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# XARA

*A potential application of CompactLight technology*


Louise Cowie

on behalf of the XARA team at Daresbury


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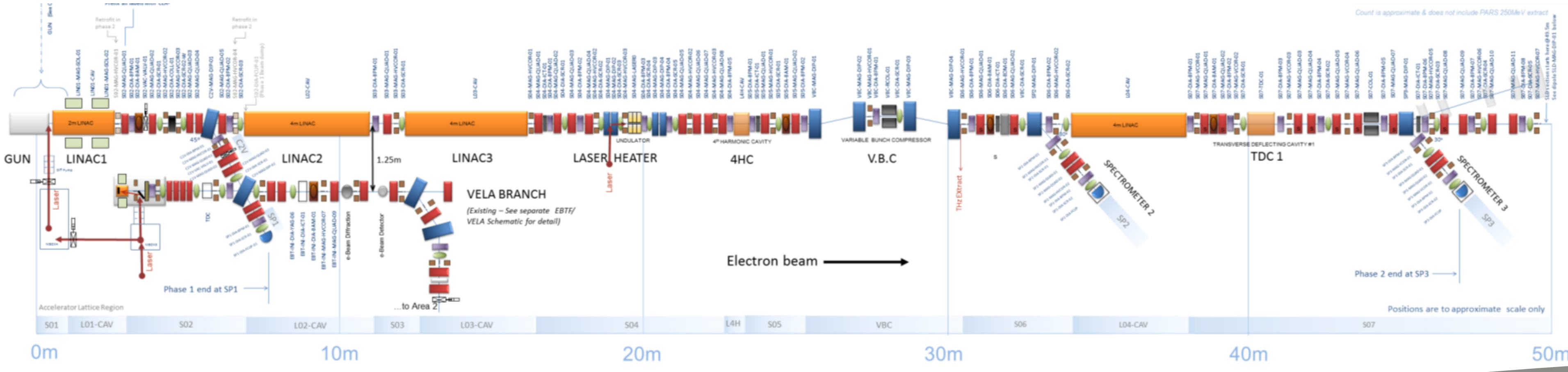
# CLARA

- S-band linear acceleration up to 250 MeV
- Bunch charge 20-250 pC
- High repetition rate up to 400 Hz
- Electron bunch lengths 250-850 fs
- FEL wavelengths in the UV

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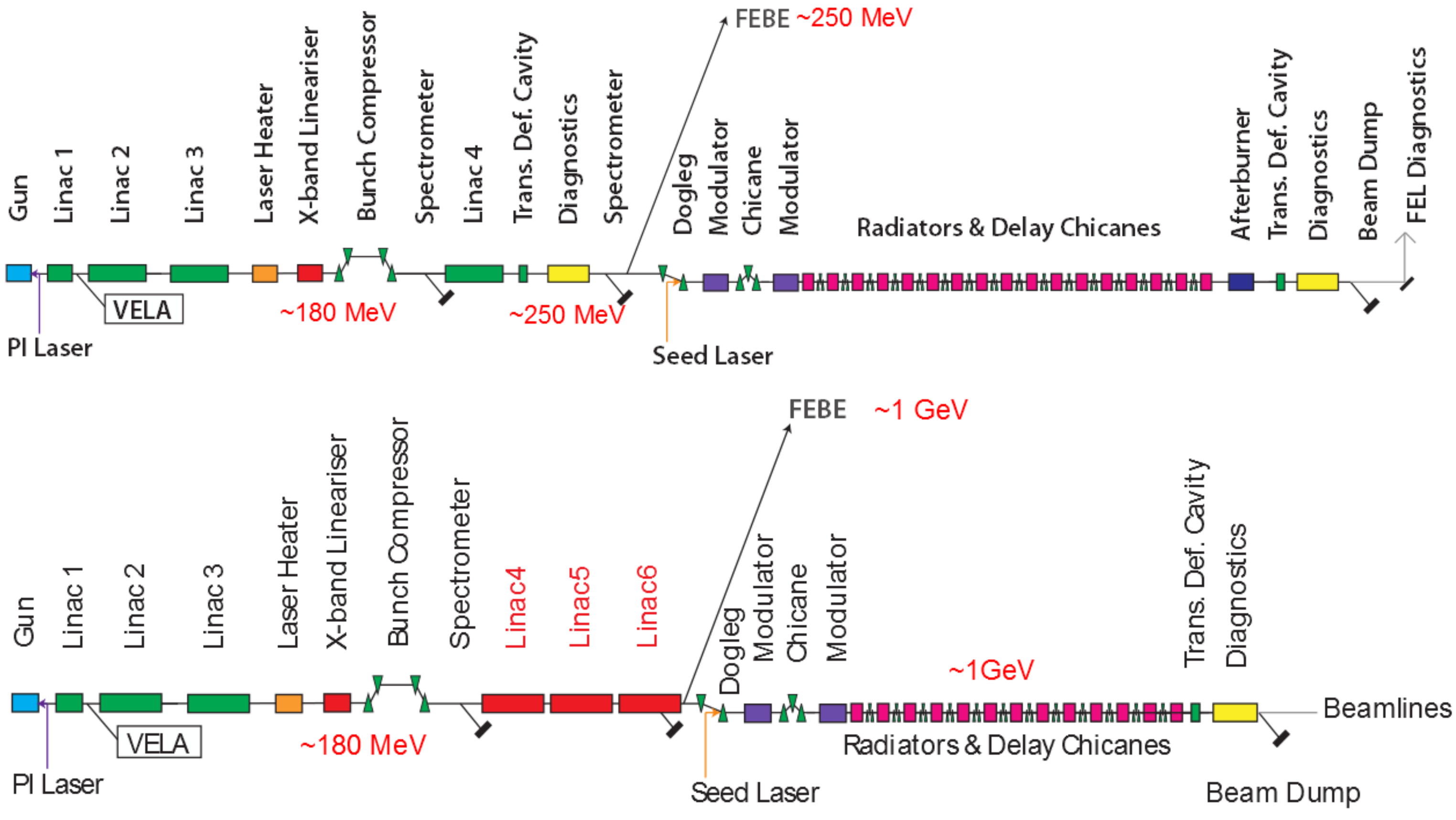
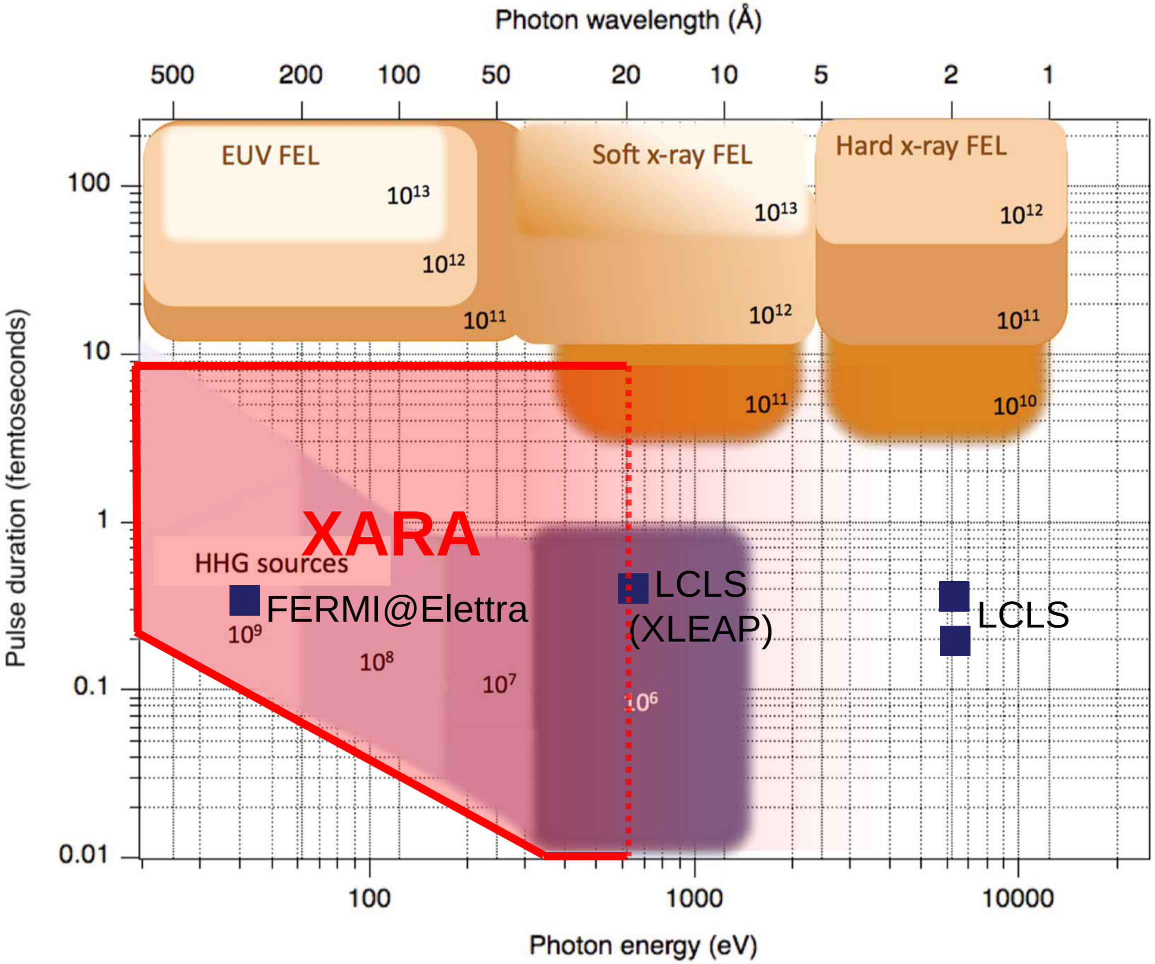
# Upgrade proposal: XARA

