John Adams Institute for Accelerator Science

Imperial College London

Royal Holloway University of London

UNIVERSITY OF OXFORD

Laser Wakefield Acceleration

Octoberfest!

October 2014

Peter Tudor

John Adams Institute for Accelerator Science

Points to cover

- Setting the scene
  - Conventional accelerators
- LWFA scheme and limitations
- Multiple Pulse LWFA scheme
- Fibre Lasers
- FET Proposal
- Future applications

Conventional accelerators

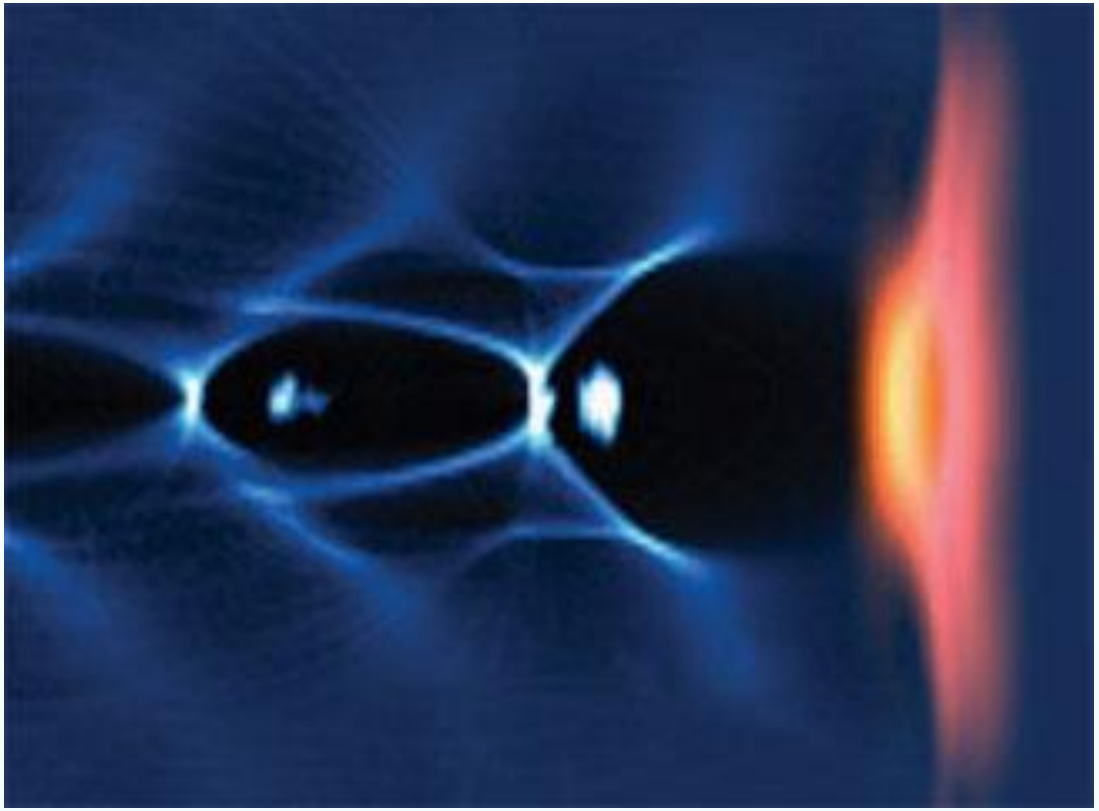
- Are able to produce high beam energies
- But:
  - Typically large structures
    - Large footprint
  - Expensive to build
  - Expensive to run
  - Requires large amount of maintenance work
- Not practical for proliferation of tech

LWFA Scheme

- High intensity laser pulse is fired into a plasma, causing large electron displacement
  - Via ponderomotive force
- This leads to a wakefield, forming a large gradient of electric field
- This can be used to accelerate electrons

What is a wakefield?

- **Oscillating electrons in a plasma lead to a wakefield**



Dr. Warren Mori, on behalf of SciDAC's Advanced Accelerator Group - http://www.scidacreview.org/0602/html/sa2.html

What is the motivation for LWFA?

