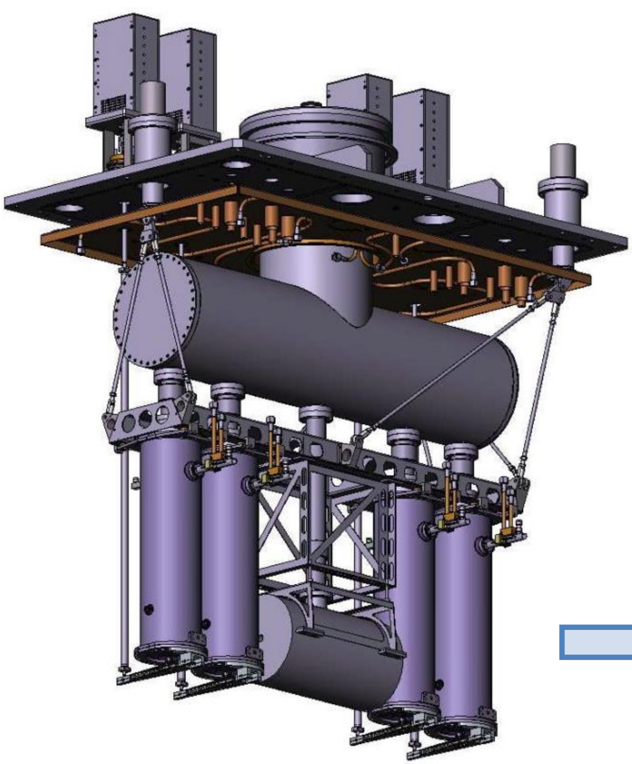
- maintain SRF cavities @ 2 K
- 2 K load: 15.4 W / 28 W
- 4 K load: 5.7 W / 9.7 W
- 77K load: 162 W / 244 W

