FLASHForward ▸▸ X-2

Beam quality preservation in a plasma booster

Vladyslav Libov[1,2], A. Aschikhin[1], J. Dale[1], R. D'Arcy[1], A. Martinez de la Ossa[1], T. Mehrling[1,2], J.-H. Roeckemann[1], L. Schaper[1], B. Schmidt[1], S. Schroeder[1,2], S. Wesch[1], J. Zemella[1] and J. Osterhoff[1]

[1]Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany

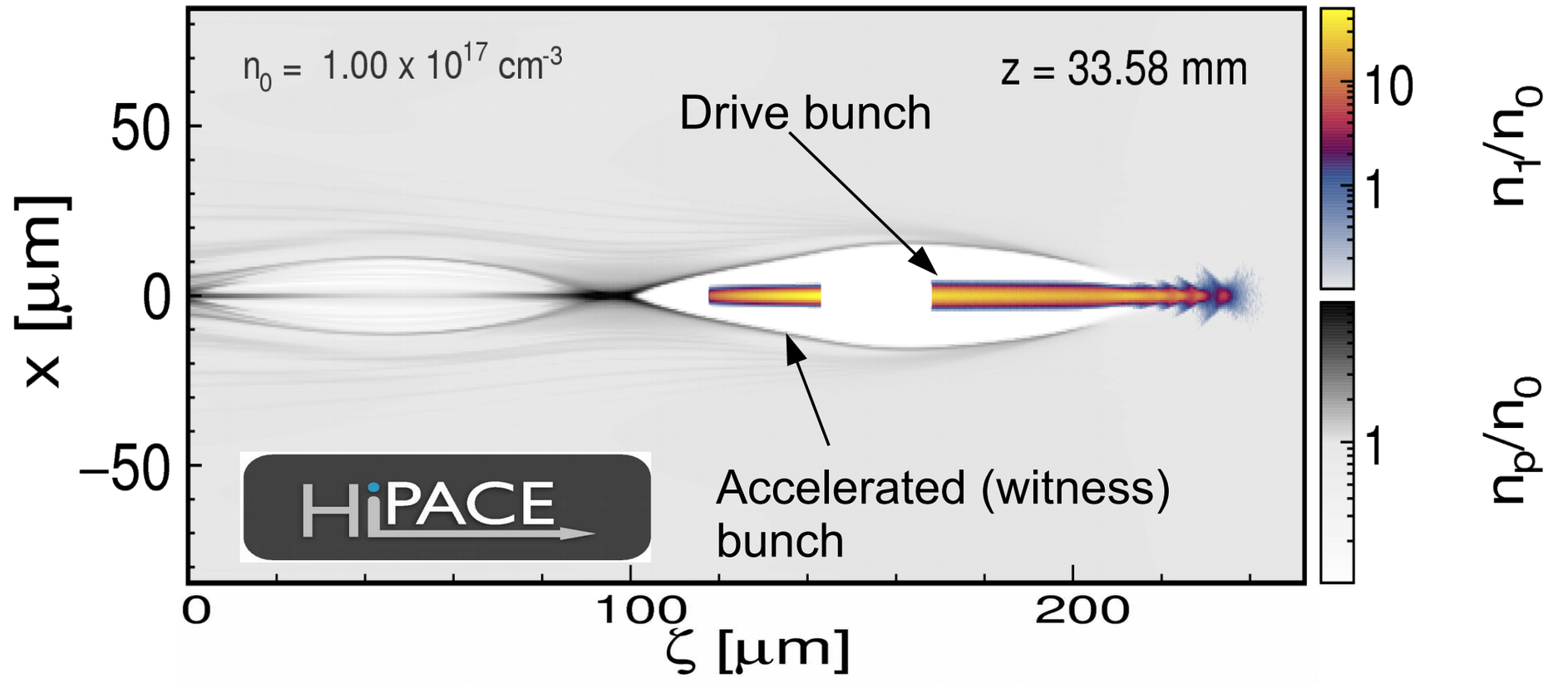
[1]University of Hamburg, Germany

MATTER AND TECHNOLOGIES
ACCELERATOR RESEARCH AND DEVELOPMENT

Plasma booster for high-energy applications

> **Beam-driven** plasma wakefield acceleration (PWFA) is the only path to high-average-power plasma-based accelerators

