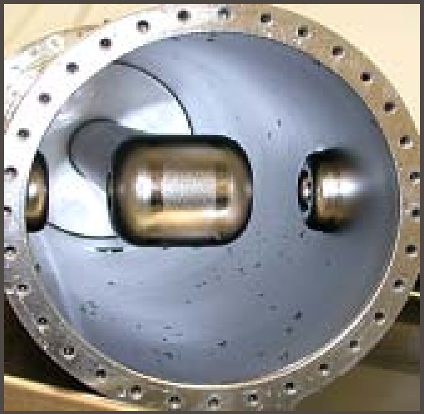
TRIUMF

Canada's national laboratory for particle and nuclear physics
Laboratoire national canadien pour la recherche en physique nucléaire
et en physique des particules



Commissioning of the 20MV Superconducting Linac Upgrade at TRIUMF

Marco Marchetto | TRIUMF

Accelerating Science for Canada
Un accélérateur de la démarche scientifique canadienne

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Summary

- o Introduction
  - ISAC facility
- o ISAC-II project
  - ISAC-II Phase II upgrade
  - Beam commissioning results
- o Operational experience
  - Beam delivery
  - Future program
- o Conclusions

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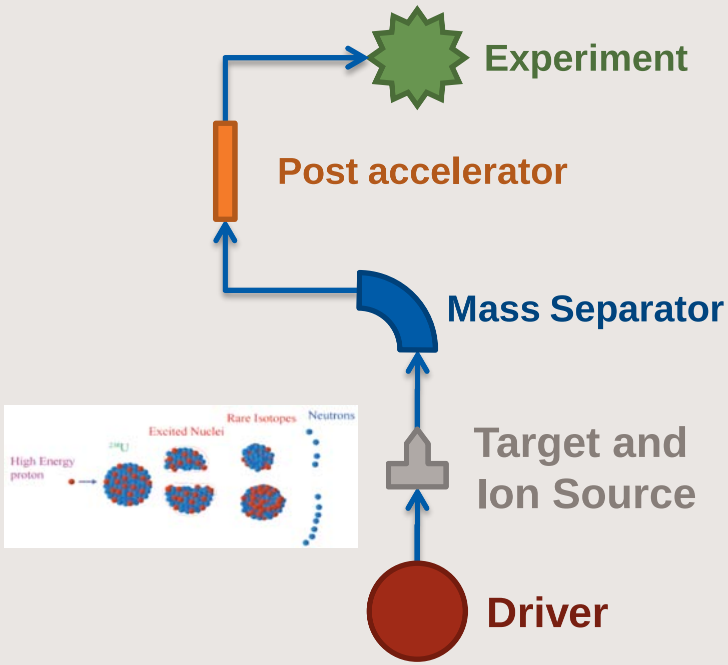
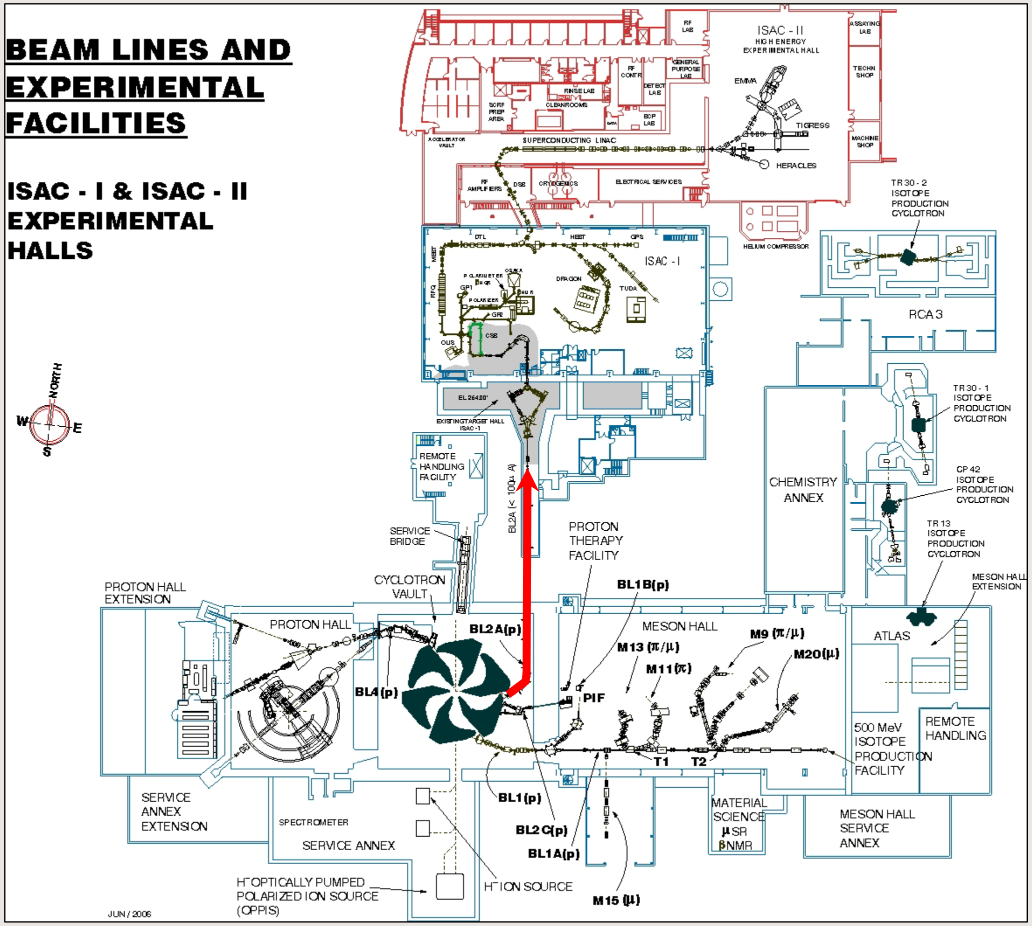
ISAC at TRIUMF

- ISOL facility for rare isotope beam (RIB) production



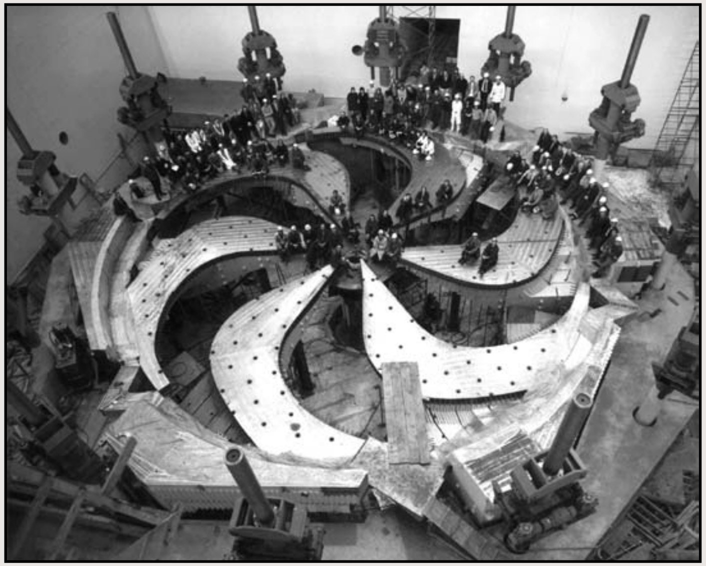


- Highest power driver beam (50 kW)
- Most intense radioactive beam of certain species

