TRIUMF

CANADA'S NATIONAL LABORATORY FOR PARTICLE AND NUCLEAR PHYSICS

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

Reliable Production of Multiple High Intensity Beams with the 500 MeV TRIUMF Cyclotron

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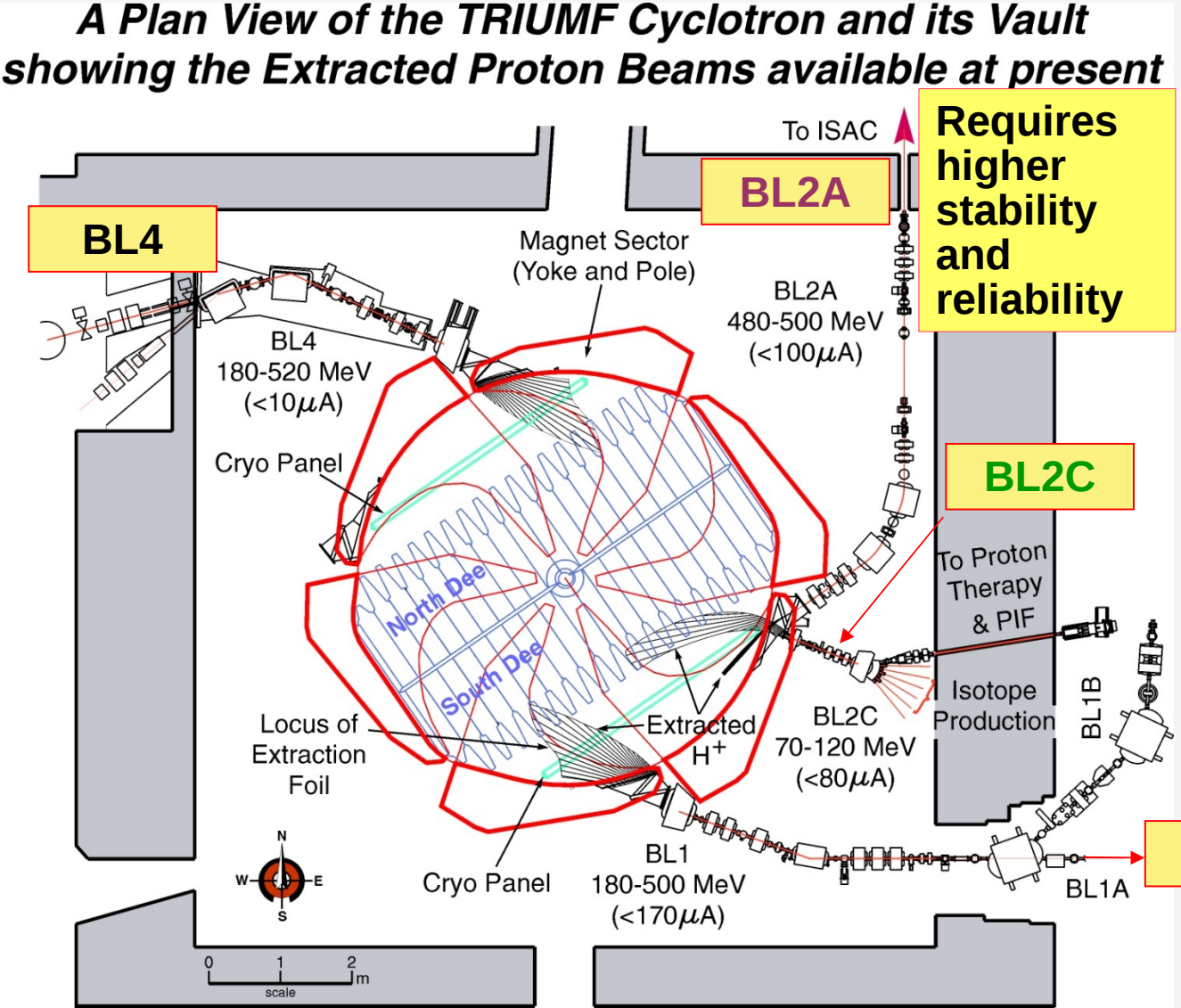
on behalf of cyclotron beam development team

CYCLOTRONS'2010, Sept. 6-10, 2010

- Introduction
- Development Highlights
- Summary

TRIUMF 500 MeV H⁻ Cyclotron

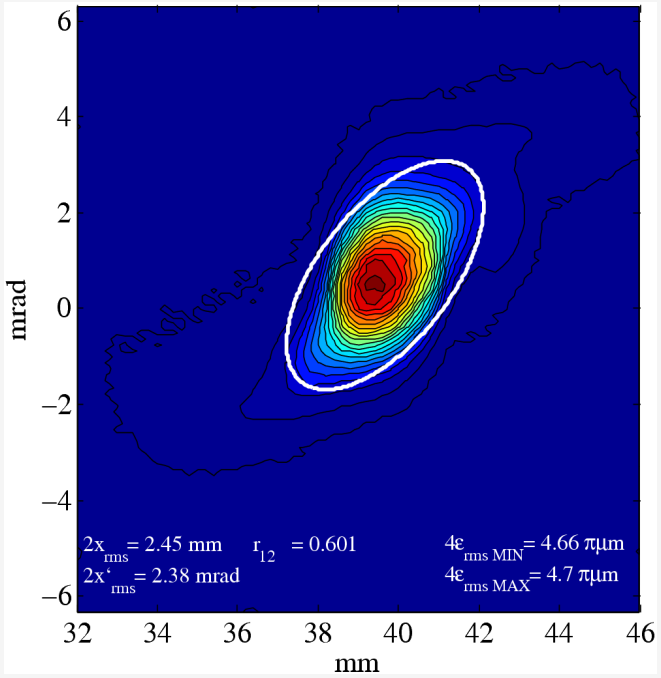
Present stable performance limited to <300 μA

