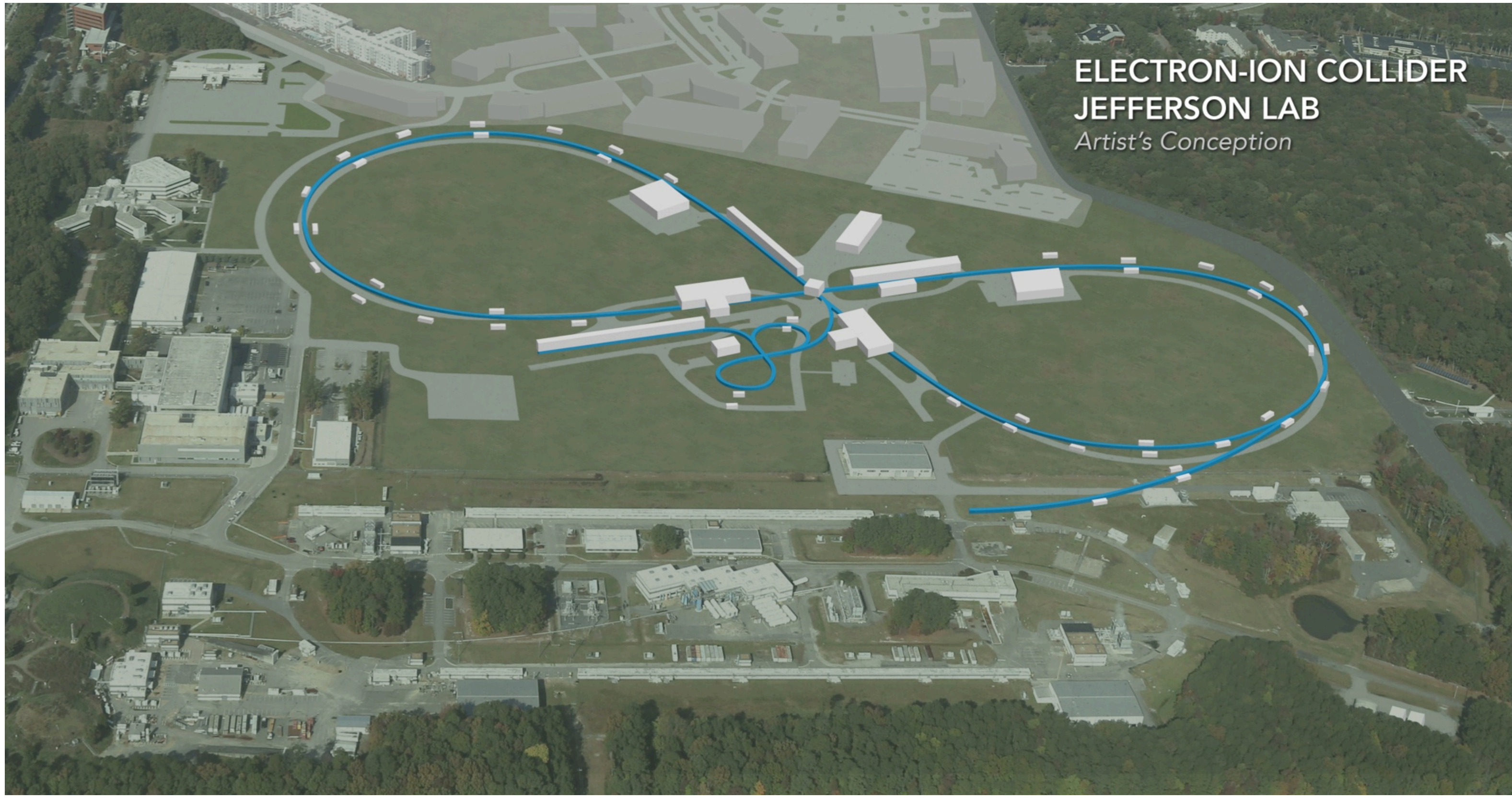
JLEIC SRF

R. Rimmer

for the JLEIC SRF team



EIC Accelerator Collaboration Meeting

October 29 - November 1, 2018

Jefferson Lab

U.S. DEPARTMENT OF ENERGY | Office of Science

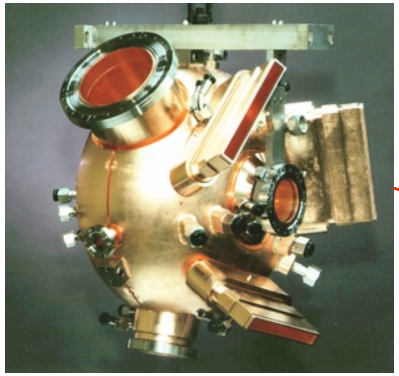
JSA

Overview

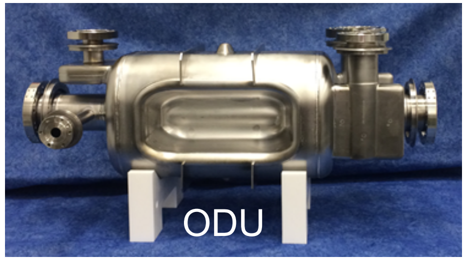
- JLEIC RF systems recap
- e-ring progress
- i-ring progress
- Cooler ERL
- Harmonic kicker
- Cooler injector
- Crab cavities (see also HyeKyoung's talk)
- Impedance and new HOM damped cavity
- Fast Feedback systems
- Transient problem (John Fox's talk)
- Conclusions and future work
- Ion complex (Fanglei's talk)
- CEBAF injection (Jiquan's talk)

JLEIC

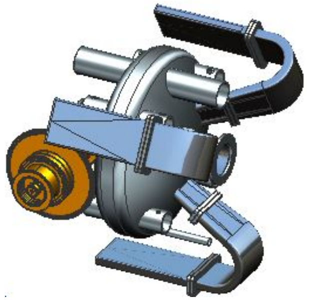
- Define RF system requirements
- Support the pre-CDR
- Cooler ERL injector, and harmonic kicker
- New Ion ring cavities
- New e-ring cavities (?)
- Cavity prototyping
- Fast feedback
- Impedance (incl. IR)
- CEBAF as injector



476.3 MHz e-ring (NCRF PEP-II)

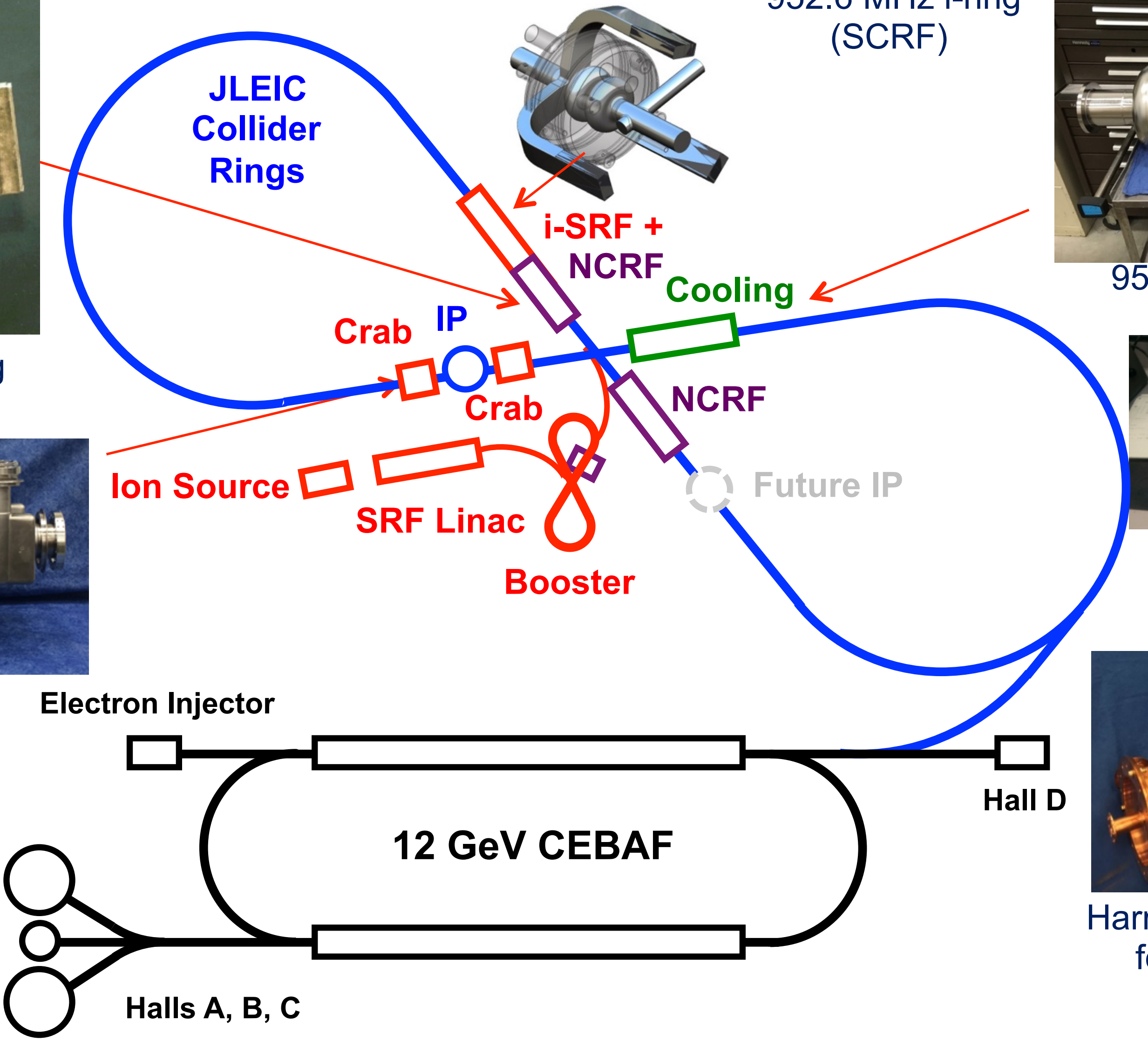


952.6 MHz crab (SCRF)

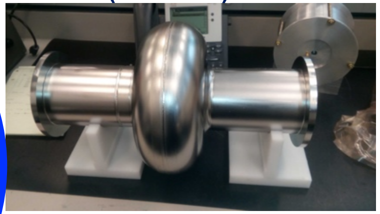


952.6 MHz e-ring (SCRF)

952.6 MHz i-ring (SCRF)



952.6 MHz cooler ERL (SCRF)

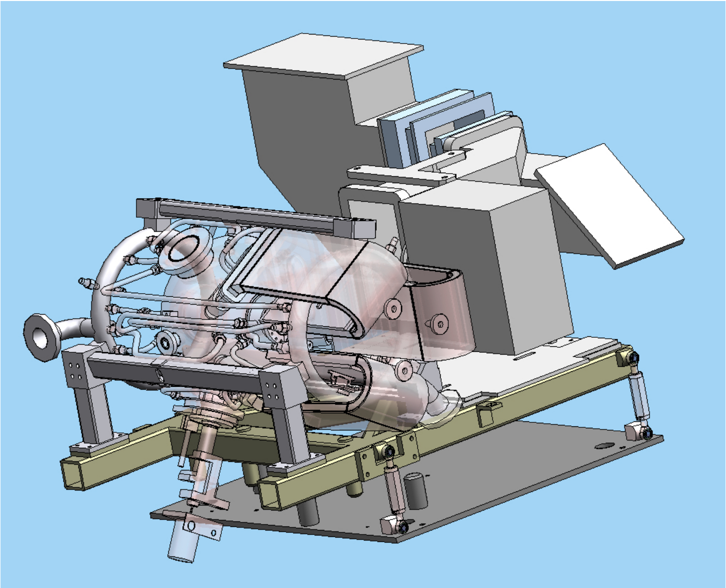


952.6 MHz booster (SCRF)

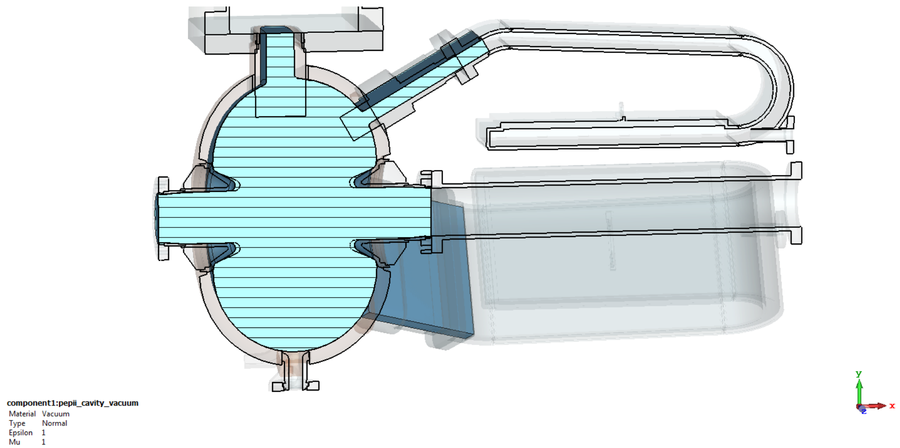
Harmonic Fast kicker for cooling ring

e-ring cavities

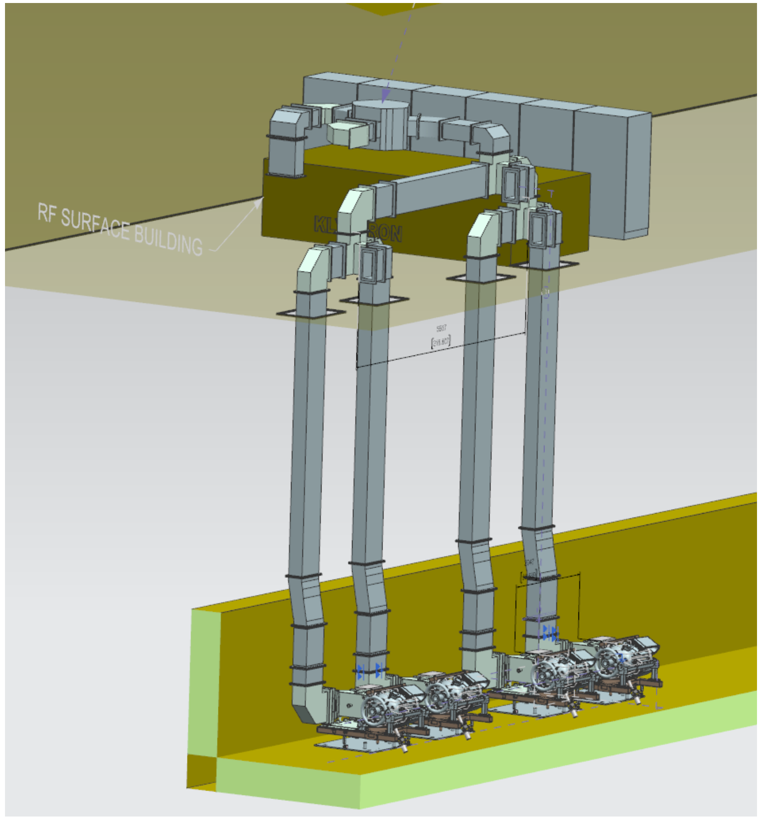
- e-ring baseline uses PEP-II RF at 476.3 MHz
- Need to adjust input beta for better match at 3A
- Large contribution to impedance budget
- Reconstructing RF model
- Starting station layouts
- Developing upgrade option



