SRF Systems for the Jefferson Lab Electron Ion Collider (JLEIC)

Presented by

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SRF2017, Lanzhou, China

MOXA06

Outline

- What is JLEIC?
- Why is it challenging?
  - High level parameters, frequency choice
- Storage ring cavities
  - HOM damping options
- Cooler
  - ERL Linac and injector
  - Cooler Circulator Ring (CCR) and Harmonic fast kicker
- Crab cavities (ODU)
- Gap transient mitigation experiments
- Modular cryostat
- Conclusions

JLEIC Design Update (Apr. 2017)

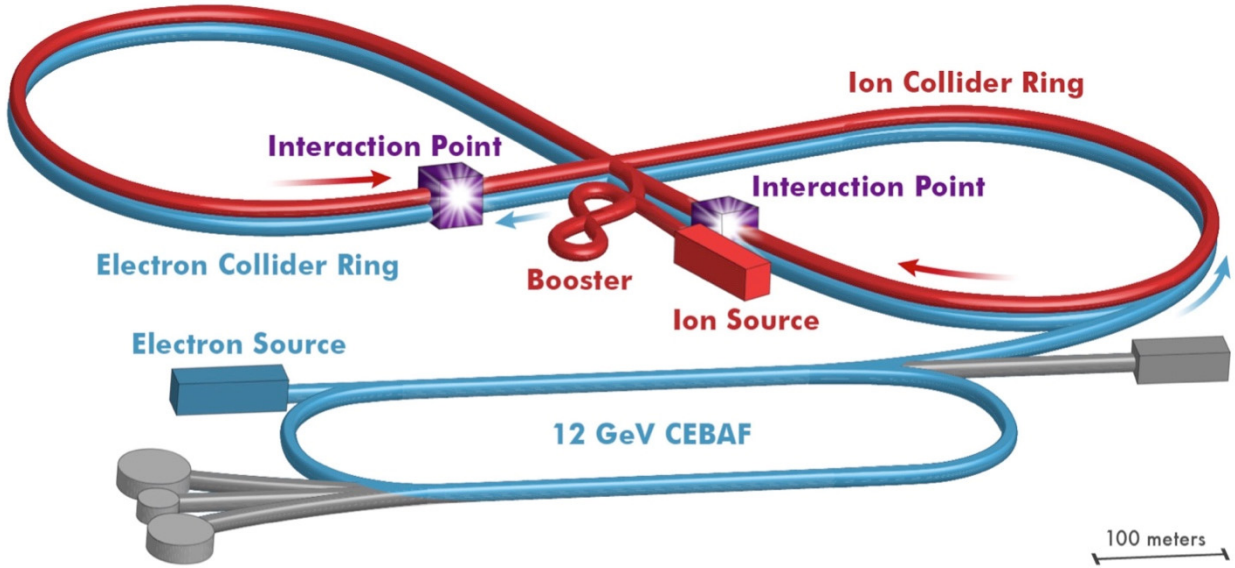
energy range:

E_e: 3 to 12 GeV

E_p: 40 to 100-400 GeV

$\sqrt{s}$: 20 to 65- 140 GeV

(upper limit depends on magnet tech. choice)

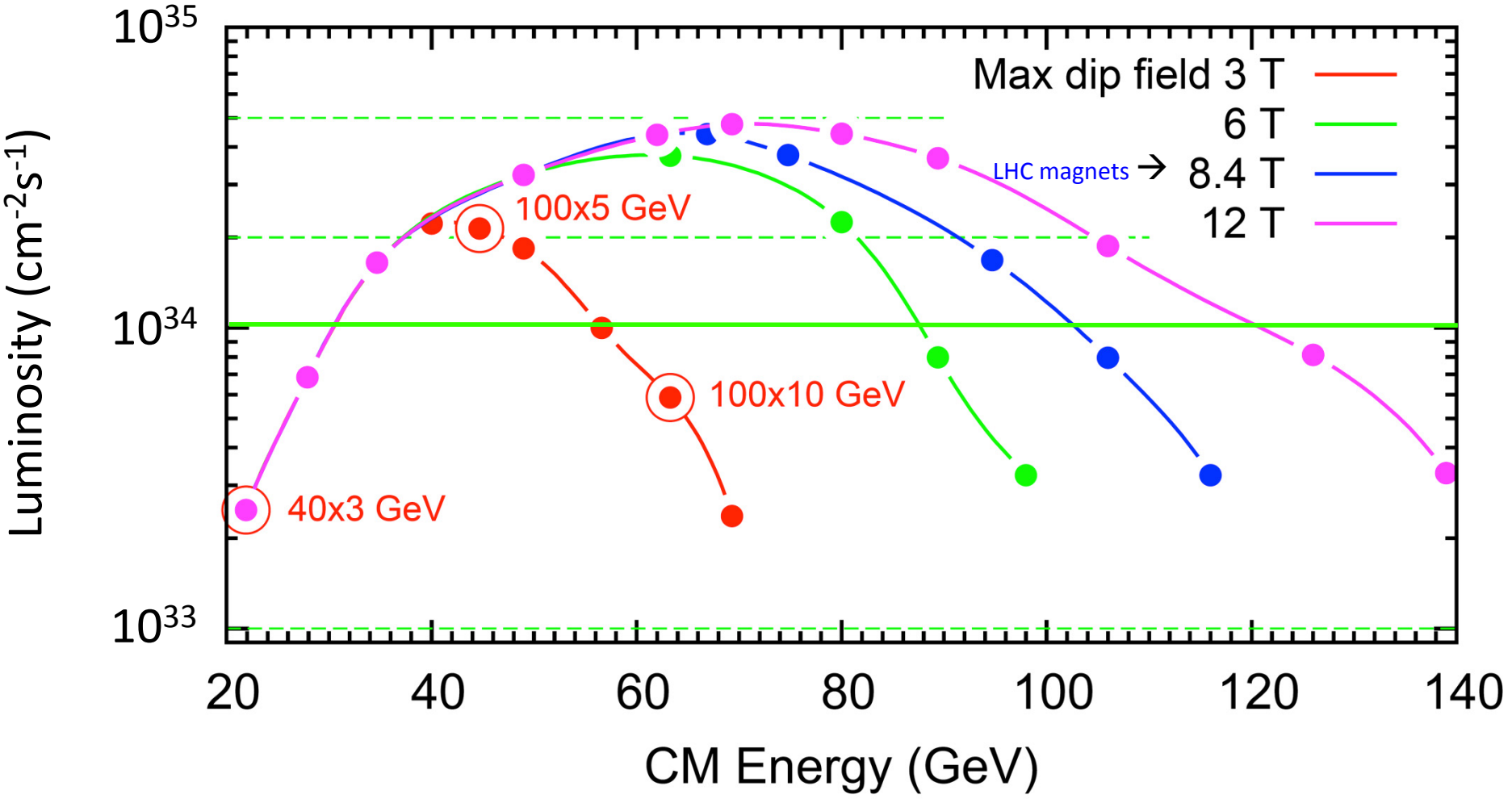


- **Electron complex**
  - CEBAF
  - Electron collider ring
- **Ion complex**
  - Ion source
  - SRF linac
  - Booster
  - Ion collider ring
- Fully integrated IR and **detector**
- DC and bunched beam **coolers**

