FLASHForward beam-driven wakefield acceleration at FLASH

John Dale

DESY Hamburg

JAIfest, 10 December 2015

FLASHForward

Alexander von Humboldt Stiftung/Foundation

LAOLA

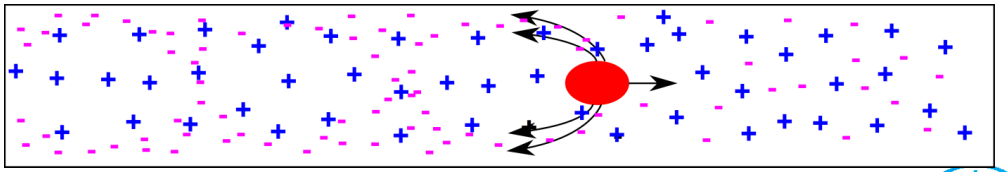
HELMHOLTZ ASSOCIATION

Overview

- Plasma wakefield accelerators
- FLASHForward
  - Team
  - Mission and goals
- FLASHForward beamline
  - FLASH
  - FLASHForward
  - Laser and test labs
  - Target chamber
  - Diagnostics
  - Installation status
- Experiments
  - Internal injection
  - External injection
  - Transformer ratio
- Summary

Plasma wakefield acceleration

- Charged particle beam drives wake (laser in LWFA)
  - Electron, positron, proton, etc
- Space charge pushes out (- charge) or draws in (+ charge) the plasma electrons (Ponderomotive force in LWFA)
  - Plasma electrons over shoot and setup plasma oscillation
- As in LWFA, PWFA can be in linear or non-linear regime
- Acceleration physics similar to LWFA
- Acceleration GV/m



Plasma wakefield acceleration

- LWFA disadvantages
  - Diffraction: Laser expands and stops driving the wake
  - Dephasing: $v^{group} < c \rightarrow$ electrons outrun the wake
  - Shot to shot variation (few %)
  - Low wall plug efficiency

- Ultra relativistic driver and wake
  - No dephasing
  - Electrons are self-focused in the plasma
  - Particle accelerators have less shot to shot variation.

- Can use meter scale plasmas

FLASHForward Team

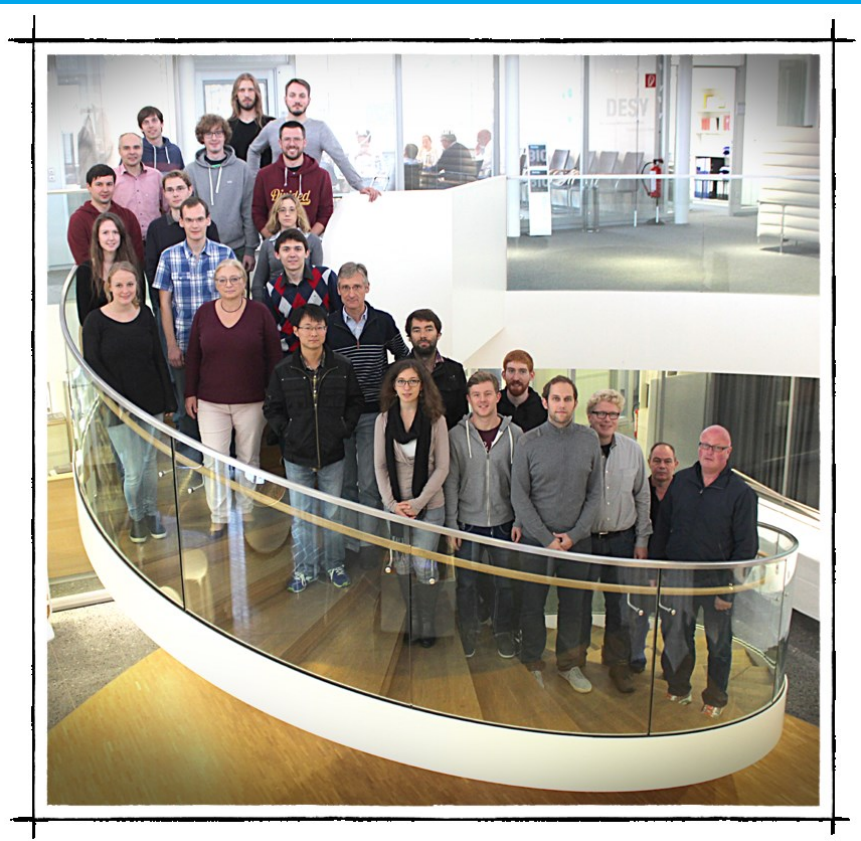
Project Coordinator
Jens Osterhoff

Staff scientists (3)
Eckhard Elsen
Bernhard Schmidt
Sven Karstensen

Postdocs (12)
Lucas Schaper
Charlotte Palmer
Alberto Martinez de la Ossa
John Dale
Vladyslav Libov
Johann Zemella
Matthew Streeter
Zhanghu Hu
Timon Mehrling
Laura di Lucchio
Richard D'arcy
Stephan Wesch*

