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MICHIGAN STATE UNIVERSITY

Rare Isotope Accelerator
RIA
Project

Richard C. York

July 2005

12th International Workshop on SRF

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RIA Status

MICHIGAN STATE UNIVERSITY

- **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

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**

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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

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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***

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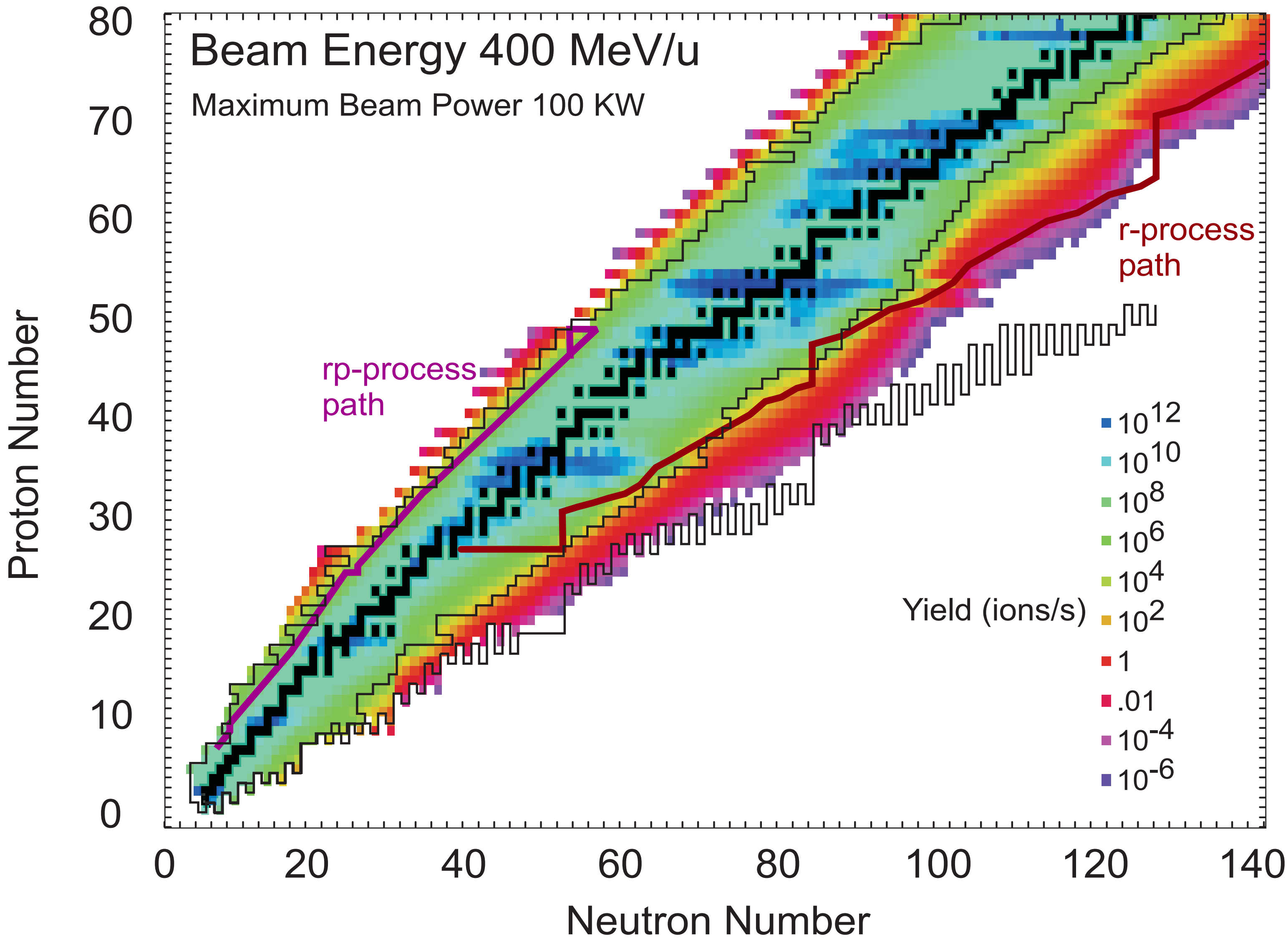
RIA Benefits - cont'd

- **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

Nucleosynthesis in the r-process

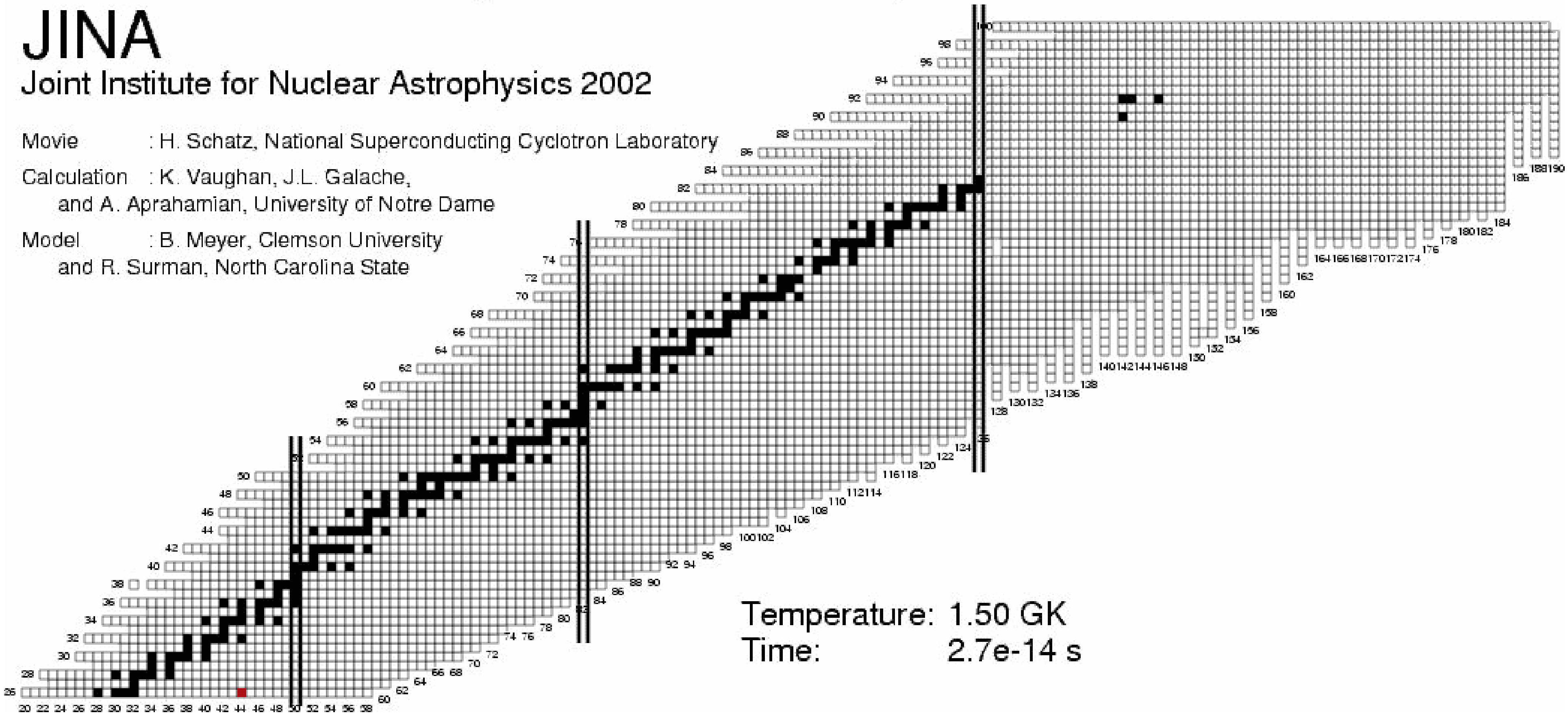
JINA

Joint Institute for Nuclear Astrophysics 2002

Movie : H. Schatz, National Superconducting Cyclotron Laboratory

Calculation : K. Vaughan, J.L. Galache, and A. Aprahamian, University of Notre Dame

Model : B. Meyer, Clemson University and R. Surman, North Carolina State



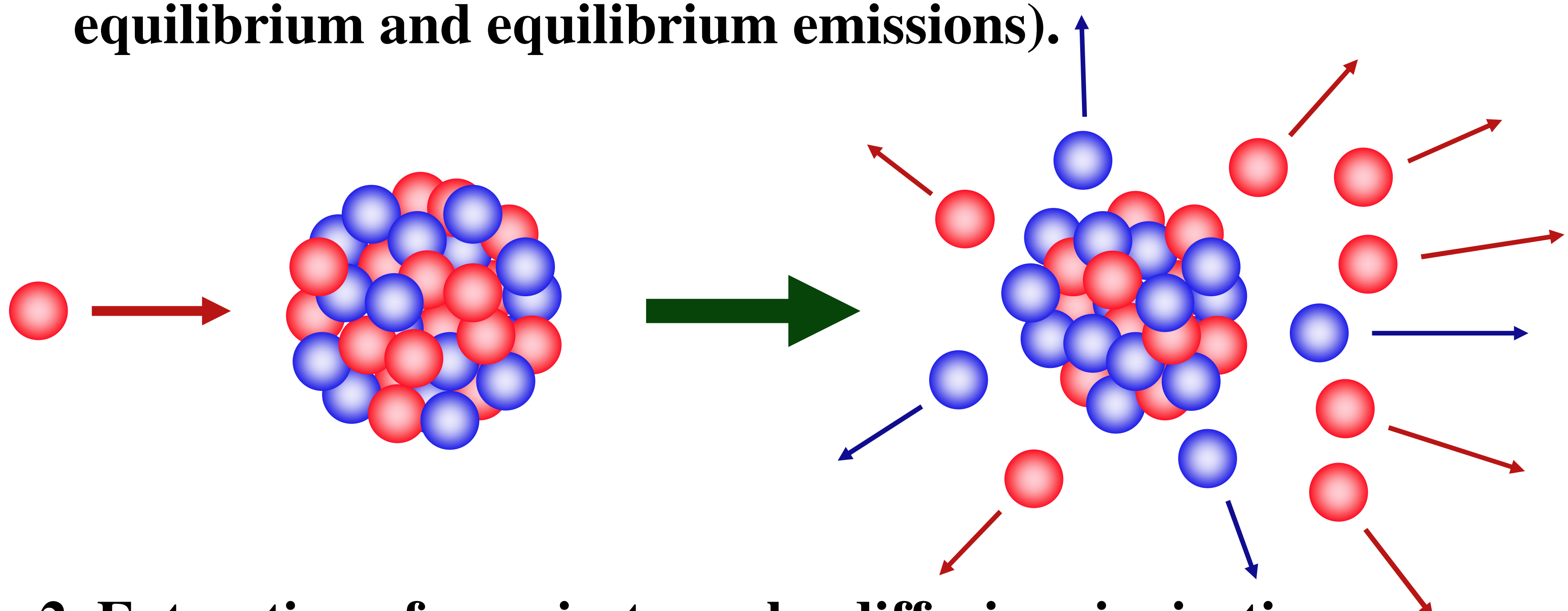
Temperature: 1.50 GK

Time: 2.7e-14 s

Production of Rare Isotopes at Rest

Target Fragmentation

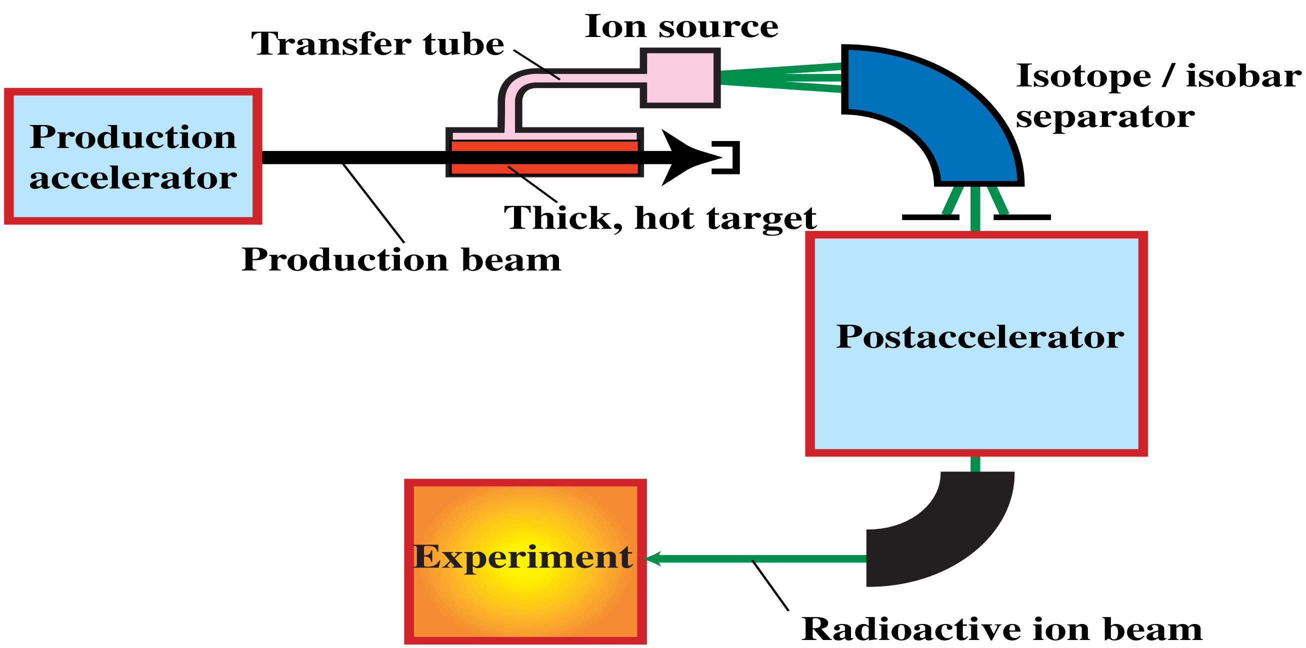
1. Random removal of protons and neutrons from heavy target nuclei by energetic light projectiles (pre-equilibrium and equilibrium emissions).



2. Extraction of rare isotopes by diffusion; ionization and acceleration: beams of high quality.

Classical ISOL Facility Concept

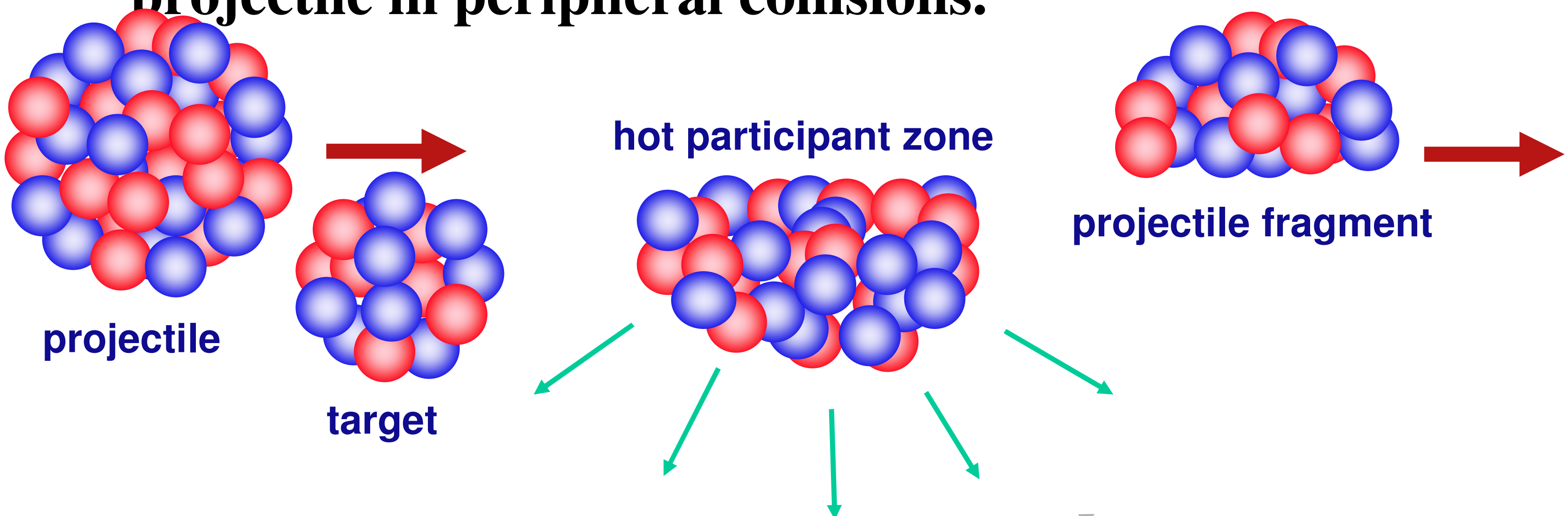
- Excellent beam quality and low beam energies are possible
- Limited to longer lifetimes ($\tau > 1s$)
- Isotope extraction and ionization efficiency depend on chemical properties of element: difficult, element-specific development paths
- The most neutron-rich isotopes will have too low intensities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



