A Specialized High-Power (50 kW) Proton Beamline for BNCT

Morgan P. Dehnel, Thomas M. Stewart, Tue Christensen, David E. Potkins,
D-Pace, Inc., PO Box 201, Nelson, BC, Canada
Hirofumi Seki, Shinji Shibuya, Steve Domingo, Glenn James, Pat Creely, Steve Bucci,
AccSys Technology, Inc., 1177 Quarry Lane, Pleasanton, CA 94566, USA

NA-PAC13

Pasadena, CA, USA

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Outline:

- Motivation for Accelerator Based BNCT
- Ion-Optics
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  - Ion-Optical Elements (Magnetic)
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    - Magnets, Vacuum, Diagnostics, Support
  - Generic Target Distribution
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Motivation for Accelerator Based BNCT 1:

- Boron Neutron Capture Therapy (BNCT) is a two step non-invasive therapeutic treatment of cancer.

  (1) Tumour-localizing Boron-10 delivery agents are injected into the patient.

  (2) The patient is exposed to epithermal neutrons which have a very high probability of reacting with the concentrated Boron-10 in the cancer cells resulting in an energetic α and a recoiling nucleus which ionize molecules within 5-9 microns killing the cancer cell.

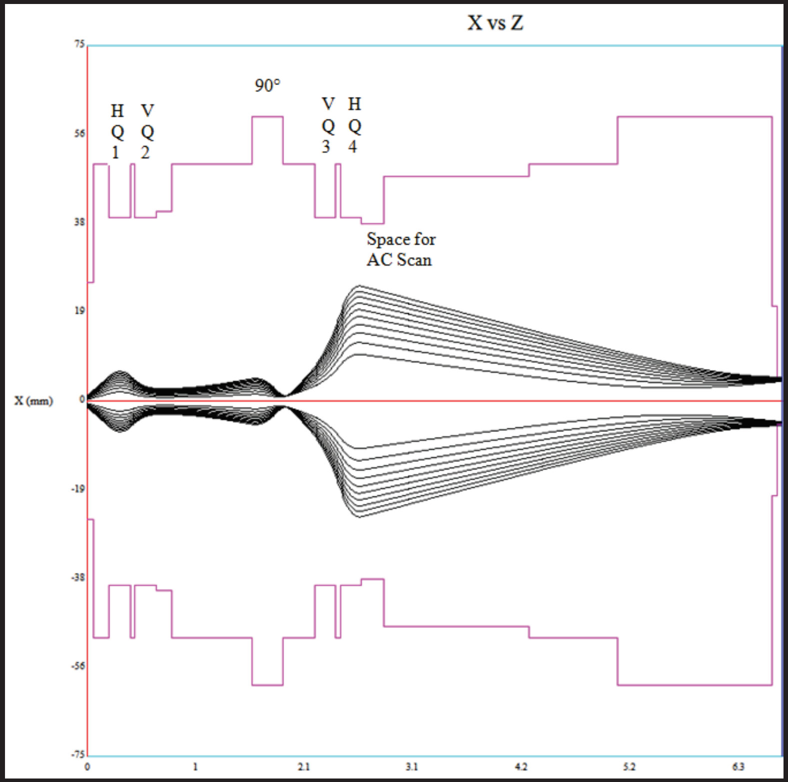
Motivation for Accelerator Based BNCT 2:

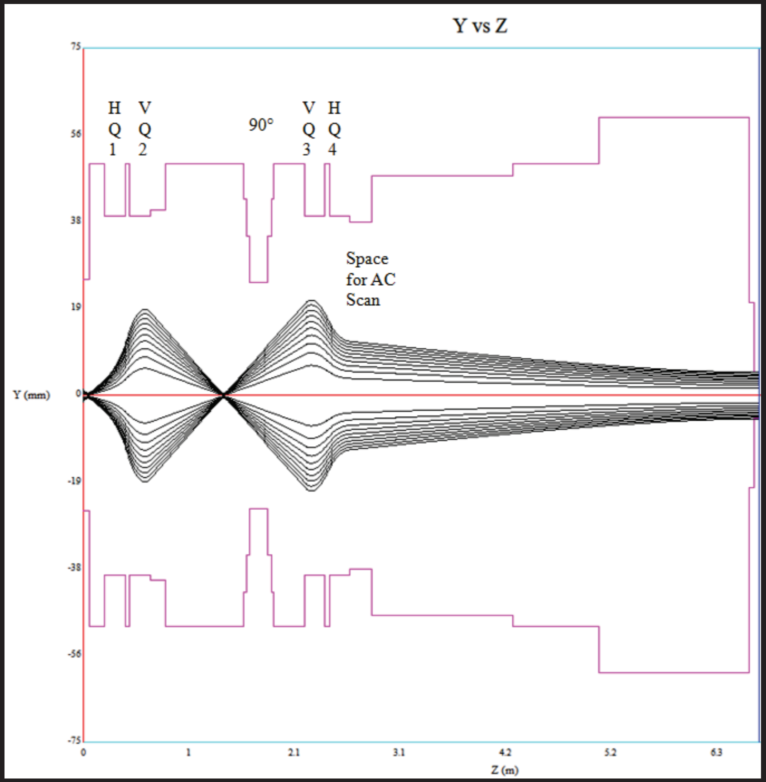
- BNCT has a 50 year history at research nuclear reactors.
- Strong growth in BNCT implementation in hospitals is anticipated, since:
  - It can be de-coupled from nuclear reactors by use of particle accelerators.
  - Low energy (p,n) reactions require inexpensive accelerators
  - Accelerator-based systems can be turned-off (relatively safe)
  - Accelerator-based systems are compact
  - PET techniques provide much better dosimetry

