UPDATE ON SCRF DEVELOPMENT AT TRIUMF

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Abstract

- Since 2007 TRIUMF started development of E-LINAC which is a 50 MeV 10 mA CW electron superconducting linear accelerator to be used as a driver to produce radioactive ion beams through photofission. The accelerator is based on five 1.3 GHz TTF/ILC elliptical bulk Nb cavities technology to be mounted in three cryomodules; an injector cryomodule with one cavity and two accelerating modules with two cavities each.
- The ISAC-II project superconducting heavy ion linear accelerator was successfully completed in 2010 and we now have in operation 40 superconducting bulk Nb QWR cavities assembled in eight cryomodules. Results and plans of the SCRF program and experience of ISAC-II operation at TRIUMF will be discussed.

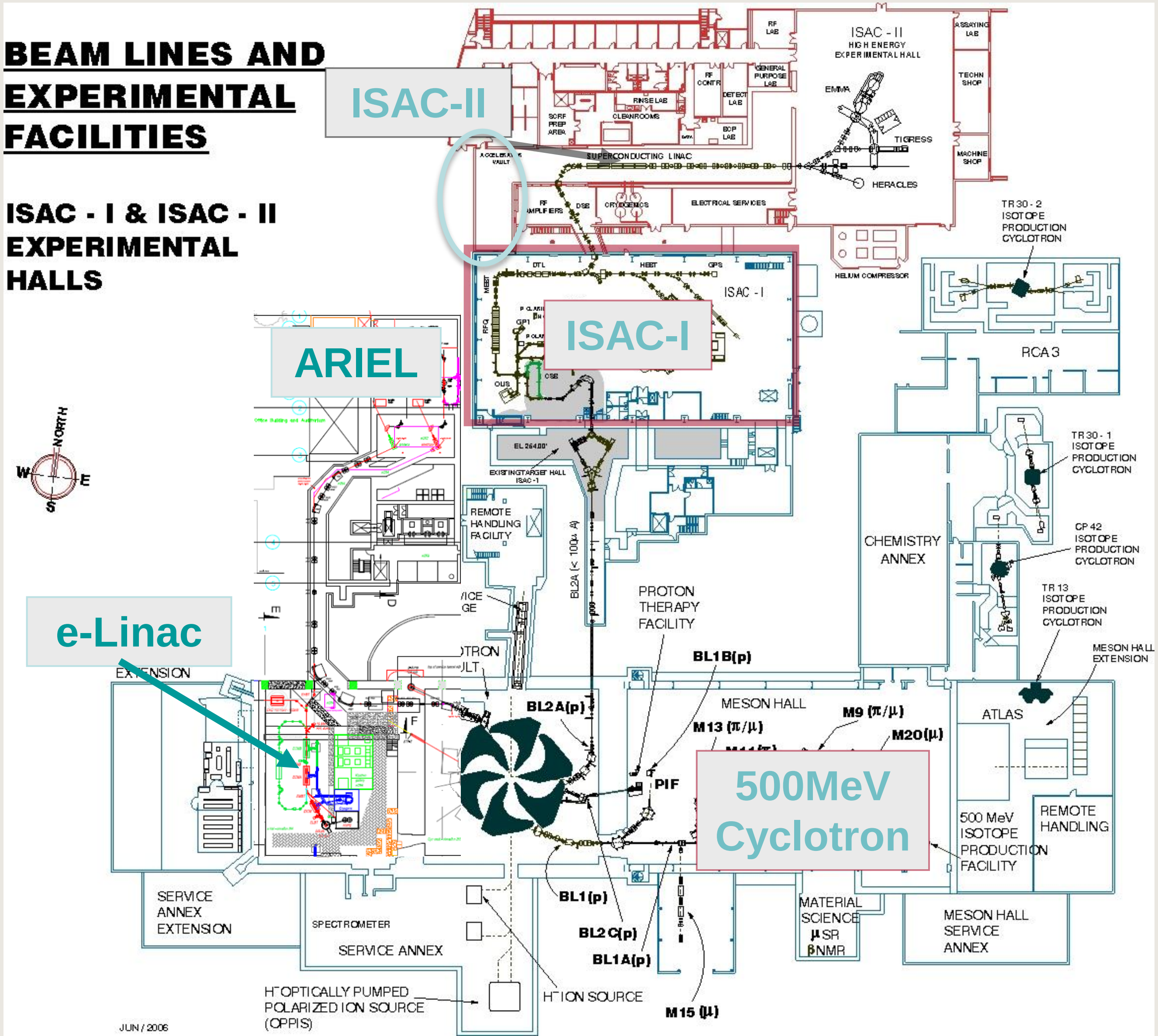
Content

- SCRF development for e-LINAC
- ISAC-II Results

SCRF Development for e-LINAC

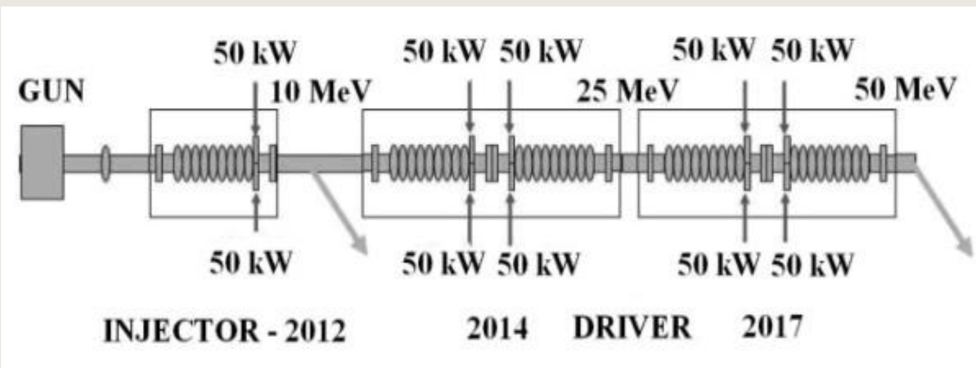
ARIEL Facility and VECC test area

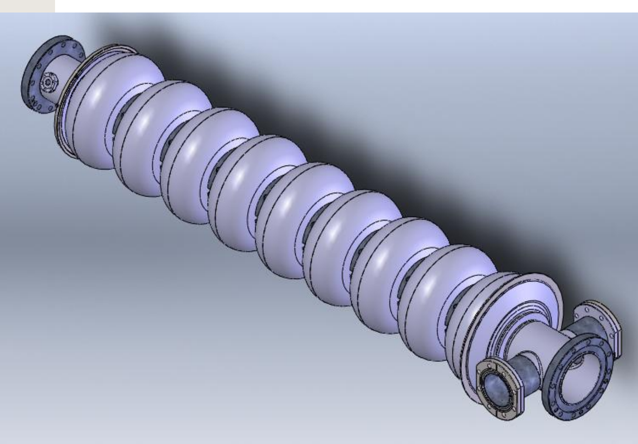
- ISAC: World class ISOL facility for the production and acceleration of rare isotope beams (RIB)
- Highest power driver beam (50 kW protons)
- 40MV SC heavy ion post-accelerator – fully variable in energy
- Now adding ARIEL to increase from one to three simultaneous beams
- Add e-LINAC (50MeV 10mA cw - 1.3GHz SC)
- E-LINAC/VECC test area established in ISAC-II building