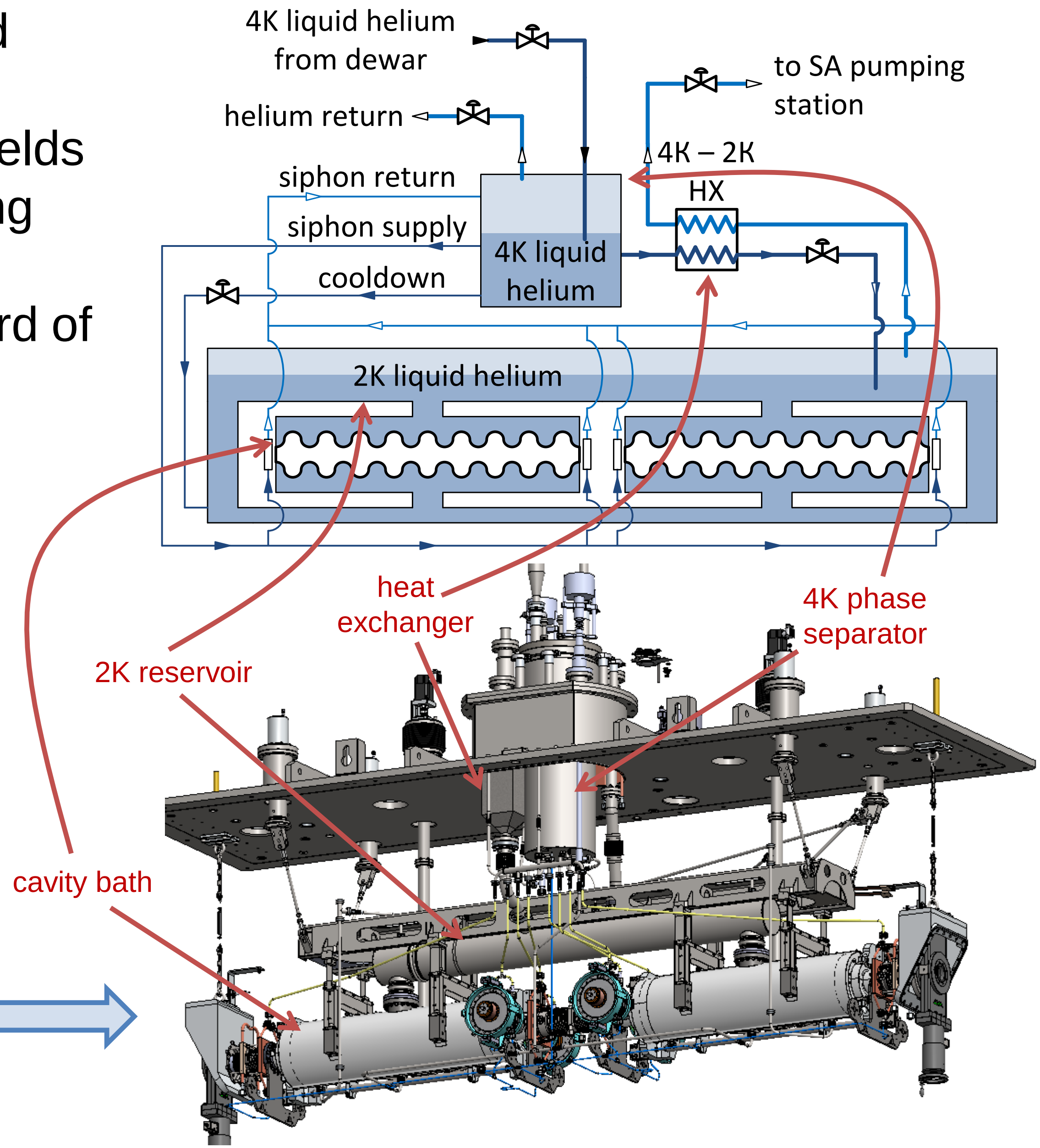


N. Muller et al., TRIUMF's Injector and Accelerator Cryomodules, SRF2015

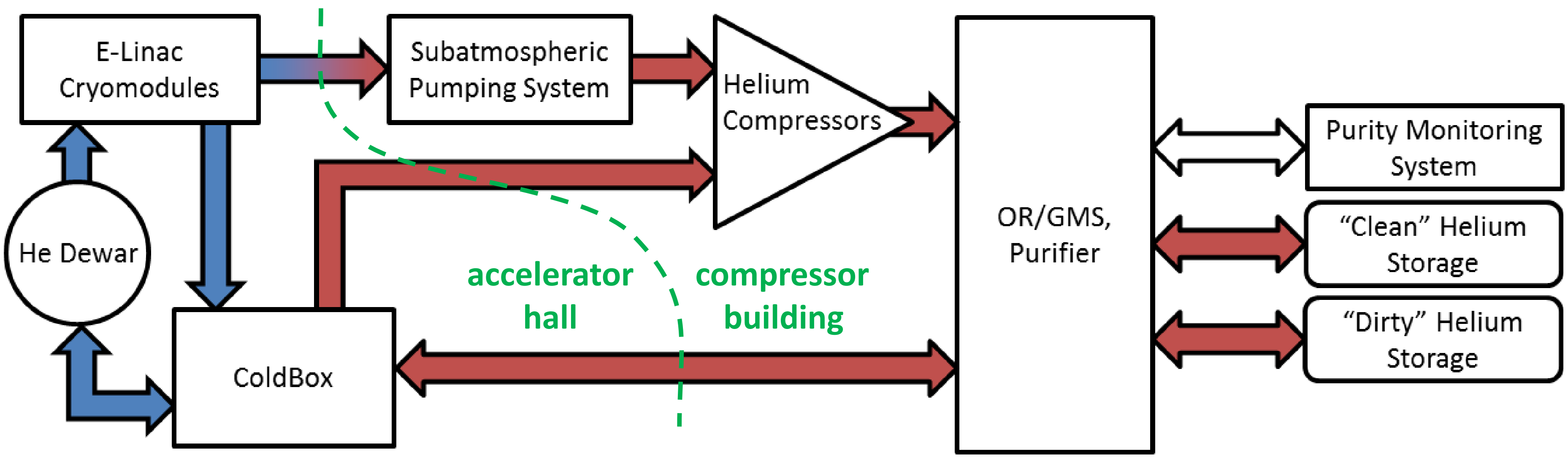
ARIEL Project: Cryomodules Design

- utilize expertise with top-load design of ISAC cryomodules
- 80 K LN2 cooled thermal shields
- few siphon driven LHe cooling loops for RF couplers
- 4 K to 2 K conversion onboard of each cryomodule





ARIEL Project: Cryogenic System Architecture



Areas of special attention:

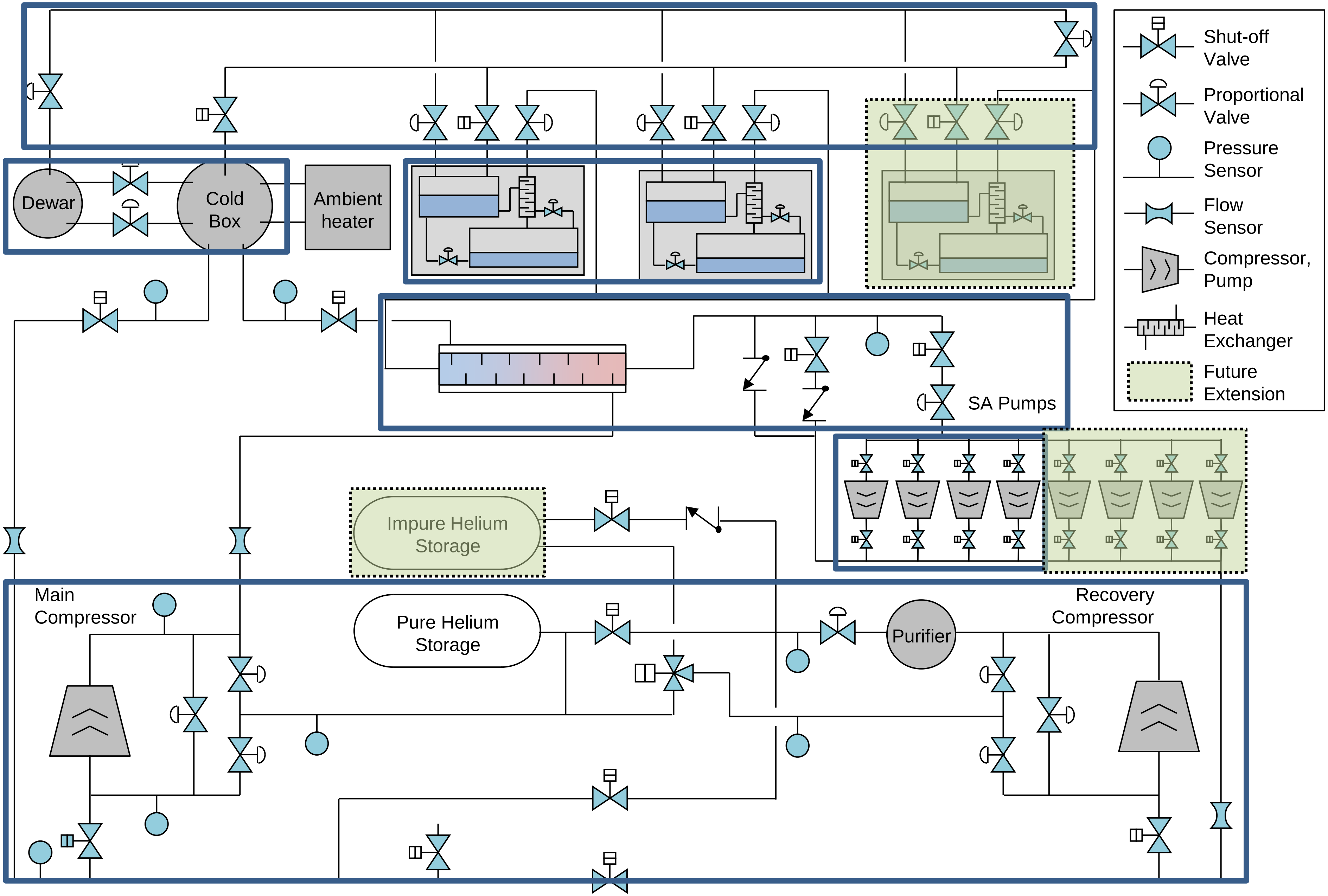
- mitigation of impurities – enhanced ORS of compressors, welded joints of SA line, entire SA flow is passed through freeze-out purifier
- failure scenarios (power, water, impurities) – recovery compressor and impure storage tank
- integrated control system, safety interlocks and machine protection

Outstanding operational issues:

