Status of the FRIB Front End

Eduard Pozdeyev

On Behalf of FRIB Project

NA-PAC'13, Pasadena, October 4, 2013

MICHIGAN STATE UNIVERSITY

U.S. DEPARTMENT OF ENERGY | Office of Science

This material is based upon work supported by the U.S. Department of Energy Office of Science under Cooperative Agreement DE-SC0000661.
Michigan State University designs and establishes FRIB as a DOE Office of Science National User Facility in support of the mission of the Office of Nuclear Physics.

Outline

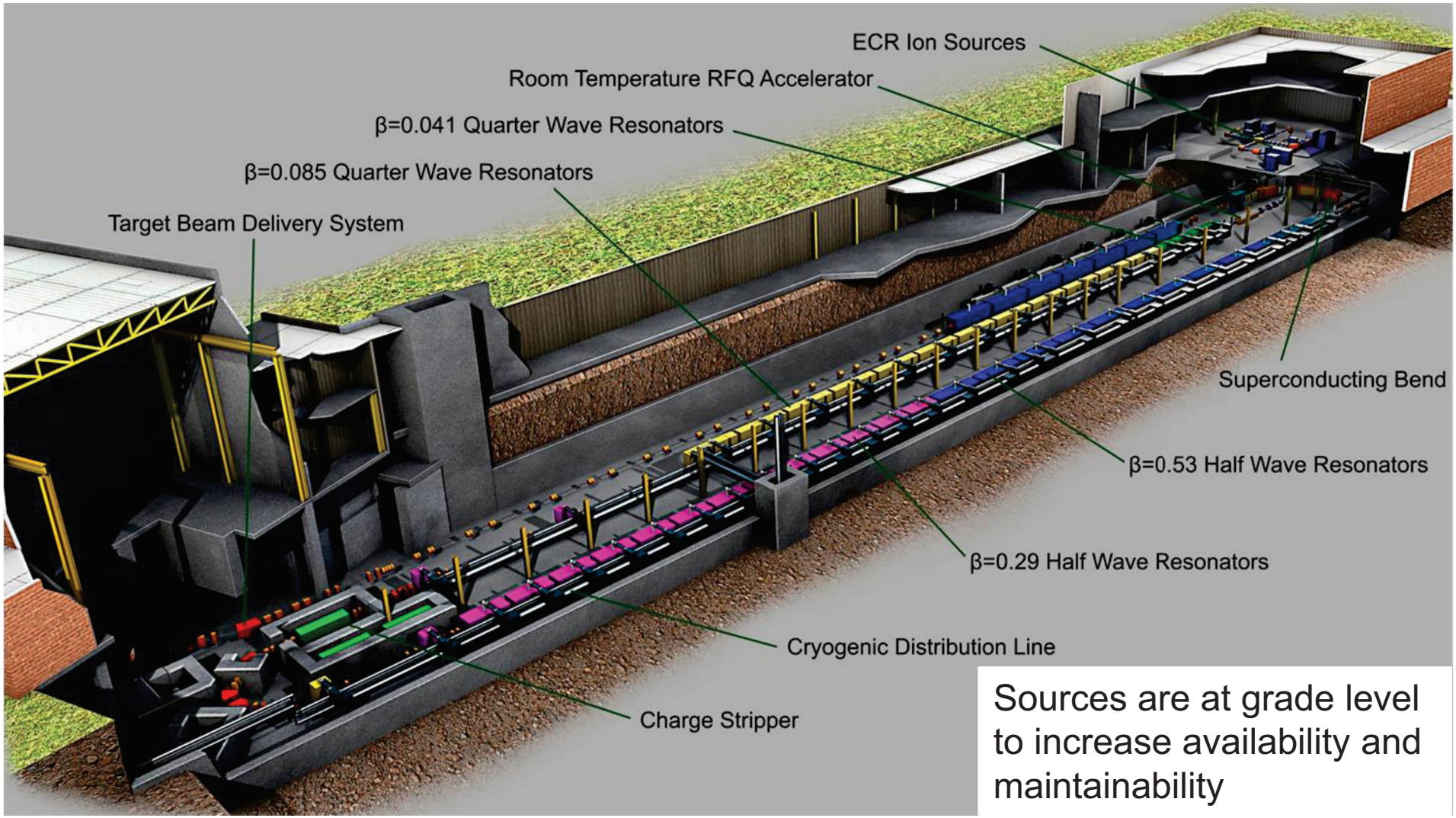
- Design requirements
- FRIB Front End layout
- Ion source
- RFQ
- Beam transport and other subsystems
- Summary

FRIB Front End Requirements Are Challenging

FRIB will be a premier multiuser nuclear physics facility providing stable ion beams with energies above 200 MeV/u and a beam power up to 400 kW.

