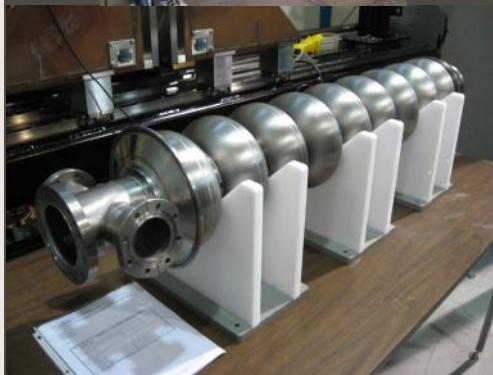
TRIUMF

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

TRIUMF ARIEL-I: Buildings & E-linac

International Peer Review
2013 Nov 13

Shane Koscielniak
e-linac project leader



Accelerating Science for Canada
Un accélérateur de la démarche scientifique canadienne

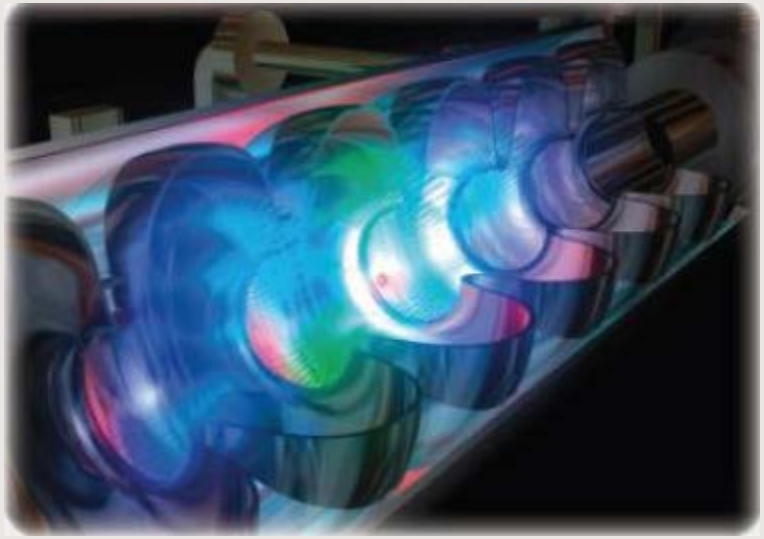
Owned and operated as a joint venture by a consortium of Canadian universities via a contribution through the National Research Council Canada
Propriété d'un consortium d'universités canadiennes, géré en co-entreprise à partir d'une contribution administrée par le Conseil national de recherches Canada

ARIEL & E-linac Outline

- Introduction
- ARIEL Construction
- E-gun & ELBT
- SRF Cavity & Cryomodules
- Beam lines
- Cryogenic & HPRF
- Conclusion

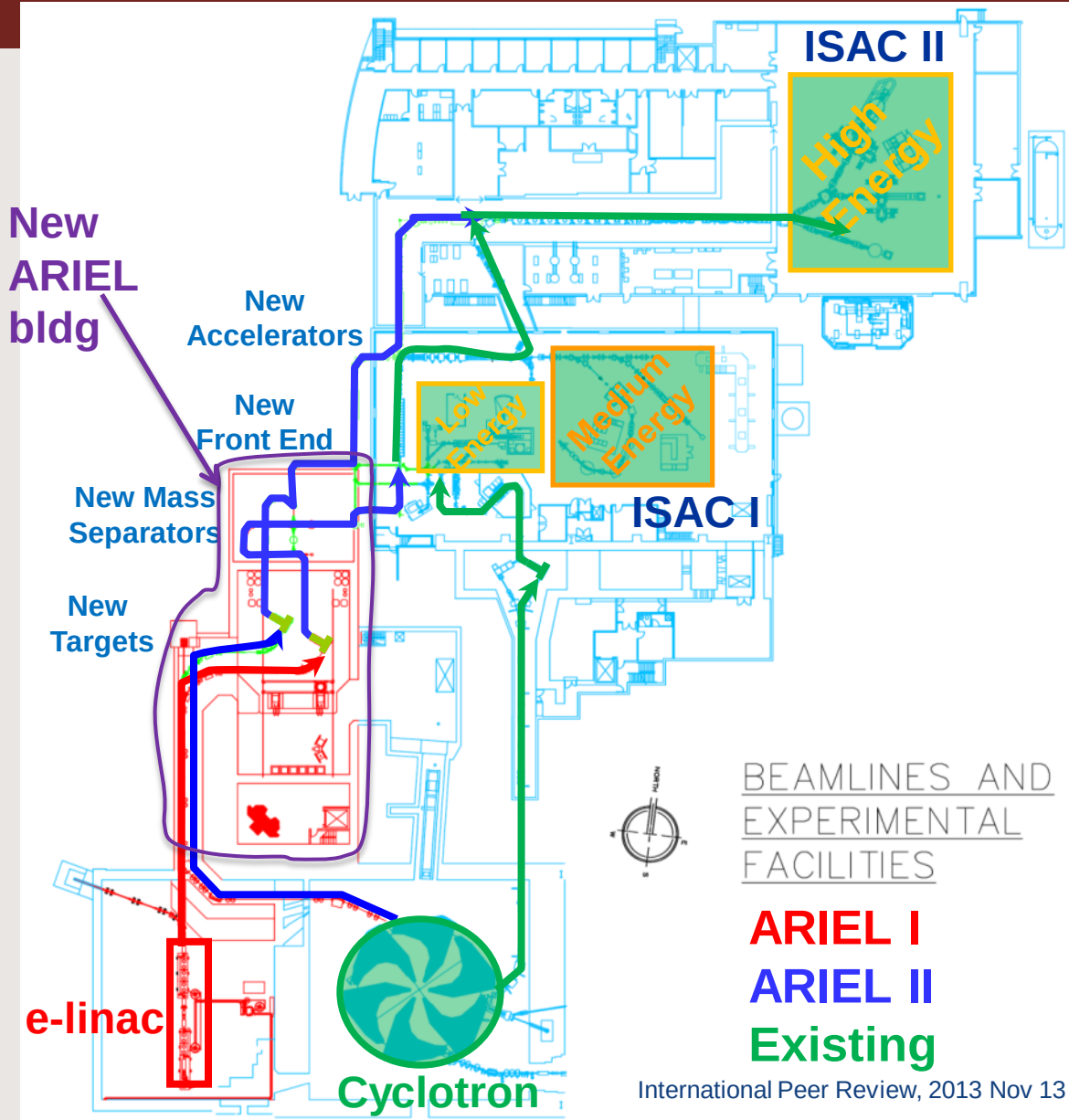
ARIEL Mission Statement

The primary mission of ARIEL is to deliver unprecedented intensities of rare, short-lived exotic isotopes, and in particular those with extreme neutron excess, to simultaneous and multiple experiments, at the existing and world-leading ISAC accelerator complex.



A secondary mission of ARIEL is to anticipate future uses of e-linac technologies such as free electron lasers, and including commercial uses such as the production of medical isotopes by photo-fission.

ARIEL will triple RIB science at ISAC



10-Year Vision: expanded RIB program with:

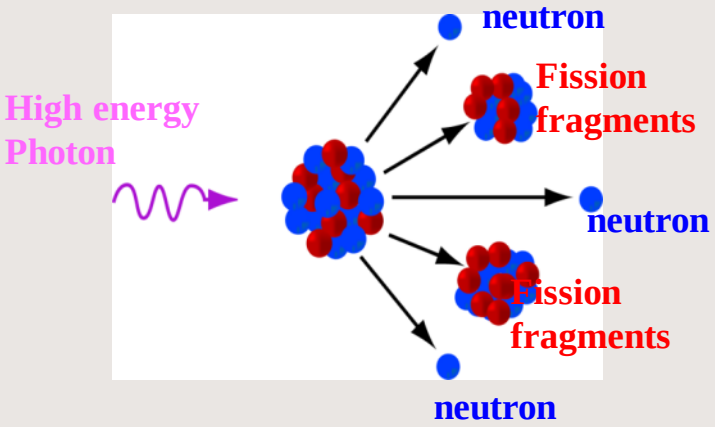
- three simultaneous beams
- increased number of hours delivered per year
- new beam species
- increased beam development capabilities

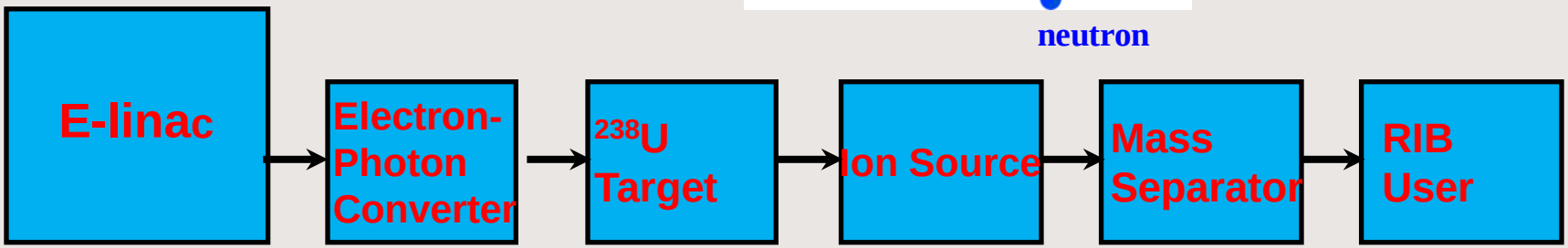
Implementation:

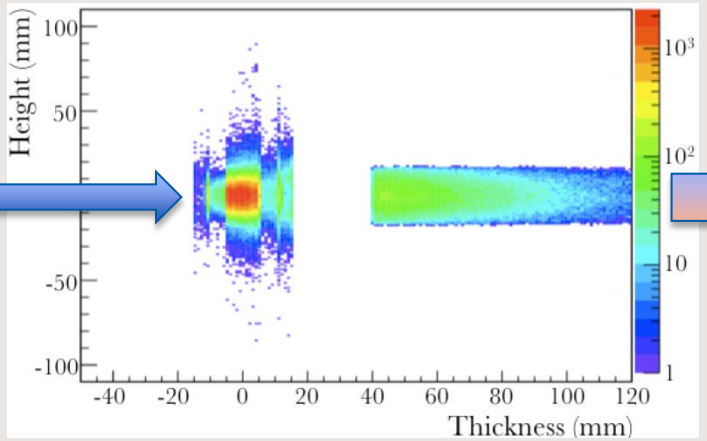
- Complementary electron linac driver for photo-fission
- New target stations and front end
- New proton beamline
- Staged installation

Photo-fission production of Rare Isotope Beams

Photofission of ^{238}U proposed by W. T. Diamond (Chalk River) in 1999 as an alternative production method for RIB.







RIB & neutrons, γs

ARIEL funding sources and timeline

- Design/Install manpower: National Research Council of Canada;
- e-linac construction: Canada Foundation for Innovation (CFI)
- ARIEL buildings: B.C. Provincial government.
- 2008 October: U.Victoria CFI application for e-linac Phase 1
- 2009 July: CFI awards M$17.8 to U.Vic-led consortium to build e-linac, contingent on matching funds for labour (NRC) and buildings (Province).
- 2010 June 22: Province (B.C.) awards funds for ARIEL building
- 2010 Sept 01: Project START

- 2008 Sept: International Peer Review
  - Recommends early e-linac system integration test (with e-beam)
- 2009 June: VECC (Kolkata, India) Collaboration MoU2 signed
  - Fast track ELBT & Injector CM design
  - 1.3GHz SRF test-stand
  - 100kV e-gun program

ARIEL Conventional Facilities

- **Culmination of 3 years work**
- **Meets needs of entire ARIEL I+II Scope**
- **ARIEL building** (3,250 m^2) housing target preparation annexe, target hall with two target stations, and RIB mass separator, and related support services and functions
- **ARIEL Tunnel** housing electron and proton beamlines
- Proton/ **Electron hall** transformation to house the e-linac
- Cryogenic **Compressor building** (250 m^2)
- **Stores building** (600m^2) to house demolished stores functions and displaced persons
- Site access changes – new **Badge building**
- Other demolition and site preparation

New Stores Building and Badge Room

Occupancy: 2011 September

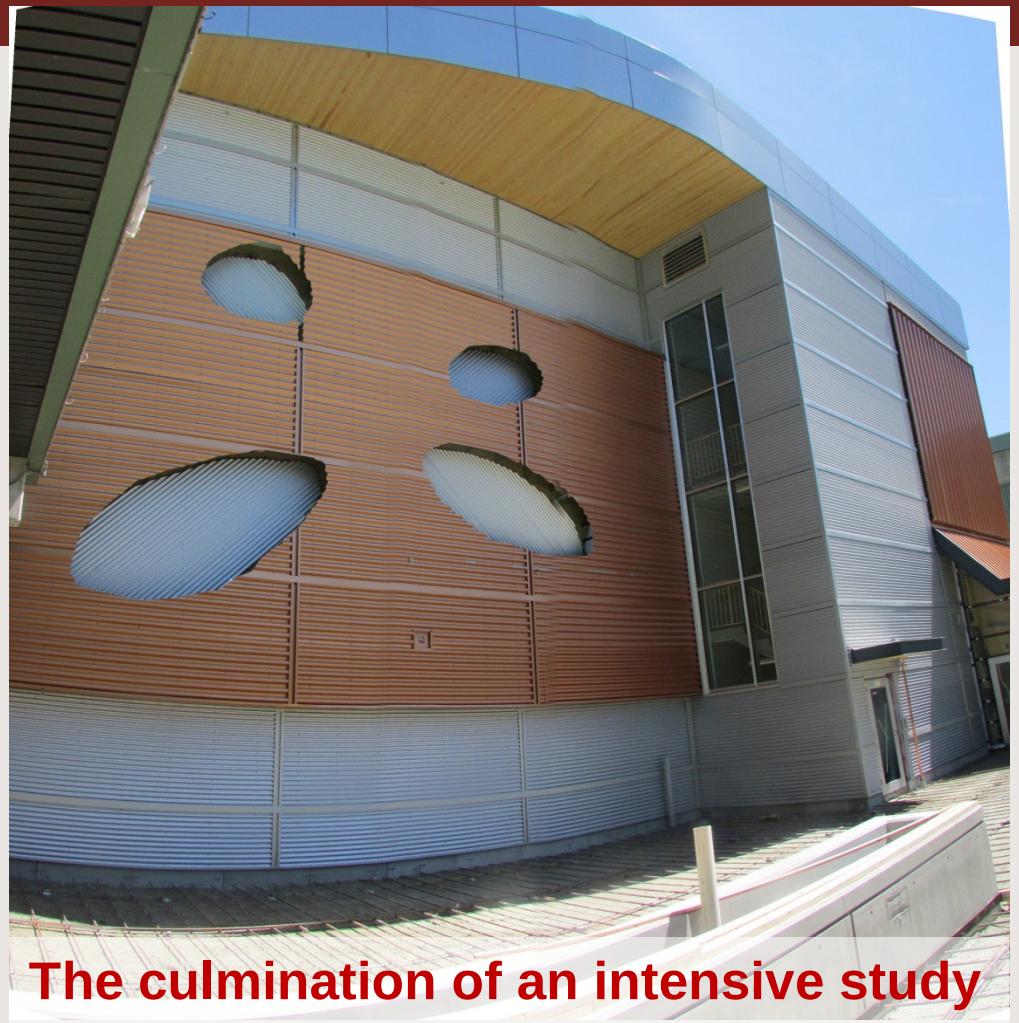
Occupancy: 2011 November

Ground Breaking 2011 March

Helium Compressor Building

GHe tank delivered 2013 Jan

ARIEL Construction Complete

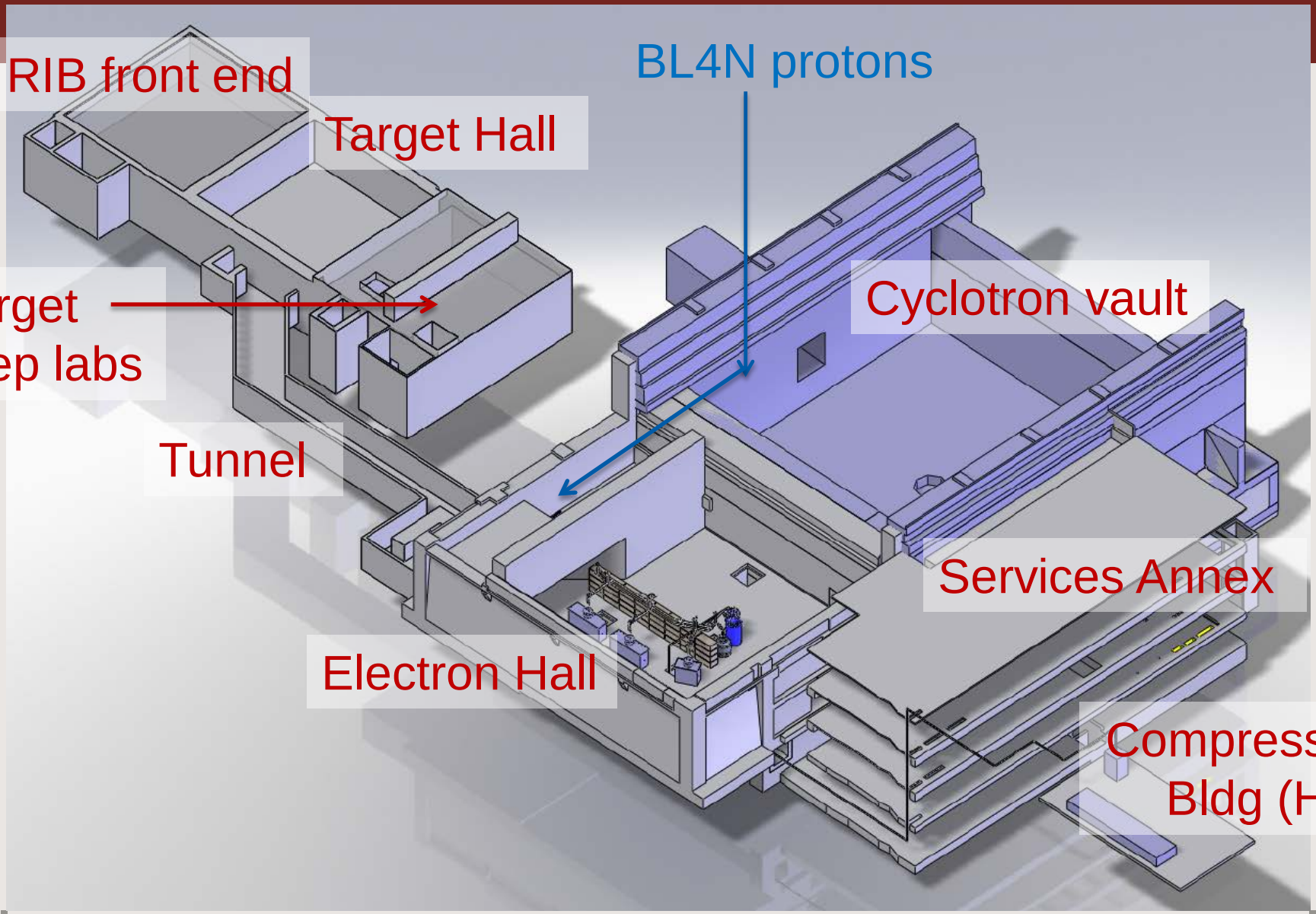


The culmination of an intensive study of what is needed to facilitate smooth and routine Rare Ion Beam delivery.

