Laser-driven plasma accelerators

Daniel Symes
Central Laser Facility
CERN PBC workshop 10 December 2021

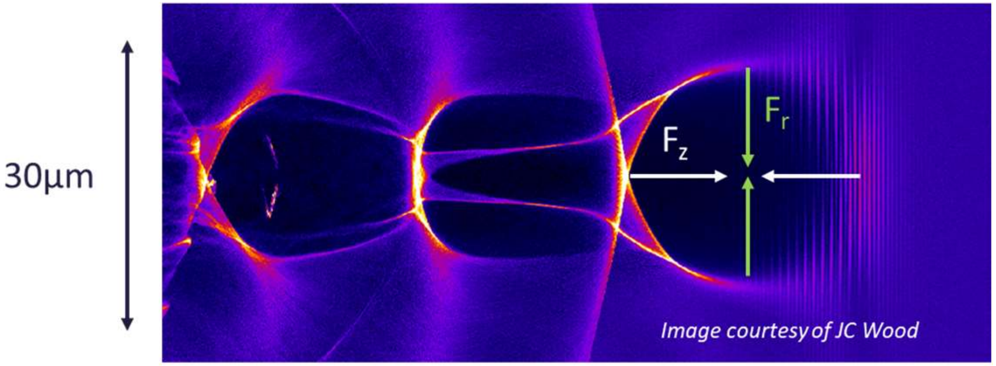
Outline

1 Laser-plasma accelerators and future applications

2 LPA experiments and performance

3 Extreme Photonics Applications Centre at CLF

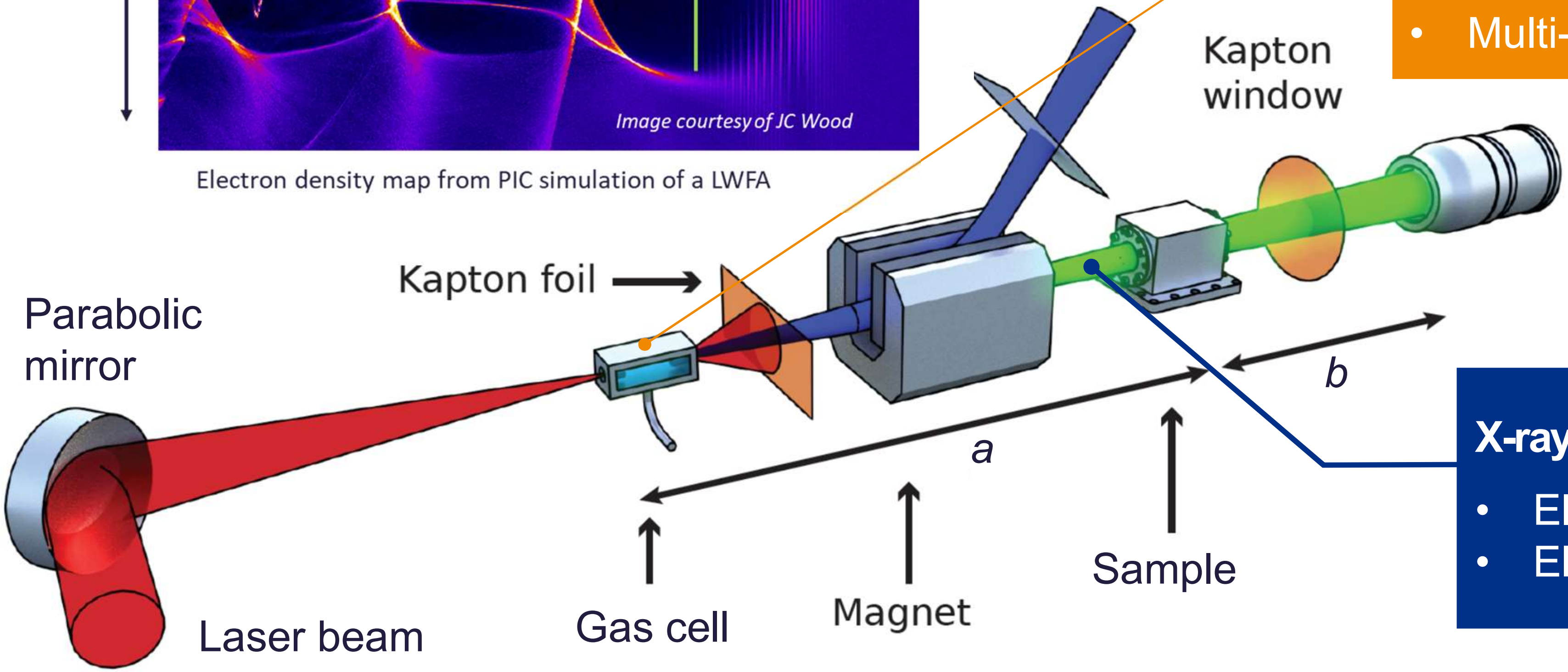
Plasma can support extremely high accelerating fields (100 GeV / m)



