Cavity - Experience and Future Production

PERLE Collaboration Meeting

June 3-5, 2020

PERLE | Powerful energy recovery linac experiments

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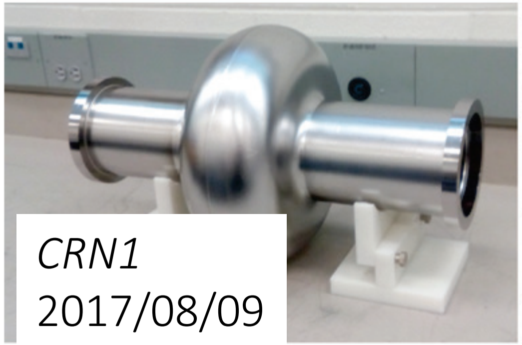
Jefferson Lab

U.S. DEPARTMENT OF ENERGY | Office of Science

JSA

Ensemble of Cavities Fabricated at JLab

- 802 MHz bare cavities produced (Nb & Cu)

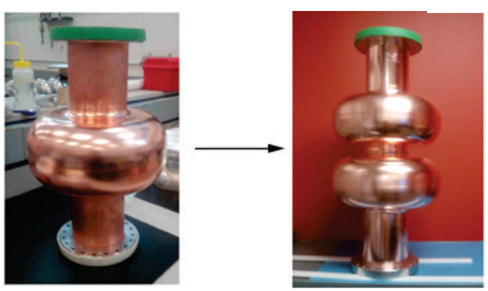


CRN1
2017/08/09

CRN5
2018/10/18

CRN-Cu1
2018/02/20

CRN-Cu2
2018/03/09



CRN-Cu1-2 (low power)
2018/03/08
- Up to 2 cells can be stacked for bench measurements

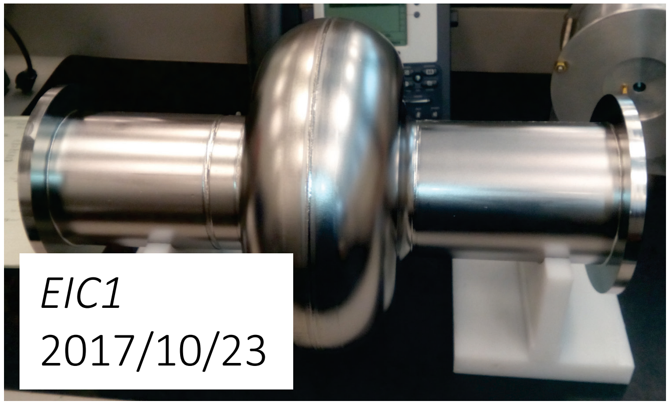
CERN-JLab Collaboration:
- Prototype fabrication and vertical dewar tests of Nb cavities
- completed in early 2018
- Results reported at

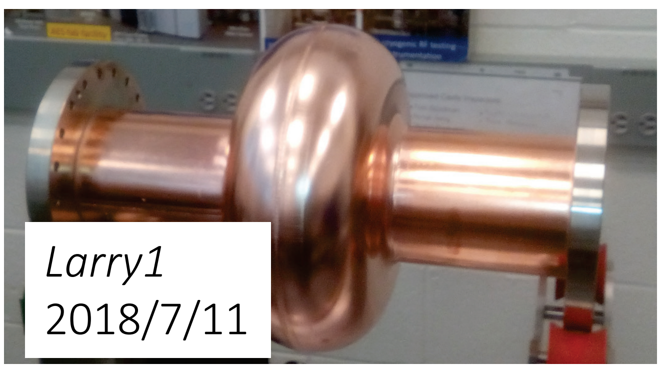
FCC Week 2018
9-13 April 2018
Beurs van Berlage
Amsterdam

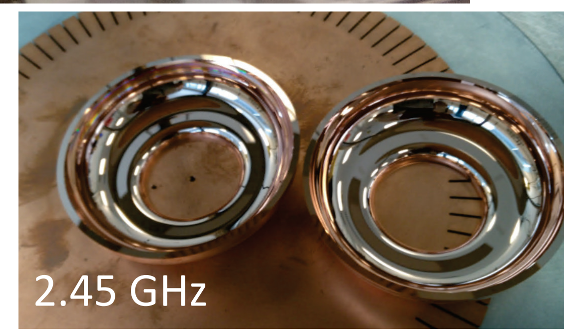
- All copper cavities shipped to CERN (2018)
- *CRN1* shipped to Fermilab for N-doping or infusion studies (2018)
- CRN5 at JLab
- No funds and activities since then at JLab

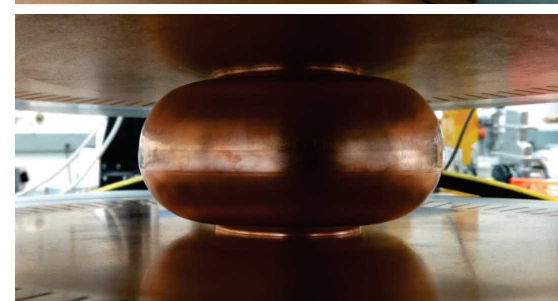
Ensemble of Cavities Fabricated at JLab

- Concurrently produced bare cavities at 953 MHz with similar shape (Nb & Cu)
  → Not too far from 802 MHz, so results might be of interest for this project as well







