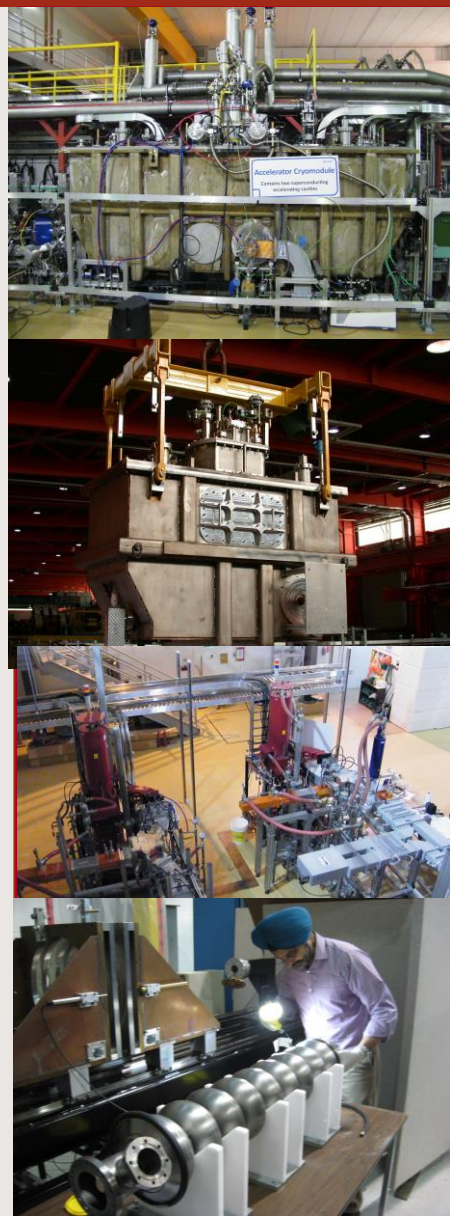
TRIUMF

COMMISSIONING OF THE SRF LINAC FOR ARIEL

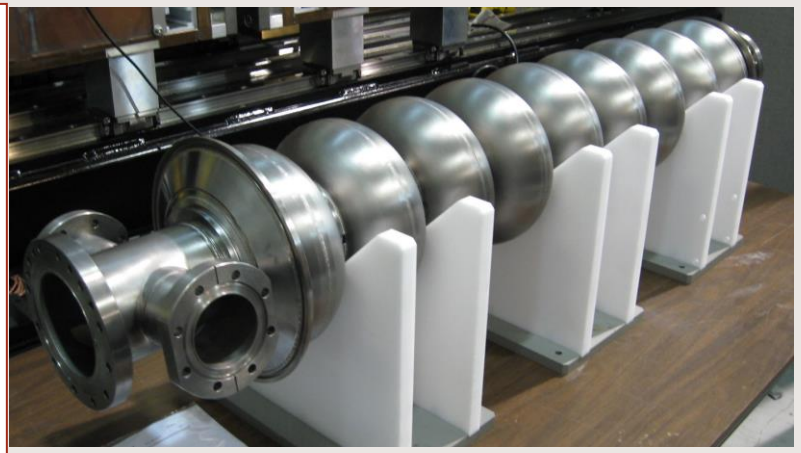
V. Zvyagintsev, Z. Ang, T. Au, S. Calic, K. Fong, P. Harmer, B. Jakovljevic, J. Keir, D. Kishi, P. Kolb, S.R. Koscielniak, A. Koveshnikov, C. Laforge, D. Lang, R.E. Laxdal, M. Laverty, Y. Ma, A.K. Mitra, N. Muller, R. Nagimov, W.R. Rawnsley, R.W. Shanks, R.L. Smith, B. Waraich, L. Yang, Z. Yao, Q. Zheng

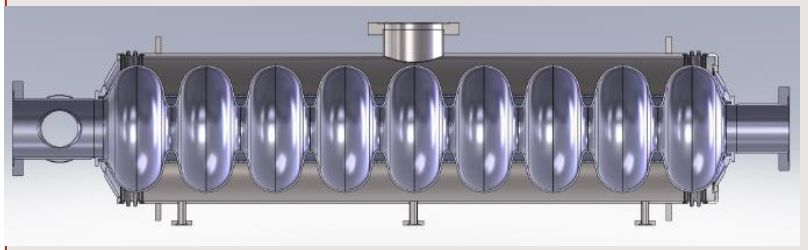
TRIUMF Canada's National Laboratory for Particle and Nuclear Physics,
Vancouver, BC V6T 2A3, Canada

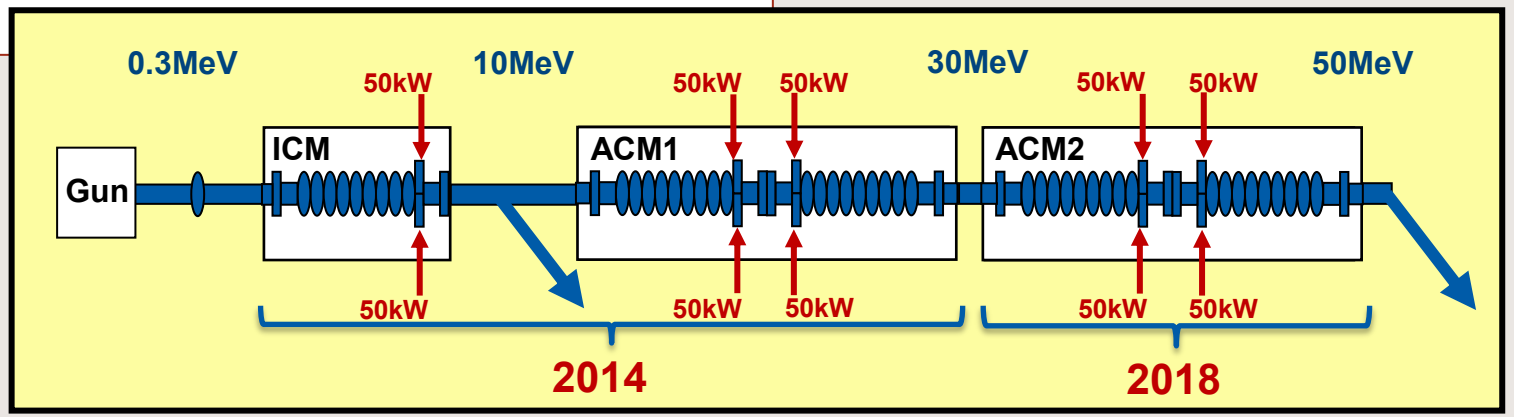


E-Linac SRF Specifications

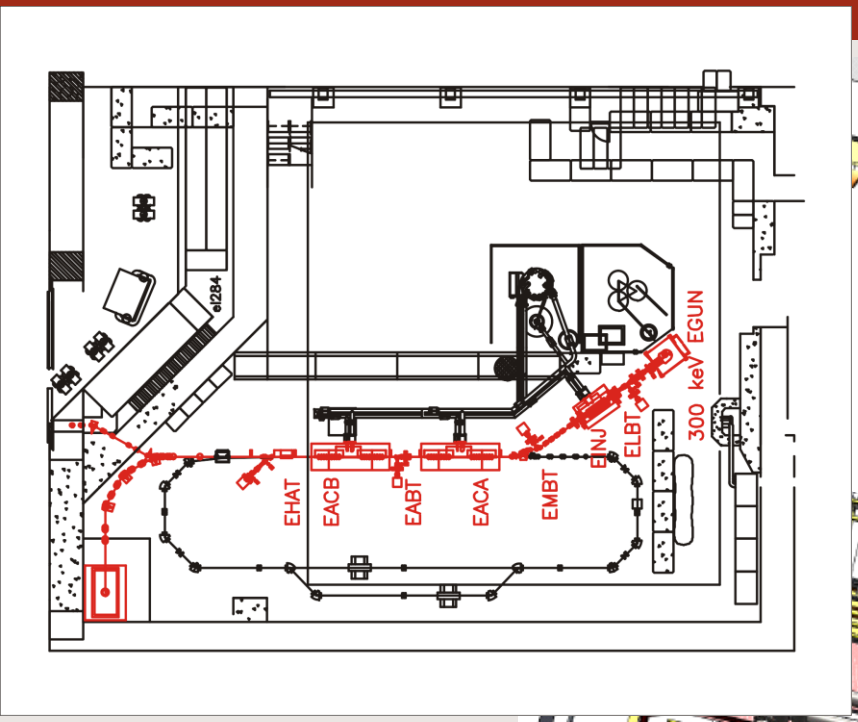
- The ARIEL E-Linac SRF specification – dominated by RF beam loading
  - 10mA at 50MeV - 0.5 MW CW
  - CPI 75kW VWP 3032 coupler to deliver 50kW CW -> 10 couplers
  - 2x 50kW couplers per cavity -> 5 cavities
  - 10MeV energy gain per cavity
  - 10W at 2K -> Qo=1e10
  - Reduce trapped HOMs
  - Large (90mm) single chimney sufficient for CW operation up to 50W
  - One cavity in ICM and 2 in ACM

