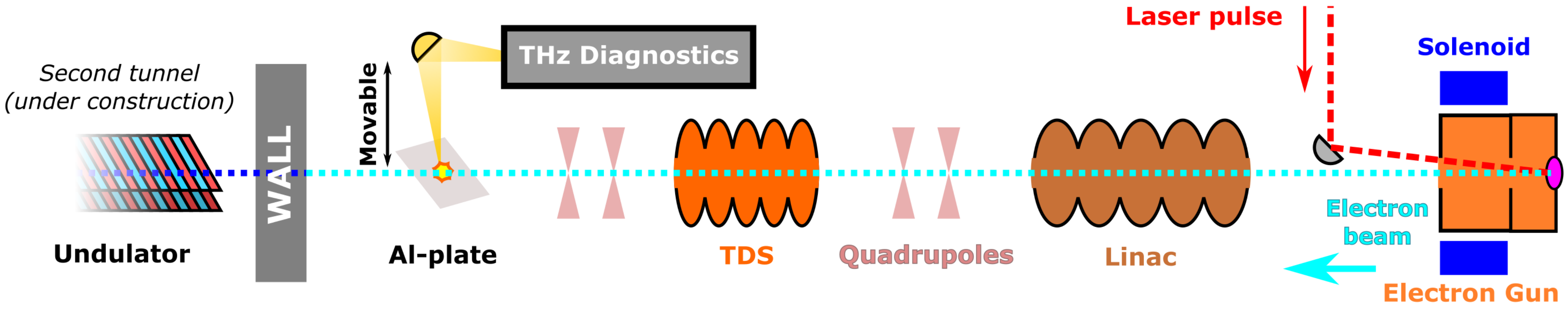
Electron beam studies from intensity modulated photo-cathode laser pulses for seeding a THz FEL

Georgi Georgiev
Zeuthen, 11.03.2021

Introduction

PITZ facility and THz program



- Photo Injector Test Facility at DESY in Zeuthen (PITZ)
- THz program at PITZ
  - Accelerator based THz radiation source
  - For pump-probe experiments at European XFEL
- Proof of principle experiment with undulator
  - THz free electron laser (THz FEL)

Key components in this study

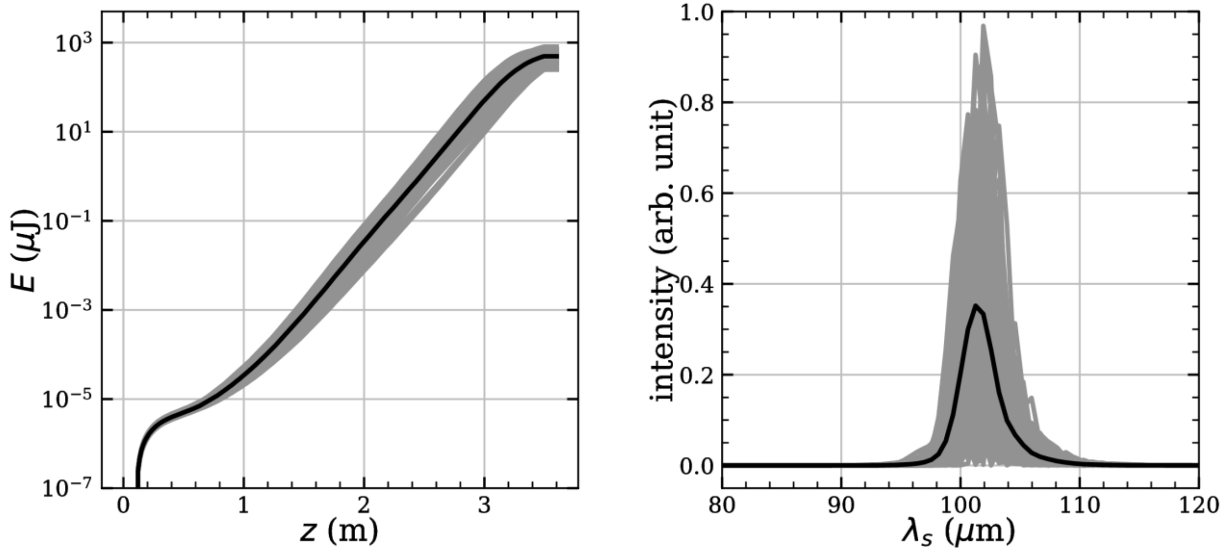
- RF photo-electron gun (Photoinjector)
- Main solenoid of RF gun
- Linac RF cavity
- Transverse deflecting structure (TDS)
- Al-plate for THz generation
- THz diagnostic station

