Status of FRIB

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On Behalf of FRIB Project

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, the State of Michigan and Michigan State University. 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.

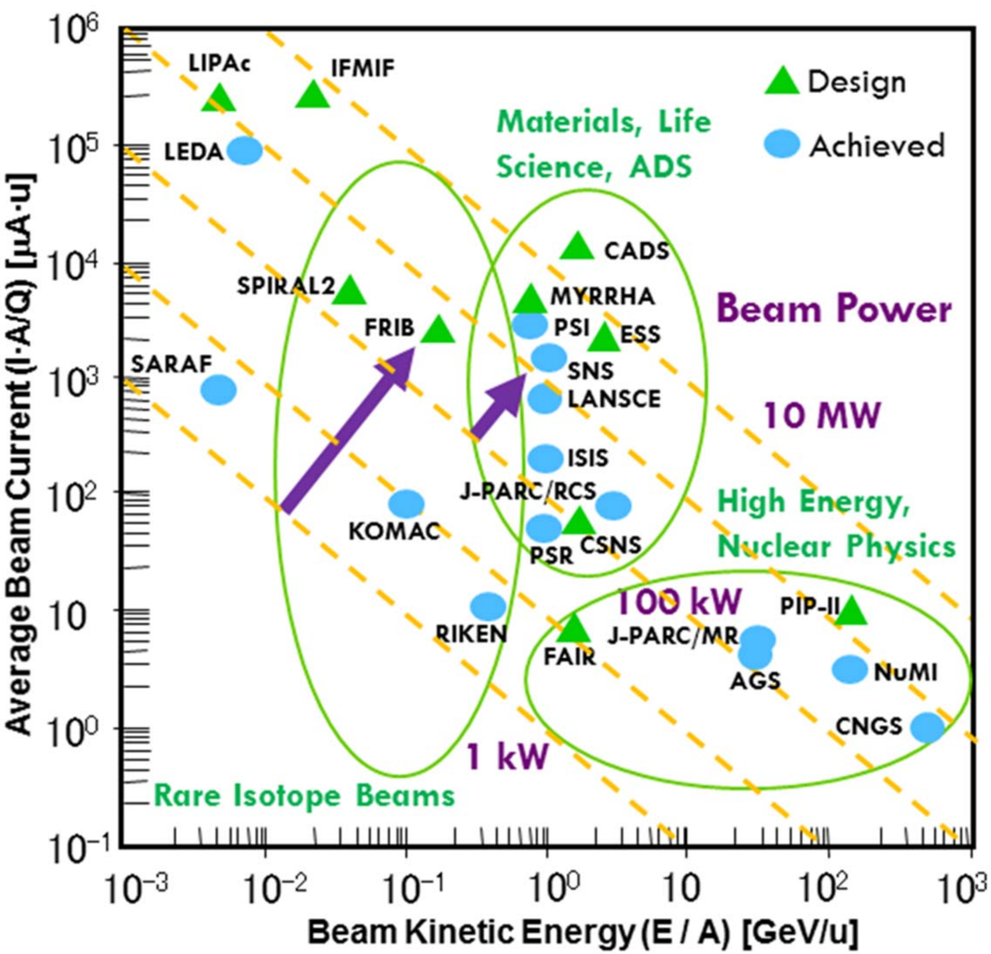
Outline

- Introduction
- Status of civil construction
- Front End installation and start of beam commissioning
- Delivering technical scope: status of technical equipment
- Acknowledgments and summary

Introduction

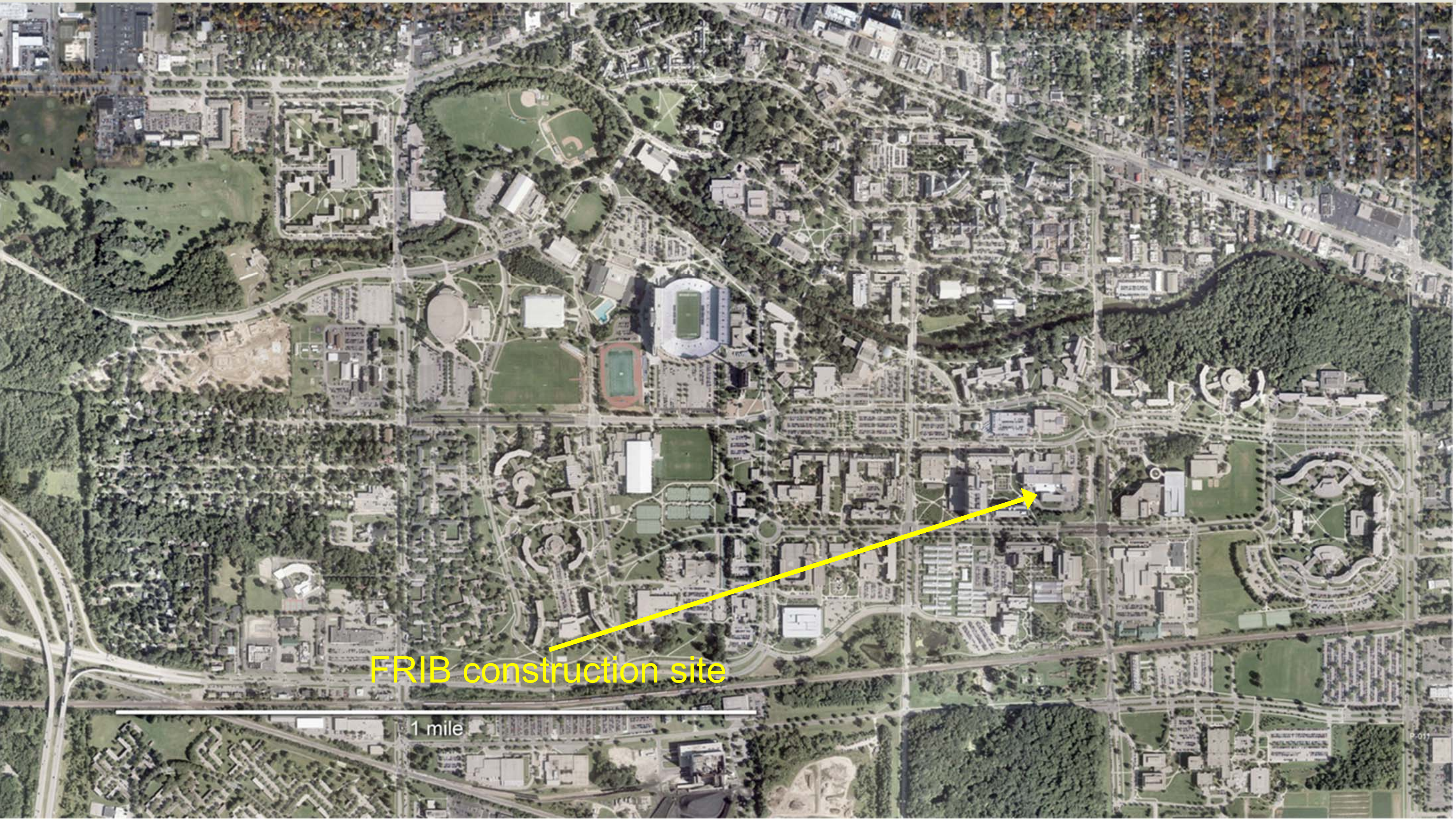
Facility for Rare Isotope Beams Premier DOE-SC National User Facility

- Ions up to uranium, E>200 MeV/u, beam power on target 400 kW, Superconducting linac
- Rare isotope beams by fragmentation, gas stopping, reacceleration
- FRIB pushes the beam power on target by two orders of magnitude comparatively to existing medium and heavy ion facilities
- FRIB scientific focus aligned with National Science Priorities
  - Properties of nuclei
  - Astrophysical processes
  - Test of fundamental symmetries
  - Societal application and benefits



FRIB Construction Site Located on MSU Campus

Enrollment 50540, Staff 12100; Campus 40 km^2; Endowment \$2.3B; Established 1855



Facility for Rare Isotope Beams
U.S. Department of Energy Office of Science
Michigan State University

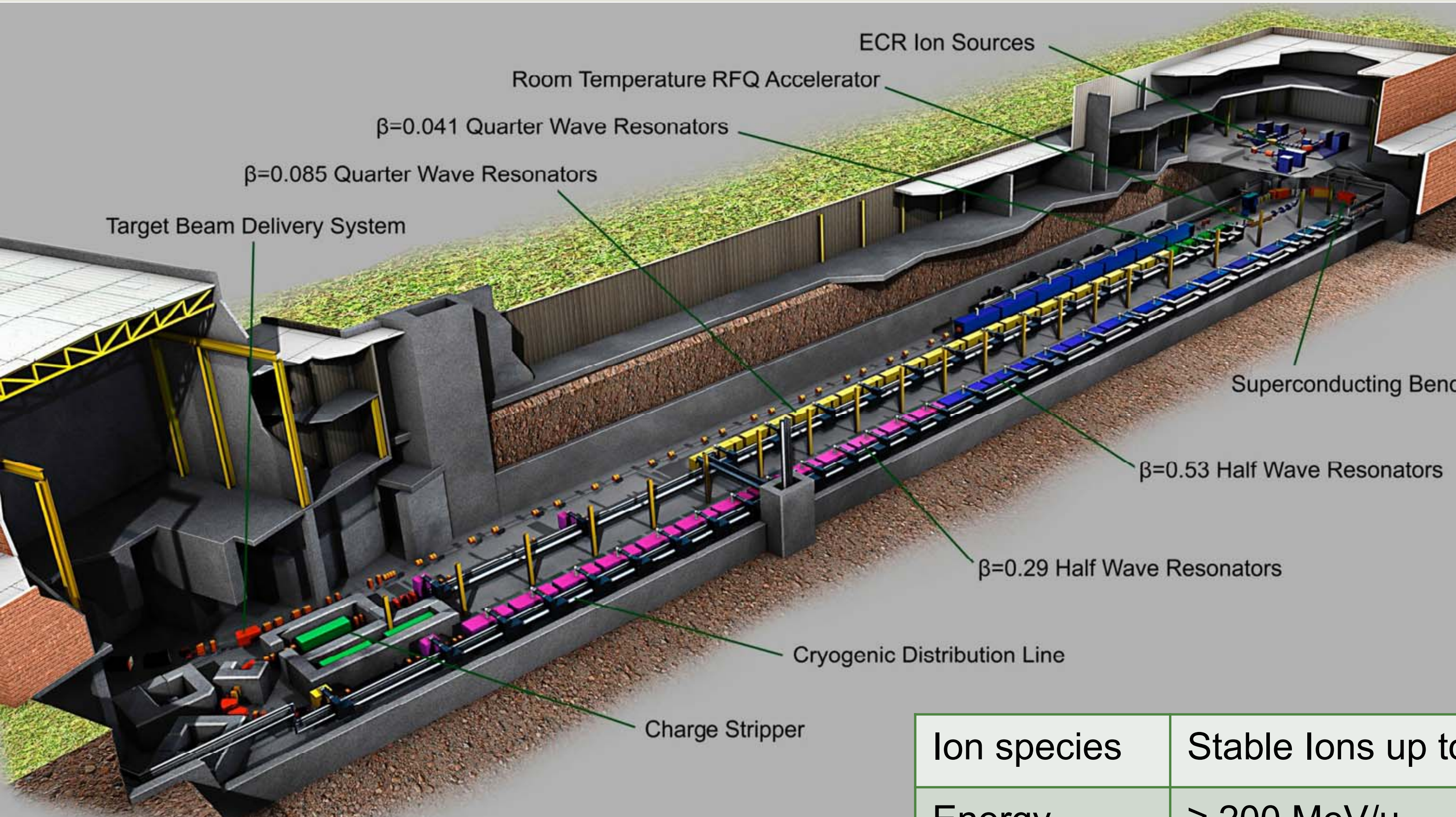
FRIB Project Time Line

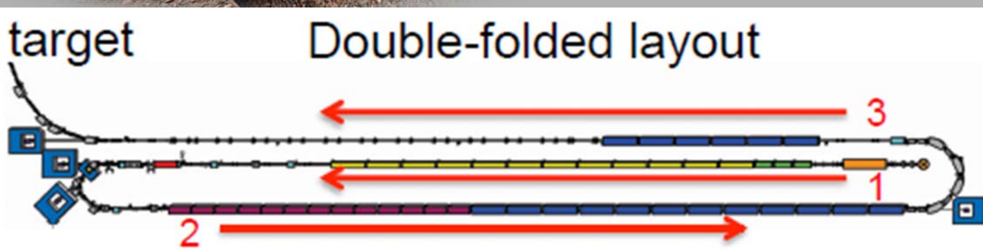
- 2008-12: DOE selects MSU to establish FRIB
- 2009-6: DOE and MSU sign corresponding cooperative agreement
- 2010-9 CD-1: conceptual design complete & preferred alternatives decided
- 2013-8 CD-2/CD-3a: performance baseline, start of civil construction & long lead procurement
- 2014-8 CD-3b: start of technical construction