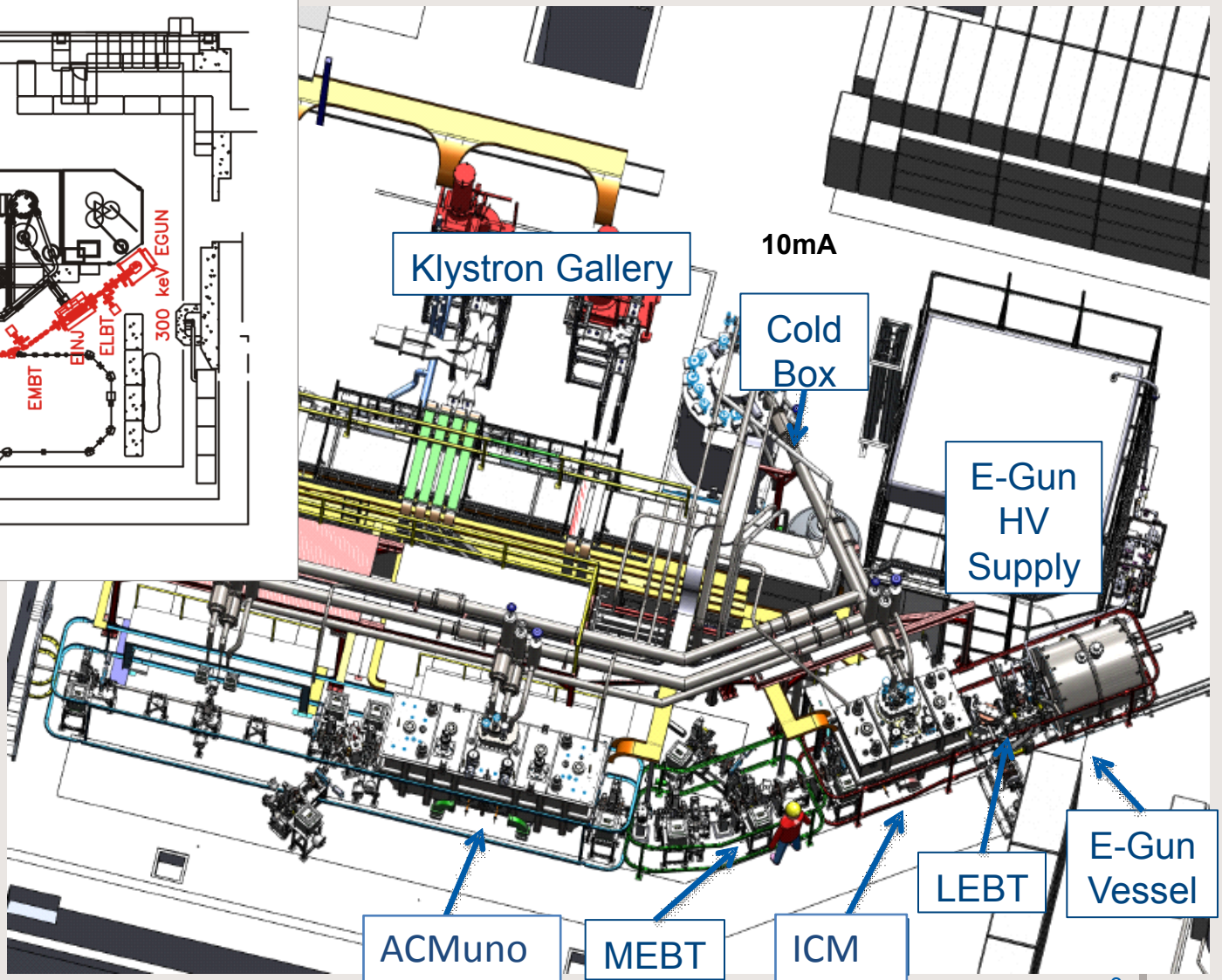




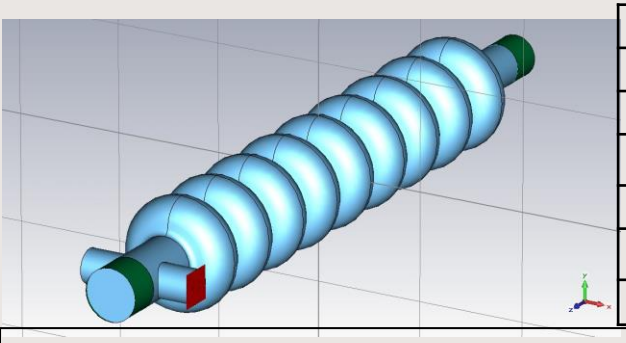


E-Linac Accelerator Vault – Phase I



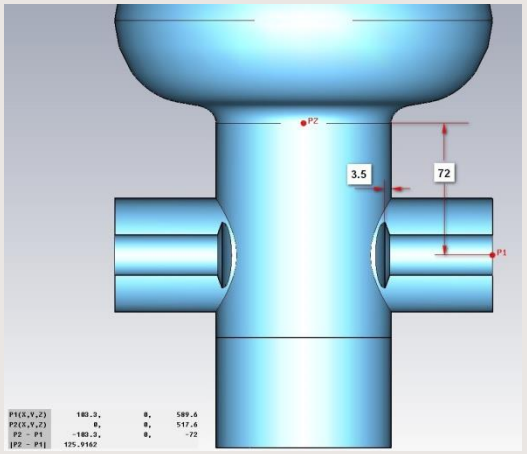


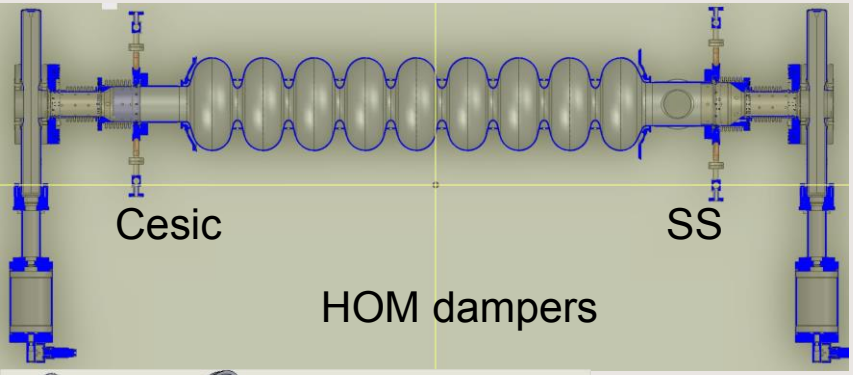
Cavity Design

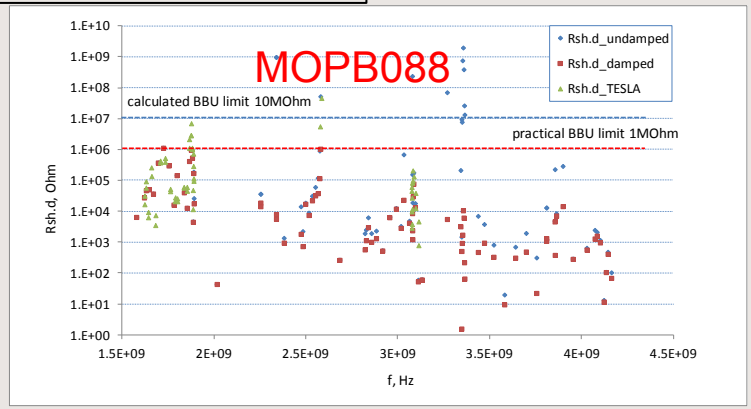


	TRIUMF	DESY	TRIUMF/DESY
Frequency [MHz]	1300	1300	-
R_{sh}/Q [Ohm]	1000	1030	3% less
Geometric factor G [Ohm]	290	270	7% more
E_p/E_a	2.1	2.0	5% more
B_p/E_a [mT/(MV/m)]	4.4	4.2	5% more
Cell coupling [%]	2.0	1.9	

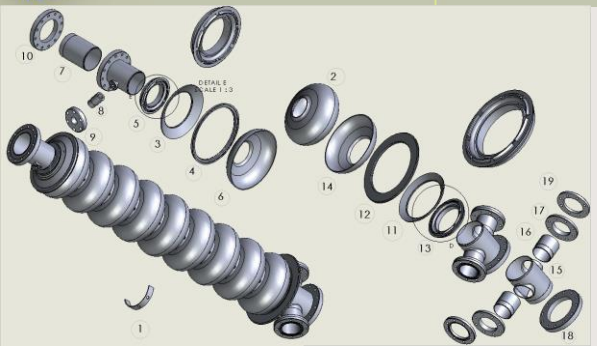
TRIUMF e-LINAC cavity is similar to 1.3GHz 9 cell DESY TESLA cavity. 2 symmetrically opposed 75kW CPI couplers



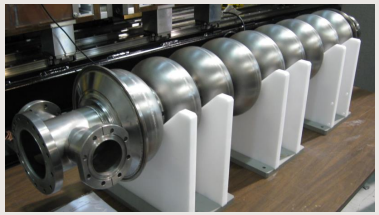




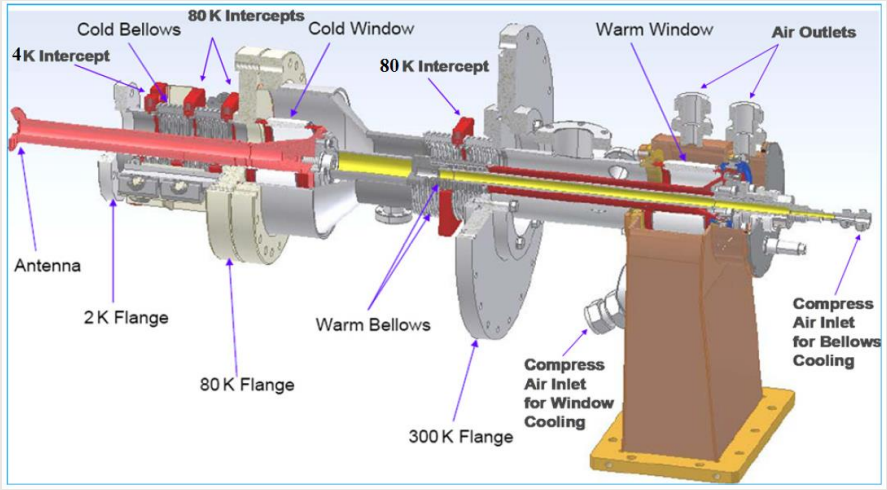
P. Kolb, et al., "HOM Measurements on the ARIEL eLINAC Cryomodules", MOPB088, SRF2015