Engineers (2)
Kai Ludwig
Frank Marutzky

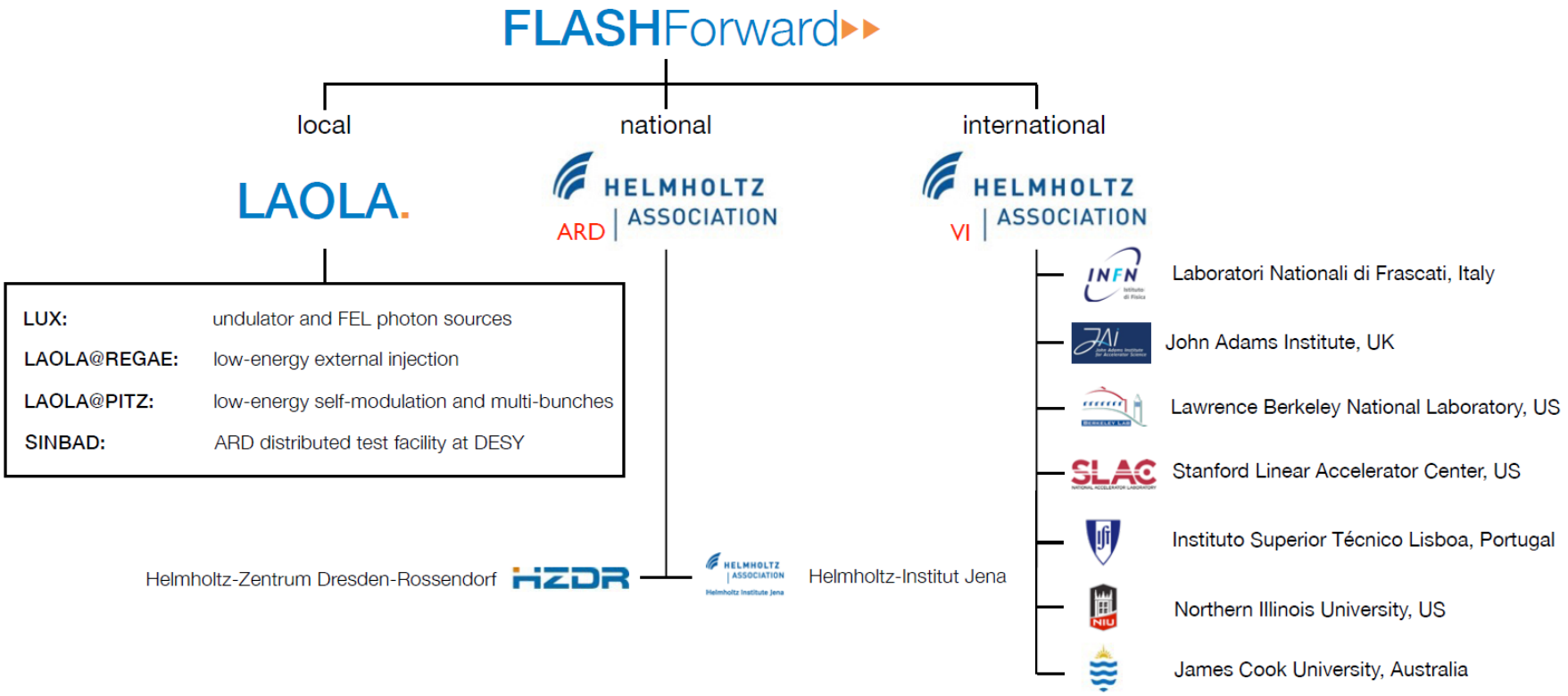
Students (13)
Jan-Patrick Schwinkendorf
Jan-Hendrik Erbe
Lars Goldberg
Olena Kononenko
Gabriele Tauscher
Violetta Wacker
Stefan Weichert
Steffen Wunderlich
Alexander Aschikhin
Simon Bohlen
Jan-Niclas Gruse
Fabian Pannek
Dennis Borrisenko



* Joining in January

+ many DESY technical support groups

Collaboration



Mission and goals

- FLASHForward:
  - Full approved DESY project since July 2014.
  - An extension to the FLASH FEL facility.
  - New beamline for beam-driven plasma wakefield accelerator research.

