Los Alamos NATIONAL LABORATORY

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Ceramic enhanced accelerator structure low power test and designs of high power and beam tests

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Ceramic Enhanced Accelerator Structure (CEAS) for Higher Shunt Impedance*

CEAS concept

- Geometry
- Physical picture
- Ceramics

CEAS cavity design

- Enhanced shunt impedance
- Plainness of design

CEAS low power test

- Verification of shunt impedance enhancement

Beam test design

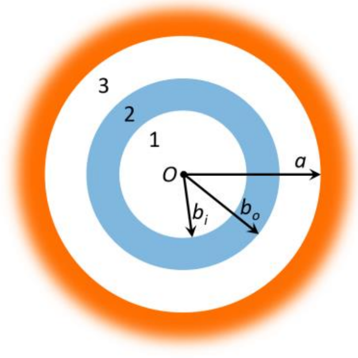
- Sub-relativistic beam acceleration

High power test design

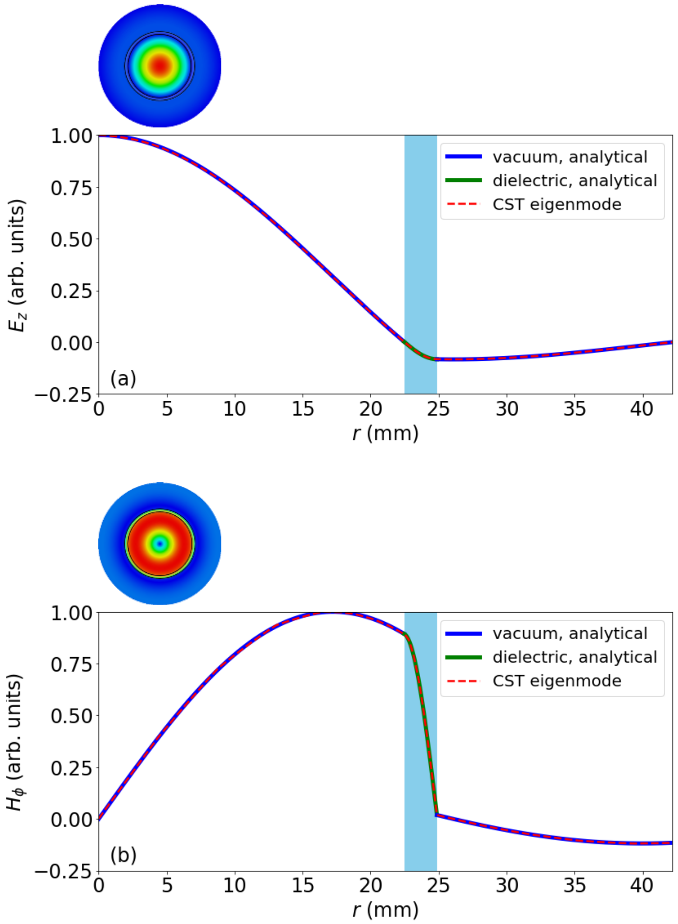
- Accelerating gradient limit

* We discuss time-independent shunt impedance here and elsewhere.

CEAS Concept*



- TM_{020} mode
- Reduced ohmic loss
  - Central region field enhancement by high dielectric permittivity.
  - Reduced sidewall magnetic field.
- Minimized electric field on dielectric
  - Ceramic insertion placed at the node of the longitudinal electric field.



* J. Upadhyay et al., *Nucl. Instrum. Methods Phys. Res. A*, vol. 1034, no. 166669, 2022.

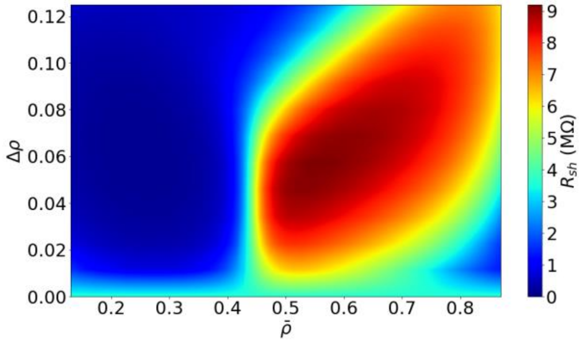
Ceramics of Study

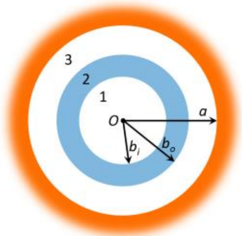
- Euclid Techlabs BT37 ceramic
  - $\epsilon_r = 37.6$, $\tan\delta = 2.75\times10^{-4}$
- Skyworks 3500 series ceramic
  - $\epsilon_r = 34.5$, $\tan\delta = 1.06\times10^{-4}$

CEAS Cavity at 5.1 GHz

- Parameter optimization
  - Analytical maximization of shunt impedance.
  - Refinement by CST eigenmode simulations.
- Low power test cavity design
  - Semi-loop coupler at inner region.
  - Clamped structure.