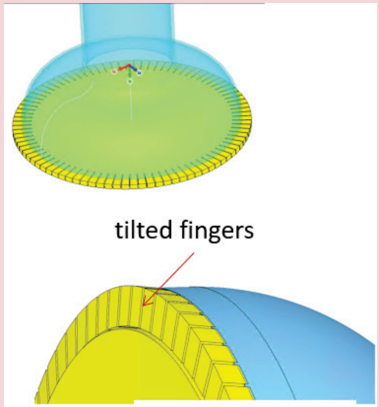


Ensemble of Cavities Fabricated at JLab

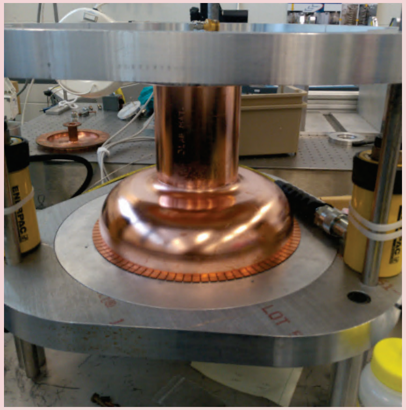
- Some copper cells were diamond-turned
- Goal: "Build-to-print" → weld → Nb-coat
- R&D aim: Investigate whether typical Q_0-slope in Nb-sputtered cavities - starting at rather low E_{acc} - can be overcome with coating on 'perfectly' smooth substrate
- JLab lost electron-beam weld expertise in 2019 up to now → will try furnace brazing to join copper cells → sample braze test on mirror-finished coupons ok → pandemic halted further efforts

Larry2 -
2 cells precision-machined with mirror finish (rms surface roughness ≤ 5 nm)

as-turned cell structure* simulated in RF meas. device



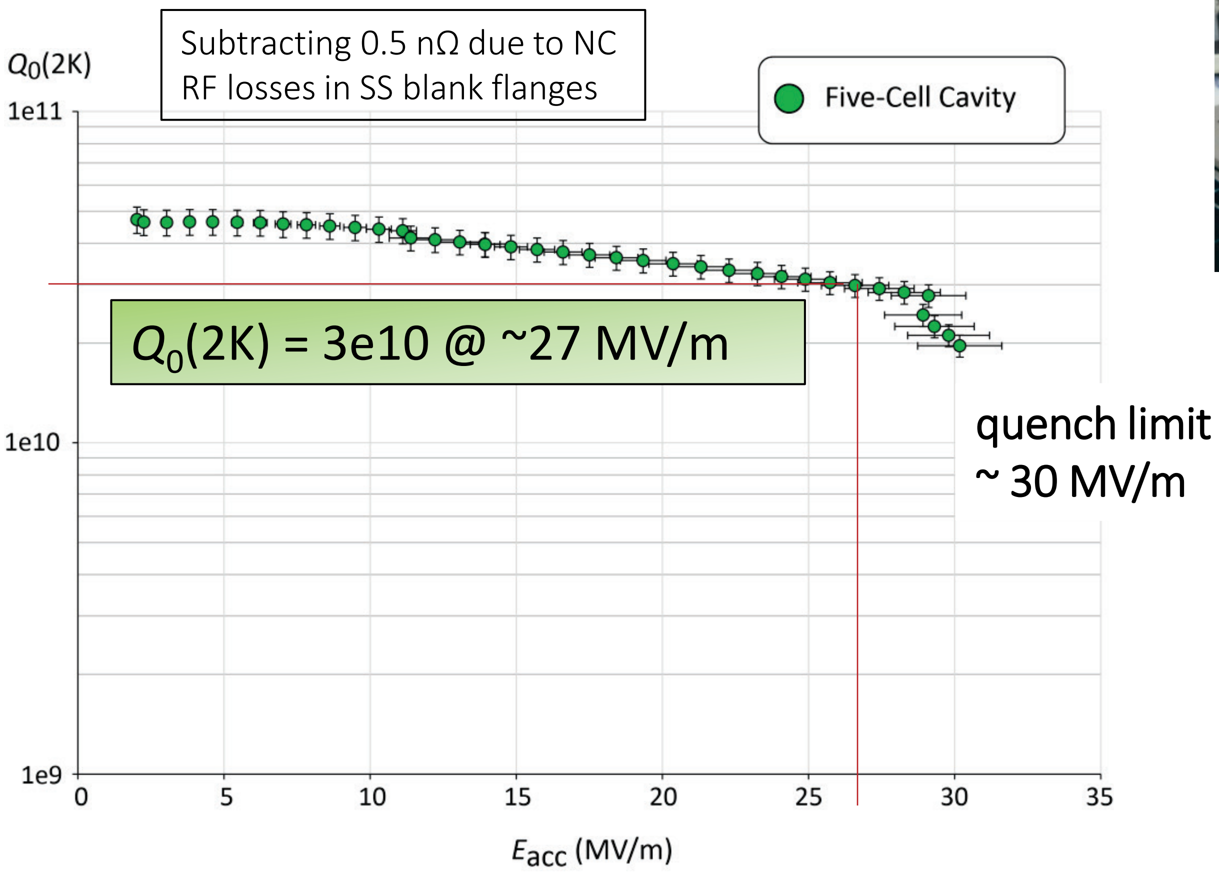
half-cell clamped to beam tube for π-mode measurement*

