Recent Progress in the SRF Program at TRIUMF/ISAC

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TRIUMF

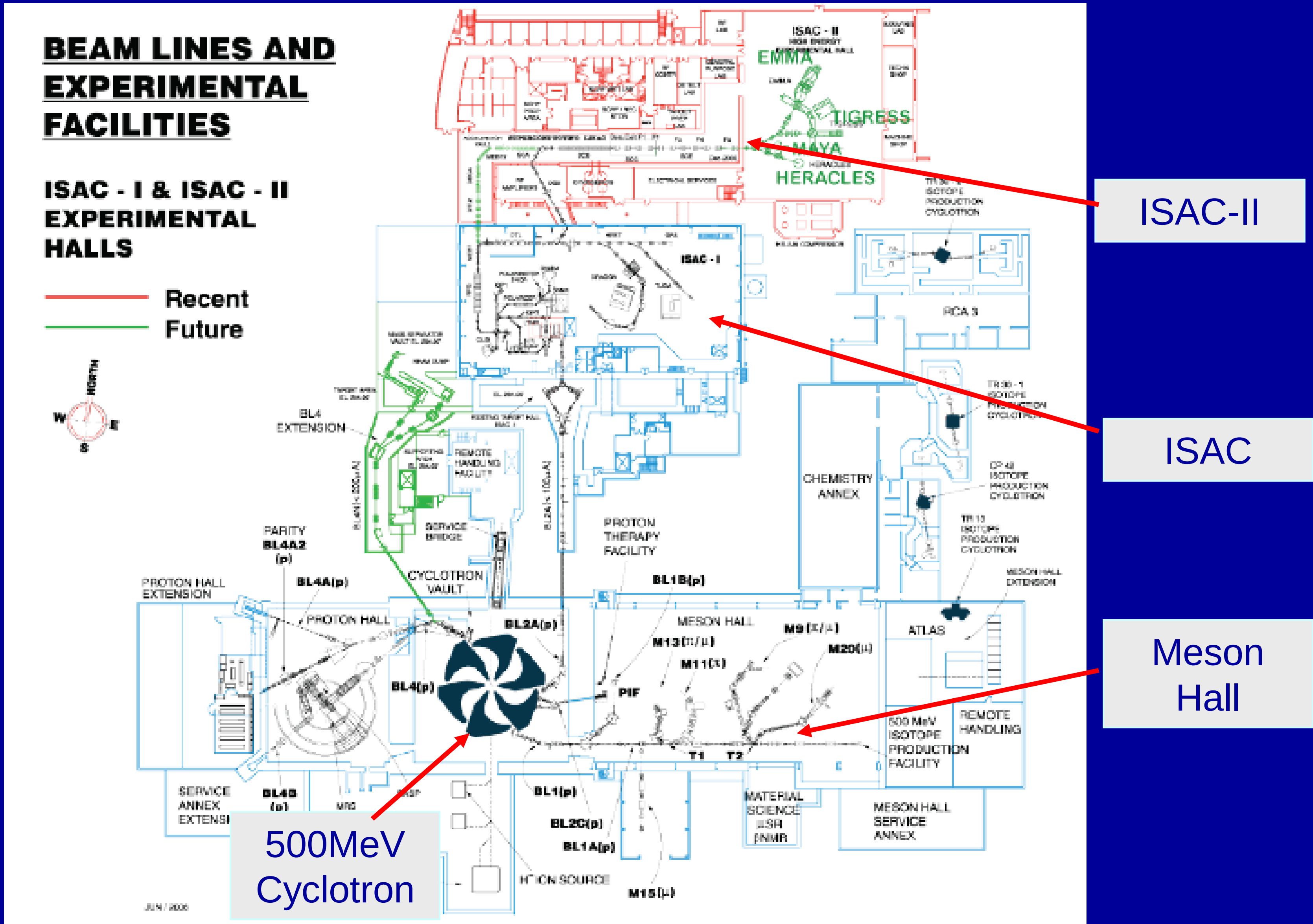
Outline

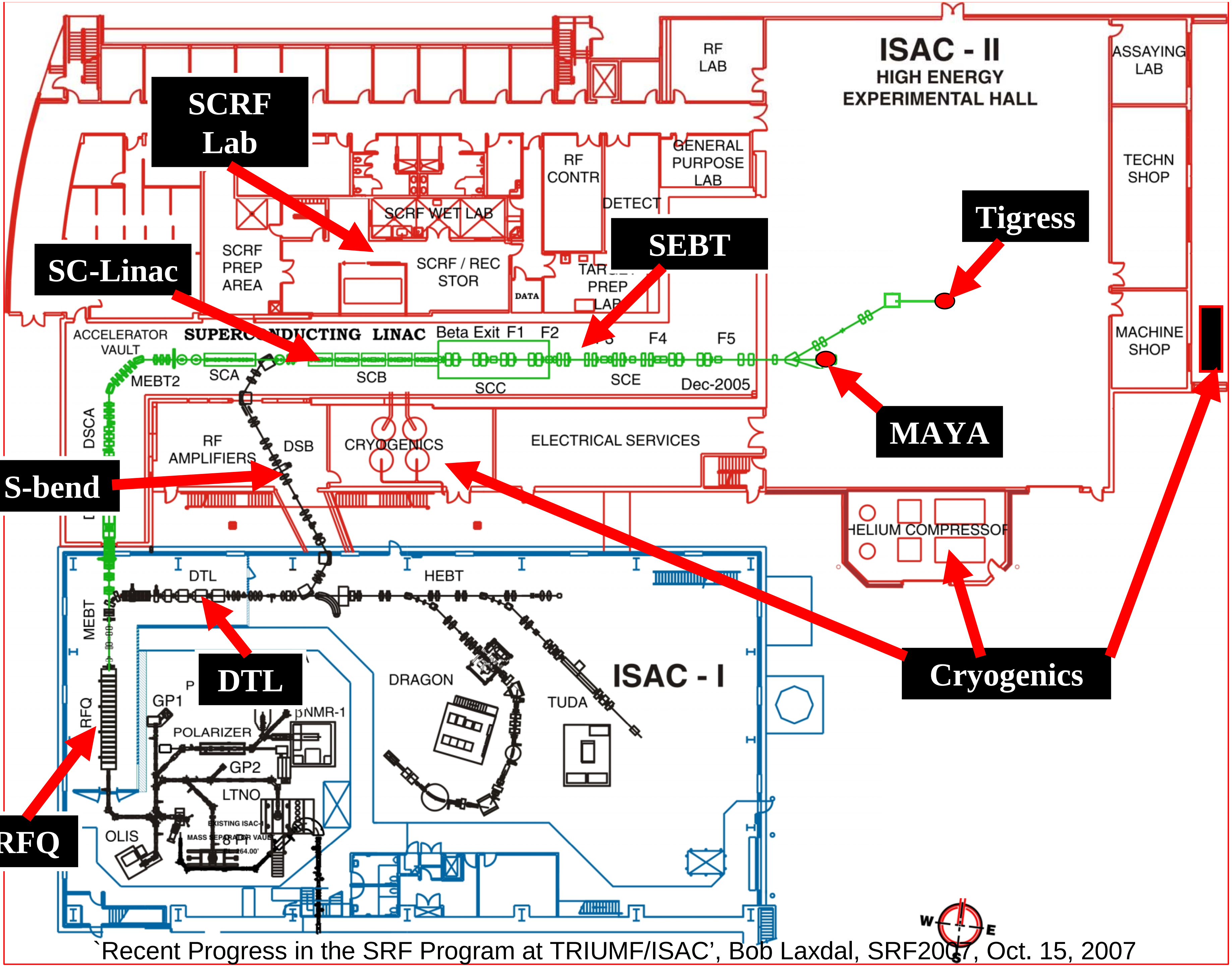
Outline:

- ISAC-II Superconducting Heavy Ion Linac
  - ISAC-II design and goals
  - Operating experience
- Present initiatives
  - β=0.11 Cavity prototyping
- Future plans
  - Upgrade to 1.3GHz
  - Proposal for e-Linac

TRIUMF

Canada's National Laboratory for Particle and Nuclear Physics





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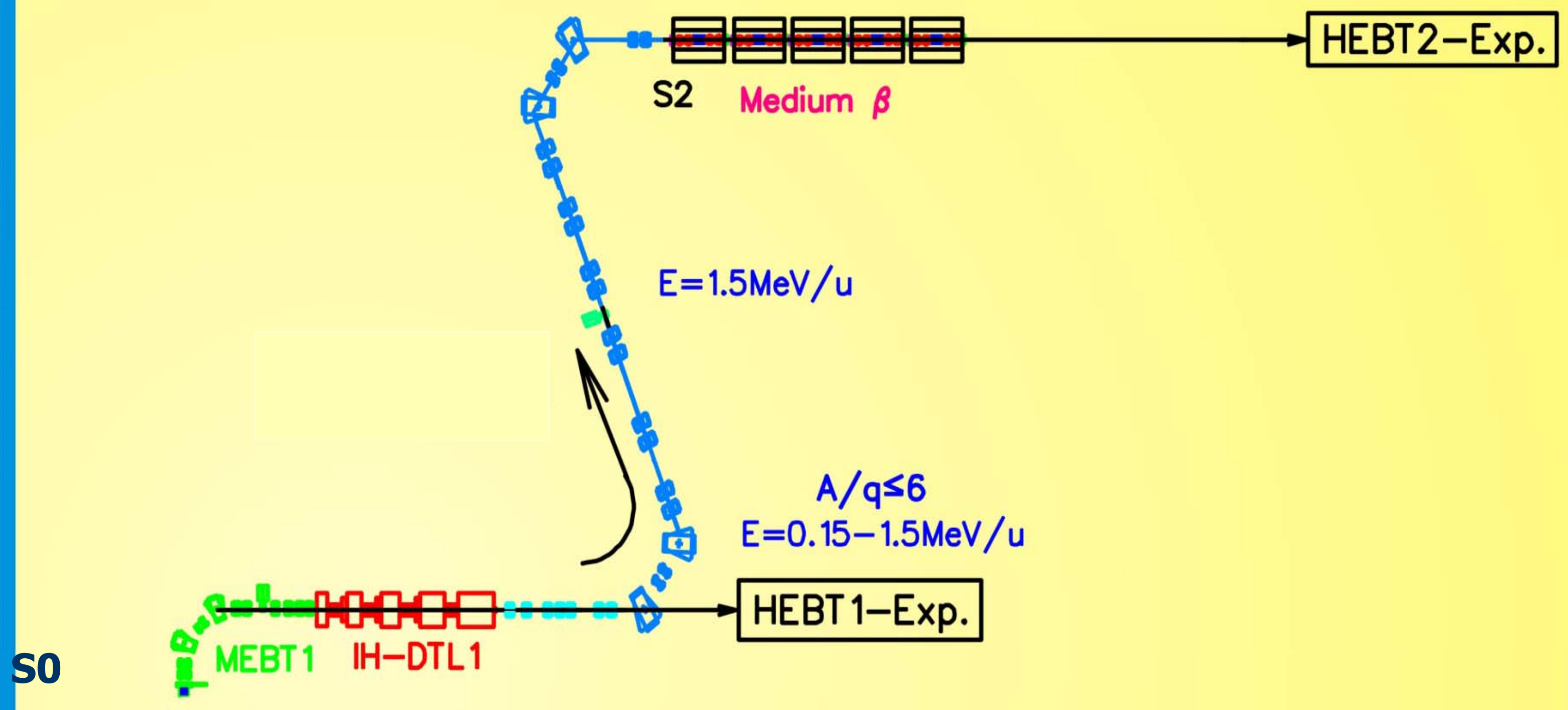
ISAC-II Design and Goals

ISAC-II (Phase I - Medium Beta Section)

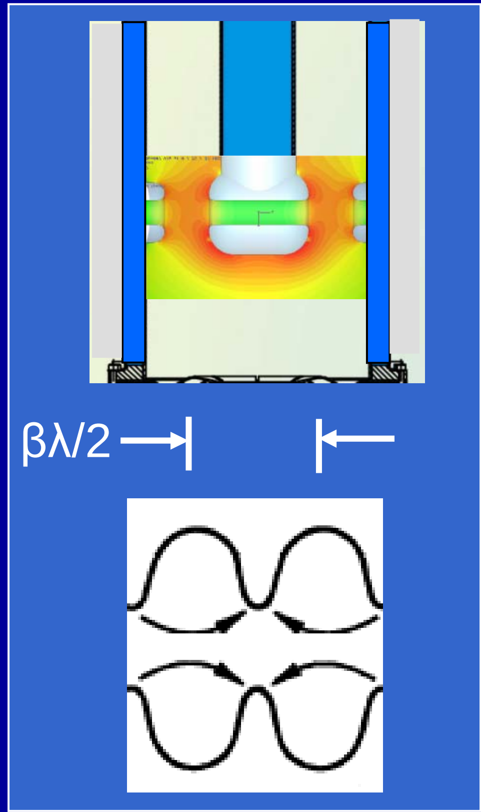
E=4.5MeV/u A/q=6



ISAC-II Linac Design Goal

Low beta (0.1) vs High beta (1) performance

- E_{peak} at design P_{cav} gives a physical parameter that can be useful in comparing cavity performance
  - Typically E_{peak}/E_a=4-5 for low beta QWR's while E_{peak}/E_a~2 for elliptical cavities.)
- For CW machines performance limited by LHe consumption - P_{cav} (Q at operating point) and not maximum achievable gradient (Cornell Ea~15-20MV/m for elliptical cavities or Ep~30-40MV/m)
- TRIUMF's goal for ISAC-II linac is to operate cw with Ep$\geqslant$30MV/m (Ea$\geqslant$6MV/m)