Electron density map from PIC simulation of a LWFA

Laser plasma accelerator (LPA)

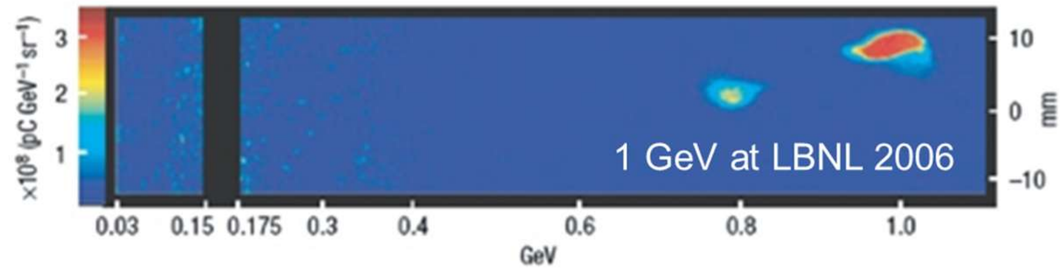
- cm-scale gas target
- Intense laser driver
- Multi-GeV electrons

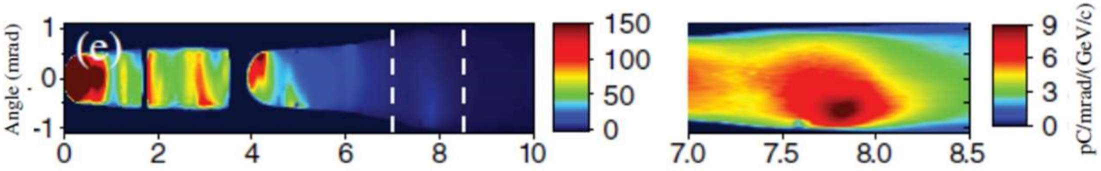


X-ray generation

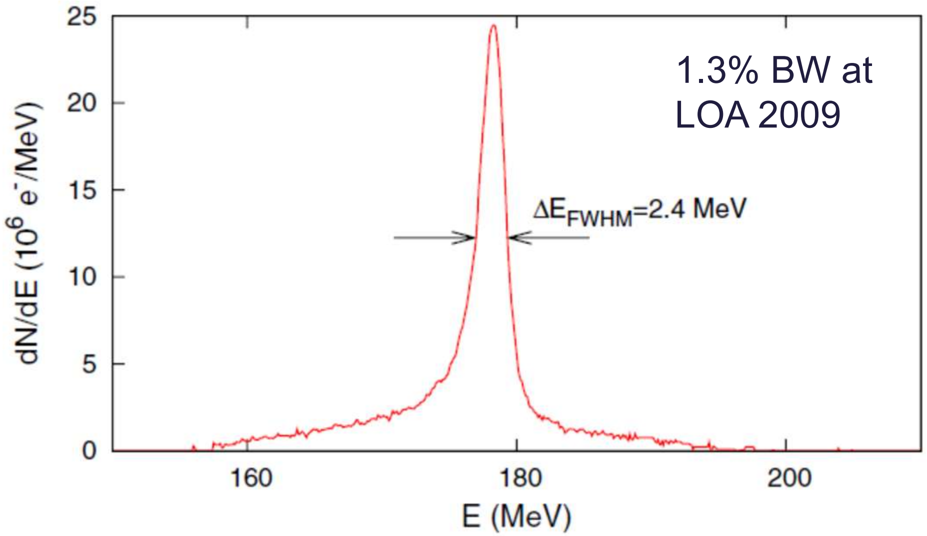
- Electron oscillations
- Electron impact