- Ions up to Uranium
- World record intensity for highly charged heavy ions
  - 8.5 pμA of ^{238}U with minimum charge of 33+, 13 pμA out of ECR
- Two-charge-state transport to increase intensity
- Control of beam phase space to limit losses and satisfy experimental needs
  - Transverse emittance < 1.0 μ·mm·mrad, longitudinal (99.5%) < 1.5 keV/u·ns
- Variability of beam intensity and pulse length to meet experimental needs
  - Bunch intensity – up 9 orders of magnitude
  - Beam pulse length / frequency – 0.6 μs – CW / <30 kHz
- High reliability, maintainability, and availability
  - Front End downtime to change ion species ~ 8 hours
- Upgradability
- Proven, reliable technical solutions with evolutionary performance level upgrades

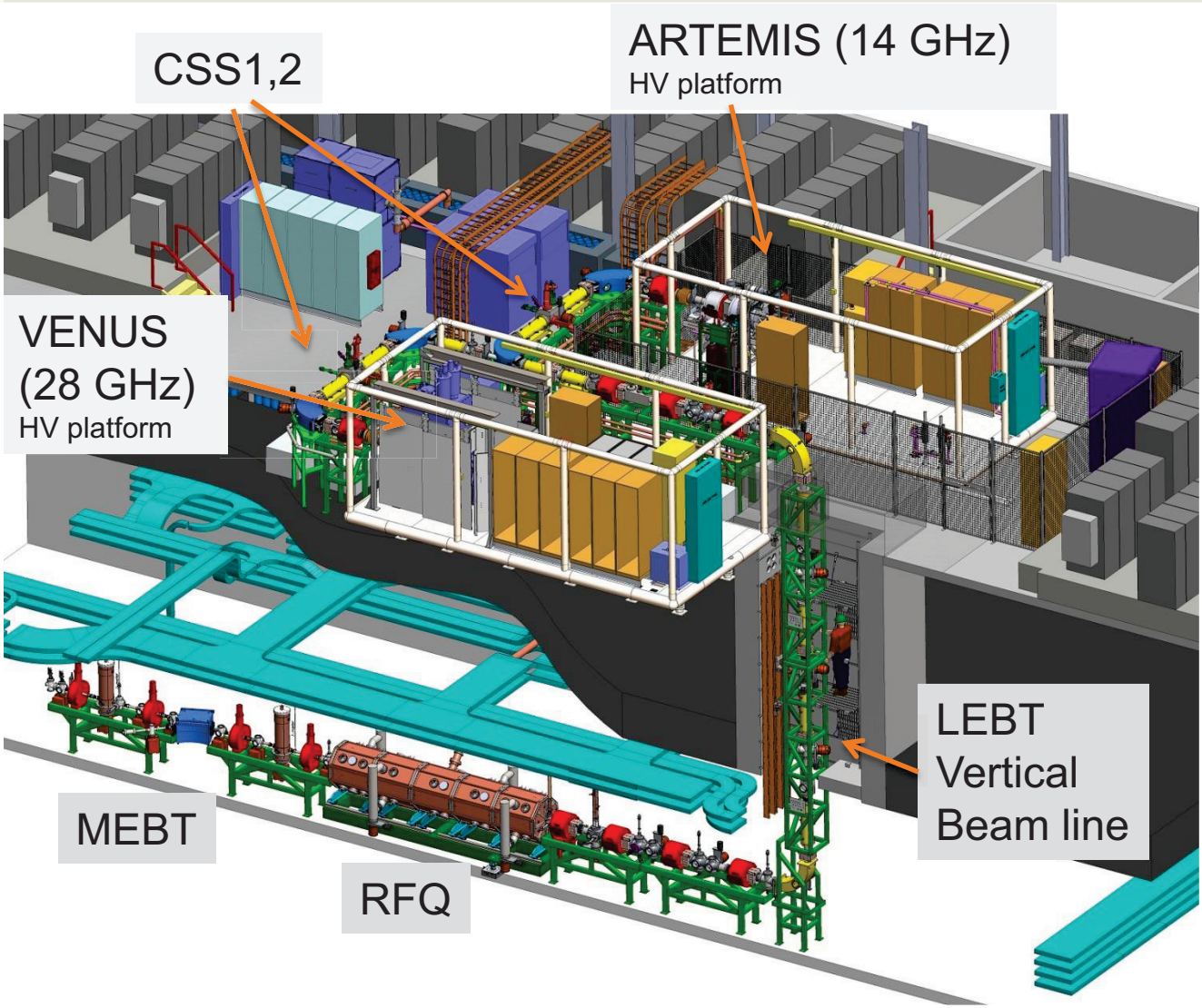
FRIB Driver Accelerator Layout



Sources are at grade level to increase availability and maintainability

Front End Layout

- Two ECR sources on high voltage (HV) platforms
