Development of Brazeless Accelerating Cavities

Chunguang Jing
Euclid Techlabs, LLC

Team members: S. Antipov, S. Kuzikov, P. Avrakhov, E. Knight, E. Gomez, Ed. Dosov…
Collaborators: AWA (John Power) and SLAC (Valery Dolgashev)

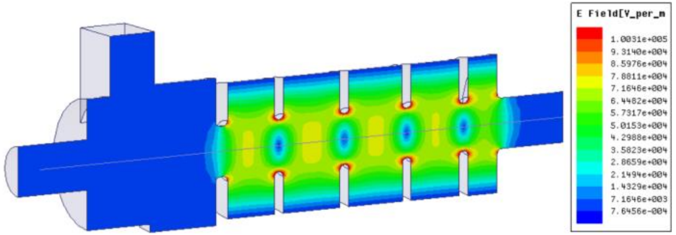
HG2021, 04/20/2021

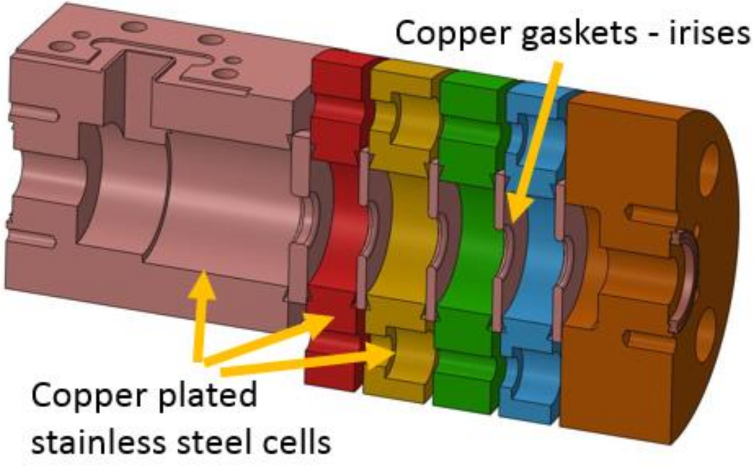
Motivation

- **Fabrication simplification and Price reduction for accelerators**
- Originally based on Euclid’s Patent US9913360B1
- Funding Source: DoE SBIR Grant #DE-SC0017749
- Tightly in collaborations with AWA (PoC: John Power) and SLAC (PoC: Valery Dolgashev)
- Three types of structure were tested in 2020-2021
  - 1 MeV low energy accelerators tested at Euclid
  - Short pulse high power wakefield power extractor tested at AWA
  - Side-coupled X-band accelerating cavities tested at SLAC

Low Energy Accelerators (design 1)

1 MeV, ~9 GHz, π – SW, 12 MV/m, 200kW

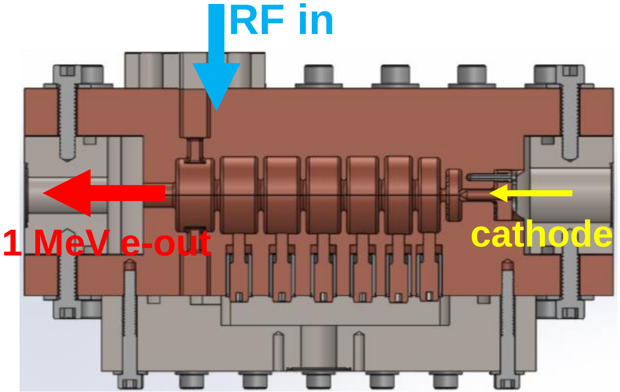


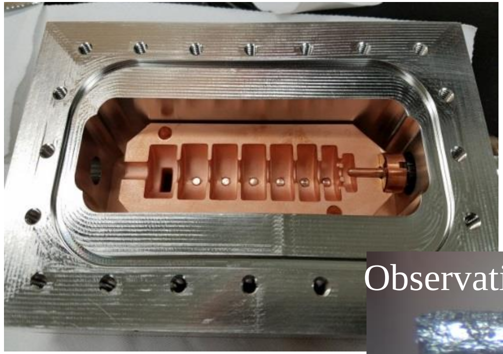


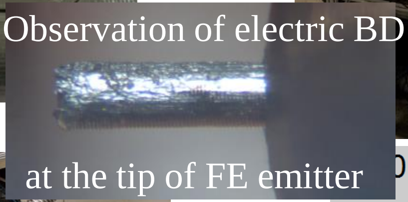
S. Antipov, US Patent US9913360B1

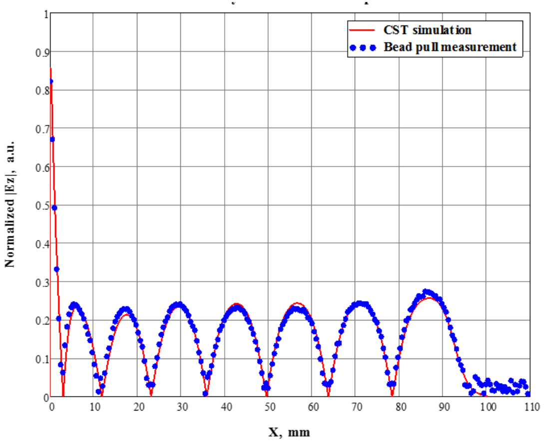
- Tested to ~10MV/m (power limited) without observable breakdowns.
- Tuning and copper plating and soft gaskets are concerns.

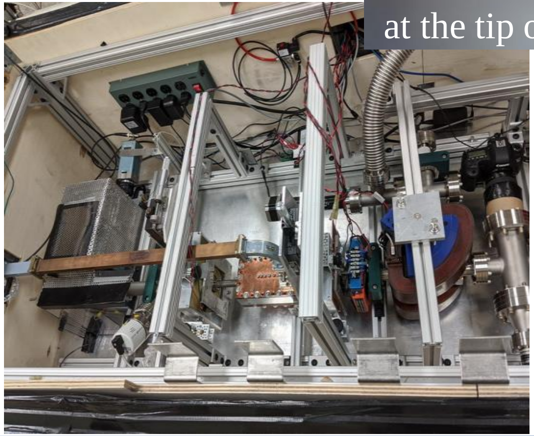
Low Energy Accelerators (design 2)

