Simulation of a Passive LPS Synthesizer Concept Based on 3D-Printed Dielectric-lined Waveguides.

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Introduction

> Precise control over the longitudinal phase space (LPS) of electron bunches in accelerators can be of interest for example for bunch-compression
→ *Ideal case: Completely linear LPS for maximum compression*

> Here: A concept for a completely passive way to alter the LPS of a given e-bunch
→ *Arbitrary, pre-defined shapes can be achieved*
→ *Longitudinal Phase Space Synthesizer (LPSS)*

> The concept is based on 3D-printed dielectric-lined waveguides
→ *Cheap + rapid prototyping and production*

Other Concepts So Far

> Eric Hemsing and Doa Xiang,
Cascaded modulator-chicane modules for optical manipulation of relativistic electron beams,
PRSTAB, 16, 010706, 2013

> Active triple laser modulator + chicane + interleaved quadrupoles layout

> Works very well in simulation, but hard to implement (large scale, needs laser, etc.)

Dielectric-lined Waveguide (DLW) – Theory Primer

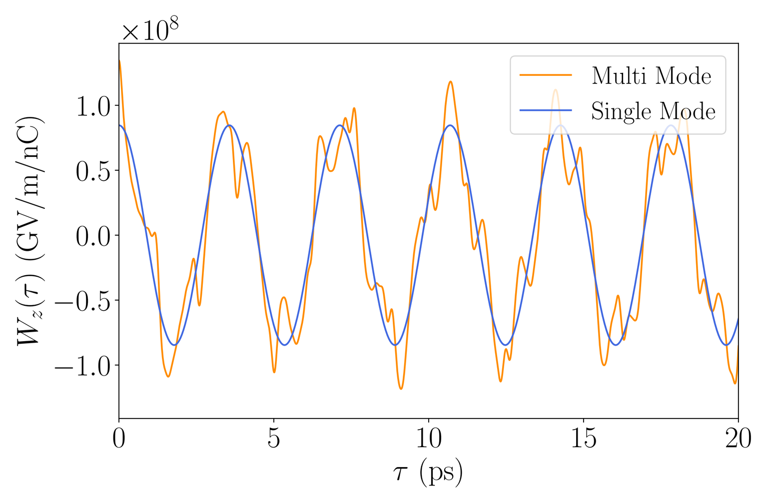
> Wakefields in a DLW are given by the convolution of the bunch current profile I(t) with the geometry dependent single particle wake potential $W_z(\tau)$

→ Overall wake potential: $$V(t) = -\int_{-\infty}^{t} I(\tau) W_z(t-\tau) d\tau.$$

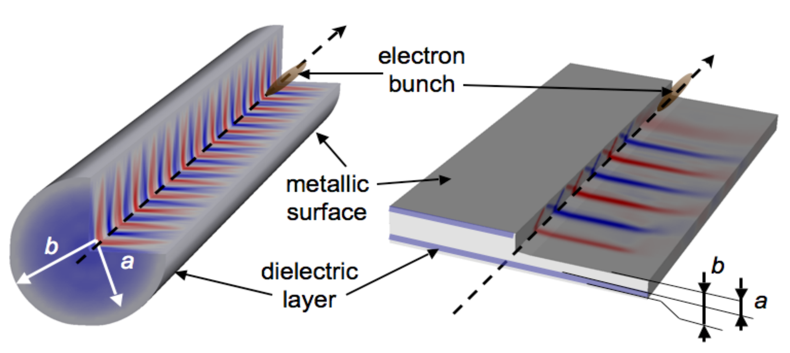
G. Voss and T. Weiland, DESY M82-10 (1982) and DESY 82-074 (1982).

> Wakefields can act back in the bunch itself, or a subsequently injected witness bunch

