LEAPS WG2 Compact Sources

Recent developments

Jens Osterhoff
Head of Plasma Accelerators
DESY Accelerator Division

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

Compact Source R&D in LEAPS

Novel (GV/m) accelerator technologies for miniaturization of photon sources

- Beam-driven plasma acceleration
- Laser-driven plasma acceleration
- Laser-driven dielectric acceleration

> **EuPRAXIA** CDR submitted end of 2019; ESFRI Roadmap application ongoing for hosting site in Frascati

> **ATHENA**: project for distributed novel accelerator research facility in Helmholtz, Germany; construction phase until 12/2021

> **ACHIP**: international collaboration to develop accelerator on a chip

plasma acclerators focus on average power and applicability

Target applications

FEL
Medical imaging
PETRA IV injector

SINBAD/ATHENA$_e$

Laser-driven novel accelerators

KALDERA

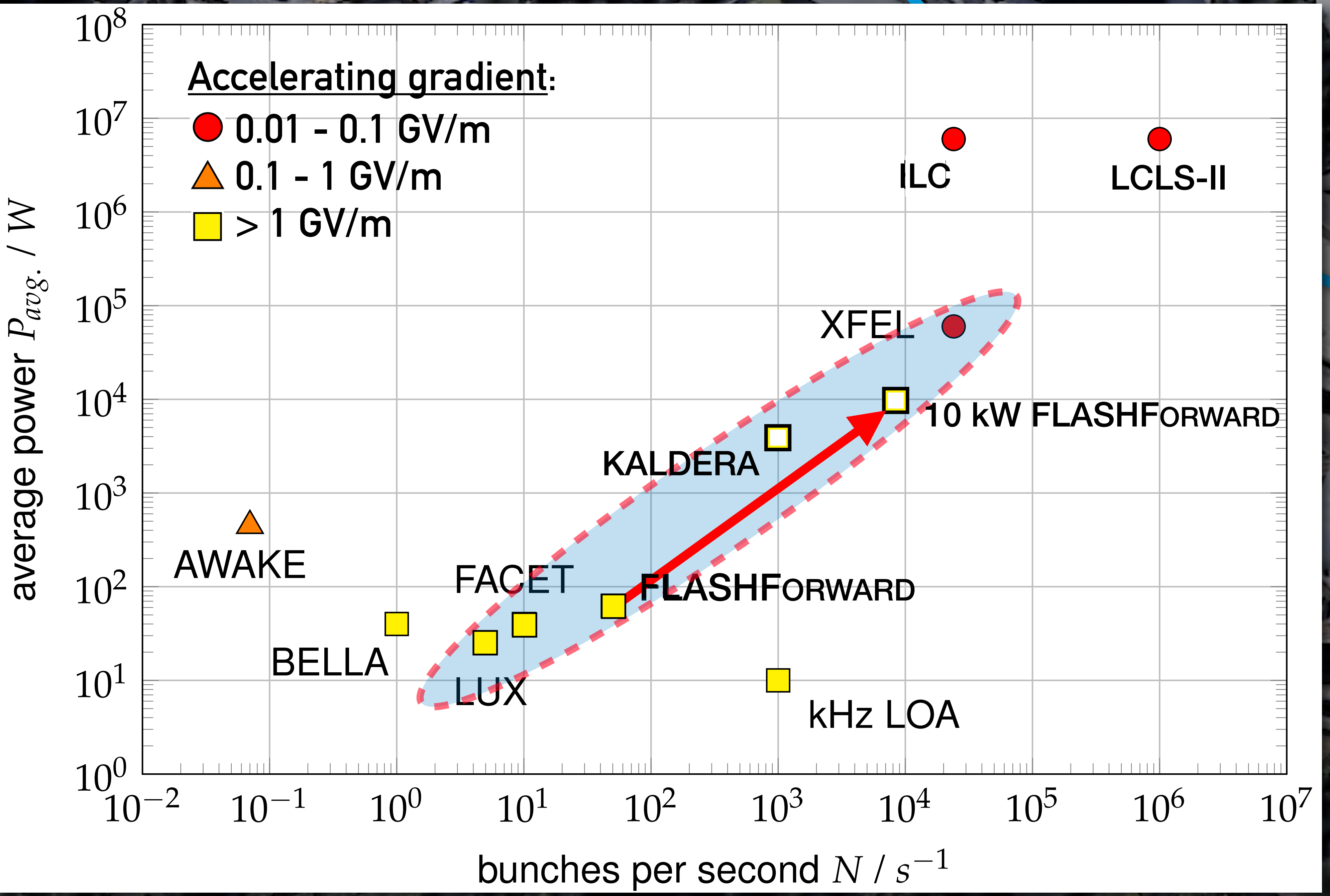
kHz, kW laser driver

Key R&D objective

10 kW booster stage
for photon science
and toward particle physics

FLASHFORWARD

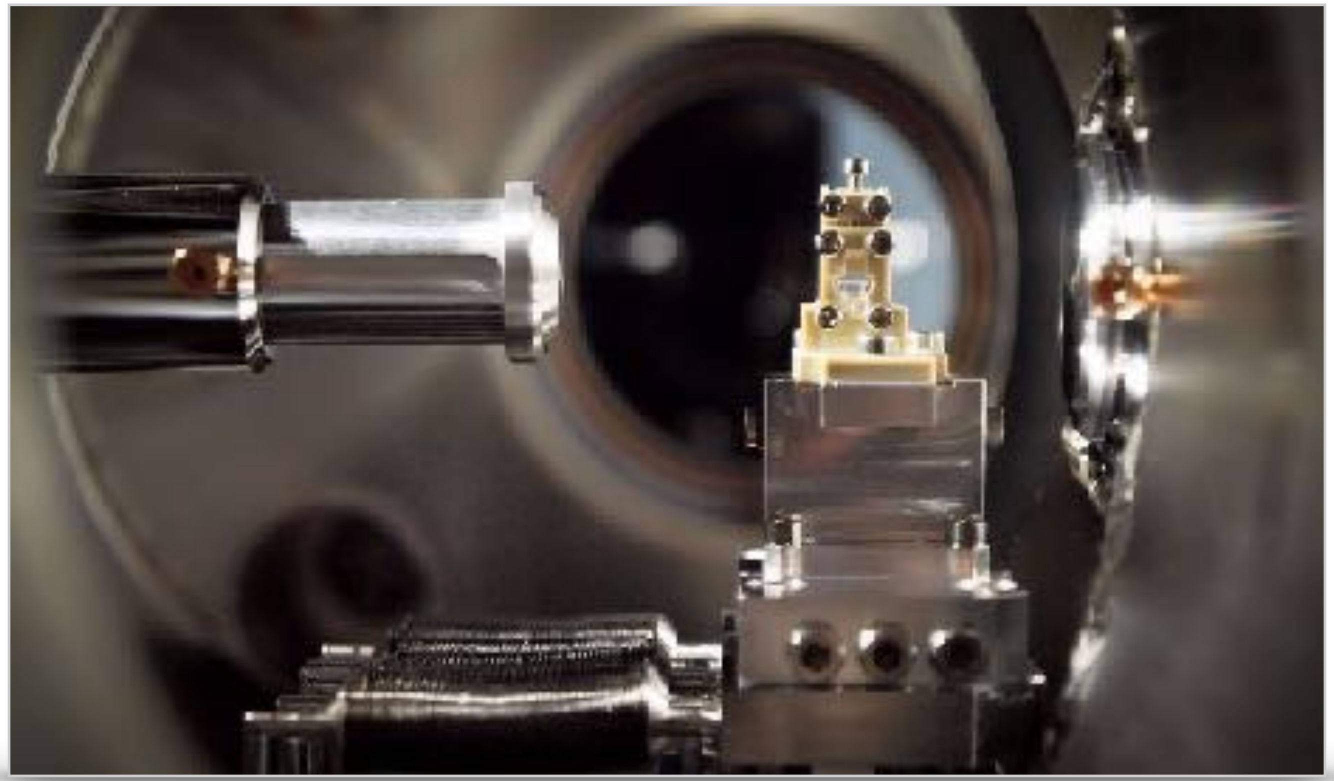
Beam-driven plasma research
at ~1 GeV, MHz, 10 kW



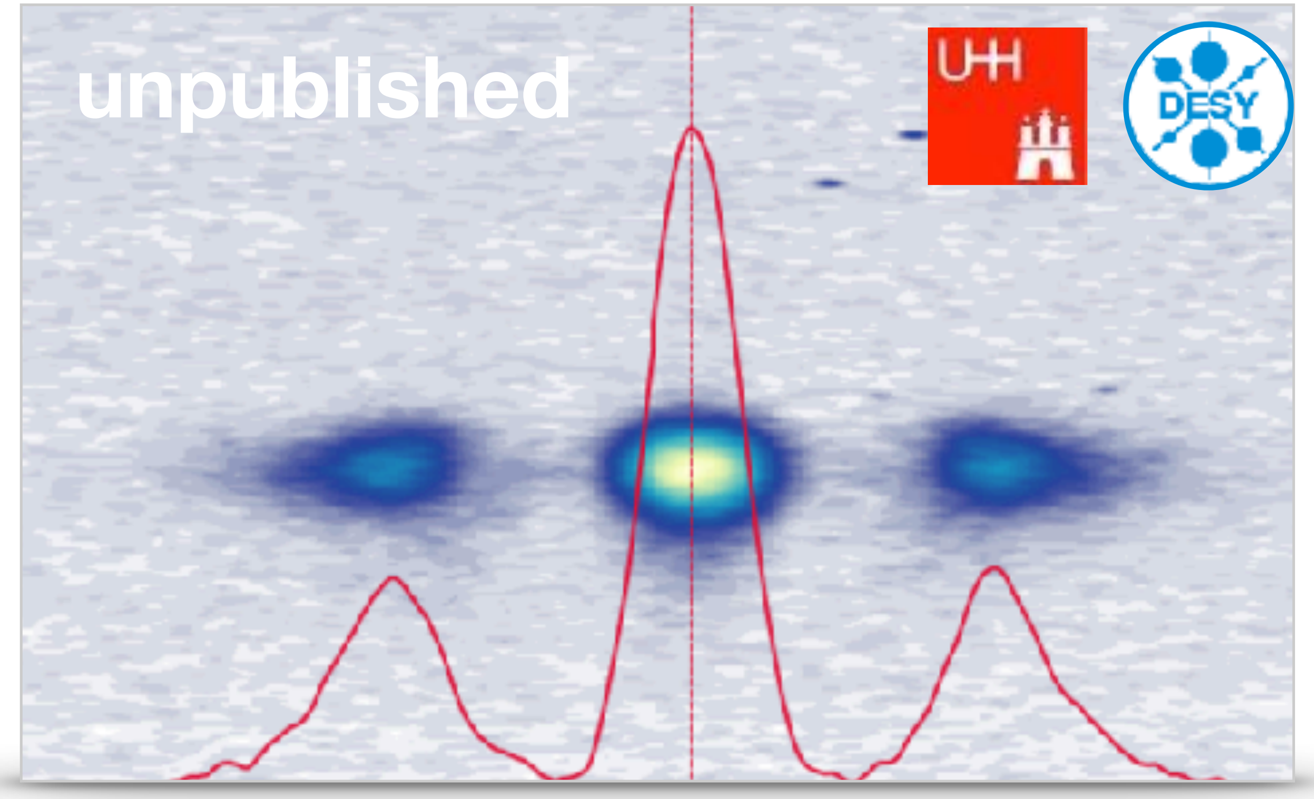
LUX - laser plasma acceleration for photon science

