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Experience with Wakefield Acceleration at SwissFEL

ALEGRO workshop, March 19-22 2024, Lisbon, Portugal

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Rasmus Ischebeck

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Mike Seidel

Diagnostics

RF

Beam Dynamics

Large Research Facilities

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Overview

- SwissFEL
- EuPRAXIA
- Passive structures
- SwissFEL passive dielectric structure
  - Single Bunch Experiment & Simulations
  - Two Bunch Experiment

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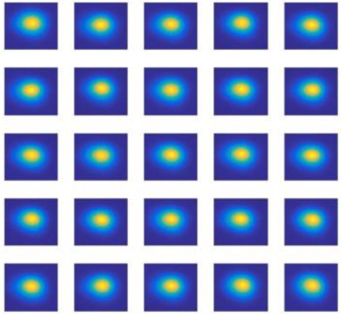
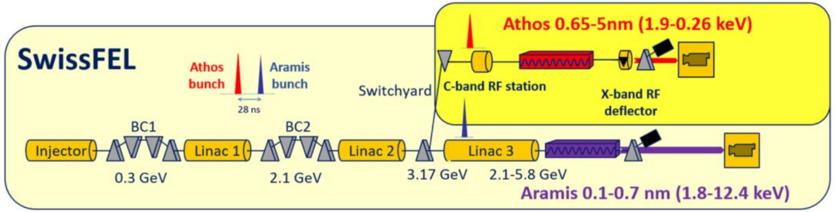
SwissFEL

Parameter	Value
Length	740 m
LINAC frequency	5.7 GHz (C-band)
Repetition rate	100 Hz
Energy	up to 6.1 GeV
Bunch charge	10 – 200 pC
Trajectory jitter	< 10% of beam size
Relative energy jitter	~10^{-4}
Arrival time jitter	< 10 fs
Slice emittance	200 nm (for 200 pC)
Bunch length	< 1 fs – 50 fs

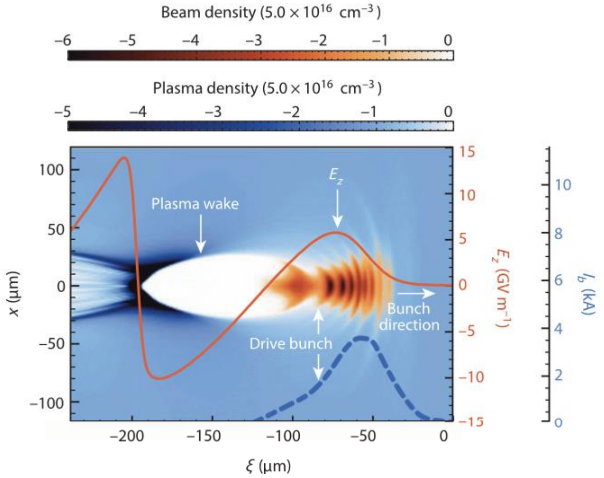


Courtesy: Eduard Prat

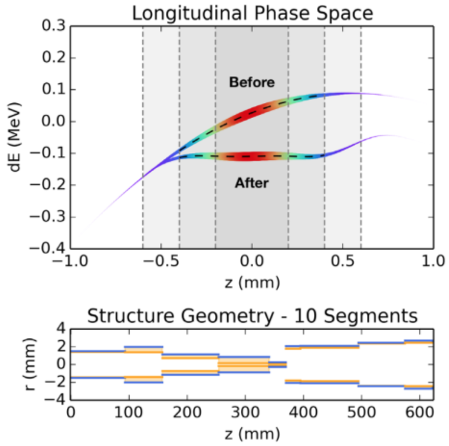


EuPRAXIA

- Goal: reproduce SwissFEL performance using a plasma accelerator
- Challenge: produce beams with low energy spread
- Small wavelength of plasma wake leads to large difference in acceleration of particles within a bunch with a finite length
- One possible solution is the use of wakefield structures

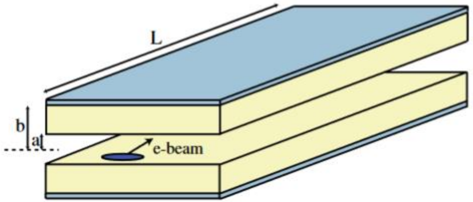
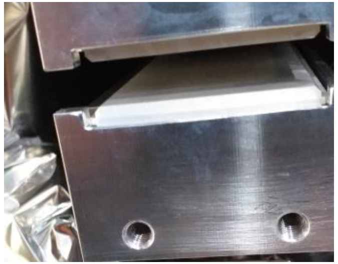
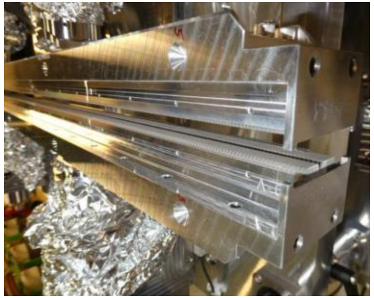
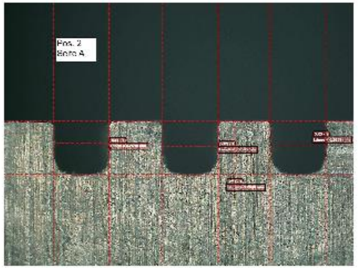
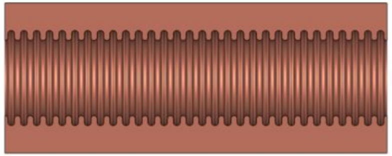
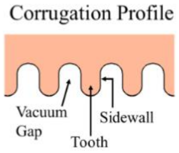


Positron acceleration in plasma wakefields, Cao, et al.



Longitudinal phase space synthesis with tailored 3D-printable dielectric-lined waveguides, Mayet, et al.

