Few-cycle probing of laser and electron driven plasma wakefield accelerator experiments

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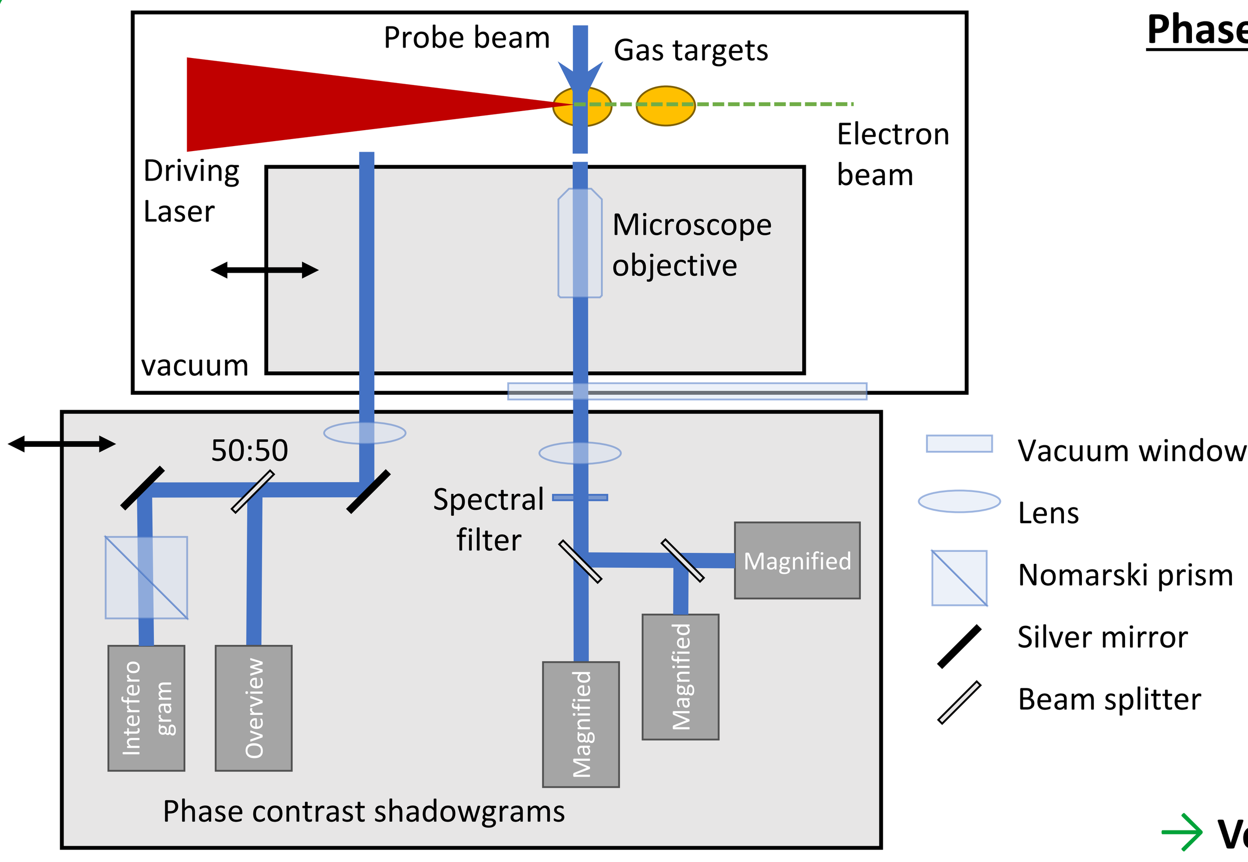
Introduction

