Superconducting Twin Axis Cavity for ERL Applications

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Acknowledgement

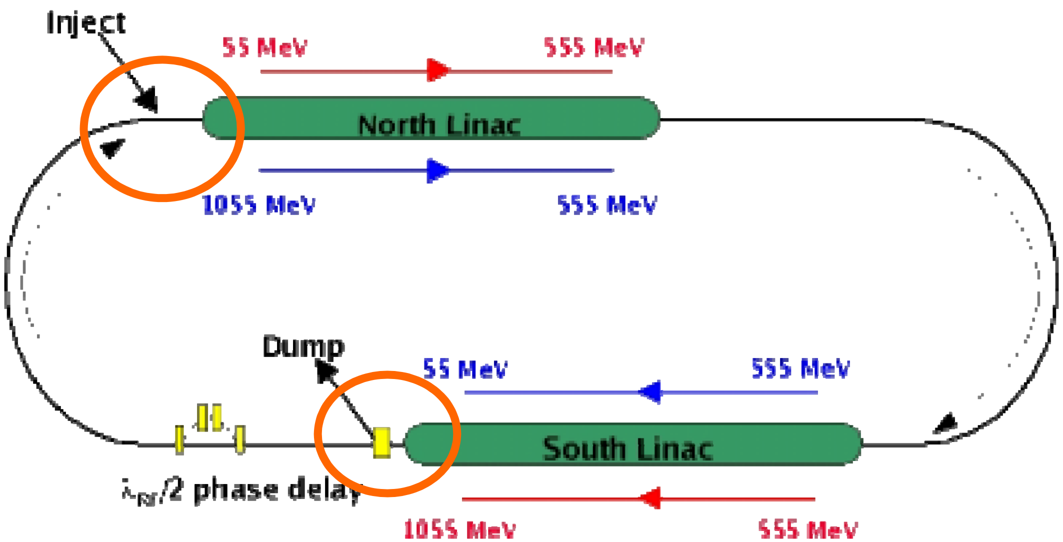
- JLab and ODU CAS collaborated to develop superconducting twin axis cavity under DOE Accelerator Stewardship Test Facility Pilot Program.
- Frank Marhauser, Andrew Hutton – JLab
- Laura Sweat, Subashini De Silva, Jean Delayen – ODU
- JLab machine shop and SRF Institute for cavity fabrication, processing and test.

Outline

- Introduction – Motivation
- Earlier Proposals for Applications in ERLs
- Design Optimization and Properties of Twin Axis cavity
- Fabrication, Processing and Lessons Learned
- Performance
- Summary and Path Forward

Introduction

- ERL became an essential part of next generation accelerators and light sources to be cost efficient and environment friendly.
- JLab has been one of leading organizations in ERL community.
  - CEBAF demonstrated 1 GeV, 1 pass energy recovery in 2003
  - 55 MeV injection energy recovered at end of South Linac.



Two Beams in Arc 1

- Key to success for ERLs: capability of keeping the injected beam energy low and increasing bunch charge while preserving beam emittance.

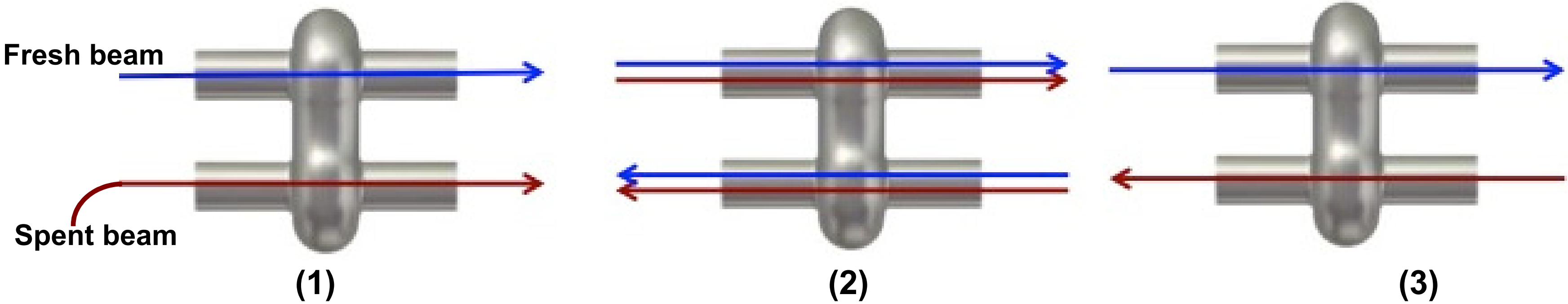
Challenges and Opportunities*

In a 'conventional' ERL, beam is accelerated in a superconducting cavity and decelerated in the same cavity after use. Beam energy is given back to the cavity during deceleration.

(1) Challenge: Beam merger
- Low energy fresh beam and high energy spent beam have to be merged. Beam merger increases emittance of injection beam. Light source performance depends on low beam emittance.

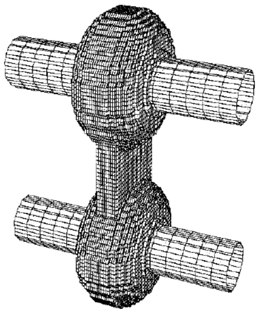
(2) Recirculating ERL
- As number of recirculation increases effective beam current multiples: Increasing risk of BBU.