Wakefield structures

	Dielectric	Metallic
Flat	  Dielectric Wakefield Acceleration of a Relativistic Electron Beam in a Slab-Symmetric Dielectric Lined Waveguide, Andonian, et al.	 
Round		  Design of a cylindrical corrugated waveguide for a collinear wakefield accelerator, Siy, et al.

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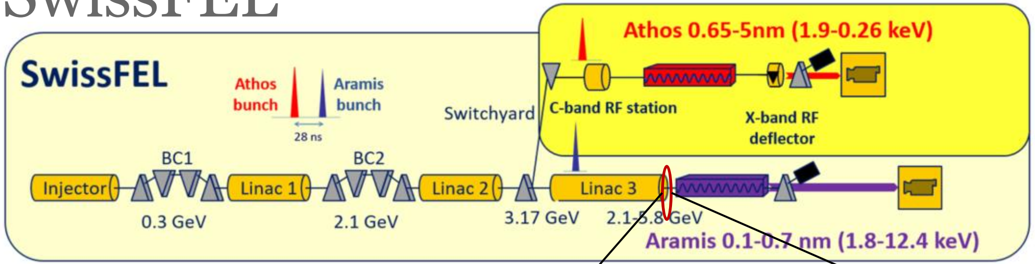
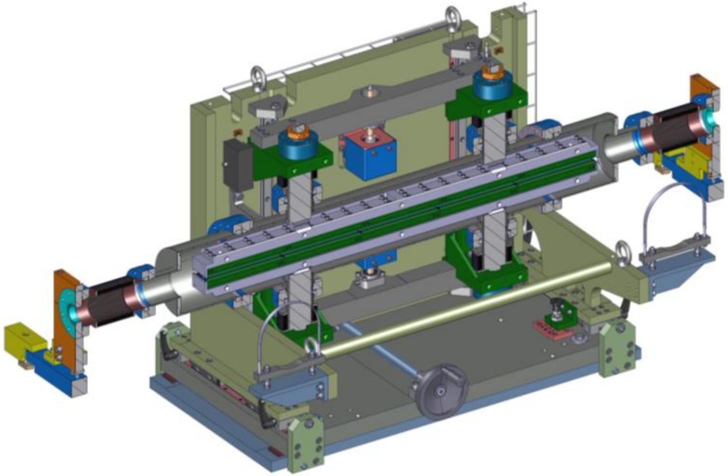
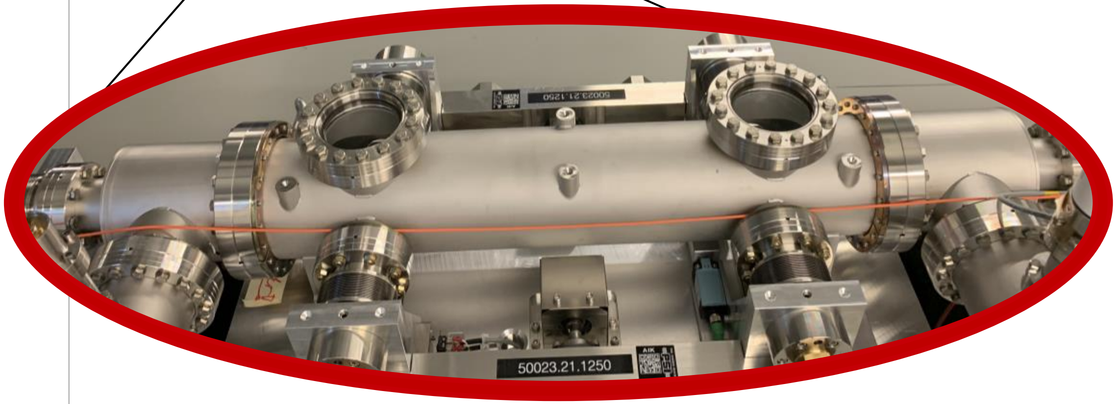
SwissFEL







- Flat slab dielectric passive structure with adjustable gap
- Routinely used to make ultrashort pulses, adjust FEL bandwidth

Courtesy: P. Heimgartner

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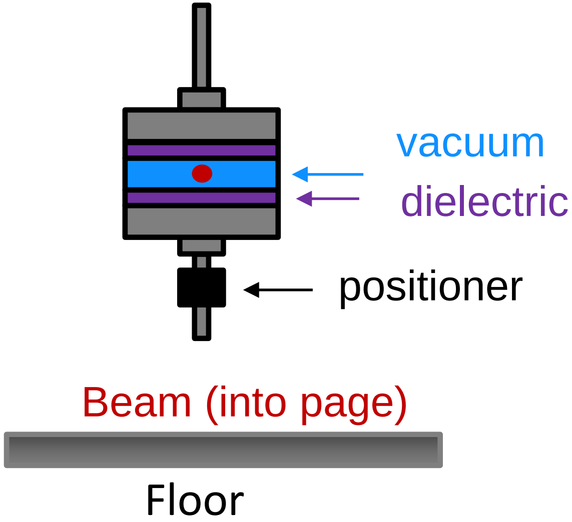
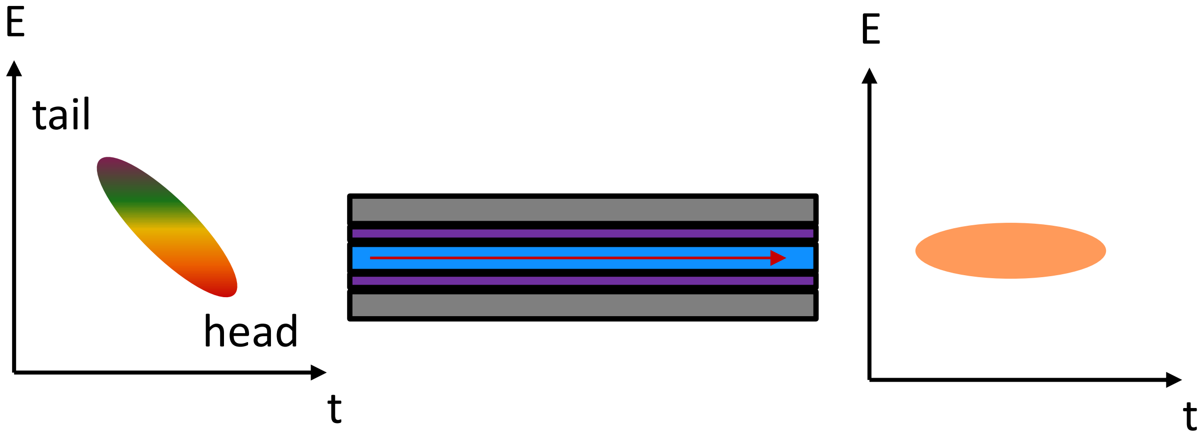
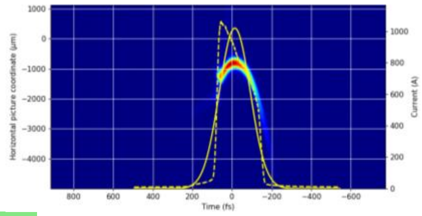
Passive structure – single bunch experiment

