TRIUMF

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

The Operational Experience of e-Linac Cryogenic System at TRIUMF

Presented by Alexey Koveshnikov
Cryogenic Group Leader

Workshop on Cryogenic Operations - 2018

Cryogenics Operations 2018

TRIUMF: Canada's National Science Laboratory

- TRIUMF Laboratory
  - founded 50 years ago as TRI-University Meson Facility
  - owned and operated by consortium of 20 Canadian universities
  - ~ 500 scientists and staff, postdocs, students, visitors, etc.
  - research focus on rare isotopes, structure of matter, life science

- Cryogenic Systems
  - SC Solenoid: Sulzer TCF200 Helium Refrigerator (currently 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

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TRIUMF
celebrates its 50th anniversary

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

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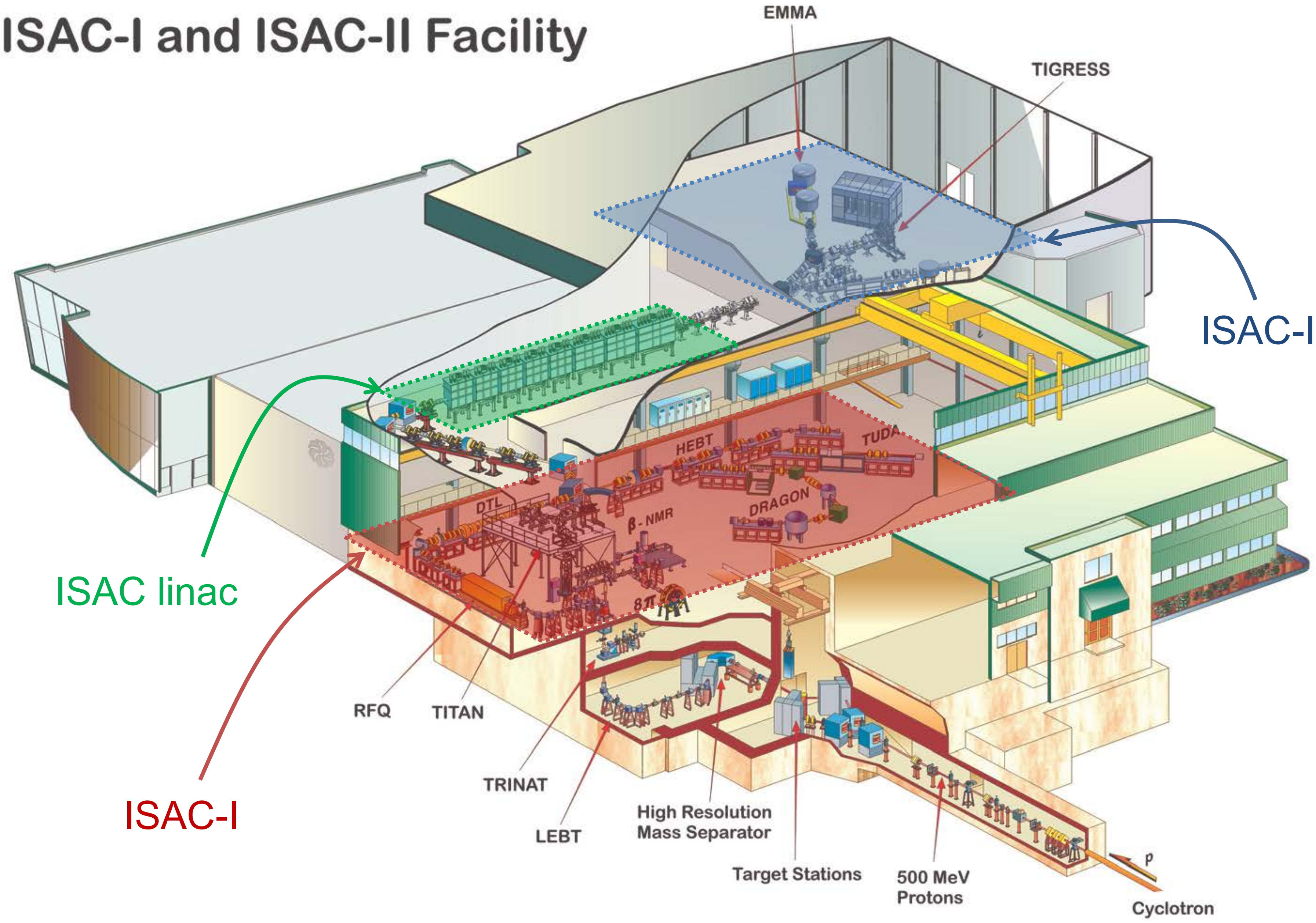
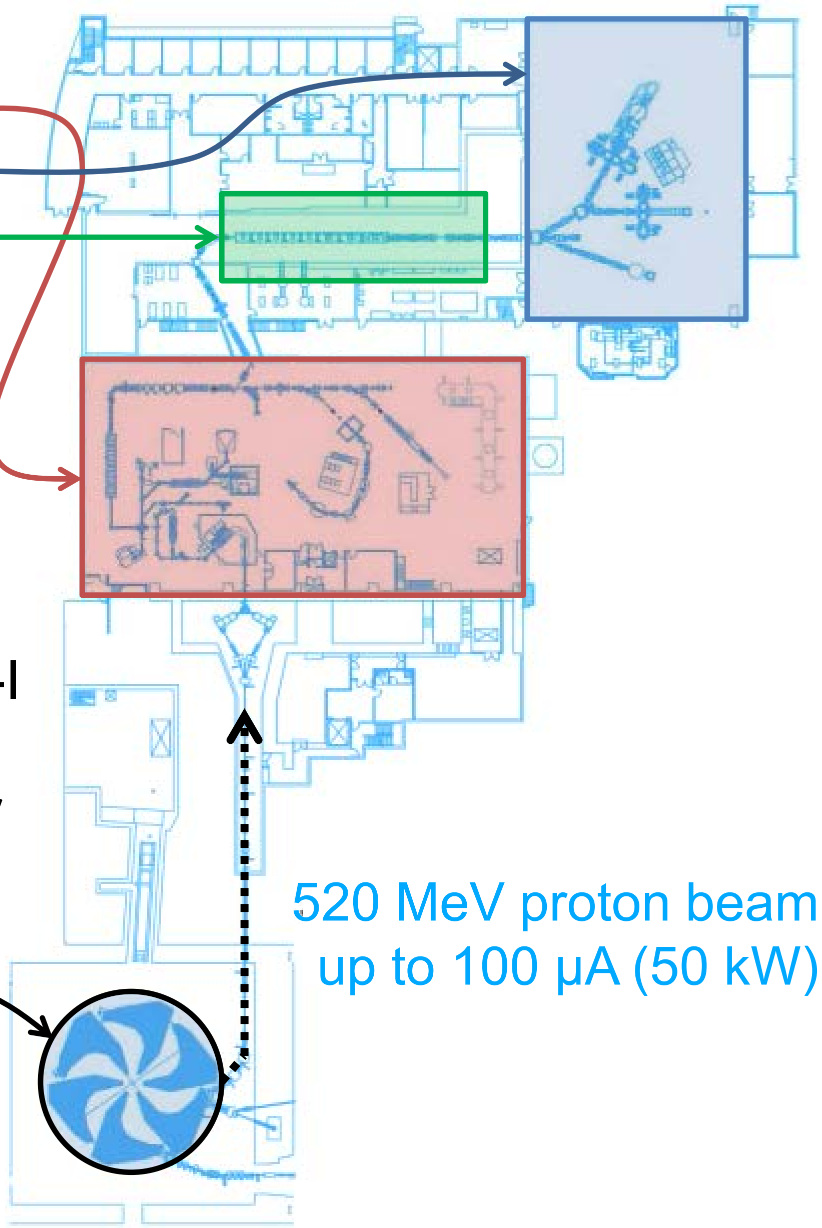


Discovery, accelerated

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
- Life sciences

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**

520 MeV proton beam
up to 100 μA (50 kW)

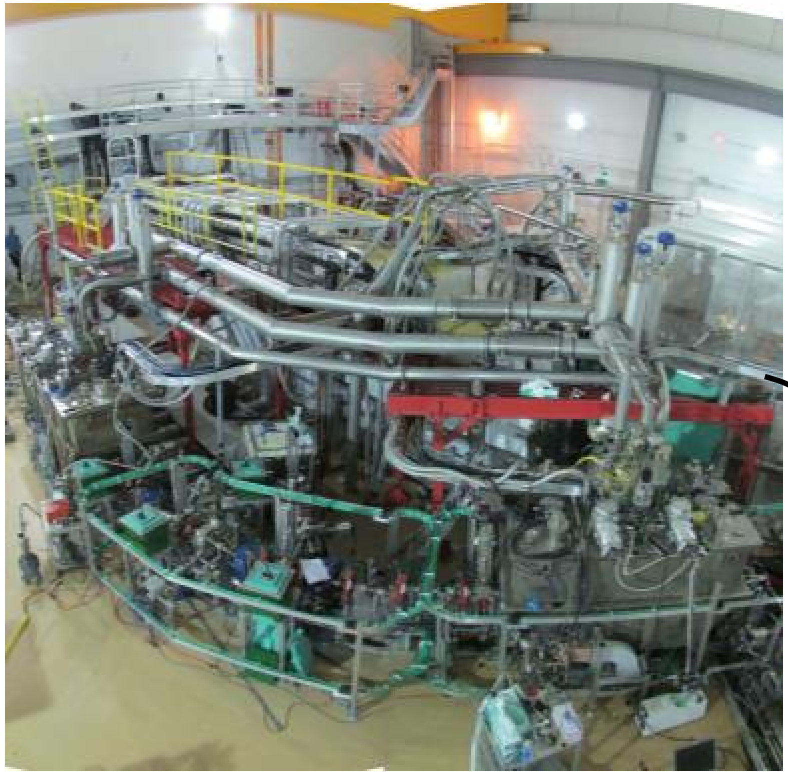
TRIUMF Cyclotron (commissioned in 1972)