- X-band Accelerator for Research and Applications
- The 4th CLARA linac is replaced by an X-band accelerating section to reach 1 GeV
- Novel FEL technology
- An EUV/soft x-ray FEL facility for ultra fast chemistry and biology, and a centre of accelerator R&D.



# User case

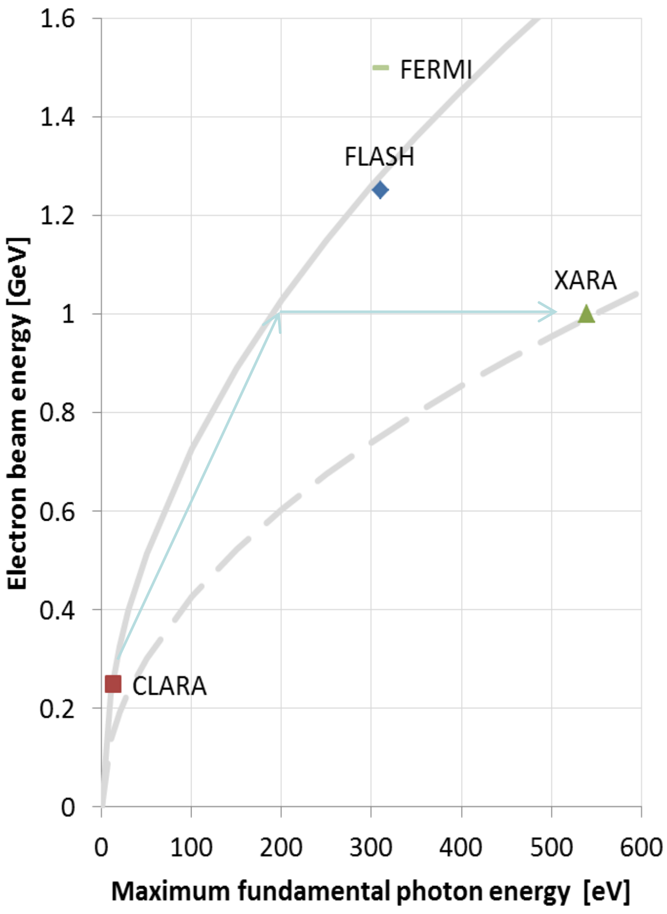
- The EUV to soft x-ray region is of tremendous interest for ultra-fast chemistry, AMO physics etc.
- FELs:
  - high pulse energy
  - short pulses, typically >few-fs
- HHG:
  - even shorter pulses down to tens of attoseconds
  - BUT relatively low pulse energy, especially at shorter wavelengths *(numbers on plot = photons per pulse)*
- The goal of XARA is to match HHG's wavelength range and pulse durations but with higher pulse energy.




Modified from: *Roadmap of ultrafast x-ray atomic and molecular physics*, Linda Young et al 2018 J. Phys. B: At. Mol. Opt. Phys. 51 032003

# Photon energy range

- The photon energy of FEL radiation is proportional to the electron beam energy squared.
- CLARA at 250 MeV was designed for a shortest wavelength of 100 nm (12.4 eV)
- Increasing to 1GeV would therefore give a factor of 16 change to 6 nm (200 eV)
- Utilising more ambitious undulator technology would allow a significant further reduction, potentially as far as ~2.3 nm (540 eV), so as to cover the ‘water-window’ region of particular scientific interest.

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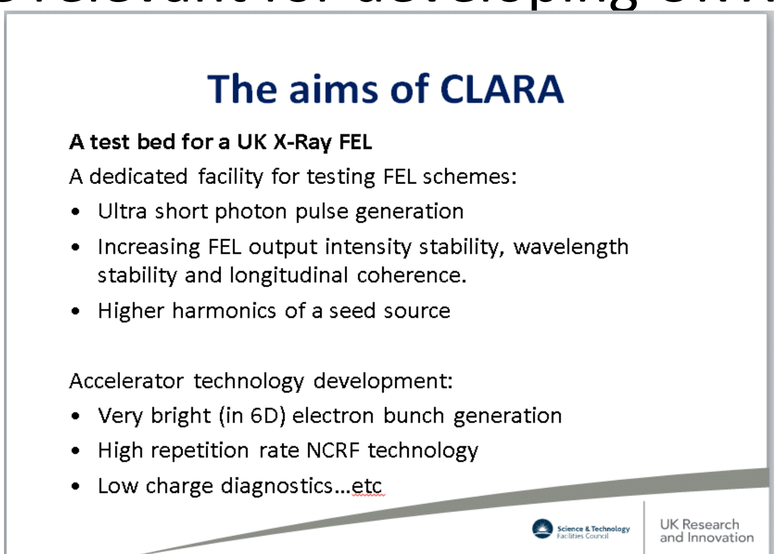
# Accelerator Science on XARA

