The Cockcroft Institute
of Accelerator Science and Technology

The Cockcroft Institute

IoP PA&B Group meeting, April 2017

Lancaster University

University of Liverpool

Manchester 1824
The University of Manchester

University of Strathclyde

Science & Technology Facilities Council

The Cockcroft Institute Triple Celebration

Monday 10th April 2017, Daresbury Laboratory

1. Full membership for the University of Strathclyde
2. The relocation of the Institute to the main Daresbury Laboratory site
3. The start of a new round of core funding from STFC

The Cockcroft Institute (2004-)

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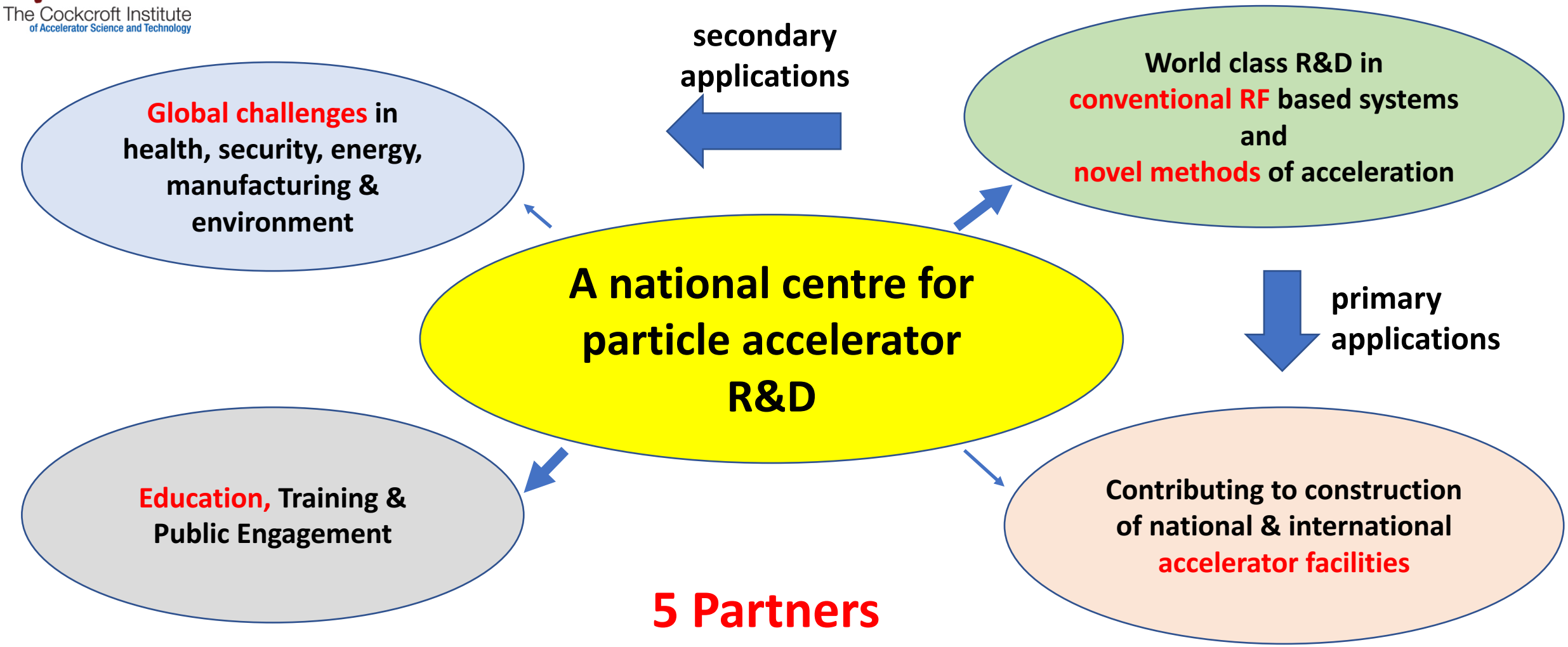

5 Partners

Lancaster University
University of Liverpool
The University of Manchester
University of Strathclyde
Science & Technology Facilities Council

The Cockcroft Institute
of Accelerator Science and Technology

The Cockcroft Institute Today

PEOPLE

- 4 Universities
  - 7 Departments
  - 12 Research Groups
- STFC Accelerator Department (ASTeC)
  - 5 Groups
- > 225 Staff & students
  - 33 Academic investigators
  - 63 STFC accelerator staff
  - 54 Postdocs
  - 8 Admin staff
  - 74 PhD students

RESOURCES

- Research Grant Income - £8.5M/yr.
- Academic Staff Salaries - £2.7M/yr.
- ASTeC Recurrent Income - £6M/yr.
- CLARA/VELA e^- facilities at Daresbury
- SCAPA laser facilities at Strathclyde
- Access to CLF lasers at RAL, ELI, etc.
- Access to CERN/FNAL/SLAC facilities

OUTPUTS

- > 100 publications per year in refereed journals
- Components for ESS, ELI-NP & HL-LHC facilities
- Health & security applications – Impacts!

Lancaster University
UNIVERSITY OF LIVERPOOL
MANCHESTER 1824 The University of Manchester
University of Strathclyde
Science & Technology Facilities Council

University of Strathclyde – Full Membership

- Not a small perturbation to the Cockcroft Institute!
- A large, diverse, well-established research powerhouse
- 3 research groups, encompassing RF based & novel acceleration
- Major in-house facilities: SCAPA laser labs (350 TW) & RF labs

Laser Plasma Interactions; Electron Acceleration & Compact Radiation Sources	**RF & THz Sources; Muon Ionization Cooling**	**Free Electron Laser (FEL) Optimization**
SILIS/SCAPA	ABP	McNEIL

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Relocation of the Institute to the main Daresbury Lab site

Nov-Dec 2016: 125 staff & students

CI now at the heart of the lab!

- Meets space requirements
- Closer to lecture theatre & cafes
- Nearer to accelerators & labs
- Reduced costs!

Daresbury Lab "A Block"

Sci-Tech Daresbury CI Building

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STFC Partnership & New Core Funding

STFC has a dual role in the Cockcroft Institute

- Research Partner (STFC Accelerator Dept. - ASTeC)
- Funding agency for the university group

STFC (PPARC) has provided core funding since 2004

- £7m grant 2004-2012
- £16.4 grant 2009-2017
- FEC value of support is currently £2.5m/yr.
- £0.9m capital equipment funding for 2017/18 (with Uni. match)

We look forward to continuing this unique partnership with STFC for many years to come!