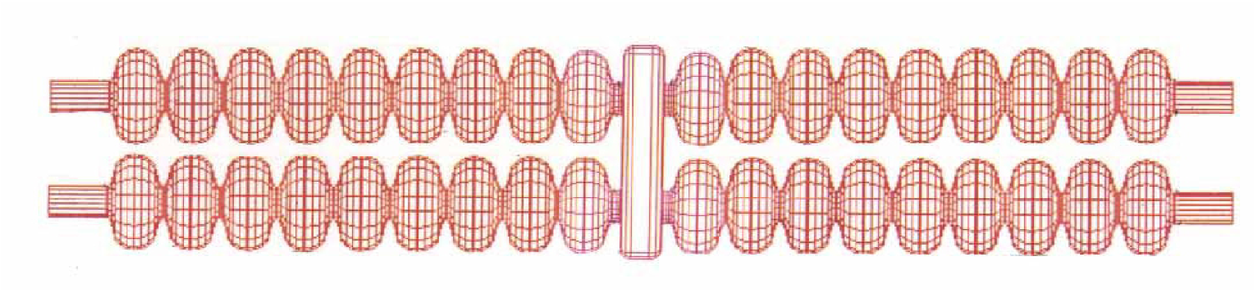
(3) Optics in ERL
- Beams with different energy in a single beam line makes focusing complicated.



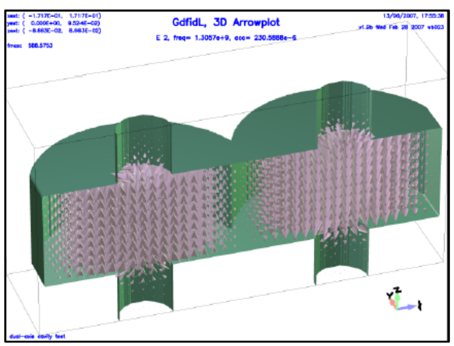
Earlier Proposals

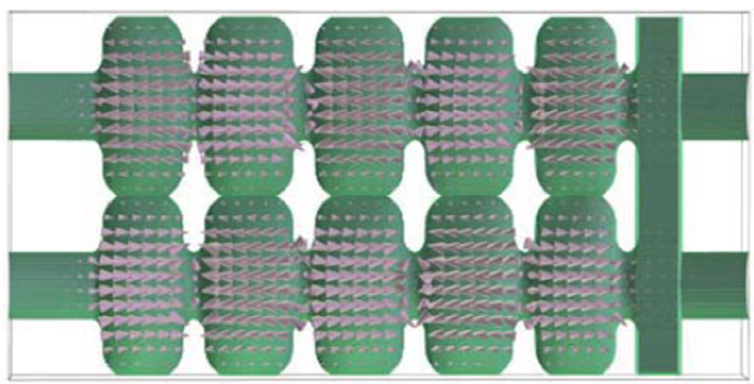
- Multi-beam accelerating structure by Noguchi and Kako at KEK (2003)
  - Multicell with one coupled cell proposed to avoid transverse kick by HOM.





- Dual axis cavity by Wang, Noonan, Lewellen at ANL (2007)

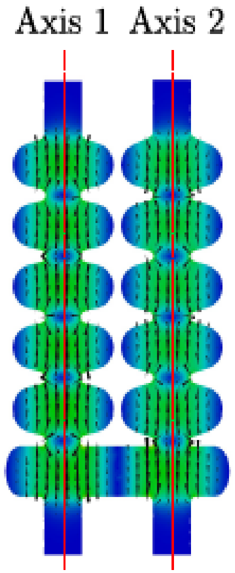




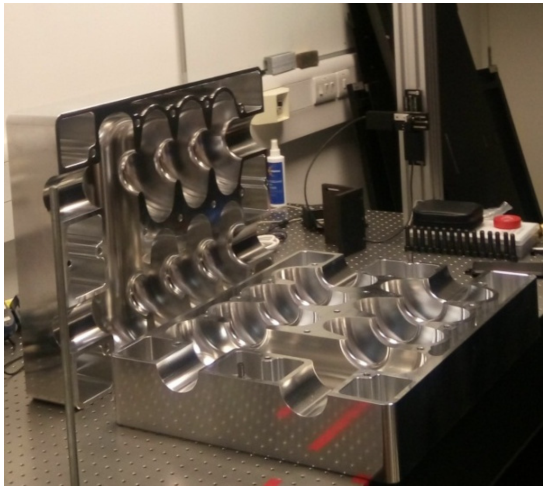
- However these cavities were not materialized

Recently…

- AERL (Asymmetric dual axis ERL) developed by John Adams Institute at Oxford University and Cockcroft Institute at Lancaster University.
  - Cavity for Ultra high flux compact source of THz and X-ray.
- Decoupling all resonant modes except accelerating mode to maximize the beam current of their application.
  - Decelerating cavities have different HOM frequencies through tuning.