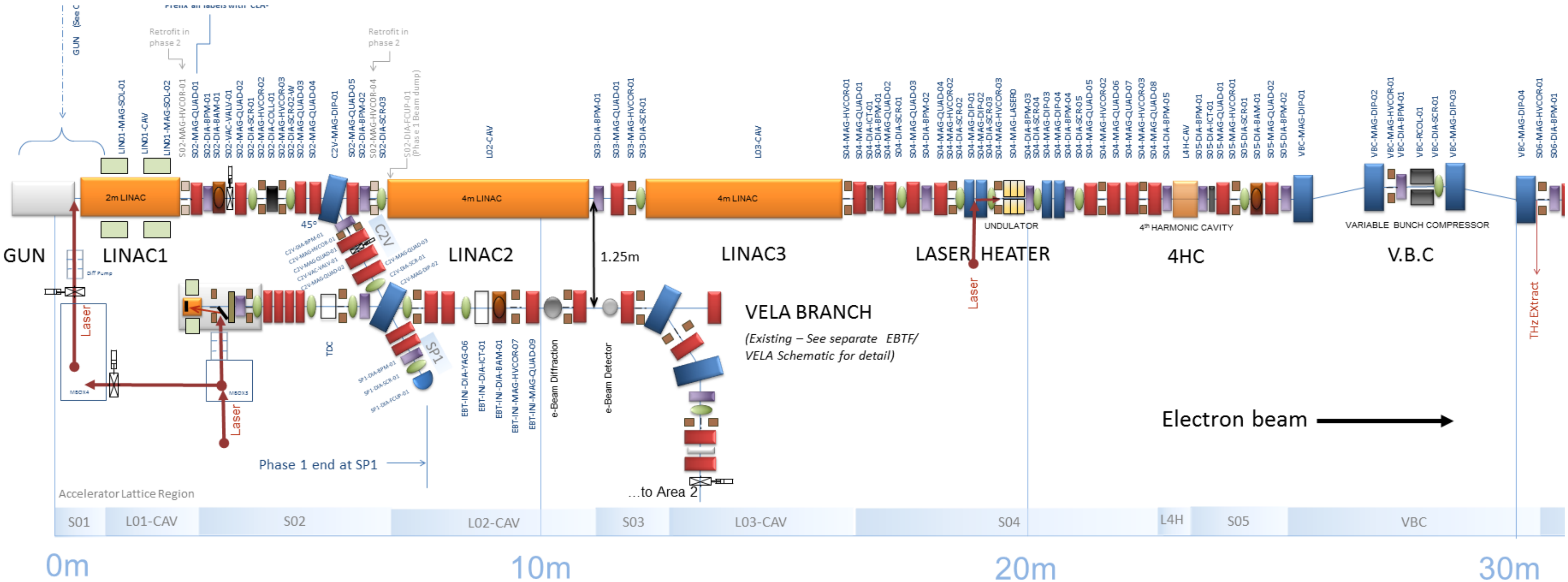
- Compact accelerator development:
  - X-band technology
  - Compact FEL section
  - Single cycle FEL pulses
- Full energy electron beam exploitation line
- Even more relevant for developing UK XFEL technologies
- Plus..



# Full Energy Beam Exploitation

- Experimental user station:
  - Nominally at 250 MeV/c – up to 1 GeV/c on XARA
  - Sub-100 fs electron bunches at 250 pC
  - High peak-currents > 4 kA
- Experiments:
  - Wakefield Accelerator experiments:
    - Structure WFA (dielectric, with mask in arc for 2 bunch)
    - Beam-driven PWFA
  - VHEE
    - Strong links with Christie Hospital and Manchester University

# S-band injector




180 MeV/c linearised <100 fs 250 pC electron bunch

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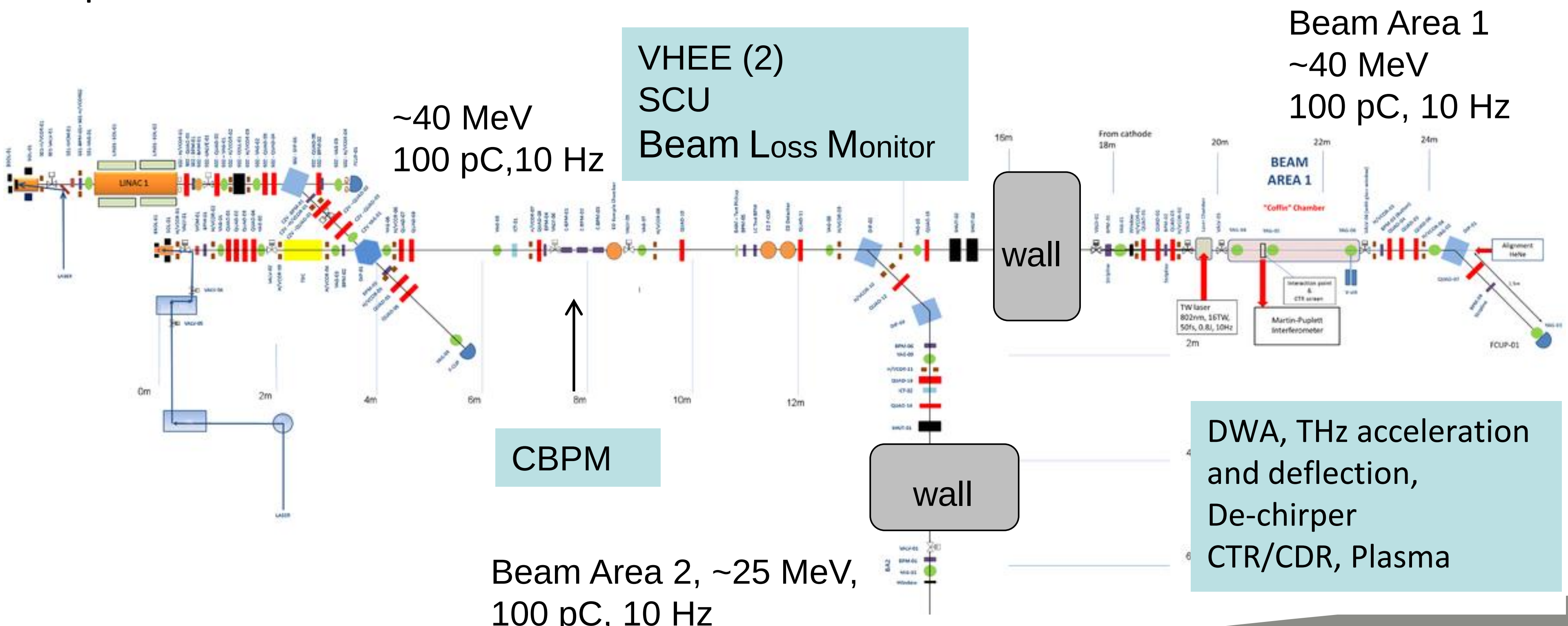
# Benefits of CLARA as injector

- Photoinjector operating at 400 Hz with dual feed H-coupler and load-lock cathode exchange system
- High level software : a C++/python API interface to EPICS & a virtual machine: Automated accelerator controls for repeatability and self-optimisation- cavity conditioning, cresting, BPM calibration, beam alignment.
- CLARA electron beam already been exploited for accelerator R&D, higher energies and multi-bunch operation will add to capabilities

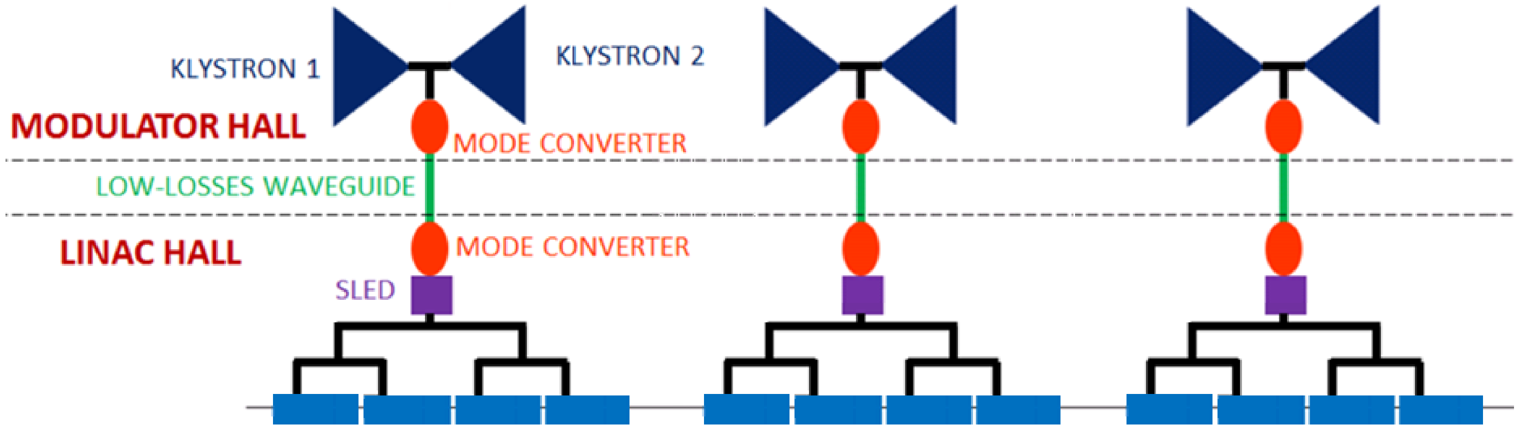
# CLARA/VELA – Exploitation Experiments

5 experiments in the accelerator hall & 7 in BA1 (4 using TW laser). Separate enclosure allowed exploitation experiments in the accelerator hall while setting up experiments in BA1.



