DESIGN OF A W-BAND CORRUGATED WAVEGUIDE FOR STRUCTURE WAKEFIELD ACCELERATION

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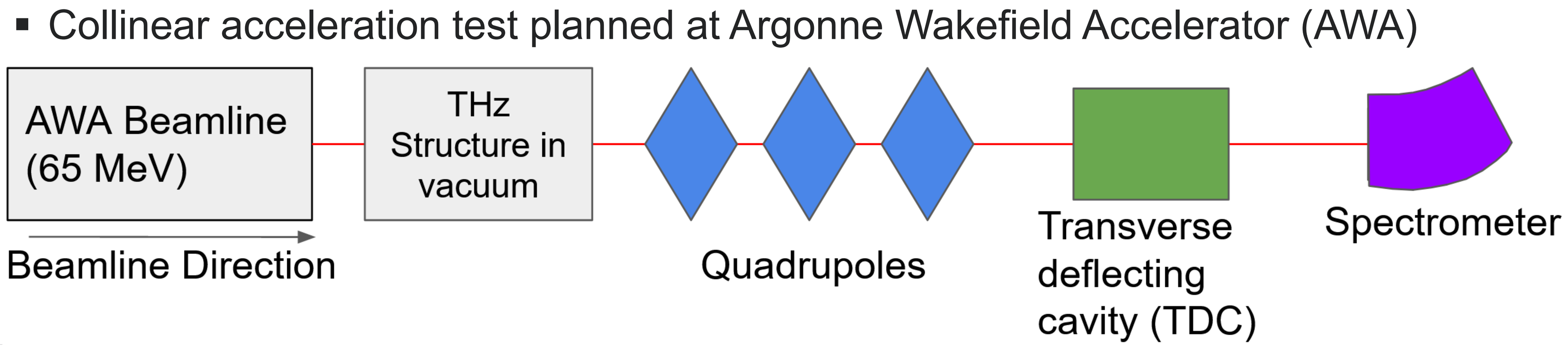
ABSTRACT

- **Structure Wakefield Acceleration (SWFA)** in the **terahertz (THz) regime:**
  - Aims to provide high-gradient high-efficiency acceleration
  - Enables more compact and cost-effective accelerators
- A **W-band corrugated waveguide** has been designed for a collinear wakefield acceleration experiment at the Argonne Wakefield Accelerator (**AWA**)
  - Structure optimized for maximum gradient for the nominal AWA electron bunch at 65 MeV
- Analytical theory and simulations show good agreement
  - **Accelerating gradient of 84.6 MV/m** achieved with a 10 nC Gaussian bunch

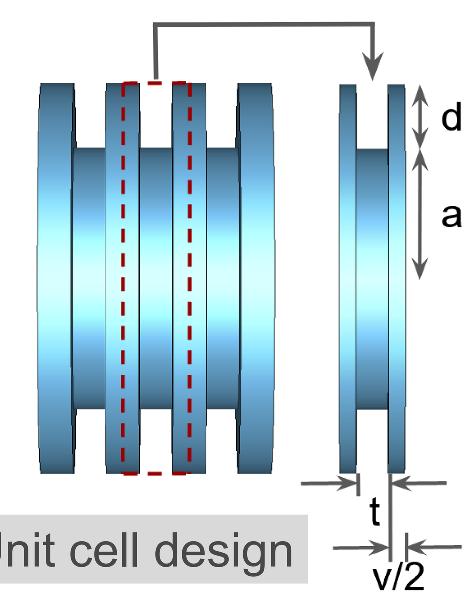
INTRODUCTION

- Advantages of THz structures for SWFA combined with bunch shaping techniques[1]:
  - **High gradient**:
    - High shunt impedance => Stronger beam interaction
    - High frequency structure with short RF pulse => Lower breakdown rate[2]
  - **High efficiency**:
    - Longitudinal bunch shaping => transformer ratio (acc. gradient over dec. gradient) past theoretical limit of 2 for symmetric bunches
  - **Compact** structure from small transverse size
- Collinear acceleration test planned at Argonne Wakefield Accelerator (AWA)



