Active Energy Compression of Laser-Plasma Accelerated Beams

illustration: DESY / scicomlab

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Demonstration Experiment at LUX

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LPA + conventional accelerator beamline

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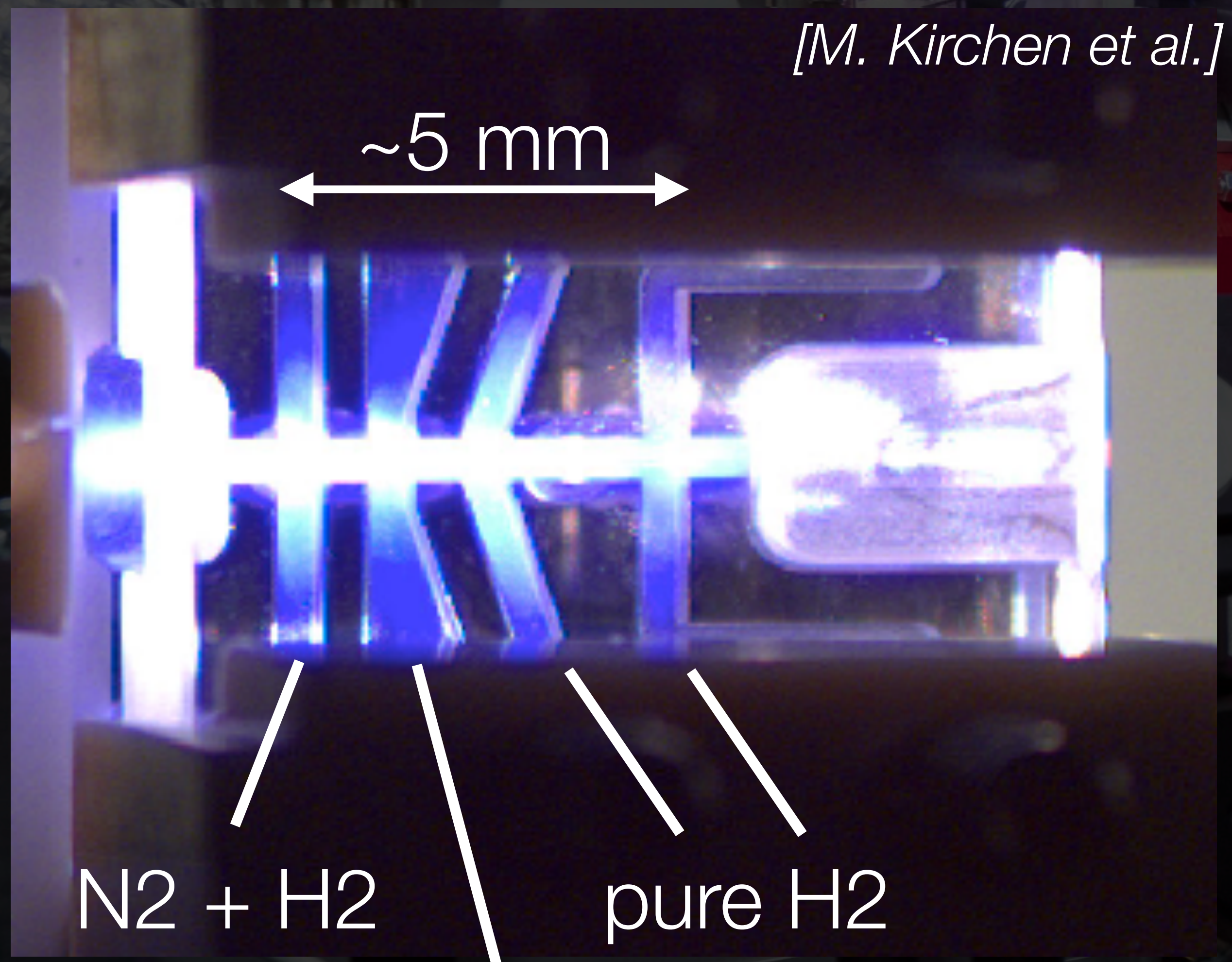
continuous flow capillary target



Downramp assisted ionisation injection [M. Kirchen, S. Jalas et al., Phys. Rev. Lett. 126, 174801 (2021)]

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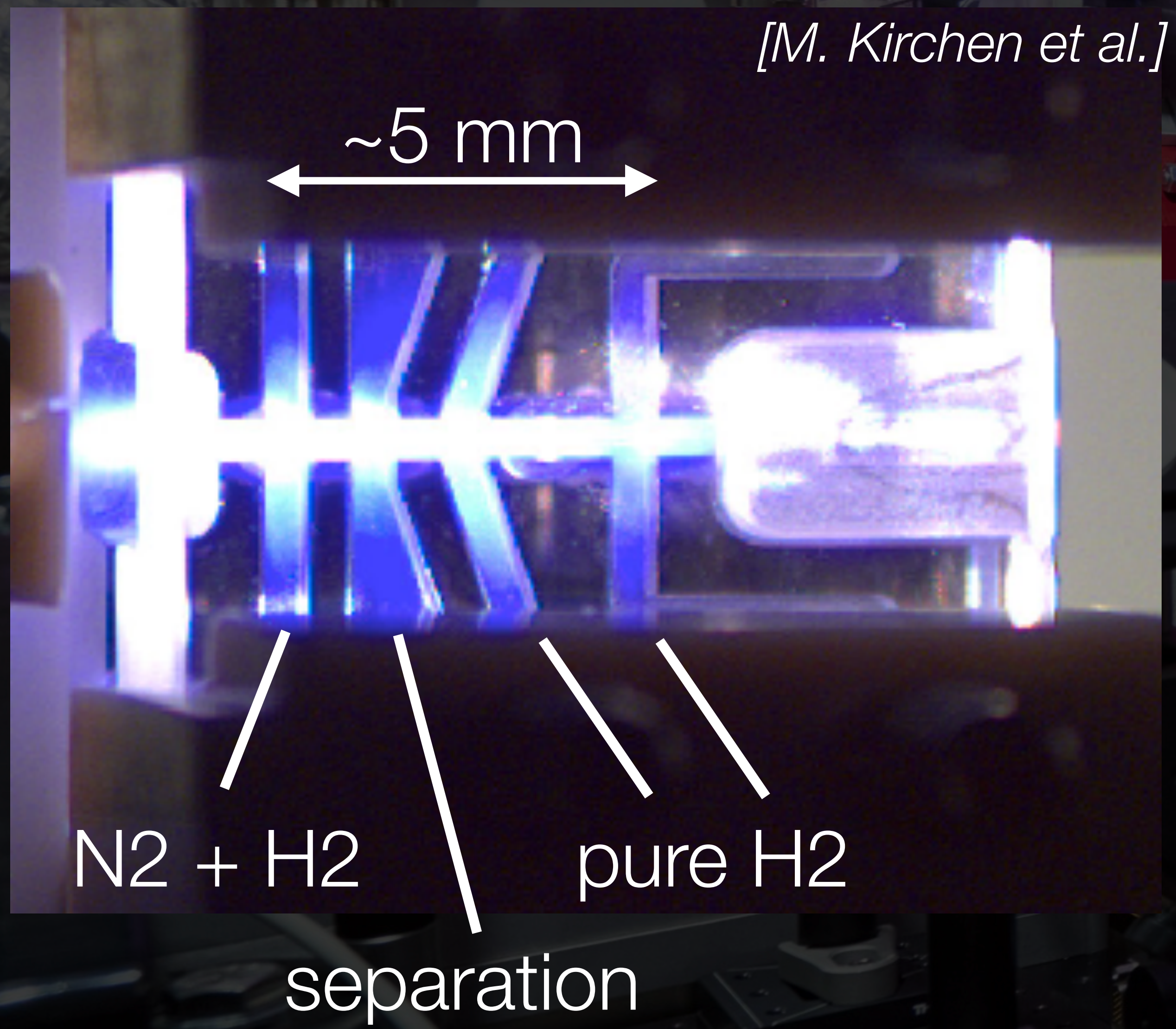
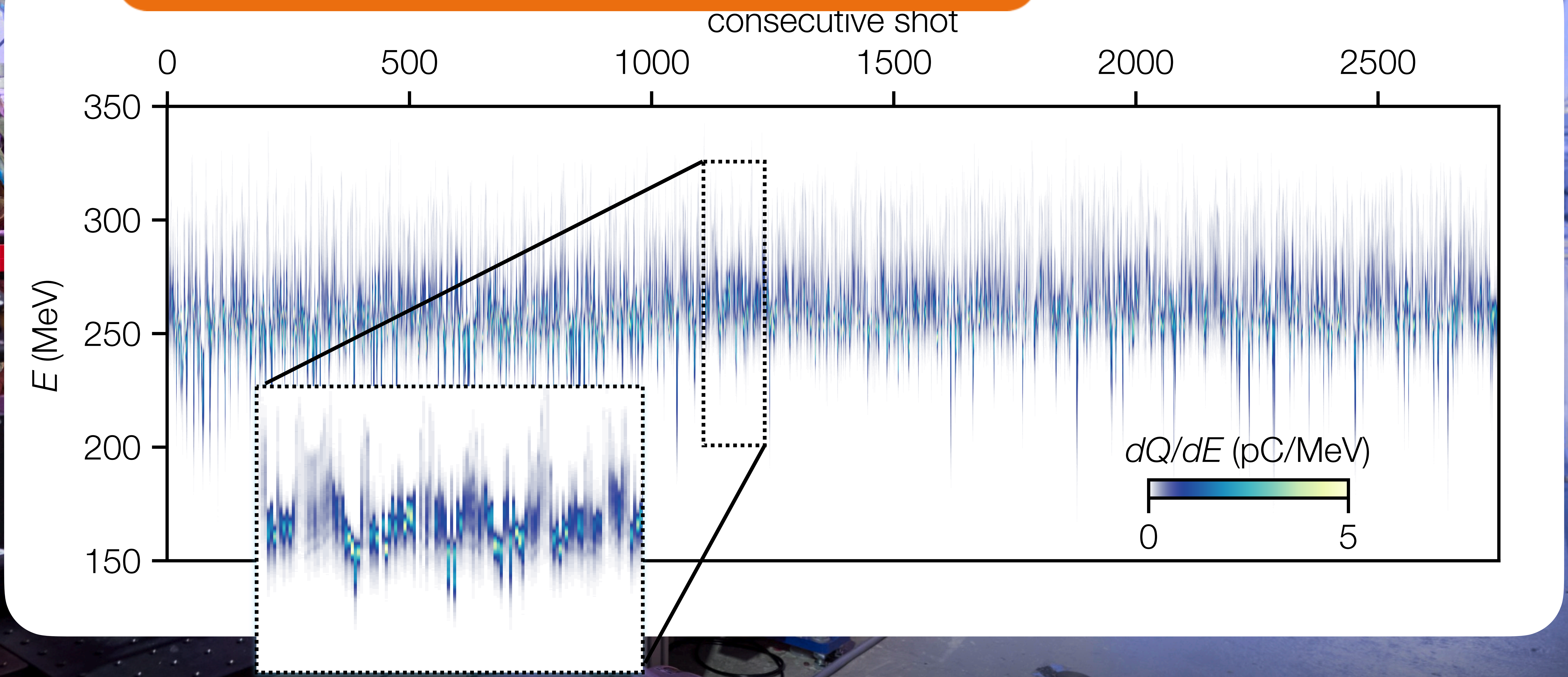


