ARIEL E-linac Cryogenic System:
Commissioning and First Operational Experience

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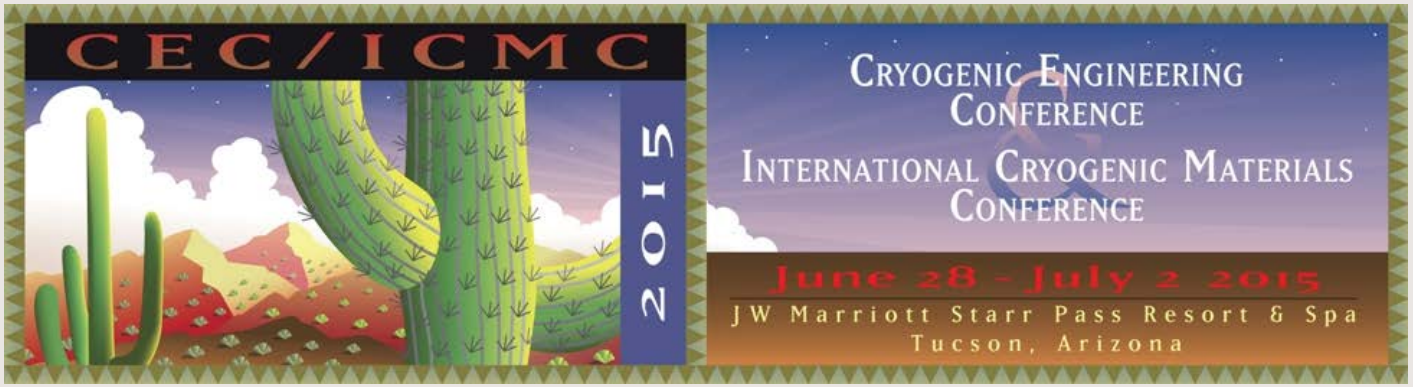
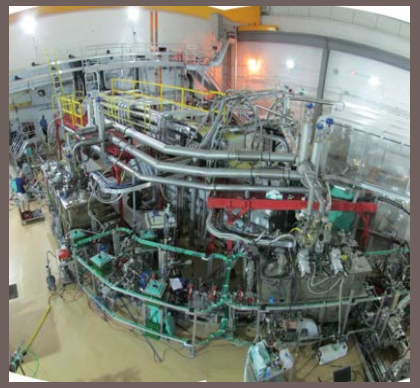
Presented by **Alexey Koveshnikov,**
Cryogenic Group Leader





Owned and operated as a joint venture by a consortium of Canadian universities via a contribution through the National Research Council Canada
Propriété d'un consortium d'universités canadiennes, géré en co-entreprise à partir d'une contribution administrée par le Conseil national de recherches Canada

Outline:

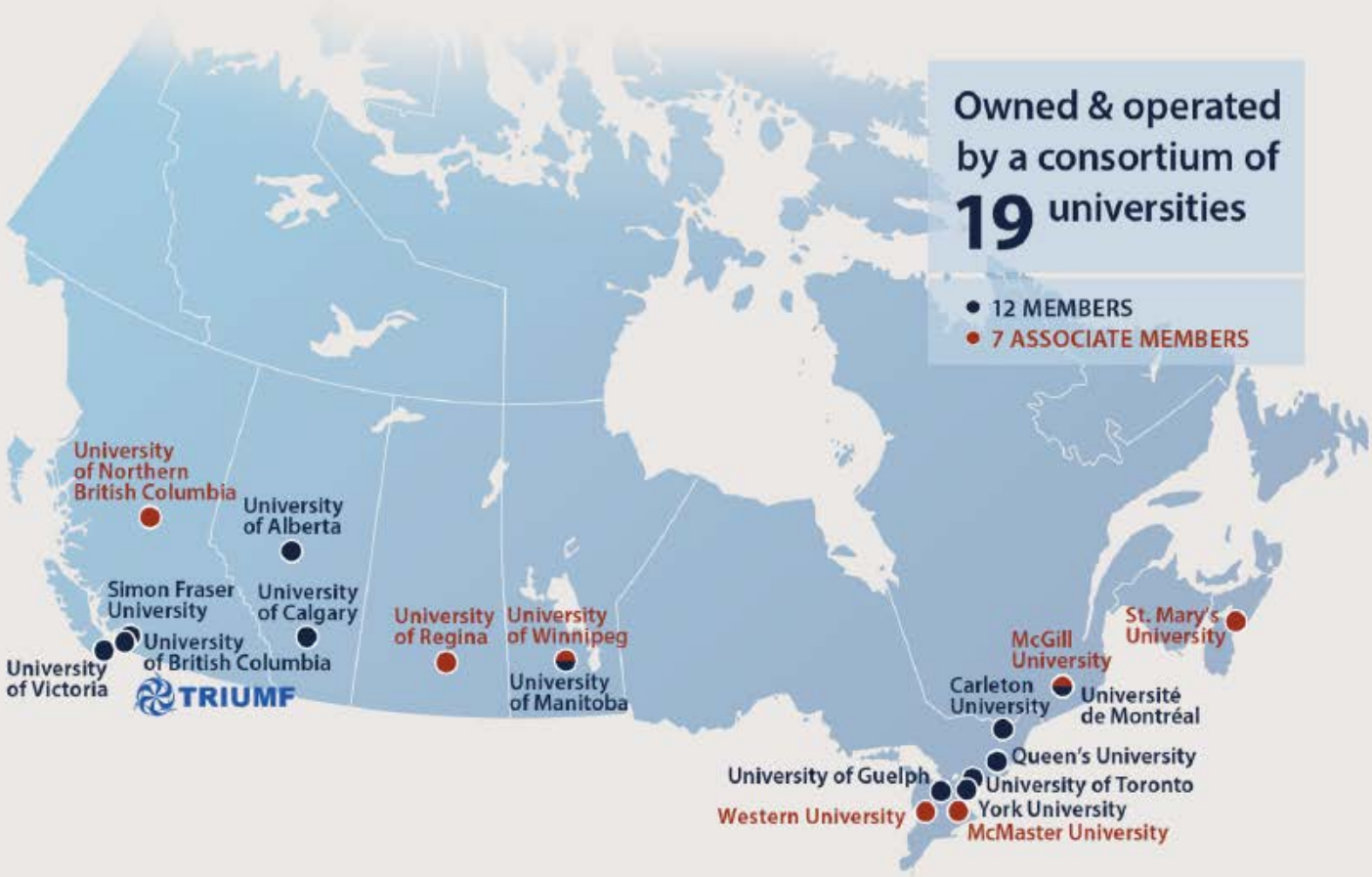
Introduction

- ARIEL project
- E-linac

2. Cryogenic System Layout
3. ARIEL e-linac cryosystem installation
4. ARIEL e-linac cryosystem commissioning
5. Results

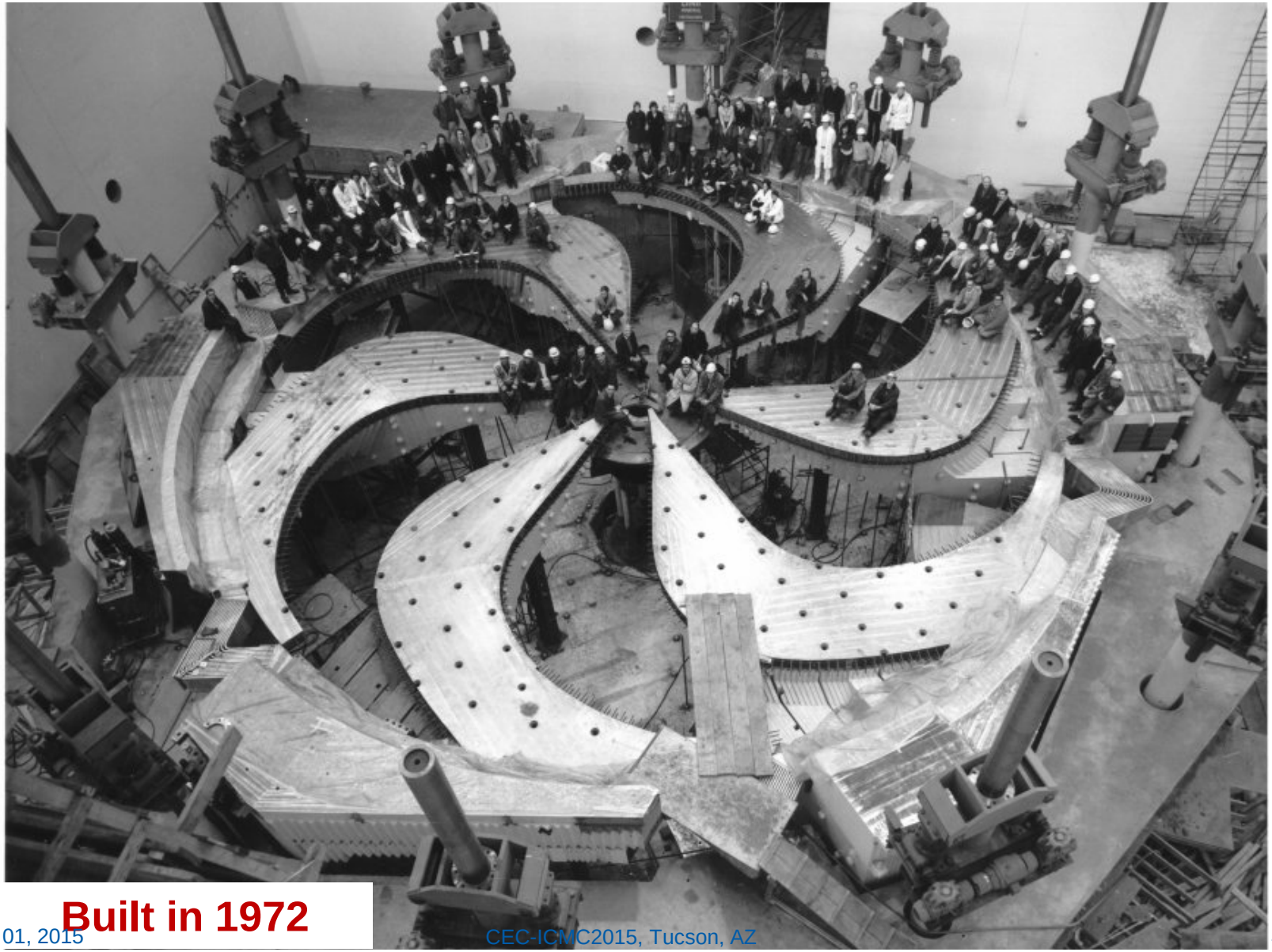
Summary

State of TRIUMF



The state of the laboratory is strong!

