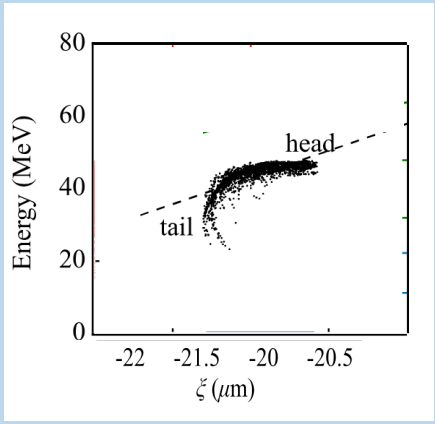
EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS

EuPRAXIA
Preparatory Phase

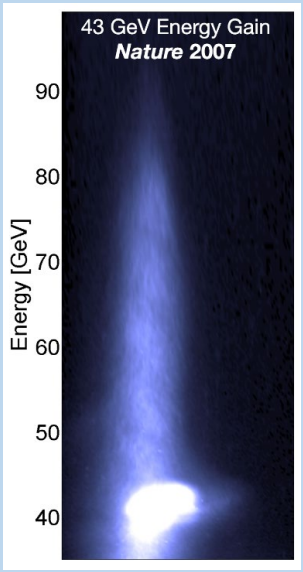
Reduction of Projected Energy Spread with a Dielectric Wake Field Structure

Evan Ericson

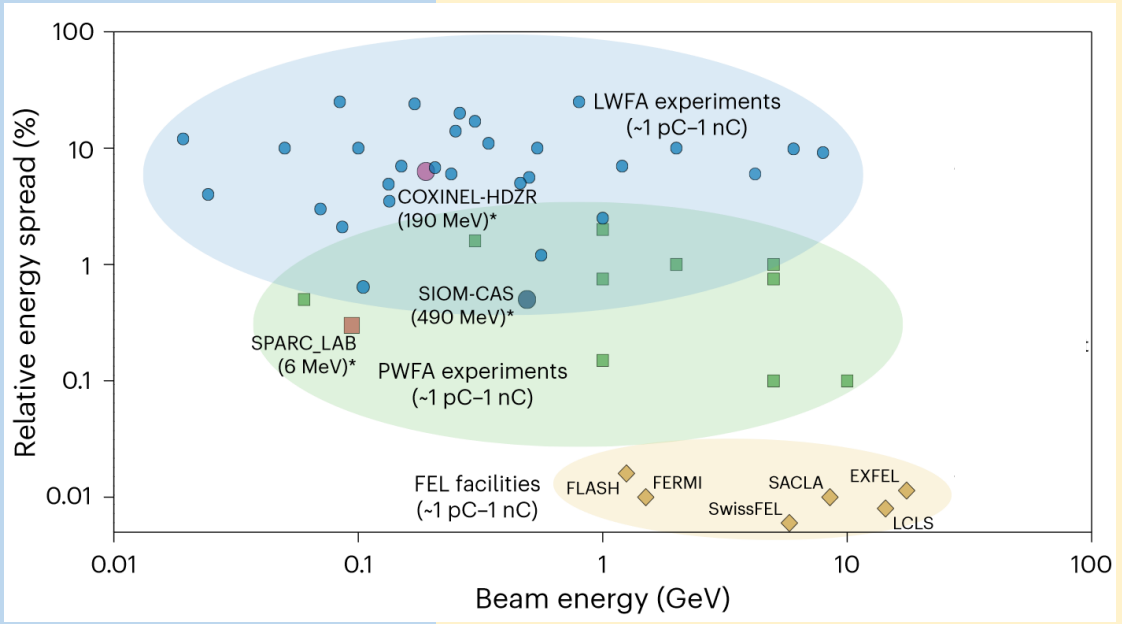
This project has received funding from the European Union´s Horizon Europe research and innovation programme under grant agreement No. 101079773



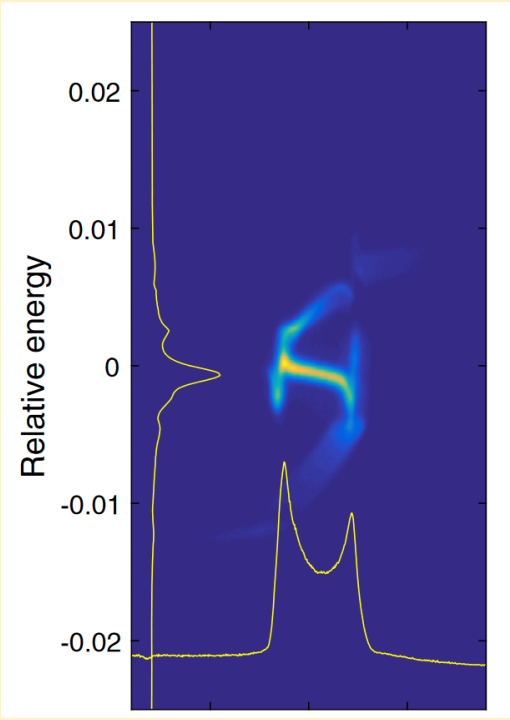
Near-GeV Electron Beams at a Few Per-Mille Level from a Laser Wakefield Accelerator via Density-Tailored Plasma, Ke, et al.



Energy doubling of 42 GeV electrons in a meter-scale plasma wakefield accelerator, Blumenfeld, at al.



Prospects for free-electron lasers powered by plasma-wakefield-accelerated beams, Galetti, et al.



Demonstration of Large Bandwidth Hard X-Ray Free-Electron Laser Pulses at SwissFEL, Prat, et al.