LPA can achieve 8 GeV and ~1% spread
(Not at the same time…)





8 GeV at LBNL 2019



- Few fs duration
- μm source size
- mrad divergence
- ϵ_n ~ 0.1 mm mrad

Science and Technology Facilities Council

- High quality beam properties demonstrated but not all **simultaneously**
- Efforts focusing now on achieving high energies with **stable, consistent performance**

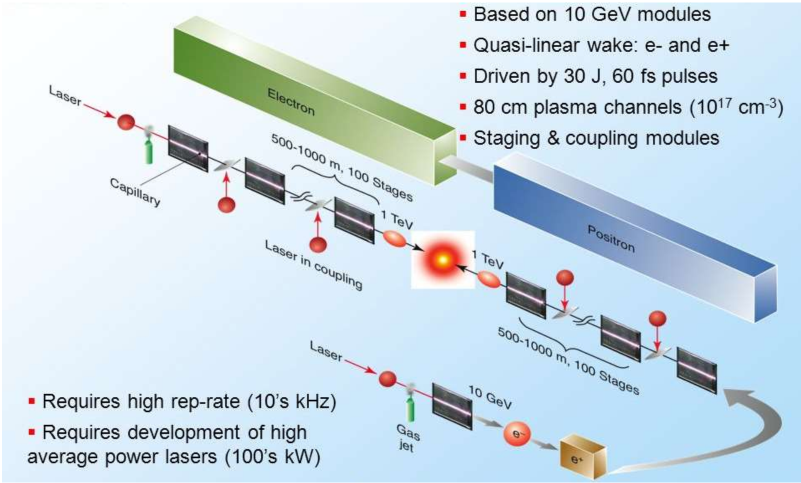
Leemans 2006, Nat. Phys. **2**, 696; Gonsalves 2019, PRL **122**, 084801; Rechatin 2009, PRL **102**:164801

Future applications for LPA

Compact accelerator technology
- LPA injector for storage rings
- LPA e- e+ collider
- Test beams for development

X-ray sources
- Betatron, bremsstrahlung & Inverse Compton Scattering
- LPA-driven FEL

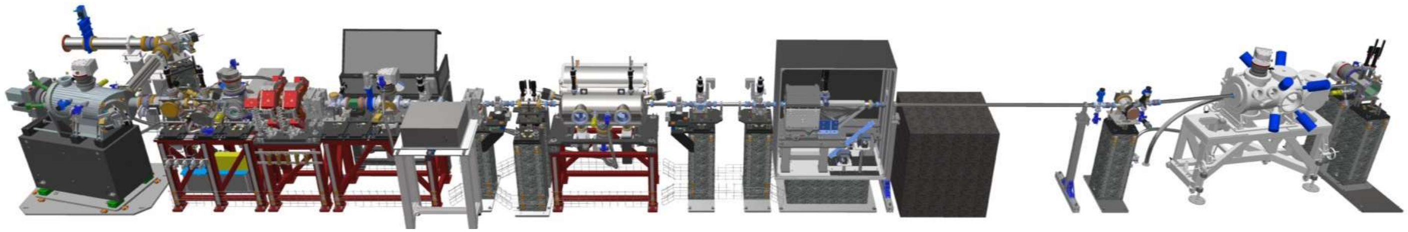
Synchronised sources
- e+, muons, γ-rays
- Femtosecond pump-probe



Conceptual LPA Collider
Leemans & Esarey 2009 Physics Today
Schroeder 2010 PRSTAB **13**, 10130

Multi-kW, kHz repetition-rate KALDERA laser under construction

Leemans EAAC 2019
"High average power laser plasma accelerator project at DESY"



LUX X-FEL beamline under construction at ELI-Beamlines
www.eli-beams.eu/research/x-ray-sources/laser-undulator-x-ray-source-lux/

Maier 2012 PRX **2**, 031019
"Demonstration Scheme for a Laser-Plasma-Driven Free-Electron Laser"

