A New Center for Heavy Ion Therapy & Research in the US

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March 20, 2024
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Motivation

Progress in cancer therapy with ions heavier than protons, i.e., helium, carbon, oxygen and even neon, requires research and development capability. Ion research activity, however, is limited from the absence of U.S. accelerator facilities offering ion beams for therapy – placing the U.S. significantly behind Europe and Asia. A new center for ion therapy research is under development in Waco, TX, in collaboration with established accelerator entities, both academic and industrial, along with medical partnerships. The advanced technologies will produce both clinical and research beams, offering a complete range of ions, intensities and energies required by the medical community, including the capability to perform groundbreaking, ultra-high dose (FLASH) therapy research.

With dramatic advances in beam delivery, patient treatment, and next generation accelerators,

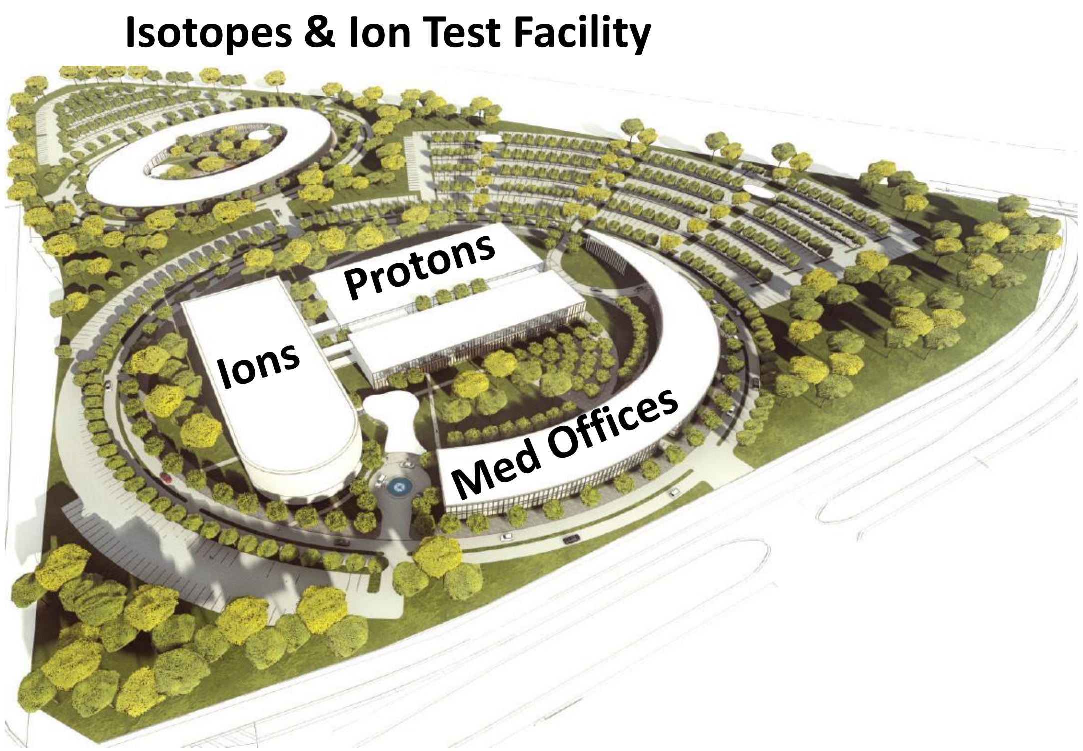
THIS UNIQUE FACILITY will restore US leadership in CANCER therapy and research.

Collaborating Institutions: MDAnderson, Fermi National Accelerator Lab, Brookhaven National Lab, Crocker Nuclear lab, Lawrence Berkeley National Lab, UCDavis, Michigan State University, Baylor University, Particle Accelerator Corporation, Radiabeam Technologies, TechSource, Kumata-N-Tech, NIRS, Sumitomo

Optimizing a broad-community ion user facility

The Ion Campus - Overview

- ***Proton and Heavy Ion Radiotherapy***
  - Protons in a separate facility (230 MeV therapy cyclotron)
  - Heavy Ion Beam Facility
    - All therapy ions supported – including protons - oxygen and neon
    - Priority: *helium and carbon therapy (deuterons for imaging)*
    - FLASH capable
    - Ions for material science (DOD, DARPA, Space applications)
  - Operation:
    - Turnkey, min operational overhead
    - Low maintenance and low health risk
- ***Theranostics Radioisotope production & Ion Test Facility***
  - Commercial radioisotope machines
  - Future area reserved for dedicated ion beam R&D facility



Outline

1. Proton and Heavy Ion Radiotherapy including FLASH radiotherapy overview
2. Overview of Accelerators and operating parameters (conventional)
3. Modular Approach to support broad-community therapy and research
    1. Multi-ion Source (two or more sources with different ions)
    2. Radio Frequency Quadrupole (RFQ) ultra-low energy module – for cell research
    3. Low Energy Module (compact cyclotron) – for Radiobiology research
    4. Medium Energy Module (cyclotron) – Radiotherapy for eye and skin cancers
    5. Ion Therapy Module (Fixed Field Gradient Accelerator, FFGA) – Heavy ion radiotherapy
4. Center for Particle Beam Therapy
    1. Facility layout
    2. Renderings
5. Summary

Cancer Radiotherapy

~2/3 OF US CANCER PATIENTS UNDERGO RADIATION THERAPY

Advances driven by new accelerator technologies

PHOTON AND ELECTRON BEAM THERAPY – used to treat the majority of cancer patients

- High radiation dose to healthy tissue (cure limited by toxic side effects)
- Secondary Cancers and no retreatment

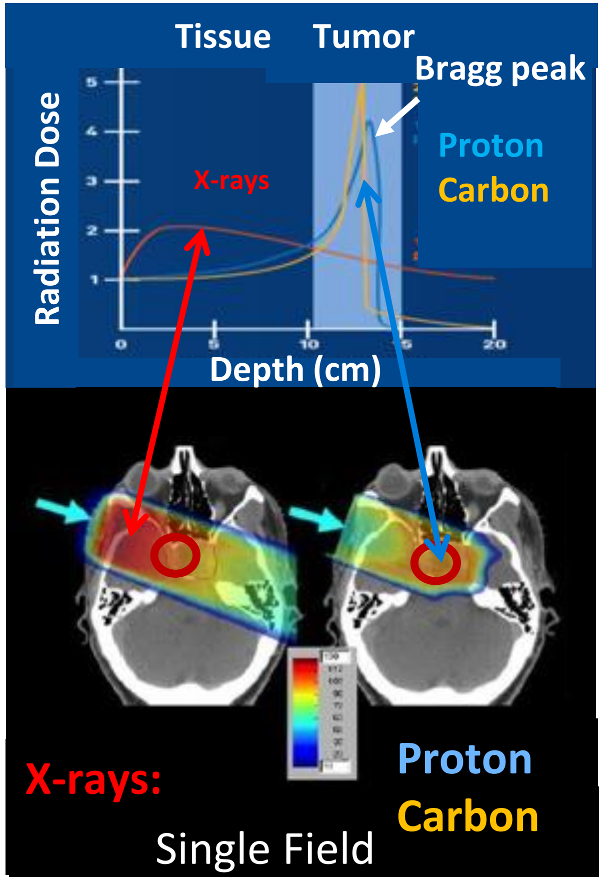
PROTON AND ION BEAM THERAPY

- Precision targeting and increased tumor kill with ions (He & C)
  - Bragg peak protects normal tissue and radio-sensitive organs (brain and spinal cord)
- Critical for pediatric tumors and retreatment

FLASH THERAPY: GROUNDBREAKING!

- Acute dose of particle radiation (x5-10 increase) delivered in a fraction of a second
  - Preclinical trials: dramatic reduction of toxicity and death of normal tissue
  - Increased tumor kill/ ***Complete remission in recurring cancer (T-cell lymphoma)***
  - ***Triggers an immune response to cancer – metastases can be successfully treated***

[1] Bourhis J, et al. doi: 10.1016/j.radonc.2019.06.019



Ions are Unique

Ions have a much higher radiobiological effect (x2-4) relative to photon and proton radiotherapy. They can successfully treat cancers that are not treatable using photons (due to radiation toxicity) or cancers uncurable with protons. Ion beams also have significantly increased precision targeting capability critical for pediatric cancers.

Ions uniquely treat:

- Pediatric cancers – helium ions are a priority with MDAnderson/Mayo
  - not generally treatable with photons due to normal tissue damage (growth plates, for example)
  - ion therapy is more precise than proton therapy – avoids damage to sensitive organs: brain and spinal chord
- Gliomas (Beau Biden, John McCain, Ted Kennedy)
- Non-squamous head and neck malignancies
- Mucosal melanomas
- Chordomas and chondrosarcomas of the skull base and spine/sacrum
- Sarcomas
- Pancreatic and hepatic carcinomas
- Lung Cancers
- Renal cell carcinoma
- Locally unresectable tumors – advanced breast cancer and advanced or recurrent pelvic malignancies are two common uncurable cancers

Carbon and He Radiotherapy – Japanese clinical data

Tumors not treatable with Conventional Photon or Proton Radiotherapy

- Advanced Head and Neck tumors
- Large skull-based cancers
- Recurrent post-op rectal cancer and inoperable sarcomas
- Re-irradiation (retreatment) after conventional photon therapy

“Hypofractionated” treatments possible with ions – fewer no. of sessions

- *Reimbursement schedule competitive with conventional photon radiotherapy*
- Lung cancer – remission in single treatment session *vs 30 with protons*
- Liver cancer – remission in 1-2 treatment sessions *vs 30 with protons*
- Pancreatic Cancer – remission in 8-12 treatments *vs 30 with protons*
- High-risk Prostate cancer – remission in 12-16 treatments *vs 30 with protons*

