SUPA

Scottish Universities Physics Alliance

SUPA Nuclear & Plasma Physics Theme

Prof. Dino Jaroszynski

Edinburgh, Glasgow, HWU, Strathclyde, UWS, Dundee

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Nuclear and Plasma Physics

Excellence: Team of >61 Researchers (incl. >20 academics) + >70 PhD students = >>100 publications p.a. + invited talks + >£6m grants p.a. (fluctuates)

Strong links with other themes in SUPA, SULSA, SINAPSE, Particle Physics, Astro & Space Physics, Energy, Photonics & Industry, Energy, Associate member of Cockcroft Institute, NPL

Diversity – Cross-disciplinary flag-ship project: SCAPA brings together NPP and Themes from all Pools: Nuclear + plasma physics = applications & new science

Innovation: ELI, high-field physics, NPL, applications of particle beams, radiation, detectors, imaging: KE opportunities

Training: CDT in the application of next generation accelerators & Nuclear MSc, NPL- graduate training.

Scottish Centre for the Application of Plasma-based Accelerators

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SCAPA

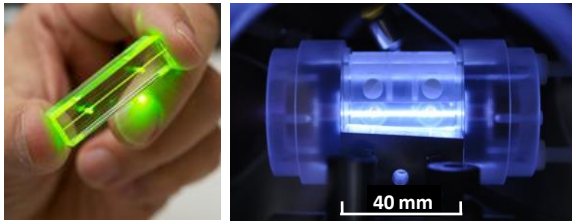
- **Building construction complete**
- **Now installation of equipment**

• Expansion of **ALPHA-X** laser-plasma accelerator facilities at Strathclyde with new laboratories.

• In-depth programme of **Applications**.
• Accelerator and source **Research & Development**.
• Knowledge Exchange & **Commercialisation**
• Engagement in European and other large projects.
• **Training:** Centre for Doctoral Training in the Application of Next Generation Accelerations

• **3 shielded areas** with **7 accelerator beam lines**.

• High-intensity femtosecond laser systems:
  a) 300-350 TW (with provision for PW) @ 5 Hz,
  b) 40 TW @ 10 Hz,
  c) sub-TW @ 1 kHz.
• High-energy **proton, ion and electron** bunches.
• High-brightness fs duration **X-ray & gamma-ray** pulses.



Compact GeV electron accelerator and gamma-ray source

APPLICATIONS

- **Radiobiology**
- **Ultrafast Probing**
- **High-Resolution Imaging**
- **Radioisotope Production**
- **Detector Development**
- **Radiation Damage Testing**

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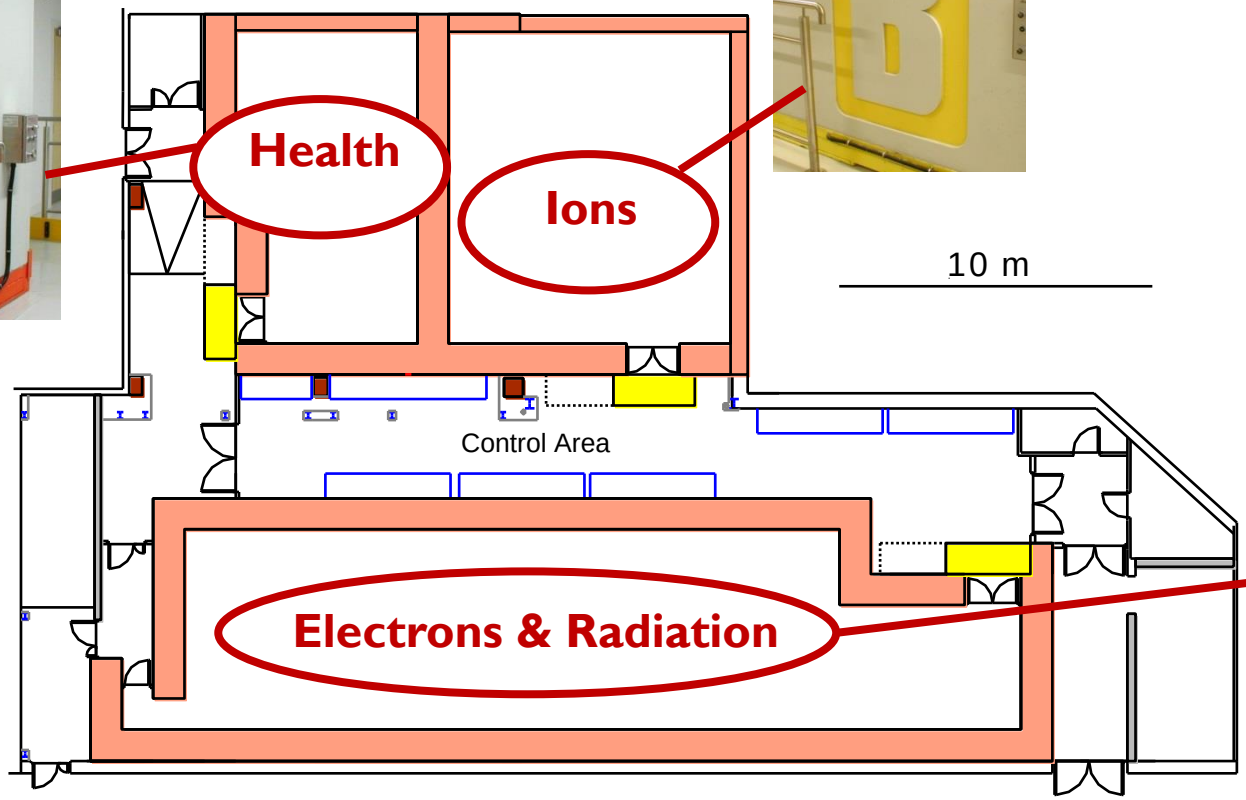
SCAPA Bunkers



