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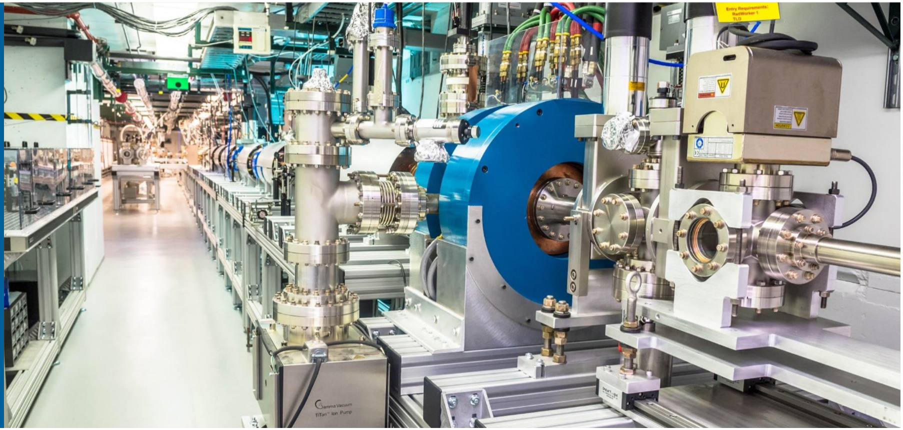
Argonne NATIONAL LABORATORY

Simulation and Experimental Results of Dielectric Disk Accelerating Structures



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August 8, 2022

Outline of Talk

- Introduction
- Previous DDA Research
- Multicell DDA Structure
- Future Works

Introduction

Motivation for Research

- Improve RF to beam Power Efficiency
  - Better efficiency = smaller footprint = cheaper to build
  - 500 MeV Demonstrator
    - High power linear electron accelerator
    - Production of high energy beam with short footprint using Advanced Accelerator Concepts (AAC) structures.
    - Need high accelerating gradient.

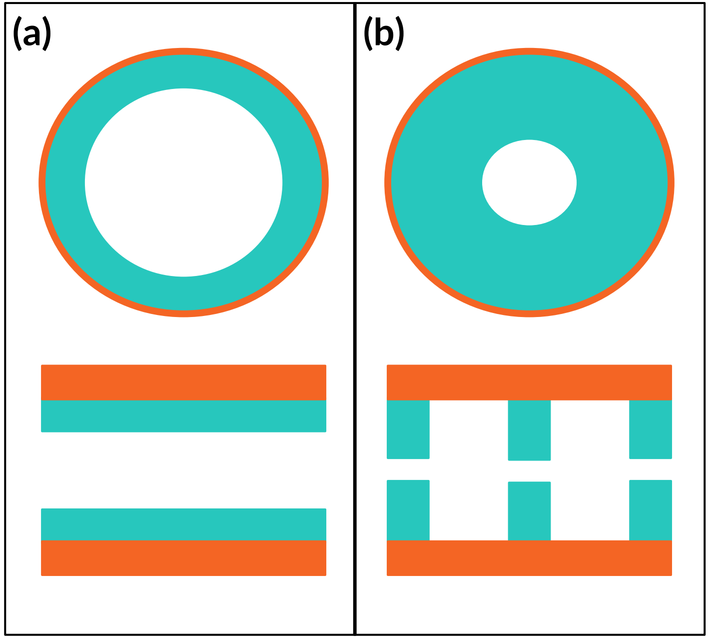
- Demonstrate Short Pulse Accelerating (~10 ns)
  - High gradient production requires high power (hundreds of MW) but this can cause breakdown
    - Breakdown rate is proportional to pulse length
    - Short filling time allows structure to see flat top of pulse
      - » Large group velocity

$$t_f = \frac{L}{v_g}$$

Dielectrics in Accelerating Structures

- **Dielectric slows down speed of EM field to match it to velocity of beam**
- **Dielectric Loaded Accelerator (DLA) vs Dielectric Disk Accelerator (DDA)**

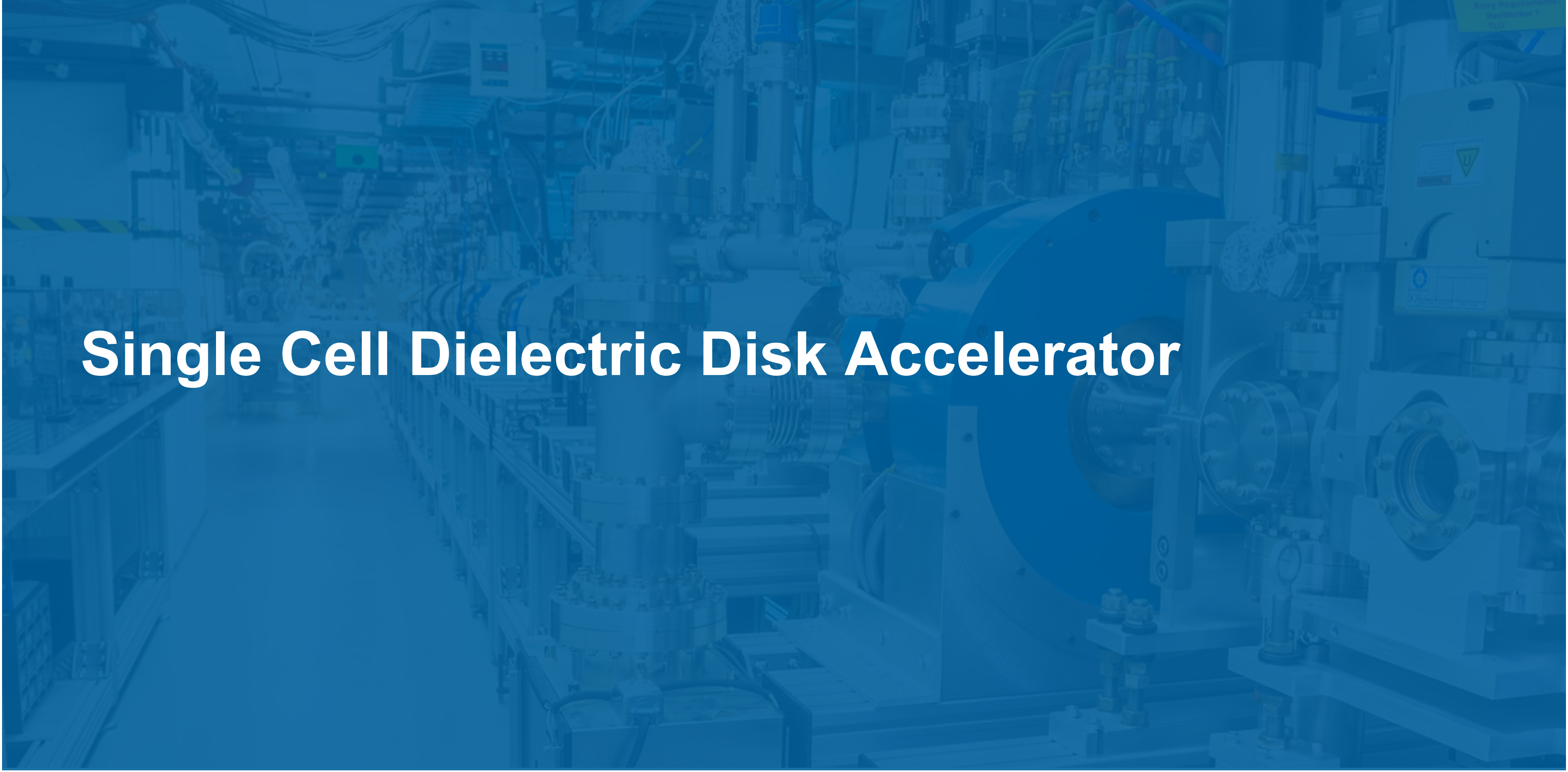
Parameter	DLA	DDA
Dielectric Constant	9.8	50
Group Velocity	0.11 c	0.16 c
Quality Factor	2295	6430
r	50.0 MΩ/m	208.8 MΩ/m
r/Q	21.8 kΩ/m	32.5 kΩ/m
Required Input Power	1.22 GW	0.96 GW
$\eta_{rf-beam}$	27%	39%
$\eta_{AC-beam}$	9%	13%
E_{max}	365 MV/m	660 MV/m