- Two achromatic charge selection systems
- Low energy beam transport (LEBT)
  - E=12 keV/u
  - Chopper
  - Collimation system
  - Vertical transport line
  - Buncher and velocity equalizer
- Radio frequency quadrupole (RFQ)
  - E=12 keV/u – 500 keV/u
- Medium energy beam transport (MEBT)
  - Two bunchers, solenoids
- Instrumentation, power supplies and radio frequency (RF) amplifiers, controls, facilities



Front End Performance Expectations

Parameter	Operations 28 GHz Source	Commissioning 14 GHz Source
Ion species	Up to Uranium	Ar, Kr
Q/A	1/3 – 1/7	1/4, 1/5
Beam intensity (eμA, typical)	350	20
Energy (keV/u)	500	500
Emittance (πμm, 99.5%, norm., typical)	1.0	1.0
Longitudinal Emittance (πkeV/u·ns, 99.5%, typical)	1.5	1.5
Repetition rate (MHz)	40.25, 80.5*	40.25
Beam pulse length (μs) / pulse frequency (kHz)	0.6 – CW / <30	0.6 – CW / <30

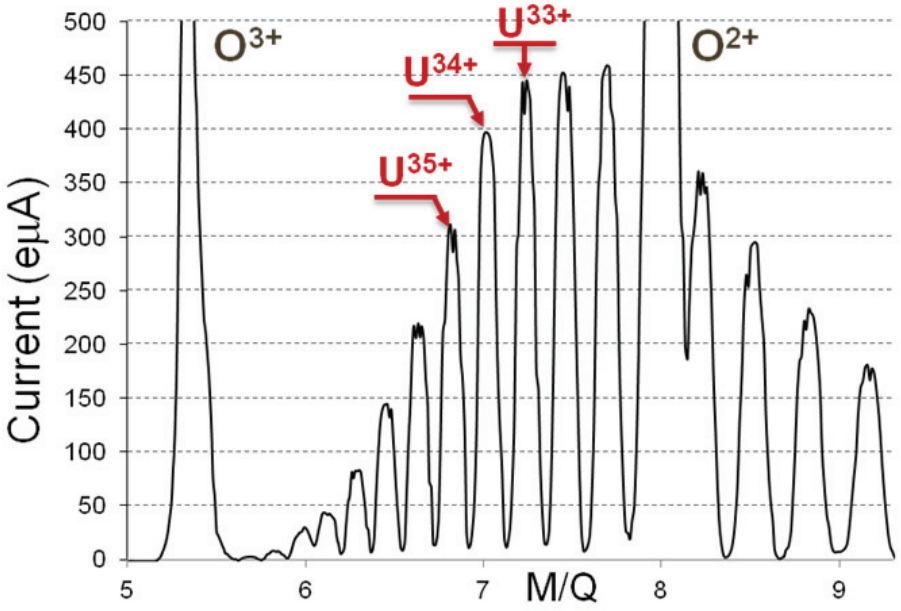
* - two charge states from ECR ion source accelerated