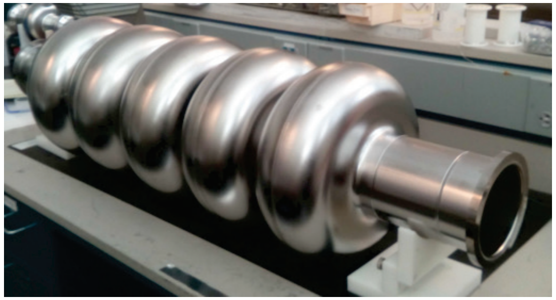


Simulated frequency (vacuum)	Measured frequency (cell *EIC1-E2*) if in vacuum
931.5934 MHz	931.6083 MHz

* oversized equator

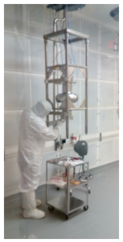
Last Vertical Test Result at 2K (*CRN5*)

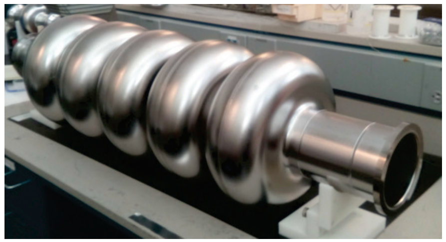




Last Vertical Test Results at 2K (*CRN5* & *CRN1*)

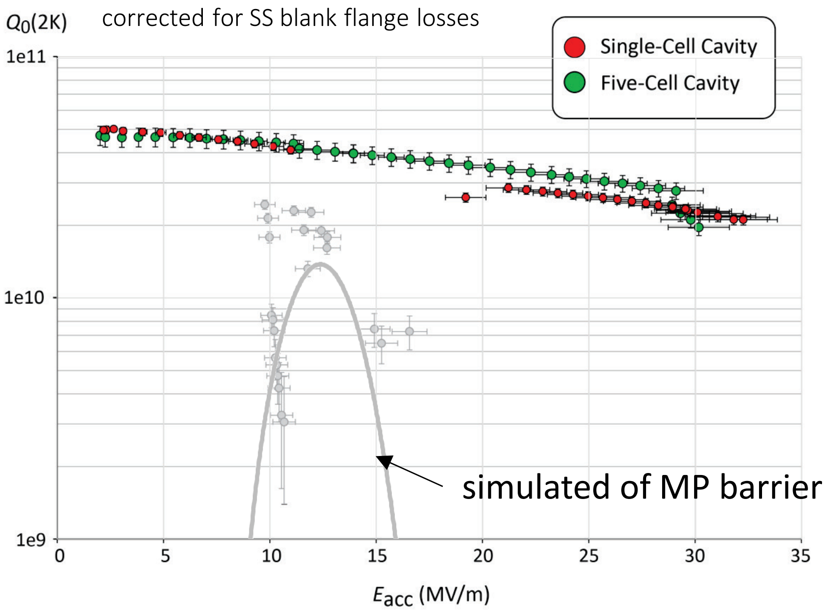
- *CRN1*: MP activities observed at ~10 MV/m, but quickly processed through





main post-processing steps

Post-Processing steps	Unit	*CRN1*	*CRN5*
Bulk *BCP*	µm	160	216
High-Temperature heat treatment	°C, hrs.	800, 3	800, 3
Final *EP*	µm	30	30
Low temperature bake-out	°C, hrs.	120, 12	120, 12

