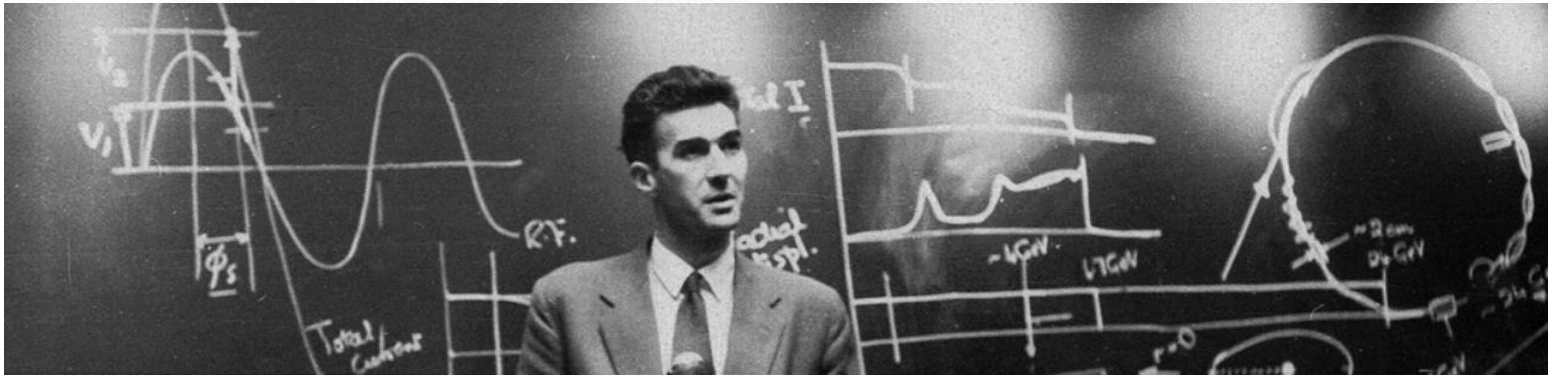
# JAI updates

IOP Particle Accelerators and Beams Group meeting
Royal Holloway, University of London
7 April 2017

**Andrei Seryi**
John Adams Institute for Accelerator Science

# What is JAI



Sir John Adams (24 May 1920 - 3 March 1984) - the 'father' of  CERN accelerators.

- **The John Adams Institute for Accelerator Science is a centre of excellence in the UK for advanced and novel accelerator technology, created in 2004 to foster accelerator R&D in the universities**

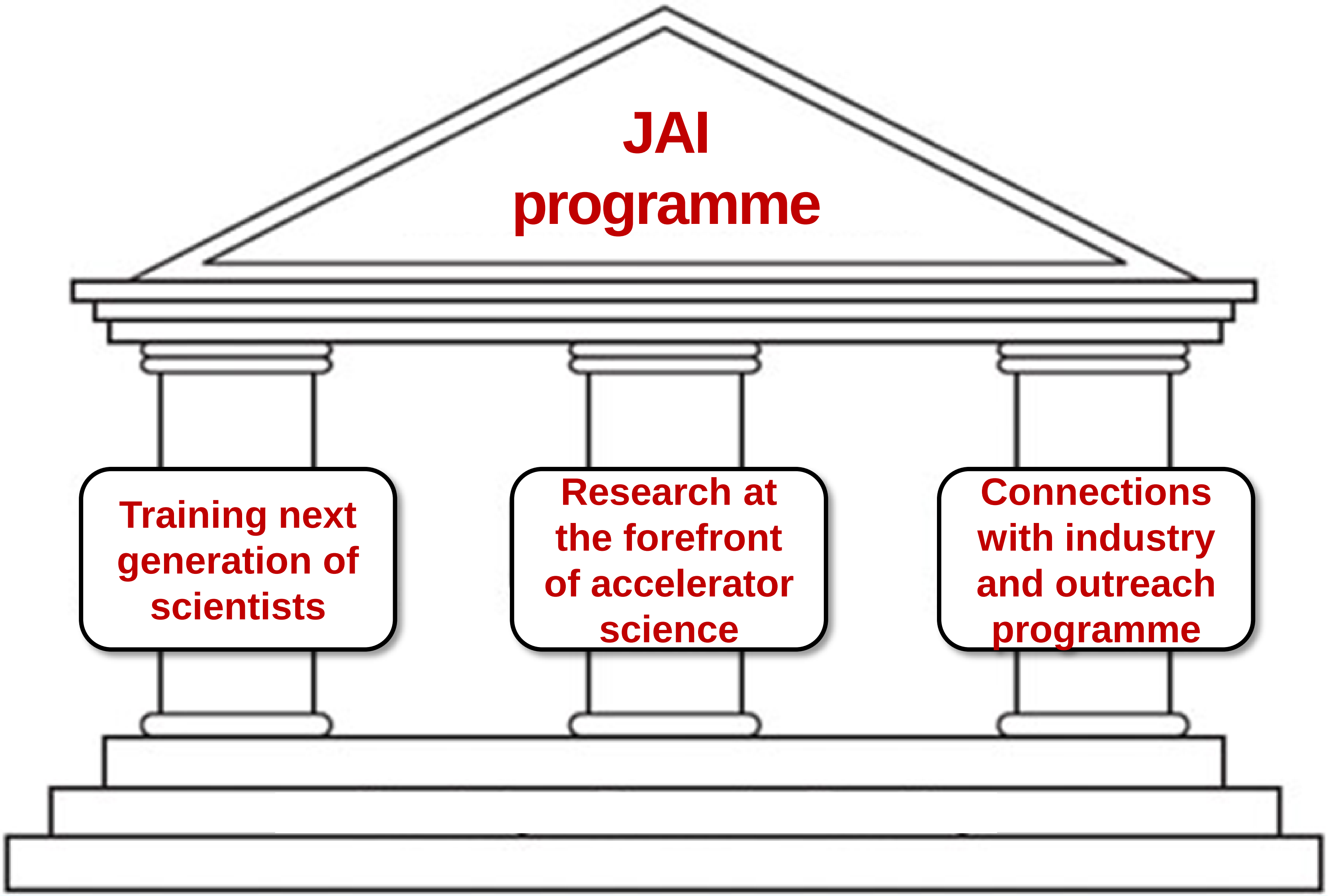
- **JAI is based on 3 universities: University of Oxford, Royal Holloway University of London and, since 2011, Imperial College London**

http://www.adams-institute.ac.uk

# JAI mission

- **The JAI's mission is to work with other national and international accelerator laboratories and institutes, to promote and develop accelerator science in the UK**
- **The main objectives of the Institute are:**
  - **To develop novel and advanced accelerator technologies for particle physics and other applications**
  - **To train a new generation of accelerator scientists and engineers**
  - **To disseminate knowledge about the benefits of accelerator technology to a wide community through outreach projects**
  - **To make major contributions to the design and development of new particle physics facilities**
  - **To develop new scientific facilities such as new light and neutron sources**
  - **The development and construction of applied accelerator technologies (medical, energy etc.)**

# Foundation of JAI programme



# Research program evolution

## … -2012

Enabling accelerator techniques for scientific, medical and energy applications

Advanced accelerator Instrumentation and beam diagnostics

Training

## 2012 -2017

Enabling accelerator techniques for scientific, medical and energy applications

Next generation compact light sources and laser-plasma acceleration FEL

Advanced accelerator Instrumentation and beam diagnostics

Training

## 2017 -2021

FEL and novel light sources — WP2

Plasma acceleration — WP3

Future colliders and particle physics facilities — WP4

Intense hadron beams — WP5

Training — WP1

# Research Directions (examples)

## 2012 -2017

**Enabling accelerator techniques for scientific, medical and energy applications**

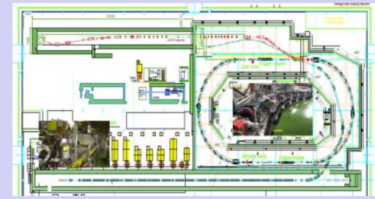
**Next generation compact light sources and laser-plasma acceleration FEL**