PEP-II raft assembly



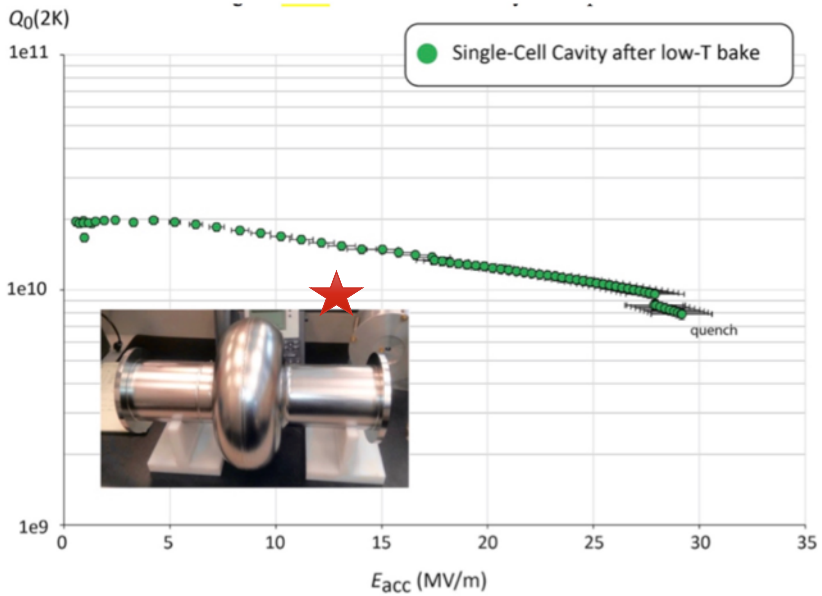
RF model

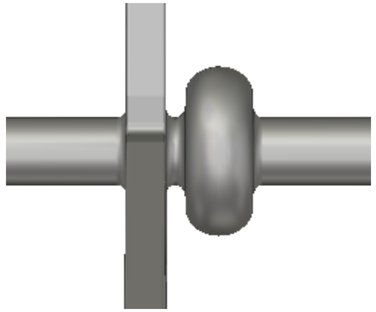


PEP-II station layout

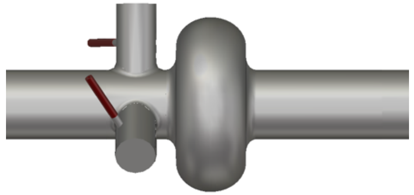
i-ring: new 952.6 MHz SRF Cavities

New 952.6MHz High-current cavity shape
- 4 different HOM damping schemes evaluated
- Focus on 3 waveguide damper design for ion ring
- Possibly on-cell damper for e-ring
- 1-cell prototype tested

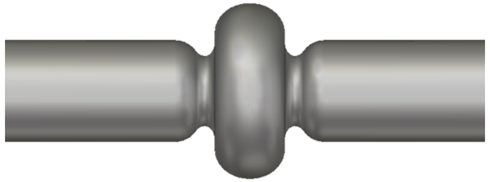




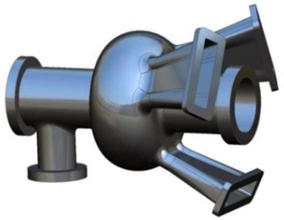
1) 3WG.



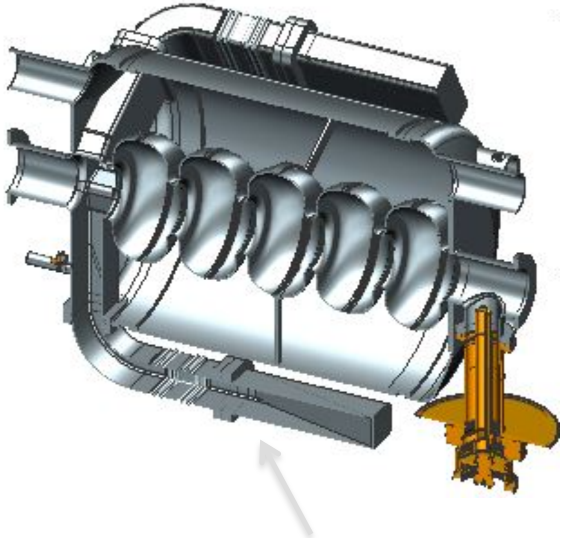
2) 3 coax dampers.

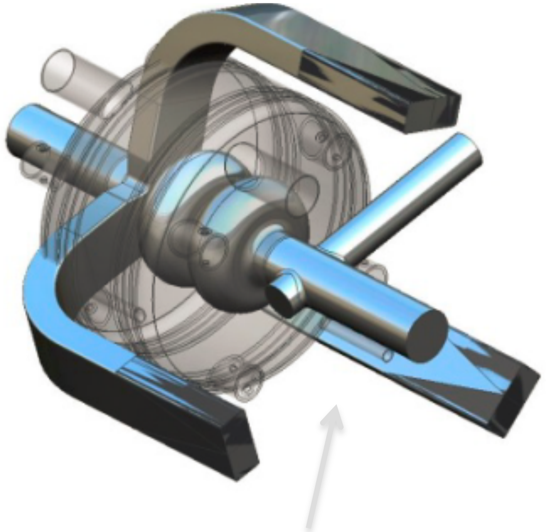


3) enlarged beam pipes



4) on-cell dampers





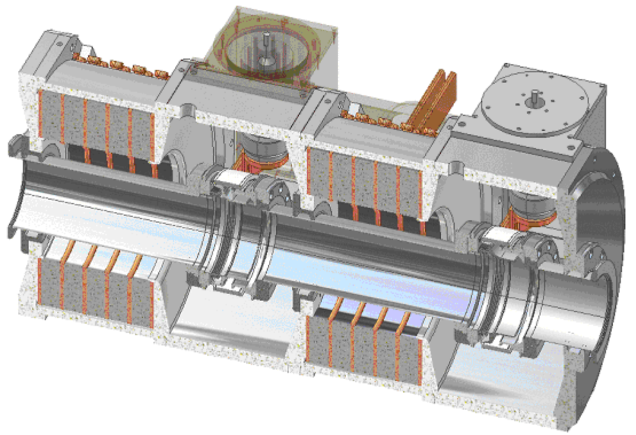
Cooler needs **5-cells** in the ERL, 1 or 2 -cells in the injector.
Ion ring might use **2-cells.**

Ion Ring Bunch Formation Cavities

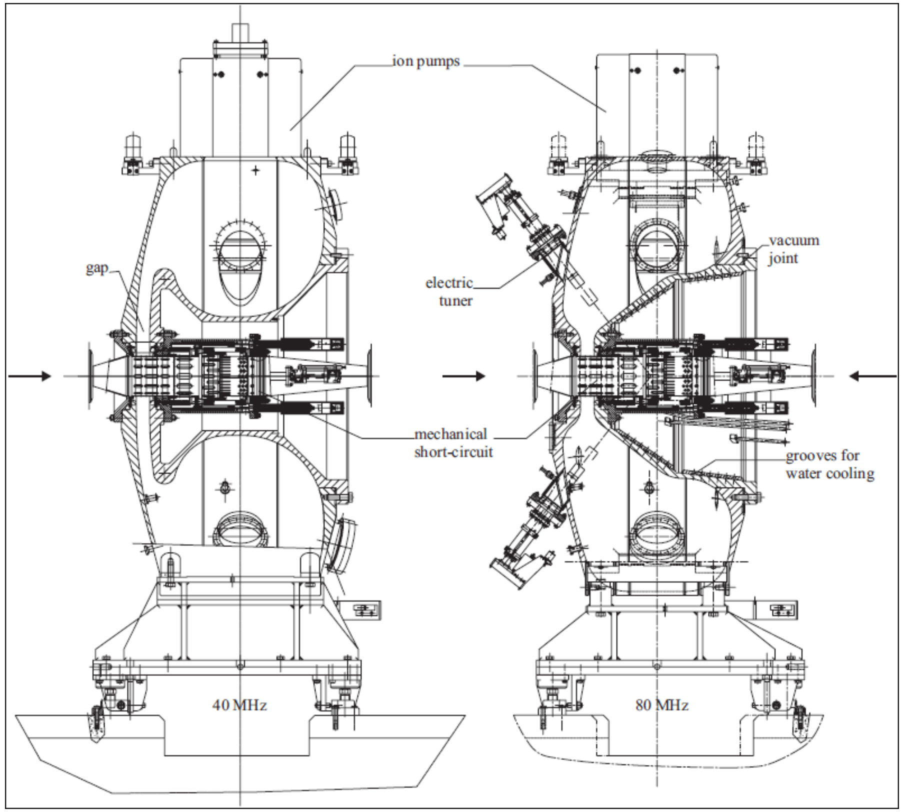
J. Guo

JLEIC ion bunch formation injects h=56 , E=2 GeV (Pb) to 8 GeV (p) long bunches into the ion ring, then perform binary RF splitting 6 times into h=3584.

Cavity function	β range	Energy (GeV)	Frequency (MHz)
Collider ring acceleration	0.957-0.999	2.0-20	7.05-7.44
Collider ring bunch splitting	0.999	20	14.87
			29.75
			59.49
			118.98
			237.96
Collider ring bunch splitting, bucket manipulation, acceleration, bunching	0.999-1.000	20-100	475.9-476.4



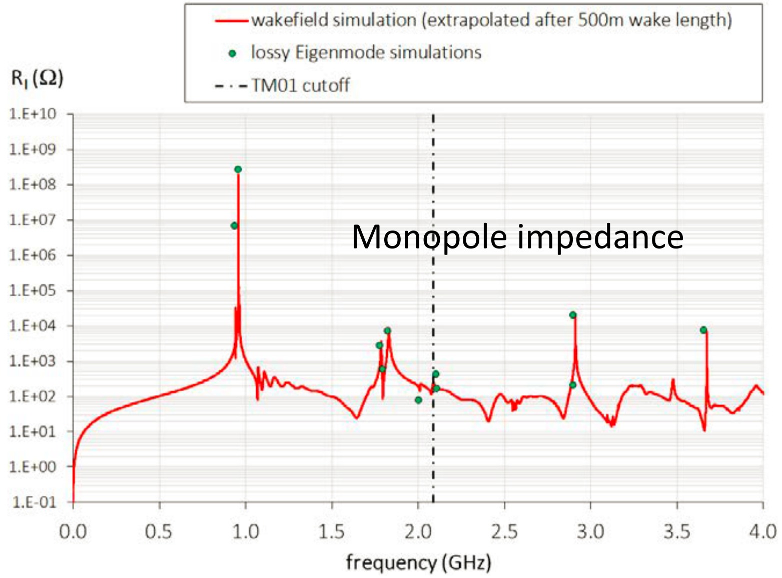
CERN PS 13.3-20MHz low Q Ferrite loaded cavity, as a reference for JLEIC ion ring 7 MHz acceleration cavities and ion booster acceleration/bunching cavities