Rare Isotope Beam Facilities: ARIEL Extension

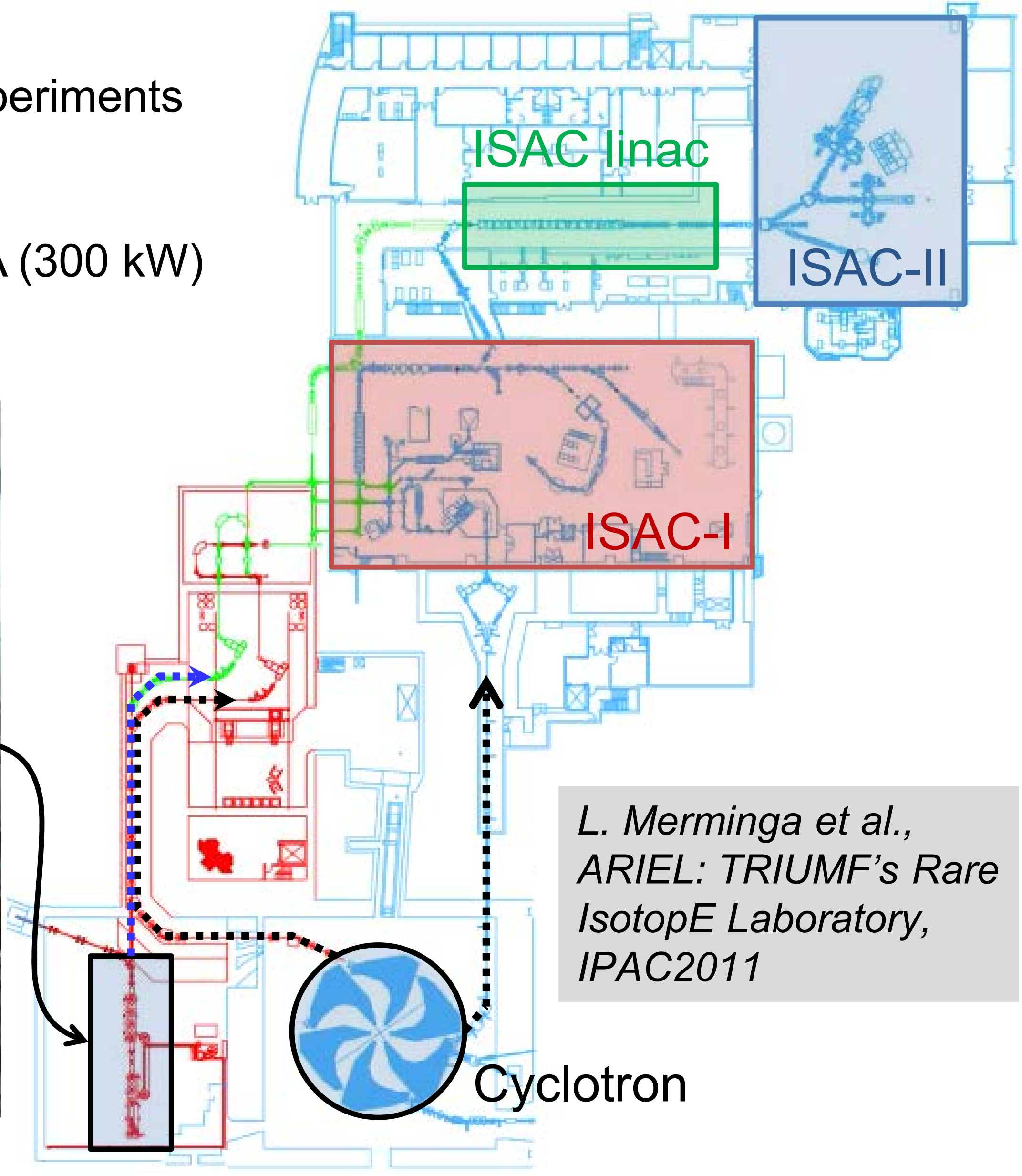
Rare Isotope Beam Facilities: ARIEL Extension

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



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e-Linac: SRF Specification

- 30 MeV @ 10 mA (300 kW beam)
- 3 (5) elliptical 1.3 GHz SRF cavities
- 1 injector and 1(2) accelerator cryomodules (1 & 2(4) 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

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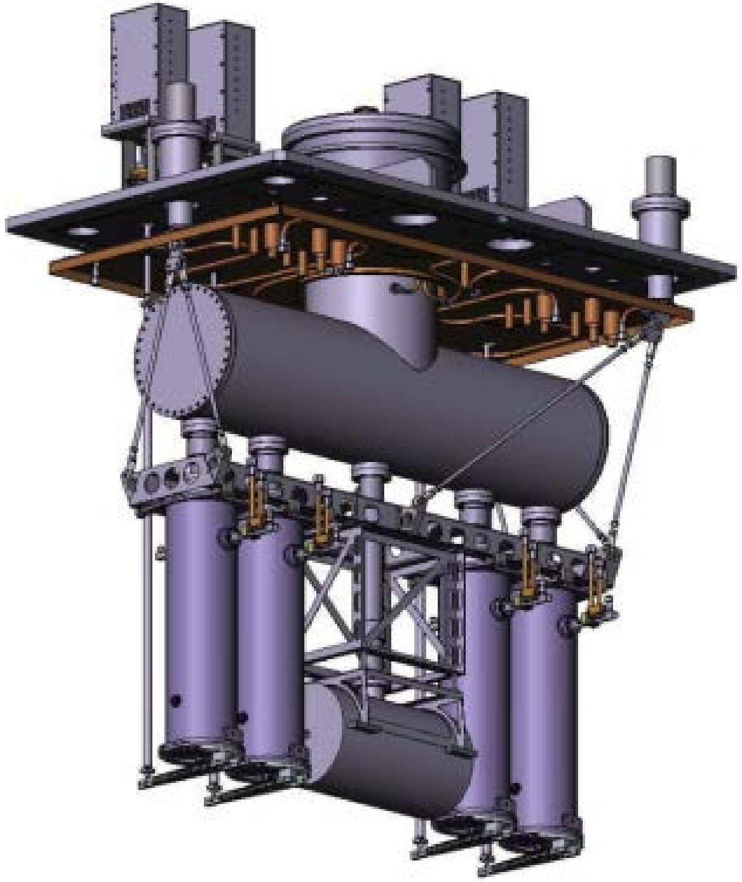
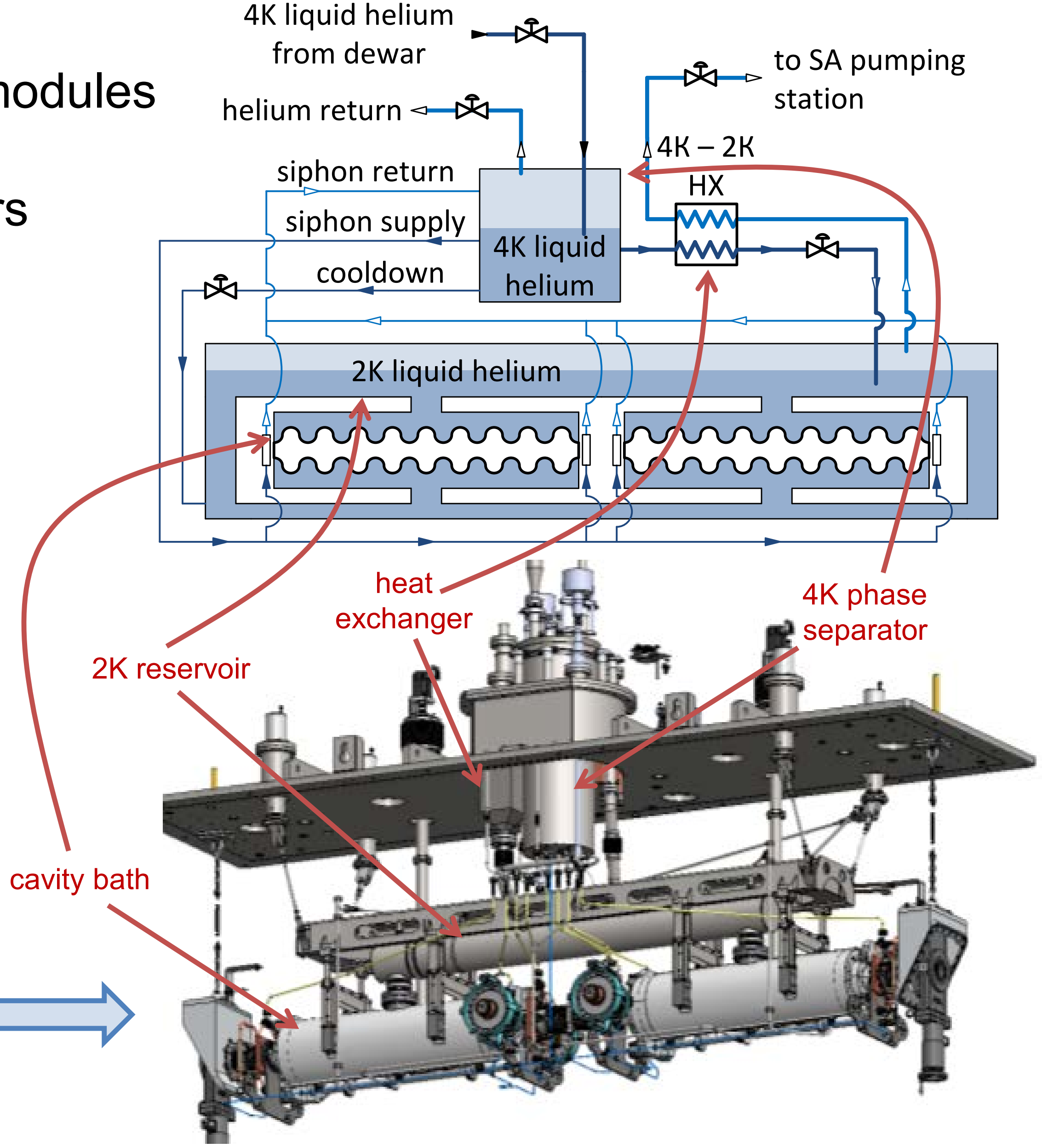
e-Linac: Cryomodules Design

