

Accelerator Activities at DESY.

Seminar at ALBA Synchrotron
Barcelona, Spain
1 June 2026



Wim Leemans
Director Accelerator Division



HELMHOLTZ



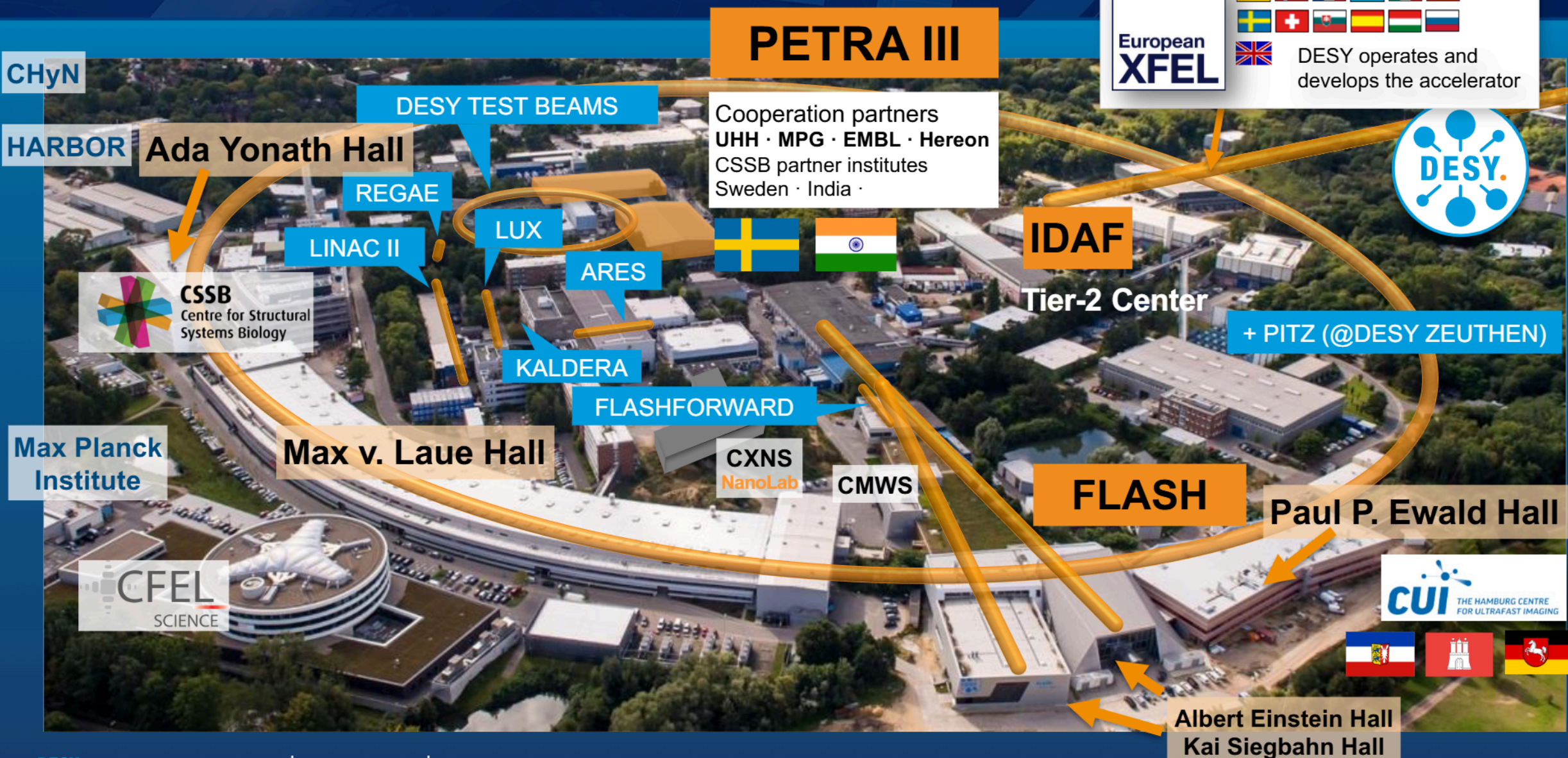
DESY is a Helmholtz research centre for fundamental science

Accelerator-based research is being performed at two locations in Hamburg and Zeuthen near Berlin in Germany



DESY has a unique combination of powerful analytical tools

They are embedded in a broad ecosystem for science and innovation



DESY Accelerator Division

Operation of user facilities for photon research and R&D for the accelerators of the future

Operations



PETRA III - ready to upgrade to PETRA IV

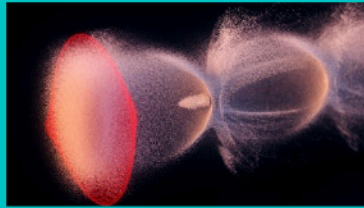


FLASH - with new capabilities

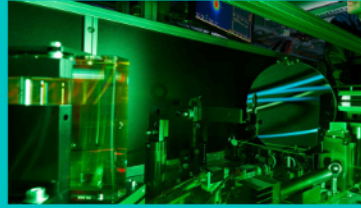


European XFEL - just finished a big upgrade

Research & Development - Toolkit



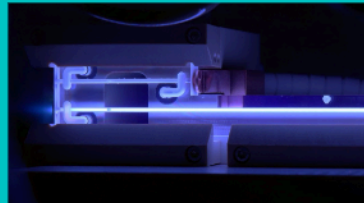
KALDERA & Plasma injector



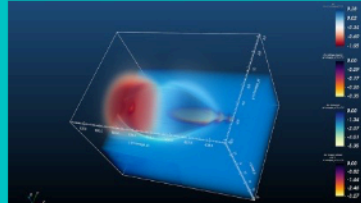
High-energy lasers



PITZ (Zeuthen)



Plasma: FLASHForward



Computing



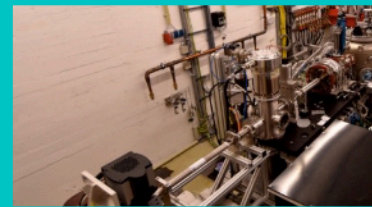
ARES



Superconducting technology



Beam control & diagnostics



REGAE

Big project ahead



PETRA IV

Cooperations Outreach Innovation

Technologies such as μ TCA, lasers and superconducting accelerators

Medical applications with clinical partners

Training of the next generation

between 2020-2025:

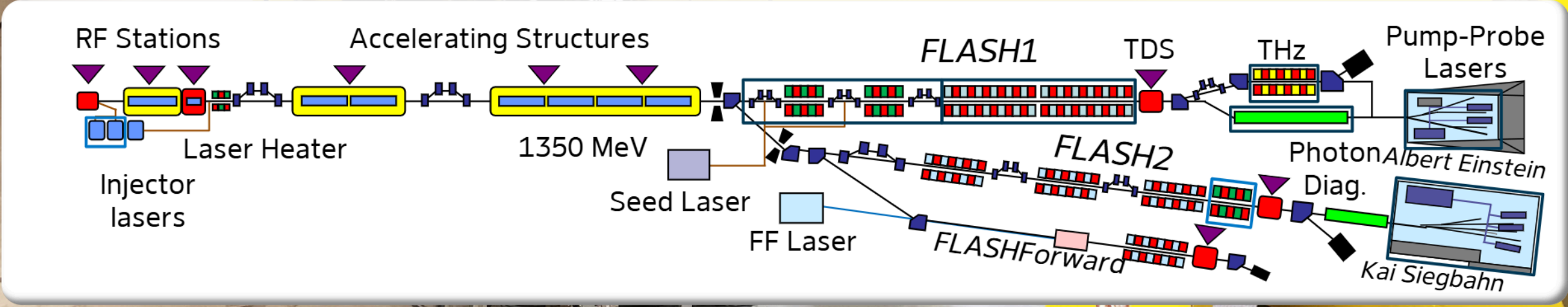
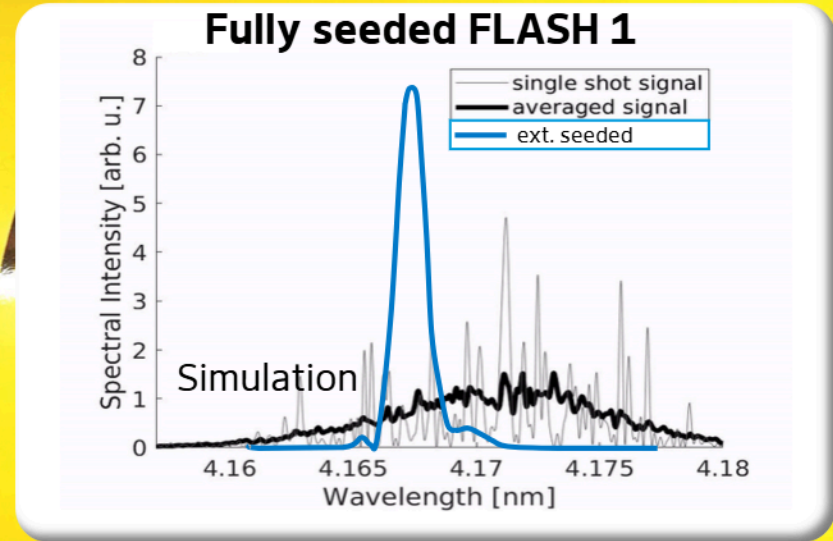
~75 PostDocs

~80 PhD, MSc, BSc

EPACE Doctoral training network

FLASH, world's first soft x-ray FEL now provides seeded (FLASH1) and SASE (FLASH2)

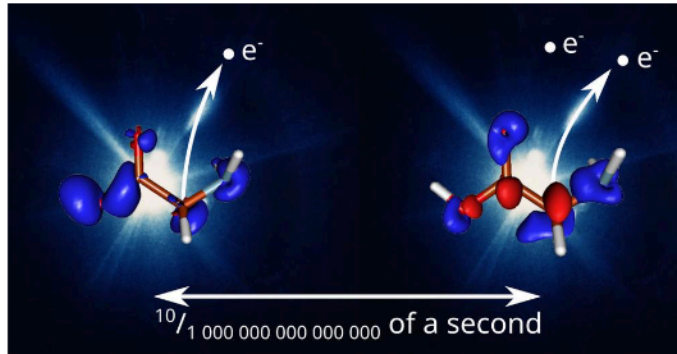
Upgraded FLASH free-electron laser restarted on 4 August 2025 after a 14-month shutdown



FLASH provides high rep rate XUV and soft X-ray beams

It is complementary to the European XFEL as well as PETRA III and enables time-resolved science

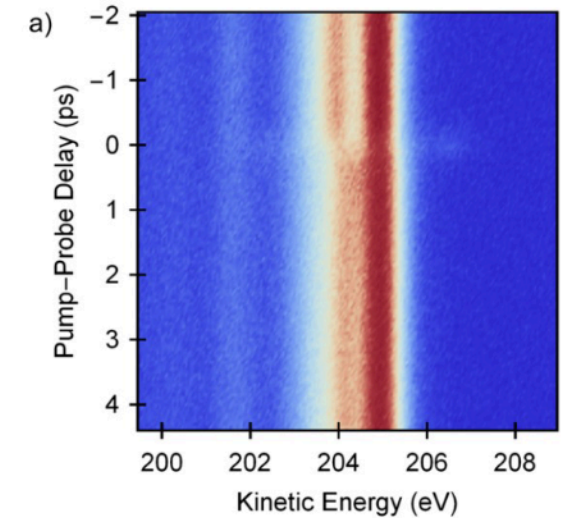
Electronic dynamics



D. Schwickert *et al.*, Science Adv. 8, eabn6848 (2022)

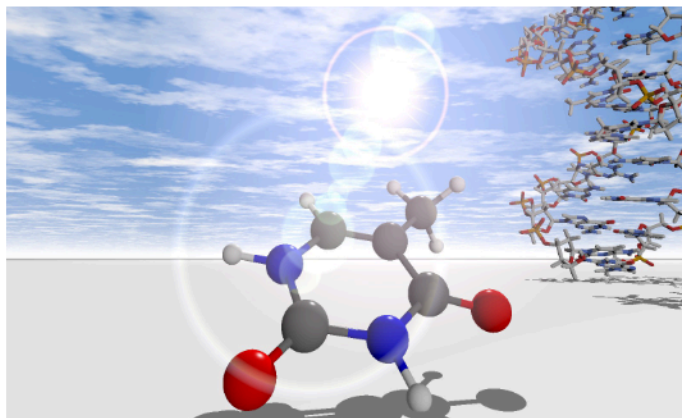
- > 7500 h/a facility operation
- > 4500 h/a linac for user experiments
- 750 h/a accelerator R&D
- 300 unique users/year
- Max. 30 user beamtimes/year
- up to 40 publications/year

Novel Photovoltaics

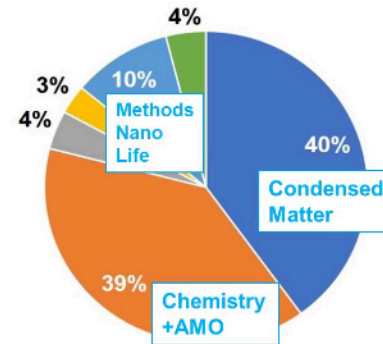


F. Roth *et al.*, Nature Comm. 12, 108001 (2021)

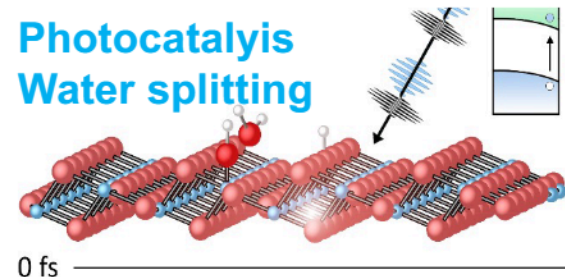
Nucleobase Photoprotection



Mayer *et al.*, Nature Comm. 13, 198 (2022)

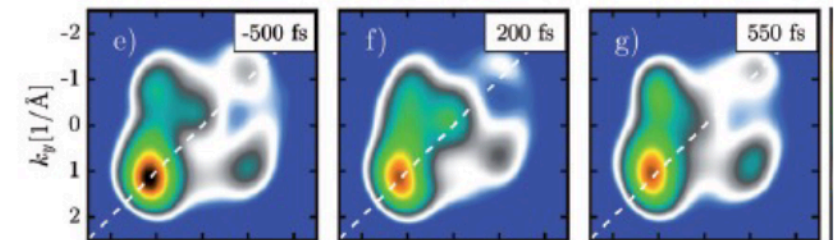


Photocatalysis Water splitting



M. Wagstaffe *et al.*, PRL 130, 108001(2023)

Functional surfaces



K. Baumgärtner *et al.*, Nature Comm 13, 2741, (2022)

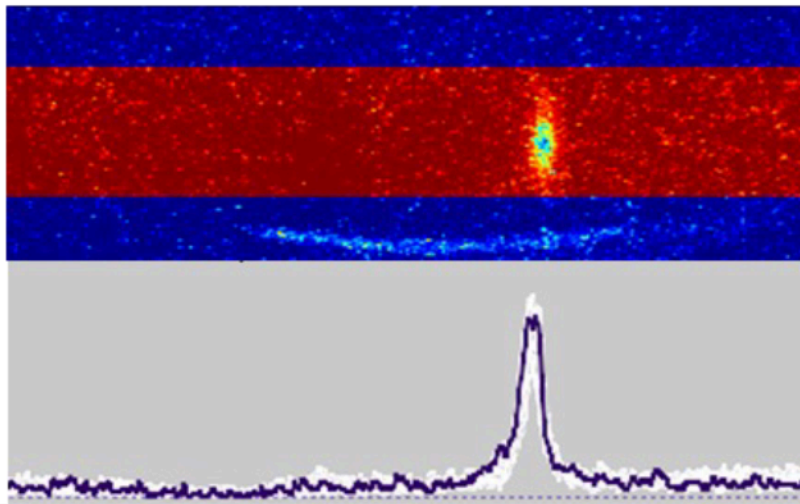
First lasing of seeded FLASH1

Tremendous progress in the commissioning of the new beamline



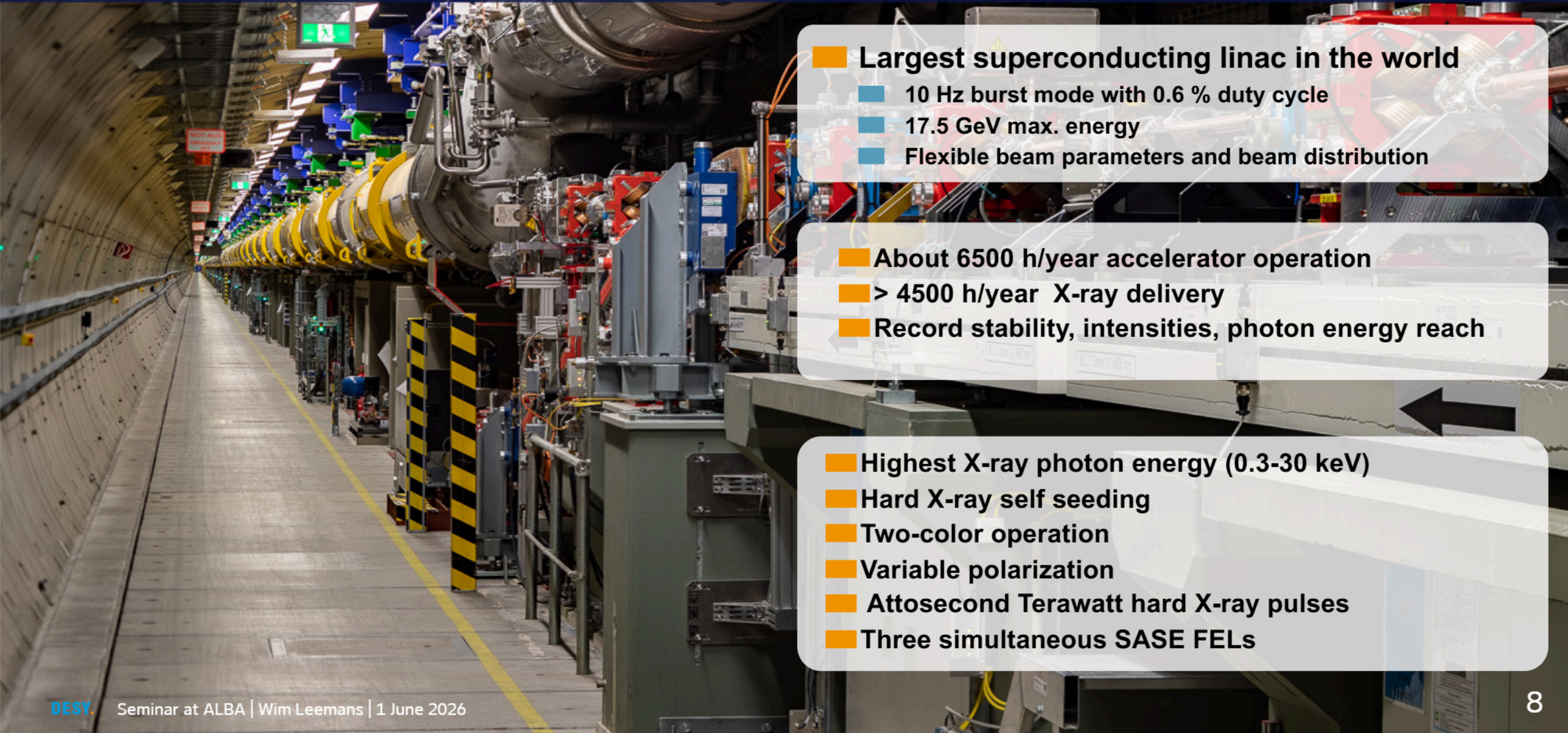
EEHG spectra at 9.4 nm (March)

