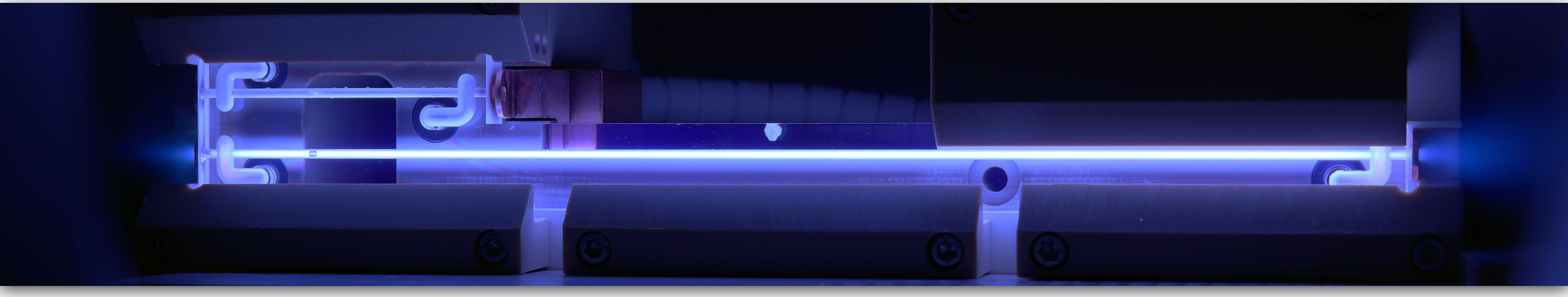
FLASHFORWARD▸▸

Beam-driven plasma wakefield research at DESY



Matthew Wing

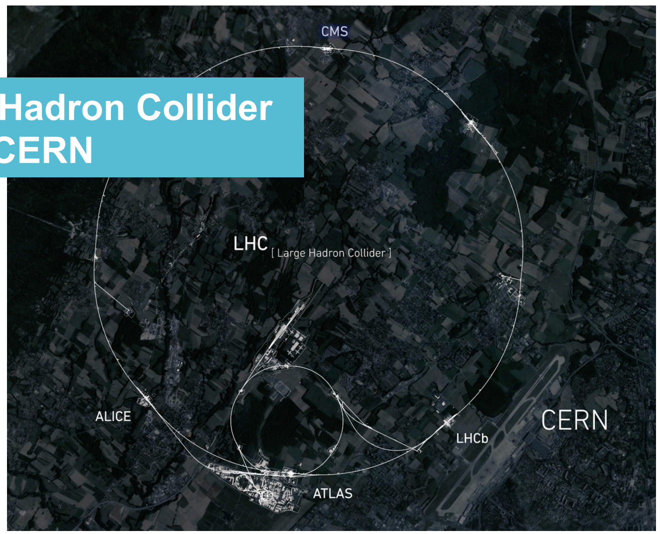
J. Beinortaitė, J. Björklund Svensson, L. Boulton, G. Boyle J. Chappell, S. Diederichs, B. Foster, M.J. Garland, P. González Caminal, H. Jones, A. Kanekar, C.A. Lindstrøm, G. Loisch, T. Long, S.M. Mewes, F. Peña, Á. Ferran Pousa, A. Scaachi, S. Schreiber, S. Schröder, R. Shalloo, M. Thévenet, S. Wesch, J.C. Wood, J. Osterhoff and R. D’Arcy

