TRIUMF

ISAC-II SCRF

V. Zvyagintsev

2013-02-27

- Introduction
- SCRF Basics
- ISAC-II SC Cavity Design
- Fabrication and preparation
- Conditioning and tests
- Operation
- Maintenance

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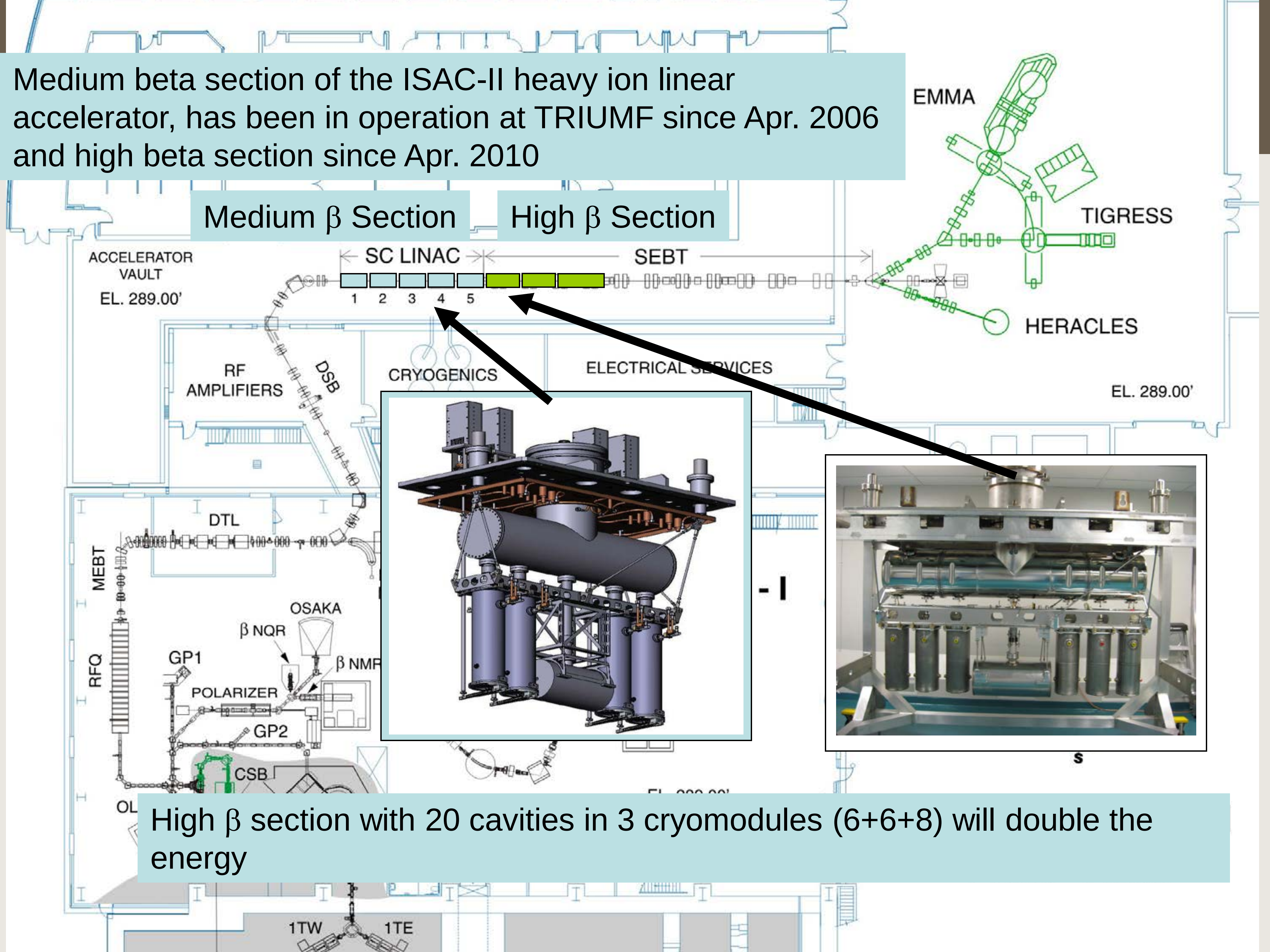
ISAC-II Results

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.

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

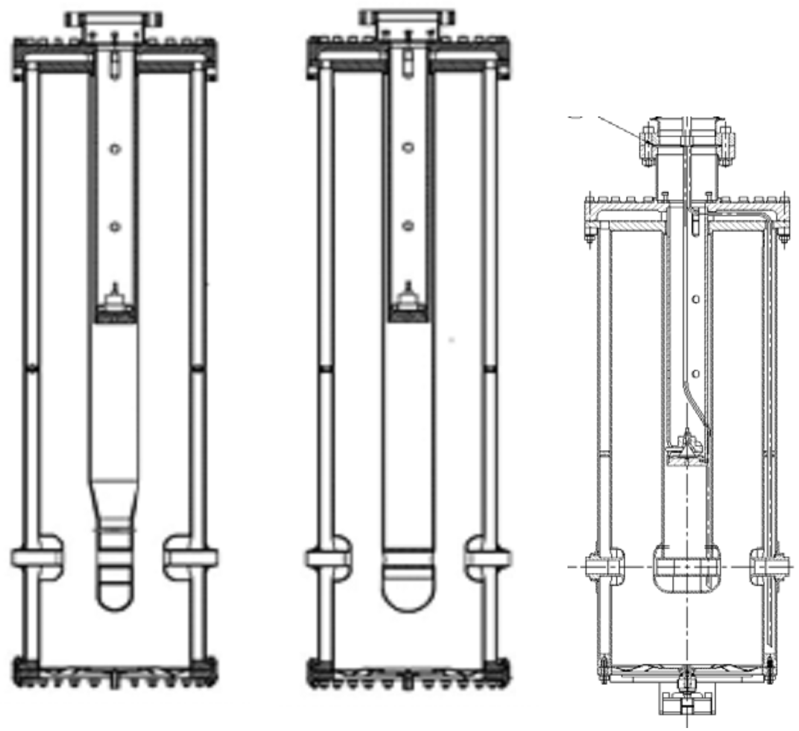
Medium β Section

High β Section



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

ISAC-II 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.

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Superconducting radio frequency

http://en.wikipedia.org/wiki/RF_Superconductivity

Physics of SRF cavities

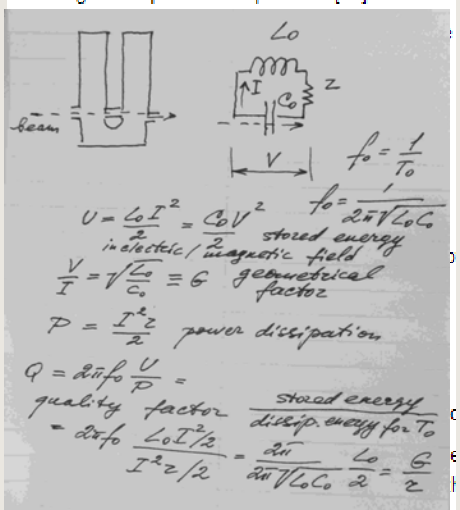
The physics of Superconducting RF can be co
parameters of SRF cavities.

By way of background, some of the pertinent p

$$Q_o = \frac{\omega U}{P_d},$$

where:

- ω is the resonant frequency in [rad/s],
- U is the energy stored in [J], and
- P_d is the power dissipated in [W] in the ca



An RF cavity parameter known as the Geomet
given by

$$G = \frac{\omega\mu_0 \int |\vec{H}|^2 dV}{\int |\vec{H}|^2 dS},$$

and then

$$Q_o = \frac{G}{R_s}.$$

The geometry factor is quoted for cavity design

$$R_{s\ normal} = \sqrt{\frac{\omega\mu_0}{2\sigma}}.$$

For copper at 300 K, $\sigma = 5.8\times10^7\ (\Omega\cdot m)^{-1}$ and at 1.3 GHz, $R_{s\ copper} = 9.4\ m\Omega$.

For Type II superconductors in RF fields, R_s can be viewed as the sum of the super

$$R_s = R_{BCS} + R_{res}.$$

The *BCS resistance* derives from BCS theory. One way to view the nature of the BC
alternate sinusoidally for the AC currents of RF fields, thus giving rise to a small ene
temperature, $T<T_c/2$, by

$$R_{BCS} \simeq 2\times10^{-4}\left(\frac{f}{1.5\times10^9}\right)^2 \frac{e^{-17.67/T}}{T}\ [\Omega],$$

where:

- f is the frequency in [Hz],
- T is the temperature in [K], and
- T_c=9.3 K for niobium, so this approximation is valid for T<4.65 K.

