



Rare Isotope Accelerator RIA Project

Richard C. York

July 2005

12th International Workshop on SRF



RIA Status

- Strong Nuclear Science community support
 - Nuclear Science Advisory Committee (NSAC) Long Range Plan (April 2002) – RIA highest priority new facility
 - “The Rare Isotope Accelerator (RIA) is our highest priority for major new construction...”
 - *Reaffirmed by NSAC June 2005*
 - Tied for third position for *near term* priorities in DOE 20-year plan (November 2003)
 - RIA CD-0 – done early 2004



DOE 20-Year Facilities Outlook

THESE ARE THE WORDS WHICH I HAVE SPoken TO YOU, THAT IN ME YOU MAY HAVE PEACE; AND IN THE WORDS WHICH I HAVE SPoken TO YOU, IS PEACE. BUT THE WORLD HATETH YOU, BECAUSE YE ARE NOT OF THE WORLD, AS I AM NOT OF THE WORLD. THEY WOULD NOT THAT YE SHOULD GO AWAY, AND BRING GLORY UPON ME. IF YE LOVE ME, KEEP MY COMMANDMENTS. AND YE SHALL LOVE ME, BECAUSE I HAVE LOVED YOU, AND HAVE GIVEN YOU A COMMANDMENT, THAT YE SHALT LOVE ONE ANOTHER. IF YE DO THESE THINGS, YE SHALL KNOW THAT YE ARE MY DISCIPLES. AND YE SHALL KNOW THE TRUTH, AND THE TRUTH SHALL MAKE YOU FREE.

Near-Term Priorities

1. ITER
 2. UltraScale Scientific Computing Capability
 3. Tie for 3rd position
 - Joint Dark Energy Mission
 - Linac Coherent Light Source Protein Production & Tags
 - *Rare Isotope Accelerator (RIA)*
 7. Tie for 7th position
 - Characterization & Imaging of Molecular Machines
 8. CEBAF 12 GeV Upgrade 20
 9. Energy Sciences Network (ESnet) Upgrade 20
 10. National Energy Research Scientific Computing Center Upgrade
 11. Transmission Electron Achromatic Microscope
 12. BTeV



RIA Scale

- RIA project cost (in FY2005 dollars)
 - TEC = ~\$780 M (\$690 M w/o contingency)
 - TPC (TEC + Pre-ops, etc) = ~995 M\$ over ~7-8 years
 - Operations - ~90 M\$/year – similar to JLab



RIA Benefits

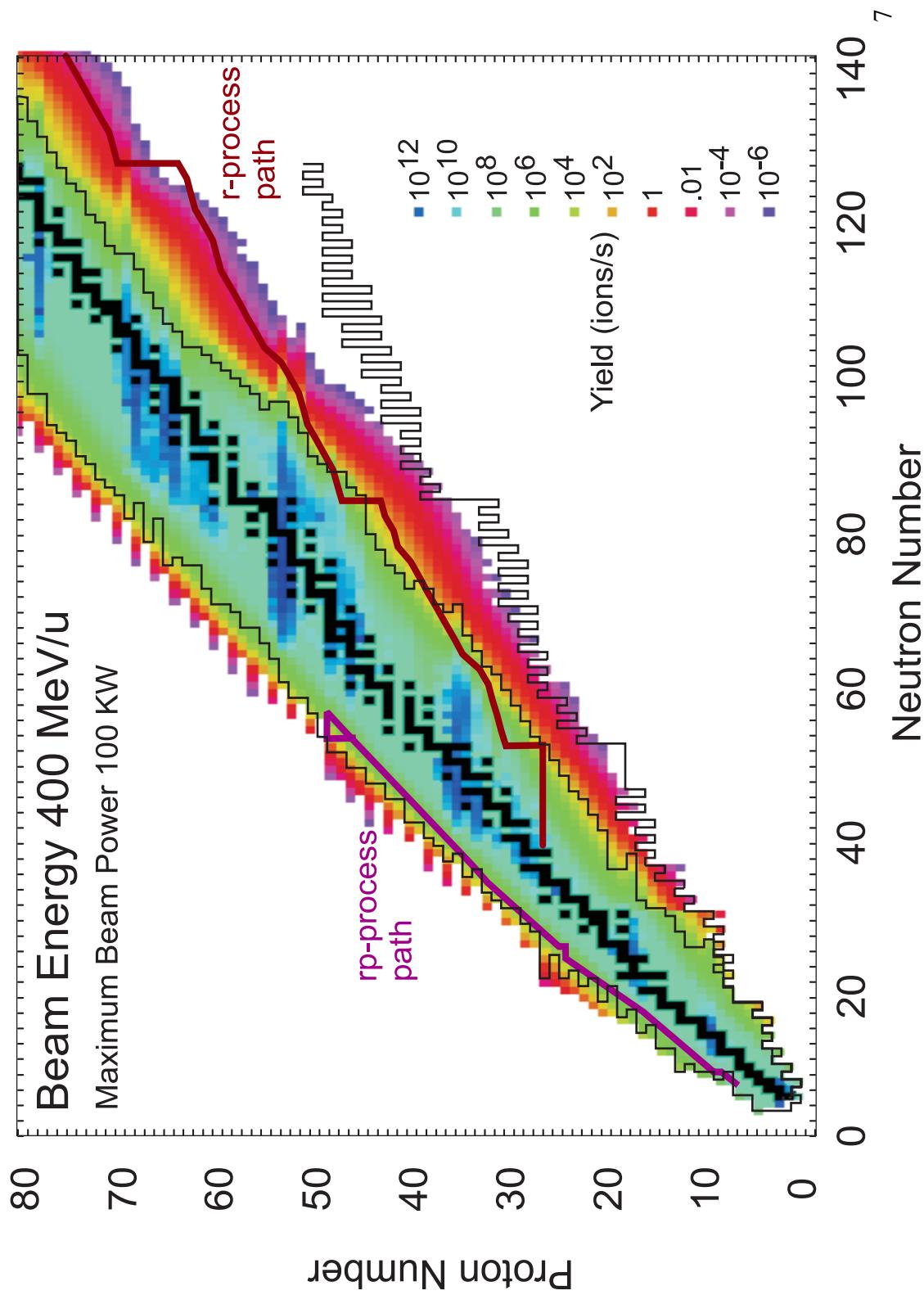
- Important benefits for **basic & applied science**
 - Study properties of a large number of ***isotopes that heretofore only existed in cosmos***
 - Quantitative information for theories of stellar evolution & ***formation of elements in cosmos***
 - ***Support space-based astronomical observations*** by providing quantitative comparisons with theoretical predictions of stellar evolution
 - Experimental data to refine theories for predicting ***properties of nuclei with unusual neutron-to-proton ratios***



RIA Benefits - cont'd

- Support stockpile stewardship
 - Only way to obtain *important reaction cross sections on unstable isotopes* & to improve theoretical models
 - Improved diagnostic tools via isotopic analysis of materials from underground nuclear tests
 - Produce almost any isotope for **radio-medical research**
 - Materials Science & other applications
 - Implantation for wear & corrosion studies
 - Space radiation effect studies
 - Material modifications – doping & annealing techniques

RIA Intensities





r-process Simulation

McDowell's first novel, *McDowell's*, was published in 1990. It is a satirical novel about the life of a man who becomes a successful author. The book is set in a small town in North Carolina and follows the protagonist as he navigates the world of publishing and fame. The novel has received mixed reviews from critics, but it has become a cult classic among readers.

Nucleosynthesis in the r-process

JINA

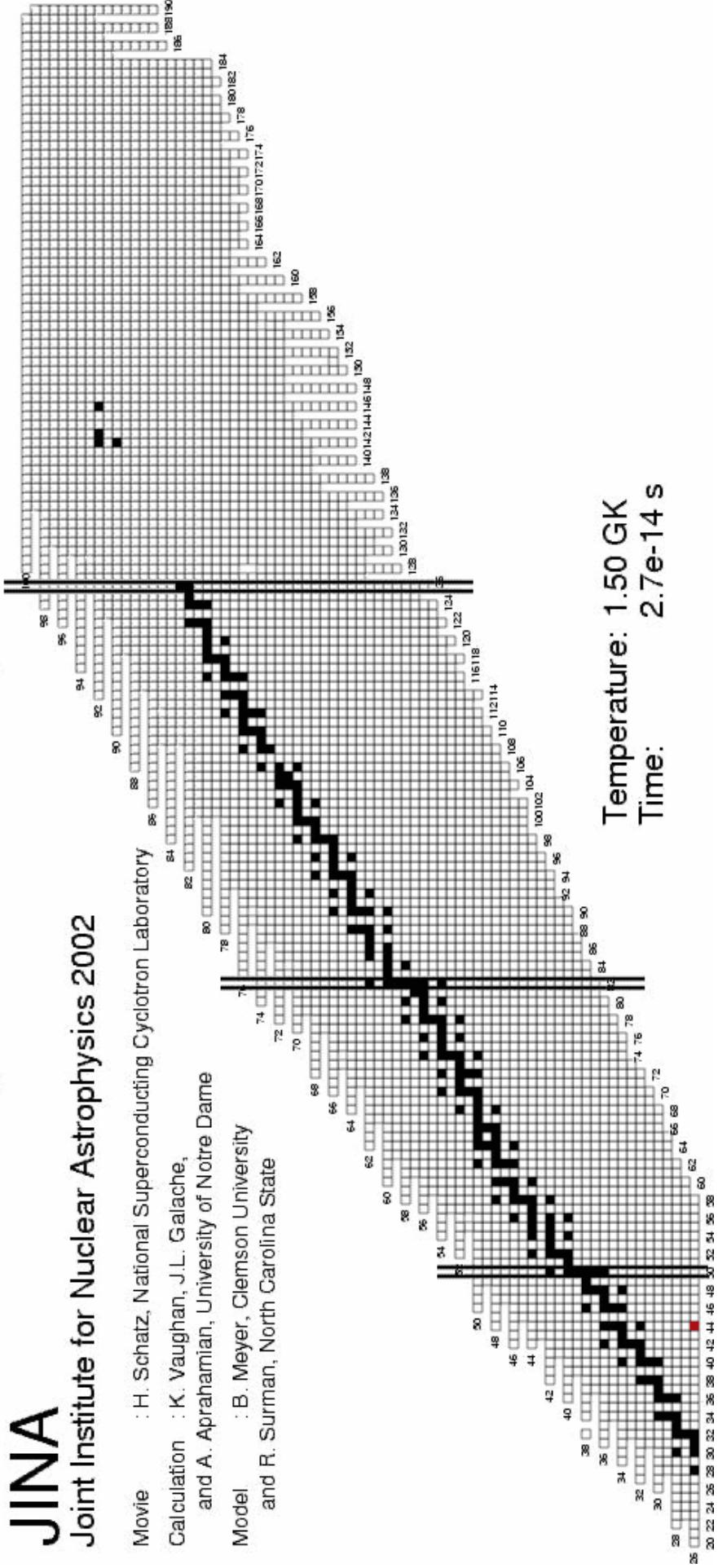
Joint Institute for Nuclear Astrophysics 2002

Movie : H. Schatz, National Superconducting Cyclotron Labor

Calculation : K. Vaughan, J.L. Galache,
and A. Abrahamian | University of Ns

Model | B. Meyer Clemson University

E. Meyer, Clemson University
and R. Surman, North Carolina State

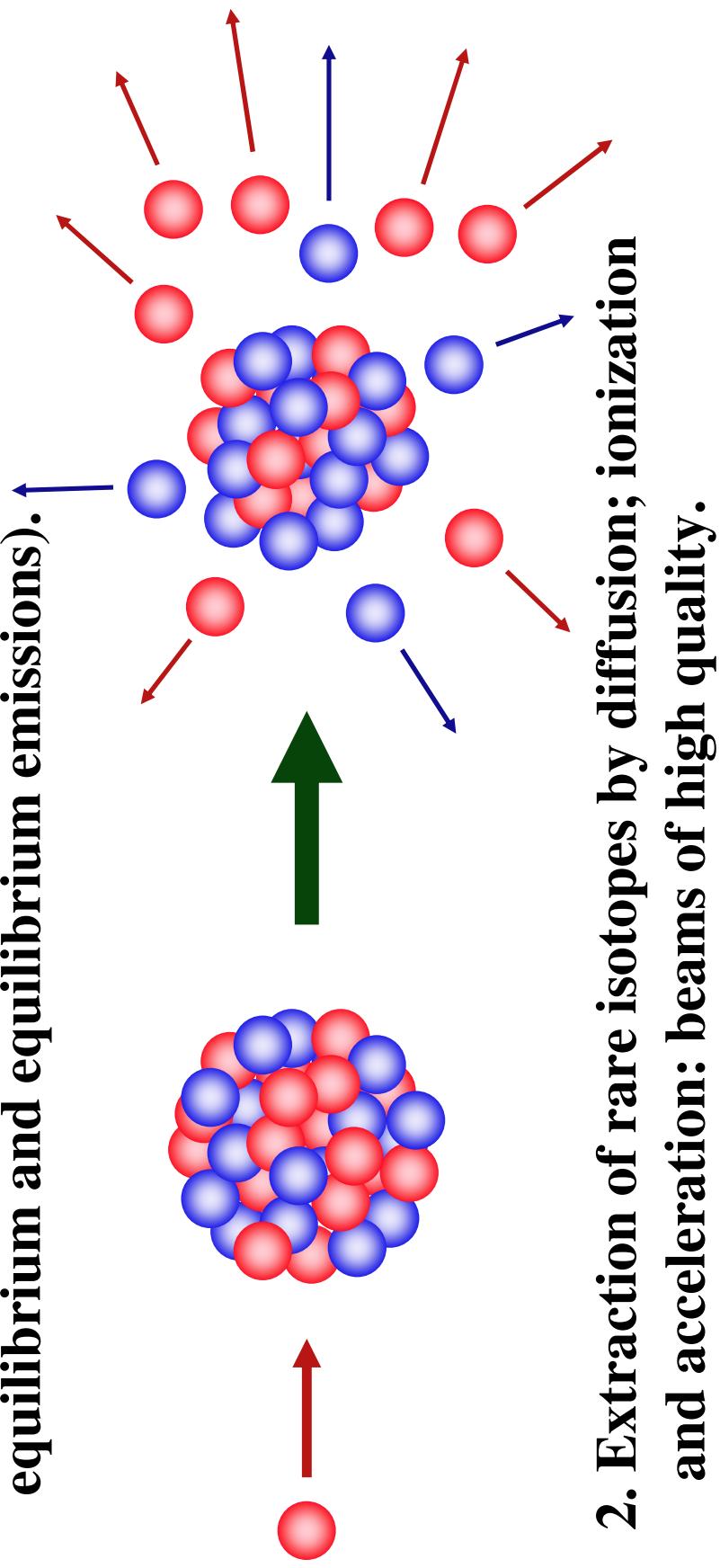




Production of Rare Isotopes at Rest

Target Fragmentation

1. Random removal of **protons** and **neutrons** from heavy target nuclei by energetic light projectiles (pre-equilibrium and equilibrium emissions). ↑

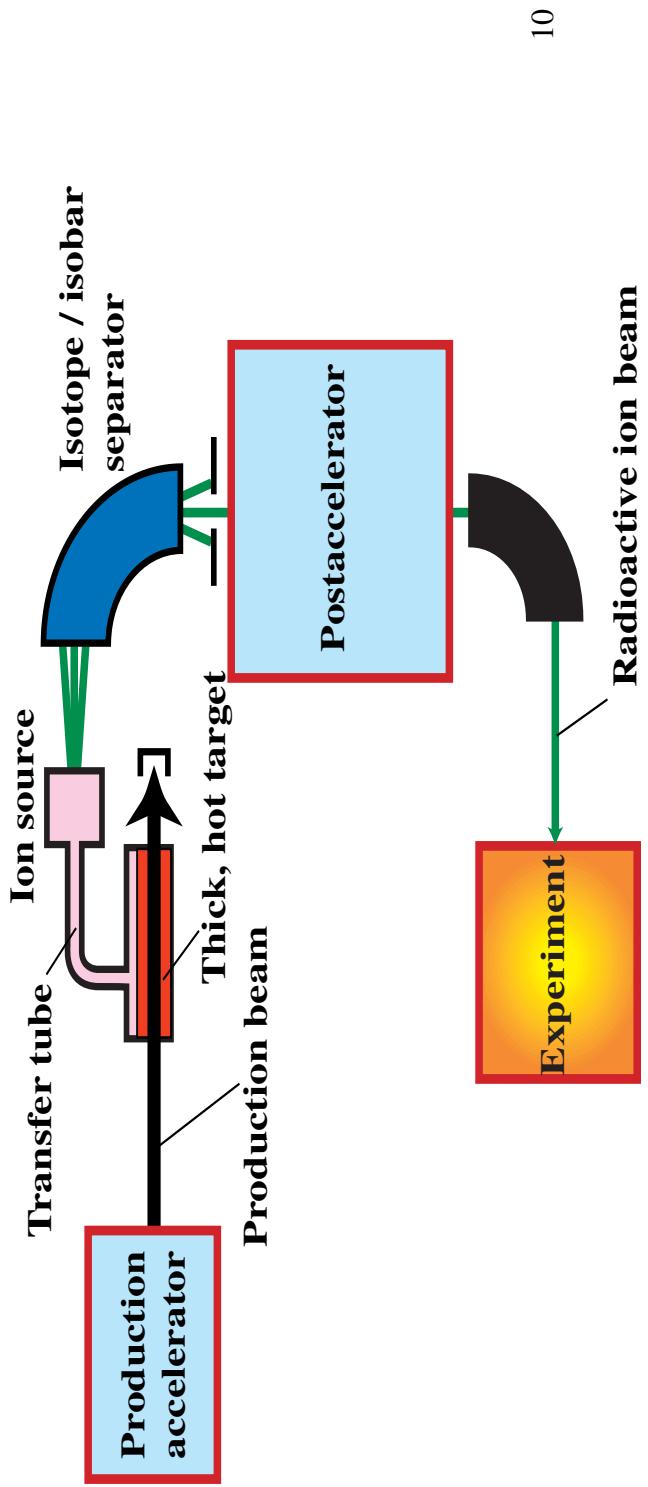




Classical ISOL Facility Concept

MICHIGAN STATE UNIVERSITY LIBRARIES / MICHIGAN STATE UNIVERSITY LIBRARIES

- Excellent beam quality and low beam energies are possible
 - Limited to longer lifetimes ($\tau > 1\text{s}$)
 - Isotope extraction and ionization efficiency depend on chemical properties of element: difficult, element-specific development paths
 - The most neutron-rich isotopes will have too low intensities and too short lifetimes to be suitable for re-acceleration