2020 plasma accelerator roadmap
- New Journal of Physics **23**, 031101

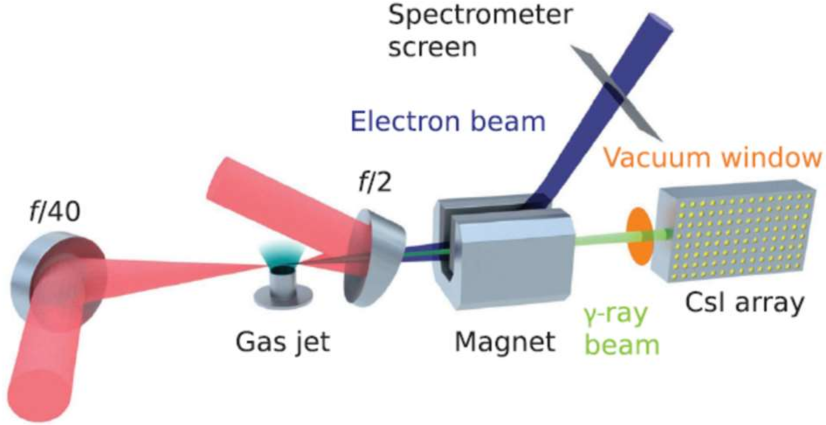
Electron-laser collision experiments

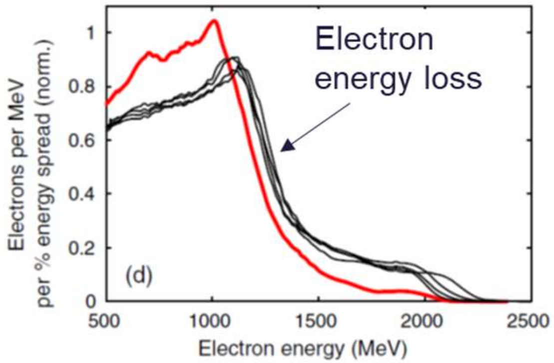
Dual beam Gemini laser at CLF enables high intensity laser interaction with electron beam

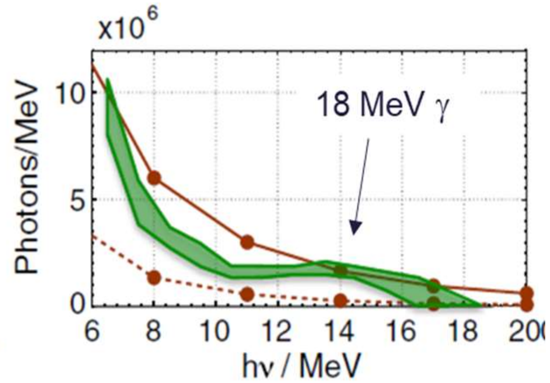
- > GeV electrons, $I_L > 10^{20}$ Wcm^{-2}
- Quantum parameter $\chi \sim \gamma\,(I_L / I_{Sch}) > 0.1$
  [$I_{Sch} \sim 2 \times 10^{29}$ Wcm^{-2}]
- Studies of radiation reaction & non-linear ICS

- Electron beam and laser focus are μm-scale
  - spatial overlap is difficult
  - statistics are limited

