C^3 Demo R&D Overview and Goals

Cool Copper Collider Workshop, SLAC

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SLAC NATIONAL ACCELERATOR LABORATORY

Stanford University | U.S. DEPARTMENT OF ENERGY

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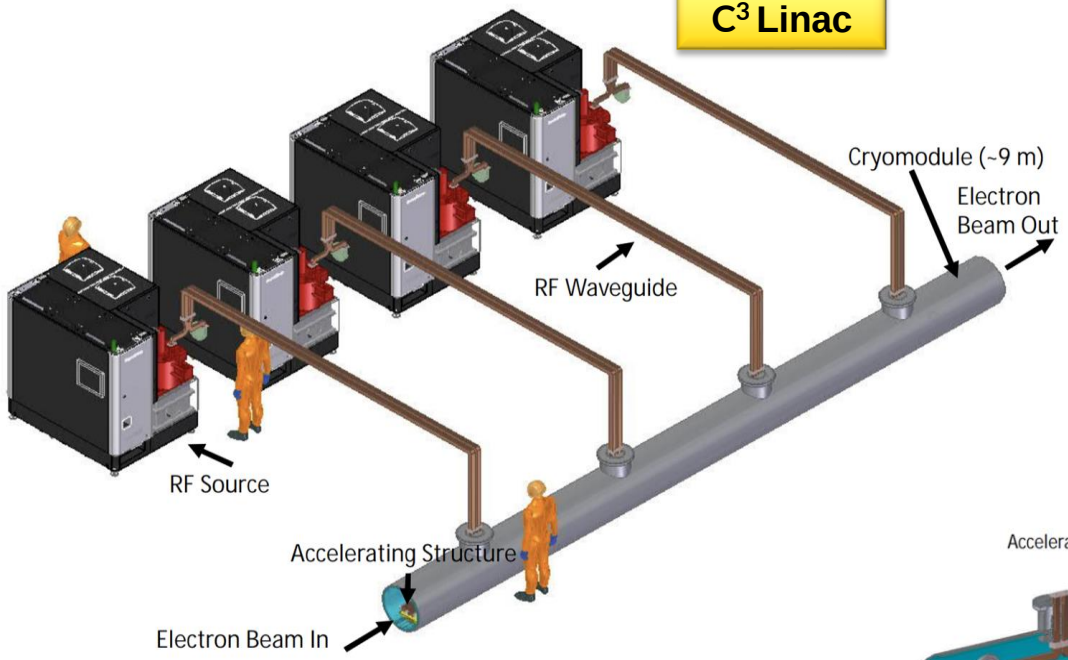
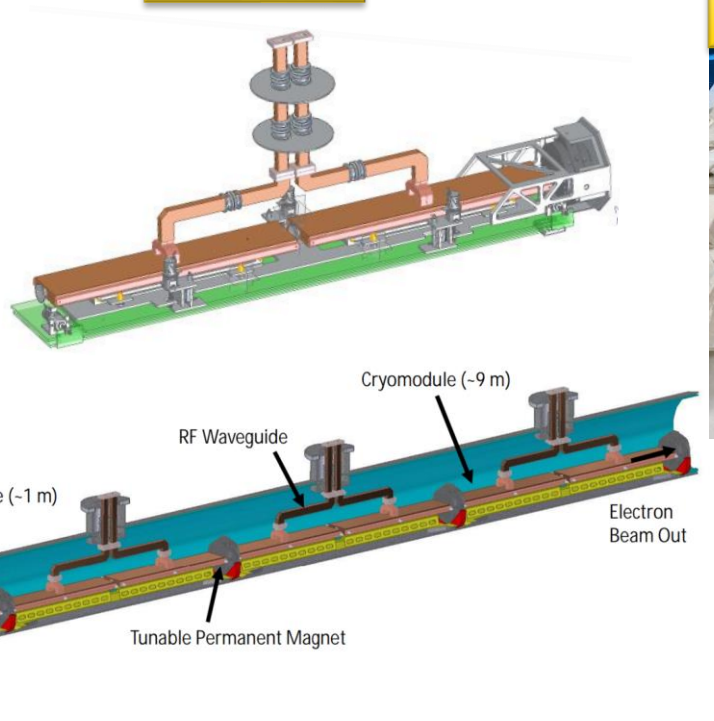
Introduction Staged Approach

- C^3 technology: Modularized linac technology based on liquid N2 cooled c-band cavity.
- Each cryomodule (CM) is about 9 m long and has 4 rafts.
- Each raft has 2 accelerator structures and one quadrupole magnet.
- Each CM can reach up to 0.9 GeV with 4 X 50MW klystrons.

C^3 Linac



CM & Raft



Prototype Structure

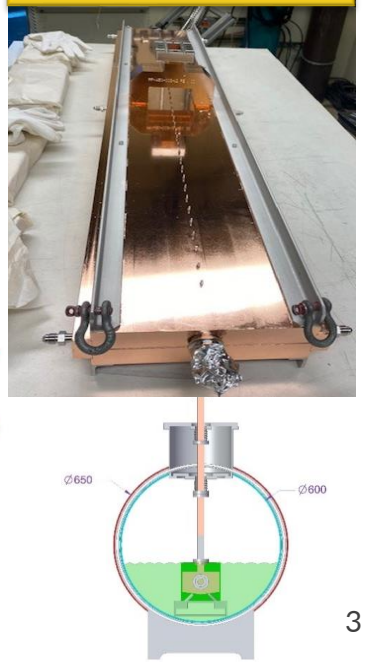


Table of Parameters – 250/550 GeV

Collider	CLIC	ILC	C^3	C^3
CM Energy [GeV]	380	250 (500)	250	550
Luminosity [x10^{34}]	1.5	1.35	1.3	2.4
Loaded Gradient [MeV/m]	72	31.5	70	120
Geometry Gradient [MeV/m]	57	21	63	108
Length [km]	11.4	20.5 (31)	8	8
Num. Bunches per Train	352	1312	133	75
Train Rep. Rate [Hz]	50	5	120	120
Bunch Spacing [ns]	0.5	369	5.26	3.5
Bunch Charge [nC]	0.83	3.2	1	1
Crossing Angle [rad]	0.0165	0.014	0.014	0.014
Site Power [MW]	168	125	~150	~175
Design Maturity	CDR	TDR	pre-CDR	pre-CDR

Ref: M. Bai et al, SLAC-PUB-17629

Table of Parameters – 250/550 GeV

- **Main linac cryogenic heat load**
  - **9 MW ($C^3$250, $C^3$550-8km) – 0.4 W/cm^2 on structure**
  - **13.4 MW $C^3$550-7km without Pulse compressor - 0.6 W/cm^2 on structure**

Gradient (MV/m)	Power diss. (W)	rf flat top (ns)	Pulse compr.	Comments	Power/area (W/cm^2)	ΔT Cu-bulk to LN_2 (K)
70	2500	700	N	C^3 -250	0.393	2.3
120	2500	250	N	C^3 -550	0.393	2.3
155	3900	250	N	C^3 -550 in 7 km	0.614	2.5
120	1650	250	Y	C^3 -550	0.259	2.1

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Introduction Staged Approach

Design Study C^3-250-550 GeV LC at the next P5!