DLA DDA

J. Shao, C. Jing, J. G. Power, M. Conde, and D. Doran, "Study of a dielectric disk structure for short pulse two-beam acceleration," in Proceedings of IPAC2018, Vancouver, BC, Canada, Summer 2018.

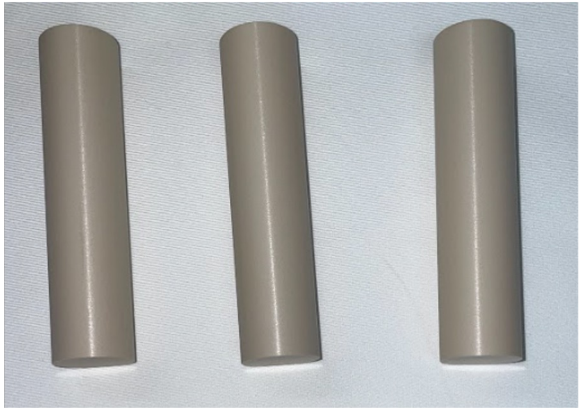
Single Cell Dielectric Disk Accelerator

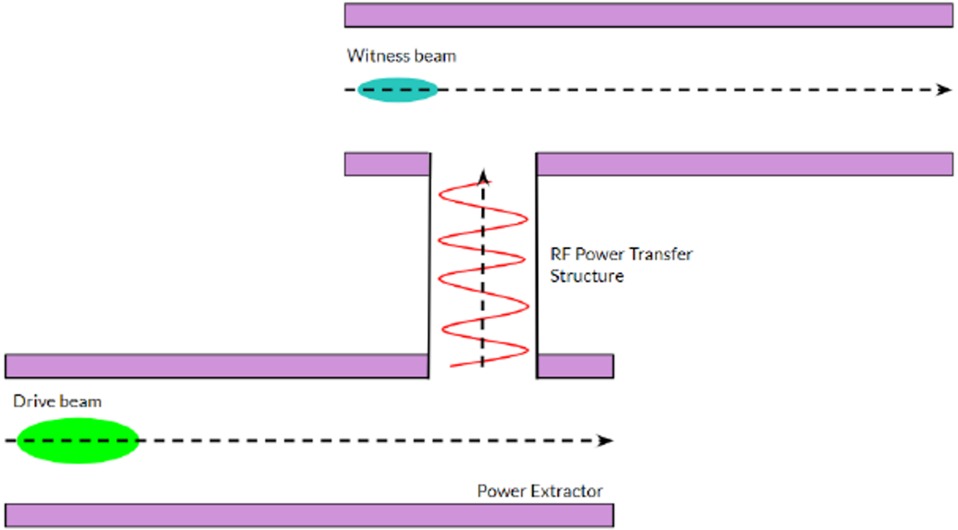


Objectives of Research

- Goal
  - High Gradient, short pulse, while exploring threshold of dielectric ceramic
    - Ceramic was chosen for high dielectric constant and low loss tangent

- Methodology
  - Multiple prototypes test
    - Single cell, Proof of concept
    - Two Beam Acceleration Scheme





AWA and PETS

- Argonne Wakefield Accelerator (AWA)
  - Linear accelerator at ANL in the High Energy Physics division
  - ~34 m long research linear accelerator
    - Very high charge drive beam (~400 nC)

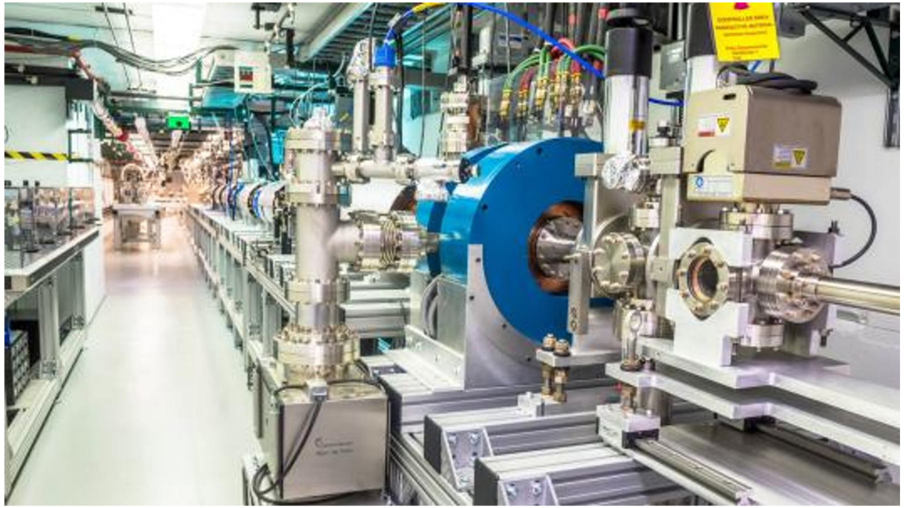
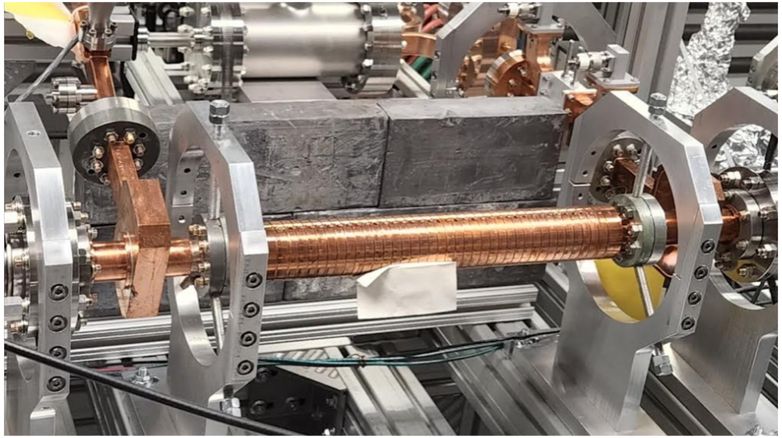


Image courtesy of AWA.