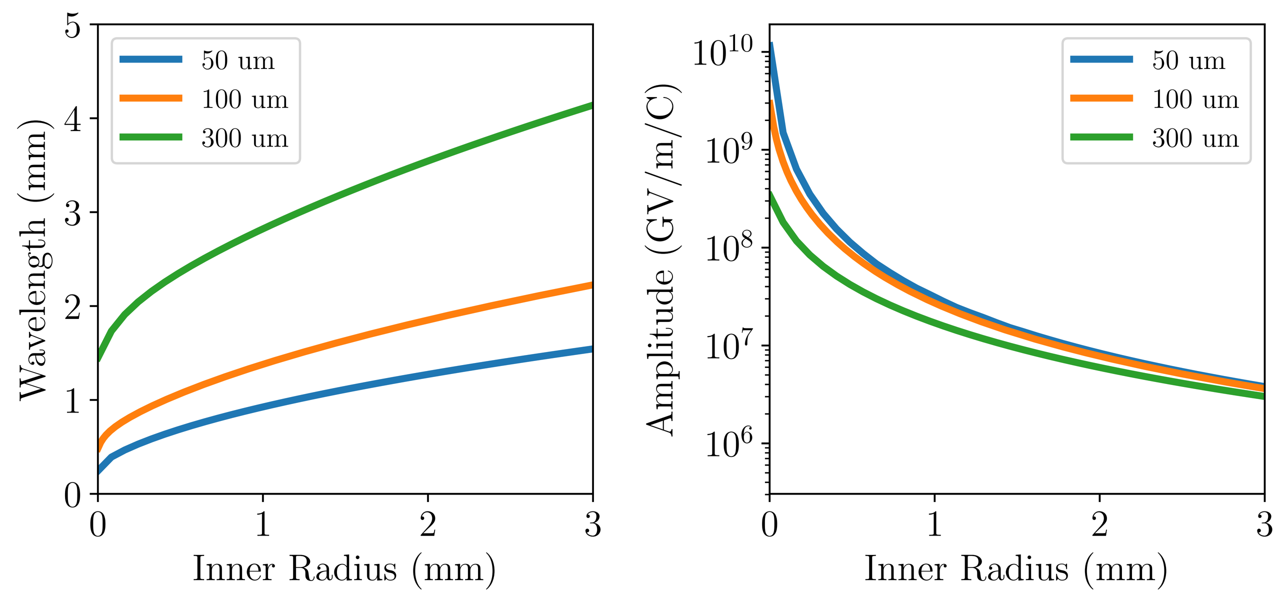
> Shape of the single particle wake potential depends on the mode structure supported by the given DLW geometry



Cylindrical Planar



(colors: wall thickness)



> Both wavelength and amplitude vary a lot depending on the inner radius

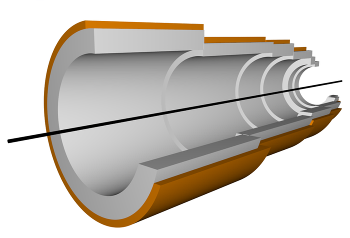
> Very high field strengths can be achieved in small structures

> Number of supported modes → Wall thickness

> **Main message**: Many degrees of freedom to play with!

Passive DLW-Based LPS Synthesizer Concept

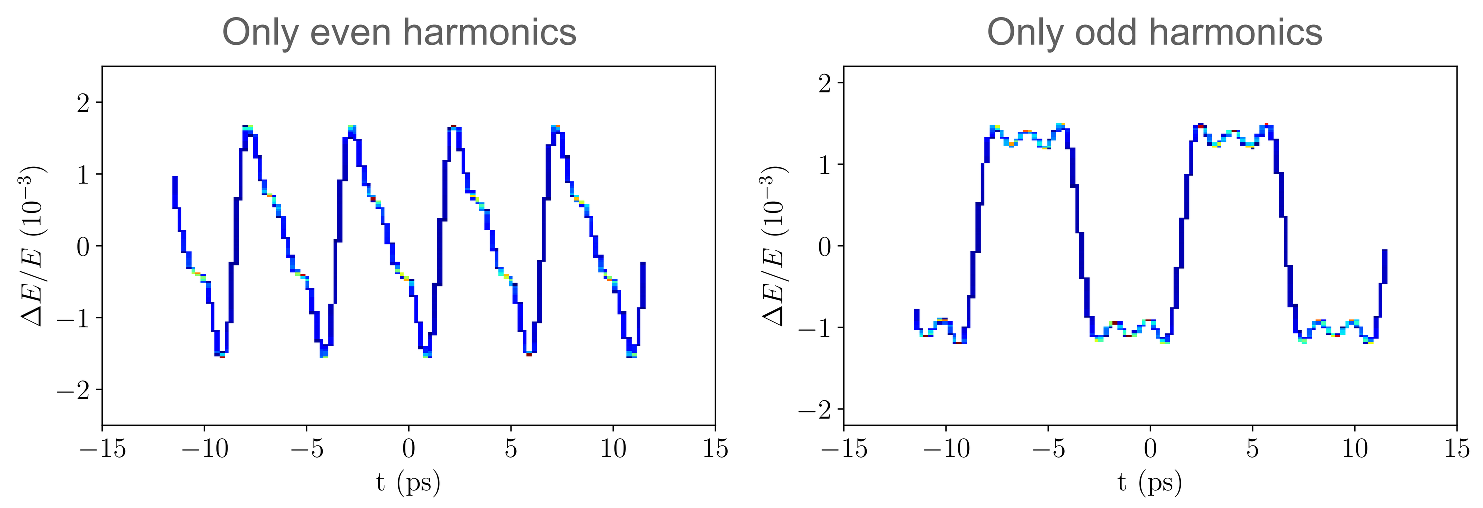
> **Main idea**: 3D-printed segmented DLW



