STFC Accelerator Capabilities

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Executive Director, Programmes Directorate, STFC

EuCARD^2, Birmingham
20th January 2016


Harwell Campus
Rutherford Appleton Laboratory
Diamond Light Source
Daresbury Campus
Hartree Centre
Daresbury Laboratory
CERN: LHC
ILL and ESRF
Planck
ESO and ALMA
Square Kilometre Array

History

- Starting in 2002, the UK research councils made a targeted effort to re-establish and develop a UK-based accelerator science and technology capability
- Two new Institutes established:
  - John Adams Institute
  - Cockcroft Institute
- We have succeeded in attracting internationally recognised accelerator experts (back) to the UK
- We are training a new generation of postdocs and students
  - Example: the number of PhD students in the field has gone from < 5 to over 50 in the past decade

Science & Technology Facilities Council

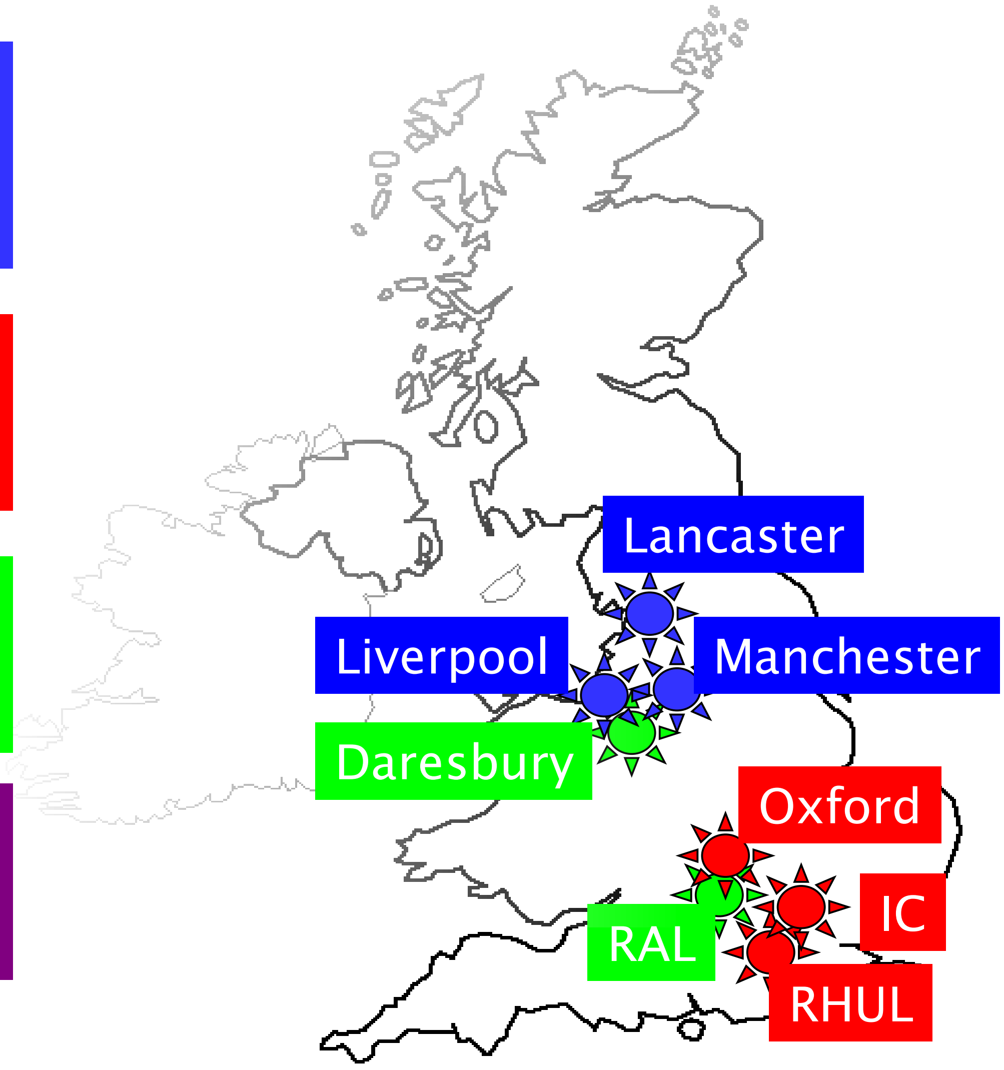
Geography

Cockcroft Institute
- Lancaster, Liverpool, Manchester, and STFC

John Adams Institute
- Oxford, RHUL, IC

National Laboratories
- Daresbury, RAL

Other University Groups



Funding

- The accelerator R&D programme funded though STFC Science Programmes Office is about £12M per year
- This is complemented by resources within our national laboratories
- The programme leverages additional resources from
  - International Labs
  - Universities
  - Other research councils
  - Regional development agencies
  - European Commission programmes
  - …
- Strategic input from ASB

Cockcroft Institute Building at Daresbury

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The programme (1)

- Support for the Cockcroft and Adams Institutes, university rolling grant effort, accelerator groups at RAL and DL + underlying technologies
- LHC and its upgrade
- ISIS
- DIAMOND
- High Power Proton Accelerators – front end test stand for MW ISIS upgrade
- Future lepton colliders (mainly CLIC with CERN, and muon accelerator contributions)
- Novel accelerator techniques (FFAG, AWAKE, Laser Plasma)

The programme (2)

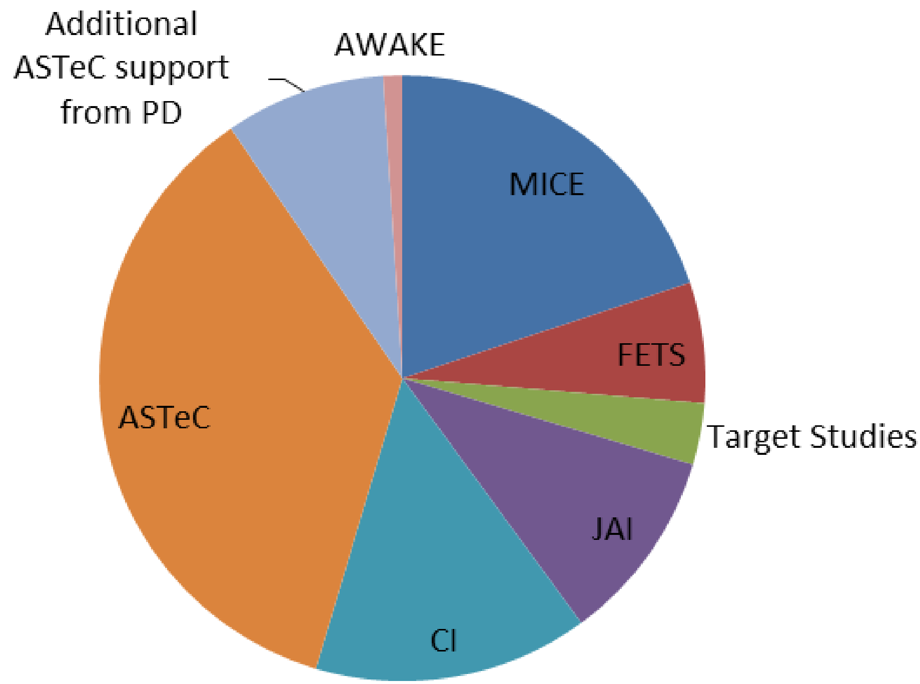
- Laser plasma work at CLF, IC, JAI, Strathclyde and partners
- The MICE experiment at RAL
- Next generation Neutrino Facilities
- Medical applications (EMMA, ALICE…)

Proton Therapy (Christies Hospital Manchester, UCLH London)

Medical Diagnostic Radio-isotopes etc.