EPFL PSI

Rasmus Ischebeck

Diagnostics & Instrumentation

Paolo Craievich

Fabio Marcellini

Radio Frequency Systems

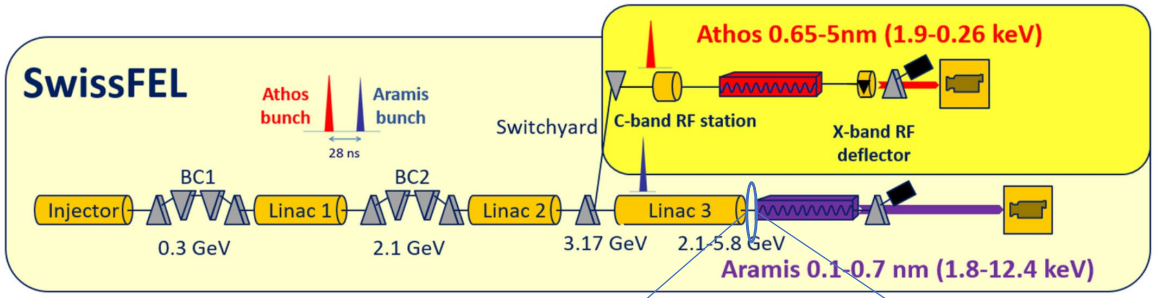
Sven Reiche

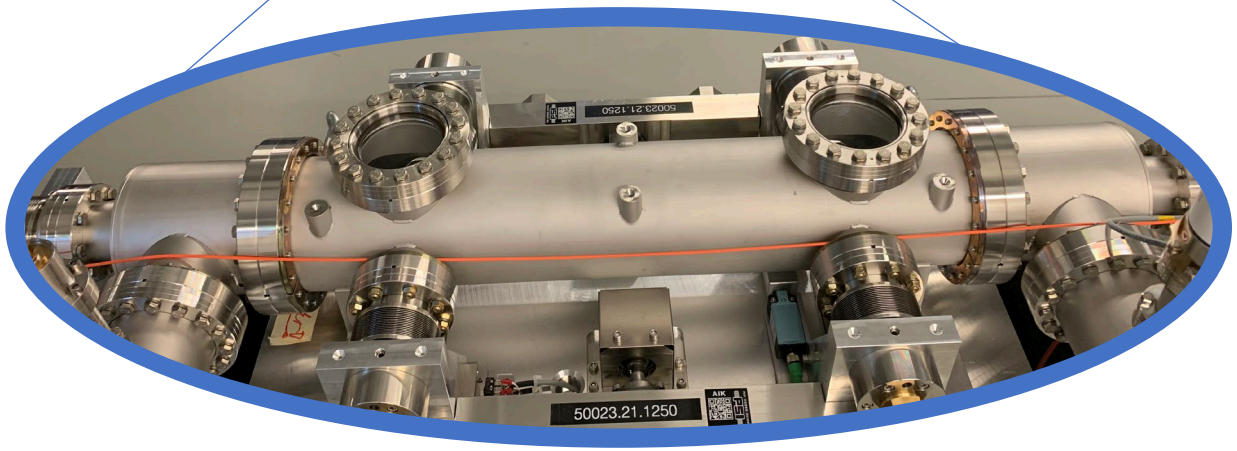
Eduard Prat

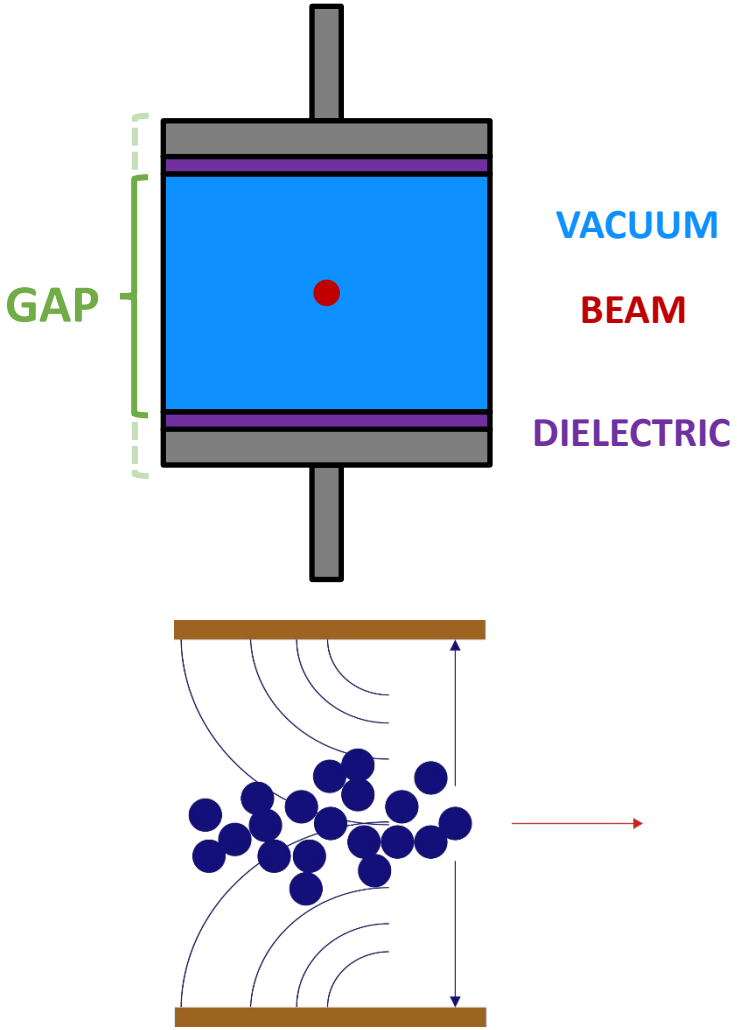
Beam Dynamics

Mike Seidel

Large Research Facilities

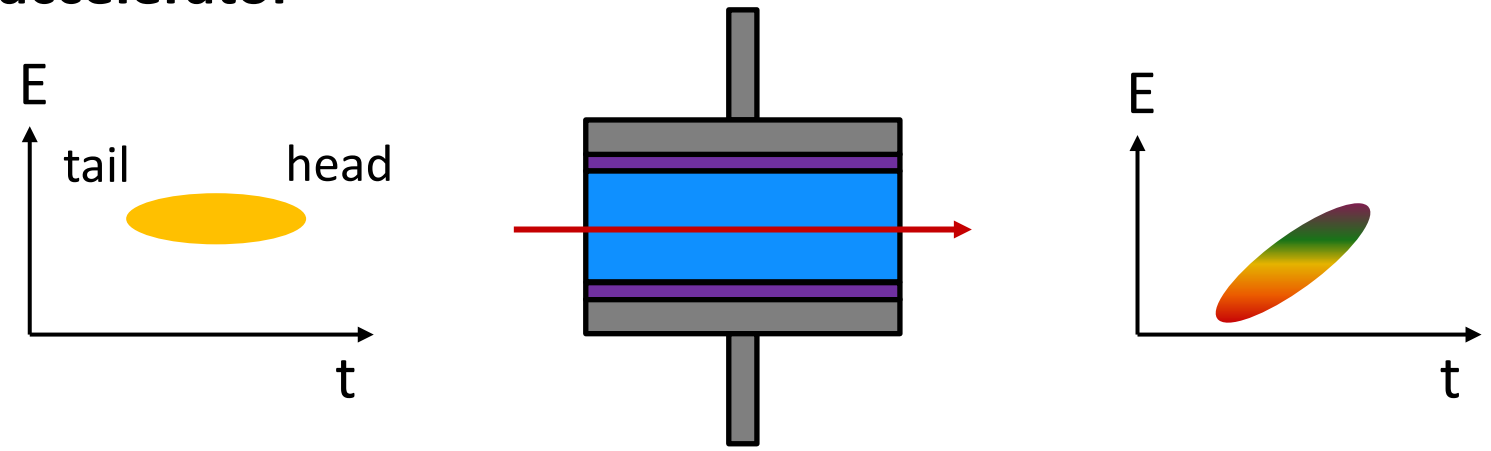




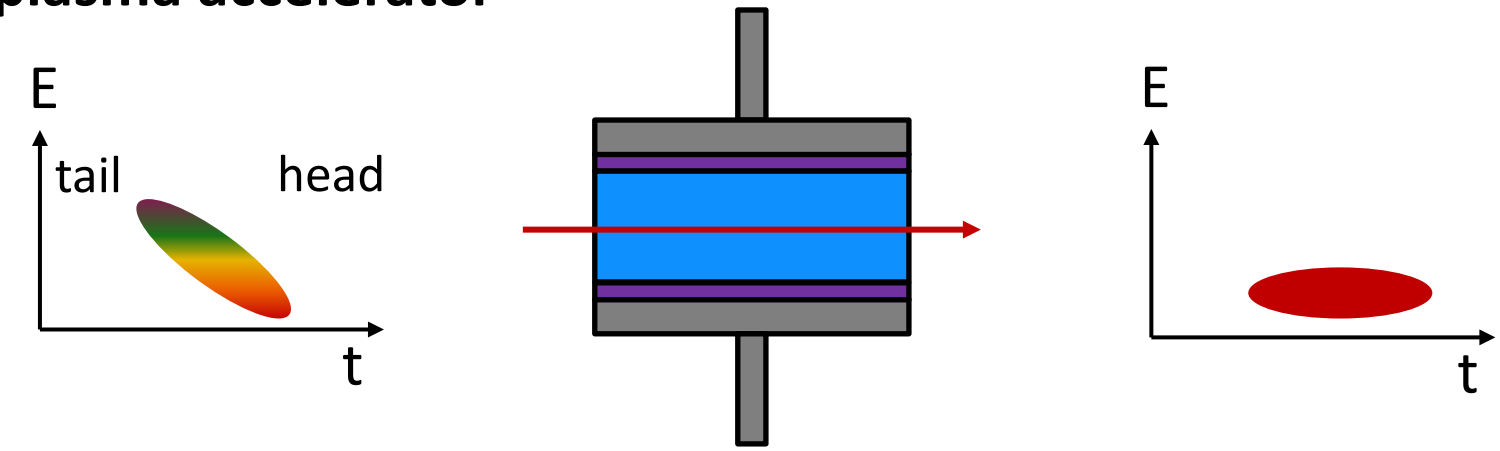


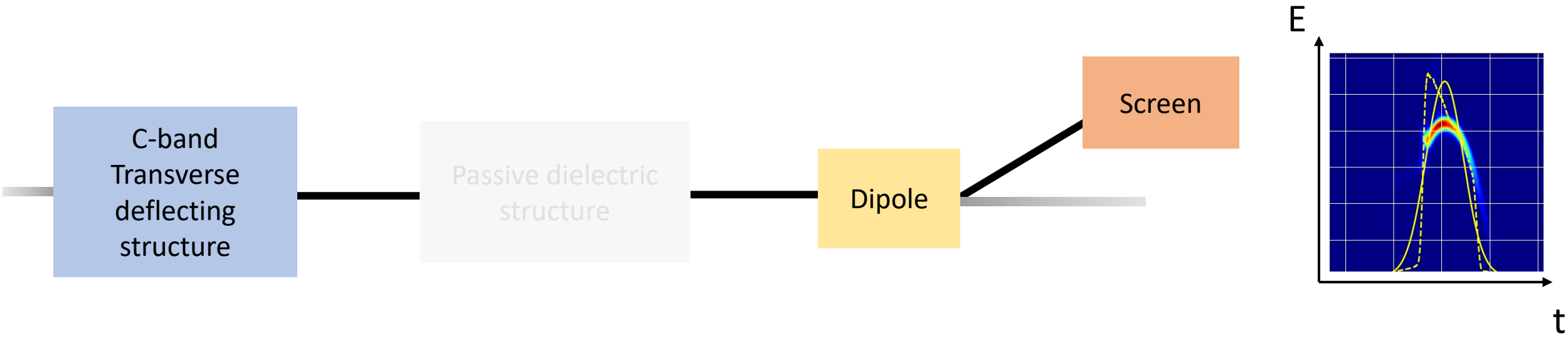
Inherently synchronized with witness beam

Chirping for RF accelerator



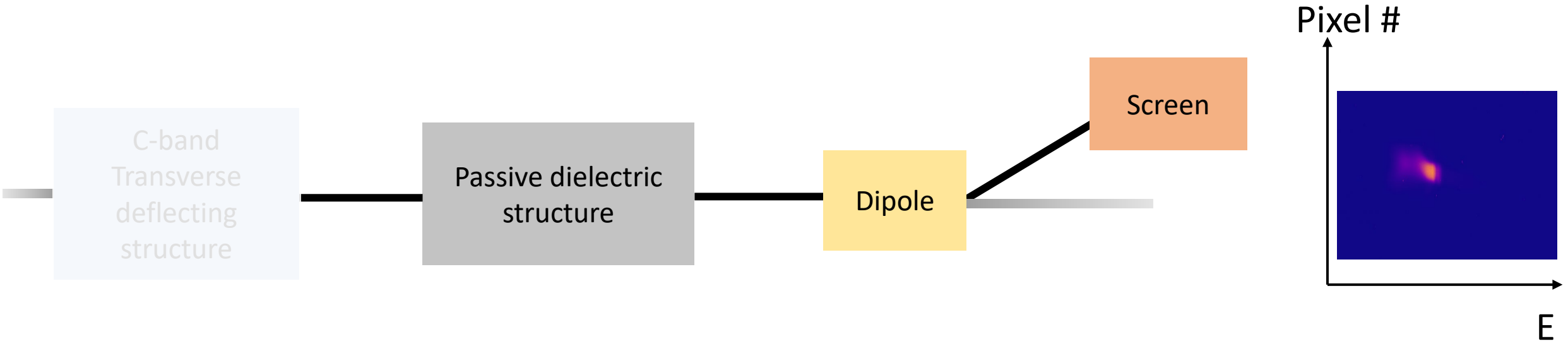
Dechirping for plasma accelerator





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 three bunch lengths (76 fs, 38 fs, 16 fs), 300 images total



Measurement procedure:

1. Passive structure gap is fully opened to limit its effect
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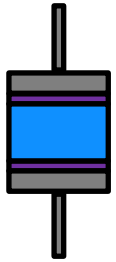
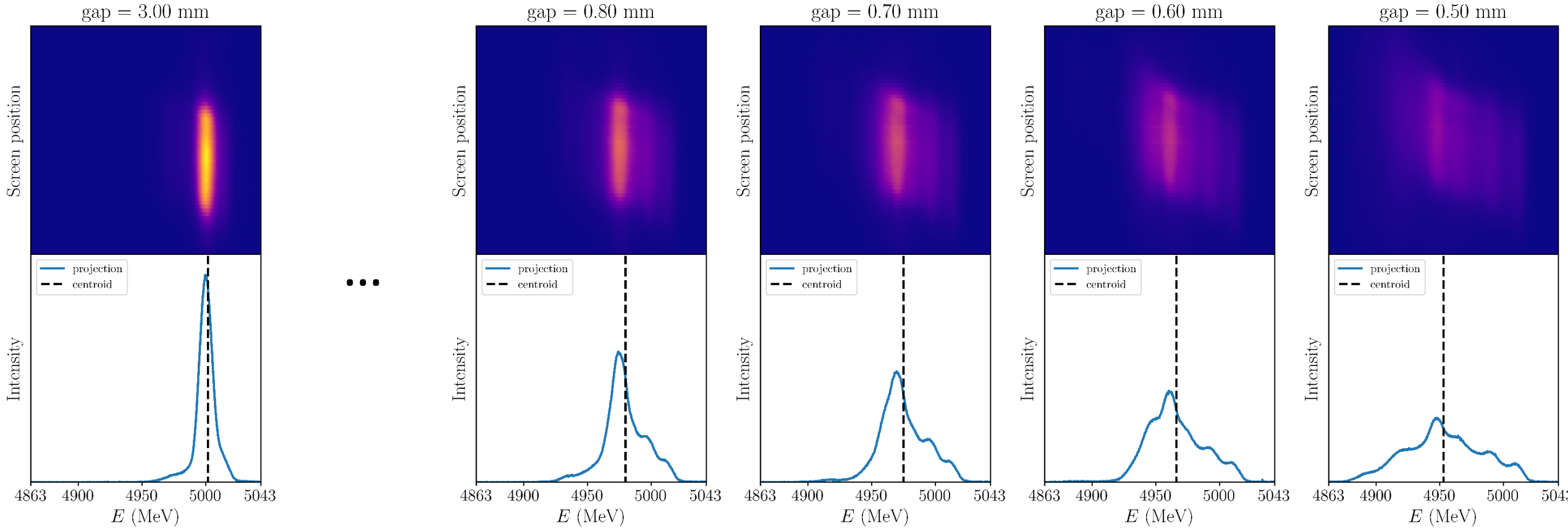
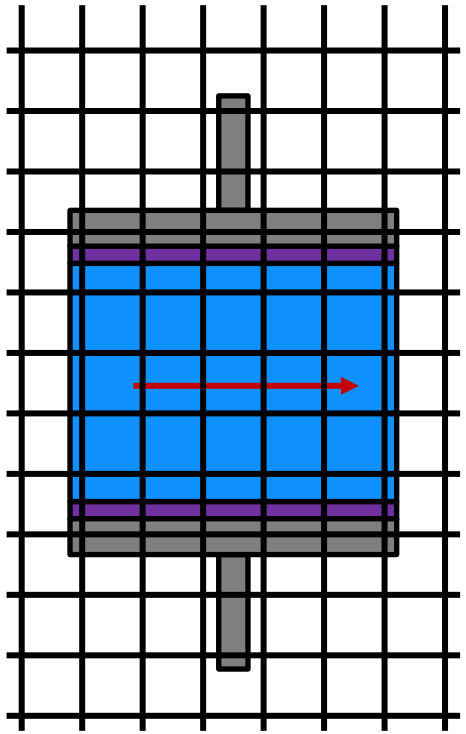
3. TDS is turned off
4. Passive structure gap is gradually closed
5. Dipole & screen measure energy of beam coming out of the passive structure
6. Process is repeated for three bunch lengths (76 fs, 38 fs, 16 fs), 300 images total

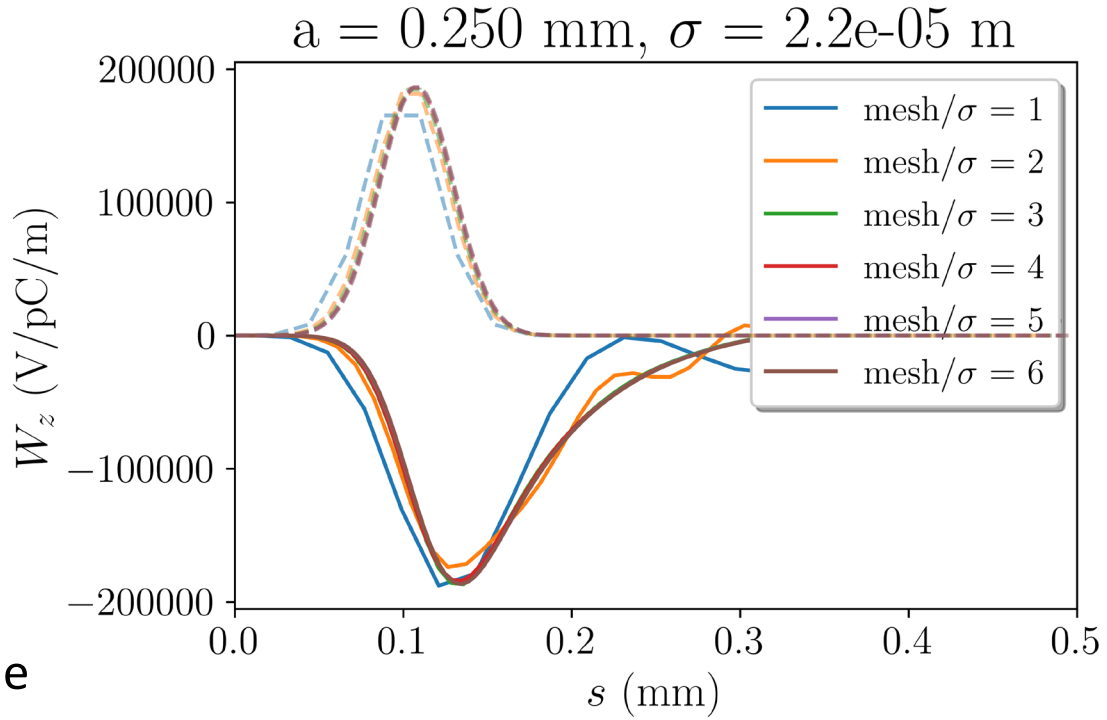
The wakefields change both the energy spread and centroid energy





5 mesh elements per σ produces accurate wake potentials



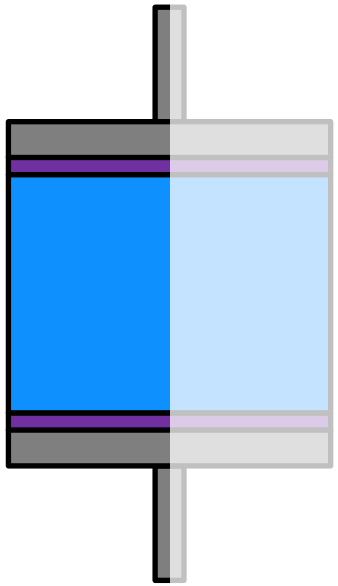


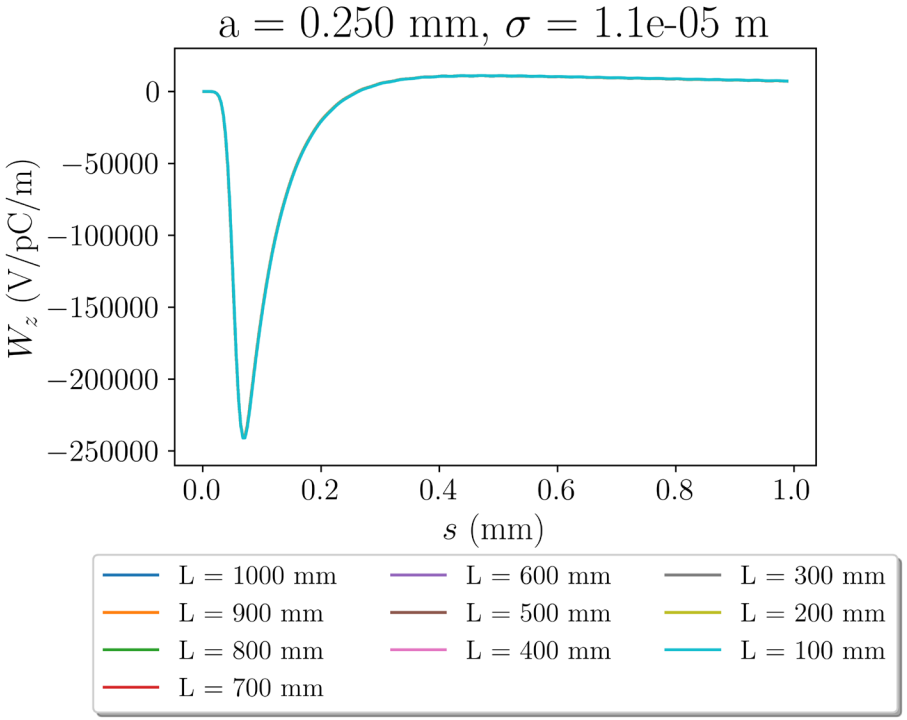
Mesh setting determines how accurately the