Minimum requirement for Demonstration:

- **Demonstrate operation of fully engineered and operational cryomodule**
  - Simultaneous operations of min. 3 cryomodules
  - Demonstrate operation during cryogenic flow equivalent to the main linac
- **Demonstrate beam dynamics**
  - Fully damped-detuned accelerating structures and beam-based alignment
  - Operation with a multi-bunch photo injector
  - Beam diagnostic line
- **Demonstrate full operational gradient 120 MeV/m (and higher > 155 MeV/m) w/ single bunch**
  - Must understand margins for 120 - targeting power for (155 + margin)
  - 18X 50 MW C-band sources - off the shelf units
- **Manufacturability development with industry on rf source, structures and cryomodules.**

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Staged Approach

❖4 stages – goals & scope - Impact & Applications

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- 3: CM linac scale-up full demonstration for linear collider (LC)
  - Beam dynamics demonstration: wakefields, alignment, and stability (jitter, vibration, etc) control.
  - Full cryogenic (gas/LN) flow rate at equivalent heat load of LC.

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- 2: CM scale-up minimum demonstration
  - Beam dynamics: long range wakefields, beam-based alignment
  - Availability with and without beam

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- 1: CM engineering design study and prototypes
  - Beam acceleration, beam loading, energy stability
  - Initial verification of RF and CM design

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- 0: Proof of concept for the most critical structure performance parameters

Introduction Staged Approach

❖4 stages – goals & scope - Impact & Applications

- 3: CM linac scale-up full demonstration for linear collider (LC)

2028- 2030

  - Beam dynamics demonstration: wakefields, alignment, and stability (jitter, vibration, etc) control.
  - Full cryogenic (gas/LN) flow rate at equivalent heat load of LC.

2026- 2028

- 2: CM scale-up minimum demonstration
  - Beam dynamics: long range wakefields, beam-based alignment
  - Availability with and without beam

2023- 2026

- 1: CM engineering design study and prototypes
  - Beam acceleration, beam loading, energy stability
  - Initial verification of RF and CM design

2022 - 2023

- 0: Proof of concept for the most critical structure performance parameters

Introduction Staged Approach

❖4 stages – goals & scope - Impact & Applications

- 3: CM linac scale-up full demonstration for linear collider (LC)
  - A linac of 3 cryomodules
  - A multi-bunch photo injector and beam diagnostic line
  - Cryogenic system for 5.5 L/s LN flow test (9 MW equivalent heat load)

2028- 2030

- 2: CM scale-up minimum demonstration
  - A linac of single CM (8 rf stations and 8 rf structures)
  - A multi-bunch photo injector and beam diagnostic line

2026- 2028

- 1: CM engineering design study and prototypes
  - A linac of half CM (2 rf stations and 4 rf structures)
  - Full cryomodule cryogenic study

2023- 2026

- 0: Proof of concept for the most critical structure performance parameters
  - Regular structure baseline high power test

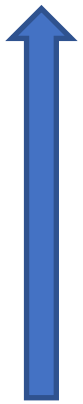
2022 - 2023

Introduction Staged Approach

❖4 stages – goals & scope - Impact & Applications

2028- 2030

2026- 2028

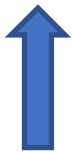


✓ Security

✓ Medical: linac therapy

✓ Industrial: high energy CT, irradiation with electrons or x-rays

2023- 2026



○ Compact cost-effective low energy linac based on single rf structure

2022 - 2023

▪ 0: Proof of concept for the most critical structure performance parameters

○ Proof of fundamental high gradient C^3 structure

Introduction Staged Approach

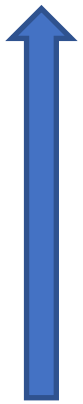
❖4 stages – goals & scope - Impact & Applications

2028- 2030

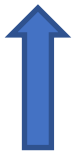
2026- 2028

2023- 2026

2022 - 2023



- ✓ Medical: VHEE therapy
- ✓ Compact high energy (100s keV to 1MeV) Compton source
- ✓ Lower energy injector for booster ring
- ✓ High brightness injector feasibility



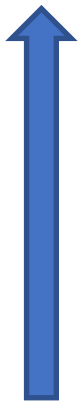
- **Compact high energy linac**
  - 1: CM engineering design study and prototypes
    - A half CM with 2x50MW klystrons – 0.4 GeV over 5 meters

Introduction Staged Approach

❖4 stages – goals & scope - Impact & Applications

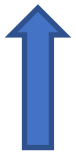
2028- 2030

2026- 2028



- ✓ Energy booster with existing facilities like LCLS-X
- ✓ Compact light sources like FEL.

2023- 2026



- Compact high energy linac with cost –effective RF source

2022 - 2023

- 2: CM scale-up minimum demonstration
  - A single CM linac with 4x50 MW klystrons of ~ 0.9 GeV over 9 meters

Introduction Staged Approach

❖4 stages – goals & scope - Impact & Applications

2028- 2030

2026- 2028

- ✓ Positron production
- ✓ Muon producion
- ✓ Advanced accelerator concept study like PWFA
- ✓ Full energy linac injector for storage ring.