%-level energy spread and jitter



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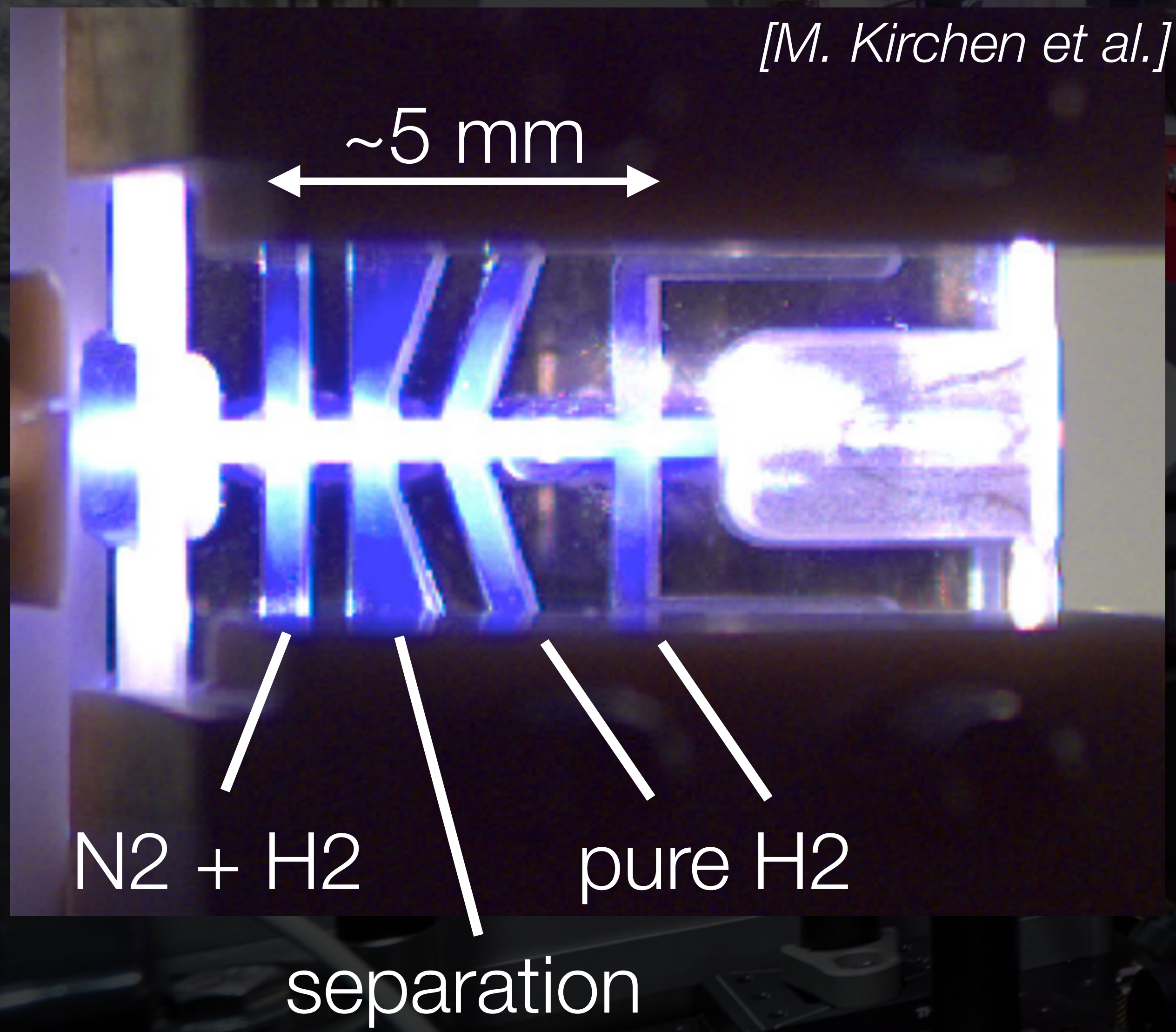

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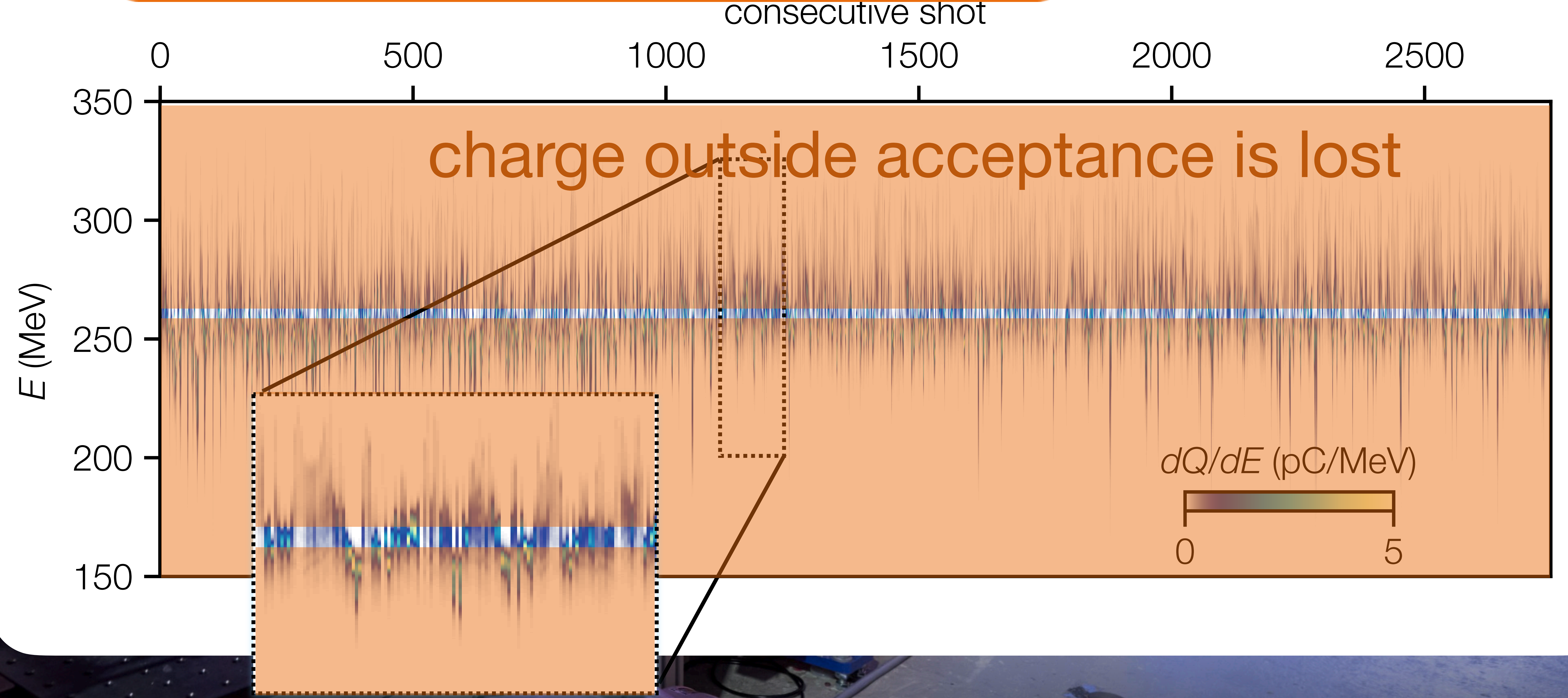
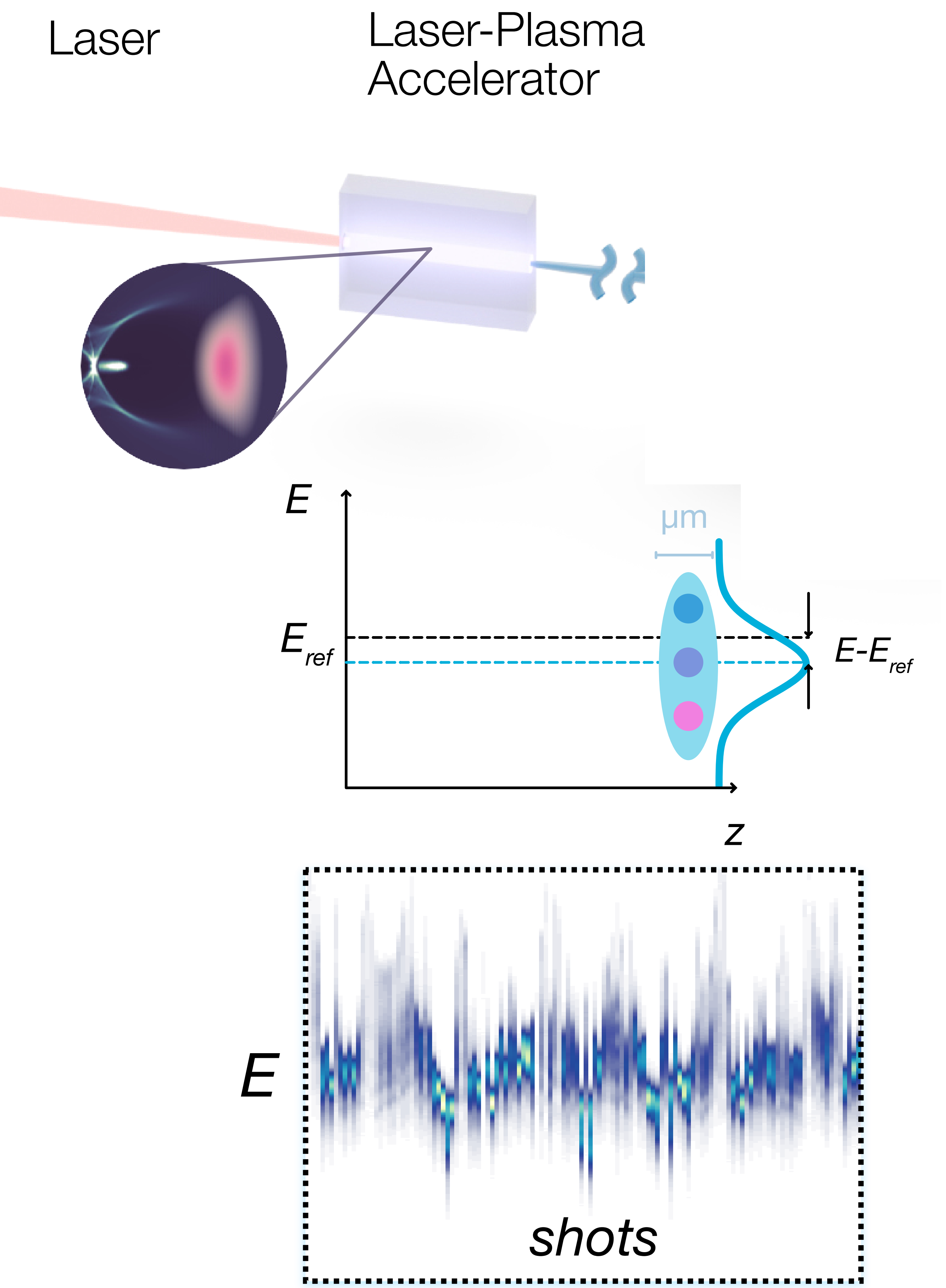


Downramp assisted ionisation injection [M. Kirchen, S. Jalas et al., Phys. Rev. Lett. 126, 174801 (2021)]