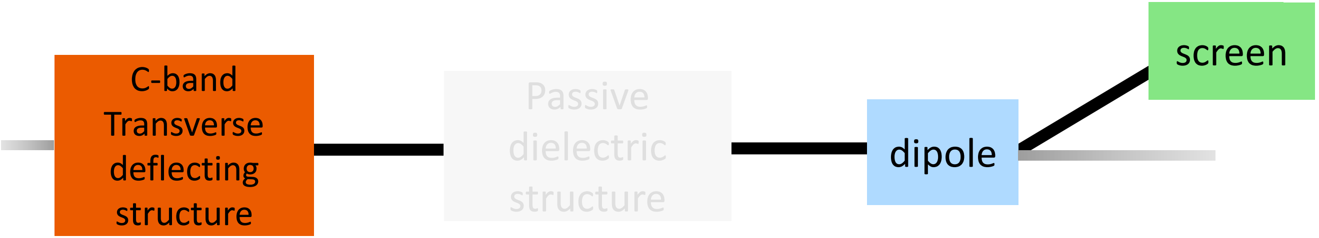
- Dielectric induces wakefields that act on the beam
- Gap controls strength of the effect
- Reduces correlated energy spread
- Centroid energy changes





Passive structure – single bunch experiment

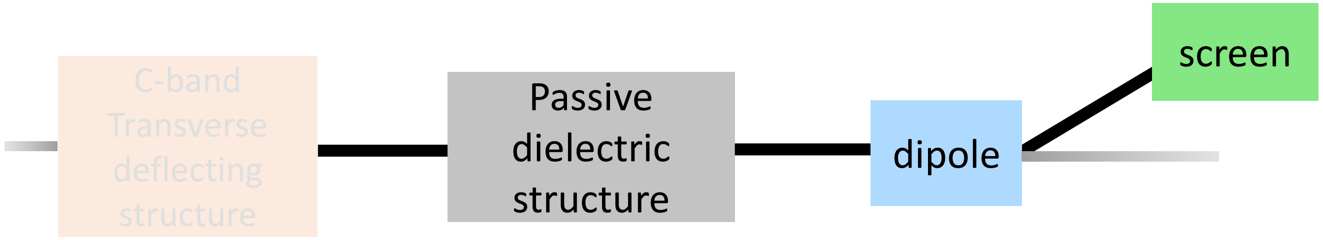


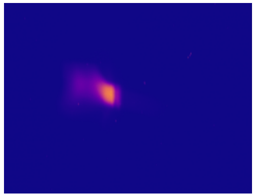


Measurement procedure:

1. Passive structure gap is fully opened to limit its effect
2. TDS is used to get the longitudinal phase space of the beam sent into passive structure
3. TDS is turned off
4. Passive structure gap is gradually closed
5. Dipole & screen measure energy of beam coming out of the passive structure
6. Process is repeated for multiple bunch lengths (76 fs, 38 fs, 16 fs)

Passive structure – single bunch experiment





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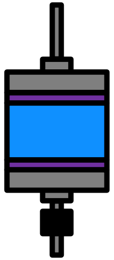
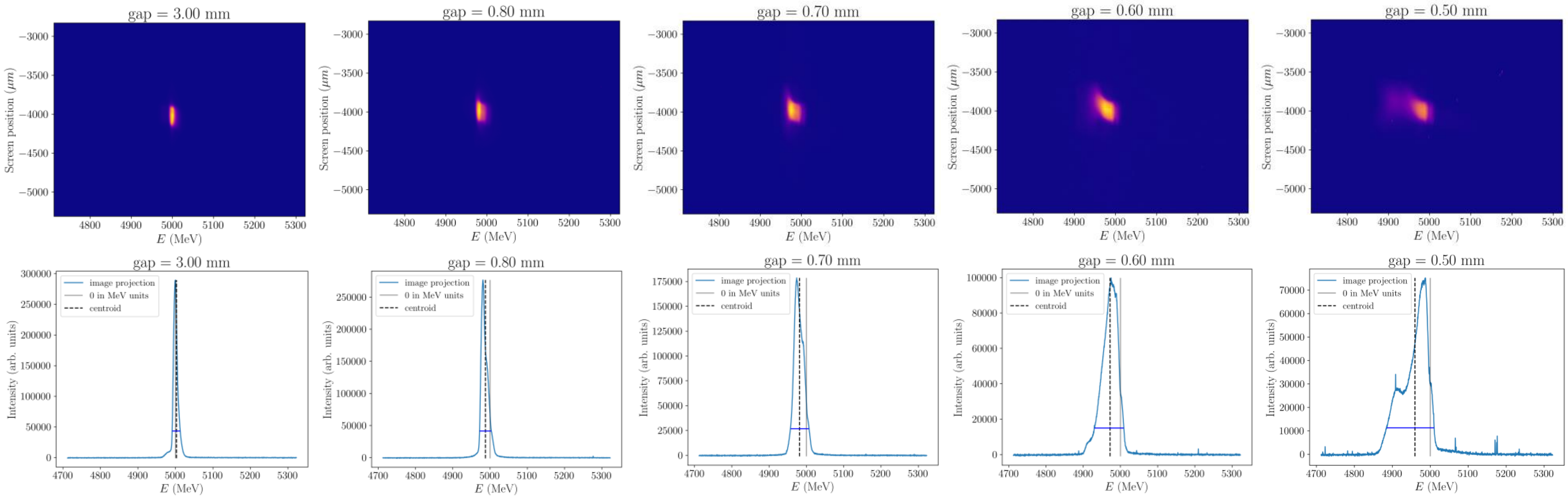