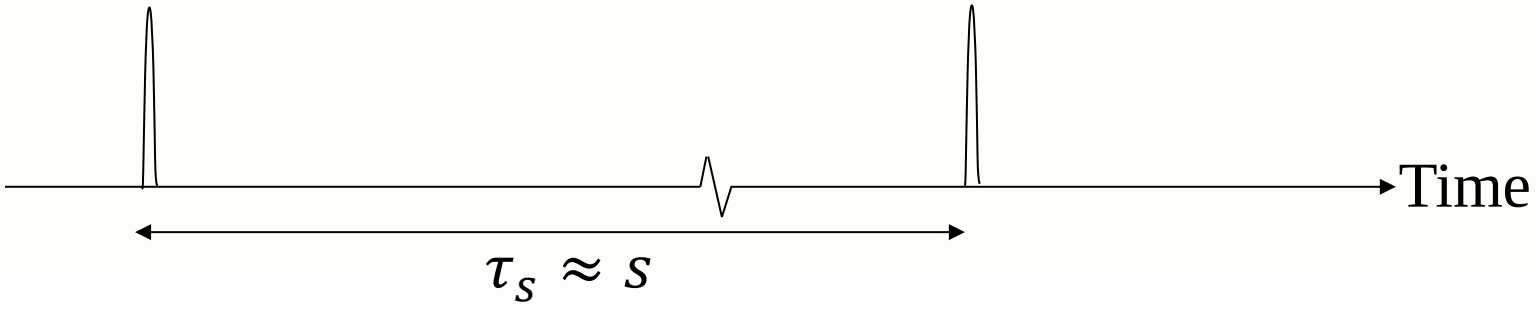
- **Large accelerating gradients**
  - **Up to 1GV / cm**
  - **3 orders of magnitude larger than RF**

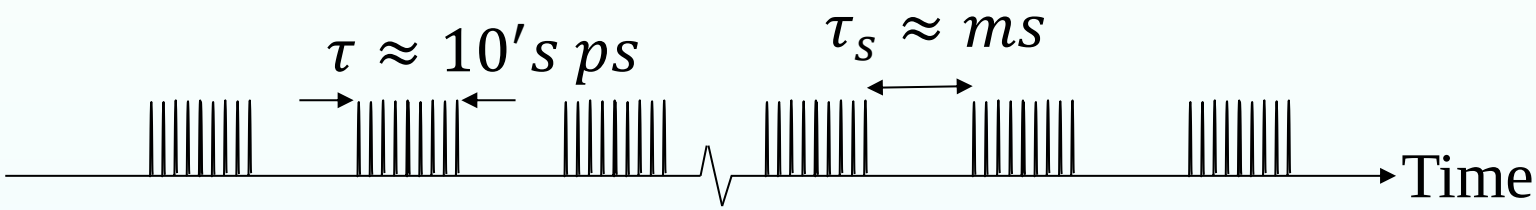
- **Have the potential to revolutionise accelerator technology.**
  - **Smaller accelerators**
  - **Cheaper accelerators**

Limitations of current LWFA schemes

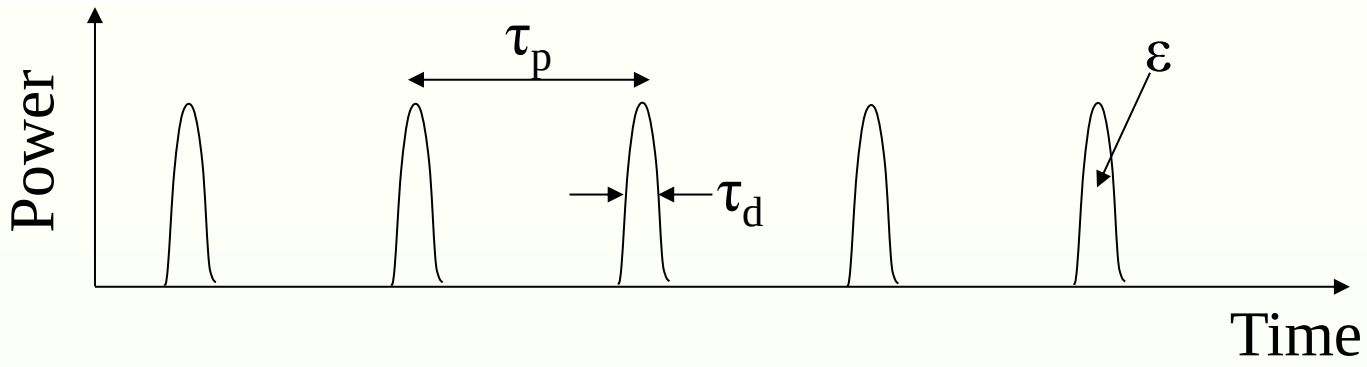
- **Current laser systems which drive LWFA are capable of high peak powers (J's in 10's fs), but:**
  - **Low repetition rate (≤1Hz)**
  - **Low wall plug efficiency (≤0.1%)**
- **Rep rate is limiting for applications and experiments**
  - **E.g. FELs and medical diagnostic etc**
- **Repetition rate and efficiency need to be improved for LWFA to be viable**