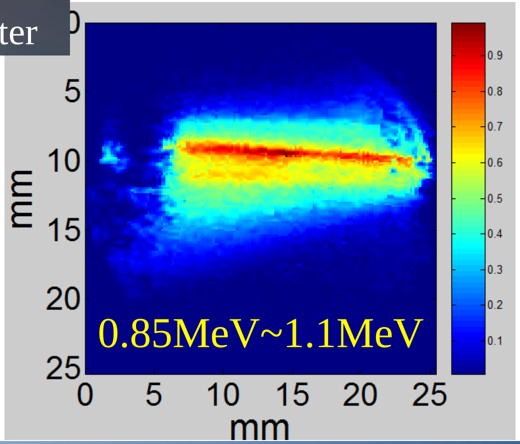




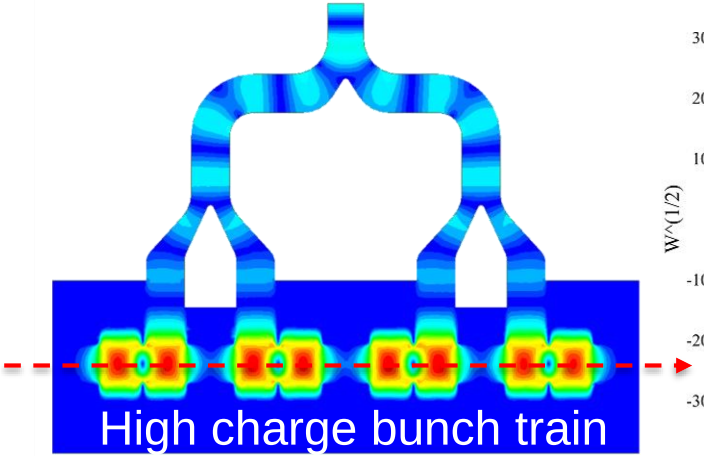


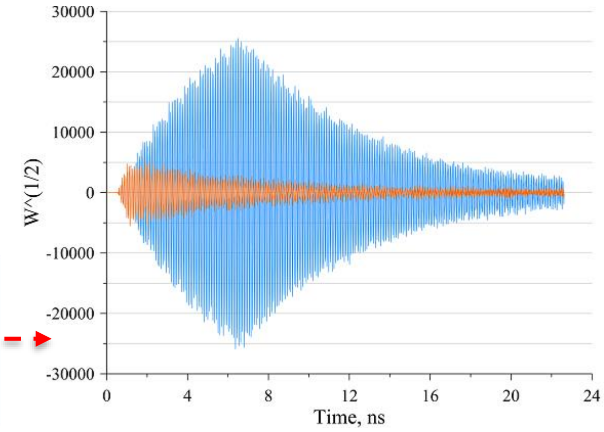


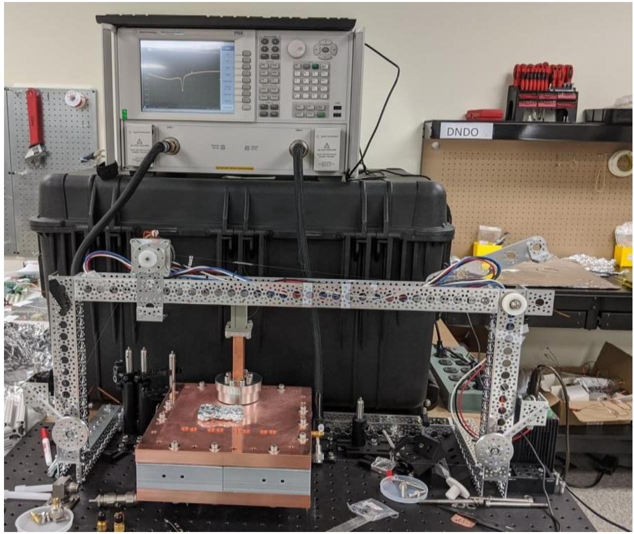


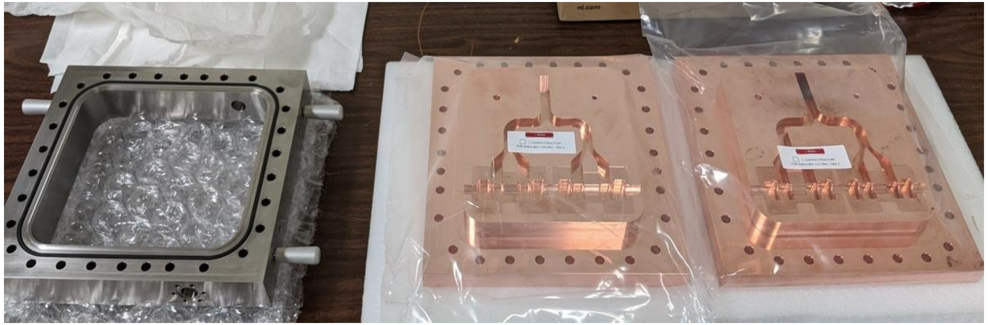


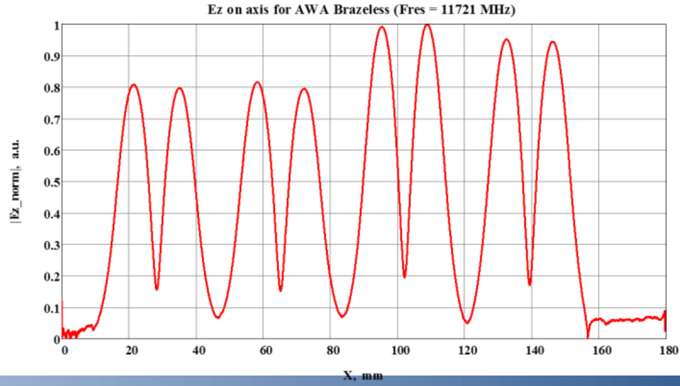
Scale up to higher power





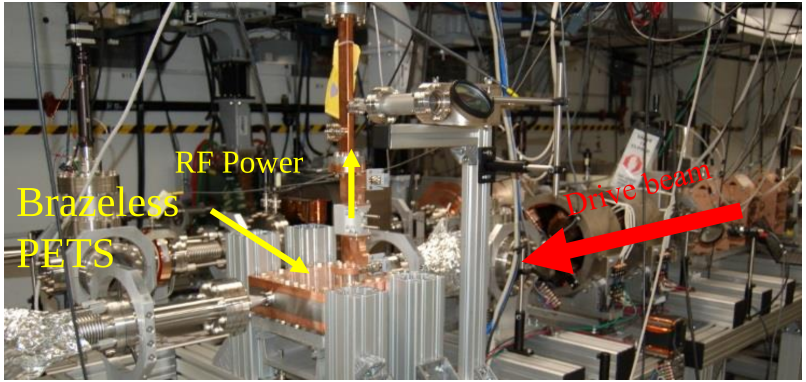


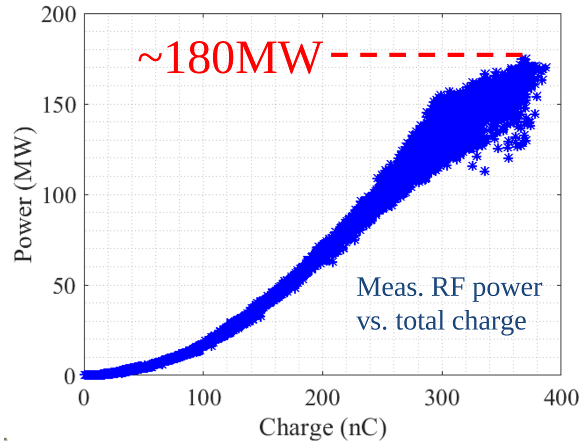


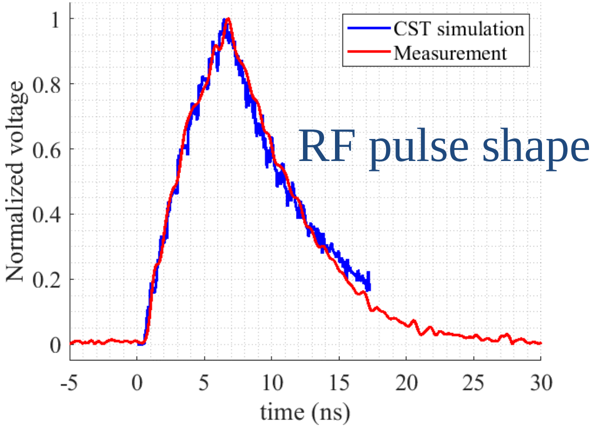


High Power RF generation at AWA

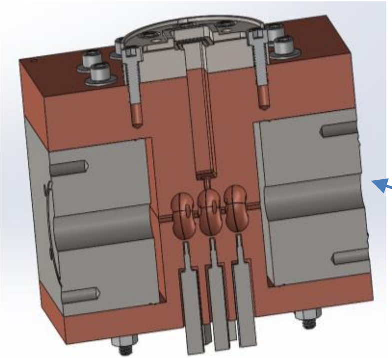
- Experiment was finished in the week of 10/19 at AWA
- A bunch train of 8-bunch, ~50nC each were transport through the Brazeless Power Extractor
- 180MW of rf power was measured
- No obvious breakdown events were detected.
- Experimental results match well with the simulation.