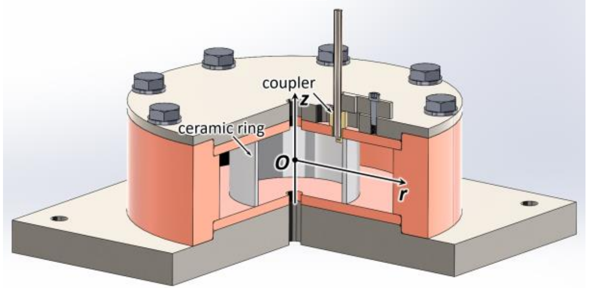
Example: CEAS geometry with Skyworks 3500 ceramic





$$\overline{\rho} = (b_i + b_o)/2a$$

$$\Delta\rho = (b_i - b_o)/a$$



CEAS Enhanced Shunt Impedance

- CST eigenmode simulation results*.

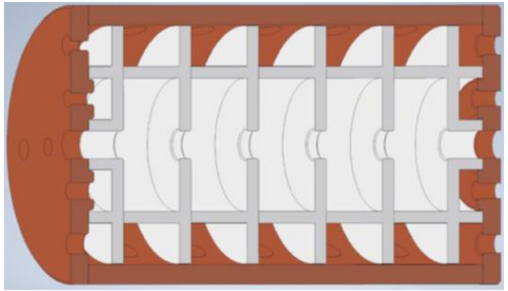
Parameters	Conventional pillbox cavity	Euclid Techlabs BT37 ceramic CEAS cavity	Skyworks 3500 ceramic CEAS cavity
operating mode	TM_{010}	TM_{020}	TM_{020}
resonant frequency f_0	5.100 GHz	5.100 GHz	5.101 GHz
geometric ratio R/Q	408.6 Ω	363.4 Ω	350.7 Ω
intrinsic quality factor Q_0	11135	15664	18709
shunt impedance R_{sh}	4.55 MΩ	**5.69 MΩ**	**6.56 MΩ**
shunt imp. per length r_{sh}	155 MΩ/m	194 MΩ/m	223 MΩ/m
power saved	N/A (control group)	**20%**	**30%**

* Copper electrical conductivity used: 4.6×10^7 S/m, c.f. ideal copper electrical conductivity 5.8×10^7 S/m.

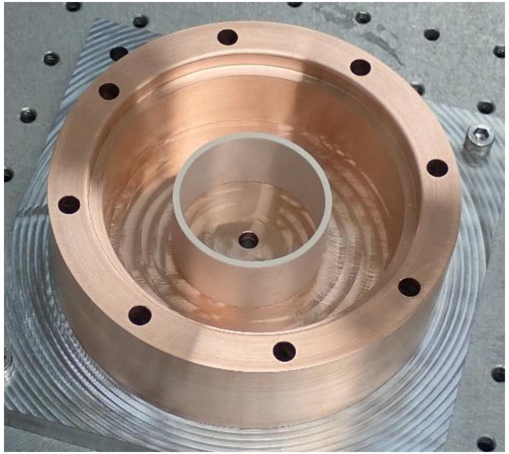
CEAS Advantages

- Enhanced shunt impedance compared to metallic pillbox cavity.
- Geometry simplicity.
  - Reduced complexity of ceramic component fabrication.
  - Elimination of ceramic-ceramic bonding.
- Reduced risk of beam halo interception.
  - Ceramic tube farther away from beam axis.
- Reduced risk of dielectric breakdown.
  - Minimized electric field on ceramic tube.