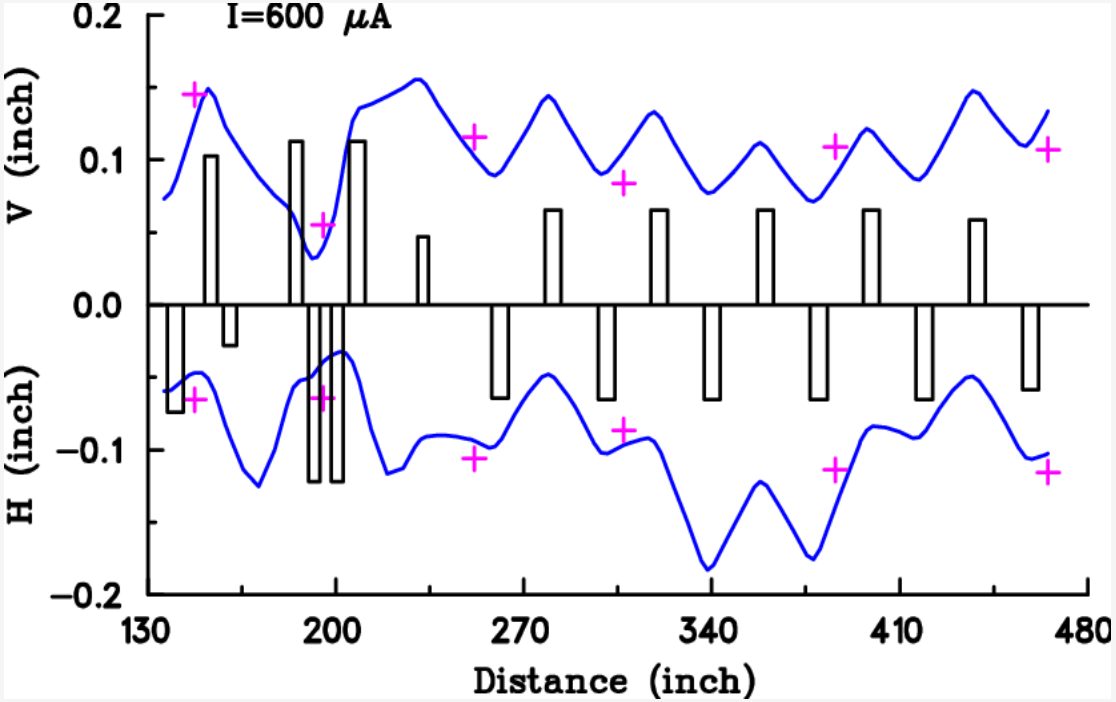


Requires higher stability and reliability

- the largest linear dimension's cyclotron in the world
- Has been in smooth operation for ~35 years
- Can simultaneously provide multiple cw proton beams of variable currents to various experiments
- **Achieved 290 μA for production in 2010:**
  75 μA (BL2A) +
  75 μA (BL2C) +
  140 μA (BL1A)