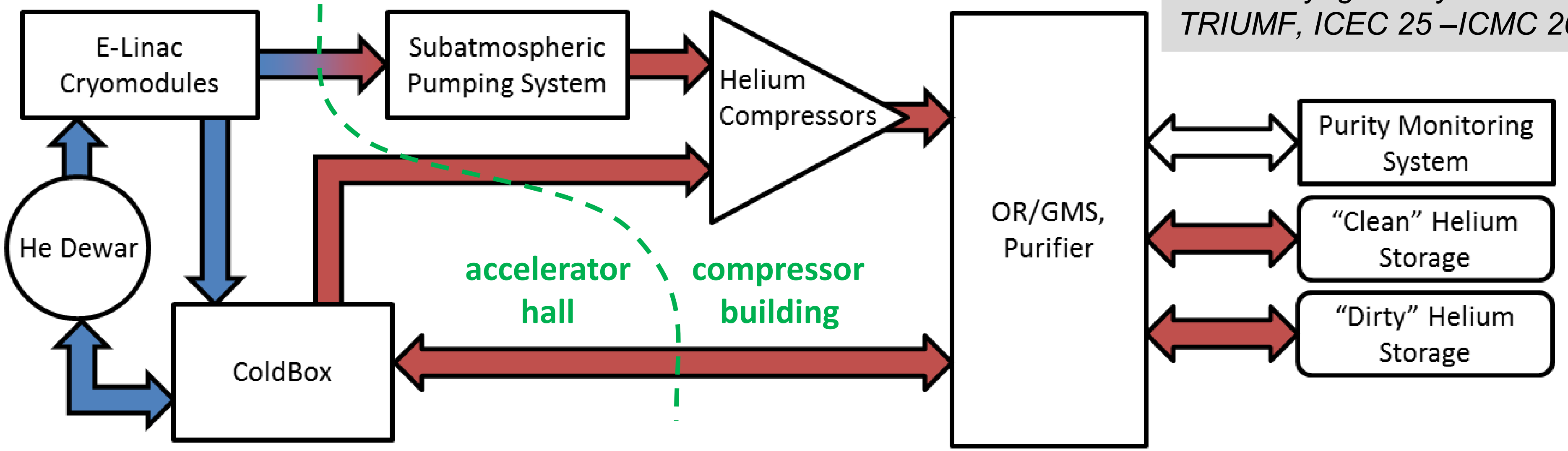
- utilize expertise with top-load design of ISAC cryomodules
- 80 K LN2 cooled thermal shields
- few siphon driven LHe cooling loops for RF couplers
- 4 K to 2 K conversion onboard of each cryomodule





e-Linac: Cryogenic System Architecture

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



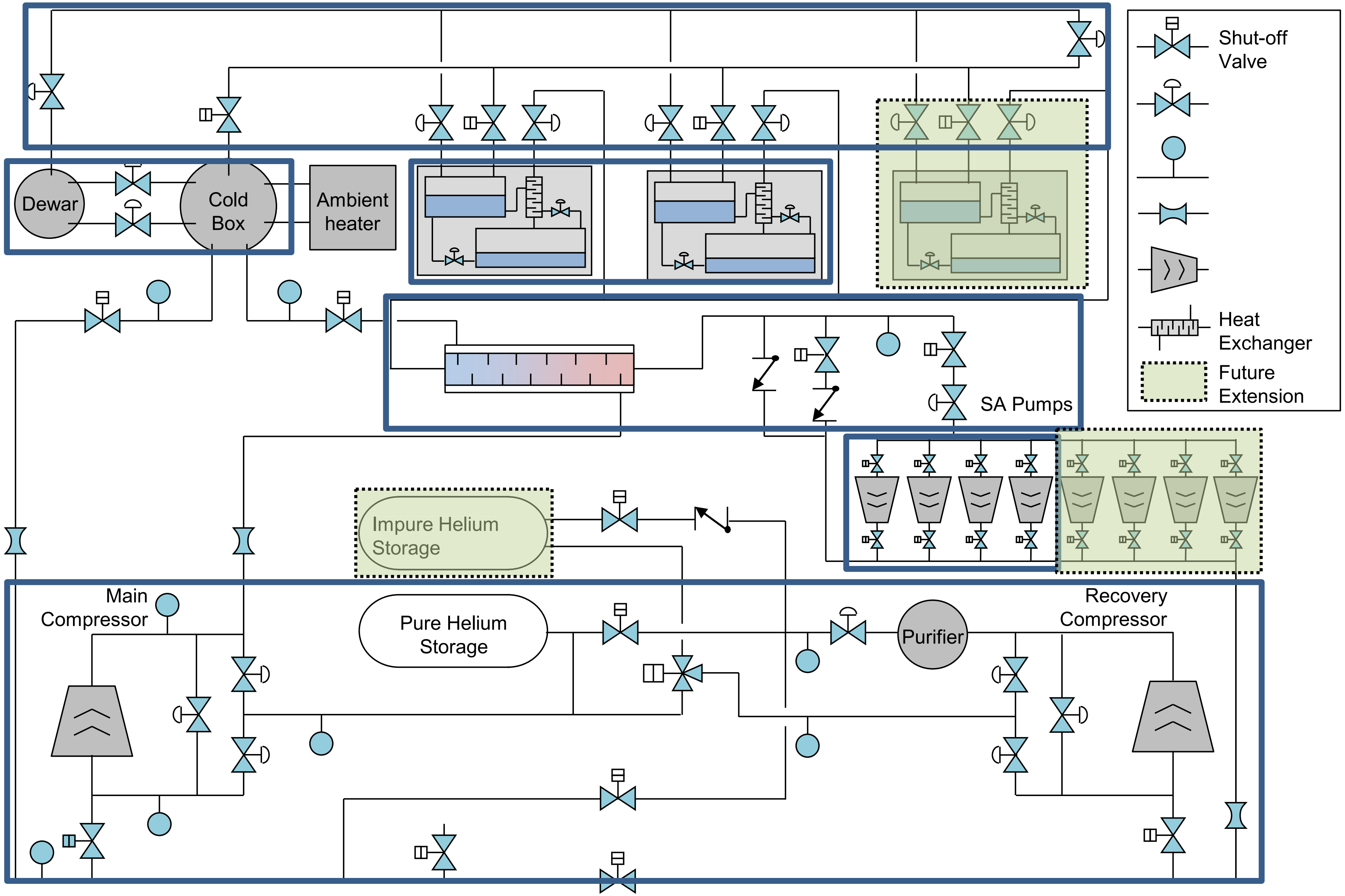
Areas of special attention:

- 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

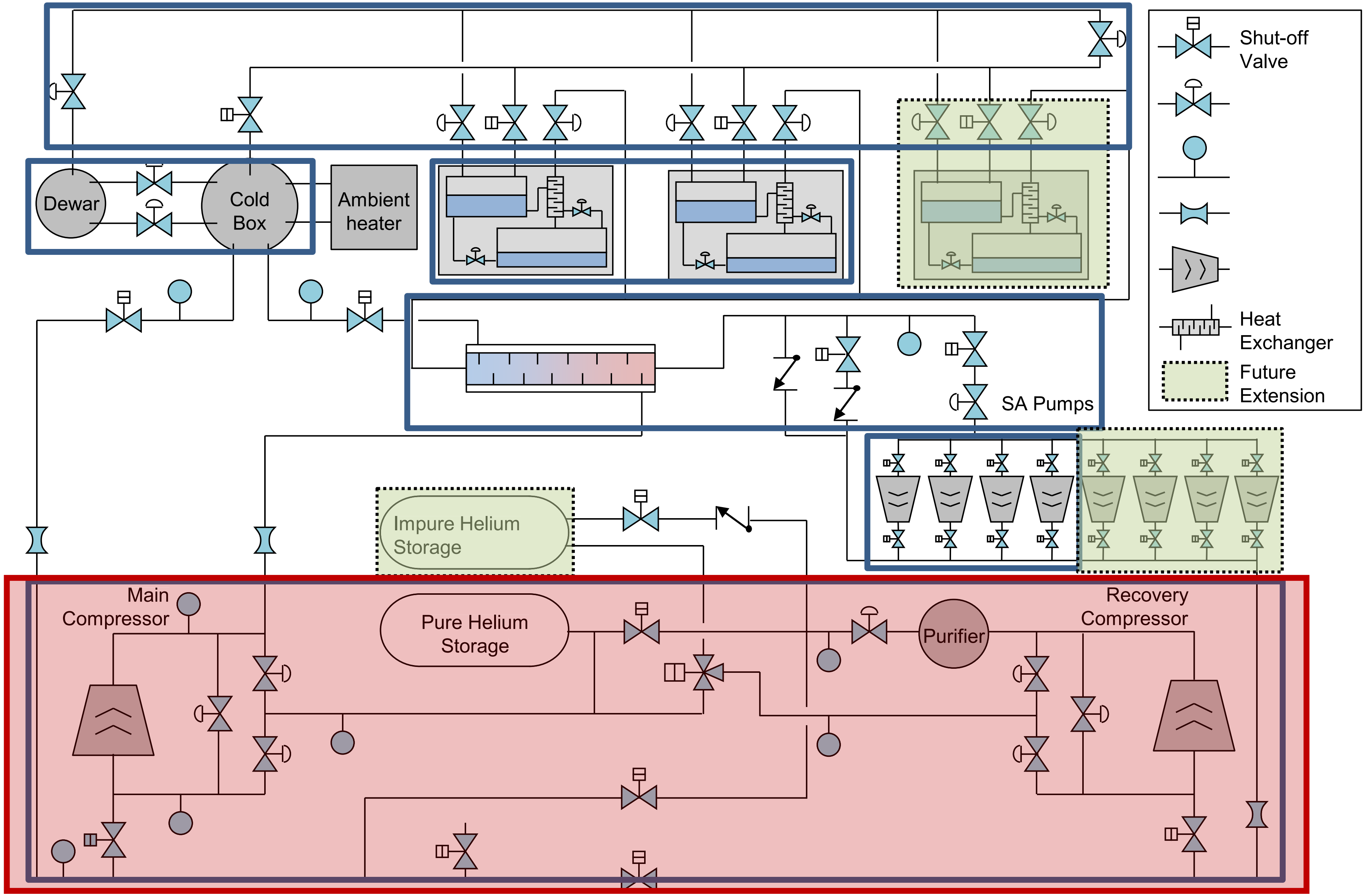
Outstanding operational issues:

- 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

e-Linac: Cryogenic System Architecture



Cryogenic System – Compressors and Gas Management



Cryogenic System – Compressors

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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 PG)
- air-cooled

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Cryogenic System – Oil Removal 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 4 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)

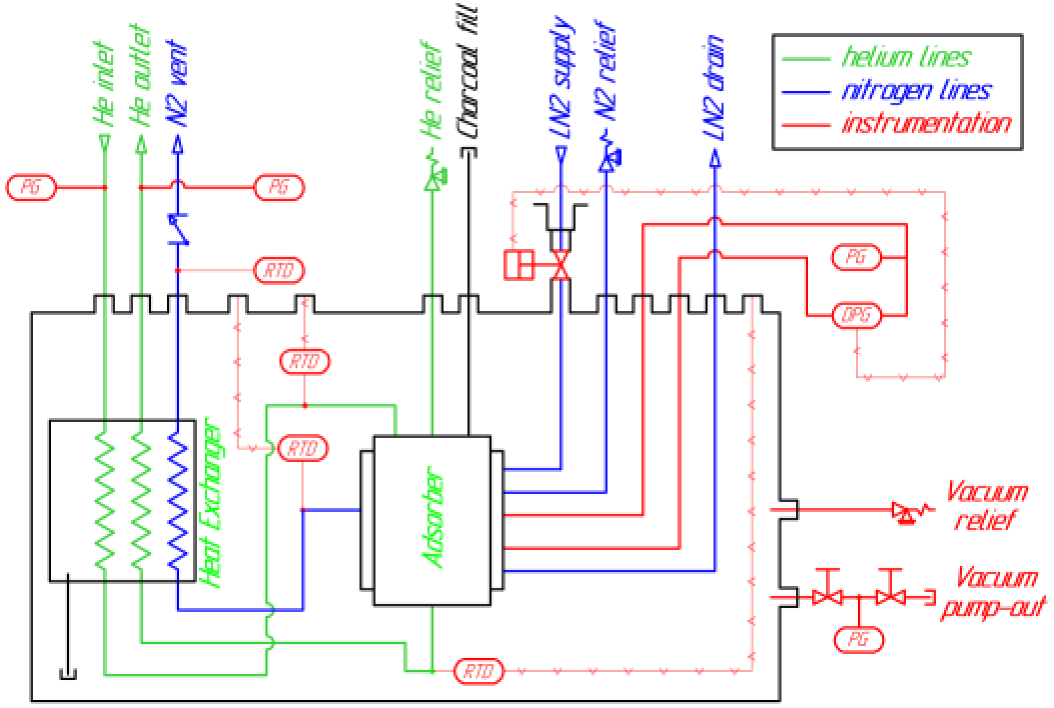
Cryogenic System – Helium Purifier

Stand-alone purifier:

- designed by Fermilab, manufactured by Meyer Tools
- specified for 60 g/s @ 25 bar, 10 ppm N2

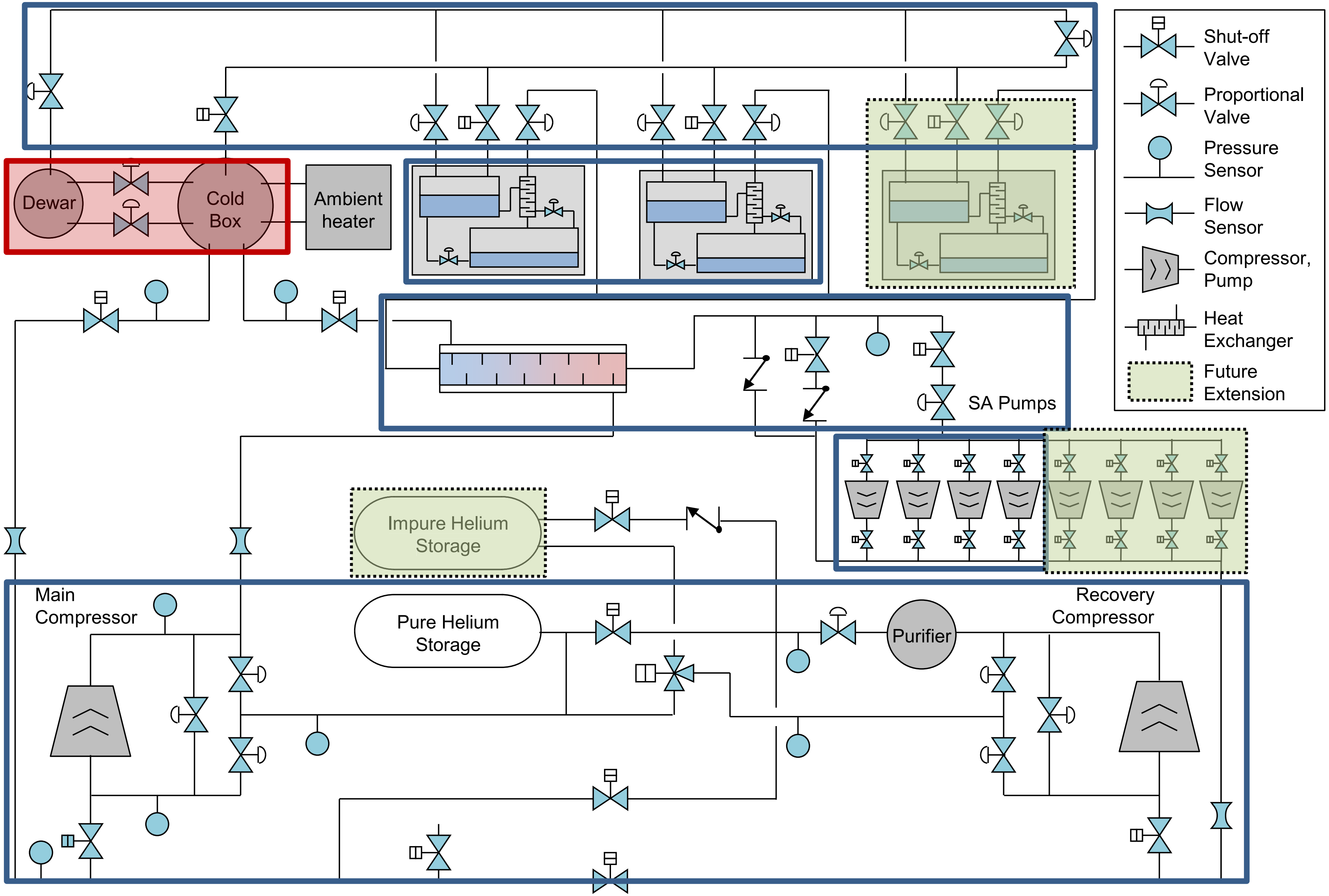
Purity monitoring:

- 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



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Helium Liquefier: Standard ~0.8 kW ColdBox

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Helium Liquefier: Standard ~0.8 kW ColdBox

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

ColdBox supplied by Air Liquide

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

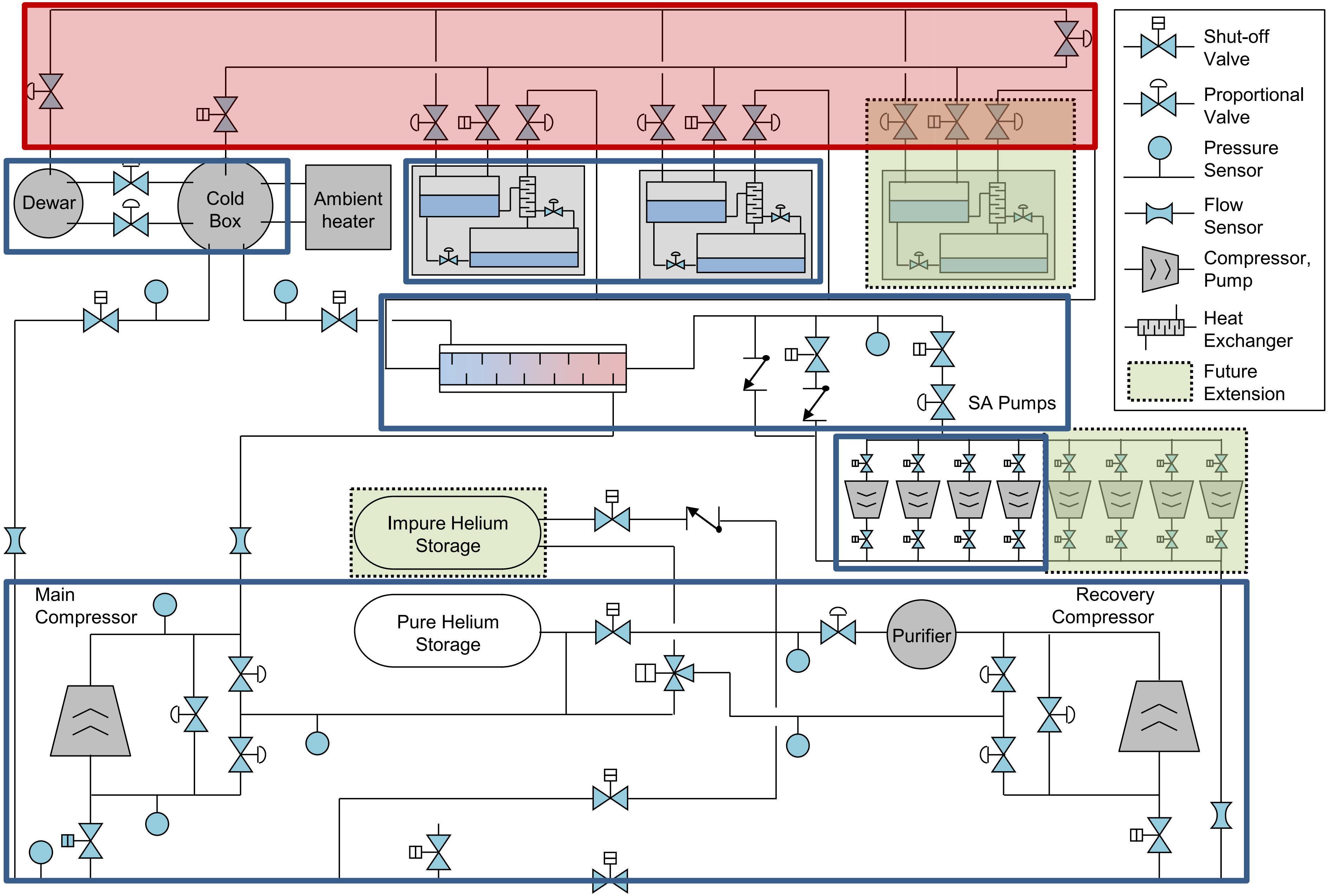
Lessons learned:

- cooperation for better integration of control system – still an issue
- instabilities of ColdBox operation (periodical turbine trips) – is under investigation with manufacturer
- We didn't master yet to automate the helium return during cooldown due to the temperature instabilities and turbine trips

Future work:

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

Cryogenic System – Liquid Helium Distribution



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Liquid Helium Distribution

Modular design:

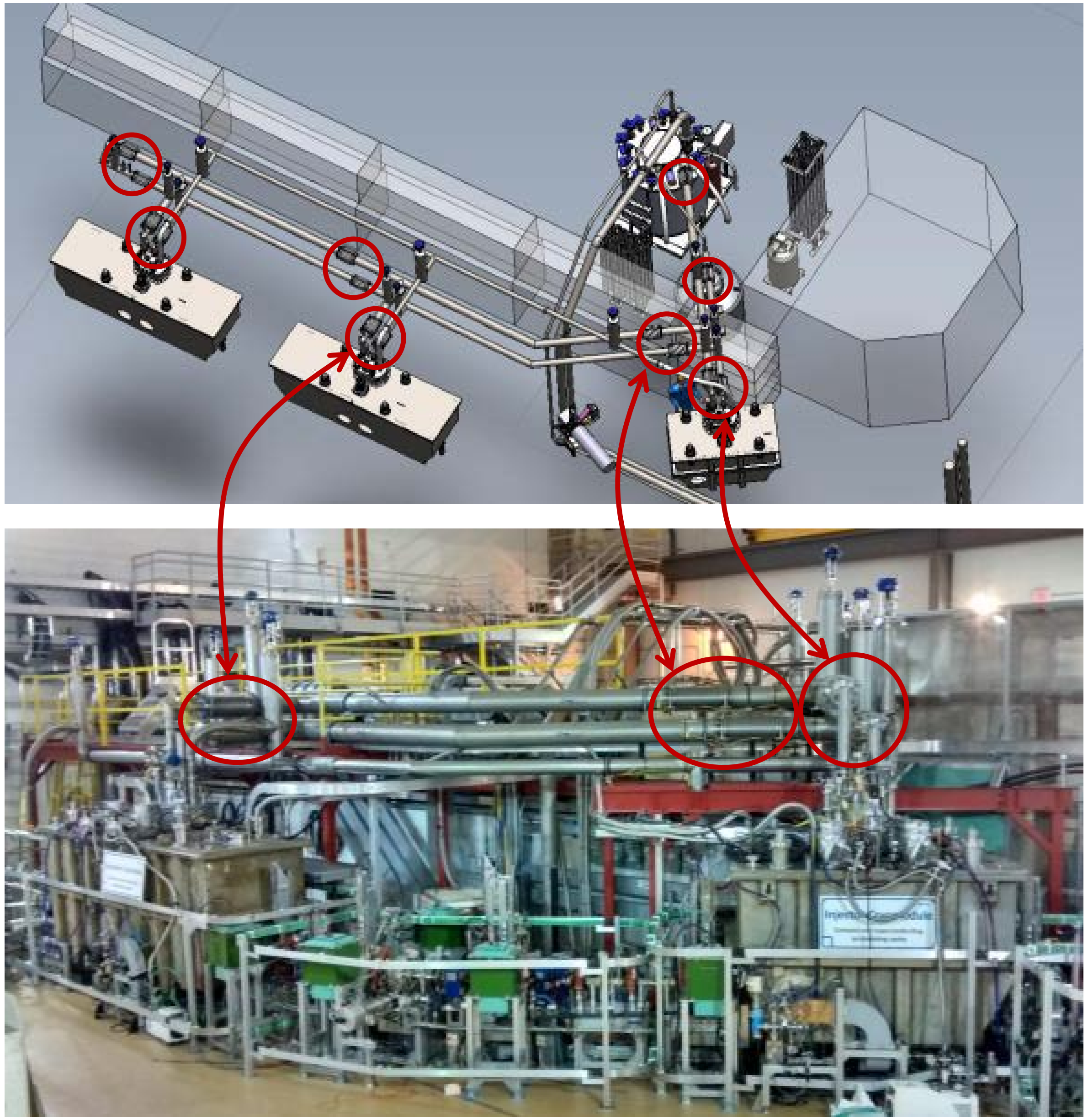
- support operation of one to three cryomodules
- frequent reinstallations of supply and return sections of cryomodules
- accelerator hall access hatch is limited in size

Suppliers:

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

Cryogenic process lines:

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



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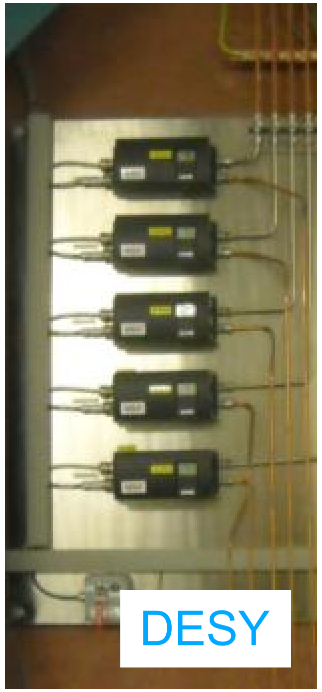
Liquid Helium Distribution