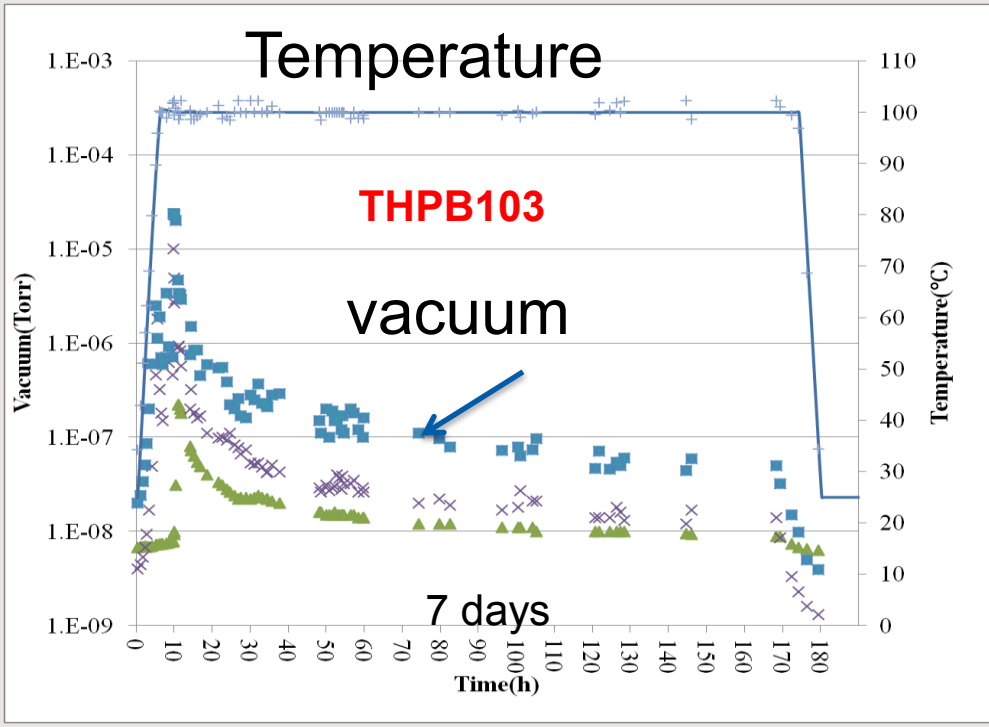
4 9-cell cavities fabricated at PAVAC



RF Power Couplers



The CPI VWP 3032 75kW CW Coupler

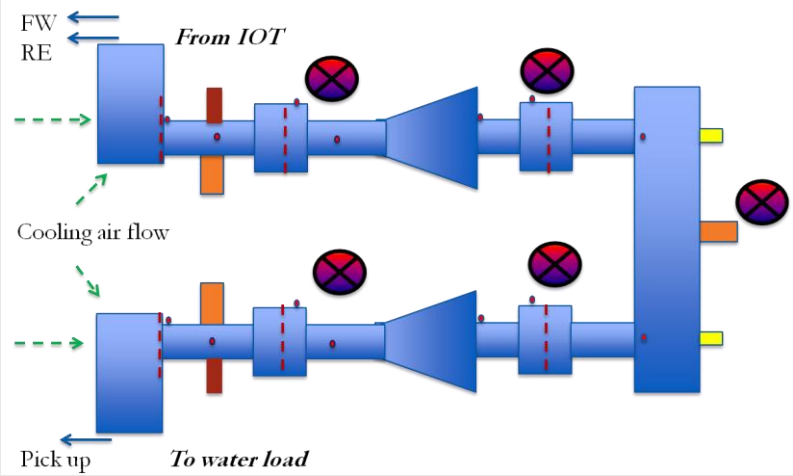


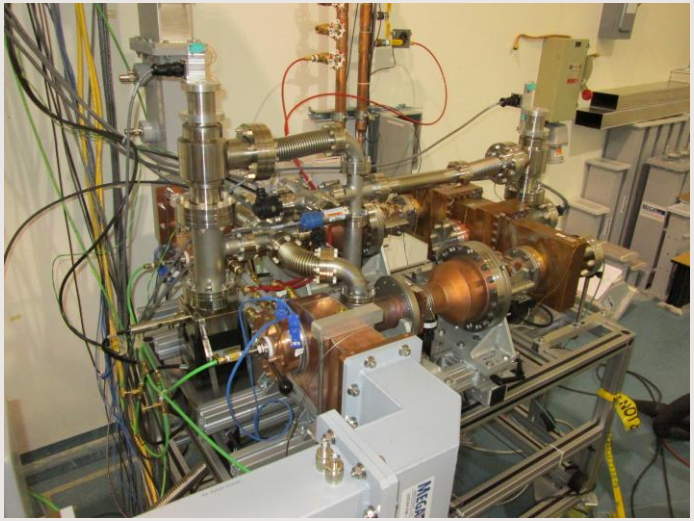
Handling
Assembly in clean room
Keep sealed with filtered N2 gas

Baking
- 100C 7days
- 10C/hour
- N2 filtered gas flow to 'warm' assembly

Y.Ma, et al., "High Power Coupler Test for Ariel SC Cavities", THPB103, SRF2015

RF Power Coupler



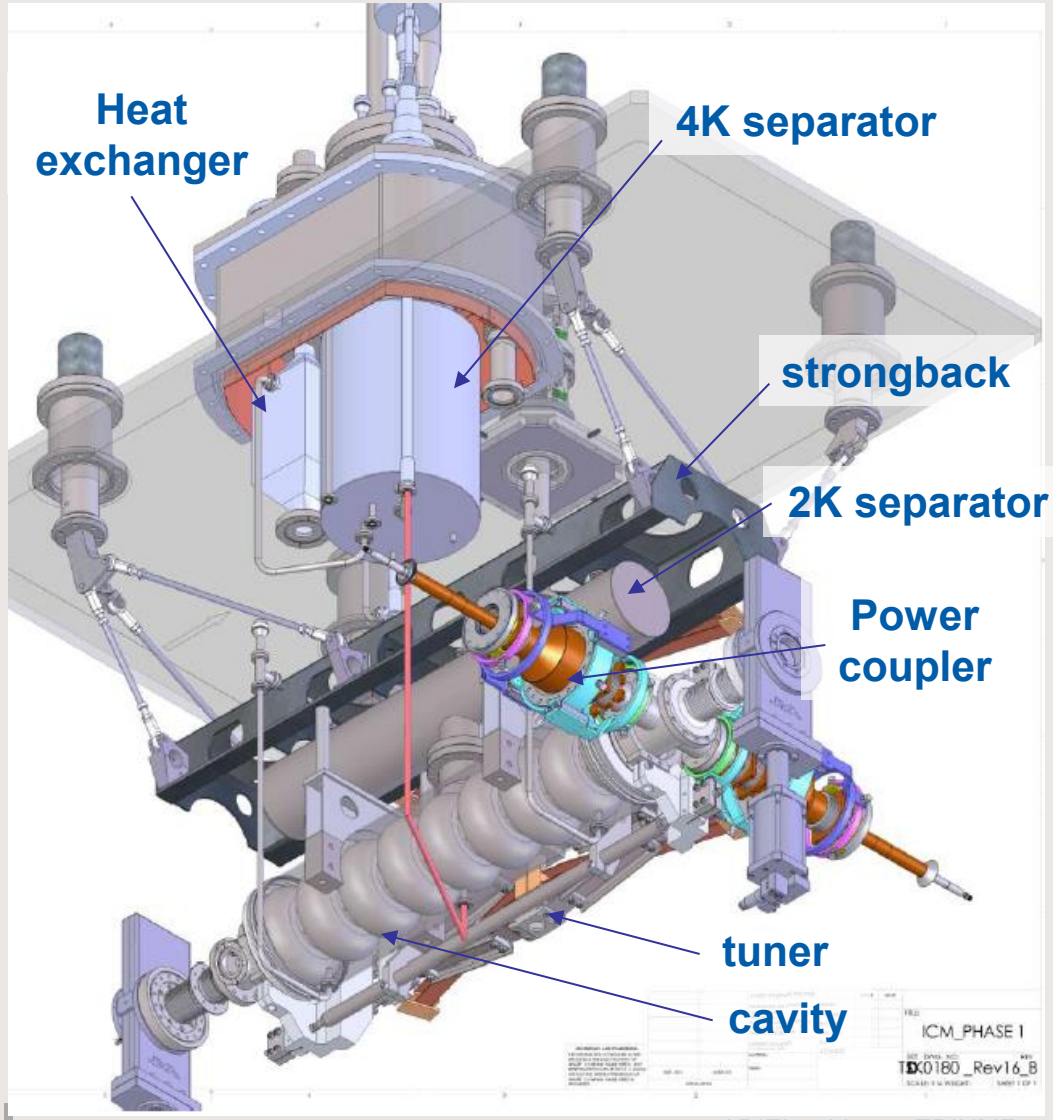


Power Coupler Test Station at TRIUMF

RF Conditioning
- TW CW up to 19.5kW - takes 3-5 days
- SW Pulse mode
  - Variable short plate in 3 positions (to move SW along the couplers)
  - Pulse with duty factor 1% 10 Hz power up to 10kW – (equivalent 40kW in TW)– 3 days

4 power couplers have been installed to the cavities in ARIEL ICM and ACM cryomodules for. beam commissioning at TRIUMF