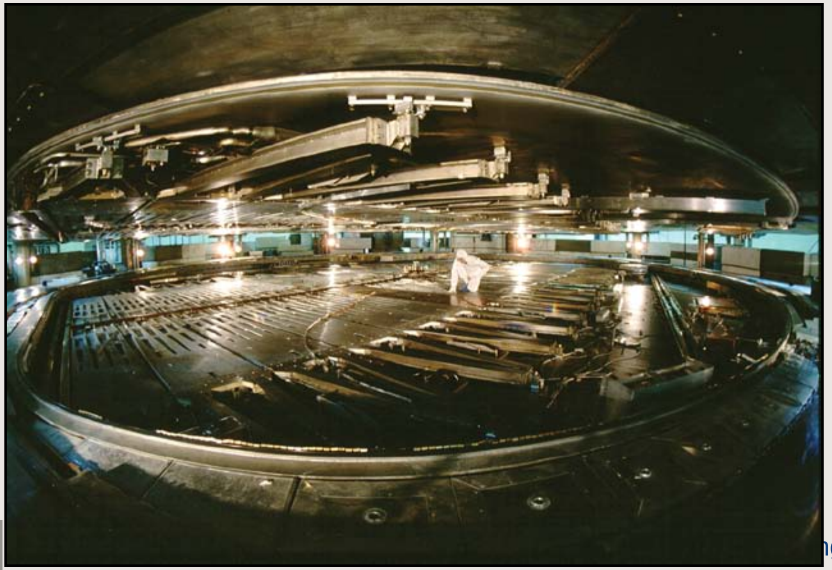
ISAC in the world

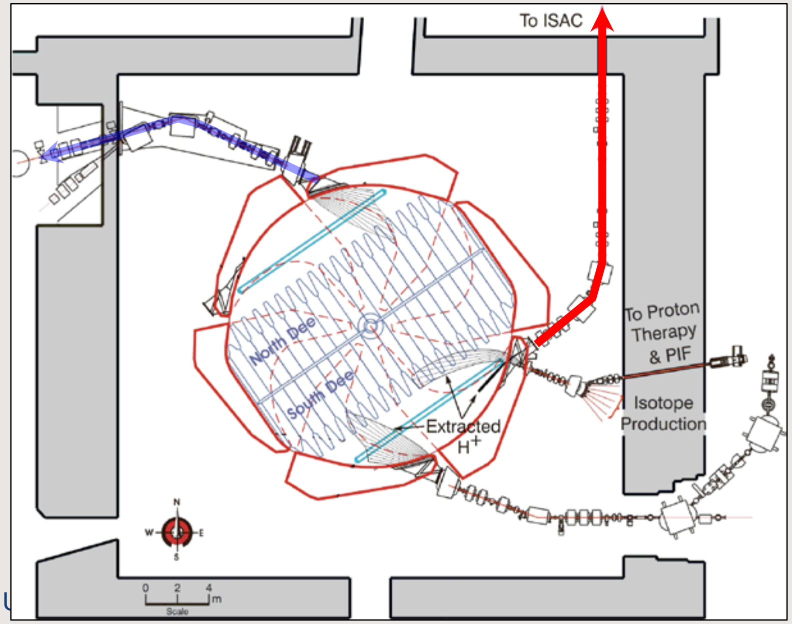
Lab	Facility	Type	Driver	Post-accelerator	Voltage (MV)	Energy (MeV/u)
Existing						
TRIUMF	ISAC	ISOL	500MeV, 50kW p	RFQ, DTL, SCL	52.5	6.5-18
CERN	ISOLDE	ISOL	1.4GeV, 2.8 kW, p	RFQ, DTL	13	3
GANIL	Spiral-I	ISOL	3kW HI	cyclotron		~5-25
ORNL	Holifield	ISOL	50MeV, 500W p,d	tandem	25	
ANL	CARIBU	Gas-catcher	Radio-active source	ATLAS sc linac	52	~7-17
Future						
CERN	HIE-Isolde	ISOL	1.4, 2.8kW, p	SCL	40	6.5-18
MSU/ NSCL	FRIB	Gas-catcher	400kW HI	RFQ, SCL		12-20
GANIL	SPIRAL-II	ISOL	200kW d	cyclotron		5-25

ISAC driver



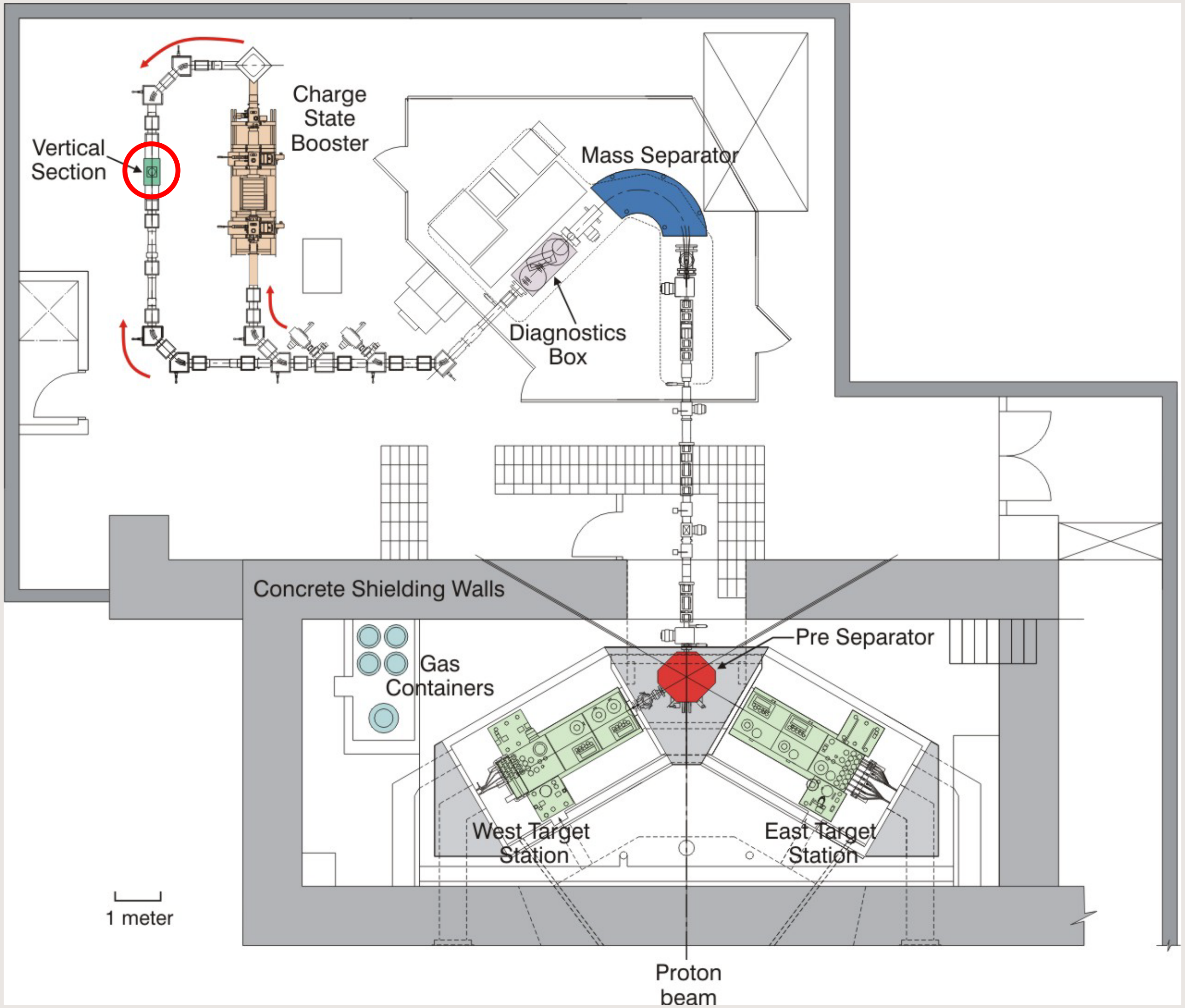
- o H^- cyclotron as proton driver;
- o ISAC proton accelerated to 500 MeV up to 100 μA;
- o ARIEL : one more proton line for RIB production. Cyclotron can operate at 300 μA.