FRIB High Power Ion Source Based on VENUS (LBNL) Parameters

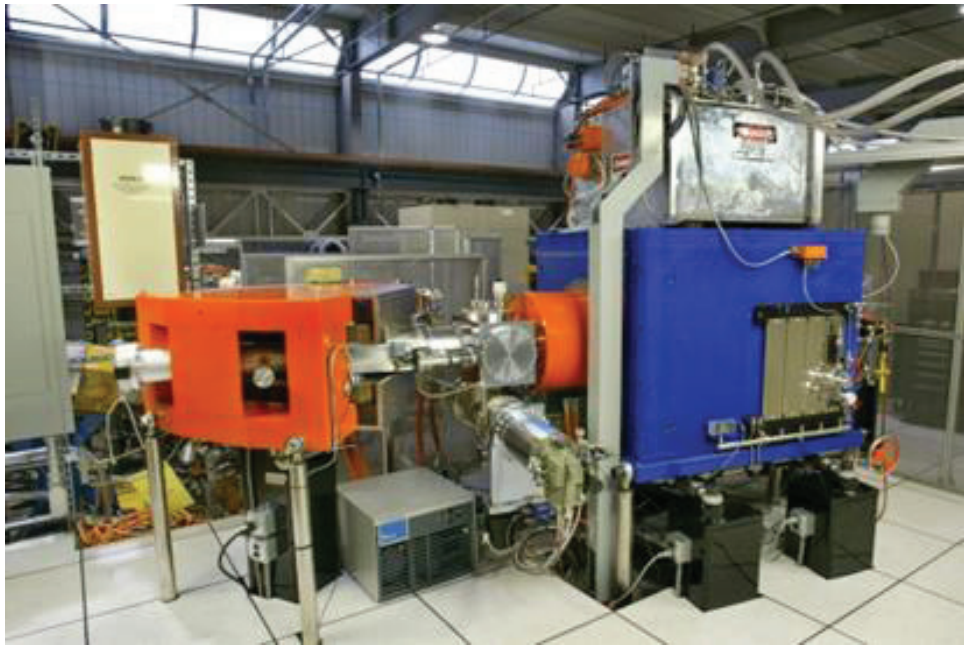
VENUS demonstrated world-record 440 μA of $^{238}U^{33+}$

- Stable operations for 10 hours
- ~700 μA of Uranium expected after FRIB RFQ with two charge states 33+ and 34+

