Benefits of Beam Development Shifts

Paving the Way for 500uA Extraction from the TRIUMF 520MeV Cyclotron

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WAO 2012

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Introduction to the Cyclotron

- 6 sector pinwheel Design
- Maximum Operating Energy of 523MeV (0.77c)
- Tank is 56’ across
- Main RF frequency of 23.06000MHz
- Main Magnet 5600Gauss (14.7kAmps DC)
- Accelerates 278keV “Bunched” H- particles from 300kV ion source
- First beam full energy beam in 1974
- Maximum current achieved 420uA in 1988 (@ 50% duty cycle)
- Variable energy and current output

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Introduction to the Cyclotron

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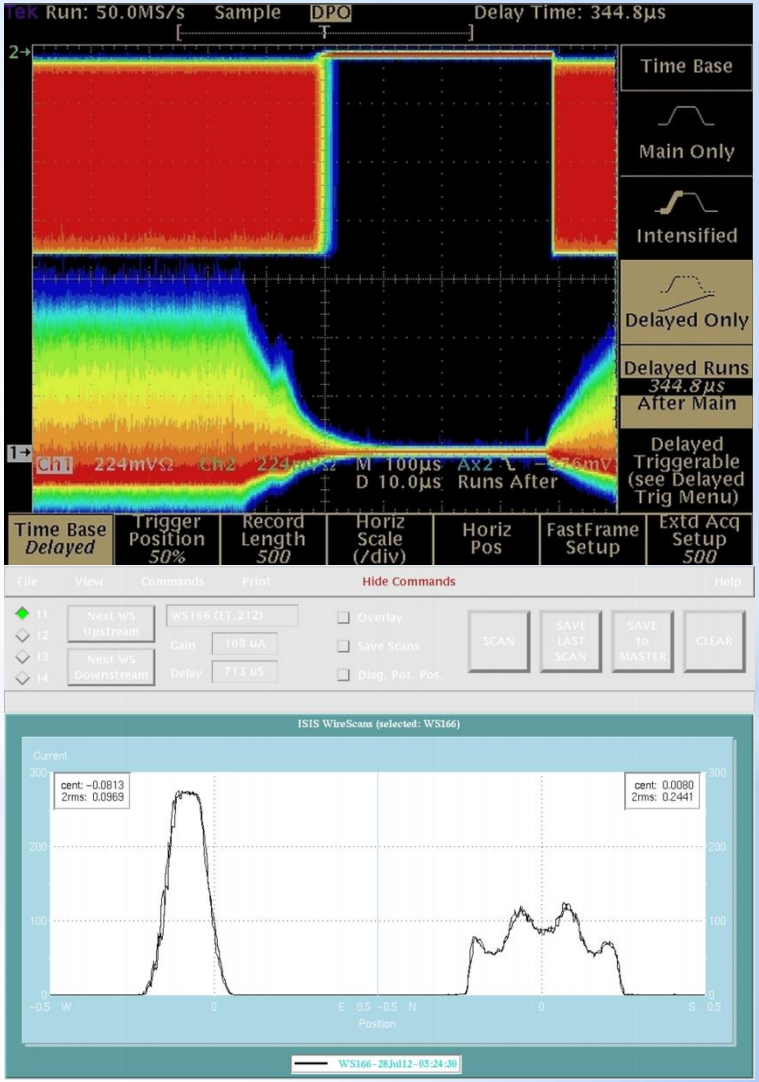
Typical Conditions

- 3 high current beam lines: 1A, 2A and 2C4
- Can run independently or all at once
- 1A and 2A @ 480MeV
- 2C4 @ 100MeV, 110MeV soon
- Cyclotron Spills <1.5%, Transmission ~65%
- Time of flight, 340uS without RF booster
- Main RF @ 92kV
- Tank Vacuum 4E-8T
- High current operation of 200-250uA

Standard Tuning Procedures

- ISIS buncher tuning
- Correction Plates
- ‘Main’ Bz Coils
  0/5/15/25/35/45 for minimum Time of flight
- Inflector/deflector adjustment
- RF Booster Phase
- Always watch spills, Cyclotron Transmission and NBIF ratio
- Watch thermocouples to avoid tank or equipment irradiation