The 530 MeV Cyclotron at TRIUMF: The World's Largest Cyclotron

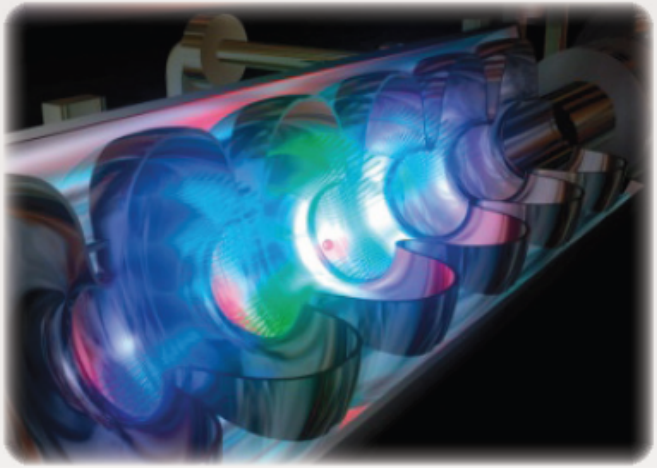


Built in 1972

ARIEL

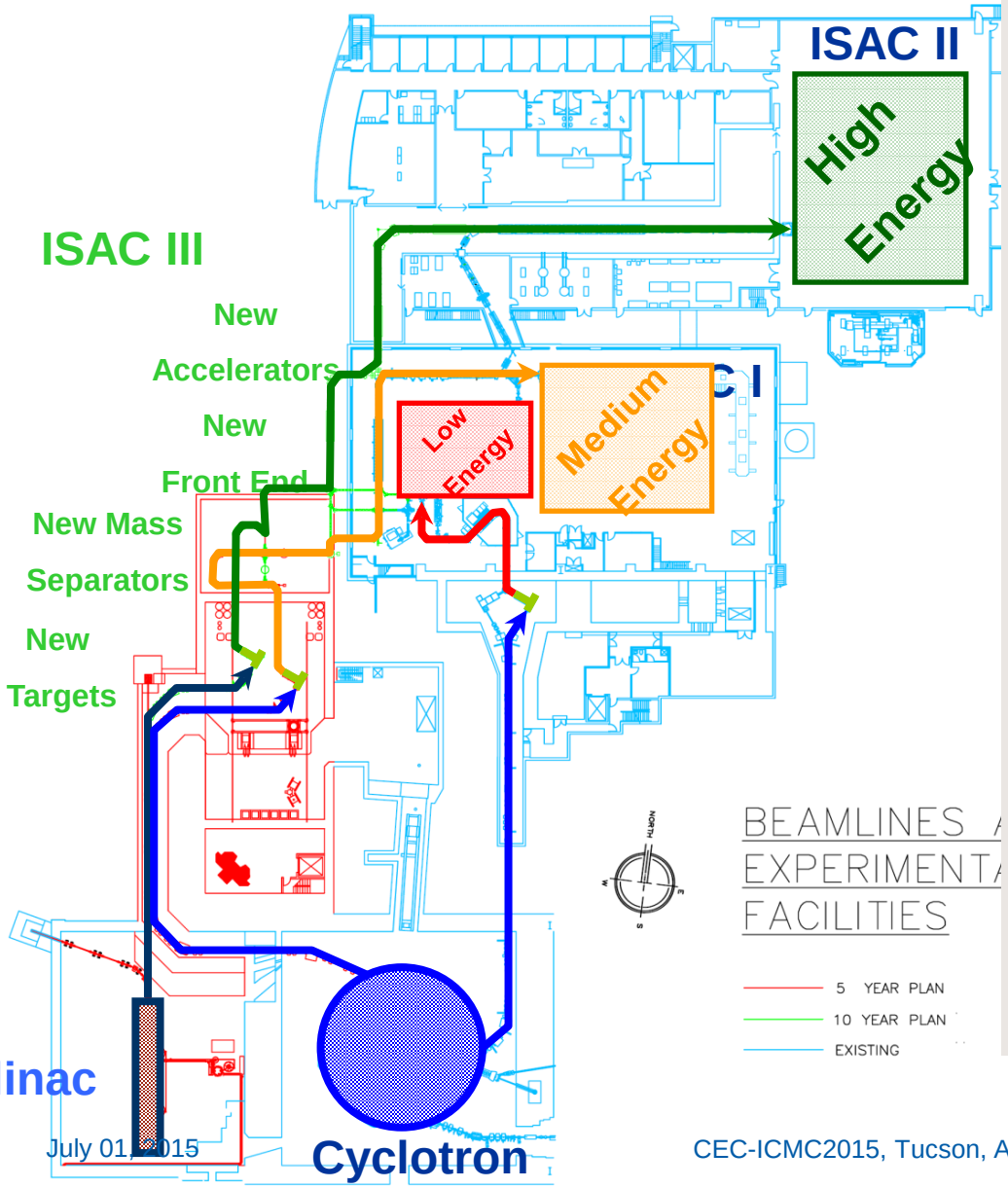
TRIUMF ARIEL

ADVANCED RARE ISOTOPE LABORATORY



ARIEL will be TRIUMF's flagship Rare Isotope Beam facility for the production of isotopes for physics and medicine. ARIEL uses proton-induced spallation and electron-driven photo-fission of ISOL targets for the production of short-lived, rare isotopes that are delivered to multiple experiments simultaneously at the ISAC facility.

ARIEL Project 10-Year Plan: Motivation



- New complementary electron linac (e-linac) driver for photo-fission
- New proton beamline
- New targets an front end

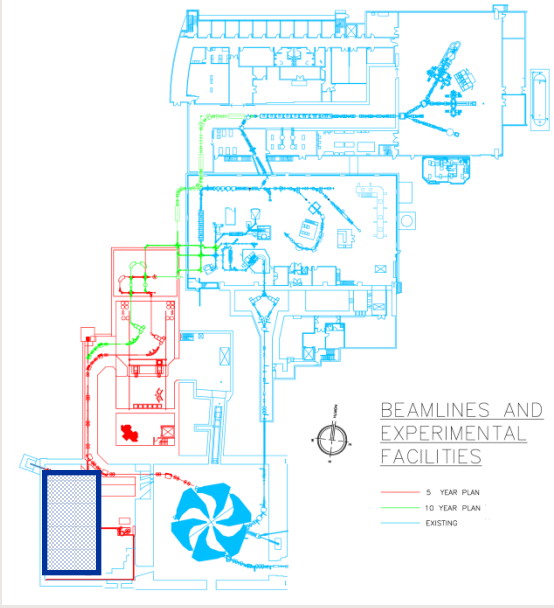
- Allows substantially expand RIB program with:
  - three simultaneous beams
  - increased number of hours delivered per year
  - new RIB beam species
  - increased beam development time

Time line for ARIEL facility

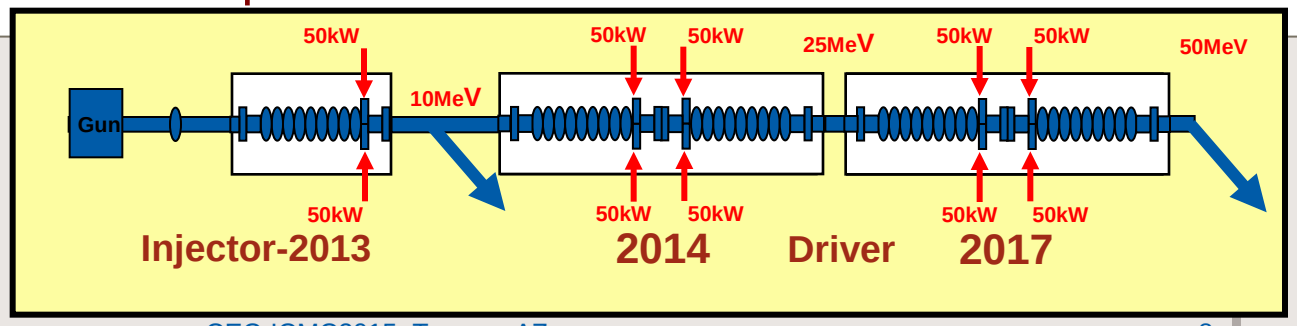
- Funded now ARIEL I (to be implemented till end of FY2015):
  - E-linac demonstrates Electron beam at 25 MeV, 100 kW from SRF linac – license pending
  - Civil construction to encompass objectives of ARIEL Phases I & II
  - E-Hall and Compressor Building complete

- Next five-year plan – ARIEL II (2015-2020):
  - Electron Target Station
  - ARIEL Front-end for ISAC
  - Electron beam at 50 MeV, 500 kW
  - Proton beam at >480 MeV, 100 μA from the H- cyclotron using new proton beamline
  - Proton target station
  - 2nd ARIEL Front-end for ISAC

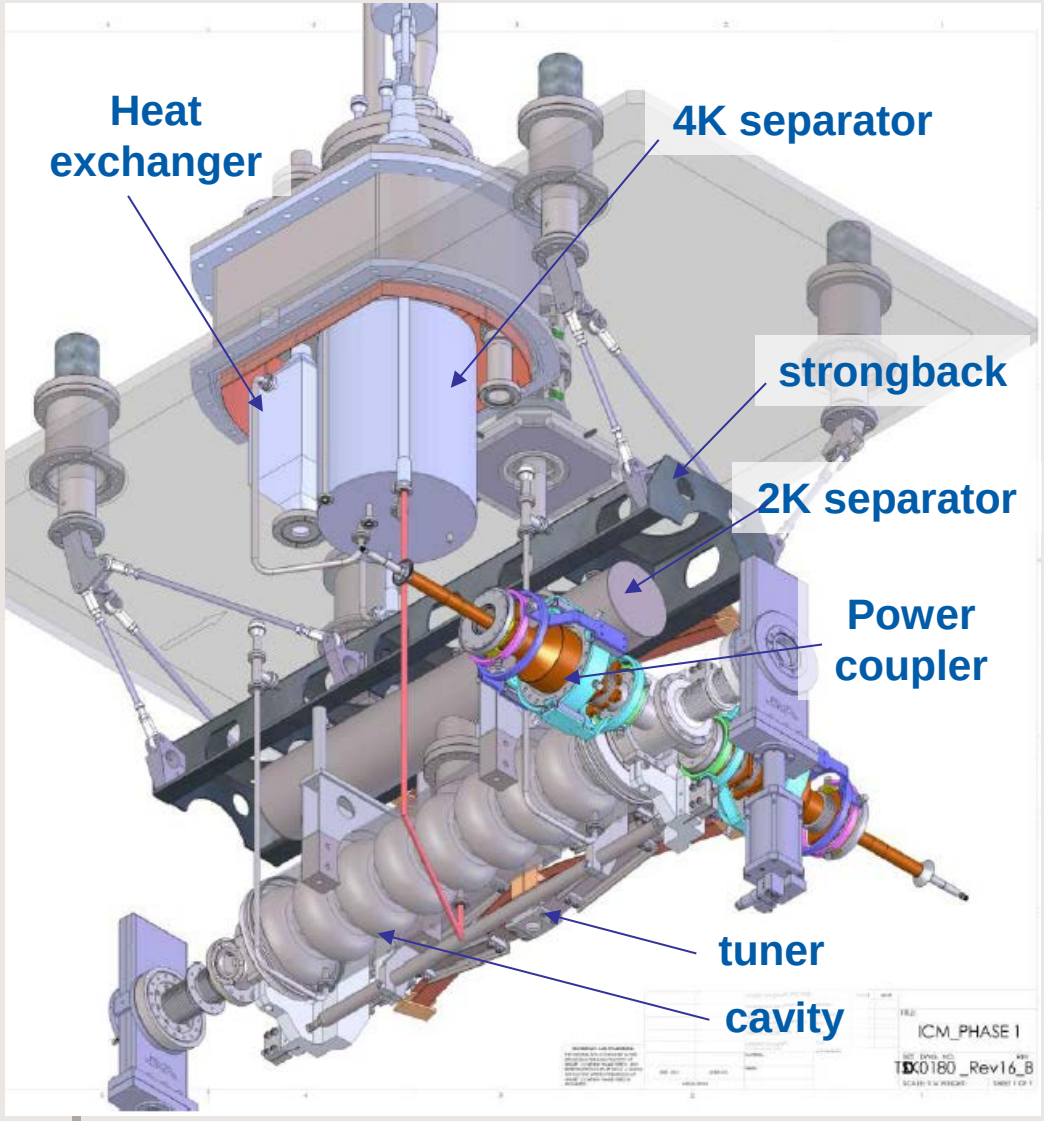
TRIUMF and e$^-$-linac



- Electron driver for photo-fission: independent and complementary to 500 MeV cyclotron
  - Composed of five elliptical cavities at 1.3 GHz
  - Final specification 50 MeV/10mA ->0.5 MW beam power, cw – by 2017 (cash flow dependent)
- Staged installation: 25-30 MeV and 3 mA - 2014
- Injector cryomodule (ICM) - designed, built and tested as part of the VECC collaboration - 2013