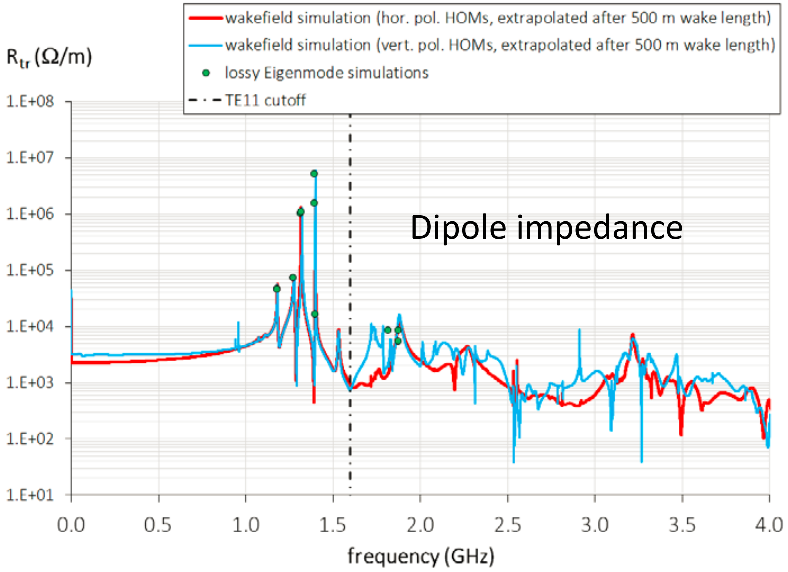


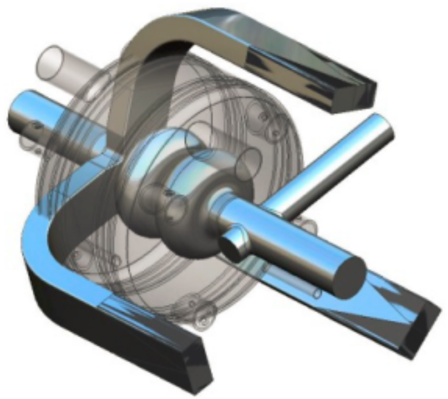
CERN PS 40MHz and 80MHz "button" cavities for LHC bunching
A sliding beampipe shields the cavity from HOM excitation when the cavity is not in use
May use as a reference for most of the bunch splitting cavities

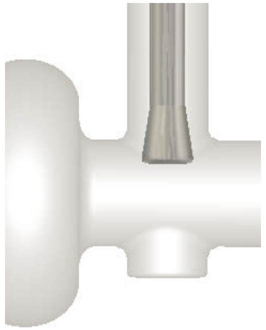
Two-cell WG damped SRF Cavity for JLEIC Ion Ring

F. Marhauser

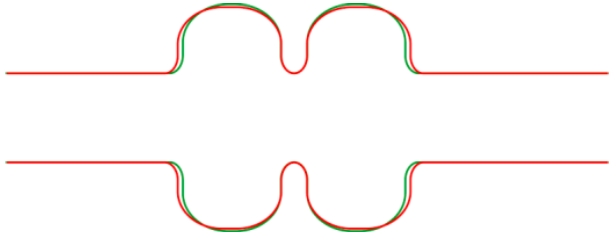








FPC



0 mode optimization

Baseline stable – see Rui Li's talk

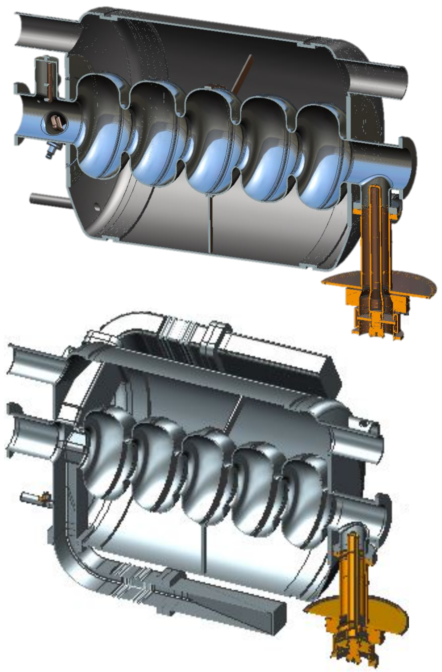
In this ion ring cavity design iteration

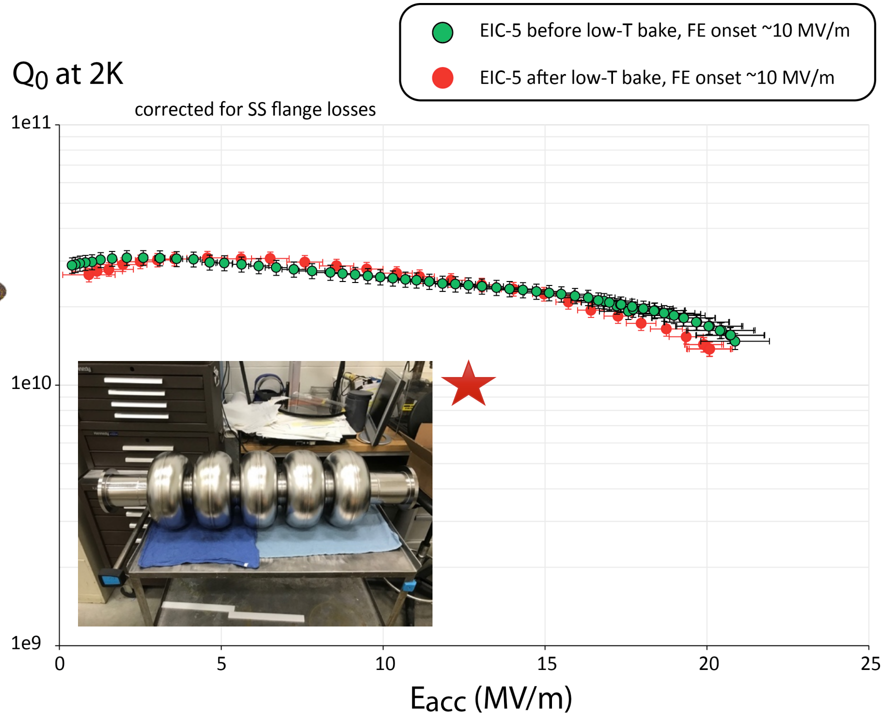
1. 2-cell 952.6 MHz cavity with π mode R/Q=211Ω
2. Currently the coax FPC designed at ~10^6 Qext without intruding the coupler tip into the iris radius, but the desired Qext is 2.4×10^4 to 6×10^4 for transient beam loading correction. May need to step up the beampipe.
3. Desired Vc=2.4MV, cavity drive power **480 kW**. 24 cavities needed.
4. Impedance of the worst HOM offender about one order of magnitude better than 3-coax
5. TM010 0 mode R/Q=2.3Ω with Qext=2.98×10^6, which is most dangerous mode. Optimization to reduce the R/Q further not easy as the other HOM becomes stronger. However Qext can be reduced significantly if we reach our FPC Qext goal.

Cooler ERL 5-cell cavity

- Evaluated coax and WG end groups
- Estimated HOM power for various fill patterns including gaps
- Worst case ~6 kW so prefer WG
- 5-cell bare prototype tested

f_{RF} (MHz)	952.636			
Cooling bunch rate (MHz)	119.075	238.15	476.3	952.6
Gun laser rate (MHz)	10.825	21.65	43.3	86.6
bunch train repetition rate (MHz)	0.349	0.698	1.397	1.397
CCR circumference (m)	213.955			
ERL path length (m)	2573.32 ((8184-5.5)λ)			
Laser bucket pattern	7 on, 1 off, 7 on, 1 off, 7 on, 1 off, 6 on, 1 off	14 on, 2 off, 13 on, 2 off	27 on, 4 off	54 on, 8 off
Charge per bunch (nC)	3.2			
Average ERL injection current (mA)	30	60	120	241
HOM power per cavity (kW)	0.33	0.76	2.0	5.9
HOM power per cavity scaled to CCR current 1.5A (kW)	6.7	3.9	2.6	1.9

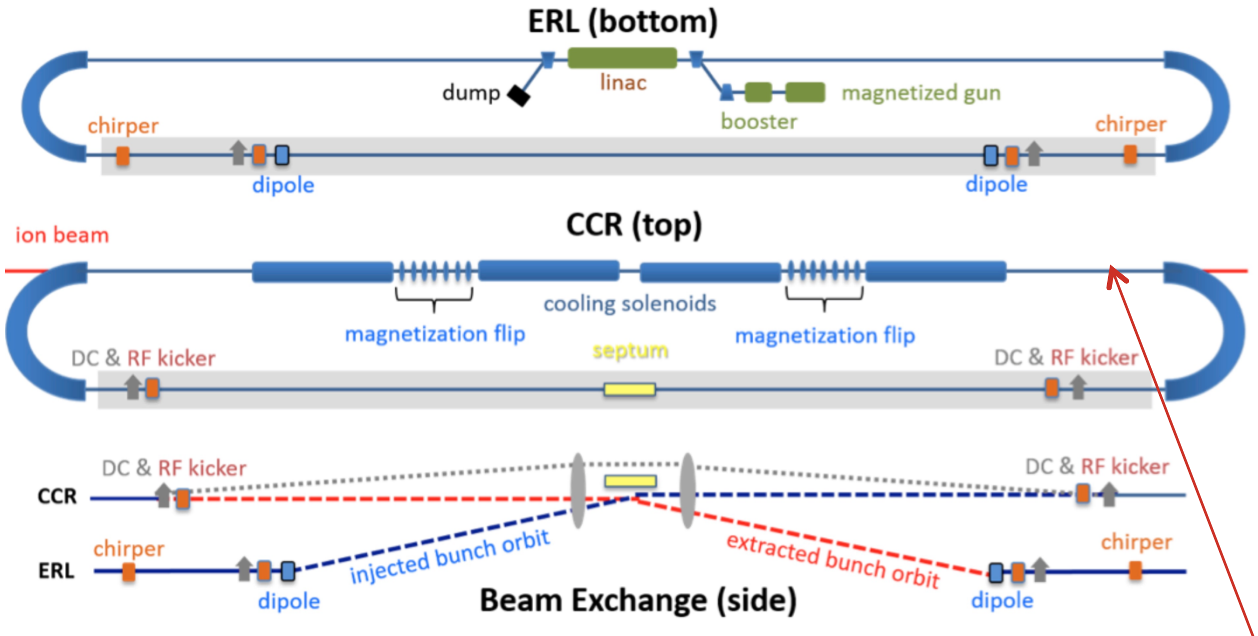




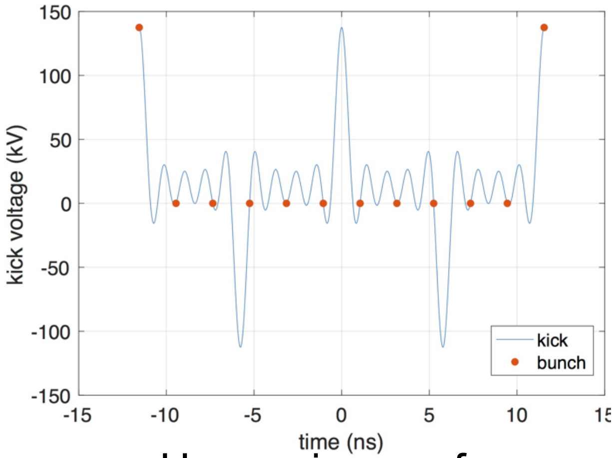
HE Cooler and CCR: Harmonic kicker

G. Park

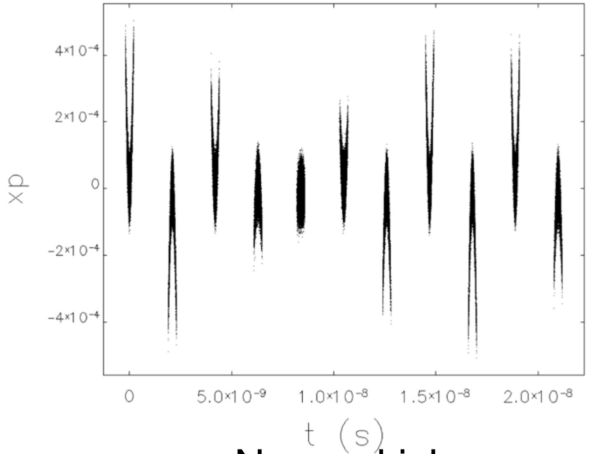
- High current ERL and injector
- Updated Harmonic kicker
- Prototype cavity under design
- FY19 plan:
  - Simulate with magnetized beam
  - Check multipoles
  - Fabricate vacuum cavity
  - Test with harmonic RF driver