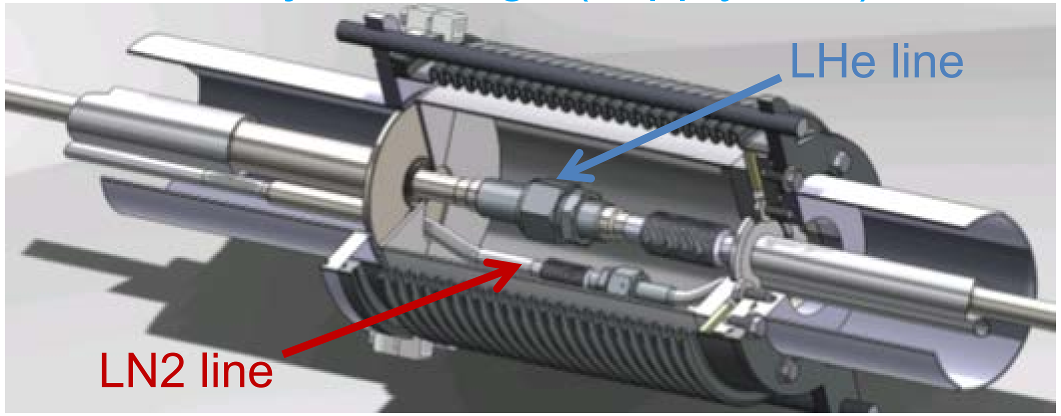
Installation and operation:

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

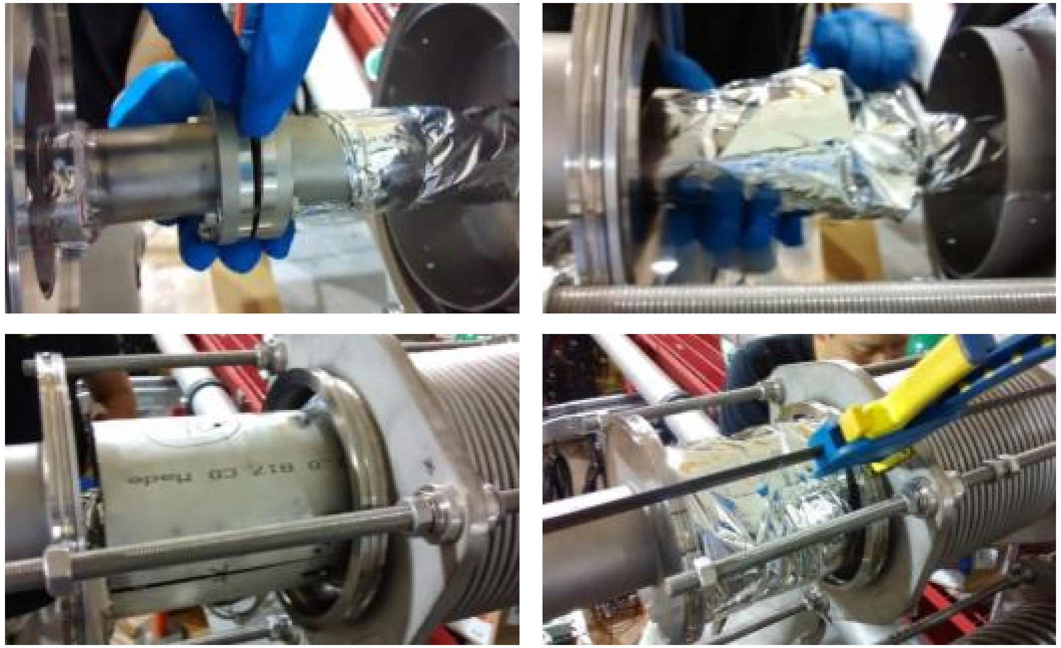
Radiation protection of pneumatic valve positioners:



Field joint design (supply side)



Assembly procedure (return side)



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Cryogenic System – Sub-atmospheric Helium Return Line

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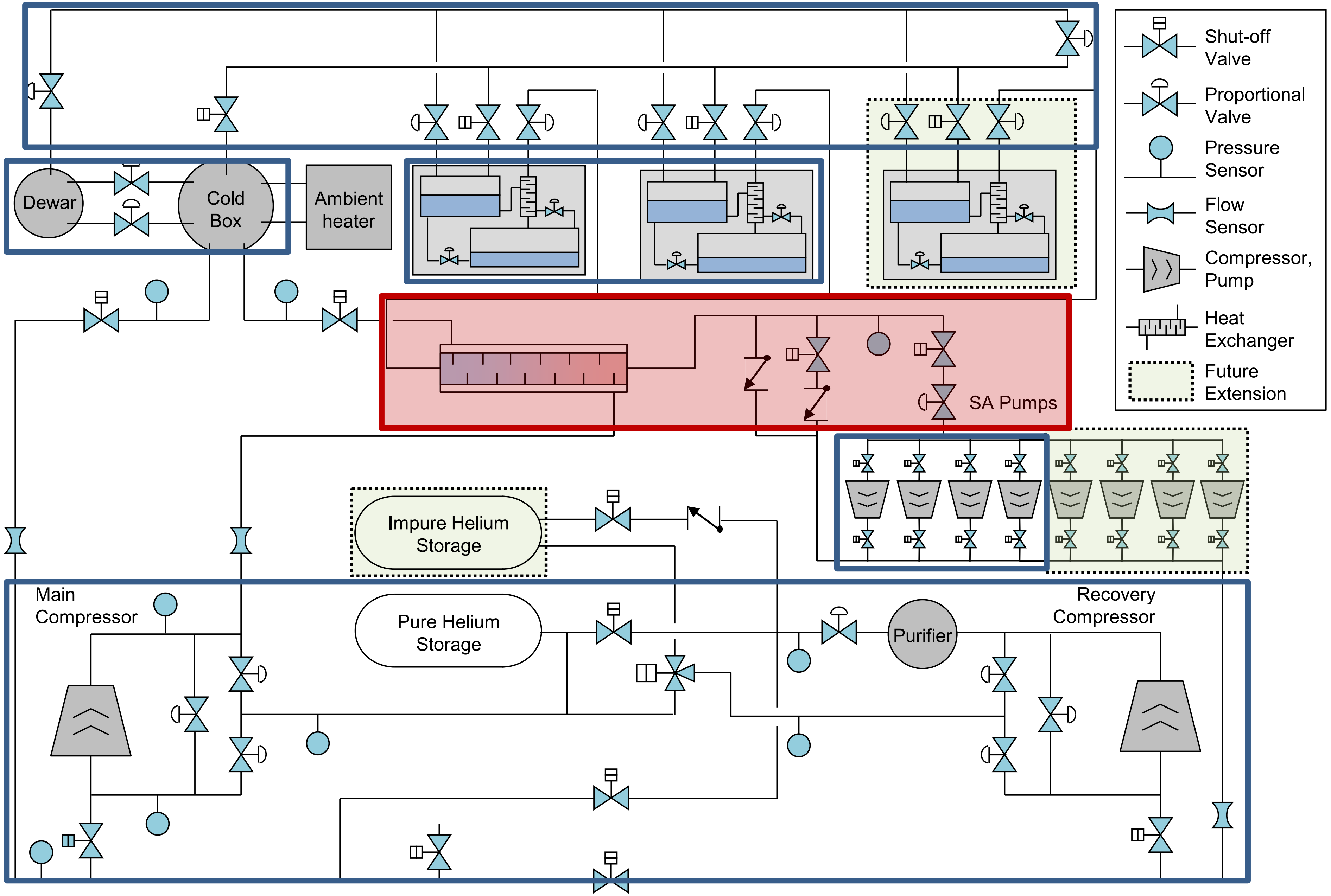
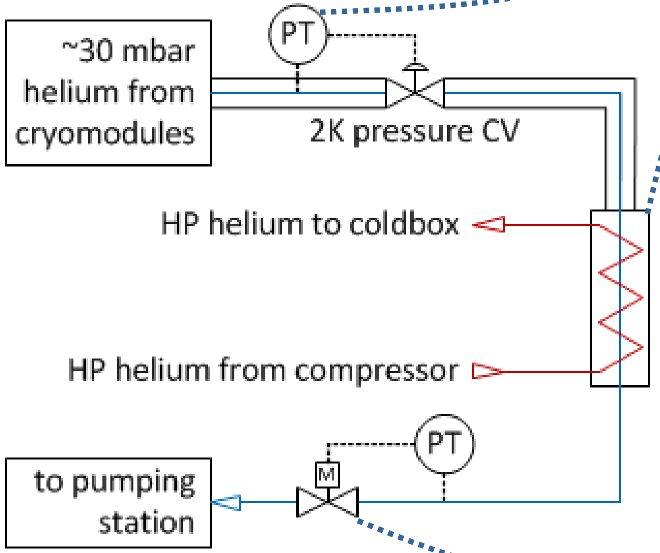