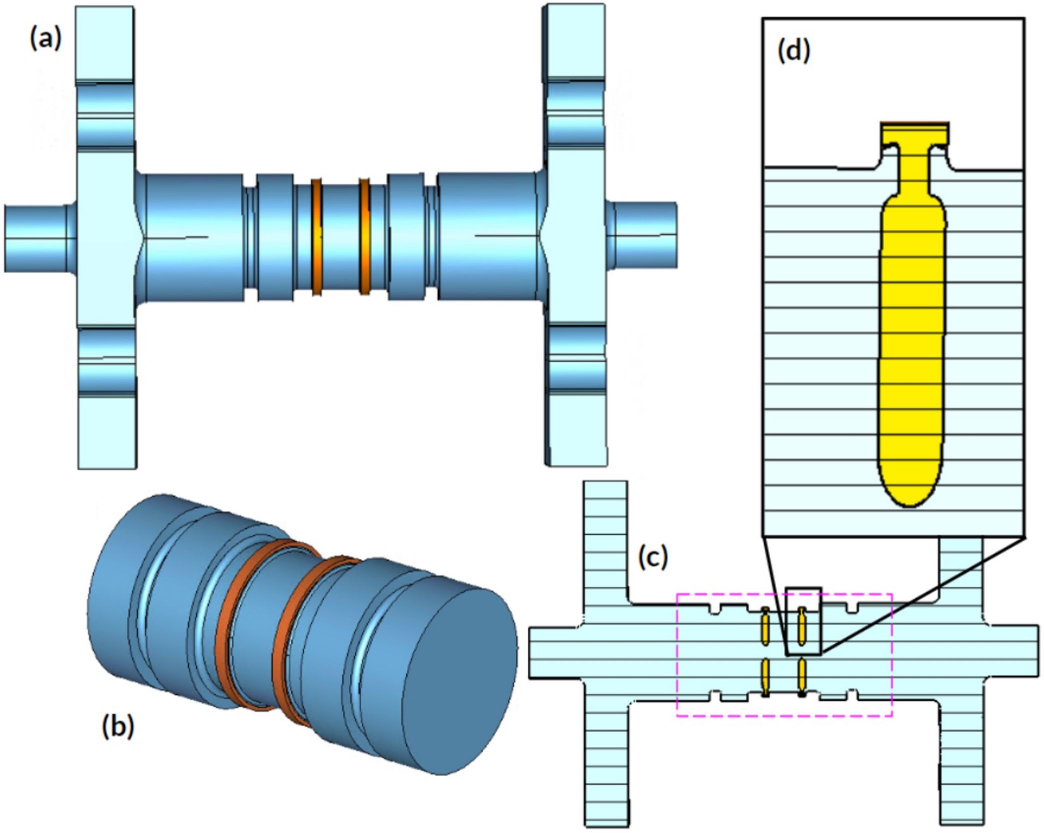


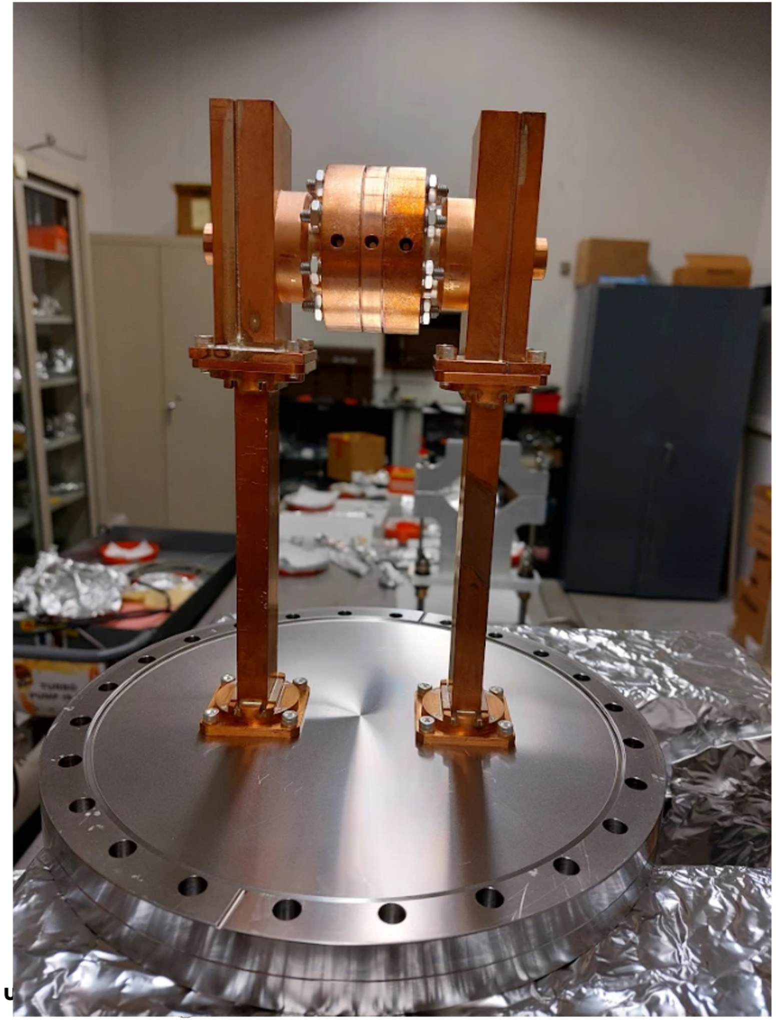
- Power Extractor and Transfer Structure (PETS)
  - Relativistic wakefield power extractors are made up of two parts: deceleration section and section that extracts EM wave.
  - When decelerated, drive beam produces RF packet moving in same direction.
  - Used to produce high RF power for DDA tests