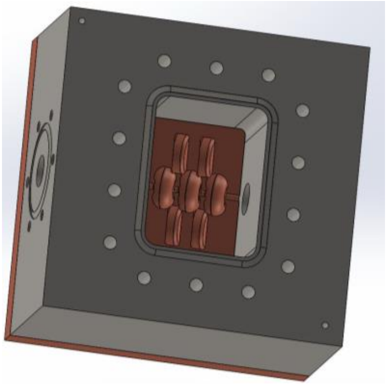


Scale up to higher gradient

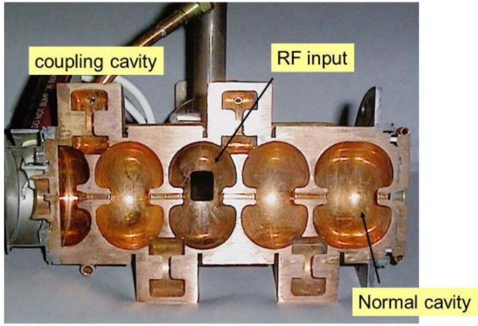


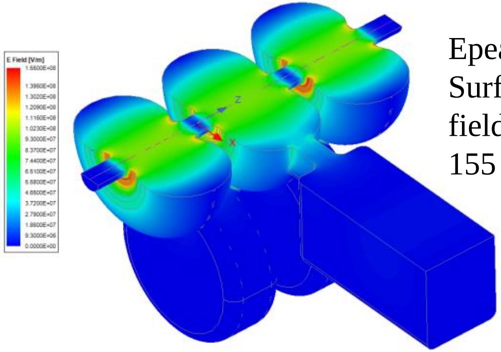
Shunt Impedance: 130 MOhm/m

Split-block version of classical Varian design

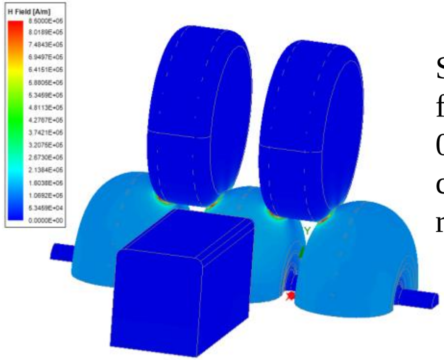


Varian 600c biperiodic $\pi/2$-mode SW structure:





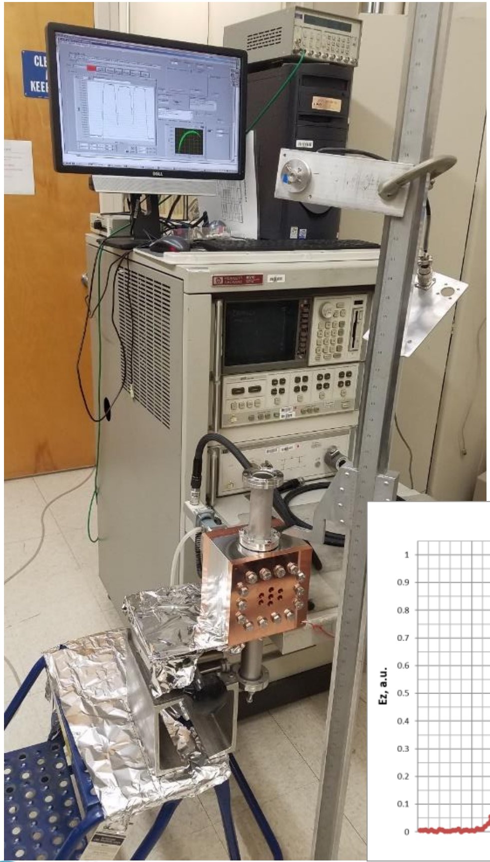
Epeak/Eacc = 2.65, Surface electric fields with peak of 155 MV/m@1MW.

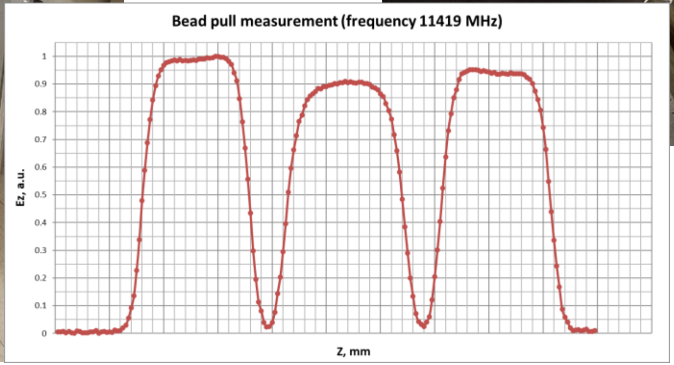


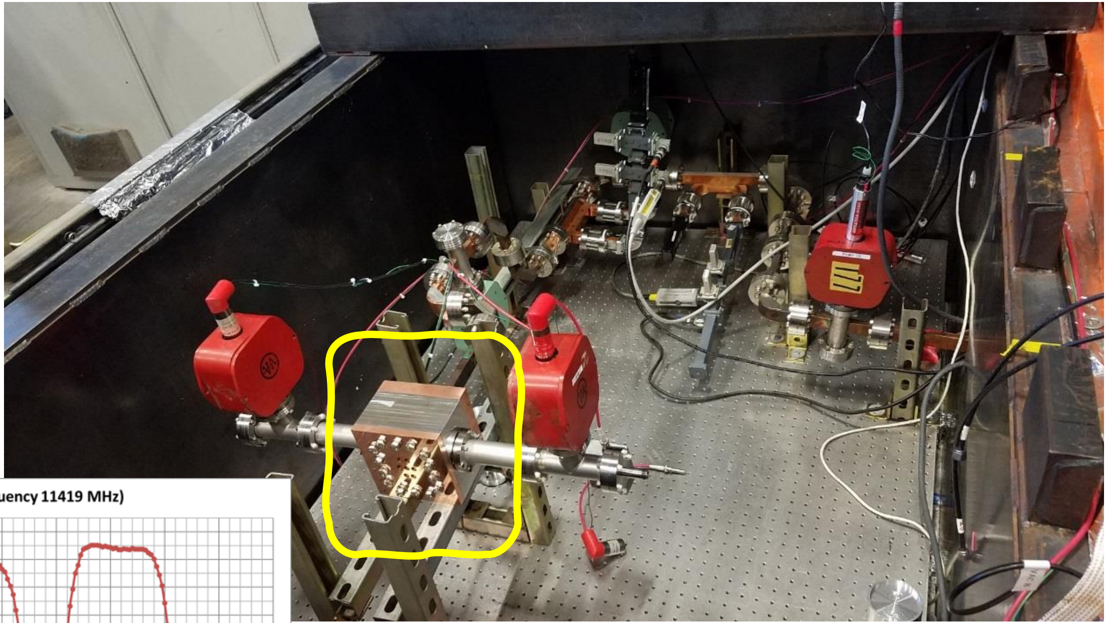
Surface magnetic fields with peak of 0.85 MA/m, calculated with fillet rounding of 0.1 mm

Test at SLAC

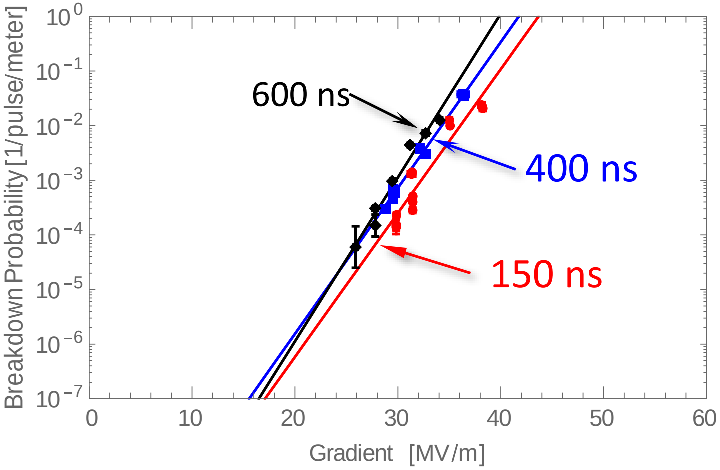
3C-SW-A1.5-T3.03-Brazless-Cu-Euclid-#1 installed at SLAC

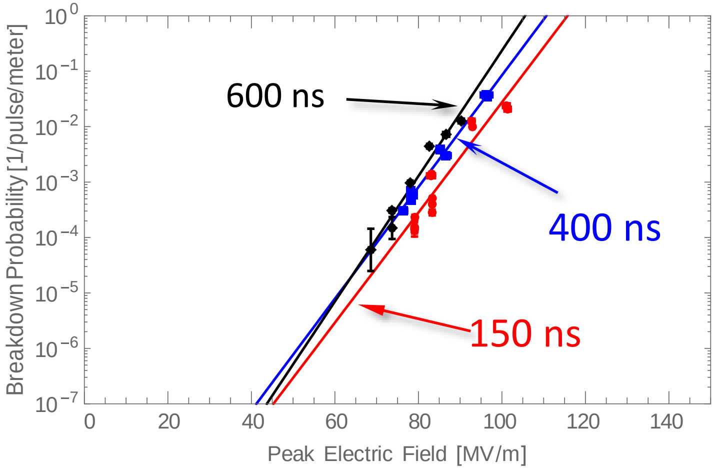


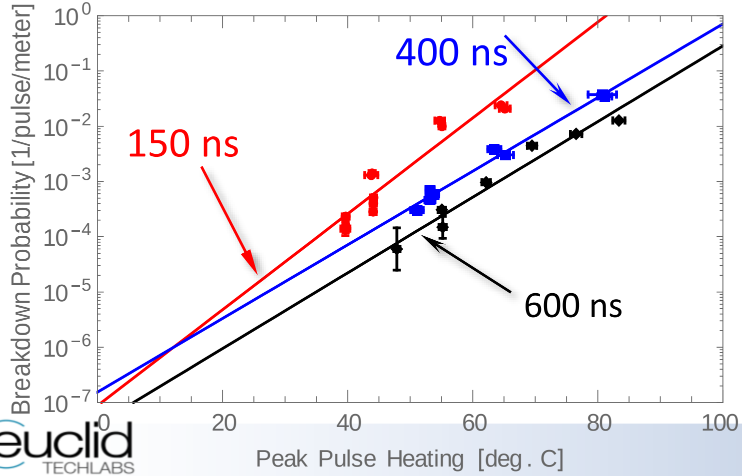




Results Analysis (I)