Note that for superconductors, the BCS resistance increases quadratically with freq
superconducting cavity applications favor lower frequencies, <3 GHz, and normal-co

The superconductor's *residual resistance* arises from several sources, such as rand
quantifiable residual resistance contributions is due to an external magnetic field pin
to estimate their net resistance. For niobium, the magnetic field contribution to R_s c

$$R_H = \frac{H_{ext}}{2H_{c2}} R_n \approx 9.49\times10^{-12} H_{ext}\sqrt{f}\ [\Omega],$$

where:

- H_{ext} is any external magnetic field in [Oe],
- H_{c2} is the Type II superconductor magnetic quench field, which is 2400 Oe (190
- R_n is the normal-conducting resistance of niobium in ohms.

For 141 MHz cavity

Rs~3e-3 Ohm – copper at RT

Rbcs~6e-9 Ohm Nb at 4K

2 million times less

Rh~60e-9 unshielded
Shielding factor ~ 50
=> Rh~1e-9 Ohm

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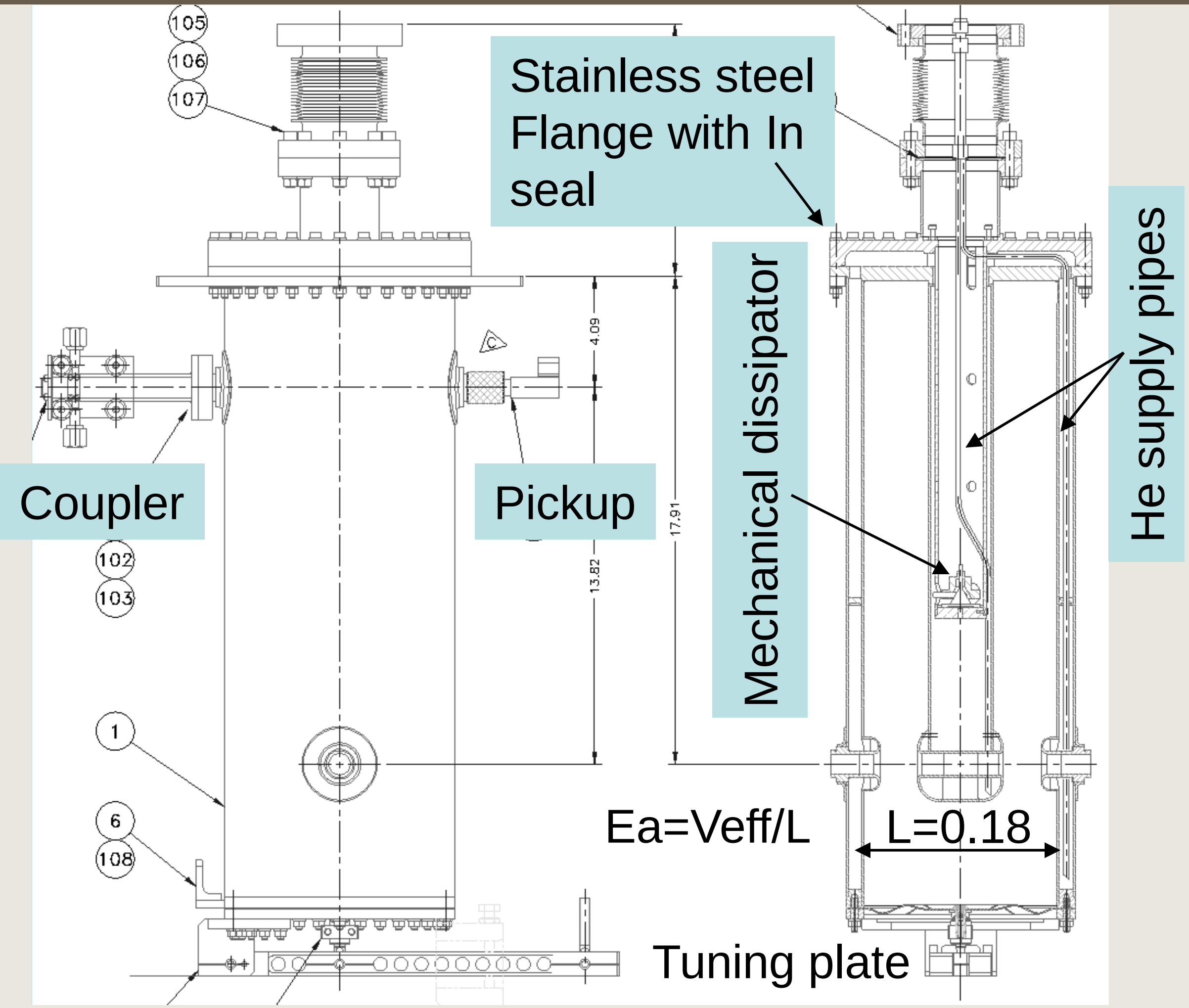
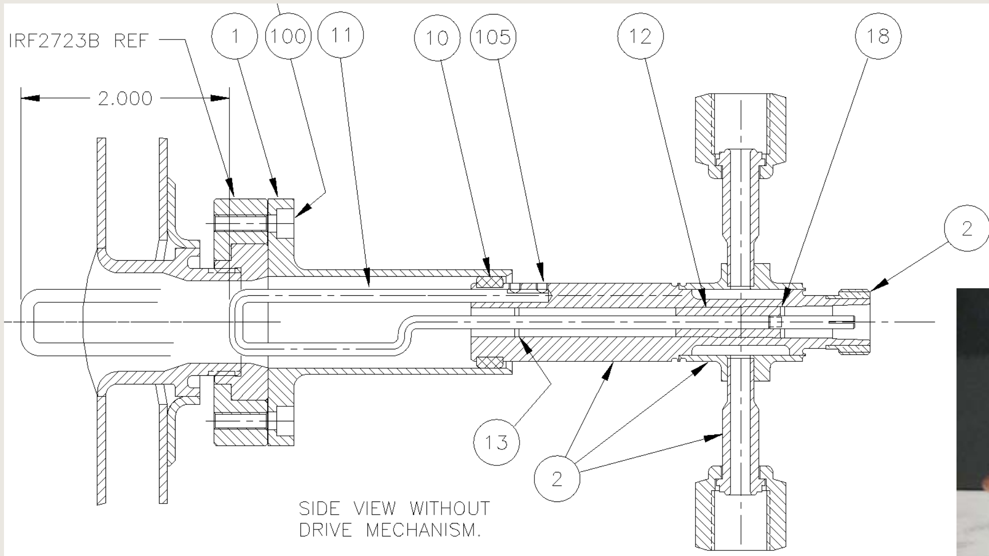
SCC Cavity Design