VENUS M/Q scan



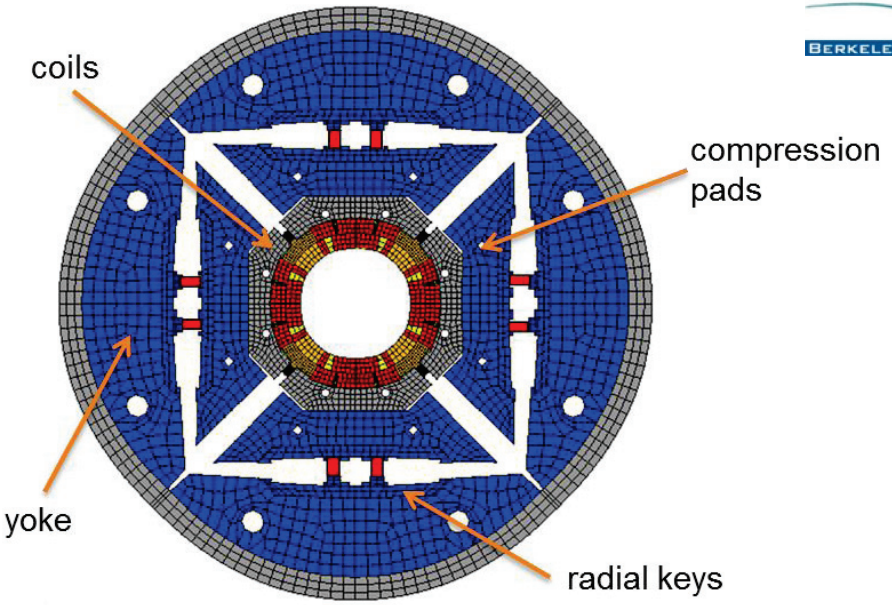
VENUS @ 88" Cyclotron LBNL



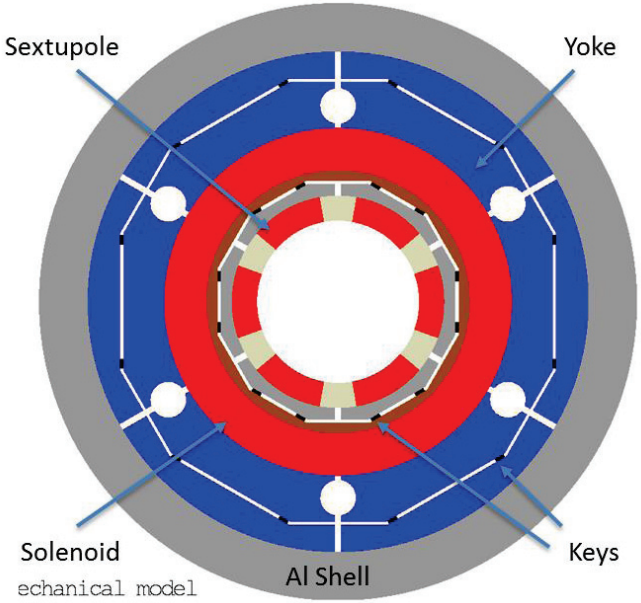
Novel Radial Key-Bladder Clamping Scheme Pursued for FRIB ECR Cold Mass

- Approach developed by Berkeley for LARP high field magnets
- Radial bladder-key design addresses VENUS magnet technical risk
  - Allows disassembling magnet, changing components, fine control of pre-stress state
- FRIB – LBNL/SUPERCON collaboration established, design lead by SUPERCON

Mechanical model of HQ Quadrupole Developed by LBNL



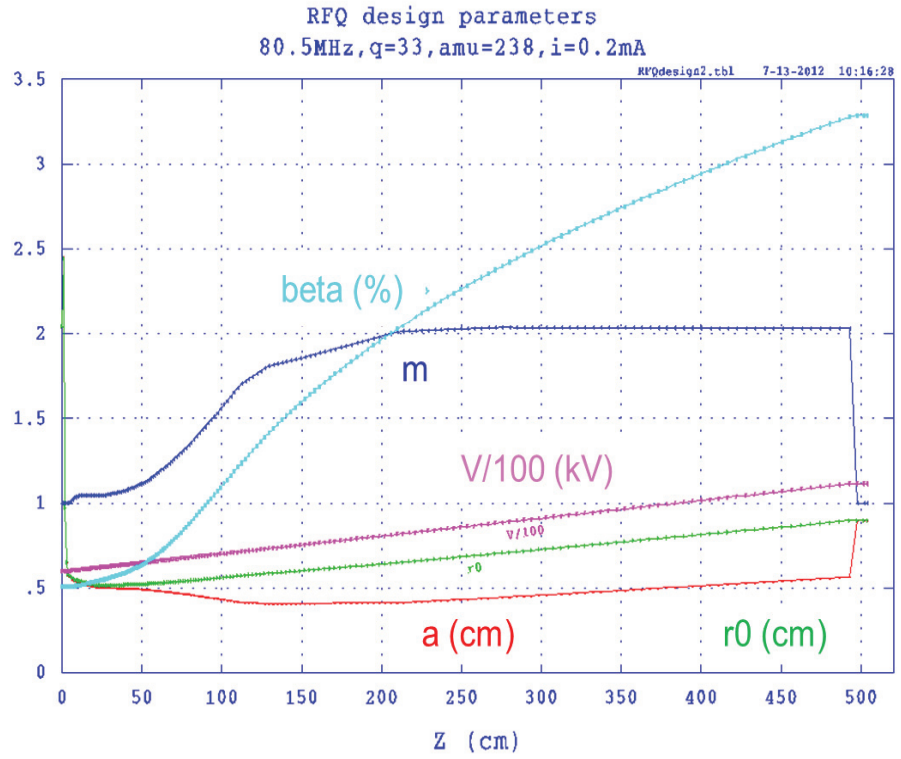
Mechanical model of 56 GHz ECR magnet Developed by LBNL