# X-band linac

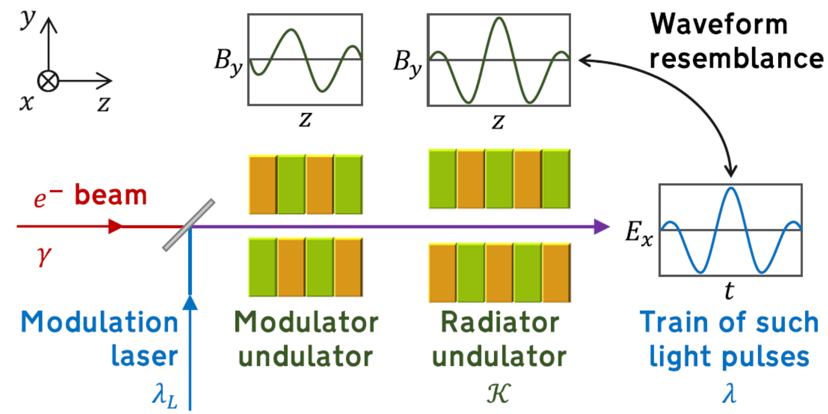
- Based on EuPRAXIA@SPARC_LAB/CompactLight/Electrons into SPS RF module
- 4 x 1 m 80 MV/m x-band cavities per module
- 3 modules

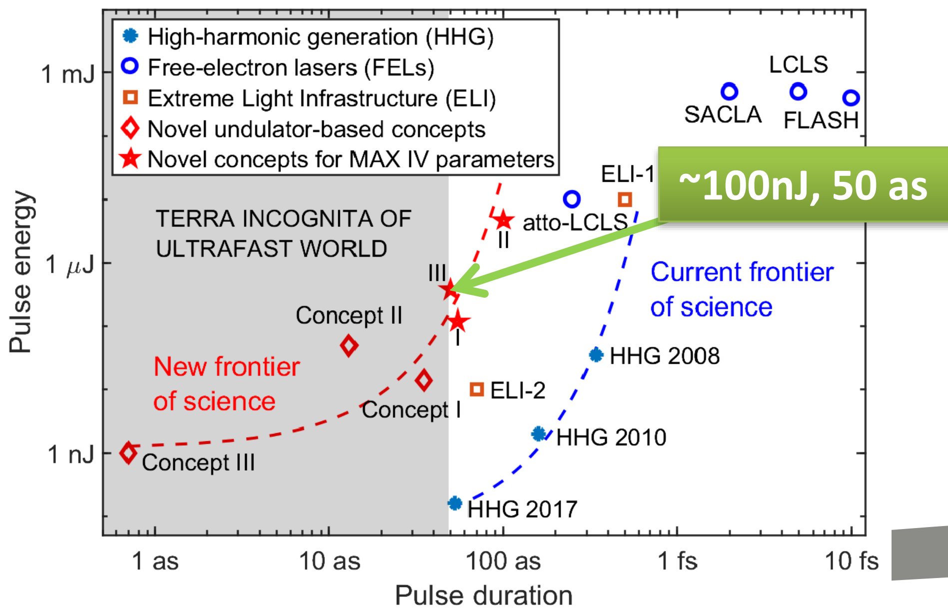



M. Diomede et al 2014, NIMA Vol. 909

# FEL options (1)

- New FEL techniques for few-cycle pulses would enable:
  - Attosecond pulses
  - Very compact undulator (few meters)
  - ~100nJ pulse energy, higher than HHG

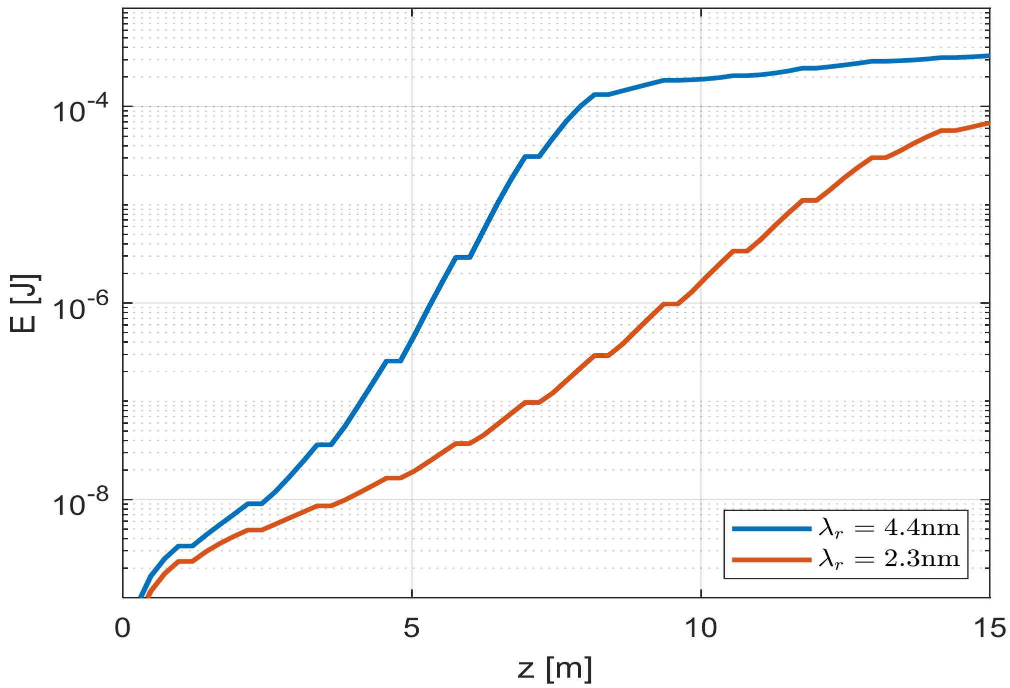


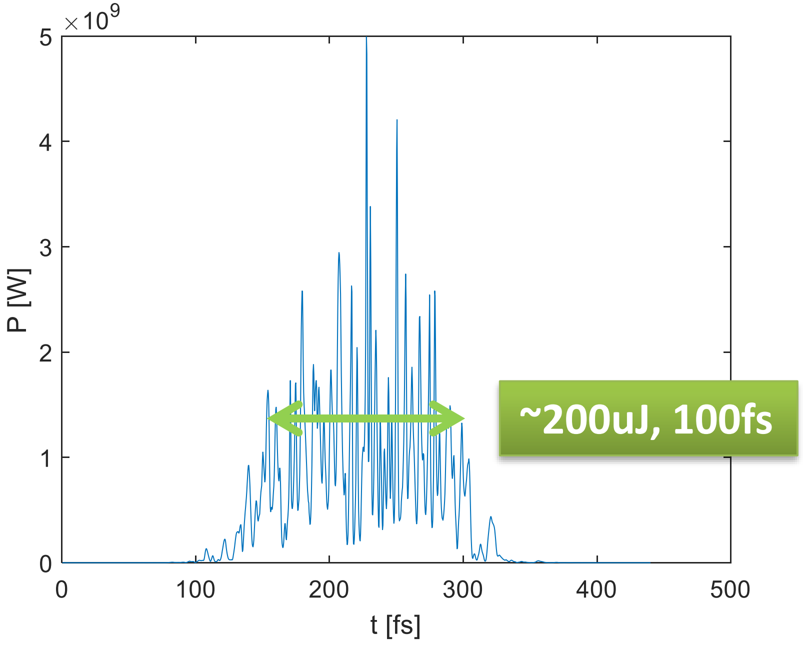




Tibai Z et al 2014, Phys. Rev. Lett. 113 104801
Alan Mak et al 2019 Rep. Prog. Phys. 82 025901

# FEL options (2)

- A longer undulator (~15 m) would allow access to a larger parameter space, including longer pulses with significantly higher pulse energy (>100 uJ).
- Results below show a simple SASE case at 2.3 nm and 4.4 nm.
- Seeding and associated advanced FEL schemes could also be implemented.