Scottish Focus – but built on wider collaborations

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SINAPSE

SUPA Physics Scotland

www.supa.ac.uk

Science & Technology Facilities Council

EPSRC Engineering and Physical Sciences Research Council

CDT: *Centre for Doctoral* ***Training***

Queen's University Belfast

Cockroft Institute & Daresbury Laboratory

Associate Member since 2013

Edinburgh
Glasgow
UWS
Strathclyde

NPL

TIC: *Technology and Innovation Centre*

SCAPA

Fraunhofer UK

Fraunhofer Centre for Applied Photonics

EuCARD

NHS

NATIONAL NUCLEAR LABORATORY

esa

eli Nuclear Physics (ELI-NP) attosecond beamlines

CLF central laser facility

Laserlab Europe

ALPHA-X: Advanced Laser Plasma High-energy Accelerators towards X-rays – **Template for SCAPA**

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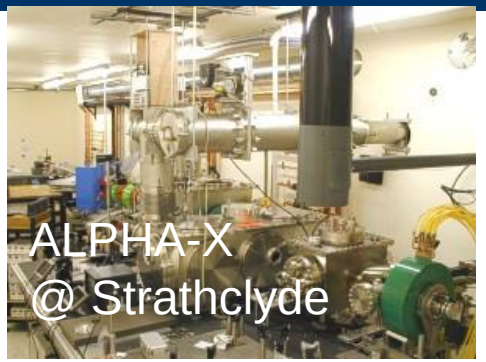
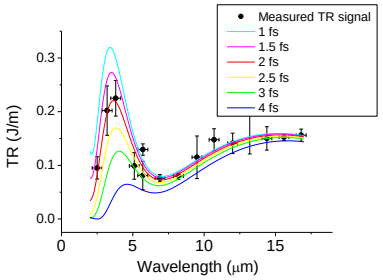
Compact R&D facility to develop and apply femtosecond duration particle, synchrotron, free-electron laser and gamma ray sources

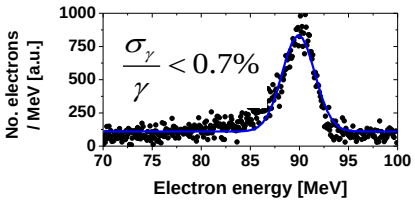


Jaroszynski et al., (Royal Society Transactions, 2006)

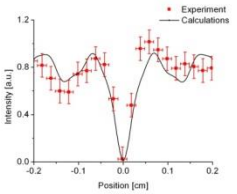
CTR: electron bunch duration: 1-3 fs



electron beam spectrum



phase contrast imaging with 50 keV photons



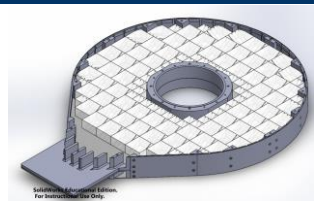
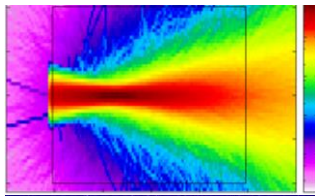
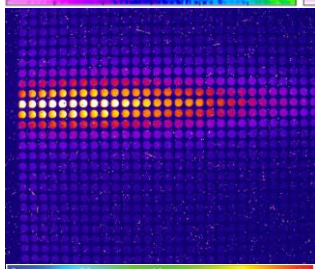
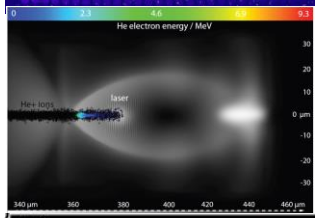
Brilliant particle source: 10 MeV → GeV, kA peak current, fs duration