New facilities will have better stability & higher rep rate







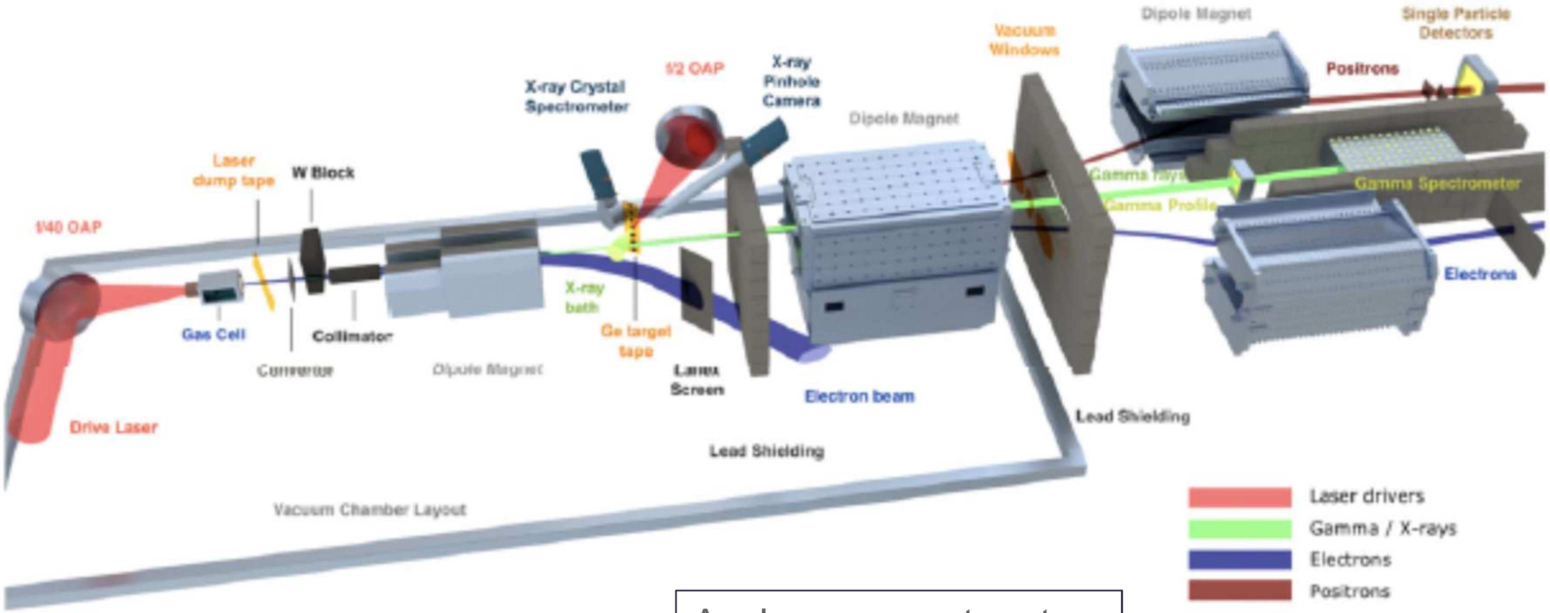
Science and Technology Facilities Council

Cole 2018, PRX **8**, 011020; Poder 2018 PRX **8**, 031004; Sarri 2014 PRL **113**, 224801

LPA platform for photon-photon collisions

Experimental challenge is to achieve sufficient SNR and statistics

- 100 MeV γ from LPA-bremsstrahlung through keV x-ray bath
- Directional e-e+ pairs from $\gamma\gamma$ collisions
- Should be able to detect with ~1000 laser shots



Heavy shielding to reduce background from γ striking components and dumps

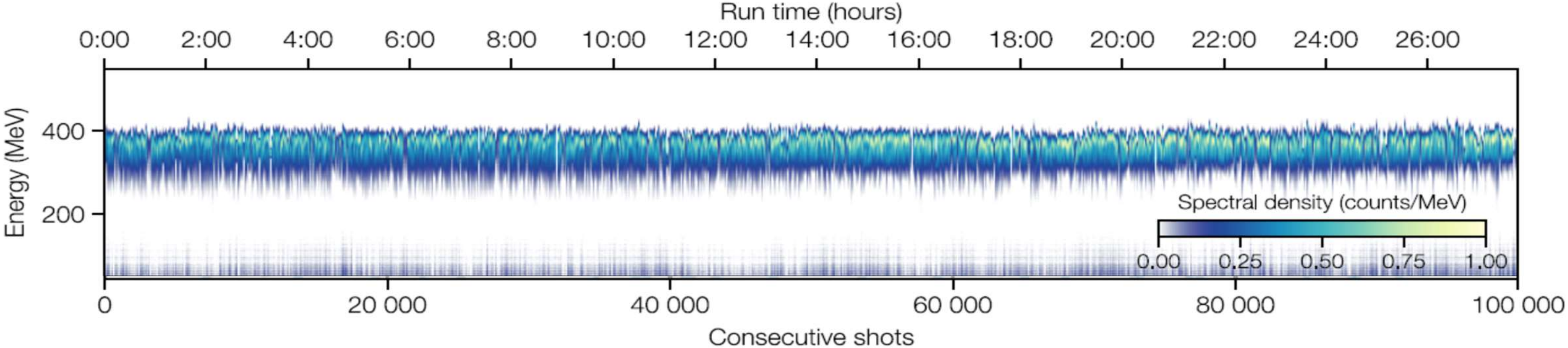
Analyser magnet system to transport generated e-e+ pairs to detectors