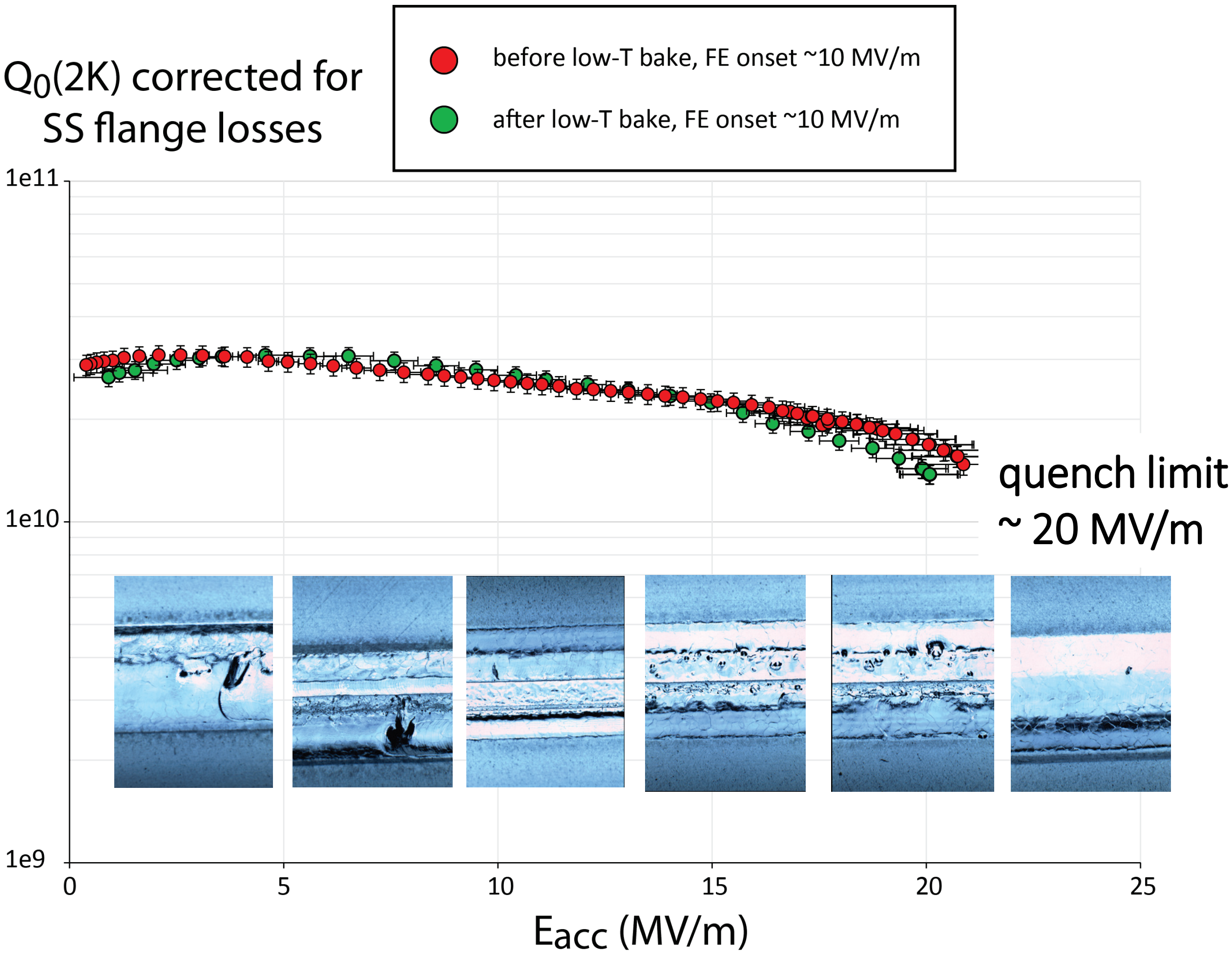


tabulated results

RF results	Unit	*CRN1*	*CRN5*
E_{acc} at quench	MV/m	32.3	30.1
E_{pk} at quench	MV/m	61.3	68.1
B_{pk} at quench	mT	129.0	126.3
FE onset field	MV/m	~20	~25
FE-induced radiation (max.)	mR/hr.	2.3	0.06
Residual resistance	nΩ	3.19	n.m.
Max. Q_0-value	/1e10	4.97	4.72
Q_0-value at 25 MV/m	/1e10	2.62	3.12
Lorentz Force Detuning	Hz/(MV/m)²	-7.1	-1.5