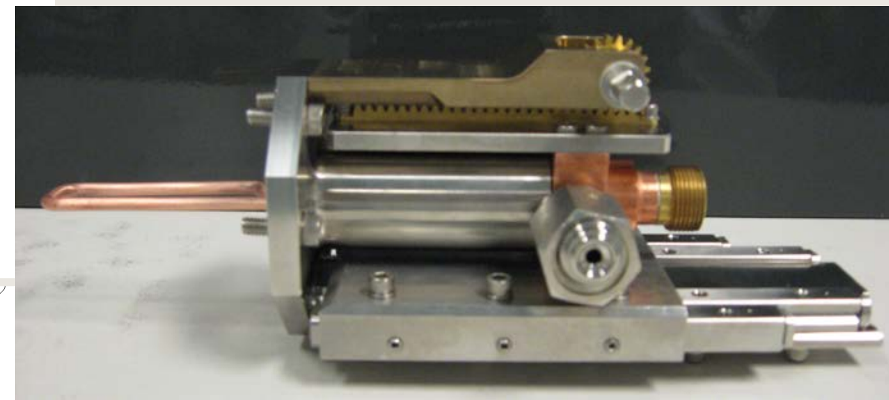


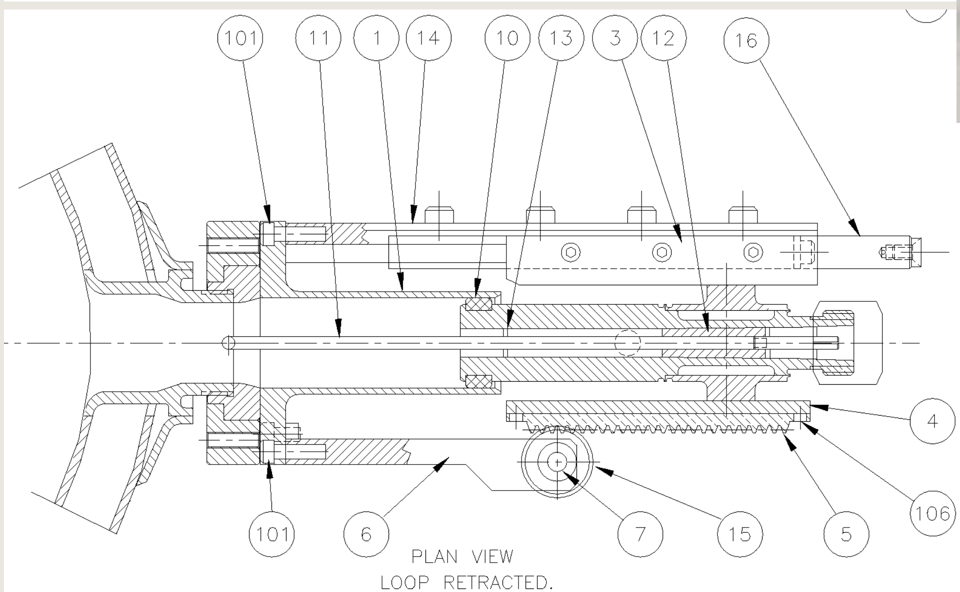
Direct venting
Filtered nitrogen venting instead of venting from the thermal isolation vacuum to avoid particulates drifting into cavity

Coupler Design



Heat sink for liquid nitrogen flux
Shapal RF window is thermal drain for inner conductor

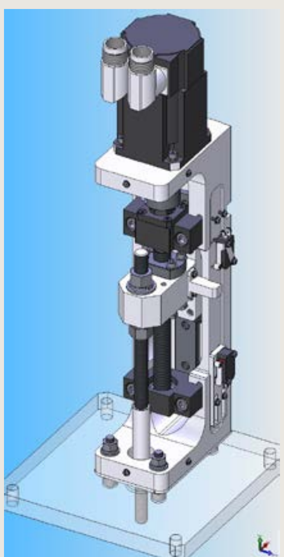


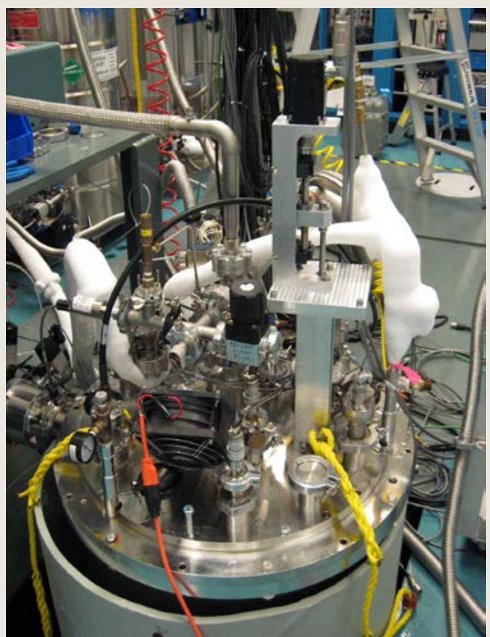


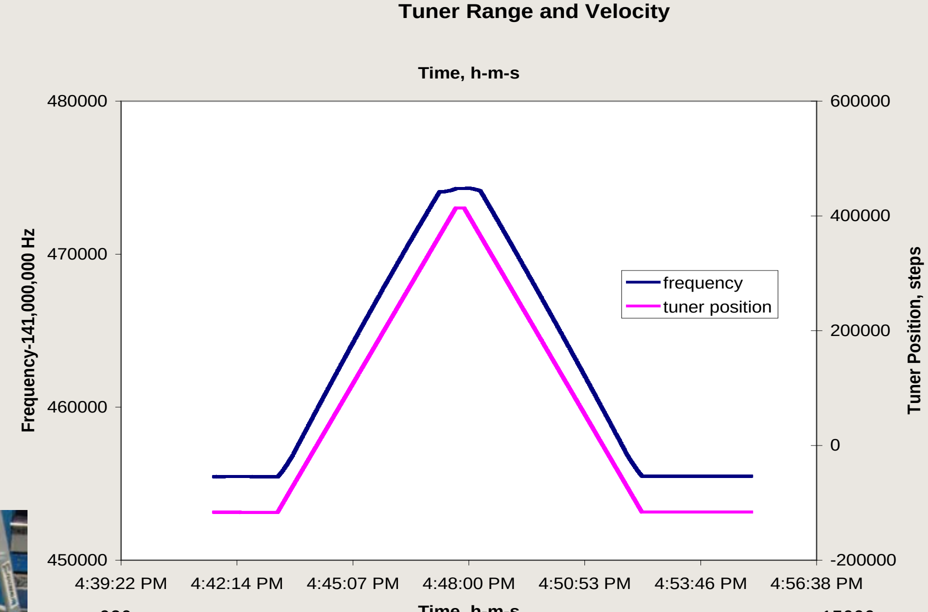
Trolley plate with cross-roller bearings provides smooth movement and holds load from rf cable and bellows with nitrogen

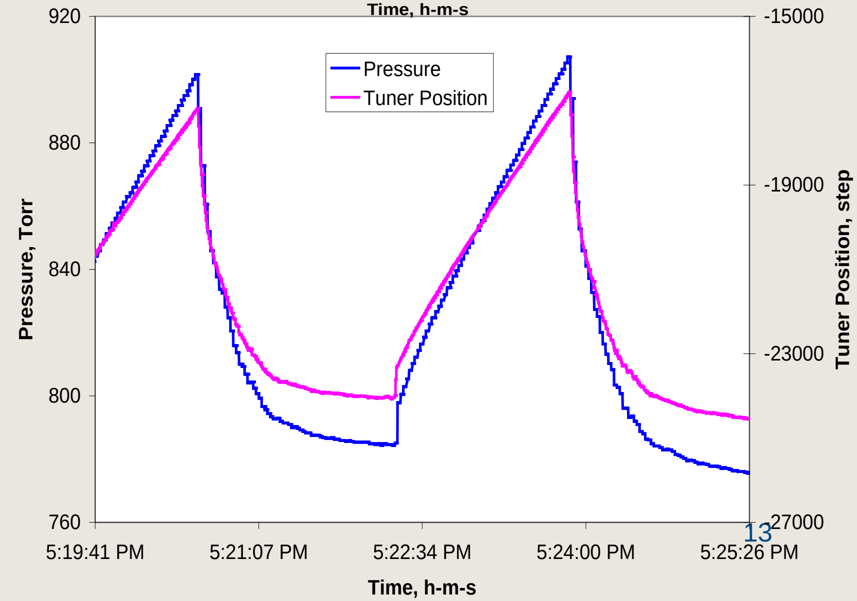
SCC Tuner

Static Test:
Range ~18.5 kHz, Velocity 76 Hz/s,
Resolution 0.04 Hz/step
Dynamic tests:
•He pressure variations
Ea= 6.4MV/m,Pf=166W, Df~40 Hz
Pressure variation 137 T ->Dfo~330 Hz
Velocity ~5.5T/s=13Hz/s
•Reference signal variations
1 Hz FM up to 10Hz deviation









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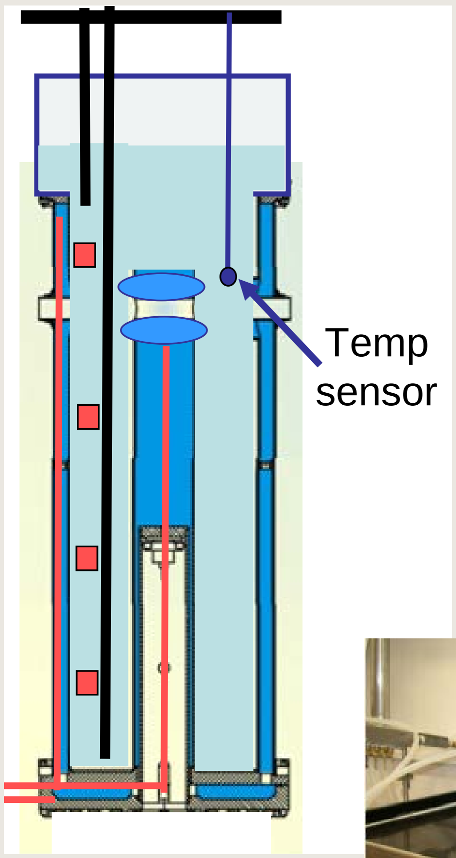
Cavity Production at PAVAC

