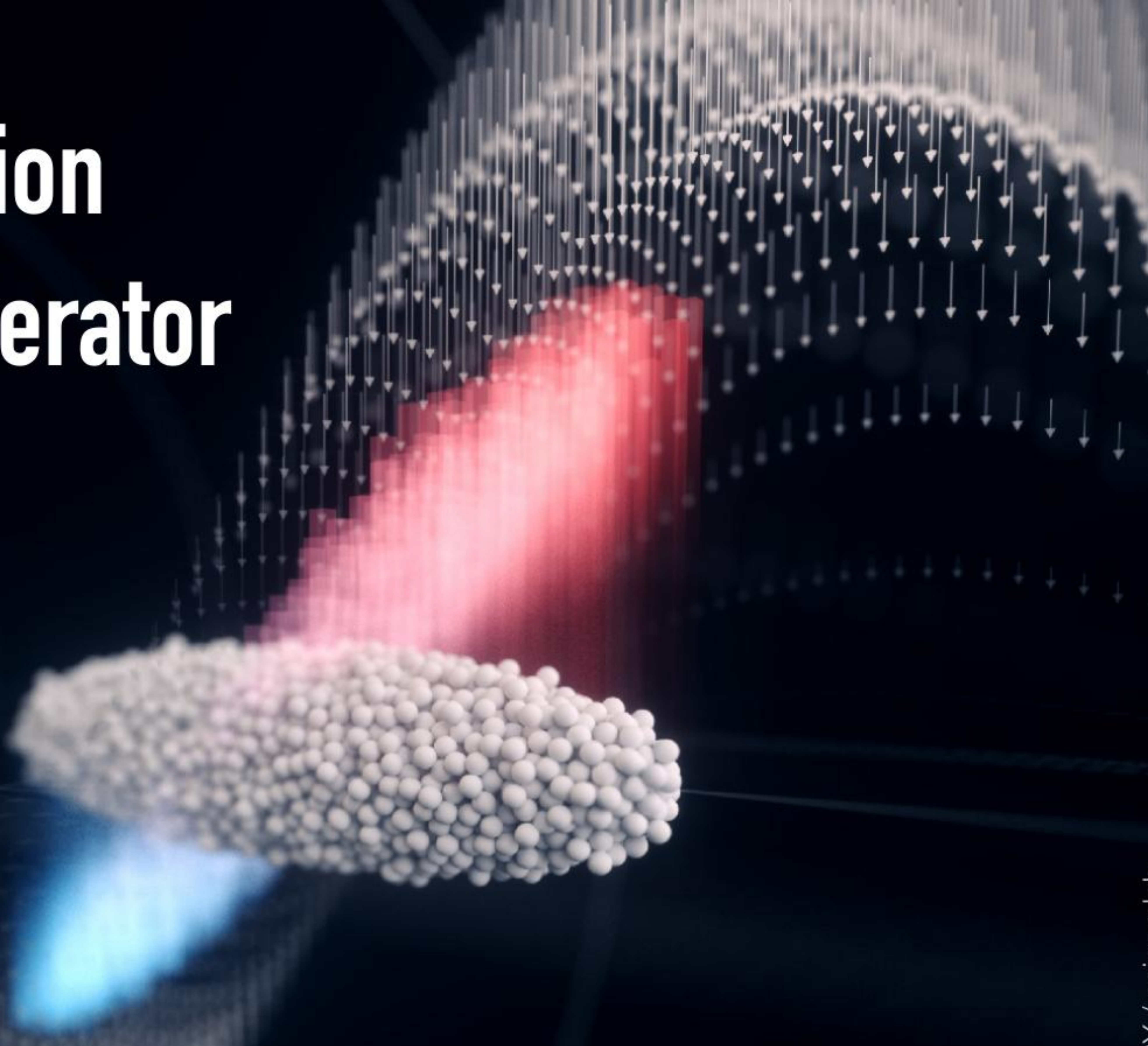
Active Energy Compression of a Laser-Plasma Accelerator