Merge plasma acceleration and modern accelerator technology

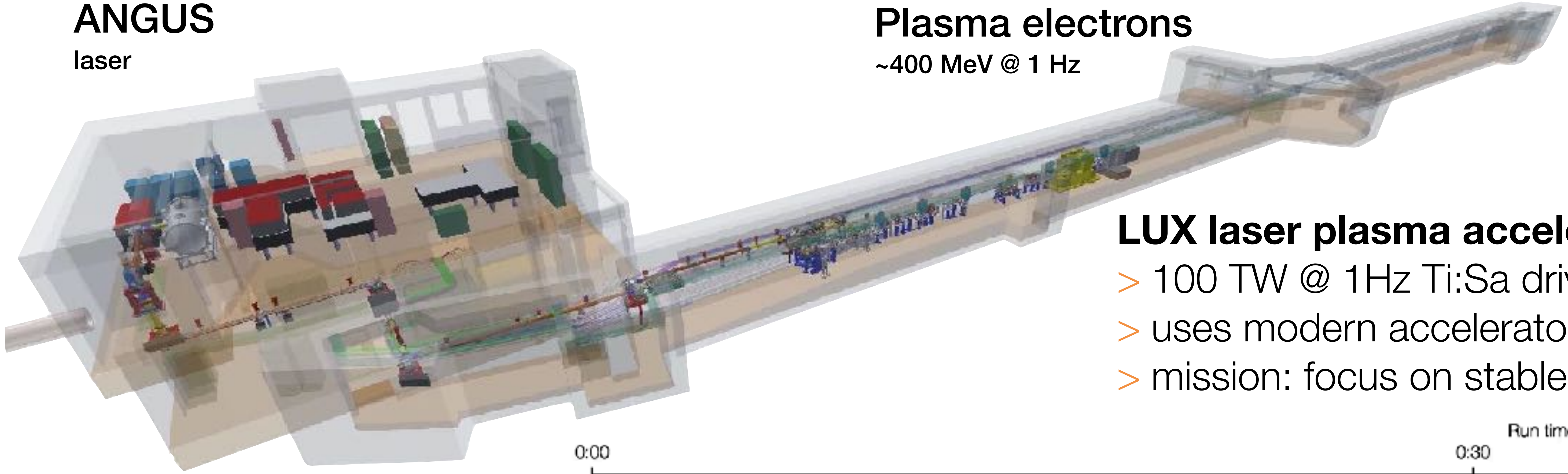
ANGUS
laser



Plasma electrons
~400 MeV @ 1 Hz



Undulator radiation
down to 4 nm spontaneous emission

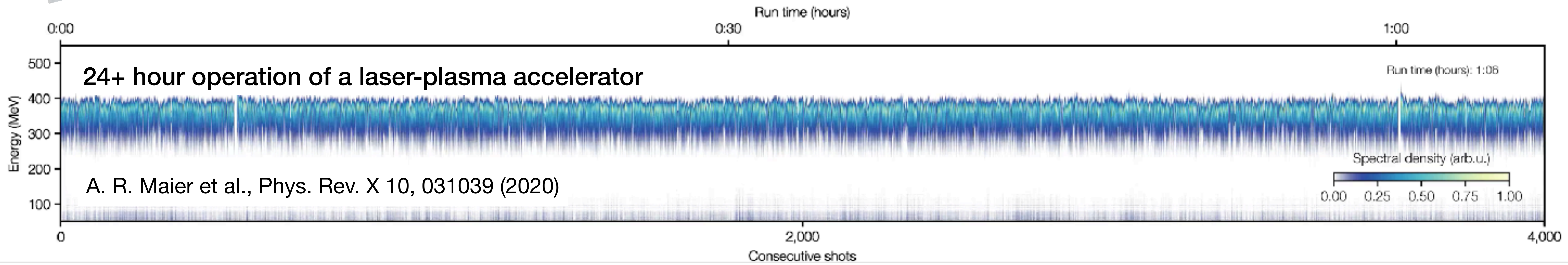


LUX laser plasma accelerator

> 100 TW @ 1Hz Ti:Sa drive laser
> uses modern accelerator technology
> mission: focus on stable beams

Next: KALDERA

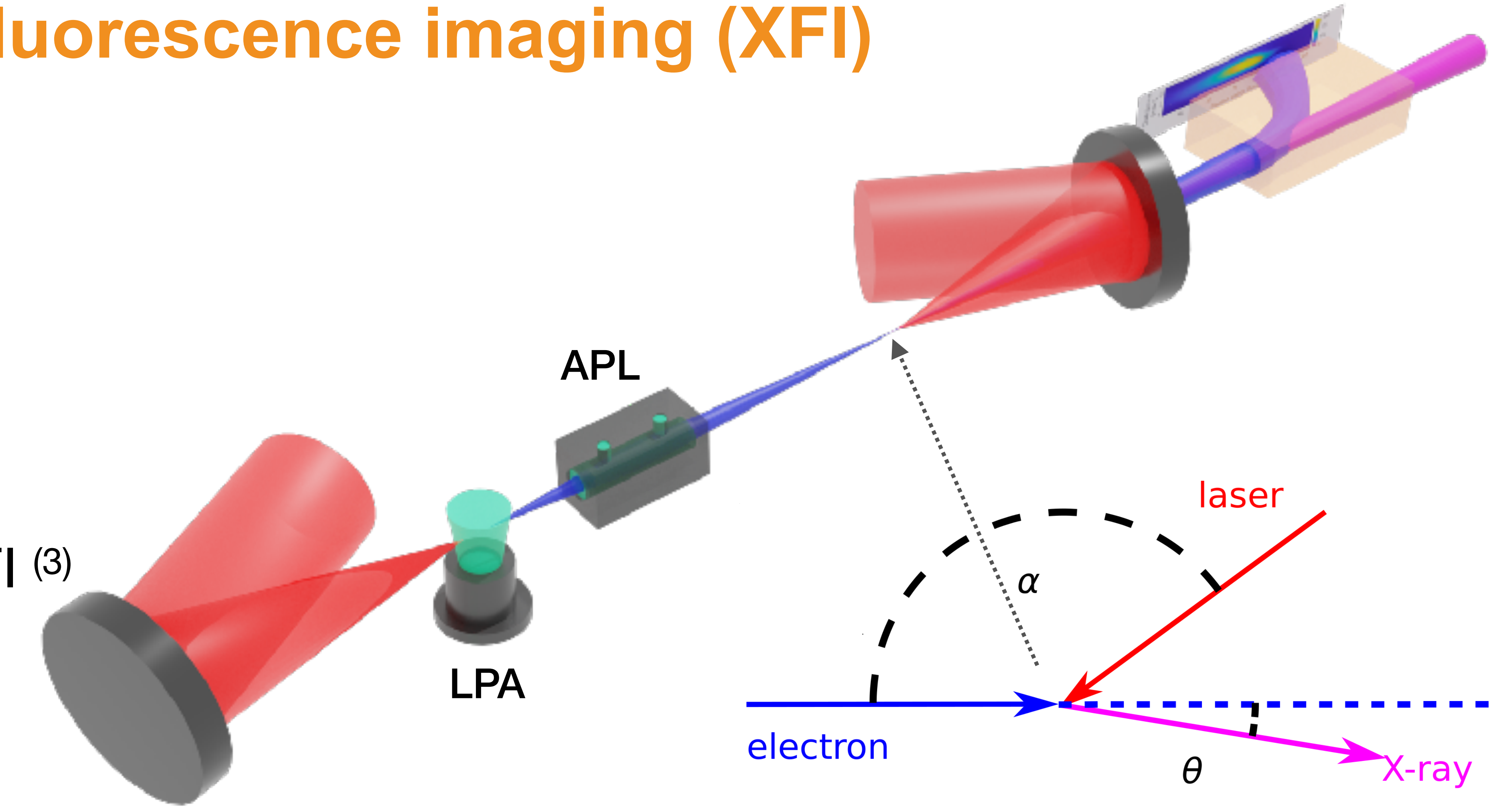
> Laser in development: 100TW @ 1 kHz
> Implementation of feedback loops for high-quality reproducible electron beams



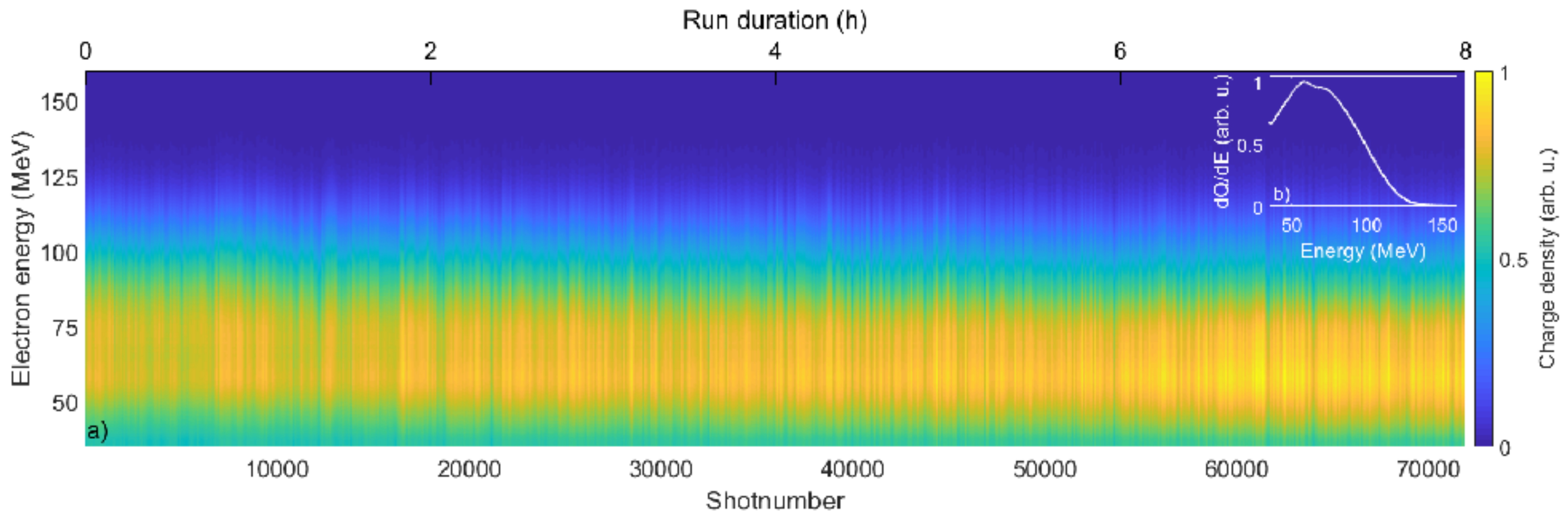
PLASMED X - compact X-ray source for imaging applications

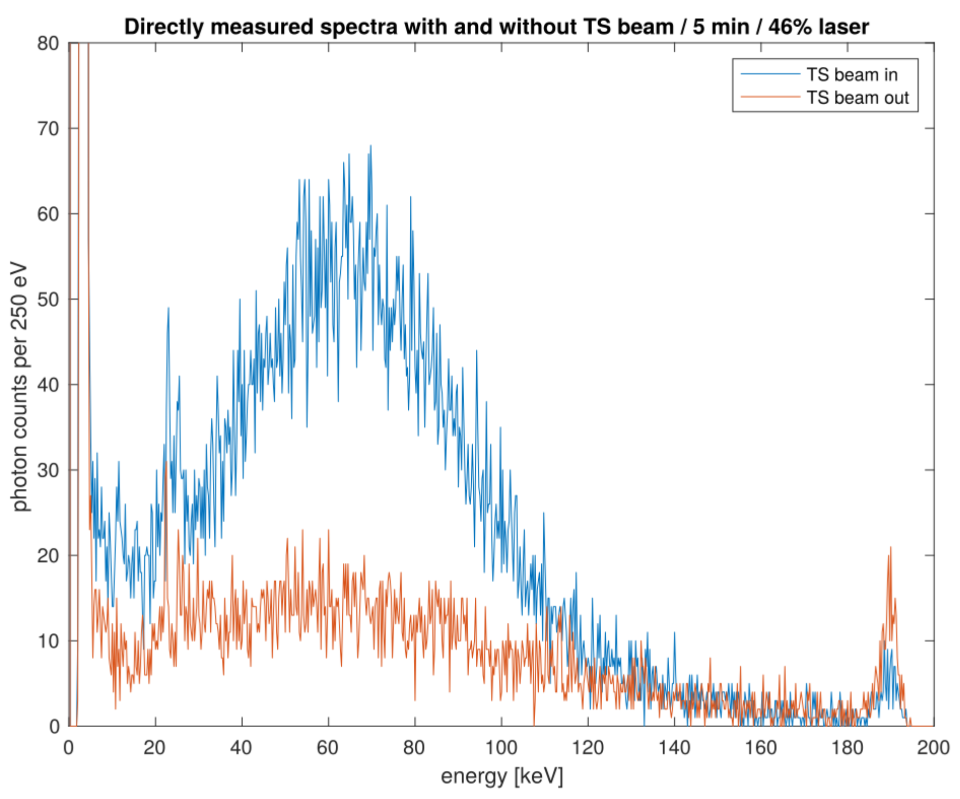
Active plasma lens allows for narrowband pulses for X-ray fluorescence imaging (XFI)