> High beam energies requires **staging** of individual PWFA modules
→ external injection

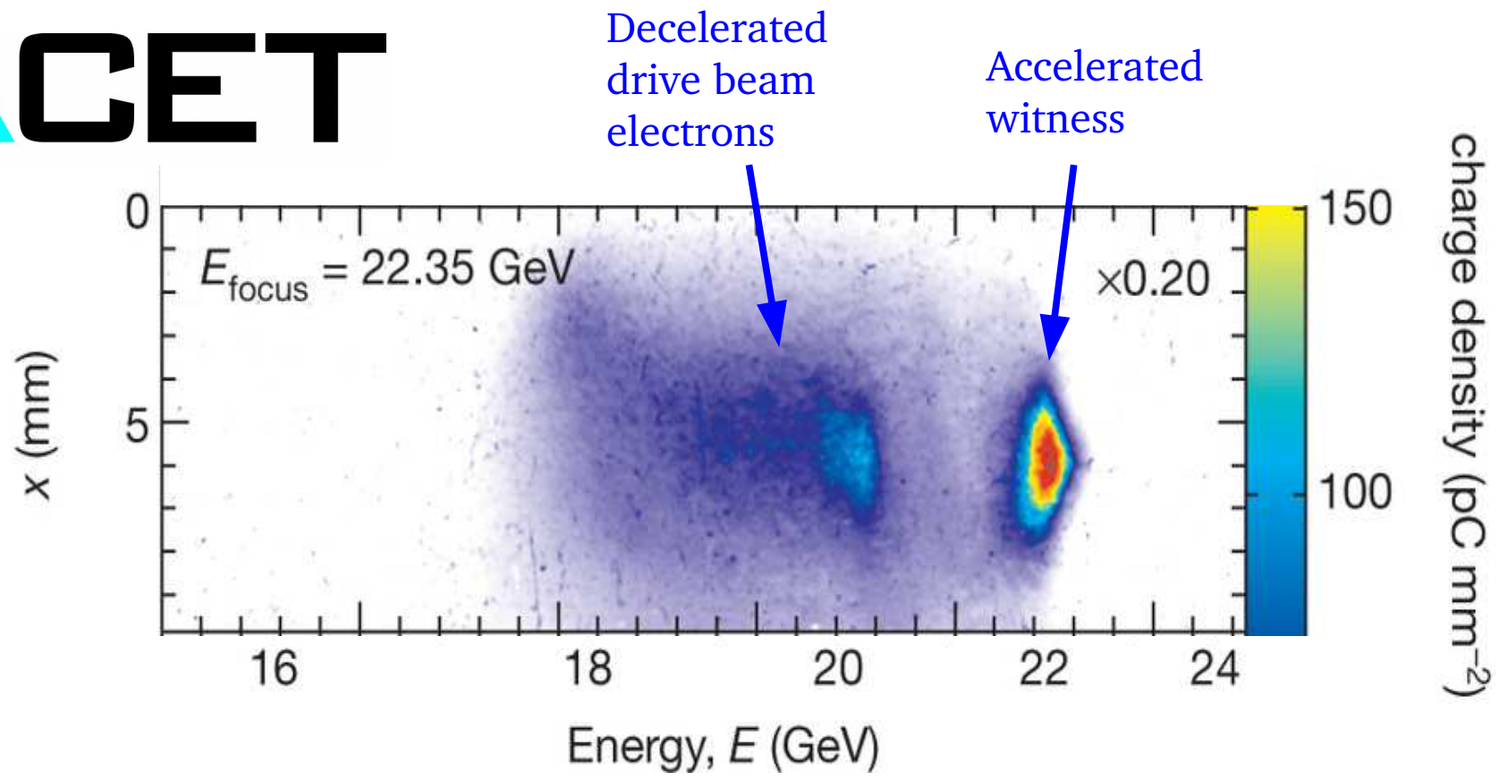


T. Mehrling et al.,
PPCF **56**, 084012 (2014)

Demonstration of external injection

> Driver-witness pair using a mask in a dispersive section
> **High-efficiency** acceleration of the witness beam by **1.6 GeV** with final energy spread of ~**1%**

