SCAPA: Scottish Centre for the Applications of Plasma-based Accelerators

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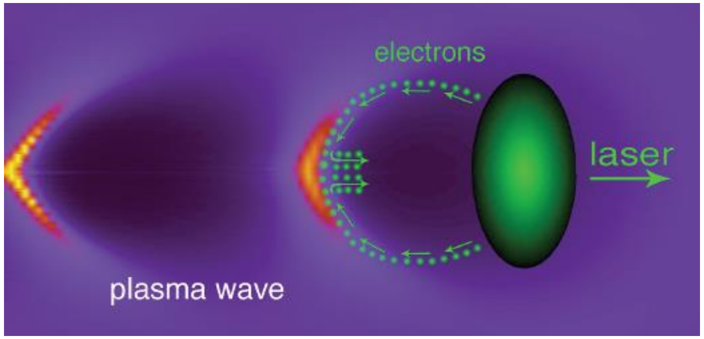
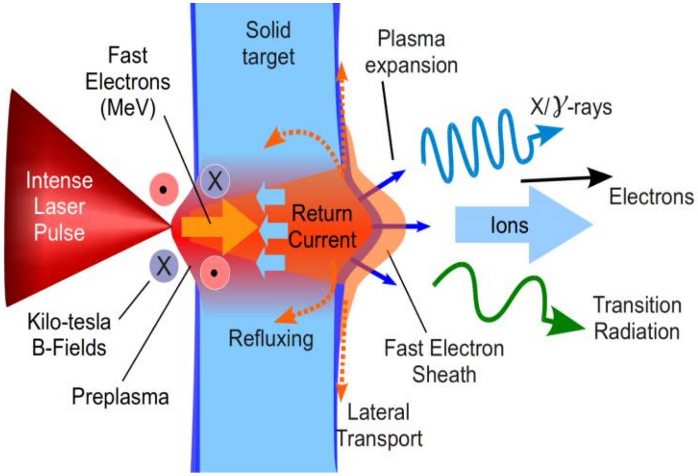
SCAPA: Vision

- SCAPA is a university-based centre for high power laser-plasma science with a focus on the development and exploitation of potentially transformative, laser-driven accelerators and radiation sources
- Complements high power laser facilities at the CLF
- Configured experimental arrangements – dedicated beamlines to enable long term development, optimisation and stabilisation
- Flexible access arrangements possible (e.g. split periods to enable data analysis; pump-prime access to test ideas; proposals for access and expressions for interest for grant planning)
- High repetition rate (up to 5Hz) 350 TW and (up to 10Hz) 40 TW (gas load dependant – aiming at 2Hz initially)

Laser-plasmas as particle accelerators

- RF acc. fields 10-100 MV/m
- Laser-plasmas 10^3-10^4 higher
- To get the same energy need x1000 smaller scale!





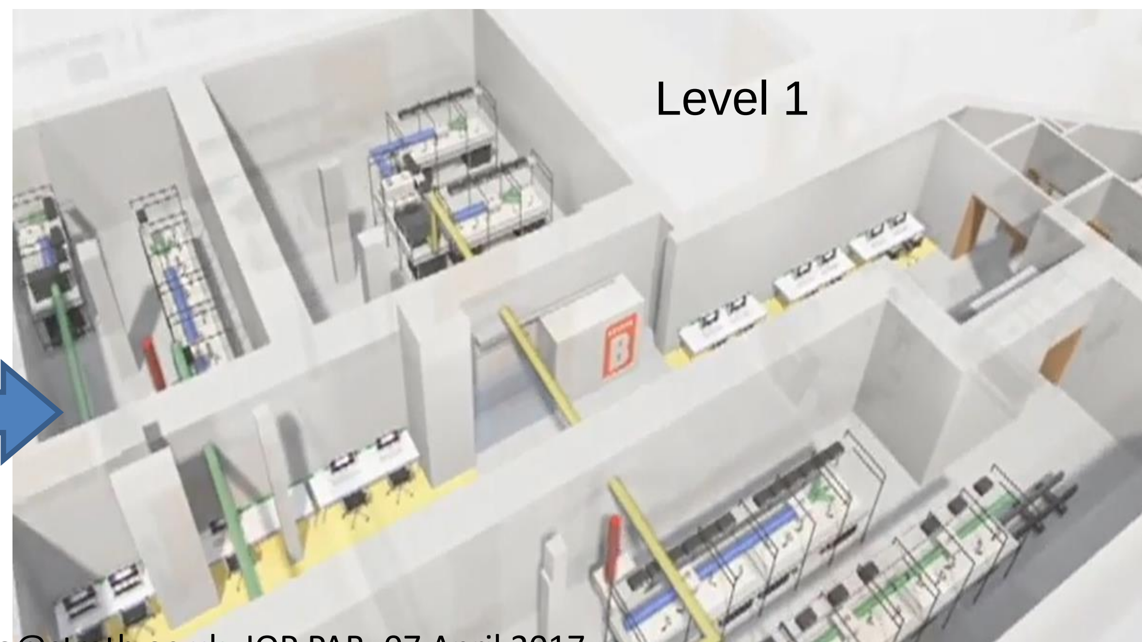
SCAPA: >1000m^2 laboratory space

Strategic investments:

£5.2M – building (Strathclyde & SUPA)

£3.5M – laser (Strathclyde & SUPA)

>£2M – beamlines (£1.7M – EPSRC;
£460k STFC-CI; £300k SUPA)



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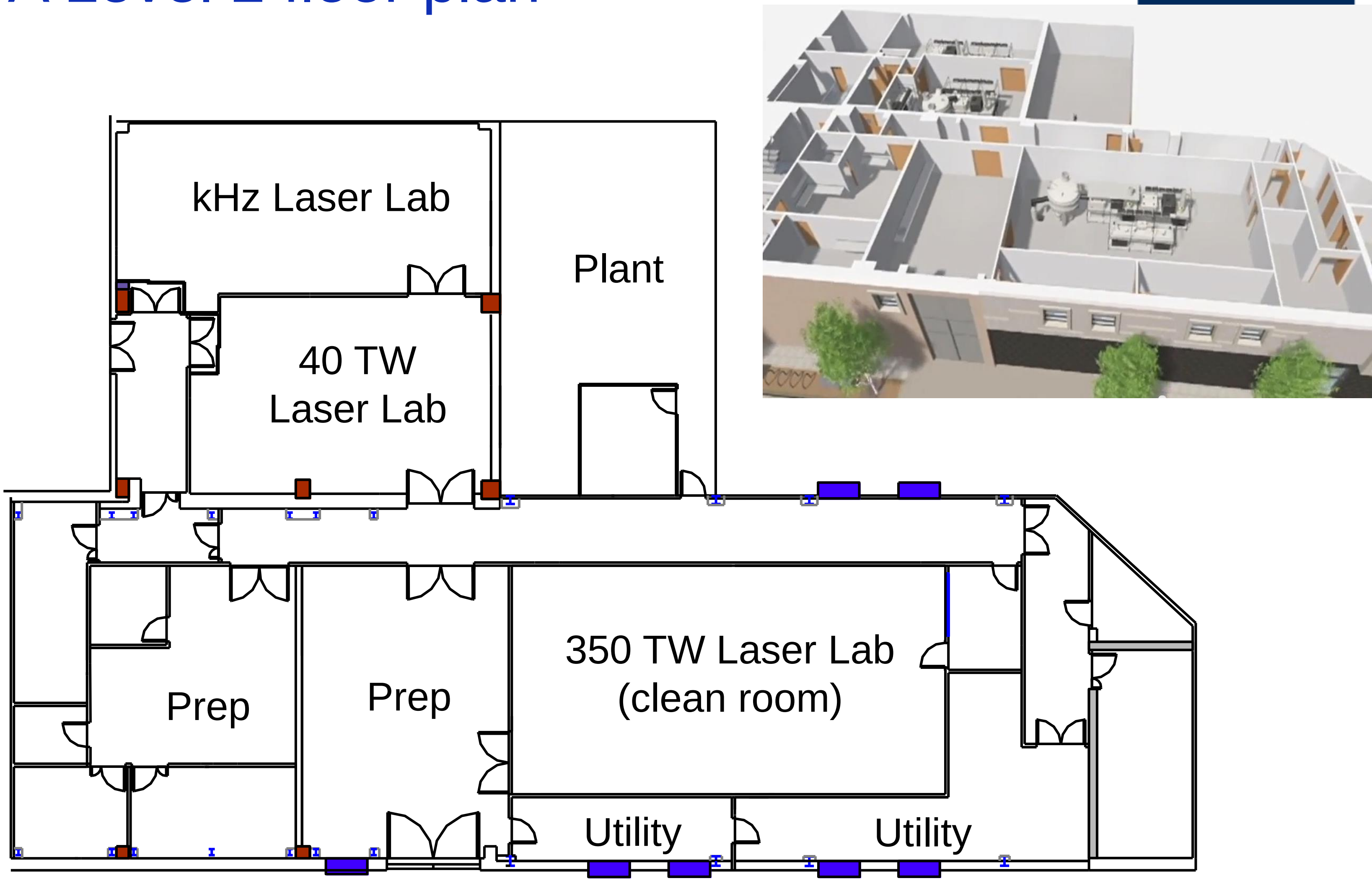
- **3 shielded areas** containing 7 accelerator beam lines.
- High-intensity femtosecond laser systems:
  a) 350 TW at 5 Hz,
  b) 40 TW at 10 Hz,
  c) sub-TW at kHz.
- High-energy **ion and electron** bunches,
- Secondary bright **X-ray/γ-ray** and **neutron** pulses.