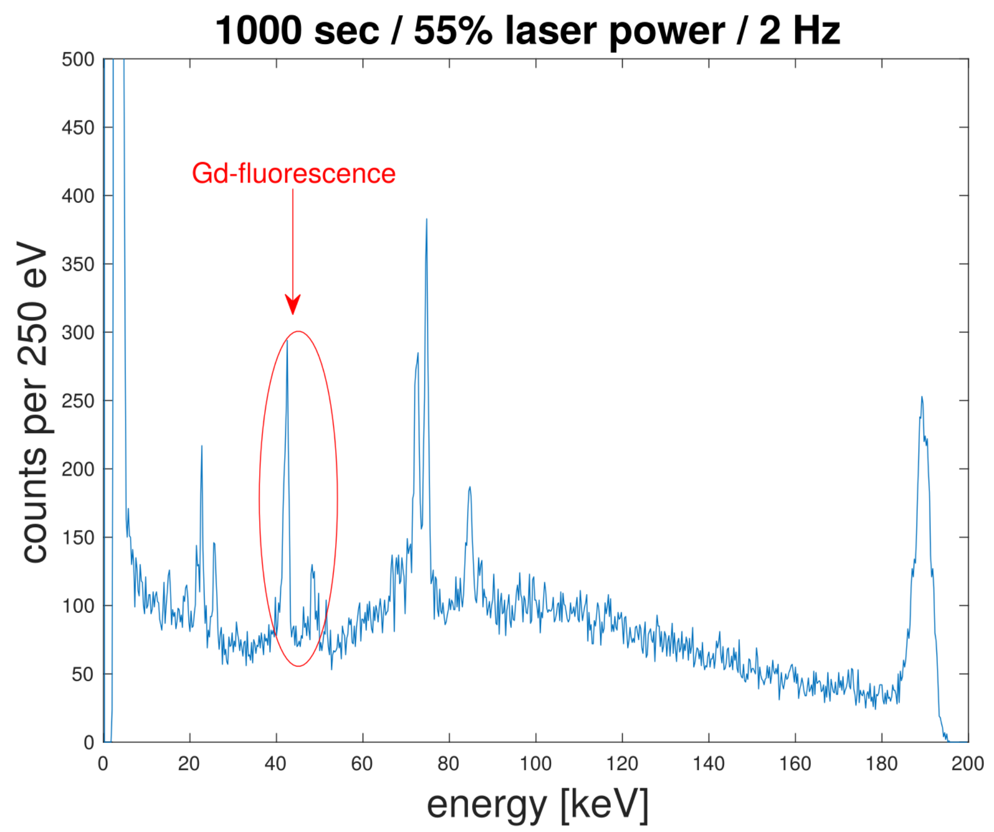
- Stable and reliable laser plasma accelerator demonstrated at 65 MeV, with 8 h continuous operation at 2.5 Hz (1)
- An active plasma lens allows for restricting the X-ray spectrum (2)
- First proof-of-principle experiments showed high significance detection of XFI (3)
- Scheme enables novel imaging modalities in health and industry (4)



$$\hbar\omega_\gamma = \hbar\omega_L \frac{2\gamma^2(1-\beta\cos\alpha)}{1+a_0^2/2+\gamma^2\theta^2} \sim 4\gamma^2\hbar\omega_L$$







Supported by
DESY Strategy Fund

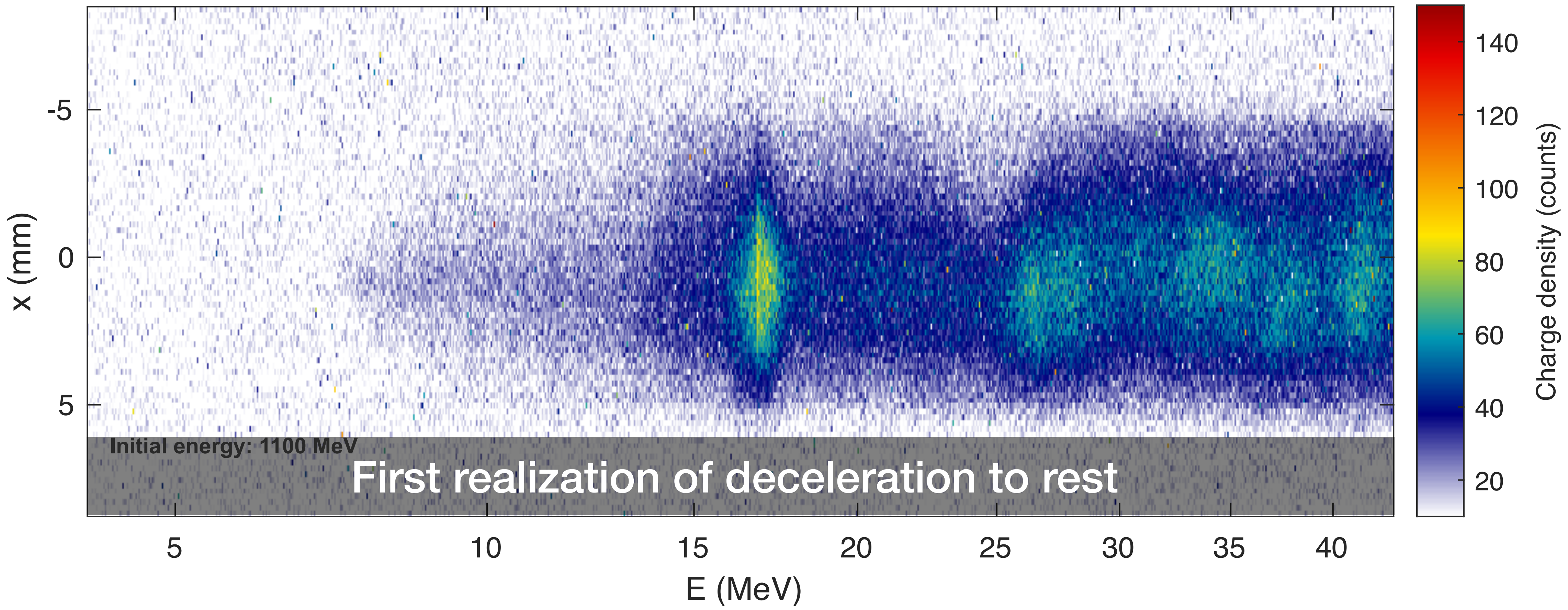
Bundesministerium für Bildung und Forschung
Innovationspool

(1) Wood *et al.*, in preparation
(2) Brümmer *et al.*, PRAB **23** (2020)
(3) Staufer *et al.*, in preparation
(4) Grüner *et al.*, Sci. Reports **8** (2018)

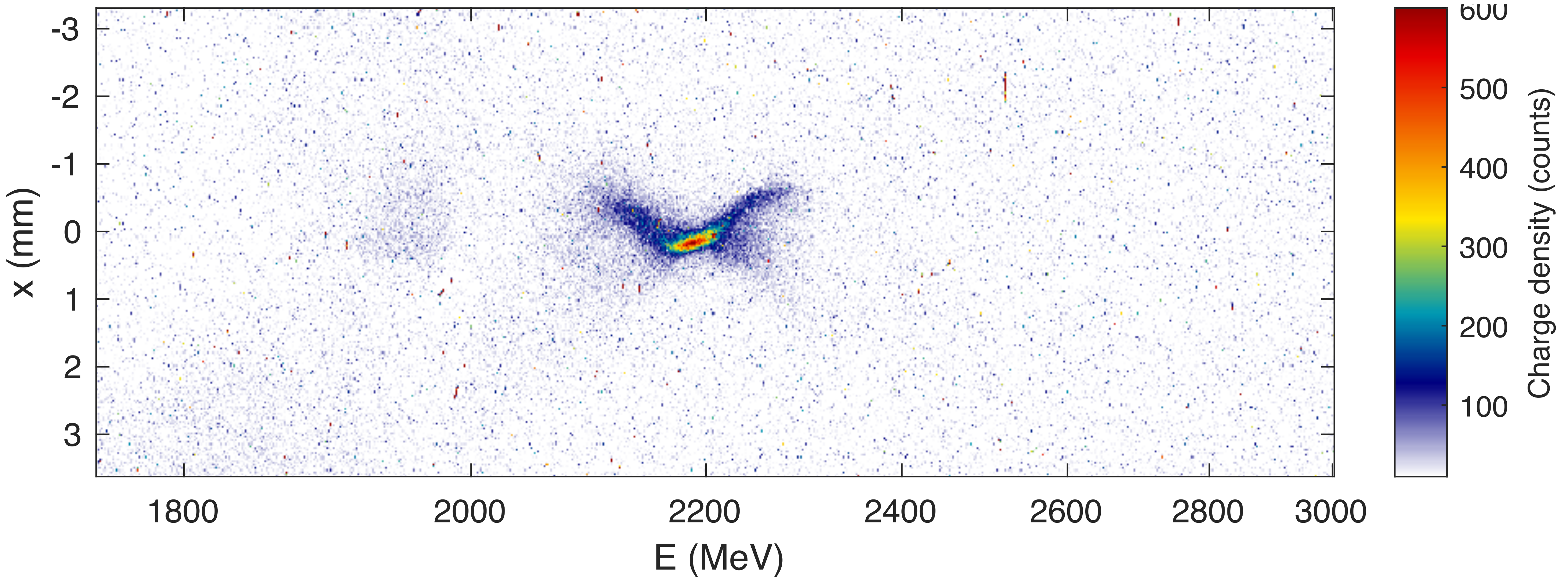
FLASHFORWARD▸▸ - 1.1 GeV energy gain and loss achieved in a 195 mm plasma module

Plasma accelerator demonstrating 6 GV/m field strength

Energy extraction → plasma beam dump (+ efficiency)



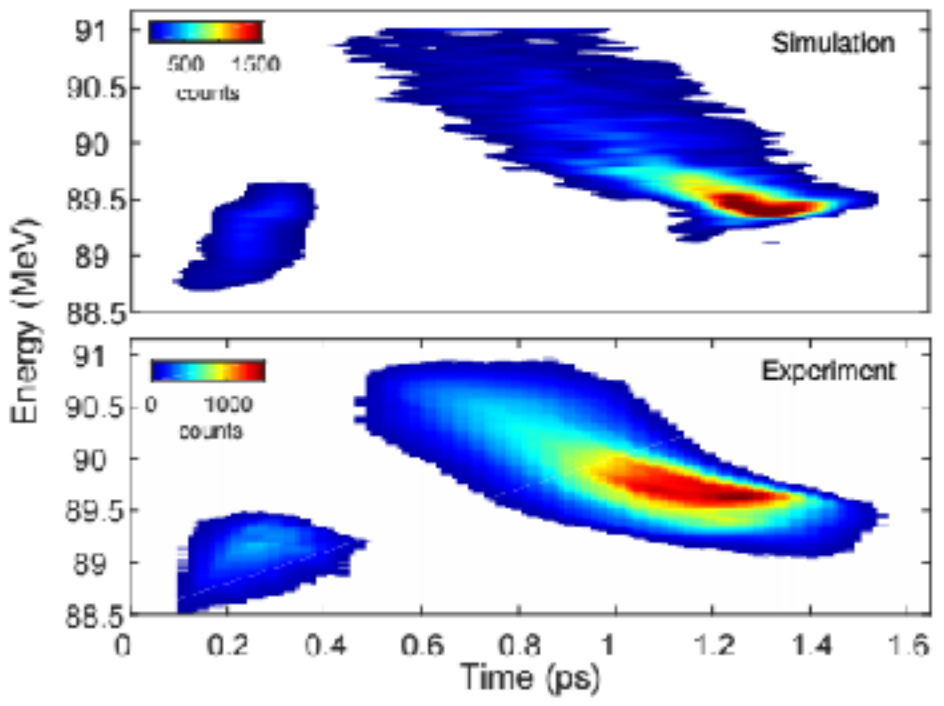
Energy doubling to 2.2 GeV → plasma booster