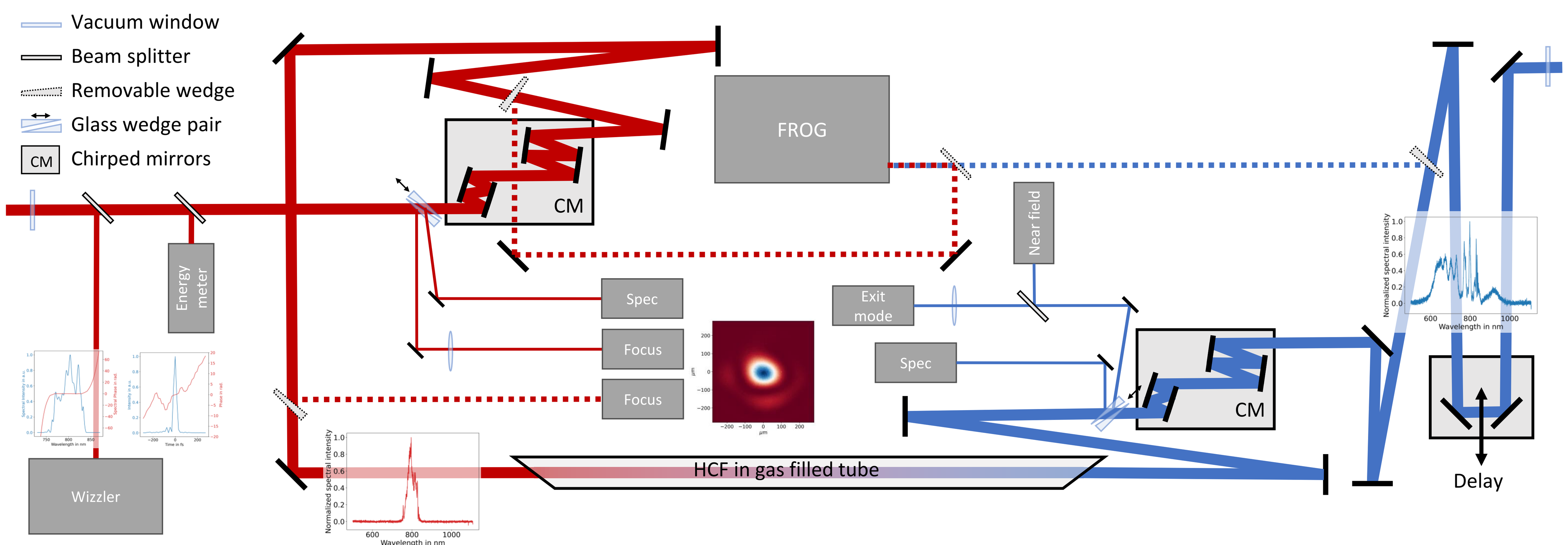
- Electrons are accelerated in a plasma wakefield using a two-stage setup
- The first stage is driven by a ultra-intense laser pulse and generates a high charge electron bunch
- In the second stage this bunch drives its own wakefield and transforms the electrons quality and stability
- Few-cycle probe pulses give an insight in the plasma dynamics during acceleration
- Plasma density oscillations are captured for the laser and electron driven wakefields
- Shadowgrams with high temporal and spatial resolution are recorded and evaluated



Phase contrast shadowgrams in LWFA and PWFA

- Hybrid LWFA and PWFA experiment setup and probe imaging
- The high intensity Laser drives the wakefield in the 1st gas target
- Electrons bunches are accelerated up to GeV energies
- In the 2nd gas target the wakefield is driven by the electron bunch
- Both stages are probed by the few-cycle probe pulse
- The plane of interest can be imaged by different setups
  - Overview
  - Interferogram
  - Microscope
  - Multi-plane and multi-color

→ **Versatile imaging with high spatial and temporal resolution**



Few-cycle probe setup with online beam diagnostics

- The probe pulses are picked from the main beam to ensure synchronization
- Beam diagnostics are an essential part of the setup, recording the input and output parameters
- In the gas filled hollow core fiber (HCF) the pulses are broadened by self-phase modulation
- For best temporal resolution, pulses are broadened from initially 50nm FWHM to a bandwidth between 600nm to 1000nm and compressed by chirped mirrors

