Compact Traveling Wave X-band Linac with RF Power Flow Outside Accelerating Cavities

Valery Dolgashev (SLAC), Philipp Borchard (Dymenso LLC);
Roman Kostin, Sergey Kuzikov (Euclid Techlabs LLC)

The 2024 International Workshop on Future Linear Colliders, LCWS2024,
University of Tokyo, Tokyo, Japan, 8th-11th of July

U.S. DEPARTMENT OF ENERGY Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Funding and Team

Office of Accelerator R&D and Production,

Accelerator Stewardship and Accelerator Development Programs

Team

- Agustin Romero, Anatoly Krasnykh, *SLAC*;
- Sergey Kuzikov, Roman Kostin, *Euclid Techlabs LLC*;
- Philipp Borchard, *Dymenso LLC*;
- Drew Packard, *General Atomics*;
- Sergey Kutsaev, *Radiabeam;*
- Mark Holl, William Graves, *Arizona State University*.

Motivation for
Traveling Wave Accelerating Structures RF Power Flow Outside Accelerating Cavities

XX International Linac Conference, Monterey, California, August 21-21, 2000

RF PROCESSING OF X-BAND ACCELERATOR STRUCTURES AT THE NLCTA*

C. Adolphsen, W. Baumgartner, K. Jobe, R. Loewen, D. McCormick,
M. Ross, T. Smith, J.W. Wang, SLAC, Stanford, CA 94309 USA
T. Higo, KEK, Tskuba, Ibaraki, Japan

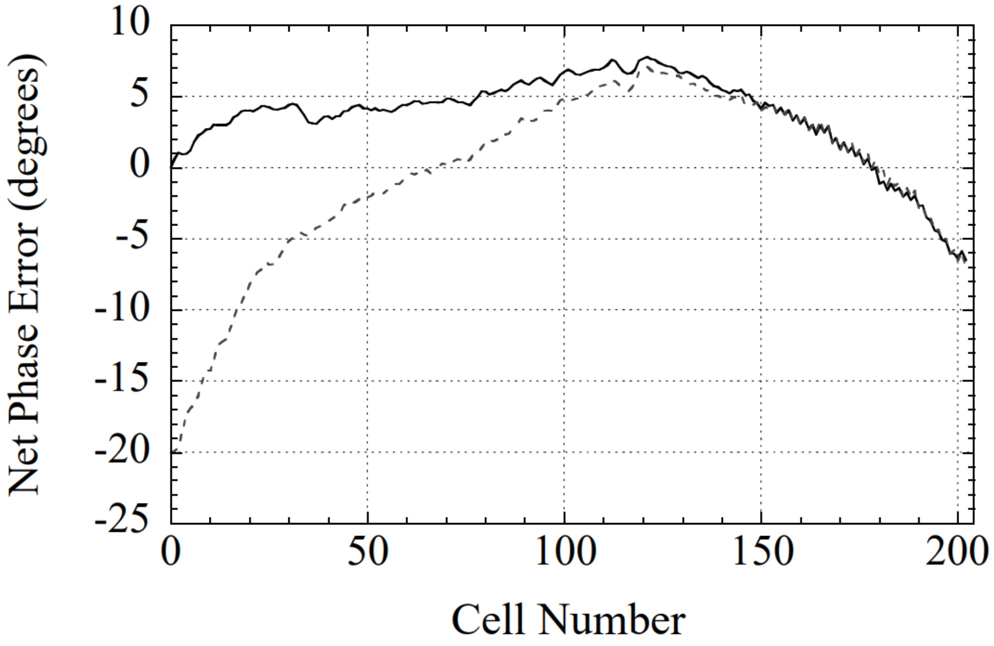
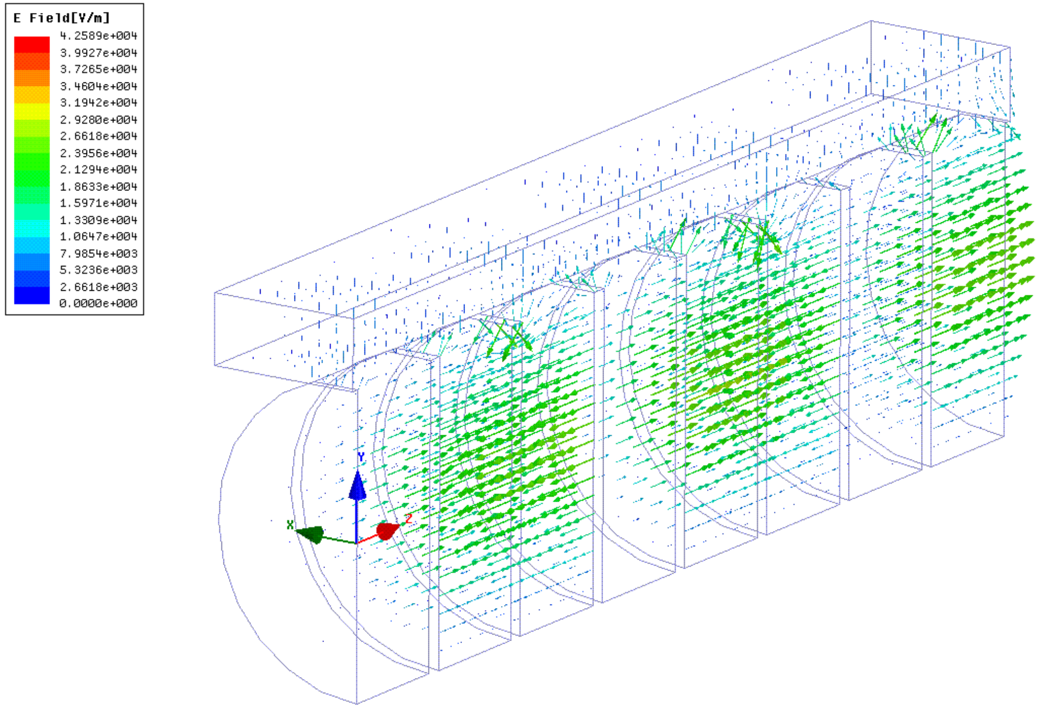


Fig. 1: Bead-pull measurement of the DS2 phase profile before (solid) and after (dotted) 1000 hours of high power operation.



Traveling Wave Accelerating Structures RF Power Flow Outside Accelerating Cavities

Valery Dolgashev, Sami Tantawi, Yasuo Higashi, Status of High Gradient Tests of Normal Conducting Single-Cell Structures, *Robert Siemann Symposium and ICFA Mini-Workshop, July 7th - 10th, 2009, SLAC National Accelerator Laboratory*

Outline and Project Goals

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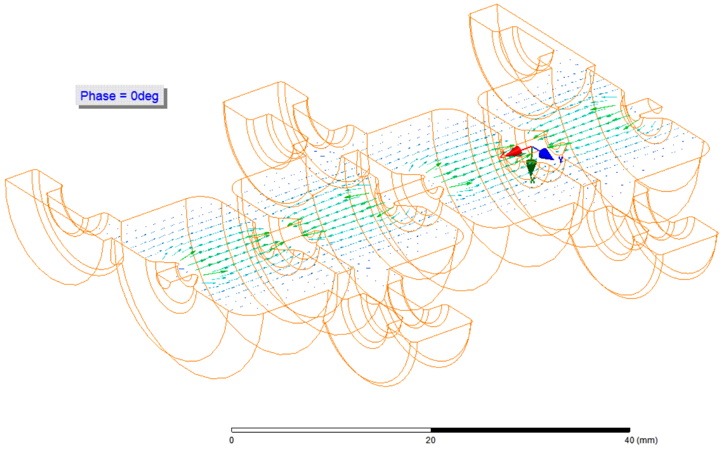
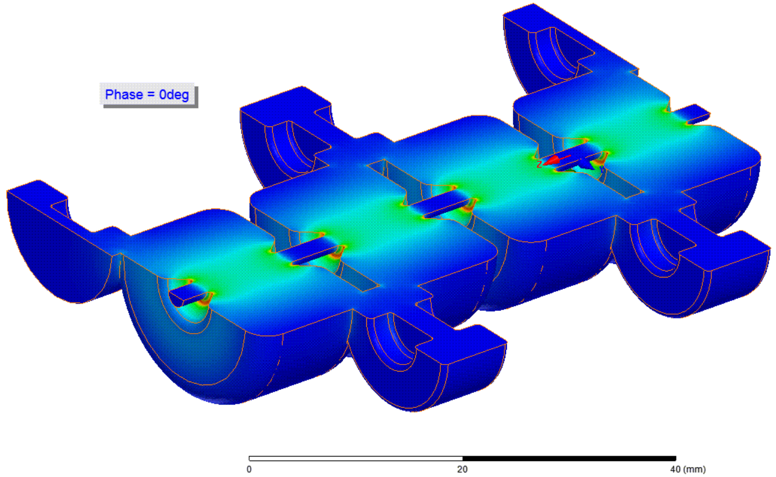
1. Introduction of high efficiency traveling wave accelerating structure
2. Advantages of the new structure
3. Concept of the new accelerating structure
4. Concept of high efficiency linac with pulse-to-pulse changeable energy
5. Parameters of the linac
6. Beam dynamics in the buncher
7. Verification of fields in complete accelerating structure
8. Scattering parameters
9. Mechanical Design
10. Manufacturing
11. Concept of high-power test in Arizona State University
12. Summary

Introduction of High Efficiency Traveling Wave Accelerating Structure with RF Power Flow Outside Accelerating Cavities

Side-Coupled Standing Wave Accelerating Structure

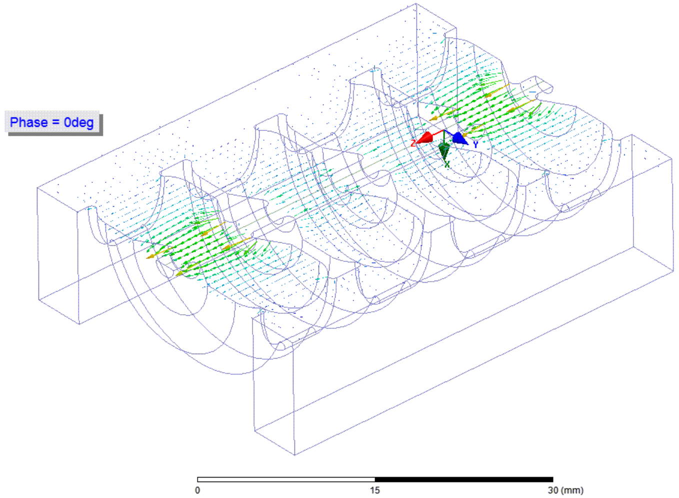


Vector plot of electric fields

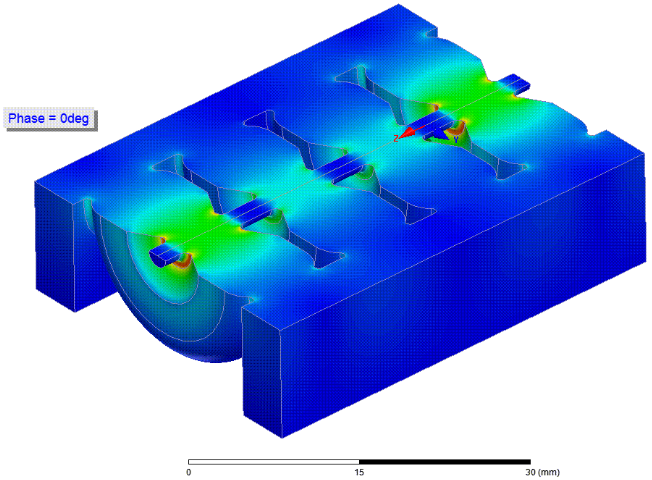


Surface electric fields

New Traveling Wave Accelerating Structure



Vector plot of electric fields



Surface electric fields

Advantages of new traveling wave structure

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Advantages over side-coupled standing wave structures

- No transverse fields kicking the beam off axis.
- The beam loading does not increase wall losses.
- No need in expensive and lossy circulator.