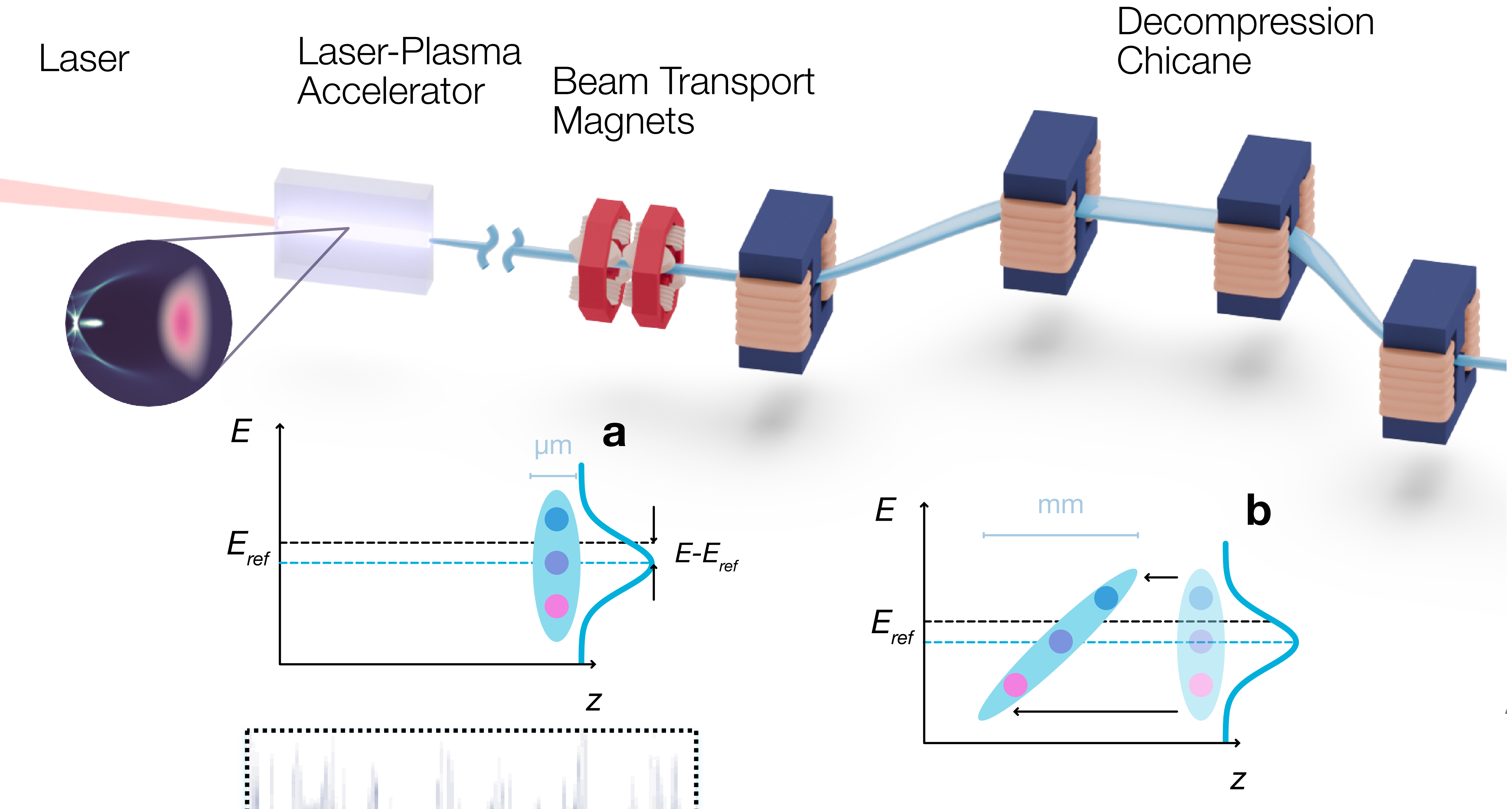
LPA beams are intrinsically short

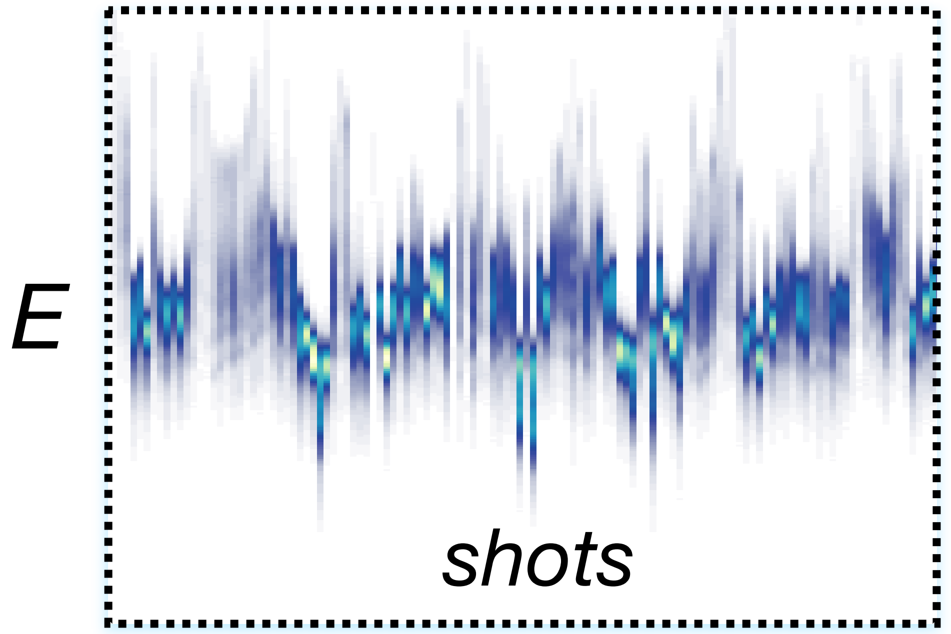
but show percent-level energy spread & jitter



A dipole chicane reduces the longitudinal slice energy spread

by imprinting an energy dependent delay.

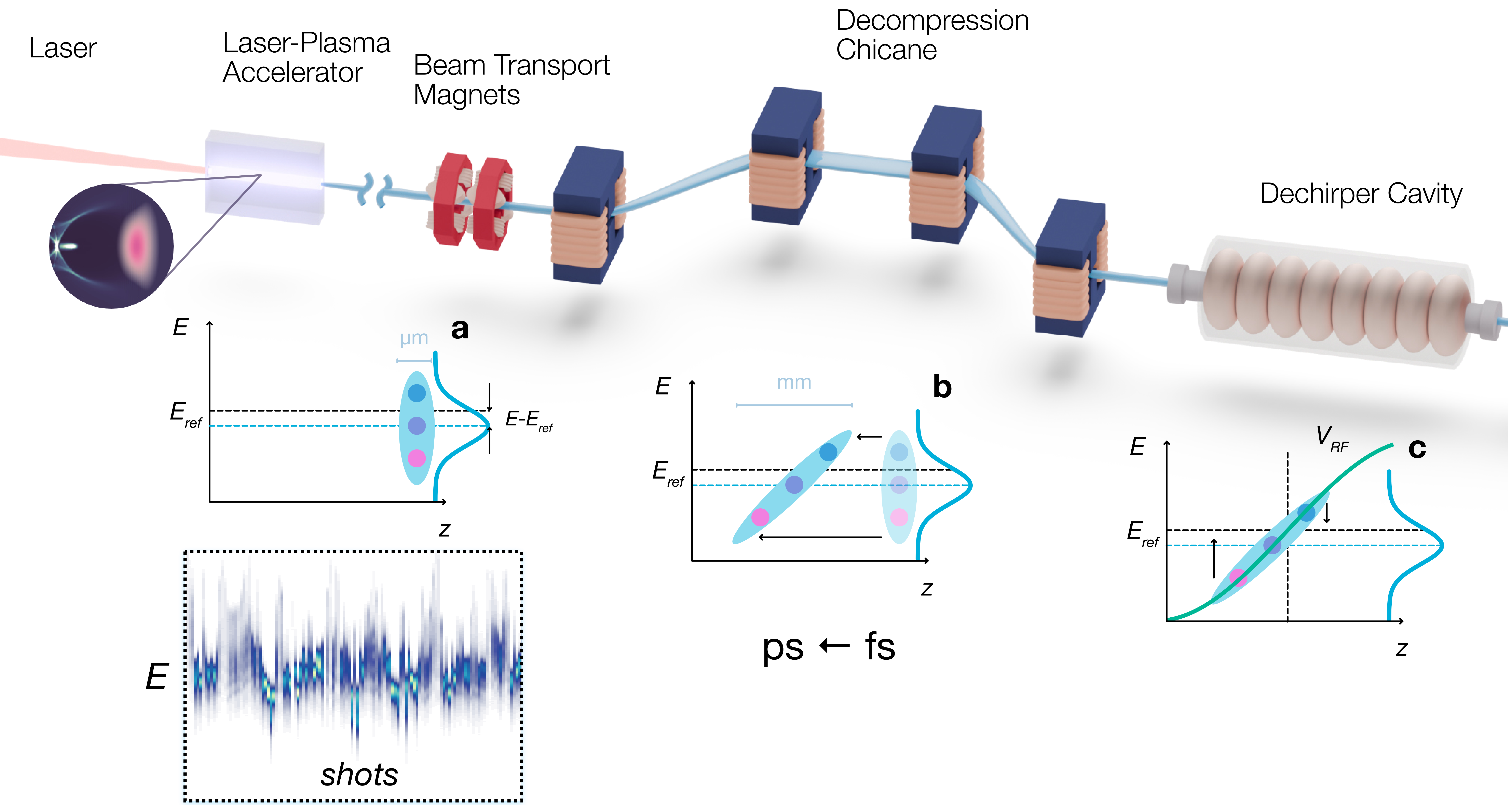




ps ← fs

The spectrum is compressed inside an (active) RF cavity

removing the chirp imprinted earlier.



Energy spread & jitter reduced simultaneously

for the cost of beam current.

Laser and plasma-based compression for mega-amp, ultrashort electron bunches at FACET-II

Kelly Swanson

Wednesday

Sala Pithecusa

11:33 - 12:06

20m of additional beamline installed in 2024

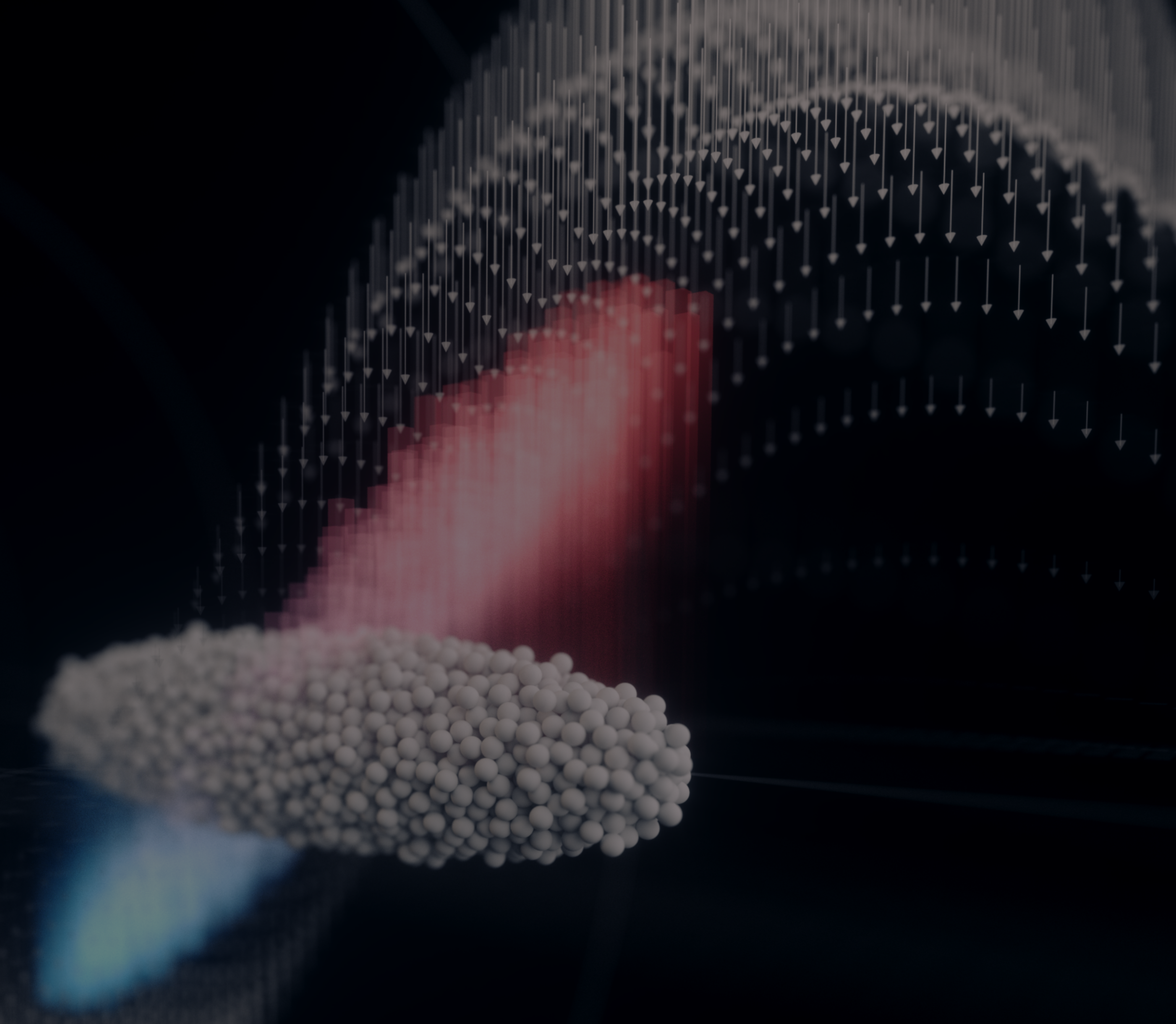
LUX

Decompression chicane

S-band RF cavity

360° RF phase scan

energy spectrum is compressed for a larger range of RF phases



$$V_{RF} = \frac{E_{ref}/e}{k_{RF}\, R_{56}}$$

S-band RF has a 10 cm wavelength (3 GHz)