Ion-Optics 1:

- 20 mA (ave), 2.5 MeV, protons, 50 kW, CW, 400 MHz.
  - Twiss parameters provided by AccSys for 1 rms (35.9% beam intensity) thru 10 rms (99.3% beam intensity)
  - Initial D-Pace design undertaken with 1st Order Beamline Simulator code.
  - In order to provide acceptance overhead for space-charge emittance growth ensure that 3x 10 rms emittance envelopes can be transported without loss.
  - AccSys physicists confirm beamline acceptance is appropriate with space-charge based beam transport modeled with TRACE-3D

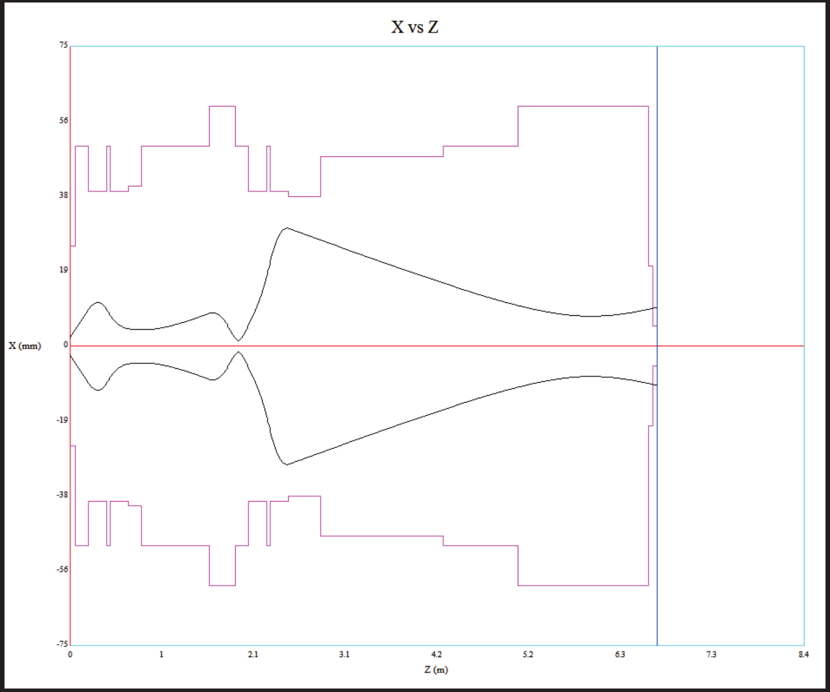
Ion-Optics 2:

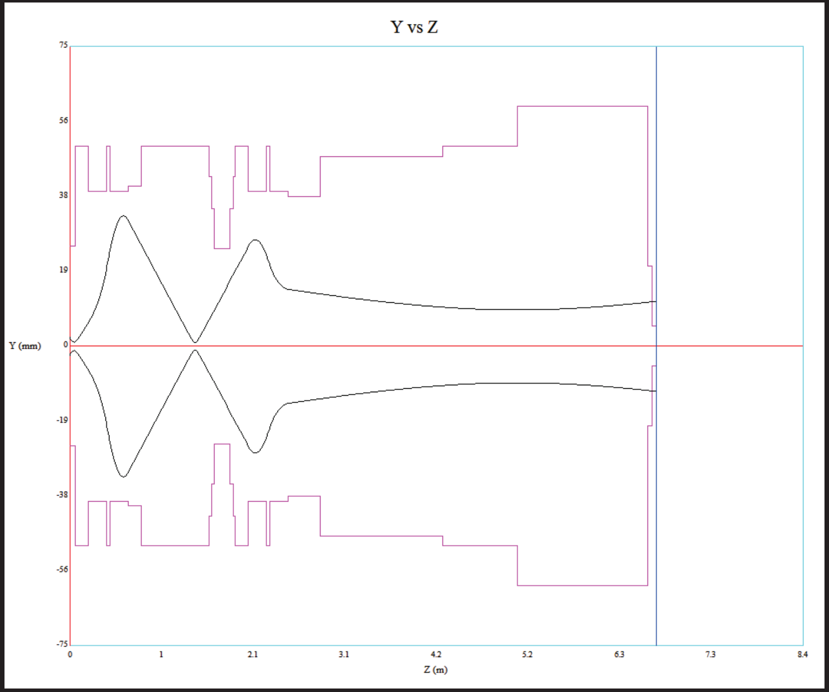




Horizontal and Vertical 1-10 rms emittance beam envelopes through the HEBT Beamline for the case of a 10 mm diameter DC Target Spot Size. The quadrupole magnet settings are:
HQ1 = 2,993 G, VQ2 = 2,337 G, VQ3 = 1,557 G, HQ4 = 1,397 G.

