



PERFORMANCES OF THE ISAC HEAVY ION LINACS

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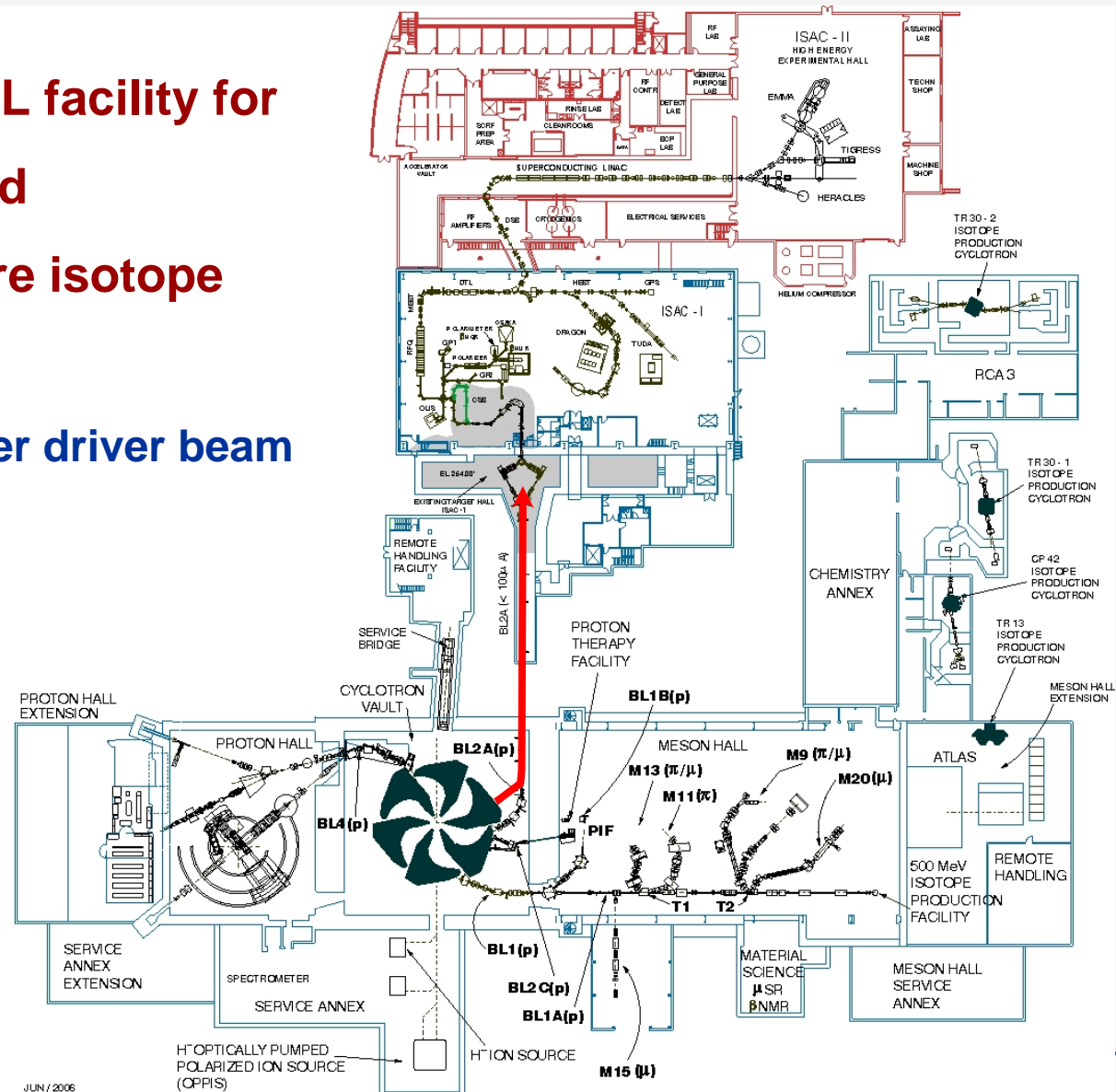
*Owned and operated as a joint venture by a
consortium of Canadian universities via a contribution
through the National Research Council Canada*

Outline

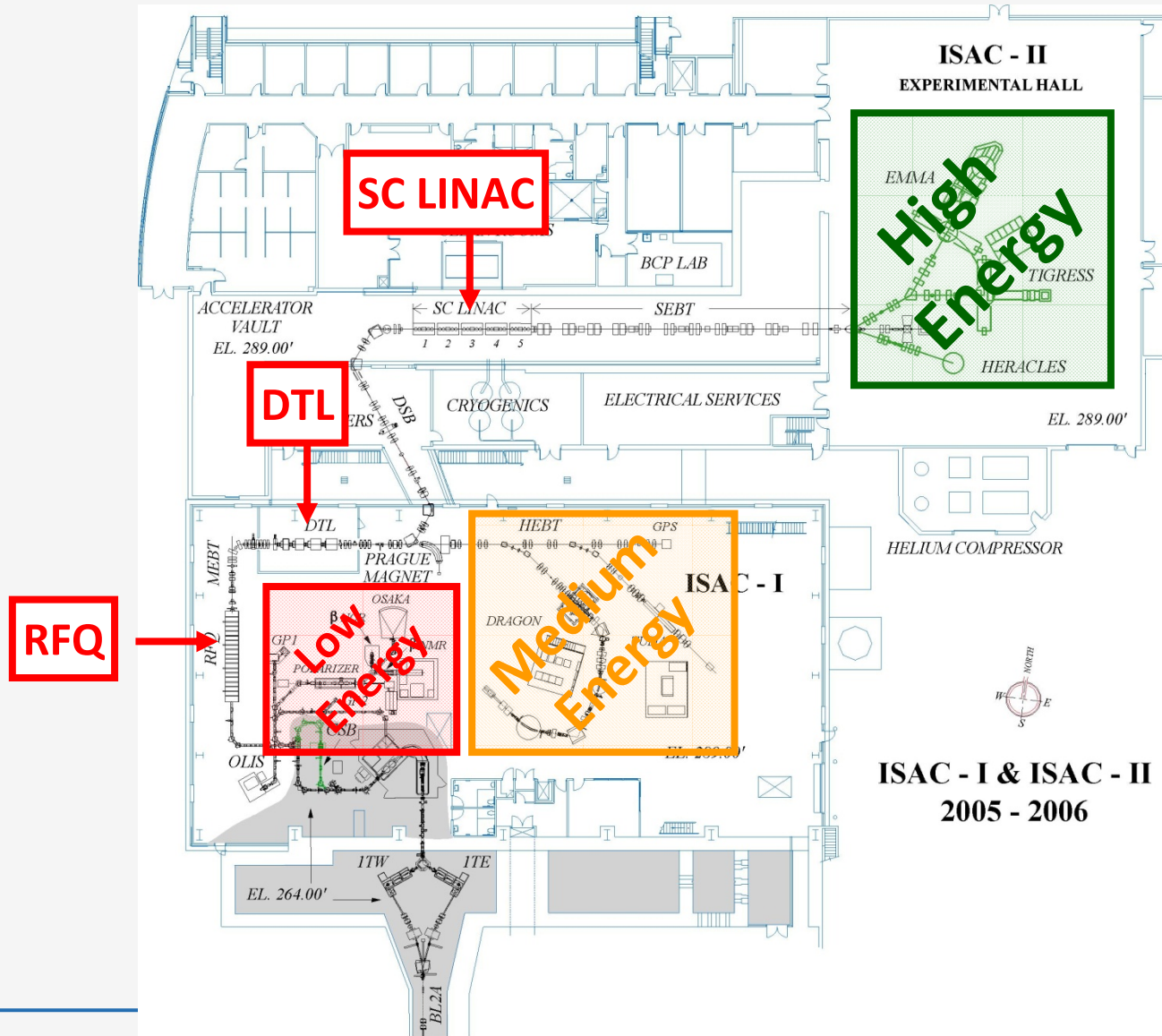
- **ISAC post accelerators**
 - RFQ and DTL
 - SC linac
 - Linac performances
 - Technical and operational issues
 - Rf ancillaries and beam diagnostics
 - Solenoid
 - Particulate control
- **Beam delivery operation**
 - Tuning RIBs
 - Beam delivery group
- **Conclusion**

ISAC at TRIUMF

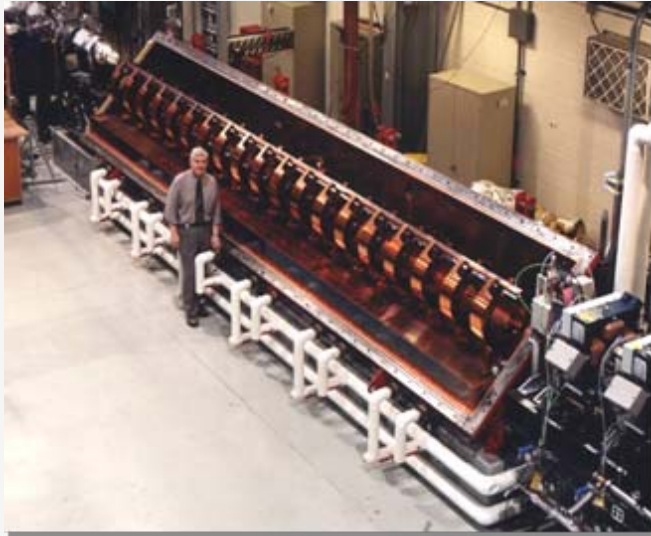
- World class ISOL facility for the production and acceleration of rare isotope beams (RIB);
- Highest power driver beam (50 kW);



Heavy Ion Accelerators



ISAC-I Room Temperature Linacs

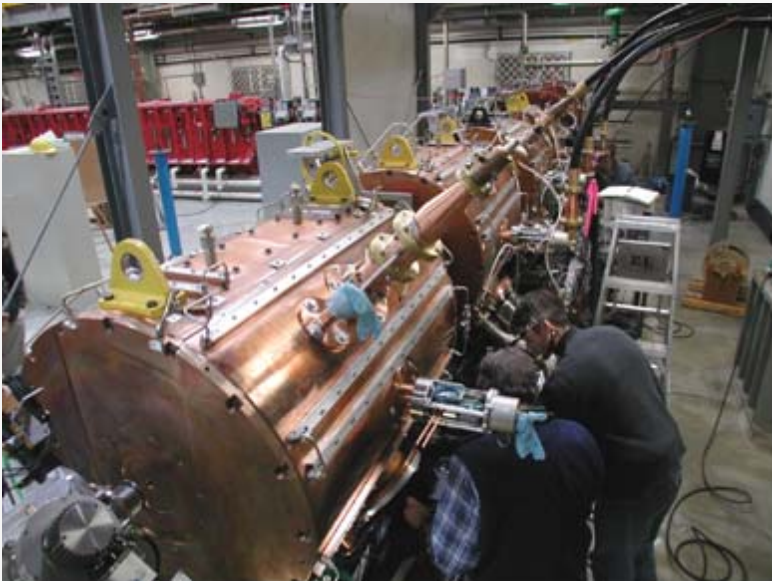


▪ RFQ (Radio Frequency Quadrupole)

- 8m long CW, 85 kW;
- $E_{in}=2 \text{ keV/u}$ $E_{out}=150 \text{ keV/u}$, $3 \leq A/Q \leq 30$;
- beam prebunched at the injection;

▪ DTL (drift tube linac)

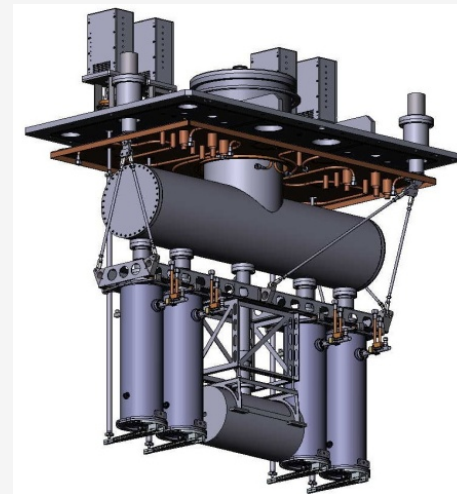
- Separated functions;
- Five IH interdigital RF cavities;
- Three split-ring bunchers;
- $E_{\text{design range}}=0.15\text{-}1.5 \text{ MeV/u}$, $2 \leq A/Q \leq 6$;
- Triplets between tanks;
- ISAC II injector 1.5 MeV/u.