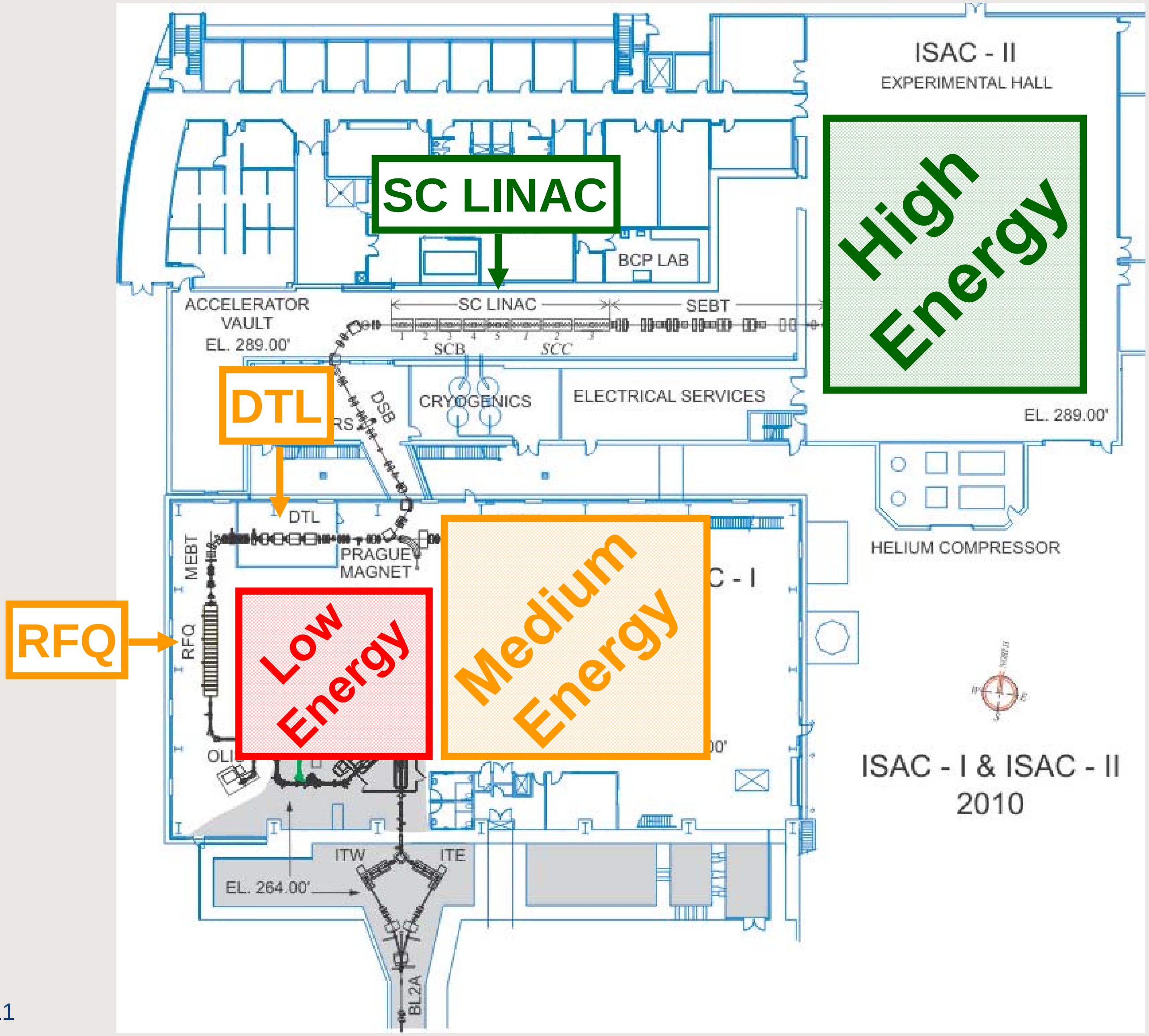


Target stations and Mass separator

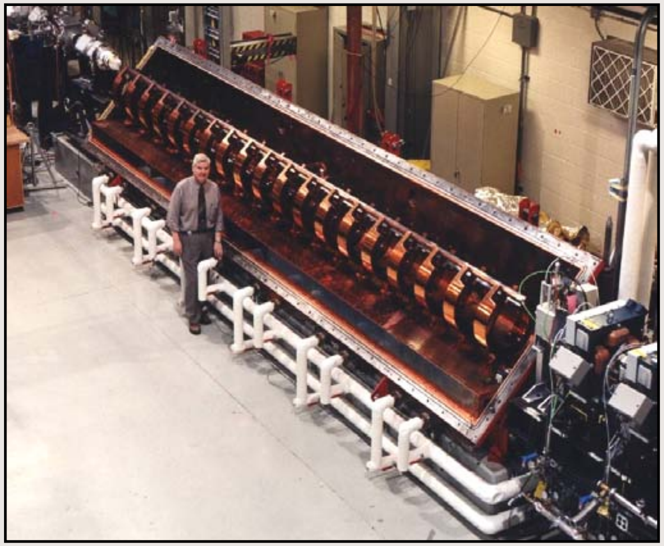
- o Two underground target stations;
- o Proton beam sent to one of the target station at the time
- o Pre-separator inside the shielded area
- o Mass separator on high voltage platform
- o Charge breeder: ECR

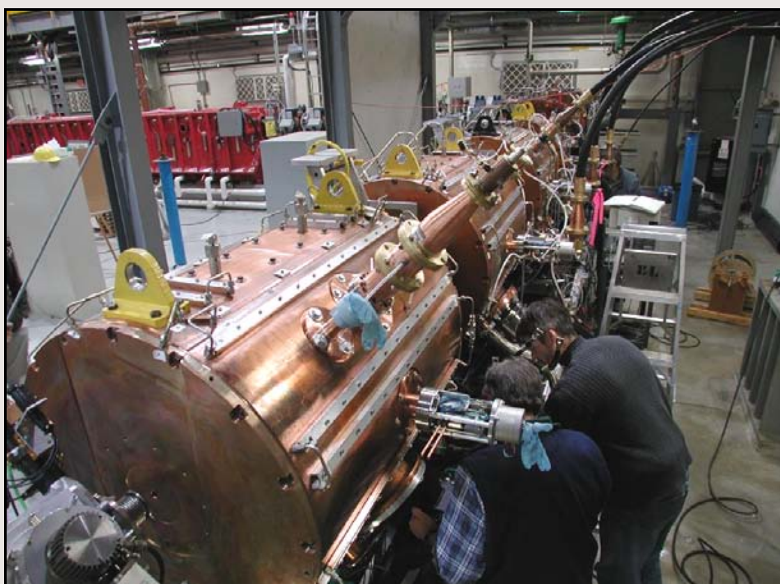


Experimental facilities



ISAC I Linac





- o Two normal conducting accelerators
- o RFQ
  - 8m long CW machine
  - 150 keV/u, $3 \leq A/q \leq 30$
  - high quality transverse and longitudinal emittance: 0.2 π μm and 1.5 π kev/u·ns.
- o DTL
  - Separated functions
  - Five IH interdigital RF cavities
  - Three split-ring bunchers
  - Variable energy machine
  - 150 keV/u ≤ E ≤ 1.8 MeV/u, $2 \leq A/q \leq 7$
  - ISAC II injector 1.5 MeV/u

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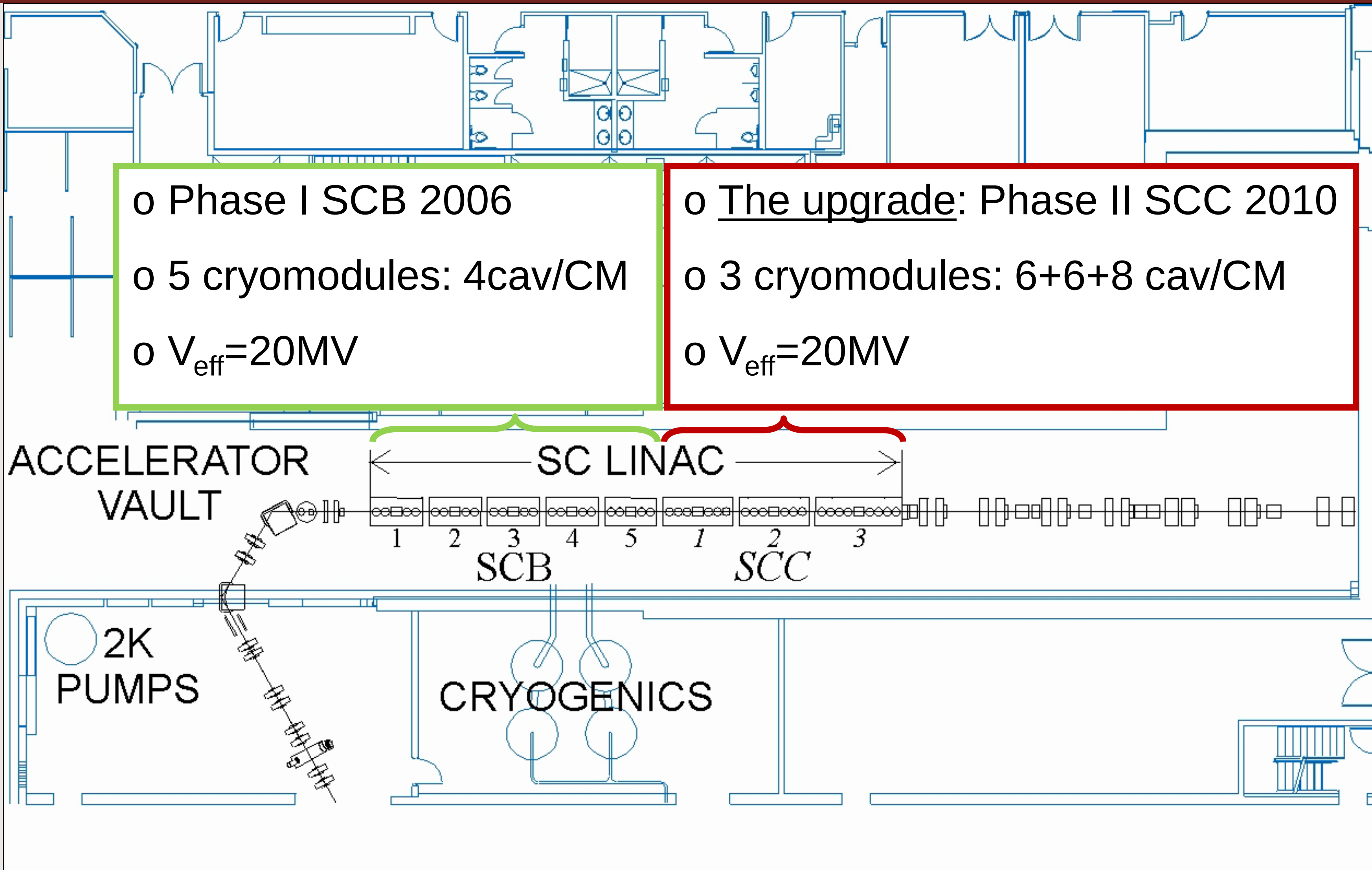
ISAC-II – The idea

- 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≥6.5MeV/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~150
  - Add ECR Charge State Booster (CSB) to increase the charge state for A>30 to meet the RFQ A/q acceptance