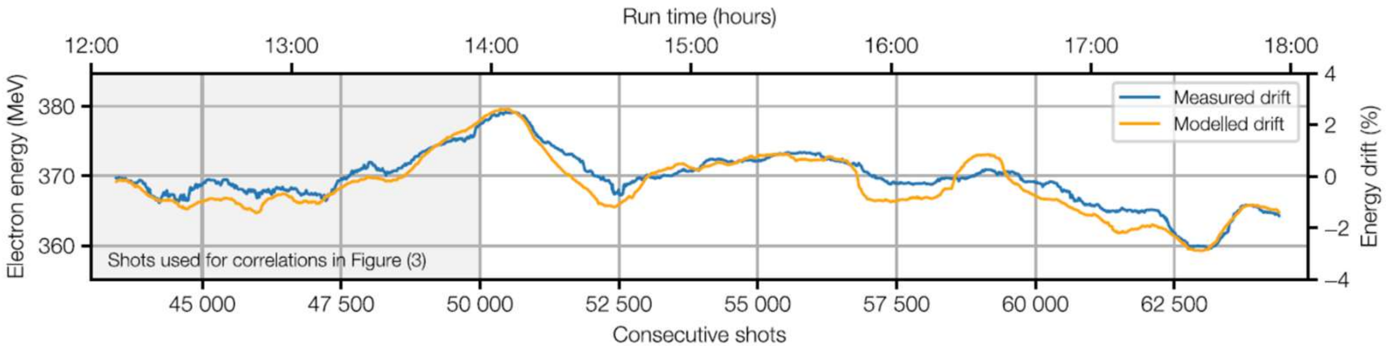
Science and Technology Facilities Council

Can easily switch configuration for electron-laser or γ-laser collisions

Kettle 2021, NJP **23**, 115006

Recent results have demonstrated stable LPA operation over extended periods



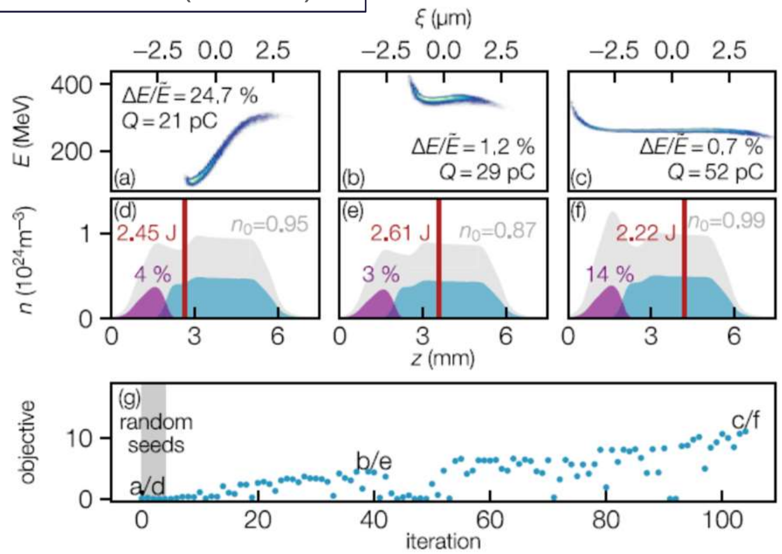


Electron energy drift correlated to laser properties that can be measured **non-invasively and corrected** with active feedback