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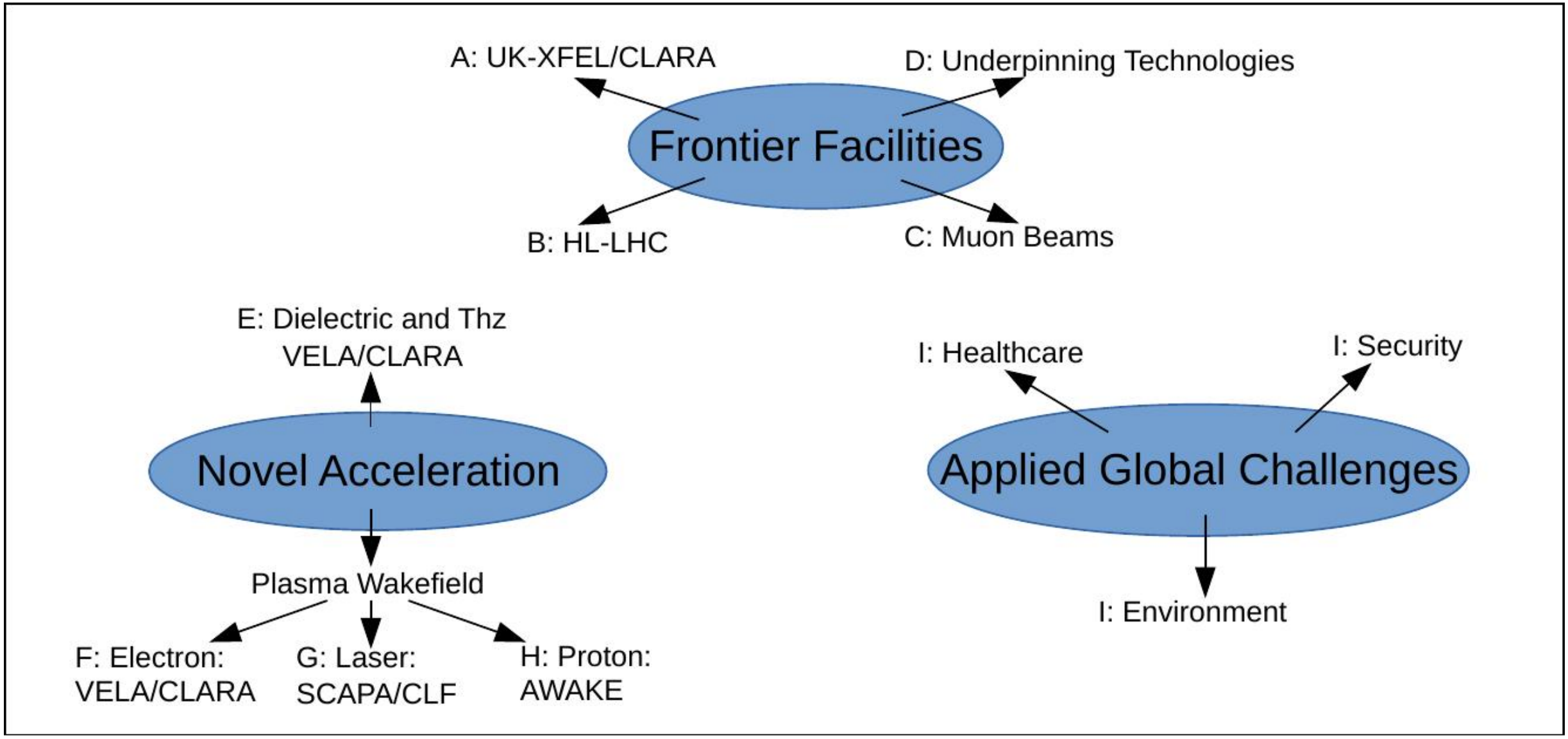
Research Directions & Themes/Projects

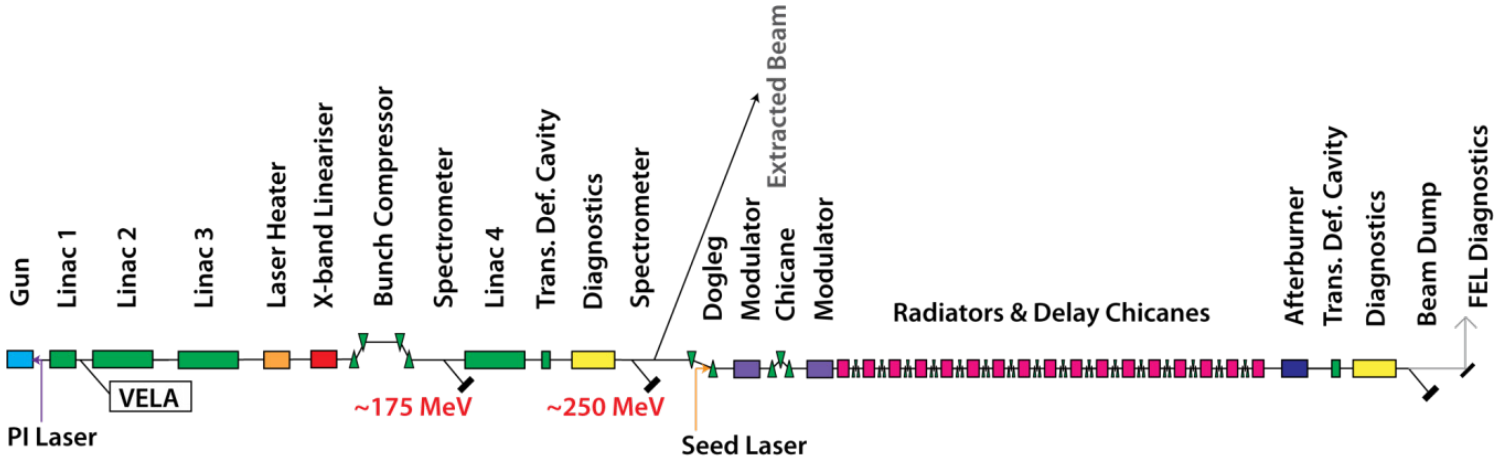
1. Scientific Frontier Machines & Underpinning Technologies (RF based)
   - CLARA and R&D for a future UK X-ray Free Electron Laser (XFEL) facility
   - High Luminosity LHC upgrade at CERN (Crab cavity)
   - Muon g-2 experiment at Fermilab (beam & spin dynamics)
   - Superconducting RF cavities for the European neutron Spallation Source (ESS) in Sweden
   - Accelerating cavities for ELI-NP electron beam in Romania
   - Thin superconducting film coatings for RF cavities
   - Laser treatment of beam pipes to suppress secondary electron cloud
2. Novel Methods of Particle Acceleration
   - Laser driven plasma acceleration of electron beams & compact radiation sources (SCAPA/CLF etc.)
   - Electron driven plasma acceleration of electron beams (SLAC/FACET & CLARA)
   - Proton driven plasma acceleration of proton beams (AWAKE at CERN)
   - THz radiation driven acceleration of electron beams (CLARA/VELA)
   - Dielectric Laser Acceleration (SwissFEL)
3. Global Challenges in Health, Security, Energy, Manufacturing & Environment
   - Proton beam therapy at the NHS Christie Hospital
   - Cargo scanning using X-rays from compact electron accelerator
   - Radioactive isotope production
   - Waste water treatment