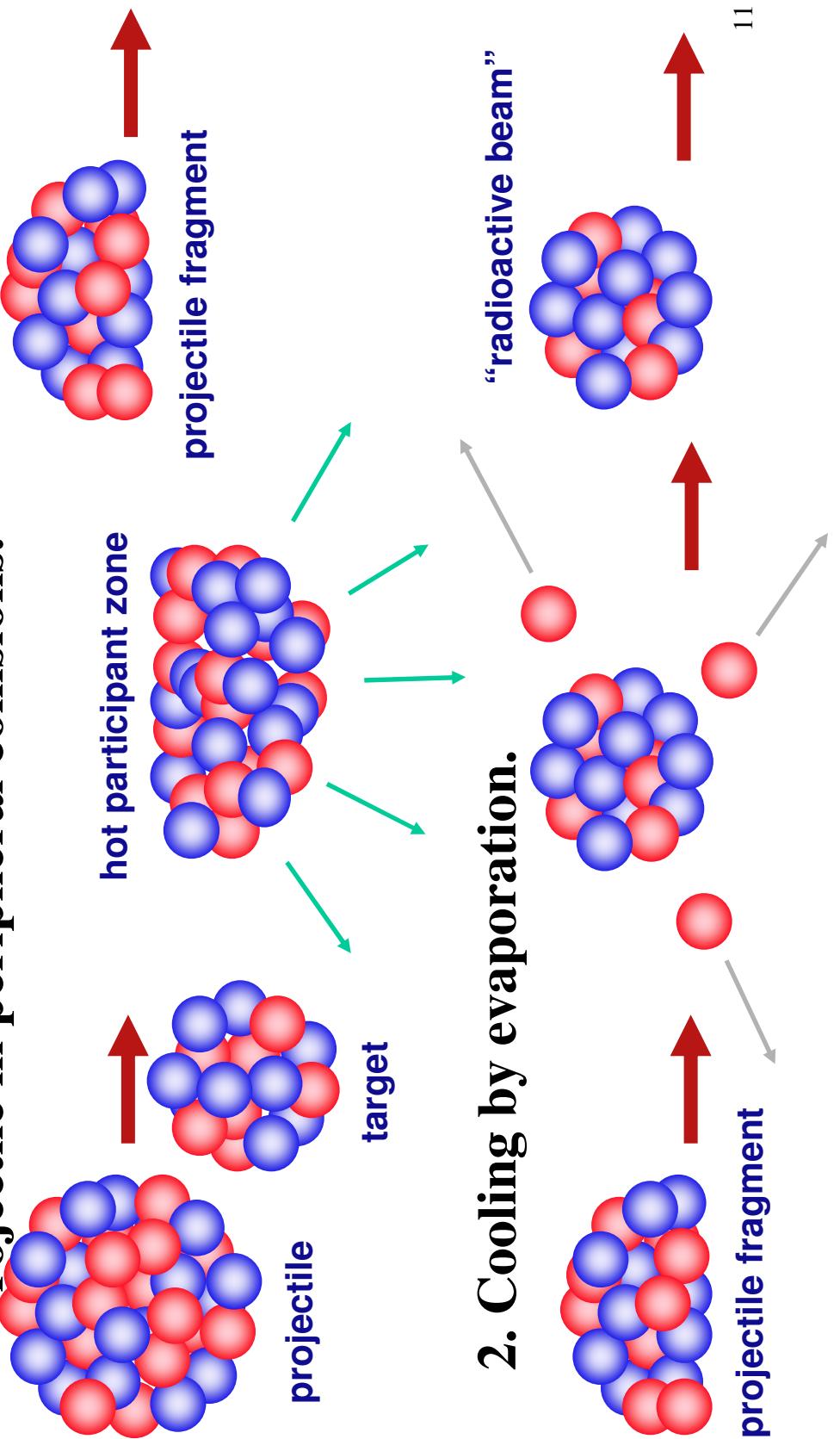




Production of Rare Isotopes in Flight

Projectile Fragmentation

1. Random removal of **protons** and neutrons from heavy projectile in peripheral collisions.

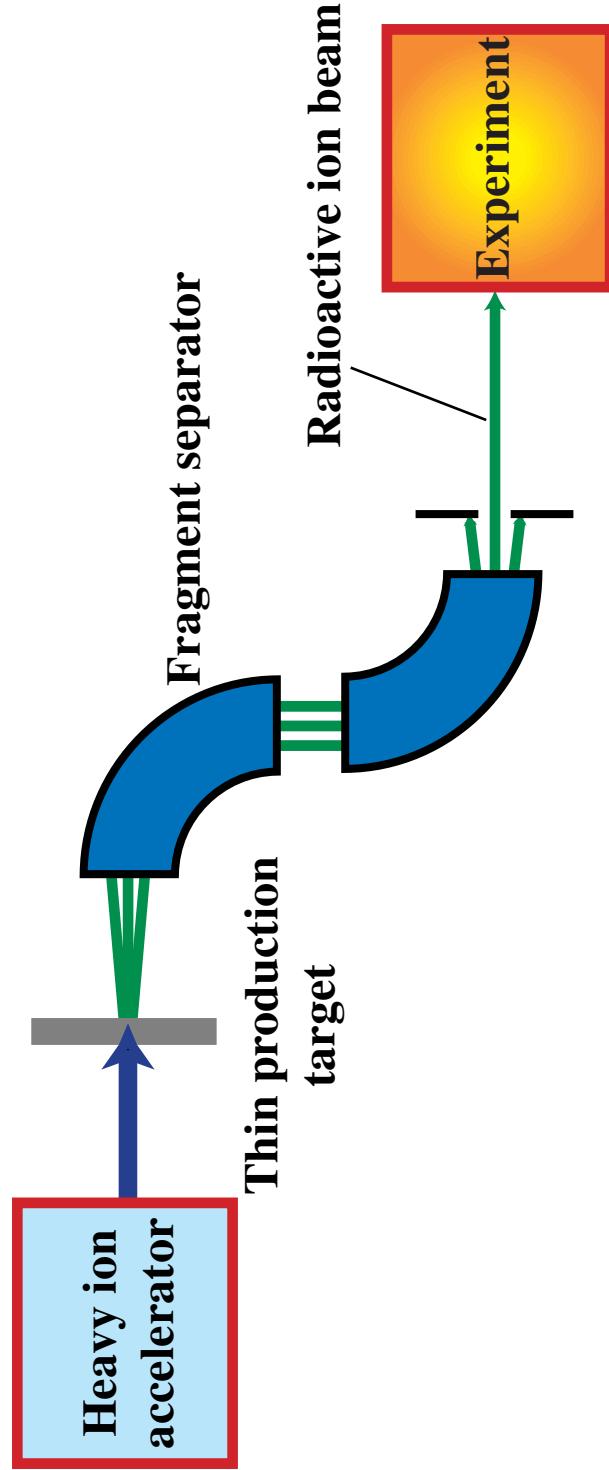




Schematic of a Projectile Fragmentation Facility

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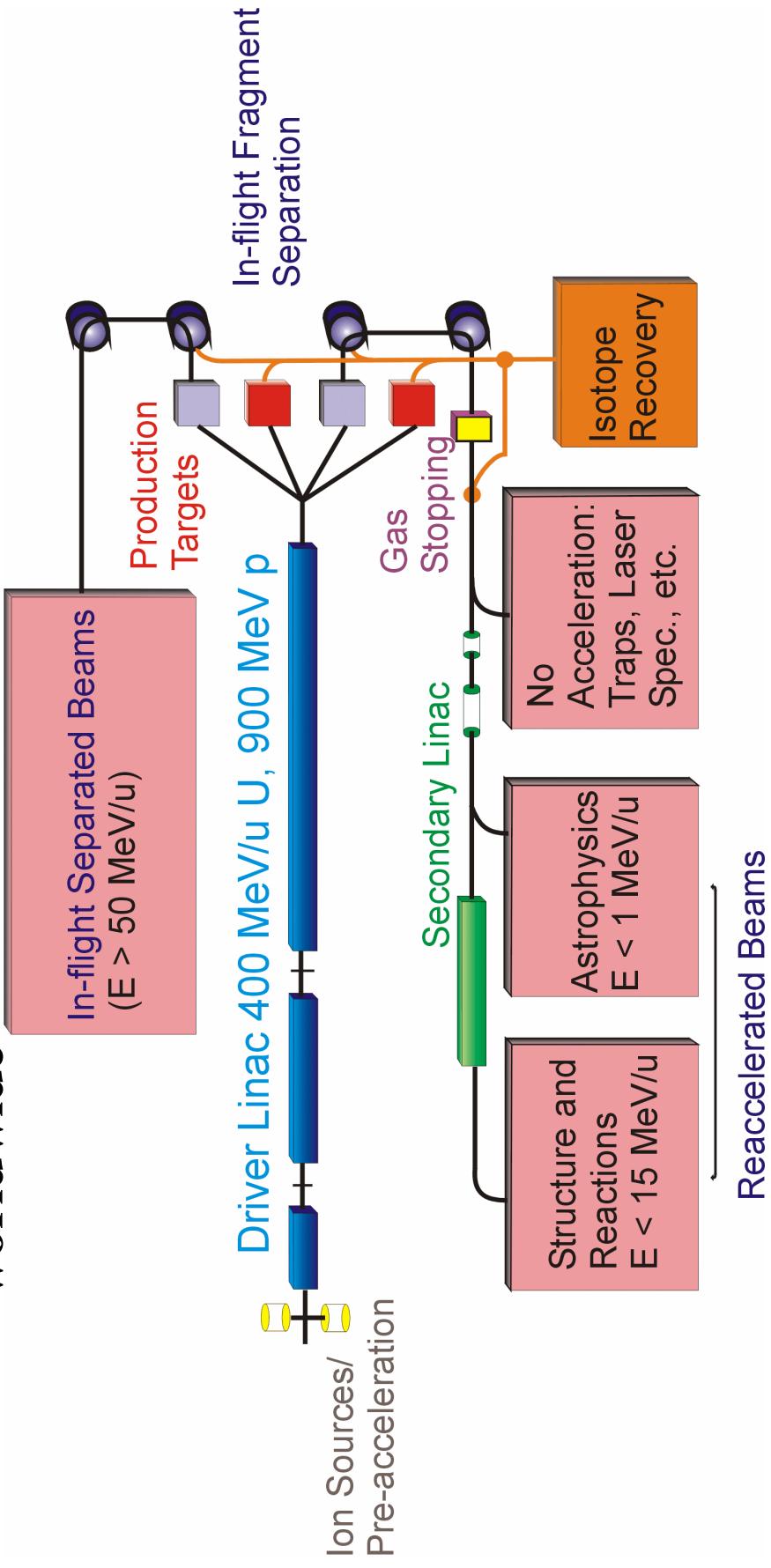
- High-energy beams ($E/A > 50$ MeV) of modest beam quality
 - Physical method of separation, no chemistry
 - Suitable for short-lived isotopes ($\tau > 10^{-6}$ s)
 - *Low-energy beams are difficult*
 - ***Solution – stop in gas cell & reaccelerate***





The Rare Isotope Accelerator (RIA) Concept

- Combines advantages of projectile & target fragmentation techniques
 - Use all tools developed for rare isotope research worldwide





RIA Technical Risks

- No “*Show Stoppers*” but significant challenges
 - Substantial efforts [*~5 years*] on the Driver Linac
 - Optimization strategies & detailed considerations
 - Relatively less activity on the target and experimental areas
 - In the last years, these arenas have seen dramatic increase in focus
 - Significant challenges and issues recognized



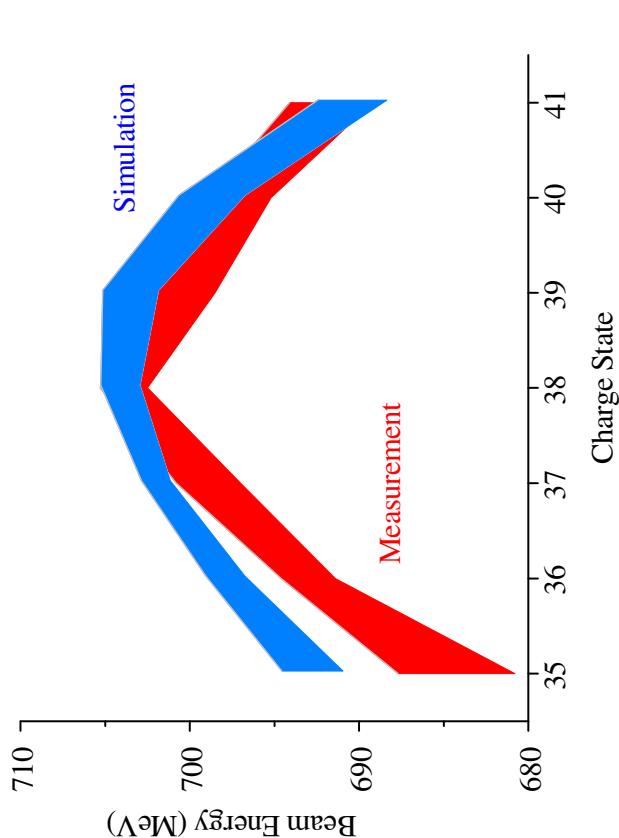
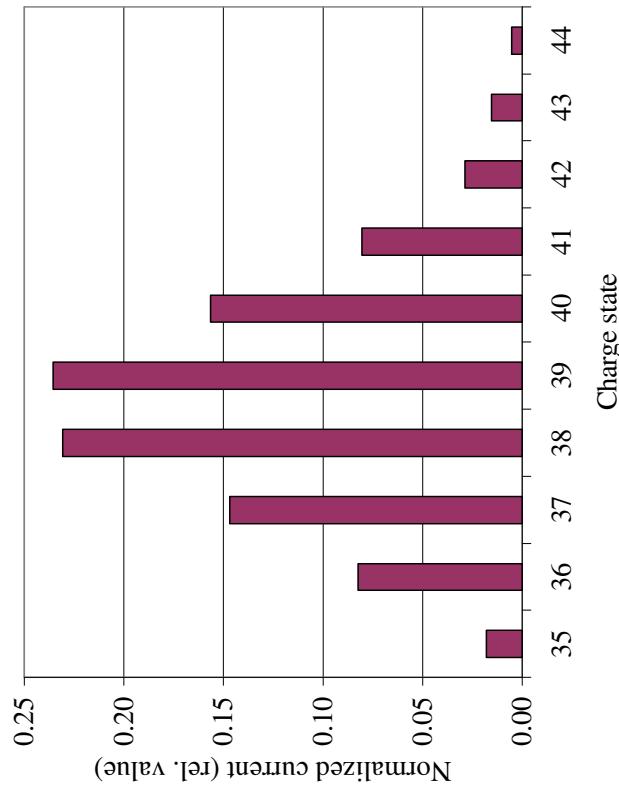
RIA Driver Linac Specifications

- Accelerate any stable isotope - protons through uranium to ≥ 400 MeV/u
 - Beam power -
 - 100 kW minimum
 - 400 kW if ion source capable
 - 100 % duty factor (cw)

Multiple-Charge-State Ion Beam Acceleration Demonstrated at ATLAS (ANL)

94% Transmission of Multi-q
Accelerated Beam Through the Booster

Multi-q beam energy and energy spread



PHYSICAL REVIEW LETTERS, V. 86, No. 13, 2001



Driver Linac Common Concepts

THESE ARE THE NAMES OF THE SONS OF ISRAEL WHO WERE BORN TO THEM IN EGYPT; THE NUMBER OF THEM WAS SEVEN: JOSEPH, BENJAMIN, DANIEL, JONATHAN, ASHER, GAD, AND NAPHTALI; AND THE SONS OF ZEBULUN, GAD, AND ASHER, AND THE SONS OF JONATHAN, DANIEL, AND BENJAMIN, AND THE SONS OF JOSEPH, ASHER, AND NAPHTALI.