ISAC-II Superconducting Linac

■ Five cryomodules:

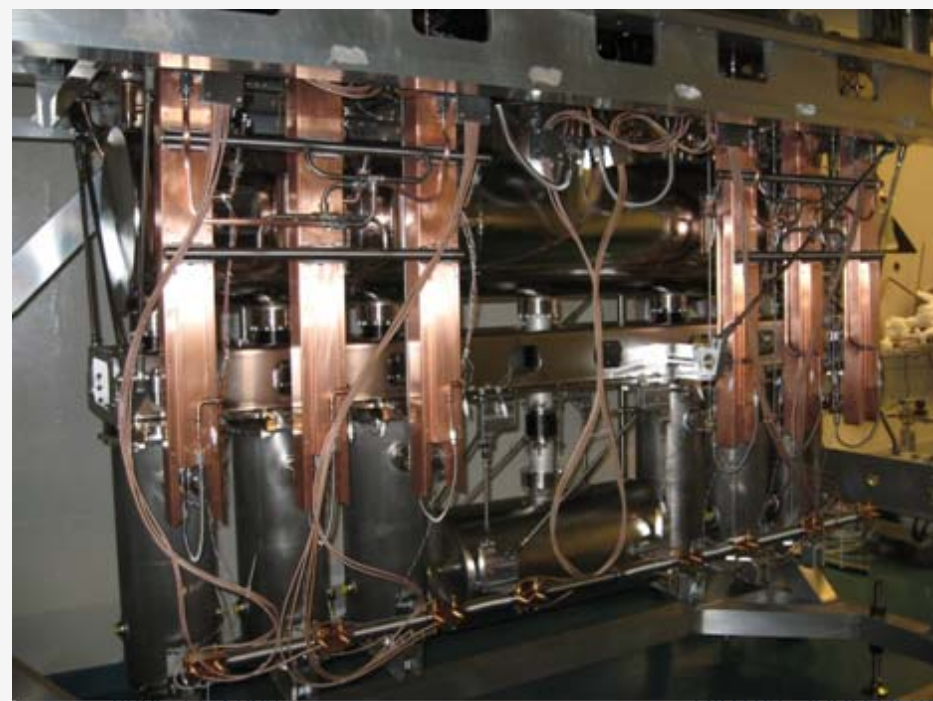
- Four bulk niobium superconducting cavities per cryomodule (20 cavities, 20 MV);
- One 9T superconducting solenoid.



ISAC-II Phase II Upgrade

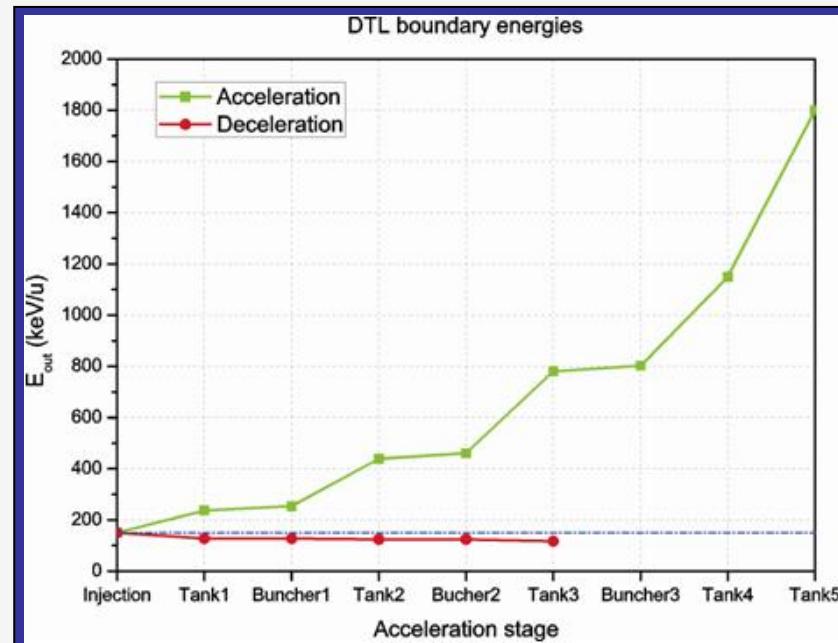
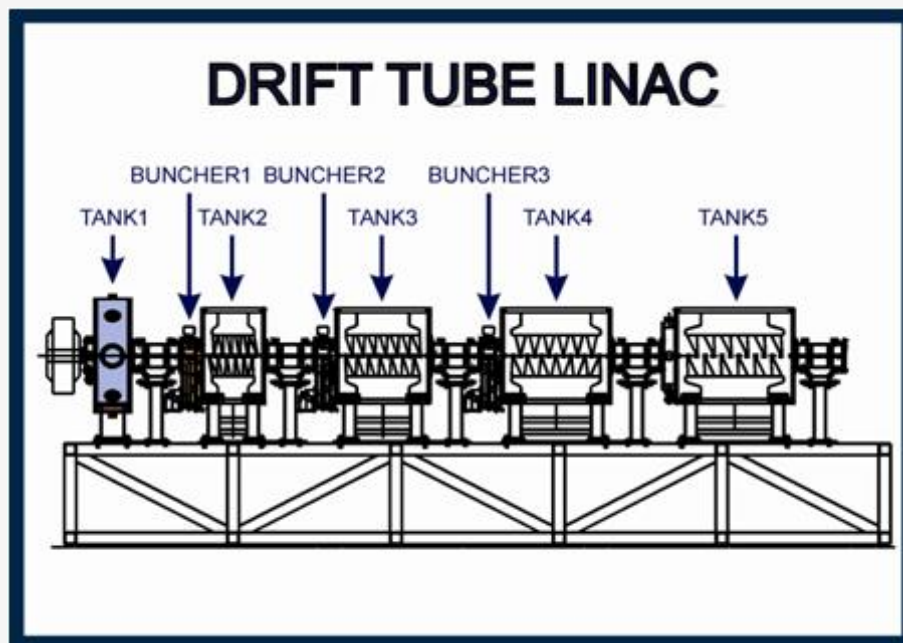
▪ Three new cryomodules:

- 6+6+8 bulk niobium superconducting cavities (20 more cavities for a total of 40 MV of acceleration);
- One superconducting solenoid per cryomodule.
- Cold test of SCC1 next week



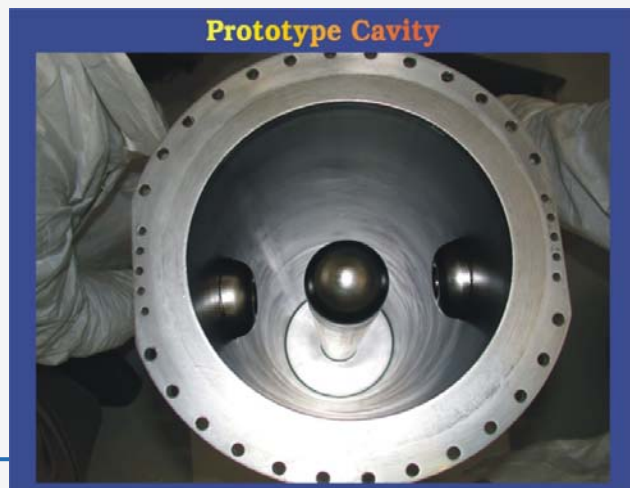
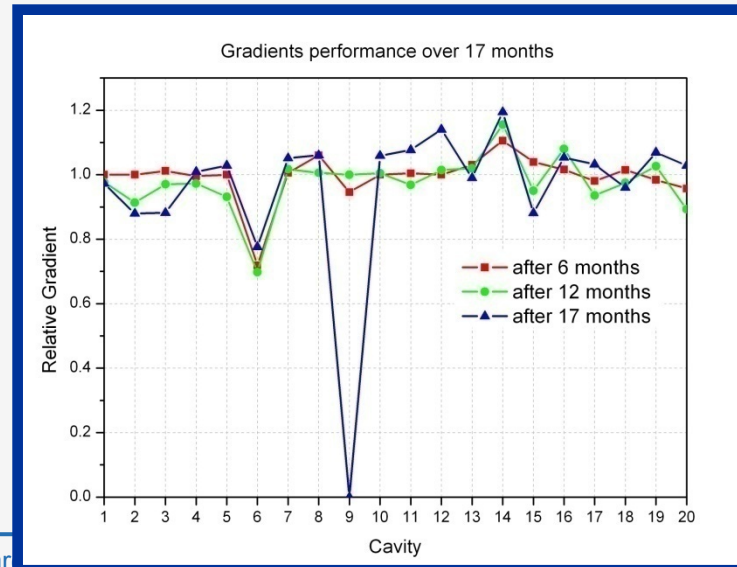
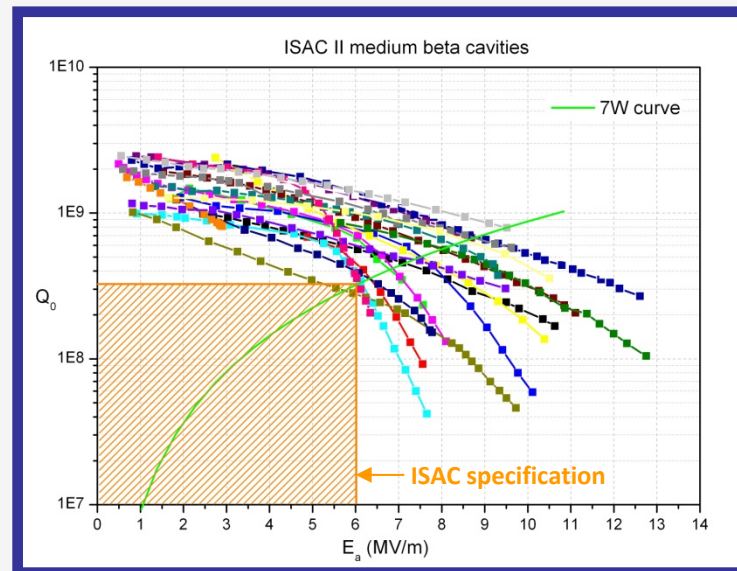
DTL Performances