Injector Cryomodule



Houses

- one nine-cell 1.3GHz cavity
- Two 50kW power coupler

Features

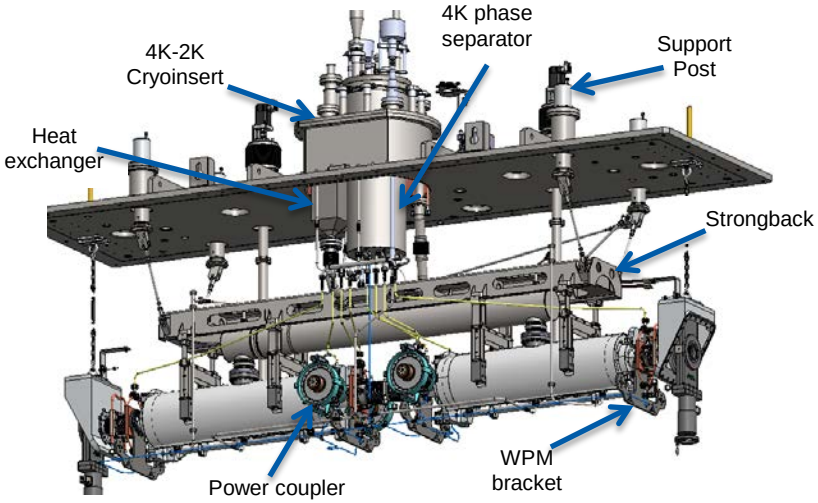
- 4K/2K heat exchanger with JT valve on board – expand LHe from 1.4bar to 32mbar
- Scissor tuner with warm motor
- Two layers of mu metal – warm and cold
- LN2 thermal shield
- CESIC® HOM damping material in warm/cold beam-pipe transition
- WPM based alignment
- Stainless steel ribbed tank with hatches for access

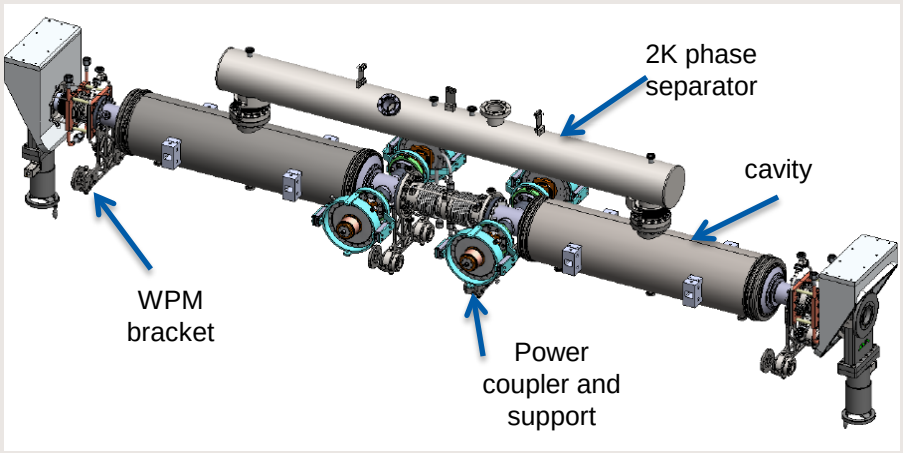
Accelerator Cryomodule

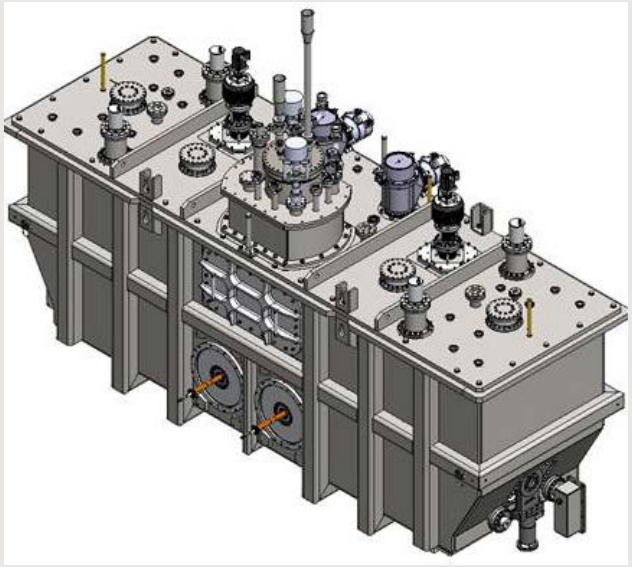
- The ACM uses same basic design as ICM but with two 1.3GHz nine cell cavities each with two 50kW power couplers
- There is one 4k/2k insert identical to the ICM
- Physical dimensions