E-field plot of 1.3 GHz operating mode



7-cell aluminum cavity

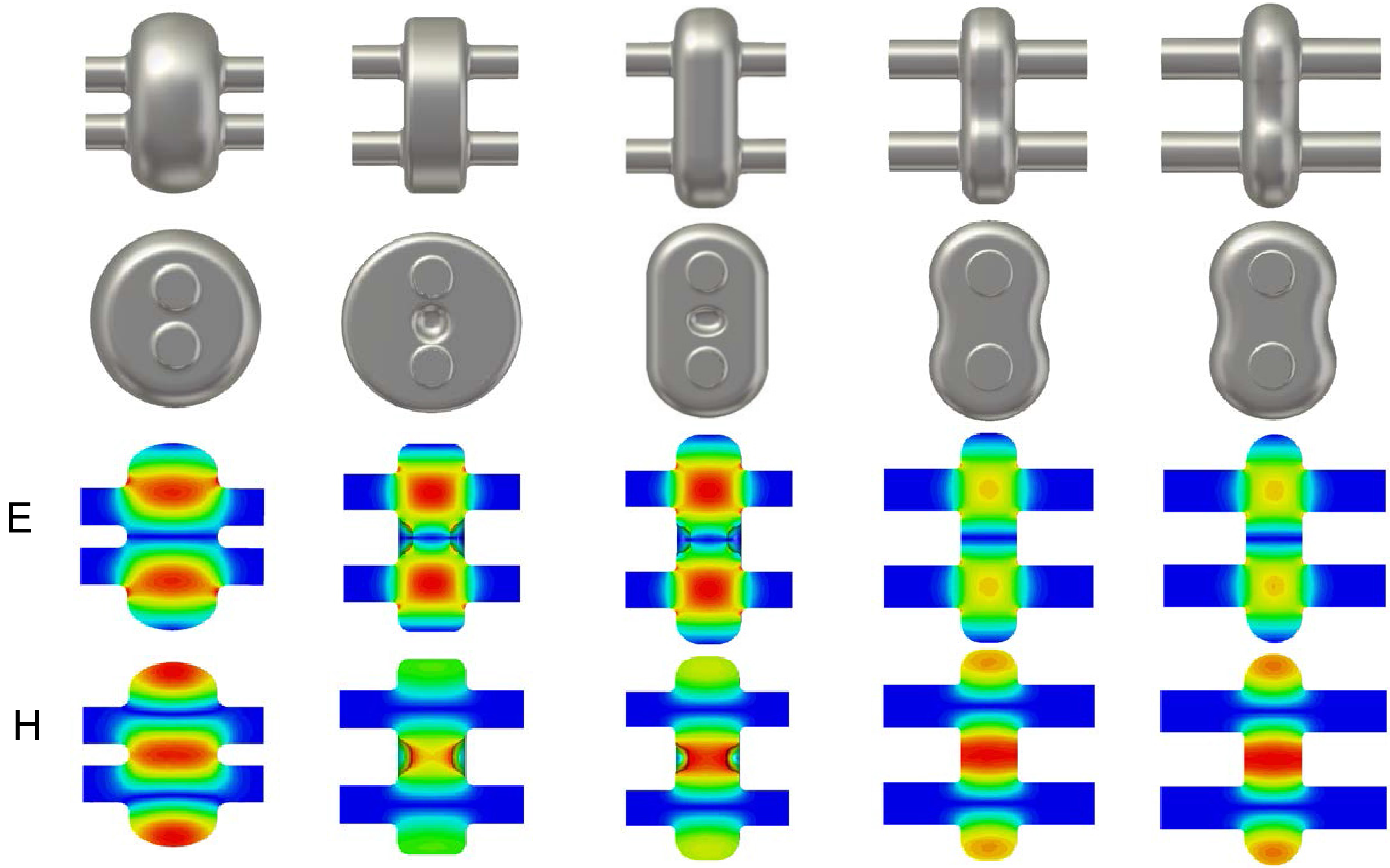
11-cell copper cavity parts ready for completion

Objective of Twin Axis Cavity

- Frequency 1.497 GHz (JLab/CEBAF) chosen without particular machine beam requirements.
- Focus on electromagnetic design optimization.
  - Reasonable E_p/E_{acc} and B_p/E_{acc}
  - No mutipacting up to design gradient
  - Minimize multipole
- Design toward ease of fabrication.
  - Use of currently mature fabrication and processing technique
- Utilize proof of principle cavity in other area of research.
  - Example: Nb_3Sn deposition, make cavity compatible with the deposition process to make cavity more energy efficient.

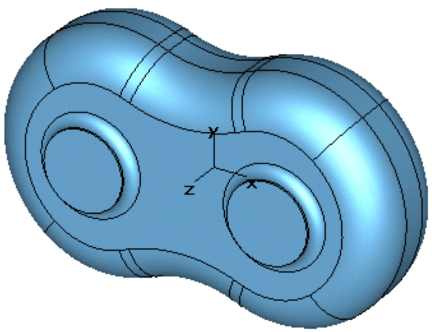
➔Path toward compact light source for university labs

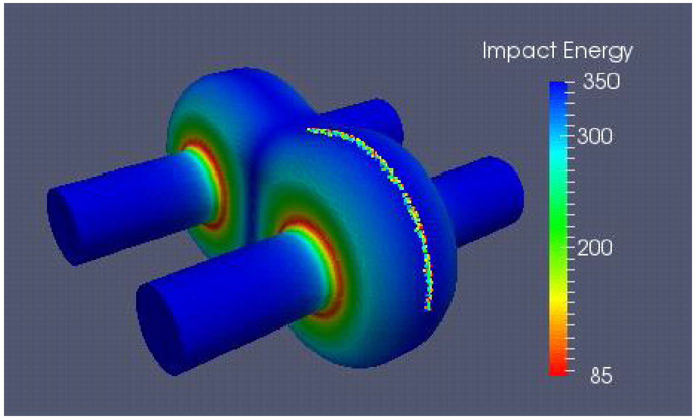
Single Cell Design Evolution



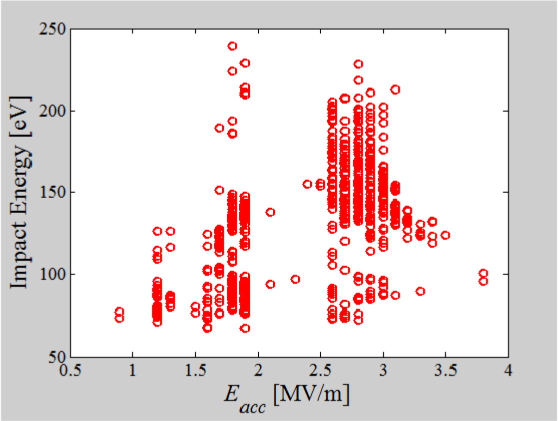
Multipacting Studies

- E_{acc} = 15 MV/m is an envisioned operating field
- 3D ACE3P/Track3P resonant MP studies performed up to E_{acc} = 16 MV/m
  - **Electron impact energy range of 50-2000 eV considered**



