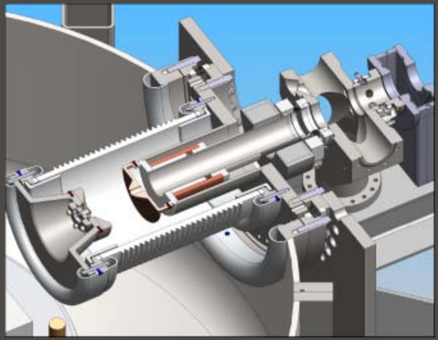
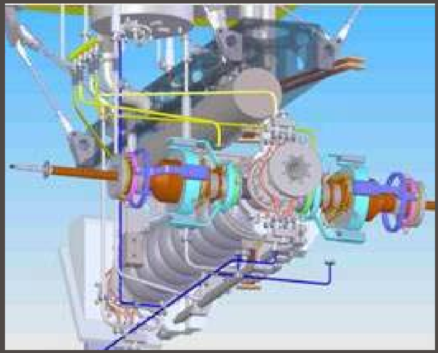
ARIEL Superconducting Electron Linac for Rare Isotope Program at TRIUMF





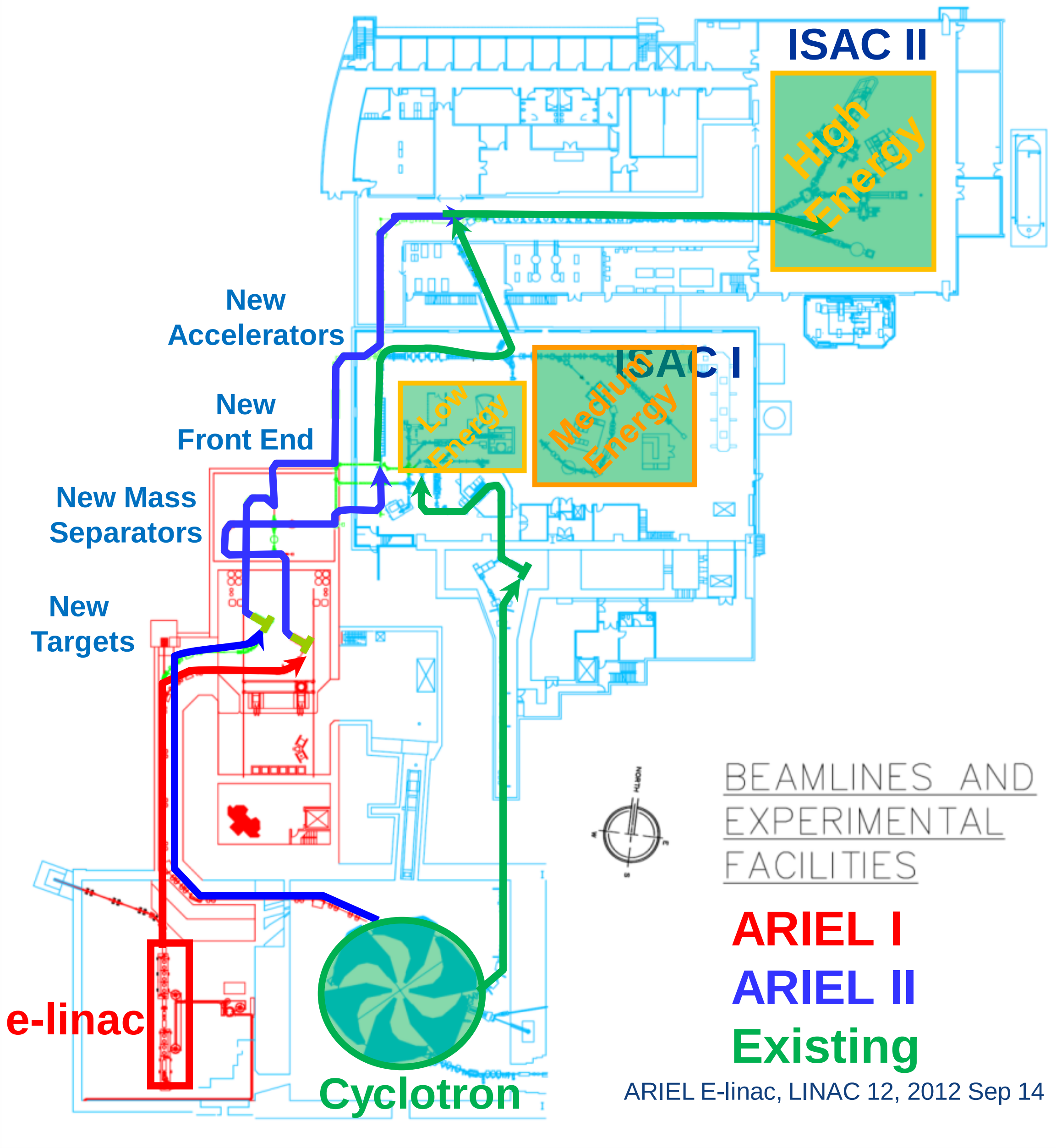
LINAC'12, Tel Aviv, Israel, 2012 Sept 12

Shane Koscielniak
for e-linac team

Outline

- Motivation: RIB science at ISAC
- Challenges of high-power CW SRF
- ARIEL Civil Construction
- E-linac progress – if time pemits
- Conclusion

ARIEL triples RIB science at ISAC



10-Year Vision: expanded RIB program with:

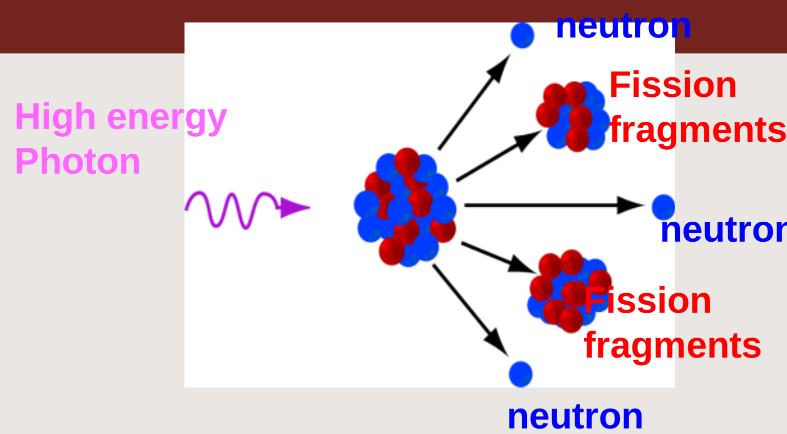
- three simultaneous beams
- increased number of hours delivered per year
- new beam species
- increased beam development capabilities

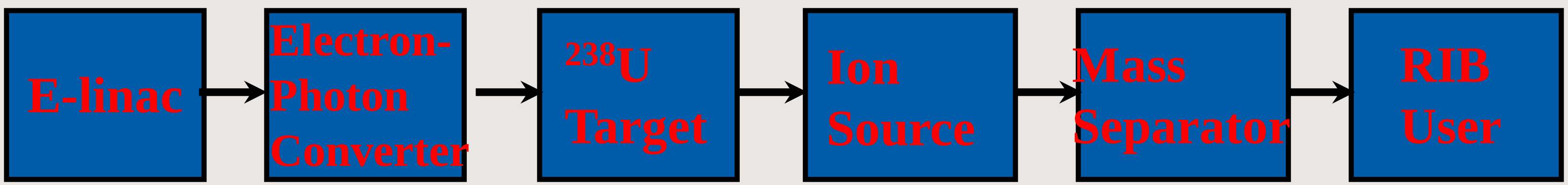
Implementation:

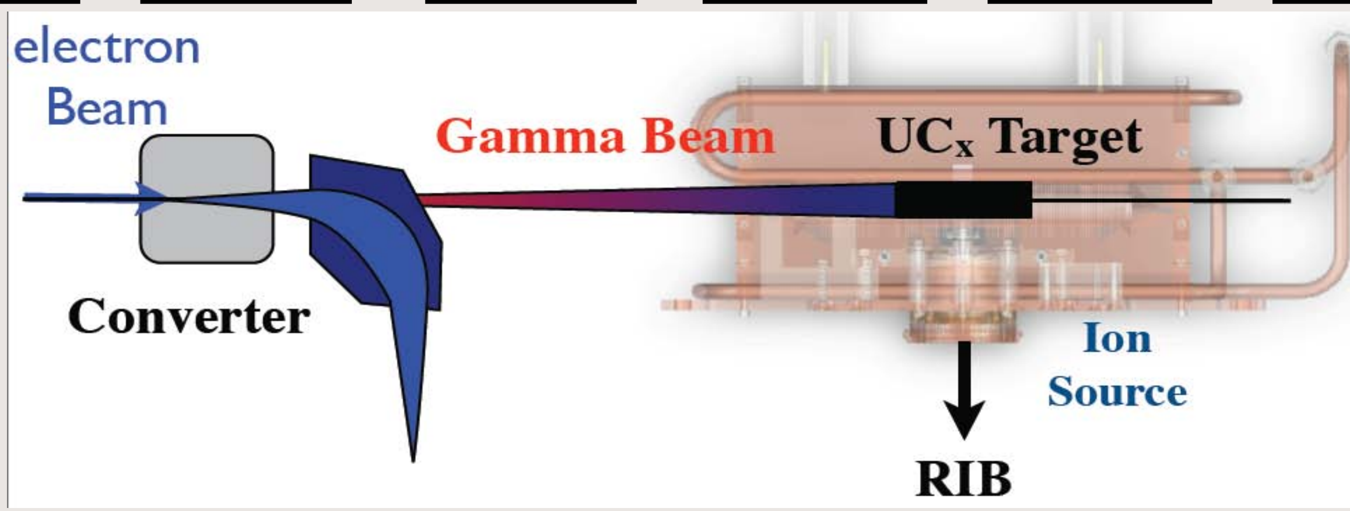
- Complementary electron linac driver for photo-fission
- New target stations and front end
- New proton beamline
- Staged installation

Photofission

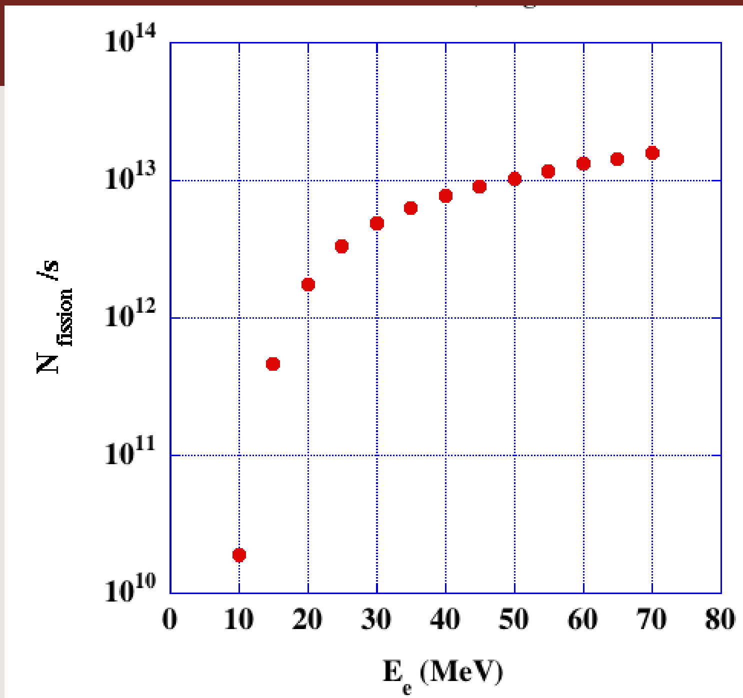
Photofission of ^{238}U was proposed by W. T. Diamond 1999 as an alternative production method for RIB.







E-Linac Physics Requirements



Number of photo-fission /second versus electron energy for 100 kW e-beam on Ta convertor and U target.

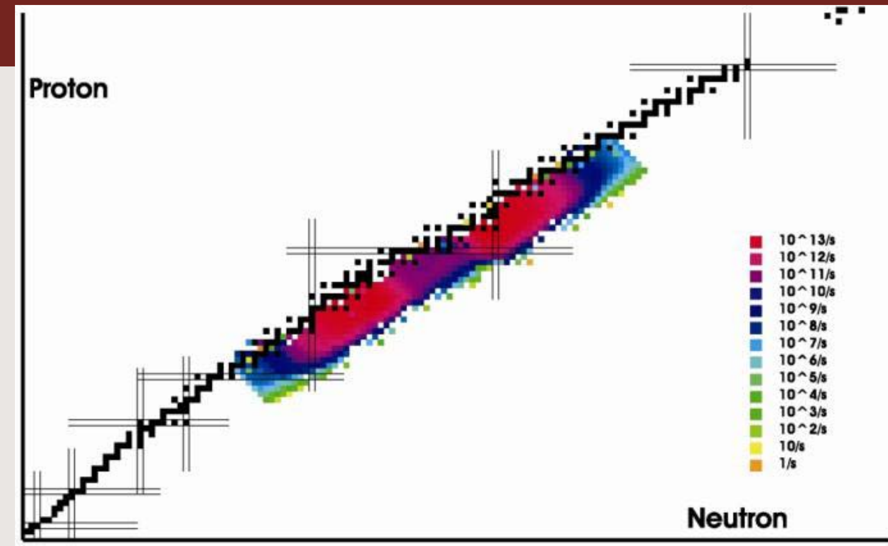


Photo-fission products distribution using 50 MeV 10 mA electrons on Hg convertor & UC_x target

For in-target fissions up to 5×10^{13}/s

Beam power (MW)	0.5
Duty Factor	100%
Average current (mA)	10
Kinetic energy (MeV)	50

E-Linac: Accelerator Overview

300 keV thermionic gun:
650 MHz modulated

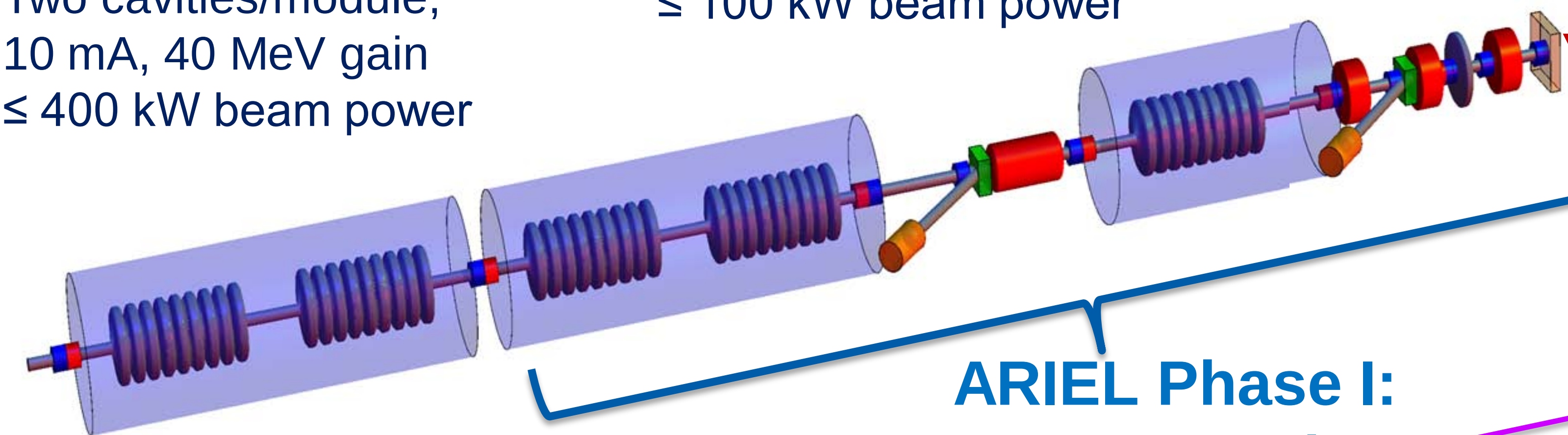
Accelerator:

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

Injector:

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

NC Buncher

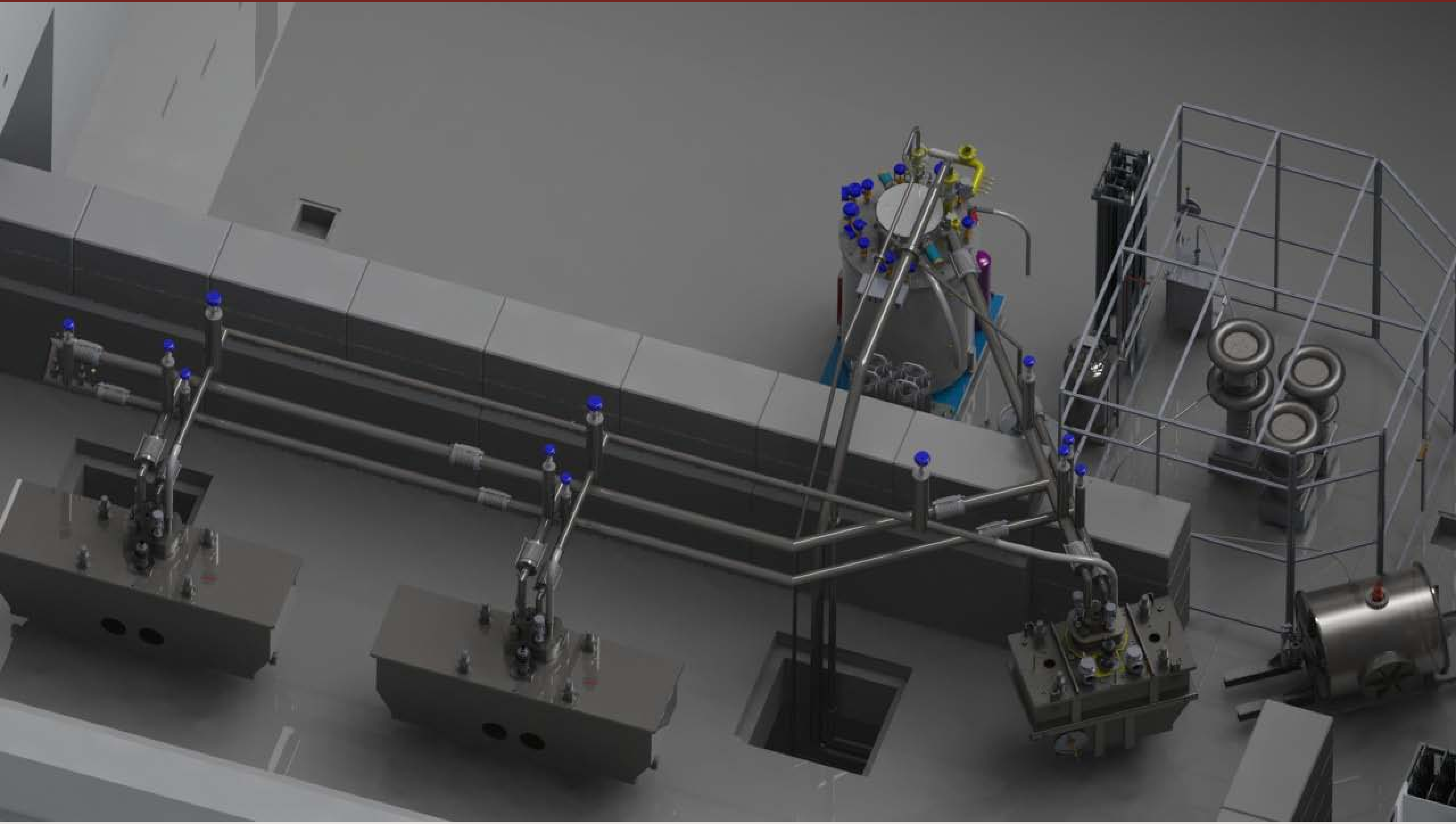


ARIEL Phase I:
25 MeV, 200kW

ARIEL Phase II:
50 MeV, 500kW

Installed Cryoplant for Phase I & II

E-Linac in e-hall



Adapt existing equipment designs when possible

- E-linac funding is based on the condition that it be useful to the nuclear physics AND high energy physics (e.g. ILC).
- Moreover, a design tenet was to adopt or adapt existing equipment design wherever possible.
- Hence the building block is a modified TTF style 9-cell cavity.

Challenges of CW operation

- Higher heat load in all RF components: cavity, input coupler, HOM absorber, etc
- Limited choice of c.w. klystrons, c.w. couplers

	Fission driver, 10 MV/m 4 cavity	ERL mode 20 MV/m 4 cavity	TESLA TDR 23.4 MV/m 12 cavity
RF Load (W)	41.6	166.4	4.95
2K Sum (W)	44.4	251.5	9.05
5K Sum (W)	29.1	34.5	15.94
Input Couplers	713	265	80.9
80K Sum (W)	717.6	601.2	183.02

Beam power related

2K & 80K sums almost 4× TESLA values

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Challenges of CW operation

- TESLA/ILC poster child for high gradient & low duty factor.
- Static heat load >> dynamic load
- Cryomodule design emphasis: “keep the heat out”

- ARIEL e-linac, and Cornel ERL Injector, are poster children for high-power CW electron linacs.
- Dynamic heat load >> static load.
- Cryomodule design emphasis: “get the heat out”

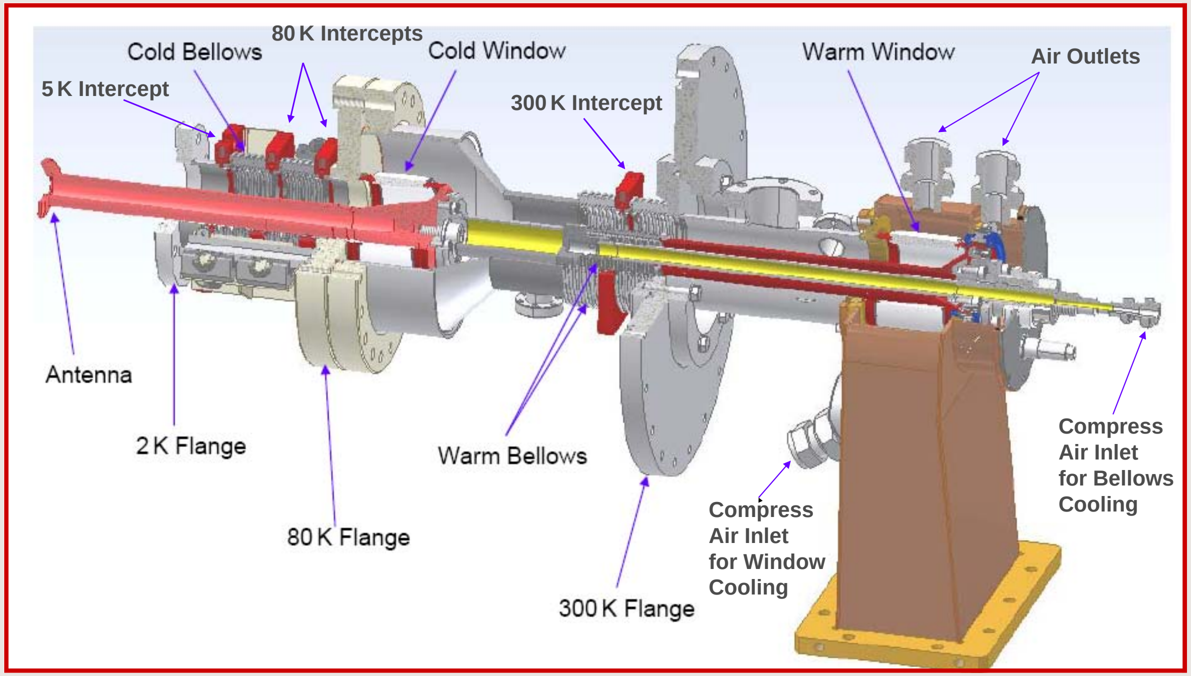
- Larger diameter chimney to 2-phase pipe*
- Slightly larger diameter LHe jacket
- No 4K thermal shield – not cost effective

*c.f. BESSY FEL CM: heat-flow <1 W/cm^2 at 1.8 K

TRIUMF

High-power CW input couplers

- RF Couplers are a heat load both to the cavity and to themselves.
- This is a problem already solved by Cornell since 2007.

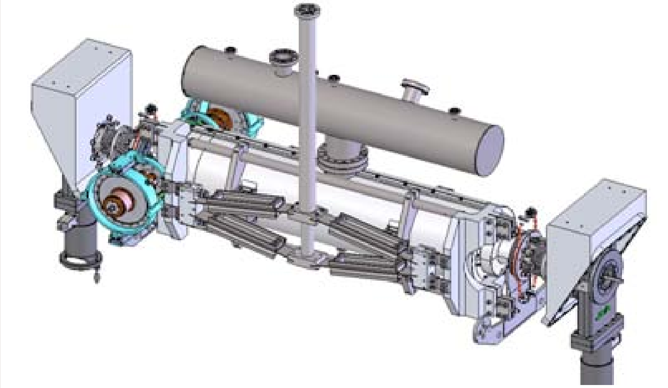


S. Belomestnykh: Cryomodules for high current CW linacs and ERLs; 2007 July 26

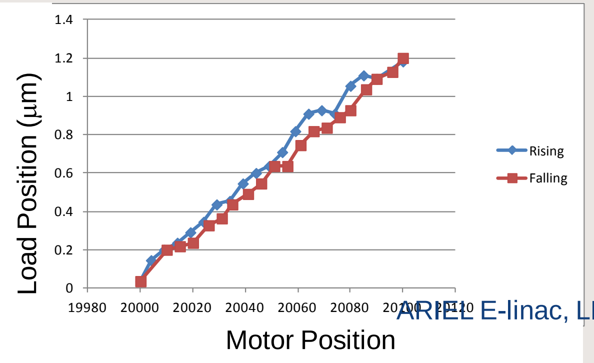
Choice of cold tuner

CW low gradient operation has benefits

- No periodic beam-load transients & small Lorentz-force detuning
- No need for piezo actuators
- Small number of cavities, makes e-linac vulnerable to loss of a cold tuner.
- To mitigate risk, a warm tuner drive was chosen to operate a modified Jefferson lab screw jack tuner.



Scissor tuner

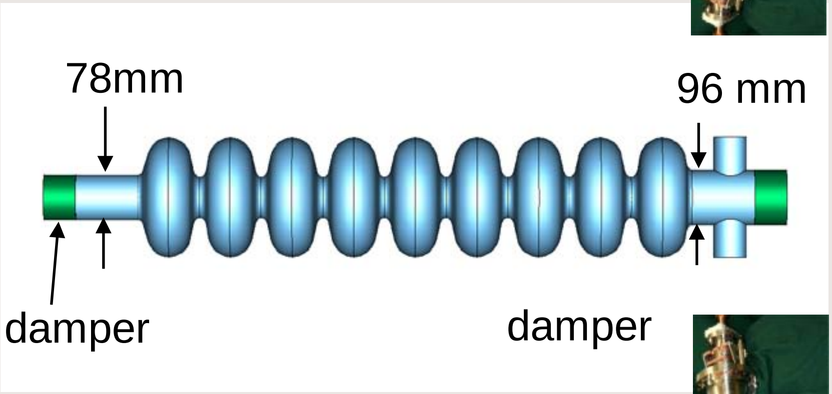


"Backlash free" demonstration

Cavity Shape & HOM damping

- Use Cornell coupler → must increase pipe OD c.f. TTF cavity
- For the single-pass RIB beam, low bunch charge (16pC) → marginal (or no) need for HOM damping
- **BUT dream of adding recirculation path for RLA or ERL operation**
- **HOM damping target set by Regenerative (2-pass) BBU instability**
- **20-40mA BBU threshold if (R/Q)Q<10^7 for all modes**

- 9 cell cavity
- Inner 7 cells TTF geometry
- Modified end groups for larger coupler &HOM damping

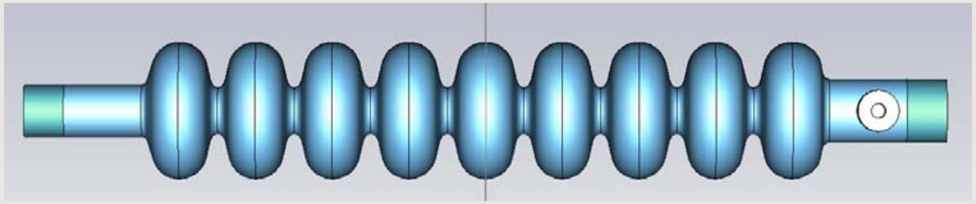


Two 50 kW Cornell/ CPI coupler per cavity

Cavity Shape

Calculated HOMs spectra for variety of geometries with SLANS and CST μλ

“Tuner side” SS ring damper



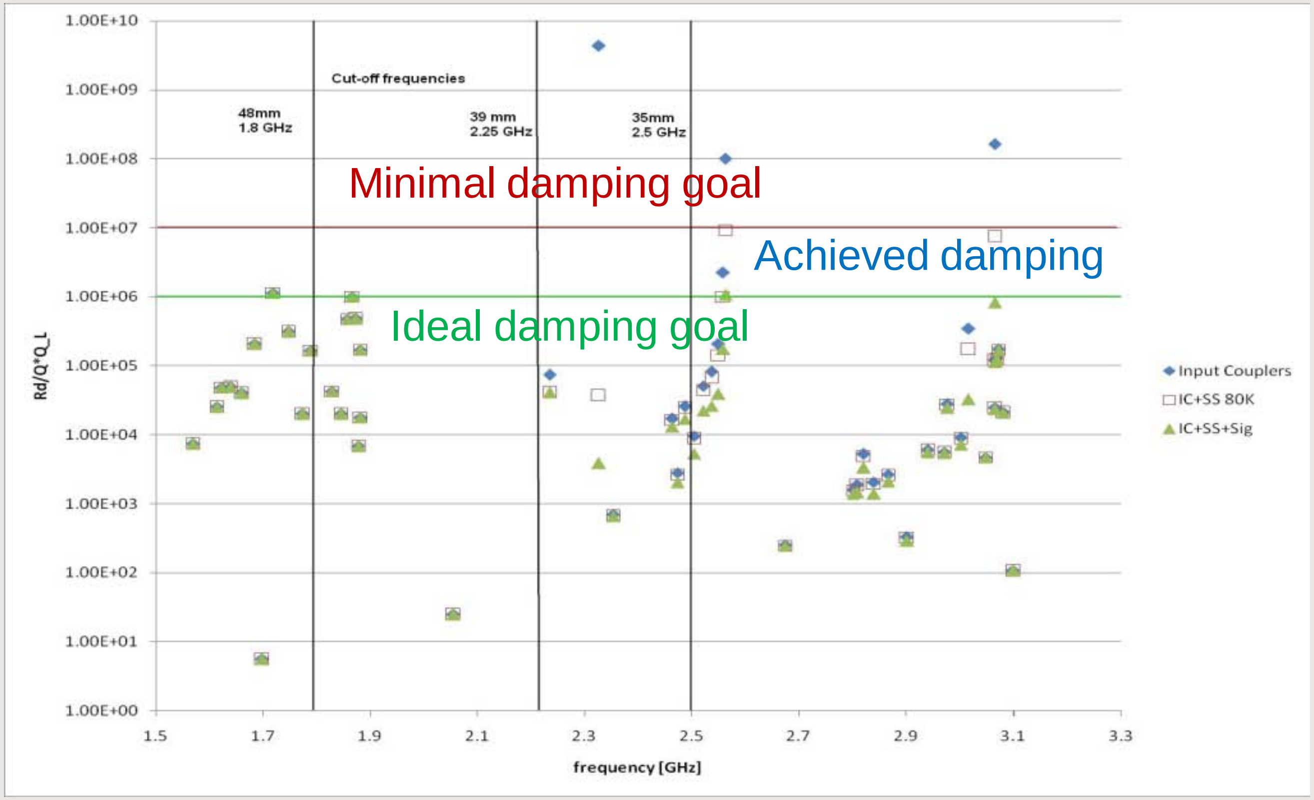
Coupler side C-Si ring damper

Tuner side	Inner 7 cells	Coupler side
39	35	48
48	35	48
55	35	48
39	37	48
55	40	48