  L x H x W = 3.9 x 1.4 x 1.3 m

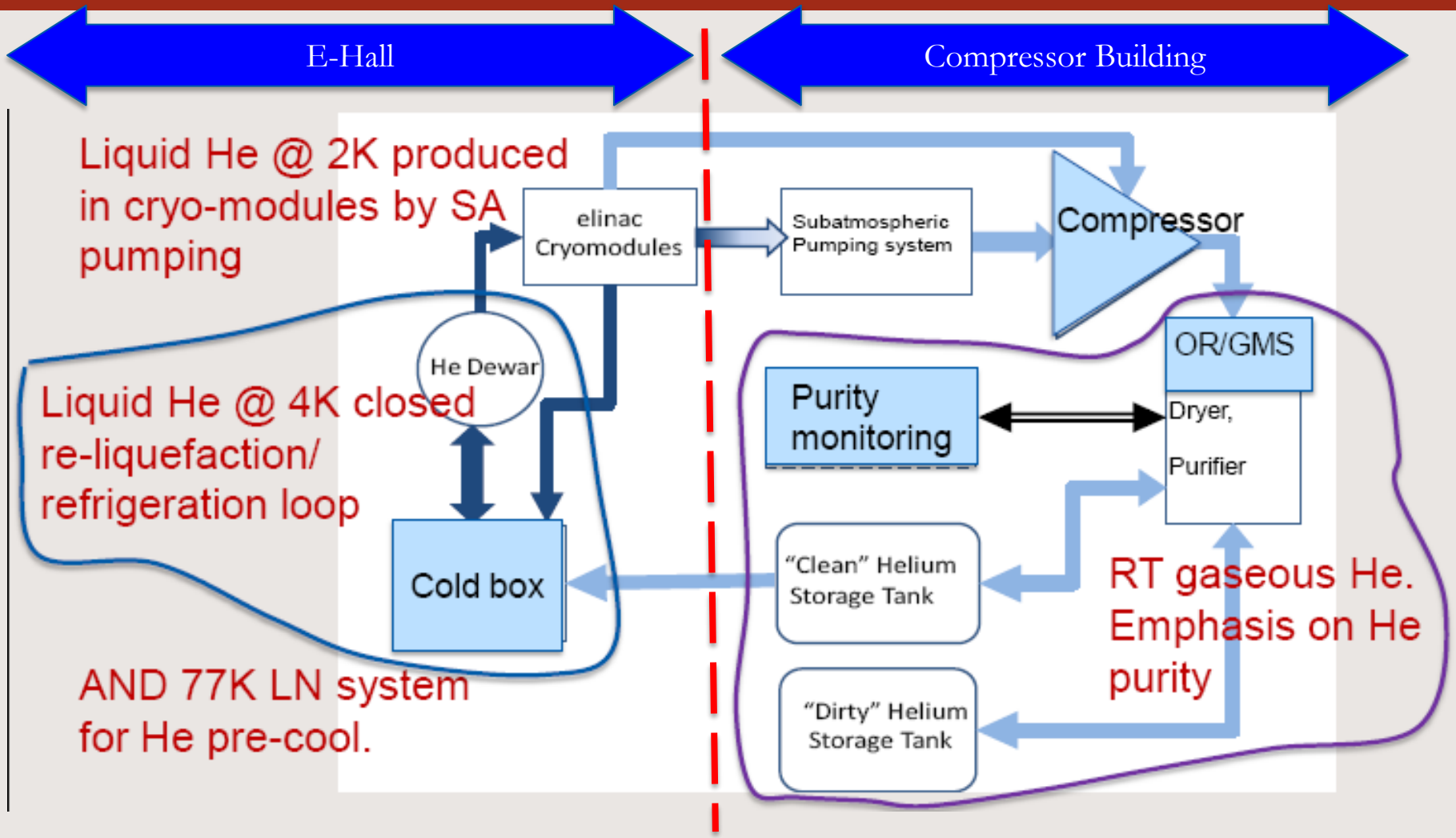
  9 tons



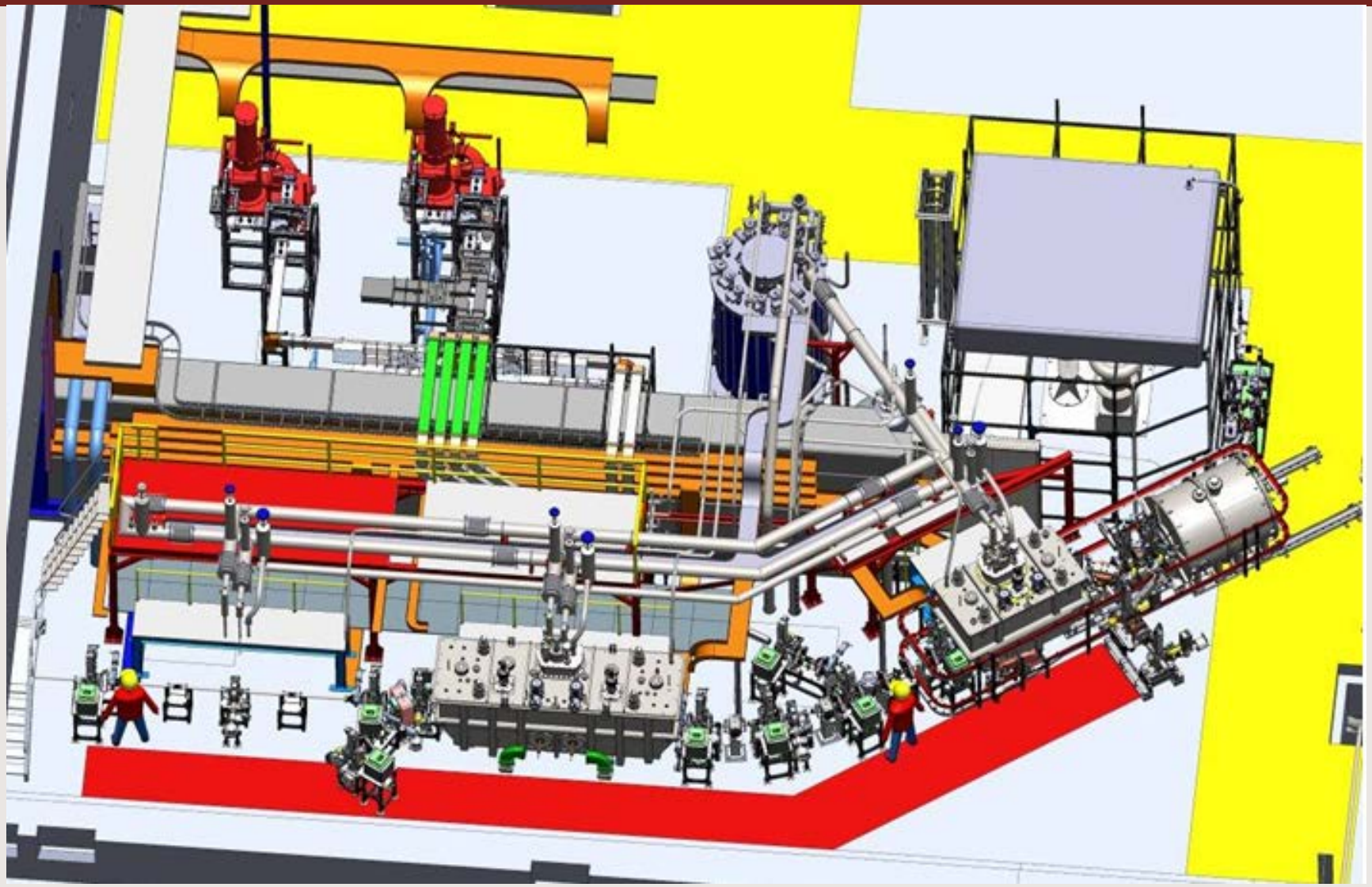




Cryogenic system schematic



Scope of Sept 30th 2014 (CFI) deliverables



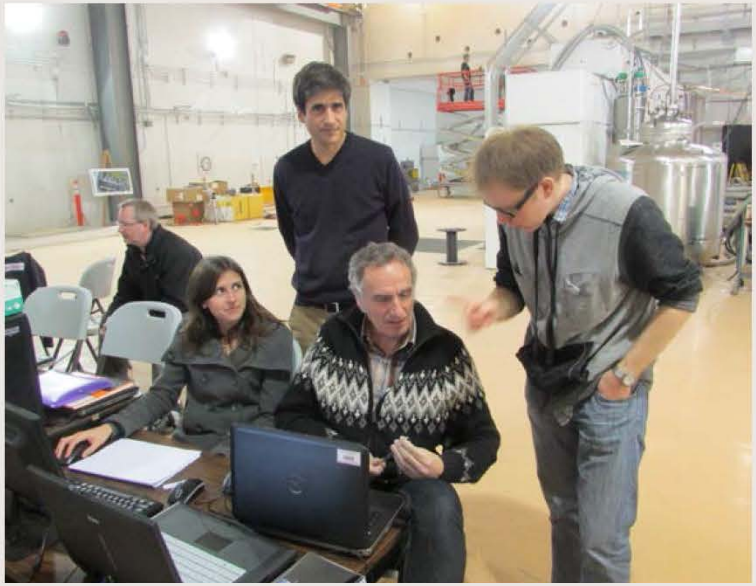
Helium Cryogenic Plant 4K Acceptance Test

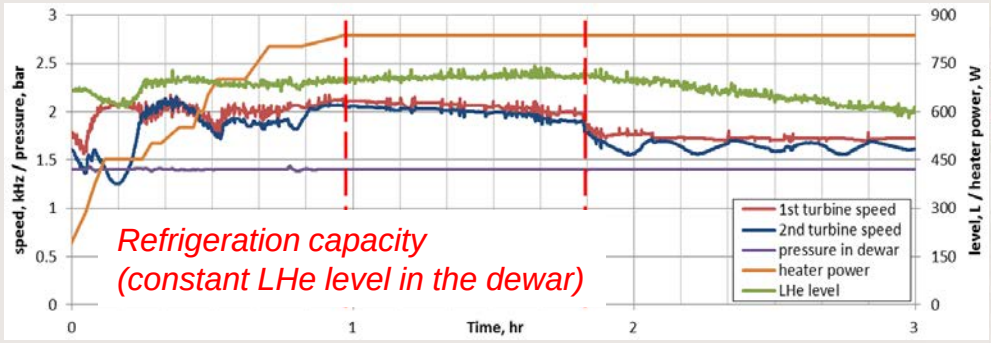
Results of the helium cryoplant acceptance tests.

Measured performance parameter	Measured (expected) values
Pure liquefaction capacity with LN2 precooling	367 (288) L/hr
Pure refrigeration capacity with LN2 precooling	837 (600) W

LHe sensor reading 155 L

First Liquid (2013 Nov 22 @ 1 AM)





Refrigeration capacity (constant LHe level in the dewar)

Sub-Atmospheric Helium System

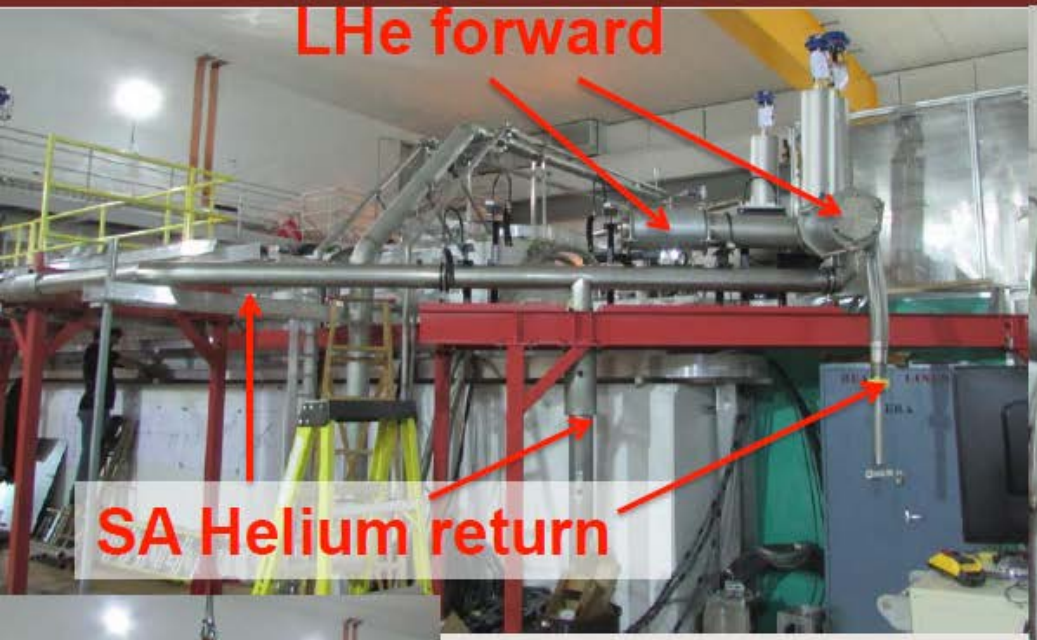
SA Heat Exchanger installed 2013 Dec 20 in e-hall

SA pumps manifold installed 2014 Jan 14 in Compressor Bldg

- SA He piping install in B3 tunnel
- LC Water install to dump HEX 2013 March 27

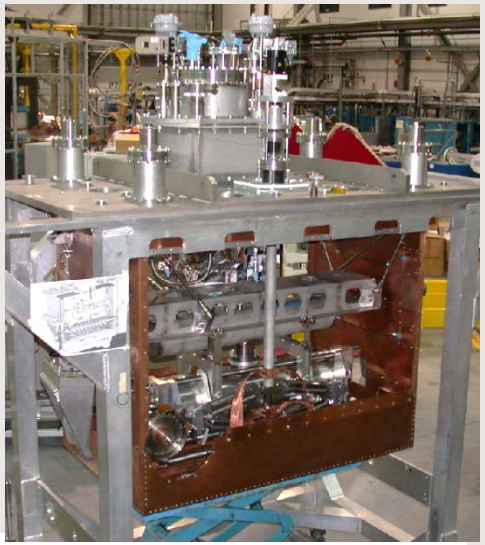
TRIUMF

Liquid & SA Helium Lines in e-hall



Busy Spring and Summer 2014

ICM Assembly



ICM mock-up – 2013

- Mock-up assembly of ICM used to test parts and procedures
- Final assembly (aided by lessons learned from mock-up) - completed in <1 month

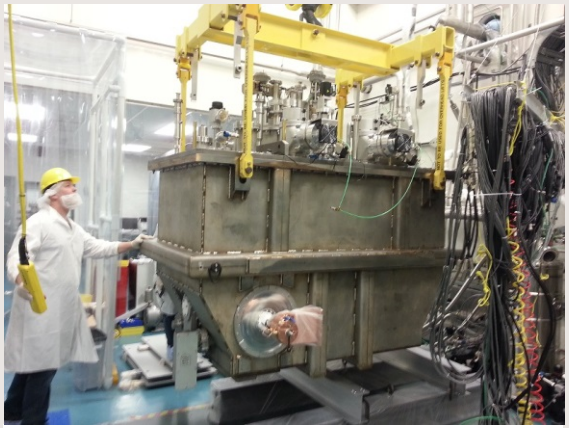
Cavity hermetic unit (March 14, 2014)

ICM top assembly

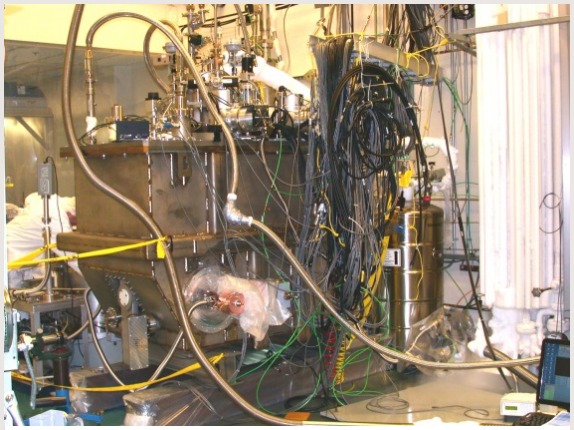
Top assembly into tank

ICM unit Complete (April 9, 2014)

ICM Cold test



ICM craned into position



ICM during cold test

Preparing cables and cryogenics

Cold test complete

- ICM delivered to cryogenic test area
- Established cool-down protocol, vacuum integrity and cryogenic performance
- Tested thermal syphon parameters
- Tuned couplers to Q_{ext}~$3x10^6$
- Established cold alignment