Courtesy S. Caspi, S. Prestemon, C. Lyneis (LBNL)

FRIB RFQ Parameters

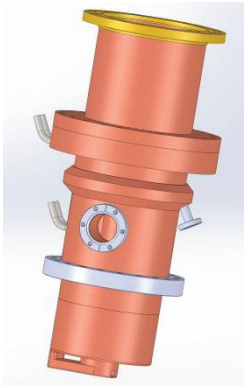
- FRIB RFQ designed to accelerate Oxygen to Uranium Beams
  - Two charge states for ions heavier than Xenon
  - External buncher and energy equalizer



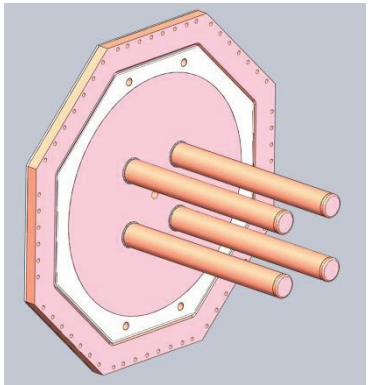
Frequency (MHz)	80.5
Operational duty factor	CW
Energy Inj./Extr. (keV/u)	12 – 500
Ion charge states (Q/A)	1/3 – 1/7
Trans. Emittance (πμm, norm.)	1.0
Long. Emittnce 99.5% (keV/u·ns)	1.5
Transmission (%)	82
Power (kW, $^{18}O^{+6}$ - $^{238}U^{+33}$)	15 - 90
Length (m)	5

RFQ Initial Engineering Design Completed Contract Awarded to Industry

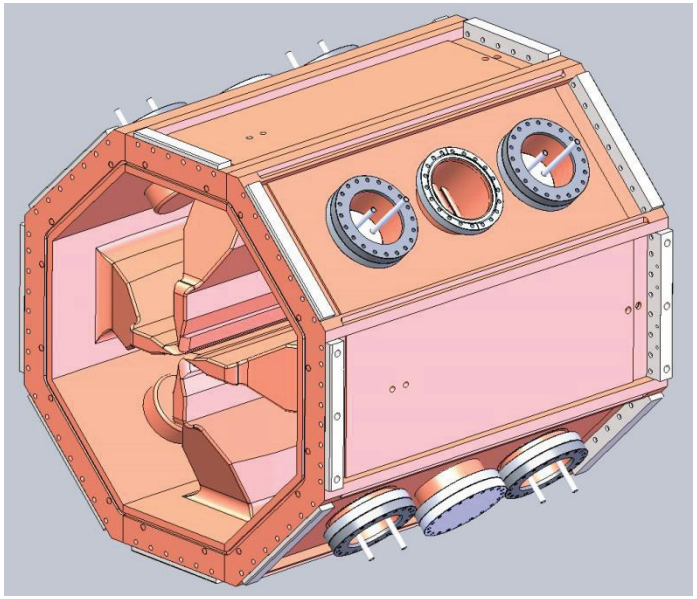
- RF and preliminary engineering design completed
- Contract awarded to Kelin, Shanghai. Tsinghua University, Beijing, coordinates communications with Kelin.
- Final engineering design is in progress. Expected delivery 6/2015.