Dielectric-assist accelerator (DAA) structure*



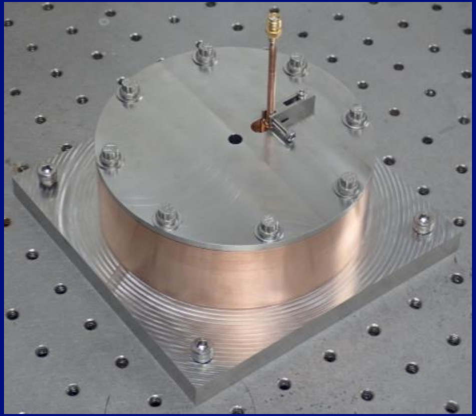
CEAS cavity with Euclid Techlabs BT37 ceramic

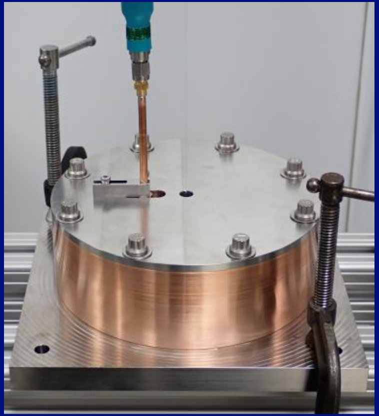


* S. Mori and M. Yoshida, "Multipactor suppression in dielectric-assist accelerating structures via diamondlike carbon coating," *Phys. Rev. Accel. Beams*, vol. 24, no. 022001, 2021.

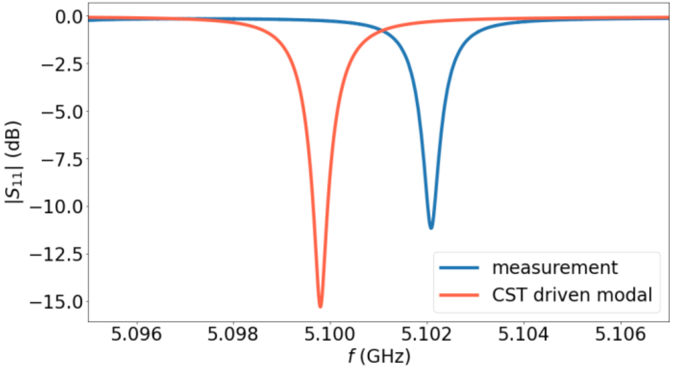
CEAS Cavity Low Power Test

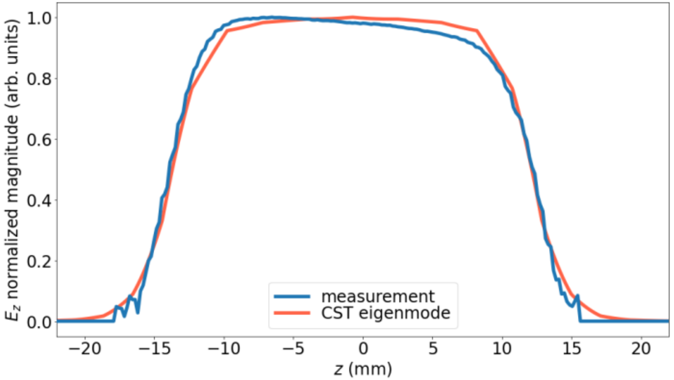
- Reflection coefficient (S_{11})
- Accelerating field magnitude profile





Example: CEAS cavity with Euclid Techlabs BT37 ceramic





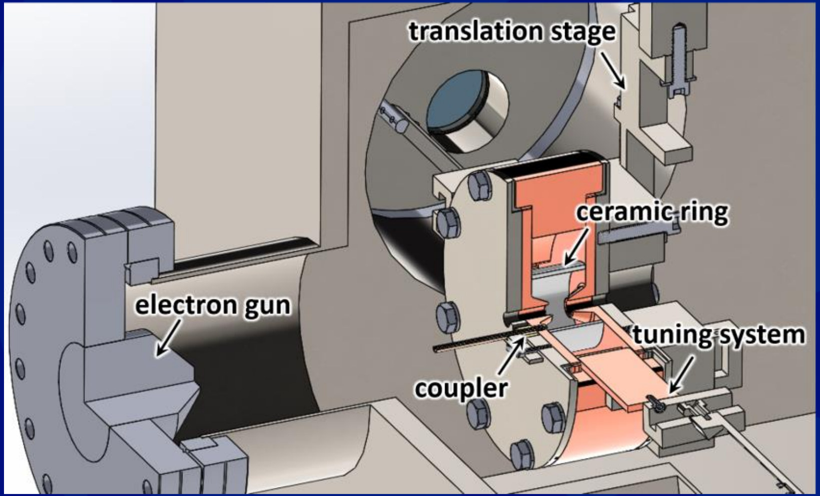
CEAS Cavity Low Power Test

- Measurement results vs. theoretical prediction.