Andreas Maier
DESY

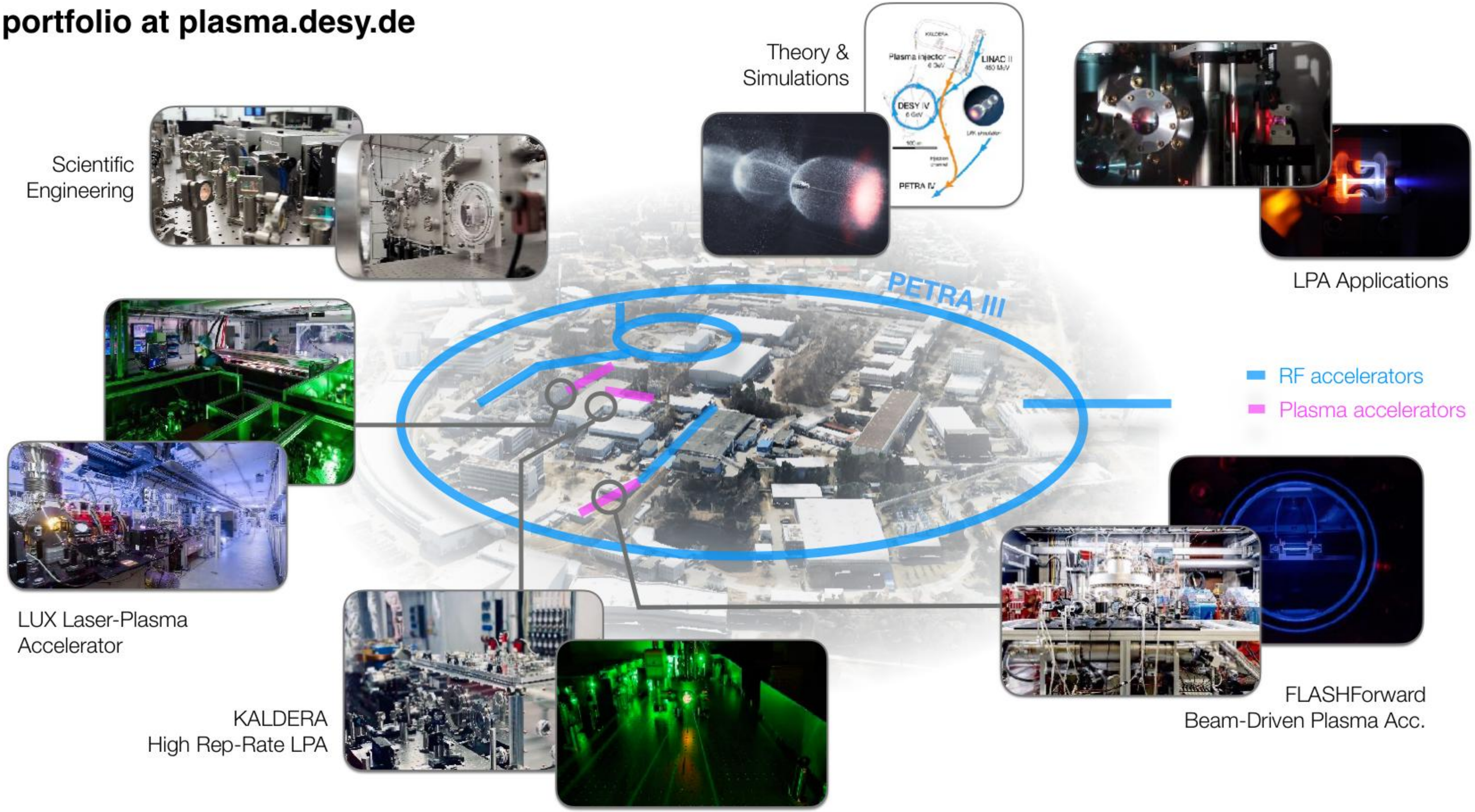
andreas.maier@desy.de

plasma.desy.de
kaldera.desy.de

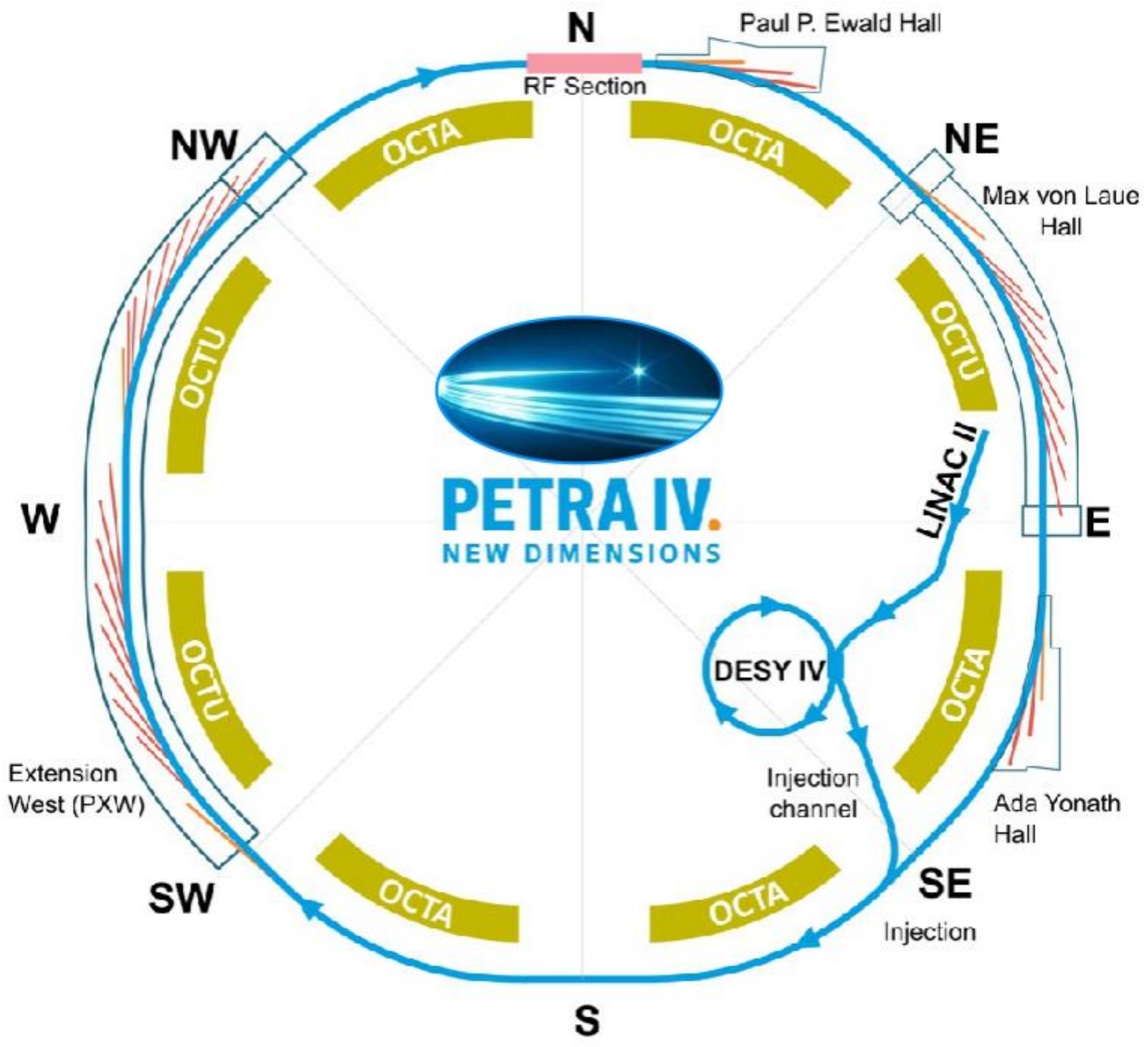
illustration: DESY / scicomlab

Plasma R&D at DESY

our portfolio at plasma.desy.de



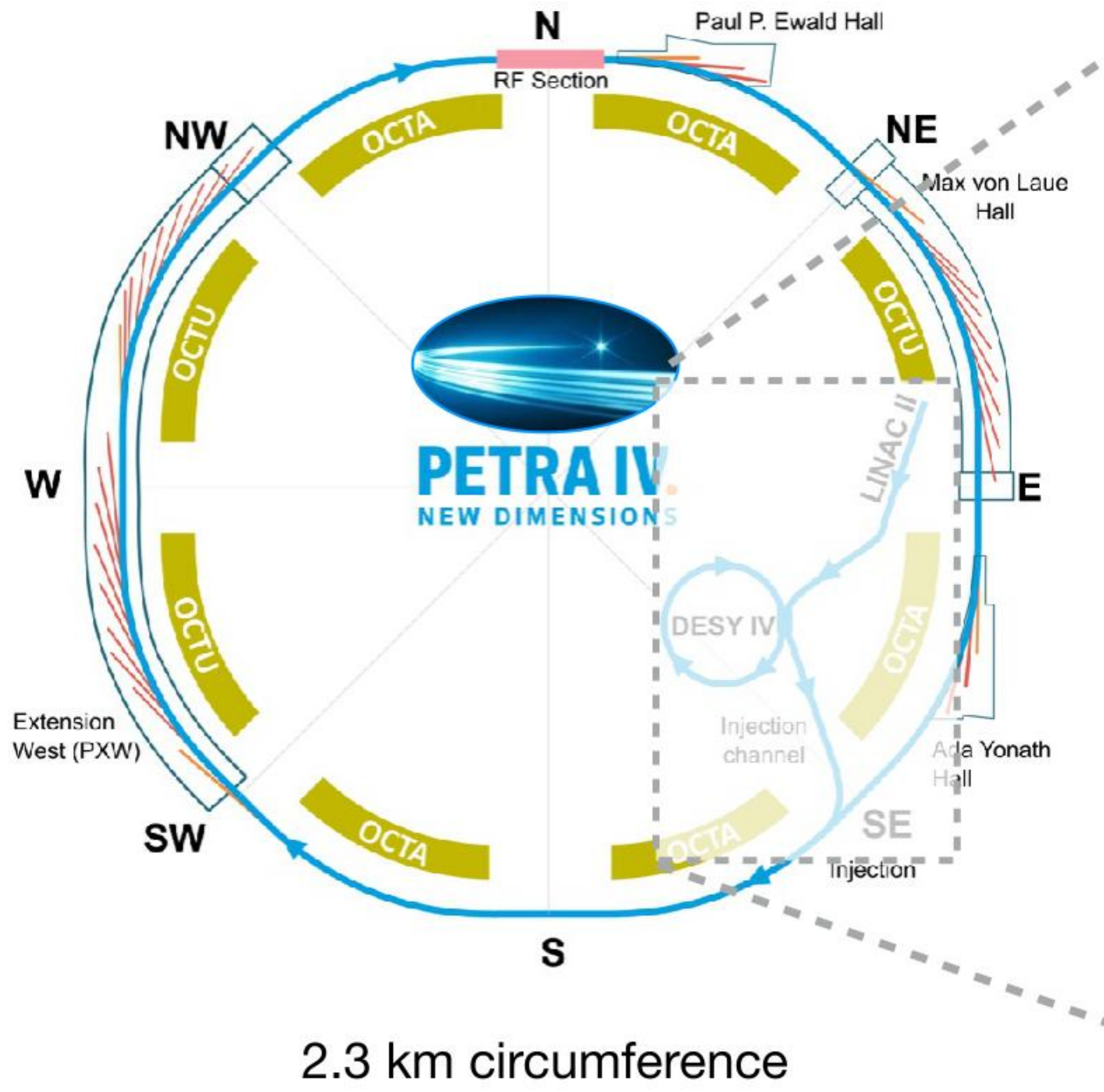
DESY is upgrading its storage ring to the 4th generation synchrotron PETRA IV

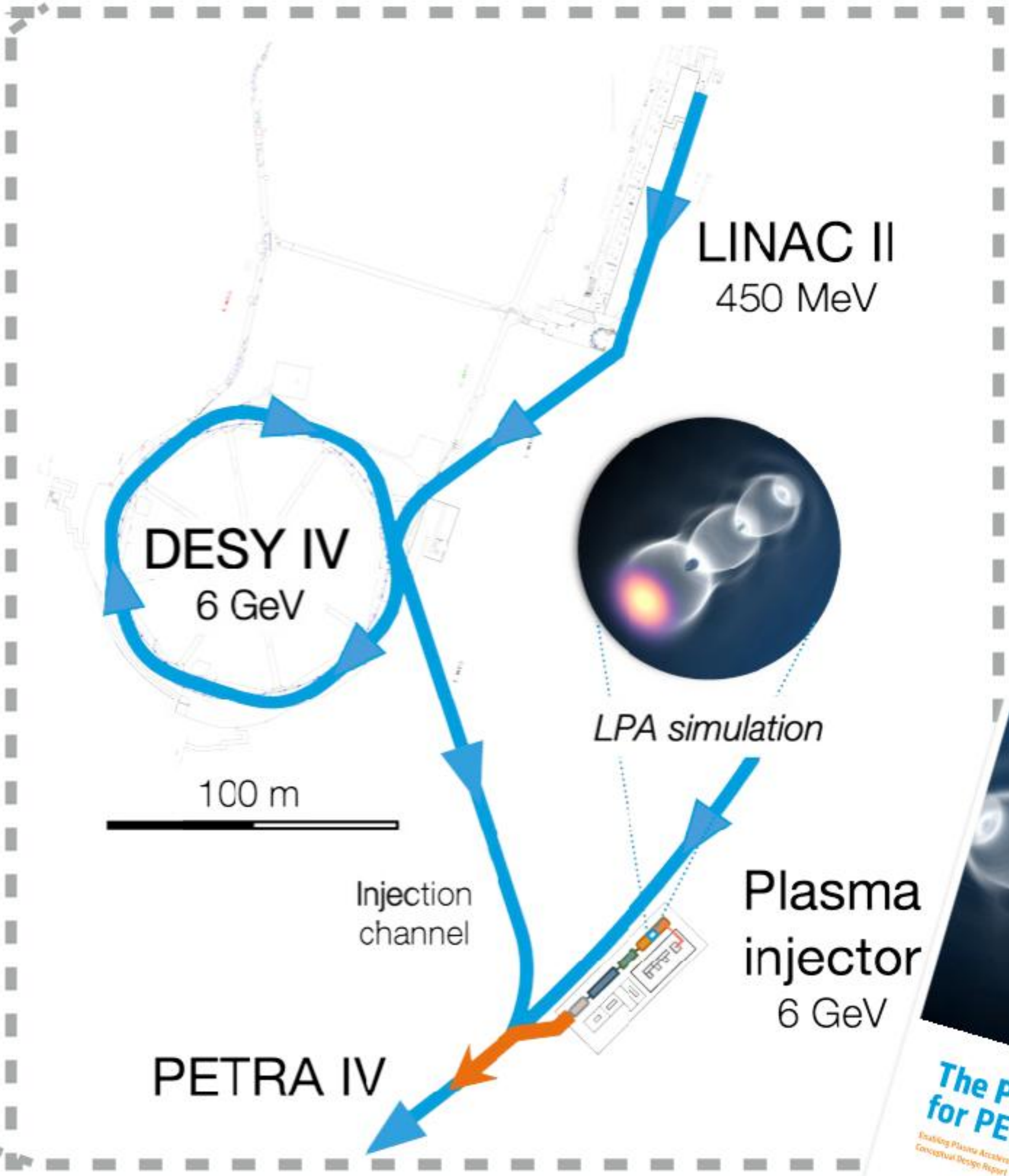


2.3 km circumference

A compact Plasma-Injector is planned in a building neighbouring the ring

injecting directly at 6 GeV. Conceptual design published.





CDR

published

A compact Plasma-Injector is planned in a building neighbouring the ring

injecting directly at 6 GeV. Conceptual design published.