Bulk Niobium Cavities at LNL

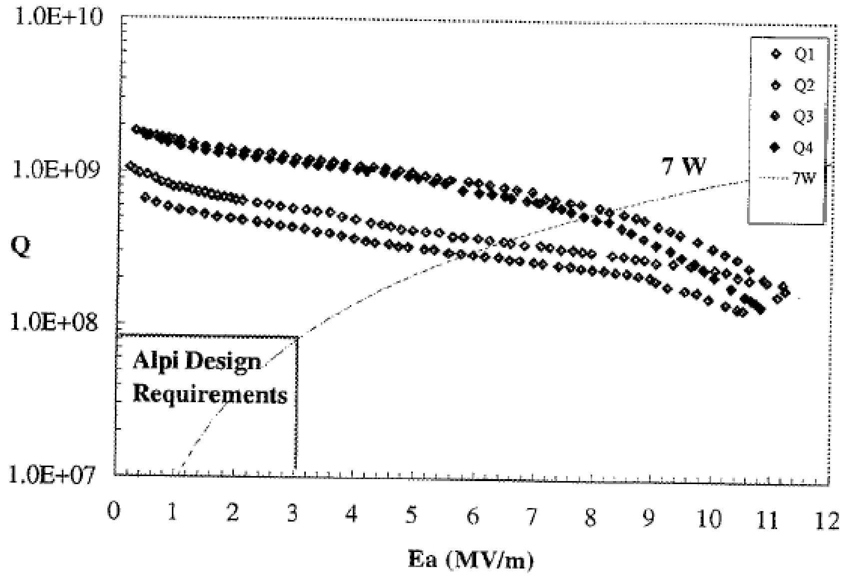


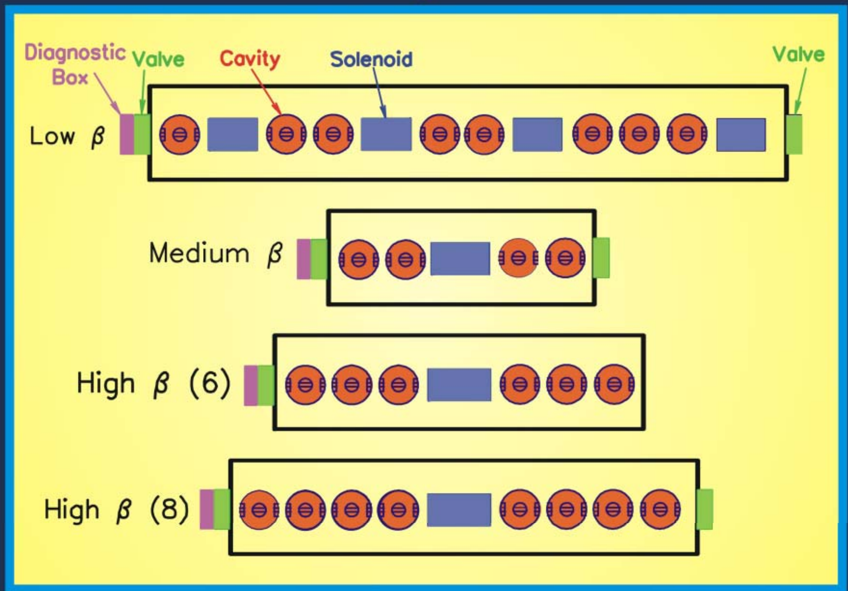
FIGURE 8. On-line performance of the bulk niobium resonators installed in cryostat n. 6.

A. Facco, Heavy Ion Acc. Tech. Argonne 1998

- Performance over 6MV/m (Ep=30MV/m) demonstrated
- Difficult to lock
  - unstable Alpi cryogenic system produces helium pressure fluctuations - tuner can't cope
  - Rf auxiliaries (coupling loops, amplifiers, cables) undersized to provide sufficient bandwidth
  - Alpi optics not compatible with high gradient

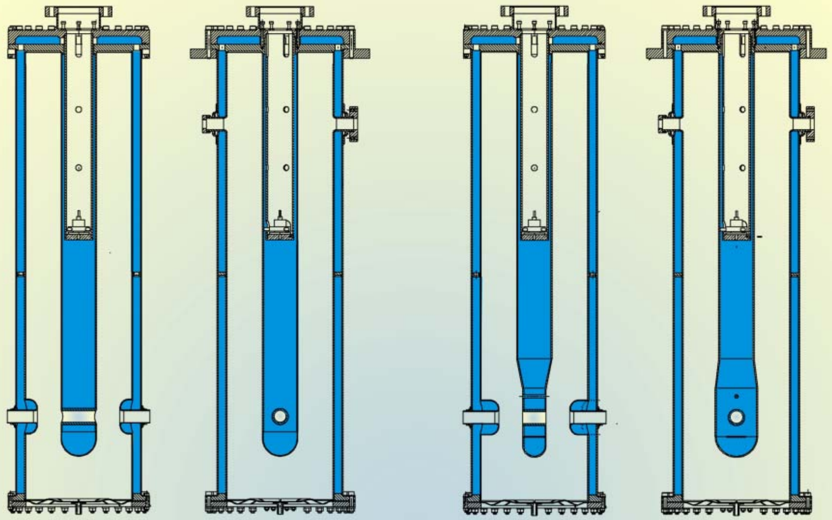
ISAC-II Linac: Medium β cavities

ISAC-II Cryomodules



Prototype Cavity

Medium Beta Cavities



(a) Nominal (β=7.1%)   (b) Flat (β=5.7%)

freq=106.08MHz

$E_p/E_a \simeq 5$

$H_p/E_a \simeq 100\ G/(MV/m)$

$U/E_a \simeq 0.09 J/(MV/m)^2$

$\Gamma \simeq 19\Omega$

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ISAC-II Toward Higher Gradient

General Considerations

- Higher stored energy, U_o
  - Overcoupling used to broaden natural bandwidth
  - Requires $P_{forward}=\pi\ U_o\Delta f_{1/2}$
    - Increase amplifier, cables and coupling loop rating
  - Eigenfrequency excursions, Δf, from microphonics (fast) and helium pressure fluctuations (slow)
    - Adopt accurate constant-tracking tuner
- Higher peak surface field
  - Clean surfaces to reduce field emission, raise Q
  - Clean assembly techniques
- Higher rf defocussing fields (at φ_s=-25deg)
  - Adopt strong focussing lattice

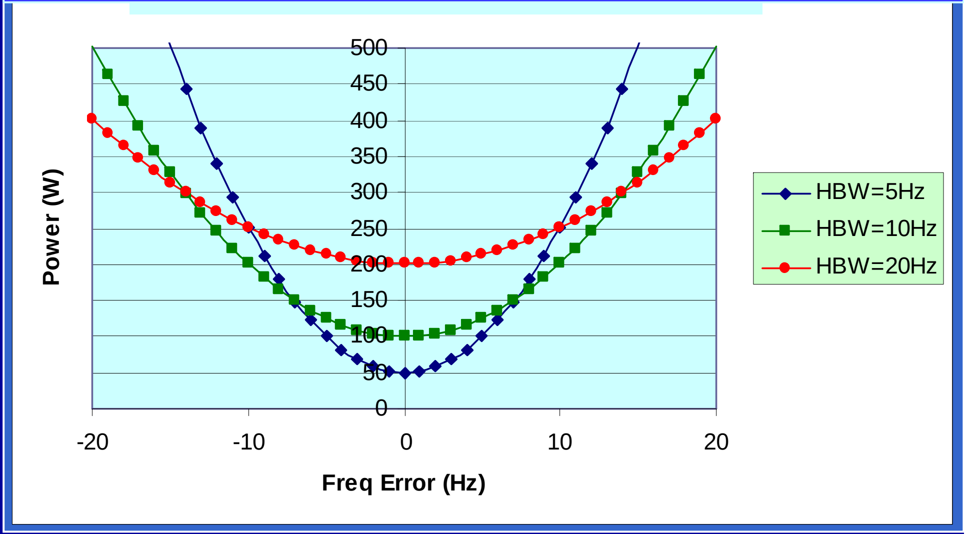
ISAC-II

- Choose Ep=30MV/m
  - dV=1.1MV/cavity, Ea=6MV/m
  - Uo=3.2 Joules
  - $P_{forward}$=200W gives $\Delta f=\pm 20$Hz
    - ☑ Amplifier and cables compatible with 800W
    - ☑ Loop compatible with $P_{forward}$=250W
  - ☑ New fast tuner developed
- ☑ Clean room assembly
  - Single vacuum space for insulating vacuum and beam
- ☑ 9T solenoid in each cryomodule
  - Solenoid complete with `bucking' coil to reduce fringe field in cavity region.

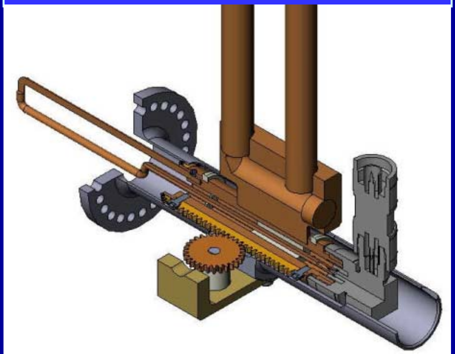
ISAC-II Linac: RF Systems

- RF power
  - Provide useable bandwidth by overcoupling
  - Require P_f =200W at cavity for $f_{1/2}$=20Hz at E_a=6MV/m, β =200
- Coupling loop
  - Developed LN2 cooled loop
  - <0.5W to LHe for P_f=250W
- Mechanical tuner
  - Precise (0.3~Hz), fast (>50Hz/sec) tuner with dynamic range of 8kHz and coarse range of 32kHz
- Tuning plate
  - Spun, slotted, `oil-can' tuning plate to improve tuning range

Forward power required for Ea=6MV/m and given bandwidth



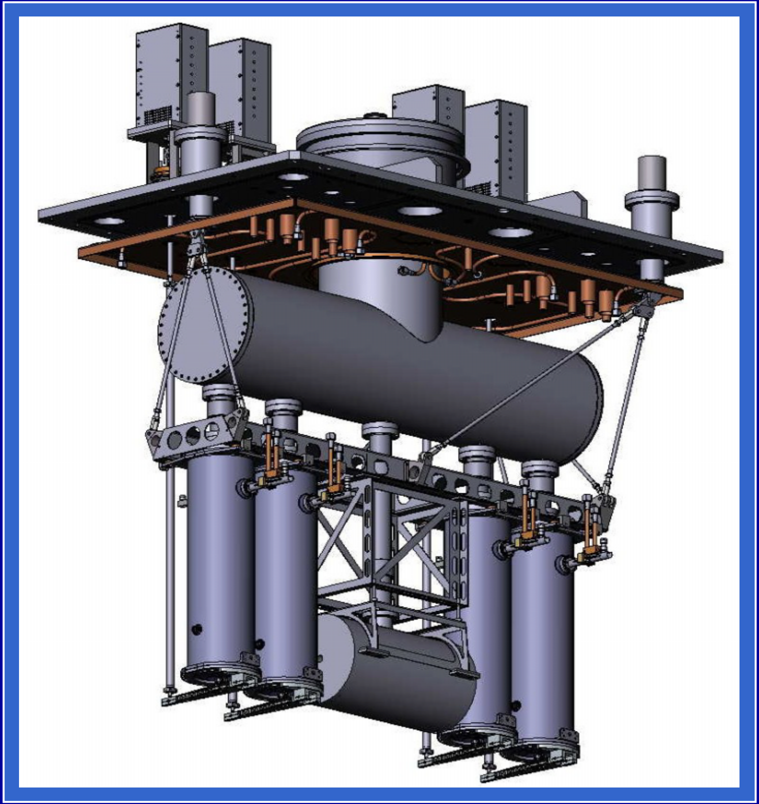
Coupling Loop



Mechanical Tuner

ISAC-II Linac: Cryomodule

- 2x2x1m stainless steel box vacuum vessel
- LN2 cooled copper sheet used as thermal shield
- Mu metal between vacuum tank and LN2 shield
- Cold mass suspended from lid on three adjustable support pillars
- Four cavities Ep=30MV/m
- One SC solenoid @ 9T
- V_{eff}=4.3MV
- Single vacuum for thermal insulation and rf