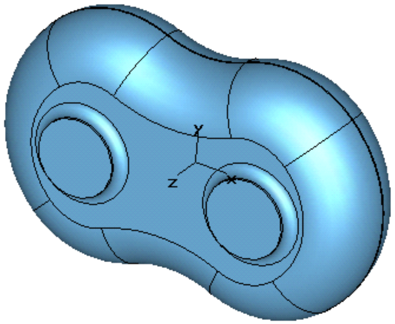


Electrons with resonant MP trajectories at cell equator (impact energy in eV)



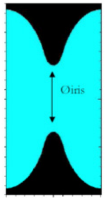
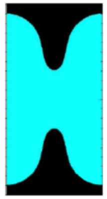
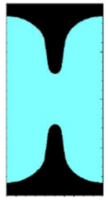
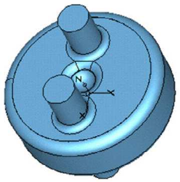
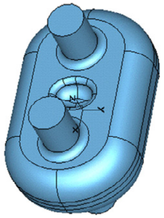
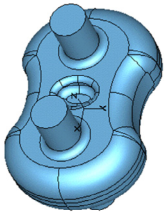
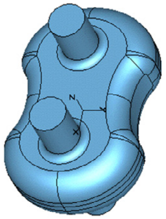
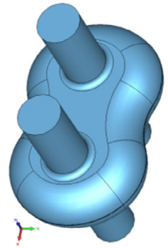
Impact energy of electrons surviving 50 RF cycles. MP barrier below E_{acc} = 4 MV/m

final design (increase equator curvature)



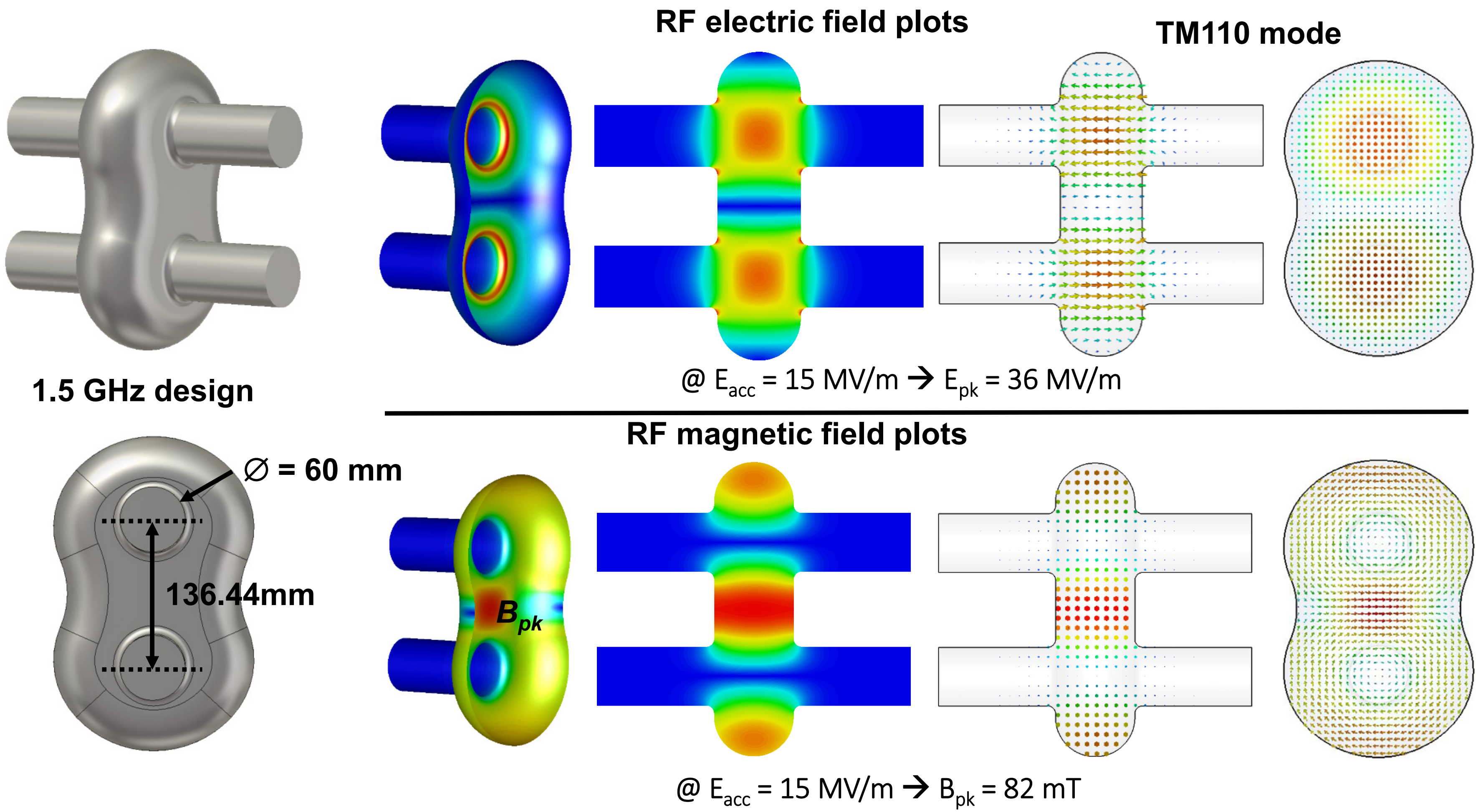
MP barrier below 4 MV/m vanished (MP barrier beyond 16 MV/m still possible)