Simple Approach

> Pick desired frequencies for a given waveform using the plot above
→ Scale segment length according to the amplitude of the mode

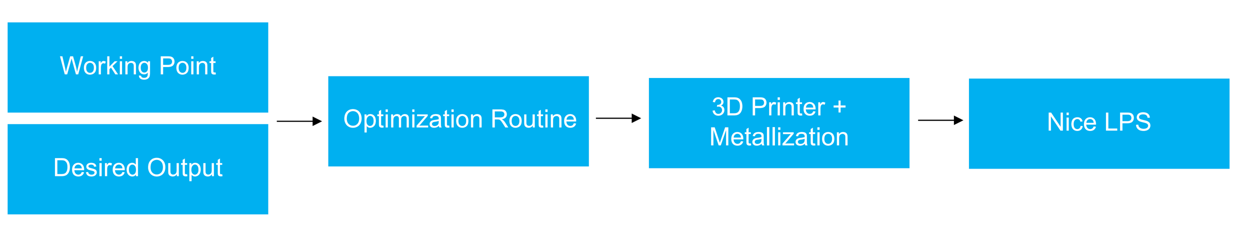
> Example ASTRA simulation:



> Problem: This procedure is only possible for a flat input LPS and current profile
→ *More sophisticated method needed*

Sophisticated Approach

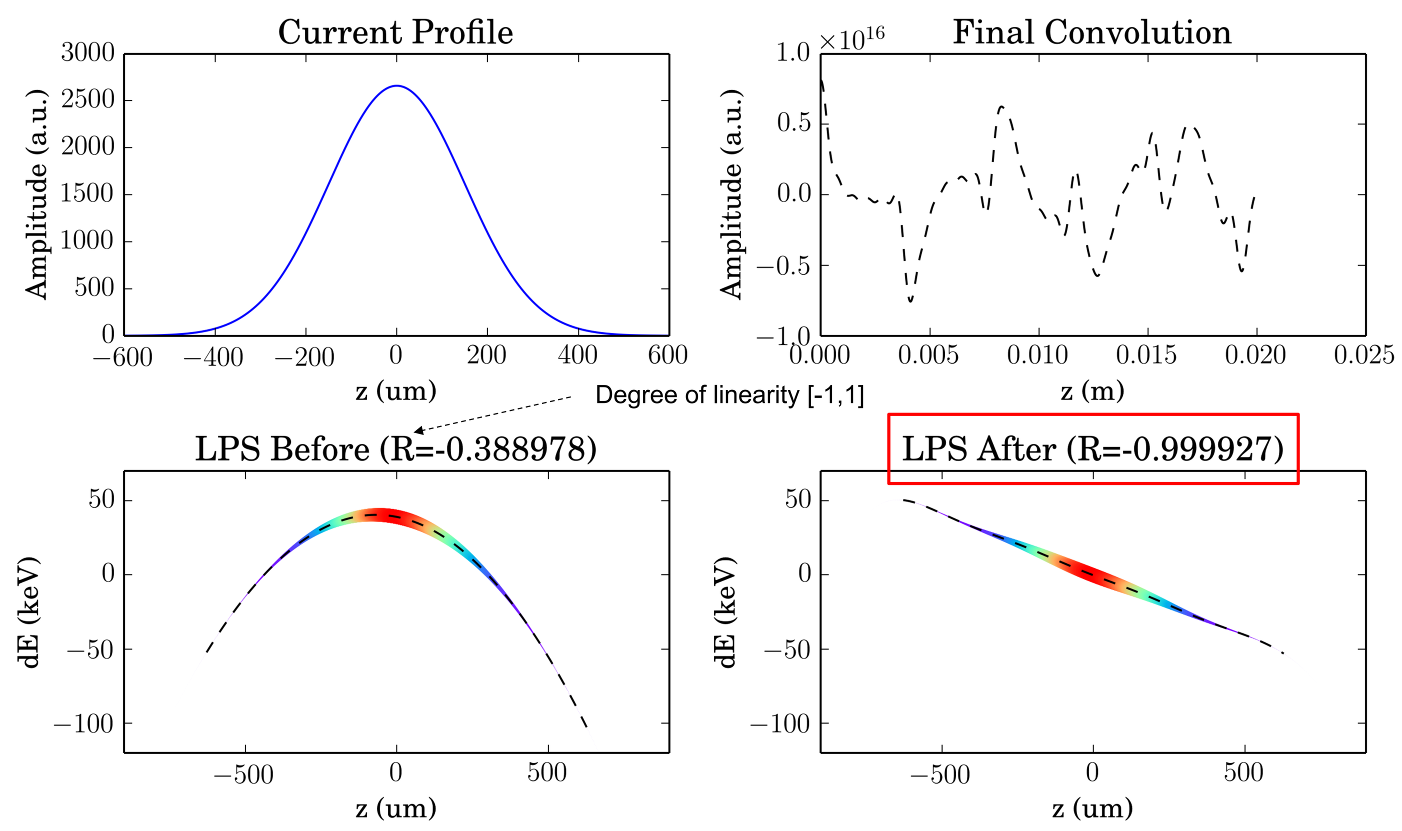
> Use an optimization algorithm to scale the individual segments according to the given input distribution and desired output LPS