Visit of French Delegation — 6 May 2024

Particle accelerators

Circular

The Large Hadron Collider
CERN



27 km circumference synchrotron
6.5 TeV proton bunches

Linear

The Stanford Linear Collider
SLAC

3.2 km long linear accelerator
50 GeV electron/positron bunches

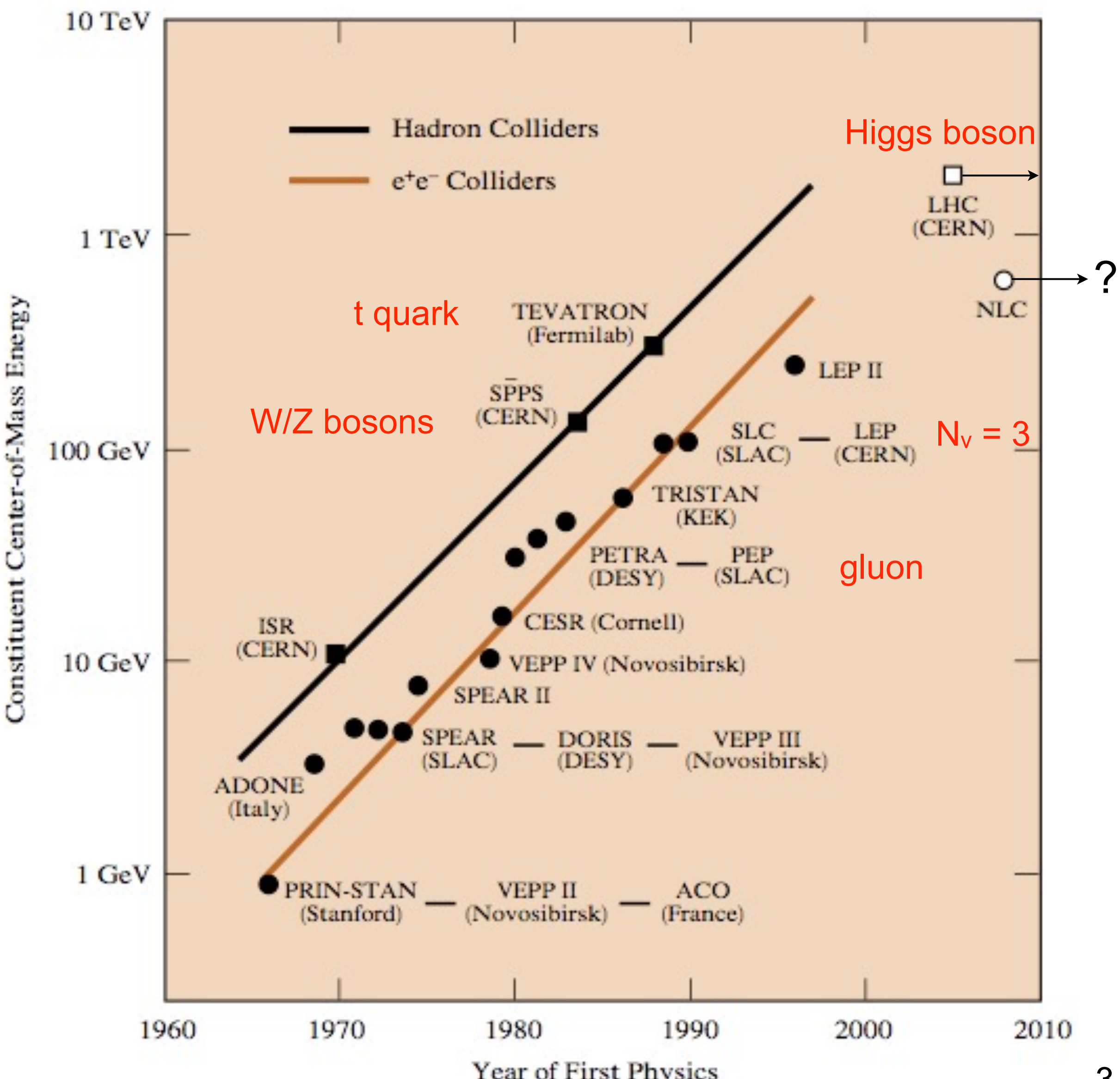
Image sources: CERN & SLAC

2

Limits of current accelerator technology

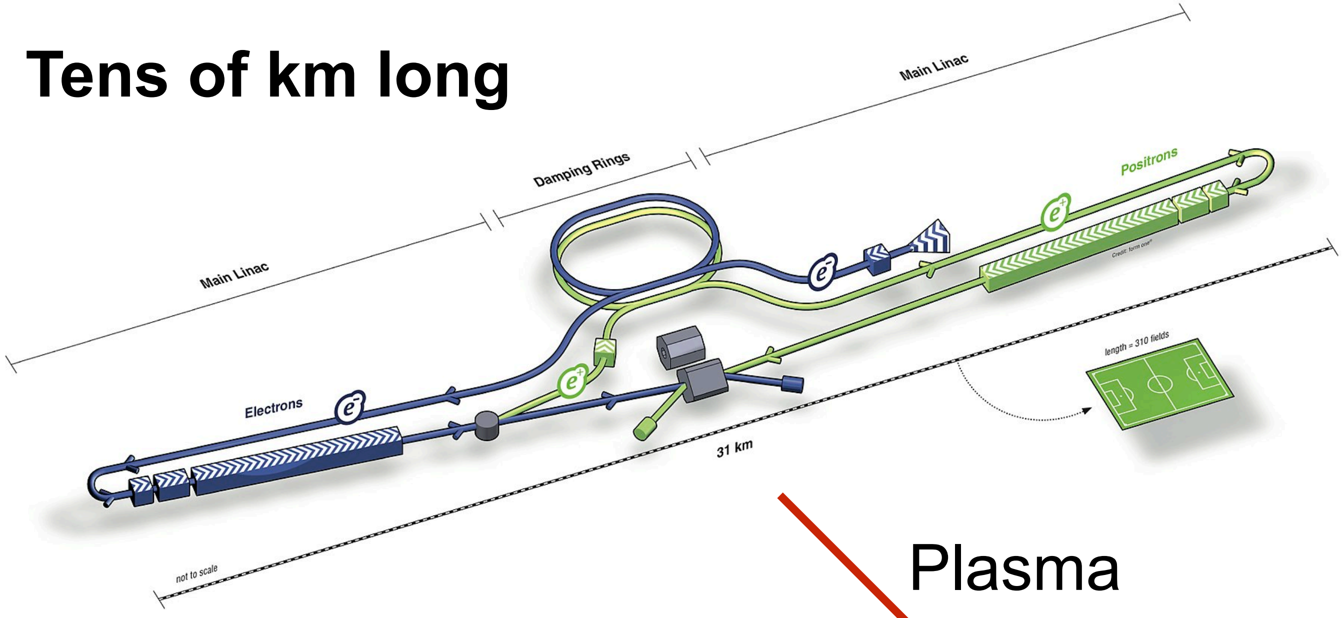
• The use of (large) accelerators has been crucial to advances in particle physics.

• Accelerators using RF cavities limited to *~100 MV/m*; high energies → long accelerators.