Multiple Pulse LWFA



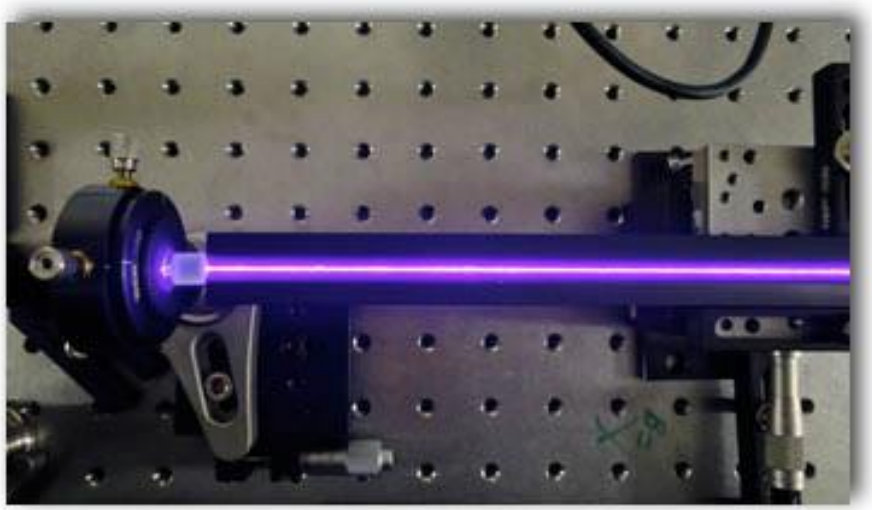


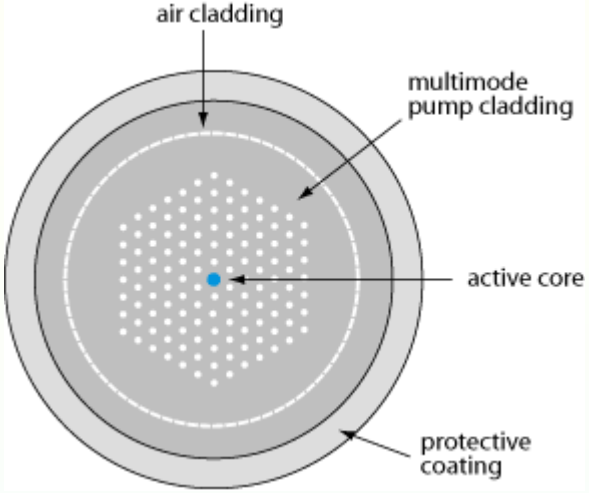
Multiple Pulse LWFA



- $\tau_p \approx Plasma\ period$ (100's fs)
- $\tau_d \leq \tau_p$
- Energy is delivered over 100s of pulses rather than a single pulse
  - Pulses resonantly excite a wakefield
  - $\epsilon \approx 10mJ$
- Can then use smaller, cheaper optical components. (Lower peak power)

Fibre lasers





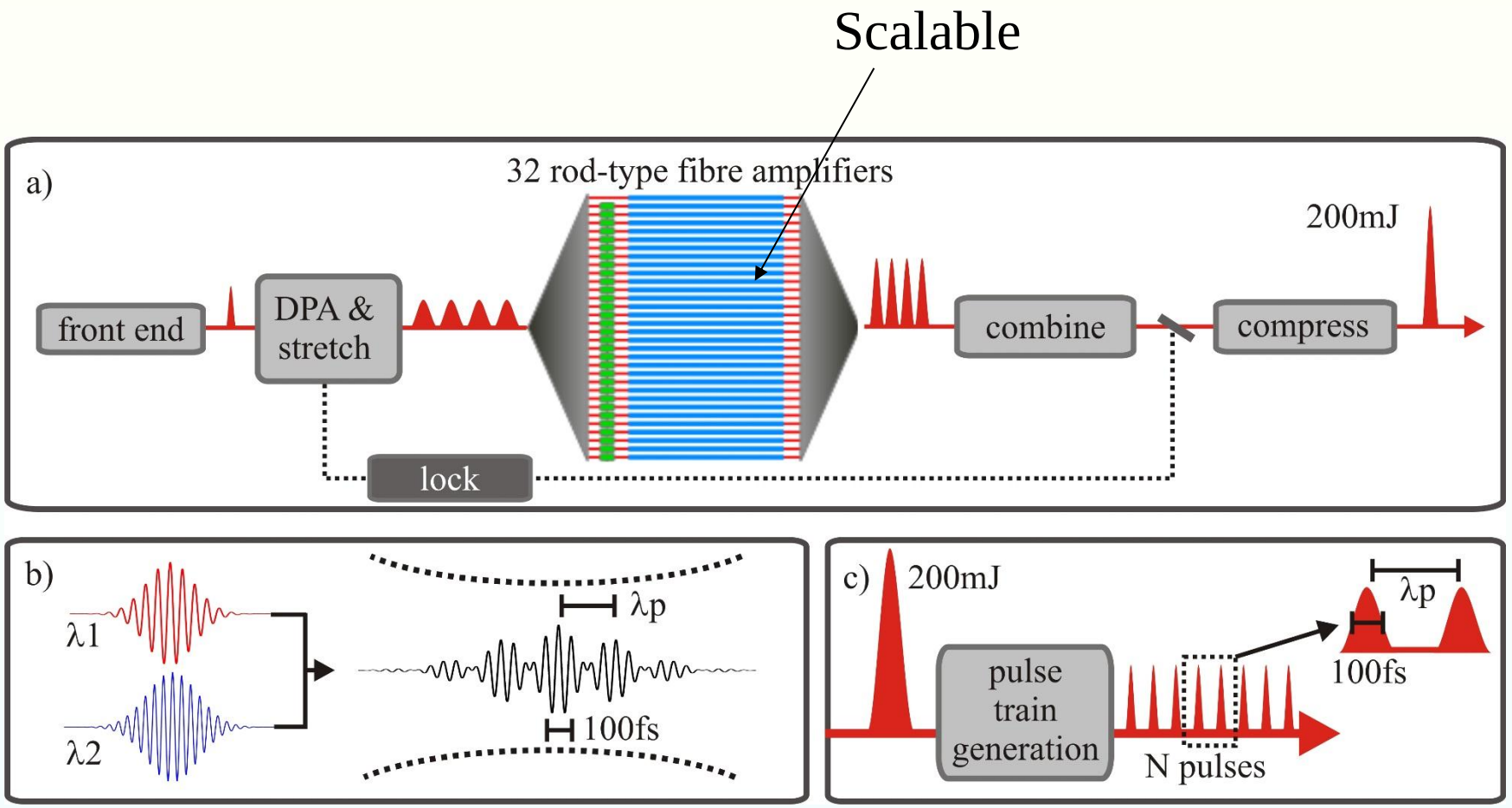
http://www.rp-photonics.com/photonic_crystal_fibers.html