Lid Assembly in Assembly Frame

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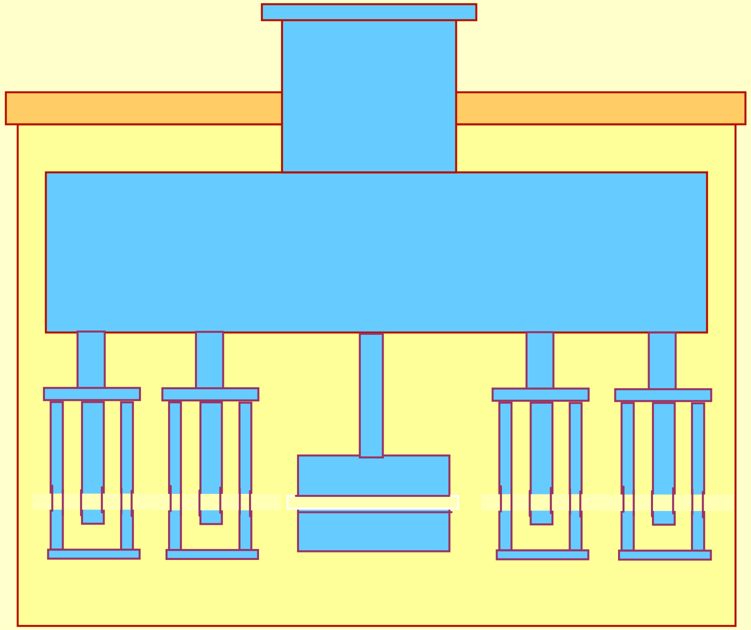
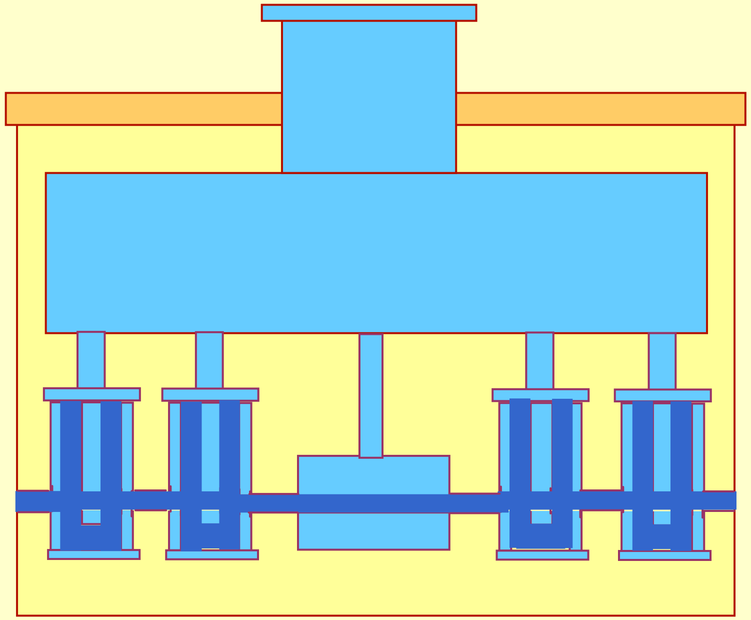
ISAC-II Cryomodule Vacuum

Single Vacuum vs Double Vacuum

- Cavity vacuum and thermal isolation vacuum share the same space
- Engineering easier but thermal vacuum must be done carefully (particulate control)
- ISAC-II, ATLAS, Legnaro, JAERI

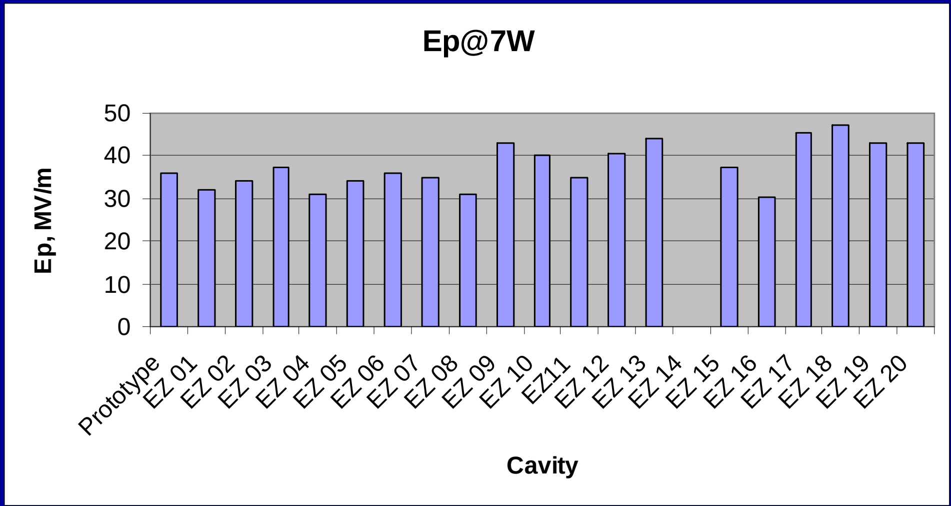


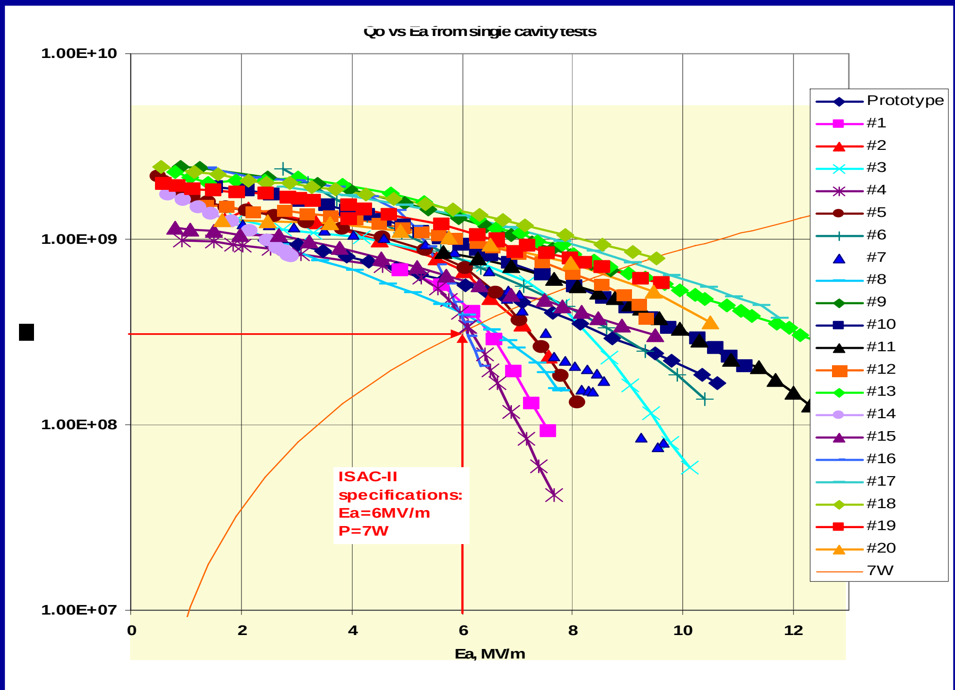
- Cavity vacuum connected through beam pipe and isolated from thermal vacuum
- Engineering more complex but eases cleanliness requirements in thermal vacuum space
- RIA, SPIRAL-II, SOREQ



Operating Experience

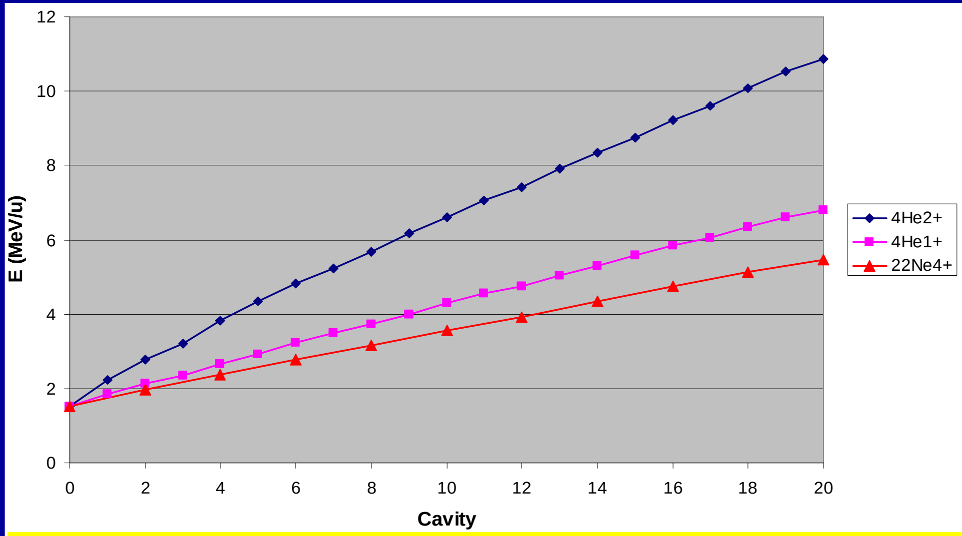
ISAC-II Linac: Single Cavity Performance



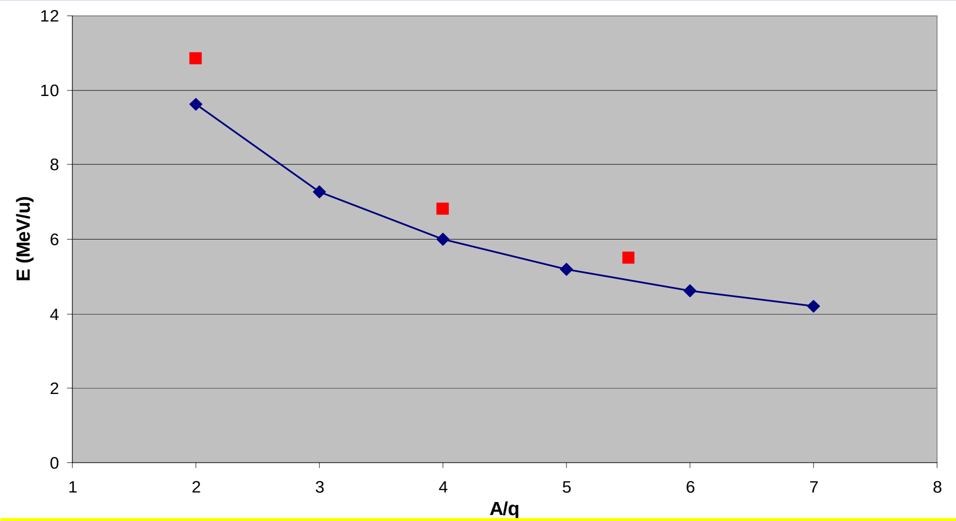


- Cavities tested initially in single cavity cryostat
- Four cavities retested with fast cooldown to reduce effects of Q-disease
- Average peak surface field at operating power of 7W is now Ep=38MV/m corresponding to a voltage gain of 1.4MV/cavity and a magnetic field of Bp=75mT and a gradient Ea=7.5MV/m.
- All cavities have been tuned to the ISAC-II frequency
- One cavity (spare) quenches at Ep=15MV/m

ISAC-II Linac: Commissioning



Energy history during acceleration.