Ion Source and Injection Line: Diagnostics and Beam Optics

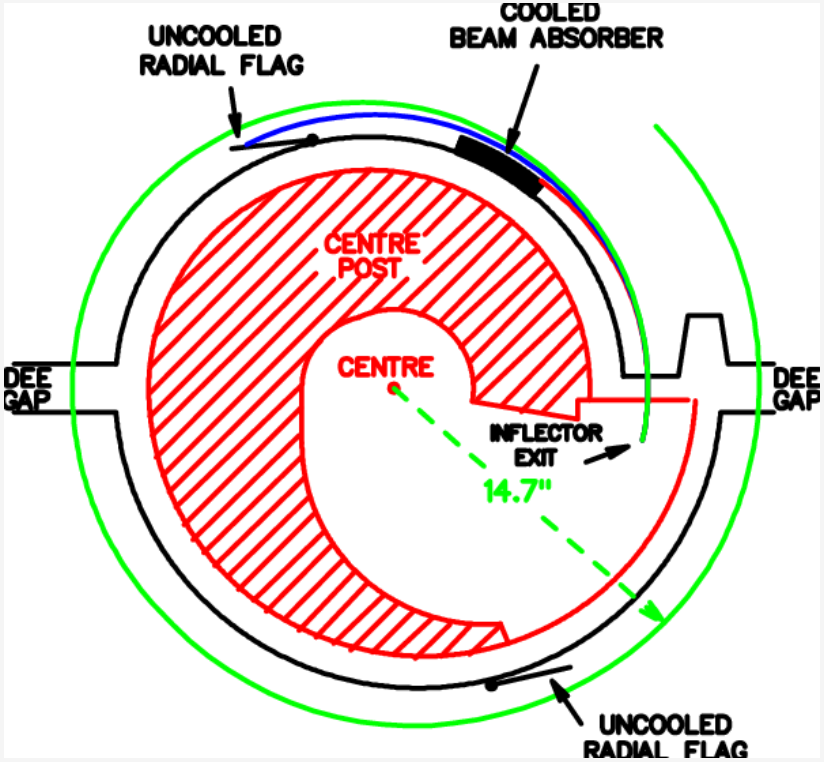


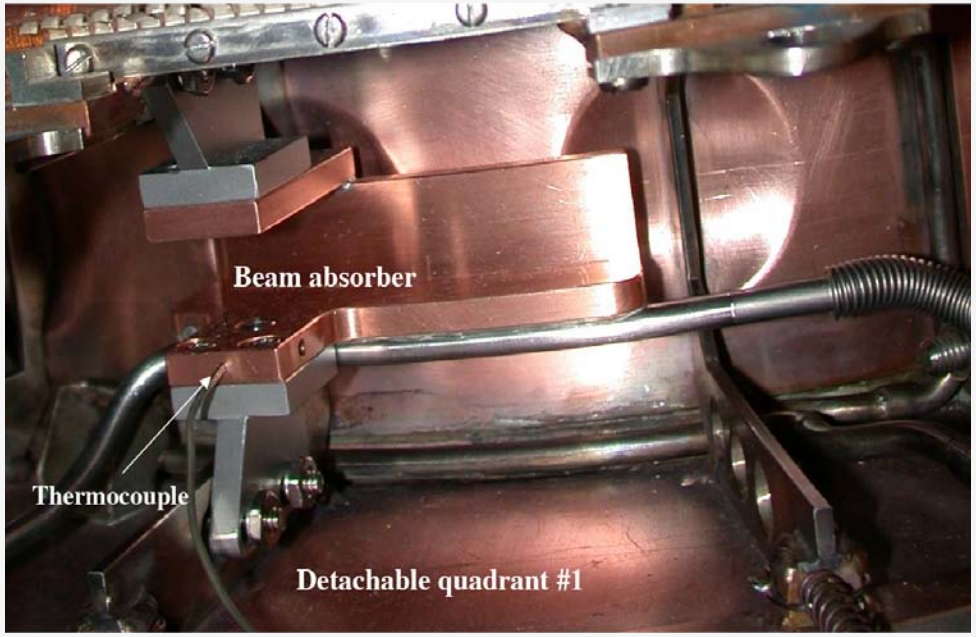


Emittance scan from the ISIS emittance rig: 0.12πmm-mrad (norm., 4rms), 600μA H^- at 300 keV, best brightness achieved so far.

- Installed a set of slits in the periodic section, separated by 90 degrees phase advance, to clean up halos and also limit the required beam current and emittance;
- Installed and commissioned an Allison type emittance rig. This facilitates matching large current beam to the periodic section.

Central Region



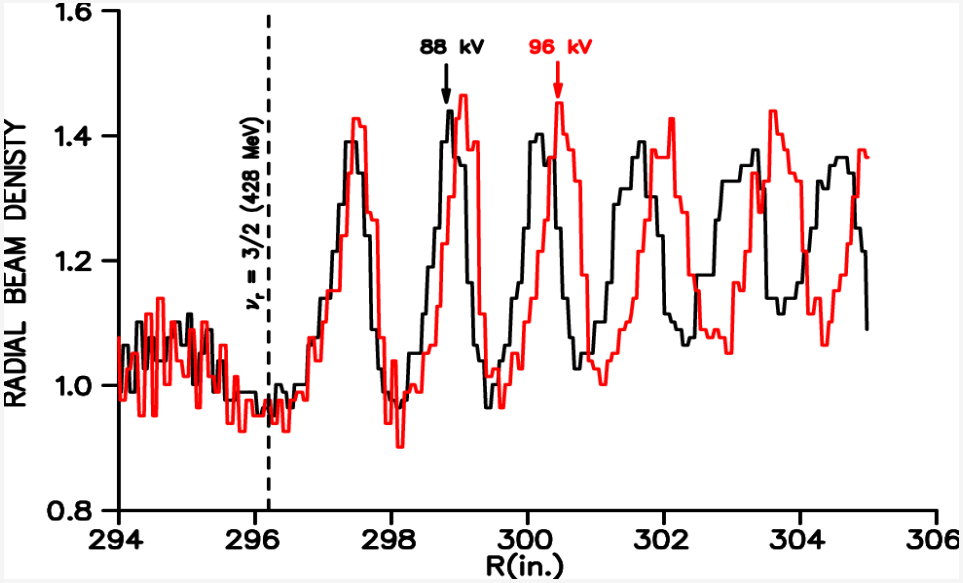


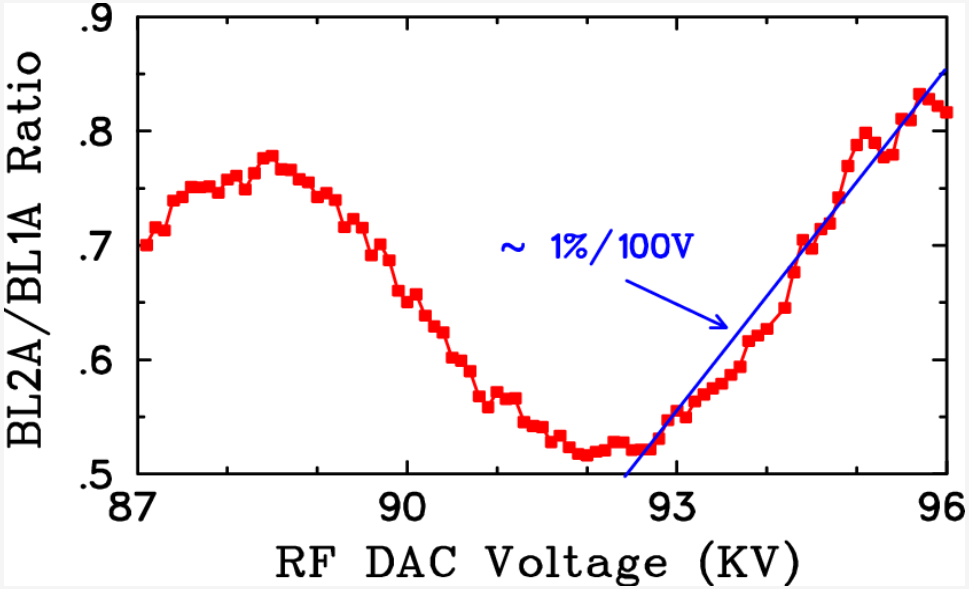
In order to be able to raise the beam intensity through the central region, major developments include:

- Inserting a cooled beam absorber to absorb unwanted phases and prevent from overheating the dee structure supports;
- Inserting radial flags on dee walls on the 2nd and 4th quarter turn;
- Adding sets of thermocouples on un-cooled electrodes near beam path.

Routine cyclotron has ~65% transmission between vertical injection and the total extracted current. Up to 70% was measured, depending on the buncher system.