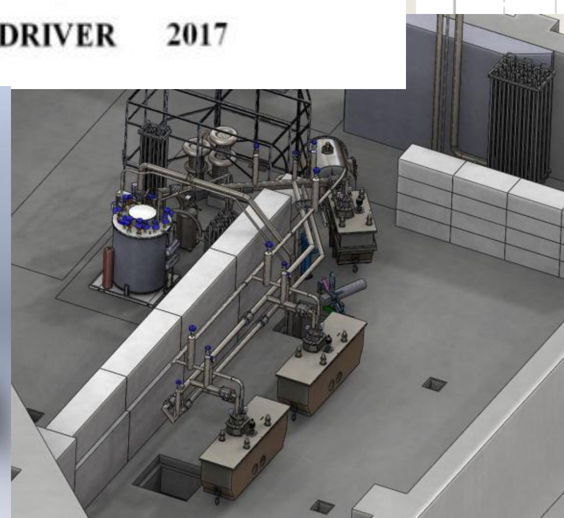


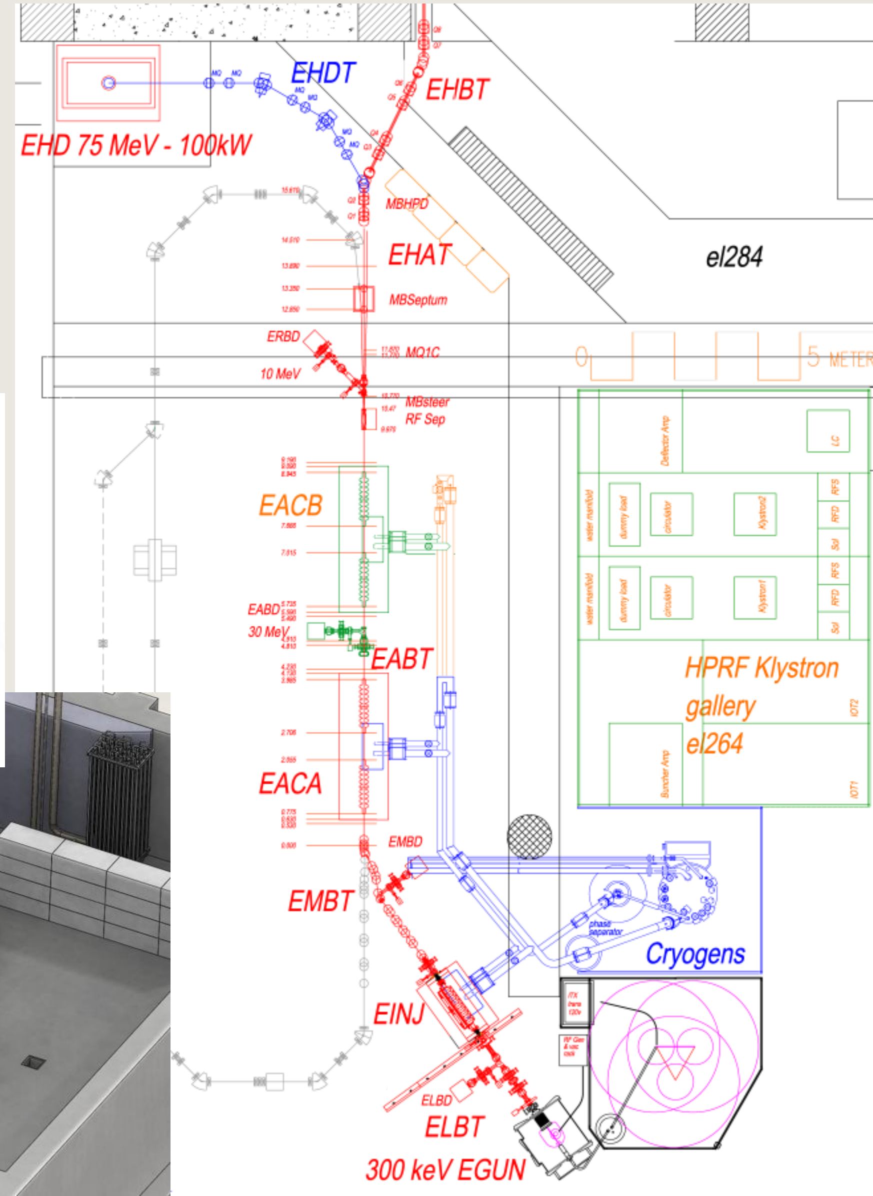
e-LINAC project at TRIUMF

In 2007 TRIUMF started developments toward an electron driver for photofission which will be independent and complementary to the 500MeV cyclotron. The e-LINAC is composed of five 9 cell elliptical cavities at 1.3GHz in 3 cryomodules with final goal by 2017 of 50MeV/10mA, 0.5MW beam power, CW operation.



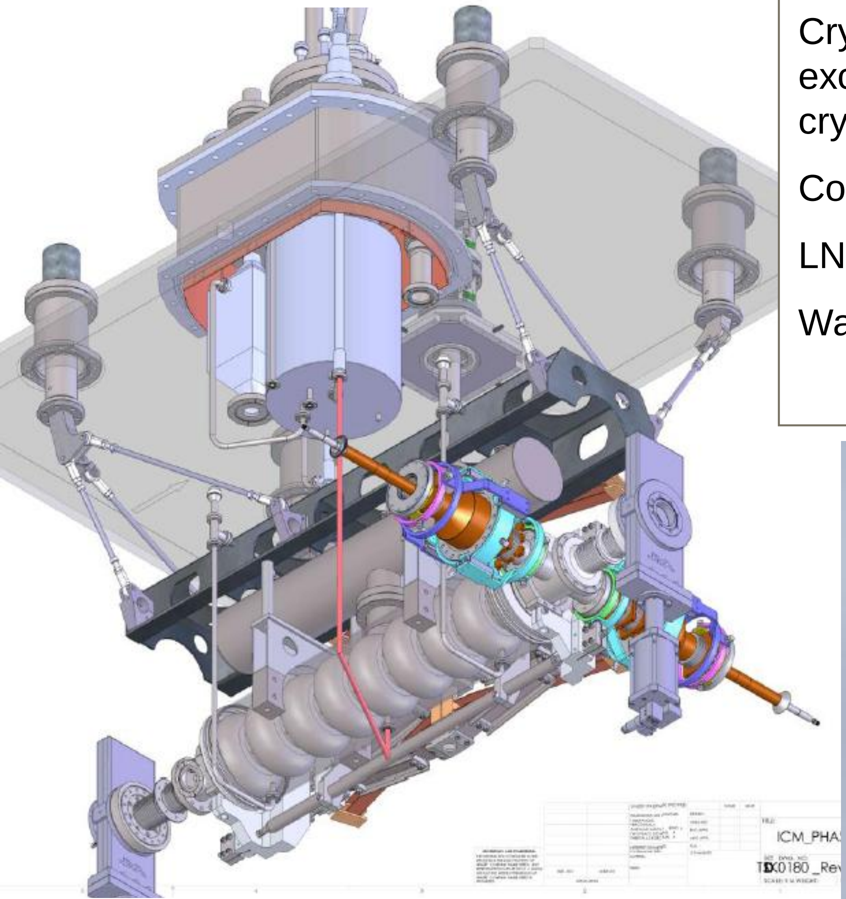






e-LINAC Cryomodule: Top-load Box Concept

ICM Cryomodule



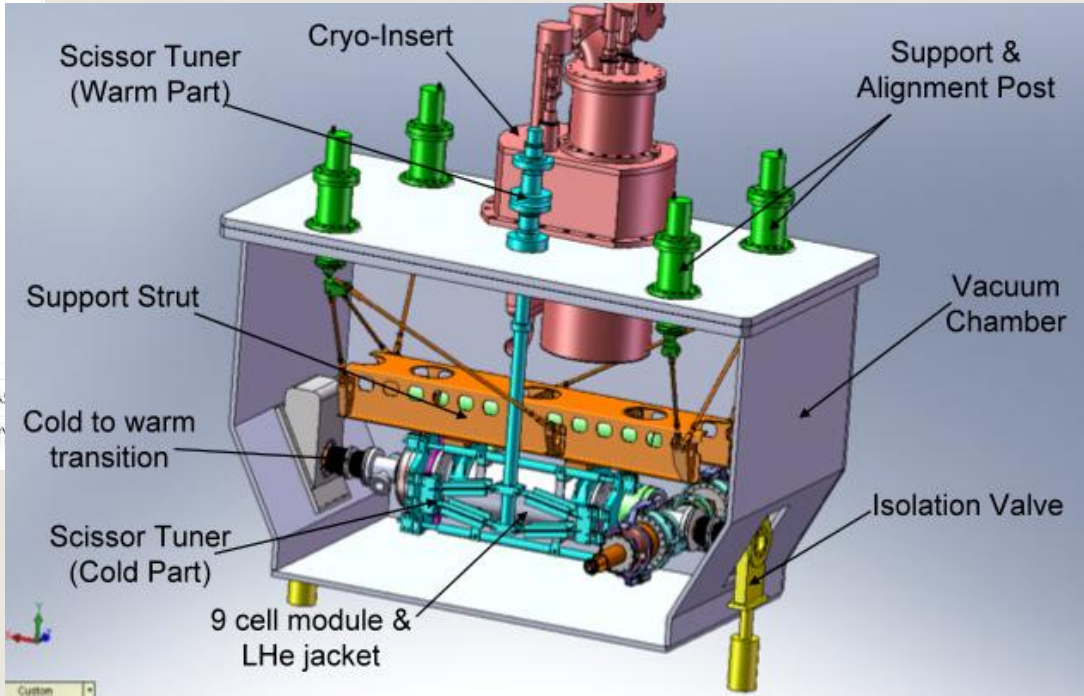
Top loading box concept

Cryogenic insert with 4K phase separator JT valve and heat exchanger on board to produce 2K liquid; insert removable with cryomodule in situ

Cold mass supported by strong- back

LN2 cooled thermal shield; 4K circuit for intercepts

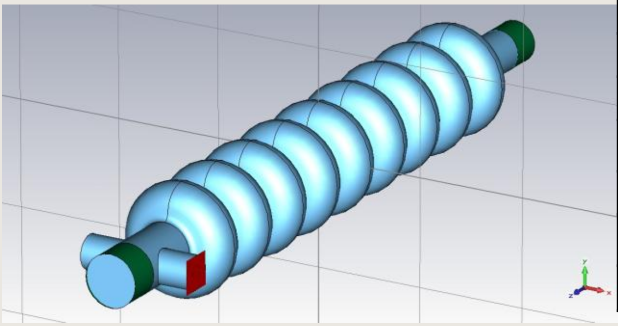
Warm and cold mu-metal



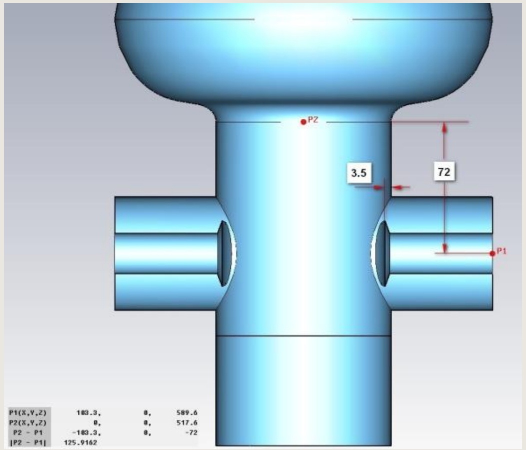
Pair of alignment pick-ups upstream and downstream of each cavity

