Design Integration of the FRIB Driver Linac

Yan Zhang

On behalf of the FRIB driver linac team

IPAC 2013, May 15, 2013, Shanghai

MICHIGAN STATE UNIVERSITY

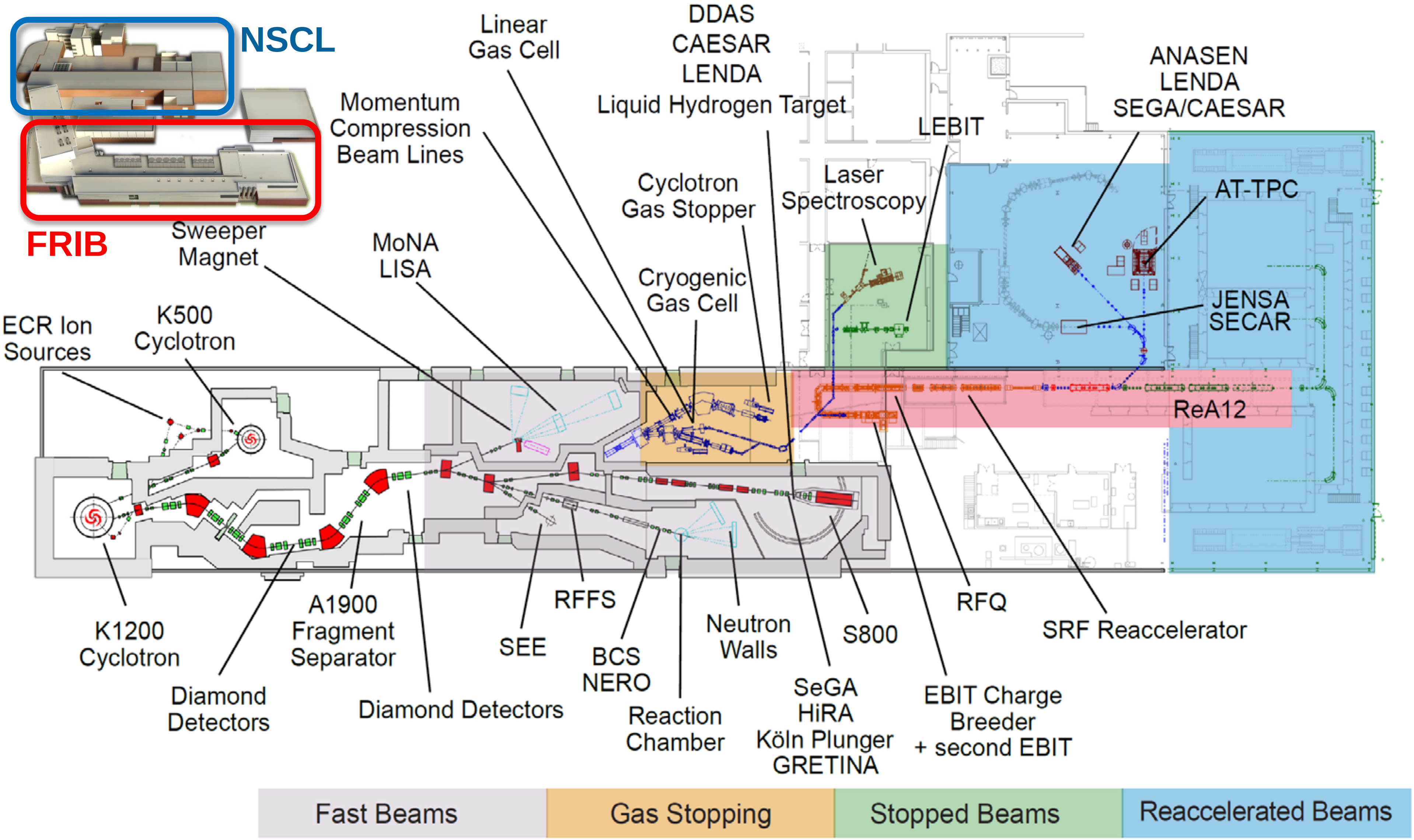
U.S. DEPARTMENT OF ENERGY | Office of Science

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

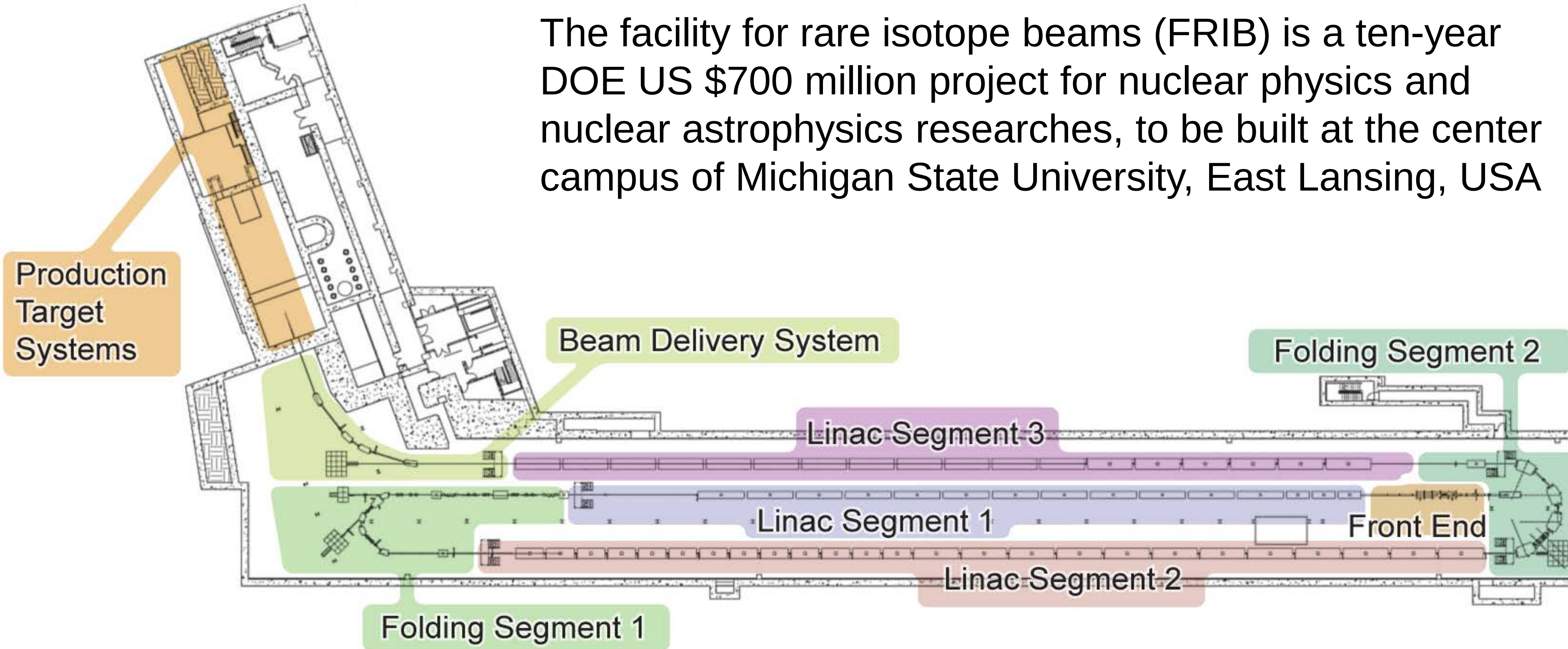
- Introduction to NSCL and FRIB
- SRF and Cryomodule
- Cryogenic System
- Beam Diagnostics and MPS
- Online model
- Summary

Introduction: National Superconducting Cyclotron Laboratory (NSCL)
The Largest Campus-Based Nuclear Science Facility in USA



Facility for Rare Isotope Beams (FRIB)

The facility for rare isotope beams (FRIB) is a ten-year DOE US $700 million project for nuclear physics and nuclear astrophysics researches, to be built at the center campus of Michigan State University, East Lansing, USA



The FRIB driver linac consists of a Front End which includes ECR ion sources, LEBT, RFQ and MEBT, three linac segments, a charge stripper, two 180° folding areas and a beam delivery system to transport 400 kW heavy ion beams onto a fragmentation target for production of short-lived radioactive ion beams (RIB)