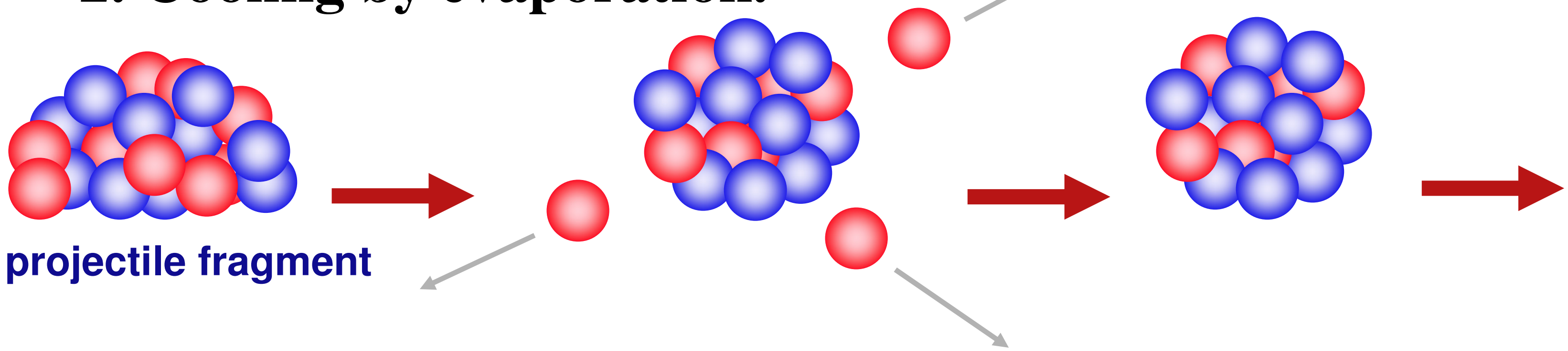
Production of Rare Isotopes in Flight

Projectile Fragmentation

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

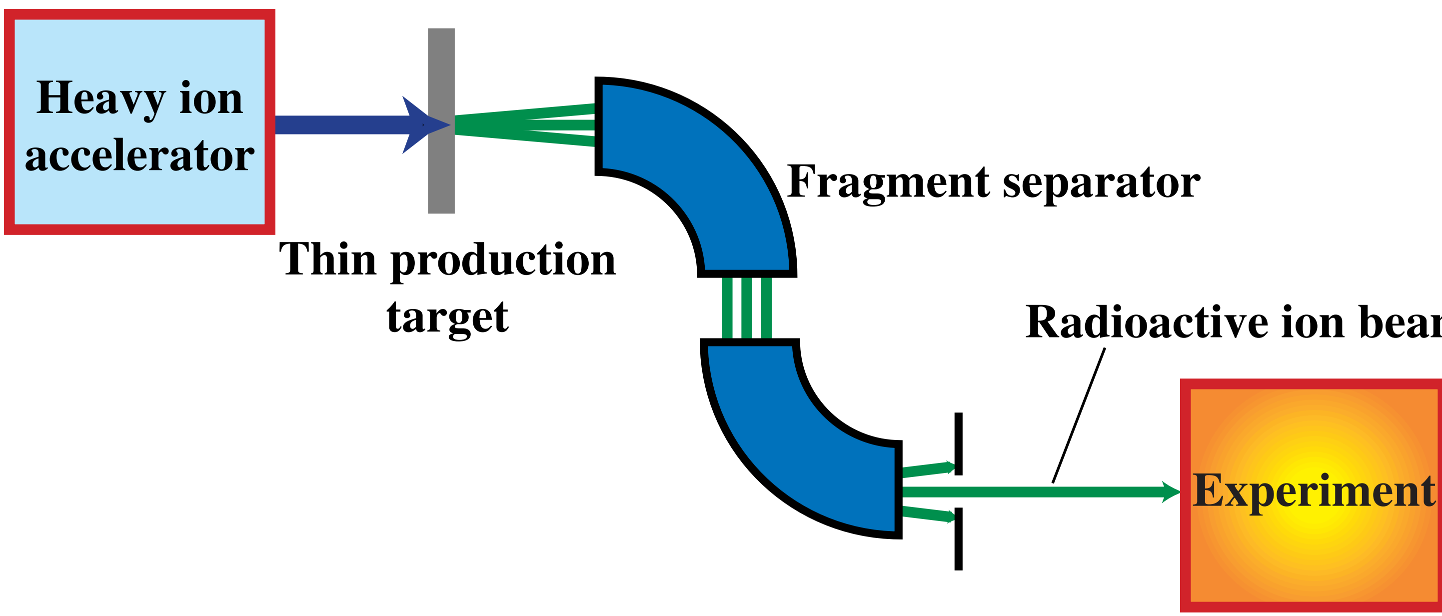


2. Cooling by evaporation.



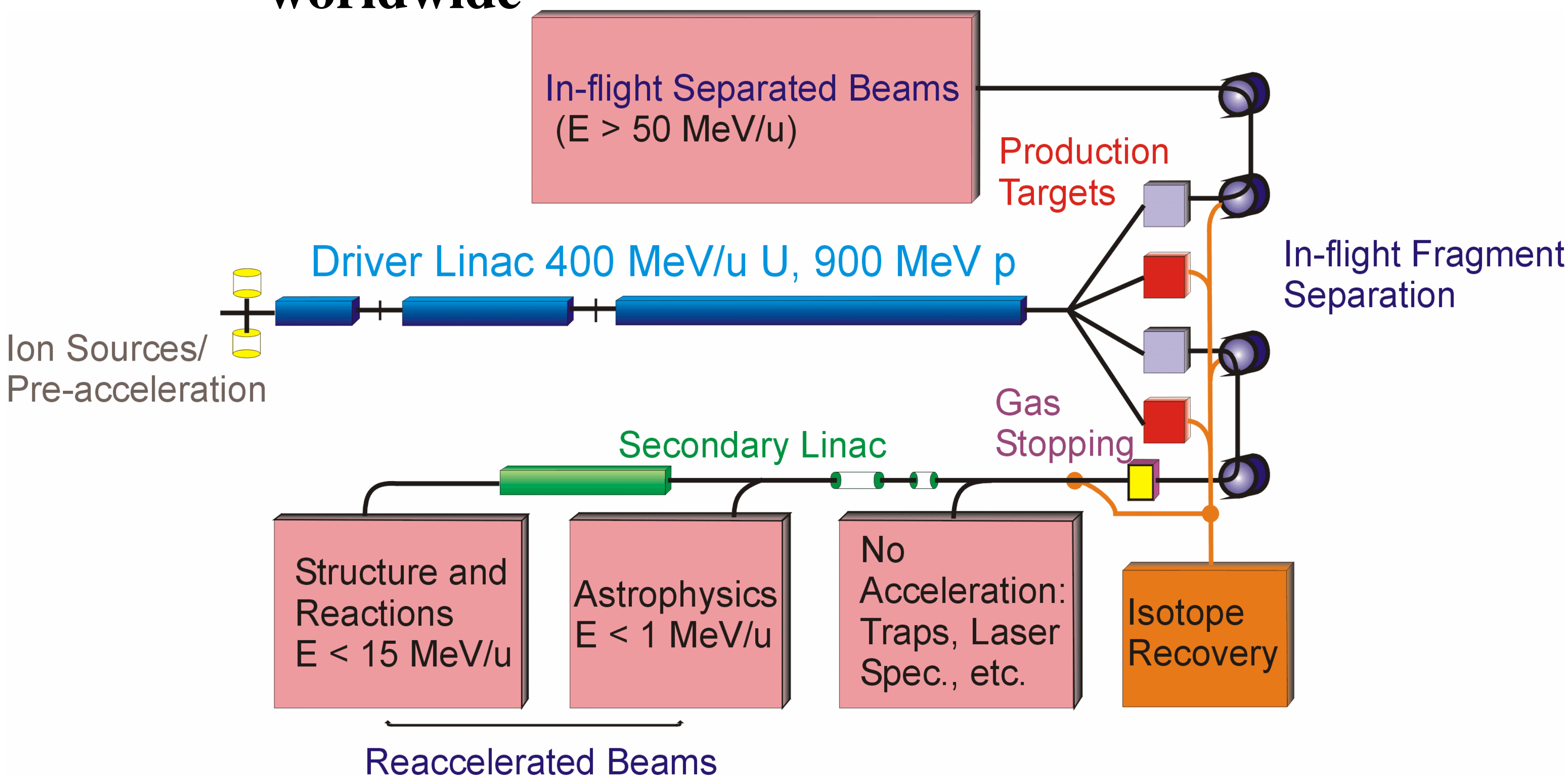
Schematic of a Projectile Fragmentation Facility

- 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***

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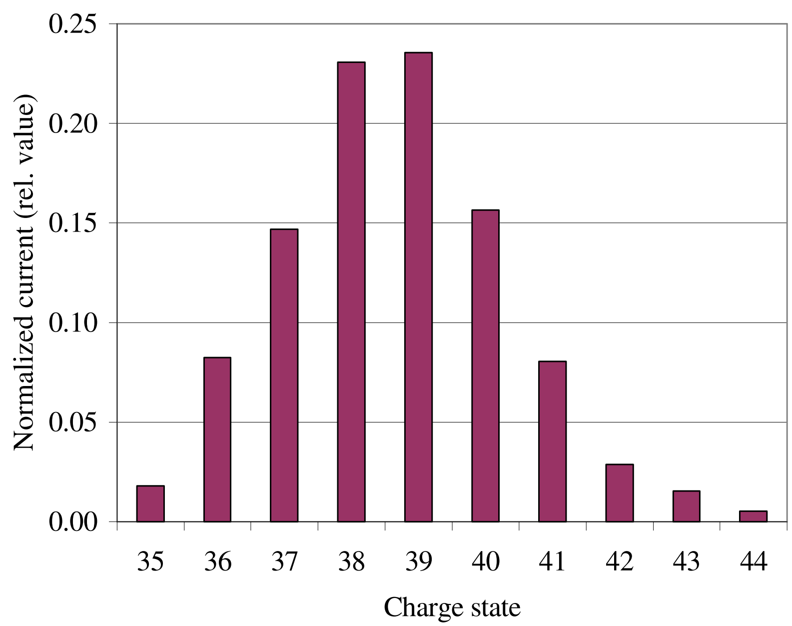
RIA Driver Linac Specifications

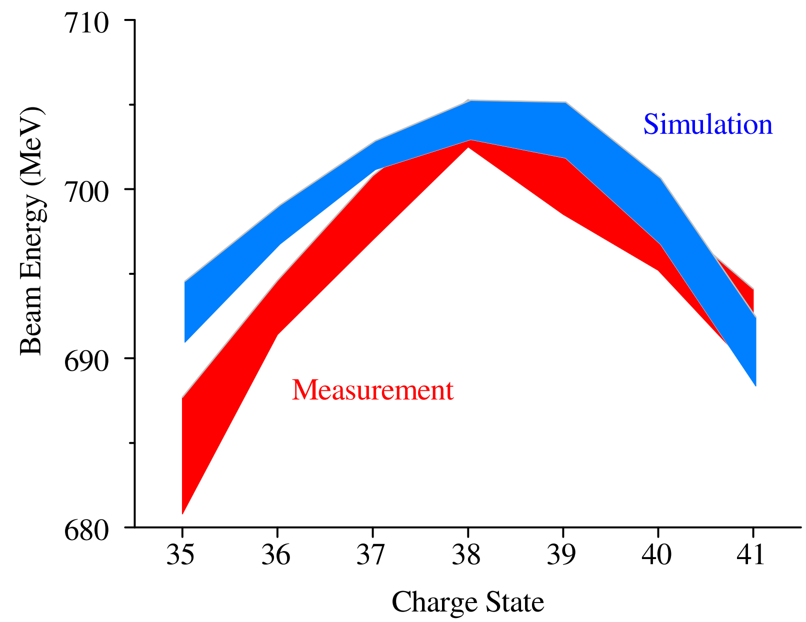
- Accelerate any stable isotope - protons through uranium to $\geq$ 400 MeV/u
- Beam power -
  - 100 kW minimum
  - 400 kW if ion source capable
- 100% duty factor (cw)

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



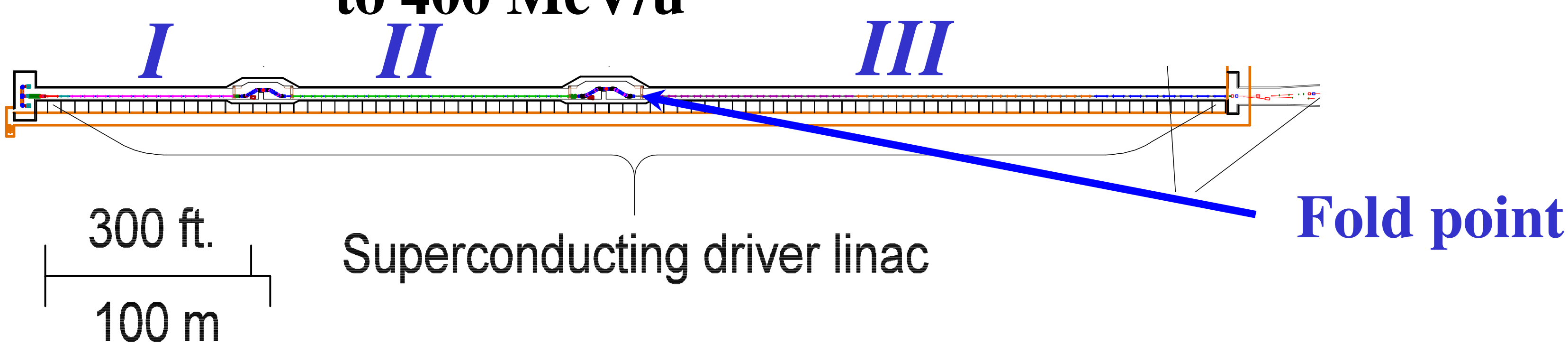
PHYSICAL REVIEW LETTERS, V. 86, No. 13, 2001

Driver Linac Common Concepts

- **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

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



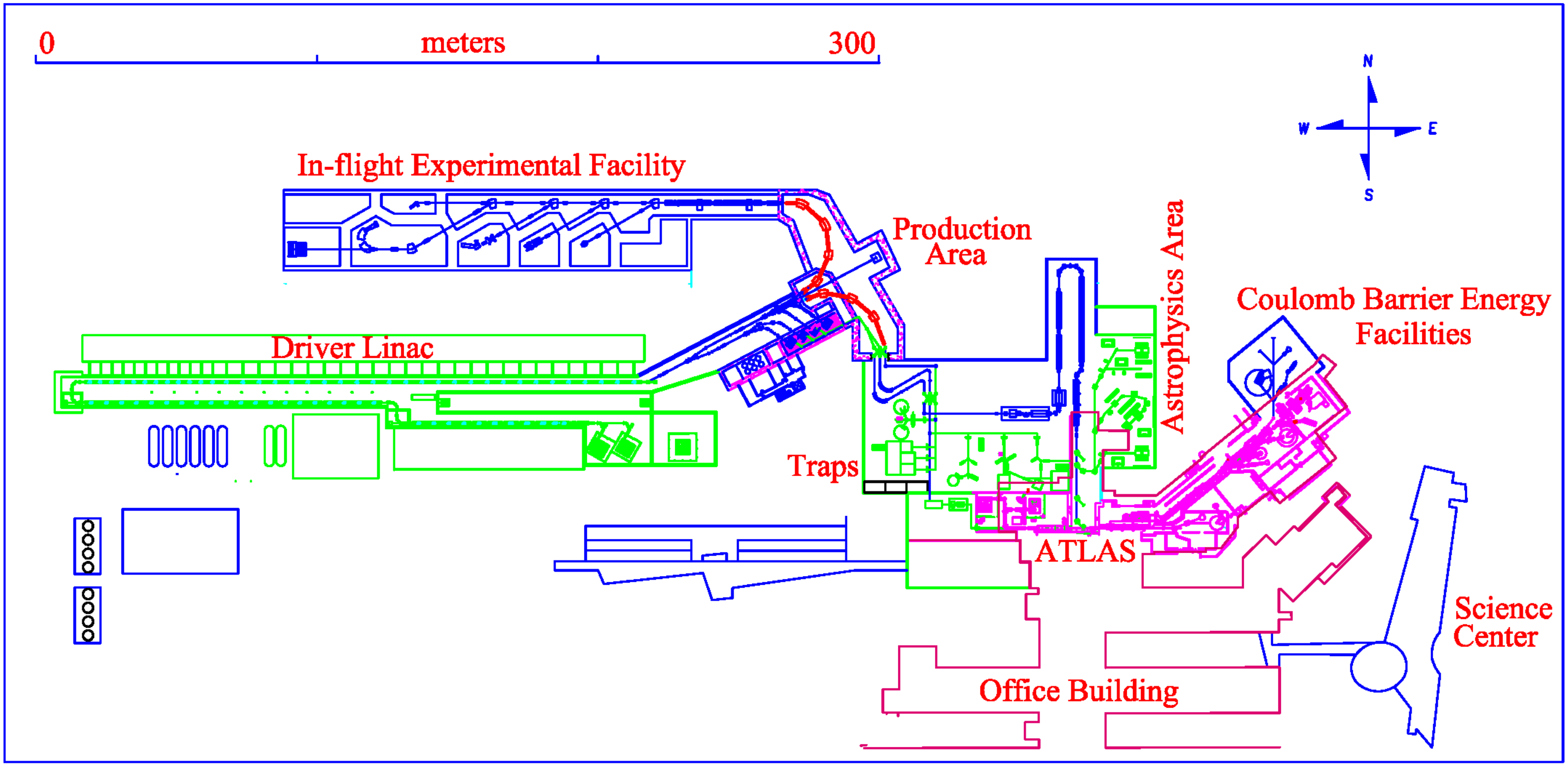
Driver Linac Sample Beam List

Multiple charge state acceleration for >Xe

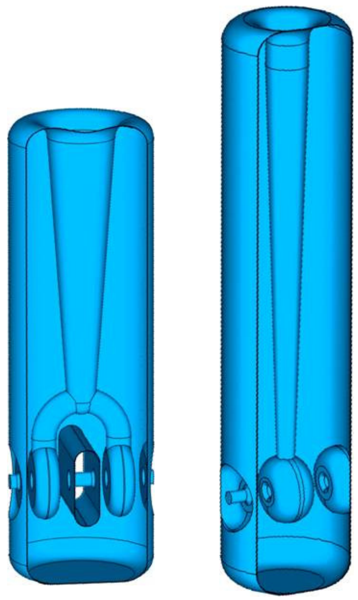
Ion	A	Z	Final Energy (MeV/u)
H	1	1	1028
^{3}He	3	2	777
D	2	1	622
O	18	8	560
Ar	40	18	566
Kr	86	36	510
Xe	136	54	470
U	**238**	**92**	**400**