ARIEL Target Hall Complete

All hands mtg 2013 Aug 2nd

TRIUMF/ARIEL Layout



Proton to Electron Hall Transformation

2009 Sept: START

- Remove shielding blocks
- Remove SASP, MRS and rails
- Recertify 50T cranes, etc, etc.

- **2012 Feb 01: Clean-up Complete**
- **Handover to contractor**

E-hall occupancy 2012 Nov 30

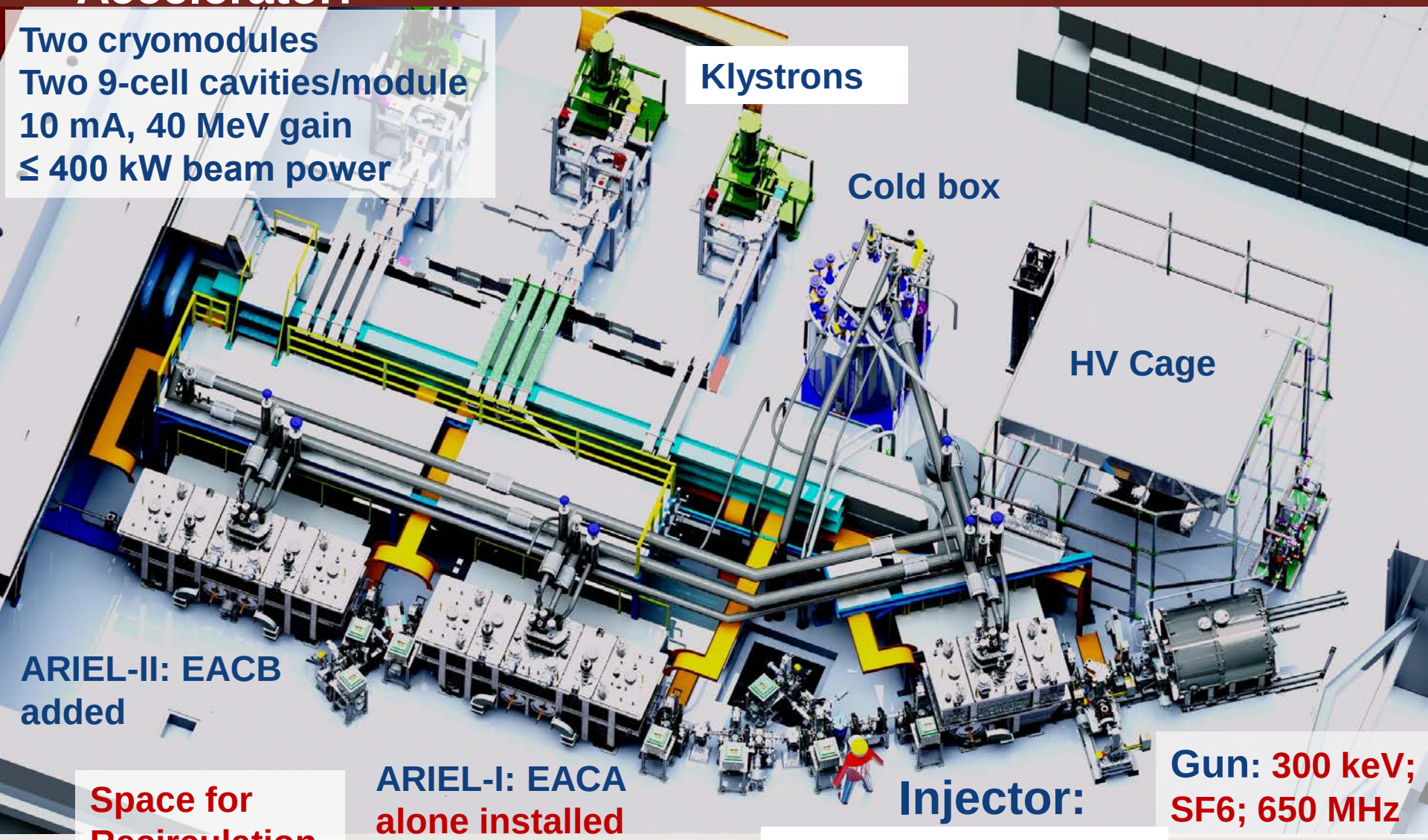
Electrical & Water Services for E-linac Phases I+II Complete

On top E-hall roof beams: rack farm, cable trays, Klystron PS & UPS

E-Linac in e-hall

Accelerator:

Two cryomodules
Two 9-cell cavities/module
10 mA, 40 MeV gain
≤ 400 kW beam power



Injector:

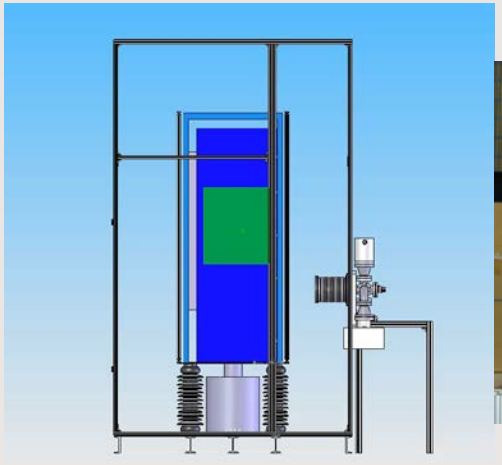
Gun: 300 keV; SF6; 650 MHz

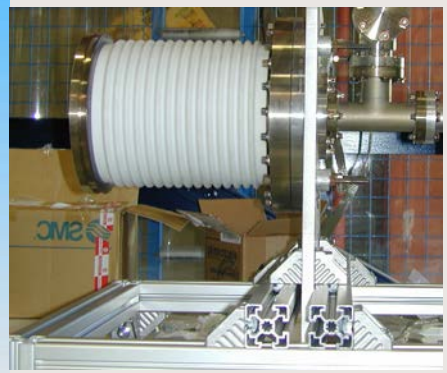
10 mA, 5-10 MeV gain
≤ 100 kW beam power

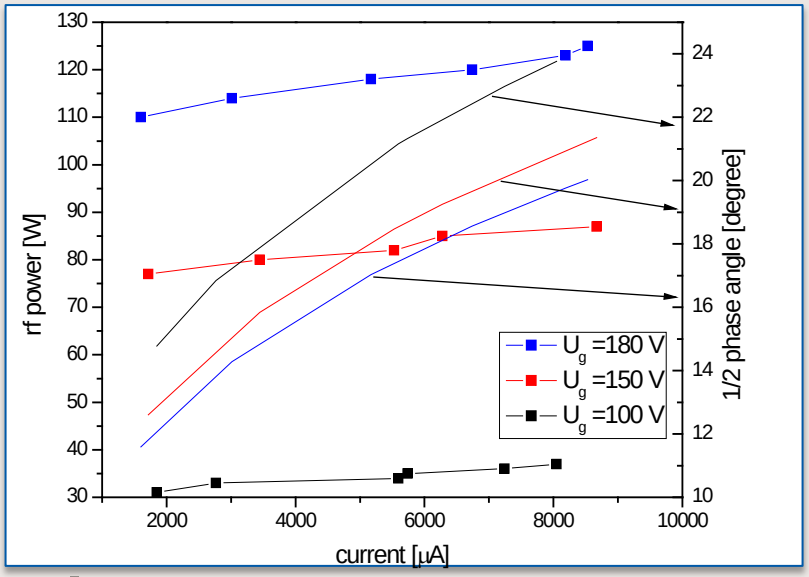
100 keV Thermionic Gun RF Modulation

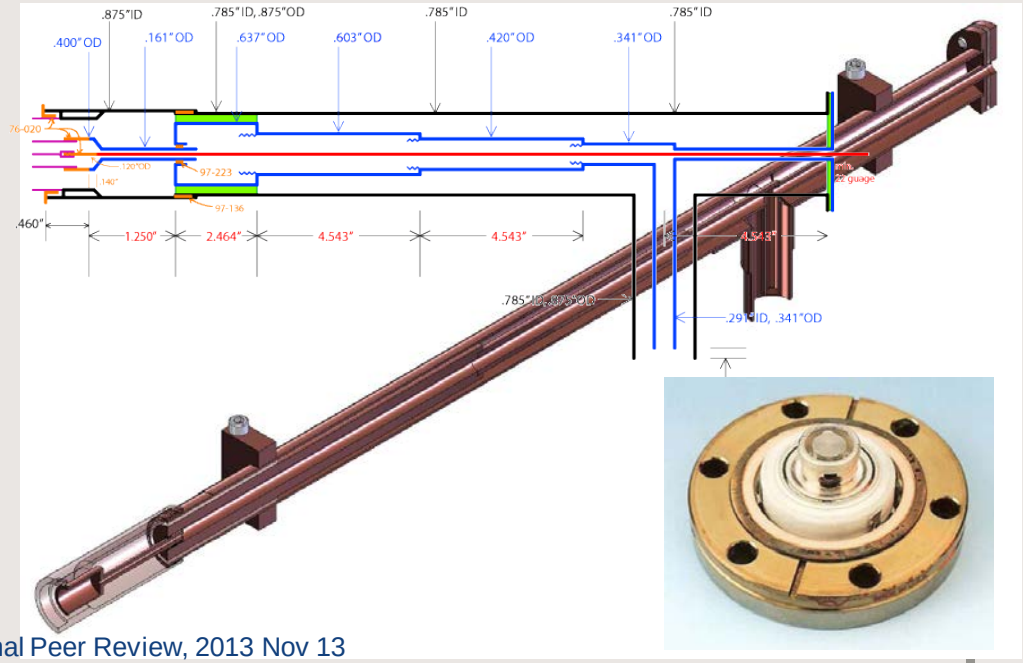
- 100kV DC gun loaned from JLab
- Gridded RF cathode (Eimac)
- TRIUMF designed RF cathode matching network

- 2011 April 7: 650 MHz modulation
- 2011 Nov 09: 16 deg RF conduction angle demonstrated



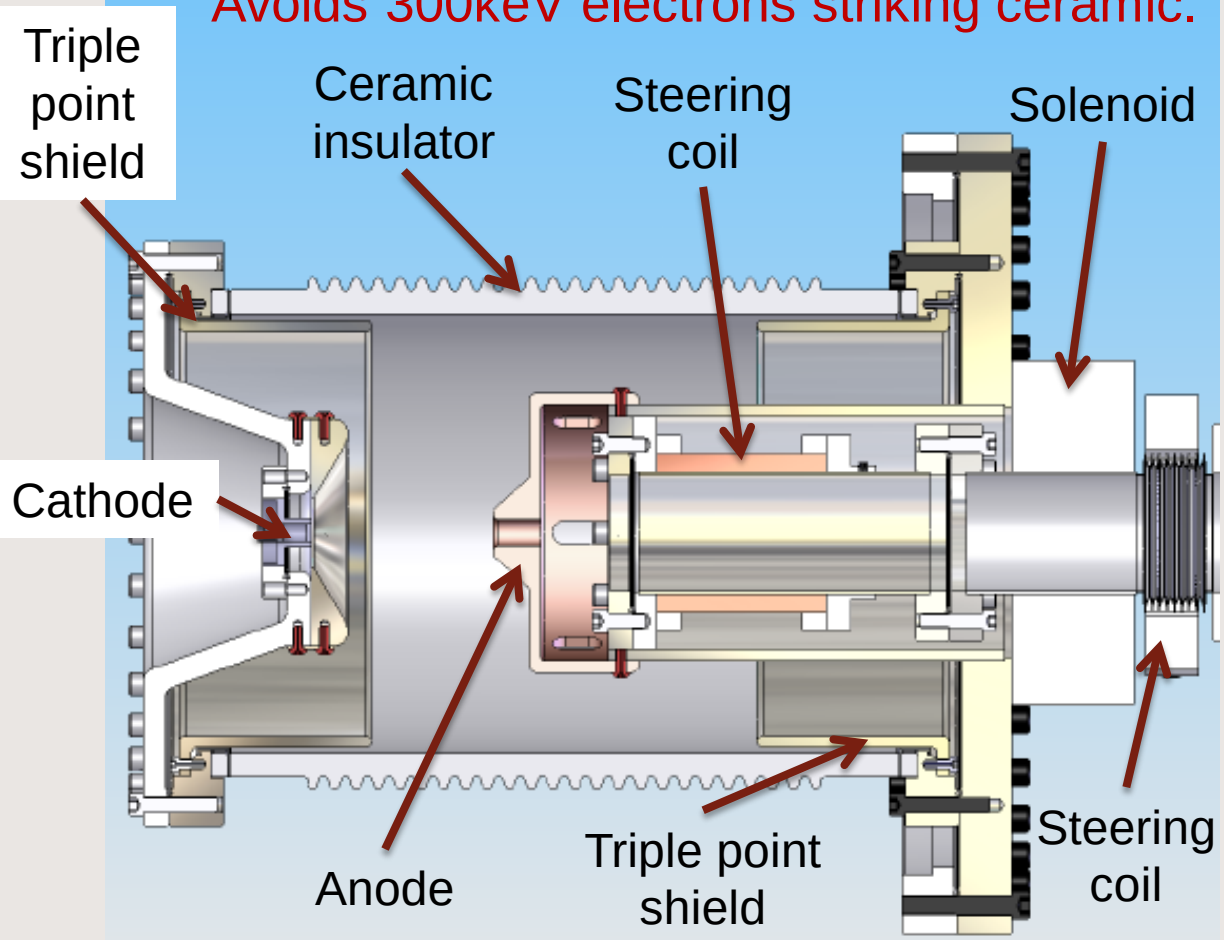






300keV Gun

Novel TRIUMF geometry places largest area of FE sites at ground potential.
Avoids 300keV electrons striking ceramic.

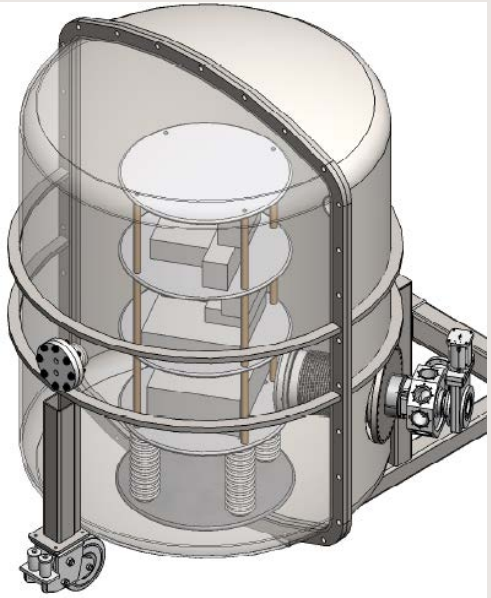


- Collaborator: C. Sinclair
- 300kV: lowest energy for injection into 10MV/m SRF cavity
- Charge/bunch 16pC
- Emittance ≤ 5 μm r.m.s. normalized

Assembled 2013 May 08

RF Modulation – Dielectric Waveguide

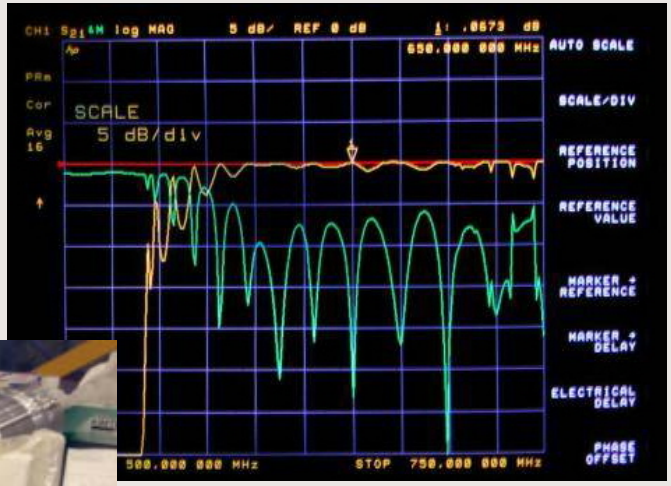
Problem: 650 MHz amp, DF pulsing, synchronization circuitry, Firewire optical etc. → increasing size/complexity of HV platform → larger SF6-filled vessel.