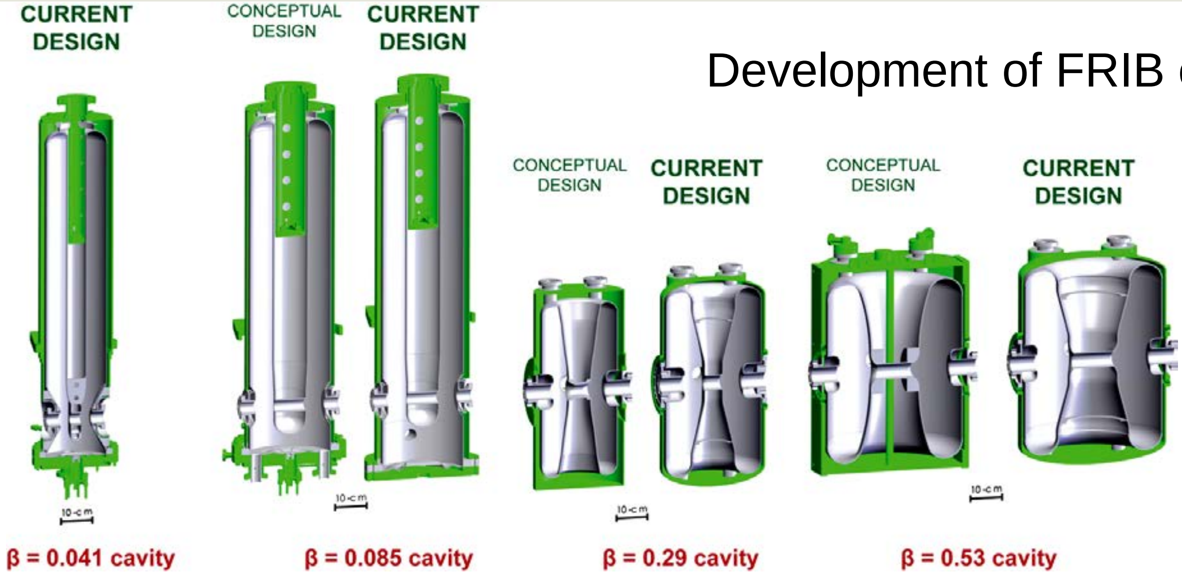
Parameter List of the FRIB Driver Linac

	Linac Segment 1	Linac Segment 2	Linac Segment 3
Cavities QWR 80.5 MHz HWR 322 MHz	0.041 QWR 12 0.085 QWR 91 0.29 HWR 4	0.085 QWR 3 0.29 HWR 72 0.53 HWR 96	0.53 HWR 52
Cryomodules	Acceleration 14 Rebunching 3	Acceleration 24 Rebunching 1	Acceleration 6 Rebunching 1
Parameters of uranium beam	E_{IN} 0.5 MeV/u E_{OUT} 16.6 MeV/u q +33/+34 352 eμA (10.5 pμA)	E_{IN} 16.4 MeV/u E_{OUT} 147.8 MeV/u q +76 to +80 655 eμA (8.4 pμA)	E_{IN} 147.8 MeV/u E_{OUT} 202 MeV/u q +76 to +80 655 eμA (8.4 pμA)

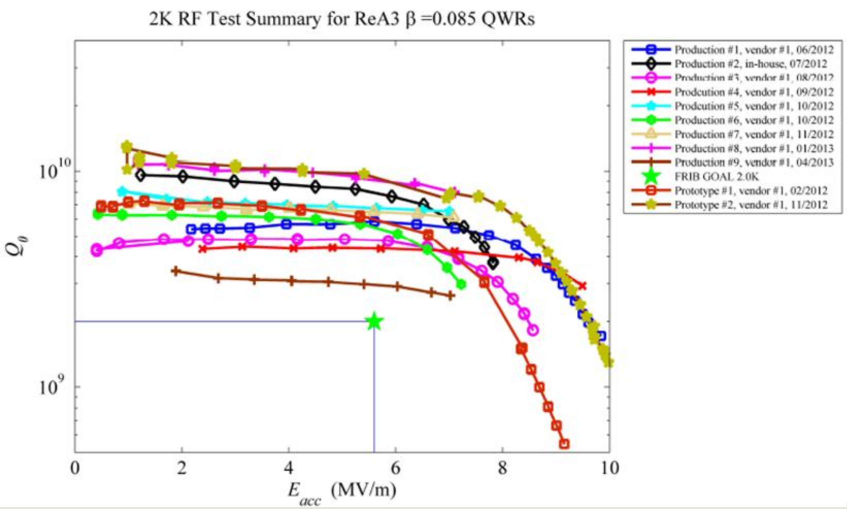
- ECR ion sources are located at the ground level which are convenient to access
- All the other linac segments are installed in a linac tunnel about 10 m underground
- Total beam path of the driver linac is about 520 m
- All ion beams can be accelerated to > 200 MeV/u and power on target 400 kW
- Design of the tunnel shielding is based on 1 GeV proton, for future upgrade – ISOL
- Spaces are also reserved for beam energy upgrade – above 400 MeV/u for all ions
- Re-accelerator has been commissioned recently and successfully reaccelerate RIB

SRF and Cryomodules

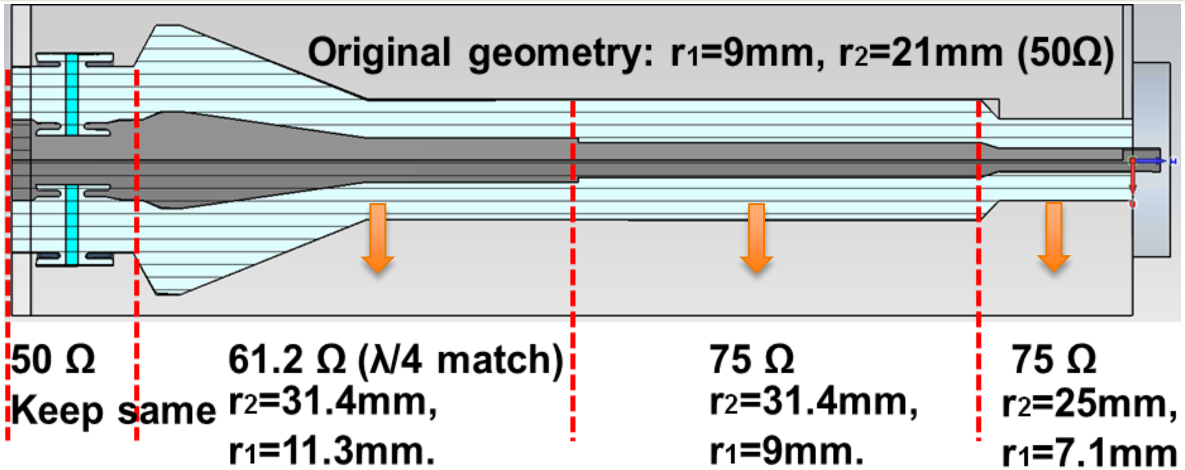
Development of FRIB cavity



CAVITY		QWR0.041	QWR0.085	HWR0.29	HWR 0.53
f	MHz	80.5		322	
V_a	MV	0.89	1.96	2.30	4.07
T	K	2 (2.1)			
E_p	MV/m	35			
B_p	mT	70			
P_d	W	1.32	3.88	3.55	7.90
P_{beam}	W	313	690	1526	2701
P_{RF}	kW	0.7	2.5	3.0	5.0