**Advanced accelerator Instrumentation and beam diagnostics**

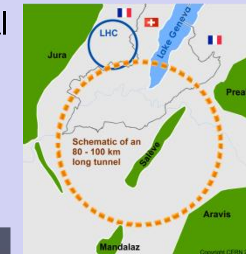
**Training**

### Examples of research

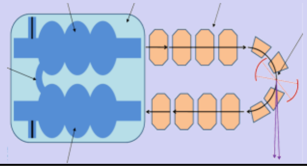
Diamond upgrade



LC Final Focus

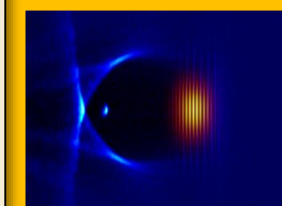


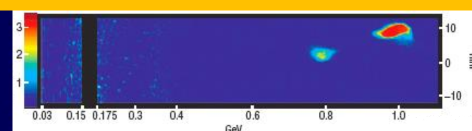

FCC IR & FF

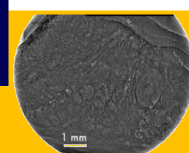


Novel ERL design of UH-FLUX

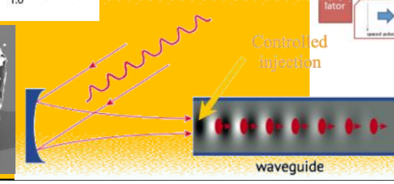
ESS

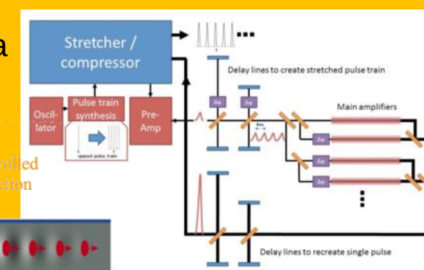


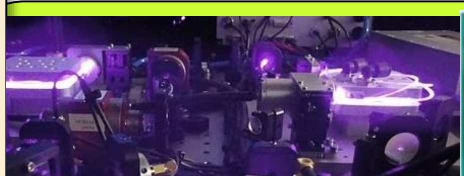


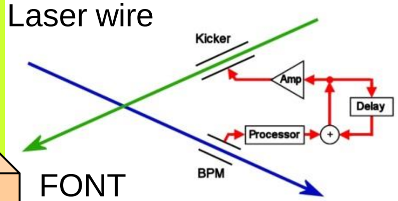

Laser-plasma acceleration



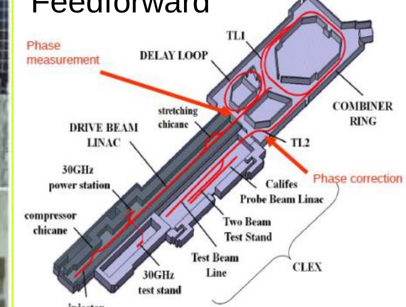
Laser wire




FONT

BPMs

Feedforward




Beam $\sigma_z$ diagnostics



Imperial College London  Royal Holloway University of London  University of Oxford

# Research Directions & achievements

## 2012 -2017

**Highlights of achievements**

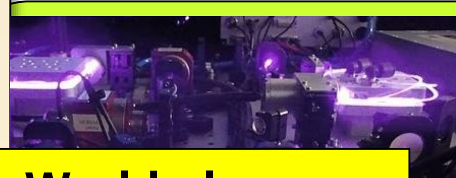
**Enabling accelerator techniques for scientific, medical and energy applications**

- Demonstrating new low ε techniques at Diamond Light Source
- Improving HL-LHC collimation system by developing electro-optics BPM embedded into collimators
- Validating nm-level beam stabilisation for ATF2 & CLIC IR
- Develop drive beam phase feed-forward system

**Next generation compact light sources and laser-plasma acceleration FEL**

- Laser-plasma acceleration to 2 GeV in a single stage
- The first demonstration of multi-pulse plasma-wave excitation
- High brightness plasma acc. X-ray sources
- Phase-contrast imaging of human tissues and high-resolution bone tomography

**Advanced accelerator Instrumentation and beam diagnostics**

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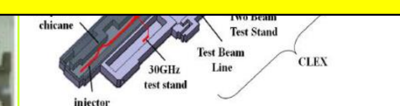
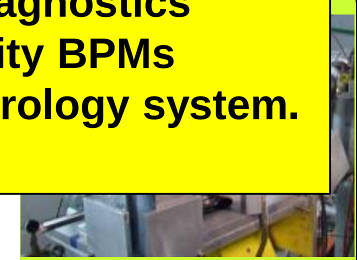


Beam $\sigma_z$ diagnostics

- OTR and Smith Purcell diagnostics
- Commercialization of cavity BPMs
- Commercialization of metrology system.

**Training**

**World-class graduate training: 60 PhD experts graduated from JAI**

# Many aspirational deliverables or new ideas were realized

## 2012 -2017

**Highlights of over-delivery**

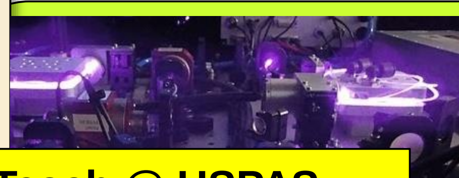
**Enabling accelerator techniques for scientific, medical and energy applications**

- Developed optics for Diamond Light Source upgrade which is now being realized in one of the sectors of DLS.
- Developed an electro-optics pick-up embedded into collimators – a key device for HL-LHC
- Developed a novel design of SCRF compact light source based on coupled asymmetrical cavities

**Next generation compact light sources and laser-plasma acceleration FEL**

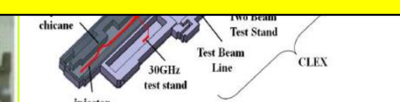
- Developed a new, non-invasive technique for measuring the angularly-resolved spectrum of betatron X-rays.
- Developed a proposal for an innovative two-stage laser and beam-driven wakefield accelerator based on self induced microbunching of an external electron beam, which can allow to create X-ray pulses with unique properties.

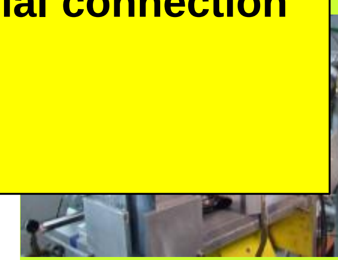
**Advanced accelerator Instrumentati[on] and beam diagnostics**



- Developed further industrial connection for AMULET technology

BPMs



Beam $\sigma_z$ diagnostics

**Training**

- Teach @ USPAS, JUAS, CAS, AAS
- Created a novel textbook

# Programme for 2017-2021 - structure

1. Training
   1. Undergrad. & grad. training
   2. Visitor programme
   3. Advanced courses jointly with CI
2. FEL and novel light sources
   1. FEL design
   2. Diamond upgrade
   3. FEL-CLF-DLS synergy
   4. Advanced beam diagnostics for UK FEL
   5. Compact laser-plasma light sources
   6. Compact SCRF X-ray and THz sources
3. Plasma acceleration
   1. Development of Wakefield acc.
   2. Laser driven ion beams
   3. Medical applications
   4. Contribution to AWAKE
4. Future colliders & PP facilities
   1. HL-LHC
   2. ILC, CLIC and MDI
   3. FCC and MDI
   4. MICE science experiment
   5. A low E gg collider
5. Intense hadron beams
   1. Future of FETS
   2. IBEX Paul trap and IOTA
   3. FFAG and ISIS-2 design
   4. ESS linac study & commission.
6. Industrial and public outreach
7. Admin and collaboration support