SCAPA Level 2 floor plan



Transfer of the 40 TW laser and ALPHA-X beamline

SCAPA 40 TW laser

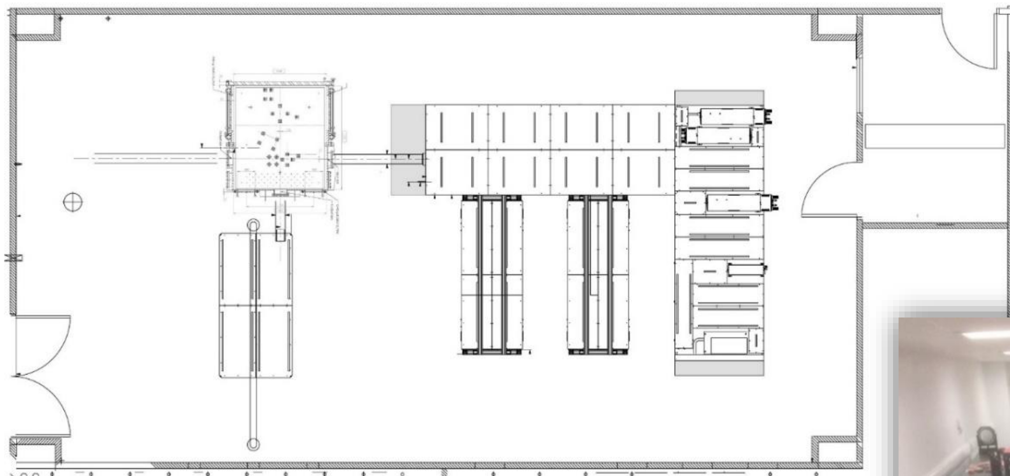
- 57m^2 laser room
- VCA (<50µm/s) RMS velocity vibration standard
- Temperature controlled ± 1.0 ˚C
- Humidity ±10 % RH

Parameter	Laser value
Peak Power	40 TW
FWHM pulse duration	≤35 fs
Energy per pulse (after compression)	Up to 1.3 J
Pulse repetition rate	10 Hz
Contrast ratio	ASE contrast 10^6:1
Short term stability	<1.2% rms (over 500 shots)
Deformable mirror	Yes
Probe beam	30 mJ uncompressed synchronised beam

Arrival of the 350 TW laser (Nov-Dec 2016)

SCAPA 350 TW laser

- 107m^2 ISO6 (Class 1000) clean room with separate 27m^2 power supply room.
- VCE (<3µm/s) RMS velocity vibration standard
- Temperature controlled ± 0.5 ˚C
- Humidity ±10 % RH

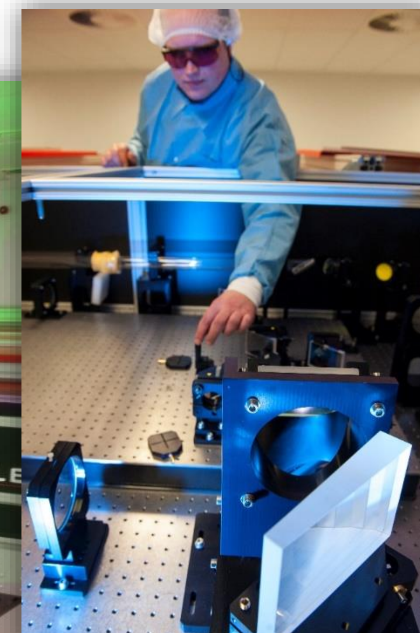


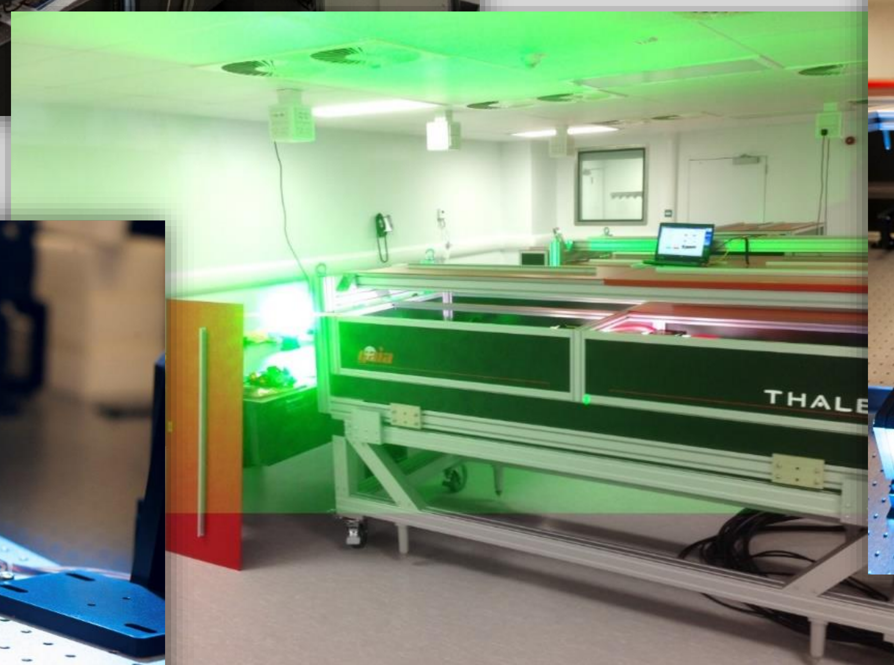
SCAPA 350 TW laser

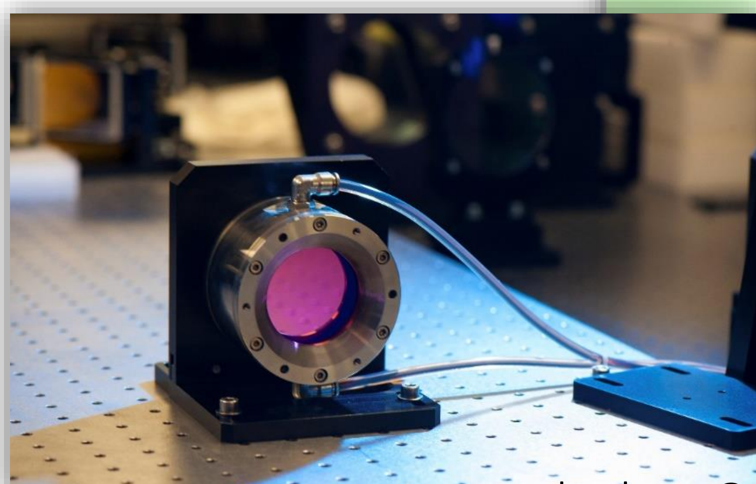
- $107 m^2$ ISO6 (Class 1000) clean room with separate $27 m^2$ power supply room.
- VCE (<3µm/s) RMS velocity vibration standard
- Temperature controlled ± 0.5 ˚C
- Humidity ±10 % RH

Parameter	Laser Warranted value at 5 Hz
Peak Power	≥350 TW
FWHM pulse duration	≤25 fs
Energy per pulse (after compressor)	≥ 8.75 J
Pulse repetition rate	5 Hz
Contrast ratio	10^{10}:1 @ 100 ps; 10^{8}:1 @ 30 ps; 10^{4}:1 @ 2ps; ASE contrast 10^{10}:1
Short term stability	<1.2% rms (over 500 shots) <1.5% rms (over working day, 8 hours)
Central Wavelength	800 ± 10 nm
Beam quality Strehl ratio	≥0.85
Pointing Stability	<5 µrad
Attenuator	10 – 100 %
Probe beam	30 mJ uncompressed synchronised beam

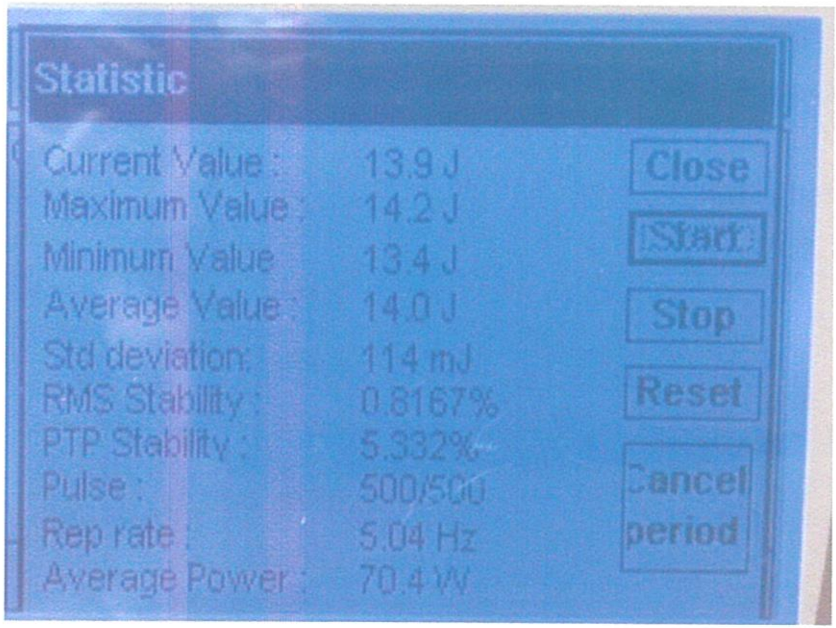
SCAPA 350 TW laser





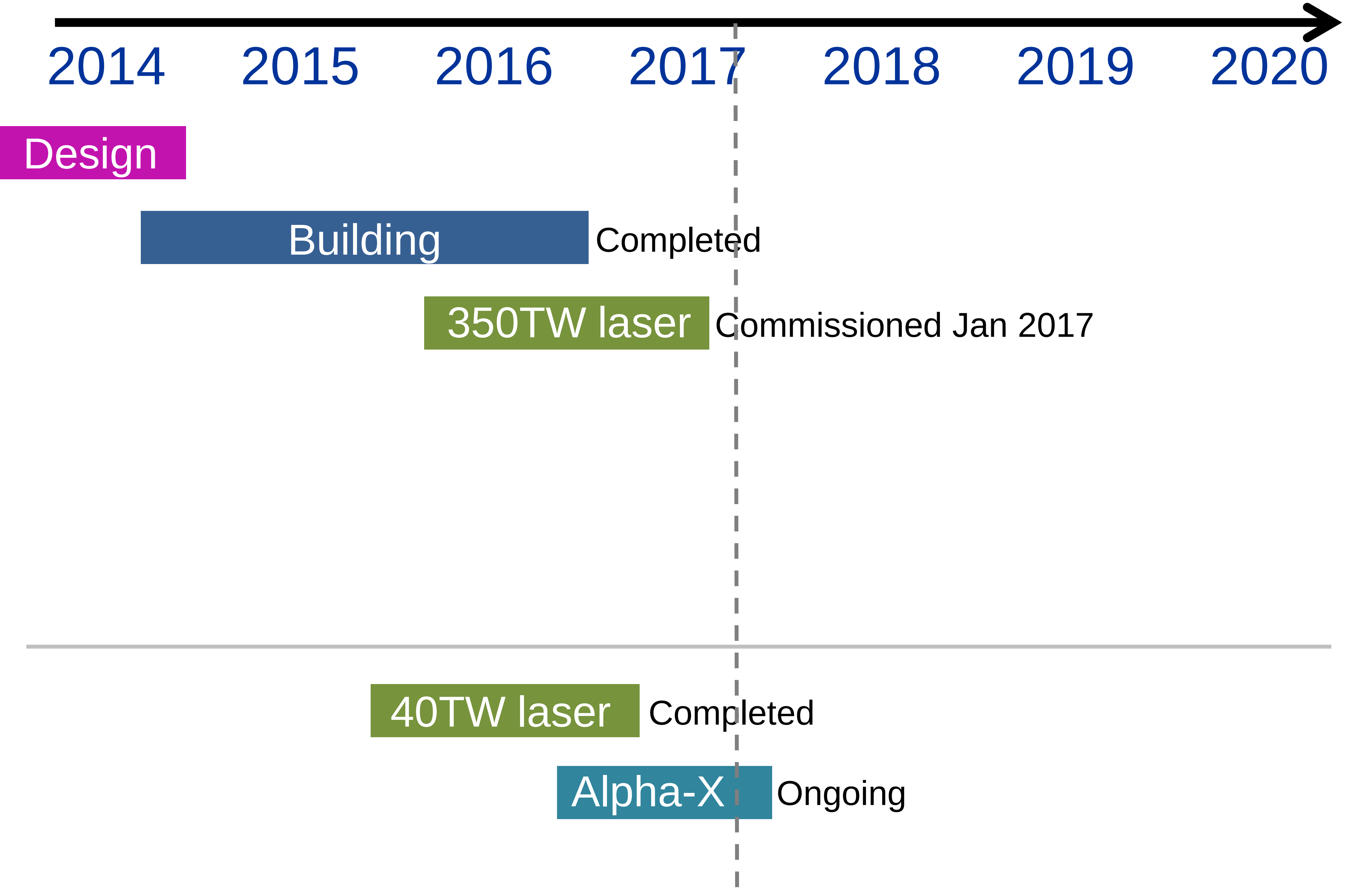


Highest average power of its type and the first 350TW laser to operate at 5Hz.