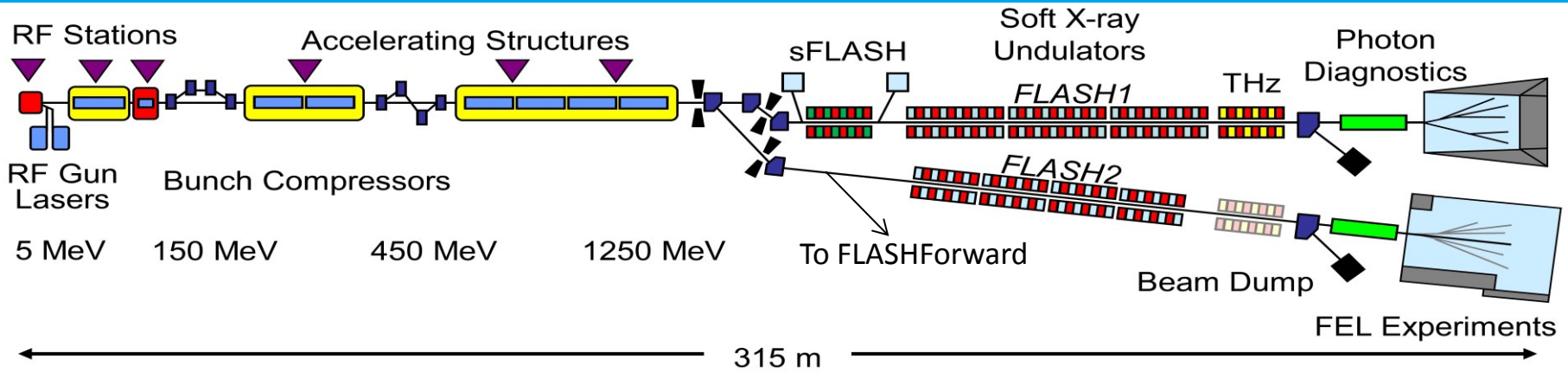
- Mission:
  - To demonstrate beam quality from a PWFA suitable for first applications in photon science.
  - Stepping stone towards high energy physics applications.

Mission and goals

- Scientific goals
  - Characterization of externally injected electron beams and their controlled release from a wakefield accelerator with energies >2.0 GeV (phase I)
  - Exploration of novel in plasma beam generation[1] and acceleration techniques to proved (in phase I)
    - >1.6 GeV energy
    - <100 nm transverse normalized emittance
    - fs duration
    - > 1kA current electron bunches
  - Demonstrate free-electron laser gain with these beams at wavelengths on the few-nanometer scale (phase II)

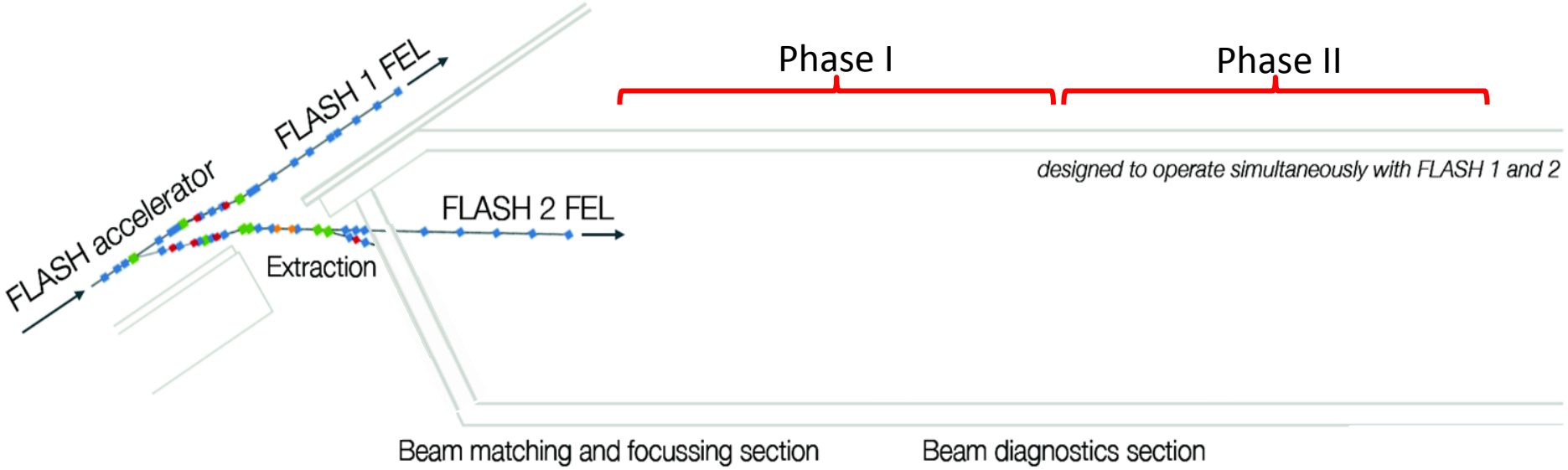
1 A. Martinez de la Ossa *et al.*, "High-Quality Electron Beams from Beam-Driven Plasma Accelerators by Wakefield-Induced Ionization Injection", Physical Review Letters 111, 245003 (2013)
A. Martinez de la Ossa *et al.*, "High-Quality Electron Beams from Field-Induced Ionization Injection in the Strong Blow-Out Regime of Beam-Driven Plasma Accelerators", NIM A 740, 231 (2014)
J. Grebenyuk *et al.*, "Beam-Driven Plasma-Based Acceleration of Electrons with Density Down-Ramp Injection at FLASHForward", NIM A 740, 246 (2014)
B. Hidding *et al.*, "Ultracold Electron Bunch Generation via Plasma Photocathode Emission and Acceleration in a Beam-Driven Plasma Blowout", Physical Review Letters 108, 035001 (2012)