ICM Move (April 28)

ICM over ISAC-II

ICM on the move

Lowering ICM to the e-Hall

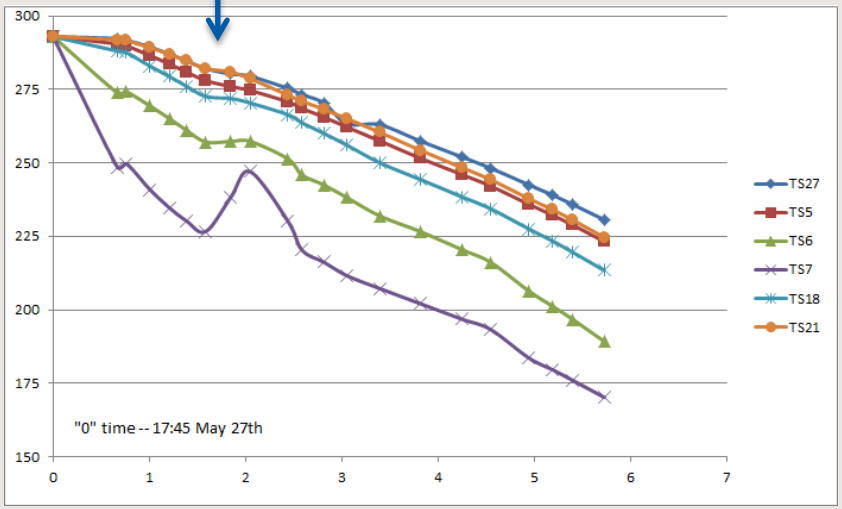
On April 28 the ICM was moved from the clean room, craned over ISAC-II hall, carted over to proton hall loading bay, craned down to e-hall and finally craned into position, six weeks after completion of the hermetic unit

ICM in position in the e-Hall

May E-log Highlight: Injector in place

- 01: ICM in e-hall, warm, under vacuum
- 12: EGUN conditioning – reached 323kV
- 27: **first electrons in e-hall - 5µA at FC1**
- 28: ICM LN2 pre-cool - temp falling
- 29: **ICM 4K cool down**

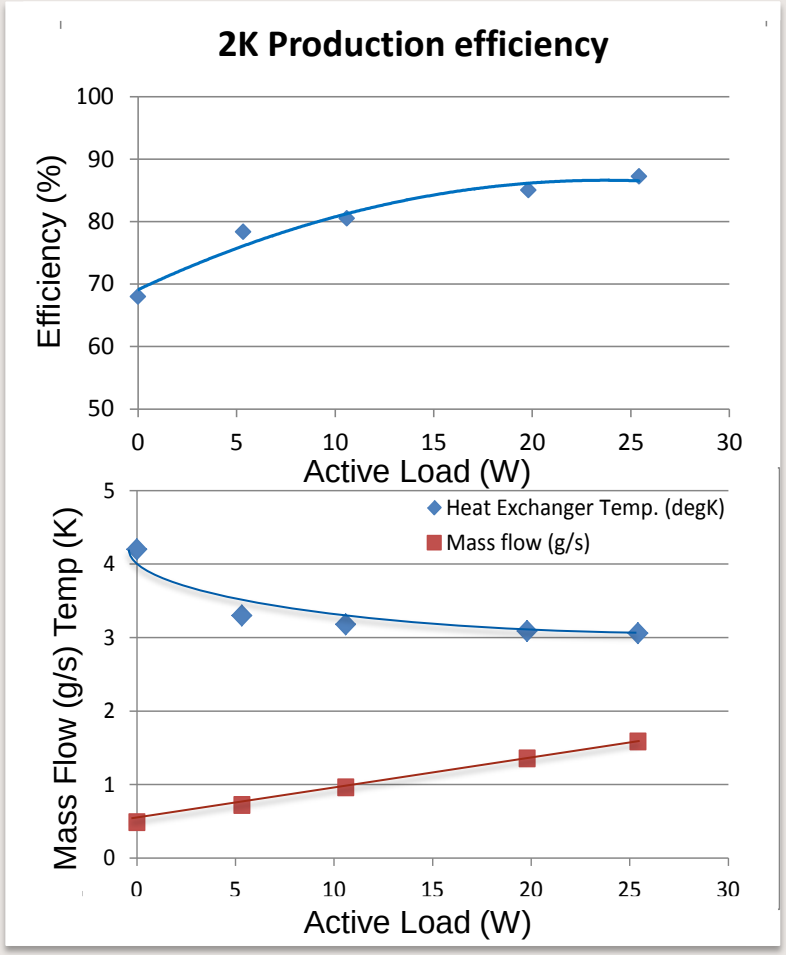
burst disc works!



ICM Cold test results

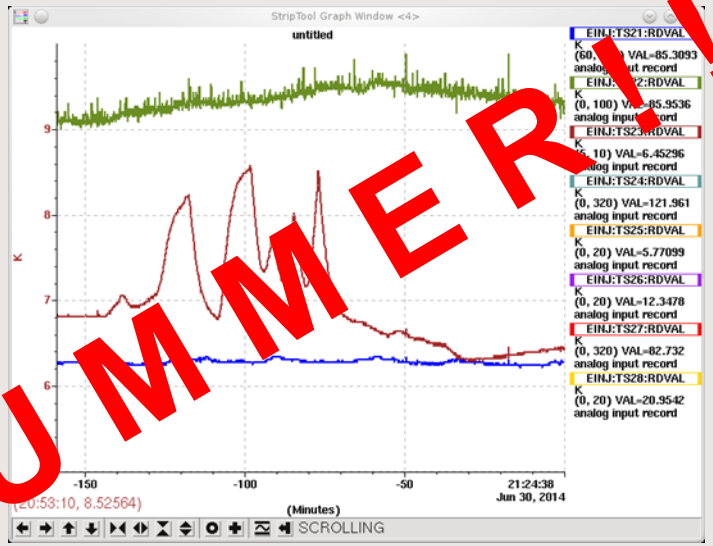
Parameter	Estimated	Measured
4K static load (no syphon)	2	3
4K static load with syphon	6	6.5
2K static load	5	5.5
77K static load	100	<130
2K production efficiency	82%	86%

- ✓ Cryogenic engineering matches design expectations
- ✓ Syphon loop performance characterized – works well – optimized in off-line cryostat tests



June E-log Highlight: ICM operates

- 18: Sub-atmospheric He pumps started
- 19: **First RF test at 2K**
  - Delivered forward power from 300W to 1.2kW.
  - Shifted cavity frequency to 1300.500MHz using tuner.
  - Locked cavity amplitude in a range of gradients from ~1-3MV/m.

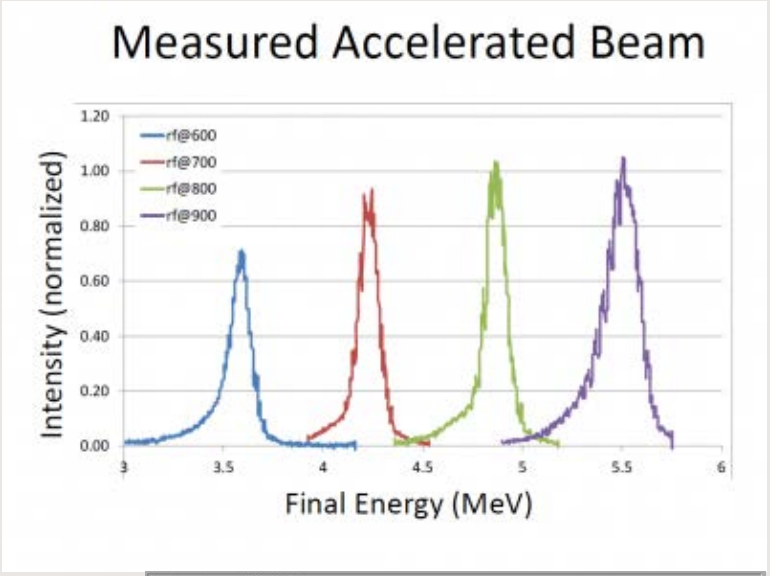


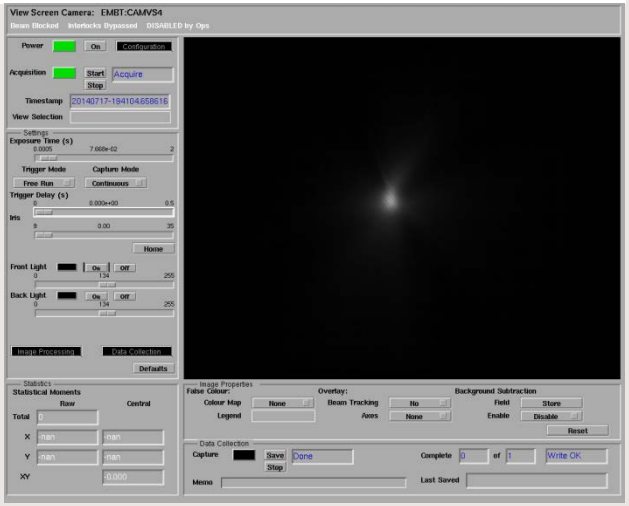
BUMMER!!!

- 29: **ICM ARIEL1 Cavity at 5 MV/m c.w. from calorimetry**
  - Limited by field emission from cavity, not couplers

July E-log Highlight: 5.5 MeV electron beam

- 03: EGUN:BPM1 characterization
- **19: 5.5 MeV beam to EMBD:VS2**
- 23: ICM warm up
- 28: ICM removed from e-hall

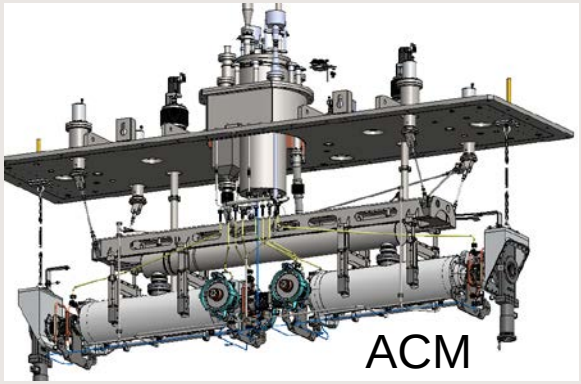


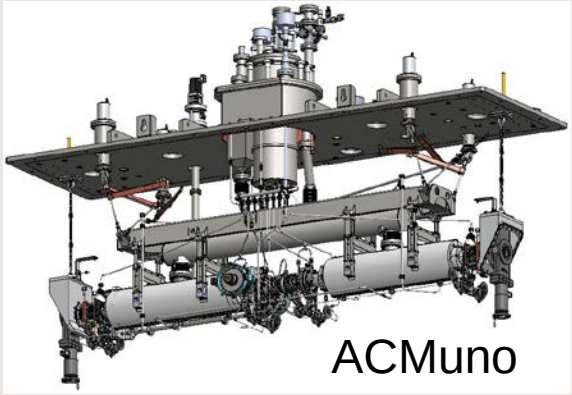


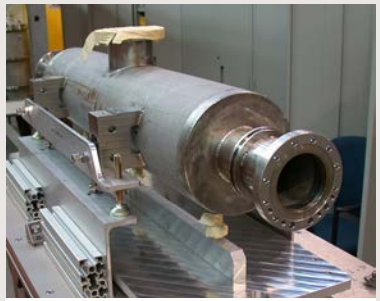
5.5 MeV beam spot

Cryomodule strategy

- Jacket and install ARIEL1 in ICM
- Jacket and install ARIEL2 and install in ACM together with a dummy cavity
  - We call the single cavity ACM configuration **ACMuno**
- ACMuno
  - Dummy cavity has all interface features including helium jacket and DC heater
  - All helium piping and beamline interconnects will be final
  - ACMuno allows a full cryogenics engineering test plus two cavity beam acceleration to 25MeV
- Goal - install the cryomodules for a combined beam test in Sept. 2014 – cryogenic engineering and funding milestone