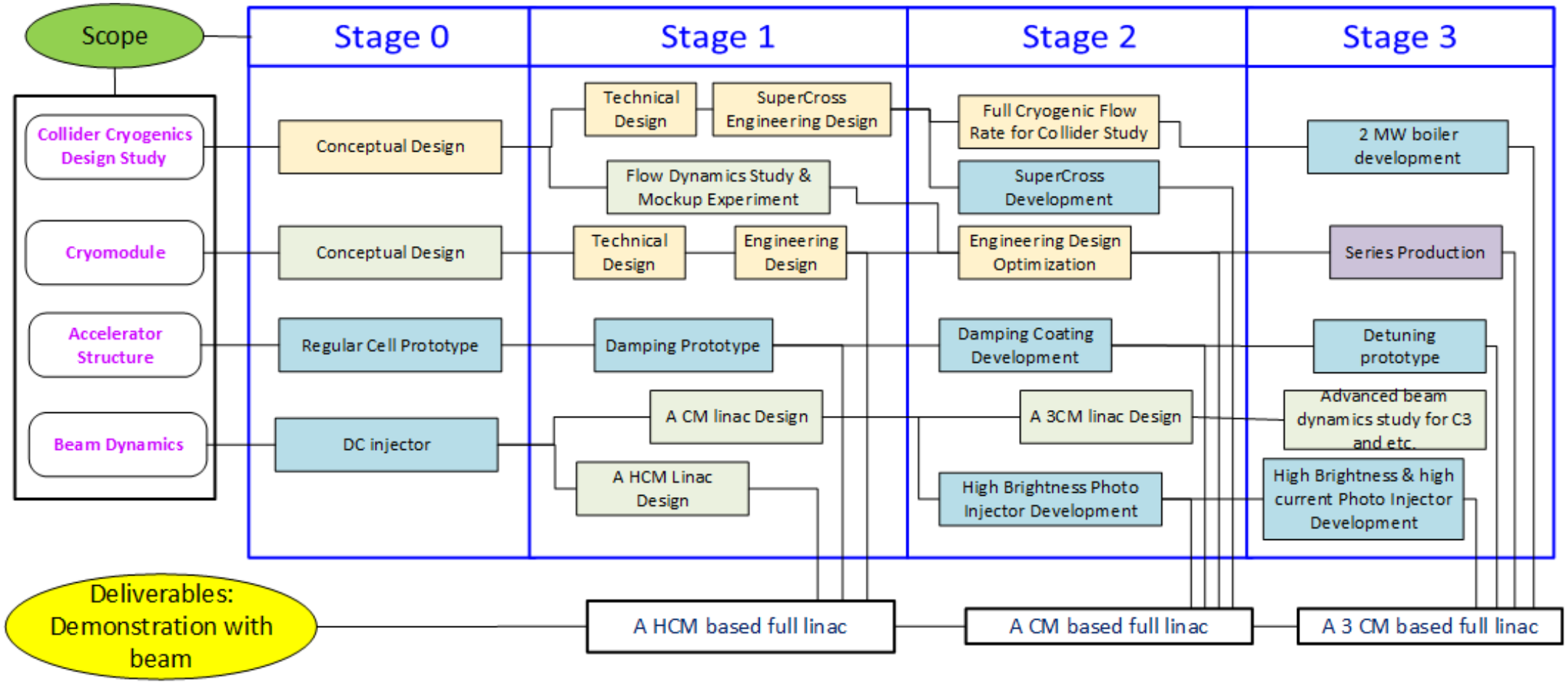
2023- 2026

- A C^3 full linac of 3 CMs ~ 3 GeV over about 30 meters

2022 - 2023

- 3: CM linac scale-up full demonstration for linear collider (LC)

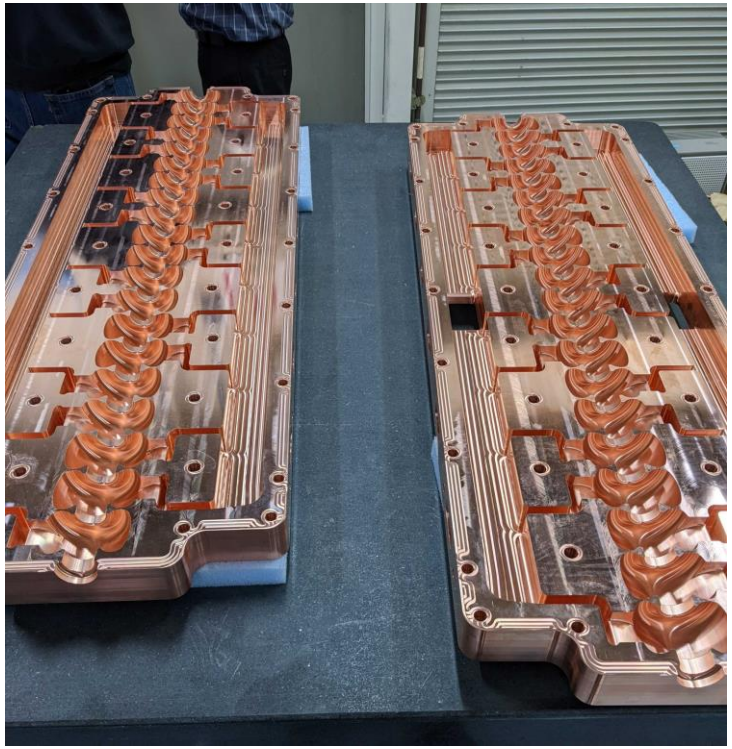
Demo R&D Plan Overview

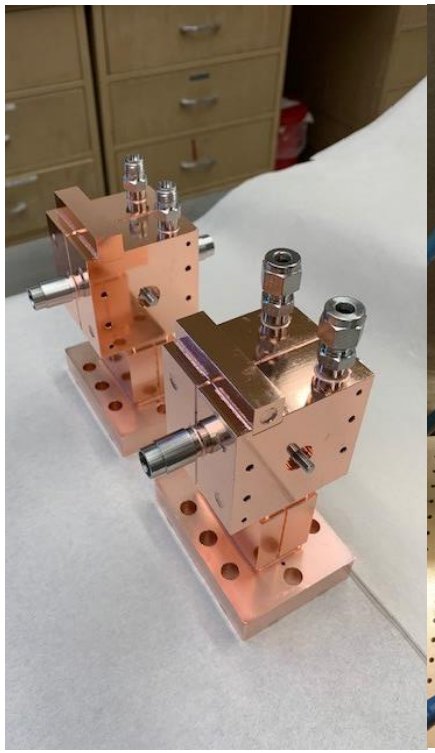


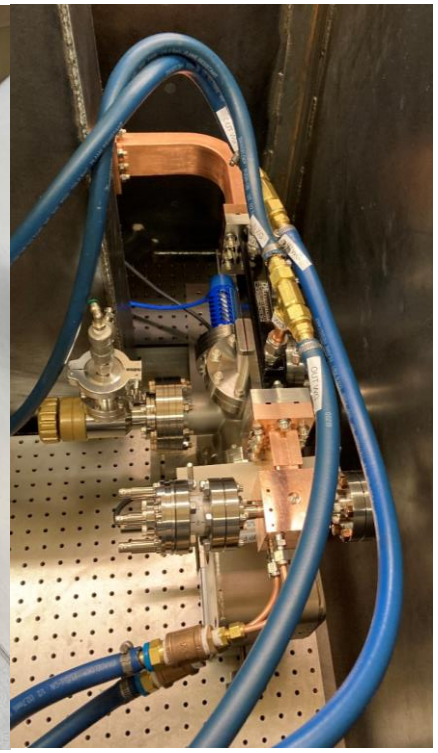
On Going R&D Progress

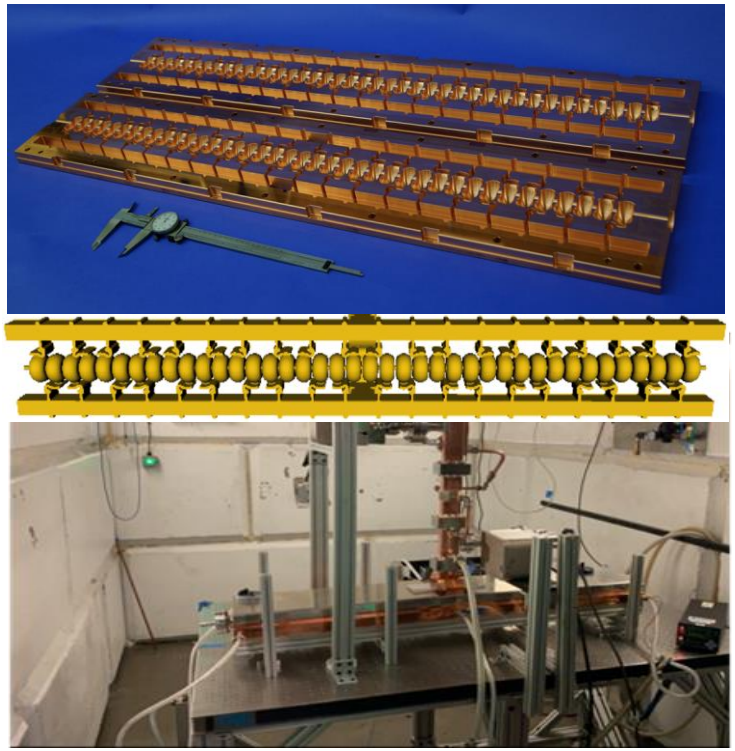
❖ **Structure** Beam dynamic Cryomodule

S-Band Wide Aperture (Injector, Capture and Booster Linac)	A single cell C-band structure High Power Test at LANL	C^3 Prototype One Meter Structure High Power Test at Radiabeam