arXiv:1504.07961

April 2017 Update

JLEIC energy reach and luminosity

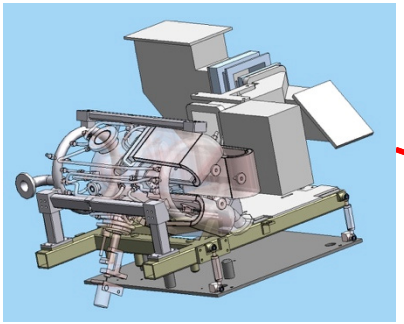


Updated high level RF parameters

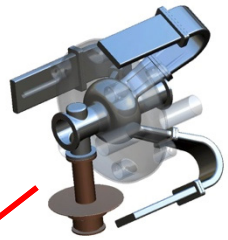
	Electron Ring NCRF				Proton SRF		Lead Ion SRF	
Energy	4	5	10	GeV	30	100	40	GeV/u
Frequency	476.3	476.3	476.3		952.64	952.77	952.57	MHz
Beam Average Current	3.000	3.000	0.708	A	0.50	0.50	0.50	A
SRpower/ring (= power to beam)	1.08	2.65	10.00	MW				
Energy Loss per Turn	0.362	0.883	14.124	MeV				
Vpeak, Total	1.82	3.59	21.69	MV	11.64	44.66	42.27	MV
Syn. Phase	11.5	14.2	40.6	degree	0.00	0.00	0.00	degree
Vgap, 1K2C	0.45	0.45	0.79	MV	0.73	1.12	1.06	MV
Vgap, 1K4C			0.47	MV				
Gradient, 1K2C	1.44	1.43	2.51	MV/m	4.62	7.10	6.72	MV/m
Gradient, 1K4C			1.49	MV/m				
PowerToBeam per Cavity, 1K2C	271.18	331.03	363.90	kW				
PowerToBeam per Cavity, 1K4C			215.62	kW				
Cavity Wall Loss Power, 1K2C	29.50	28.76	89.03	kW	0.3	0.7	0.7	W
Cavity Wall Loss Power, 1K4C			31.26	kW				
Forward Power Per Cavity, 1K2C	316.15	399.76	459.76	kW	24.00	56.54	50.65	kW
Forward Power Per Cavity, 1K4C			249.22	kW				
Reflected Power, 1K2C	15.47	39.97	6.83	kW	24.00	56.54	50.7	kW
Reflected Power, 1K4C			2.35	kW				
Qext	4615	4615	4615		5.24E+04	5.24E+04	5.24E+04	
Cavity Number, Total	4	8	34		16	40	40	

Need high efficiency RF sources. Possibly magnetrons?

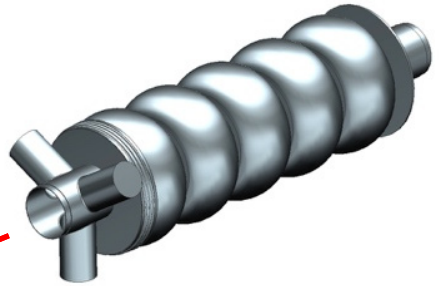
RF cavities for JLEIC



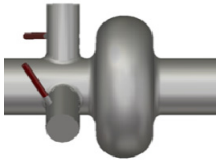
476.3 MHz e-ring
(NCRF PEP-II)



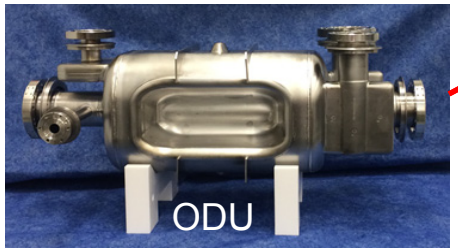
952.6 MHz i-ring
(SCRF)



952.6 MHz cooler
ERL (SCRF)



952.6 MHz booster
(SCRF)



952.6 MHz crab
(SCRF)

JLEIC
Collider
Rings

i-SRF +
NCRF

Cooling

Crab

IP

e-RF

Crab

e-RF

Future IP

Booster

SRF Linac

Ion Source

Electron Injector

12 GeV CEBAF

Hall D

Halls A, B, C

Harmonic Fast kicker
for cooling ring

JLab EIC RF Systems

- **Electron ring**: PEP-II warm RF adopted
  - Proven technology, low cost
  - Enough cavities and klystrons available
  - **476.3** MHz buckets can be filled from CEBAF linac with simple timing
  - Upgrade to **952.6** SRF in future
- **Ion ring**: new 952.6 MHz SRF bunching system
  - Plus low frequency capture, splitting and acceleration cavities
- **Cooler source and ERL** 952.6 MHz
  - Cooler baseline became **circulator ring**
- **Crab cavity system** 952.6 MHz
- Ion injector chain as developed by ANL

First 952.6 MHz Cavity Fabrication Status

Cavity	Qty.	Material	Nb blanks for half cells	Nb blanks for beam tubes	Half cells deep-drawn	Beam Tubes	Flanges	Endgroups	Cavity
1-cell	1	Nb	2/2 – wire EDM completed	wire EDM completed	2/2 - completed	Completed/ machined	Completed/ machined (Nb flanges)	2/2 Welding completed	Waiting for RF trim fixture
1-cell	2	Cu	4/4 – wire EDM completed	wire EDM completed	4/4 - completed	Rolled/ not machined yet	SS CF flanges - to be ordered	Not yet Started	-
5-cell	1	Nb	10/10 – wire EDM completed	wire EDM completed	2/10 (new fixture in place to ease release of cells)	Completed/ machined	In stock – not yet used	Not yet started	-

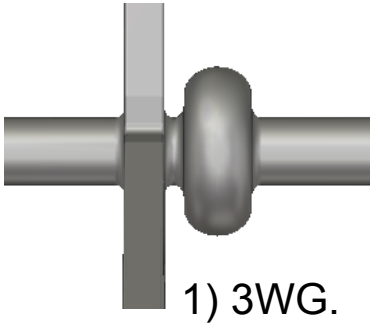
F. Marhauser et. al.

- Single-cell Nb cavity endgroups ready, getting close to complete cavity

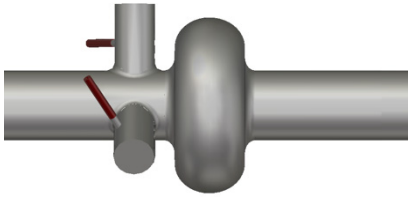



952.6 MHz SRF: HOM damping

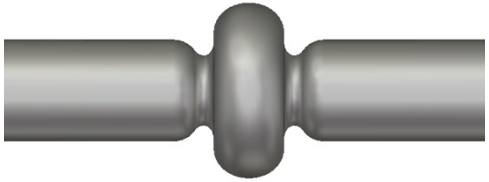
- New 952.6 MHz high-current cavity shape
- 1-cell prototype in progress
- HOM damping schemes under evaluation
- Full RF system parameter tables defined



1) 3WG.