10/11/2016 Two years into technical construction

- 2022-6 CD-4: construction completion

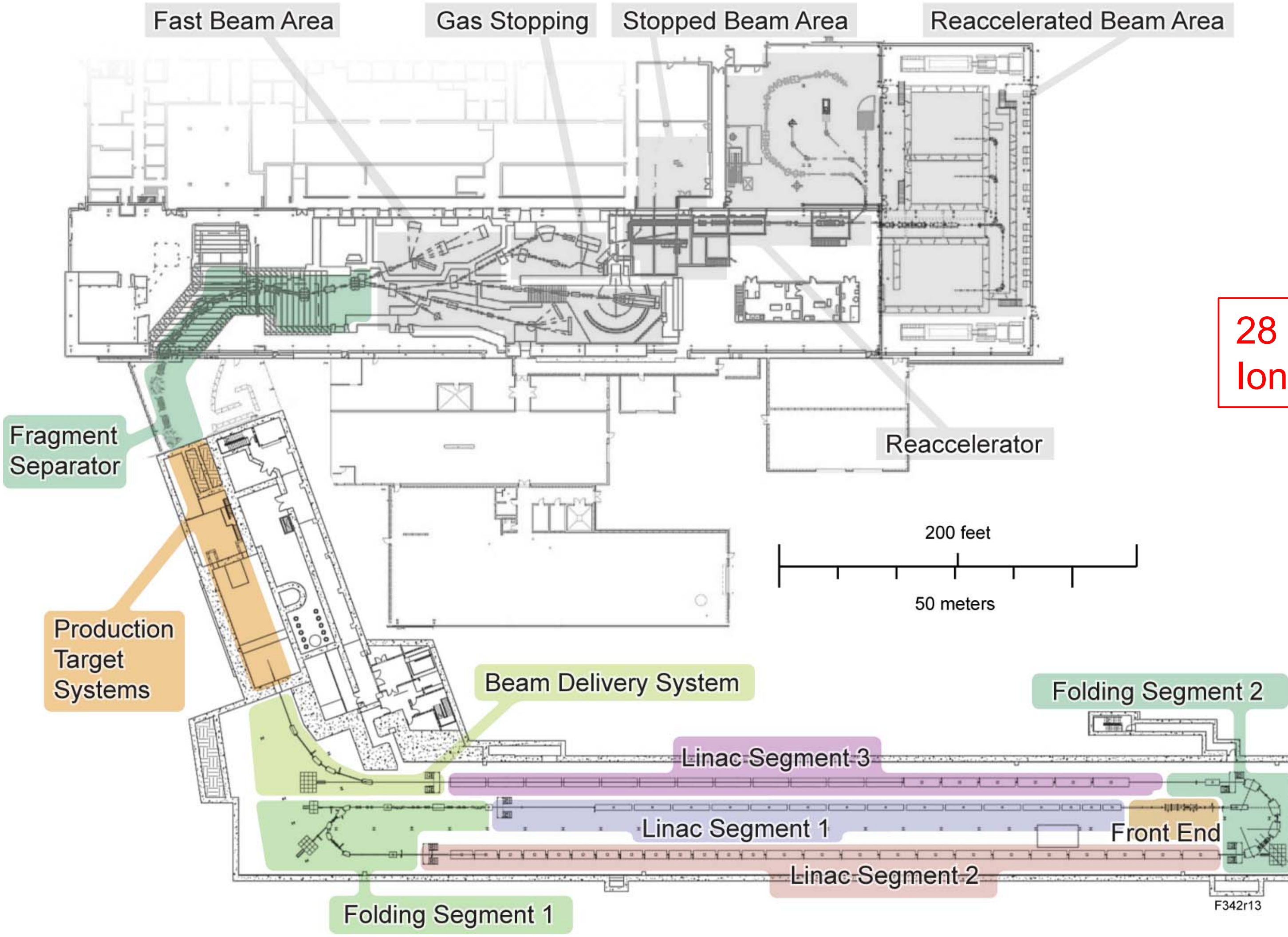
Accelerator Layout
Principle Parameters and Accelerator Sub-systems



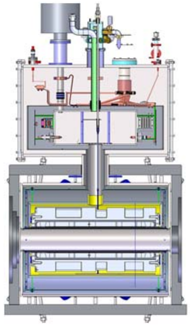


Ion species	Stable Ions up to Uranium
Energy	≥ 200 MeV/u
Intensity	~700 eμA
Duty Factor	CW
Beam power	400 kW

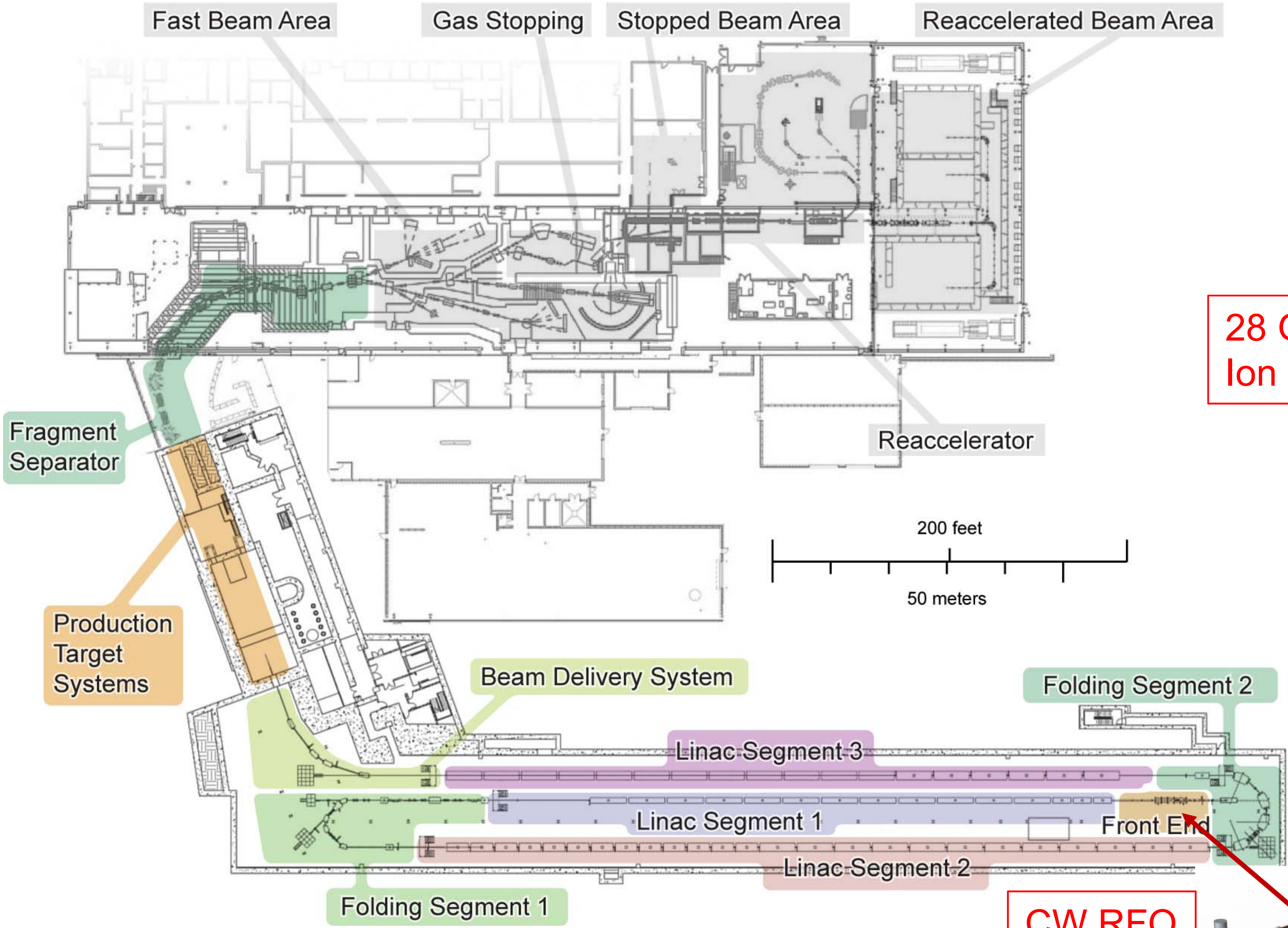
FRIB Accelerator
High Complexity Subsystems



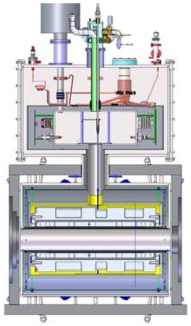
28 GHz ECR Ion Source



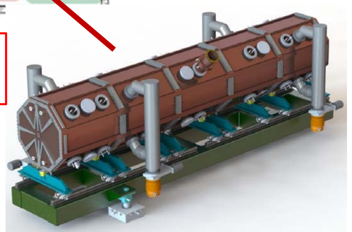
FRIB Accelerator
High Complexity Subsystems