FLASH



- FEL quality
  - (~1.25 GeV, ~0.1% energy spread, ~2 µm transverse norm. emittance)
  - Superconducting RF
  - Bunch trains at 10Hz
  - 25fs RMS beam to laser synchronisation
- Two modes of operation
  - Standard operation: Gaussian beam
    - Can operate in parallel with FLASH and FLASH 2
  - Dedicated operation
    - Double bunch
    - Triangular bunch

FLASHForward



6 hour access every two weeks during maintenance days

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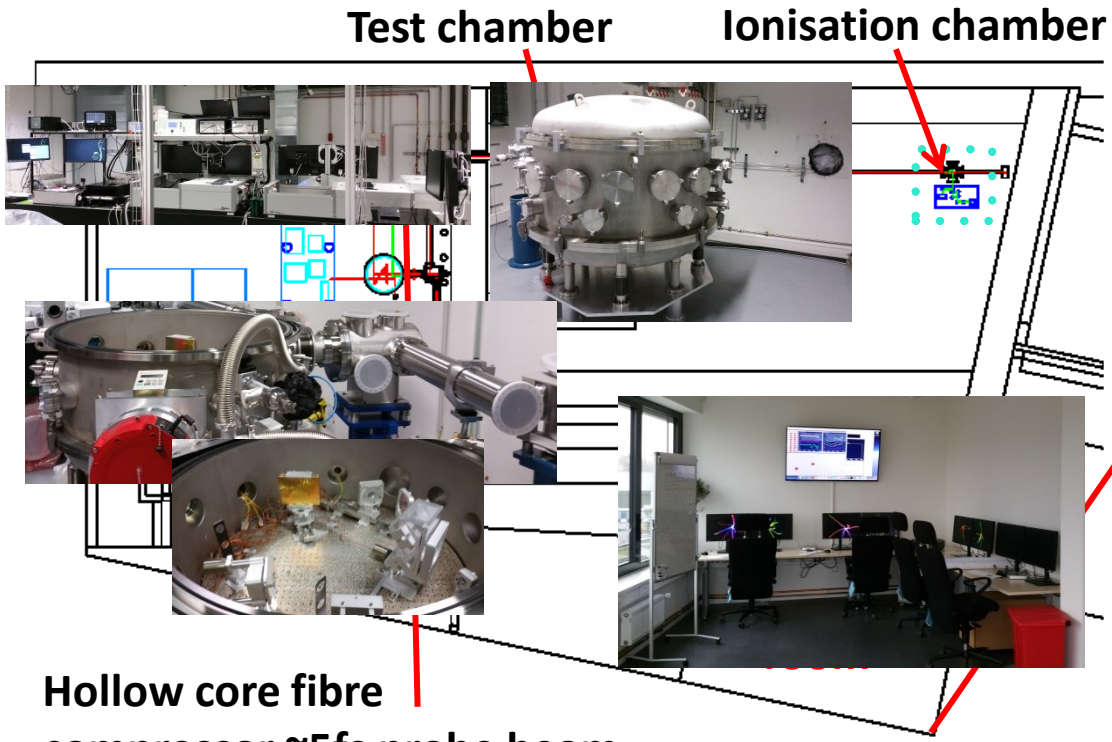