Emission in a single narrowband spectrum



- Achieved high harmonic generation at 52 nm
- Echo Enhanced Harmonic Generation at various wavelengths down to 4.5 nm
- Next step: multi-bunch (> 5) in train via advanced beam control

Developed and operated by DESY: The European XFEL accelerator and technical infrastructure



■ **Largest superconducting linac in the world**

■ 10 Hz burst mode with 0.6 % duty cycle

■ 17.5 GeV max. energy

■ Flexible beam parameters and beam distribution

■ **About 6500 h/year accelerator operation**

■ **> 4500 h/year X-ray delivery**

■ **Record stability, intensities, photon energy reach**

■ **Highest X-ray photon energy (0.3-30 keV)**

■ **Hard X-ray self seeding**

■ **Two-color operation**

■ **Variable polarization**

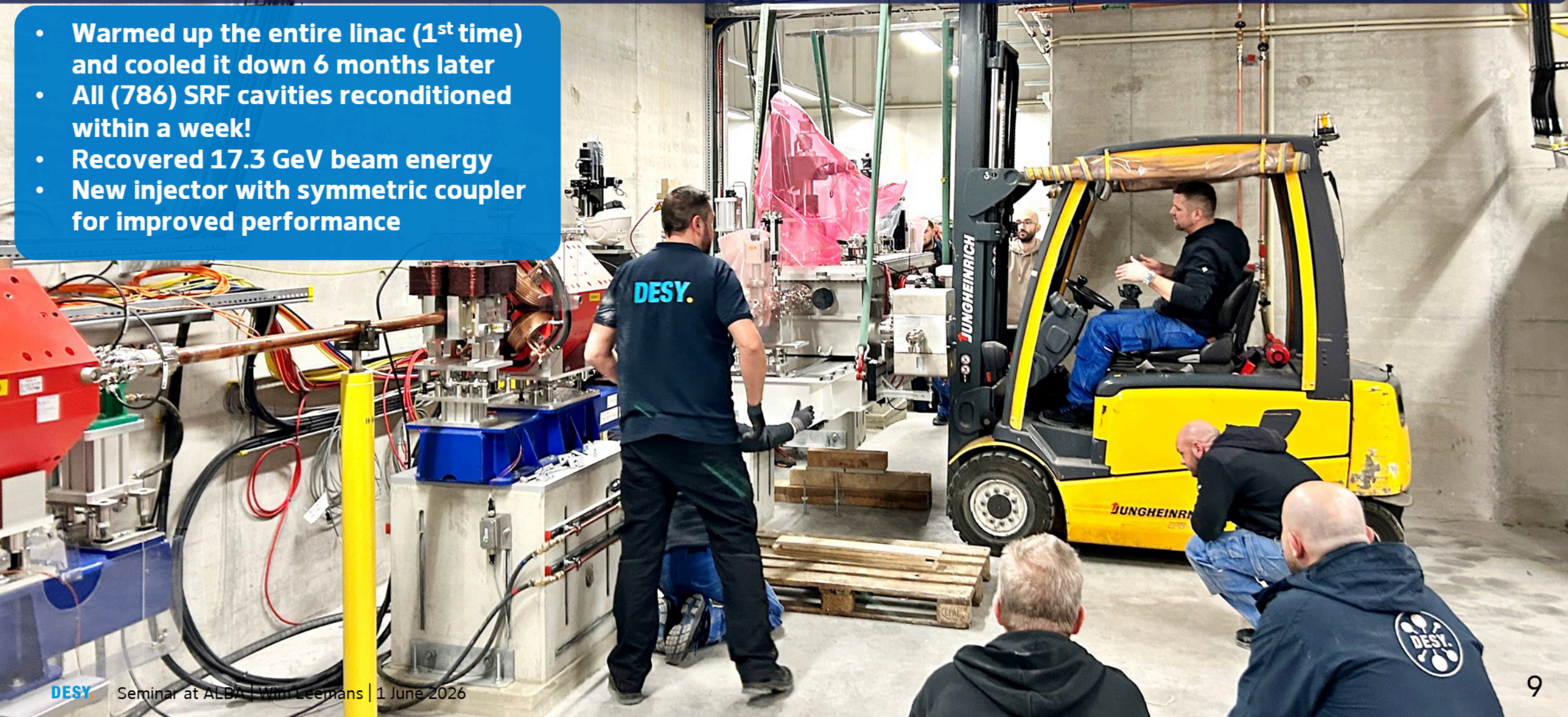
■ **Attosecond Terawatt hard X-ray pulses**

■ **Three simultaneous SASE FELs**

Maintenance break of the European XFEL successfully completed

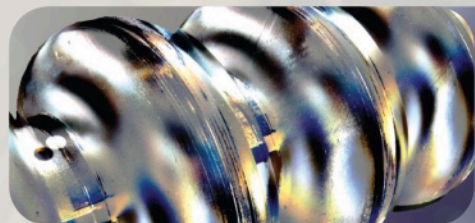
The Long Installation and Maintenance Period (LIMP) began 06.2025 and was completed 01.2026, on schedule

- Warmed up the entire linac (1st time) and cooled it down 6 months later
- All (786) SRF cavities reconditioned within a week!
- Recovered 17.3 GeV beam energy
- New injector with symmetric coupler for improved performance



European XFEL R&D: Plan for the future

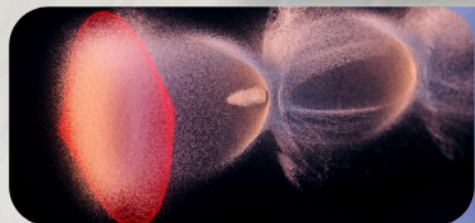
Ensuring we have the best ships for discovery



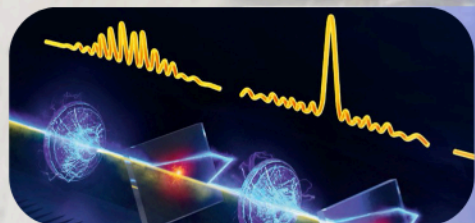
- SRF technology: providing more pulses
 - High duty cycle (HDC) and future CW operation
 - Source development as key ingredient for HDC



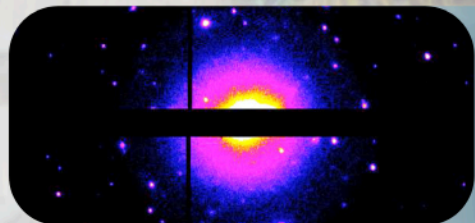
- Machine control at the frontiers of temporal resolution and autonomous accelerators



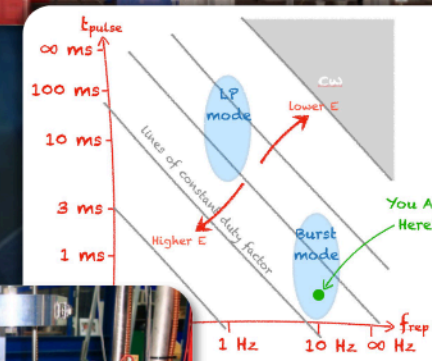
- Plasma-based accelerators
 - Can we double the beam energy and at what repetition rate?



- Novel FEL schemes
(attosecond pulses, XFEL Oscillator, seeding)



- Exploring ultrafast electron diffraction as complementary method to photon-based techniques

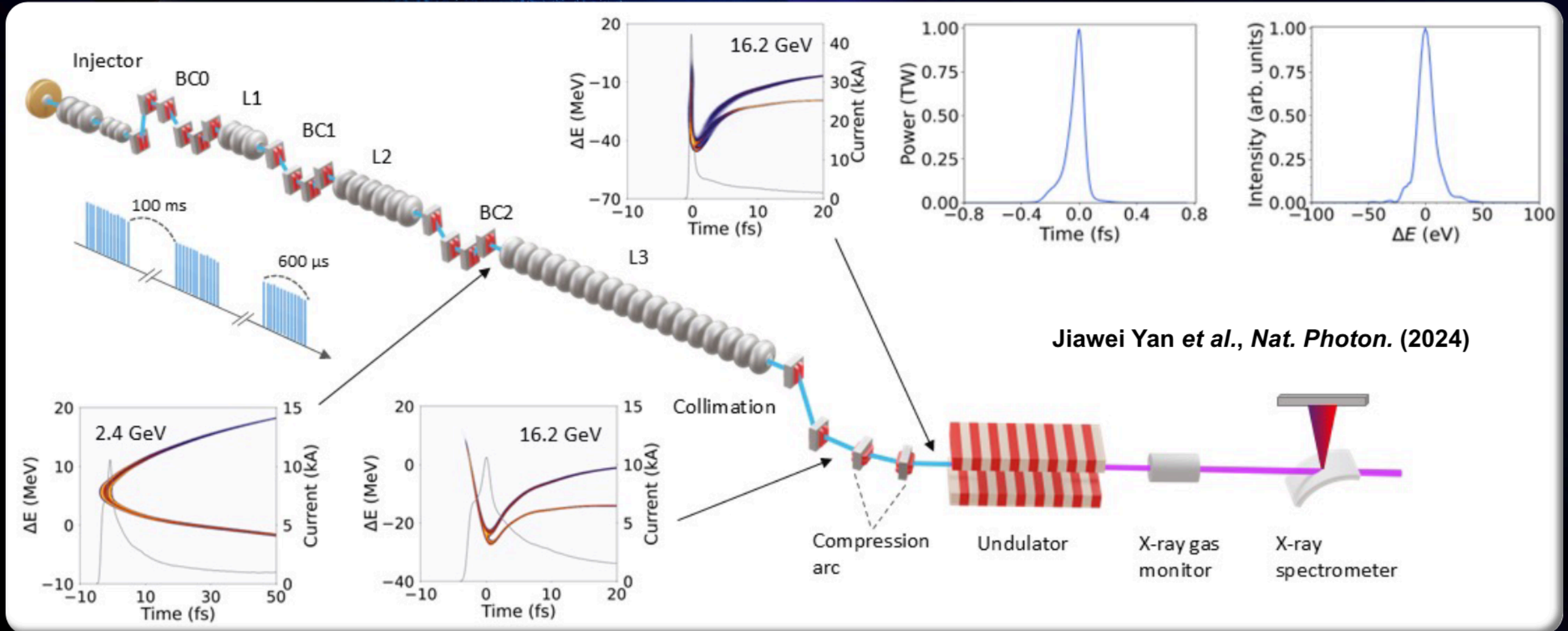


EuXFEL: Attosecond hard X-ray pulses at megahertz repetition rates

Producing terawatt-level hard and soft X-ray attosecond pulses with unrivalled intensity



Novel self-chirping approach that preserves the electron bunch charge

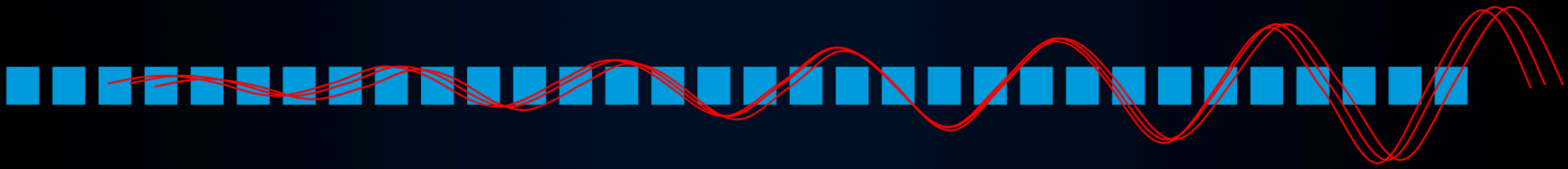


Jiawei Yan *et al.*, *Nat. Photon.* (2024)

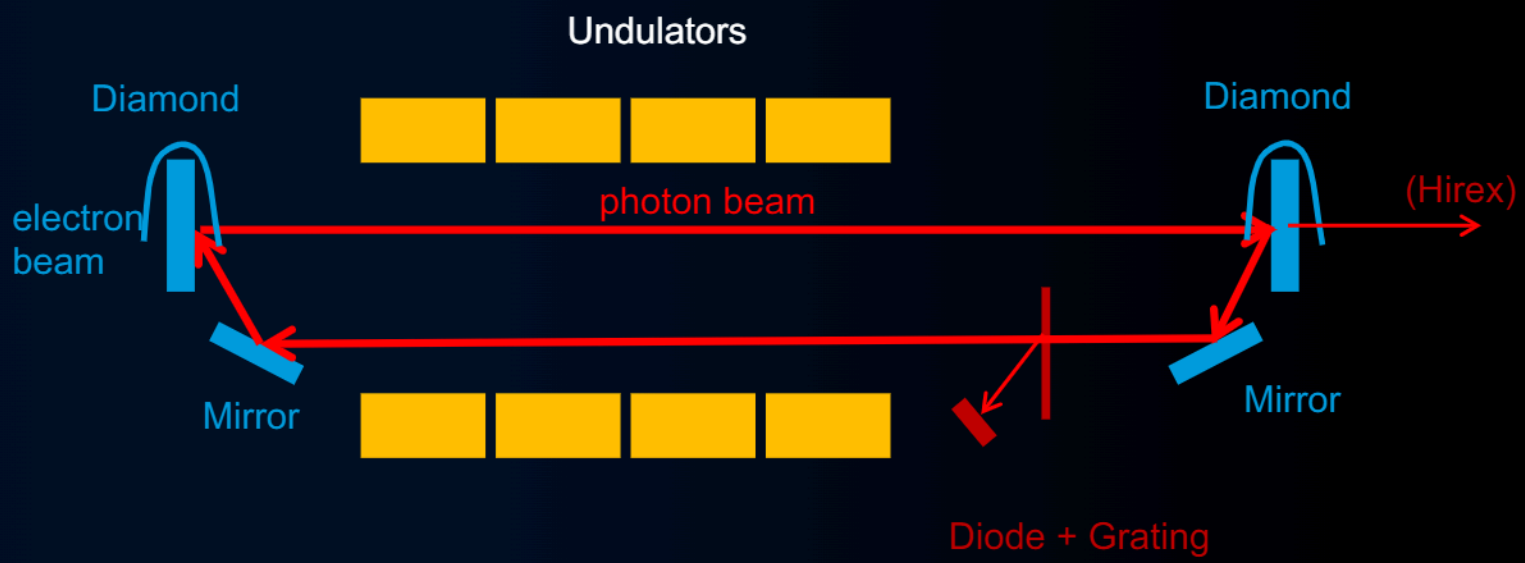
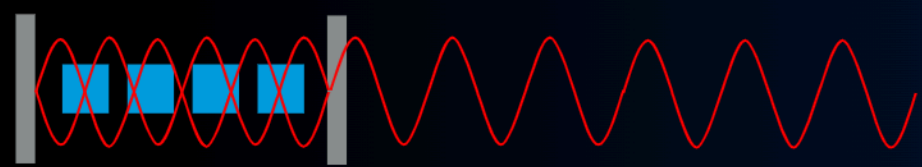
XFEL0 (cavity-based free-electron laser oscillator) has been implemented at the EuXFEL



SASE undulator (32 cells, 200 m long)



XFEL0 (last 4 cells of SASE1)