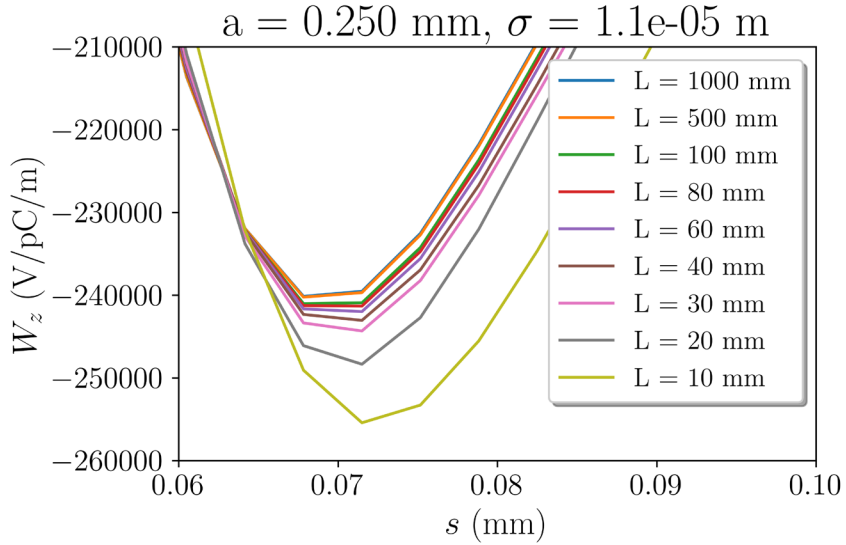
1. Source
2. Boundaries
3. Electromagnetic fields

are represented in the simulation

Less than a tenth of the structure needs to be simulated to obtain accurate wake potentials

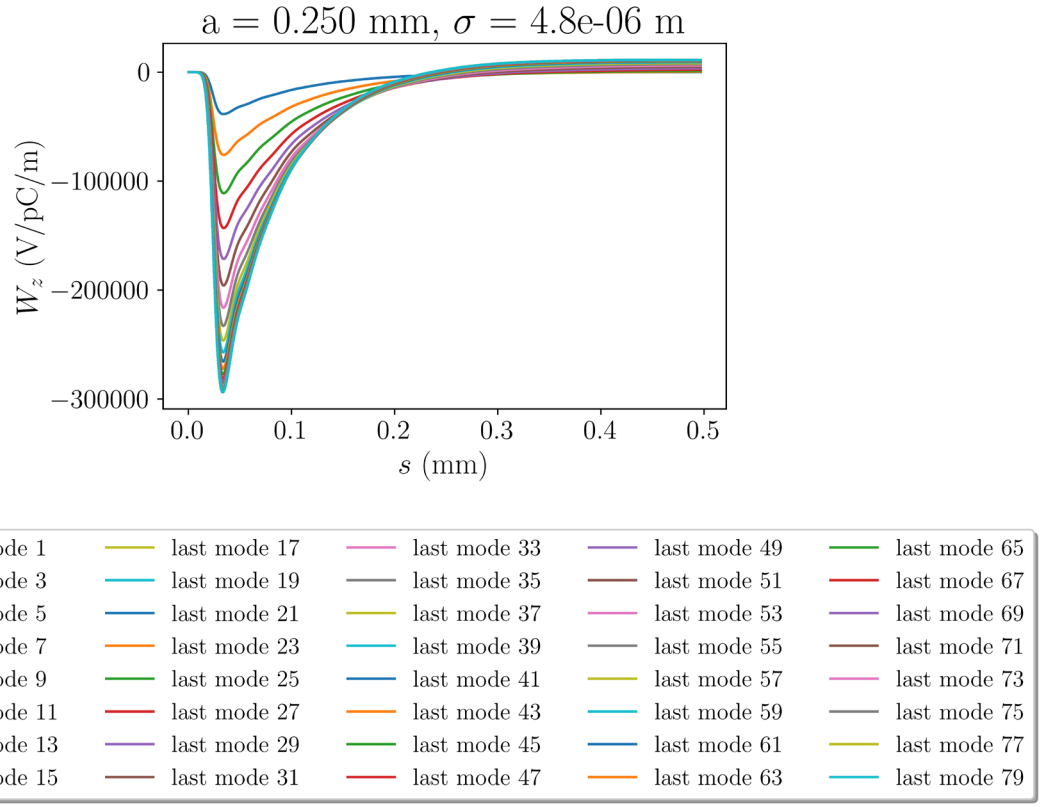


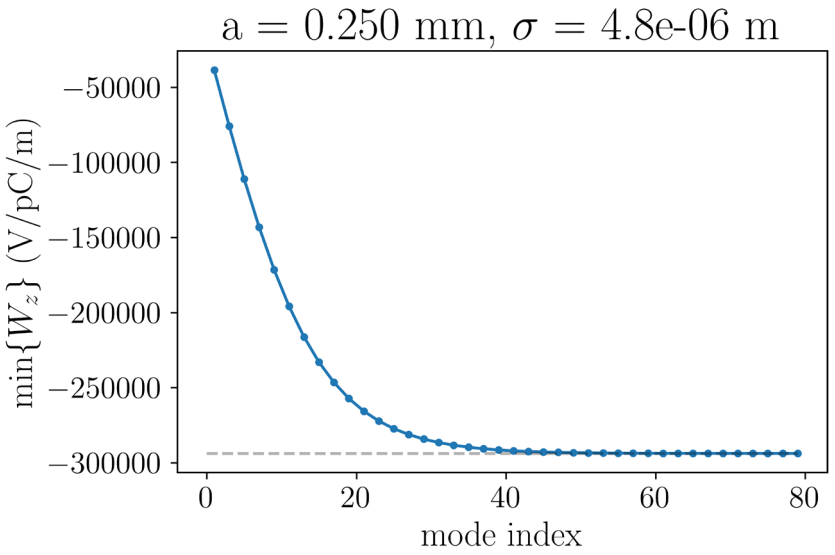


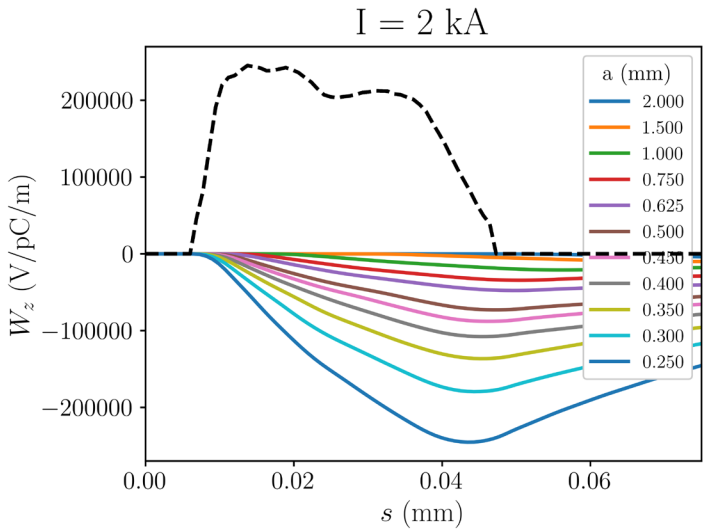


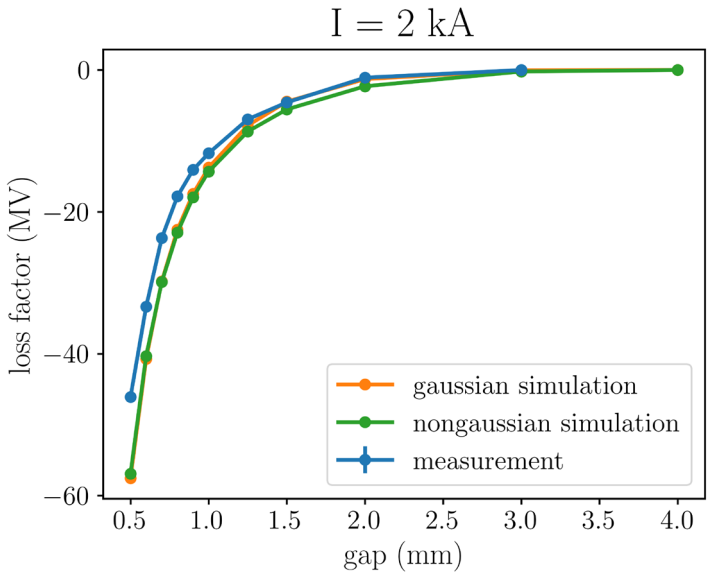
Wake potential does not change when including terms above index 45