Advantages over parallel coupled standing wave structures

- No transverse fields kicking the beam off axis.
- No need for circulator or isolating waveguide circuit.

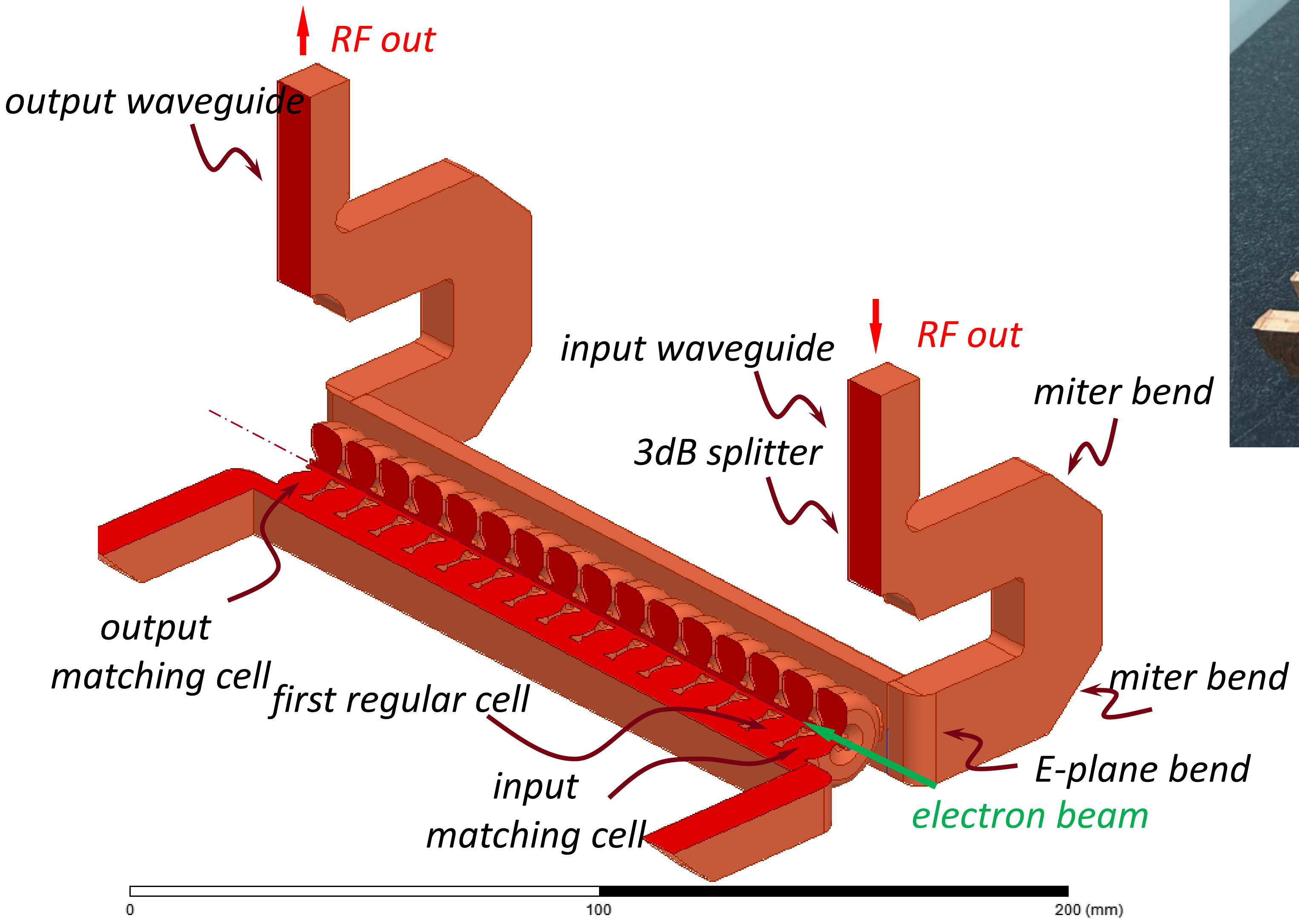
Advantages over on-axis coupled traveling wave structures

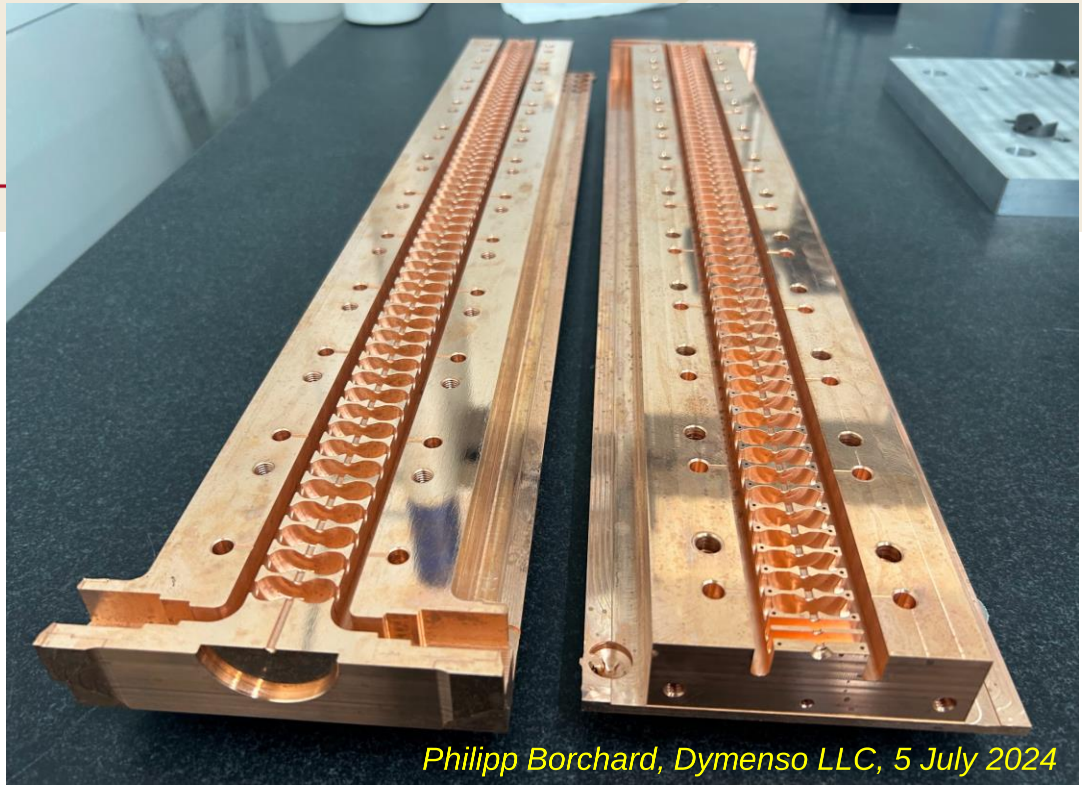
- Shunt impedance could be increases with nosecones without effecting coupling between cells.

Potential for improved RF breakdowns performance

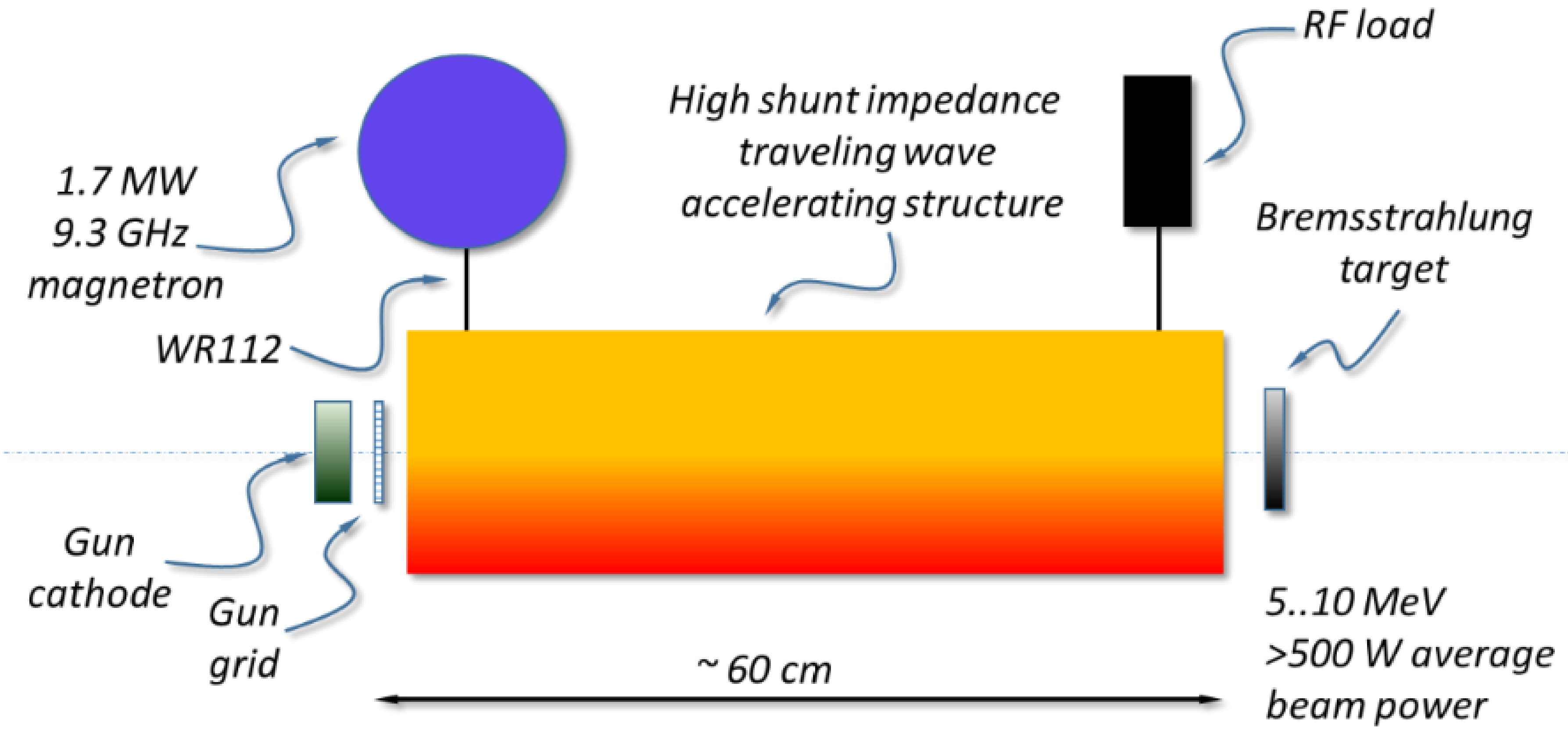
- *vs. TW and side-coupled SW:* limiting power flow to the breakdown.
- *vs. SW:* For same gradient, smaller stored energy in each cell.