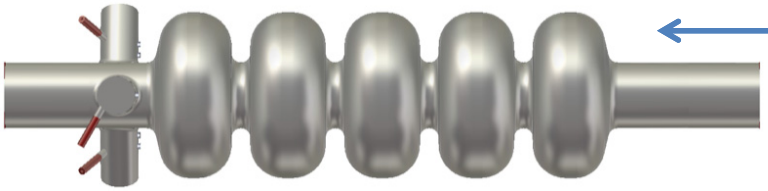


2) 3 x coax dampers.

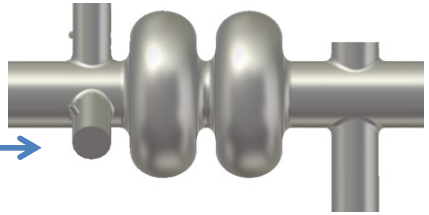


3) enlarged beam pipes (ref)

4) on-cell dampers

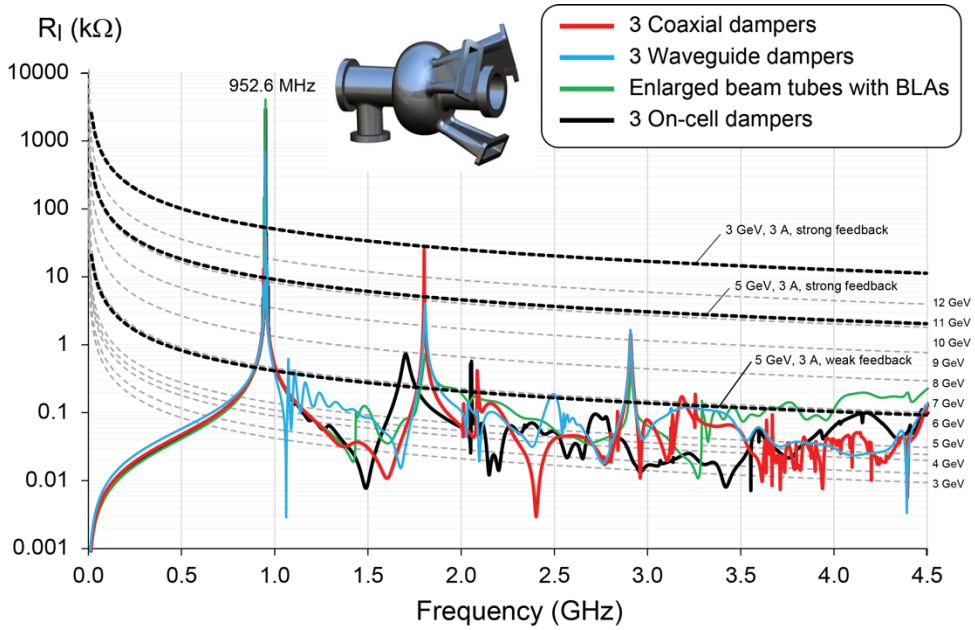


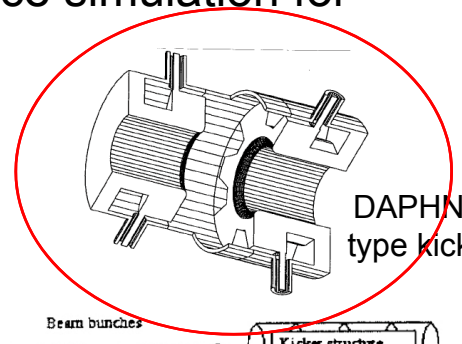
Cooler needs **5-cells** in the ERL, 1-cells in the injector. Ion ring might use **2-cells**

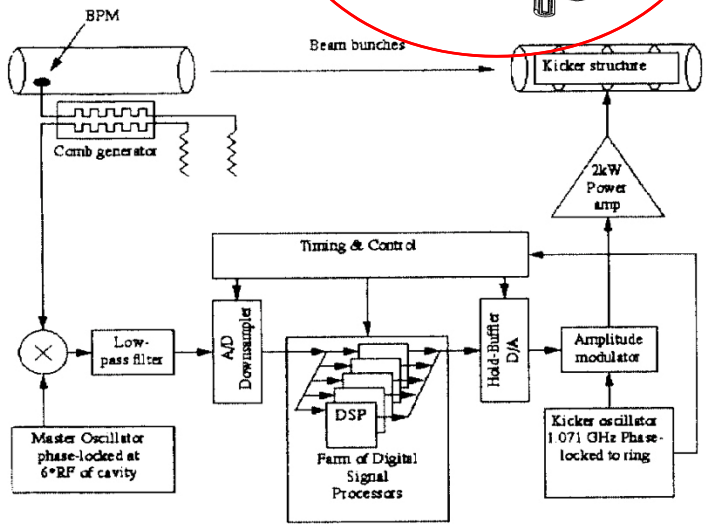


Impedance and feedback

- Broadband damping of cavity HOMs is essential
- PEP-II feedback systems allowed running above threshold. Similar systems are now commercially available
- JLEIC needs a high level system design and performance simulation for pre-CDR
- Many other ring components need to be considered
- Reliable high-power **kickers** are needed





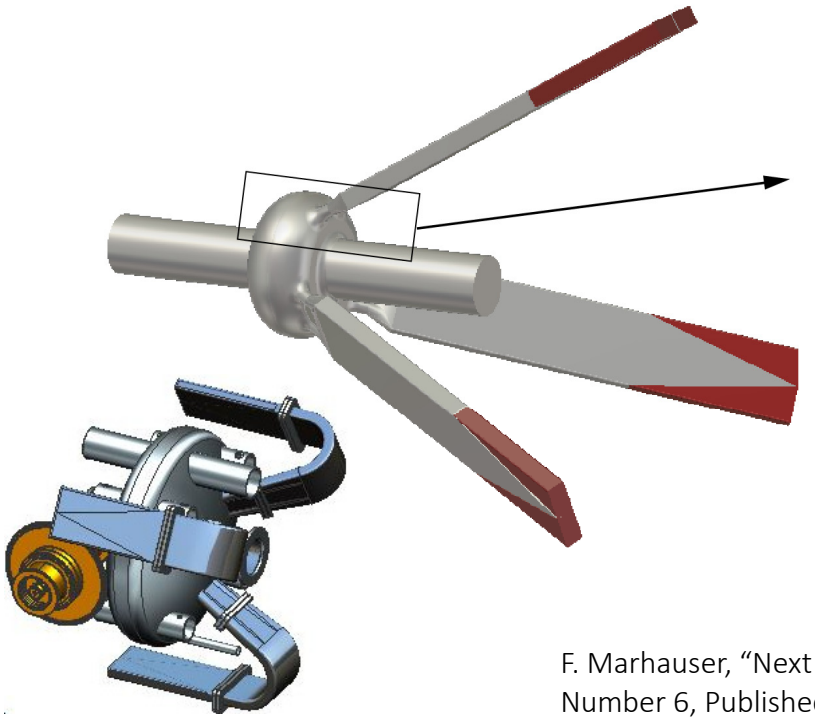


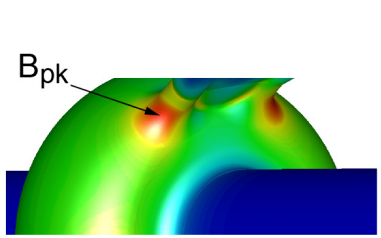
PEP-II Longitudinal Feedback system concept