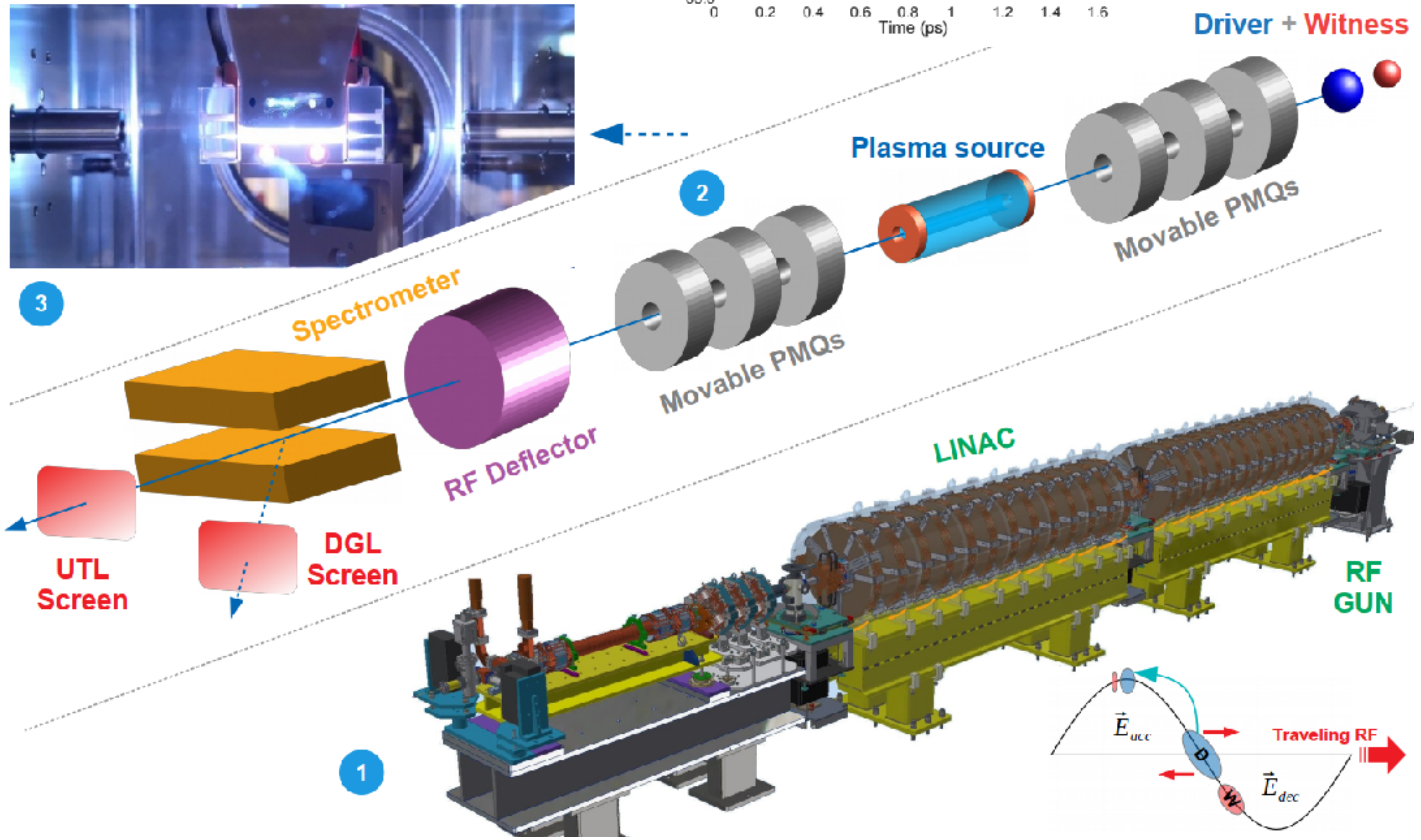


Experimental setup

- Beam-driven plasma wakefield acceleration demonstrated by using a driver (200pC) and witness (20pC) train produced with laser-comb technique
- The two bunches are compressed with velocity-bunching and focused down to 20 um (rms) with 3 movable PMQs
- The plasma operates @ $2x10^{15}$ cm^{-3} density and confined in a 3 cm long capillary (3D-printed)
- Downstream the plasma, two diagnostics stations allow to characterize the accelerated witness

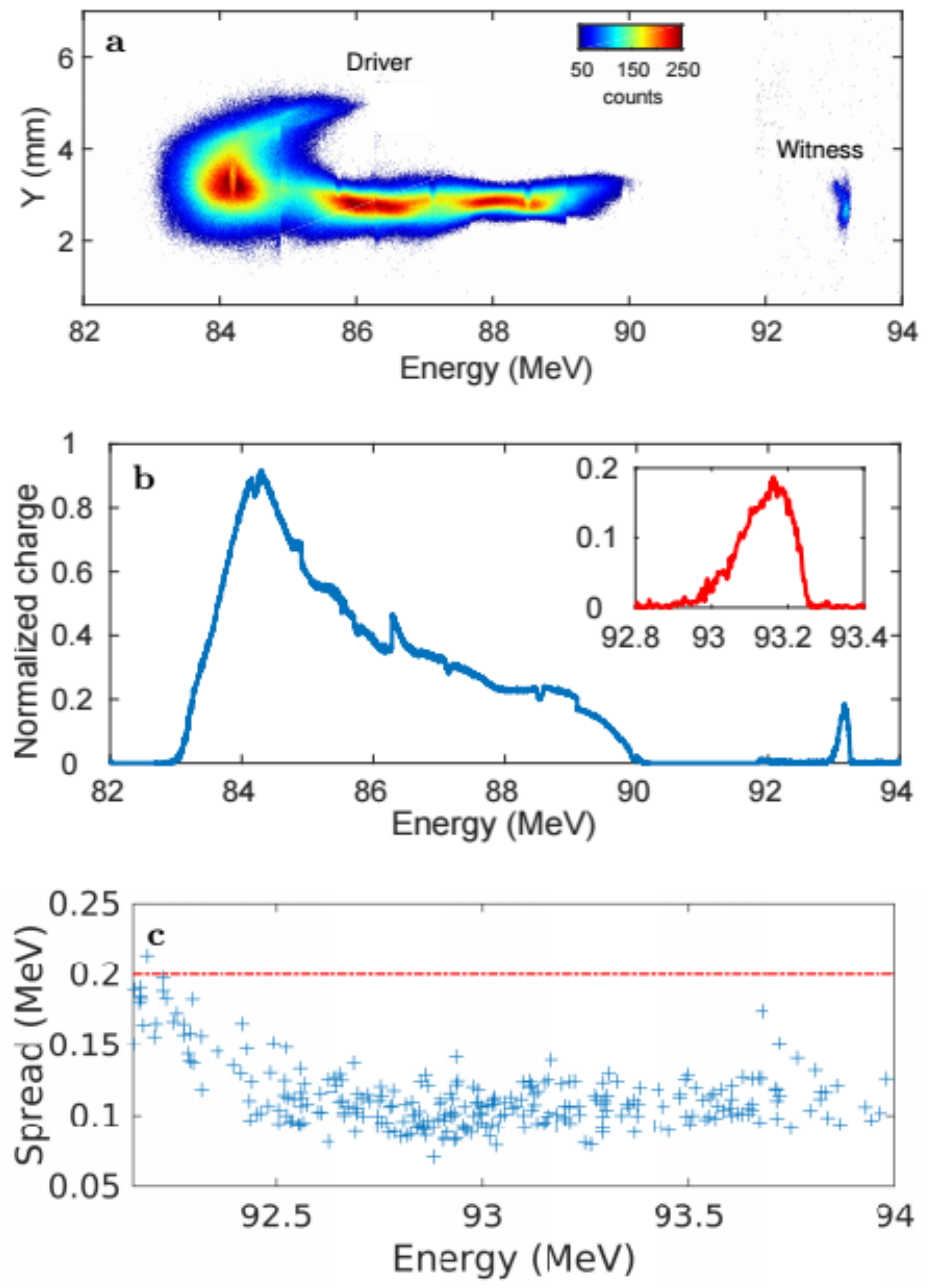
Initial longitudinal-phase space

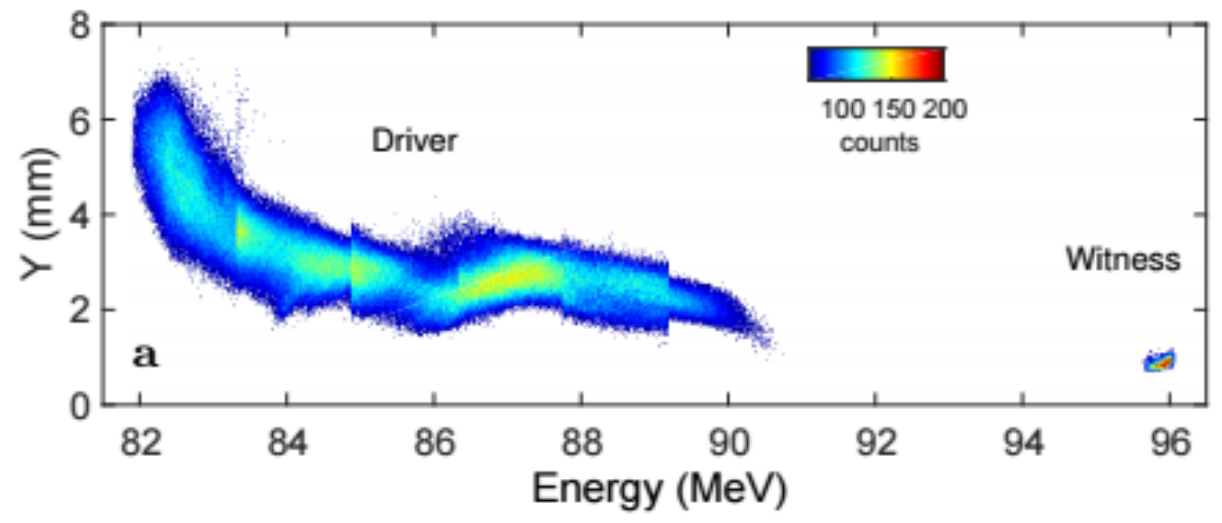




Plasma acceleration and spread reduction

- First demonstration of beam-driven plasma wakefield acceleration where the energy-spread of the accelerated witness bunch is even reduced
- The method works as an *assisted beam-loading energy spread compensation*,
  - The witness is injected into the plasma with a positive energy-chirp (larger energy particles on the head)
  - The plasma wakefield accelerates the beam and, due to its opposite slope (larger amplitude on the back) rotates the witness LPS
  - The plasma acts like an accelerator and dechirper at the same time
- Acceleration of 4 MeV reached
  - Energy spread reduced from 0.2 MeV to 0.1 MeV
  - Driver energy depleted by 7 MeV
- Maximum acceleration of 7 MeV reached
  - by increasing the driver charge to 350 pC.



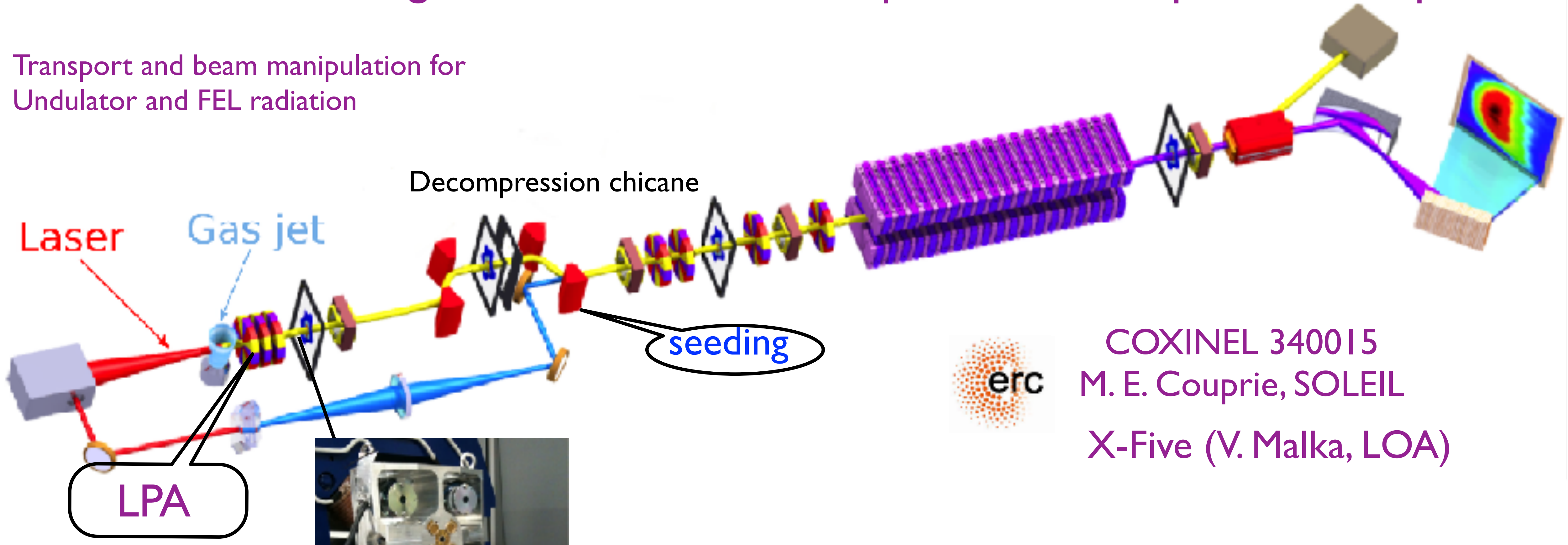


COXINEL set-up

COXINEL (COherent Xray source INferred from Electrons accelerated by Laser) aims at demonstrating Free Electron Laser amplification with present LPA performances with a existing TW laser.