Last Vertical Test Result at 2K (*EIC5*)
Weld Quality Matters

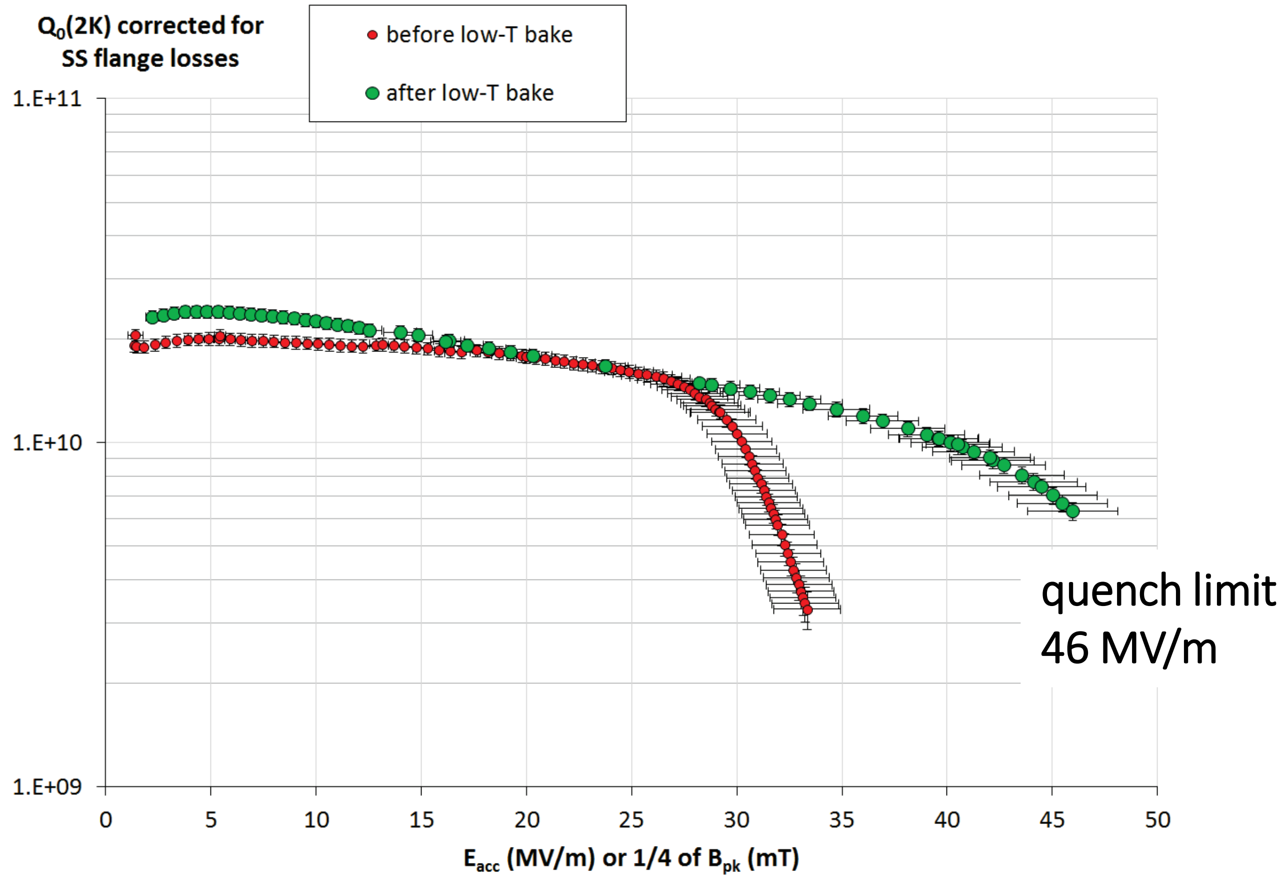
- Issues with EBW machine encountered, set gun current ≠ read-back current
  → equator welds show many blemishes