M. Litos et al.,
Nature **515,** 92 (2014)



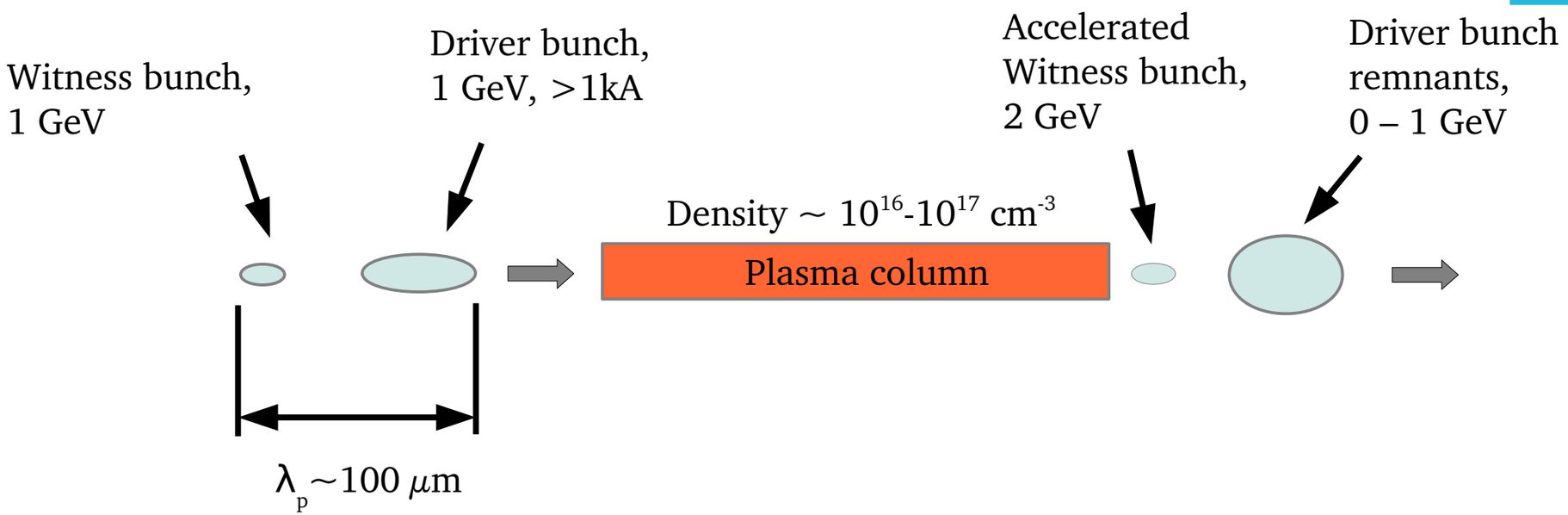
> **Remaining challenges**:
→ Emittance preservation
→ Driver energy depletion
→ High repetition rate
→ Stability, reproducibility

→ **FLASH**Forward ▸▸

FLASHForward ▸▸ X-2

> Key goal is to demonstrate **quality preservation** in external injection in PWFA

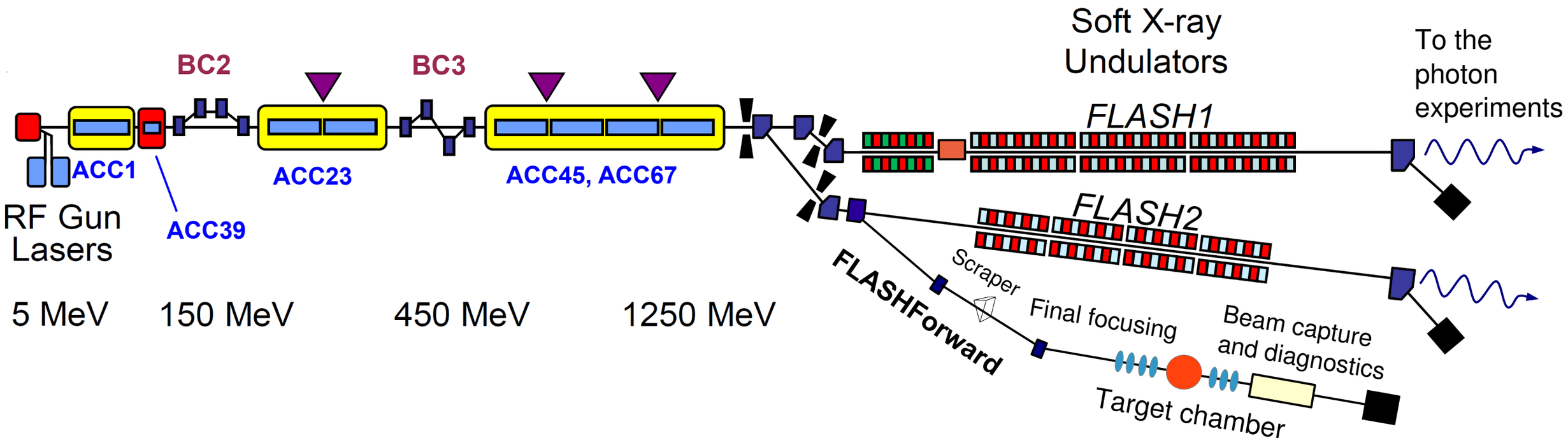
See talk **A. Knetsch** (WG7) for FLASHForward X-1