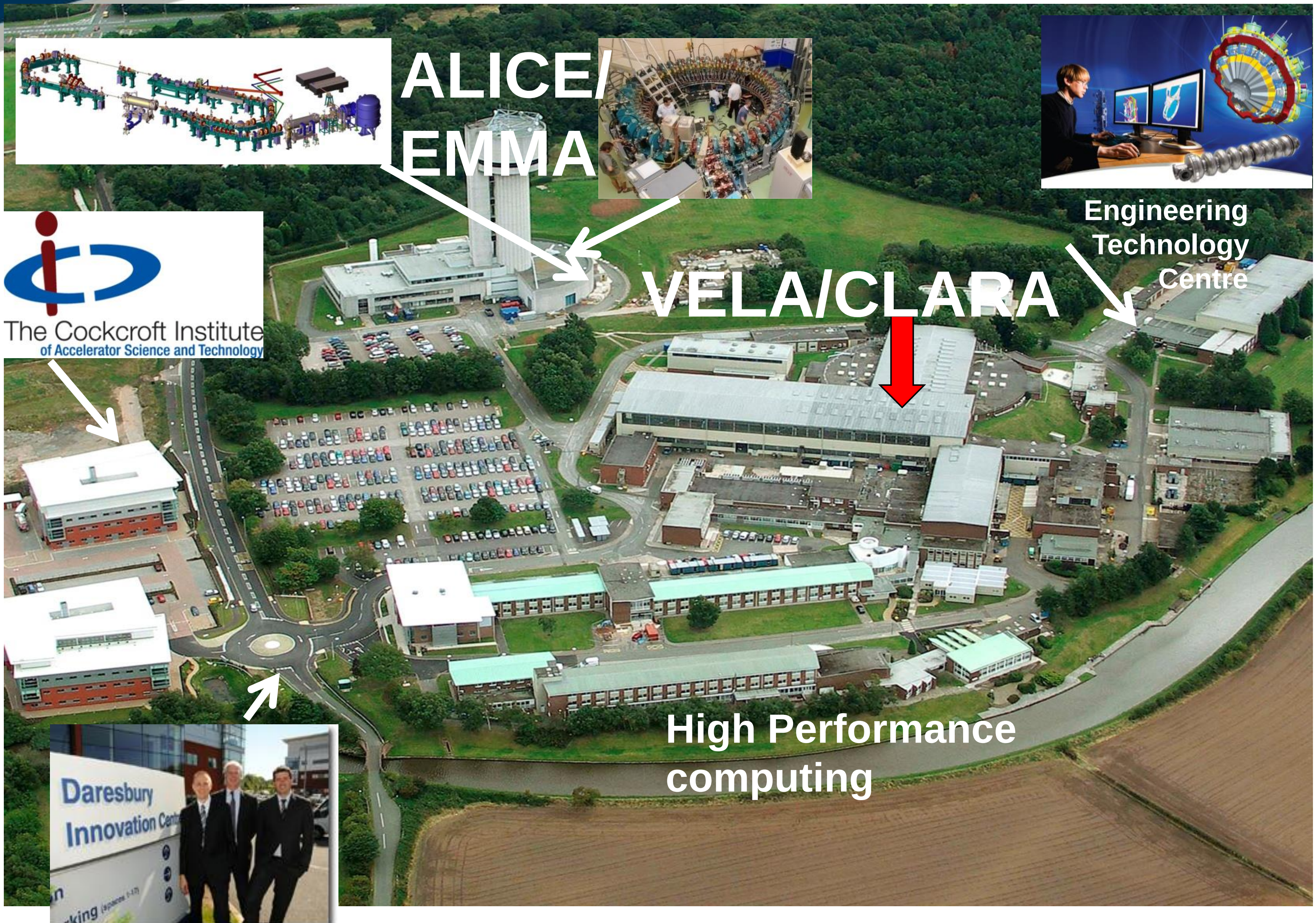
THz imaging for diagnosis of oesophegal cancer

Accelerator Programme Funding 2013/14

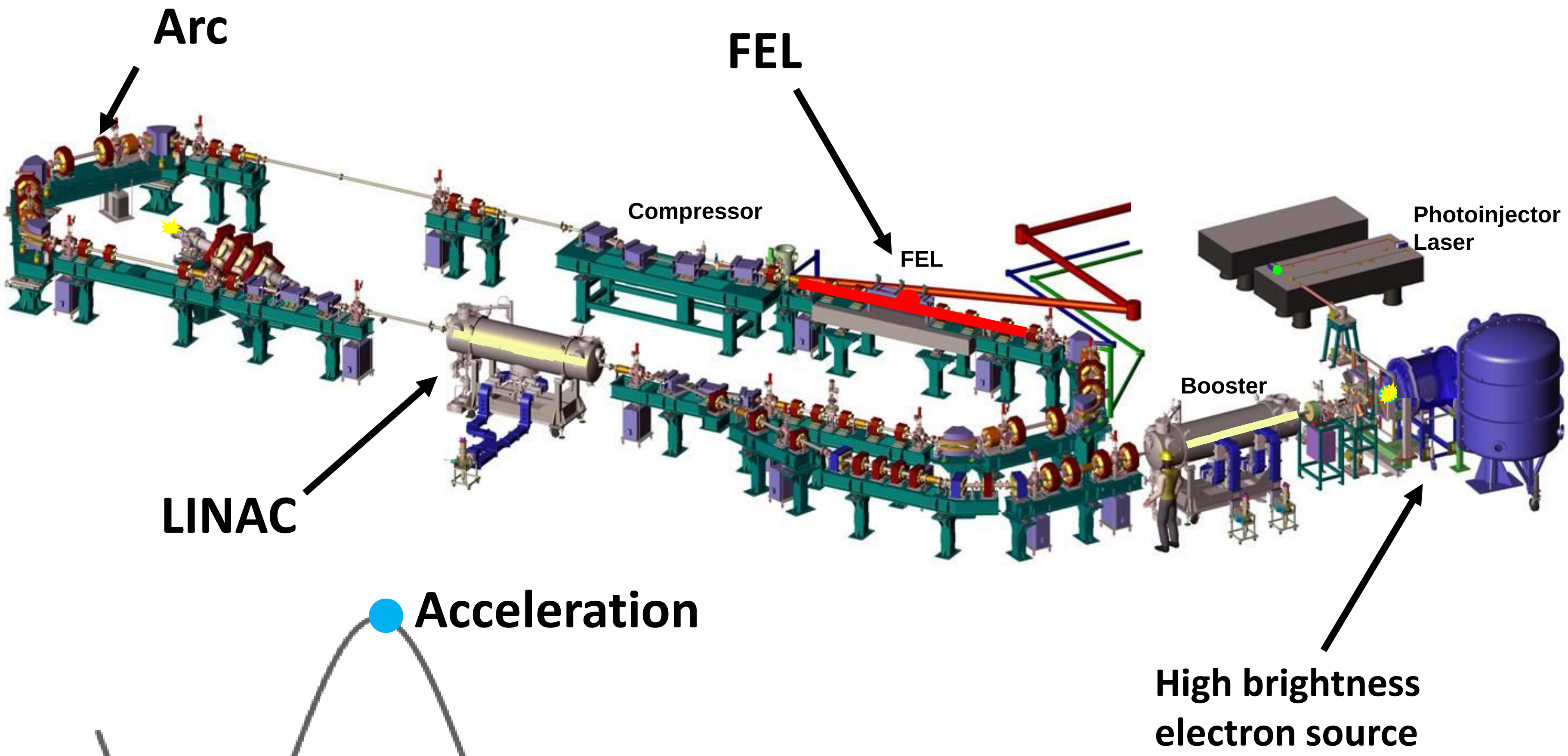


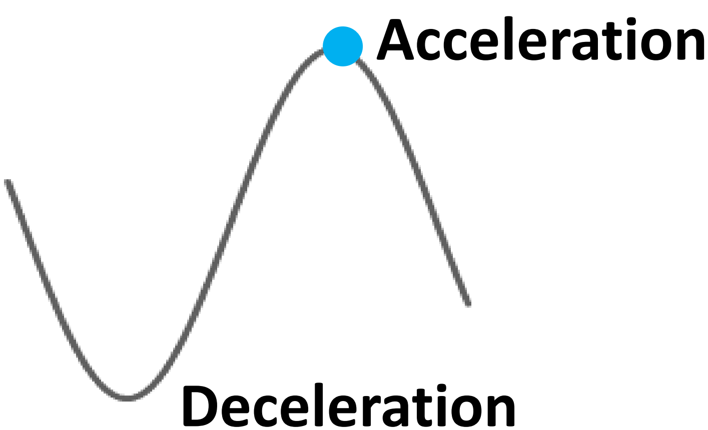
Initial structure has now bedded in
Now is the time to review balance and opportunities