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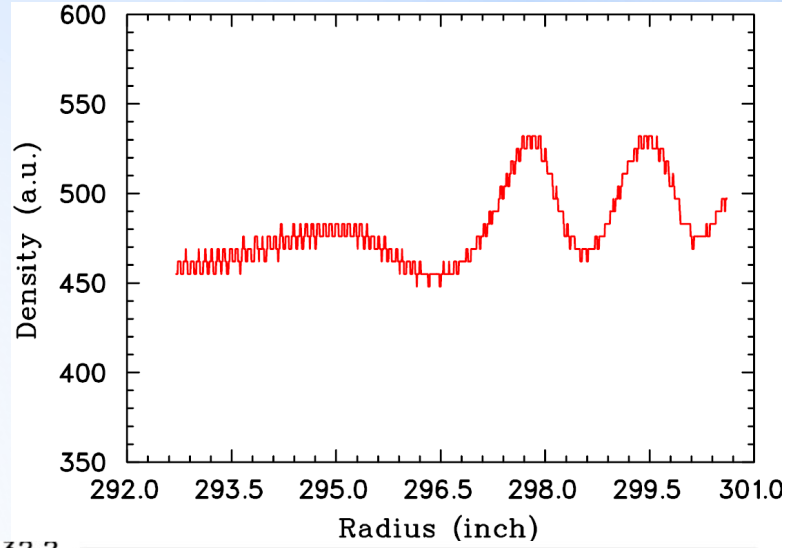
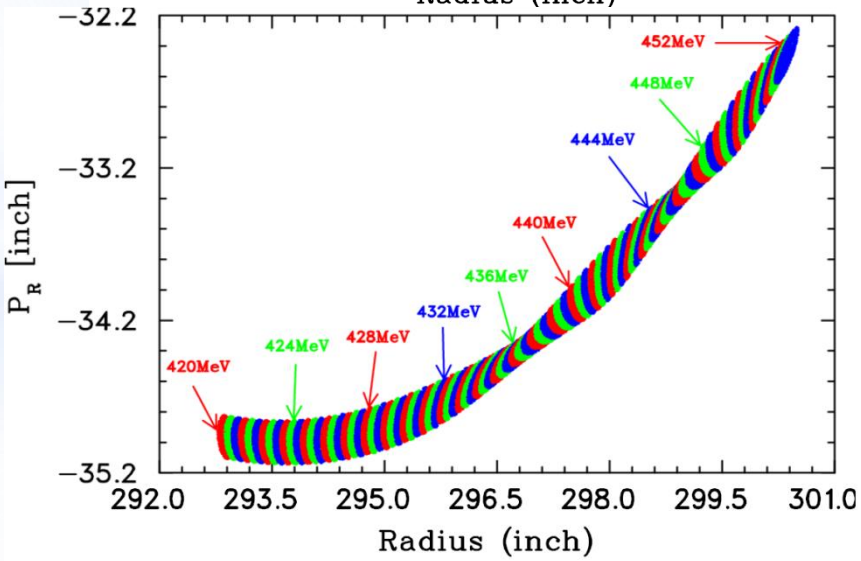
Future Operational Demands

- Go from 3, to 4 high current beamlines
- Recommissioning of BL4 from 10uA max to 100uA for Advanced Rare IsotopE Laboratory (ARIEL)
- 2C4 upgrade increases current from 80uA to 100uA
- Increase total available output from 250uA to ~440uA (1/5MW beam power)
- Increase beam stability to reduce wear on ISAC spallation targets

Vr=3/2 Resonance

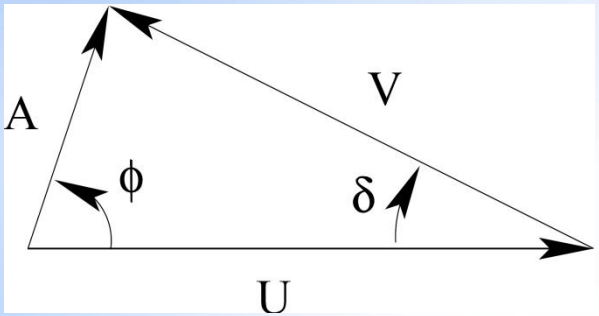
- First discovered in early 1980s
- Caused by field errors violating the symmetry of the main magnet
- Most noticeable in the 3rd harmonic of the magnetic field
- Induces beam density fluctuations and rotation of beam past 428MeV (R=296”)
- Drastically effects current stability in BL1, BL2A and BL4
- Was sometimes difficult to tune “around” causing large swings in extracted current when tuning