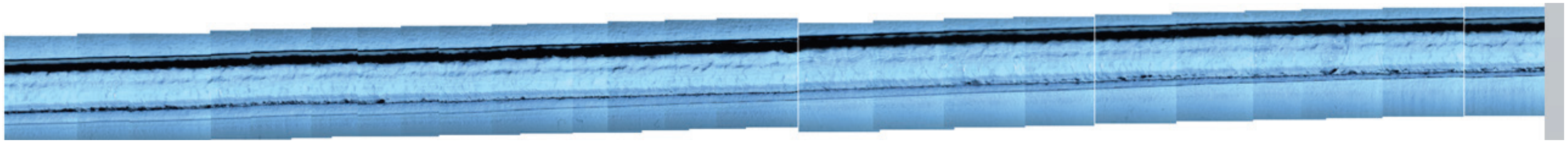
EIC5

Last Vertical Test Result at 2K (*EIC5*)
Weld Quality Matters

- In contrast – No weld issues with *EIC1* built earlier→ 46 MV/m achieved

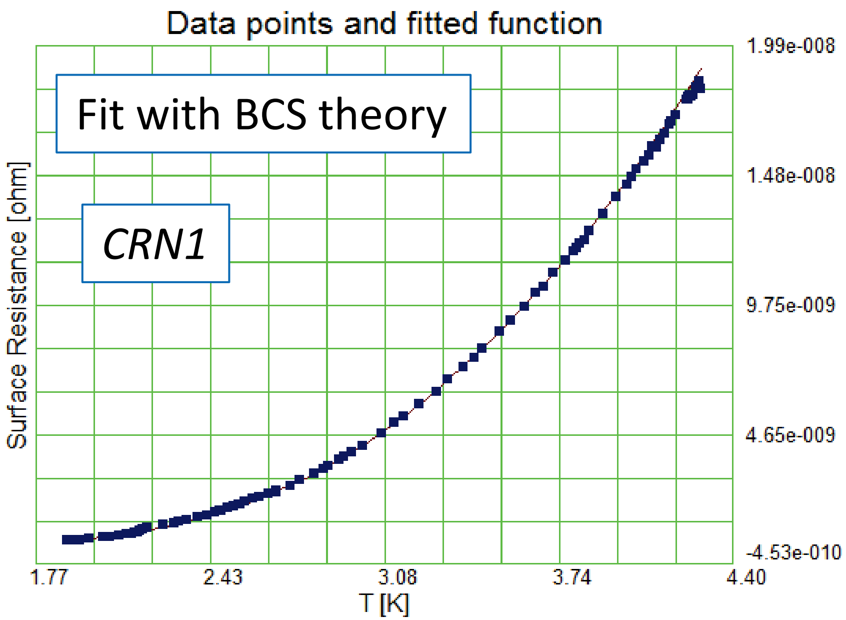


EIC1



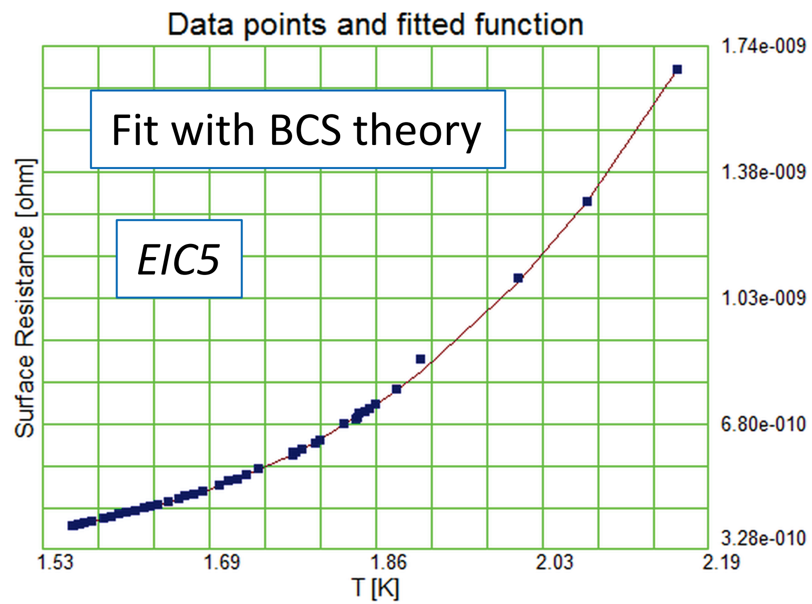
Residual Resistance

- Material used is OTIC Ningxia high-RRR (250) fine grain Nb
- Residual resistance has been assessed during tests for *CRN1 and EIC5*



R_{res} = 3.19 ± 0.79 nΩ

Note: This takes into account 2.49 nΩ due to NC RF losses in SS blank flanges for the single-cell cavity



R_{res} = 3.16 ± 1.28 nΩ

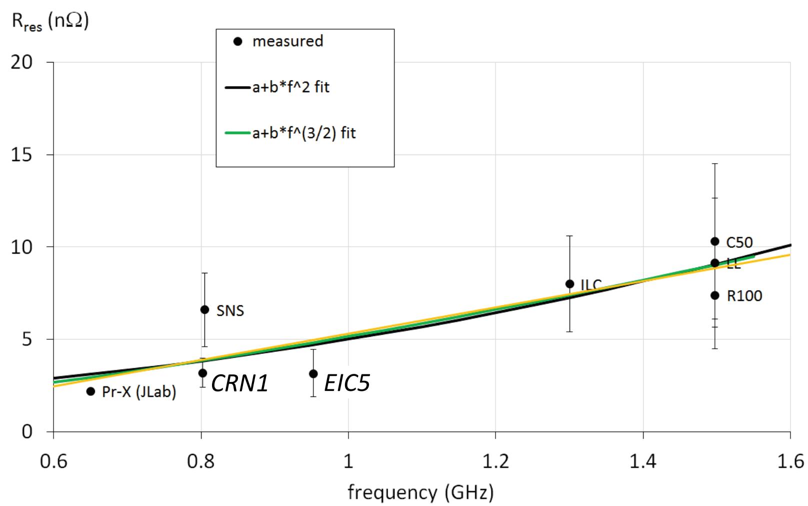
Note: This takes into account 1.31 nΩ due to NC RF losses in SS blank flanges for the five-cell cavity