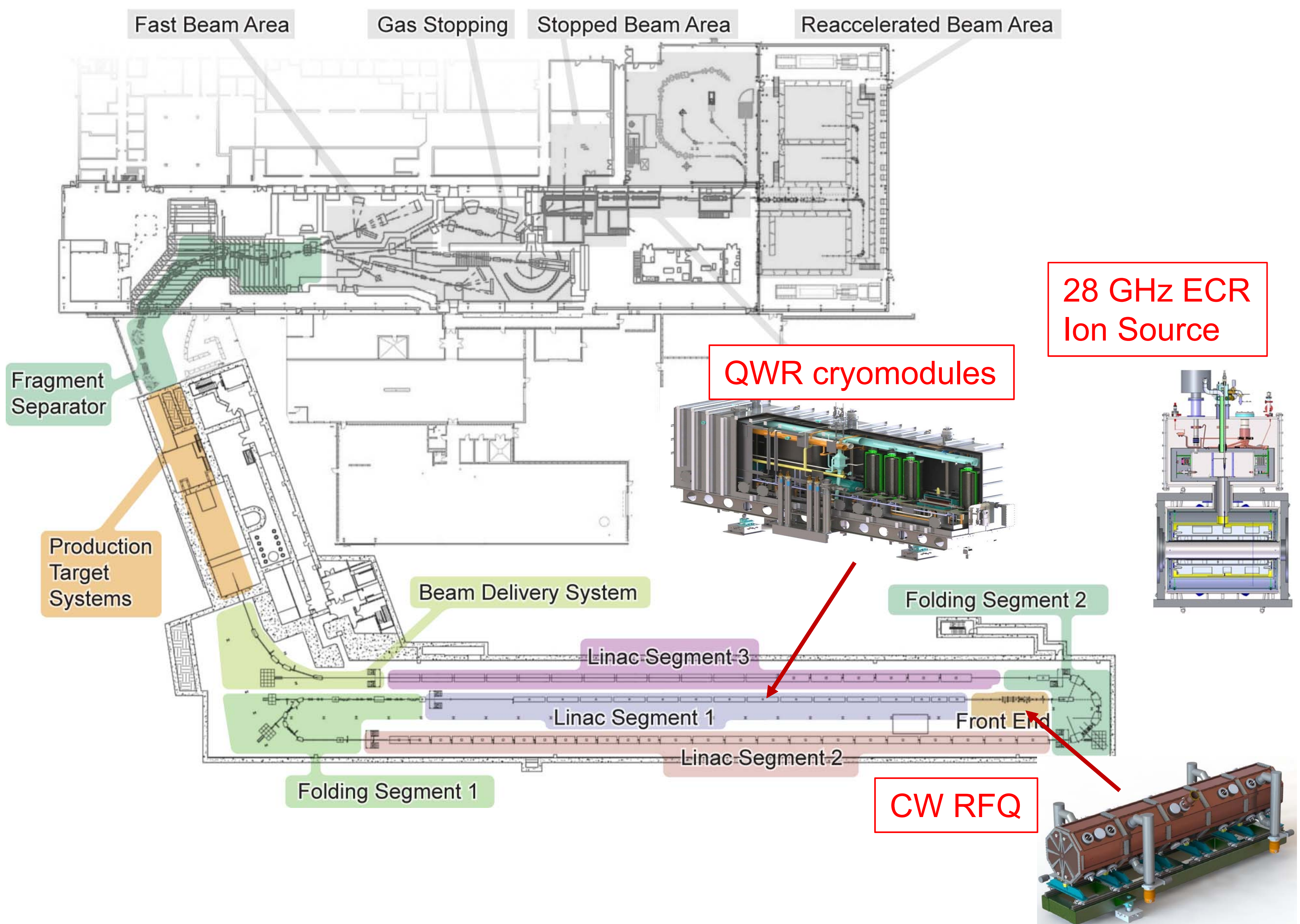
28 GHz ECR Ion Source



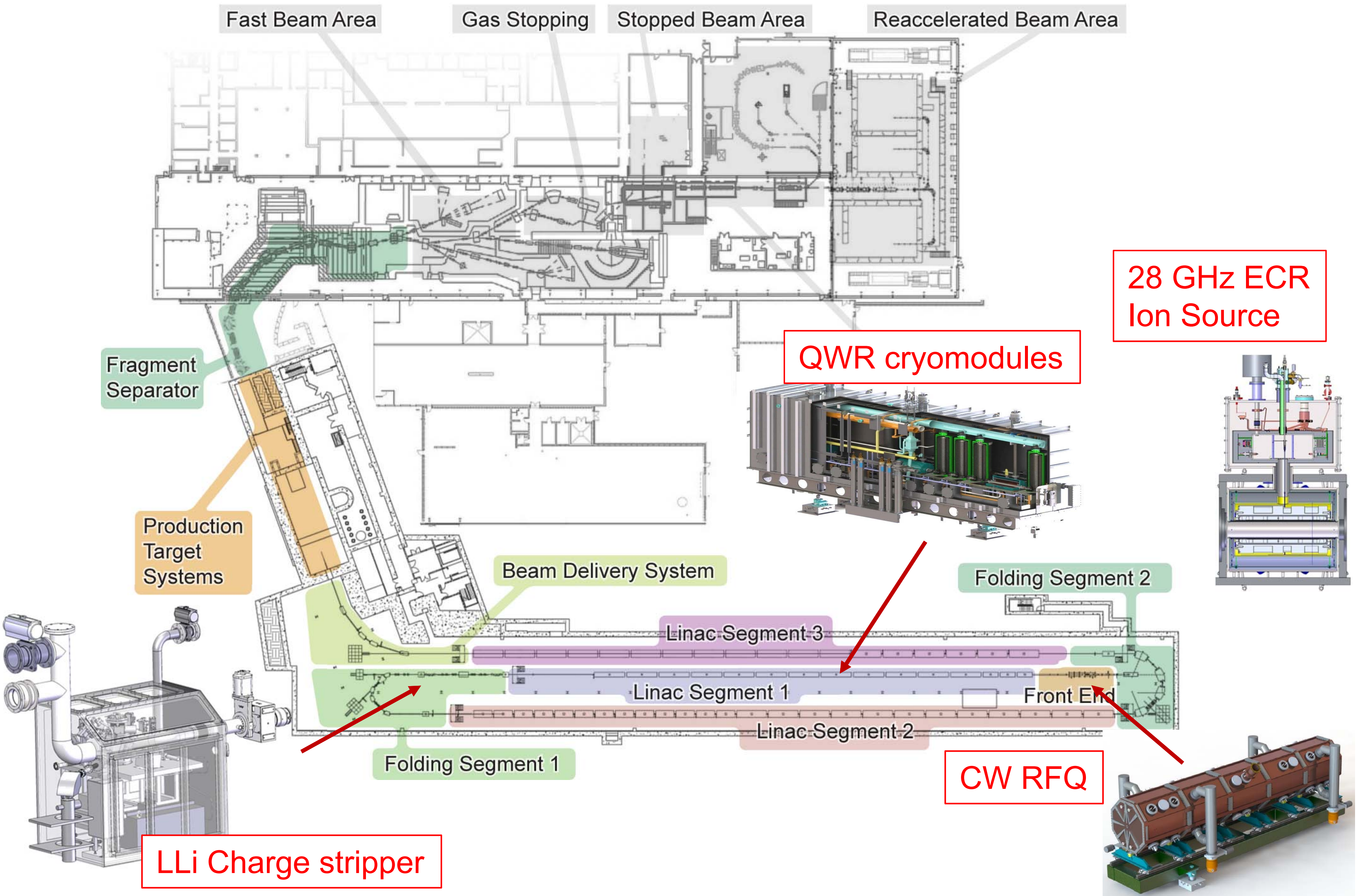
CW RFQ



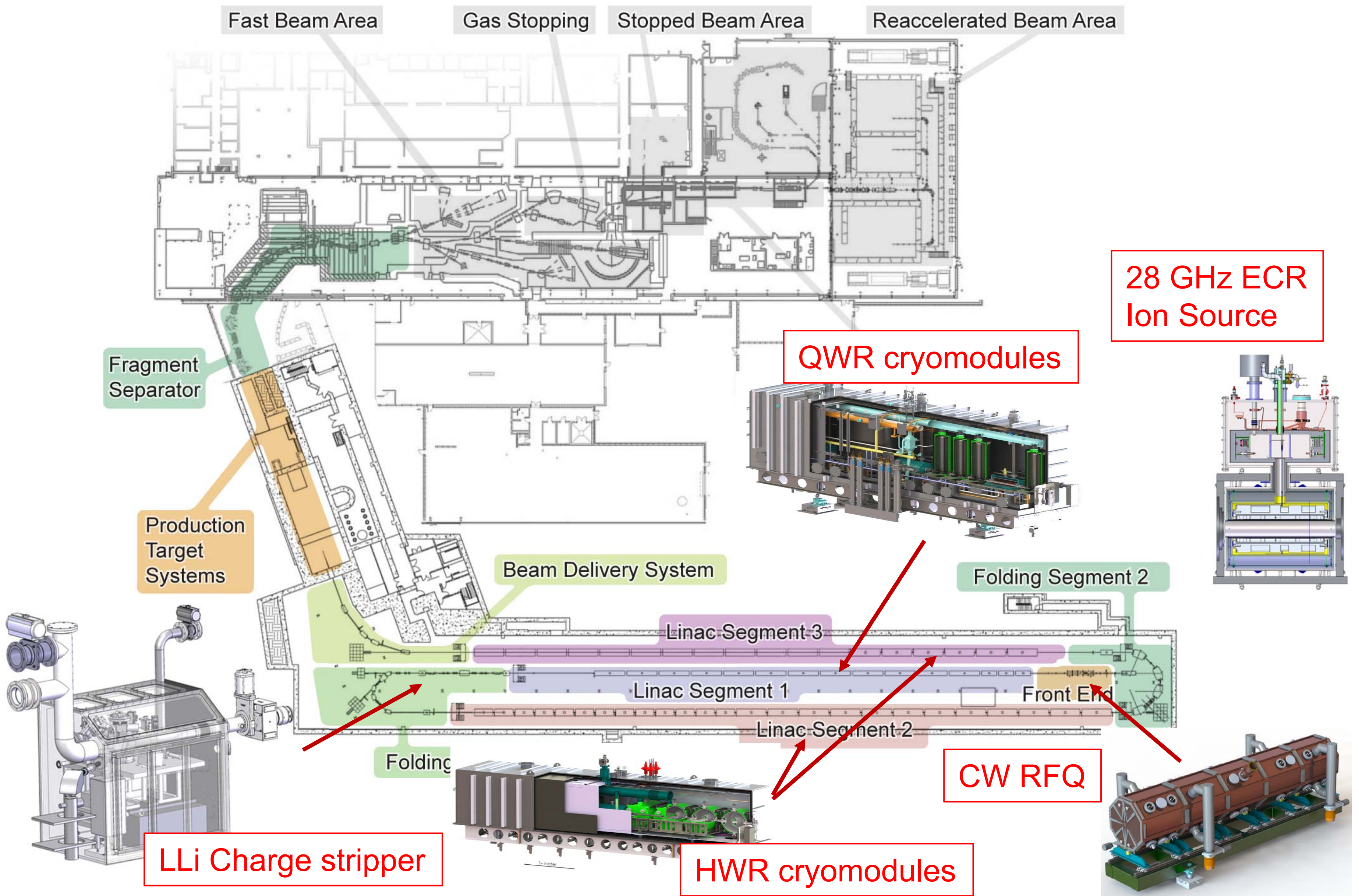
FRIB Accelerator
High Complexity Subsystems



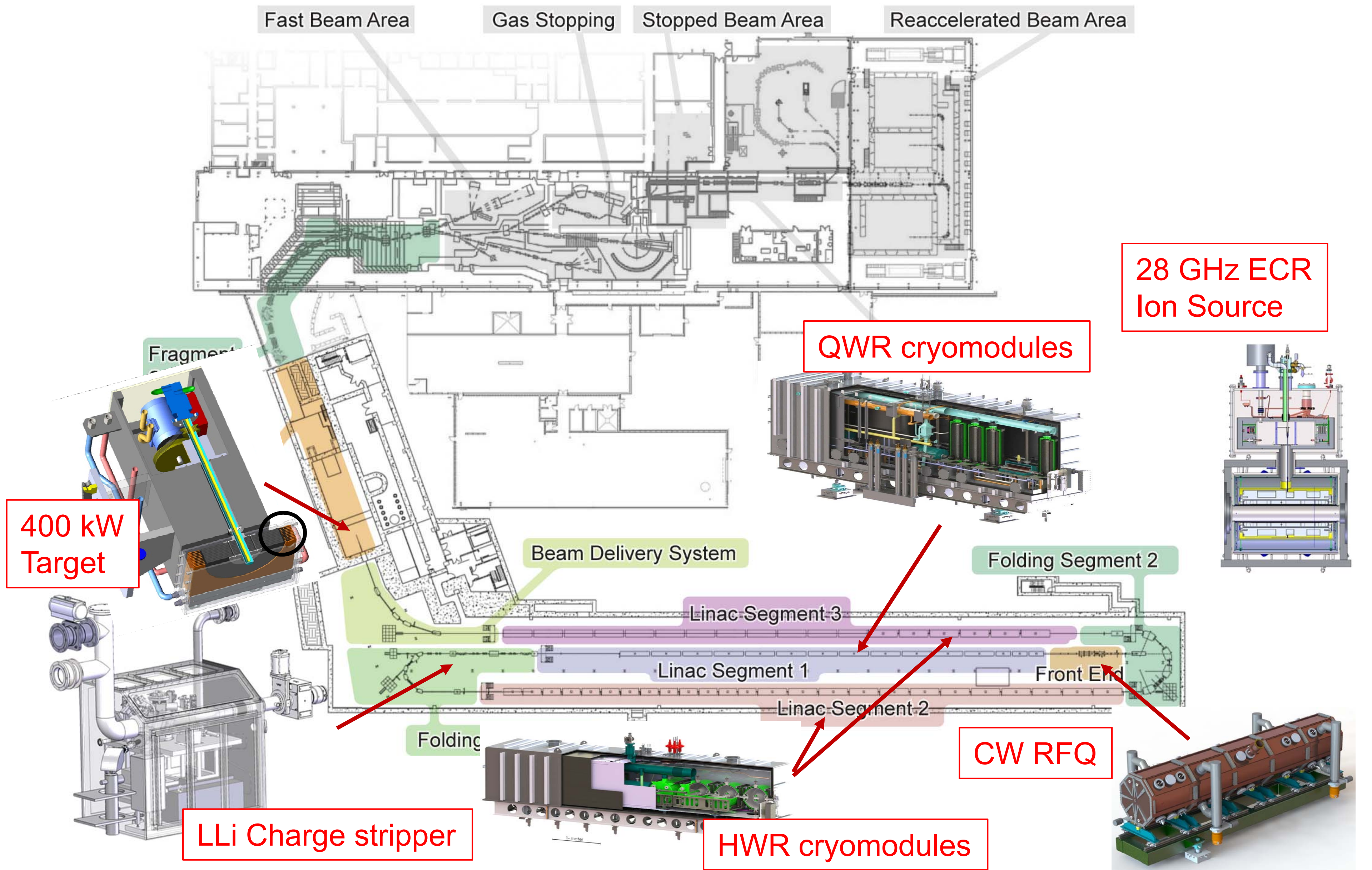
FRIB Accelerator
High Complexity Subsystems