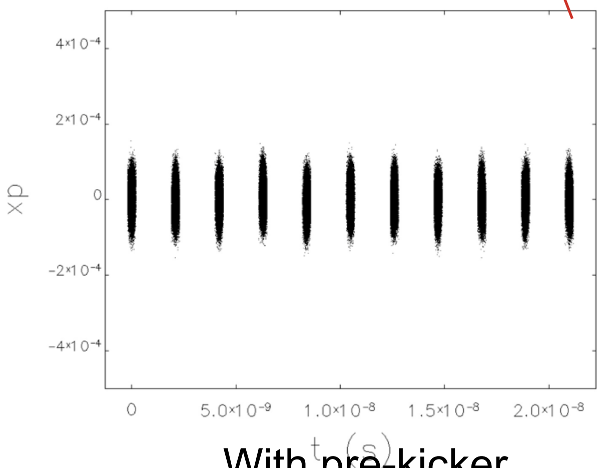
Harmonic kicker



Harmonic waveform



No pre-kicker

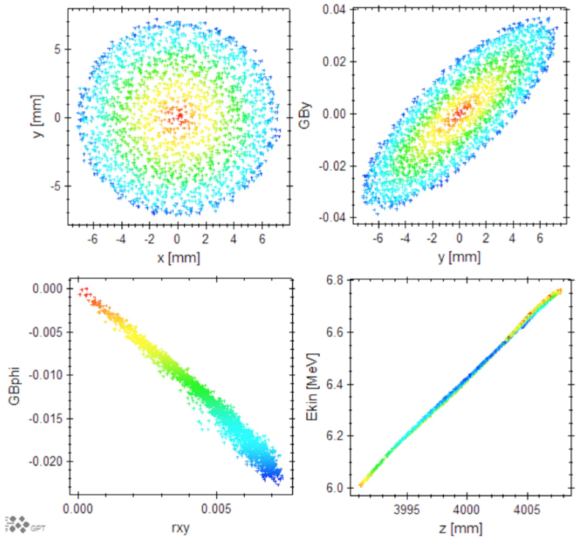


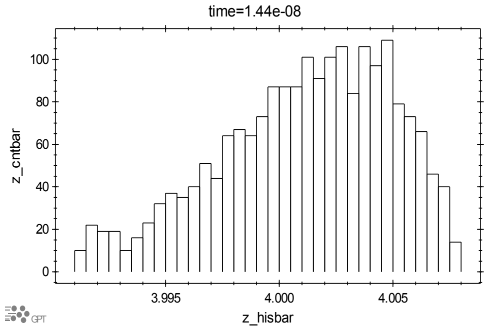
With pre-kicker

HE ERL injector

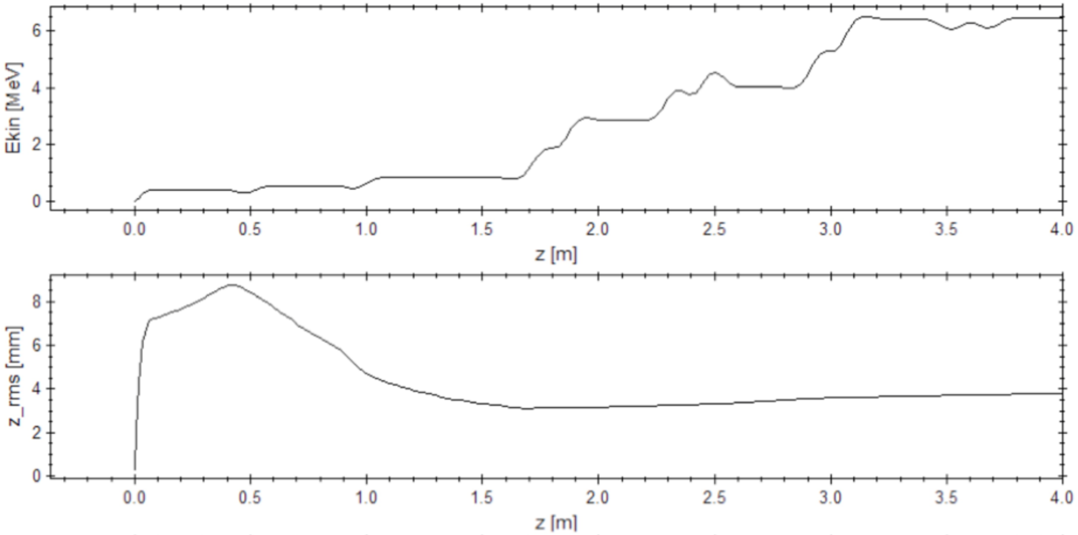
F. Hannon

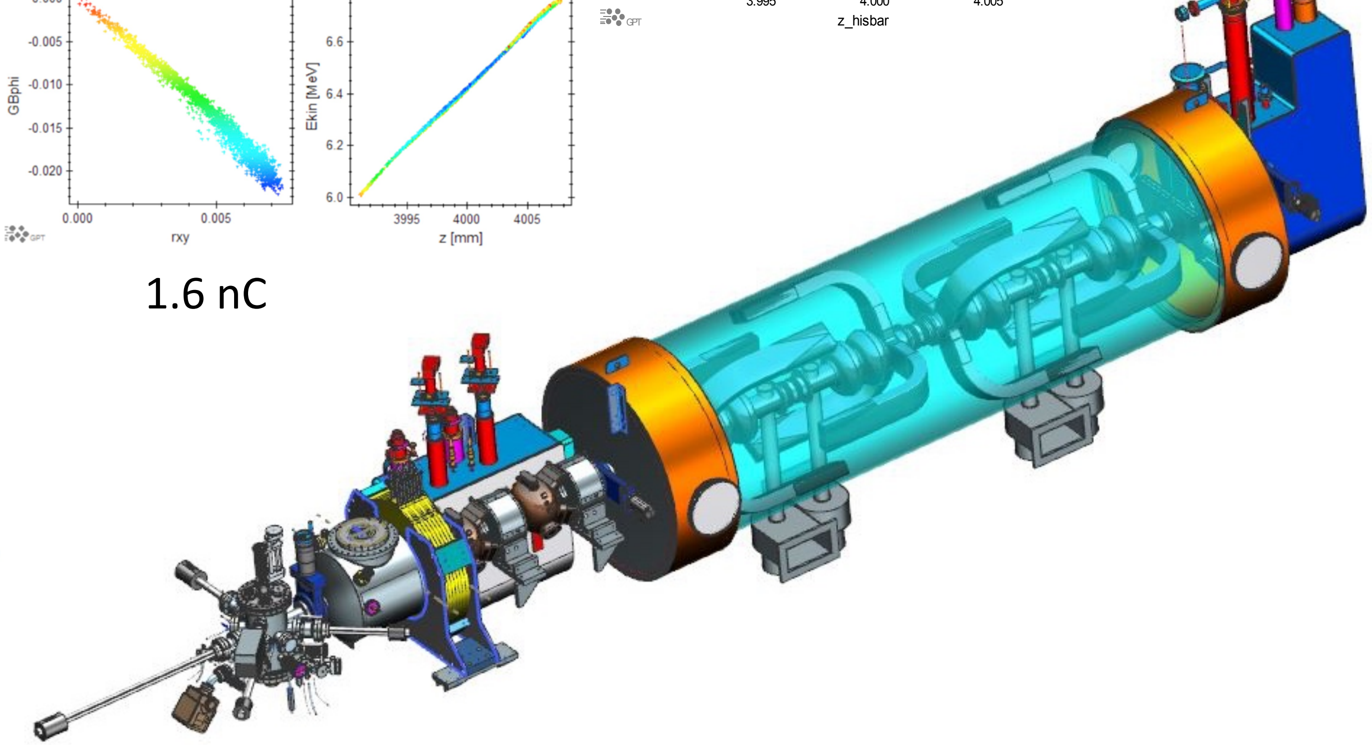
- Magnetized DC gun (Mamun's talk)
- NC capture and buncher
- SRF booster
- High-current non energy recovered
- Several merger options under study
- 476 MHz option under consideration





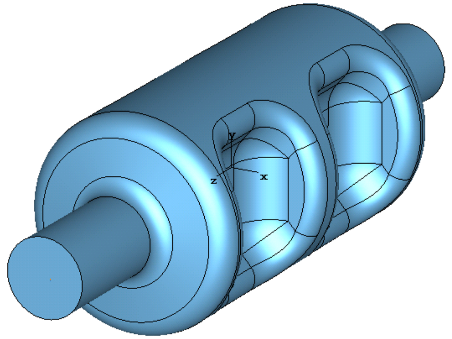
1.6 nC



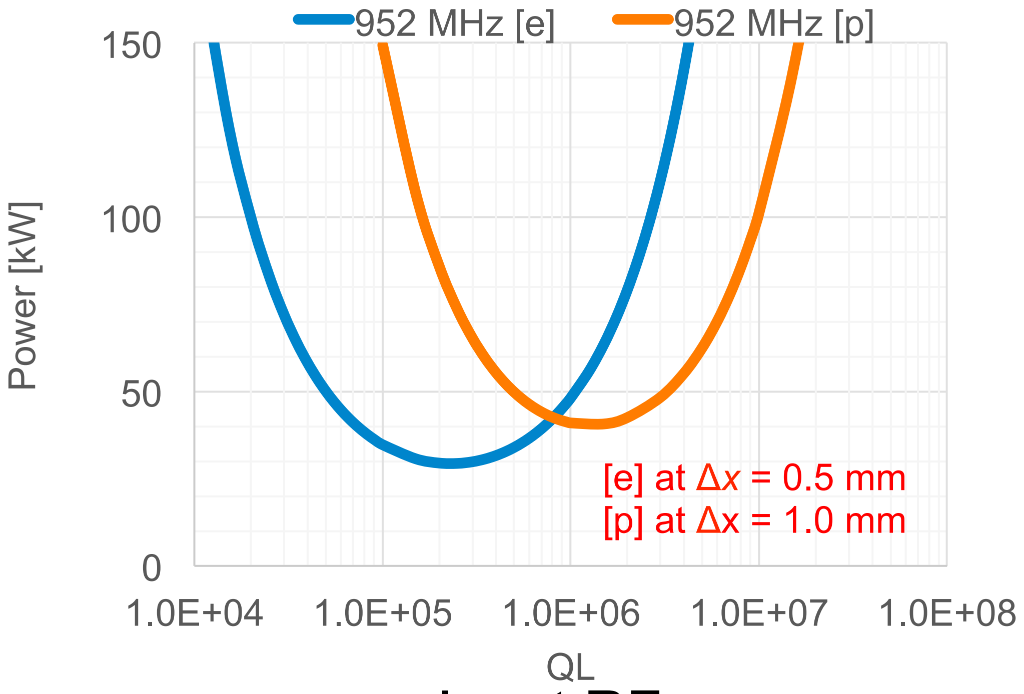


Crab Cavity – RFD 2-cell cavity (see also HyeKyoung's talk)

- After design survey, the prototype is converging to 952.6 MHz 2-cell RFD cavity.
- 10 GeV electron beam and <u>200 GeV</u> proton beam.
- Input power coupling through beam pipe provides the QL range.



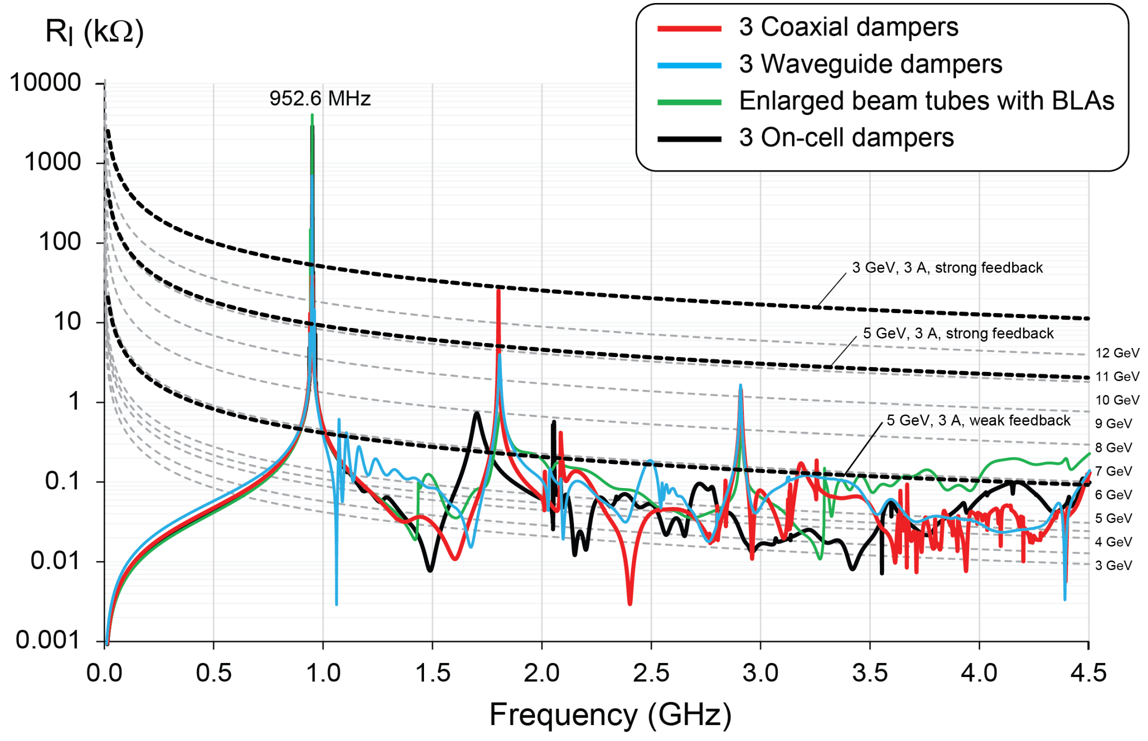
	protons	*electrons*	*Units*
Frequency	*952.6*	*952.6*	*MHz*
Required total kick	*37.34*	*2.8*	*MV*
V_t *per cavity/side*	*2.7*	*1.4*	*MV*
Number of cavities	*14*	*2*	*-*
Peak electric field	*48.6*	*25.2*	*MV/m*
Peak magnetic field	*99.9*	*51.8*	*mT*
Surface resistance	*95.0*	*95.0*	*nΩ*
Shunt impedance	*0.26*	*0.26*	*MΩ*
Dissipated power/cav	*27.8*	*7.5*	*W*