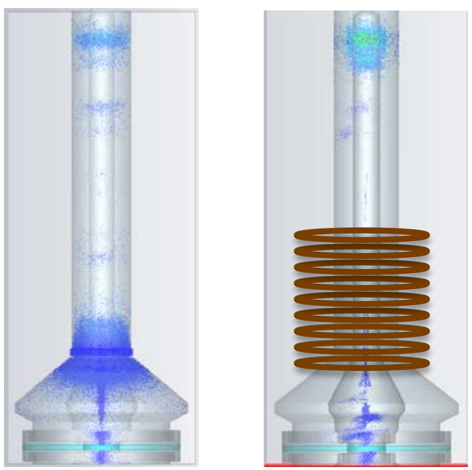


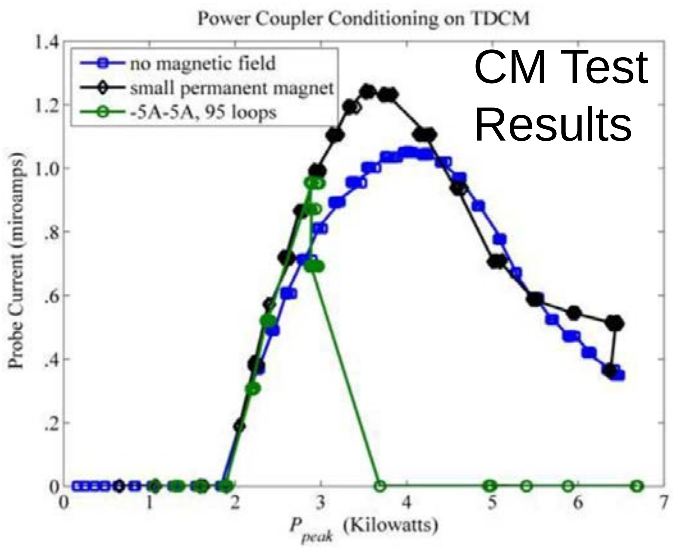
Multipacting of Cavity and RF Coupler



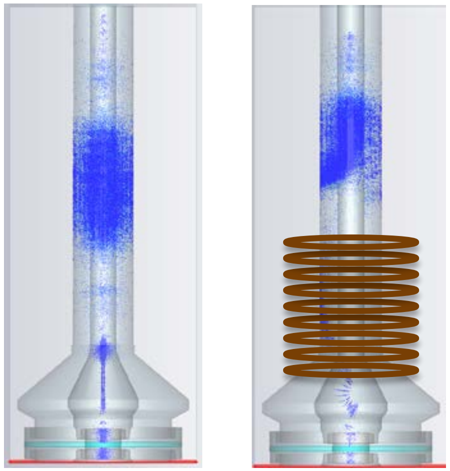
MP free new coupler design

Cavity detuned case: multipacting is suppressed



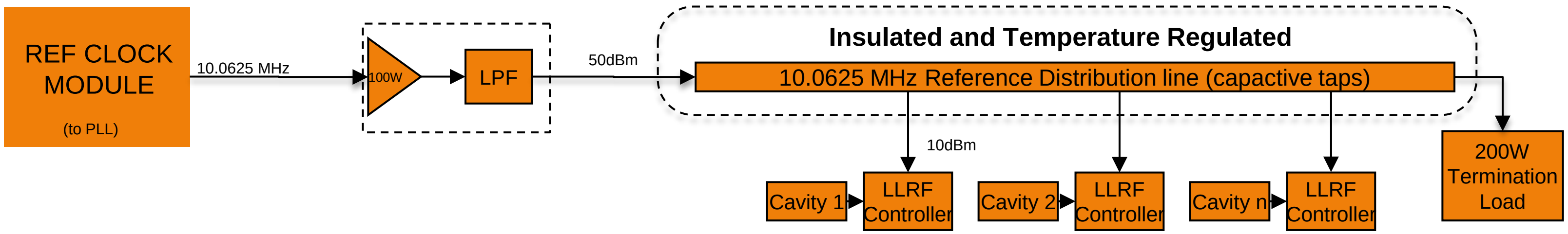


Cavity on resonance case: magnetic coil is useless

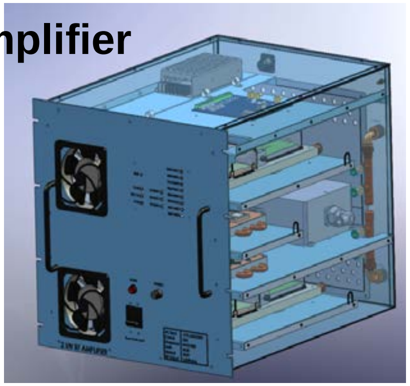


RF System

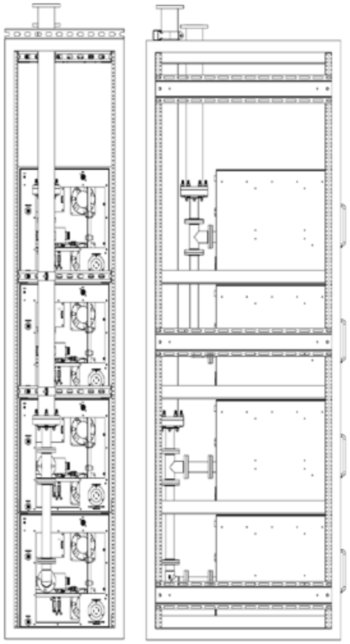
RF Reference Distribution



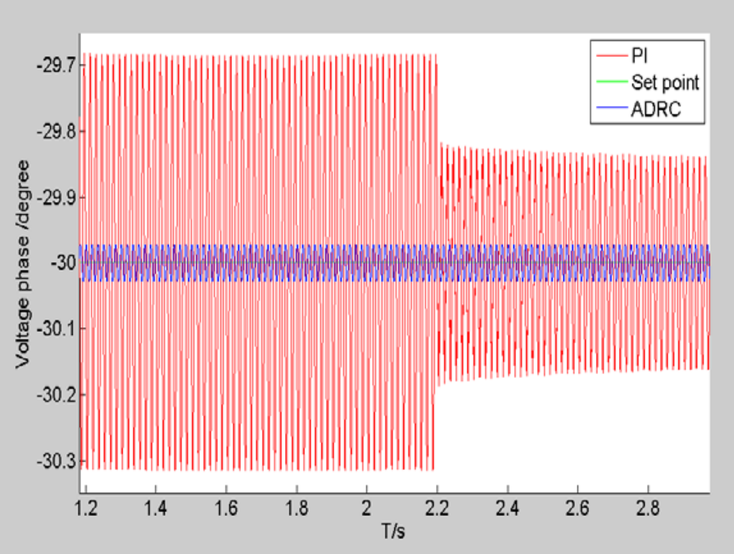
