Achromatic focusing of 20%-energy-spread bunches

Development of an achromatic spectrometer for a laser-wakefield-accelerator experiment

F. Peña*[1], E. Adli, P. Drobniak, D. Kalvik, K. N. Sjobak, C. A. Lindstrøm

Department of Physics, University of Oslo, Oslo, Norway

[1]also at Ludwig Maximilian University of Munich, Munich, Germany

1. Introduction

- Plasma accelerators can sustain accelerating gradients of up to 100 GV/m, promising to reduce the footprint of future accelerator facilities
- High-energy applications will require multiple plasma-accelerator stages
- The beam optics between such stages are challenging due to chromatic effects [1]
- The SPARTA project [2] aims to solve this problem with a nonlinear active plasma lens [3] currently under development

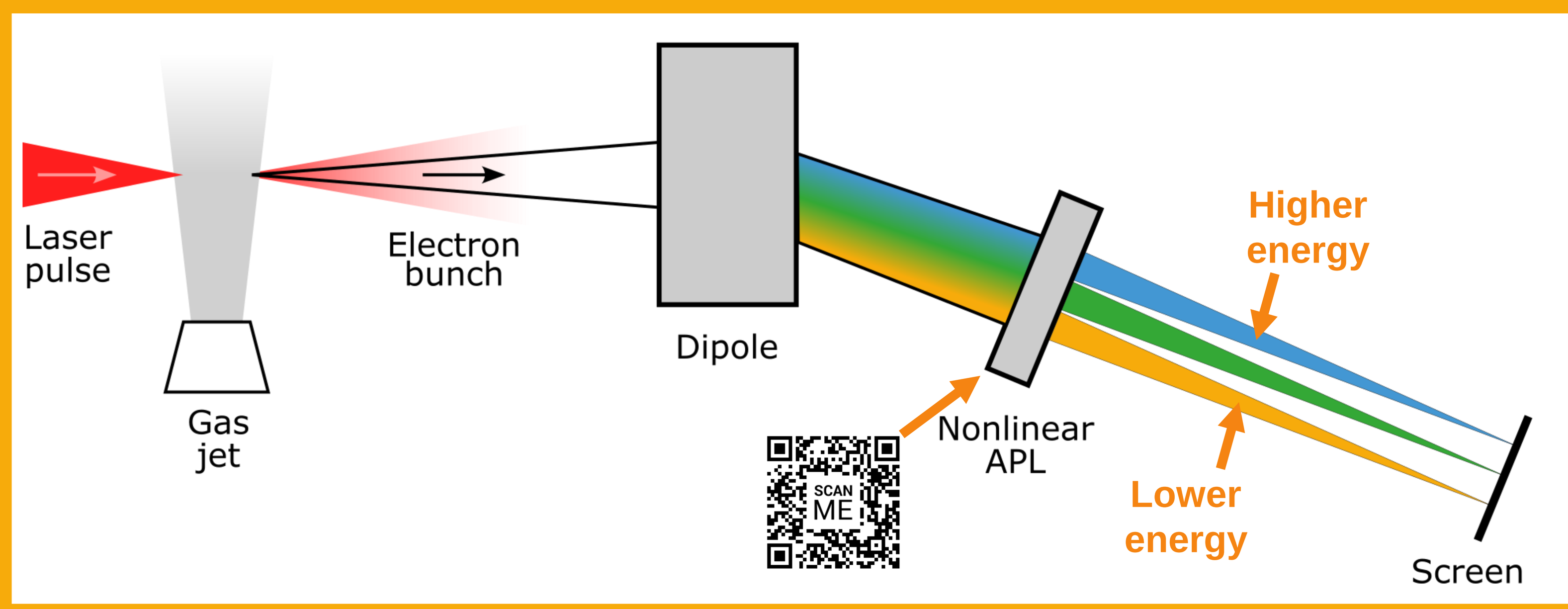
2. Motivation and goal

- Goal: Demonstrate the effectiveness of the nonlinear plasma lens for staging
- Can be done with a simpler setup that faces the same challenges
- In combination with a magnetic dipole, it can provide point-to-point imaging for the full energy spectrum, i.e., an achromatically imaging spectrometer
- Great diagnostic for plasma-accelerator experiments, which usually:
  - → have bunches with an energy spread of up to 10% and a divergence of 5 mrad
  - → need multi-shot scans to accurately measure the energy spectra [4], which is only possible with an often inexistent high energy stability