J-lab scissor tuner employed

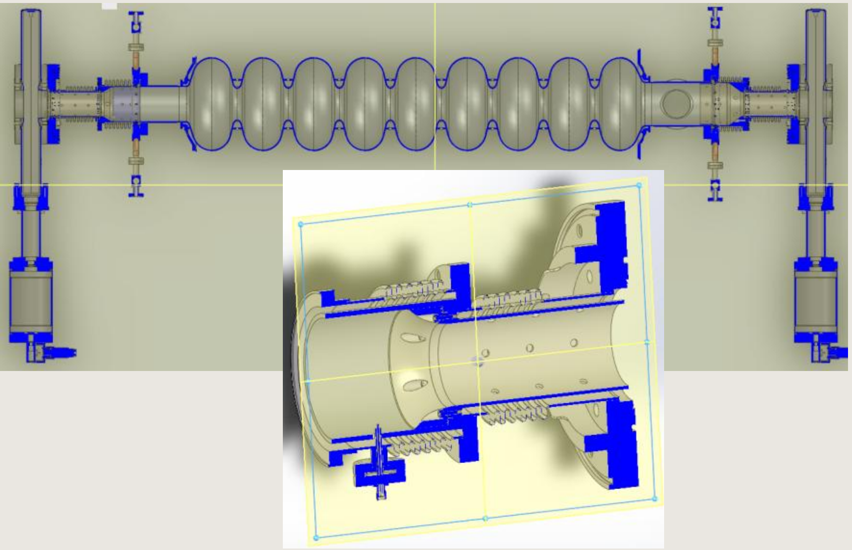
Cavity Design

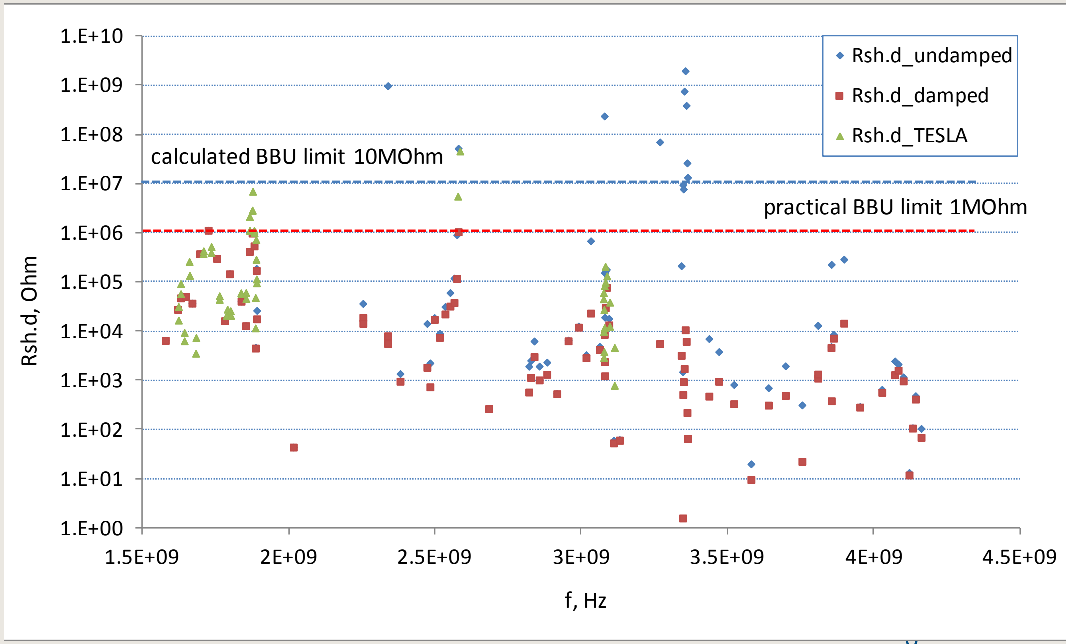


	TRIUMF	DESY	TRIUMF/DESY
Frequency [MHz]	1300	1300	-
R_{sh}/Q [Ohm]	1000	1030	3% less
Geometric factor G [Ohm]	290	270	7% more
E_p/E_a	2.1	2.0	5% more
B_p/E_a [mT/(MV/m)]	4.4	4.2	5% more
Cell coupling [%]	2.0	1.9	



TRIUMF e-LINAC cavity is similar to 9 cell DESY TESLA cavity. The concept of 2-cell Cornel ERL cavity was used for coupler section: 2 symmetrically opposed 65kW CPI couplers

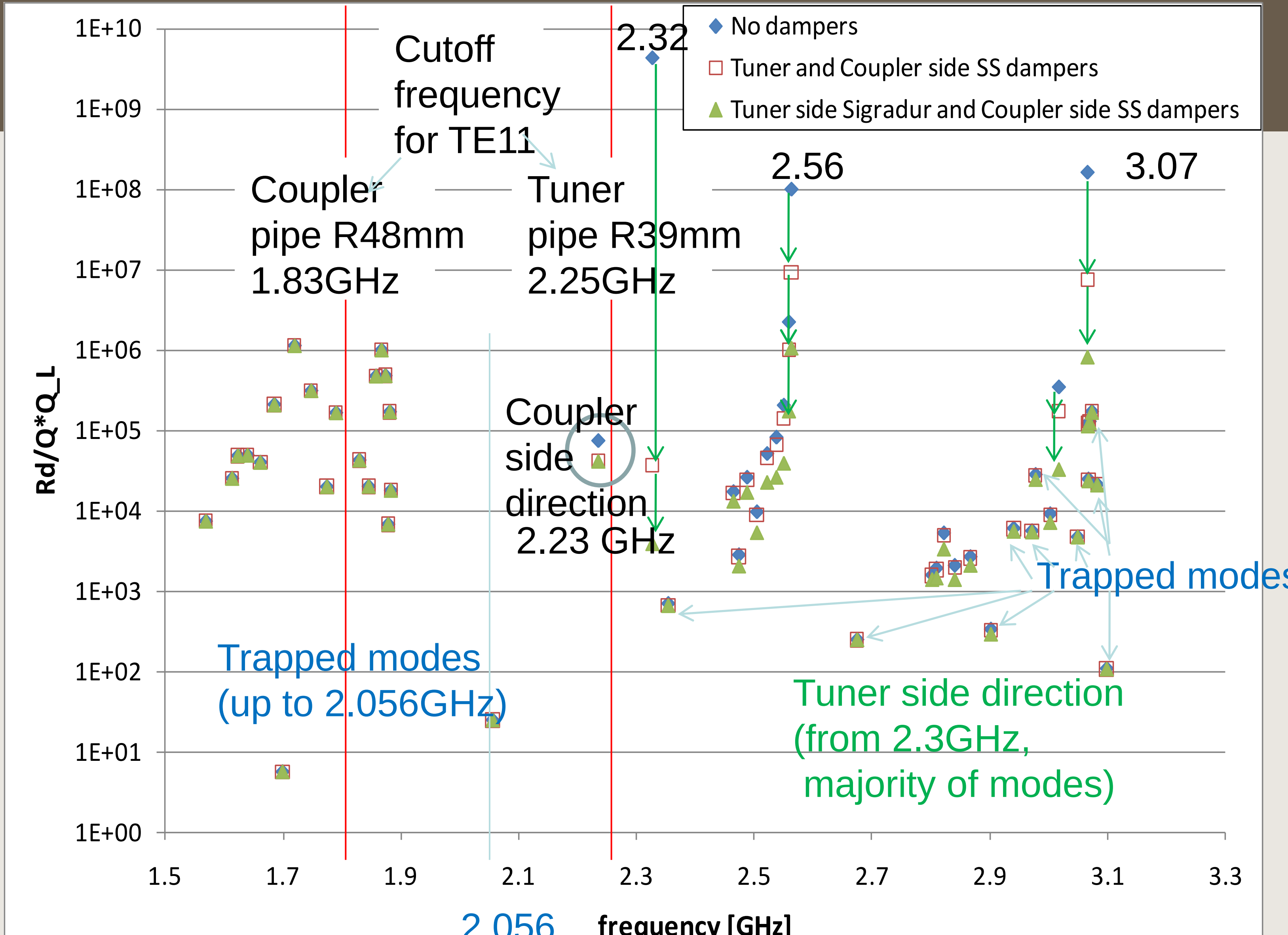




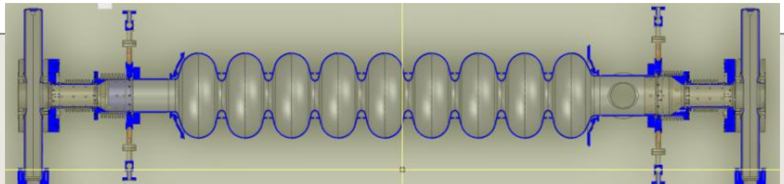
For HOM damper we are using the same concept as Cornell

TRIUMF

Directions for HOM penetration from cavity and dampers

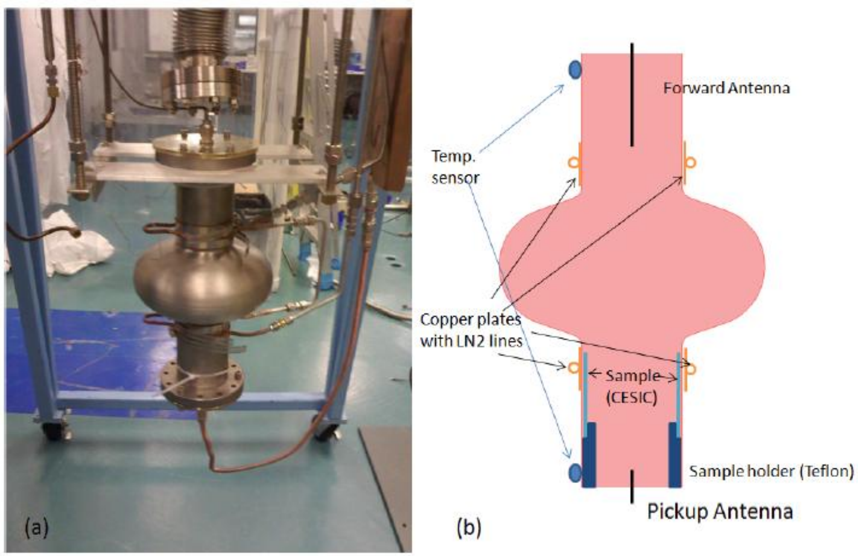


Tuner side (opposite to coupler)



Coupler side

Damper material (Cesic) tests



CESIC conductivity at 100 K:
600-6200 S/m from 1.3 GHz TM010
660-3400 S/m 2.4 GHz TM011
These conductivity values sufficiently damp all HOMs below the BBU criterion specified for the ARIEL cavities.

