# Control of free electrons in the vicinity of dielectric nanostructures

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## 1. Introduction

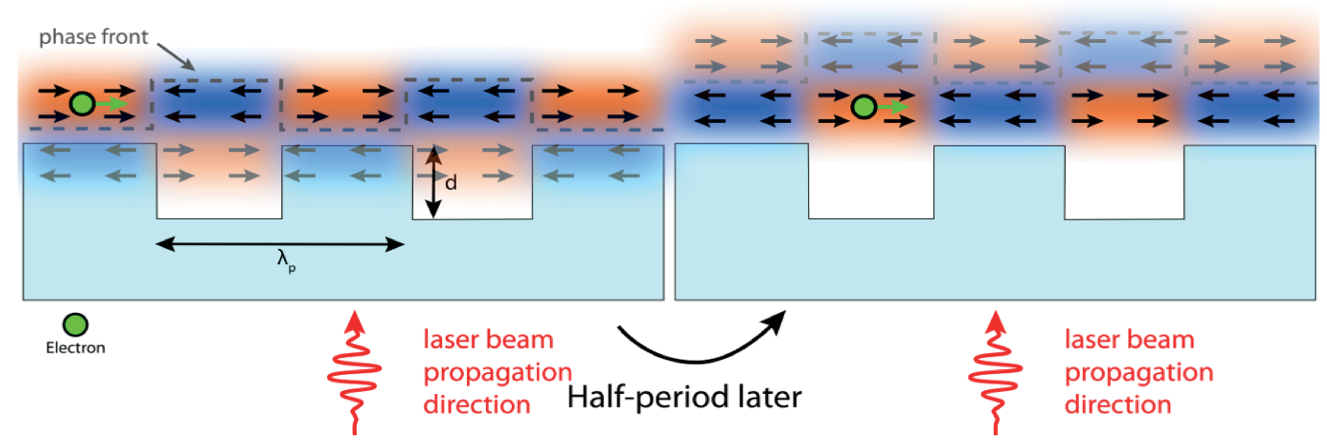
- Goal: A miniaturized MeV electron source on a chip which facilitates affordable experiments with a compact device fitting even in small laboratories [1-3]

Current progress:

- Acceleration gradients up to 1 GeV/m [4]
- Transverse and longitudinal control of electrons with special designed dielectric microstructures [5]

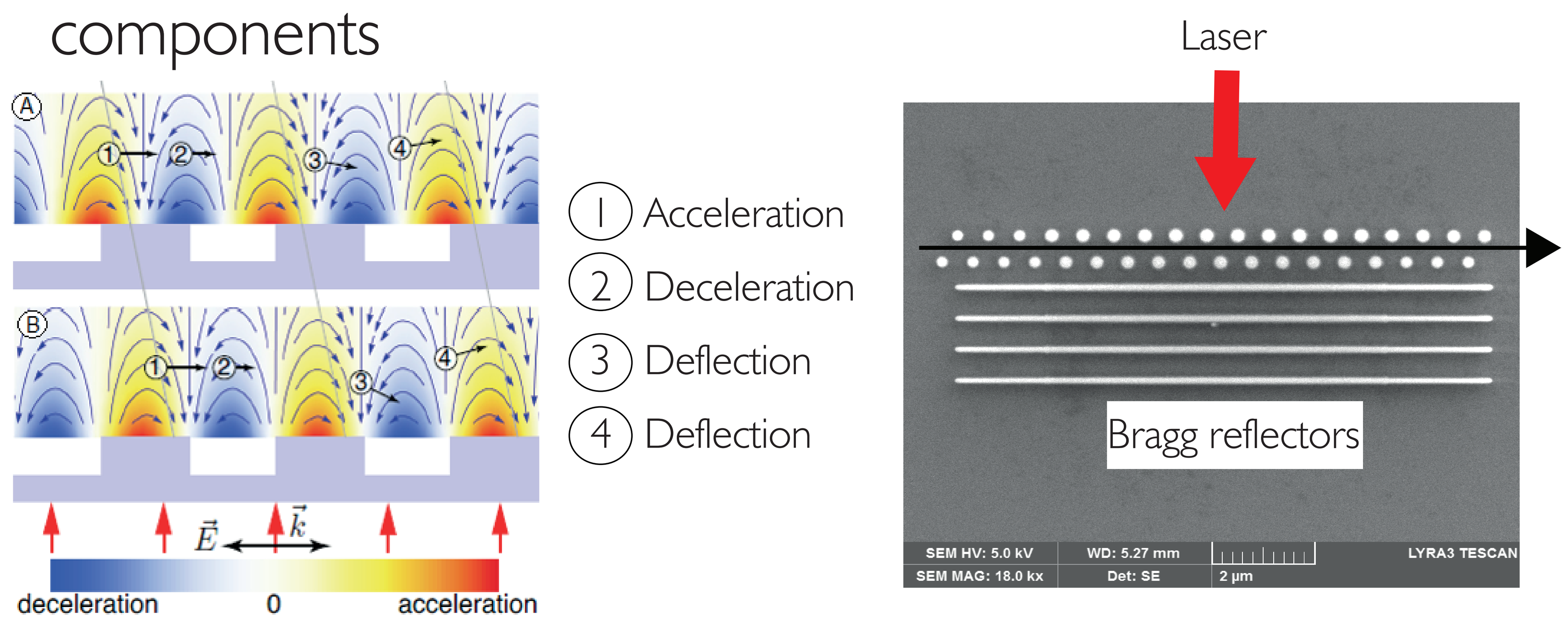
## 2. Laser-based particle acceleration with dielectric structures

