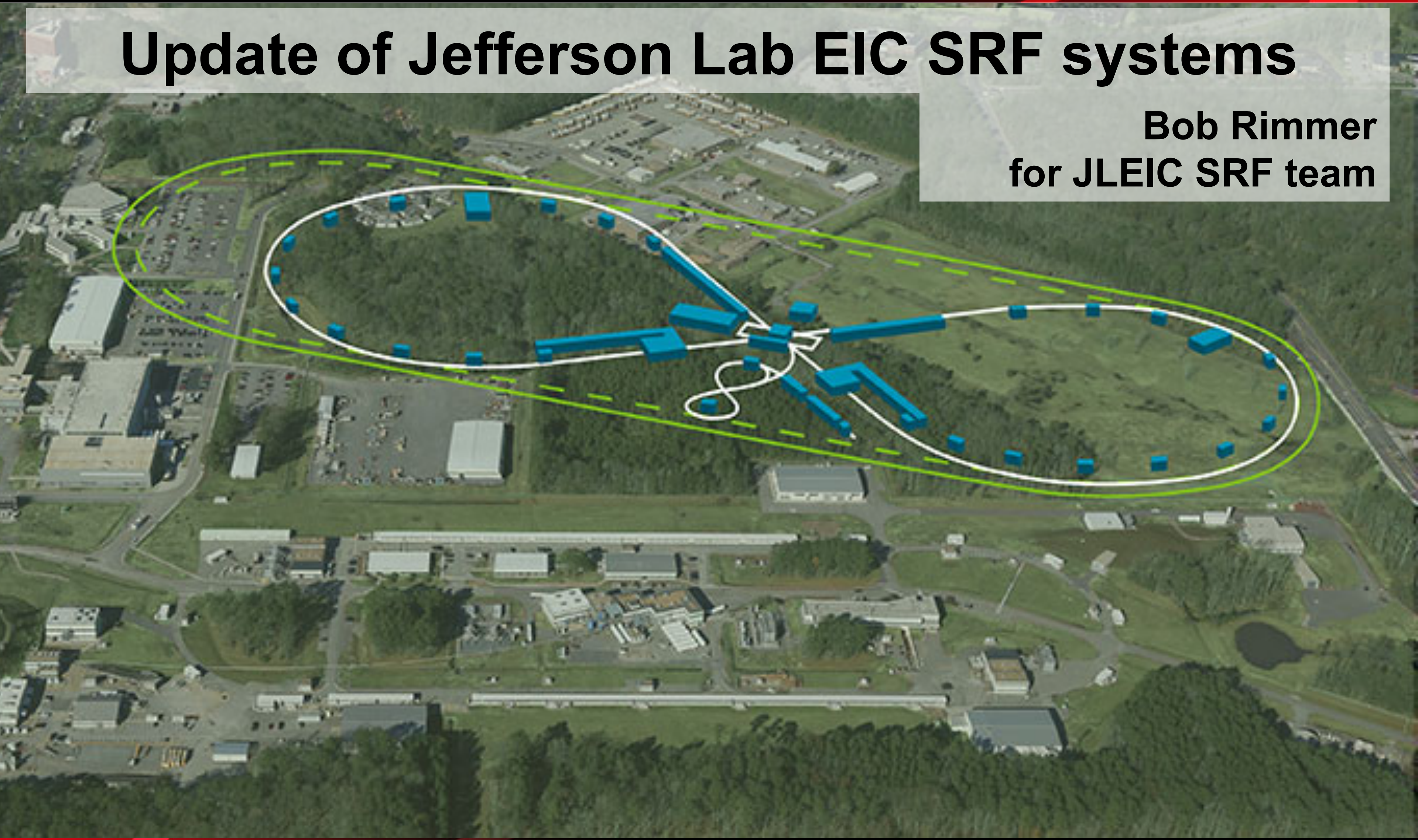
U.S. DEPARTMENT OF ENERGY | Office of Science
JSA

Update of Jefferson Lab EIC SRF systems

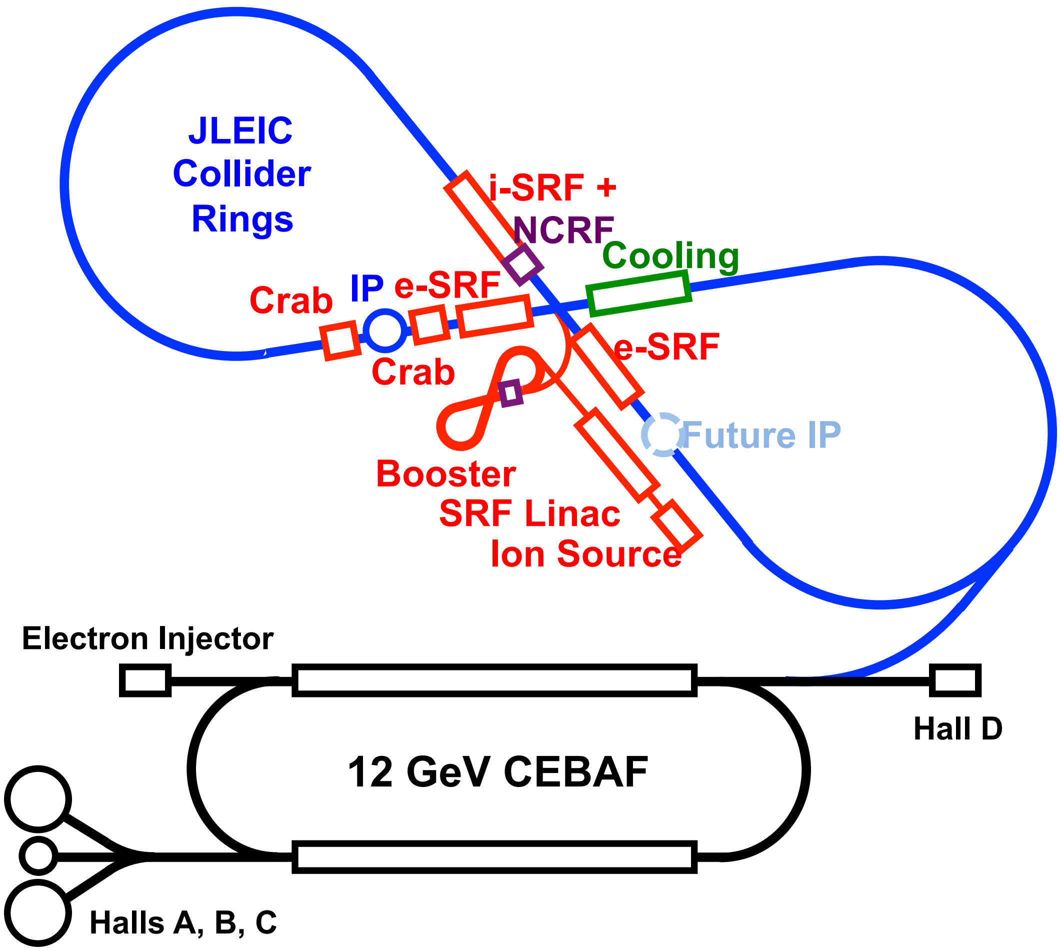
Bob Rimmer
for JLEIC SRF team

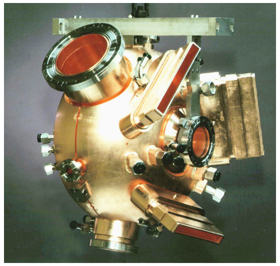


Outline

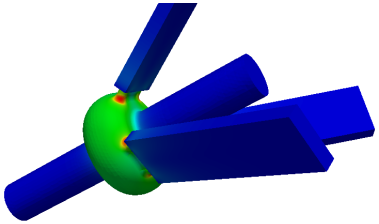
- Overview
- Electron complex
  - CEBAF as a full-energy injector (feed forward)
  - Electron collider ring (baseline unchanged, Robinson, BBU)
  - 952.6 MHz SRF option/upgrade (See Shaoheng’s talk)
- Ion complex
  - Ion collider ring (cavity update)
  - Higher energy option
  - Bunch forming scheme (See Jiquan’s talk)
  - High energy electron cooling (ERL cavity update)
    - Ultra-Fast harmonic kicker (See Yulu’s talk)
- Crab cavities (see Vasily, Salvador & Suba’s talks)
- Cryomodules
- Conclusions

Baseline parameters have remained stable



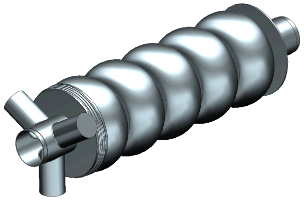


476.3 MHz e-ring
(NCRF PEP-II)

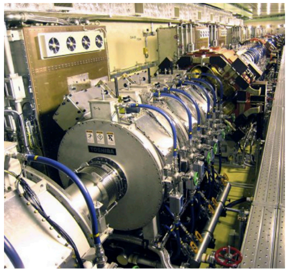


952.6 MHz i-ring
(SCRF)

952.6 MHz crab
(SCRF)

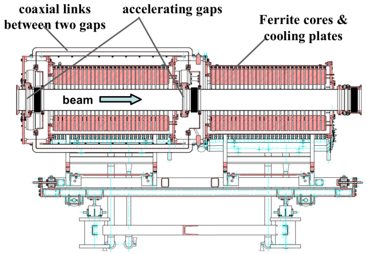


952.6 MHz ERL
(SCRF)



1MHz ion booster
(METGLAS loaded)

Or

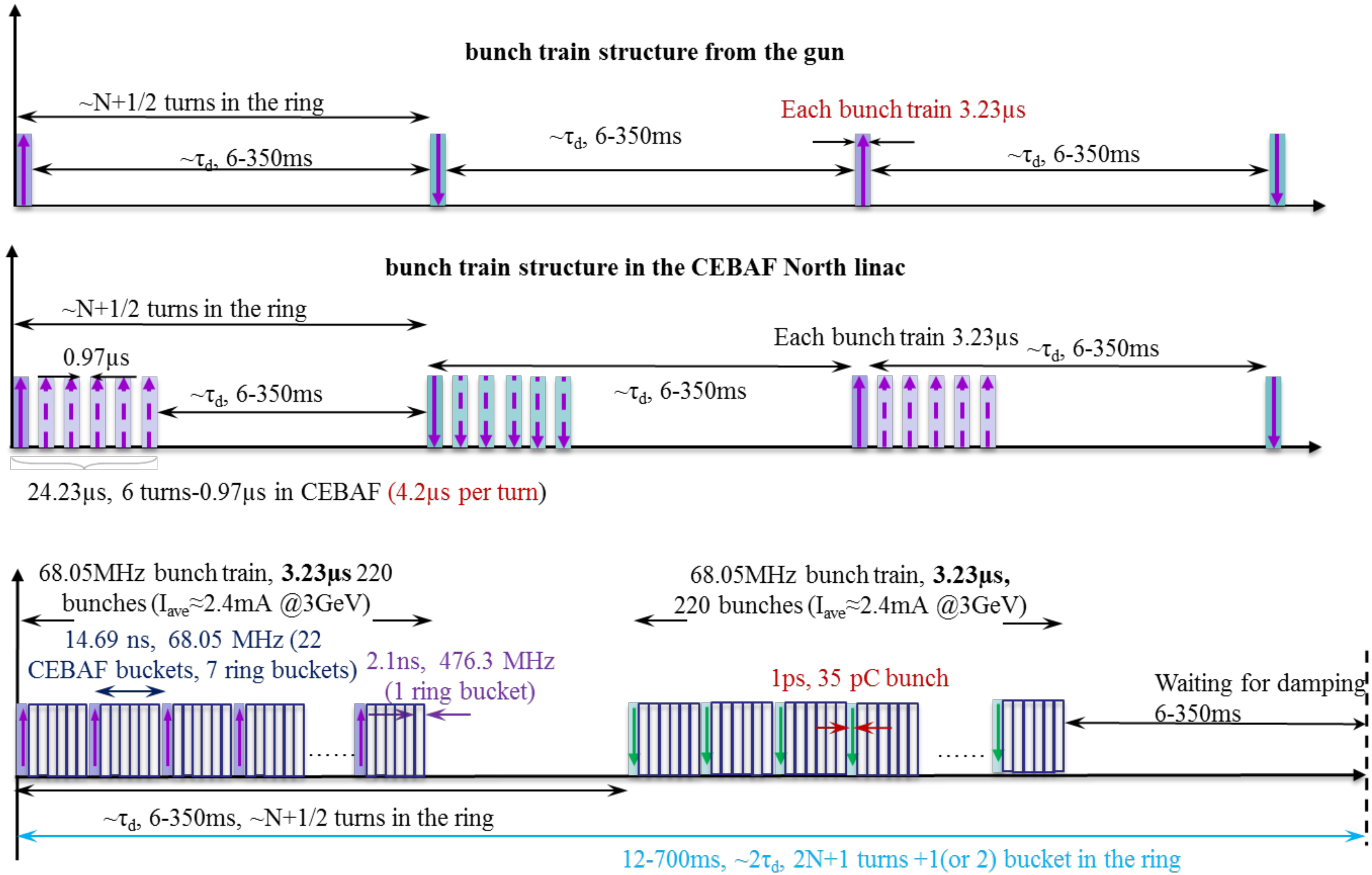


1MHz ion booster
(Ferrite loaded)

CEBAF as a full energy injector

J. Guo

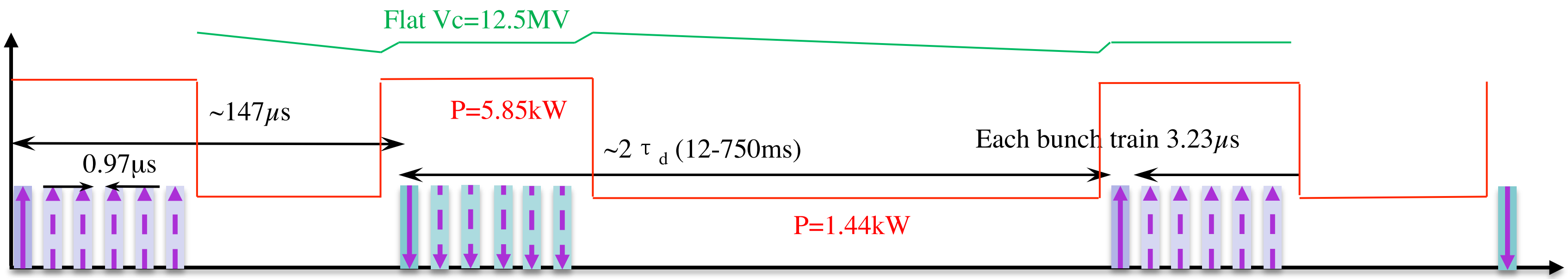
Injection train from CEBAF can be done but would cause transient beam loading



CEBAF as a full energy injector

J. Guo

Use feed-forward to counteract transient beam loading



24.23μs, 6 revolutions - 0.97μs in CEBAF (4.2μs per rev)

Cavity type	Desired Q_e	Vc (MV)	Klystron power (kW)	Energy (GeV)	Ib_{ext} (μA)	Ib_{ext} (μA) Current CEBAF CW	Q/bunch, 68MHz (pC)	2τd (ms)	ΔVc/Vc	Δp/p	JLEIC injection time (minutes)
C100	1×10^7	3	4.9	3	1500	~100 (Due to BBU)	22	750	0.14%	0.2%	~25
C50	6.6×10^6	1	1.7						0.25%		
C20	6.6×10^6	1	1.7						0.25%		
C100	3.3×10^6	3	6	3	2400	~100	35.2	750	0.24%	0.33%	~16
C50	3.3×10^6	1	2.4						0.40%		
C20	3.3×10^6	1	2.4						0.40%		
C100	1×10^7	6	5.7	6	1200	~170	17.6	71	0.06%	0.08%	~3
C50	6.6×10^6	2	1.9						0.10%		
C20	6.6×10^6	2	1.9						0.10%		

1. Calculation only considered droop from the 0.97μs gap. Other factors like delay should be corrected by pulse-to-pulse feedback.
2. Assumes 5.5 turns operation for all.
3. C100/R100 Qext needs to be lowered with stub-tuners for low gradient/high current operation.
4. No show stoppers for energy > 6GeV.

e-ring stability modeling

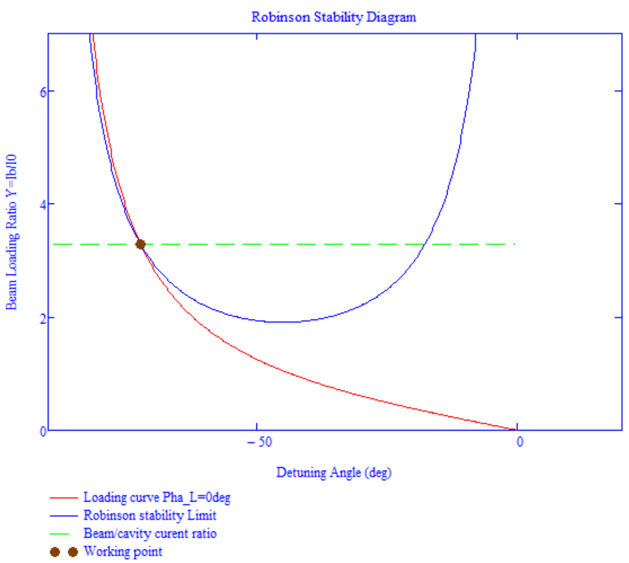
H. Wang

Developing models to understand Robinson stability margin at high current

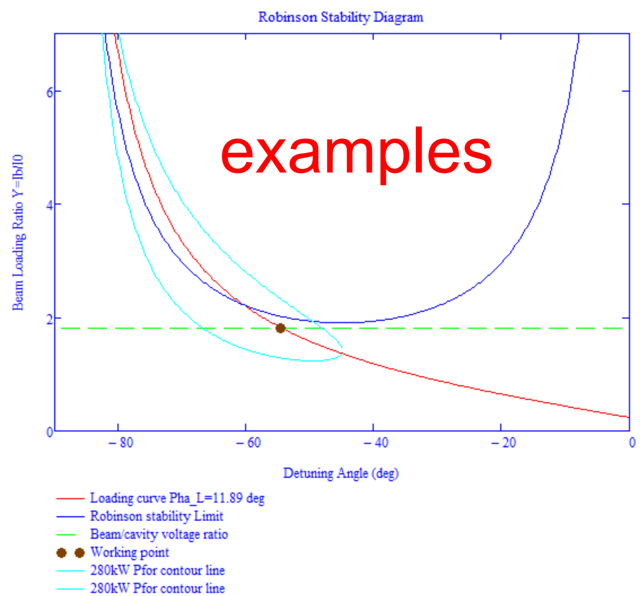
Sensitive to number and type of cavities, feedback gain, delay, power margin and gap transients