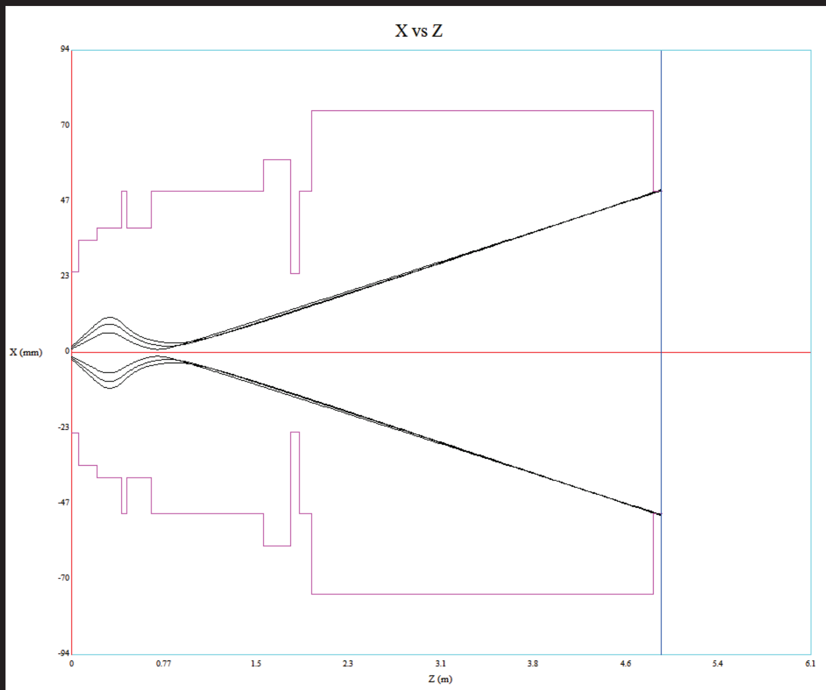
Ion-Optics 3:

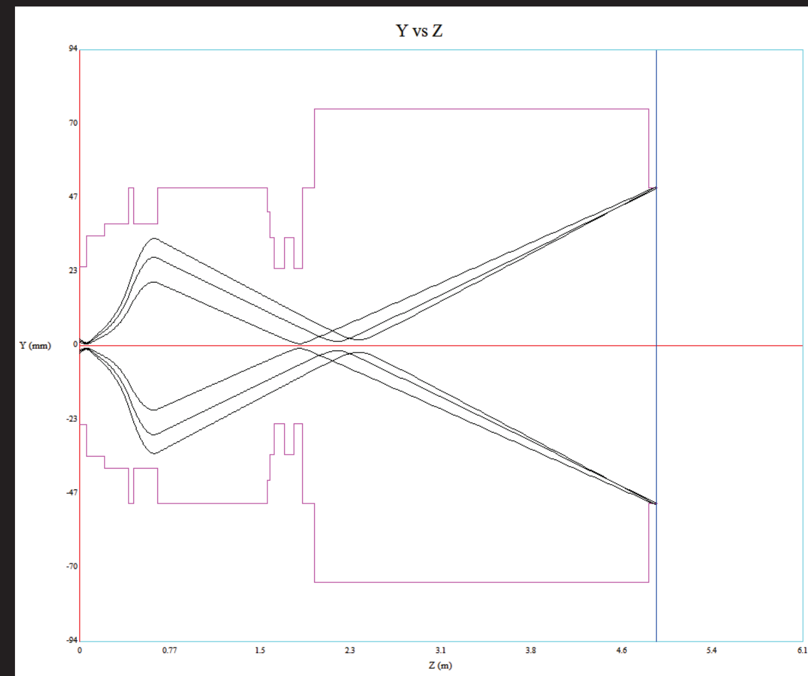




3 x 10rms Emittance Horizontal and Vertical beam envelopes. This plot confirms that a 30 rms beam envelope can be passed through the system. This provides reasonable acceptance overhead to ensure that 2.5 MeV proton beam losses will be < 1% (i.e. apertures confirmed). The quadrupole magnet settings are as follows:
HQ1 = 3,033 G, VQ2 = 2,307 G, VQ3 = 1,827 G, HQ4 = 1,607 G.