- Exploit physical limit of the machine maintaining reliability and quality
- Variable energy $E_{\text{effective range}} = 0.117\text{-}1.8 \text{ MeV/u}$, $2 \leq A/Q \leq 6$
- High transmission $>90\%$



SC Linac Performance

- Quarter wave resonator at 106.08 MHz;
- CW operation: $E_{\text{peak}} = 35 \text{ MV/m @ 7W}$
 - Little or no degradation in gradient performance over three years operation
- Phase I section total voltage of 20 MV;
- 100% Transmission
- **Accelerators combined for 97% reliability in 2009.**



RF Ancillaries Upgrade

ISAC-II RF Systems

□ RF power

- Provide useable bandwidth by overcoupling
- Require $P_f=200\text{W}$ at cavity for $f_{1/2}=20\text{Hz}$ at $E_a=6\text{MV/m}$, $\beta=200$

□ Coupling loop

- Developed LN2 cooled loop
- $<0.5\text{W}$ to LHe for $P_f=250\text{W}$

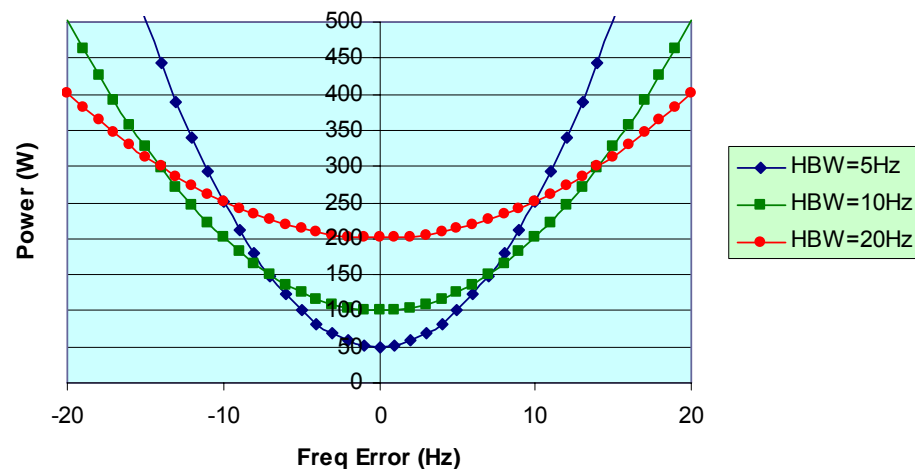
□ Mechanical tuner

- Precise ($0.3\sim\text{Hz}$), fast ($>50\text{Hz/sec}$) tuner with dynamic range of 8kHz and coarse range of 32kHz

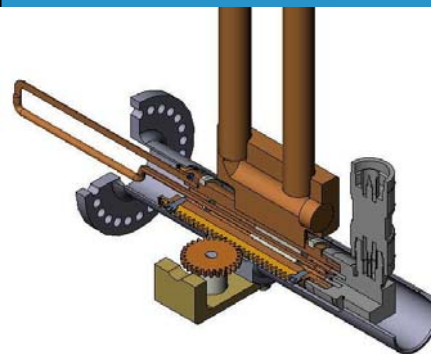
□ Tuning plate

- Spun, slotted, 'oil-can' tuning plate to improve tuning range

Forward power required for $E_a=6\text{MV/m}$ and given bandwidth



Coupling Loop

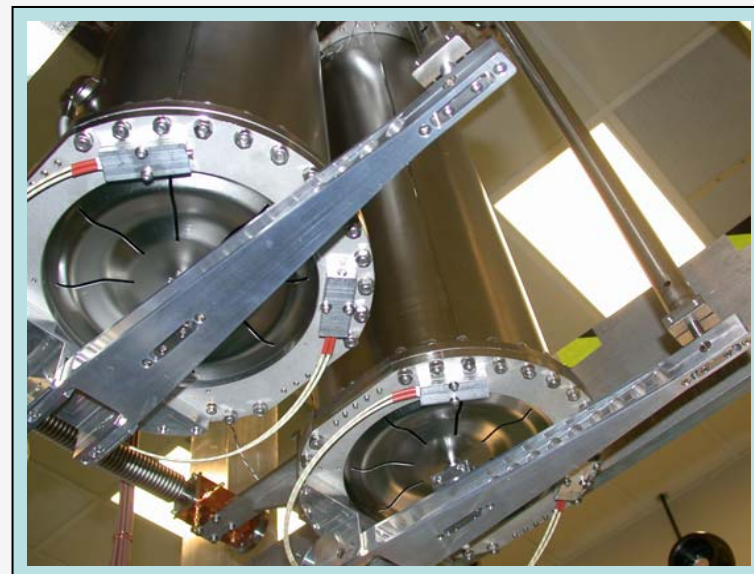
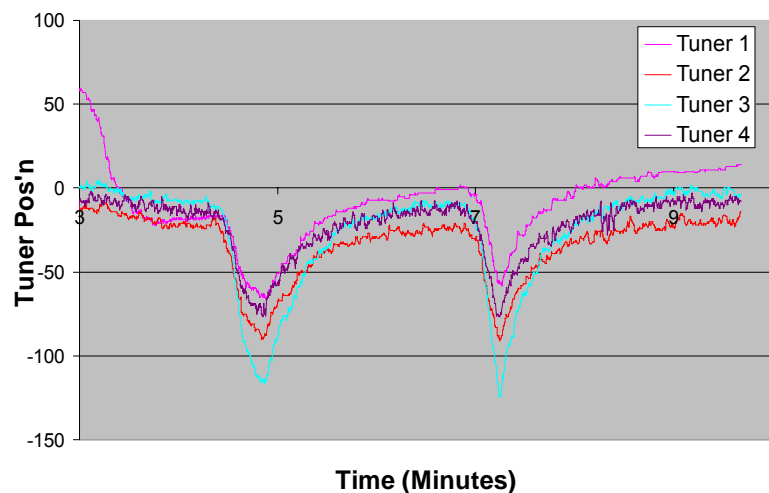
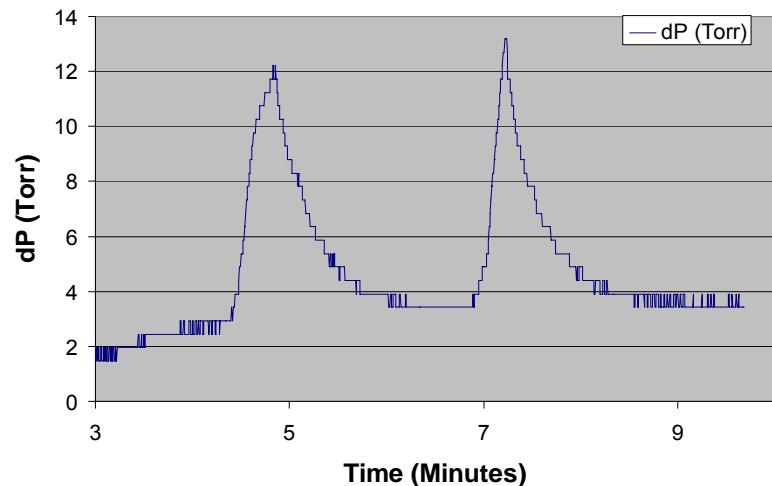


Mechanical Tuner



ISAC-II Phase I Tuner

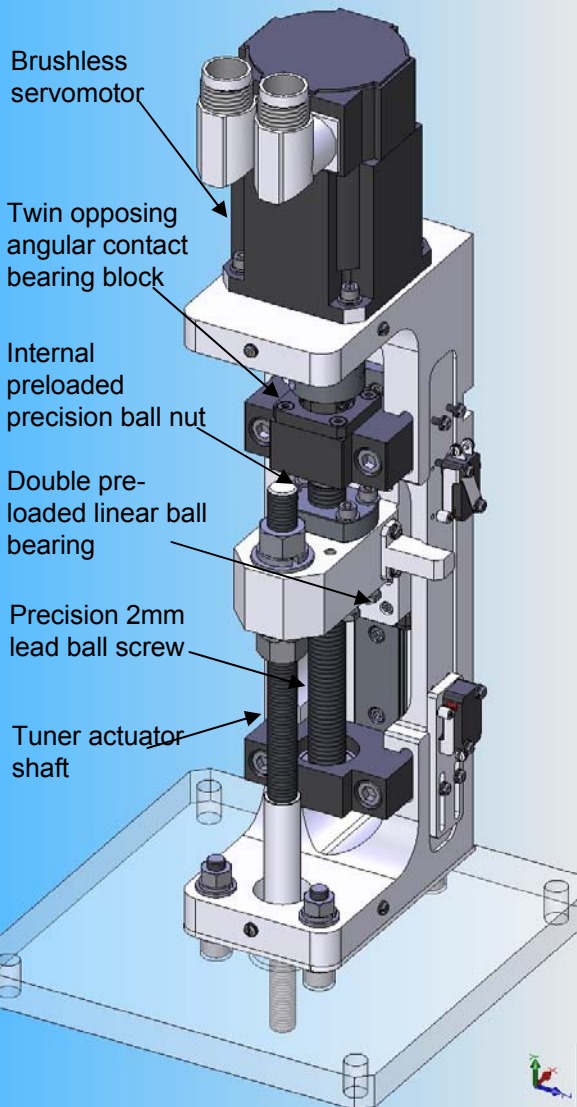
Tuner Response with Four Cavities



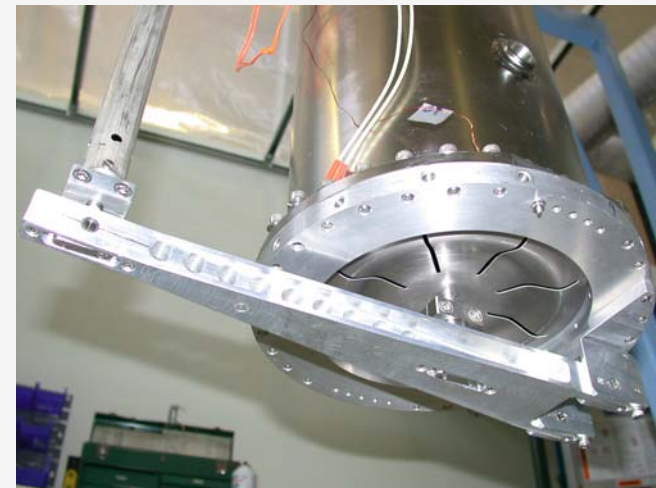
- ❑ Lever mechanism with zero backlash hinges and stiff rod connected to precision linear servo motor (Kollmorgen) in air
- ❑ High performing but expensive

ISAC-II Phase-II tuner

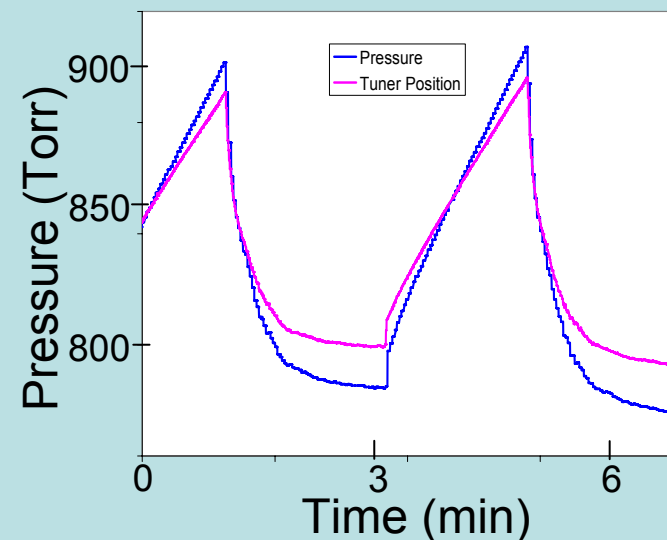
New Tuner Motor Developed



- precision brushless servomotor and ball screw on top of cryomodule
- Actuator extends (through bellows) to a lever mechanism to the tuning plate
- Tuner Position resolution 0.04 Hz/step; corresponds to 5nm/step



- Tuner operation in locked phase loop @ 6.4MV/m, $P_f=166W$, $P_c=3.3W$, $Q_0=7.13e8$ coupling $\beta \sim 200$, bandwidth $\sim \pm 20$
- Force helium pressure fluctuations to test tuner
- $\Delta P=137$ T, $\Delta f=330Hz$;
- compensation is $\Delta f/\Delta t = 13Hz/sec$.
- No increase in phase noise during test.