Collaboration SOLEIL / LOA: PhLAM

Transport and beam manipulation for Undulator and FEL radiation



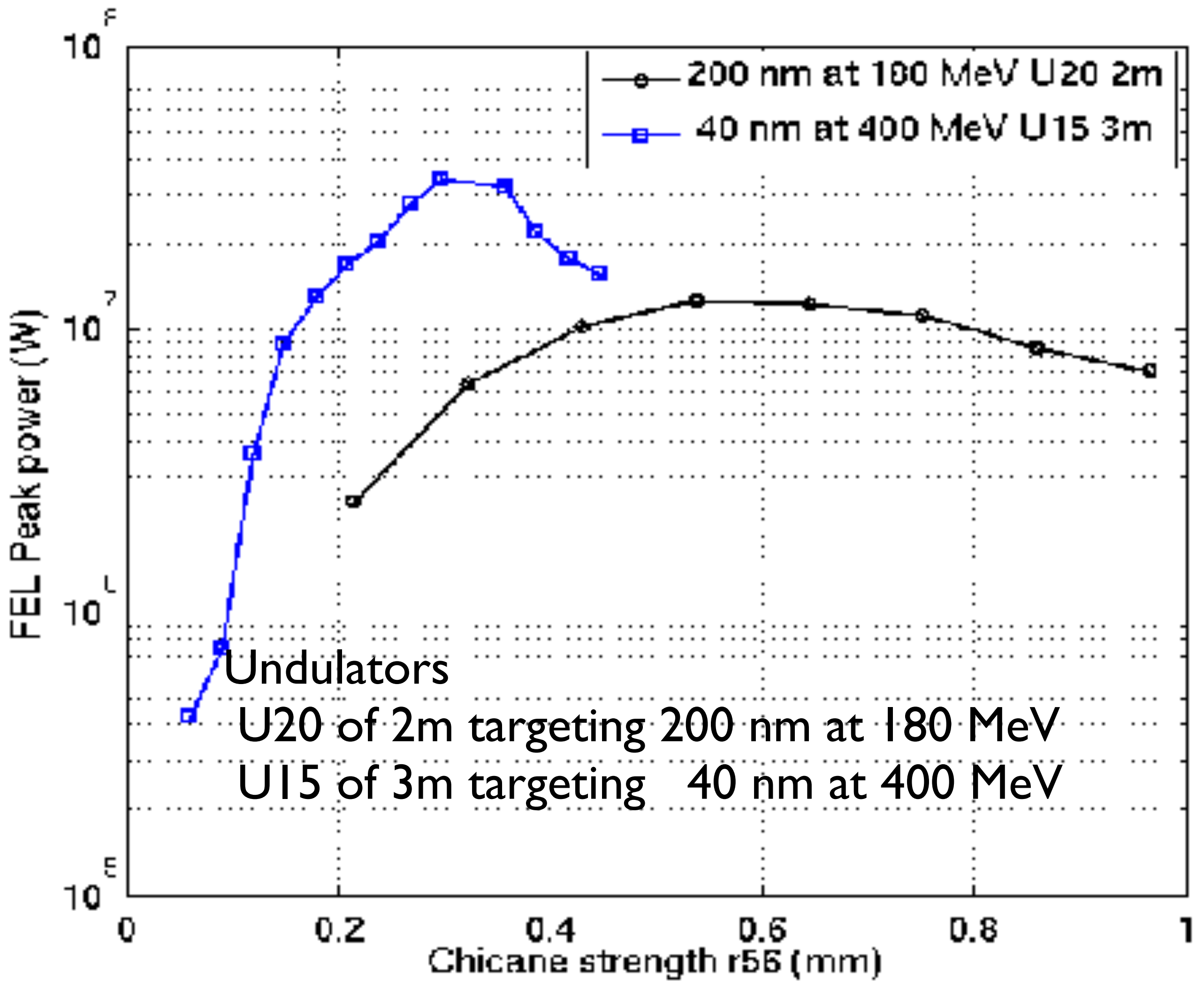
COXINEL 340015
M. E. Couprie, SOLEIL
X-Five (V. Malka, LOA)

Permanent magnet variable gradient quadrupoles for e beam focusing

F. Marteau et al.,Variable Appl. Phys. Lett. 111, 253503 (2017)
A. Ghaith et al.,, NIMA 909 (2018) 290–293
A. Ghaith et al., Intruments, MDPI, (2019)

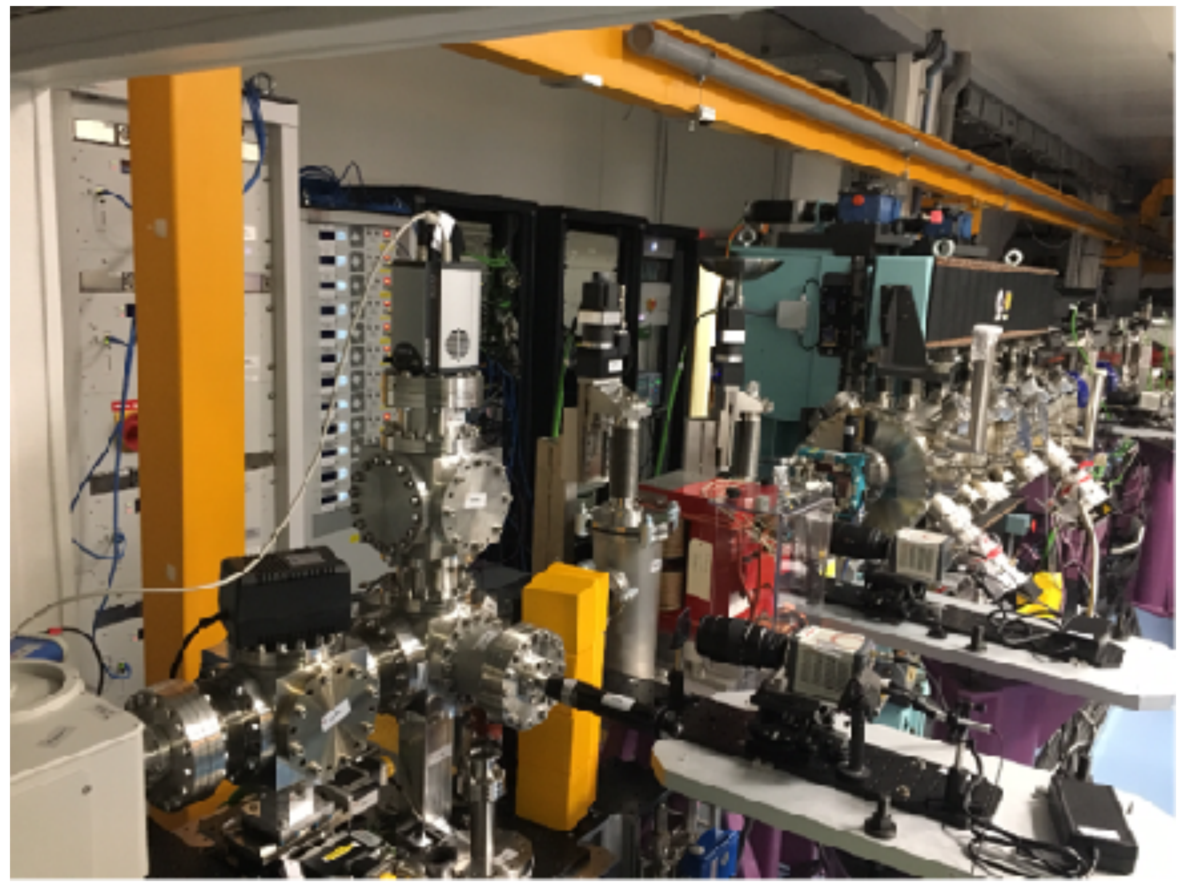
Baseline reference parameters

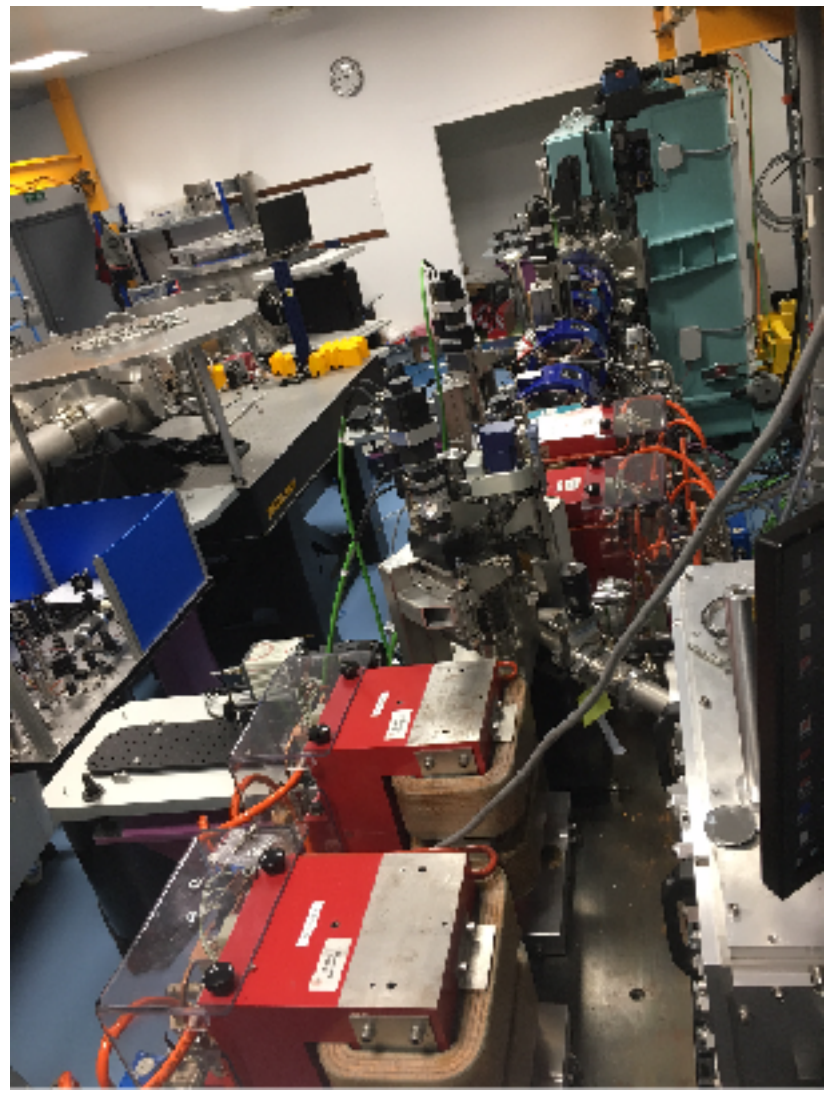
Parameters	Source
Energy (MeV)	180
Charge [pC]	34
Divergence [mrad]	1
Beam size [µm]	1
Normalized emittance [π.mm.mrad]	1
Relative energy spread [%]	1
Bunch length (µm)	1
Peak current [kA]	4