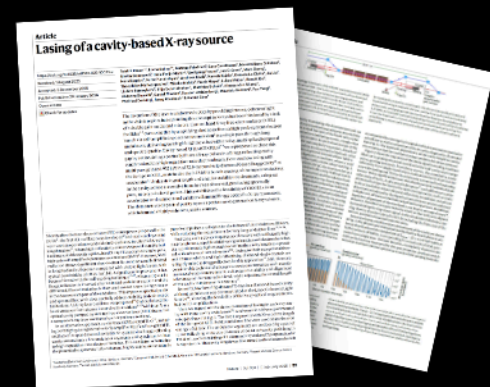
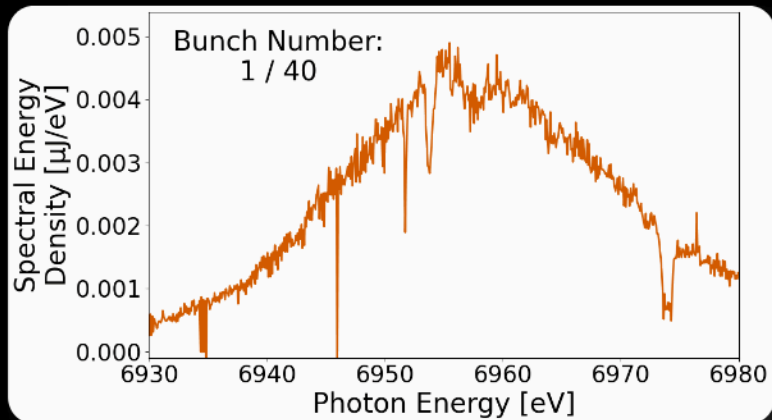
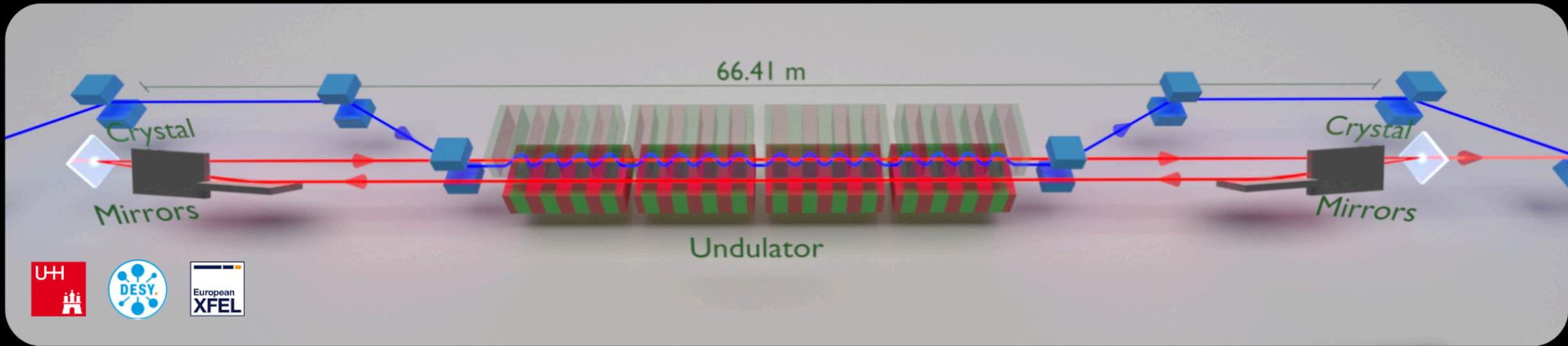


Courtesy of Harald Sinn and Patrick Rauer

66 m (= 2.2 MHz)

First lasing of a cavity-based X-ray FEL demonstrated in 2025

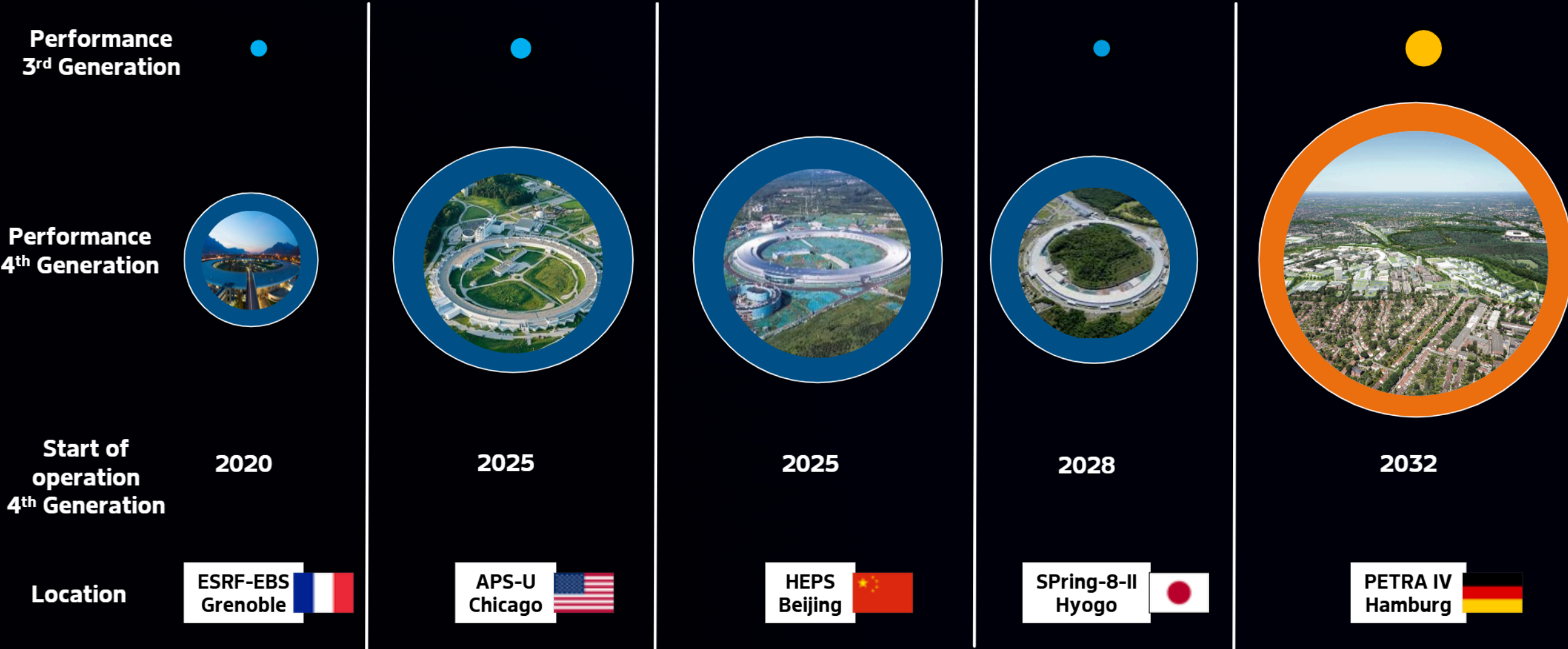
Production of longitudinally pure hard X-rays, at ~ 7 keV with < 0.2 eV bandwidth



P. Rauer et al., Lasing of a Cavity-based X-ray Source, *Nature* 650, 93 (2026)
DOI: [10.1038/s41586-025-10025-x](https://doi.org/10.1038/s41586-025-10025-x)

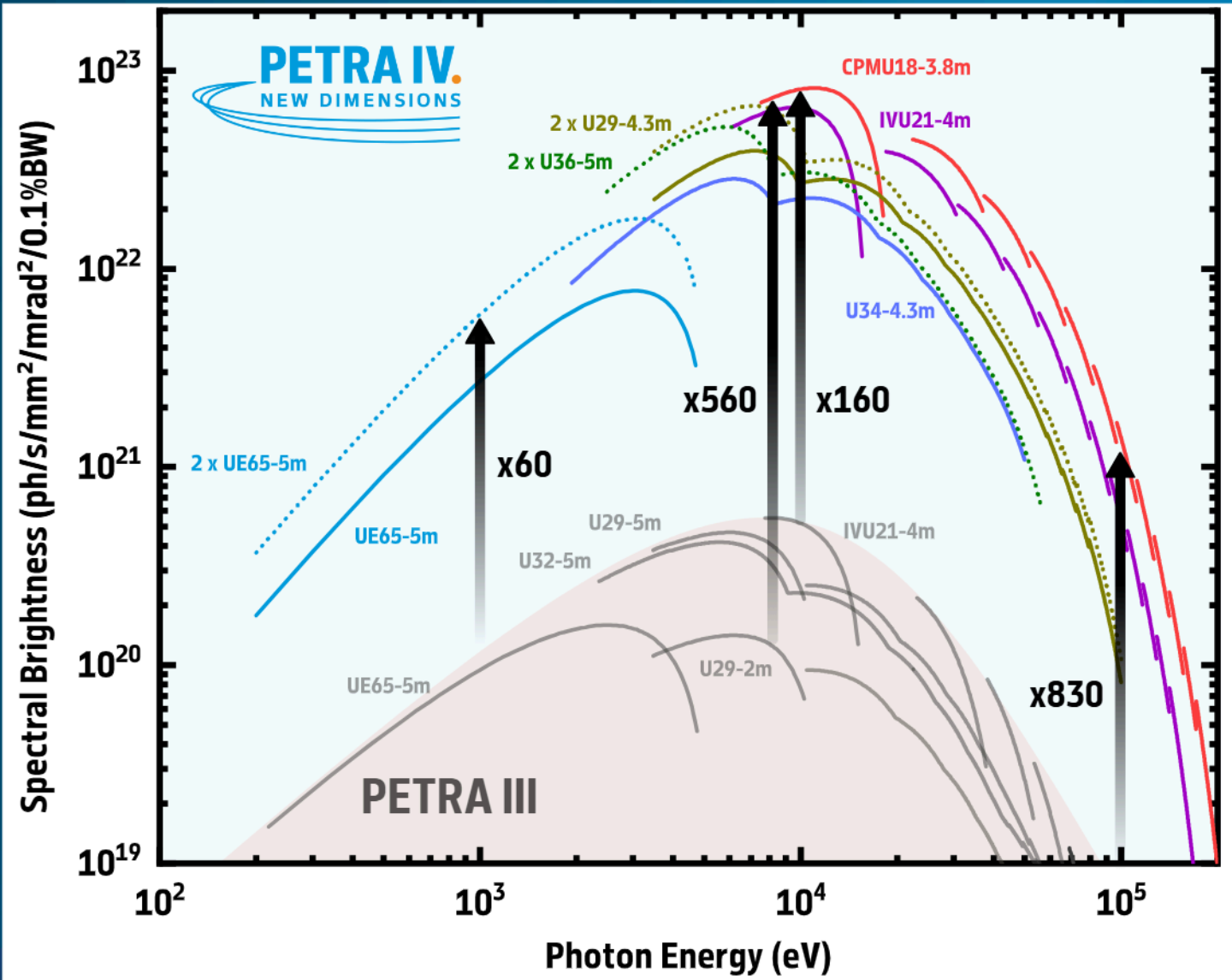
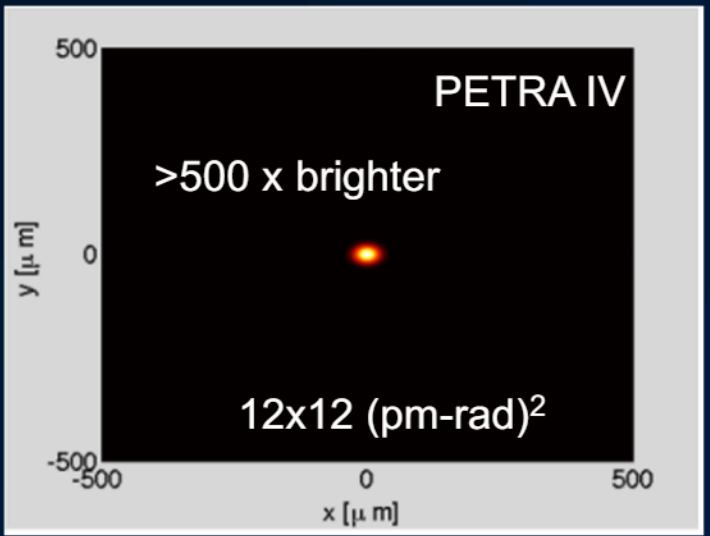
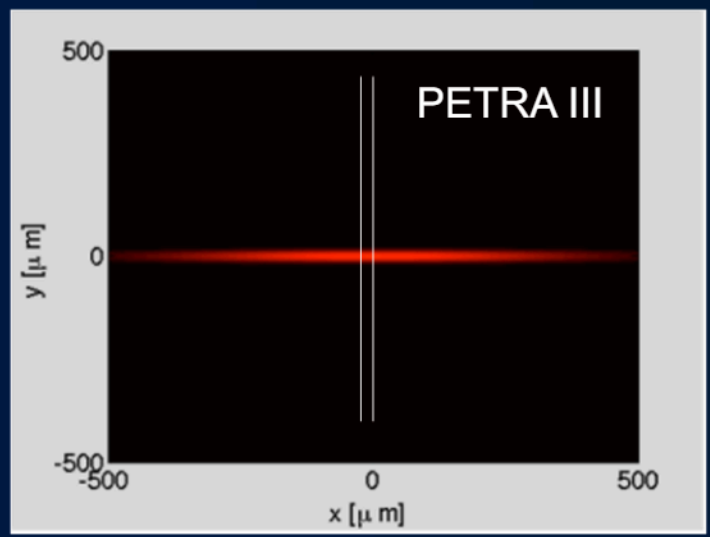
PETRA IV. – Essential upgrade to remain competitive

PETRA IV will, once again, be the most powerful high-energy synchrotron radiation source



PETRA IV. will provide brightest X-ray beams to address global challenges

The lattice has been frozen and is based on a hybrid 6 bend achromat. Dipoles to be permanent magnets.



DESY and the Helmholtz Association achieved excellent results in the Federal government's research infrastructure prioritisation process



Forschungsinfrastruktur (FIS) Priorisierungsverfahren



Publication of the Evaluation report, 27 March 2026

Endorsement and funding recommendation to the BMFTR! We eagerly await the BMFTR's decision.

WR

WISSENSCHAFTSRAT

2026

Statement on
**PETRA IV – The ultimate
4D X-ray Microscope**
of the Deutsches
Elektronen-Synchrotron
(DESY)

Link: <https://www.wissenschaftsrat.de/download/2026/3152-26>

PETRA IV is affirmed as a flagship project of outstanding strategic importance – scientifically, technologically, economically, and socially. Its impact will extend far beyond the German research landscape, fostering national competitiveness and contributing to global scientific progress. Executed with diligence, the project represents a cornerstone investment that aligns with Germany's science policy ambitions. With its exceptional vision and high project maturity, PETRA IV stands out as an exceptional opportunity for German and European photon science – one of the most advanced synchrotron initiatives worldwide.

PETRA IV. has three major construction/installation pillars

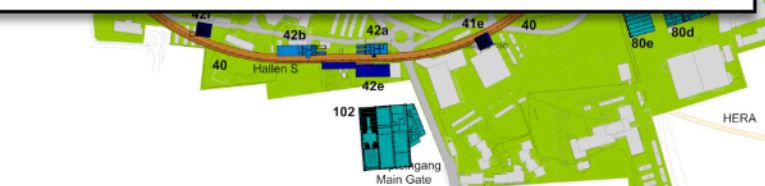
Extension/Refurbishment of the existing infrastructure, accelerator complex, and experimental facilities



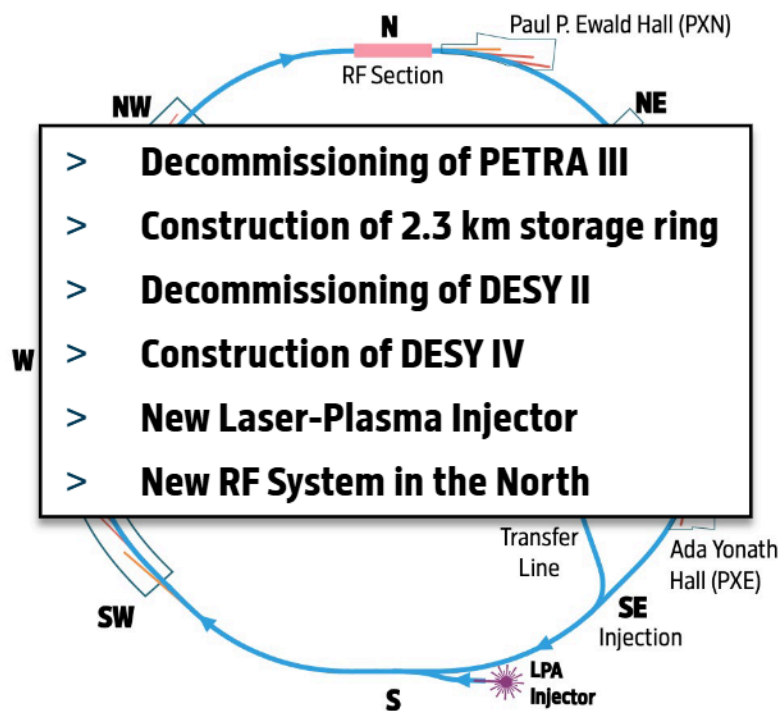
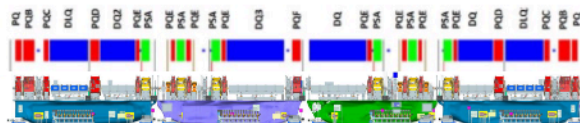
Civil Construction and Infrastructure



- > **New PXW hall to house 18 new beamlines**
- > **Modern, climatized accelerator tunnel and supporting technical infrastructure**
- > **Focus on sustainability and minimising environmental impact**