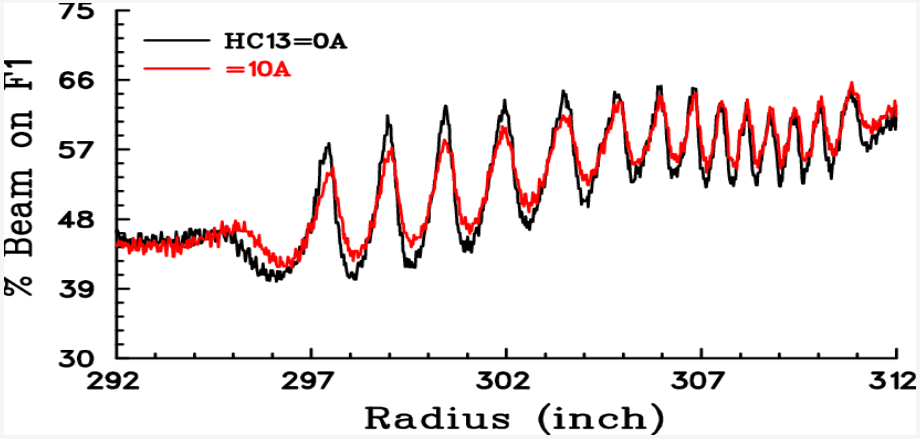
Extraction Stability

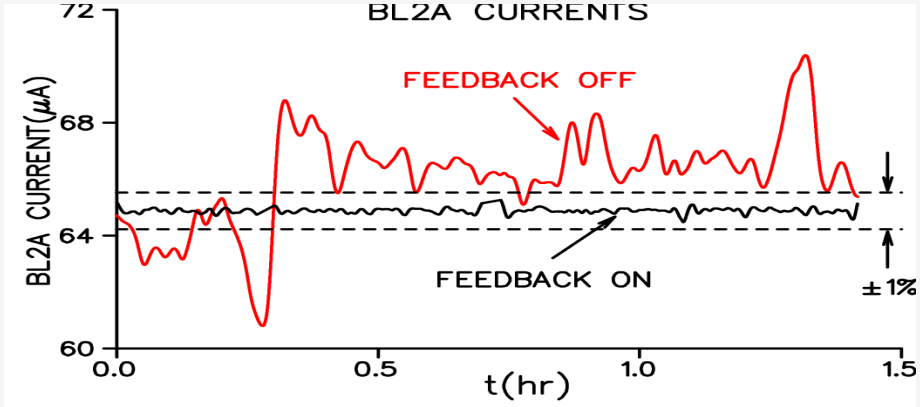


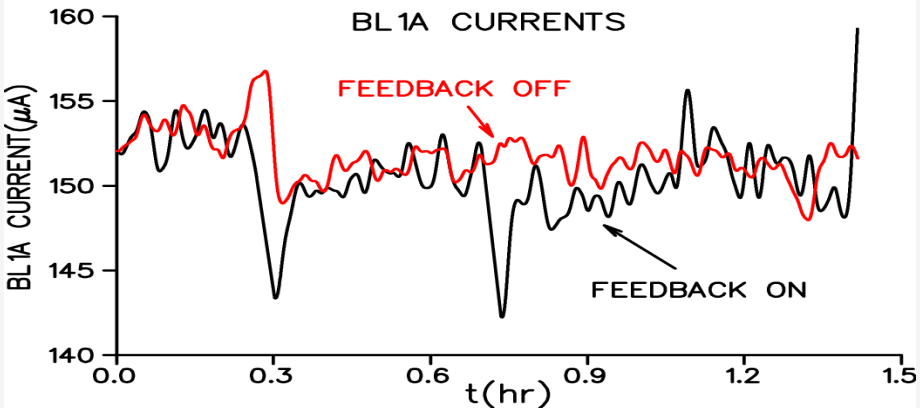


- The 3rd harmonic field gradient error drives 3/2 resonance at 428 MeV (γ=1.5), causing a radial modulation of beam density. This modulation starts at 428 MeV and persists to 500 MeV extraction.
- The density oscillations fluctuate left and right if, for example, the rf voltage fluctuates.
- Very slight changes in the circulating beam can result in large fluctuation of the ratio of intensities BL2A/BL1A (“split” ratio), as the stripper foil is configured in radial “shadow mode”.