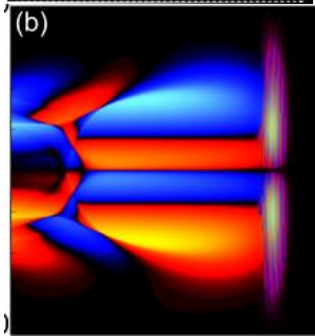
NPP research

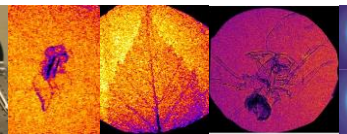
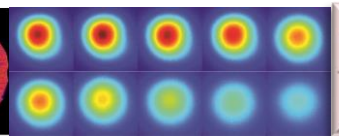
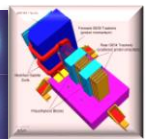
Selected examples of research undertaken

NPP Main results

- **Radiotherapy** – Dosimetry, radiobiology – collaboration between Strathclyde & Glasgow (Three experiments) – A. Subiel et al.,
- **Sprites** in dusty atmospheres – D. Diver et al., Glasgow
- **Trojan Horse** – way to very high brightness beams: laser and beam driven accelerators (B. Hidding et al., Strathclyde)
- **Dense matter interactions** and laser driven ion acceleration (P. McKenna et al., Strathclyde)
- **Compton backscatter:** LWFA & laser (C. Murphy et al., Edinburgh)
- **Nuclear physics studies** at Maintz (D. Ireland et al., Glasgow)
- **Attosecond pulses** from LWFA – theory (ZM Sheng et al., Strathclyde)
- **High power mm-wave** (THz) source (beam driven) – W. He et al., Strathclyde
- **Polarimeter** – D. Watts et al., Edinburgh
- **Fast timing hodoscope** - Hall B with CLAS12 – Dan Watts Edinburgh
- **Coherent attosecond VUV pulses** from LWFA – Dino Jaroszynski et al., Strathclyde
- **Radiotherapy and medical radioisotopes produced by LWFA** – collaboration between Strathclyde, Glasgow and SINAPSE



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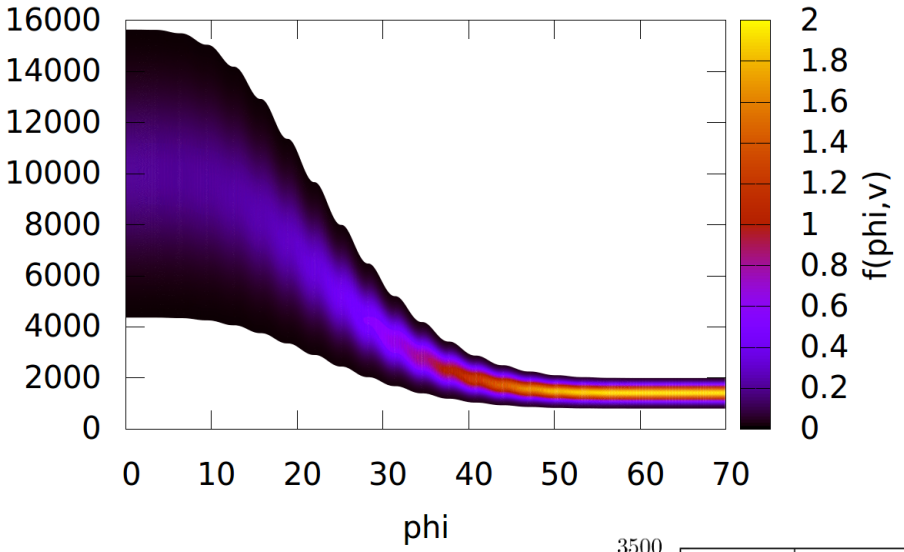
ELI: High Field Physics: radiation reaction

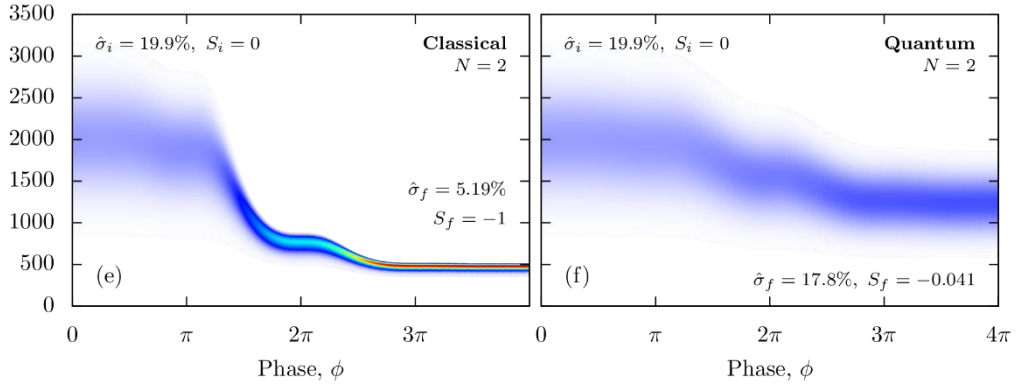
Cooling of electron beam due to radiation reaction and including quantum effects