→ **Operative as a day-to-day probing and beam diagnostic**

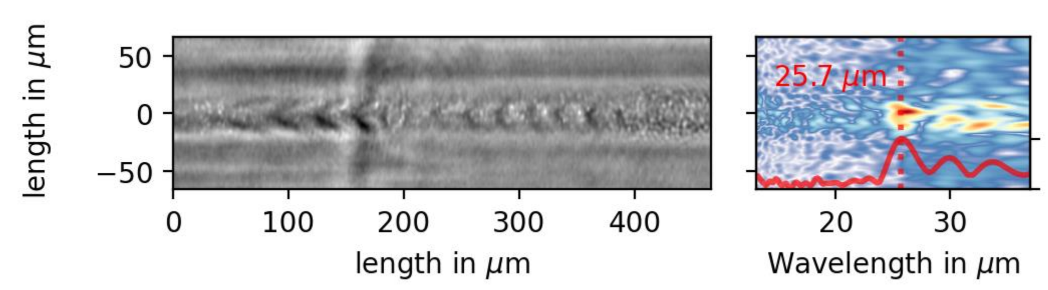
Fast Fourier Transform (FFT) analysis

- Plasma waves driven by a Laser and an electron beam are evaluated
- The peaks in the retrieved spectrum indicate the oscillation period of the plasma waves
- Plasma electron density can be calculated via:

$$\lambda_p = 2\pi c\sqrt{\frac{\epsilon_0 m_e}{e^2 n_0}} \rightarrow n_{e,0}[10^{18}cm^{-3}] = \left(\frac{33.4}{\lambda_p[\mu m]}\right)^2$$

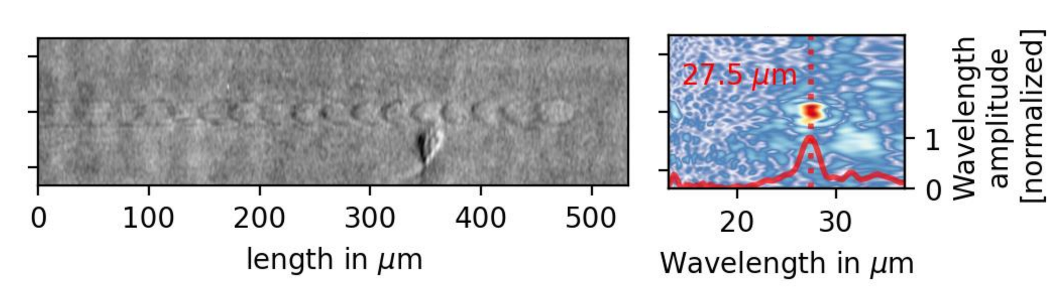
→ **Fast evaluation for quasi online diagnostic**

Shadowgram + FFT of the LWFA stage in the 1st gas target



- The "head" of the laser pulse driving the plasma wake on the right is followed by sphere like modulations, which after a few periods are starting to elongate (approaching the lower density front of the target)
- A clear peak in the amplitude shows the wavelength of the plasma oscillations at around 27 µm, which converts to a density of 1.3×10^{18} cm^{-3}