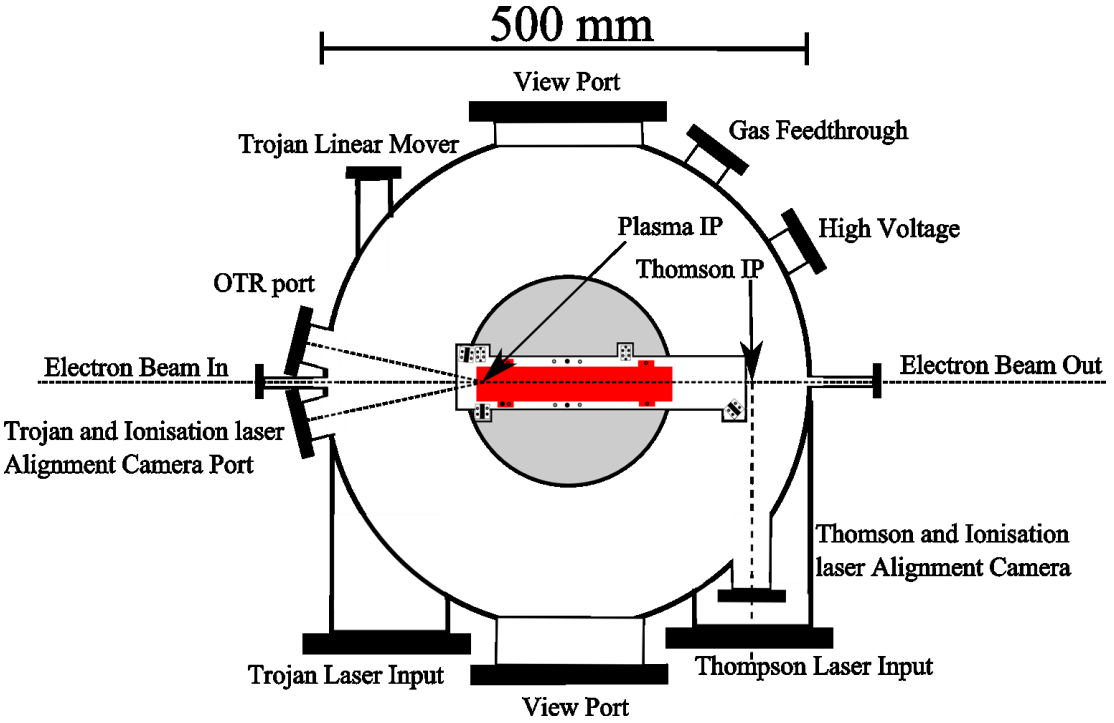
Amplitude laser

- 25fs
- 25TW (high power arm)
- 0.14TW (low power arm)
- 10 Hz
- <20µrad stability

Hollow core fibre compressor ~5fs probe beam from low power arm

FLASHForward Target chamber

- Capabilities
  - Manipulating PWFA in 6D
  - Profiling and aligning electron and laser beam
  - Thomson and Trojan injection lasers
  - Transverse measurements of capillary
- Electron beam Parameters at Plasma IP
  - radius < 5 µm
  - orbit jitter < 10 µm
  - pointing jitter < 0.5 mrad
- Contains
  - Wires, Knife edges, OTR screens, Scintillator screens
  - Multiple cameras for wide viewing and precision measurements
- Access only available 8 hours every two weeks during user operation.
- Design being upgraded
  - LWFA operation
  - Plasma lensing experiments



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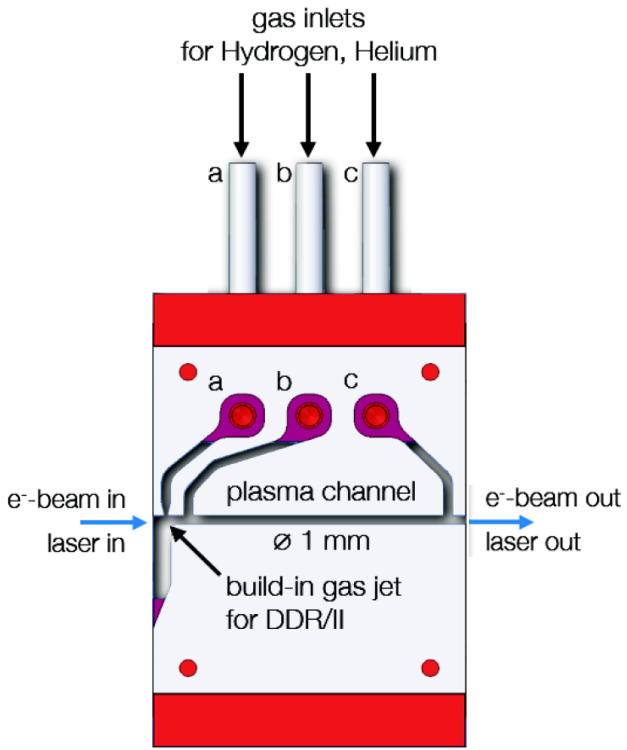
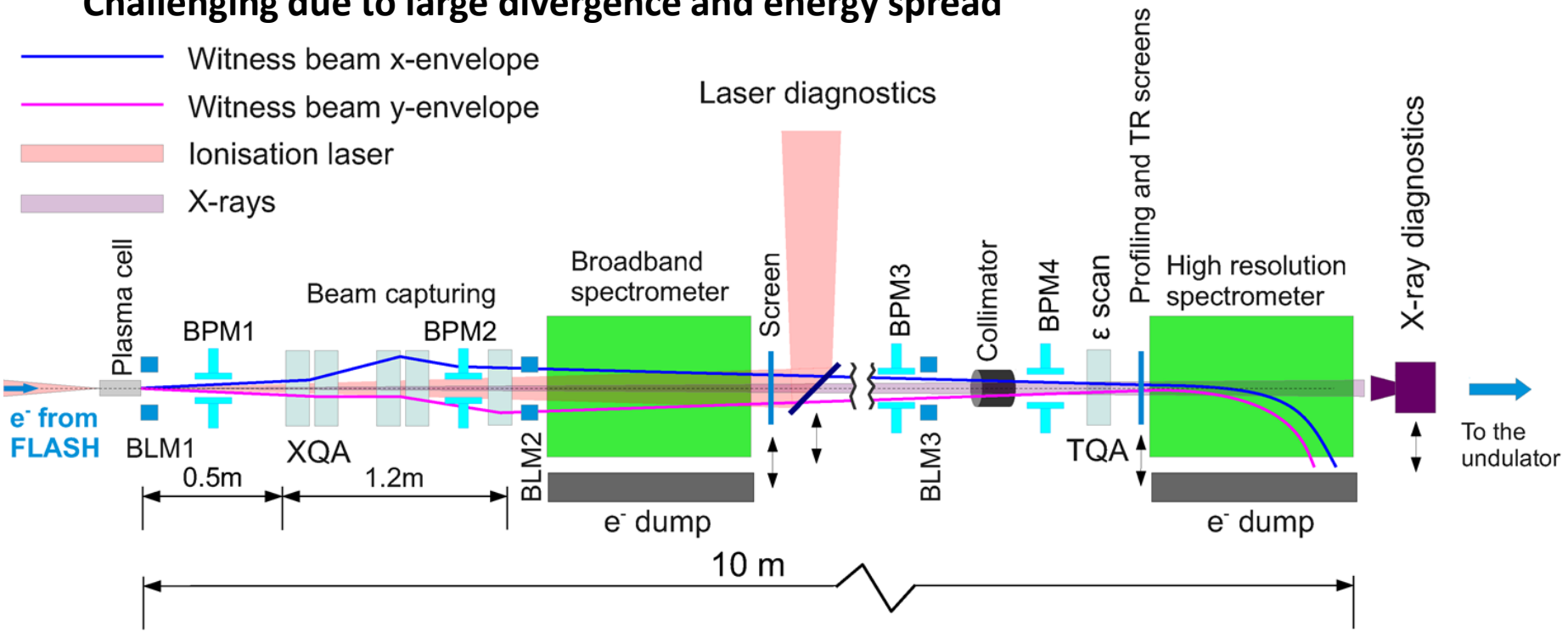
Gas target