3 Research Directions – 9 Research Themes



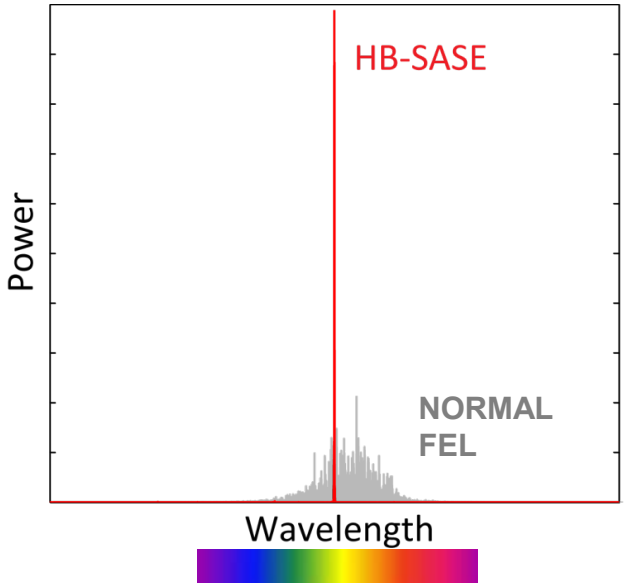
CLARA

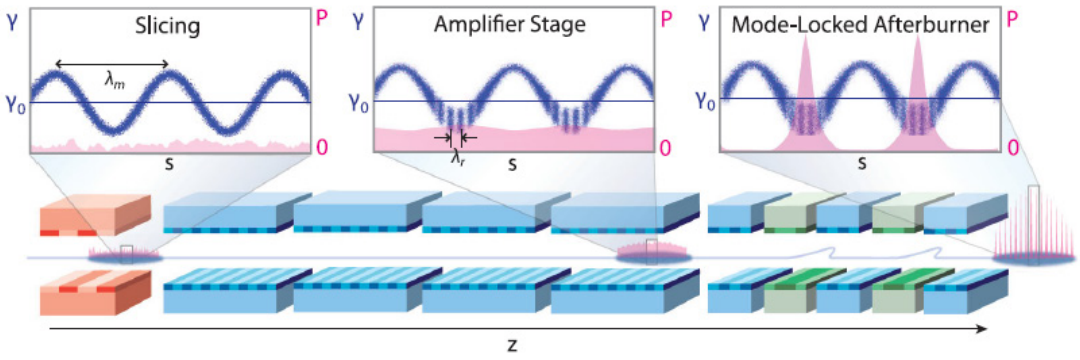
- CLARA is a purpose built dedicated flexible FEL Test Facility
- CLARA is a scaled down version of an X-ray FEL containing all of the key technical components, where all lessons learnt can be directly applied to any future UK FEL.
- The key objectives are:
  - To develop new methods for improving the quality of the light output from FELs
  - Prove new technologies
  - Develop the UK skill base
  - Lower the total cost of a UK FEL
  - Lower the risks associated with UK FEL.
- CLARA has been clearly stated to be ***the flagship project*** for the CI in the grant renewal bid (as recommended by SAC 2015)

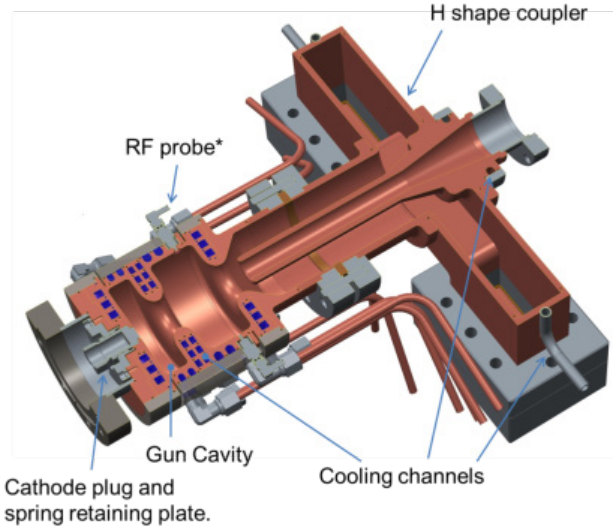


Summary of operating modes

MODE	FLAT	ULTRASHORT	SHORT	LONG
Energy	240 MeV	240 MeV	150—**240** MeV	**150** – 240 MeV
Pulse Duration	250fs flat region	50 —35 fs FWHM	585 fs FWHM	1.875 ps FWHM
Charge	250 pC	25—50 pC	250 pC	250 pC
Peak Current	400 A	500 — 1500 A	400 A	125 A
Norm Emittance (mm-mrad)	0.5 (Target) 1.0 (Max)	1.0 (Target) 1.5 (Max)	0.5 (Target) 1.0 (Max)	0.5 (Target) 0.8 (Max)
RMS Energy Spread (keV)	25 (Target) 100 (Max)	100 (Target) 150 (Max)	25 (Target) 120 (Max)	25 (Target) 75 (Max)
Purpose	• 800nm Seeding and Harmonic Generation	• Single Spike SASE (+ mode-locked single spike SASE)	• 100nm saturation • Schemes only requiring spectral characterisation, • Highest harmonic upconversion potential • Shortest pulse durations in absolute terms.	• 266nm schemes requiring long wavelength modulation of the pulse energy (Mode-Locking, Mode-Locked Afterburner, Slice + Taper).

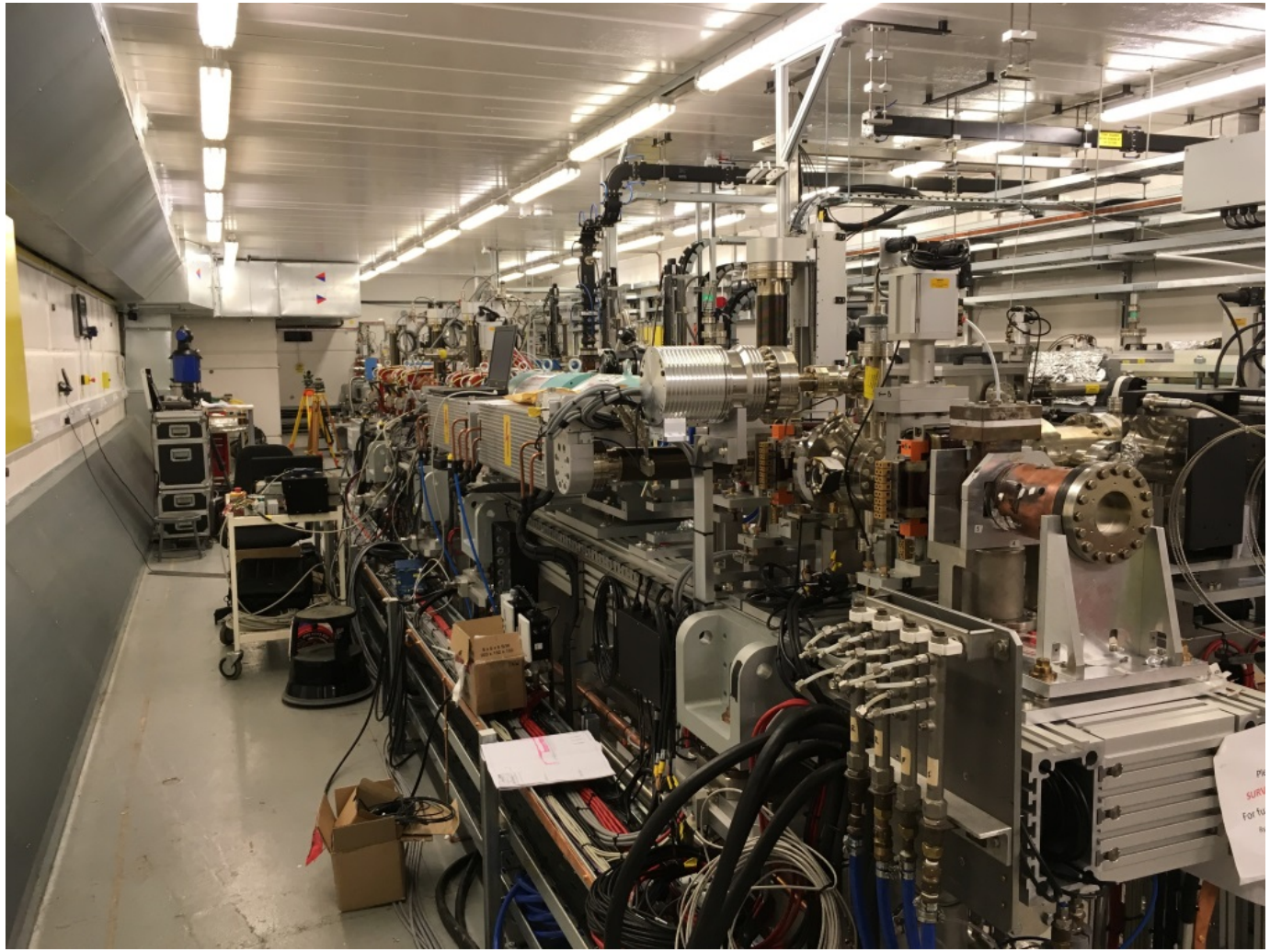






400 Hz Photo-injector

CLARA Phase 1



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£4m Electron Hall refurbishment (+/- 1^0C)