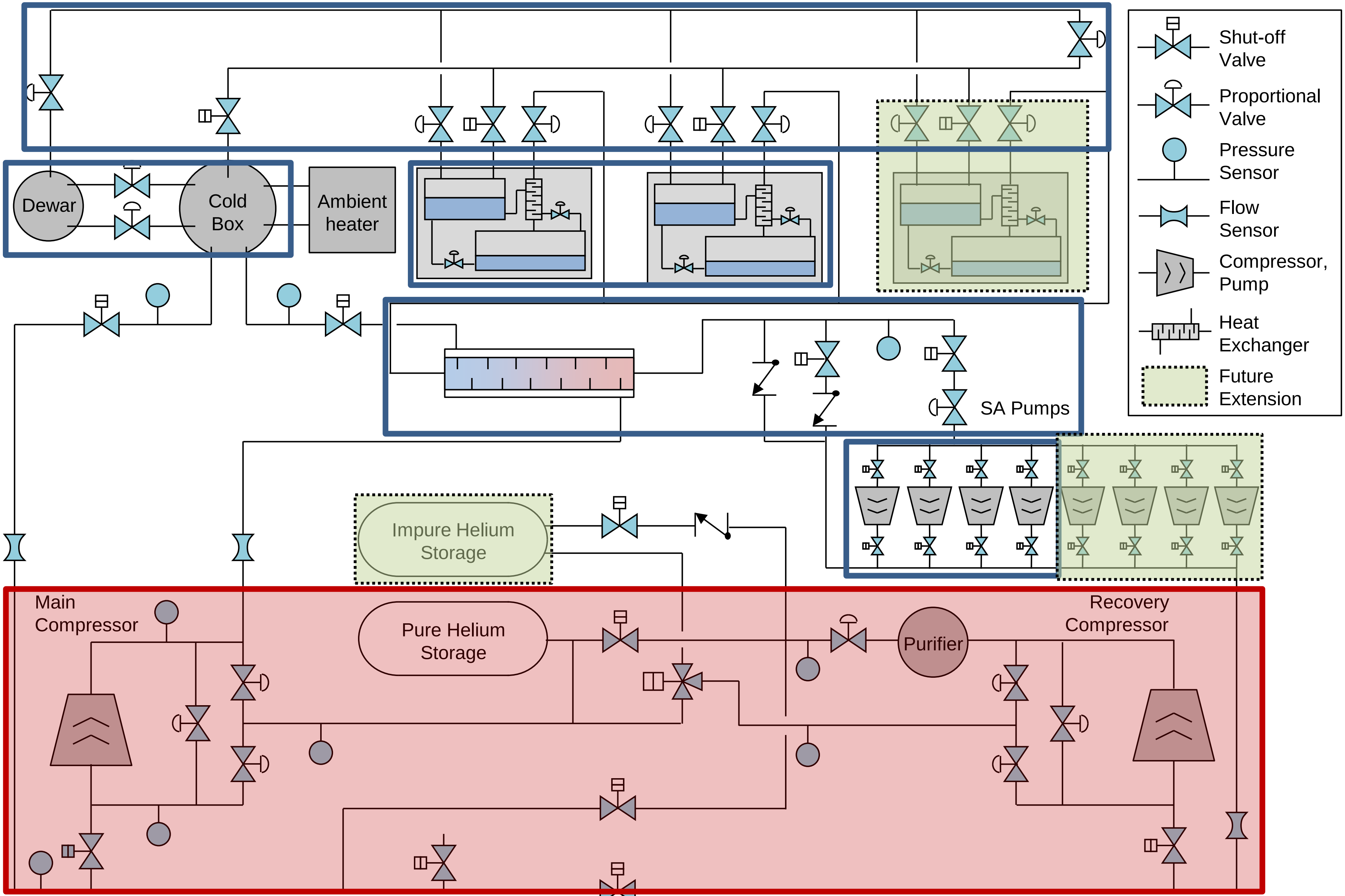
- response of the control system to the failure scenarios – operator’s intervention is always required
- large number of manually actuated control valves, ambiguity of the system state from controls point

A. Koveshnikov et al., Integration and commissioning of the ARIEL e-linac cryogenic system at TRIUMF, ICEC 25 –ICMC 2014

ARIEL Project: Cryogenic System Architecture



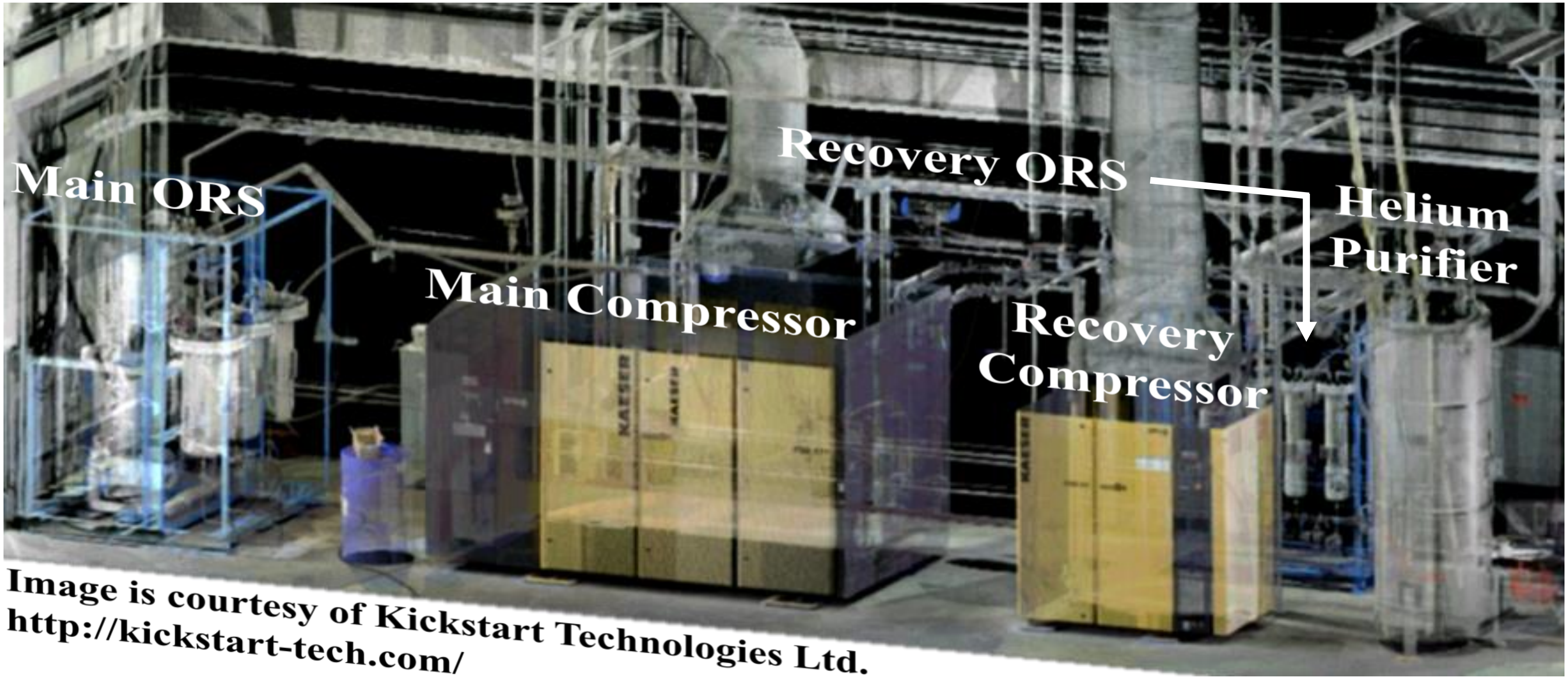
Cryogenic System – Compressors and Gas Management



Cryogenic System – Compressors

Main compressor
- KAESER FSD571SFC
- discharge pressure: 14.2 bar(a)
- mass flow rate: 112.4 g/s
- power: 378 kW
- water-cooled

Recovery compressor
- KAESER CSD85
- discharge pressure: 15 bar(a)
- mass flow rate: 14.7 g/s
- power: 57 kW (backed up with emergency diesel generator power)
- air-cooled



Cryogenic System – Oil Recovery System

Oil removal system:

- third additional coalescer to decrease risks of oil migration
- high-temperature bakeable design of charcoal adsorber (150 C)
- larger carbon bed of the adsorber

Operational experience:

- no oil migration detected within 3 years of normal operation
- still not enough runtime to validate the performance of ORS

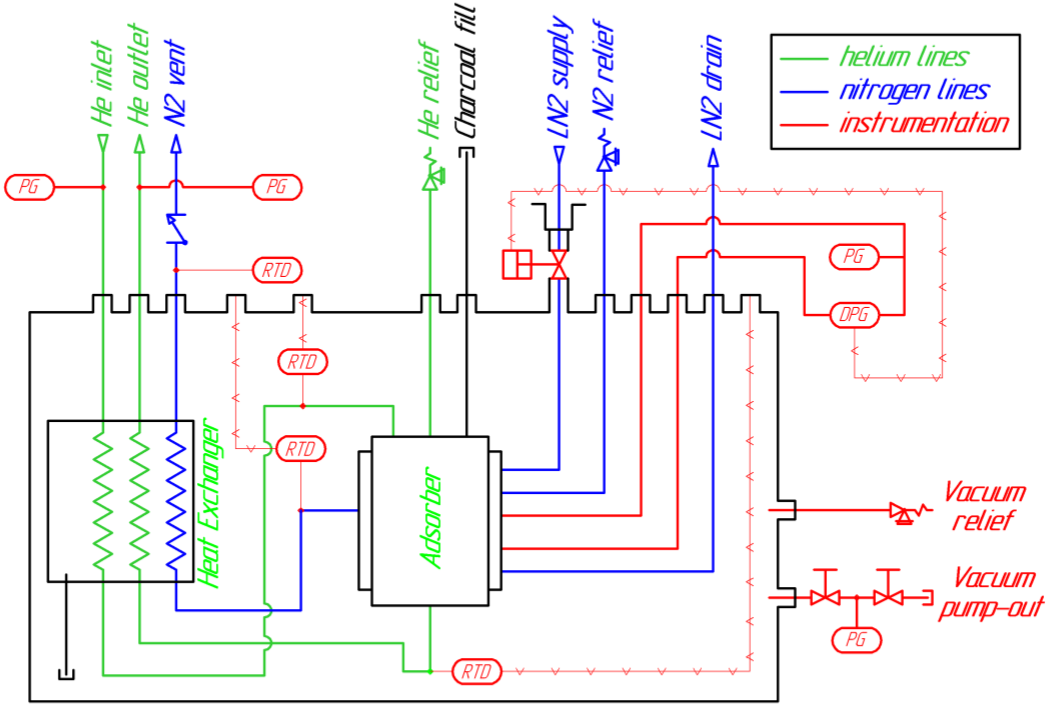
Recovery compressor use-cases

- nominal operation: pass SA flow through purification system without mixing with coldbox process helium
- power outage: collect helium boil-off vapors from cryomodules and dewar (implementation issues)
- stand-by mode: circulation of helium inventory through purifier
- purification mode: re-purification of contaminated helium from impure tank (for future extension)

Cryogenic System – Helium Purifier

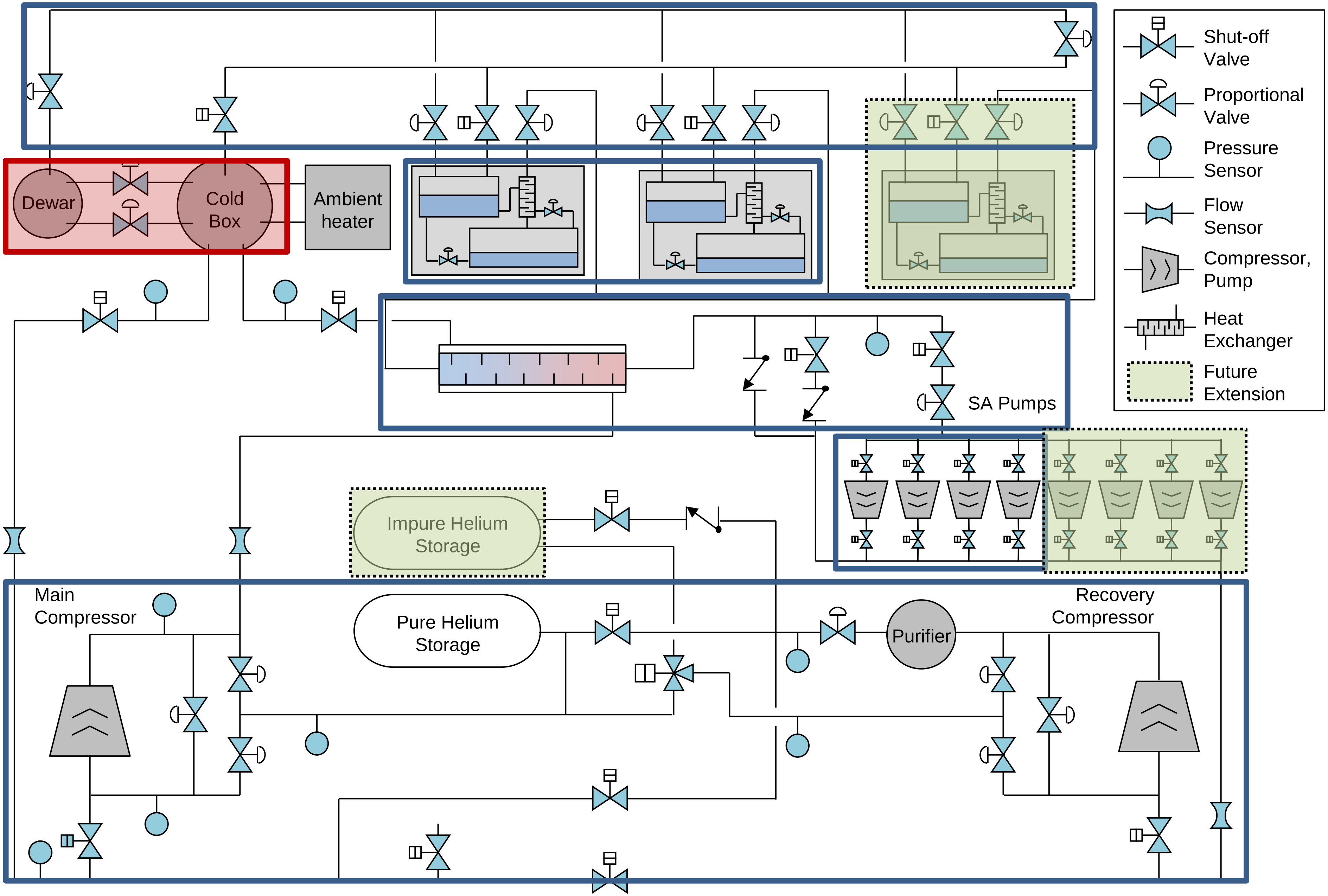
Stand-alone purifier:
- designed by Fermilab, manufactured by Meyer Tool
- specified for 60 g/s @ 25 bar, 10 ppm N2

Purity monitoring:
- online monitoring with Linde MCD at compressors side (installed as a part of cryoplant)
- water content monitor at coldbox side
- interlocks for contaminated helium storage (future)