Requirements

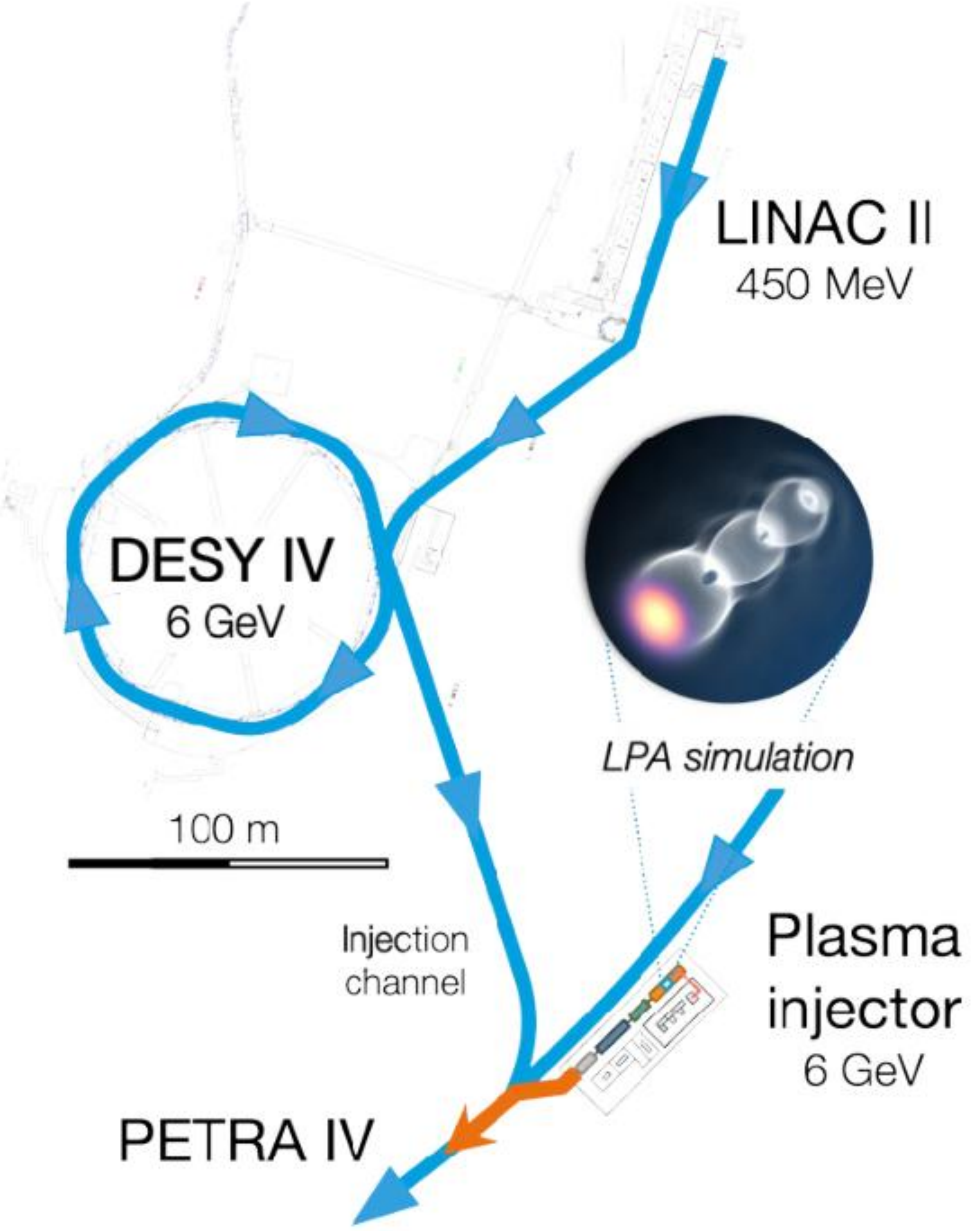
- Filling the ring (within 10 minutes)
- Top-up operation (1% charge every 6 minutes)

Alberto Martinet de la Ossa

Maxence Thevenet
& team

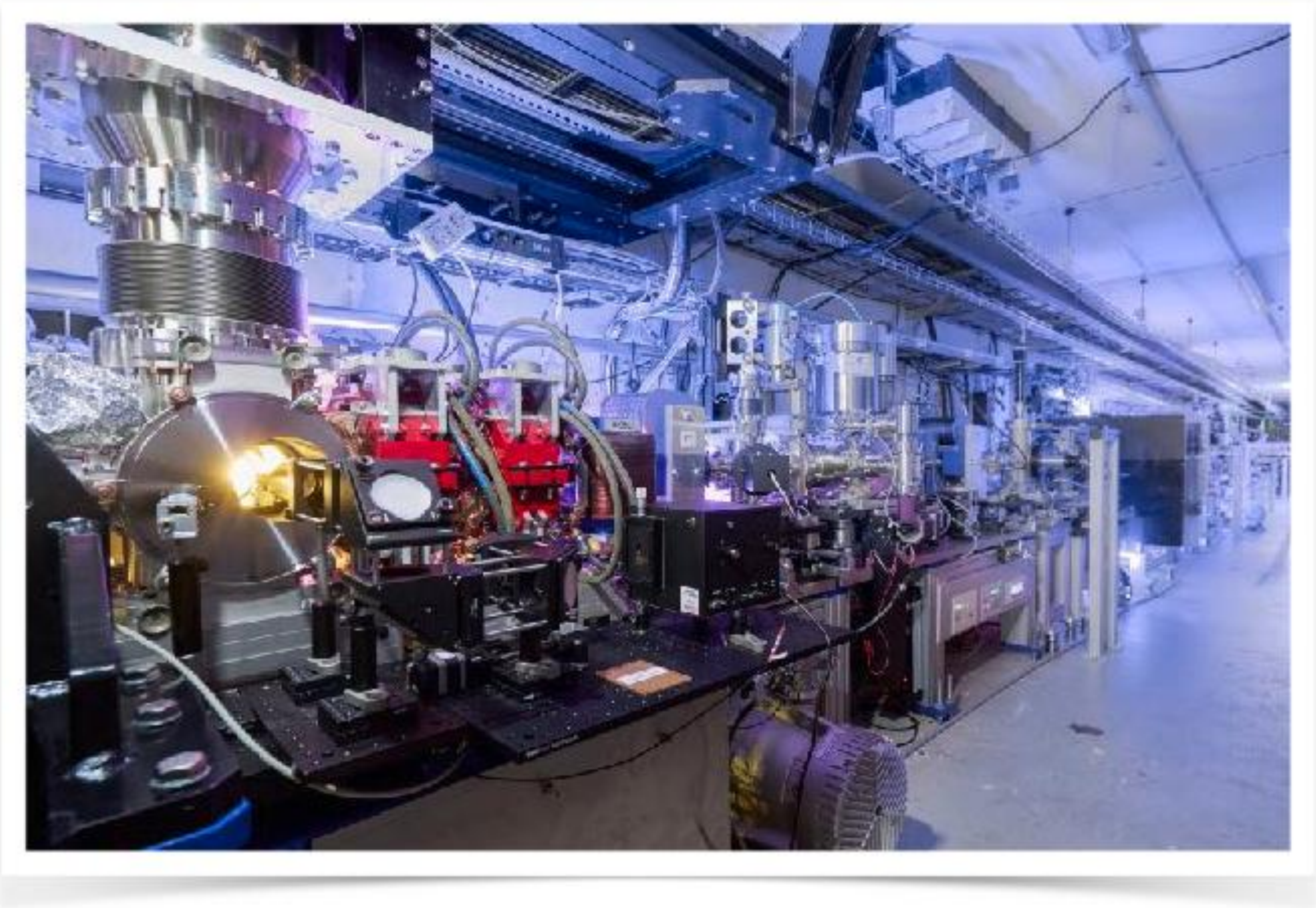
Beam parameters

Beam Energy	6 GeV
Energy spread and Jitter	< 0.3%
Charge injection rate	> 2.6 nC/s
Availability	> 98%



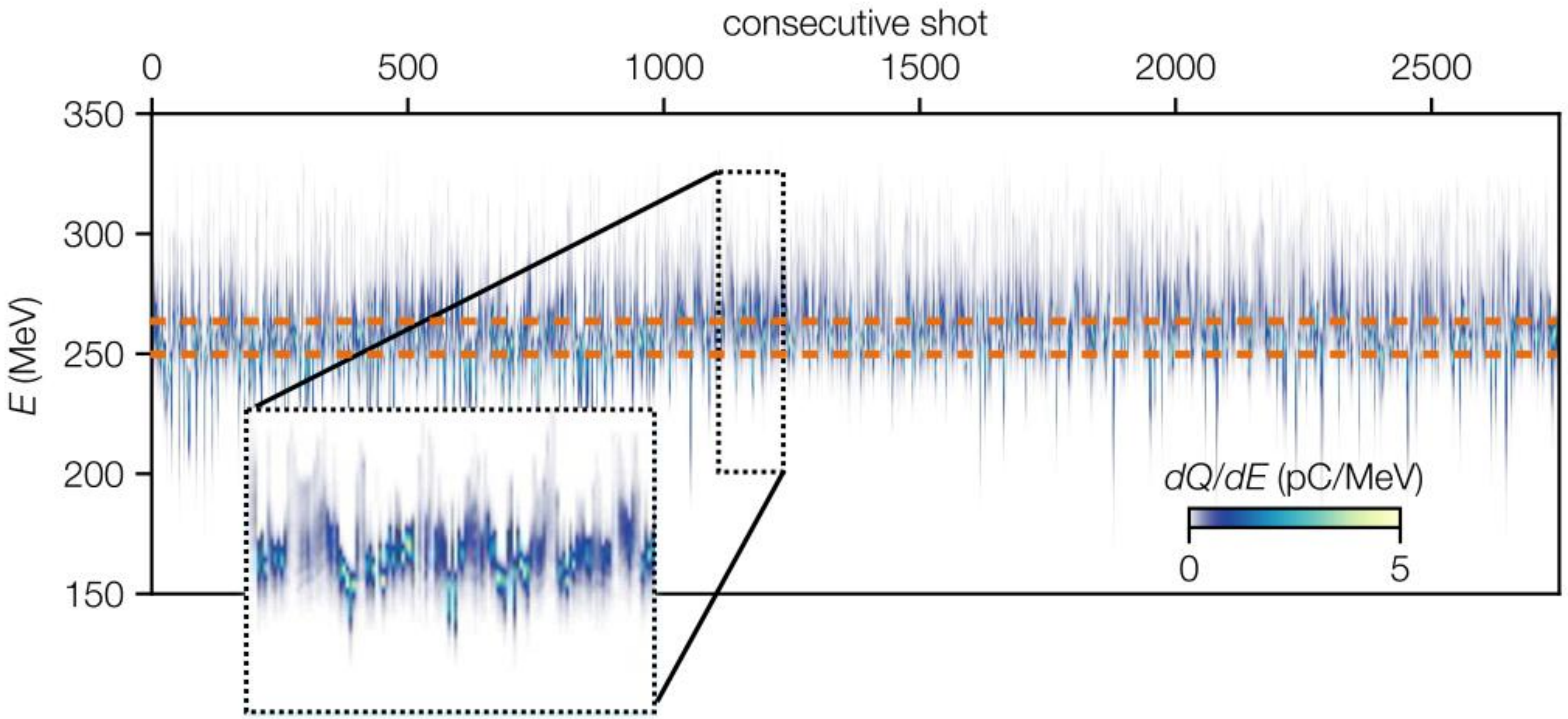
State-of-the-Art LPAs achieve percent level energy spread and jitter.

A storage ring accepts only a few permille in both.