Shadowgram + FFT of the PWFA stage in the 2nd gas target

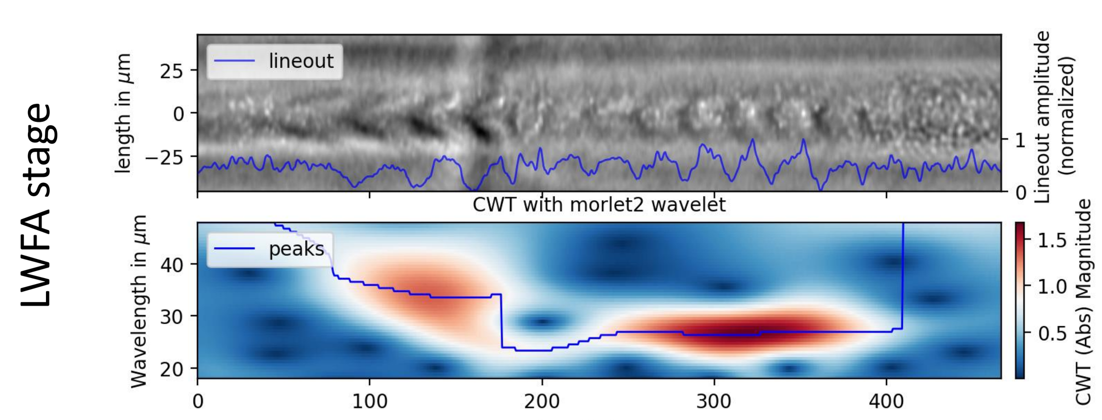


- Driven by the electron bunch, the first oscillation period is a clear sphere shaped feature, followed by similar modulations
- The FFT analysis on the right side shows a plasma wavelength of about 28 µm and a density of 1.2×10^{18} cm^{-3}

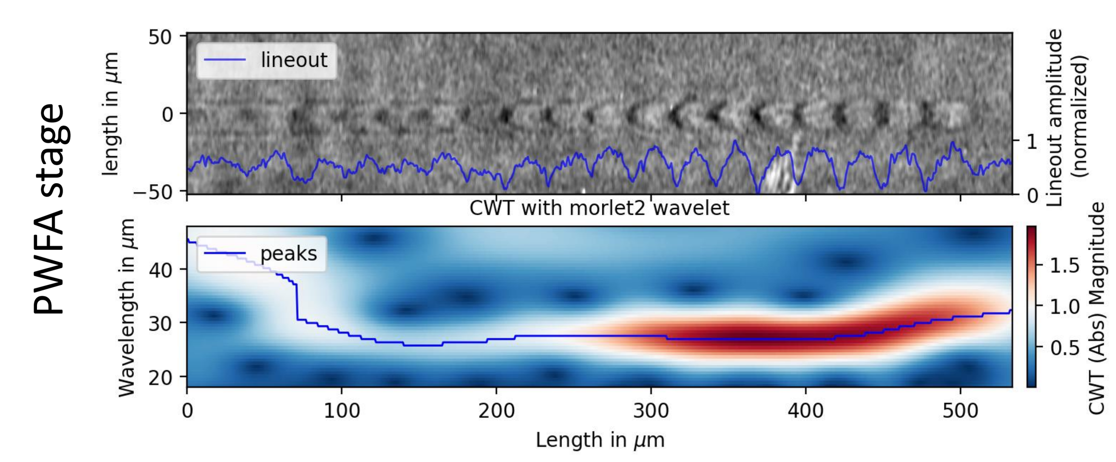
Continuous wavelet transform (CWT) analysis

- The CWT is extracting the change of the plasma wavelength along the propagation and acceleration axis
- A lineout along the longitudinal axis shows the intensity modulation of the shadowgram
- For each longitudinal position, the peak amplitudes in the CWT indicate the local plasma wavelength; The blue line connects the peaks

→ **Useful for more detailed plasma dynamics analysis along the acceleration axis**