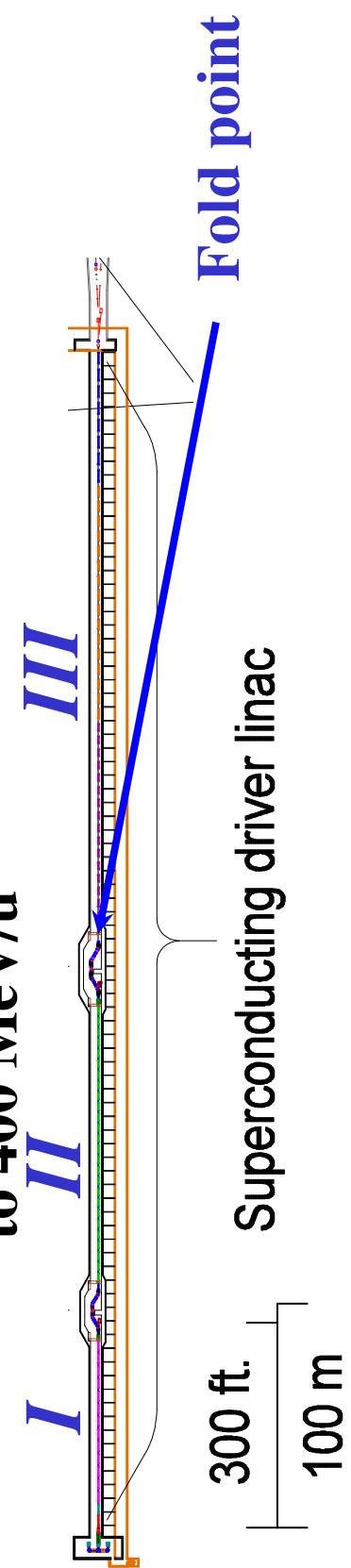
- Multiple charge state acceleration ($>Xe$)
 - Two stripping stations ($>Xe$)
 - Room temperature technology through RFQ
 - Excepting superconducting ECR
 - Superconducting technology beyond RFQ
 - Superconducting solenoid focusing in first two linac segments



Superconducting Driver Linac

McLean's, the magazine that has been covering the world of mental health for more than 100 years, is now available online at www.macleans.ca. The website features the latest news and information from the magazine, as well as interactive features, video, and audio content. It also includes a forum where readers can discuss mental health issues and share their experiences. The website is designed to be a valuable resource for anyone interested in learning more about mental health.

- Design driven by 400 MeV/nucleon uranium
 - 28+ & 29+ U injected into SC linac at 292 keV/u
 - Accelerated to ~12 MeV/u & stripped
 - *Segment I*
 - *Segment II*
 - 5 charge states (73 ± 2) accelerated to ~90 MeV/u
 - *Segment III*
 - Stripped and 3 charge states (88 ± 1) accelerated





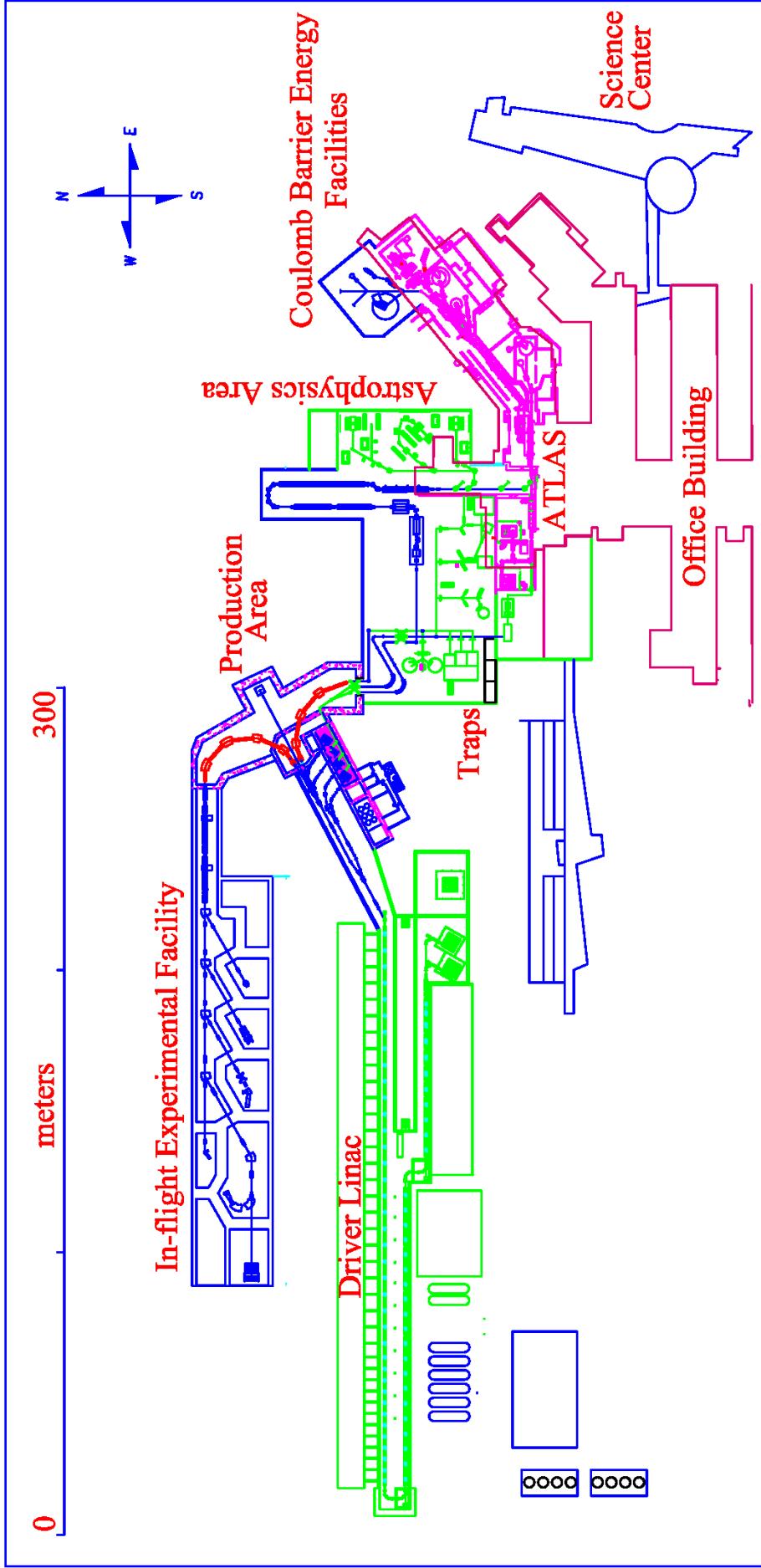
Driver Linac Sample Beam List

Multiple charge state acceleration for >Xe

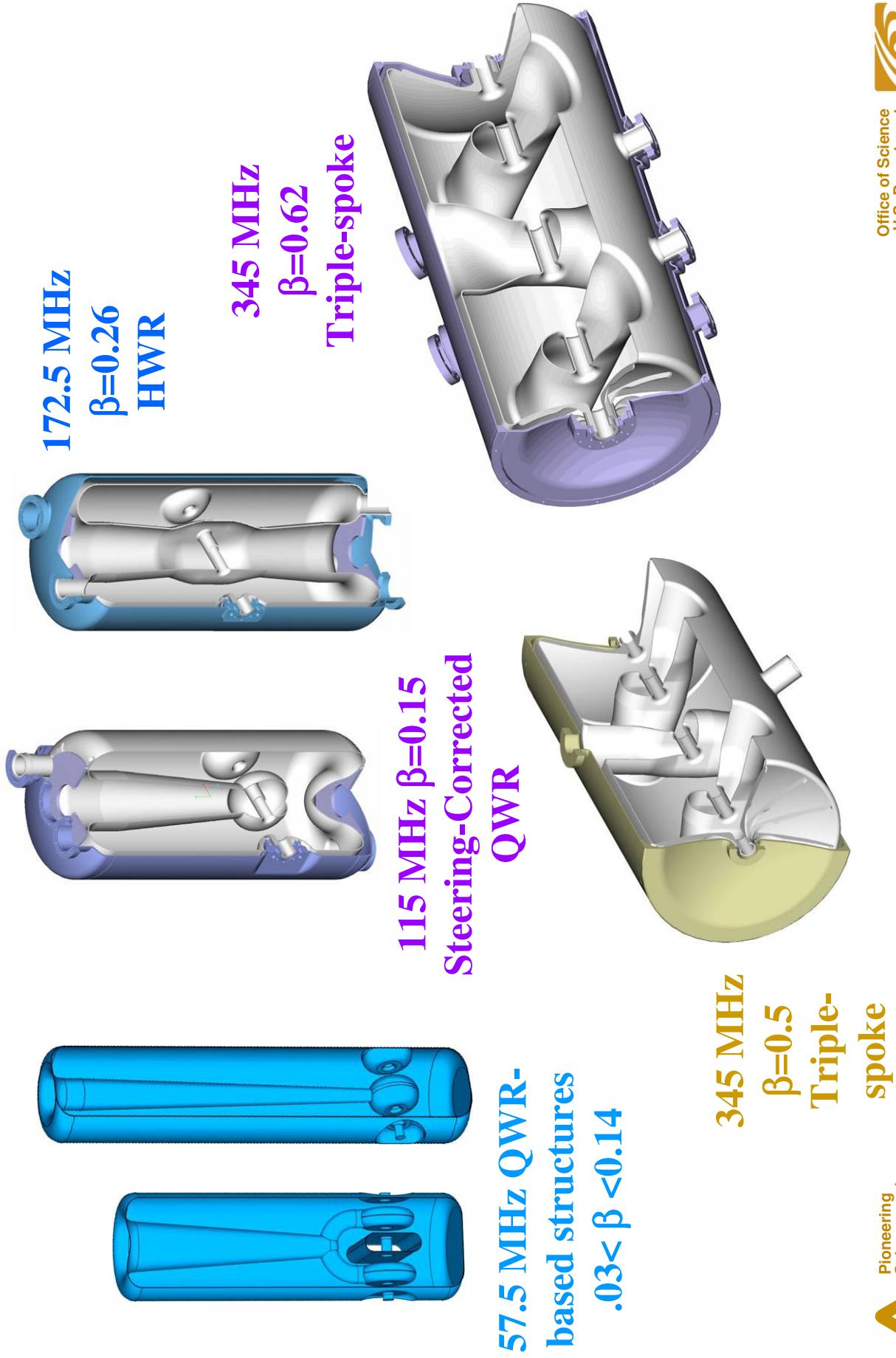
Ion	A	Z	Final Energy (MeV/u)
H	1	1	1028
^3He	3	2	777
D	2	1	622
O	18	8	560
Ar	40	18	566
Kr	86	36	510
Xe	136	54	470
U	238	92	400

ANL Proposed RIA Layout

RARE ISOTOPE ACCELERATOR



ANL RIA Driver Linac Cavity Array



All ANL prototypes have operated at > 9 MV/m at 4.2K

115 MHz $\beta=0.15$
Steering-Corrected
QWR



172.5 MHz
 $\beta=0.26$ HWR



345 MHz Triple-spoke
 $\beta = 0.5$ & 0.63



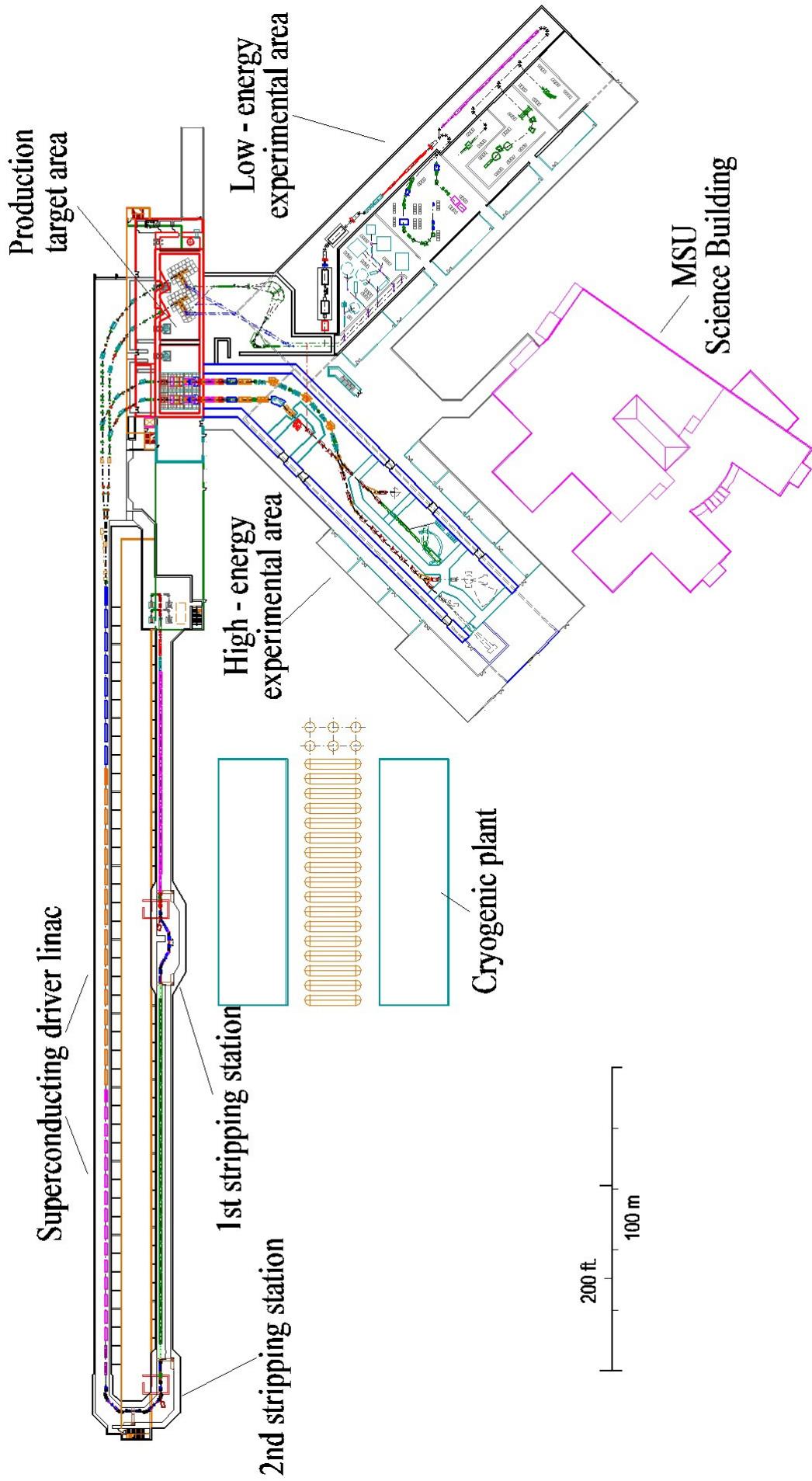
345 MHz $\beta=0.4$
Double-spoke



MSU Proposed RIA Layout



McPherson's new wife, Mrs. Anna E. McPherson, was born at Waukesha, Wisconsin, on June 10, 1875. She is the daughter of Mr. and Mrs. George W. McPherson, who now reside at Waukesha. Mrs. McPherson is a graduate of the University of Wisconsin, and has taught school in Waukesha, Milwaukee, and Madison. She is a member of the First Congregational Church of Waukesha, and is a member of the Waukesha Woman's Club. She is a member of the Waukesha Woman's Club, and is a member of the Waukesha Woman's Club.