2 kW Amplifier



4 kW Output

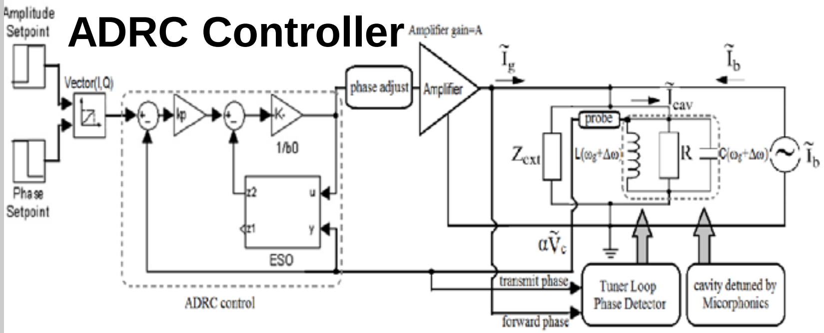


Phase Fluctuations - PID vs ADRC

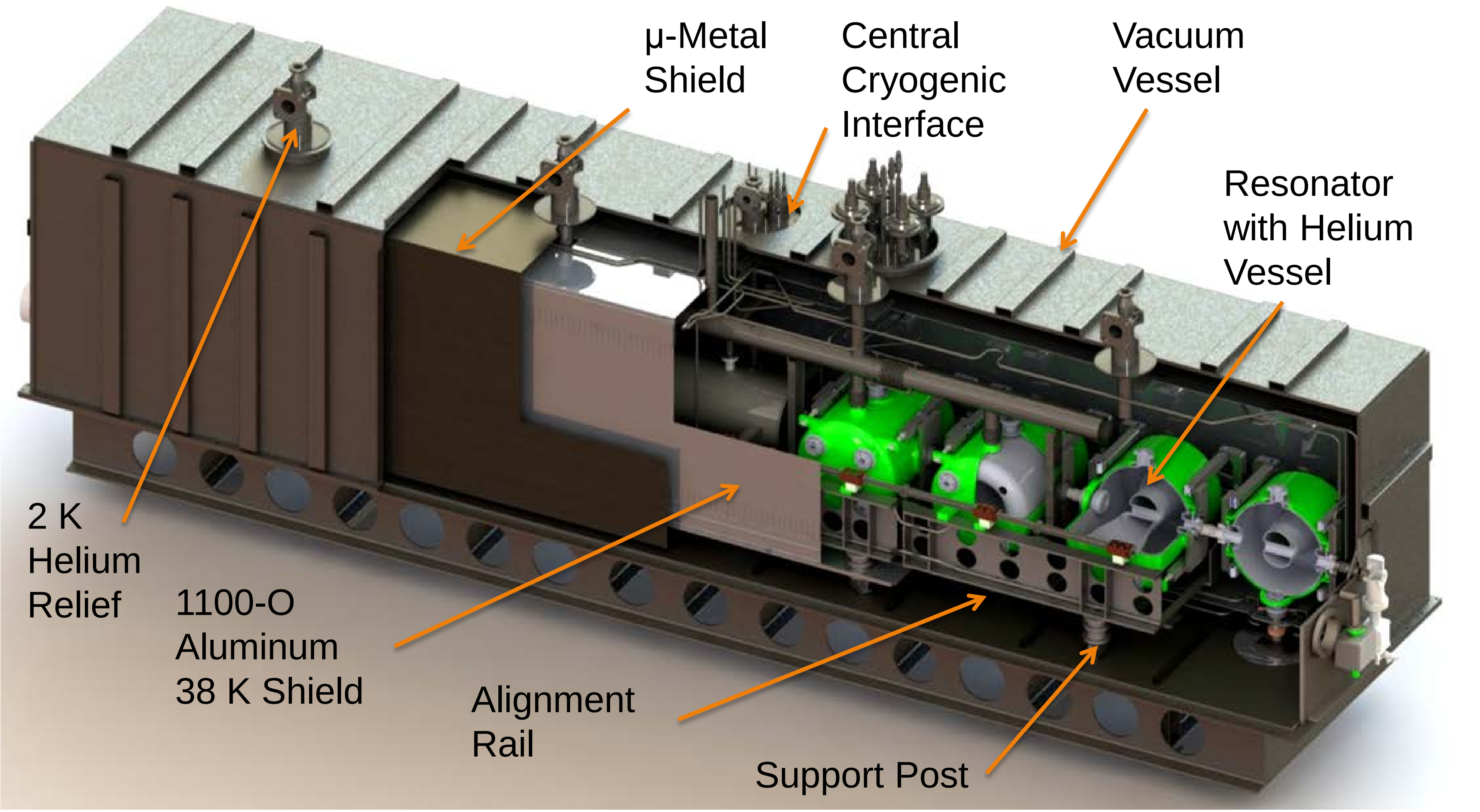


LLRF

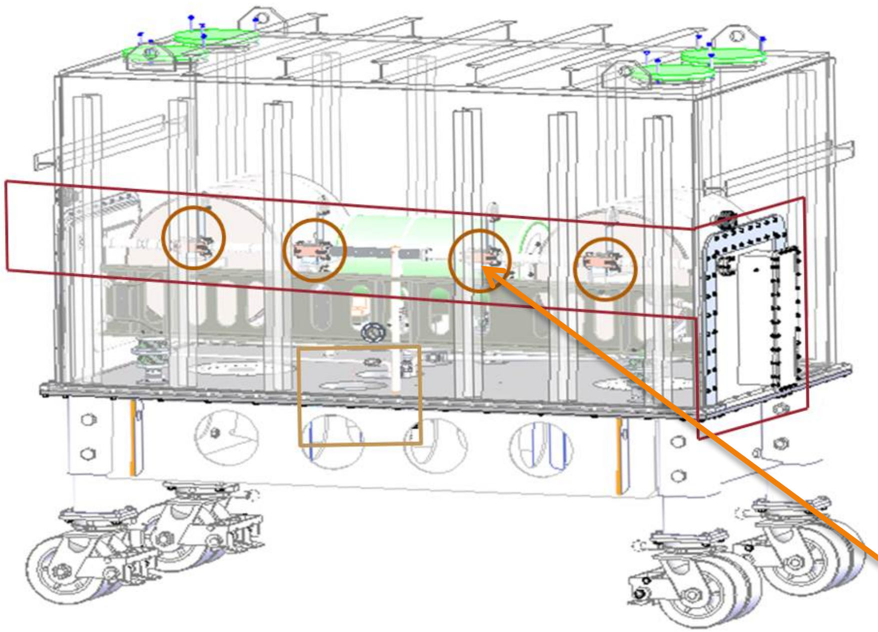
ADRC Controller

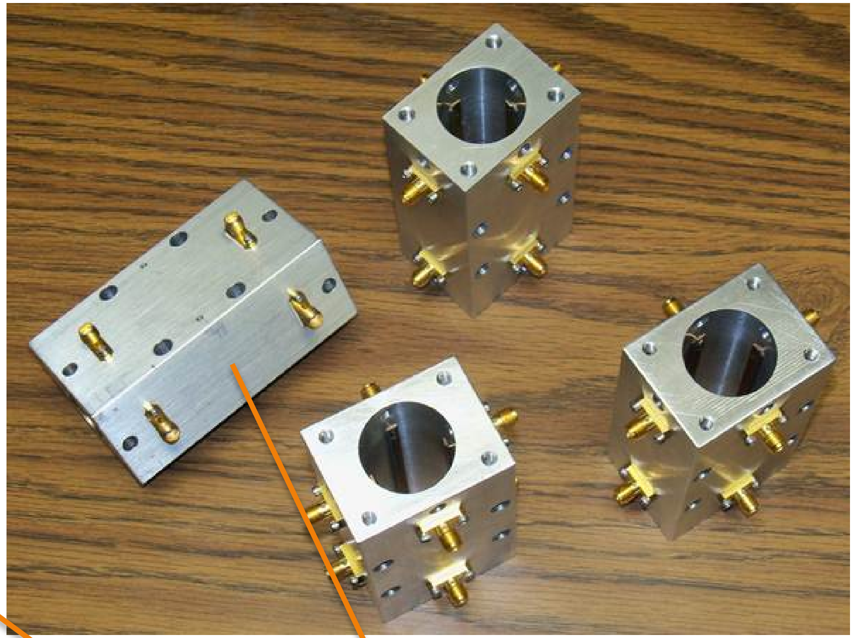


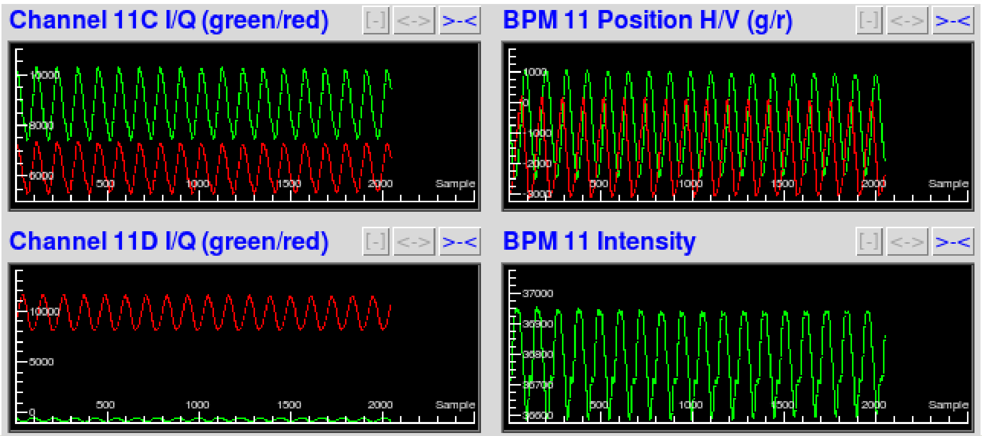
Cryomodule


μ-Metal
Shield
Central
Cryogenic
Interface
Vacuum
Vessel
Resonator
with Helium
Vessel
2 K
Helium
Relief
1100-O
Aluminum
38 K Shield
Alignment
Rail
Support Post