Kravets, Noble, Jaroszynski, PRE (2013)

Yoffe et al., ARXIV 1410.1759 (2014)

Noble et al., Journal of Mathematical Physics 54, 043101 (2013)



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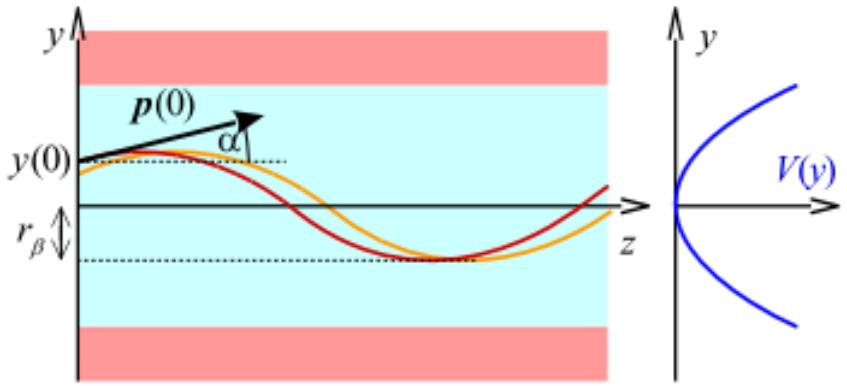
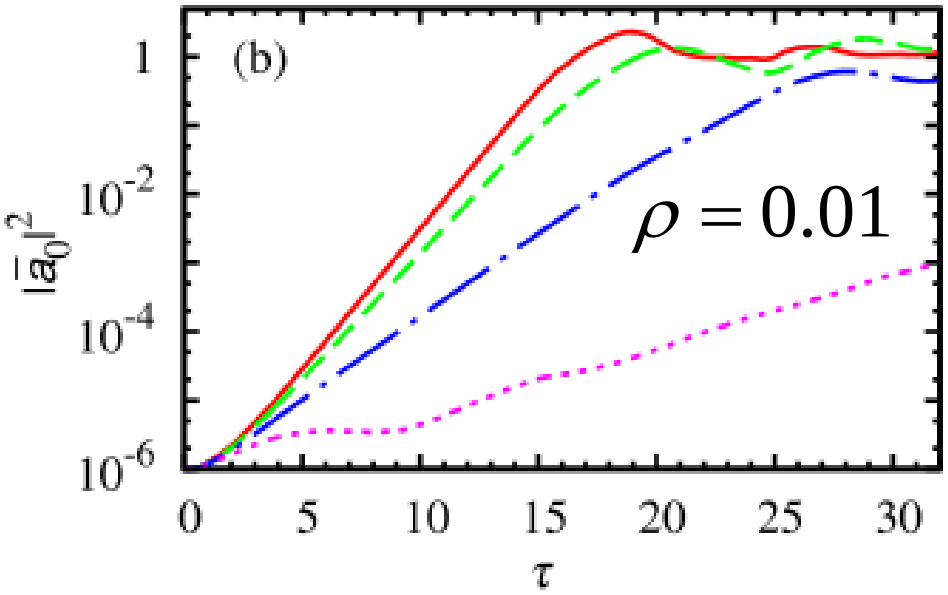
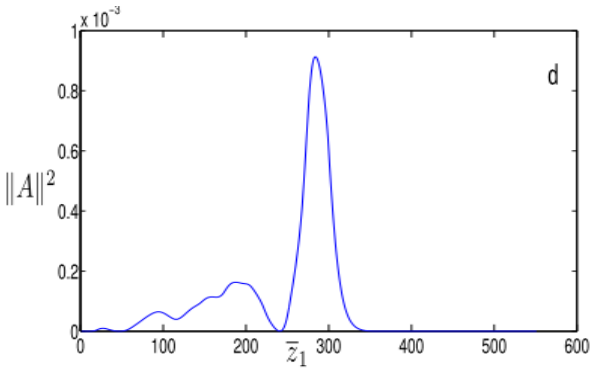
Ion Channel Laser: towards a compact coherent X-ray source



Similar to FEL but with variable wiggler parameter for each electron

Ersfeld et al., NJP (2014)





$$\rho = \left[\eta_h^2 \eta_m \bar{\eta}_f \omega_b^2 R_\beta^2 \Big/ \left(8\tilde{\gamma}_0 c^2\right)\right]^{1/2} \approx 3.3 \times 10^{-3}\left[\left(n_b/10^{18}\,\mathrm{cm}^{-3}\right)\Big/\tilde{\gamma}_0\right]^{1/2}\left(R_\beta/\mu\mathrm{m}\right).$$