Iris radii (mm)

Cavity & HOM Damping

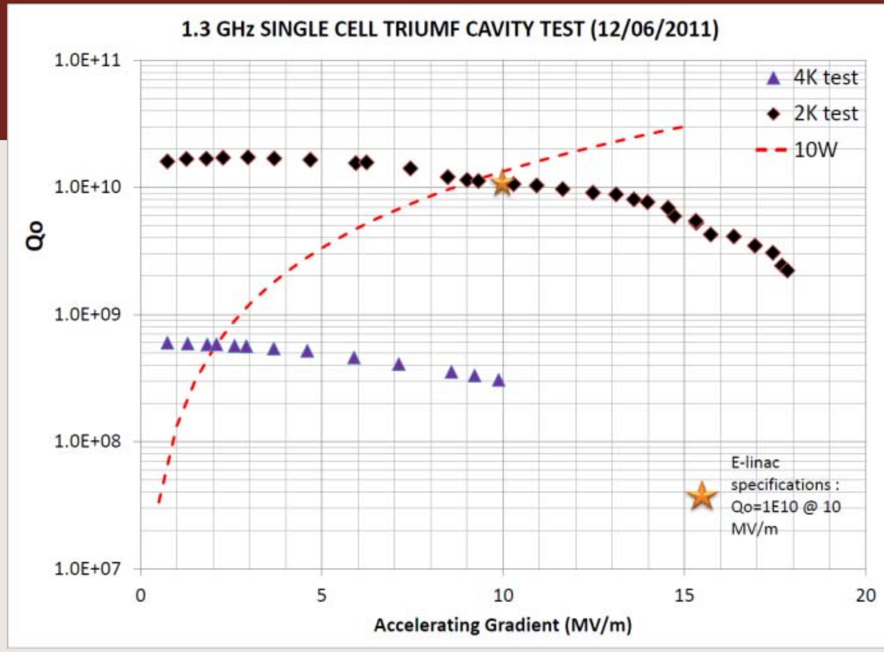
HOM frequency spectrum and shunt resistance for 9-cell cavity



- 39/35/48 mm iris geometry gives the lowest maximal $(Rd/Q)\times Q_L$
- Damping by SS ring on coupler end, CESIC ring on tuner end
- All modes $(Rd/Q)\times Q_L < 2\times10^6$ ohm

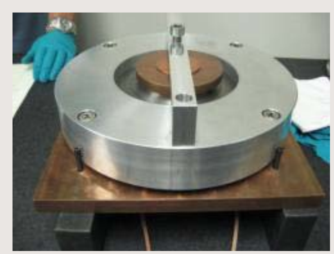
TRIUMF

Cavity Status

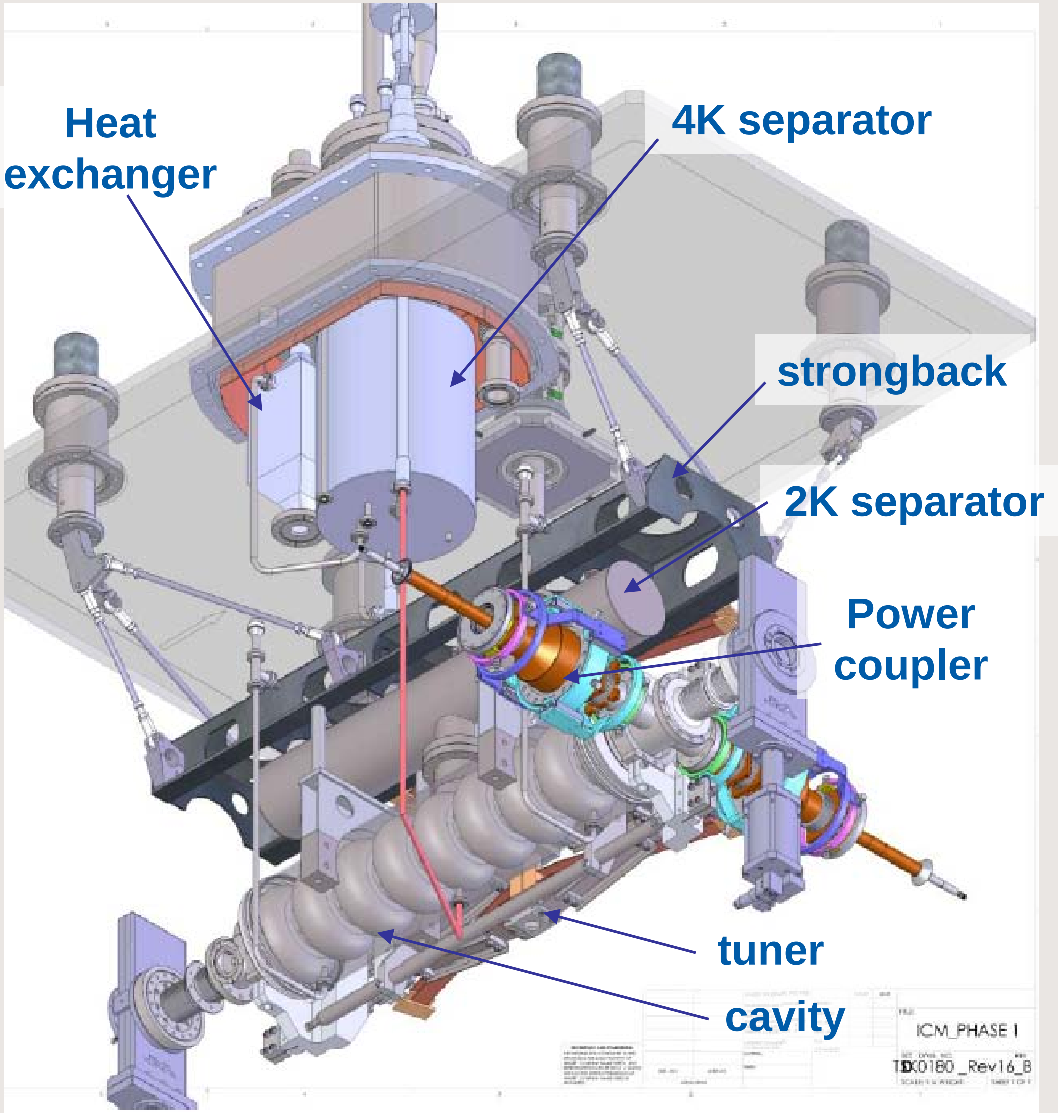


2011 Dec Success:
7 out of 7 PAVAC/TRIUMF single-cells meet Q0 requirements

- **7 cell Cu cavity delivered 2012 Feb**
- **Nine cell cavity design fixed & tooling optimized**
- **Four Nb cells formed and welded**
- **9-cell delivery 2012 Dec**



Injector Cryomodule



Cryomodule concept borrows significantly from ISAC-II

Top loading box concept with cavity mounted to strongback that is suspended from struts

Box gives headroom for on-board 2K/4K HX and 4K separator

- All procurements in hand
- Fabrication underway
- Cavity, 4K/2K insert (95% done)

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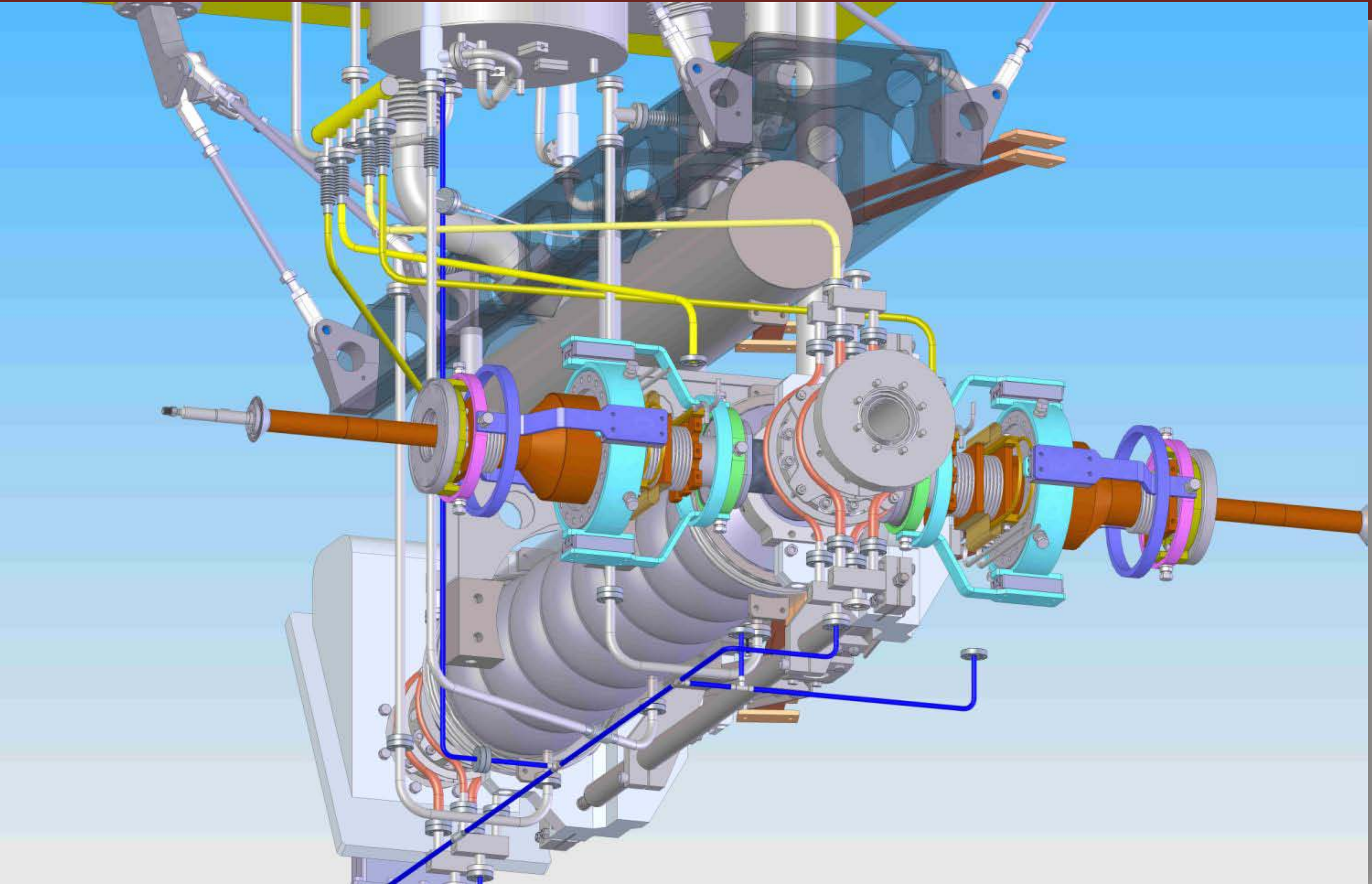
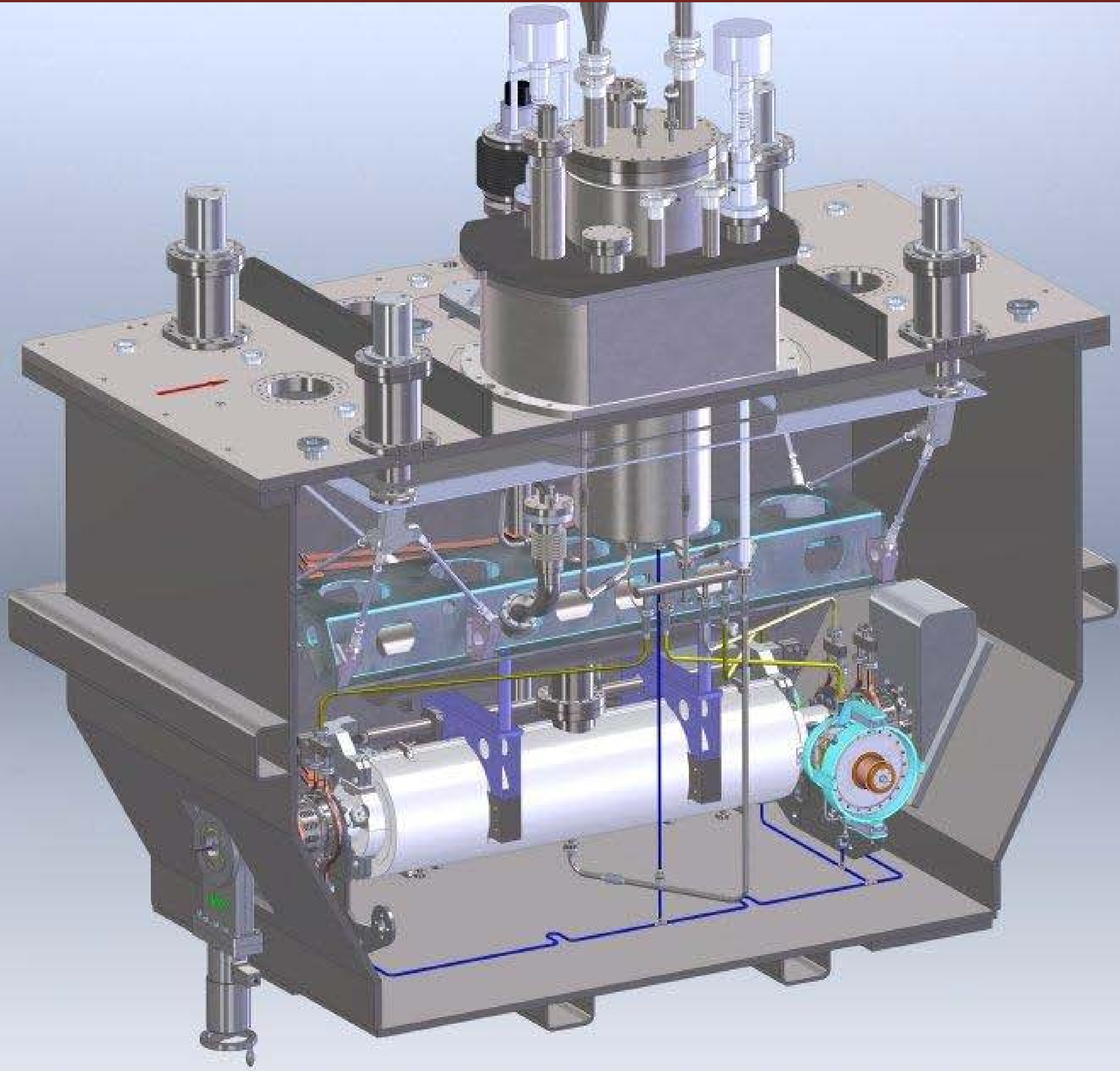
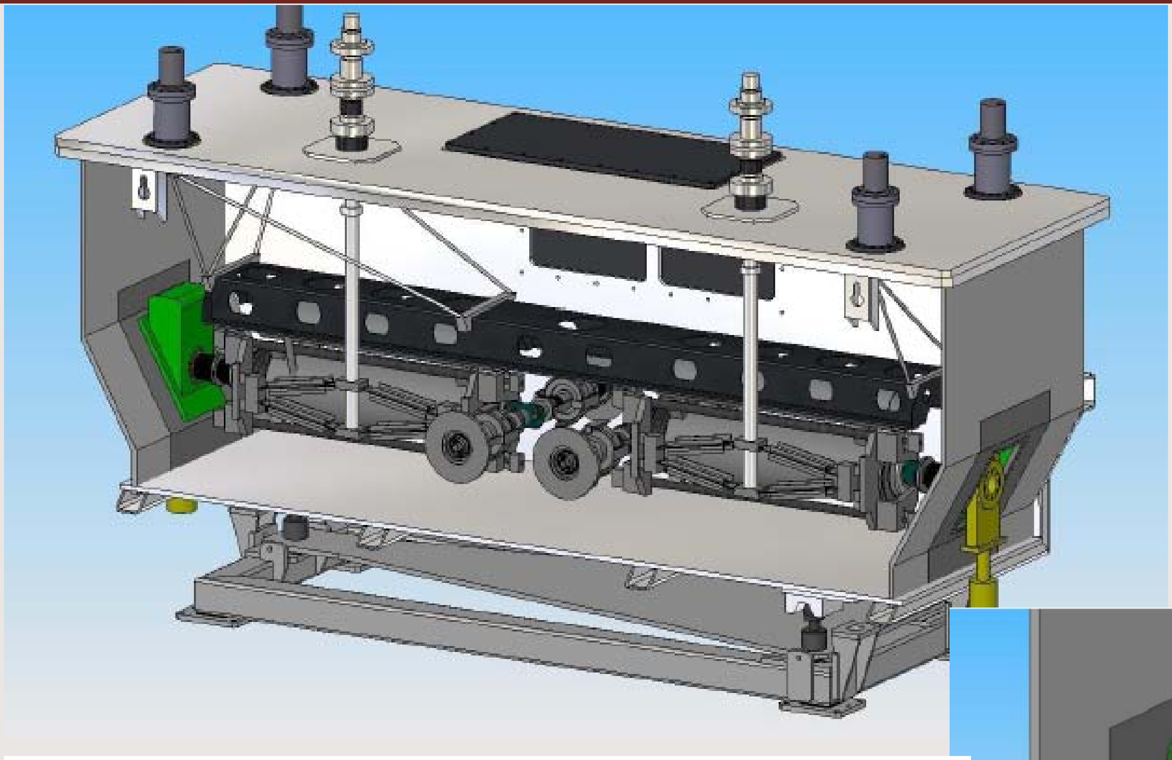
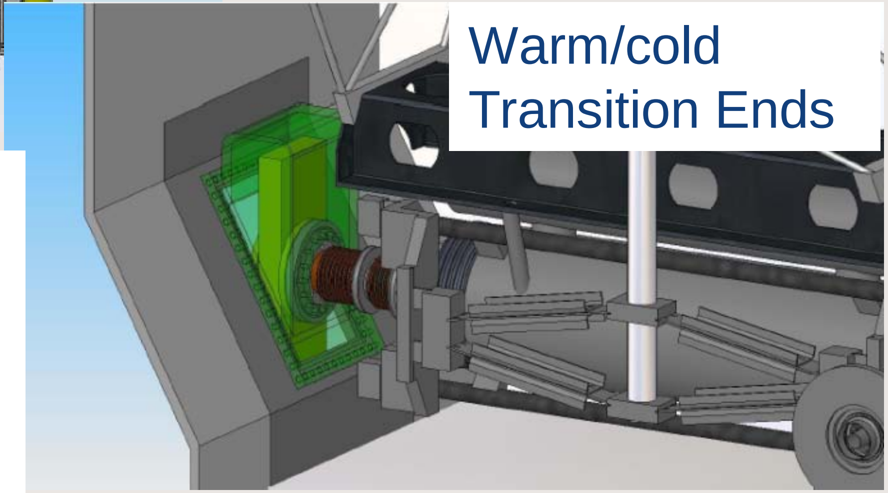
EINJ: Injector Cryomodule Detailing