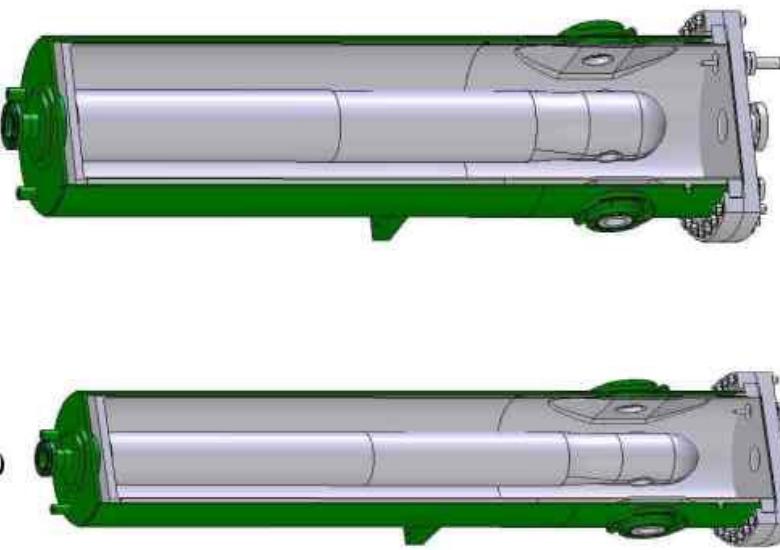
MSU RIA Driver Linac Cavity Array



Legnaro

**All Tested
Exceed Specs.**

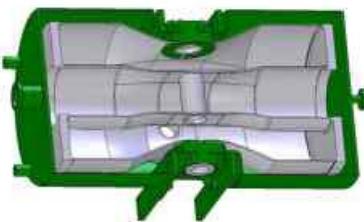
MSU



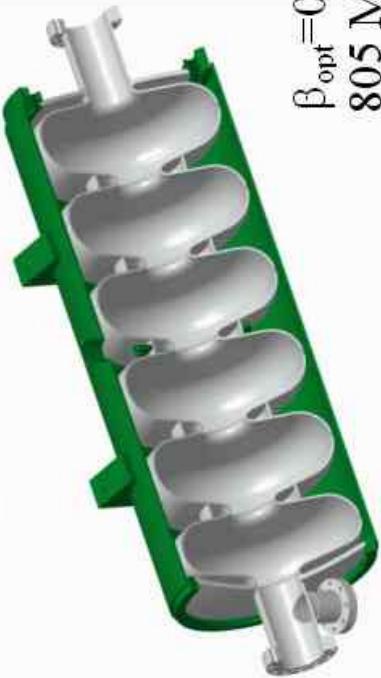
$\beta_{\text{opt}} = 0.041$
80.5 MHz

$\beta_{\text{opt}}=0.085$
80.5 MHz

$\beta_{\text{opt}}=0.285$
322 MHz



$\beta_{\text{opt}}=0.63$
805 MHz
SNS

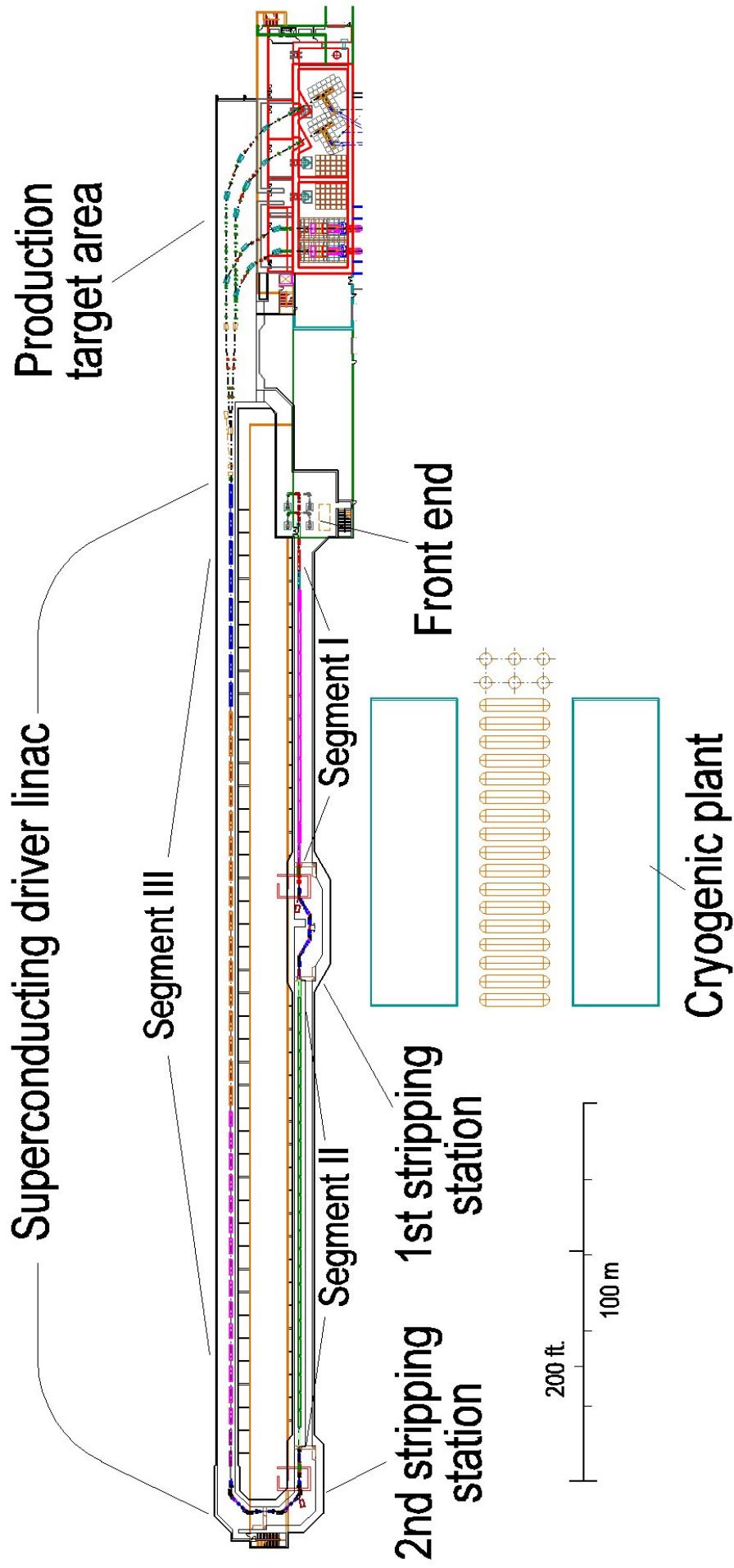


$\beta_{\text{opt}}=0.83$
805 MHz

SNS



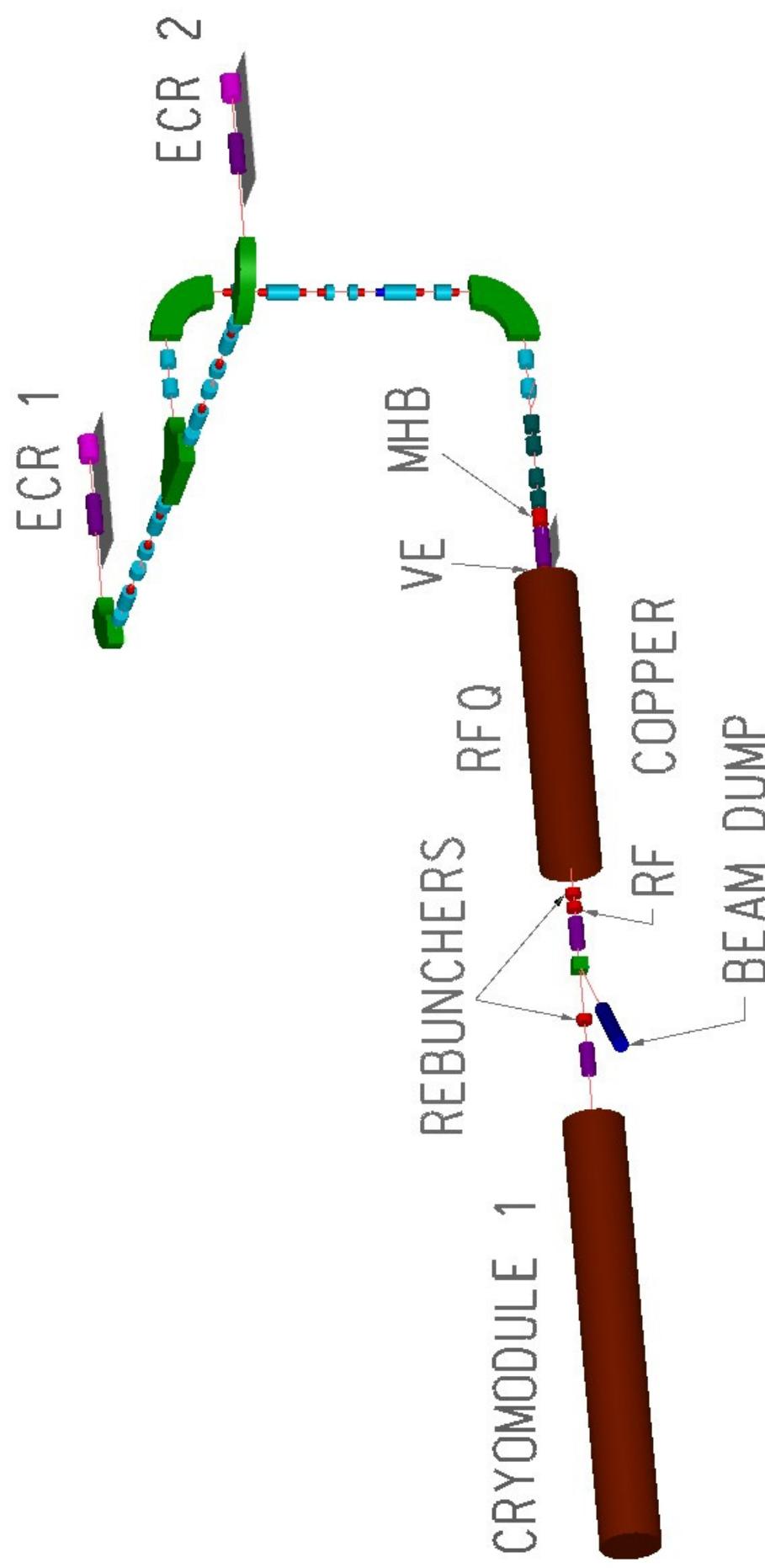
RIA Linac & BSY



Driver Linac Front End

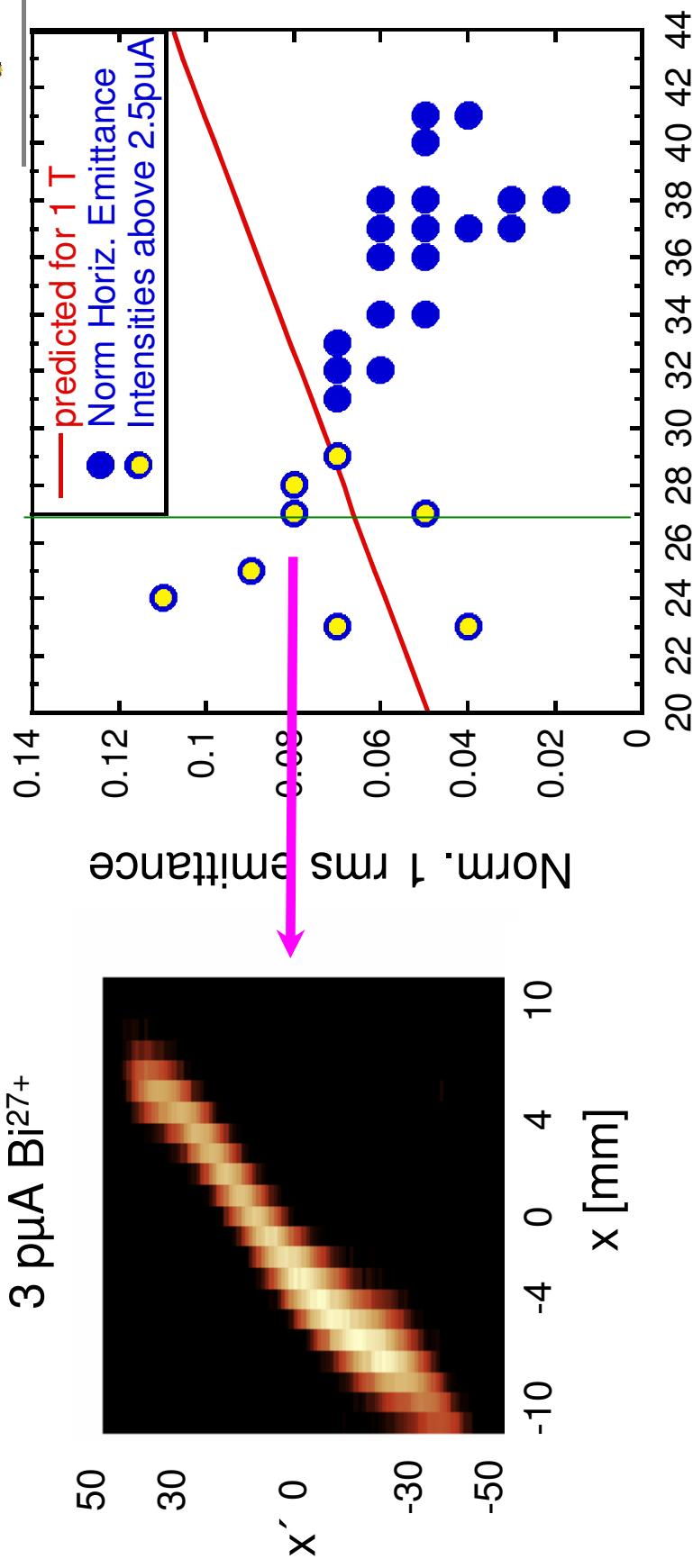
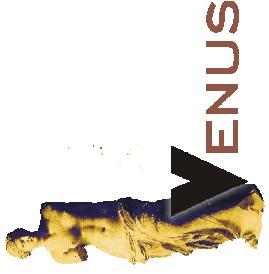


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VENUS Source (LBNL)