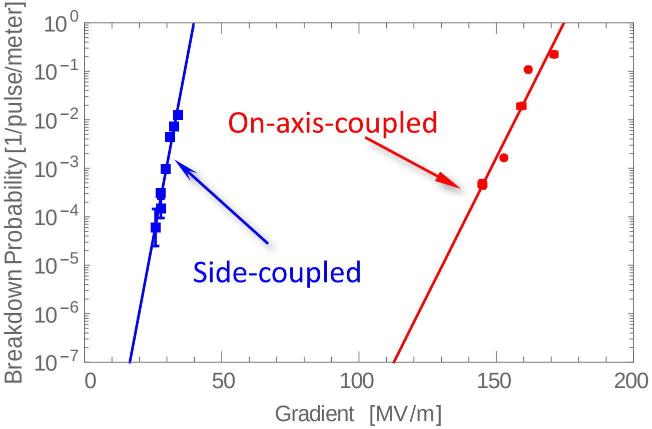


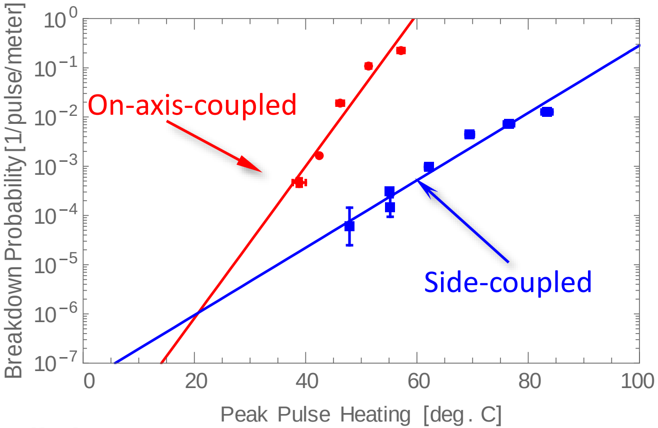


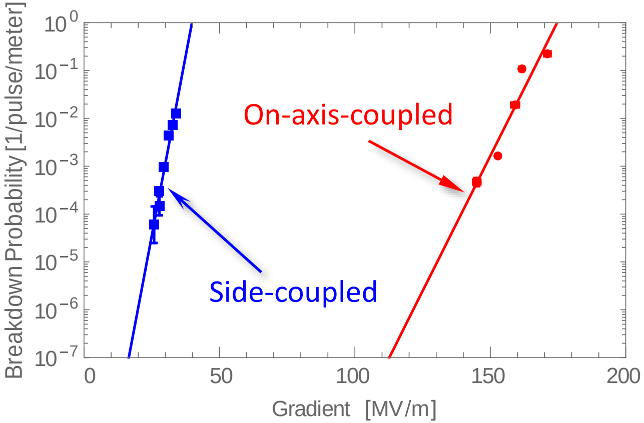
Peak surface fields is a better predictor of the breakdowns probability than the peak pulse heating. There is some dependence on pulse length but it is weak, not like in pillbox-like cavities. We note that unlike in most of the structures which we tested, peak pulse heating and peak Ponying vector are in the same place – on sharp edge of the coupling cell.

Results Analysis (II)

Comparison of performance of side-coupled (A1.5-T3.03-Cu) and on-axis coupled (A3.75-T2.2-Cu) structures with similar ration Epeak/Eacc ~ 2.6,shaped pulse with **150 ns** flat part, all breakdowns



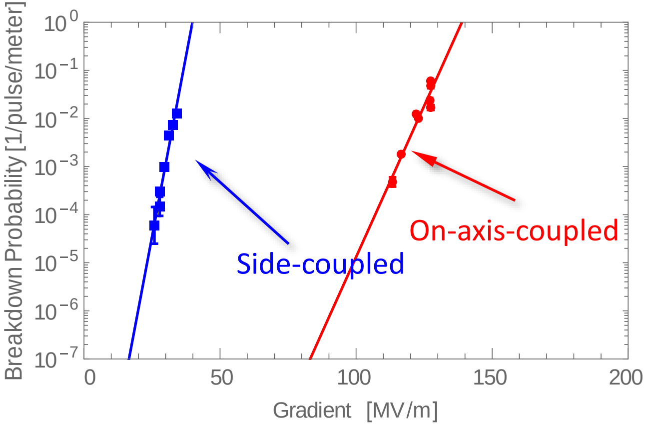


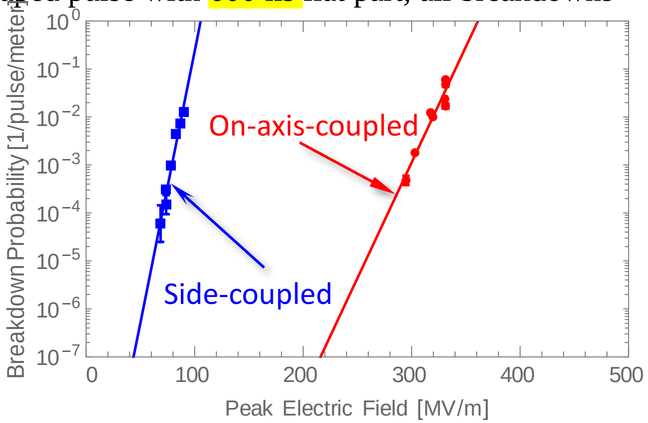


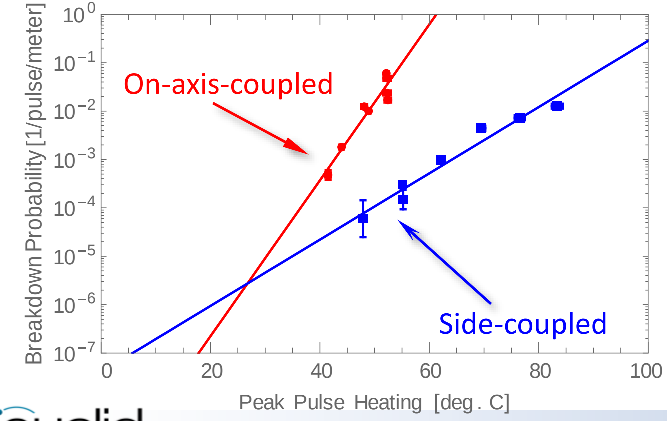
When we compare structure with the same Epeak/Eacc and wildly different Hmax*Z0/Eacc (5.3 in side-coupled vs 1.1 in on-axis coupled) and with short pulse with 150 ns flat part, we see that peak magnetic field or associated with it peak pulse surface heating is much better predicator of breakdown rates than the peak surface electric field.