Accelerator Complex



Experimental Facilities EDR

Engineering Design Report

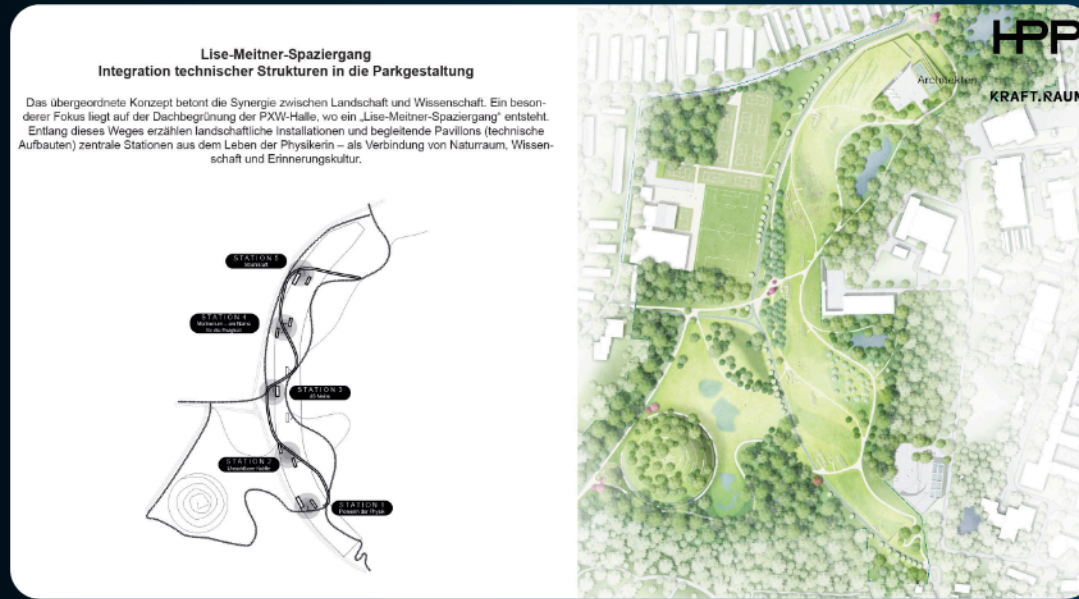


- > **31 new photon beamlines**
- > **60 new/refurb. endstations**
- > **62 new/refurb. Laboratories**
- > **New business model**

PETRA IV has made significant progress in civil construction plans

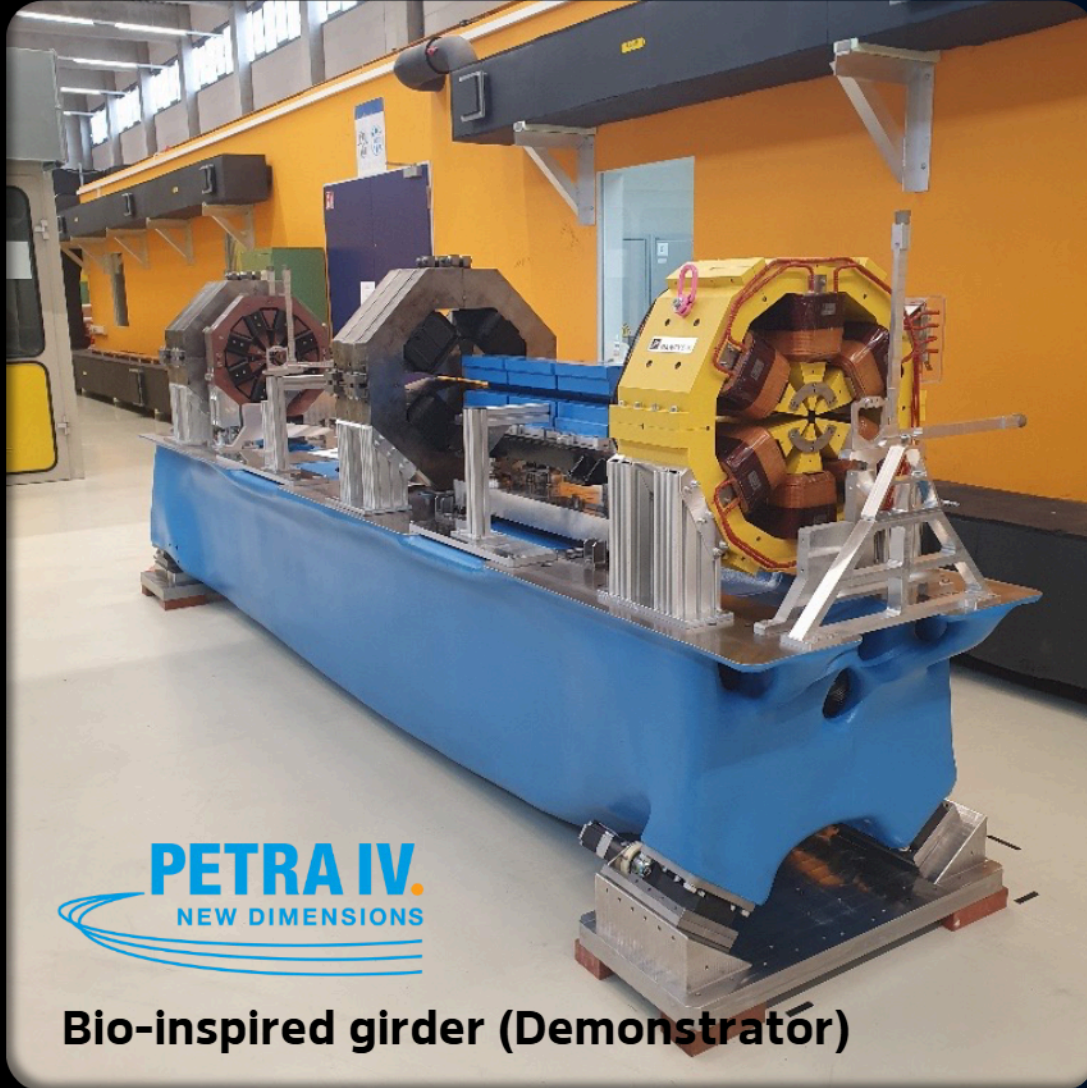
Civil construction could start in Q1 2028, pending funding availability in Q1 2027

- Design of the PXW Hall in Lise Meitner Park by HPP/Kraftwerk (contract awarded: August 2025)
- Engineering Design Report: 1,300 pages (Oct. 2025)
- Conceptual Design Reports prepared for all 31 beamlines
- Digging/construction to be done while PETRA III keeps running, till shutdown



Technology developments for PETRA IV: sustainability meets precision

Pre-project phase has allowed development, construction and testing of components at PETRA III



PETRA IV.
NEW DIMENSIONS

Bio-inspired girder (Demonstrator)

PETRA III is testbed for PETRA IV prototyping



Hot Swap redundancy concept for magnet power supplies



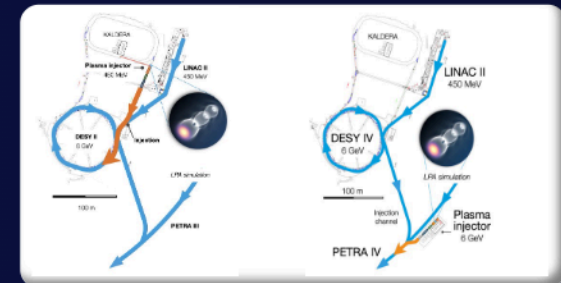
PETRA IV prototype HOM damped cavity



MicroTCA based electronics



RF system based on solid state amplifiers

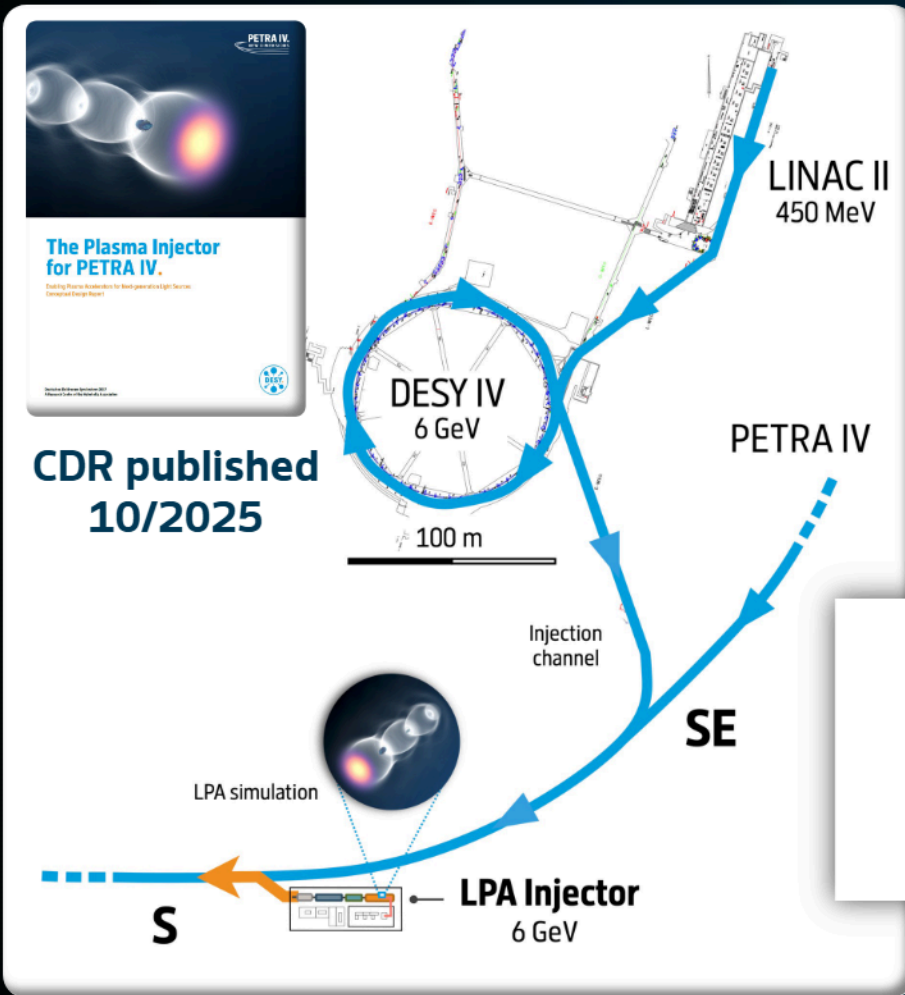


PETRA III prototype laser plasma injector

Proposed in 2019 as our Moonshot

One of the key innovations is the inclusion of a laser plasma accelerator

A full energy (6 GeV) injector will be built, tangential to the ring



The laser plasma injector is a new element that is unique worldwide.



WR

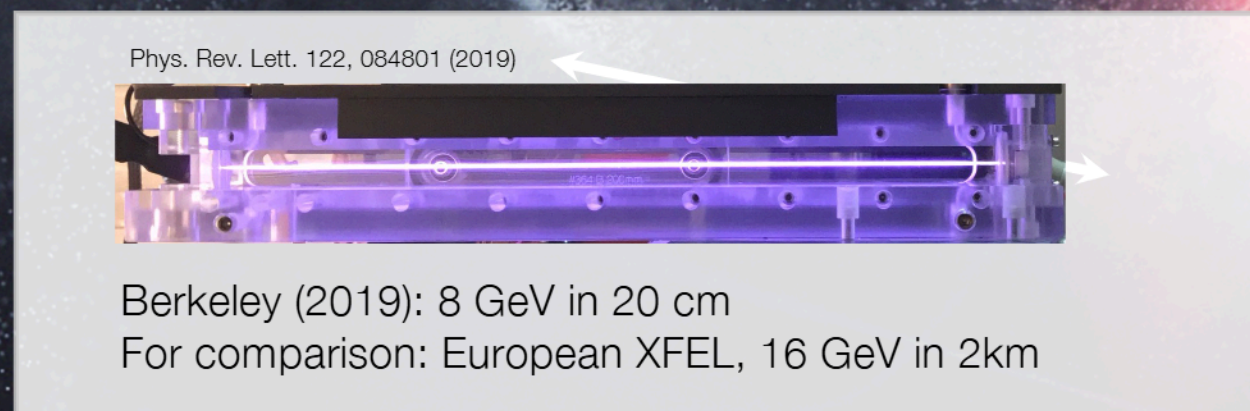
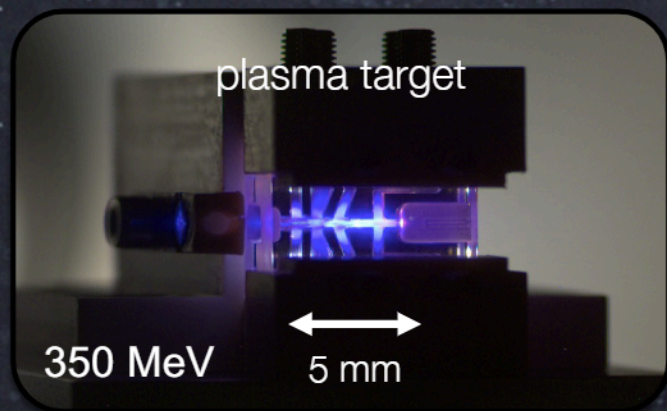
WISSENSCHAFTSRAT

Statement on
PETRA IV – The ultimate
4D X-ray Microscope
of the Deutsches
Elektronen-Synchrotron
(DESY)

The project's technological ambition is both appropriate and necessary to maintain Germany's leadership position. The proposed inclusion of frontier accelerator developments such as the LPA reflects strategic foresight, even though some components present cost estimation challenges due to the absence of commercial or technical precedents. If implemented successfully, this novel