- **Fibre lasers have:**
  - **High repetition rate, MHz**
  - **High wall plug efficiency, η = 20 – 30%**
  - **Higher average power than single shot systems**
- **The limitation**
  - **Low pulse energy**

FET Proposal

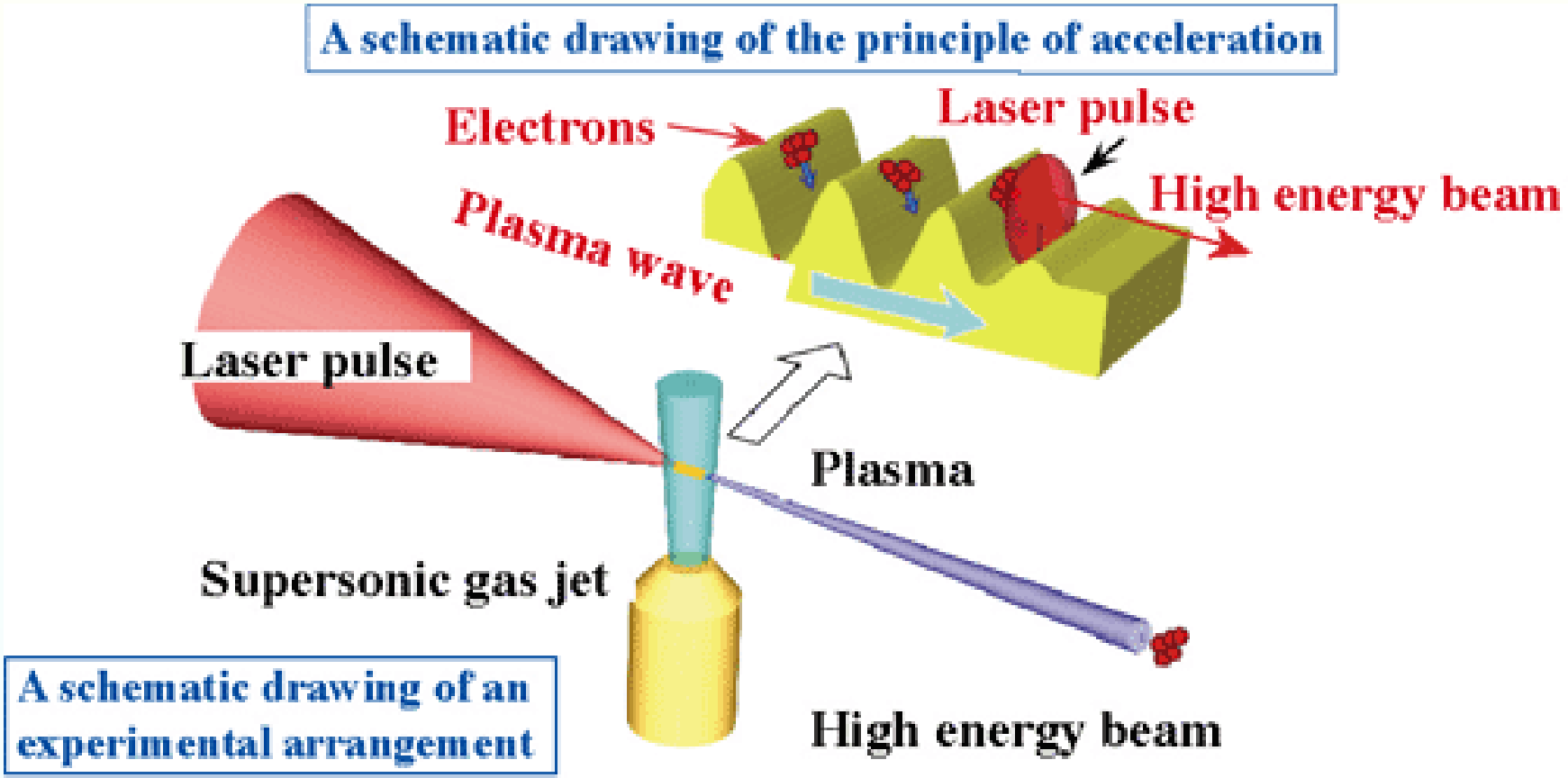
- Future Emerging Technologies (FET) proposal has been submitted as a partnership between Oxford, Jena, Imperial, UCL and ESRF.
- Intention is to build a demonstration LWFA with:
  - Electron energies up to 250MeV
  - Repetition rate of 10kHz.
  - Scalable architecture
- Application to EPSRC for funding to investigate MP-LWFA by Oxford and Imperial