# Research directions

## 2017 -2021

**FEL and novel light sources**

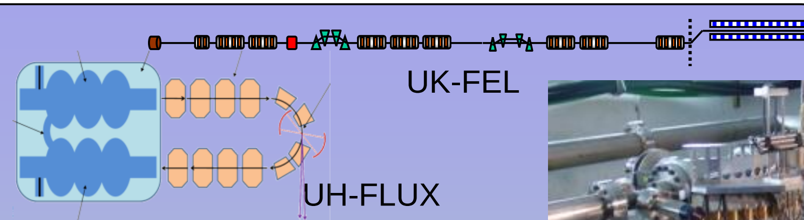
**Plasma acceleration**

**Future colliders and particle physics facilities**

**Intense hadron beams**

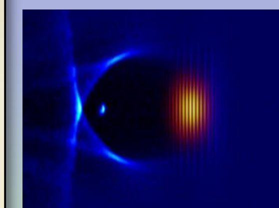
**Training**

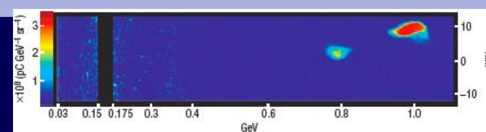

Diamond upgrade


UK-FEL

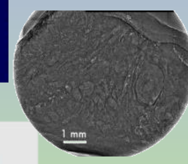
UH-FLUX

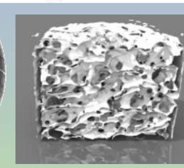

Beam diagnostics

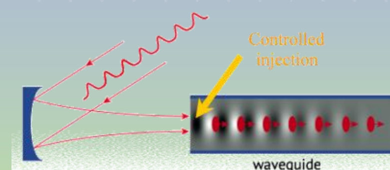


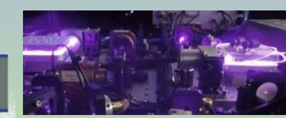


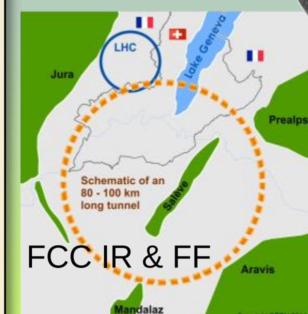

MP LWFA



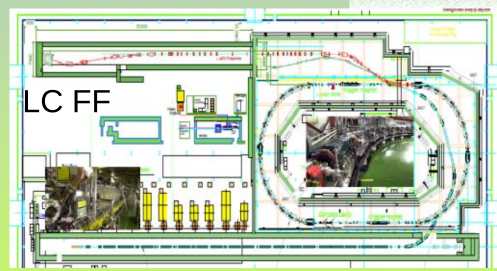



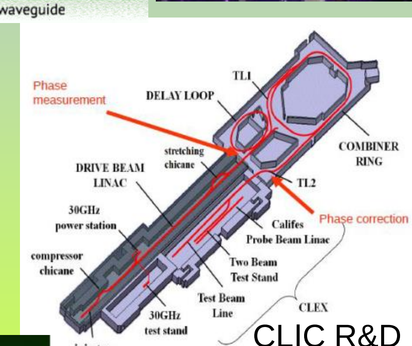


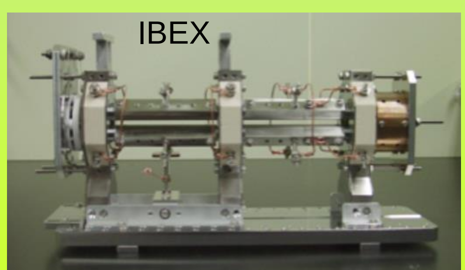


FCC IR & FF


LC FF



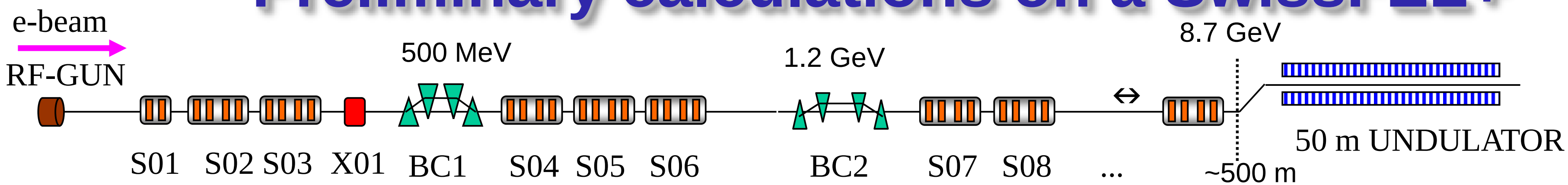
CLIC R&D


IBEX

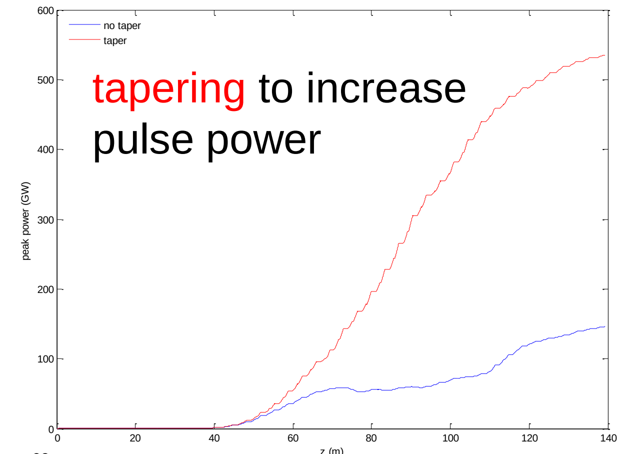
AWAKE

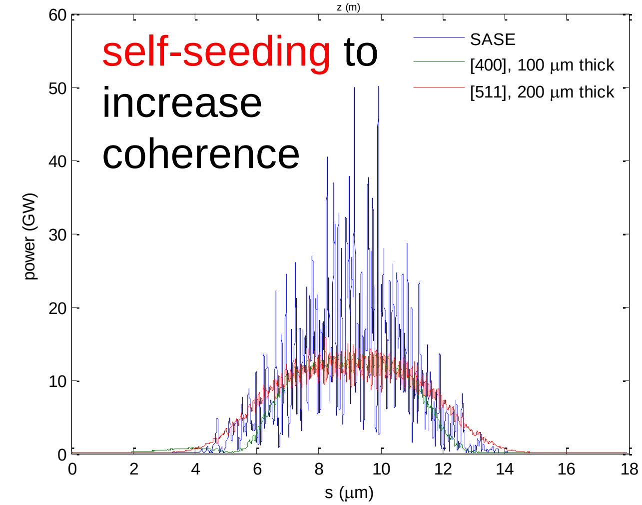