Implementation Concept





Concept of High Efficiency 9.3 GHz Linac With Pulse-to-pulse Changeable Energy

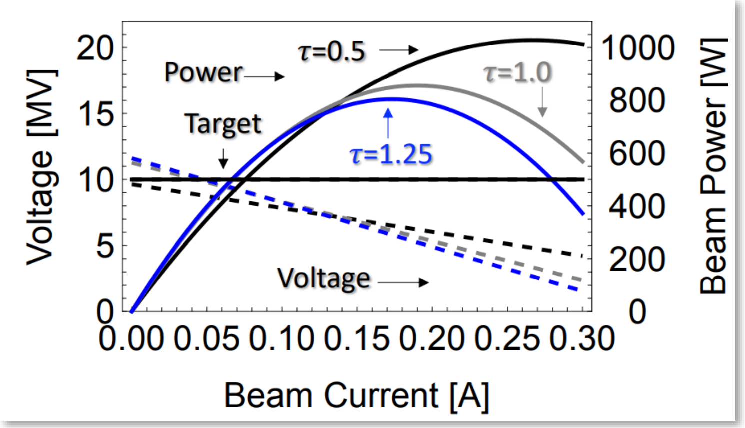


A schematic of a compact X-band linac with tunable output energy based on the high shunt impedance travelling wave accelerating structure. The linac does not need a circulator to protect magnetron. Output beam energy is changed by changing beam-loaded gradient.

Parameters of high efficiency linac with pulse-to-pulse tunable energy

Target Requirements

Metric	Requirements
Energy Tuning Range	<5 MeV...10 MeV
Output average beam power at 10 MeV	>500 W
Maximum cavity size	10x10x60cm
Target capital cost	< 1 M$
Other Design Features	
Travelling wave accelerating structure with outside power flow	
No circulator	
Duty factor	0.08%
Frequency	9.3 GHz



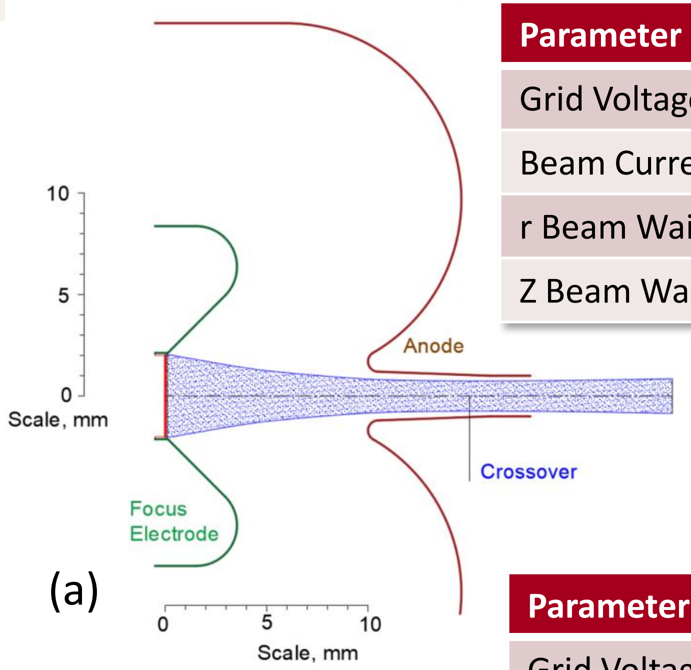
Analytical model: The net voltage gain (dashed curves) and average beam power (solid curves) for the constant gradient structure with length of 60 cm.

Analytical model: Accelerating Structure and Linac Parameters

Parameter	Value
Operating frequency	9.3 GHz
Qo	6800
Average Shunt Impedance	144 MOhm/m
Phase Advance per Cell	120 deg.
Beta = 1 Cell length [mm]	10.745 mm
Structure type	**Constant Gradient**
Linac length, L [cm]	60
Attenuation parameter, τ	1.0
Group Velocity, % the speed of light	2 …0.3
Beam current at 5 MeV	200 mA
Beam current at 10 MeV	70 mA
Average beam power at 5 MeV	800 W
Average beam power at 10 MeV	500 W

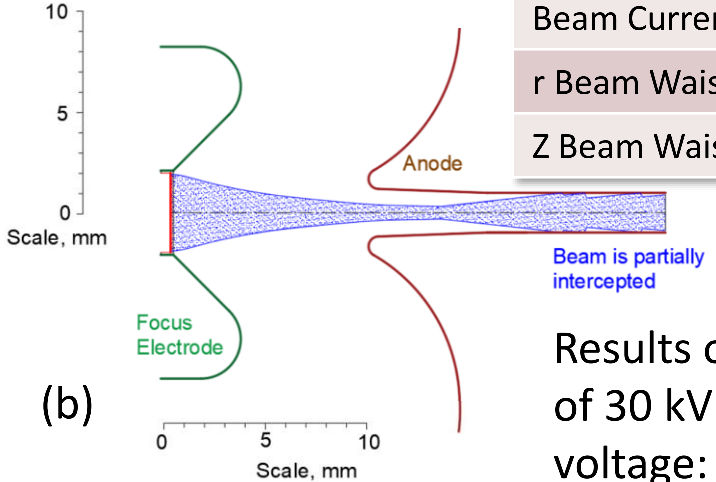
A. E. Romero and V. A. Dolgashev, High Efficiency Travelling Wave X-Band Linac With Tunable Output Energy, SLAC-PUB-17681, June 2022.

Beam Dynamics in Gridded Gun



(a)

Parameter	Value
Grid Voltage	60 V
Beam Current	500 mA
r Beam Waist	0.74 mm
Z Beam Waist	15 mm

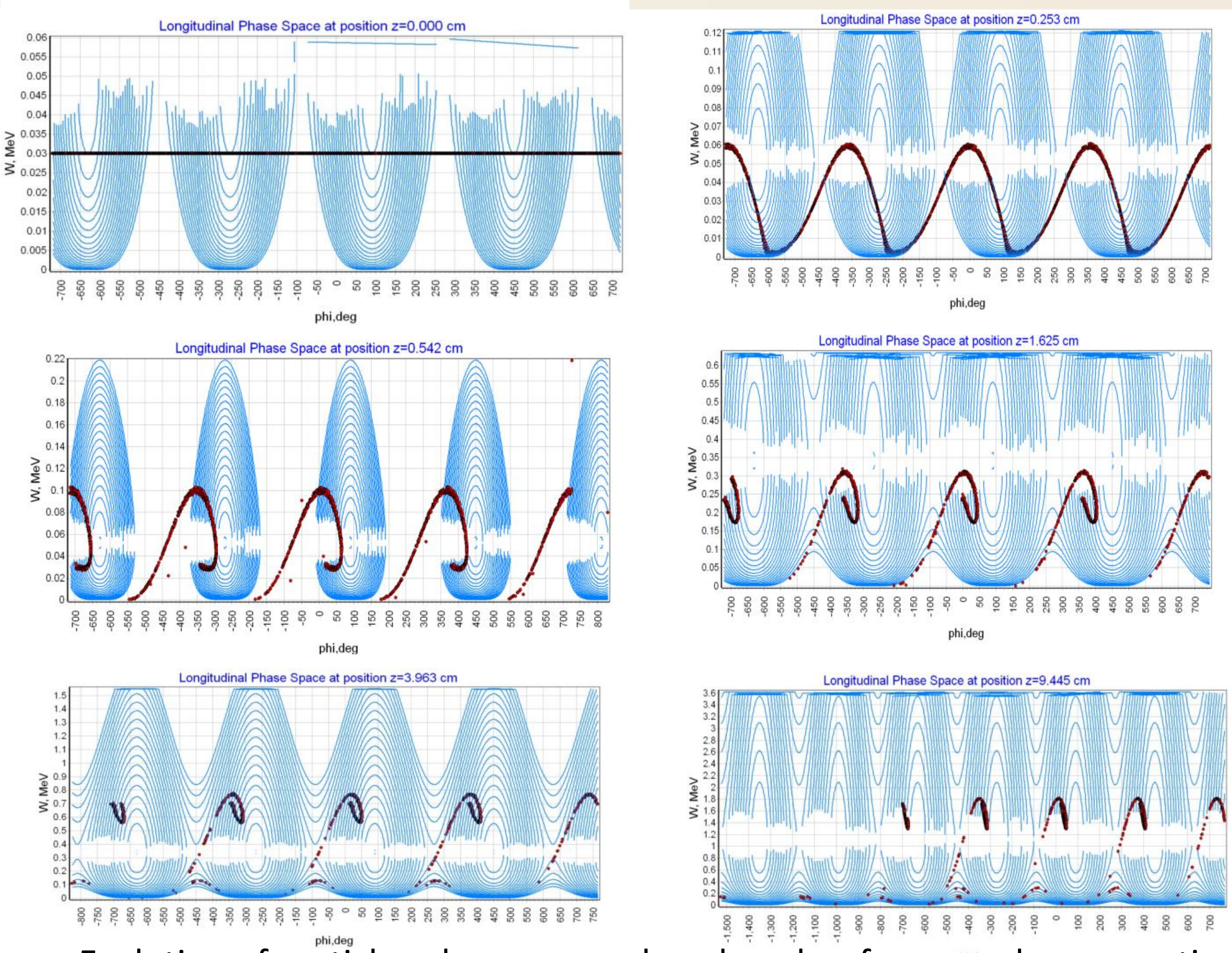


(b)