> **Principal experimental requirements**

→ *Driver-witness pair*, separated by a fraction of the plasma wavelength, both sufficiently short
→ Longitudinal and transverse shaping of the driver beam *(wake optimisation, transformer ratio)*
→ Control over centroid offsets *(hosing mitigation → stability)*
→ Transverse matching of the witness *(emittance preservation)*
→ Longitudinal shaping of the witness *(beam loading → low energy spread)*
→ Controlled release of the witness *(emittance preservation)*

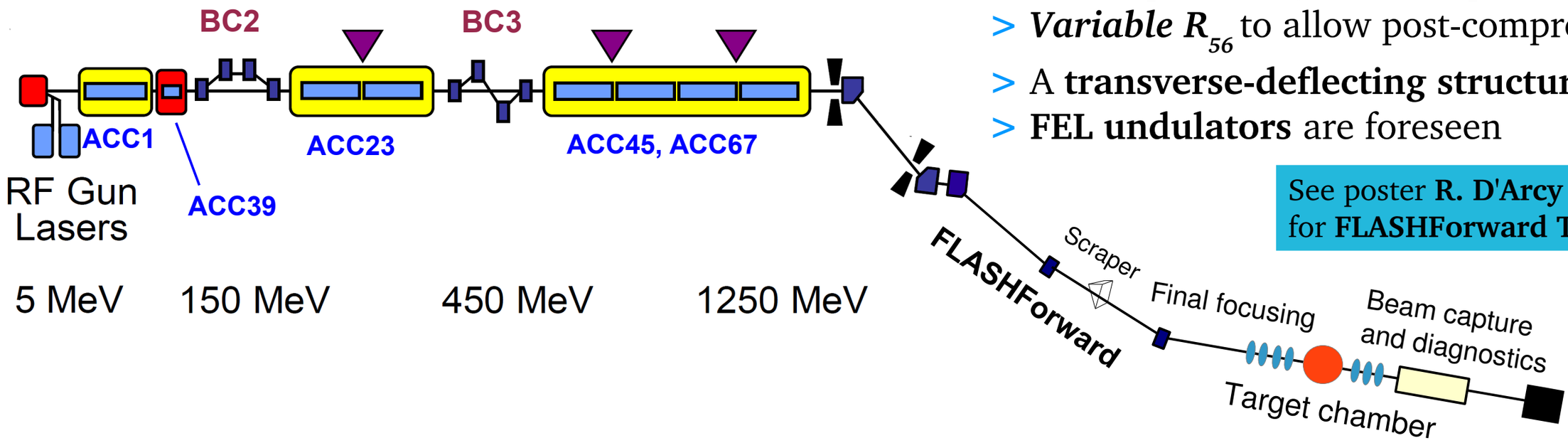
FLASHForward: a unique PWFA beamline at FLASH



> **FLASH** is world's first soft X-ray FEL
→ provides ***GeV*** e^- beams of ***few kA*** currents, ***100 fs*** durations and ***few μm*** *emittances*
→ **suitable for PWFA experiments**

See talk **J. Osterhoff** (WG1/WG8) for FLASHForward overview

FLASHForward: a unique PWFA beamline at FLASH



> Beam spots $<10\mu m$ at the plasma cell
> ***Variable*** R_{56} to allow post-compression
> A **transverse-deflecting structure** is foreseen
> **FEL undulators** are foreseen