RF Property Optimization

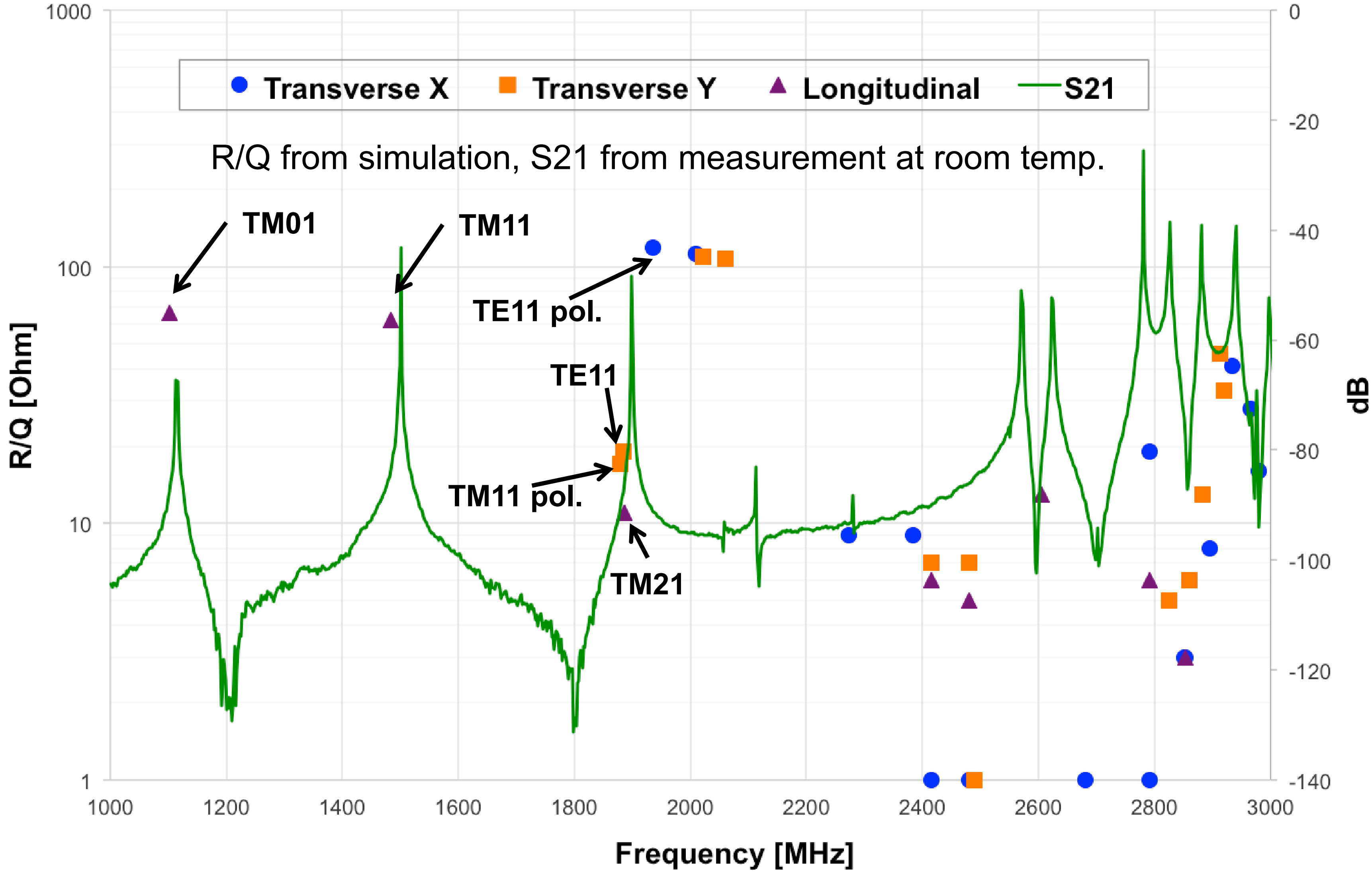
	Original Cebaf	High Gradient	Low Loss	(a)	(b)	(c)	(d)	**Final design**
								
E_{pk}/E_{acc}	2.56	1.89	2.17	2.33	2.22	2.20	2.20	**2.42**
B_{pk}/E_{acc} [mT/(MV/m)]	4.56	4.26	3.74	7.72	7.17	7.10	5.05	**5.49**
R/Q [Ohm]	96.5	111.9	128.8	58	66	68	69	**60.7**
G [Ohm]	273.8	265.5	280.3	328	323	305	318	**318**
LOM [MHz]	None	None	None	852, 1456	974	1044	1157	**1103**
1st HOM [MHz]				1774	1819	1815	1841	**1806**
Iris dia.[mm]	70	61.4	53					**60**
k_{cc} [%]	3.29	1.72	1.49					**1.80**