Daresbury Test Facilities: ALICE, EMMA, VELA and CLARA



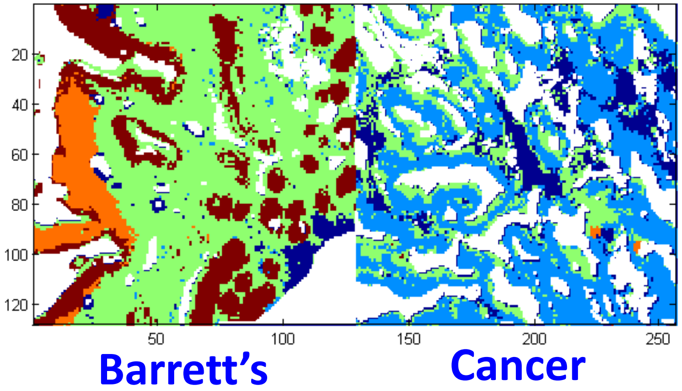
The ALICE Energy Recovery Linac





Using the ALICE IR-FEL to Develop A Cancer Diagnostic

- Oesophageal cancer is the fastest rising incidence of cancer in the western world and survival rates are very poor
- Oesophageal cancer often progresses from **Barrett's oesophagus**: lining of the oesophagus is damaged by stomach acid and changed to a lining similar to that of the stomach.
- **The challenge is to identify patients with Barrett's oesophagus who will develop oesophageal cancer.**
- **Potential solution: Spectroscopy and microscopy in the IR**
- Use different wavelength's in the IR to probe different tissue types and make diagnosis much more reliable – requires very high intensity IR for the required spatial resolution
- The team of academics and clinicians has now extended the work to cover prostate and cervical cancers also



each cluster corresponds to a (broad) tissue type

Blue: Stroma (cancerous sample)

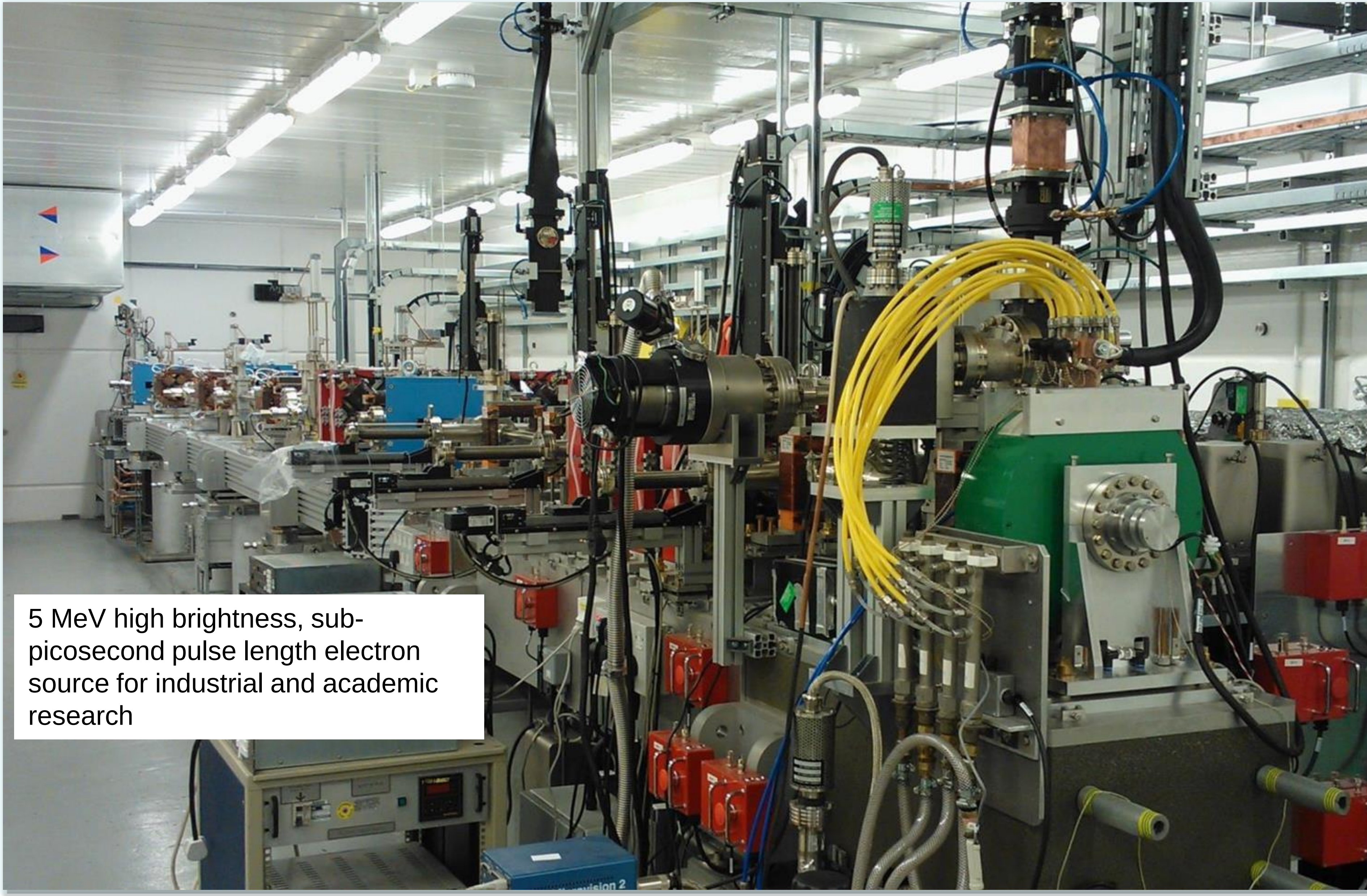
Brown: Goblet Cells and Barrett's Oesophagus Tissue

Orange: Barrett's Oesophagus Nuclei

Green: Stroma (benign sample)

Cyan: Cancer

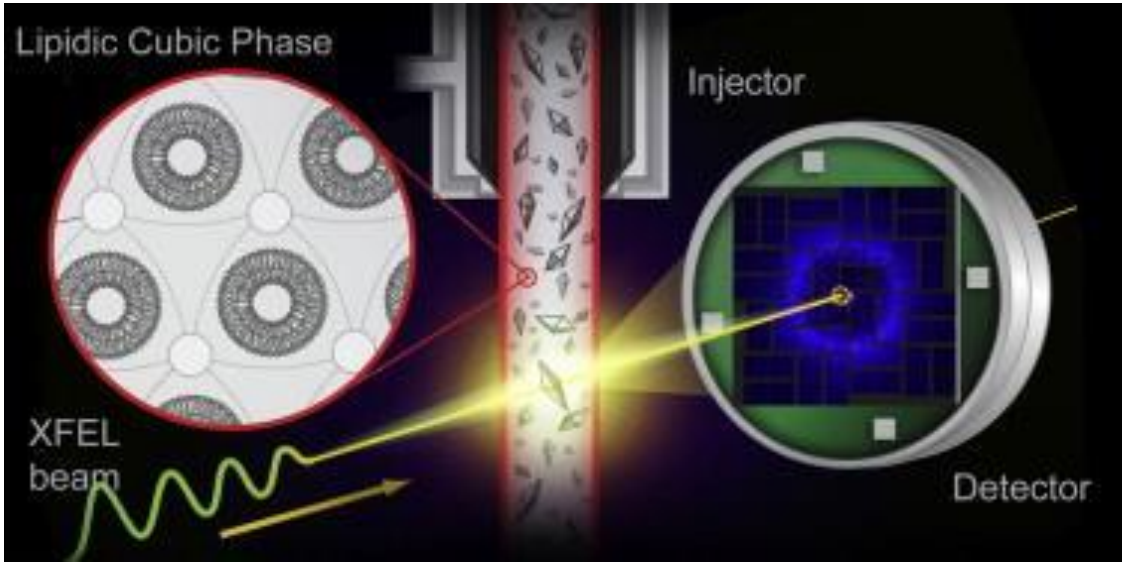
VELA



5 MeV high brightness, sub-picosecond pulse length electron source for industrial and academic research

What can you do with a Free Electron Laser?