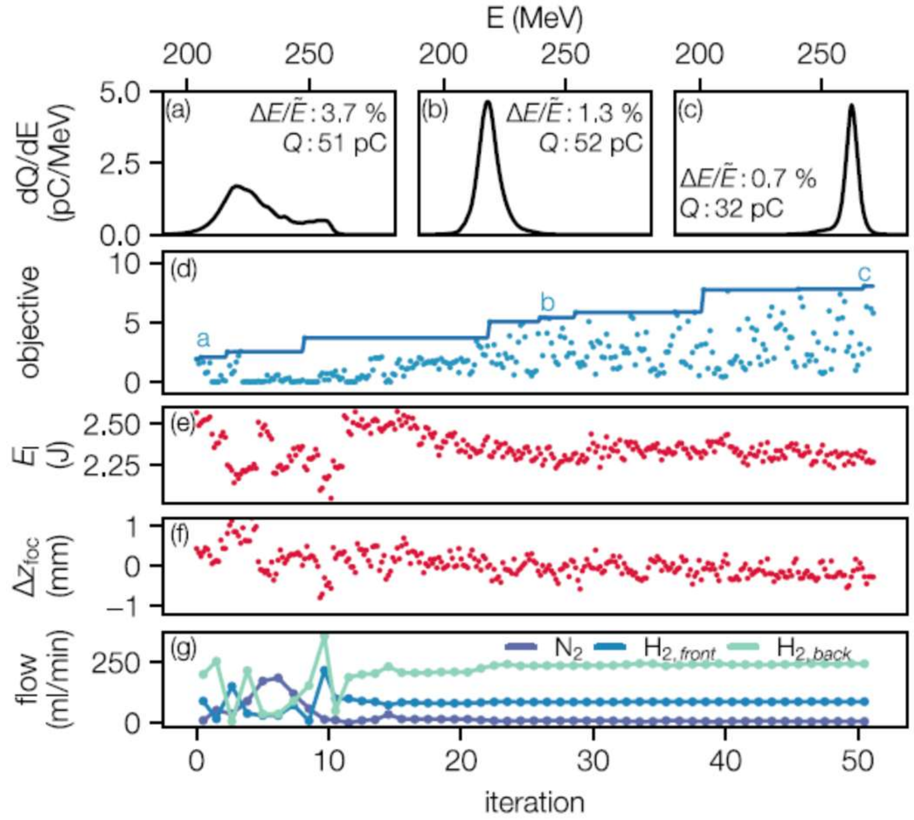
Maier 2020 PRX 10, 031039

Bayesian optimization of LPAs

Simulation (FBPIC)



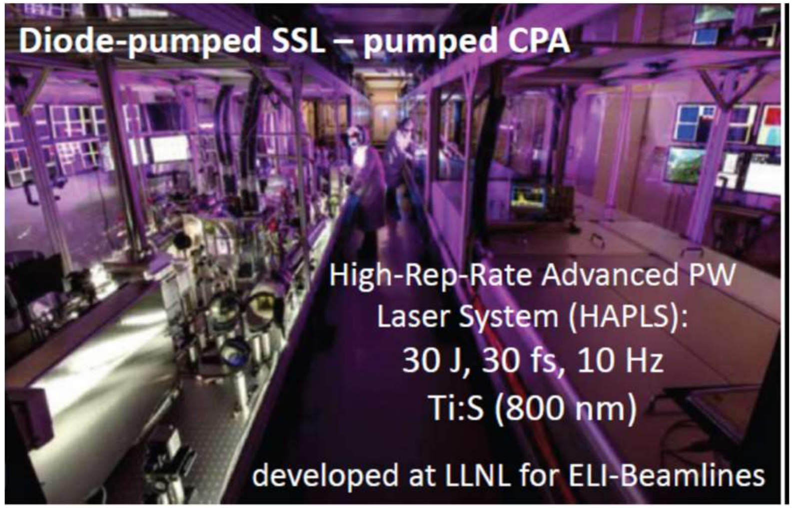
Experiment (LUX)



Laser pulse shaping and varying target parameters optimises a specified property.
Simulation and experiment produced <1% energy spread

Shaloo 2020 Nature Comm. **11**, 6355; Jalas 2021 PRL **126**, 104801

Transition from academic research toward laser-plasma accelerator facilities



- New high power laser technology
- Customised building infrastructure
- Industrial approach to machine design