ANL Proposed RIA Layout

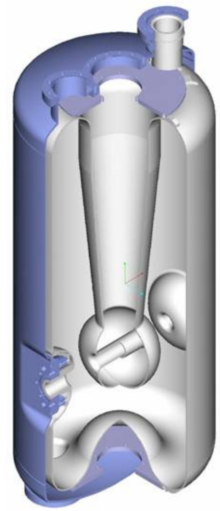
RARE ISOTOPE ACCELERATOR



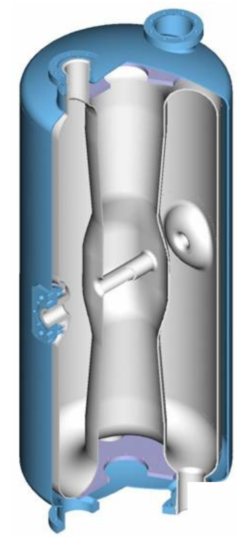
ANL RIA Driver Linac Cavity Array



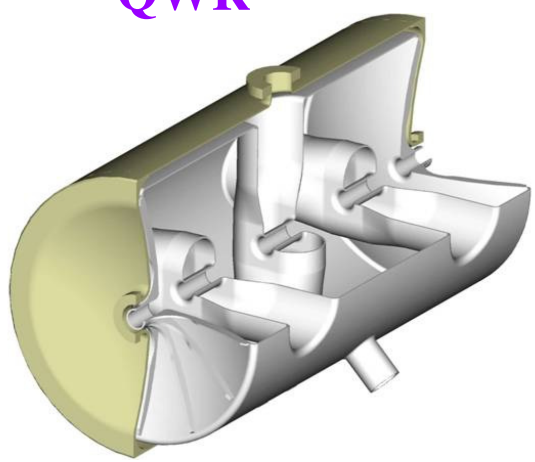
57.5 MHz QWR-
based structures
.03< β <0.14



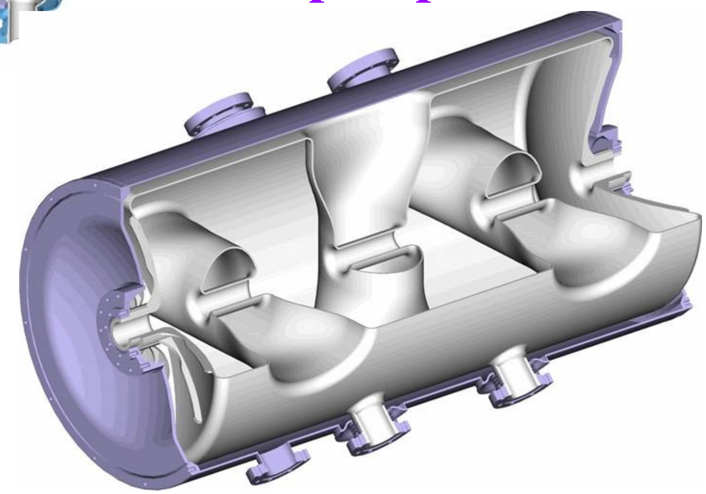
115 MHz β=0.15
Steering-Corrected
QWR



172.5 MHz
β=0.26
HWR



345 MHz
β=0.5
Triple-
spoke



345 MHz
β=0.62
Triple-spoke

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

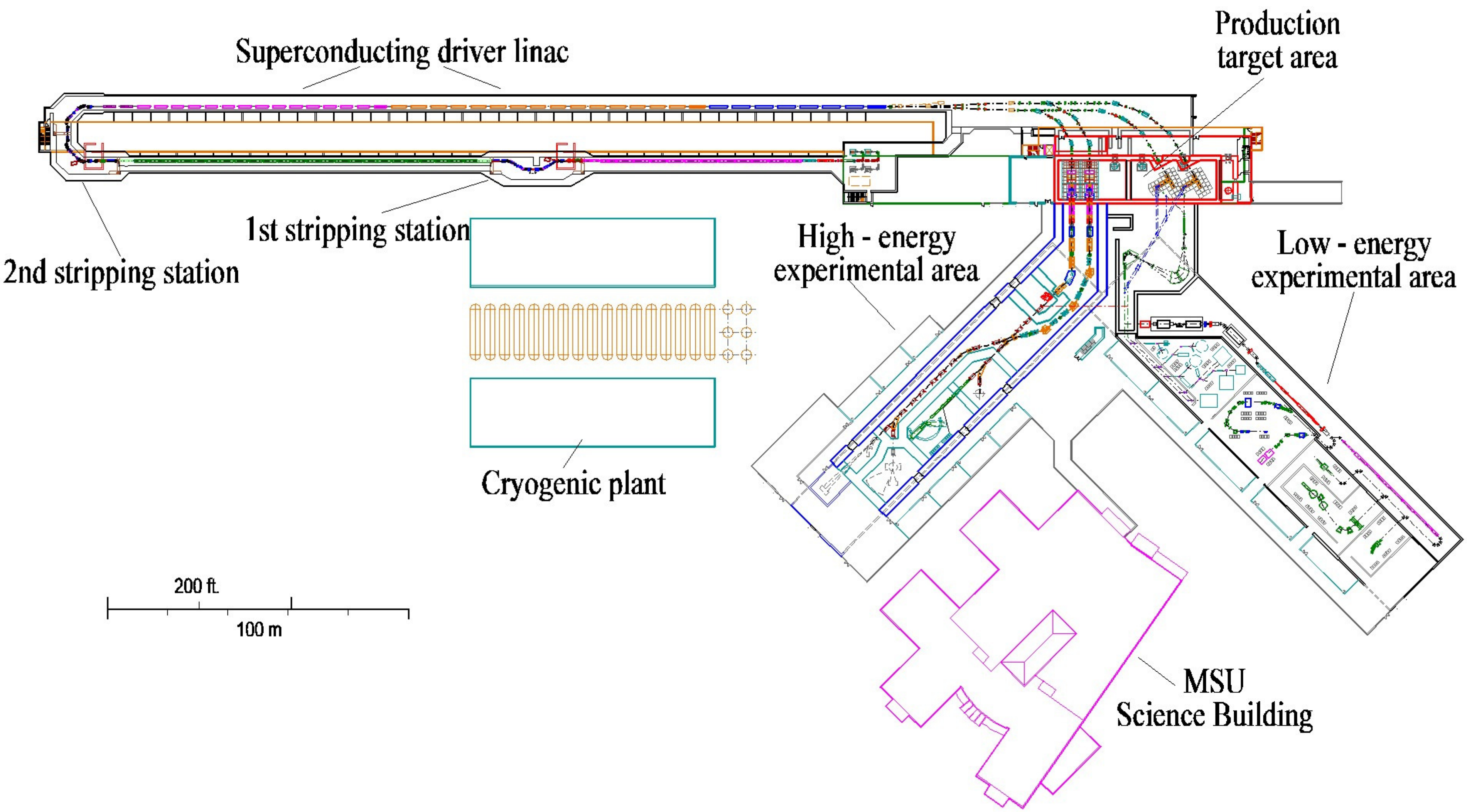
115 MHz β=0.15
Steering-Corrected
QWR

172.5 MHz
β=0.26 HWR

345 MHz Triple-
spoke β = 0.5 & 0.63

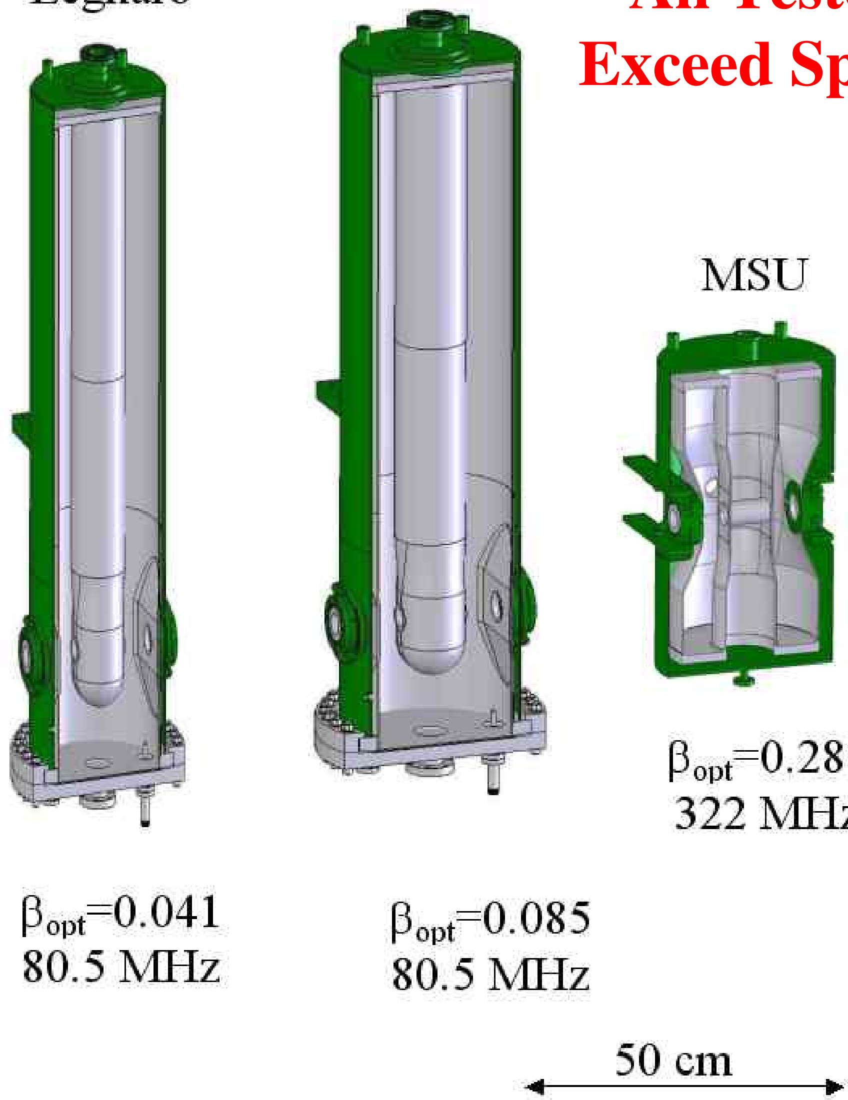
345 MHz β=0.4
Double-spoke

MSU Proposed RIA Layout



MSU RIA Driver Linac Cavity Array

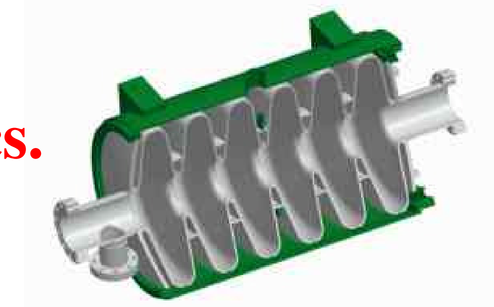
All Tested
Exceed Specs.