FLASH – a groundbreaking modality in cancer treatment

FLASH targets radiobiology of tumors not healthy tissue

- **Enhanced protection of normal tissue, reduced side effects**
  - Many beam delivery questions
- ***FLASH requires state-of the art Accelerator Technologies***
  - *Clinical FLASH beams require high duty cycles or CW beams*
  - *Diagnostics and accurate dose deposition highly challenging*
  - *Cyclotrons and clinical electron linacs highly limited for FLASH R&D*
    - Clinical linac electron beams can only penetrate a few cm
    - FLASH requires ultra-high, instantaneous intensity continuous beams
    - Only CW proton beams achieve FLASH intensities (from iso-cyclotrons, no energy degrader)

FLASH IS IN THE PRE & CLINCAL TRIAL STAGE for specific cancers

Conventional Accelerators for ions (KE/nucleon)

Synchrotrons *(>100 MeV – TeV/n energies)*

- Pulsed: changing magnetic fields (0.5-50Hz rep rate)
- Swept-frequency accelerating systems
- Current limited by size
- Variable energy

Cyclotrons *(~10 MeV – 100 MeV/n CW)*

- Fixed magnetic fields
- For CW beams, fixed-frequency accelerating system
- Higher energies:
    - ***Very large at higher energies for CW beam or***
    - ***Pulsed synchrocyclotron for compact footprint (swept freq RF)***
- mA currents for CW; *fixed energy (per charge to mass)*

Linacs *(any energy)*

- Largest footprint, most costly
- Ultra-high currents – 100 mA
- Variable energy @ *synchrotron duty cycles*

Gradient Cyclotrons/FFGAs (~10 MeV – 2 GeV/n)

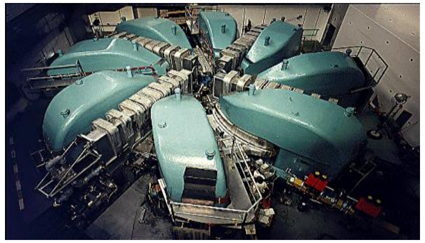
- Fixed magnetic fields, (Fixed Field Gradient Accelerator, FFGA)
- CW (fixed freq RF) or kHz pulsed beams to high energy
- Most compact @≥100 MeV/n
- High current , *FFGA can support variable energy extraction*

Synchrotron

Low Current (<mA), High Energy, Hz pulsed

Cyclotron

High Current (<Amp) Low Energy (600MeV), CW or kHz pulsed

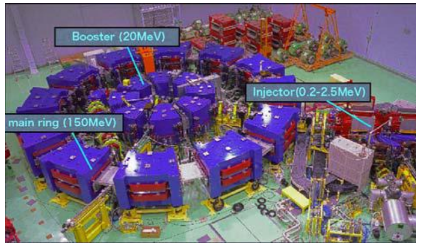


Linac

High Current, High Energy, Pulsed or CW: Large, expensive, high power if not superconducting

FFGA

High Current (<Amp), High Energy (GeV), CW or pulsed, compact



Energy Reach of Ion Accelerator Types (approximate)

- Ion therapy energies require up to 250 MeV/nucleon for helium and 430 MeV/nucleon for carbon
- Beyond ~150 MeV/nucleon, the size & cost of a cyclotron increases dramatically. The next-generation Fixed Field Gradient accelerator developed for this facility reduces the size and cost of the therapy machine by half compared to cyclotrons. (Current commercial ion therapy machines are low dose synchrotrons without FLASH capability.)

< MeV/n

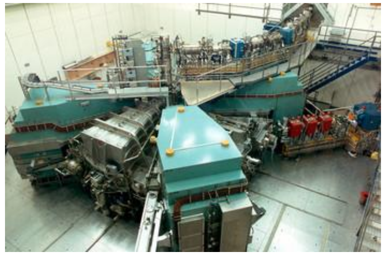
Tandems (large), RFQs,
Cockcroft Waltons (very large)

few MeV/n

CW/pulsed:
Drift Tube linac
Lowest losses
Cyclos have high central region losses (40-80%) for CR vertical axis injection

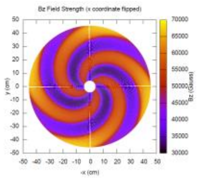
≤50 MeV/n

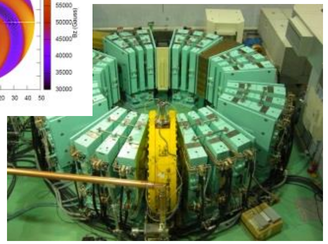
CW:
Sector iso-cyclotron (PSI Injector)



≤150 MeV/n

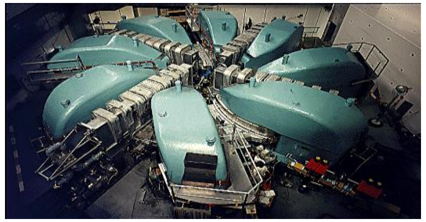
CW:
AVF cyclotrons and gradient cyclotrons
Pulsed:
synchrocyclotrons and conventional FFGAs





≤1 GeV/n

CW:
AVF cyclotrons (very large),
FFGAs (nonscaling, compact)
Pulsed:
synchro- cyclotrons and scaling FFGAs

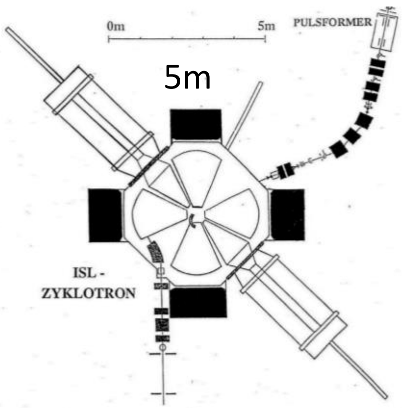


Multi-GeV – TeV/n

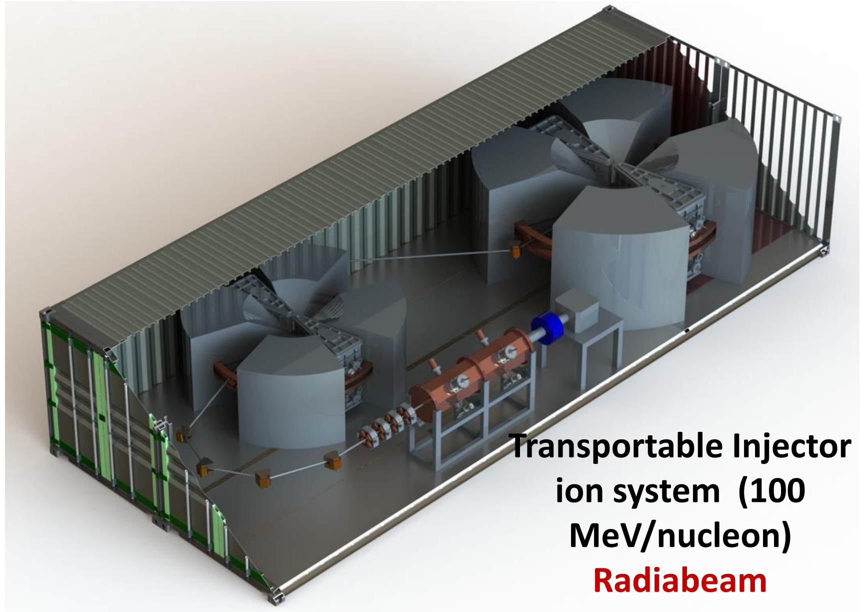
Pulsed:
Synchrotrons (<100 Hz duty cycle)

Modular Approach to Accelerator Systems – each module produces research and clinical beams including FLASH

- ***Continuous (CW) and Variable energy Beam for FLASH***
  - *Eliminates all current ion therapy accelerator facilities*
- ***Compact Machine Modules***
  - *Eliminates linacs*
  - *Requires high-gradient Radiofrequency (RF) acceleration:*
    - *eliminates broadband RF (Texas A&M and LBNL ion cyclotrons)*
- ***Low Maintenance/Low personnel risk***
  - *Eliminates compact (AVF) cyclotrons (high beam loss)*
  - *High gradient (fixed frequency) acceleration system*
- ***Turnkey** – min complexity = min operational overhead*
  - *Eliminates superconducting*
  - *MODULAR: RFQ, low & med energy cyclotrons, therapy FFGA*
    - Simplifies accelerator operation and the design of each module
    - Modules transportable
    - Lower energy modules support heavier ion beams for material science



HZB ion cyclotron:
10 m diameter with broadband RF tuner



Transportable Injector ion system (100 MeV/nucleon)
Radiabeam

Module 1:

0.4 - 4 MeV/nucleon

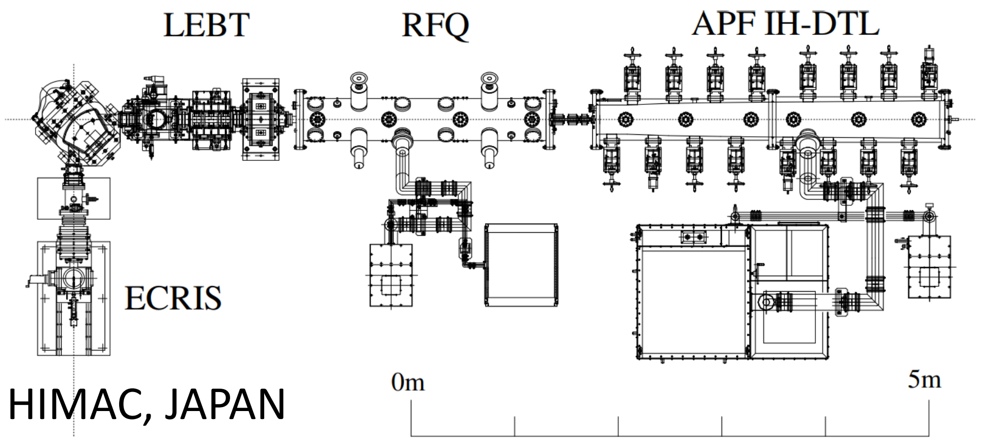
Low energy ion beams for cell and mice research

- Conventional and FLASH dose delivery
- Cell radiobiology
- Ion and dose R&D for specific cancers (cell response)
- Skin cancer research – potentially melanoma therapy

Description of Equipment (existing)