Expected E_{final} for 6MV/m and actual E_{final}

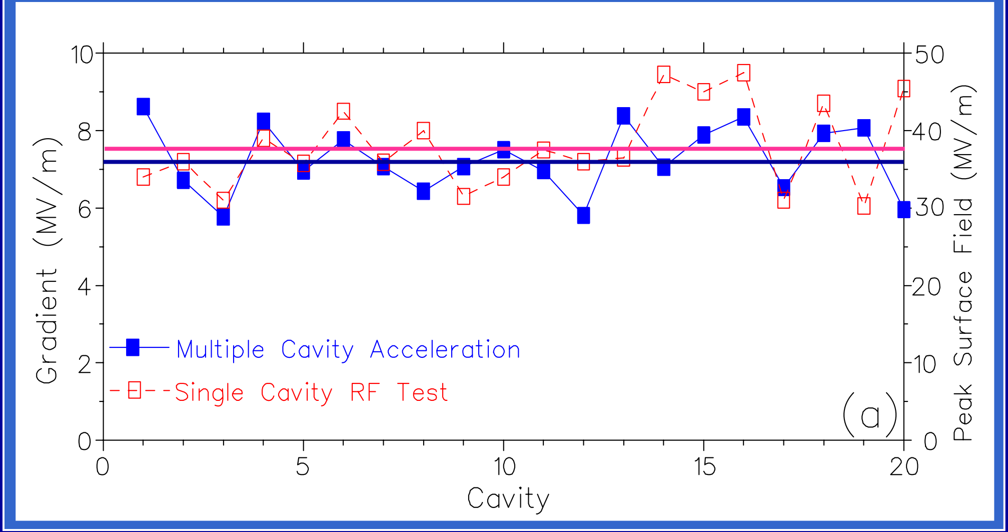
Commissioning beams

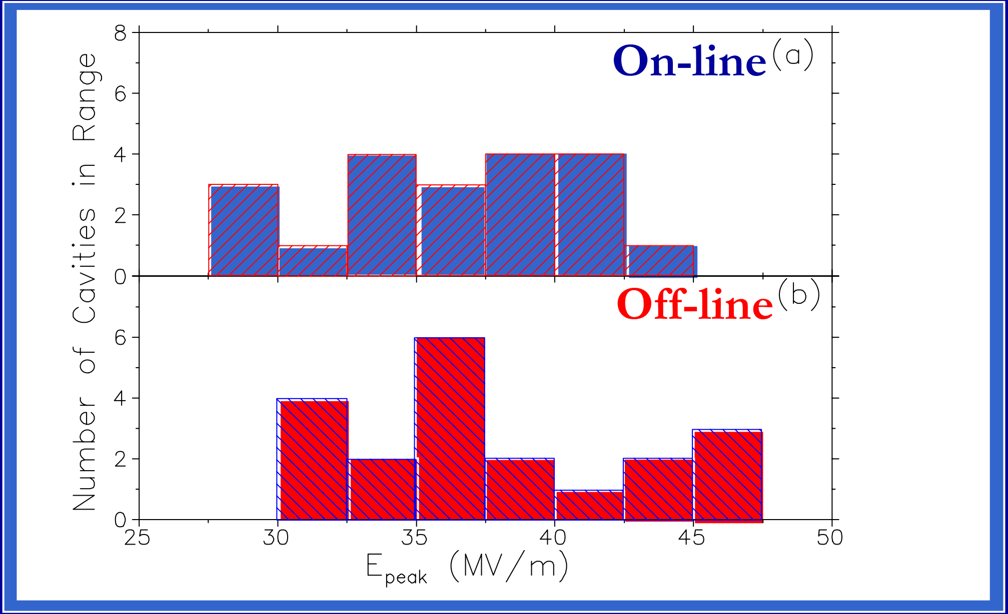
- A/q=5.5 (22Ne4+)
- A/q=4 (40Ca10+, 20Ne5+, 12C3+, 4He1+)
- A/q=2 (4He2+)

Performance

- Power @ 7W/cavity
- Design gradient is 6MV/m (Ep=30MV/m)
- Average gradient is 7.2MV/m (Ep=36MV/m)
- Final energy is 10.8, 6.8 and 5.5MeV/u for A/q=2, 4, 5.5 respectively
- Transmission >90%

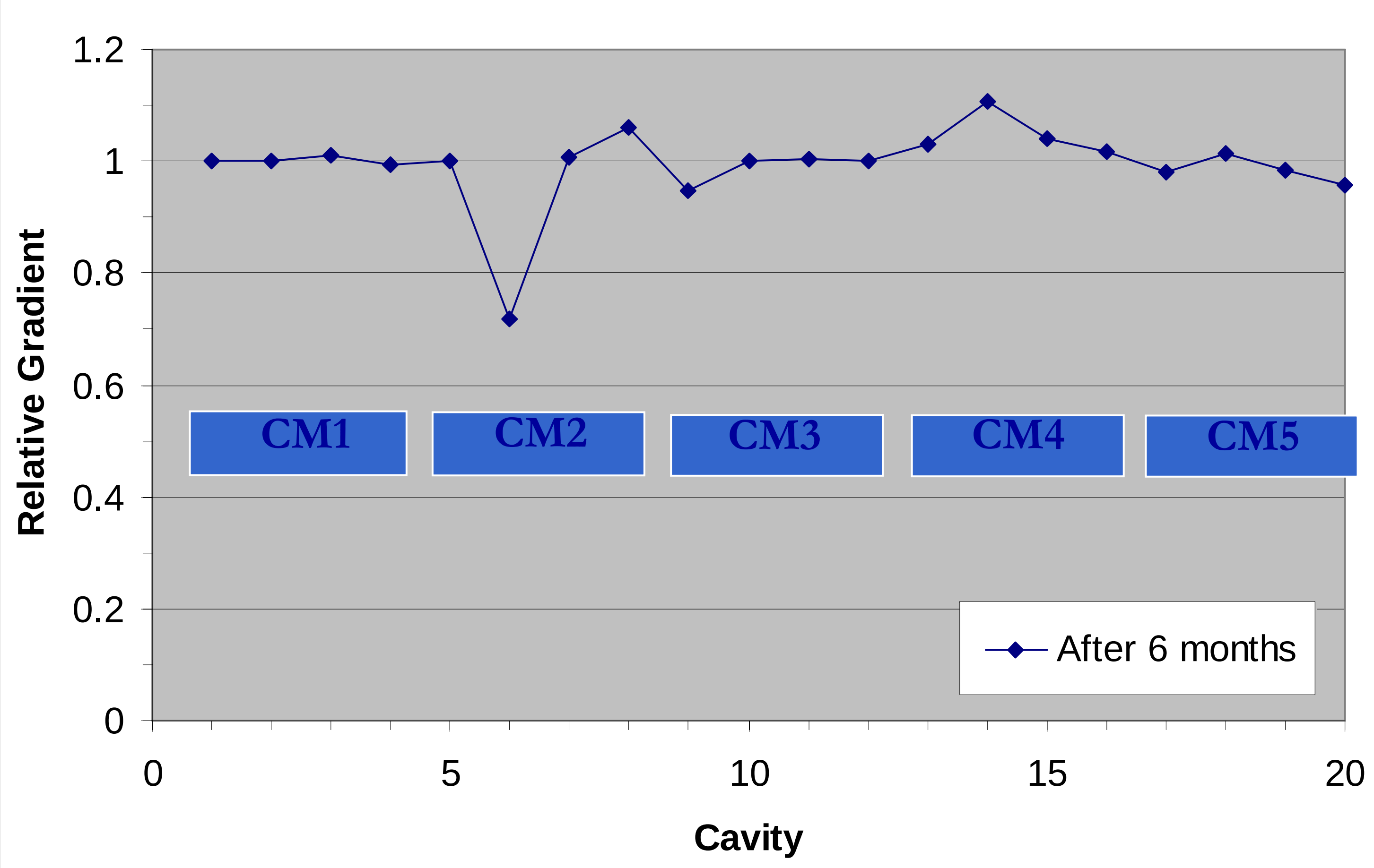
Cavities: On-line vs. Off-line Performance





- On-line gradients calculated from beam acceleration at 7W/cavity averaged over three different ions. The average gradient for the on-line cavities is 7.2MV/m corresponding to a peak surface field of 36MV/m
- Off-line results give an average gradient at 7W/cavity of 7.6MV/m corresponding to Ep=38MV/m
- Some contamination evident in a few cavities but on-line performance down by only 5% from off-line tests

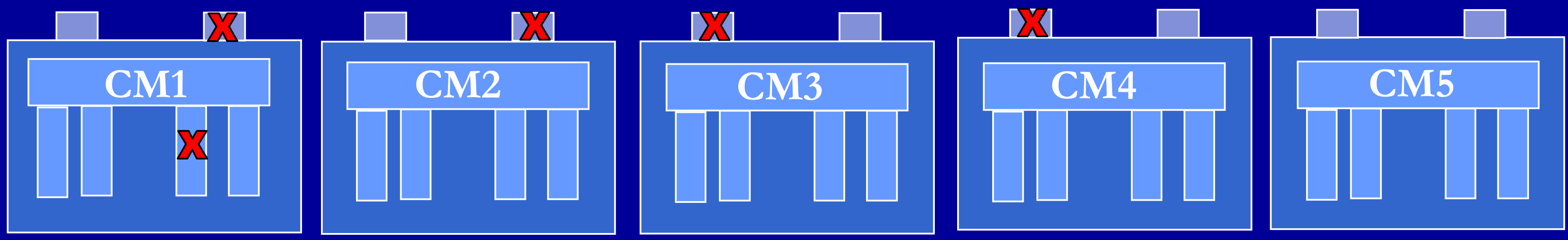
ISAC-II Linac: Relative Gradient



Average gradient (@7W) down by only 1% in the first six months compared to initial gradients.

- **Cavity CM2:CAV2 has modest reduction in performance due to Q-disease**

ISAC-II Linac: Shutdown Work



•The linac was warmed up Jan. 19, 2007 during the cyclotron annual shutdown. Job list included:

- •Remove CM1 to the clean room for repair of the coupling loop drive and replacement of a turbo-pump
- •Replace three other turbopumps *in situ* using `clean' procedure (no explanation to date for high failure rate)
  - •Vent with filtered dry nitrogen, construct plastic barrier, …
  - •Results were a surprise

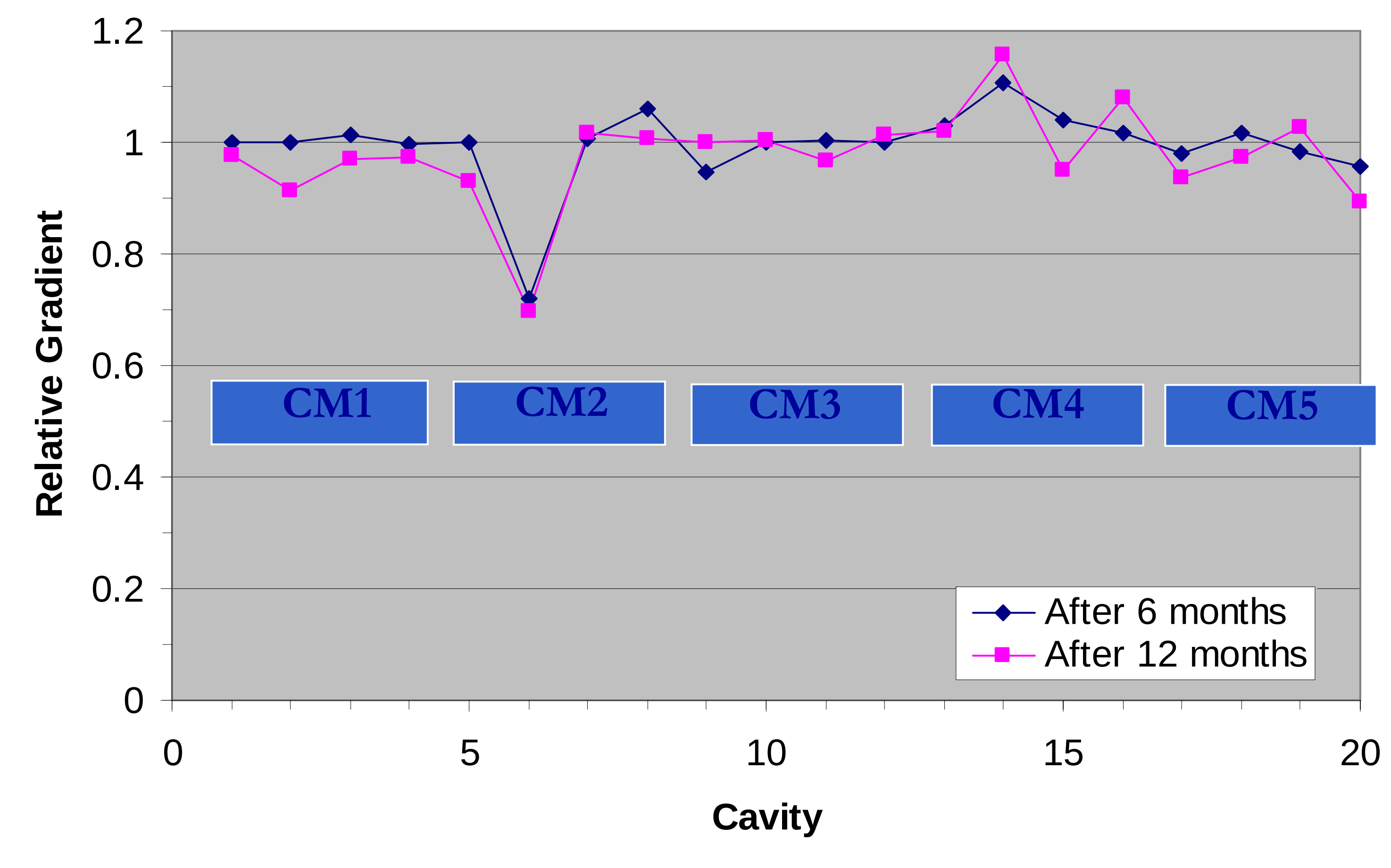
ISAC-II Linac: Shutdown Work

Varian 550 turbo-pump on CM4 suffered catastrophic falure!