ISAC-II Phase-I Coupling Loop

❑ Developed from INFN Legnaro adjustable coupling loop

❑ Modifications

✓ Stainless steel body for thermal isolation

✓ Copper outer conductor thermally anchored to copper LN2 cooled heat exchange block

✓ Aluminum Nitride dielectric inserts thermally anchor the inner conductor to the outer conductor

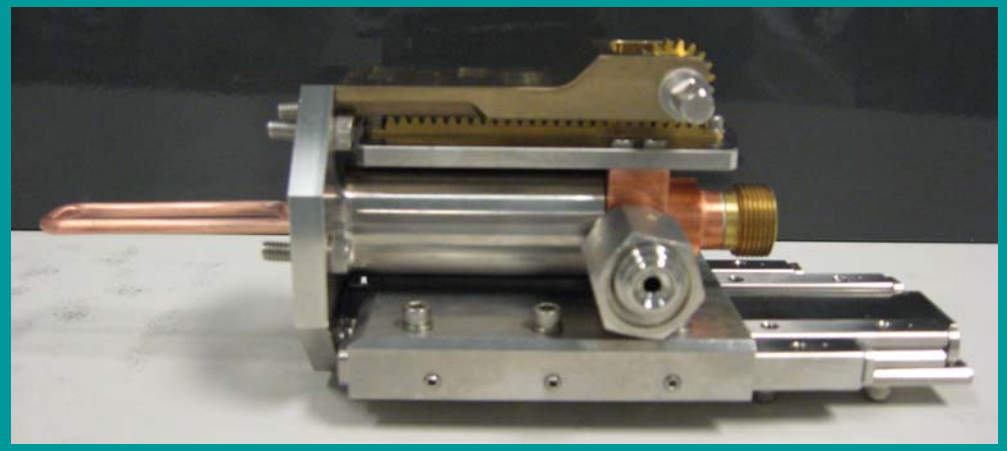
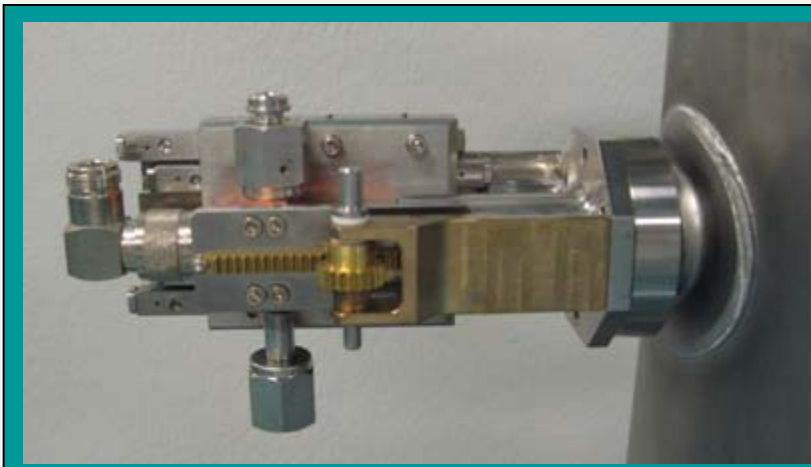
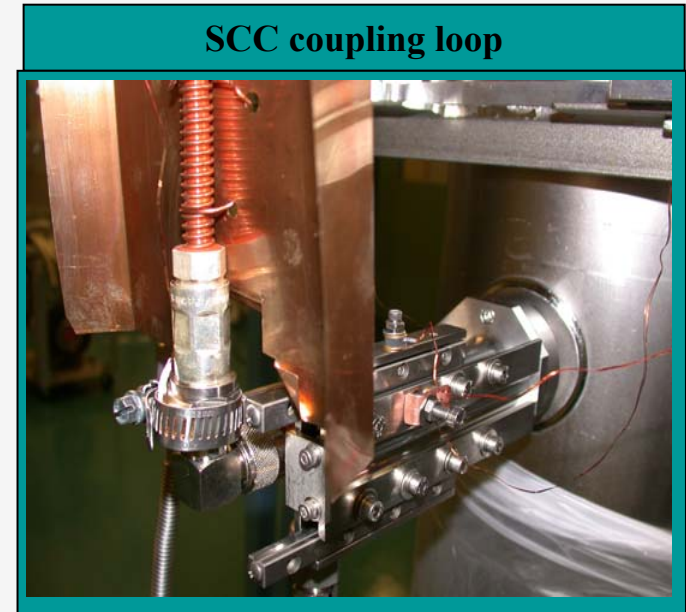
✓ Achieved $<0.5\text{W}$ helium heating with $P_f=250\text{W}$

❑ Mechanically vulnerable – side loads

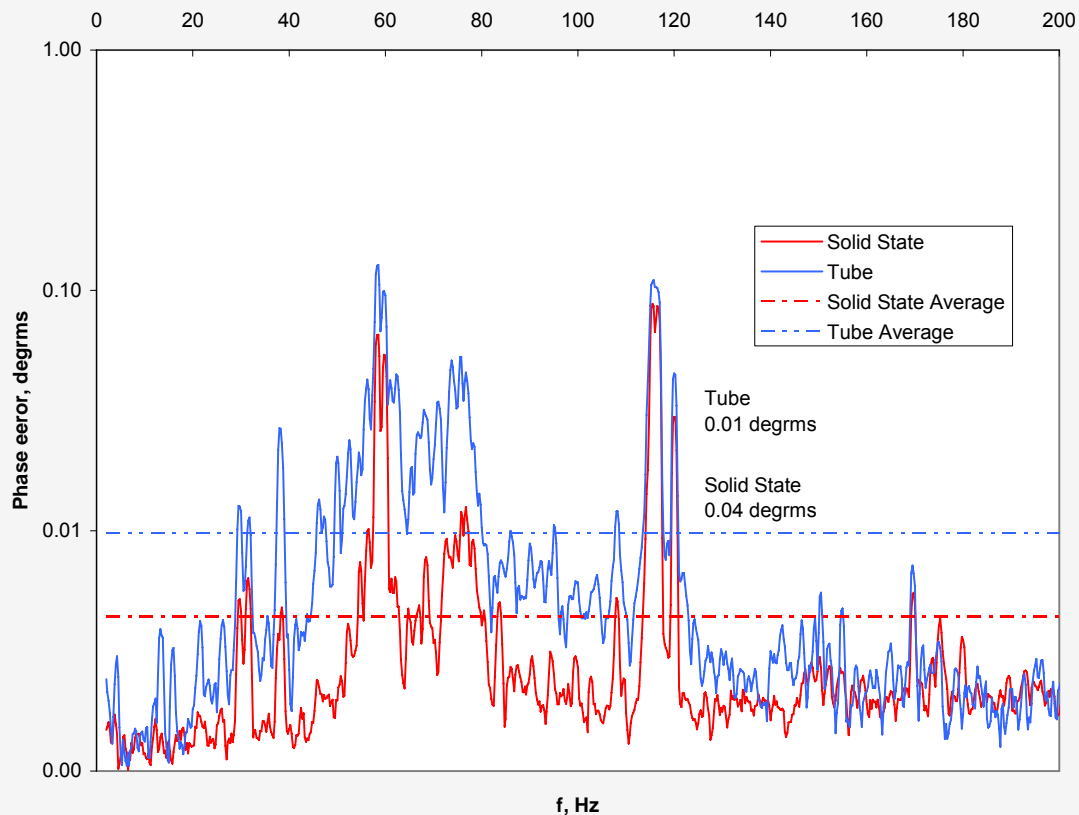


ISAC-II Phase-II Coupling Loop

- Developed new coupling loop with improved mechanical drive
 - Uses non-magnetic cross roller bearings
 - Reduce side loads by making the LN2 feed more symmetric
 - Performance tests show at $P_f=200W$ the heat load to the helium is $<0.5W$



RF Amplifiers – Moving to Solid State

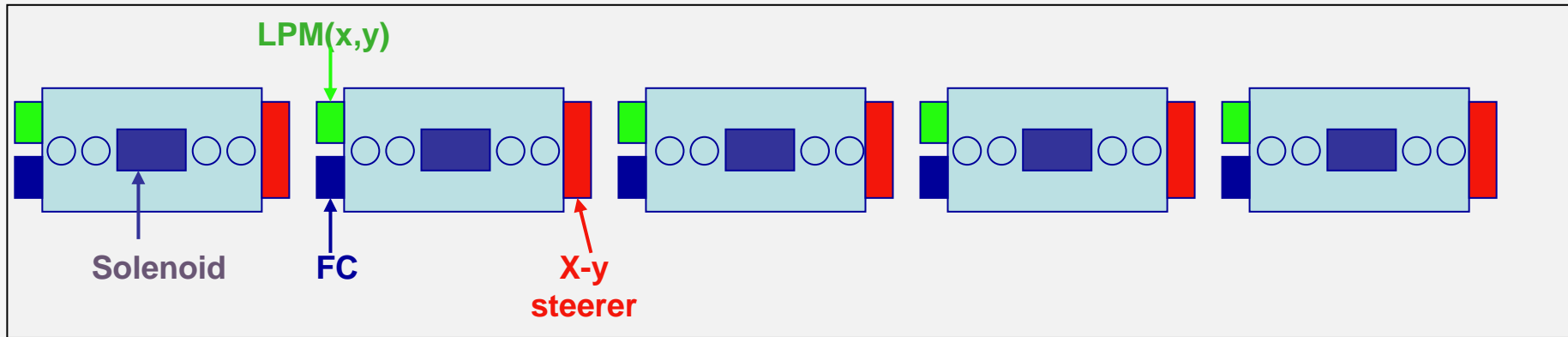


Solid State Amplifier from QEI designed for ISAC-II Phase II Cavities showed very good performance and twice less noise level in RF System of the cavity in comparison with tube amplifier