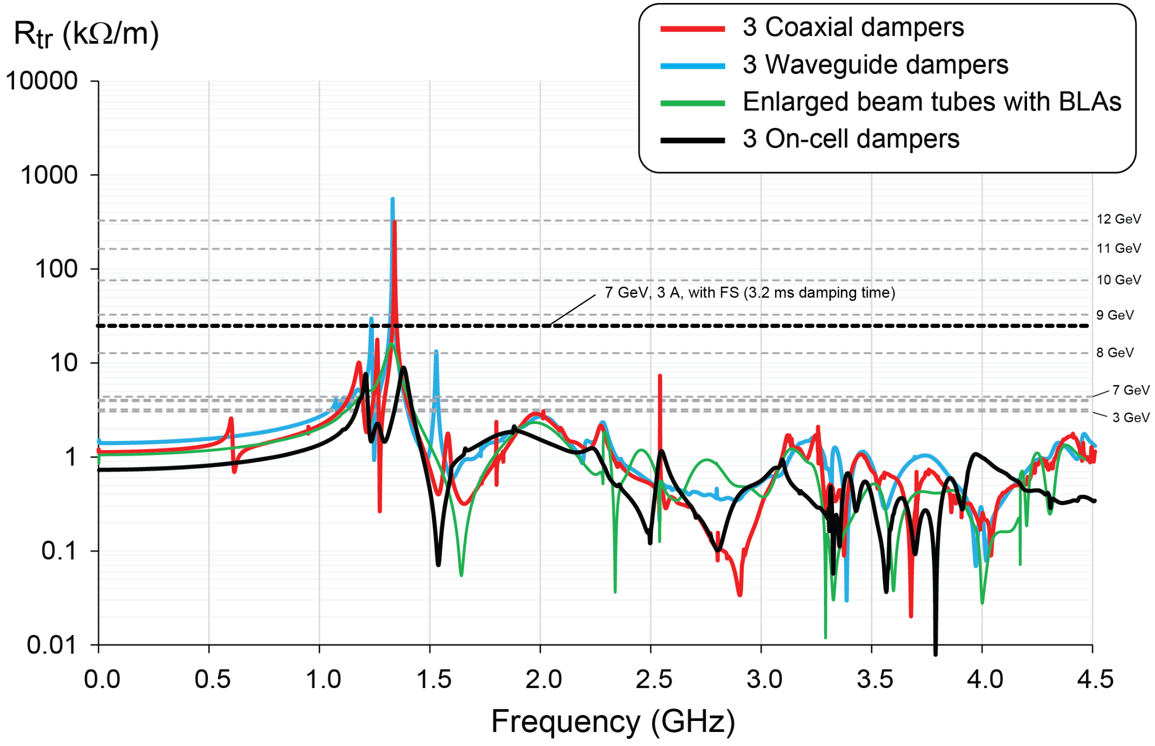


Input RF power

Collider Ring Impedance Thresholds

- Broadband damping of HOMs with on-cell dampers better than with any other design including enlarged tubes to un-trap low frequency modes
- PEP-II type feedback systems allow running above threshold.
- Beam tube absorbers might still be needed outside of cryomodules for high frequency power



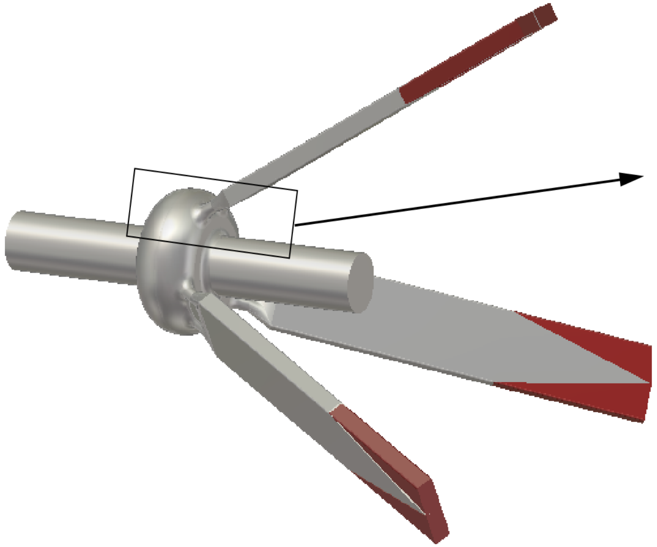


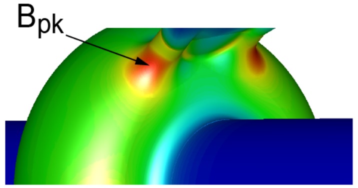
F. Marhauser, "Next Generation HOM-damping", Special Issue on Superconducting RF for Accelerators, to be published

Heavily-Damped Collider Ring Cavity

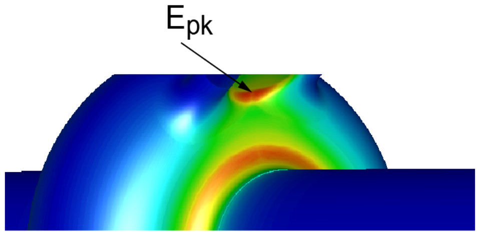
New LDRD

- Progress has been made to design of a heavily damped 952.6 SRF single-cell cavity with on-cell waveguide dampers
- The effective and broadband HOM damping with a similar arrangement of three waveguide dampers is well proven with normal-conducing cavities (e.g. BESSY 500 MHz cavity and PEP-II 476 MHz cavity)
- The magnetic field enhancement at the surface (openings) can be limited to a factor of ~2 compared to standard elliptical cavities, around ~15 MV/m are feasible

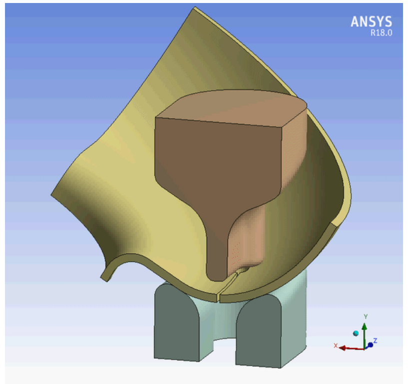




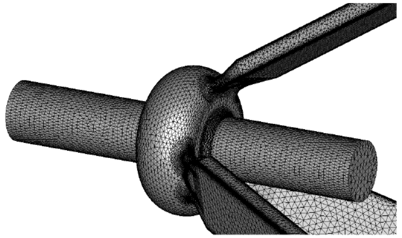
RF magnetic field contours

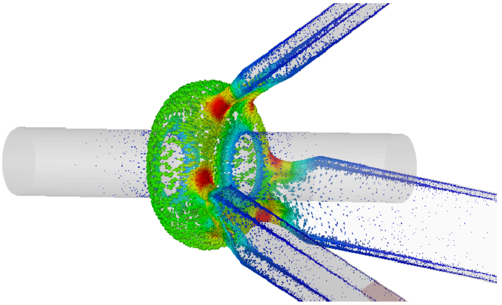


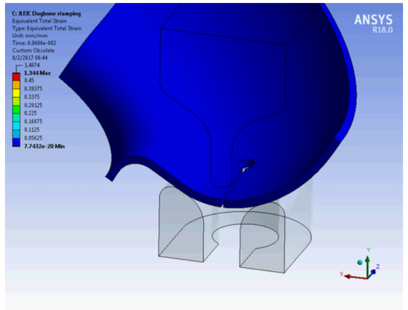
RF electric field contours

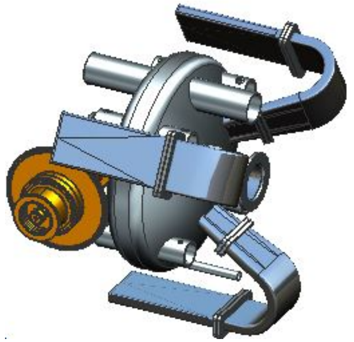



First mechanical forming test


Tetrahedral mesh representation


Surface currents

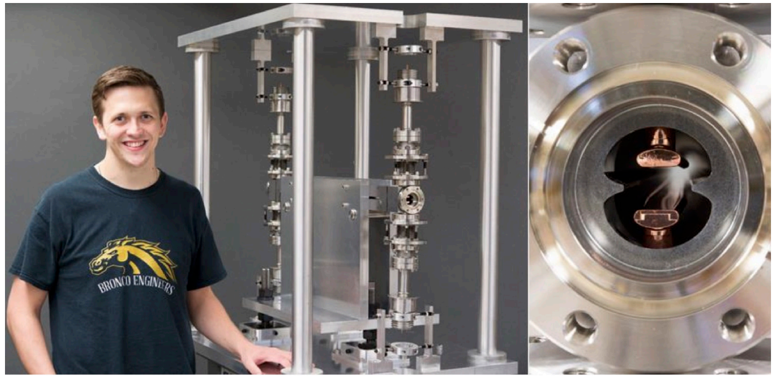




F. Marhauser, “Next Generation HOM-damping”, Superconductor Science and Technology, Volume 30, Number 6, Published 15 May 2017.

Impedance and feedback

- Broadband damping of cavity HOMs is essential
- Many other ring components need to be considered
- PEP-II feedback systems allowed running above threshold. Similar systems are now commercially available
- System will be coupled to main RF for low modes
- Reliable high-power **kickers** are needed (Zack's talk)



APS type transverse kicker

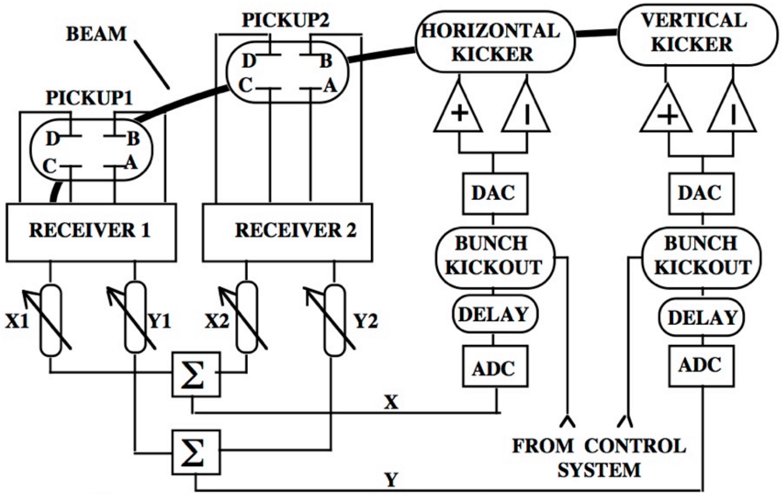
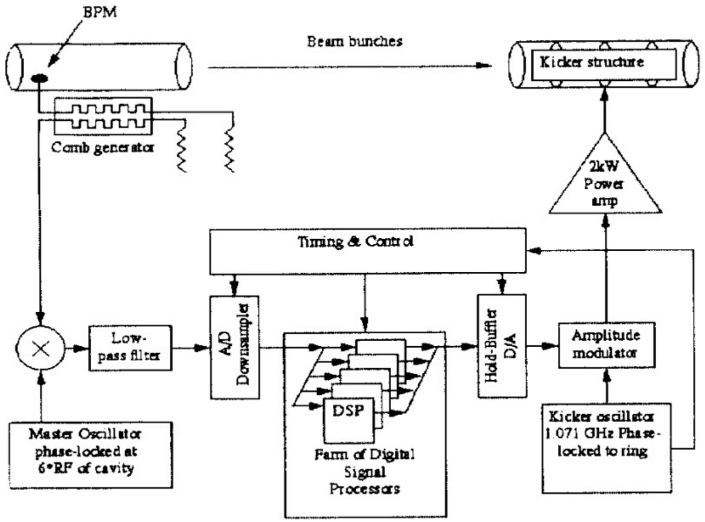
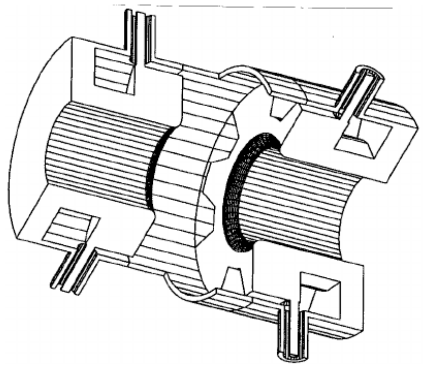


Figure 1: Transverse feedback system concept.



PEP-II Longitudinal Feedback system concept



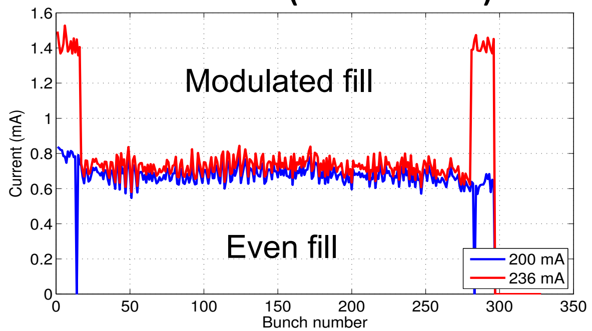
DAPHNE type kicker

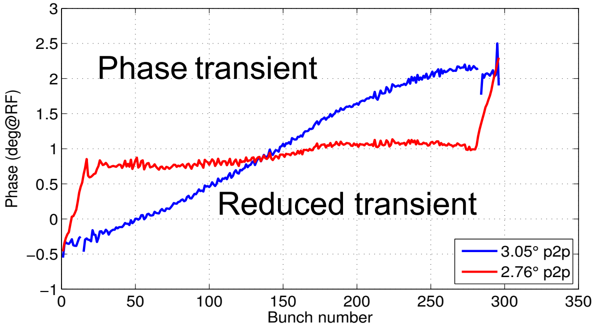
Beam Transients in collider rings (see also John Fox's talk)

Gaps in high current rings cause strong transients (e.g. KEK-B, PEP-II). Difficult to correct by RF alone.

Does Fill Pattern Modulation* Work? YES!

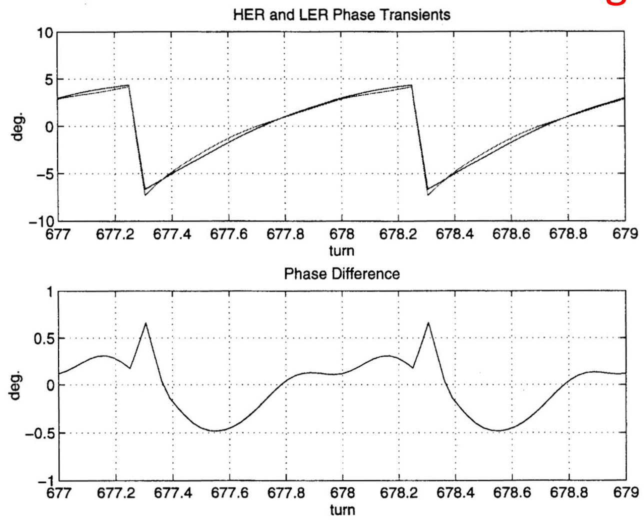
ALS data (electrons)





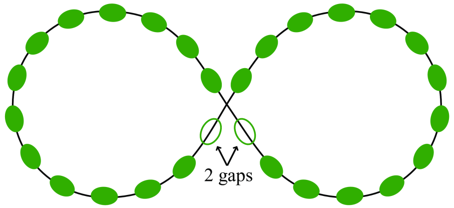
D. Teytelman, Dimtel, Inc., San Jose, CA, USA.
"Transient beam loading in FCC-ee (Z)", FCC Week 2017

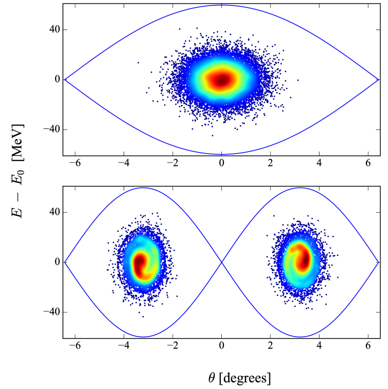
Or match transients between rings?