There was no time for taking the cryomodule off-line for cleaning so we removed the fragments that we could reach, vacuumed the LN2 shield, pumped down and crossed our fingers.

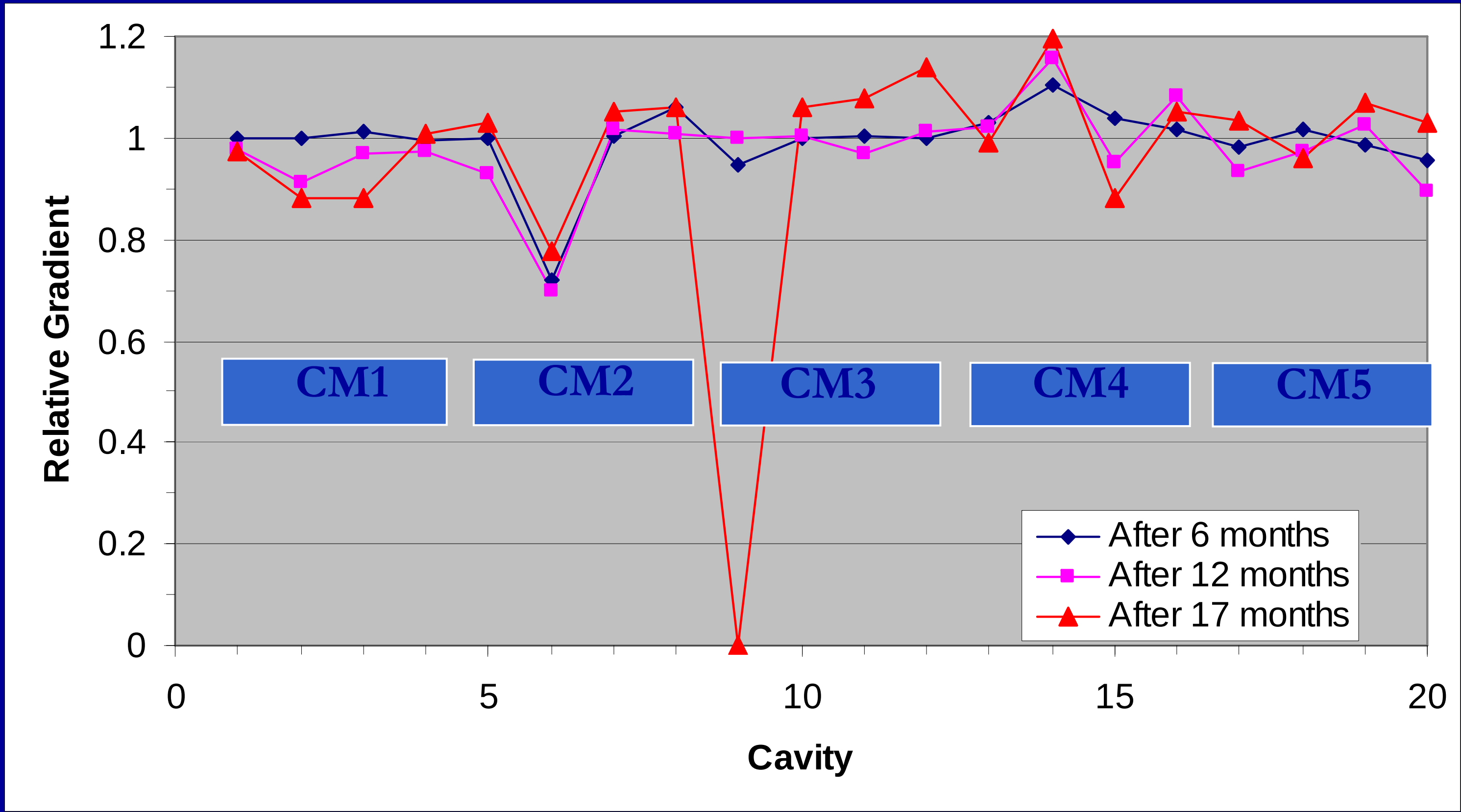
- **Remember that cavity vacuum shares isolation vacuum**

ISAC-II Linac: Relative Gradient



- Average gradient within 98% of gradients measured during first commissioning.
  - No deterioration due to shutdown activities

ISAC-II Linac: Relative Gradient

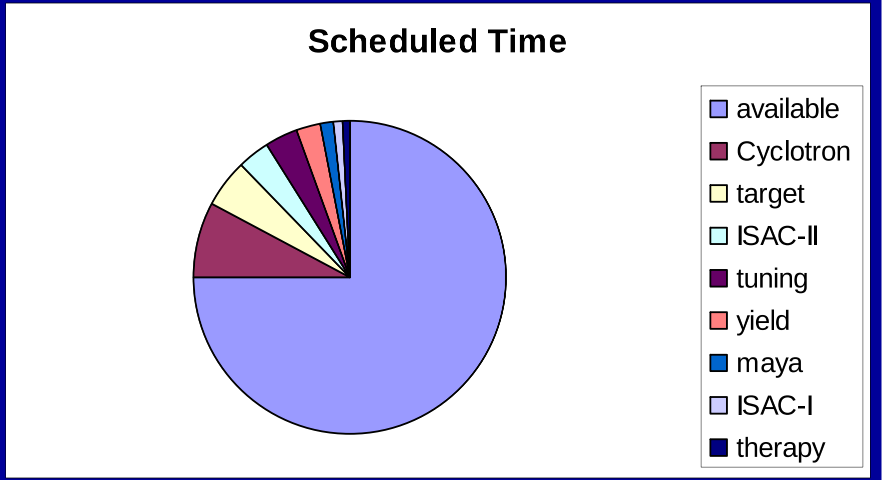


•One cavity failed in the last running period due to an open connection in the cryomodule vacuum space

•No deterioration in gradient performance over the run

Initial Beam Delivery

- Seven weeks of beam time
  - 1100 hours scheduled
  - 825 delivered (75% availability)
    - Includes availability of driver, target, linear accelerators and procedures
  - ISAC-II Linac downtime – 36 hours (3%)
    - 16 hours cryogenics
    - 20 hours – ISAC-II rf
      - One cavity inoperable – requires retune 10 hours
      - Five amplifier tubes required replacement
        - » All are now replaced (see Amiya Mitra poster



ISAC-II Linac: Performance

CW heavy ion SC-linacs with Nb technology

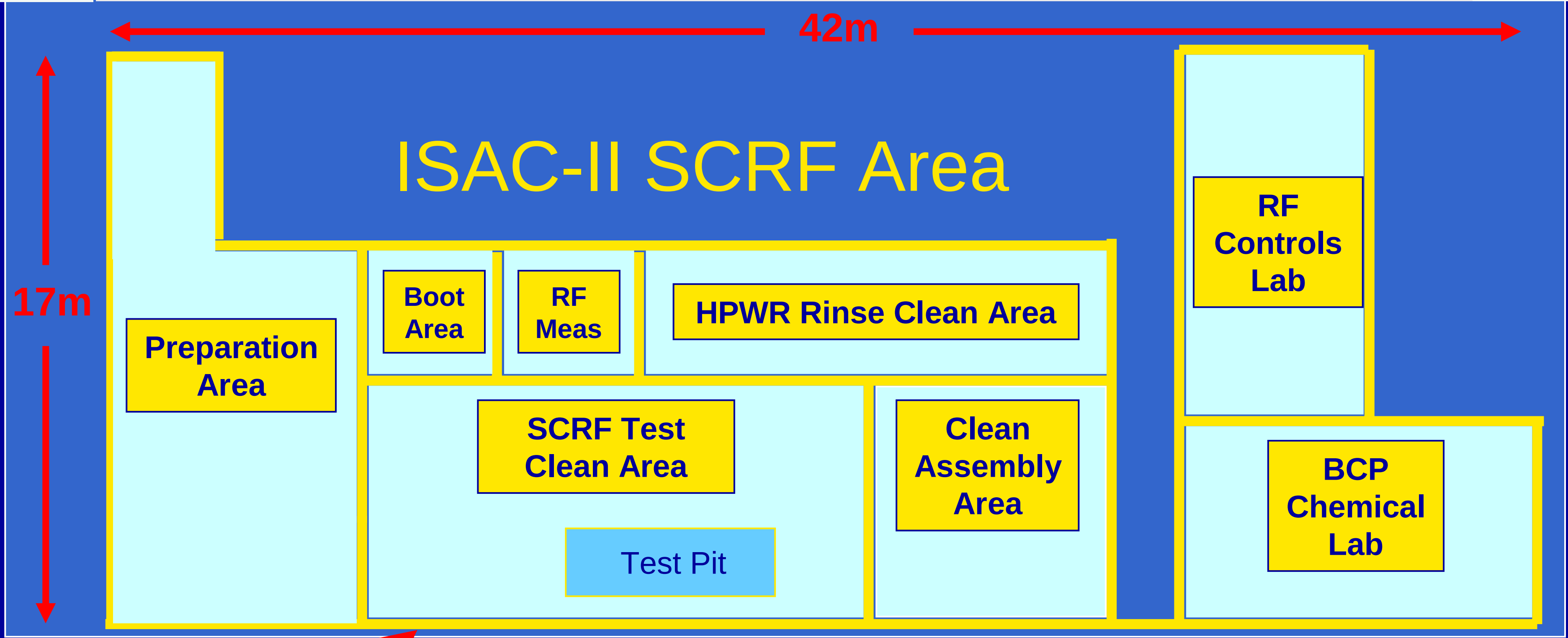
- ATLAS
  - Bulk niobium – Ep~15-20MV/m
- INFN-Legnaro
  - Sputtered Nb on Cu (former Pb) - Ep~22MV/m
  - Bulk niobium cavities – higher gradients demonstrated but little on-line experience
- JAERI
  - Explosively bonded Nb on Cu – Ep~25MV/m
- ISAC-II
  - Bulk niobium cavities – Ep=35MV/m

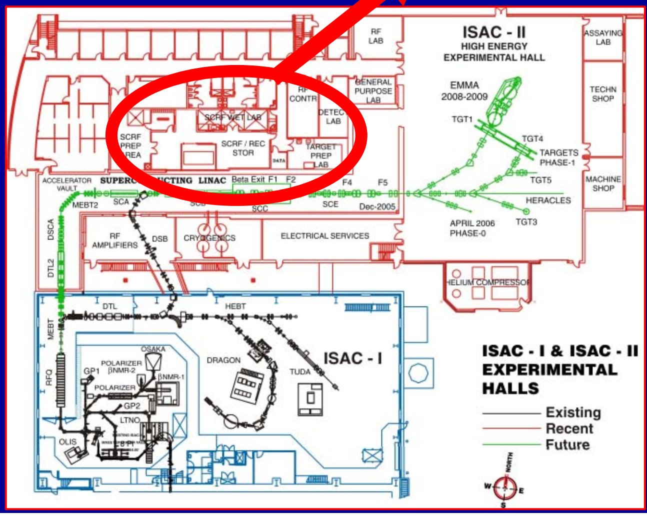
SRF Facilities

SRF@TRIUMF - Capability

- Clean room (500m^2)
  - Overhead crane, rf test pit (4mx1.5mx2.5m)
  - Single cavity and Cryomodule assembly area
- High Pressure Water Rinse (HPWR)
  - 18MOhm water, high pressure pump
- BCP etching
  - Pre-weld etch facility now operational
  - Full cavity etch facility being prepared
    - Ready by end of 2007
- 100-140MHz rf test equipment
- Helium distribution lines from present refrigerator (Phase I) with return to cold box for closed cycle operation
- Trained technicians and engineers