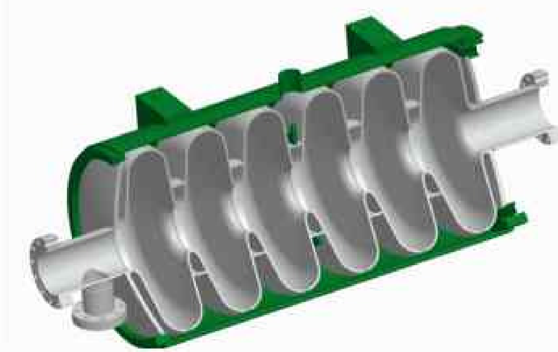
Legnaro: β_{opt}=0.041, 80.5 MHz

MSU: β_{opt}=0.085, 80.5 MHz

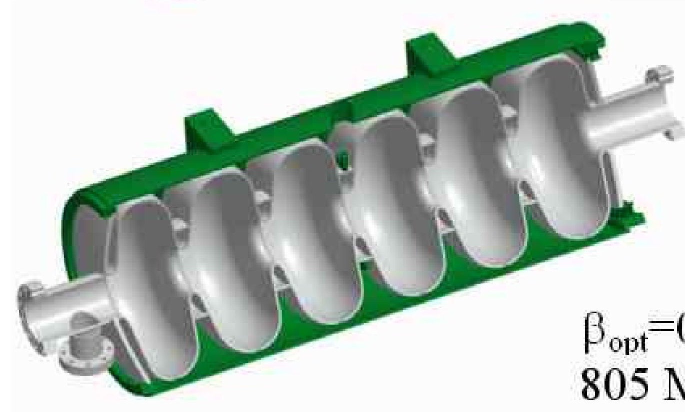
MSU: β_{opt}=0.285, 322 MHz



β_{opt}=0.49
805 MHz
MSU/JLAB

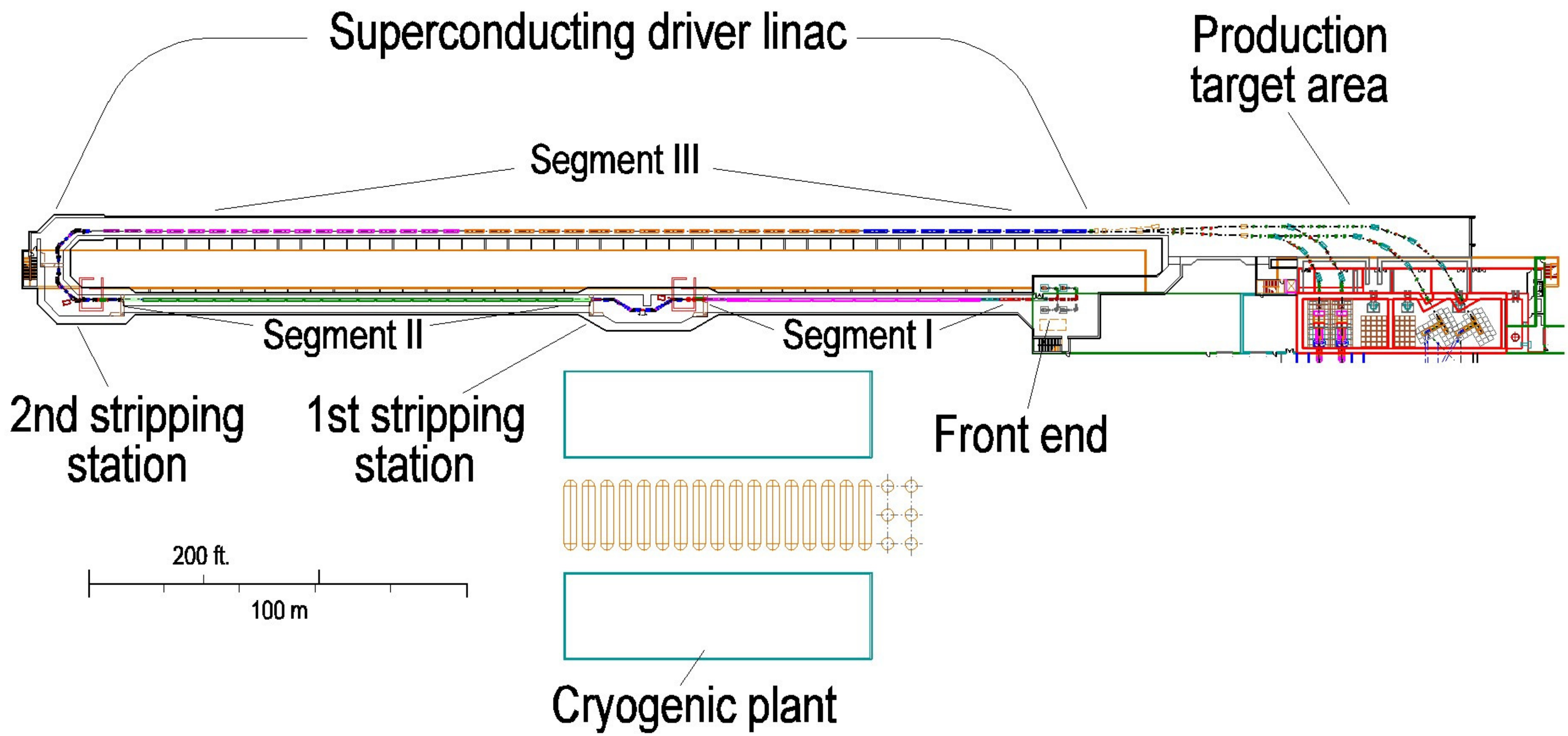


β_{opt}=0.63
805 MHz
SNS

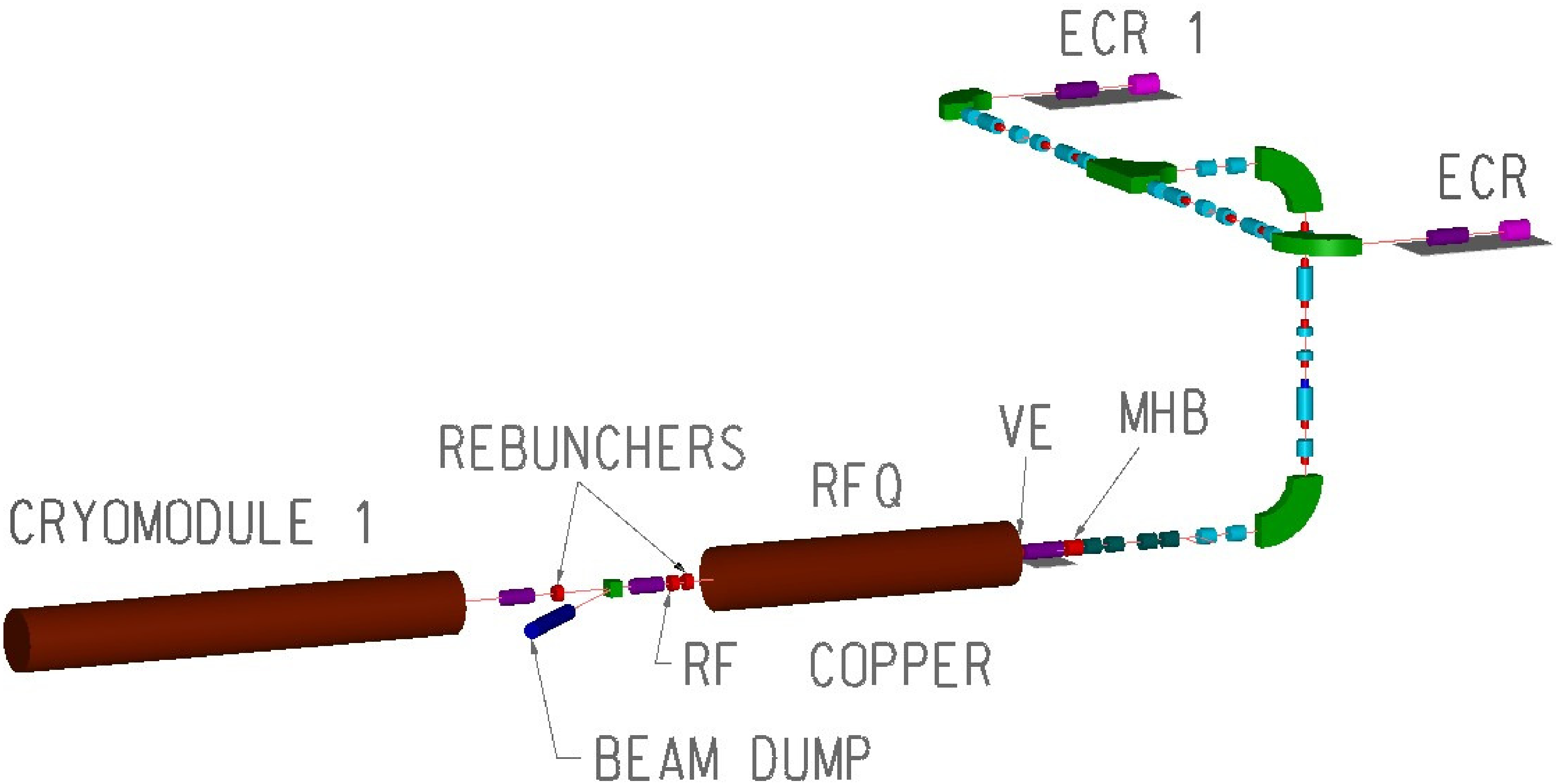


β_{opt}=0.83
805 MHz
SNS

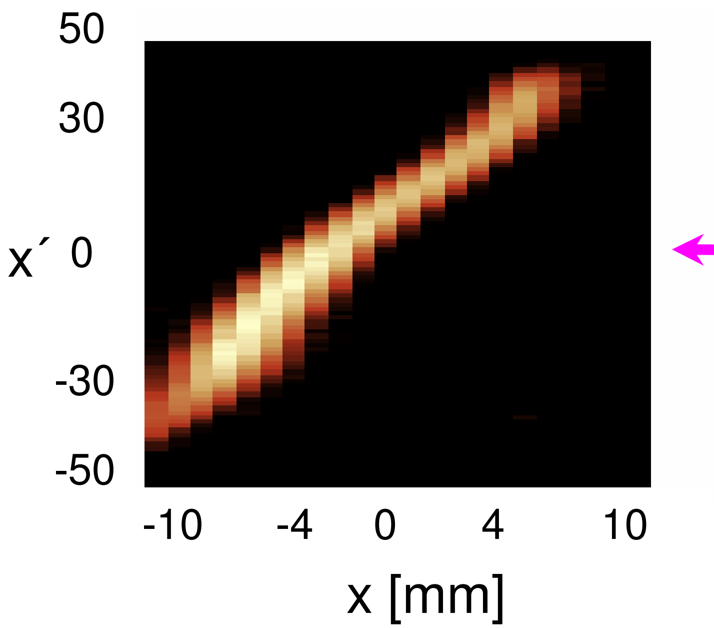
RIA Linac & BSY

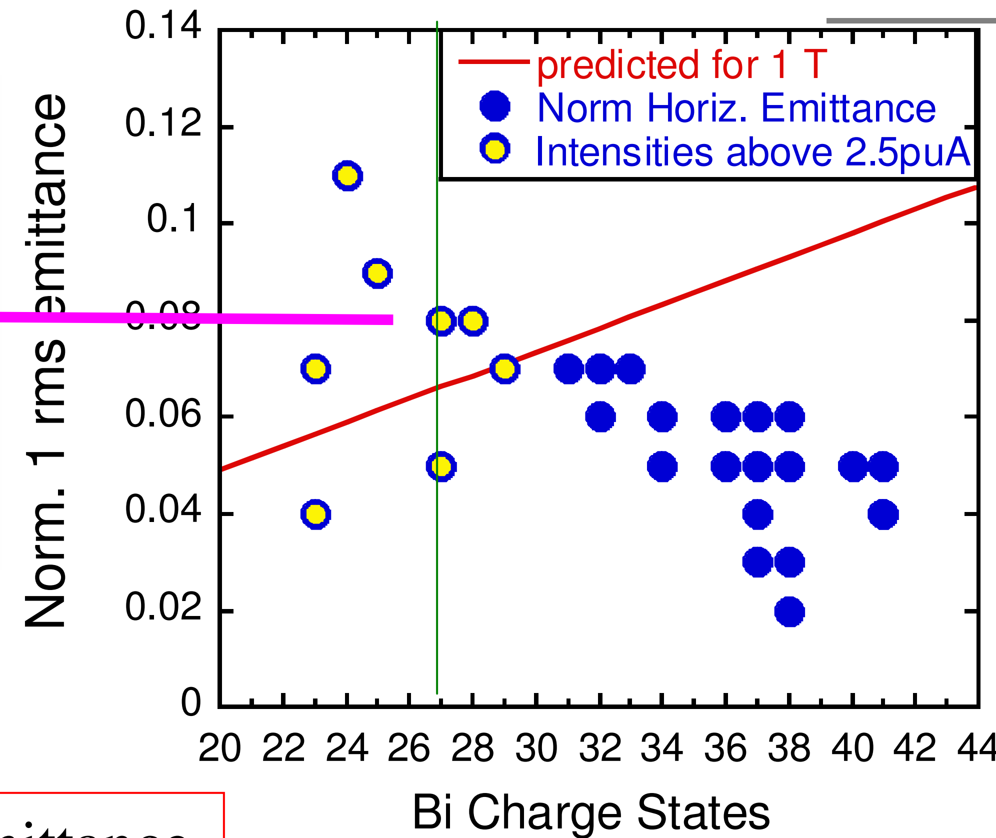


Driver Linac Front End



VENUS Source (LBNL)
Bismuth Emittance Measurements



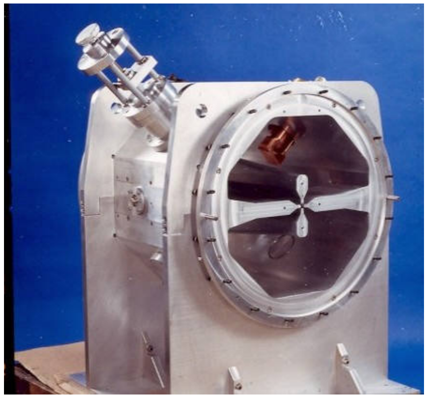


Measured Bi^{27+} RMS emittance

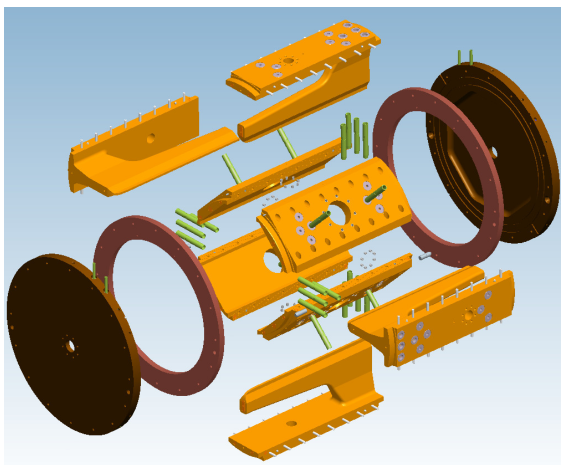
~ 0.08 π-mm-mrad

Courtesy of D. Leitner

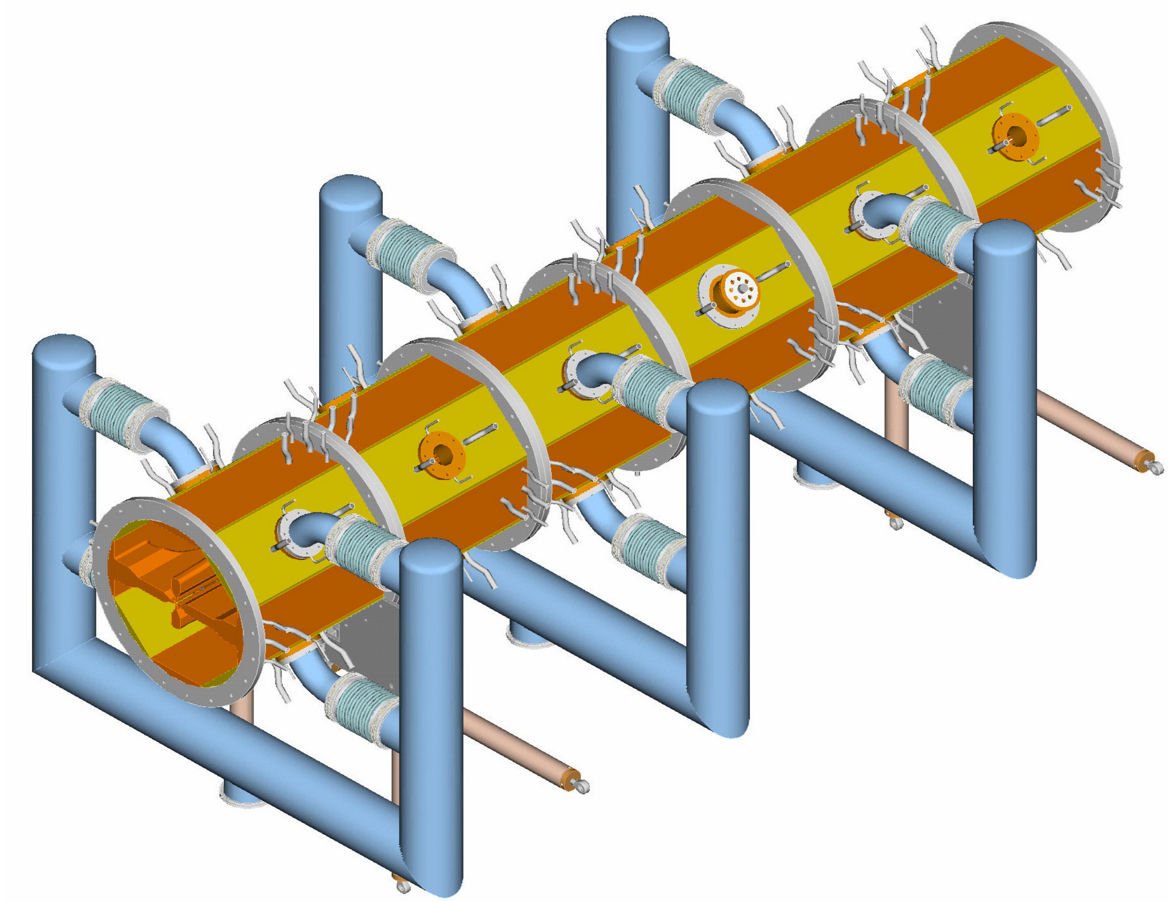
ANL 57.5 MHz RFQ



Aluminum Cold Model



Exploded View of one-segment RFQ resonator

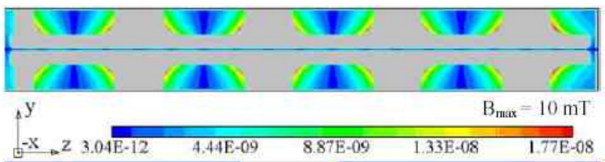


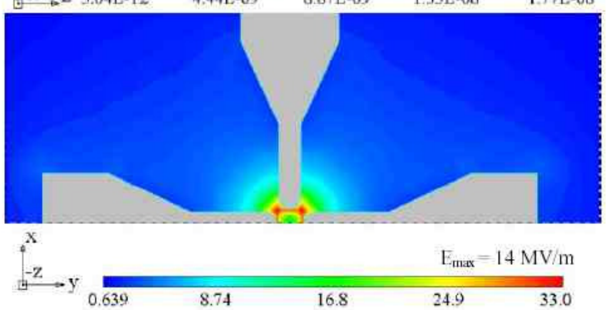
Two-q RFQ assembly design

MSU 80.5 MHz RFQ

MAFIA RF Modeling

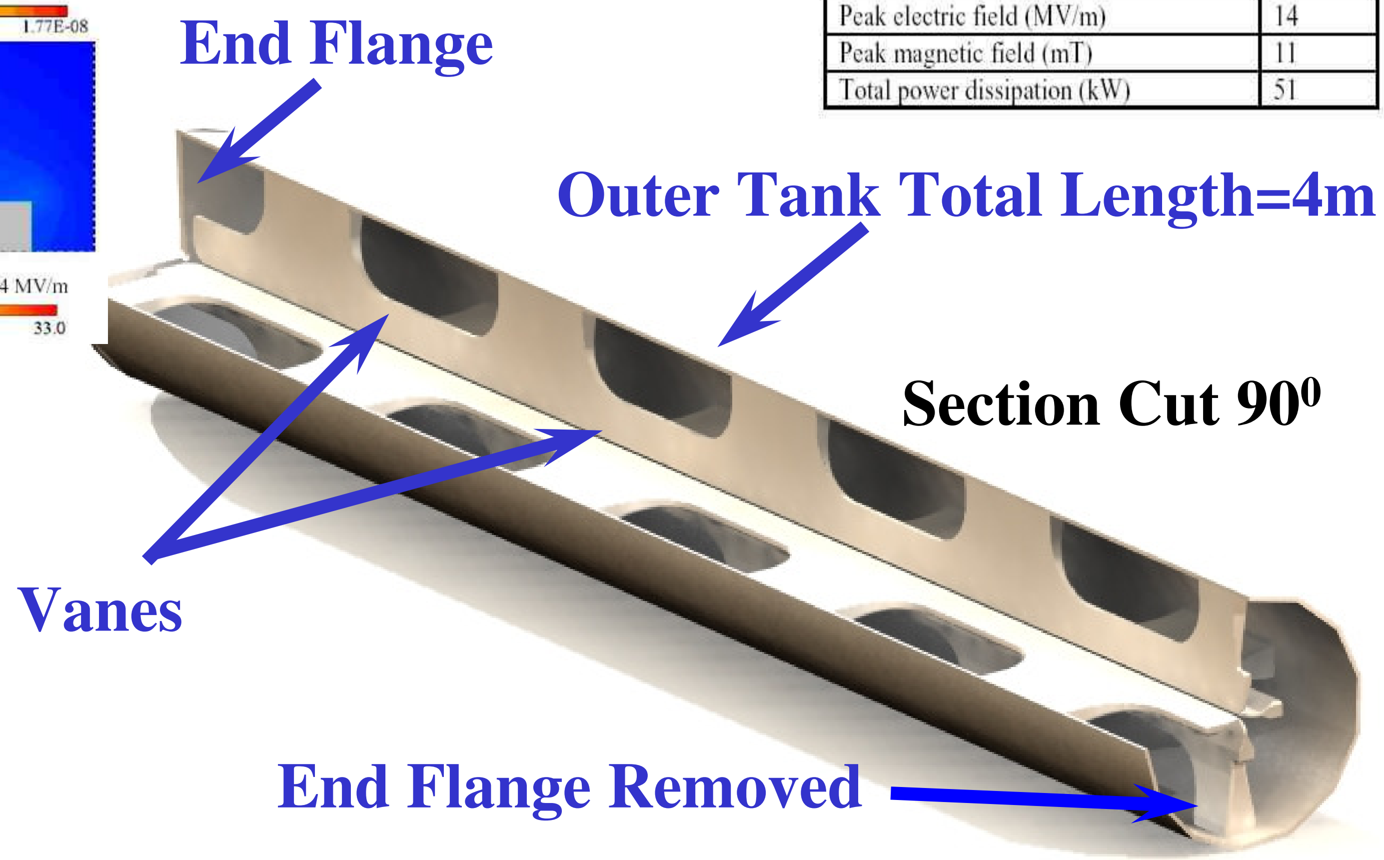
Magnetic flux density in y-z cross section (thru vertical vanes)





Electric field in x-y cross- section.

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 (kΩ·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



End-to-End Simulations

- 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