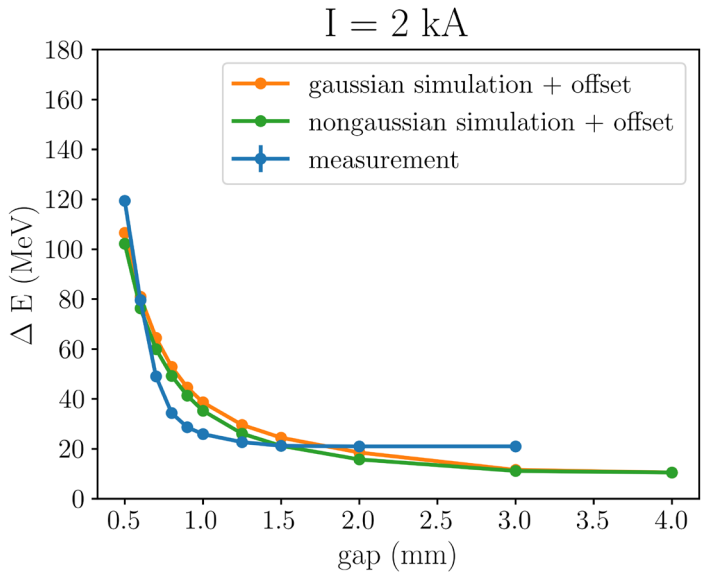
$$W = \sum_{i=1}^{?} w_{m,i}$$

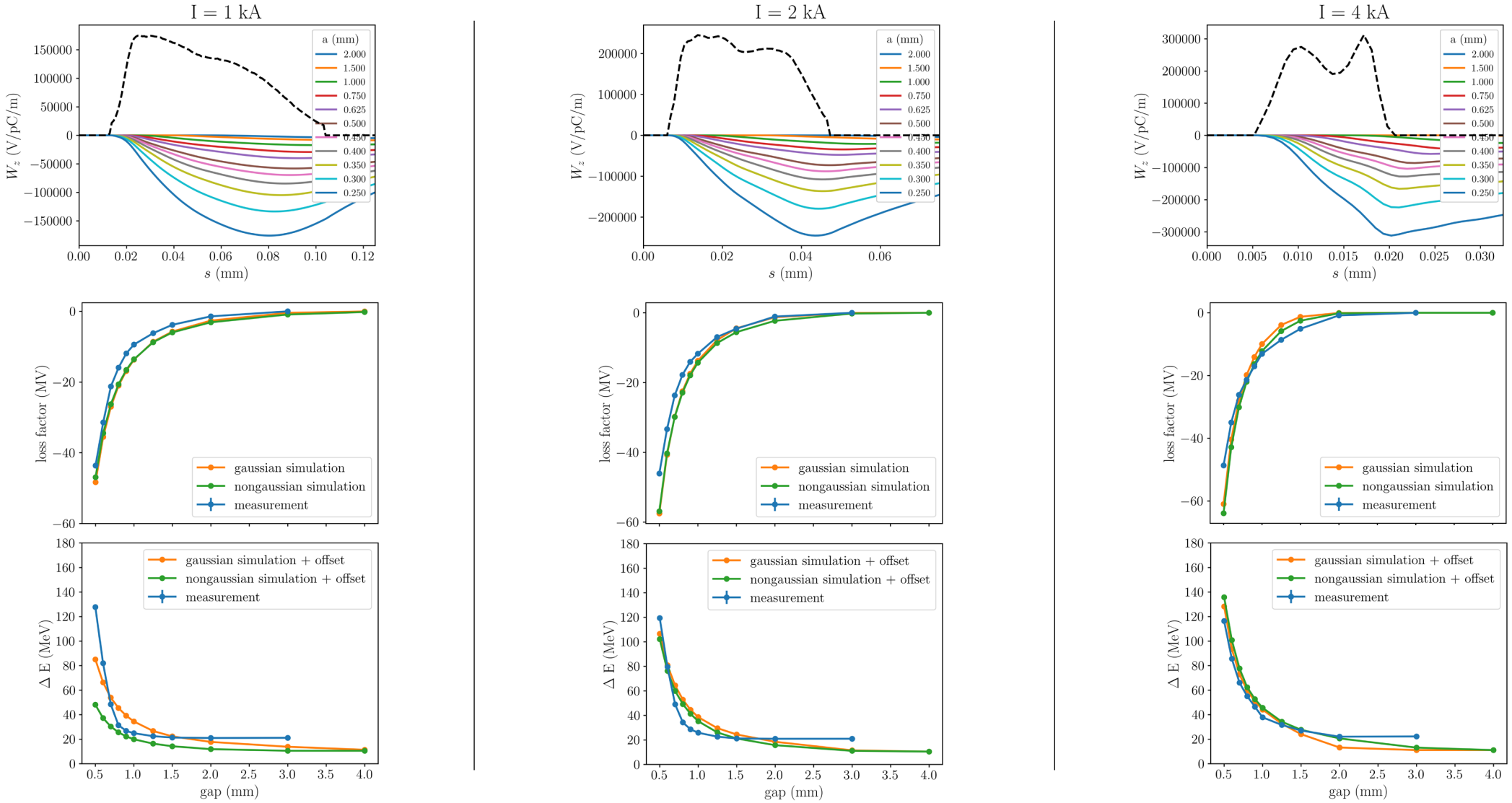





I = 2 kA
a (mm)
2.000
1.500
1.000
0.750
0.625
0.500
0.450
0.400
0.350
0.300
0.250
200000
100000
0
−100000
−200000
W_z (V/pC/m)
0.00
0.02
0.04
0.06
s (mm)

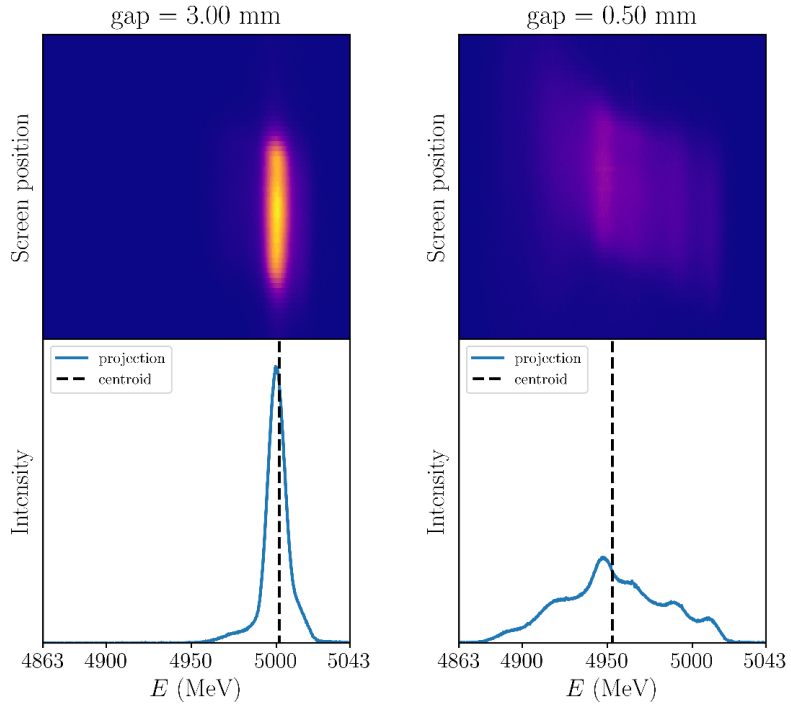

I = 2 kA
0
−20
−40
−60
loss factor (MV)
gaussian simulation
nongaussian simulation
measurement
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
gap (mm)

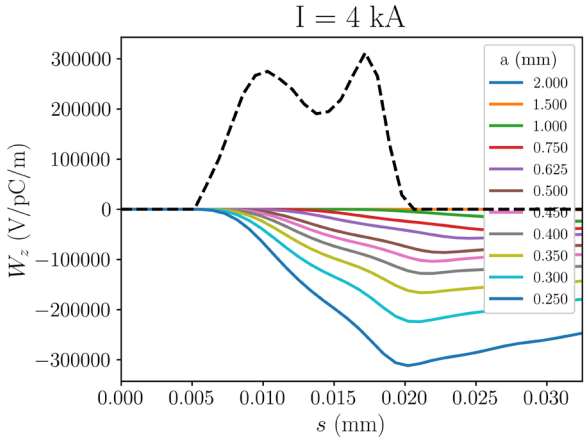

I = 2 kA
180
160
140
120
100
80
60
40
20
0
Δ E (MeV)
gaussian simulation + offset
nongaussian simulation + offset
measurement
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
gap (mm)

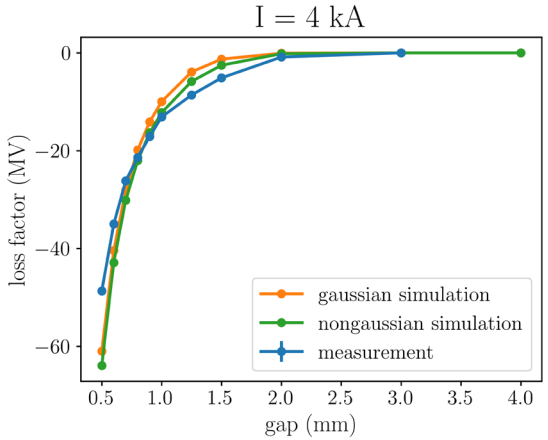

I = 1 kA
I = 2 kA
I = 4 kA
a (mm)
2.000
1.500
1.000
0.750
0.625
0.500
0.450
0.400
0.350
0.300
0.250
W_z (V/pC/m)
s (mm)
loss factor (MV)
gaussian simulation
nongaussian simulation
measurement
Δ E (MeV)
gaussian simulation + offset
nongaussian simulation + offset
measurement
gap (mm)

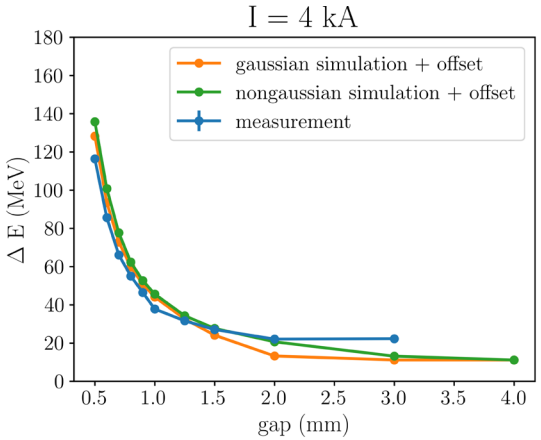
Conclusion

- We have demonstrated the manipulation of the longitudinal phase space of beams from an RF accelerator using a wakefield structure
- I think we should use wakefield structures to control the energy spread of plasma particle accelerators