# WP2.1: FEL design

# Preliminary calculations on a SwissFEL+



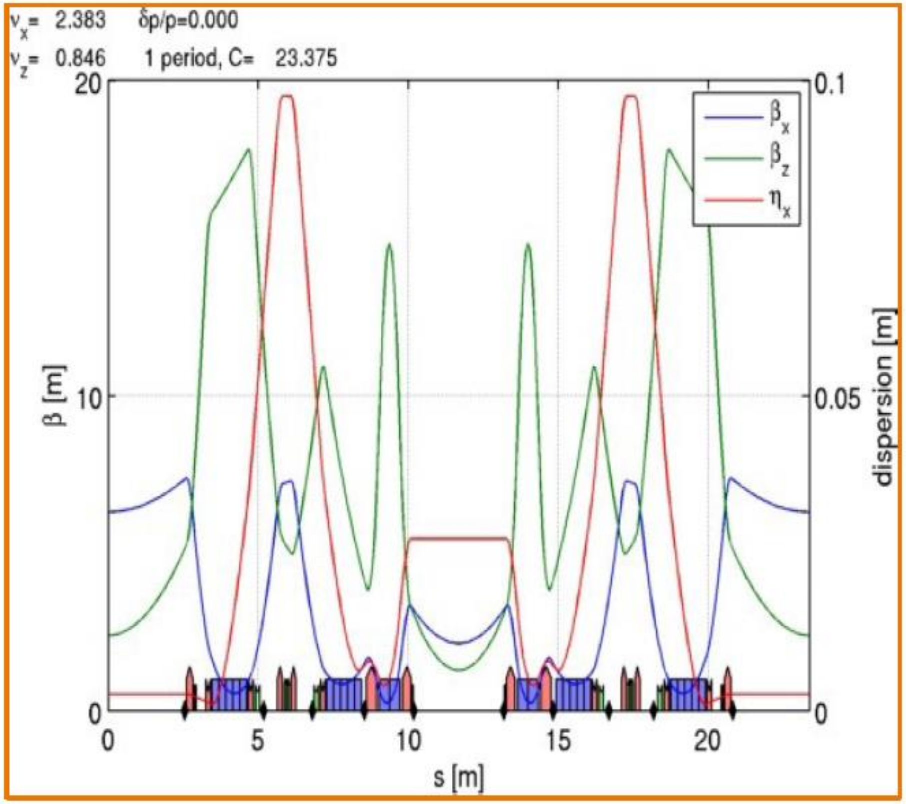

| | |
|---|---|
| Energy | 8.7 GeV |
| Repetition rate | 100 Hz (each FEL) |
| Max. photon energy | ~ 18.6 keV |
| Pulse duration | 20-30 fs |
| Photons/pulse (10 keV) | ~ $10^{12}$ |
| No. of FELs | up to 4 (?) |
| Possible FELs | SXR (0.1 – 2 keV) |
| | MXR (1.5 – 6 keV) |
| | HXR (5 – 15 keV) |
| Experimental stations | 3 per FEL |
| Facility length | ~ 850 m |
| Power consumption | ~ 7MW |

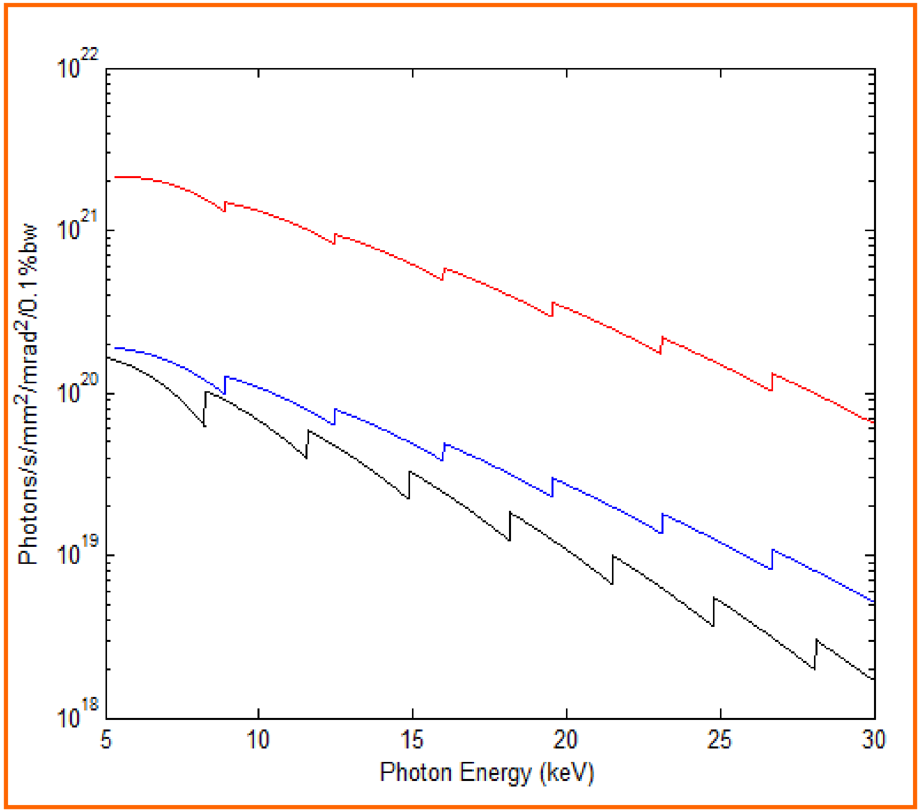


# WP2.2: Diamond upgrade

The novel optics will allow an order of magnitude higher brightness

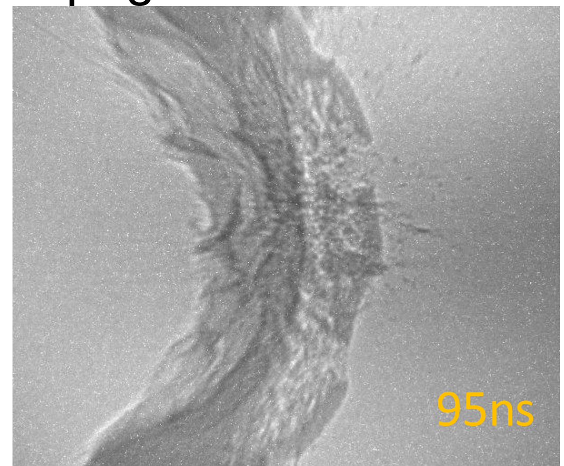


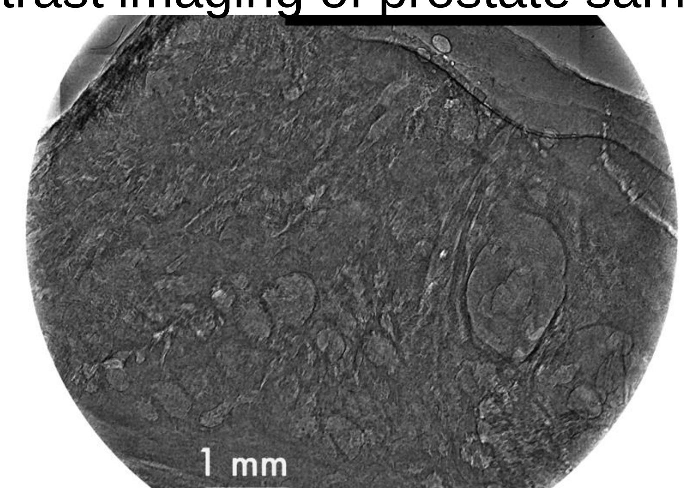
# WP2.5: Compact laser plasma radiation sources

Gemini betatron x-ray source now > **$10^{24}$** photons per ($mm^2$ $mrad^2$ sec 0.1%BW)

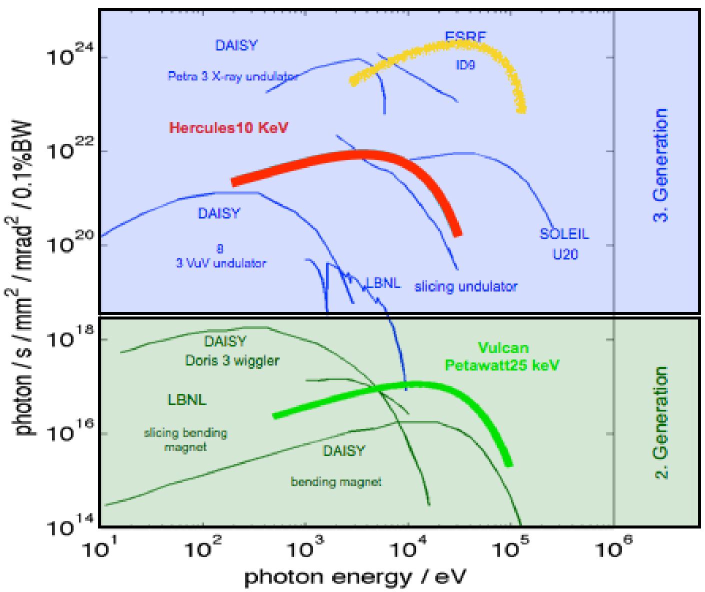
Used for imaging fast phenomena; e.g. shock propagation in dense material.