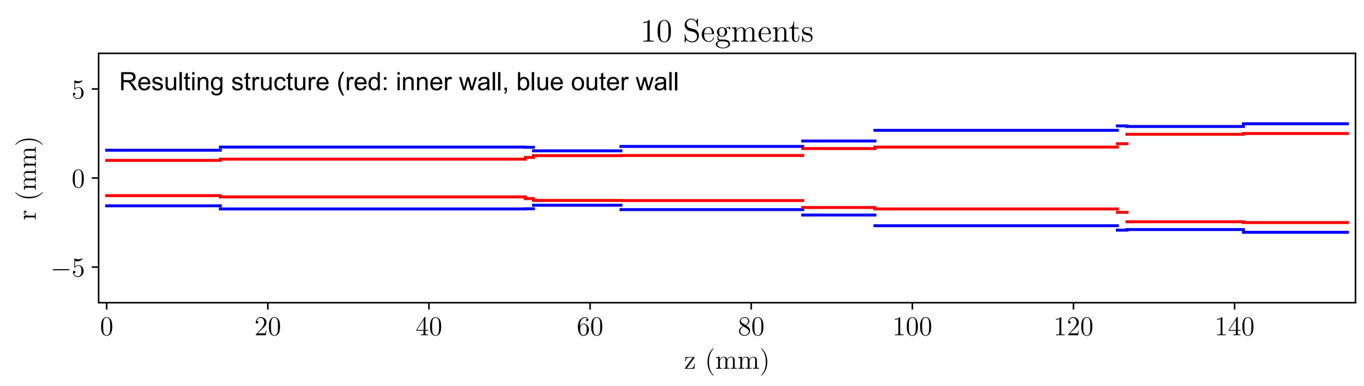


> *Optimization problem*: 3N independent variables
(segment radius, length and wall thickness times N)
→ Possible algorithm: Particle Swarm Optimization
→ ...based on ASTRA simulation or a fast semi-analytical approach

Example: Complete Linearization (Goal: R = -1)

Input: Gaussian beam with: σ_t = 500 fs, E_0 = 150 MeV, Q = 250 pC





> *Traditionally*: Tune for example a harmonic cavity's phase and amplitude to achieve LPS linearization for the current working point
> *Here*: Tune the working point a bit for the LPSS, or swap in a suitable LPSS device → Overcome the fixed geometry limitation by inserting multiple structures into the beamline (if 3D-printed → cheap)

Challenges

> Needs high charge (100s of pC), or long structures
> Small apertures might be problematic
> Position and pointing jitter might trigger dipole modes → Deflection

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