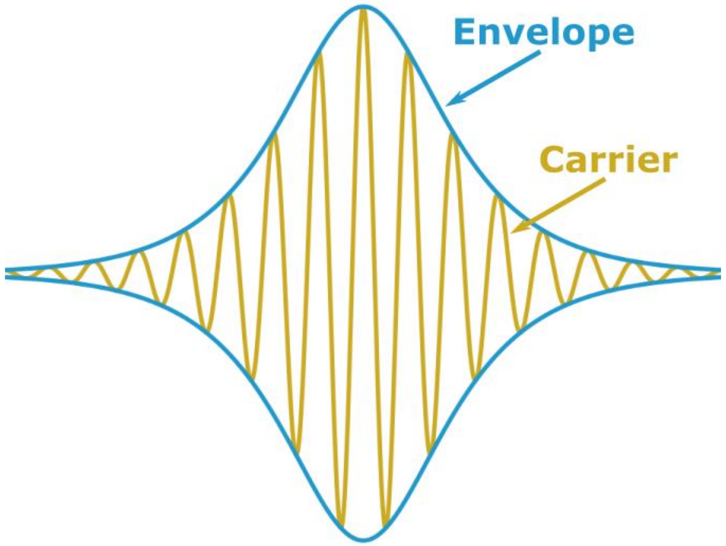
Seeding for FELs

Temporal photocathode laser modulation

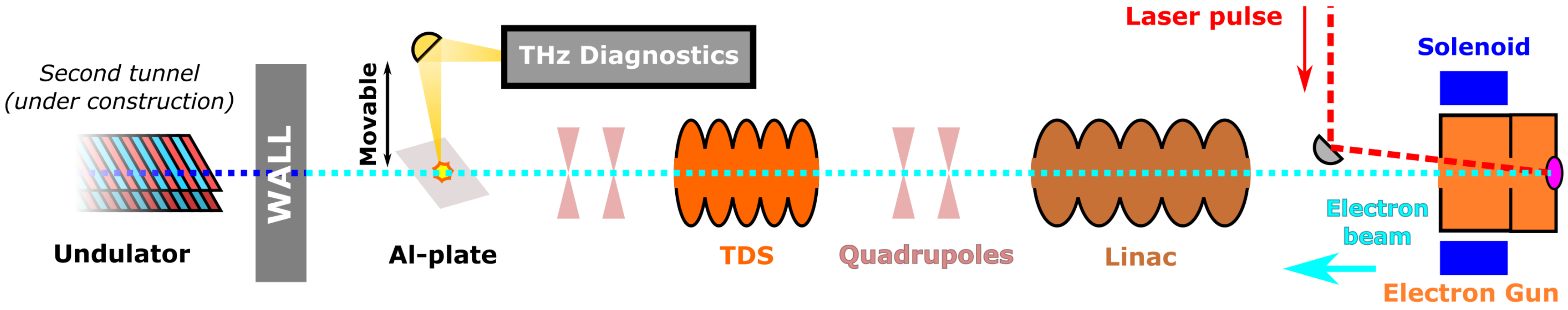
- Performance of SASE FEL for PITZ
  - Self-amplified spontaneous emission
  - Saturation energy ~ 500 µJ @ 4 nC
  - Frequency and energy variations
- Seeding for THz
  - Amplify **seed signal** in FEL
  - Goal: **carrier-envelope phase stability**
- Photocathode laser pulse modulation
  - Laser intensity → electron density
  - Time domain intensity modulations

Pulse energy growth along undulator and final THz spectrum for 100 pulses and their average (simulation, courtesy X.K. Li @ PITZ)