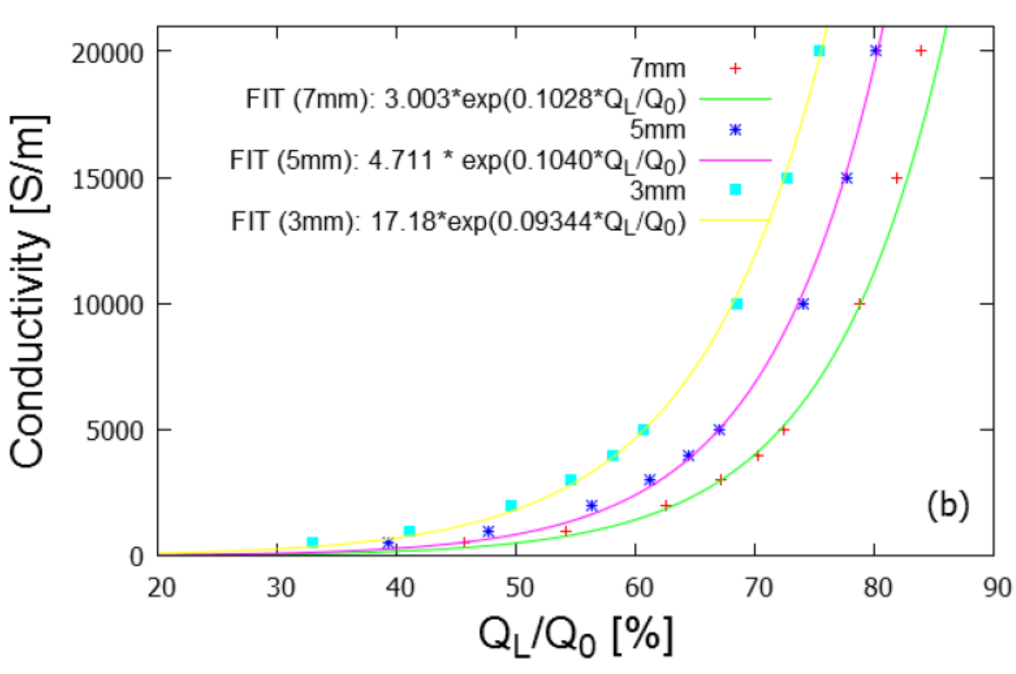
$$\frac{1}{Q_L} = \frac{1}{Q_0} + \frac{1}{Q_C} + \frac{1}{Q_{ext}}$$

Q perturbation measurements

$$Q_{ext} = \frac{\omega_n \cdot U_n}{P_a}$$

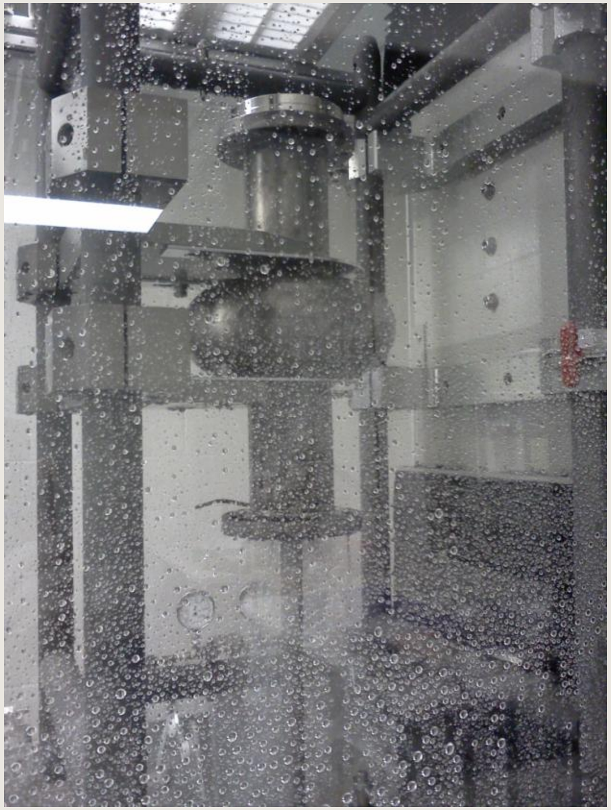
$$P_a = \frac{R_s}{2}\int_S |\mathbf{H}|^2 dA$$

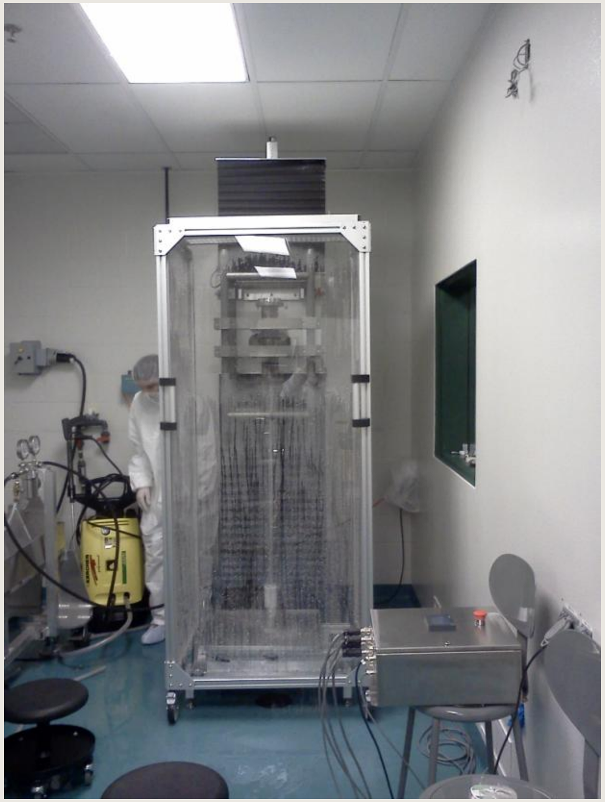
$$R_s = \sqrt{\frac{\pi f \mu_0}{\sigma}}$$



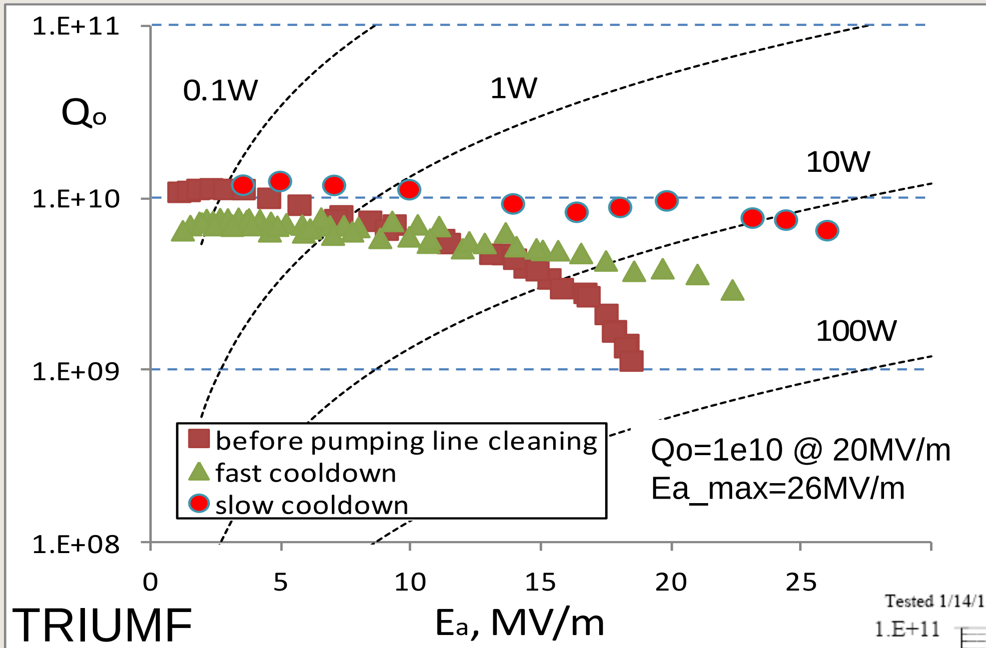
HWPR

- HPWR vertical rinse unit now operational in SRF wet lab



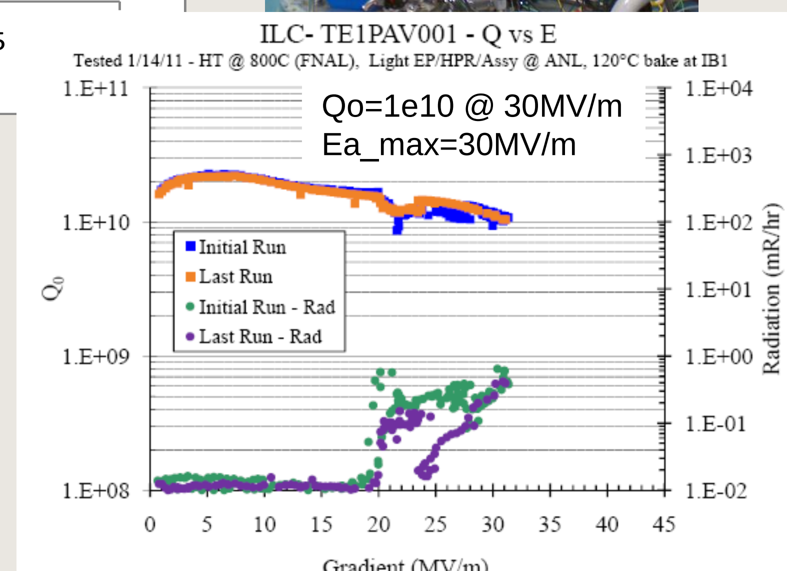


Single cell cavity test



Objectives:

- Qualifying PAVAC for 9 cell cavities production
- Development for Nb SC cavity surface preparation: BCP, HPWR, clean assembly
- Preparations for 9-cell cavity test

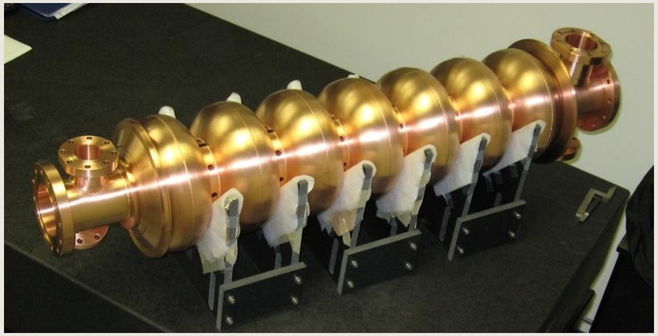


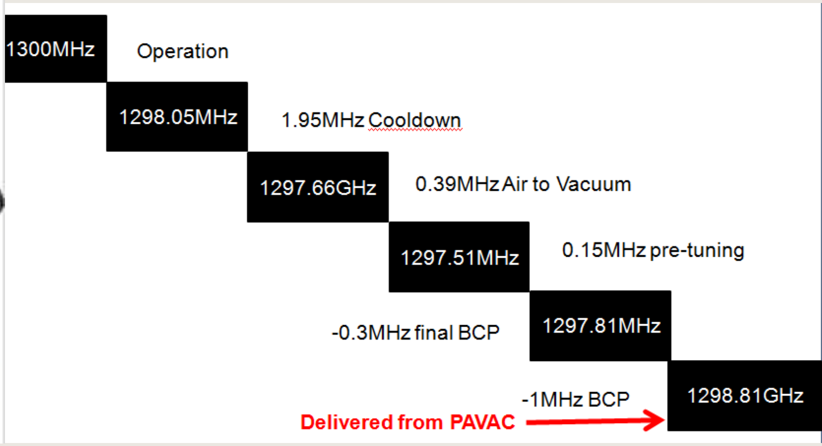
FERMILAB

TRIUMF

Cavity Fabrication

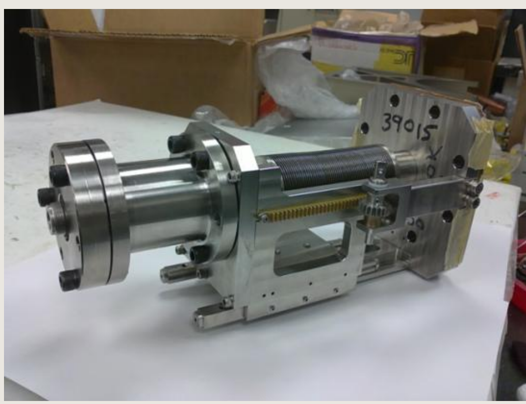
- 7-cell Cu cavity is delivered from PAVAC
- 9-cell cavity design is fixed and contract is signed
- 12 half cells formed and meet correct frequency – welding preps and parameters developed

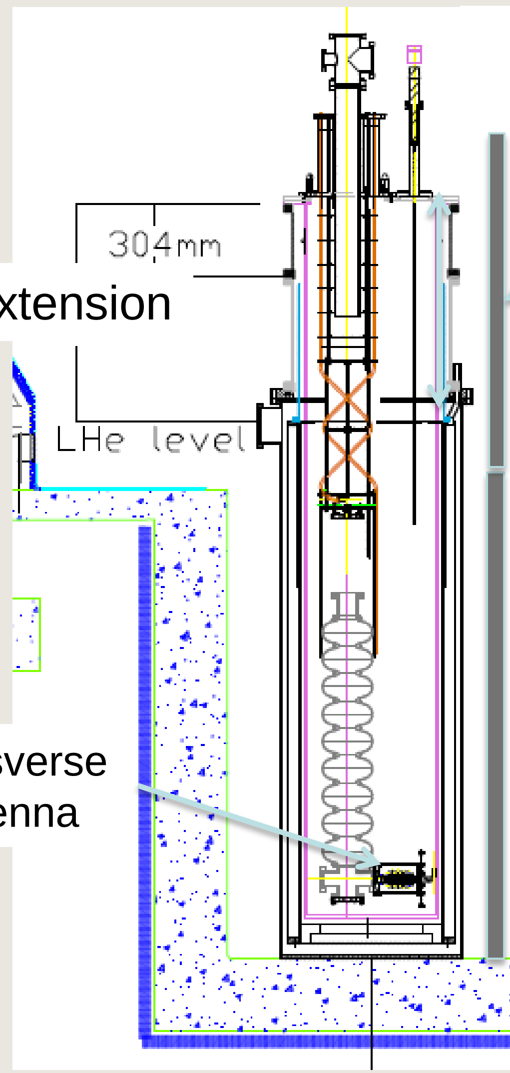


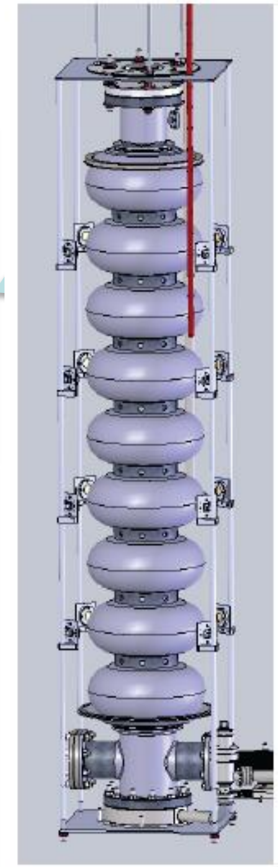


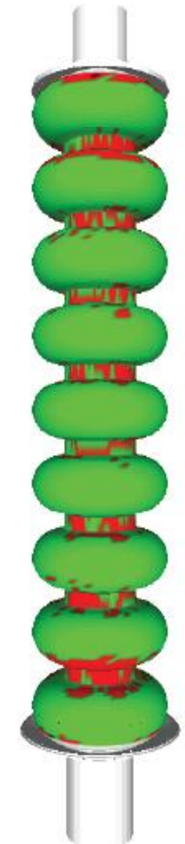
Multi-cell test cryostat

- Existing 141MHz cryostat being modified to be used for vertical SRF tests of nine cell cavity
- Fabrication in progress
- Cryogenic diagnostics in hand
- New transverse, variable rf antenna now assembled and tested
- Second sound monitor hardware and software are developed and tested