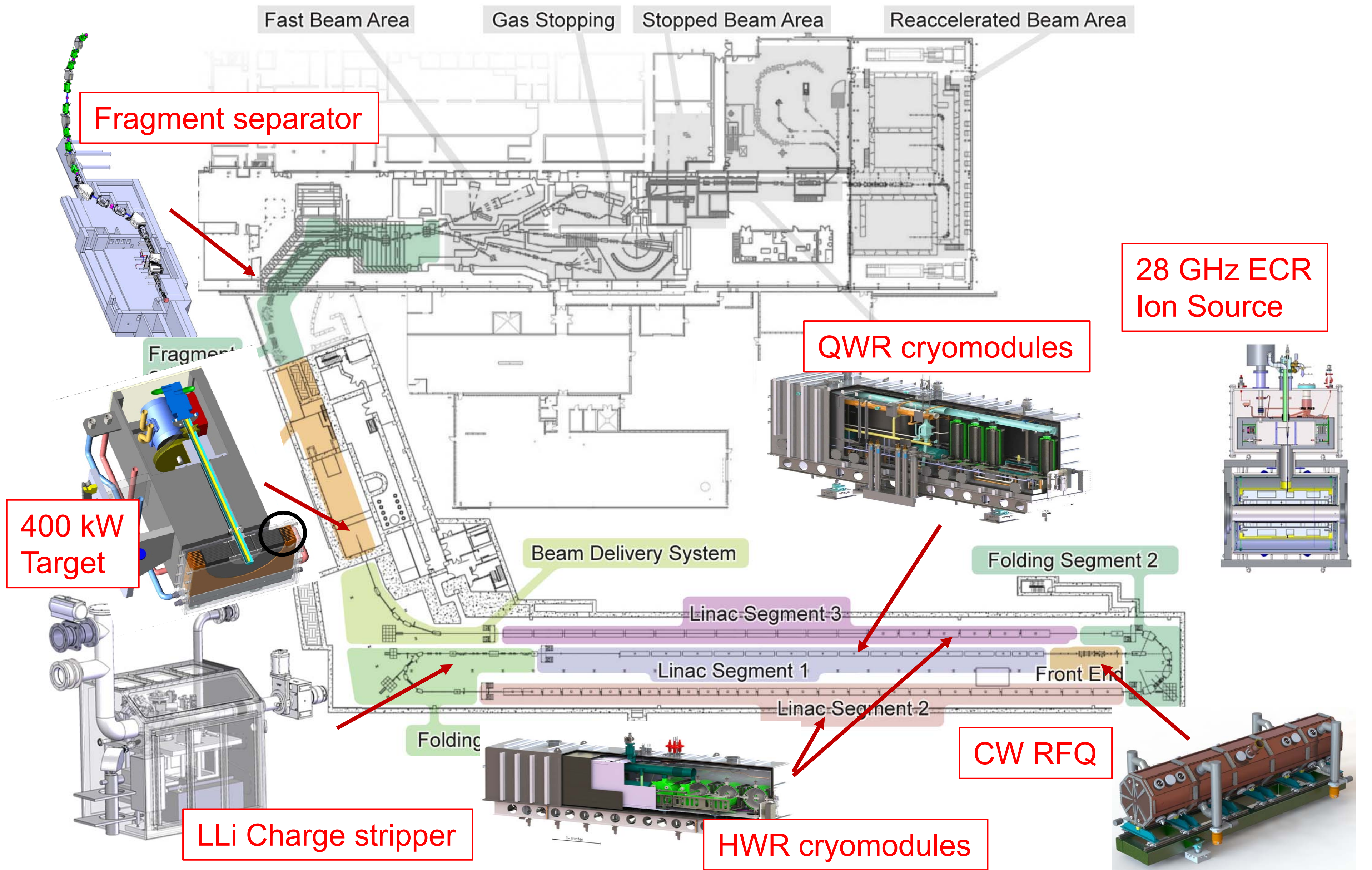
FRIB Accelerator
High Complexity Subsystems



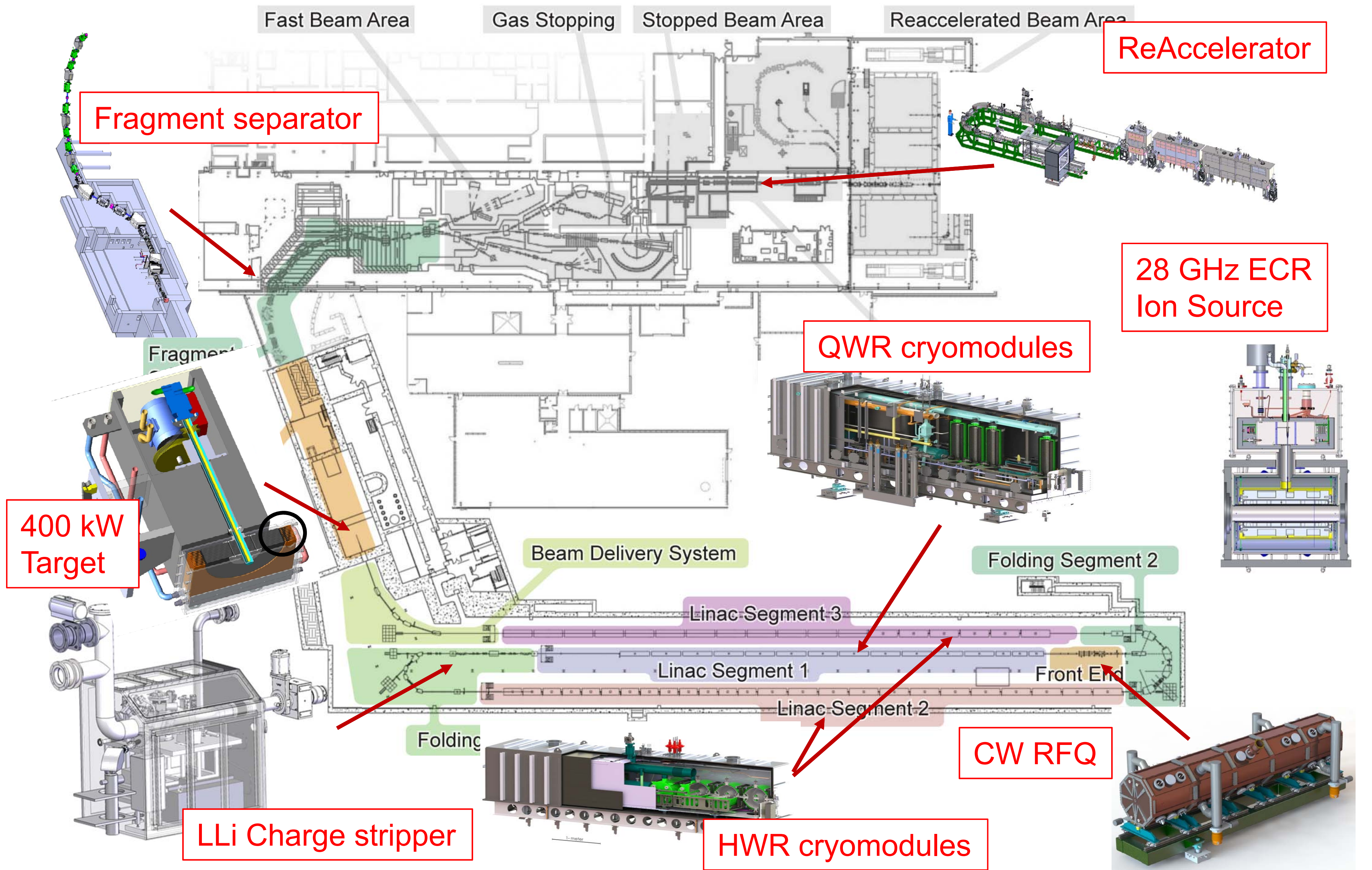
FRIB Accelerator
High Complexity Subsystems



FRIB Accelerator
High Complexity Subsystems



FRIB Accelerator High Complexity Subsystems



Status of Civil Construction

FRIB Construction Site

Accelerator and target buildings, accelerator tunnel, and three office additions to existing NSCL

FRIB Civil Construction Progress [1]

Linac building completed, Front End equipment Installed
Target building mostly completed, Work inside on-going

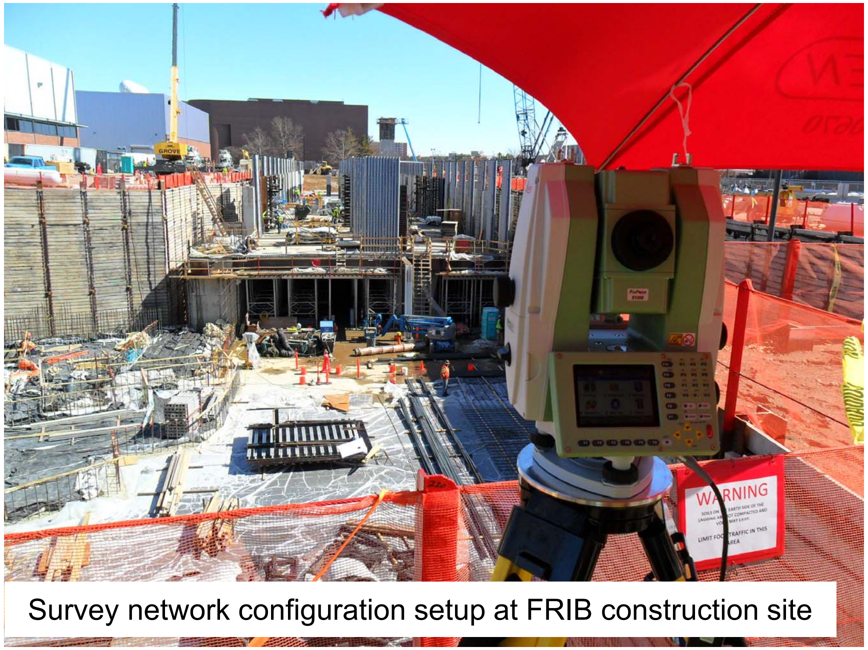
FRIB Civil Construction Progress [2]

Linac tunnel construction completed
Installation of Accelerator Equipment Started

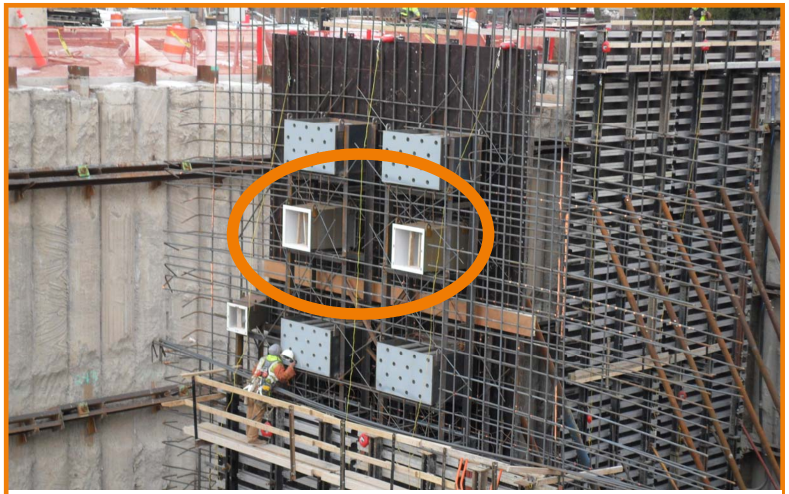
Alignment Network Installed During Civil Construction at NSCL & FRIB

- Responsibility of the ASD alignment group, work coordinated with the site contractor
- Alignment network integrates FRIB new construction with existing NSCL site
- Monitoring construction ground settlement and abnormalities

Monuments grouted for permanence



Survey network configuration setup at FRIB construction site



Construction verification measurements, target cell north wall alignment portal imbeds, 28 January 2015