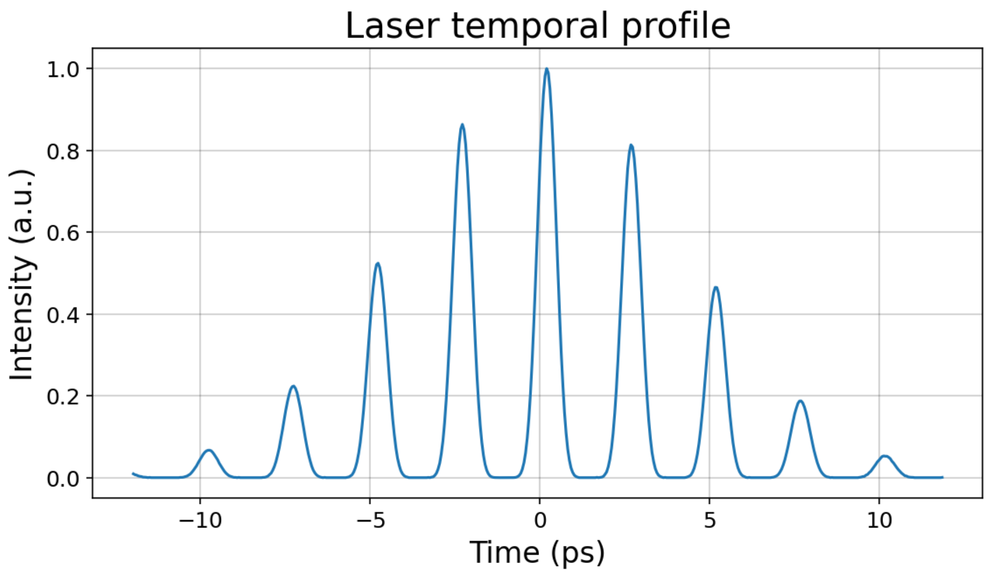




Simulation setup



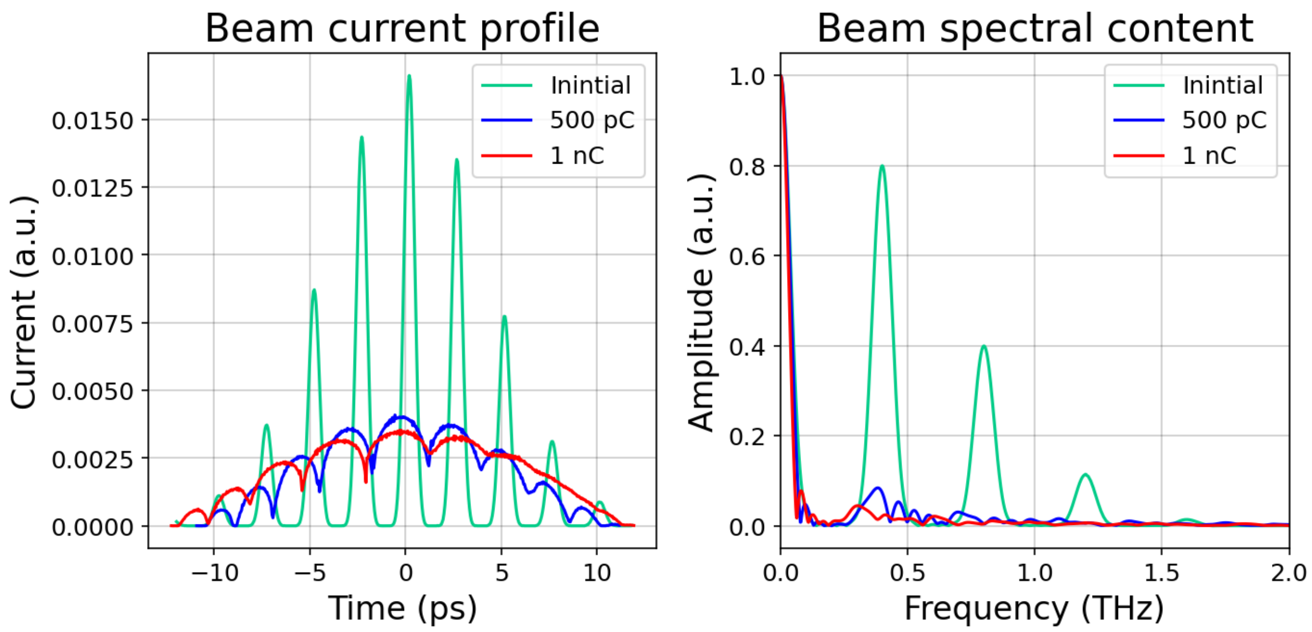
- Tracking with ASTRA code
  - Space charge effects
  - Initial beam – laser pulse
- Gun solenoid field
- Gun – final momentum 6,7 MeV/c
- Linac – final momentum 20,7 MeV/c



Simulation with modulation by Lyot filter

Beam charge of 500 pC and 1 nC comparison

- Laser pulse
  - Truncated Gaussian envelope
  - Pulse modulation - 4 ps period
  - To match experiment
- *At minimum transverse size on Al-plate*
- Space charge forces
  - Repulsion force between electrons
  - **Degrade** pulse structure
  - Decrease spectral peak