- Sumitomo Compact ECRIS ion source
  - Collaboration with NIRS, Japan for a FLASH source
- Two independently tunable RFQs in single module
  - Originally ion injector to HZB cyclotron, Berlin
  - Capable of accelerating therapy and heavier ions

Length (split into two stages) [m]	3
diameter [m]	0.5
number of stems per stage	10
minimum aperture [mm]	2
min/max Ein [keV/u]	15.16/29.72
min/max Eout [keV/u]	178.35/355.09
charge-to-mass-ration	1/8 - 1/2
frequency [MHz]	85 - 120
duty factor	100% (cw)
max power consumption p. stage [kW]	20



Radiobiology, Eye/skin, Therapy and Research beams

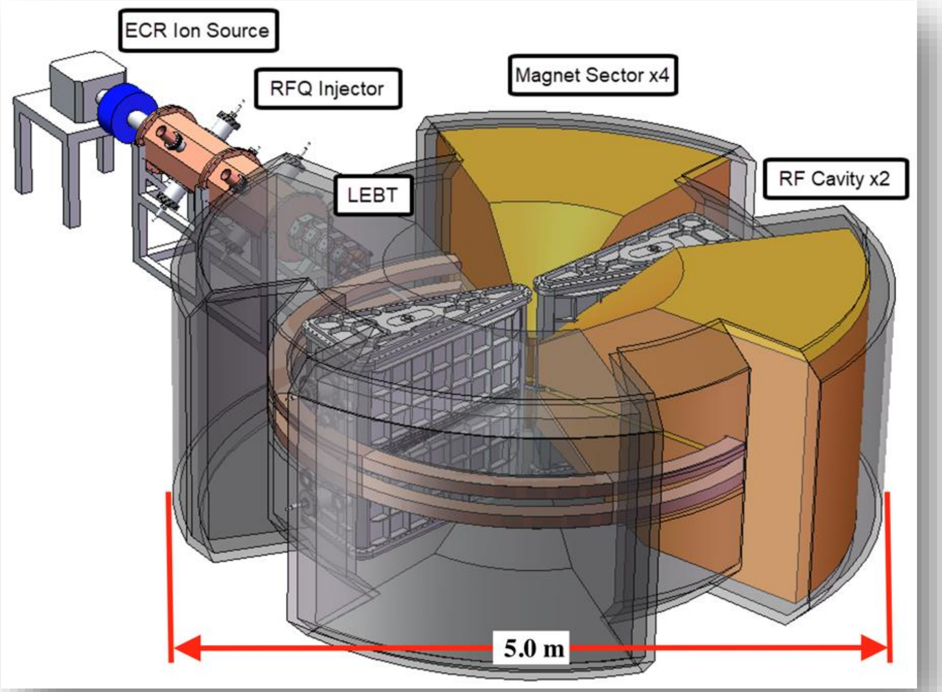
Low Energy Module 2	Medium Energy Module 3	Therapy Module
Sector CW Cyclotron 4 – 24 MeV/nucleon (q/m=1/2)	**Sector CW Cyclotron 24 – 100 MeV/nucleon** (q/m=1/2)	**Fixed Field Gradient Accelerator (CW FFGA) 100-250 MeV/nucleon** therapy energy ions (q/m=1/2)
low-loss horizontal injection	Low loss horizontal injection	Nonlinear, alternating gradient strong focusing isochronous racetrack lattice
RF ~50 MHz, 8^{th} harmonic for q/m=1/2	RF identical to LE Cyclotron 8^{th} harmonic for q/m=1/2	Long straight for variable energy extraction *(no bulk energy degrader)*
Booster accelerator required between RFQ and cyclotron	Cyclotrons RF matched and cogged (8^{th} harmonic)	Long straight for high-gradient acceleration modules
Dual Extraction: Radiobiology beamline	Dual extraction: Eye/skin therapy line and clinical research	Gantry and Leo Chair for beam delivery

LE Cyclotron Module 2:
4 - 24 MeV/nucleon

Iso-cyclotron for research and low-energy therapy
- Conventional and FLASH dose delivery
- Radiobiology and small animal research including FLASH
- Shallow tumors – therapy
- RF supports lower charge to mass ions/lower energies

Cyclotron Development
- Conventional iso-cyclotron - FLASH capable
  - Multi-ion and variable energy steps
  - Design well advanced
- Dual port extraction
  - Supports two treatment/research rooms

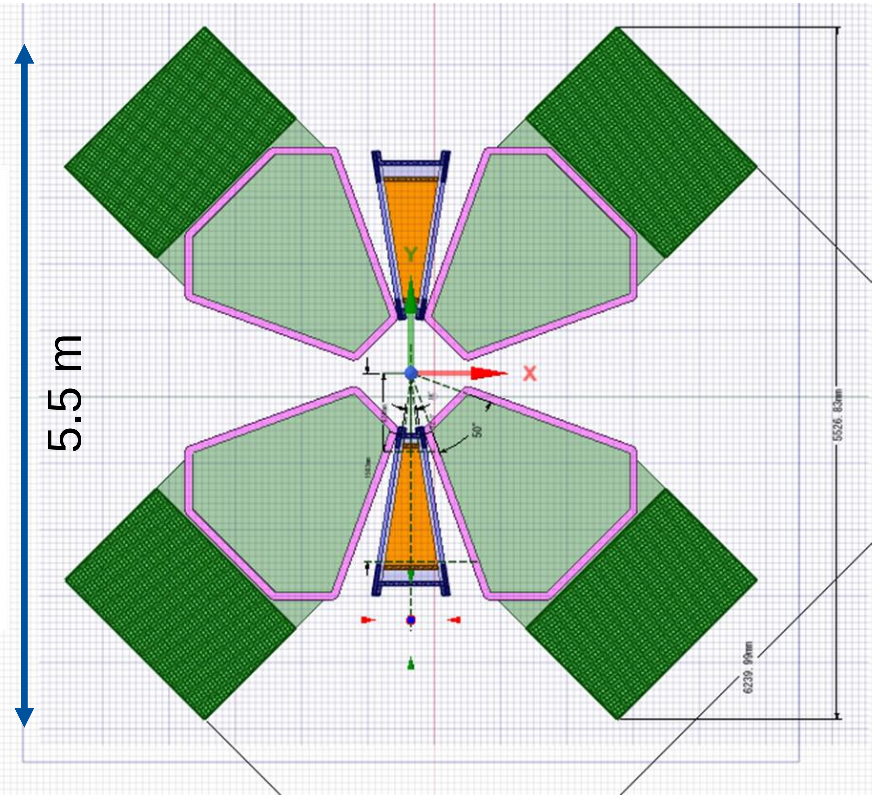
Energy per nucleon	q/A	harmonic	Ions
2.6 MeV	1/6	24	TBD B^{2+}, C^{2+}, $^{30}Si^{5+}$
6 MeV	1/4	16	He^{1+}, B^{3+}, C^{3+}, O^{4+}
10.7 MeV	1/3	12	B^{4+}, C^{4+}, N^{5+}, O^{5+}
24 MeV	1/2	8	H_2^{+}, C^{6+}, He^{2+}, N^{7+}, O^{8+}, Ne^{10+}, Si^{14+}



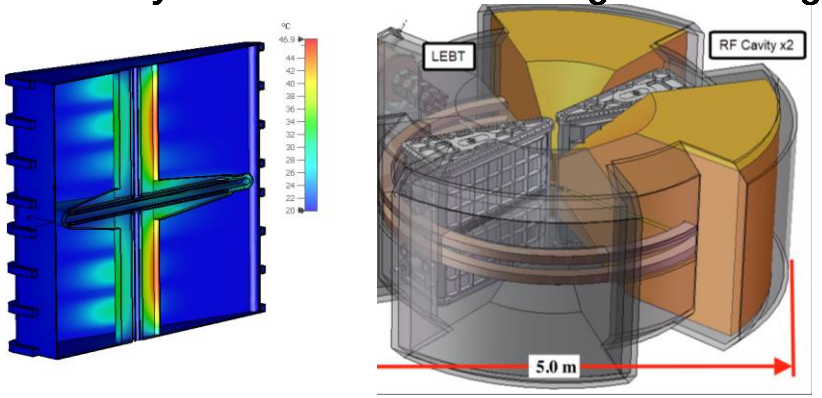
LE cyclotron – conventional cyclotron design

- **Conventional cyclotron** (weak focusing dipole field) – 24 MeV/u max extraction energy
  - Can be split across two conex containers
  - Individual magnet coils on a main power bus
- **Magnet and RF engineering underway**
  - Circular coil interfered with high-gradient cavities
  - ANSYS magnet design will start after HE cyclotron magnet engineering

Energy per nucleon	q/A	harmonic	Ions	LET approx
0.6 MeV	1/12	48	TBD – off of RFQ	
2.6 MeV	1/6	24	B^{2+}, C^{2+}, $^{30}Si^{5+}$, $^{36}Ar^{6+}$, Co^{10+}, Cu^{11+}, Kr^{14+}, Xe^{22+}	43-180
6 MeV	1/4	16	He^{1+}, B^{3+}, C^{3+}, O^{4+}, Ne^{5+}, Si^{7+}, S^{8+}, Ca^{10+}, $^{36}Ar^{9+}$, V^{13+} Co^{15+}, Cu^{16+}, Kr^{22+}, Xe^{33+}	TBD
10.7 MeV	1/3	12	B^{4+}, C^{4+}, N^{5+}, O^{5+}, Ar^{6+}, Al^{9+}, Ne^{7+}, Cl^{12+}, Si^{10+}, V^{17+}, Co^{20+}, Cu^{21+}, Kr^{29+}, Xe^{44+},	0.84-52.7
24 MeV	1/2	8	H_2^{+}, He^{2+}, N^{7+}, O^{8+}, Ne^{10+}, Si^{14+}, $^{32}S^{16+}$, $^{36}Ar^{18+}$, Ca^{20+}	0.3-4.3



Prelim Layout for mechanical design of LE stage



Engineering examples of of LE stage

HE Cyclotron: Medium Energy Module 3 – low energy radiotherapy

Medium energy ion beams for eye/skin therapy and research

Both FLASH and conventional dose capability and dedicated beamline for shallow cancer therapy and research.