LUX Laser-Plasma accelerator at DESY

- long-term stable operation at ~300 MeV
- but shot-to-shot variation in beam energy



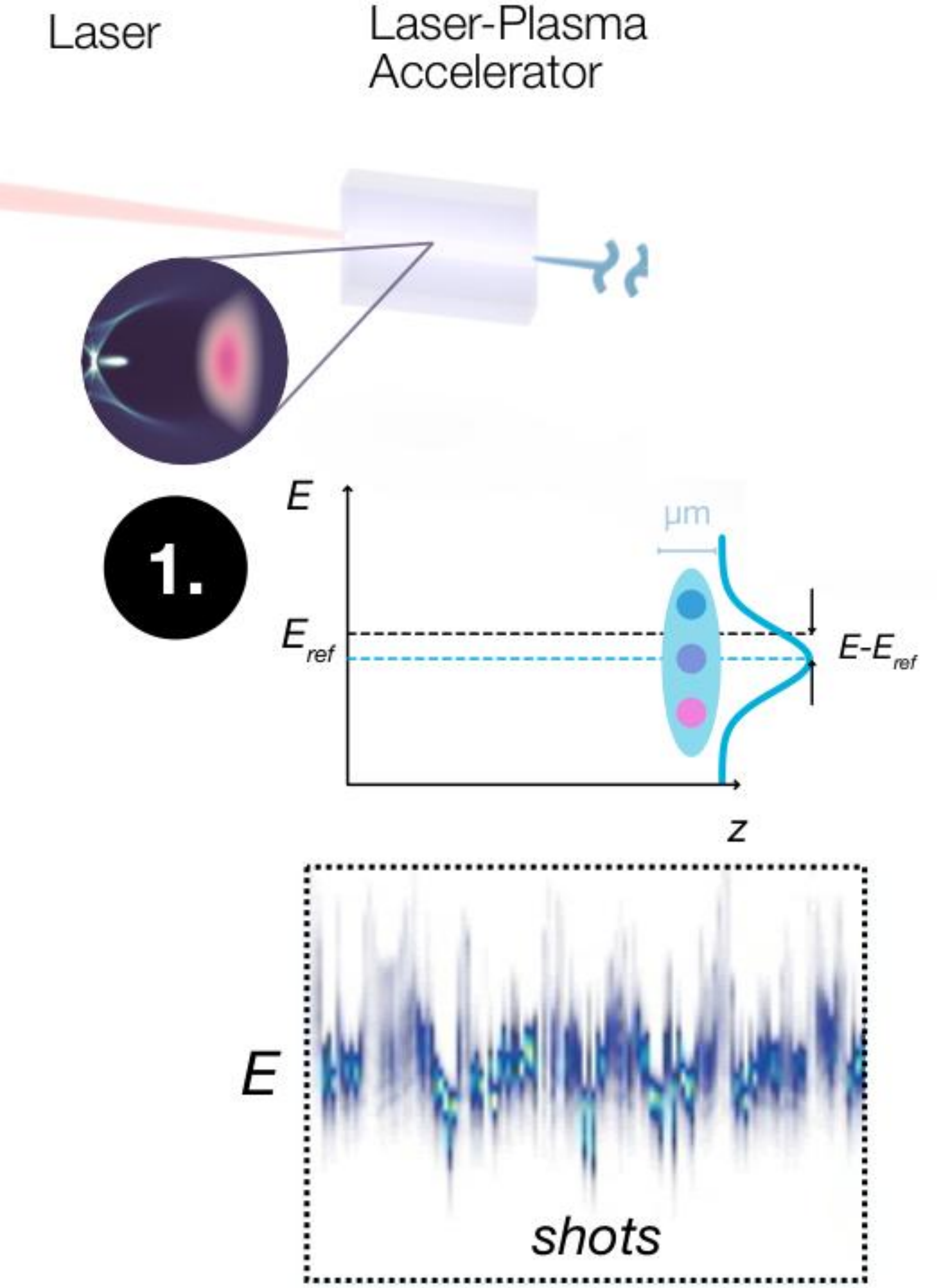
Charge outside ring acceptance is lost

Actively energy compress the LPA beams

to match the ring acceptance

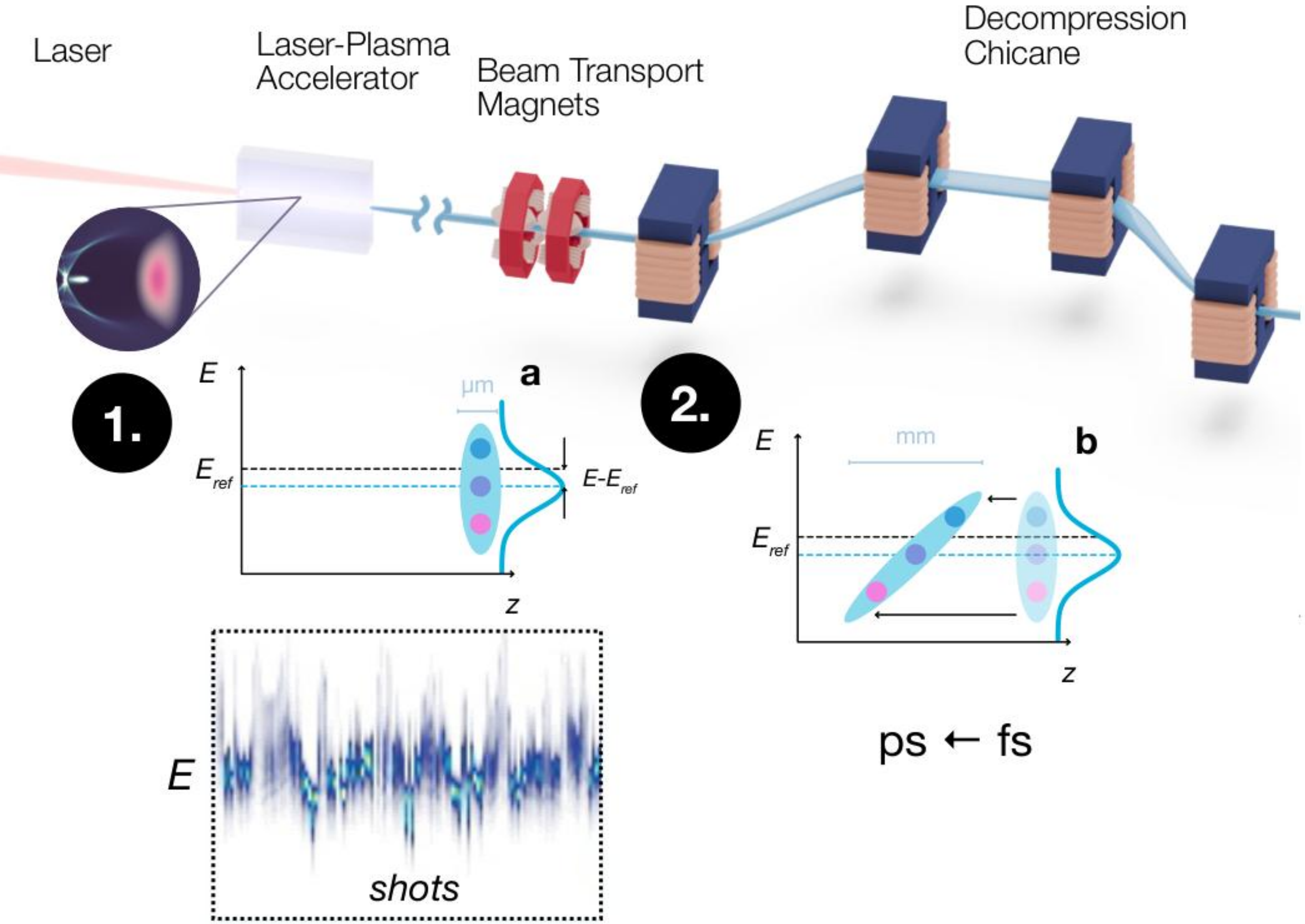
LPA beams are intrinsically short

but show percent-level energy spread & jitter



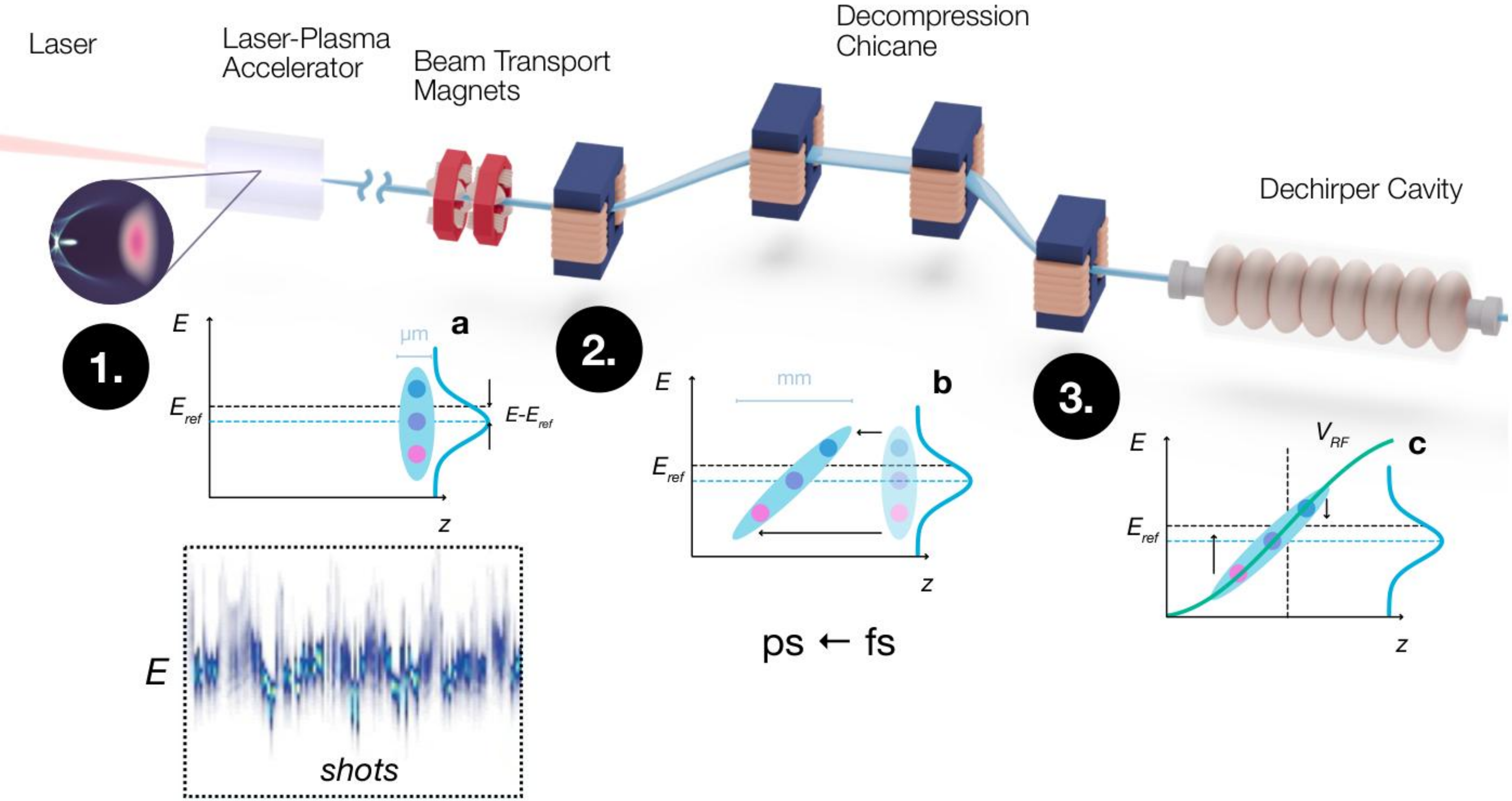
A dipole chicane reduces the longitudinal slice energy spread

by imprinting an energy dependent delay.