Calibrate against other rings (PEP-II, BEPC-II, KEK-B)

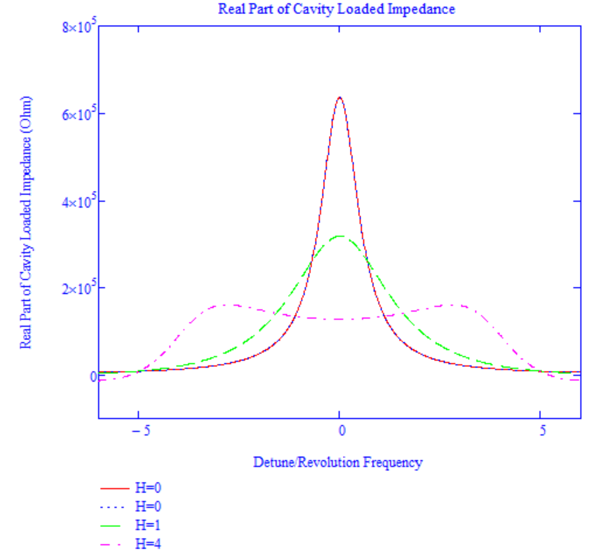
Work in progress…



Without feedback

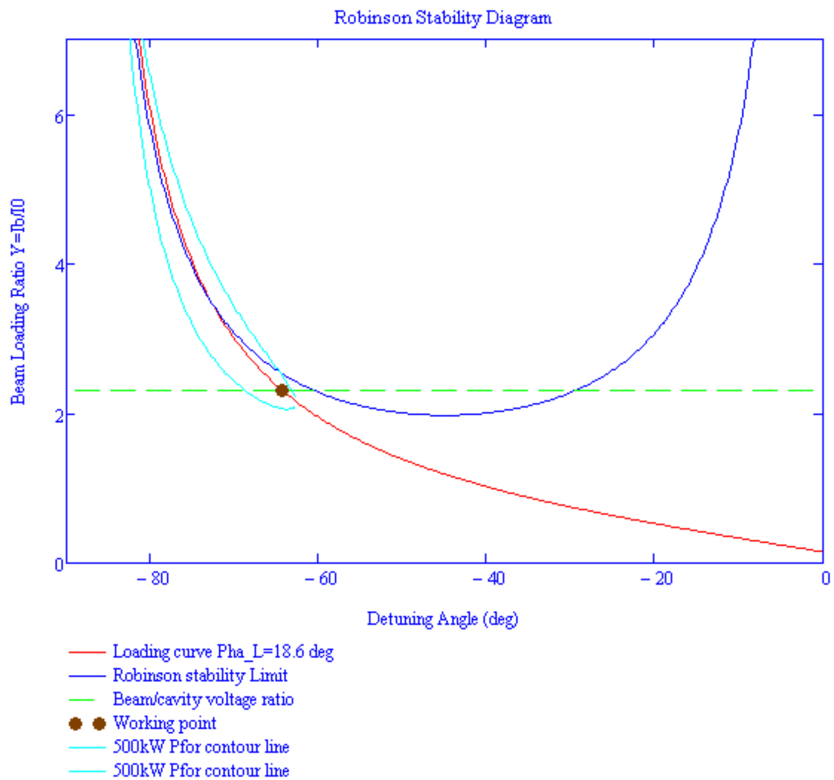


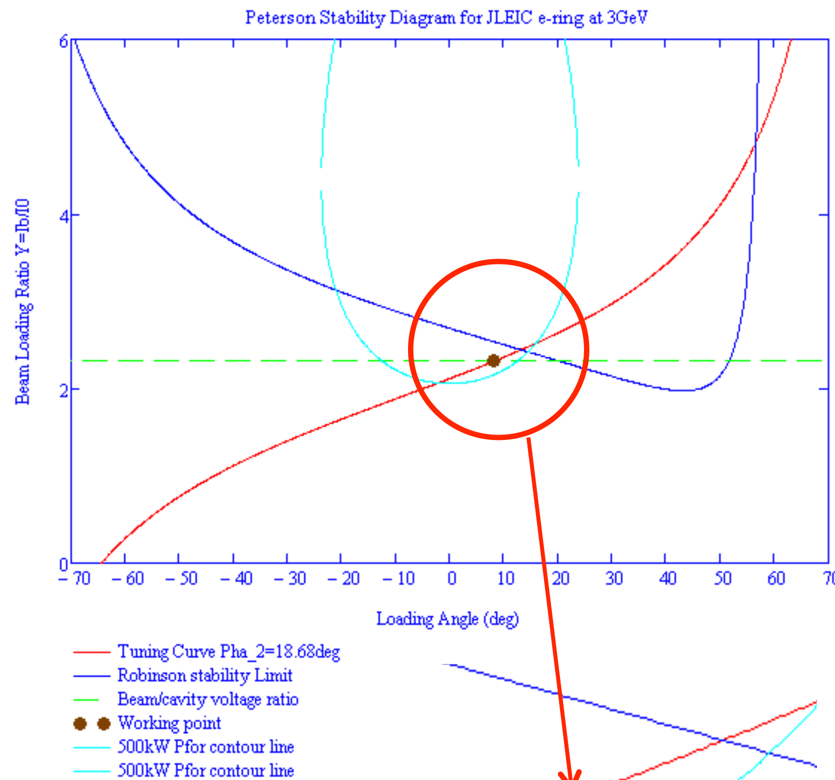
With direct feedback

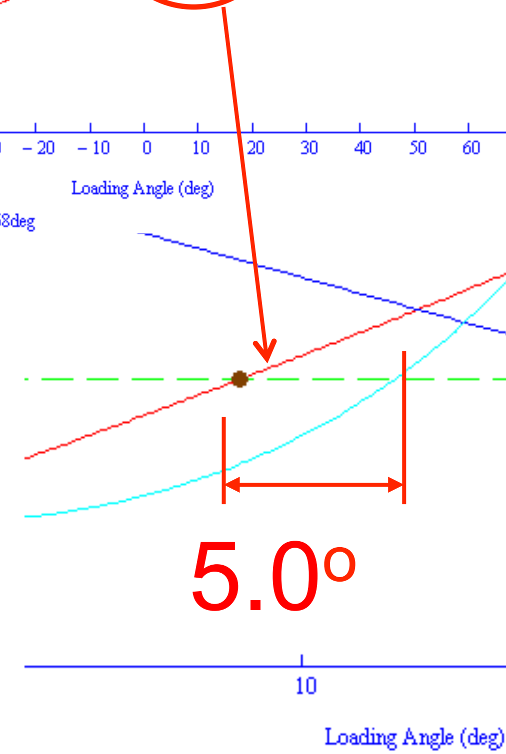


Impedance with feedback

Calculation with PEP-II NCRF Cavities for JLEIC E-ring **3 GeV**



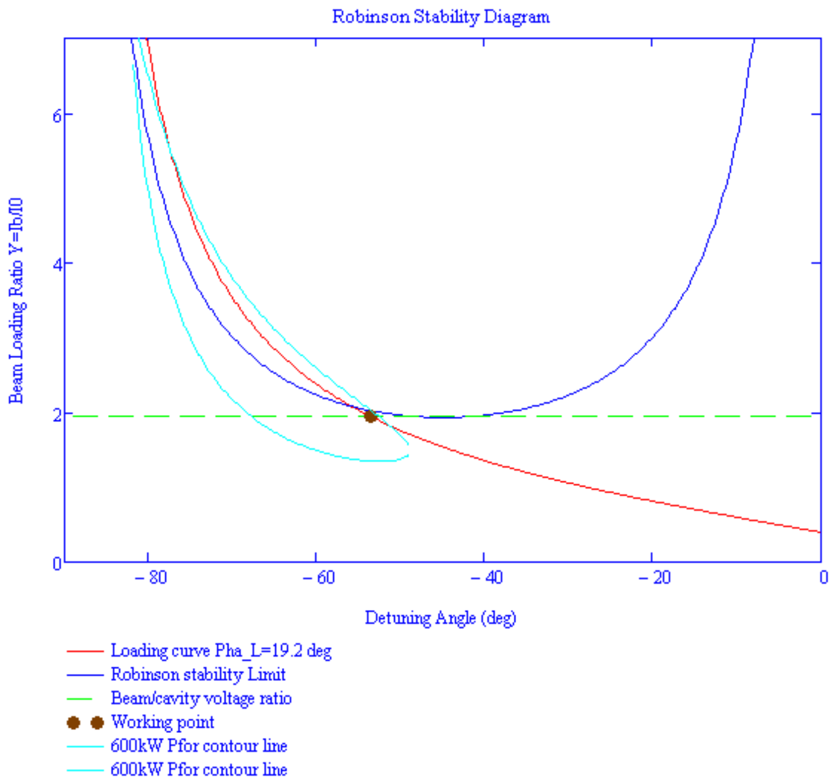


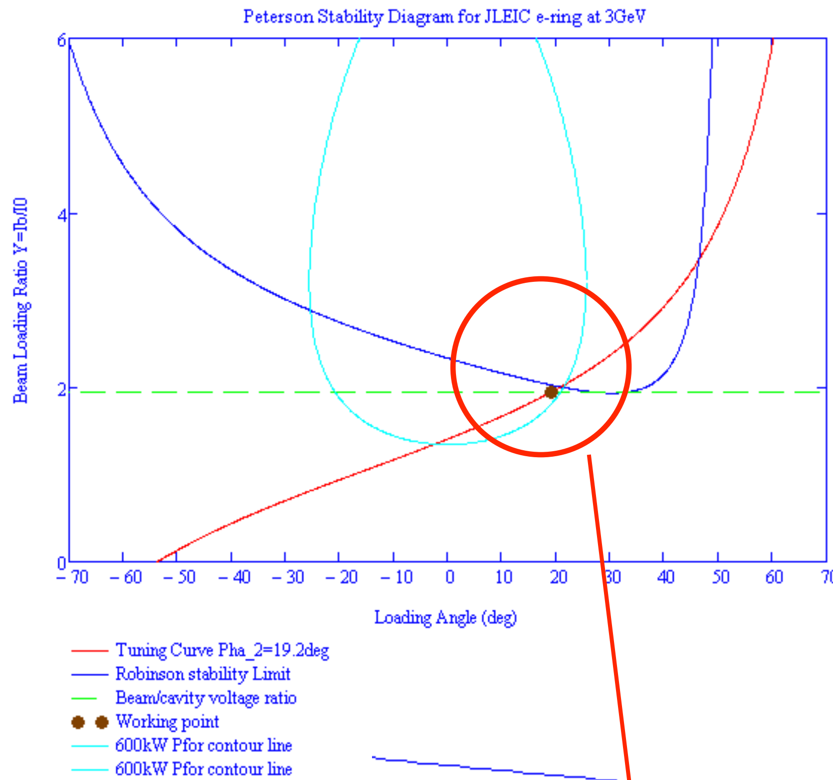


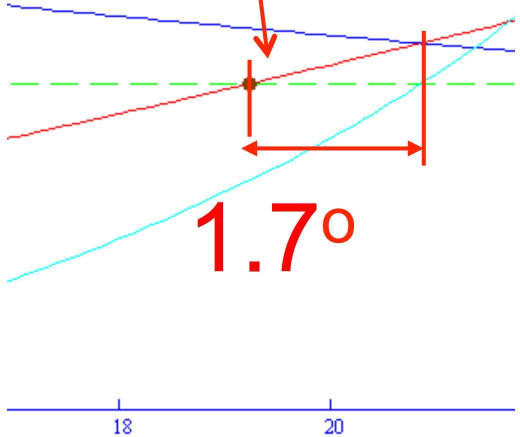
476MHz single-cell 1 NCRF cavity
Vtotal=0.725MV
ϕ_s=80.9°
I_b=3.0A
Bunch train fill=3464/3492
Clearing gap=0.8% (<5.0deg on loading angle)
FB gain=0.45
Group delay=450ns
Klystron power=500kW

H. Wang

Calculation with PEP-II NCRF Cavities for JLEIC E-ring **5 GeV**





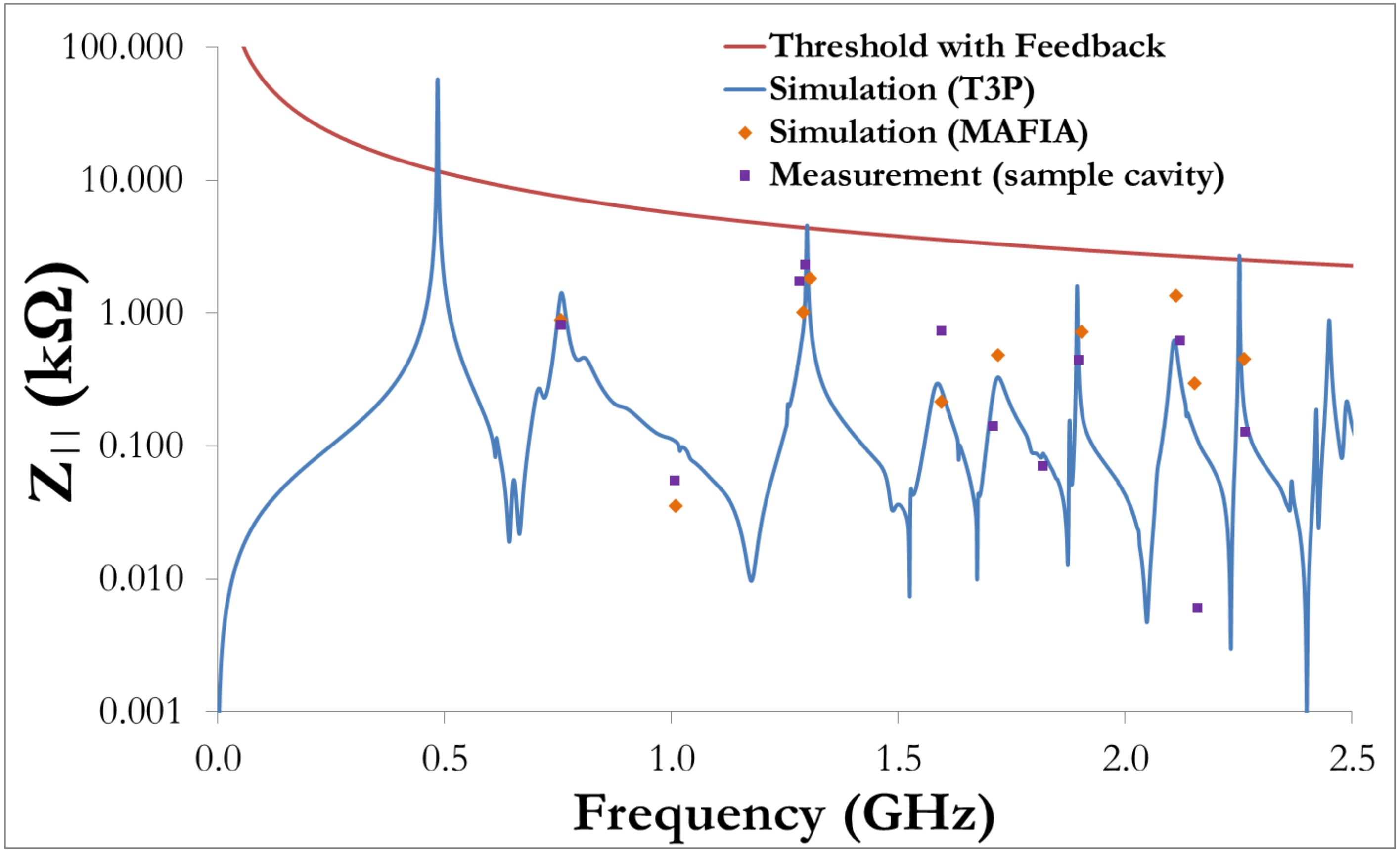


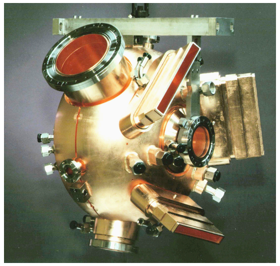
476.3MHz single-cell 1 NCRF cavity
Vtotal=3.423MV
ϕ_s=75.1°
I_b=3.0A
Bunch train fill=3464/3492
Clearing gap=0.2% (<1.7deg on loading angle)
FB gain=1.5
Group delay=450ns
Klystron power=600kW

H. Wang

e-ring CBI Threshold (assuming feedback)