Laser architecture



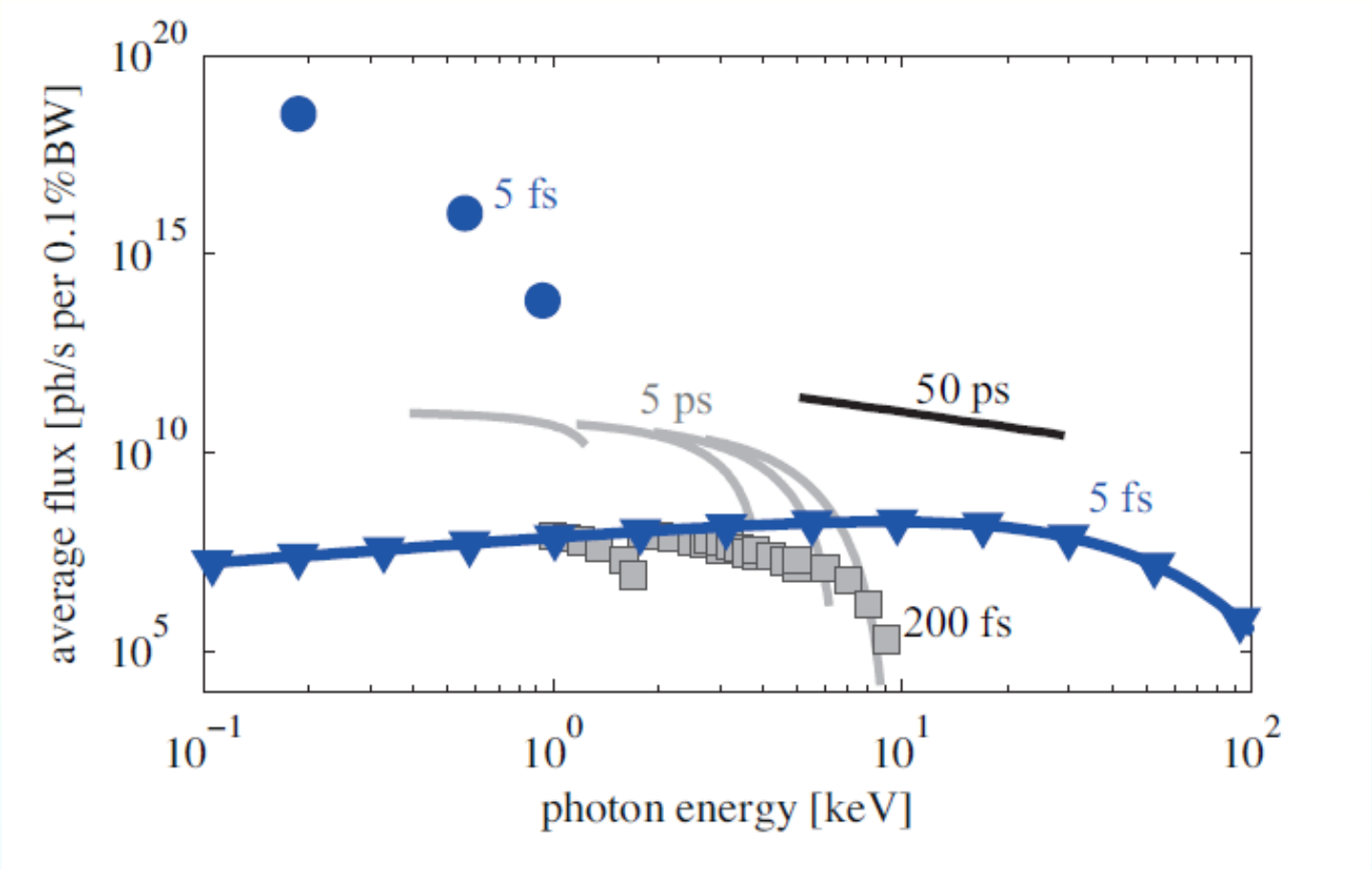
Laser architecture courtesy of Jena group