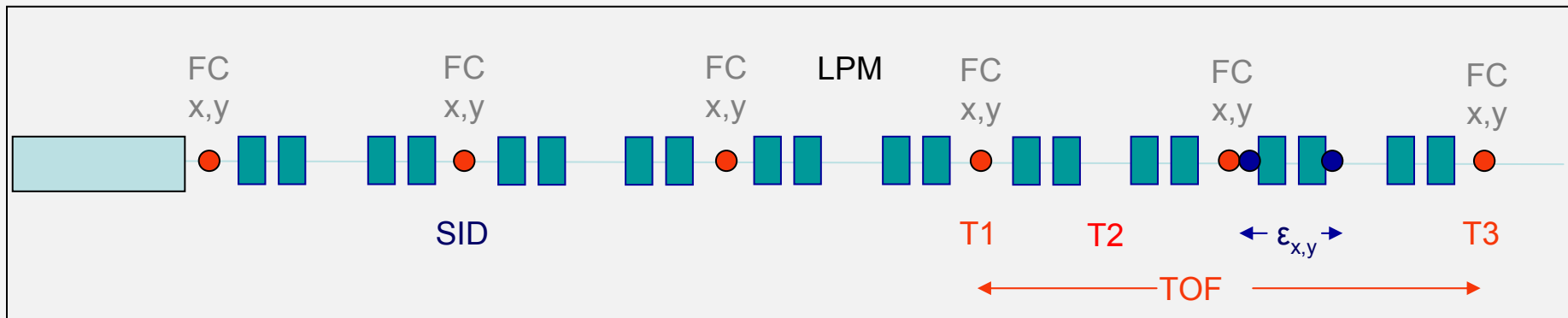
Beam Diagnostics

ISAC-II Linac Diagnostics

Linac

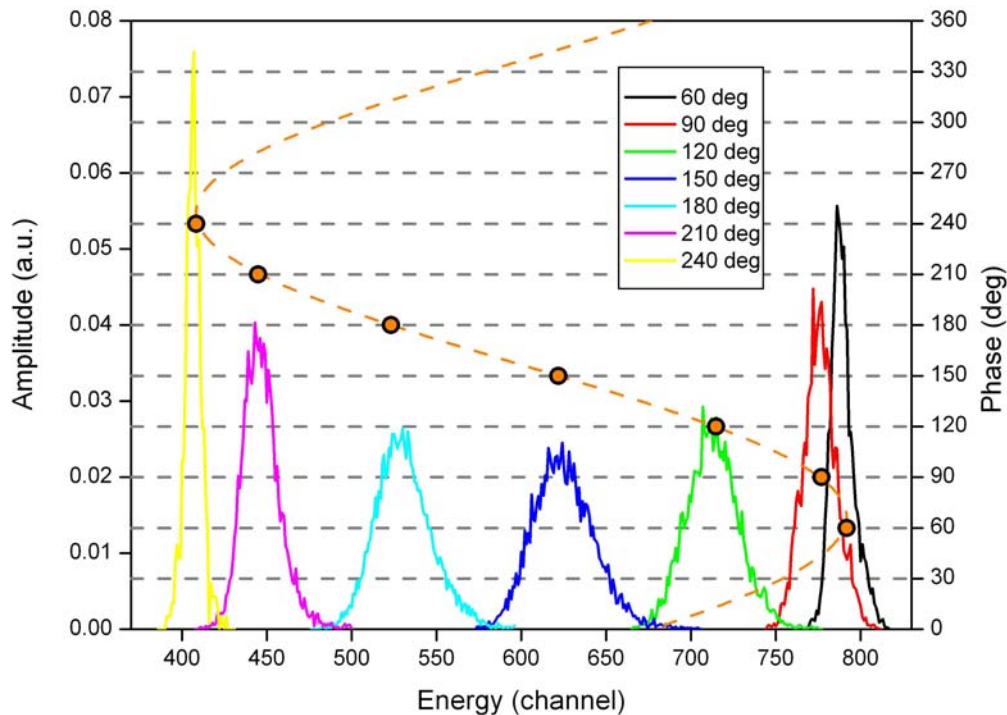
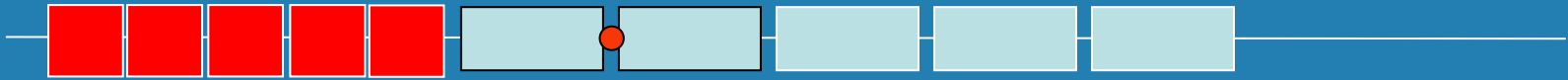


Beamline



ISAC-II Linac Cavity Phasing

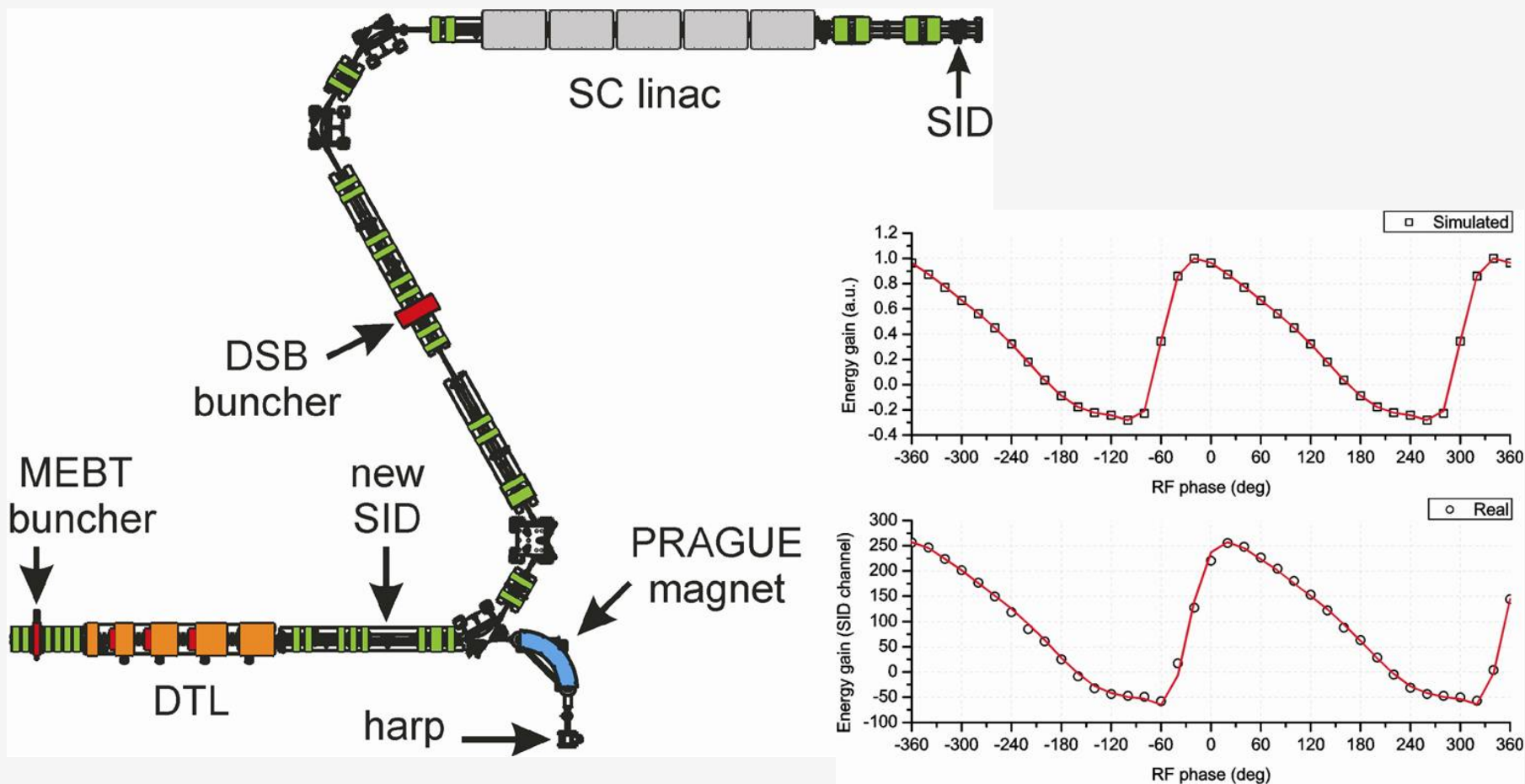
Medium Beta



- Si detector in downstream detector measures energy of particles scattered from a Gold foil
- Ion Energy is measured for different cavity phases
- $\varphi = 0$ deg determined from cosine fit to energy data
- Cavity set to $\varphi = -25$ deg for acceleration

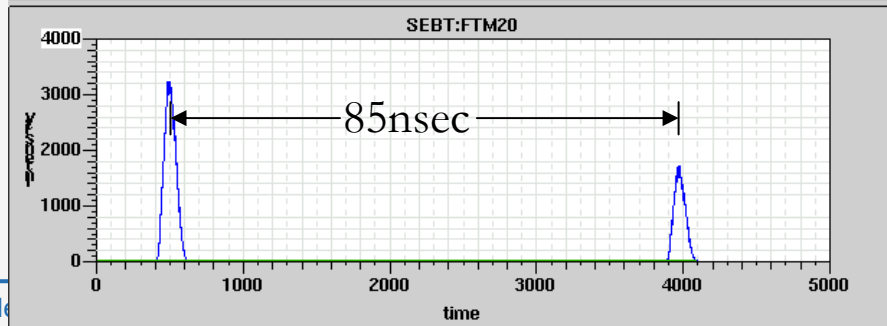
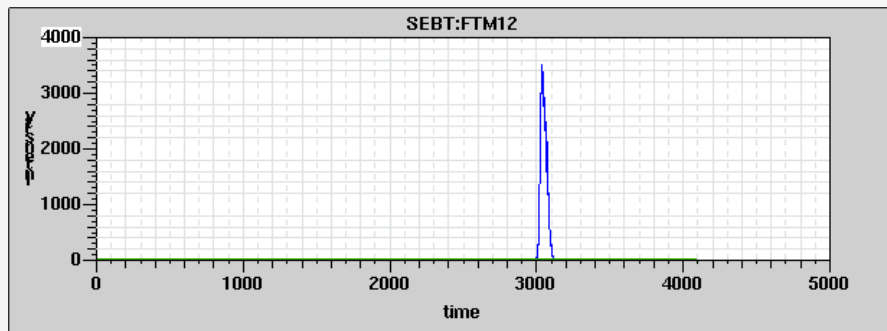
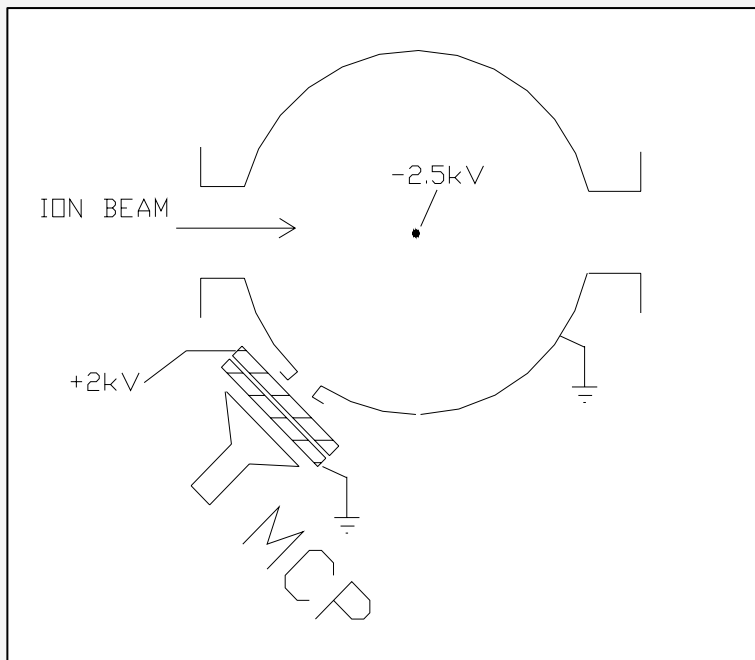
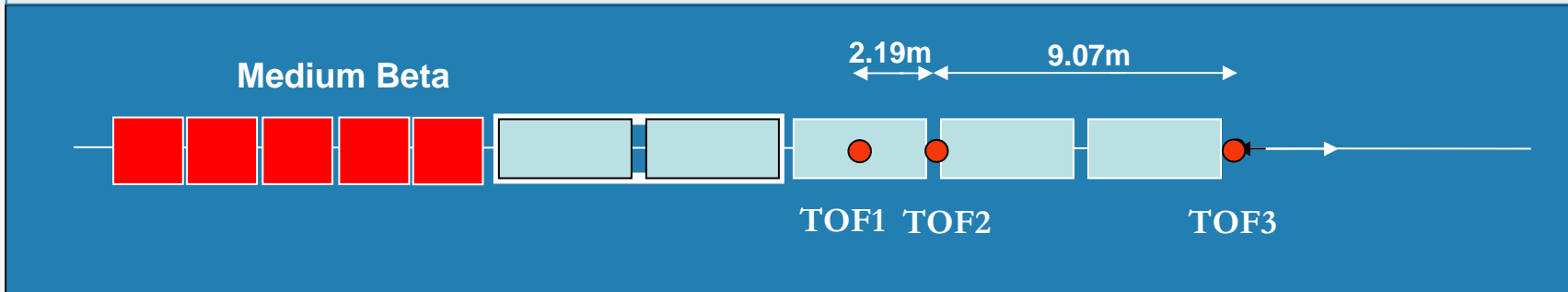
DTL Tuning Upgrade