Extraction Stability - cont'd



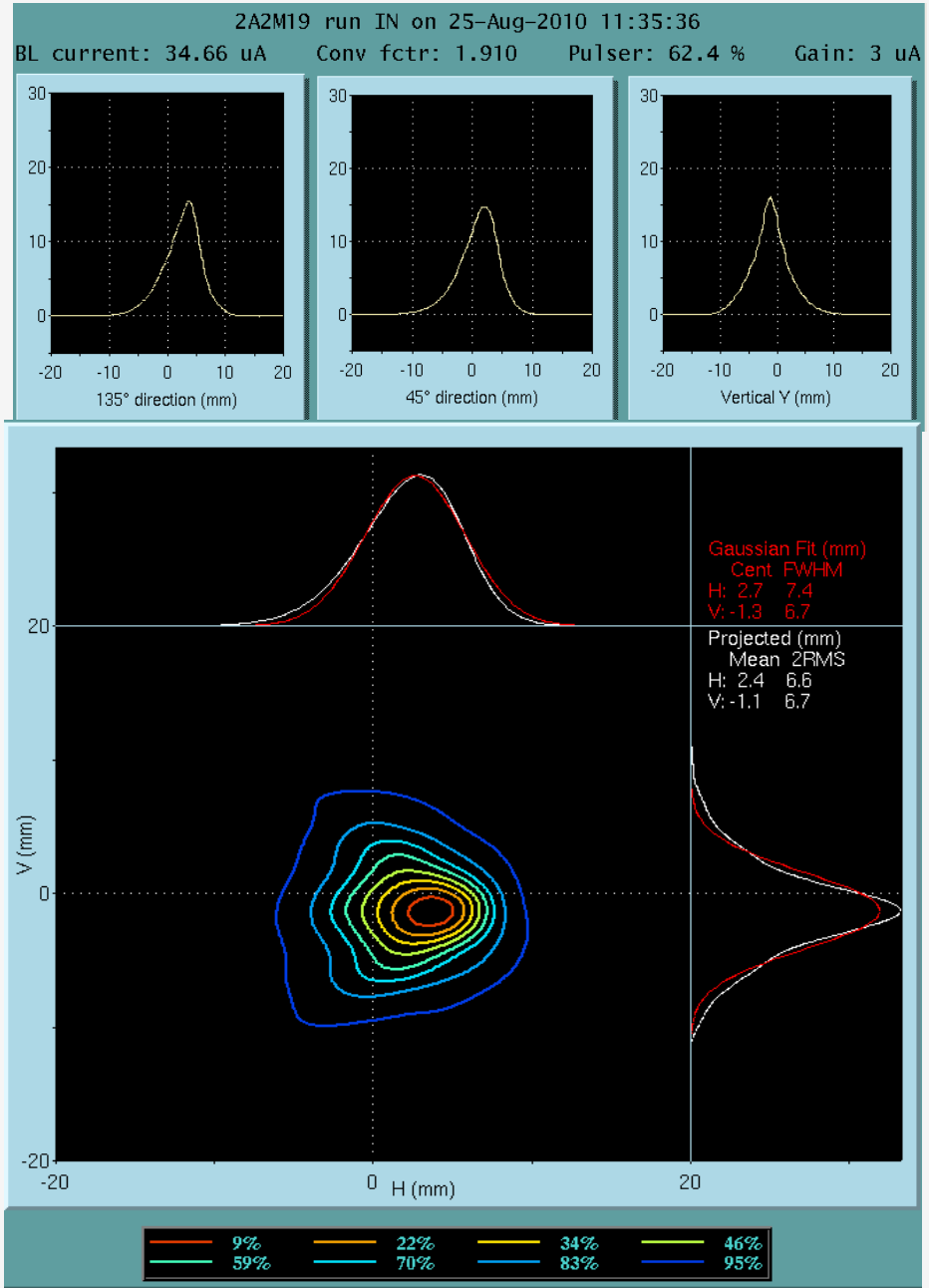




The ISAC target cannot tolerate such fluctuation, so we stabilize the BL2A current by:

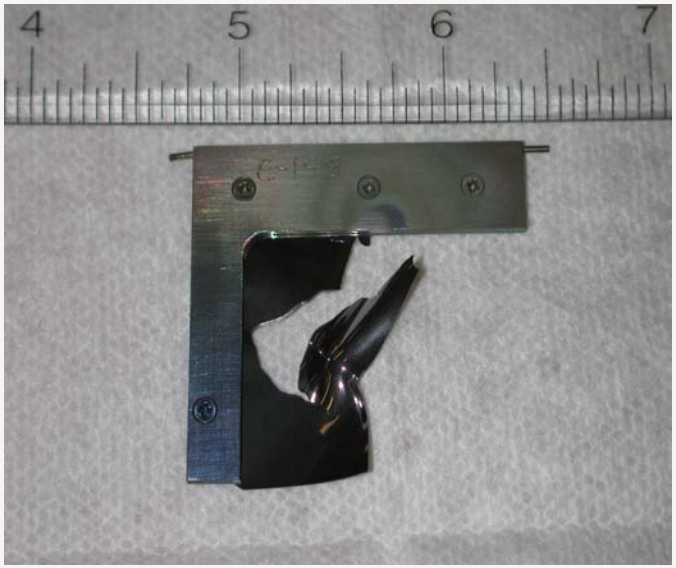
- compensating the 3/2 resonance with a set of harmonic coils to generate a 3rd harmonic field gradient. But this could only partially compensate and reduce the oscillation amplitude by ~40%.
- further, using a feedback loop between the stripper and the pulser (of ~1kHz) at injection line to regulate the beam's duty cycle.

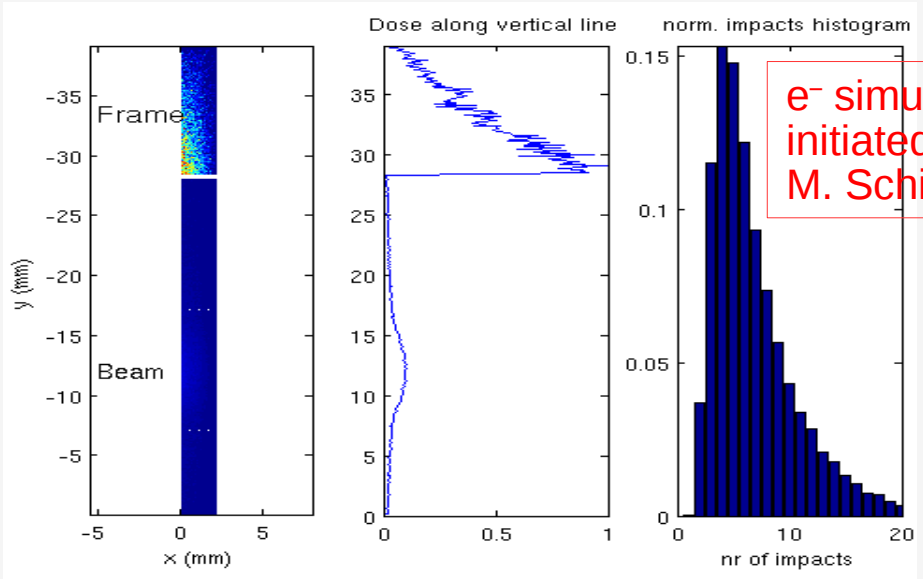
Tomography of Beam Density on ISAC Target



To protect the ISAC target, and to get the most out of it, it is important to monitor that the density of beam on the target remains within specifications. But it's difficult to measure, so we implement the MENT algorithm to reconstruct tomography of beam distribution on the target, by using a 3-wire monitor measured profiles in the vertical, +45^{o} and -45^{o} directions.

Extraction Probes and Foils





We tolerate beam losses of ~1 nA/m. This is 10^{-5} level at 100 µA. Beam spills are primarily due to large angle scattering from stripper foil. For a 5mg/cm^2 foil, 10^{-5} particles have angle > 7mrad, these are outside 4" beam pipe as R_{12} ~ 1 cm/mrad.

So, it was suggested that 3 – 5 times thinner foils be used to reduce scatter. Foils deformed during use in the past. This is believed to be related to the temperature rise on the top frame, according to the simulation studies. Improvements were thus made:

- Highly-oriented pyrolytic graphite foils, of thickness ~2 mg/cm^2, are now used.
- Tantalum frame with a thin copper cushion is now used in place of stainless steel. Also, additional heat relief features were introduced in the mechanism.