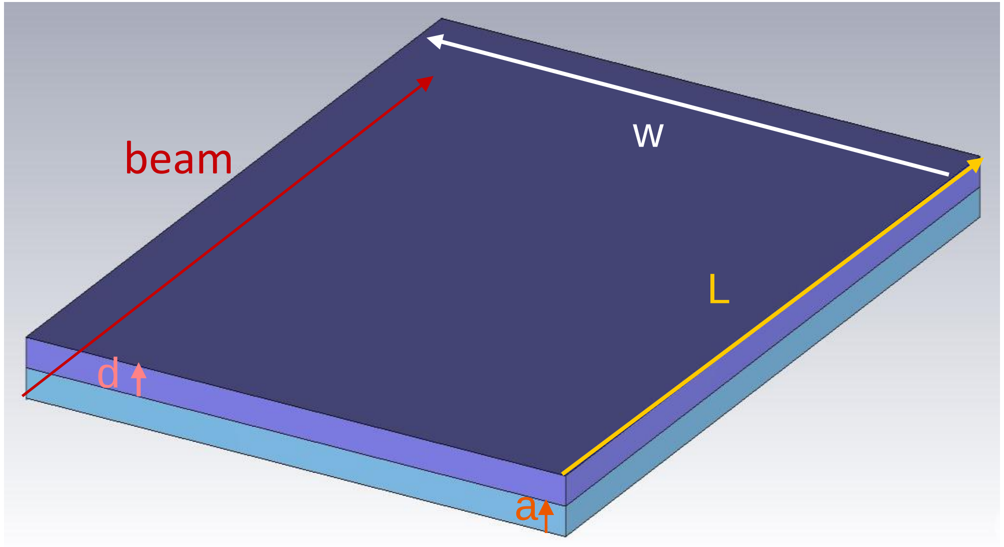
- How does the dechirping effect depend on structure gap?



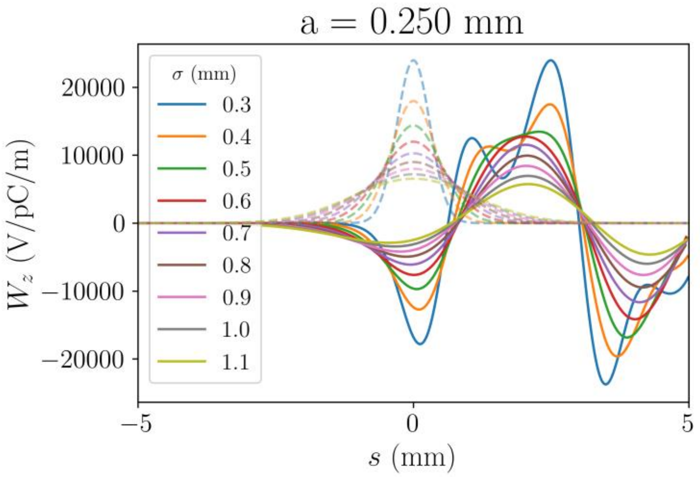
Passive structure – simulations

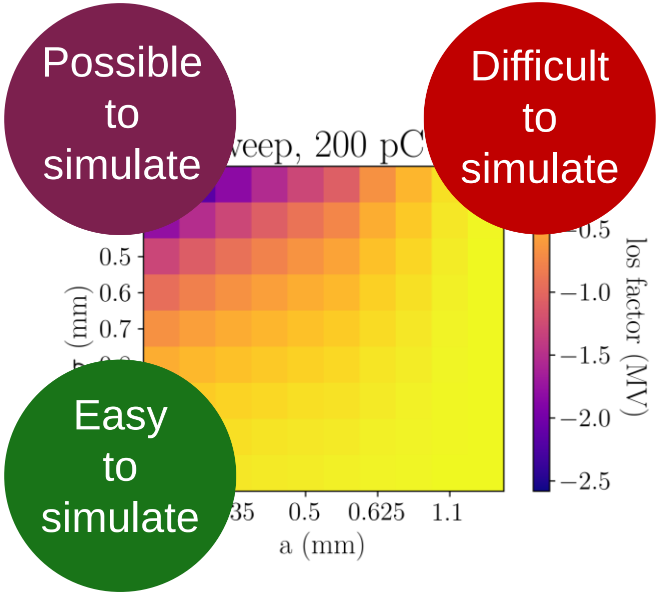
- ***Began*** simulations using CST

Parameter	Value
half-gap, a	0.25 mm – 1.5 mm
Dielectric thickness, d	0.4 mm
Length, L	1 m
Width, w	15 mm
Alumina Permittivity, ε_r	~10



Passive structure – simulations





- 128 GB RAM PC limited to simulating σ = 0.3 mm bunches
- To simulate SwissFEL bunches, σ = 4.8 µm, we used ECHO