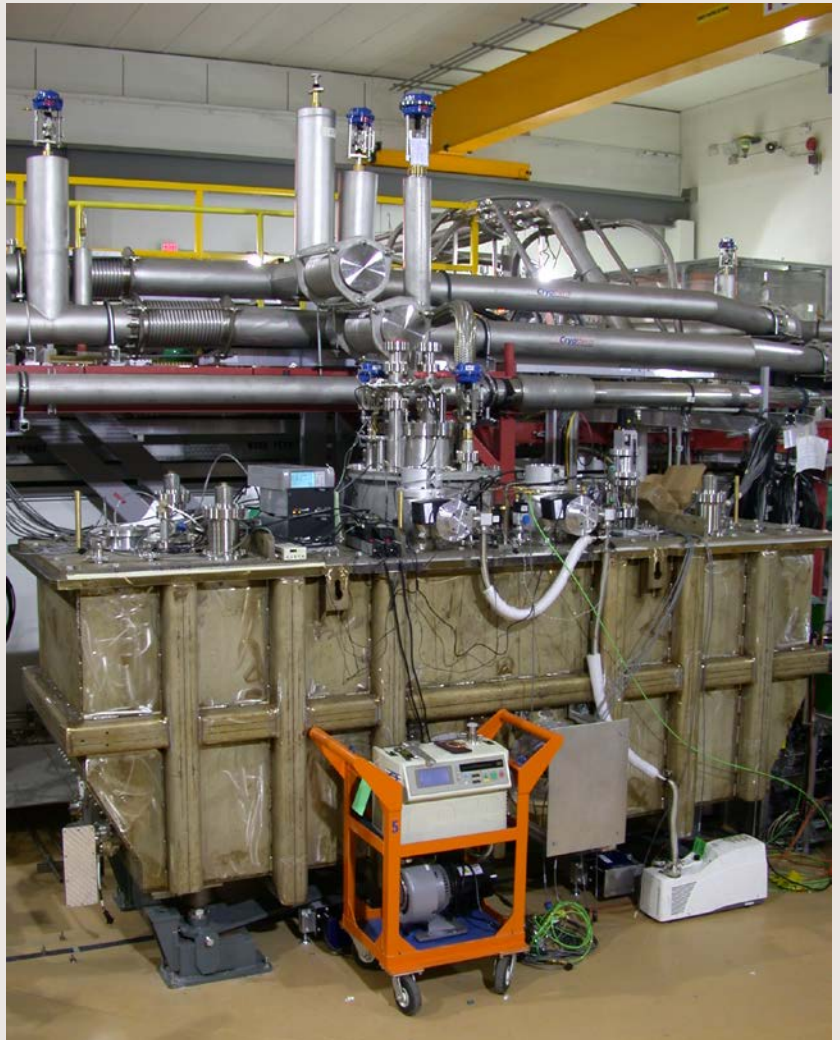

ACM


ACMuno


Dummy cavity

ACMuno

ACMuno assembly proceeds through June-Aug.



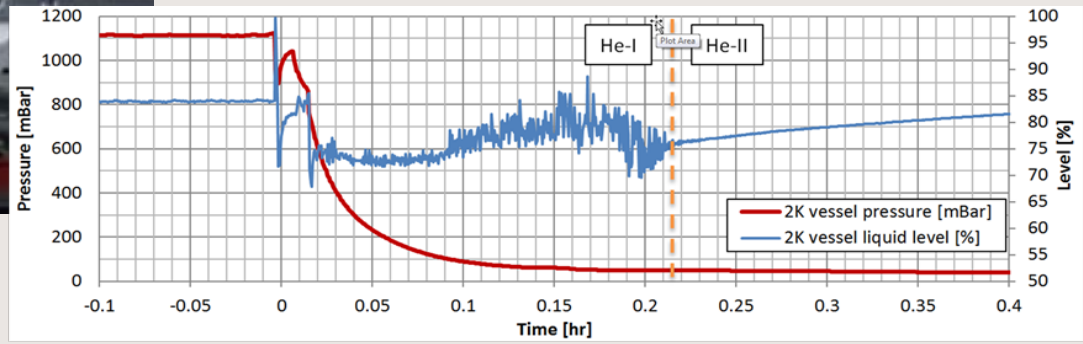
ACMuno – ready for cooldown Sept. 1

Extending LHe Distribution

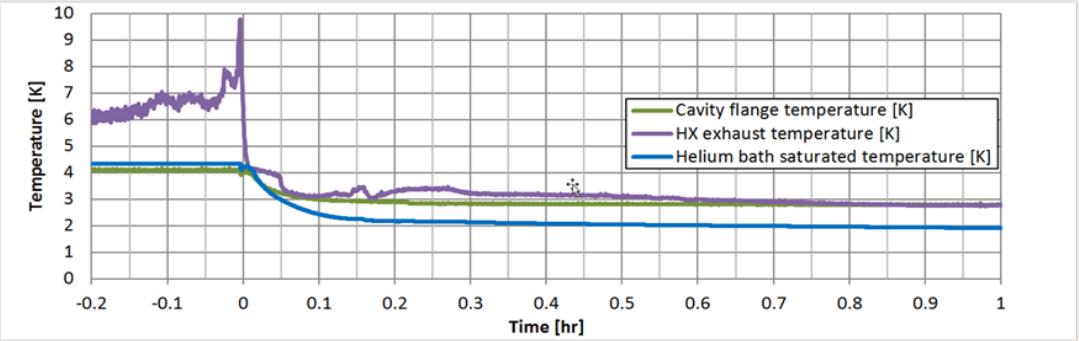
Aug 01: U-turn on Injector LHe distribution system is undone.

Aug 06: Accelerator supply and return sections craned to e-hall and installed.

- System Components are installed and operational
- Successful cool down of ICM & ACM to 4K
- Sub-Atmospheric Pumping and 2K operation of both CMs



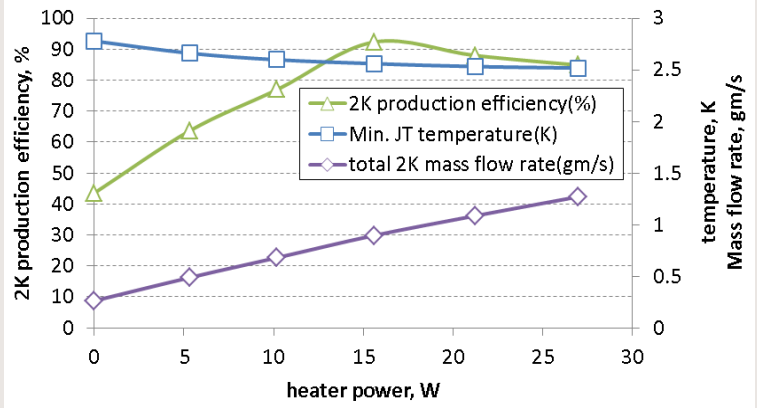
The 1st 2K cooldown. The λ-point transition (above), the bath temperature at 2K (below).



ACMuno First Cold test results

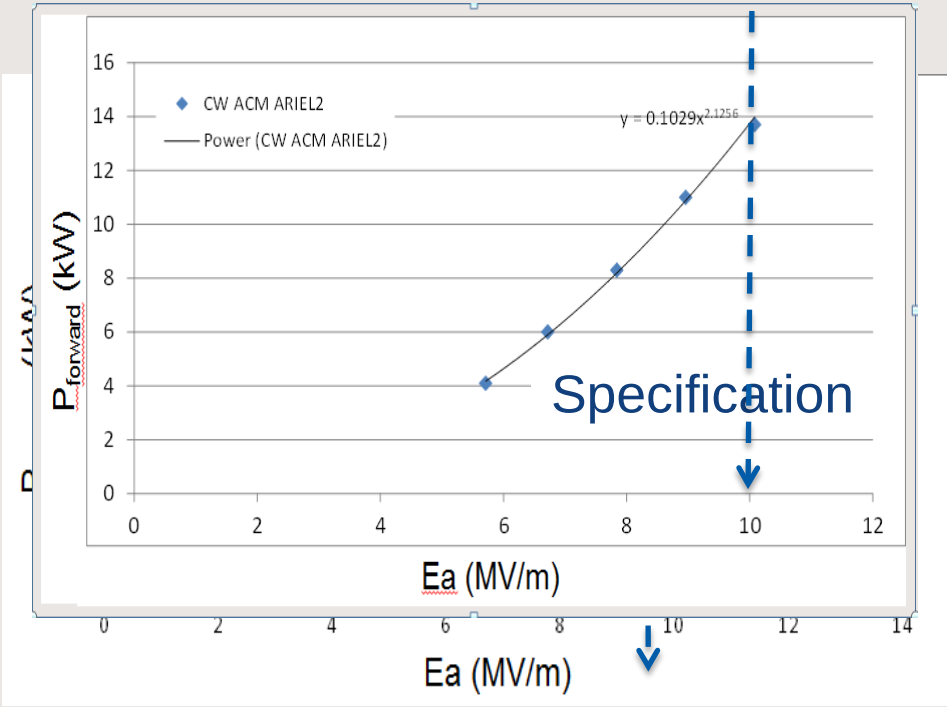
Parameter	Estimated	Measured
4K static load with syphon	>7	6.4
2K static load	>7	6.5
77K static load	100	TBD
2K production efficiency	82%	>90%

- ✓ Cryo-engineering looks good – static loads as expected – cooldown straightforward
- ✓ Initial RF tests – CW performance limited to 7MV/m and pulsed performance to 10MV/m by multipacting in couplers – no field emission to 10MV/m



Sept E-log Highlight: SRF success

- 10: ACM RF test at 2K – it all works
- 16: ICM is back in e-hall on beamline
- 22: ICM & ACM both at 2 Kelvin
- 23: ICM demonstrates 12 MV/m
- 24: ACM demonstrates 10 MV/m
- 26: Two cold cavities locked at 1.3005GHz
- ***Ready for electron beam!***