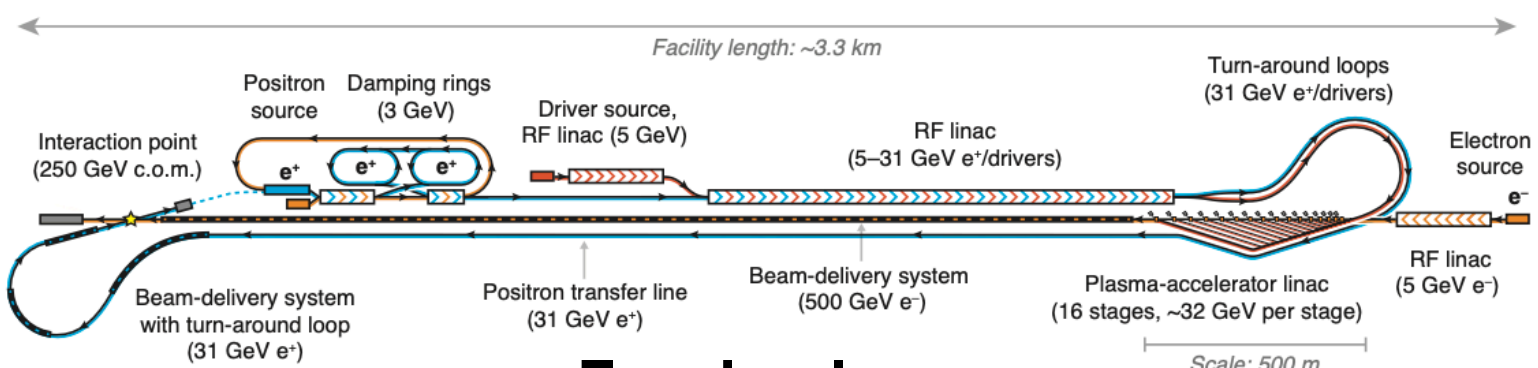


Use novel accelerator technology

Tens of km long



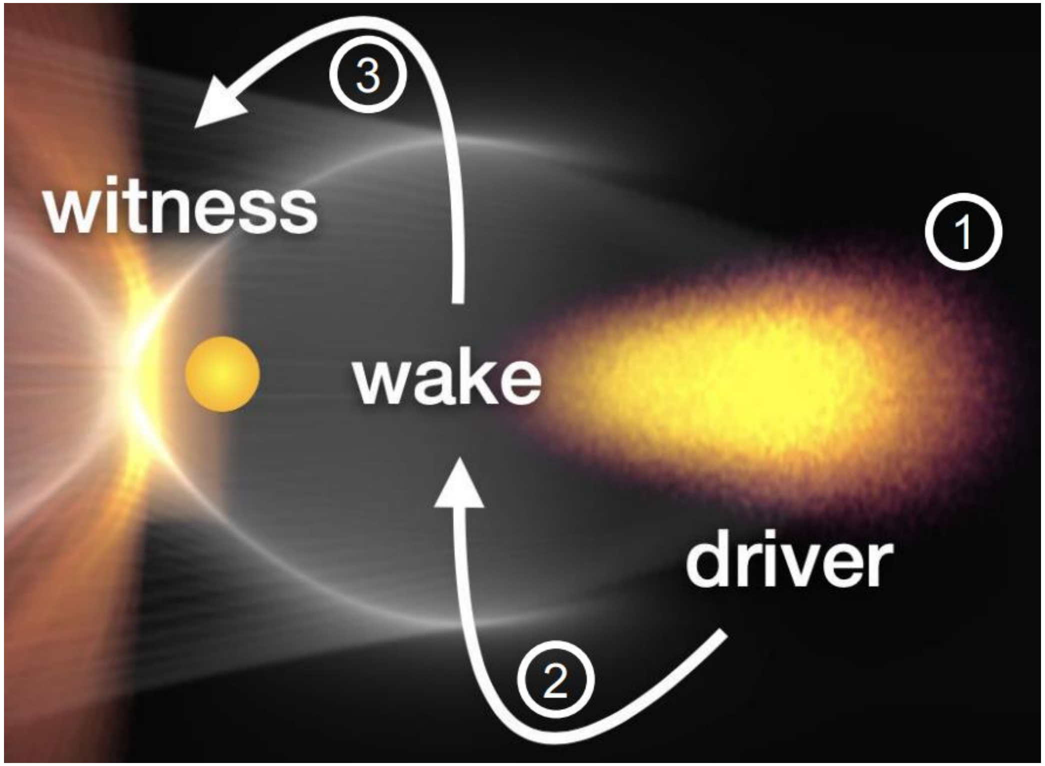
Plasma



Few km long

Plasma wakefield acceleration — how and why ?

- Plasma electrons disturbed by incoming particle/laser beam.
- Plasma ions remain ~static.
- Bubble-like structure of +ive and –ive charge density.
- Oscillation of plasma electrons creates strong electric fields.
- Longitudinal fields can accelerate witness bunch of electrons.