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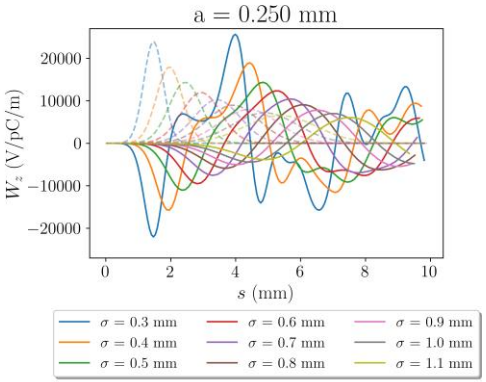
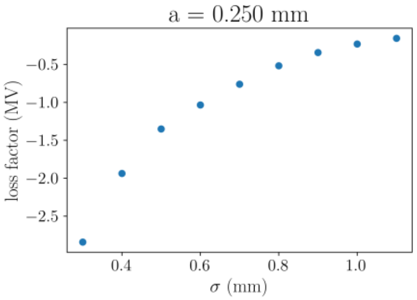
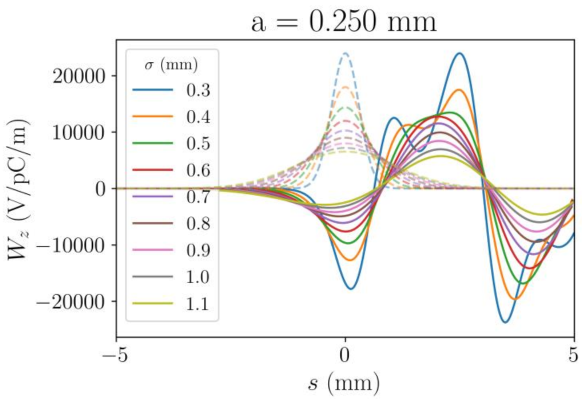
Passive structure – simulations

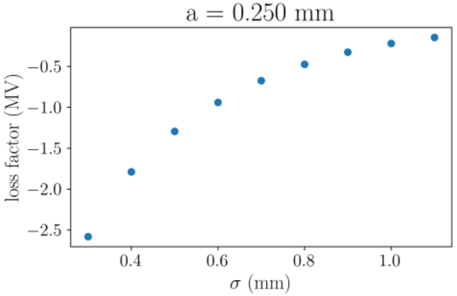
ECHO





CST



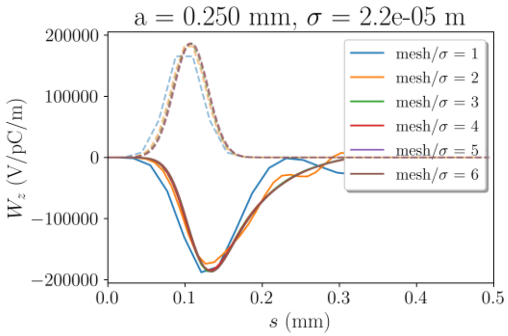


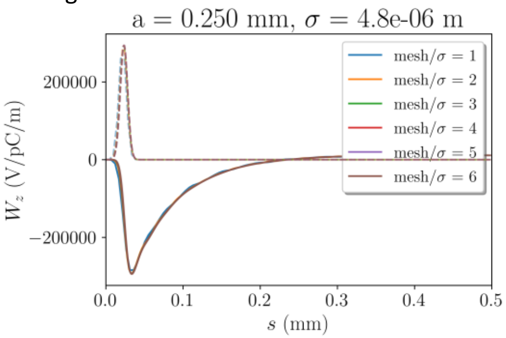
- Wake potentials are slightly different between codes but the loss factors are similar

Passive structure – simulations

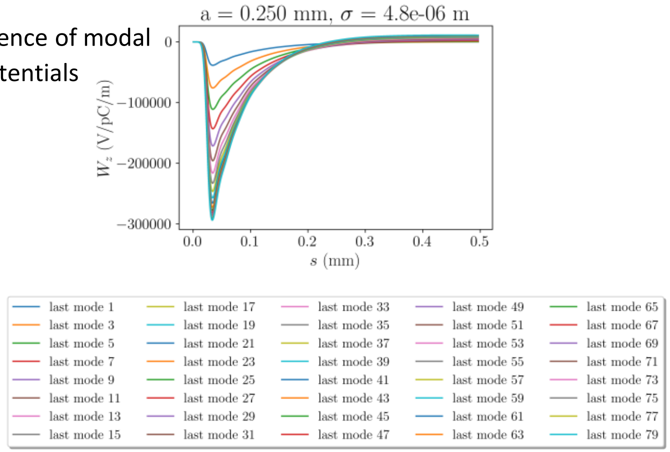
- Structure length/Bunch length ~= 1,000,000