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HL-LHC-UK

- ***HiLumi*-LHC** design study FP7 2011-2015 : UK success and leadership.
- The UK hosted the ***HL-LHC*** kick-off meeting at Cockcroft Institute in November 2013.
- Discussions with STFC for UK project followed, with early SoI for LHC-UK
- SoI (final one) submitted early 2015
- Proposal submitted in March 2016
- CERN finance approved October 2015
- STFC finance approved March 2016
- 7 UK institutes as members
  - £8M of UK and CERN funding over 4 years, with institute and university money combining with STFC
  - A reflection of efficient use of resources to leverage, and UK reputation
- **Formed and led by the Cockcroft Institute (Appleby spokesperson, Burt PM)**
- Main UK activities:
  - *WP1 : Collimation*
  - *WP2 : Crab cavities*
  - *WP3 : Diagnostics*

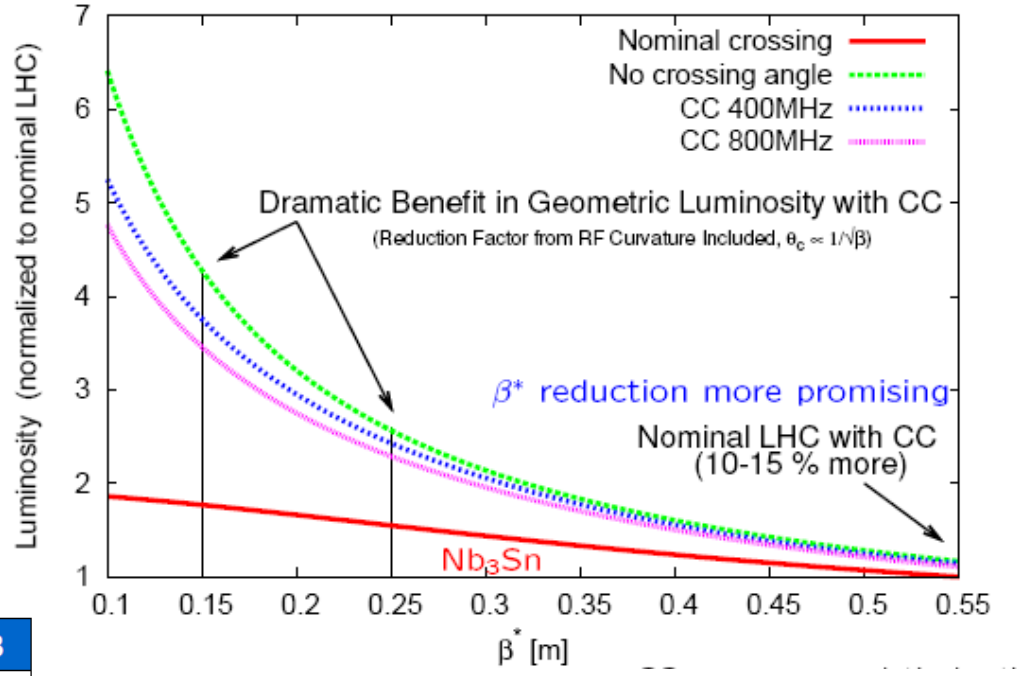
Appleby (CI) is now the chair of the HL-LHC collaboration board.

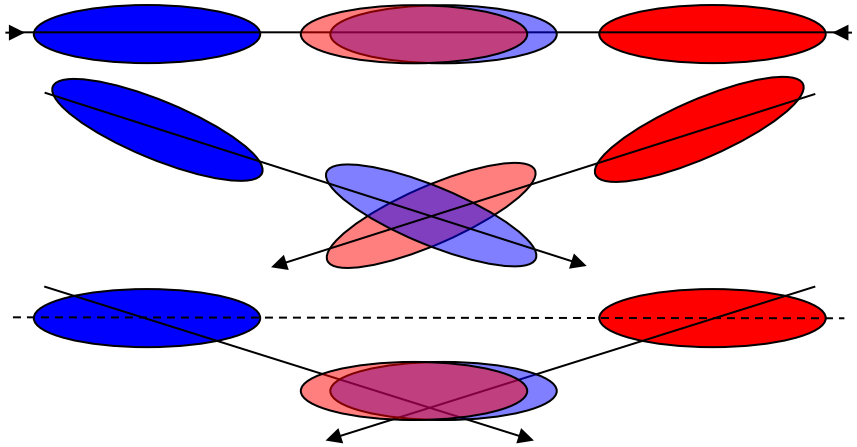
Crab cavities

- Increasing the crossing angle decreases the long range effect but decreases geometric overlap
- Rotating the bunches with crab cavities before and after collision can reduce this effect

$$L \propto \frac{N_b^2}{\sigma^2} R_\Phi F_{RF}$$

	2011	2012	after LS1	after LS3
Energy	3.5 TeV	4 TeV	7 TeV	7 TeV
β* [cm]	100	60	55	15
2ϕ [μrad]	260	313	247	473
$R_\Phi(\sigma_z = 7.55\text{cm})$	0.94	0.85	0.82	0.37
$R_\Phi(\sigma_z = 10.1\text{cm})$		0.76	0.74	0.28





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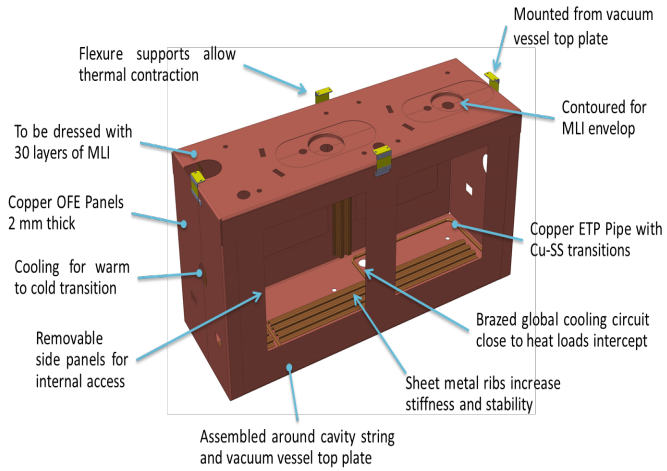
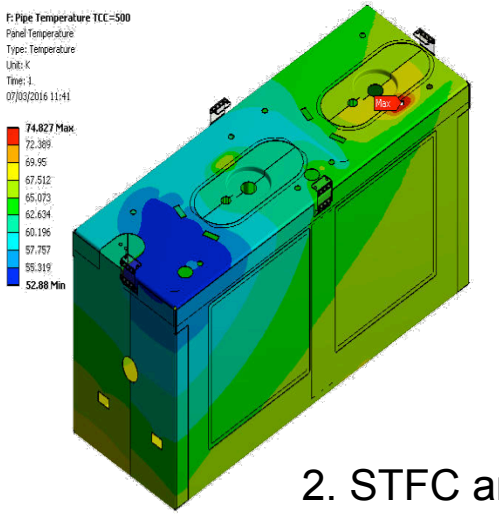
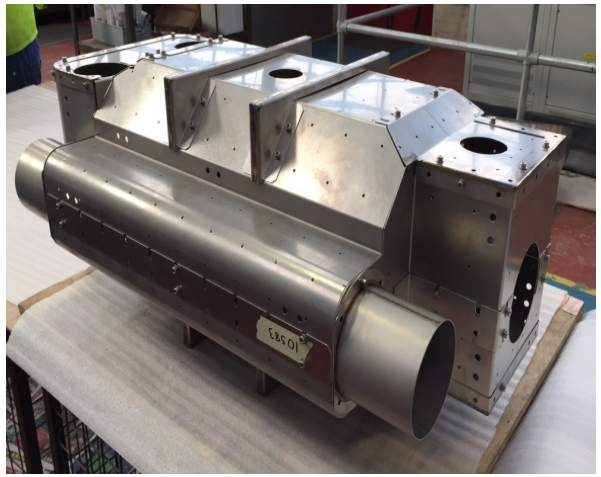
Cryomodules & Shields