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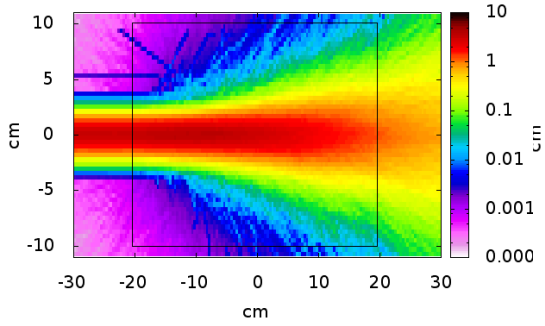
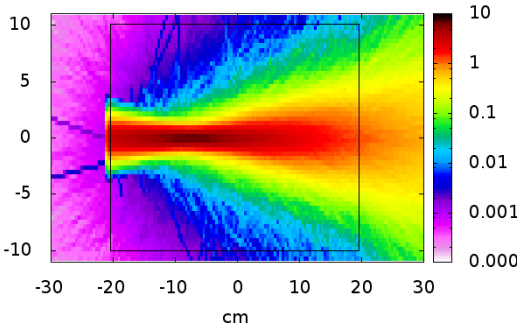
Focussing Very High Energy Electrons for Radiotherapy

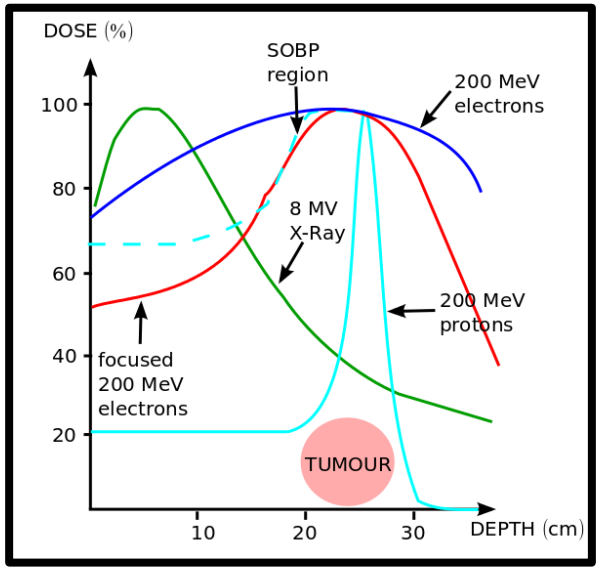
Focused beam simulation studies

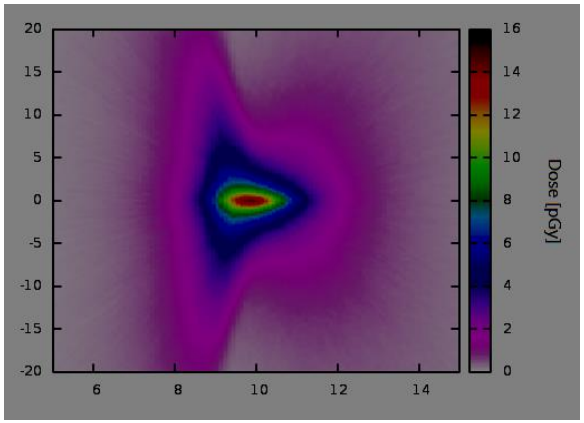
unfocused



focused

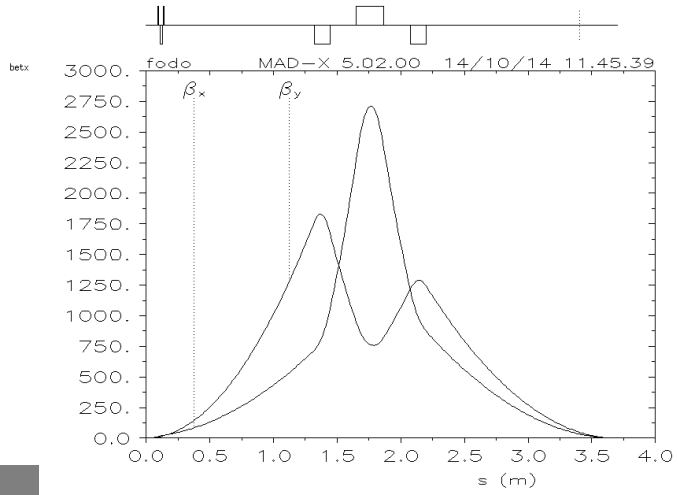


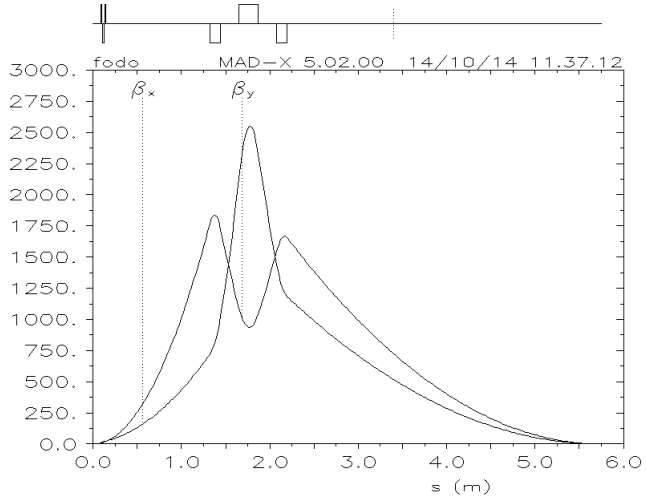




250 MeV strongly focussed

Beam transport





Theoretical and numerical studies of laser-plasma based electron acceleration and radiation

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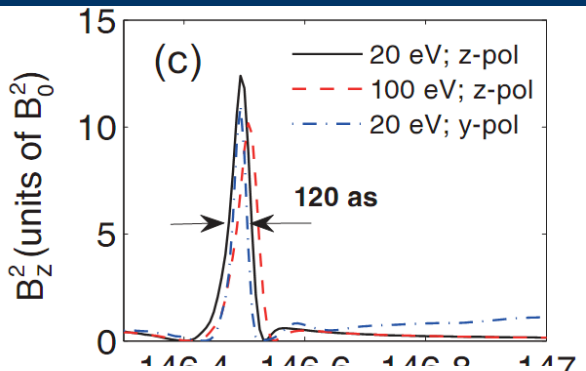
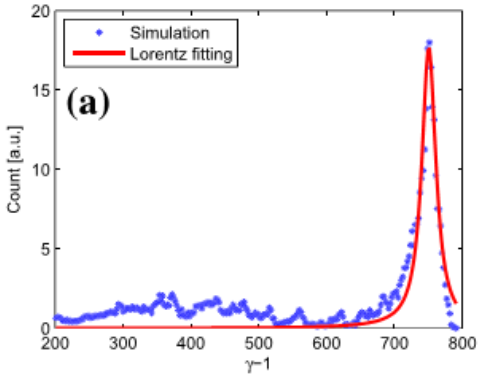
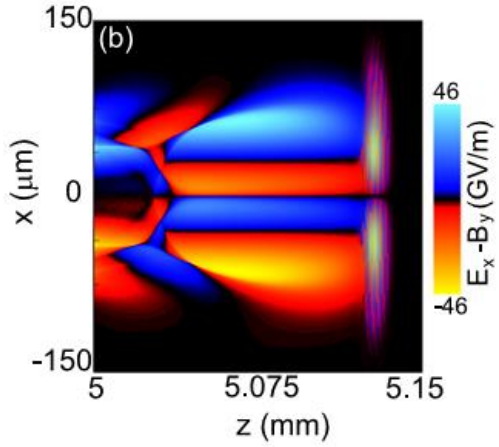