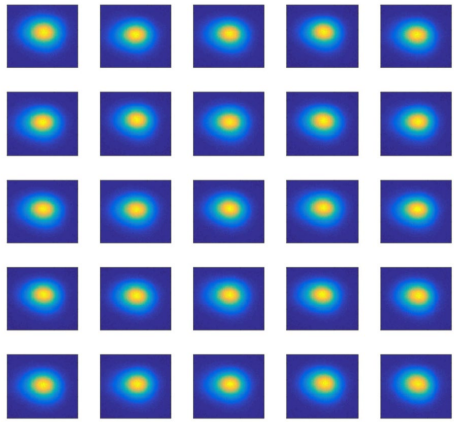




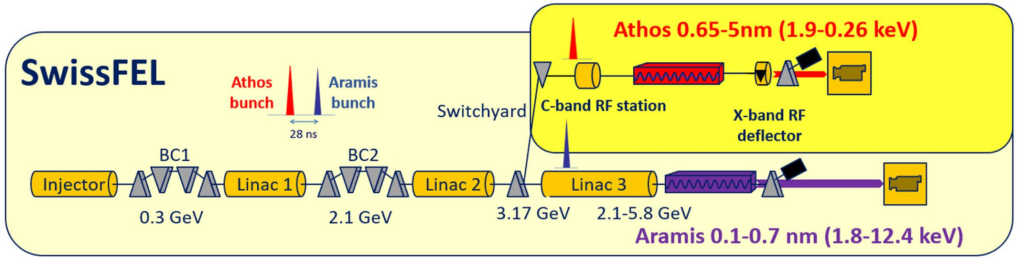
EXTRA SLIDES

SwissFEL & EuPRAXIA

Parameter	SwissFEL
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

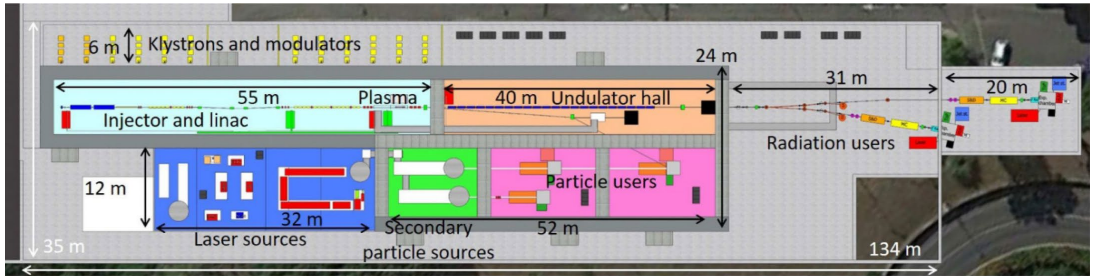


Courtesy: Eduard Prat

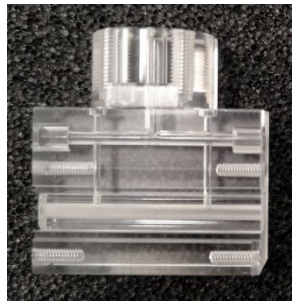


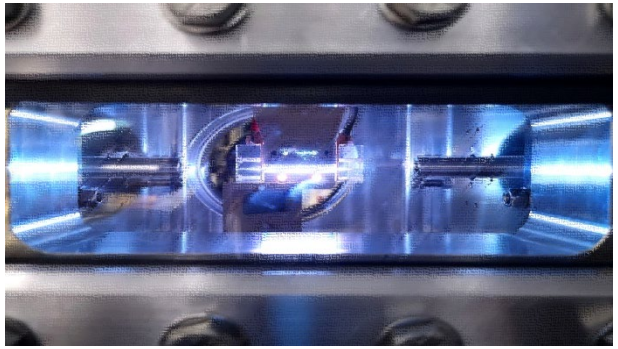
SwissFEL & EuPRAXIA

Parameter	SwissFEL	EuPRAXIA [*]
Length	740 m	150 m
LINAC frequency	5.7 GHz (C-band)	11.9942 GHz (X-band)
Repetition rate	100 Hz	~ 50 Hz
Energy	up to 6.1 GeV	1 – 1.2 GeV
Bunch charge	10 – 200 pC	30 – 50 pC
Trajectory jitter	< 10% of beam size	–
Relative energy jitter	~ 10^{-4}	–
Arrival time jitter	< 10 fs	–
Slice emittance	200 nm (for 200 pC)	500 nm
Bunch length	< 1 fs – 50 fs	10 fs



EuPRAXIA Conceptual Design Report, Assmann, et al.

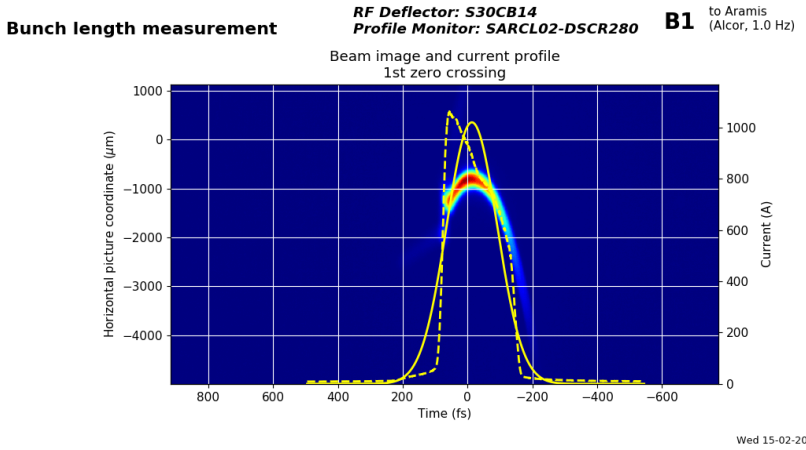




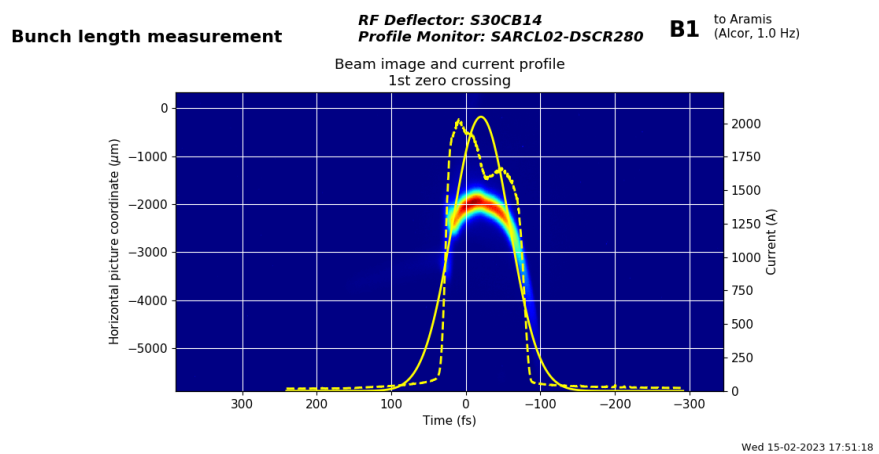
Presented by A Biagioni at EuPRAXIA-DN School April 2024

[*] Presented by C Welch at EuPRAXIA-DN School April 2024

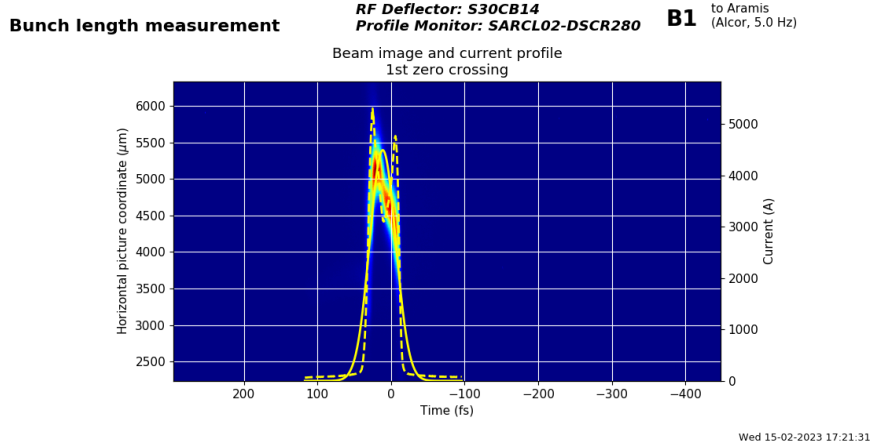
1 kA


Bunch length measurement
RF Deflector: S30CB14
Profile Monitor: SARCL02-DSCR280
B1
to Aramis
(Alcor, 1.0 Hz)
Beam image and current profile
1st zero crossing
Horizontal picture coordinate (μm)
Current (A)
Time (fs)
Wed 15-02-2023 18:02:23