Results Analysis (III)

Comparison of performance of side-coupled (A1.5-T3.03-Cu) and on-axis coupled (A3.75-T2.2-Cu) structures with similar ration Epeak/Eacc ~ 2.6,shaped pulse with **600 ns** flat part, all breakdowns



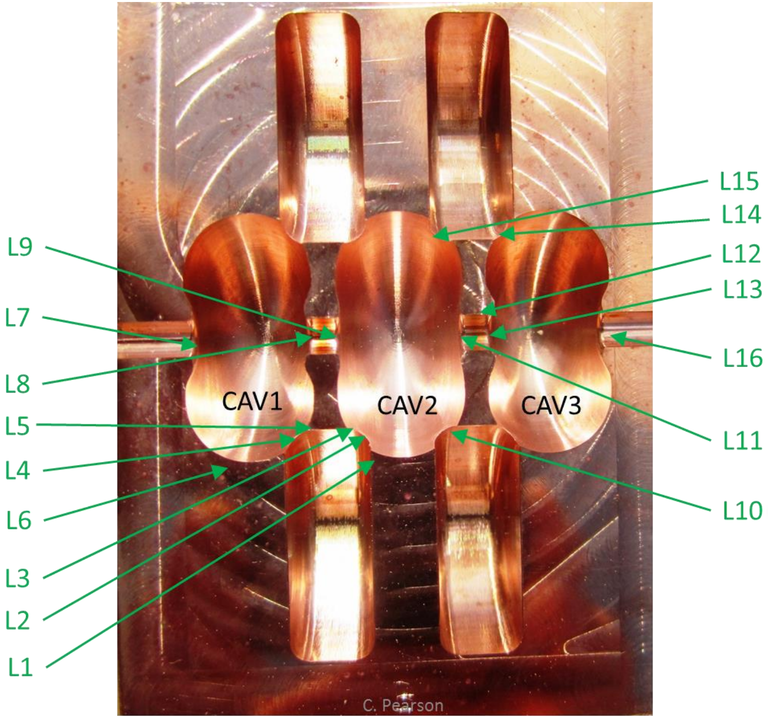




When we compare structure with the same Epeak/Eacc and wildly different Hmax*Z0/Eacc (5.3 in side-coupled vs 1.1 in on-axis coupled), we see that peak magnetic field or associated with it peak pulse surface heating is much better predicator of breakdown rates than the peak surface electric field.

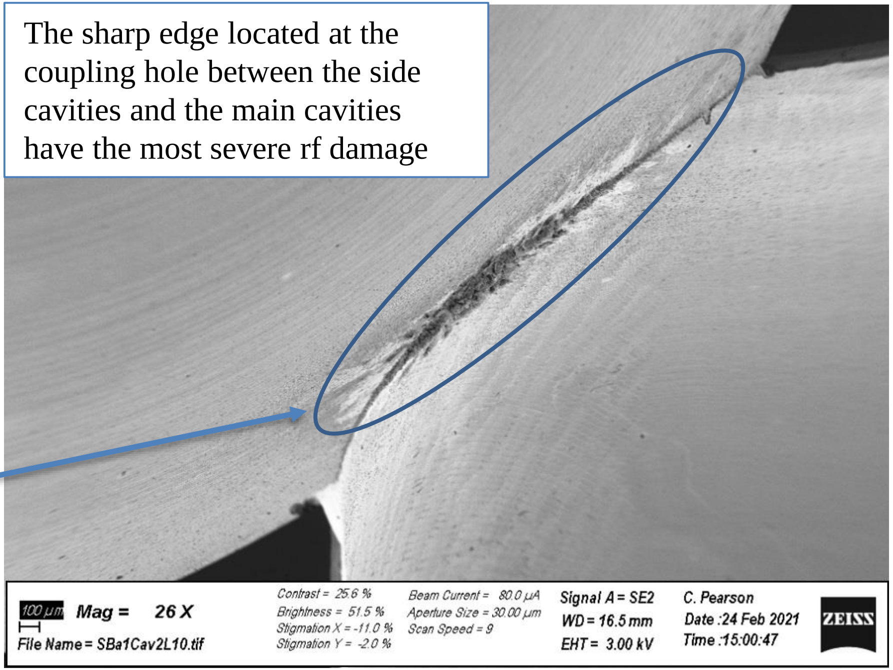
Post Test Examination

Areas for SEM

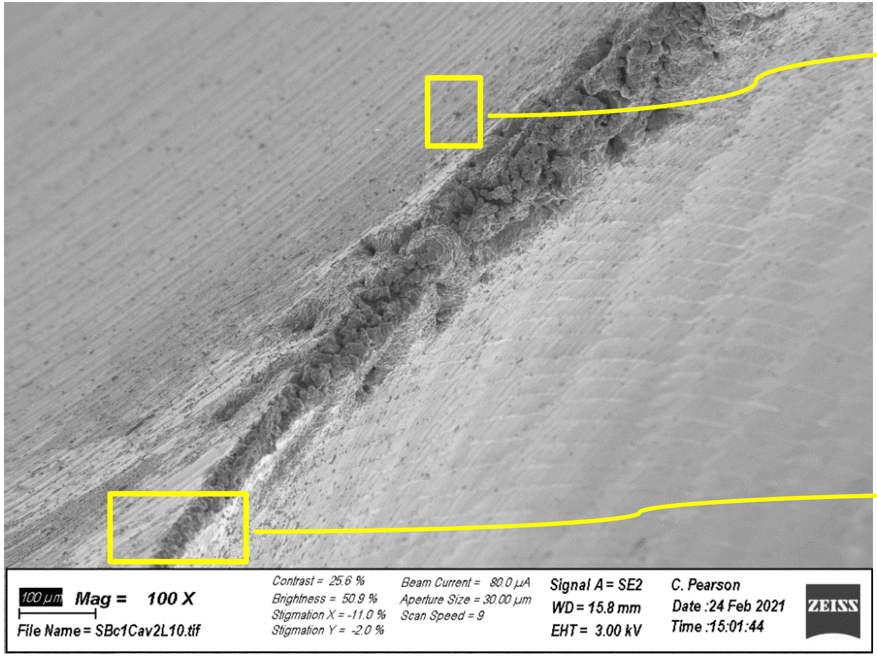


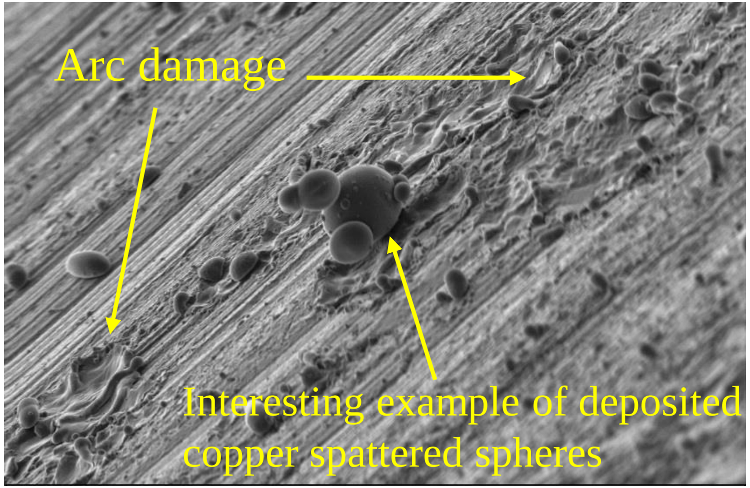
Coupling holes have significant rf damage

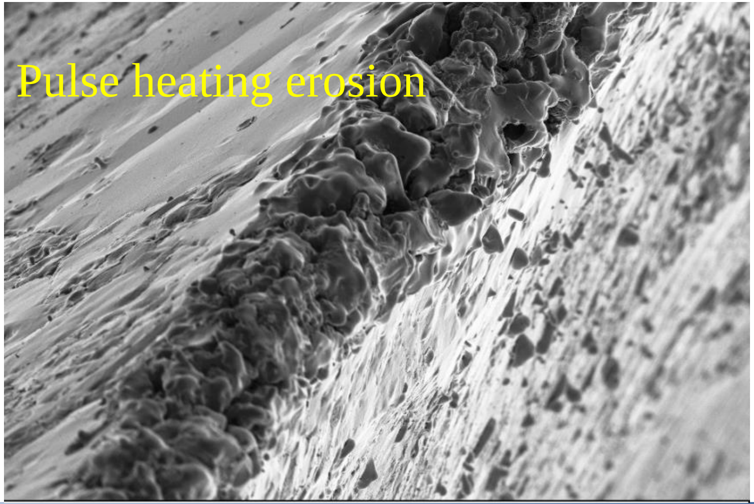
The sharp edge located at the coupling hole between the side cavities and the main cavities have the most severe rf damage