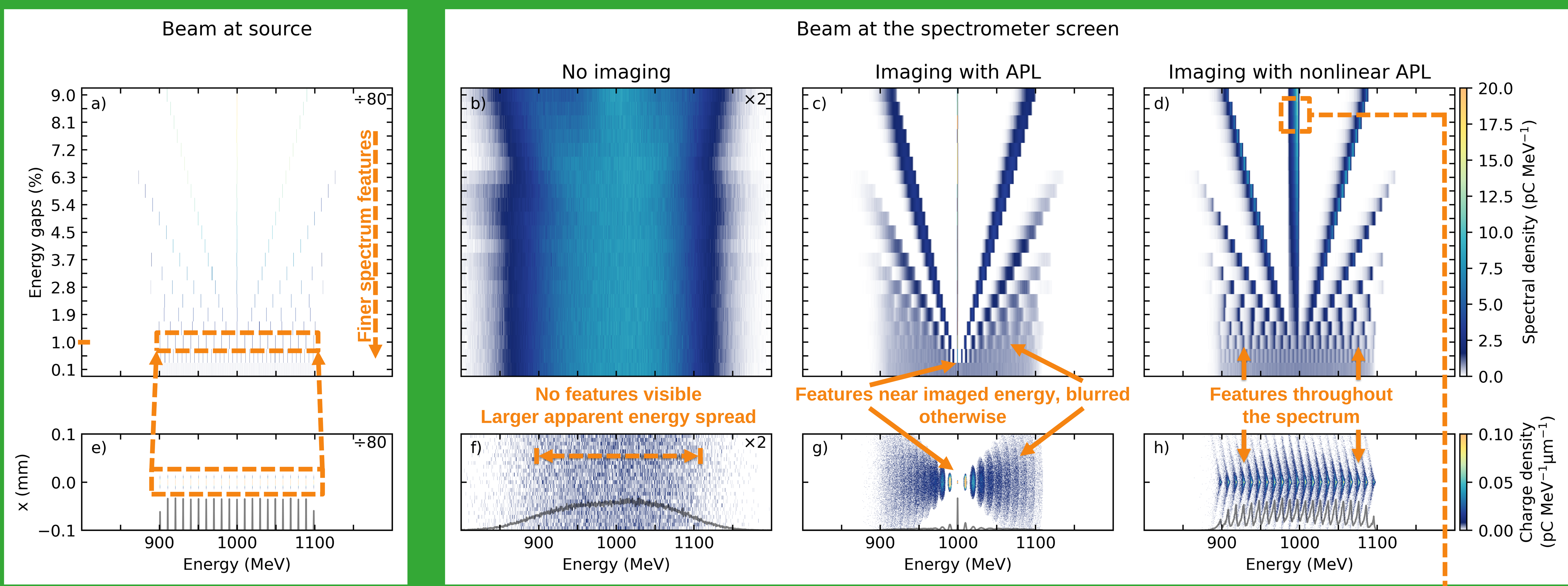
3. Experimental setup and simulation details

- To simulate an achromatic spectrometer we use the ABEL framework [5] and the tracking code ImpactX [6]
- The laser–plasma interaction is not simulated, instead an electron bunch is instantiated with:

  charge $Q = 1\ \mathrm{nC}$, normalized emittance $\epsilon_{N,x} = \epsilon_{N,y} = 2\ \mathrm{mm\ mrad}$, waist beta function $\beta_x^* = \beta_y^* = 1\ \mathrm{mm}$, divergence $\sigma_{x'} = \sigma_{y'} = 1\ \mathrm{mrad}$, energy spread $\delta_E = 10\%$, number of particles $n = 200000$



4. Comparison of novel optics with established imaging



- The electron energy is arranged to discrete values
- The energy gaps are scanned