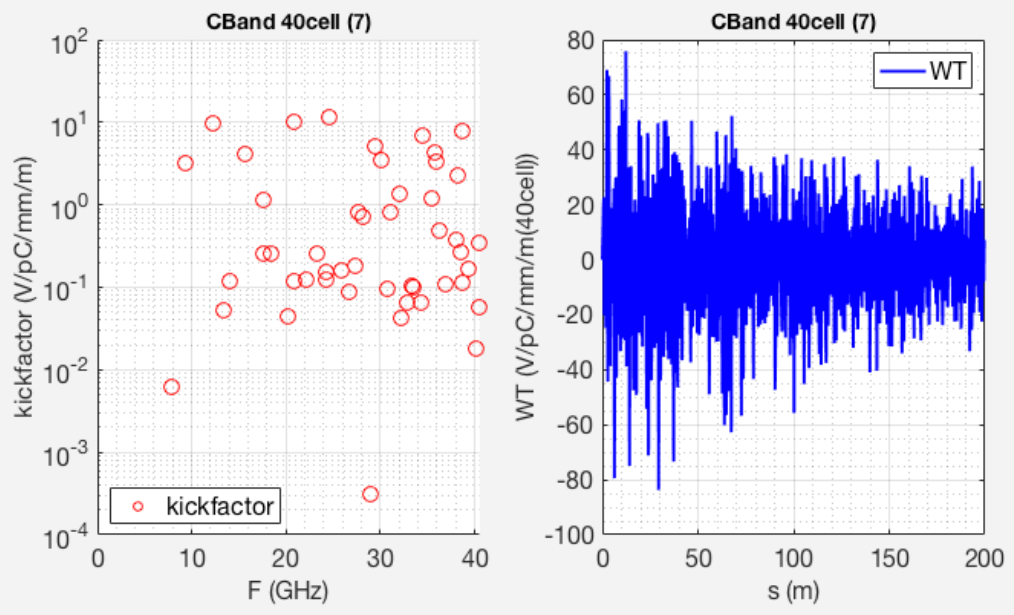




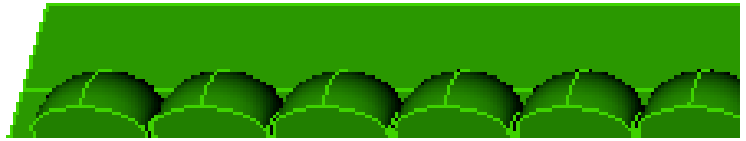
On Going R&D Progress

❖ **Structure** Beam dynamic Cryomodule

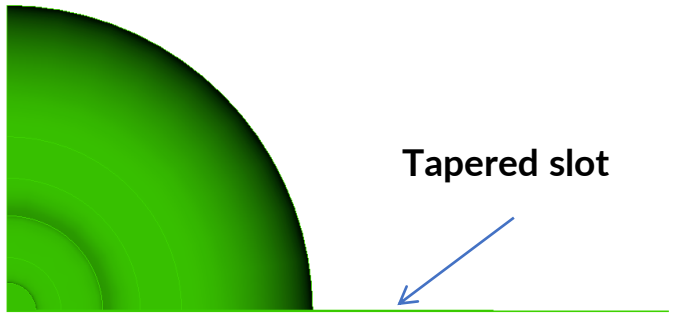
Wakefield of 1-m structure of 40 identical cells