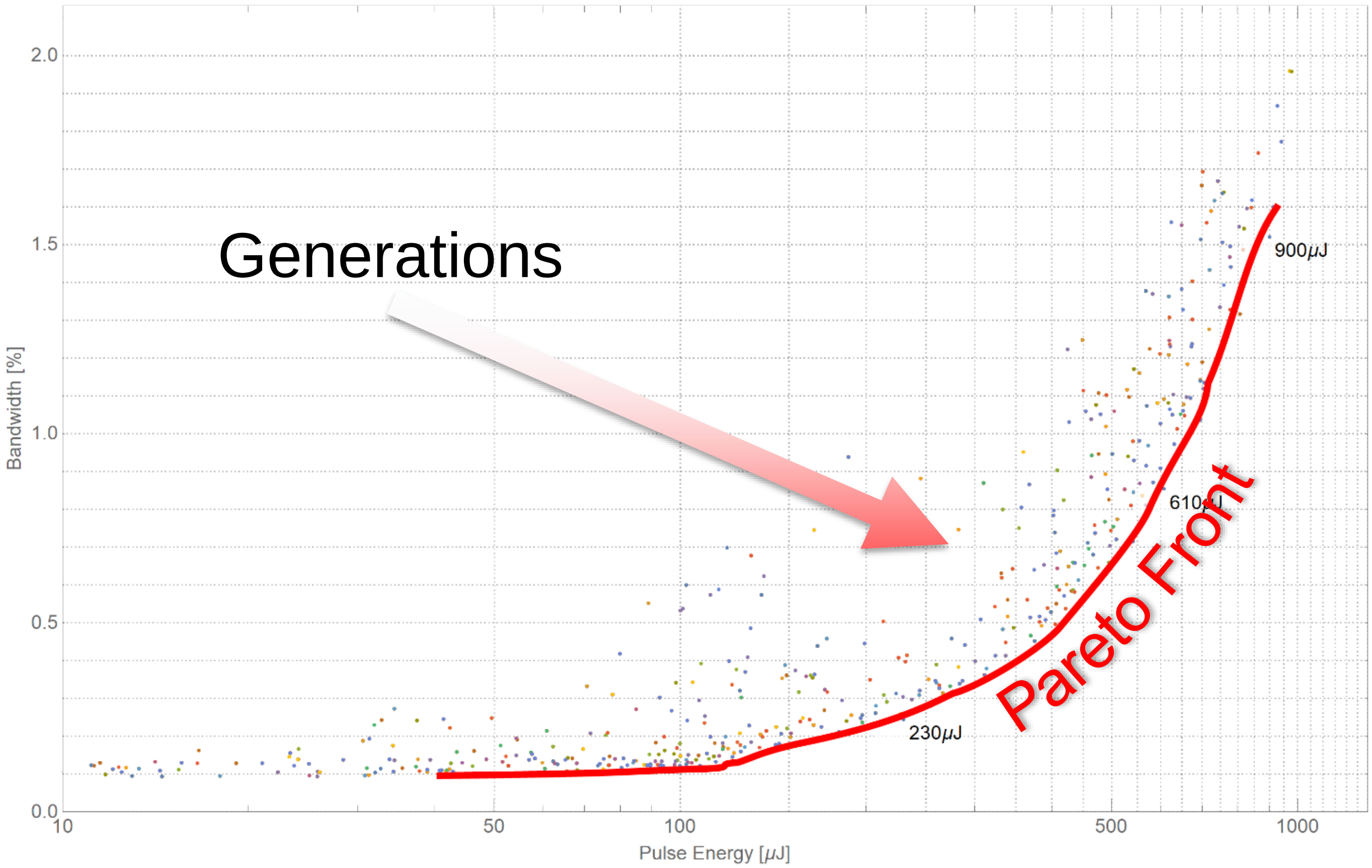
# Multi-bunch operation

- Photoinjector cathode can be exchanged for an alkali antimonide cathode
- An upgrade to 10 MHz green photoinjector laser allows multi-bunch operation
- Multi-bunch operation allows drive/witness plasma acceleration beam exploitation.
- Multi-bunch operation enable operation of a RAFEL (regenerative amplifier FEL) – a high-gain FEL with an optical cavity to improve temporal coherence and shot-to-shot stability.

# Start to end simulations

- Using python-based Simulation Framework
  - ASTRA to Elegant to Genesis2 (transparently!)
- Longitudinal matching only
  - All linac phases/amplitudes
  - Bunch Compressor angles
  - Dielectric De-chirper “gap”
- Includes: CSR, 3D-SC (Injector), LSC, Wake-fields (!)
- MOGA optimisation looking at SASE:
  - Bandwidth (min) and Energy (max) at 12.5m

# Start to end simulations

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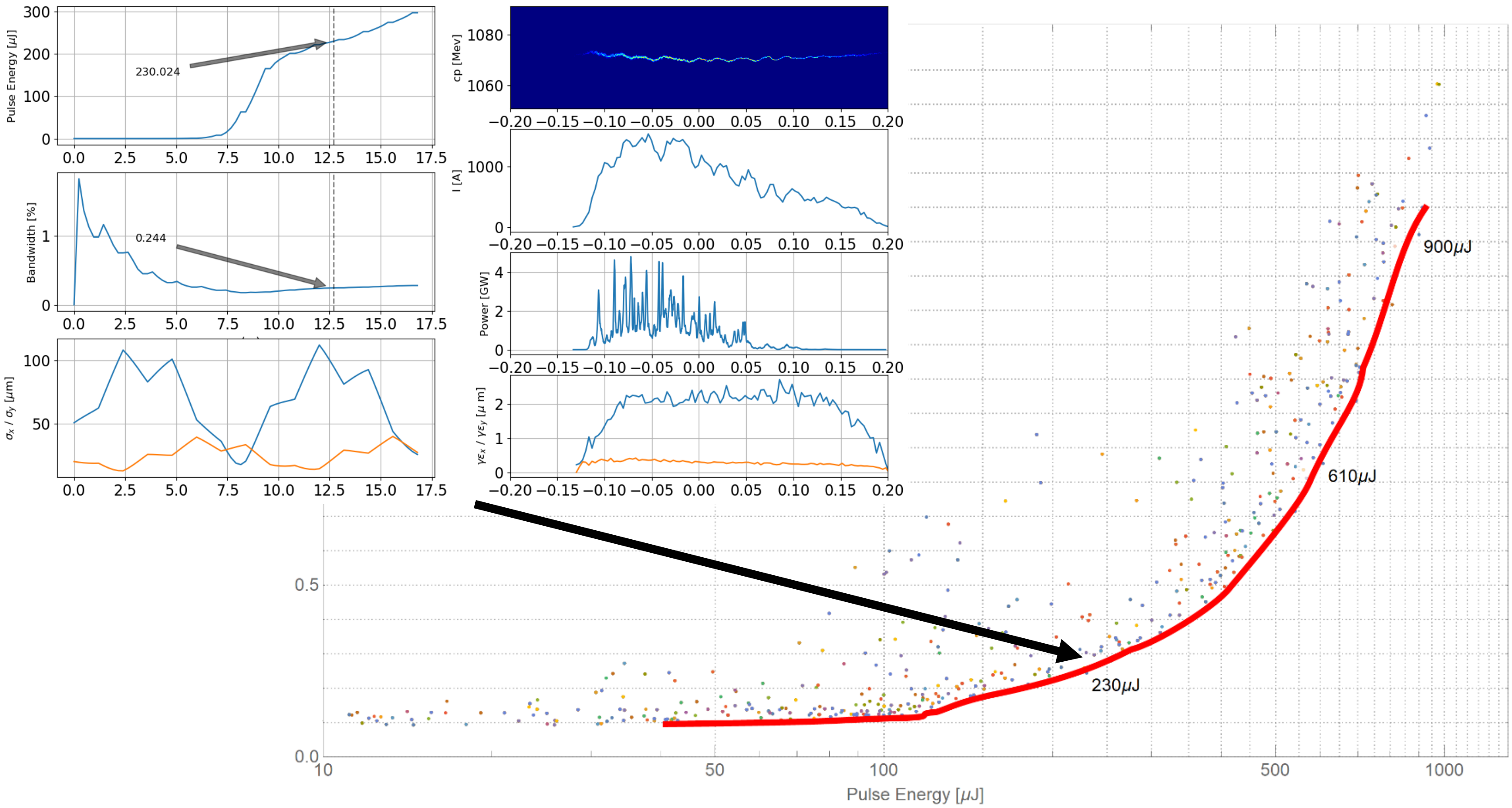
# Start to end simulations