S. Wang



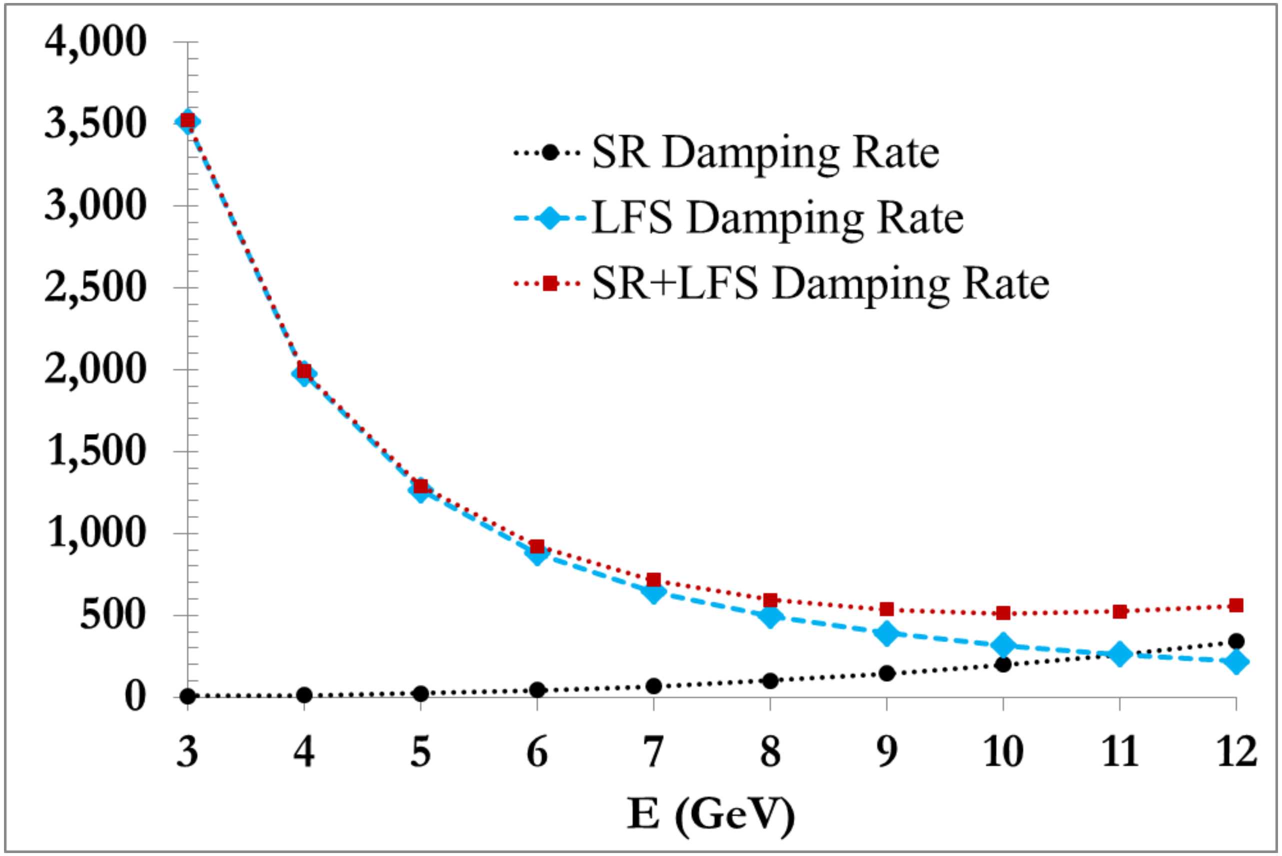


$$Z = \frac{V^2}{2P_{loss}}$$

$$Z_{||}^{thresh} = \frac{2Ev_s}{N_{cav} I_b f_{HOM} \alpha \tau_s}$$

CBI: Damping rate by Longitudinal Feedback System

Improved understanding of LFB damping rate as a function of energy

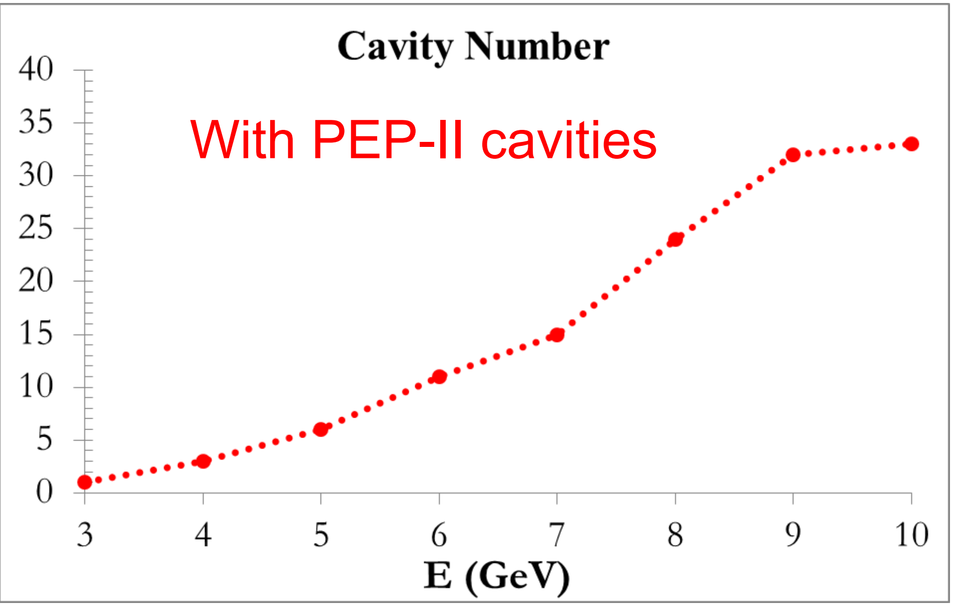


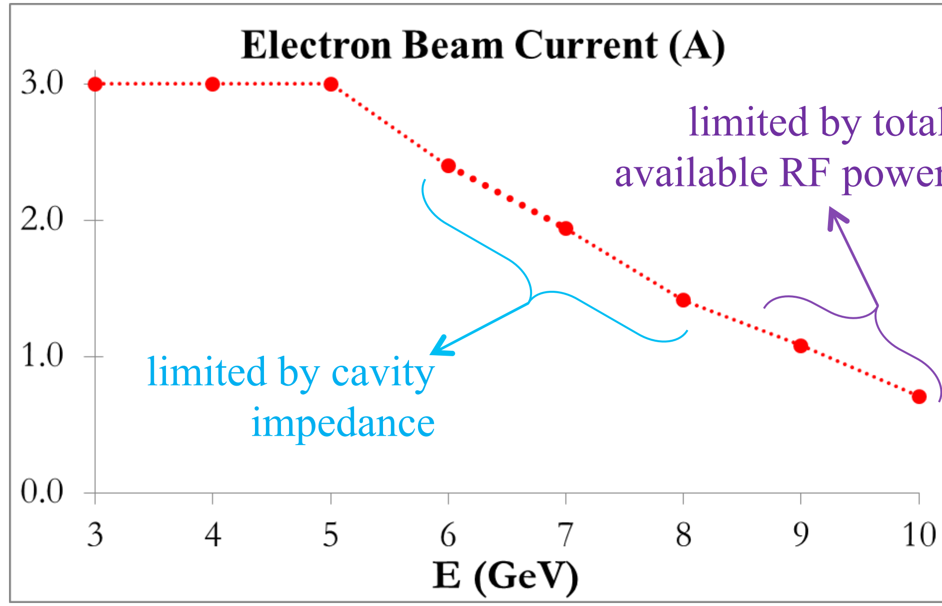
Feedback kicker voltage = 1.5 kV
Feedback system phase resolution = 8.7 mrad

S. Wang

e-ring CB stability modeling NCRF

PEP II, Both feedback system and fewer cavity number help to increase the beam current at low energy operation in electron ring





Current may be limited between 5-8 GeV unless we can increase feedback gain or improve HOM damping

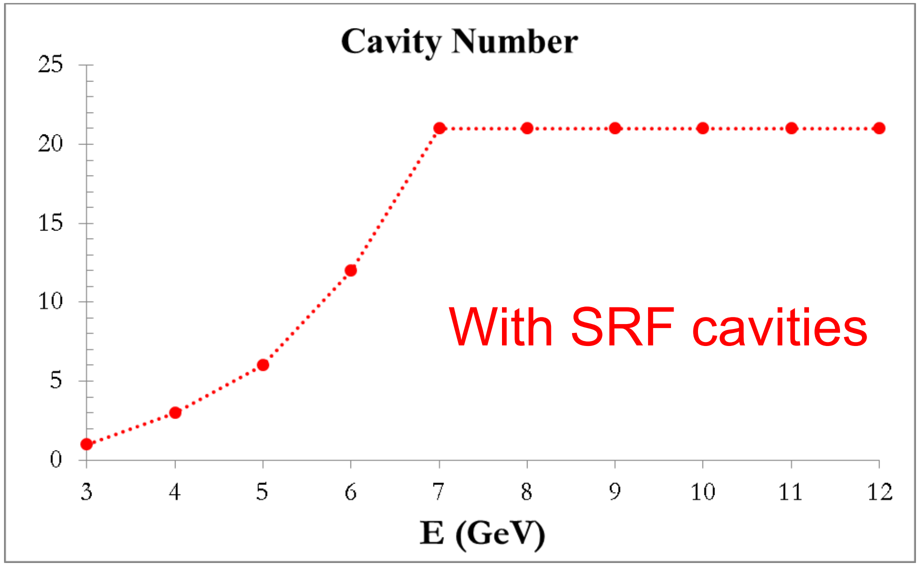
It is not practical to use PEP II cavities for energy above 10 GeV

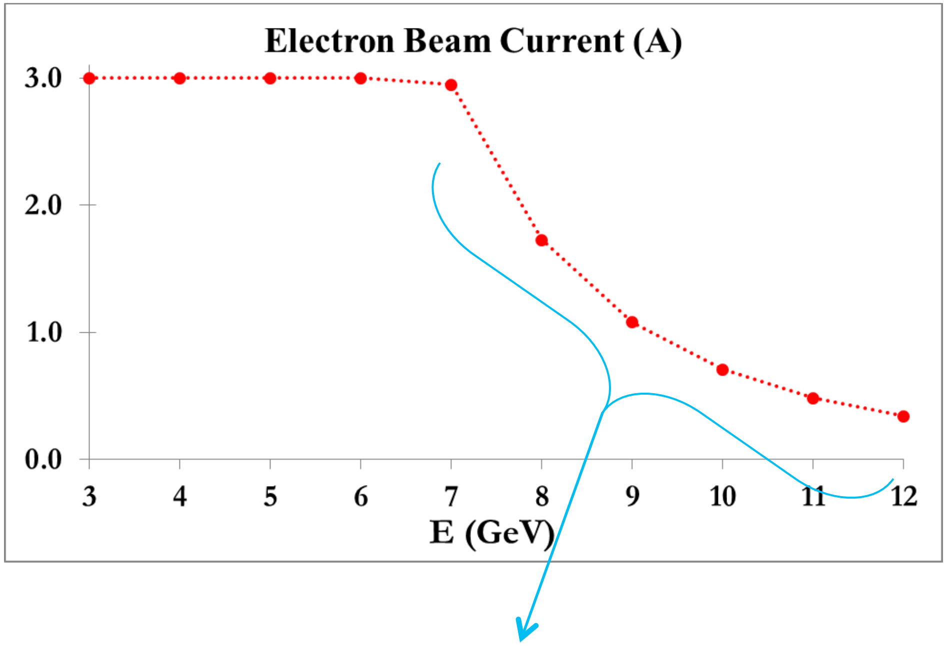
Eventually can replace PEP-II cavities with SRF

S. Wang

e-ring stability modeling SRF

Both feedback system and fewer cavity number help to increase the beam current at low energy operation in electron ring



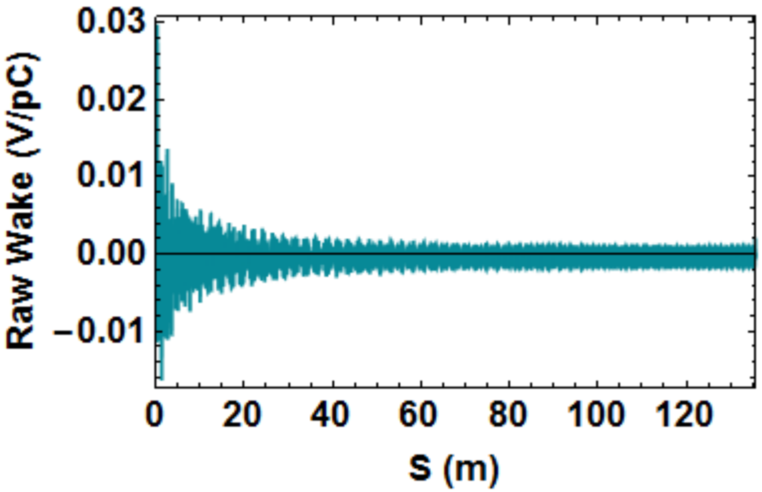


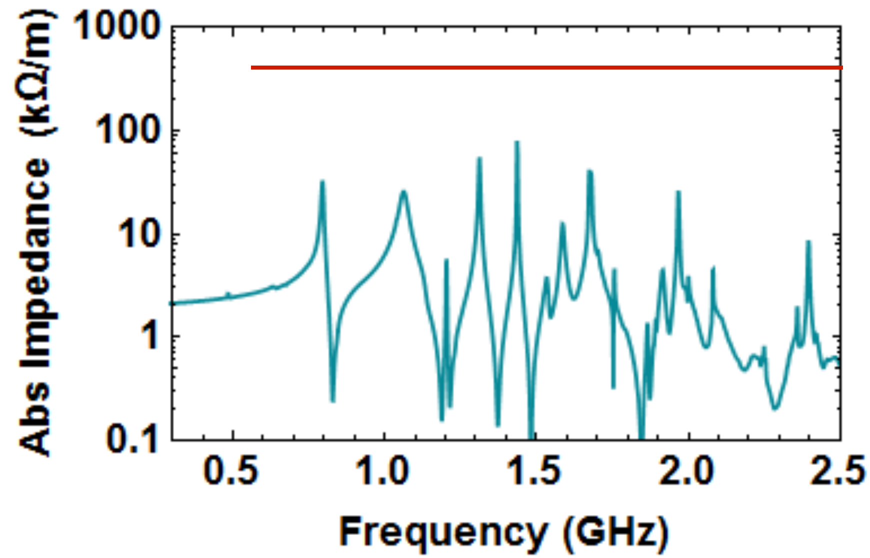
Beam current is limited by total available RF power, currently, 10 MW is assumed.

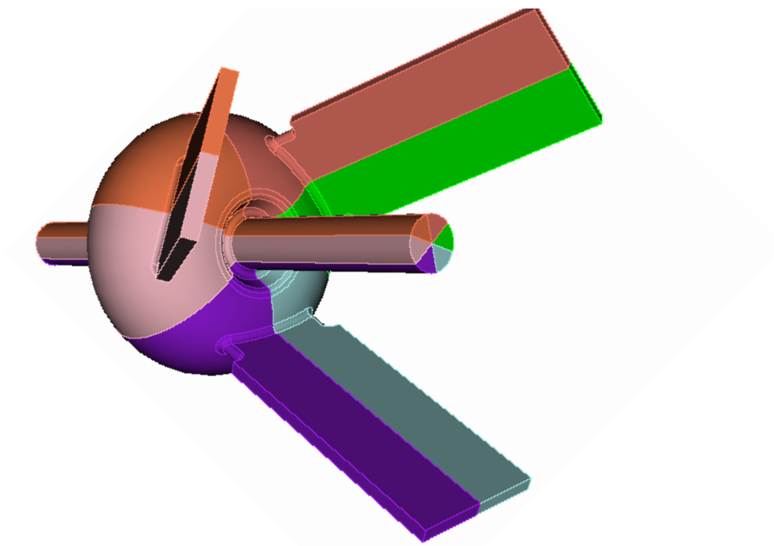
S. Wang

PEP II cavity, Transverse Impedance

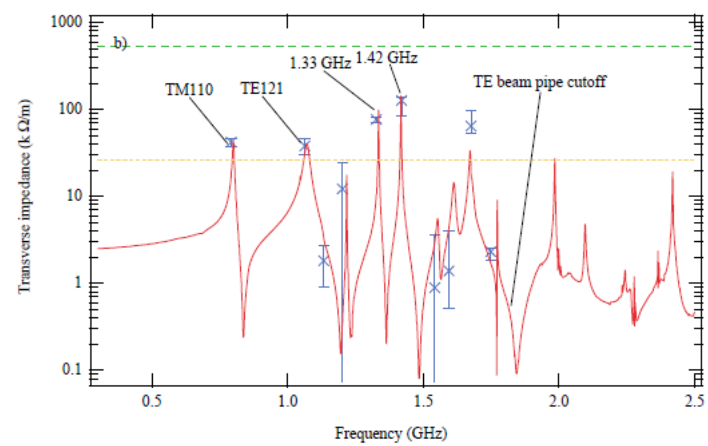
S. Wang







PEP-II cavity model

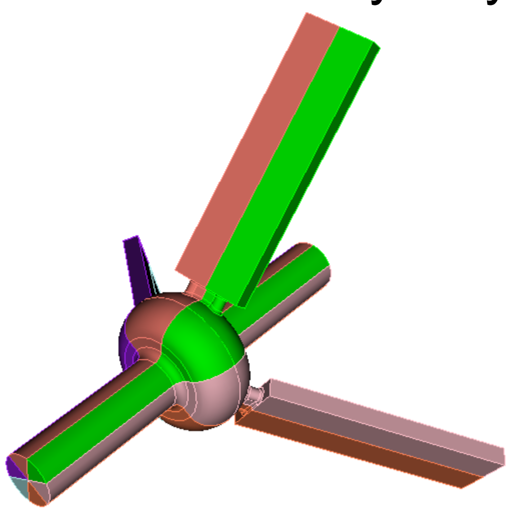


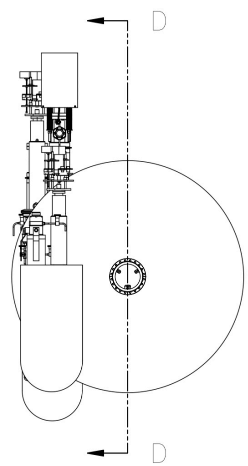
Rimmer, Byrd, Li, PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS, VOLUME 3, 102001 (2000)

ion-ring design concept

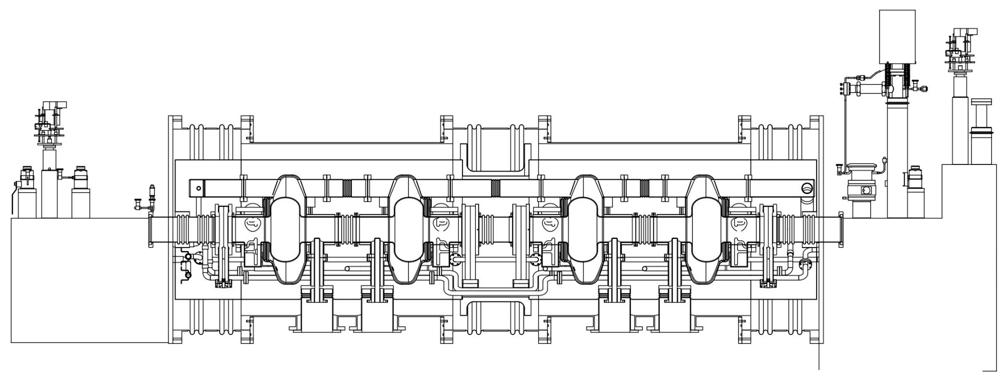
S. Wang

- 952.6 MHz SRF HOM damped 1-cell cavities, modular Jlab cryomodule
- High frequency/high voltage for short bunch (re-bucket at energy)
- Medium-power couplers , no synch. rad. Power.
- Tunable within one harmonic (harmonic jumps for path length changes with energy)
- Impedance is a concern so HOM damping is still needed.
- Multi-cell cavity may be needed for higher energies (upgrades)