- ***F.Y. Li et al.,*** Ultra-bright attosecond pulse from laser wakefield acceleration, ***Phys. Rev. E 90, 043104 (2014).***

- ***M. Zeng et al.,*** Novel ionisation injection into laser wakefields towards stable and high quality --- Self-truncated ionization injection, ***Phys. Plasmas 21, 030701 (2014).***

- ***L.L. Yu et al.,*** Positron acceleration using multiple laser modes, ***Physics of Plasmas 21, 120702 (2014), selected as Editor's Pick 2014***







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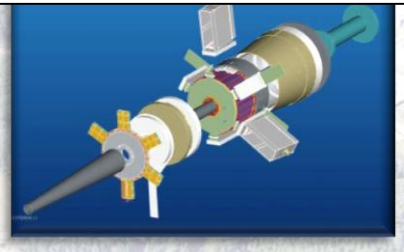
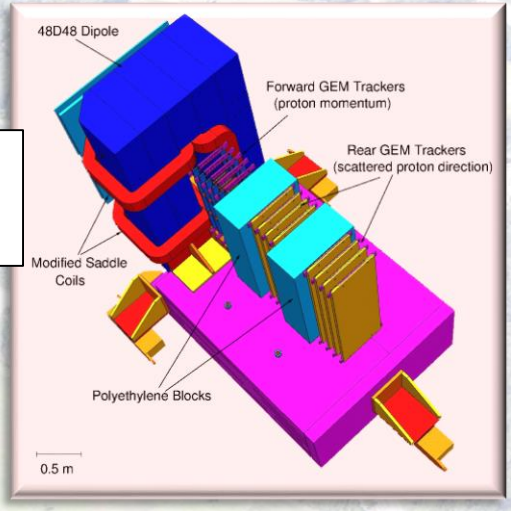
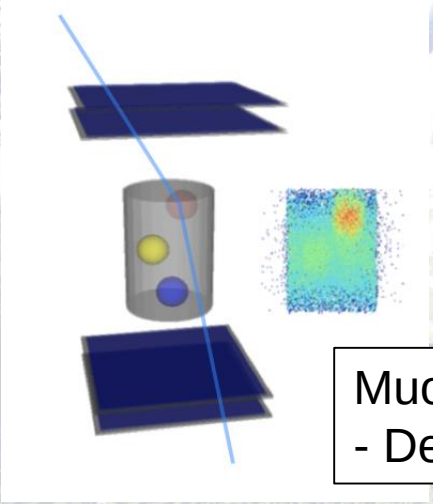
Glasgow Nuclear Physics Group – Highlights 2014