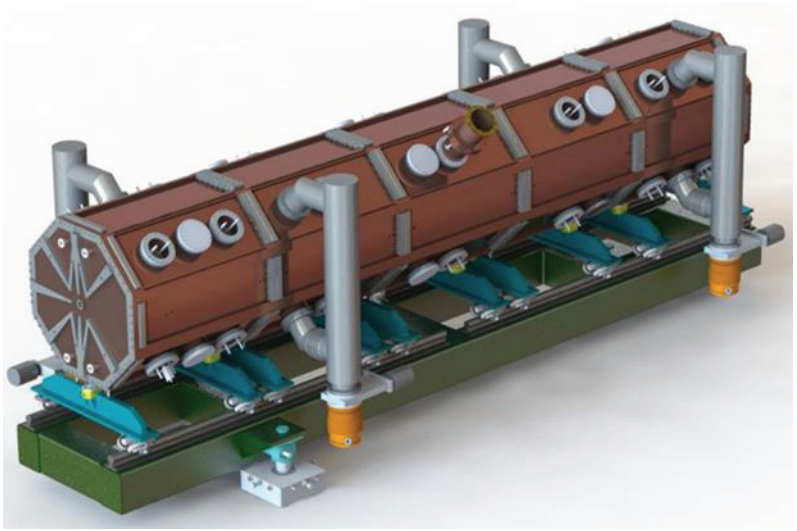
Coupler and end wall



1st segment assembly



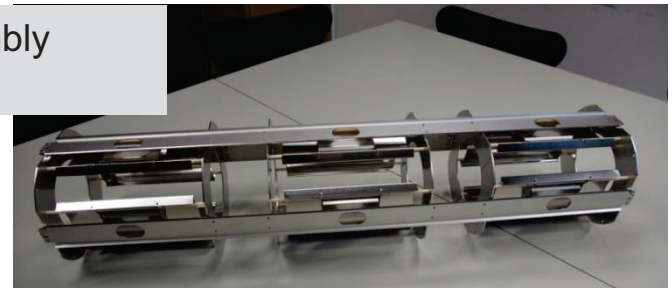
RFQ assembly on support stand



Beam Line Can Transport Two Charge States for Charge States Above 25+

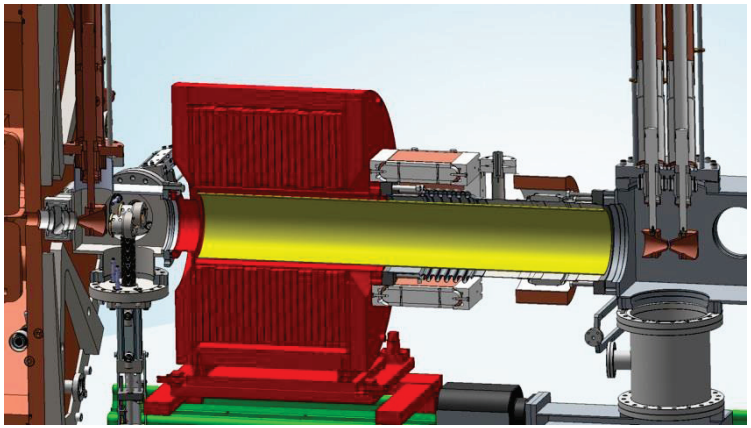
- Electrostatic components used to transport beam
- Energy spread removed using buncher and RF energy equalizer before RFQ

Electrostatic triplet assembly
(no vacuum enclosure)



Multiharmonic buncher
F=40.25, 80.5,120.75 MHz
P~100 W total

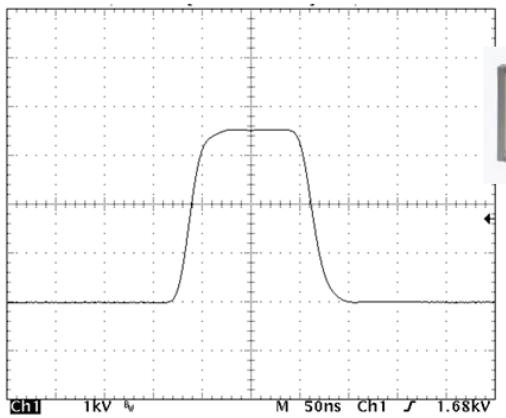
HV drift tube to adjust time of flight,
+-30 kV, tube is inside vacuum chamber



Electrostatic bends to avoid separating two charge states They also serve as MPS beam aborts.