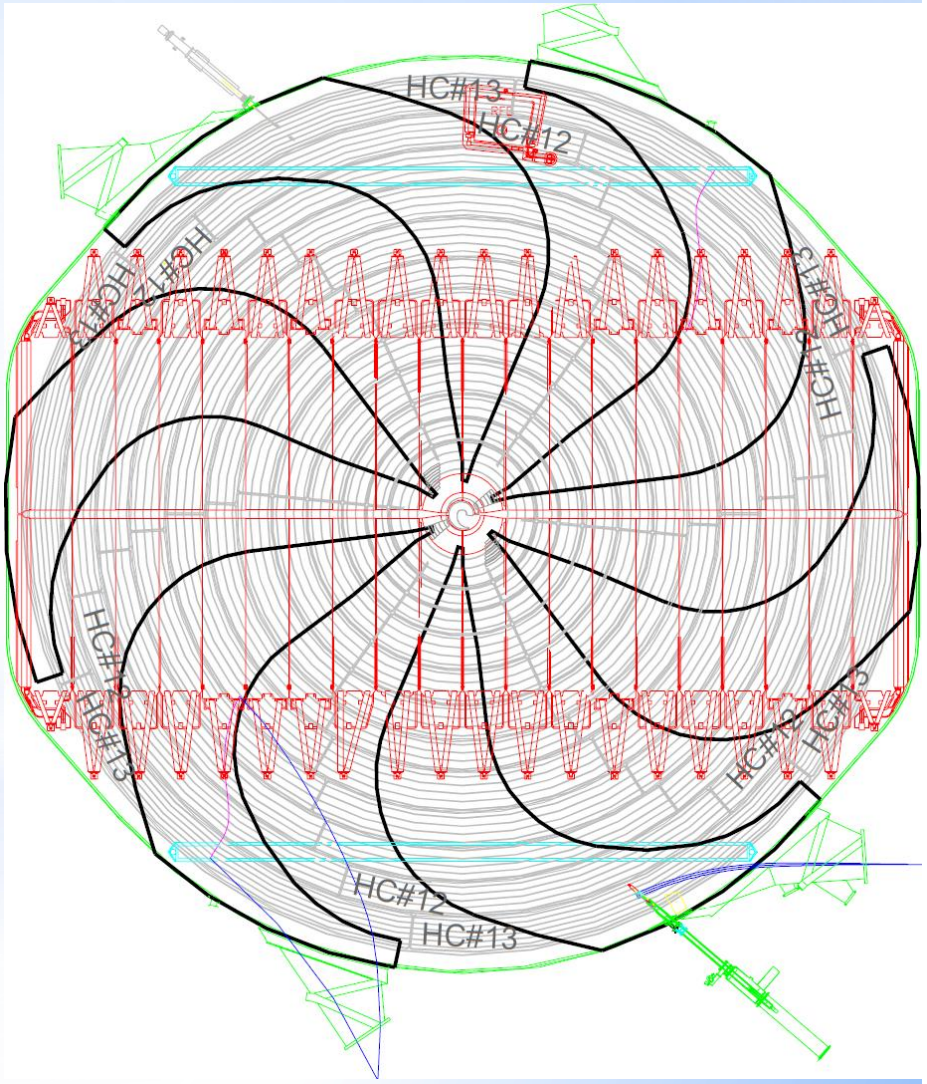




Resonance Correction

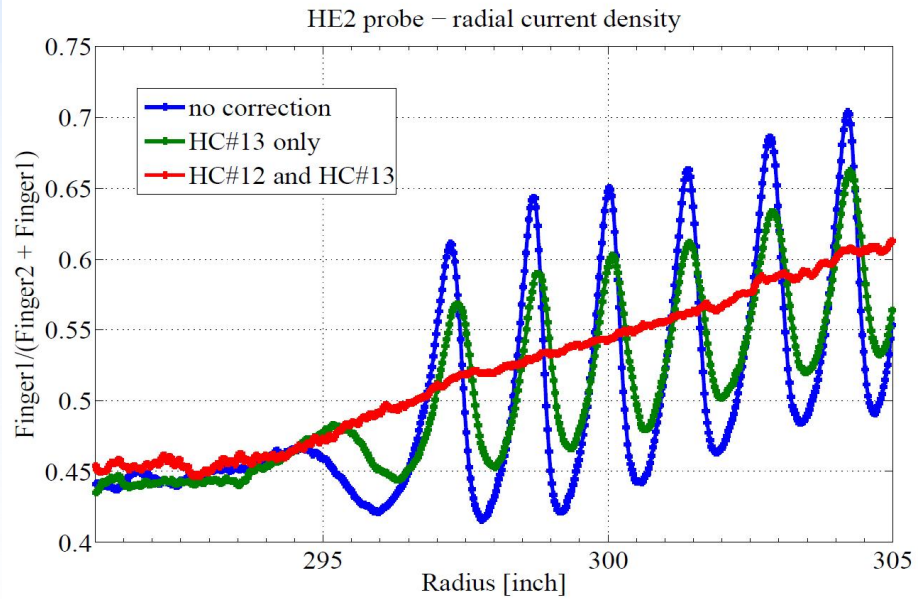
- Partial correction with HC#13
- Full correction with HC#12 and HC#13
- Harmonic coils originally designed to correct for errors of 1st harmonic
- Azimuthal offset between HC12 and HC13 allowed for 3rd harmonic component to be created and fully correct the resonance