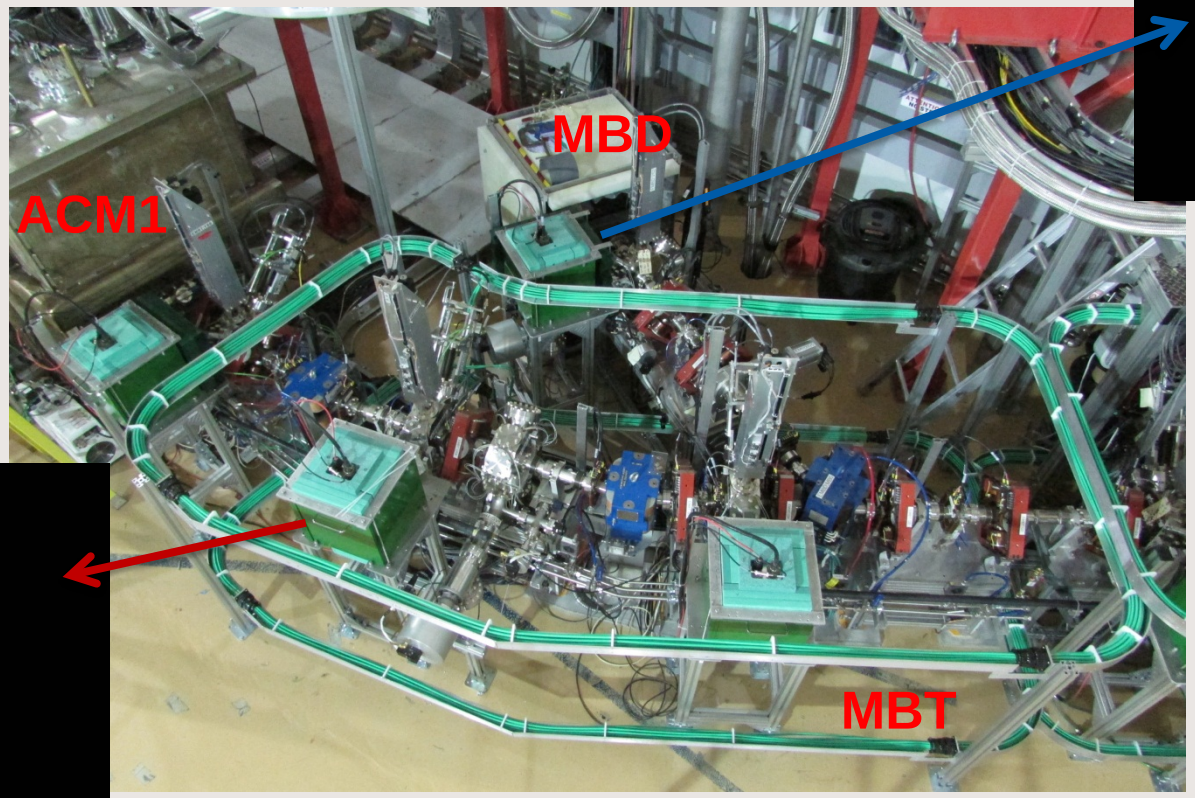


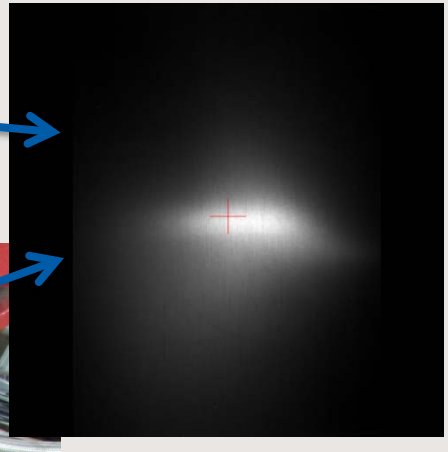
Sept. 22 – Oct. 1

- An amazing week of key milestones and late nights
  - Sept 22 – ICM and ACM cooled to 4K
  - Sept. 23 - ICM/ACM to 2K - ICM to 12MV/m CW
  - Sept. 24 - ACM to 10MV/m CW
  - Sept. 25 – 2nd LLRF system commissioned
  - Sept. 26 – two RF systems on-line
  - Sept. 29 – 20MeV acceleration
  - Oct. 1 – 23 MeV acceleration

Sept E-log Highlight: 10 MeV Injector

- **29-23:28: 10.6 MeV beam on MBD:VS2**
- **29-23:46: 10.6 MeV beam on MBT:VS6**

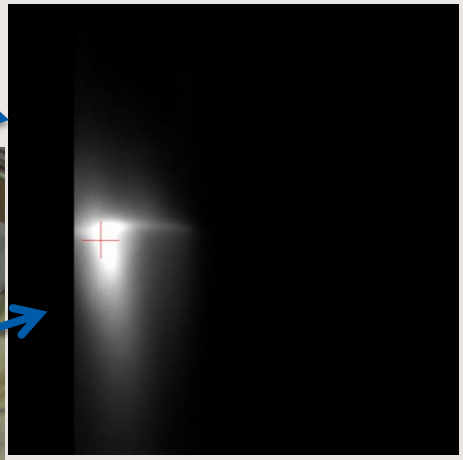


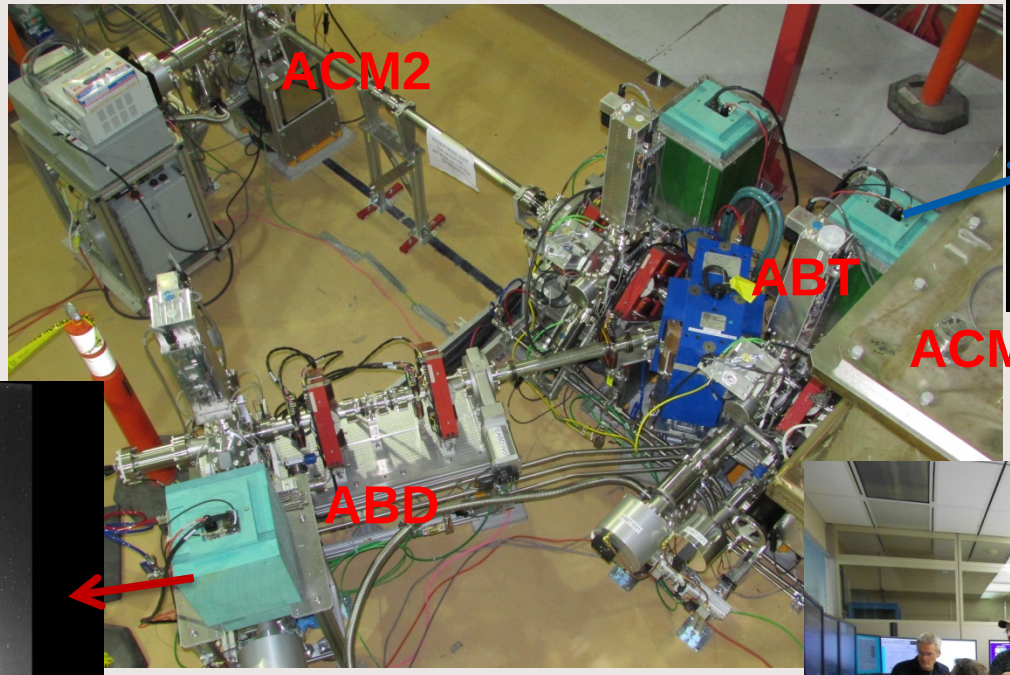


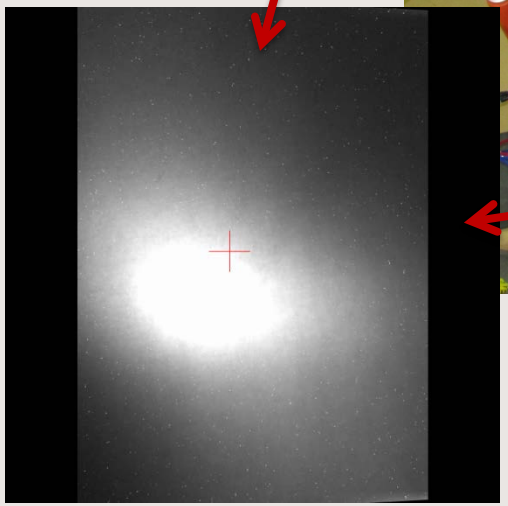
Sept E-log Highlight: 10 MeV Accelerator*

* Single cavity

- 30-00:06: 10.6 MeV on EABT:VS1
- 30-01:35: 20 MeV beam on EABD:VS2







October 1st:

22.9 MeV @ ABD

Overall Commissioning Timeline

July 19
5.5 MeV beam @ MBD

July 28
ICM moved to ISAC for cavity refurbishment

Sept 12
ACM @ 7 MV/m c.w. @ 2K

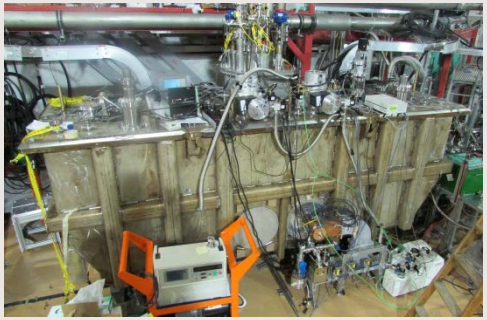
Sept 24
ACM @ 10 MV/m c.w.

May | June | July | August | September

May 01
ICM in e-hall

June 26
ICM @ 5.5 MV/m
Limited by field emission

August 29
ACMUno in e-hall on beamline



Sept 16
ICM in e-hall on beamline

Sept 23
ICM @ 12 MV/m c.w.
Limited by coupler

Sept 30
20 MeV beam @ ABD

All Done!

E-linac Cryogenic System Summary

- Project accomplished both on budget and on schedule
- E-linac cryogenic system capable to support 1.3 GHz superconducting linac operation at 2K
- Air Liquid cryoplant of ~800W provides LHe at 4.5K
- 2K is achieved by onboard 4K/2K conversion and sub-atmospheric pumping (31.2 mTorr)
- Main challenge for 24/7 beam production is potential impurities due to leaks into S/A part of the system; solution:
  - Hermetically sealed S/A pumps with canned motors
  - Online purity multipoint monitoring
  - Full S/A He gas flow (up to 15 g/s) rated purifier
  - Enhanced gas management and oil removal systems of the ALAT cryoplant

On a Larger Scale

- Mission ~~Impossible~~ accomplished:
  - All CFI-funded equipment installed
  - Injector & Accelerator cavities establish ≥10MV/m
  - 23 MeV Electron beam - 25 MeV in reach
- Future Activities
  - Complete tuning dump installation
  - Send e-beam to HDT/D
  - Raise beam power to 10 kW c.w., 100kW pulsed
  - ACM duo, raise energy to 30 MeV
  - Tunnel beamline build out FY15/16

People who made it happening:

TRIUMF

Canada's national laboratory for particle and nuclear physics
Laboratoire national canadien pour la recherche en physique nucléaire
et en physique des particules

Thank you!

Merci!