WPM – Monitor Alignment of Cold Element

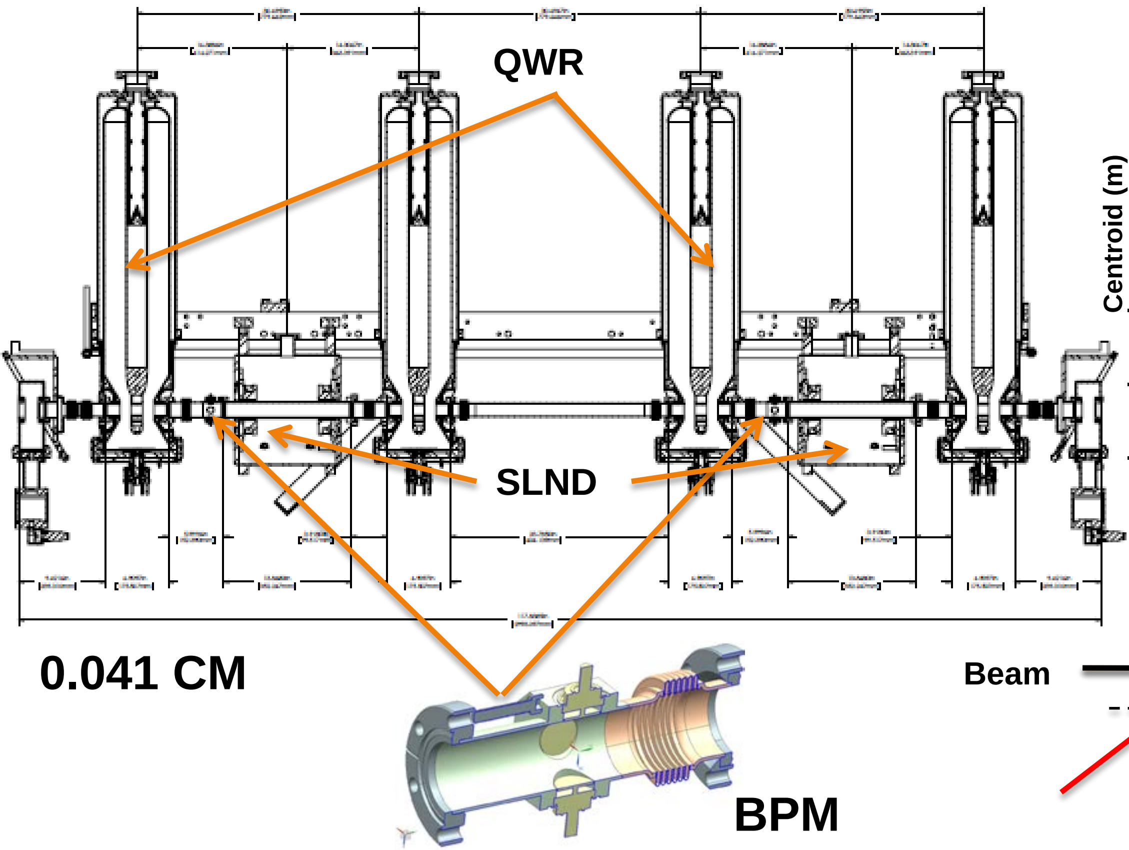


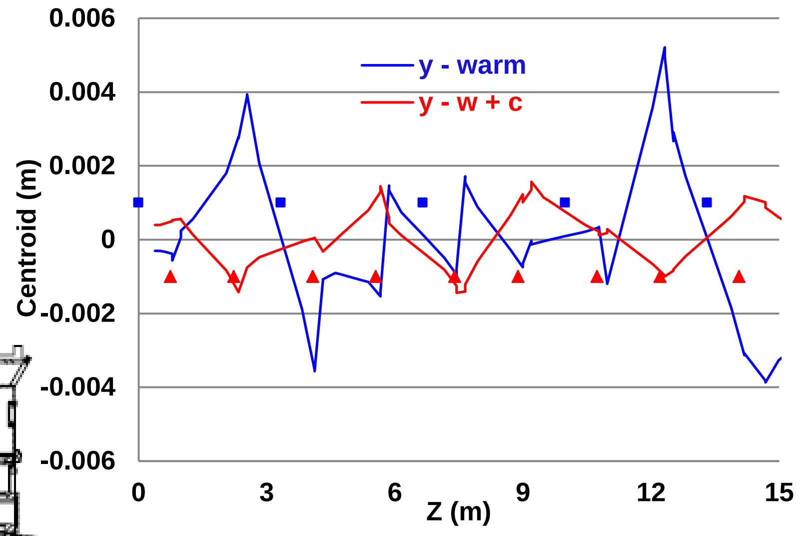


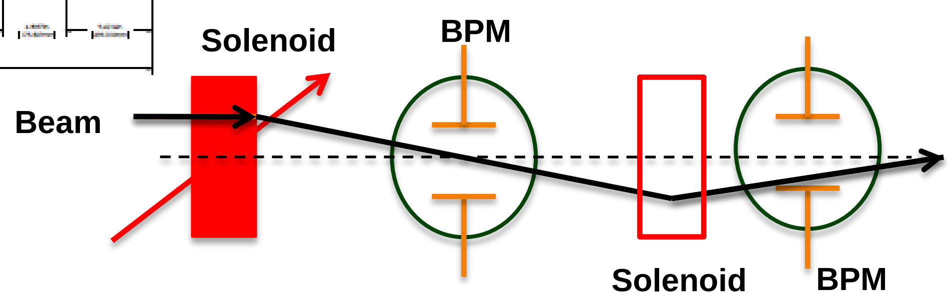


measured wire vibration frequency for the bench top set-up is 22.5 Hz

Cold BPMs

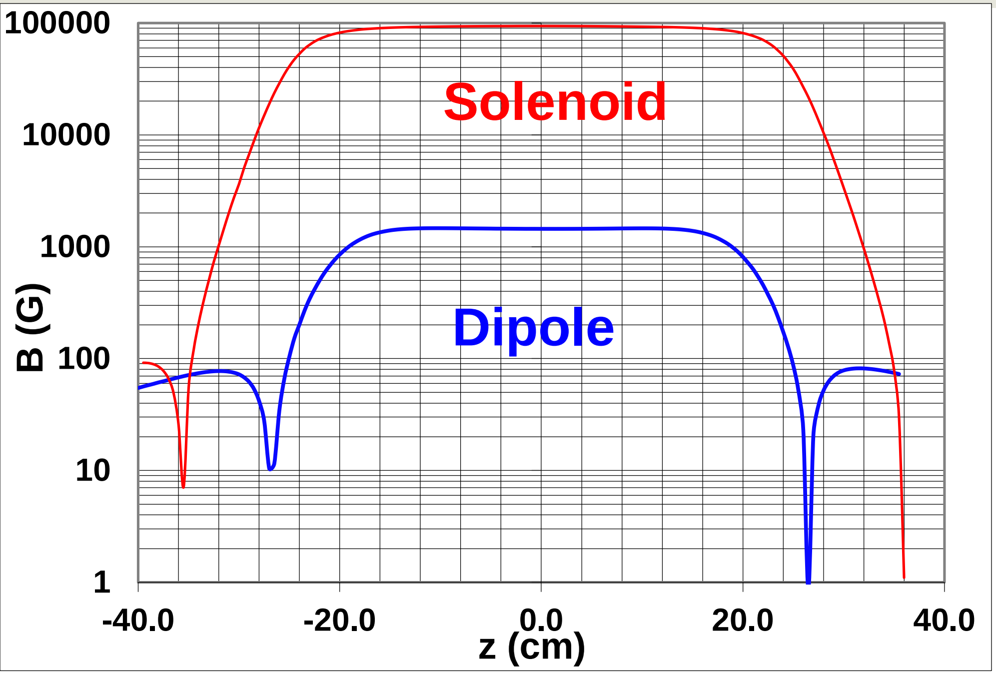




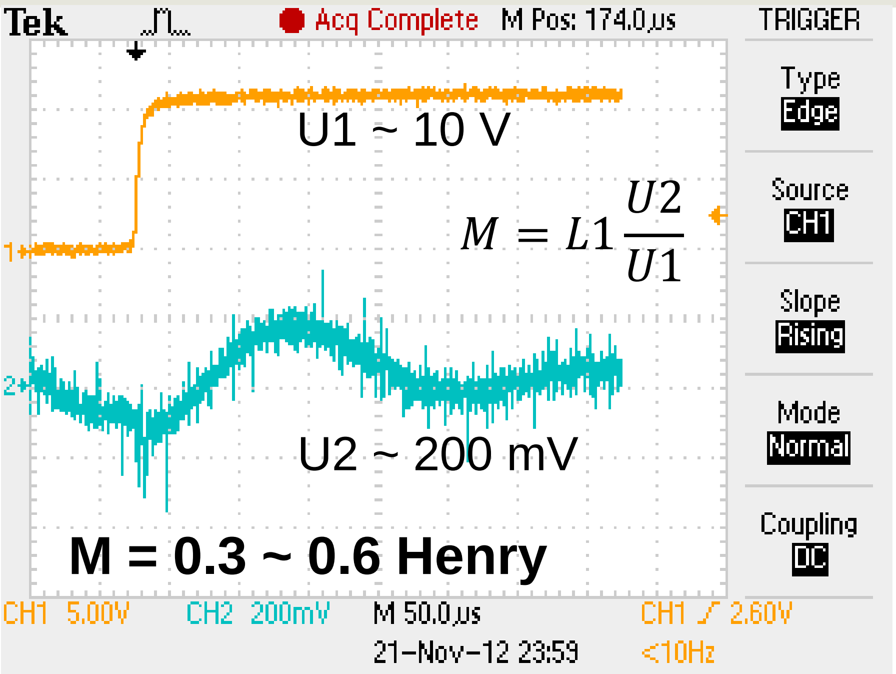


- Transverse phase advance of a LS1 cryomodule is close to 180°
- Beam based trajectory correction could solve the problem, but it is time consuming
- Install cold BPMs and perform model-based corrections reduces beam tuning time

Degauss with Solenoids and Correctors

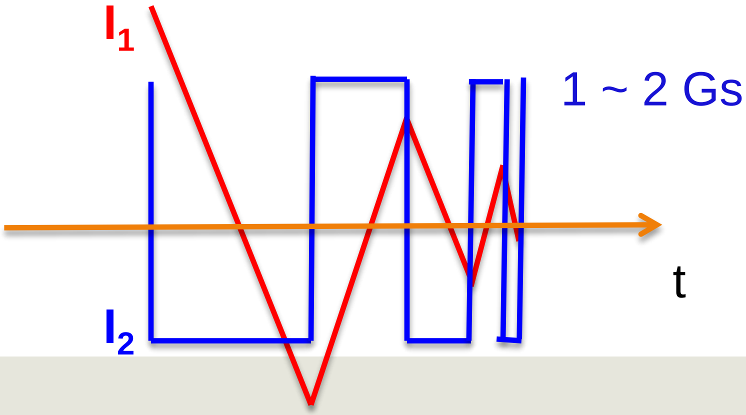


Measurement of Solenoid and Dipole Fields

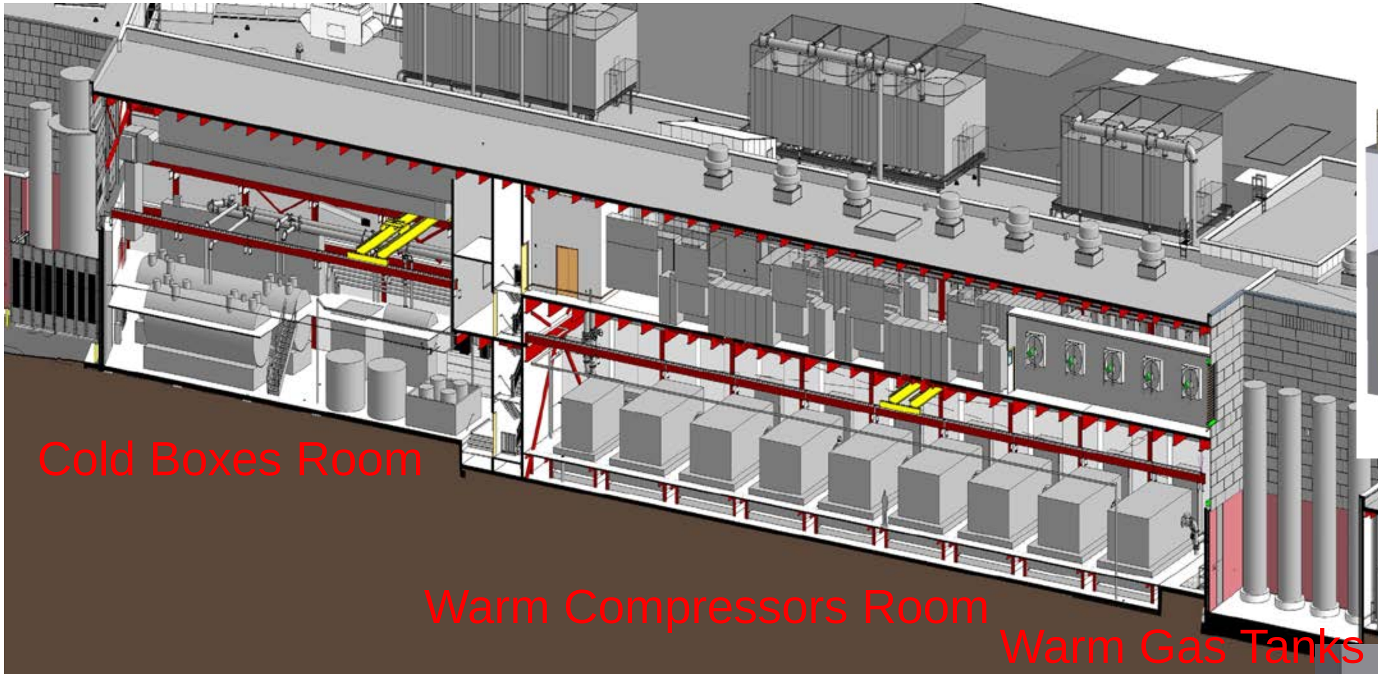


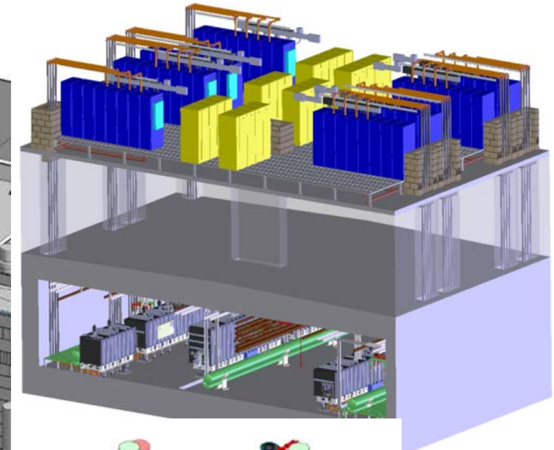
Measurement of Mutual Inductance

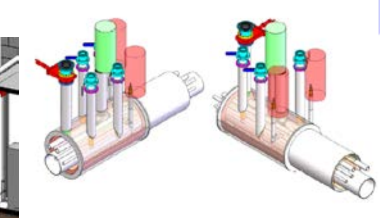
- Each solenoid is equipped with dipole correctors for both horizontal and vertical orbit corrections.
- Mutual inductance alone is not a concern.
- Stray fields are comparable near cavity surfaces.
- Degauss should be performed simultaneously.