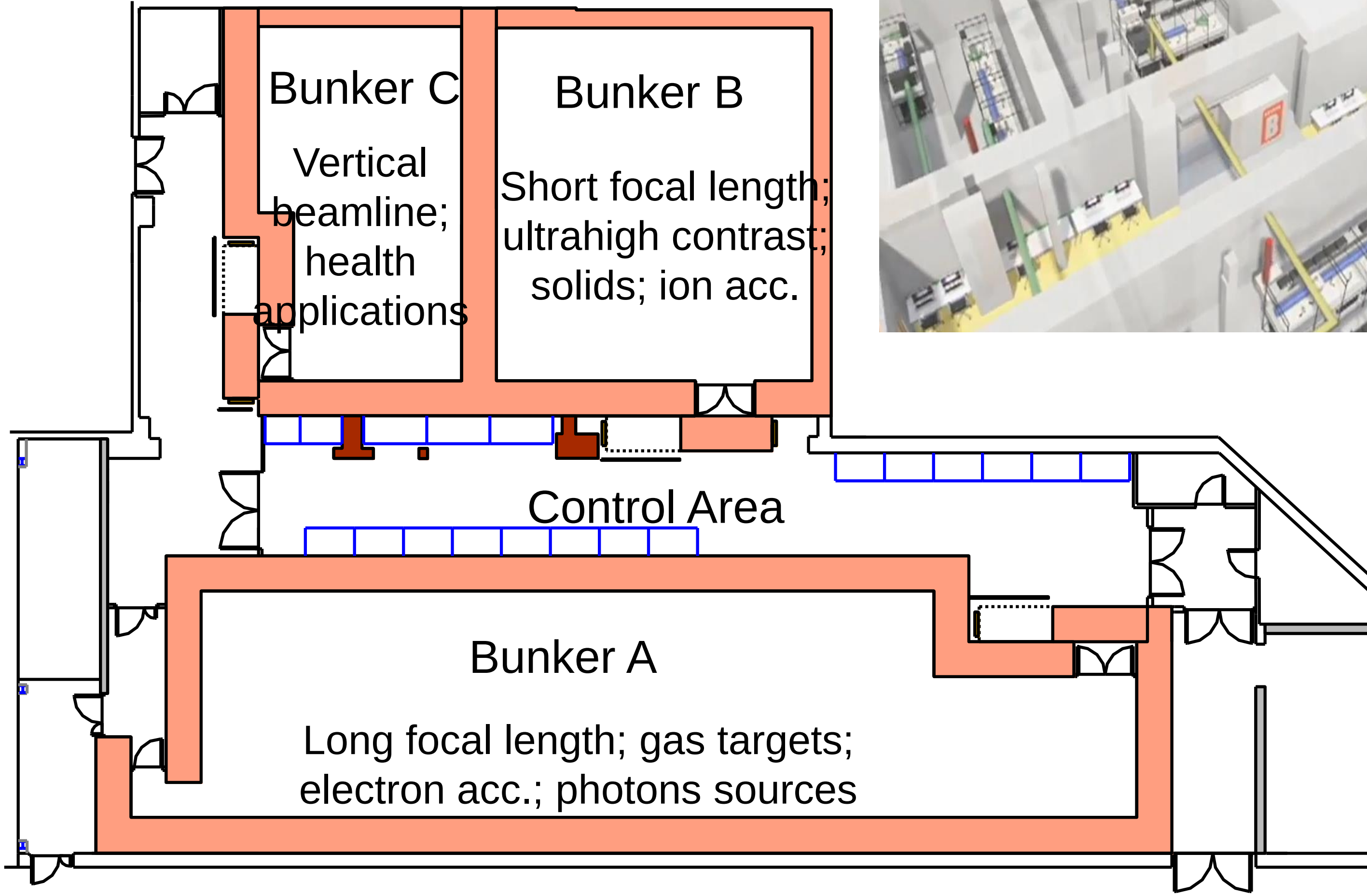


14.0J at 0.82% RMS over 500 shots

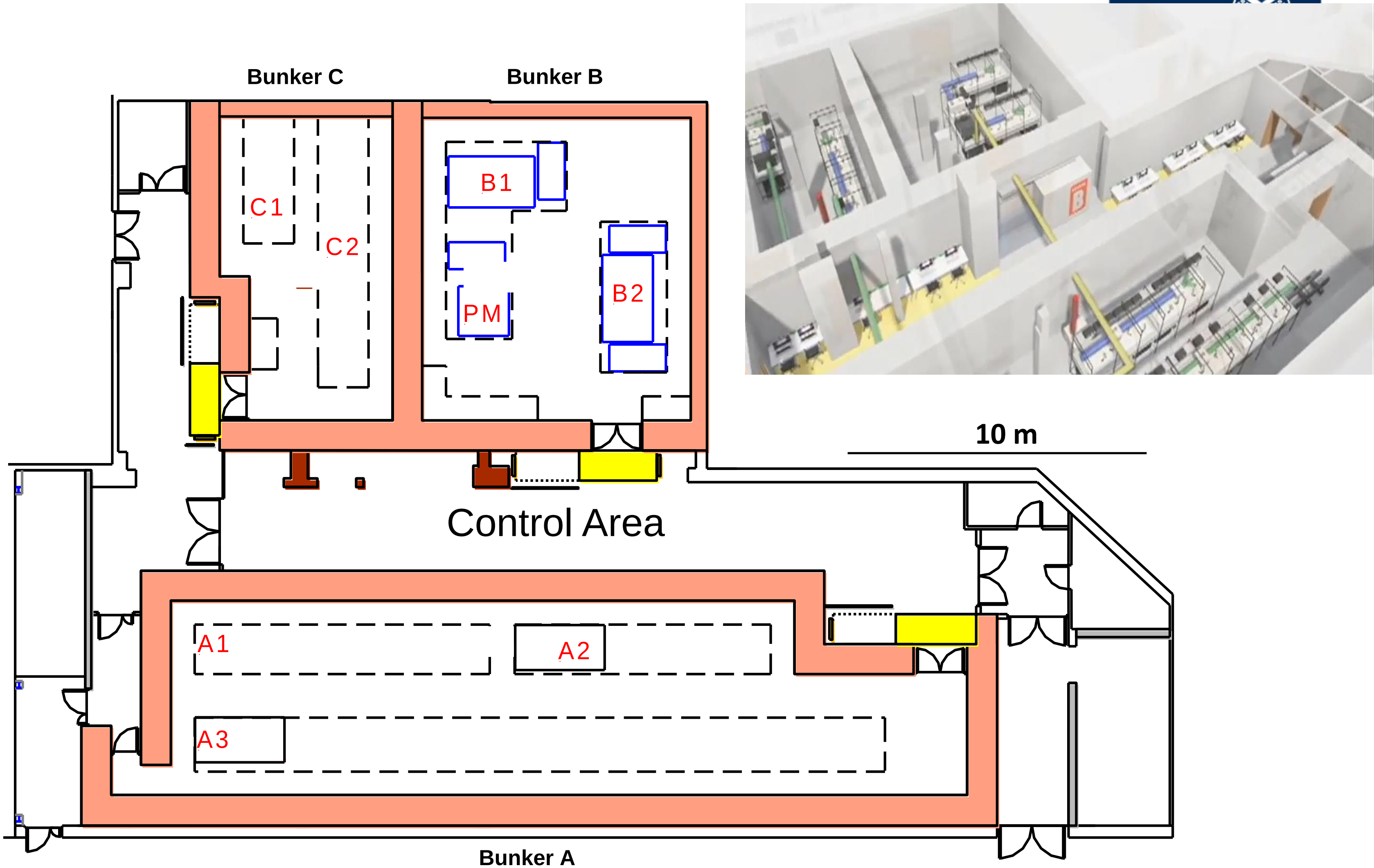
SCAPA time line



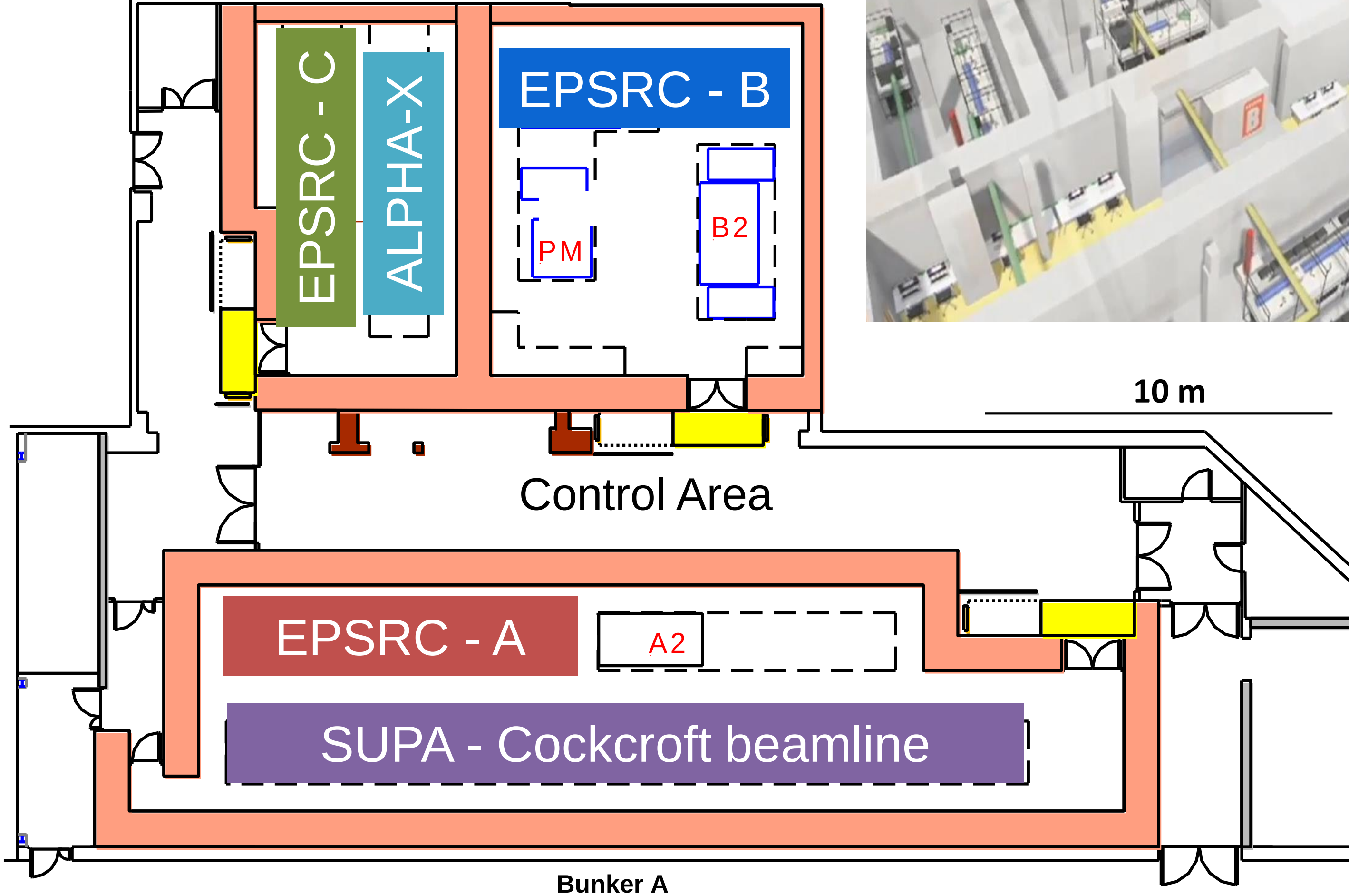
SCAPA Level 1 floor plan



SCAPA Level 1 floor plan

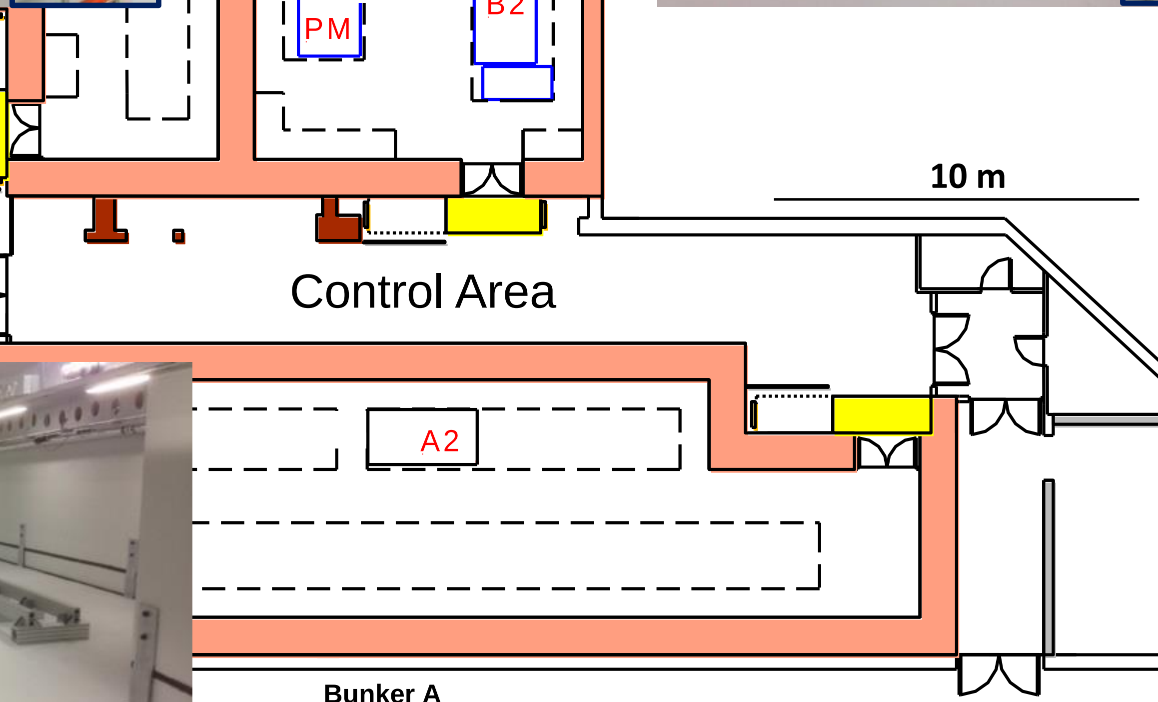


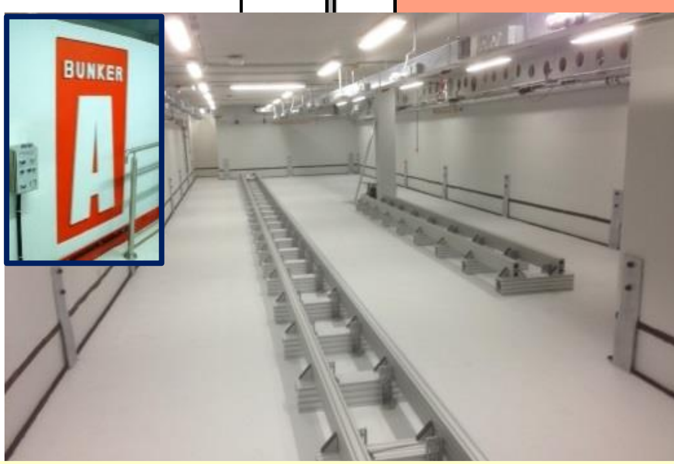
SCAPA Level 1 floor plan



Bunker C: Medical applications

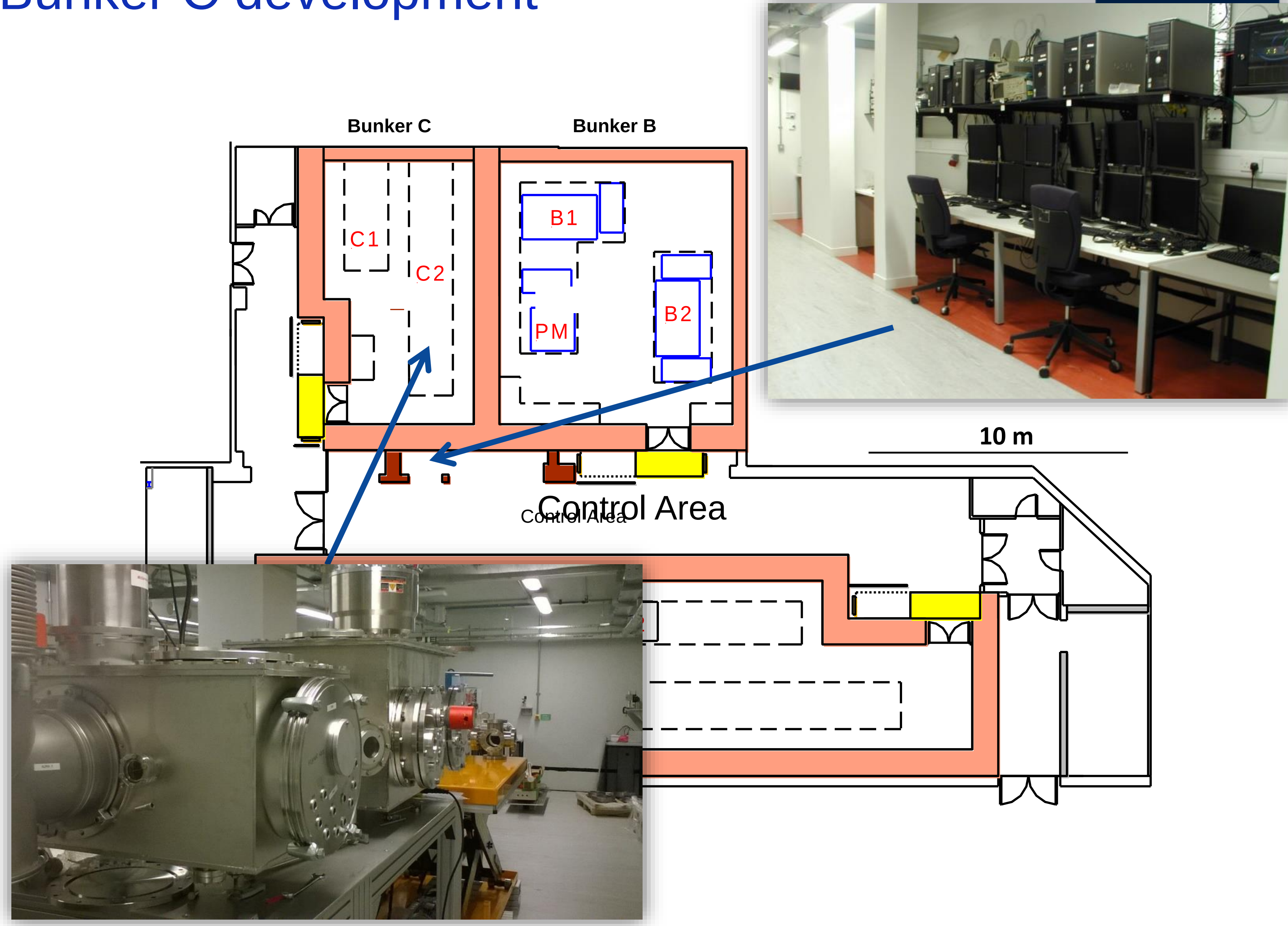
Bunker B: Proton & ion sources



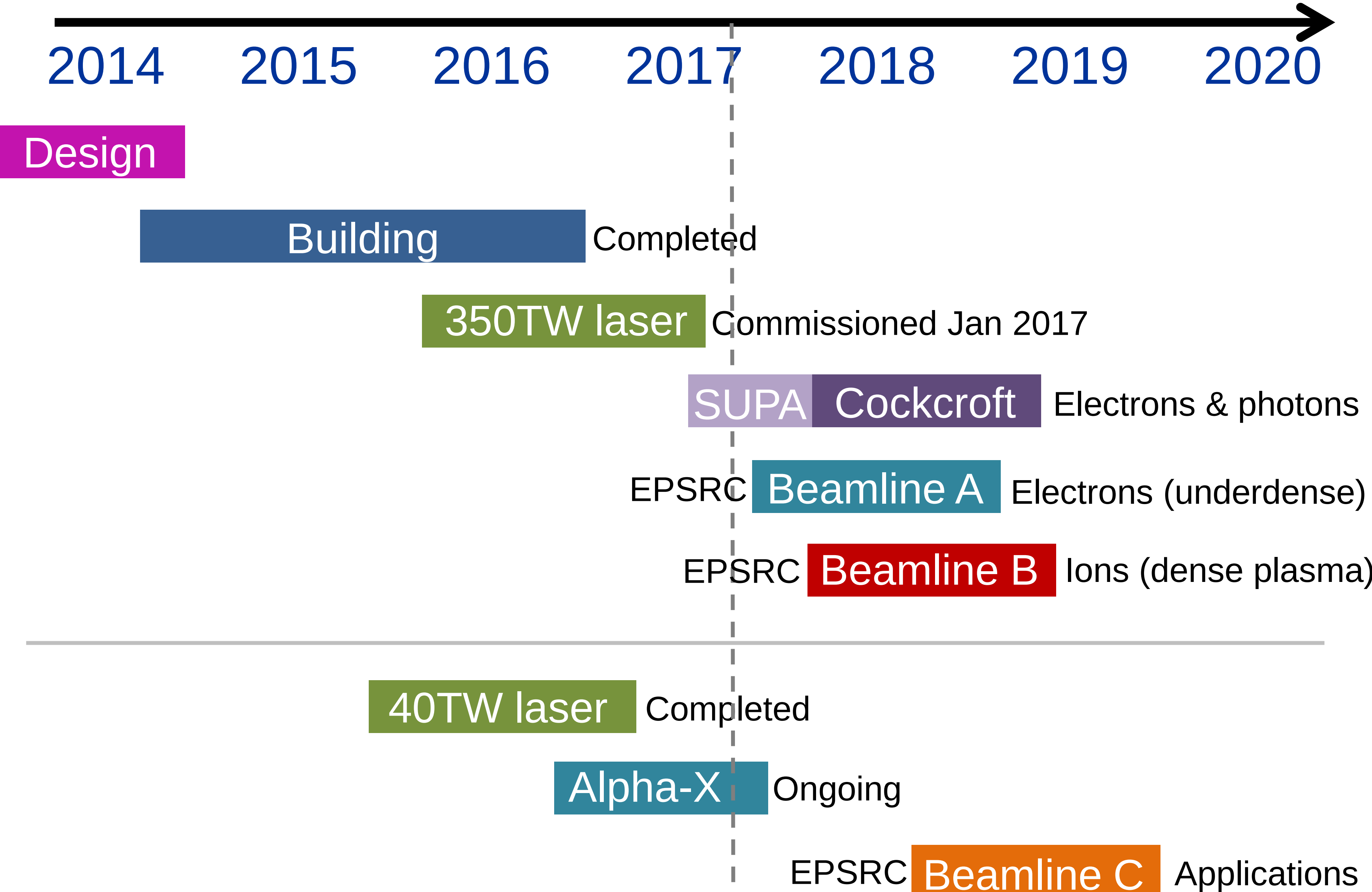


Bunker A: Coherent X-ray sources

Bunker C development



SCAPA time line



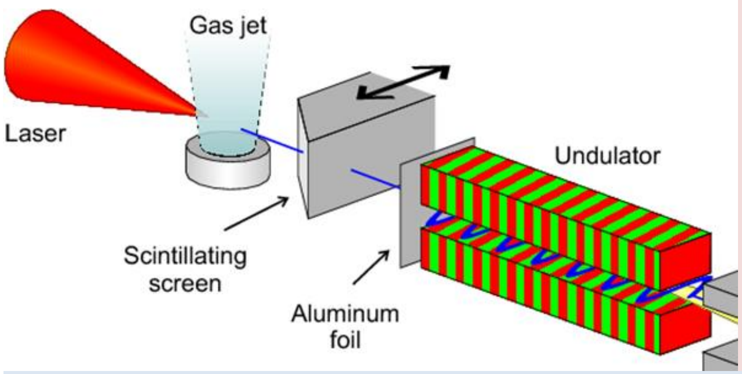
SCAPA: Access and usage

University of Strathclyde Glasgow

- Sustainability is important - Fees to recover running costs, depreciation and technical support
- Fee level is ~£15k/week for the 350TW and £7.5k/week for the 40 TW laser (not yet including beamline costs), based on expected 36 weeks per laser per year after ’steady-state’ achieved
- Fees covered via collaborative RCUK and EU grants