ISAC-II SC-Linac

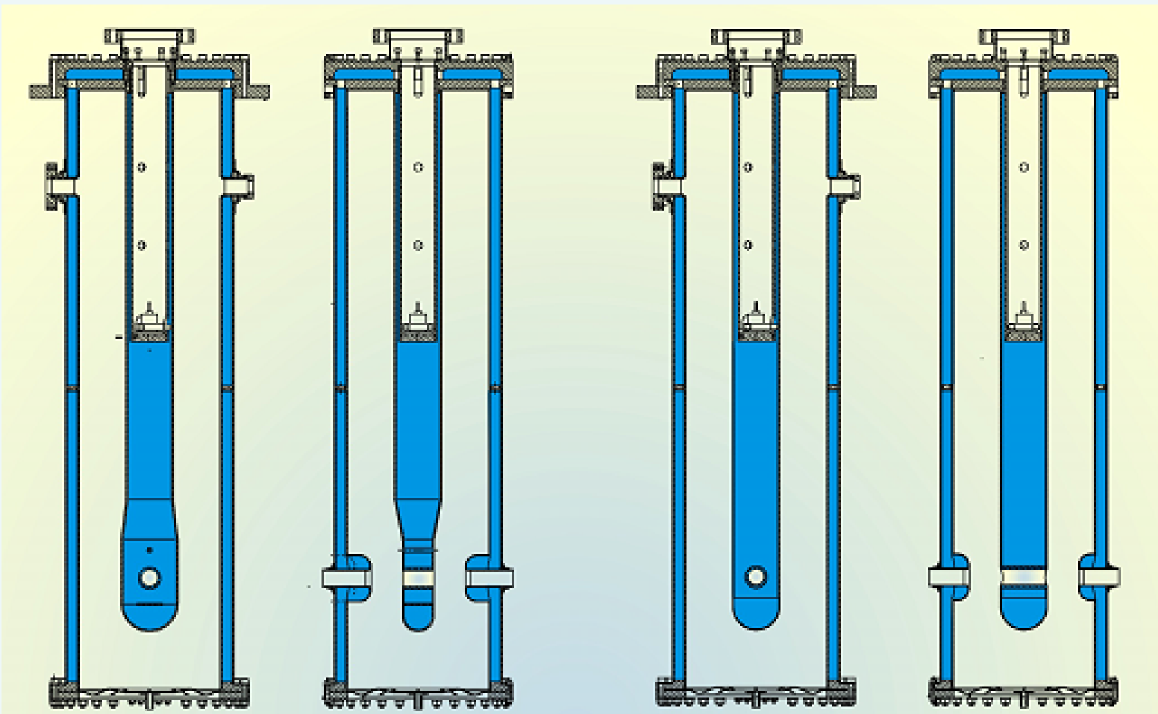
- o Phase I SCB 2006
- o 5 cryomodules: 4cav/CM
- o V_{eff}=20MV

- o <u>The upgrade</u>: Phase II SCC 2010
- o 3 cryomodules: 6+6+8 cav/CM
- o V_{eff}=20MV



ISAC-II QWR Cavities

Phase I

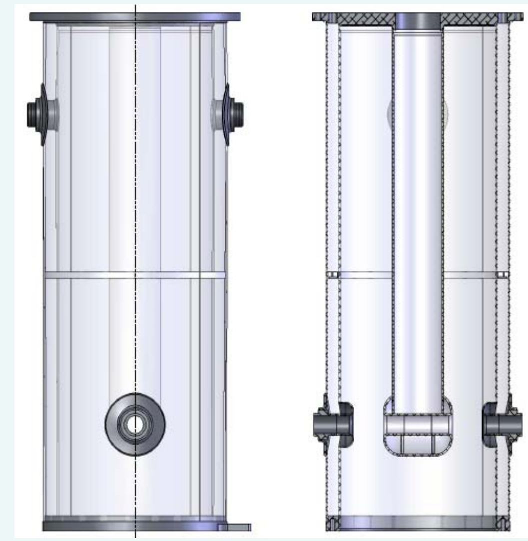


106.1 MHz β=5.7%
SCB(1-8)

106.1 MHz β=7.1%
SCB(9-20)

Phase II

(the upgrade)



141.4 MHz β=11%
SCC

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

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

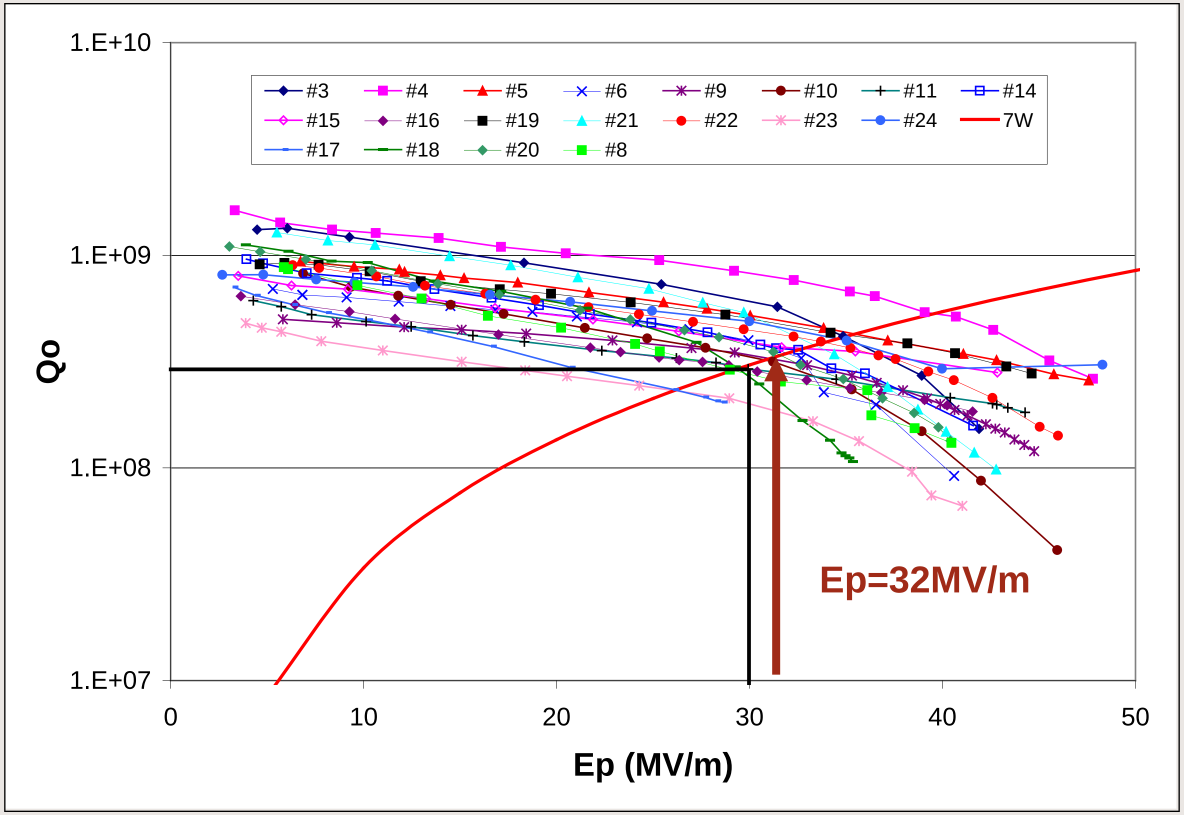
- Production/development
- Frequency tuning after manufacture
  - New procedure for fine-tuning frequency using etching developed
- Hardware
  - Mechanical tuner with brushless servo-motor and anti-backlash ball screw
  - Variable coupler with improved mechanical stability
  - Clean venting system through 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

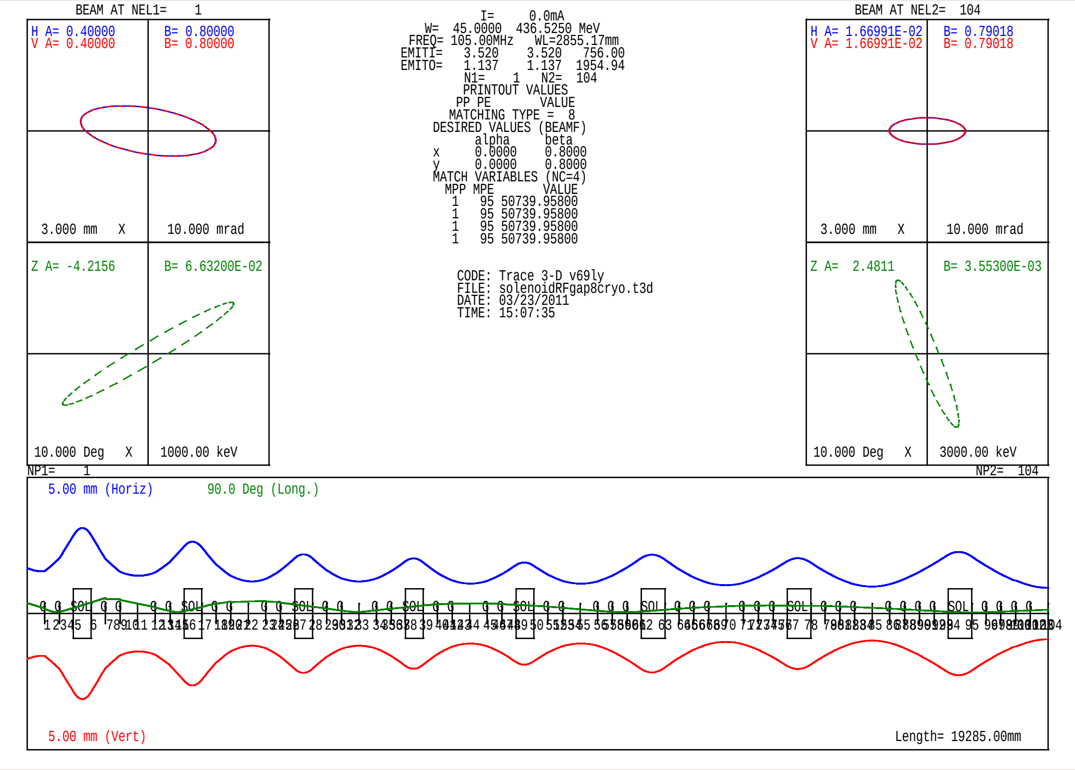
Preparation: cavities are degreased, chemically etched, rinsed with high pressure water, dried and then assembled on test frame



- 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.