Accelerator Cryomodule





Warm/cold Transition Ends

- **Single-cavity EINJ prototypes most features of two-cavity EACA design.**
- **2011 June: focus narrowed to completion of EINJ design, and fabrication in 2012**

ARIEL Civil Construction

Site Preparation: demolition, relocation, construction

- 2011 October
- CONGESTED SITE
- Old Stores &RH Demolition
- Excavation and shoring
- Makes way for ARIEL building

New Stores Bldg

Ground Breaking:
2011 March

Completion:
2011 September

New Badge Building

Construction started:
2011 August

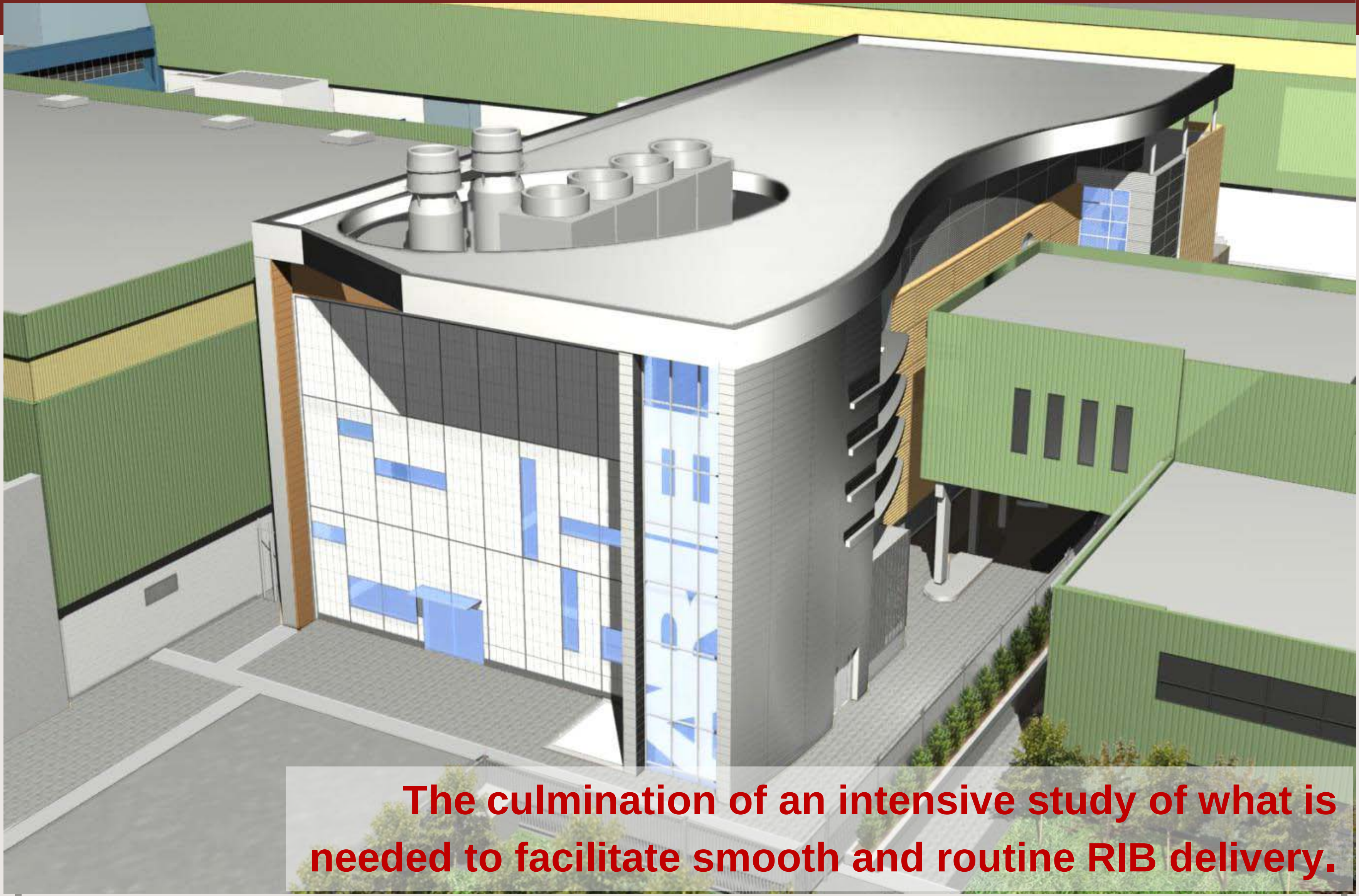
Occupancy:
2011 November

Helium Compressor Building

Foundations, structural steel, perimeter wall: 2012 July 30

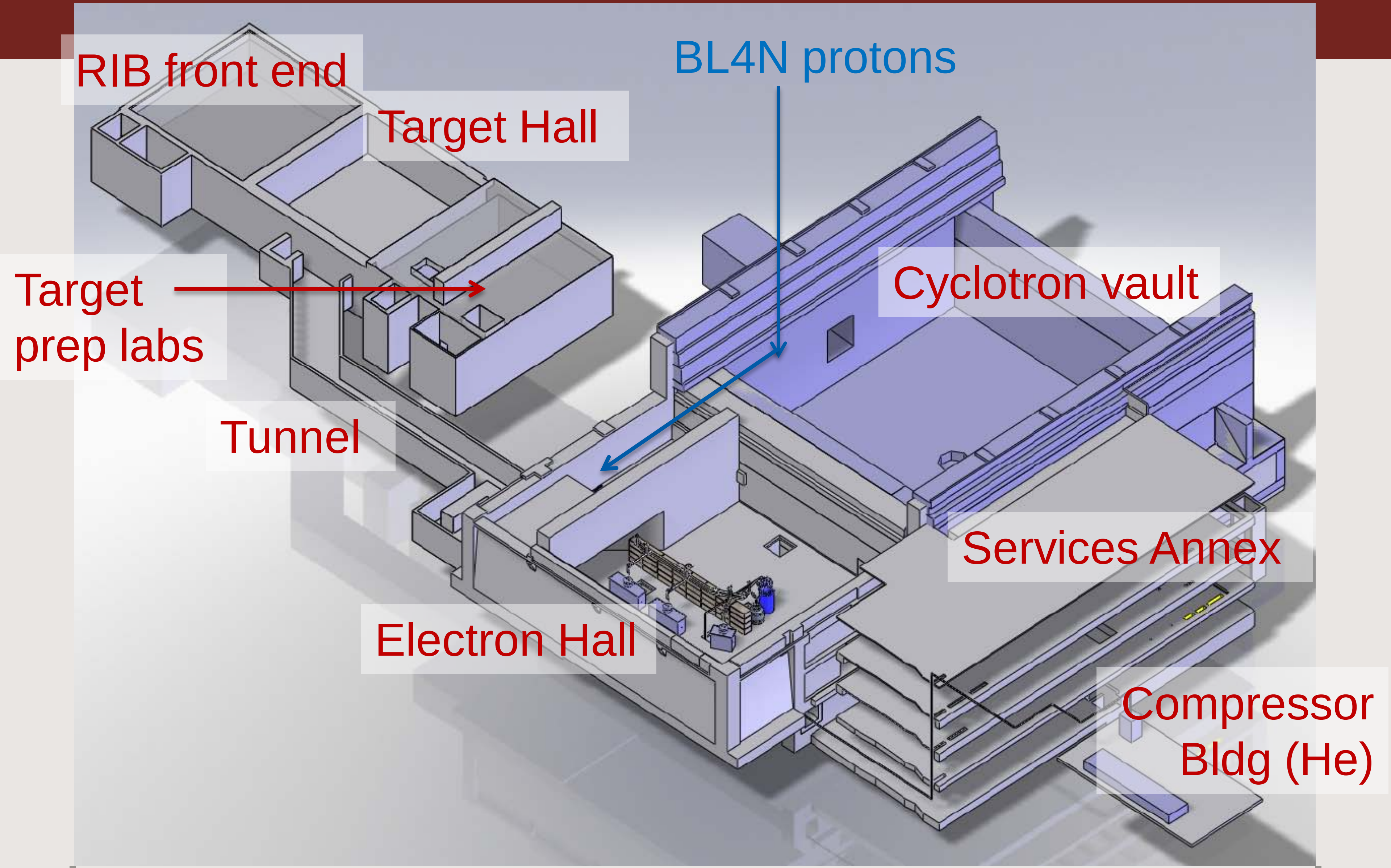
- **Envelope cladding, roof, mech & elec services 2012 Sept 03**
- **Expect occupancy: 2012 December**