$$R_{56} = 10 \text{ cm}$$

$$V_{RF} = 45 \text{ MV}$$

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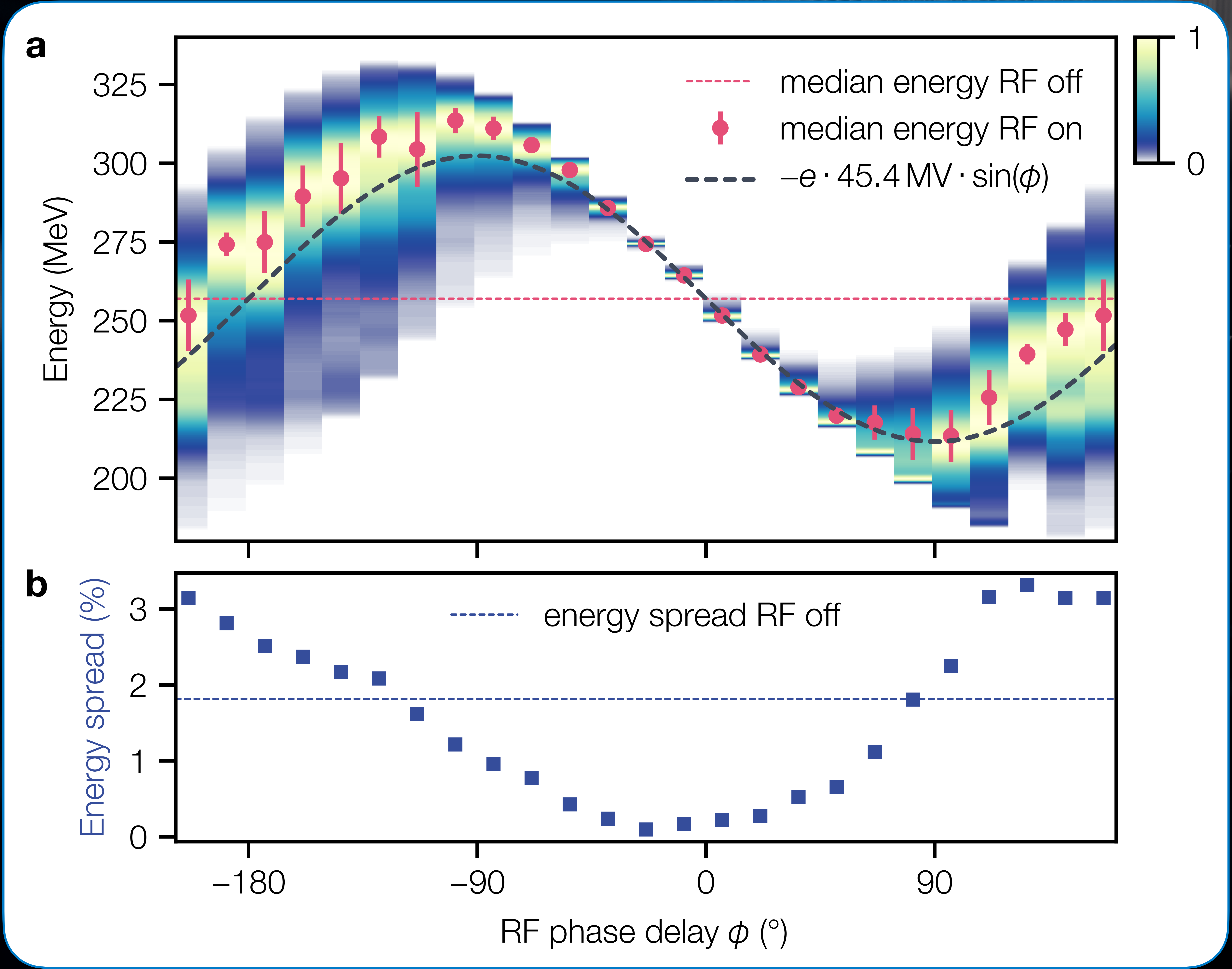
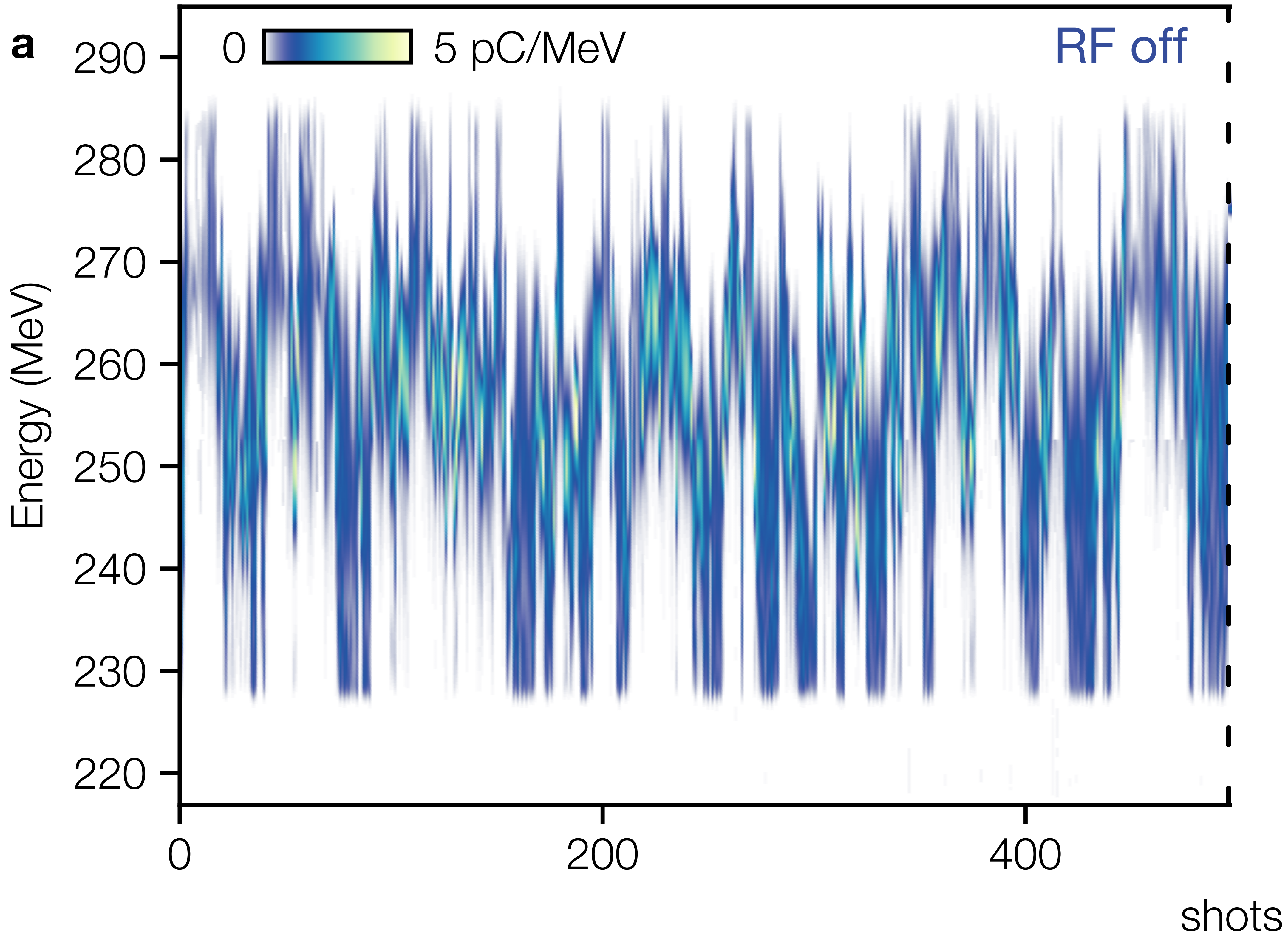


Active energy compression of plasma accelerated beams to the permille

0.048% energy jitter & 0.097% energy spread, factor ~25 energy compression

P. Winkler et al. *Nature* (2025)



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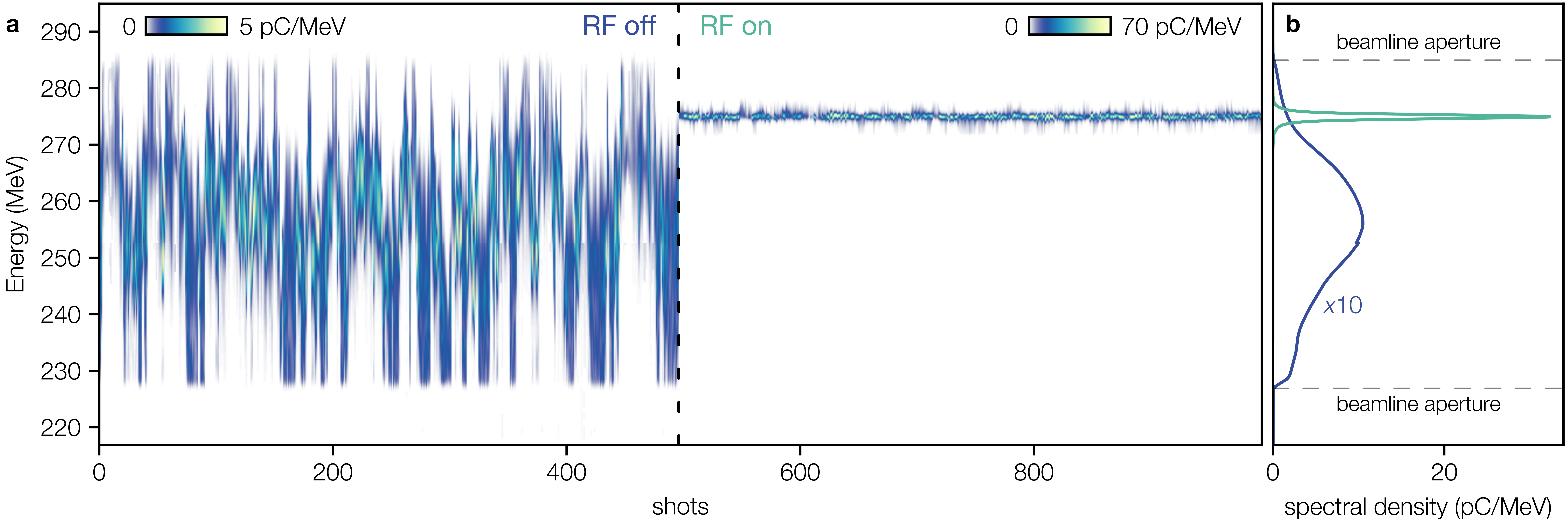