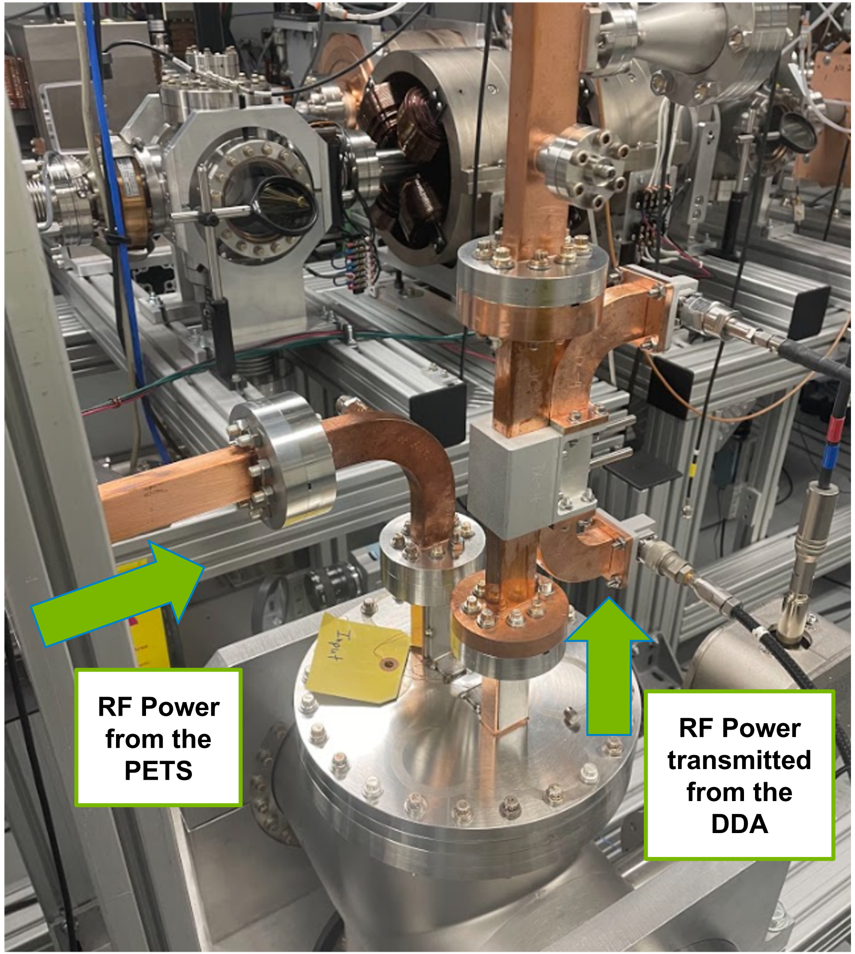
Clamped Single Cell Structure

- To avoid complications with brazing, this prototype was clamped
- Special head detail
- Elliptically Rounded edges
- High Dielectric Constant = 50, low loss ceramics

Parameter	Value
Disk Outer Diameter	20.9 mm
Disk Inner Diameter	3.0 mm
Matching Cell Aperture Diameter	18.0 mm
Disk Thickness	1.5 mm
Dielectric Cell Length	8.54 mm
Matching Cell Diameter	22.8 mm
Dielectric Cell Diameter	18.7 mm
Number of Ceramics	2

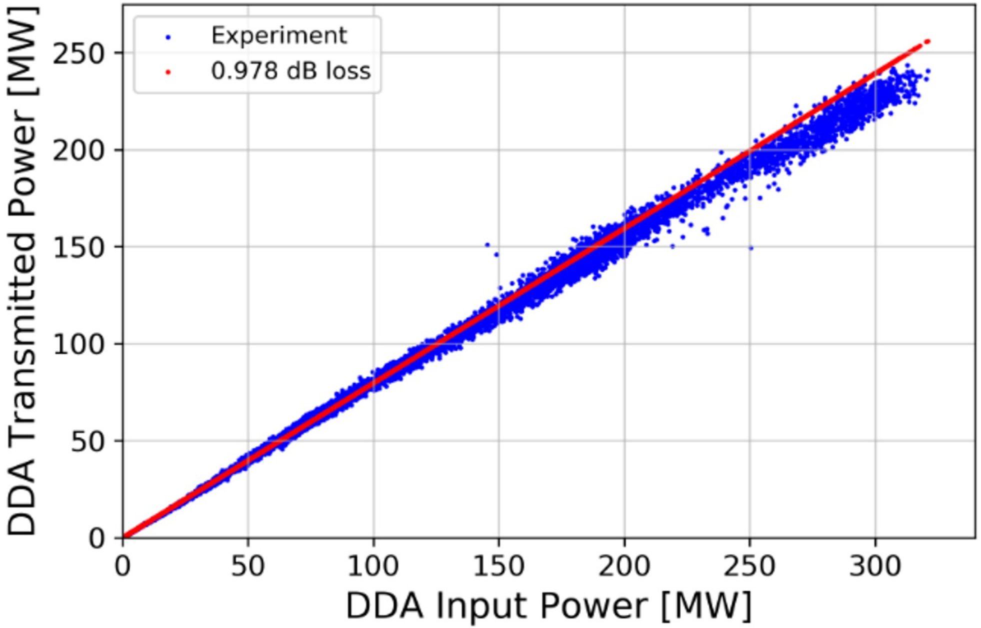





RF Power from the PETS
RF Power transmitted from the DDA

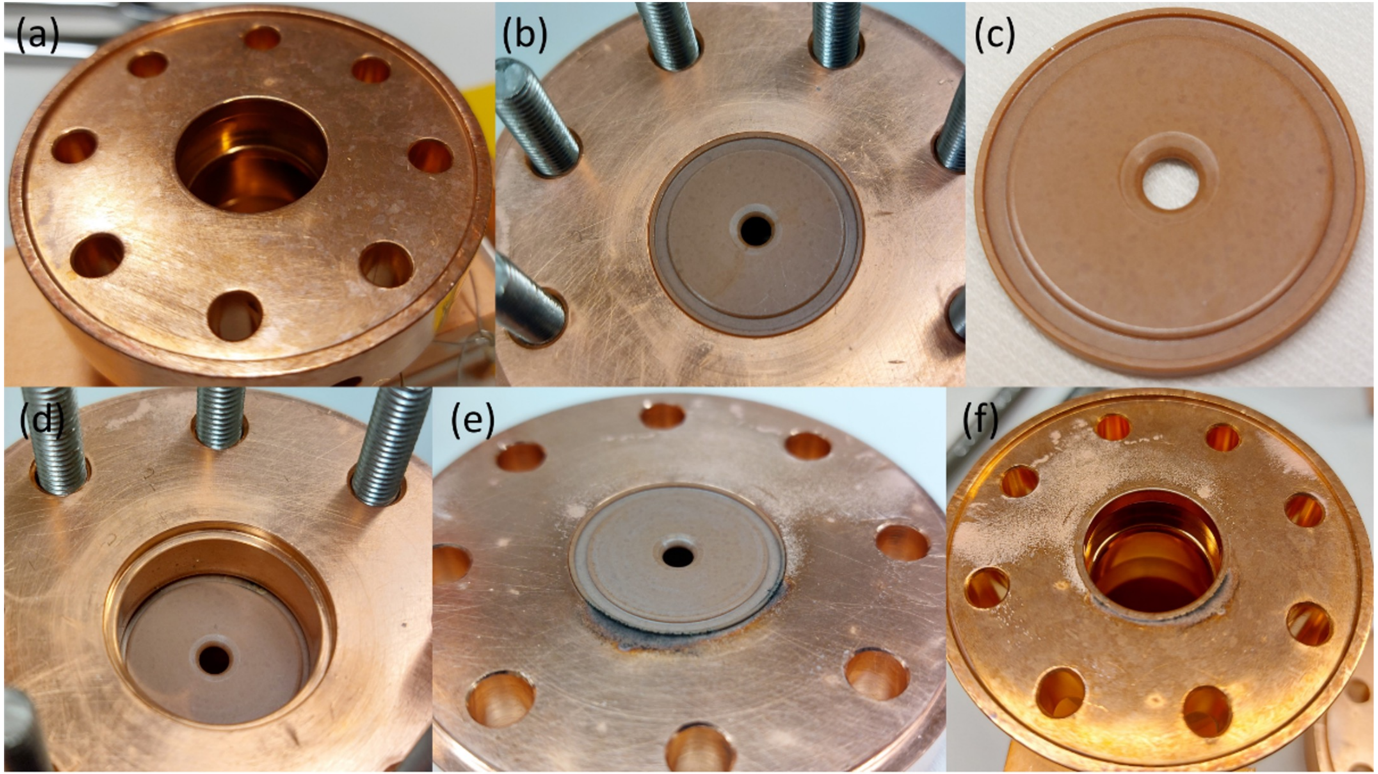
Results from Single Cell High Power Experiment