Funding

New STFC Project: Jefferson Lab Upgrade
- Funds (£1.5M) to contribute to detectors in Halls A & B







Muon Tomography: Research Contract from NNL/Sellafield
- Develop muon detector for imaging waste containers

Glasgow: Nuclear Physics Group – Highlights 2014

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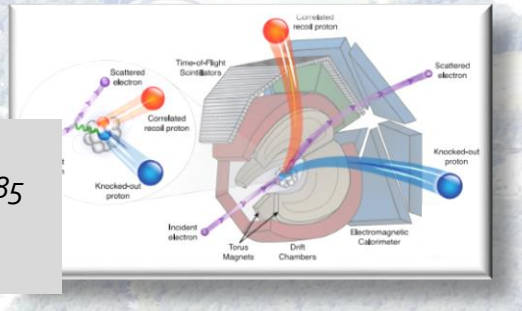
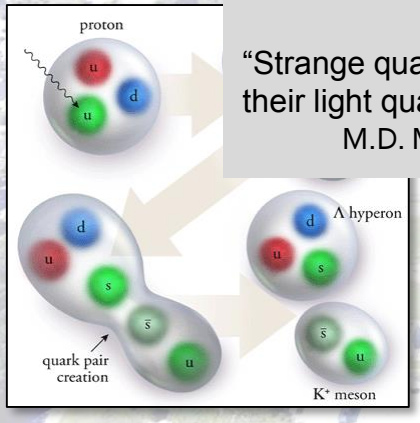
Key Publications

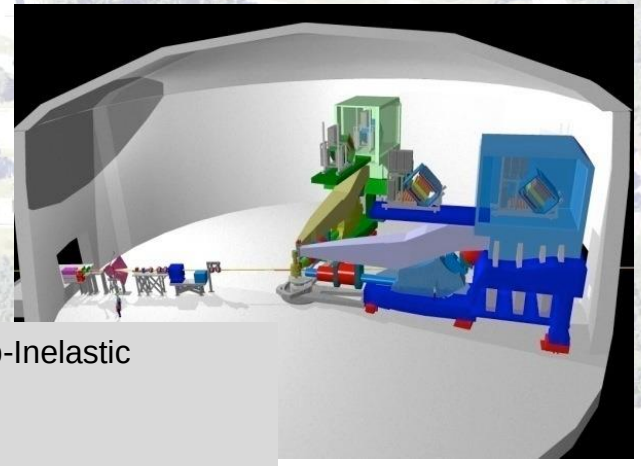


Momentum sharing in imbalanced Fermi systems
O. Hen *et al.*, **Science 346** (2014) 614, *doi:10.1126/science.1256785*
The Jefferson Lab CLAS Collaboration
Selected for Science Express (16 October 2014)

PRL Editors' Suggestion

"Strange quark–anti-quark pairs are less likely to be produced in hadronic collisions than their light quark counterparts, providing insight into color confinement in QCD."
M.D. Mestayer, K. Park et al. (**CLAS Collaboration**) Phys. Rev. Lett**. 113,** 15204 (2014)





Measurement of the Target-Normal Single-Spin Asymmetry in Deep-Inelastic Scattering from the Reaction He3↑(e,e′)X
J. Katich *et al.*
Phys. Rev. Lett. **113**, 022502 – Published 11 July 2014

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Scottish Centre for the Application of Plasma-based Accelerators (SCAPA)

- Expansion of **ALPHA-X** laser-plasma accelerator facilities at Strathclyde with new laboratories.

SCAPA – unique facility

- In-depth programme of **Applications**.
- Accelerator and source **R & D**.
- Knowledge Exchange & **Commercialisation**
- Engagement in European and other large projects.
- **Training:** Centre for Doctoral Training e.g. to supply the need for 100's of researchers at ELI and industry

- **3 shielded areas** with 7 accelerator beam lines.