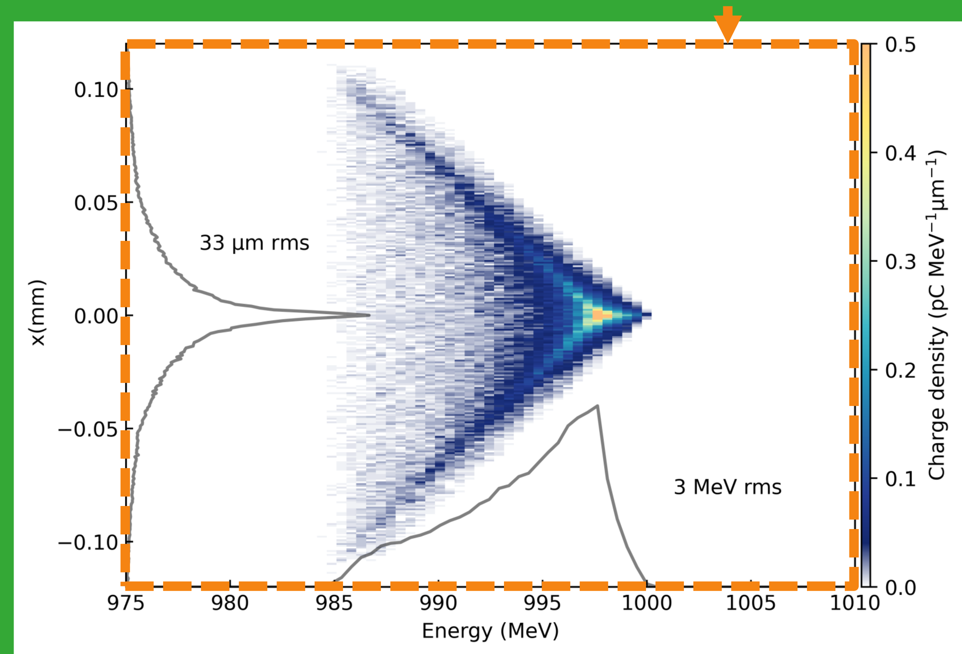
- Divergence dominated

- Suitable for single-shot emittance, multi-shot spectrum measurement

- Suitable for single-shot, high-resolution, broad-band spectrum measurement

5. Point spread function

- Characteristic shape induced by achromatic imaging system
- With these simulation parameters, the resolution limit is 0.3% rms
  - → sufficient for single-stage plasma accelerators
- In principle, measurements can be de-convolved with the point spread function to reach higher resolution



6. Conclusion and Outlook

- Simulations show that the nonlinear plasma lens can be used to achromatically image bunches across a 20% energy spectrum
- Resolution could be sufficient for plasma-accelerator experiments

- Planned to start measurement in late 2026 at the Centre for Advanced Laser Applications (CALA) in Germany
- These results pave the way towards achromatic staging for plasma accelerators

* felipe.pena@fys.uio.no

Contribution ID: 512

7th European Advanced Accelerator Conference (EAAC), Elba, Italy, 21–27 September 2025

References:

[1] C. A. Lindstrøm, “Staging of Plasma-Wakefield Accelerators”, Phys. Rev. Accel. Beams 24, 014801 (2021).
[2] European Commission, “Staging of plasma accelerators for realizing timely applications” (2023).
[3] P. Drobniak et al., “Development of a Nonlinear Plasma Lens for Achromatic Beam Transport”, NIM-A 1072 (2025): 170223.
[4] F. Peña, et al., “Energy Depletion and Re-Acceleration of Driver Electrons in a Plasma-Wakefield Accelerator”, Phys. Rev. Res. 6, 043090 (2024).
[5] J. B. Chen et al., “ABEL: The adaptable beginning-to-end linac simulation framework”, (in these proceedings).
[6] A. Huebl et al., “Next Generation Computational Tools for the Modeling and Design of Particle Accelerators at Exascale”, in Proc. NAPAC’22, Albuquerque, NM, USA, Aug. 2022, pp. 302-306.

European Research Council
Established by the European Commission

The project is funded by the European Research Council (project SPARTA, ERC Grant Agreement No. 101116161). We acknowledge Sigma2 - the National Infrastructure for High- Performance Computing and Data Storage in Norway for awarding this project access to the LUMI supercomputer, owned by the EuroHPC Joint Undertaking, hosted by CSC (Finland) and the LUMI consortium.