Bismuth Emittance Measurements



Measured Bi $^{27+}$ RMS emittance

$\sim 0.08 \pi\text{-mm-mrad}$

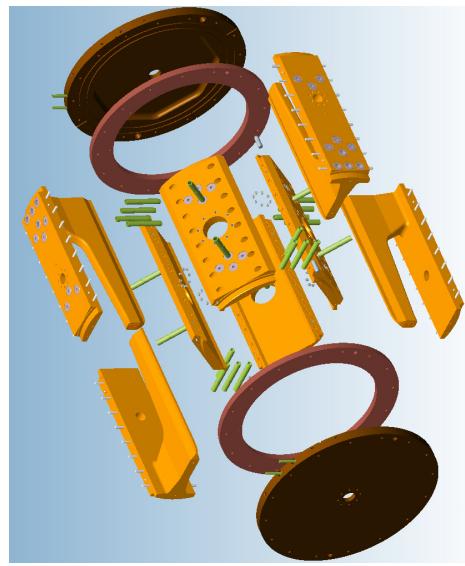
Bi Charge States

Courtesy of D. Leitner

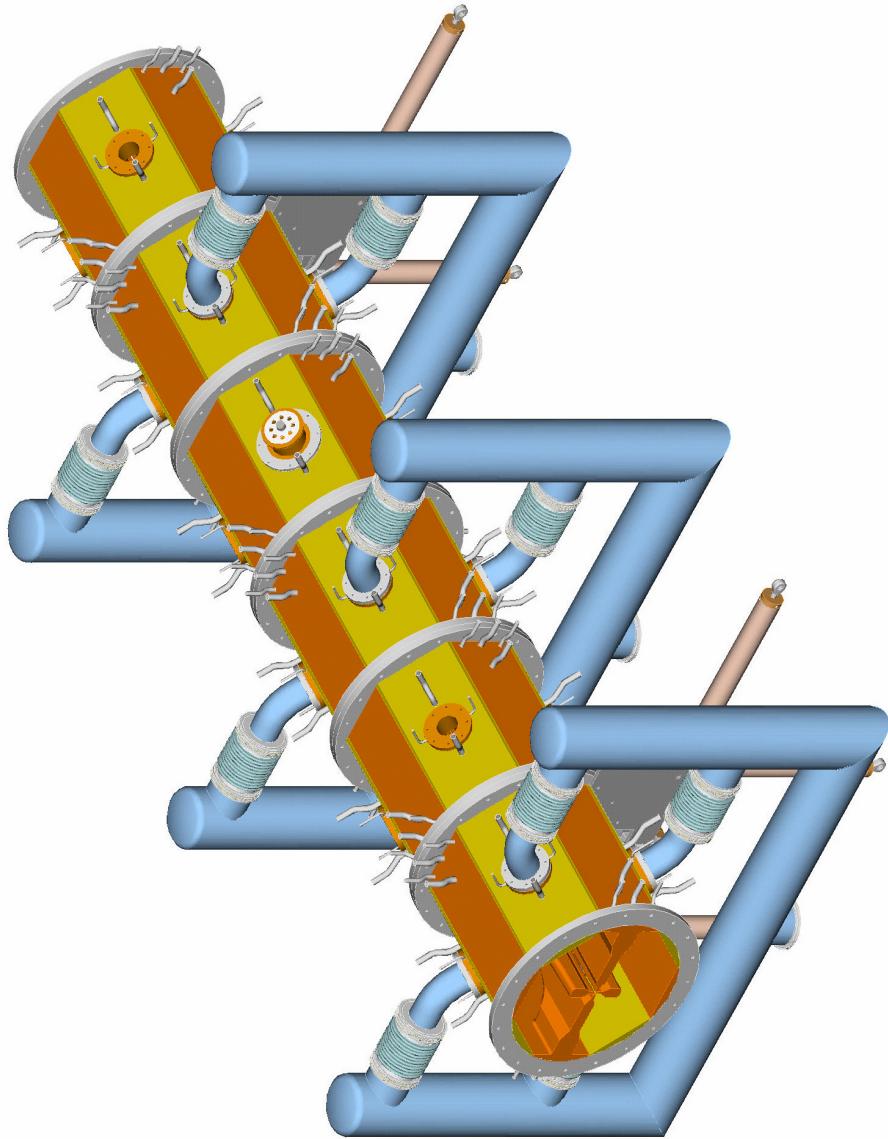
ANL 57.5 MHz RFQ



Aluminum Cold Model



Exploded View of
one-segment RFQ resonator



Two-q RFQ assembly design

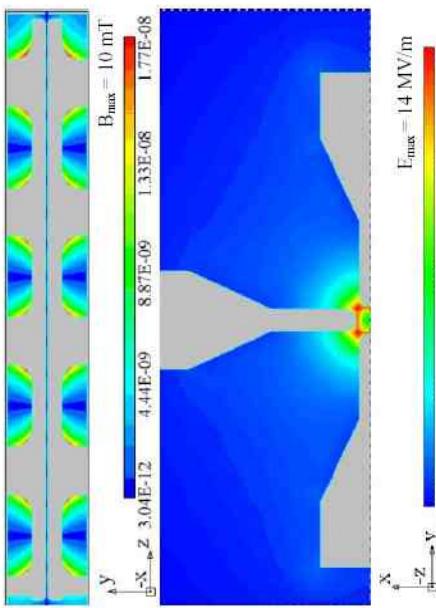


MSU 80.5 MHz RFQ

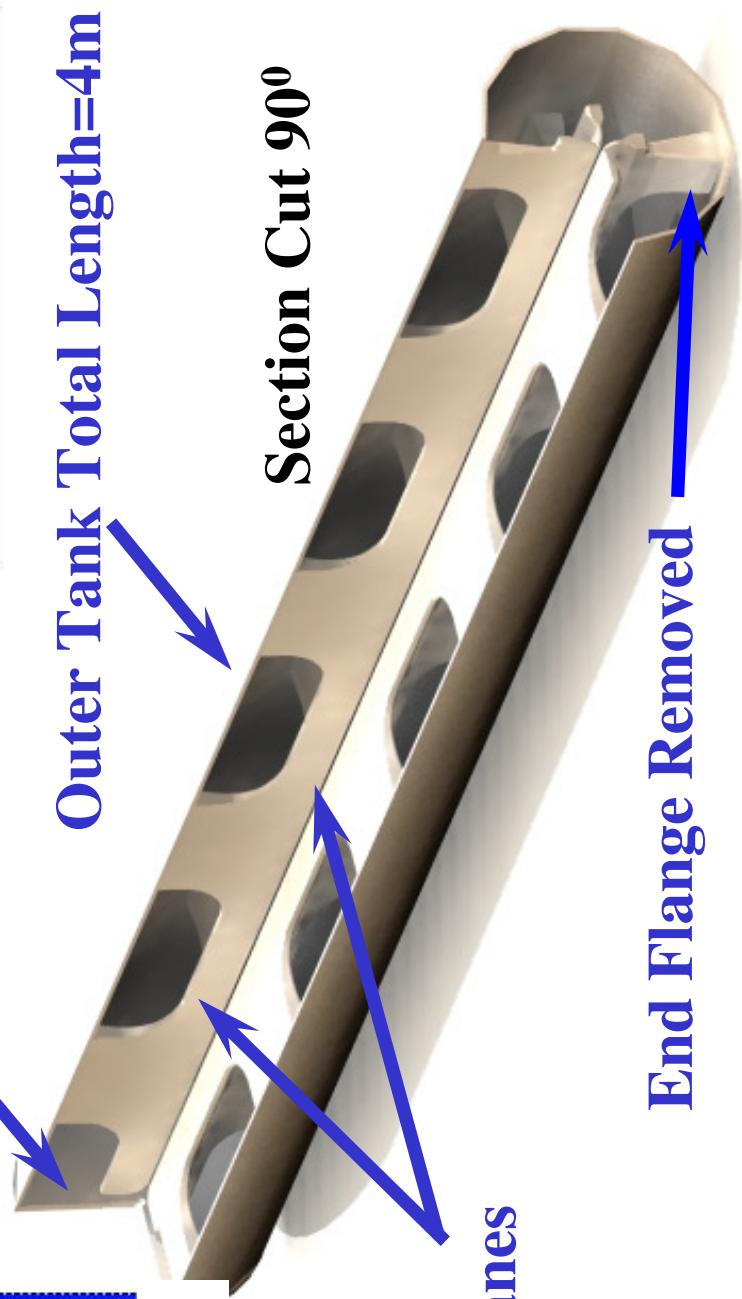
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MAFIA RF Modeling

Magnetic flux density in y-z cross section
(thru vertical vanes)



Name (unit)	Value
Resonator length (m)	4
Tank inner diameter (m)	0.54
Resonant cell number	9
Window width (m)	0.56
Window height (m)	0.17
Average aperture radius (cm)	0.55
Vane tip radius (cm)	0.45
Operating mode frequency (MHz)	80.5
Nearest quadrupole mode (MHz)	88.6
Nearest dipole mode (MHz)	93.8
Specific shunt impedance ($k\Omega \cdot m$)	389
Quality factor	13000
Inter-vane voltage (kV)	70
Peak electric field (MV/m)	14
Peak magnetic field (mT)	11
Total power dissipation (kW)	51



Outer Tank Total Length=4m

End Flange

Vanes

Electric field in x-y cross-section.



End-to-End Simulations

McLean's, the magazine that has been covering the world of mental health for more than 100 years, is now available online at www.macleans.ca. The website features the latest news and information from the magazine, as well as interactive features, video, and audio content. It also includes a forum where readers can discuss mental health topics with each other and with experts. The website is a valuable resource for anyone interested in learning more about mental health issues.

- Included
 - Experimentally based input beams
 - Misalignment and rf errors
 - Charge-stripping foil model
 - Adequate transverse and longitudinal performance for multi-charge state beam acceleration
 - Transverse and longitudinal emittance growths acceptable
 - No beam loss observed

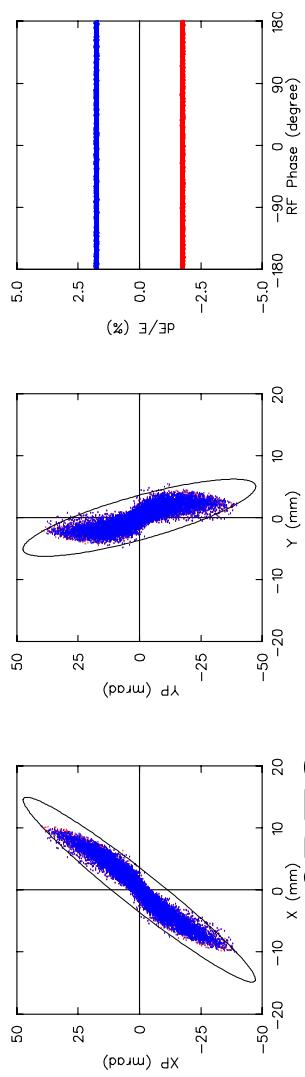


RIA Front End Simulation Results

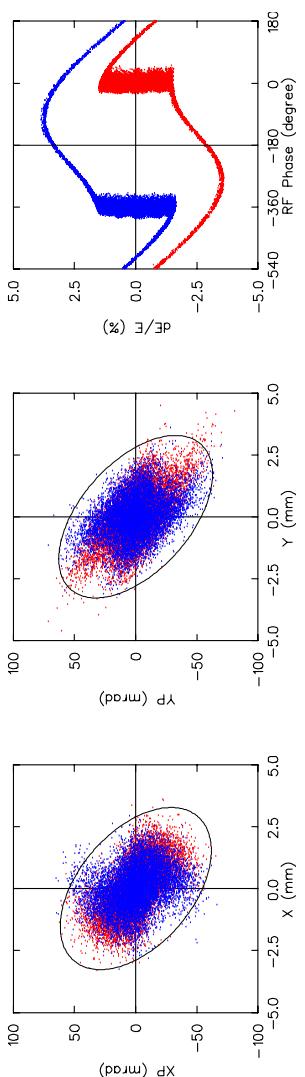
THESE ARE THE NAMES OF THE SITES WHICH WERE EXAMINED IN THE FIELD AND WHICH ARE KNOWN TO BE OCCUPIED BY THE MAMMALS LISTED IN TABLE I. THE SITES ARE ARRANGED IN ORDER OF INCREASING ALTITUDE. THE ALTITUDE IS INDICATED FOR EACH SITE. THE NUMBER OF MAMMAL SPECIES FOUND AT EACH SITE IS INDICATED IN PARENTHESES. THE NUMBER OF MAMMALS OF EACH SPECIES FOUND AT EACH SITE IS INDICATED IN PARENTHESES. THE NUMBER OF MAMMALS OF EACH SPECIES FOUND AT EACH SITE IS INDICATED IN PARENTHESES.

- Two charge-state U²³⁸ beam acceleration
 - Beam intensity: 8 p μ A
 - 100kV high voltage platform
 - Phase spaces based on LBNL emittance measurement

Entrance of LEBT



JEntrance of RFQ



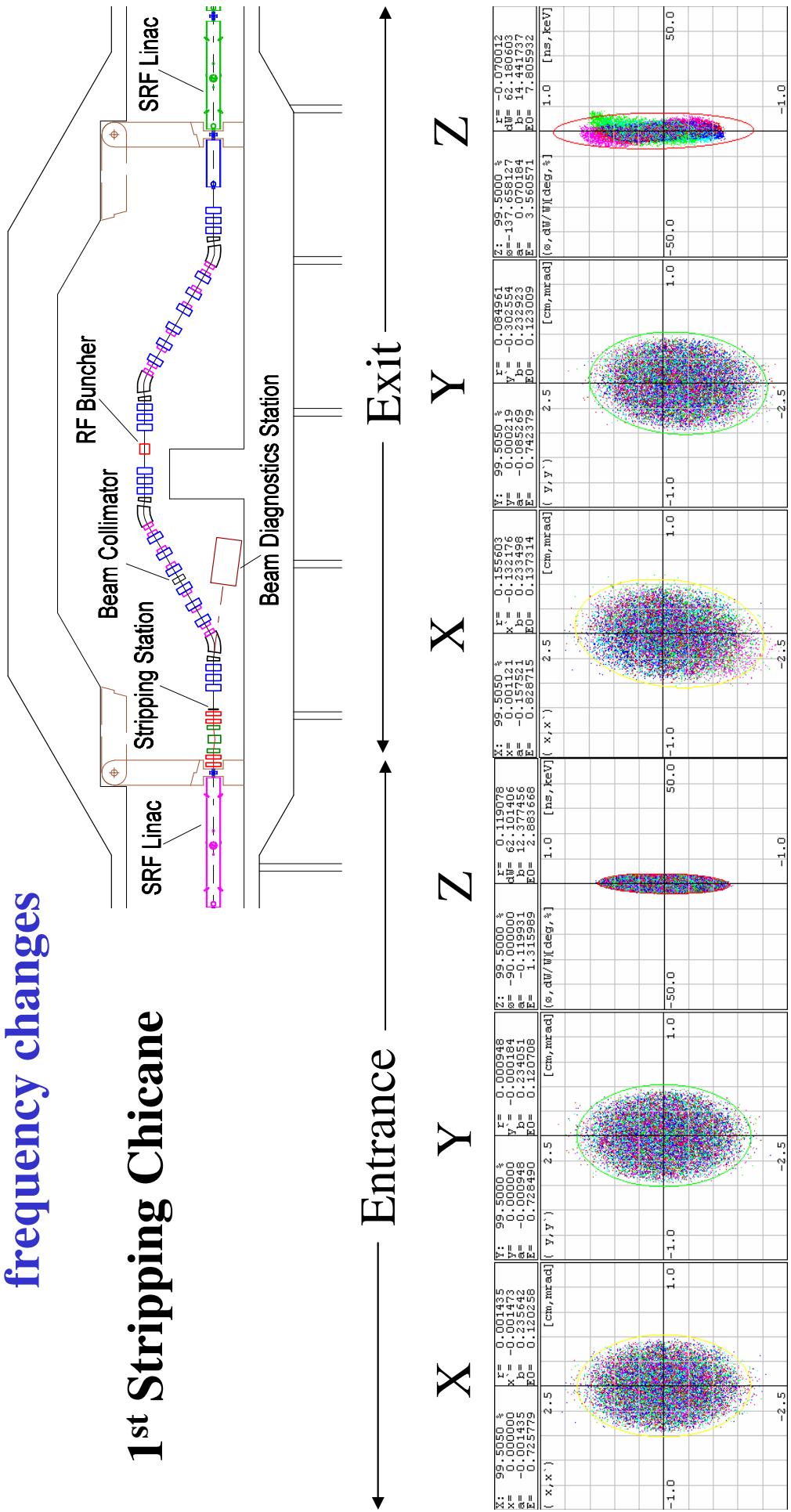
Exit of front end

$\varepsilon_{n,T}$ (99.5%)	$\sim 0.9 \pi$ mm-mrad
$\varepsilon_{n,L}$ (99.5%)	$\sim 1.2 \pi$ keV/u-ms



Driver Linac Stripping Chicanes

- High symmetry – good higher-order corrections
 - Positioned to support longitudinal matching at frequency changes





Charge-Stripping Foil Model

- Based on simulation results from code TRIM
 - Elastic and inelastic scattering
 - Energy loss and straggling
 - Carbon foils with $\pm 5\%$ thickness variation used in simulation
 - Small transverse beam spot ($\sim 3\text{mm}$) and Short bunch length ($\sim 8^\circ$ rf) at both stripping locations

Stripping Foil	Emittance Growth Transverse/Longitudinal
1 st	$\sim 21\% / \sim 64\%$
2 nd	$\sim 45\% / \sim 103\%$



Misalignment and RF Errors

Medieval Latin was the language of the Roman Catholic Church and of learned people throughout Europe during the Middle Ages. It was used as a vehicle for the transmission of classical learning and for the development of a common literary tradition across the continent. The language was influenced by various sources, including Latin, French, and Germanic languages, and it developed its own unique features over time. Medieval Latin was used in a variety of contexts, including religious texts, legal documents, and scientific treatises. It played a significant role in the development of European literature and culture.

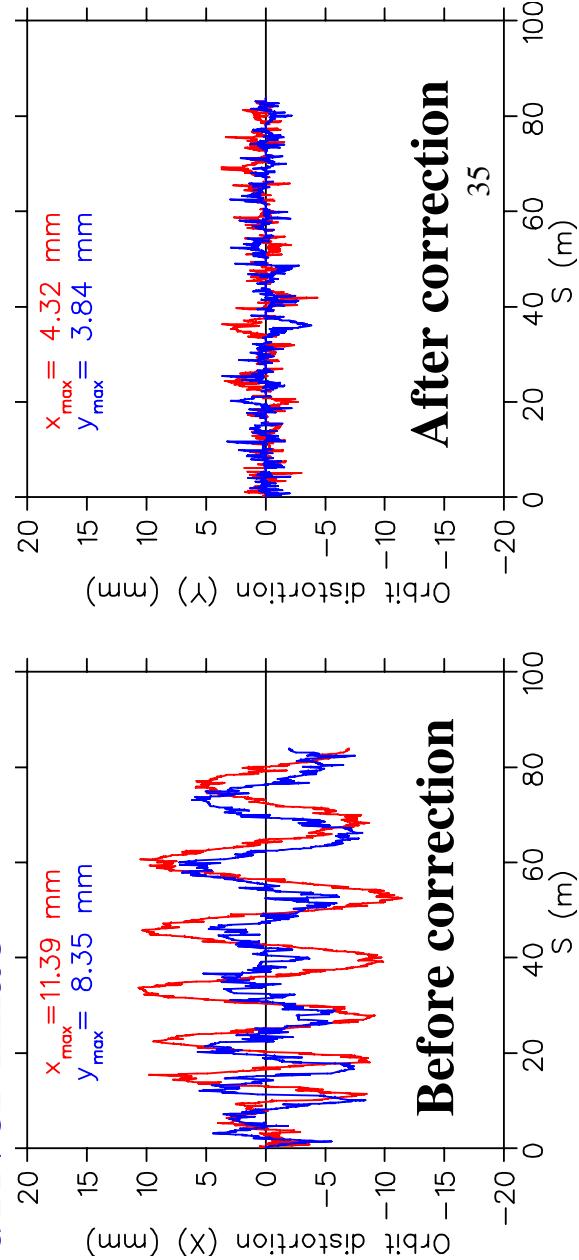
RIA Driver Linac	$\sigma_{x,y}$ [mm]	Maximum RF Errors for SRF Cavity		
		Focusing Element	SRF Cavity	Phase [deg]
Segment I	0.5		1.0	± 0.5
Segment II	0.5			± 0.5
Segment III	1.0			

- Misalignment - Gaussian distribution cut-off at 2σ
 - RF errors - uniform distribution



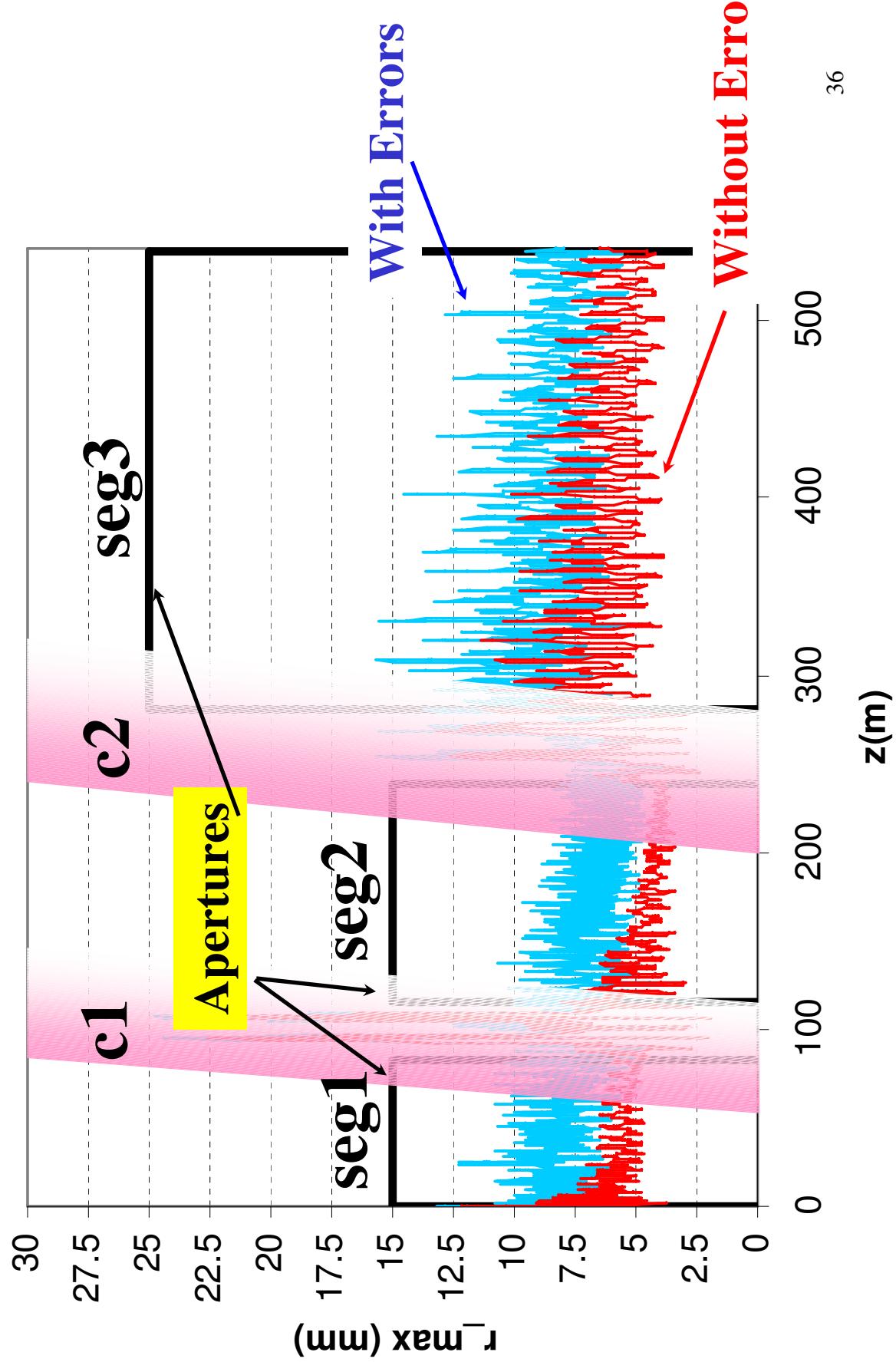
Alignment Correction Scheme

- Segments I, II – Horizontal/vertical dipole windings for each focusing solenoid magnet
 - Segment III – Warm dipole correctors beside focusing quadrupole doublet
 - All BPMs in the warm region between cryomodules
 - Central orbit distortions limited within $\pm 5\text{mm}$ after corrections in all three segments of driver linac