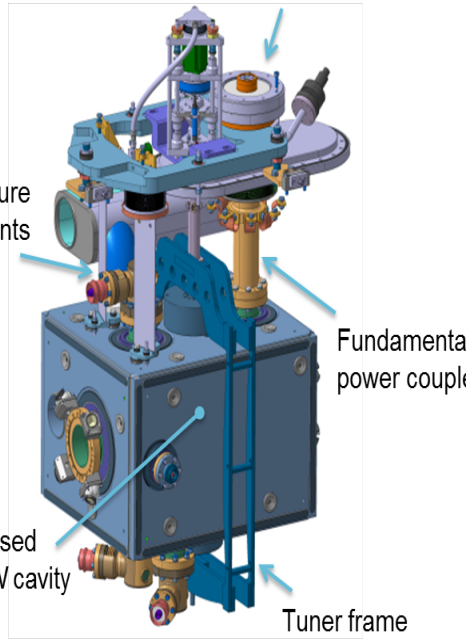


3. Cockcroft and STFC technology will produce the pre-series cryomodule for HL-LHC crabs.

1. STFC have led the development of the thermal and magnetic shields for the SPS cryomodule, and Cockcroft produced the cold magnetic shield.



2. STFC and Lancaster have developed the blade supports for HL-LHC. This novel scheme allows thermal expansion without creating stresses while stiffening against microphonics.



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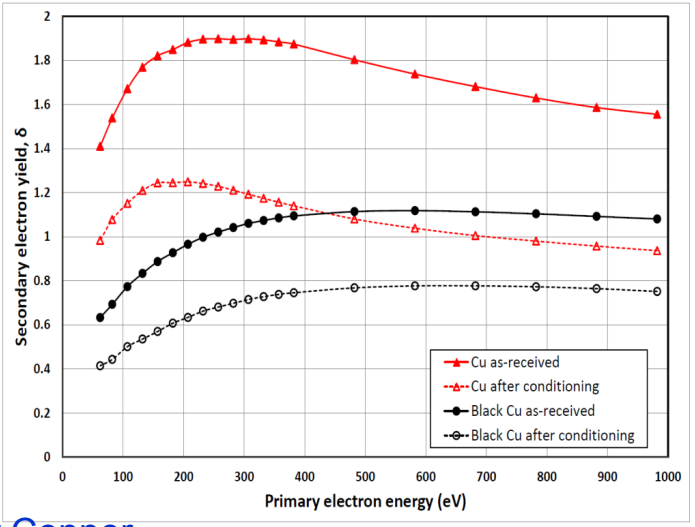
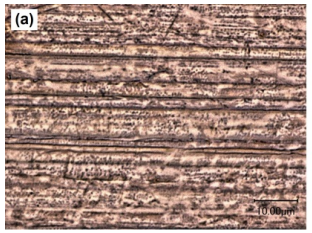
Reduction of Secondary Electron Yield For e-Cloud Mitigation by Laser Ablation Surface Engineering (LASE)

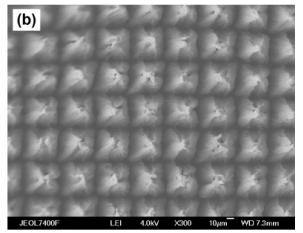
ASTeC &
U. Dundee

Science & Technology Facilities Council

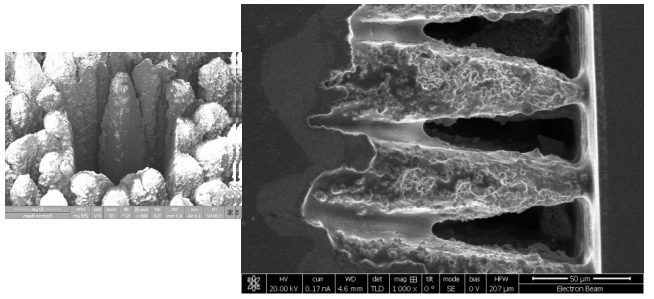
SEY of Cu as a function of incident electron energy