Electron bunch production



http://www.aist.go.jp/aist_e/latest_research/2004/20040812/20040812.html
Energy Technology Research Institute (ETRI) of
the National Institute of Advanced Industrial Science and Technology (AIST)

Comparison of light sources

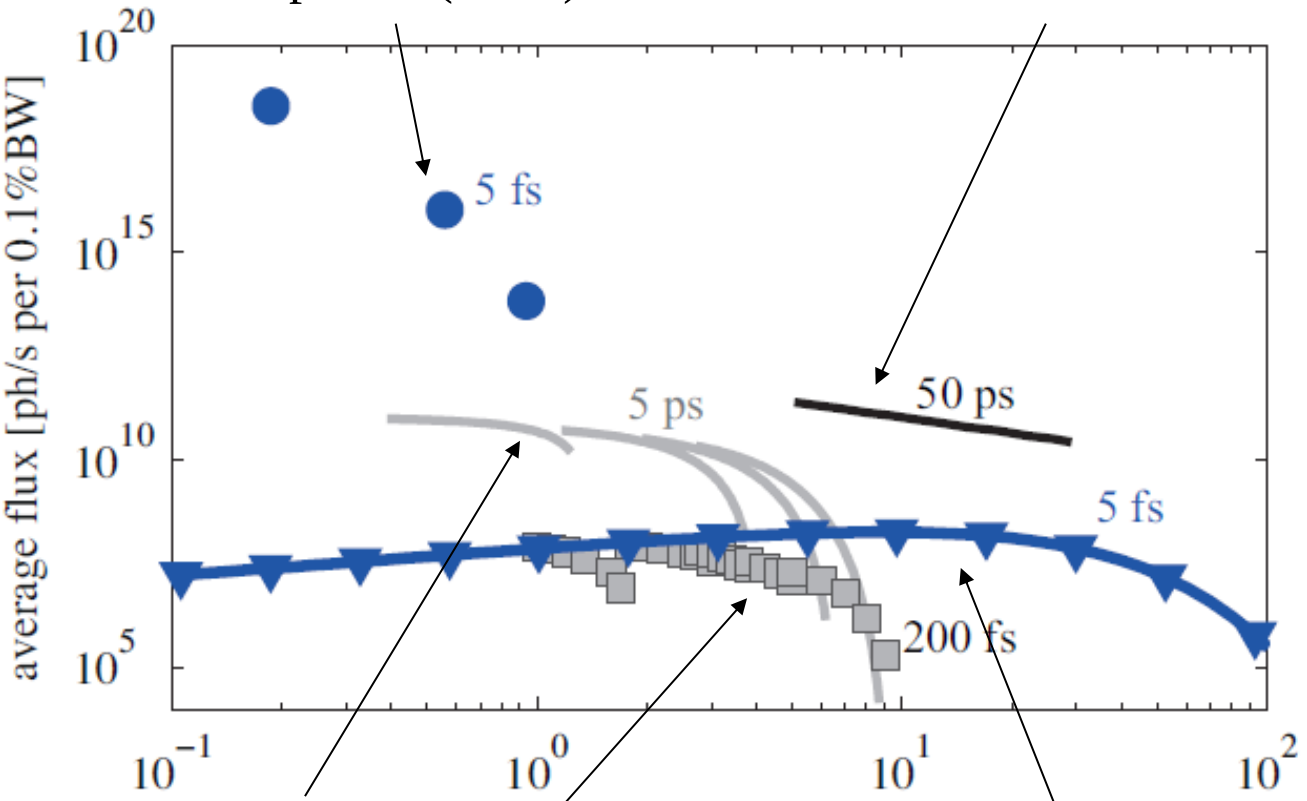


http://arxiv.org/abs/1401.7874v1
Multi-Pulse Laser Wakefield Acceleration: A New Route to Efficient,
High-Repetition-Rate Plasma Accelerators and High Flux Radiation Sources

Comparison of light sources

MP-LWFA driven FEL pulses (TGU)

ID9 beam line, ESRF



Diamond- Low α mode

LLNL FEL

MP-LWFA betatron pulses (1.3GeV)

http://arxiv.org/abs/1401.7874v1

Multi-Pulse Laser Wakefield Acceleration: A New Route to Efficient, High-Repetition-Rate Plasma Accelerators and High Flux Radiation Sources

Future Applications

- **Allow the proliferation of compact and efficient accelerators capable of GeV electron energies**
- **Ideal for use in universities**
  - **Good tool for education and research**
- **Use in hospitals**
  - **High resolution X-ray imaging**