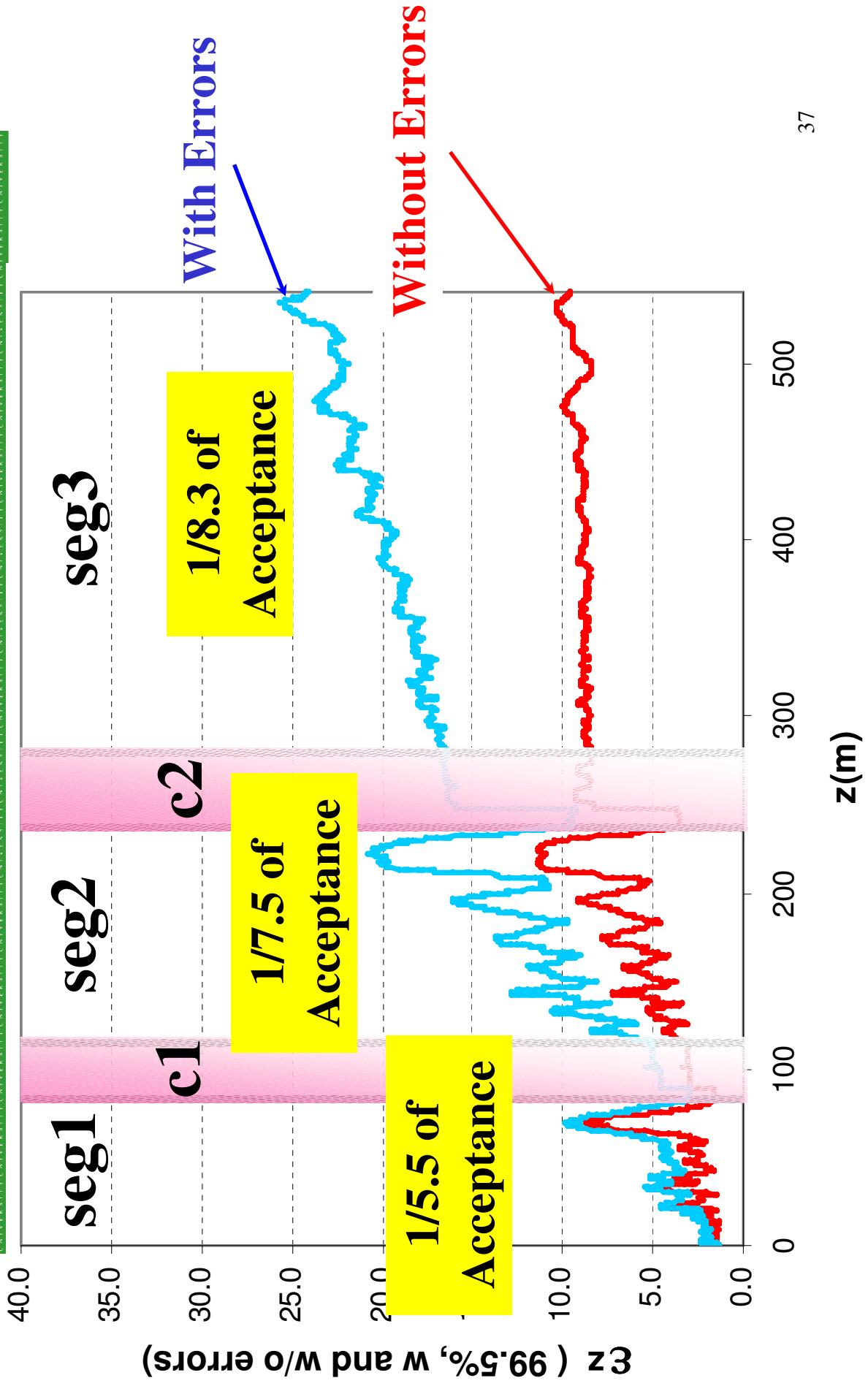


Driver Linac Transverse End-to-End





Driver Linac Longitudinal End-to-End

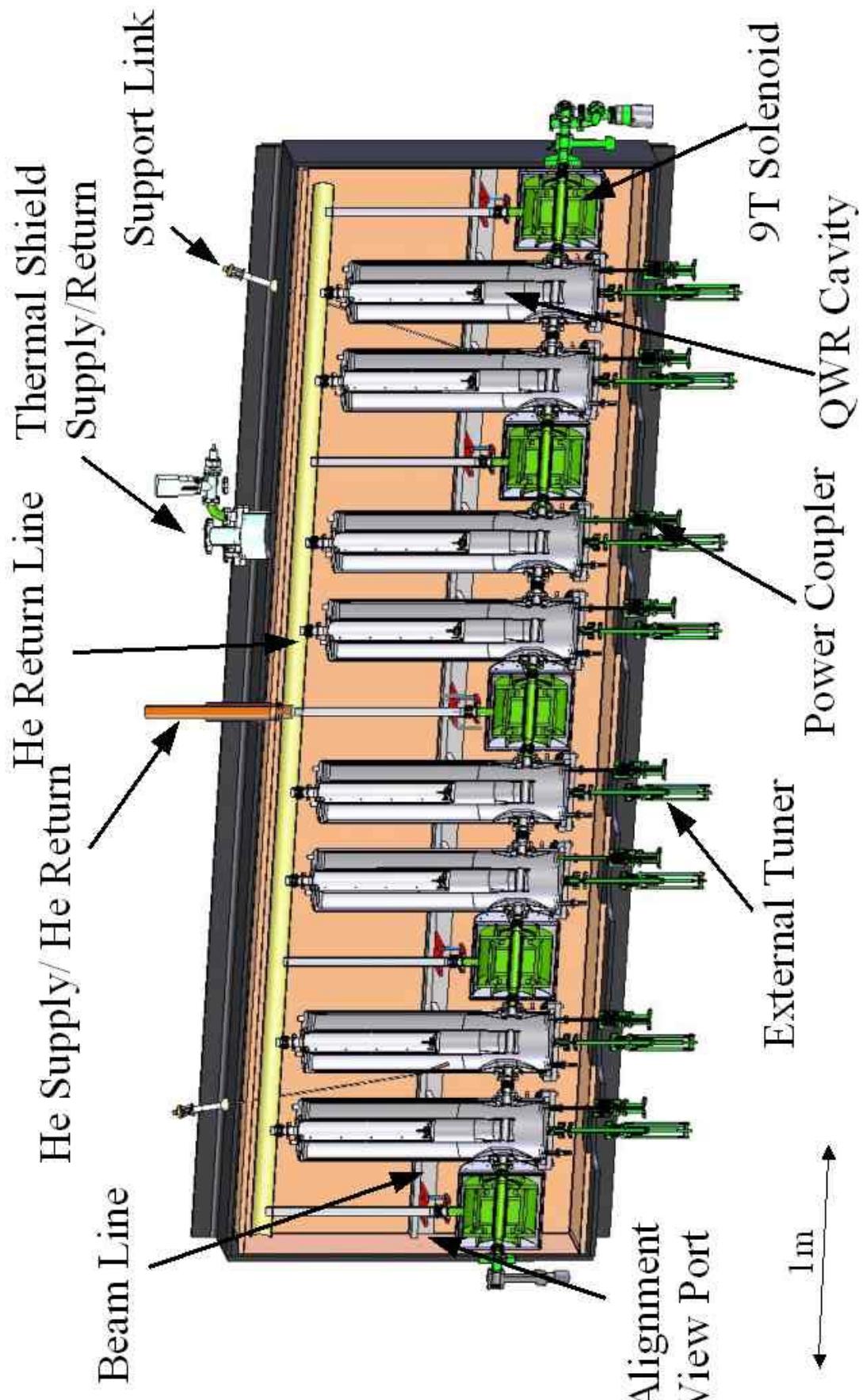




Segments I & III Cryostats

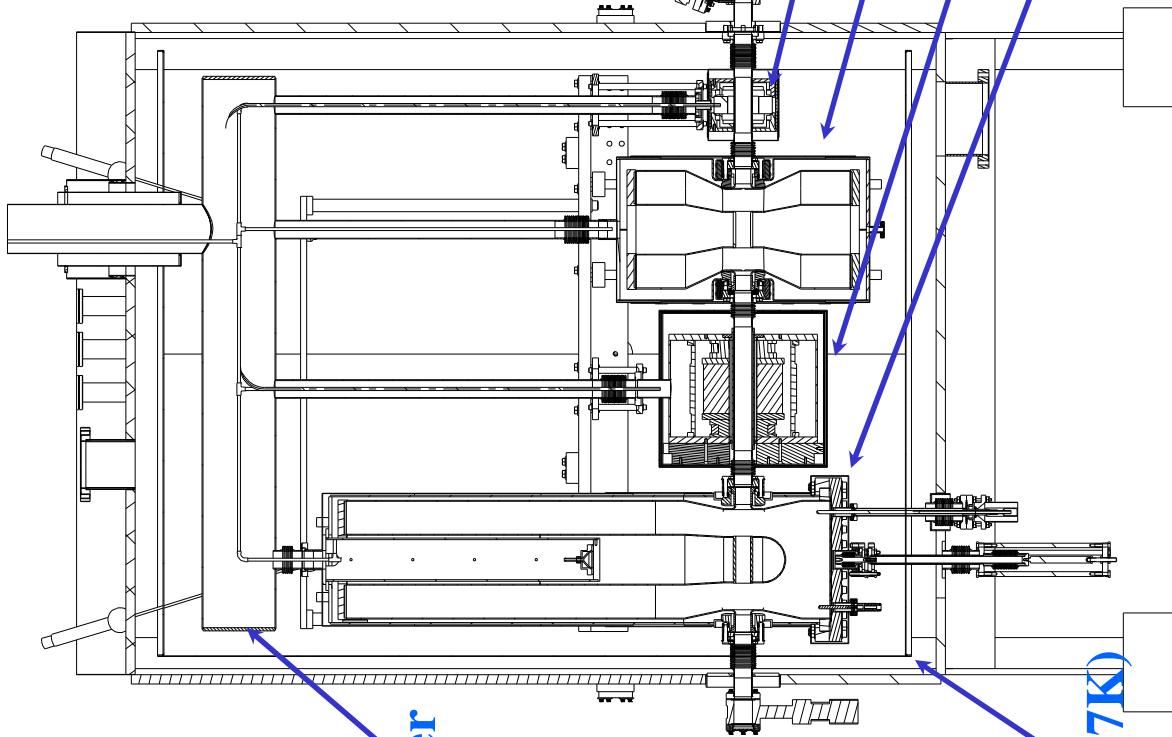
McDonald's has been a part of our community since 1955. We're here to help you make the most of your day. From breakfast to dinner, we offer a variety of delicious menu items to satisfy your cravings. Our commitment to quality and service has made us a favorite among families and individuals alike. So why not stop by today and see what we have to offer?

Isolated vacuum & superconducting solenoid focusing



Low- β Cryomodule Prototype

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Top plate w/ header



Cold Mass

0.6 T Quadrupole

$\lambda/2$, $\beta_{\text{opt}}=0.285$

9 T Solenoid

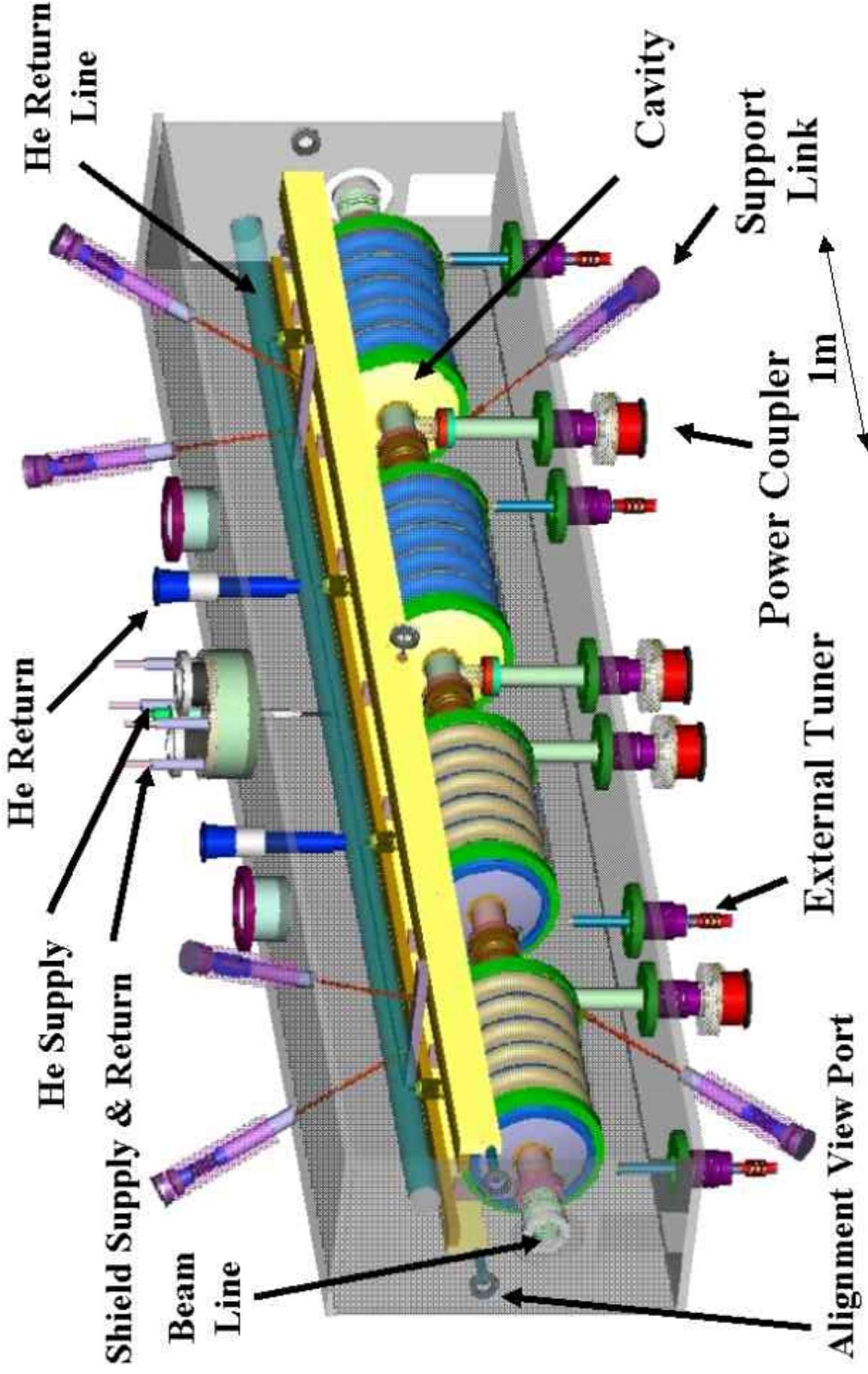
³⁹

Thermal Shield (77K)