Linde MCD

Cryogenic System – Helium Liquefier



Helium Liquefier: Standard ~1 kW Coldbox

Helium cryoplant requirements:
- liquefaction w/ LN2: 288 L/h
- refrigeration w/ LN2: 600 W
- mixed w/ LN2: 240 L/h + 130 W
- dewar pressure: ±2 mbar within 2 seconds, ±10 mbar in total

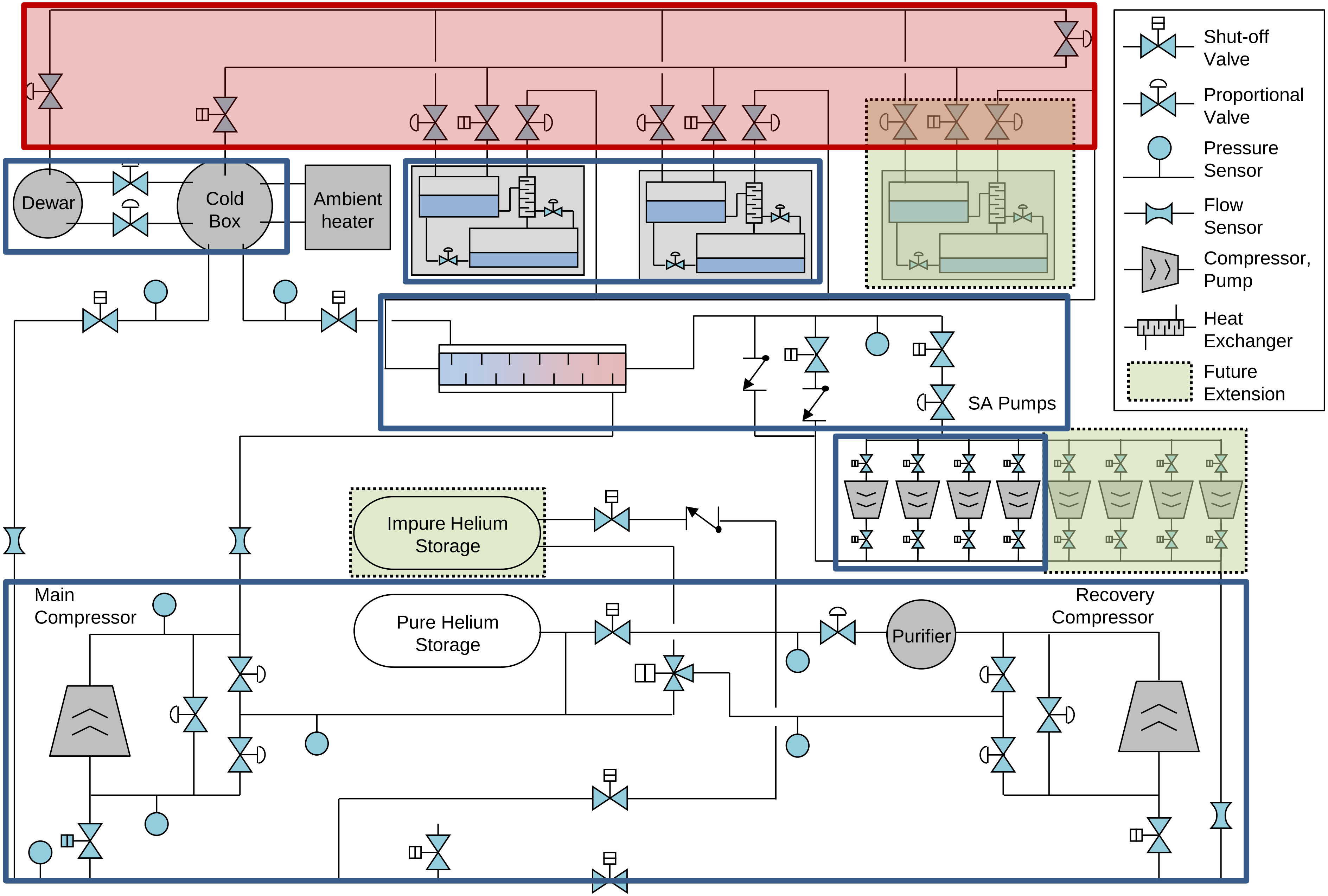
G. Hodgson et al., Acceptance Tests and Commissioning of the ARIEL e-Linac Helium Cryoplant, Cryogenics 2014 (IIR)

Coldbox supplied by Air Liquide

Lessons learned:
- cooperation for better integration of control system – still an issue
- stability of dewar pressure does not lead to pressure stability in 4 K space of cryomodules
- instabilities of coldbox operation (periodical turbine trips) – to be investigated with Air Liquide
- helium return at cooldown cannot be automatically routed based on temperature (instabilities and trips)

Future work:
- reimplementation of some of the control sequences
- extra diagnostics (sensors, valve positioners)

Cryogenic System – Liquid Helium Distribution



Liquid Helium Distribution

Modular design:

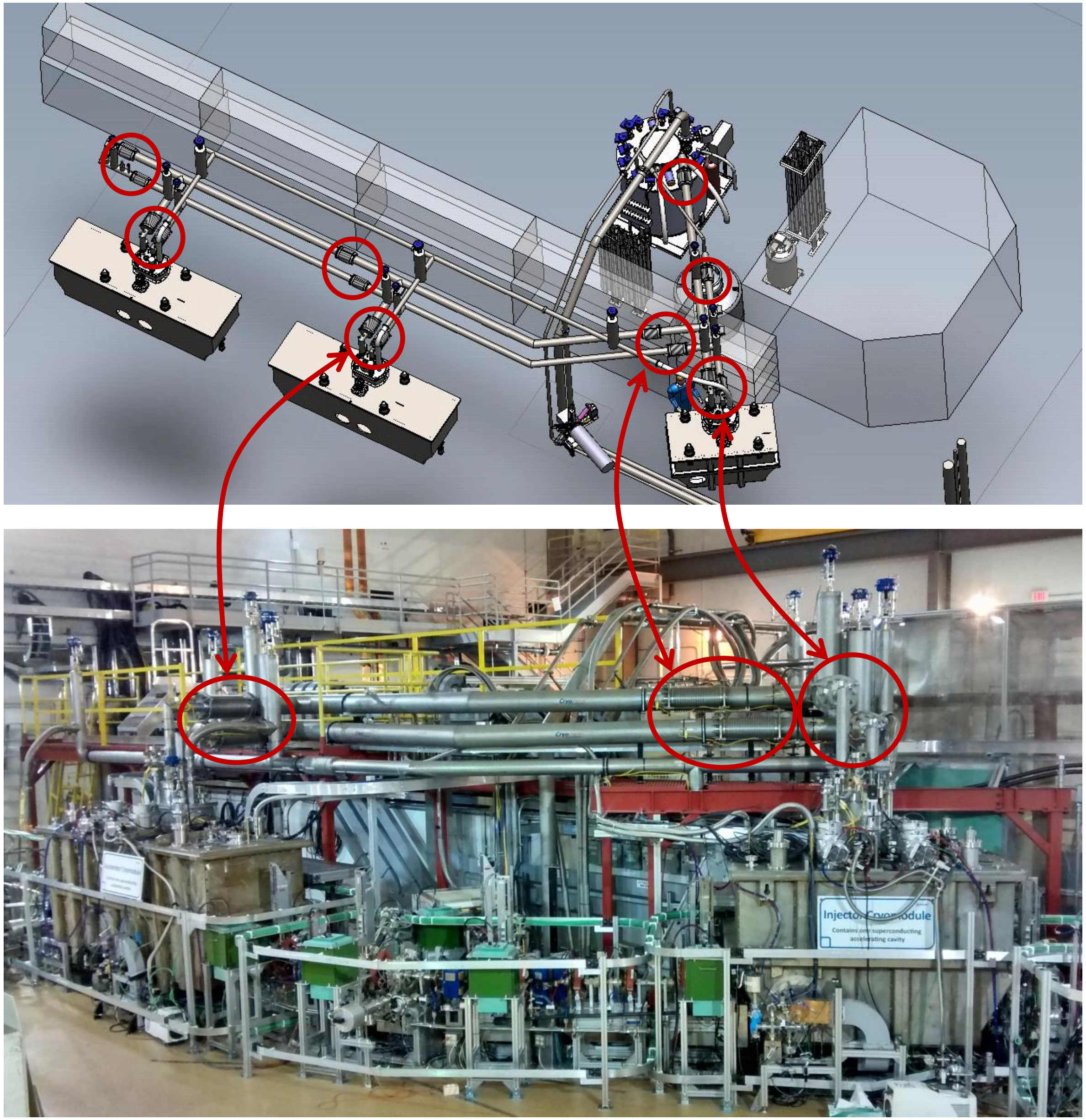
- support operation of one to three cryomodules
- frequent reinstallations of supply and return sections of cryomodules
- accelerator hall access hatch is limited in size