Results in variable arrival time at IP

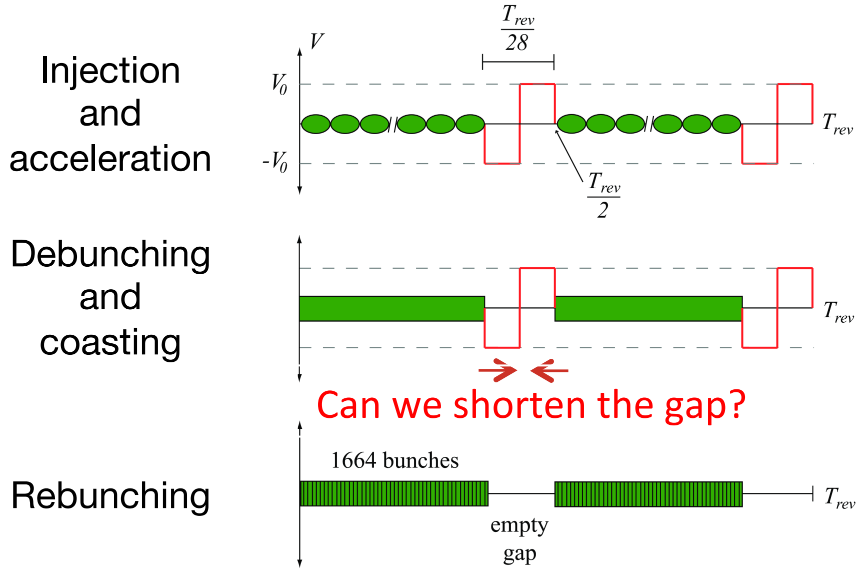
Baseline: ions binary bunch splitting.
Results in long gaps





Alternative: barrier bucket re-bunching?

Randy's talk



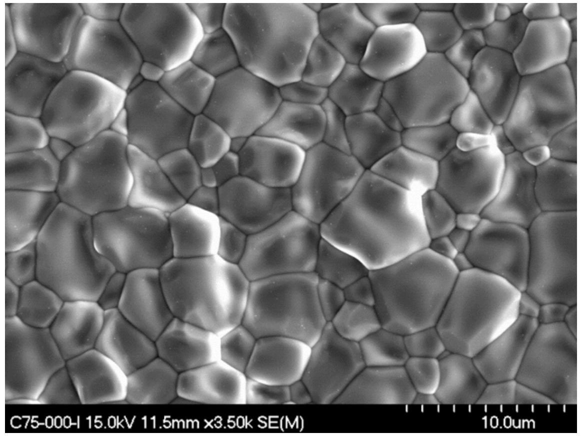
* J.Byrd et. al.,Phys.Rev. ST Accel. Beams 5, 092001 (2002)

Conclusions and future work

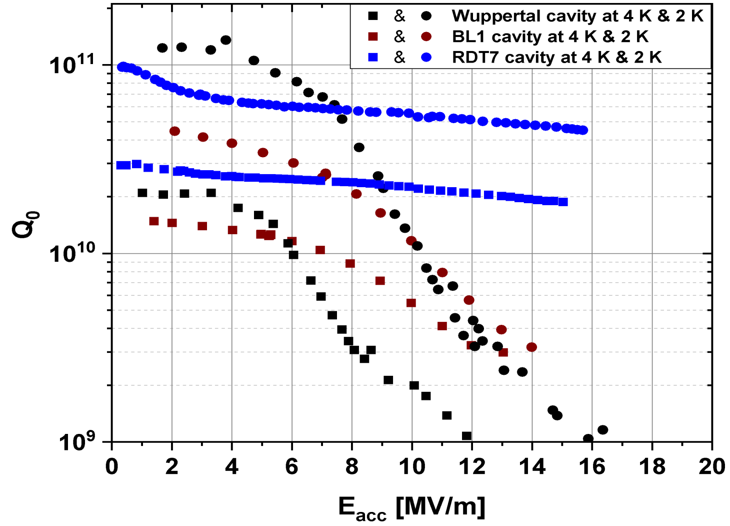
- Consistent RF system parameters determined for pre-CDR
- i-ring cavity concept developed
- ERL HOM damper down-select made
- Cooler injector and Harmonic kicker good progress made
- Crab cavity design converging
- On-cell damper concept progressed
- Ring Impedance models started

To do:

- Investigate 476.3 MHz for cooler
- Test harmonic kicker cavity
- Develop waveguide end groups and on-cell dampers
- Work on transient mitigation
- Try Nb_3Sn on 1-cell prototype?
- Revisit parameters for higher energy



Nb_3Sn



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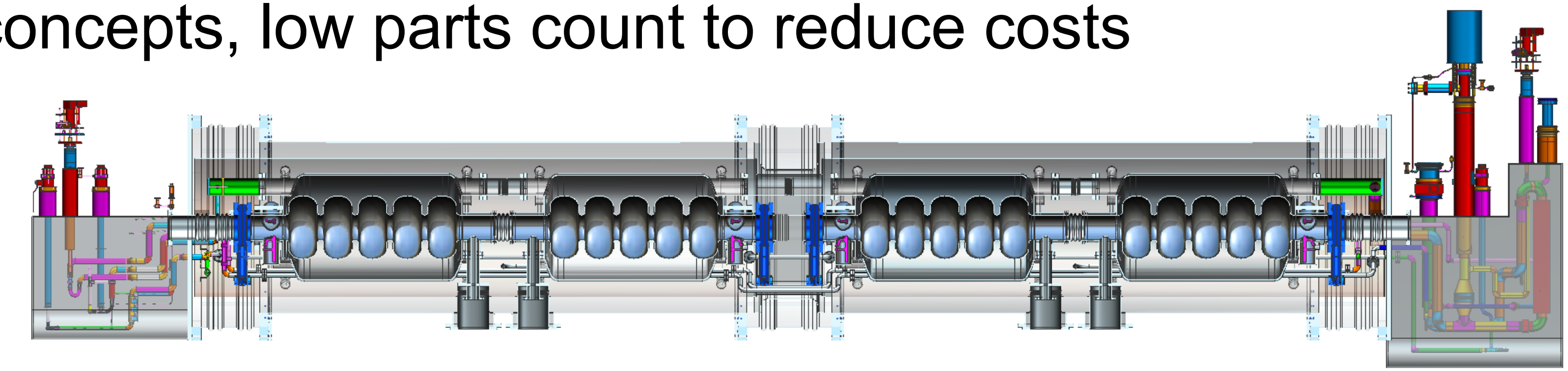
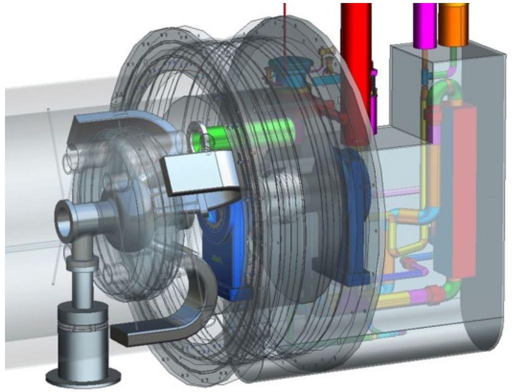
Thank You

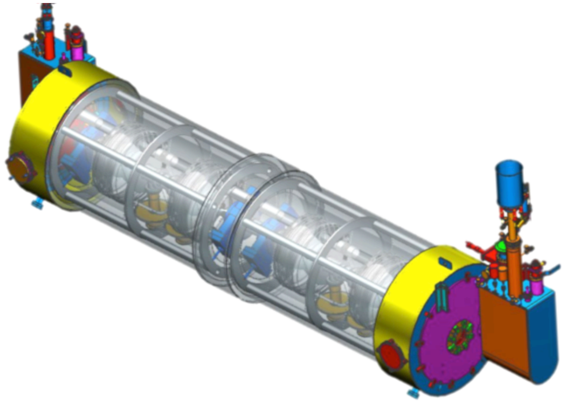
Modular cryostat

- Take the best features of previous JLab designs
- Modular approach to hold various different cavities
- Design suitable for industrial production
- Simple concepts, low parts count to reduce costs

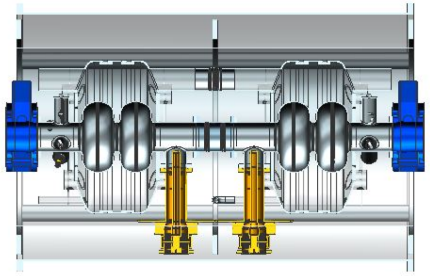




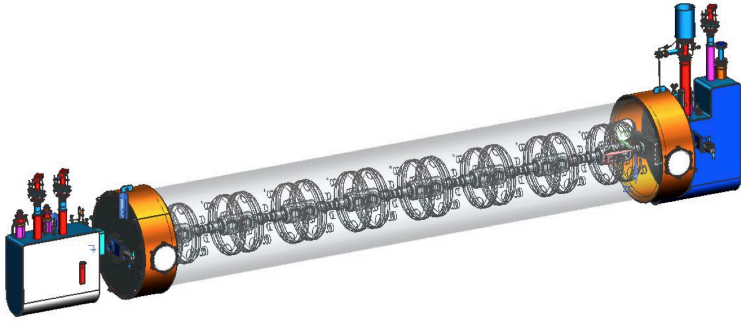
Waveguide damper concept



4 x 2-cell cavities

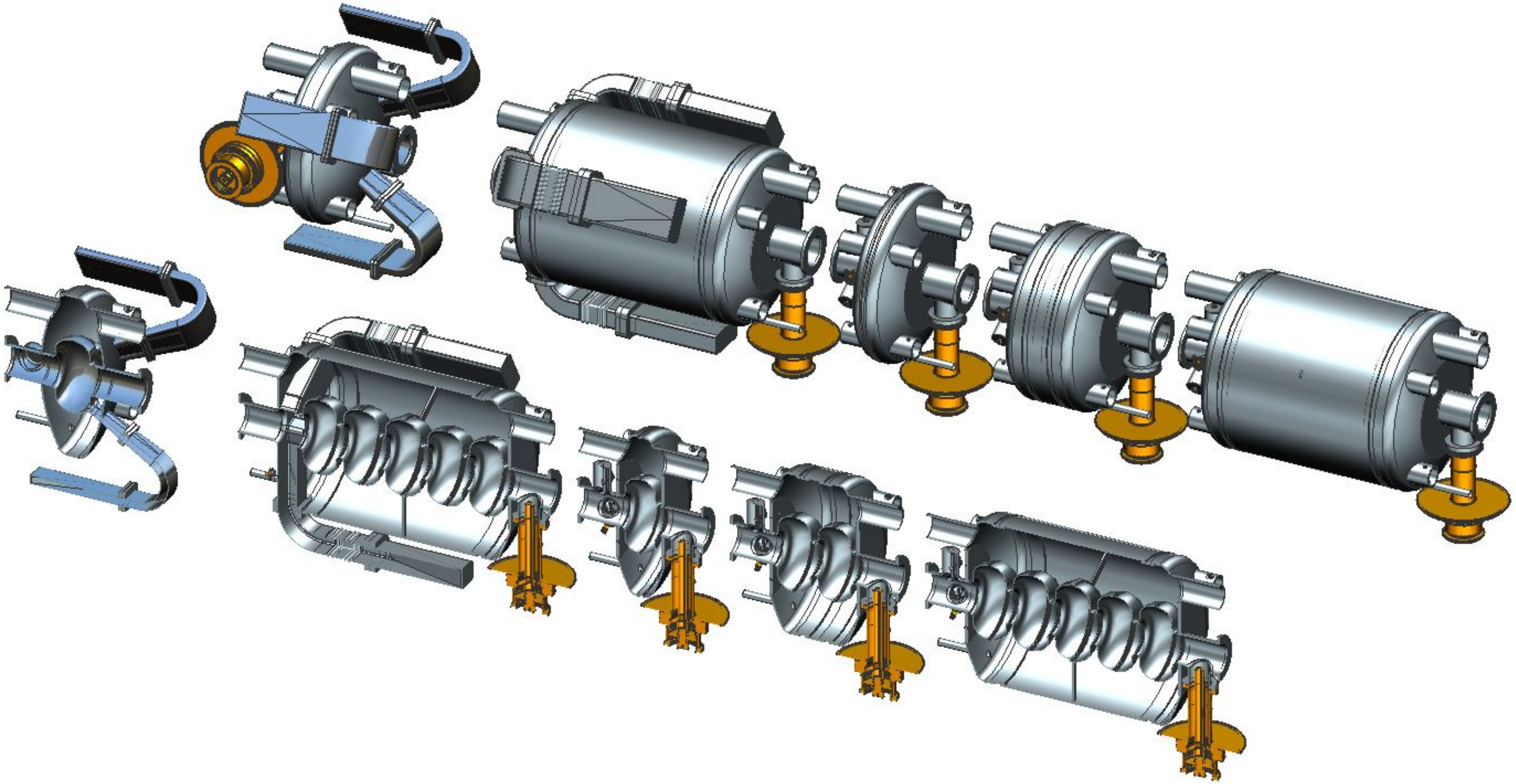


2-cell "pair"