- Light travels slower through dielectric material than through the vacuum inbetween the material, acting as a phase mask
- Modulation of the optical fields along the grating, creating an accelerating mode
- Electrons have to match mode velocity
- Transparent structures allow very high laser peak fields



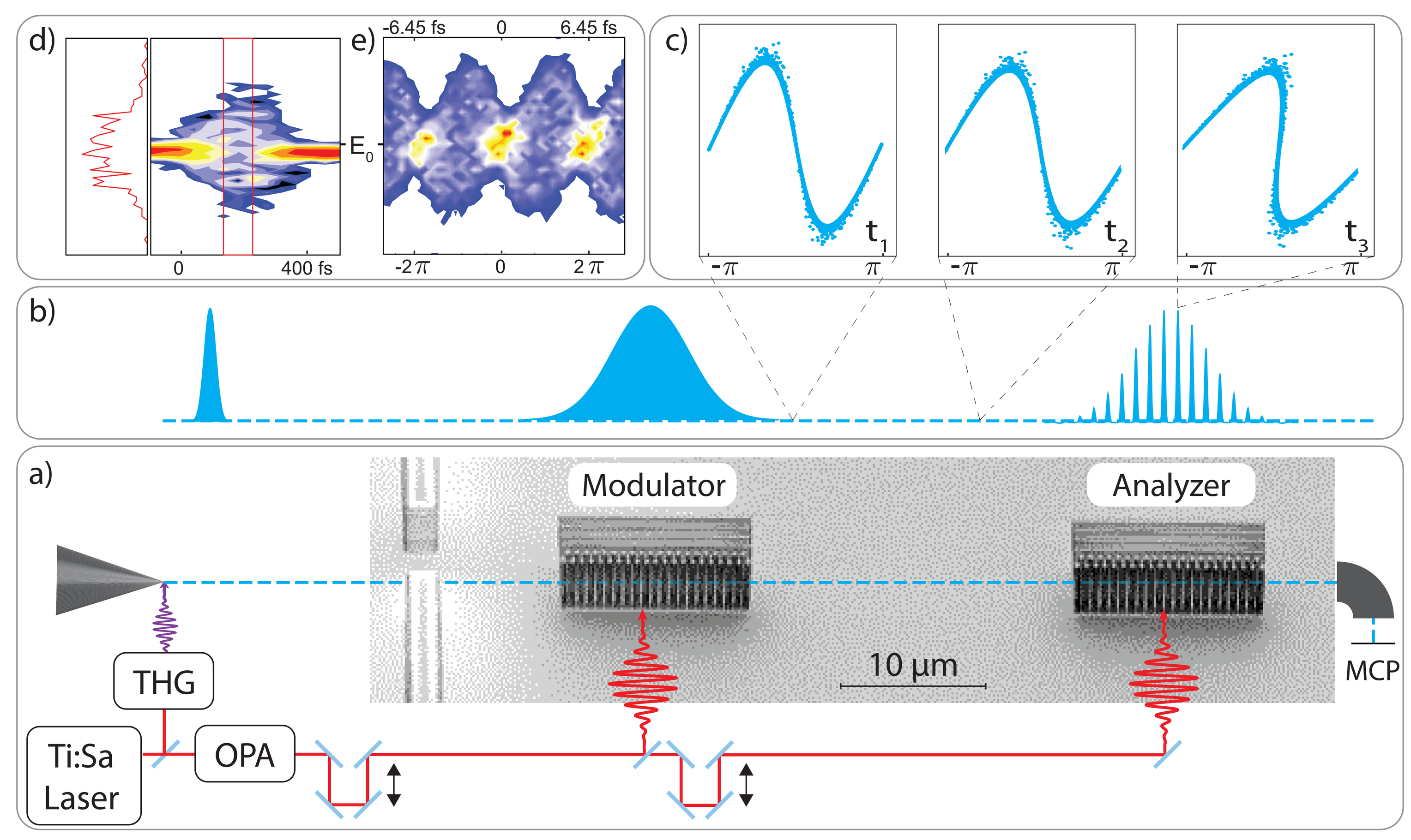

$\lambda_p = \lambda\beta m$

## 3. Accelerating, decelerating and deflecting field components



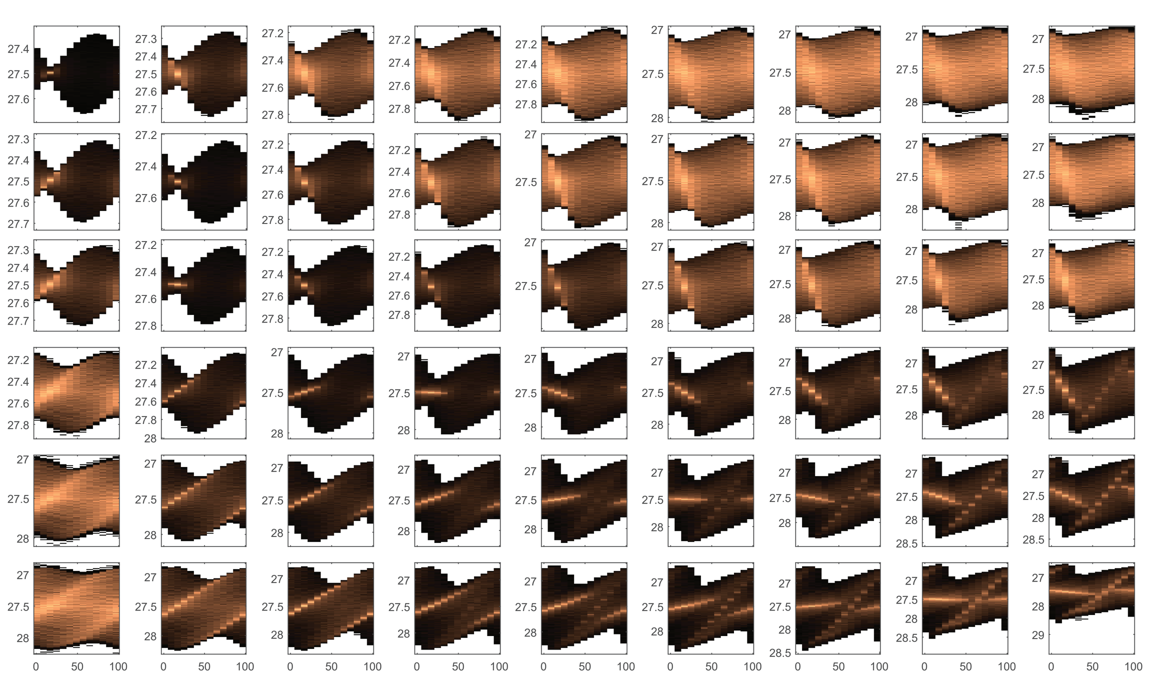

- Excited mode also contains deflecting field components
- Symmetric geometry and illuminations also lead to symmetric fields -> dual pillar structures
- Highest achieved gradient so far: 1 GeV/m
- Wide variety of structures possible

## 4. Generation and characterization of attosecond electron bunch trains




a) Experimental setup
b) Evolution of the electron pulse duration
c) Sketch of the phase space evolution during the electron drift
d) Example spectrogram of the electrons after interaction in the modulator only
e) Example spectrogram with both structures illuminated