- High-intensity femtosecond laser systems:
  - a) 280-340 TW (provision for PW) @ 5 Hz,
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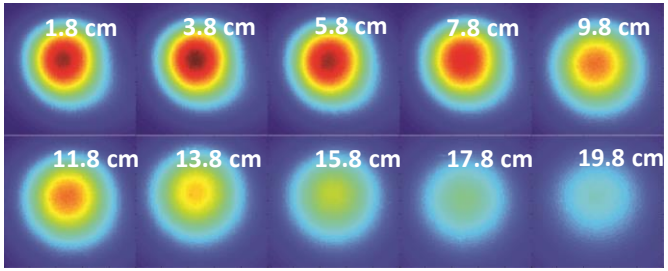
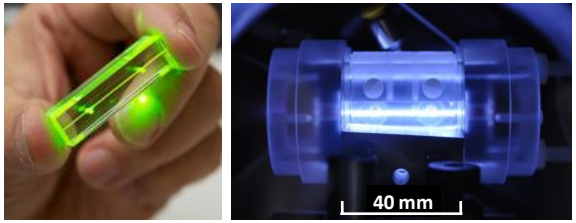


LWFA beam dosimetry



Compact GeV electron accelerator and gamma-ray source

APPLICATIONS

- **Radiobiology**
- **Ultrafast Probing**
- **High-Resolution Imaging**
- **Radioisotope Production**
- **Detector Development**
- **Radiation Damage Testing**

New grants and awards

- EPSRC – 'Physics of Life' area for plasma-assisted detection of airborne bacteria, joint with Ulster University, combined value about **£14m** (Glasgow)
- Anacail spin-out receives SMART award for portable device (Glasgow)
- EPSRC: Advanced laser-ion acceleration strategies towards next generation healthcare **£4.6m** (fraction to Strathclyde)
- EPSRC: Gyro-TWA for EPR and DNP **£412k** (Strathclyde)
- STFC CLASP – Novel Gyro-TWA for high power mm-wave Radar Remote Sensing **£295k** (Strathclyde)
- STFC mini-IPS – Millimetre wave klystrons **£145k** (Strathclyde)
- EOARD Low contrast surface artificial materials **£100k** (Strathclyde)
- EPSRC Equipment for Vector Network Analyser **£40k** (Strathclyde)
- Industry: Muon tomography; Ongoing research contract with Sellafield Ltd / NNL **£600k p.a.** (Glasgow)
- 2 STFC Rutherford Fellowships (Edinburgh NP group)
- JLAB project grant (Joint Glasgow/Edinburgh) one of the Nuclear physics projects selected put forward for PPRP. Will fund major new equipment for upgraded JLAB **(£1.4m).**
- STFC Project Grant ISOL-SRS **~£4.7M** (PI - Edinburgh NP)

Publications

- Glasgow: > 50 Peer reviewed (4 PRLs, 2 Editor Suggestions)
- Edinburgh: > 30 (1 Nat. Phys., 1 PRL, 1 JINST)
- Strathclyde: >40 (6 PRL)
- UWS: > 20 (4 PRL)

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Strategy – multi-disciplinary teams to create an applications programme

To bring together multi-disciplinary teams to develop:

- Radiobiology and dosimetry for health care
  - Radiotherapy using high energy electron and proton beams
  - High energy gamma rays – gamma knife
  - Develop theoretical understanding
- Radio-isotope production for health care:
  - Particle and photo-nuclear processes
- X-ray scattering – synchrotron-like source
- Coherent radiation – plasma-based
- Nuclear physics – photo-nuclear physics and application of ions
- Detectors – to provide access to large projects
- High field physics – to provide access to RAL, ELI, IZEST

Uniqueness and Competitiveness

- SCAPA: **Unique** laser-plasma accelerator facility:
- Generalised synchrotron source concept
- …. but much more compact because based on lasers - provides **particles** and **tuneable coherent and incoherent radiation** and **attosecond pulses**
- **Game changing technology** afforded by compactness and unique properties and ability to combine different sources on the same bench.
- Very competitive because much less expensive than conventional accelerators.
- New opportunities to commercialise the sources and the applications

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Strategy - SCAPA: develop an Academic Programme

- Creation of a Scottish centre of excellence for laser-plasma based radiation sources (SCAPA) producing
    - Ultra-short pulse X-rays (femtosecond – attosecond)
    - Coherent EM radiation
    - Gamma rays
    - Electrons, protons, light ions and secondary particles

  and their applications in
    - Electron & X-ray diffraction
    - Particle detector development
    - Radiation damage (space instrumentation, HiPER, ITER)
    - Hot dense matter (fusion studies)
    - Condensed matter physics
    - Molecular biology and medicine
    - Compact next-generation microwave based sources
    - Injectors, study of astrophysical systems in the lab


FIN
Thank you