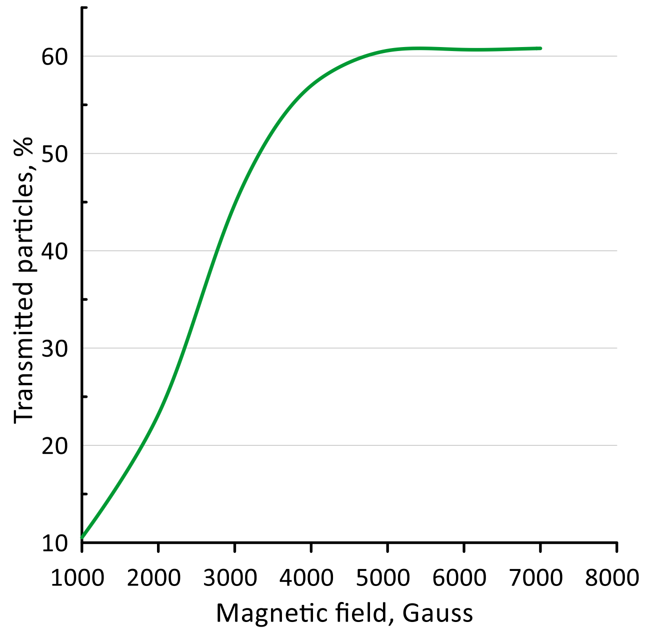
Parameter	Value
Grid Voltage	35 V
Beam Current	120 mA
r Beam Waist	0.34 mm
Z Beam Waist	13 mm

Results of beam dynamics simulations of 30 kV triode gun for different grid voltage: a) 60 V; b) 35 V.

Beam Dynamics in the Buncher



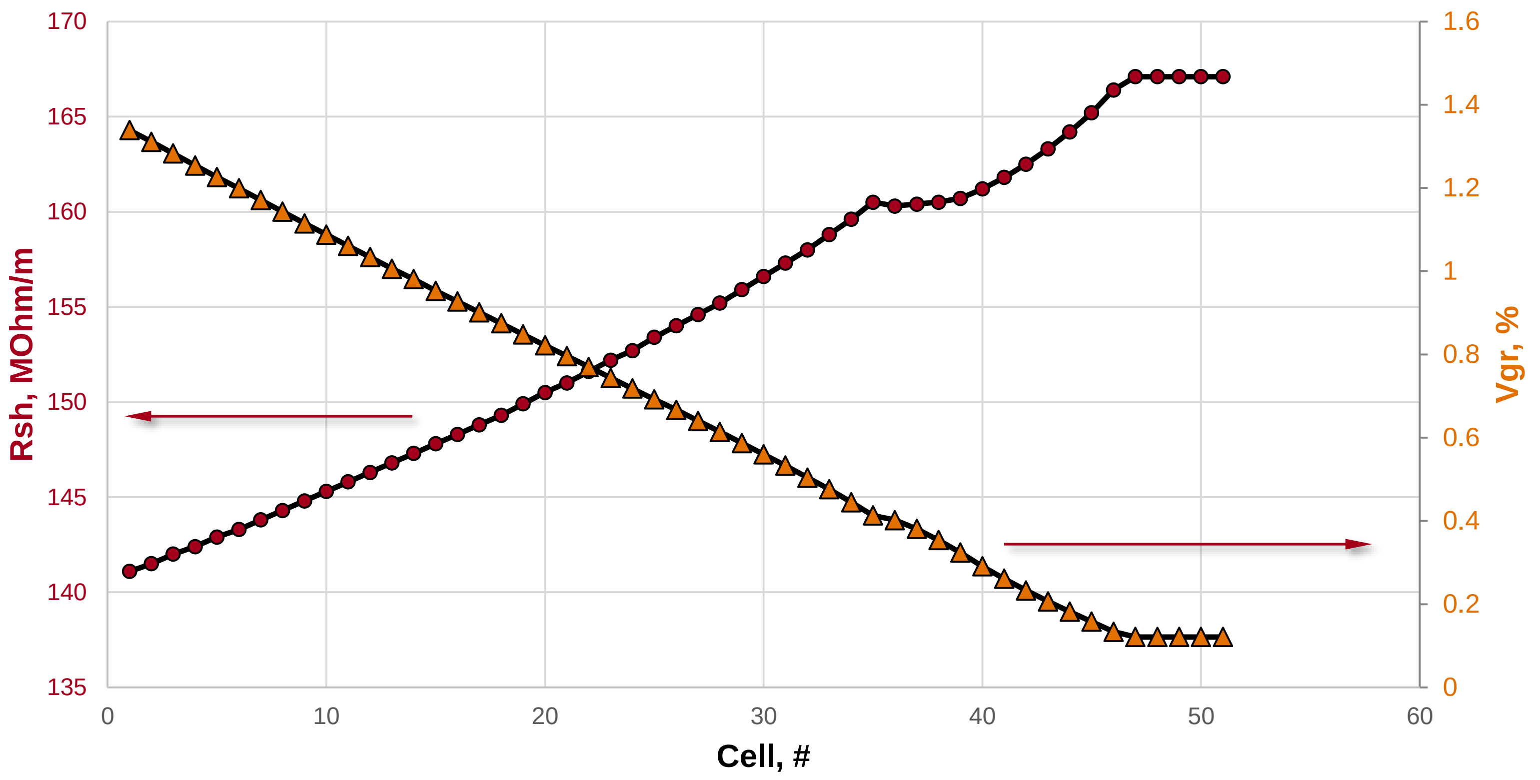
Evolution of particles phase space along buncher for several cross-sections simulated by Sergei Kutsaev's Hellweg 2D.



Percentage of transmitted particles through the buncher *vs.* focusing magnetic field.

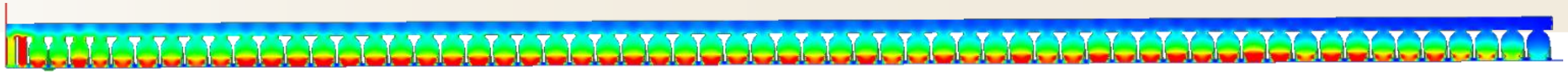
Sergey V. Kutsaev, "*Electron dynamics simulations with Hellweg 2D code*," NIM A, Volume 618, Issues 1–3, 1–21 June 2010

Parameters of Constant Gradient Traveling Wave Structure

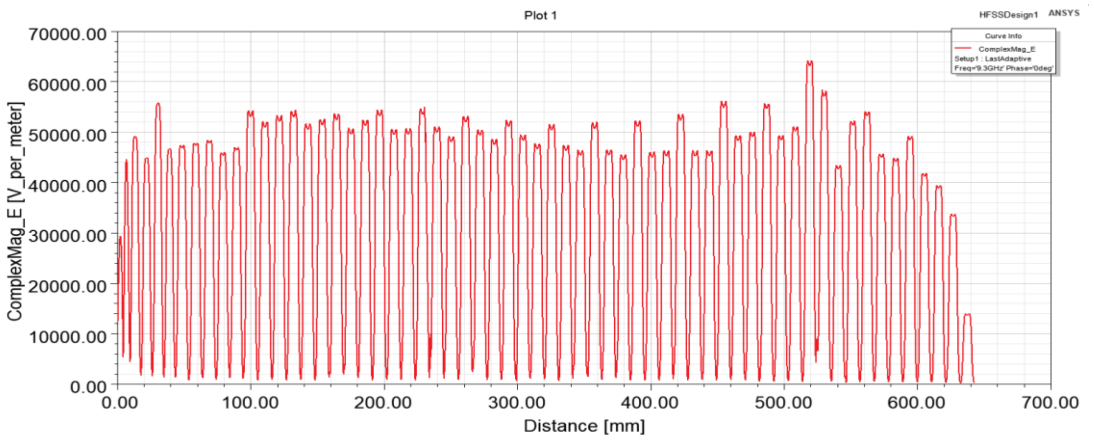


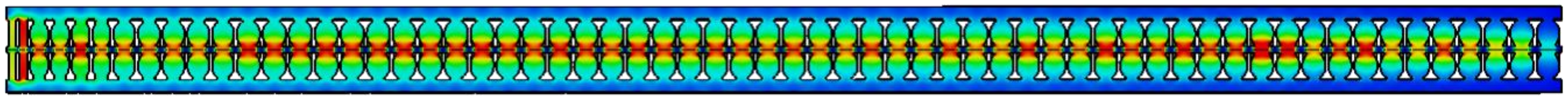
Shunt impedance and group velocity plot of beta=1 portion of the linac