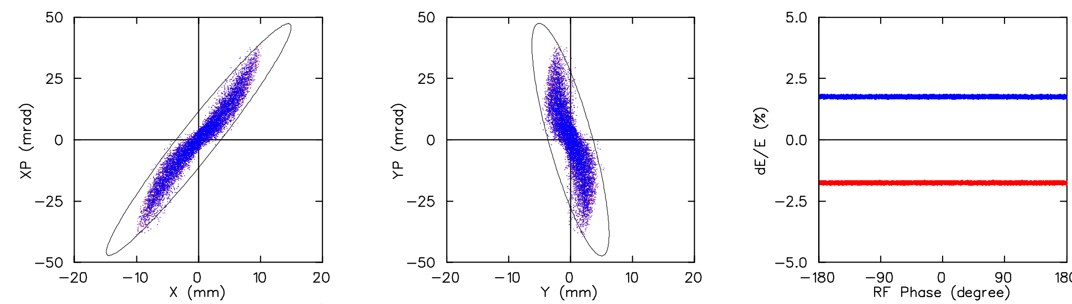
RIA Front End Simulation Results

- Two charge-state U^{238} beam acceleration
- Beam intensity: 8 pμA
- 100kV high voltage platform
- Phase spaces based on LBNL emittance measurement

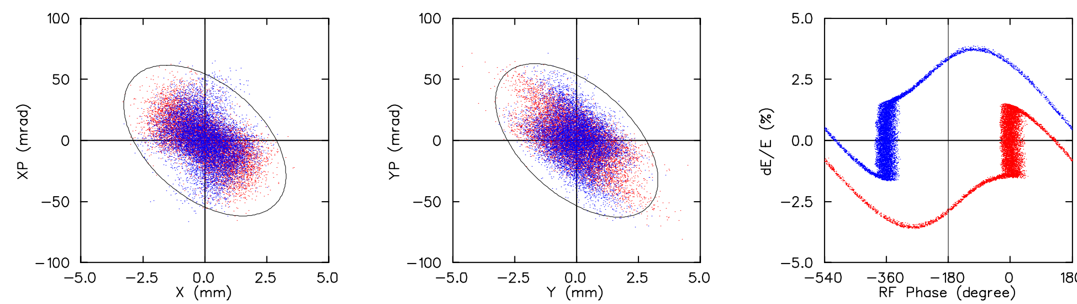
- Small transverse emittance growth
- Beam emittance at SCL entrance

$\varepsilon_{n,\,T}$ (99.5%)	~0.9 π mm-mrad
$\varepsilon_{n,\,L}$ (99.5%)	~1.2 π keV/u-ns

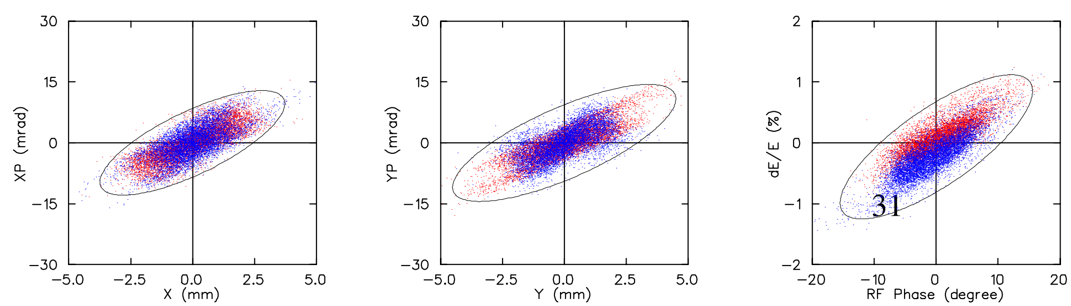
Entrance of LEBT



Entrance of RFQ



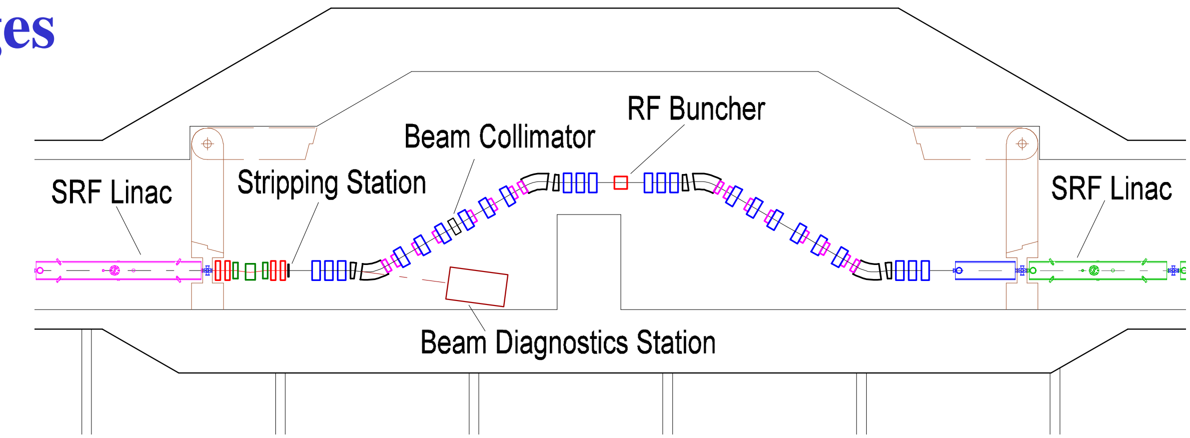
Exit of front end

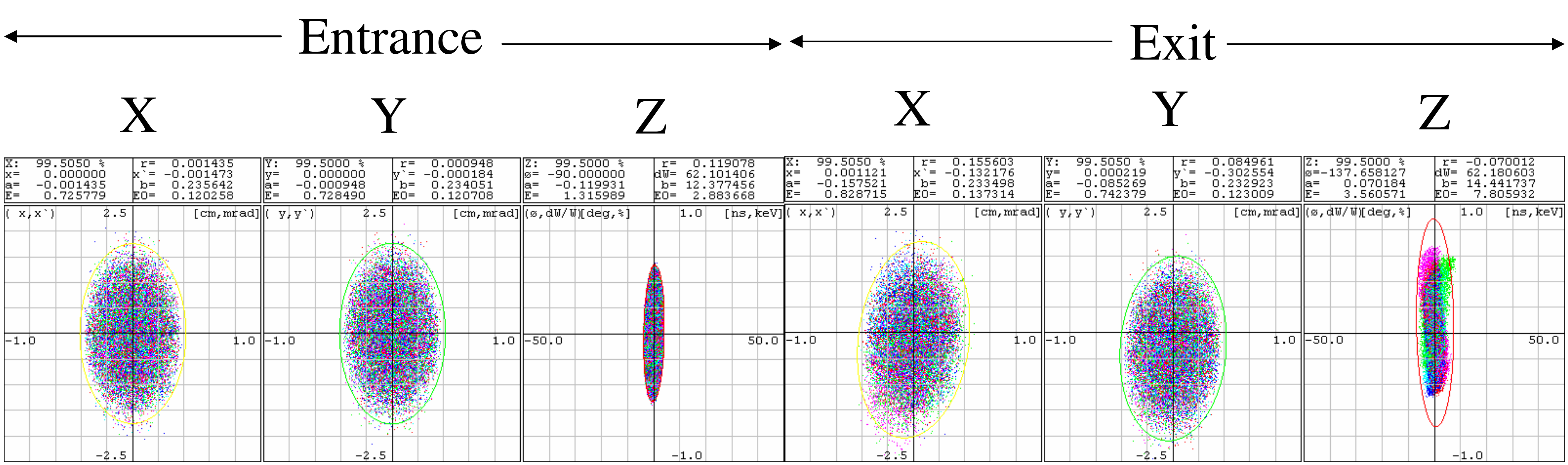


Driver Linac Stripping Chicanes

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

1st Stripping Chicane





Charge-Stripping Foil Model

- Based on simulation results from code TRIM
  - Elastic and inelastic scattering
  - Energy loss and straggling
- Carbon foils with ± 5% thickness variation used in simulation
- Small transverse beam spot (~3mm) and Short bunch length (~8° rf) at both stripping locations

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

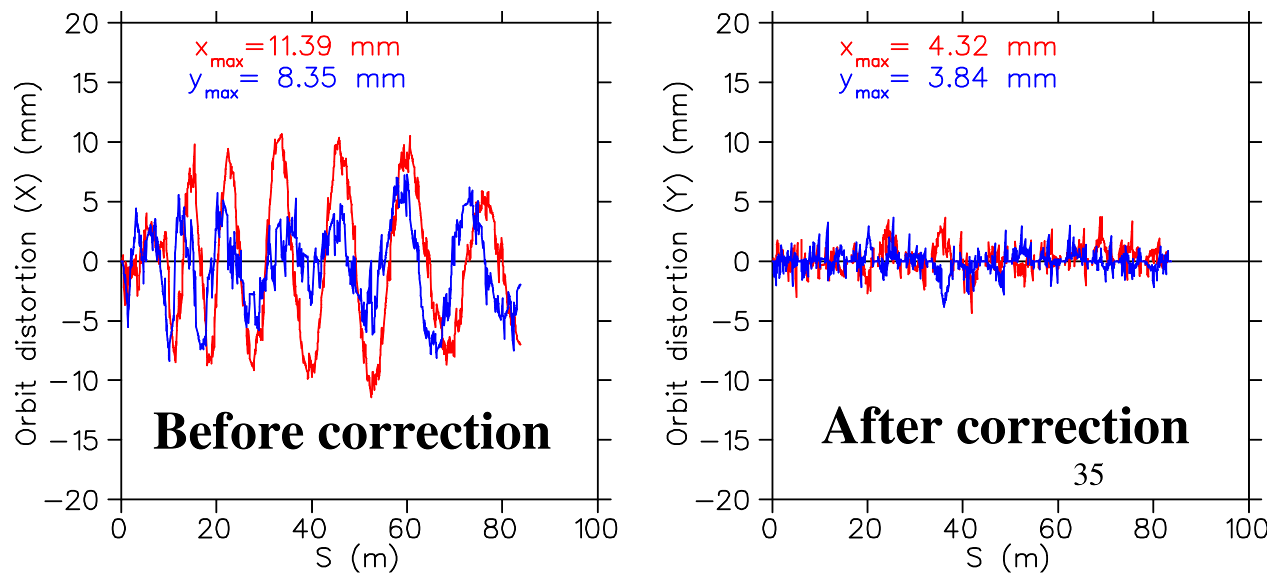
Misalignment and RF Errors

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

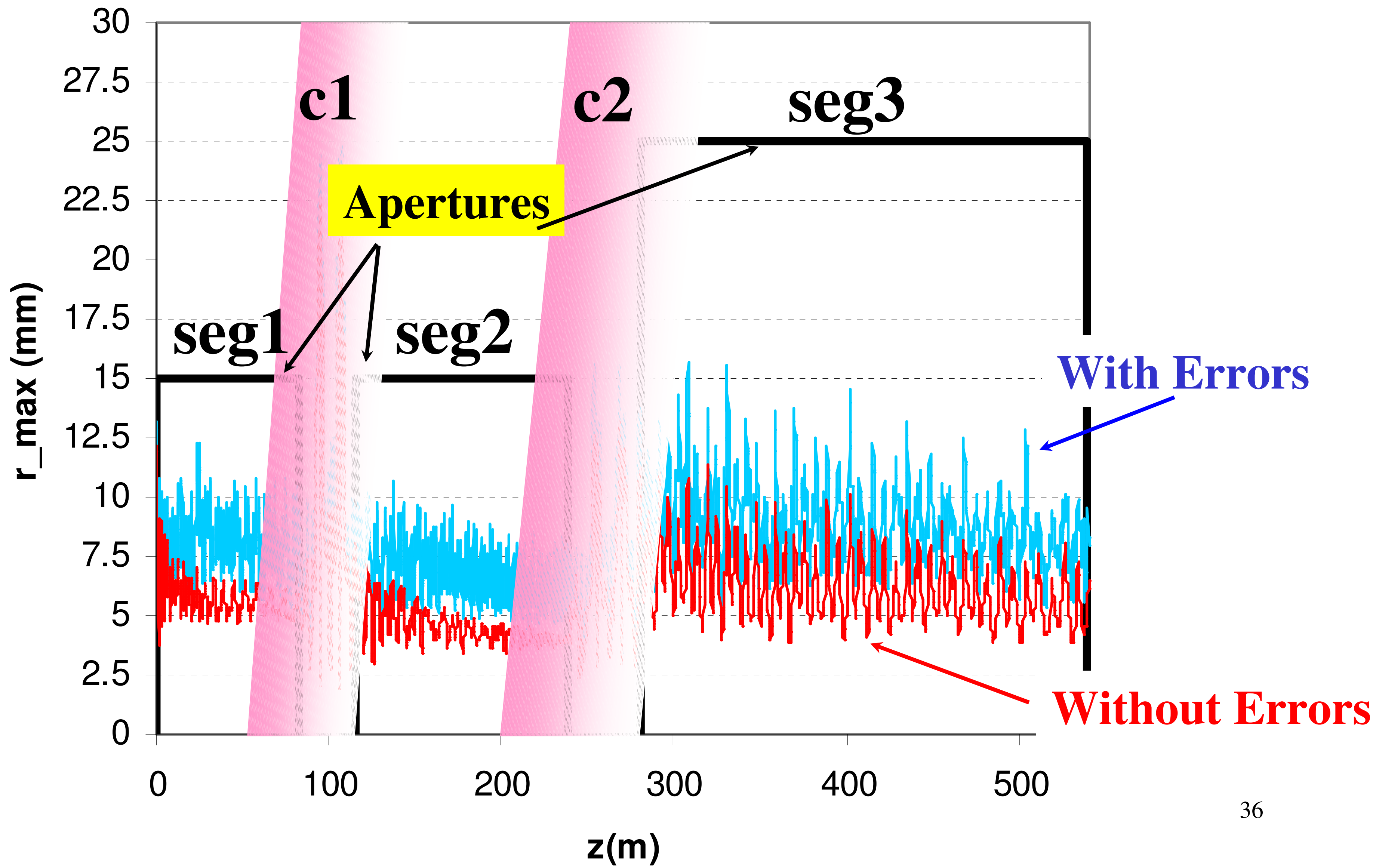
- Misalignment - Gaussian distribution cut-off at 2σ
- RF errors - uniform distribution