Gun vessel & RF modulation equipment HV platform

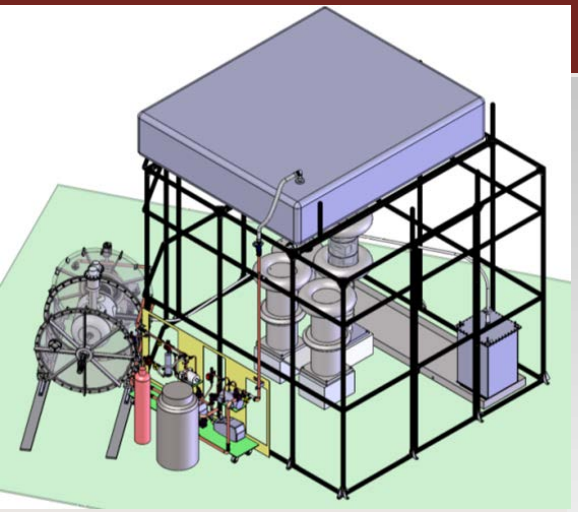
Proposal 2011 April: move modulation H/W outside vessel and transmit RF via ceramic/dielectric waveguide

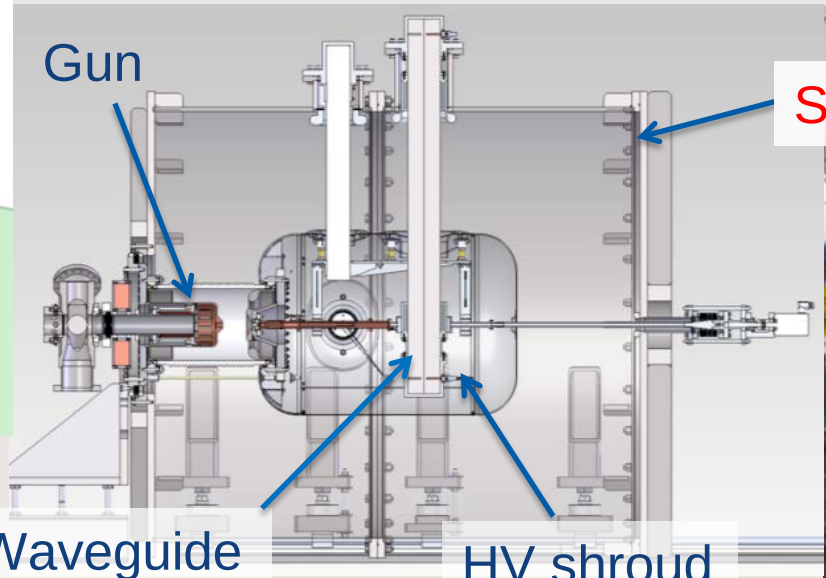
2011 Oct 06: Transmission optimized at 650 MHz on prototype



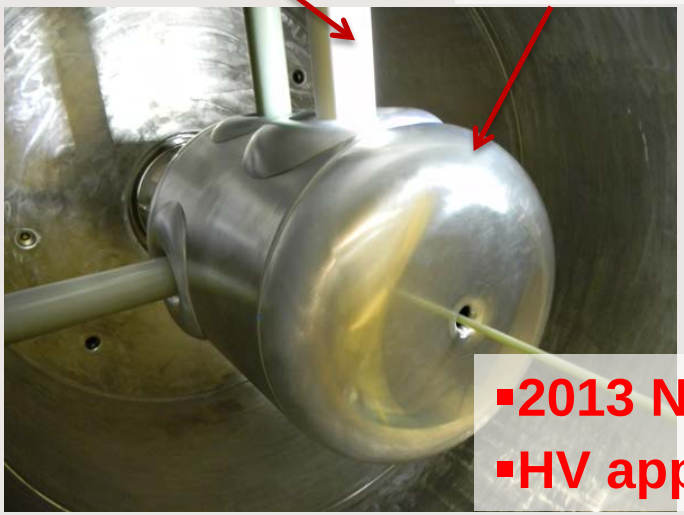
2013 Aug 16: Ceramic waveguide & impedance tuner almost complete

300keV Gun Progress



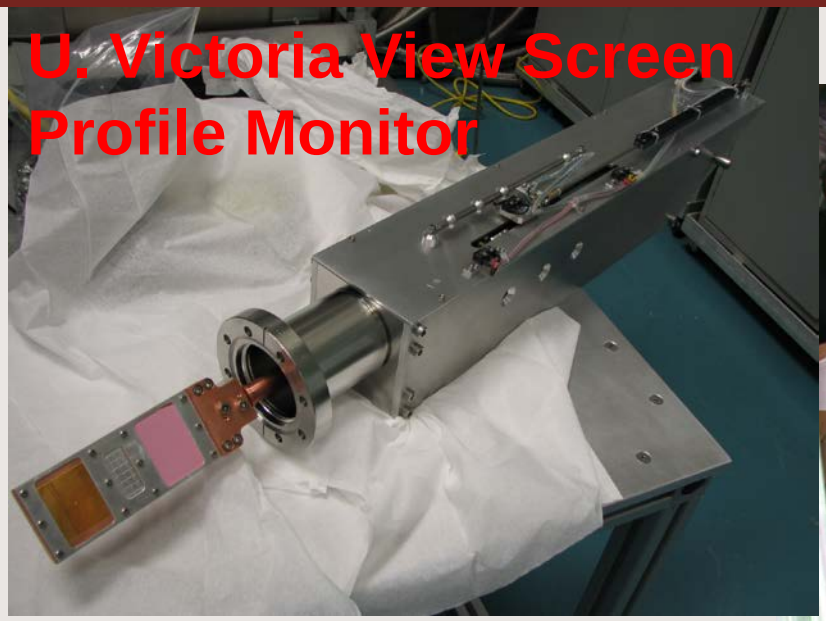


350kV HVPS

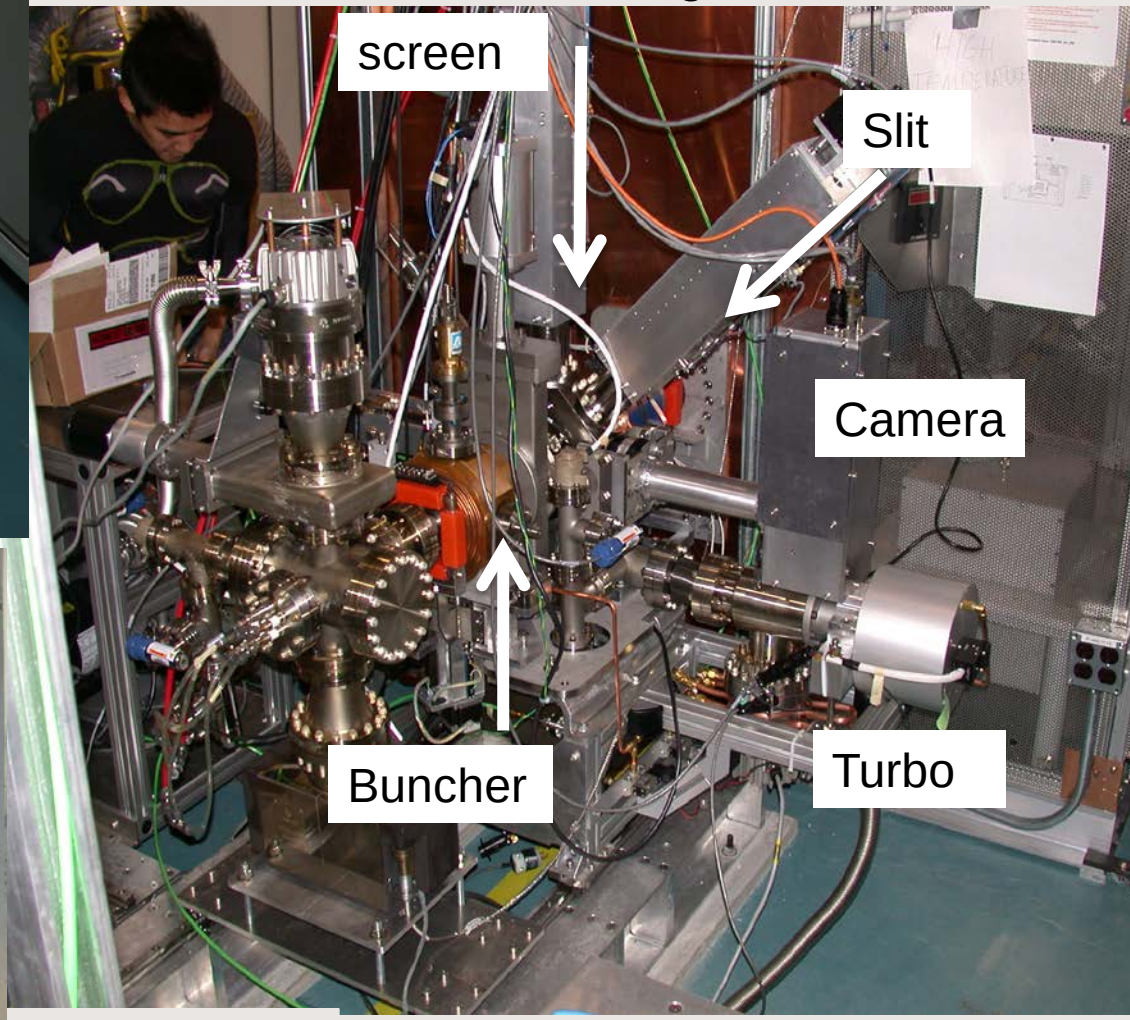


- 2013 October: Shroud & waveguide installed
- **2013 Nov 7: Vessel filled with N2**
- **HV applied. Results pending…**

VECC ELBT Test Stand & Diagnostics

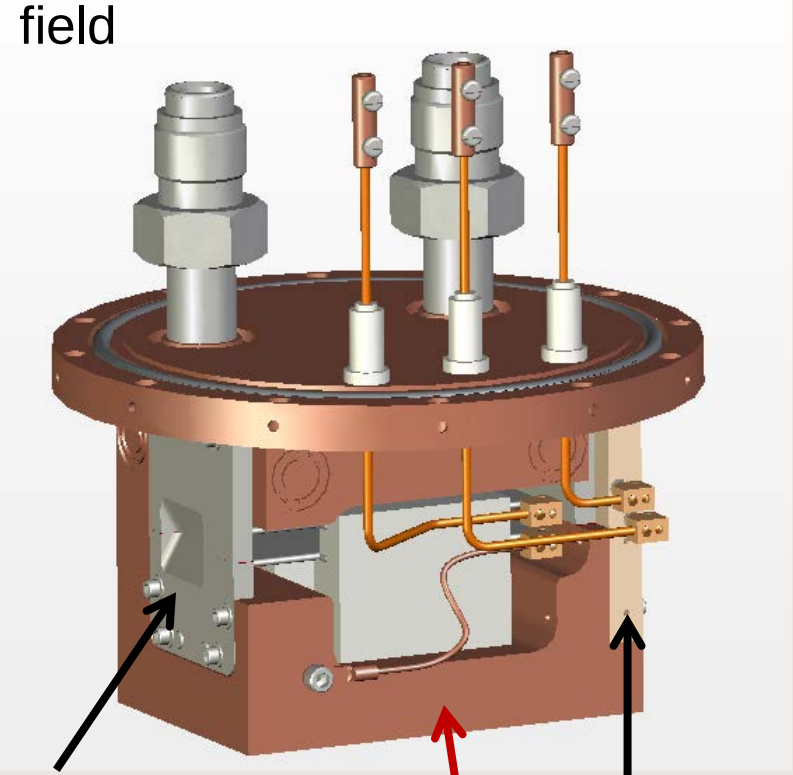


100kV e-gun & solenoid



ELBT Allison Emittance Scanner

Two slits and transverse electric field

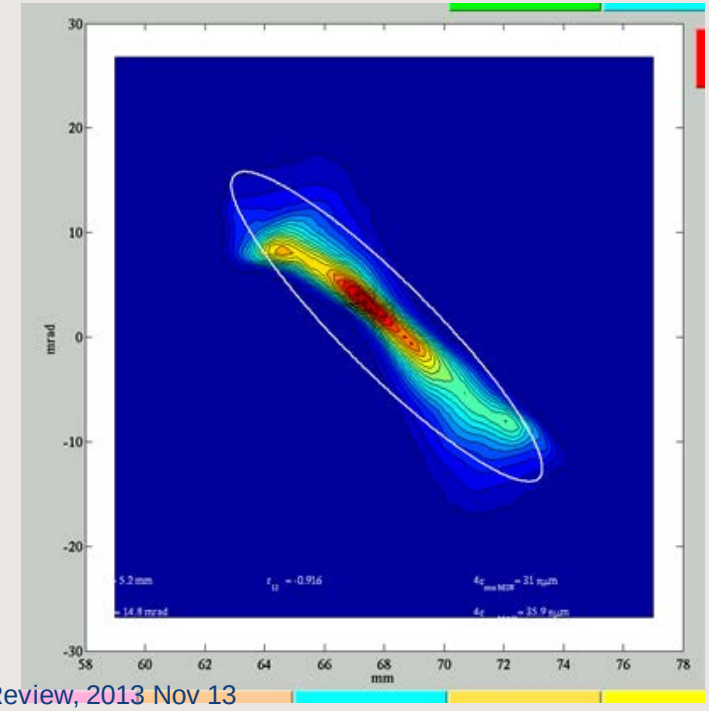


Copper entrance slit with sapphire shims

Faraday Cup

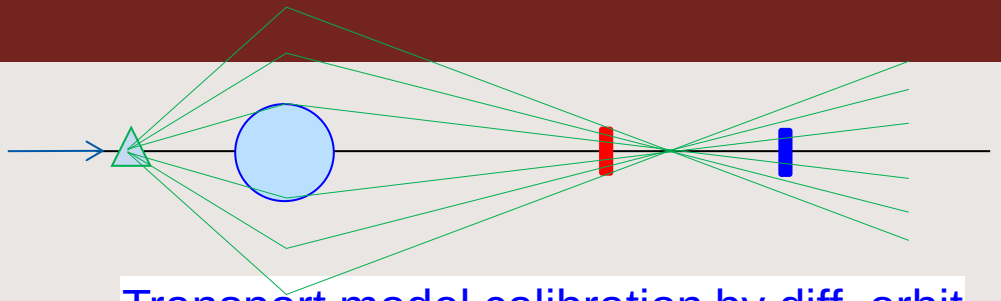
Emittance rig copper body

- Success: tested up to 700W and 100W/mm^2 power density
- Proc. BIW2012, TUCP04
- Find that 90% of the beam is within ε=30μm (norm) – agrees with profiles taken with screen and camera

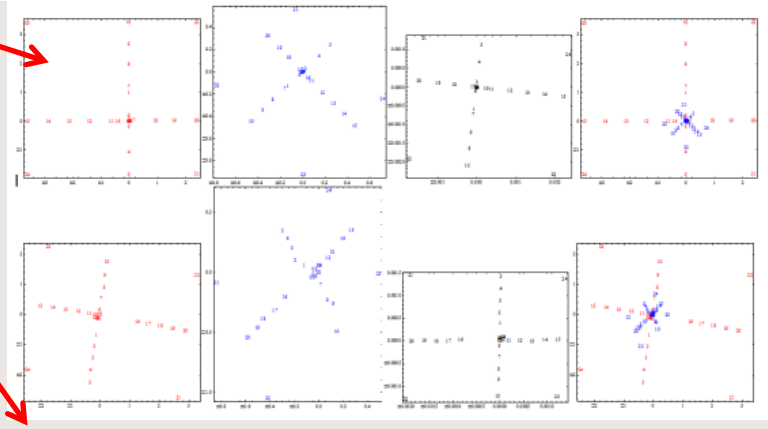


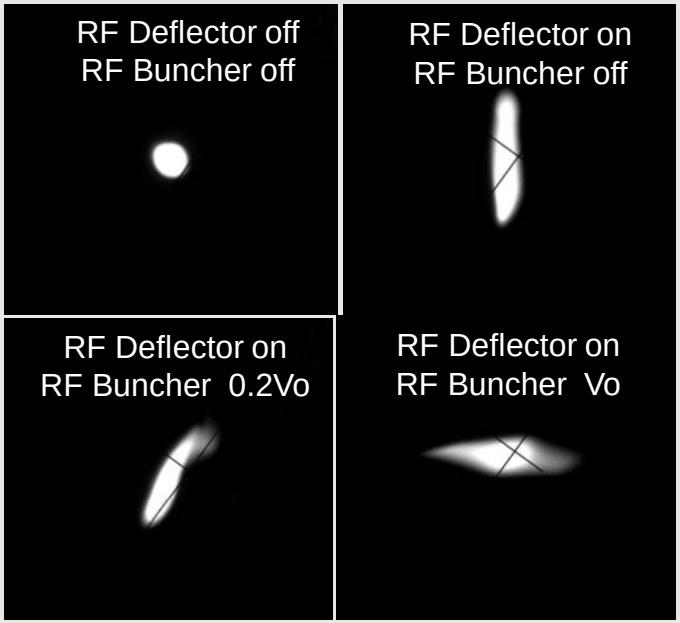
VECC/ISAC ELBT Beam Tests

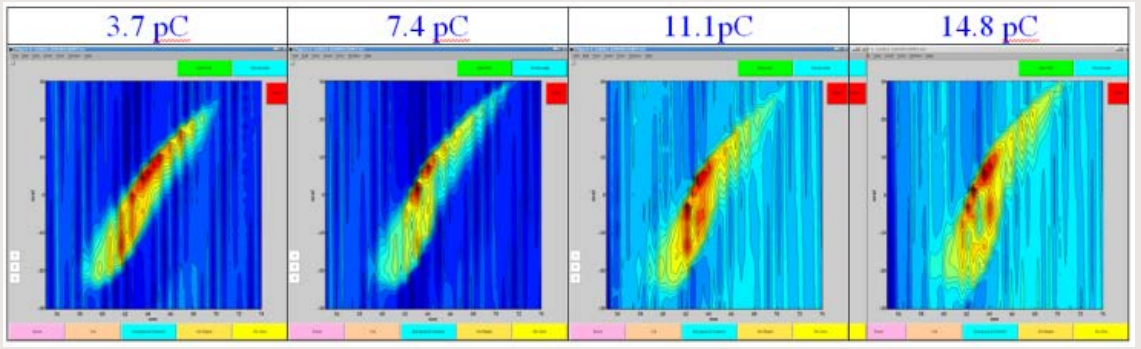
- Complete beamline installation
  - Spectrometer leg
- Transport model (matrices)
- Phase space measurements
- Emittance vs bunch charge
- Longitudinal matching to ICM



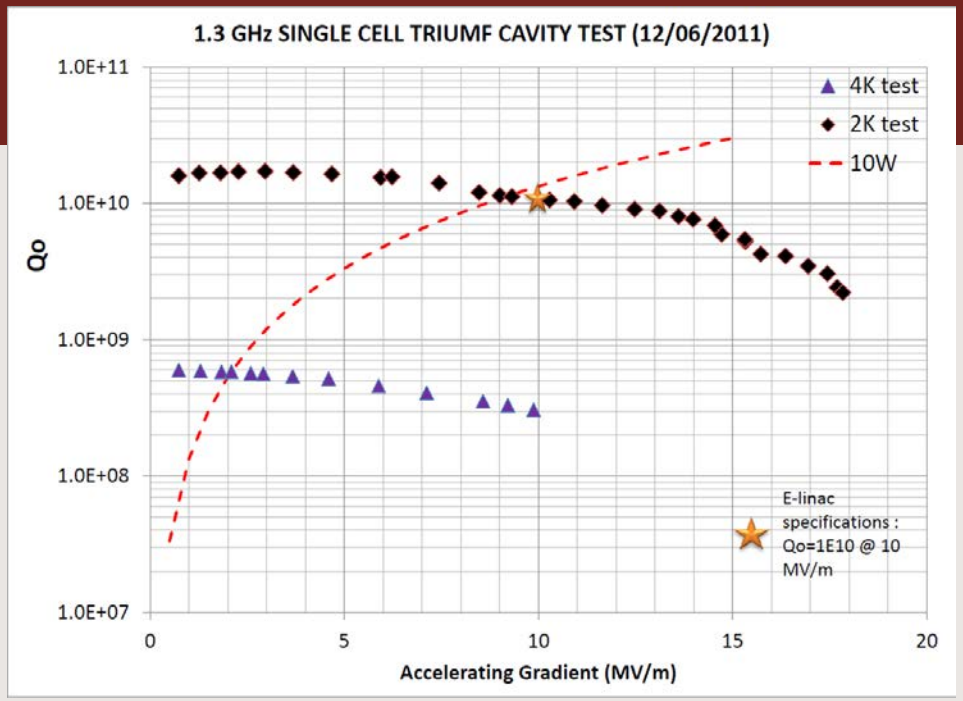
Transport model calibration by diff. orbit