medically relevant material; e.g. phase contrast imaging of prostate sample




**Gemini 2015**




other light sources from A. Rousse *et al*, EPJD, 2008

# WP2.6: Compact SCRF X-ray and THz light source

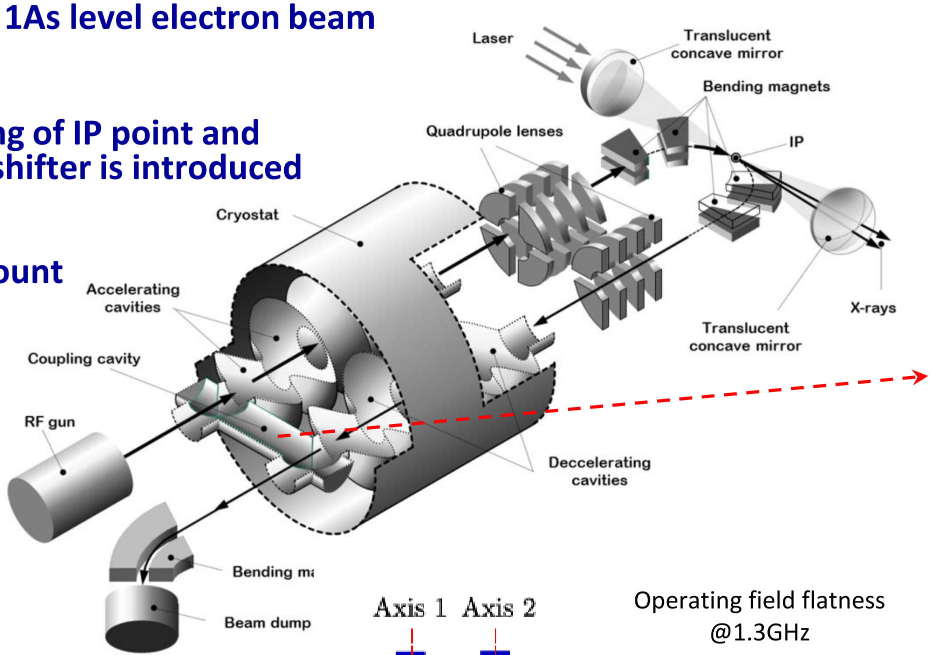
**Asymmetric Energy Recovery Linac**

**Advantages:**

**a) capability to drive 1As level electron beam average current**

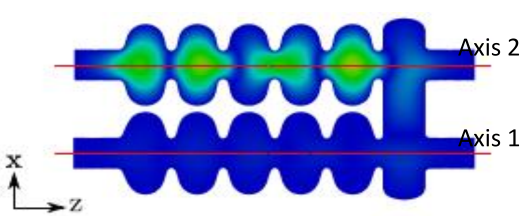
**b) independent tuning of IP point and accelerator if phase shifter is introduced in the coupling cell**

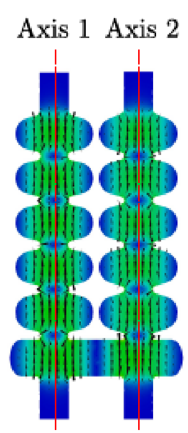
**c) field tuning to account for beam change at interaction point**




Al prototype for low-level RF measurements

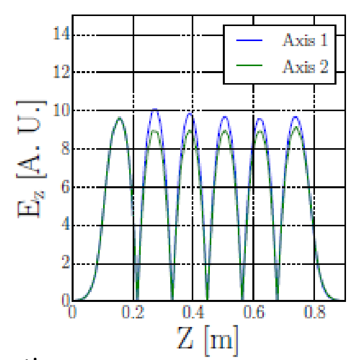
Electric field contour plot of dipole partial eigenmode at 1.73GHz




Electric field contour plot of operating eigenmode at 1.3GHz

Operating field flatness @1.3GHz

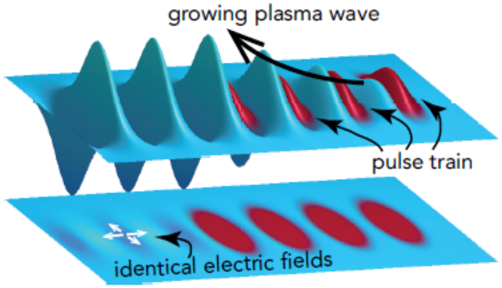


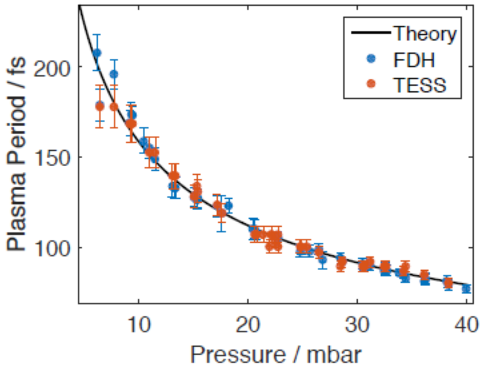
# WP3.1: Development of wakefield accelerators

## WP3.1.2: Development of efficient high rep-rate LWFA

- Multi-pulse laser wakefield acceleration may offer route to high repetition rate plasma accelerators driven by trains of low-energy laser pulses
- Proof-of-principle experiments
  - Ti:sapphire laser
  - FDH and TESS to measure wakefield
- Two-pulse expts
  - Wakefield interference clearly observed
  - Cancellation of wakefield by second pulse is first step to "energy recovery"
- Multi-Pulse expts (N = 7):
  - Strong resonance when pulse separation matches plasma period
  - Excellent agreement with linear theory

Cartoon of MP-LWFA scheme



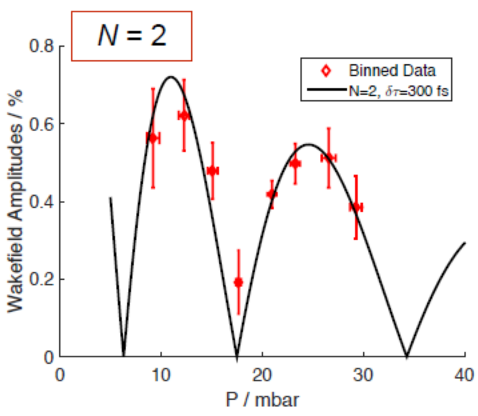



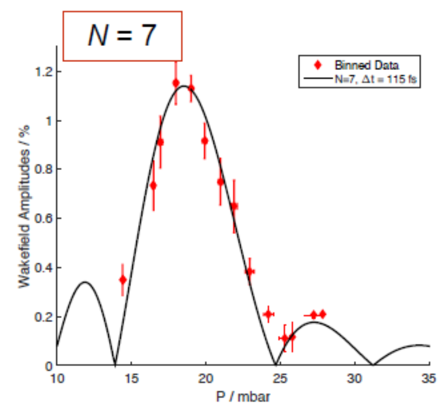

FDH and TESS are in excellent agreement with each other and expected plasma period

Expected wake amplitude:

$$\frac{\delta n_e}{n_{e0}} \propto \left(\frac{\delta n_e}{n_{e0}}\right)_{N=1} \times \left| \frac{\sin\left(\frac{1}{2} N \omega_{p0} \delta\tau\right)}{\sin\left(\frac{1}{2}\omega_{p0}\delta\tau\right)} \right|$$

Preliminary analysis!