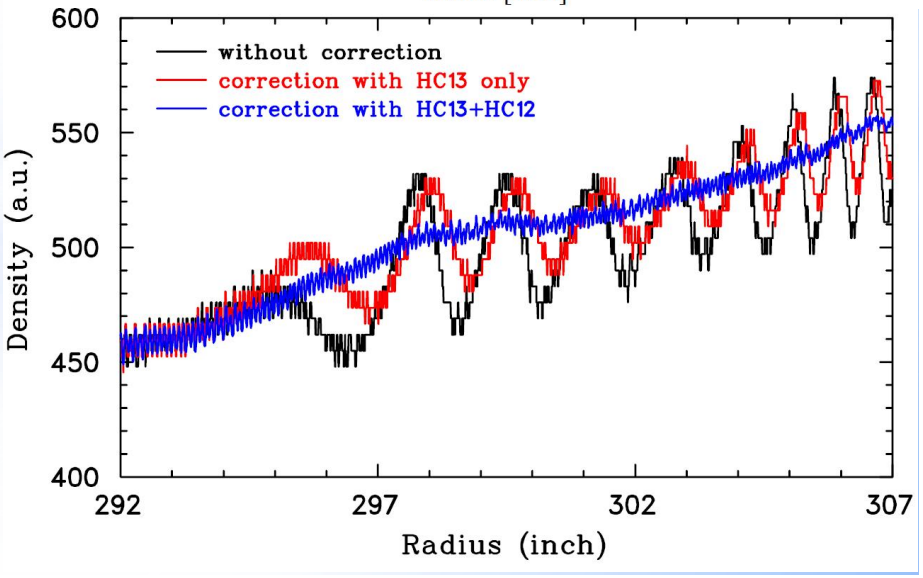




Resonance Correction

- Correction superimposed on existing HC12 1st harmonic correction
- Works beautifully, stability is now VERY good
- Cyclotron is now much easier to tune at high current
- Solution found by our beam physicists and implimented during development shifts