Final RF Design

- Transverse field components of operating mode minimized at beam tube centers
- Beam tubes slightly shifted off the peak electric field to cancel dipole effect

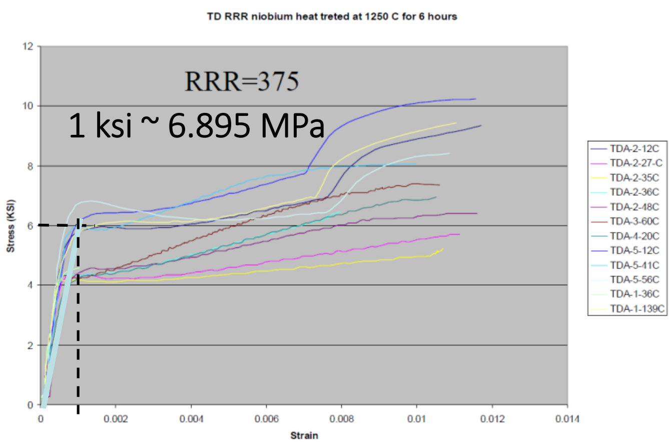


LOM/HOM Spectra



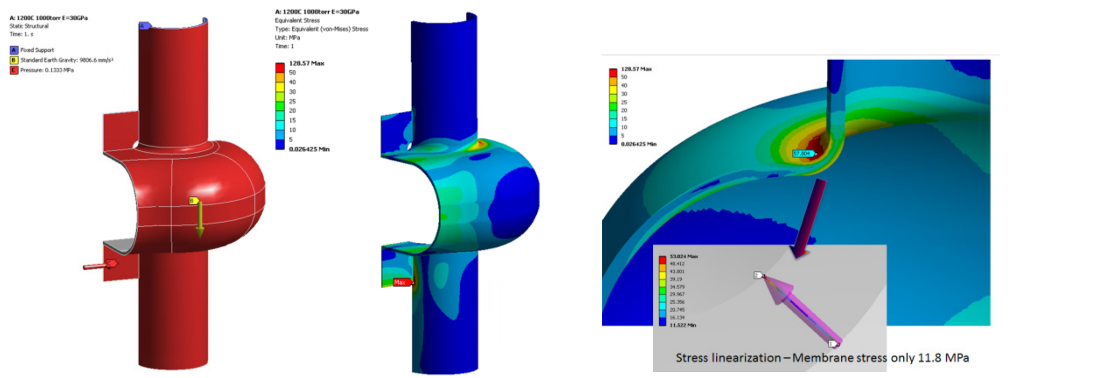
Engineering

- Withstand dewar over pressure during cool down and maintain cavity design geometry during the cold test.
- Cavity compatible with Nb3Sn vapor deposition process.
- High temperature possibly reduces Young's modulus after heat treatment (800 C) or vapor deposition (1200 C).
  - Use the lowest reported YM (30 GPa) and yield strength (30 MPa) for analyses.
  - Localized high stress area observed but linearized stress 11.8 MPa leaving enough safety margin.
  - 1/8 inch thickness sufficient but stiffener is added to avoid deflection.