Ion-Optics 4:





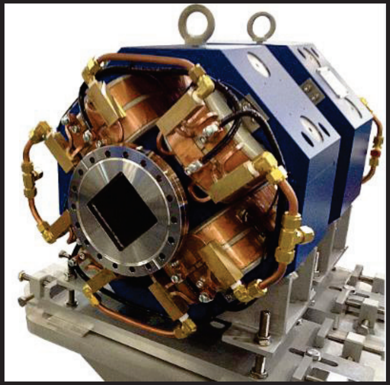
10rms, 2x 10rms, 3x 10rms Emittances used to yield Horizontal and Vertical beam envelopes can pass through the bending magnet's 0° thru port to yield up to a 100 mm beam spot according to AccSys' needs. This provides reasonable overhead to ensure that beam losses will be < 1% for 2.5 MeV protons (i.e. apertures confirmed). The quadrupole magnet settings are as follows:

1x 10 rms Emittance Beam: HQ1 = 3,306 G, VQ2 = 2,105 G
2x 10 rms Emittance Beam: HQ1 = 3,116 G, VQ2 = 1,985 G
3x 10 rms Emittance Beam: HQ1 = 3,026 G, VQ2 = 1,934 G

HEBT Beamline 1:
Ion-Optical Elements (Magnetic)

(1) Upstream Quadrupole Doublet:	**Bore** = 82.3 mm	**Effective Length (EL)** = 202.3 mm	B_{Max} = 0.4 T
(2) DC XY Steering Magnet:	**Iron Gap** = 105 mm	**EL** = 184 mm	B_{Max} = 0.01 T
(3) 90° Bender Magnet:	**Iron Gap** = 52 mm	**EL** = 300 mm	B_{Max} = 1.3 T
	Pole Face Rotations = 0°	**Pole Shape** = Rogowski	
(4) Downstream Quadrupole Doublet:	**Bore** = 82.3 mm	**EL** = 202.3 mm	B_{Max} = 0.4 T
(5) AC XY Scan Magnet:	**Iron Gap** = 97 mm	**EL** = 212 mm	B_{Max} = 0.0165 T
	Frequency = <100 Hz		

All magnets designed with alignment fiducials for Ball Mounted Reflectors (BMR) used with laser tracker.



1,4

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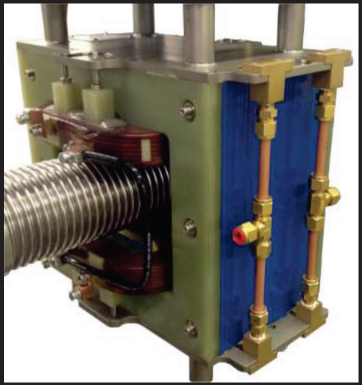