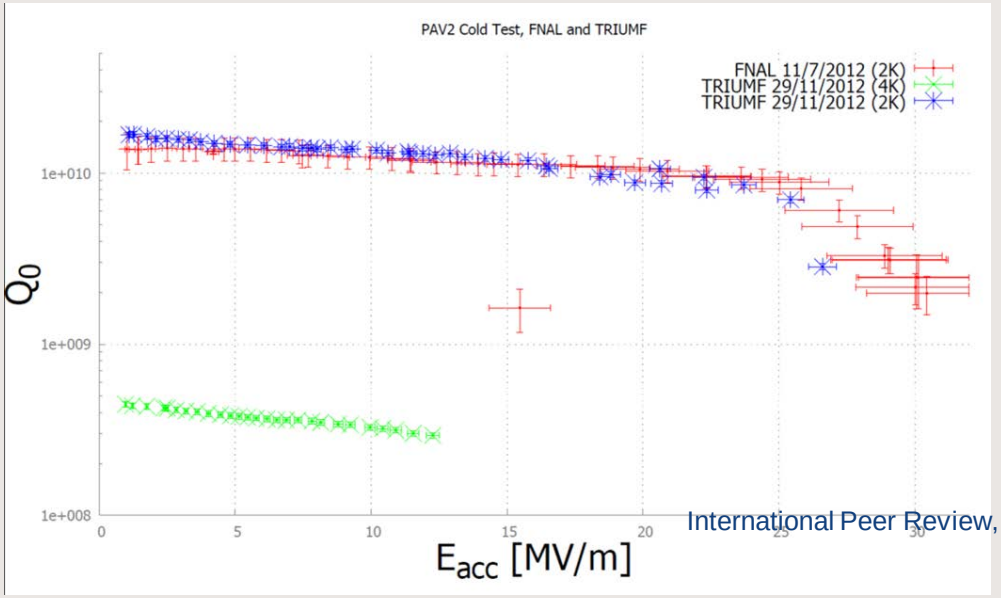






1.3 GHz Single-Cell Cavity Development

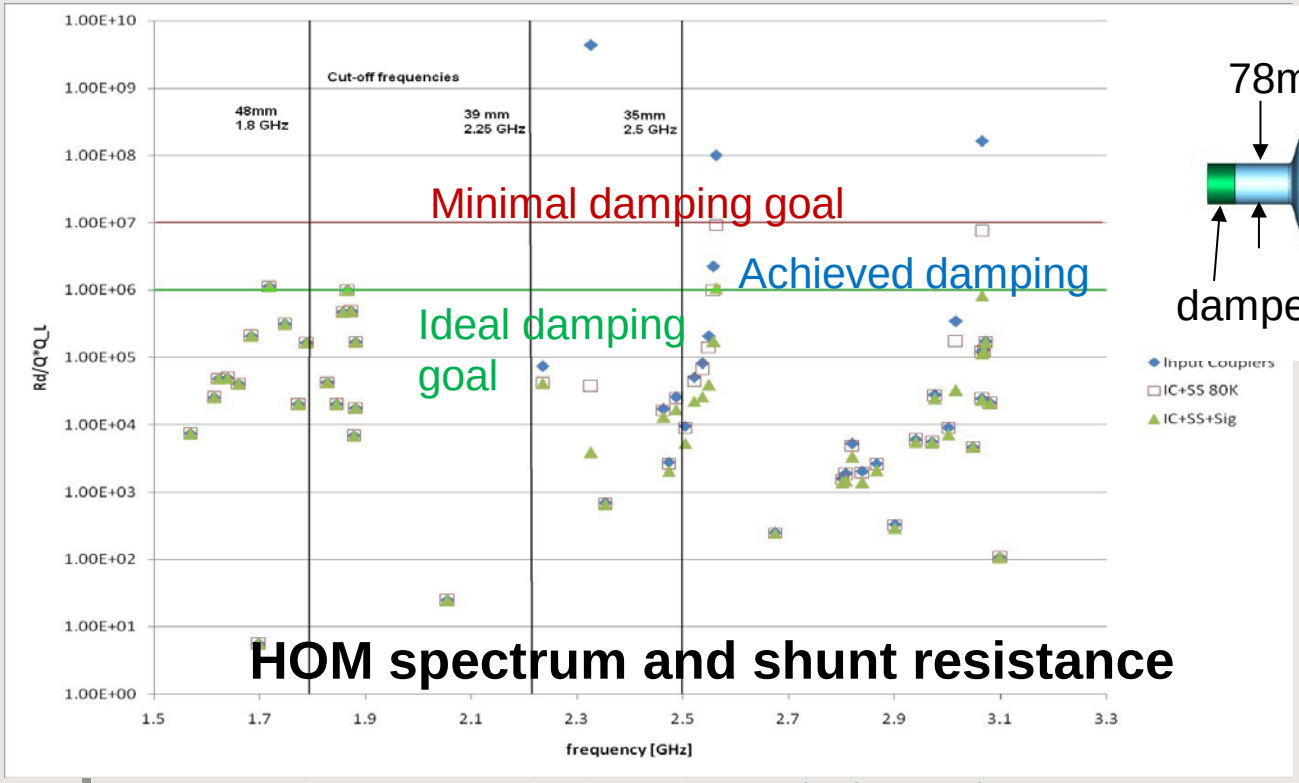




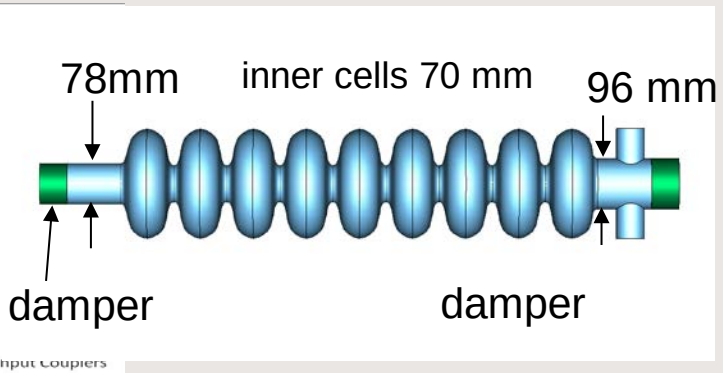
- 2010 May: Nb single cells received from PAVAC
- PAVAC, a local company with EBW & Nb expertise, is Tech Transfer Partner on path to ILC Vendor Qualification.
- 2011 Dec: Success: first PAVAC/TRIUMF single-cell meets spec, 10MV/m Q = 10^{10}
- 7 from 7 cells meet spec.
- 2012 Sept: broke through the multipacting barrier at 18MV/m - now up to 25 MV/m
- See also R. Laxdal SRF talk

9-Cell Cavity HOM Damping

- **Foresee RLA or ERL operation**
- HOM damping requirement set by regenerative Beam Break Up (2-pass)
- 2011 March: $(R_d/Q) \times Q_L < 10^7$ ohm gives 20 mA (per pass) threshold.
- 2011 Sept: All modes $(R_d/Q) \times Q_L < 2 \times 10^6$ ohm achieved (in simulation)



HOM spectrum and shunt resistance



1.3 GHz 9-Cell Cavity Development

- 2011 Dec: Order placed with PAVAC for four 9-cell Nb cavities.

ARIEL1:

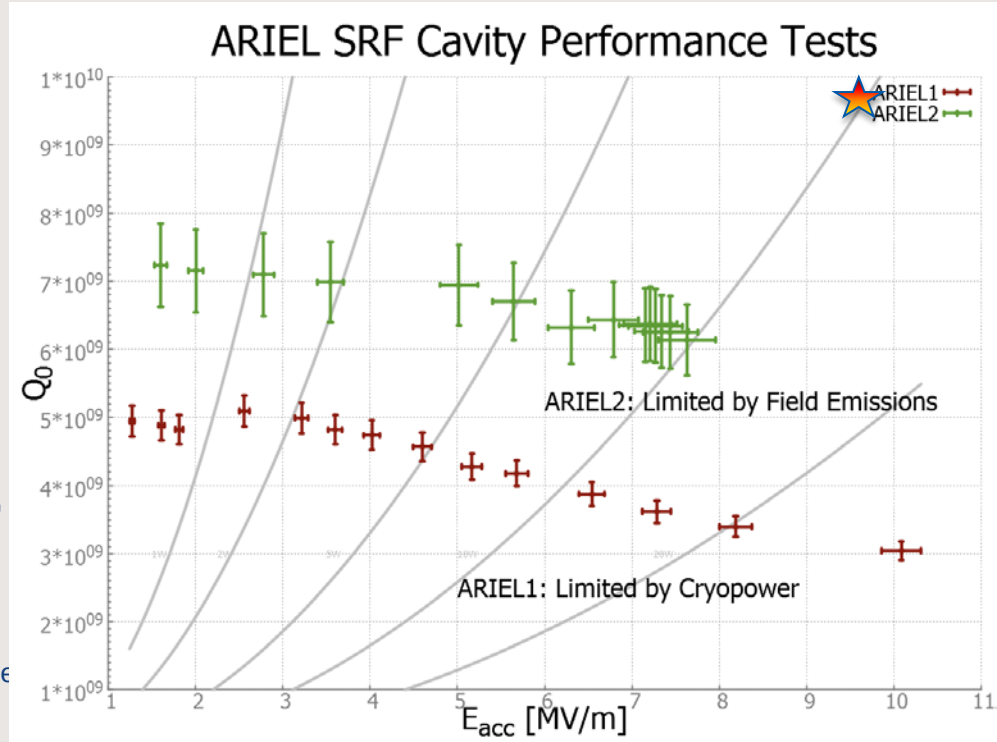
- Delivered 2013 May 28
- 10 MV/m demonstrated, Q= 3×10^9
- Limited by cryogenics (no quench)
- Degassed at FNAL to release H_2
- Retest in 2 weeks

ARIEL2:

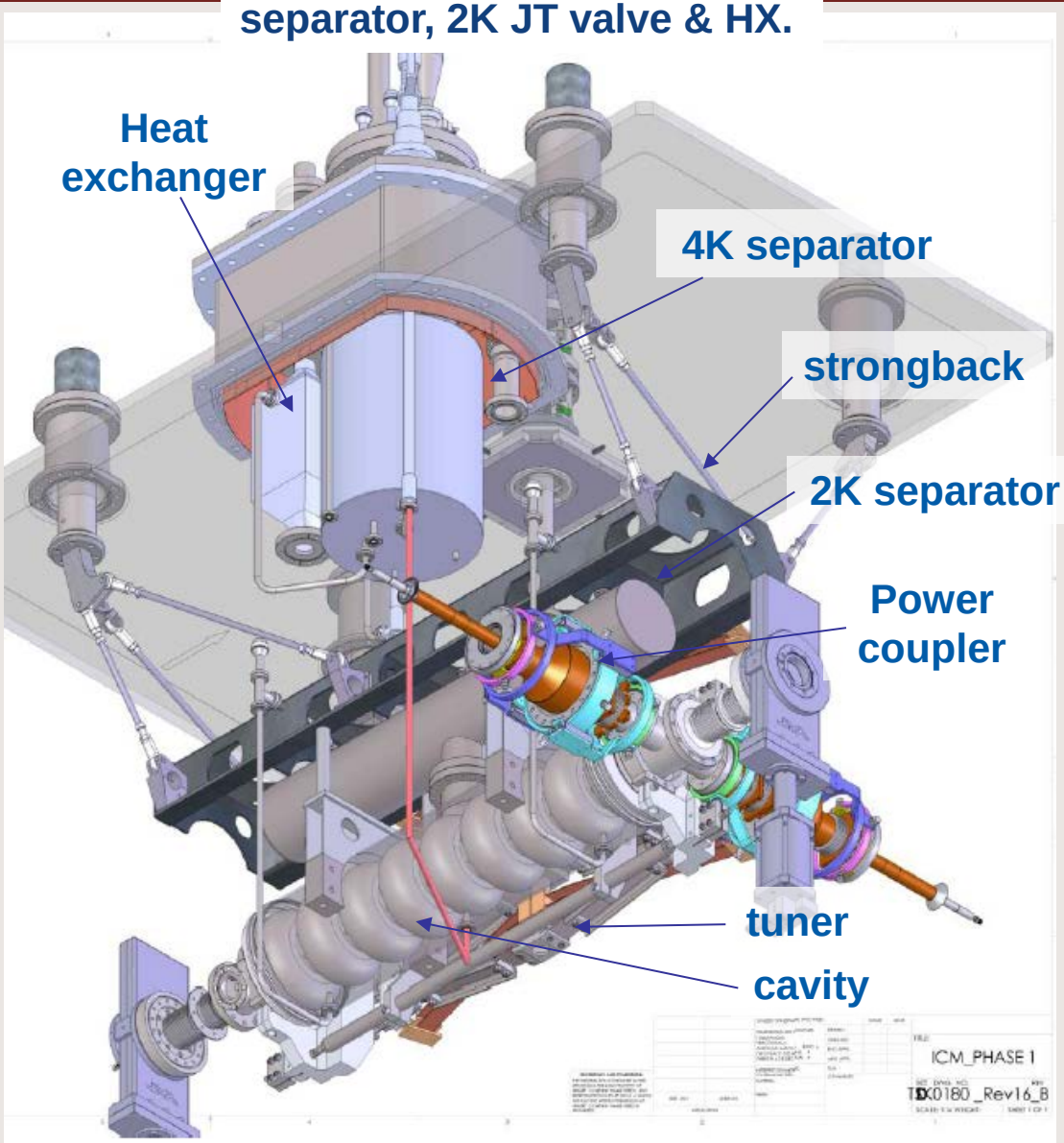
- 7.5 MV/m reached, Q= 6×10^9
- Limited by Field Emission

ARIEL3

- 7 inner cells fabricated and welded, 2 end groups in production.

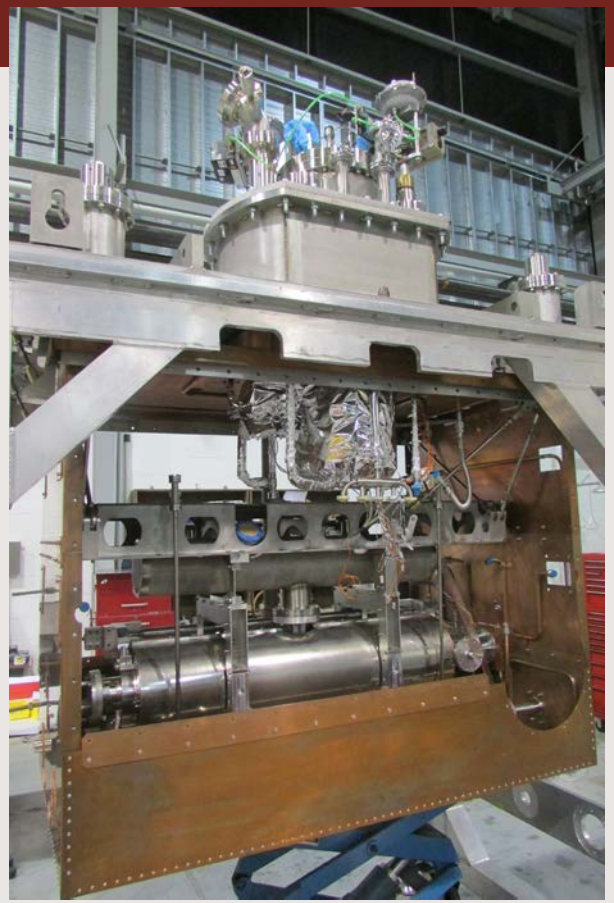


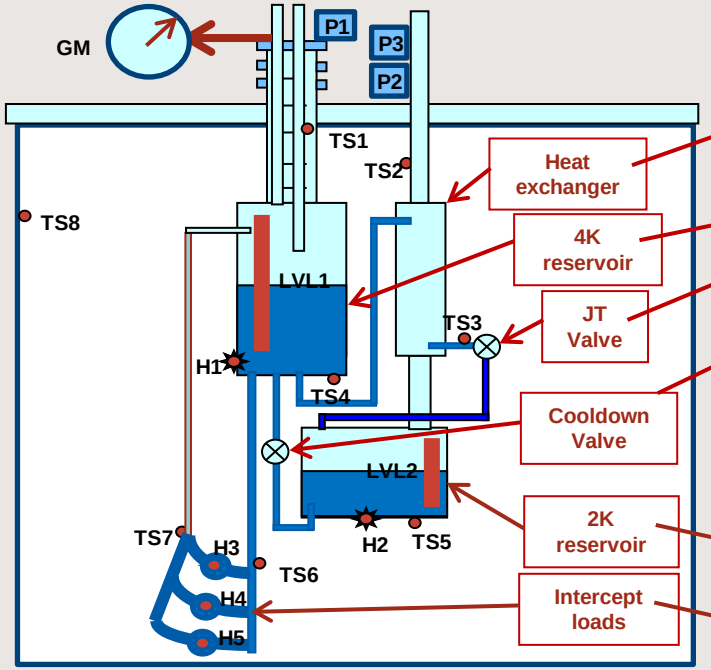
Injector Cryomodule

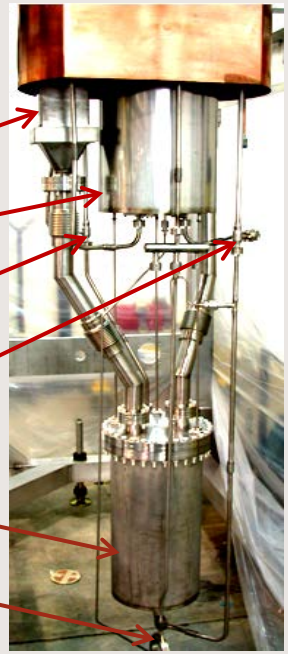


- **C.W. Design:** consistent with small static and large dynamic heat loads.
- Borrows many features from successful ISAC-II CMs.
- Top loading box concept with cavity mounted to strong-back that is suspended from struts.
- 2K LHe generated where its needed.
- Box gives headroom for on-board 2K/4K HX and 4K separator
- Injector prototypes most features of the Accelerator

4K/2K Cryogenic Insert







- Produces 2K LHe on-board cryomodule
- Tested, refined, operable, installed at mock-up

2013 Jan - March

- Measured static load of 4K (2W) and 2K (0.5W) reservoirs
- Measured efficiency of 2K conversion of 66% at 0.5 g/s
- Measured 4K siphon circuit efficiency – static load of 1.6W