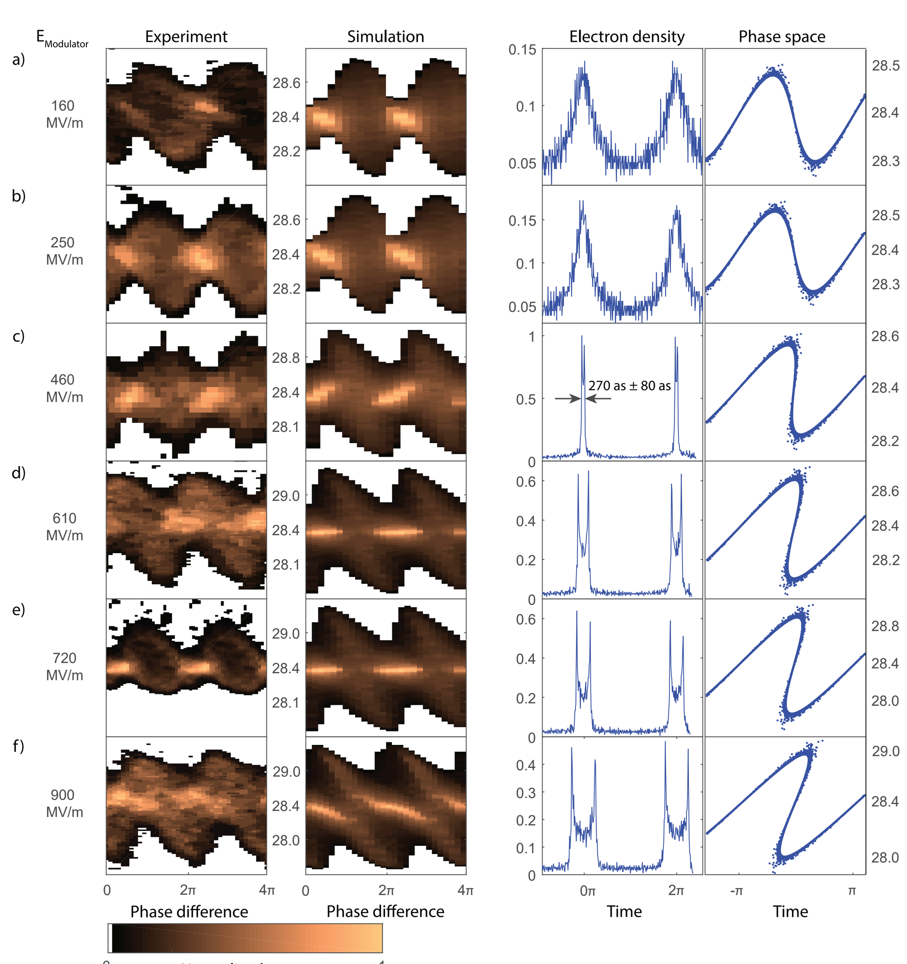
## 5. Energy streaking spectrograms and simulation of the microbunch duration

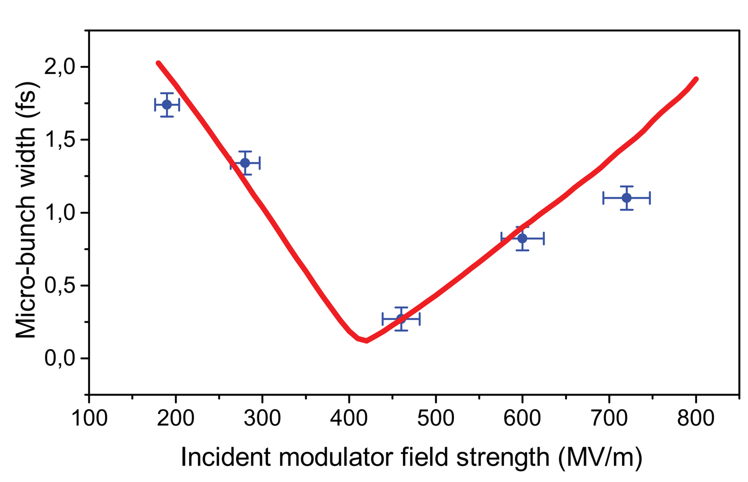


Simulations of diverse combinations of modulator and analyzer peak field.
The relative phase between the driving modulator and analyzer field is scanned.
The resulting spectrograms show characteristic and unique features.
The experimental data is matched via the width and slope of the high density feature.

Experimental data, simulation results (FDTD + GPT), retrieved time traces and phase space diagrams for various laser intensities in the modulator.
a-b) laser intensity in the modulator is too low (temporal focus behind reference point)
c) laser intensity is almost ideally matched to the drift length to achieve minimal pulse duration. In this case 270 ± 80 as
d) - f) temporal focus shifts closer to the modulator, resulting in different degrees of over-bunching at the reference point