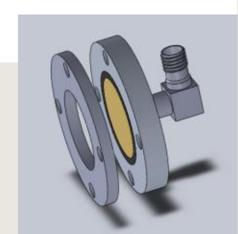








Second sound monitor:
16 transducers

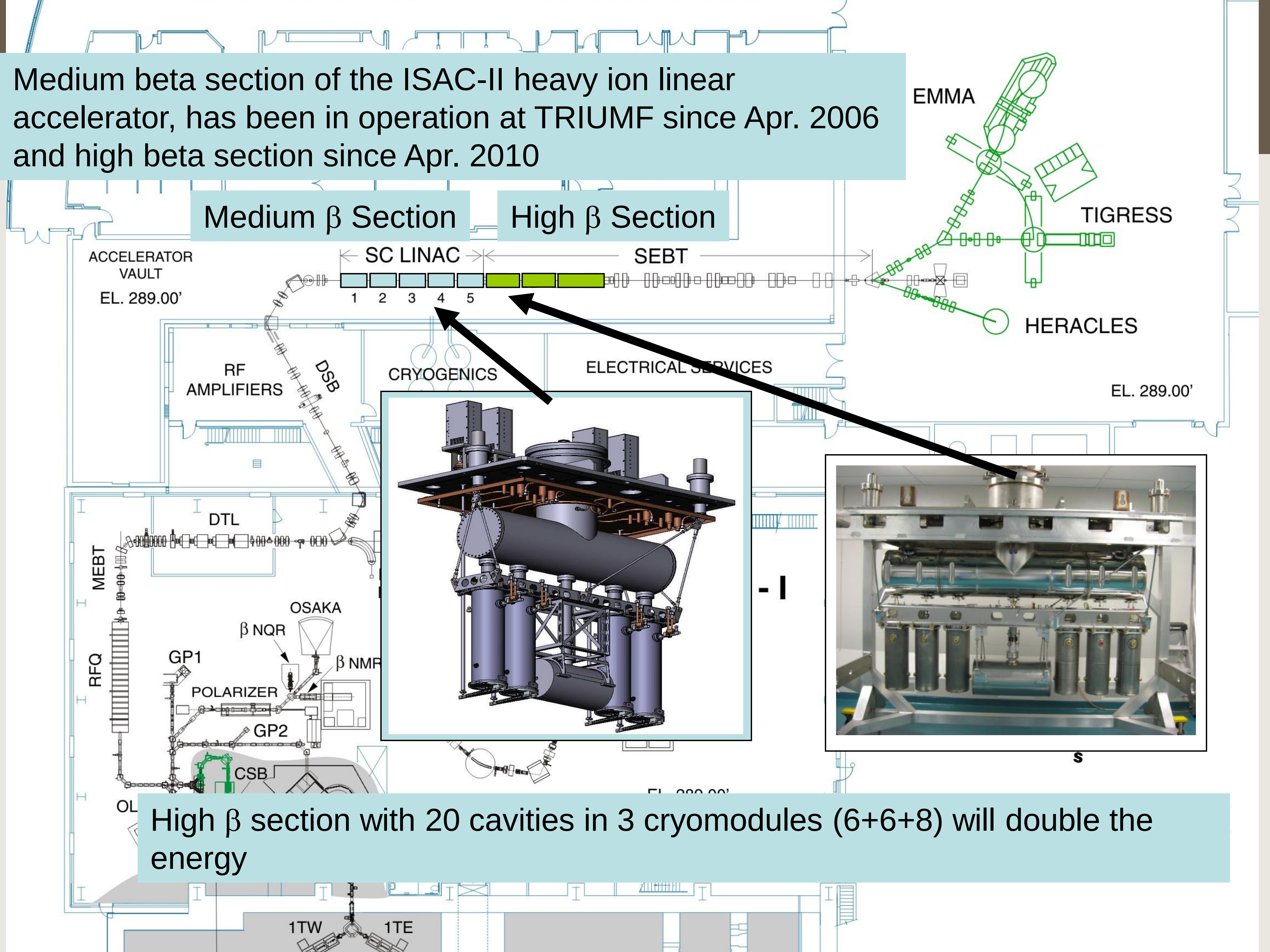


ISAC-II Results

Medium beta section of the ISAC-II heavy ion linear accelerator, has been in operation at TRIUMF since Apr. 2006 and high beta section since Apr. 2010

Medium β Section

High β Section



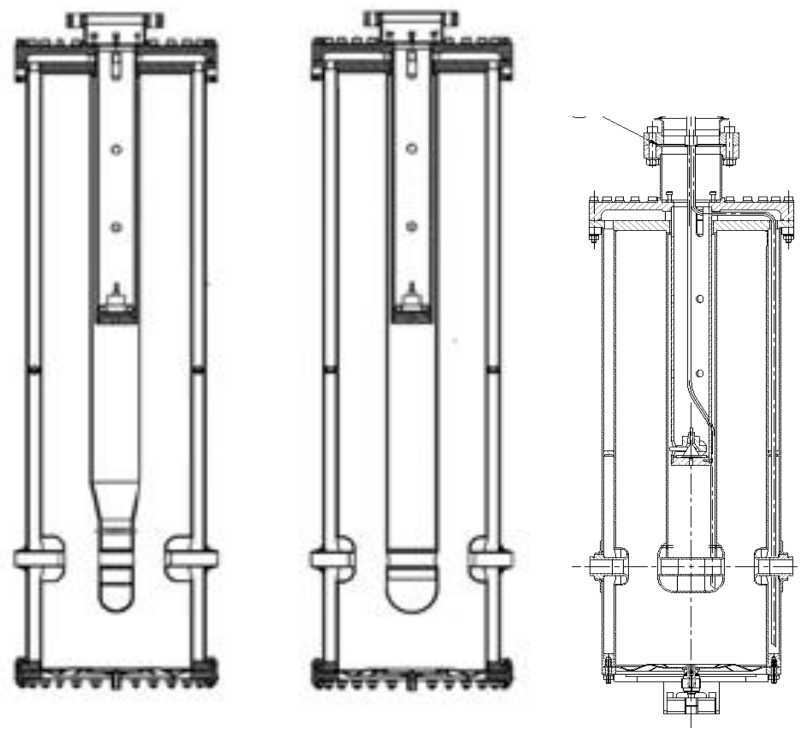
High β section with 20 cavities in 3 cryomodules (6+6+8) will double the energy

ISAC-II Results

Design goal, the final energy is equivalent to acceleration of a beam with A/q=6 to 6.5MeV/u, is achieved at input energy 1.5 MeV/u in March 2010 after comissioning of Phase-II of the ISAC-II accelerator.

Since April 2010 ISAC-II has supported a full physics program with both stable and radioactive beams being delivered. To date stable beams of 16O5+, 15N4+, 20Ne5+ and radioactive beams (and their stable pilot beams) of 26Na, 26Al6+, (26Mg6+), 6He1+, (12C2+), 24Na5+, (24Mg5+), 11Li2+, (22Ne4+) including 74Br14+ from the charge state booster have been delivered. In addition short commissioning periods between beam delivery runs are used to characterize the machine and to satisfy licensing requirements.

ISAC-II QWR Cavities



Phase-I
Zanon (Italy)

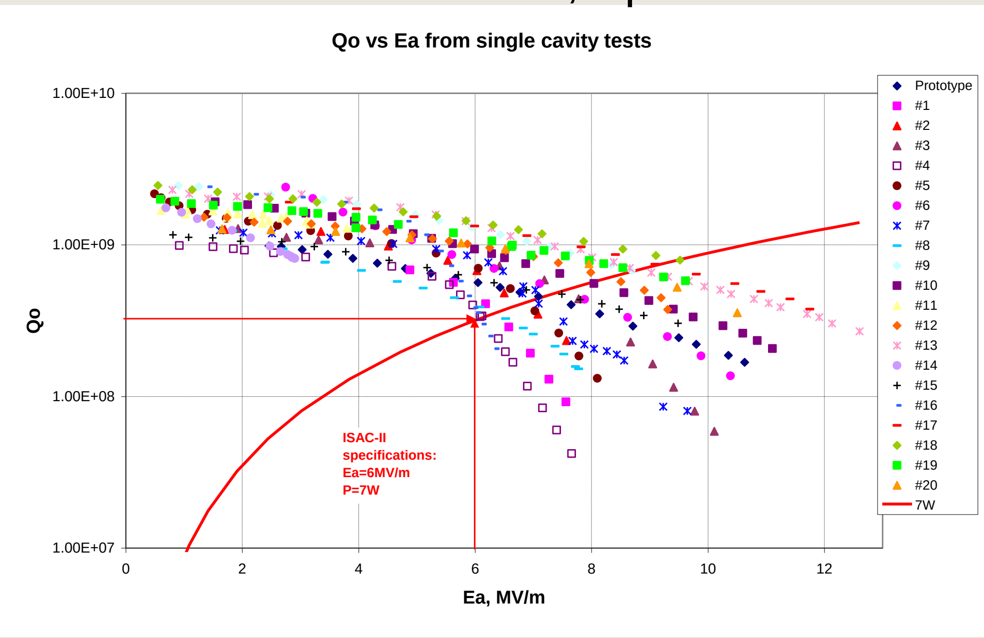
Phase-II
PAVAC (Canada)

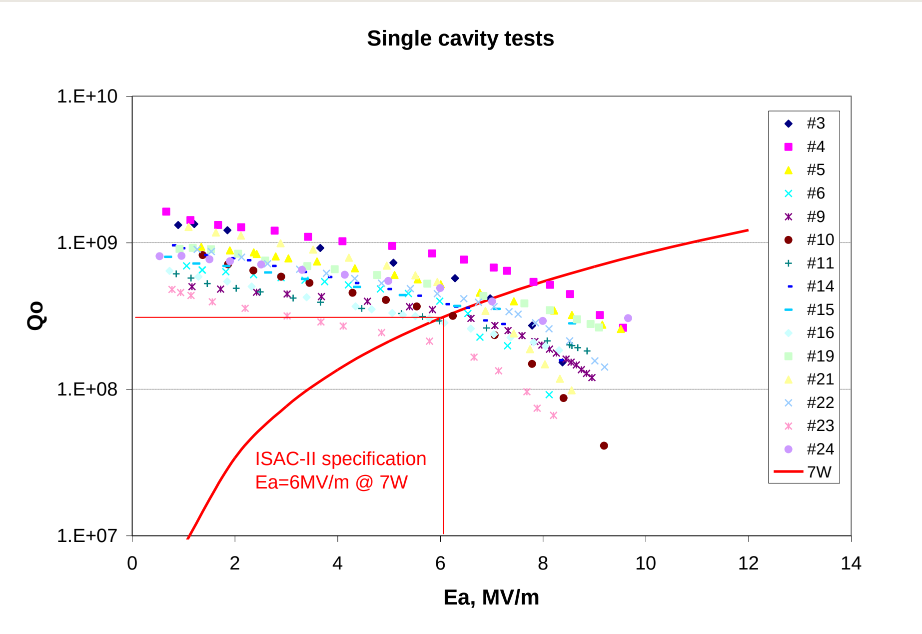
	flat	round	donut
f(MHz)	106.080	106.080	141.440
RsQ(Ohm)	20.1	19.1	26.0
βo	0.064	0.075	0.112
TTFo	0.870	0.898	0.936
Ep/Ea	5.2	4.7	4.9
Bp/Ea(mT/(MV/m))	10.3	10.1	10.0
U/Ea2 (J/(MV/m)2)	0.100	0.094	0.067

The difference between the cavities is in the beam tube region of the inner conductor. The round inner conductor shape of the beta 7.1% 106MHz is modified by squeezing to attain the 5.7% beta cavity. To provide the structure with optimum beta of 11% we went to 141MHz with corresponding decreasing of cavity length. A beam tube is added to improve the transit time factor. All cavities are specified for CW operation at 7W power dissipation with acceleration voltage 1.08MV corresponding to 30MV/m electric and 60mT magnetic peak field.