These changes have resulted in 4 times longer lifetime of the foils, improved beam quality and stability, and also has made the 2A beam current stabilization feedback loop working reliably.

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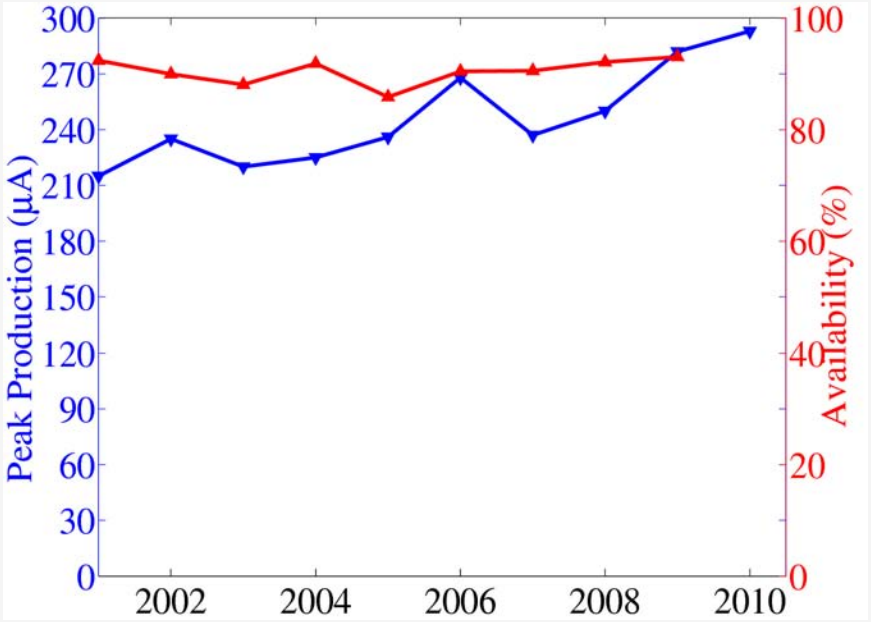
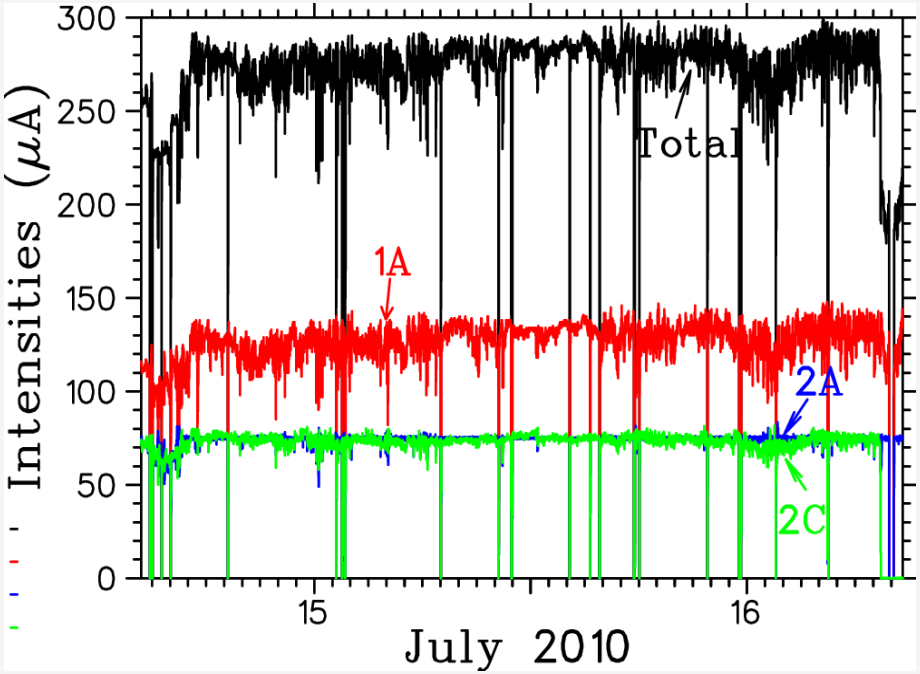
CYCLOTRON PEAK PRODUCTION & AVAILABILITY





- Operates with >85% uptime.
- Extracted current increased from 200 to ~300 μA.

SUMMARY

The TRIUMF Cyclotron:

- Provides multiple high intensity proton beams simultaneously. A reliable total production current up to 300 μA has been achieved;
- Stability of extracted beam has been improved to meet the requirement by the ISAC target;
- Spills in the existing beamlines are sufficiently low.

Thank you!