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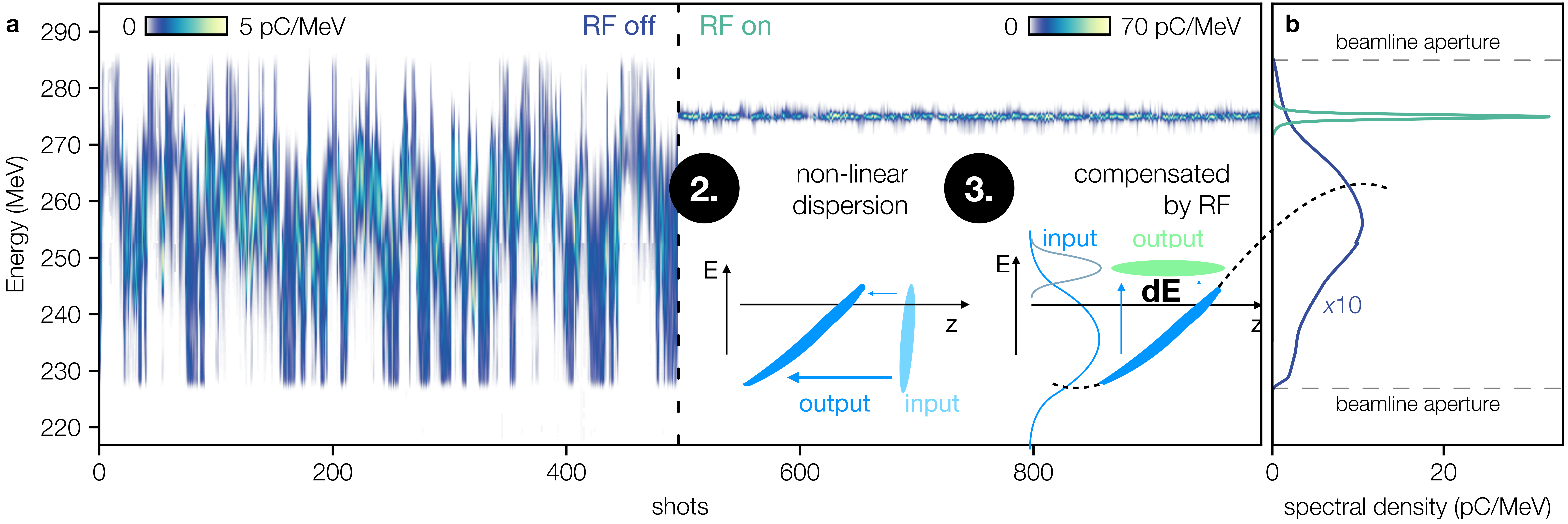
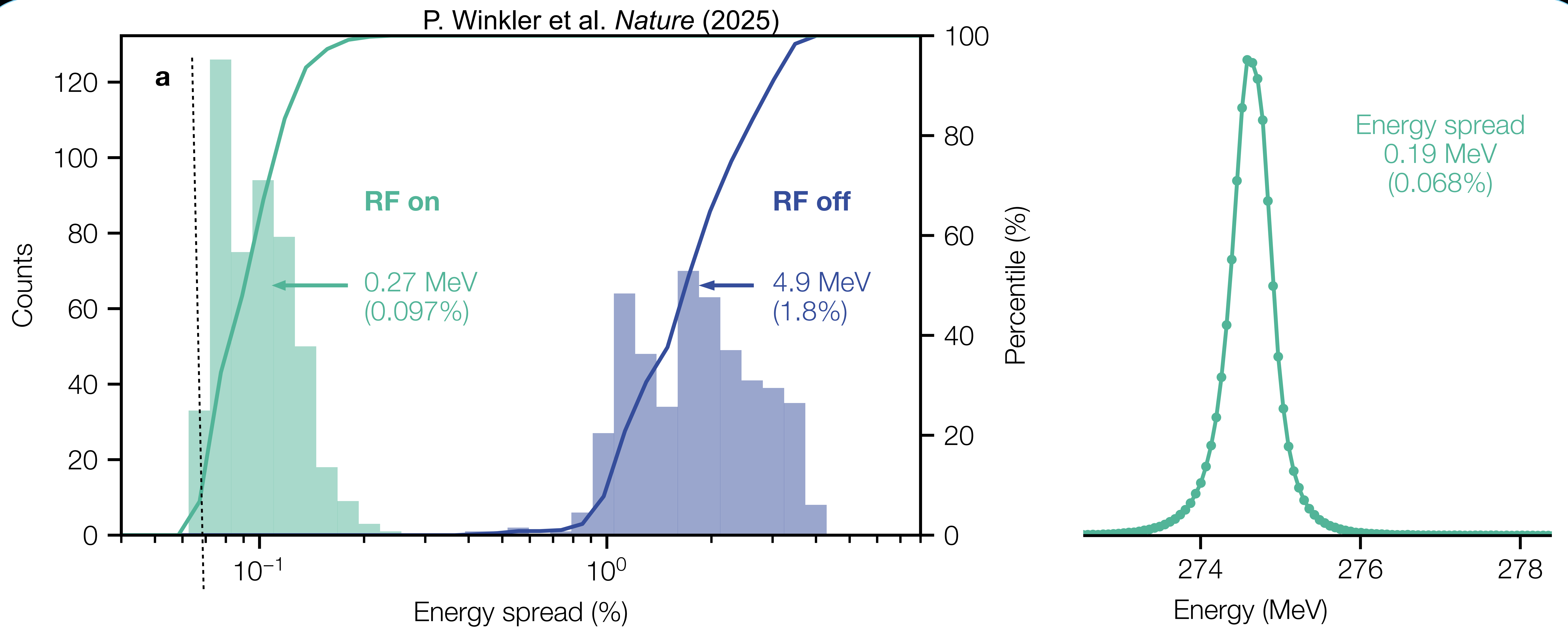


Energy spread is compressed to resolution limit of the spectrometer

uncorrelated slice energy spread should be between E-4 and E-5



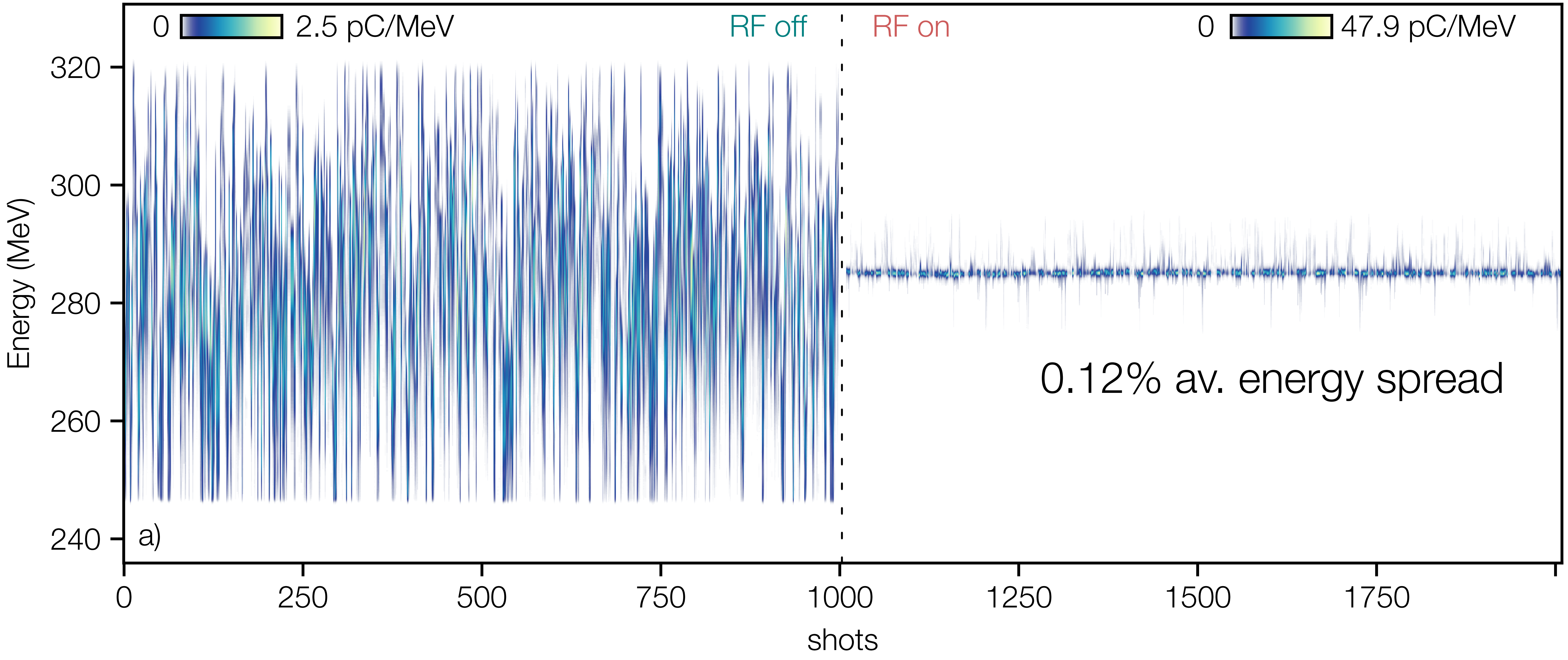
[S. Antipov, A. Martinez de la Ossa et al., Phys. Rev. Accel. Beams 27, 100704 (2024)]