Advanced gradient cyclotron design

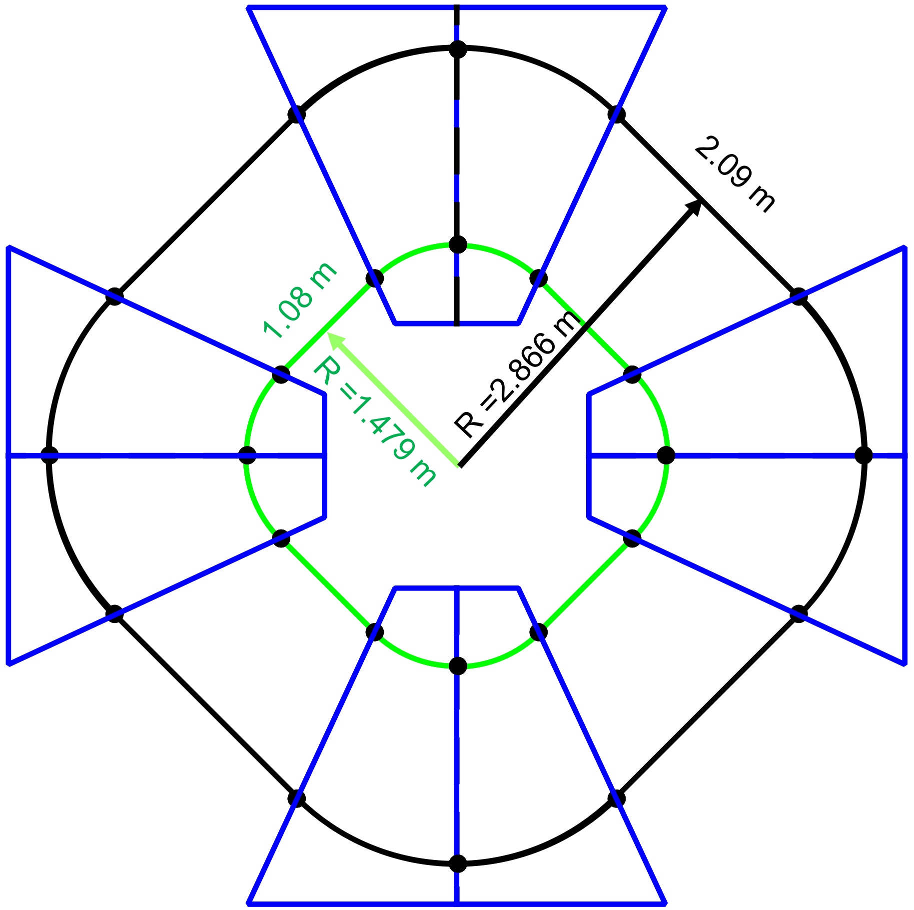
Turnkey, continuous-beam operation @100 MeV/nucleon. Hardware systems under development. Controls and operation integrated with Low Energy cyclotron Module. Significantly smaller machine components and cost than a combined LE/ME single machine.

Strategic high energy ion beams

Higher energy ion test beams specifically targeted for development by space agencies for SEE testing. Currently pulsed high energy ion beams only available at Brookhaven National Lab from the AGS synchrotron. Beam time is highly oversubscribed.

Higher energy heavier ion species supported

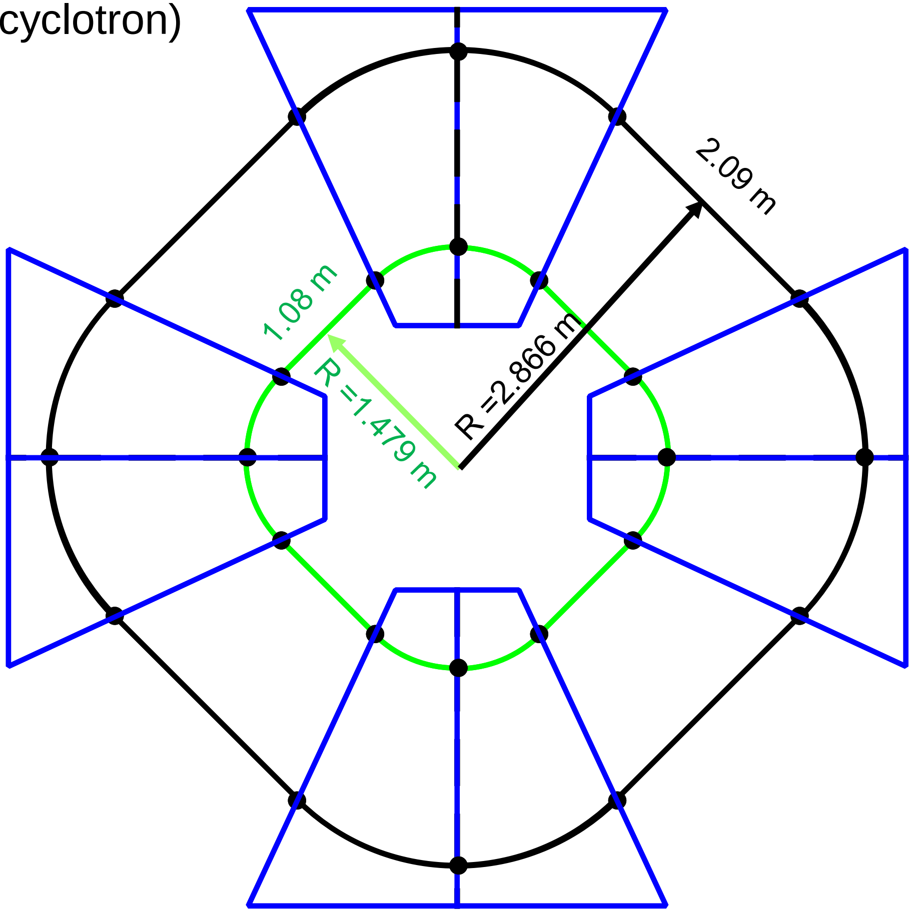
Higher energy heavier ion test beams >50 MeV/nucleon are specifically targeted for development by Aerospace Institutions/ Industries



Preliminary geometry of HE ring

HE Cyclotron: Gradient vs conventional

- **Gradient CW cyclotron** (strong-focusing field gradient plus constant dipole field)
  - Gradient radial field reduces aperture, size, and weight (vs conventional iso-cyclotron)
  - Gradient (strong-focusing) field increases beam stability
- Full Magnet design in progress –
  - 6 cm gap (2 cm trim coils 4 cm beam gap)
  - Circular coil again not supported due to interference with RF cavities
- RF cavity design (2D) – frequency (~50.6 MHz, 8th harmonic for q/m=1/2)
  - HE cyclotron sets the RF frequency for LE cyclotron
  - *Critical for turnkey operation – all stages timed, under identical RF controls*



Preliminary geometry of HE ring

Ions and energies supported

Energy/nucleon	q/A	harmonic	Ions
10.7 MeV	1/6	24	LE Cyclo – not supported
24 MeV	1/4	16	He^{1+}, B^{3+}, C^{3+}, O^{4+}, Ne^{5+}, Si^{7+}, S^{8+}, Ca^{10+}, $^{36}Ar^{9+}$, V^{13+} Co^{15+}, Cu^{16+}, Kr^{22+}, Xe^{33+}
42.7 MeV	1/3	12	B^{4+}, C^{4+}, N^{5+}, O^{5+}, Ar^{6+}, Al^{9+}, Ne^{7+}, Cl^{12+}, Si^{10+}, V^{17+}, Co^{20+}, Cu^{21+}, Kr^{29+}, Xe^{44+},
96 MeV	1/2	8	H_2^{+}, He^{2+}, N^{7+}, O^{8+}, Ne^{10+}, Si^{14+}, $^{32}S^{16+}$, $^{36}Ar^{18+}$, Ca^{20+}