ARIEL building design



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

ARIEL layout



Excavation, Shoring, Construction

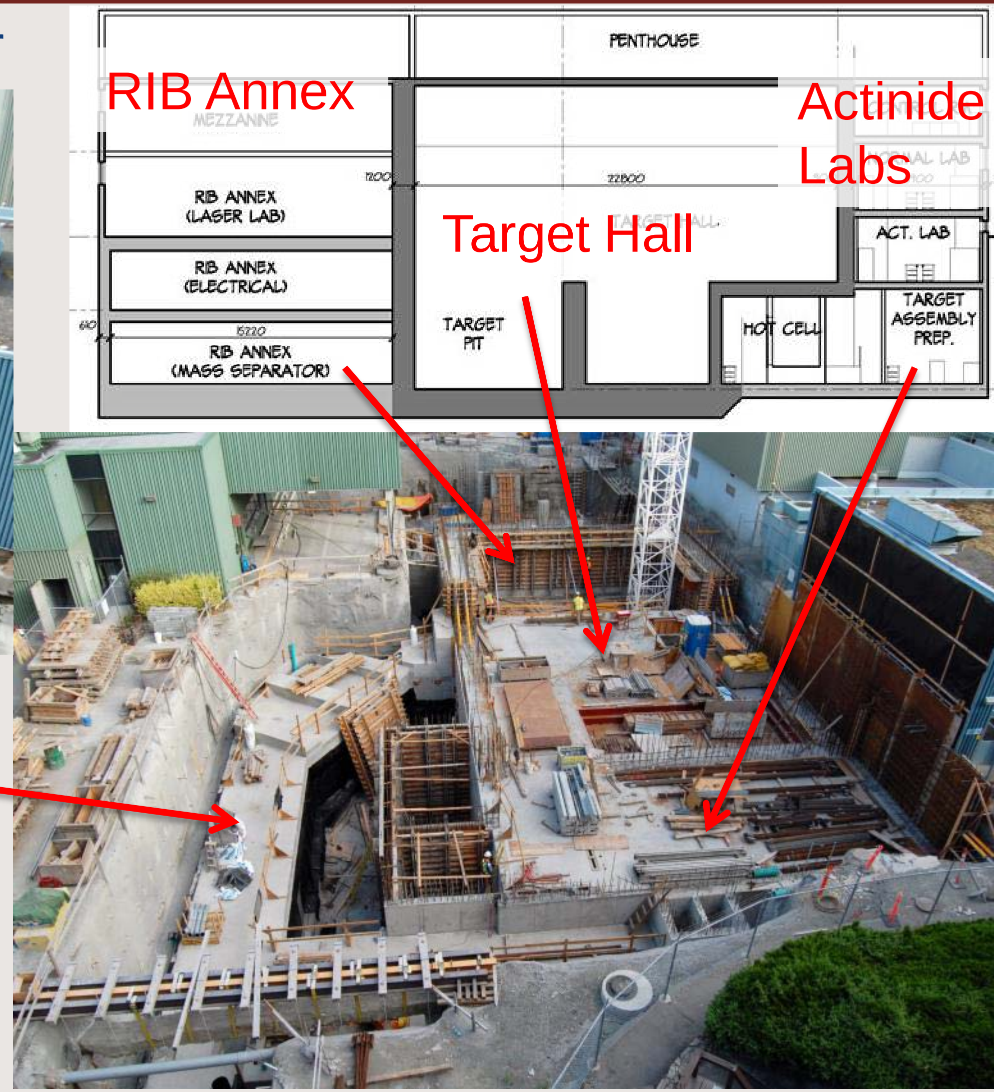
Excavation started: 2011 November

ARIEL site: 2012 May

Tunnel

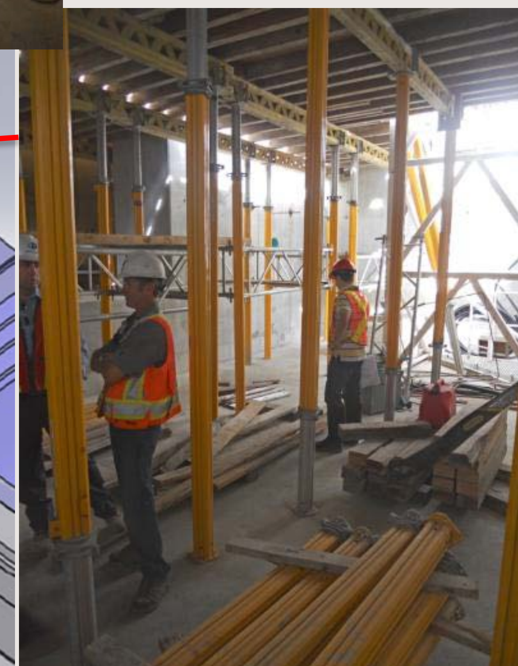
ARIEL site: 2012 Aug 29

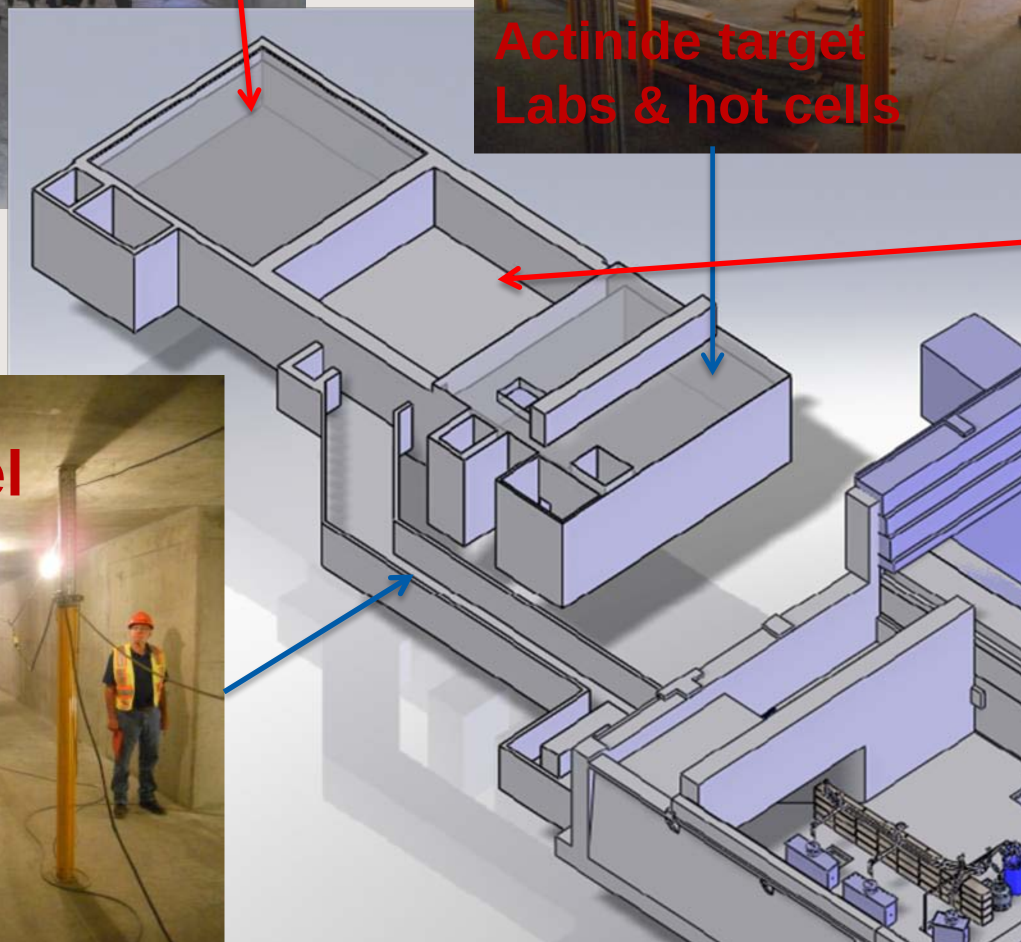
Building occupancy expected: 2013 April



ARIEL Construction

Target Hall





Electron Hall

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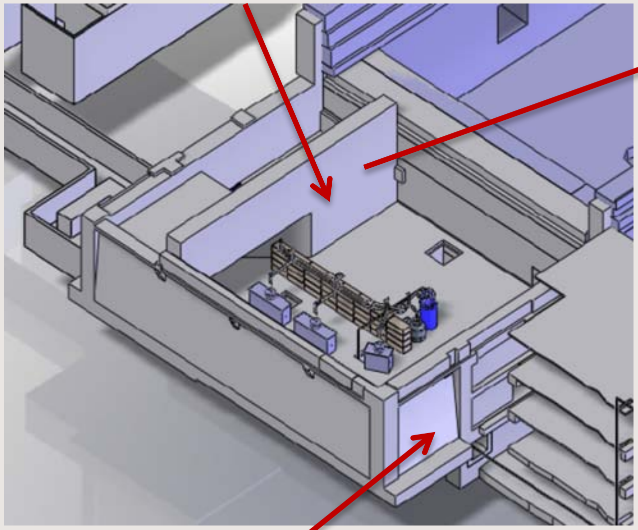
Electron Hall Renovation: shielding

2012 April 30

North Wall:

shield e-hall from BL4N



- South wall B2 up to ground for ERL/RLA
- Final pour, 2012/April

2012 July 31: Site of future proton BL4N

Electron Hall Renovation: crane, catwalks,etc

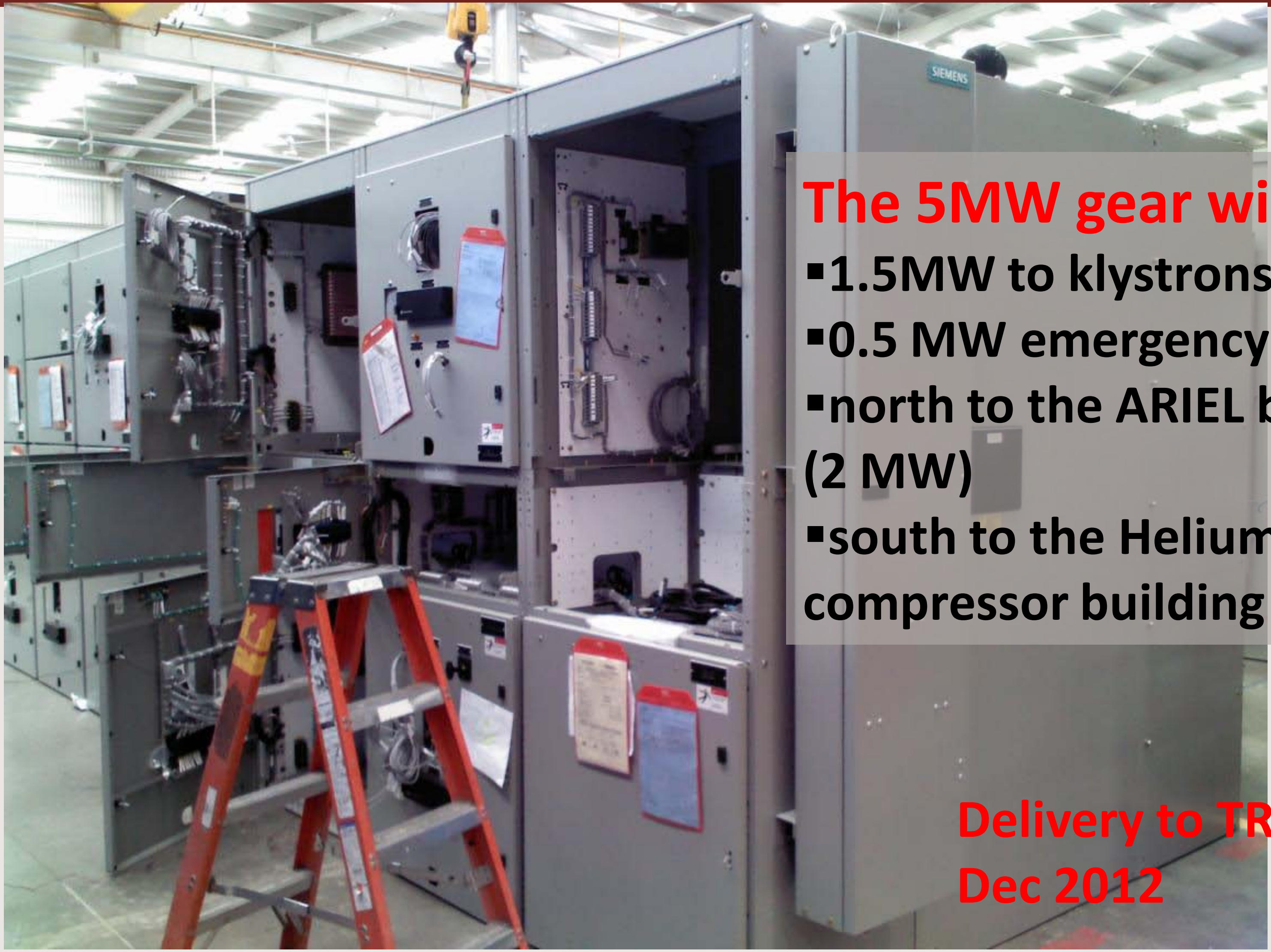
E-hall 2012 March 13

Breakthrough from ARIEL tunnel to E-hall, July 7th

E-hall 2012 Sept 03, prior to sealing roof beams

Expect E-hall occupancy 2012 October

Siemens 12.47 kV Switchgear, factory test 2012 Aug 23



The 5MW gear will feed:

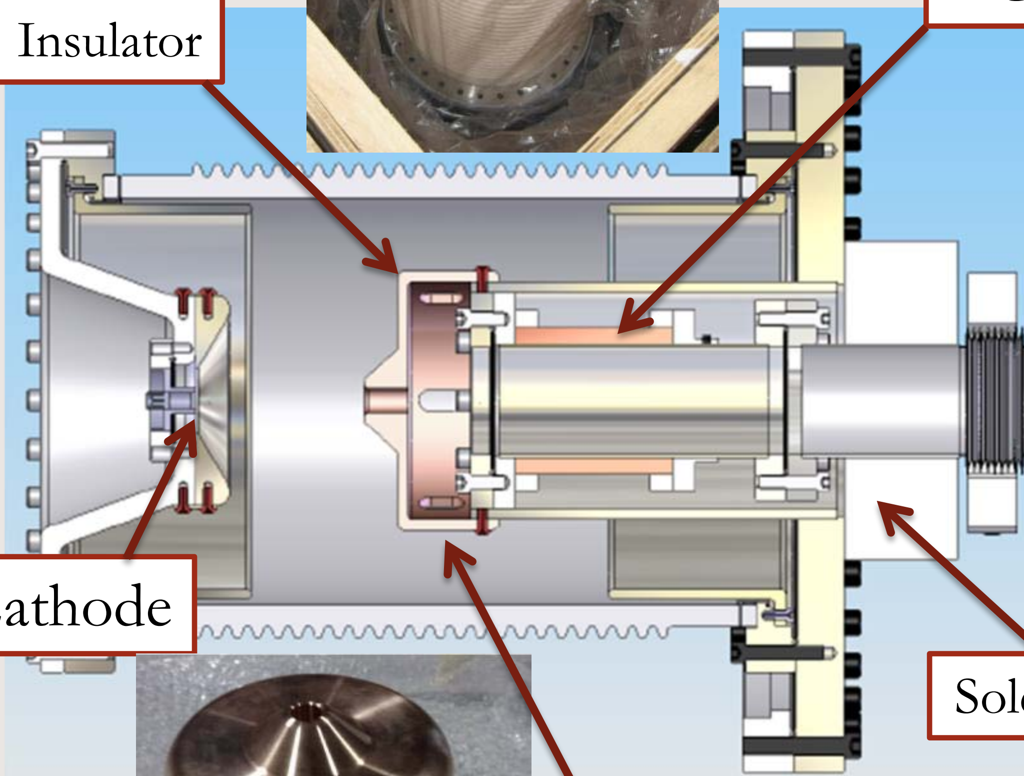
- 1.5MW to klystrons,
- 0.5 MW emergency power,
- north to the ARIEL building (2 MW)
- south to the Helium compressor building (1 MW)