谢谢！

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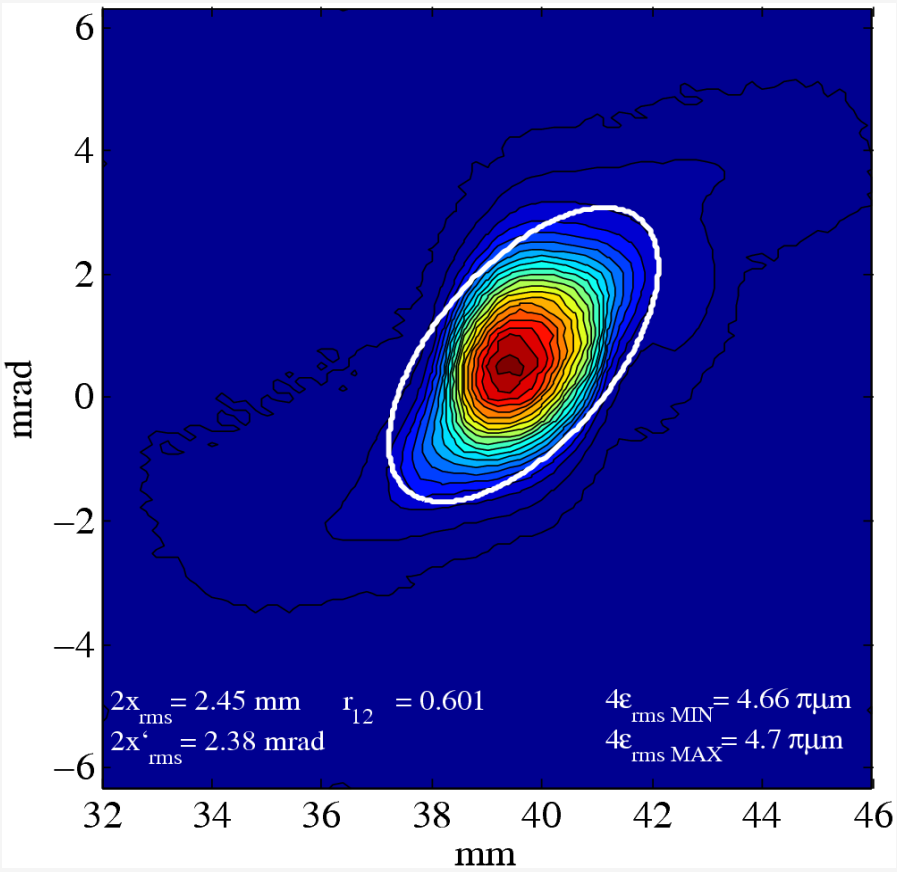
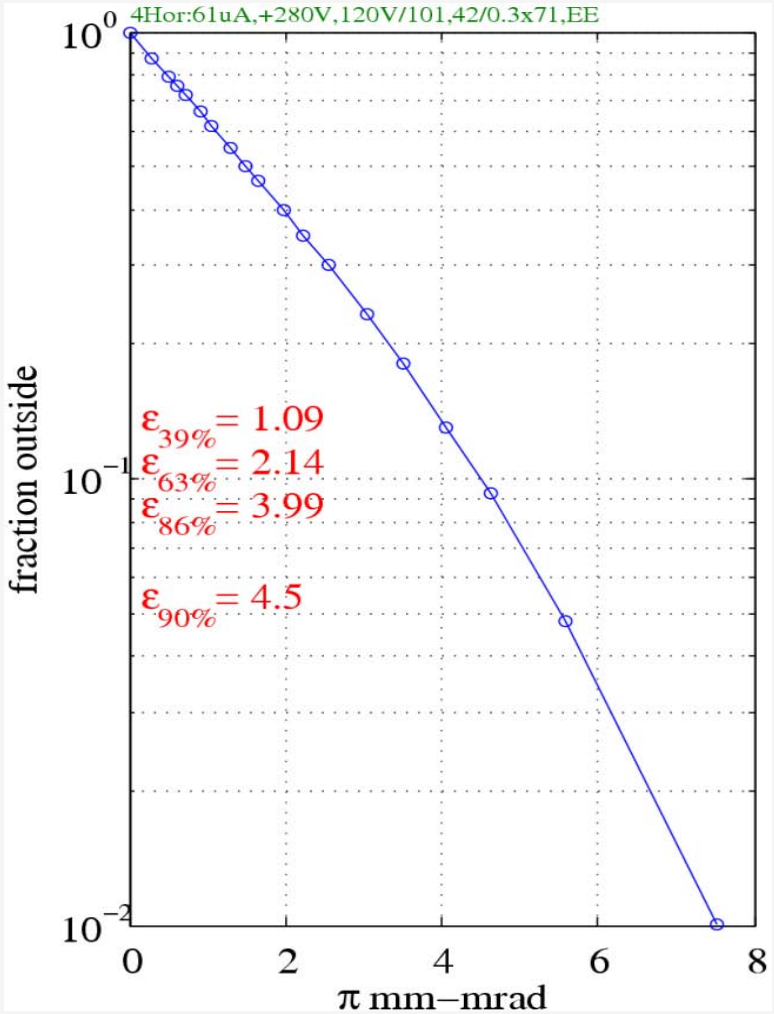
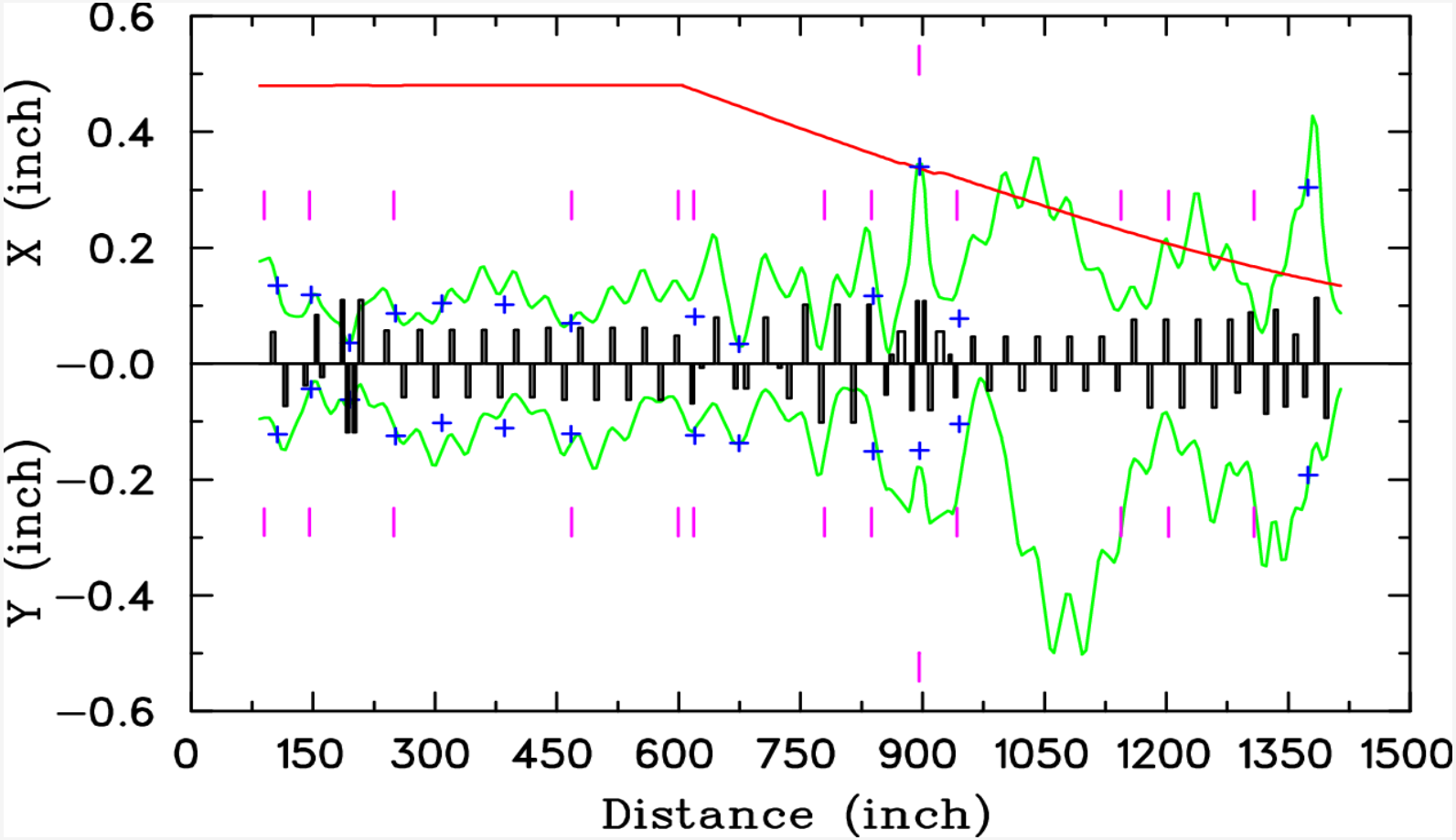
Emittance Scan at Injection Line