TRIUMF: Alberta | British Columbia | Calgary | Carleton | Guelph | Manitoba | McMaster | Montréal | Northern British Columbia | Queen's | Regina | Saint Mary's Simon Fraser | Toronto | Victoria | York

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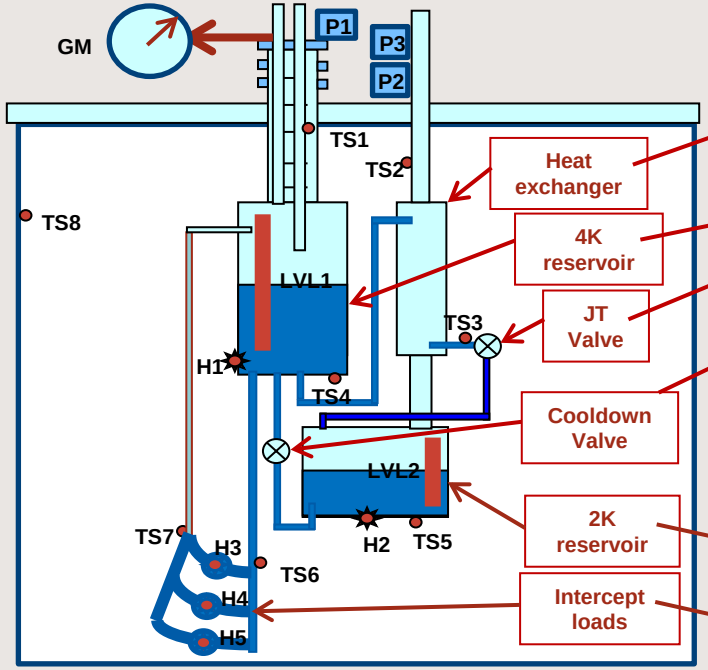
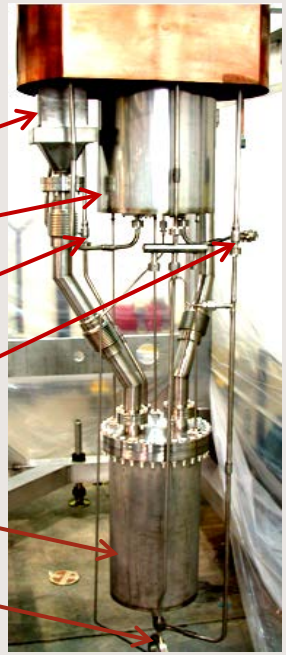
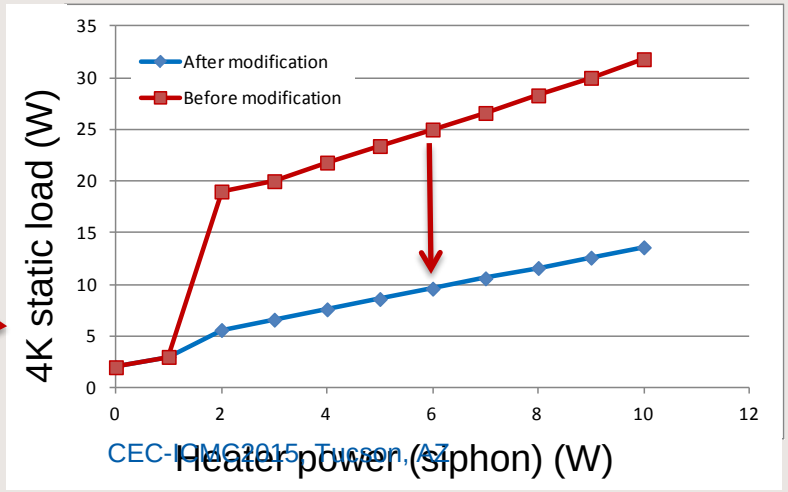
4K/2K Cryogenics unit test configuration

- Test 1
  - Measured static load of 4K (2W) and 2K (0.5W) reservoirs
  - Measured efficiency of 2K conversion of 66% at 0.5 g/s mass flow
  - Measured 4K siphon circuit efficiency – extra heat load caused by convection in 4K reservoir ~15-20W
- Test 2 – after modifying siphon circuit
  - siphon loop now well behaved with static load of 1.6W





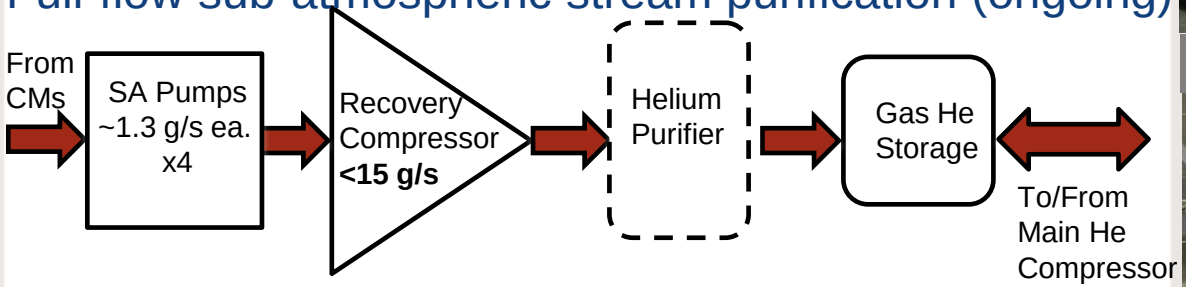
Add siphon exhaust guide tube and teflon funnel in 4K reservoir - reduces convective load



Cleanliness Next to Godliness

- Reliable operation of Cryosystem depends on low level of impurities in process gas (He). Typically ~1-3ppm.
- Sub-atmospheric line is the main source of impurities

Full-flow sub-atmospheric stream purification (ongoing)



Permanent Solution

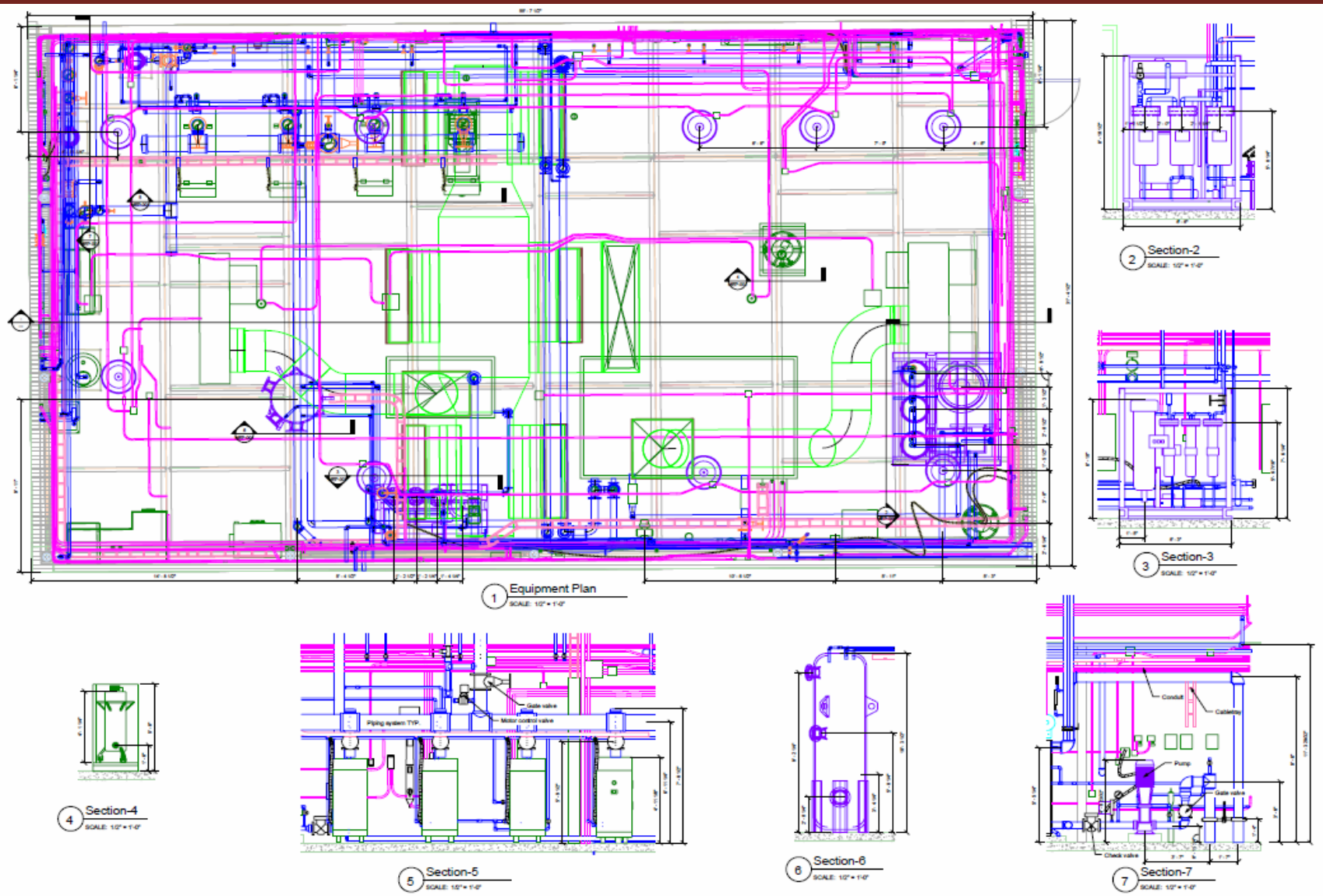
- **Purifier is on track:** equipment installed, He piping, and LN2 lines are connected.
- Commissioning is scheduled for mid-October upon controls completion

SA Pumps

Multicomponent Detector

Main And Recovery Compressors

Some Creative catching-up



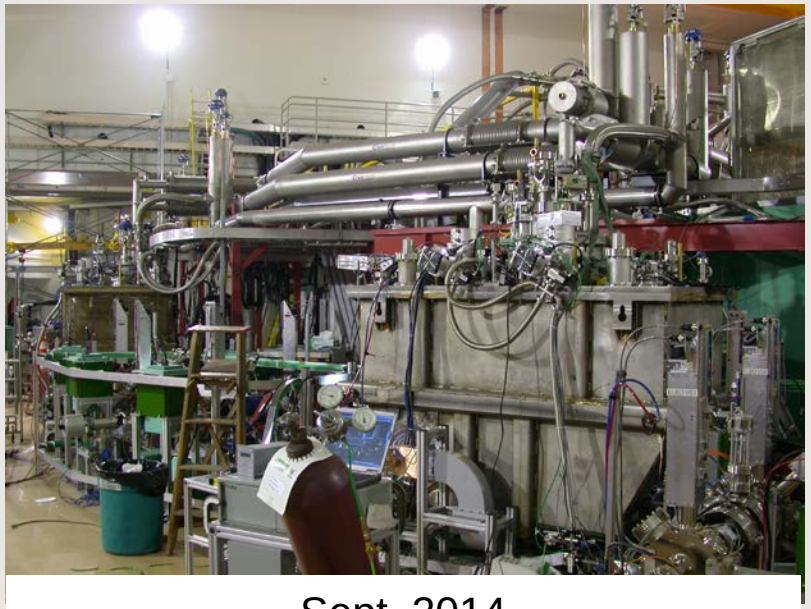
July 01, 2015

Plan and Sections Sample Drawing

Progress in SRF Systems

- Progress in the past 2 years
  - Cryogenics acceptance tests complete
  - Two klystrons and HV supplies installed and commissioned
  - ICM and ACM assembled, installed and commissioned
  - First beam acceleration demonstrated

January 2014



Sept. 2014

SRF Summary

- ✓ The ICM1 and ACMuno cold tests have demonstrated that the cryo-engineering is robust and matches specifications
- ✓ ICM1 and ACMuno cavities meet specifications
- Plan to operate each cavity at 13MV/m for 25MeV beam tests through to the end of 2015