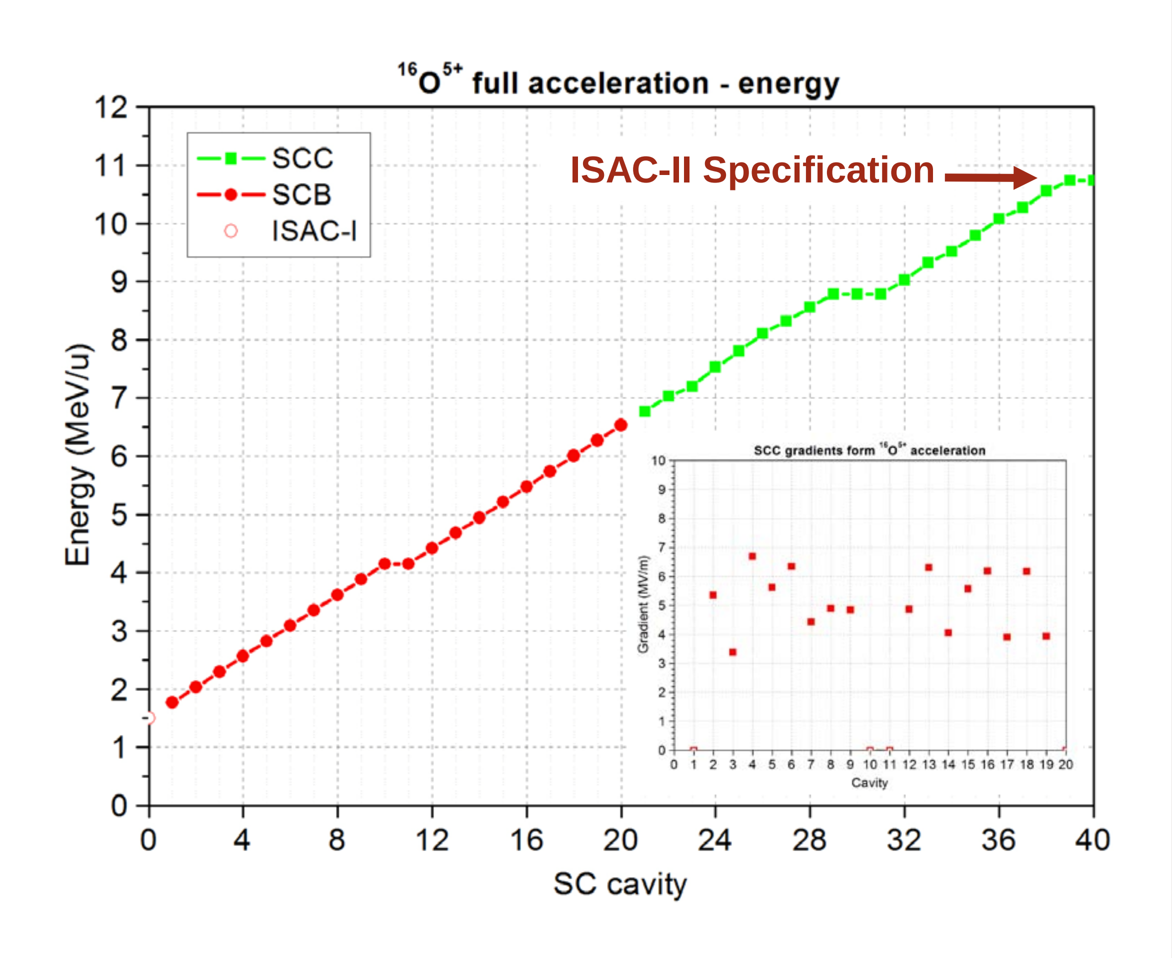
Beam commissioning

- 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

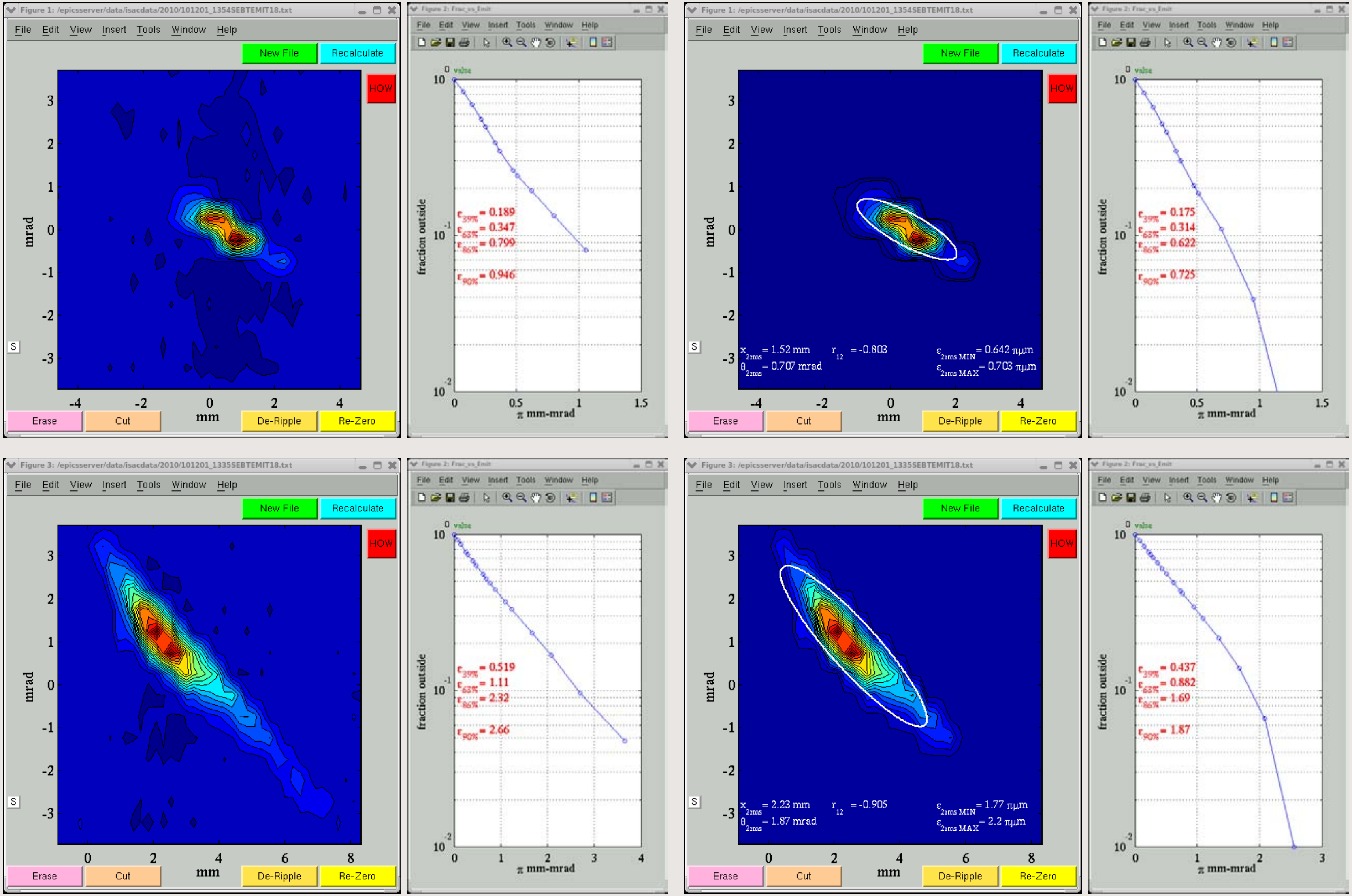


Performance from Acceleration

- $^{16}O^{5+}$ accelerated to 10.8MeV/u equivalent to 6.5MeV/u for A/q=6 (meets ISAC-II original specification on first acceleration)
- SCB's set to average E_p=30.3MV/m, SCC's set to average E_p=27MV/m
- One cavity unavailable in SCB and Four cavities unavailable in SCC due to RF cable problems