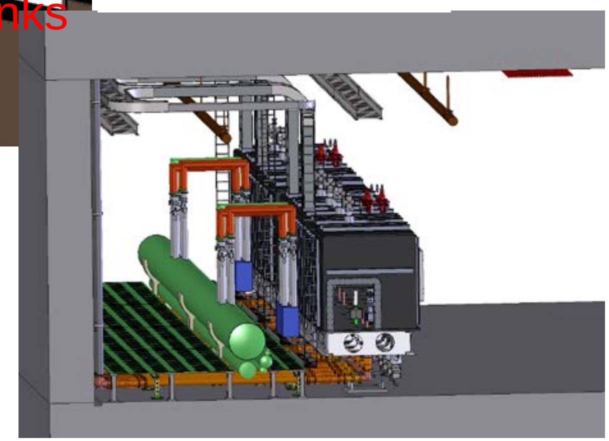


Cryogenic System







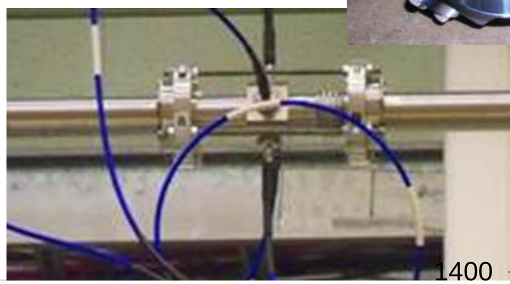


Heat Load (W)	2 K	4.5 K	38/55 K
Cryomodules	2420	1440	6230
SC magnets		670	1000
Cryodistribution		950	5000
Total	2420	3060	12230

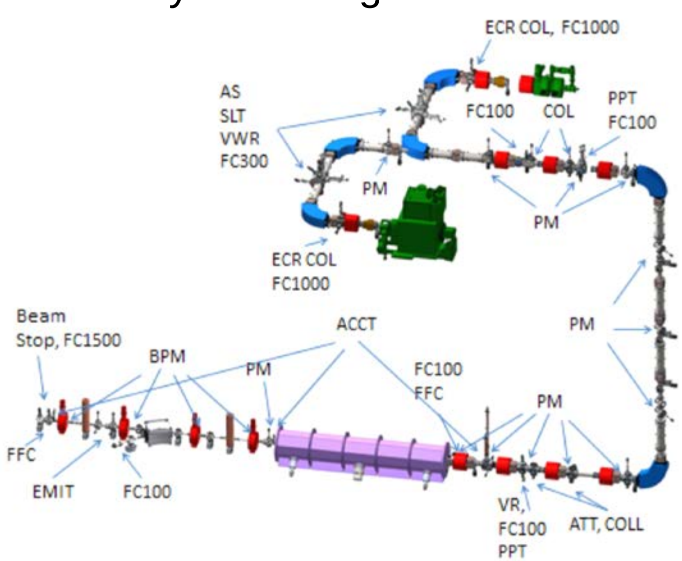
Beam Diagnostics and MPS

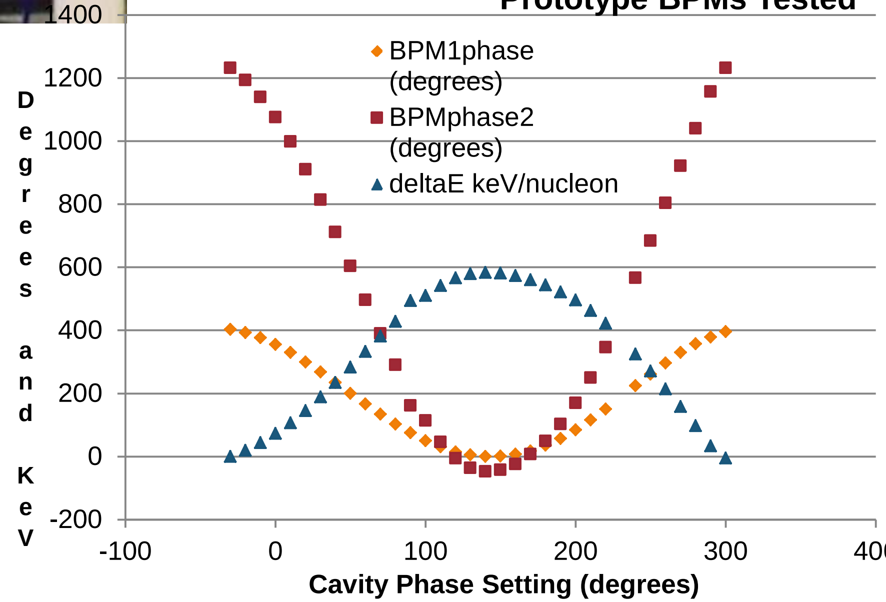
Beam Diagnostics in Front End:

- 4 Slits
- 3 View Screens
- 8 Faraday Cups
- 2 Fast Faraday Cups
- 13 Profile Monitors
- 3 Beam Current Monitors
- 4 Beam Position Monitors
- 4 Emittance Monitors
- 2 Intensity Reducing Screens