STRUCTURE DESIGN

- Unit cell design of the W-band corrugated waveguide in CST Eigenmode solver
  - High shunt impedance and high gradient

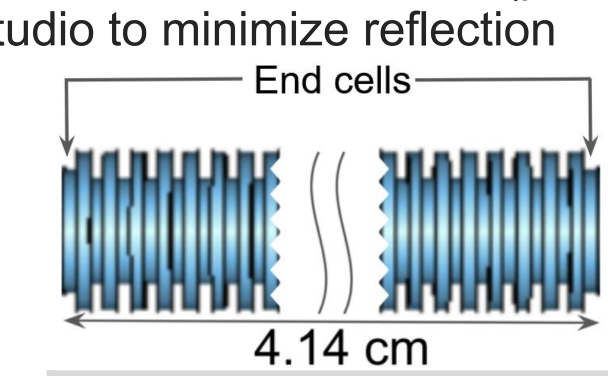


Unit cell design

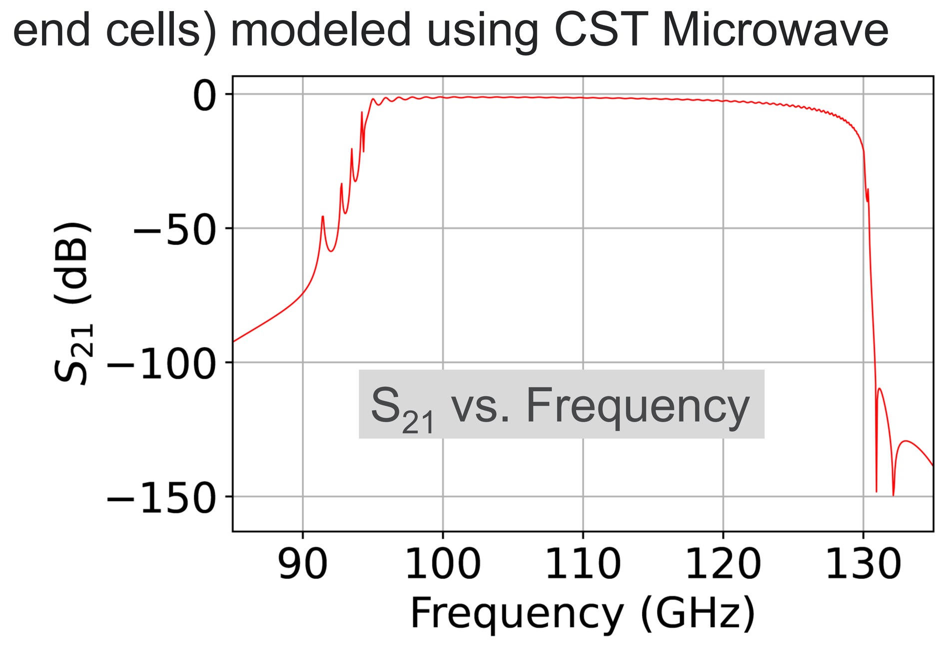
Unit cell design parameters

Aperture radius (a)	1.016 mm
Corrugation depth (d)	0.5 mm
Plate thickness 1 (t)	0.254 mm
Plate thickness 2 (v)	0.254 mm
Frequency (f)	110.2 GHz
r/Q	36.5 kΩ/m
Group Velocity (v_g)	0.261 c
Nominal AWA bunch charge (q)	10 nC
Bunch RMS length (σ)	0.5 mm
Accelerating gradient (E_z)	85.8 MV/m

- A full structure of 80 cells (plus two end cells) modeled using CST Microwave Studio to minimize reflection