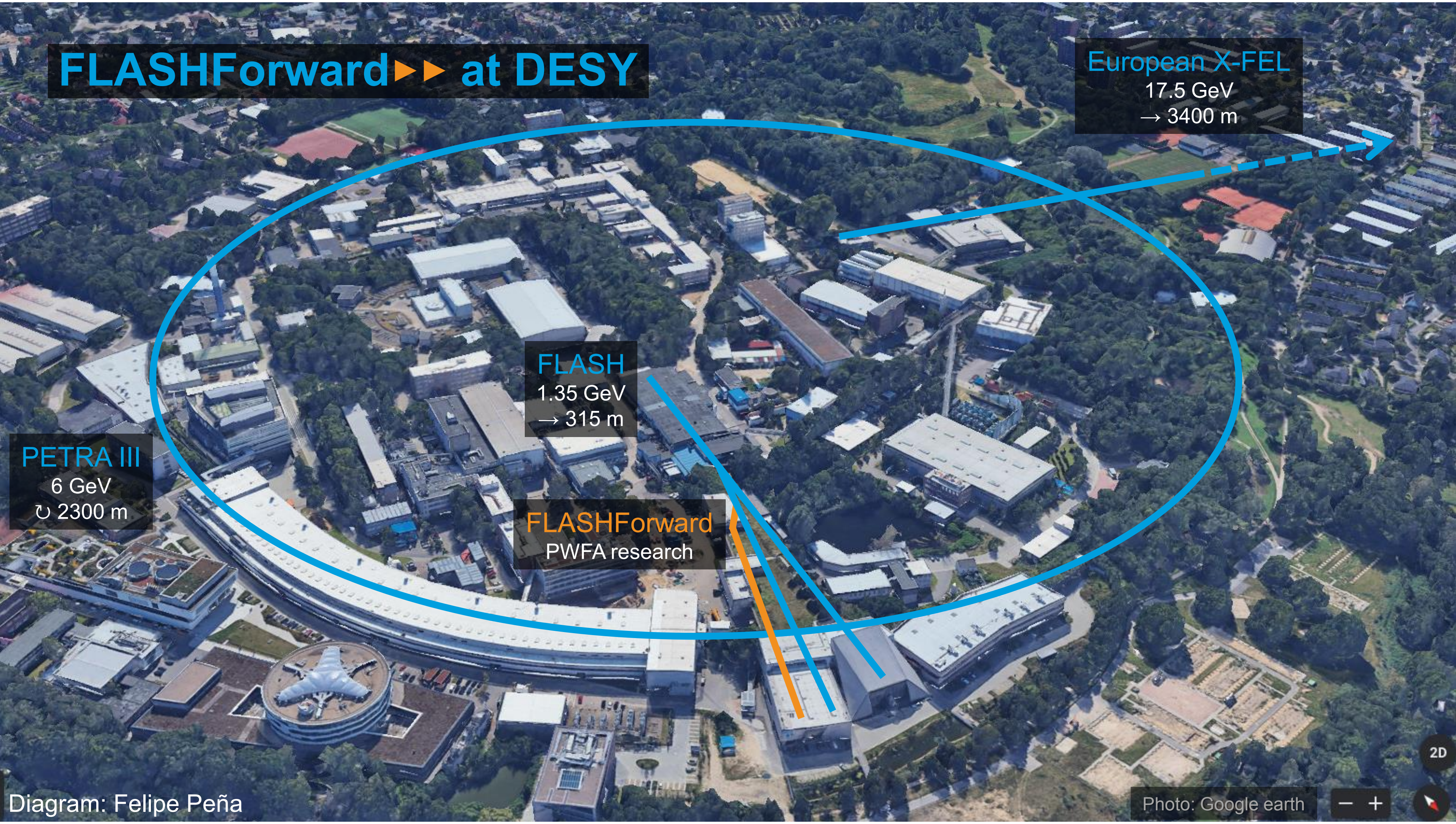
Plasma wakefield acceleration is a promising technique to realise shorter of higher energy particle accelerators.

Plasma wakefield acceleration landscape

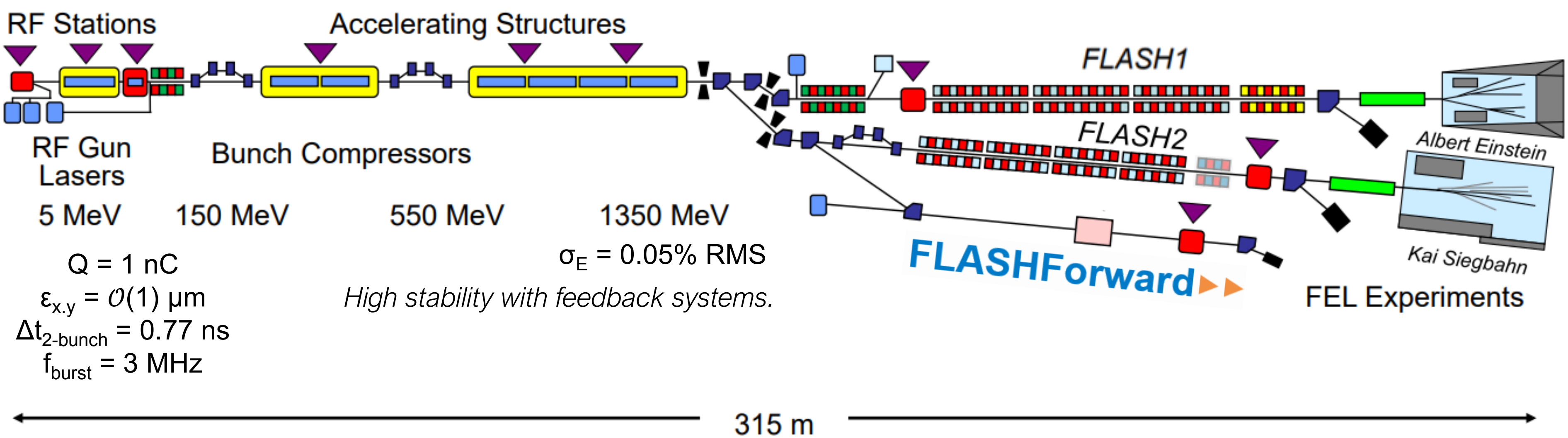
- Can use lasers, electron or proton bunches to drive wakefields.
- Accelerating gradients of 100 GV/m have been achieved but need:
  - Small energy spread;
  - High repetition rate and high bunch charge;
  - Efficient and highly reproducible beam;
  - Small beam sizes.
- Lots going on worldwide, e.g. FACET, CLARA, AWAKE, APOLLON, BELLA, KALDERA, ELI, Shanghai, etc.
- One of the accelerator R&D areas in European particle physics roadmap.