Laser-Plasma Acceleration

- Reduced food print
- percent-level stability



electron beam

plasma wakefield

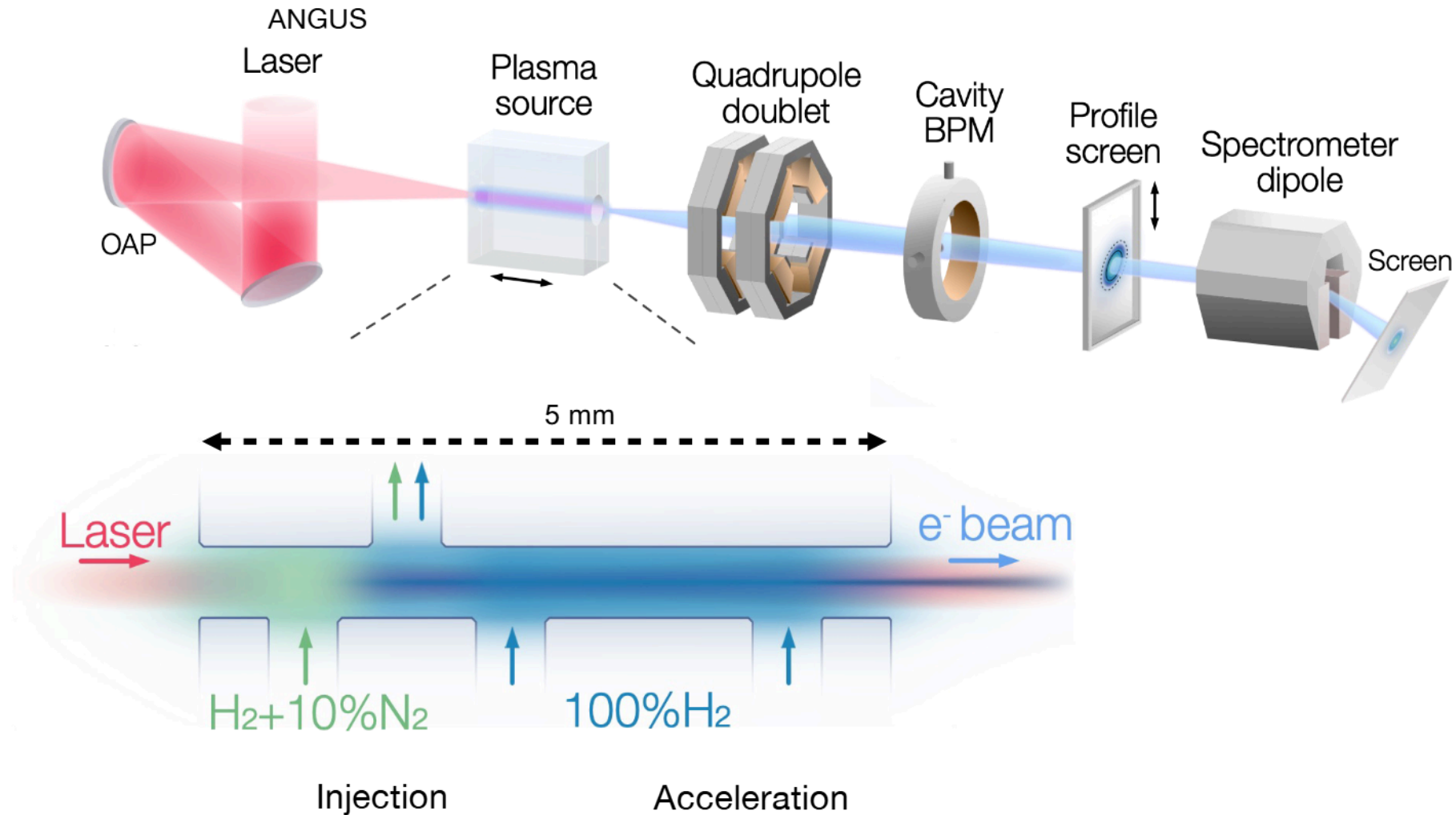
$E_z \sim 100$ GV/m

laser pulse

Tailored gas based targets have been developed to allow fine control

Down-ramp assisted localized ionization injection

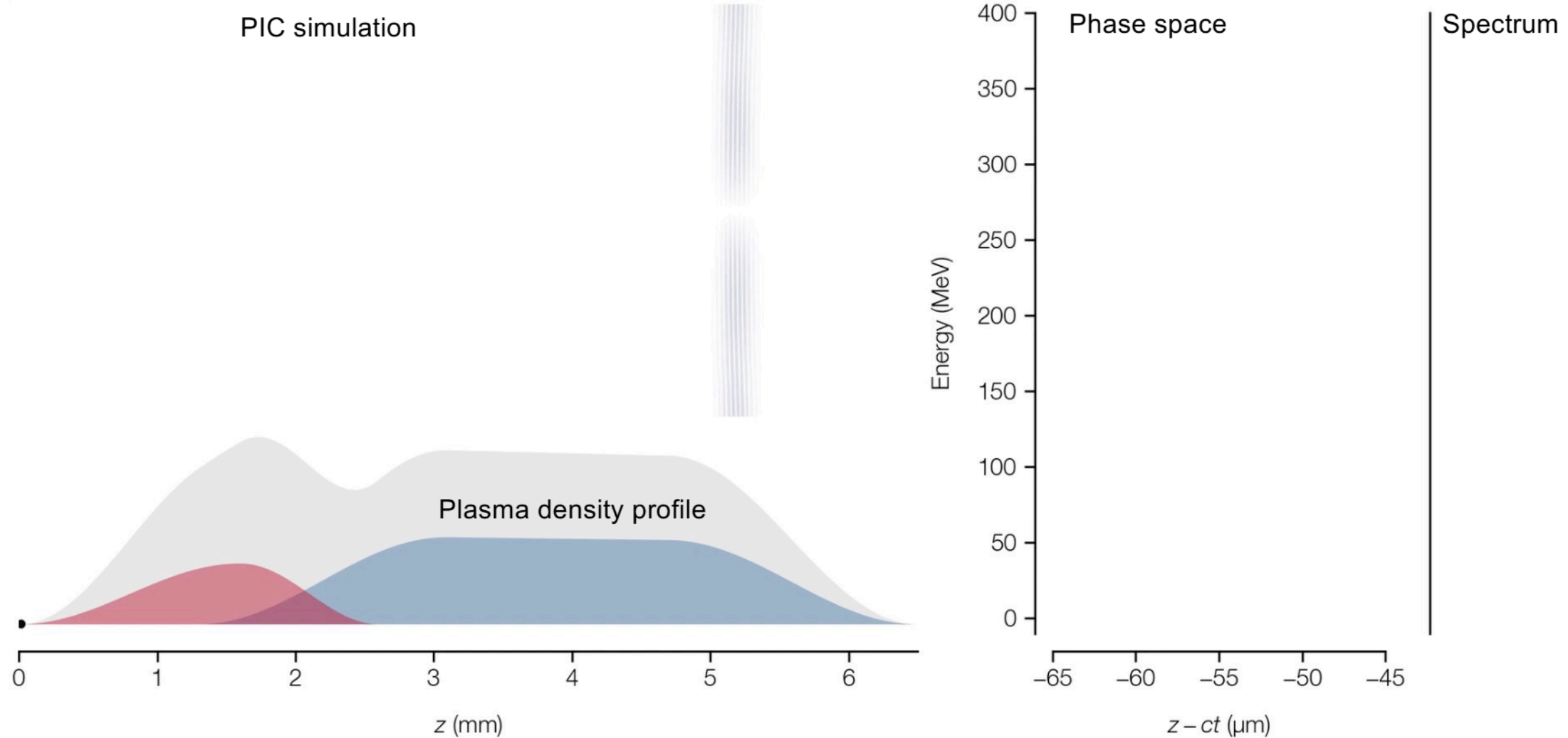
M. Kirchen et al., PRL 126, 174801 (2021)



We engineer the plasma to obtain high quality beams

Optimal beam loading is key to narrowing the spectrum

M. Kirchen et al., PRL 126, 174801 (2021)

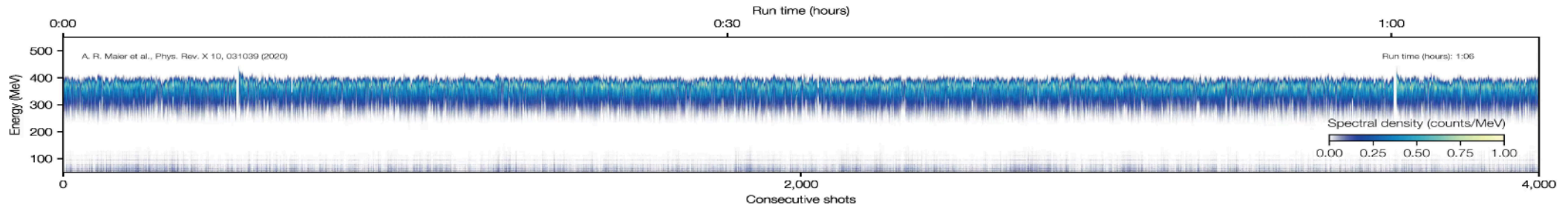


We have achieved major breakthroughs in the past 5 years

They paved the road for further investments: long term operation, machine learning, feedback

A. Maier *et al.*, PRX 10, 031039 (2020)

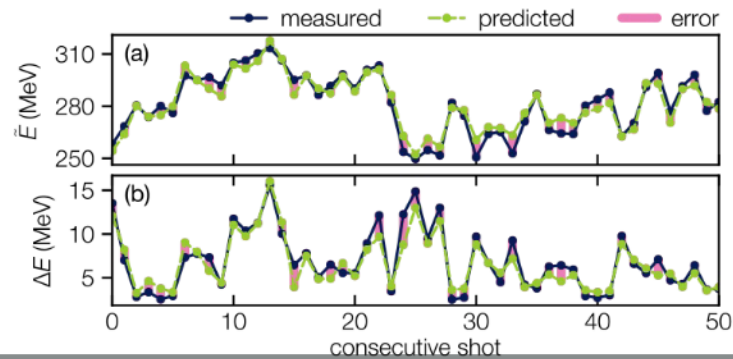
Long-term operation, decoding the source of fluctuations



M. Kirchen *et al.*, PRL 126, 174801 (2021)

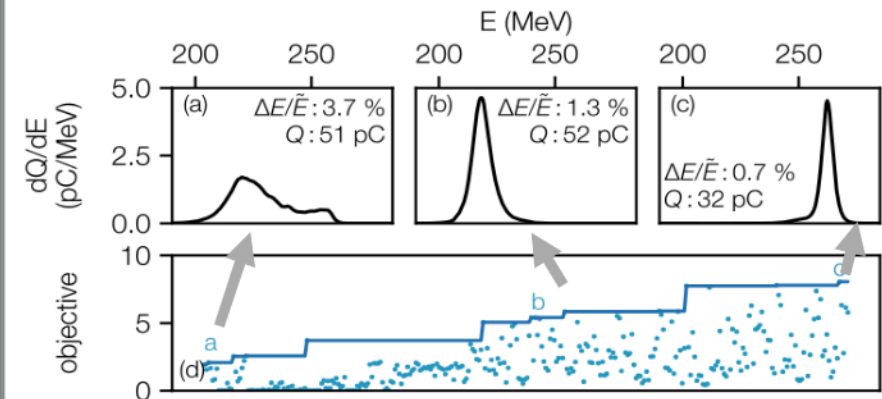
Science case active stabilization

Understanding knobs that control performance



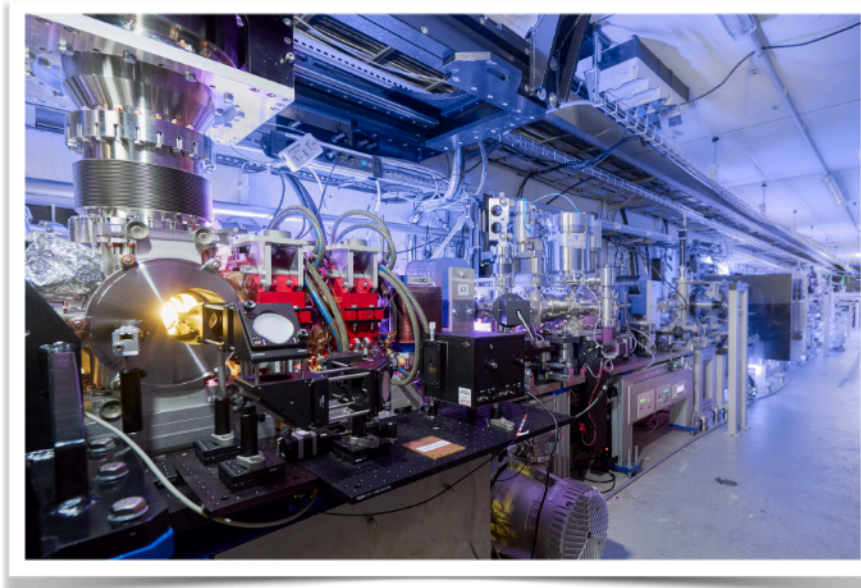
S. Jalas *et al.*, PRL 126, 104801 (2021)

Autonomous tuning using machine learning



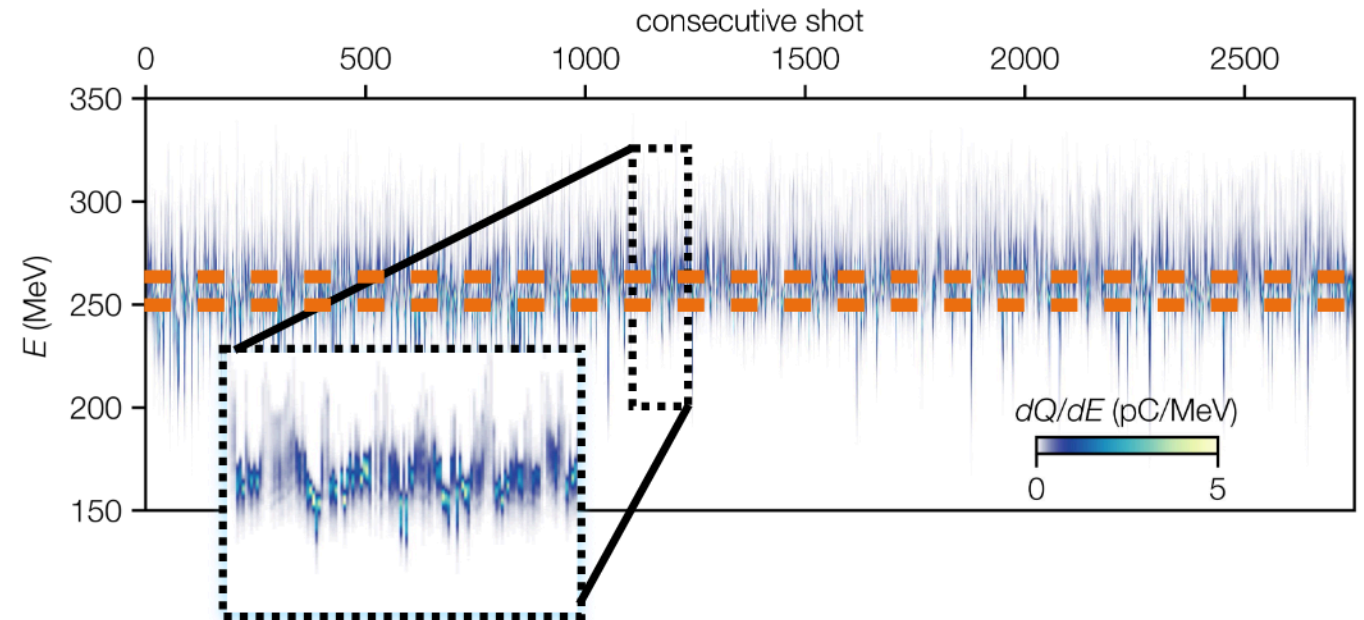
State-of-the-Art LPAs achieve percent level energy spread and jitter.

A storage ring accepts only a few permille in both. Finding a path forward is crucial.



LUX Laser-Plasma accelerator at DESY

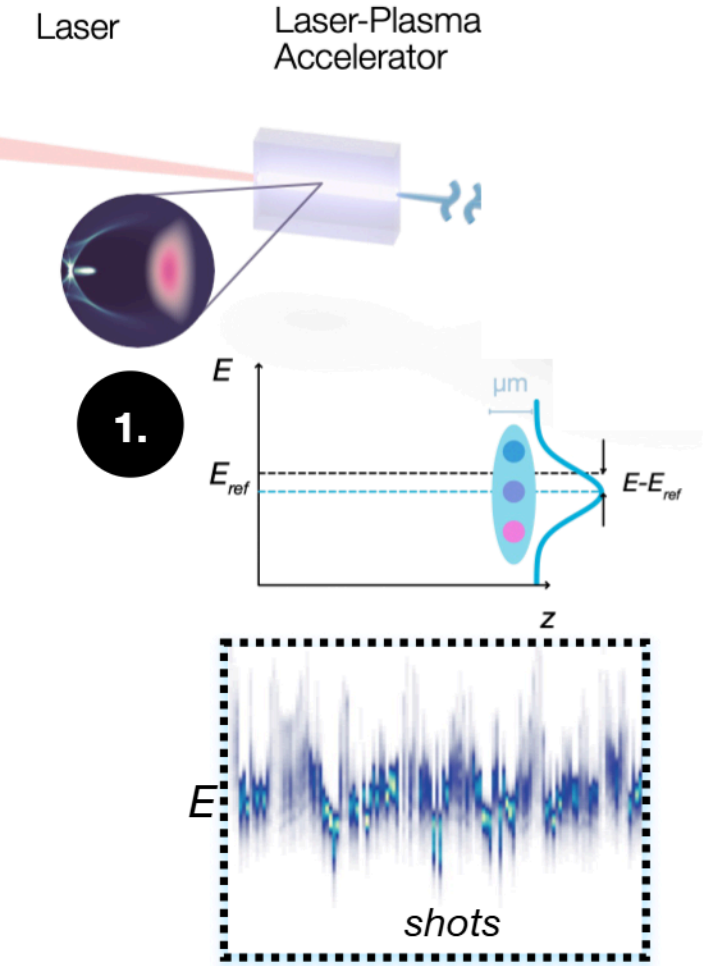
- long-term stable operation at ~300 MeV
- but shot-to-shot variation in beam energy at the several percent level
 - Rep rate too low for feedback (see later)