Full structure with 80 cells plus two end cells

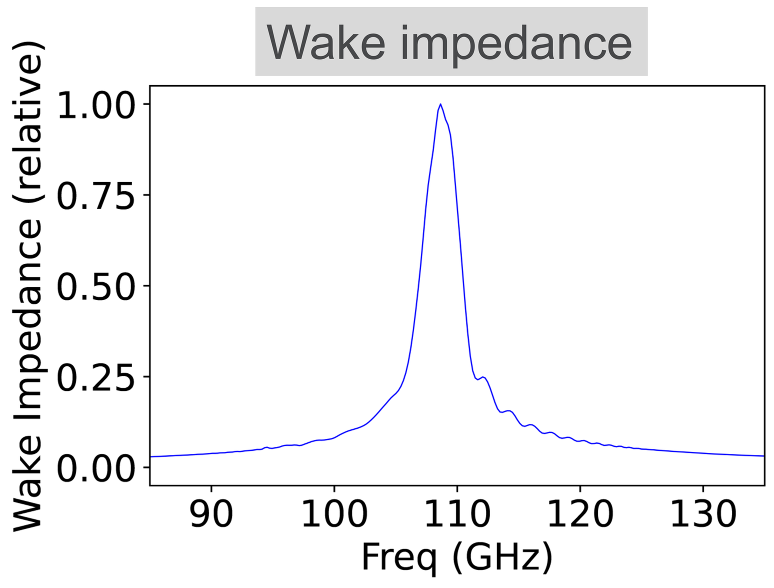


S_{21} vs. Frequency

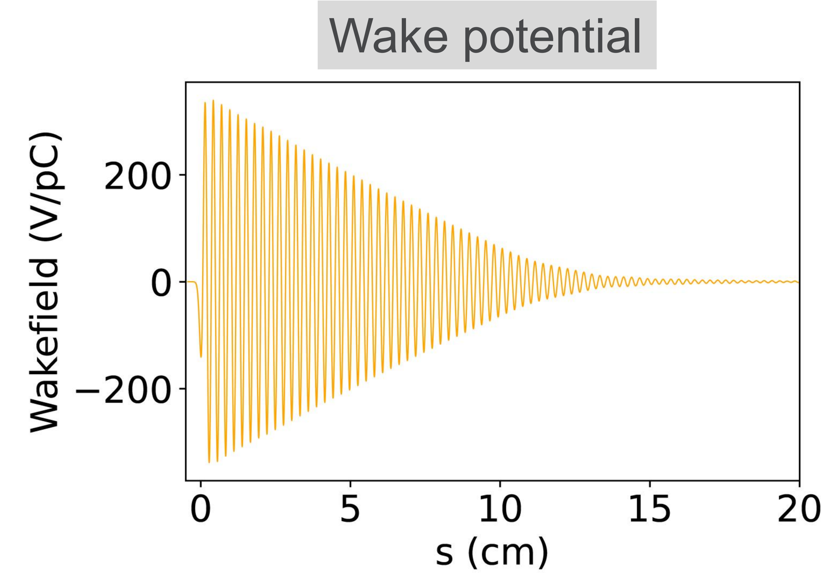
WAKEFIELD SIMULATIONS

- Wakefield excitation in the full structure simulated in CST Wakefield solver

Wake impedance

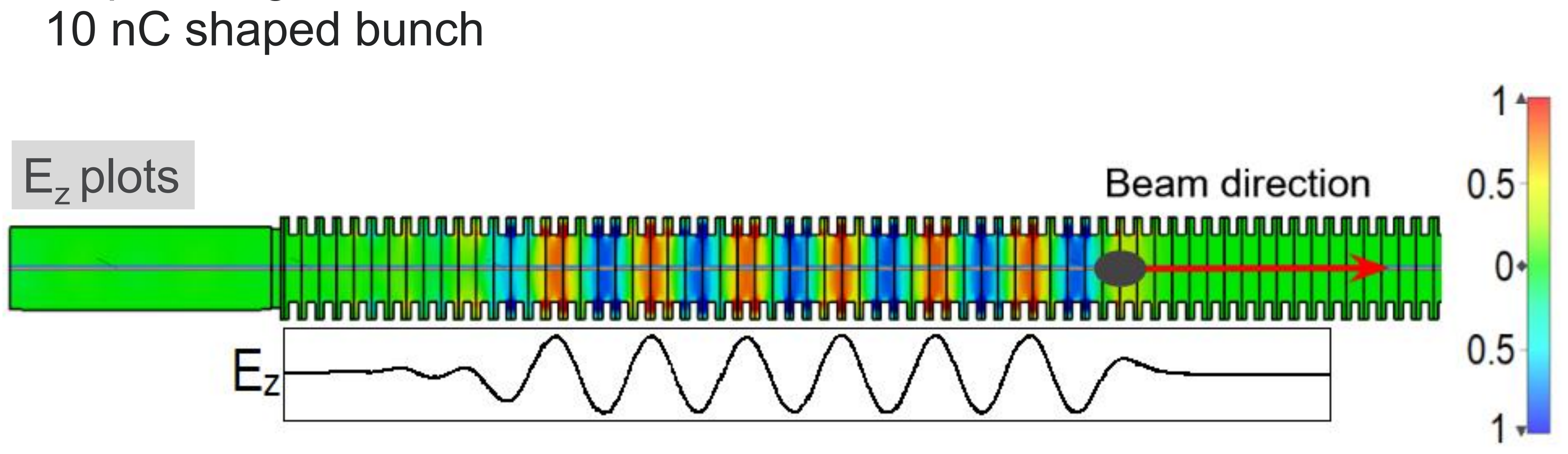


Wake potential