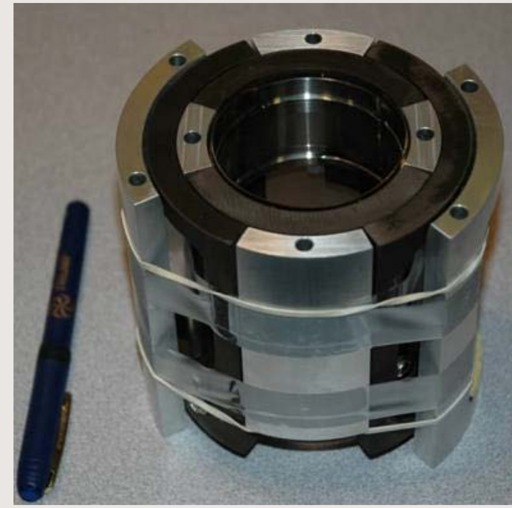
Delivery to TRIUMF Dec 2012

Outline

E-linac Progress Report

Electron Gun Components





Ceramic Insulator

Steering Coil

Cathode

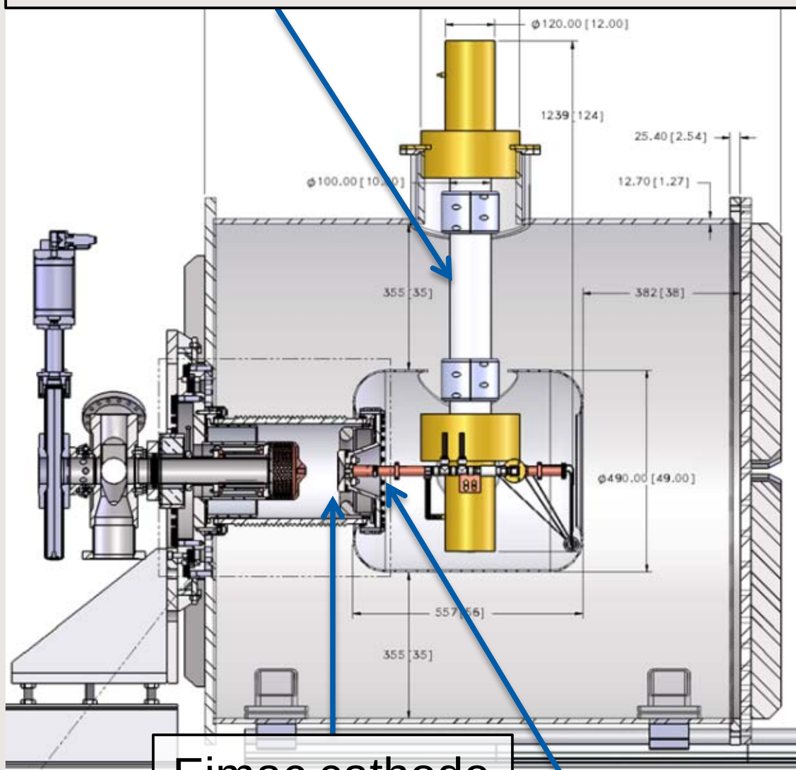
Solenoid

BeCu Anode

All fabricated or procured

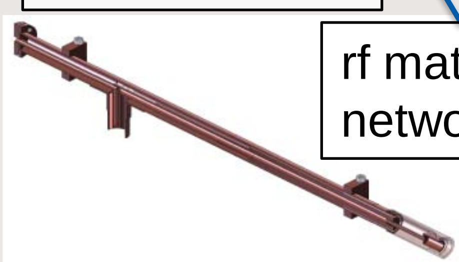
SF6 vessel & Gun RF modulation

RF horns and ceramic waveguide

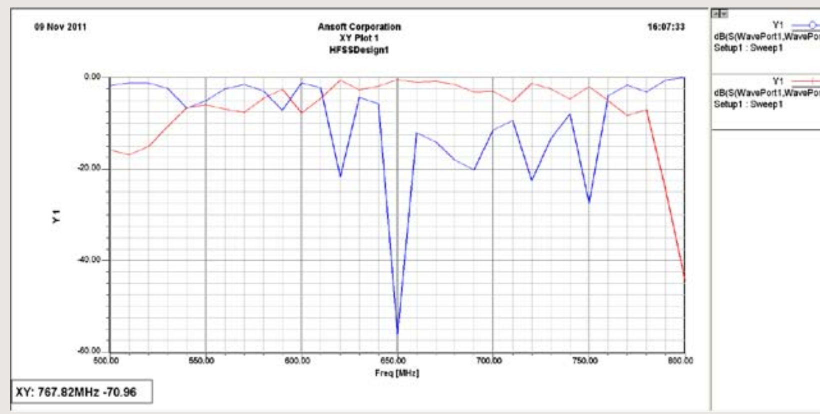


Eimac cathode

rf matching network



Successful dielectric waveguide R&D program with scale model & HFSS

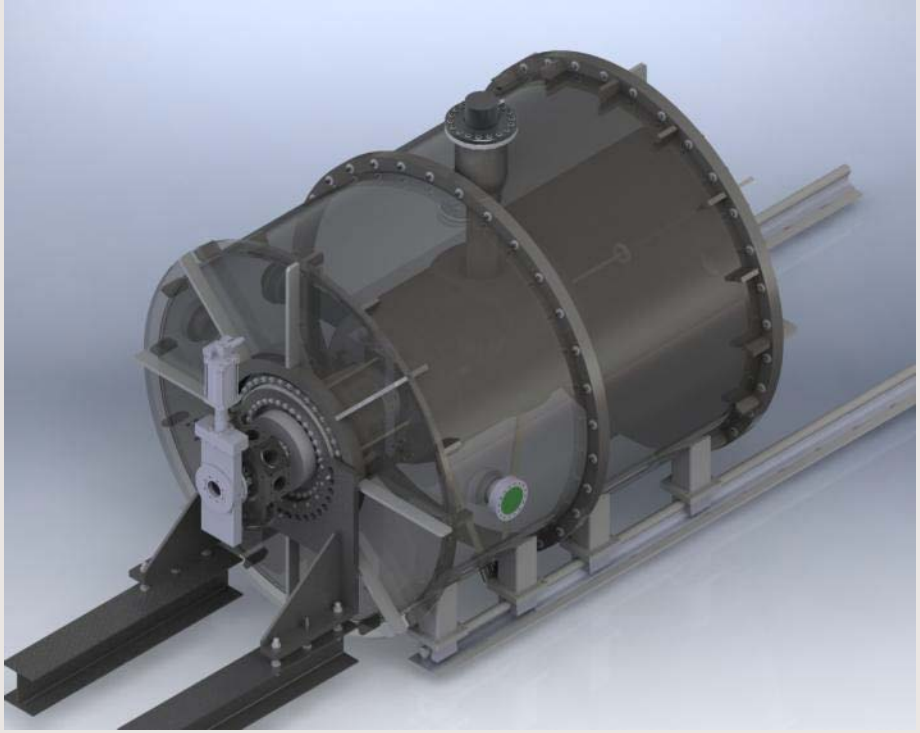


Transmission optimized at 650 MHz

300 kV 10 mA Electron Gun Gun Status

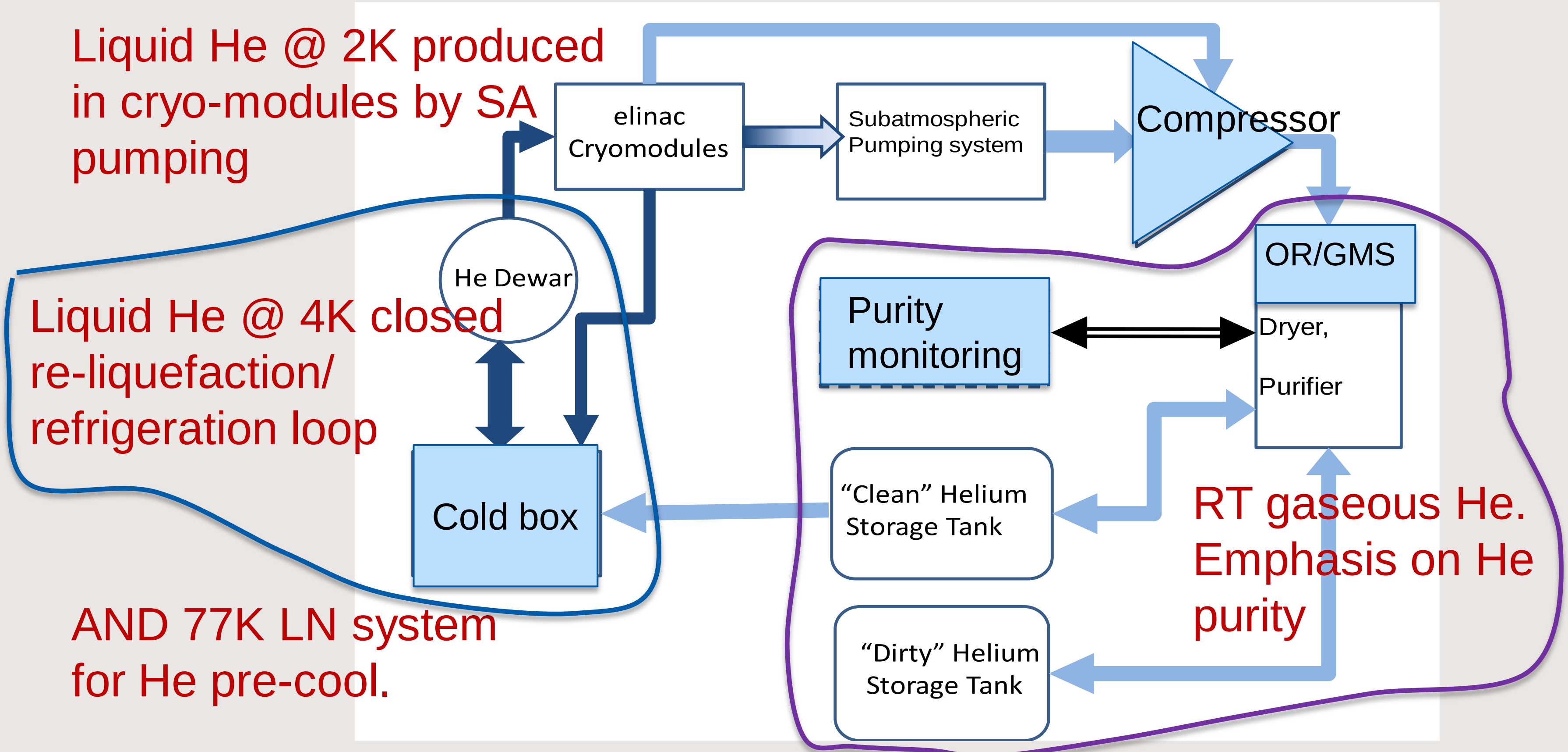
- Most long lead items delivered
- SF6 vessel tender package released: 2012 Sept

Electrode polishing under way



Installation begins: 2012 Dec

Cryogenic System Design/Procurement



- White boxes: TRIUMF responsibility
- Pale blue boxes: cryoplant ordered from Air Liquide Advanced Technology, 2011 Oct

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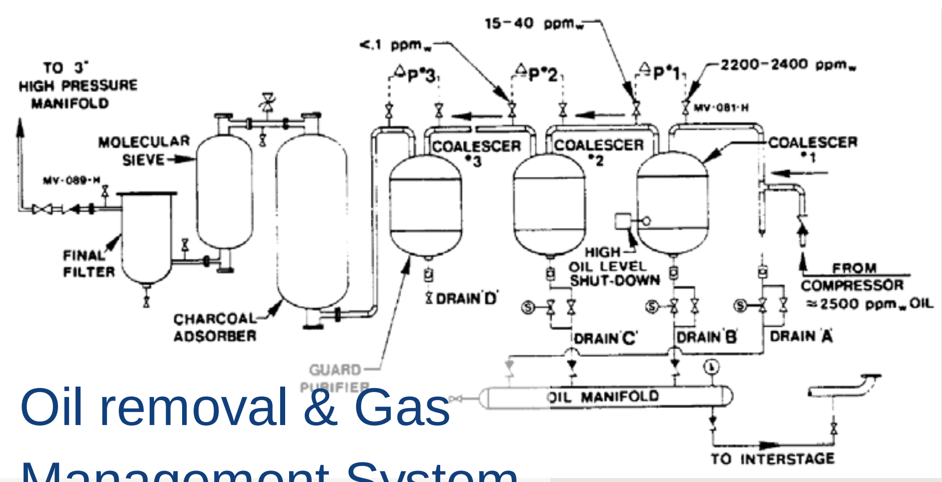
Supplied by ALAT