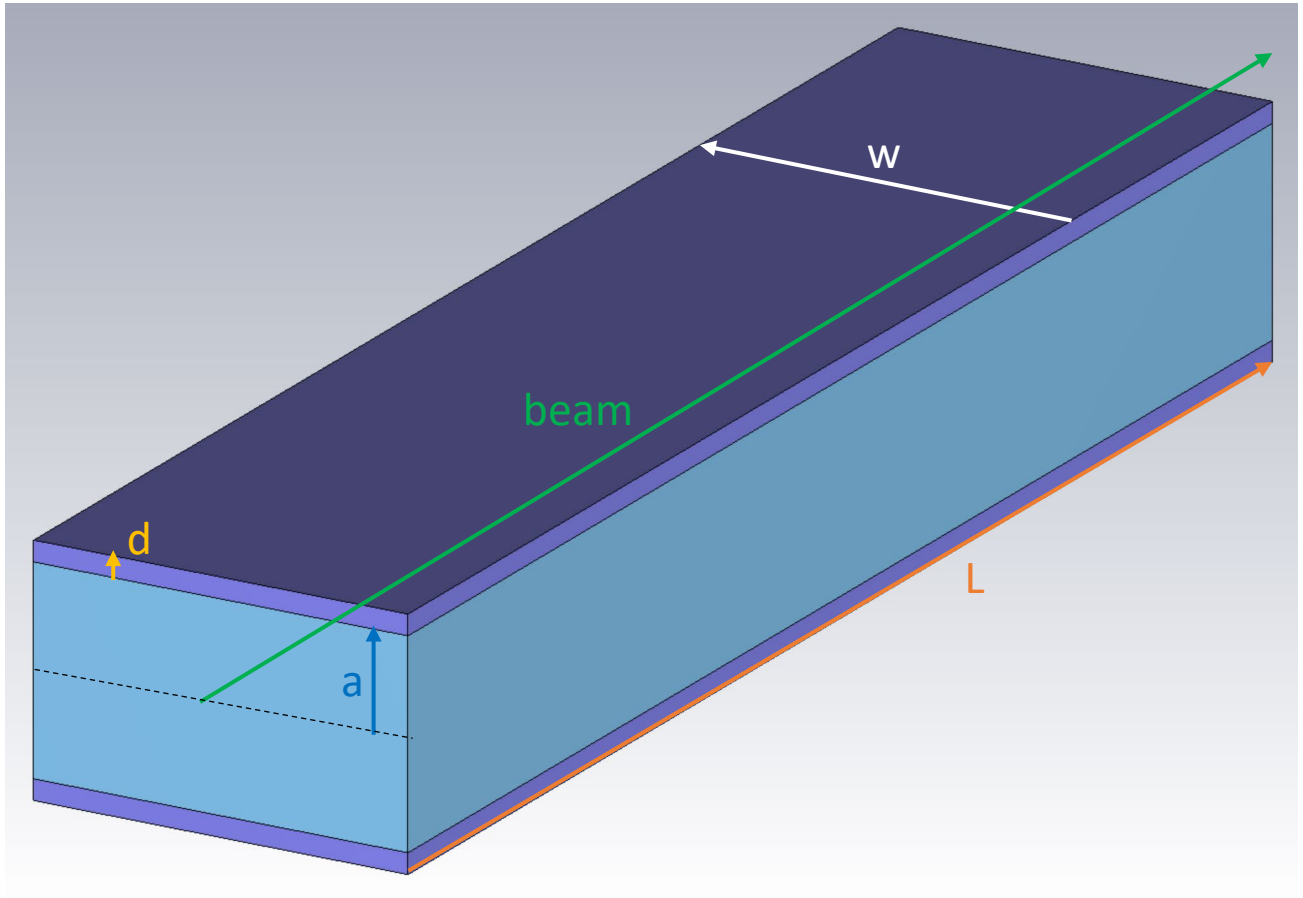
2 kA

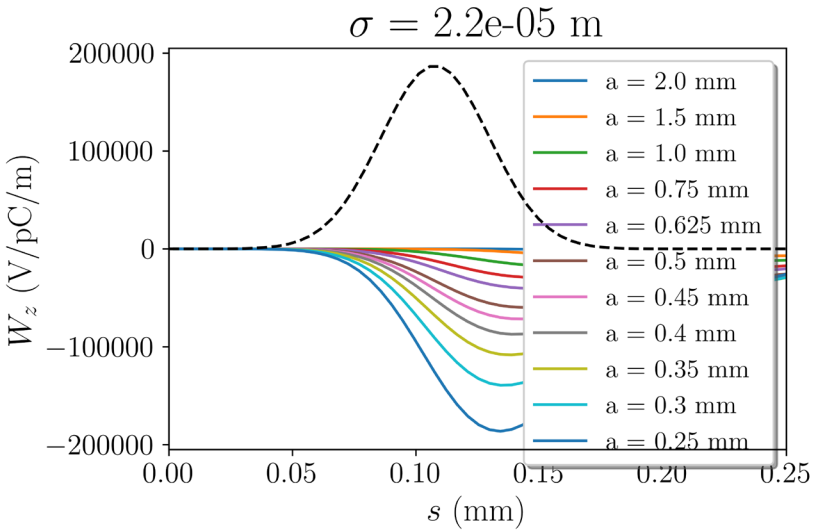

Bunch length measurement
RF Deflector: S30CB14
Profile Monitor: SARCL02-DSCR280
B1
to Aramis
(Alcor, 1.0 Hz)
Beam image and current profile
1st zero crossing
Horizontal picture coordinate (μm)
Current (A)
Time (fs)
Wed 15-02-2023 17:51:18

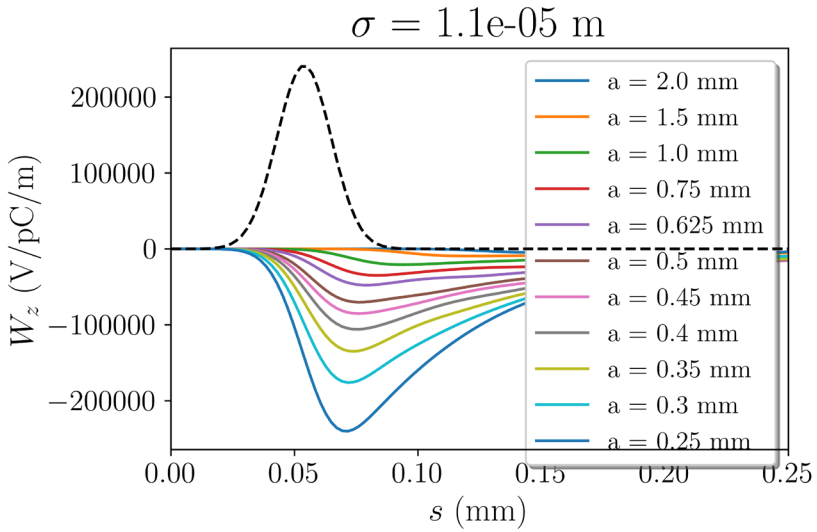
4 kA

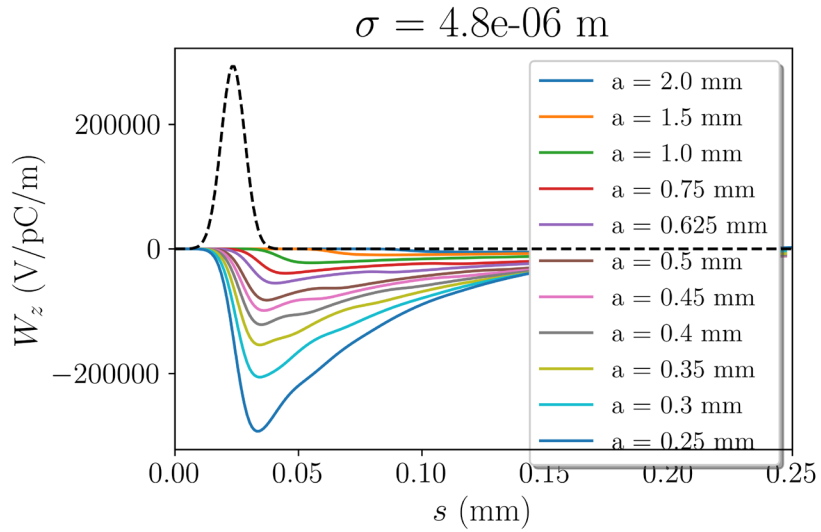

Bunch length measurement
RF Deflector: S30CB14
Profile Monitor: SARCL02-DSCR280
B1
to Aramis
(Alcor, 5.0 Hz)
Beam image and current profile
1st zero crossing
Horizontal picture coordinate (μm)
Current (A)
Time (fs)
Wed 15-02-2023 17:21:31

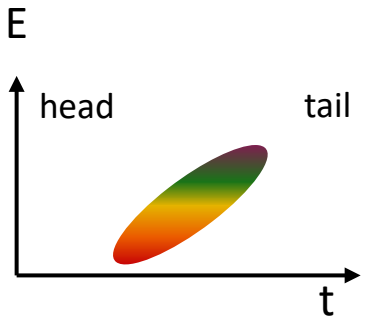
Parameter	Value
half-gap, a	0.25 mm – 1.5 mm
Length, L	1 m
Width, w	15 mm
Dielectric thickness, d	0.4 mm
Alumina Permittivity, ε_r	~ 10

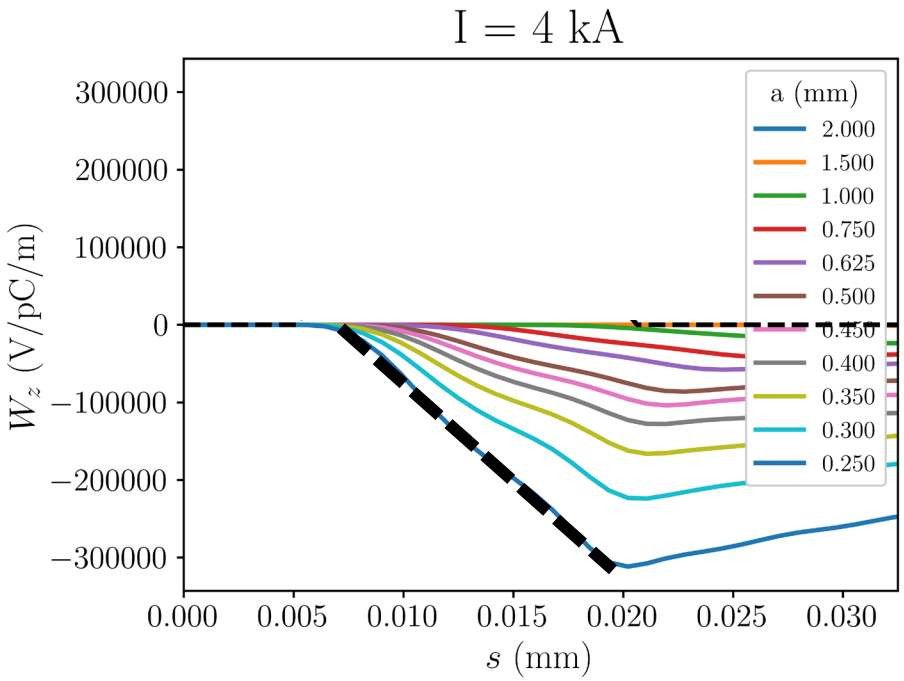


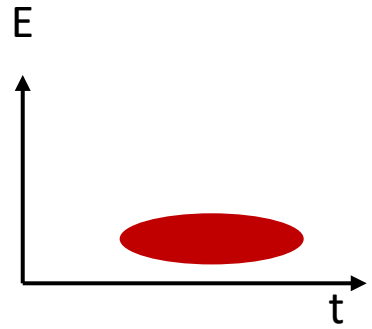

σ = 2.2e-05 m
200000
100000
0
−100000
−200000
W_z (V/pC/m)
0.00
0.05
0.10
0.15
0.20
0.25
s (mm)
a = 2.0 mm
a = 1.5 mm
a = 1.0 mm
a = 0.75 mm
a = 0.625 mm
a = 0.5 mm
a = 0.45 mm
a = 0.4 mm
a = 0.35 mm
a = 0.3 mm
a = 0.25 mm