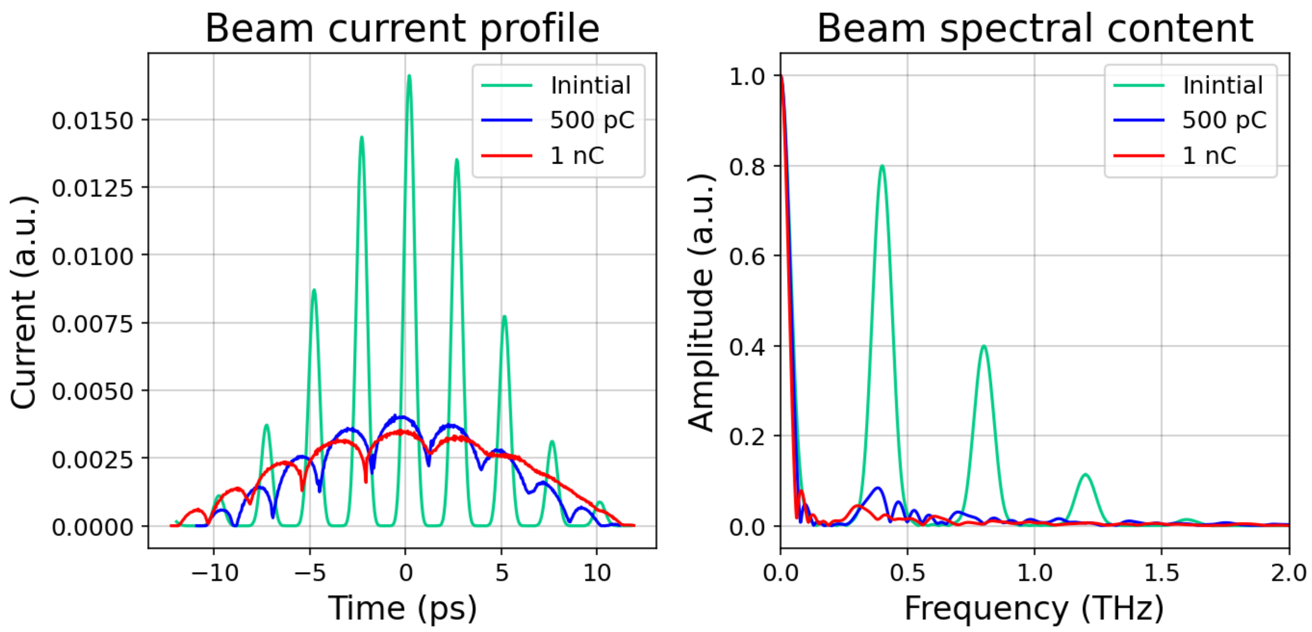


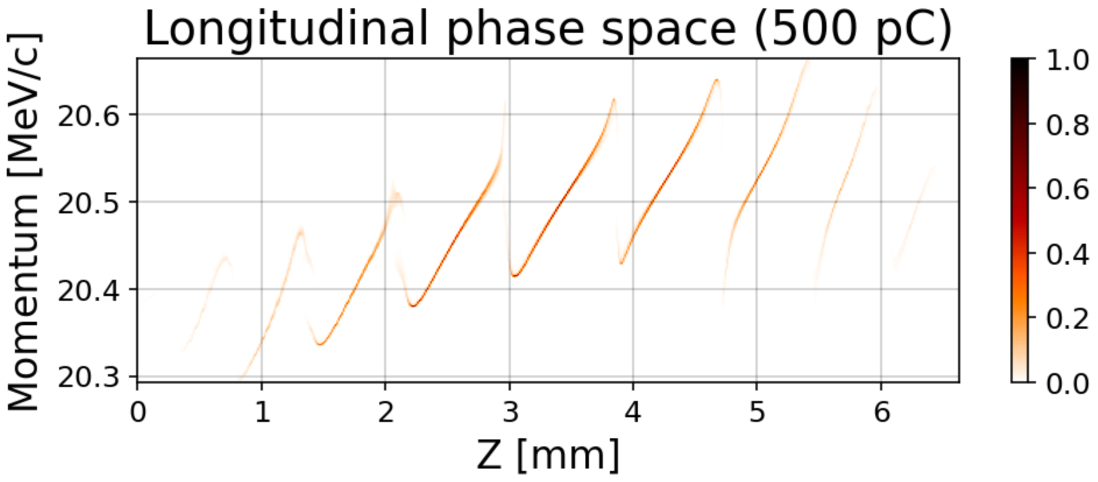
Charge	Peak H. [%]	Freq. [THz]
500 pC	17,4	0,276
1 nC	10,3	0,264

Simulation with modulation by Lyot filter (2)

Longitudinal phase space

- Particle momentum vs time distribution
- Space charge forces
  - Repulsion force between electrons
  - Energy chirped sub-pulses
- Good separation remains in phase space
  - Contrasting beam current





- Modulation recovery
  - Longitudinal phase space rotation
  - Magnetic chicane

Photocathode laser modulation

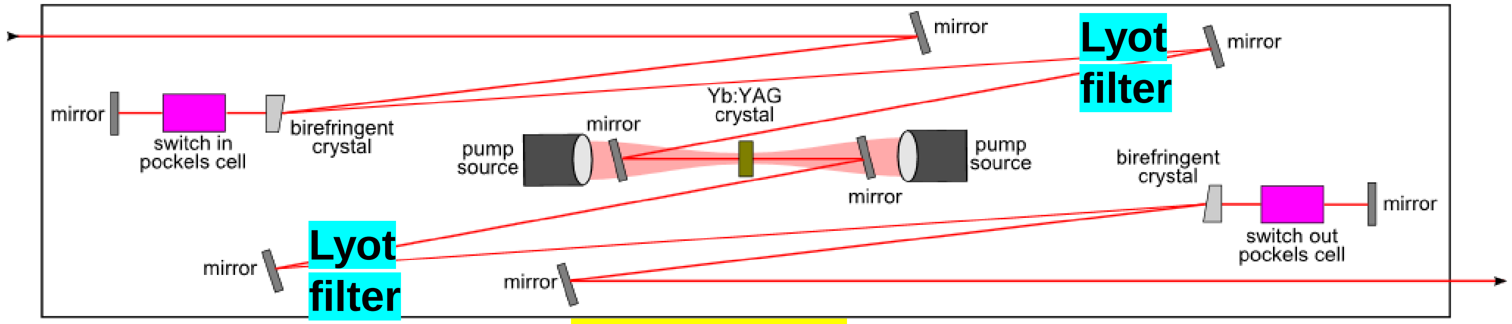
Lyot filter

- Lyot filter – laser bandpass filter
  - Wavelength dependent polarization rotation
  - Polarizer
- Frequency difference beating in THz range