Suppliers:

- assembly: Cryotherm
- cryogenic valves: WEKA
- valve positioners: Siemens SIPART

Cryogenic process lines:

- LHe supply: 12 mm, VCR
- GHe return: 40 mm, Conflat flanges
- LN2 shield: 12 mm, VCR



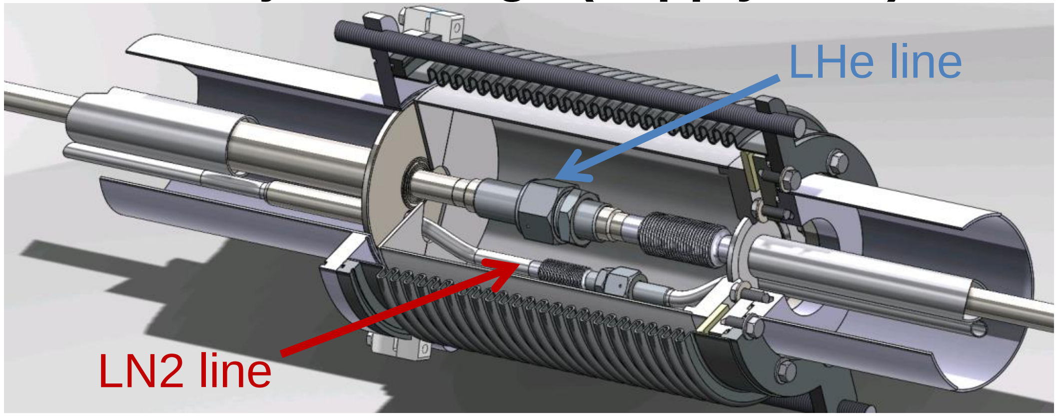
Liquid Helium Distribution

Installation and operation:

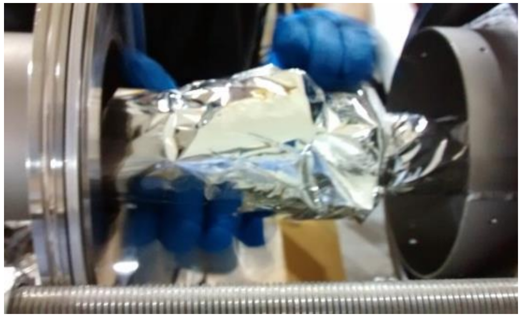
- friendly design: ~2 hours assembly time per field joint (2 person job)
- one issue with leaking VCR fitting, caused soft vacuum

Radiation protection of pneumatic valve positioners:

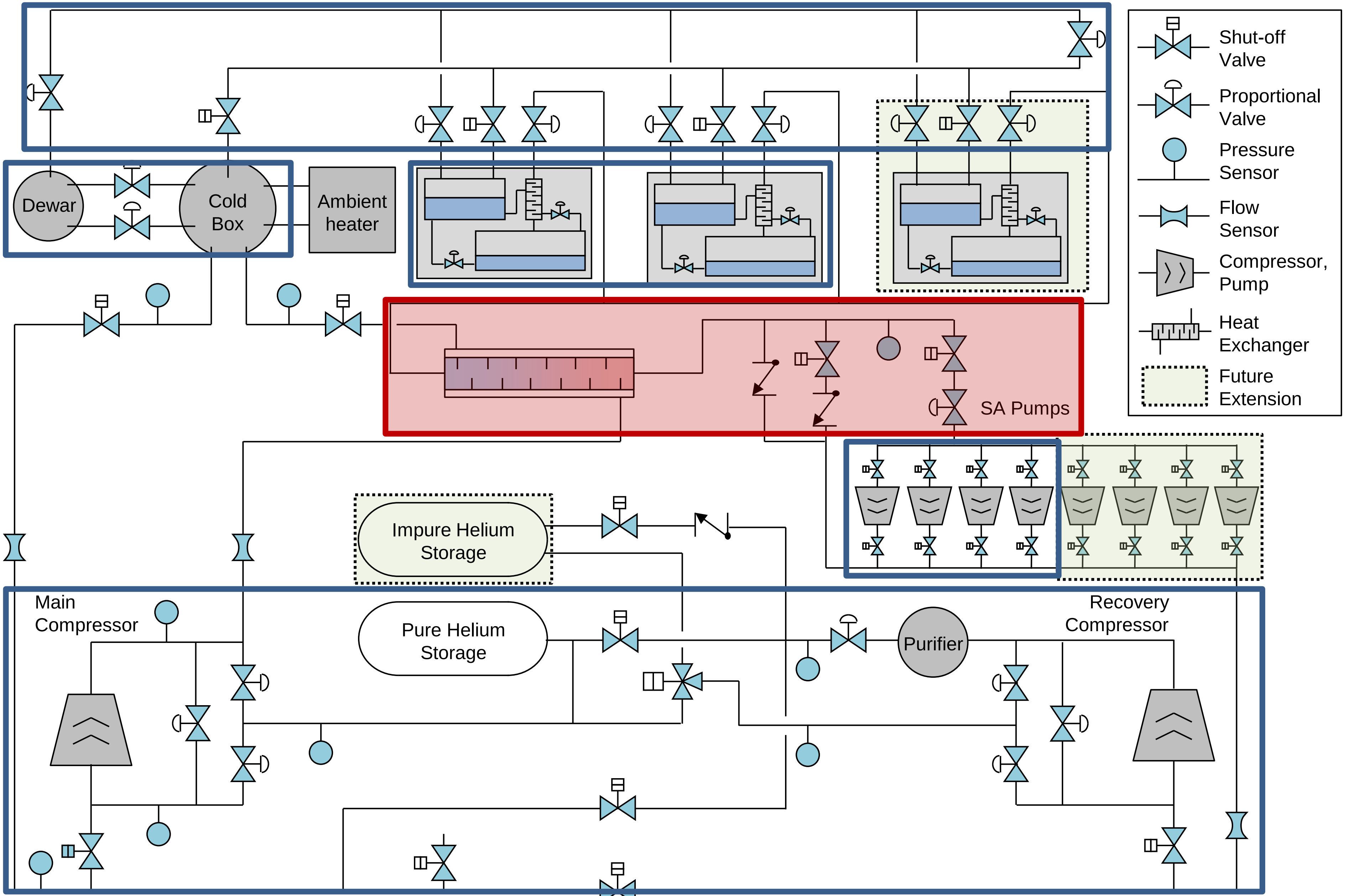
Field joint design (supply side)