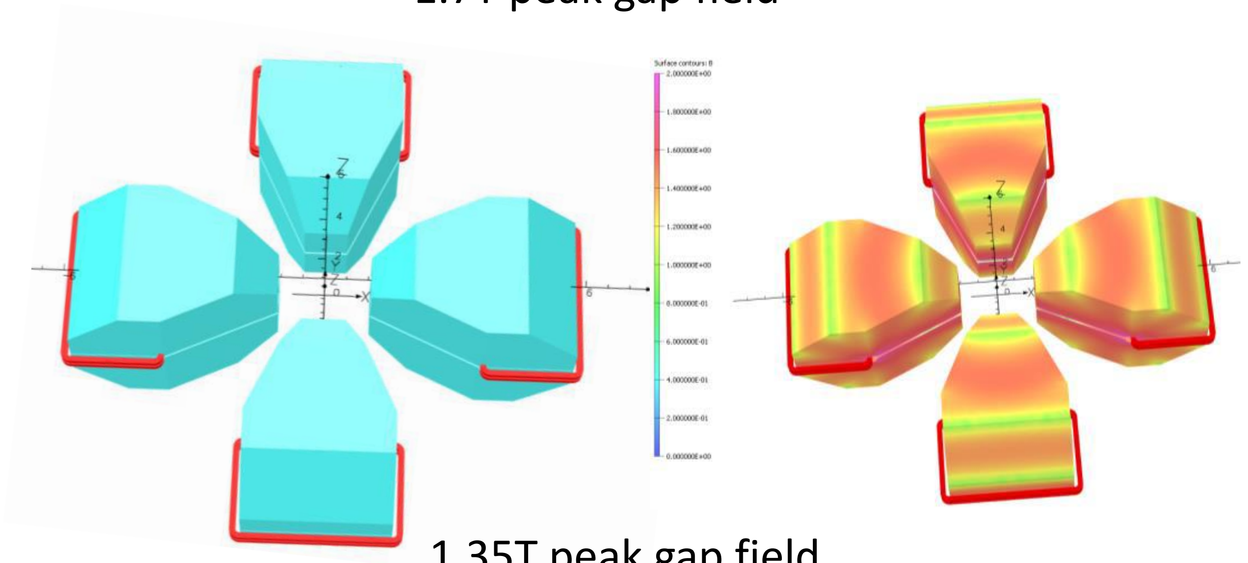
HE Cyclotron – Coil and Magnet Design

RadiaBeam

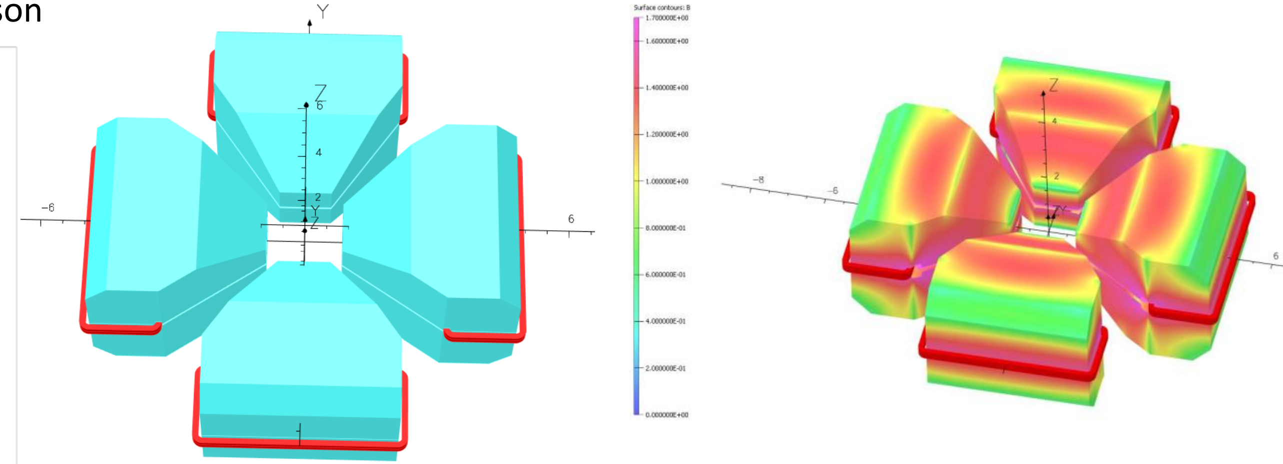
The magnet has a 60 mm gap and to obtain the specified field the total current in the coil should be 50 kA. However, the parts of the iron core saturated to the field above 2 T for the 1.7T peak field version (right top picture).

Reducing the peak field in the gap to 1.35T reduced the saturation to <1.7T and reduced the outer radius of the yoke (right pictures).