Injector Cryomodule



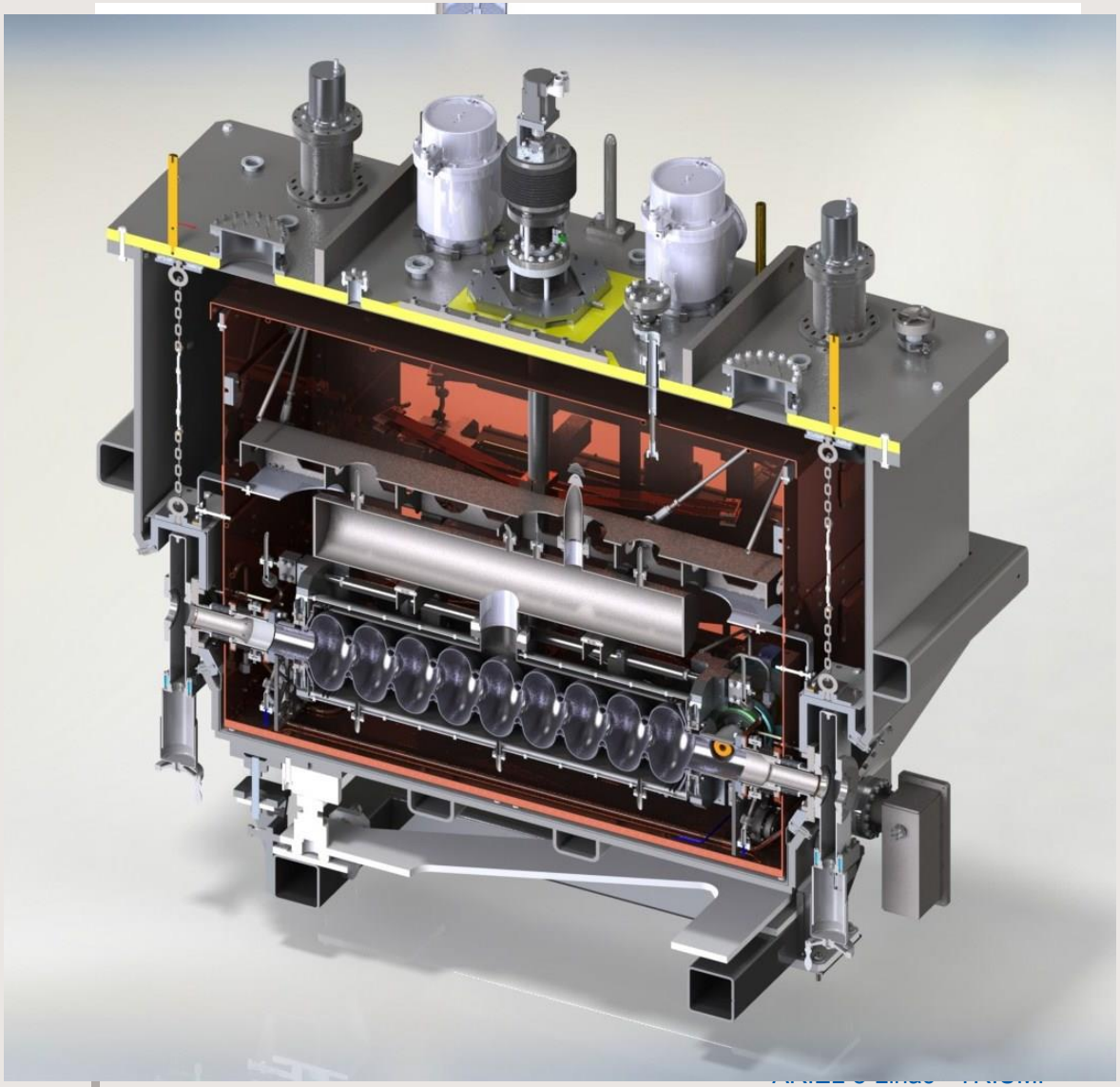
Houses

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

Features

- 4K/2K heat exchanger with JT valve on board
- Scissor tuner with warm motor
- LN2 thermal shield – 4K thermal intercepts via syphon
- Two layers of mu-metal
- WPM alignment system

Injector Cryomodule



Houses

- one nine-cell 1.3GHz cavity
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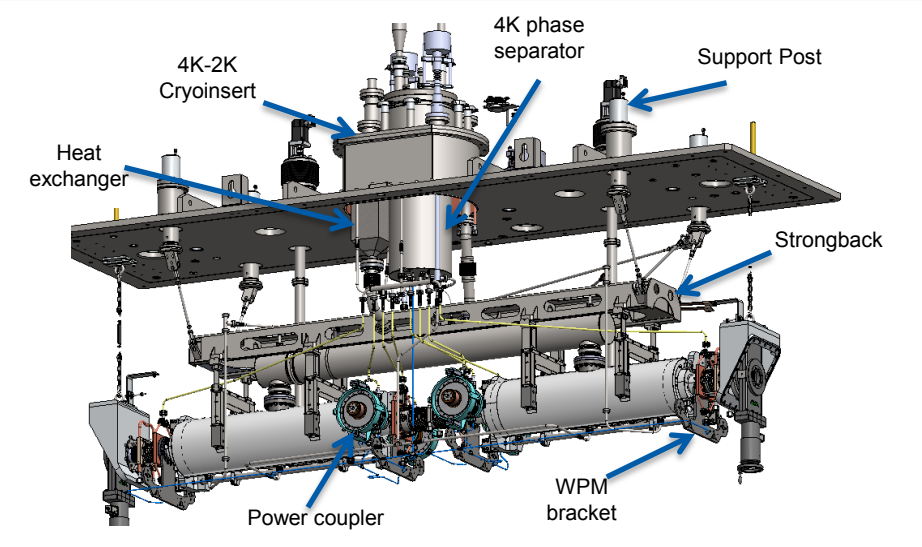
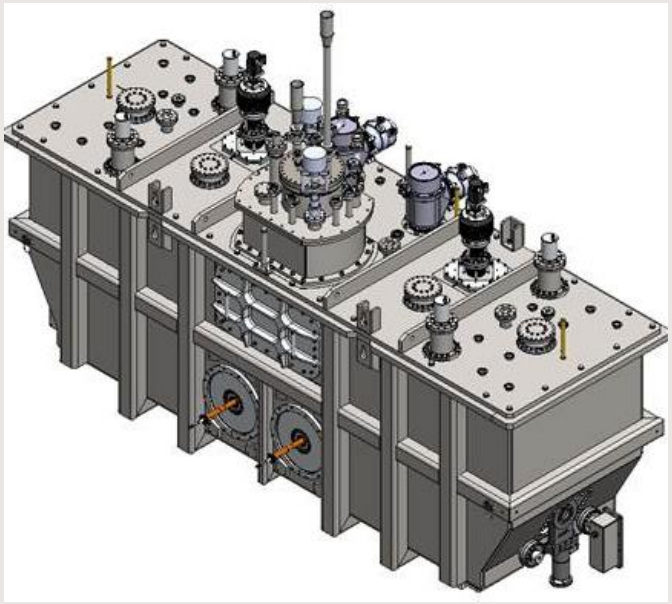
Features

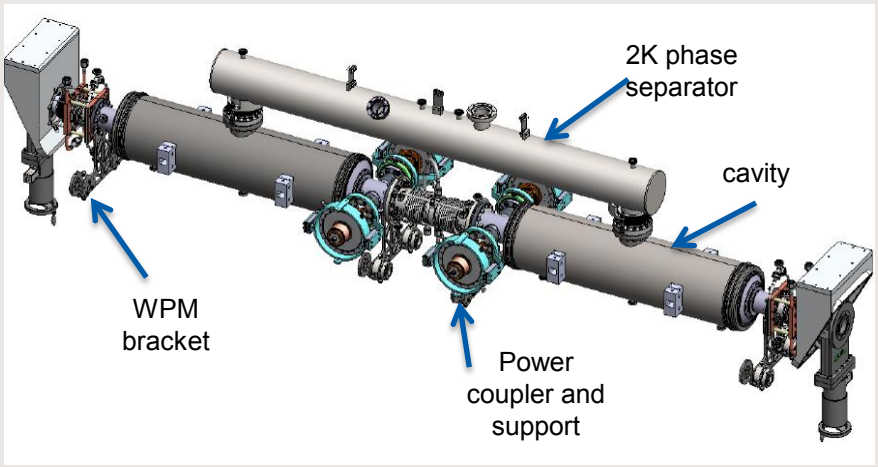
- 4K/2K heat exchanger with JT valve on board
- Scissor tuner with warm motor
- LN2 thermal shield – 4K thermal intercepts via syphon
- Two layers of mu-metal
- WPM alignment system