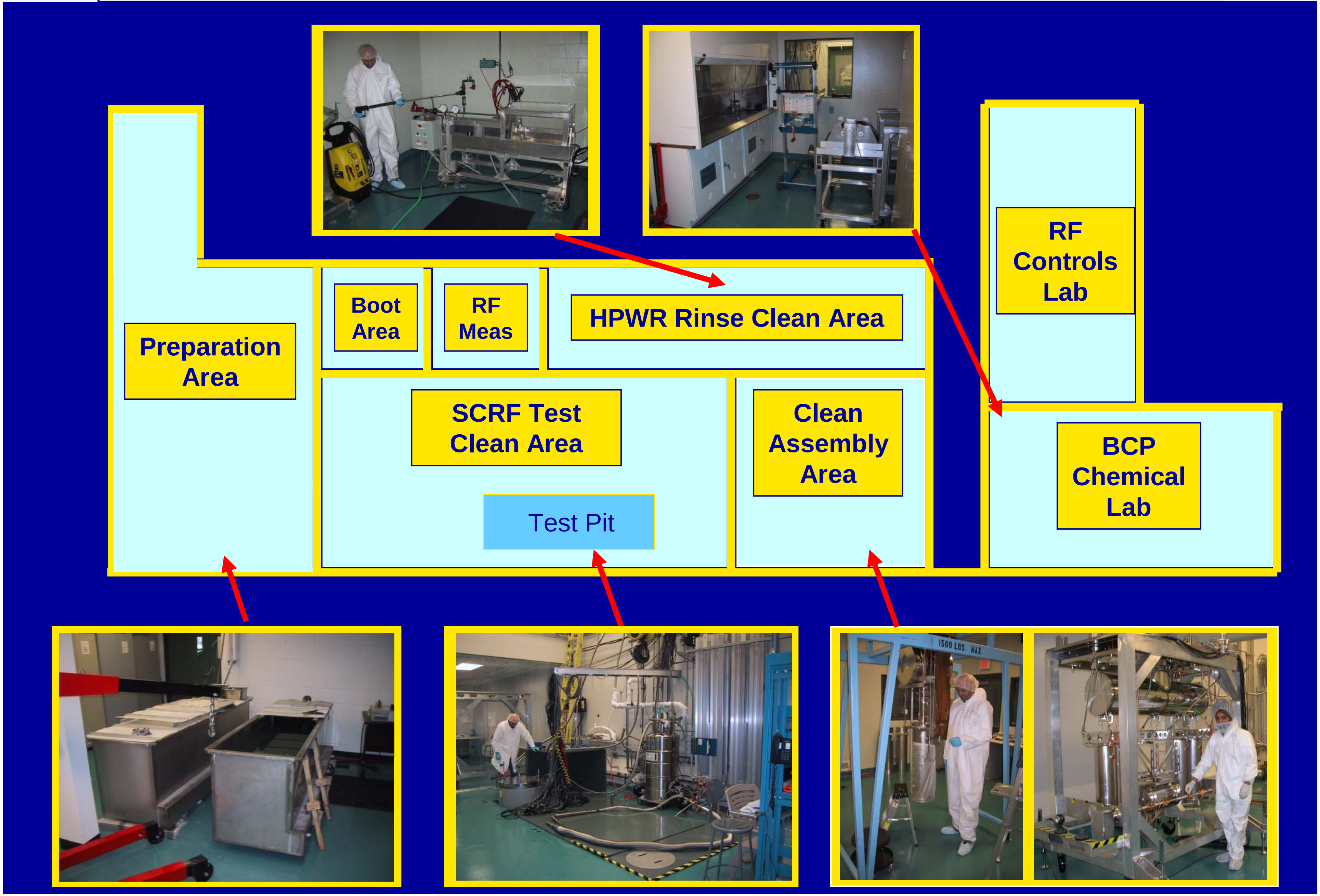
SRF@TRIUMF: Infrastructure



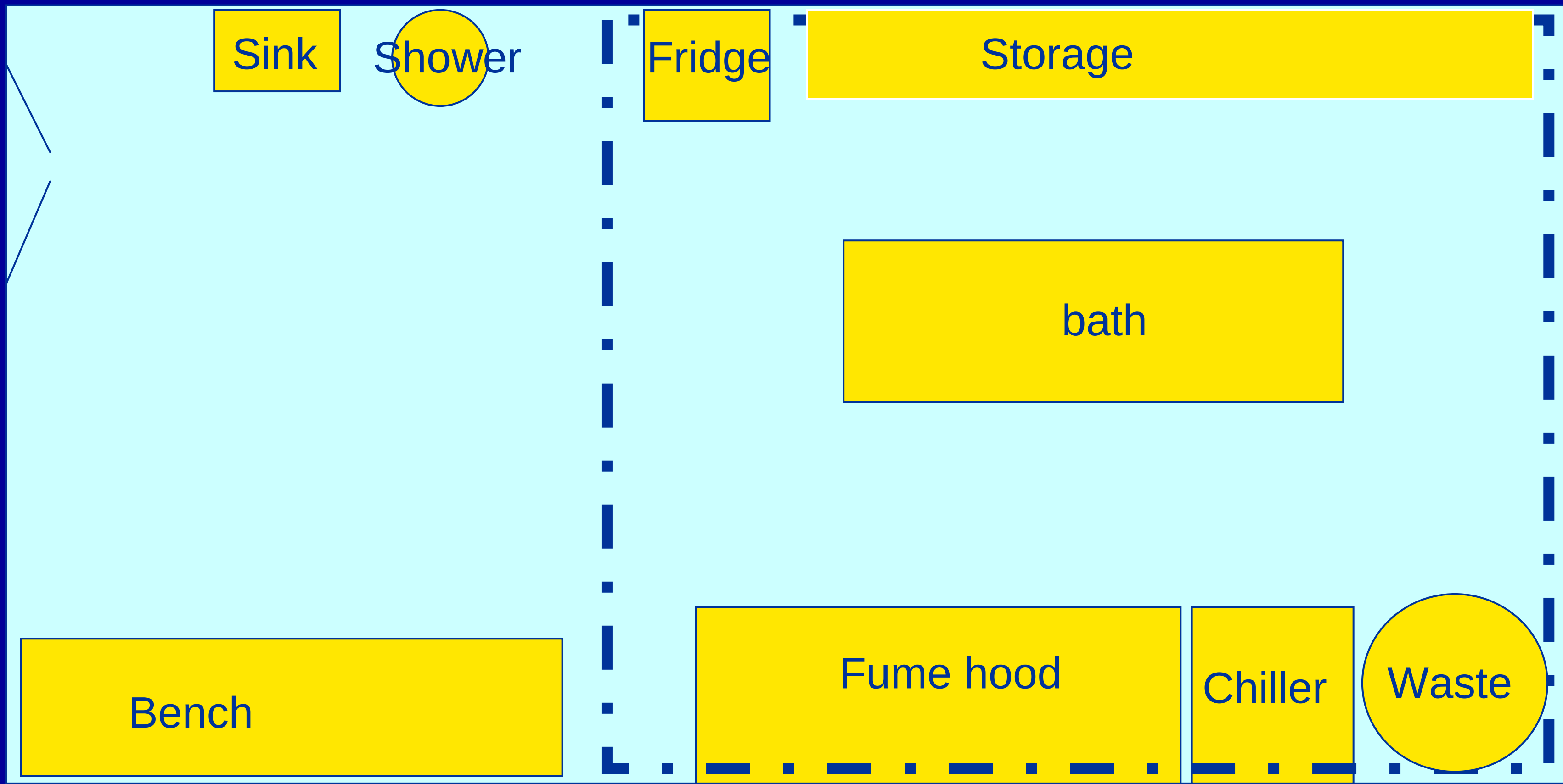


- The ISAC-II building houses the SCRF test and assembly areas
  - ~ 500m^2 of floor space, overhead crane
  - Ultrasound cleaning tanks, HPWR area, shielded rf test area, cryomodule assembly area, BCP lab (in construction)
  - Over 40 single cavity tests performed and five cryomodules assembled since 2004

SRF@TRIUMF : Infrastructure



Chemical Lab Layout

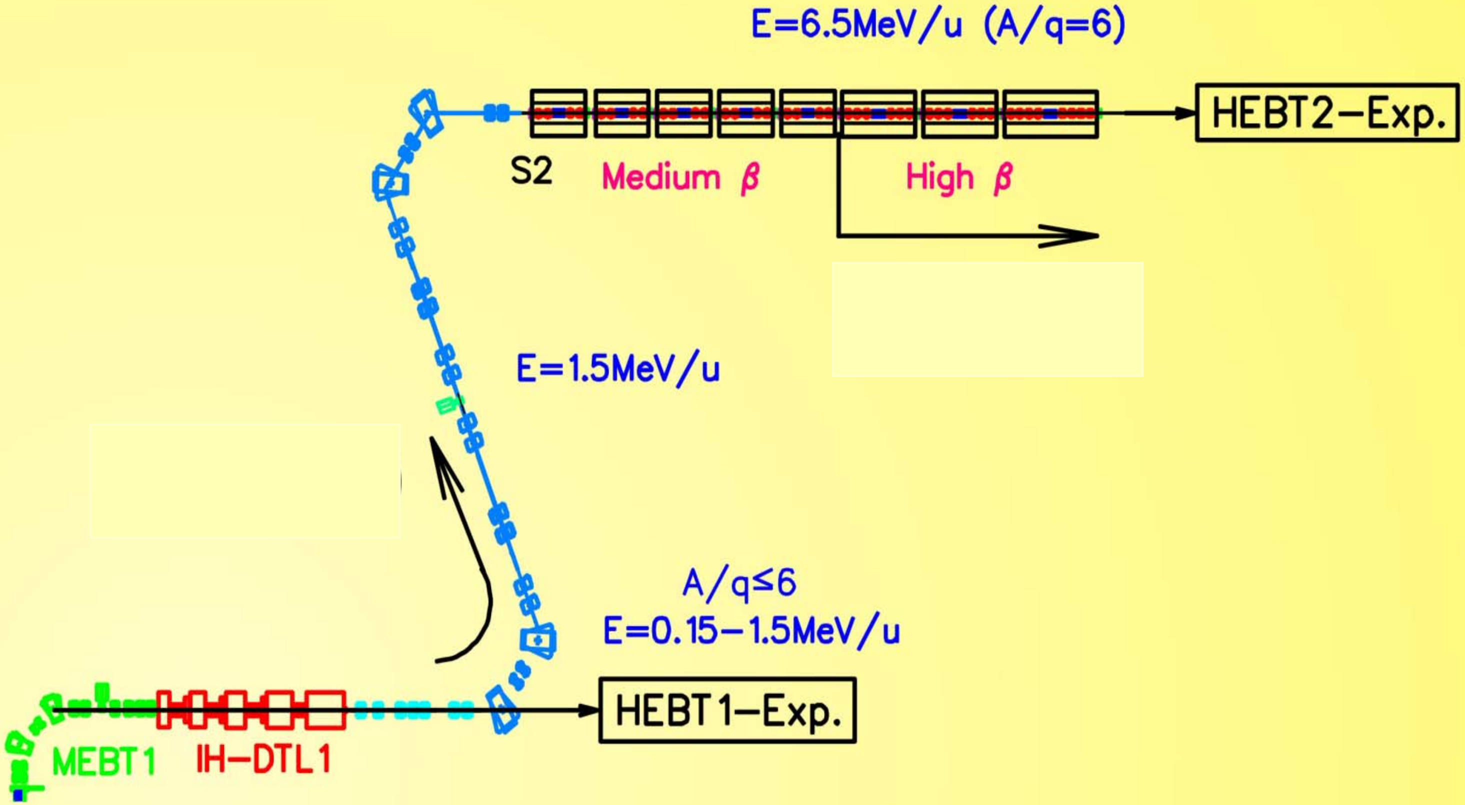


•Layout and equipment compatible with processing TRIUMF quarter wave cavities, including future low beta cavity, or ILC nine-cell cavities.