UKRI Science and Technology Facilities Council

Large-scale purpose built facilities

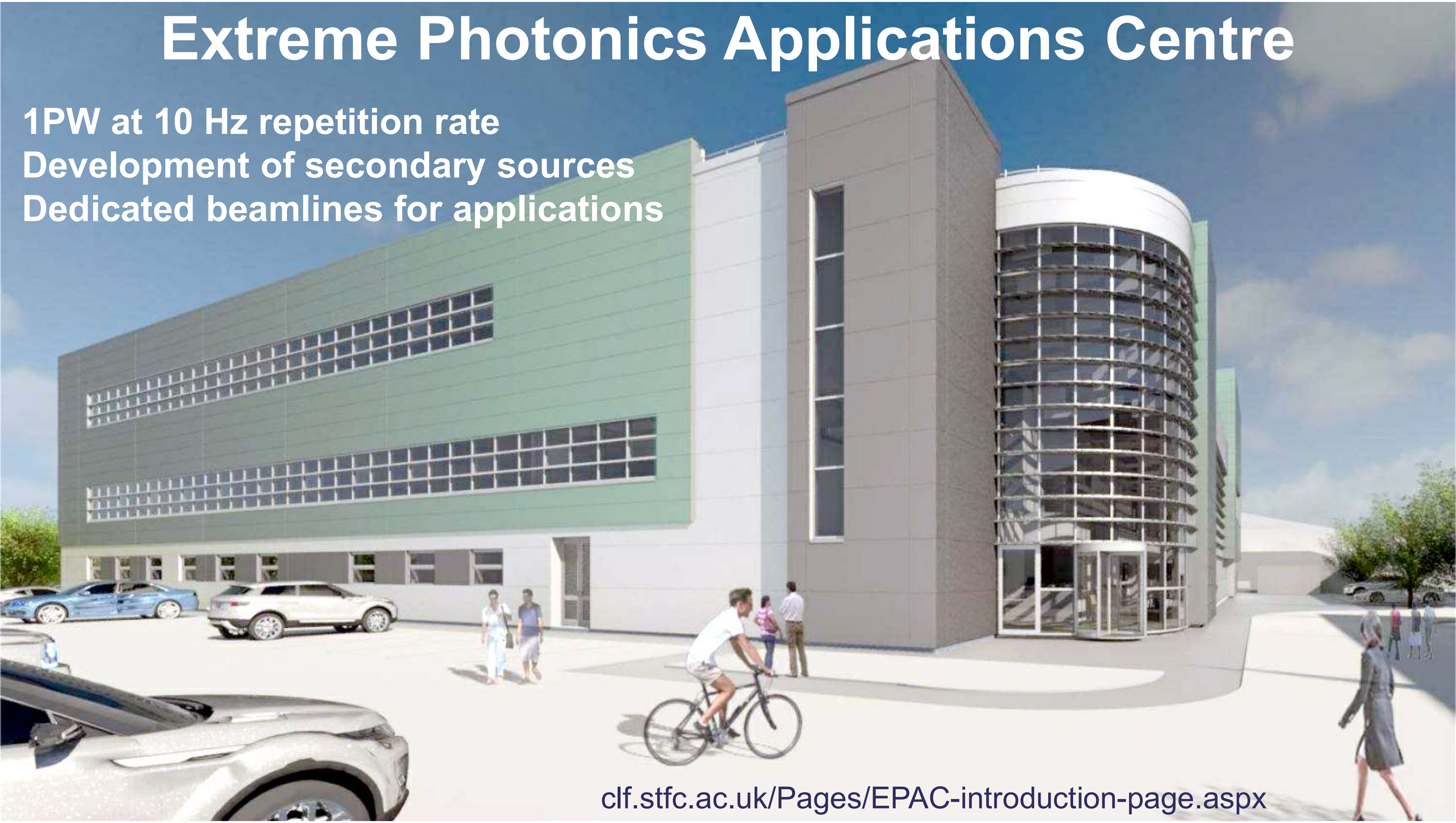
ELI
Three high power laser user facilities
Now starting operations
(100s MEuro)

EuPRAXIA
100 Hz 5 GeV plasma accelerator
On ESFRI Roadmap 2021
Aiming for operations in 2028
(100s MEuro)

EPAC
UK 10 Hz PW laser user facility.
Operational in 2025
(100 MEuro)

Extreme Photonics Applications Centre

1PW at 10 Hz repetition rate
Development of secondary sources
Dedicated beamlines for applications



clf.stfc.ac.uk/Pages/EPAC-introduction-page.aspx


Extreme Photonics Applications Centre
Building handover April 2022
Operational 2025
clf.stfc.ac.uk/Pages/EPAC-introduction-page.aspx

Summary

LPA research is focusing on beam quality

- Machine-learning optimization has been demonstrated
- Better lasers are improving stability and reliability
- Enables applications and statistical experiments

Large investments are being made in LPA development

- PW lasers at 10 Hz will soon be operational
- Large-scale user facilities are under construction
- A key objective is to produce laser-driven sources for scientific and industrial applications

Science and Technology Facilities Council

Thank you

Extreme Photonics Applications Centre (EPAC)

Science and Technology Facilities Council @STFC_Matters Science and Technology Facilities Council

central laser facility