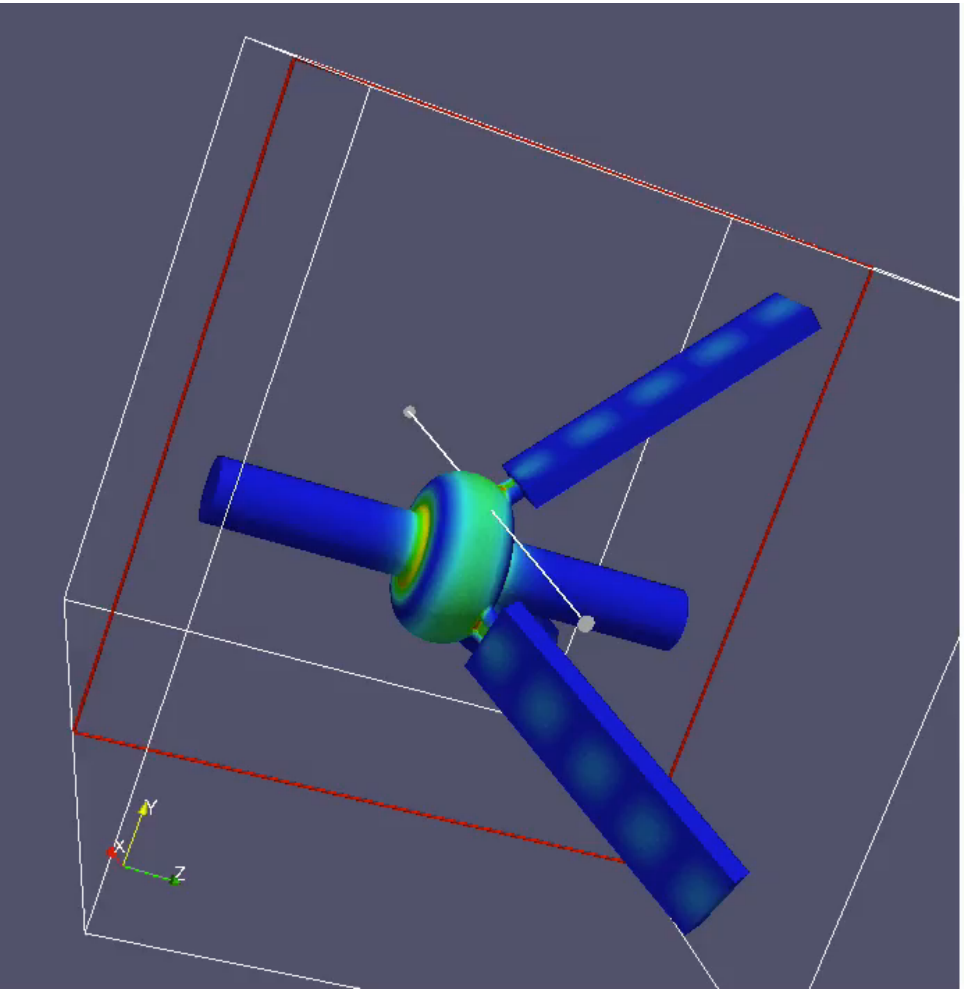


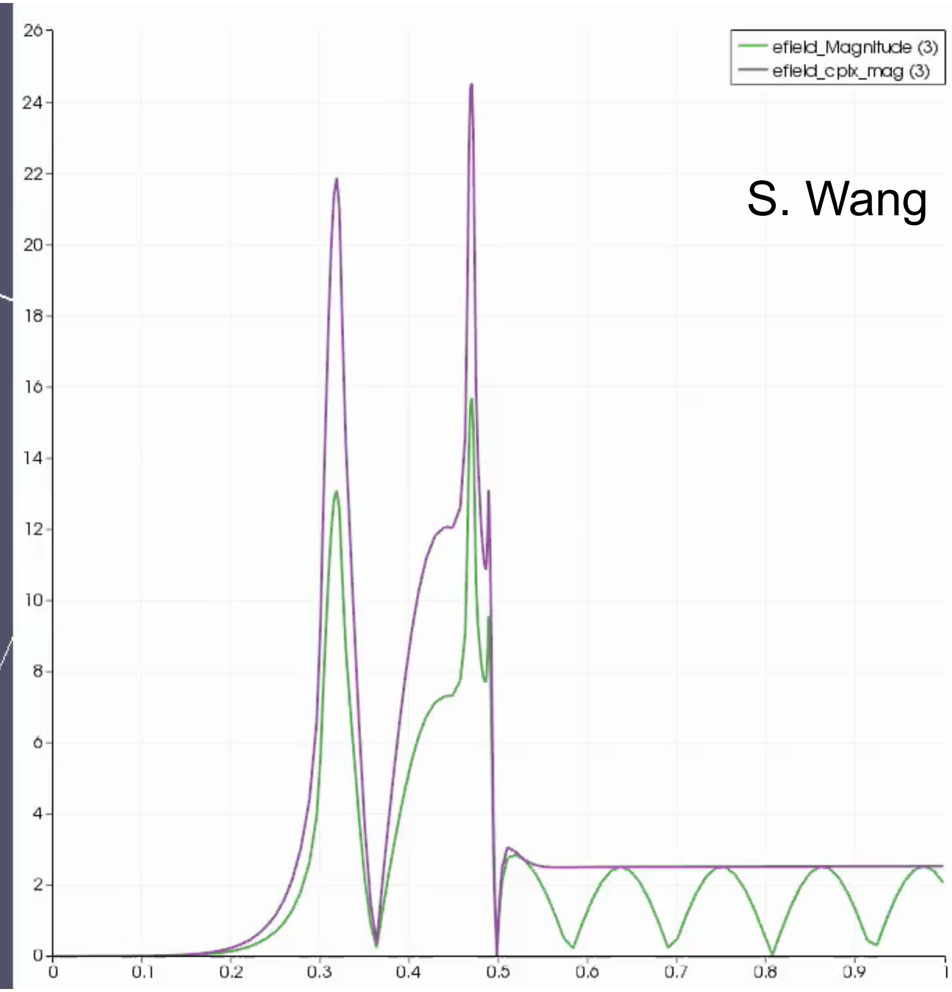
On-cell HOM damped cavity concept



952.6 MHz single cell 4-seater CM
(~4.3m flange to flange. Waveguide HOMs not shown)

On Cell Waveguide Damping SRF Cavity





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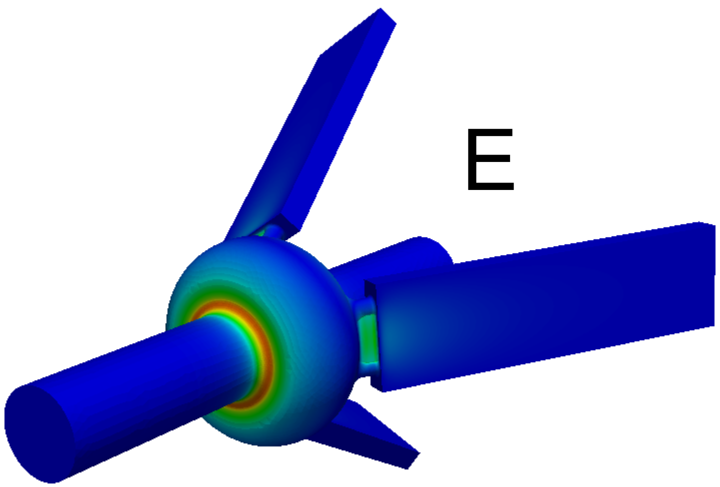
Geometry and basic parameters of the optimized OCD SRF cavity

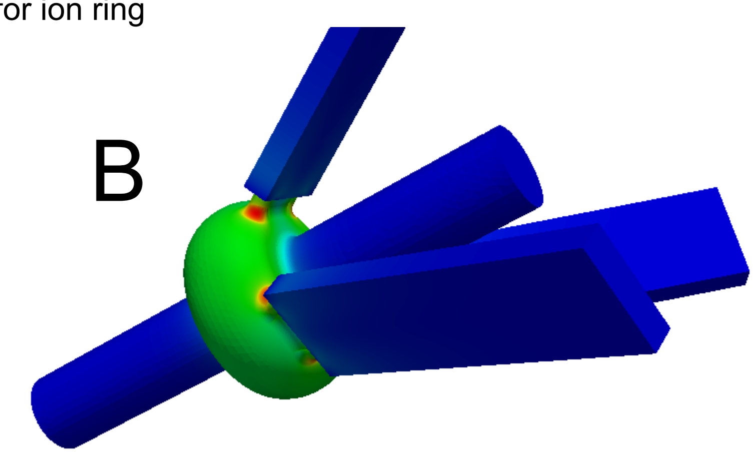
OCD = On Cell Damper

V_{gap} = 1.77 MV is the highest situation for 12 GeV electron operation.

Vgap (MV)	Bmax (mT)	Emax (MV/m)
1.77	99.4	26.7
G	**R/Q**	**G·R/Q**
235.55	105.2	24779.8
Q0	**Rshunt**	**frequency**
1.77E+10	1.86E+12	9.526E+08
Eacc (MV/m)	**Emax/Eacc**	**Bmax/Eacc (mT/MV/m)**
11.25*	2.37	8.83

*8 MV/m for ion ring

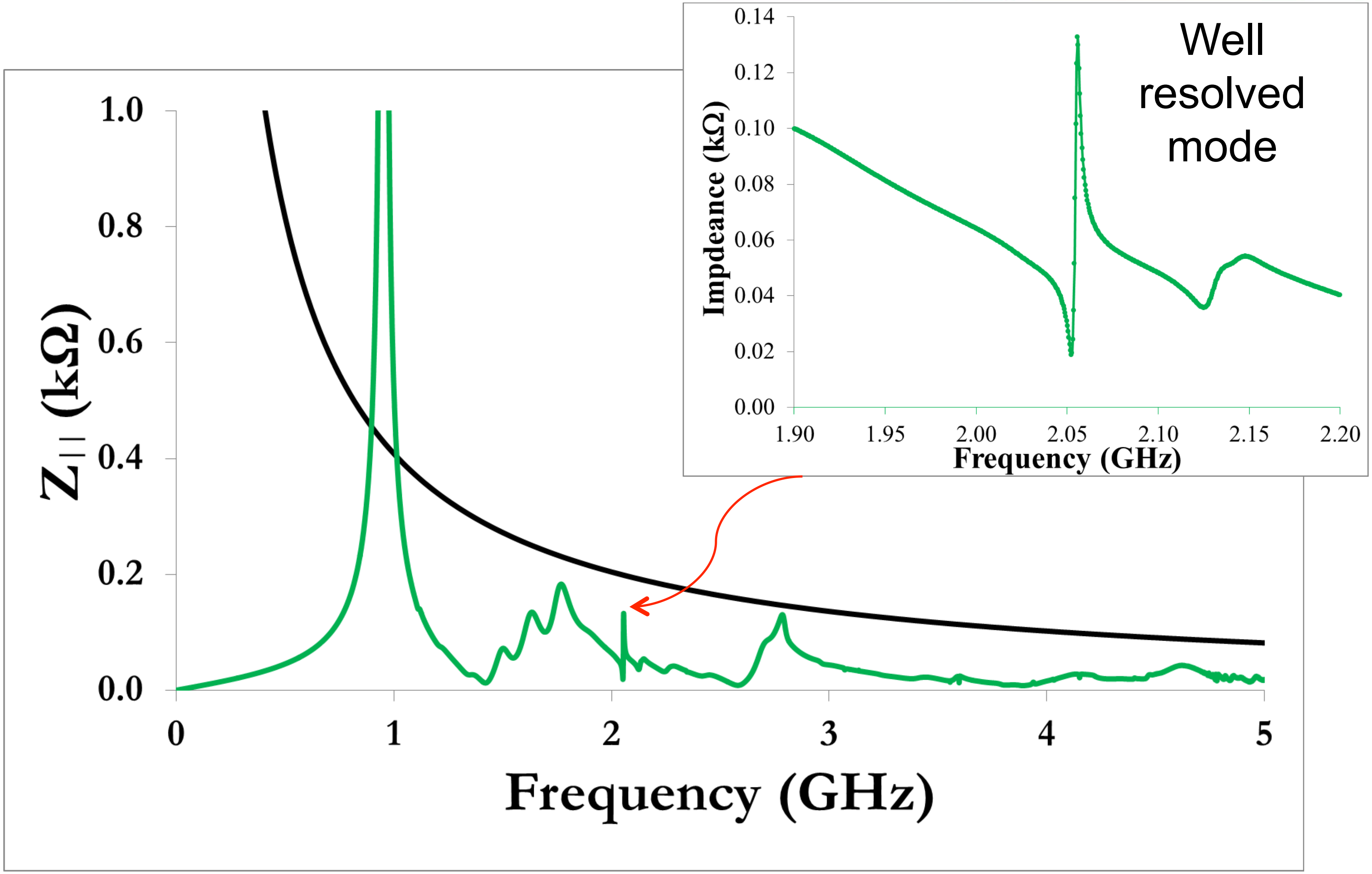




Beam pipe radius is 55 mm.

S. Wang

Longitudinal Impedance T3P Result and CBI Threshold (feedback)



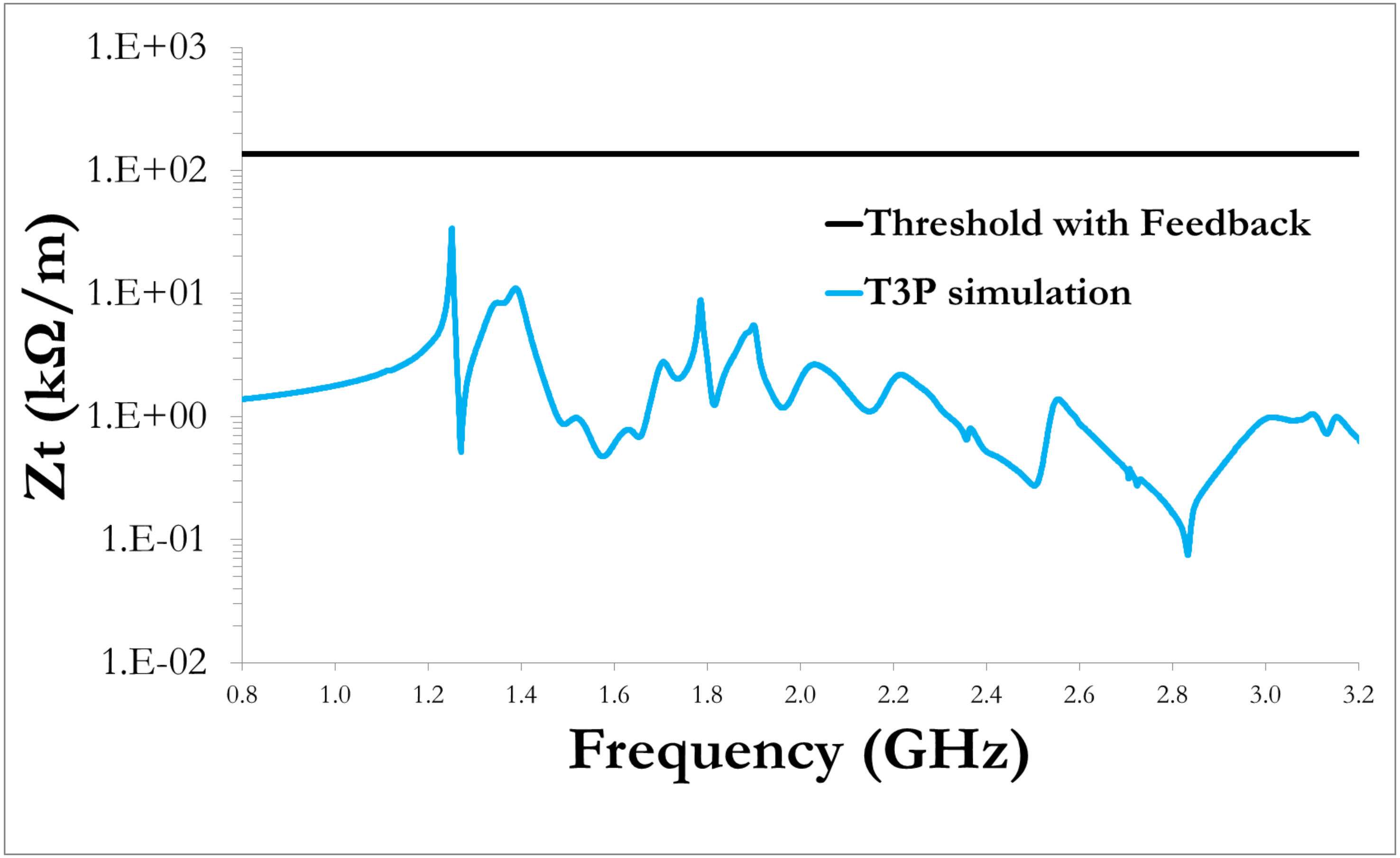
Z=V²/2P$_{loss}$

$$Z_{||}^{thresh} = \frac{2E\upsilon_s}{N_{cav} I_b f_{HOM} \alpha \tau_s}$$

S. Wang

Jefferson Lab

Transverse Impedance T3P Result and CBI Threshold (feedback)



$$Z_{x,y}^{thresh} = \frac{2E}{N_{cav} f_{rev} I_b \beta_{x,y} \tau_{x,y}}$$

3.2 ms damping time of feedback system is used according to PEP II.

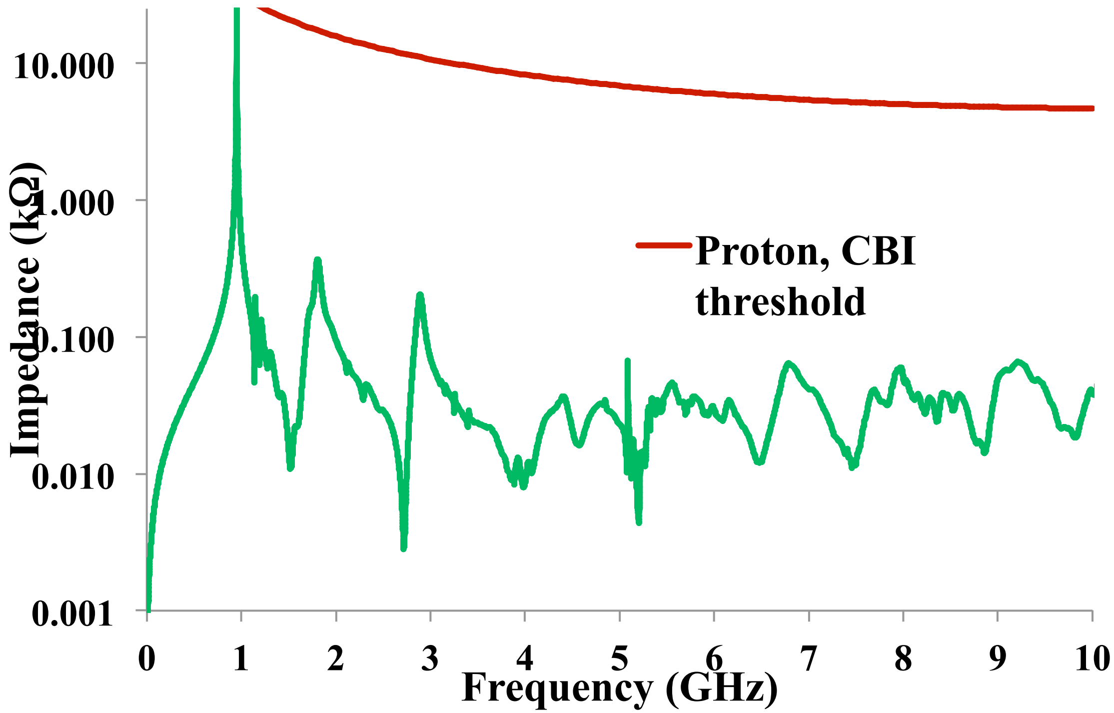
1998, Barry, "INITIAL COMMISSIONING RESULTS FROM THE PEP-II TRANSVERSE COUPLED-BUNCH FEEDBACK SYSTEMS.