Charge outside ring acceptance is lost

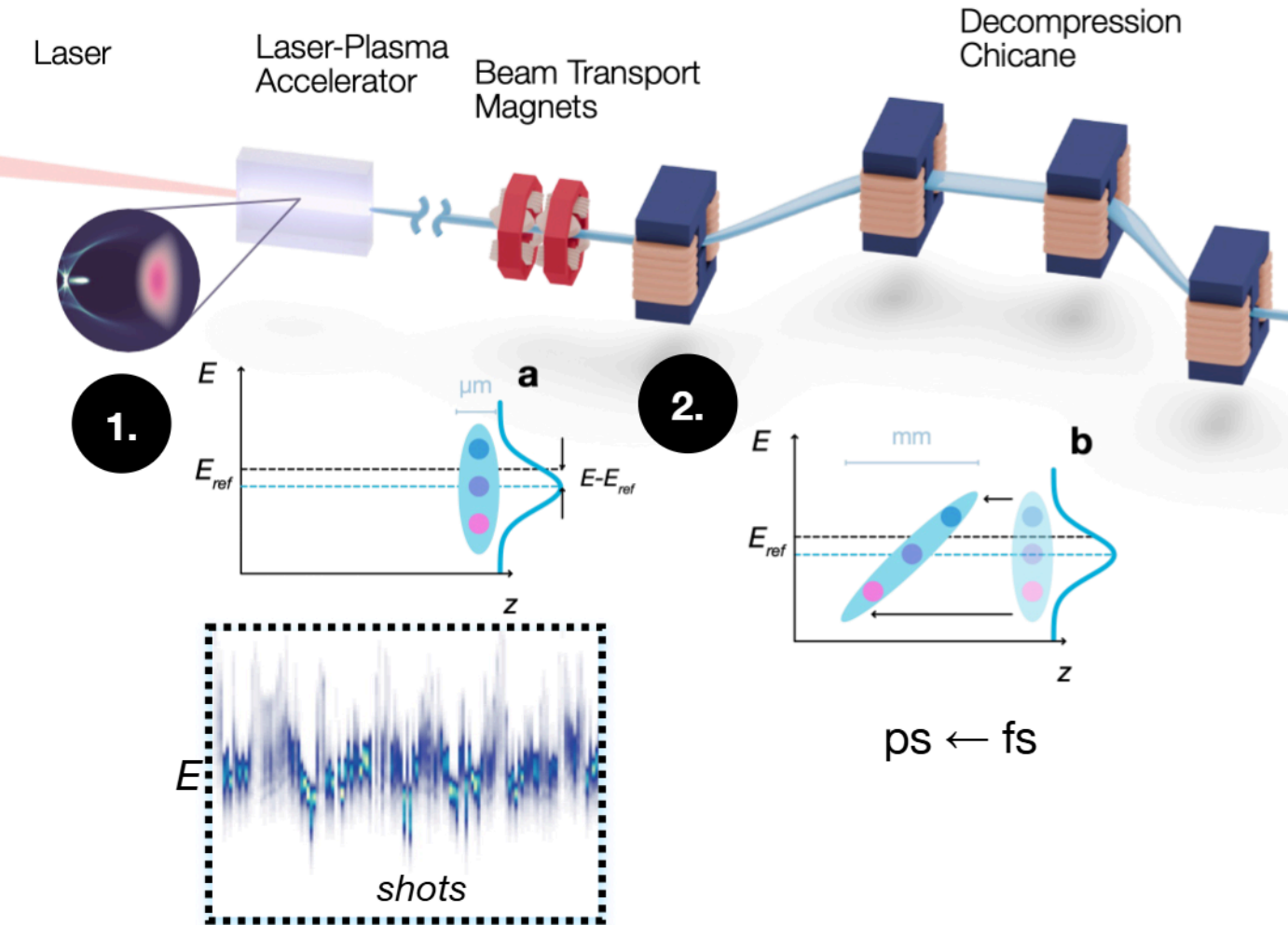
LPA beams are intrinsically short

but show percent-level energy spread & jitter



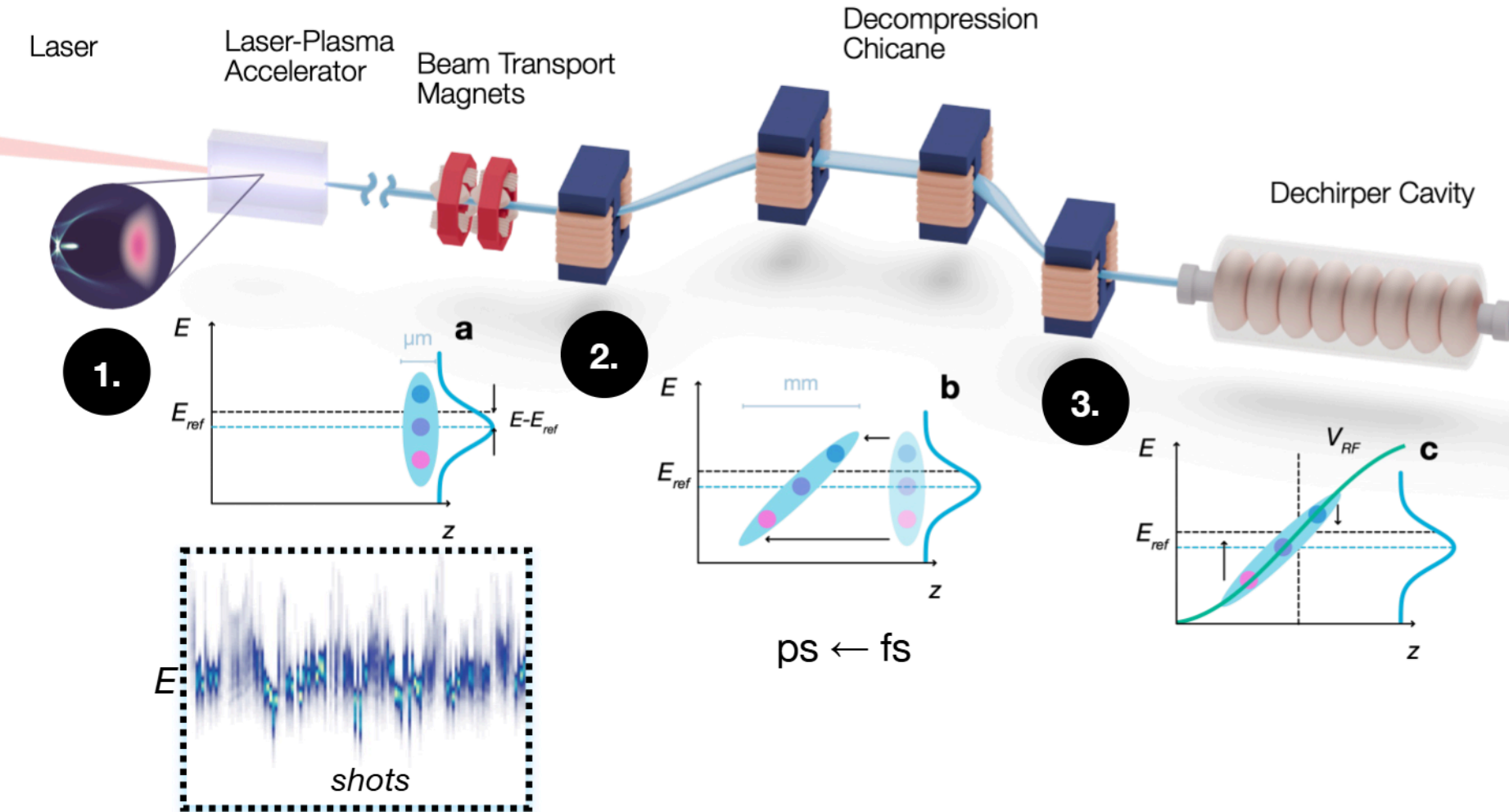
A dipole chicane reduces the longitudinal slice energy spread

by imprinting an energy dependent delay.



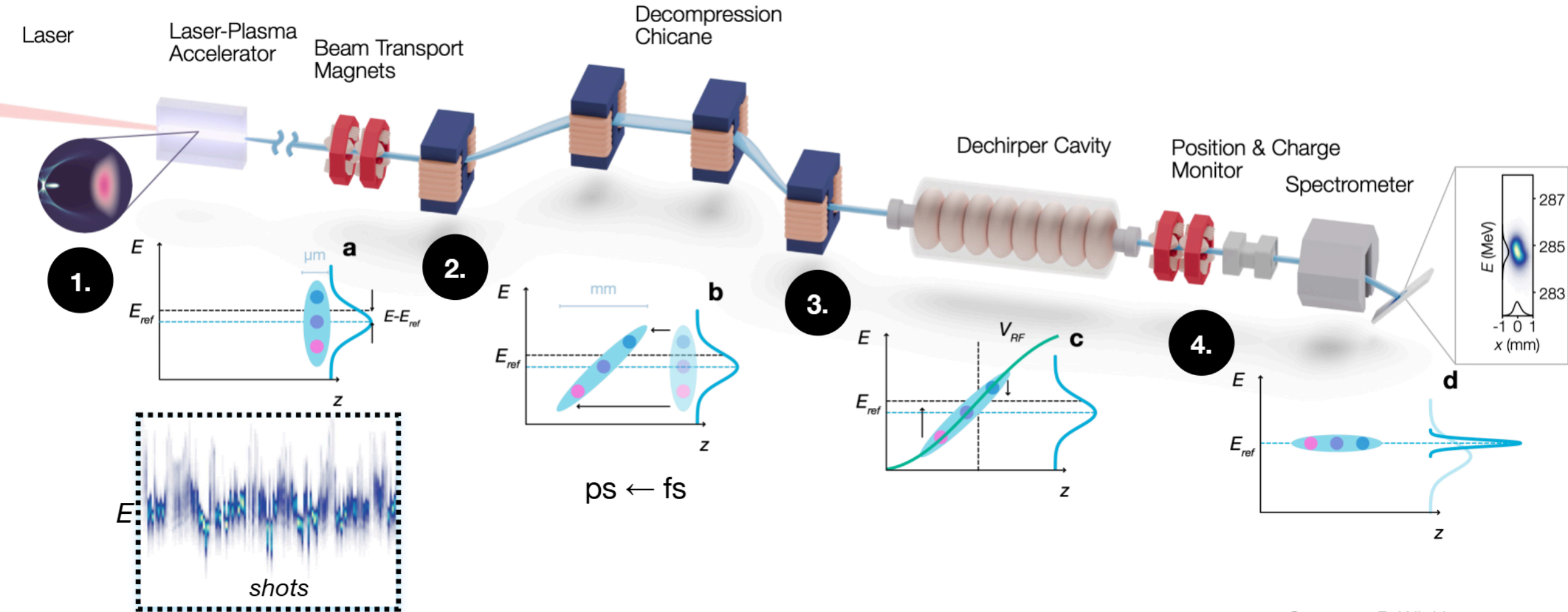
The spectrum is compressed inside an (active) RF cavity

removing the chirp imprinted earlier.



Energy spread & jitter reduced simultaneously

at the cost of beam peak current.



Courtesy: P. Winkler

20m of additional beamline installed in 2024



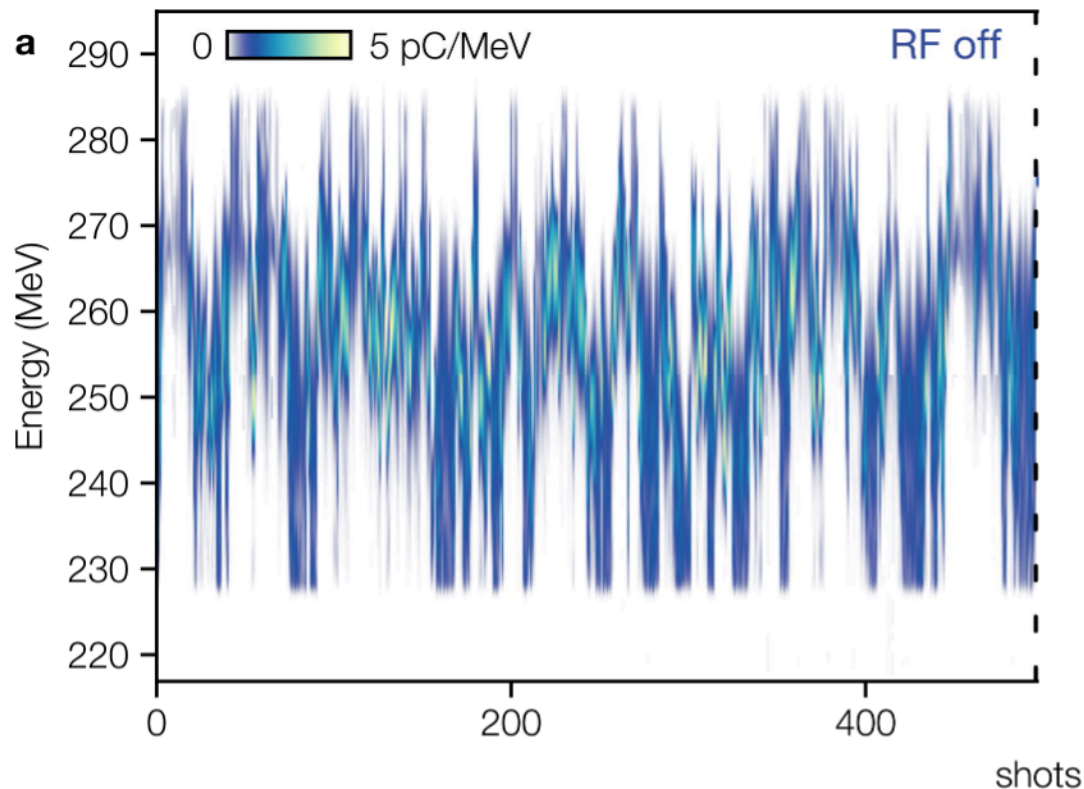
Decompression chicane



S-band RF cavity

Active energy compression of plasma accelerated beams to the permille

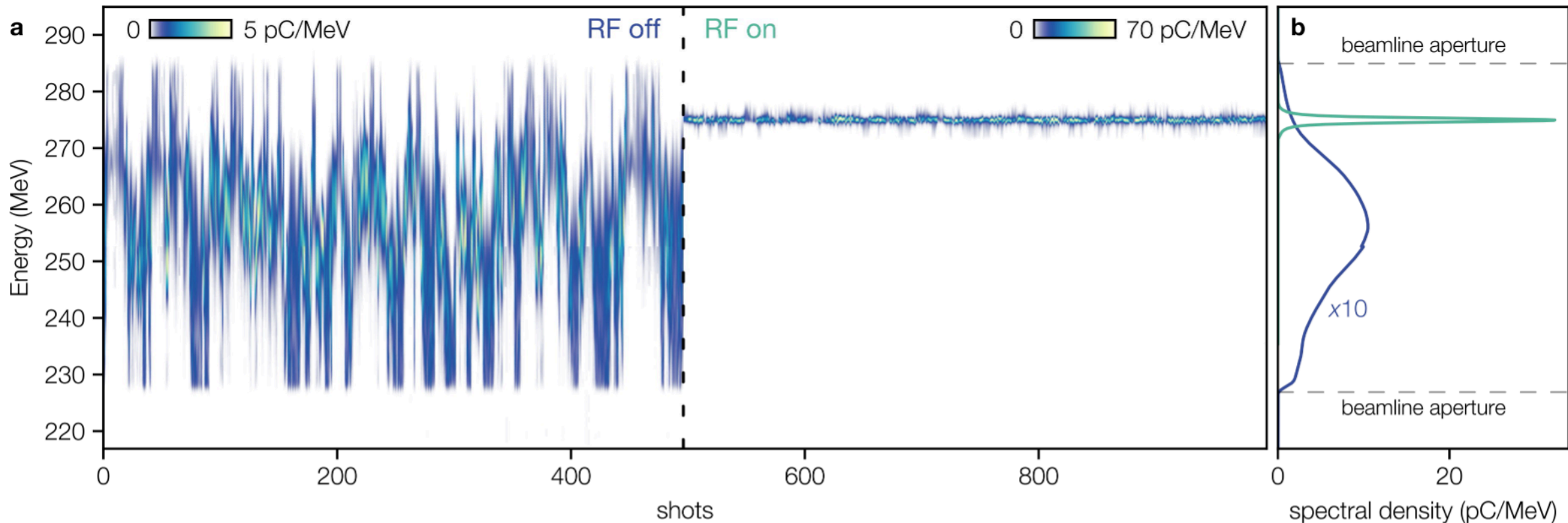
0.048% energy jitter & 0.097% energy spread, factor ~25 energy compression



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

Active energy compression of plasma accelerated beams to the permille

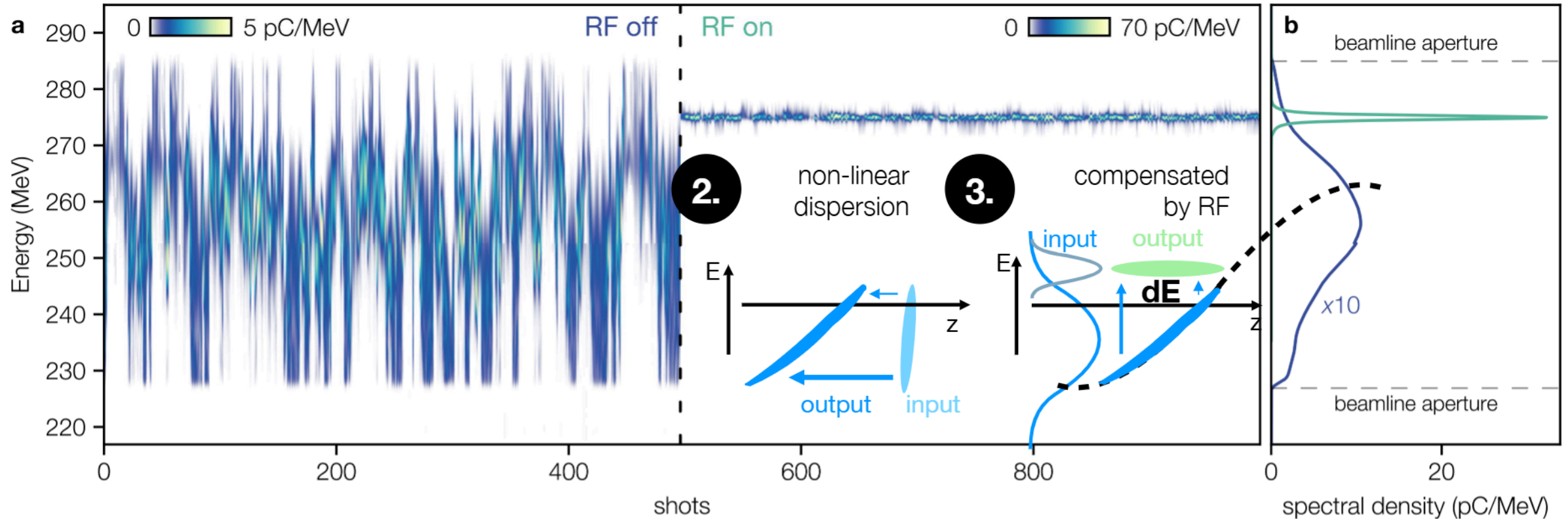
0.048% energy jitter & 0.097% energy spread, factor ~25 energy compression



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

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. *Nature* 640, p. 907–910 (2025)]

360° RF phase scan

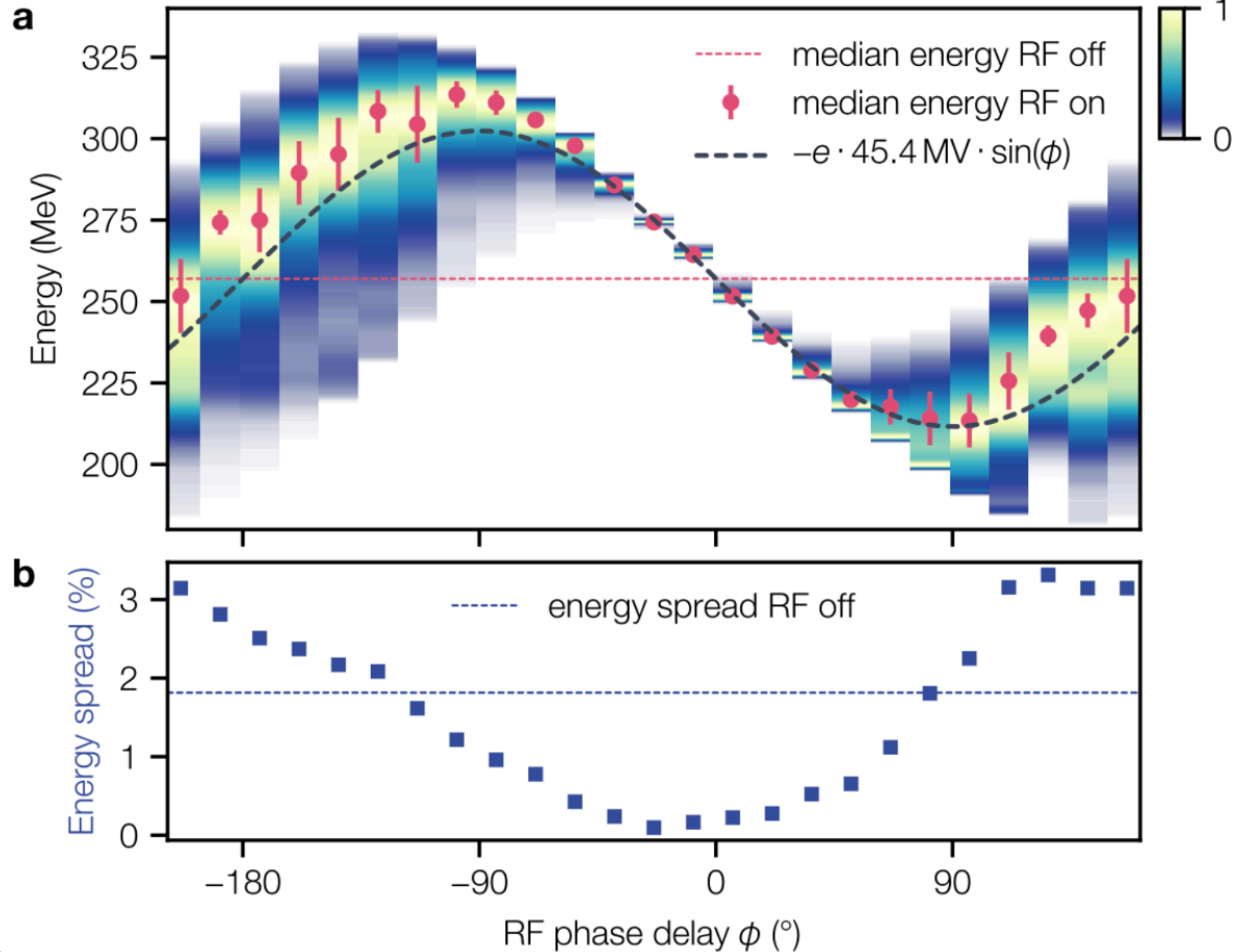
energy spectrum is compressed
for a larger range of RF phases