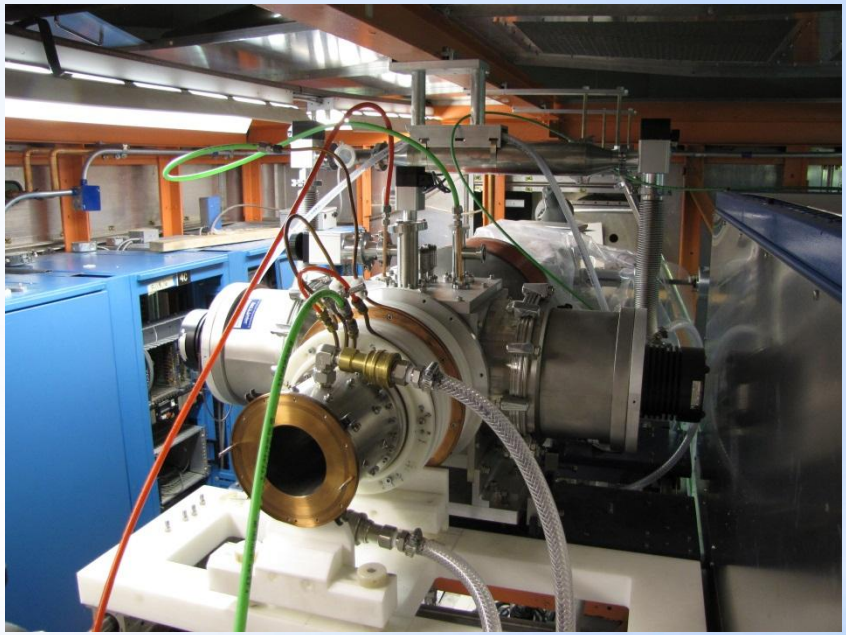


VIB Replacement

- Entire Vertical Injection Beamline Replaced
- New electrostatic optics design
- Provision for 3rd Bunching system (re-buncher)
- Designed to be capable of 22pC space charge density H- transport (double the old line)
- 2 years of successful use
- Optics proven easier to tune than old injection line

I3 Source Refurbishment

- Current I1 CUSP source limited to ~600uA
- I3 being gutted and replaced with new optics and CUSP Source
- Will allow the CUSP source to run at full voltage
- Goal of 1mA injection with lower emittance



Tank Contamination

- 7Be T1/2 = 53.29days
- 22Na T1/2 = 2.6088 years
- BL1A and BL2A extraction energy lowered from 500MeV to 480MeV without definitive results
- Suspect coming from EX1 probe housing
- Probe raised after resonance corrected
- X1Z raised from 0.350” to 0.450”
- Check counts next shutdown in January

High Current Tuning

- extraction >250uA
- Open ISIS slits 125 &126 far as possible
- Tune 1st buncher amplitude for transmission (check 2nd and main phase too)
- Check optics at the end of the injection line
- Ensure ISIS beamline matching is good
- Peak Bz0 for transmission, checking main Bz's with emphasis on 15, 35 and magic triplet
- Tune outer Br coils(>43) for spills watching tank thermocouples
- Watch spills, transmission, NBIF and thermocouples
- Do it again and again…and then again
- Can attain 300uA+ with 60% transmission, low spills

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Conclusion

- Cyclotron tuning is complex and demanding
- Development shifts allow dedicated time for problem solving and idea testing
- Having set procedure as in our “standard tuning” reduces stress on operators and mitigates potential damage
- Tuning takes skill, experience, knowledge and patience
- Complex or high risk tuning problems best worked out in meetings or by committee
- Accelerator operations is ultimately a team effort, more heads the better

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Acknowledgments

[1] T. Planche , Y.-N. Rao, R. Baartman, “Correction Of r = 3/2 Resonance in TRIUMF Cyclotron”, Vancouver, BC 2012

[2] Y.-N. Rao, R. Baartman, G. Dutto, and L. Root, “Studies of the r = 3=2 Resonance in the TRIUMF Cyclotron”, PAC’09, Vancouver, BC, May 2009, TH6PFP09, p. 3940–3942.

[3] R. Baartman, G.H. MacKenzie, and M.M. Gordon, “Amplitude growth from the rapid traversal of a half-integer resonance”, 10th Int. Conf. on Cyclotrons and their Applications, East Lansing, MI, April 1984, p. 40–43, http://cdsweb.cern.ch/record/152883

[4] R. Baartman, “Optics design of the ISIS Vertical Section Replacement” Vancouver, BC, September 2009.

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Thank You