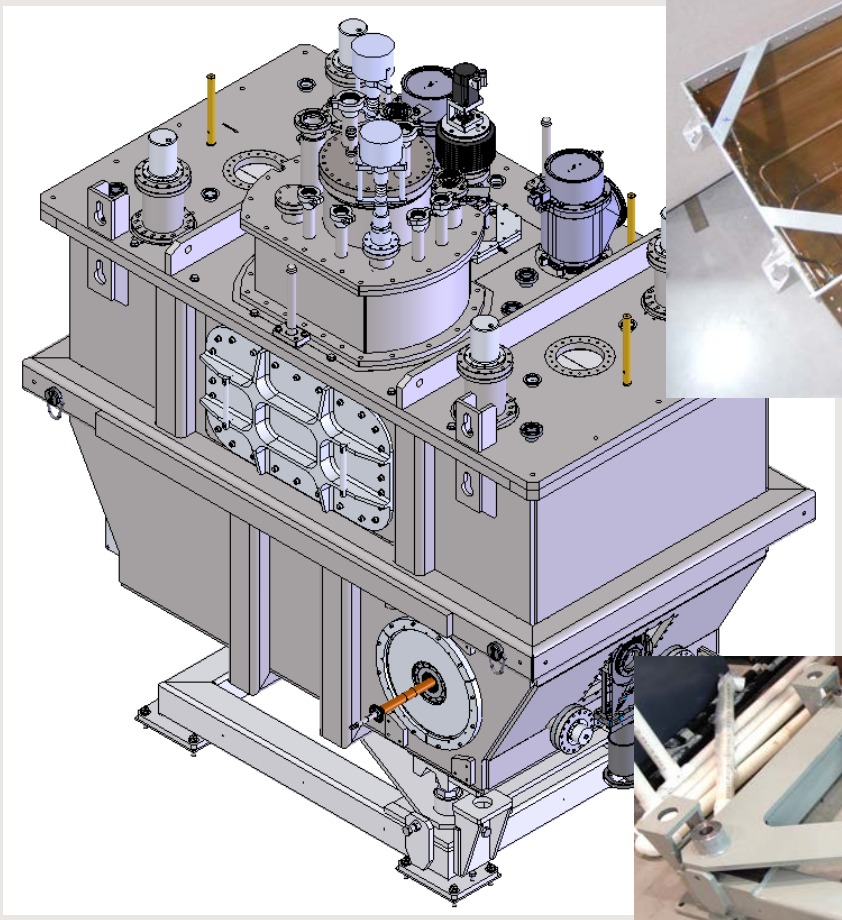
Injector Cryomodule Progress

All sub-assemblies fabricated

Assembled:

- Lid
- Tank (Vacuum vessel)
- Stand
- LN2 thermal shield
- Warm Mu-Metal liner

Others In Mock Up



Mock-Up Assembly Status

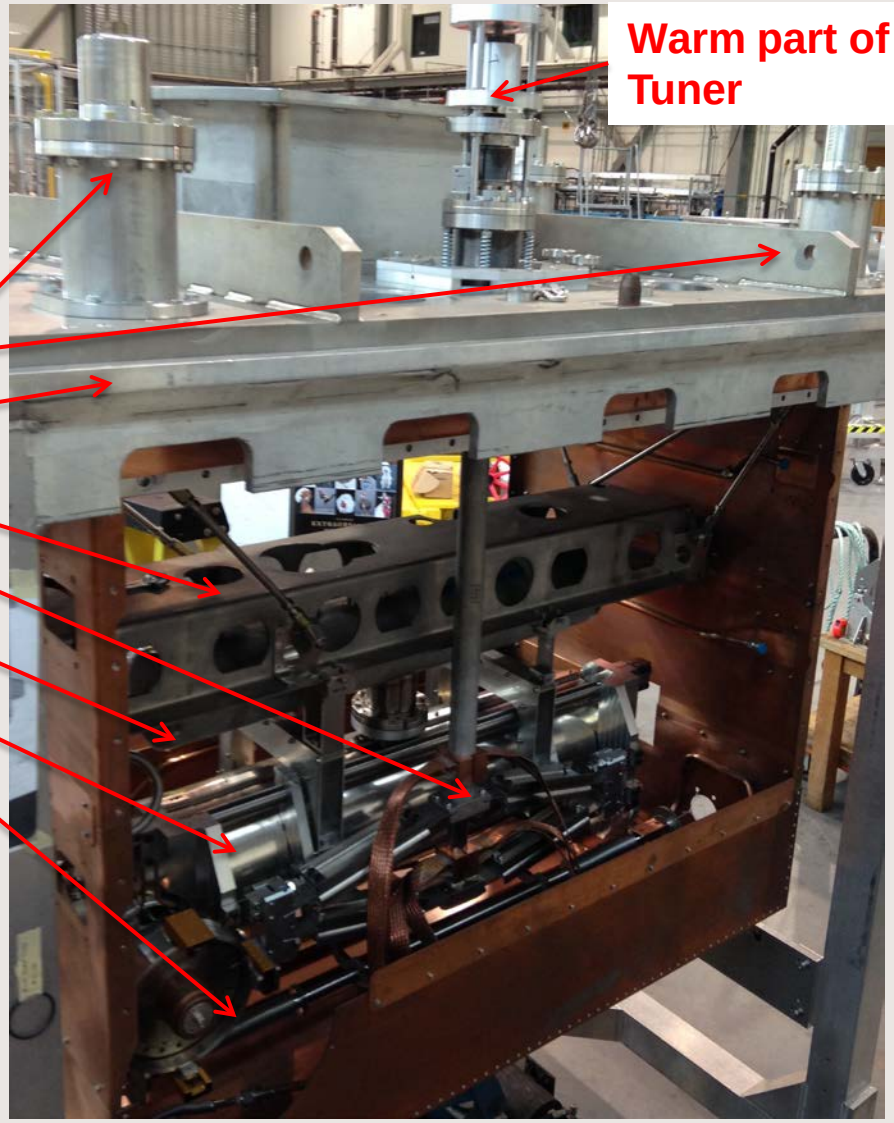
A mock-up is used to study assembly and ensure all parts will assemble and operate during final assembly with no interferences or conflicts.

Installed

- Tuner warm part
- Support Towers
- Lid
- Struts & strong back
- Cold tuner
- 2K Reservoir
- Cold mu metal shield
- Wire Position Monitor
- 4K/2K Insert

Pending

- Warm Cold Transition
- Cavity & He jacket



Accelerator Cryomodule Progress

Sub-assembly complete:

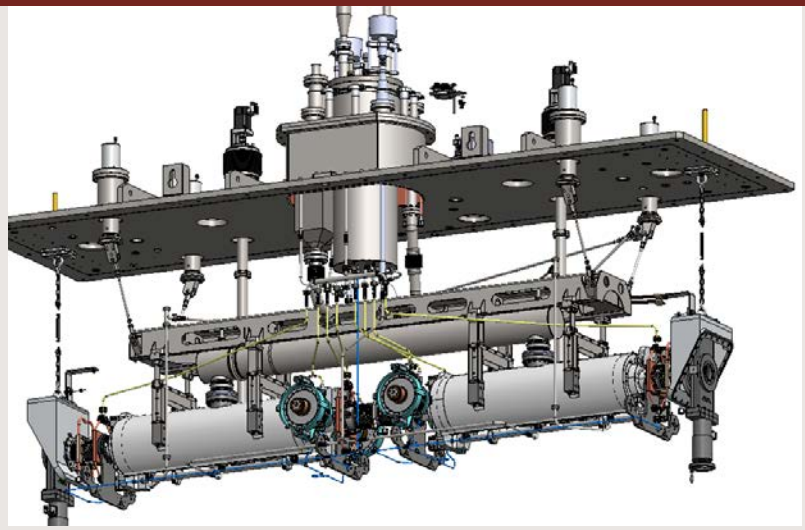
- Stand
- Tank and Lid, leak checked

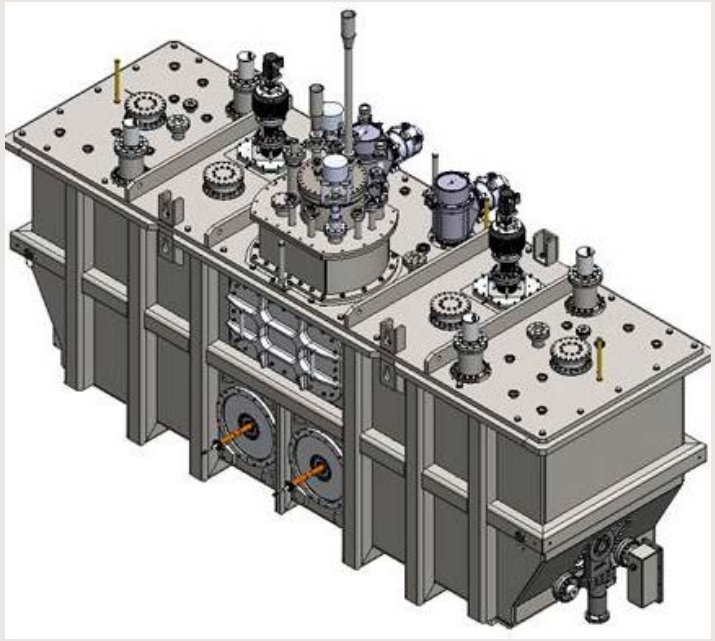
Fabrication starting Nov/Dec:

- Warm mu-metal shield
- 4K/2K Insert
- Support Tower
- Warm/cold transition

In Final Design Review:

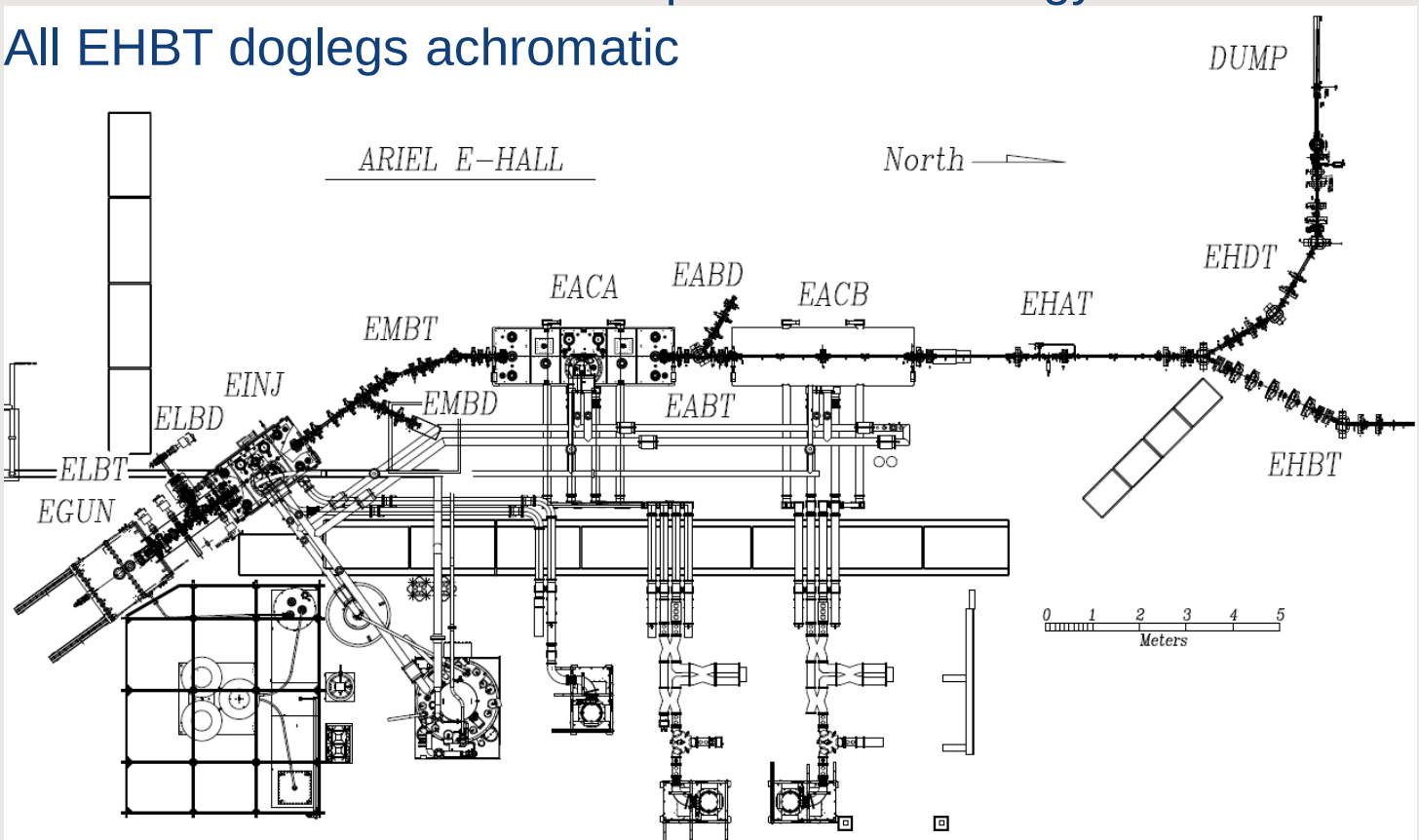
- Strong-back and struts
- LN2 thermal shield
- 2K Reservoir detailing
- Inter-cavity transition



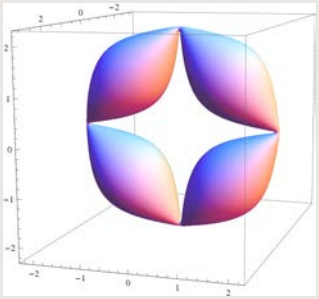


Beam Lines

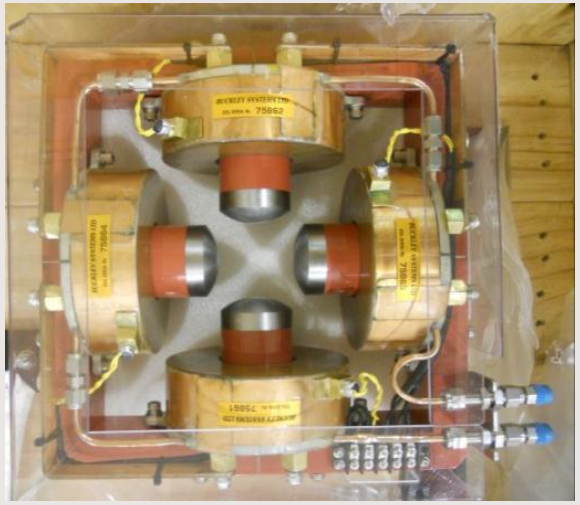
- ELBT through EHAT transport and acceleration compatible with
  - Low brilliance thermionic gun (16 pC, 6π μm r.m.s) – now
  - High brilliance photonic gun (100 pC, 10π μm r.m.s) – future
- EMBT to EHAT design consistent with expansion to RLA or ERL
- EHAT to EHDT & EHBT compatible with energy 25-75 MeV
- All EHBT doglegs achromatic



Optimal Short Quadrupole



- Short quads have Length of steel = Aperture Diameter.
- **Motivations:** Extreme congestion in beam lines.
- Avoid very low fields to improve reproducibility.
- Round poles & circular coils are simpler/cheaper to construct.
- **2011 July:** Baartman "Optimal Short Quad Shapes" PRST-AB 15, 074002
- **2011 Aug**: Quads for entire e-linac rationalized in 3 types.
- **2013 Feb:** Prototypes received
- **2013 Aug: All 80 quads received.**