Present Developments

TRIUMF ISAC-II Linac-Future

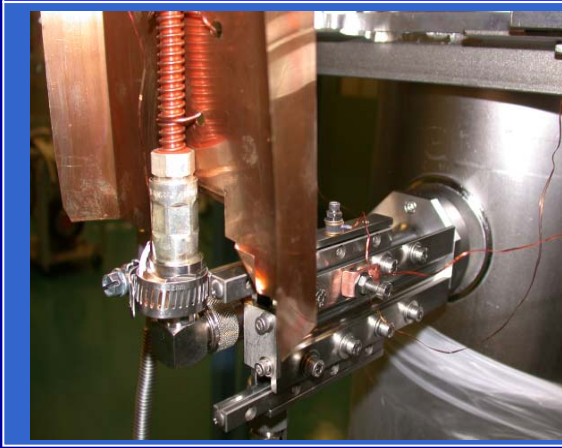
ISAC-II (Phase II - High Beta Section - 2009)



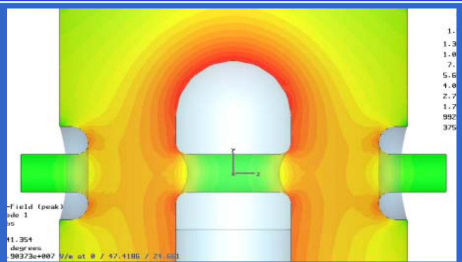
SRF Present Developments

- High beta coupling loop
  - Improved motor drive on coupling loop
- High beta cavity development
  - Built two full scale models in copper at PAVAC with standard inner conductor
  - Modeling new inner conductor detail for high beta cavity with improved field shape

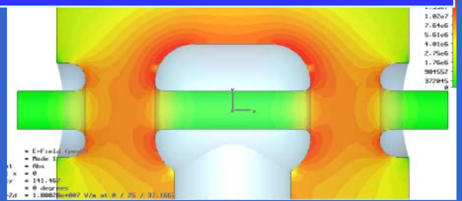
SCC coupling loop



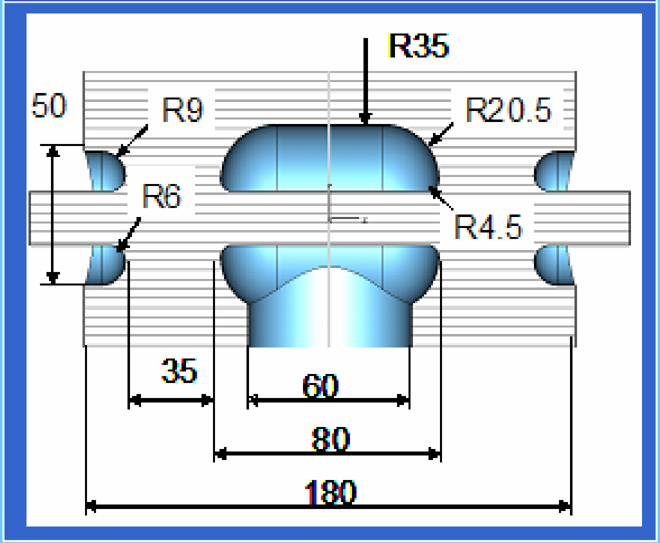
RF Modeling



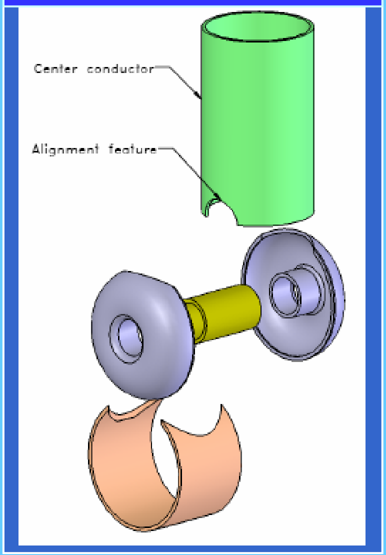
New donut shape



New Inner conductor detail



Fabrication Model

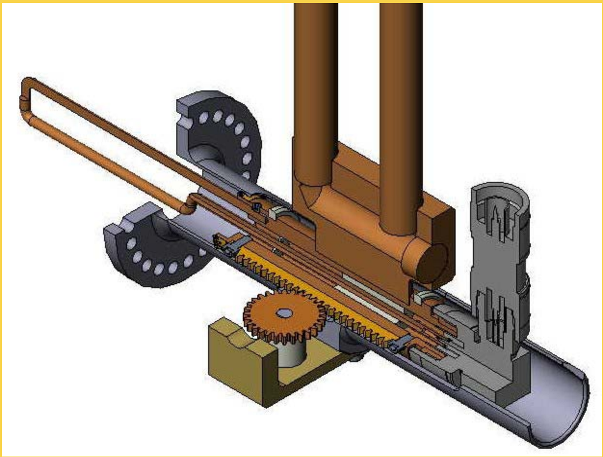


SRF Present Developments

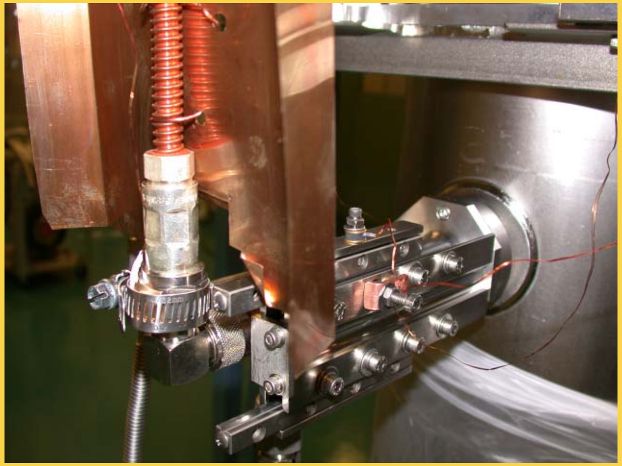
•Coupling loop development for high beta section

- •Problem:
  - • Medium beta loop variable drive stiffens in some cavities during cooldown due to side loads
- •Solution:
  - •Cross roller bearings replace teflon guide bushing
  - •Side loads from LN2 circuit reduced by using center feed
  - •Thermal tests confirmed design goals
    - •Smoother travel
    - •<0.5W from loop to 4K at Pf=200W

Medium Beta Design



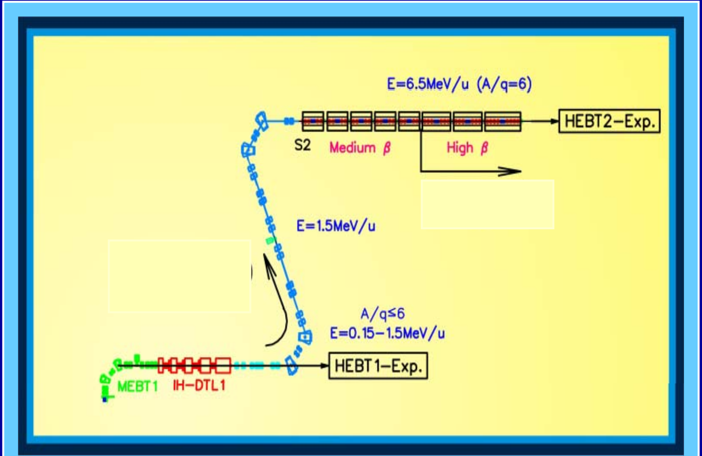
New Design



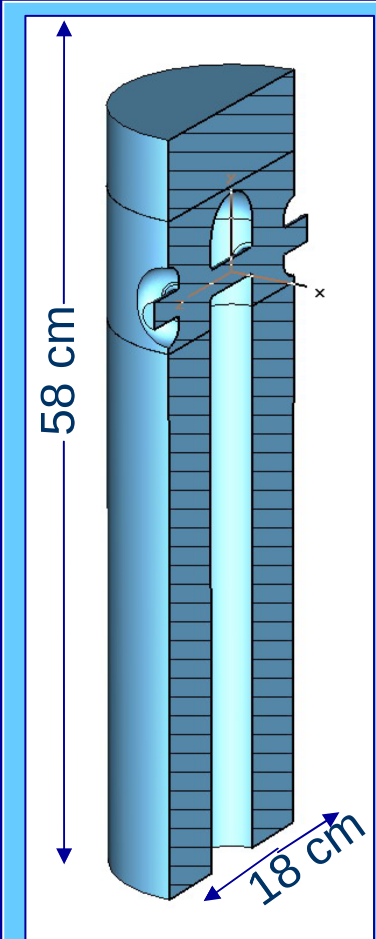
ISAC-II Beta=0.11 Cavity

•The Phase-II Extension of ISAC-II calls for the addition of 20 `high beta' (β=0.11) quarter wave cavities by the end of 2009

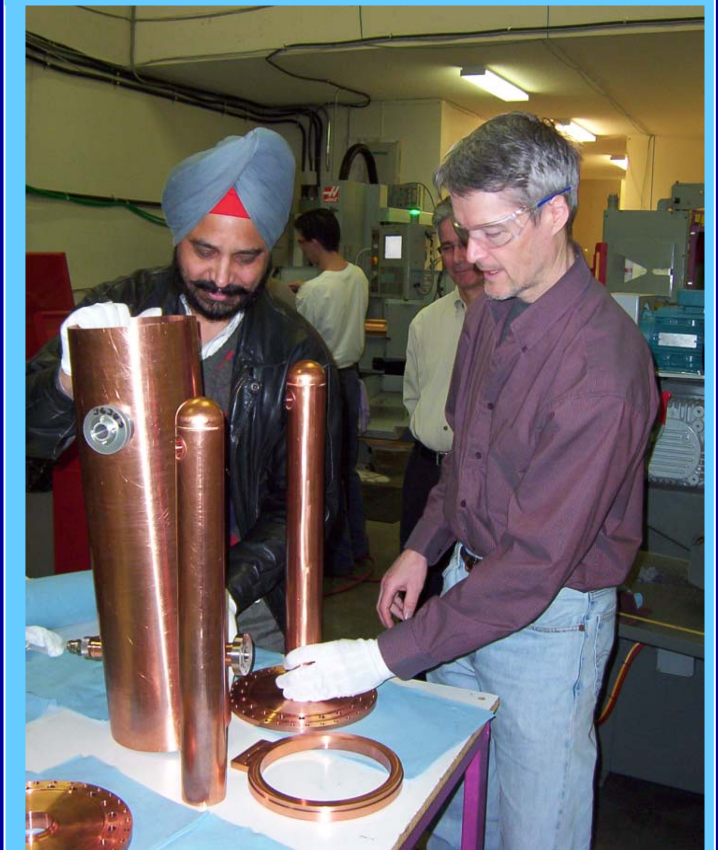
•TRIUMF is presently prototyping two bulk niobium quarter wave cavities with a local company, PAVAC



Medium Beta Prototype



Copper Prototype



PAVAC: Local Fabricator

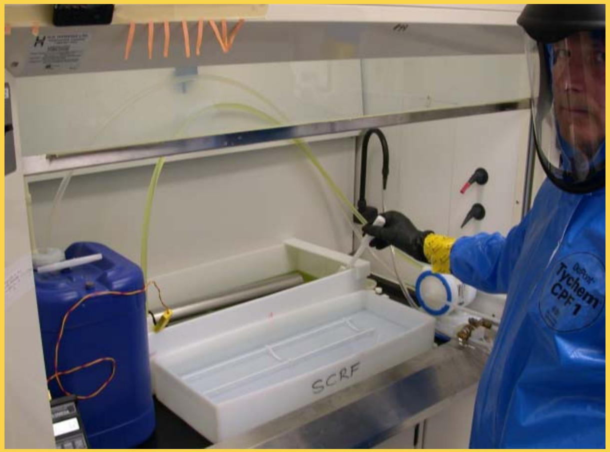
- Who is PAVAC?
  - A Canadian Company located in Richmond B.C.
- Specializing in
  - Electron Beam Welding
  - Pulsed Electron Beam Drilling and Surface-Micro Machining
  - Pulsed Electron Beam Coating (PEB-PVD)
- Presently fabricating two β=0.11 prototype cavities for testing by year end

PAVAC

Forming and Machining

EB Welding

Pre-weld Etching - TRIUMF



Future Developments

TRIUMF and the ILC

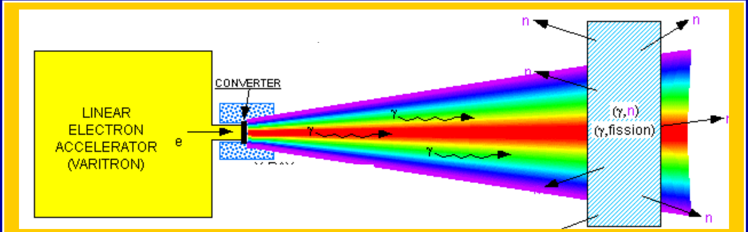
•TRIUMF has now joined the Tesla Technology Collaboration (TTC)

•Possible roles for TRIUMF

- •Qualification of Pavac as a North American supplier of ILC elliptical cavities
  - •Production of several single cells and at least one nine cell elliptical cavity
- •Large grain and single crystal material, cavity tuners, LLRF
- •Build in house expertise in electron accelerator technology by designing, fabricating and installing an accelerator based on electron technology

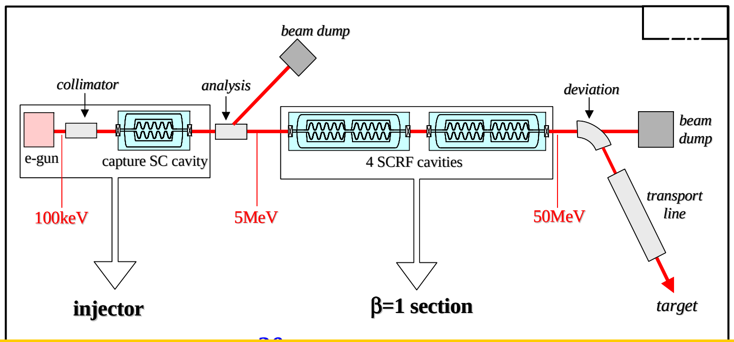
TRIUMF and Electrons

- TRIUMF is discussing a proposal to build another RIB driver to compliment the capabilities of the 500MeV cyclotron
  - A strong candidate for this driver is a high intensity SC electron linac (50MeV, 1-10mA) (50kW-0.5MW), single pass or double pass, to produce radioactive ion beams via photo fission
  - Could be configured as an energy recovery linac (ERL) with an IR-FEL on the back straight section for accelerator studies