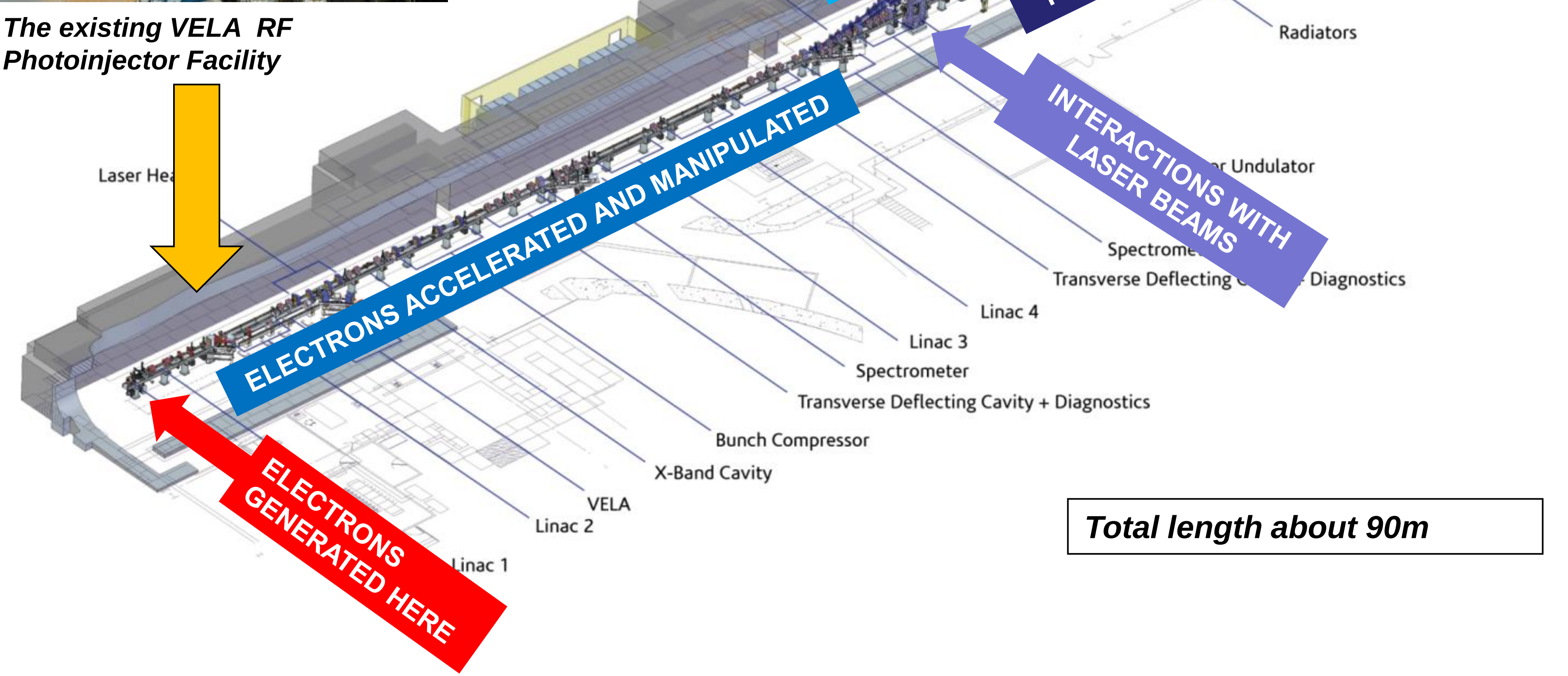
- Millions of people take ARB drugs every year to reduce their blood pressure (Amias, Teveten, Aprovel, …)
- The joining of the drug molecule to the cell membrane stops a hormone from interacting with the cell and then constricting the blood vessels
- Tiny crystals containing many copies of the drug joined to the cell were examined with a FEL to understand the exact atomic details of how it works – all the theories about what this would look like were wrong
- Better understanding could lead to more effective drugs
- **This experiment is only possible with an X-Ray FEL**



H. Zhang et al., Cell, 23 April 2015

What will CLARA look like?

The existing VELA RF Photoinjector Facility



Total length about 90m

CLARA Status

Phase 1 of CLARA is being installed now alongside VELA. Commissioning with beam will commence in May 2016 whilst procurement continues on the other hardware required to complete CLARA.

FFAGs

- **See talk by Carol Johnstone for details**
- **Fixed Field Alternating Gradient accelerators**
- **Combine properties of cyclotrons and synchrotrons:**
  - Cyclotron features beyond energy for carbon therapy
  - But better beam control
  - Much higher beam current capability (e.g. for radioisotope production)
- **But unique features, so needed to build one**
  → EMMA
- **EMMA design came from an international collaboration**
- **Engineering design and construction: mainly done by STFC**
- **Commissioning: STFC and international collaboration**

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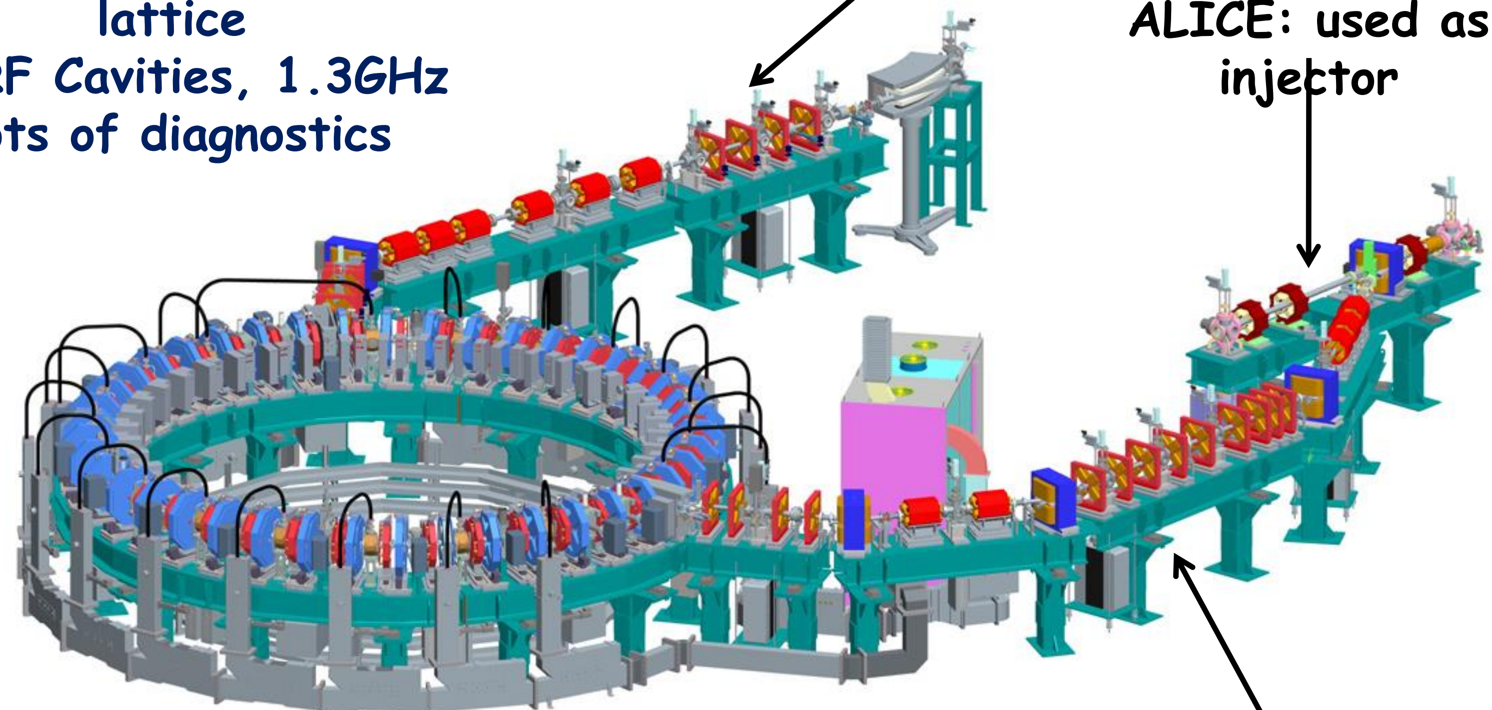
EMMA Layout

EMMA
10-20 MeV electrons
42 cells, linear doublet lattice
19 RF Cavities, 1.3GHz
Lots of diagnostics