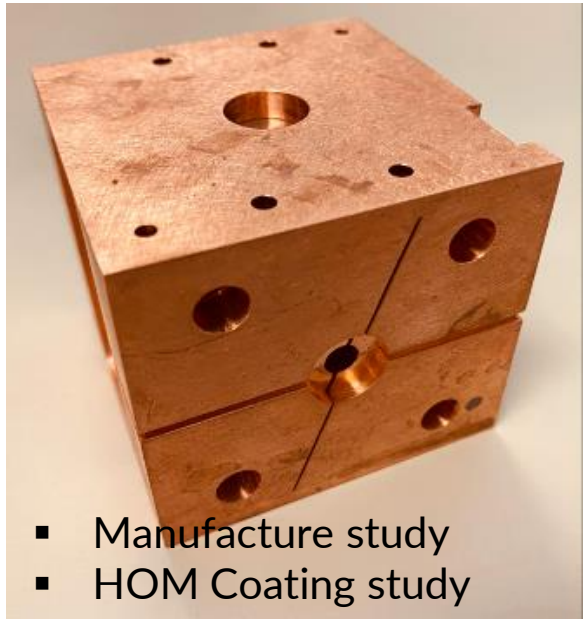
HOM Damping Design



slot height: 300 ~ 100 micron
Slot surface conductivity: 1e6 s



Damping Slot Prototype/coating

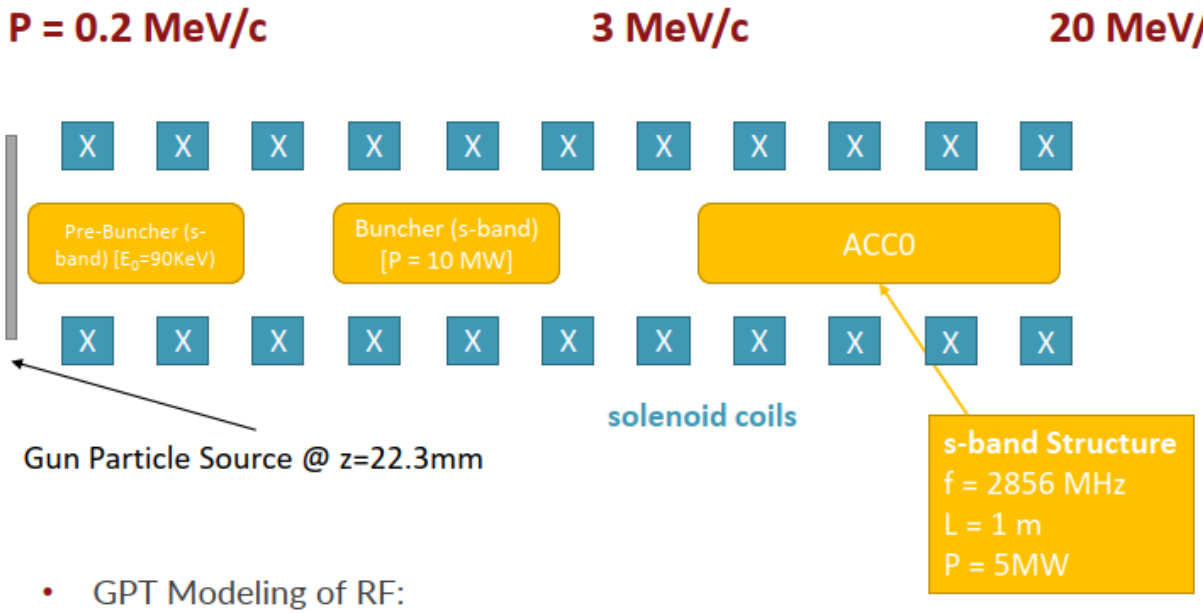


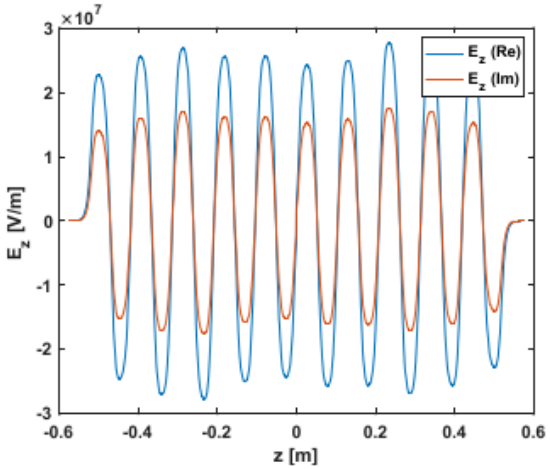
- Manufacture study
- HOM Coating study

On Going R&D Progress

❖ Structure **Beam dynamic** Cryomodule

High Current (300 mA) DC Injector Design Study





- GPT Modeling of RF:
  - Pre-buncher = cylindrical symmetric pillbox cavity in TM010 mode
  - Buncher = 2/3π TW structure
  - Standing-wave accelerating structure using field profile imported from HFSS
- Optimize: Solenoid Field profile, Buncher phase, Pre-Buncher -> Buncher z-offset

3

On Going R&D Progress

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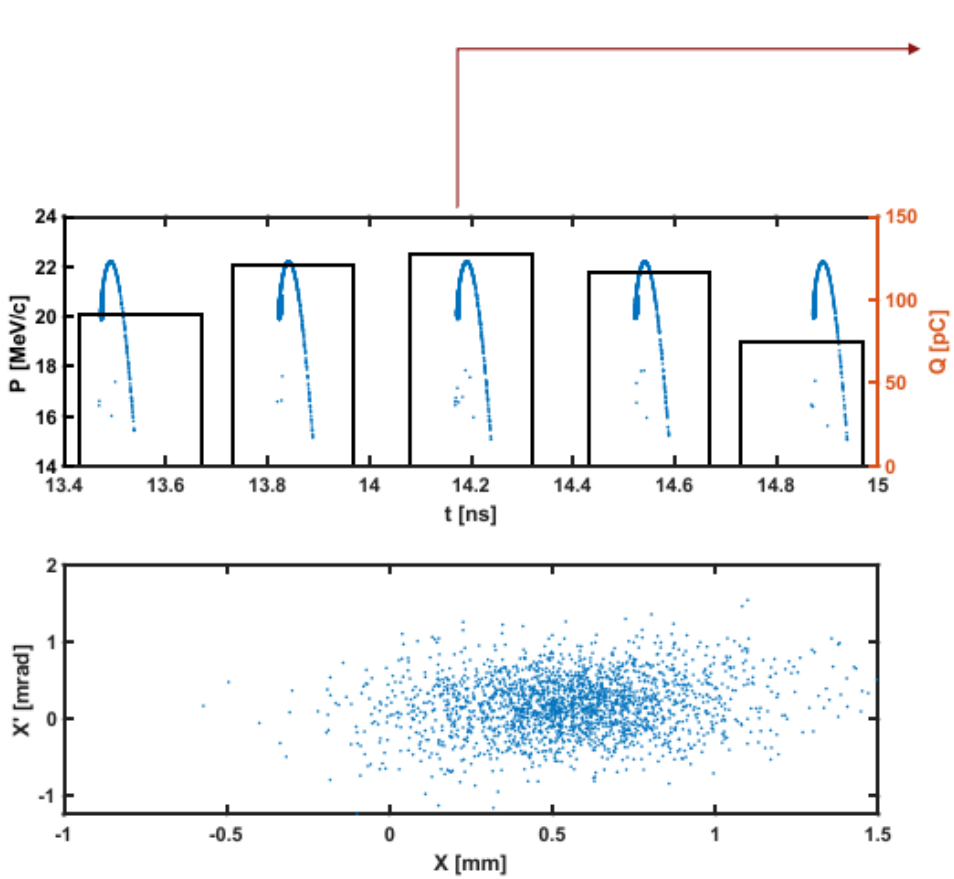
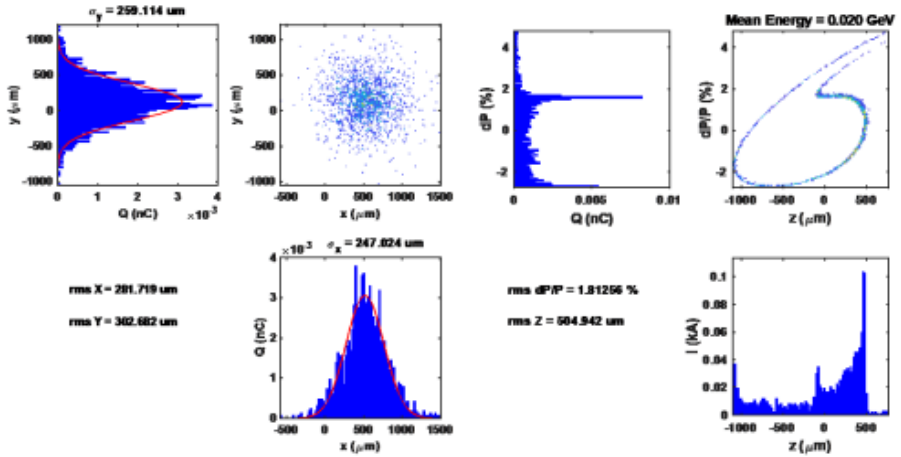