Untreated Laser treated

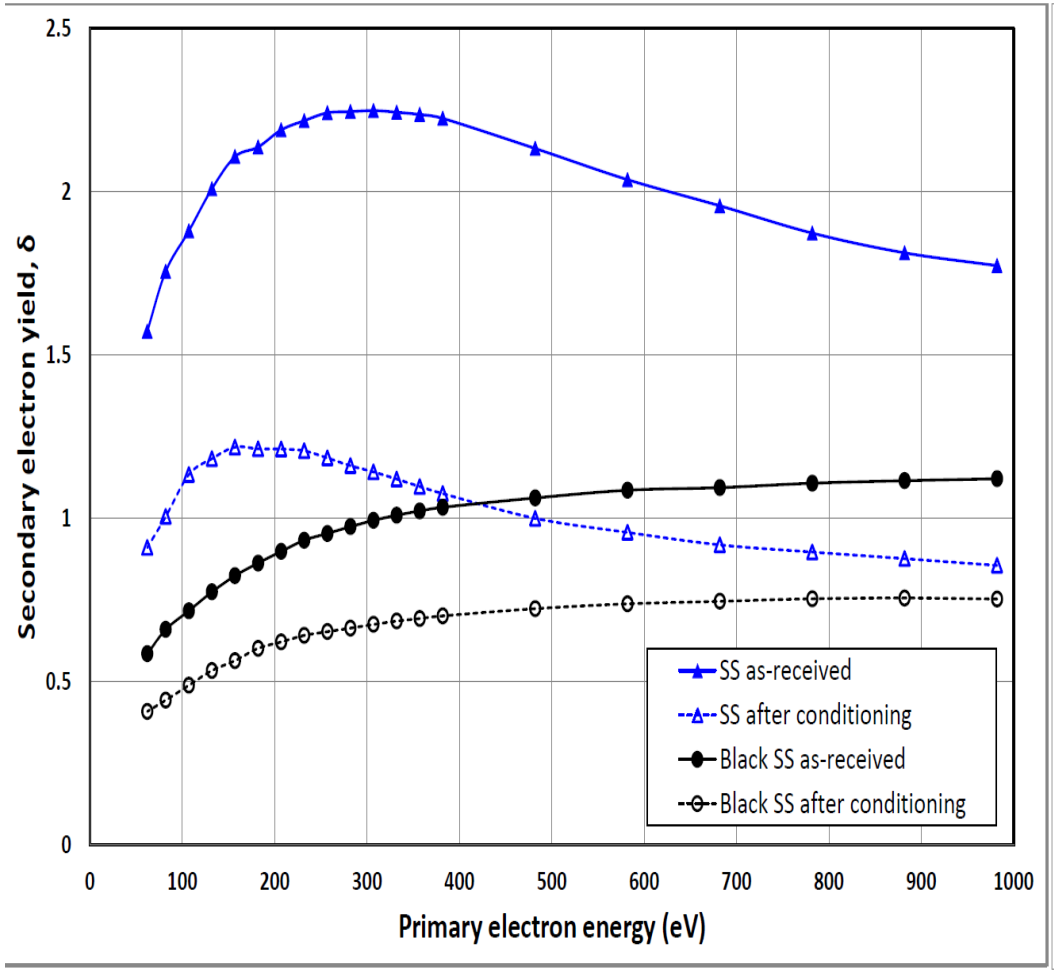


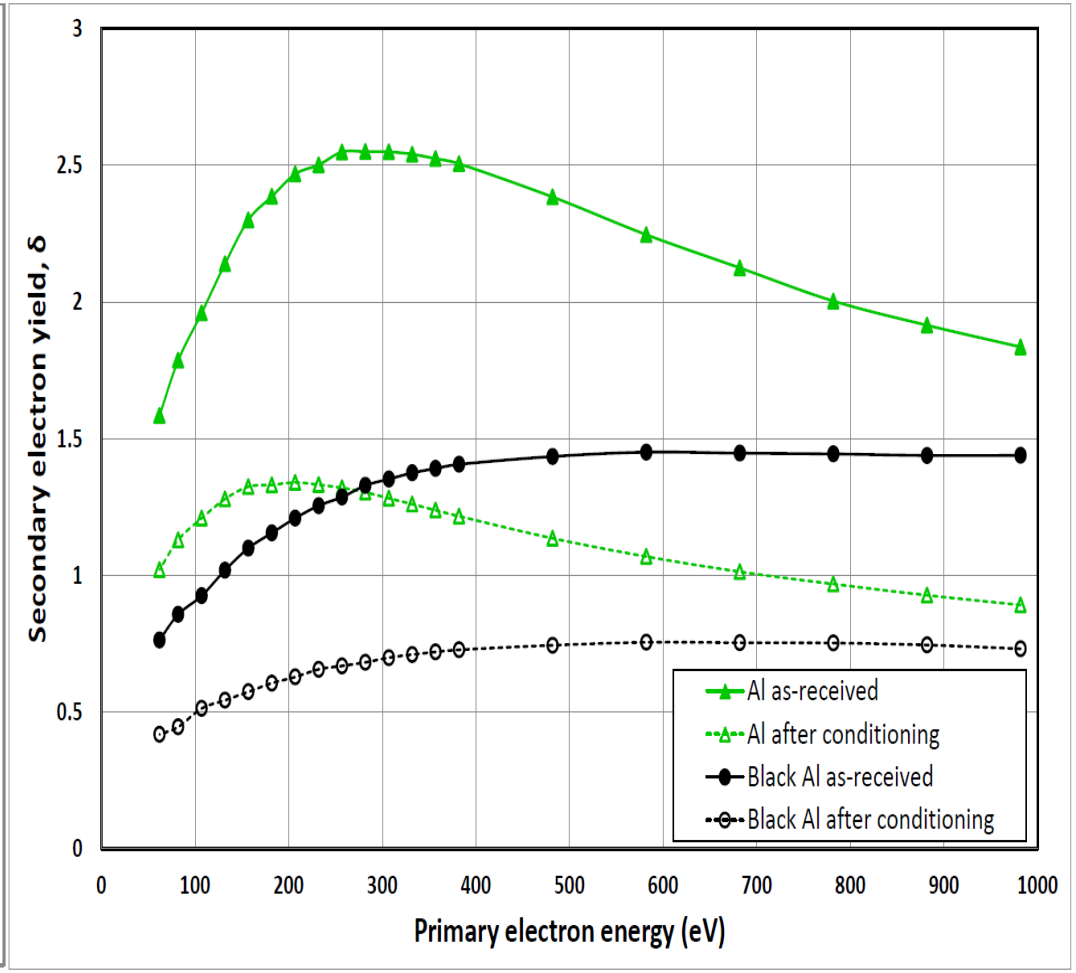
Original data June 2014
Applied Physics Letters 12/2014; 105(23): 231605

For Copper
Nd:YVO4 Laser

- Max Average Power = 10 W at λ = 532 nm
- Pulse length =12 ns at Repetition Rate = 30 kHz
- Argon or air atmosphere
- Beam Raster scanned in both horizontal and vertical direction

SEY of SS and Al as a function of incident electron energy





Original data June 2014
Applied Physics Letters 12/2014; 105(23): 231605

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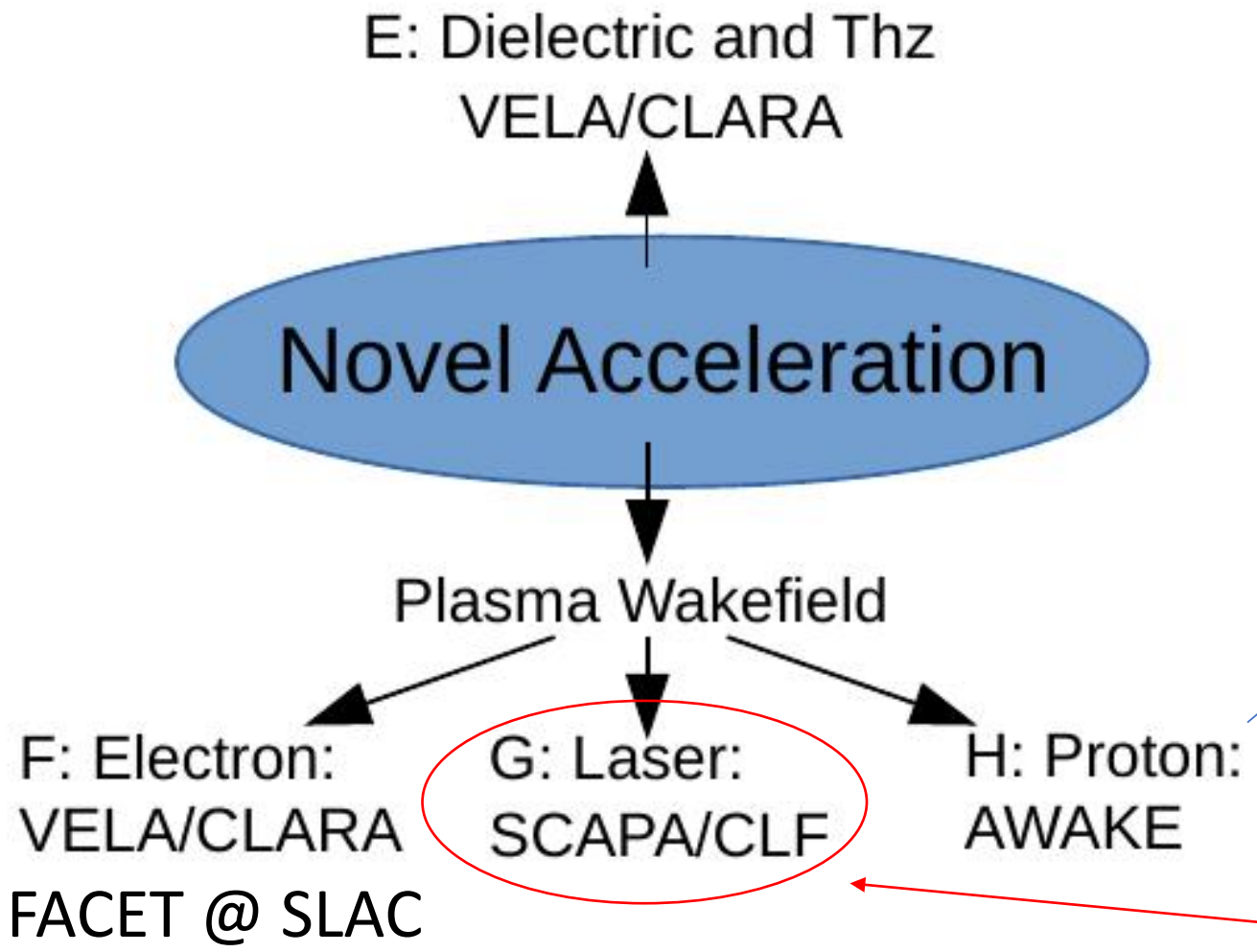
The main conclusion

- **LASE** can be a key solution for the e-cloud suppression in high energy particle accelerators:
  - $\delta < 0.6$
    - No outgassing problems
      - Insignificant to moderate increase in impedance
        - Easy implementation
          - Robust
            - Highly reproducible
              - Inexpensive
                - In-situ

Novel Methods of Particle Acceleration



Exciting first results at CERN in late 2016 indicating micro-bunching of the proton beam!