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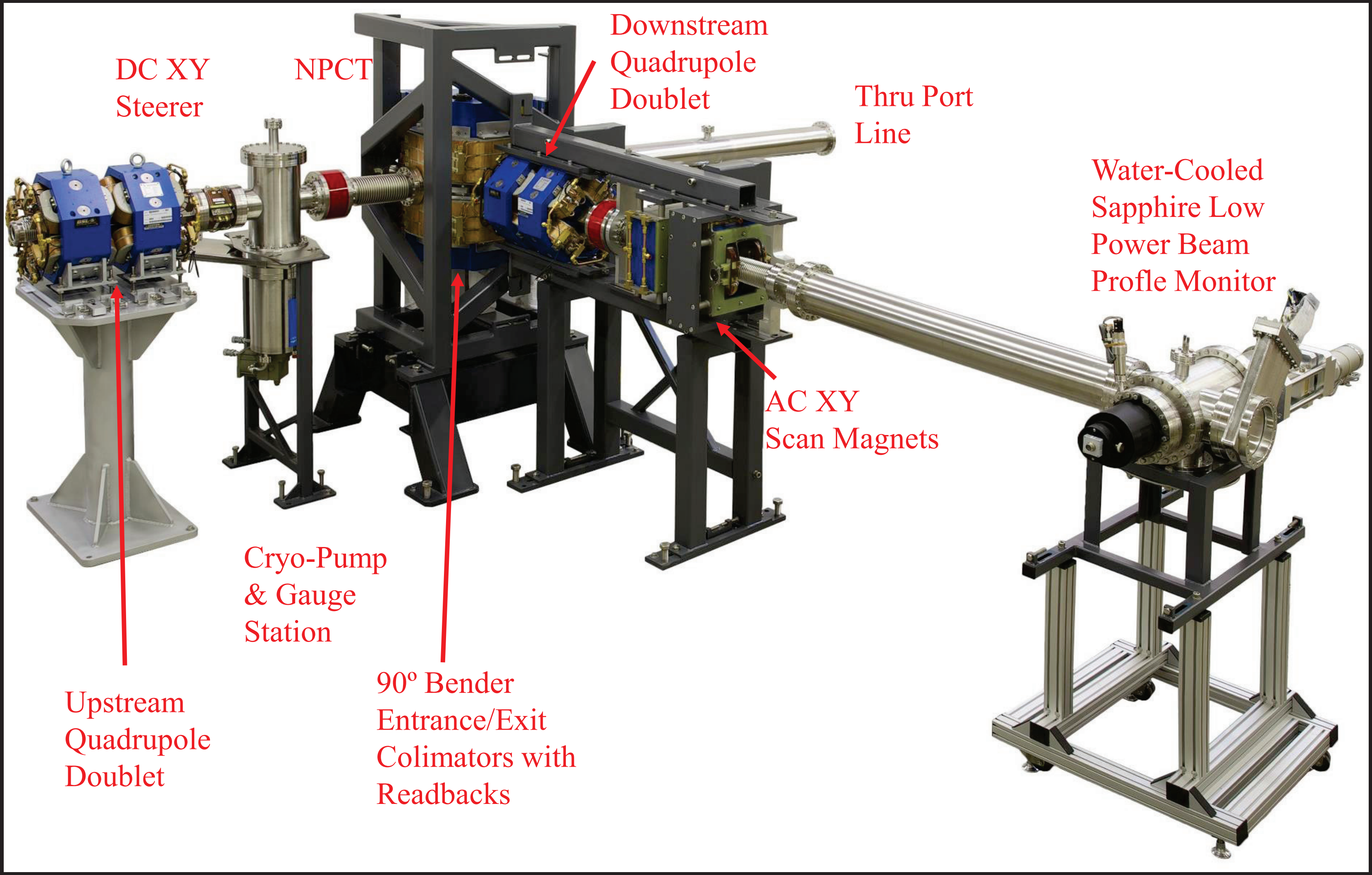
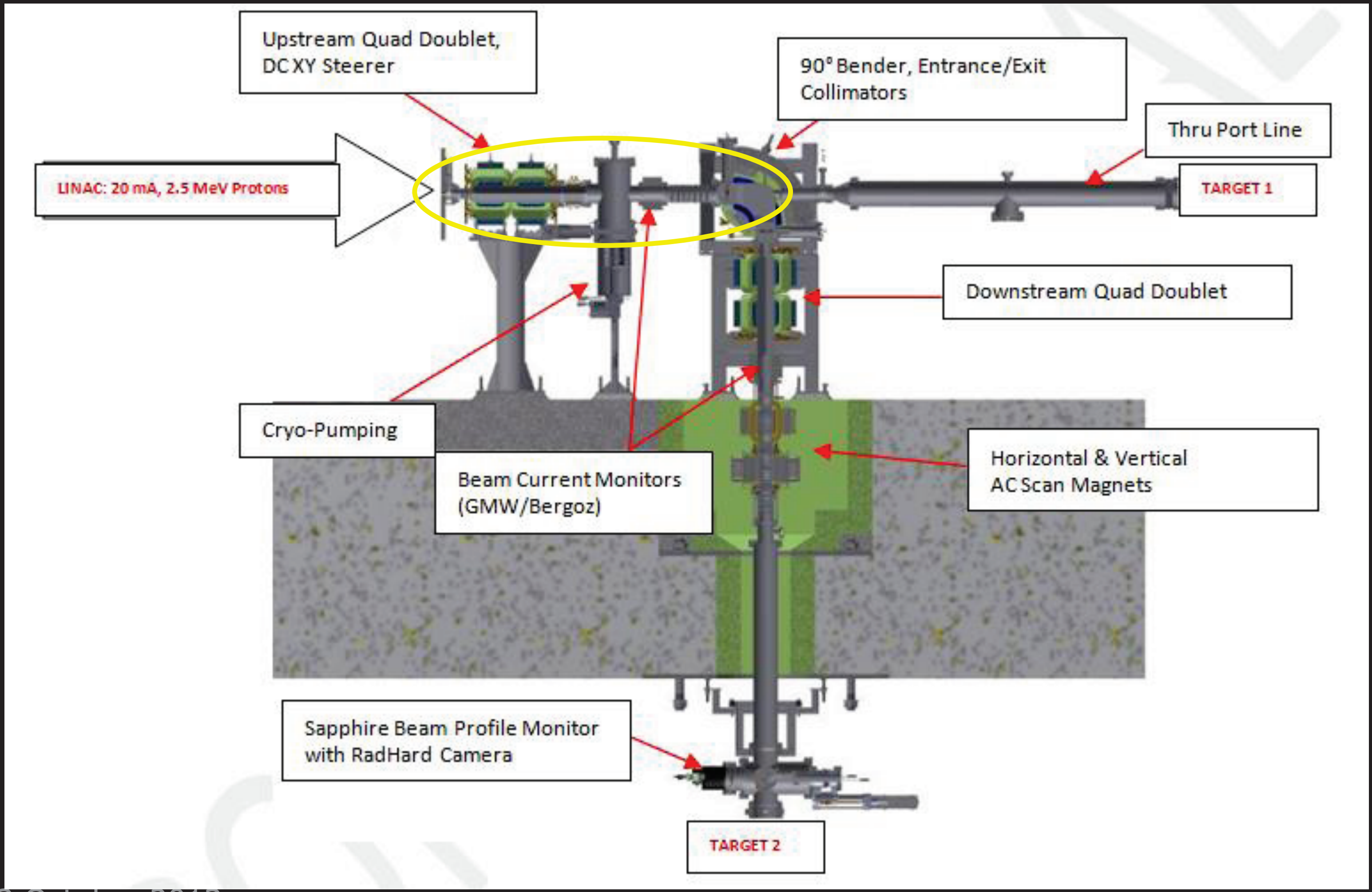
HEBT Beamline 2:

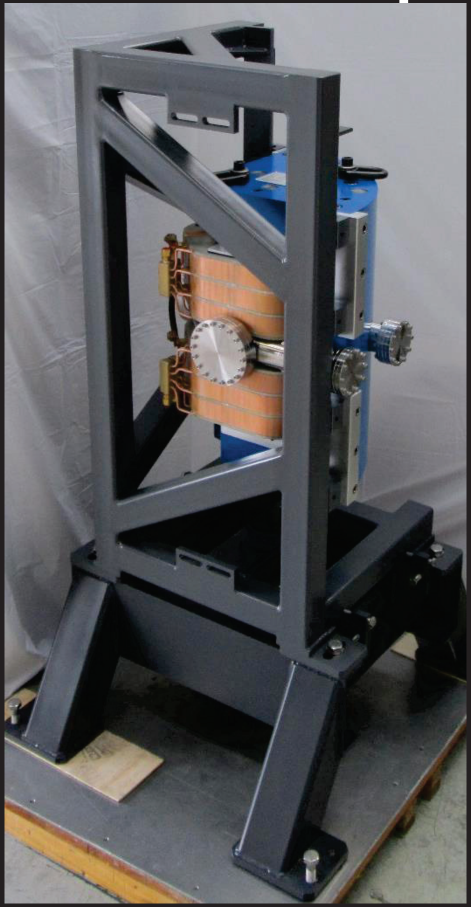


HEBT Beamline 3:
Upstream Horizontal Section

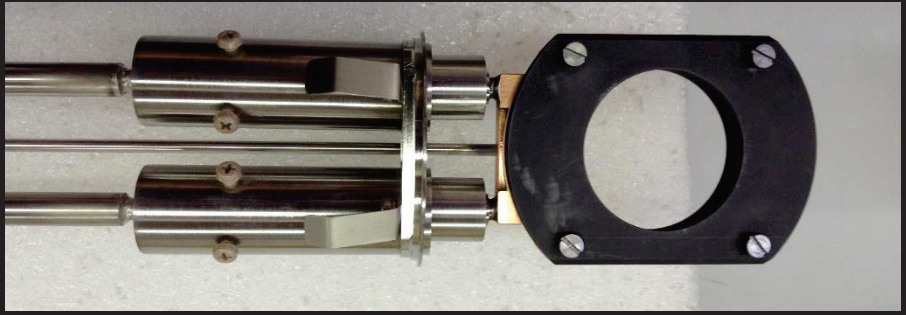


HEBT Beamline 4:
Upstream Horizontal Section

HEBT Beamline 5:
Upstream Horizontal Section - Bender