- Window-less to avoid emittance growth.
- Plasma creation by:
  - Laser
  - Electron beam
  - High voltage discharge
- Plasma densities of $1x10^{16}$ – $5x10^{17}$ cm^{-3}
- Tailored plasma density profiles
  - Density down ramp
  - Adiabatic beam extraction
- Transverse windows for diagnostics

Diagnostics

Challenging due to large divergence and energy spread



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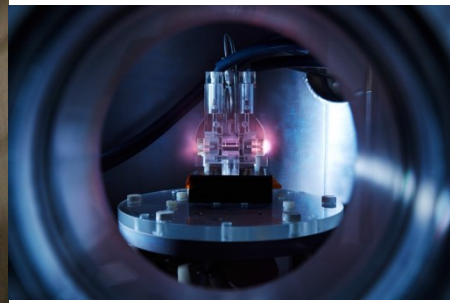
Installation status

- Electron beamline
  - Magnet positions set.
  - Beamline drawings being produced.
  - Stones placed.
- Laser:
  - Commissioned this week.
  - Vacuum pipes to the test lab being installed (completed mid January).
- Laser beamline
  - Installed up to the entrance of the tunnel
  - Drawings for the connection to the beamline underway
- Target chamber undergoing design upgrades
  - Adding LWFA capabilities
  - Adding plasma lenses
- Diagnostics
  - Concept complete
  - Starting technical drawings



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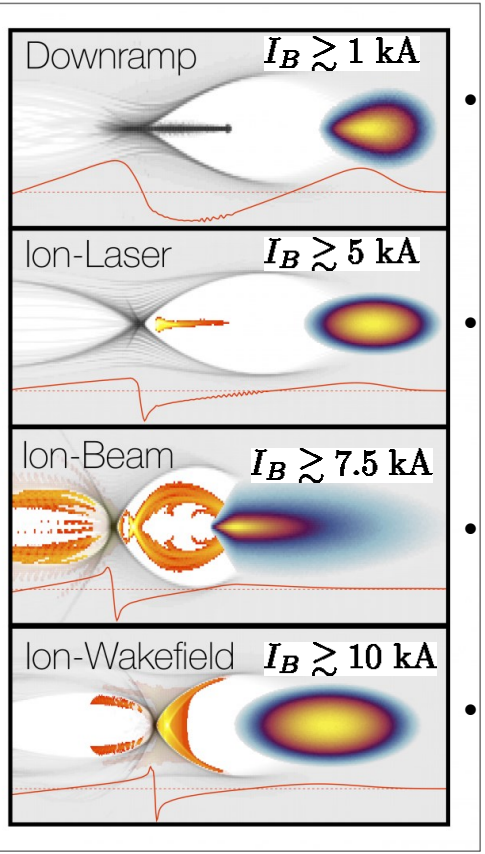
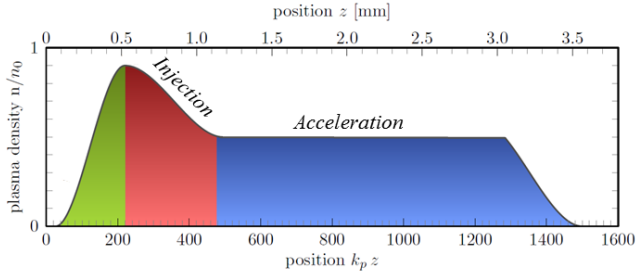
Internal injection



- Density down-ramp injection
  J. Grebenyuk et al., NIM A 740, 246 (2014)



- Laser-induced ionization injection (Trojan Horse injection)
  B. Hidding et al., Physical Review Letters 108, 035001 (2012)