Increasing the R56 from 10 cm to 17 cm reduces required RF power by a factor 3

while performance would still be good enough for injection

$$V_{RF} = \frac{E_{ref}/e}{k_{RF}\; R_{56}}$$

$$P_{RF} \propto V_{RF}^2$$



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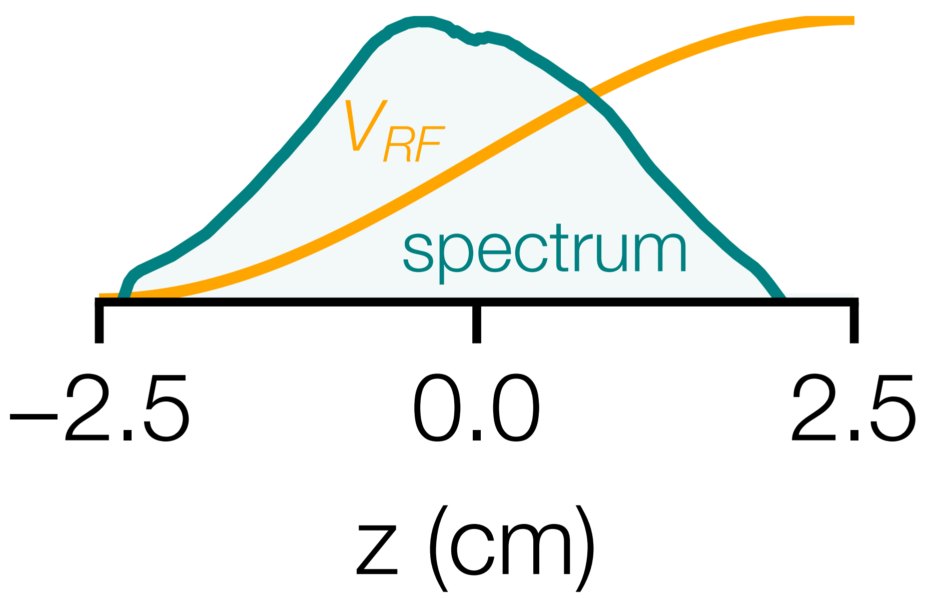
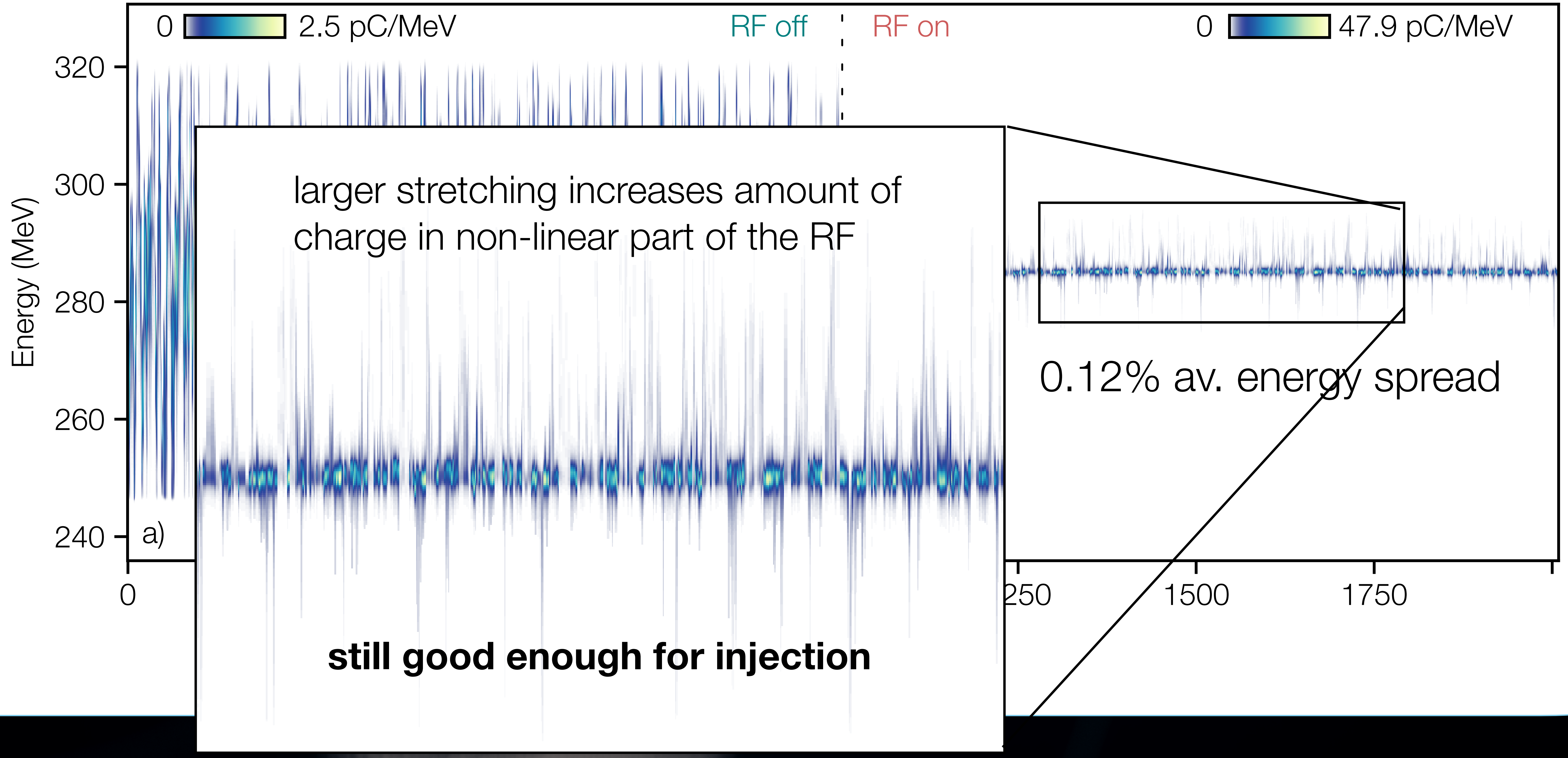
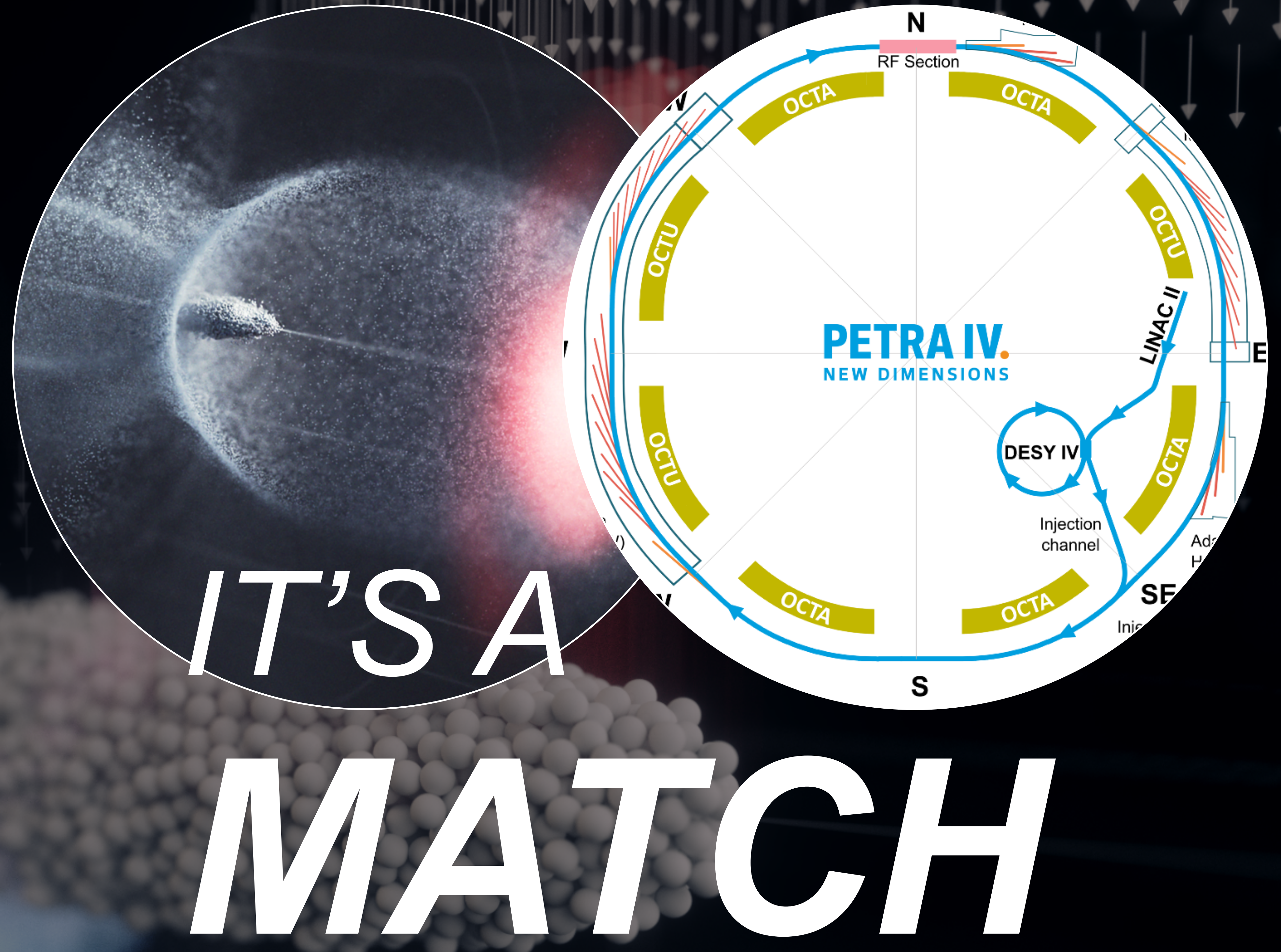




Conclusion

- Performance so far associated with modern RF accelerators.
- well suited for synchrotron injectors.
- The RF power required scales with the input beams energy stability
- scaling to higher energies (or higher current): X-band or plasma dechirper



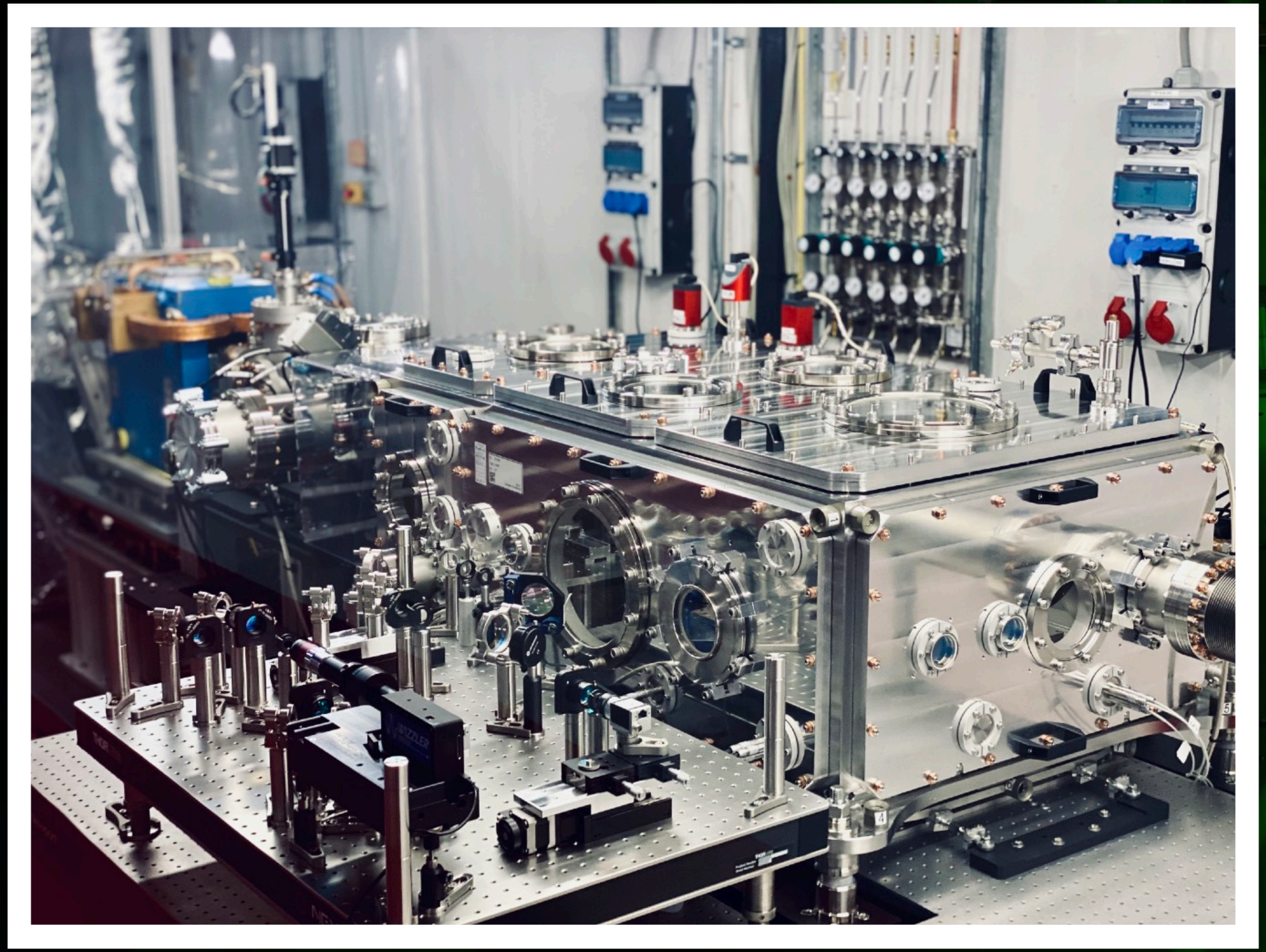
[A. Ferran Pousa et al., PRL 129, 094801 (2022)]

[A. Martinez de la Ossa et al., PIP4 CDR (2023)]

[S. Antipov et al., PRSTAB 24, 111301 (2021)]

KALDERA - DESYs new flagship laser

First phase with 100 Hz, 0.5 J is online allowing for first electron experiments



Report — *Alberto Martinez de la Ossa* — 15:00 - 15:15

Paul Winkler — 15:15 - 15:30

gr… | **Status of the KALDERA drive-laser development for a ne…** *Dr Guido Palmer* — Laser

F… | **High average power laser plasma acceleration at DESY** *Dr Manuel Kirchen* — LPA