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

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

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

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

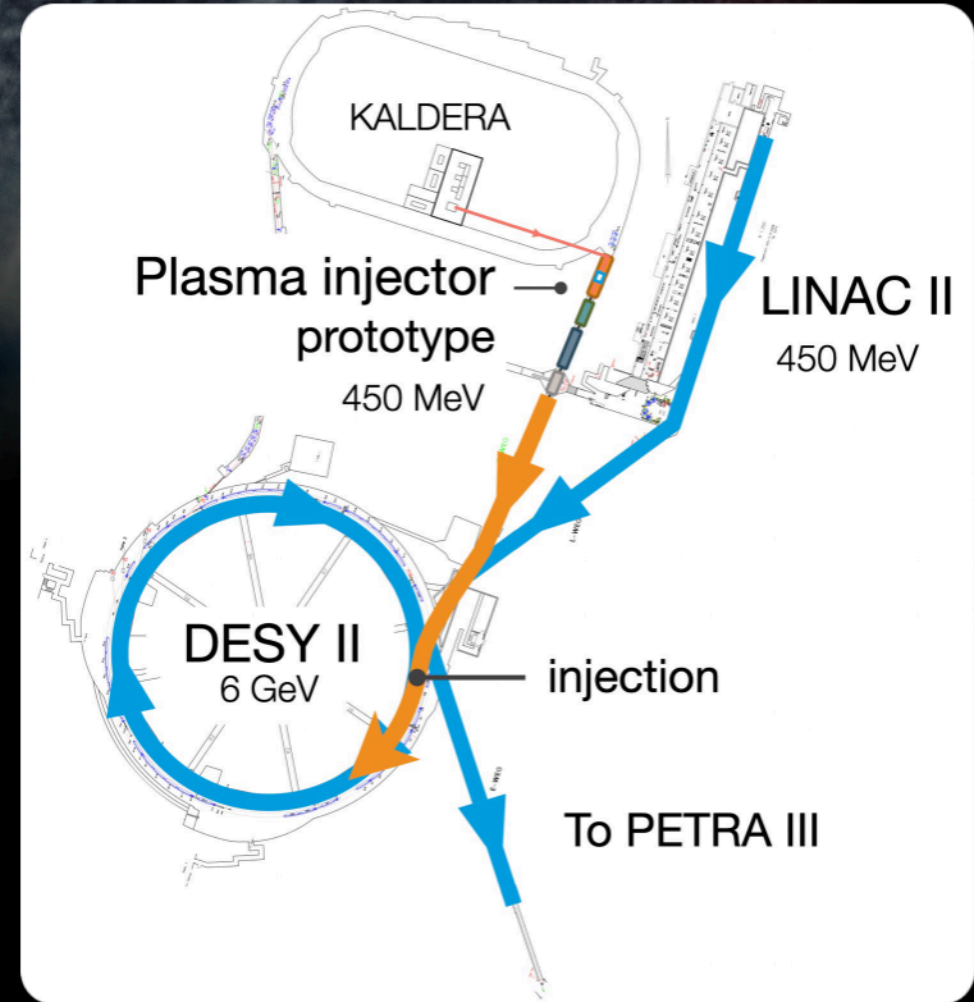


Next step: Demonstrate full technology chain at lower energy

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 (~ 350 MeV)

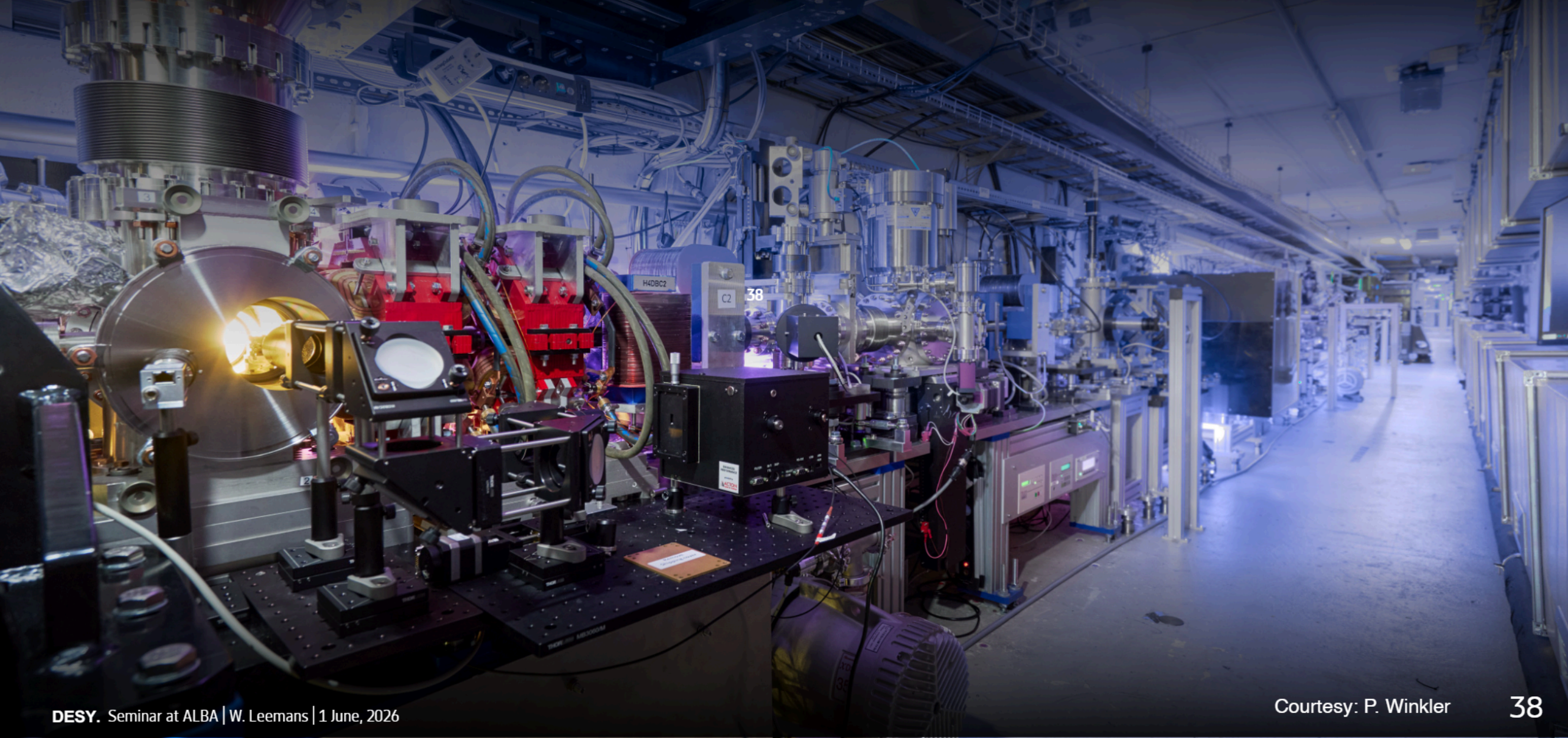
37



Reuse LUX plasma accelerator for injector studies



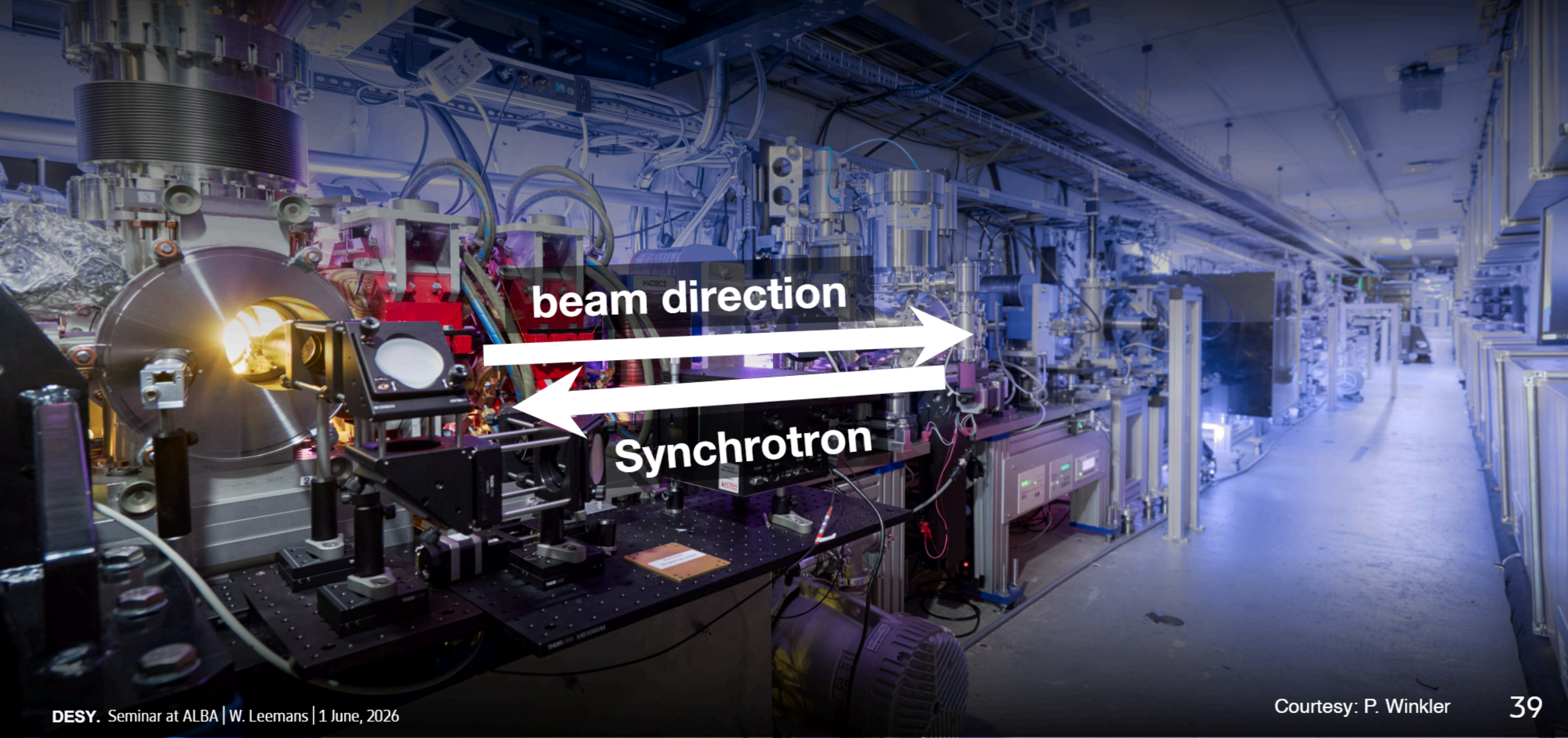
ANGUS Laser delivers 3J at 1.25 Hz to accelerate electrons up to ~300 MeV (LINAC II: 450 MeV 12.5 Hz)



Reuse LUX plasma accelerator for injector studies



ANGUS Laser delivers 3J at 1.25 Hz to accelerate electrons up to ~300 MeV (LINAC II: 450 MeV 12.5 Hz)



beam direction

Synchrotron

Reuse LUX plasma accelerator for injector studies



ANGUS Laser delivers 3J at 1.25 Hz to accelerate electrons up to ~300 MeV (LINAC II: 450 MeV 12.5 Hz)

Unbuilt LPA and rebuilt in reversed order to inject into DESY II

Stage installation into 2 phases to allow for re-commissioning of the LPA before injection studies.

Phase 1 ~9 month

Flip LUX

operation permission #1

Phase 2 ~3 month

commission

connect

operation permission #2

inject

~1 week in March

July 2025
Goodbye LUX.



November 2025
Hello (F)LUX - Start commissioning.



Connection (F)LUX to DESY II proceeded well.

February 2026. Phase 2 completed. Ready for validation by safety authorities and onwards to injection!

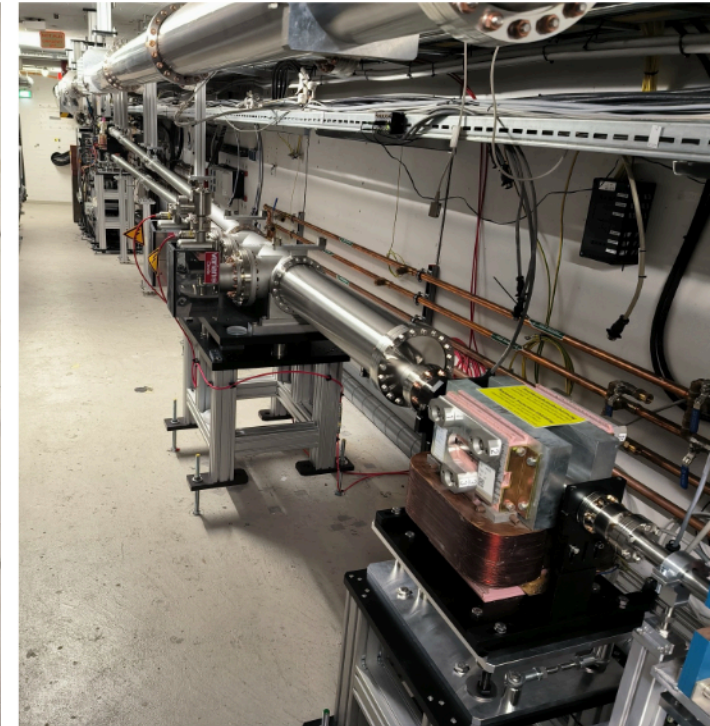


L-Weg

LUX pipe



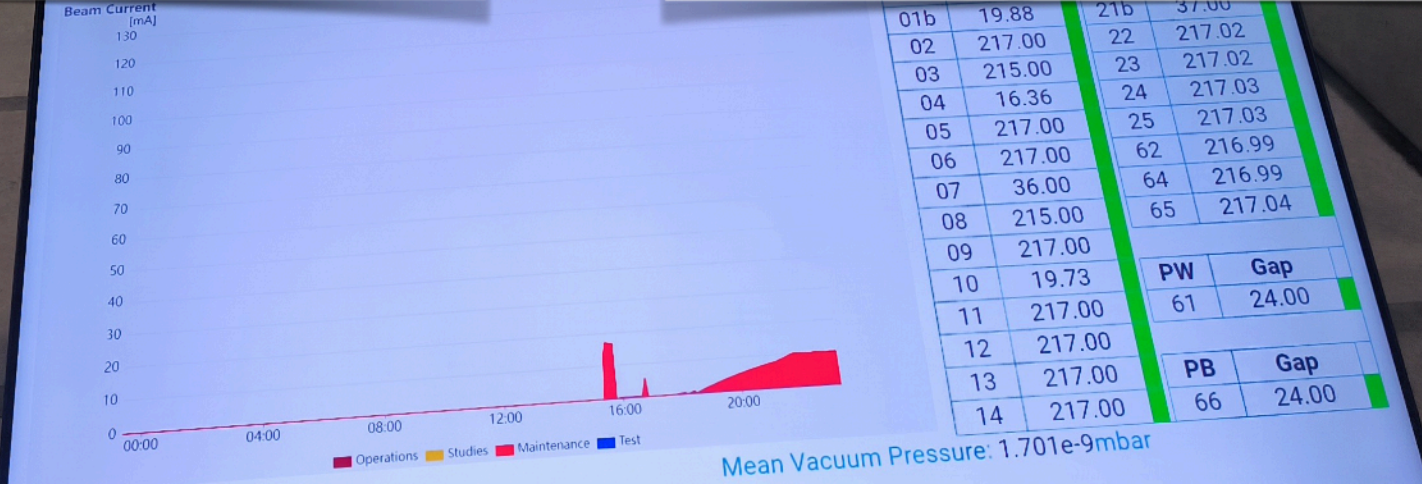
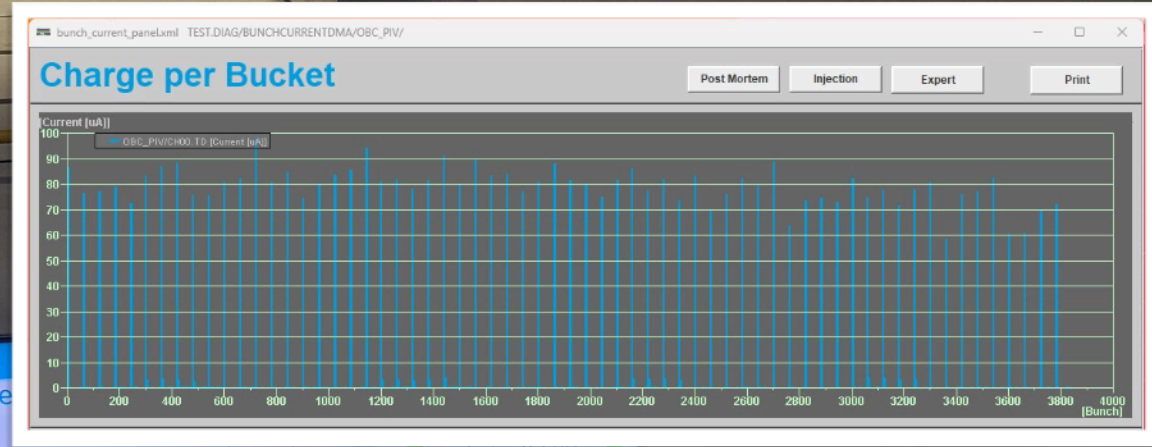
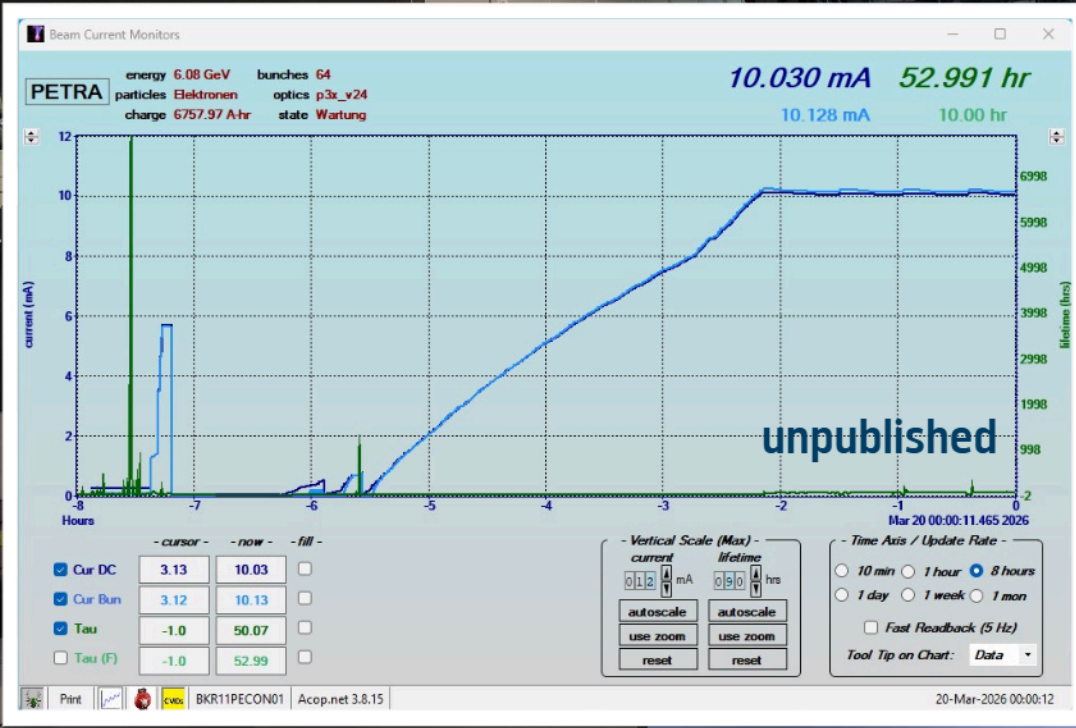
last bending dipole to parallelise to L-Weg