A. Loulergue et al., New J. Phys. 17 (2015) 023028 (2015)

M. Labat et al., PRAB 21, 114802 (2018)





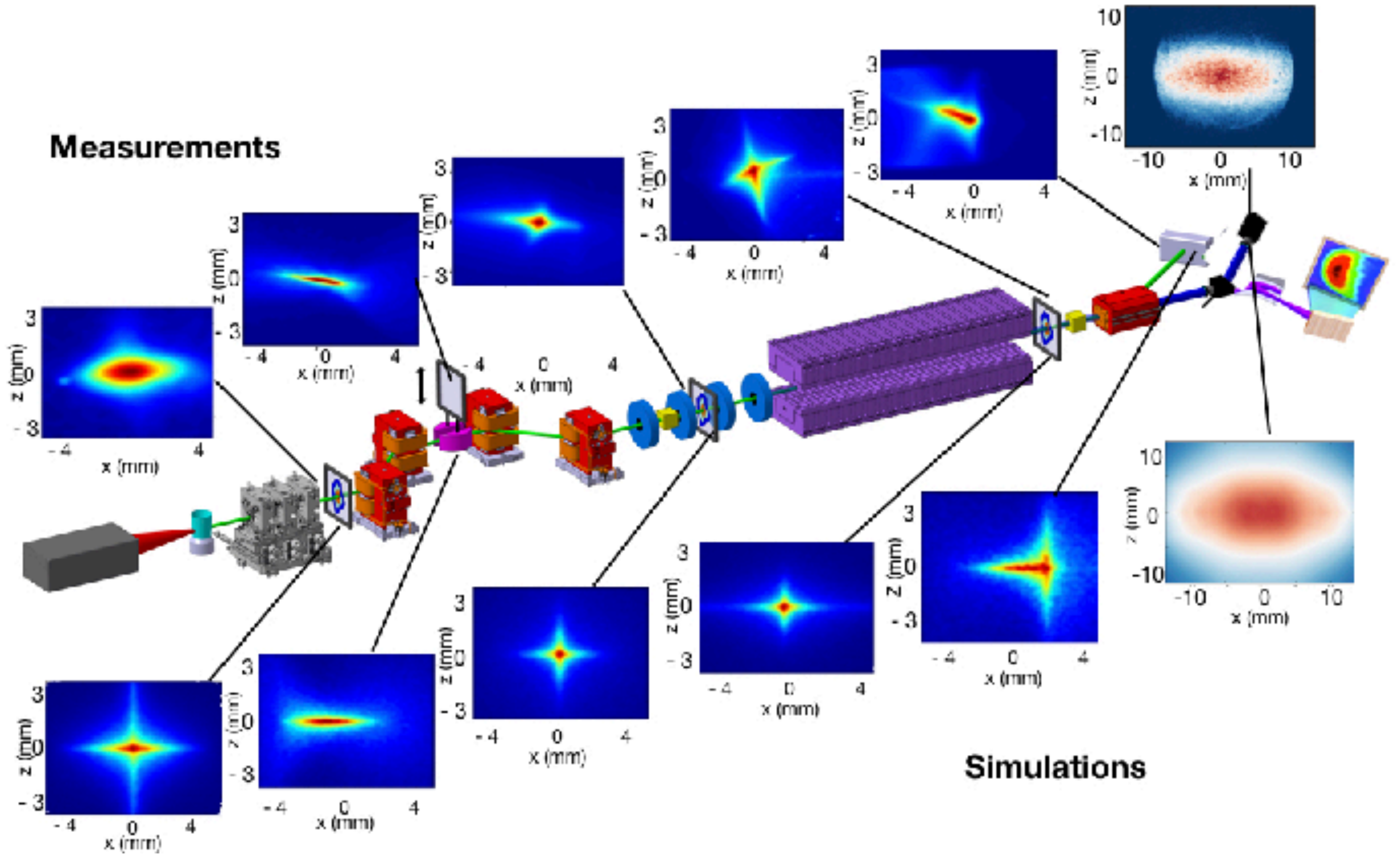
COXINEL experimental results

Mastered electron beam transport

E beam characteristics
Low charge density than expected…

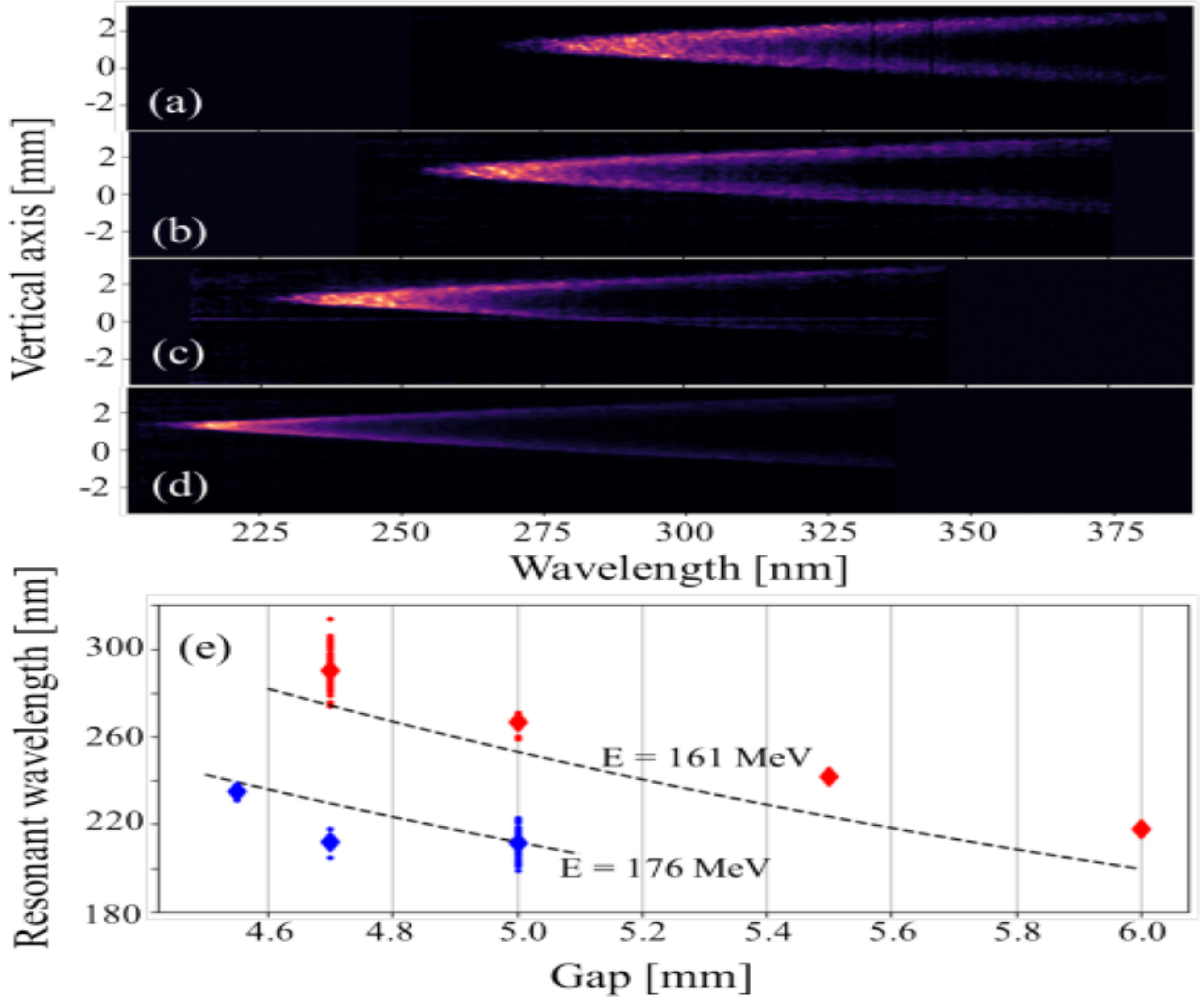
T. André et al., Control of laser plasma accelerated electrons for light sources, Nature Communications (2018) 9:1334

D. Oumbarek_Espinos et al., Applied Science, 9(12), 2447 (2019).
D. Oumbarek_Espinos et al., Plasma Physics and Controlled Fusion, Volume 62, Number 3, 034001 (2020)

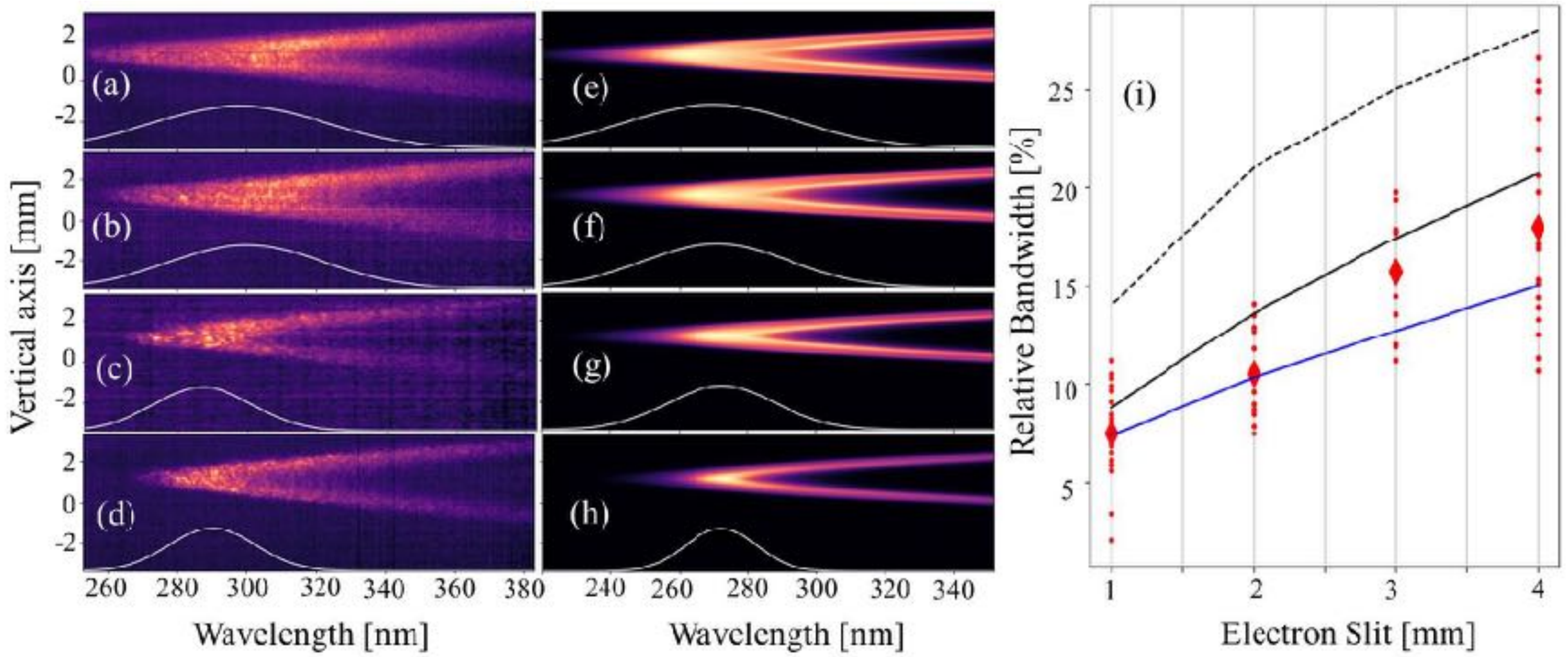


Undulator radiation control

Resonant wavelength tuneability by gap change

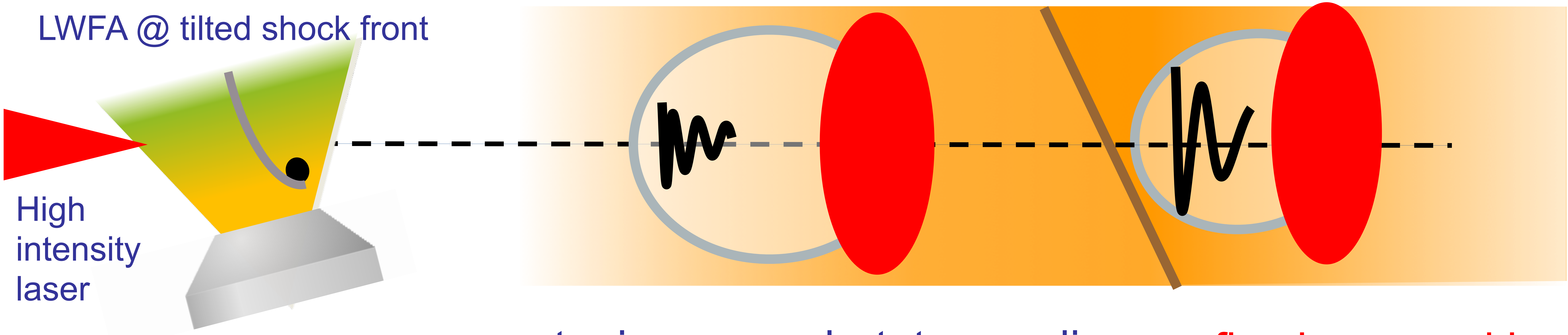


Control of the radiation spectral purity by reduction of the electron beam energy spread with a slit inserted in the chicane