Front End Installation and Start of Beam Commissioning

Installation of Technical Equipment Proceeds Ahead of Schedule

Milestone	Baseline Schedule	Forecast Schedule
BOD	3/27/2017	3/27/2017
Start Installation of FE equipment	4/2017	11/2015 (actual)
Start ECR ion source beam commissioning	12/2017	10/2016 (imminent)
Complete FE commissioning	5/2018	Fall 2017 (plan)

- Installation of technical equipment prior to BOD requires close coordination with the site contractor
- The site contractor is frequently used to install technical equipment
  - Superior rigging capabilities
  - Safety on the site is contractor’s responsibility

14 GHz ECR Ion Source Artemis Installed Device Readiness and Hazard Reviews Completed

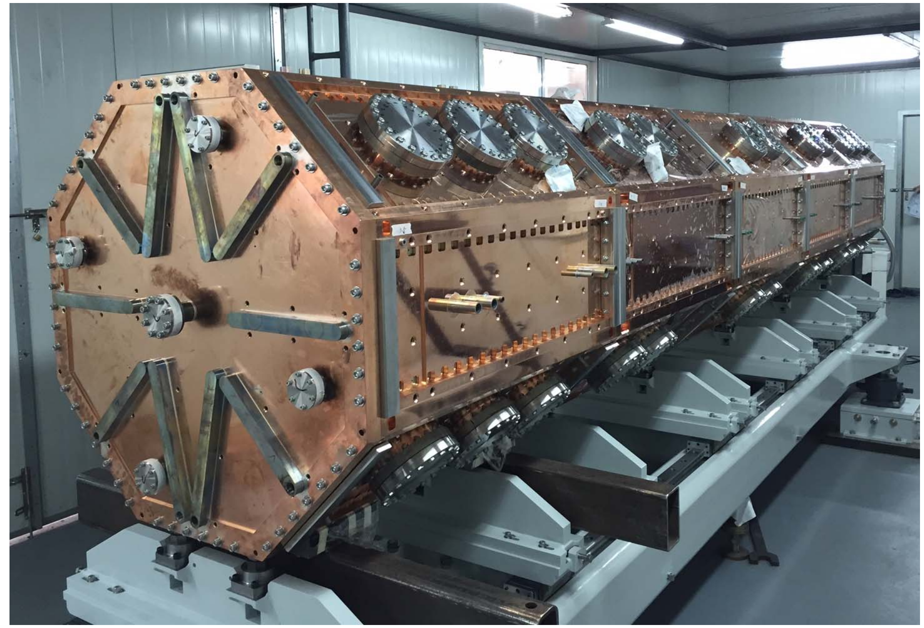
- Installation of the room temperature 14 GHz Artemis on a HV platform and all supporting equipment has been competed
  - 14GHz ECR Ion Source Artemis
  - 100 kV HV platform
  - LCW systems with cooling skids
  - 350 kVA isolation transformers
  - Equipment racks, power supplies, klystron
  - Safety systems
  - Documentation and configuration control
- Device Readiness and Hazard Reviews completed in September 2016
- Waiting for permission to run beam


ARTEMIS 14 GHz ECR ion source on HV platform

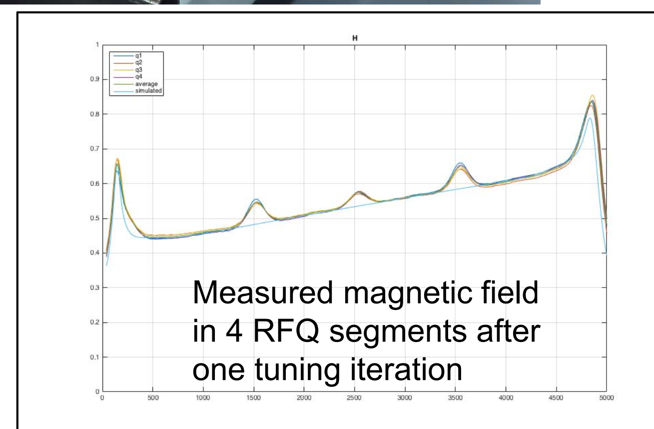

HV platform (5/2016)

RFQ Ready for Installation
Cooling/Frequency Control System Installed and Tested

- RFQ manufacturing completed in 06/2016
- RFQ was tuned as part of the acceptance plan
  - Leak check and alignment were verified
- RFQ received in 09/2016 and is ready for installation
- RFQ two heat exchanger skids were installed and tested. Stability 0.1C demonstrated (without RFQ)
- The RFQ amplifier has been procured and is being installed, based on ReA3 RFQ amplifier

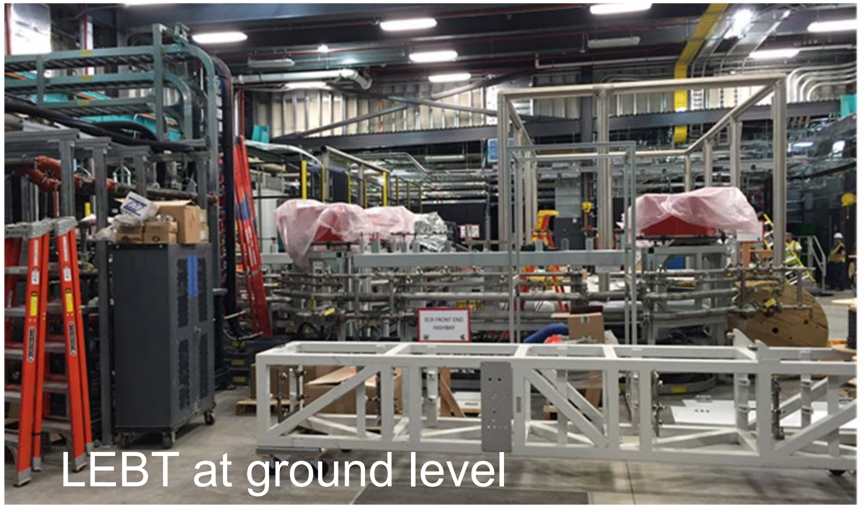


One of RFQ skids



Front End Beam Line Installation Proceeds Ahead of Schedule

- Components required to assemble the Front End beam line have been procured and received
  - Some diagnostics components are expected in 11/2016
- LEBT ground level
  - Beam line stands, utilities, and magnets installed
  - Vacuum chamber to be installed in 12/2016
  - Integrated testing to start in January 2017
- Tunnel LEBT and MEBT
  - Beam line stands, bunchers, and some magnets installed
  - Vacuum chamber to be installed in 01/2017
  - Integrated testing to start in February/March of 2017

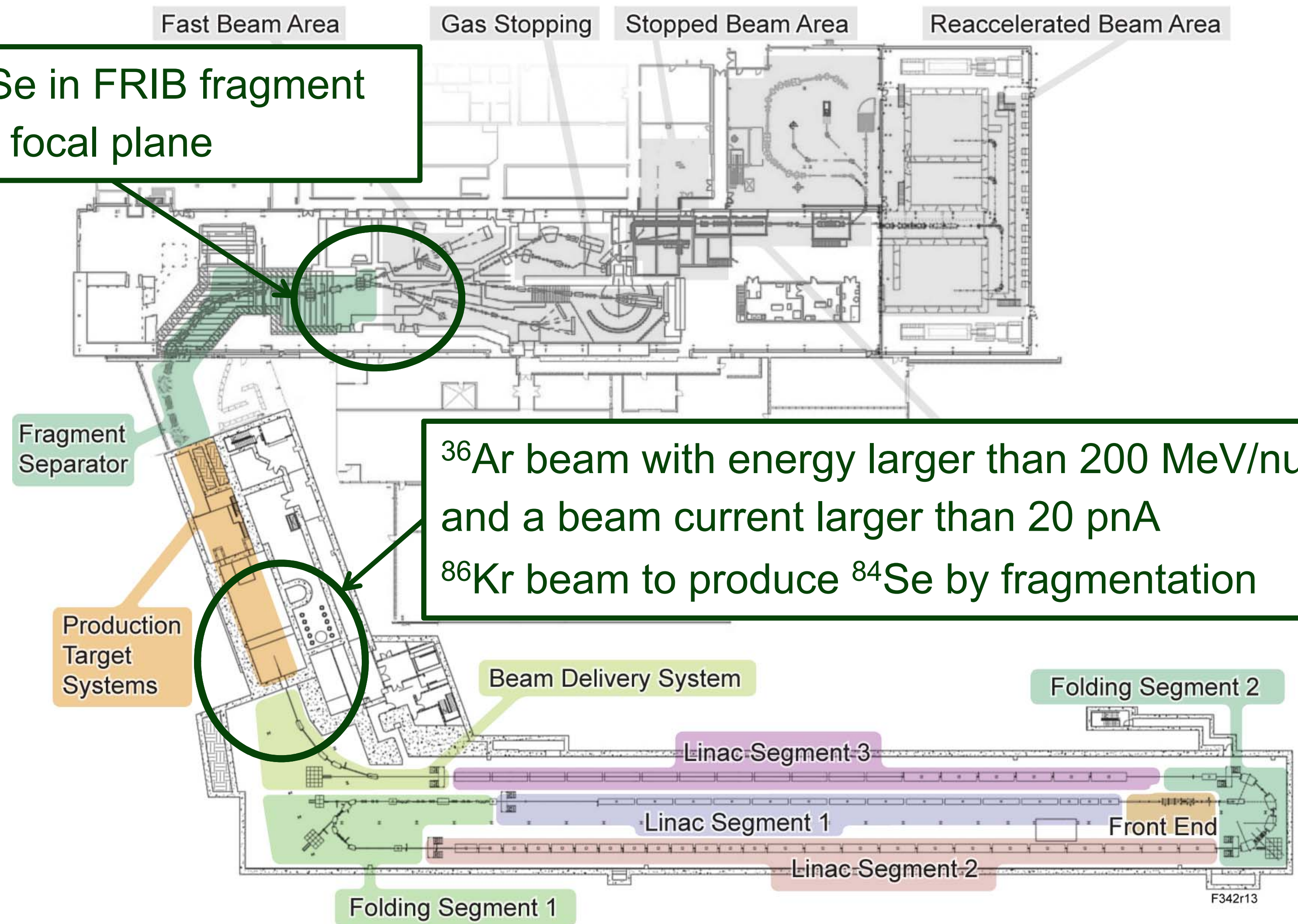


Commissioning Performance Requirements Defined by FRIB Key Performance Parameters for CD-4

Detect ^{84}Se in FRIB fragment separator focal plane

^{36}Ar beam with energy larger than 200 MeV/nuc and a beam current larger than 20 pnA

^{86}Kr beam to produce ^{84}Se by fragmentation

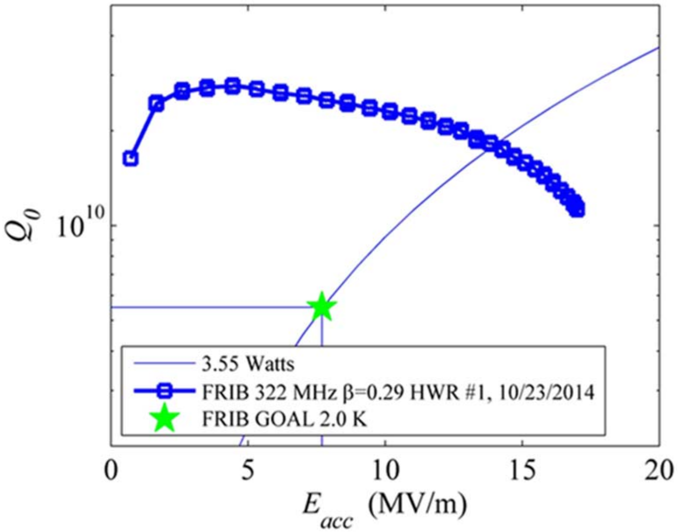


Status of Other Accelerator Systems and Technical Equipment

Procurement and Installation

Status of SRF Work and Cryomodule Assembly and Installation

Talk by Ting Xu, FRIB
Wednesday, 14:00
Superconducting Cryomodule Development and Production for the FRIB Linac