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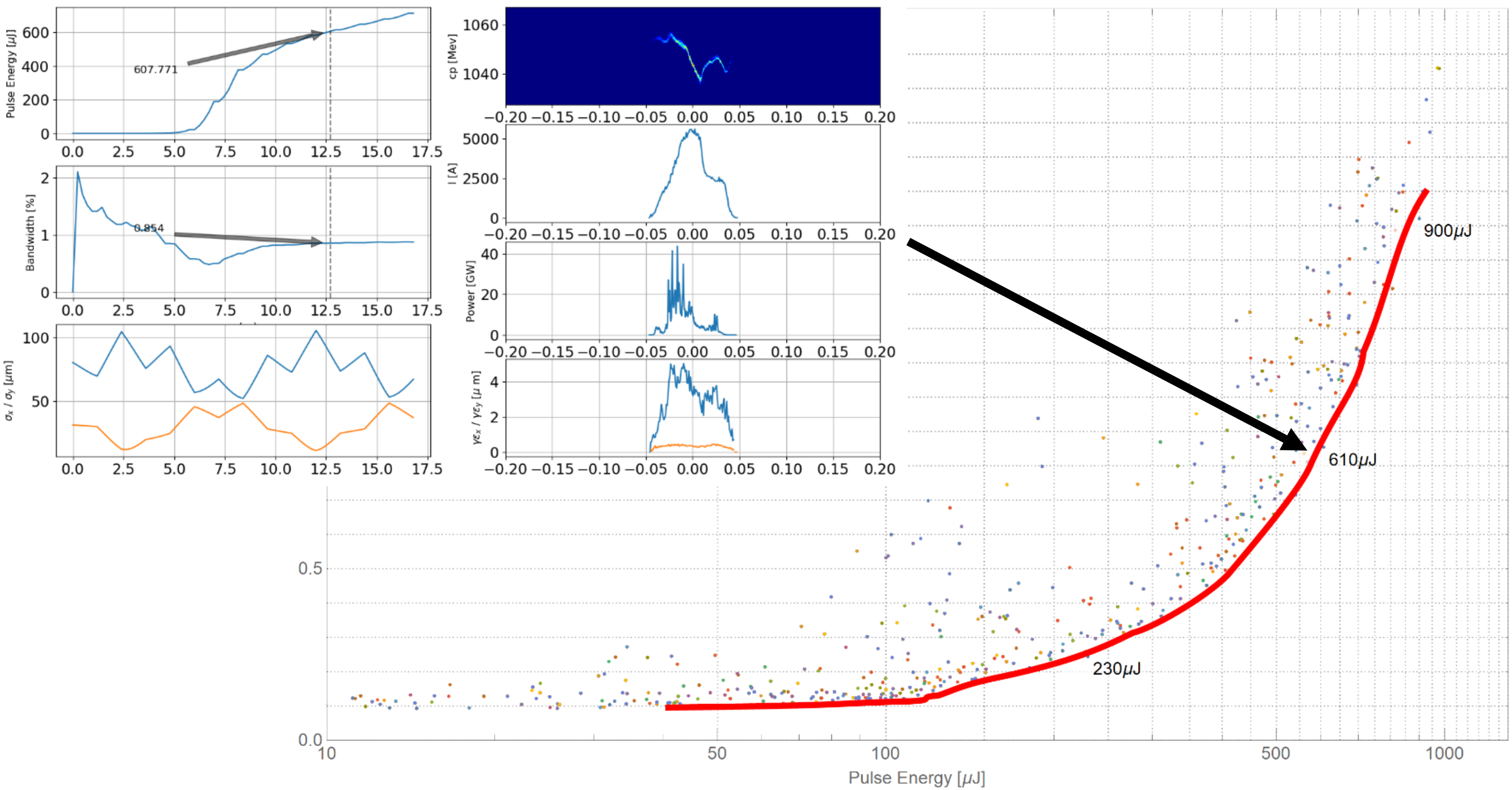
# Start to end simulations

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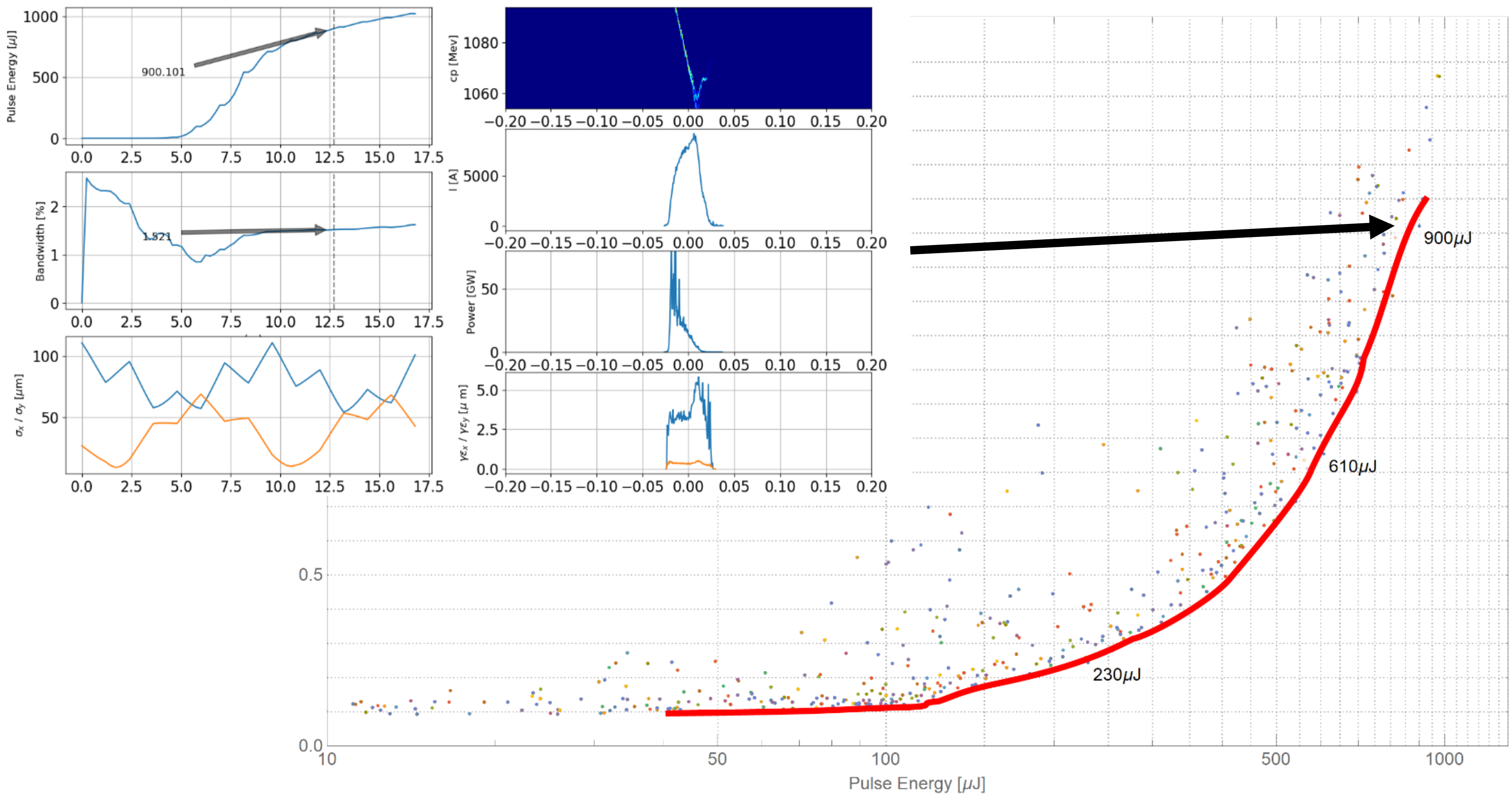
# Start to end simulations