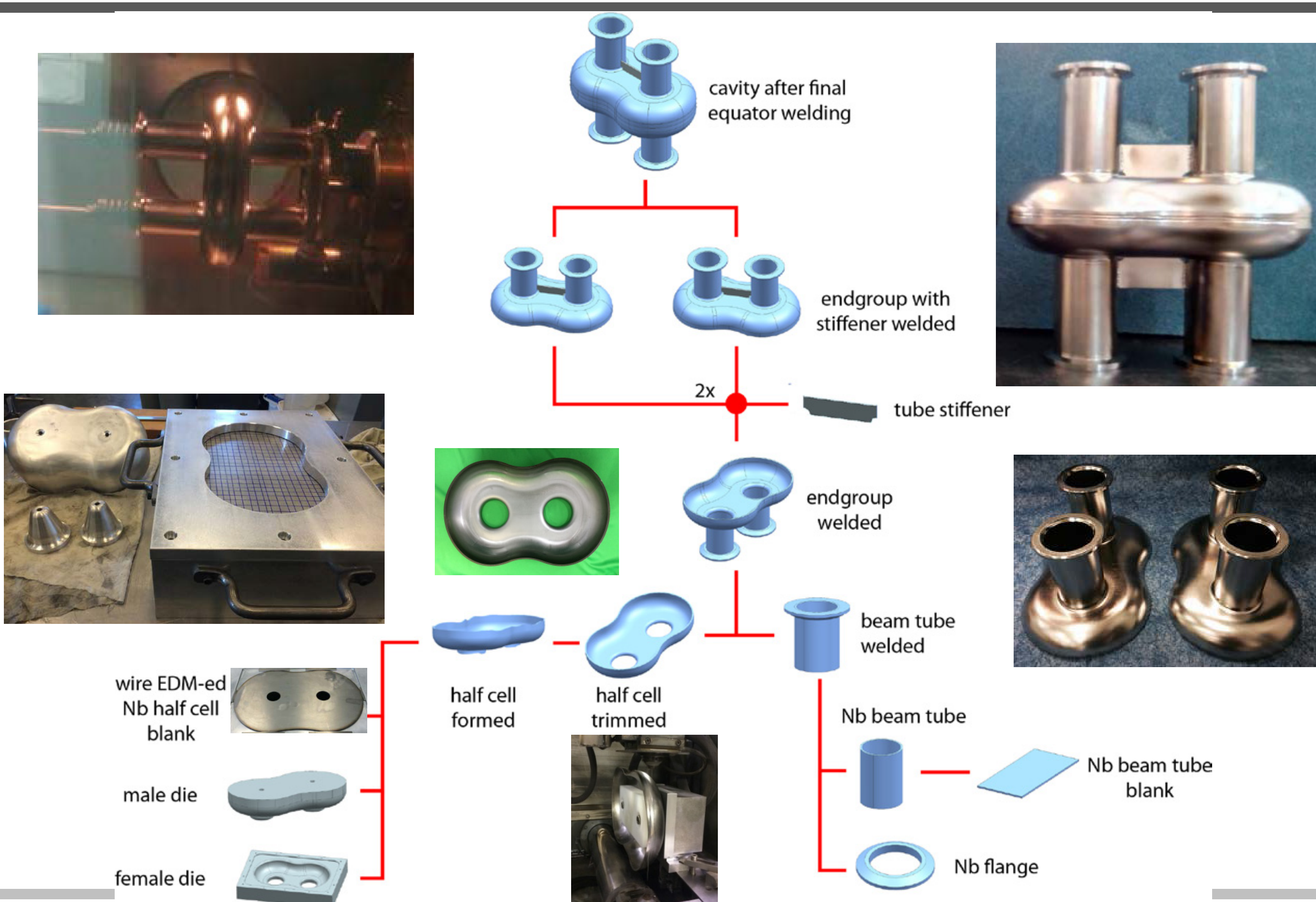
G.R. Myneni et al., Proc. of SRF 2003

VTA setup with gravity and outside pressure of 0.133 MPa considered



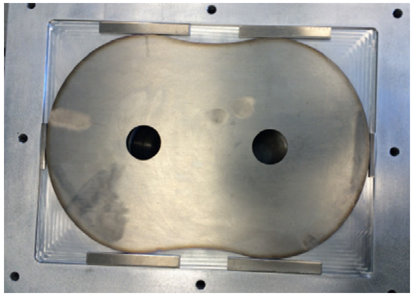
with stiffener

Fabrication Flowchart

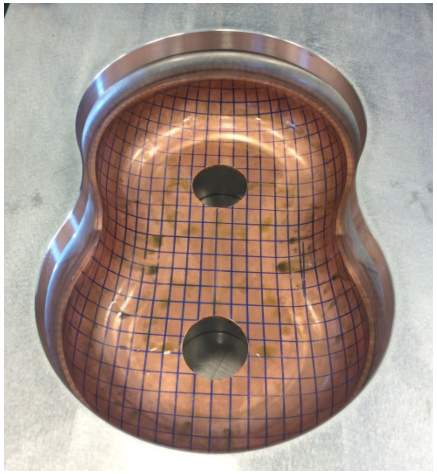


Lessons Learned from Fabrication (1)

- Blank study – one iteration was enough to determine final blank shape.
- Half cell deep drawing was uneventful.
- Half cell shape (flat surface between beam pipes) allows minimal trimming fixture.
- Spring back was surprisingly uniform in spite of non-axisymmetric perimeter.
- Material thickening at equator was however not uniform. ➔ This made weld joint machining complicated and contributed to weld problem.



Final Nb blank

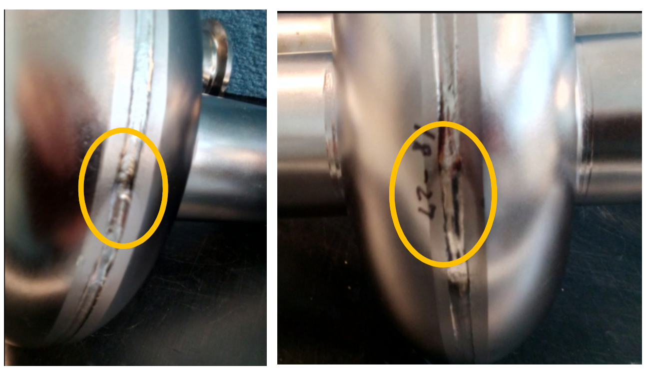


1st stage forming

EDM trimming

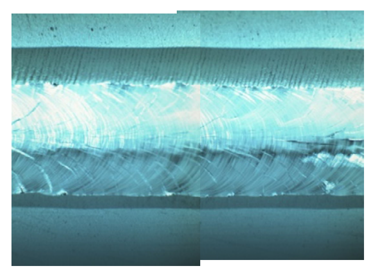
Lessons Learned from Fabrication (2)

- Final equator welding was eventful!!
  - EBW machine not capable of smooth transitioning between weld parameter (beam current and speed) to account figure 8 profile.
  - Non uniform weld joint thickness did not help.
  - Full penetration weld left a couple of melt-through holes which were patched later.
  - 2nd prototype was prepared more carefully to have uniform thickness all around the perimeter. Improved but still had same issues.
  - Welding issues likely avoidable using newer machine (smooth welding parameter transition) and/or more practice.