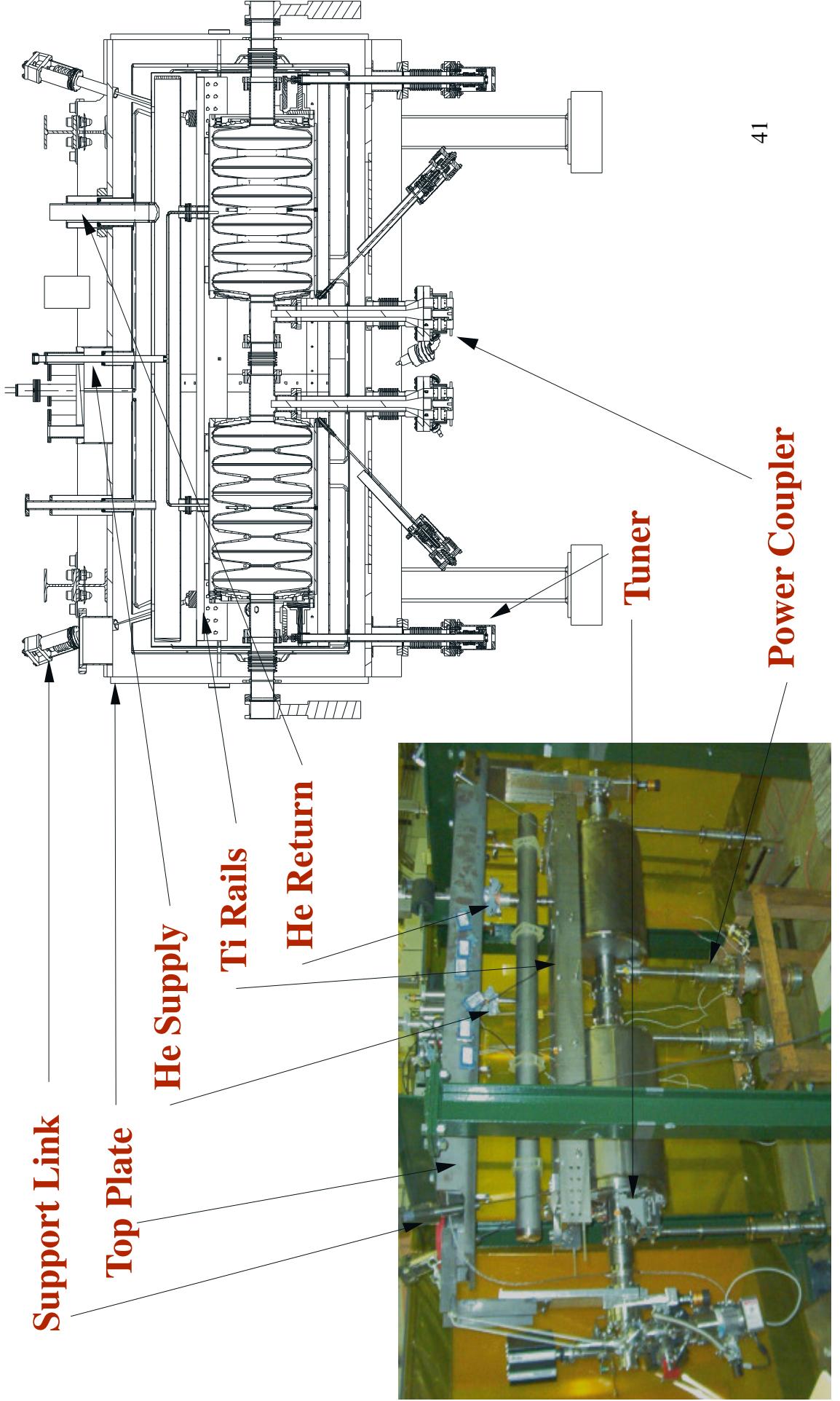
$\lambda/4$, $\beta_{\text{opt}}=0.085$

Segment III Cryostats



$B_{\text{opt}}=0.49$ Prototype Systems Test

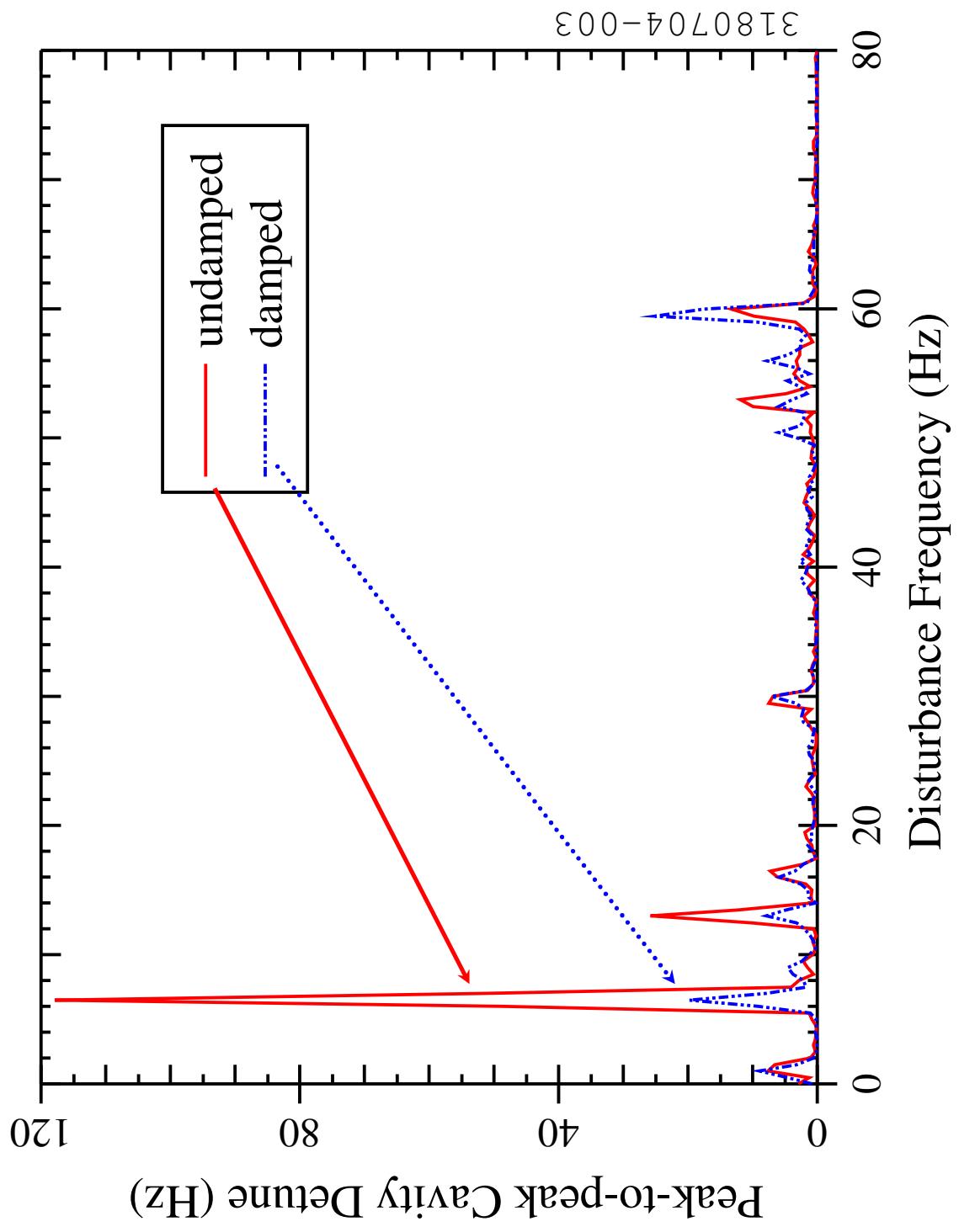
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Microphonics Control



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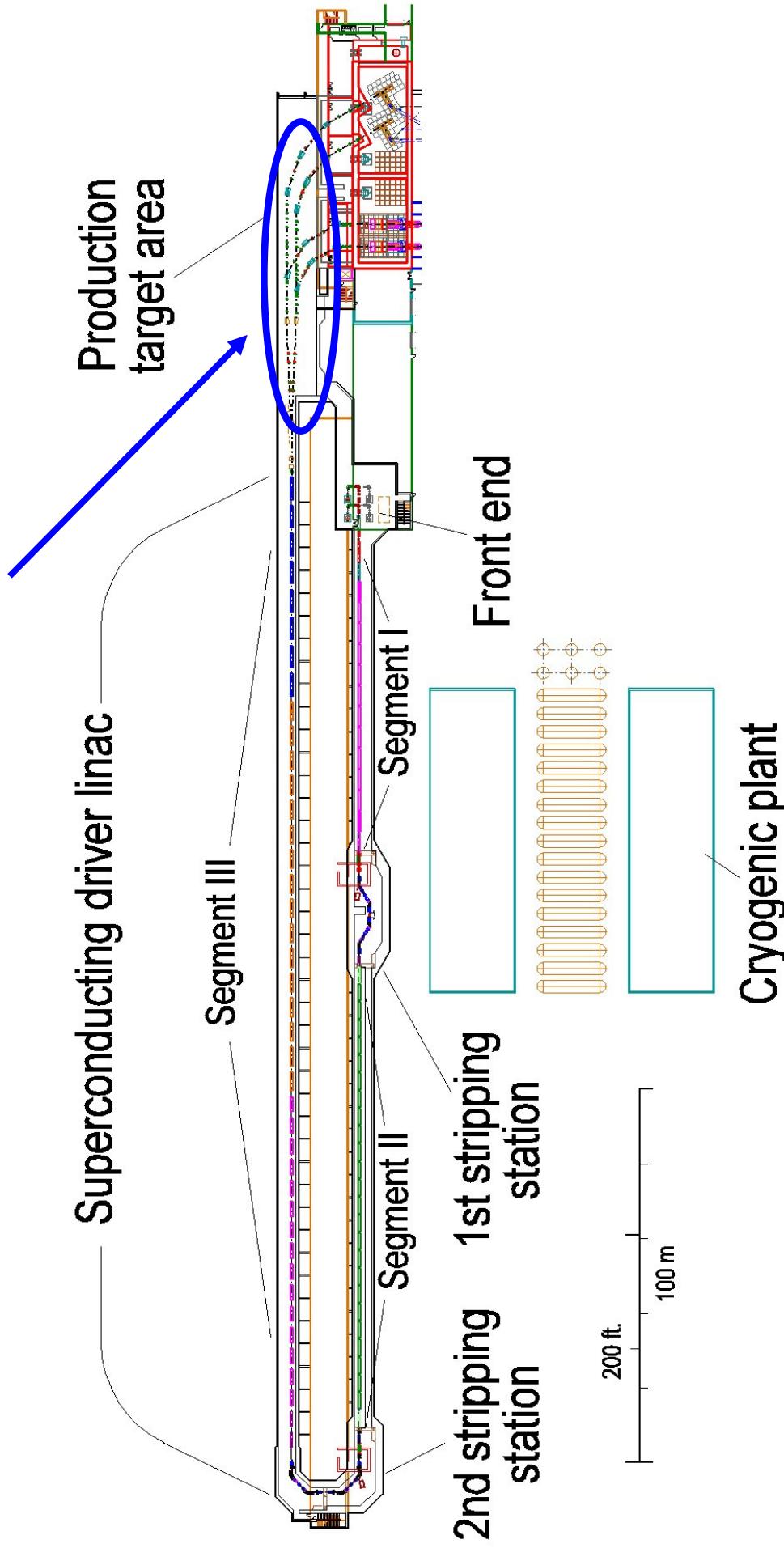




RIA Layout - BSY

McPherson's first major work was the construction of a new bridge across the Missouri River at Fort Pierre, South Dakota. This project required the removal of a large amount of earth and rock from the riverbed, which caused significant damage to the surrounding land. The U.S. Army Corps of Engineers ordered McPherson to repair the damage, but he refused, stating that it was his responsibility to protect the environment. He was eventually forced to leave the project and return to his home state of Michigan.

Beam Switch Yard

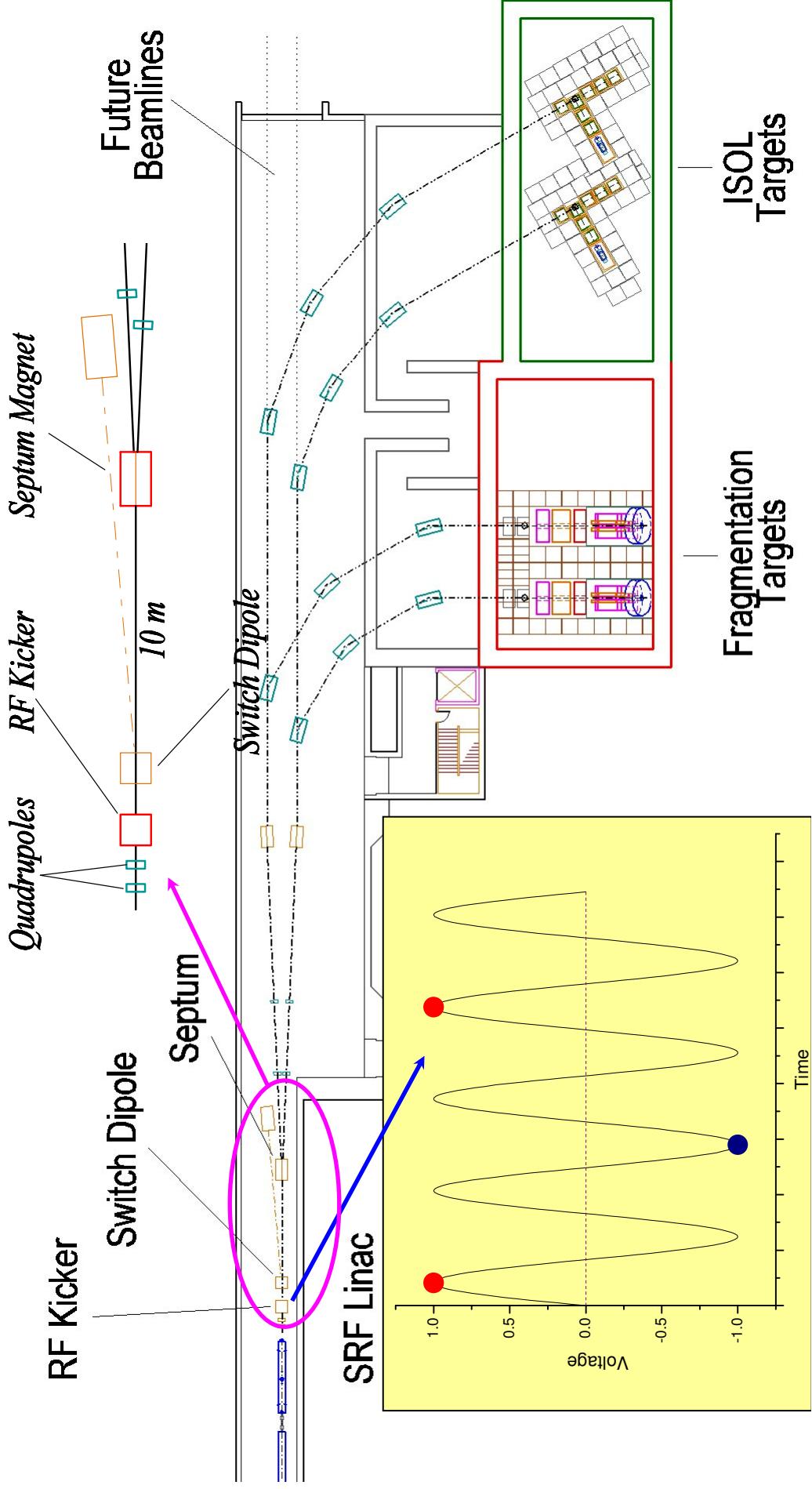




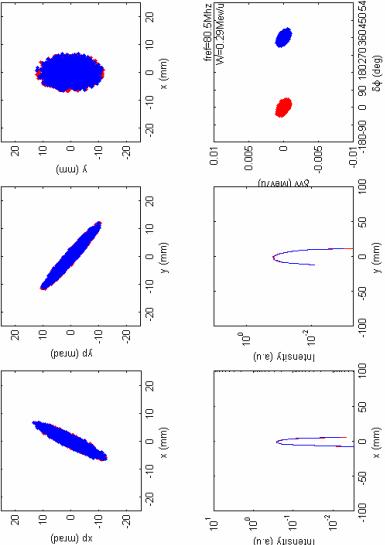
Driver Linac Switch Yard

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- Baseline – provide two beams (of same isotope) to two targets simultaneously (μ -bunch)