- Reached 320.9 MW of effective input power
  - 171 RF pulses above 300 MW
  - Accelerating gradient of 102 MV/m
- Linearity sign of no breakdown or multipacting.
- No RF, vacuum, or optical signals of breakdown observed
- Successfully ran up to maximum available RF power.
- PRAB in preparation on results

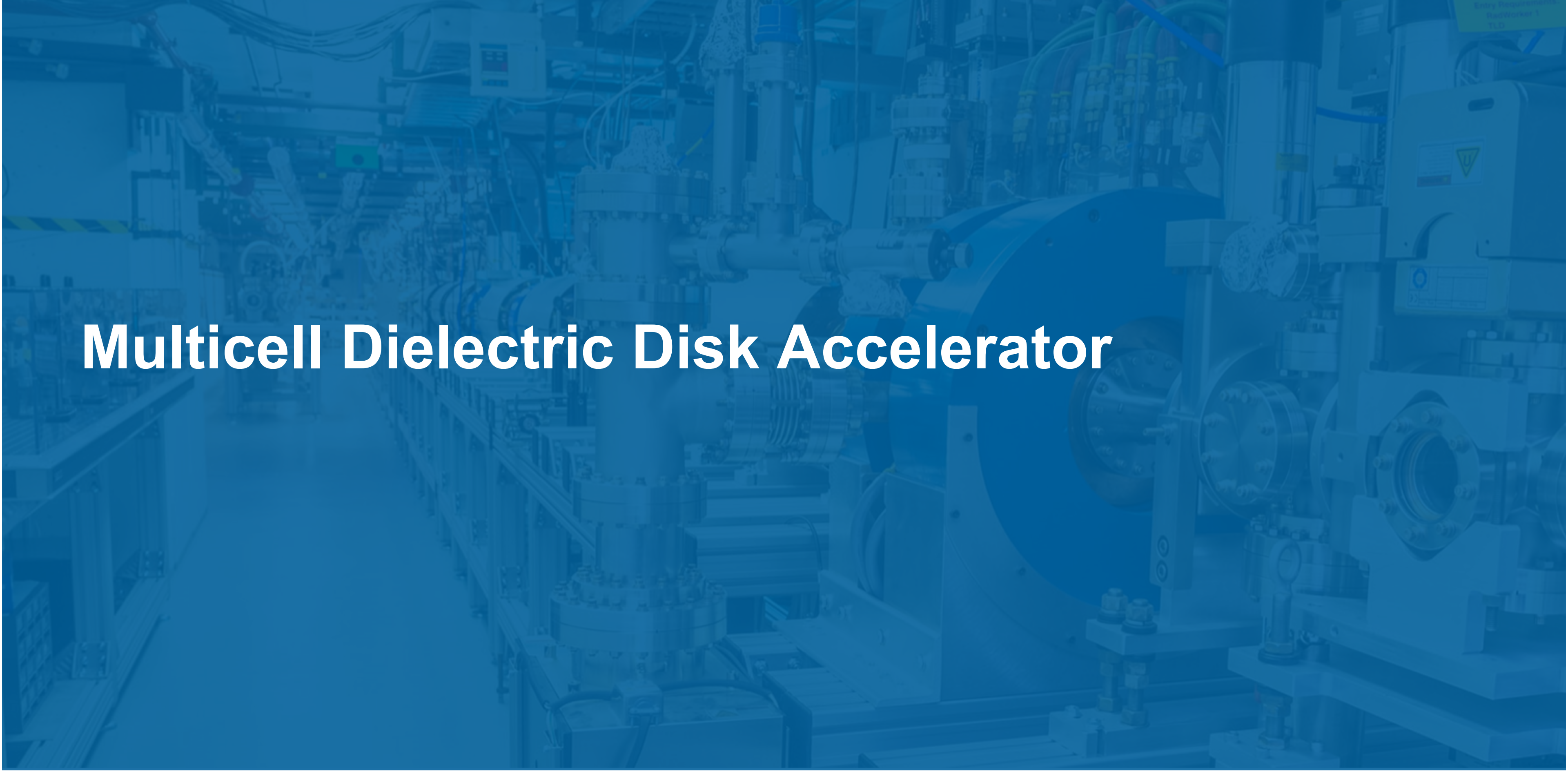


Post-Experiment Visual Inspection

Maximum surface field was 147 MV/m (seen on iris of ceramic).