Diagnostics beam line: beam properties measurement

Section of ALICE: used as injector

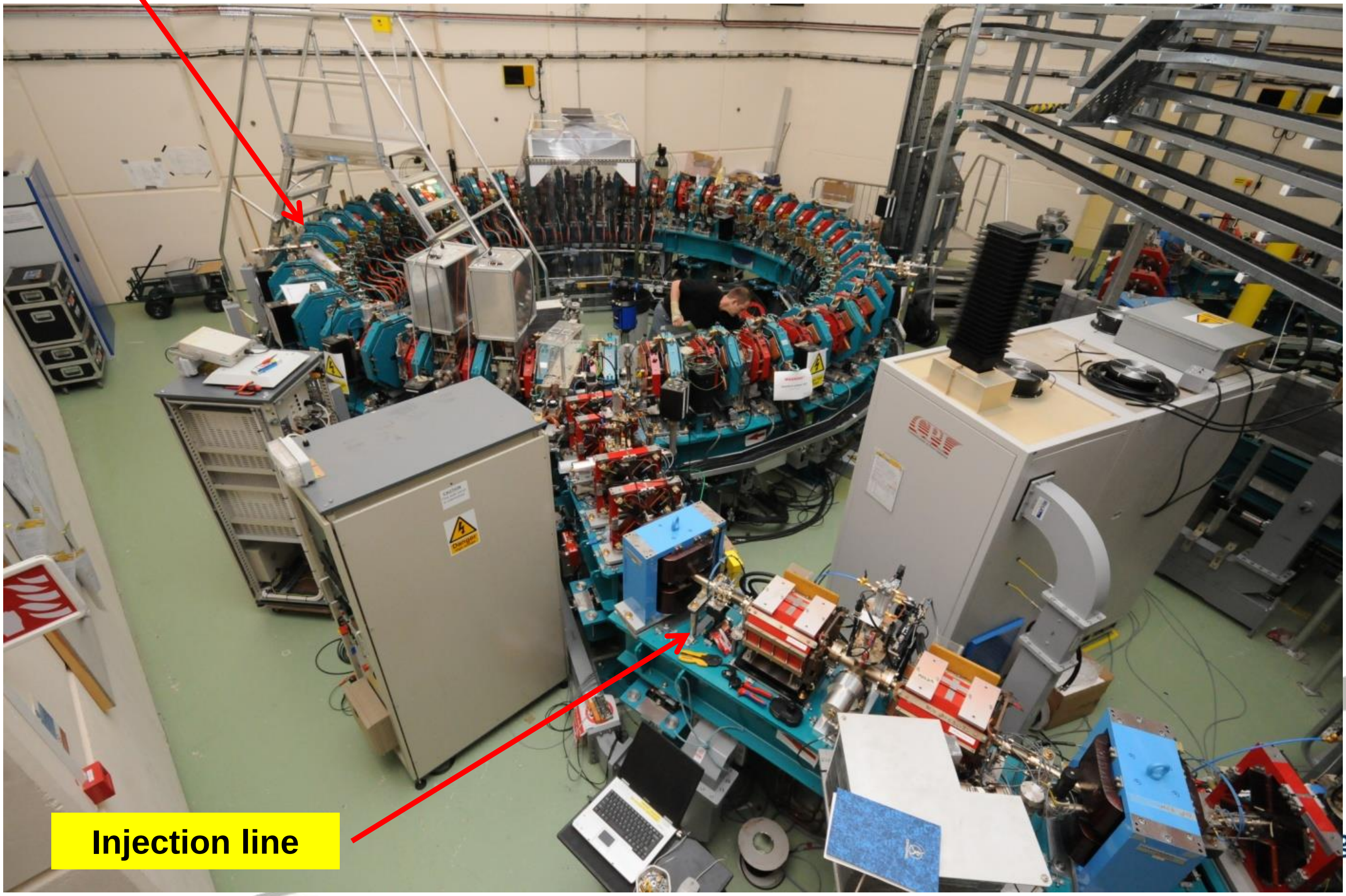


Injection line

EMMA ring

EMMA Construction - from 2007 to 2011

EMMA ring



Injection line

Status

- Experimental measurements are been successful
  - EMMA works!
  - has demonstrated the features of FFAGs
  - shown that they are viable for various applications
- EMMA is now mothballed
- But work being done on FFAGs for:
  - ion beam analysis – Huddersfield & PAC (Carol's talk)
  - proton therapy and pCT – Manchester (Hywel's talk)
  - large beam current radioisotope production – Huddersfield & PAC
  - upgrade to ISIS neutron spallation source – STFC
  - etc

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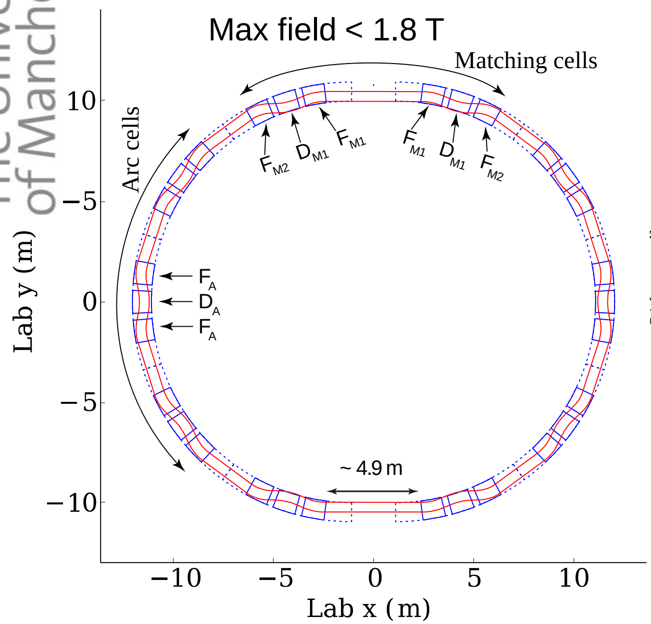
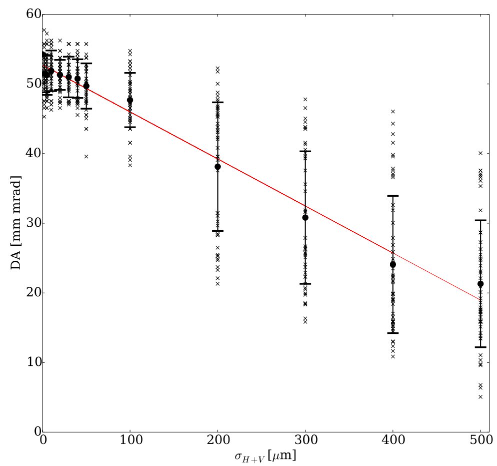
NORMA: 350 MeV NC FFAG, 1 kHz pulses + imaging






PHYSICAL REVIEW ST ACCELERATORS AND BEAMS

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Accepted Paper

Normal-conducting scaling fixed field alternating gradient accelerator for proton therapy

Phys. Rev. ST Accel. Beams

J. M. Garland, R. B. Appleby, H. Owen, and S. Tygier

Accepted 10 September 2015

ABSTRACT

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In this paper we present a new lattice design for a 30~-~350~MeV scaling FFAG accelerator for proton therapy and tomography - NORMA (NOrmal-conducting Racetrack Medical Accelerator). The energy range allows the realisation of proton computed tomography (pCT) and utilises normal conducting magnets in both a conventional circular ring option and a novel racetrack configuration, both designed using advanced optimisation algorithms we have developed in PyZgoubi. Both configurations consist of ten FDF triplet cells and operate in the second stability region of Hill's equation. The ring configuration has a circumference of 60~m, a peak magnetic field seen by the beam of~