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# Summary

- X-band upgrade to CLARA to reach 1 GeV
- EUV/soft x-ray FEL:
  - A useful wavelength for users
  - Pushes to shorter pulse durations (single cycle)
- Extends capability for electron beam exploitation
- CompactLight technologies enable low cost, efficient use of the existing building, while operating at the forefront of accelerator development

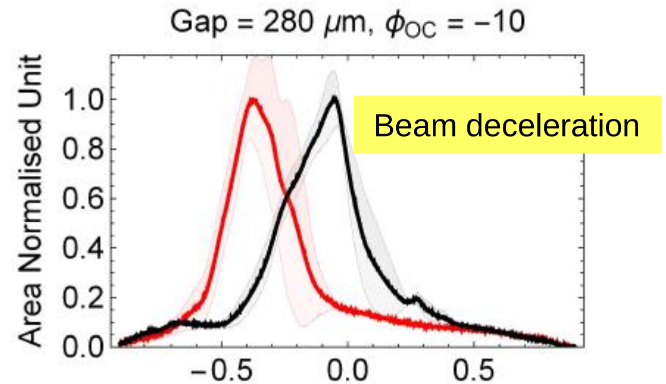
# Acknowledgements

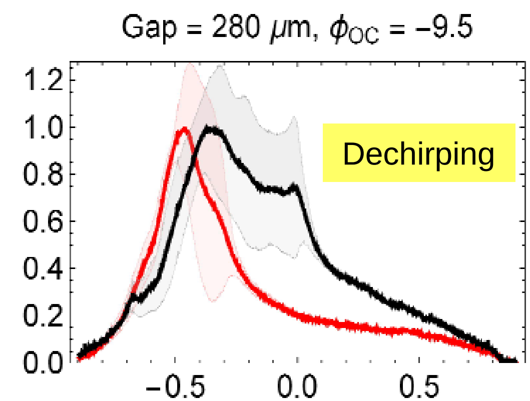

- David Dunning and James Jones at ASTeC for simulations and slides
- CompactLight collaboration & X-band community for making this idea feasible

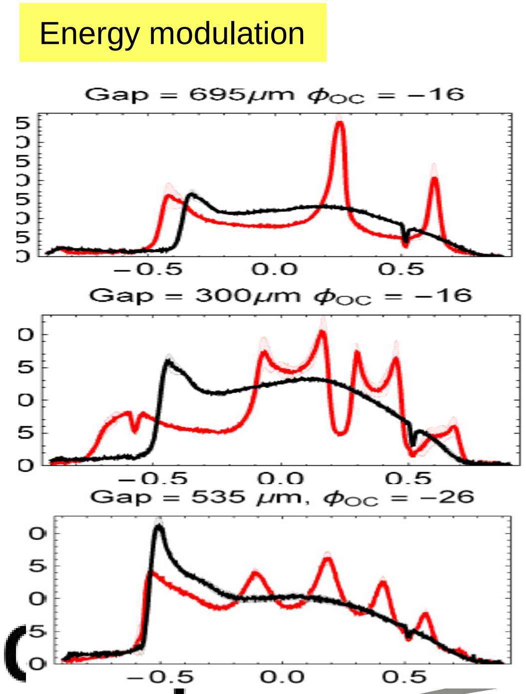
# Dielectric Dechirper Studies

Y. Saveliev, T. Pacey et al, ASTeC/CI

- **First dielectric wakefield experiments (UK)**
- Demonstrated "capability" to conduct Dielectric Wakefield Acceleration R&D on CLARA
- All dechirper effects demonstrated
- **7.5MV/m** decelerating field measured (**~30MV/m** accelerating field assuming no beam losses in structure and TR=2)



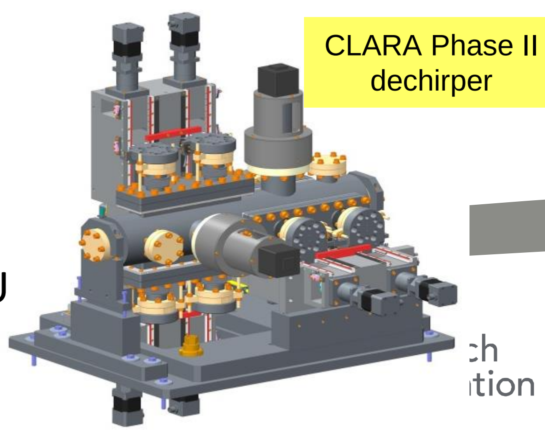





**Basis for future developments** :

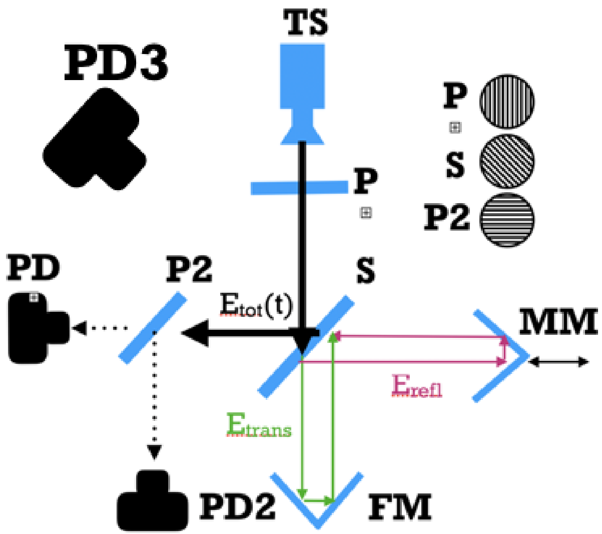
- CLARA Phase II dechirper implementation
- DWA structure as bunch length diagnostic
- Transverse beam dynamics and BBU
- International collaborations