Frequency-Dependence of Residual Resistance

- Added *R100* production (8 *C100*-type cavities) and few R&D cavities

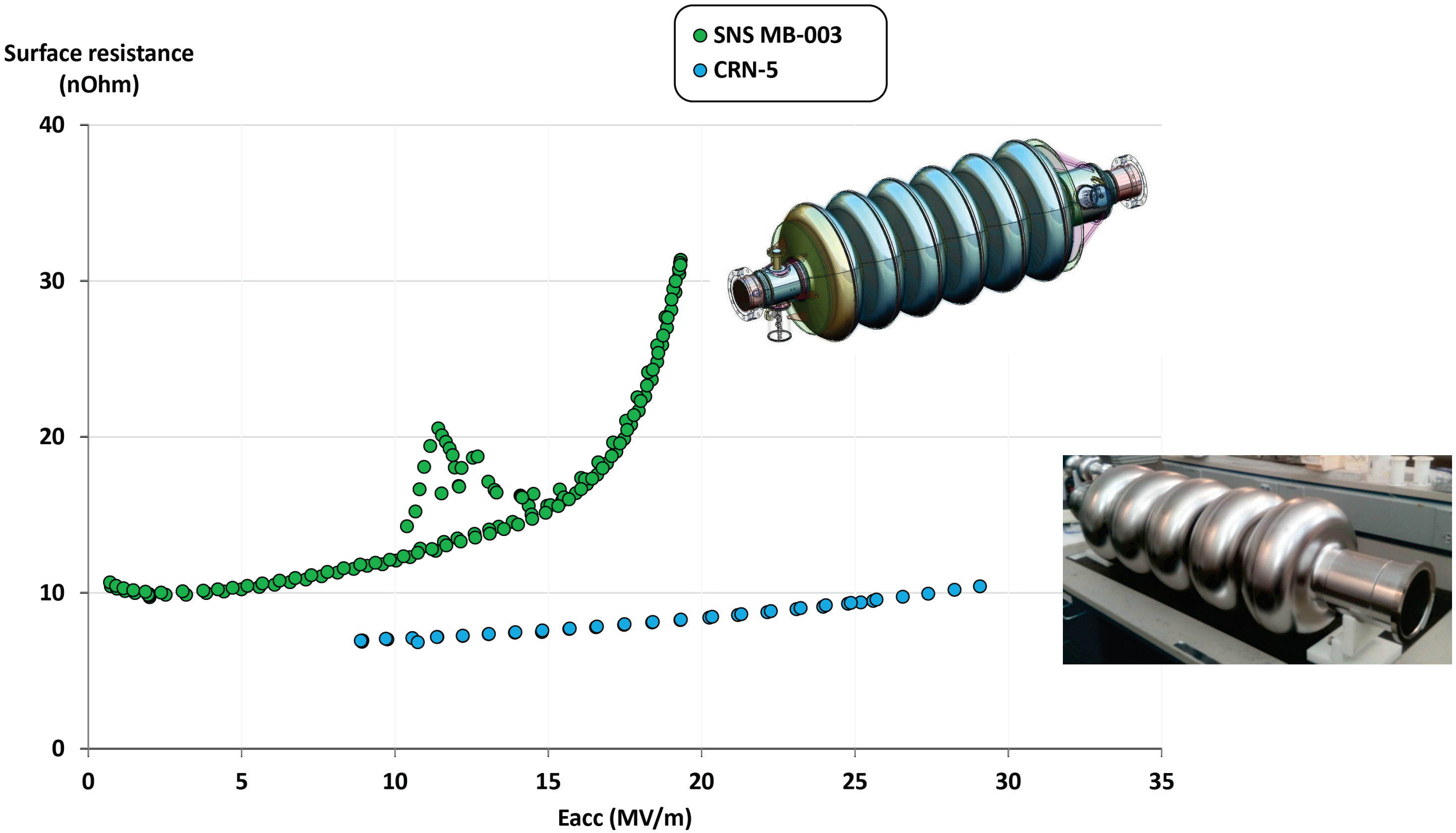
Frequency	MHz	650	802	805	953	1300	1497	1497	1497
Project		Project-X	CERN	SNS	JLEIC	ILC	CEBAF C50	CEBAF Upgrade	CEBAF Upgrade R100
# of cavities		1	2	83	1	24	83	86	2
Surface treatment		BCP + bake	BCP + light EP + bake	BCP (+bake*)	BCP + light EP + bake	EP + bake**	BCP	BCP + light EP + bake	BCP + light EP + bake
R_{res} (avg. $\pm$ STD)	nΩ	~2.2	3.2 ± 0.8	6.6 ± 2	3.2 ± 1.3	8.0 ± 2.6	10.3 ± 4.2	9.2 ± 3.5	7.4 ± 2.9

* only for a small fraction of high-beta cavities
** six ILC cavities were not baked



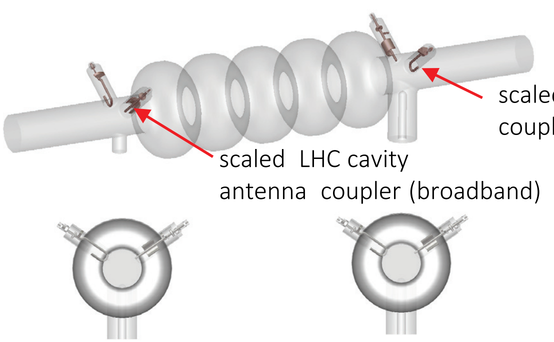
Surface Resistance

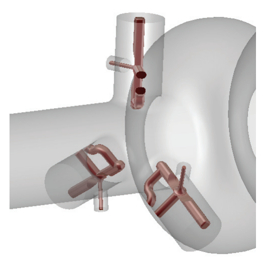
- Comparison of ~800 MHz cavities
- *CRN5* versus typical (but recent) medium-beta (MB) proton cavity built for SNS



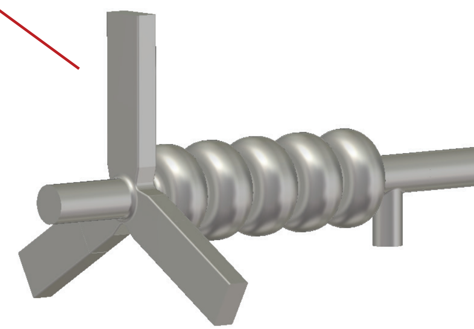
Future Production ?