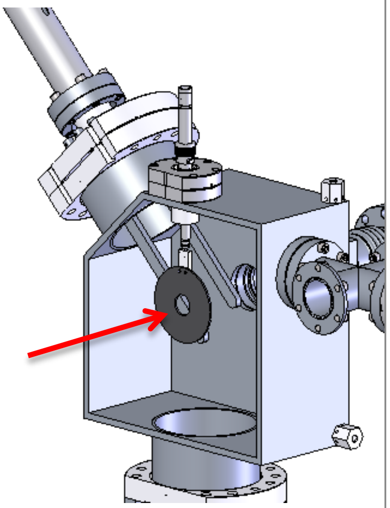


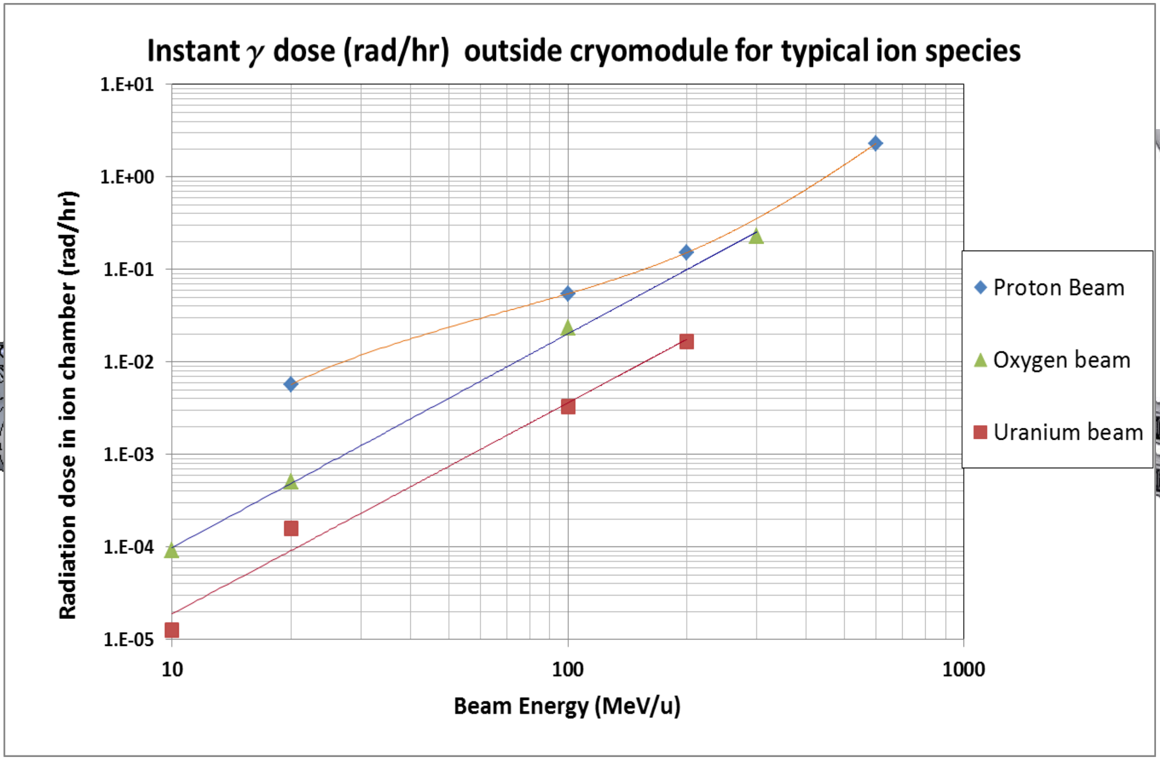
Prototype BPMs Tested

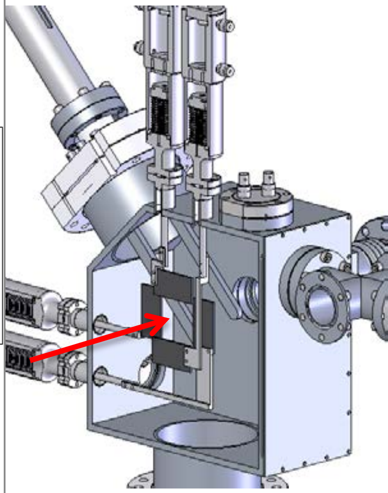




Halo Scraper Ring (HSR) –
Beam Collimator and BLM at Low Energy



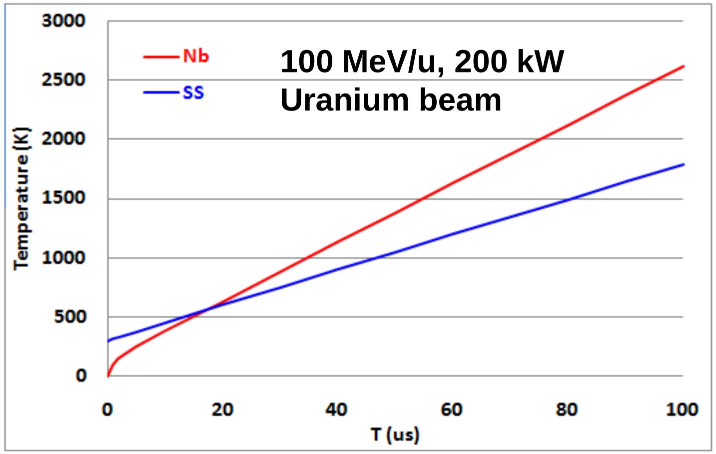


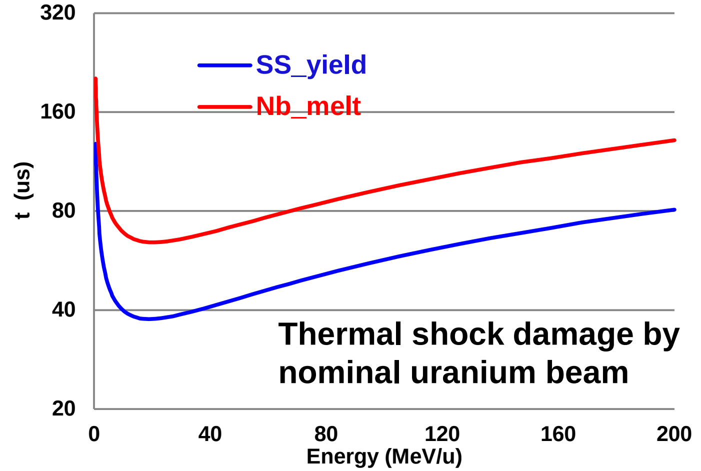


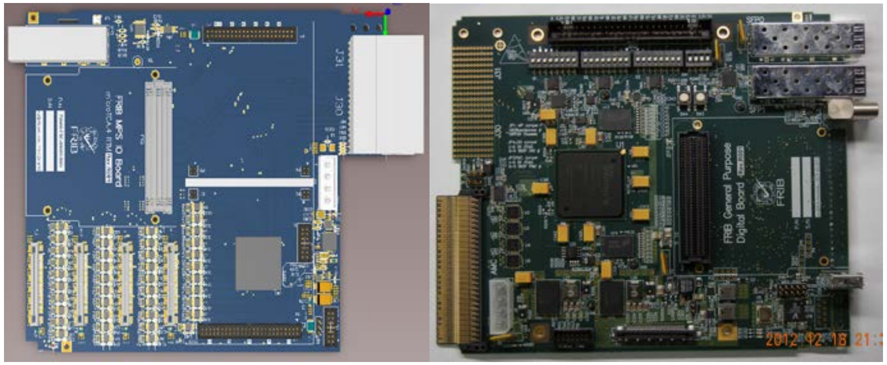
	^{238}U Energy	Loss Power	Ion Chamber Signal	Halo Ring Signal
Slow Loss at Halo Ring	**10 MeV/u**	**0.7 W**	**0.07 pA***	**10 nA**
Fast Loss 1st β041 failure	**0.5 MeV/u**	**~230 W/m**	**8×10^{-5} pA***	**38 μA**

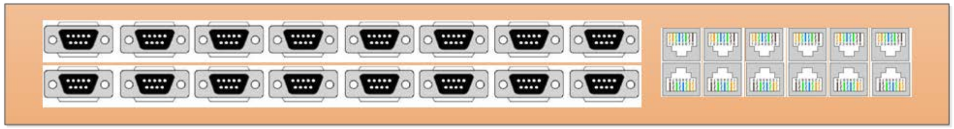
Machine Protection System – MPS

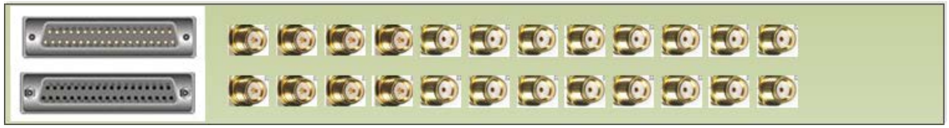
- Fast response time needed: 35 μs
  - Detector 15 μs, MPS 10 μs and beam in pipe 10 μs







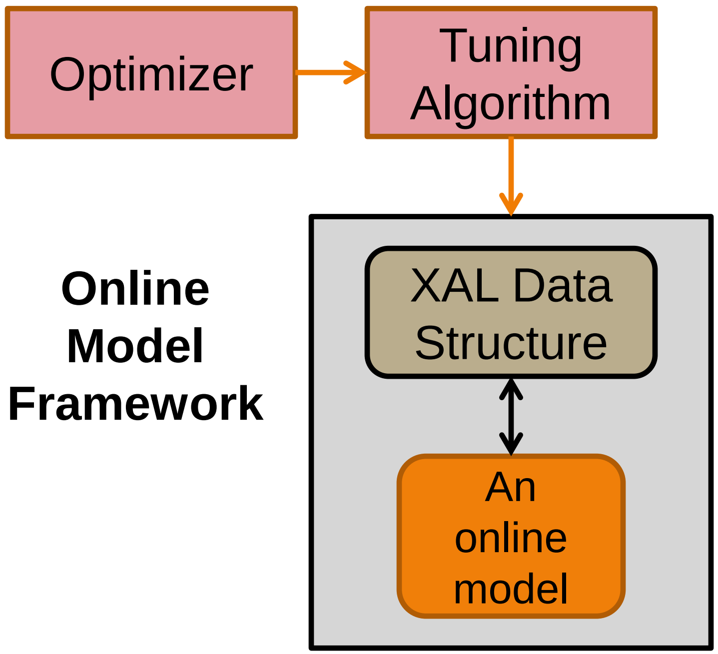




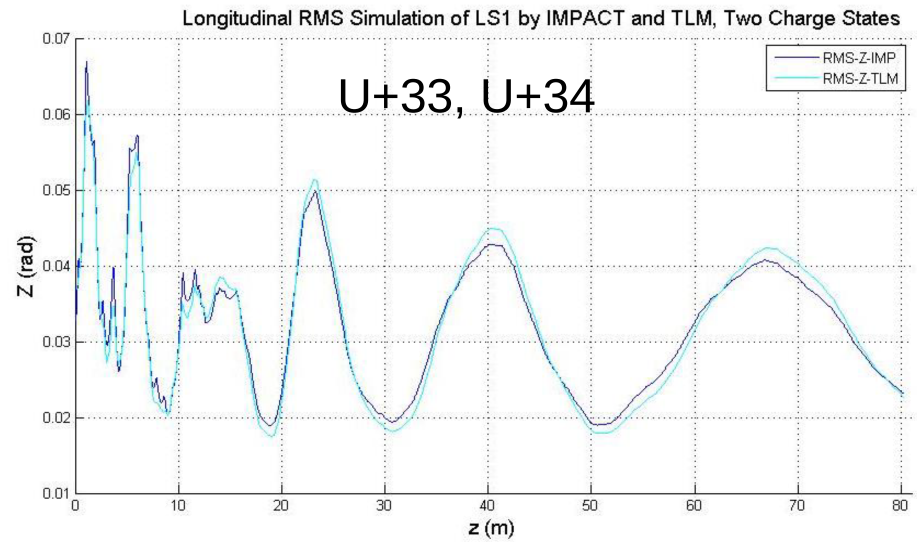
RF, BCM, BLM, HSR, Bending Magnets in Fast Protection System (FPS), other elements in Run Permit System (RPS)

Online Model – OpenXAL

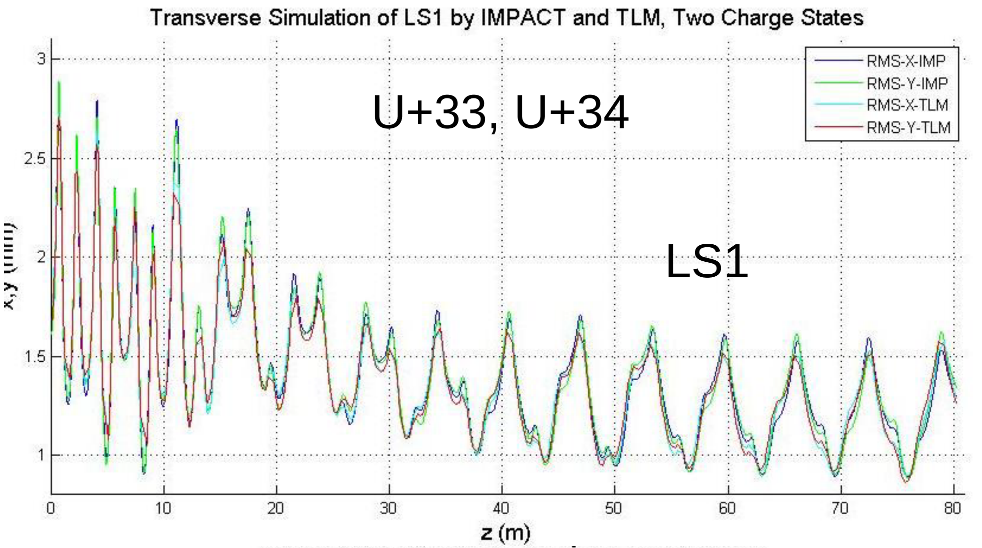
- Open source software tools from the successfully demonstrated XAL at SNS
- An collaboration with multiple laboratories for OpenXAL is established
  - FRIB, SNS, ESS, CSNS, TRIUMG, GANIL
- MySQL database interface added
  - Lattice into RDB, XAL configuration generated from RDB
- FRIB specific devices added
  - Electrostatic element – quadrupole, bending, Einzel lens
  - Solenoid
- Physics algorithm verification and design benchmark
  - Preliminarily benchmarked against IMPACT and COSY
  - Detail is going on, especially for x-y coupling
- Preliminary services and application development
  - Architecture agreed
  - Initial application and services development are ongoing
- **OpenXAL Collaboration Satellite Meeting**
  - **Room 5G, 5/16 Thursday, 9 am to 12 pm**