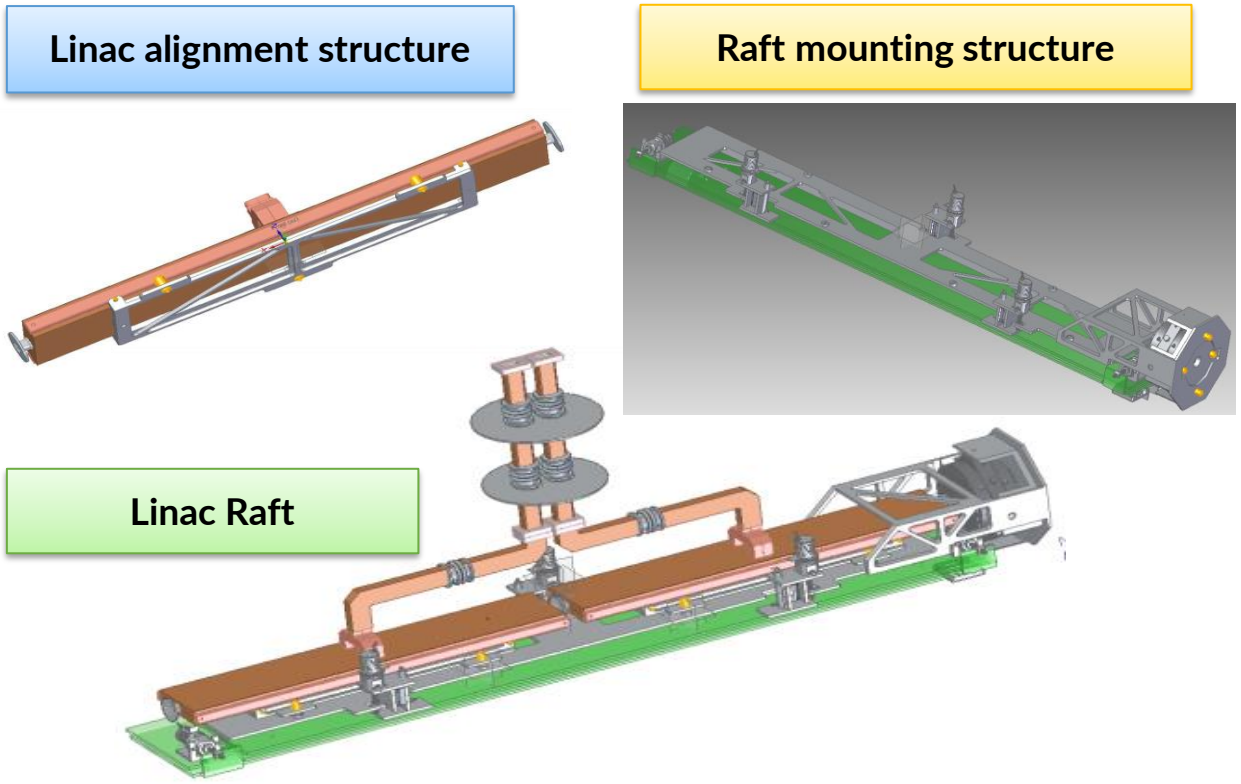


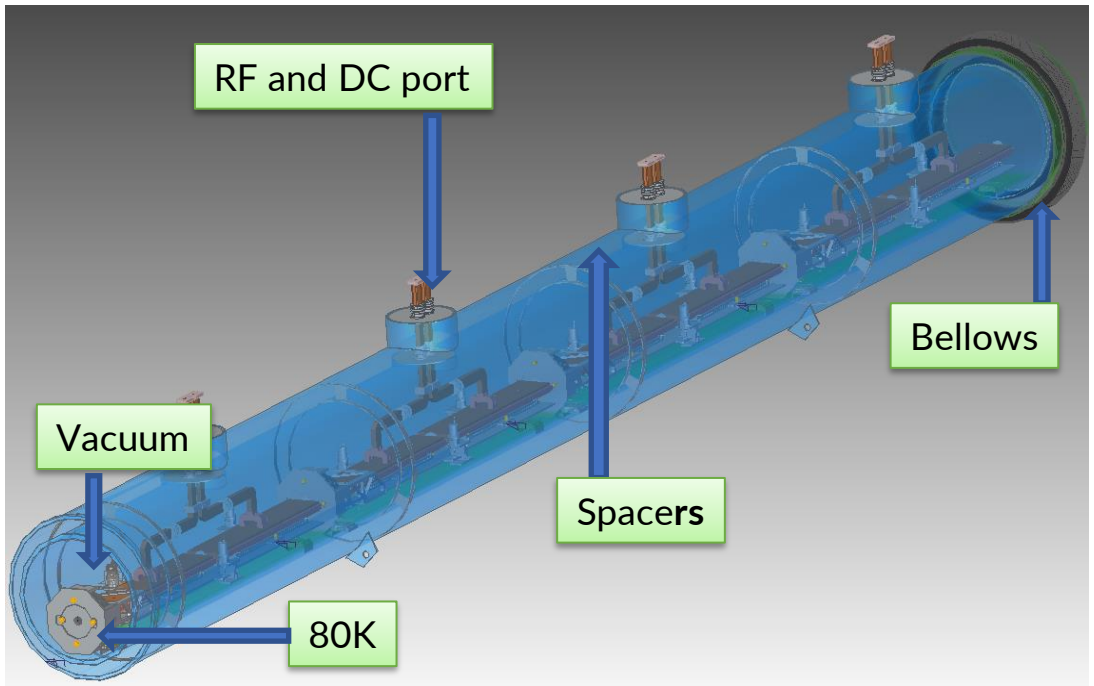
- Capture Efficiency = 61 % (I_{out} = 366 mA)
- Q_{bunch} = 115 pC

On Going R&D Progress

❖ Structure Beam dynamic **Cryomodule**

- Raft design and alignment
- Thermal dynamics





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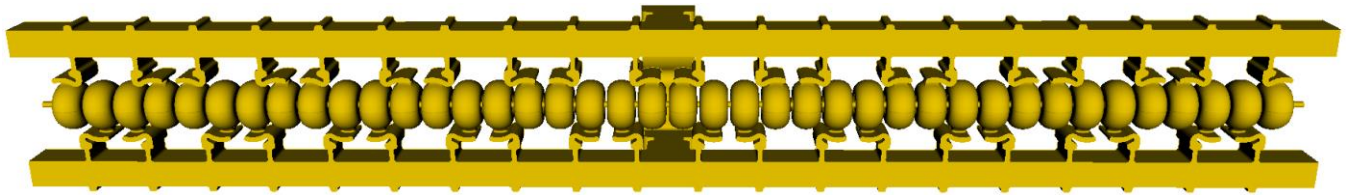