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

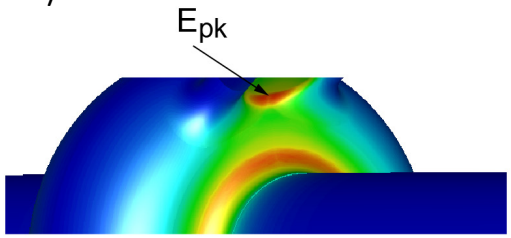
Heavily-Damped Collider Ring Cavity

- 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

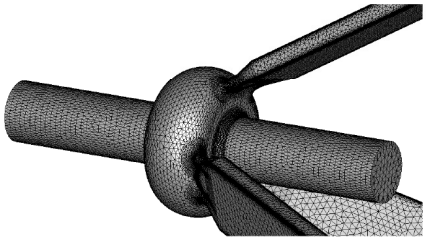




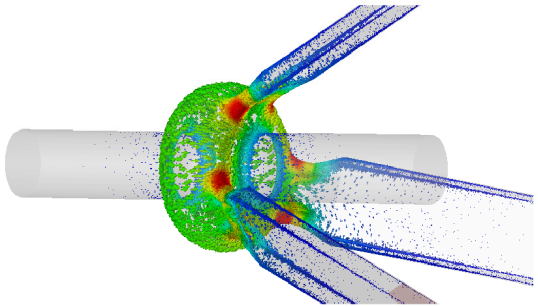
RF magnetic field contours



RF electric field contours



Tetrahedral mesh representation



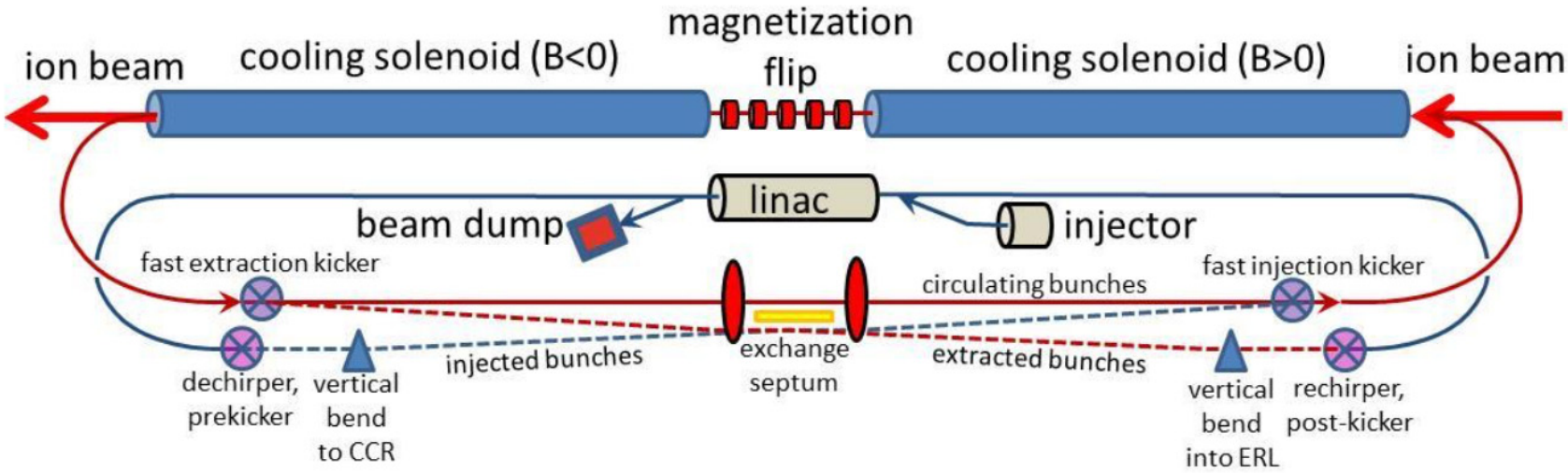
Surface currents

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

High Energy Cooling

- High energy cooling is a high priority R&D item
- Experiments at IMP suggest bunched-beam cooling works!

top ring: CCR



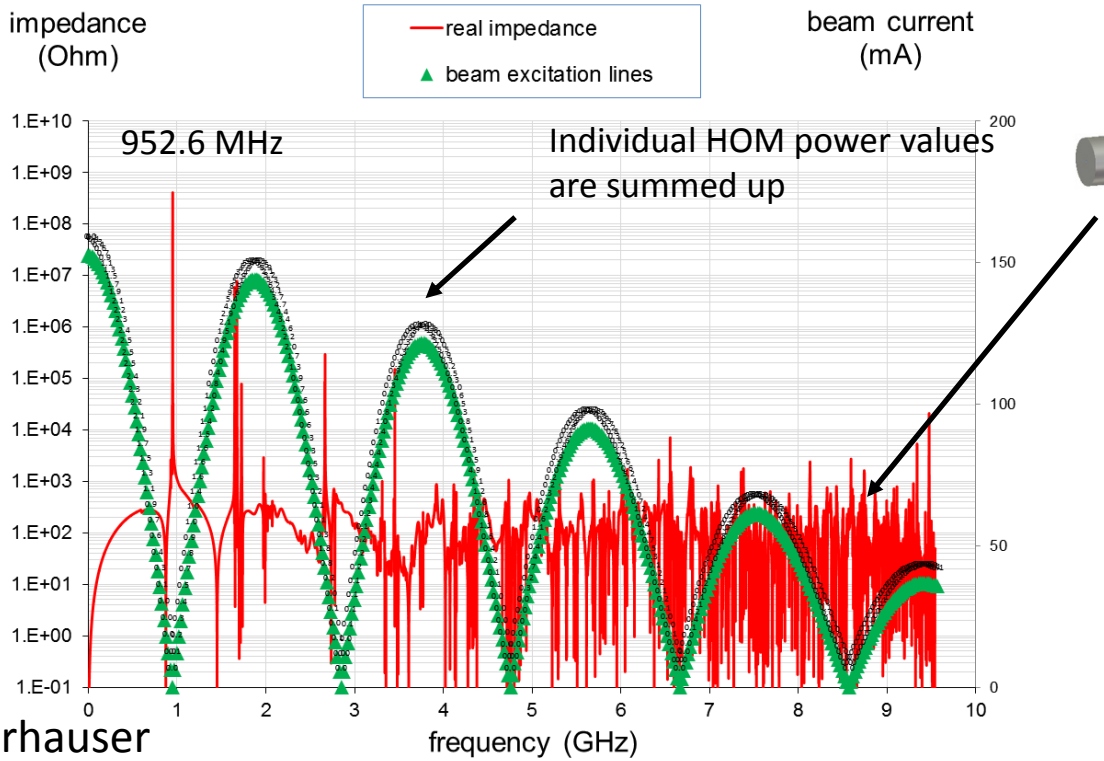
Multi-Turn High Energy Electron Cooler Baseline Design