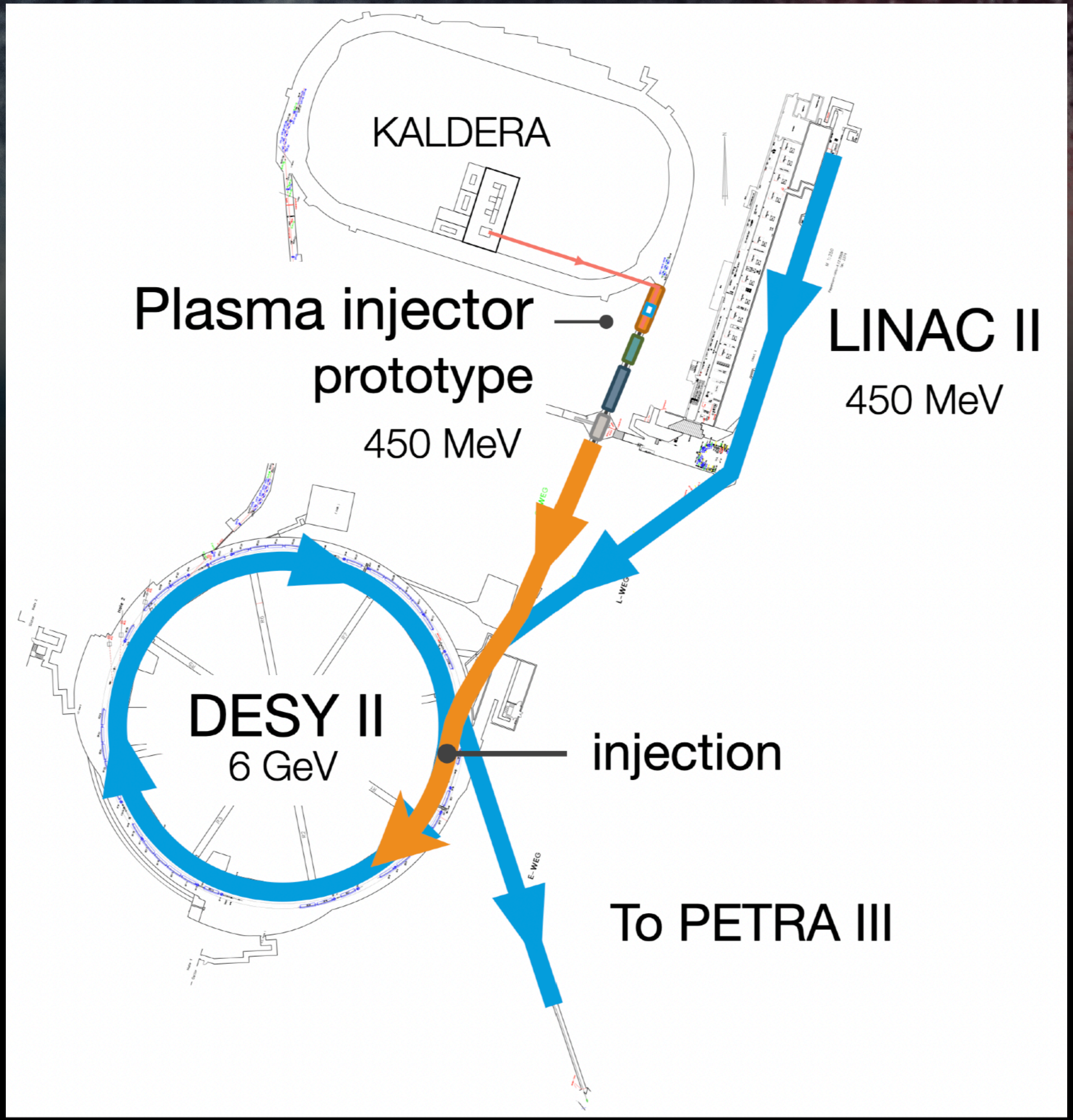
oks :30 | **Development of the L2-DUHA dual output front end at EL…** *Alex Johannes Whitehead*

riv… | **High repetition rate TiSa lasers for laser plasma accelera…** *Vincent Leroux*

Next: Demonstrate full technology chain at lower energy

Injection of LPA beams into the DESY II booster ring

- Conceptual design report published
- Energy compression demonstrated
- Demonstrate full technology chain (incl. synchronisation, matching …) at lower energy (~400 MeV)
- planned injection into DESY II in 2026



Acknowledgements

The DESY Plasma Group (MPL)


Andi Maier
Group Leader


Wim Leemans
Division Director

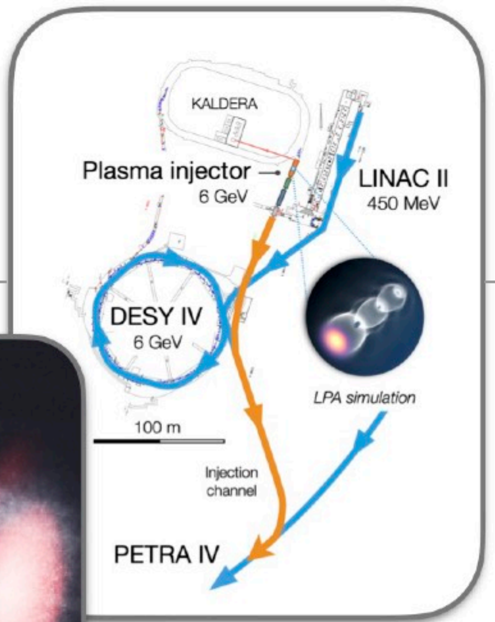
See our webpage at plasma.desy.de
for a full list of teams and activities.

Photo: Marta Mayer (DESY)