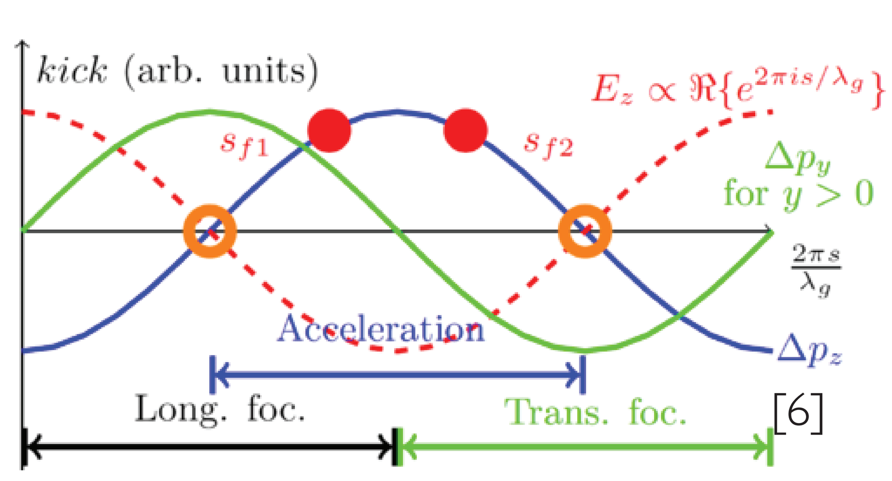
The forth column shows the phase space distribution of the microbunches: the vertical axes represent the electron energy. When the maximum and minimum of the energy modulation coincide in time, the temporal focus is reached.




Simulation results (red curve) and experimental results (blue points) for the micro bunch length as a function of incident modulator field strength

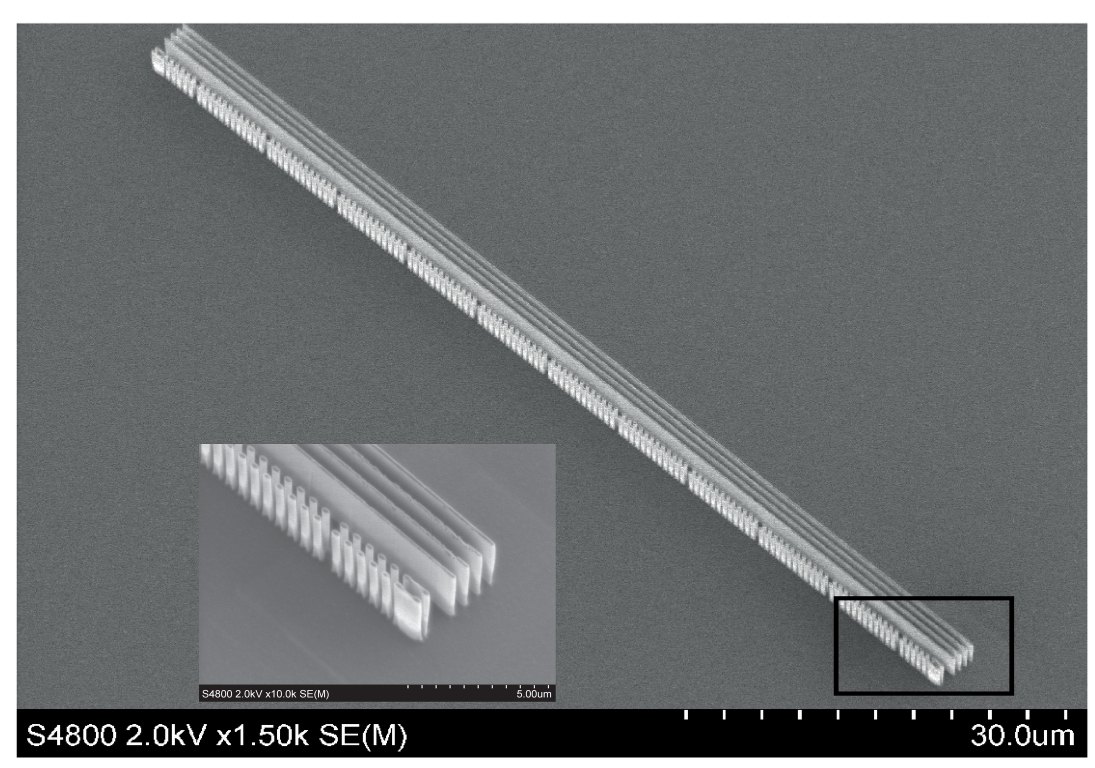
## 6. Alternating phase focusing (APF): transverse and longitudinal bunch confinement




Deflecting forces can be mittigated:

- Use relative phase between electrons and laser at red solid circles
- Alternating between two phase regions causes positive and negative transversal kick
- Transverse forces average to 0 and beam can be confined

- Mimimized electron loss in longer structures
- Transverse and longitudinal electron bunch confinement
- Special structure introduces phase jumps

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