- Experiments are ideally performed collaboratively, to benefit from support of local researchers with in-depth knowledge of the system
- Level of diagnostic and other equipment available will depend on funding

Proposals will be reviewed by an expert panel, based on:
(1) scientific excellence; (2) effective use; (3) likely impact; (4) technical risk; and (5) grant support to ensure sustainability

Laser-plasmas as particle accelerators – Expected SCAPA beam parameters

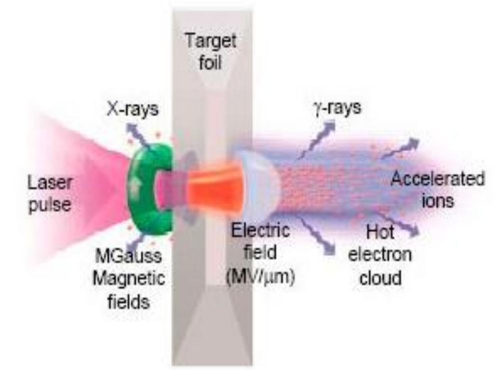


Photon beams

- peak brilliance >10^{23} photons/s/mm^2/rad^2/0.1%BW
- from VUV to 10 MeV gammas.
- Bright coherent sources in soft X-ray water window and shorter wavelengths. Plus bright (less coherent) pulses of very hard X-rays and gamma rays.

Electron beams

- up to 4 GeV
- 10 pC of charge,
- 0.3 mrad divergence,
- 3 fs duration, 3 kA peak current.
- Separately, 10-100 times more charge could be generated at 10-100 times more divergence in the 1-10 MeV electron energy range.