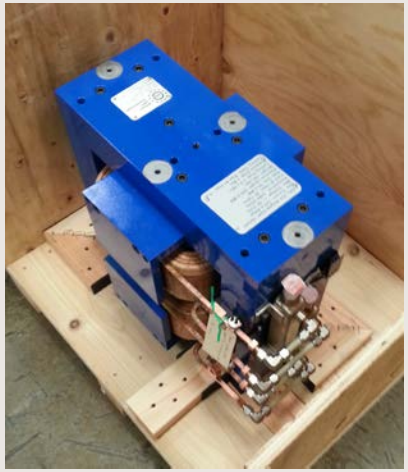
Weak: K ≤ 0.2 T

Strong: K ≤ 1.3 T

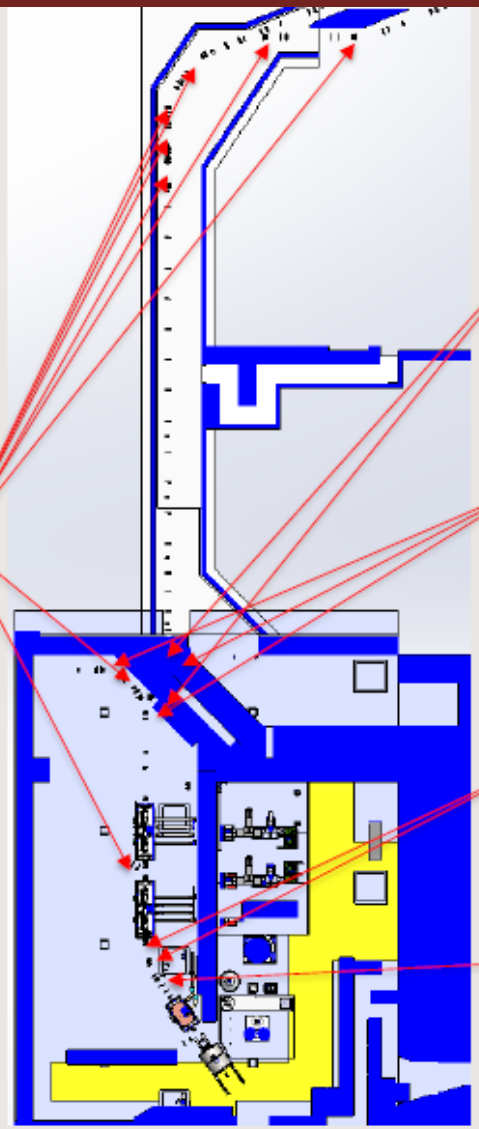
Medium: K ≤ 0.7 T

Dipole Magnets

S34 (qty=8)
Delivery
Oct/Nov 2013



Everson Tesla S34
ready to ship



DLVD (qty=2)
DN under review
Tender: November

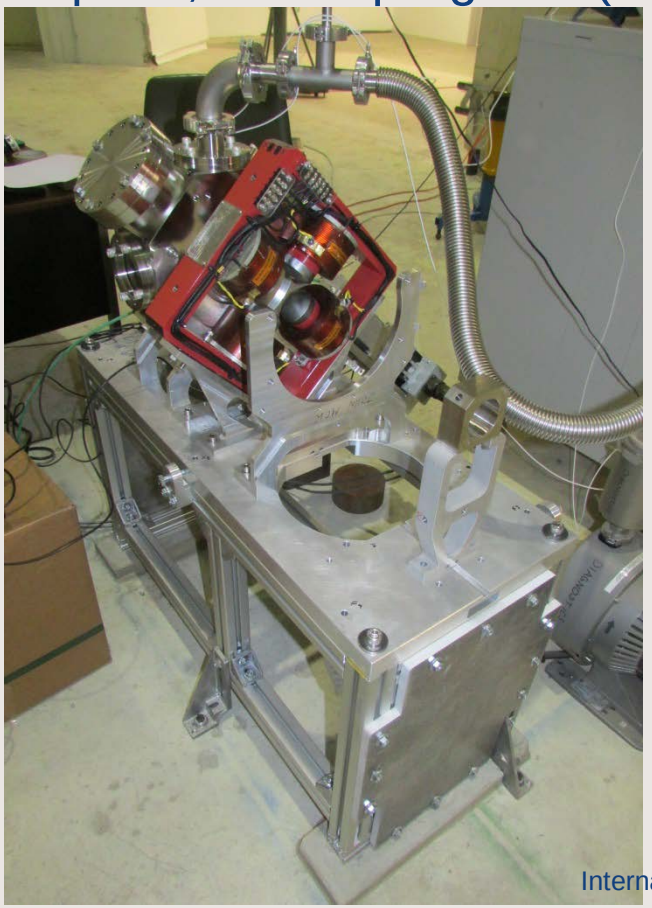
Y30 (qty=3)
Contract let
Sept 23

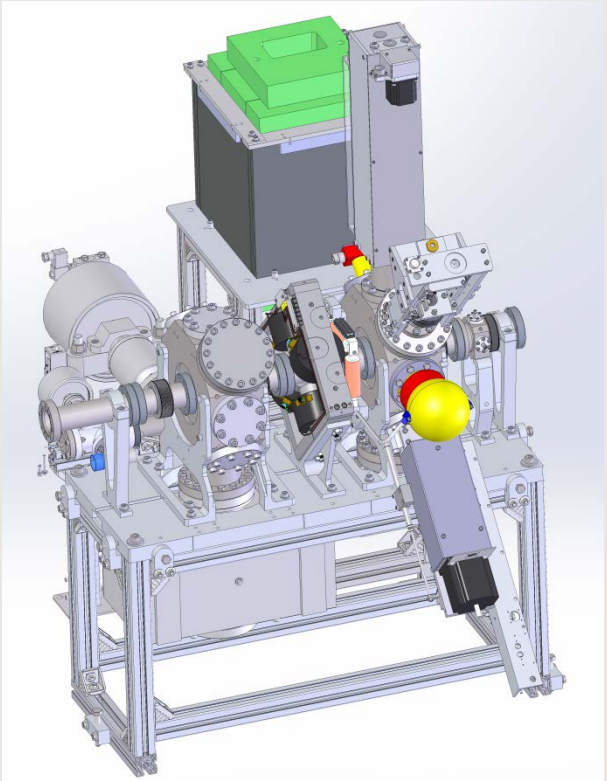
EMBT (qty=2)
Received 20th
June 2013

EMBD:MB0
(qty=1)
Received Jan

Beamline Stands

- All E-hall stands detailed.
- 200µm alignment tolerance
- Fabrication pending prototype: parts complete, test in progress (2013 Nov)

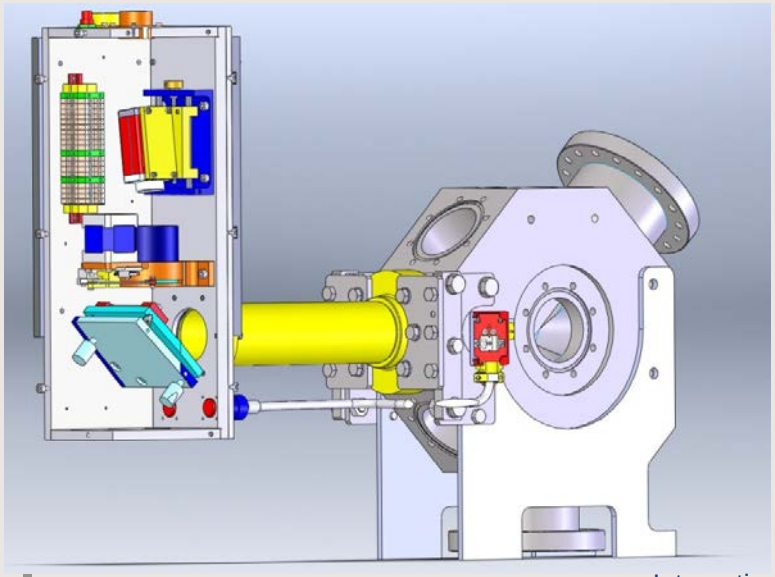




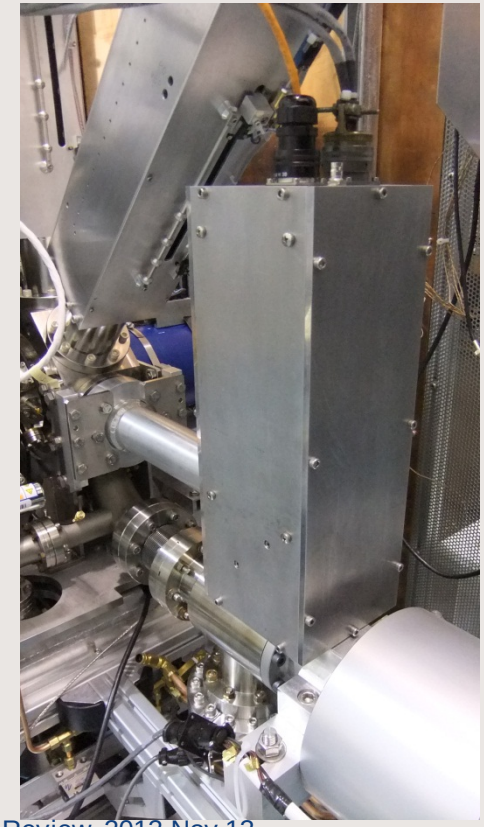
Milestones	installed & equip tested
EMBT	2014 May 01
EHAT/EHDT	2014 June 12
EHBT in tunnel	2014 Sept 30

Beam Profile Monitors

17 constructed; on track



Prototype camera box and screen at ELBT test area

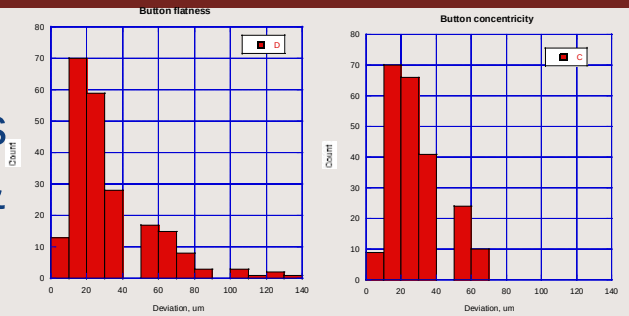


Ladder with targets

Beam Position Monitors

Backbone system

All 220 button electrodes received from Kyocera & dimensionally inspected.



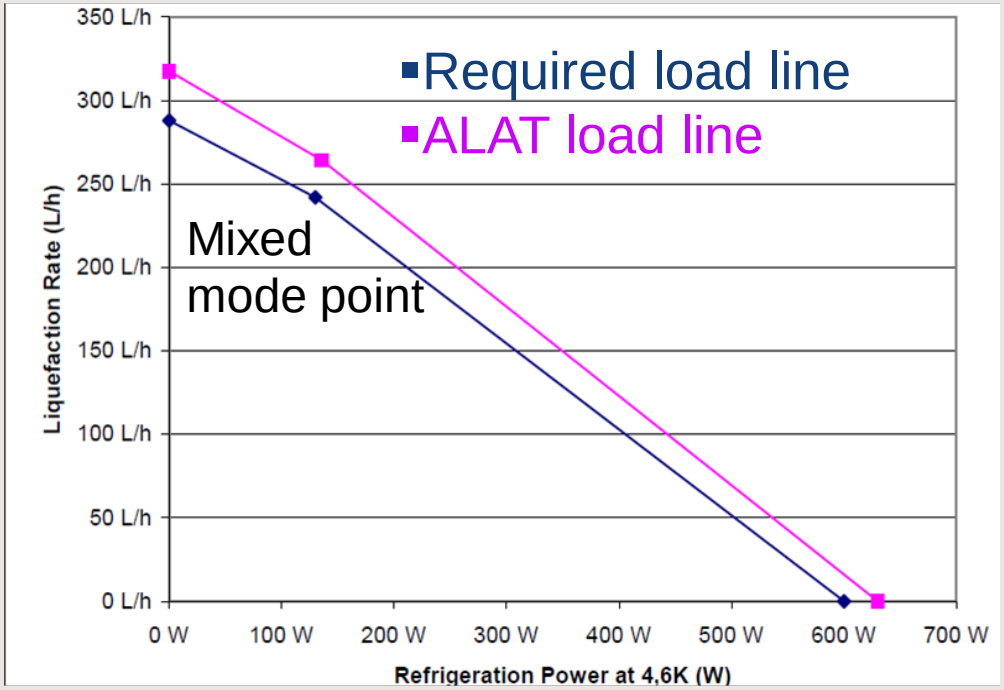
BPM Electronics

- Operates in pulse and CW modes. Fresh data available each microsecond.
- Need 56 units total
- Need 26 units by May 1st for e-hall.
- 3 complete, 23 more in assembly.
- On track.

Helium Cryogenic Plant 4K Acceptance Test

The plant shall demonstrate 3 modes:

- Mixed Mode: >130W @ 4,6K and 242 L/h
- Liquefaction: 288 L/h at 4.6K in the dewar
- Refrigeration: 600W at 4.6K in the dewar



- 2.5 years effort to this point
- Needs GHe system
  - Compressors
  - Storage Tank
  - ORGMS
  - Purity Monitoring
- Needs LHe system
  - Cold box
  - Dewar
- Warm/Cold He piping
- Needs LN2 system
- Final preparations Nov 11-15
- ALAT crew arrives Nov 18
- Test performed Nov 18-30

GHe System installation

- Oil Removal & He gas management system
- Delivered 2013 March
- Operating

Kaeser compressors

- 2013 Jan: Delivered
- 2013 Sept: Operating

LHe System Status

Leak Check at factory 2013 Jan 24

4K Cold box delivered 2013 March 28

Dewar received 2012 Dec.

- Dewar and LN2 Phase separator controls done
- Ready for 4K test

- Services installed
- Turbines installation Nov 11-15

Cryogenic System Milestones

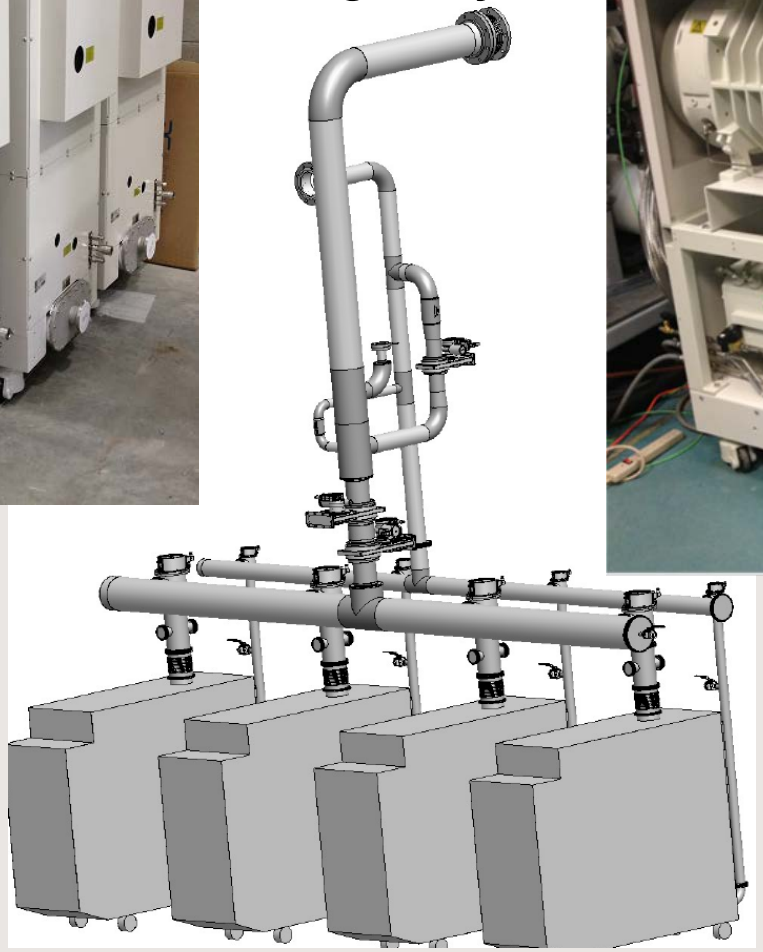
- **ALAT 4K test expected complete: 2013 Nov 25**

NEXT STEP: 2K test in e-hall needs:

- Sub-atmospheric He pumping system - installed
- 2K SA Line in e-hall complete & vac tested: 2014 April
  - He SAL HEX – delivery 2013 Nov 15
  - Sub-Atmospheric Line – delivery 2014 March
- LHe-to-CM distrib lines complete & tested: 2014 Jan
  - Cold transfer lines – delivery 2013 Dec
- Cryomodules with 4K/2K inserts in e-hall
- LN2-to-CM distrib lines complete & tested: 2014 March

2K Sub-Atmospheric Helium Pumps

Design layout

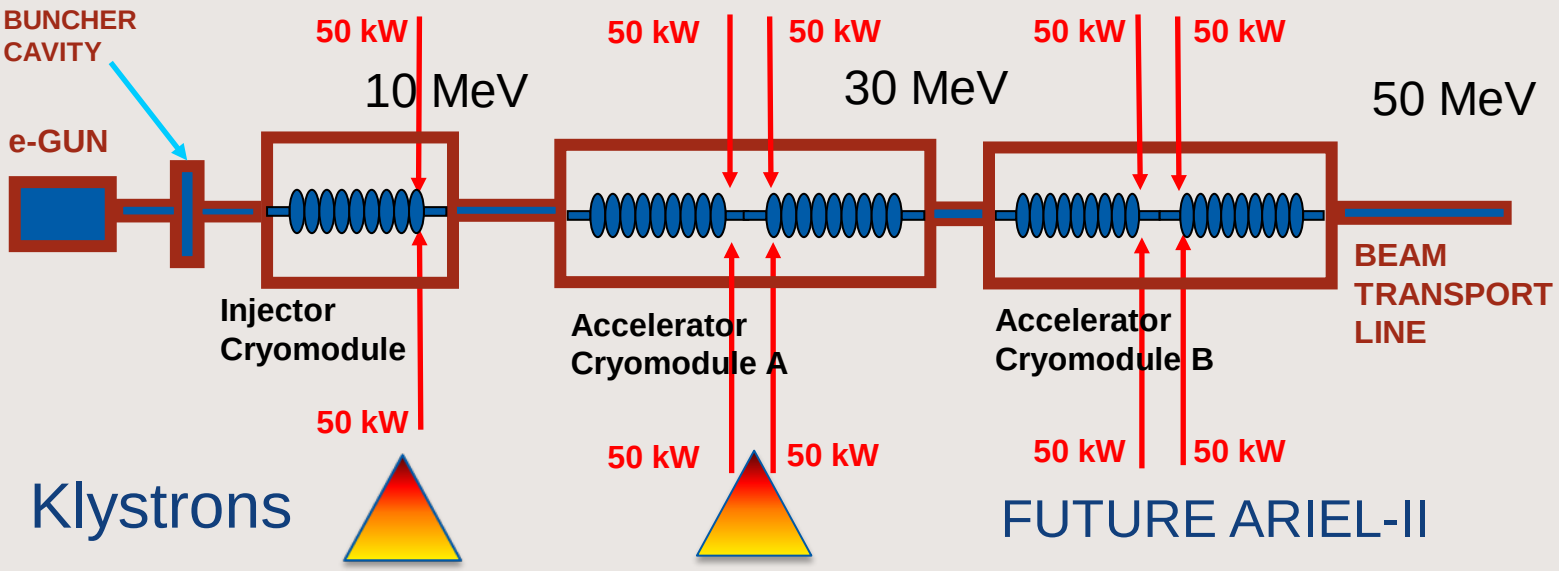


- 4 BUSCH Combi DS3010-He
- Roots blower & screw type backing pump
- Helium throughput 1.4 g/s at 24 mBar each

- 2013 March 15: delivered
- Tested at TRIUMF 1.3 GHz SRF facility

High Power RF

ARIEL	Year	Energy	Capability	Cavities	Couplers
Phase I	2015	30 MeV	300kW	3	6
Phase II	2020	50 MeV	500kW	5	10



Two 290 kW klystron and HVPS ordered.

- 1st klystron provides 100 kW rf for EINJ beam test May 2014.
- 2nd klystron provides 200 kW rf for EACA beam test Sept 2014.

klystron HVPS installation

A. Mitra, A. Spichiger of Ampegon, and R. Shanks.

600kW 65kV Power Supply

- HVPS uses IGBT-based, pulse step modulators (PSM)
- PM-14-10-VR is based on modulator PSM12-2400 for DESY XFEL
- 2013 May 29: Factory test
- Received Aug 14.
- Energized Sept 21.

- Powered with UPS, and communication between KPS and PLC established – Sept 12
- 720 kV transformer energized via Siemens 12.5 kV Switchgear – Sept 21
- Water cooling for KPS complete and interlocked.