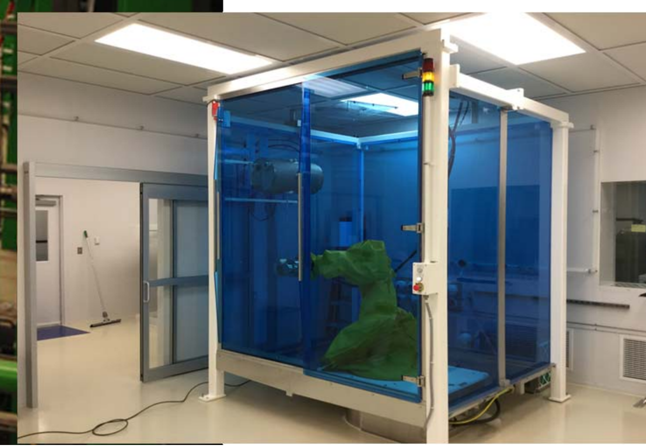
Design Optimization Goal:
Optimum performance at low production cost

Infrastructure for SRF Work Established
"SRF High Bay" Built at MSU

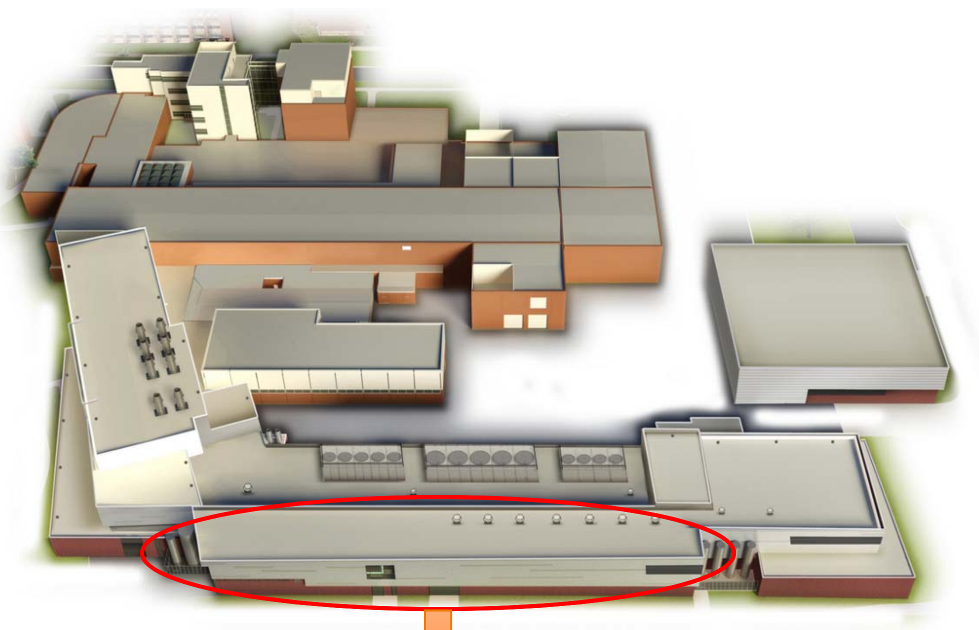
Beneficial occupancy	**05/2014**
Clean 1st cavity	07/2014
Cryogenics system	09/2015
RF test 1st cavity	11/2015
Vertical test area	01/2016
Cryomodule test	09/2016

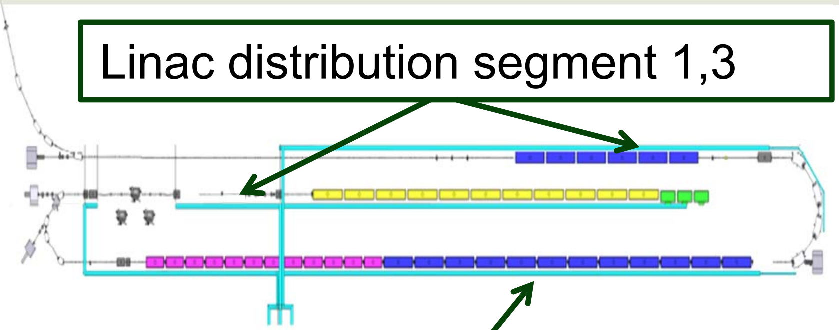
Throughput:
- 5 cavity per week
- 1 cryomodule per month

Robotic high-pressure Rinse System



FRIB Cryogenic Systems Scope and Layout

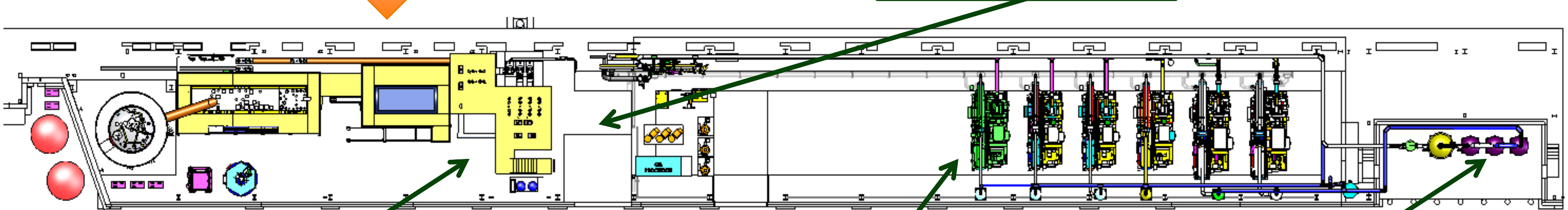




Linac distribution segment 1,3

Linac distribution segment 2

Control room



Cold box room

Compressor room

Oil removal

Integrated Cryogenics Design Optimized for Reduced Cost, Simplified Maintenance

- Cost significant: cryogenics systems accounts for ~ 20% linac cost
- An integrated design of the cryogenic refrigeration, distribution, and cryomodule systems is key to efficient SRF operations

- Ganni cycle: floating pressure process
- Distribution lines segmented
- Cryomodules connected with U-tubes: simplifies maintenance
- 4-2 K heat exchangers housed inside cryomodules

Installation of Cryogenic Systems In Progress

Six(6) 30 k gal Gas Tanks Installed

Transfer line installation in tunnel

Commissioning milestones

Warm compressors	10/2017
4 K cold box	12/2017
2 K cold box	03/2018
Cryo ready for Linac	07/2018

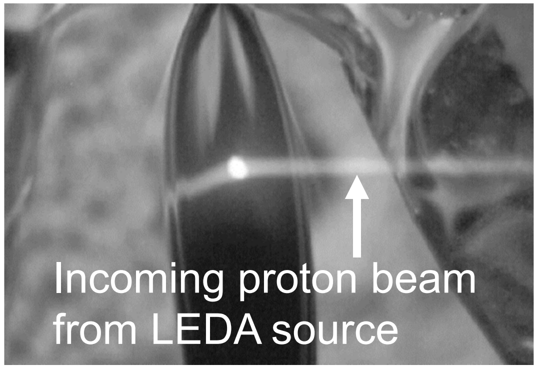
Lower Cold Box delivery 10/2016

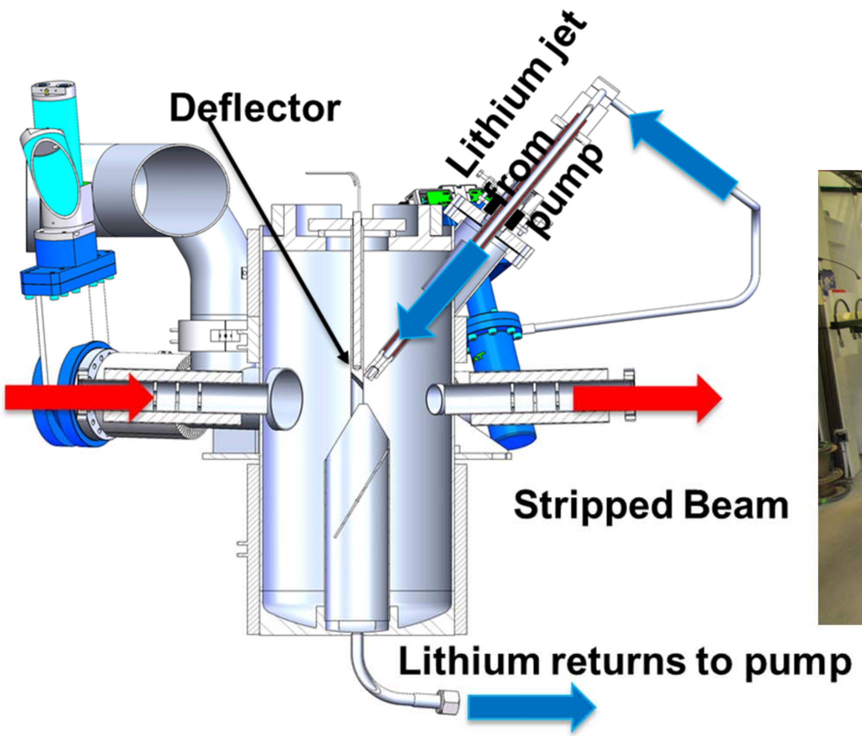
Upper Cold Box installed

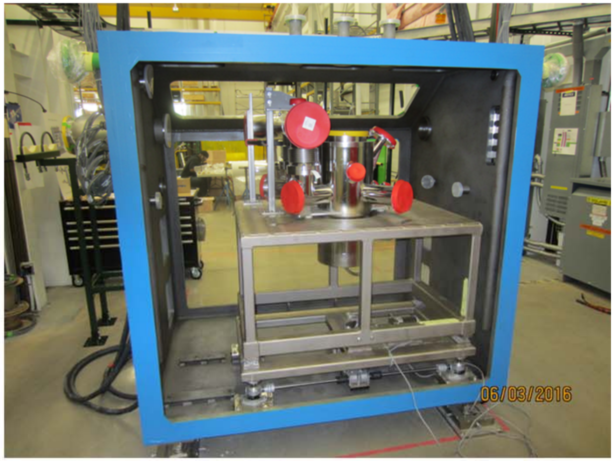
All 6 Warm Compressors Installed

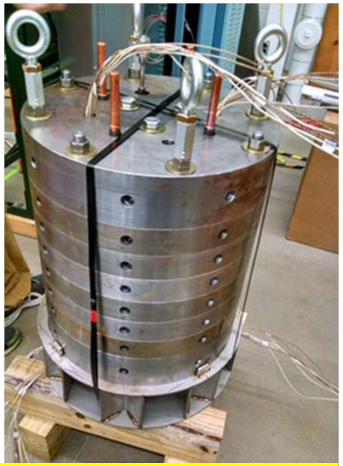
Liquid Lithium Charge Stripper Under Construction

- Development and prototyping in collaboration with ANL (right photo)
- Construction of the stripper in progress at FRIB (photos and model below)





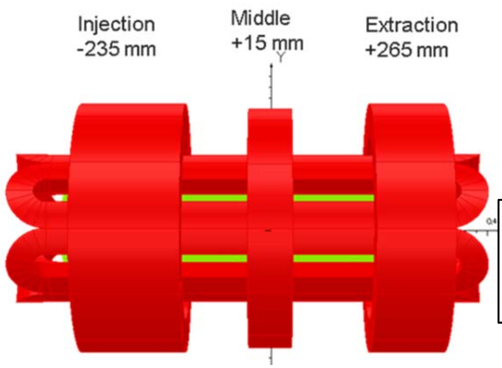




Electromagnetic lithium pump

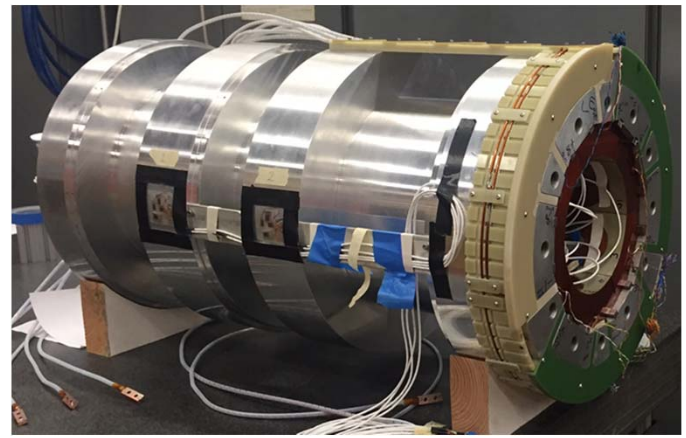
28 GHz SC ECR Ion Source Developed in Collaboration With Berkeley

Magnet designed and manufactured by Berkeley Magnet group. Expected delivery to FRIB first quarter 2017