Assembly procedure (return side)

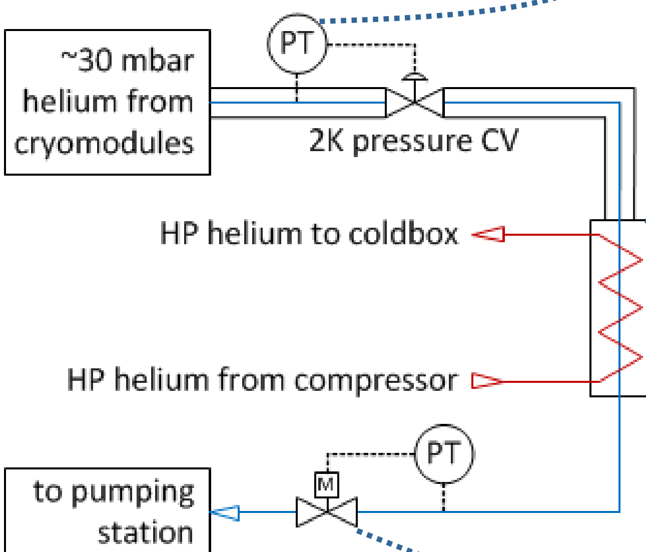


Cryogenic System – Sub-atmospheric Helium Return Line

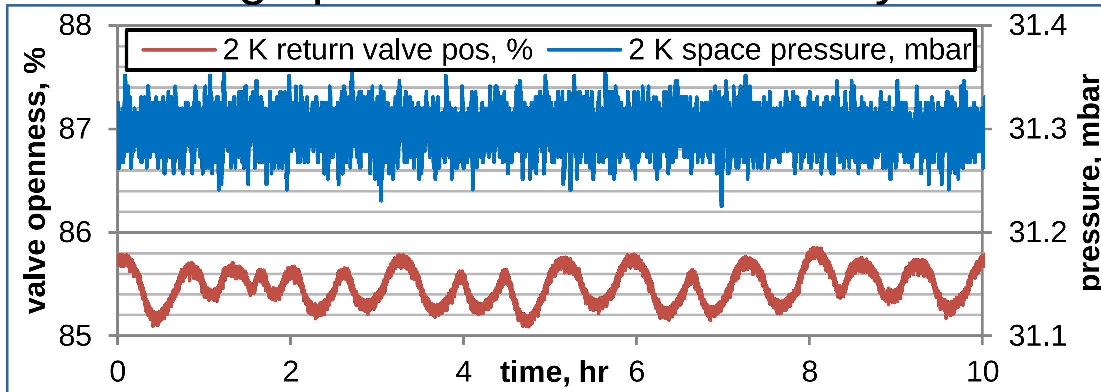


Sub-atmospheric Helium Return Line

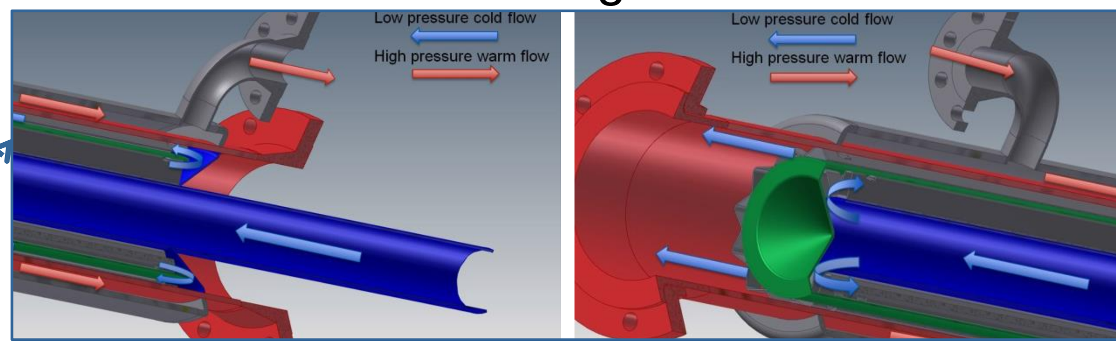
- hermetic welded cold joints
- passive heater to minimize maintenance, some savings on power and LN2
- 2-stage pressure control to control suction of SA pumps
- issues with low resolution of motorized gate valve (pre-pumping line is needed)