- Beam-induced ionisation injection
  A. Martinez de la Ossa et al., NIM A 740, 231 (2014)

- Wakefield-induced ionization injection
  A. Martinez de la Ossa et al., Physical Review Letters 111, 245003 (2013)

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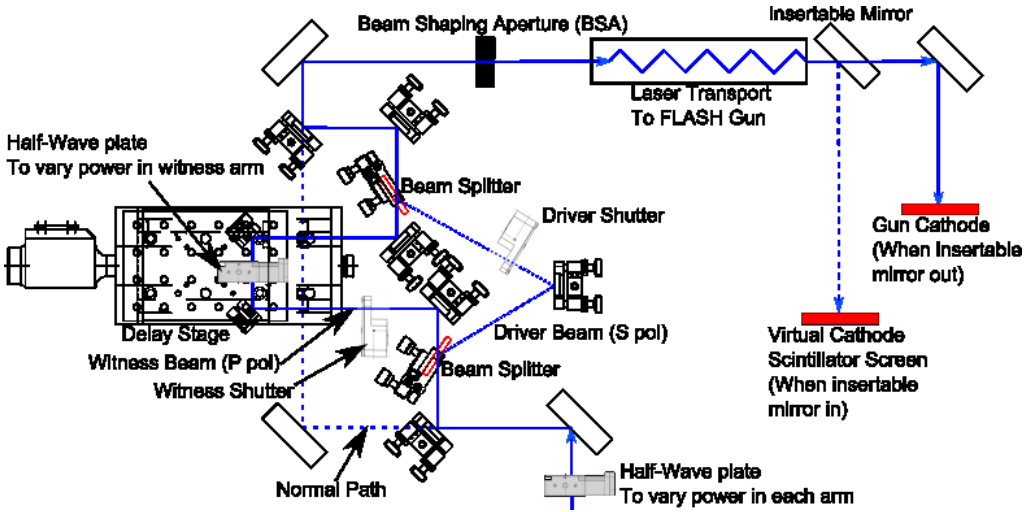
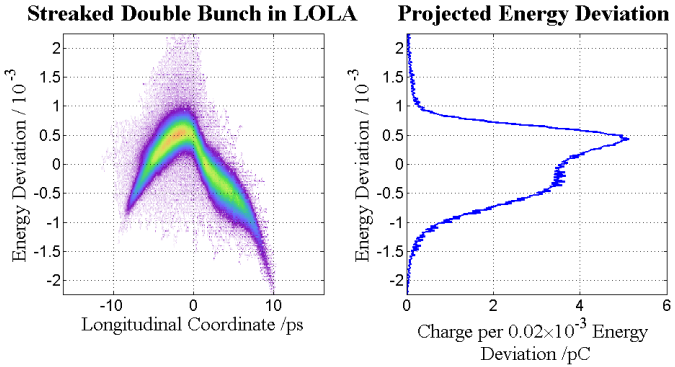
External injection

- Need to generate two electron bunches within the same RF bucket
  - Separation needs to be on the order of the plasma bubble size (~100 µm)
- Pulse stacker in laser injector hutch
  - Generates two laser pulses from one
  - Vary the intensity in each pulse
  - Changing the initial time delay between the pulses
- Pulse stacker installed and stabilised
- Initial machine studies have demonstrated:
  - Electron bunches generated
  - Individual bunch charge adjustable
  - Delay between the bunches adjustable
  - Bunches can be transported through FLASH
- Have not achieved good compression of both bunches
- New strategy has been developed. Next shift on 15th January