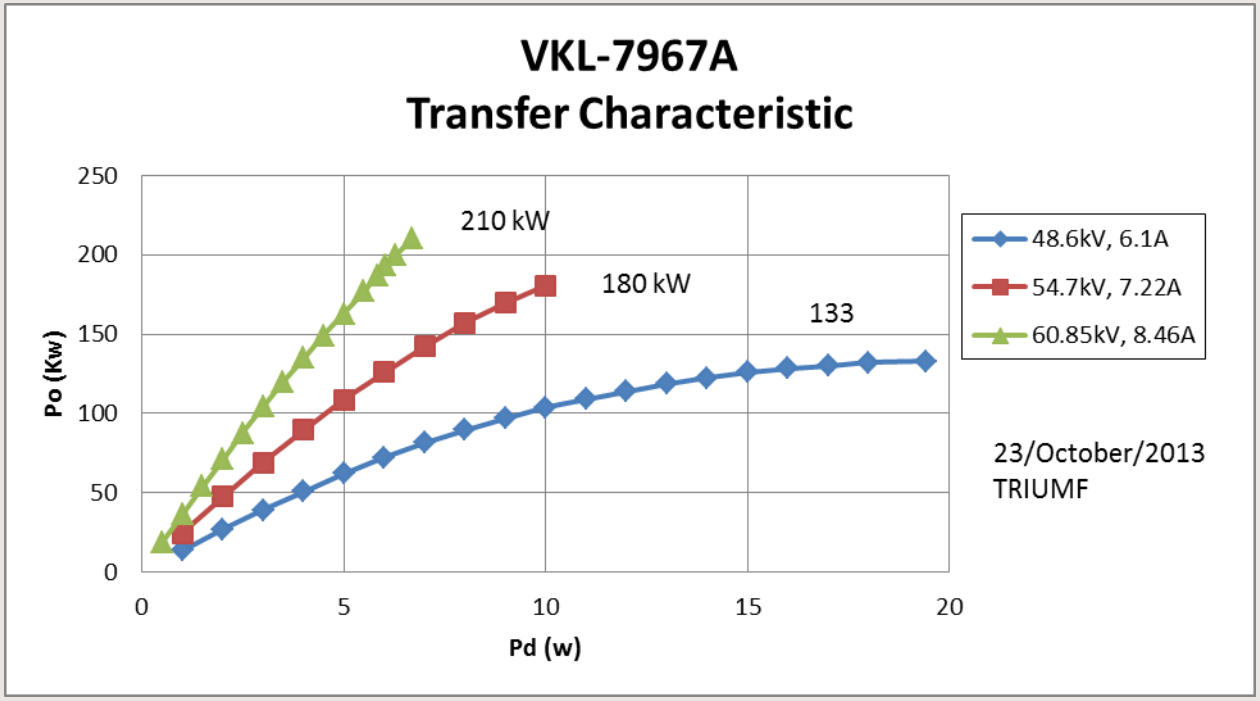
Klystron e-hall installation

Coordinated purchase with Helmholtz Zentrum “Berlin Pro”

- 2013 Aug 07: 300 kW Power divider received
- 3 Stub Phase Shifter spec in progress

- 2013 Jan 21: CPI Factory Test - 300kW achieved
- 2013 June 21: installed at TRIUMF
- 2013 Sept 25: circulator and water cooled waveguide loads installed

Klystron &HVPS Acceptance Test



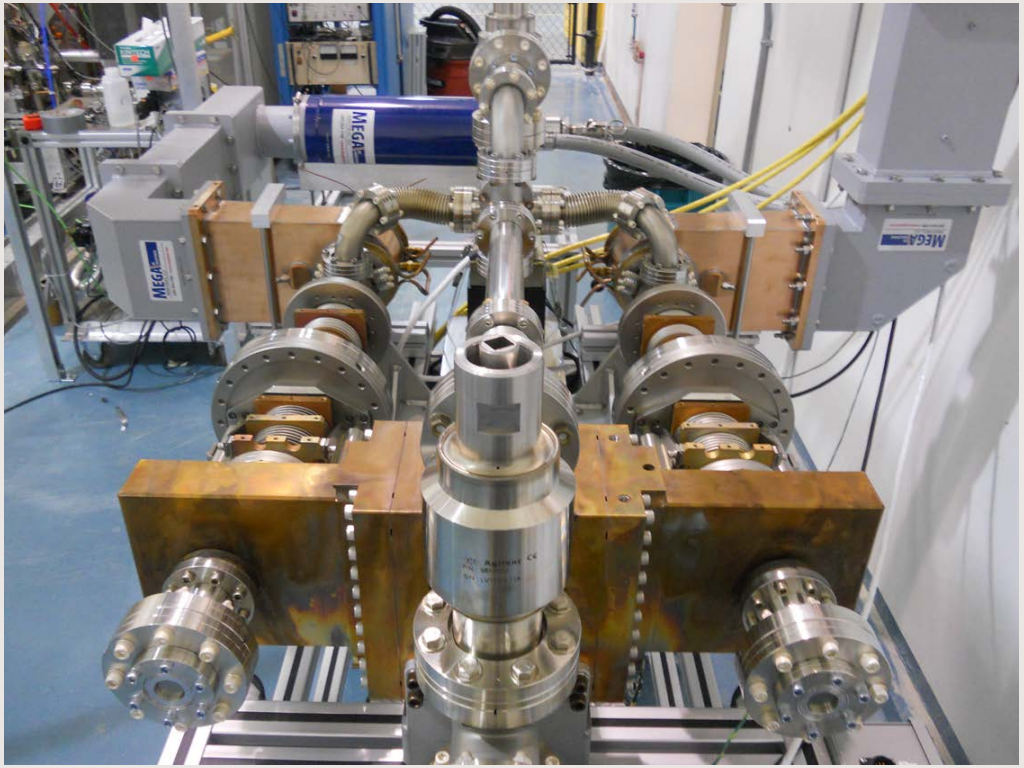
CW Power Output vs. RF Input Drive

Milestones

- EINJ klystron/HVPS 210kW RF demonstrated: 2013 Oct 21-25
- HPRF test to EINJ waveguide load complete: 2014 Jan 29
- EACA klystron and HVPS acceptance test complete: 2014 June 13

Power Coupler Conditioning Station

- Cornell/CPI Coaxial Couplers tested to 60kW at Cornell
- Need 50kW in cryomodule with cold intercept at 80K.
- Achieved 40kW equivalent with no intercept



- Four couplers conditioned at room temperature – procedure established – major success
- One week bakeout of warm window under N2 flow at 100C
- Achieved 12.5 kW c.w. in traveling wave
- 10kW pulsed in standing wave with a variable short
- Equivalent to 40kW in traveling wave

E-linac Major Milestones

CFI Project completion is defined as:

- 25 MeV & 100kW peak power at low duty factor at the e-hall beam dump
- AND installation (but not operation) of the EHBT in the ARIEL tunnel.

  - 300kV E-gun operating: 2013 Nov
  - EINJ 10 MeV beam at VECC: 2014 Feb
  - EMBT ready: 2014 May
  - EHAT & EHDT ready: 2014 July
  - EACA installed & equipment test: 2014 August
  - EACA beam commissioning to EHDT start: 2014 Sept 01
  - CFI completion: 2014 Sept 30

Conclusion

Outstanding Progress Across All Areas:

- ARIEL Buildings & E-Hall Occupancy
- 300keV Gun being commissioned
- ELBT complete & diagnostics tested
- Built & operating system integration test facility with VECC
- 1.3GHz cavity development highly advanced
- Injector Cryomodule assembly highly advanced
- Accelerator Cryomodule started fabrication
- Klystron & HVPS Acceptance Test Complete
- Cryogenic Plant 4K Acceptance Test: Nov 18-25
- 2K Cryogenic system well advanced
- Magnet procurements almost complete.

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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ARIEL E-linac Team

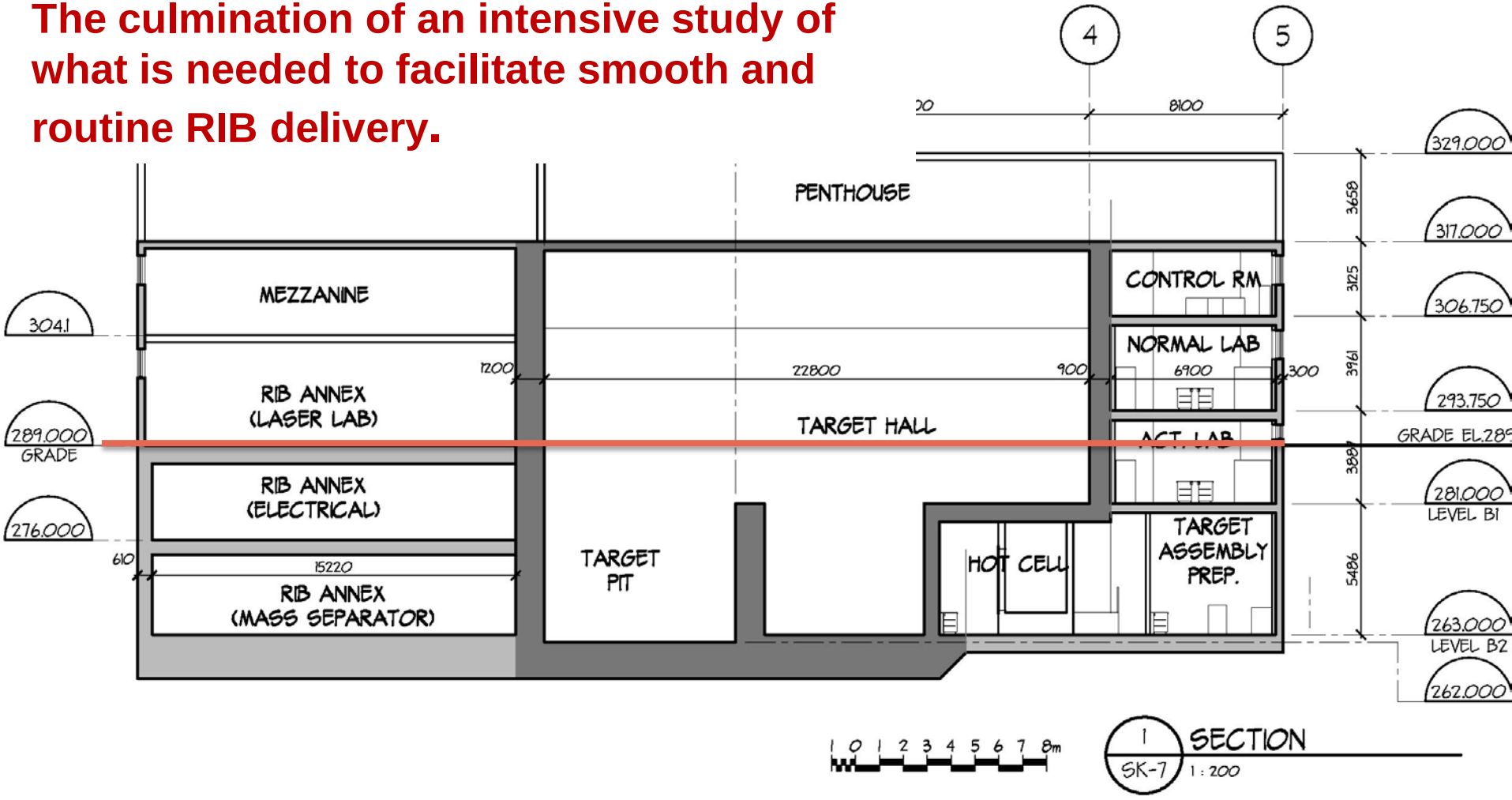
Thank you e-linac team:

Ames, Austen, Baartman, Ballard, Beard, Bylinsky, Chao, Clark, Dale, Drozdoff, Emmens, Fong, Hurst, Kaltchev, Khan, Koveshnikov, Laxdal, Levy, Louie, Mammarela, Merminga, Mitra, Mitrovic, Morrey, Preddy, Reeve, Ries, Richards, Rowbotham, Sitnikov, Teodoropol, Trinczek, Trudel, Verzilov, Waraich, Yosifov, Zvyagintsev.

At U.Vic: Karlen, Langstaff, Birney, Lenkowski, Abernathy,Storey.

ARIEL CF Design

The culmination of an intensive study of what is needed to facilitate smooth and routine RIB delivery.



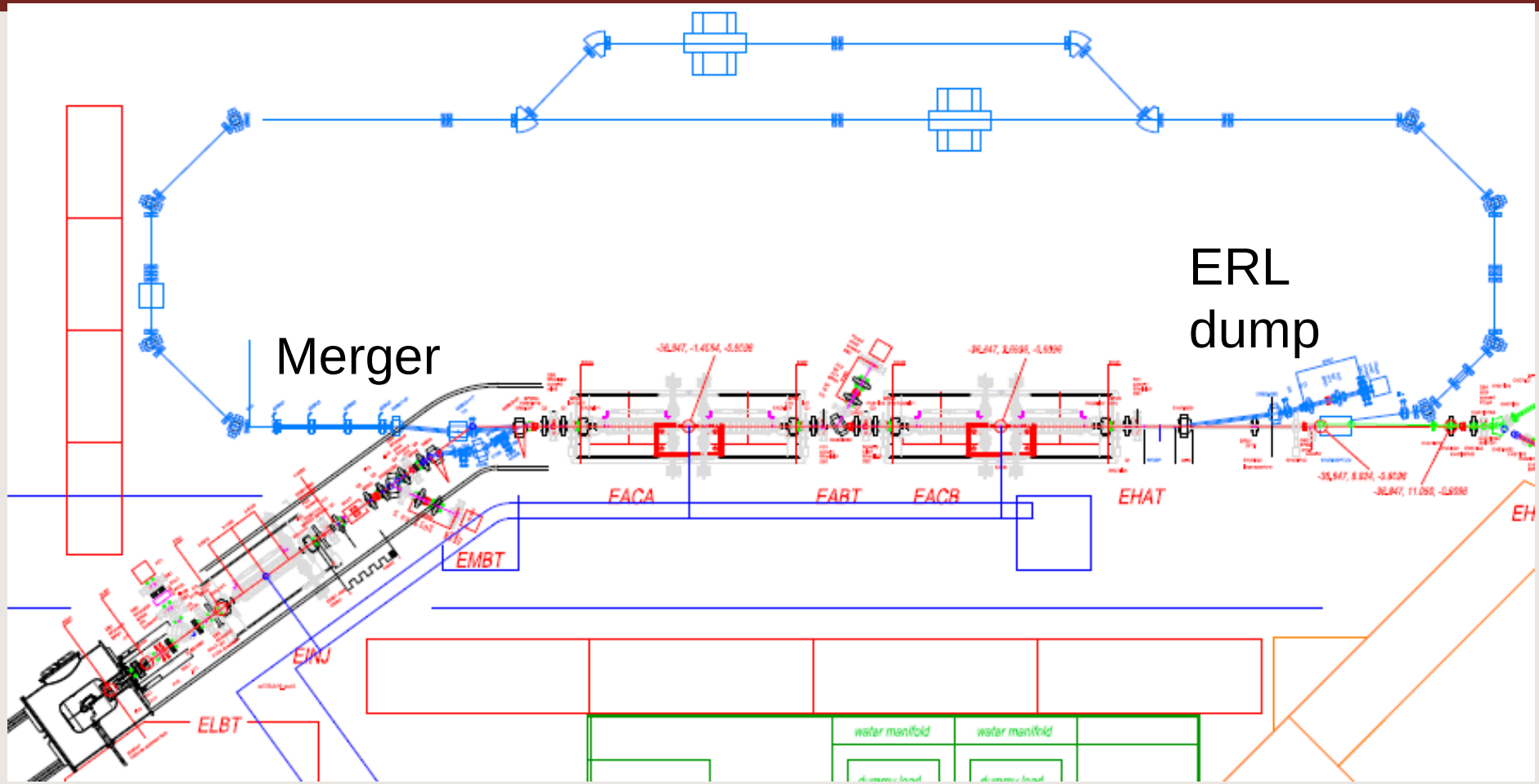
BL4N Shield Wall Complete

Site of future ARIEL-II proton BL4N

Contractor Package:

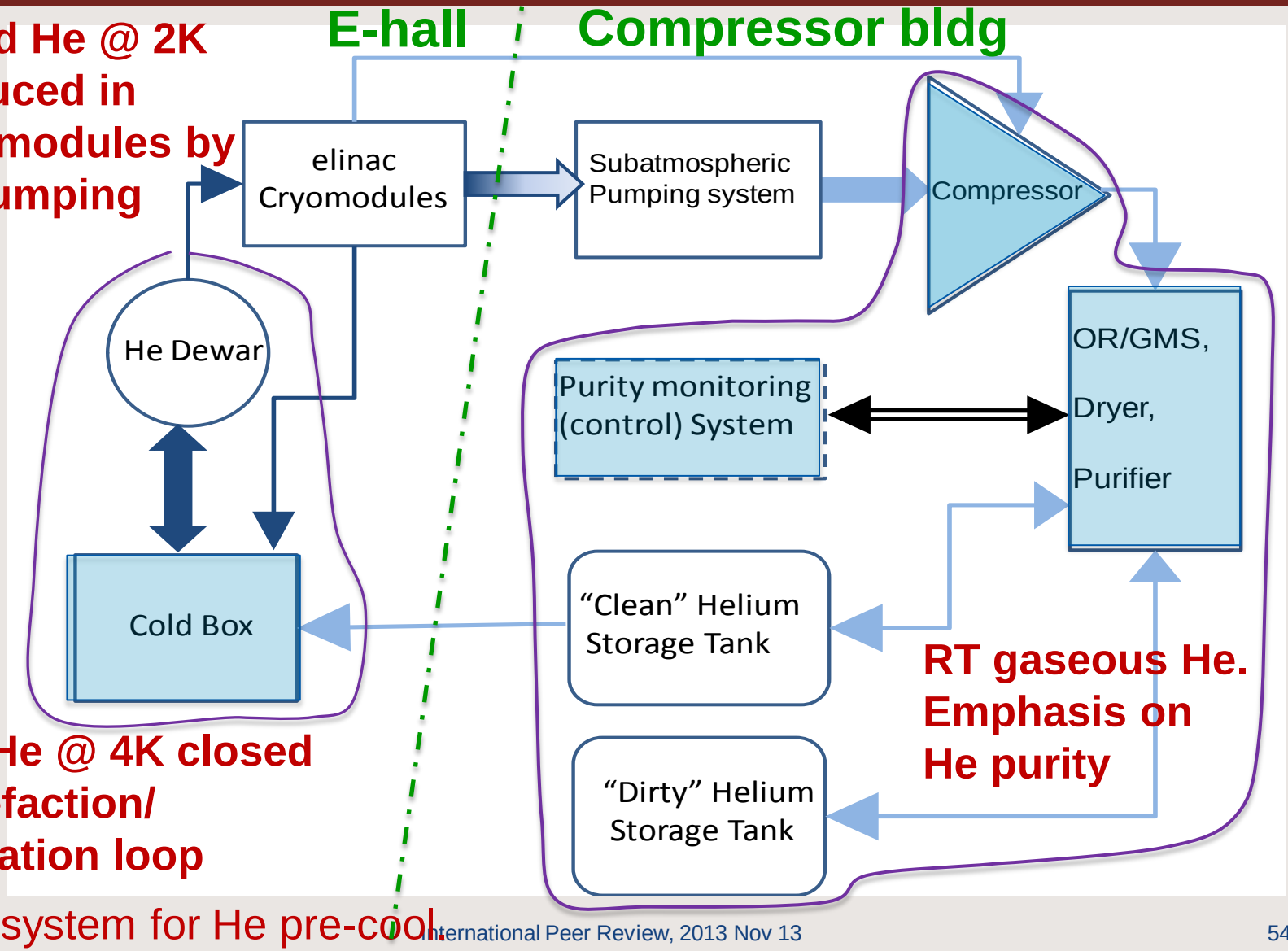
- Poured-in-place concrete
  - N. Wall (shields e-hall from BL4N)
  - Cave over 50MeV area
- Shielding upgrades
  - S wall B2 up to ground
  - W & E walls at grade
- Move & seal roof beams
- Install services

Future Recirulation Ring



Ring, merger & ERL beam line not funded at this time.