BCP Etching at TRIUMF

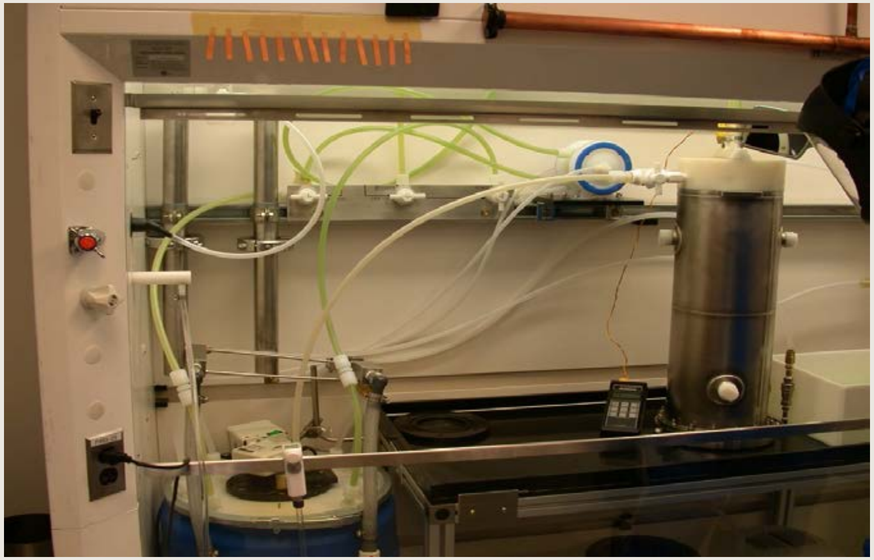
BCP 1:1:2

HF,HNO3,H3PO4



Temp sensor

H_2O

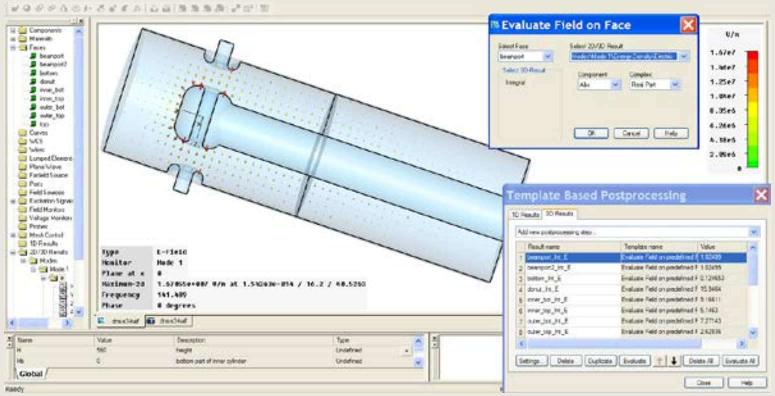


Pre-weld etching ~20um

~10^0C

~1um/min

~100um etch



Differential etching for frequency compensation

Differential sensitivity for ½

2 kHz/um for

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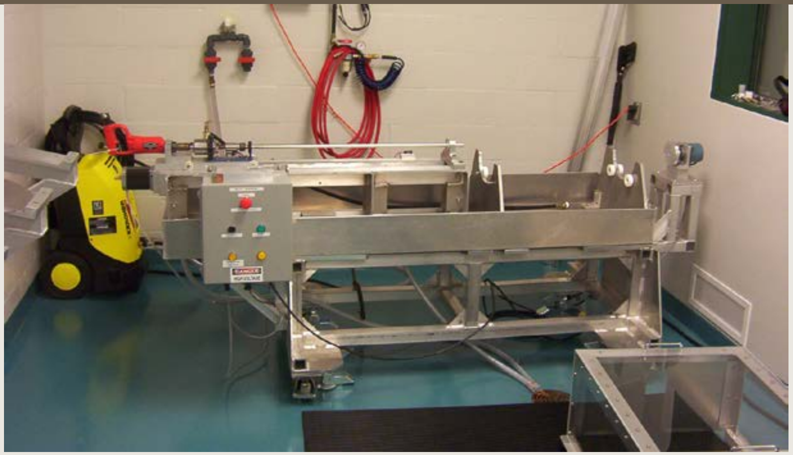
Cavity Preparation



Typical treatment before the test Involves
- 40min high pressure rinse
- 24 hour air dry in a clean room

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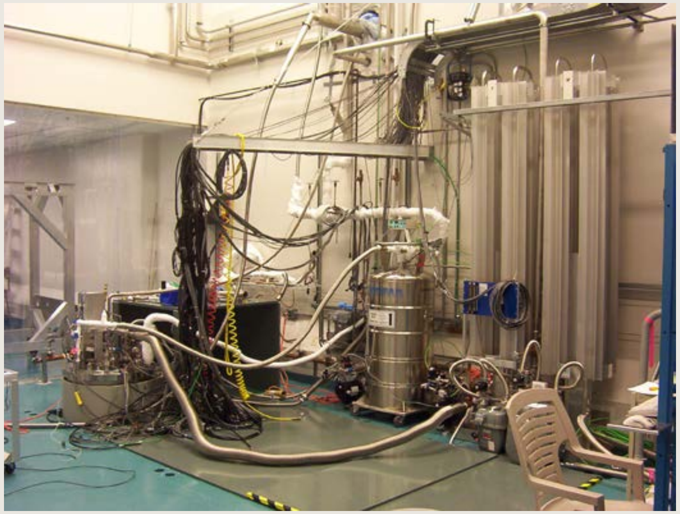
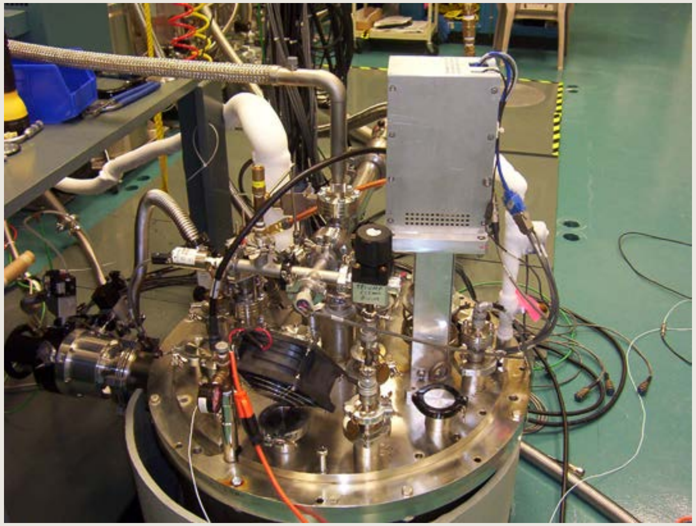
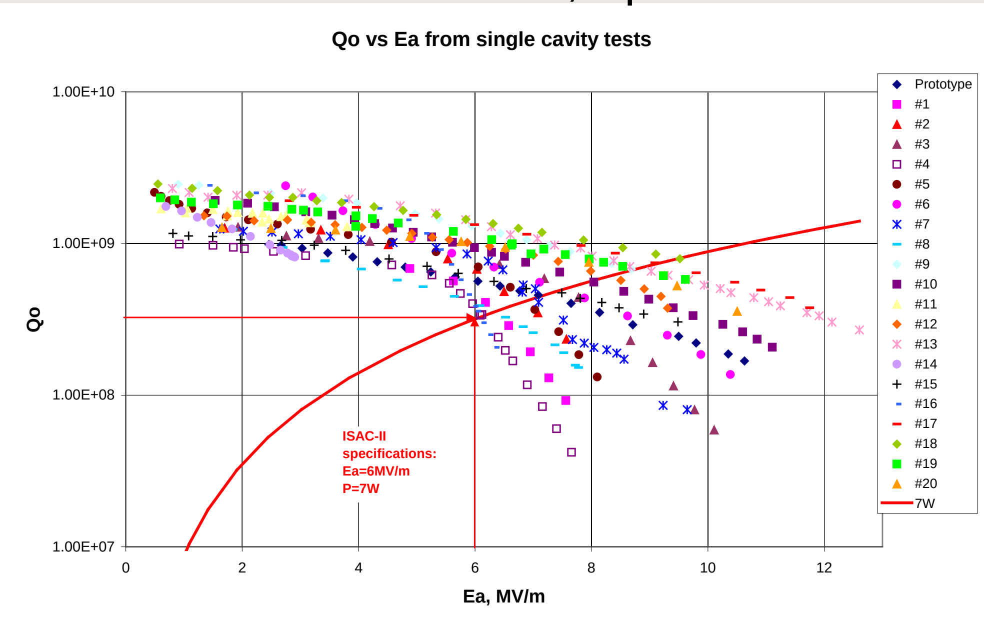
Single cavity test