The spectrum is compressed inside an (active) RF cavity

removing the chirp imprinted earlier.



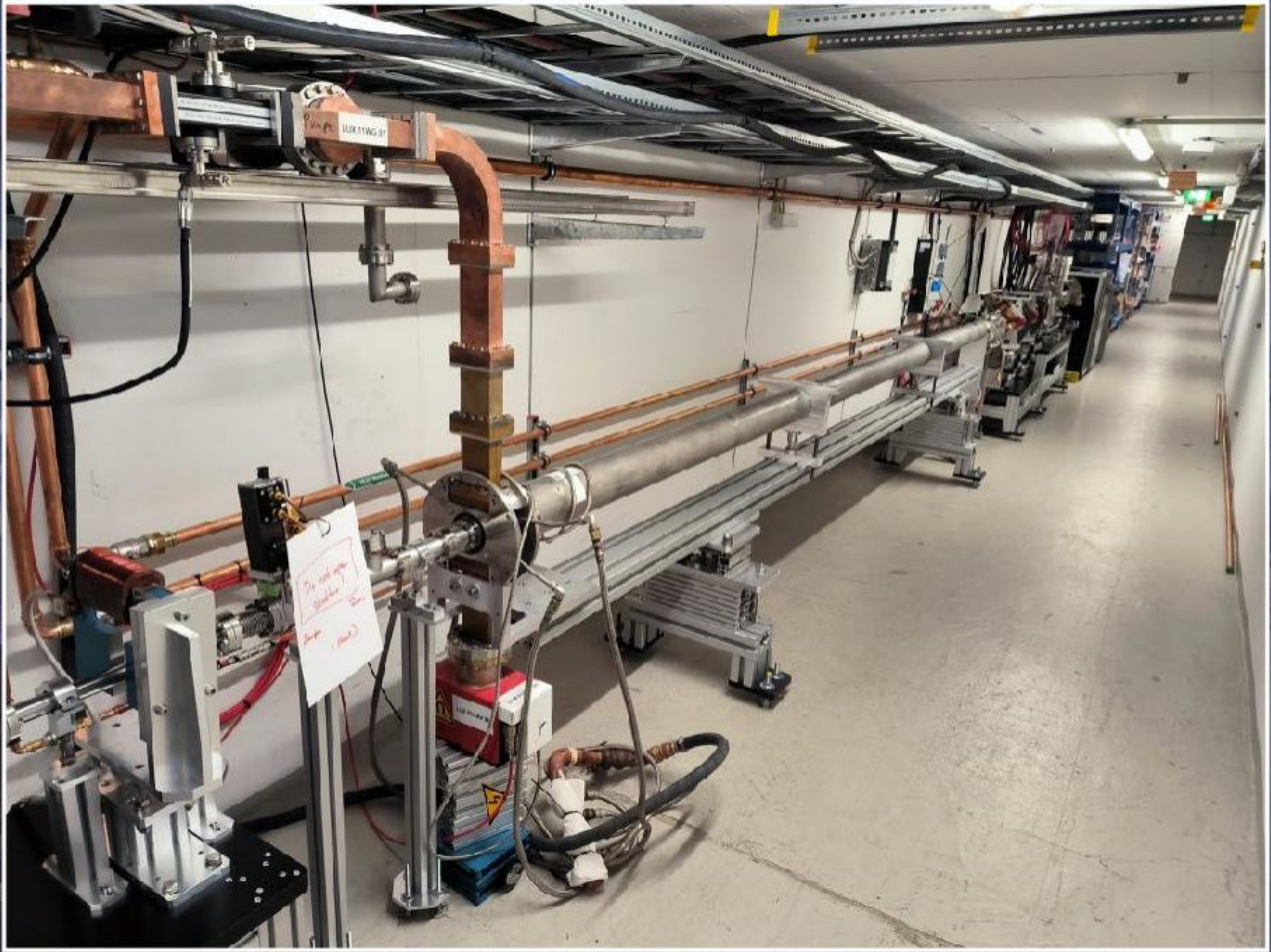
Energy spread & jitter reduced simultaneously

for the cost of beam current.