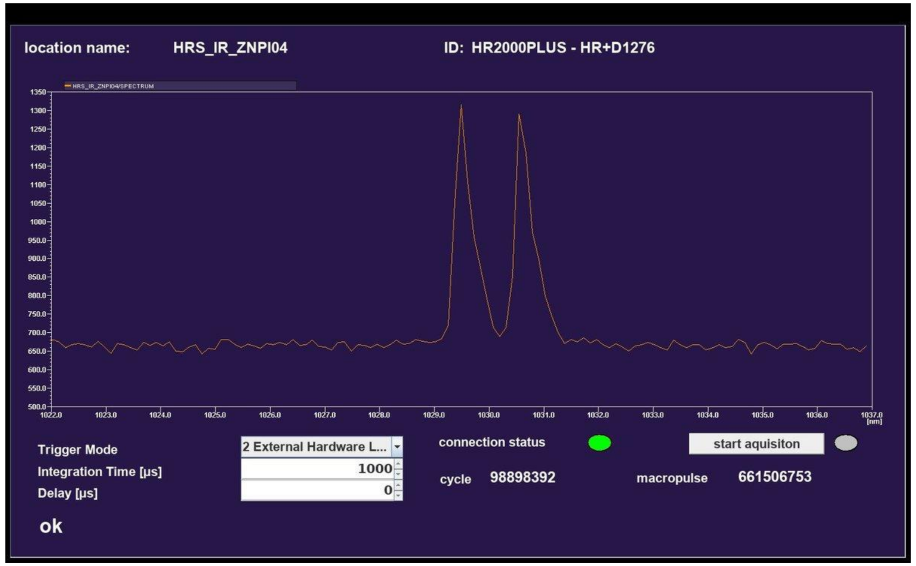
Crystal retardation

$$T = \cos^2(r(\lambda) + \alpha)$$

Tuning angle

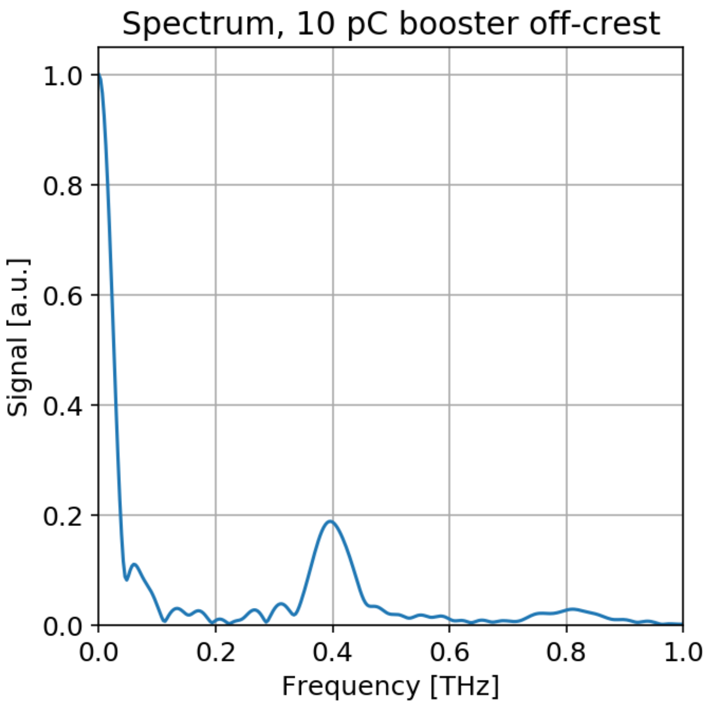


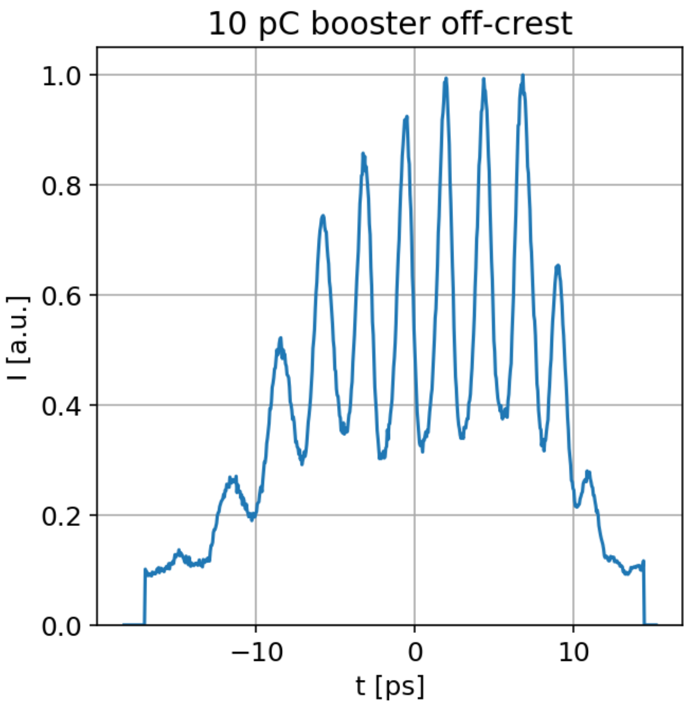
Courtesy: M. Gross



Experiment: electron beam profile

- Measure with beam chirping
  - Energy-trajectory: dipole dispersion
  - Dispersed beam image on screen
- RMS length ~7 ps
- Modulation frequency - 0.4 THz
- Spectral peak height: ~20 %