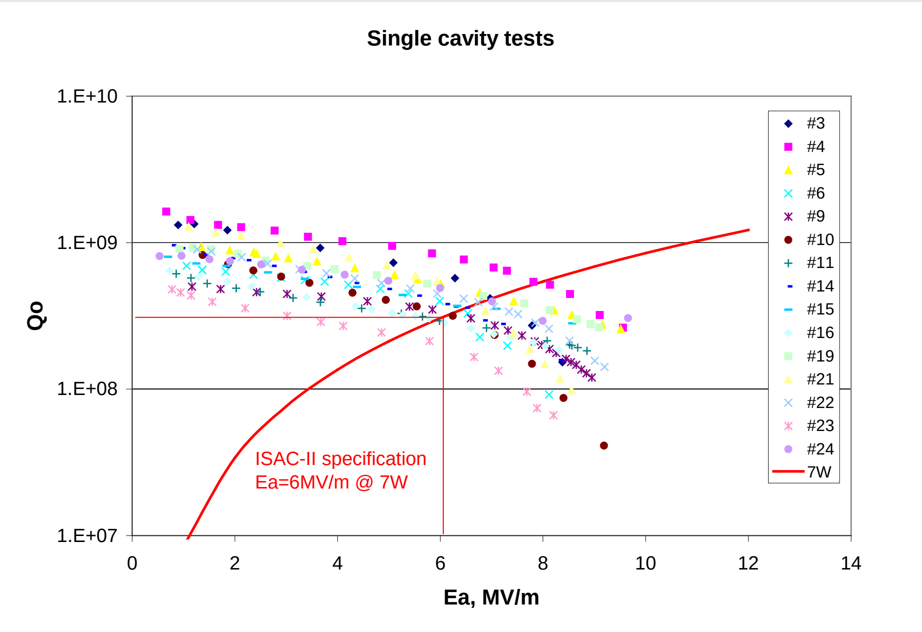


Single cavity test results

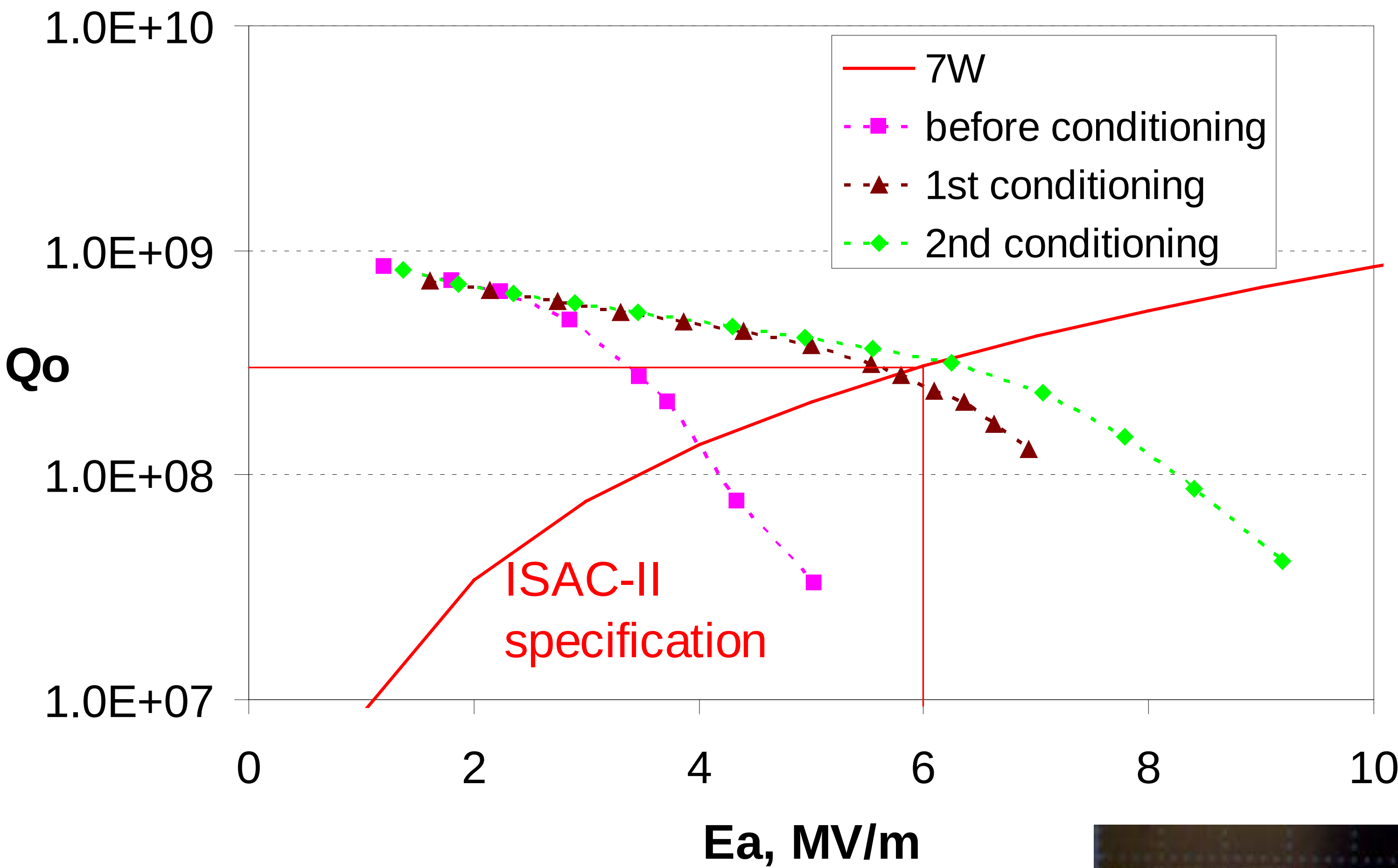
Phase-I, Ep=

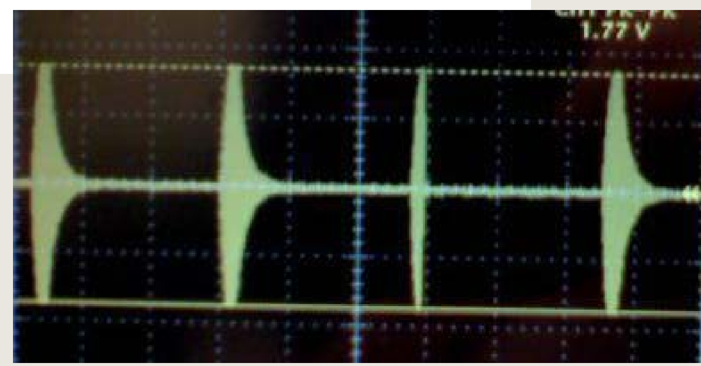


Phase-II



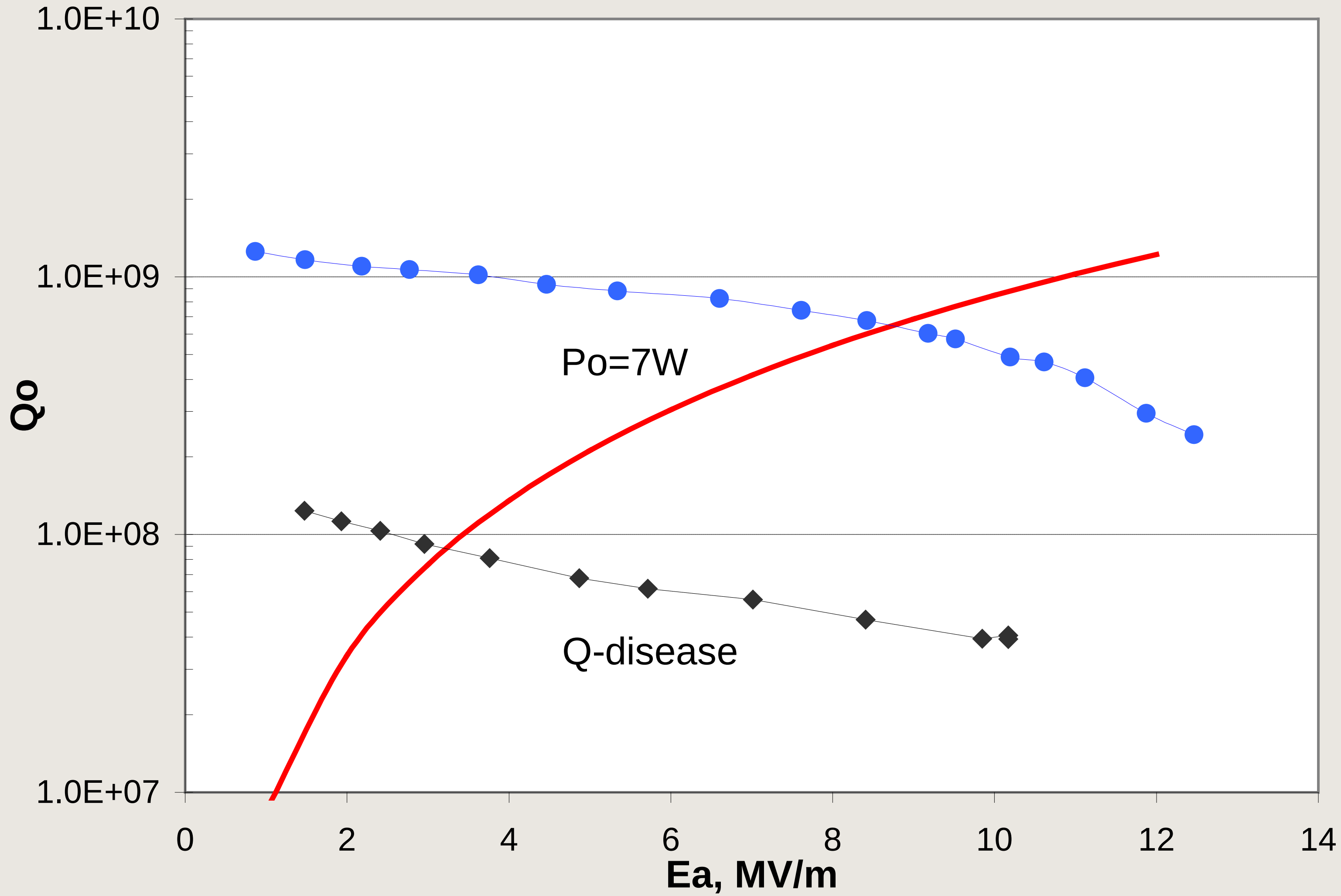
- Both Phases prepared with the same procedure : degreased, BCP etch, 40 minutes high pressure rinsing with ultra-pure water, air dried for 24h and assembled in clean room.
- Cavities are baked for 48 hours during pumpdown: single cavity cryostat 85-90C, cryomodules 70-75C.
- Thermal shield of cryomodule 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



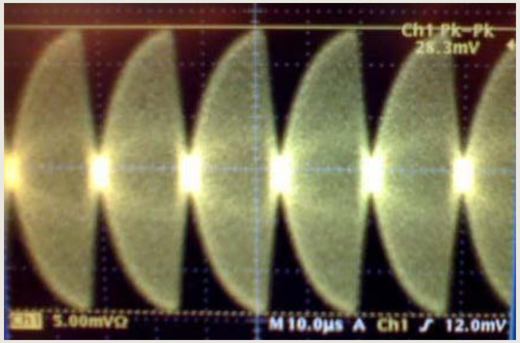


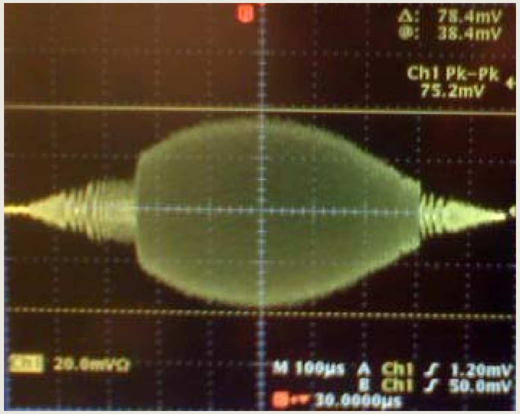
Q-curves measured after cavity RF conditioning cycles

RF pulsing (0.1s/1s) of overcoupled cavity with Pf~200-400W. For better efficiency we do leak of ~10^{-5} Torr He in the cavity volume.