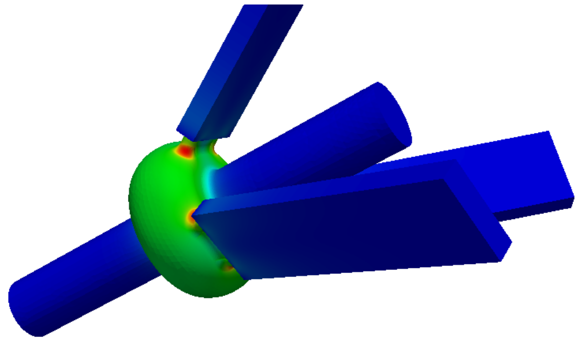
S. Wang

Ion ring CB stability

S. Wang

Plenty of headroom in ion ring with strongly HOM damped SRF cavity.
Can relax requirements? Use simpler dampers?
Need to study reactive beam loading

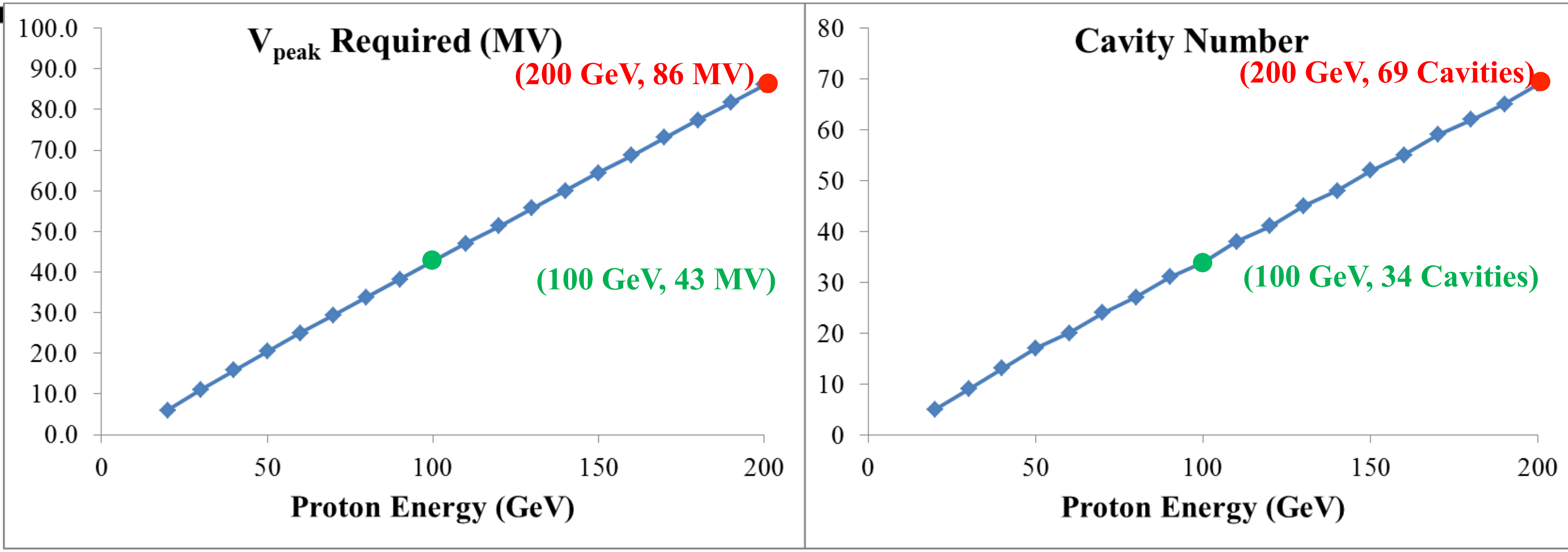




952.6 MHz i-ring cavity (SCRF)

Higher Energy Protons in Ion Ring?

S. Wang



$$V_{peak}\cos(\varphi_s) = \frac{2\pi c^2 \eta E}{\omega^2 \sigma^2 He}\left(\frac{\delta E}{E}\right)^2 \qquad \varphi_s = 0$$

- So, multi-cell SRF cavities are needed; (2-cell?)
- Or, we have to increase the bunch length ***s*** from 1.2 cm to 1.7 cm at 200 GeV

Ion bunch forming: RF Frequencies Needed

J. Guo

Baseline:

- Booster accelerating and compression:
  - bunch spacing 282m, β=0.283-0.995, f=0.30-1.06MHz
- Collider ring capture/accelerating:
  - 1 accelerating gap, bunch spacing 80m (56m occupied, 28m empty), β=0.956-1, f=3.57-3.72MHz
- Collider ring splitting
  - 6 frequencies: f=7.44, 14.88, 29.77, 59.54, 119.08, 238.16MHz
- Collider ring final splitting and add/remove extra buckets
  - 476.1-476.5MHz
- Collider ring bunching
  - 952.6MHz, high voltage SRF

In baseline

Not designed yet

Option 1, binary splitting up to 119MHz in the booster

- Move f=3.72, 7.44, 14.88, 29.77, 59.54 MHz frequencies to booster
- 119MHz cavities needed in both the booster and the collider ring
- 238 and 476MHz cavities needed in the collider ring

Option 2: two long barrier buckets in the collider ring

Form 2 rectangular bunches and split only one time into two bunch trains with 476MHz bunches.

- Only splitting frequency needed is 476.32MHz in the collider ring

Cryogenic system temperature

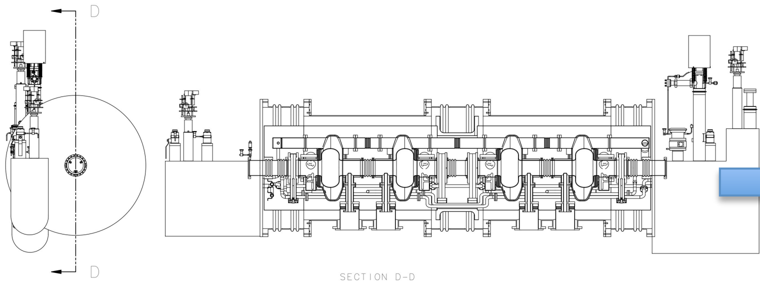
S. Wang

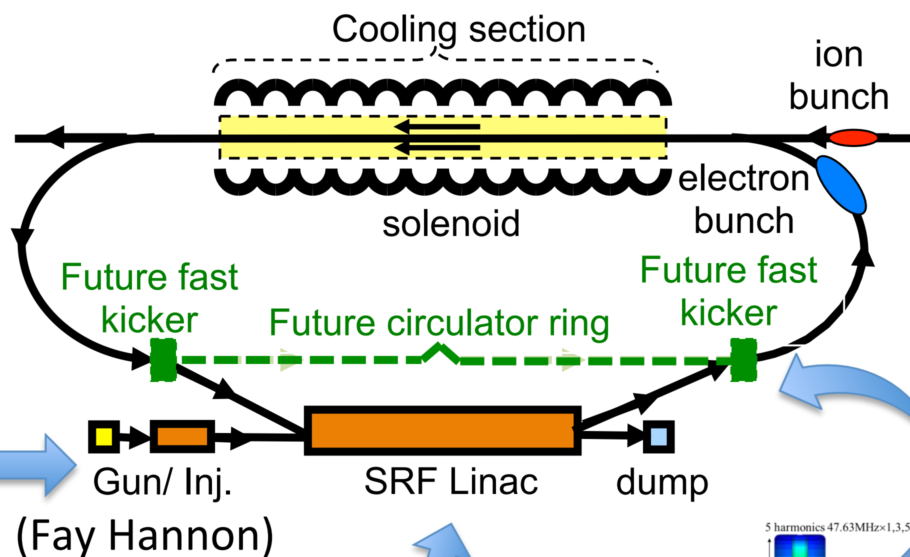
For the cryogenic system, 2 K is preferable. Note the Q_{ext} are made same for both cases.

	Proton									Lead
Energy (GeV)	20	30	40	50	60	70	80	90	100	40
N cavity	5	9	13	17	20	24	27	31	34	33
2.0 K										
Coupling Beta	3.11E+05									
Qext	5.24E+04									
Forward Power per Cavity (kW)	63.8	68.9	67.4	65.6	70.5	68.0	71.1	68.9	71.1	67.6
Total Forward Power (MW)	0.32	0.62	0.88	1.11	1.41	1.63	1.92	2.14	2.42	2.23
Cavity Power (W)	0.8	0.9	0.9	0.8	0.9	0.9	0.9	0.9	0.9	0.9
Total Cryogenic Power (W)	4.1	8.0	11.3	14.3	18.1	21.0	24.7	27.4	31.1	28.7
4.2 K										
Coupling Beta	1.17E+04									
Qext	5.24E+04									
Forward Power per Cavity (kW)	63.8	68.9	67.4	65.6	70.5	68.0	71.11	68.9	71.2	67.60
Total Forward Power (MW)	0.32	0.62	0.88	1.11	1.41	1.63	1.92	2.14	2.42	2.23
Cavity Power(W)	21.8	23.5	23.0	22.4	24.1	23.2	24.3	23.5	24.3	23.1
Total Cryogenic Power (W)	108.8	211.5	299.0	380.2	481.1	556.8	654.8	728.3	825.0	760.8

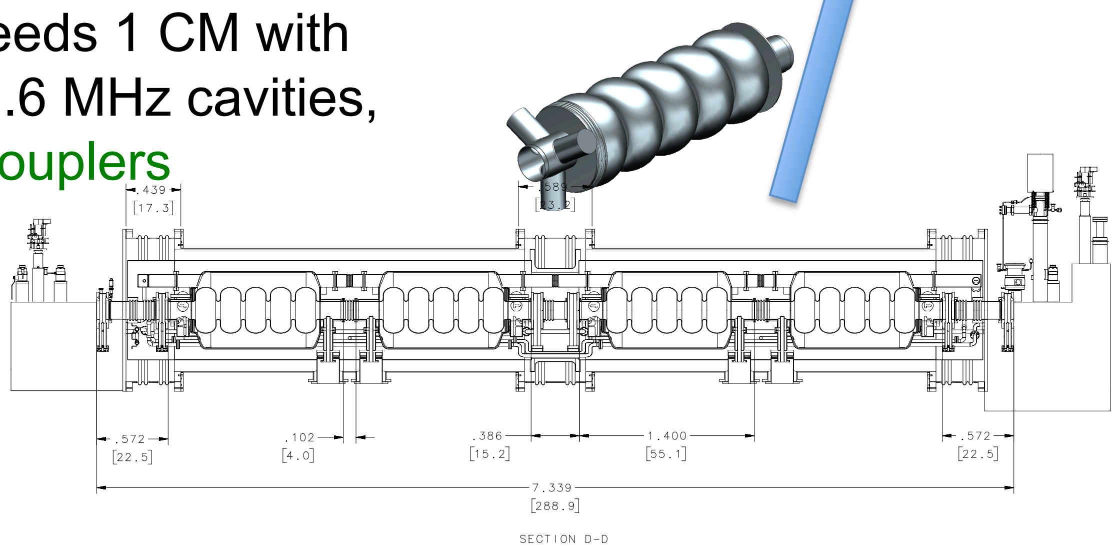
e-cooler ERL

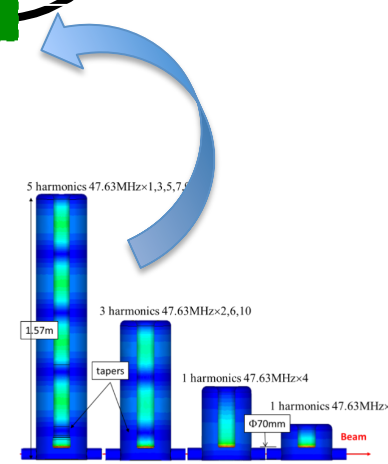
Injector Cromodule similar to storage ring, 1 CM, 4 x 1-cell 952.6 MHz cavities, high-power couplers.





ERL LINAC needs 1 CM with four 5-cell 952.6 MHz cavities, lower-power couplers



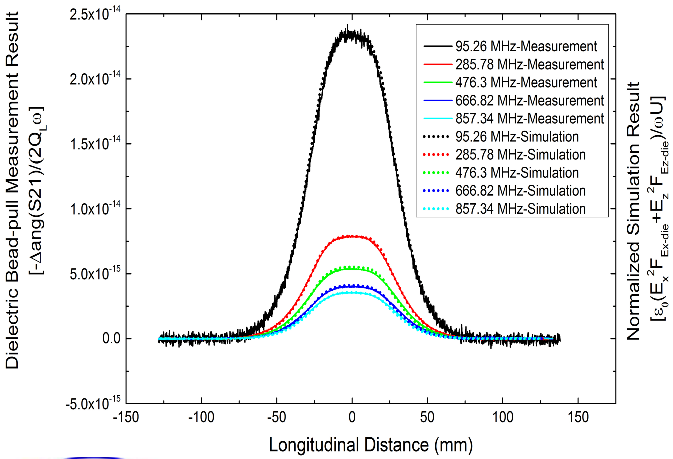


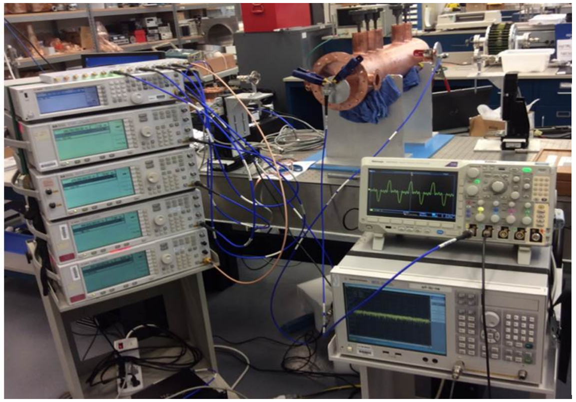
Harmonic kicker system (Y. Huang)

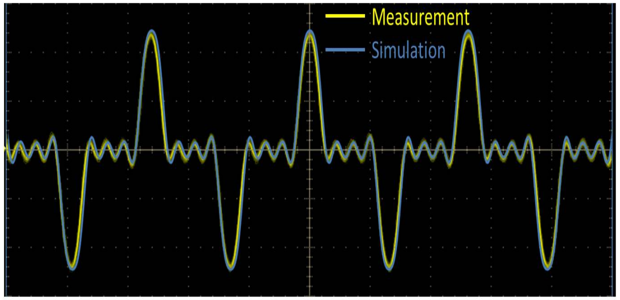
JLEIC Harmonic fast Kicker Development

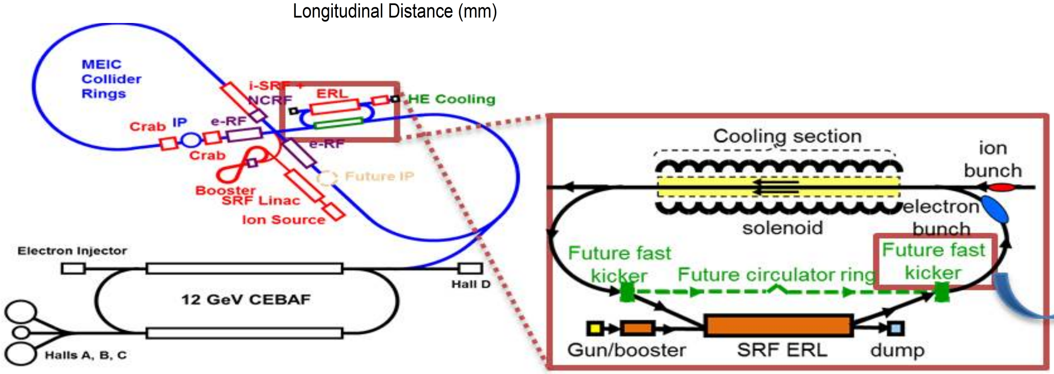
Y. Huang

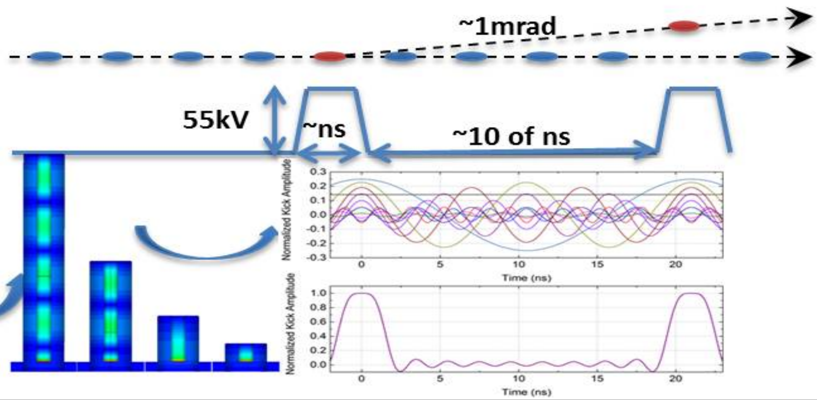
- Built a half-scale **5-mode** copper prototype;
- RF bench tests match well with the simulation;
- Demonstrated combination of 5 harmonics.
- See talk ***Development of RF Kicker,*** *Y. Huang*











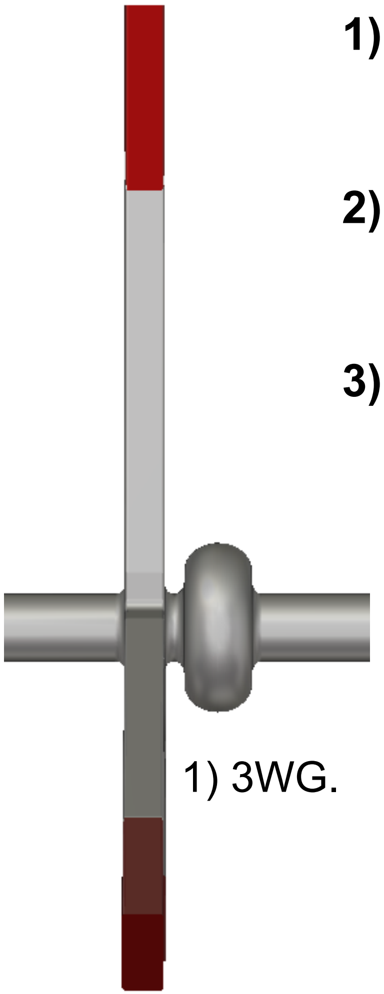
ERL: Comparison of HOM damping schemes

(F. Marhauser et al. , “Enhanced Method for Cavity Impedance Calculations”, Proc. PAC Conf. 2009)

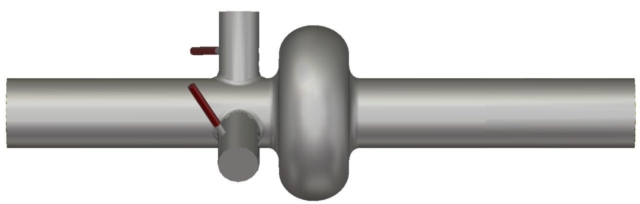
1) **Cavity with 3 waveguide dampers** (TE10 cutoff = 1.06 GHz)
   Cavity iris/beam tube ID = 110mm
   (TE11 cutoff b.t. = 1.60 GHz, TM01 cutoff b.t. = 2.09 GHz)

2) **Cavity with 3 coaxial dampers** (scaled CEBAF C100 type dampers)
   Cavity iris/b.t. ID = 110mm
   (TE11 cutoff b.t. = 1.60 GHz, TM01 cutoff b.t. = 2.09 GHz)

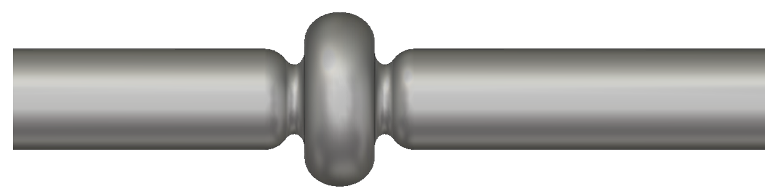
3) **Cavity with enlarged beam tubes only** (reference case)
   Cavity iris/b.t. ID = 110/160 mm
   (TE11 cutoff = 1.10 GHz, TM01 cutoff = 1.43 GHz)



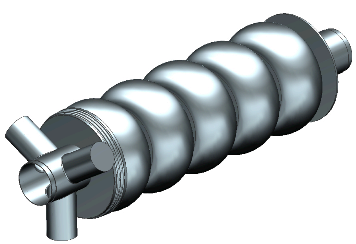
1) 3WG.