Alignment Correction Scheme

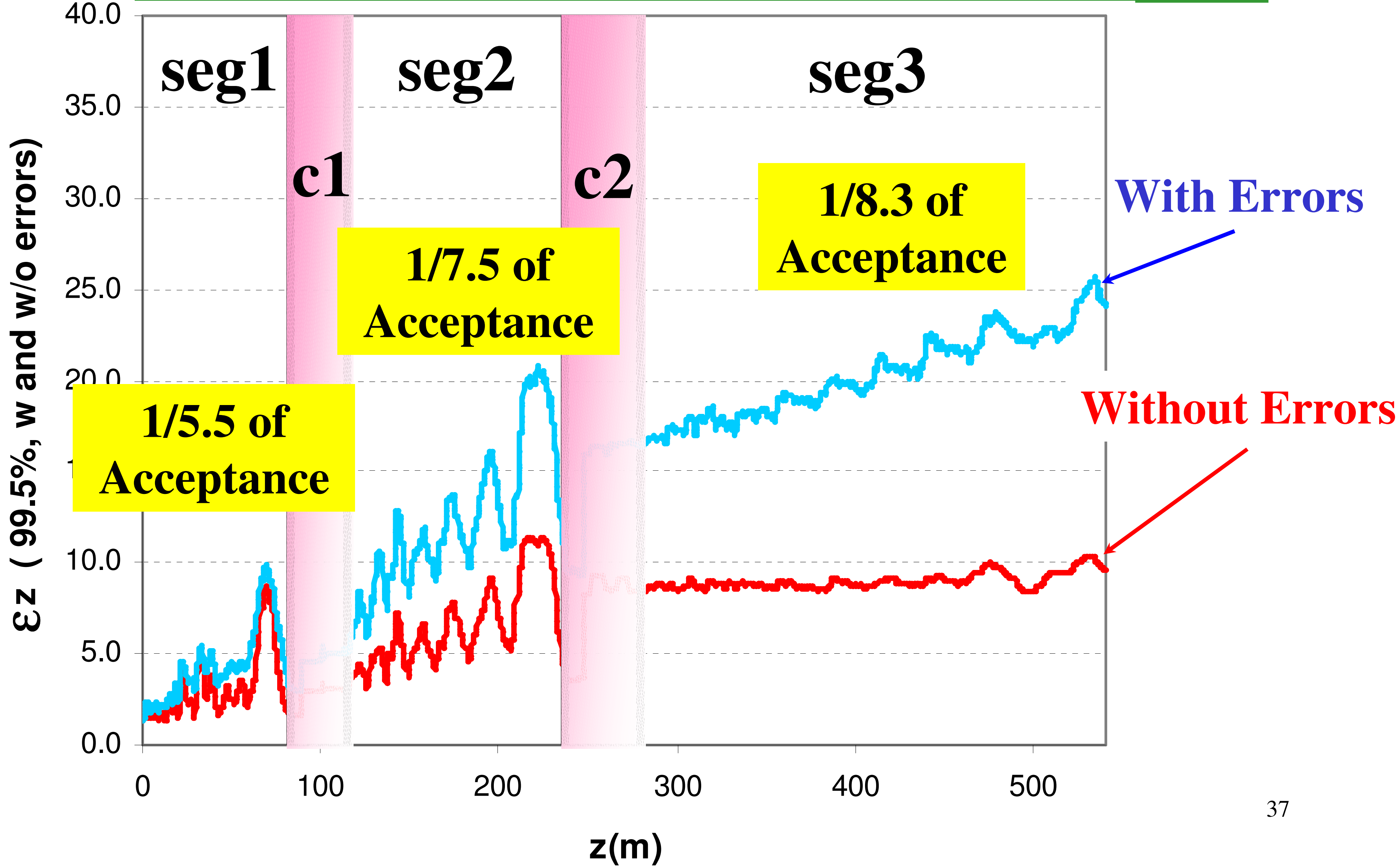
- Segments I, II – Horizontal/vertical dipole windings for each focusing solenoid magnet
- Segment III – Warm dipole correctors beside focusing quadrupole doublet
- All BPMs in the warm region between cryomodules
- Central orbit distortions limited within ± 5mm after corrections in all three segments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



Driver Linac Transverse End-to-End

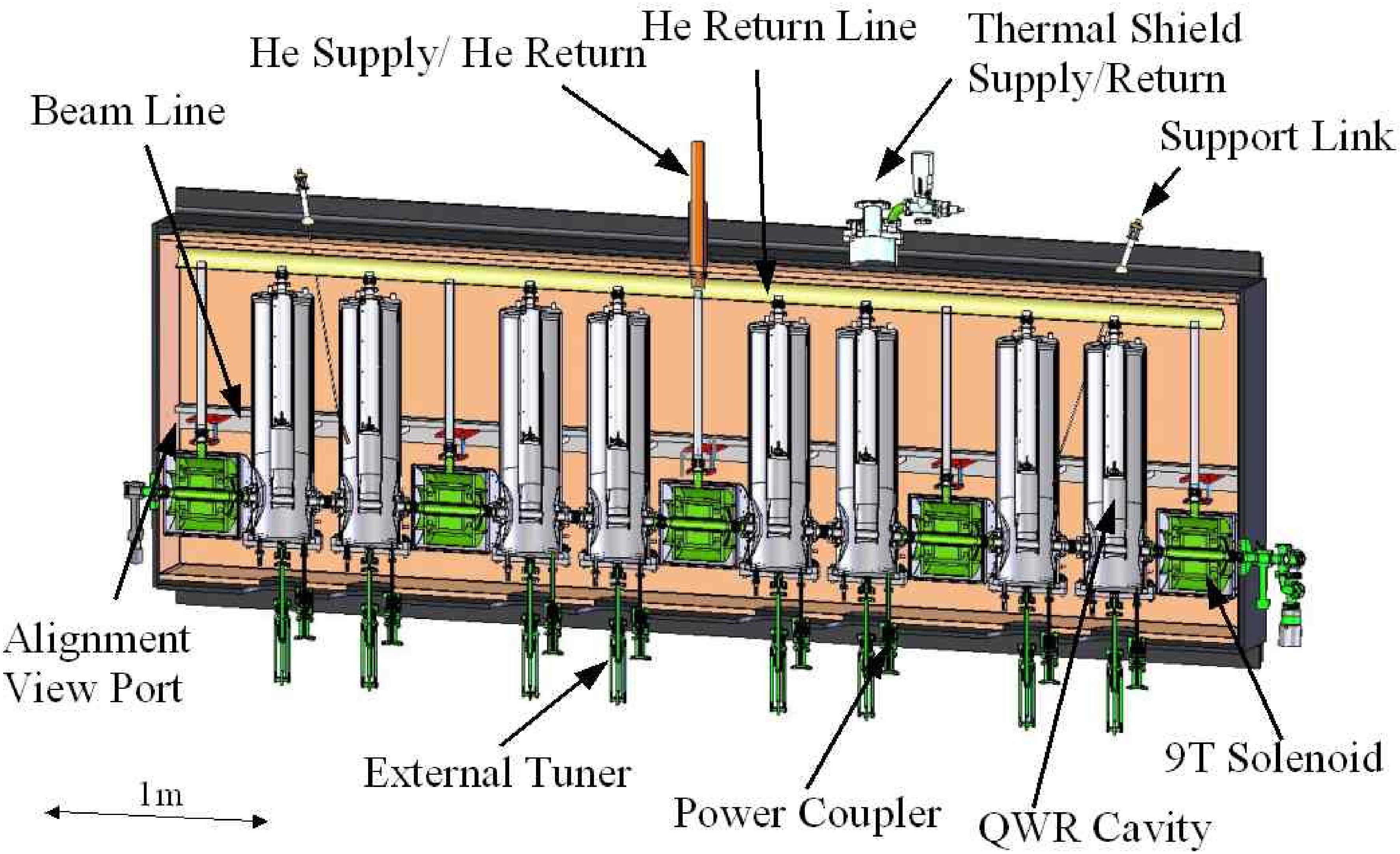


Driver Linac Longitudinal End-to-End



Segments I & II Cryostats

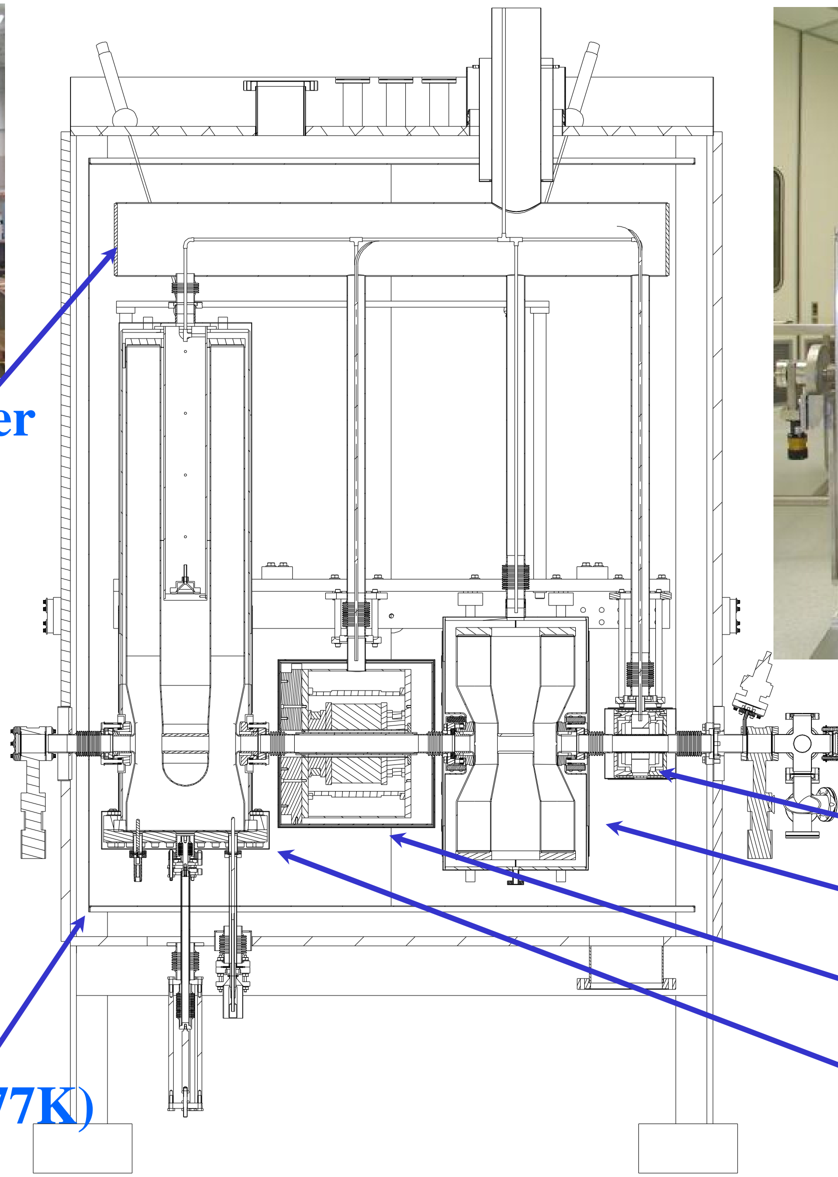
Isolated vacuum & superconducting solenoid focusing



Low-β Cryomodule Prototype

Top plate w/ header

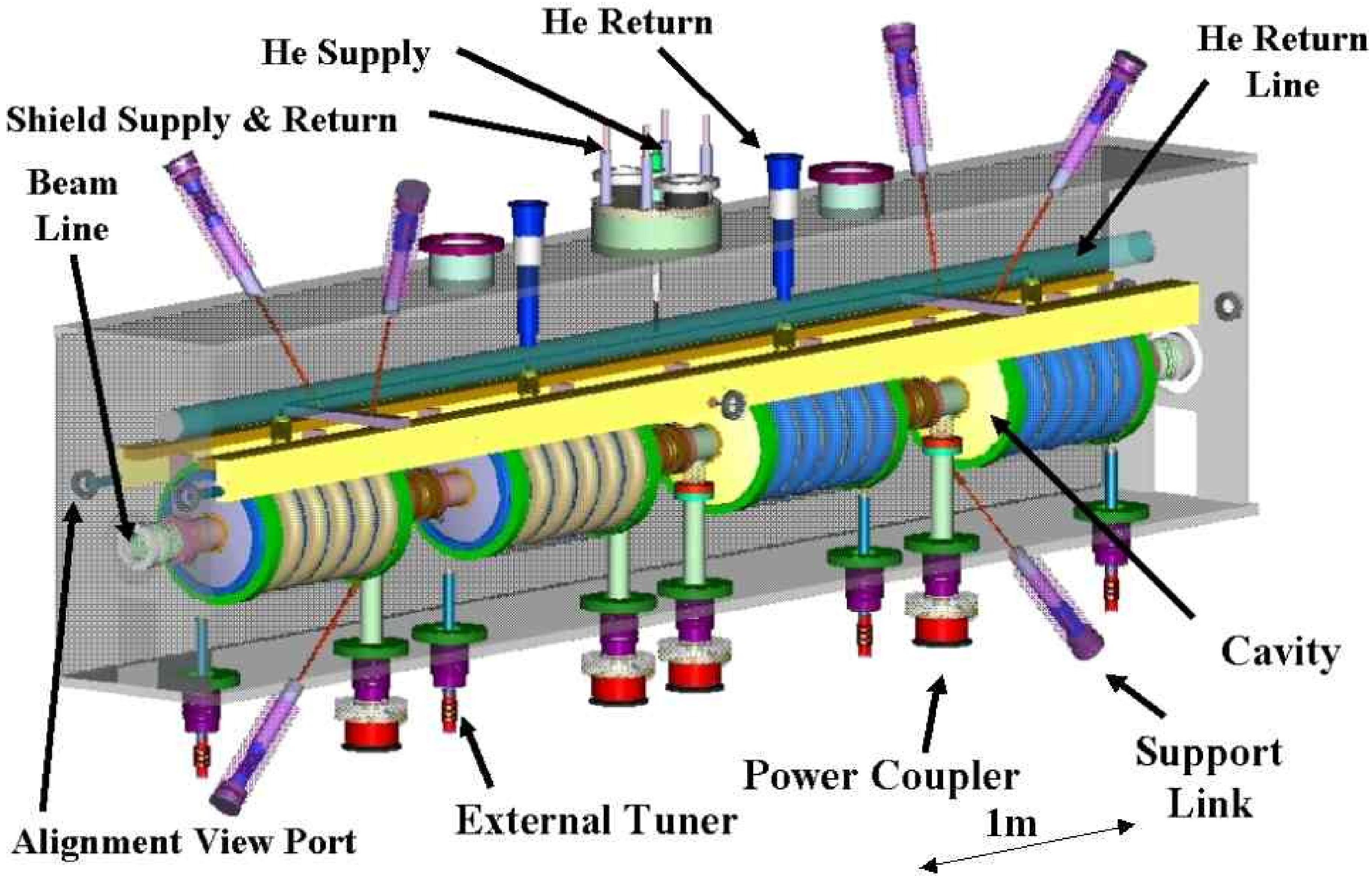
Thermal Shield (77K)