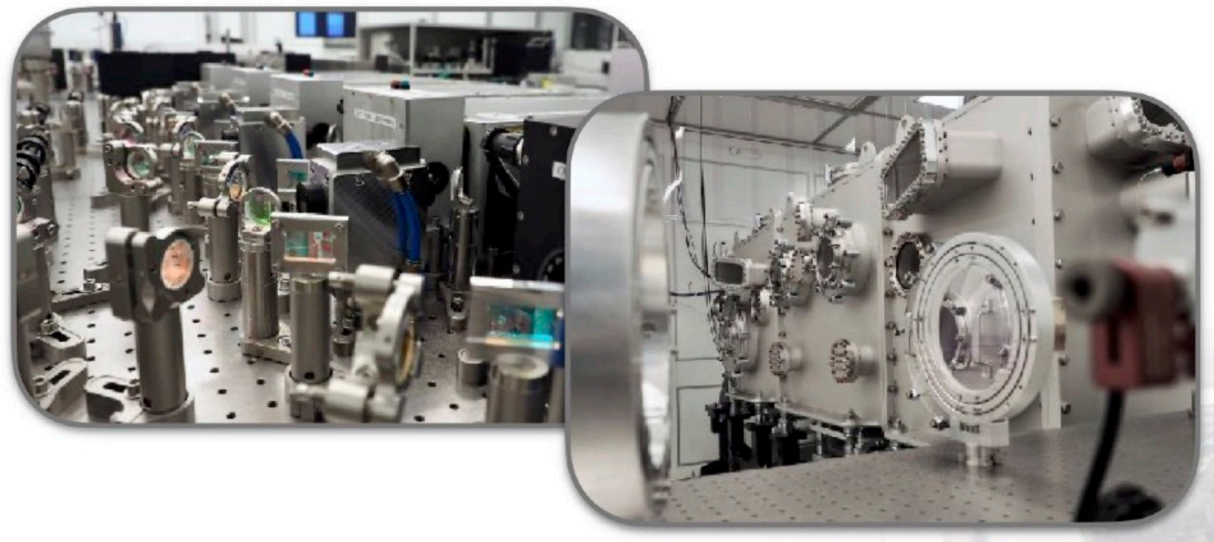
Plasma R&D at DESY

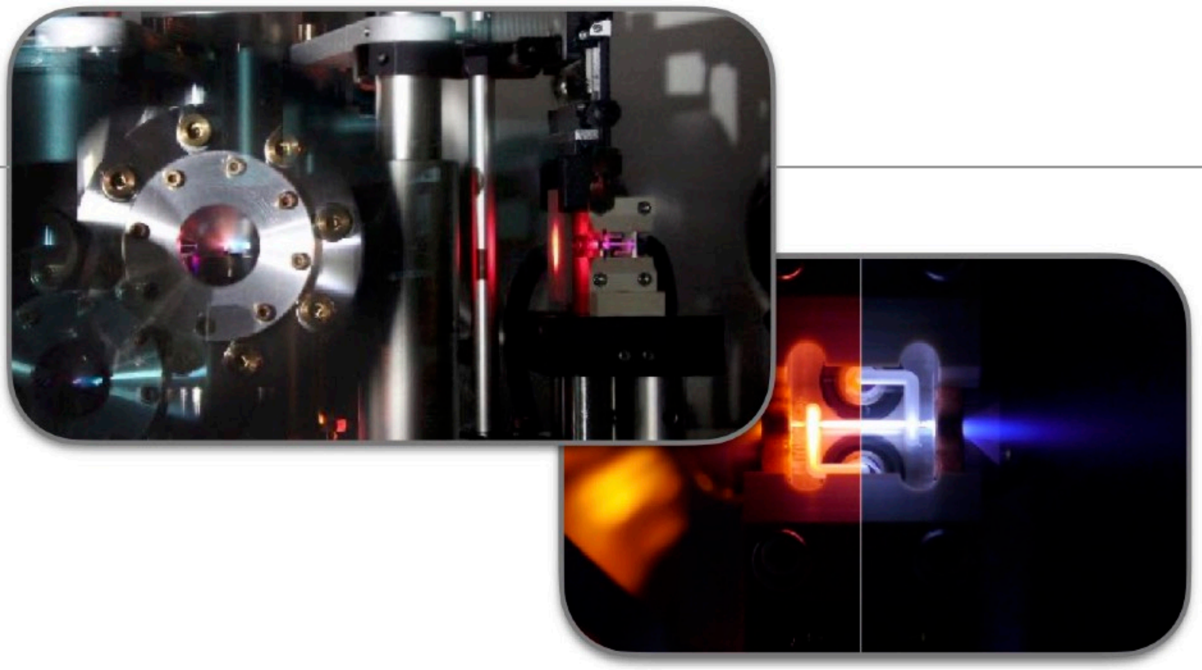
Our portfolio at plasma.desy.de

Theory & Simulations



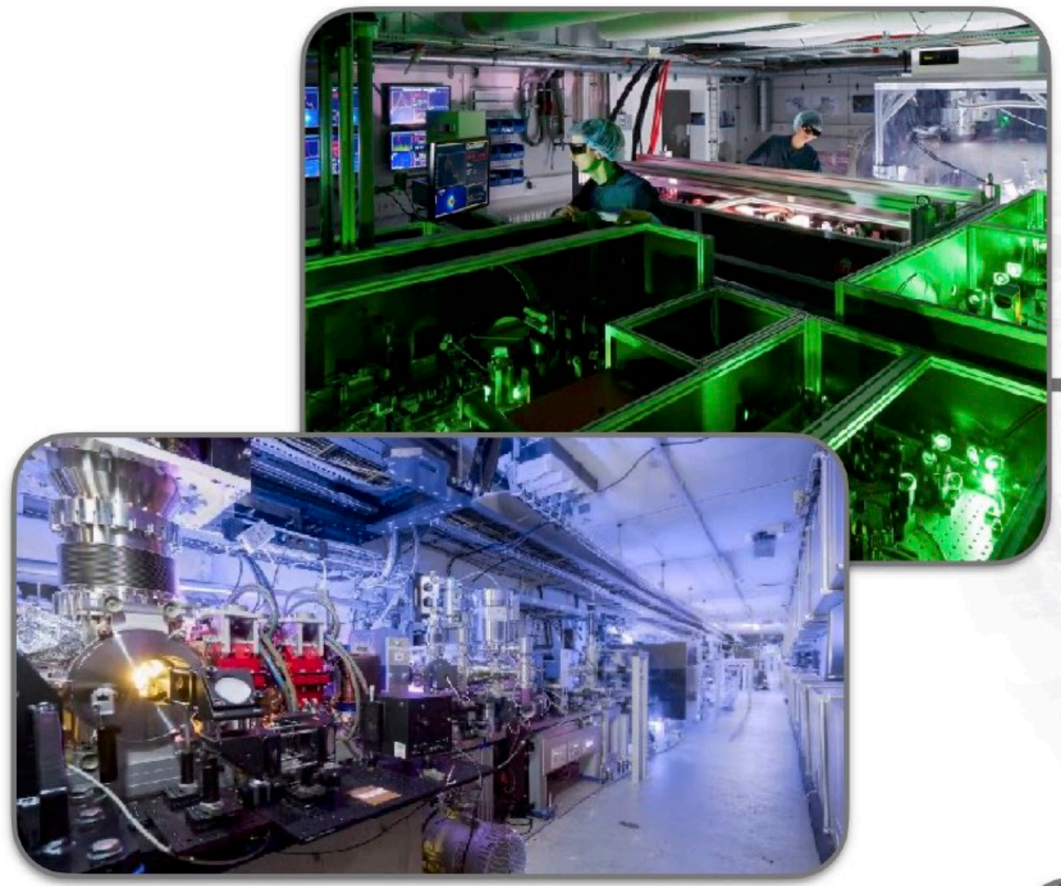
Scientific Engineering



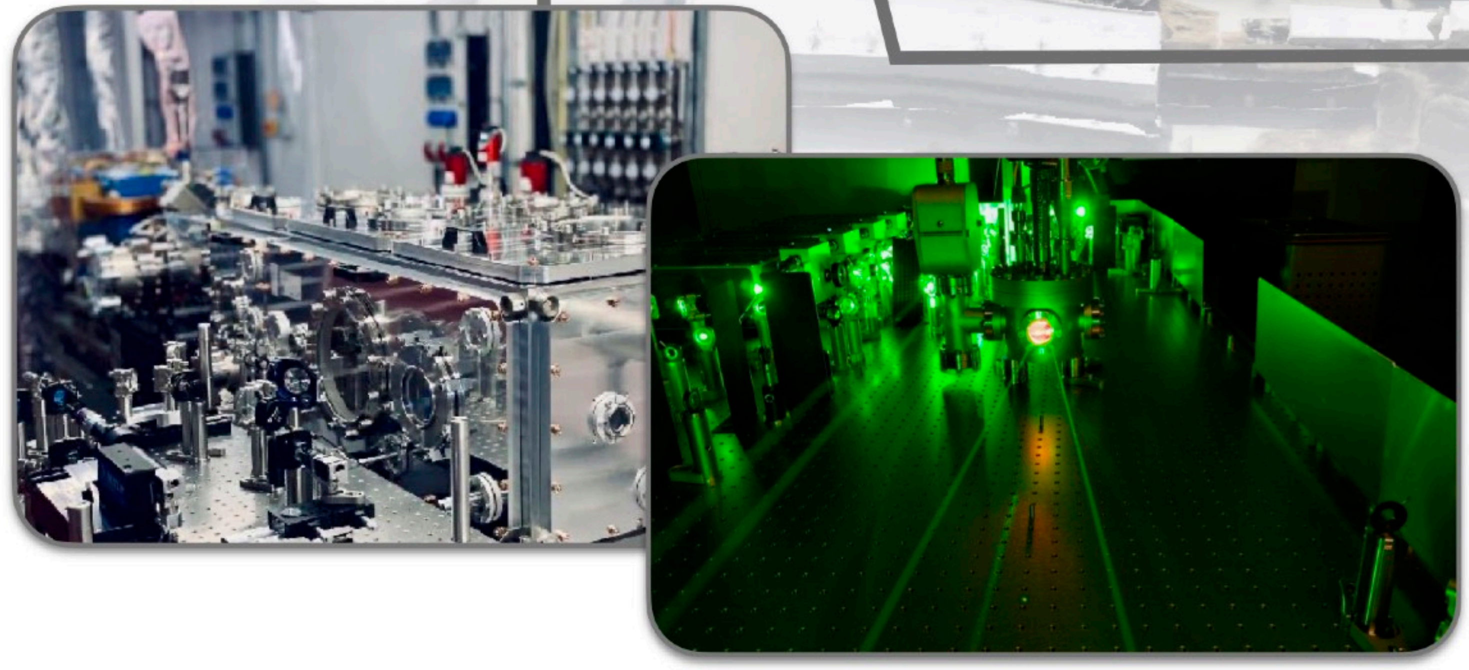


LPA Applications

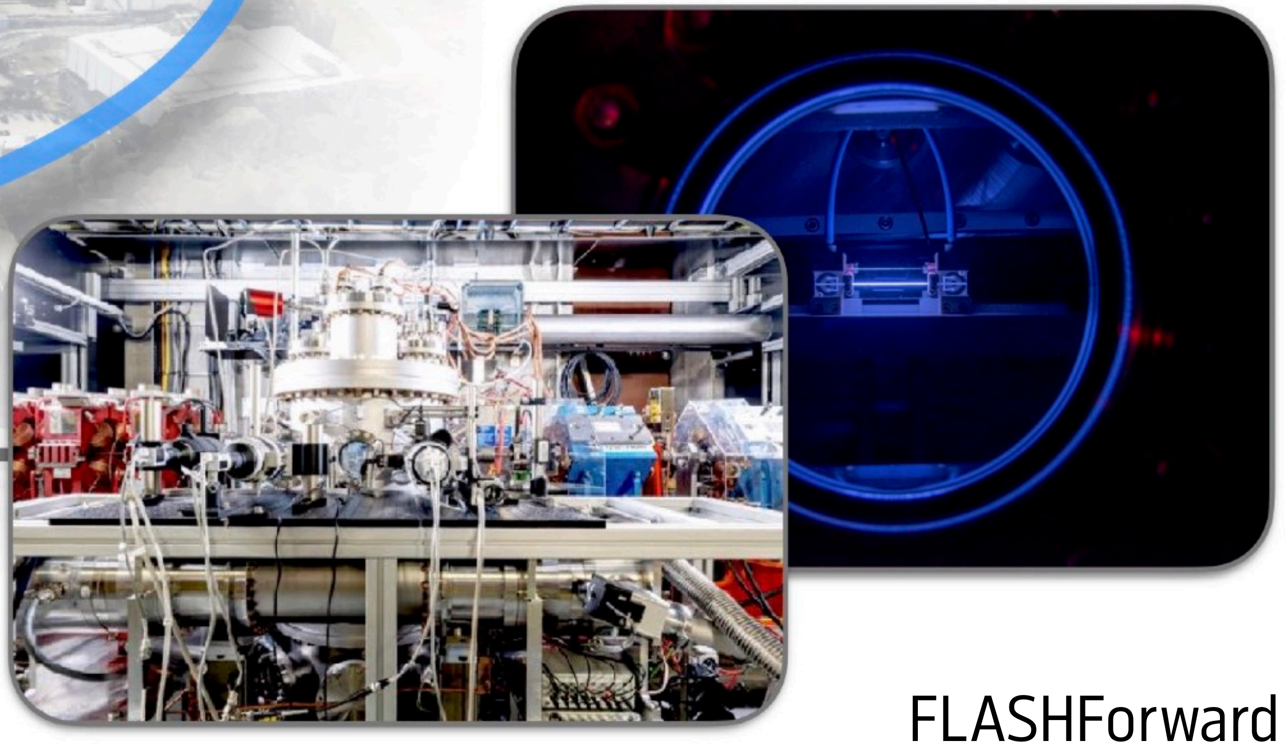
- RF accelerators
- Plasma accelerators



LUX Laser-Plasma Accelerator



KALDERA High Rep-Rate LPA



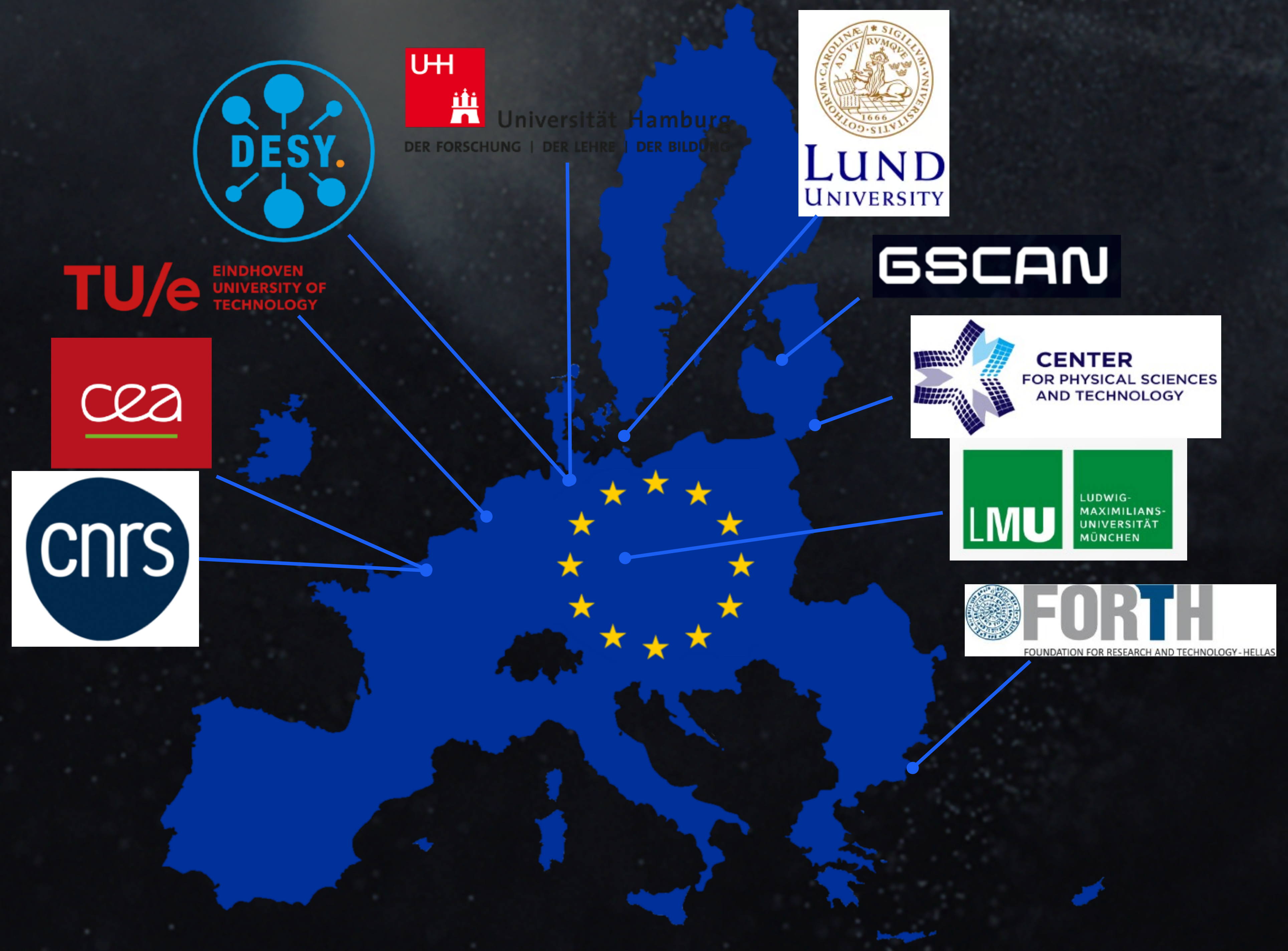
FLASHForward Beam-Driven Plasma Acc.

EPACE

European Compact accelerators, Applications, Entrepreneurship

MARIE CURIE ACTIONS

- ✦ 15 PhD opportunities in plasma acceleration in Europe!
- ✦ Funded as an MSCA Doctoral Network
- ✦ Applications open, PhDs start in September 2025
- ✦ Contact: lisa.crinon@desy.de, visit www.epace.eu



Research Topics

- kHz laser-wakefield acceleration
- Snapshot tomography of laser-plasma acceleration
- Machine-Learning-Enhanced Laser Plasma Accelerators
- Tailored plasma targets for Laser Wakefield Acceleration
- Production of high-density spin-polarized hydrogen-atom target
- Spin polarisation in plasma accelerators
- VHEE radiotherapy with beams from a wakefield accelerator
- Compact muon and electron source for radiological system for medical applications
- Advancing radiotherapy with laser-plasma accelerators
- ICS soft x-ray source for semiconductor wafer metrology
- Inverse Compton Scattering (ICS) x-ray source from a high-repetition-rate LPA
- Controlling plasmas on hydrodynamic time scales to improve plasma accelerators
- Theoretical study of superluminal laser-plasma acceleration
- Plasma mirrors towards high-quality compact electron accelerators
- Better beam quality in plasma accelerators through high-performance computing

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