2) 2 x C100 type coax dampers.



3) enlarged beam pipes (reference)

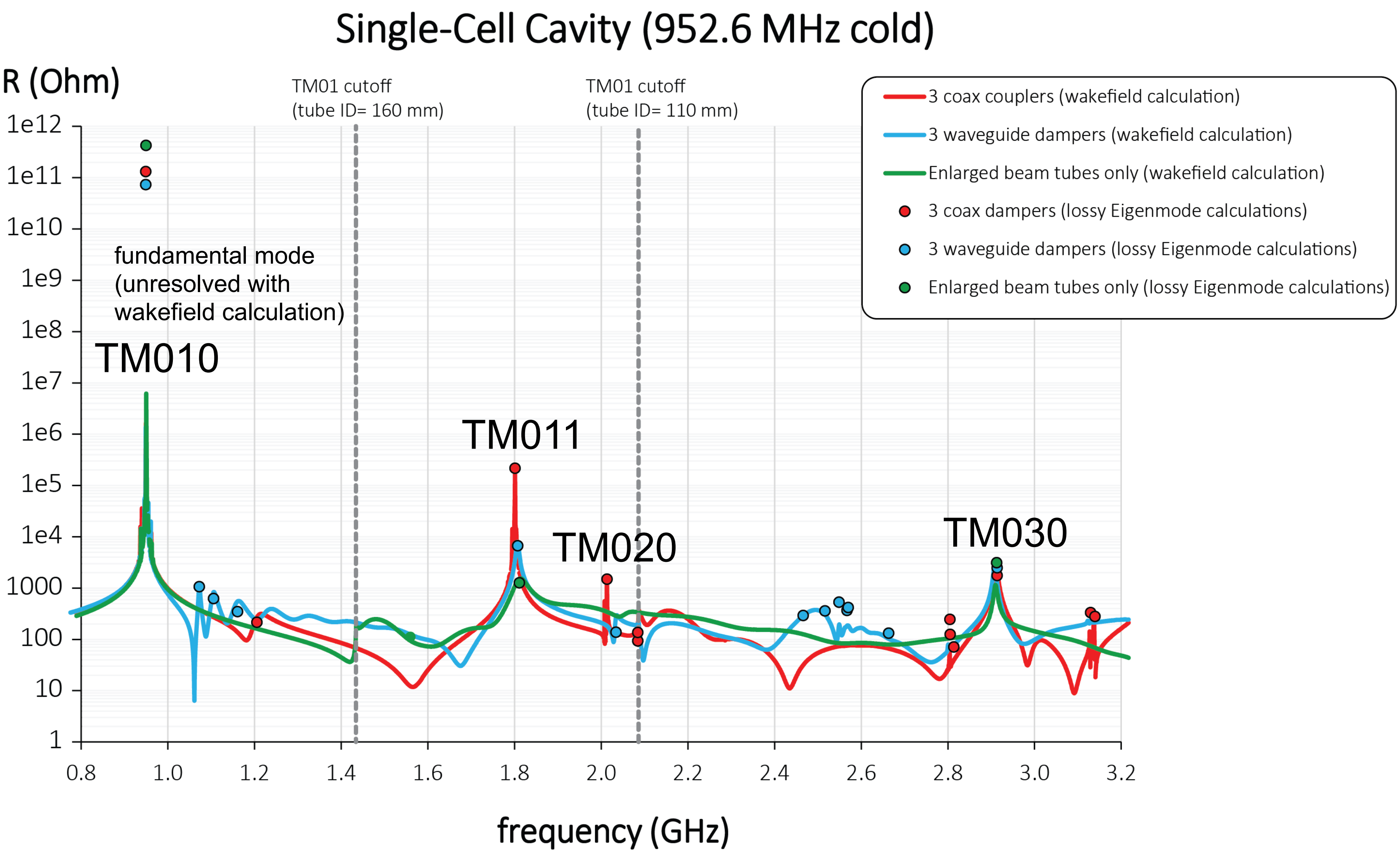


Cooler needs 5-cells in the ERL, 1-cells in the injector

F. Marhauser

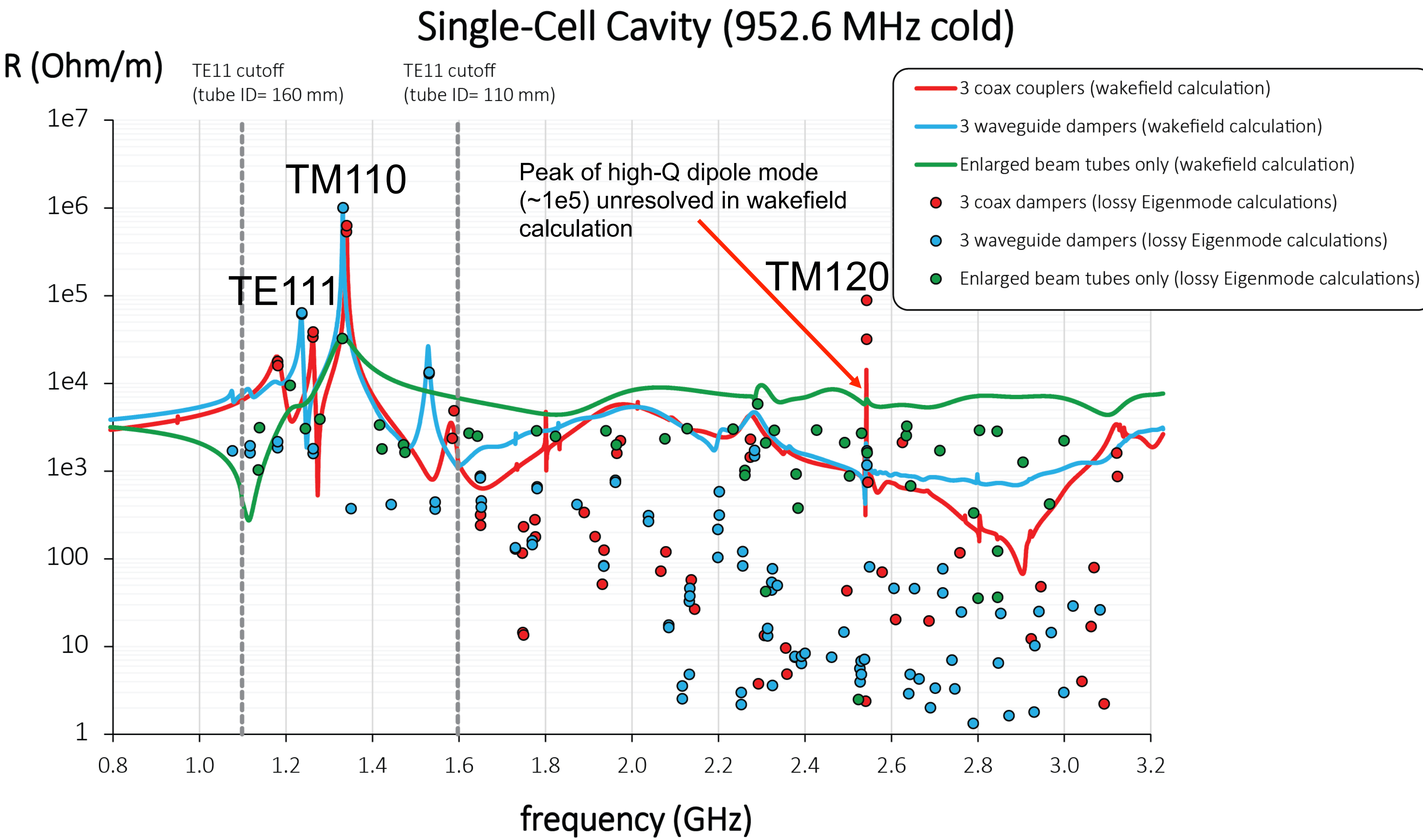
Monopole Modes

F. Marhauser



Dipole Modes

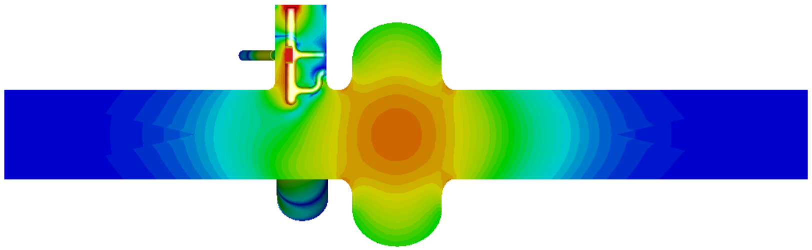
F. Marhauser



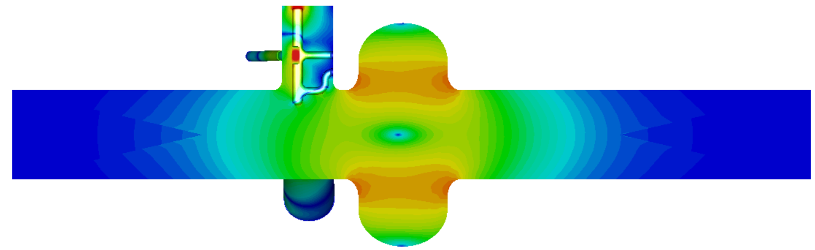
Dipole Modes

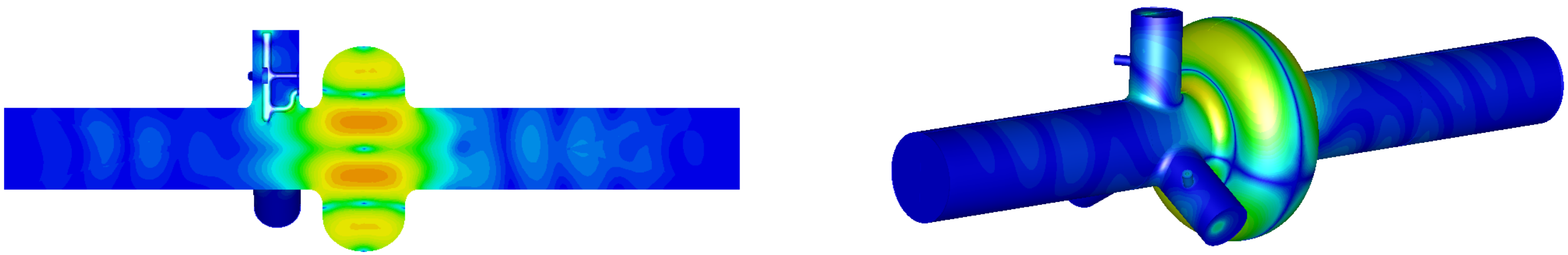
F. Marhauser

TE111



TM110





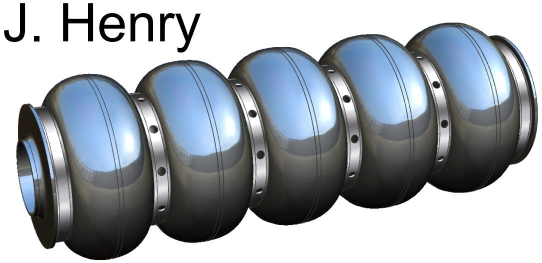
TM120 (2.54 GHz), Q~1e5

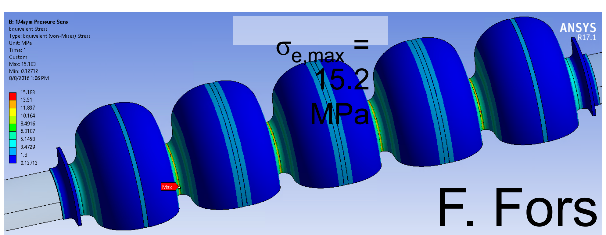
(maybe can improve by adjusting HOM can dimensions)

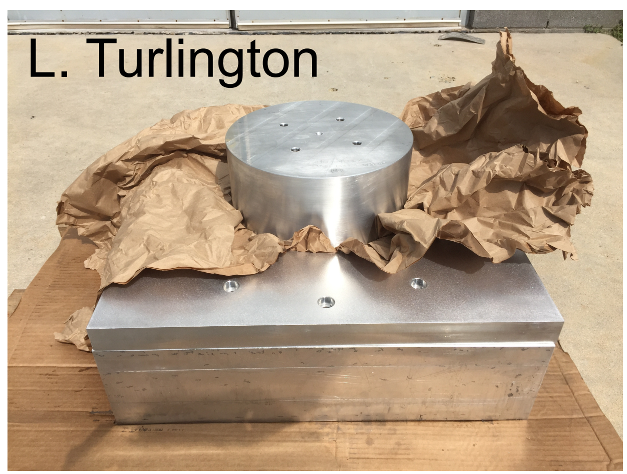
952.6 MHz cavity prototype

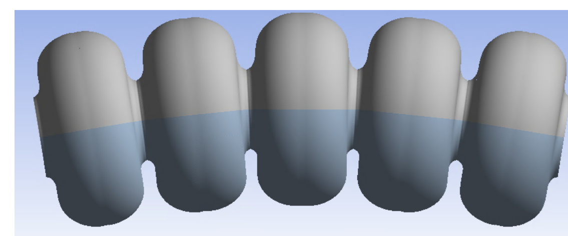
- Cell RF design is complete
- Preliminary engineering analysis is complete
- Cell dies have been fabricated
- Test blanks will be pressed soon (this week?)
- Beam tube dies are in progress (110 mm)
- **End group design** will be chosen based on simulation results
- Impedance requirements (Q spec)
- HOM power (i-ring, e-ring, ERL)
- Will produce single-cell first (possibly using ingot material)

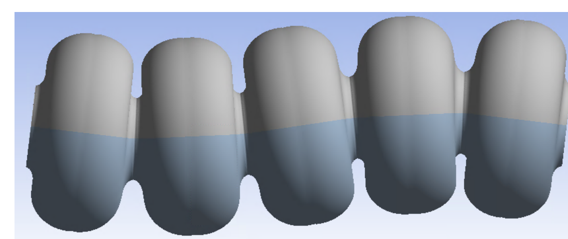
J. Henry





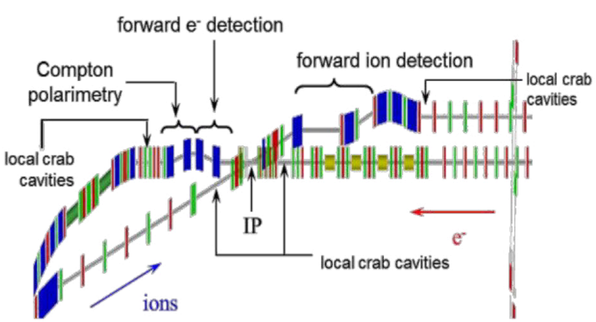


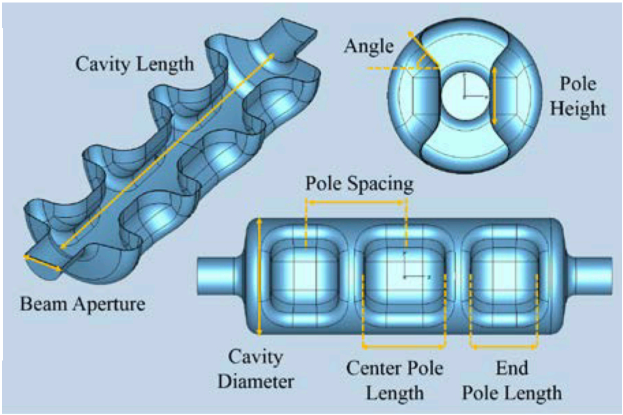


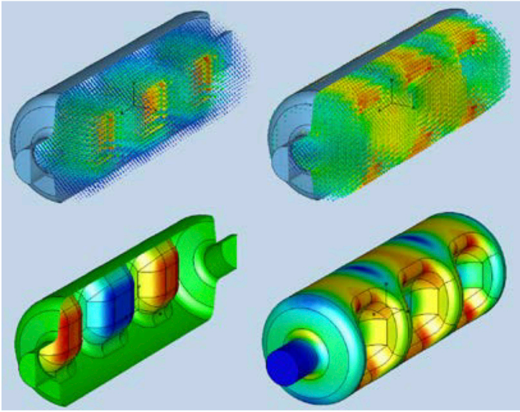


Crab cavity system

Crab cavity locations, frequency and shape are being optimized by **ODU** and JLab (CASA) – *see talks:*
Update of JLEIC Interaction Region Design *,Vasiliy Morozov (Jefferson Lab),* ***Crab Crossing Design and Simulations****, Salvador Sosa (Old Dominion University)*
SRF Crab Cavity R&D*, Subashini De Silva (Old Dominion University)*
Multi-cell structure is attractive for JLEIC large crossing angle







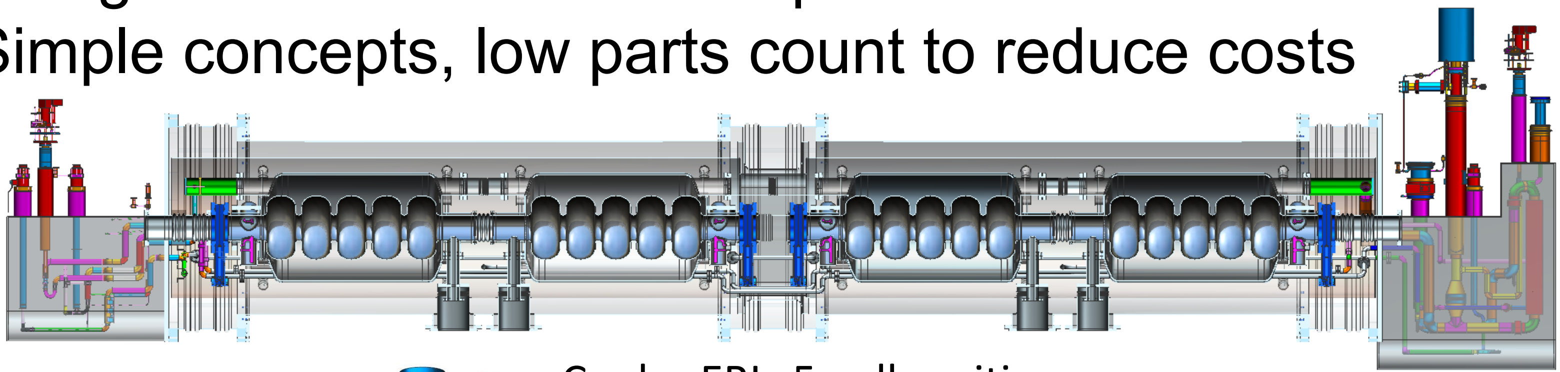
ANALYSES OF 476 MHZ AND 952 MHZ CRAB CAVITIES FOR JLAB ELECTRON ION COLLIDER, HyeKyoung Park, A. Castilla, J. R. Delayen, S. U. De Silva, V. Morozov. WEPMR034 Proceedings of IPAC2016, Busan, Korea.