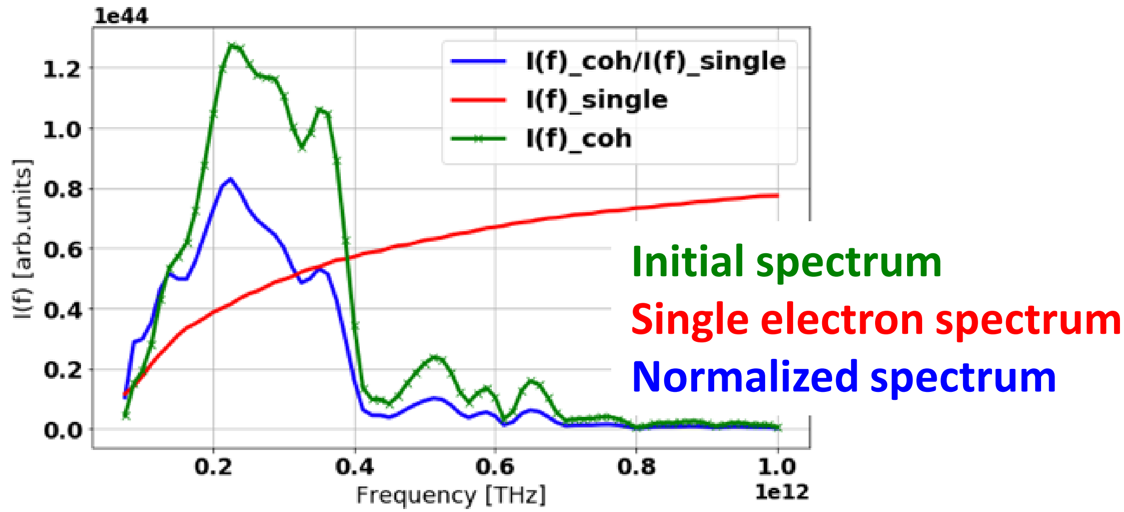


# Coherent Cherenkov Diffraction Radiation for Longitudinal Bunch Profile Diagnostics

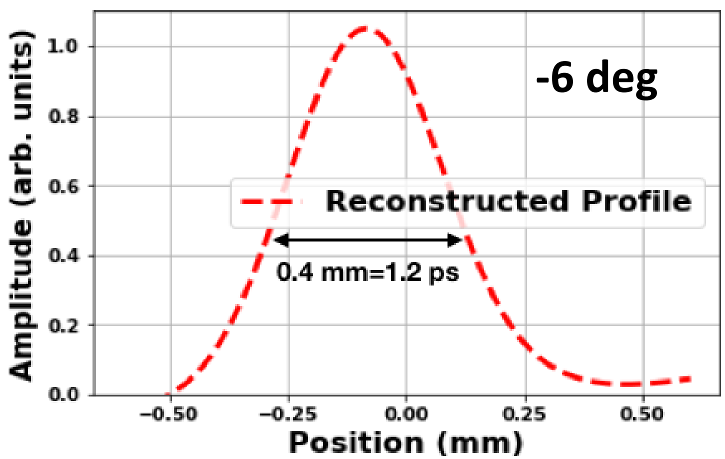
P. Karataev, K. Fedorov et al, RHUL/JAI

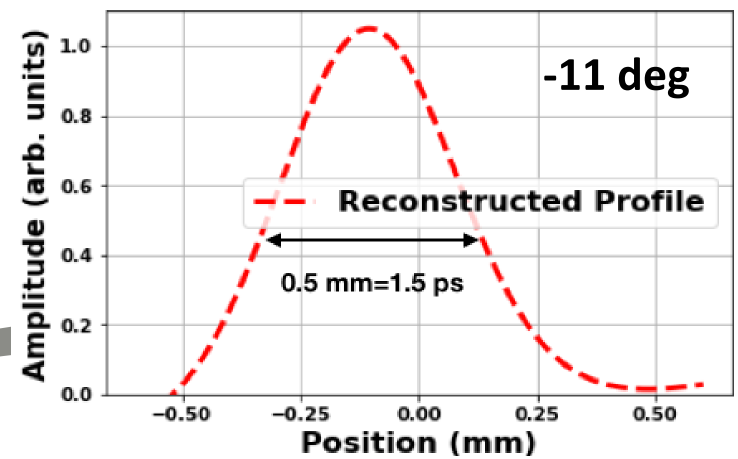
The radiation spectrum has been measured using Martin-Pupplet Interferometer




Longitudinal profile obtained via Kramers-Kronig method measured for two RF phases

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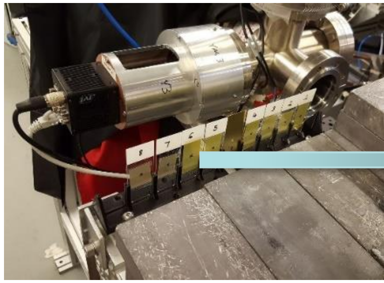
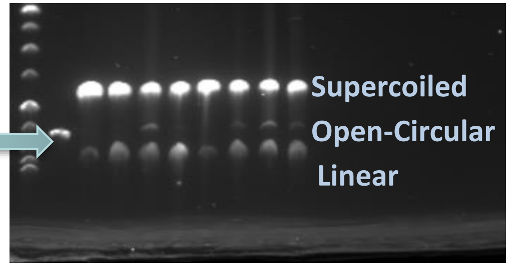
# VHEE DNA SSB/DSB EXPERIMENT at CLARA

R. M. Jones, K. Small et al, UMAN, Christie, ASTeC/CI

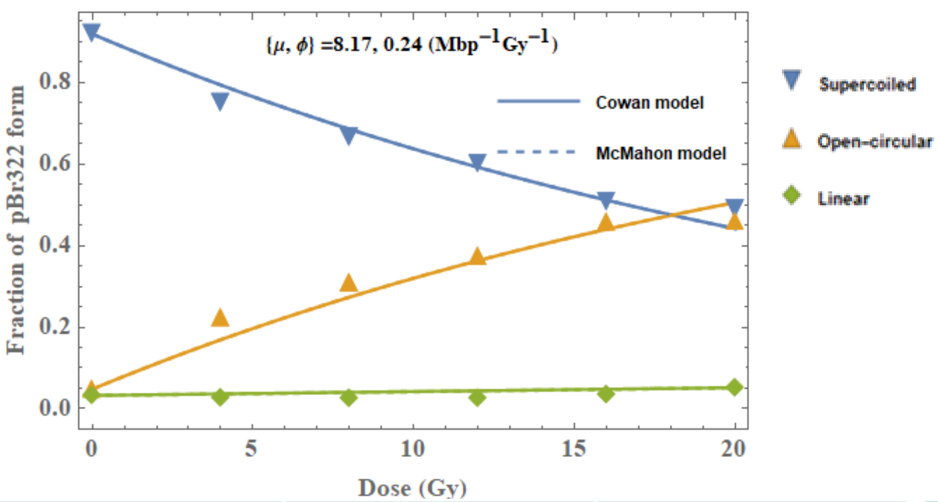




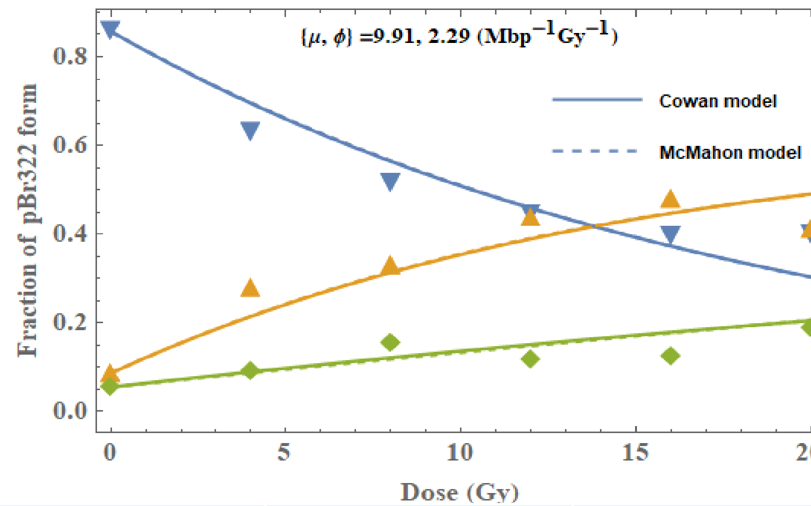

## Plasmid Constituents

Based on these fractional components the SSB (Single Strand Break) and DSB (Double Strand Break) rates are determined

**Plasmid Proportion vs. Dose for 20 MeV Electrons**




**Plasmid Proportion vs. Dose for 30 MeV Electrons**




| Model | μ ($Mbp^{-1}$ $Gy^{-1}$) | ϕ ($Mbp^{-1}$ $Gy^{-1}$) |
|---|---|---|
| McMahon | 8.18 | 0.22 |
| Cowan | 8.17 | 0.24 |

| Model | μ ($Mbp^{-1}$ $Gy^{-1}$) | ϕ ($Mbp^{-1}$ $Gy^{-1}$) |
|---|---|---|
| McMahon | 9.94 | 1.98 |
| Cowan | 9.91 | 2.29 |

μ is representative of Single Strand Breaks (SSB), Φ is representative of Double Strand Breaks (DSB)