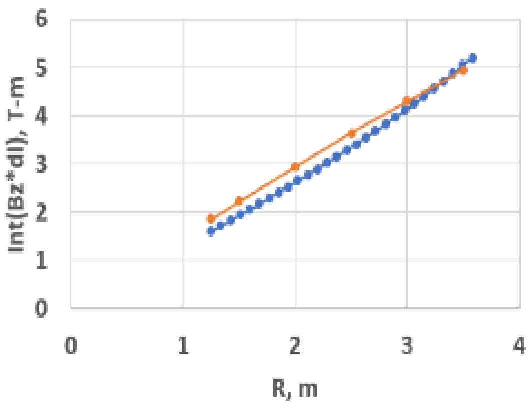
1.7T peak gap field



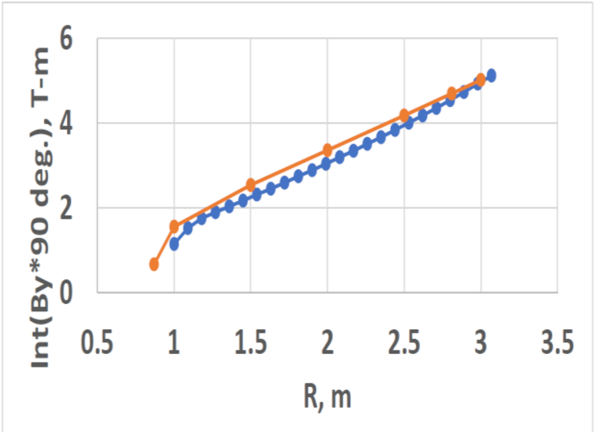
1.35T peak gap field



1.7T peak integrated field comparison

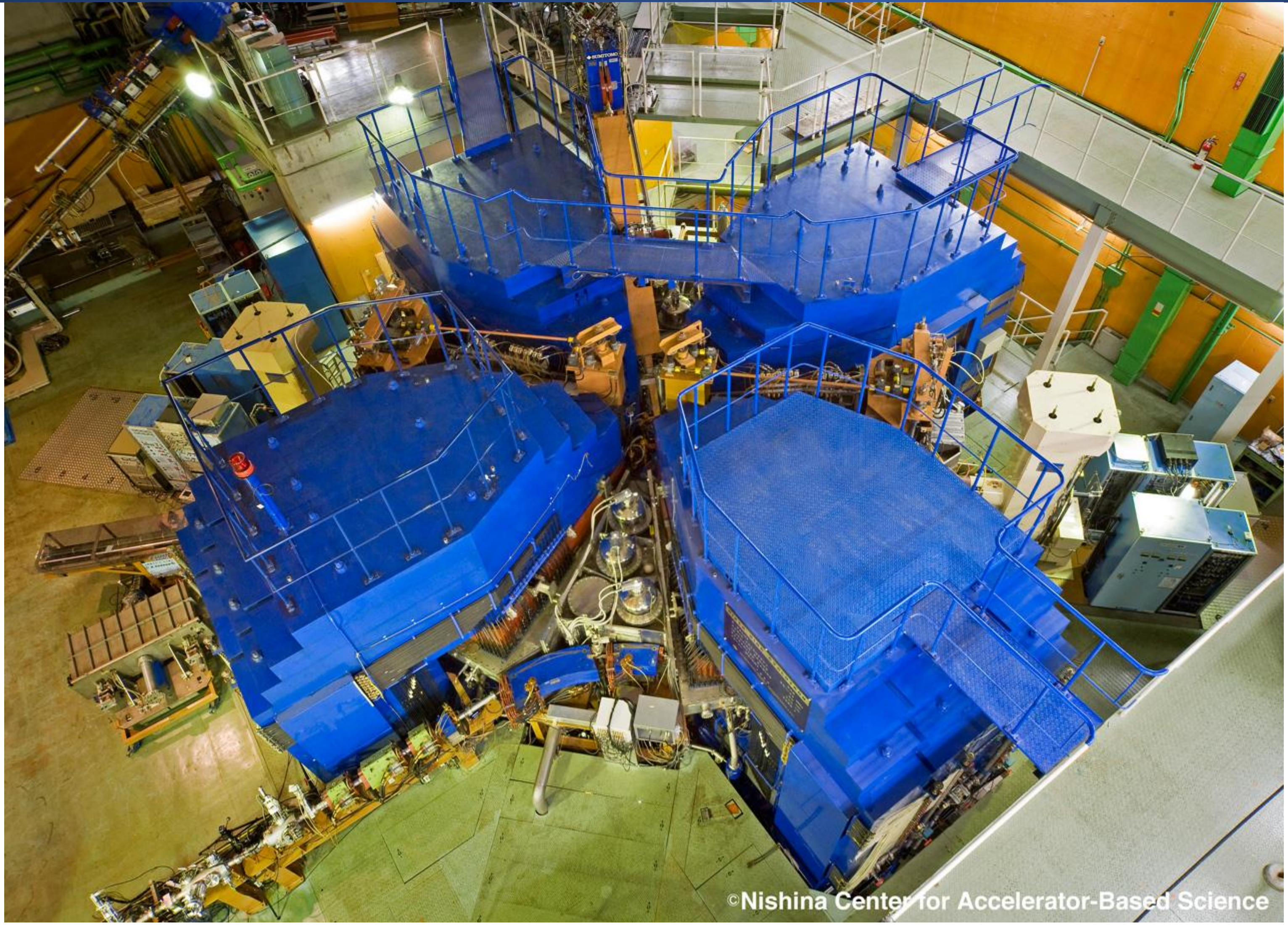


1.35T peak integrated field comparison

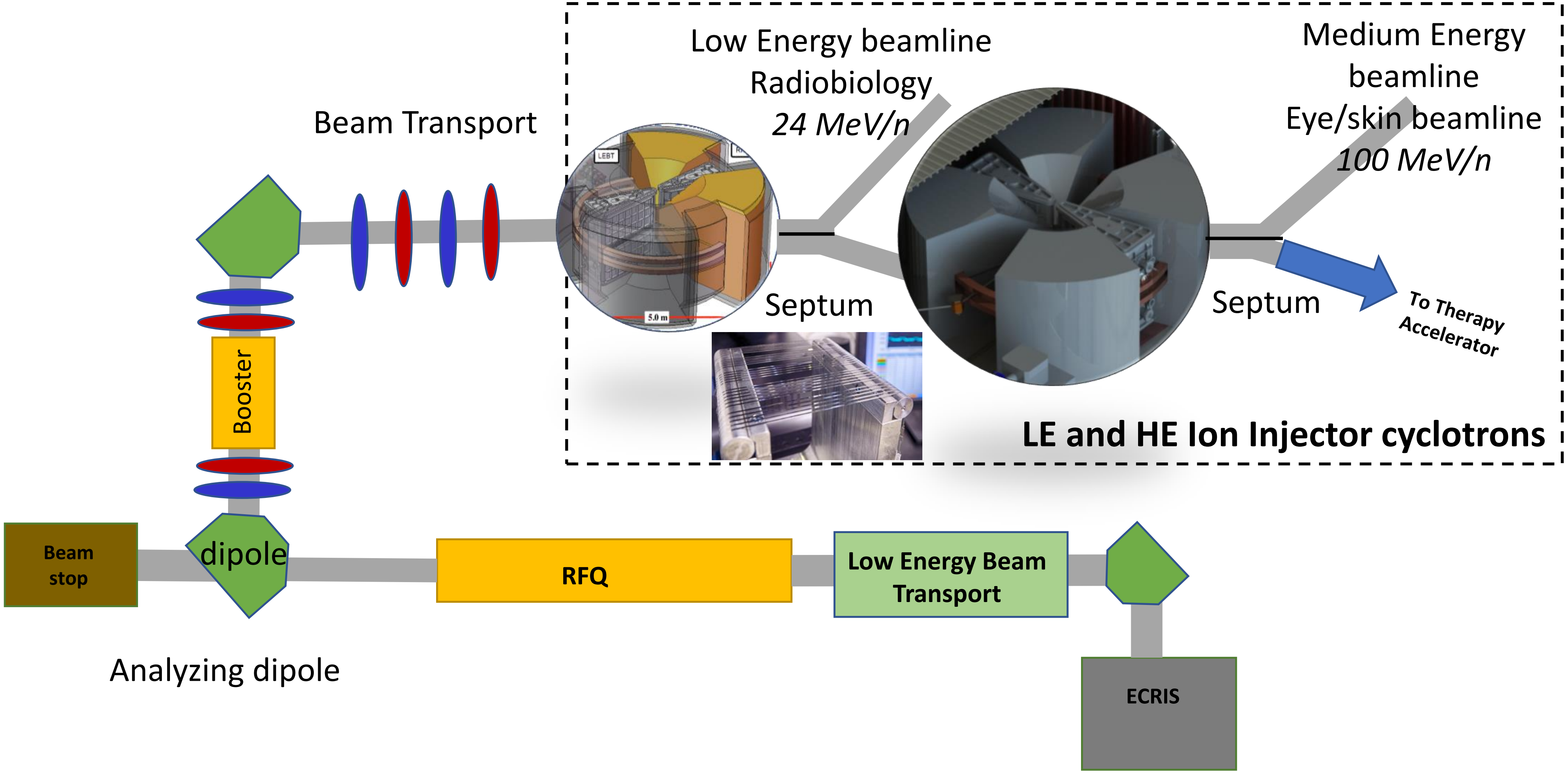


RIKEN – 320 MeV/n normal conducting cyclotron

A single unit cyclotron becomes more massive with significant operational overhead versus the modular approach proposed.



Modular of Pre-therapy Modules



Potential Heavy Ion Beams supported at CL

Potential ion beams available at CL ion accelerator complex with an upgraded heavy ion source. Both the low-energy and high-energy cyclotron stages are combined

Energy per nucleon	q/A	harmonic	Ion Species	LET approx
0.6 MeV	1/12	48	TBD – RFQ beamline	
2.6 MeV	1/6	24	B^{2+}, C^{2+}, $^{30}Si^{5+}$, $^{36}Ar^{6+}$, Co^{10+}, Cu^{11+}, Kr^{14+}, Xe^{22+}	43-180
6 MeV	1/4	16	He^{1+}, B^{3+}, C^{3+}, O^{4+}, Ne^{5+}, Si^{7+}, S^{8+}, Ca^{10+}, $^{36}Ar^{9+}$, V^{13+} Co^{15+}, Cu^{16+}, Kr^{22+}, Xe^{33+}	TBD
10.7 MeV	1/3	12	B^{4+}, C^{4+}, N^{5+}, O^{5+}, Ar^{6+}, Al^{9+}, Ne^{7+}, Cl^{12+}, Si^{10+}, V^{17+}, Co^{20+}, Cu^{21+}, Kr^{29+}, Xe^{44+},	0.84-53.7
24 MeV	1/2	8	H_2^{+}, He^{2+}, N^{7+}, O^{8+}, Ne^{10+}, Si^{14+}, $^{32}S^{16+}$, $^{36}Ar^{18+}$, Ca^{20+}	0.3-4.3
24 MeV	1/4	16	He^{1+}, B^{3+}, C^{3+}, O^{4+}, Ne^{5+}, Si^{7+}, S^{8+}, Ca^{10+}, $^{36}Ar^{9+}$, V^{13+} Co^{15+}, Cu^{16+}, Kr^{22+}, Xe^{33+}	
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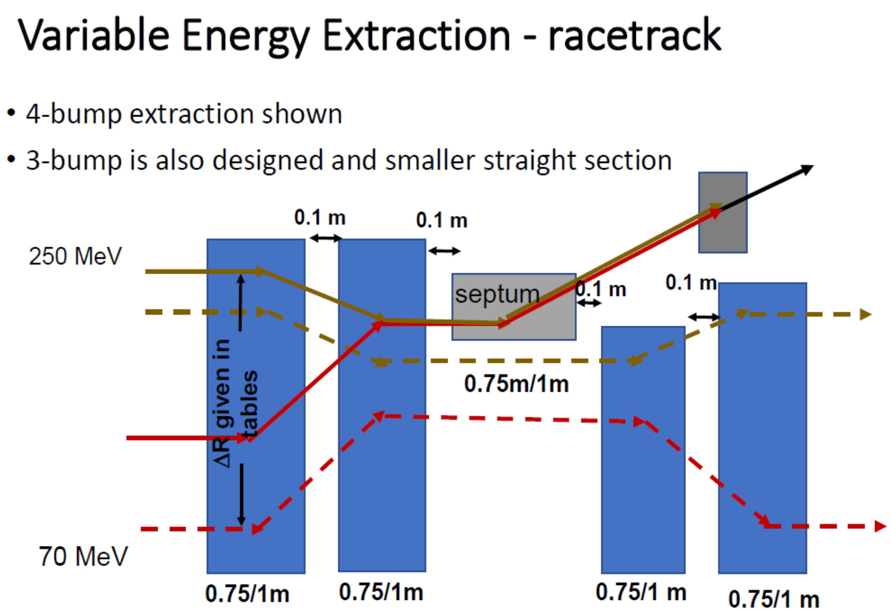
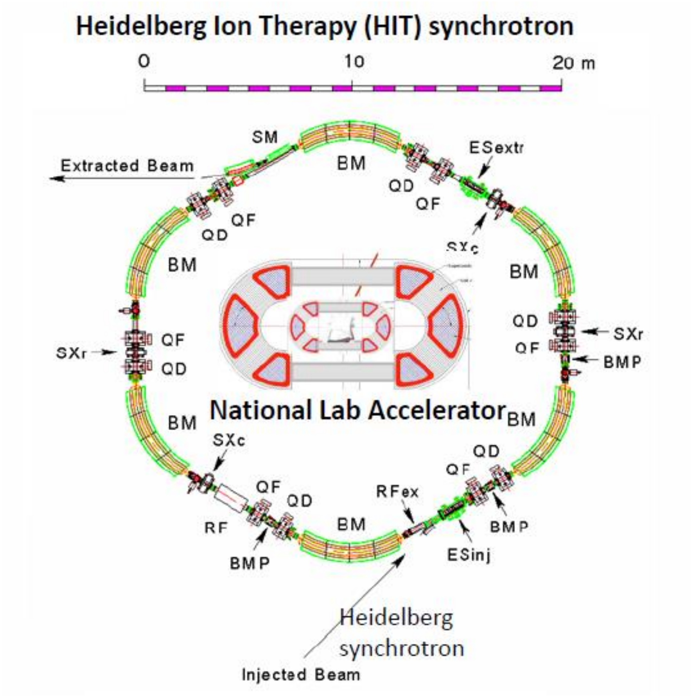
96 MeV	1/2	8	H_2^{+}, He^{2+}, N^{7+}, O^{8+}, Ne^{10+}, Si^{14+}, $^{32}S^{16+}$, $^{36}Ar^{18+}$, Ca^{20+}	

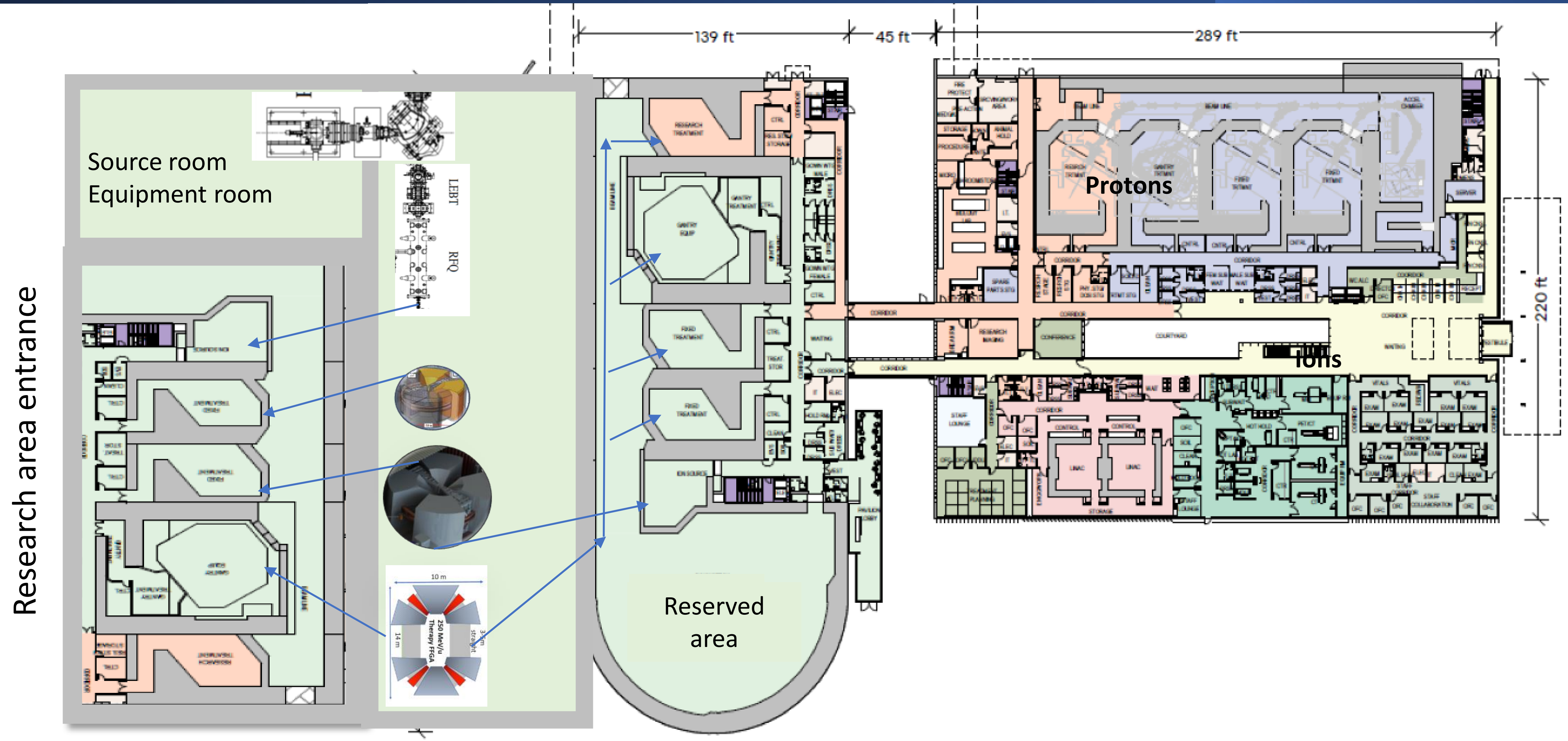
Therapy Module: Nonlinear iso-FFA: 100-250 MeV/nucleon for q/A=1/2