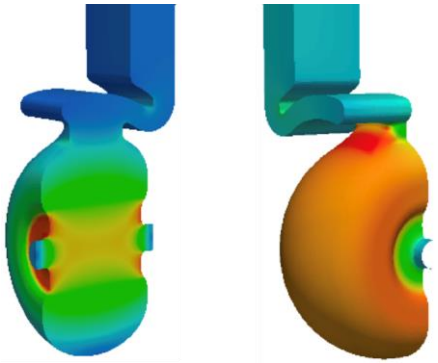

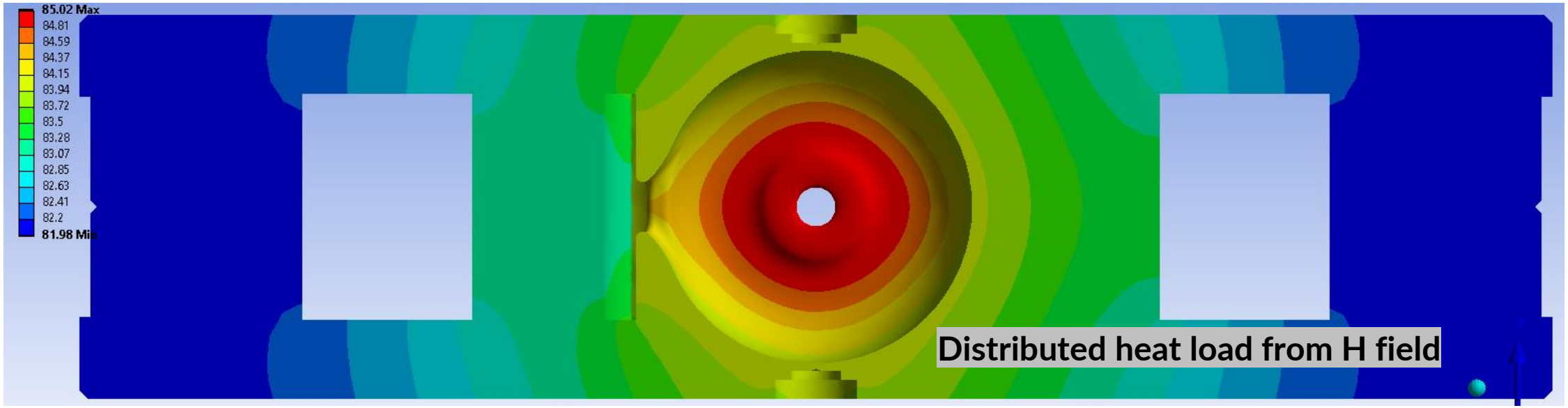

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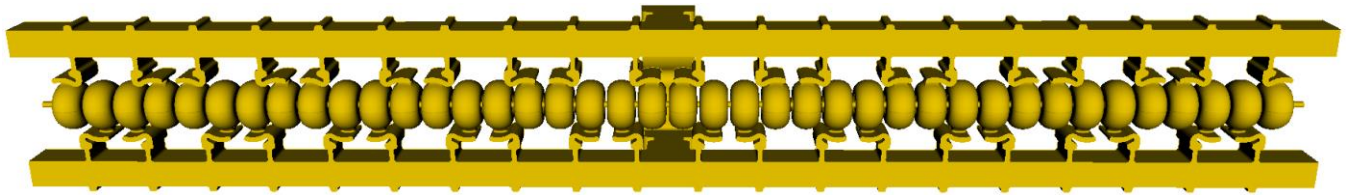