Mesh convergence

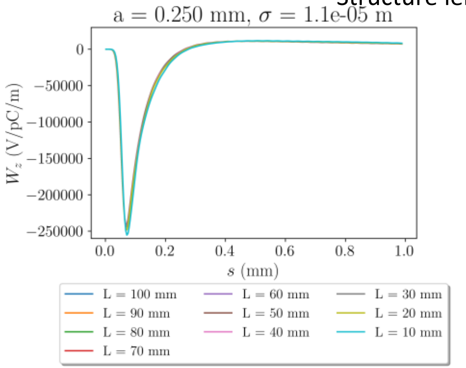


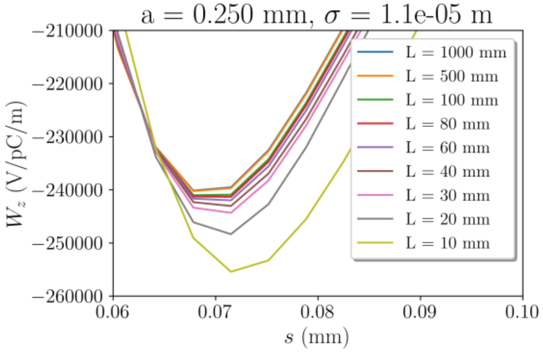


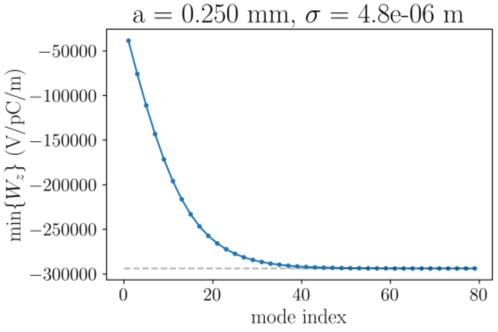
Convergence of modal wake potentials



Structure length convergence

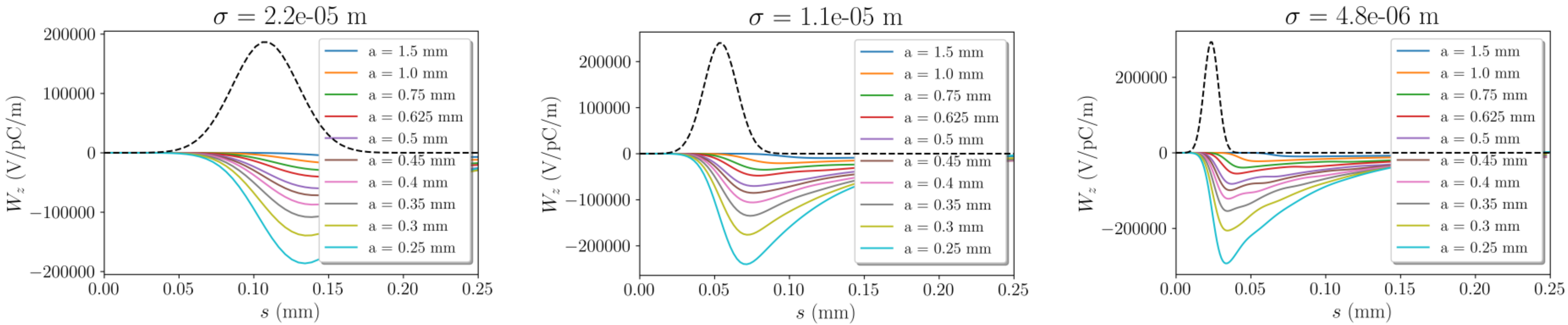






Passive structure – simulations

- Performed gap sweeps for 3 gaussian current distributions (gap = 2a)



- Wake potential amplitude grows for small gap and short bunches

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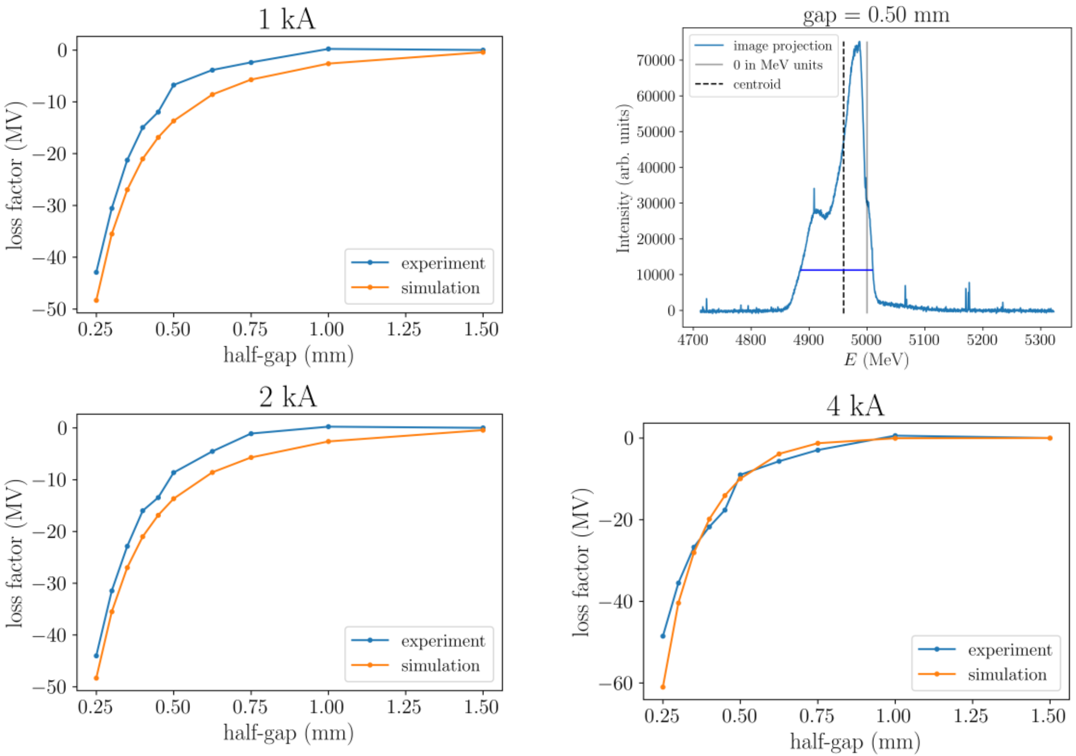
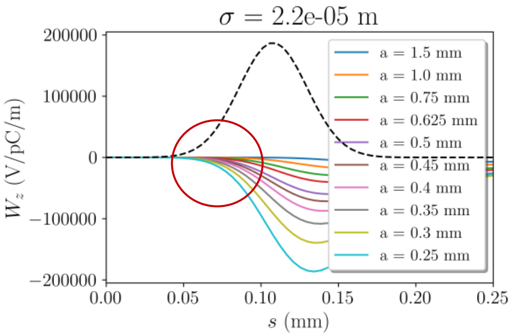
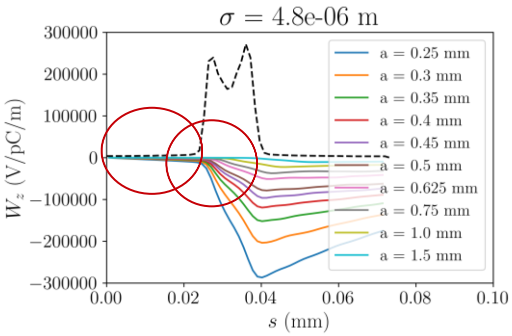
Passive structure – comparison of simulations with single bunch experiment