20m of additional beamline installed in 2024

LUX

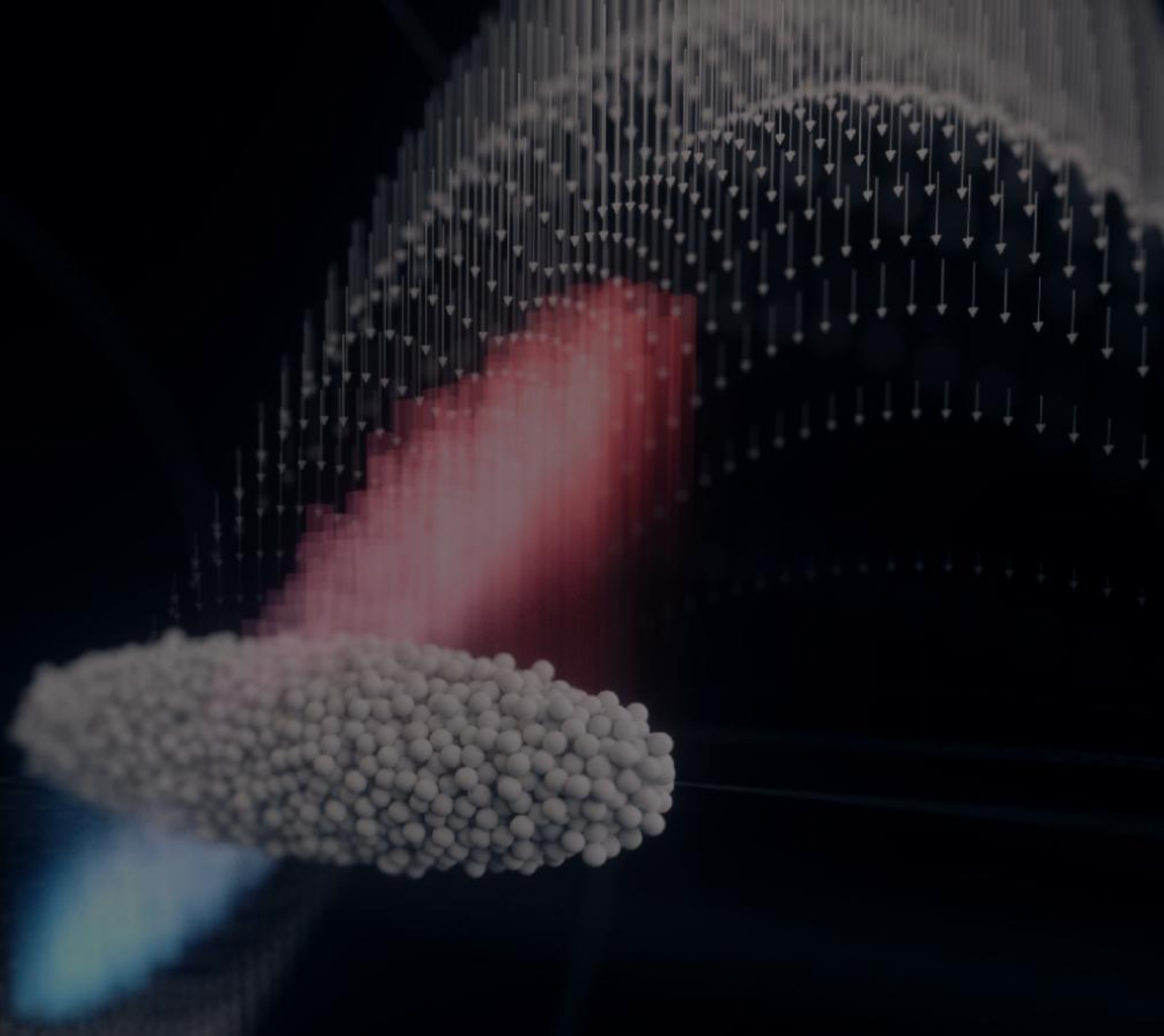
Decompression chicane



S-band RF cavity

360° RF phase scan

energy spectrum is compressed for a larger range of RF phases



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

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

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

360° RF phase scan

energy spectrum is compressed for a larger range of RF phases

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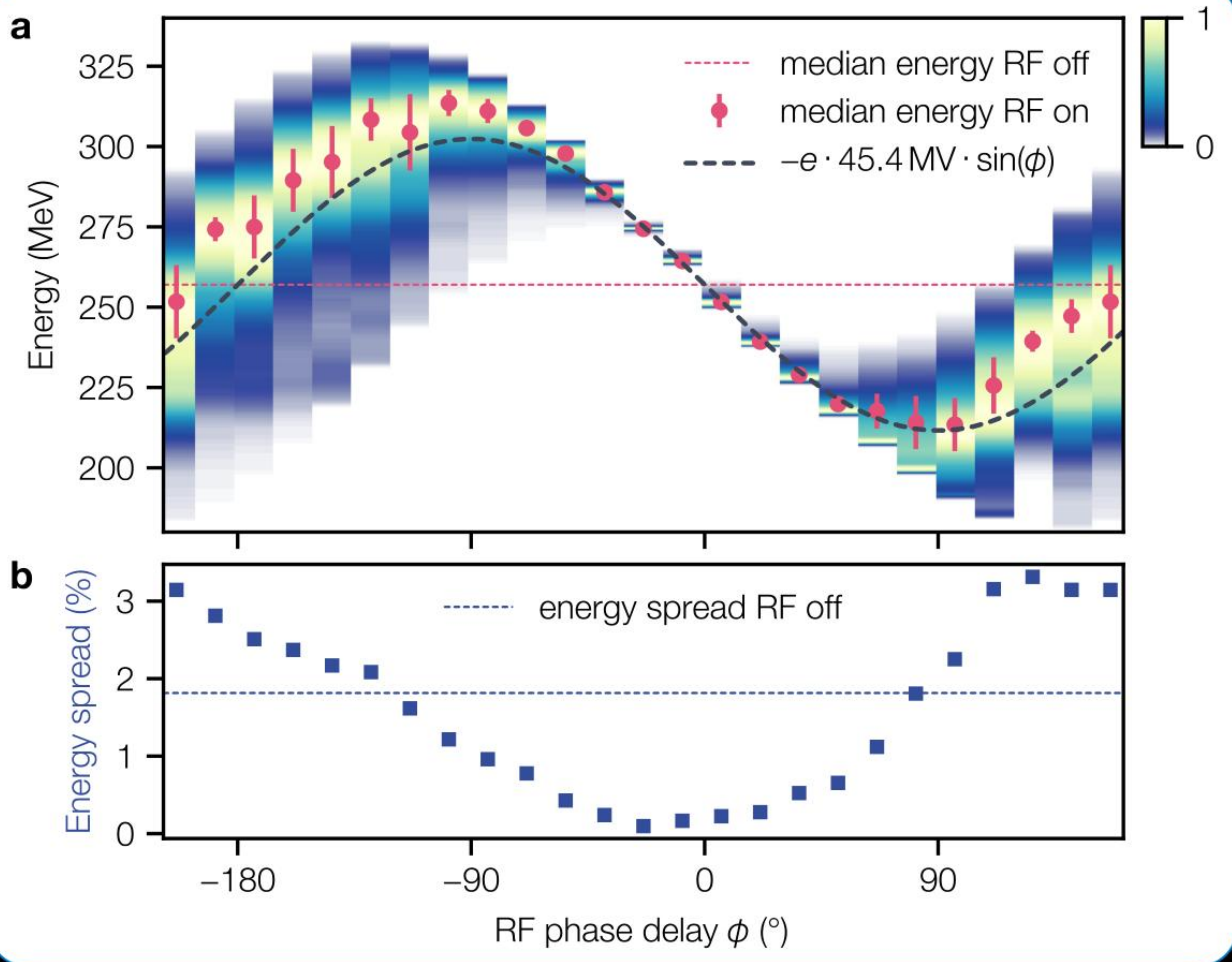
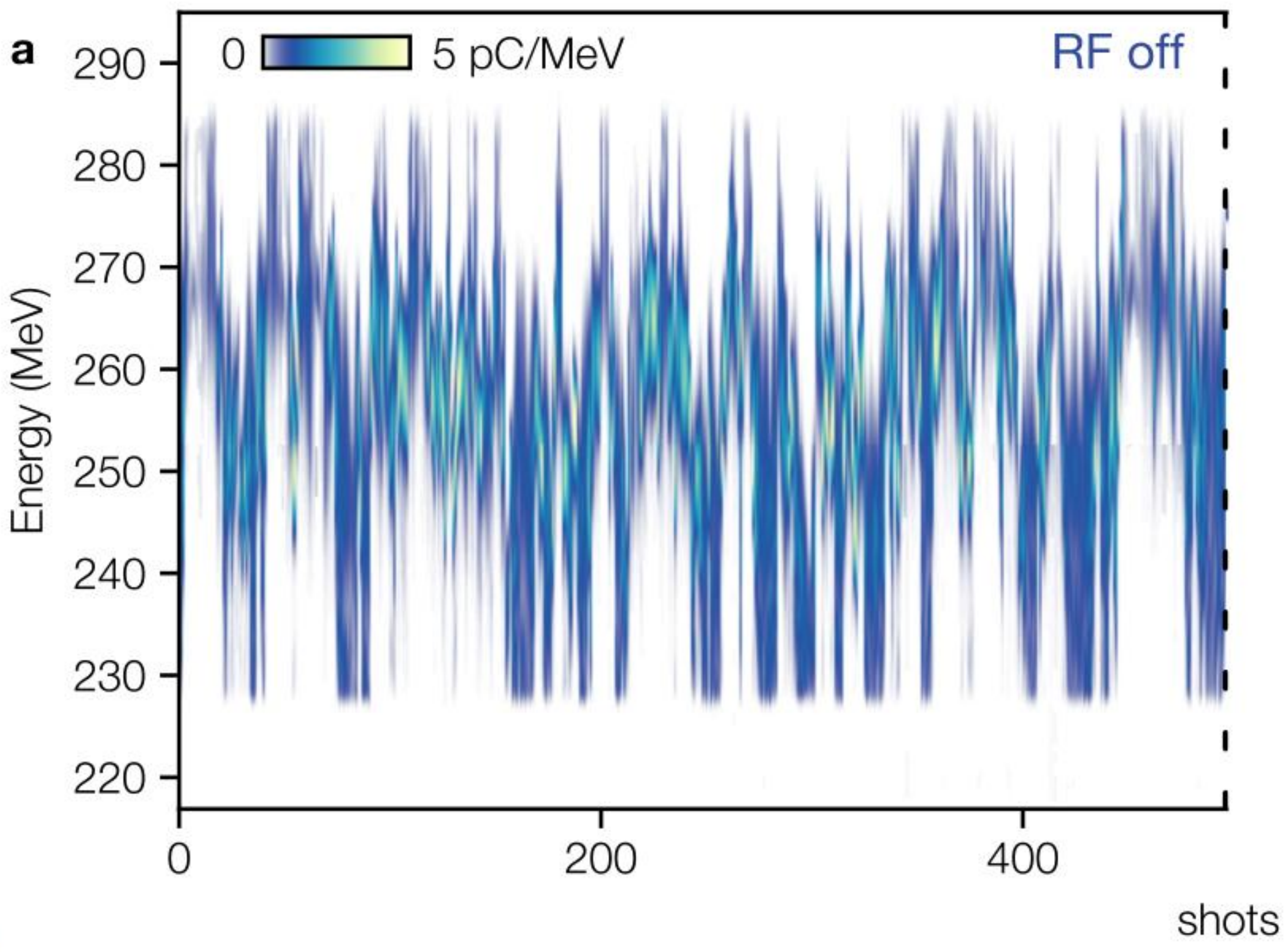


Active energy compression of plasma accelerated beams to the permille

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



[P. Winkler et al. *Natue* 640, p. 907–910 (2025)]

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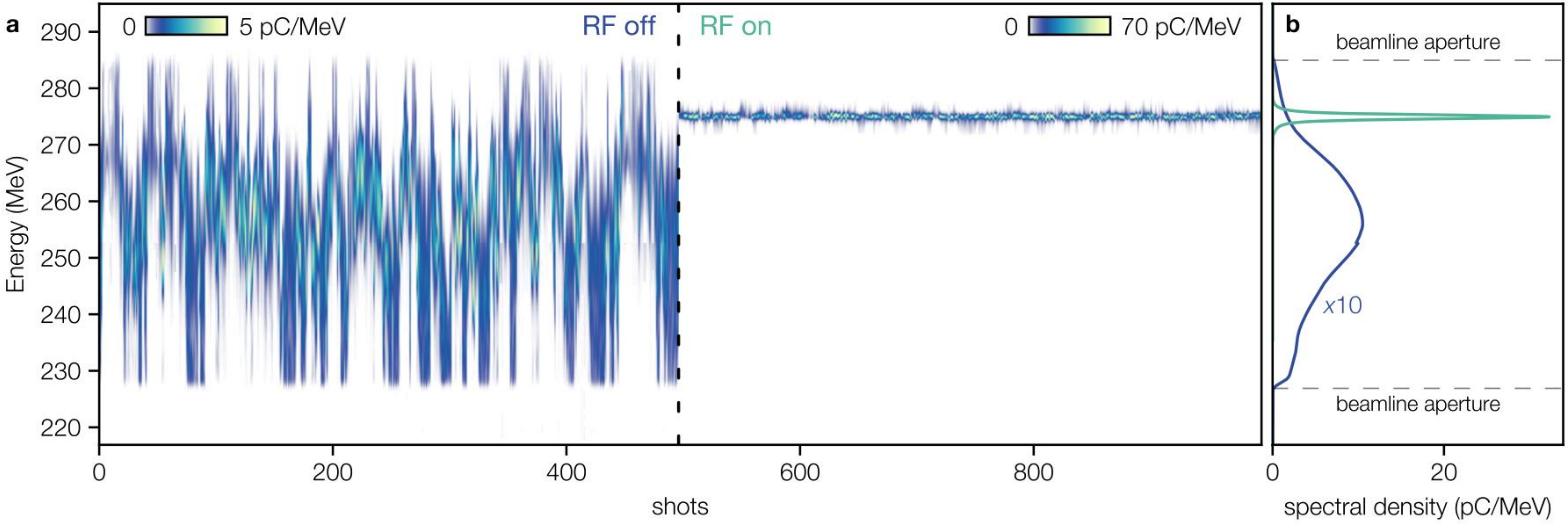

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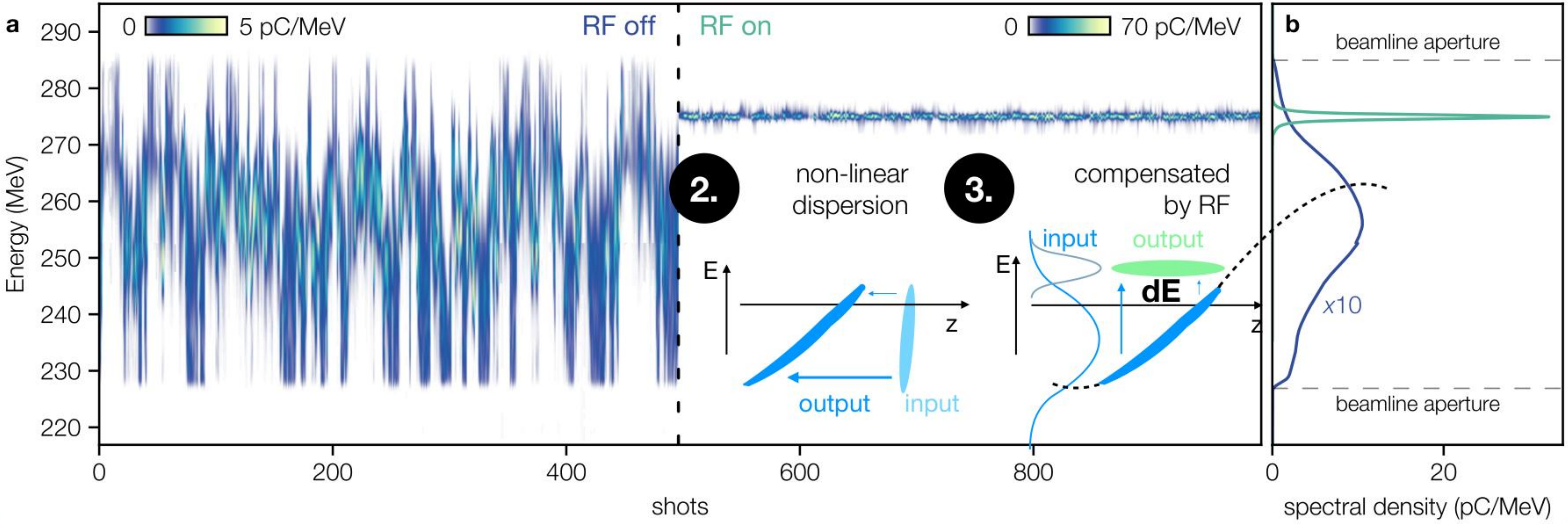
A non-zero RF phase allows to compensate non-linear dispersion