- Electric field plot with peak gradient of 84.6 MV/m on axis, when a 10 nC, 0.5 mm Gaussian electron bunch traverses the structure
- Future study: Gradient improvement with a shaped bunch
  - Expected gradient of ~200 MV/m with a transformer ratio of 5 from a 10 nC shaped bunch

E_z plots



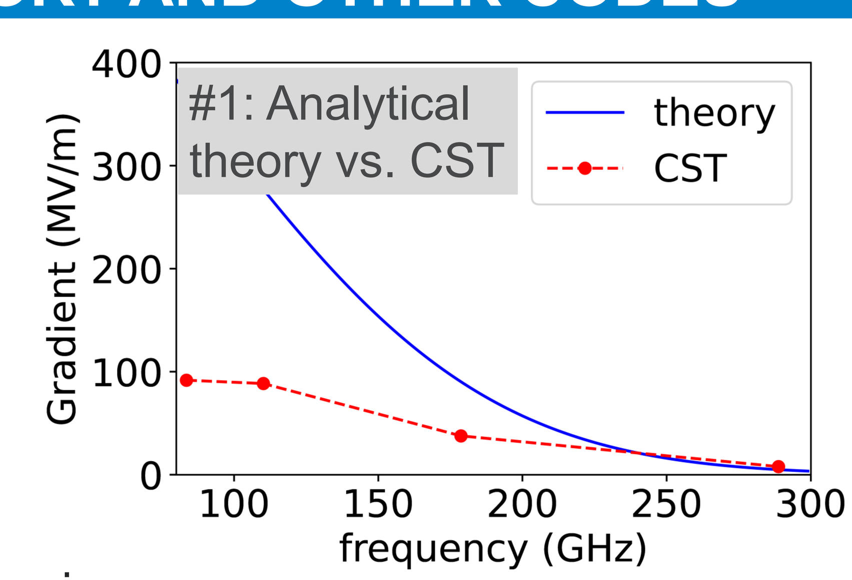
BENCHMARKING WITH THEORY AND OTHER CODES