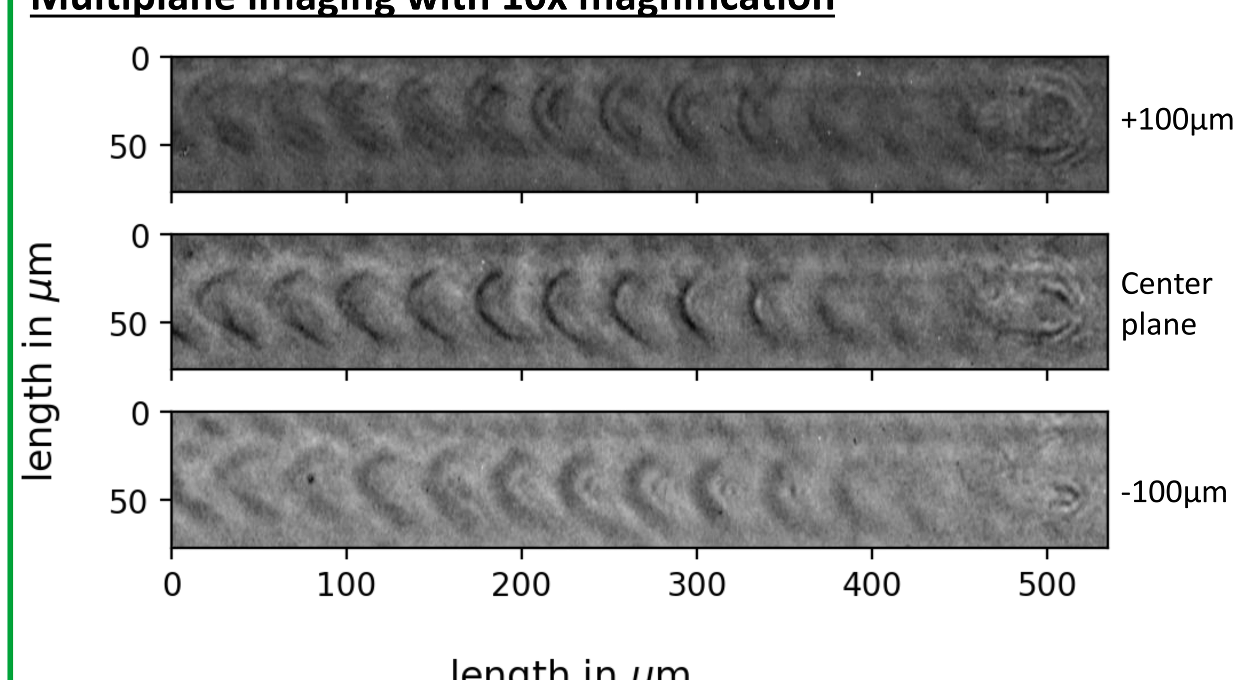


- The local wavelength of the first few oscillations between the head of the laser and the shock is around 27 µm (1.3×10^{18} cm^{-3})
- Before the shock, at the front of the target, the density decreases and the modulations elongate



- The CWT analysis shows a slightly longer width of the first period (32 µm) compared to a constant wavelength (27 µm) in the following oscillations
- Far behind the driving electron bunch, the modulations elongate

Multiplane imaging with 10x magnification



- High resolution multiplane images of LWFA
- Will be used for density reconstruction

Next steps

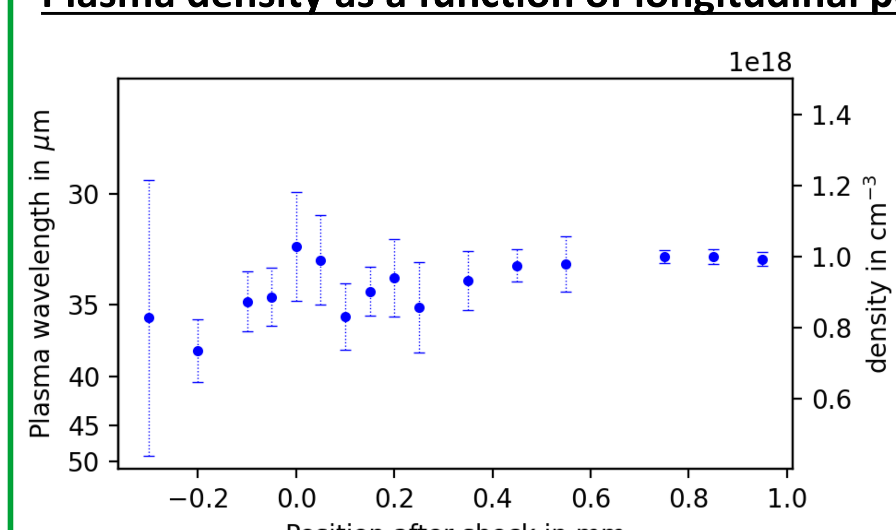
- Apply to PWFA
- Record at multiple spectral ranges (time steps) for temporal evolution