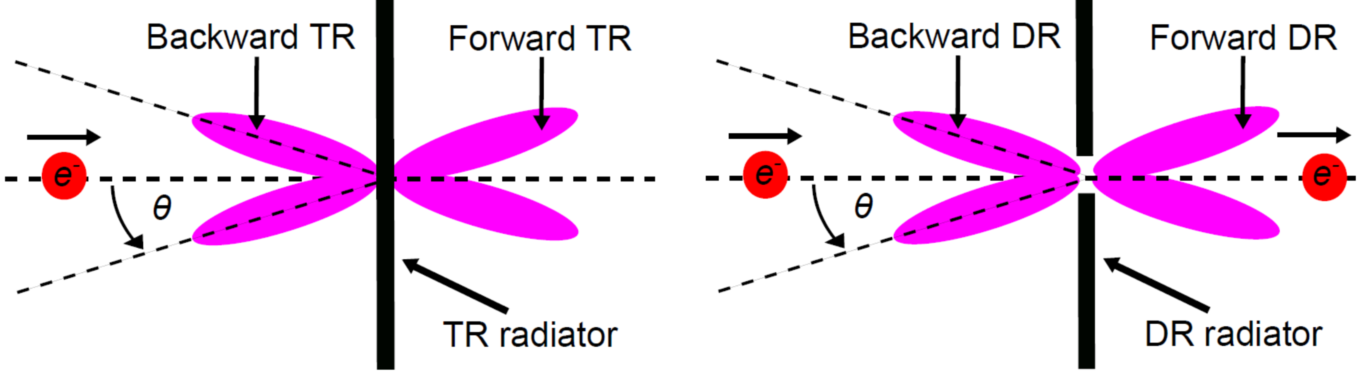




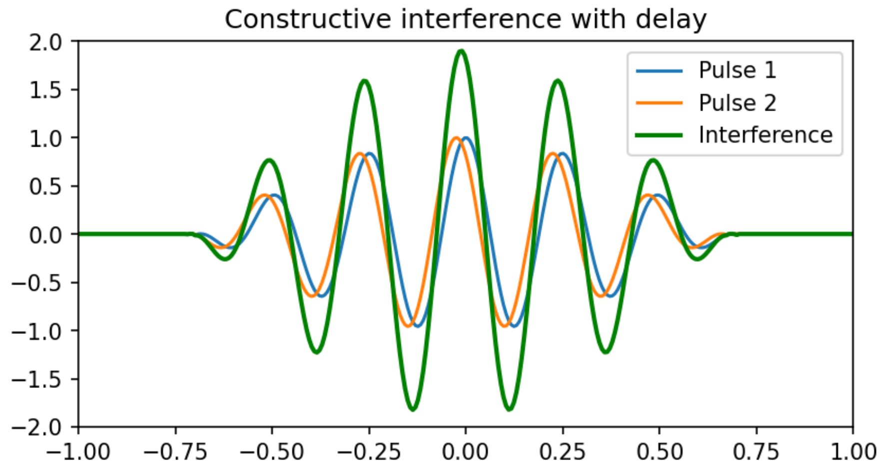
Transition radiation

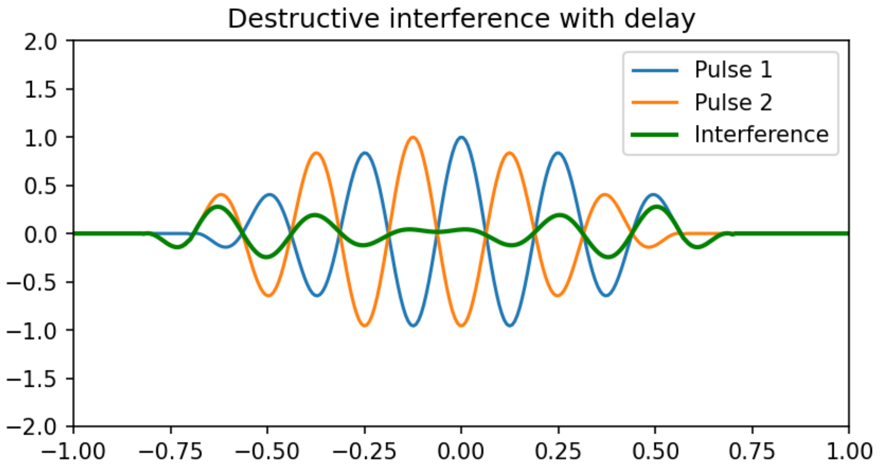
- Electron passes material boundary
  - Different dielectric constants
  - Ginzburg-Frank formula
- Coherent transition radiation
- TR spectrum measurement
  - Michaelson interferometer

Courtesy: P. Boonpornprasert



(a) transition radiation (TR) (b) Diffraction radiation (TR)



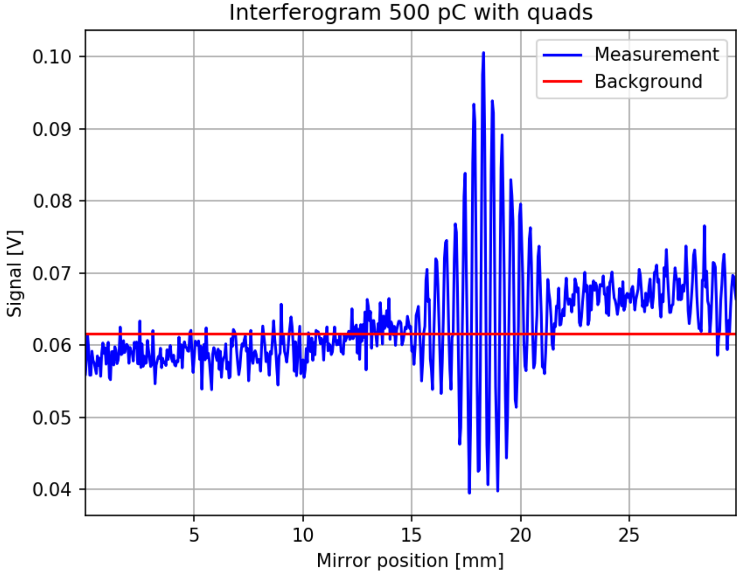


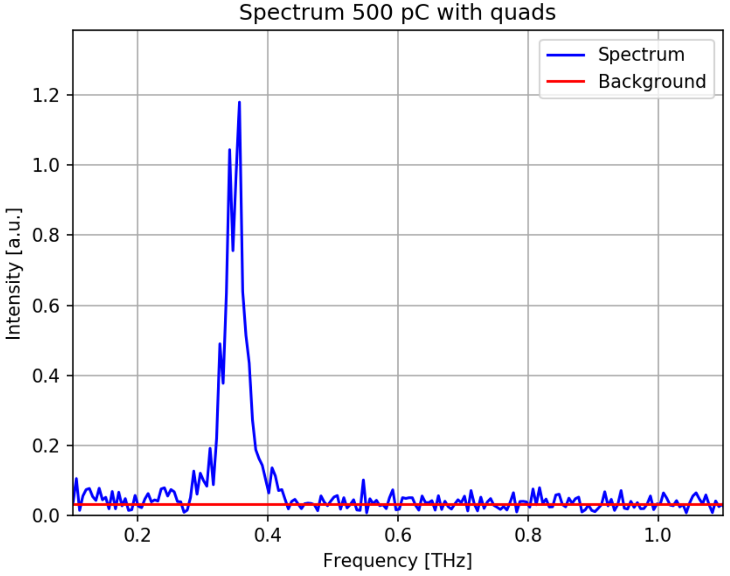
Experiment: transition radiation spectrum