bottom ring: ERL

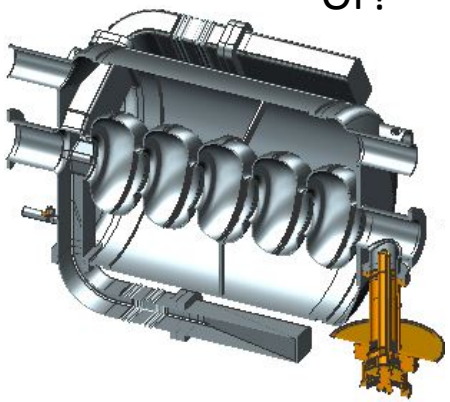
- Developing the **ERL linac** and **injector** (similar to FELs)
- CCR Harmonic Fast injection/extraction kicker (**New**)
- Impedance and wakefield calculations are important

HOM Power in ERL Cooler Cavities

- Note that the spectral lines are weighted by the nominal 20 mm **flattop** bunch length, which produces the roll-off at the high frequency end (beyond 10 GHz however there will be a ripples due to the beer-can distribution, i.e. peak currents will raise again to some extent)
- The monopole HOM power up to 9.5 GHz is **137 Watts @ 2nC** bunch charge.
- The HOM power is **350 Watts @ 3.2nC** bunch charge

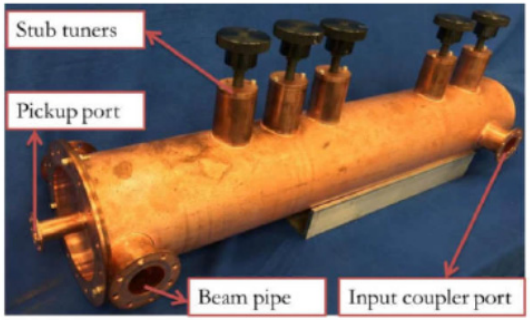


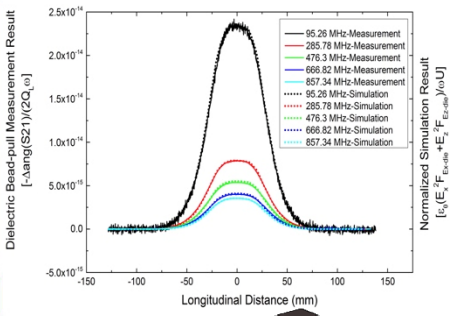
Or?

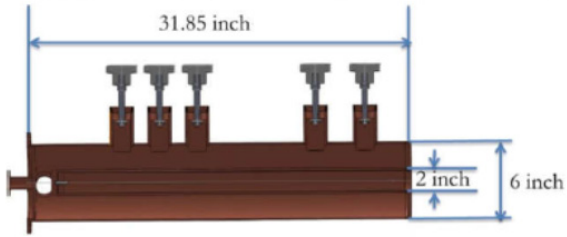


F. Marhauser

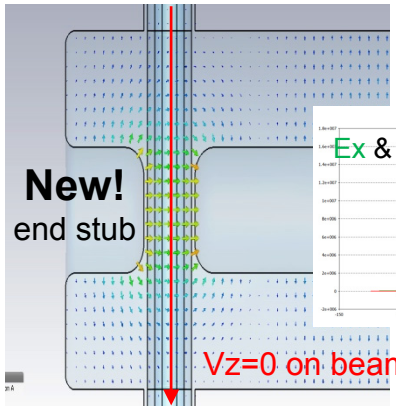
Harmonic Fast Kicker R&D

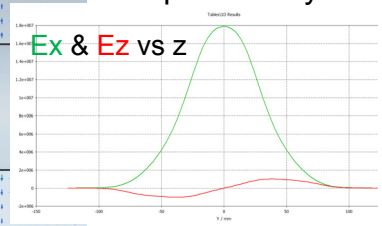


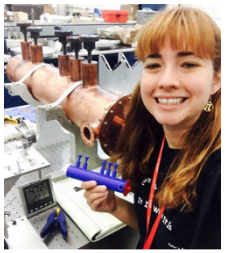




5-harmonics, copper prototype kicker Cavity, Yulu Huang, IMP/JLab PhD Thesis, 2016

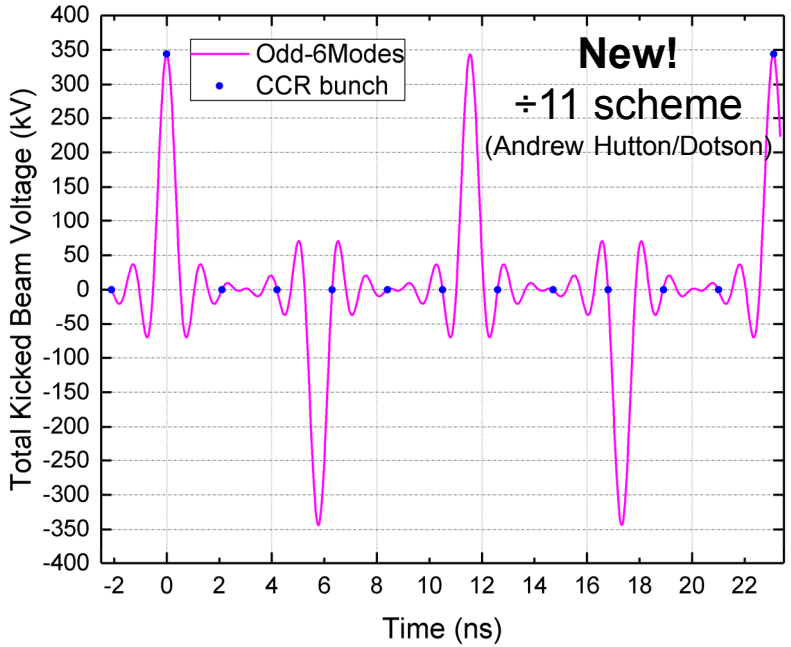






Vz=0 on beam axis for the 952.6MHz mode

Improved symmetry in gap, Sarah Overstreet summer student project 2017



138 kV kick voltage (2.5mrad@55MeV)

Baseline cavity design:

- six odd harmonics of 86.6MHz to 952.6MHz + possible DC, one cavity design for all harmonics, one-pair for CCR
- High shunt impedance, ~3kW @138kV per cavity
- Asymmetric inner conductor design for the 952.6MHz mode to minimize the beam loading effect

Compatible for future proposal of beam based tests at UITF/LERF Gun needs to operate at 136MHz rep rate

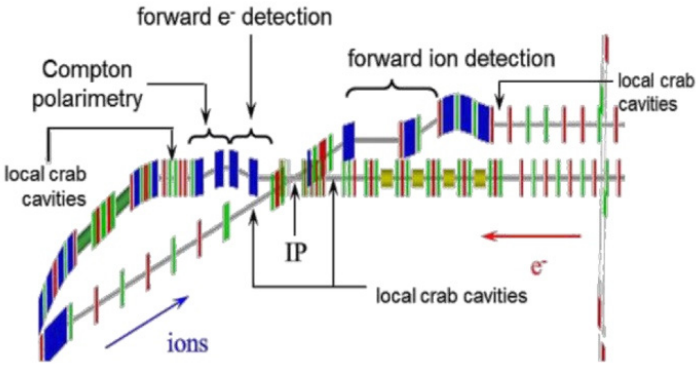
JLEIC Crab cavity

Design by ODU

- 952.6 MHz “RF dipole” like LHC
- Modest RF system (no beam loading)
- Must have good HOM damping
- Cryostat may be similar to other cavities
- Multi-gap RF dipole would be very desirable

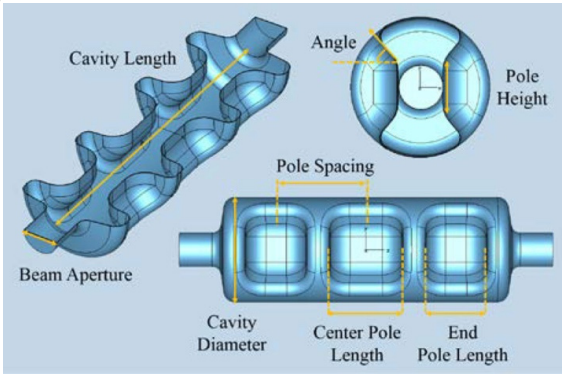
Parameter	Unit	Electron	Proton
Energy	GeV	10	100
Bunch frequency	MHz	952.6	
Crossing angle	mrad	50	
Betatron function @ IP	cm	10	
Betatron function @ crab cavity	m	~200	363.44
Integrated kicking voltage per IP side	MV	~2.8	20.82
Number of cavities per IP side (single cell RFD)		3	18
Number of cavities per specie		6	36

Parameters still evolving



Location in IP

LARP/LHC prototype*



Multi-gap concept

EFFECTS OF CRAB CAVITIY MULTIPOLES ON JLEIC ION RING DYNAMIC APERTURE, Salvador Sosa, V. Morozov, S. U. De Silva, J. R. Delayen, WEPIK044 proceedings of IPAC2017, Copenhagen, Denmark

CRAB CAVITY R&D, Jean Delayen, JLEIC Collaboration Meeting Spring 2017

*L. Ristori HL-LHC AUP Director’s Review – June 13 2017

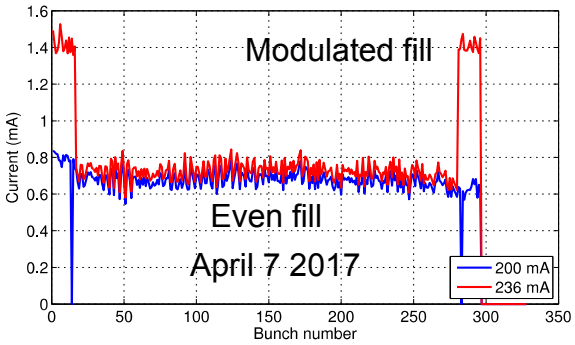
Beam Transients in collider rings

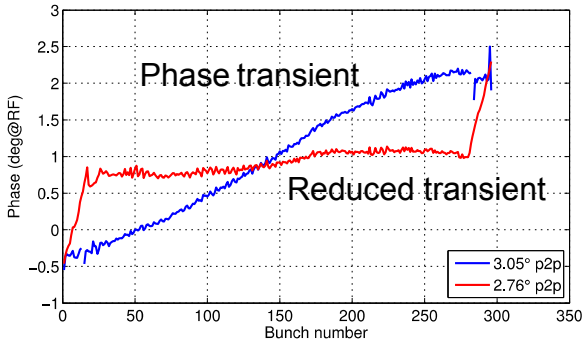
Gaps in high current rings cause strong transients (e.g. KEK-B, PEP-II). Cannot be corrected by RF alone.

Does Fill Pattern Modulation* Work? YES!

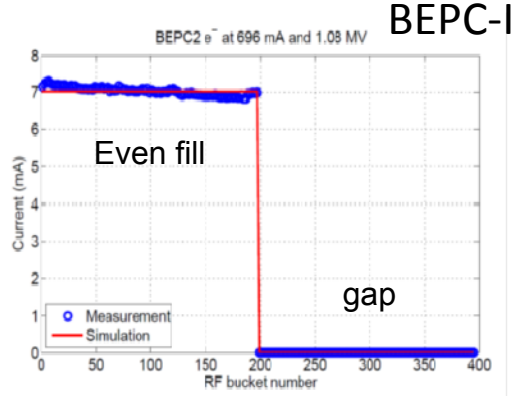
Collaboration with LBNL, JLab, IHEP and DimiTel.