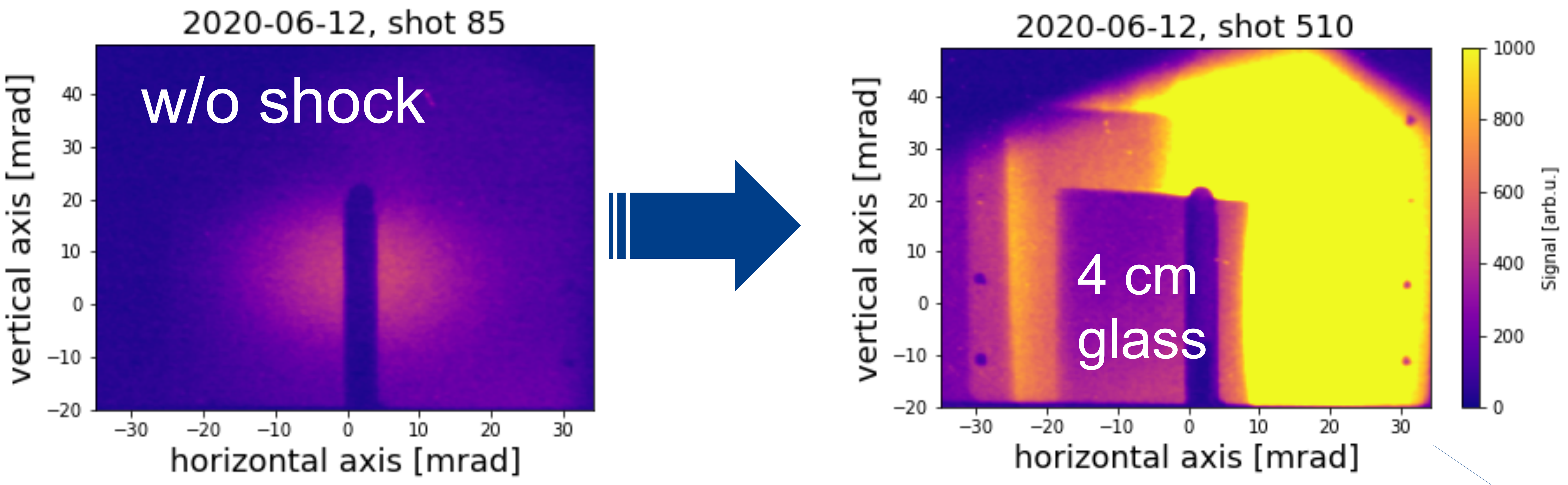


A. Ghaith et al., Tunable High Spatio-Spectral Purity Undulator Radiation from a Transported Laser Plasma Accelerated Electron BeamScientific Reports 9: 19020 (2019). A. Ghaith et al. Instruments 2020, 4, 1, E. Roussel et al., Plasma Physics and Controlled Fusion, Volume 62, Number 7, 074003 (2020)

High-flux pink X-ray pulse generation with LWFA beams



asymmetry increases betatron radius → flux increased by more than 100x to

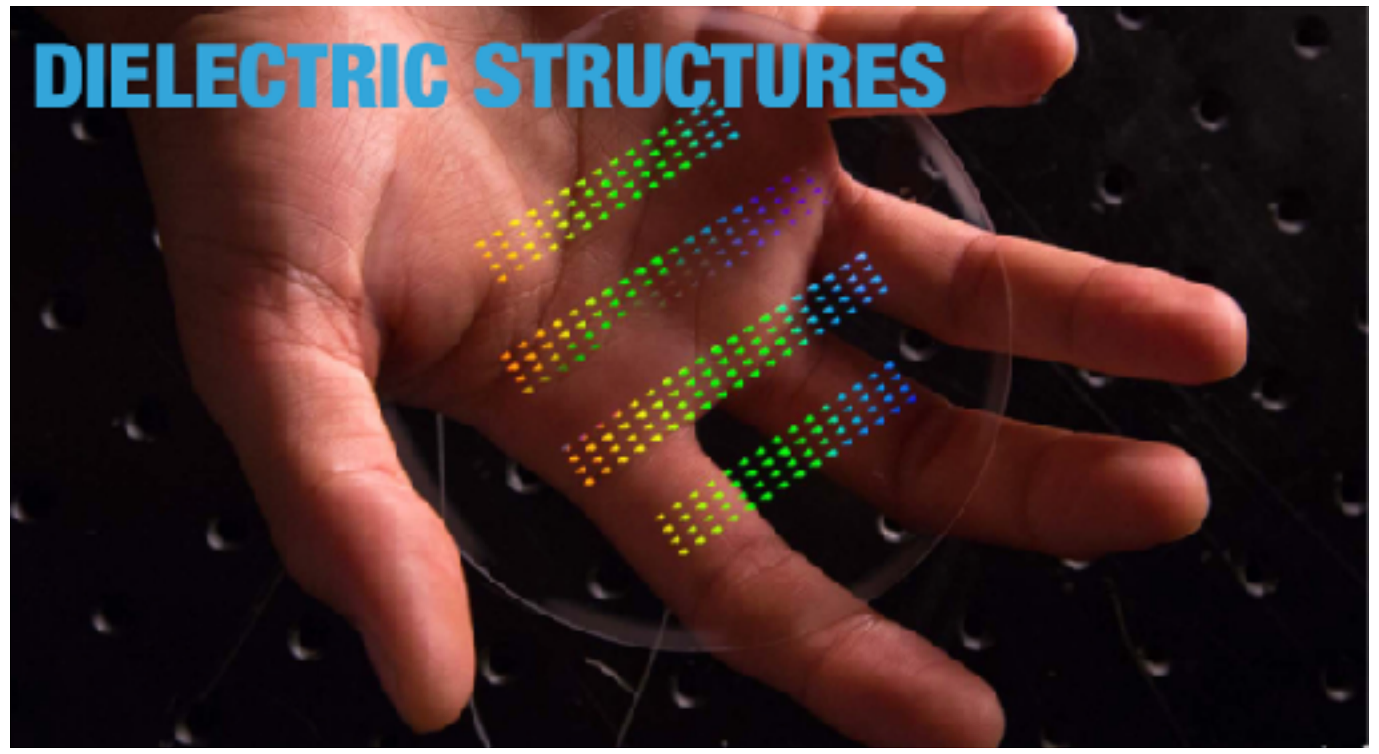


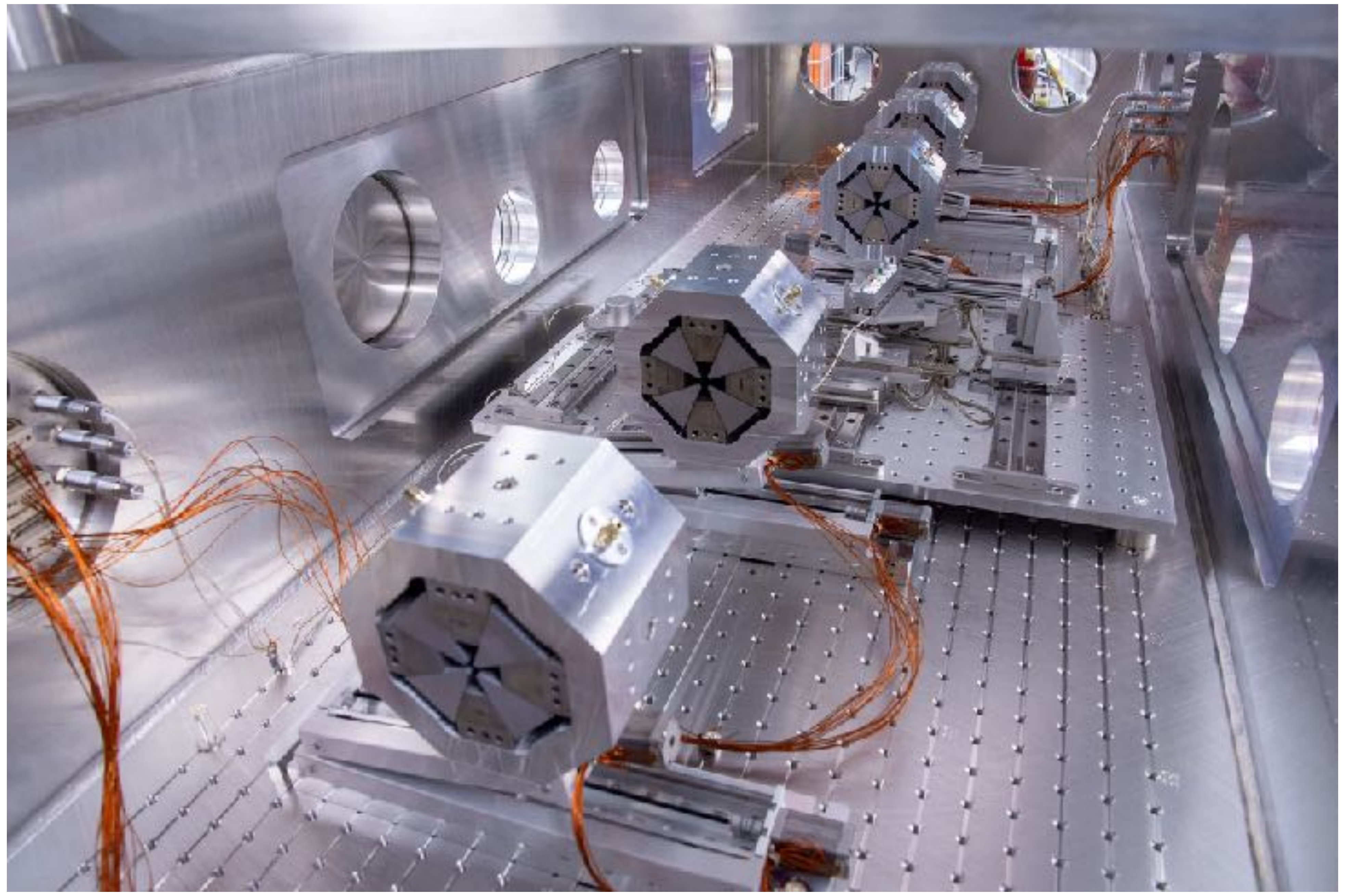
$2x10^8$ ph/eV/sr/pulse @ 9 keV

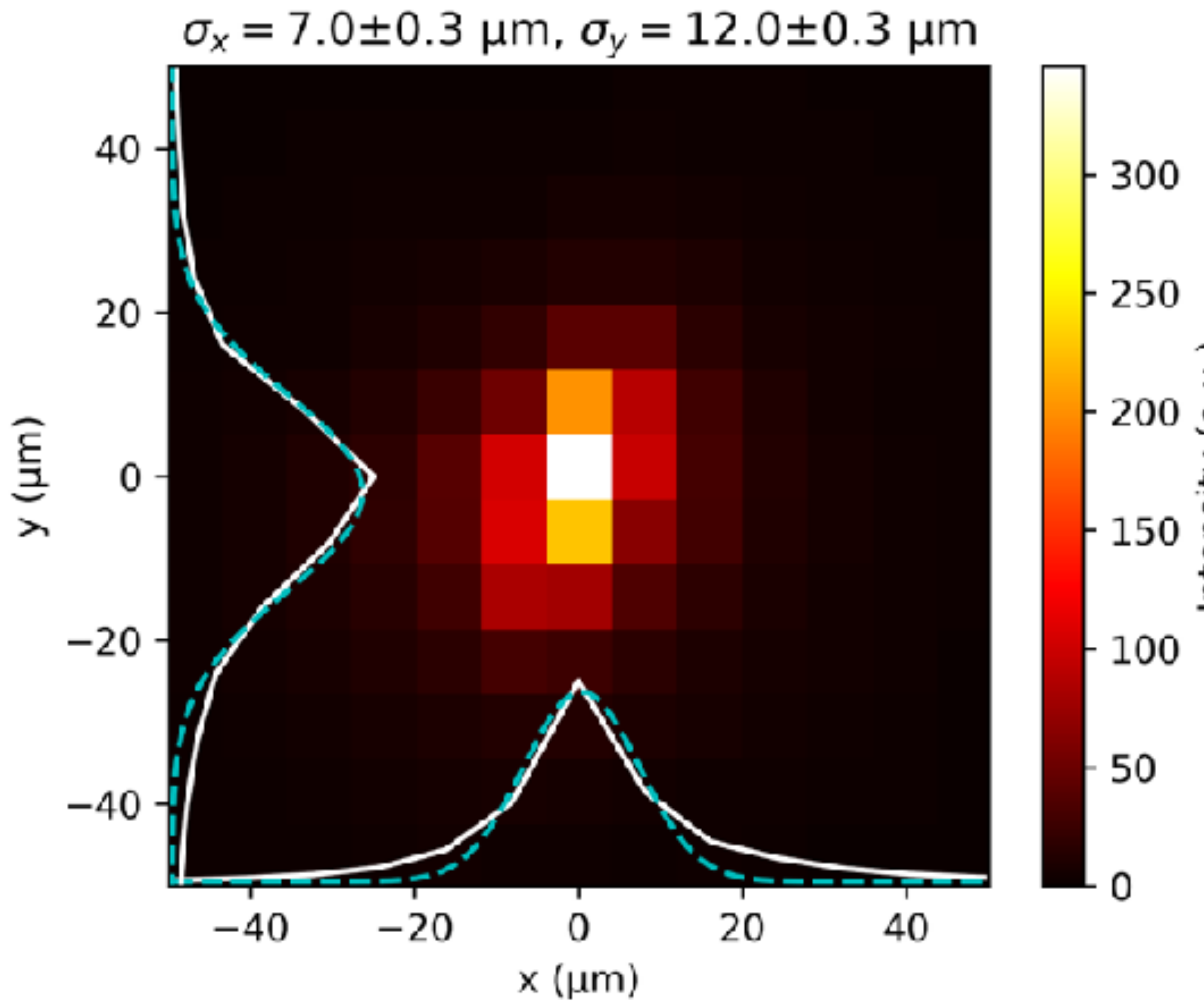
enabling single-pulse probing of laser produced warm dense matter