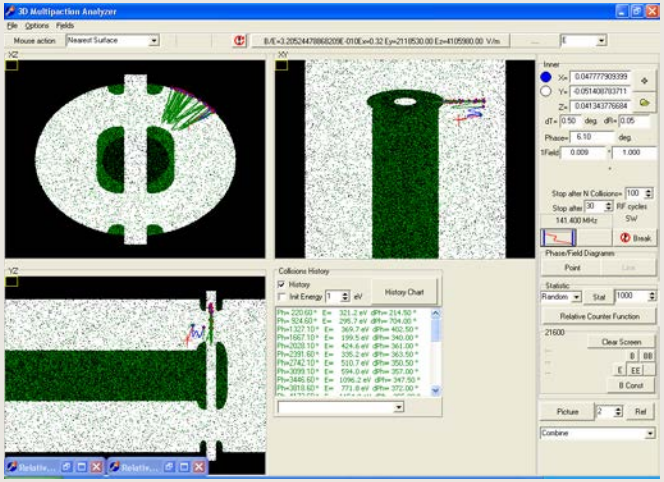


Cavity#4 after stay in the range of temperature 50-100K got Q-disease
10 times Q-drop, very much helium boiling at high fields
Q-curve shape changed – knee to concave





Simulation by MultP-M code		Measured
E_a, kV/m	Cavity region	E_a, kV/m
12.0 – 26.0	accelerating gap, donut – coax outer conductor	10 – 24
27.0 – 33.0	donut – coax outer conductor	28 – 33
35.0 – 54.0	coax line donut – end cap	42 – 50
58.0 – 193.0	donut – end cap	77 – 80



“MULTIPACTING SIMULATION IN ISAC-II SUPERCONDUCTING CAVITIES”

May 8, Morning Poster 8:30-12:30, FR5PFP076

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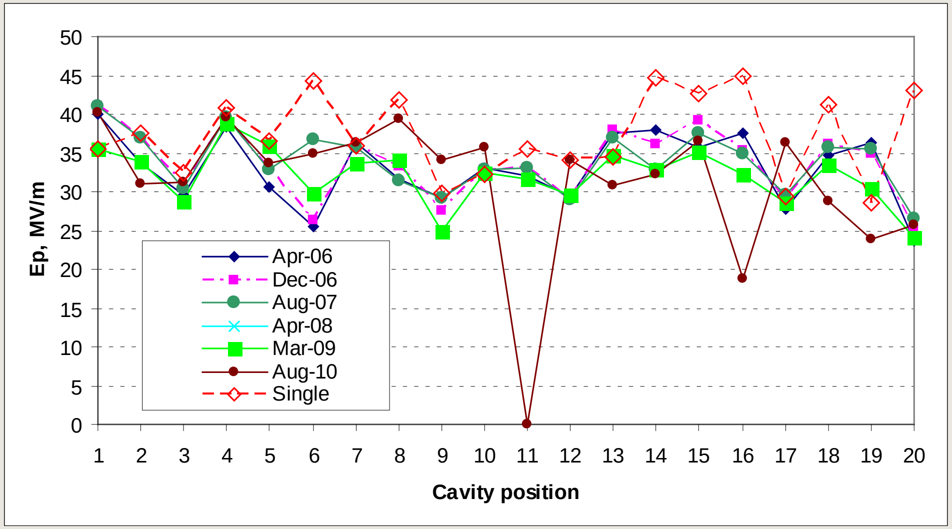
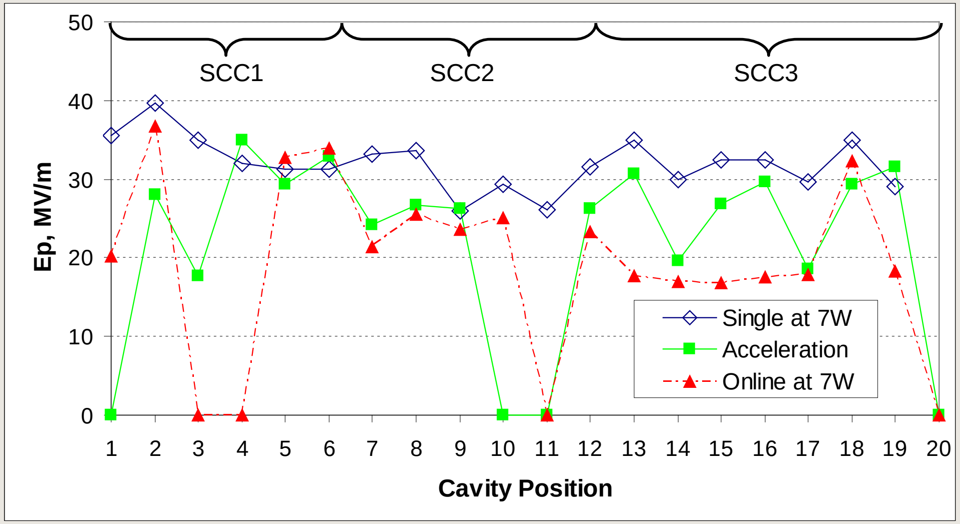
Online Performance