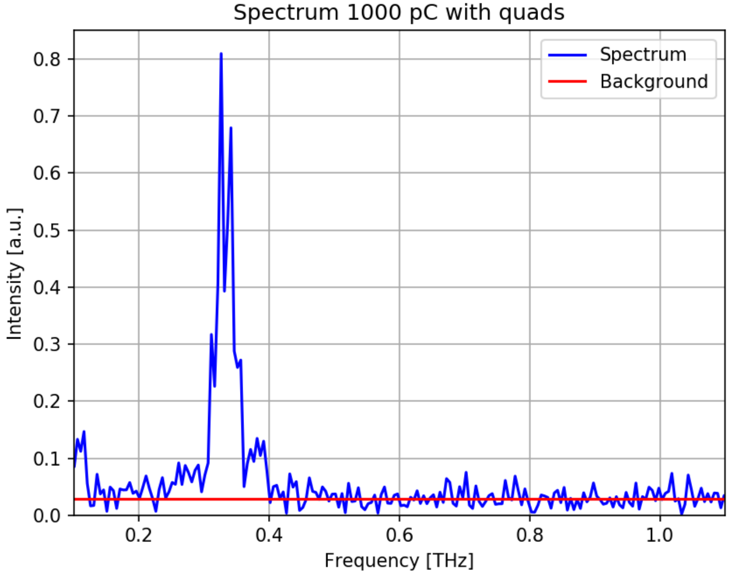
Interferogram of THz pulse

- Fourier transform → spectrum
- Peak frequency
  - **Very stable** over hour

Case	Peak [a.u.]	Peak w/o bkg	Freq. [THz]
500 pC @ Imin	0,627	0,593	0,356
500 pC @ Imin-20A + quads	1,18	1,15	0,356
1 nC @ Imin	0,546	0,511	0,324
1 nC @ Imin-20A + quads	0,809	0,781	0,326

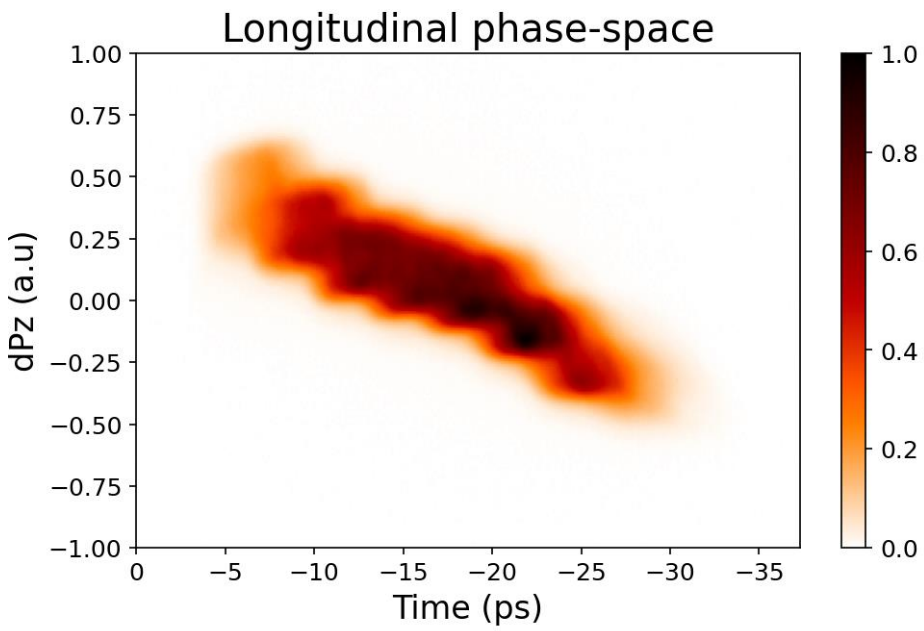


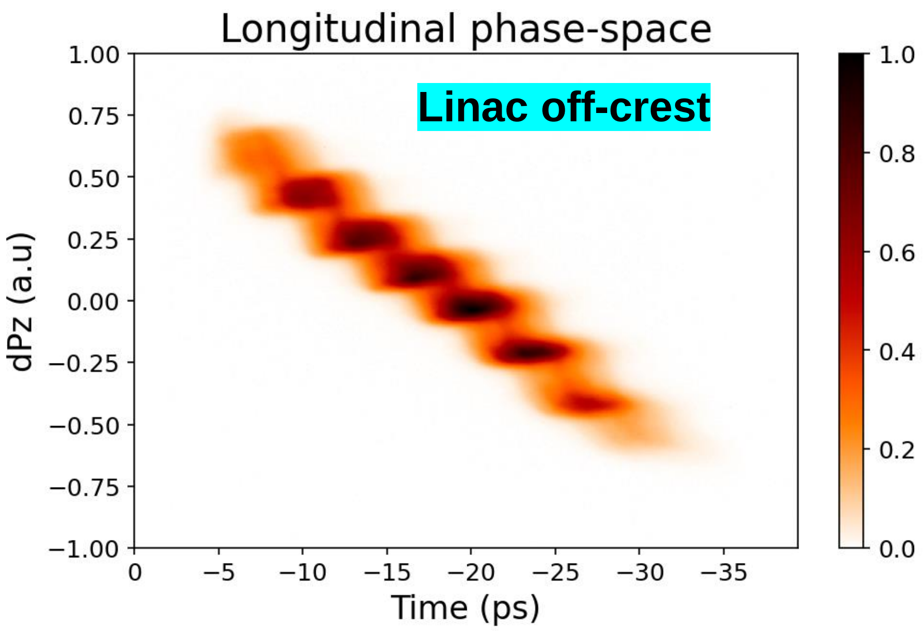




Experiment: longitudinal phase space

- Particle momentum vs time distribution
- Limited by resolution of measurement
- Modulations revealed with beam chirping
  - Stretching phase in linac cavity