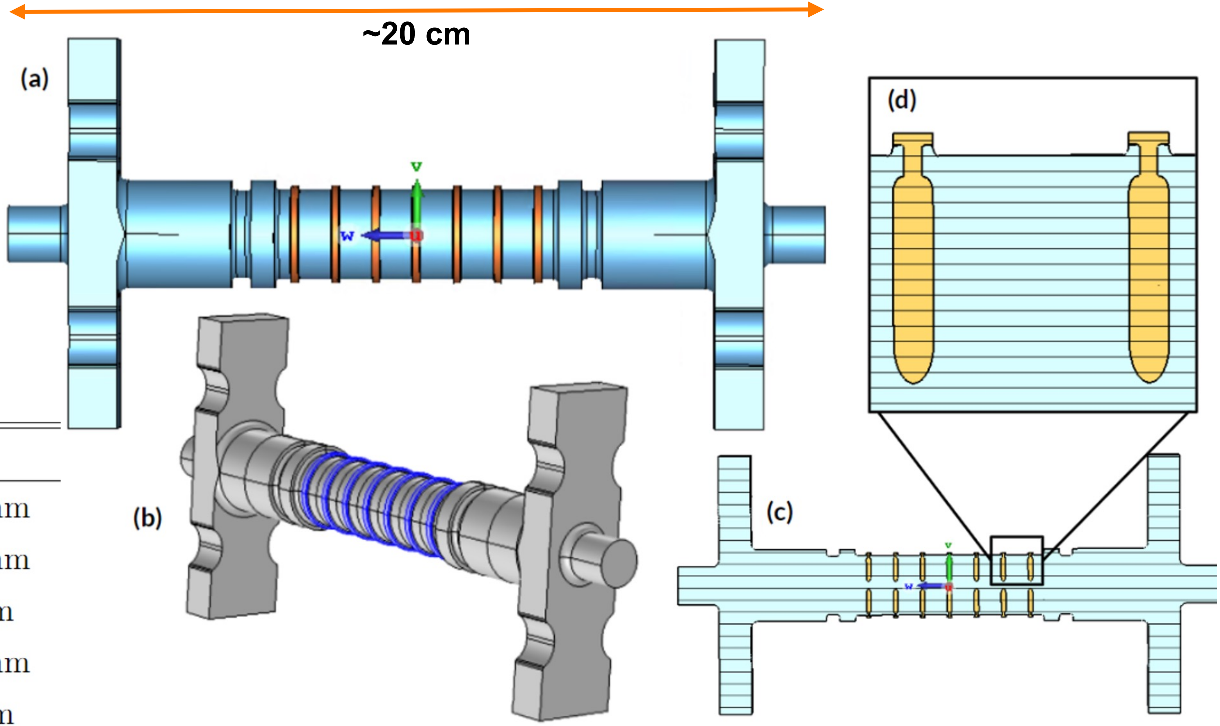


Multicell Dielectric Disk Accelerator



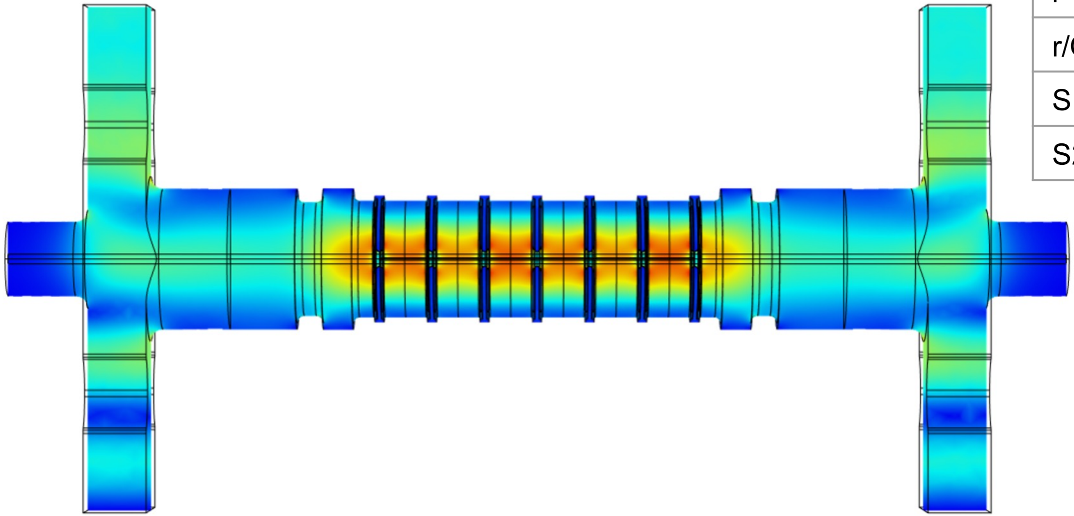
Clamped Multicell Structure

- Due to success of first clamped structure, multicell will also be clamped
- Special head detail similar to clamped single cell
- 7 ceramic = six dielectric cells



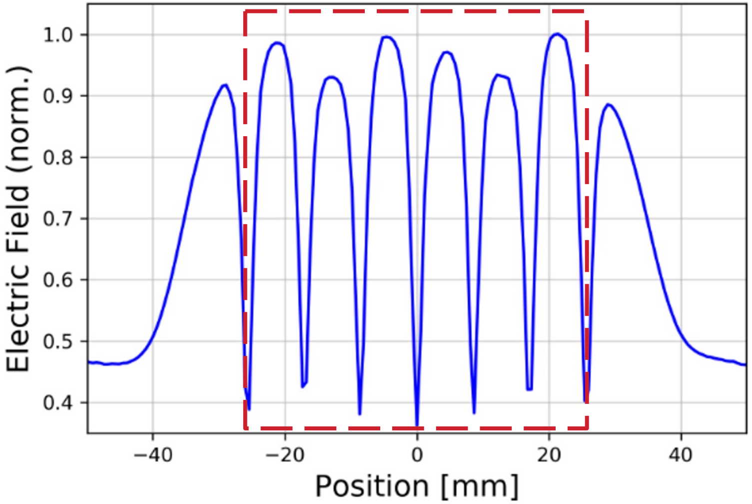
Parameter	Value
Disk Outer Diameter	20.48 mm
Disk Inner Diameter	2.239 mm
Matching Cell Iris Aperture Diameter	18.4 mm
Matching Cell Aperture Diameter	22.86 mm
Disk Thickness	1.45 mm
Dielectric Cell Length	8.541 mm
Number of Ceramics	7

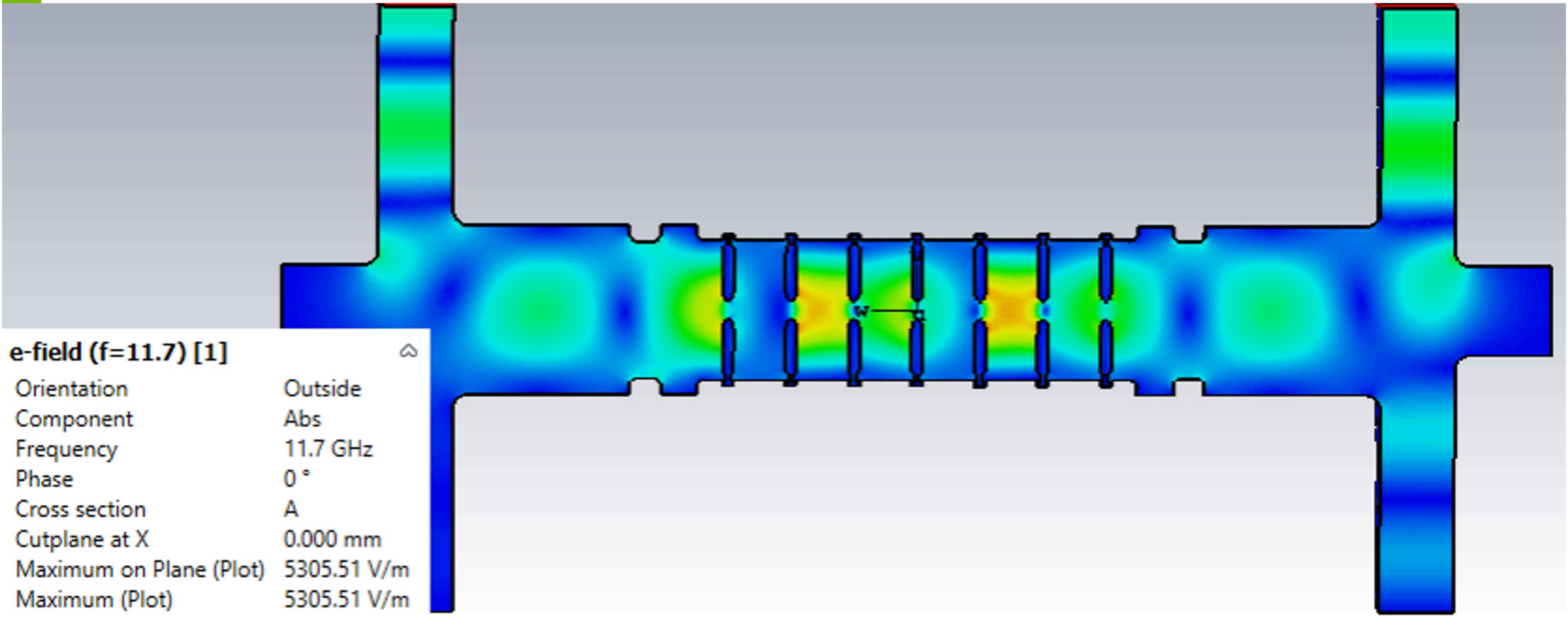
Results of Simulations



Maximum electric field over one RF period.