Phase-I



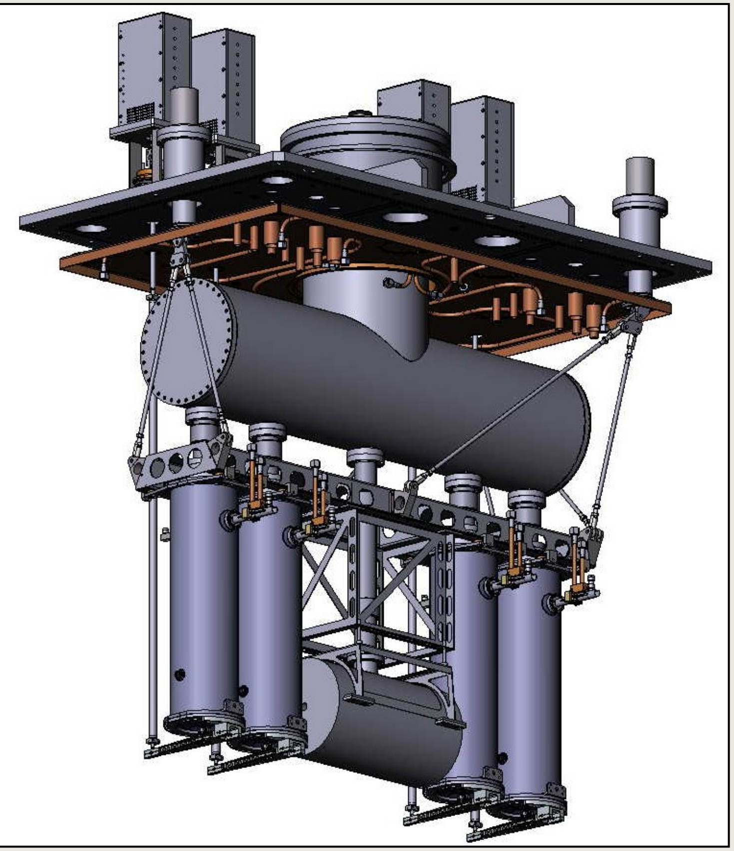
Phase-II

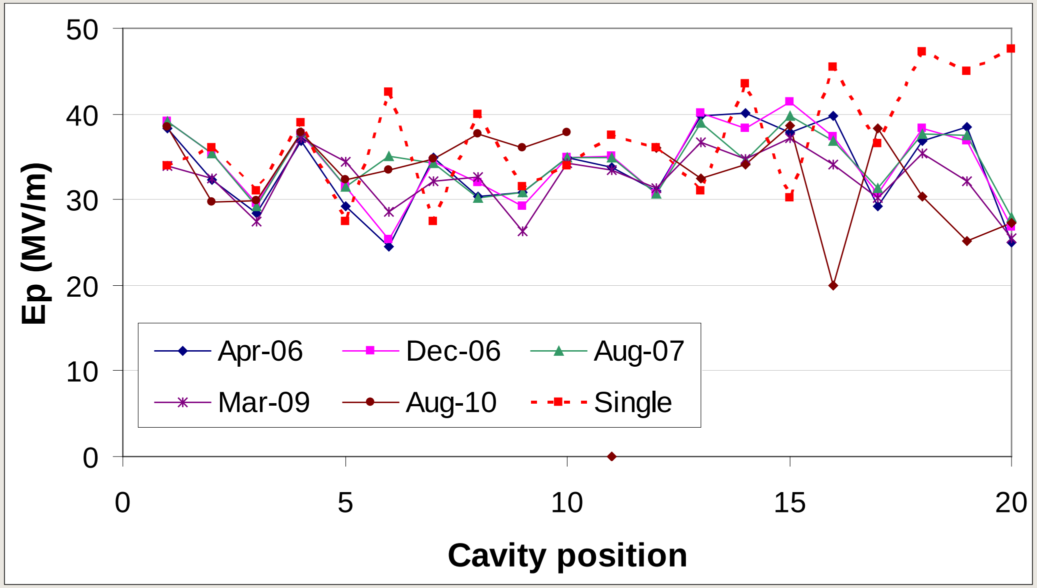


Test	Metric	PHASE I (MV/m)	PHASE II (MV/m)
Single Cavity	<Ep> @ 7W	37	32
Installed	<Ep> @ 7W	33	26
Acceleration	Stable <Ep>	30-32	27

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).

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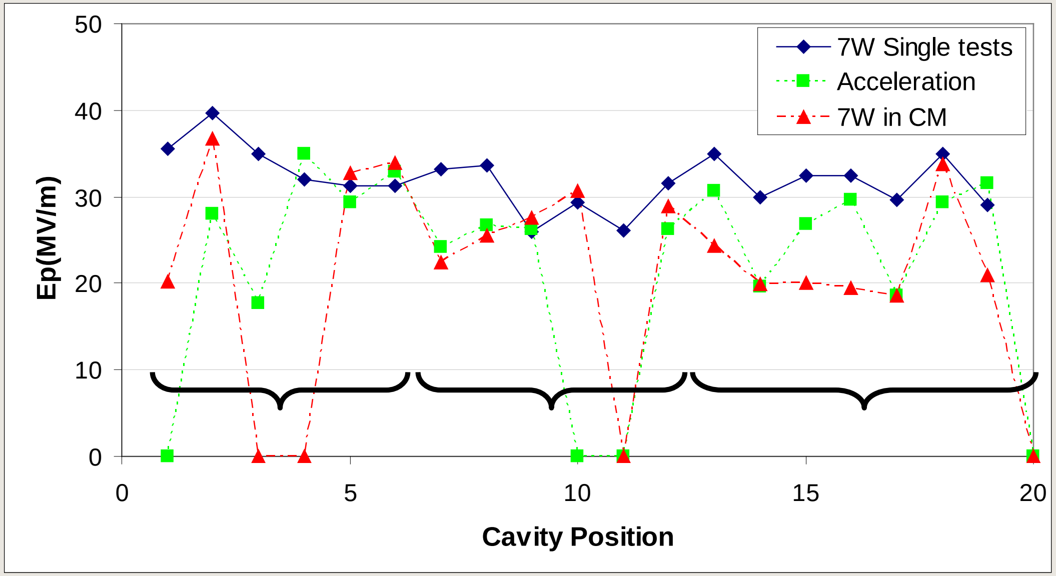
PHASE II EXPERIENCE



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.