Helial Cold Box

Main Compressor

Figure 6 : CSD 82 View

Recovery Compressor



Oil removal & Gas Management System

Schedule

2013 March: ALAT cryoplant at TRIUMF

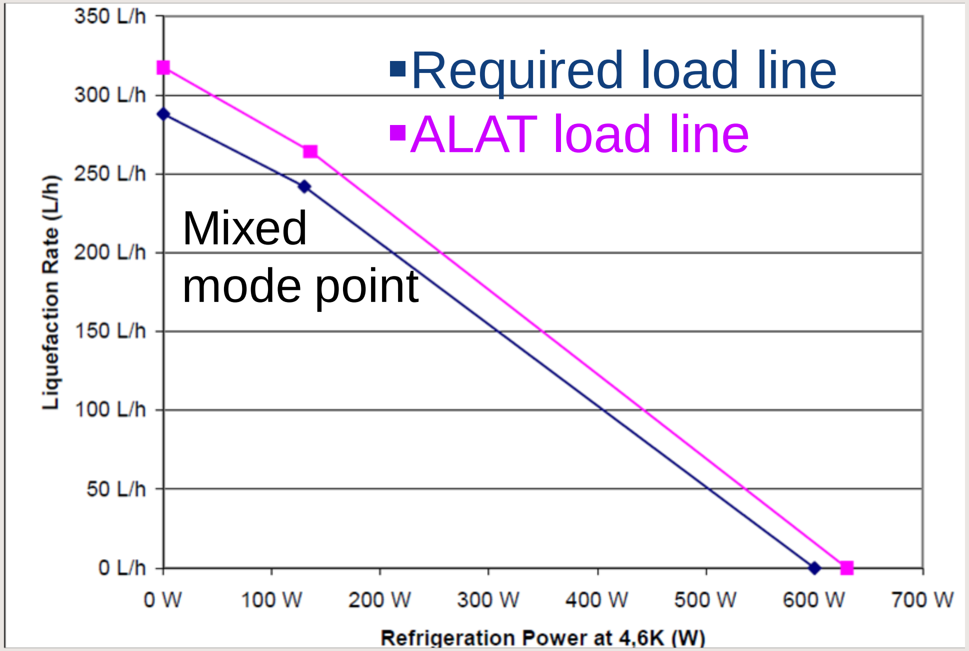
2013 October: commissioned

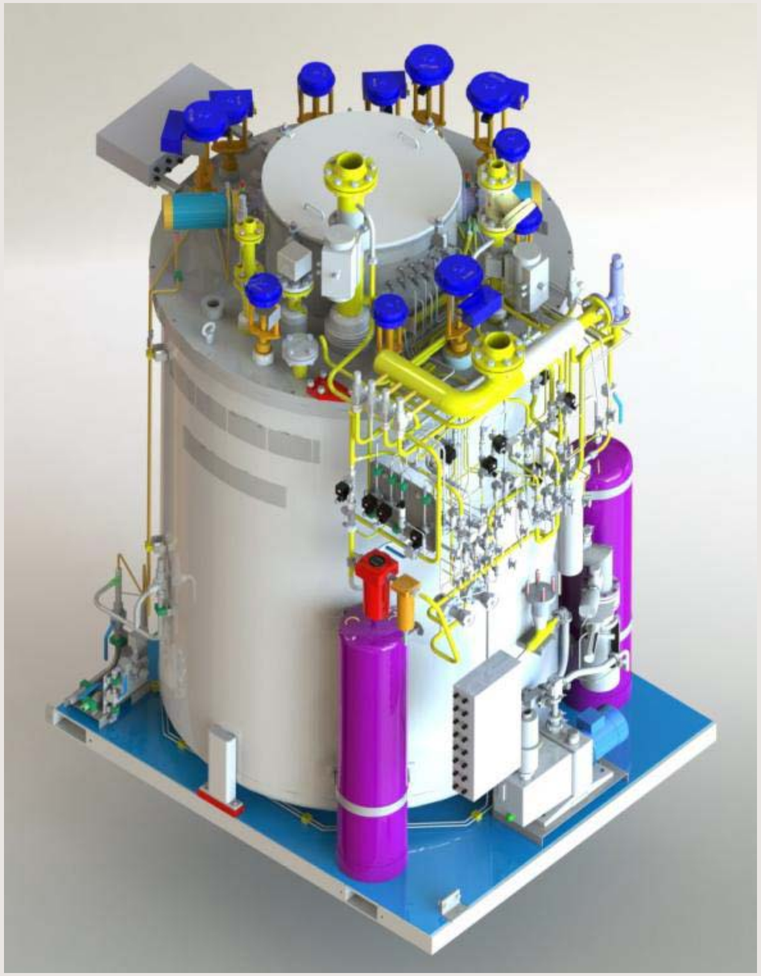
Successful Final Design Review concluded 2012 May15

Cryo-plant specs

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





ALAT Helial-2000 cold box

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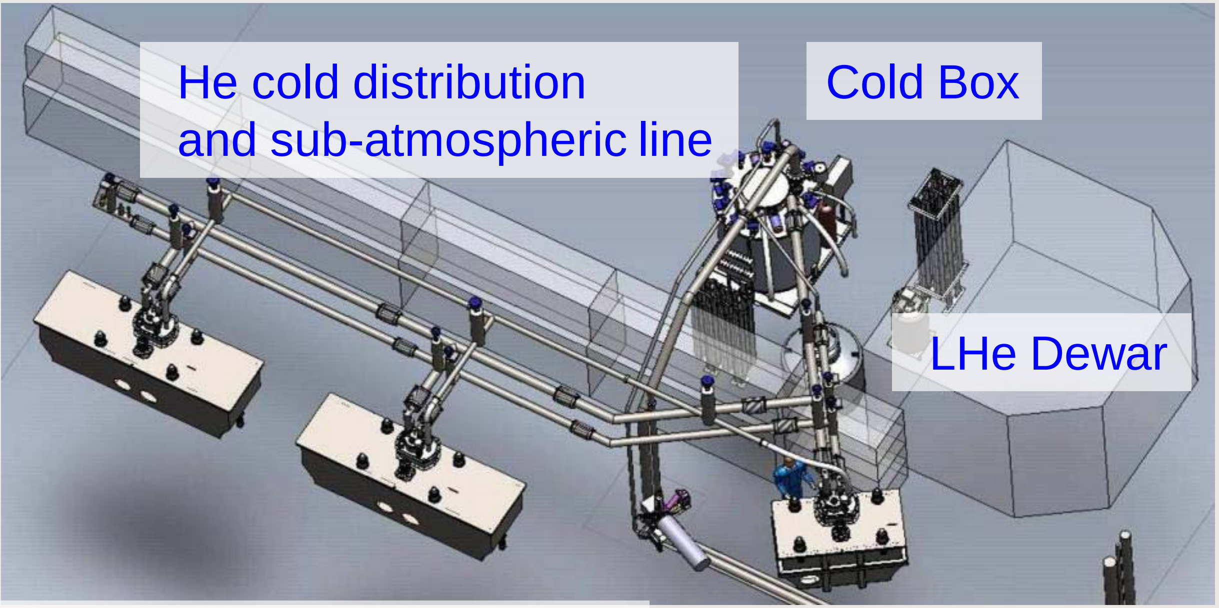
Other major components

- Dewar in hand; will widen neck
- He Purifier- procure in collaboration with FNAL
- LHe Distribution System: tender issued 2012 Aug
- 2K sub-atmospheric components:
  - Pumps: contract awarded 2012 Aug
  - He heaters: prototyping



Fabrication 2012 Aug 02

He buffer tanks modeled on ISAC-II

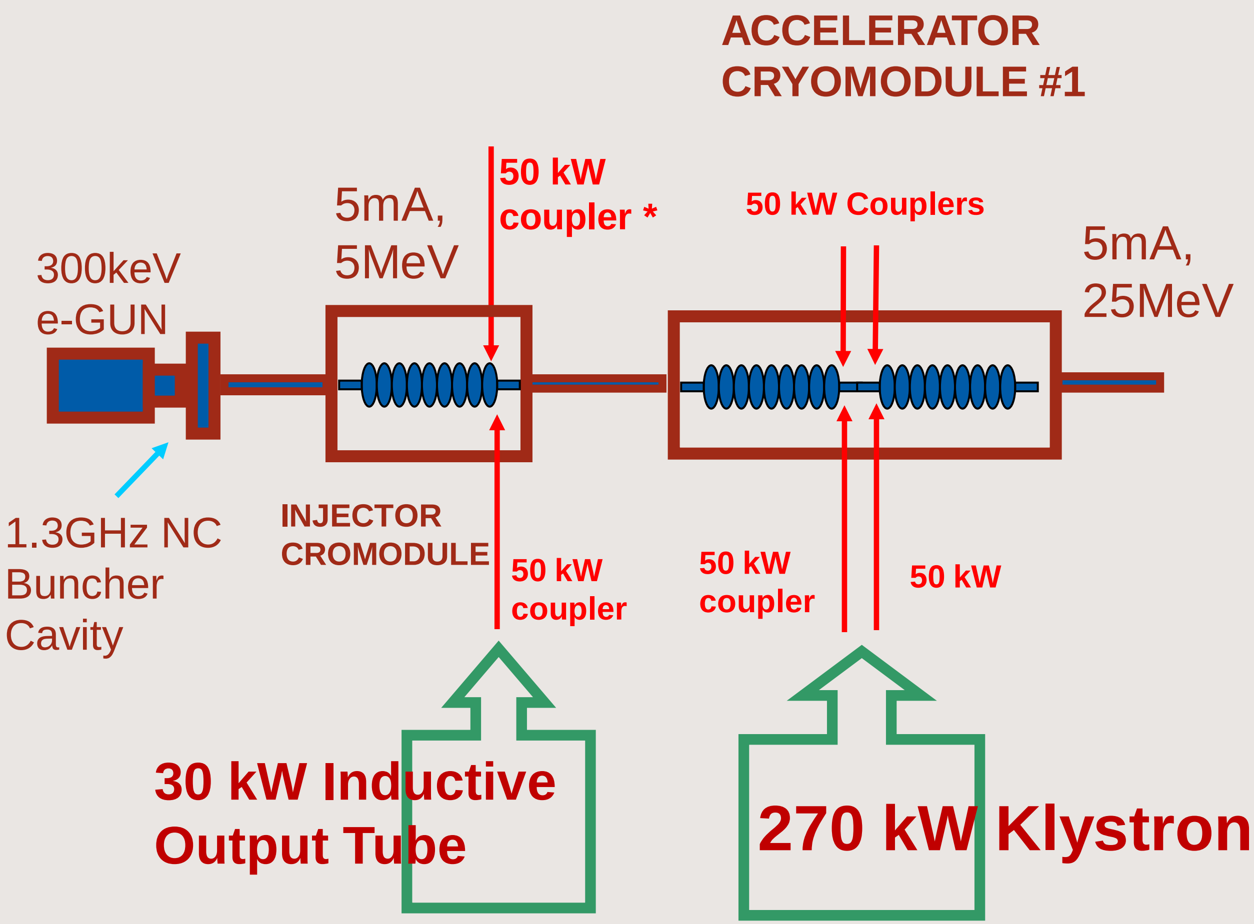
- Tanks rated 15 Bara
- Capacity ~113 m^3 each
- Delivery 2013 Jan

Sub-atmospheric pumps

	Phase1	Phase2
ICM	1.9gm/sec	1.9gm/sec
ACM1	3.7gm/sec	3.7gm/sec
ACM2	NA	3.7gm/sec
Sub-total	5.6gm/sec	9.3gm/sec
Total	5.6gm/sec	9.3gm/sec

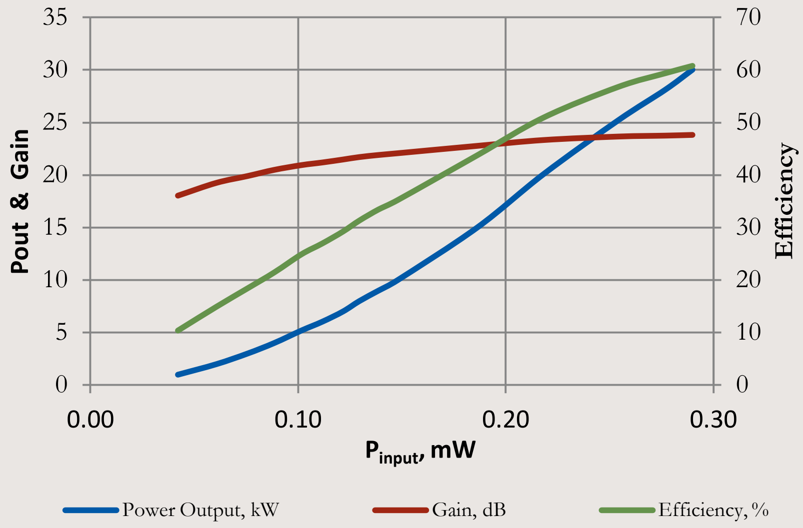
- BUSCH –Combi DS3010-He
- Dry technology – roots blower & screw type backing pump
- Four units ordered 2012 Aug
- Delivery 2013 February

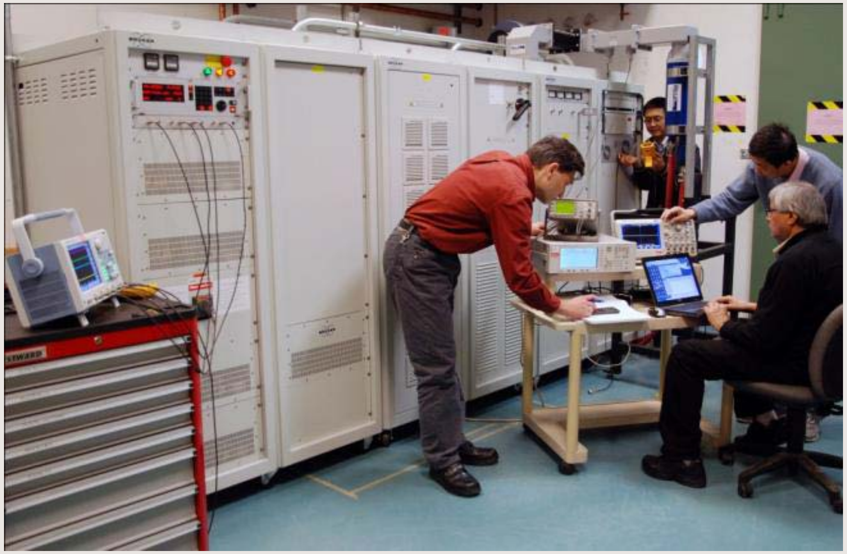
High Power RF staging: 5mA, 25 MeV in 2014



30 kW IOT Transmitter

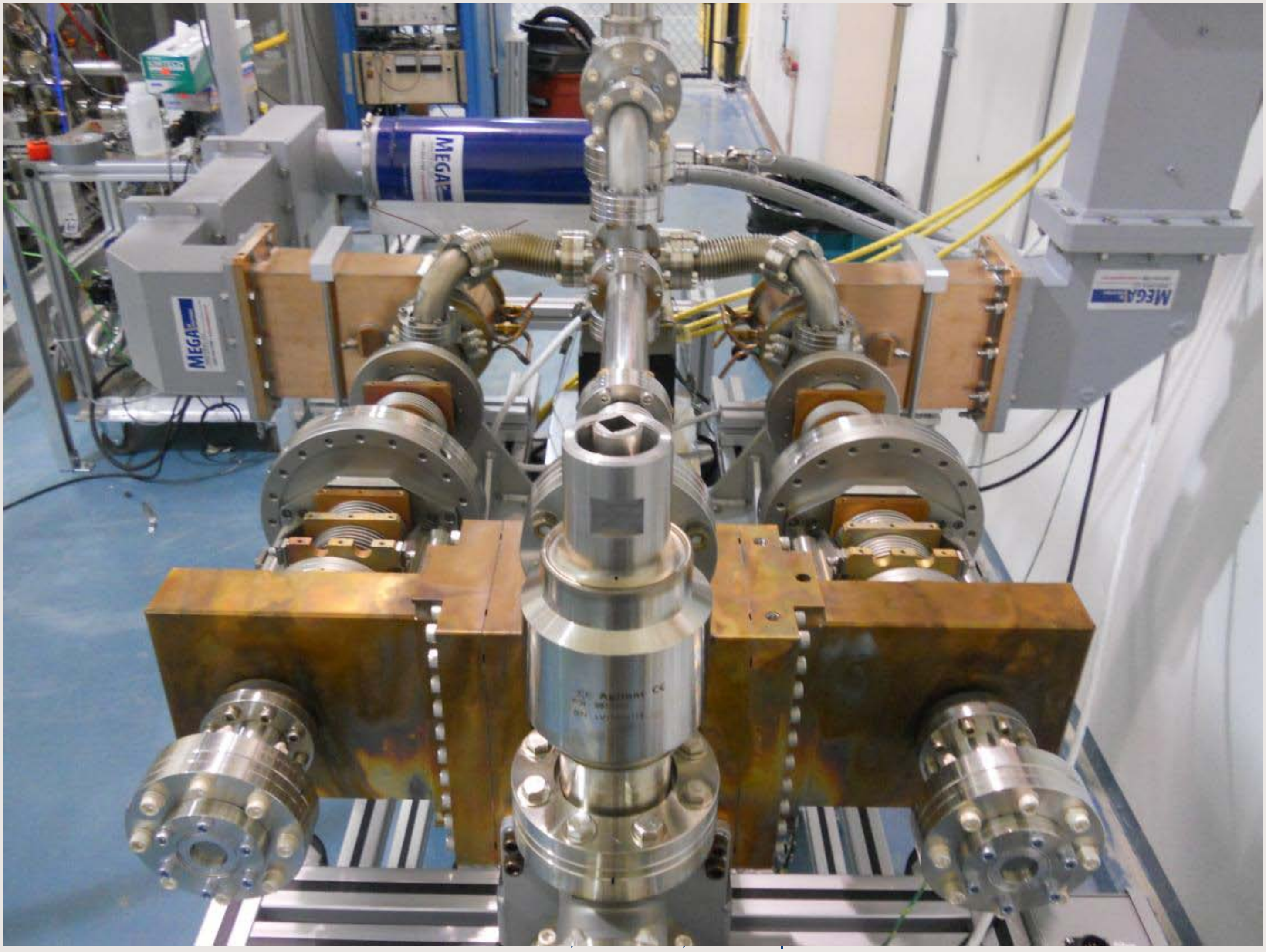
- IOT transmitter will be used for EINJ beam test 2013 Jan;
- RF input coupler conditioning (10kW) 2012 March onward