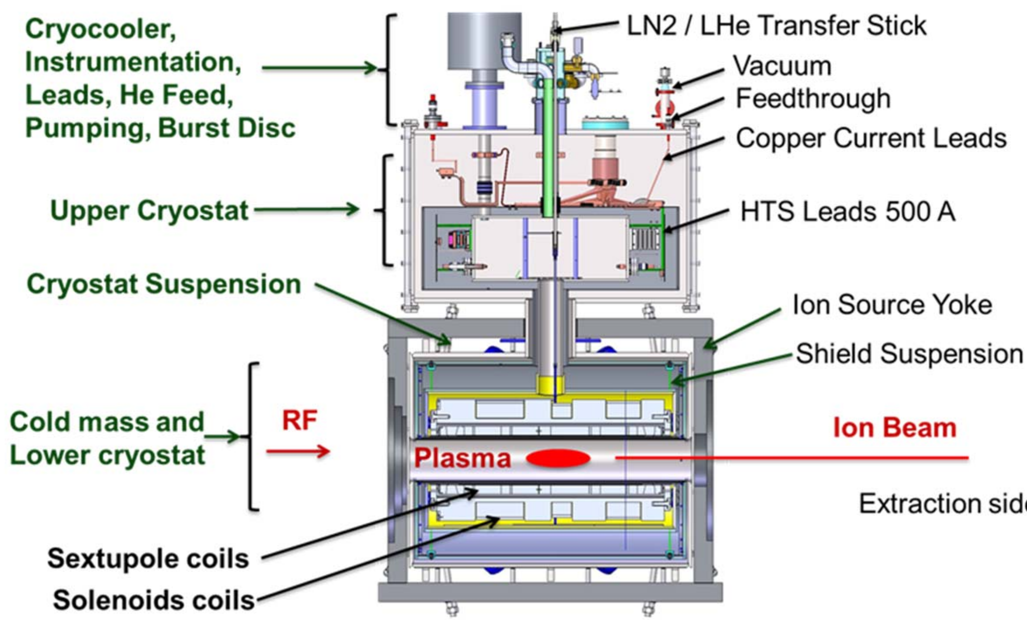


Sol. field 4T max
Sext. field 7T max

Sextupole only testing at Berkeley using actual power supplies provided by FRIB

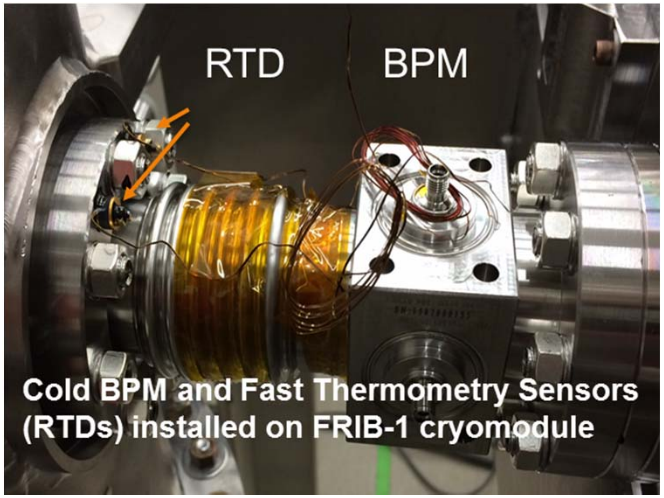


Cryostat and conventional components are designed and procured by FRIB
Procurement to start in 1/2017

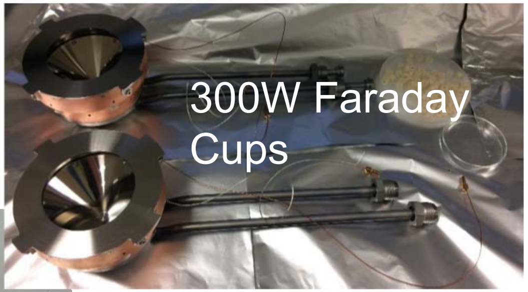


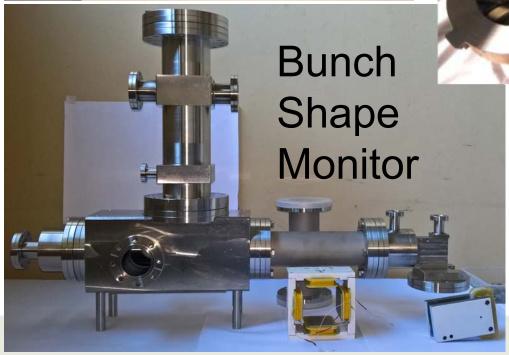
FRIB Diagnostics and Instrumentation for Beam Tuning and Machine Protection

Accelerator Systems - Diagnostics	TOTAL	Status
Beam Position Monitor	147	Ready
Beam Current Monitor (ACCT)	12	Ready
BLM - Halo Monitor Ring	66	Prod
BLM - Ion Chamber	47	Prod
BLM - Neutron Detector	24	Prod
BLM – Fast Thermometry System	240	Ready
Profile Monitor (Lg., Sm. Flapper)	41	Ready
Bunch Shape Monitor	1	Prod
Allison Emittance Scanner (2 axis)	2	Ready
Pepper pot emittance meter	1	Prod
Faraday Cup	7	Ready
Fast Faraday Cup	2	Prod
Viewer Plate	5	Prod
Selecting Slits System - 300 W	5	Prod
Collimating Apertures - 100 W	2	Prod
Intensity Reducing Screen System	2	Prod



Cold BPM and Fast Thermometry Sensors (RTDs) installed on FRIB-1 cryomodule





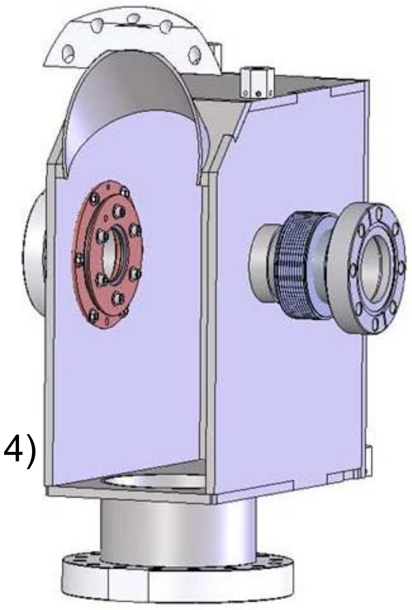
Loss Detection and Machine Protection

Multi-time Scale Mitigation Necessary

- Low-energy ions has low detection sensitivity & high impact
- Must mitigate both acute & chronicle beam loss (by beam inhibition)

Mode	Time	Detection	Mitigation
FPS	~35 μs	LLRF controller Dipole current monitor Differential BCM Ion chamber monitor Halo monitor ring Fast neutron detector Differential BPM	LEBT bend electro-static deflector
RPS (1)	~100 ms	Vacuum status Cryomodule status Non-dipole PS Quench signal	As above; ECR source HV
RPS (2)	>1 s	Thermo-sensor Cryo. heater power	As above

- Halo monitor rings between cryomodules
- Differential BCM
- Thermo-sensors inside cryomodules



Z. Liu et al, Nucl. Instrum. Meth. A767, 262 (2014)

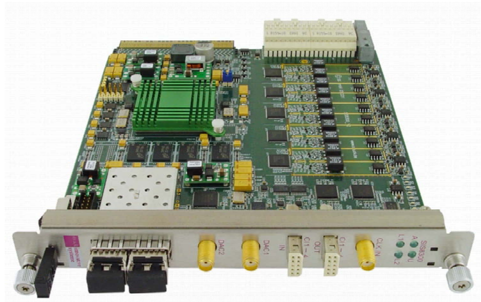
Data Acquisition based on μTCA.4

CAENels AMC-PICO-8
8 chan @ 1MS (35kHz BW)

65x Halo Ring Monitors
42x Ion Chambers
24x Neutron Detectors

8x Faraday Cups
2x Allison Scanner
41x Profile Monitors

Not required for MPS, but shared DAQ system



Struck SIS8300-L2
10 chan @ 125MS

12x Beam Current Monitor (Differential BCM)

FRIB Digital Board
General purpose

147x Beam Position (BPM)

20x Event Receiver
20x Machine Protect System

Developed at FRIB, used by Diagnostics, LLRF, and Controls

Machine Protection System requirements

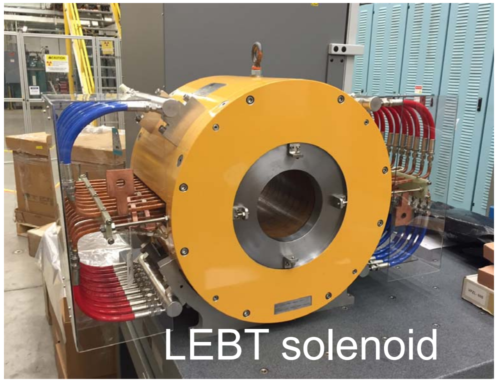
- Detect and respond to beam loss events
  - **15 μsec to detect >10% beam loss**
  - 150 μsec to detect 10% beam loss
  - Detect chronic small losses of 1 W/m or less
- 15 μs requirement →
  - Fast sampling data acquisition, >= 1 MSPS
  - Analog signal response, DC to 35 kHz

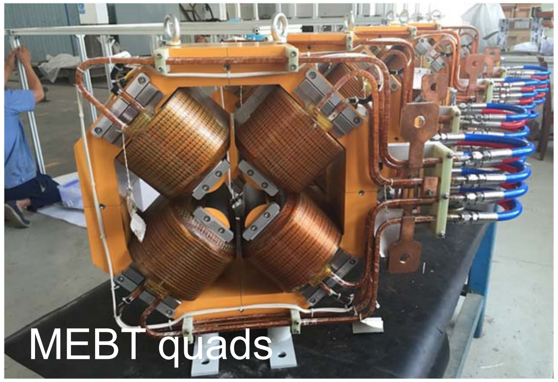
75% of devices covered by these three MTCA cards

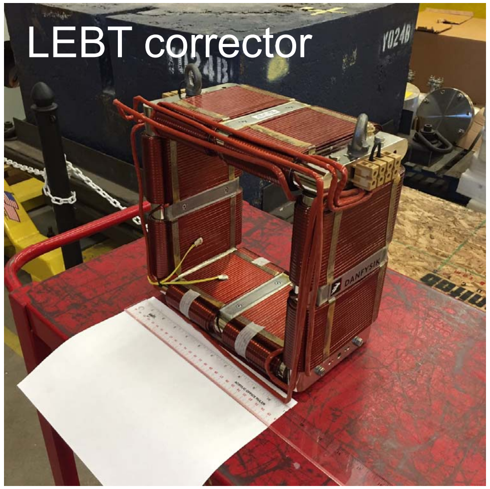
All utilize FPGA for real-time signal processing and Machine Protection (MPS)

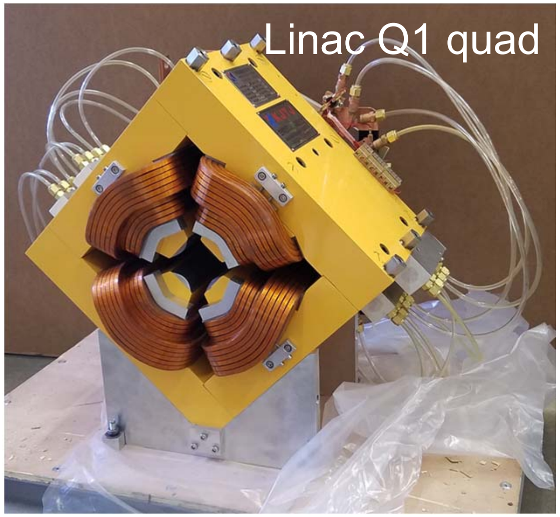
Magnet Procurement On Schedule

- Room temperature magnets procured from industry
- FE magnets procurement completed. Magnets received, partly installed
- Linac magnets are being manufactured, partially received
  - Complete delivery within a year

