Commissioning of the 20MV Superconducting Linac Upgrade at TRIUMF

Marco Marchetto | TRIUMF
Summary

- Introduction
  - ISAC facility

- ISAC-II project
  - ISAC-II Phase II upgrade
  - Beam commissioning results

- Operational experience
  - Beam delivery
  - Future program

- Conclusions
Introduction
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Conclusions
- ISOL facility for rare isotope beam (RIB) production
- Highest power driver beam (50 kW)
- Most intense radioactive beam of certain species
## ISAC in the world

<table>
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<tr>
<th>Lab</th>
<th>Facility</th>
<th>Type</th>
<th>Driver</th>
<th>Post-accelerator</th>
<th>Voltage (MV)</th>
<th>Energy (MeV/u)</th>
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<tr>
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<td>ISAC</td>
<td>ISOL</td>
<td>500MeV, 50kW p</td>
<td>RFQ, DTL, SCL</td>
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<td>6.5-18</td>
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<td>ISOLDE</td>
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<td>1.4GeV, 2.8 kW, p</td>
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<td>ISOL</td>
<td>3kW HI</td>
<td>cyclotron</td>
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<td>Holifield</td>
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<td>200kW d</td>
<td>cyclotron</td>
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<td>5-25</td>
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</tbody>
</table>
ISAC driver

- H⁻ cyclotron as proton driver;
- ISAC proton accelerated to 500 MeV up to 100 µA;
- ARIEL: one more proton line for RIB production. Cyclotron can operate at 300 µA.
Target stations and Mass separator

- Two underground target stations;
- Proton beam sent to one of the target station at the time
- Pre-separator inside the shielded area
- Mass separator on high voltage platform
- Charge breeder: ECR
Experimental facilities

- SC LINAC
- DTL
- RFQ
- Low Energy
- Medium Energy
- High Energy
Two normal conducting accelerators

RFQ
- 8m long CW machine
- 150 keV/u, $3 \leq A/q \leq 30$
- High quality transverse and longitudinal emittance: $0.2 \pi \mu m$ and $1.5 \pi$ kev/u·ns.

DTL
- Separated functions
- Five IH interdigital RF cavities
- Three split-ring bunchers
- Variable energy machine
- $150 \text{ keV/u} \leq E \leq 1.8 \text{ MeV/u}$, $2 \leq A/q \leq 7$
- ISAC II injector 1.5 MeV/u
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ISAC-II – The idea

- The idea (~1999) was to expand ISAC capabilities
- Need higher energies to support Nuclear Physics studies at and above the Coulomb barrier:
  - Goal energy $E \geq 6.5\text{MeV/u}$ for $A/q=6$ with full energy variability
  - The decision was to develop a superconducting heavy ion linac of 40MV
- Need broader mass range to $A \sim 150$
  - Add ECR Charge State Booster (CSB) to increase the charge state for $A > 30$ to meet the RFQ $A/q$ acceptance
Phase I SCB 2006
- 5 cryomodules: 4 cav/CM
- $V_{eff}=20$ MV

The upgrade: Phase II SCC 2010
- 3 cryomodules: 6+6+8 cav/CM
- $V_{eff}=20$ MV
ISAC-II QWR Cavities

Phase I
- 106.1 MHz $\beta = 5.7\%$
- SCB(1-8)

Phase II
- 106.1 MHz $\beta = 7.1\%$
- SCB(9-20)
- 141.4 MHz $\beta = 11\%$
- SCC

ISAC-II design values:
- $V_{eff} = 1.1$ MV
- $P_{cav} = 7$ W
- $E_p = 30$ MV/m
- $H_p = 60$ mT
Phase II Upgrade

- 7.5M$ project
  - 2.7M$ - cryogenics – refrigerator and distribution
  - 1.4M$ - cavities
  - 2.4M$ - cryomodules
  - 1M$ infrastructure – RF amplifiers, power supplies, installation

- Development of PAVAC Industries as a Canadian supplier of bulk niobium SRF resonators

- Initiated development in 2007, ordered production cavities March 2008

- Tight schedule – mandated end date of March 31, 2010

- Coincided with the end of the TRIUMF Five year plan and also the end of project budget

- The project was completed on time and on budget
Developments/Challenges

- Production/development
- Frequency tuning after manufacture
  - New procedure for fine-tuning frequency using etching developed
- Hardware
  - Mechanical tuner with brushless servo-motor and anti-backlash ball screw
  - Variable coupler with improved mechanical stability
  - Clean venting system through RF pick-up ports
- A few challenges
  - Four cavities developed vacuum leaks after etching at TRIUMF
  - RF amplifier company went bankrupt after delivery of 11 units
  - Competition with planning for next five year plan – initiated 1.3GHz program
Clean room cold test

- Each cryomodule undergoes a cold test prior to delivery to the vault
- Establish warm off-sets for cold alignment using WPM and optical targets
- Check cavities and RF systems
- Measured cryogenic static load – 14-18W
- Establish vacuum integrity
- Check solenoid operation
Cavity characterization

Preparation: cavities are degreased, chemically etched, rinsed with high pressure water, dried and then assembled on test frame