Paul McKenna's talk

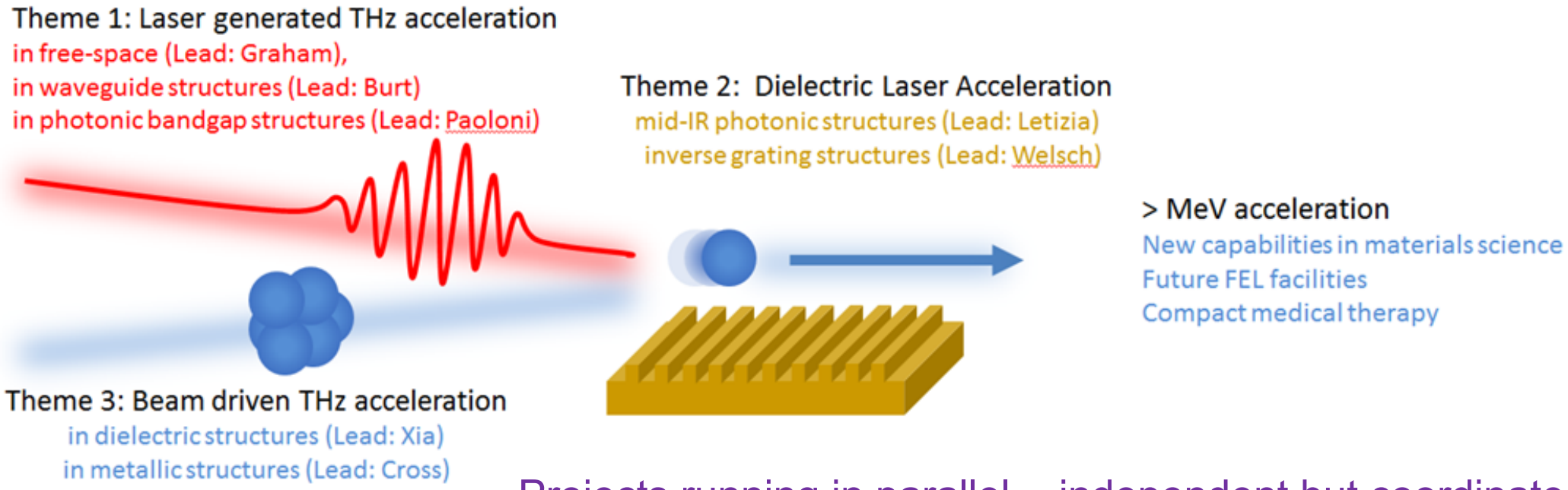
Novel Acceleration Techniques

E. Dielectric and THz Acceleration (DATA) - exploiting the VELA/CLARA test facilities

Universities: Burt(0.1), Letizia(0.6), Paoloni(0.2), Gratus(0.2), Tucker(0.1) Appleby(0.1), Graham(0.4), Owen(0.1), Xia(0.1) Welsch(0.1), Cross(0.2), Ronald(0.1); 16 PDRA years required; **10 PDRA years requested**

ASTeC: 7 FTE years staff effort

10.0 Academic FTE years



Projects running in parallel - independent but coordinated

Cross-project sharing of PDRA expertise (e.g. EM simulation; beam dynamics; laser/THz)

Strength & Impact in exploitation of Daresbury Acceleration test facilities

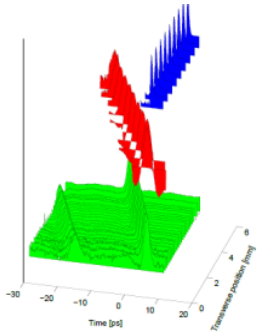
VELA: 5MeV, ~1ps ; CLARA: 50MeV, σ_t ~ 100fs. Flexible experimental station & beamline

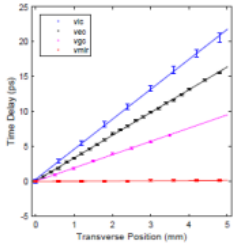
Collaboration across CI universities and ASTeC

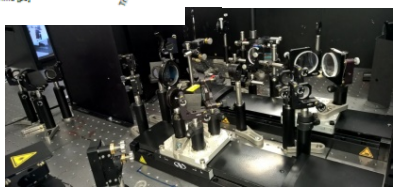
Established capability

THz sources with subluminal, dispersion free propagation

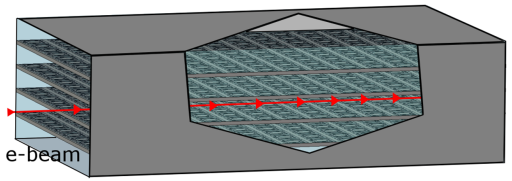
Submitted to Nat. Comms.

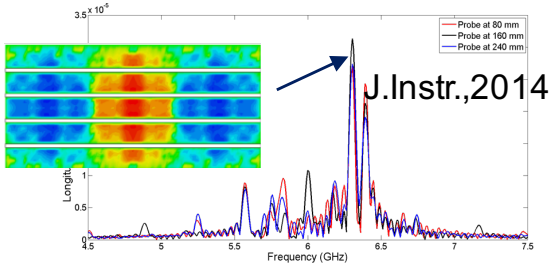






Dielectric laser & photonic electromagnetic simulation



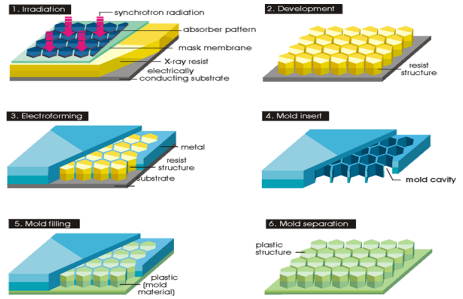


J.Instr.,2014

Structure manufacture

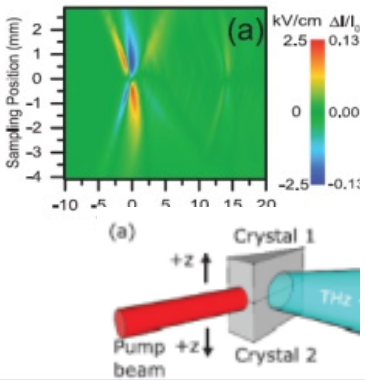
Inverse grating manufacture:
Liverpool collaborating with PSI

UV-LIGA at Lancaster (metal)

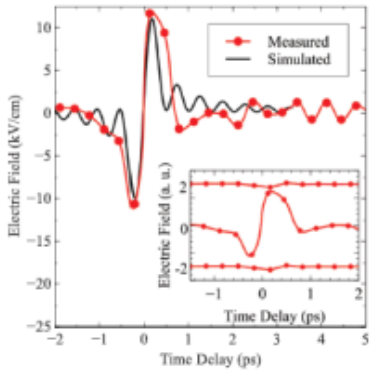


THz sources with 'longitudinal' polarisation

Appl Phys Lett 105 (2014)

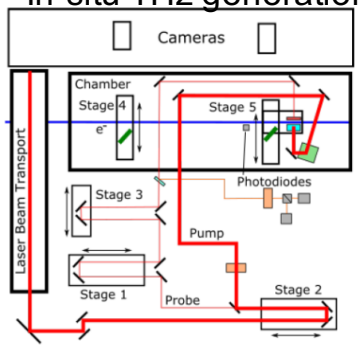


Appl Phys Lett 108 (2016)