Single cavity test results

Phase-I, Ep= Phase-II

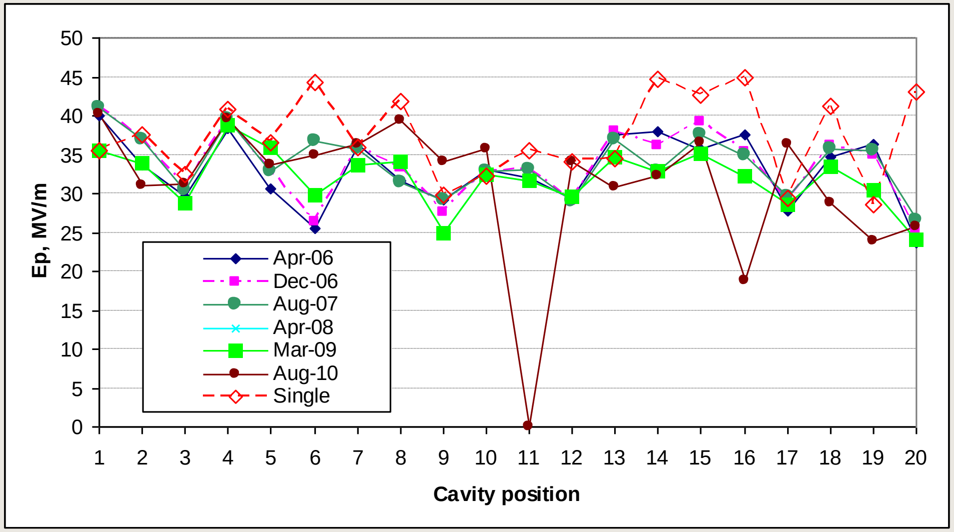




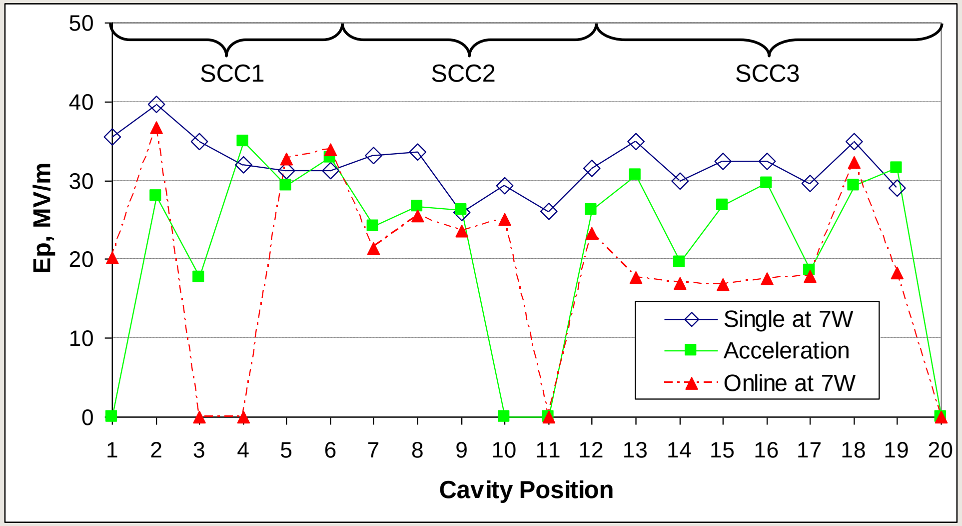
- Both Phases prepared with the same procedure : degreased, BCP etch, 40 minutes high pressure rinsing with ultra-pure water, air dried for 24h and assembled in clean room.
- Cavities are baked for 48 hours during pumpdown: single cavity cryostat 85-90C, cryomodules 70-75C.
- Thermal shield of cryomodule is pre-cooled with LN2 24h before helium cooling is started. (cavities stay above 200K).
- Fast LHe cooling to avoid Q-disease due to hydride precipitation. (cooldown rates around 80-100K/hour between 150-50K).
- Earth magnetic field shielded by warm μ-metal layer (1mm SCB and 1.5mm SCC) fastened inside vacuum vessel in cryomodule and cryoperm shield in single cavity cryostat

Online Performance

Phase-I



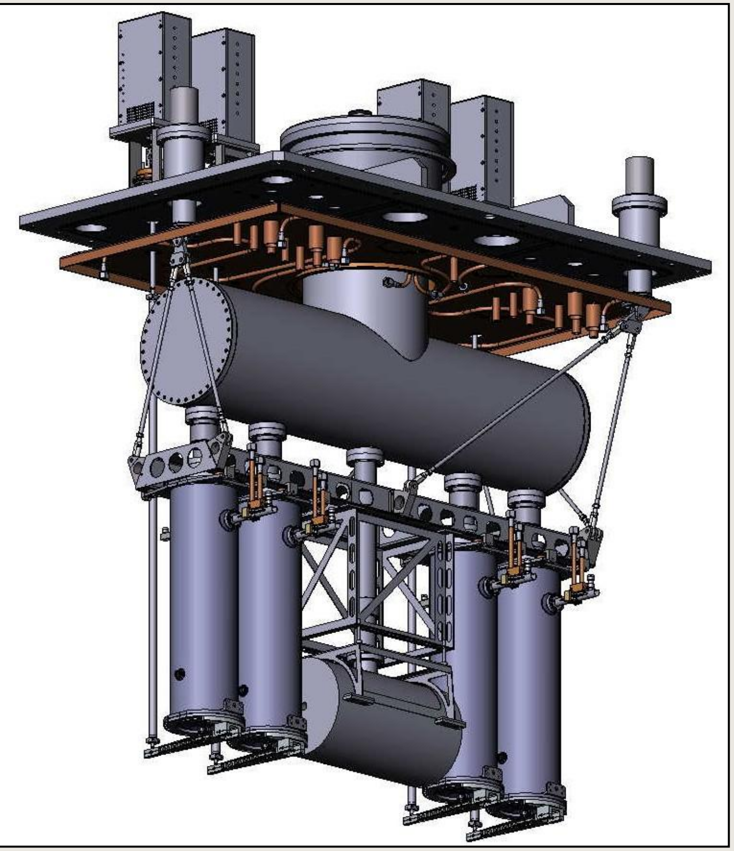
Phase-II



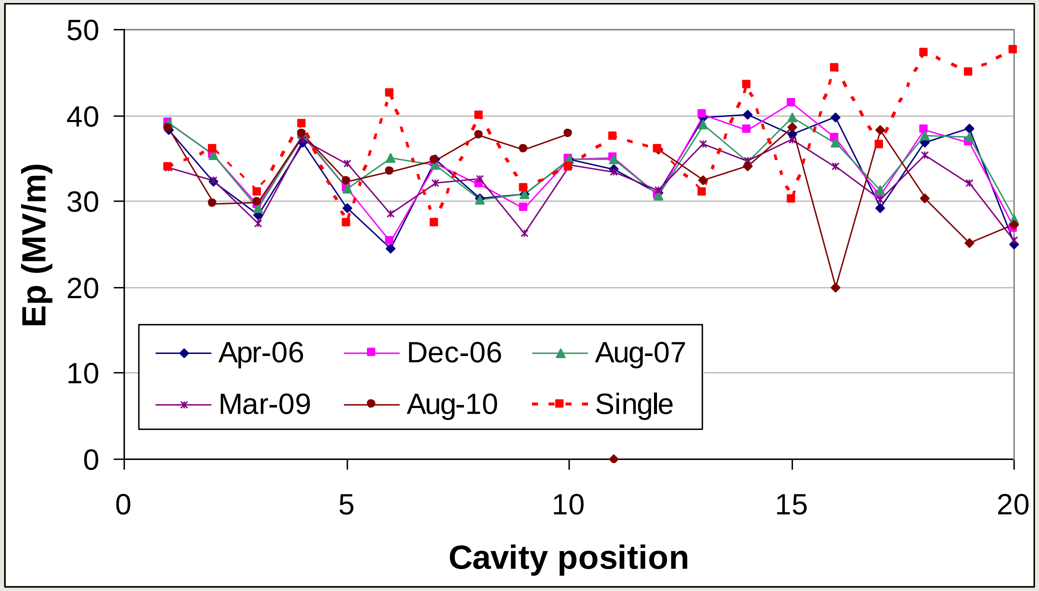
Test	Metric	PHASE I (MV/m)	PHASE II (MV/m)
Single Cavity	<Ep> @ 7W	37	32
Installed	<Ep> @ 7W	33	26
Acceleration	Stable <Ep>	30-32	27