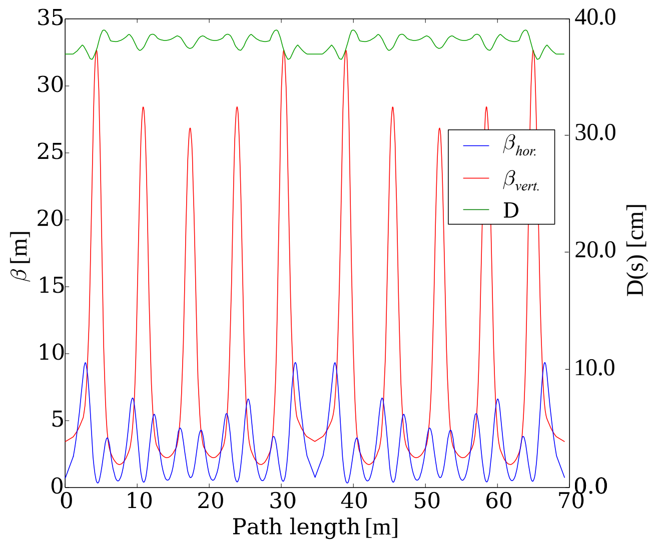
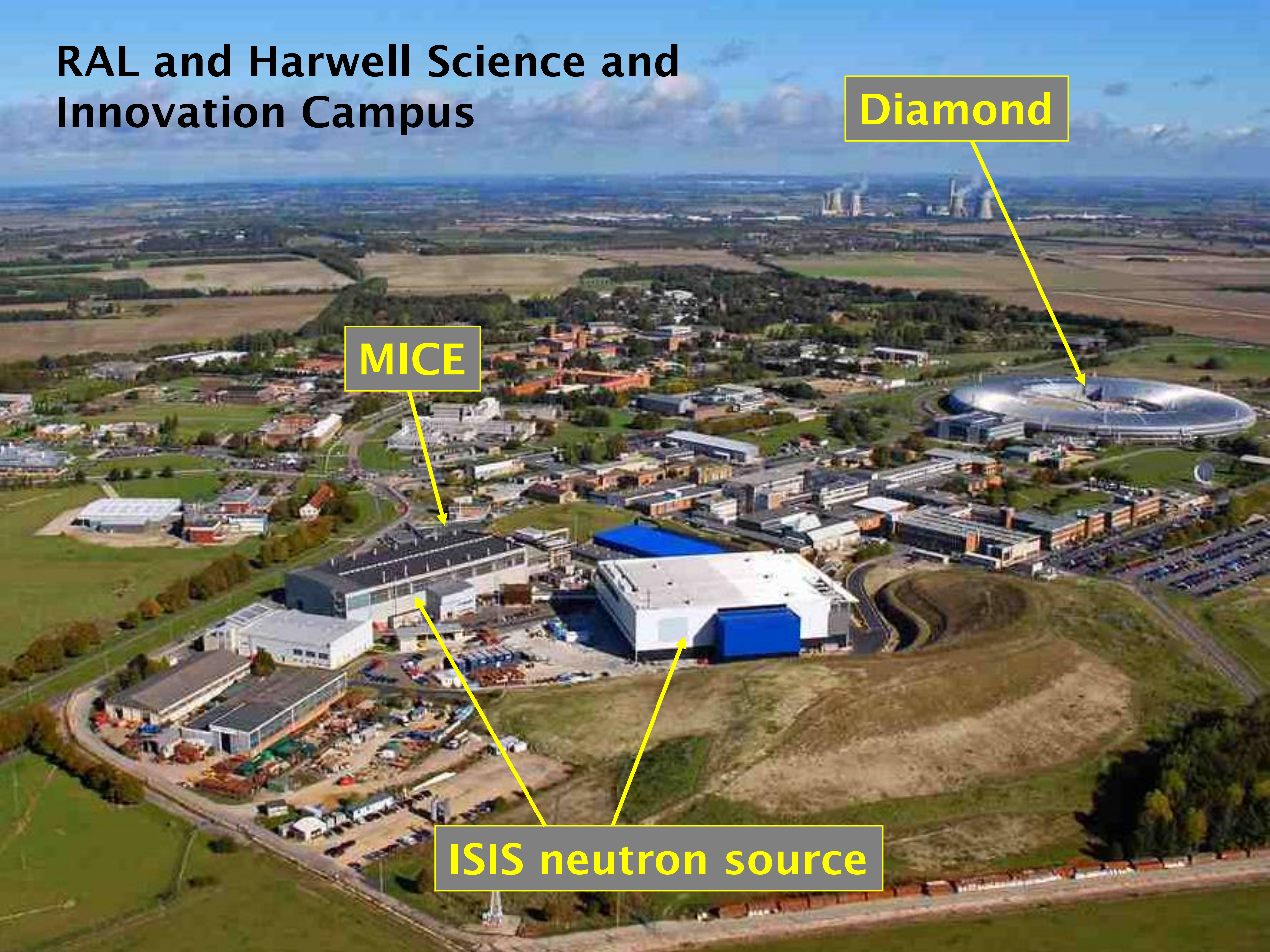


TABLE IV. The main parameters of the NORMA racetrack with $L_{RT} = 2.0$ m after initial optimisation when $f_{RT} = 1.0$, and after scaling when $f_{RT} = 0.91$.

Parameter [unit]	$f_{RT} = 1.0$ **(unscaled)**	$f_{RT} = 0.91$ **(scaled)**
Average radius r_0 [m]	9.61	10.55
Circumference [m]	64.4	70.7
Av. hor. orbit excur. [m]	0.44	0.49
Average ring tune (Q_h, Q_v)	7.70, 2.66	7.71, 2.68
k	26.4	26.4
Peak F_{M1} field [T]	**1.91**	**1.74**
DA [mm mrad]	52.0	57.7
Magnet-free drift [m]	4.4	4.9

RAL and Harwell Science and Innovation Campus



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Diamond Light source

Energy	3 GeV
Circumference	561.6 m
No. cells	24
Symmetry	6
Straight sections	6 x 8m, 18 x 5m
Insertion devices	4 x 8m, 18 x 5m
Beam current	300 mA (500 mA)
Emittance (h, v)	2.7, 0.03 nm rad
Lifetime	> 10 h
Min. ID gap	7 mm (5 mm)
Beam size (h, v)	123, 6.4 mm
Beam divergence (h, v) *(at centre of 5 m ID)*	24, 4.2 mrad

Commissioned in 2006 and open for users in January 2007

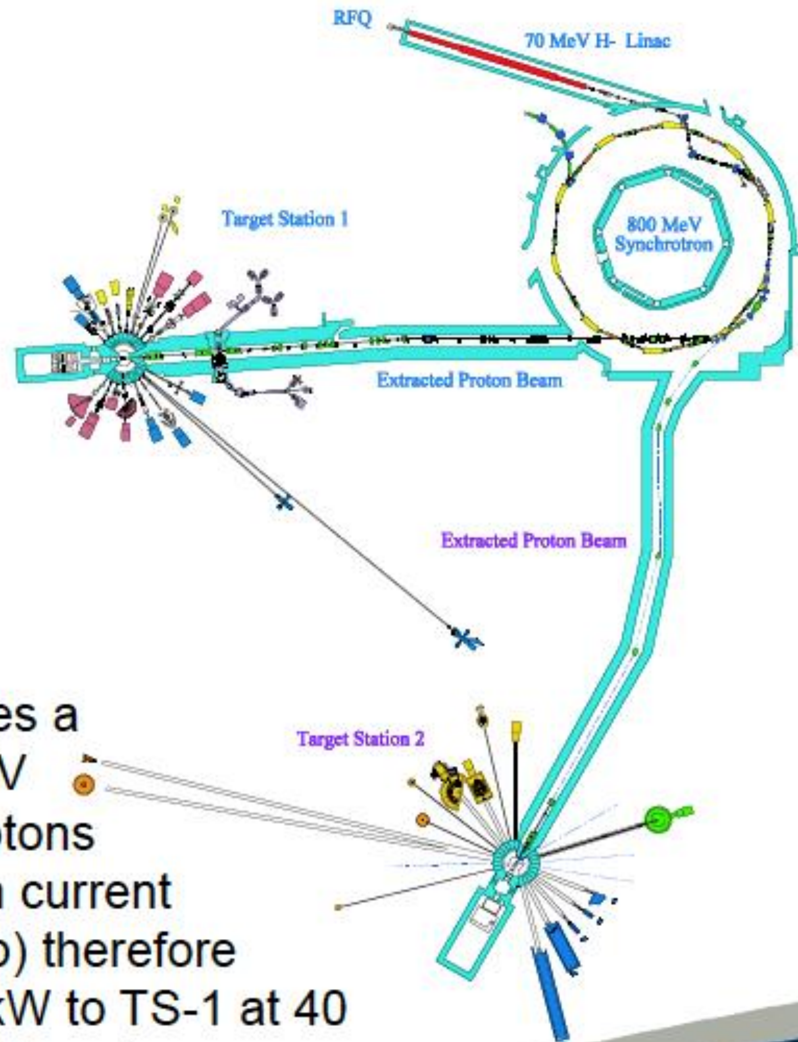
Currently operating 13 beamlines with 10 in-vacuum insertion devices

Additional beamlines planned.