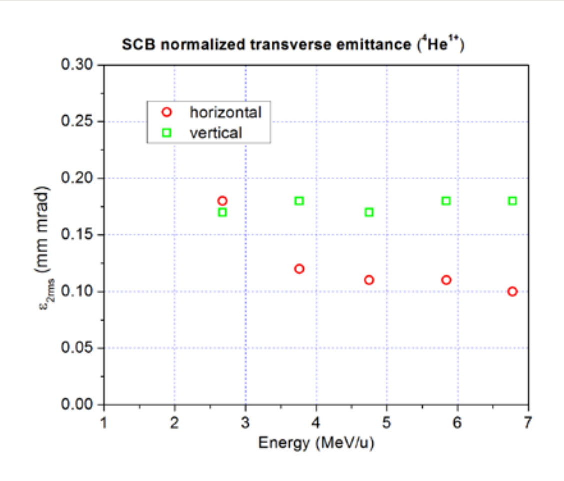


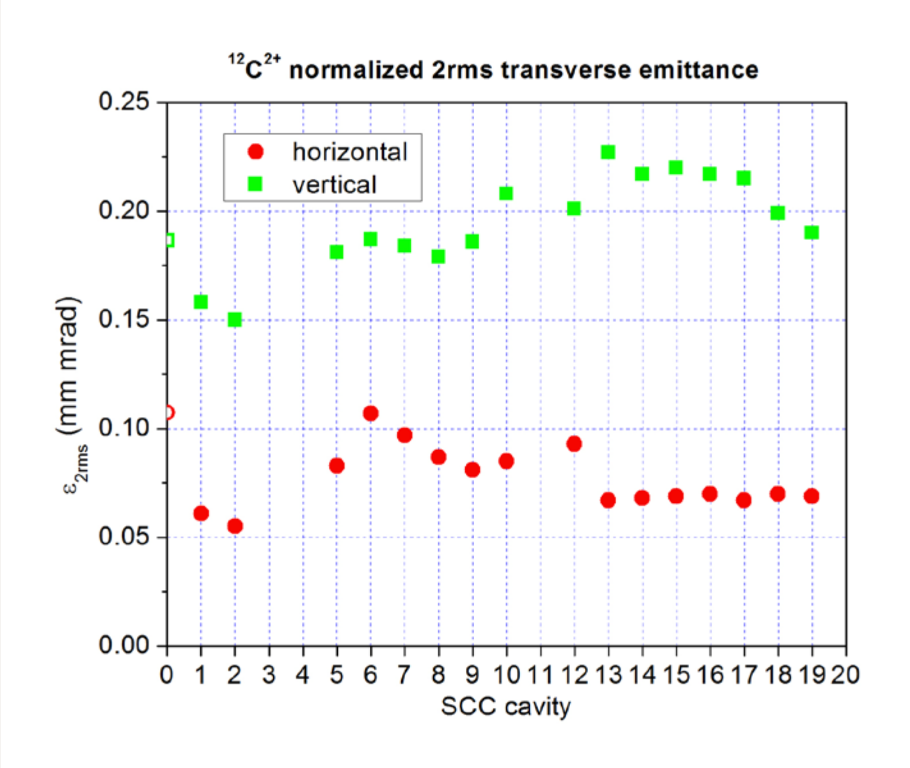
Beam quality - transverse emittance



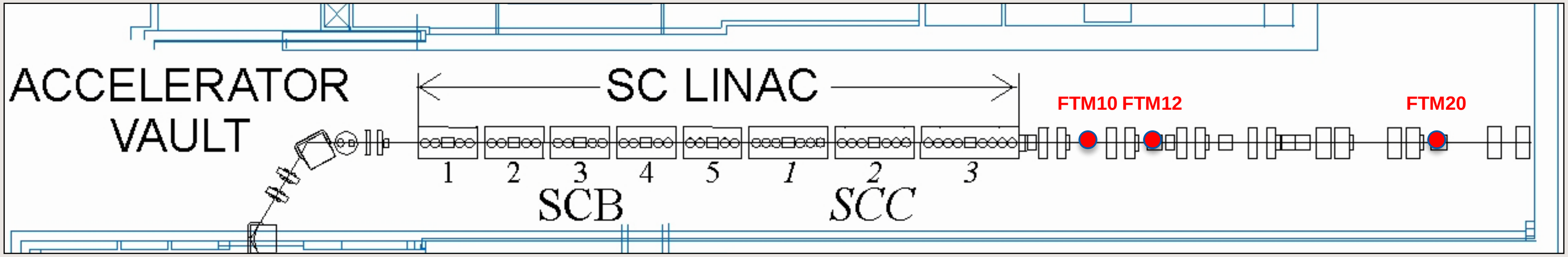
Beam quality – transverse emittance

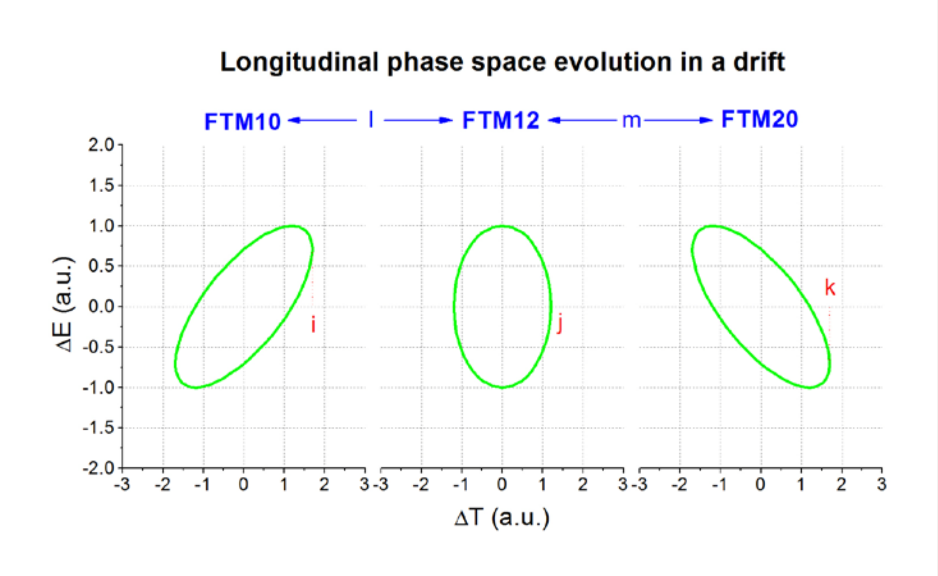
- Beam from the ECR ion source (Pantechnik SUPERNANOGAN) with no stripping in the MEBT section
- Measured emittance is in line with the expected value of 0.2 π mm mrad
- In line with SCB measured emittance
- No emittance growth
- Expected beam quality confirmed at the high energy experimental stations

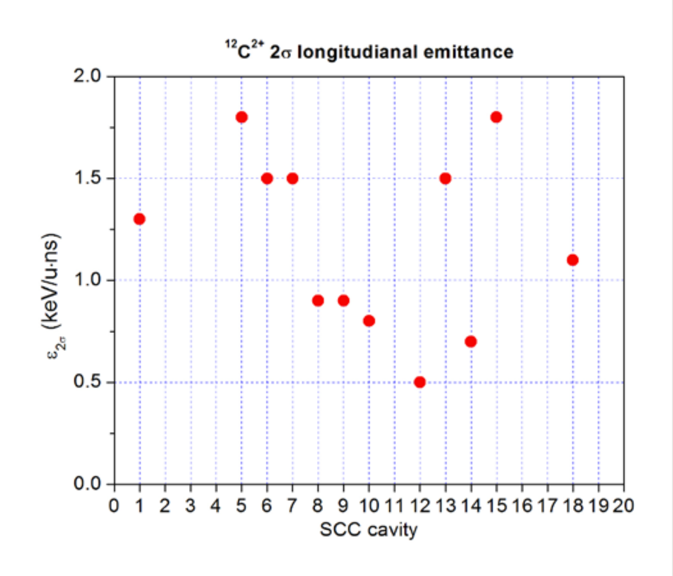




Beam quality – longitudinal emittance







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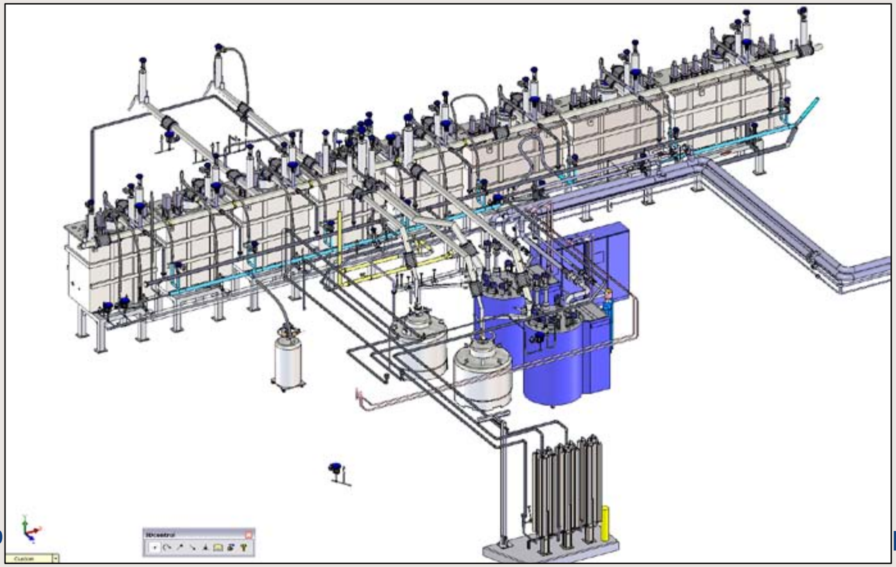
ISAC-II Phase II installation schedule