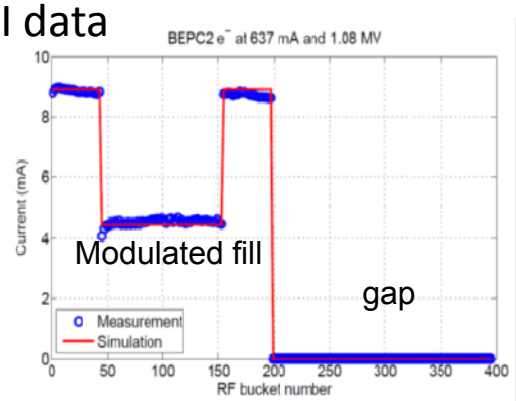
ALS data

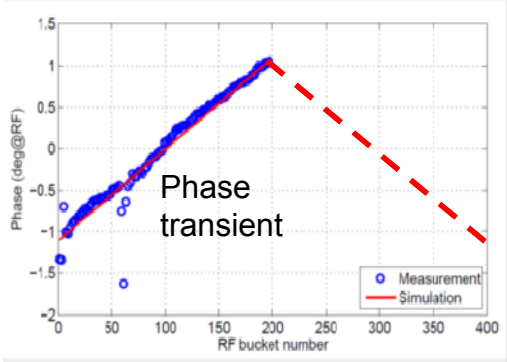


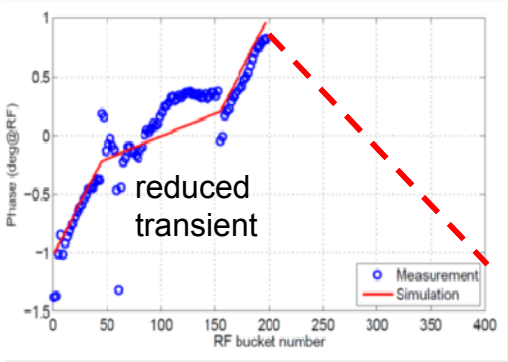


BEPC-II data







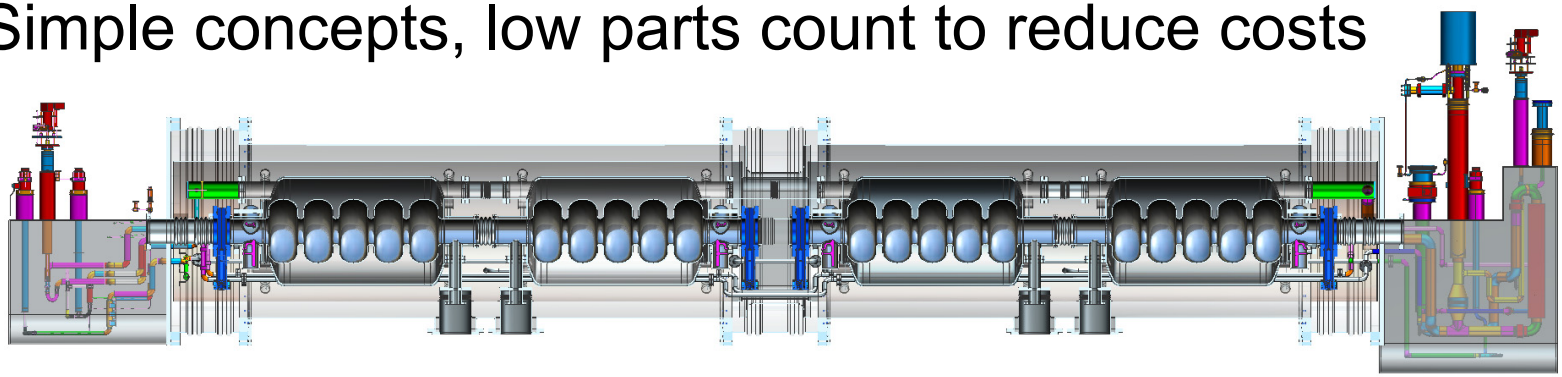


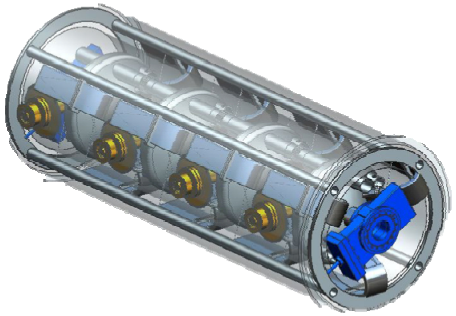
D. Teytelman, Dimtel, Inc., San Jose, CA, USA.
"Transient beam loading in FCC-ee (Z)", FCC Week 2017

*J.Byrd e.tal.,Phys.Rev. ST Accel. Beams 5, 092001 (2002)