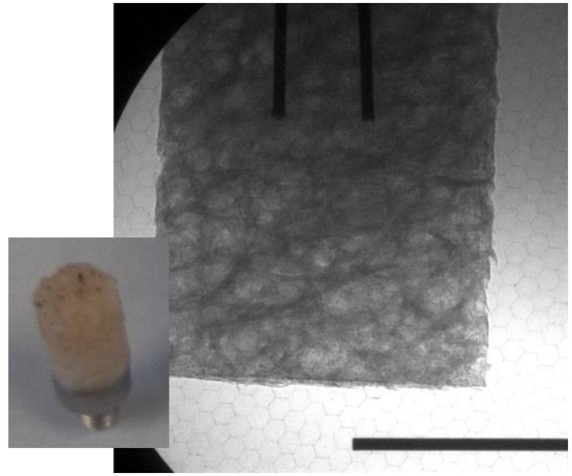


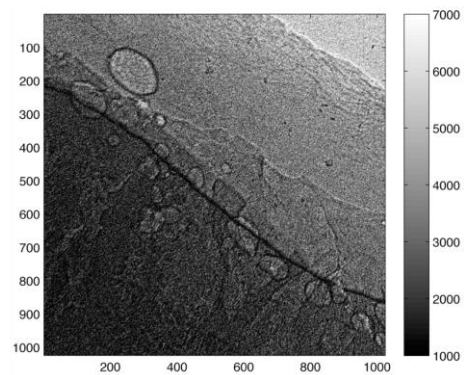

Simon Hooker at al

# WP3.3: Medical application of laser-acc. particles

- **Betatron radiation could prove to be an interesting source for medical radiography**
  - **Small source size and collimated beam allows for high resolution phase contrast imaging of soft tissue, e.g. breast, prostate…**
  - **Hard photon energy with small source size allows for high resolution imaging of bone, biological samples**



X-ray radiograph of femural bone sample (left, and photo inset) tomographically reconstructed (right)

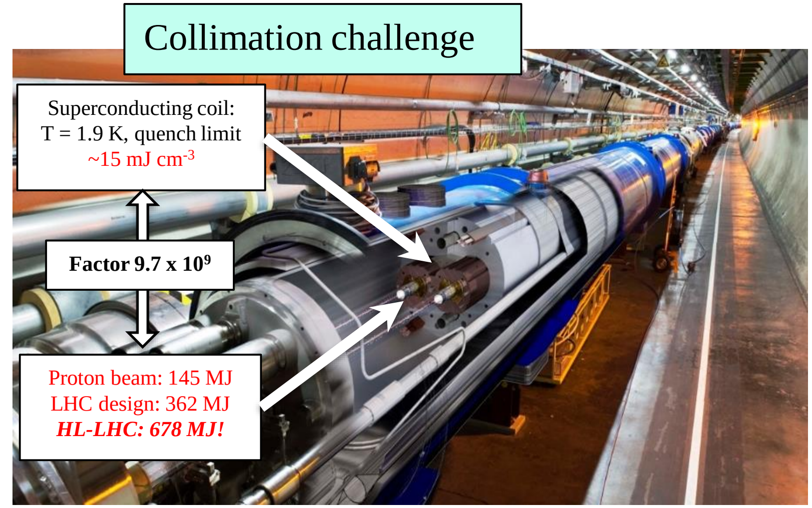



Phase-contrast imaging of prostate (left) and tomograph of pre-natal mouse (right)

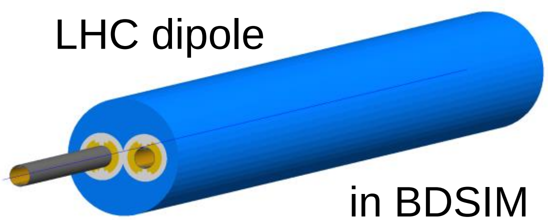
# WP4.1: High Luminosity LHC

## *Collimation challenge:*

- **to efficiently clean the LHC beam, while…**
- **protecting cryogenic magnets from huge stored beam energy (doubles at HL-LHC!)**
- **mitigating beam backgrounds that reach the experiments!**

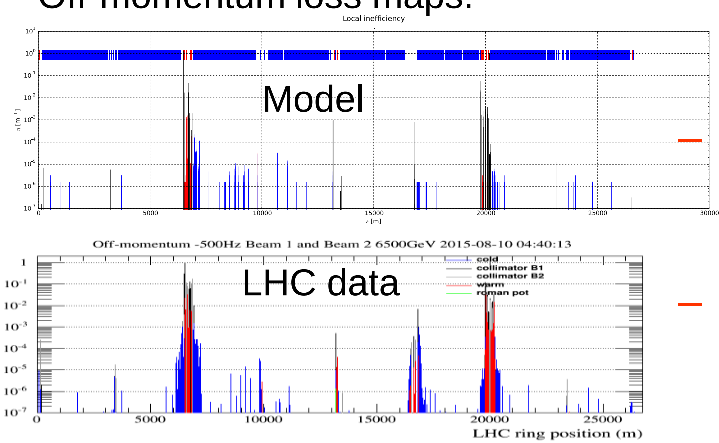



LHC dipole

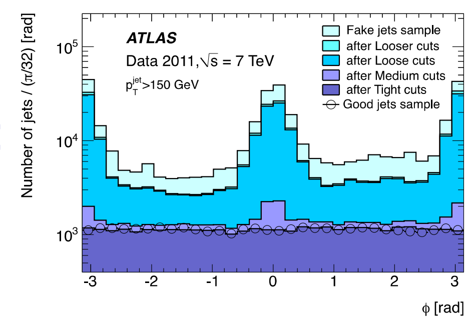


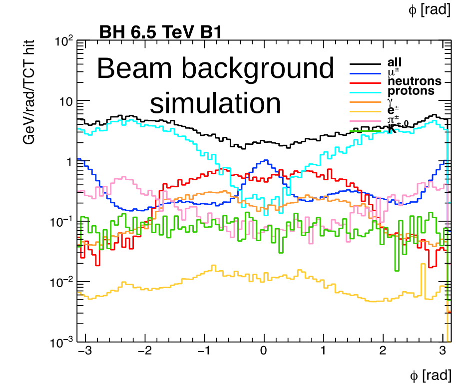
in BDSIM

Off-momentum loss maps:




- JAI-RHUL experts already integrated in team at CERN. Main contributions:
  - **Off-momentum loss maps**: new model recently validated with energy deposition measurements at LHC.
  - **Advanced simulations of beam dynamics** to design the new triplet layout for HL-LHC.
  - RHUL-developed tool (BDSIM) to model **LHC beam backgrounds measured at ATLAS**.

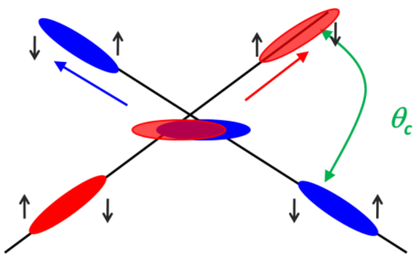


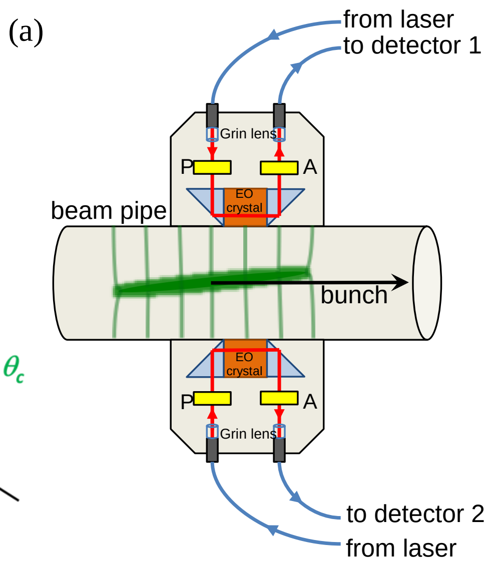



# WP4.1: High Luminosity LHC

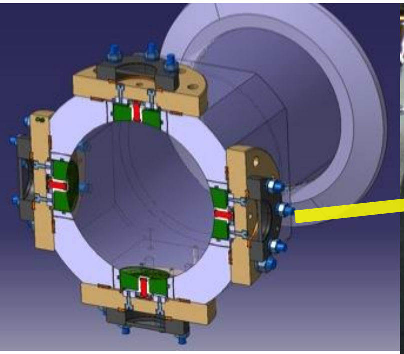
## *Diagnostics:* Electro-optic Beam Position Monitors