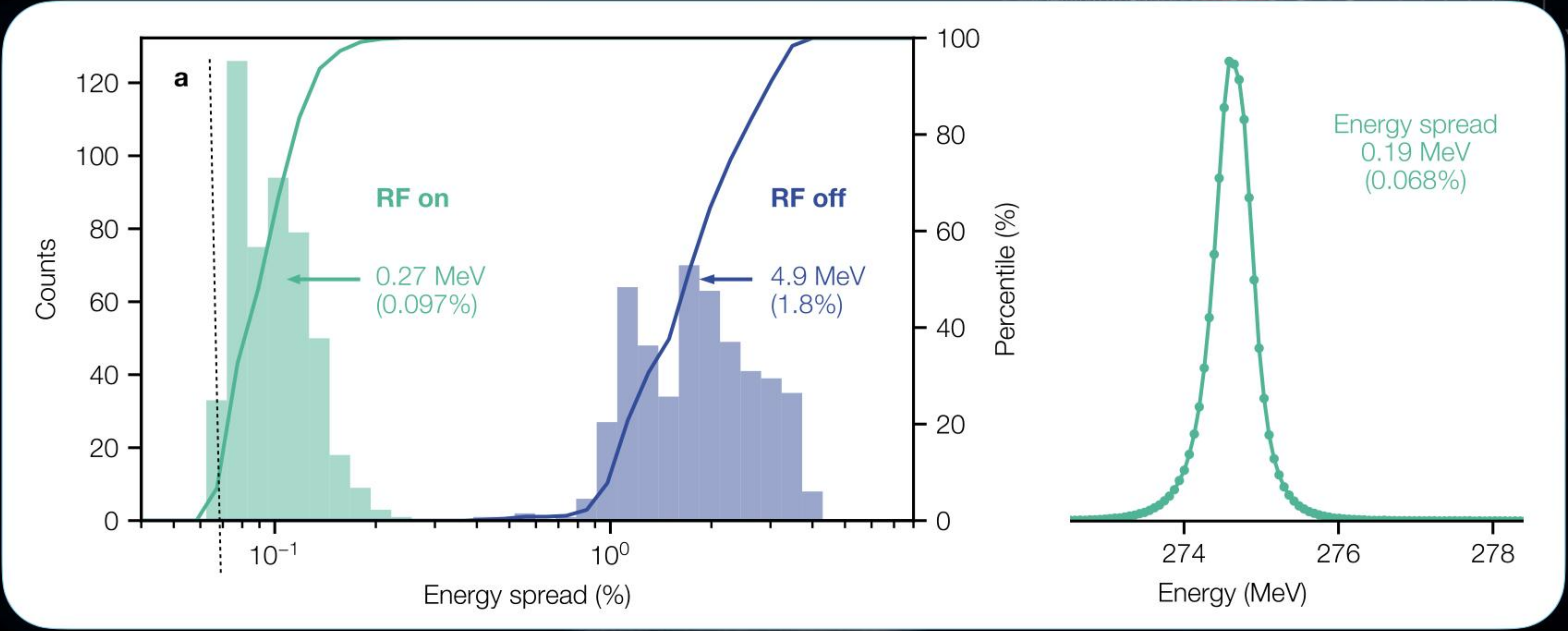
imprinted by the dipole chicane / the beamline as a whole



[P. Winkler et al. *Natue* 640, p. 907–910 (2025)]

Energy spread is compressed to resolution limit of the spectrometer

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



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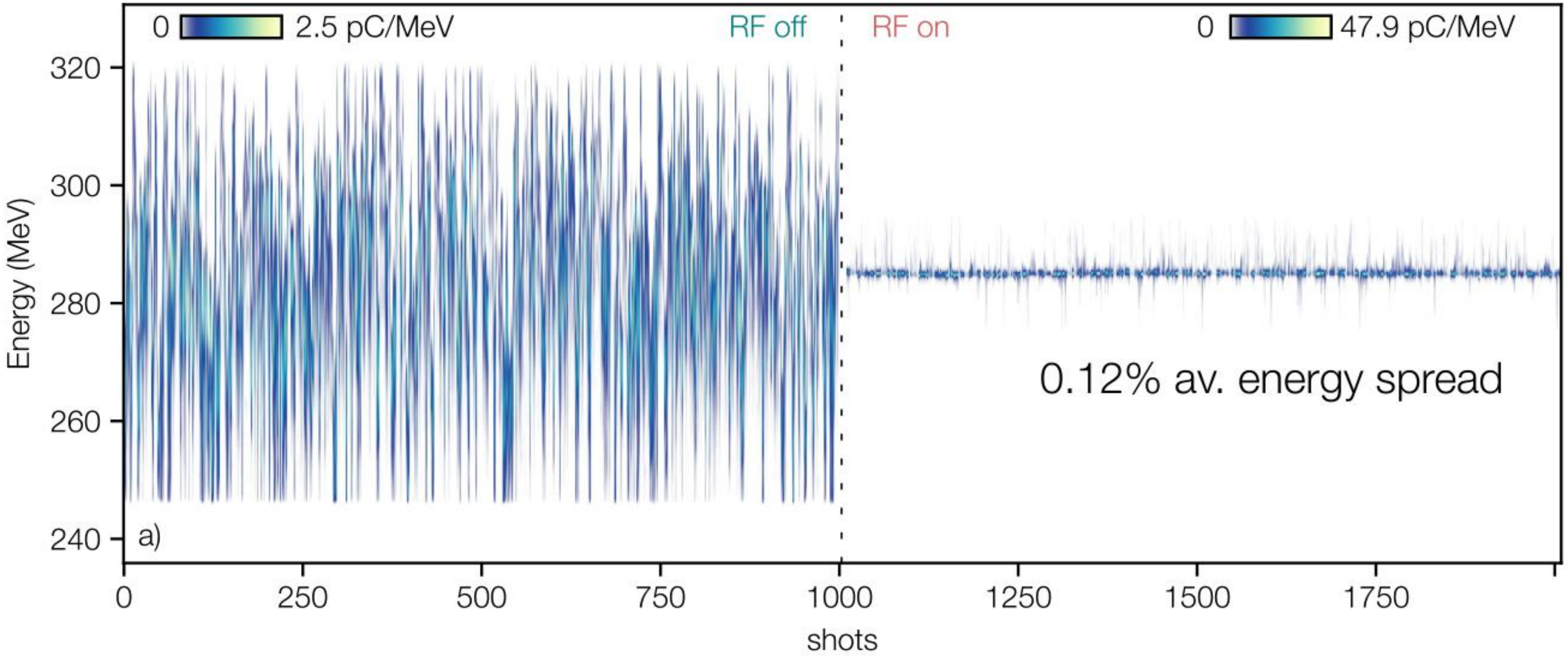
Increasing the R56 from 10 cm to 17 cm reduces required RF power by a factor 3