- Reducing procedural time; moving toward an automated procedure
 - Utilize fit to phase dependent acceleration profile to set phase

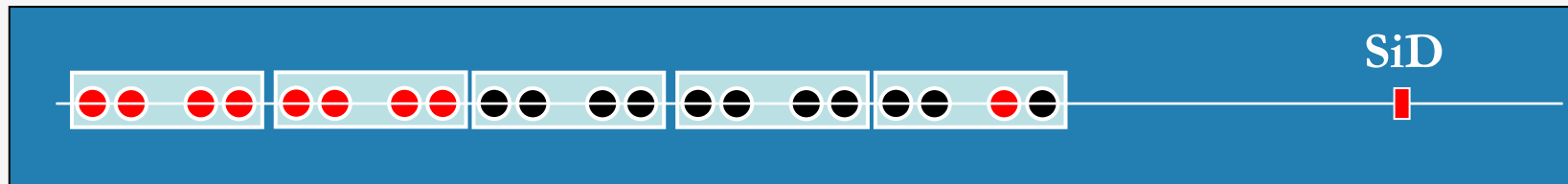


ISAC-II Energy Measurement

Three monitor system giving three TOF measurements. The quoted energy is derived from the weighted average of the three calculated energies.



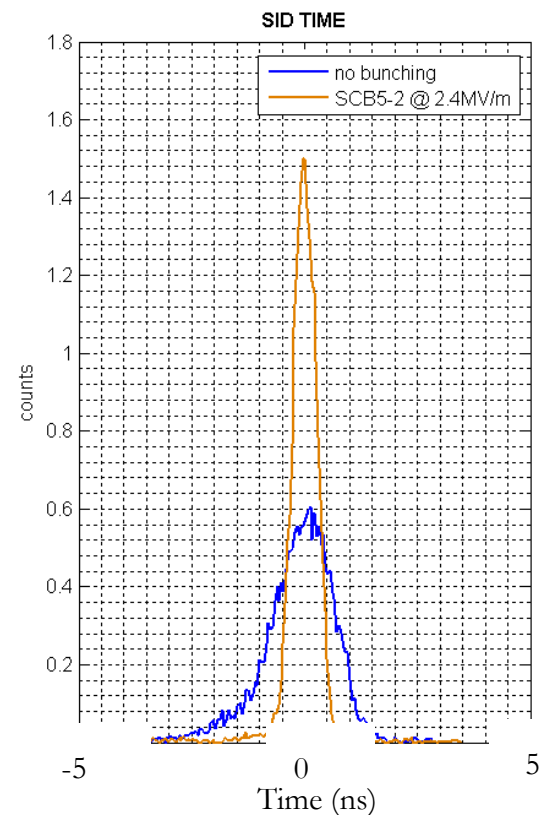
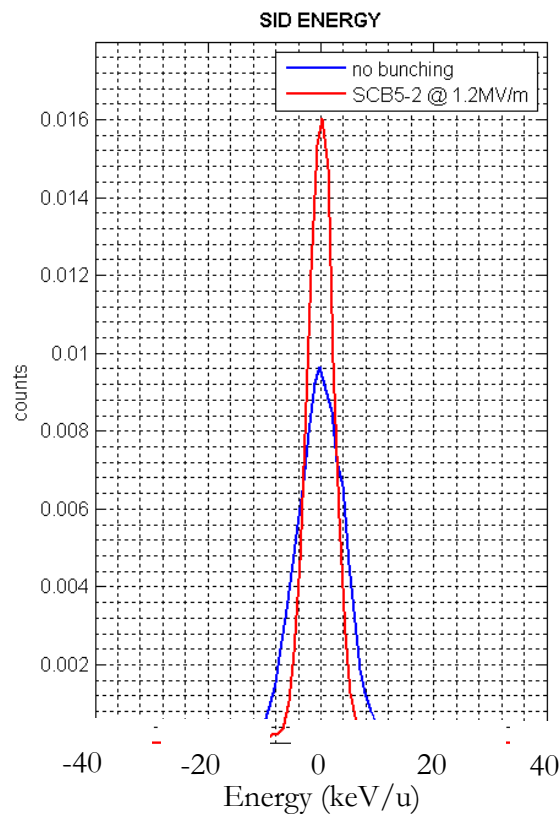
Cavity Bunching and Debunching



Use downstream cavities to improve time and energy spread of accelerated beam.

•Shows flexibility of SC machine

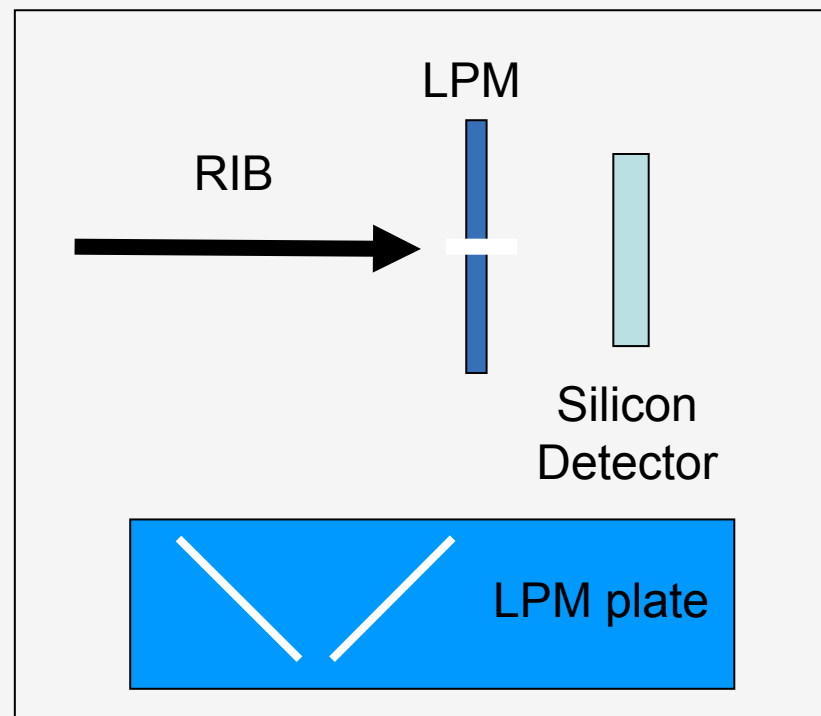
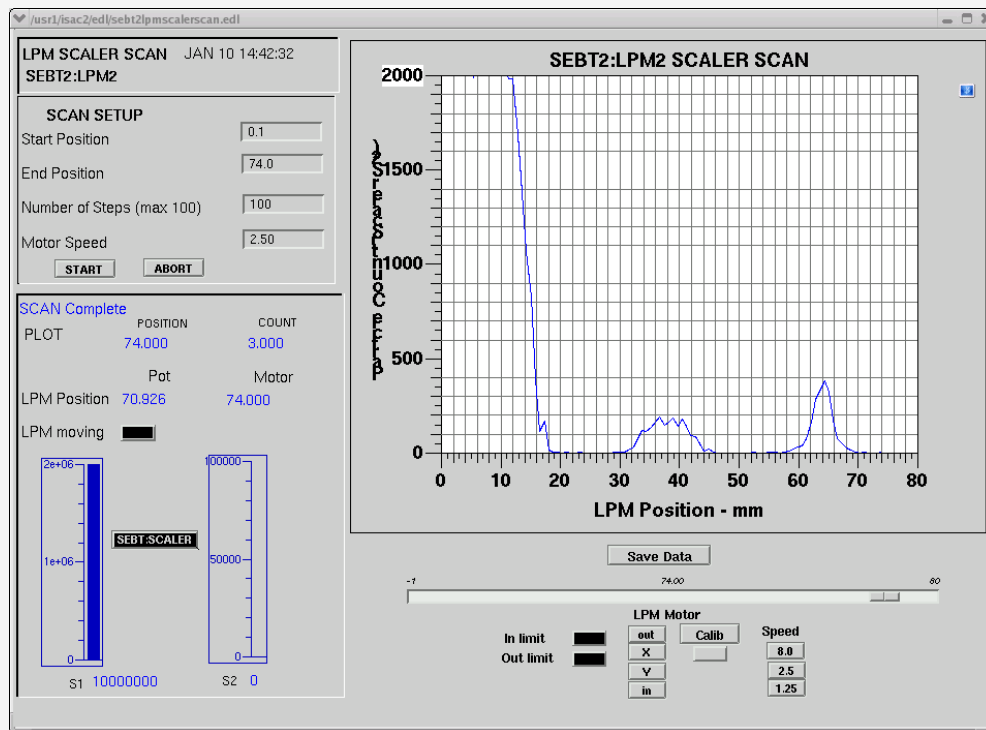
•E=3.7MeV/u 4He1+



Low Intensity Diagnostics

- Intensity measured with
 - Silicon detector ($<1e4$), channeltron ($<1e6$)
 - Now developing Diamond detectors