Verification of Fields in Complete Accelerating Structure

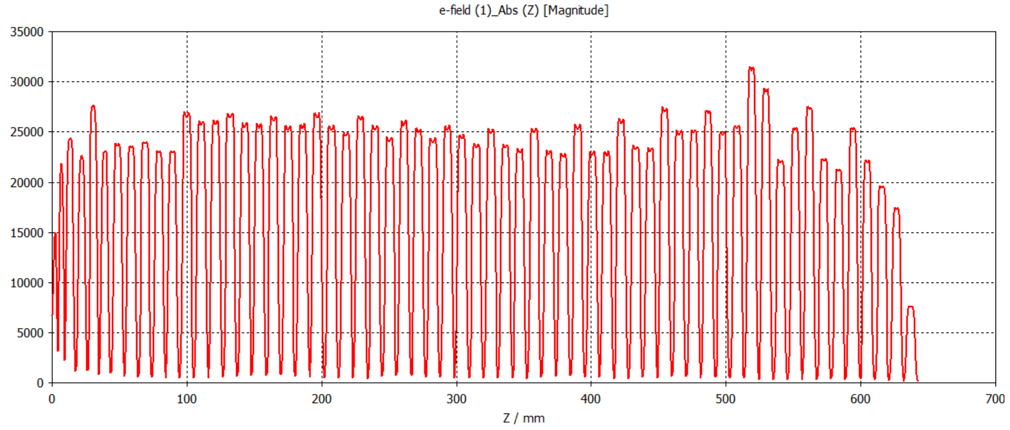


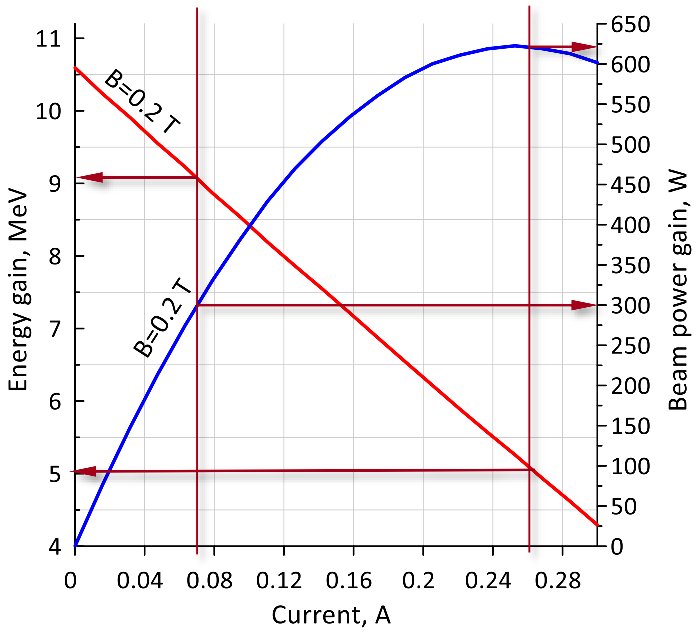
Contour plot and on-axis plot of Electric field in the full structure calculated by HFSS.





Contour plot and on-axis plot of Electric field in the full structure calculated by CST Microwave Studio.

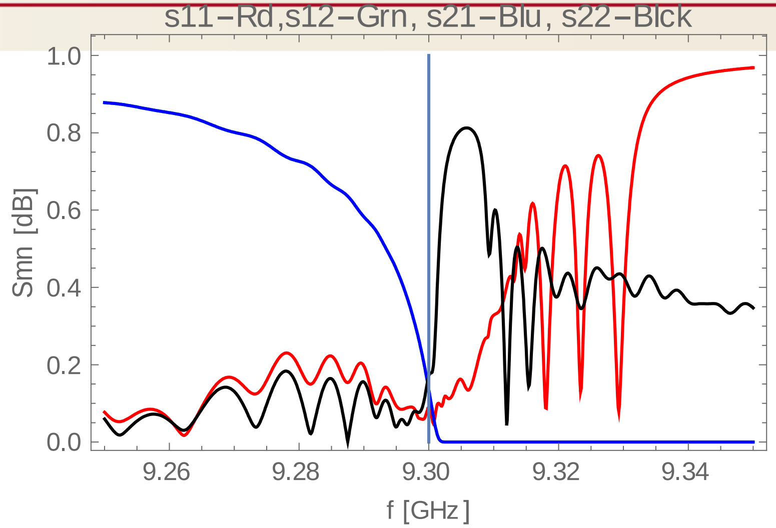




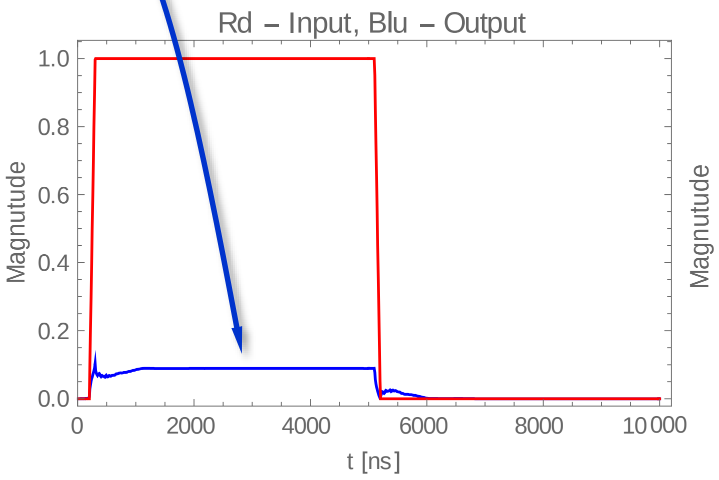
Energy gain (red curves) and beam power (blue curves) for U_g=30 V, nominal current 196 mA gun) vs current for magnetic field 0.2 T as calculated by Hellweg 2D

Scattering Parameters of the Constant Gradient Accelerating Structure

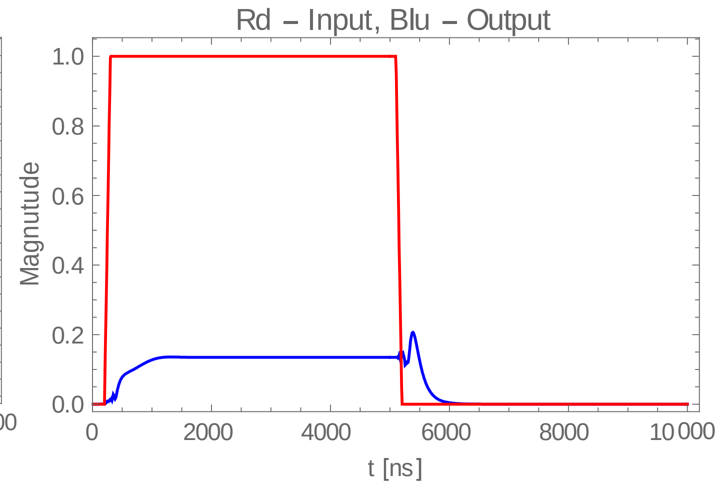
Less than 1% of input rf power reflected back to magnetron



S-parameters of the linac calculated by CST microwave studio



Expected reflected rf pulse

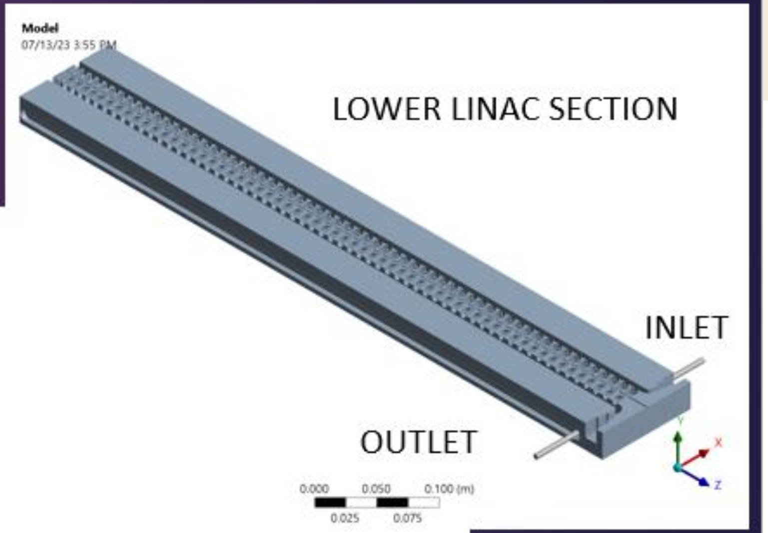


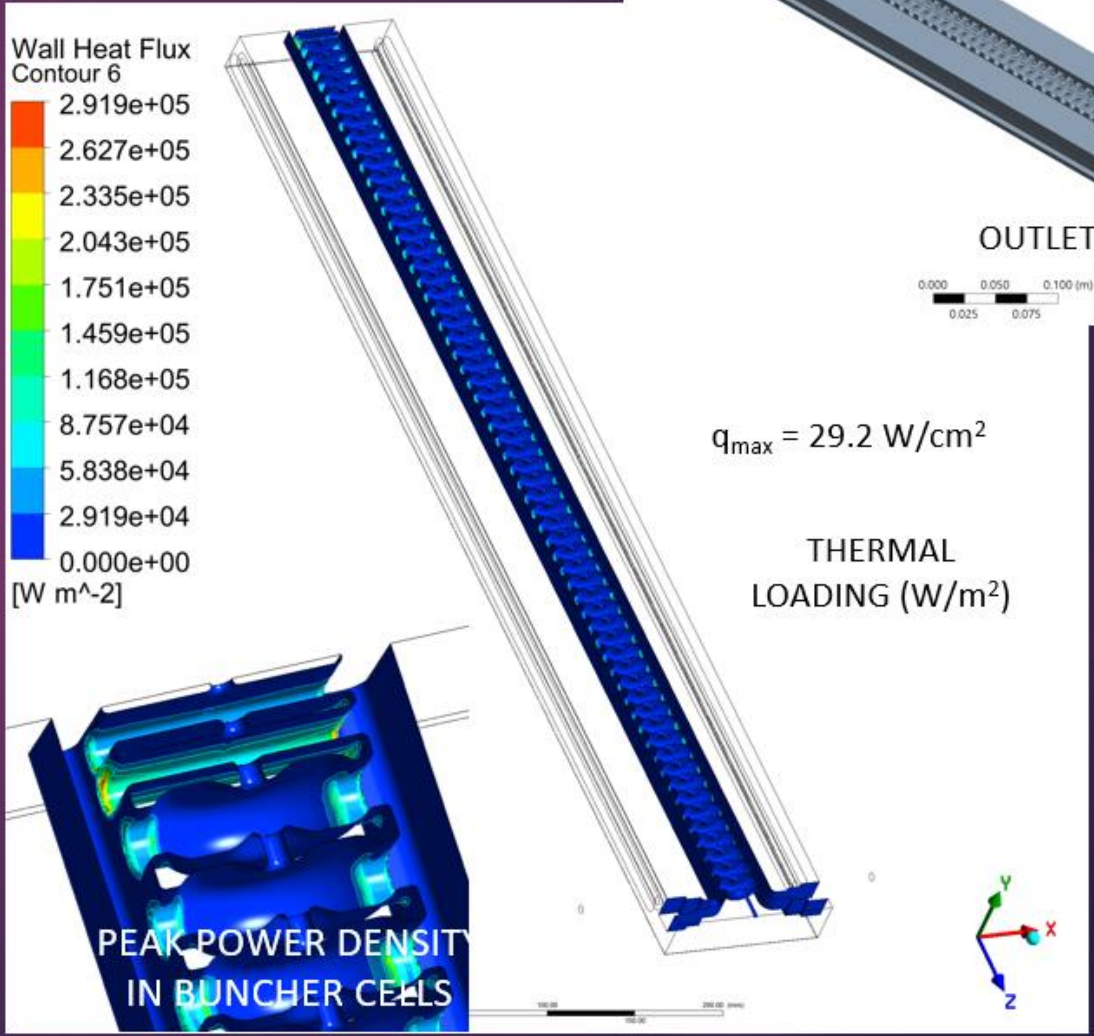
Expected transmitted rf pulse

TERMAL ANALYSES

- CFD THERMAL SIMULATION (ANSYS FLUENT)
- TRANSIENT THERMAL SIMULATION (ANSYS MECHANICAL)
- STRUCTURAL SIMULATION (ANSYS MECHANICAL)