MULTI-CELL RF-DIPOLE DEFLECTING AND CRABBING CAVITY, S. U. De Silva, H. Park, J. R. Delayen. Proceedings of IPAC2016, Busan, Korea. WEPMW022

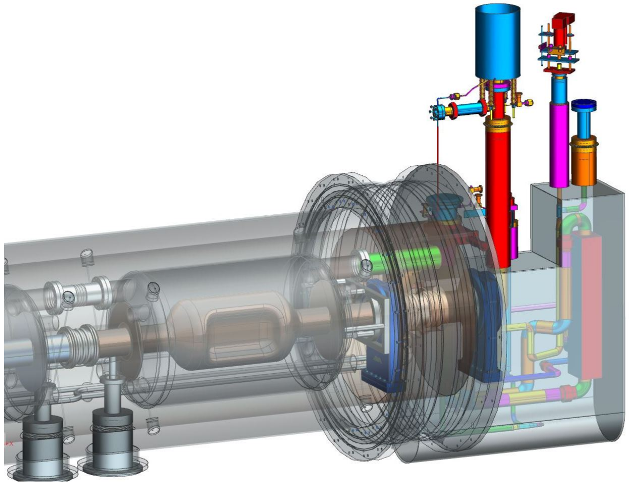
Modular Cryostat

R. Rimmer/J. Henry

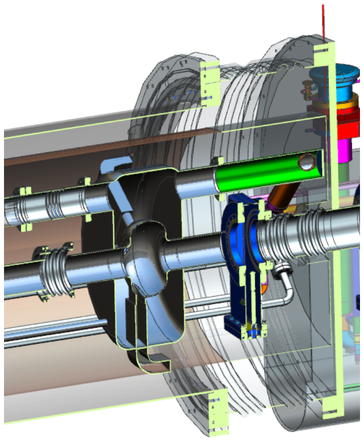
- Take the best features of previous JLab designs
- Modular approach to hold various different cavities
- Design suitable for industrial production
- Simple concepts, low parts count to reduce costs



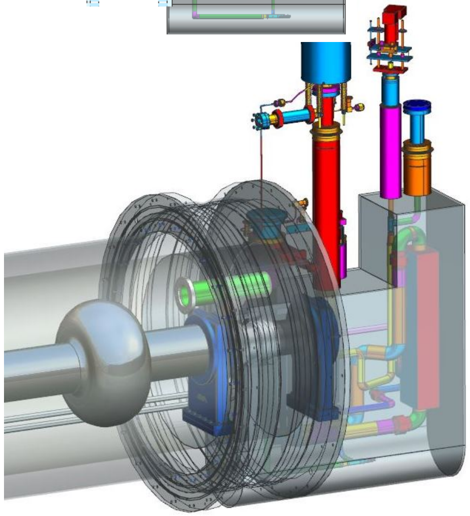
Cooler ERL, 5-cell cavities



476.3 or 952.6 MHz Crab cavity



952.6 MHz Ion ring concept



476.3 MHz 1-cell?

Conclusions

- No major changes to the baseline
- e^- Injection from CEBAF still looks good
  - e^+ under investigation
- e-ring and i-ring system stability looks OK
  - Continue optimization in FY17, study transients
- Cooler baseline ERL and optional CCR look good
  - Fast harmonic kicker looks very promising
  - Engineering design in FY17
- 952.6 MHz cavity designs are progressing
  - Cell shape finalized, first prototype in FY17
  - HOM damping schemes being refined
  - Cryostat models will be updated
- Multi-cell crab cavity looks good
- Bunch forming scheme needs refinement

Backup

Beam current in PEP II

SLAC-PUB-14677,
"LAST YEAR OF PEP-II B-FACTORY OPERATION",
J. T. Seeman

3.1 GeV → I+

9 GeV → I-

Table 1 : PEP-II Collision Parameters

Parameter	Units	Design	April 2008 Best	Gain Factor over Design
I+	mA	2140	3213	x 1.50
I-	mA	750	2069	x 2.76
Number bunches		1658	1732	x 1.04
β_y*	mm	15-25	9-10	x 2.0
Bunch length	mm	15	10-12	x 1.4

"Seven RF stations were added for a total of 15 stations to handle the highest beam currents in the two rings (3.2 A x 2.1 A)."

PEP II Parameters

	MEIC	LER
Qs	0.008	0.0334
Alpha	7.6e-4	1.23e-3
$E_{Loss\ per\ Turn}$	0.17 MeV	0.65 MeV
Frev	0.212 MHz	0.136 MHz
R	57.9 m	13.75 m

Ring Parameters

Electron Ring Parameters

Circumference	2150.097	m
Rev Frequency	0.139	MHz
RF frequency	476.3	MHz
Harmonic Number	3416	
Radius of Dipole	110.452	m
Dipole Bend Angle	2.801	degree
Crossing Angle	81.700	degree
Angle Factor	1.454	
Beta Function at RF Cav	25.000	m
Momentum Compaction	2.142E-03	
Linear SR Power Limit	10	kW/m
Total SR Power Limit	10	MW
CavityActiveLength	0.31	m
Cavity Insertion Length	1.125	m
Geometric Factor	170.8	
R/Q	233.3	
Qzero	3.00E+04	
Shunt Impedance	7.00E+00	MΩ

Ion ring Parameters

Rev Frequency	0.139	MHz
RF frequency	952.6	MHz
Harmonic Number	6832	
Momentum Compaction	6.413E-03	
Bunch Length	12	mm
CavityActiveLength	0.157	m
Cavity Insertion Length	1.91	m
temperature	1.8	K
BCS Resistance	3.88	nΩ
Residual Resistance	4.39	nΩ
Surface Resistance	8.3	nΩ
Geometric Factor	217.01	
R/Q	105.2	
Qzero	2.62E+10	
Shunt Impedance	2.76E+06	MΩ

PEP II, Electron Ring Parameter Table

Energy	3	4	5	6	7	8	9	10	GeV
Energy Loss per Turn	0.114	0.362	0.883	1.830	3.391	5.785	9.267	14.124	MeV
SRpower/ring (= power to beam)	0.34	1.08	2.65	4.39	6.58	8.17	10.00	10.00	MW
SR power per unit length	0.34	1.08	2.62	4.35	6.52	8.09	9.91	9.91	kW/m
Energy Spread	2.73E-04	3.64E-04	4.55E-04	5.46E-04	6.37E-04	7.28E-04	8.19E-04	9.10E-04	
Trans. SR Damping Time	376.14	158.68	81.25	47.02	29.61	19.84	13.93	10.16	mSec
Long. SR Damping Time	188.07	79.34	40.62	23.51	14.80	9.92	6.97	5.08	mSec
Beam Average Current	3.00	3.00	3.00	2.40	1.94	1.41	1.08	0.71	A
Bunch Length	12.0	12.0	12.0	12.0	12.0	12.0	12.5	16.0	mm
Vpeak	0.73	1.74	3.43	6.02	9.71	14.76	20.09	20.55	MV
Vgap	0.73	0.58	0.57	0.55	0.65	0.62	0.63	0.62	MV
Gradient	2.31	1.84	1.82	1.74	2.06	1.95	1.99	1.98	MV/m
Syn. Phase	9.1	12.0	14.9	17.7	20.4	23.1	27.5	43.4	degree
Syn. Tune	0.017	0.022	0.028	0.033	0.039	0.044	0.048	0.042	
Cavity Number	1	3	6	11	15	24	32	33	
Loading Angle ψL	-15.00	0.00	0.00	0.00	0.00	0.00	0	0	degree
PowerToBeam per Cavity	343.21	361.57	441.37	399.27	438.55	340.25	312.50	303.03	kW
Cavity Wall Loss Power	75.18	47.84	46.73	42.72	59.87	54.05	56.29	55.37	kW
Reflected Power	47.10	0.19	7.18	6.00	0.03	1.35	4.66	5.04	kW
Forward Power Per Cavity	465.49	409.60	495.28	447.98	498.45	395.65	373.45	363.44	kW
Total RF Power	0.47	1.23	2.97	4.93	7.48	9.50	11.95	11.99	MW
Vgr	0.98	0.87	0.93	0.88	0.93	0.87	1.01	0.99	MV
Vbr	1.38	1.38	1.38	1.10	0.81	0.65	0.82	0.54	MV
Robinson Instability Y	1.90	2.39	2.42	2.02	1.25	1.06	1.31	0.87	
Tuning Angle ψ	-65.8	-66.8	-66.8	-62.5	-49.5	-44.2	-49.2	-32.1	degree
δf	-162.79	-170.54	-170.48	-140.57	-85.44	-71.01	-84.76	-45.89	kHz
Injection Time with 2 ts	22.57	12.69	8.12	4.51	2.68	1.49	0.90	0.48	min

Electron Ring Parameter Table

With SRF cavities

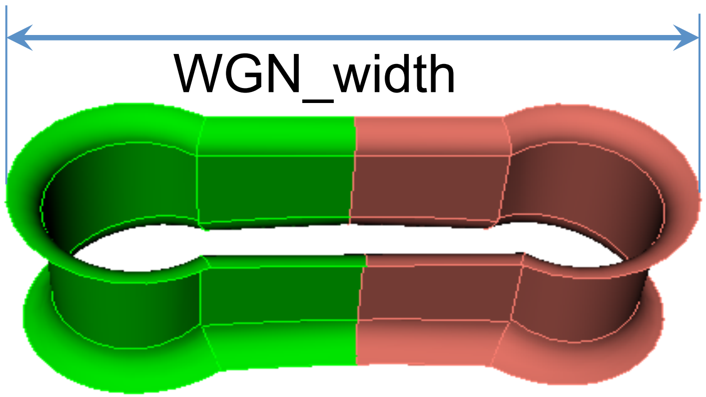
Energy	3	4	5	6	7	8	9	10	11	12	GeV
Energy Loss per Turn	0.114	0.362	0.883	1.830	3.391	5.785	9.267	14.124	20.679	29.287	MeV
SRpower/ring	0.34	1.08	2.65	5.49	10.00	10.00	10.00	10.00	10.00	10.00	MW
SR power per unit length	0.34	1.08	2.62	5.44	9.91	9.91	9.91	9.91	9.91	9.91	kW/m
Energy Spread	2.73E-04	3.64E-04	4.55E-04	5.46E-04	6.37E-04	7.28E-04	8.19E-04	9.10E-04	1.00E-03	1.09E-03	
Trans. SR Damping Time	376.14	158.68	81.25	47.02	29.61	19.84	13.93	10.16	7.63	5.88	mSec
Long. SR Damping Time	188.07	79.34	40.62	23.51	14.80	9.92	6.97	5.08	3.82	2.94	mSec
Beam Average Current	3.00	3.00	3.00	3.00	2.95	1.73	1.08	0.71	0.48	0.34	A
Bunch Length	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	mm
Vpeak	0.38	0.92	1.88	3.40	5.67	8.92	13.39	19.38	27.19	37.19	MV
Vgap	0.38	0.31	0.31	0.28	0.27	0.42	0.64	0.92	1.29	1.77	MV
Gradient	2.39	1.95	1.99	1.80	1.72	2.70	4.05	5.86	8.23	11.25	MV/m
Syn. Phase	17.7	23.1	28.0	32.6	36.7	40.4	43.8	46.8	49.5	52.0	degree
Syn. Tune	0.017	0.022	0.028	0.033	0.039	0.044	0.050	0.056	0.061	0.067	
Cavity Number	1	3	6	12	21	21	21	21	21	21	
Loading Angle ψL	-12.00	-10.00	-10.00	-10.00	-10.00	-10.00	10	10	5	5	degree
PowerToBeam per Cavity	343.21	361.57	441.37	457.62	476.19	476.19	476.19	476.19	476.19	476.19	kW
Cavity Wall Loss Power	0.10	0.06	0.07	0.05	0.05	0.12	0.28	0.58	1.14	2.14	W
Reflected Power	15.41	11.18	13.66	14.17	14.76	14.68	14.53	14.22	2.50	1.51	kW
Forward Power Per Cavity	358.72	372.81	455.10	471.84	491.00	491.00	491.00	491.00	479.84	479.84	kW
Total RF Power	0.36	1.12	2.73	5.66	10.31	10.31	10.31	10.31	10.08	10.08	MW
Vgr	0.77	0.62	0.64	0.58	0.55	0.86	1.30	1.87	2.60	3.56	MV
Vbr	1.24	0.78	0.67	0.53	0.45	0.66	0.92	1.27	1.70	2.25	MV
Robinson Instability Y	3.29	2.55	2.13	1.86	1.67	1.54	1.45	1.37	1.31	1.27	
Tuning Angle ψ	-74.3	-69.7	-65.9	-62.5	-59.4	-56.8	-34.6	-30.4	-34.2	-31.3	degree
δf	-432.52	-517.16	-503.40	-547.84	-553.68	-201.83	-40.52	-16.44	-9.66	-4.62	kHz
Injection Time with 2 ts	22.57	12.69	8.12	5.64	4.07	1.83	0.90	0.48	0.27	0.16	min

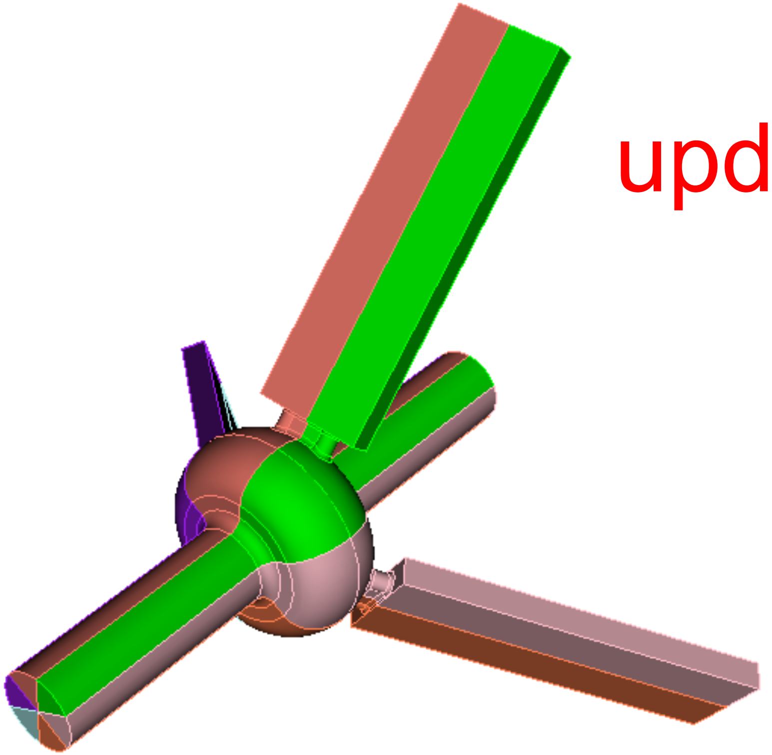
Ion Ring Parameters

	Proton									Lead ion	
Energy	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**40**	**GeV/u**
gamma	22.3	33.0	43.6	54.3	64.9	75.6	86.3	96.9	107.6	44.1	
Current	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	A
Circumference	2147.94	2149.11	2149.53	2149.73	2149.84	2149.91	2149.95	2149.98	2150.00	2149.54	m
Energy Spread	3.00E-04	3.00E-04	3.00E-04	3.00E-04	3.00E-04	3.00E-04	3.00E-04	3.00E-04	3.00E-04	3.00E-04	
Phase Slip Factor	4.40E-03	5.49E-03	5.89E-03	6.07E-03	6.18E-03	6.24E-03	6.28E-03	6.31E-03	6.33E-03	5.90E-03	
Vpeak	5.93	11.09	15.85	20.44	24.94	29.39	33.81	38.2034	42.58	40.29	MV
Syn. Phase	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	degree
Vgap	1.19	1.23	1.22	1.20	1.25	1.22	1.25	1.23	1.25	1.22	MV
Gradient	7.54	7.83	7.75	7.64	7.93	7.78	7.96	7.83	7.96	7.76	MV/m
Syn. Tune	0.038	0.047	0.050	0.052	0.053	0.053	0.054	0.054	0.054	0.050	
Forward Power	64.28	69.42	67.95	66.07	71.07	68.54	71.65	69.41	71.69	68.11	kW
Cavity Power	0.5	0.6	0.5	0.5	0.6	0.5	0.6	0.6	0.6	0.5	W
Reflected Power	64.28	69.42	67.95	66.07	71.07	68.54	71.65	69.41	71.69	68.11	kW
Coupling Beta	5.04E+05	5.04E+05	5.04E+05	5.04E+05	5.04E+05	5.04E+05	5.04E+05	5.04E+05	5.04E+05	5.04E+05	
δf	-21.1	-20.3	-20.5	-20.8	-20.1	-20.5	-20.0	-20.3	-20.0	-20.5	kHz
Qext	5.20E+04	5.20E+04	5.20E+04	5.20E+04	5.20E+04	5.20E+04	5.20E+04	5.20E+04	5.20E+04	5.20E+04	
Qloaded	5.20E+04	5.20E+04	5.20E+04	5.20E+04	5.20E+04	5.20E+04	5.20E+04	5.20E+04	5.20E+04	5.20E+04	
Active Cavity Number	5	9	13	17	20	24	27	31	34	33	
Total RF Power	321.4	624.8	883.3	1123.2	1421.5	1644.9	1934.7	2151.6	2437.4	2247.6	kW