Crab module

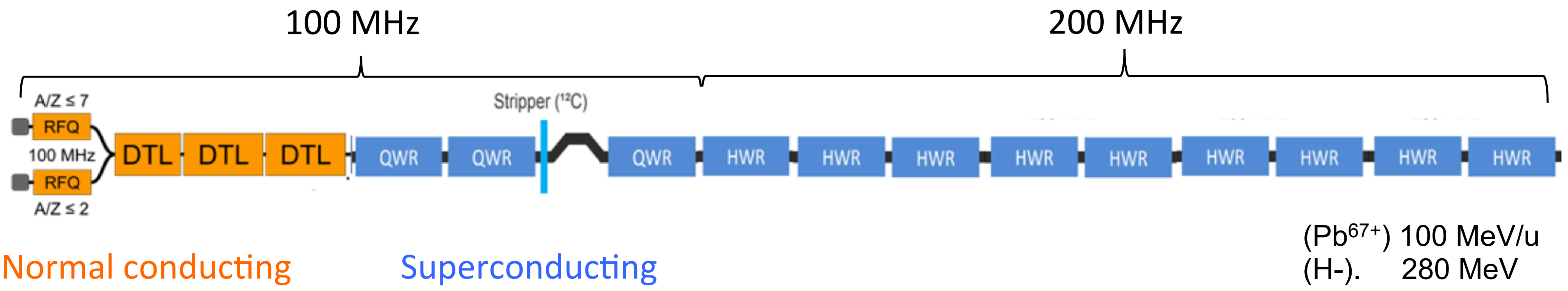
Modular helium vessel



1 to 5 cells, coax, WG or on-cell dampers

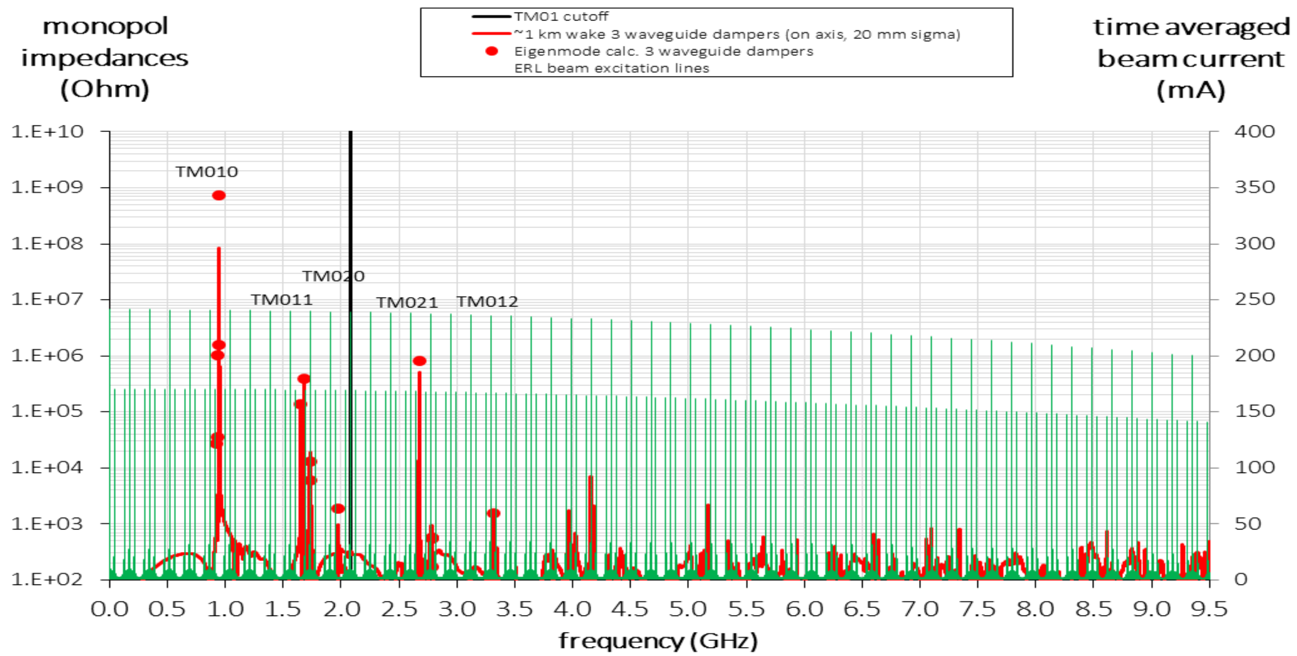
Ion Injector Linac Design

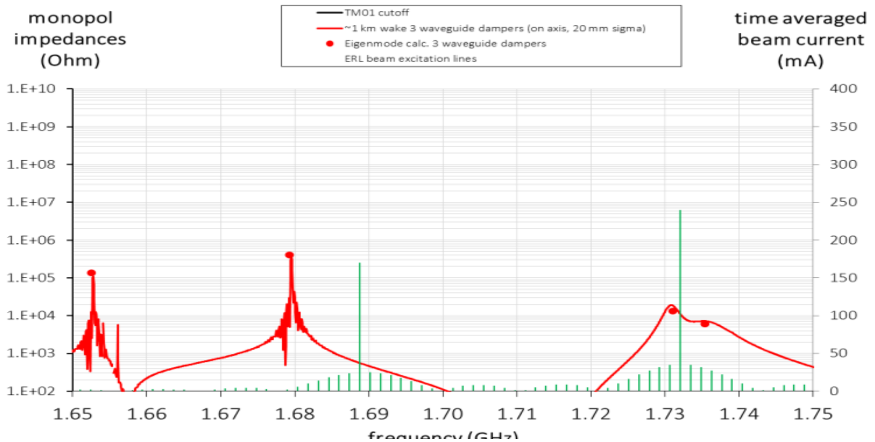
- Two RFQs: One for light ions (A/q ≤ 2) and one for heavy ions (A/q ≤ 7)
  - Different emittances and voltage requirements for polarized light ions and heavy ions
- Separate LEBTs and MEBTs for light and heavy ions
- RT Structure: IH-DTL with FODO Focusing Lattice
- Stripper section for heavy-ions followed by an SRF section
- Pulsed Linac: up to 10 Hz repetition rate and ~ 0.5 ms pulse length



JLEIC SRF --- Robert Rimmer's talk

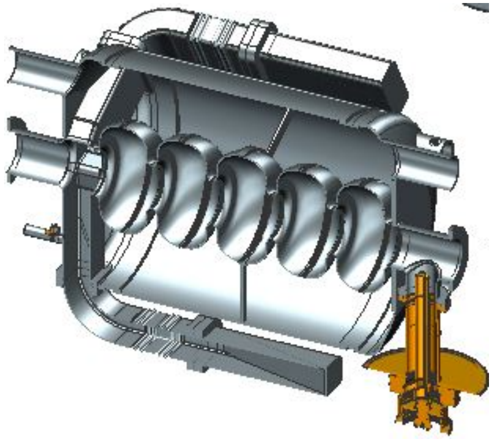
HOM Power Estimate for JLEIC CCR ERL, case 3





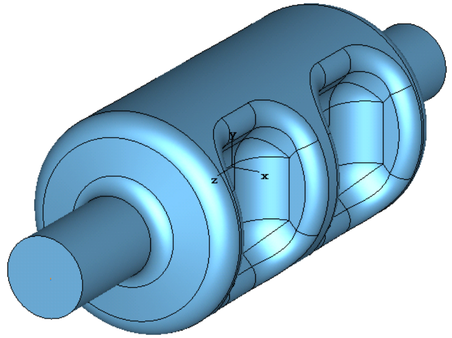
Case 3: Cooling/collision rate 476.3 MHz,
P = 2 kW up to 9.5 GHz (3 waveguide dampers) for Q = 3.2 nC

Corresponding to ERL injection current 120mA, CCR cooling current 1320mA
If CCR cooling current is scaled to 1.5A, HOM power scales to 2.6kW

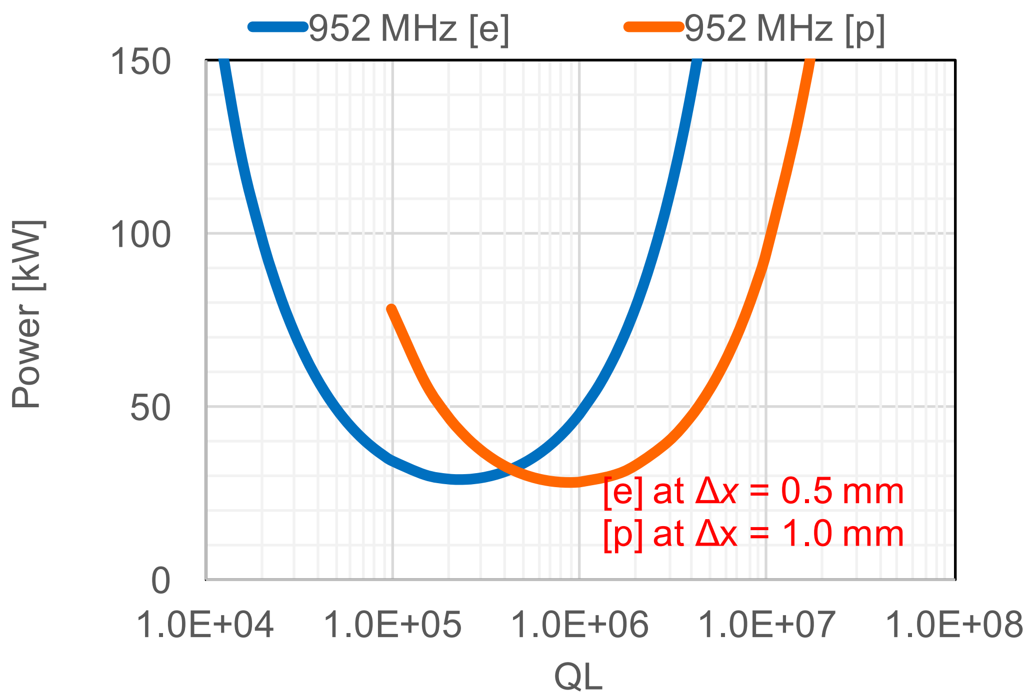


Crab Cavity – RFD 2-cell cavity

- After design survey, the prototype is converging to 952.6 MHz 2-cell RFD cavity.
- 10 GeV electron beam and 100 GeV proton beam.
- Input power coupling through beam pipe provides the QL range.



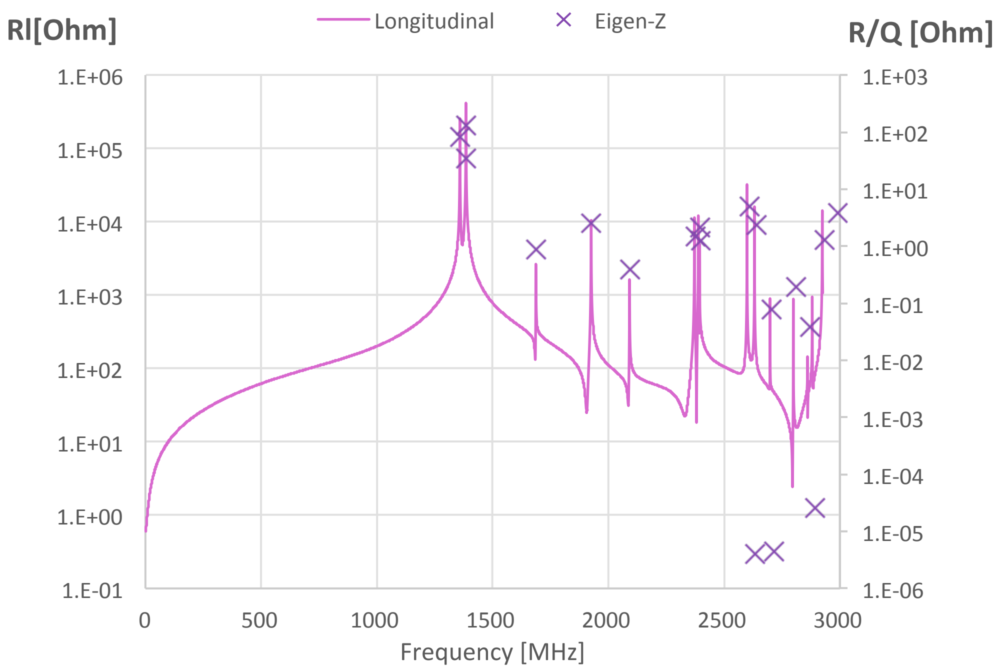
	protons	*electrons*	*Units*
Frequency	952.6	952.6	*MHz*
Required total kick	18.67	2.8	*MV*
V_t per cavity/side	1.9	1.4	*MV*
Number of cavities	10	2	-
Peak electric field	34.2	25.2	*MV/m*
Peak magnetic field	70.3	51.8	*mT*
Surface resistance	95.0	95.0	*nΩ*
Shunt impedance	0.26	0.26	*MΩ*
Dissipated power/cav	13.8	7.5	*W*