Layout of the ramped, bipolar magnet extraction system which selects the orbit and energy for extraction through a septum (left). Inner, lower-energy orbits are returned to their respective closed orbits for continued acceleration. On the right, the FLASH-capable, CW and variable-energy 430-MeV/nucleon ion accelerator nested system. Inner ring racetrack is 250 MeV/nucleon and can provide independent beam delivery.

Center for Particle Therapy and Research: Architectural notational layout for research rooms



Center for Particle Beam Therapy and Research

Center for Ion therapy and research
Chisholm, Landing, Waco, TX

- Site preparation and construction underway
- The center will incorporate state-of-the-art accelerator technologies
- Collaboration with internationally recognized accelerator entities: national laboratories, academic and industry have been established and clinical partners

This facility is critical to reinstate the US in a leadership role in cancer treatment and research

Rendering of architectural plan drawings for Medical Office Building (top), Center for Particle Beam Therapy and Research

Summary of Modular Approach for Multi-user, continuous Ion Beams

- **Very low energy RFQ Module**
  - Injection and ion(s) selection is performed prior to RFQ or prior to injection into LE cyclotron module
  - *Extraction line for ultra-low energy ions – 0.2-0.4 MeV/n (cell radiobiology)*
- **Low Energy Cyclotron Module**
  - Beam automatically matched to ME stage
  - *Extraction line for low energy ions: 24 MeV/n (Radiobiology including FLASH radiobiology)*
    - Multi-species ion beams including heavier ions possible from this stage
- **Medium Energy Cyclotron Module**
  - *Extraction line for medium energy ions: 100 MeV/n (Eye/skin treatment line)*
- **Therapy FFGA Module**
  - *Variable energy extraction line for therapy energy ions: ~100-250 MeV/n*
    - *30 cm depth for He, 11 cm for C*
- **Simultaneous Beam delivery and new technologies (Leo Chair)**
  - Separate beamlines: multi-user, multi-energy support capability (septum beam splitter)
  - Turn-key –
    - different ion species can be delivered without retuning or reconfiguring the individual modules

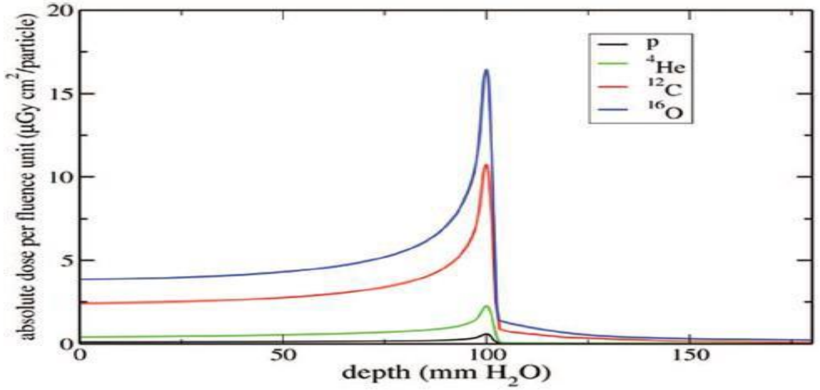
Concluding Remarks

1. Each module (4) provides standalone clinical and research ion beams without reconfiguration
   1. Cell radiobiology (0.4 MeV/nucleon)
   2. Ion radiobiology (FLASH and conventional dose beams, 24 MeV/nucleon)
   3. Skin and Eye therapy lines and research (FLASH and conventional dose beams, 100 MeV/nucleon)
   4. Heavy Multi-ion therapy (including FLASH intensities & variable energy up to 250 MeV/nucleon)
      - *Translates into full 30 cm penetration for helium and 11 cm for carbon*
2. Supports unprecedented broad Medical and Research User Community
   - Centrally located in a medical and research epicenter
     - *MDAnderson, Baylor, Scott & White, Aerospace industries, top medical and research universities . . .*
3. Strategic high energy heavy ions for DOD/Aerospace Industries
   - Significantly higher energies than existing CW heavy ion cyclotron facilities
     - *Lawrence Berkeley , Crocker Nuclear and Texas A&M cyclotron facilities*

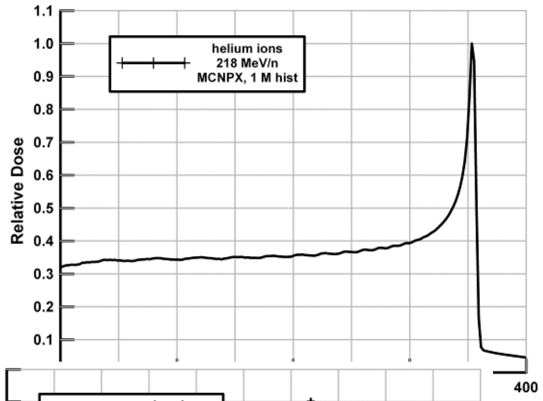
This facility is critical to reinstate the US in a leadership role in cancer and strategic ion research

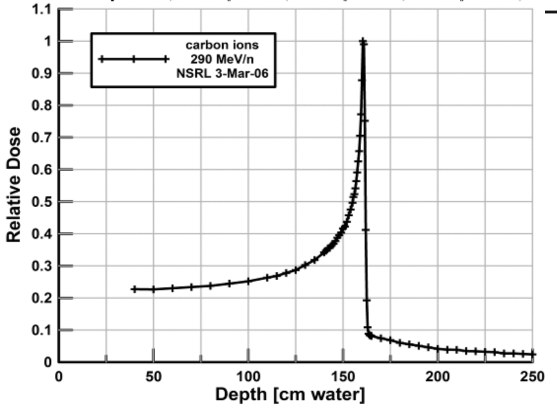
LET Characteristics of Ions

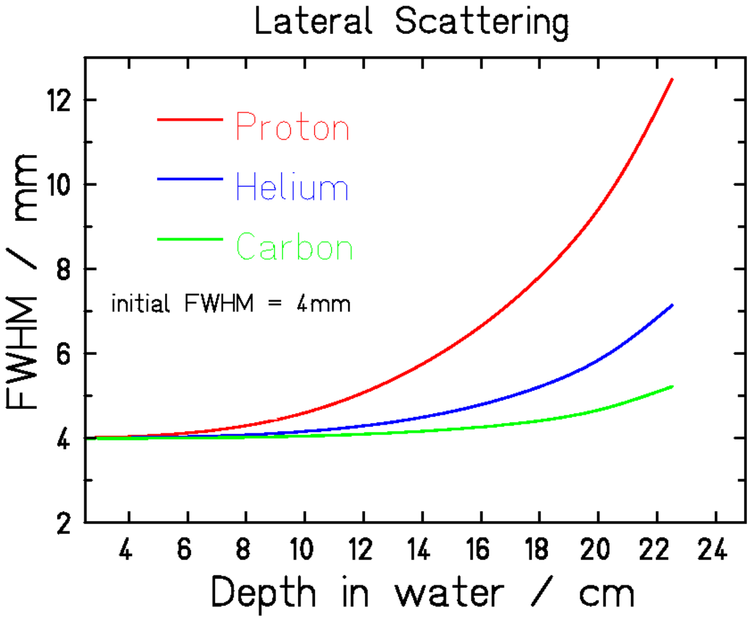
- Non-hadron beams (electrons and photons) cannot reproduce ion radiotherapy
- LET is peaks at end of the ion range with essentially no dose after distal edge
  - The Bragg peak LET increases with ion mass – argument for ions
  - However, width and falloff sharpens with heavier ions

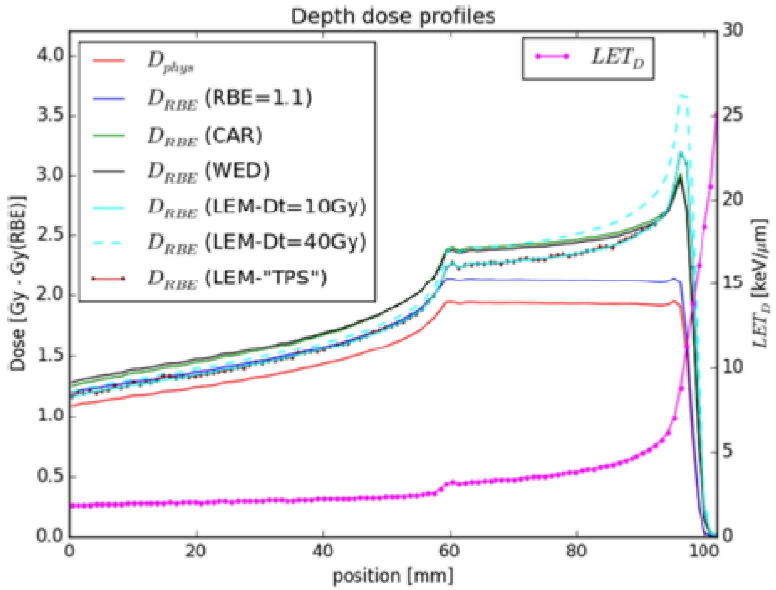


LET of protons is dramatically different from photons and electrons and ends in the high-LET point Bragg peak