Parameter	Value
Accelerating Gradient at 400 MW	108 MV/m
Group Velocity	0.24 c
Quality Factor	9,612
r	184.4 MΩ/m
r/Q	19.18 kΩ/m
S11 10 dB Bandwidth	> 600 MHz
S21 3 dB Bandwidth	> 700 MHz



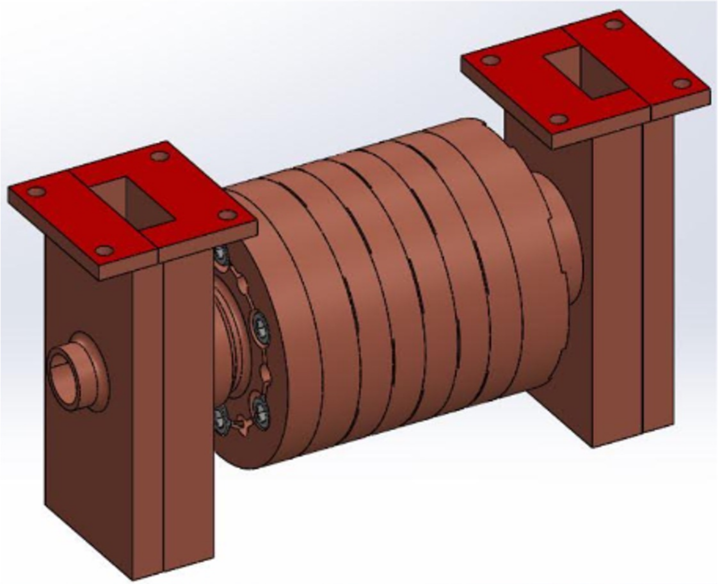

e-field (f=11.7) [1]
Orientation Outside
Component Abs
Frequency 11.7 GHz
Phase 0 °
Cross section A
Cutplane at X 0.000 mm
Maximum on Plane (Plot) 5305.51 V/m
Maximum (Plot) 5305.51 V/m

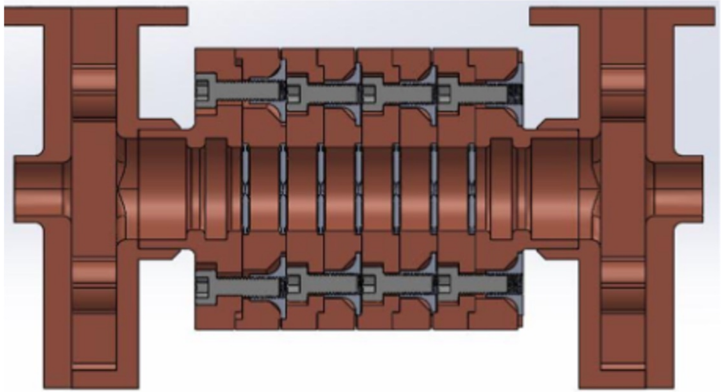
Engineering Design

- Due to clamping issues from single cell, more sophisticated clamping mechanism was designed.

- Compact enough to fit into vacuum chamber.

- Copper is annealed so that the ceramic can bite into it.





Future Plans

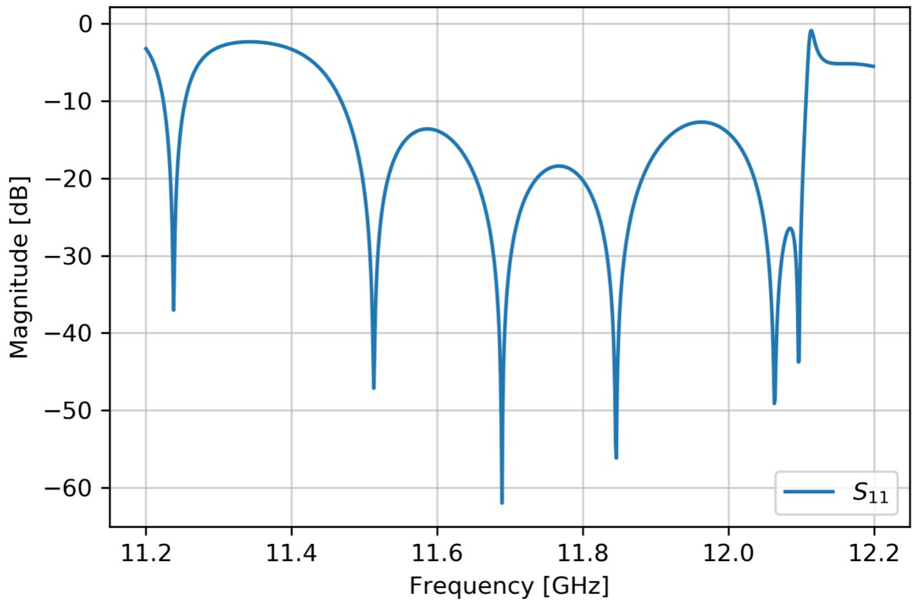
Future Plans

- Multicell DDA structure is being fabricated and will be high power tested at AWA later this year.
- Optimized multicell DDA structure will be designed, fabricated, and used to accelerate electron beam.
- Current results indicate DDA structures are viable candidates for short pulse, high gradient beam acceleration.

Thank you for listening!

Questions?

Results of Simulations



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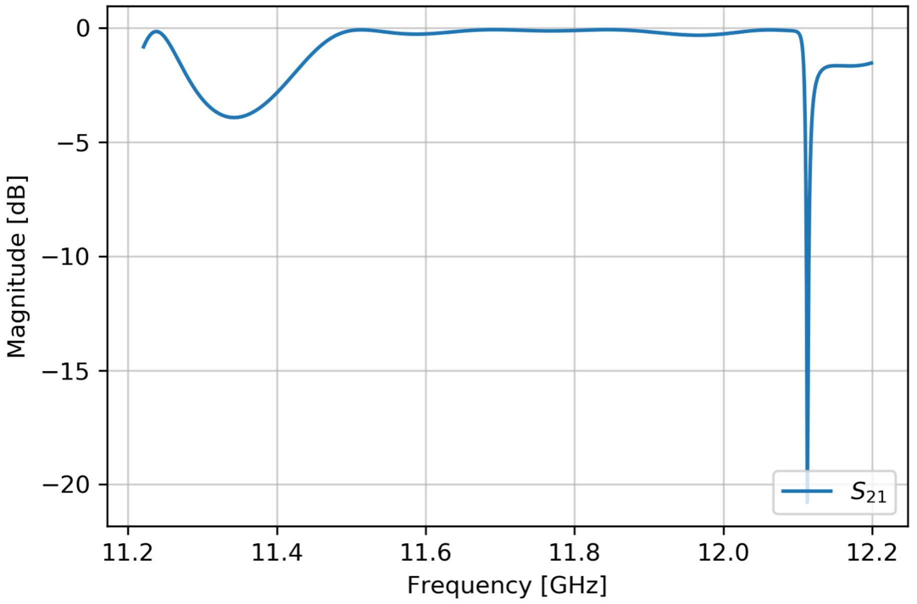
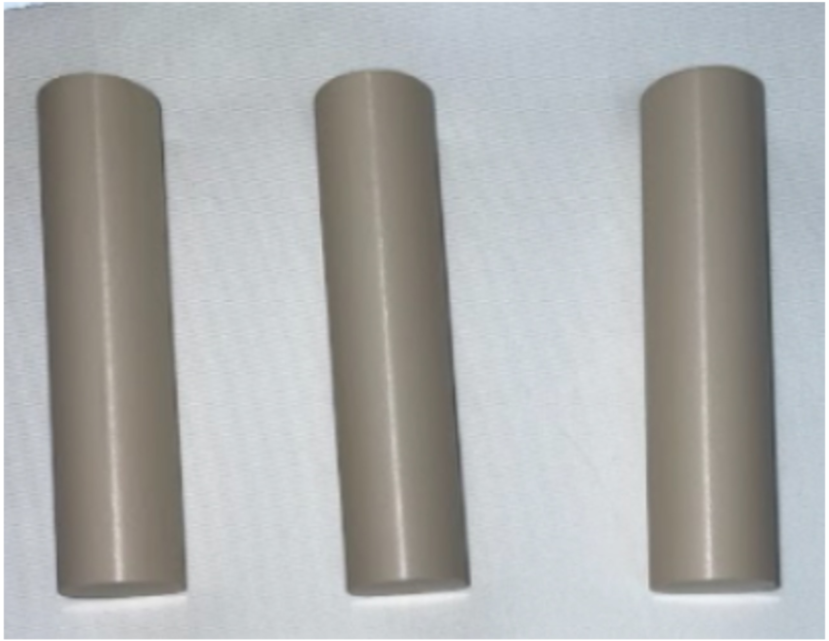