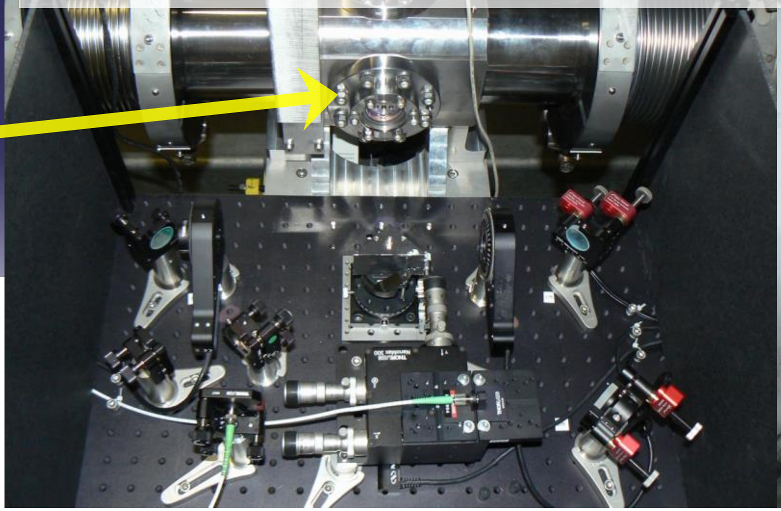
- **HL-LHC crab cavities require new instrumentation to monitor bunch rotation and optimize performance.**
- **High bandwidth electro-optical pick-ups enable intra-bunch measurements of transverse position.**
- **JAI built prototype installed in 2016 at CERN SPS for proof of principle tests, in collaboration with CERN BI group.**

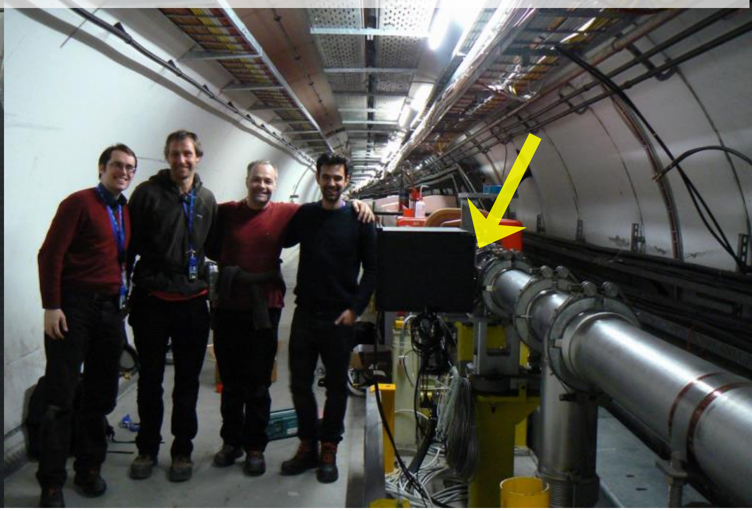



***JAI built prototype already installed for tests at CERN SPS***





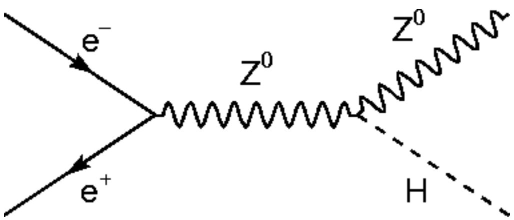


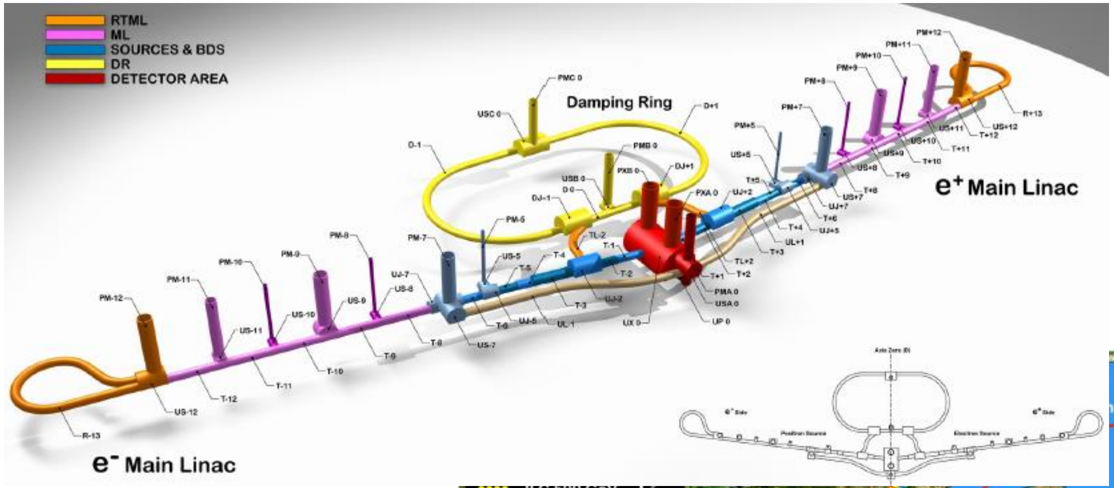
**Second prototype planned for LHC, before deployment at HL-LHC**