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

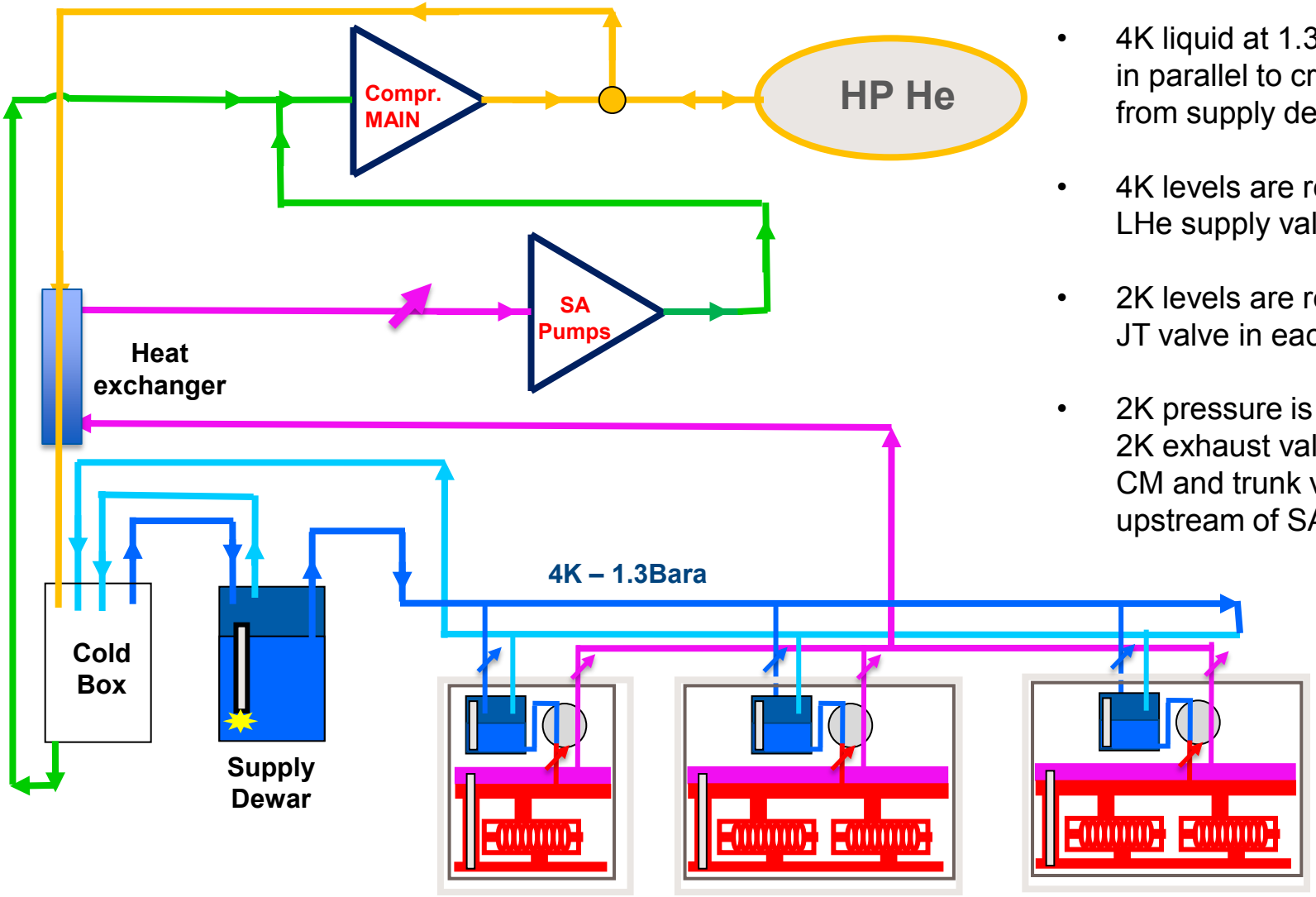






THPB115

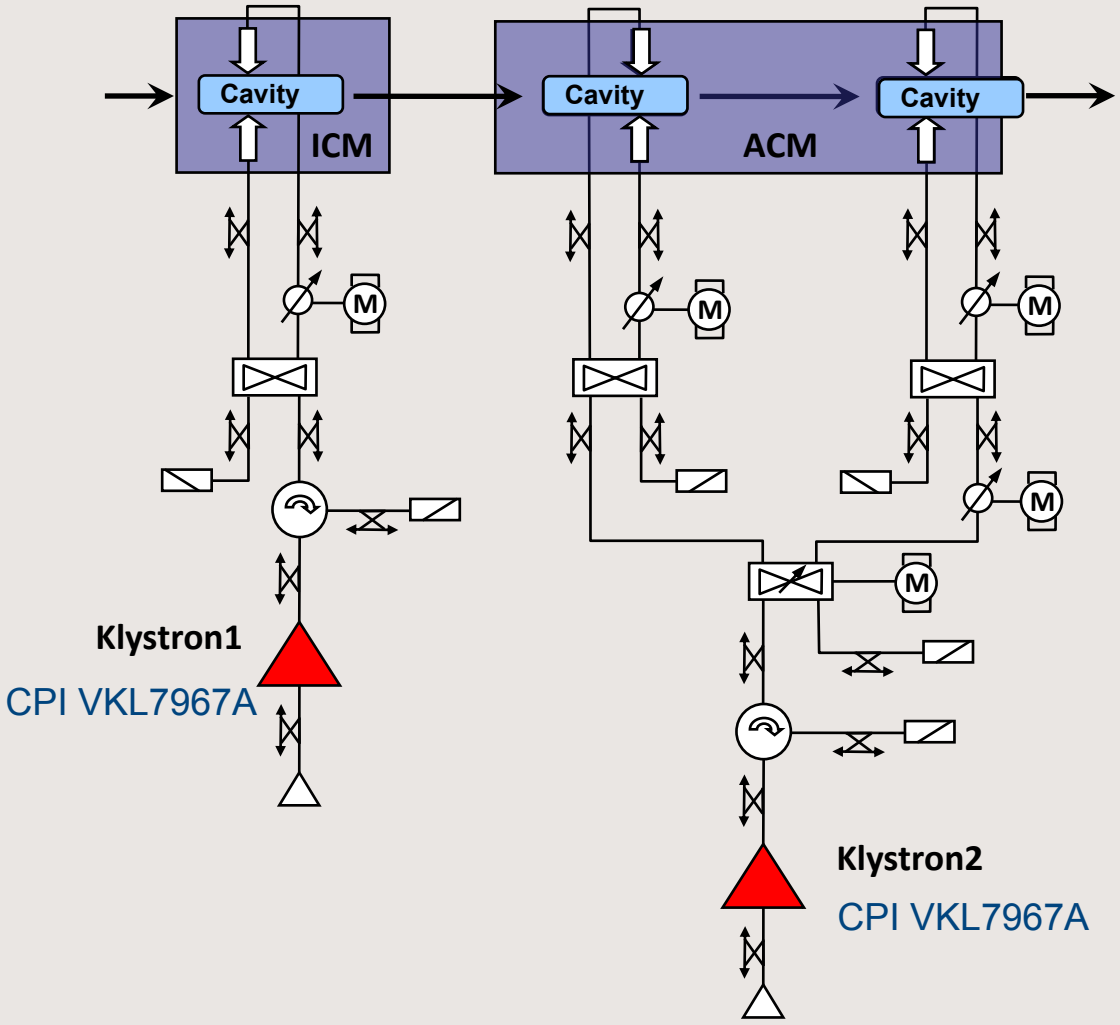
Cryogenics



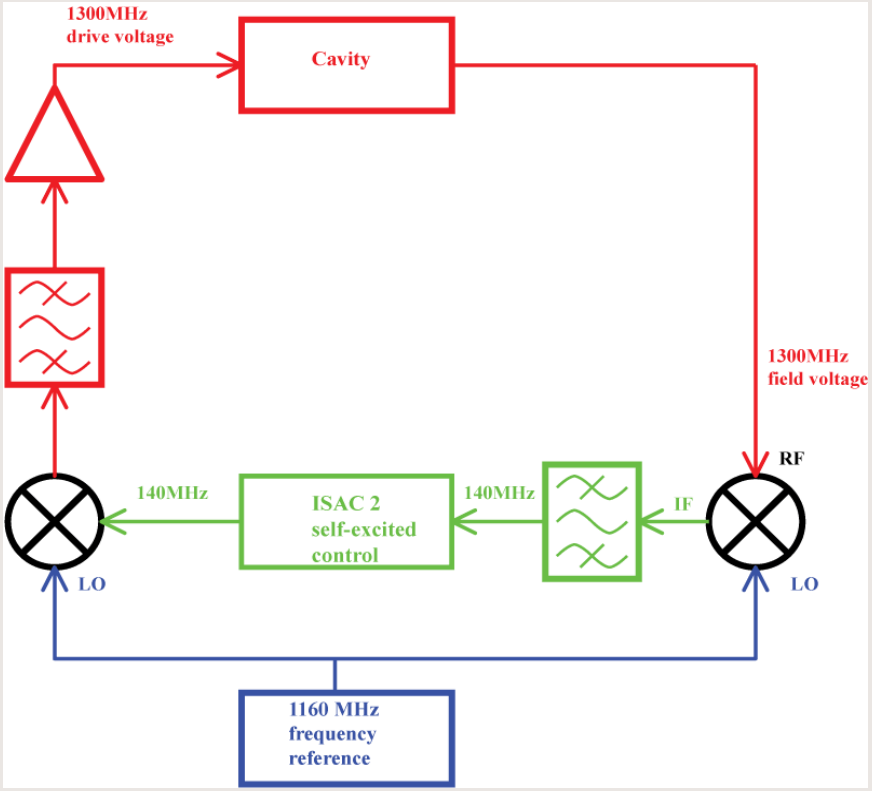
- 4K liquid at 1.3 Bar delivered in parallel to cryomodules from supply dewar
- 4K levels are regulated by LHe supply valve
- 2K levels are regulated by JT valve in each CM
- 2K pressure is regulated by 2K exhaust valve on each CM and trunk valve upstream of SA pumps

RF System Phase-I

- For Phase I we specify two 290 kW CW CPI VKL7967A klystrons with 65 kV, 10 A DC AMPEGON power supply (KPS)
- In the future, for Phase II one of these klystrons will drive next cryomodule
- We are looking for a cost effective 1.3GHz power source at ~150kW for the ICM



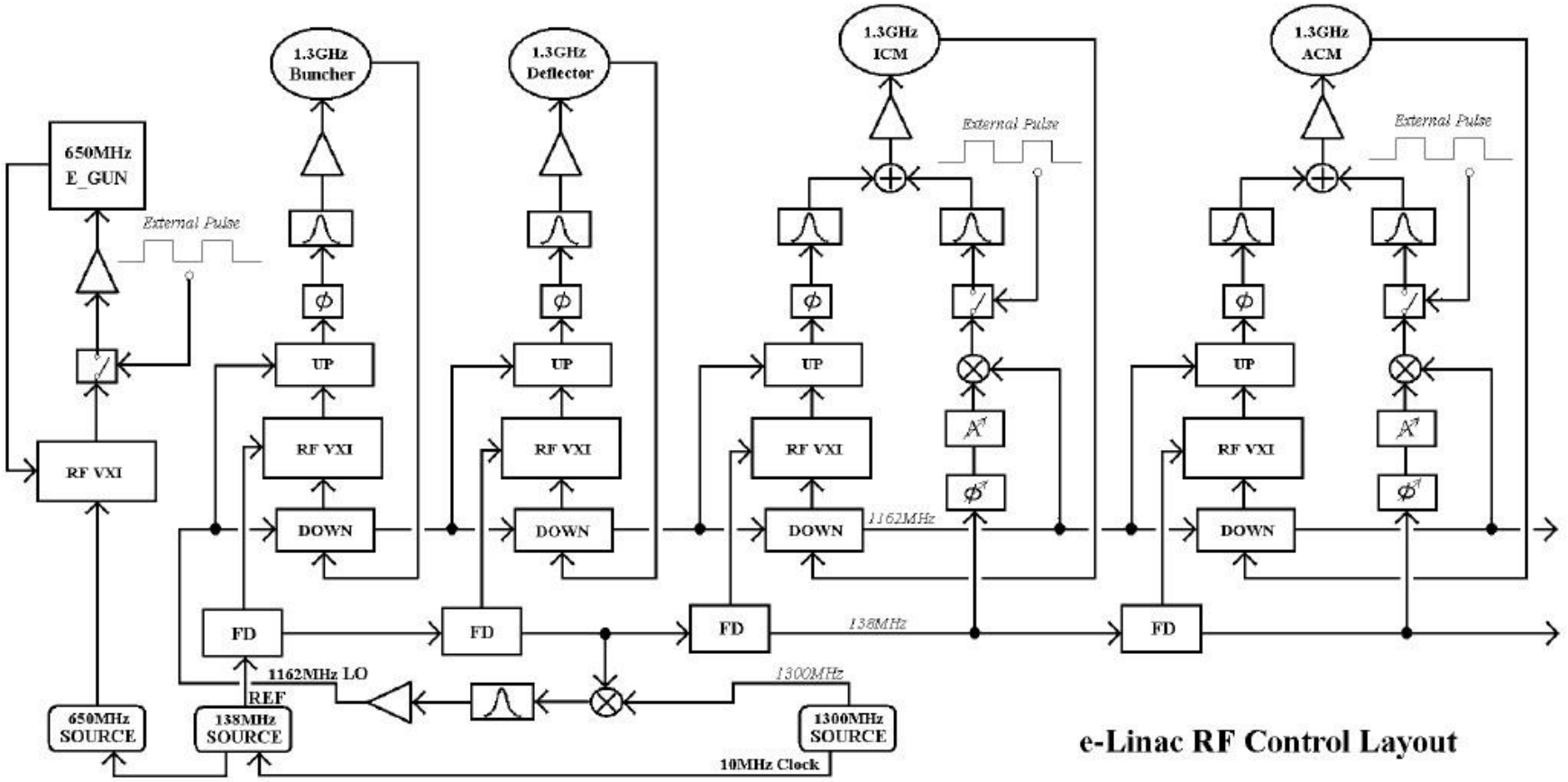
LLRF: Self-excited mode



The heterodyne technique of up and down converter is chosen to manipulate the 1.3GHz frequency and the intermediate frequency (IF) of 138MHz for RF signal processing.