FLASHForward▸▸: electron-driven plasma wakefield accelerator at DESY addressing these challenges.

FLASHForward▸▸ The Facility



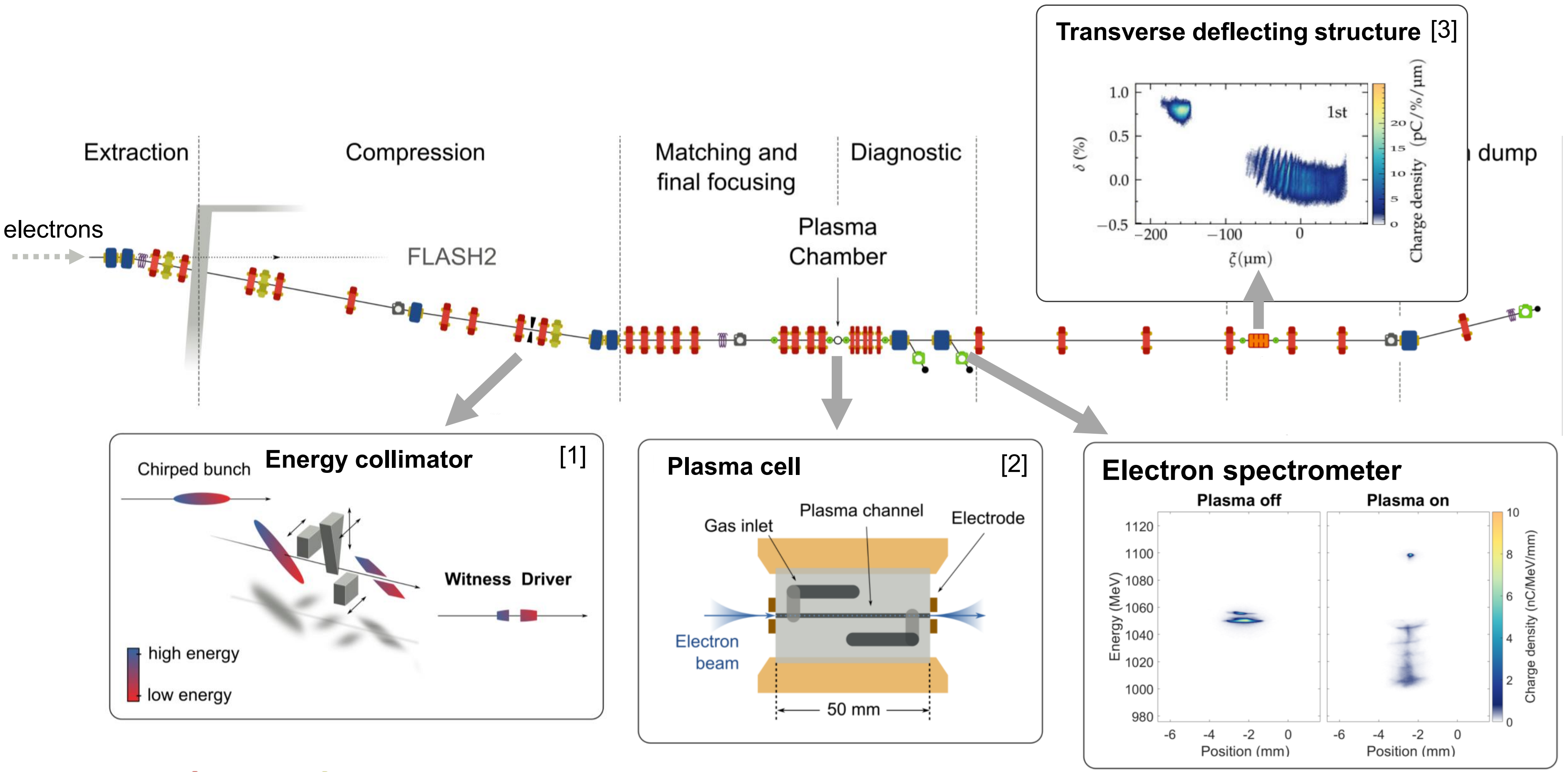
FLASHForward ▸▸ The Facility



S. Schreiber and B. Faatz, The free-electron laser FLASH, High Power Laser Science and Engineering, 3 (2015)

FLASH Free Electron User Facility — unique conditions for plasma wakefield acceleration testbed.