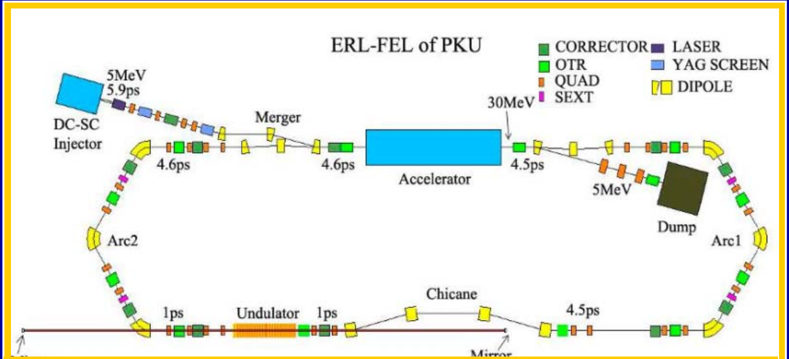


RIB production though photo-fission

Utilize ILC Technology



Single pass



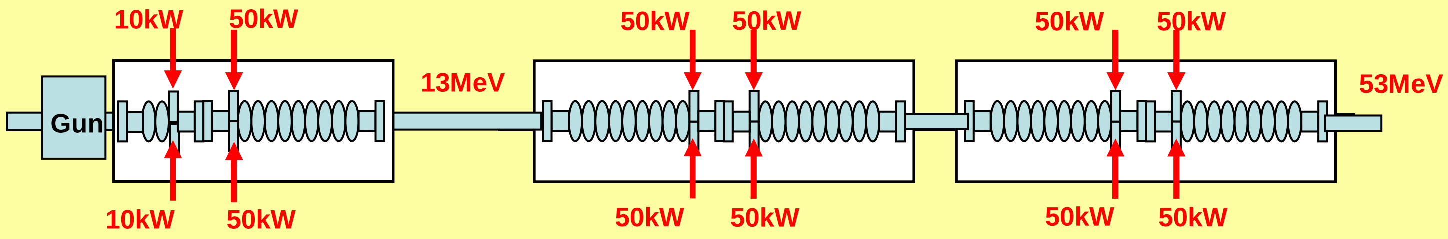
ERL with IR-FEL

Parameters of E-Linac

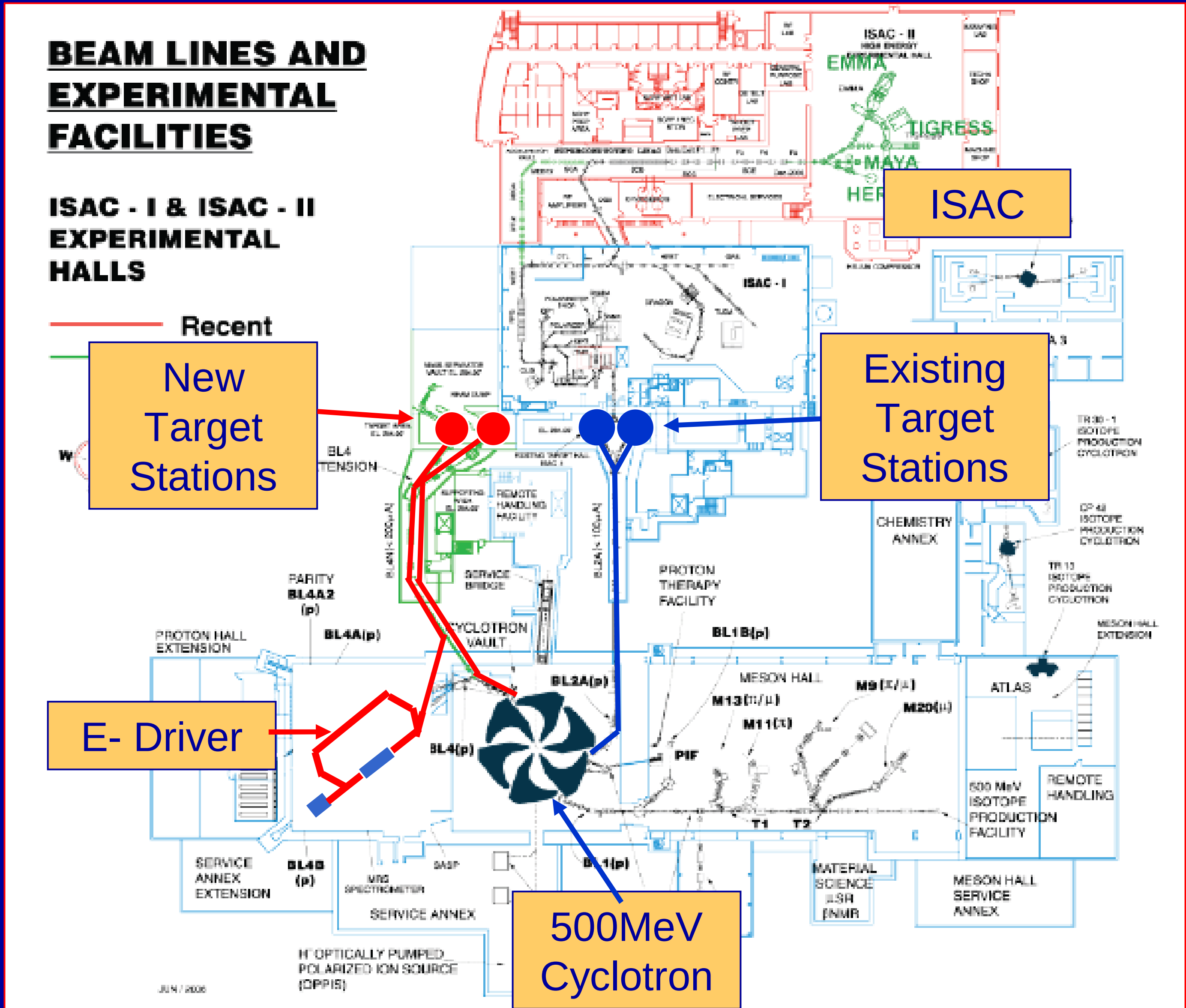
Freq (MHz)	1300
Duty cycle	Cw
Cells/cavity	9
No. of cav	5
Grad (MV/m)	10
Cavity length (m)	1
R/Q	1000
Qo	$1x10^{10}$
Pcav (W)	11

Energy (MeV)	53
Max I (mA)	10
Power/cav (kW)	100
Power/cplr (kW)	50
Qext	$1x10^{6}$
Charge (pC/bunch)	7

Capture Cavity	
# cells	2
R/Q	200



TRIUMF and Photo-fission



Proposal:

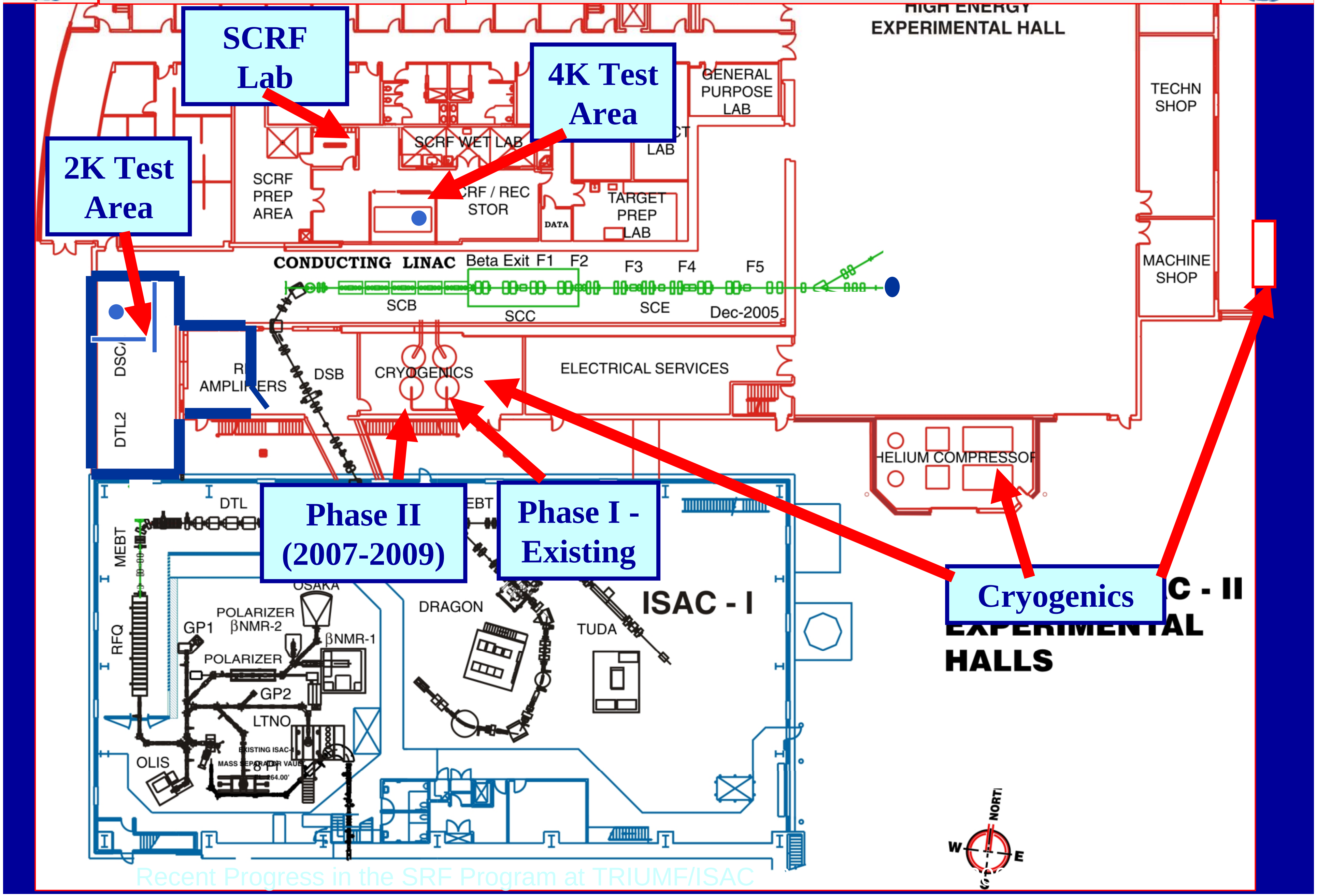
- BL4N is proposed to deliver 500MeV protons to up to three target stations for beam development and an additional RIB source for experiment
- Take advantage of the shielded and unused proton hall to add an electron driver ring to supply electrons to the new target area via a separate beamline; **three simultaneous RIB beams**
- Develop target stations in the new area dedicated to the use of actinide targets
- Include a FEL source on the back straight to allow IR light source
- TRIUMF/CLS Canadian collaboration for future light source

SRF@TRIUMF : 1.3GHz Upgrade

Require upgrade to present capabaility

- Vertical cryostat with bath insert for single cavity and nine cell cavity tests
- 1.3GHz test area – clean room?
  - Overhead crane, shielded rf test bunker
  - Possible area in ISAC-II vault
- 2K cryo system
  - Phase II 500W 4K system will be available from 2007-2009 for cold tests
  - Require sub-atmospheric pumping system plus recovery/scrubbing system
    - Outside clean room
- 1.3GHz rf test equipment
  - LLRF control board
  - Amplifier
  - Test equipment
    - Signal generator, freq counter, Power meter, scope, spectrum analyzer
  - Ancillaries
    - cables, connectors, mixers, attenuators, phase shifters

ISAC 1.3GHz Test Area



SRF@TRIUMF : Conclusion

- ISAC-II Linac now operates cw at gradients corresponding to peak surface field of 35MV/m, the highest of any operating heavy ion facility
  - Gradients 20% above design specification and only 5% below single cavity test gradients
  - Little or no degradation over the 17 months of operation including first full warm-up
  - A single vacuum system does not preclude high performance operation in the cw regime (not strongly dominated by field emission)
- Present
  - Two prototypes for β=0.11 quarter wave cavities now in production in PAVAC for testing by year end
  - Order for twenty production cavities placed in early 2008
- Future
  - SRF group tooling up for testing at 1.3GHz
    - Pursuing funding for a 50MeV e-linac as a RIB driver
    - Support TTC collaborations for ILC
    - Qualify PAVAC as North American vendor for ILC cavities

`Recent Progress in the SRF Program at TRIUMF/ISAC', Bob Laxdal, SRF2007, Oct. 15, 2007