L10 zoom in

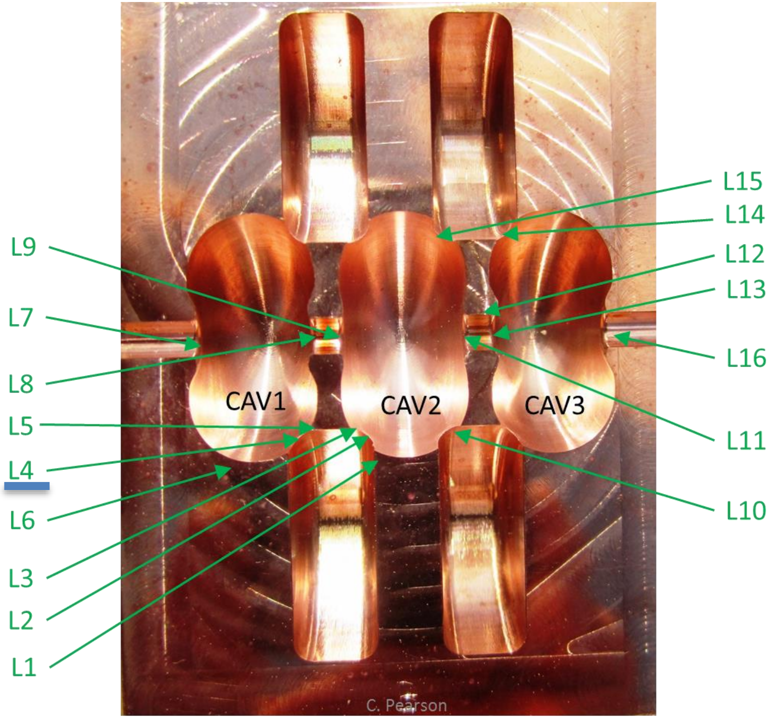

100 µm Mag = 100 X
File Name = SBc1Cav2L10.tif
Contrast = 25.6 %
Brightness = 50.9 %
Stigmation X = -11.0 %
Stigmation Y = -2.0 %
Beam Current = 80.0 µA
Aperture Size = 30.00 µm
Scan Speed = 9
Signal A = SE2
WD = 15.8 mm
EHT = 3.00 kV
C. Pearson
Date :24 Feb 2021
Time :15:01:44
ZEISS