- Pending further project decisions and funding JLab may contribute
- Recommendation had been made in past how to proceed with experimental HOM coupler R&D → Use *CRN5* → Cut off beam tube → Weld HOM-damping end-group
- HOM power of tens of Watts per cavity anticipated for PERLE
  → needs reevaluation of beam spectrum due to redesign
  → active cooling recommended for coaxial coupler



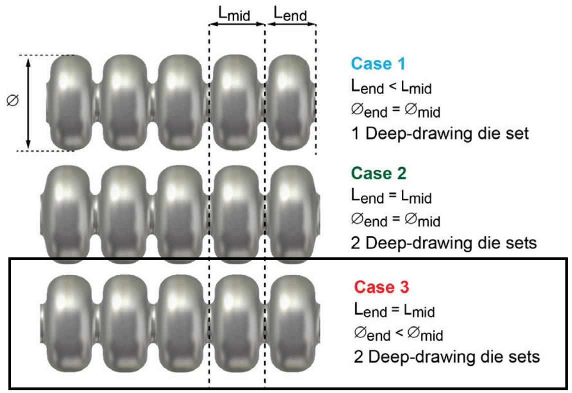


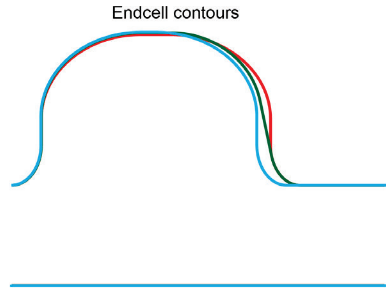
HOM 'Y' end-group with coaxial couplers

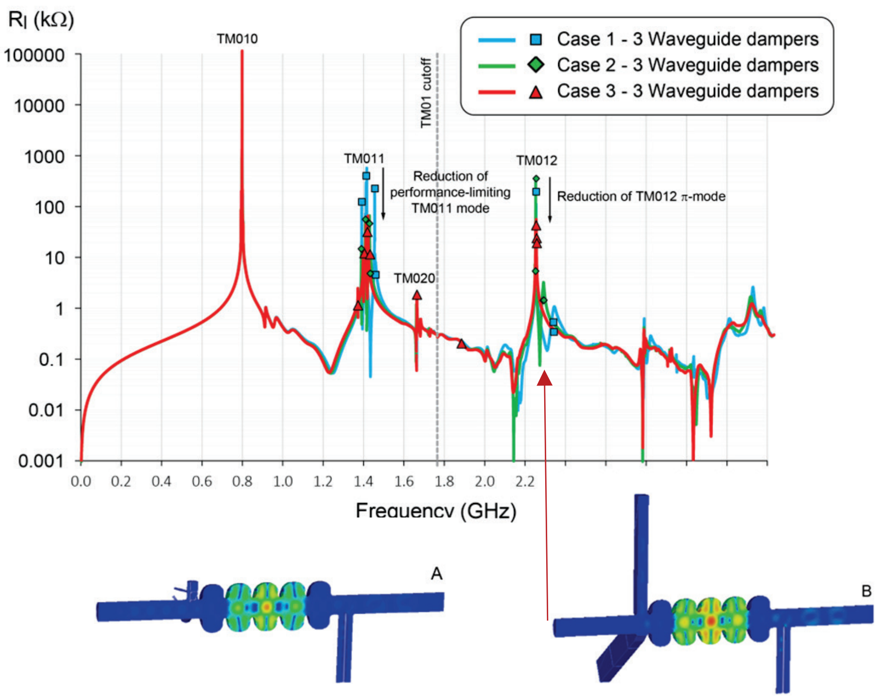


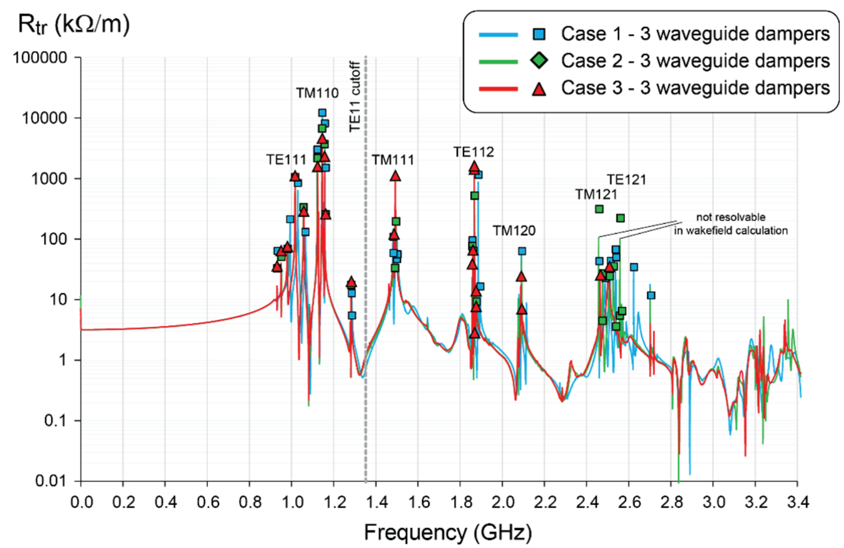
HOM 'Y' end-group with waveguide couplers

Use Differing End-Cells for Improved HOM-Damping









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Topical Review

Next generation HOM-damping

Many Thanks

Questions ?