A lattice upgrade being studied; similar to ESRF

ISIS Accelerators

- H^- ion source (17 kV)
- 665 kV H^- RFQ
- 70 MeV H^- linac
- 800 MeV proton synchrotron
- Extracted proton beam lines



The accelerator produces a pulsed beam of 800 MeV (84% speed of light) protons at 50 Hz, average beam current is 230 μA (2.9× 10^{13} ppp) therefore 184 kW on target (148 kW to TS-1 at 40 pps, 36 kW to TS-2 at 10 pps).

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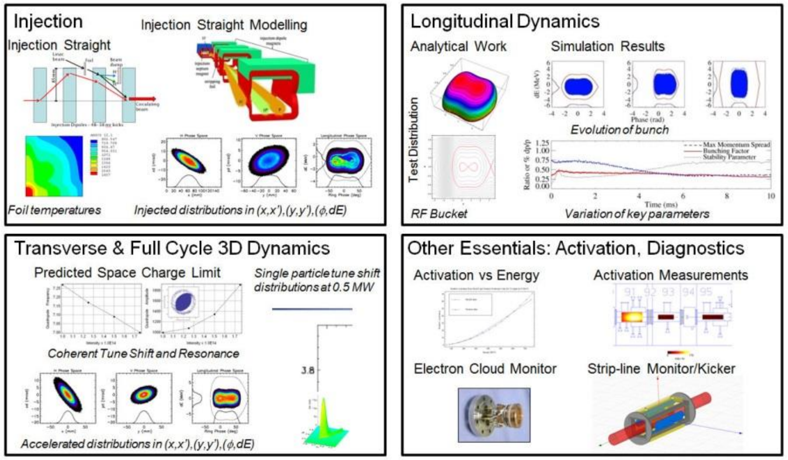
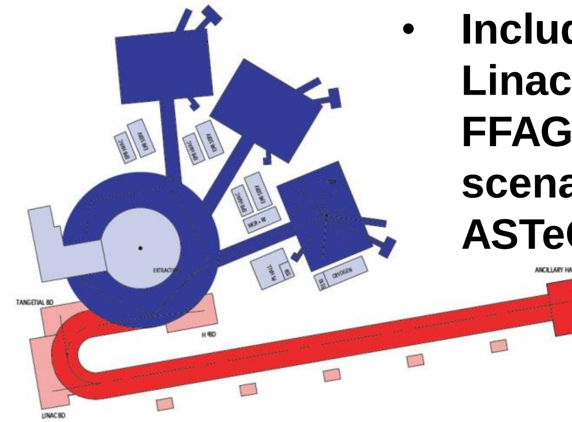
ii. designing potential ISIS accelerator upgrades for increased capability

180 MeV injection



MW regime 'ISIS-II' scenarios

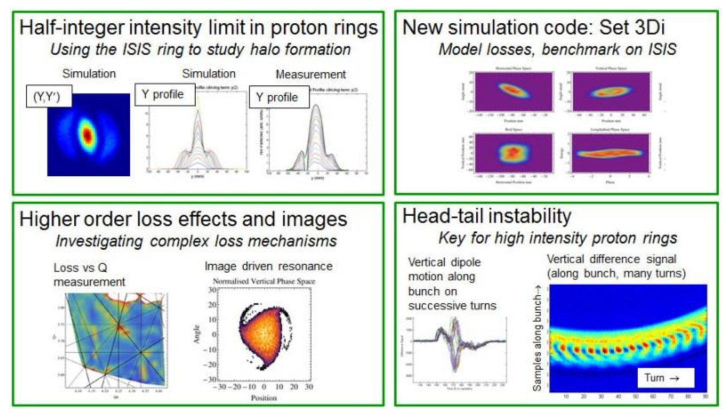


- **Including SC Linac and FFAG scenarios from ASTeC**

iii. generic proton R&D

***e.g.* ion source development**

High intensity R&D studies



iv. target upgrades

Front End Test Stand (FETS)

High brightness H^- ion source

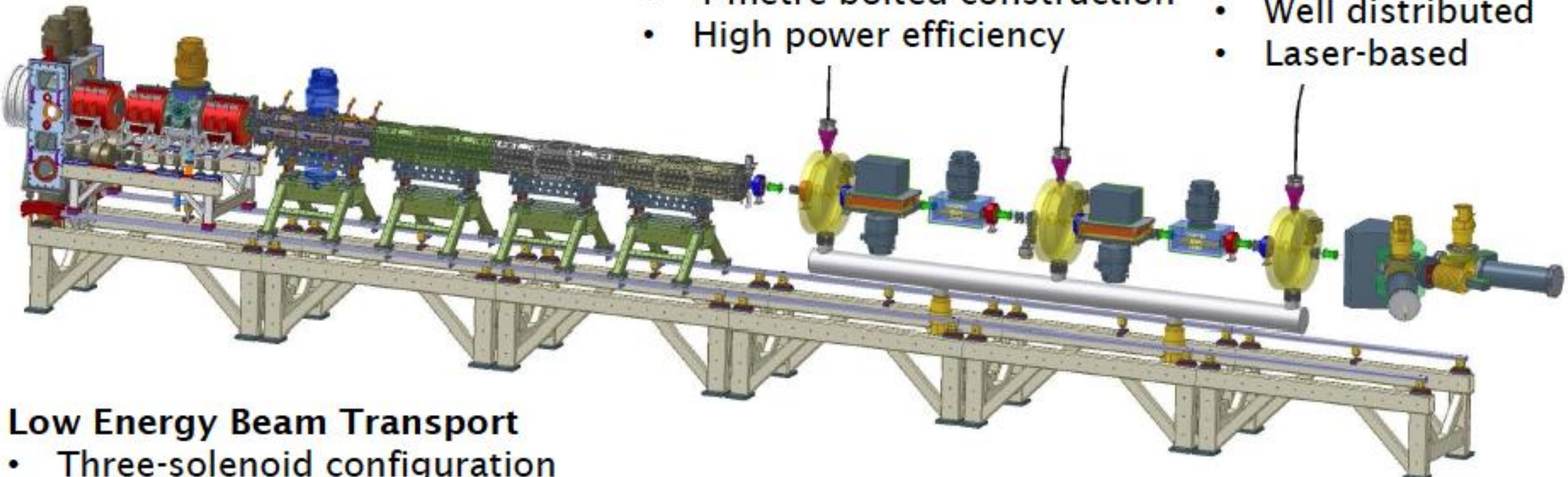
- 4 kW peak-power arc discharge
- 60 mA, 0.25 π mm mrad beam
- 2 ms, 50 Hz pulsed operation

Radio Frequency Quadrupole

- Four-vane, 324 MHz, 3 MeV
- 4 metre bolted construction
- High power efficiency

Diagnostics

- Non-interceptive
- Well distributed
- Laser-based



Low Energy Beam Transport

- Three-solenoid configuration
- Space-charge neutralisation
- 5600 Ls^{-1} total pumping speed

Medium Energy Beam Transport

- Re-buncher cavities and EM quads
- Novel ‘fast-slow’ perfect chopping
- Low emittance growth

Science & Technology Facilities Council
ISIS
ASTeC
JAI John Adams Institute for Accelerator Science
Imperial College London
The University of Warwick
Royal Holloway University of London
UCL
ESS bilbao

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Electron Acceleration

- A High Power Laser (HPL) focussed into a gas accelerates electrons to very high energy in a short distance (cm's) – "*Wakefield Acceleration*"
- Possible to produce multi-GeV+ energies at PW powers
- Game changing
- To date, LWA electron energies produced at 1.7 GeV at CLF (cf DLS 3 GeV)