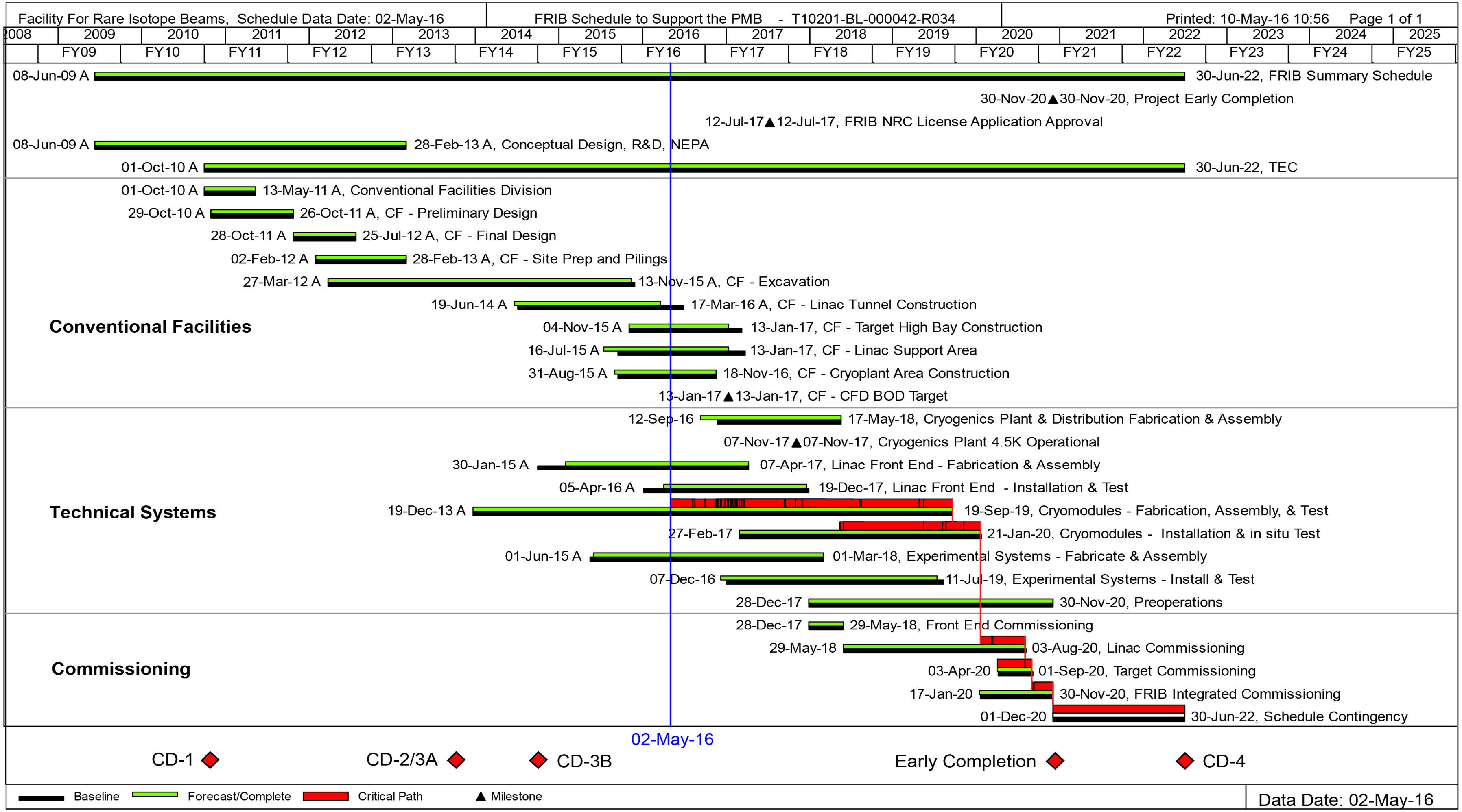








FRIB Integrated Master Schedule
Critical Path Shown in Red



It’s a Team Effort

Collaboration with Major Institutes

- ANL
  - Liquid lithium stripper
  - Beam dynamics verification; β=0.29 HWR processing and test; SRF tuner validation; beam dump
- BNL
  - Plasma window & charge stripper, physics modeling, database
- FNAL
  - Diagnostics, SRF processing
- JLab
  - Cryoplant; cryodistribution design & prototyping
  - Cavity hydrogen degassing; e-traveler **
  - HWR processing & certification*
  - QWR and HWR cryomodule design
- LANL
  - Proton ion source
- LBNL
  - ECR coldmass design; beam dynamics**
- ORNL
  - Diagnostics, controls
- SLAC**
  - Cryogenics**, SRF multipacting**, physics modeling
- RIKEN
  - Helium gas charge stripper
- TRIUMF
  - Beam dynamics design, physics modeling **
  - SRF, QWR etching*
- INFN
  - SRF technology
- KEK
  - SRF technology, SC solenoid prototyping
- IMP
  - Magnets
- Budker Institute, INR Institute
  - Diagnostics
- Tsinghua Univ. & CAS
  - RFQ
- ESS
  - AP*
- DTRA
  - RFQ power supply**

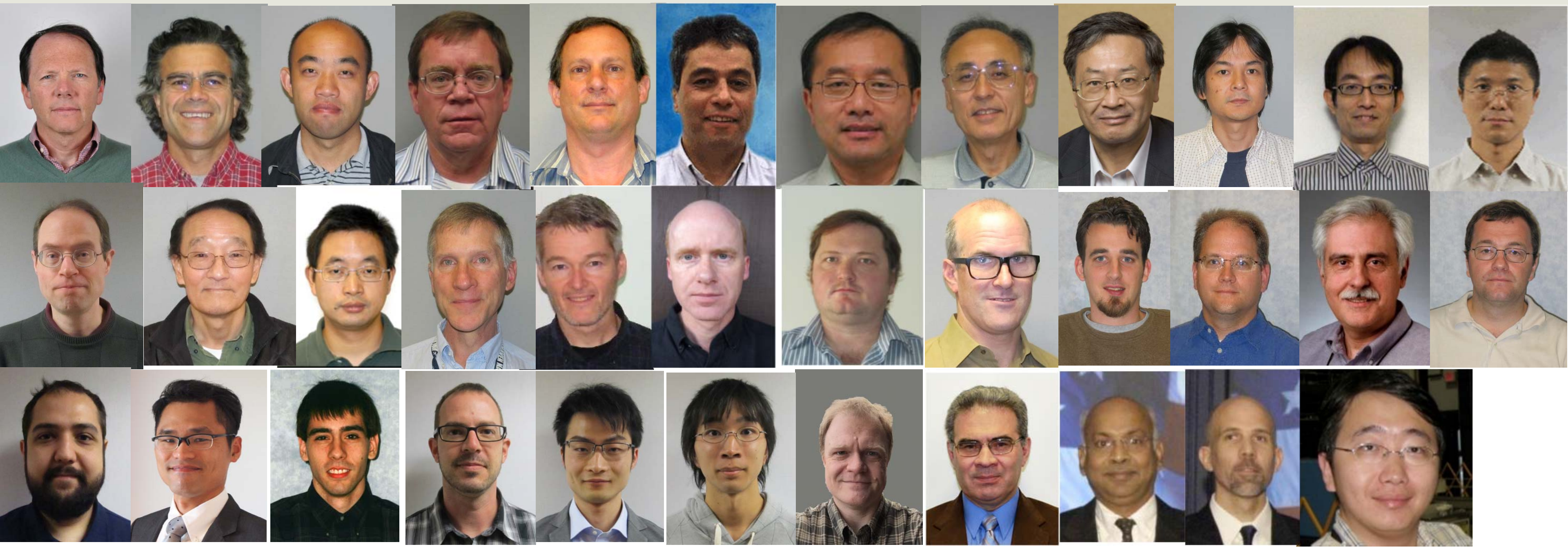
* Under discussion or in preparation

** Completed

Red: Active/actively planned WFO contract

Team of Established Experts

Some Examples Listed

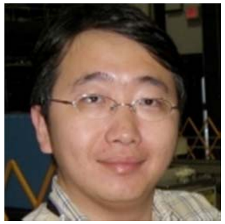


- Attracted seasoned leaders in accelerator physics and engineering
  - H. Ao (J-PARC), N. Bultman (LANL), F. Casagrande (ORNL), D. Chabot (BNL), L. Dalesio (BNL), A. Facco (INFN), F. Feyzi (Wisconsin), K. Fukushima (U. Hiroshima), V. Ganni (JLab), A. Ganshyn (Cornell), P. Gibson (ORNL), W. Hartung (Cornell), P. Knudsen (JLab), L. Hoff (BNL), Y. Hao (BNL), H.-C. Hseuh (BNL), A. Hussain (BNL), M. Ikegami (J-PARC), T. Kanemura (JAEA), R.E. Laxdal (TRIUMF), S. Lidia (LBNL), S. Lund (LLNL), G. Machicoane, A.C. Morton (TRIUMF), J. Nolen (ANL), D. Omitto (BNL), P. Ostroumov (ANL), E. Pozdeyev (BNL), T. Russo (BNL), K. Saito (KEK), G. Shen (BNL), H. Tatsumoto (J-PARC), J. Wei (BNL/THU), T. Xu (ORNL), Y. Yamazaki (KEK), T. Yoshimoto (TIT/KEK)

Keep Attracting Experts in Key Areas


- V. Ganni and P. Knudsen joined MSU to start the <u>MSU Cryogenics Initiative</u>

- P. Ostroumov joined MSU to lead FRIB upgrade and accelerator physics



- Y. Hao is joining MSU as an accelerator faculty to lead FRIB power ramp up

Coauthors

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Acknowledgements

- We thank the FRIB Accelerator Systems Advisory Committee chaired by S. Ozaki for their valuable guidance, colleagues who participated in FRIB accelerator peer reviews including A. Aleksandrov, G. Ambrosio, D. Arenius, W. Barletta, G. Bauer, G. Biallas, J. Bisognano, S. Bousson, S. Caspi, M. Champion, M. Crofford, C. Cullen, D. Curry, R. Cutler, G. Decker, J. Delayen, J. Delong, N. Eddy, H. Edwards, J. Error, J. Fuerst, K. Kurukawa, J. Galambos, J. Galayda, G. Gassner, J. Gilpatrick, C. Ginsburg, S. Gourlay, M. Harrison, S. Hartman, S. Henderson, G. Hoffstaetter, J. Hogan, S. Holmes, M. Howell, R. Kersevan, A. Hodgkinson, N. Holtkamp, H. Horiike, C. Hovater, H. Imao, R. Janssens, R. Keller, J. Kelley, P. Kelley, J. Kerby, A. Klebaner, J. Knobloch, R. Lambiase, M. Lamm, Y. Li, C. LoCocq, C. Luongo, K. Mahoney, J. Mammosser, T. Mann, W. Meng, N. Mokhov, Y. Momozaki, G. Murdoch, W. Norum, H. Okuno, R. Pardo, S. Peggs, R. Petkus, C. Pearson, F. Pellemoine, T. Peterson, C. Piller, J. Power, T. Powers, J. Preble, J. Price, D. Raparia, A. Ratti, T. Roser, M. Ross, R. Ruland, J. Sandberg, R. Schmidt, W.J. Schneider, D. Schrage, I. Silverman, K. Smith, J. Sondericker, W. Soyars, C. Spencer, R. Stanek, M. Stettler, W.C. Stone, J. Stovall, H. Strong, Y. Than, J. Theilacker, Y. Tian, J. Tuozzolo, V. Verzilov, R. Vondrasek, P. Wanderer, P. Wright, H. Xu, L. Young, and A. Zaltsman, and colleagues who advised and collaborated with the FRIB team including A. Burrill, A.C. Crawford, K. Davis, X. Guan, P. He, Y. He, A. Hutton, S.H. Kim, P. Kneisel, R. Ma, K. Macha, G. Maler, E.A. McEwen, S. Prestemon, J. Qiang, T. Reilly, R. Talman, J. Vincent, X.W. Wang, J. Xia, Q.Z. Xing.
- The FRIB accelerator design is executed by a dedicated team of the FRIB Accelerator Systems Division with close collaboration with the Experimental Systems Division headed by G. Bollen, the Conventional Facility Division headed by B. Bull, the Chief Engineer's team headed by D. Stout, and supported by the project controls, procurements, ES&H of the FRIB Project, by NSCL, and by MSU.
- Work supported by the U.S. Department of Energy Office of Science under Cooperative Agreement DE-SC0000661 and the National Science Foundation under Cooperative Agreement PHY-1102511.

Summary

- FRIB Project is two years into full technical construction
  - Overall accelerator systems construction is 57% complete
  - Major procurement is 90% spent or committed
- Accelerator design meets FRIB performance requirements
  - Accelerator lattice footprint frozen since 2011
  - All major technology development work has been completed
  - Design optimized for availability, maintainability, reliability, tunability, upgradability
- Installation of technical equipment proceeds ahead of schedule
- Looking forward to starting beam commissioning

Thank You!