ACHIP - experiments being prepared at SwissFEL

PMQ focussing system tested, beam spot characterized

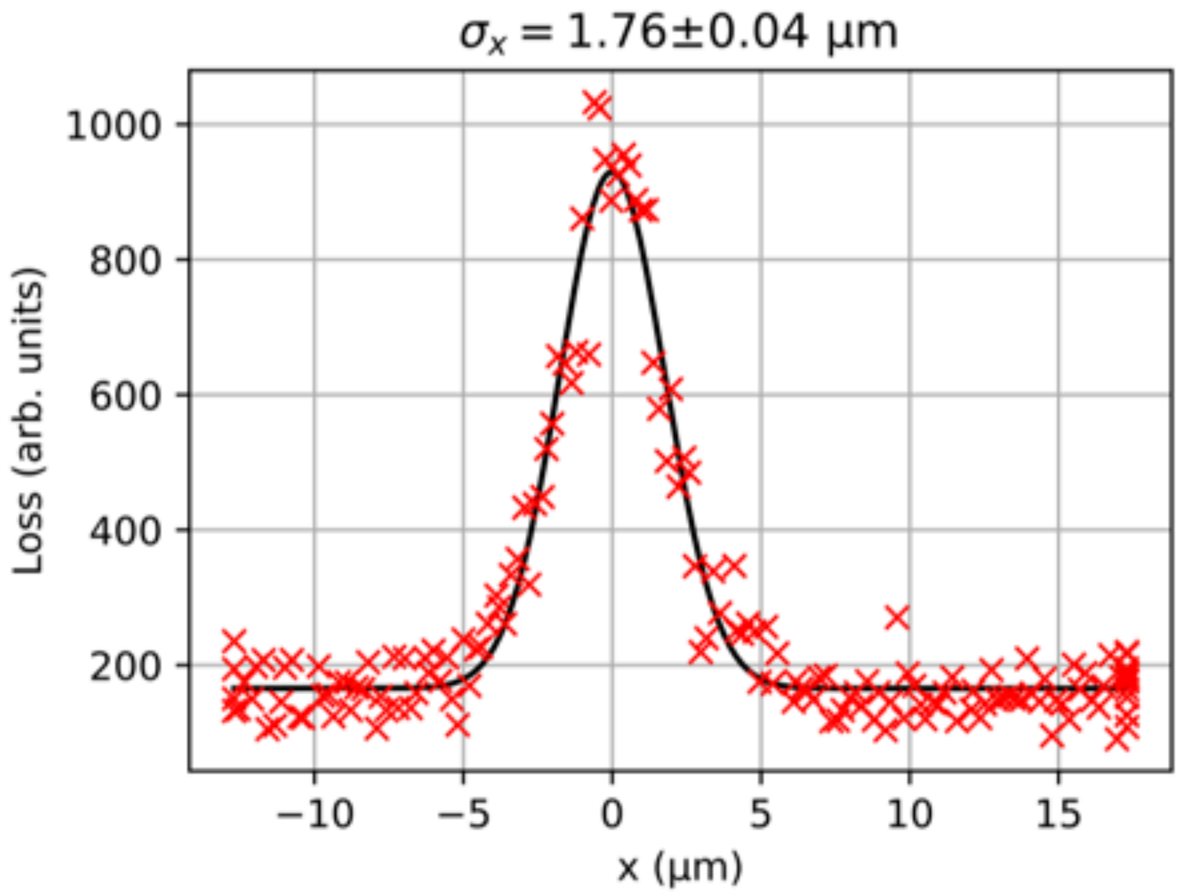


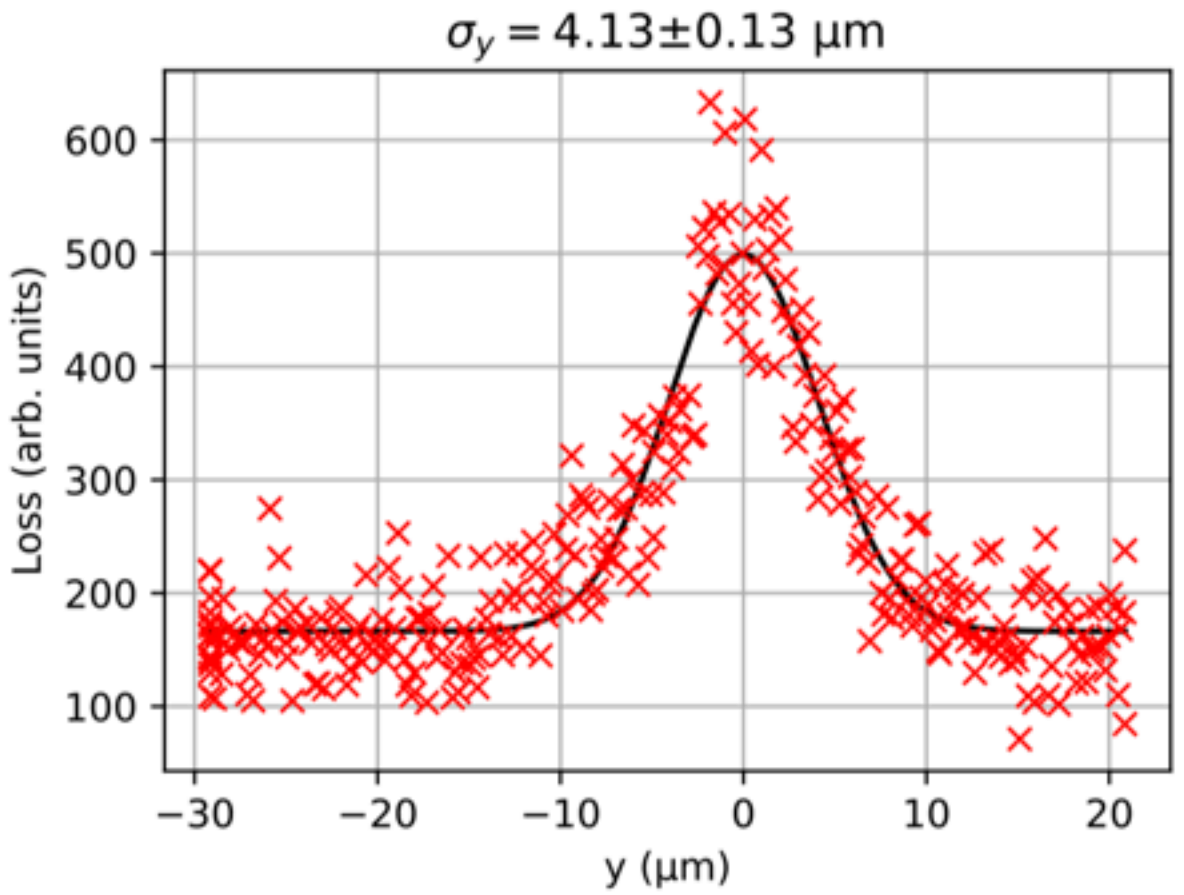




- Beam parameters

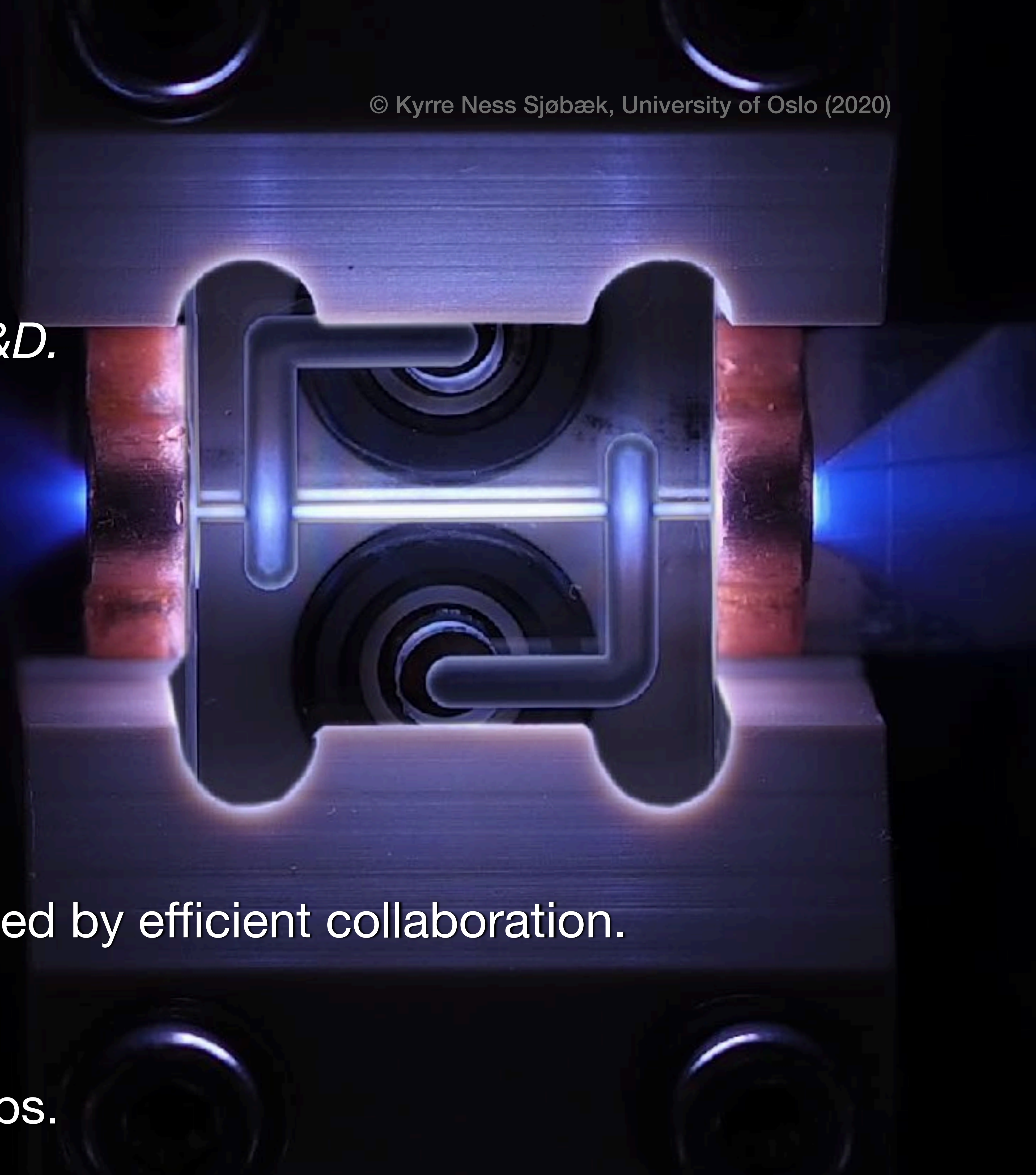
Particle Energy	3 GeV
Bunch Charge	100 fC … 200 pC
Beam size	1…100 µm
Bunch length	10 fs … 1 ps
Sample mount	5-dimensional alignment





Summary

Compact Sources in LEAPS



- *LEAPS partners are active and among leaders in compact source R&D.*
- Technology developments for application-readiness required in
  - beam quality (energy spread) and efficiency,
  - stability (24/7 operation),
  - tunability (on demand beam parameters),
  - average power (throughput).
- Excellent progress made over last few years.
- Progress would benefit from more resources and could be accelerated by efficient collaboration.
- Large joint efforts so far restricted to EuPRAXIA CDR.
- LEAPS partners support largely parallel R&D streams in their own labs.
- *Can LEAPS act as a catalyzing platform for (initially small) targeted collaborative technology developments?* Incentives needed. Seed fund with fresh money to support travel/exchange/link personnel?
- Possible pilot projects: laser-plasma-based FEL, plasma-booster for existing FEL facilities.