Sub-atmospheric Helium Return Line

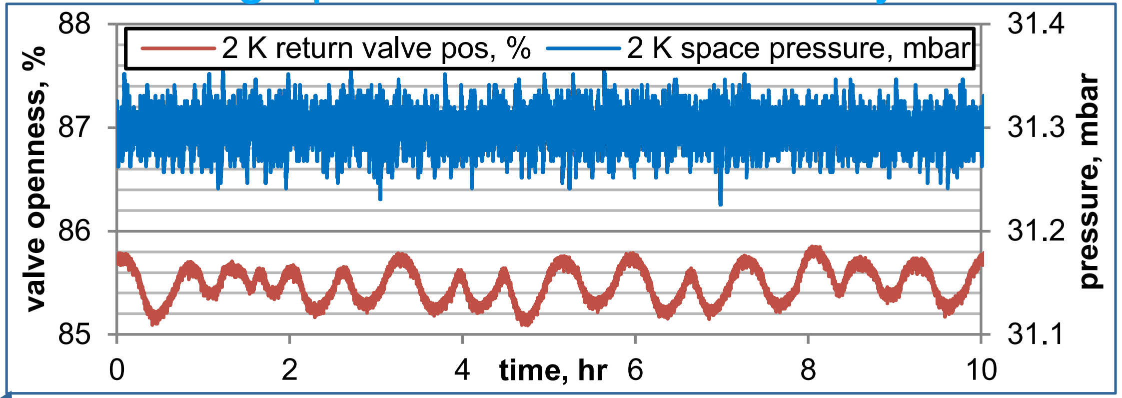
Sub-atmospheric Helium Return Line

Cold piping constructed and installed by *Demaco*

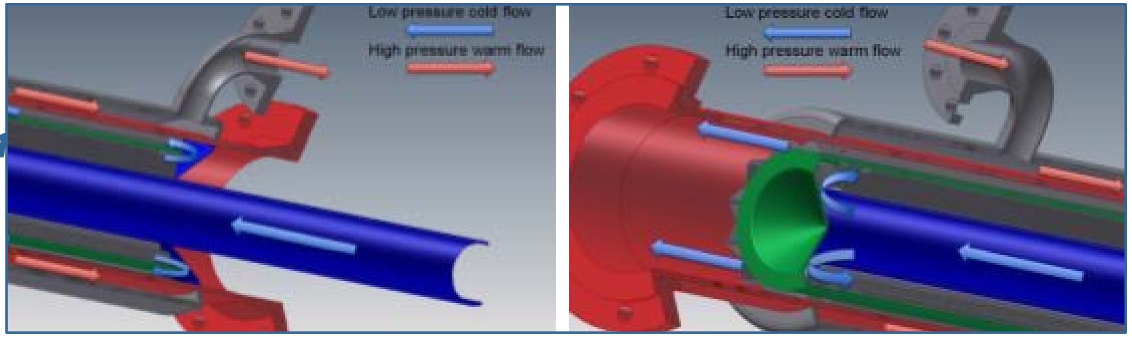
- hermetic welded cold joints
- passive heater to minimize maintenance, some savings on power and LN2
- 2-stage pressure control to control suction of SA pumps
- low resolution throttling valve is used to set pressure in the trunk
- pre-pumping line is needed



1^{st} stage pressure control in cavity bath



Passive heater utilizing HP helium stream



2^{nd} stage adaptive pressure controller (VAT)

Cryogenic System – Sub-atmospheric Pumping Units

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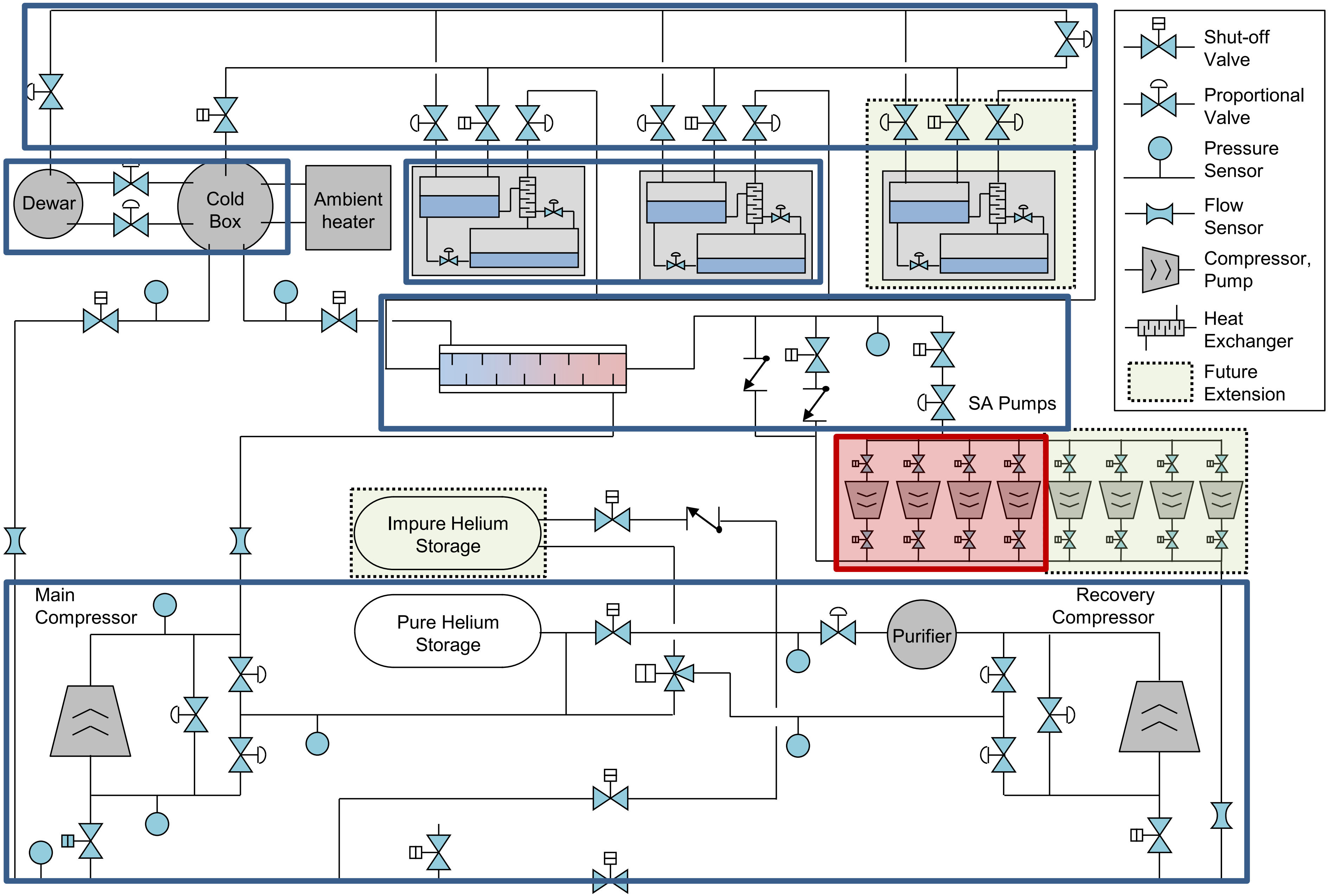

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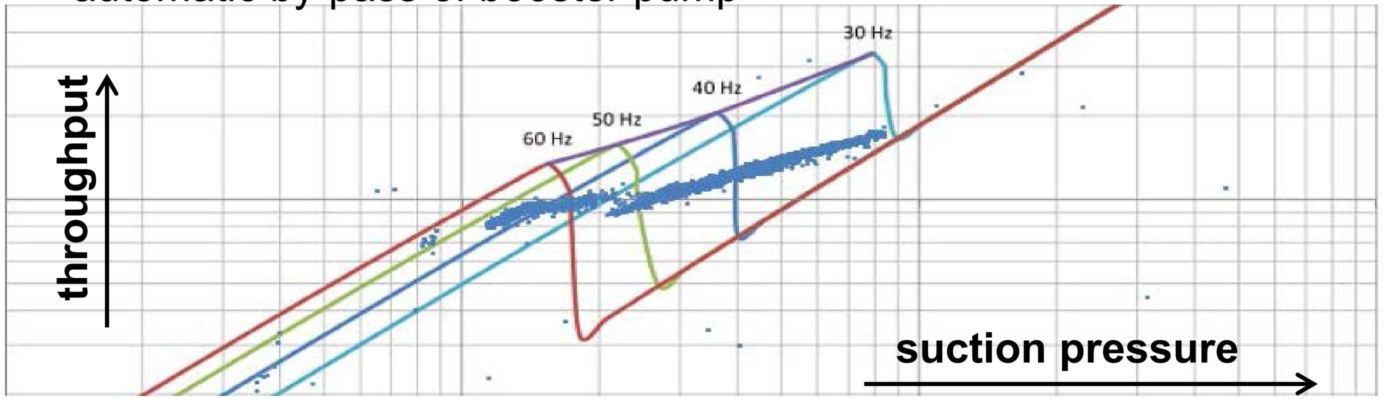
Sub-atmospheric Pumping Units

4 x Busch Combi DS3010-He

- 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 four 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 >1.3 bar(a)

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Future Work

Control System

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

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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