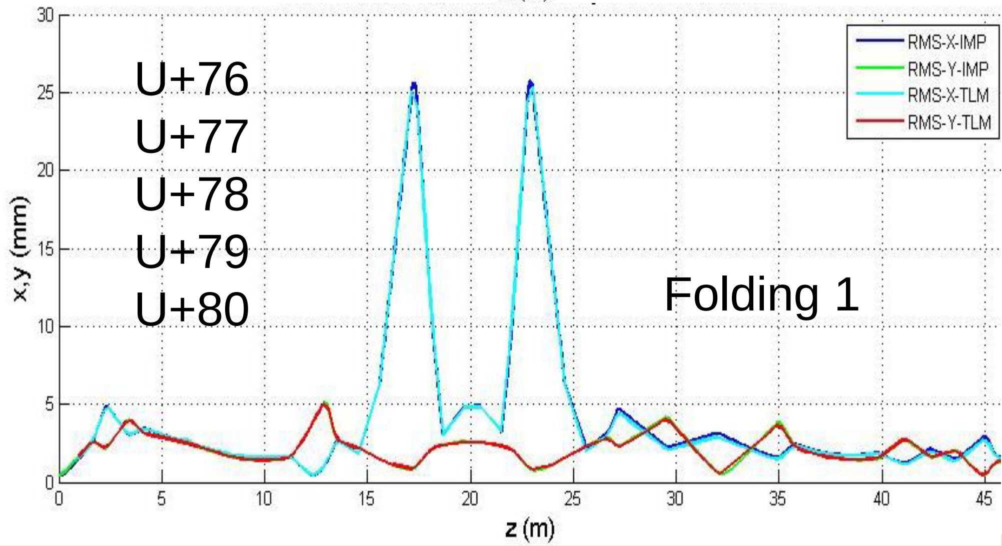


Thin Lens Model for Multi Charge State Beam



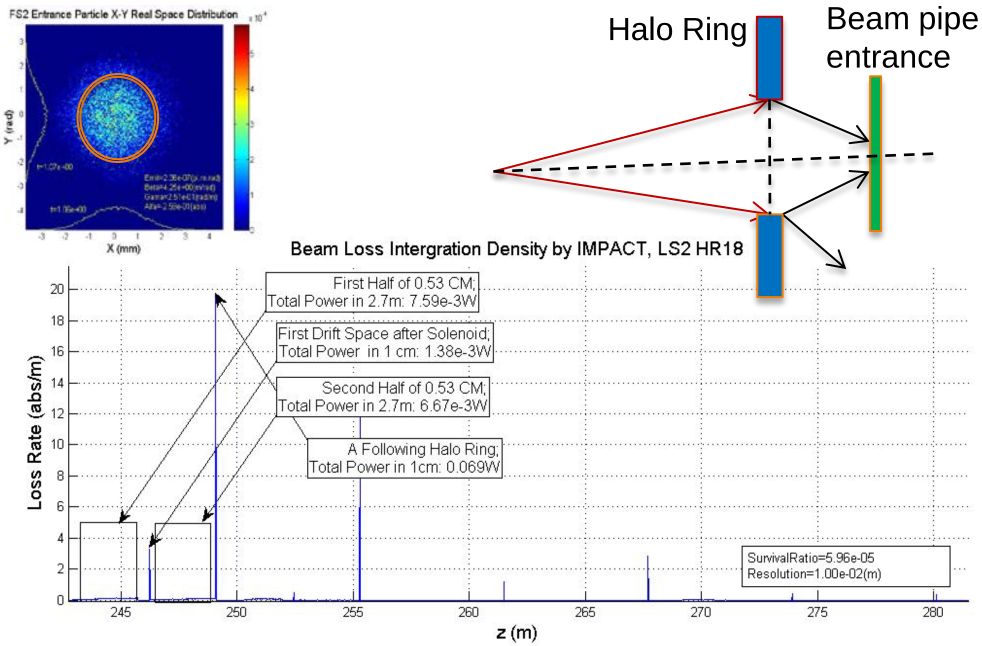
LS1, beam energy 0.5 to 17 MeV/u

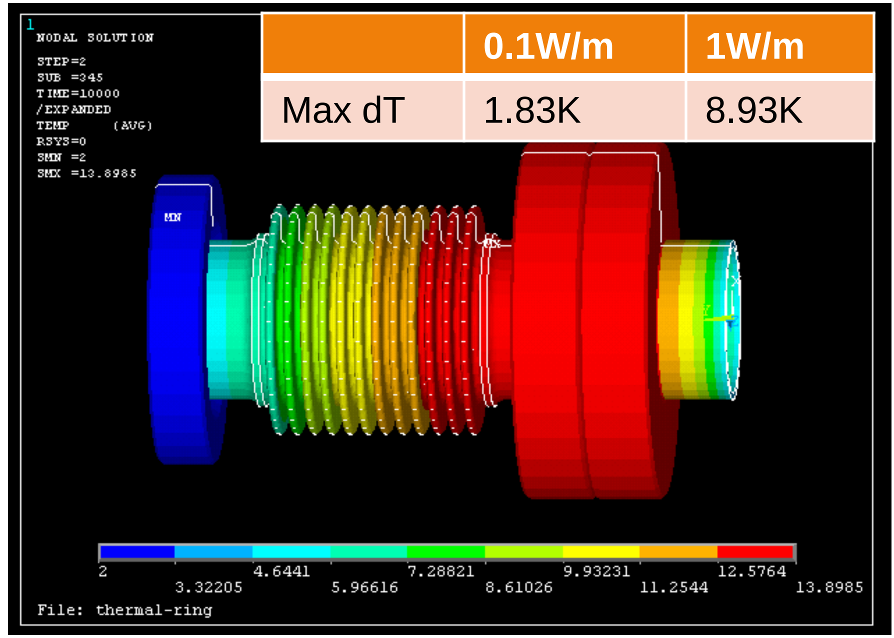




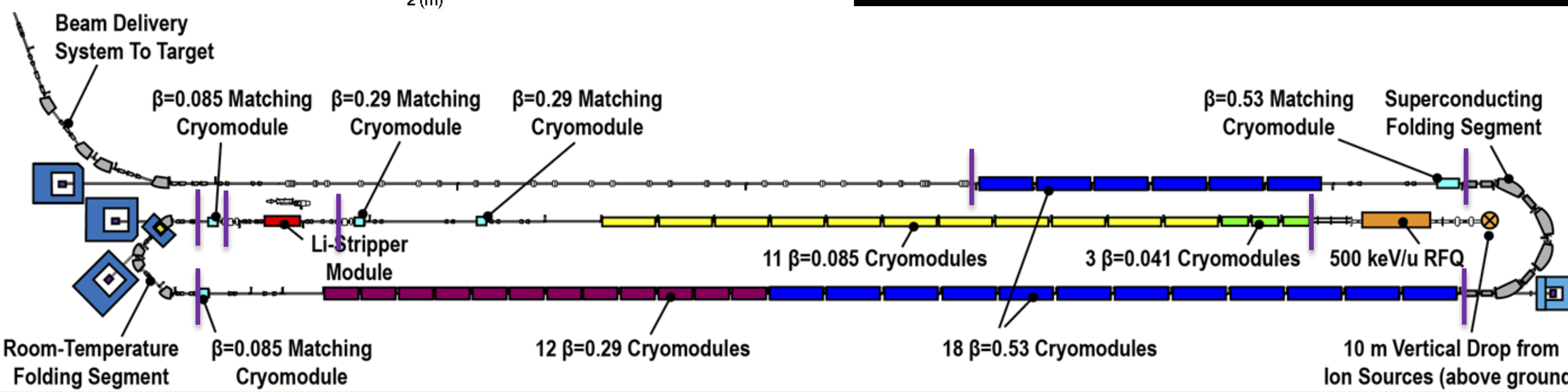
- Use thin lens model (TLM) tracking envelopes of different charge states
- Re-combine all the envelopes
- Results agree with multi-particle tracking simulations (IMP)
- Sufficient speed for online application

Minimize Uncontrolled Beam Loss





	0.1W/m	1W/m
Max dT	1.83K	8.93K



Summary

- There are many technical challenges of the FRIB project.
- We only discussed a few of them and because of limited time, a lot of challenges, even critical ones, cannot be all covered in this short talk.
- All the design and integration issues are properly addressed and in very good progress.
- We have been benefited greatly from collaborations with multiple institutes: ANL, BNL, CSNS, CU, FNAL, JLab, KEK, LBNL, LNL, SLAC, SNS, THU, TRIUMF, …, we will continue.
- We are on track to deliver the most powerful SRF linac for heavy ion beams.

Acknowledgements

Jie Wei, Yoshi Yamazaki, Winter Zheng, Zhengzheng Liu, Harry He, Felix Marti, Alberto Facco, Fabio Casagrande, Paul Chu, Peng Sheng, Dan Morris, Kent Holland, Eduard Pozdeyev, Nathan Bultman, Paul Gibson, Thomas Russo, Leitner Matthaeus,

Kenji Saito, Bob Webber, Sheng Zhao, Yihua Wu, John Popielarski, Matthew Johnson, Oren Yair, Xing Rao, Ting Xu, Shelly Jones, Daniela Leitner, Michael Syphers, Xiaoyu Wu, Qiang Zhao, Ji Qiang, Richard Talman, Bob Laxdal, Yinong Rao, John Galambos, Sasha Aleksandrov, Tom Pelaia, Chris Allen, Mark Champion, Yoon Kang, Kim Sang-Ho, Zhenghai Li, Thomas Roser, Chris Gardner, Peter Thieberger, Peter Ostroumov, Richard Pardo, Hengjie Ma, Dana Arenius, Haipeng Wang, Rongli Geng, John Mammosser, and many others.