- Nominal rep rate is 1 Hz.



Proton beams

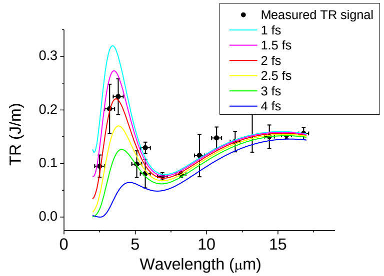
- up to ~30 MeV
- ~10^{10} protons / pulse
- ~30° divergence
- 40 fs at sources (increases due to time of flight spreading)
- Low rep rate due to focusing limitations at present.

ALPHA-X: Advanced Laser Plasma High-energy Accelerators towards X-rays – D Jaroszynski et al

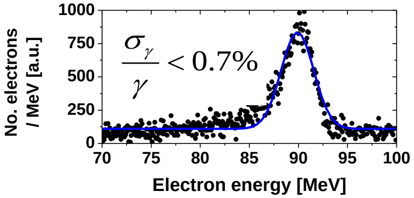
Compact R&D facility to develop and apply femtosecond duration particle, synchrotron, free-electron laser and gamma ray sources

Jaroszynski et al., (Royal Society Transactions, 2006)

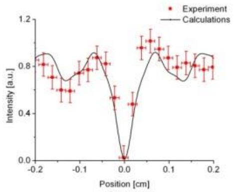
CTR: electron bunch duration: 1-3 fs

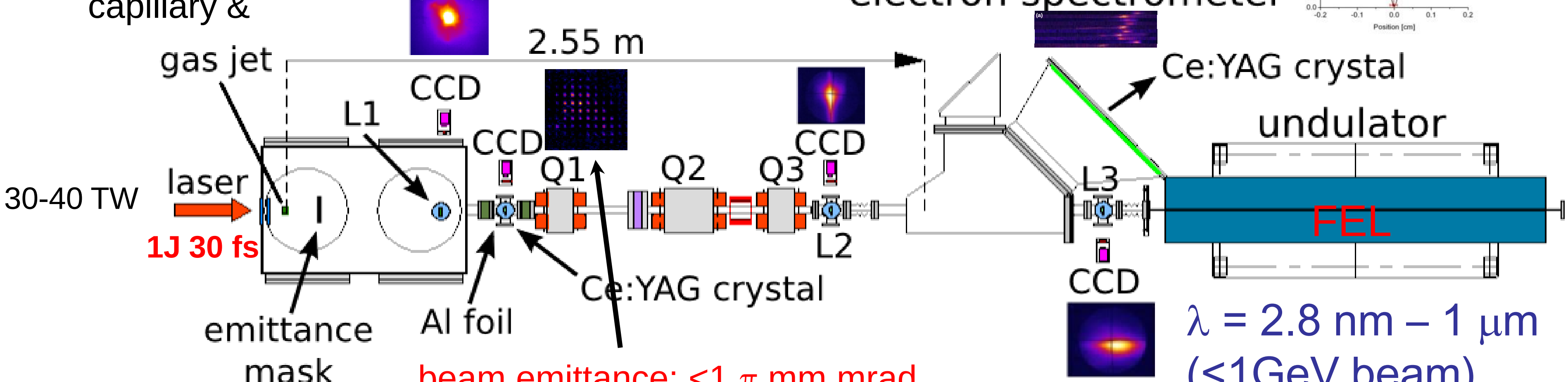


electron beam spectrum



phase contrast imaging with 50 keV photons





beam emittance: <1 π mm mrad

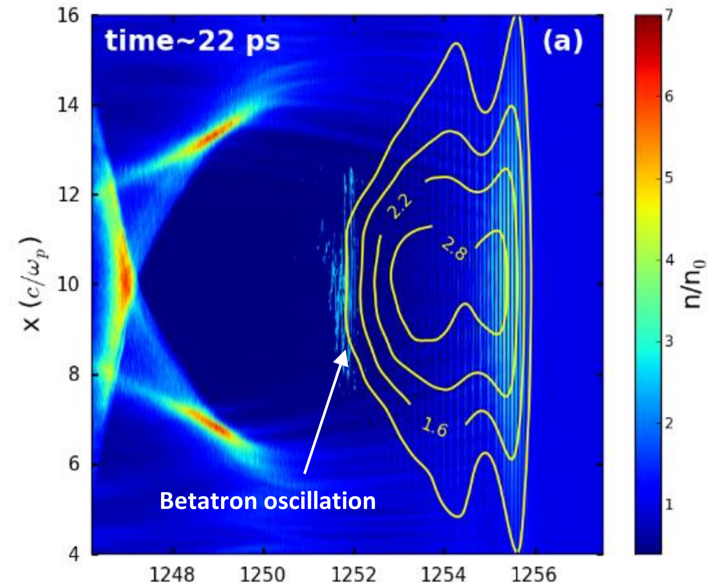
λ = 2.8 nm – 1 μm (<1GeV beam)

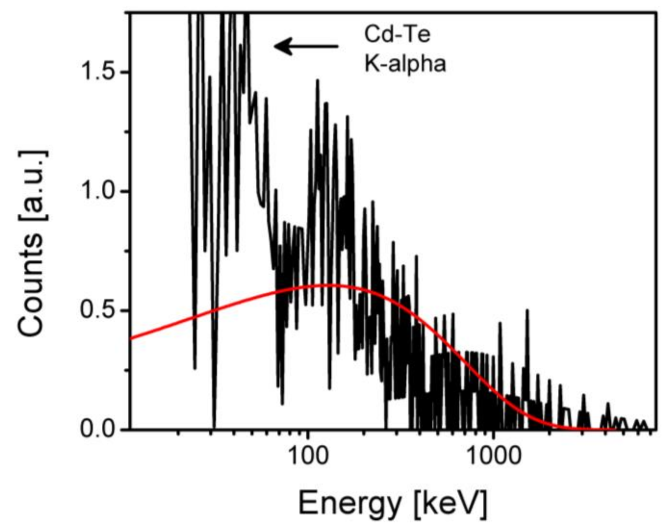
Brilliant particle source: 10 MeV → GeV, kA peak current, fs duration