Parameters	CST Simulation	Low power experiment
resonant frequency f_0	5.100 GHz	5.099 GHz
intrinsic quality factor Q_0	11135	11134
shunt impedance R_{sh}	4.55 MΩ	4.55 MΩ
power saved	N/A (control group)	N/A (control group)
resonant frequency f_0	5.100 GHz	5.102 GHz
intrinsic quality factor Q_0	15664	16147
shunt impedance R_{sh}	5.69 MΩ	**5.87 MΩ**
power saved	20%	**22%**
resonant frequency f_0	5.101 GHz	5.082 GHz
intrinsic quality factor Q_0	18709	18217
shunt impedance R_{sh}	6.56 MΩ	**6.39 MΩ**
power saved	30%	**29%**

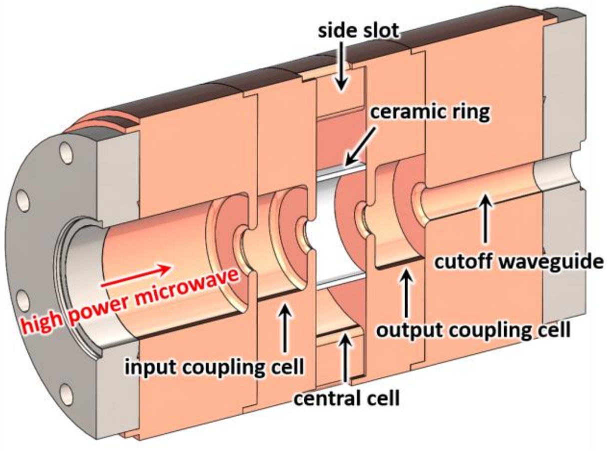
CEAS Beam Test Design

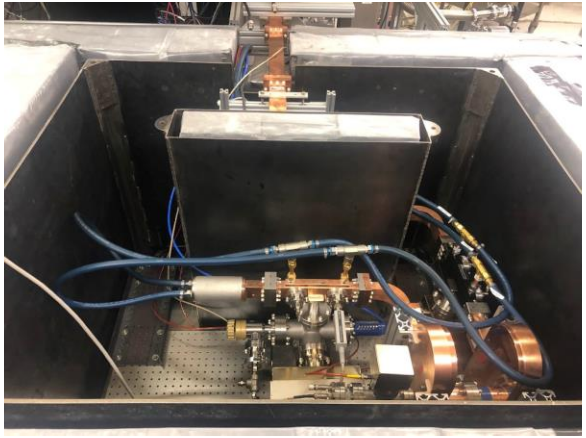
- Verification of beam acceleration capability
  - Charging on ceramic component
  - Temperature rise
- Experimental setup design at 5.1 GHz
  - 30 kV / 1 mA DC electron beam
  - 1 – 2 MV/m accelerating gradient
  - 5 MHz tuning range
- Ceramic-copper brazing test underway
  - Elimination of minuscule gaps
  - Idealized triple point geometry



CEAS High Power Test

- Test of accelerating gradient limit at 5.7 GHz
  - Standing wave single cell cavity
  - Electron multipactor
  - Dielectric / microwave vacuum breakdown
- LANL C-band Engineering Research Facility (CERF-NM)*





* E.I. Simakov, *et al.*, “Update on C-band high gradient testing at Los Alamos,” International Workshop on Breakdown Science and High Gradient Technology (HG2022), Beijing, China, 2022.

Conclusions

- Ceramic Enhanced Accelerator Structure (CEAS) operates in TM_{020} mode and uses low-loss high-permittivity ceramic insertion to enhance shunt impedance.
- CEAS geometry plainness expedites applications and reduces operational risks.
- Low power test has confirmed the shunt impedance improvement.
- Designs have been completed for beam test and high power test.

Acknowledgments

CEAS Exploratory Research Team

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- Janardan Upadhyay
- Haoran Xu (co-PI)

LABORATORY DIRECTED RESEARCH & DEVELOPMENT

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Check out contribution “Ceramic enhanced accelerator space readiness” (TAPU49) on the progress of CEAS cavity space application readiness test!