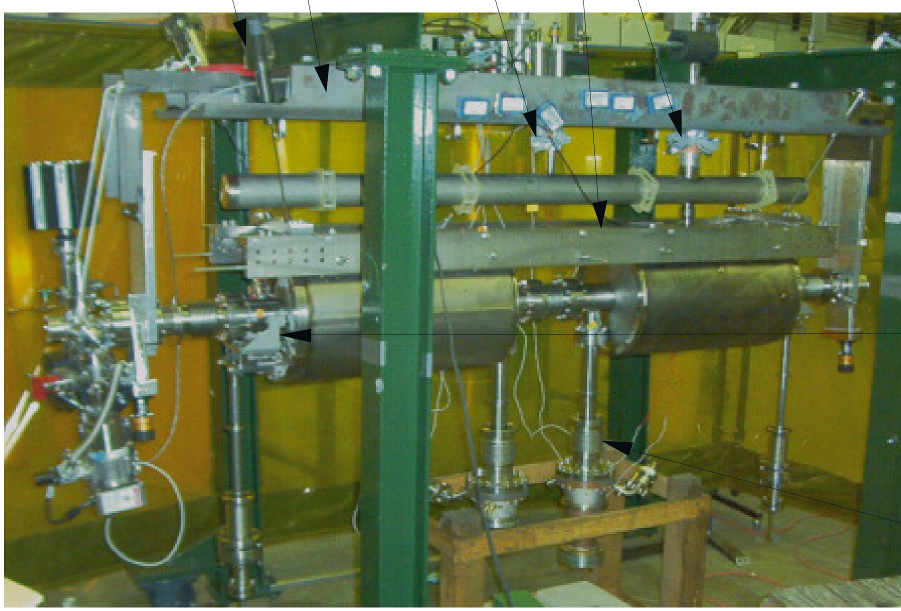
Cold Mass

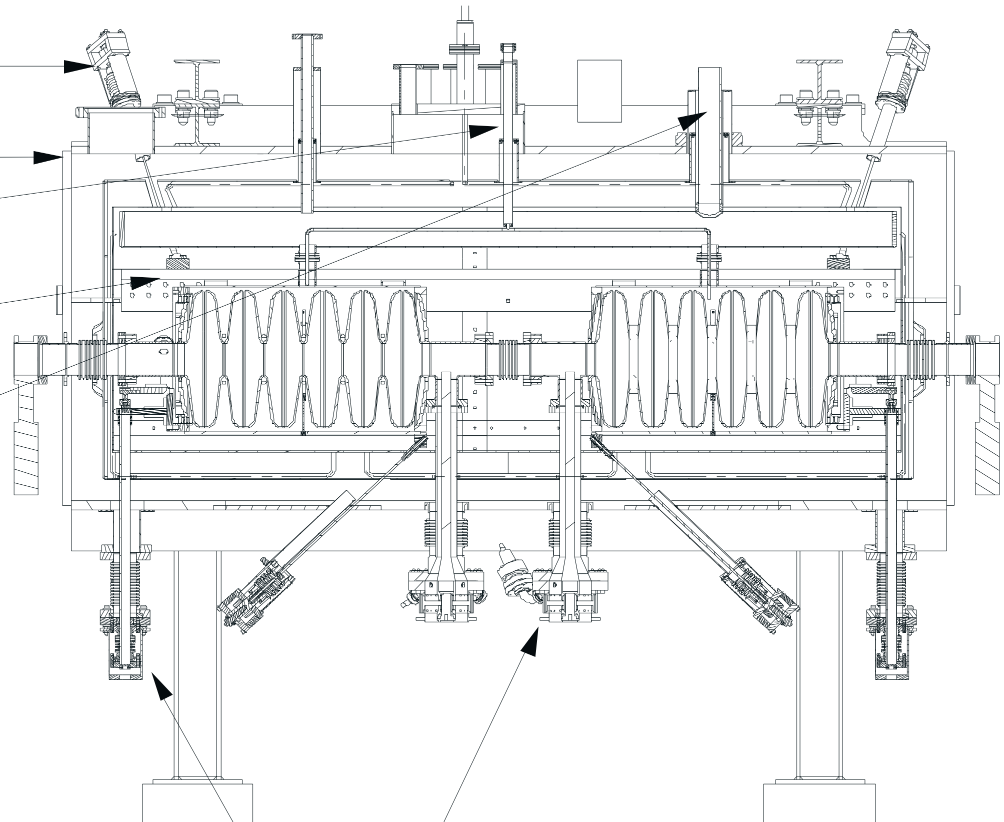
- 0.6 T Quadrupole
- $\lambda/2$, β_{opt}=0.285
- 9 T Solenoid
- $\lambda/4$, β_{opt}=0.085