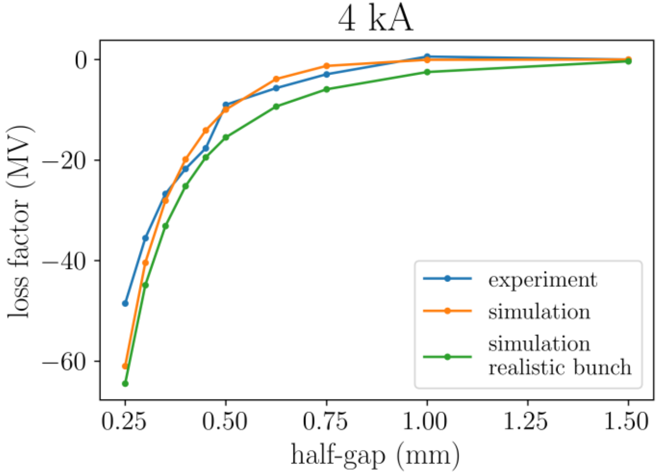


- Error analysis of experiment values to be done

Passive structure – comparison of simulations with single non-gaussian bunch experiment



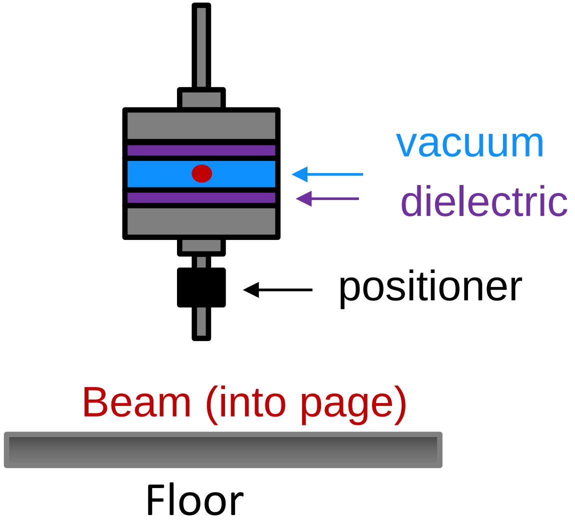


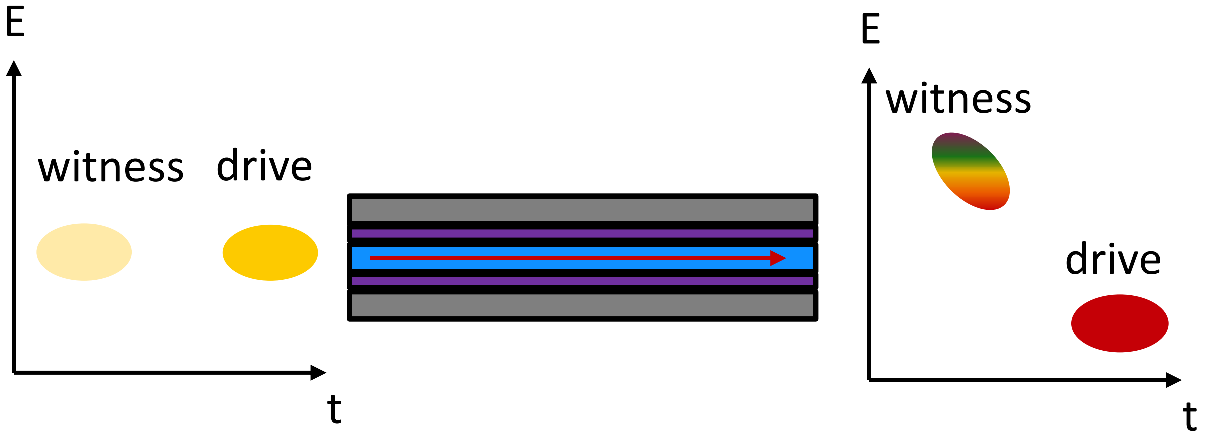


- Measured current profile is non-zero outside of where bunch "is" leading to small, non-zero wake potential for s < 0.02 mm
- Sharp increase in current leads to sudden decrease in wake potential compared to gaussian bunch
- Convergence studies on-going for non-gaussian current distributions

Passive structure – two bunch experiment

- Dielectric induces wakefields that act on the beam
- Gap controls strength of the effect
- Drive beam is decelerated
- Witness beam is accelerated, often with a chirp