vertical dogleg at end of LUX tunnel

Day 6: 10 mA of LPA beams filled into 64 buckets in PETRA III

10 mA filled in 3h



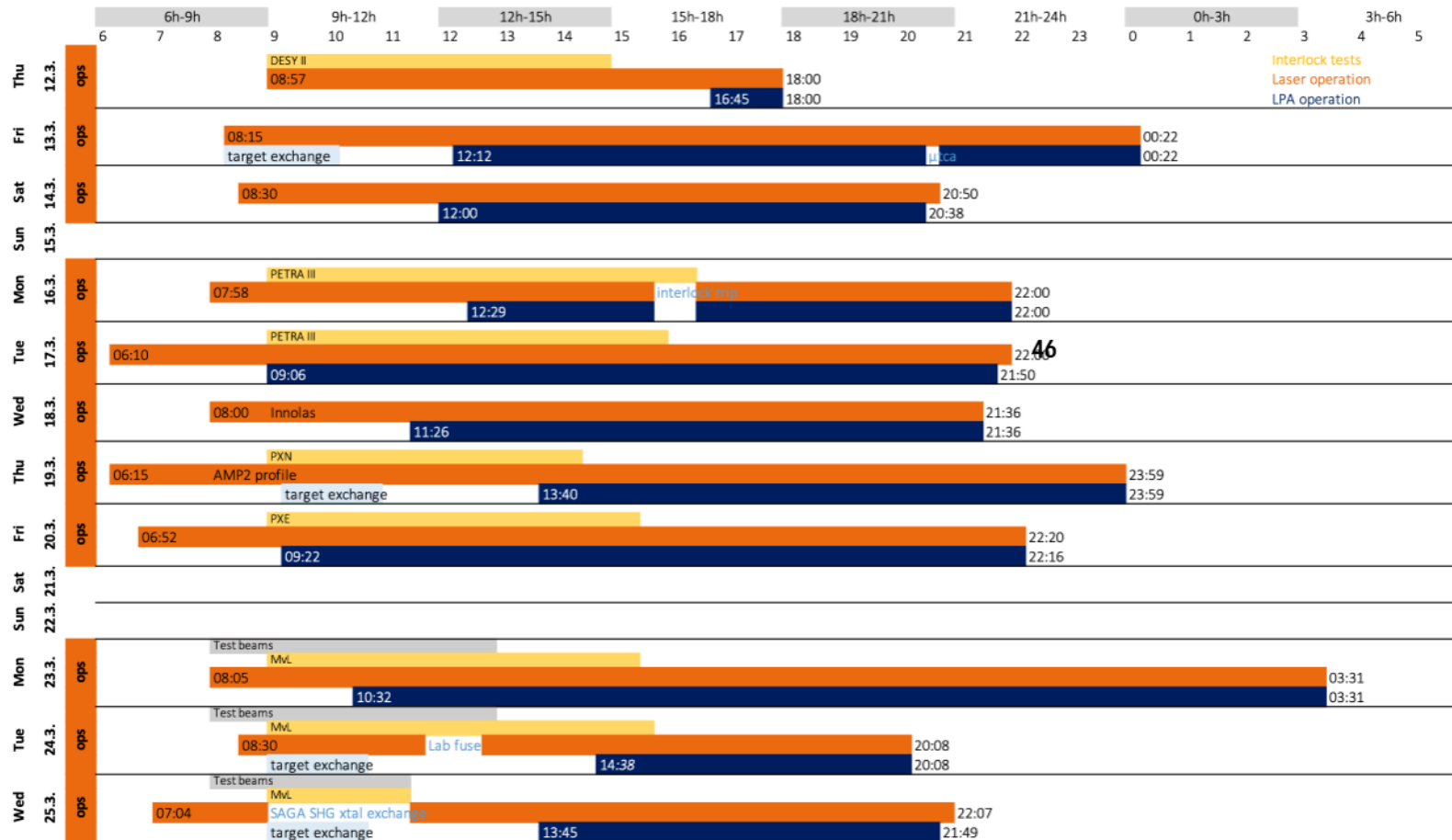
into 64 buckets
 Photon
 beamlines
 noted clean
 bunches

Max von Laue Hall,
 PETRA III, DESY

March 19, 2026, 23:24

Laser & LPA available 11 / 11 days.

Injection studies were done in parallel to annual interlock tests.



- Annual interlock tests during the day. Injection studies in the evening.
- also start of test beams 2nd week
- ramped up laser in the morning
- **Laser + LPA available 11/11 days**
- Mon 16th: interlock trip [50min]
- Tue 24th: Lab fuse trip [60min]
- Wed 25th: SHG xtal exchange [2.5h]
- replaced target 4 times (2 times to test a different target length)

Next: towards 6 GeV

The laser system must meet injection and top-off requirements

A (sub-)petawatt class laser at 10 Hz is required.

Baseline
design:
PIP^{IV} CDR



Requirements

Charge rate

~10 minutes to
fill

Charge transmission

match ring acceptance

98 % availability

The laser system must meet injection and top-off requirements

A (sub-)petawatt class laser at 10 Hz is required.

Baseline design:
PIP^{IV} CDR



Requirements

Stable high average power laser system

Stable laser guiding to 6 GeV

Charge rate
~10 minutes to fill

Repetition rate

10 Hz

Charge per shot

250 pC

Charge transmission
match ring acceptance

Pulse energy

40 J
50-100 fs

Energy gain

6 GeV
±0.1%

98 % availability

Ti:Sa or Nd:glass

LPA + HOFI/Cap discharge

The laser system must meet injection and top-off requirements

A (sub-)petawatt class laser at 10 Hz is required.

Baseline design:
PIP^{IV} CDR



Requirements

Stable high average power laser system

Stable laser guiding to 6 GeV

Post-plasma energy compression

Charge rate
~10 minutes to fill

Repetition rate

10 Hz

Charge per shot

250 pC

Charge transmission
match ring acceptance

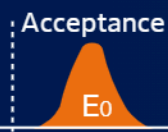
Pulse energy

40 J
50-100 fs

Energy gain

6 GeV
 $\pm 0.1\%$

Energy stability and spread < 0.3 %



98 % availability

Ti:Sa or Nd:glass

LPA + HOFI/Cap discharge

Energy compression beamline

We are evaluating different laser technologies with industry partners

Surge for activity in laser-based fusion: Systems under consideration are close to what we require

Baseline design:
PIP^{IV} CDR



Requirements

Stable high average power laser system

Stable laser guiding to 6 GeV

Post-plasma energy compression

Charge rate
~10 minutes to fill

Repetition rate

10 Hz

Charge per shot

250 pC

Charge transmission
match ring acceptance

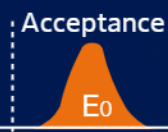
Pulse energy

100 J
100 fs

Energy gain

6 GeV
±0.1%

Energy stability and spread < 0.3 %



98 % availability

In discussion with STFC, Marvel Fusion, Trumpf Scientific, ...
for example Yb:YLF, Nd:glass, 1 μm wavelength, ...

Energy compression beamline

KALDERA

DESY's new flagship Laser for LPA



Guido Palmer
and Team



Lutz Winkelmann
and Team



July 2024

KALDERA

DESY's new flagship Laser for LPA

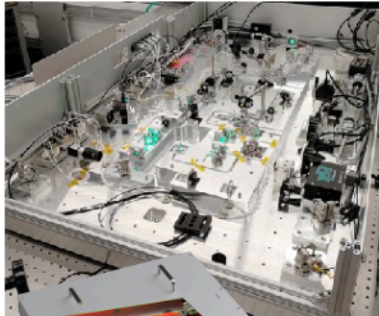


Guido Palmer
and Team

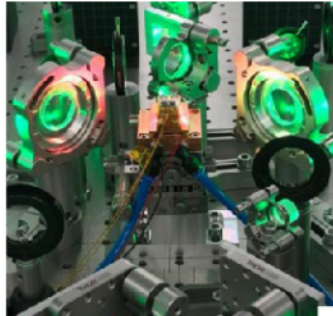


Lutz Winkelmann
and Team

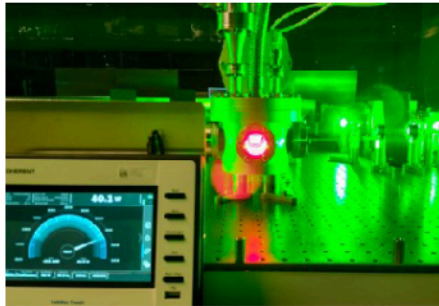
MASUBI



PICO



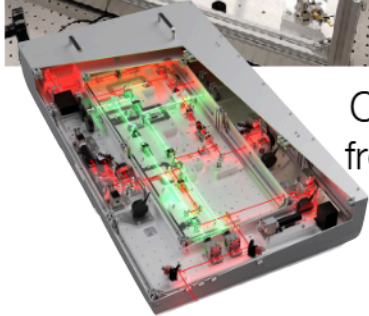
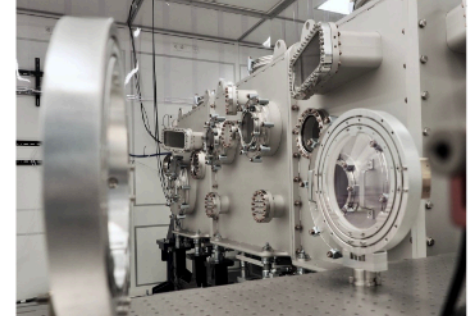
MERAPI



COLIMA

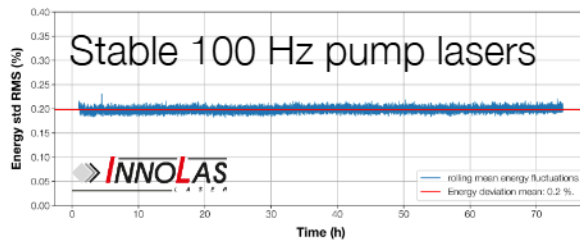


TAUPO

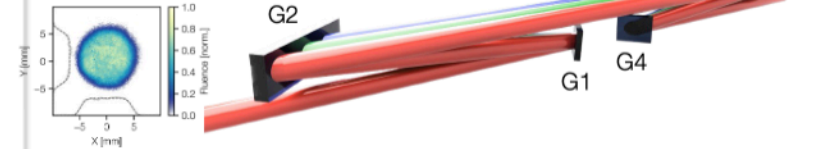


OPCPA
frontend

cryo cooled
Ti:Sa amplifiers



High average power compressor



C. Werle et al., Opt. Express 31, 37437 (2023)

100 Hz, 0.5 J ✓

100 Hz, 3 J

1000 Hz, 3 J

2024

2026

2028



MAGMA

High average power LPA - KALDERA Phase 1

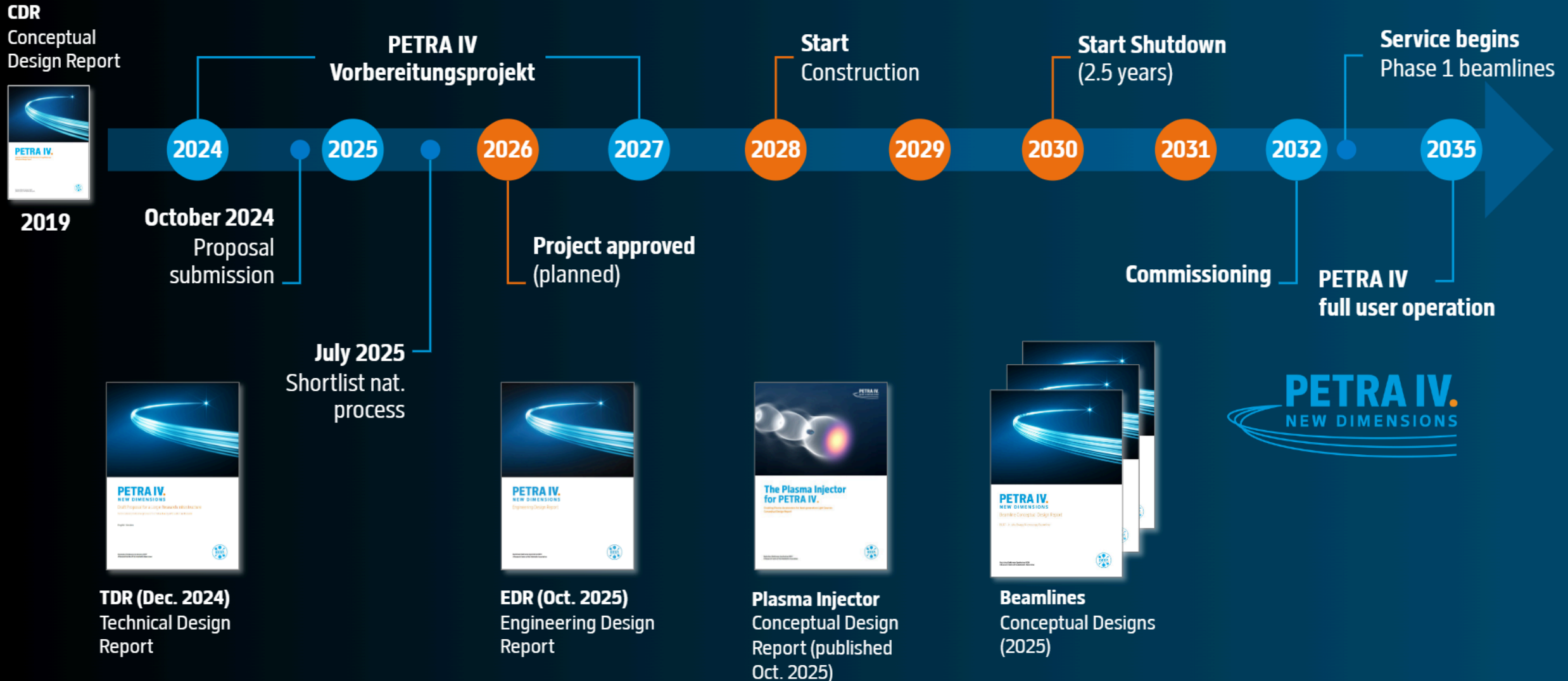


M. Kirchen
and Team



The schedule for the PETRA IV project is ready to be implemented

The decision on whether or not to build a classical injector will be a risk-based decision



Summary



- **DESY hosts three major accelerator based facilities and continues to invest in making them among the best in the world**
 - FLASH now has a seeded beamline that will operate at MHz rep rate (burst)
 - EuXFEL has achieved attosecond hard x-ray pulses and demonstrated a XFEL cavity
 - PETRA IV is on the German roadmap and will be the brightest SR based facility once completed
 - We are developing a 6 GeV laser driven plasma accelerator as injector for PETRA IV
- **We look forward to continued collaborations with ALBA!**



“Those that say it cannot be done should not interrupt those that are doing it”

George Bernard Shaw (?) or old Chinese proverb 😊