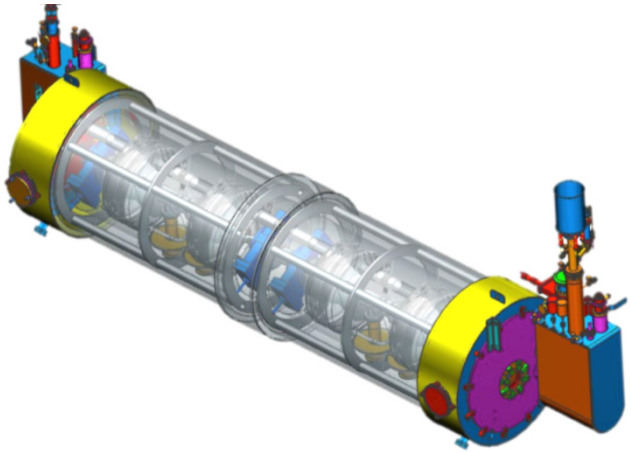
Modular cryostat

- 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

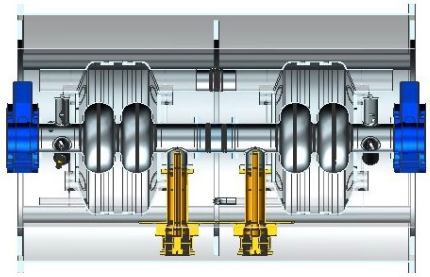




4 x 1-cell cavities
On-cell HOMs

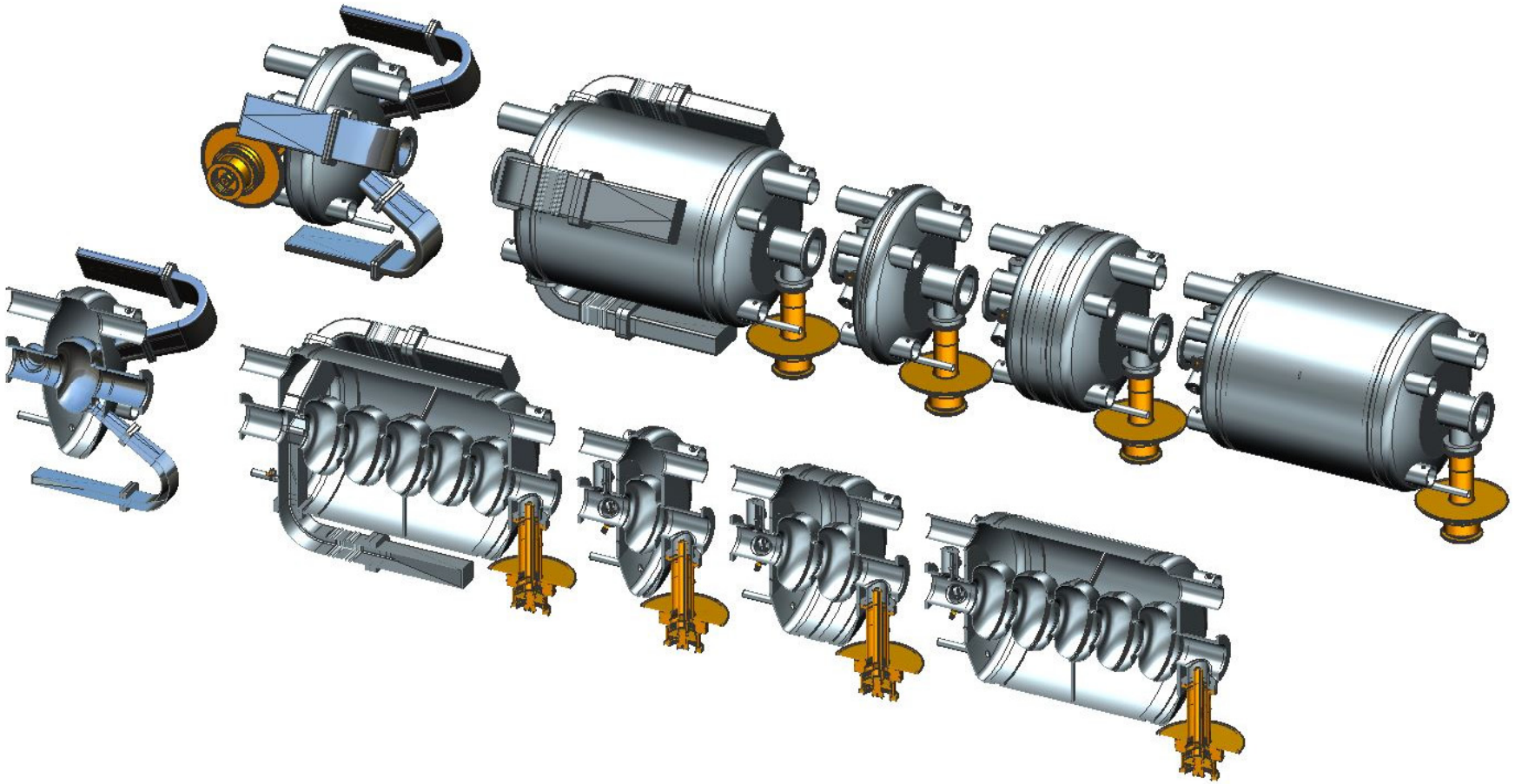


4 x 2-cell cavities



2-cell “pair”

Modular helium vessel

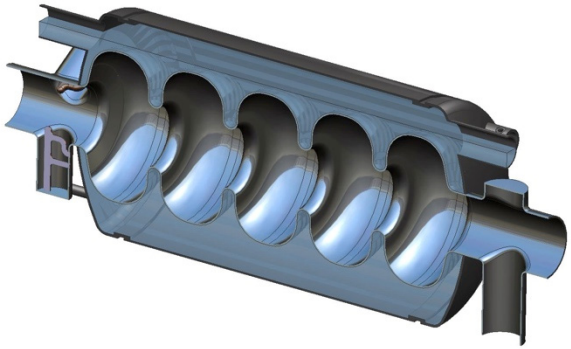


1 to 5 cells, coax, WG or on-cell dampers

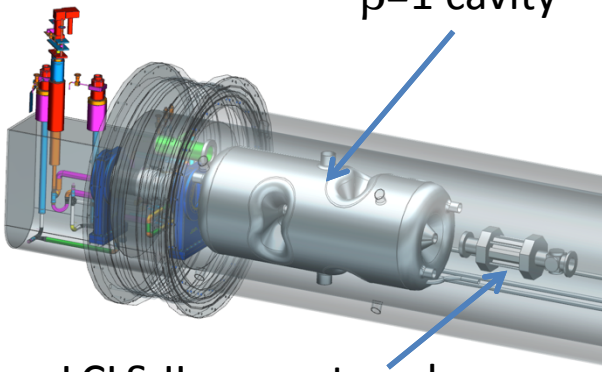
Modular cryostat: other examples

Concept is very versatile!

650 MHz 5-cell cavity?

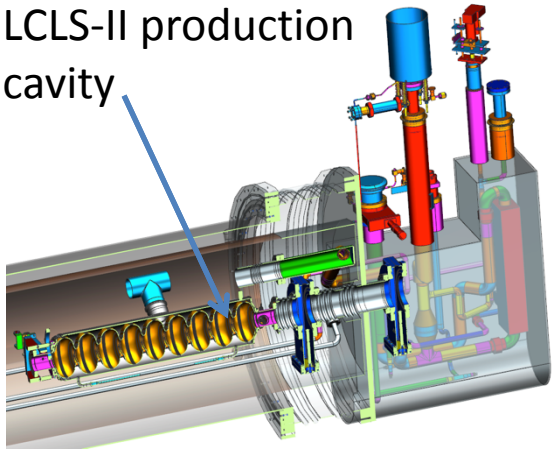


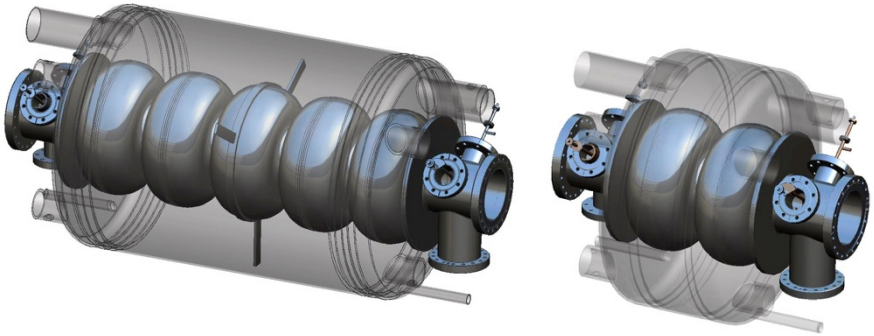
400 MHz Double spoke β=1 cavity



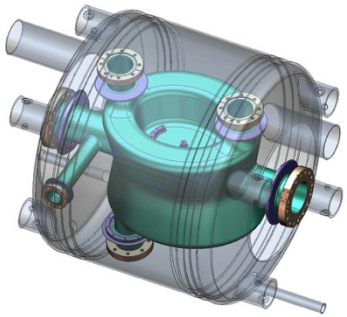
LCLS-II magnet package

LCLS-II production cavity

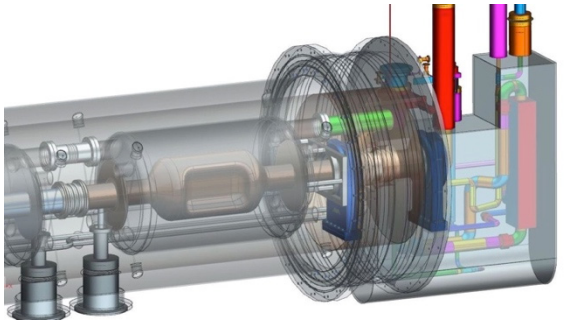




802 MHz LHeC/FCC cavity?



400 MHz DQW?



476.3 MHz RFD Crab cavity?

Conclusions

- JLEIC has several challenging SRF cavity needs
- 952.6 MHz cavity designs are progressing
  - First prototype nearing completion
  - HOM damping schemes being refined
- Strong Cooling baseline ERL and CCR require
  - 5-cell and 1-cell cavities (similar to FEL's)
  - Fast harmonic kicker (looks very promising)
- ODU "RF dipole" crab cavity looks good
- e-ring and i-ring system stability looks OK
  - Continue optimization, study feedback, transients
- Modular cryostat can hold many types of cavity
- Concepts may be useful for other projects

Thank you for your attention!