→ **Recording of multi-plane and multi-color shadowgrams for 3D density reconstruction and temporal evolution**

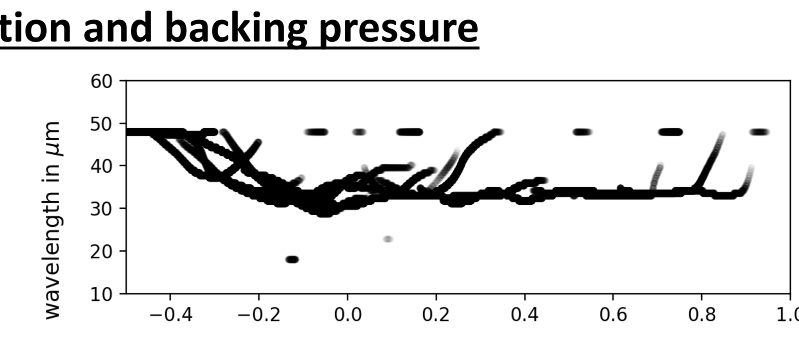
Outlook

- Recording of plasma oscillations with multi-plane and multi-colour imaging system
  - Using RGB cameras + multiband spectral filters and stretch probe pulses
- Scan plasma wavelength over full length of LWFA, PWFA gas targets
- Reconstruction of a quasi-3D, quantitative plasma density distribution
- Systematically analysing and correlating the various diagnostics

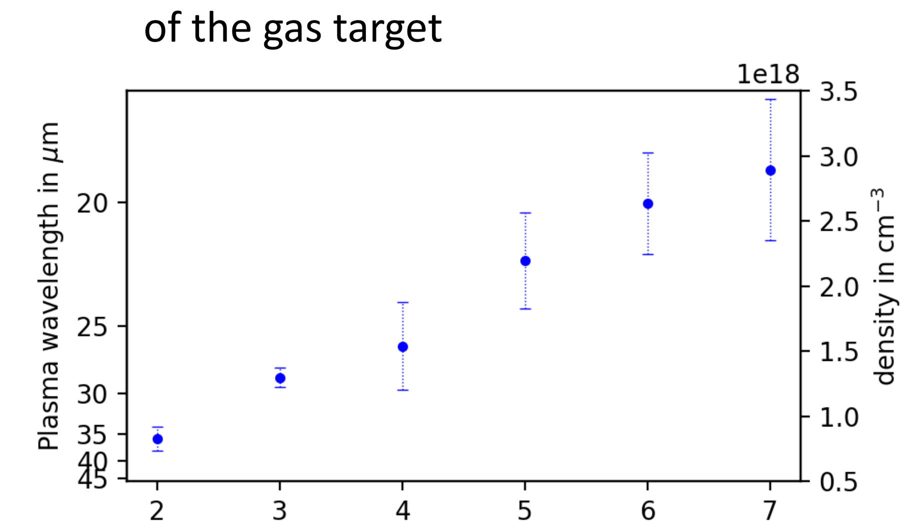
Plasma density as a function of longitudinal position and backing pressure



- Lower density at the front edge of the gas target
- Disturbances around the shock
  → Not so well defined plasma oscillations
- Constant density towards the plateau further inside the gas target



- Plasma wavelength along the first mm of the gas target



- Linear increase of plasma density with backing pressure

→ **In situ plasma density measurements assist the optimization of acceleration experiments when correlated to electron spectrometer**

References

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EUROPEAN NETWORK FOR NOVEL ACCELERATORS

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