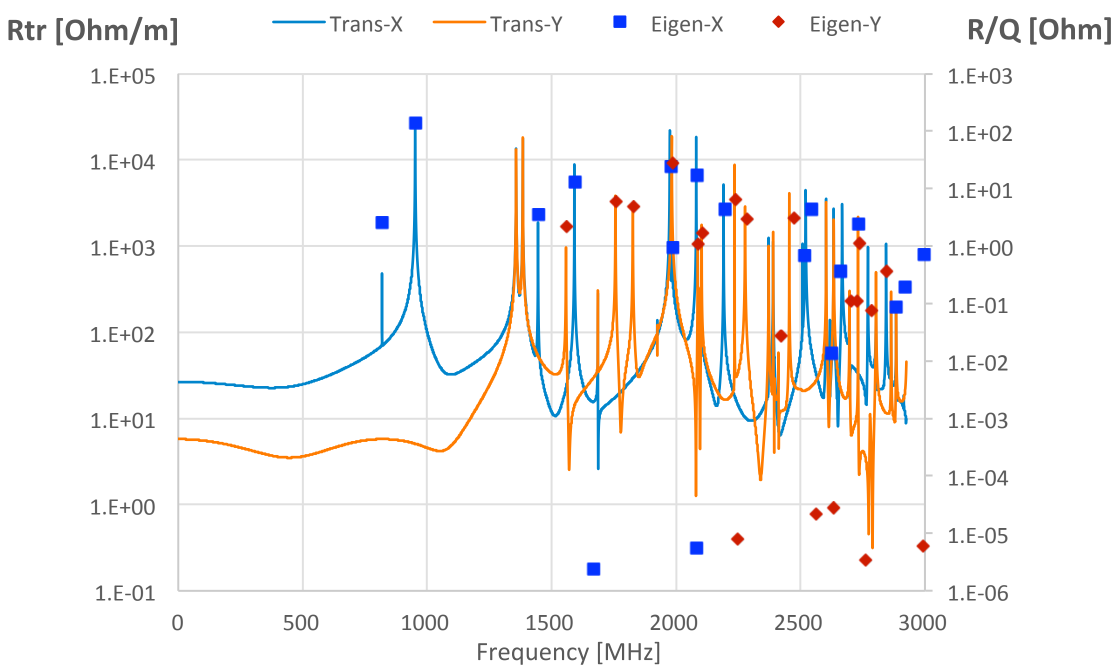


Input rf power

Impedance – Crab Cavity

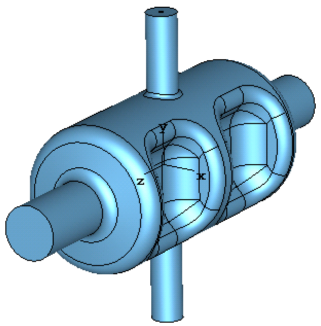
- Prototype converging to a 952.6 MHz 2-cell RFD cavity.
- Bare cavity impedance



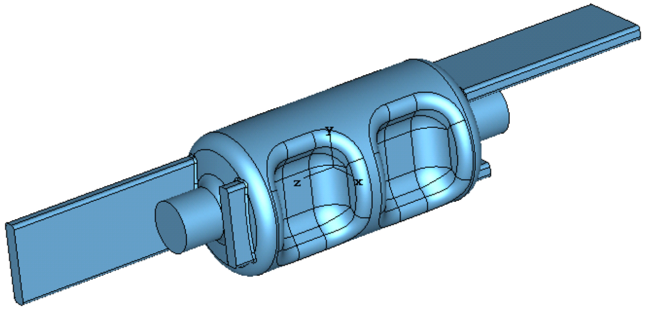


- Damping under study

2 hook couplers

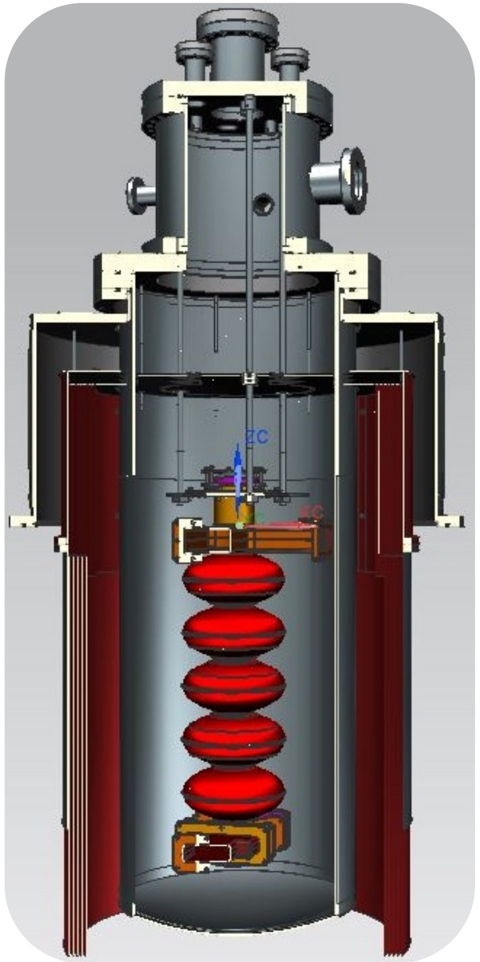


2 wave guides

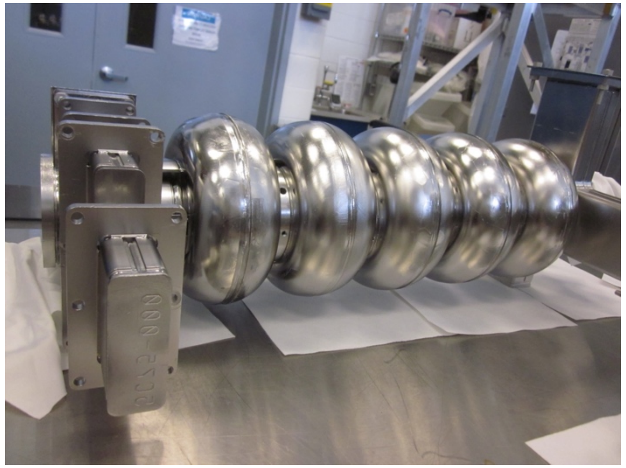


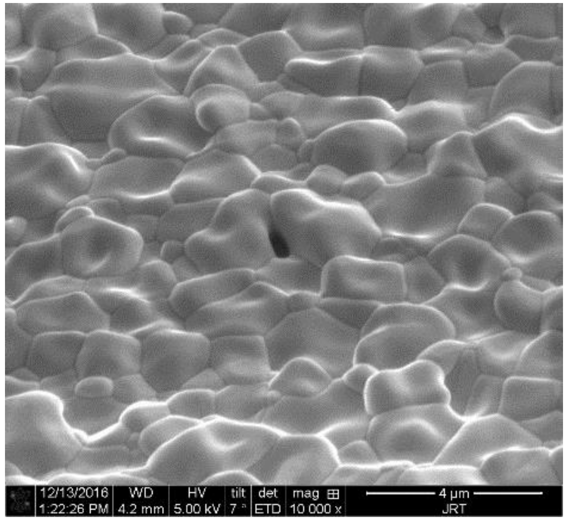
Nb_3Sn: Coating system upgrade - G. Eremeev Early Career Award

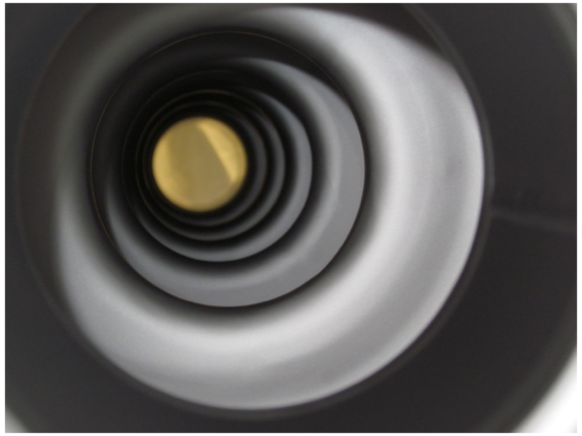
- Coating 5-cells and 1-cells goal is Nb_3Sn cryomodule with beam
- Continuous process optimization

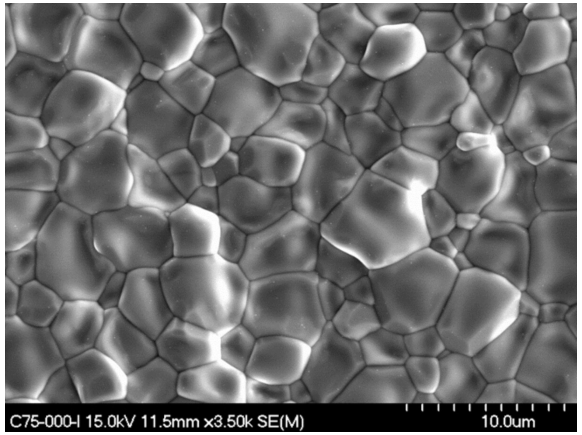


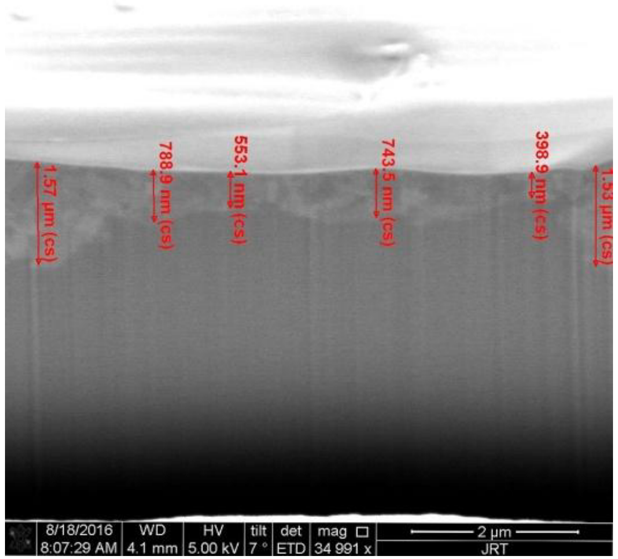
System upgrade design











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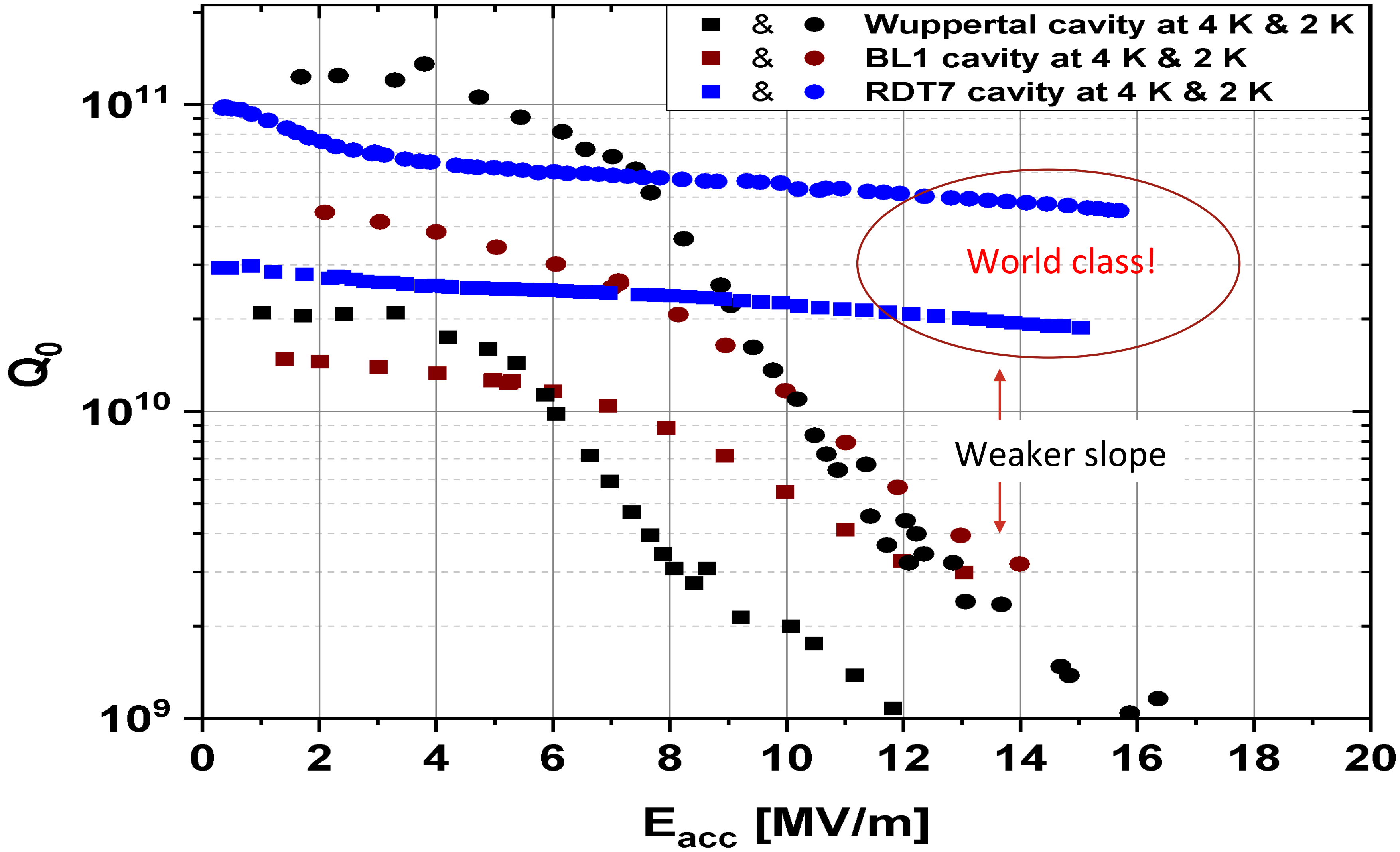
Nb_3Sn: New Cavity results



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Following titanium hypothesis, during the coating system upgrade efforts were made to avoid any potential titanium sources. Only all niobium cavities are allowed to be coated now. NbTi flanges were replaced with Nb flanges on RDT7.