RIB Profile Monitor



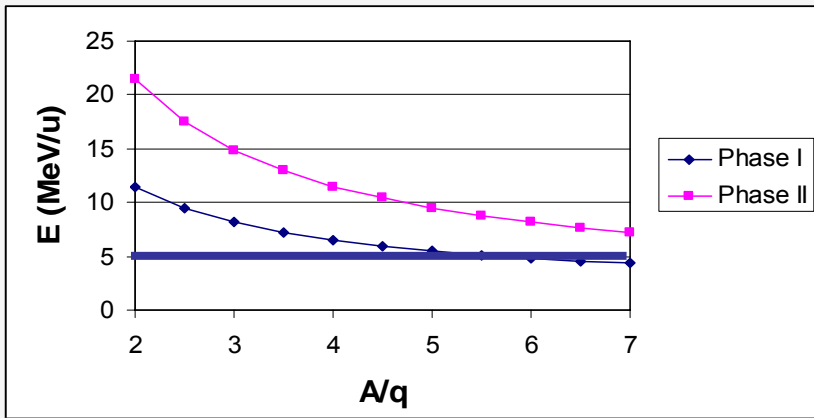
Energy Limit in ISAC-II

License

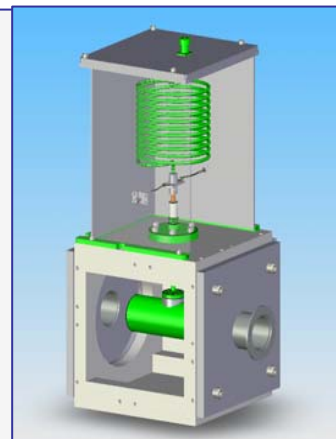
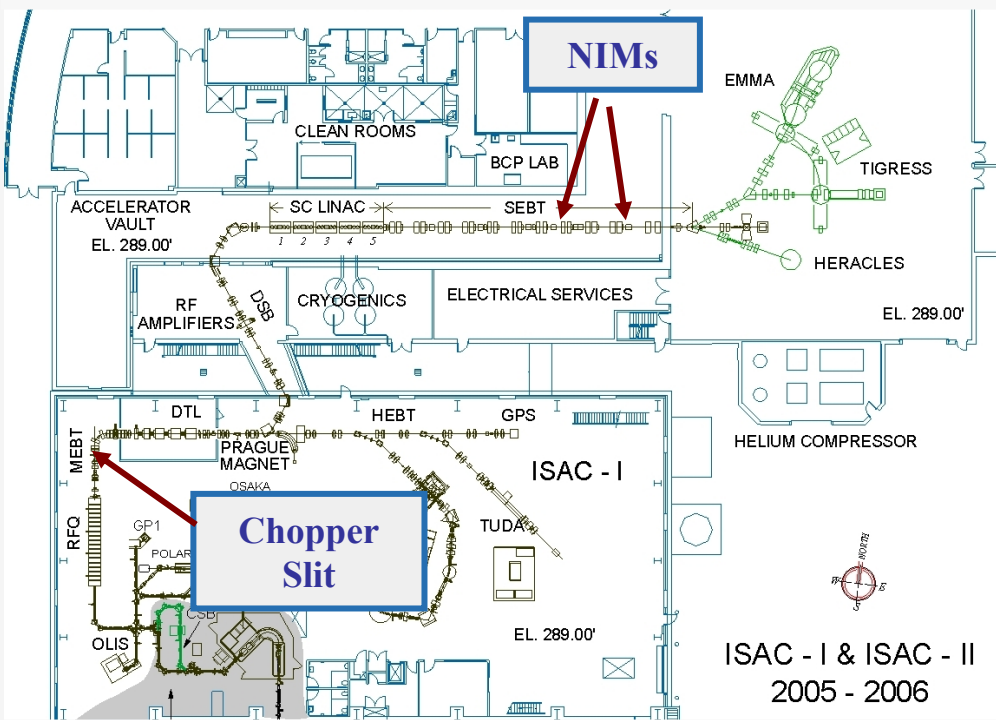
- Presently $E \leq 5 \text{ MeV/u}$ due to license limit
- require on-line intensity monitoring

On-line monitors

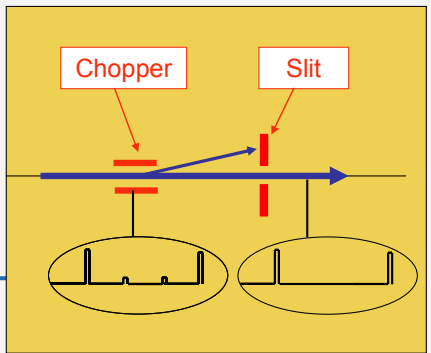
- Two types of monitors used
 - NIM – resonant pick-up in ISAC-II beamline
 - Chopper slit signal in MEBT
- Operational July 2009



Final Energy for Phase I and Phase II



Non-intercepting Monitor



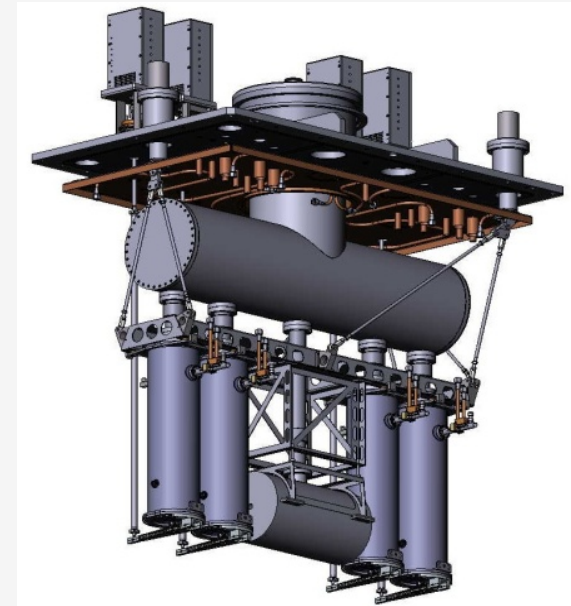
Chopper Slit

ISAC - I & ISAC - II
2005 - 2006

Operational Issues

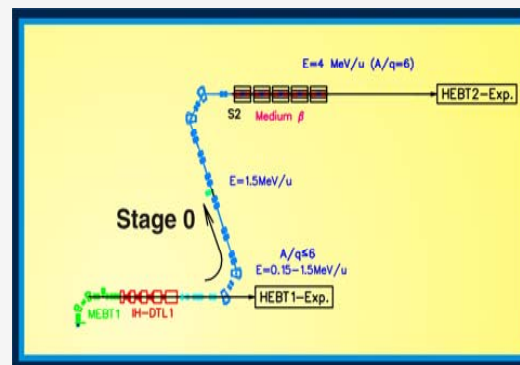
Living with the Solenoid

- 9 Tesla solenoid is in close proximity with the superconducting cavities
 - Solenoid equipped with bucking coils to reduce the field at the cavity to $<500\text{G}$ (50mT)
 - Cavity has outer jacket of reactor grade Nb that acts as a magnetic shield in case of a quench
 - Solenoid does magnetize the environment so that a degaussing cycle is required before warm-up
 - In the event of a cryogenic interruption
 - **Solenoid is turned off as a first precaution**
 - **If cavities warm above transition then the solenoid is degaussed, then heated above transition (heater installed) to quench frozen flux**
 - **Cavities and solenoid are then re-cooled**
 - **Takes about 1 hour**



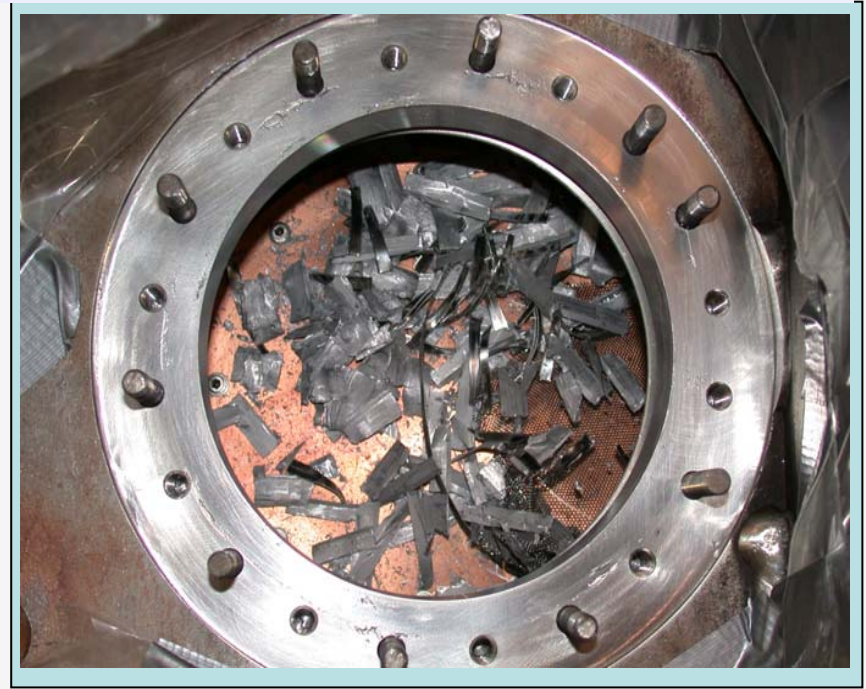
Avoiding cavity contamination

- Single vacuum space for cavities and thermal isolation
- Operational steps taken to avoid contamination
 - LN2 Cold trap positioned upstream and downstream to catch volatiles migrating down the beamline
 - Slow pumping and slow venting of vacuum space with filtered N2 to prevent dust migration
 - The new cryomodules are fitted with a dedicated venting line at each of the rf pick-ups
 - If a cryomodule feedthrough must be opened the volume is slightly overpressured with clean N2 to act as a dust barrier