- o Vault installation began <u>September 2009</u>
  - Beam line removed
  - Cryogenic distribution installed (Linde TC50 600W commissioned)
- o Final cryomodule installed <u>March 24</u>
- o First beam ($^{16}O^{5+}$) was accelerated <u>April 24</u>
- o First stable beam to an experiment <u>April 25</u>
- o First RIB's accelerated <u>May 3</u>



Operational Experience

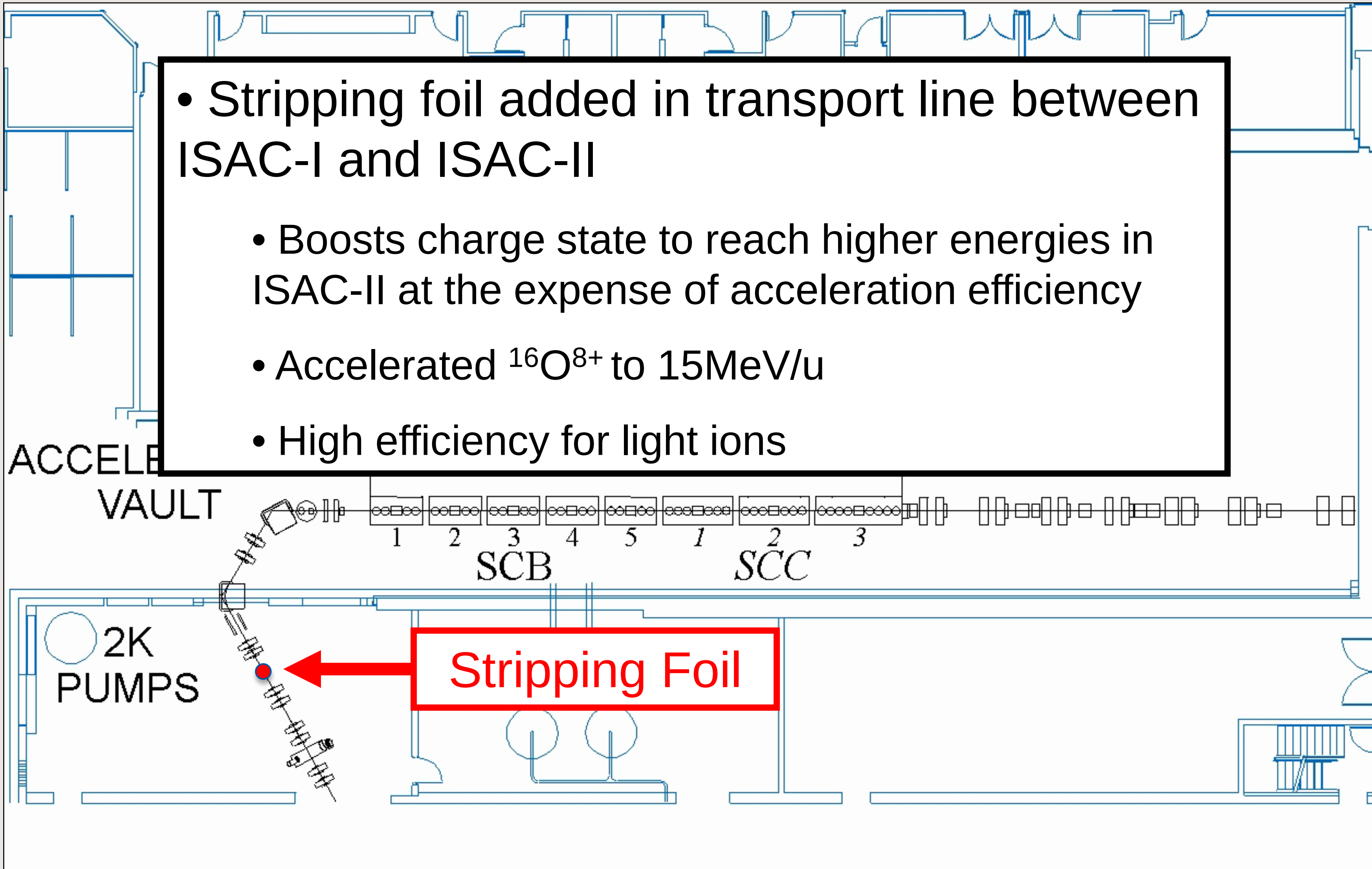
- Multipacting (low level)
  - Some cavities require extensive multipacting conditioning; low voltage pulse conditioning over a few weeks reduces impact
- RF cables
  - Four cables have developed in vacuum shorts; suspect high forward power during conditioning; we are fixing them (present shutdown)
- 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+

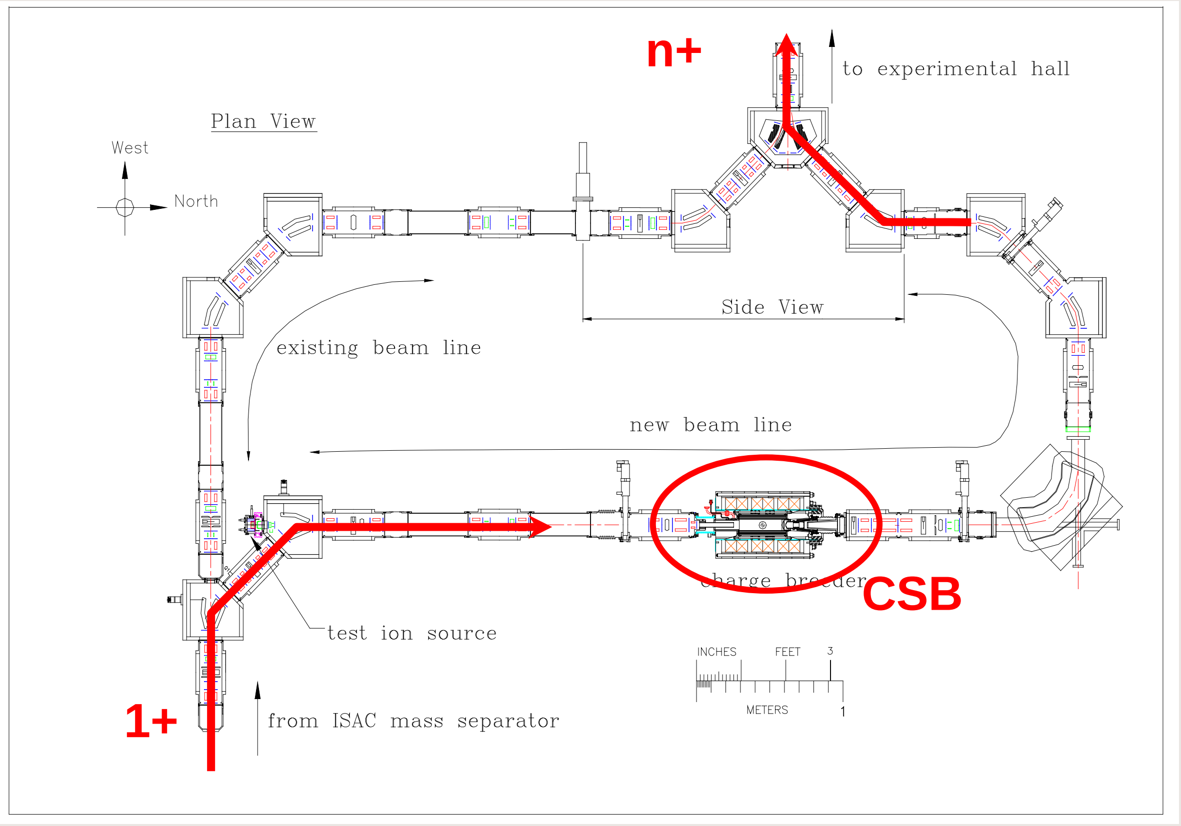
Energy Booster Stripping Foil

- 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 $^{16}O^{8+}$ to 15MeV/u
  - High efficiency for light ions