- Single cavity tests yield an average performance of 32MV/m at 7W (14% below Phase I)
- (Fact) Due to vacuum leaks after 100 µm the etching specification was reduced to 60 µm
- (Speculation) Marginal etch reduced performance; study in progress.
Beam commissioning

- All the hardware (optics, vacuum, diagnostic) is commissioned prior to send beam through the linac
- Coast the 1.5 MeV/u beam from ISAC-I: optics beam commissioning
- Solenoids perform as expected:
  - no significant steering (good alignment)
  - superconducting solenoid are set to theoretical values while matching the beam into the SC linac with quadrupoles
Performance from Acceleration

- $^{16}\text{O}^{5+}$ accelerated to 10.8 MeV/u equivalent to 6.5 MeV/u for $A/q=6$ (meets ISAC-II original specification on first acceleration)

- SCB’s set to average $E_p=30.3 \text{MV/m}$, SCC’s set to average $E_p=27 \text{MV/m}$

- One cavity unavailable in SCB and Four cavities unavailable in SCC due to RF cable problems
Beam quality - transverse emittance
Beam from the ECR ion source (Pantechnik SUPERNANOGAN) with no stripping in the MEBT section

- Measured emittance is in line with the expected value of $0.2 \pi$ mm mrad
- In line with SCB measured emittance
- No emittance growth
- Expected beam quality confirmed at the high energy experimental stations
Beam quality – longitudinal emittance

Longitudinal phase space evolution in a drift

$\Delta E$ (a.u.)

$\Delta T$ (a.u.)

$^{12}$C$^{2+}$ longitudinal emittance

SCC cavity
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ISAC-II Phase II installation schedule

- Vault installation began **September 2009**
  - Beam line removed
  - Cryogenic distribution installed (Linde TC50 600W commissioned)
- Final cryomodule installed **March 24**
- First beam ($^{16}\text{O}^5^+$) was accelerated **April 24**
- First stable beam to an experiment **April 25**
- First RIB’s accelerated **May 3**
Operational Experience

- Multipacting (low level)
  - Some cavities require extensive multipacting conditioning; low voltage pulse conditioning over a few weeks reduces impact

- RF cables
  - Four cables have developed in vacuum shorts; suspect high forward power during conditioning; we are fixing them (present shutdown)

- RF amplifiers
  - Solid state amplifiers of Phase II more stable than tube amplifiers of Phase I; Phase I amplifiers need retuning as tubes age

- Cavity performance (Q) in SCC3 significantly less than single cavity test
  - suspect Q-disease or trapped flux – under investigation

- Cryogenics
  - Impurities in Phase I cold box and motor failure in Phase I compressor cause downtime
Species delivered

- Accelerator immediately in heavy use. The following beams have been accelerated with the SC linac since April 2010 (most of them delivered to experiment).

- Stable beams
  - 16O5+, 4He2+, 16O8+, 15N4+, 20Ne5+,

- Radioactive beams with stable pilot
  - 26Na, 26Al6+, 26Mg6+
  - 78Br14+ from Charge State Booster
  - 6He1+, 12C2+
  - 24Na5+, 24Mg5+
  - 11Li2+, 22Ne4+
Energy Booster Stripping Foil

- Stripping foil added in transport line between ISAC-I and ISAC-II
  - Boosts charge state to reach higher energies in ISAC-II at the expense of acceleration efficiency
  - Accelerated $^{16}\text{O}^{8+}$ to 15MeV/u
  - High efficiency for light ions
Charge State Booster

- 14GHz Phoenix ECR source from Pantechnik
- Breeding efficiency 2-5%
- Commissioned with stable beam $^{85}\text{Rb}^{14+}$ and radioactive $^{78}\text{Br}^{14+}$
- All RIBs come with contaminants from the background gas
- Need to purify the beam in flight. Development is in progress.
Beam purification

- Most experiments need at least 90% pure beam
- Different species with similar A/q (within 0.5%) are accelerated at the same time
- Contaminants have much higher (few order of magnitude) intensity of the desired RIB
- In-flight purification techniques being developed:
  - Mass resolution in transport lines
  - Time of flight separation after energy degradation
  - New particle identification diagnostics

Demonstration of beam line resolution technique
Comparison of experimental Fr yields with in-target production predictions of 3 models

The absence of $^{215-217}$Fr experimental yields is due to the msec half-lives of these nuclides which do not survive release from the target matrix.

$^{214\text{m}}$Fr ($t_{1/2} = 3.4$ ms) & $^{218\text{m}}$Fr ($t_{1/2} = 22$ ms) were observed at $\sim 5 \times 10^5$/s

Courtesy of M. Dombsky
o SC linac is the post accelerator for the future ARIEL facility
o New complementary driver (e-linac): electron driver for Photo-Fission
o New target stations and mass separators
o New front end and post accelerators
o Goal: three simultaneous radioactive beams
o RIB multi-users facility
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- ISAC-II Phase II project
  - A 7.5 M$ project with R+D stretching over five years
  - Completed on time and on budget
- ISAC-II now at full energy
  - ISAC-II now can boost heavy ions to and above the Coulomb Barrier (unique ISOL facility)
  - ISAC-II linac meets specification
  - High beam quality available for experiments.
- ISAC is a main reference for RIB facilities world wide
Thank you

Merci