FLASHFORWARD▸▸ BEAMLINE



courtesy J. Beinortaitė

Diagram courtesy: P. González Caminal

[1] P. Muggli, *et al.* Phys. Rev. Lett. **101**, 054801 (2008); S. Schröder *et al.*, J. Phys. Conf. Ser. **1596**, 012002 (2020)
[2] J. M. Garland *et al.*, Rev. Sci. Instrum. **92**, 013505 (2021)
[3] P. González Caminal, PhD Thesis; B. Marchetti *et al.*, Scientific Reports **11**, 3560 (2021)

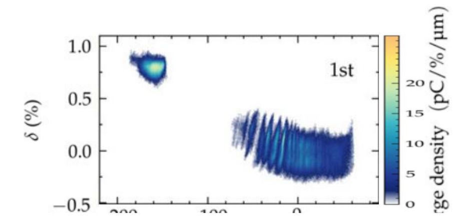
FLASHForward▸▸ Beamline

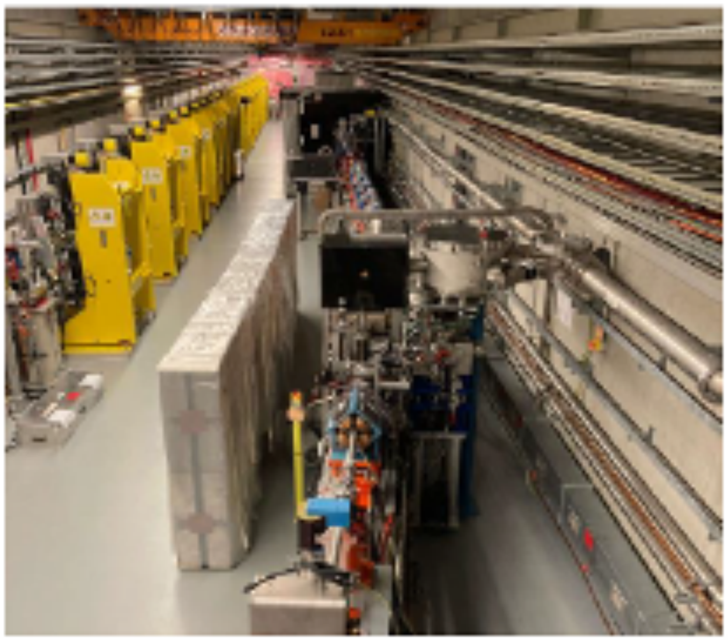
Extraction | Compression | Matching and final focusing | Diagnostic | dump

electrons

Plasma

Transverse deflecting structure [3]





Charge density (nC/MeV/mm)

Diagram courtesy: P. González Caminal

[1] P. Muggli, *et al*. Phys. Rev. Lett. **101**, 054801 (2008); S. Schröder *et al.*, J. Phys. Conf. Ser. **1596**, 012002 (2020)
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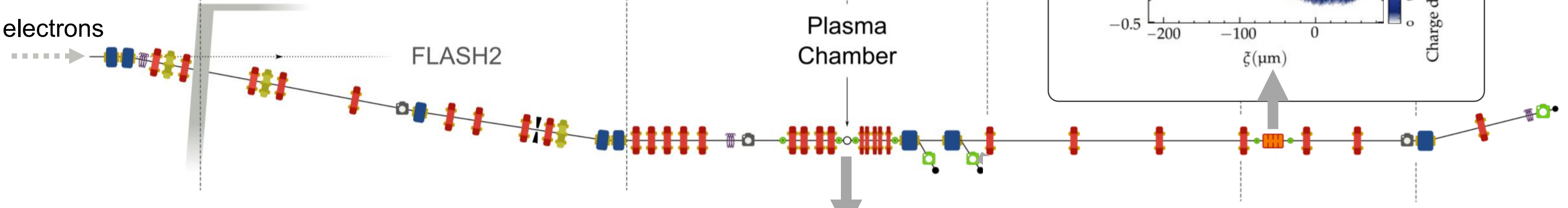
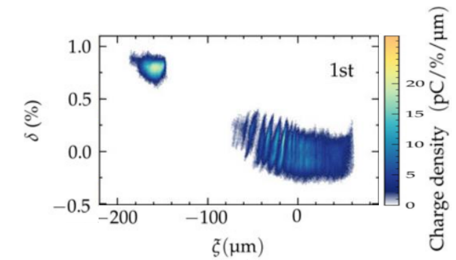
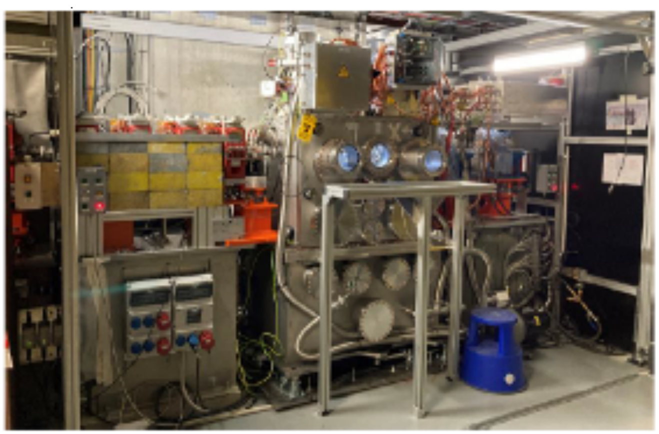
FLASHFORWARD▸▸ BEAMLINE

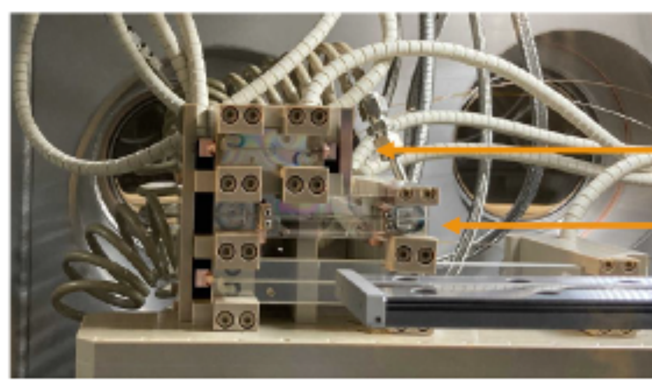


Transverse deflecting structure [3]