Betatron resonance leading to hard X-rays – D Jaroszynski et al

Cipiccia et al., Nature Physics, 2011

- Bubble partially filled by laser pulse
- Electrons see laser frequency Doppler downshifted
- Electrons in resonance with laser field
- Direct laser acceleration
- Laser drives large amplitude betatron oscillations:
  - Increase in r_β, a_β, E_c





E_c = 450 keV

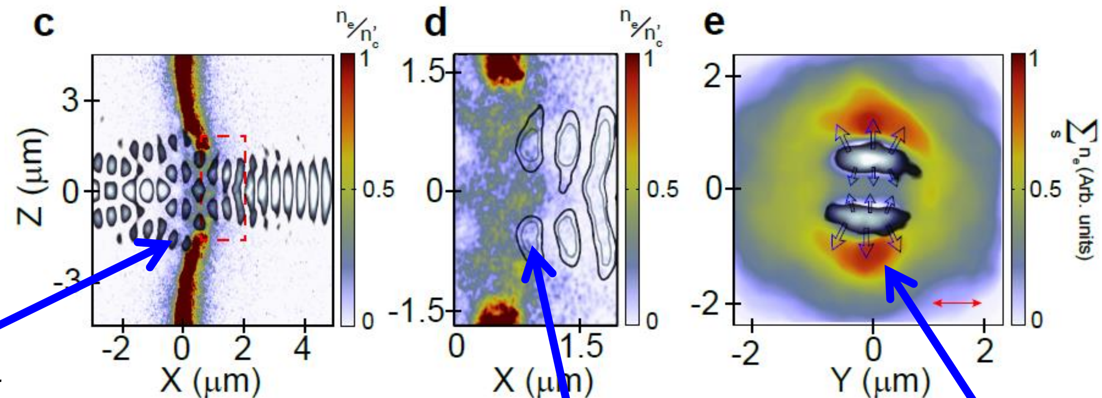
r_β = 20 μm

a_β = 150

Relativistic laser interactions with dense and near-critical density targets – P McKenna *et al*

University of Strathclyde Glasgow

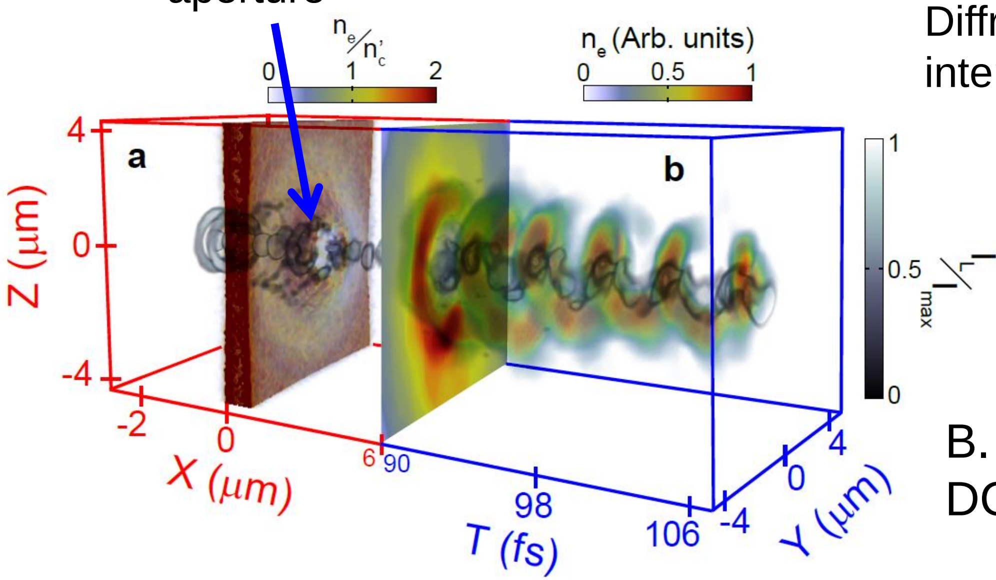
Example: Controlling collective particle motion and field evolution during relativistic induced transparency in thin foils



Relativistically induced plasma aperture

Diffraction of intense laser light

Double electron lobes formed

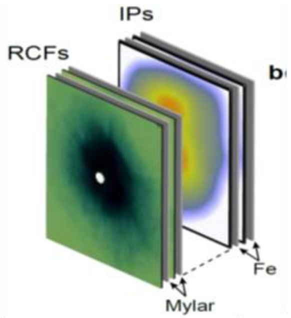


Spiralling plasma jets produced

B. Gonzalez-Izquierdo et al, Nature Physics, DOI: 10.1038/NPHYS3613 (2016)

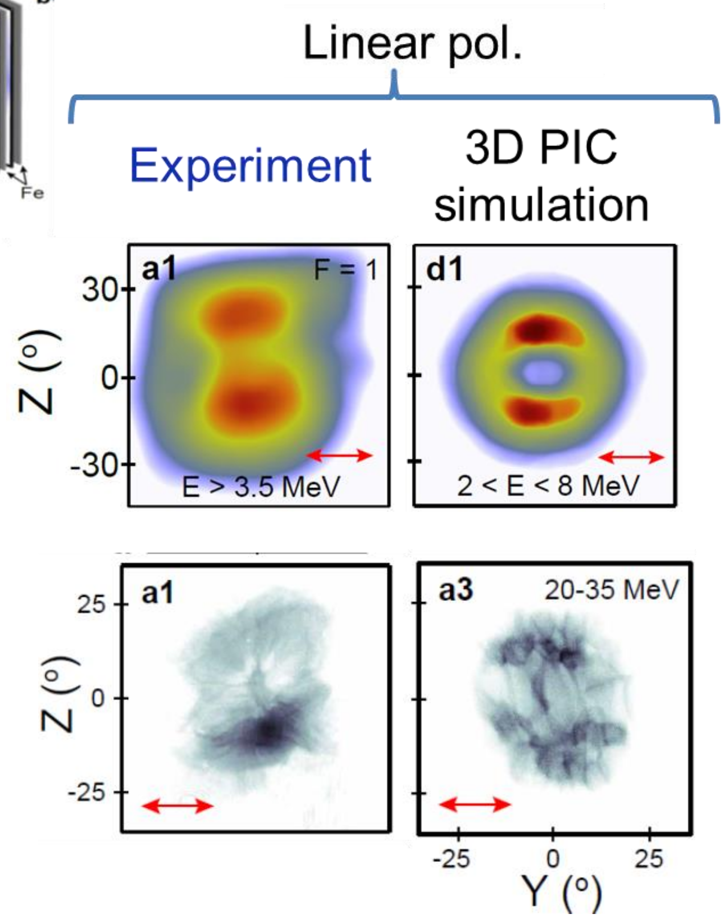
Laser-driven ion acceleration – P McKenna *et al*

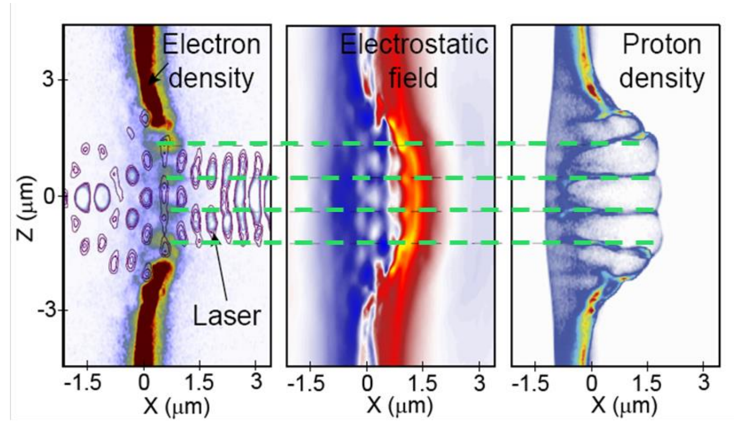
B. Gonzalez-Izquierdo et al, Nature Communications **7**, 12891 (2016)

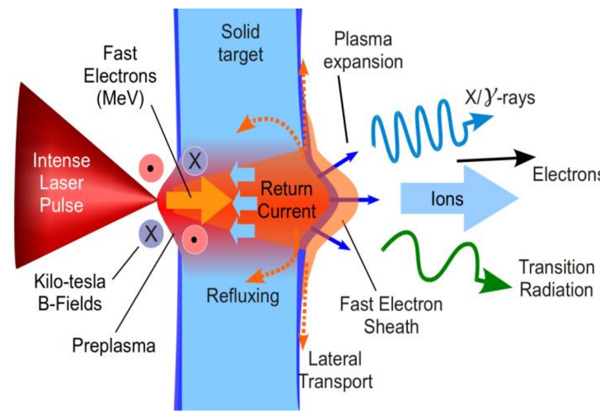


Electrons:

Protons:





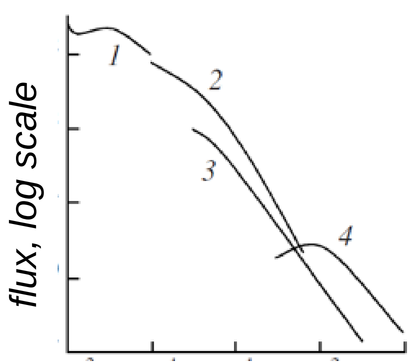


EPSRC-funded UK Programme grant (A-SAIL) to develop laser-driven ion sources towards medical applications

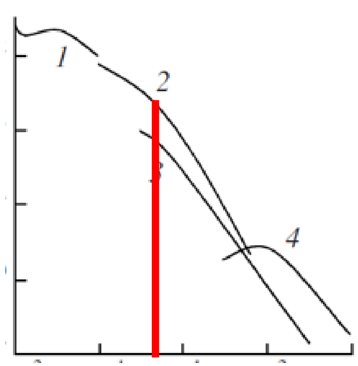
Space radiation reproduction, radiation hardness assurance, radiobiology – B Hidding *et al*

- Space radiation consists of electrons, protons, ions in wide energy range
- Is a major obstacle for space exploration, satellites and missions (onboard electronics, astronauts). Huge market.
- Space radiation is broadband – typical energy spectra are Maxwellian / power-law