Summary and outlook

- Summary
  - Space charge forces smear modulations from photocathode
  - Sub-pulses separated in longitudinal phase space

- Outlook
  - Start to end simulation with undulator
  - Bunch compressor simulation
  - Alternative techniques of generating modulations
  - Other approaches to seeding

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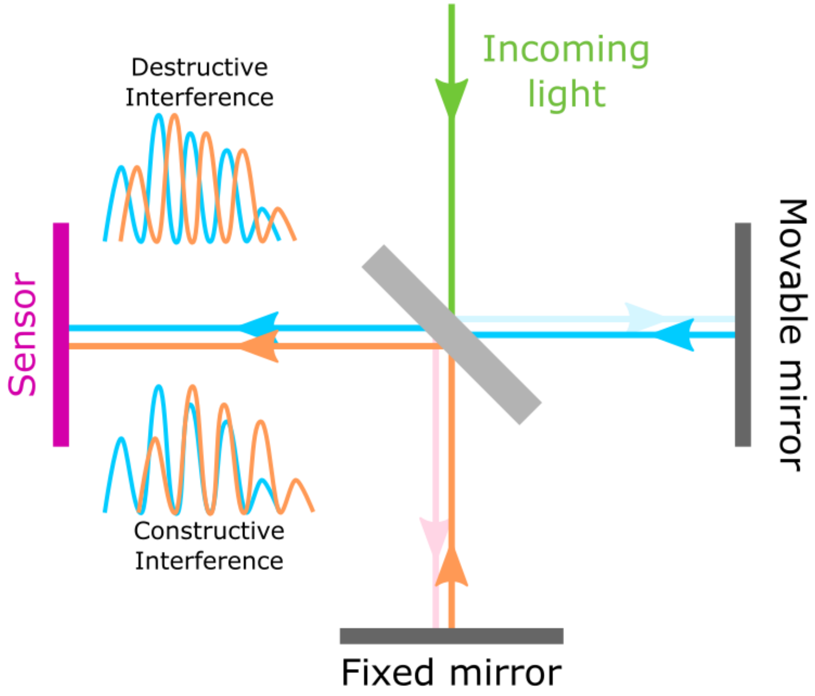
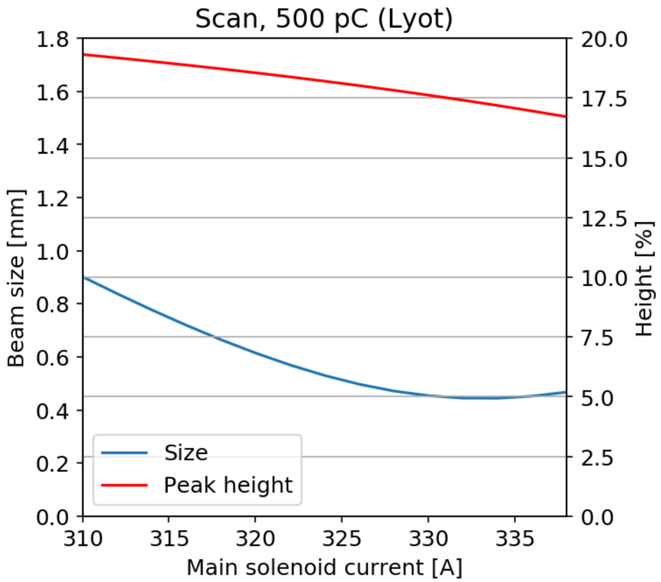
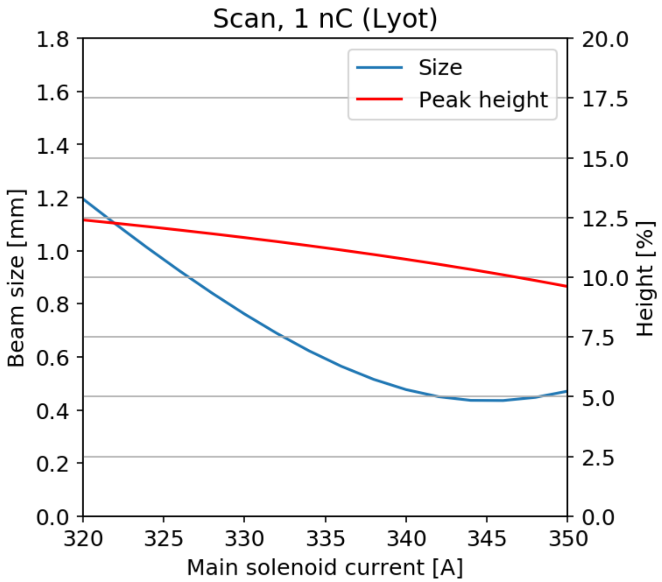
Thank you

This work was supported by the European XFEL research and development program.

Backup


Incoming
light
Destructive
Interference
Sensor
Movable mirror
Constructive
Interference
Fixed mirror


Scan, 500 pC (Lyot)
Beam size [mm]
Height [%]
Main solenoid current [A]
Size
Peak height
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
310
315
320
325
330
335


Scan, 1 nC (Lyot)
Beam size [mm]
Height [%]
Main solenoid current [A]
Size
Peak height
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
320
325
330
335
340
345
350