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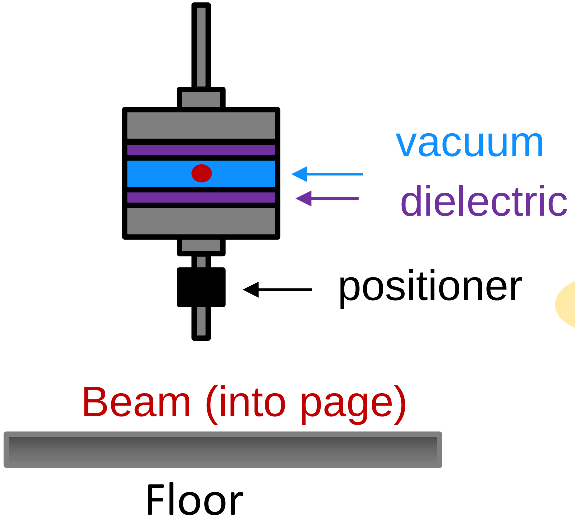
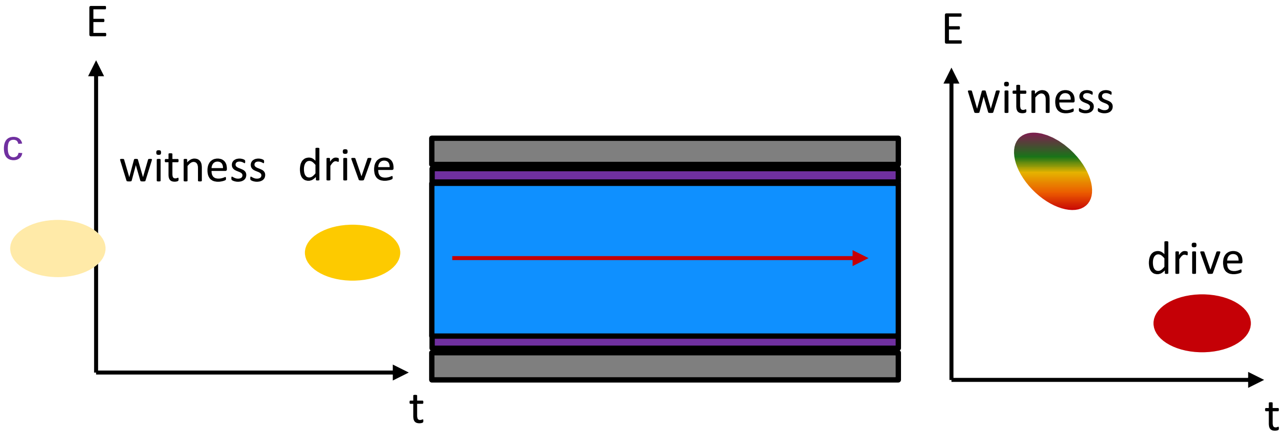
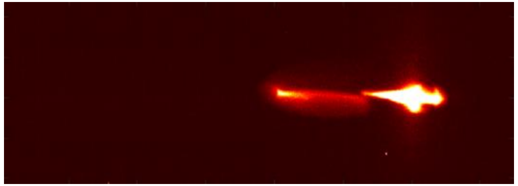


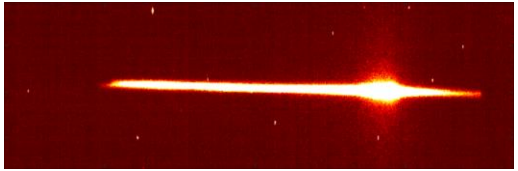


Bunch spacing and structure gap are swept during the experiment

Passive structure – two bunch experiment

Increasing energy





- Top image: drive and witness beam observed together in same region
- Middle image: Two “distinct” beams
  - First bunch is same as before
  - Second bunch has lower intensity and higher energy than first beam
- Bottom image: Large energy spread of drive/witness beams

- Measurements suggest: acceleration of a ~25 pC witness beam by a ~200 pC drive beam

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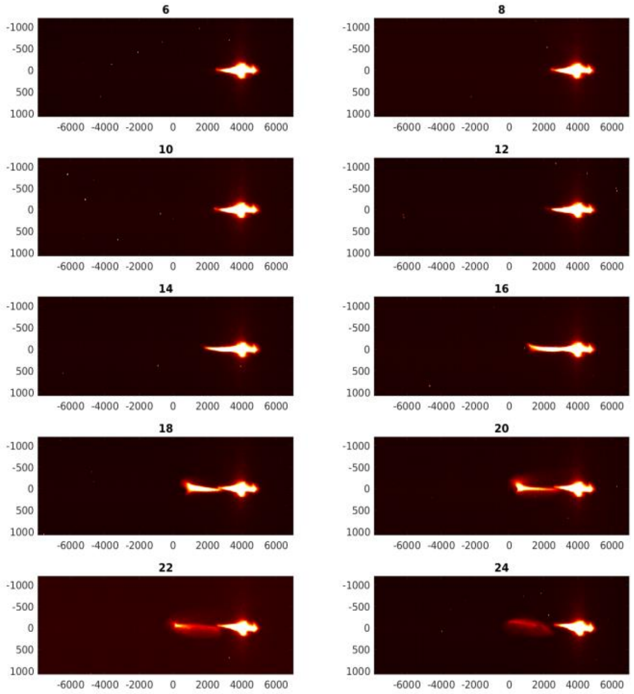
Passive structure – two bunch experiment

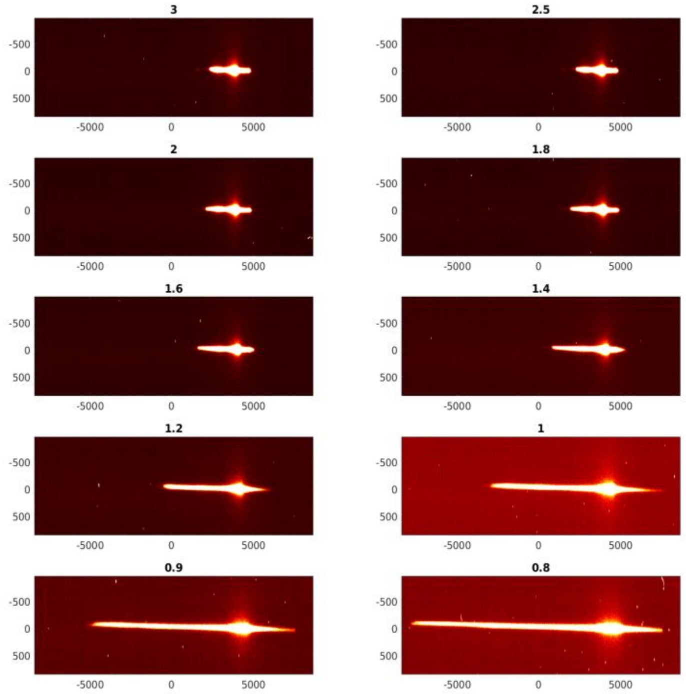
Gap = 1.6 mm

Delay Scan (headers in ps)



Delay = 15 ps

Gap Scan (headers in mm)



Conclusion & Outlook

- We have confirmed the short-range wakefields are responsible for the change in the centroid energy of the beam
- We will investigate if the short-range wakefields can explain the change in energy spread of the beam
- We will investigate the long-range wakefields to explain the two-beam acceleration measurement