Segment III Cryostats

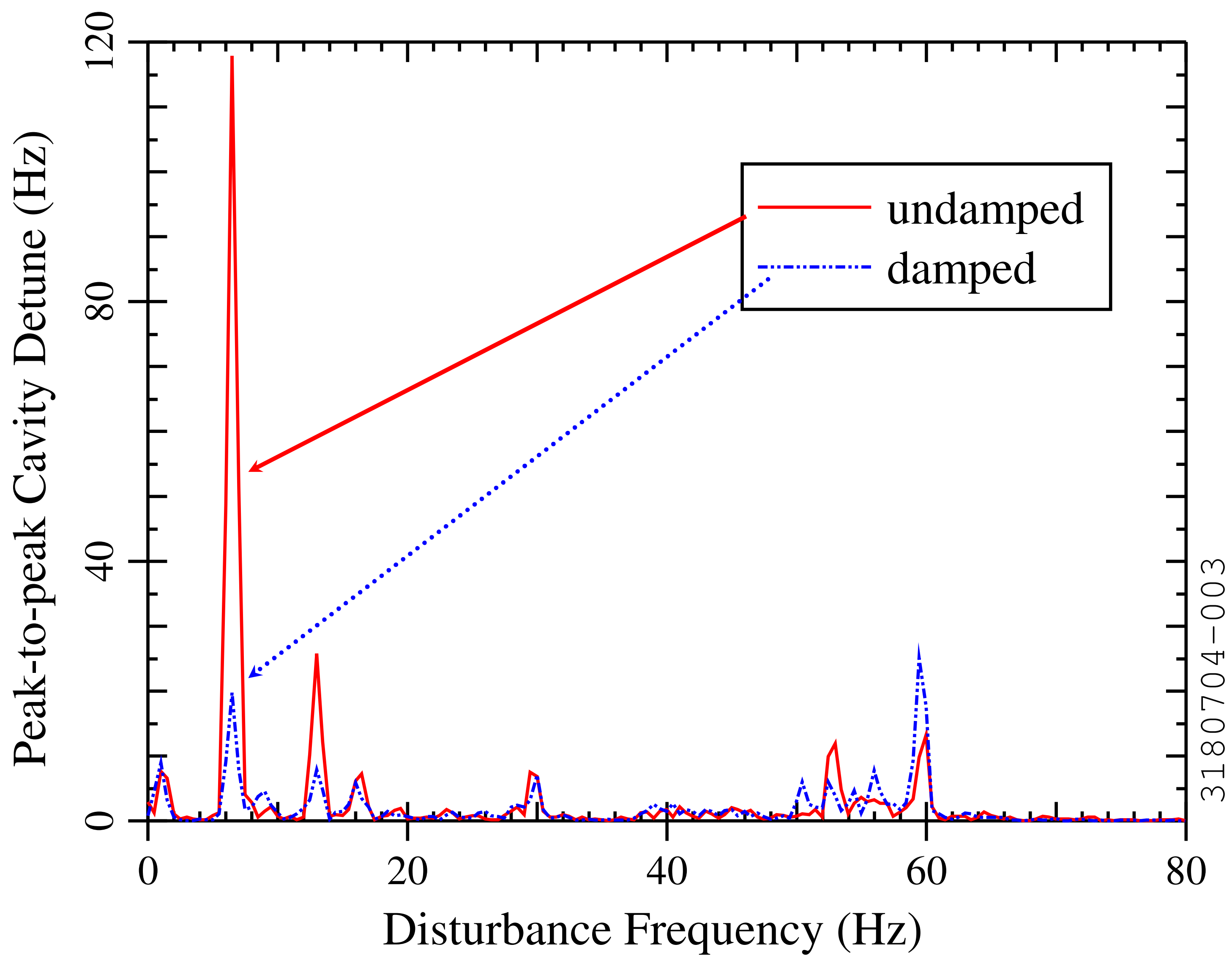


βopt=0.49 Prototype Systems Test



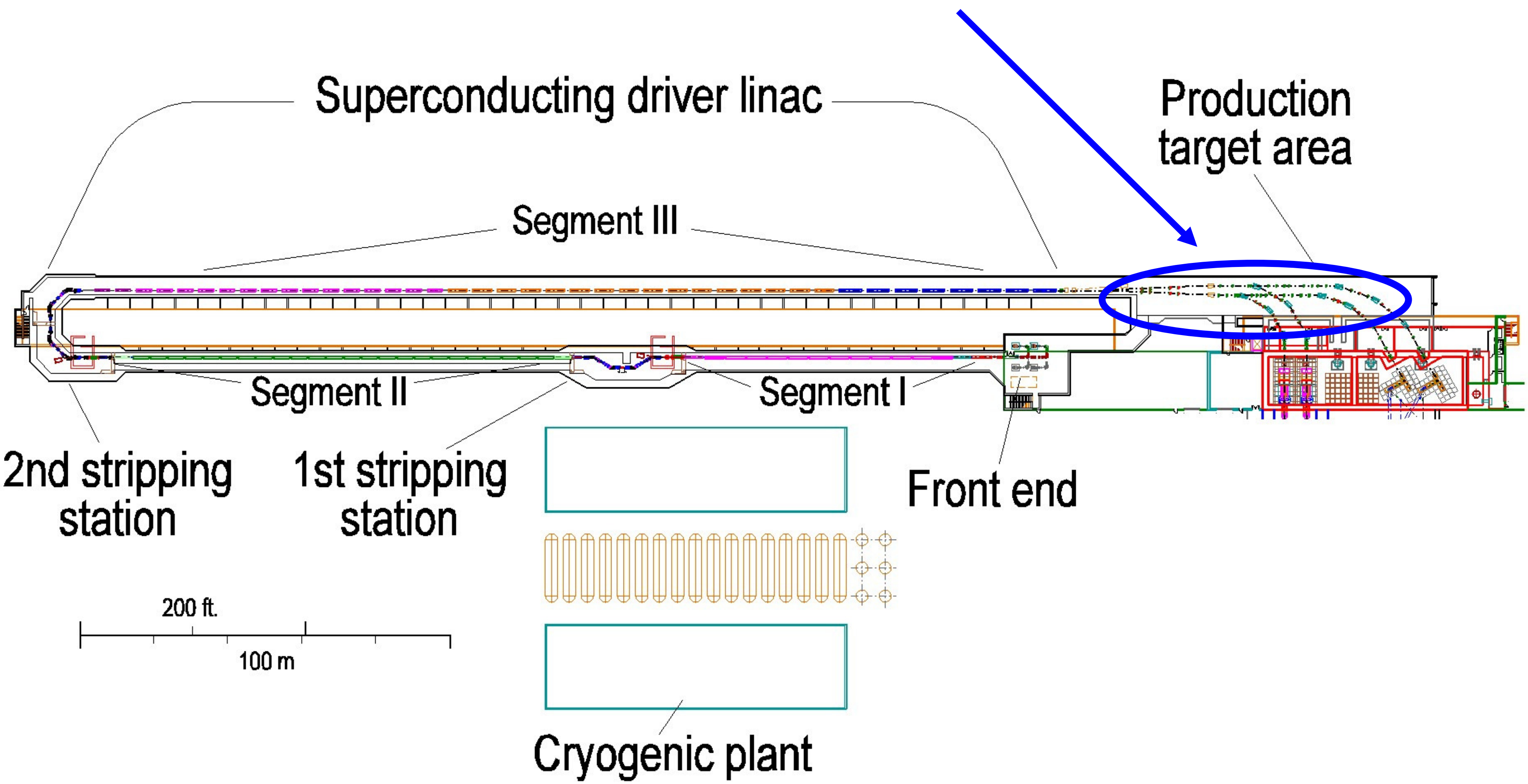


Microphonics Control



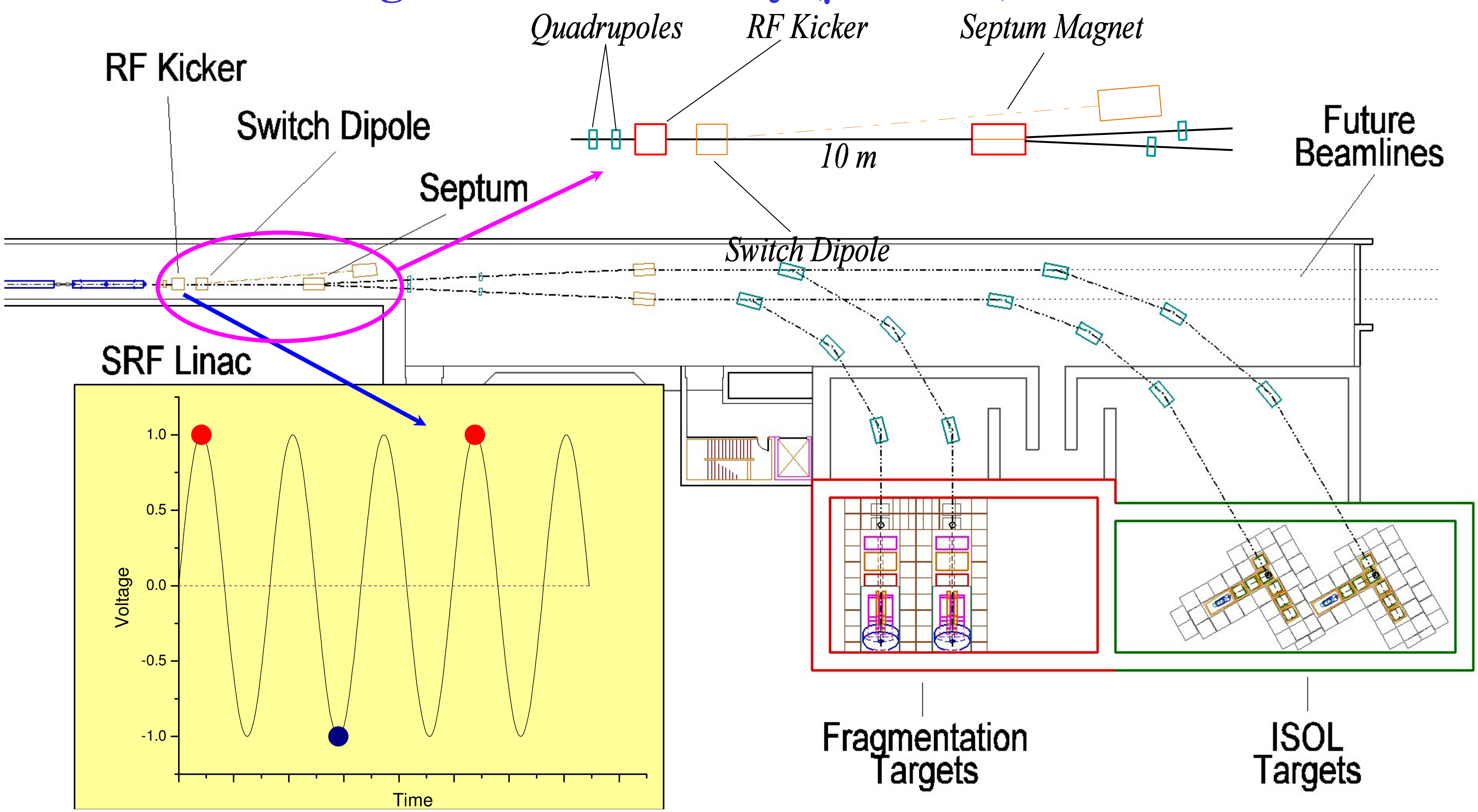
RIA Layout - BSY

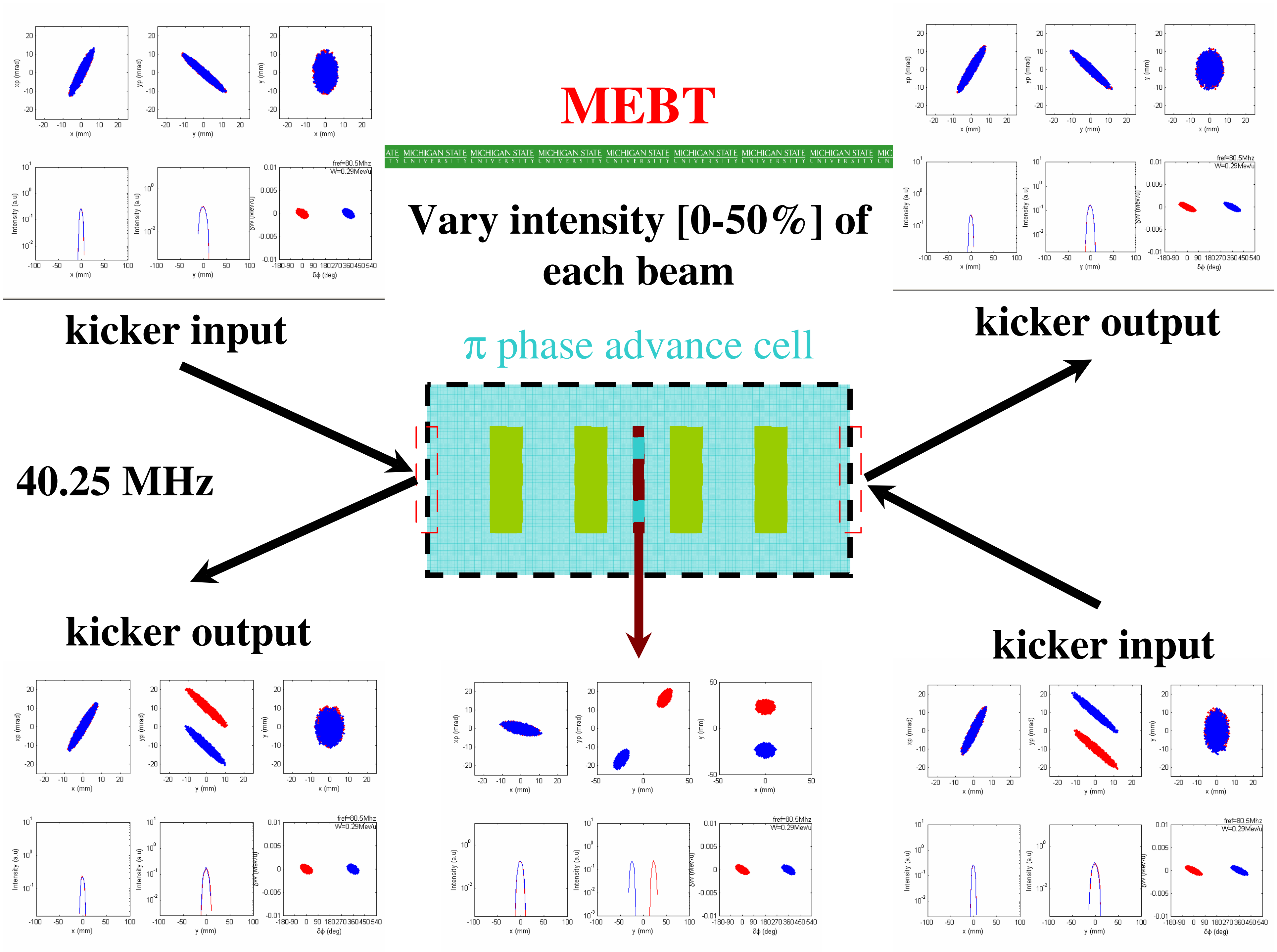
Beam Switch Yard



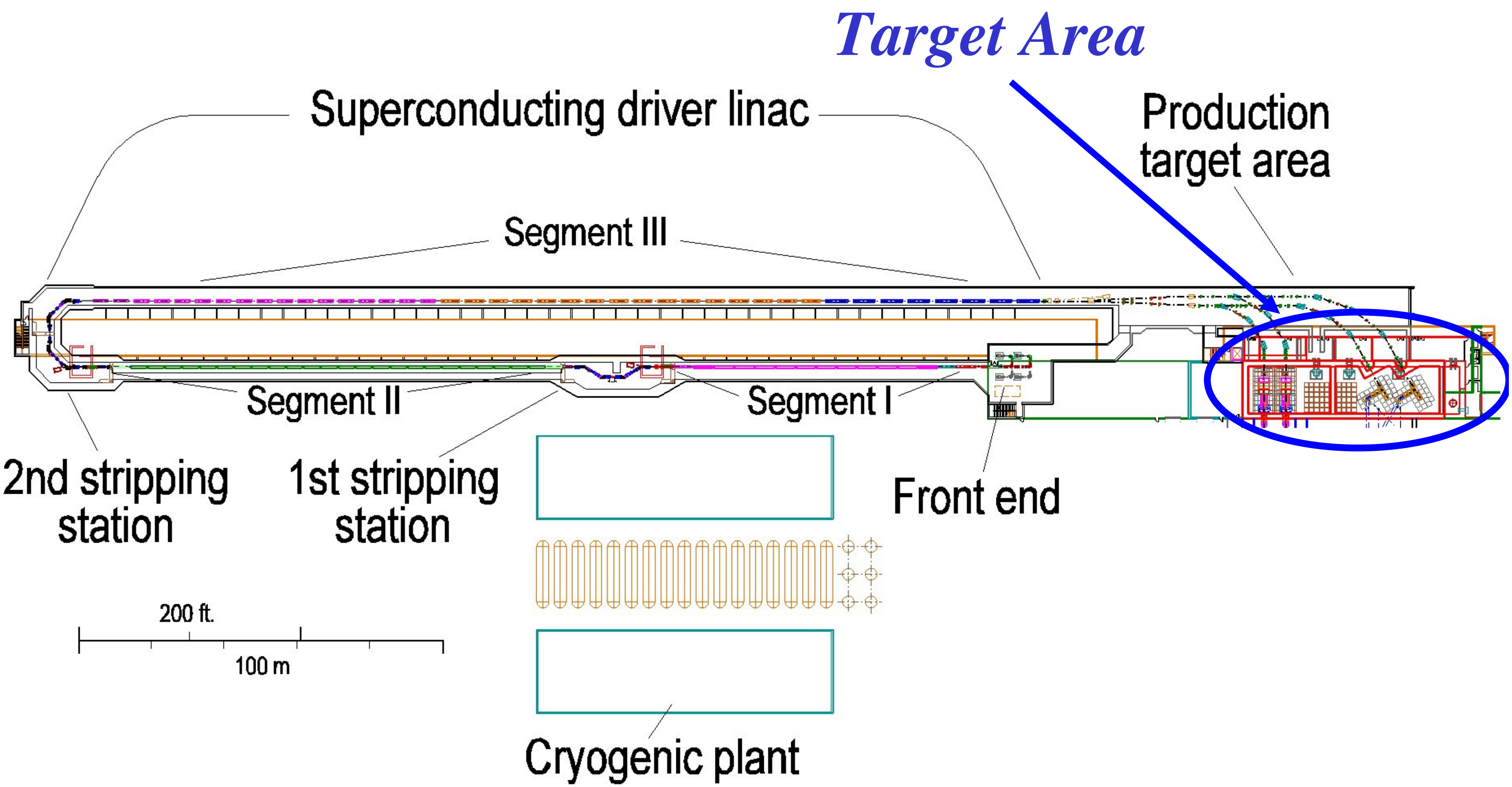
Driver Linac Switch Yard

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

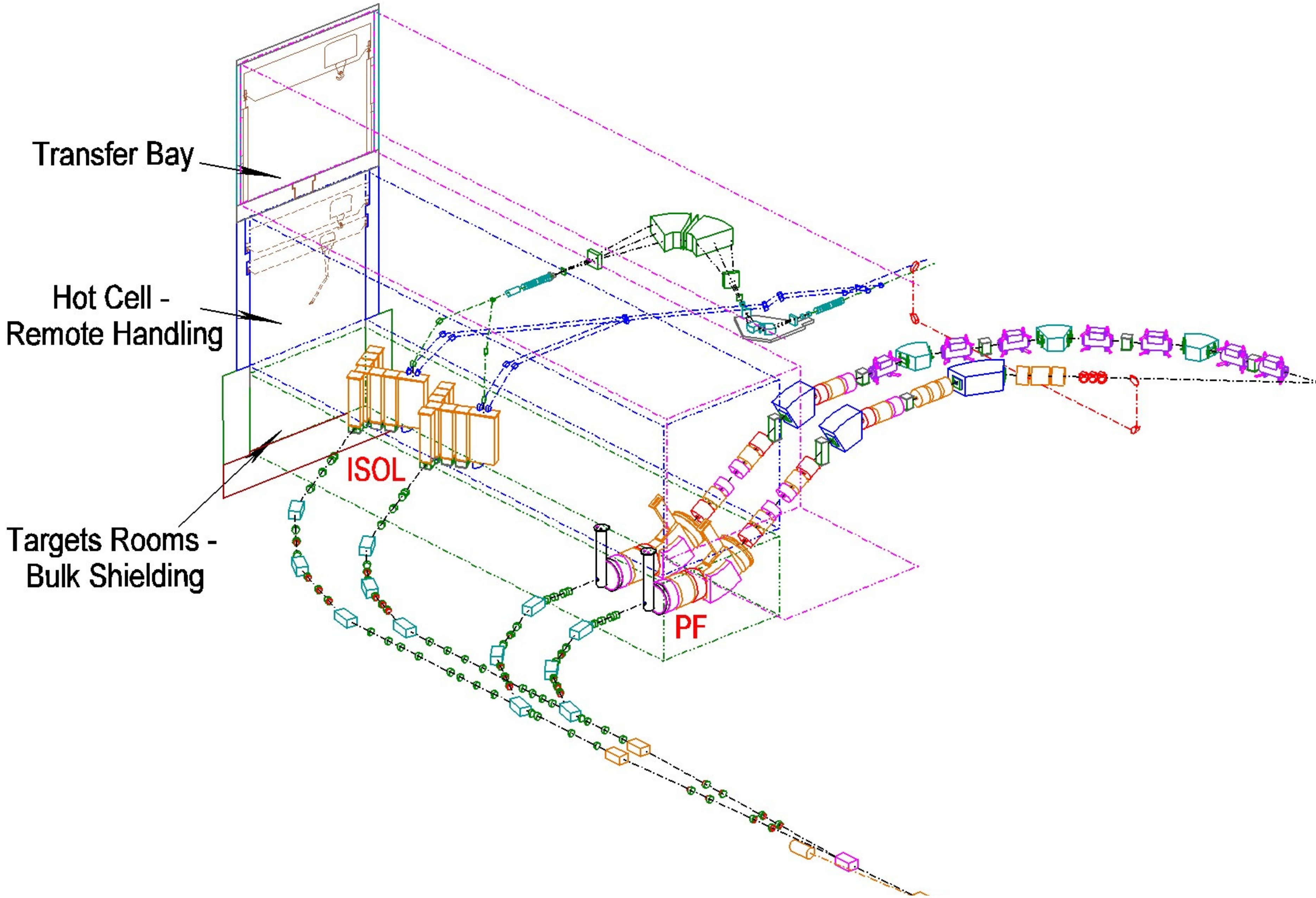



MEBT
MICHIGAN STATE UNIVERSITY
Vary intensity [0-50%] of each beam
π phase advance cell
40.25 MHz
kicker input
kicker output
kicker output
kicker input
fref=80.5Mhz
W=0.29Mev/u

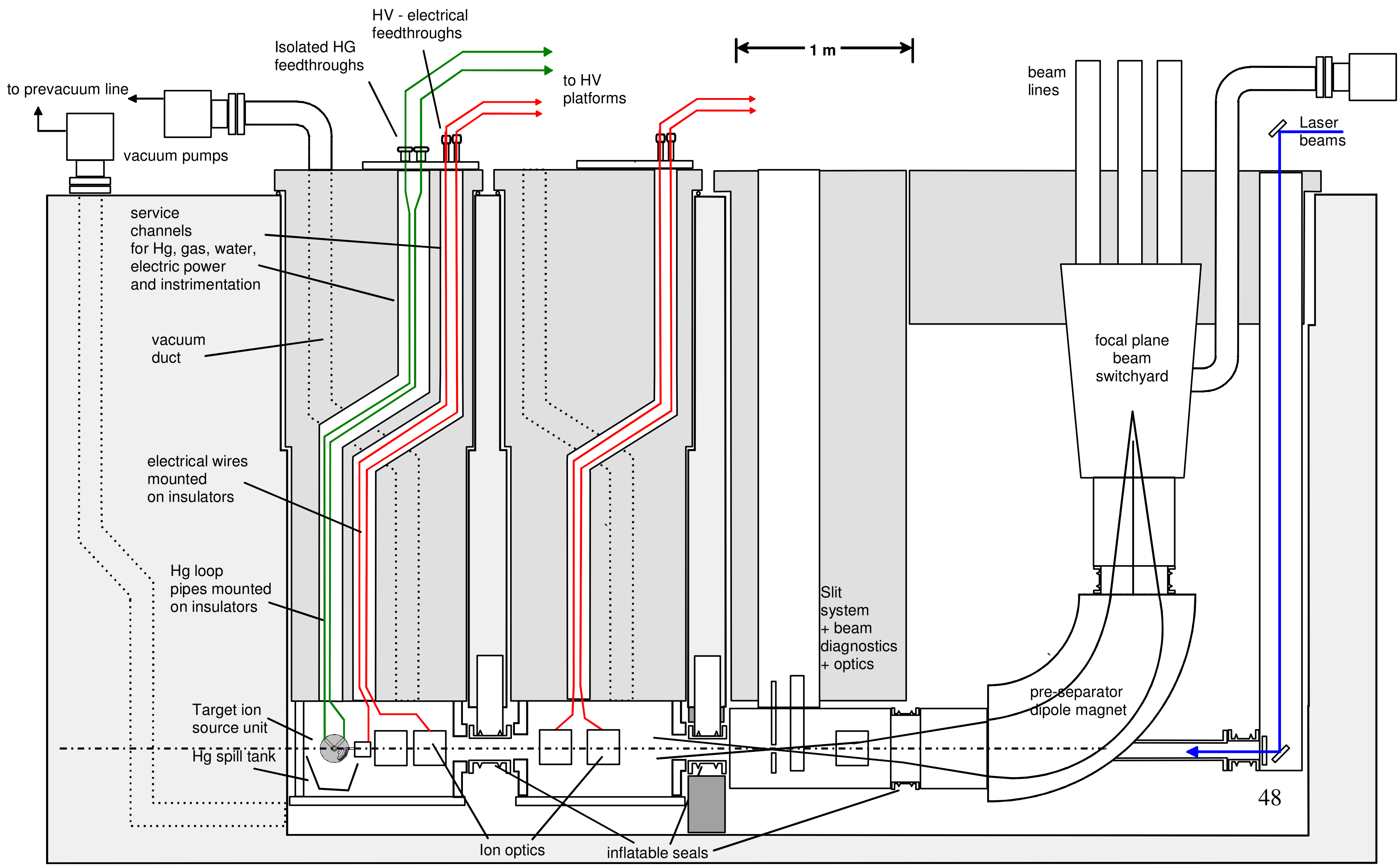
RIA Layout - Target Area



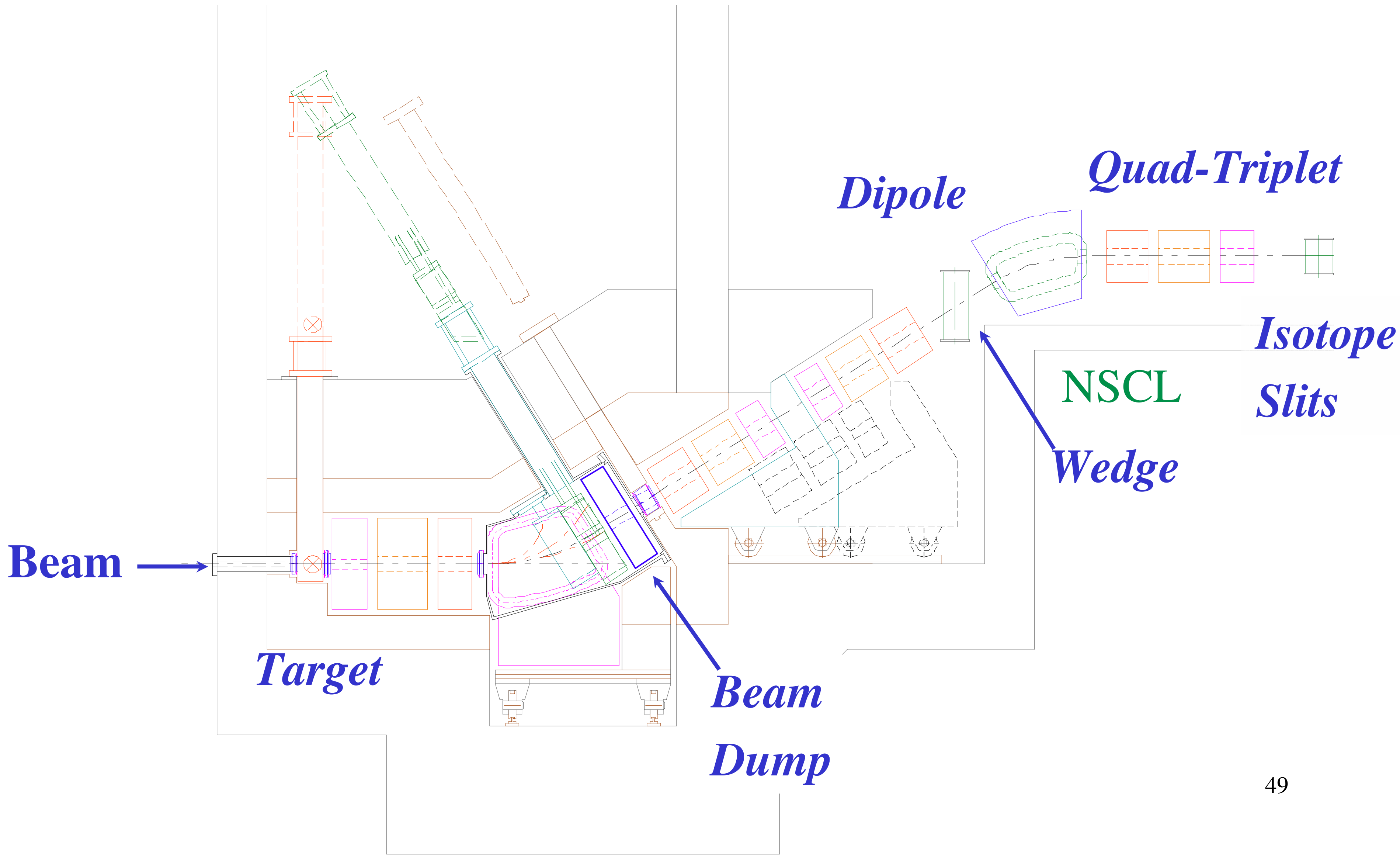
Target Area Detail



ISOL Target Station



Pre-Separator



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!**

NSCL

THE END