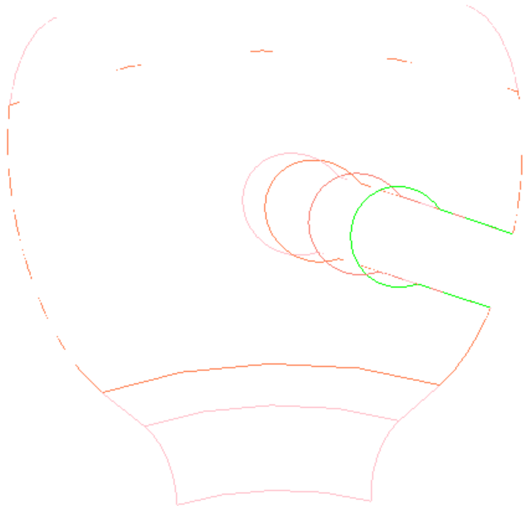
Waveguide Damping SRF Cavity Optimization by Varying the WGN width

WGN_width = 80 mm
WGN_width =100
WGN_width =120
WGN_width =129





update



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HOM Impedance vs. iris width

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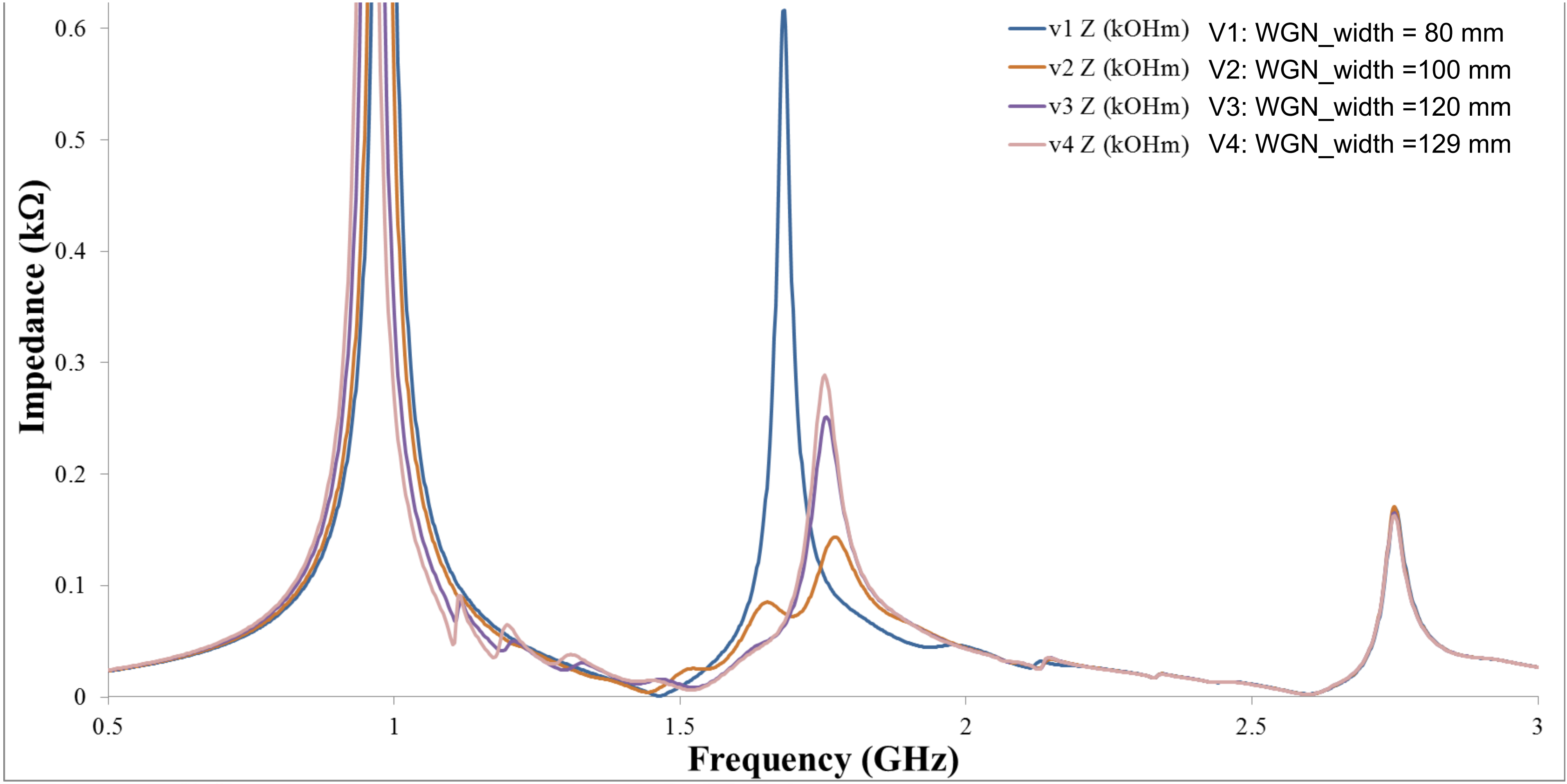
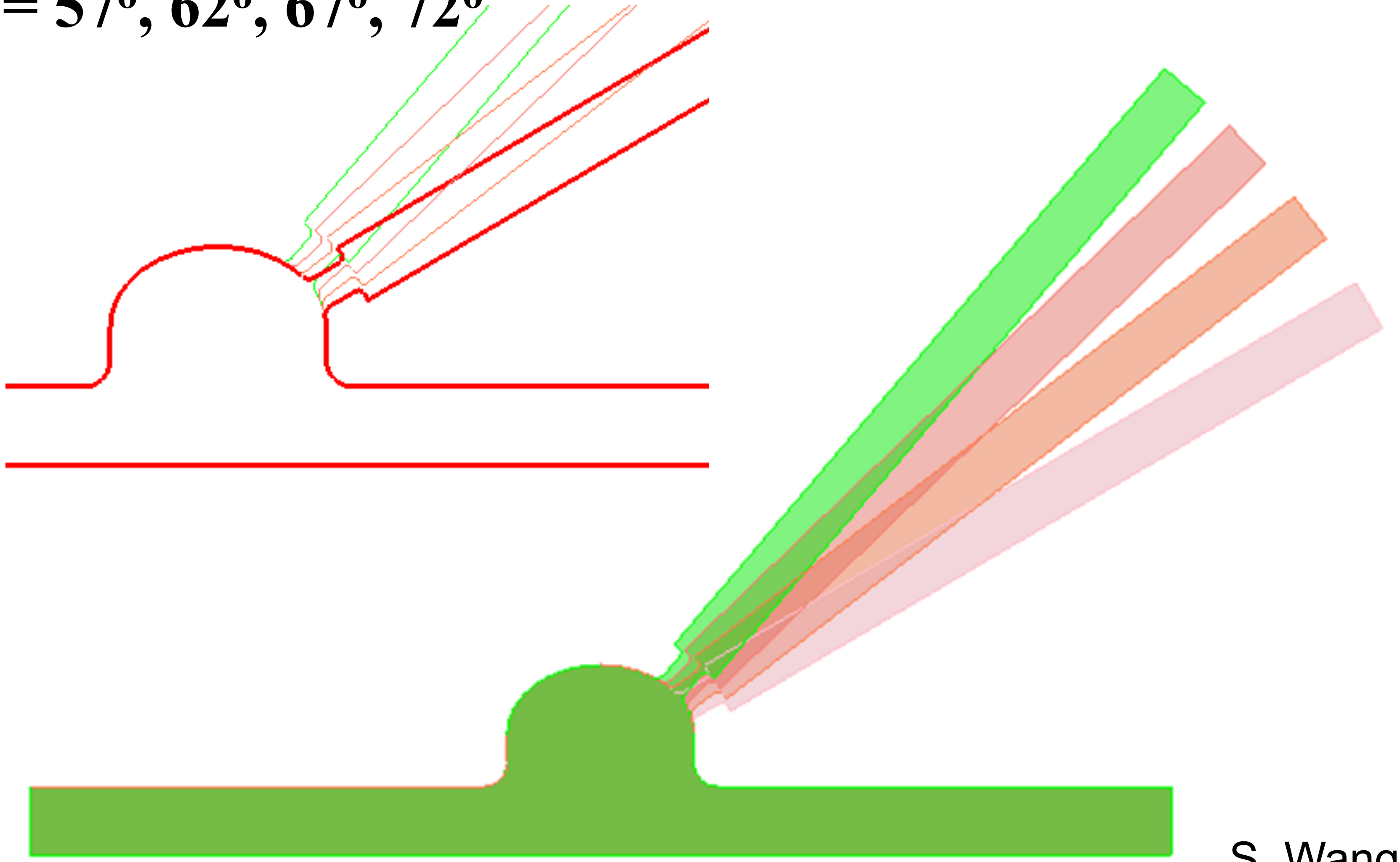


Next step: Vary the WG Angle

Waveguide-Cell angle:

$\varphi = 57^o, 62^o, 67^o, 72^o$



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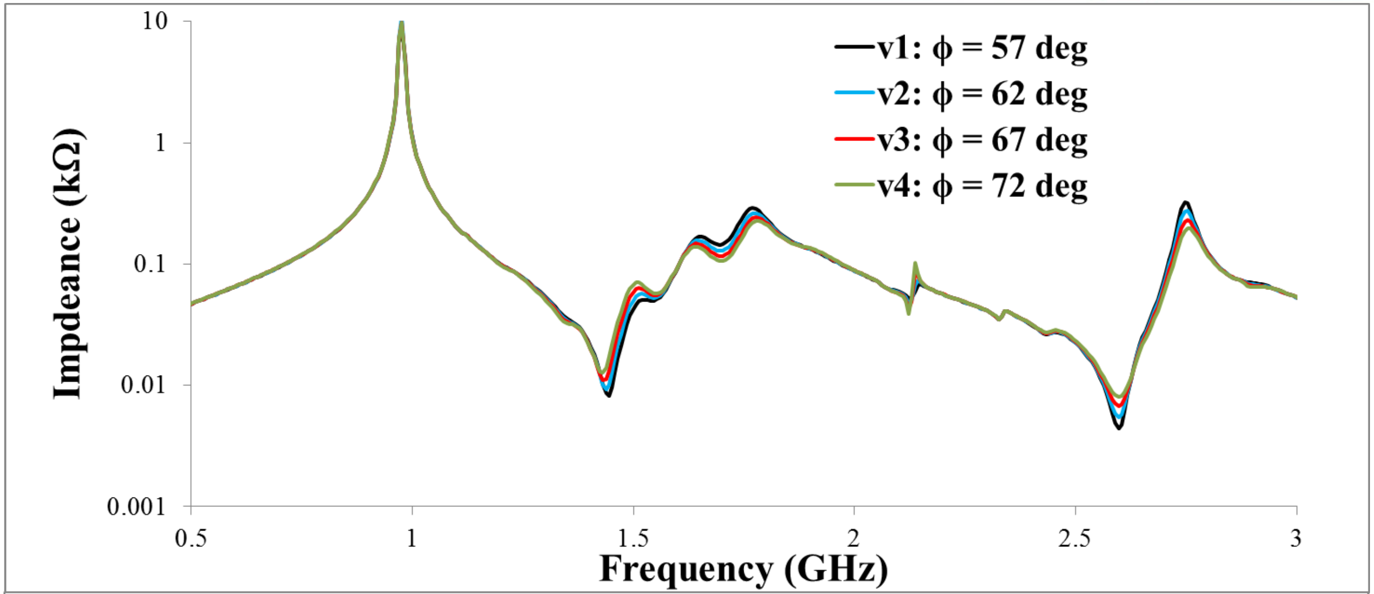
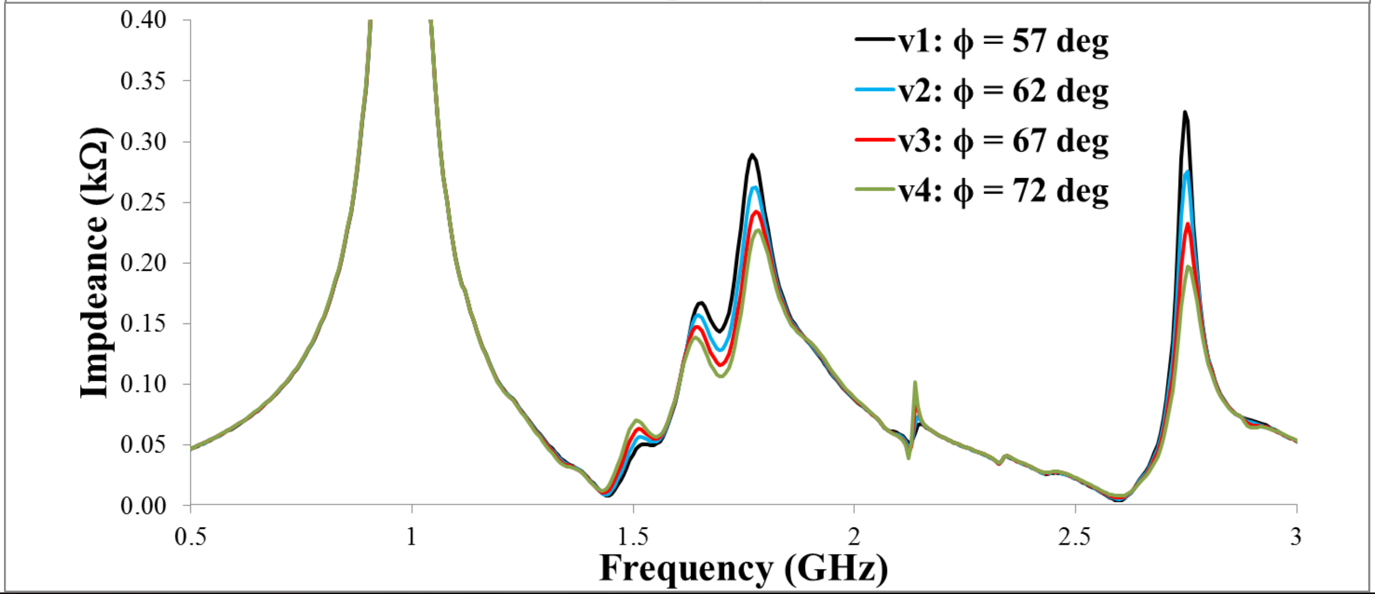
Impedance vs. waveguide position





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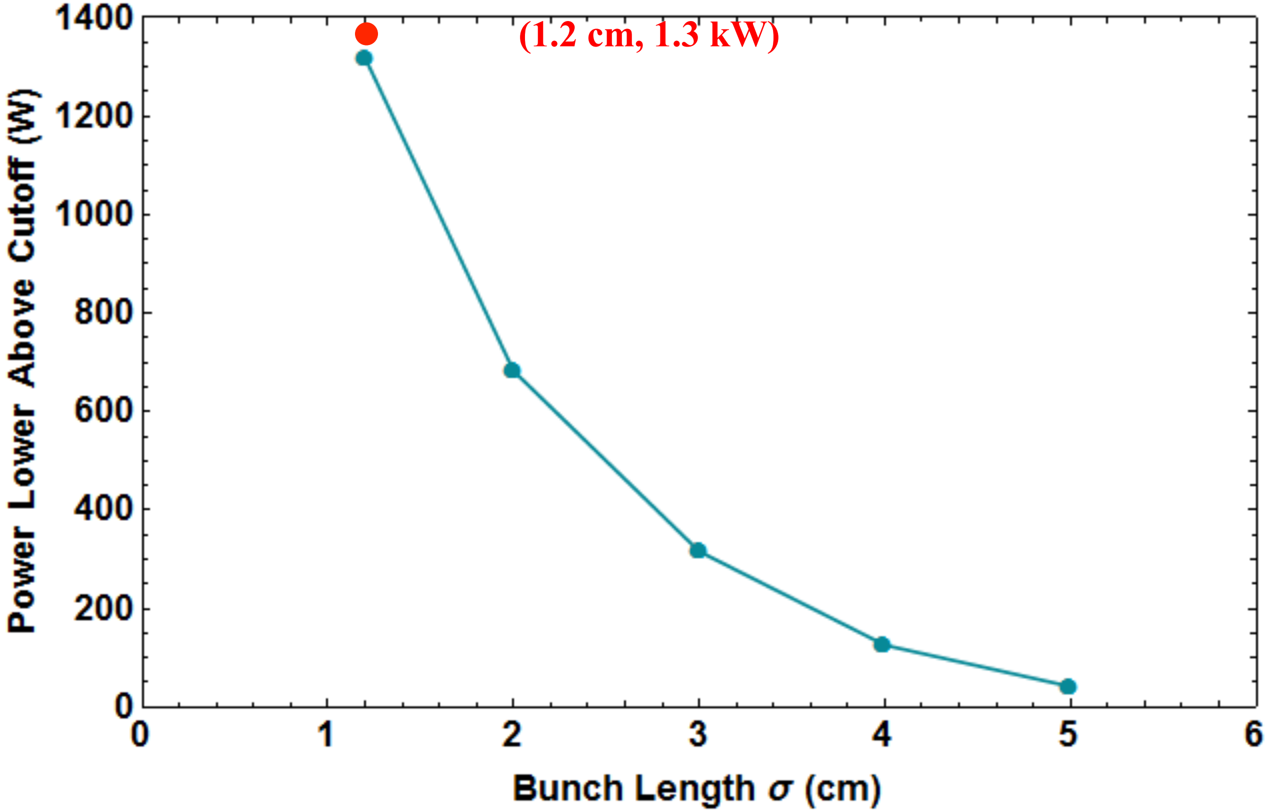
HOM Power of Bunch Train



$$P = I_{beam}^2 \times T_b \times (k_s - K(\omega_{cut-off}))$$

- I_{beam} = 3 A
- T_b = 1/(952.6 MHz)
- $\omega_{cut-off}$ = 1 GHz

S. Wang