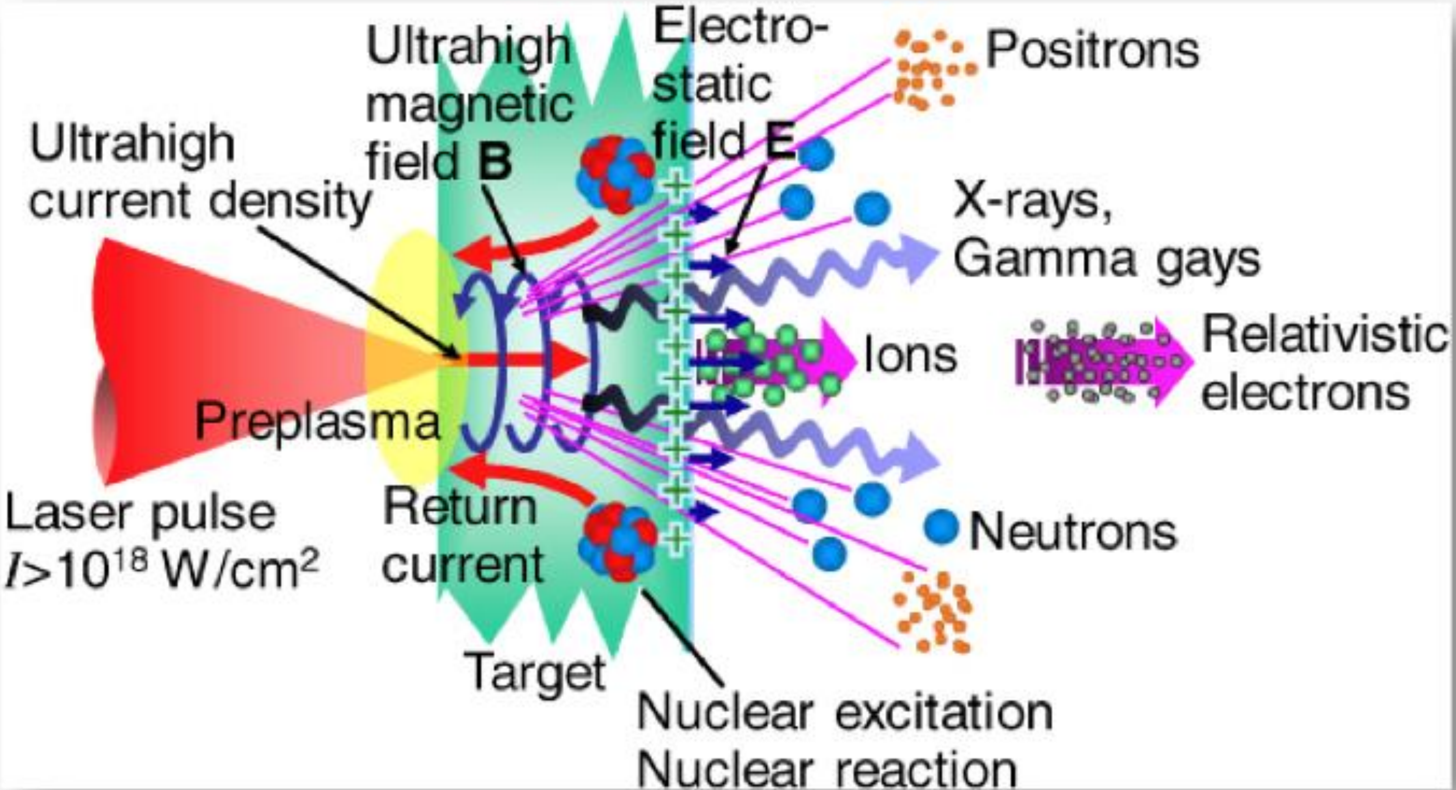
Open Workshop 31st January 2013
IoP London

Imperial College London

EPSRC
Engineering and Physical Sciences Research Council

High Power Laser Interaction

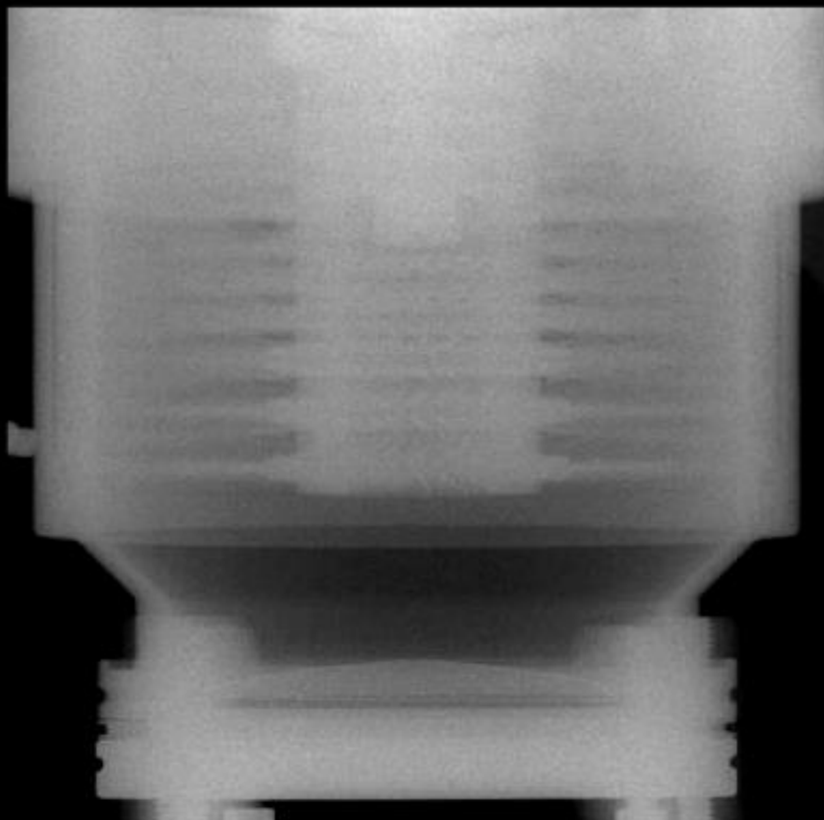
- Modest lasers can produce extreme environments

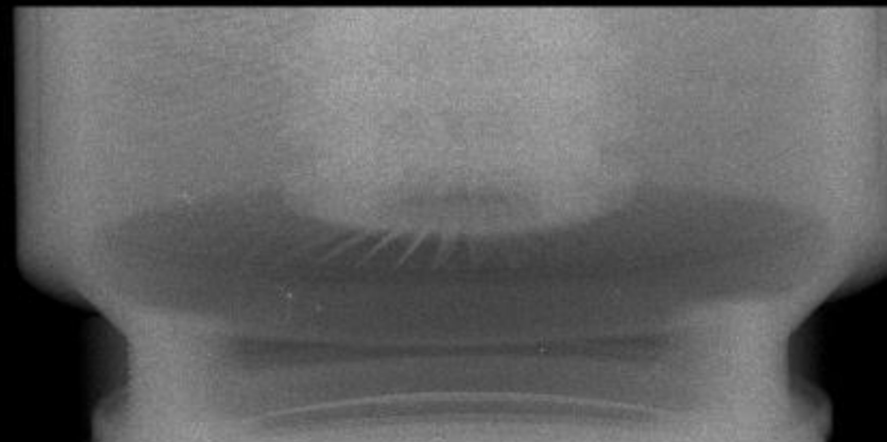


- Laser – > 10's TW drives relativistic physics > huge fields
- Extreme acceleration, over ultra short spatial and temporal extent is common place (um, mm, fs, ps)
- State of the art today is 1 PW

Courtesy J.Collier

Dynamic X-Ray Imaging





- This image shows how a 40,000 rpm turbine can be frozen using penetrating laser driven X-Rays (Vulcan)
- This is not possible any other way
- Potential applications <u>IF</u> new compact, efficient, transportable, scaleable HPL technology can be realised

UK - CERN LHC activities

Main UK activities in HL-LHC

- **High Luminosity LHC optics, tracking and beam-beam**
- **Crab cavity design and beam dynamics**
- **High Luminosity LHC collimation**
- **LHC machine-detector interface**

Strong emphasis on

- Intellectual input and design
- Computing; UK is growing in this area generally
- Some hardware.
- Additional work at Linac4, ion source, …

CLIC-UK is also a very strong partnership with CERN; many synergies and connections with the LHC work.

The UK is playing a leading role in the world's biggest scientific experiment, the Large Hadron Collider at CERN in Geneva - recreating the conditions that existed a trillionth of

Conclusions

- The UK has a vibrant accelerator programme.
- STFC will continue to support innovative R&D across its accelerator programme.
- We are collaborating with international partners, including CERN.
- The Cockcroft Institute and John Adams Institute are both involved with accelerators and related systems of relevance to medical physics and are integrating this into their R&D and training.
- STFC is also developing detectors of relevance (see next talk).

Thank you!

- Special thanks to:
  - John Thomason (ISIS)
  - Rob Edgecock (Huddersfield)
  - Jim Clarke (ASTeC)
  - Hywel Owen (Manchester/CI)