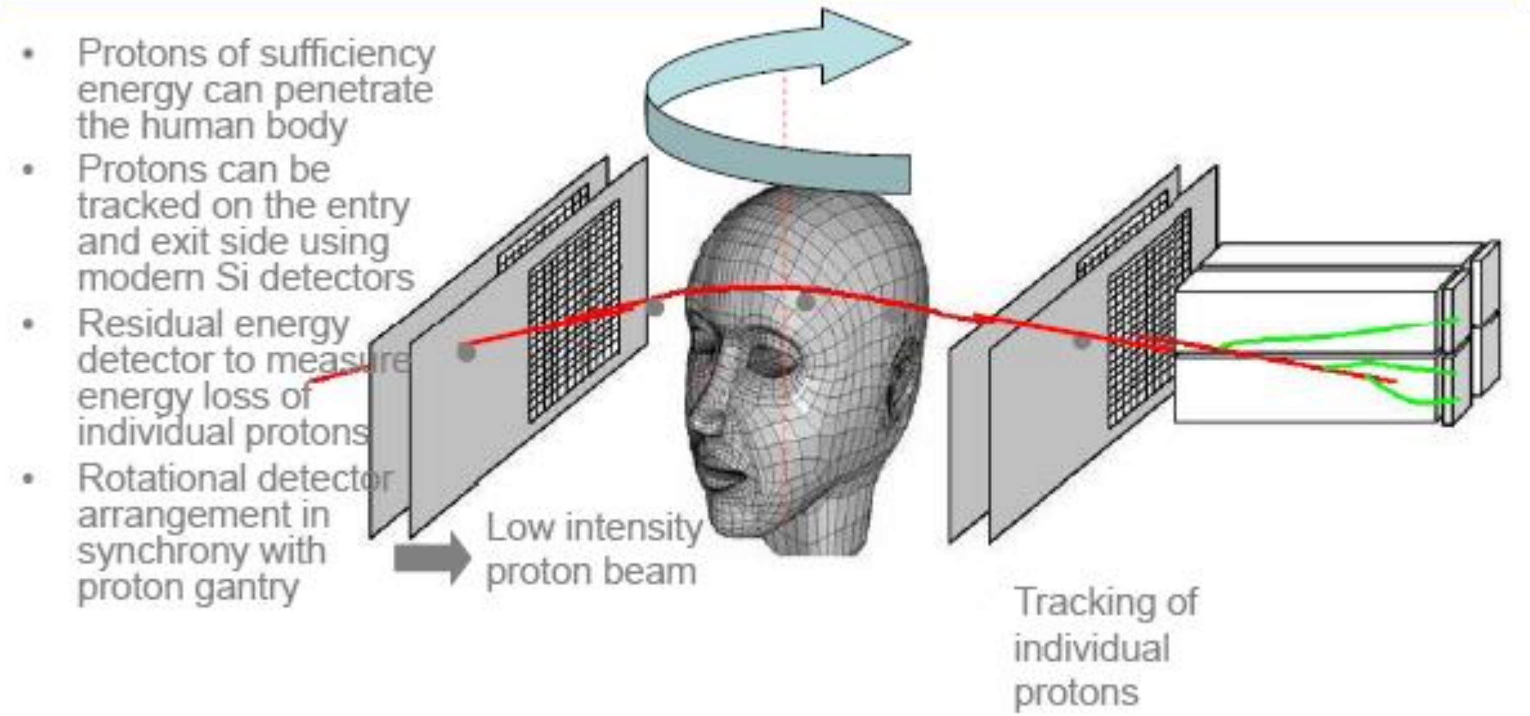


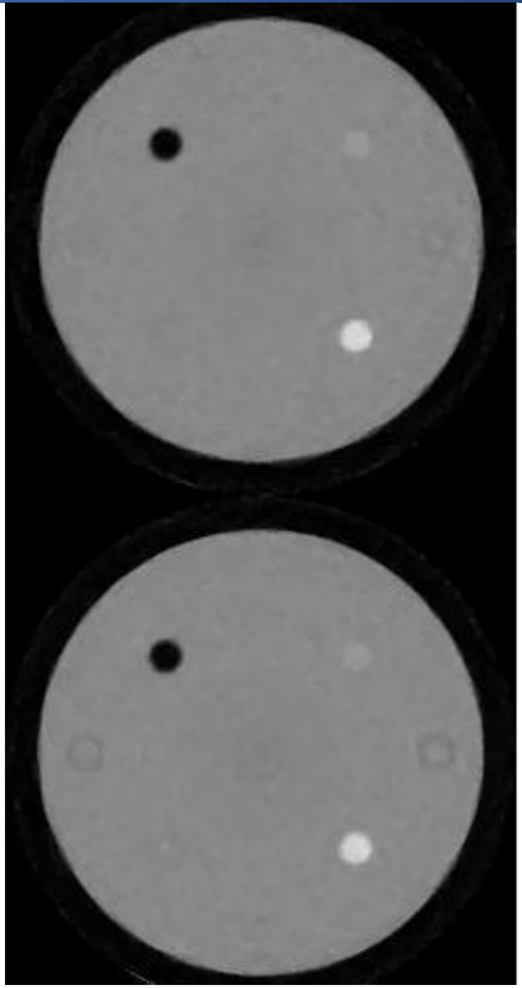




3D targeting and LET reconstruction with protons (pCT)

Precision position detection and resolution

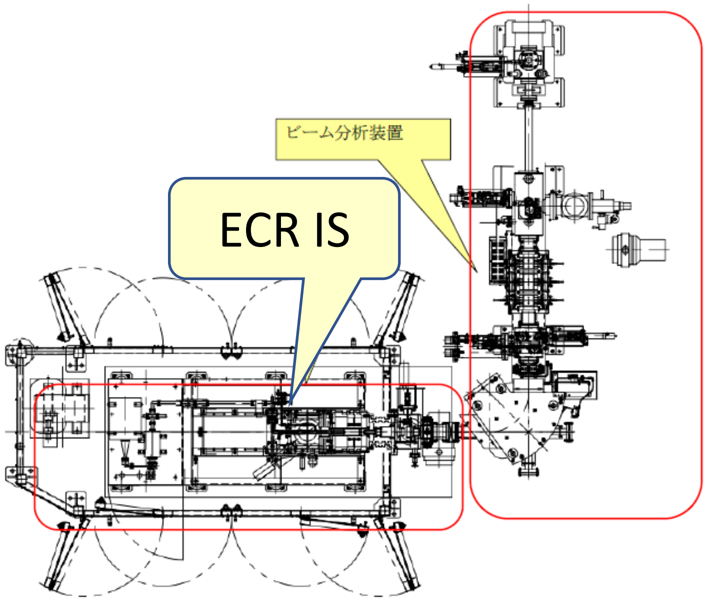


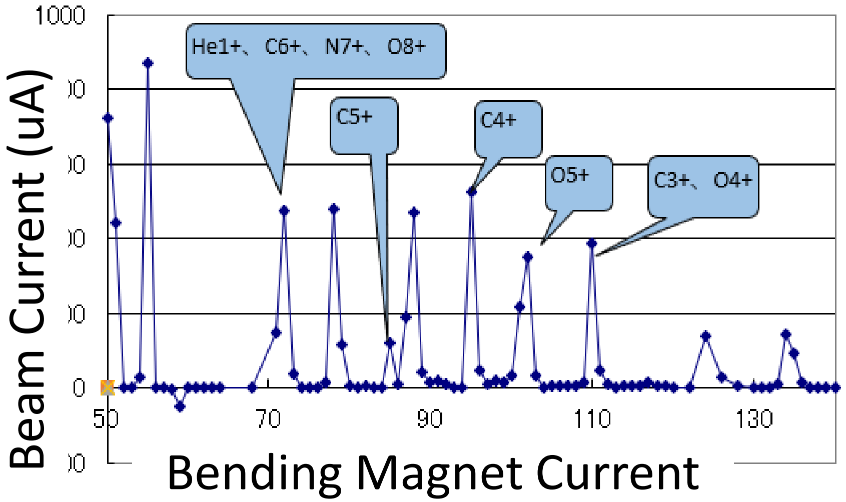


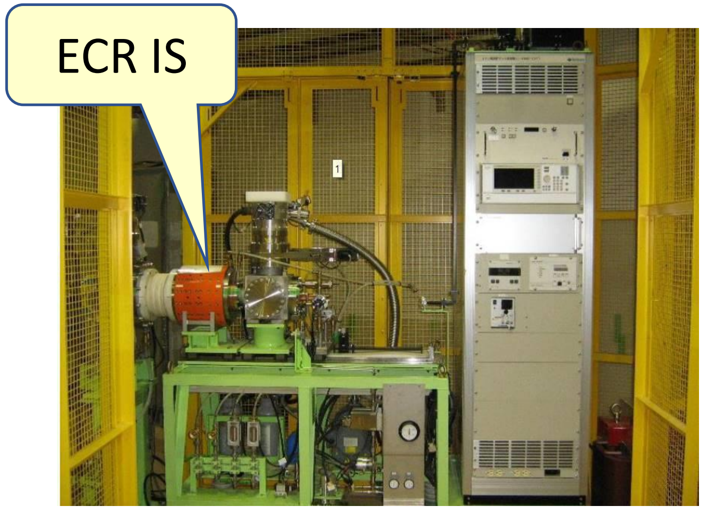
Reconstruction using only 90M events

Research collaboration with NIRS: Electron Cyclotron Resonance Ion Sources (ECRIS)

Compact ECRIS and Analyzing Magnet Layout







Compact ECRIS (Sumitomo) ion species output and installation

Elimination of contaminants will be required in Low Energy Beam Transport. Two sources may reduce contamination.

Compact ECRIS (Sumitomo) Two Sources:

1st: Therapy Ions: ${}_{12}C^{6+}$ and ${}_{4}He^{2+}$

2nd: Diagnostic Source: H_2^+, D^+