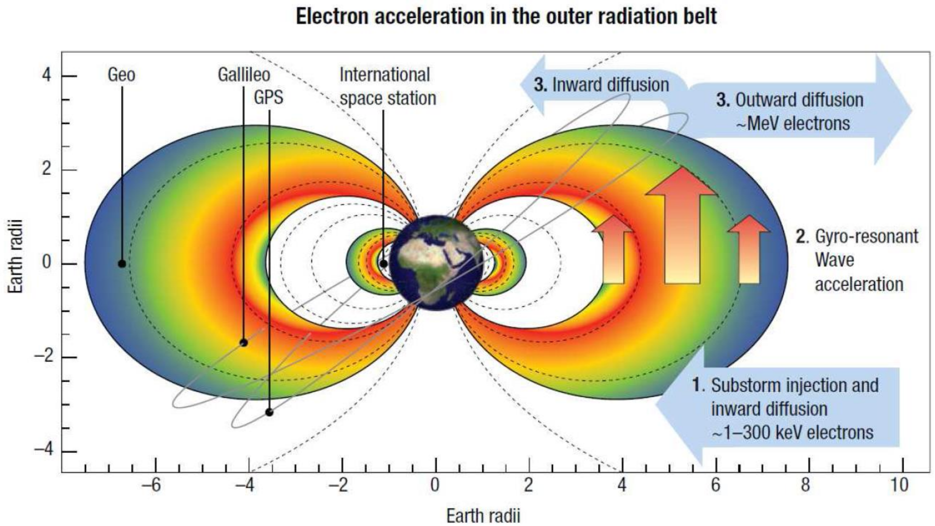
in space:



conventional testing uses *unnatural* monoenergetic beams:

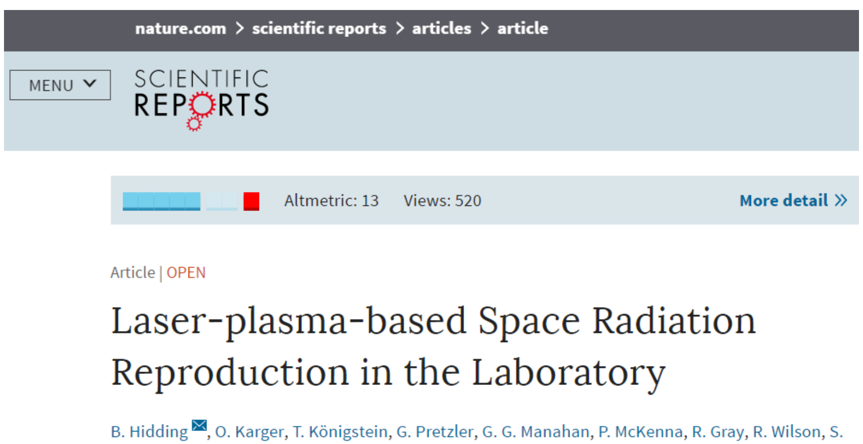


energy



Horne, "*Plasma astrophysics: Acceleration of killer electrons*", Nature Phys. 3, 2007

- Broadband radiation with exponential/power-law slope is the inherent regime of plasma accelerators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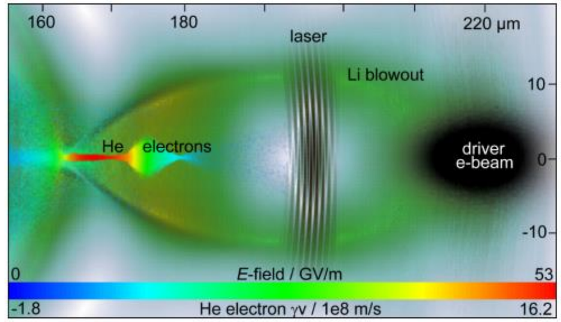
Laser-plasma-based Space Radiation Reproduction in the Laboratory

B. Hidding, O. Karger, T. Königstein, G. Pretzler, G. G. Manahan, P. McKenna, R. Gray, R. Wilson, S.

Highest quality electron beams: Trojan Horse plasma photocathode PWFA – B Hidding *et al*

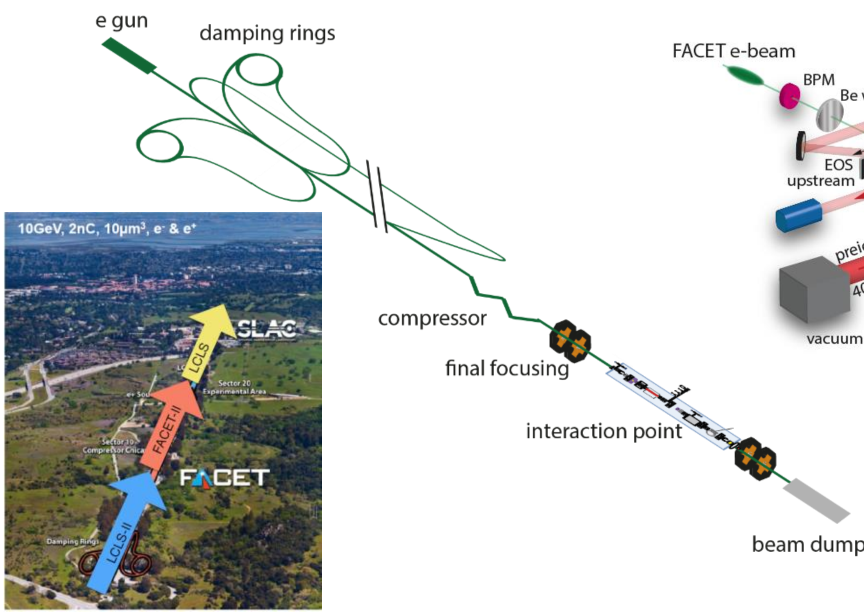
- Combine best of LWFA and PWFA, realize plasma photocathode to decouple injection and acceleration
- Emittance and brightness orders of magnitude better than even with best state-of-the-art linacs

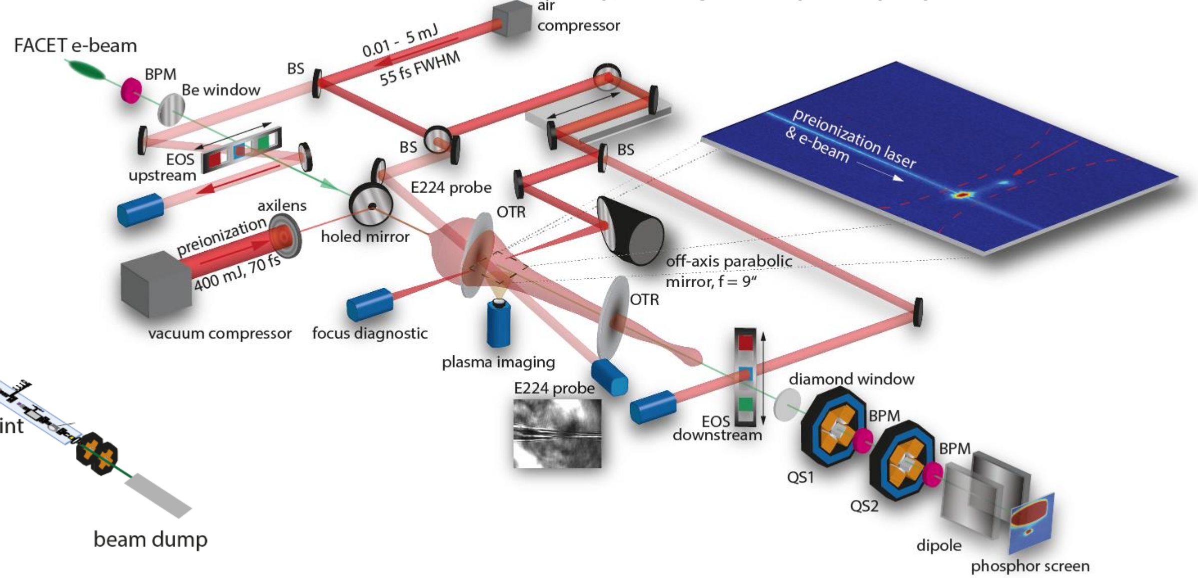


Idea 2008-2010, patents 2011,
PRL 108, 035001 (2012), PRSTAB 16, 031303 (2013), 18, 081304 (2015), 19, 011303 (2016), arXiv:1403.1109, arXiv:1412.4844(2014)
Other groups: PRL 111, 015003, PRL 111, 155004, PRL 111, 245003 (2013), PRL 112, 035003, PRL 112, 125001 (2014), PRL 117, 034801 (2016) (all theory)

<u>Experimental</u> development of TH concept: E210 Trojan Horse PWFA at SLAC FACET 2012-2016

World's most advanced PWFA experiment breakthrough success in final FACET run 2016





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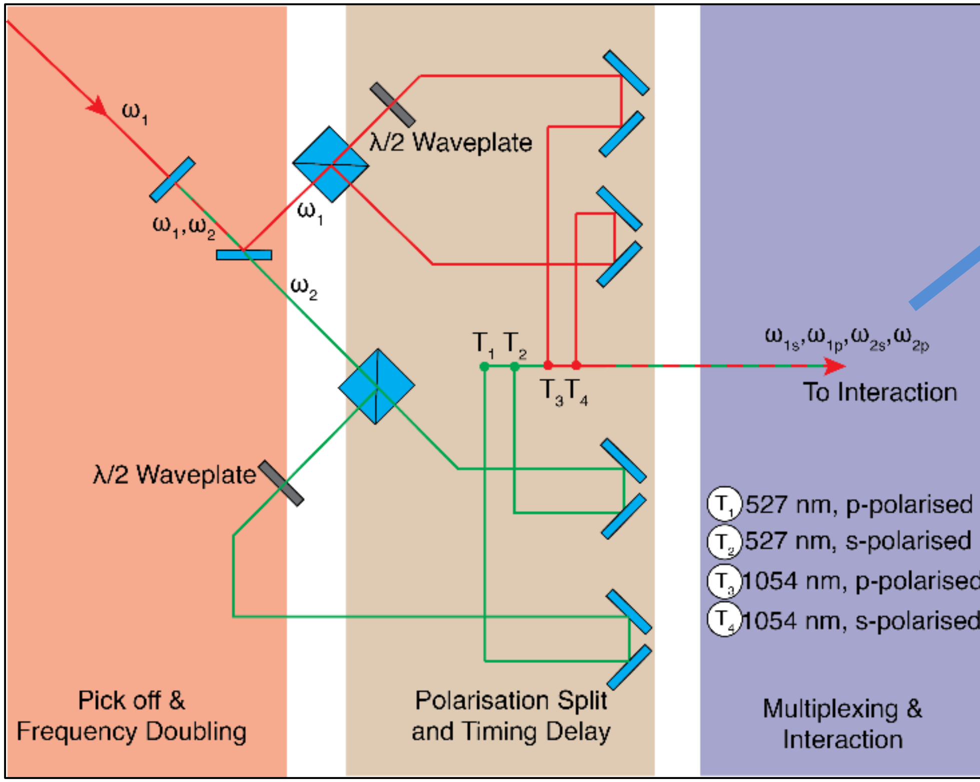
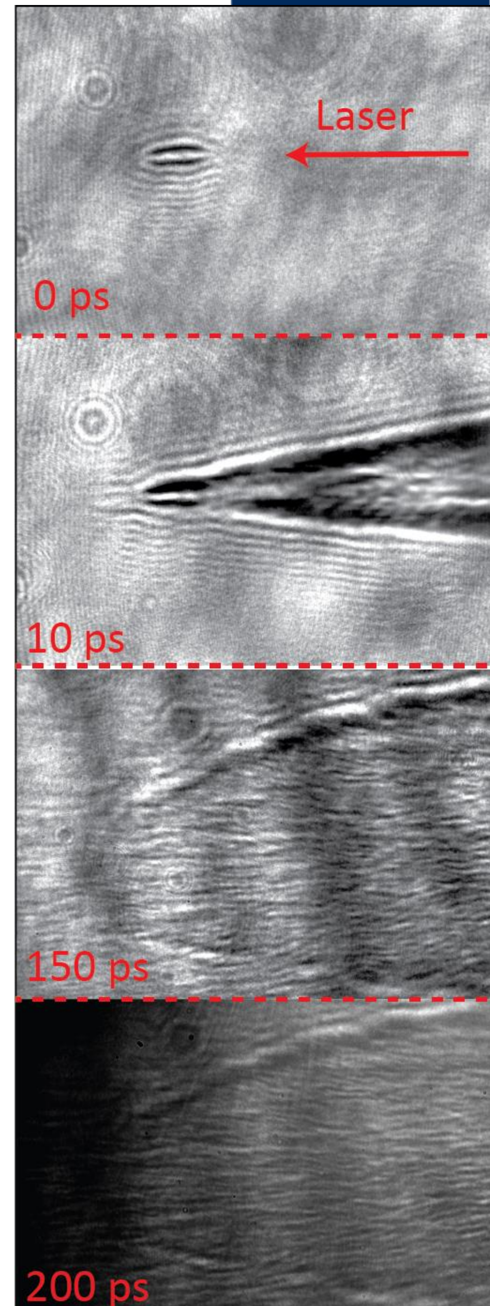
Ultrafast, Non-linear and Complex Laser Propagation Dynamics – R Gray *et al*