Plasma cell [2]



Currently installed

50 mm cell

100 mm cell

195 mm cell

FLASHFORWARD▸▸ GOALS

Develop a self-consistent plasma-accelerator stage
with high quality, high efficiency and high average power at 1 GV/m

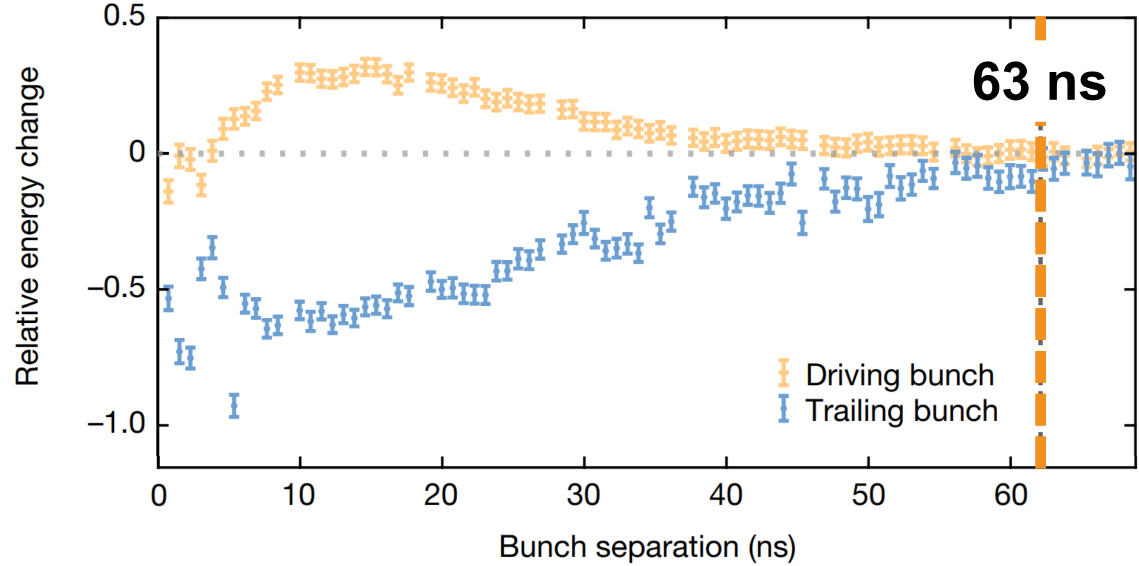
High beam quality	High efficiency	High average power
Low energy spread	Driver depletion	Rapid recovery time
Emittance preservation	Plasma-to-witness efficiency	High repetition rate

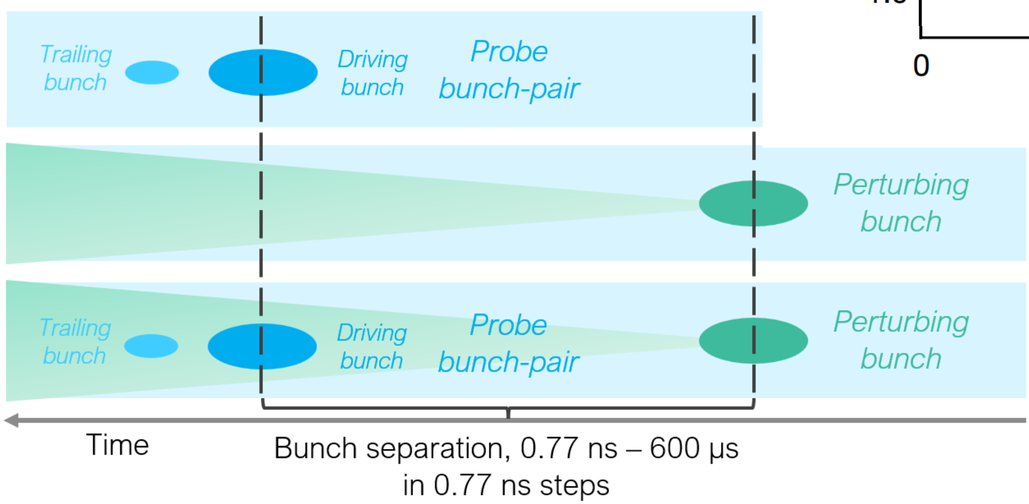
All combined with >1 GV/m with energy gain as large as possible and as stable as possible.

R. D'Arcy et al., *Phil. Trans. Roy. Soc.* **A 377** (2019) 20180392
https://forward.desy.de/

Example result: recovery time of plasma

How soon after acceleration can we accelerate another bunch in the same plasma ?





R. D'Arcy et al.,
Nature **603** (2022) 58

- Perturbed plasma recovers in 63 ns.
- **In principle, demonstration of *O* (10 MHz) repetition rate**