Peak power (MW)	1.7
Duty factor	0.08%
Ave. power loss per half (W)	680
Inlet temp. (°C)	30
Flow rate per half (GPM)	1

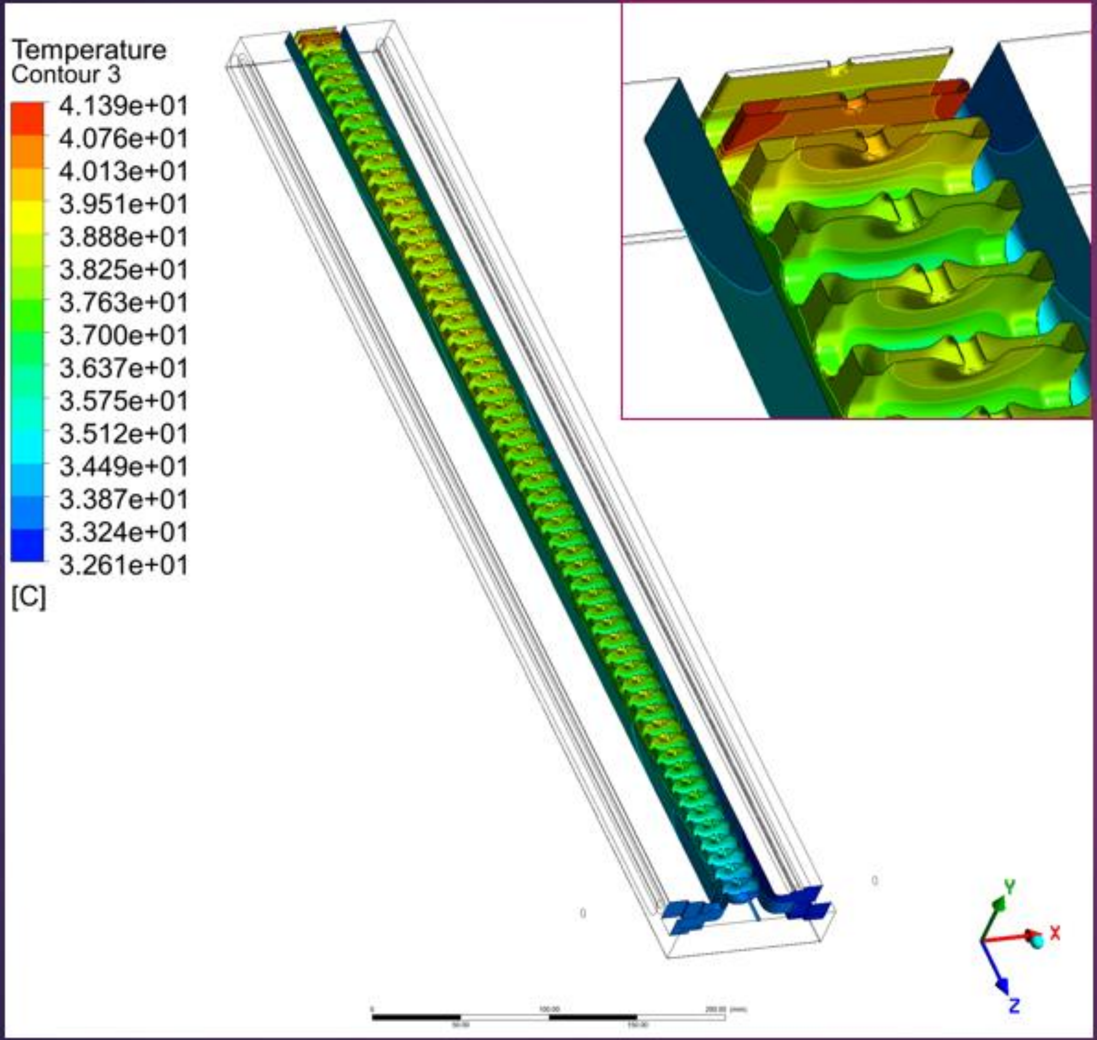




CFD THERMAL RESULTS

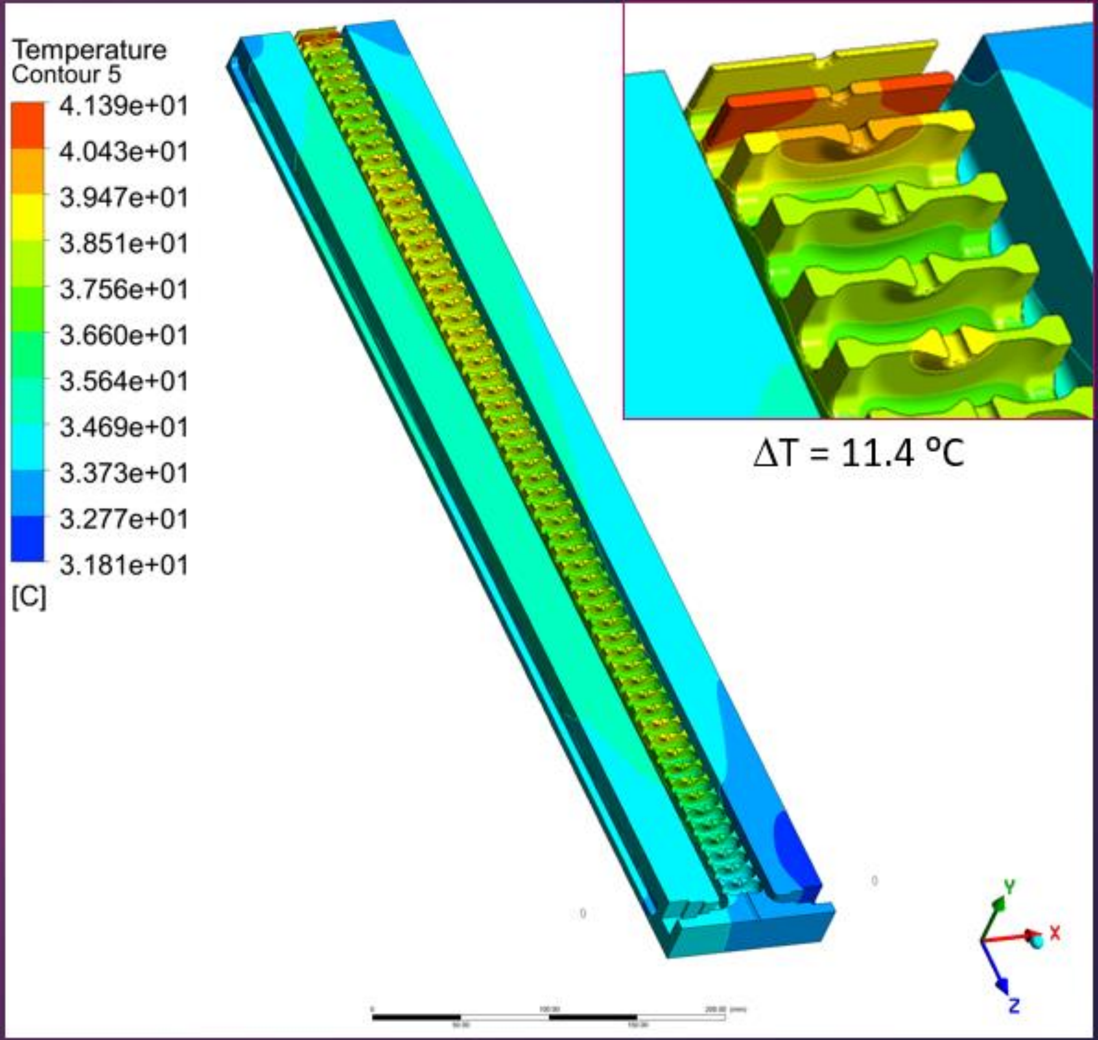
DYMENSO

Inlet temp. (°C)	30
Flow rate per half (GPM)	1



TEMPERATURE, VACUUM WALL

T_{max} = 41.4 °C

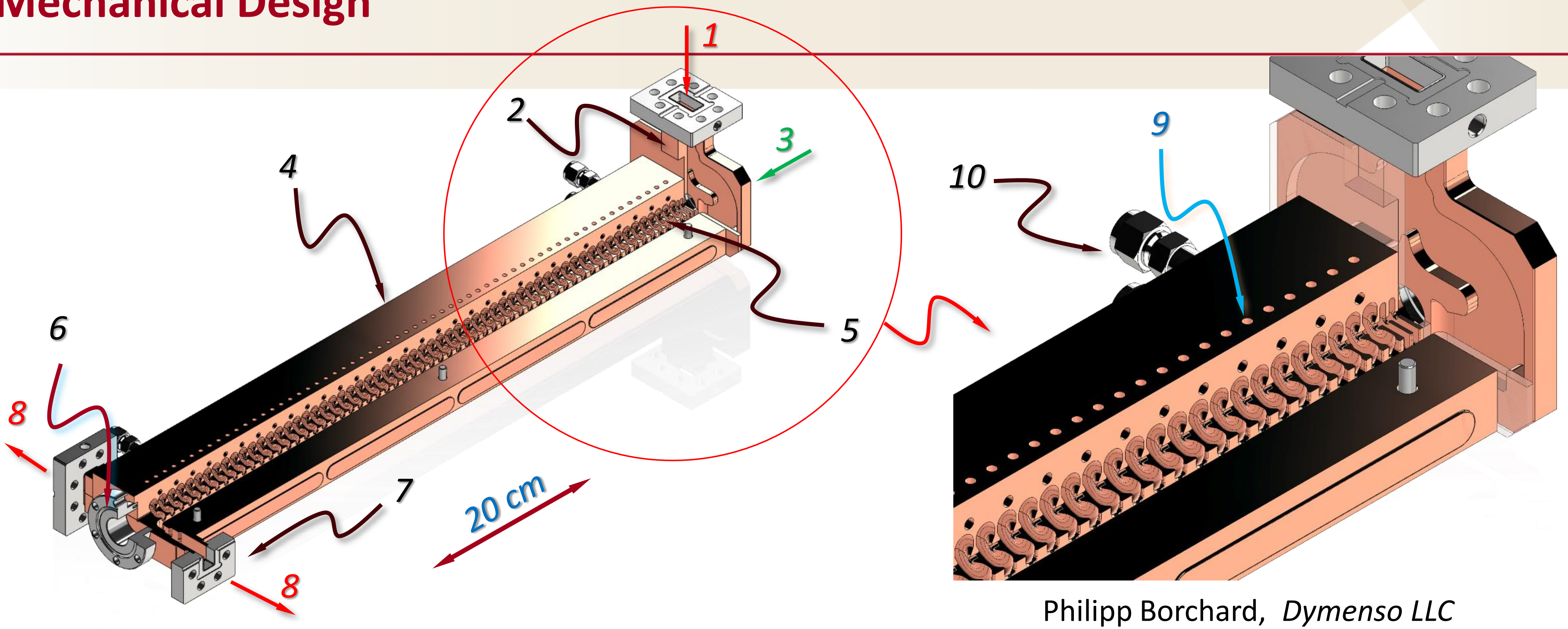


ΔT = 11.4 °C

TEMPERATURE

T_{max} = 41.4 °C

Mechanical Design

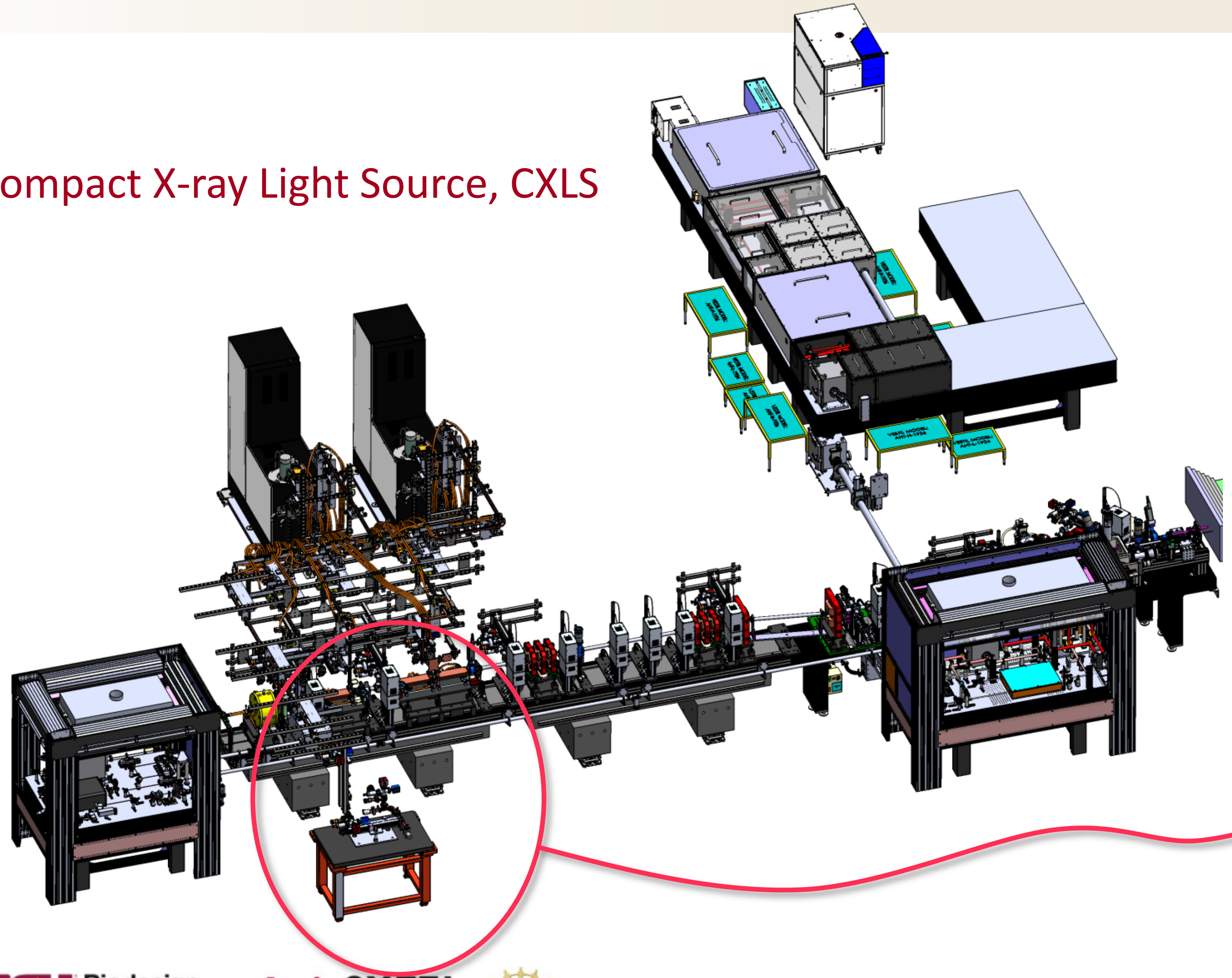


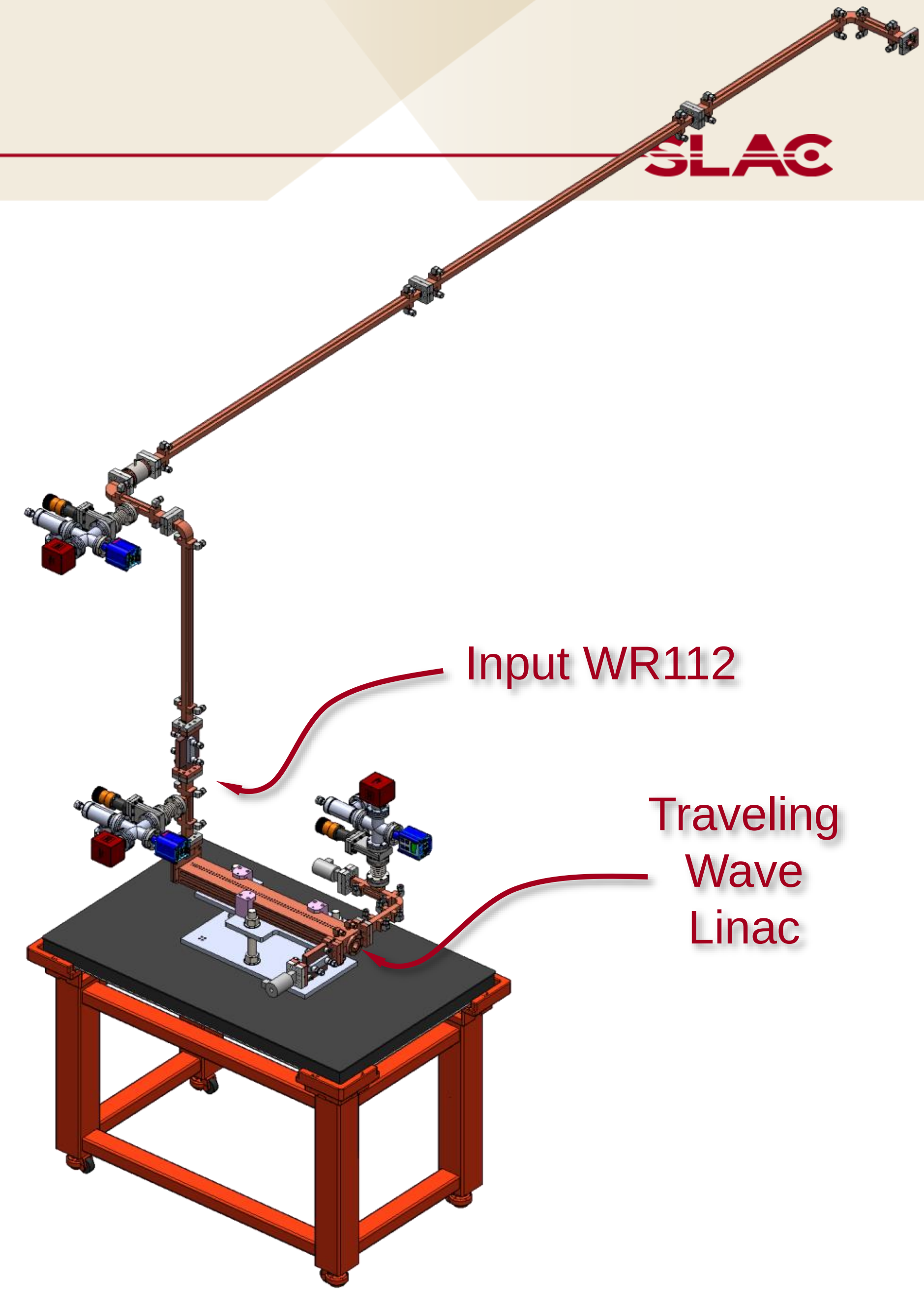
Philipp Borchard, *Dymenso LLC*

Solid model of high efficiency traveling wave accelerating structure. Upper left part is cut to show internal geometry. This is 9.3 GHz, 2π/3 phase advance structure. Notation as follows: 1 – input RF power, WR112 port; 2 – input waveguide splitter; 3 - direction of electron beam; 4 – β = 1 section of the accelerating structure; 5 – low β section for beam bunching; 6 - output beam pipe, future location of X-ray target; 7 – output waveguide; 8 – transmitted RF power, two WR112 ports; 9 - tuning pin; 10 – fitting for water cooling.