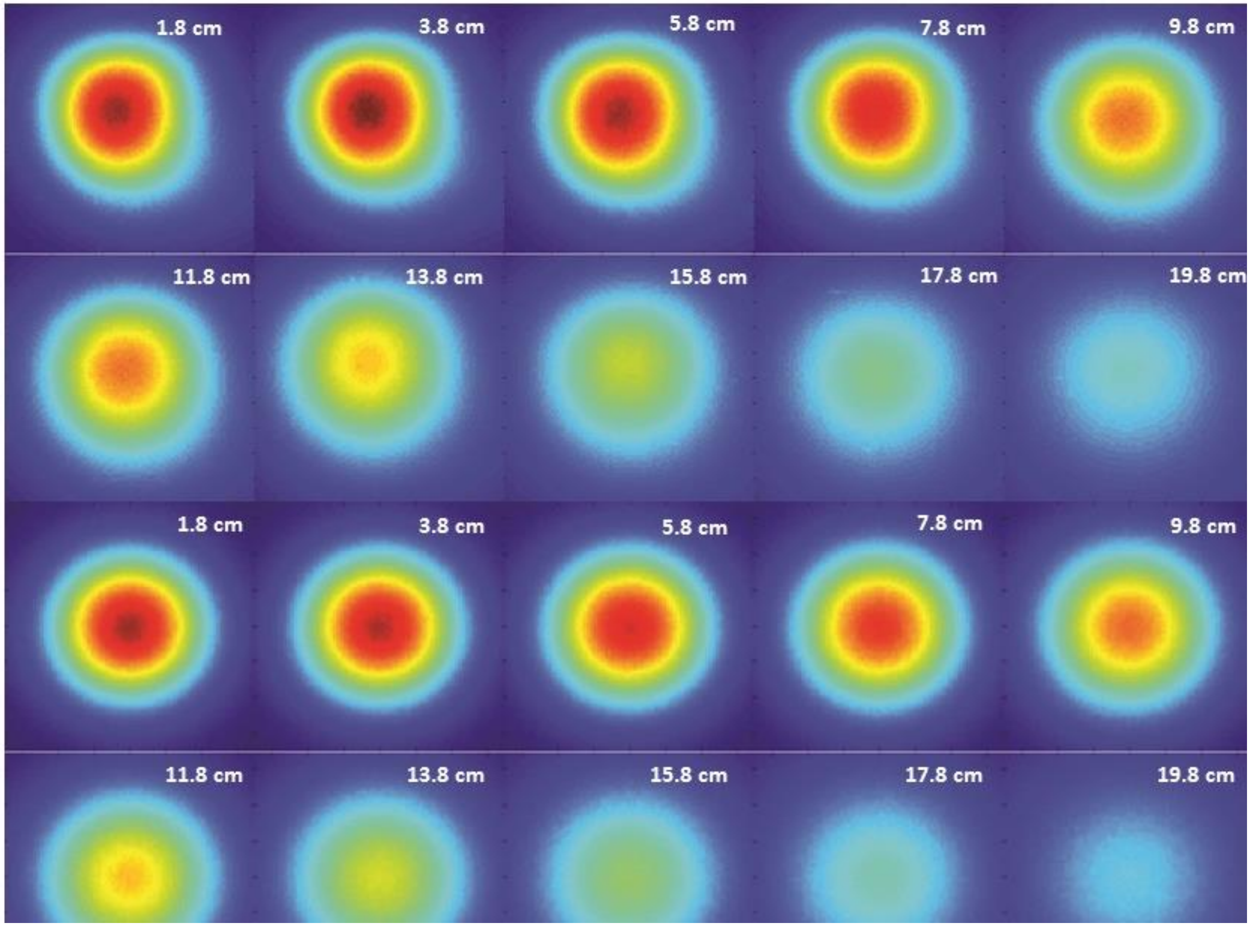


- New research group formed at Strathclyde 2016 (PI: R. Gray)
- Investigations of complex and non-linear propagation dynamics in relativistic plasmas
- Development of new ultrafast, multi-time frame optical probe diagnostic approaches

LWFA - Very High Energy Electron Therapy VHEET: Measured & calculated dose maps D Jaroszynski, M Boyd (Strathclyde biology) *et al*

University of Strathclyde

Irradiation of phantom to compare electron dose maps

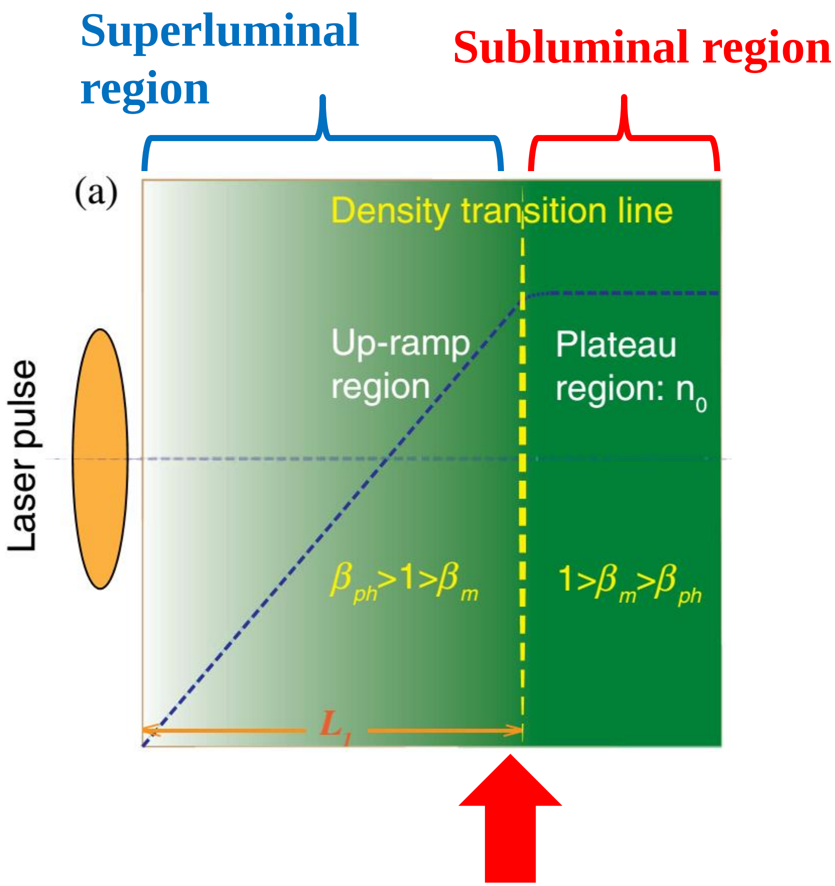


Measurement

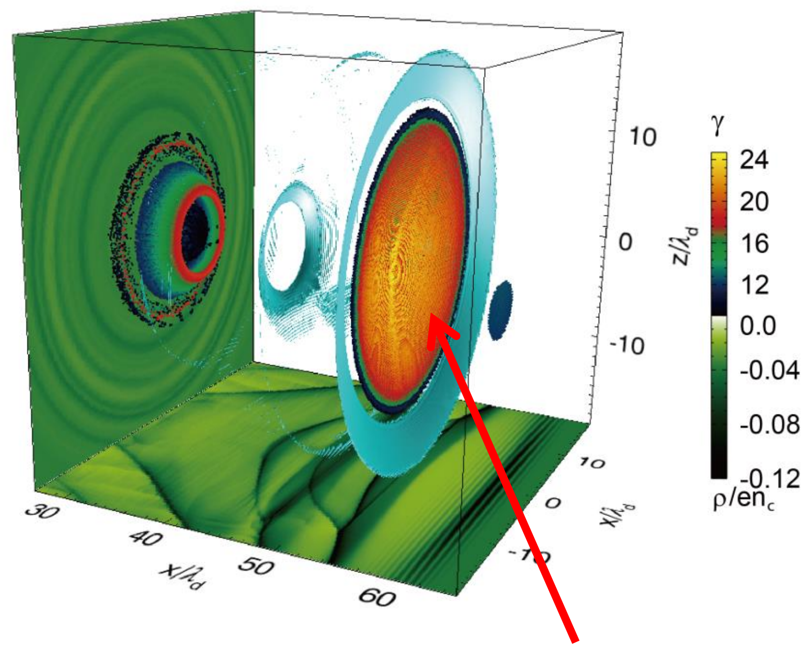
Measurement (above) vs MC calculated (below) dose maps for several depths in water for 142 MeV electron beam.

Simulation

Theory and simulation: Production of dense attosecond electron sheets by use of up-ramp density profiles – Z-M Sheng *et al*



F. Y. Li et al., PRL 2013, PRE 2014, APL2014



Controlled electron injection occurs around the density transition region

Quasi-1D electron sheet around 100 MeV

SCAPA: Summary

- SCAPA is a centre for high power laser-plasma science, focusing on the development and exploitation of laser-driven accelerators and radiation sources
- Configured experimental arrangements – dedicated beamlines to enable long term development, optimisation and stabilisation
- High repetition rate (up to 5Hz) 350 TW and (up to 10Hz) 40 TW
- Building complete and lasers commissioned; Beamlines & experiment stations to be developed over the next 18-24 months.
  - First 40 TW experiments from May 2017
  - First 350 TW experiments from early-2018
- Open to the community! – Please contact us to discuss potential experiments.

Thank you for your attention!

Acknowledgements:

- The SCAPA team
- University of Strathclyde, SFC and SUPA
- EPSRC & STFC funding councils
- Cockcroft Institute