Q. Zheng, et al., "LLRF System for TRIUMF 1.3GHz SRF E-Linac", LLRF Workshop 2013

E-LINAC LLRF System

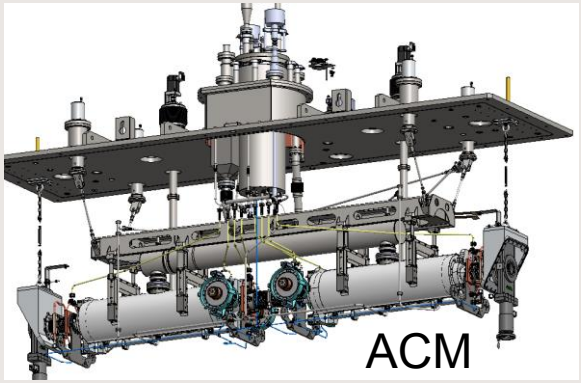


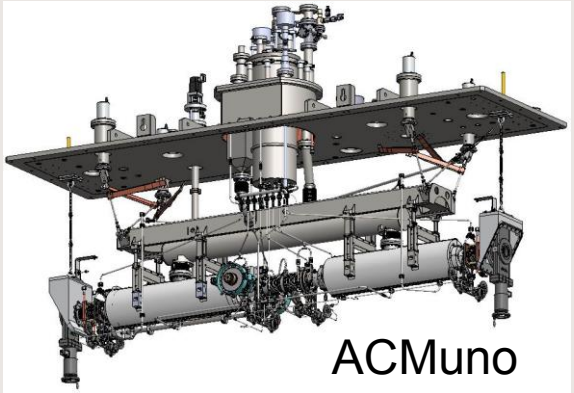
- 650MHz e-Gun
- two 1.3GHz NC
- ICM 1.3GHz SC
- ACM 1.3GHz SC

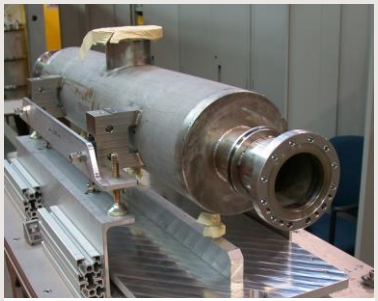
Feedforward system for high current beam acceleration is under development.

Cryomodule strategy

- Jacket and install ARIEL1 cavity in ICM
- Jacket and install ARIEL2 cavity in ACM together with a dummy cavity
- 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
- Installed the cryomodules for a combined beam test in Sept. 2014 – cryogenic engineering and funding milestone