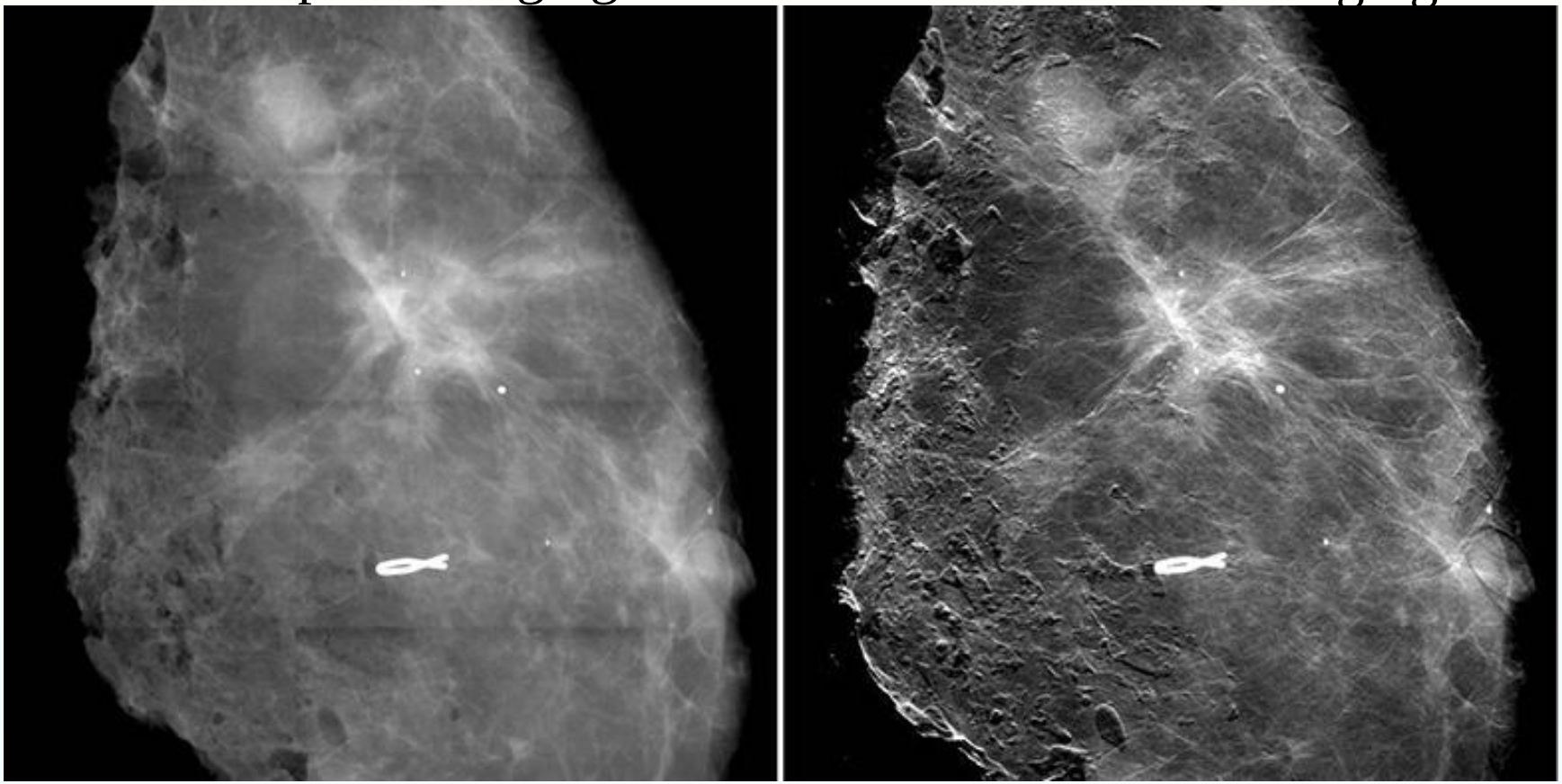
Any questions!