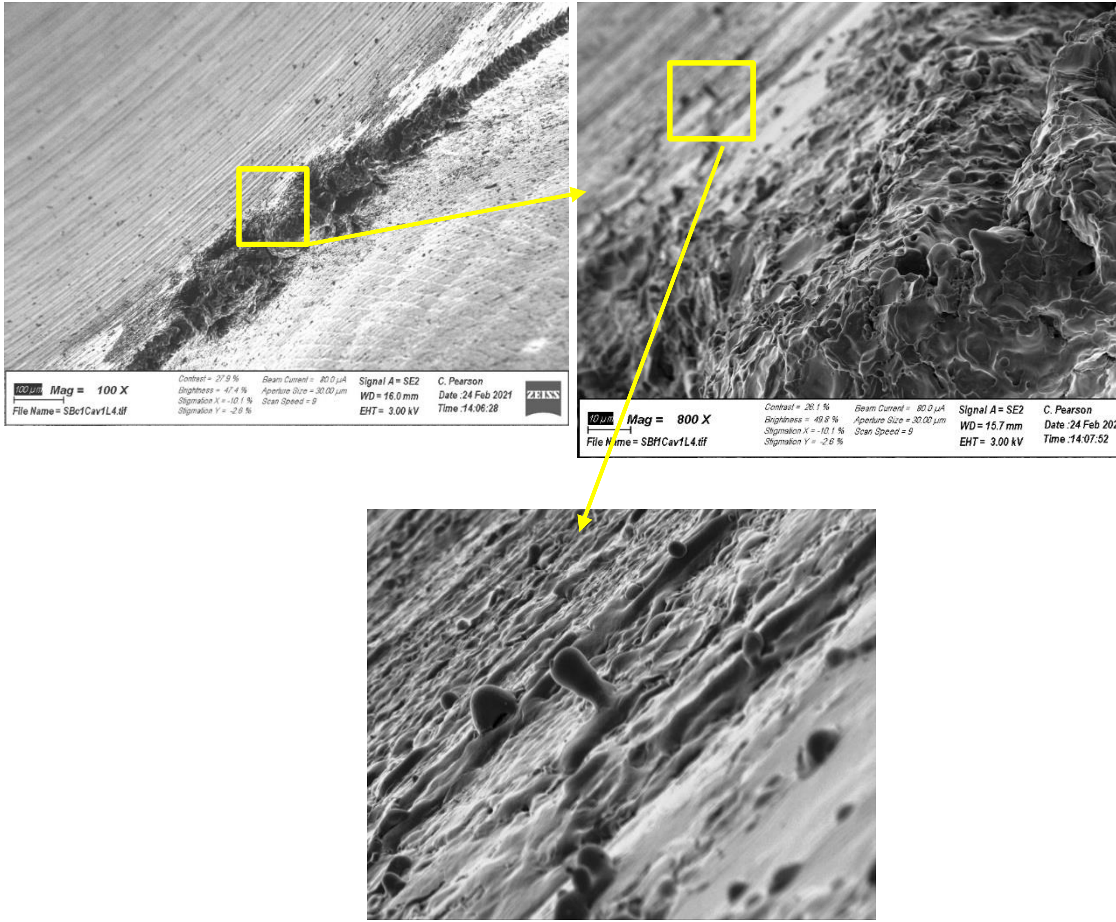

Arc damage
Interesting example of deposited copper spattered spheres


Pulse heating erosion

L4 images

Areas for SEM

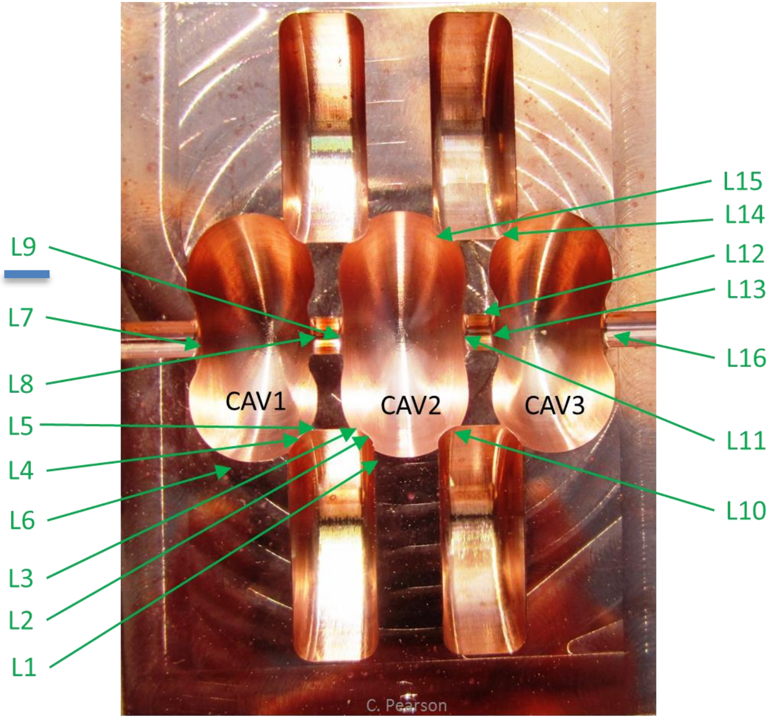


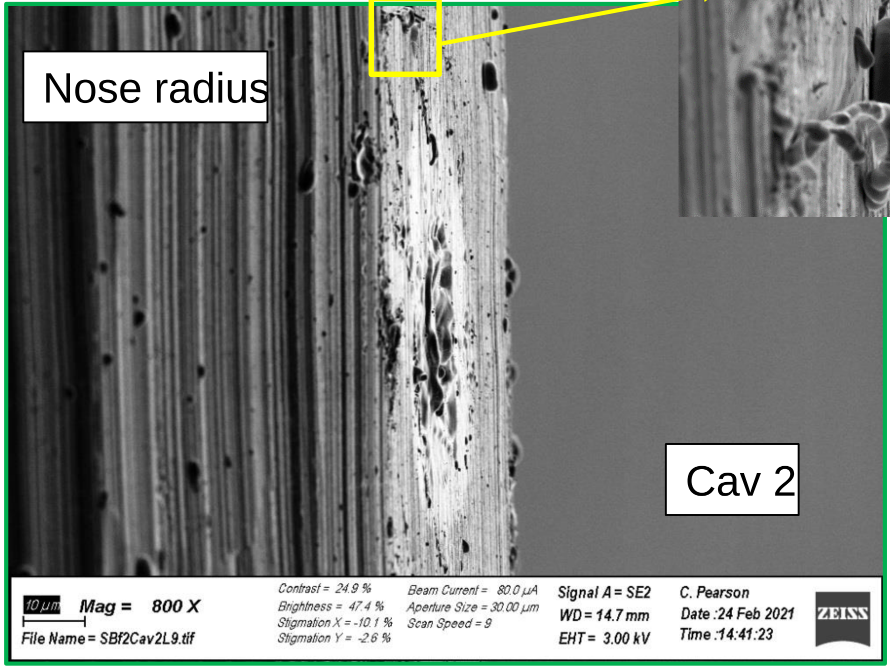


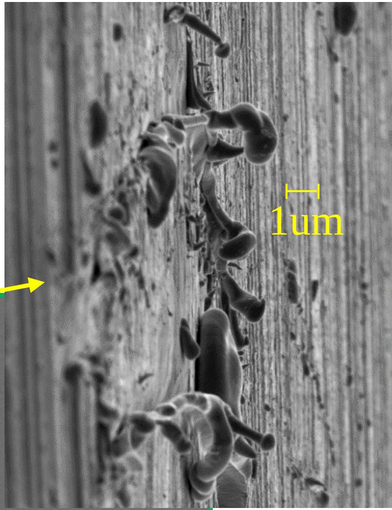
L9 images

Cavity Noses also have rf damage

Areas for SEM



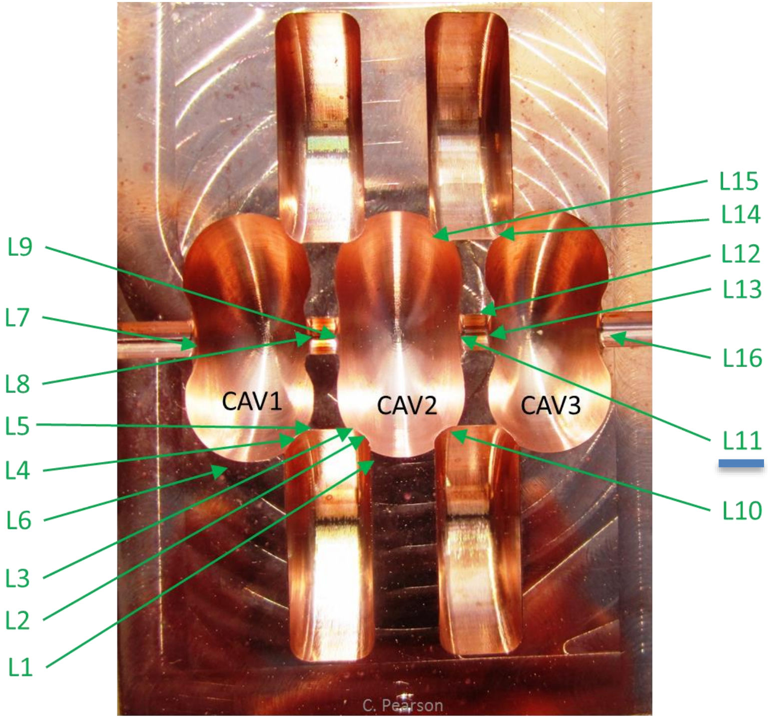


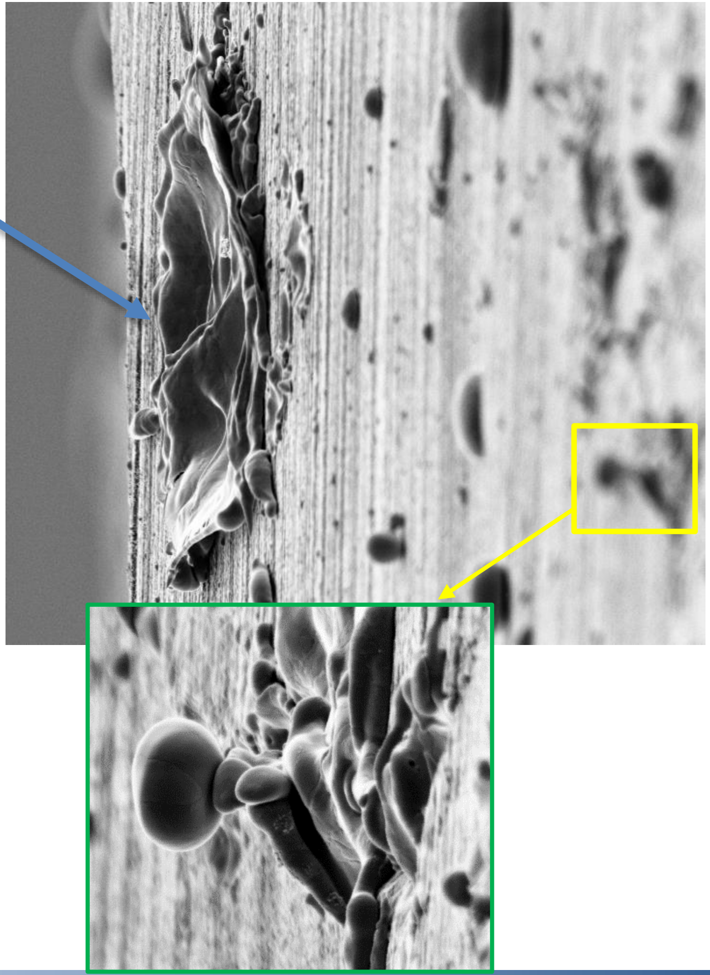


L11 images

Classical 'splash 'on Cavity Noses

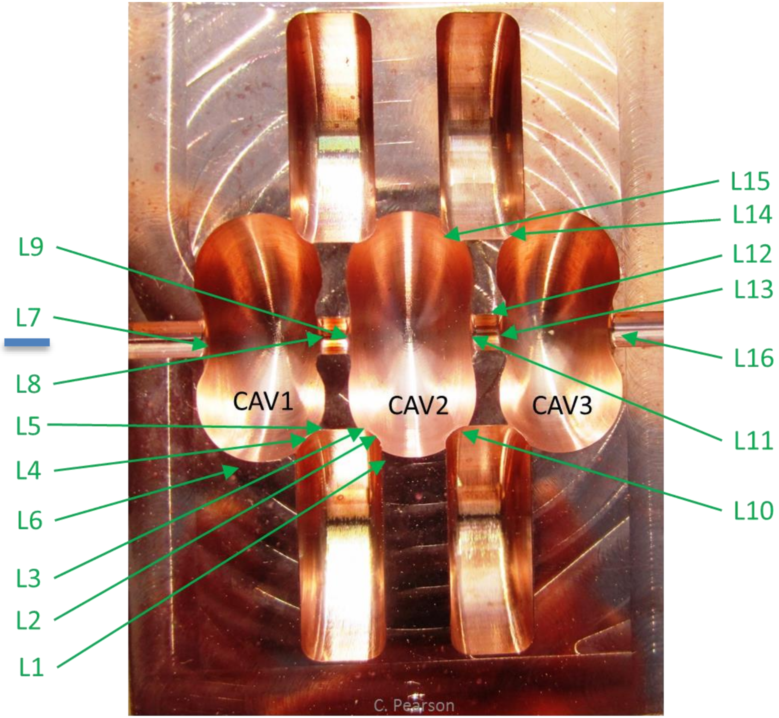
Areas for SEM

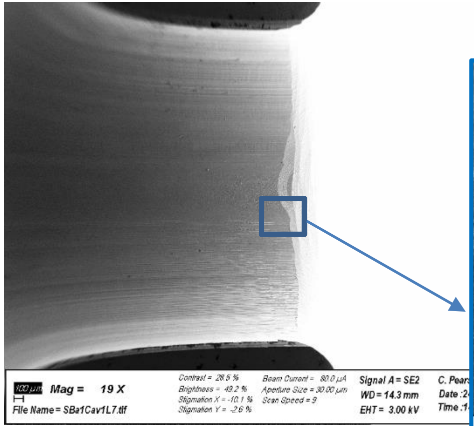


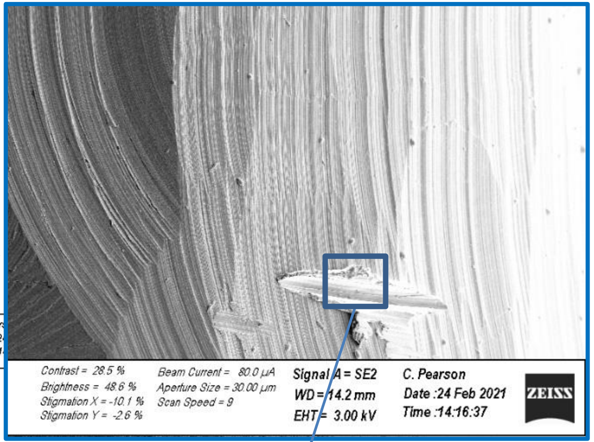


L7 images

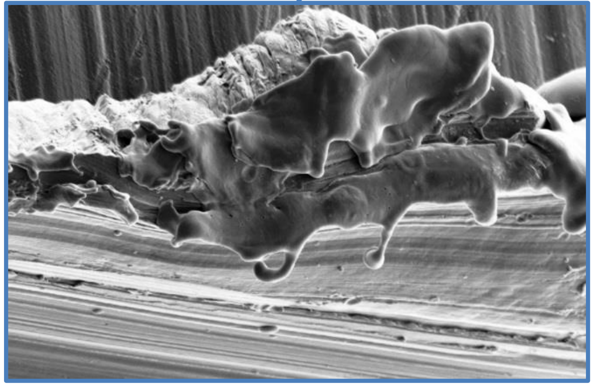
Areas for SEM







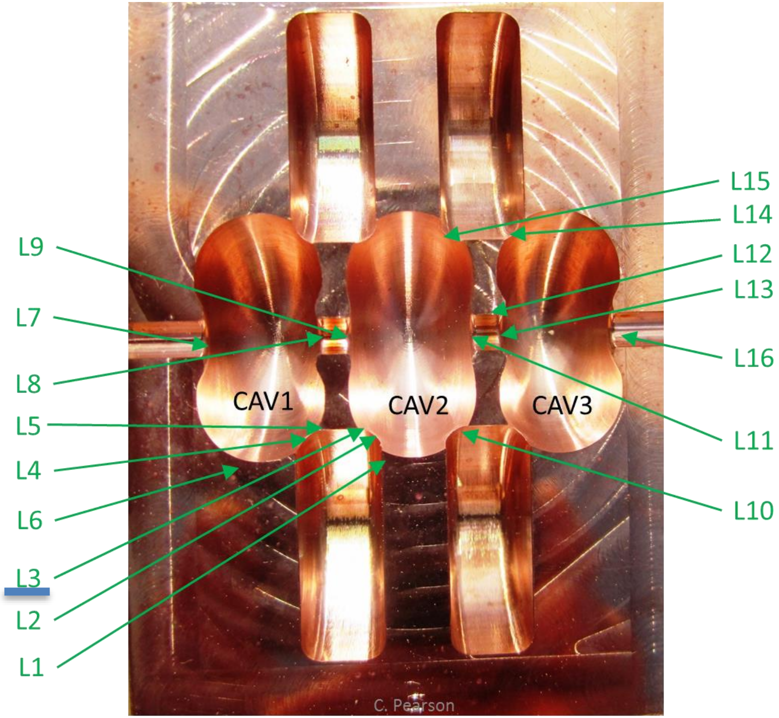
This incidental scratch (L7), seems to have attracted some rf activities.

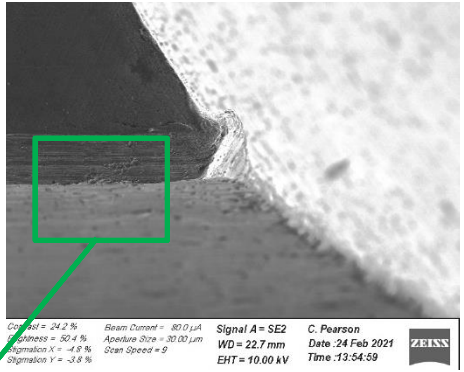


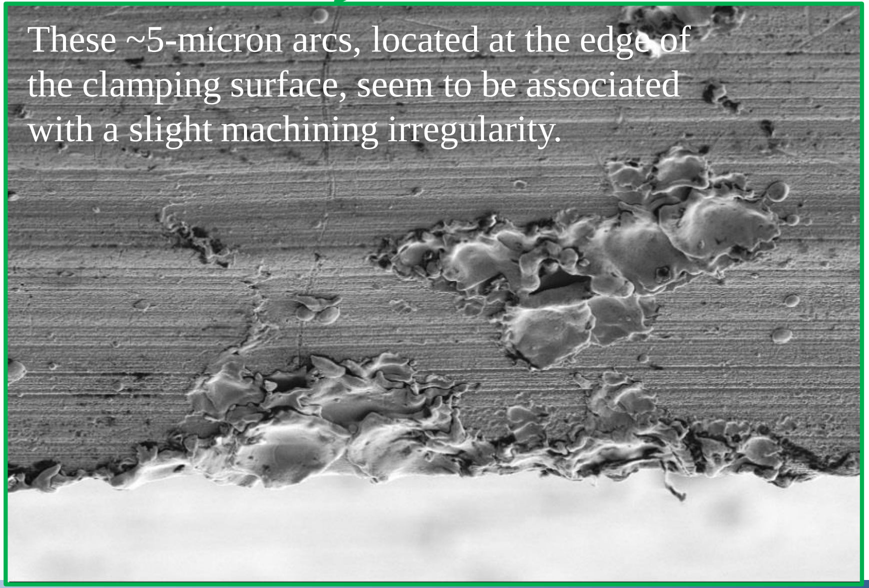
L3 images

Very little evidence of damage on the *Clamping Surfaces*

Areas for SEM