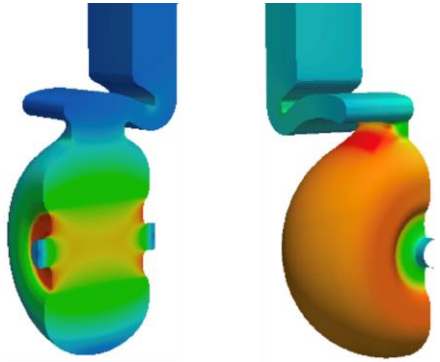

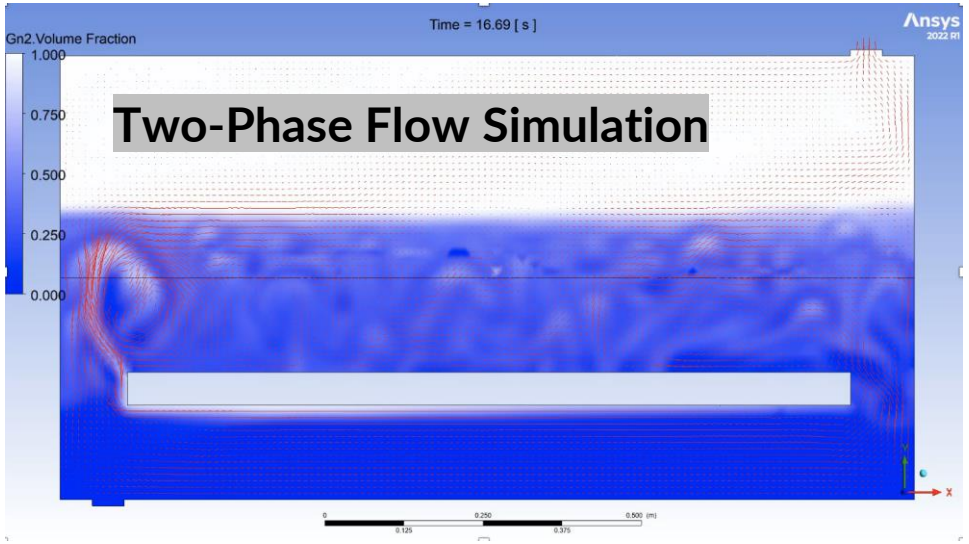

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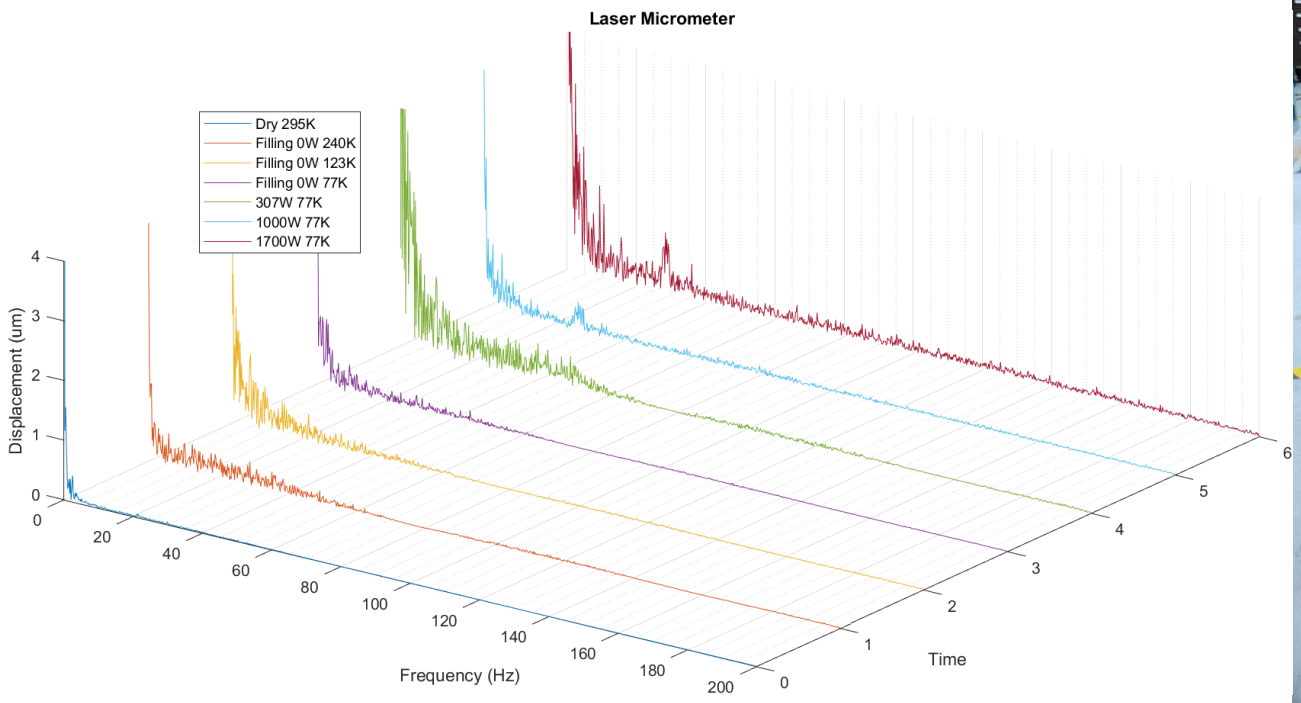
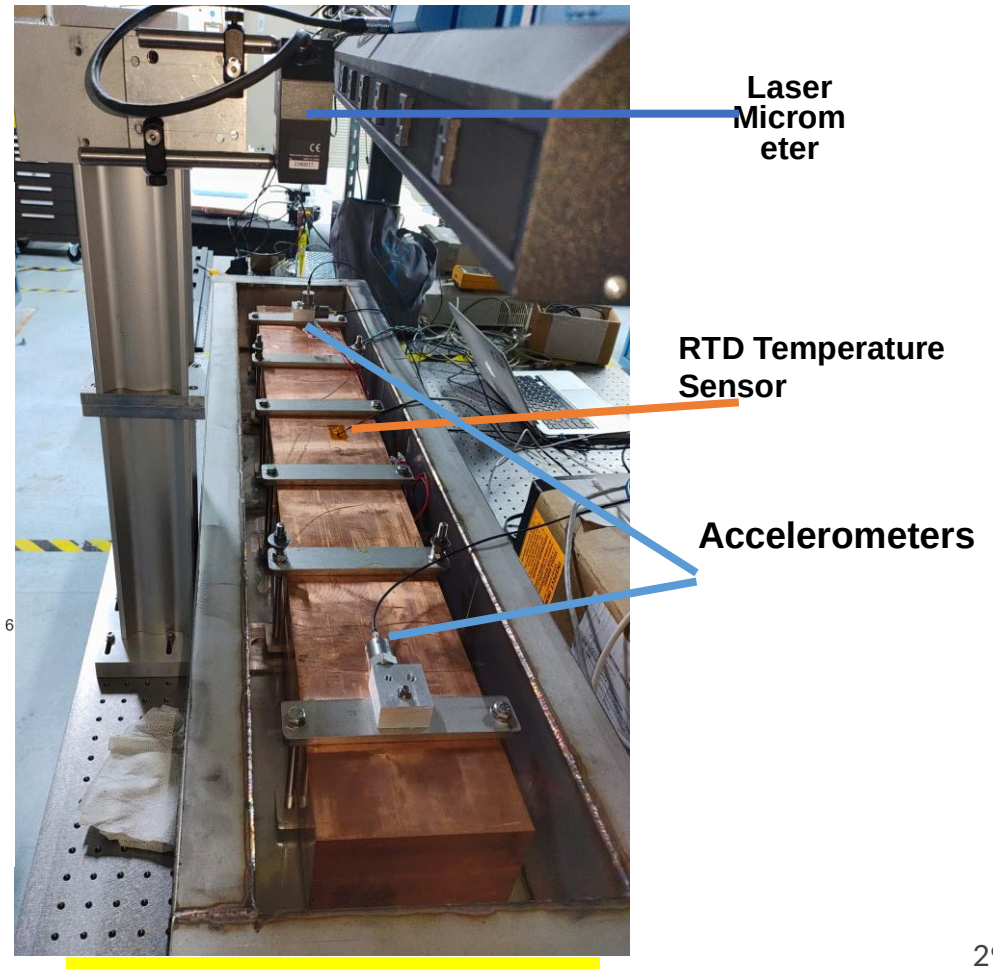
- **Thermal dynamics**

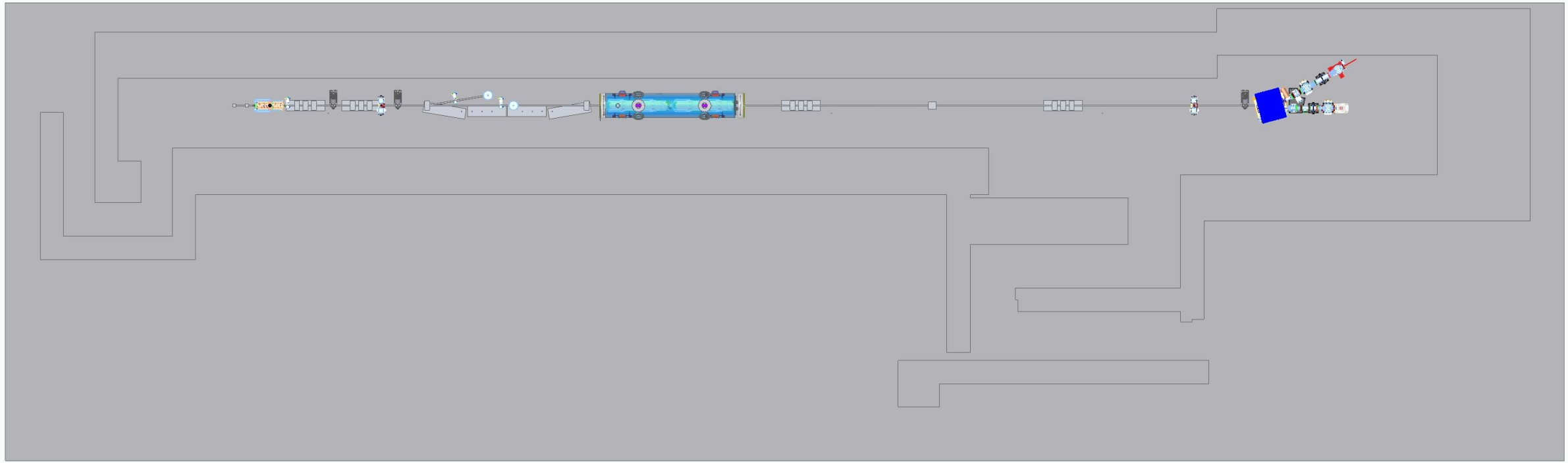




Vibration Emulation Test

On Going R&D Progress

❖ HCM Test Layout in NLCTA



Demo R&D Plan Summary

❑ In Next 4 Years

- ✓ Finish few prototype structures (with and without damping) test
- ✓ Accomplish C3 technology scale-up engineering design minimum demonstration
  - Half cryomodule demonstration with high current/charge beam
  - Built two high power c-band test stands
- ✓ Initiates industrial engagement for manufacturability development

❑ Possible applications

- ✓ Compact medical and industrial linac.
- ✓ Low emittance NC photo injector development
- ✓ Energy booster linac for LCLS-X
- ✓ Compact full energy linac injector for Synchrotron light source

Thank you so much!

Questions?