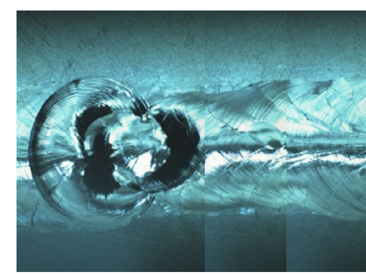


1st prototype

2nd prototype



Clean weld seam

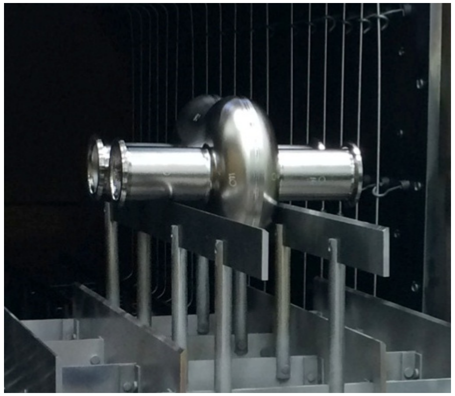


Patched area

Cavity Processing

- Bulk BCP 200 micron, average 180 micron actual
- Heat treatment 800 C 3 hours
- Light BCP 25 micron
- Flange seal surface flash BCP
- High pressure rinse
- No low temperature bake for first test
- Clean room assembly

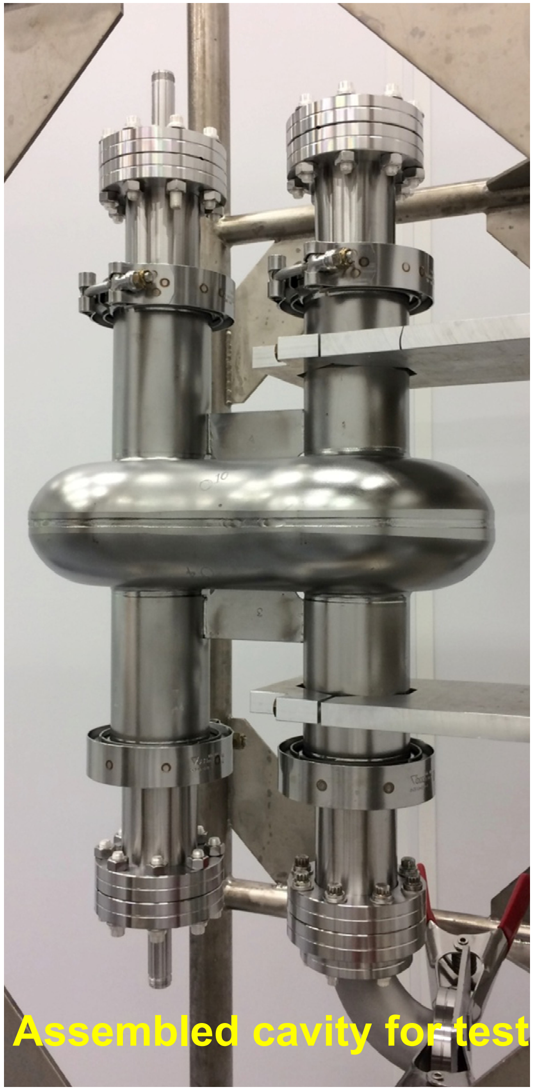
Bulk BCP setup



Heat treatment

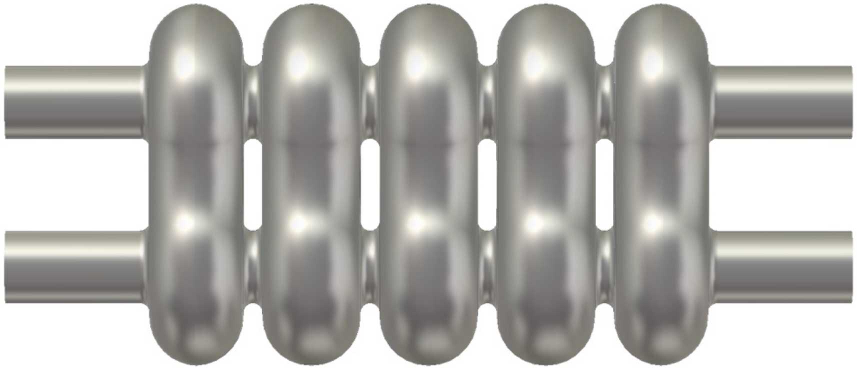
Summary

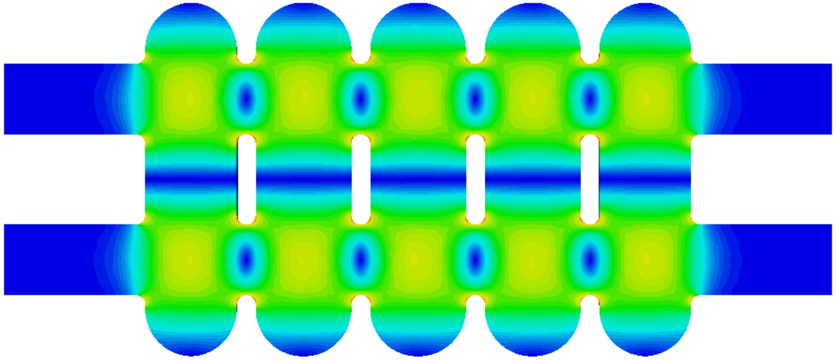
- ODU/JLab designed and fabricated first superconducting twin axis cavity.
- The optimized cavity has reasonable rf properties.
- Proved the fabrication can be done using widely used technique while we learned fabrication steps to pay attention.
- Twin axis cavity was processed using typical recipe.
- Cavity is assembled and unfortunately leak was found and it delayed high power cold test.



Path Forward

- Test proof of principle cavity!
- HOMs need to be fully characterized along with damping scheme.
- Application driven wakefield analysis is necessary to evaluate feasibility of multicell twin axis cavity.





- Single cell twin axis cavity can be incorporated in AERL application.

Thank you!