- 2011 June: Tube operated tube in excess of 30kW
- 2011July: Successful acceptance tests: ran cw at 30 kW for 24 hours, at 25kW for 40 hours and at 20 kW for 7 days without trip.
- Now running routinely

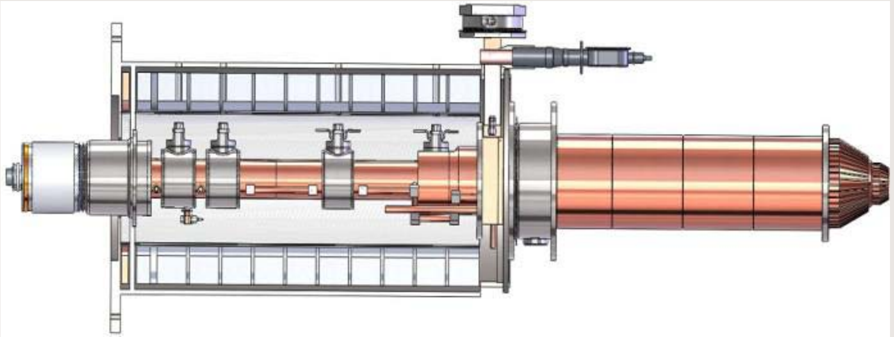
Coupler Conditioning Stand in ISAC/VECC test area



1.3 GHz 290 kW klystron & HVPS procurement

Require 200kW cw for EACA (2-cavity) cryomodule

- 2011 Aug: 290kW Klystron ordered from CPI, USA
- Coordinated purchase with Helmholtz Zentrum Berlin
- 2012 Aug: Final design review
- 2013 Jan: klystron factory test



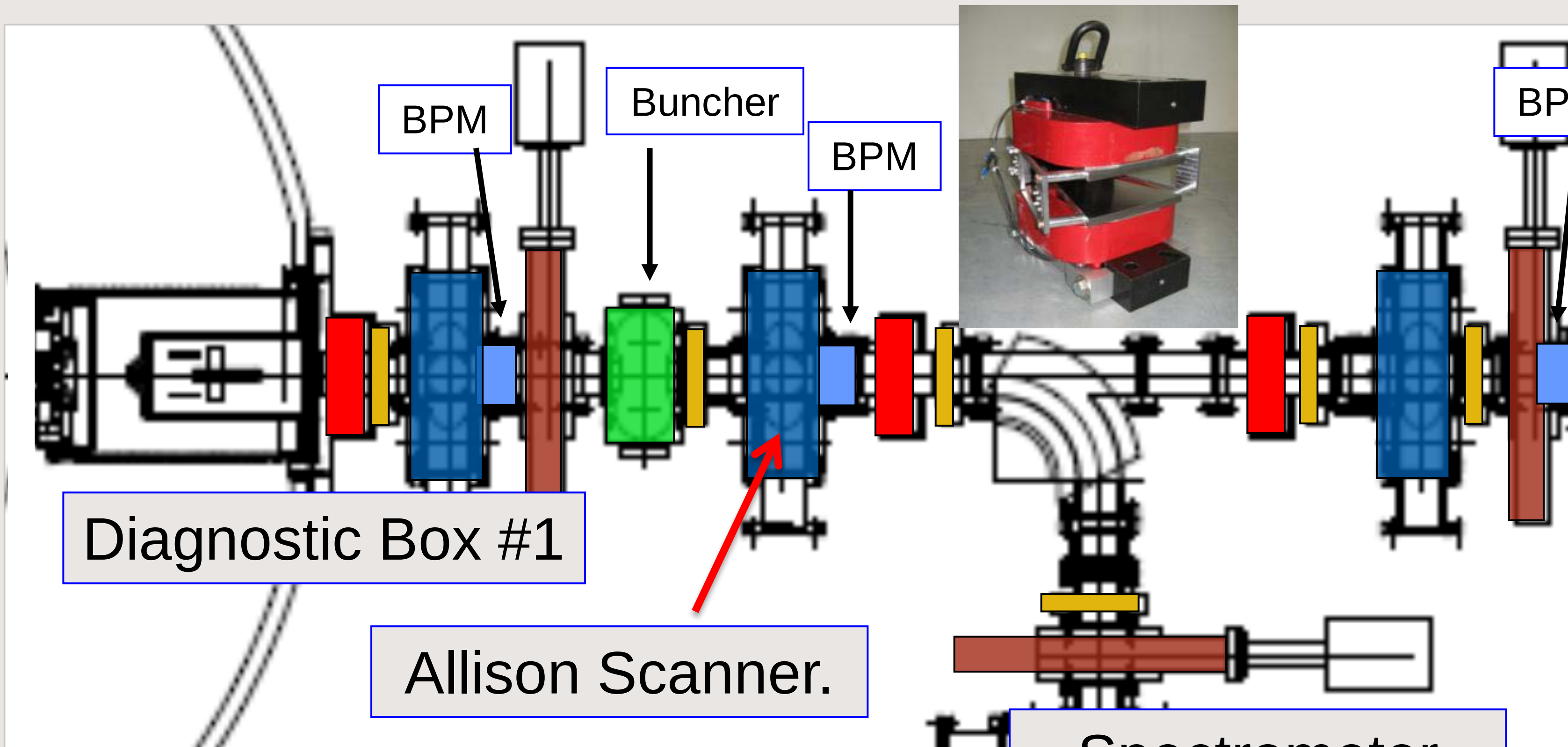
600kW 65kV Power Supply

- 2012 Feb: Tender issued
- 2012 June: Awarded Thomson Broadcast
- 2012 Aug: Preliminary design review

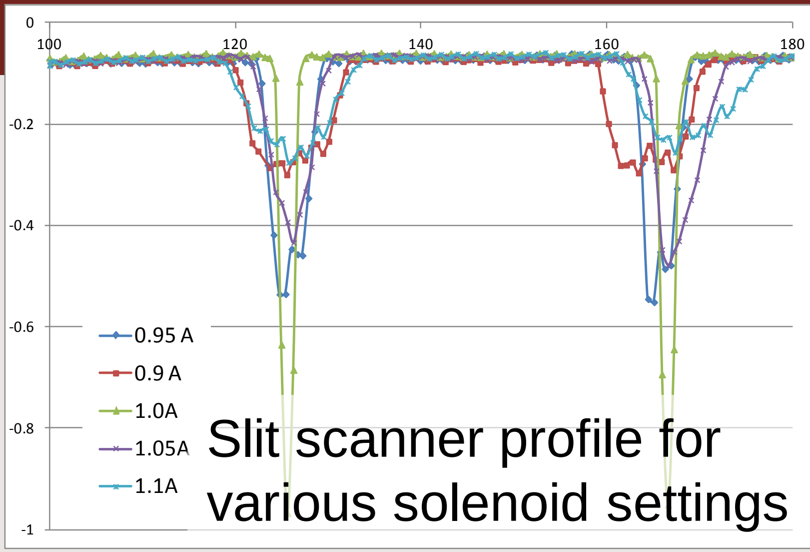
Conclusion

- Outstanding Progress Across All Areas
- Buildings Construction – on schedule for 2013 April
- Injector Cryomodule beam test – on schedule for 2013 March
- Accelerator Cryomodule beam test – on schedule for 2014 June

ELBT at ISAC/VECC test stand

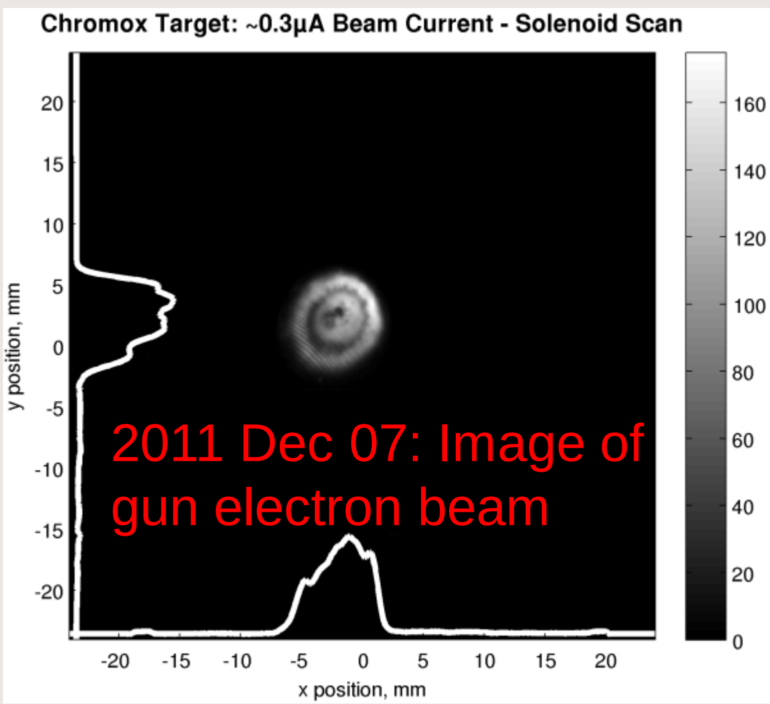


VECC ELBT Test1 – 2011 Dec/2012 Feb

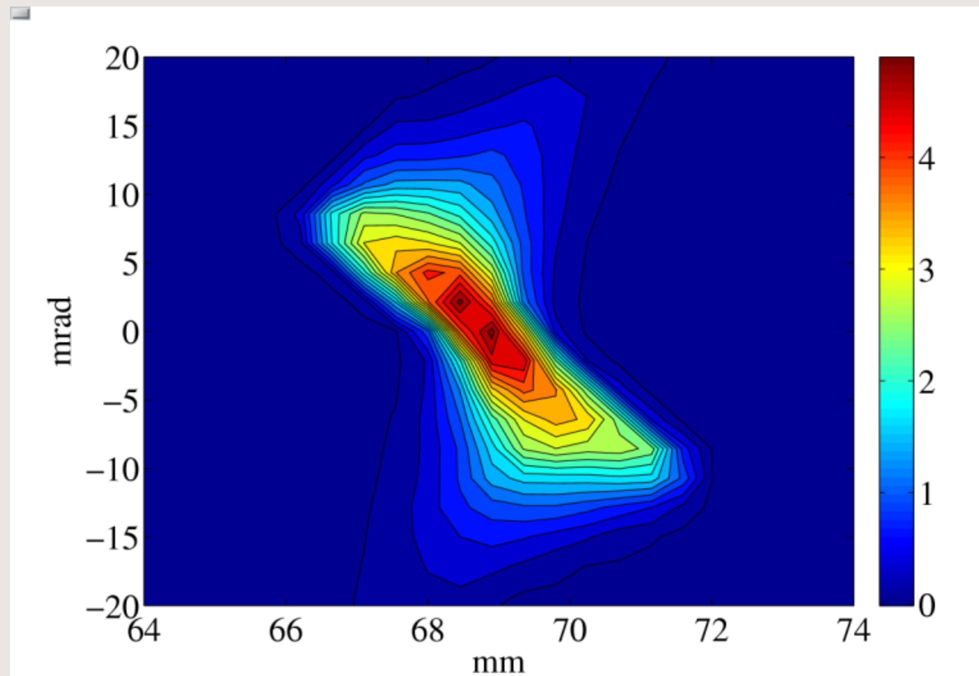


Slit scanner profile for various solenoid settings

Allison emittance scans performed 2012 Feb 09 onward up to to 660W beam power at ~20W/mm

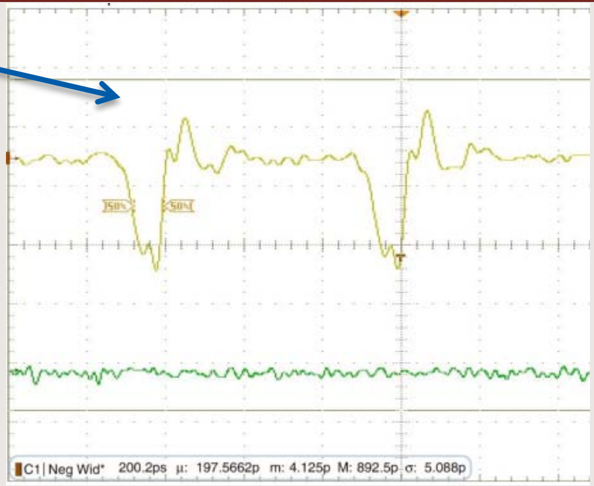


2011 Dec 07: Image of gun electron beam



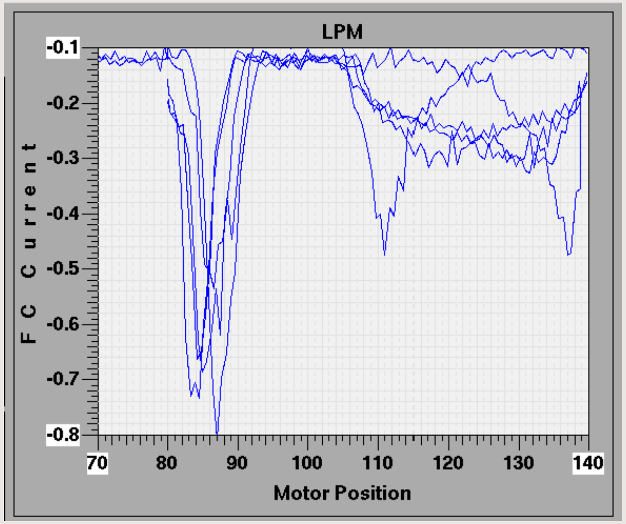
VECC ELBT Test2 – 2012 July

Fast Faraday Cup (8 mA peak current)
Bunch length ≈ 200 ps, consistent with estimate by conduction angle.



Deflector Commissioning

- Phase locked to Gun RF
- Scan buncher phase/amplitude and observe beam movement in spectrometer



Phase scan at 0, 90, 180, 270 deg – Open loop