1st stage pressure control in cavity bath

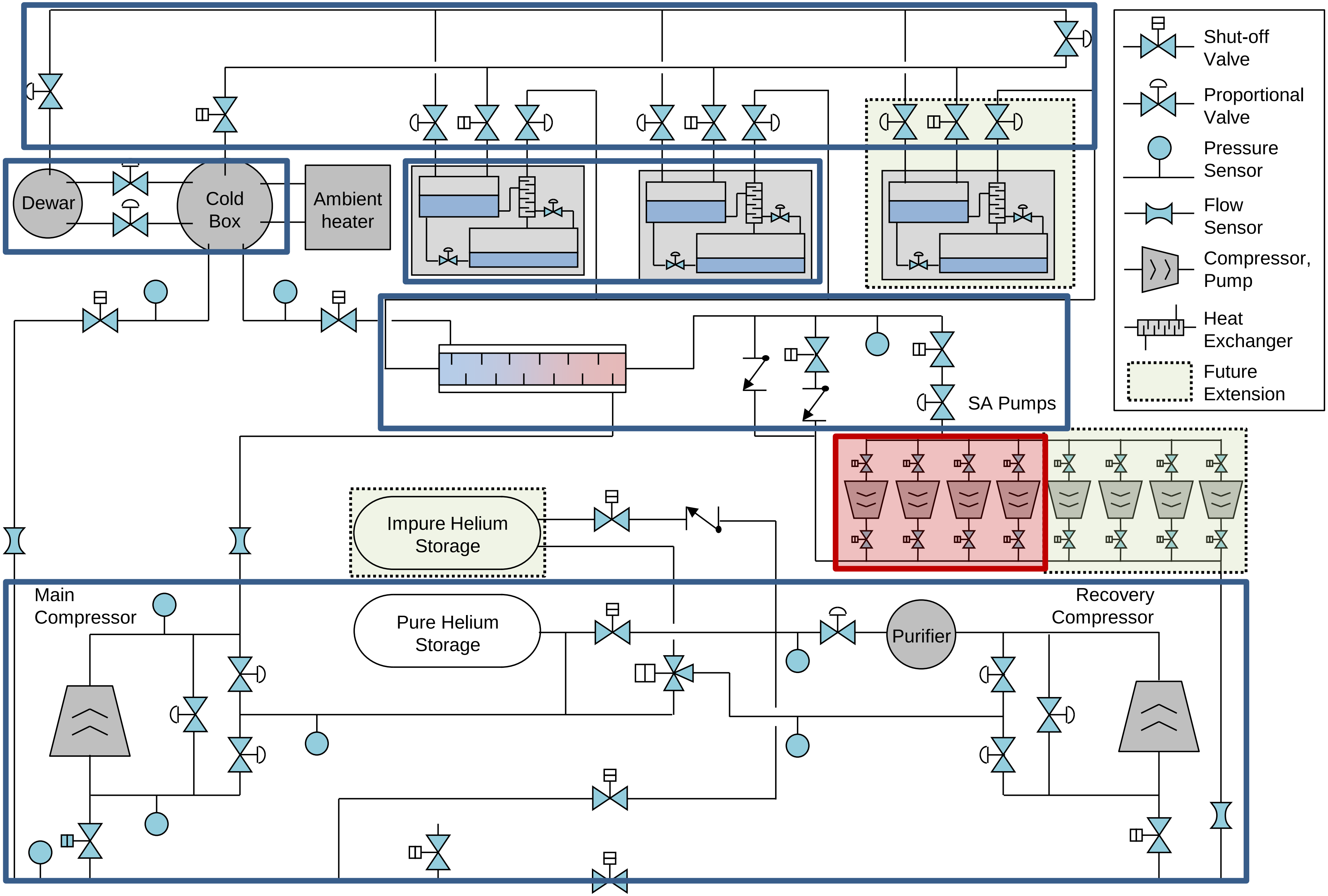


Passive heater utilizing HP helium stream



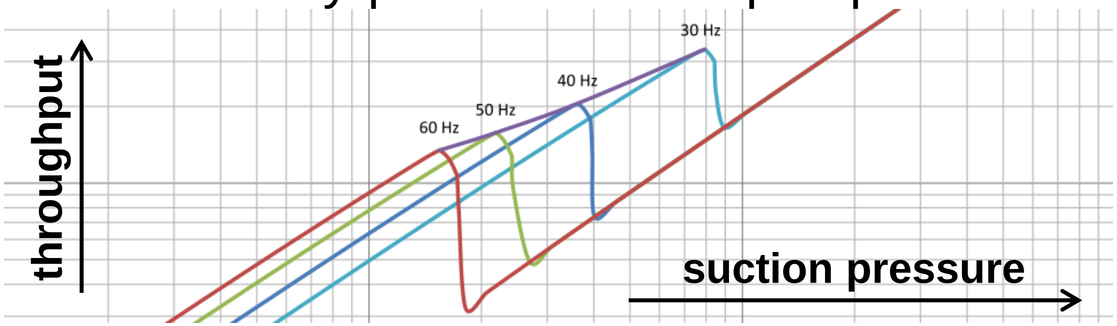
2nd stage adaptive pressure controller (VAT)

Cryogenic System – Sub-atmospheric Pumping Units



Sub-atmospheric Pumping Units

- set of “Busch PANDA WZ2000” (Roots) and “Busch COBRA NS-0600 B” (screw pump)
- VFD on the booster pump motor
- sealed pumps, canned motors, no shaft leaks
- own PLC, interlocks, start/stop procedures
- automatic by-pass of booster pump



Issues and operational experience:

- few controls issues resolved within two years in cooperation with Busch:
  - automatic start-up/shut-down cycles
  - flow control, purging cycle
  - lots of PLC code bug fixes
- highly sensitive to back-pressure, develop leaks when discharge >1.5 bar(a)

Future Work

Control System

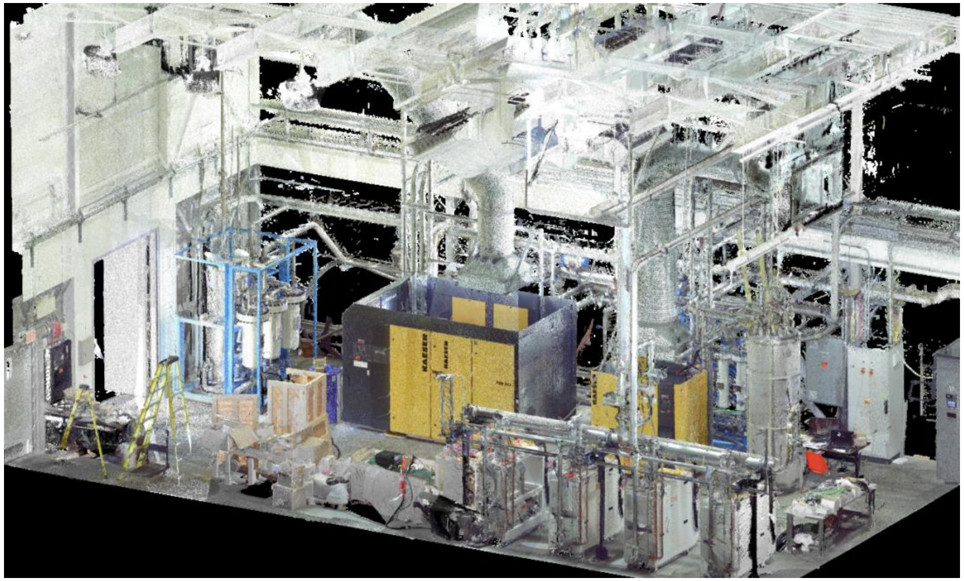
- automatic response to emergency situations (power/water outages)
- automation of some of the modes (cooldown, warm-up)
- reimplementation of coldbox logic within EPICS environment (in discussion)

Compression and gas management:

- installation of impure tank (in discussion), gas management based on level of impurities
- monitoring of the helium inventory, analysis of losses

Documentation and training of operators:

- emergency response procedures, migrating some of the responsibilities



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Thank you!

Presented on behalf of:

Cryogenics Group

- Alexey Koveshnikov
- Colin Dick
- David Kishi
- Howard Liu
- Ruslan Nagimov

Vacuum Group

- Dimo Yosifov
- Anthony Ip
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- Kevin Trithardt

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