ACM


ACMuno

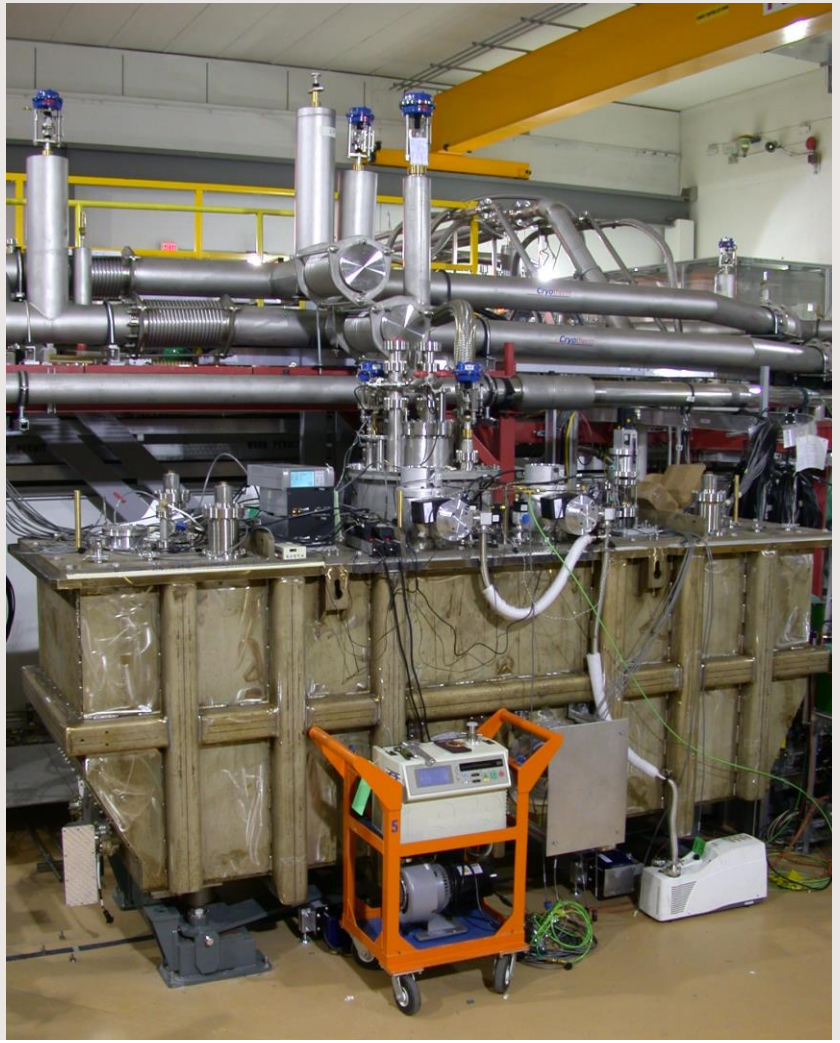

Dummy cavity

ICM and ACMuno Assembly

ICM top assembly

ACMuno assembly

Assembly of both CMs proceeds through summer of 2014

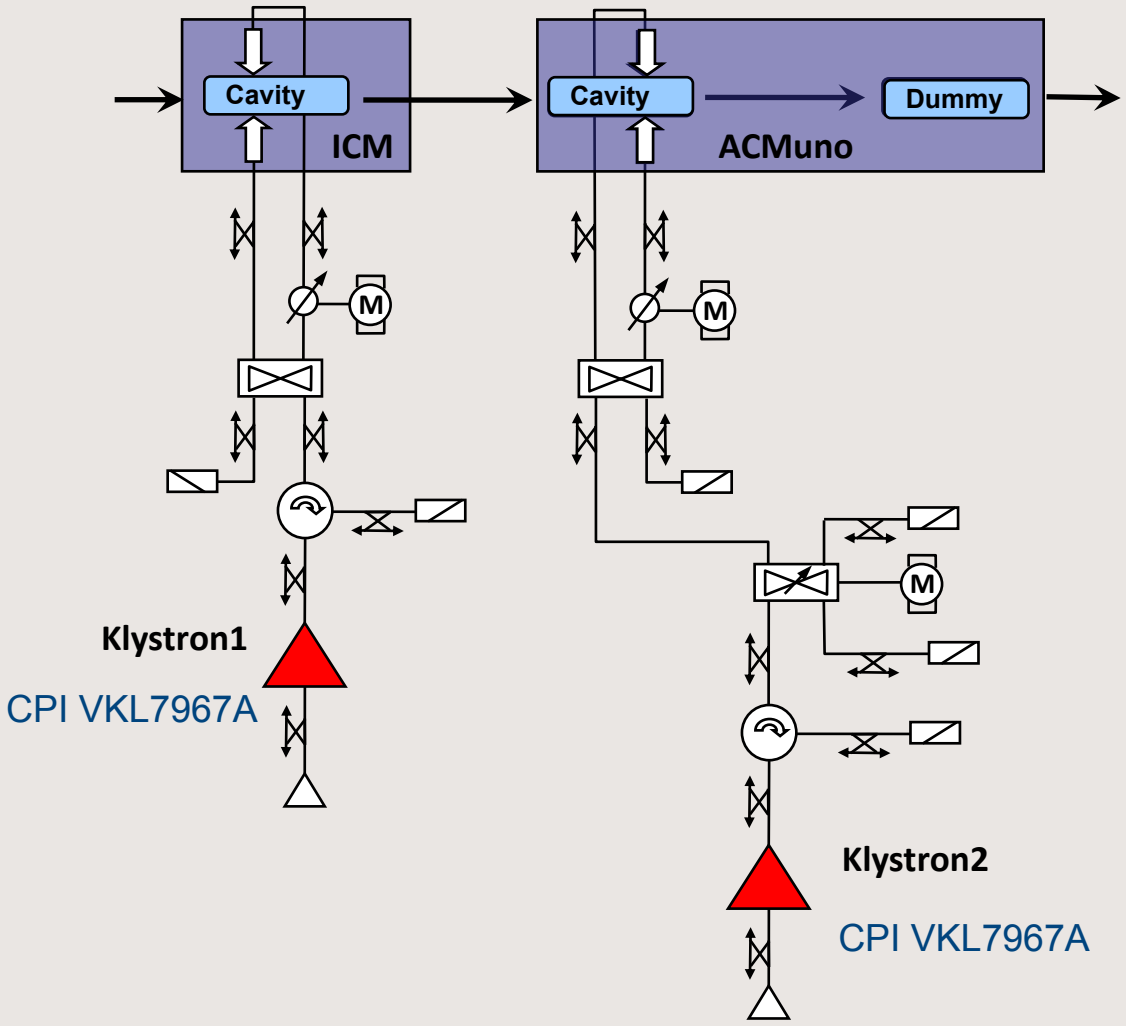


ACMuno – ready for cooldown Sept. 1

RF System Phase-I for Commissioning

RF System modification

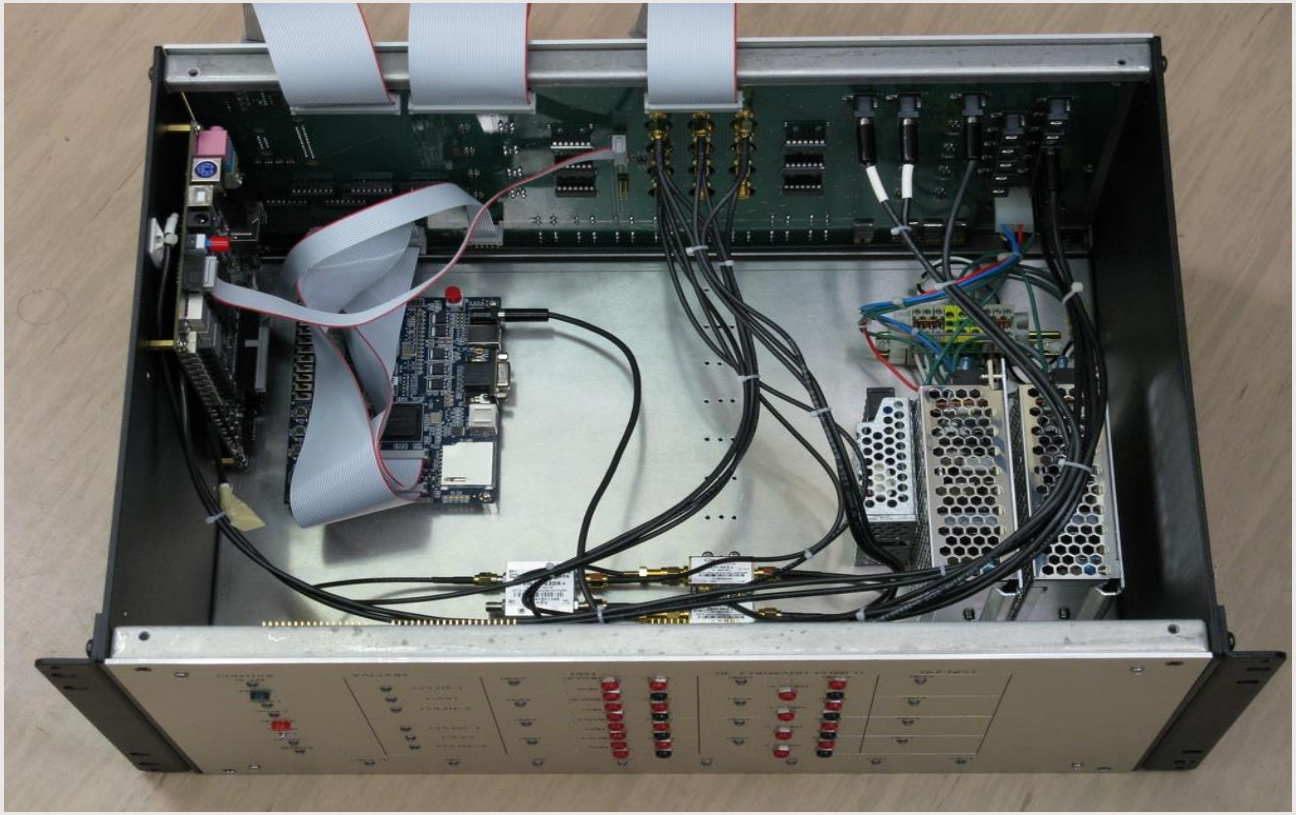
- 'Dummy' waveguide branch of variable power divider has been terminated with RF load
- The variable power divider has been tuned for full transmission to the Cavity waveguide branch



High Power RF Installation

- Installed
  - Two CPI 290kW CW 1.3GHz klystrons
  - Two 600kW 65kV klystron power supplies from Ampegon
- Each klystron reaches specification at the factory
- At TRIUMF – tests were limited by available load or circulator – one was operated to 250kW CW the other to 150kW CW
- Delivered power into a cold cavity – 25kW pulsed and 18kW CW

Crymodule Protection System



TUPB103

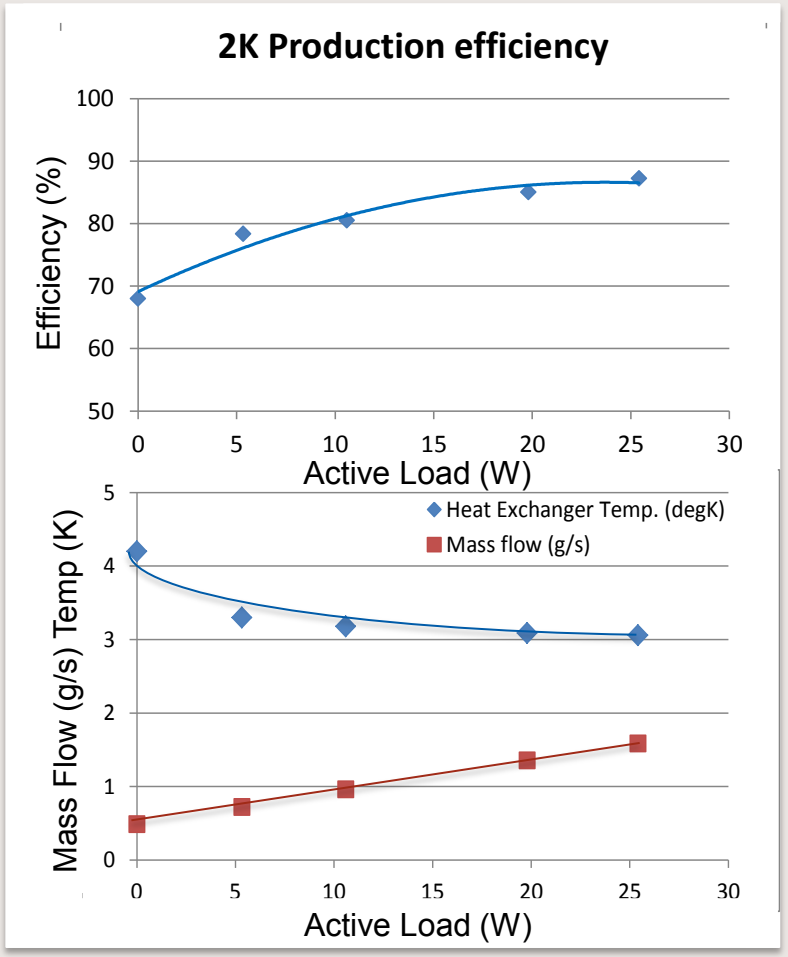
Cryomodule Protection System has been developed

Z.Y. Yao, et al., "Cryomodule Protection for ARIEL e-Linac", TUPB103, proc. SRF2015

ICM Cold test results

Parameter	Estimated	Measured
4K static load (no syphon), W	2	3
4K static load with syphon, W	6	6.5
2K static load, W	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



ACMuno First Cold test results

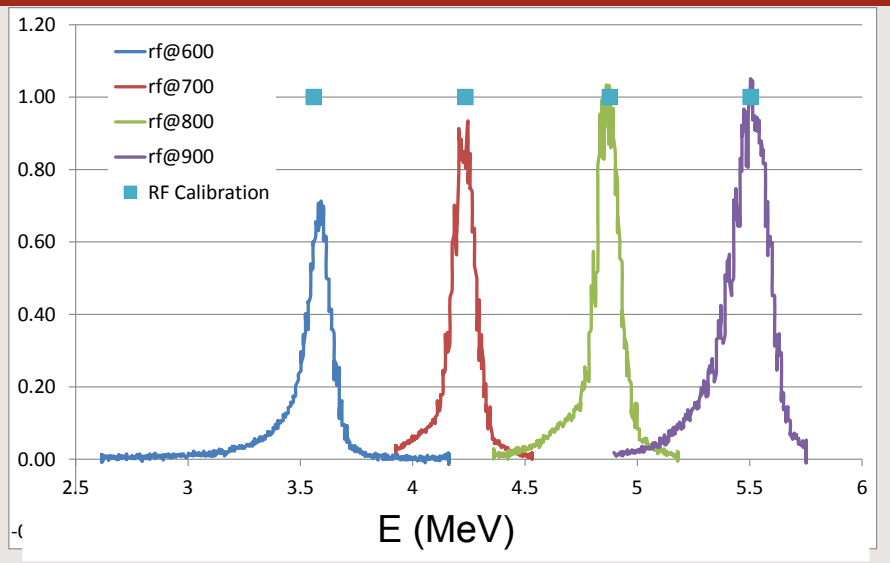
Parameter	Estimated	Measured
4K static load with syphon, W	7	6.4
2K static load, W	7	6.5
77K static load, W	100	TBD
2K production efficiency	82%	TBD

- ✓ 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

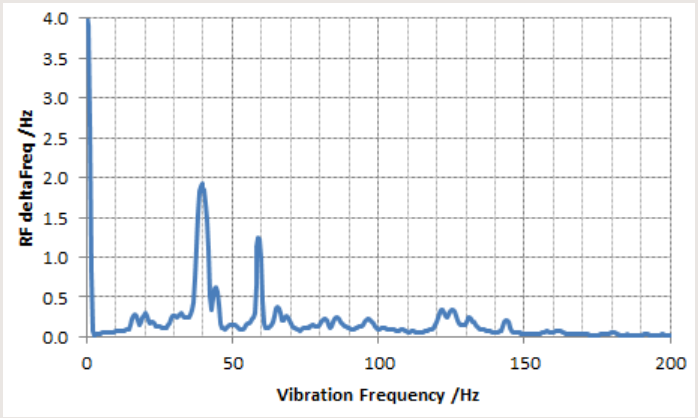
A. Koveshnikov, et al., "Integration and Commissioning of the ARIEL e-Linac Cryogenic System at TRIUMF", ICEC-ICMC2014

ICM System Performance & Acceleration

- All systems functional
  - HLRF, LLRF, tuner, power couplers
  - cavity phase lock is stable – couplers balance – rf protection in place
  - Confirmed tuning range – 400kHz
- Measured microphonics – very stable
- Successful acceleration achieved – confirms rf integration and calibration