MIEBT

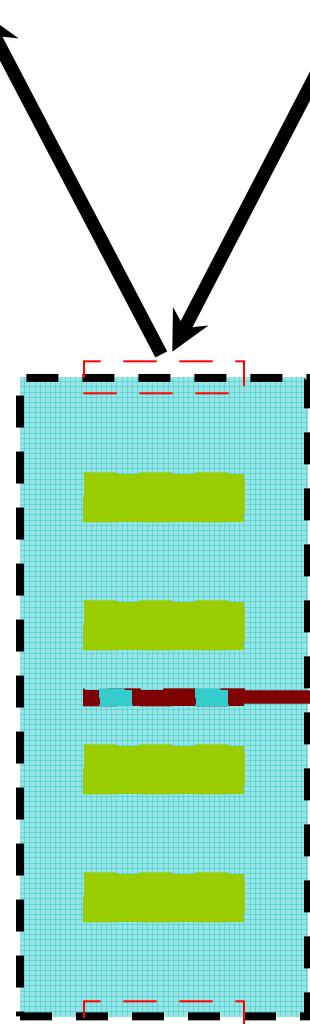


Vary intensity [0-50 %] of each beam

kicker input

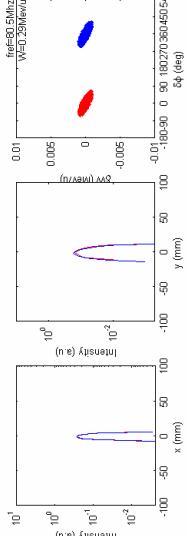
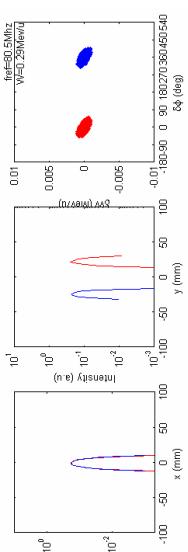
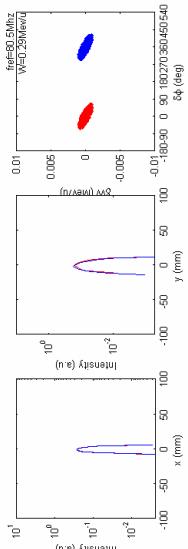
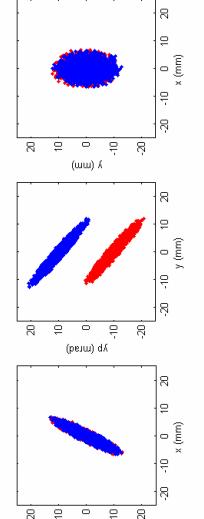
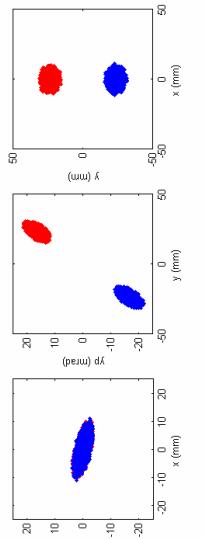
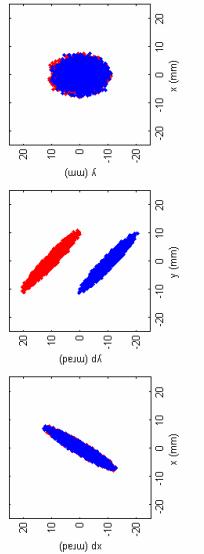
π phase advance cell

kicker output



kicker input

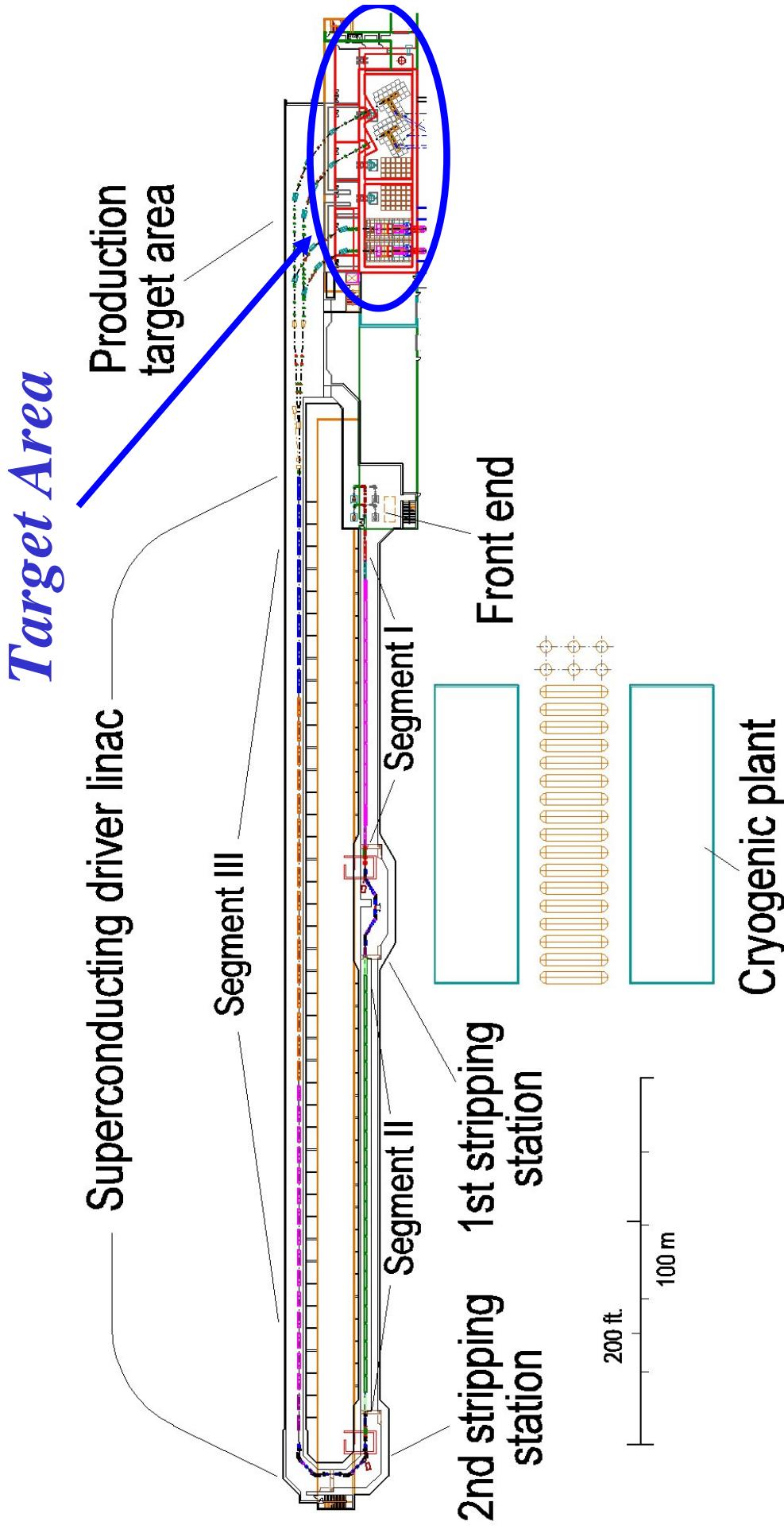
kicker output



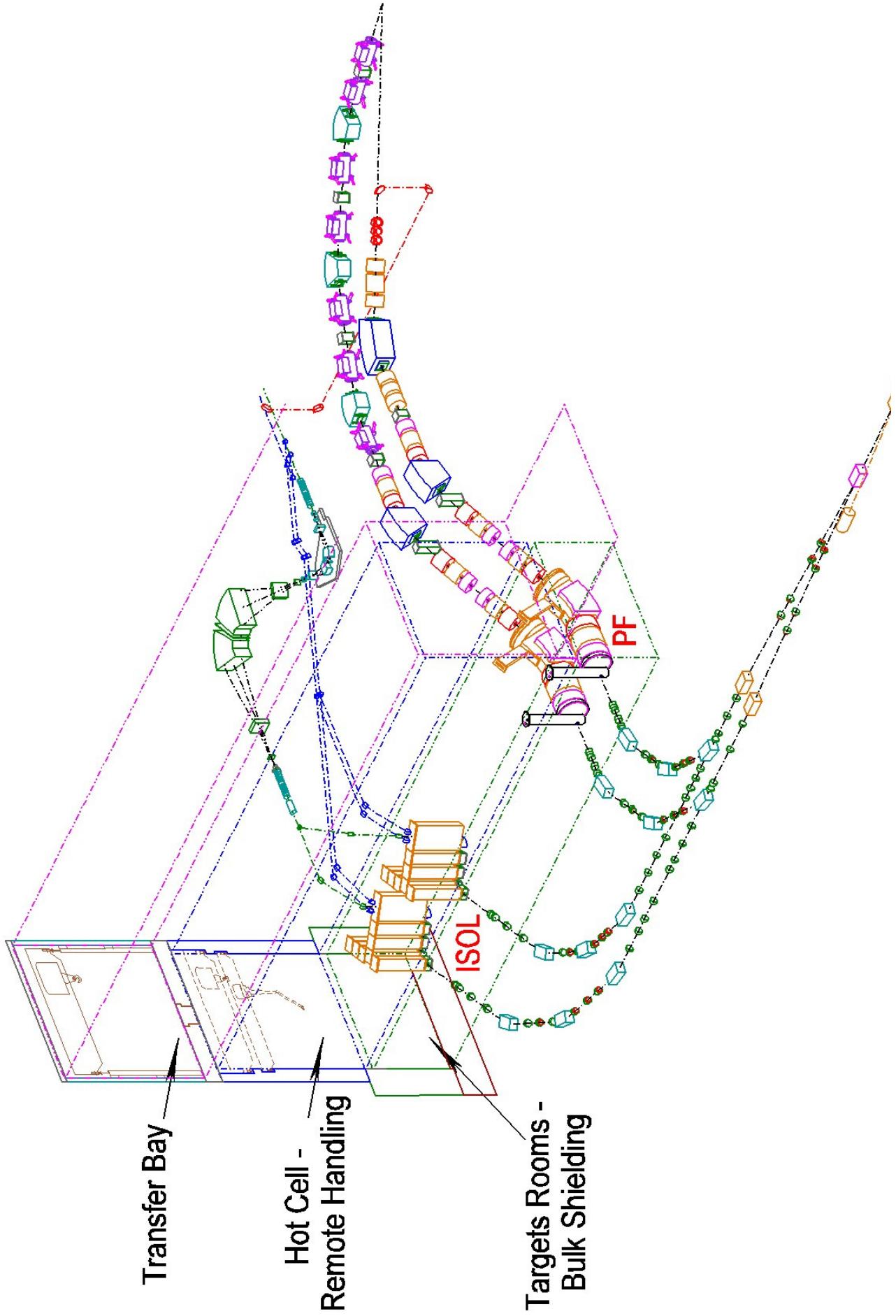


RIA Layout - Target Area

As a result, the new system will be able to identify and analyze the most important factors that influence the success of a project, such as team dynamics, communication, and resource allocation. This will allow organizations to make more informed decisions about how to manage their projects and increase their chances of success.

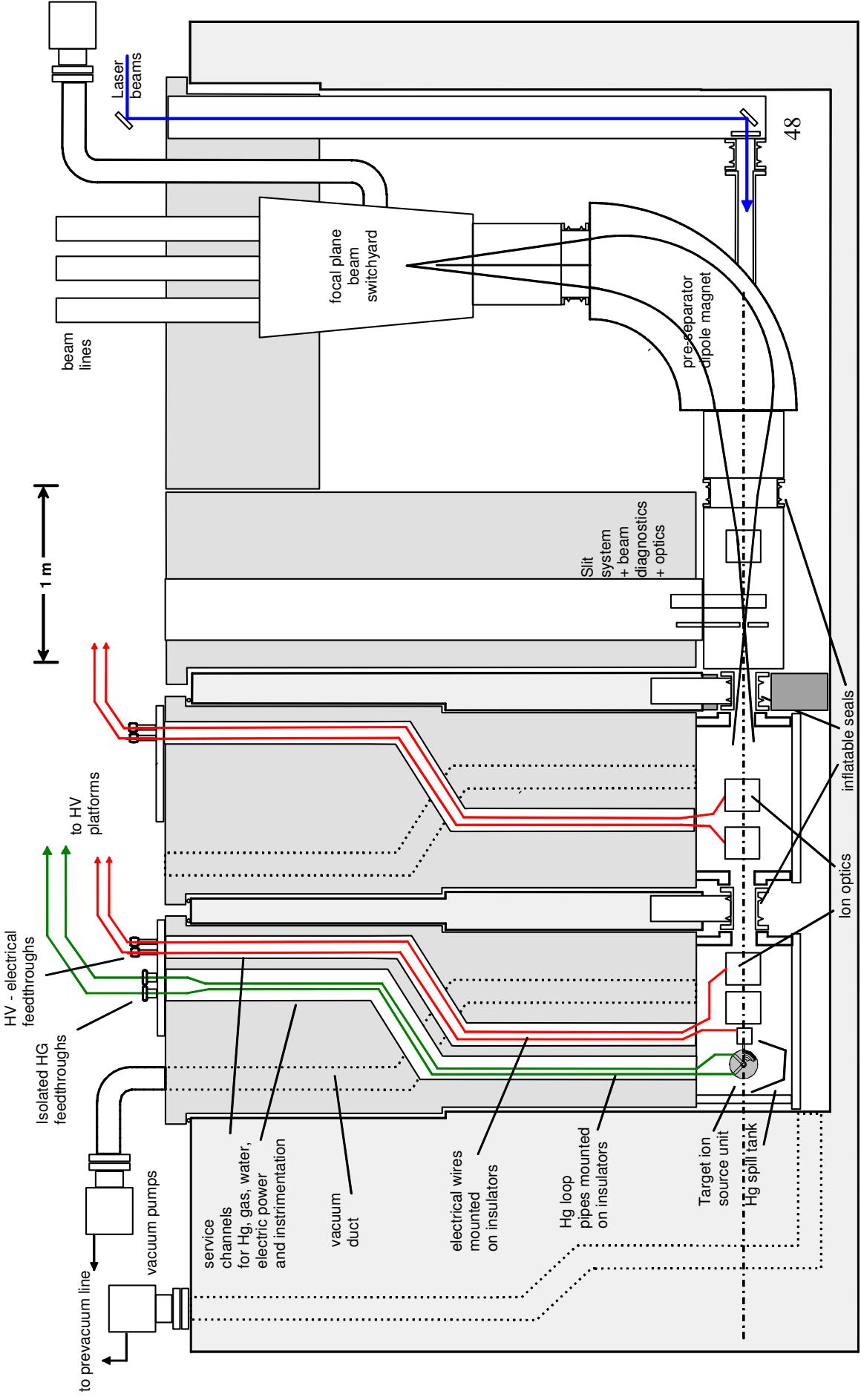


Target Area Detail



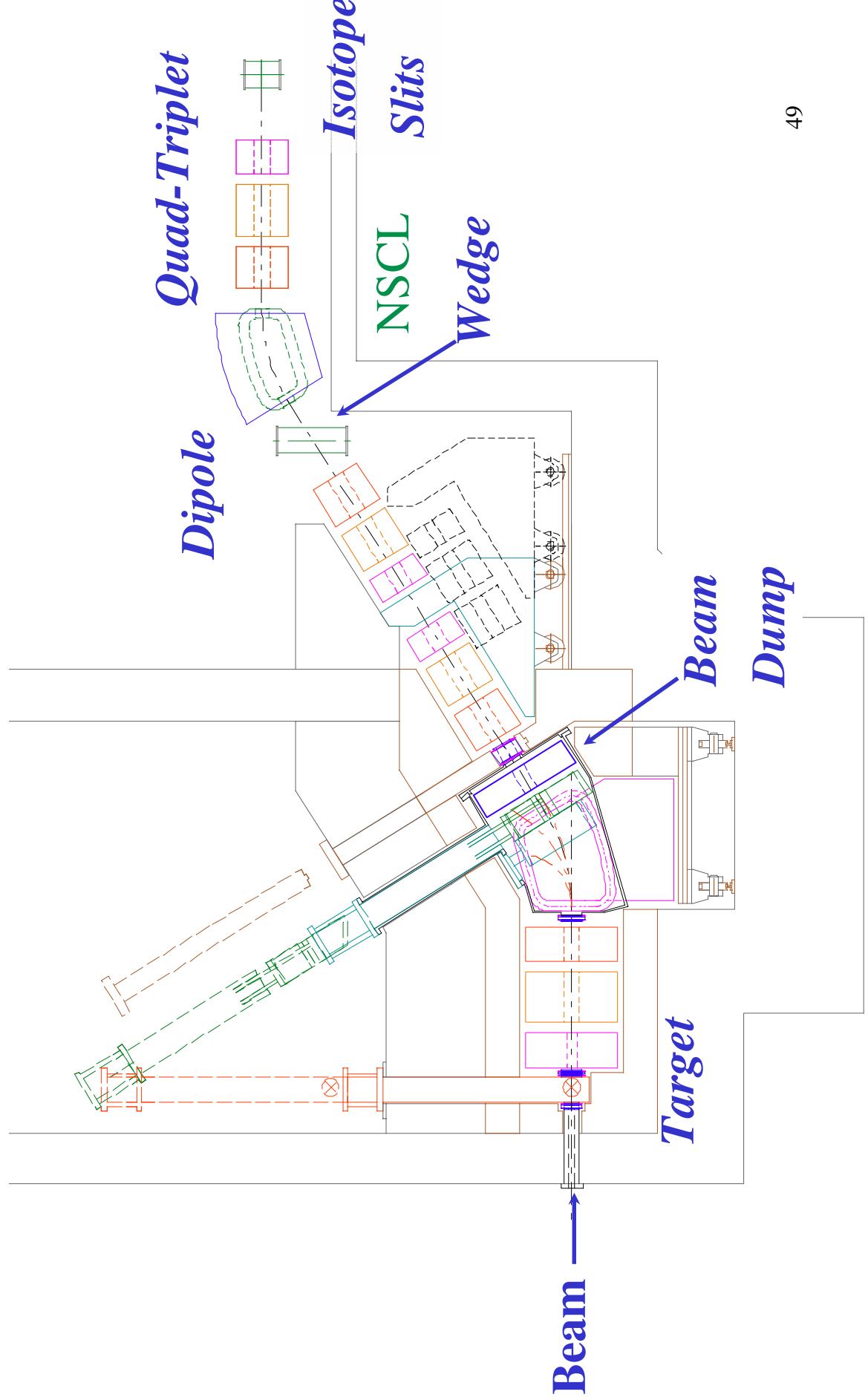
ISOL Target Station

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Pre-Separator

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Summary

- RIA facility designs have been developed
 - Driver linac and beam transport
 - Well developed detailed designs
 - No technical “show stoppers”
 - Production & experimental area concepts developed
 - No “show stoppers” but significant challenges
 - R&D path to solutions identified
 - Ready to go!



THE END