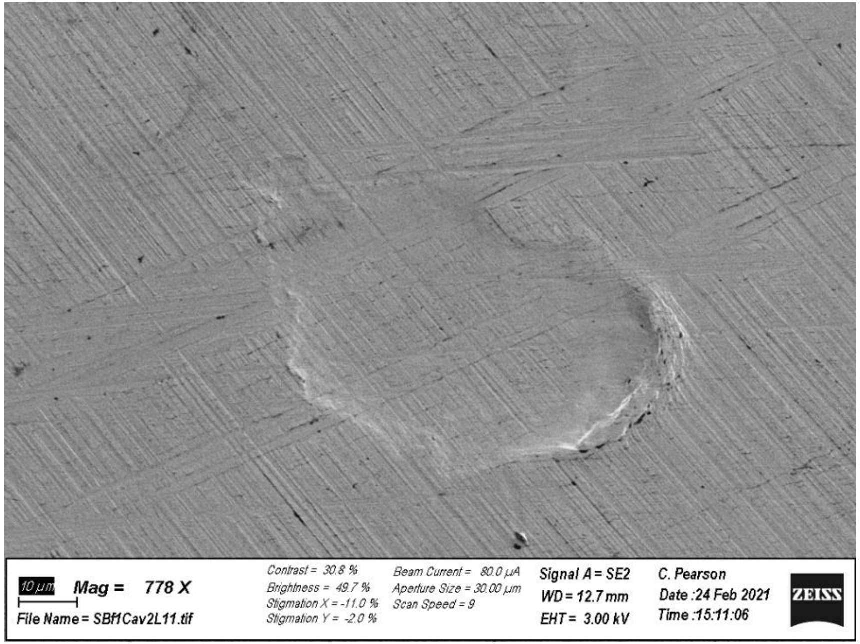






Clamping Surfaces

Most clamping surfaces look free of any rf damage



This image shows typical clamping surface,

and a small "dent" possibly Caused by the presence of some contamination at the time of clamping

Remarks

- Three types of structures using the similar brazeless fabrication process were built and tested in the past 12 months. It shows its advantages in terms of short fabrication period and ease of tolerances, in particular for the low energy accelerators.
- Short pulse (~10ns) operation seems not be a problem for 100s MW power (need to be confirmed after the examination).
- The side-coupled cavities require special attention to the high magnetic fields; need to avoid the sharp edge of the coupling cell.

Acknowledgement

- DoE SBIR program Grant #DE-SC0017749
- Thank AWA (PoC: John Power) for Power extractor experiment and data analysis
- Thank SLAC (PoC: Valery Dolgashev) for the side coupled structure test and data analysis