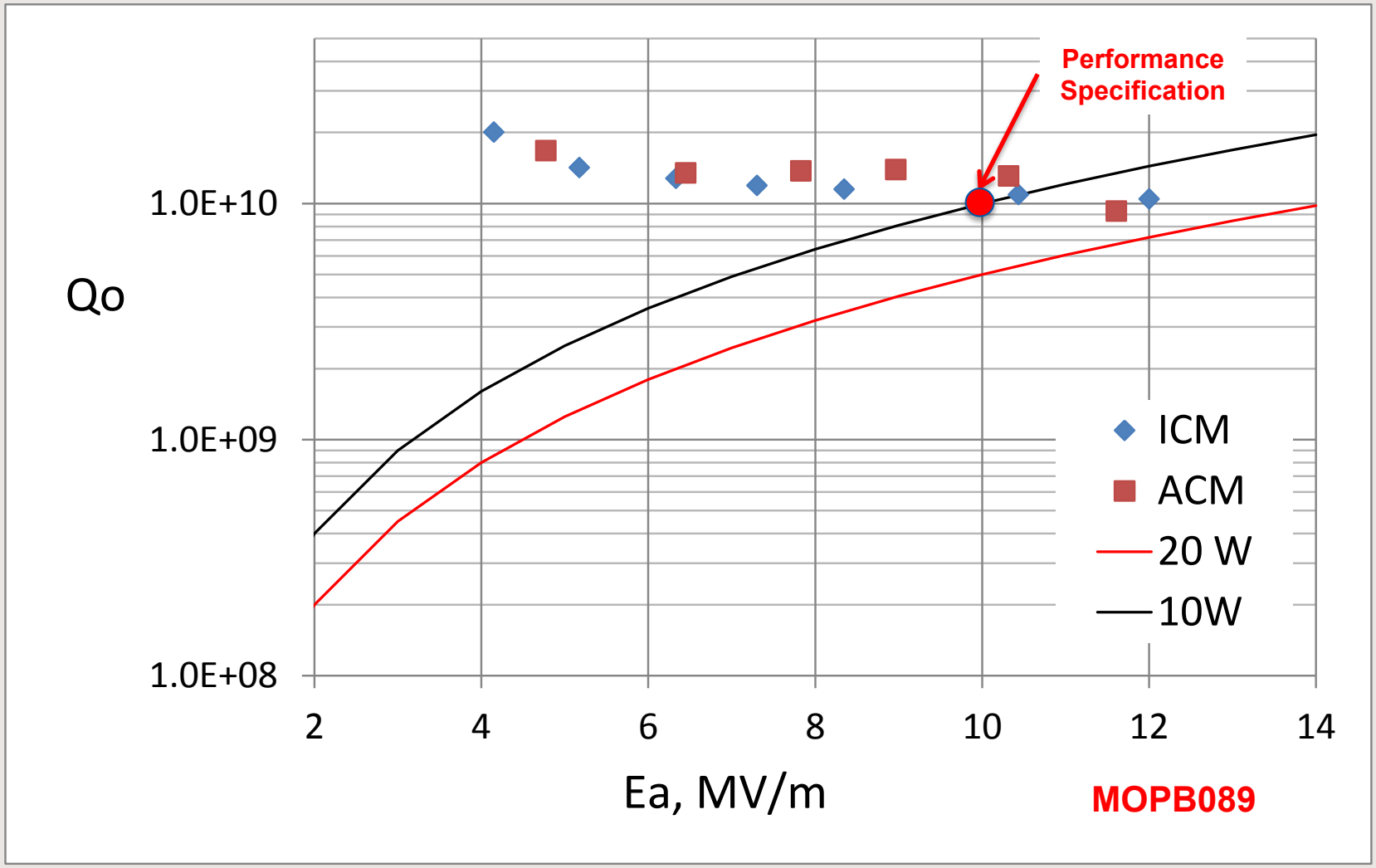


Microphonics detuning spectra



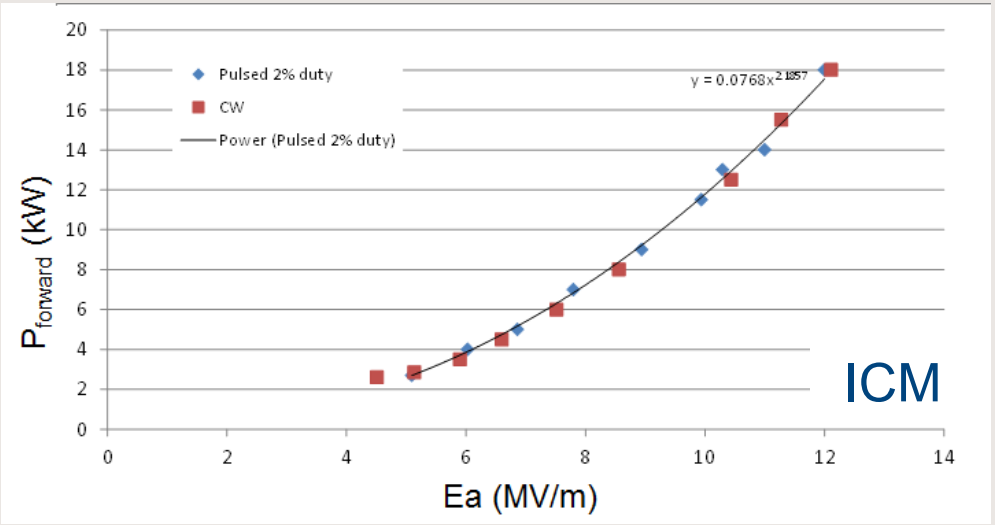
R.E. Laxdal, et al., "The Injector Cryomodule for the ARIEL e-Lianc at TRIUMF", MOPB091, LINAC12.

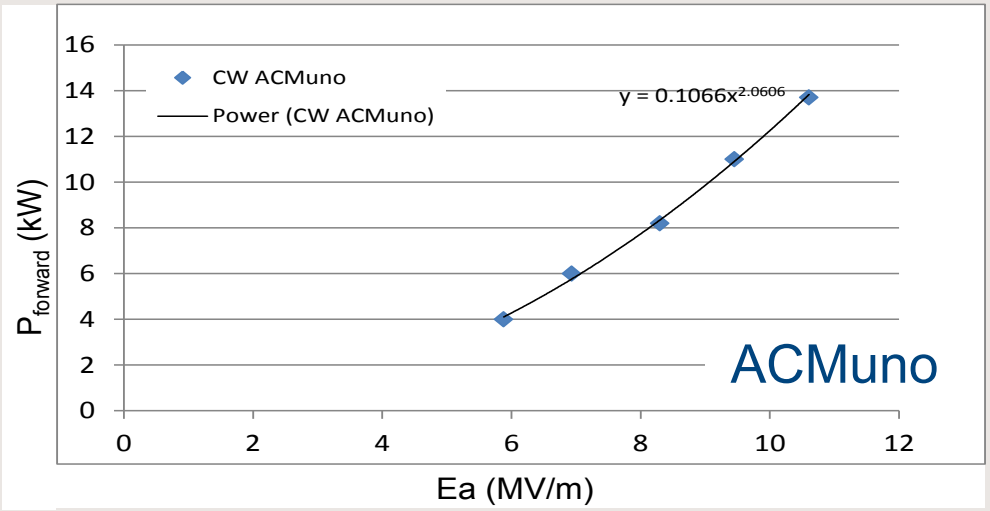
ICM and ACMuno Measured Q-values



P. Kolb, et al., "1.3 GHz Cavity Test Program for ARIEL", MOPB089, SRF2015

ICM and ACMuno gradient



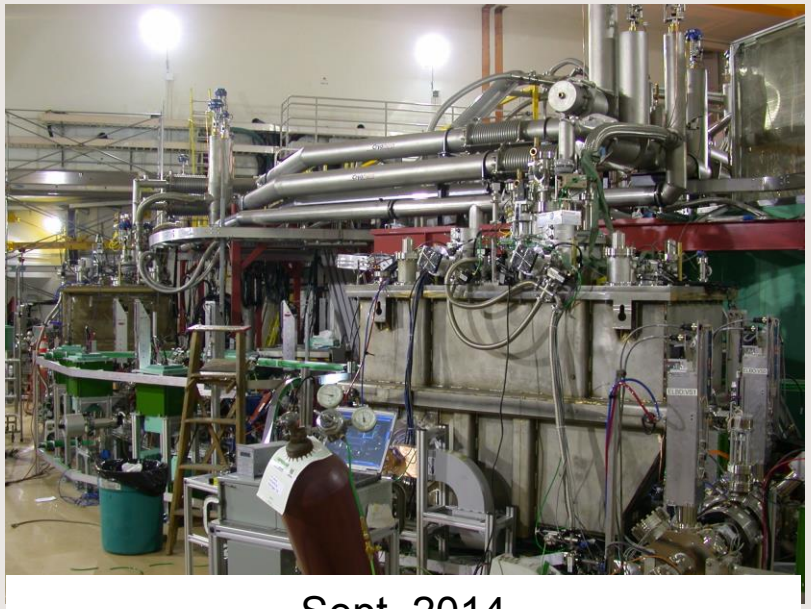


ICM cavity ok!

Progress in SRF Systems in 2014

- Cryogenics acceptance tests complete
- Two klystrons and HV supplies installed and commissioned
- ICM and ACMuno assembled, installed and commissioned
- First beam acceleration demonstrated

January 2014

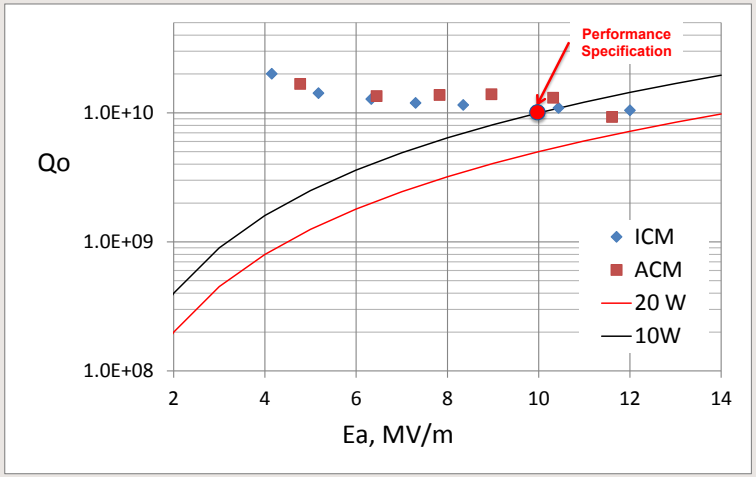


Sept. 2014

Summary

- ✓ The ICM and ACMuno cold tests have demonstrated that the cryo-engineering is robust and matches specifications
- ✓ ICM and ACMuno cavities meet specifications

- Plan to operate each cavity at 13MV/m for 25MeV beam tests through to the end of 2015
- Assemble ICM for VECC in Kolkata and install it online to confirm performance
- Install 2nd cavity in ACM and run beam tests through the end of 2016



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