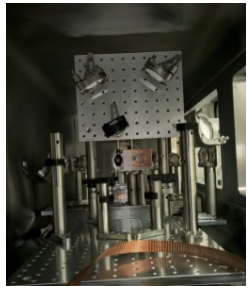


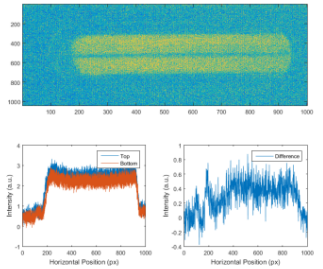
VELA experiments in THz driven acceleration (2015)

In-situ THz generation



Electron beam threaded through 500um wide interaction region, to spectrometer



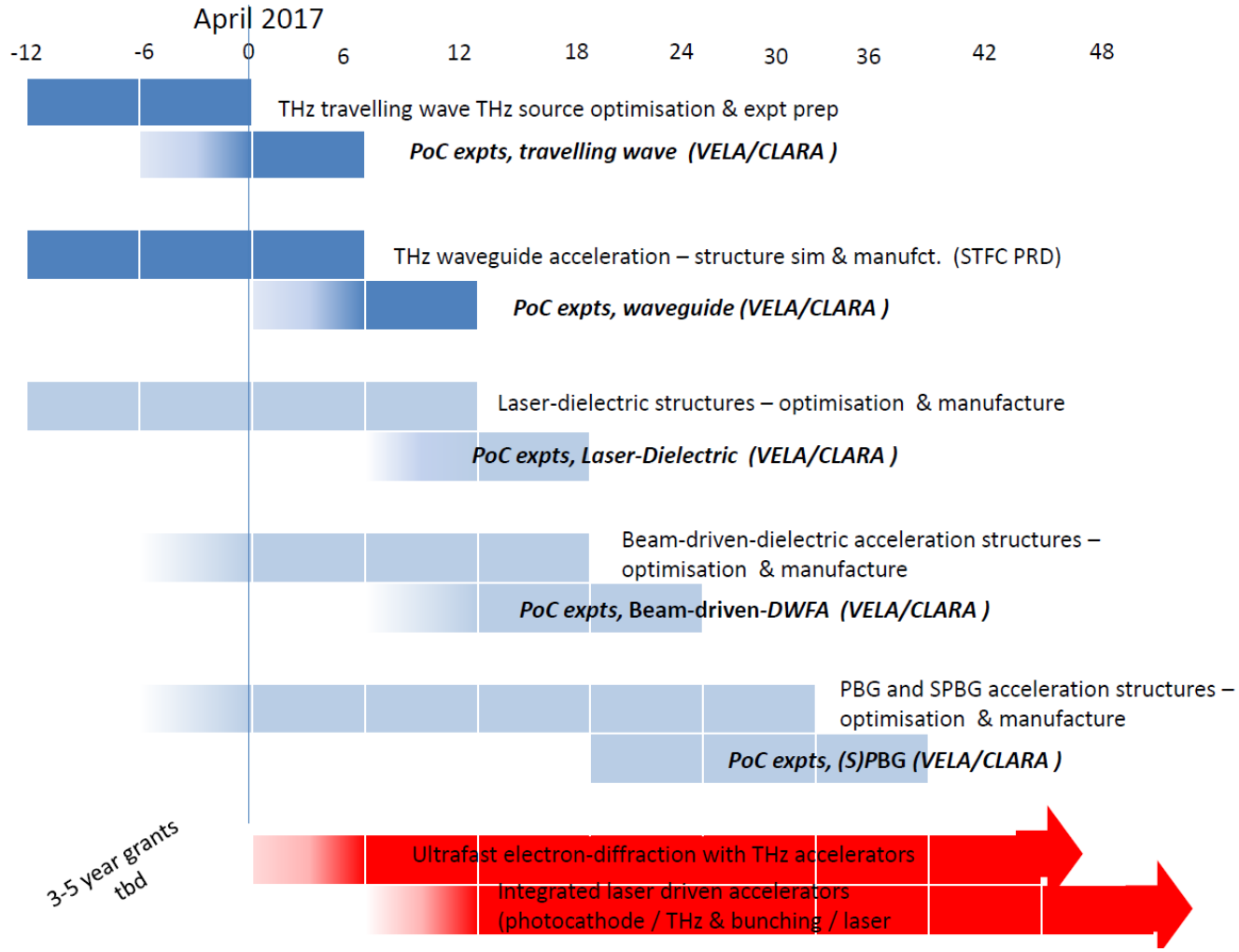


Single-shot THz and reference electron spectra

Co-ordination of accelerator facility experimental access

Programme/project planning timeline & VELA scheduling

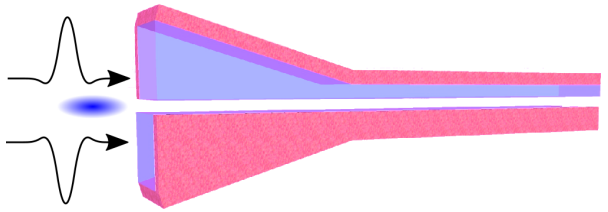
to be revised as experimental facility access, project progress and funding dictates



Future programme

THz waveguide acceleration

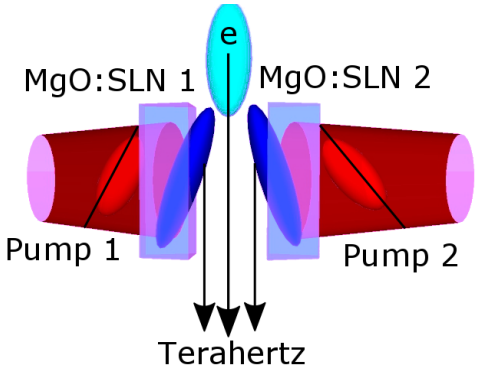
Single-cycle, sub-picosecond sources, Epeak >>10MV/m



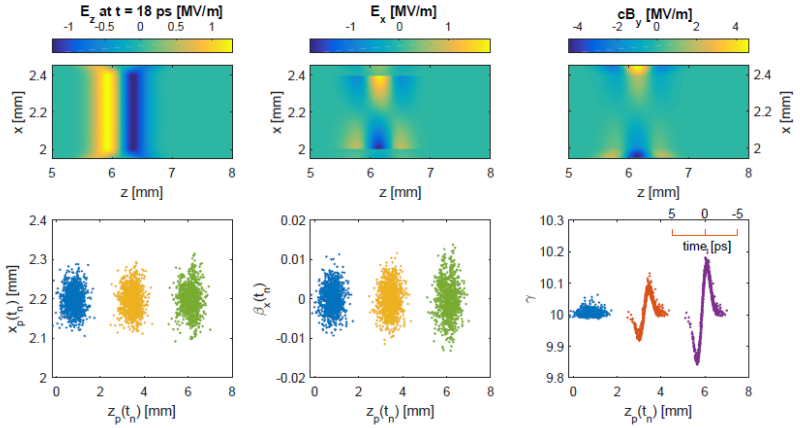
Source matched to waveguide modes & coupling:
Minimum dispersion, maximum gradient
VELA demonstrations

STFC 'Project Research Development' grant July 2016-2018 (Lancaster, Manchester, ASTeC)

Sub-luminal dispersion-less THz sources



Simulated phase-space after ~10mm interaction



First PoC experiment on VELA August 2015 (Manchester, ASTeC)
Planning for 2017 experiments (VELA & Manchester DC-gun)

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Lancaster University
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University of Strathclyde

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Summary & Conclusions

- World class R&D in particle accelerator science & technology
  - 4*/3* publications in high impact factor refereed journals
  - impact case studies of similar quality

- Support delivery of UK/Int'l accelerator facilities for world class science
- Educate the next generation of accelerator experts
- Inspire & inform school students & the general public
- Address global challenges in health, security, energy, manufacturing & the environment

The principal research activities :

1. Scientific frontier machines & underpinning technologies
2. Novel acceleration techniques
3. Applications of accelerators addressing global challenges