- 3 types of benchmarking done
  - **#1: Analytical theory vs. CST**:
    - Analytical assumptions[3]:
      (1) $d, t+v \ll a$ and $d \gtrsim t+v$
      (2) Relativistic bunch
    - Analytical gradient calculated by

$$E_z = \frac{1}{4\pi\epsilon_0}\frac{2q}{a^2}e^{-\omega^2\sigma^2/2c^2}$$

    - Good agreement with CST at high frequencies

#1: Analytical theory vs. CST

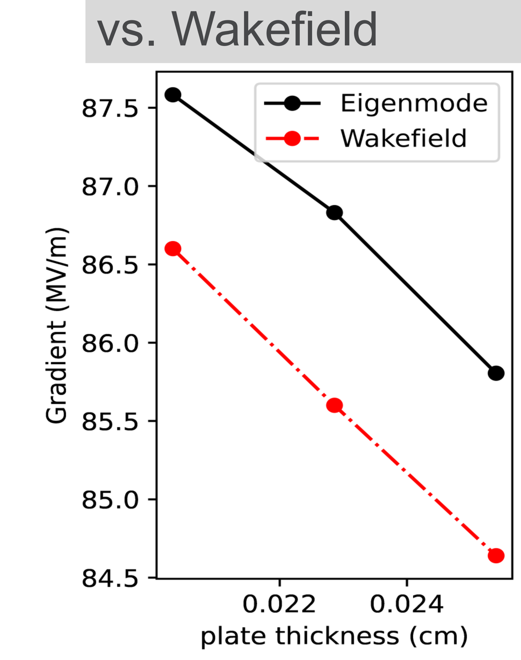


  - **#2: CST Eigenmode vs. Wakefield:**
    - Gradient calculated with unit cell parameters from Eigenmode as

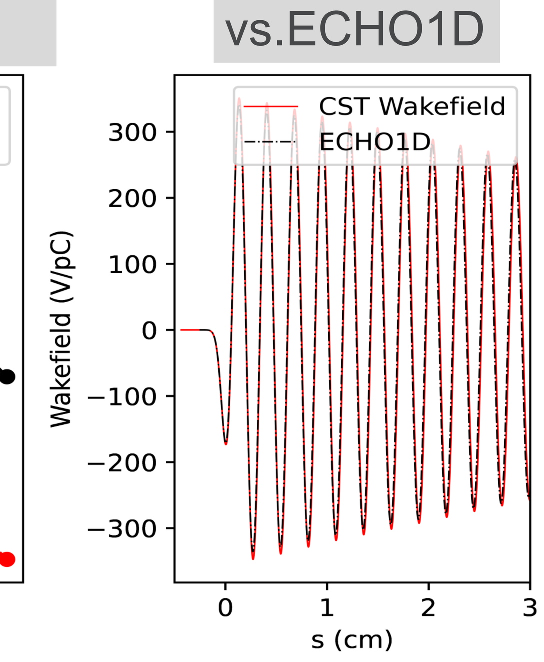
$$E_z = \frac{2qk_L}{1-\frac{v_g}{c}}e^{-\omega^2\sigma^2/2c^2}$$

    - Good agreement (~1.4% error)
  - **#3: CST and ECHO1D:**
    - Good agreement between CST and another wakefield calculation code, ECHO1D

#2: CST Eigenmode vs. Wakefield



#3: CST vs.ECHO1D



FUTURE PLANS

- Mechanical design and structure fabrication
  - Electroforming, wire-EDM, laser micromachining, additive manufacturing, etc.
- Experimental setup at AWA
- Application of advanced bunch shaping techniques

ACKNOWLEDGEMENTS

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CONCLUSIONS

- A W-band corrugated waveguide designed at 110 GHz for high-gradient high-efficiency wakefield acceleration
  - Accelerating gradient of 84.6 MV/m achieved with a 65 MeV Gaussian electron bunch of 10 nC and 0.5 mm long
  - Successful benchmarking between analytical theory and simulation codes, and between various codes
- Mechanical design and fabrication in progress
- Higher gradient expected with a longitudinally shaped bunch
- Collinear wakefield acceleration experiment planned for AWA with bunch shaping techniques to achieve high-gradient high-efficiency acceleration

REFERENCES

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