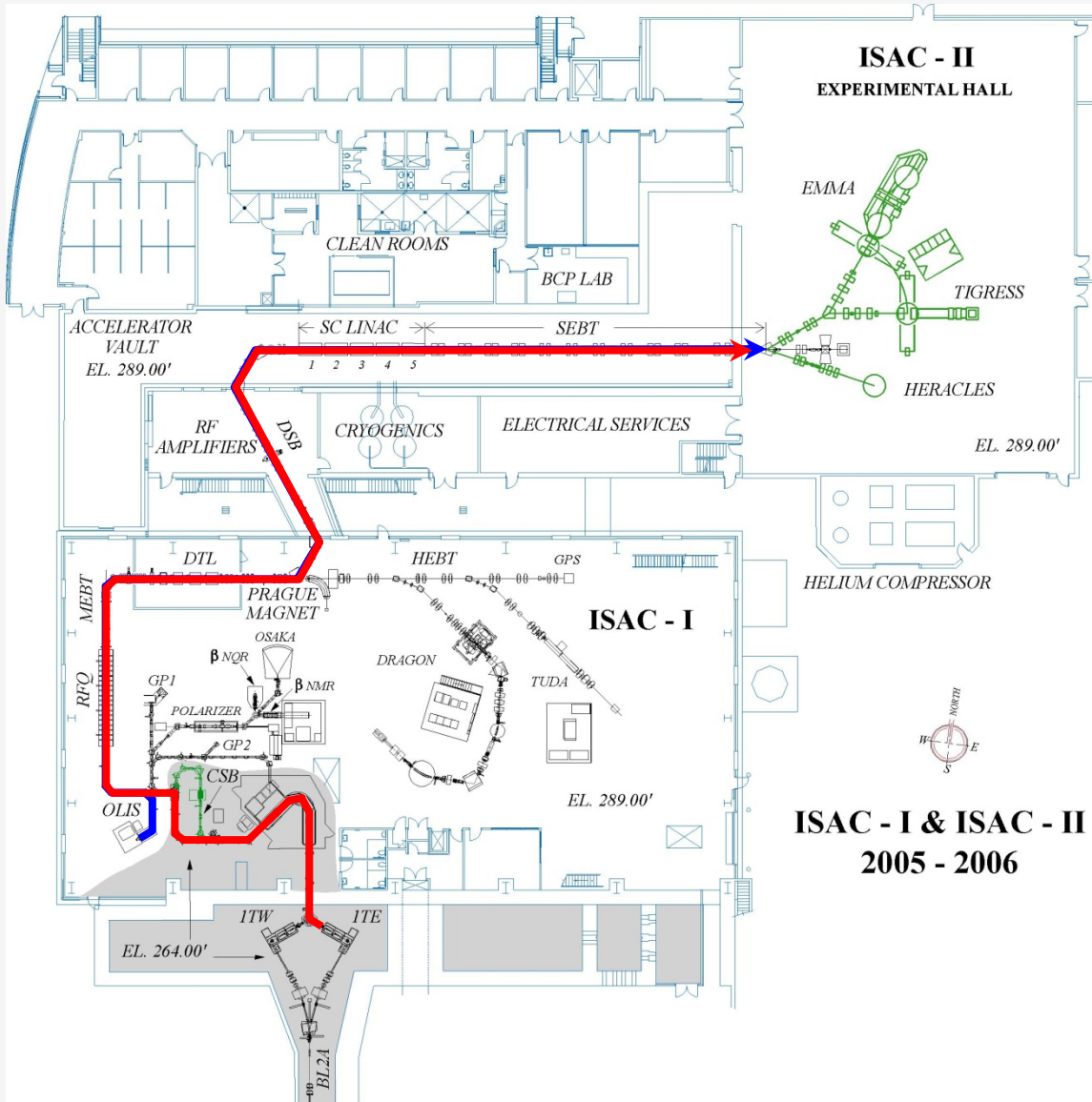
Despite procedures things happen

Varian 550 turbo-pump on CM4 suffered catastrophic failure!



- Removed the fragments that we could reach, vacuumed the LN2 shield, pumped down
- No degradation in cavity performance

Delivering Radioactive Beams



ISAC - I & ISAC - II
2005 - 2006

- RIBs are very low intensity beams 10^3 - 10^6 particle/s;
- Pilot beam of stable ions from Off Line Ion Source (OLIS); matching RIBs A/Q;
- Low intensity diagnostic.

Beam Delivery Group

- **Delivery of RIB is challenging. Delivering chain:**
 - Driver (extracts three simultaneous beams);
 - Target/Source (each ion species requires development);
 - Post accelerators (three linacs in series);
- **Beam Delivery Group formed by experts (physicists):**
 - Beam dynamics and accelerator tuning;
 - Sources and Targets;
 - High level application;
- **Role: liaison between experiment and operation,**
 - responsible for beam delivery, train operators, monitor beam quality, develop new diagnostics and tuning procedures;
- **Purpose: more availability, reliability and productivity.**

Measuring Success

E1104 – Beam delivery report

Run period: 20:30 of October 7th to 8:30 of October 22st 2008

Document closed: August 23th 2008

Associated spreadsheet: E1104 - 11Li to SEBT2 – October run.xls

Pilot beam: $^{22}\text{Ne}^{4+}$

RIB species: $^{11}\text{Li}^{2+}$

Allocated time: 360 hours (30 shifts)

Promised run time: 312 hours

Agreed rate: $2 \cdot 10^3$

Proton current requested: 68 μA

RIB Summary:

$$\text{Metric 1} = \frac{\text{beam hours delivered}}{\text{beam hours promised}} = 95.86 \% \quad \text{with 1 count/s threshold}$$

$$\text{Metric 1} = \frac{\text{beam hours delivered}}{\text{beam hours promised}} = 92.15 \% \quad \text{with } 2 \cdot 10^3 \text{ count/s threshold}$$

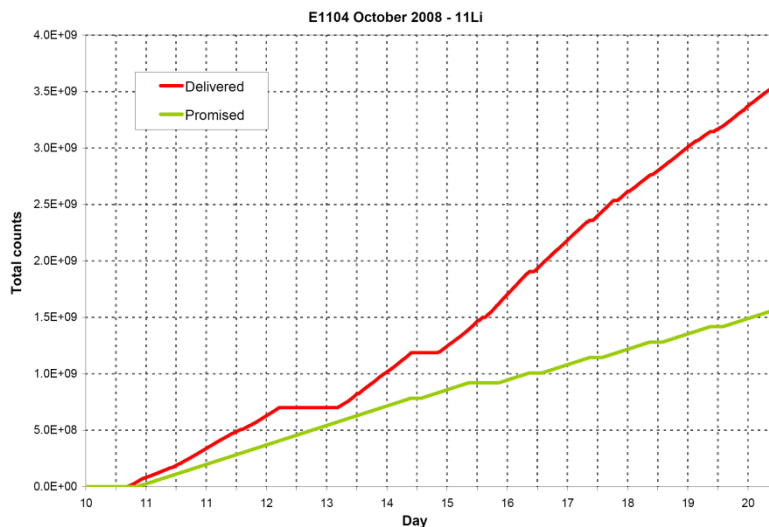
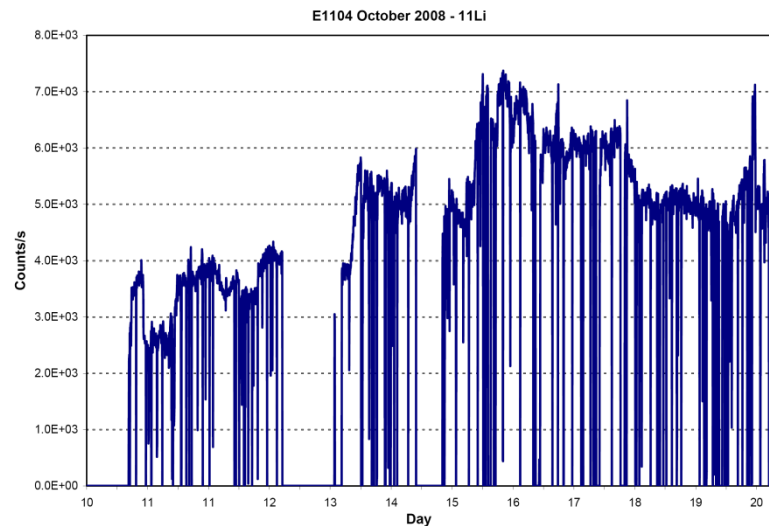
$$\text{Metric 2} = \frac{\text{actual integrated counts to user}}{\text{promised integrated counts}} = 225.77 \%$$

$$\text{Metric 3} = \frac{\text{possible integrated counts to user}}{\text{promised integrated counts}} = \text{NA}$$

PROTON Summary:

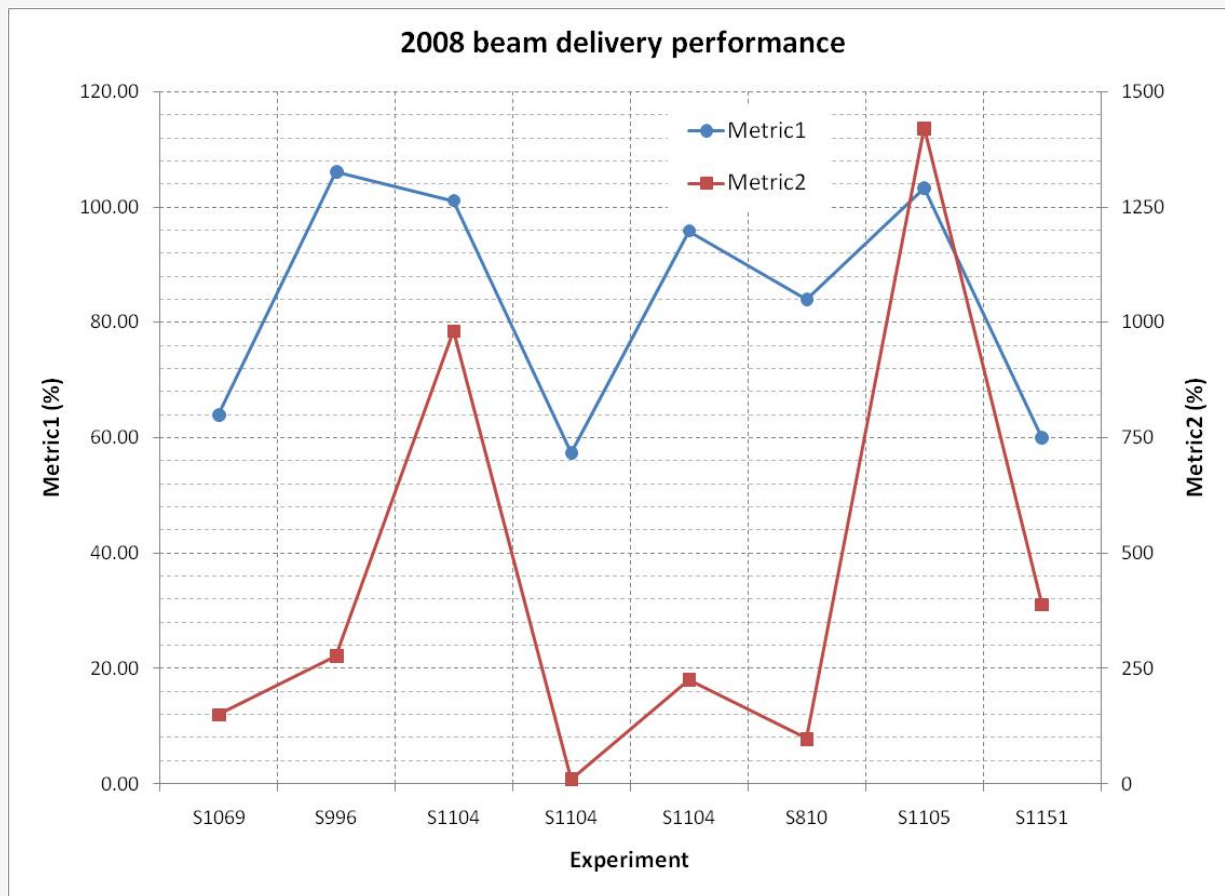
$$\text{Metric 1} = \frac{\text{beam hours delivered}}{\text{beam hours promised}} = 86 \% \quad \text{with threshold } 5 \mu\text{A below requested}$$

Note: Power bump on October 12th costs almost 24 hours.



2008 Post Accelerated RIB Performance

- Minimum goal: 75% reliability with 100% productivity
- Accelerator reliable: 97%



Future Goals

- **Increase energy and mass:**

- commission ECR charge breeder and ISAC-II Phase II superconducting linac – by end of 2009

- **Increase RIB hours**

- reducing procedural time (machine tuning by implementing high level software applications);
- delivering simultaneous RIB beams with second electron driver (ARIEL Project);

Conclusion

- The ISAC heavy ion linacs are running well with high reliability
- ISAC-II Phase II on time for completion this year
- New technologies have been developed to further improve SC-Linac
- procedural time is being reduced with more automated procedures and improved diagnostics

Thanks!