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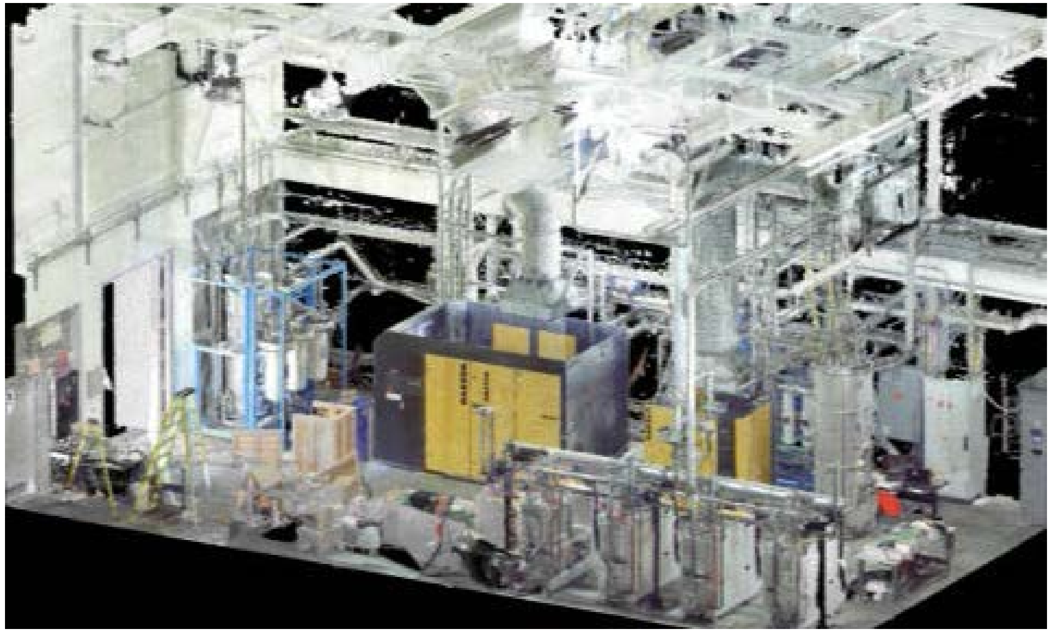
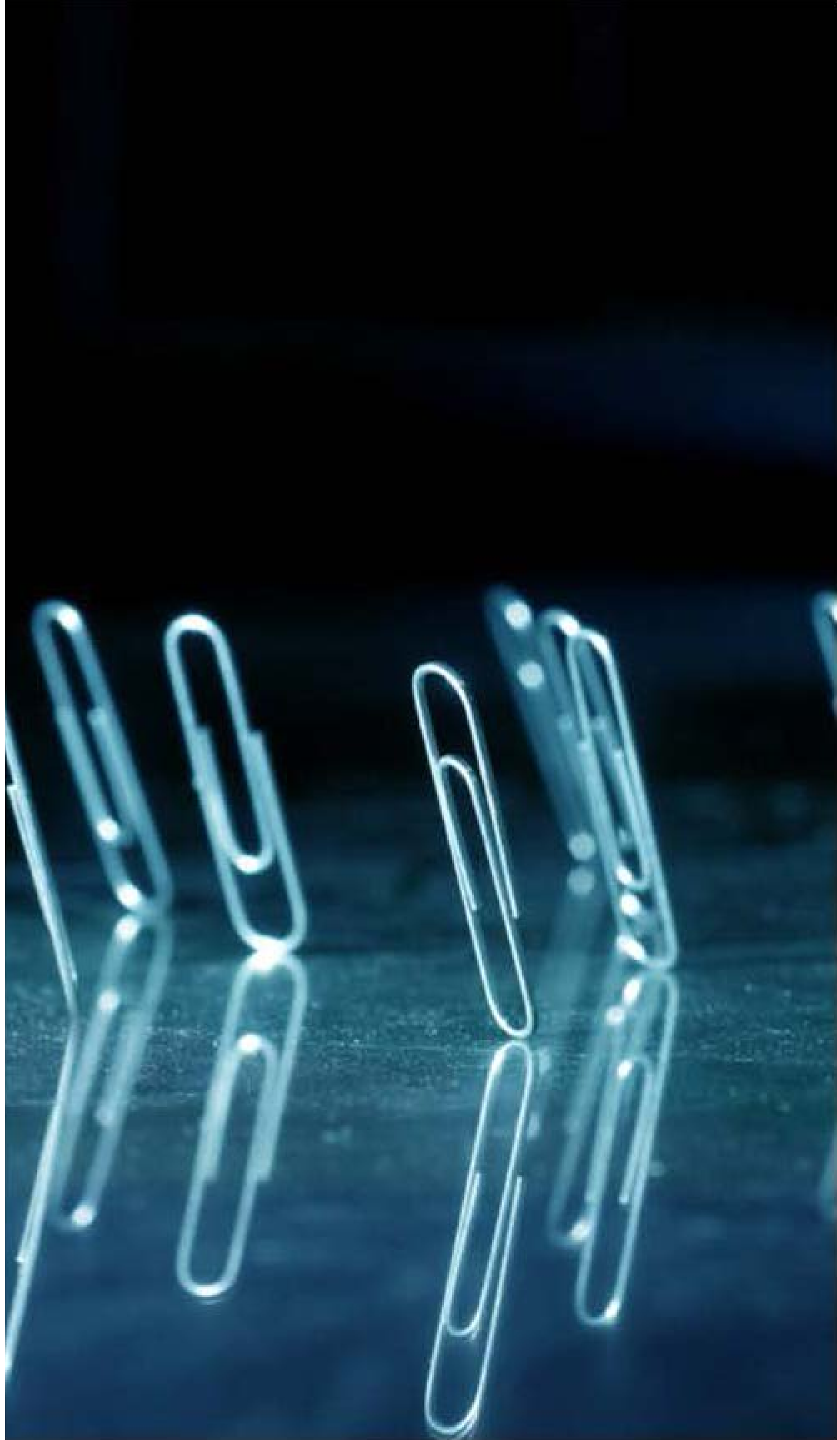
Documentation and training of operators:

- emergency response procedures, migrating some of the responsibilities





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Thank you!

Presented on behalf of:

Cryogenics Group

- Alexey Koveshnikov
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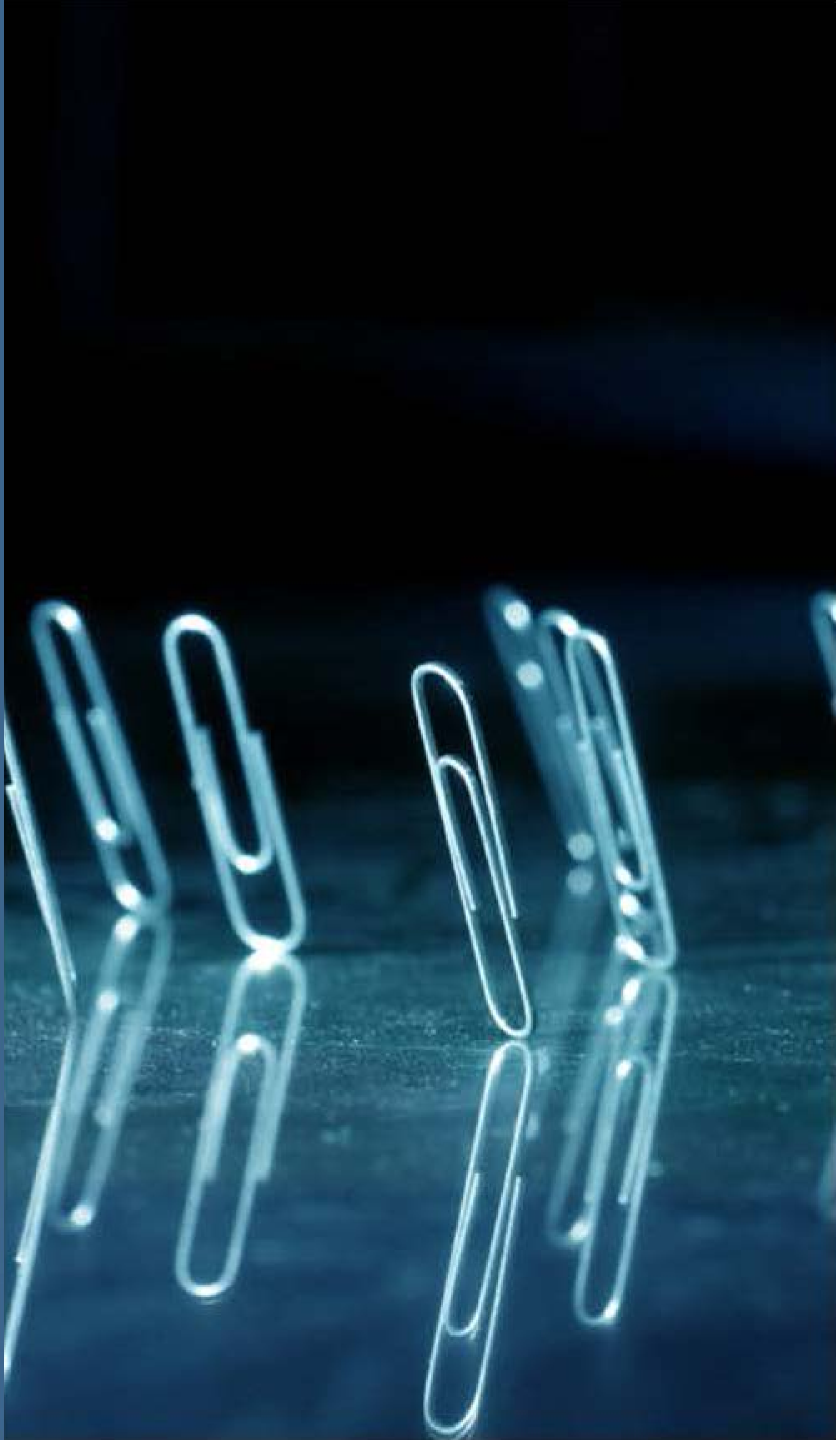

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