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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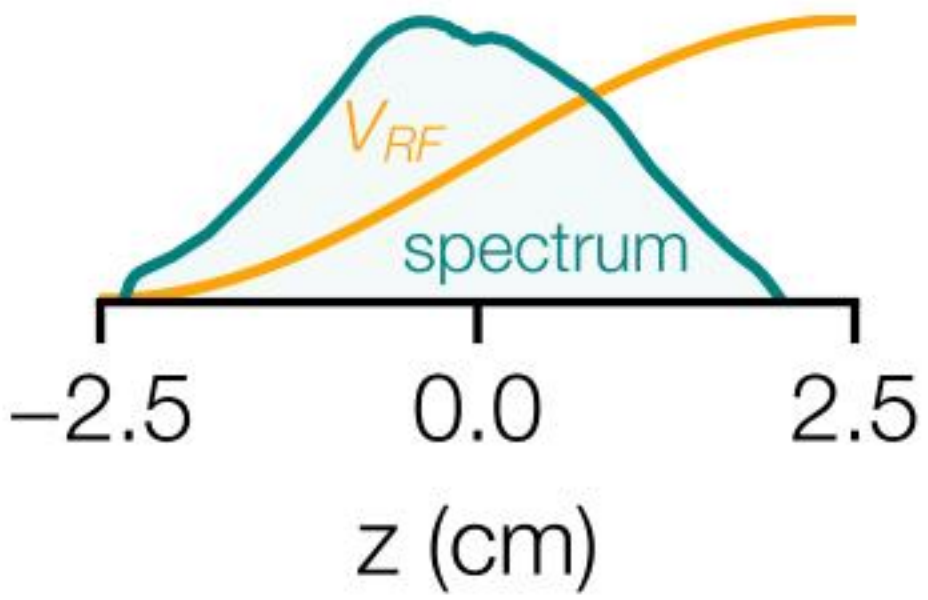
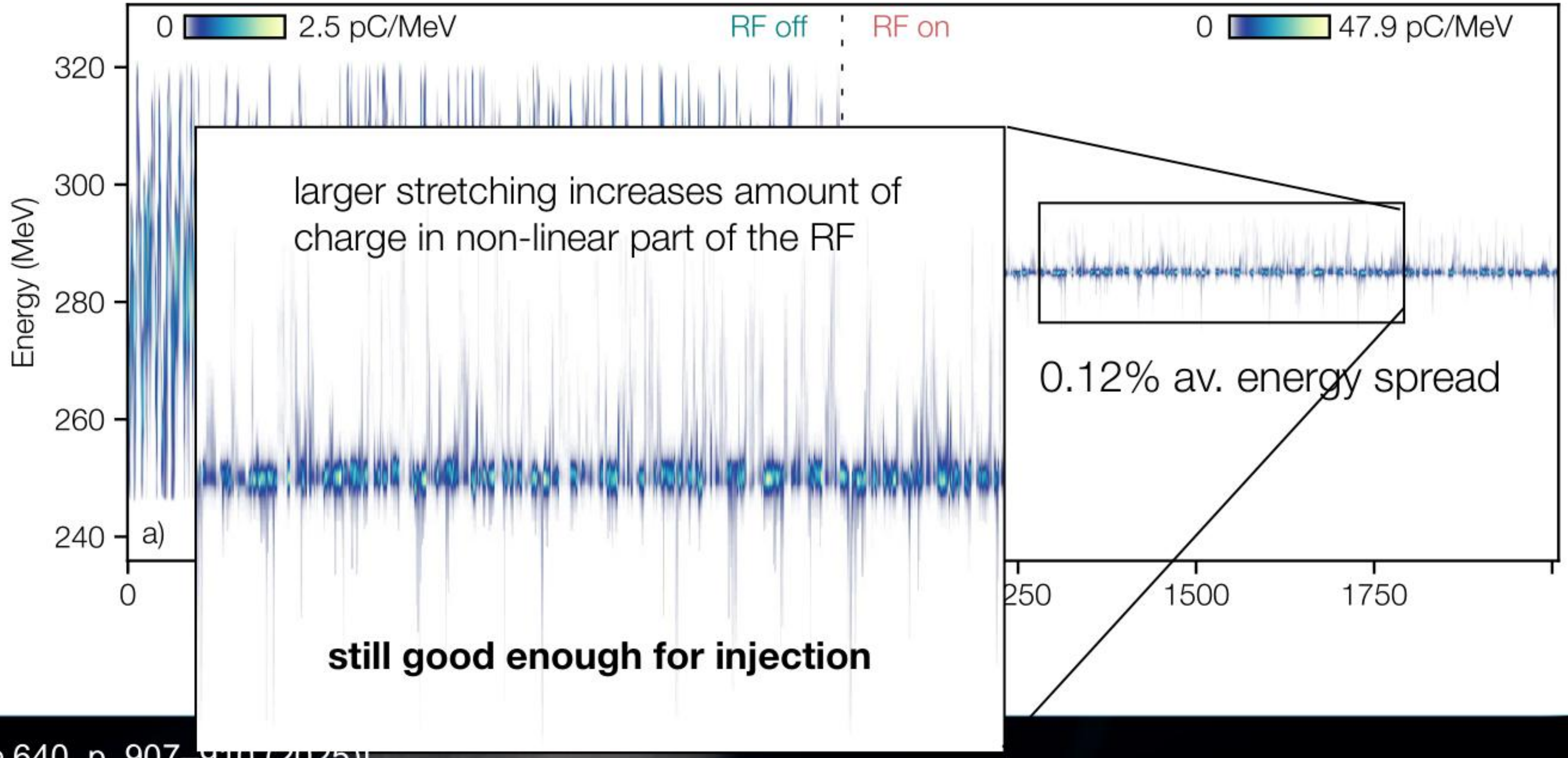
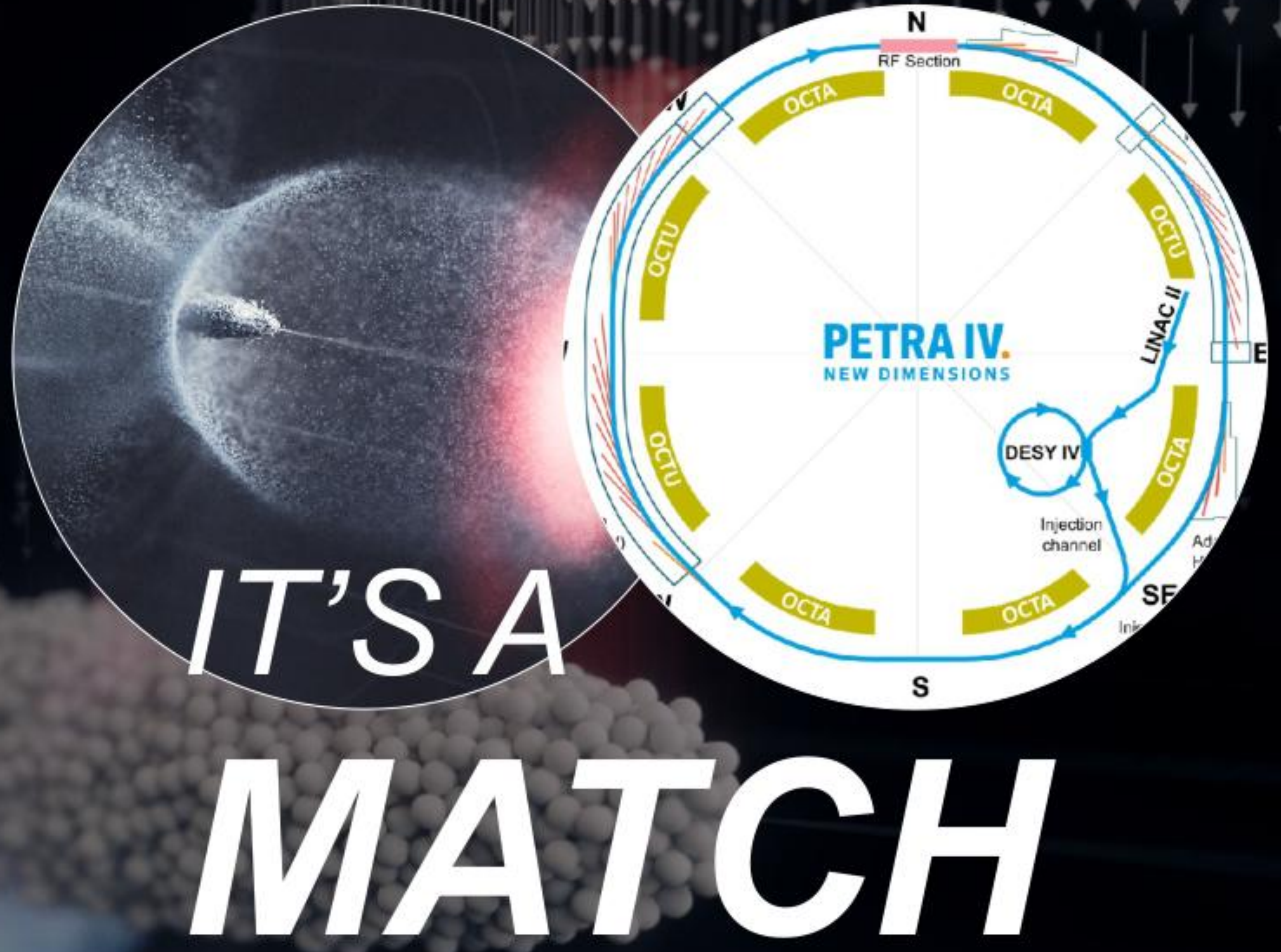




[P. Winkler et al. *Natue* 640, p. 907–910 (2025)]

Conclusion

- Performance so far associated with modern RF accelerators.
- well suited for synchrotron injectors.
- The RF power required scales with the energy stability of the input beams
- 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)]

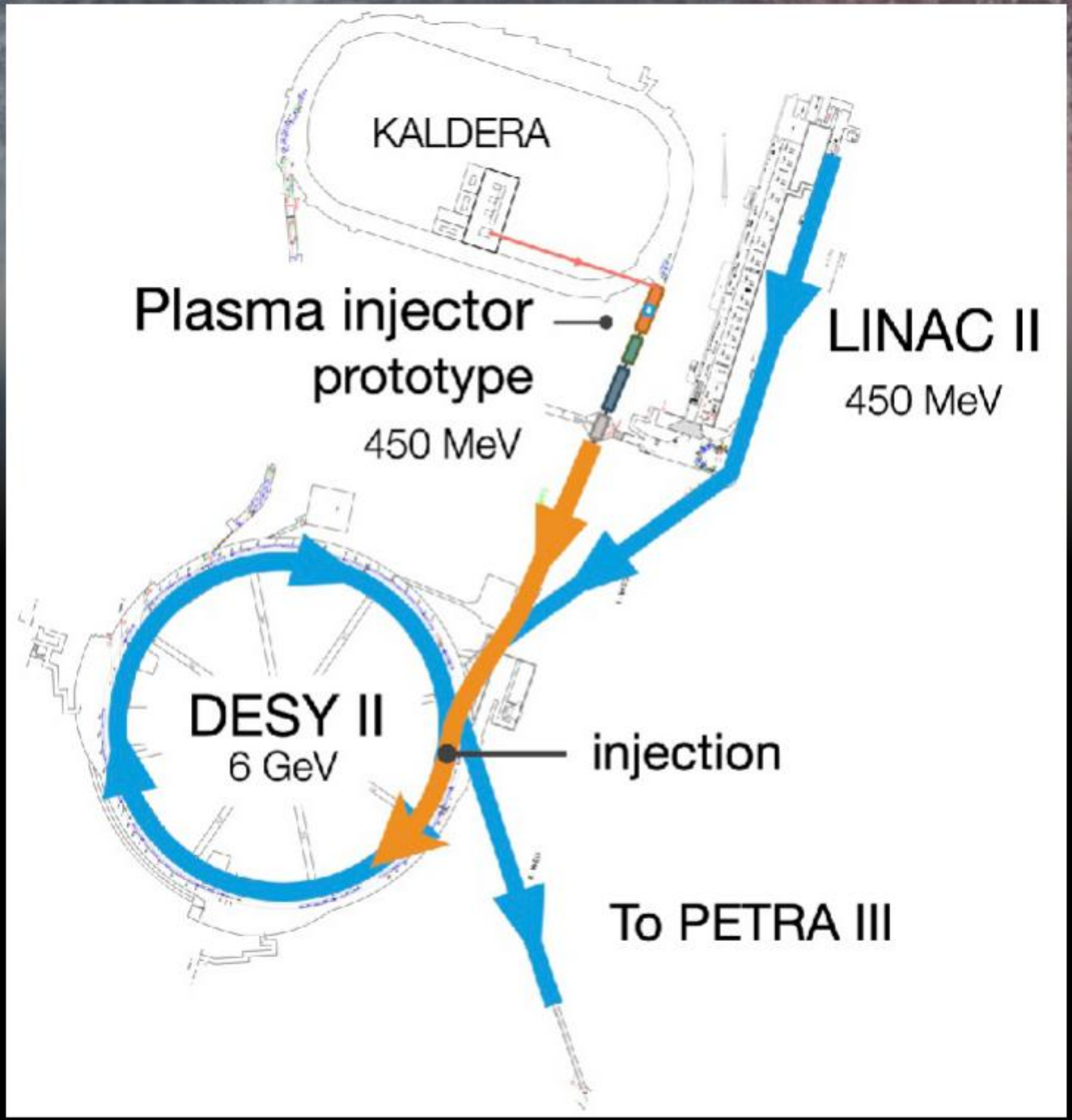
[S. Antipov et al., PRSTAB 24, 111301 (2021)]

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)
- Towards a 6 GeV injector for PETRA IV:

Plenary talk by S. Antipov (Fr, 11:30am)
“Simulations of the plasma injector for PETRA IV”



Acknowledgements

The DESY Plasma Group (MPL)

Wim Leemans
Division Director

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

Photo: Marta Mayer (DESY)

Andreas Maier

Lead Scientist
Group Leader

andreas.maier@desy.de
plasma.desy.de
kaldera.desy.de

Thanks

To the whole plasma crew at DESY

Fig: SciCom Lab