σ = 1.1e-05 m
200000
100000
0
−100000
−200000
W_z (V/pC/m)
0.00
0.05
0.10
0.15
0.20
0.25
s (mm)
a = 2.0 mm
a = 1.5 mm
a = 1.0 mm
a = 0.75 mm
a = 0.625 mm
a = 0.5 mm
a = 0.45 mm
a = 0.4 mm
a = 0.35 mm
a = 0.3 mm
a = 0.25 mm

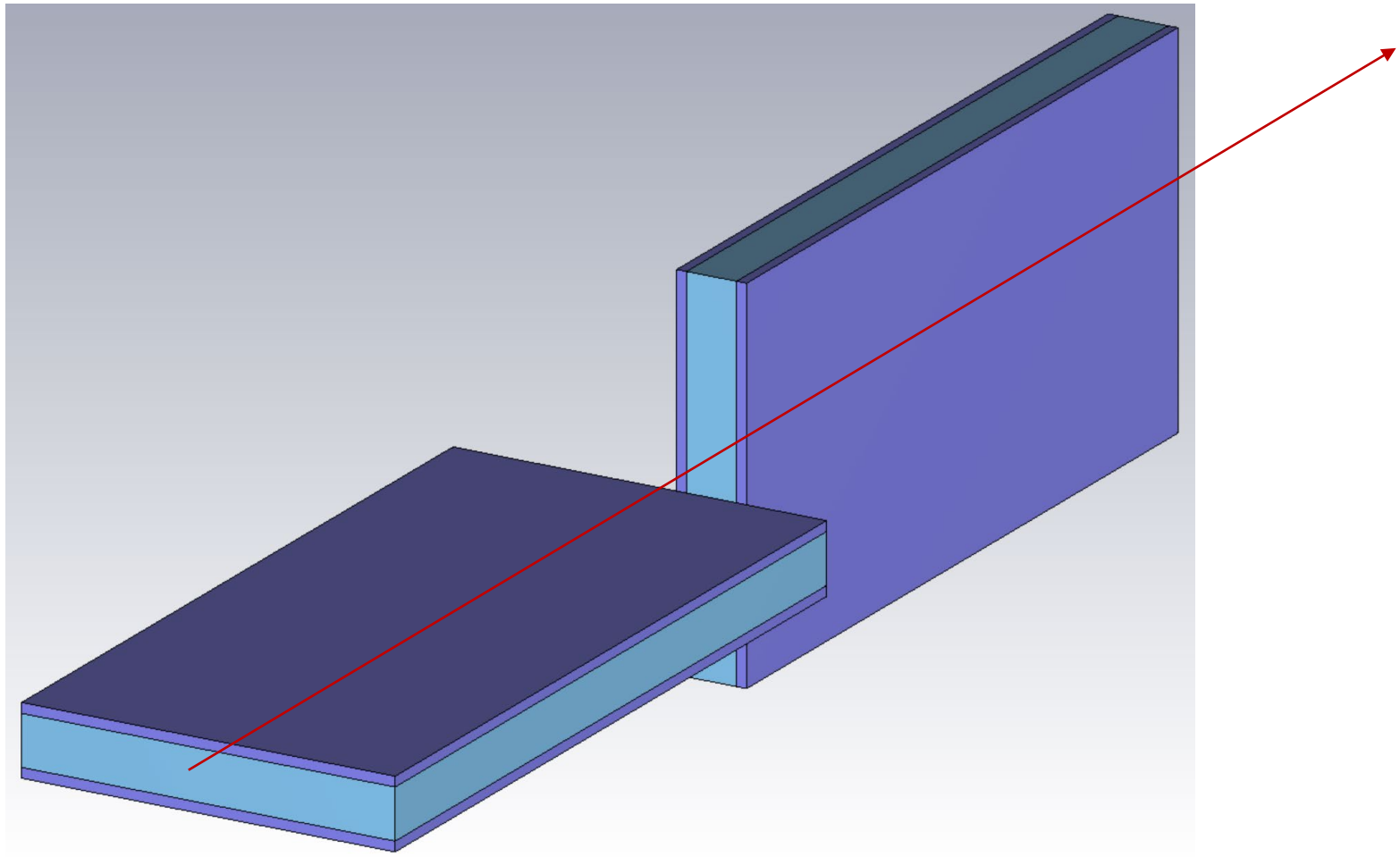

σ = 4.8e-06 m
200000
0
−200000
W_z (V/pC/m)
0.00
0.05
0.10
0.15
0.20
0.25
s (mm)
a = 2.0 mm
a = 1.5 mm
a = 1.0 mm
a = 0.75 mm
a = 0.625 mm
a = 0.5 mm
a = 0.45 mm
a = 0.4 mm
a = 0.35 mm
a = 0.3 mm
a = 0.25 mm



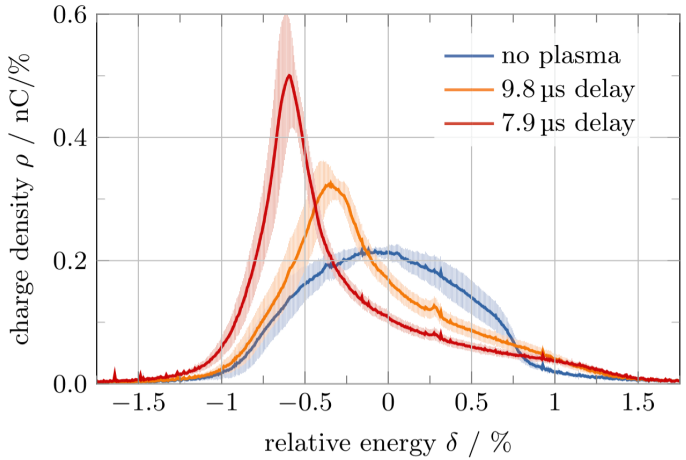




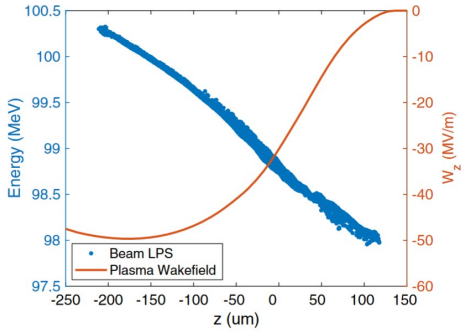
For gap = 0.5 mm, structure produces wake with slope of -26 MV/pC/m/mm
For 2*1 m structure, 200 pC bunch:
Bunches with -10.4 MV/um chirp can be dechirped



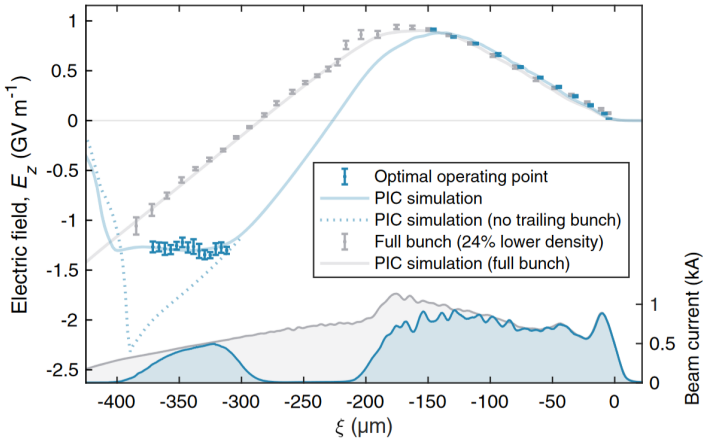
Possible solutions



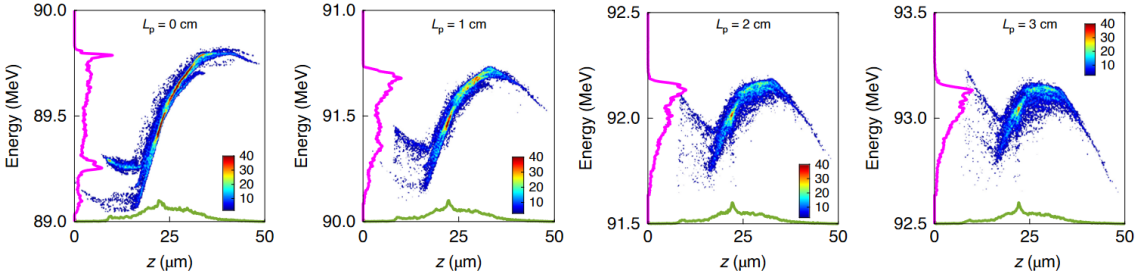
Tunable Plasma-Based Energy Dechirper, D'Arcy, et al.



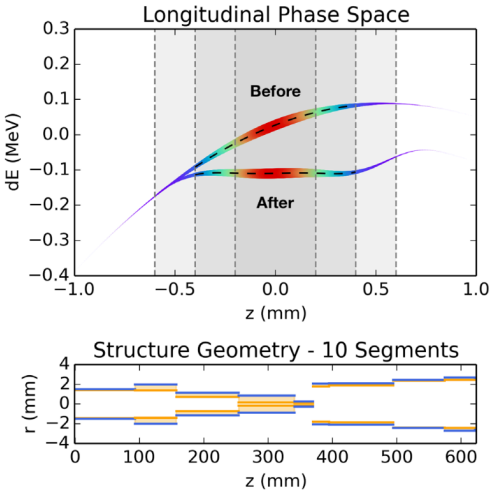
Longitudinal Phase-Space Manipulation with Beam-Driven Plasma Wakefields, Shpakov, et al.



Energy-Spread Preservation and High Efficiency in a Plasma-Wakefield Accelerator, Lindstrøm, et al.



Energy spread minimization in a beam-driven plasma wakefield accelerator, Pompili, et al.



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