Future Applications

- **Example - Mammogram**

Absorption imaging

Phase contrast imaging

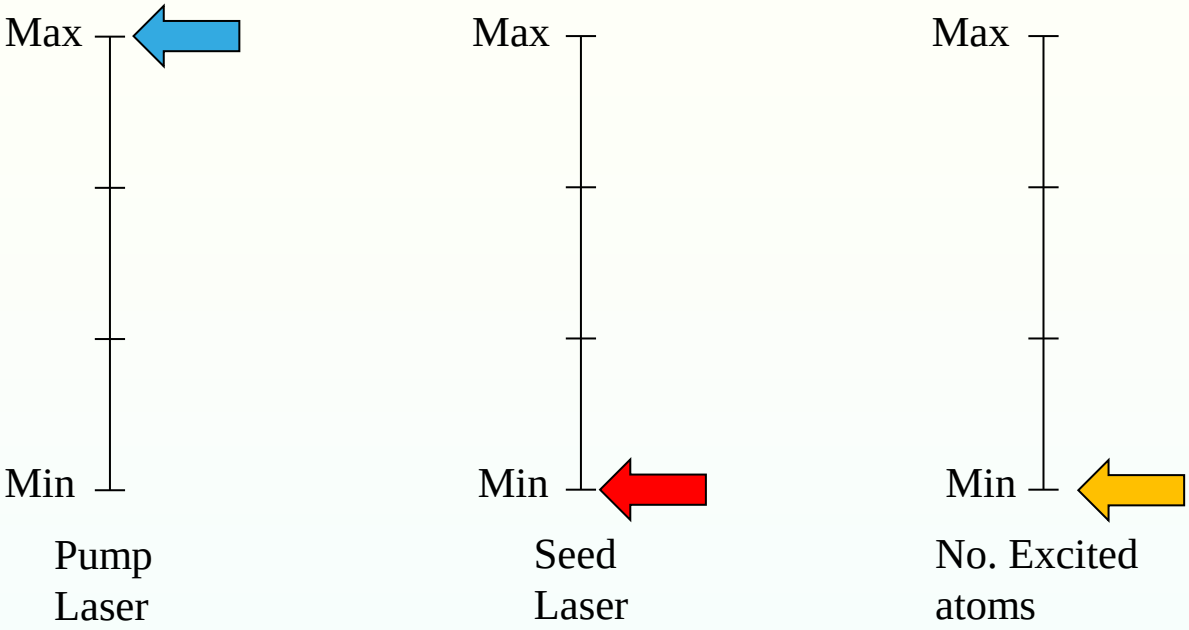


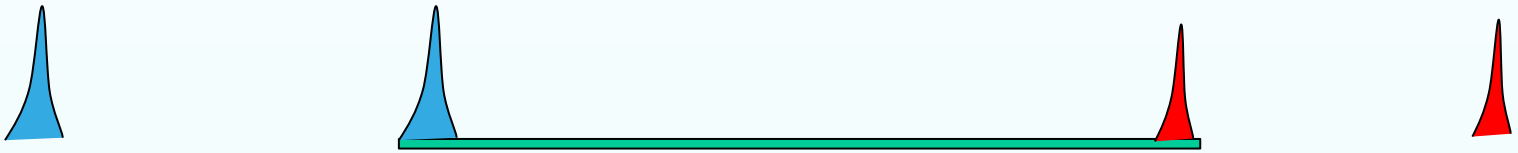
Paul Scherrer Institute, ETH Zurich – KS Baden

Doped Fibres

- The core is doped with a Rare Earth ion species. (Erbium, Ytterbium)
- The ion can be excited using a ‘Pump’ laser.
  - (Charging up the medium)
- The energy is liberated by the ‘Seed’ laser.
  - (Discharging the medium)
- This creates a light amplifier in the core of the Fibre itself.

Doped Fibres

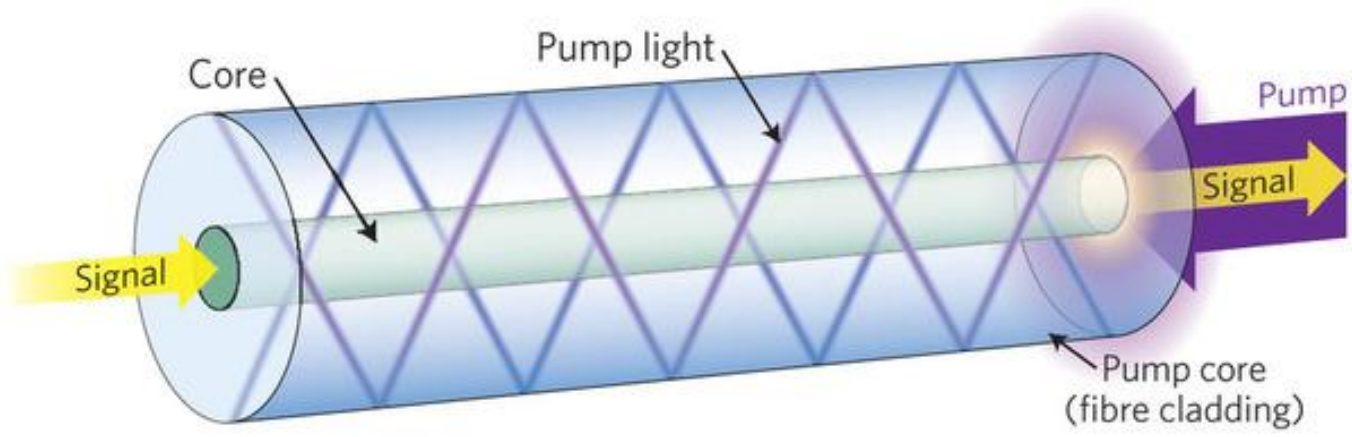




Doped Fibre

Photonic Crystal Fibres

- **Why would we use this?**
  - **Allows more pump energy to be transferred to doped core**



  - **Very high peak-power polarised laser pulses (GW, TW ranges)!**