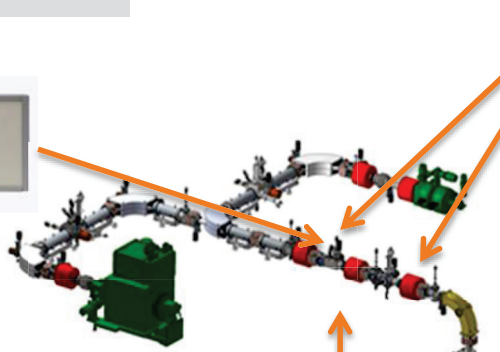
Control of Beam Intensity, Phase Space, Pulse Length, and Repetition rate

Pulsed electrostatic chopper to control pulse beam
Fast high voltage switch DEI PVX-4140
Pulse length: 0.6 μs – CW, Rep. rate: <30 kHz



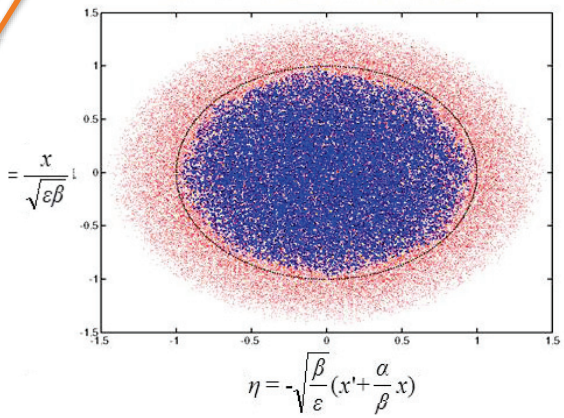
25ns Rise & Fall Times, 3500V Output
(50ns/Div horizontal scale, 500V/Div vertica

Two or four apertures to control transverse halo

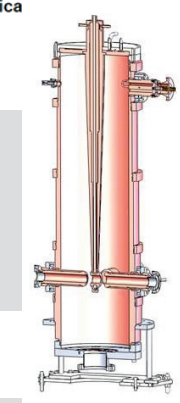


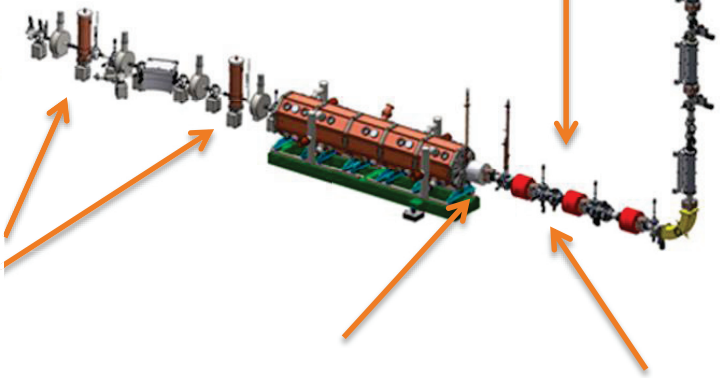
Two areas identical

Distribution in normalized coordinates



MEBT RT Bunchers
80.5 QWR (1.5 kW)
Final design near complete.





Longitudinal emittance controlled using bunchers and low energy end of the RFQ

Mesh screens will be used to reduce bunch Intensity by 10^6 – 10^9.

Other Accelerator Systems are Being Developed

- Diagnostics and Instrumentation
  - Mostly Interceptive diagnostics in LEBT
  - Beam power level (1 kW to 50 W) increases cost of interceptive diagnostics
- Vacuum
  - 5e-9 Torr to reduce losses due to charge exchange losses
  - MEBT particulate free
- Power Supplies
- RF Systems
- Controls

Progress Summary

- FRIB Front End proceeds with design and early procurement of components
  - Commissioning RT source
  - RFQ
  - Bunchers
  - ES Quads
- Design value engineered, optimized
  - RFQ energy increased from 300 keV/u to 500 keV/u, one cryomodule removed
  - 14 GHz source will be used for commissioning
  - Electrostatic optics elements
- Design integrated with civil facilities, accelerator systems, and experimental systems
- Acquisition meets budget and schedule targets
- Expected start of commissioning 11/2017 with ARTEMIS source.

Acknowledgments

- FRIB Team
- A. Facco (FRIB/LNL)
- L. Young, J. Stovall (former LANL)
- S. Prestemon, S. Caspi, H. Felice, R. Hafalia, E. Rochepault (SUPERCON/LBNL)
- Q. Xing, X. Guan, D. Wang (Tsinghua University, Beijing)
- P. Ostroumov, R. Vondrasek, R. Pardo (ANL)
- S. Alexandrov (SNS)
- L. Sun (IMP, Lanzhou)
- S. Vorozhtsov, V. Smirnov (JINR, Dubna)