Components Testing

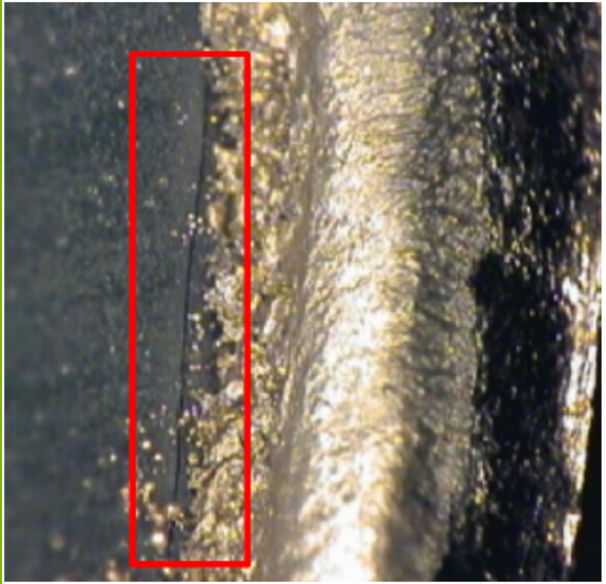
- **The ceramic selected to be used brazed single cell and clamped multicell is barium titanate (BaTiO3). Clamped single cell used is Calcium Titanium Lanthanum Aluminum Oxide.**

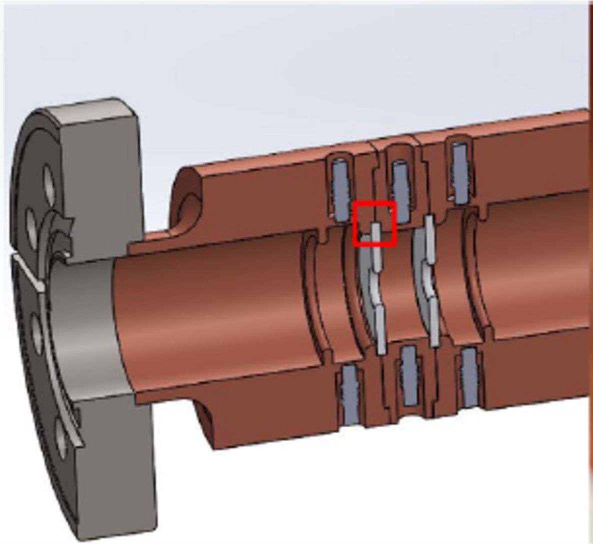
- Ceramic was chosen for high dielectric constant and low loss tangent
  - Dielectric constant is ratio of a material's permittivity to vacuum permittivity
  - It represents how that object is able to store electrical energy in an electric field

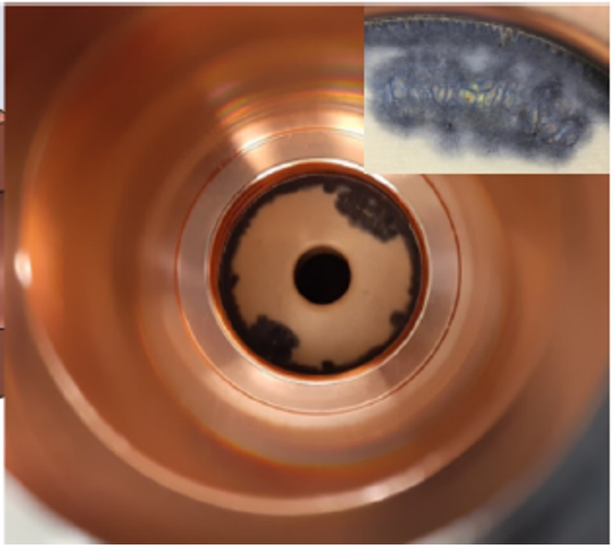
- **Loss Tangent is the ratio of the imaginary part of an object's permittivity and the real part of its permittivity.**



Damage of first two prototypes

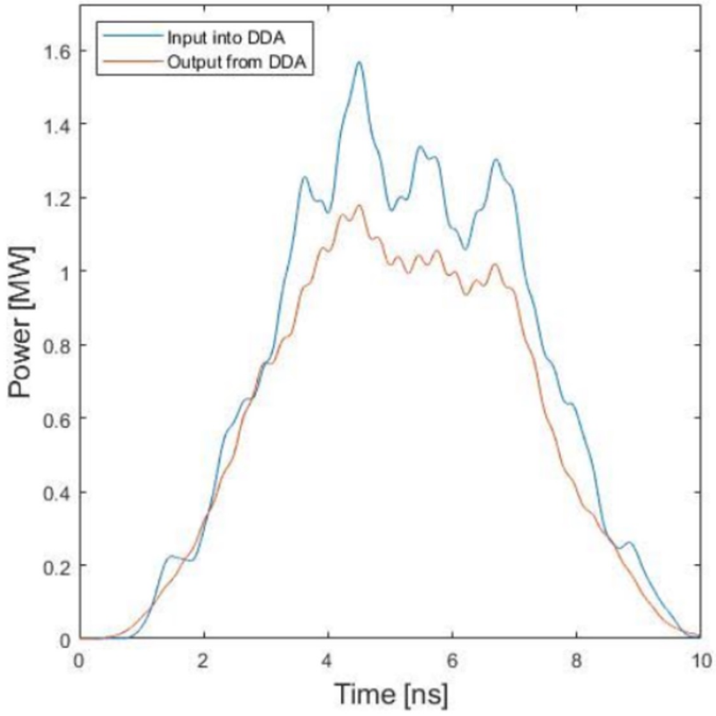






Processed Waveforms

24 nC Charge Bunch



401 nC Charge Bunch