# WP4.2: ILC, CLIC and MDI

## Accelerator R&D for electron-positron Linear Collider

## 'Higgs Factory'



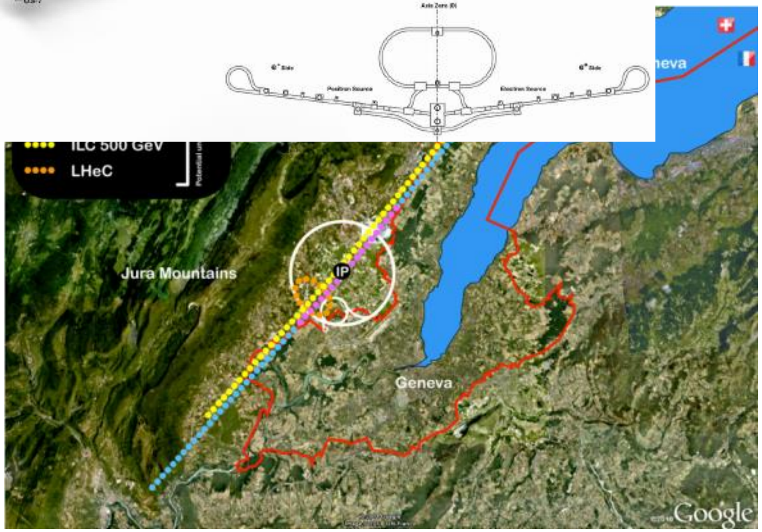





- Selected site

← Japan

CERN →

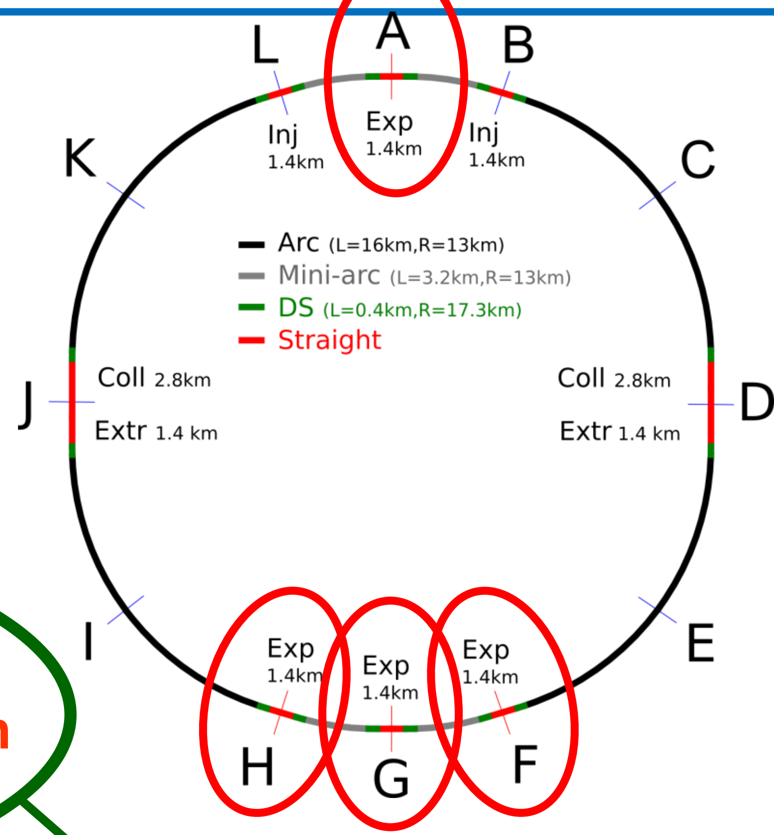



- **International Linear Collider: awaiting decision from Japan (~2018)**
- **CLIC: preparing input for European Strategy update (~2019)**

# WP4.3: FCC-hh and MDI

- **Experimental Interaction Region**
  - One of critical areas defining FCC-hh (HE-LHC) performance

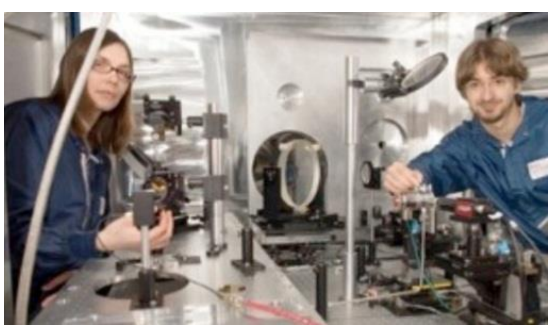
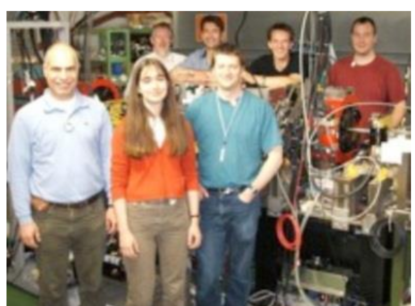
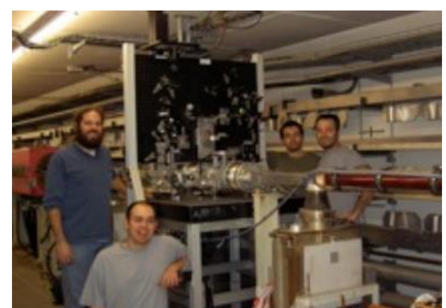
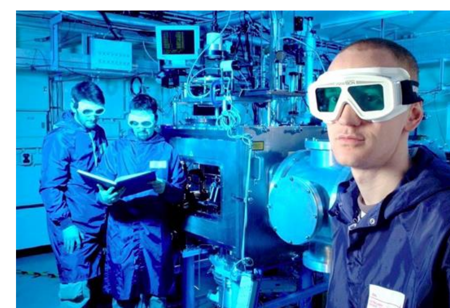
- **Design tasks of EuroCirCol IR Work Package**
  - Coordination
    - JAI/Oxford (lead), CERN, task 3.1
  - Development of the interaction region lattice
    - JAI/Oxford (lead), CERN, task 3.2
  - Design of machine detector interface
    - CI/Manchester (lead), INFN, CERN, task 3.3
  - Study of beam-beam interaction
    - EPFL (lead), CERN, task 3.4




Responsibility of JAI

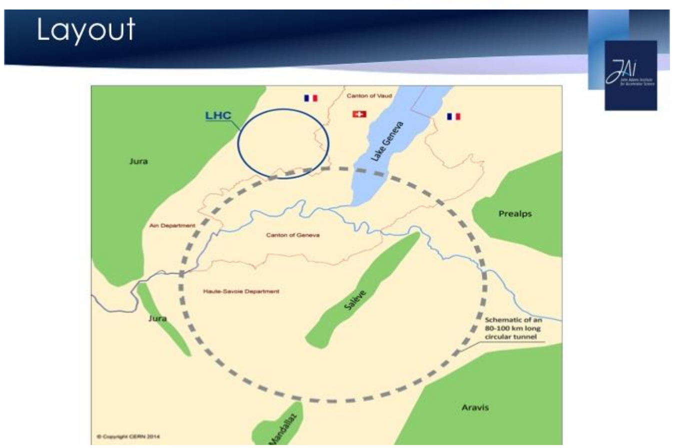
# JAI graduate training

- **PhD based on state-of-the-art studies in accelerator science**
- **Excellent record – majority graduates in 4 years**
- **Total number of PhD graduates is about 60 (20% women)**
  - **Majority of theses (91%) combine experimental research with theoretical/simulation investigations**
- **Excellent post-PhD employment opportunities**
  - **Our graduates have excellent career prospects in fields of science & technology – they now work at RAL, ASTeC, Oxford, NPL London, CERN, SLAC, BNL, DESY, LLNL, LBNL, etc.**
  - **15% of our alumni work in industry**

# Post-graduate training - students' project

**Every year students work on a design project, that allows them to put their skills into practice**


**Students present results of design project first to JAI staff, then to Advisory Board, and then to CERN colleagues**


**Presentation at CERN Council Chamber May 2016**


**Group Photo at CERN May 2016**

# JAI post-graduate training

- **JAI method of post-graduate training spreads around the world**
- **The students' design project has been applied this year, for the first time, at USPAS class, taught by JAI's A.S. and Aakash Sahai**


- **JAI taught USPAS class, following 1-week course, wrote a paper and got an oral talk at North American Particle Accelerator conference!**

# CAS at RHUL

The CERN Accelerator School and
Royal Holloway University of London
are organizing a course on

**Advanced Accelerator Physics**

**3 to 15 September, 2017**

Royal Holloway University, Egham, London, United Kingdom

# JAI and UK facilities

- **Contributed strongly to existing UK facilities and their possible upgrades**
  - The first version of optics for Diamond Light Source upgrade originated from JAI graduate student – it now being realized in part of the ring
  - Joint Diamond-JAI senior academic and junior researchers
  - Joint ISIS-JAI researcher enhance our impact on developments of ISIS upgrade and future of FETS facility
  - Made key contribution to development of Central Laser Facility upgrade plan
  - Contributed to Technical Design Reports for the 20PW upgrade for the Vulcan Laser facility and to the high rep-rate upgrade/replacement to Astra Gemini (Pulsar)

# JAI future goals

- aim to excel in our training program
- aim to contribute strongly to UK facilities and their upgrades, Diamond Light Source, ISIS neutron source, Central Laser Facility
- aim to play a key role in evolution of UK-FEL from R&D into the project phase
- will strongly engage in and lead ILC and CLIC, if hosting/construction decisions will be taken
- will strive to make practical use of our SCRF compact source (in industry) as well as plasma acceleration source (in medicine)
- will lead the key technical areas of FCC and possibly HE-LHC project into the next project stages
- will aim to realise the high power proton beam facilities based on concepts we helped to develop