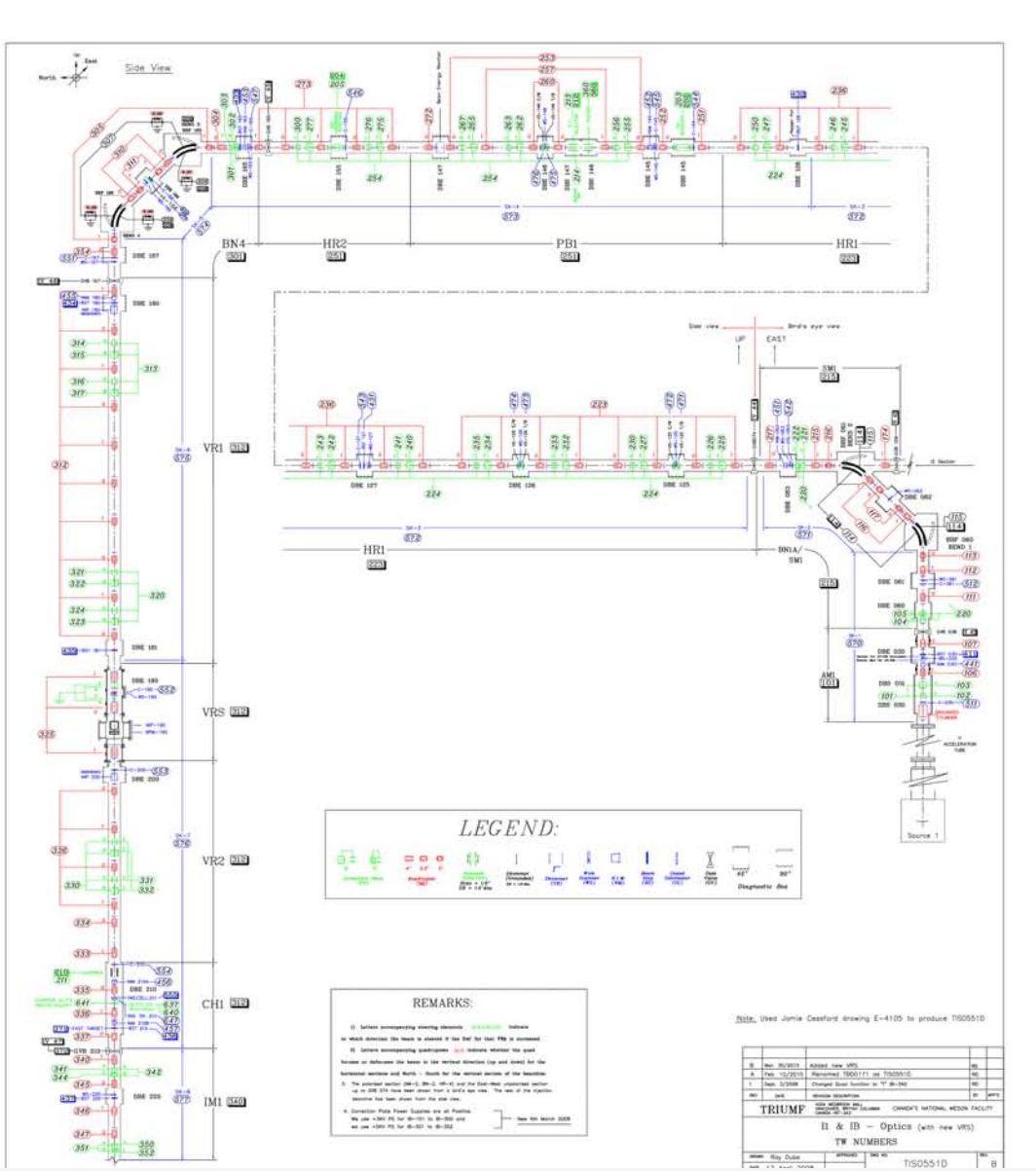
Emittance scan: 0.12π mm-mrad(norm.), 600 μA H^- at 300 keV, the best brightness achieved so far.

Injection Line Optics



- Horizontal periodic section is well matched, while the vertical section is badly mismatched.
- New vertical section has been designed, including space charge, bunching, and coupling in all 3 planes. Also, has more diagnostics and cooled apertures strategically located to enforce matching, to the periodic section and to the cyclotron.

Injection Line Layout



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