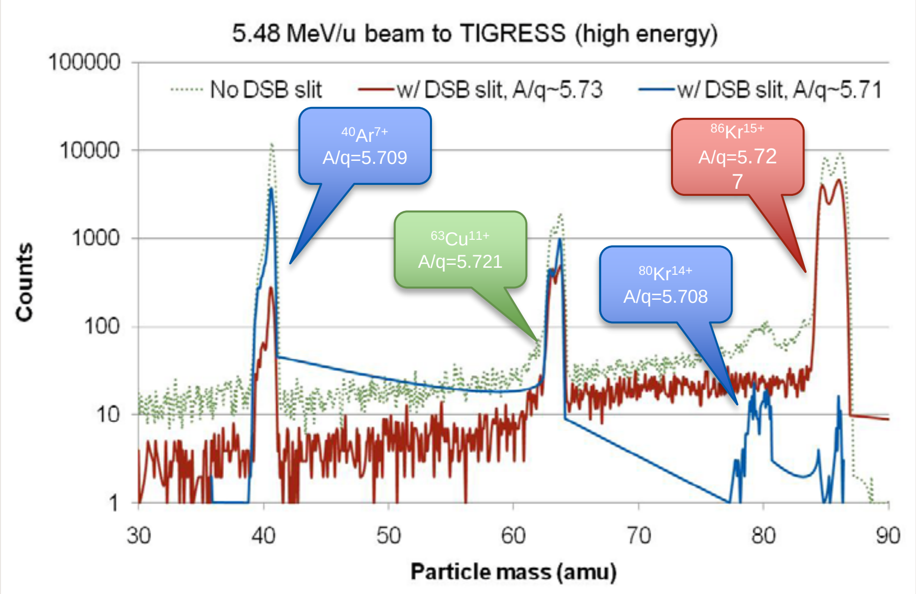
Charge State Booster

- 14GHz Phoenix ECR source from Pantechnik
- Breeding efficiency 2-5%
- Commissioned with stable beam $^{85}Rb^{14+}$ and radioactive $^{78}Br^{14+}$
- 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

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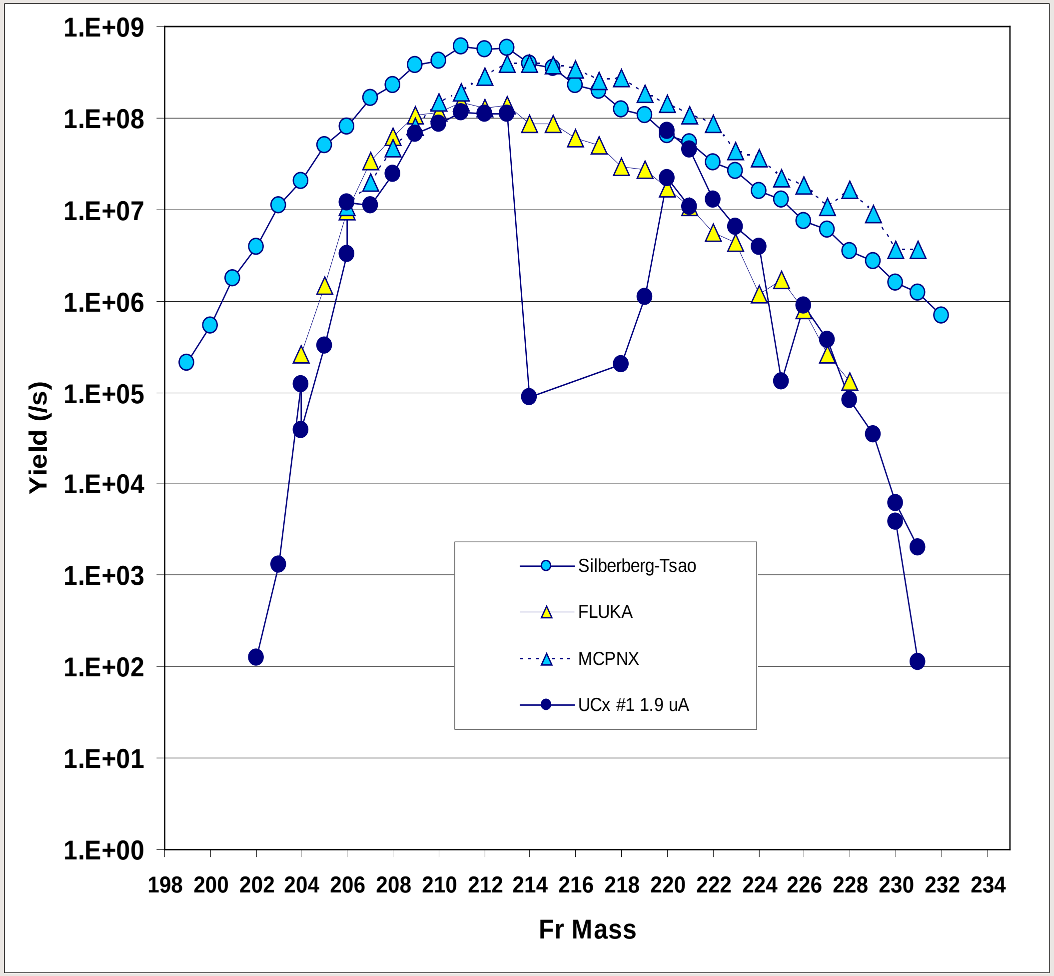
ISAC UC_x Target Fr Yields

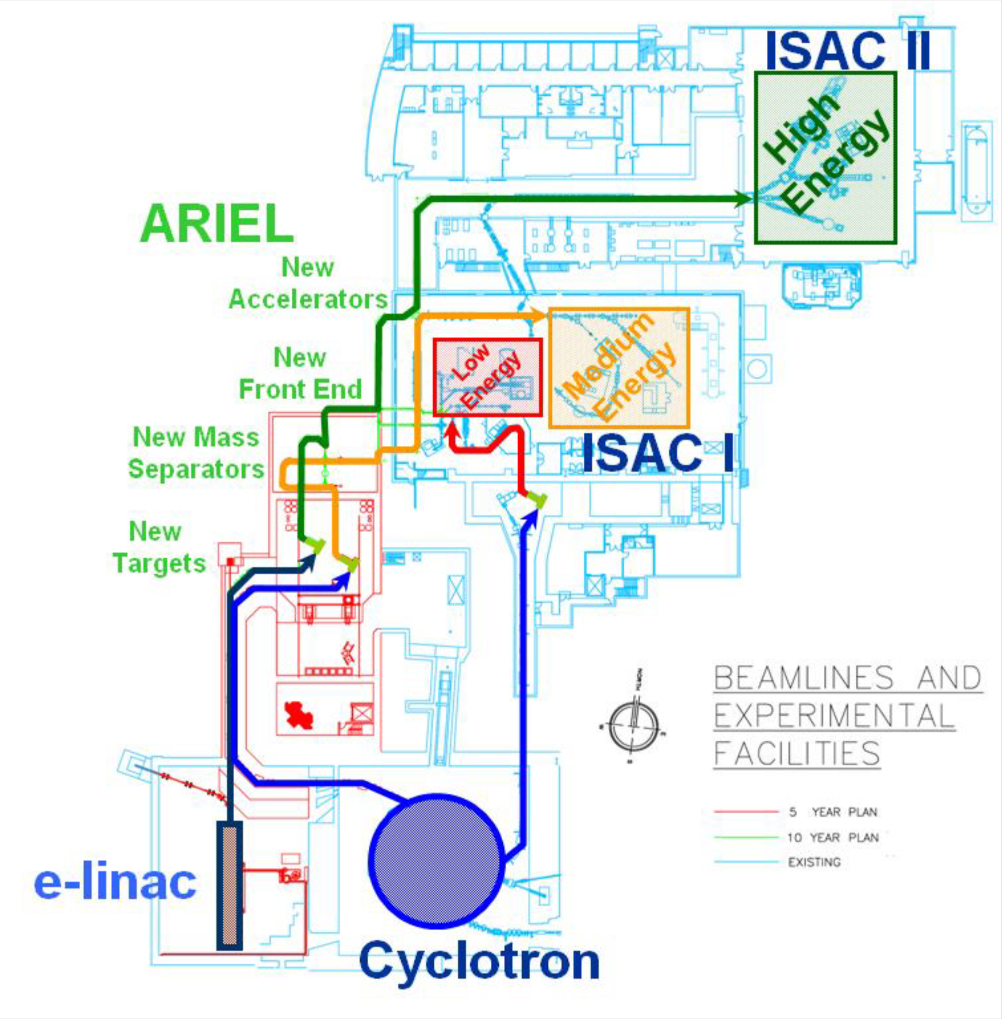
- Comparison of experimental Fr yields with in-target production predictions of 3 models
- The absence of $^{215\text{-}217}$Fr experimental yields is due to the msec half-lives of these nuclides which do not survive release from the target matrix
- ^{214m}Fr ($t_{1/2}$ = 3.4 ms) & ^{218m}Fr ($t_{1/2}$ = 22 ms) were observed at ~ 5 $\times 10^5$/s

Courtesy of M. Dombsky



ISAC and ARIEL

- SC linac is the post accelerator for the future ARIEL facility
- New complementary driver (e-linac): electron driver for Photo-Fission
- New target stations and mass separators
- New front end and post accelerators
- Goal: <u>three simultaneous radioactive beams</u>
- RIB multi-users facility



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Conclusions

- 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