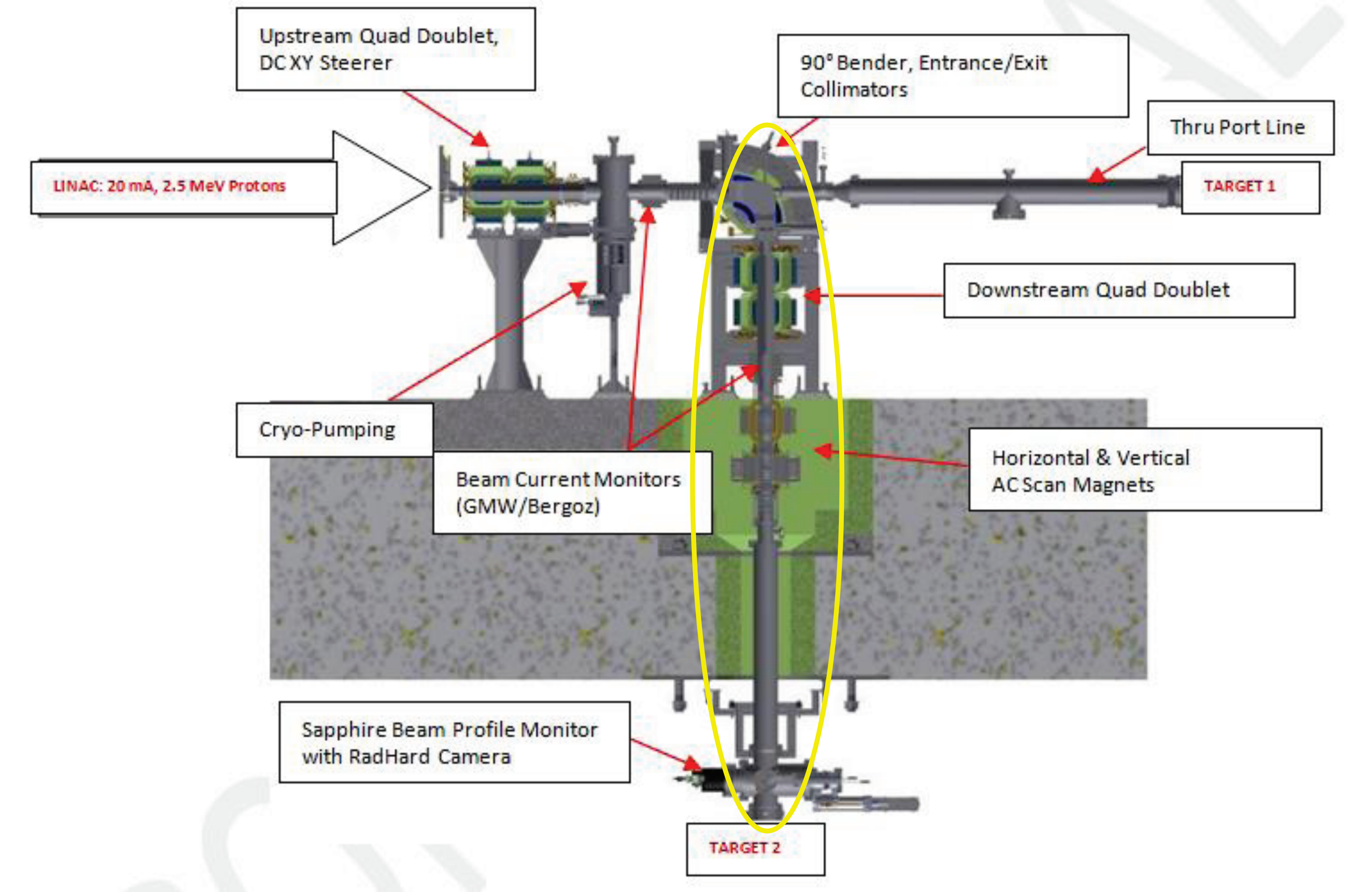


Bender
Vacuum
Box

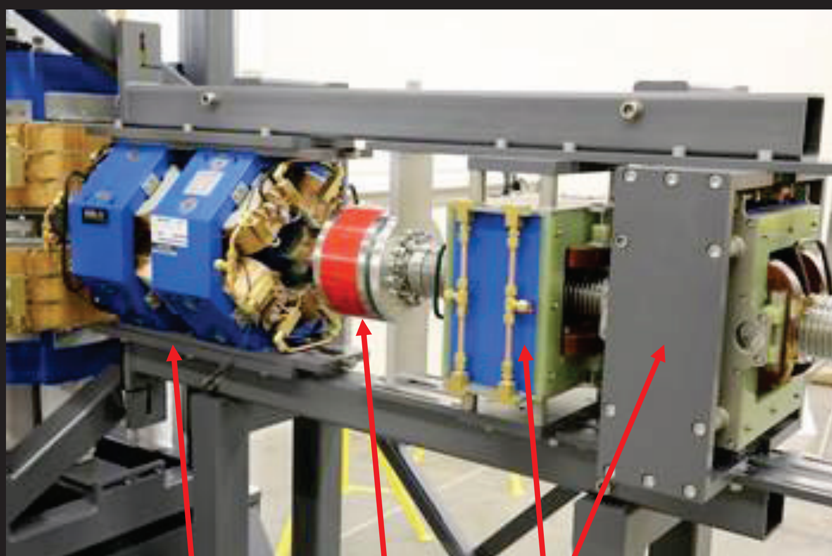


Bender
Entrance/Exit
Collimator

HEBT Beamline 6:
Downstream Vertical Section



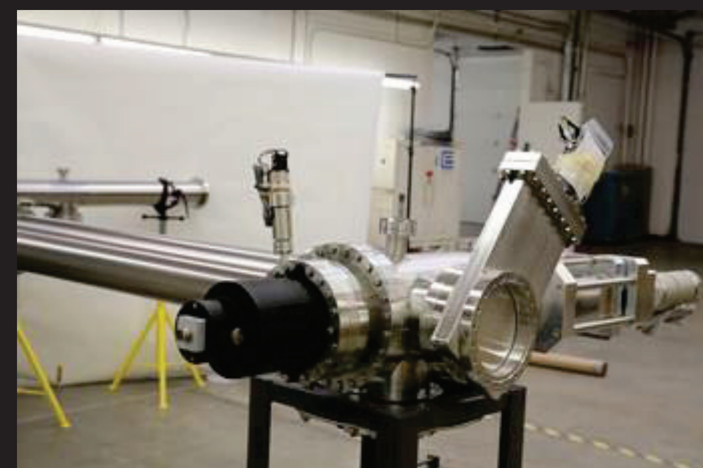
HEBT Beamline 7:
Downstream Vertical Section