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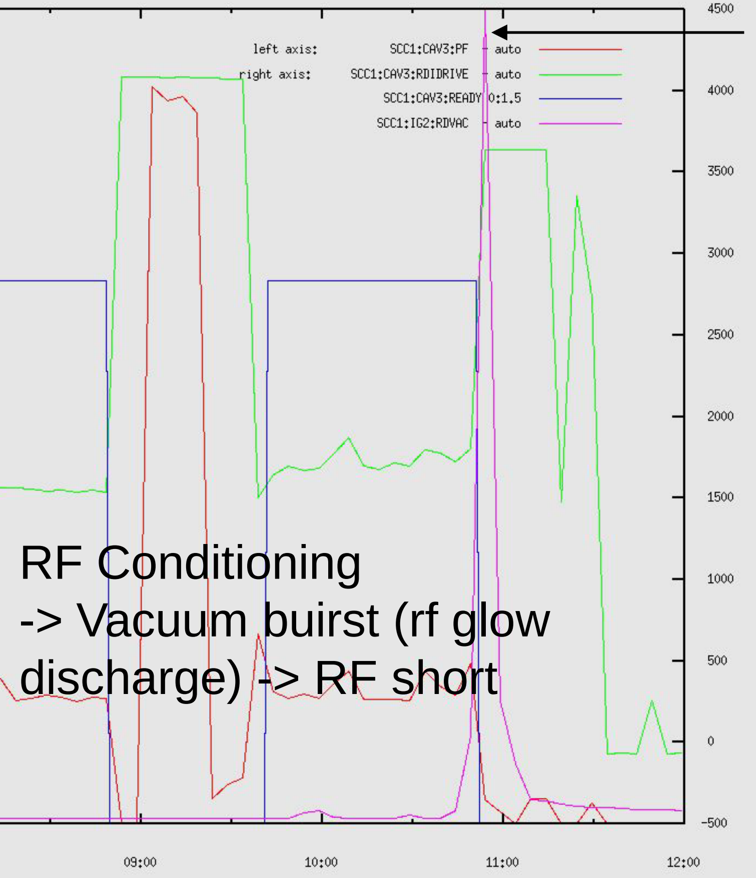
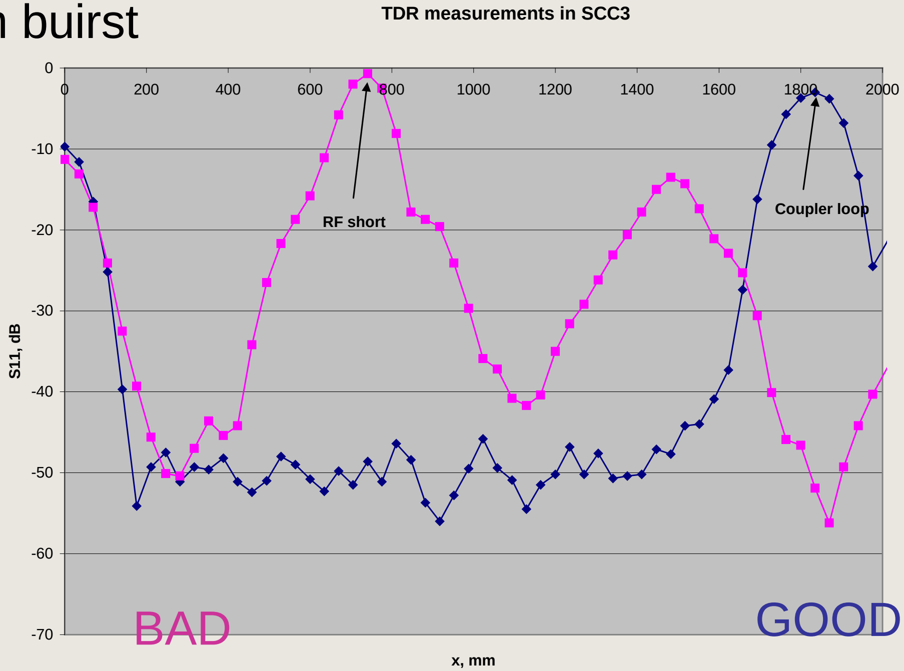
Inner coupler cables failure

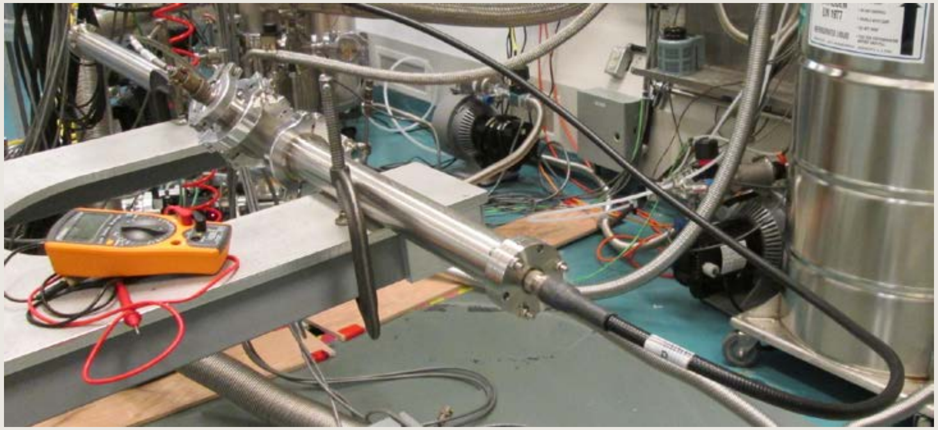


Vacuum buirst

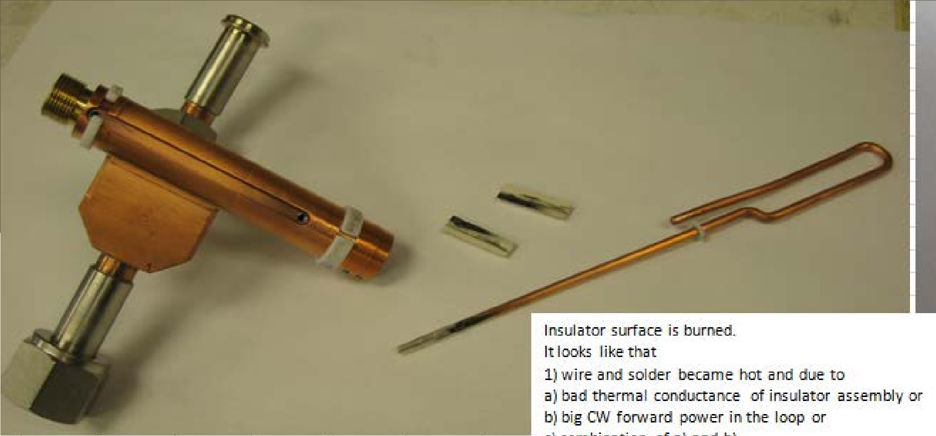
RF Conditioning
-> Vacuum buirst (rf glow discharge) -> RF short



Vacuum stand for cable tests



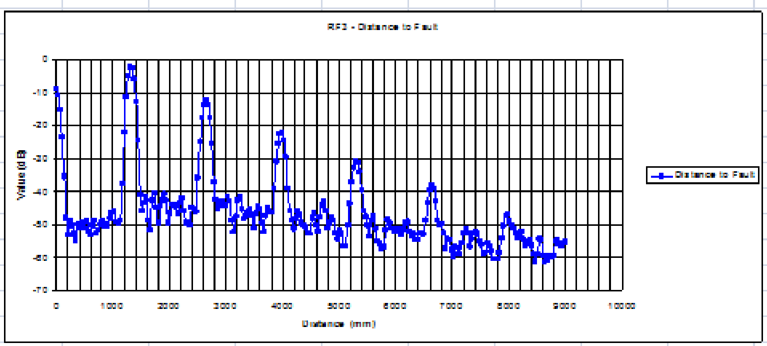
Coupler failure



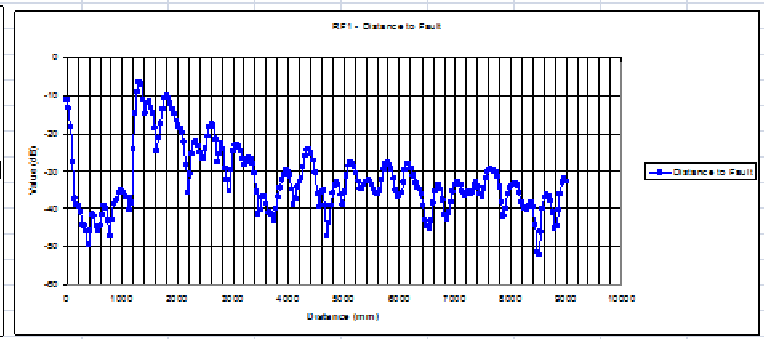
Insulator surface is burned.
It looks like that
1) wire and solder became hot and due to
a) bad thermal conductance of insulator assembly or
b) big CW forward power in the loop or
c) combination of a) and b)
1) solder became soft and deposit to insulator surface
2) RF discharge and burned surface of inner conductor, insulator and outer conductor

2013 winter shutdown
SCB3 repair work

Cavity#4 coupler line was destroyed with high RF power during multipacting conditioning



TDR measurement for SCB3#4 coupler
Very week coupling, big reflections from cavity.
Similar to pickup characteristic.



TDR measurement for SCB3#1 coupler
Good coupling, cavity produce tail after the end of the line.

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THANKS!