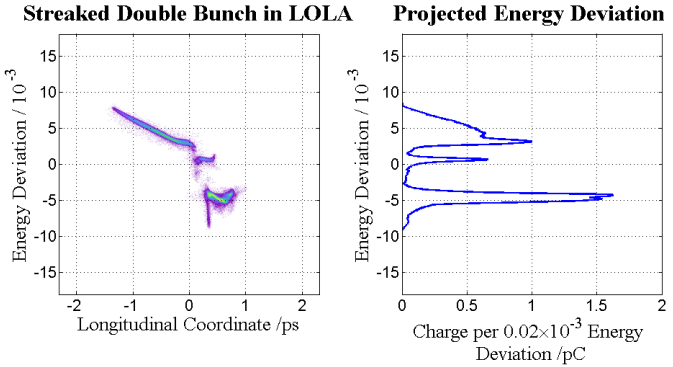


External injection

No compression



Driver compressed



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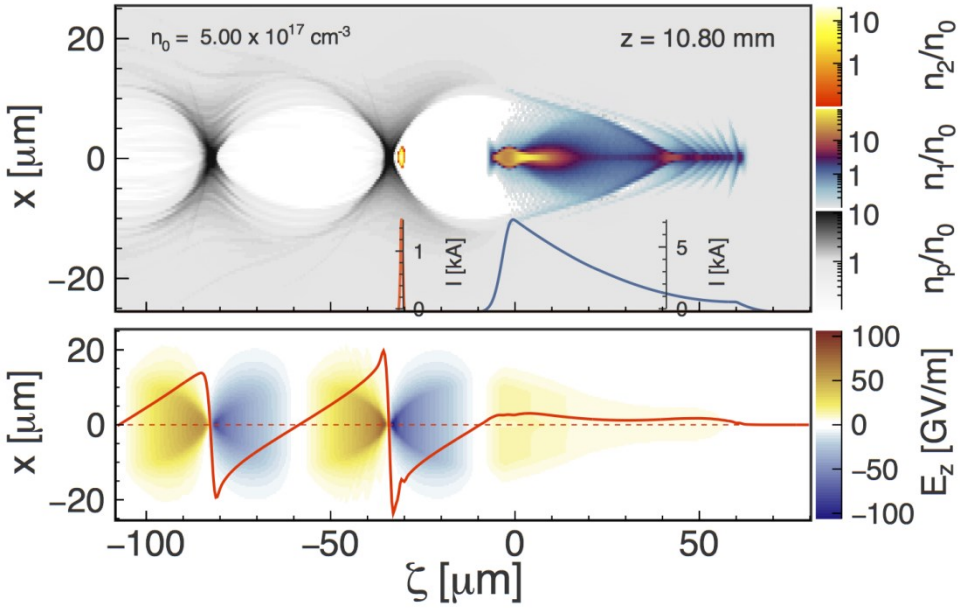
Transformer ratio

- Shaped mode: tailored triangular beams for PWFA

- Triangular profile beam:
  - 60 to 200 µm long,
  - ~1.2 GeV,
  - 0.1% energy spread,
  - 1 µm emittance,
  - requires dedicated beam time at FLASH
  - $R \leq 6$

mode demonstrated in Piot et al., Phys. Rev. Lett. 108, 034801 (2012)

- From OSIRIS 3D PIC simulations
  - Transformer ratio of ~3 is confirmed
  - 50 GV/m peak field strength
  - Boosting the energy of a witness beam to ~3 GeV in less than 10 cm feasible



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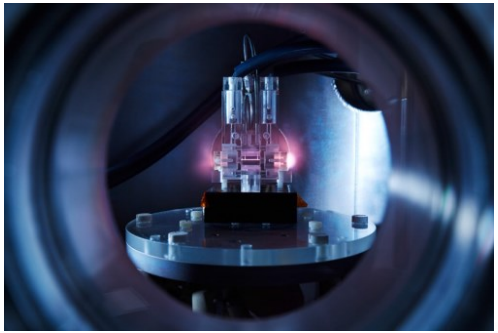
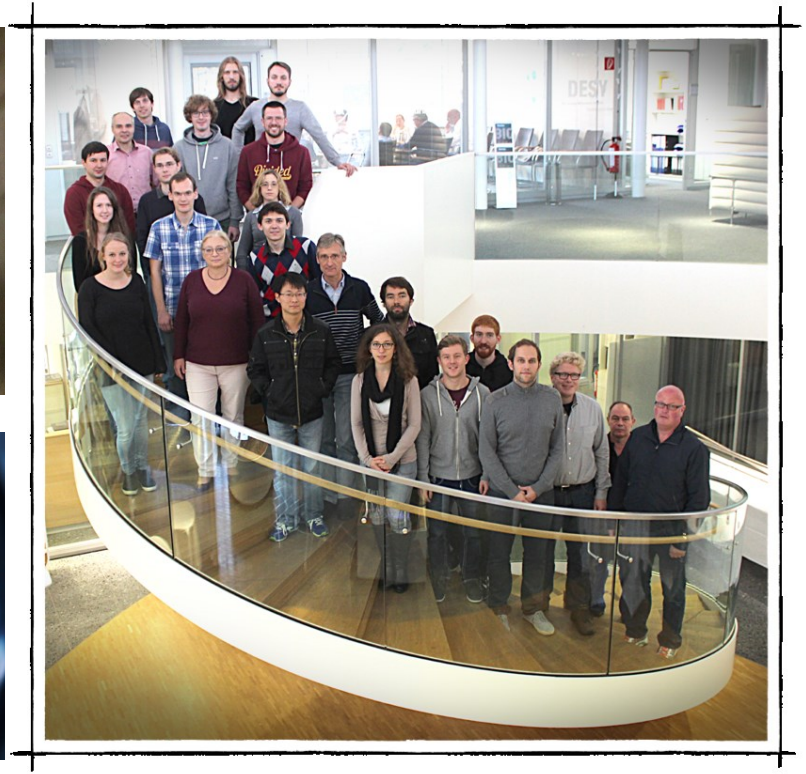
Summary

- FLASHForward will be a beamline for plasma wakefield accelerator studies
- Will study several internal and external injection techniques
- Test lab operational early next year
- Beamline installation Mid to late 2016
- Commissioning/first experiments begin Jan 2017
- Recent paper published describing the project.
  - Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 806, 11 January 2016, Pages 175-183, ISSN 0168-9002, http://dx.doi.org/10.1016/j.nima.2015.10.005. (http://www.sciencedirect.com/science/article/pii/S0168900215012103)

Thank you for listening





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