Peak field Ep=5*Ea, Acceleration voltage Va=Ea*0.18

PHASE I EXPERIENCE

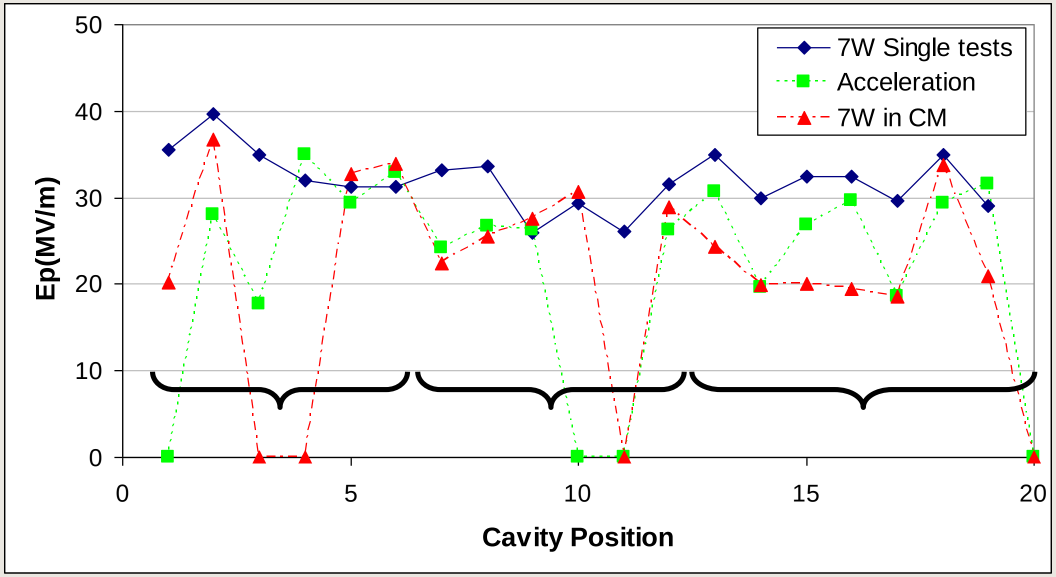


Comissioned in 2006 for 40Ca10+, 22Ne4+, 20Ne5+, 12C3+, 4He1+ and 4He2+ (A/q ratios of 5.5, 4 and 2) with final energies of 10.8, 6.8 and 5.5 MeV/u



• No major degradation of cavity performances over 4 years (see figure below).
• Cavities operated at an average peak electric surface field of chronologically 33.6, 34.2, 34.4, 32.5 and 33.2 MV/m at Pcav=7W. Average peak field of 37.1 MV/m during single tests.
• Degradations observed after helium delivery failures due to trapped flux (solenoid). Full recovery in two hours after warming up to 30K.
•Strong low-level multipacting makes beam tuning difficult especially after start-up. Pulse conditioning is required.
• Aging of tube amplifiers causes detuning and non-linearity in LLRF control periodically.
• One cavity is out of commission
•presently (coupler cable open circuit).

PHASE II EXPERIENCE



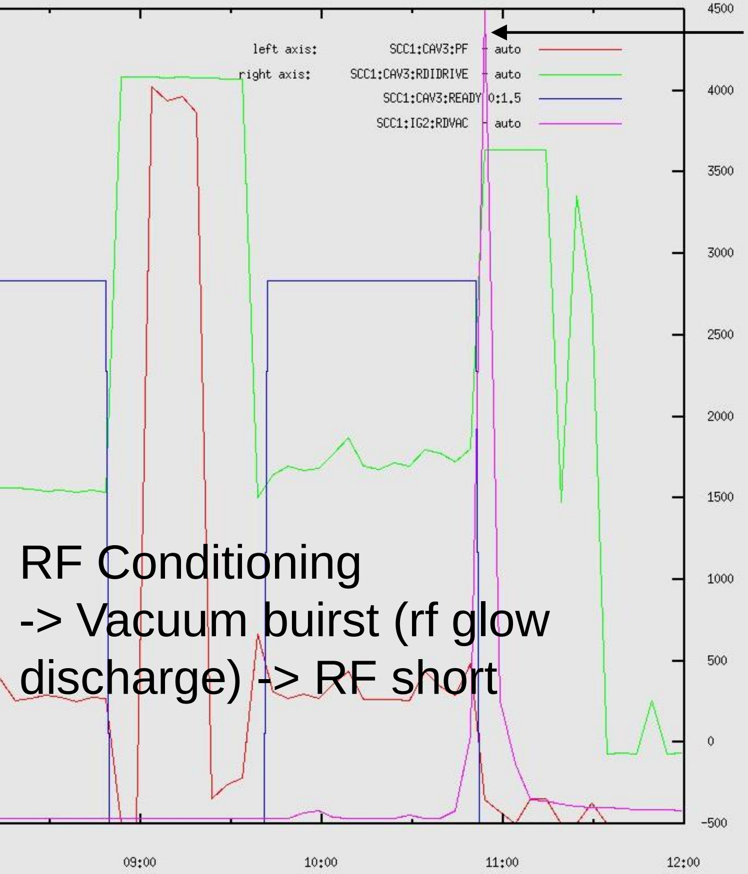
16O5+ beam (A/q=3.2) from the ISAC off-line (stable) source was accelerated to 10.8MeV/u on April 24, 2010, which is equivalent to goal specification for the ISAC-II post-accelerator is to reach 6.5MeV/u for particles with A/q=6.

- Four cavities required rework after a vacuum leak opened during the initial BCP etching - weld joining the drift tube and the inner conductor – cavities recovered by PAVAC.
- Tight schedule imposed precautionary reduction of etching to 60 microns and four cavities installed without single cavity test.
- Average peak electric surface field dropped from 32 MV/m in single cavity test to 26 MV/m for on-line tests. Under study [6]. Theories: Single cavity performance reduced due to insufficient etch and cryomodule performance due to imperfect environment/preparation (Trapped flux, Q-disease)
- Four cavities are presently out of commission (coupler cable shorts) possibly due to too high forward power during conditioning.

ISAC-II Current Status

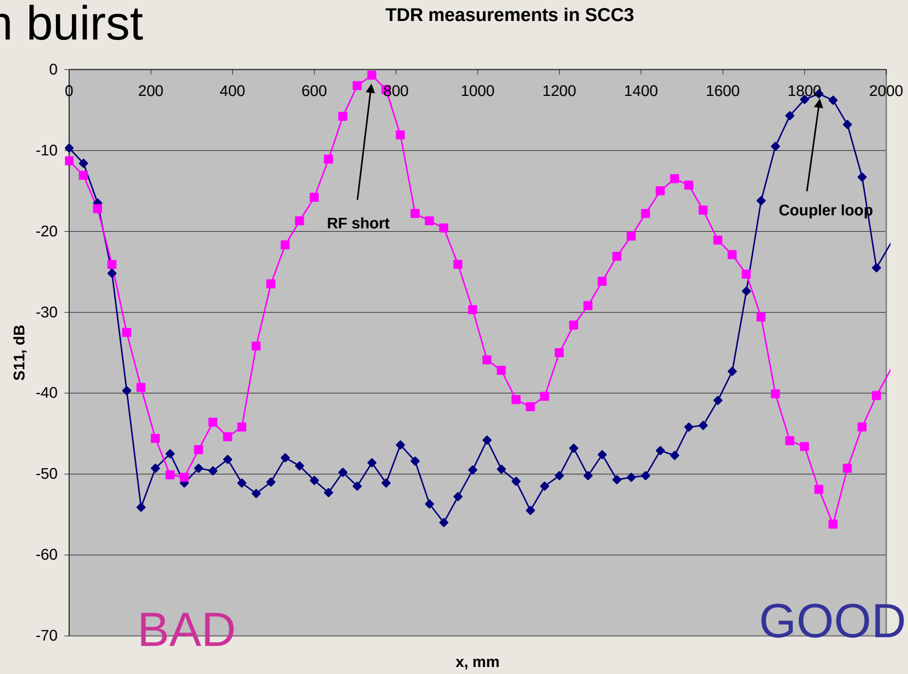
- Since the results for ISAC-II reported in [2] we have two years of successful operation. One identified problem is in the coupler line cables inside of the cryomodules with several failures due to RF breakdown in the cable isolation from RF glow discharge. Due to the flexibility of the accelerator structure consisting from many cavities with independent RF systems a failure can be easily compensated by means of increasing gradients and retuning other cavities. During planned shutdowns the damaged cables are replaced. To prevent this particular cable problem we restricted forward power levels in the RF amplifiers and initiated a cable test stand to develop a more robust cable.
- Phase I of ISAC-II is using 1 kW tube-type RF power amplifiers, with a tube lifetime of ~12,000 hours. Two prototype solid state amplifiers at 600 W are now developed. Currently they are under test to take a decision about a replacement program.

Inner coupler cables failure

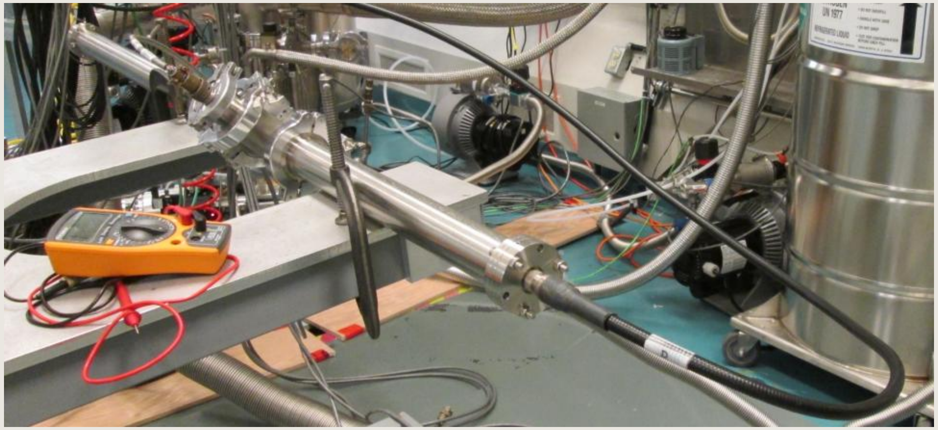


Vacuum buirst

RF Conditioning
-> Vacuum buirst (rf glow discharge) -> RF short



Vacuum stand for cable tests



CONCLUSIONS

- In the end of 2012 we expect delivery from PAVAC of the e-LINAC nine-cell cavity and start SRF tests for cavity commissioning. Main resources are concentrated in this direction.
- Another important task for SRF development is to support the ISAC-II linac for reliable operation for users.
- TRIUMF is leveraging the installed infrastructure to support fundamental studies in SRF for student education and for implementation in current and future projects.

THANKS!