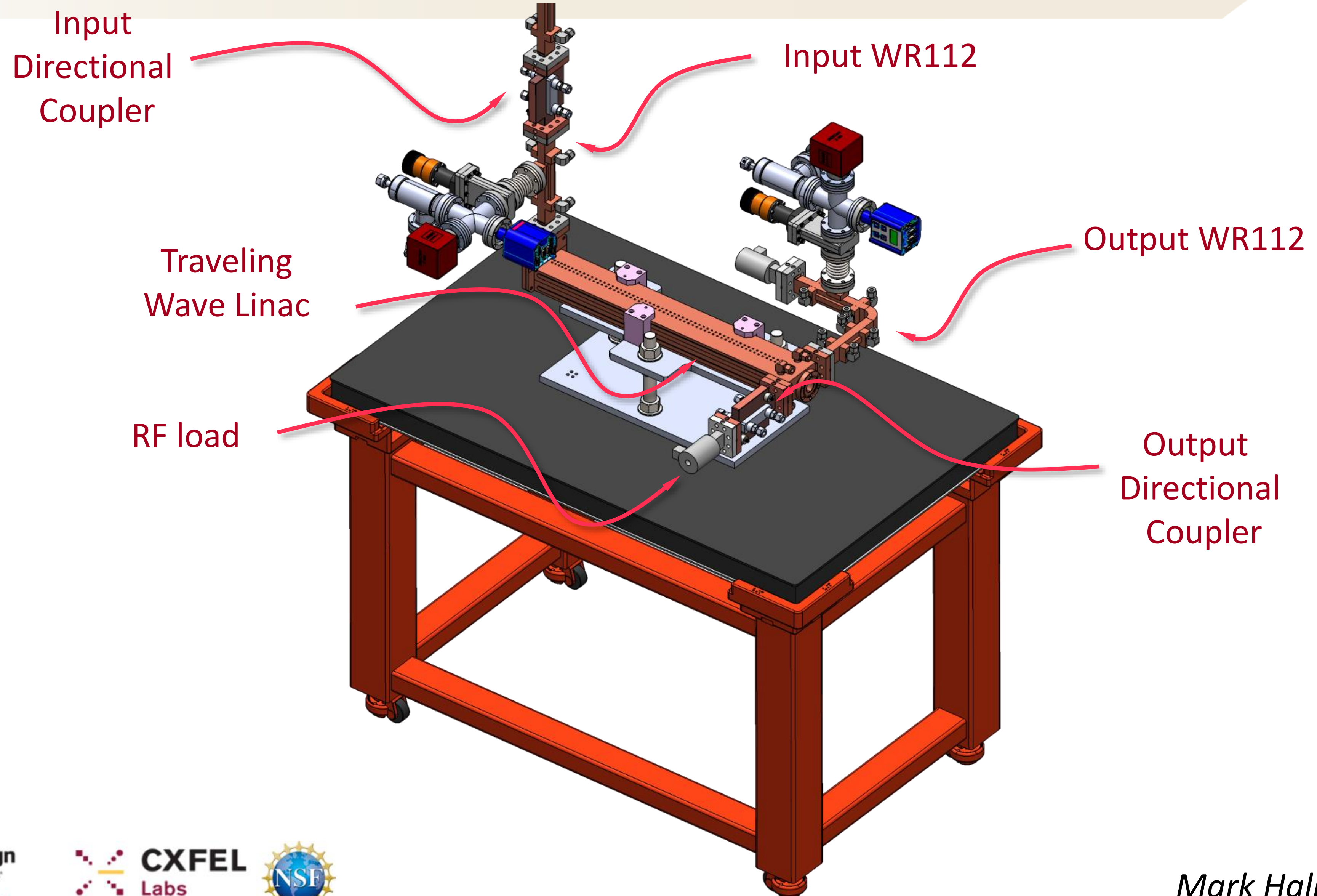
Concept of High-Power Test in Arizona State University

Compact X-ray Light Source, CXLS

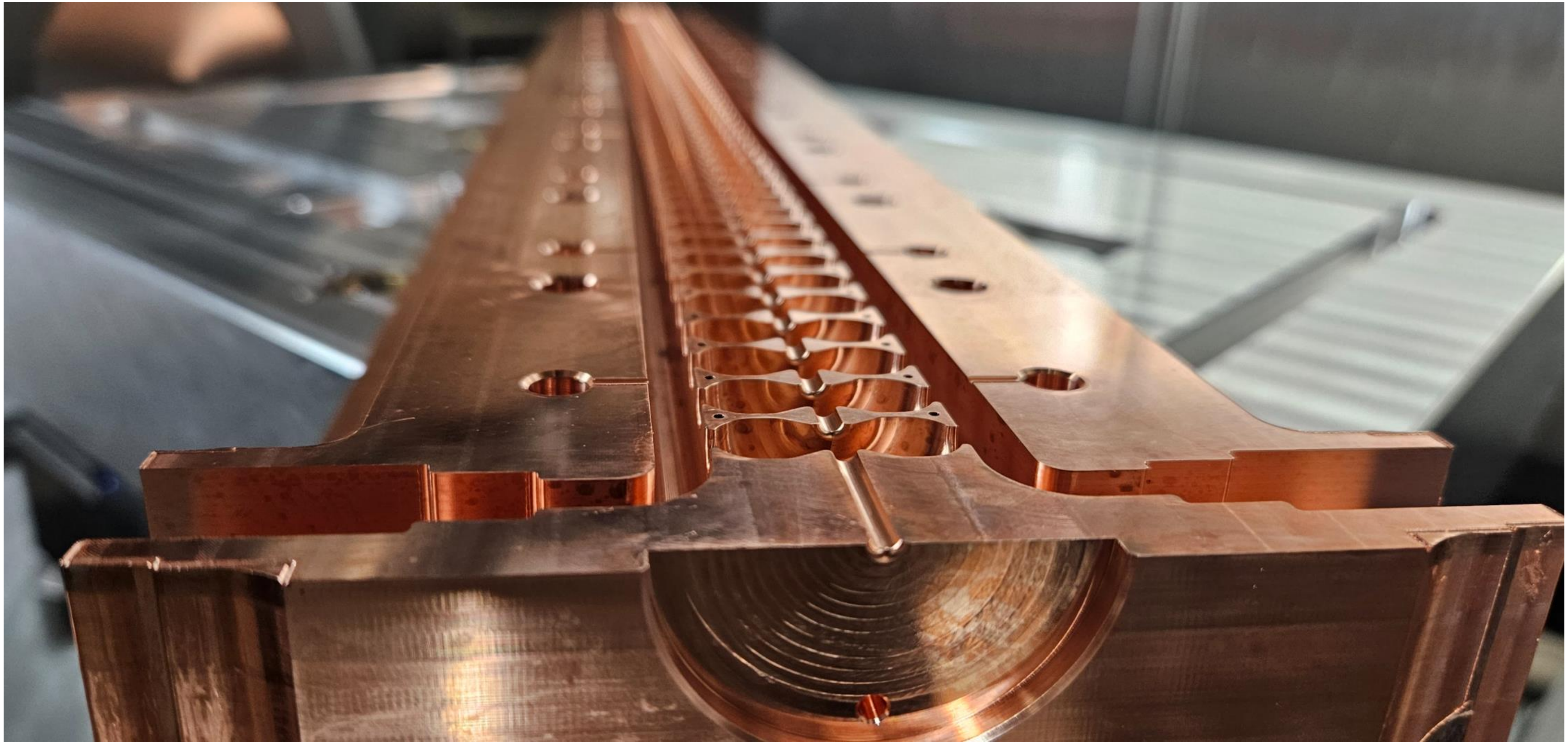




Concept of High-Power Test in Arizona State University

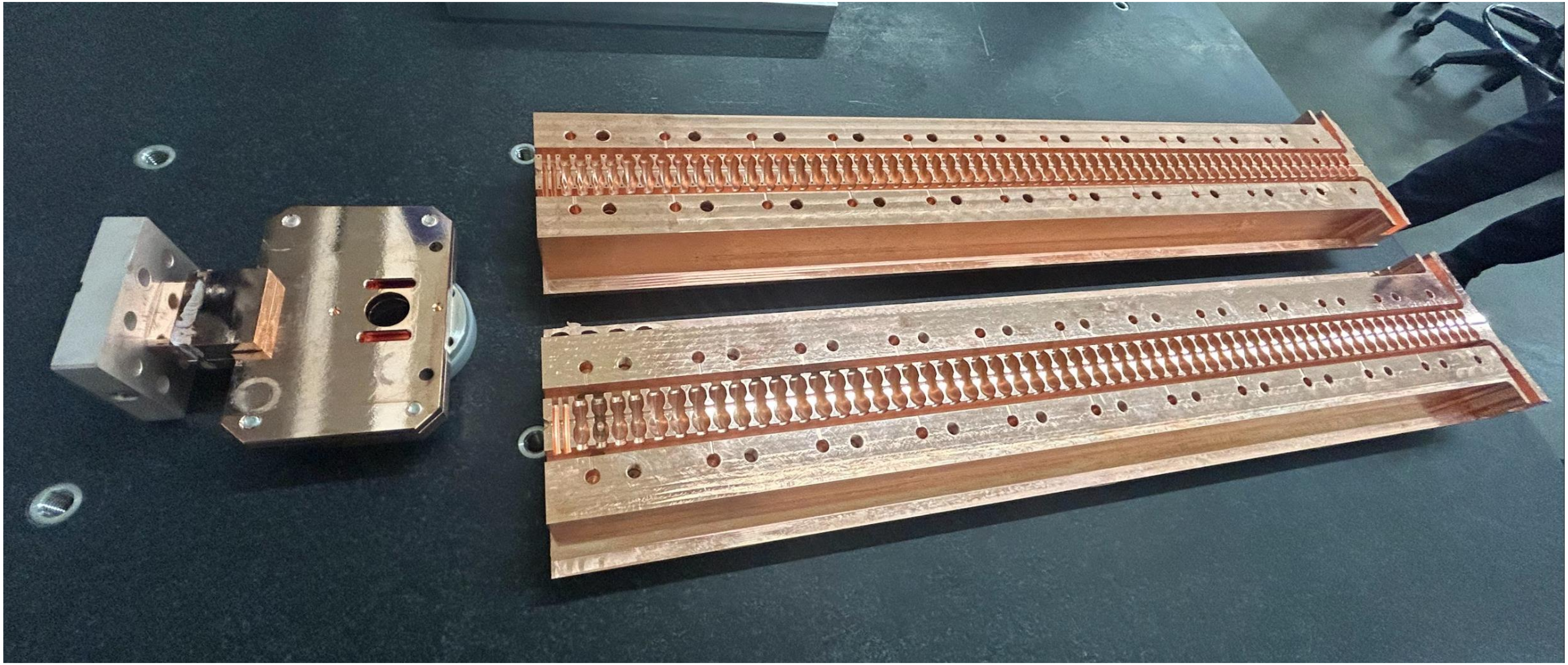


Accelerating structure manufacturing



Output side of one half of the linac

Accelerating structure manufacturing



Two halves and input coupler assembly

Accelerating structure manufacturing

Two halves, input coupler assembly, and cooling pipe covers

Philipp Borchard, Dymenso LLC, 5 July 2024

Summary

SLAC

1. We have designed 10 MeV, 500 W linac linacs with pulse-to-pulse changeable energy
2. Manufacturing of the linac is ongoing
3. We are developing tuning procedure
4. We plan high power test at Arizona State University before end of this year