Backup

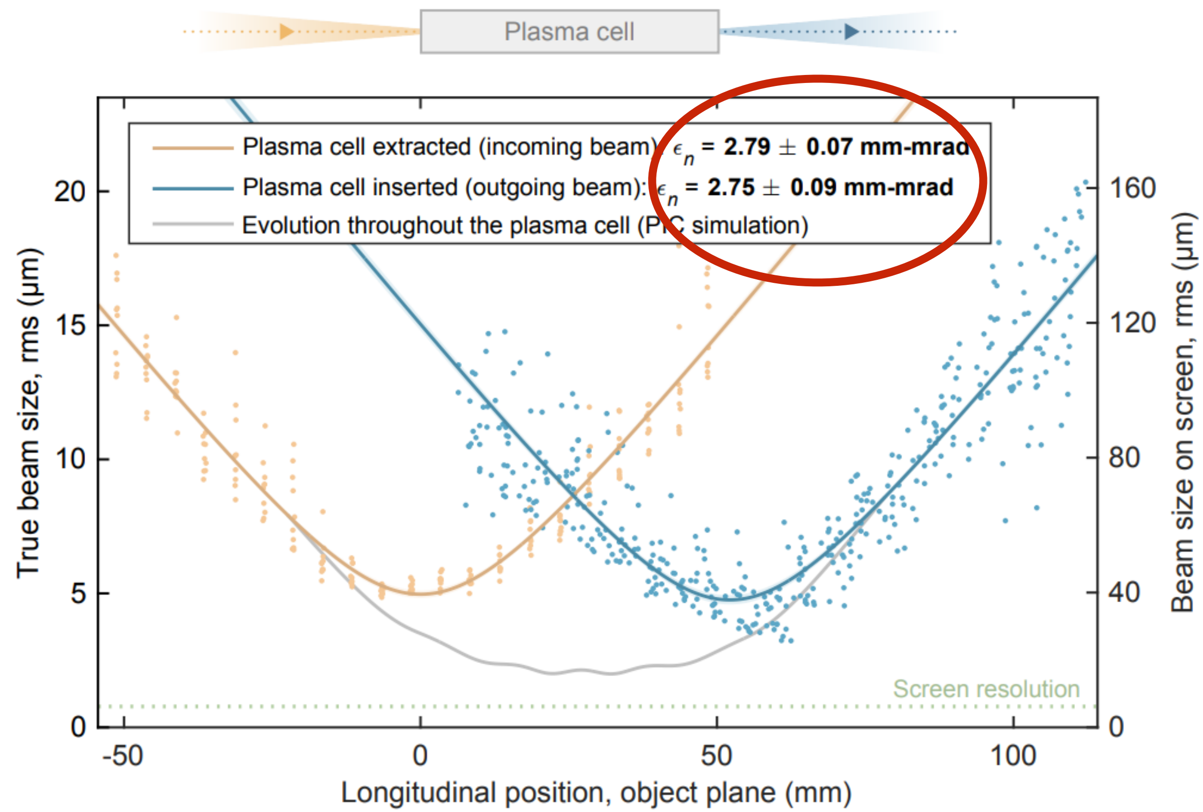
Acknowledgements

- Strong input from engineering and technical support.
- Special thanks to M. Dinter, S. Karstensen, S. Kottler, K. Ludwig, F. Marutzky, A. Rahali, V. Rybnikov, A. Schleiermacher.

Preserving beam quality

- We want a small, controlled and reproducible beam — preserve beam quality during acceleration.

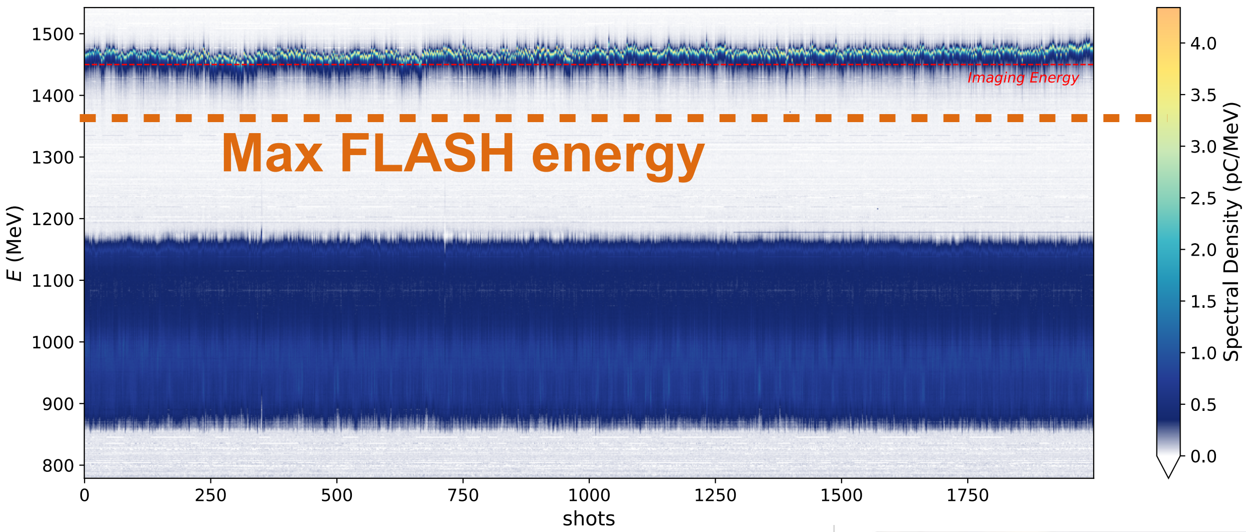
- Using a 50 mm long plasma:
  - Accelerating field ~1 GV/m
  - 100% charge coupling (40 pC)
  - Preserved energy spread (0.1% FWHM)



C. Lindstrøm et al., "Preservation of beam quality in a plasma-wakefield accelerator", preprint: doi.org/10.21203/rs.3.rs-2300900/v1

- **Emittance remains the same — beam quality preserved**

Very recent highlights



- 250 MeV gain in 195 mm cell
- Exceeding maximum FLASH energy
- To measure efficiency.

- New plasma cell development, 500 mm
- Aim for > 0.5 GeV energy gain.