Quadrupole Doublet

NPCT

XY AC Scan Magnets



Low Power Sapphire Beam Profile Monitor

HEBT Beamline 8:
Generic Target Distributions

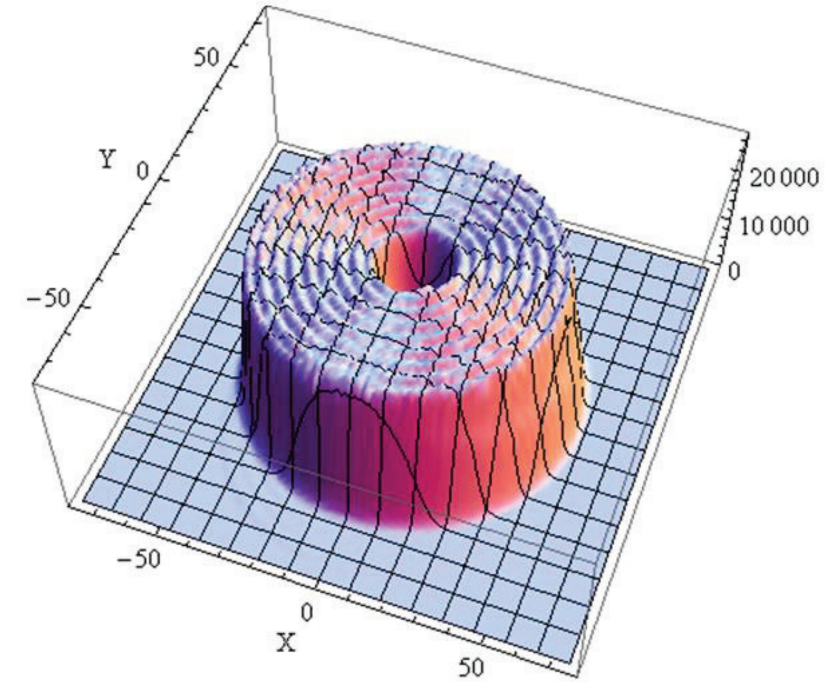


Figure 8: Beam density for radius varying from 5 mm to 45 mm. 10 rms beam spot diameter = 10 mm.

Generic Circular Beam Intensity Distribution

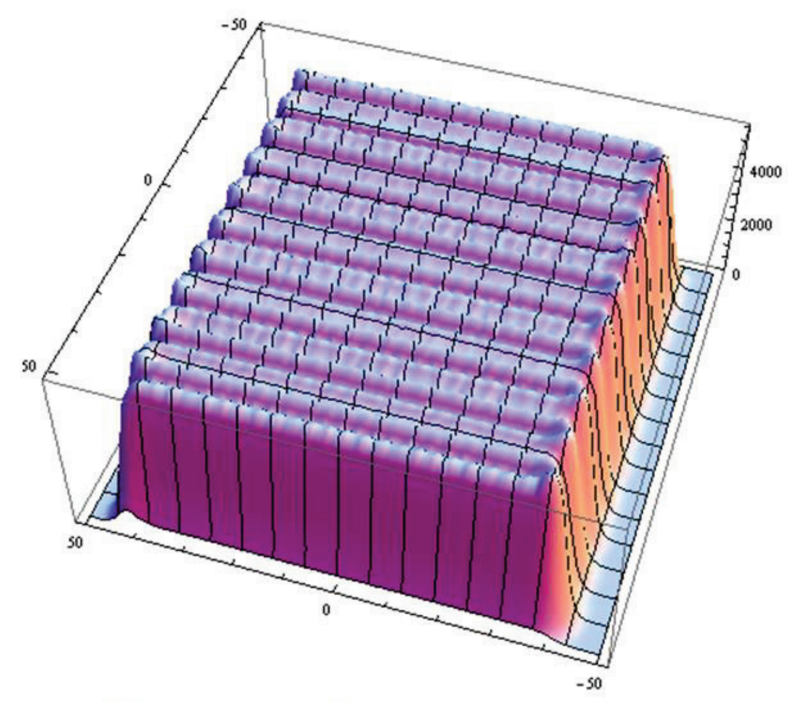


Figure 16: Beam density distribution for XY scan with 10 mm diameter 10 rms beam with 4.5 mm spacing in Y.

Generic Rectangular Raster-Scanned Beam Intensity Distribution

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THE END

Thank You Very Much