Helium Cryogenic System



Liquid He @ 2K produced in cryo-modules by SA pumping

Liquid He @ 4K closed re-liquefaction/ refrigeration loop

RT gaseous He. Emphasis on He purity

77K LN system for He pre-cool

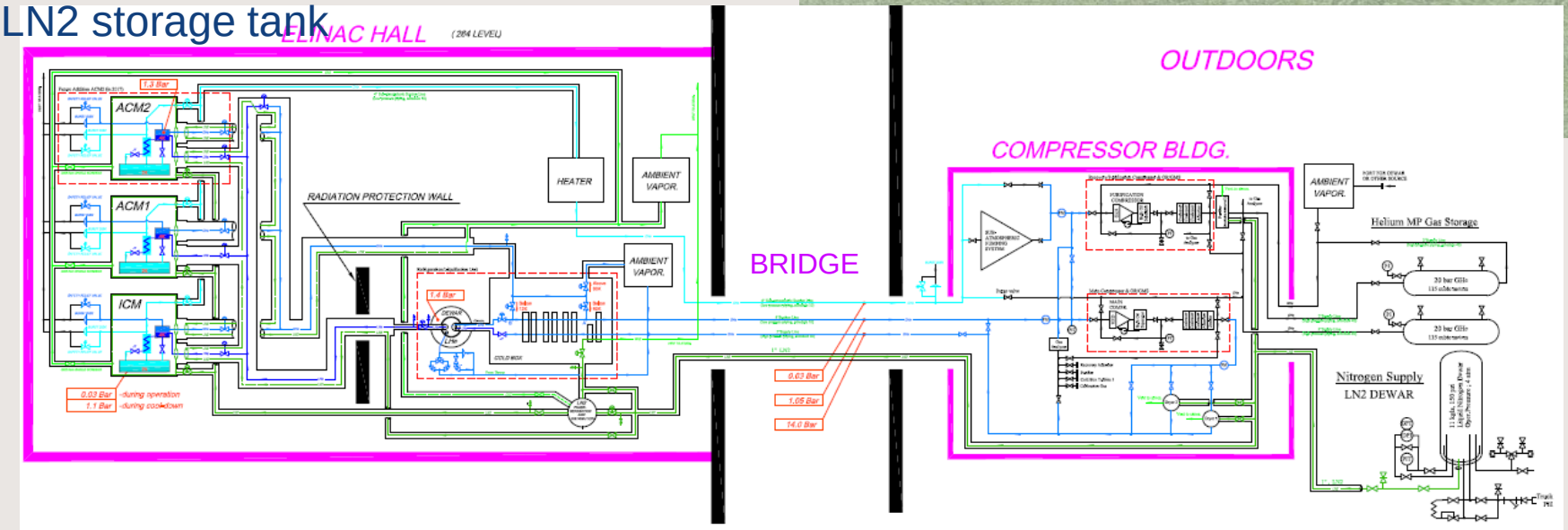
Cryogenic System

Located in Compressor Bldg:

- Main Compressor
- Purification/Recovery Compressor
- Oil Removal/Gas Management System
- Multicomponent detector
- Purifier
- Sub-atmospheric pumps

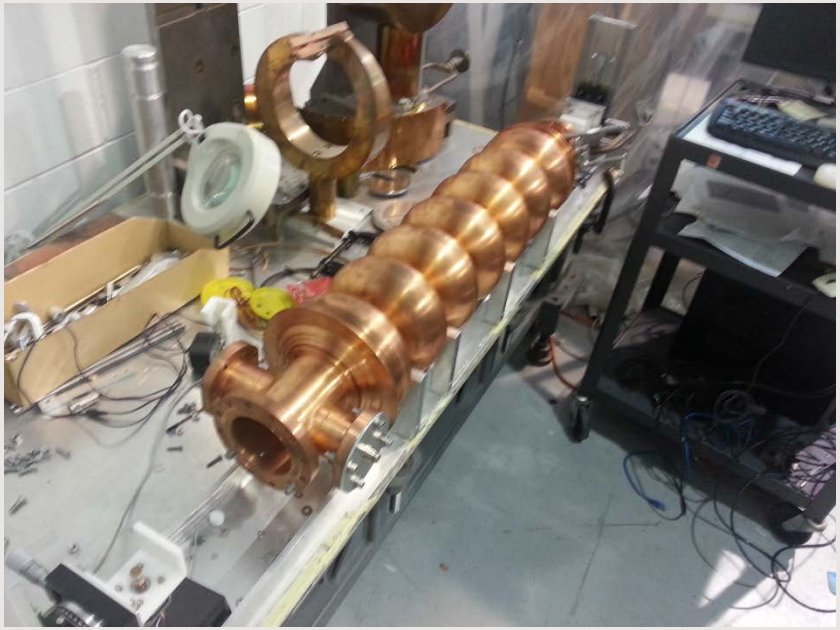
Located Outdoors:

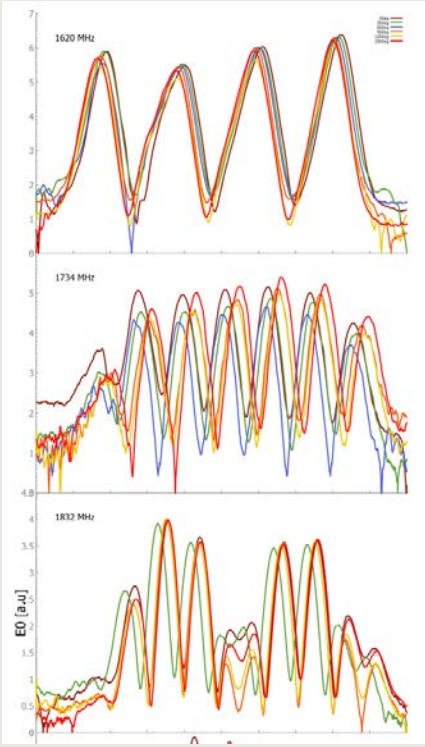
- GHe storage tanks
- LN2 storage tank

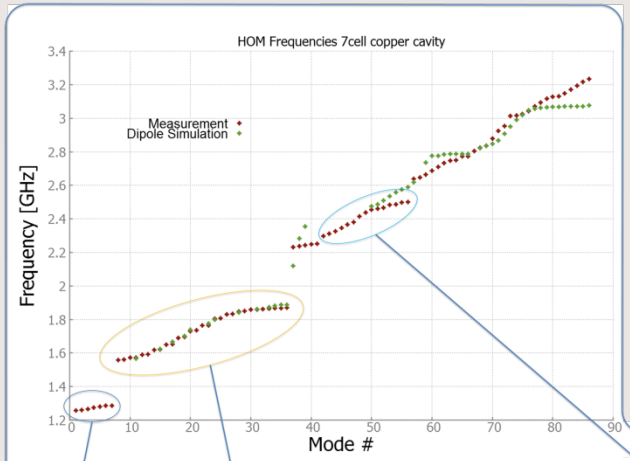


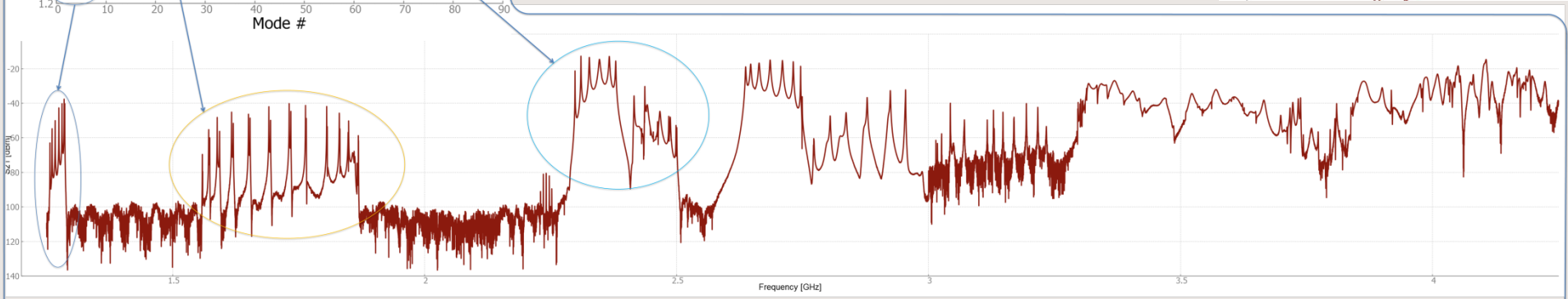
Copper 7 cell cavity: HOM measurements & bead pulls

Goal of the cavity design is to reduce the highest shunt impedance of any dipole HOM to 10^6 Ω or less.



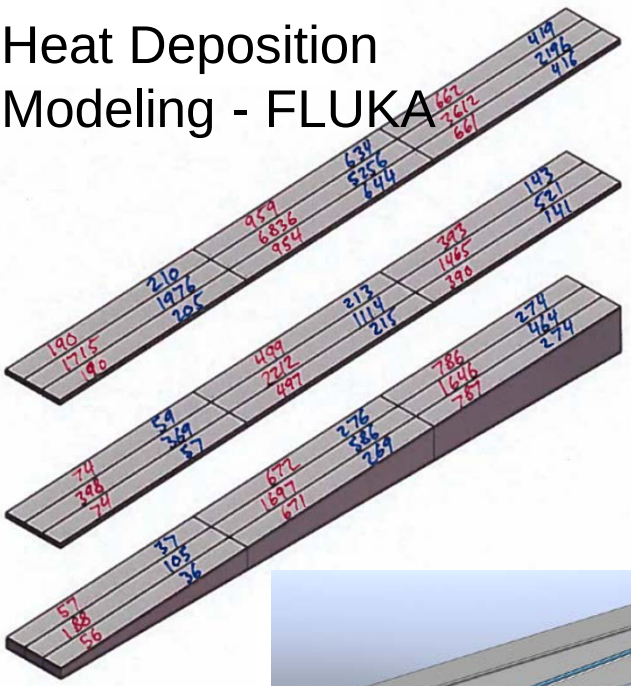


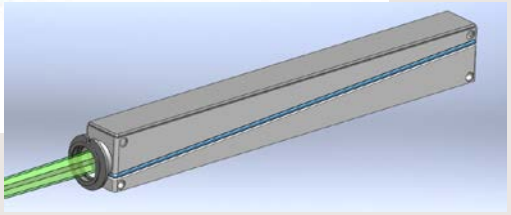




100kW tuning dump

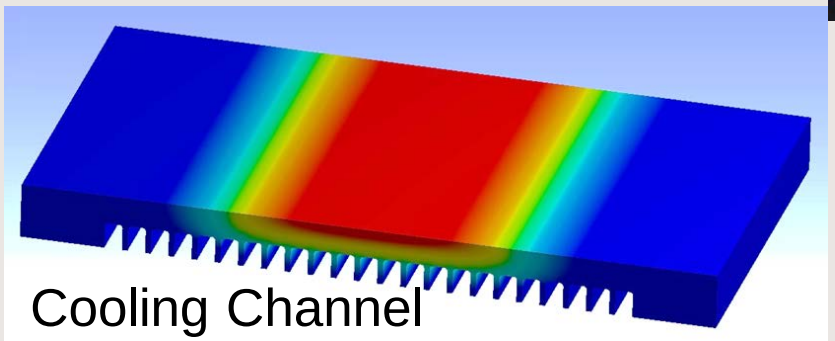
Heat Deposition Modeling - FLUKA





- Design review July 12
- Water package review October
- Tight schedule for May? 2014

BD Body Mockup ½-size

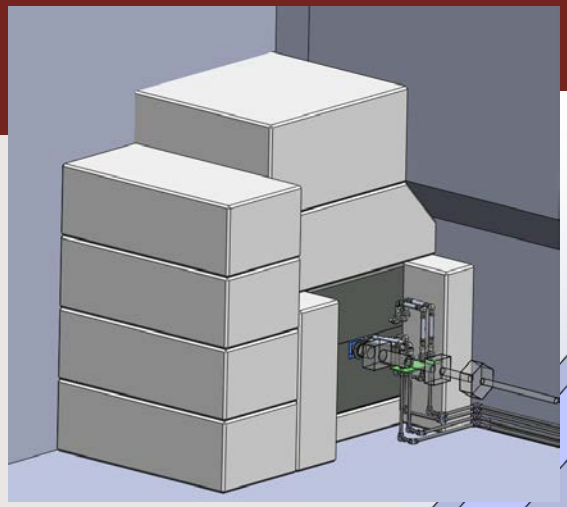


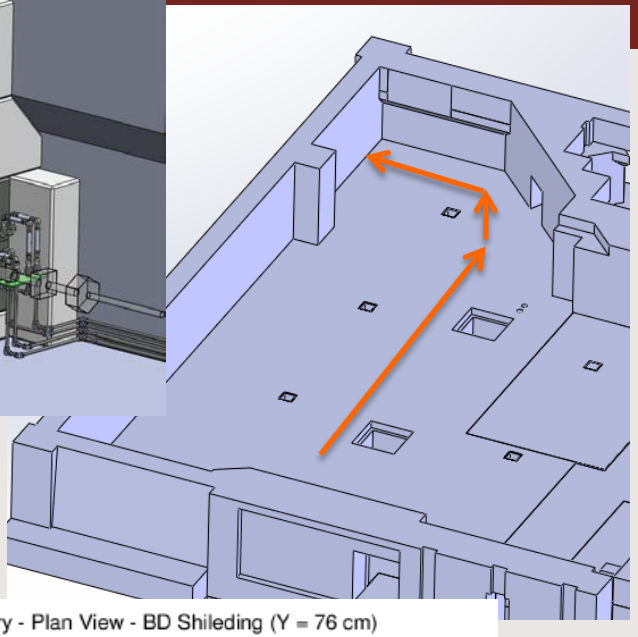
Cooling Channel Optimization

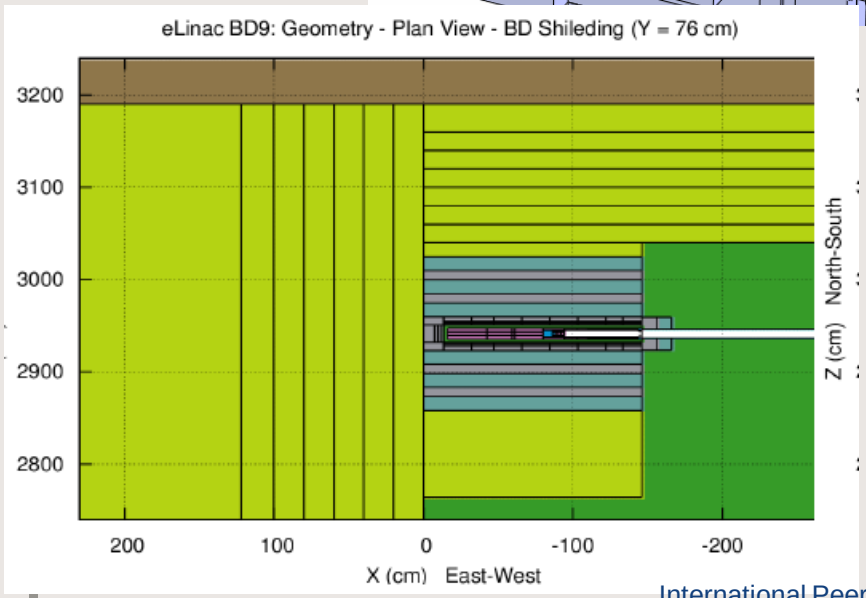
Welding completed on mockup

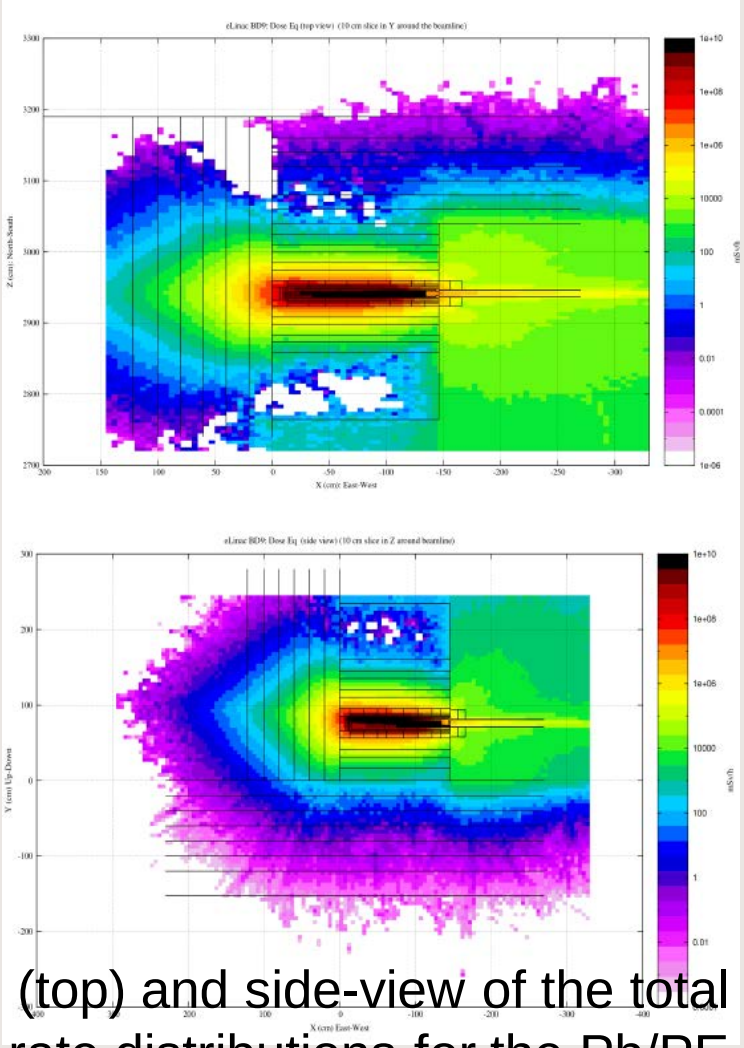
- 0.4mm lift at front and rear - correctable
- No twisting or sidewise bending of vessel
- Leak tight: 0.5*10-9 cc/sec leak rate on Varian after 3 mins

Beam dump shielding









Plan- (top) and side-view of the total dose rate distributions for the Pb/PE layer shielding configuration.