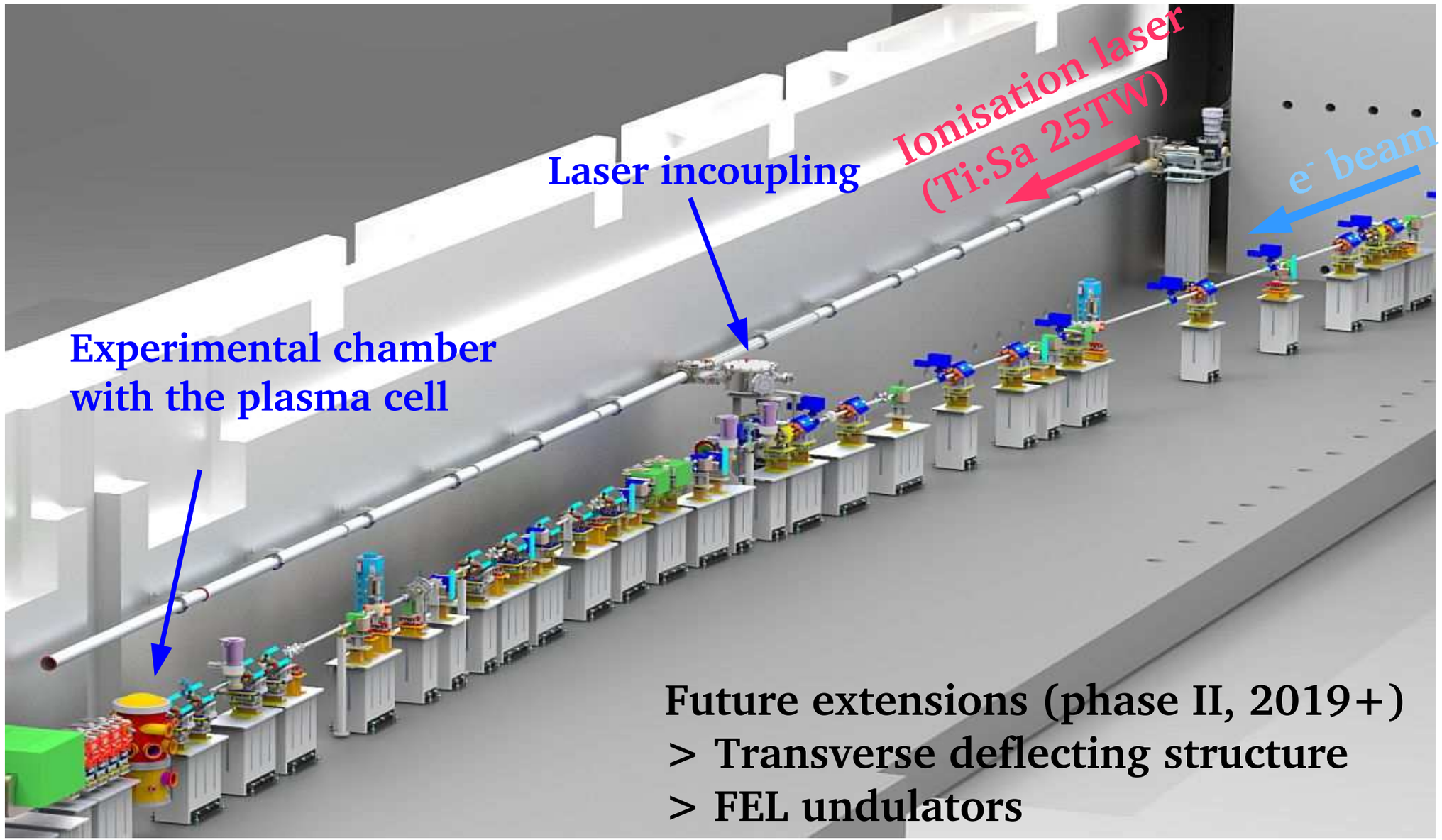
See poster **R. D'Arcy** for **FLASHForward TDS**

> Two magnetic chicanes and a 3rd harmonic module allow flexible tuning of the longitudinal phase space, including generation of **triangular current profile**
  → **transformer ratio / beam loading** optimisation
> Windowless target design → **emittance conservation**
> Active plasma lenses for focusing/capturing → **emittance conservation**
> Long plasma cells → **driver depletion**
> Repetition rate up to 1 MHz → **high repetition rate**

See talk **J.-H. Röckemann** (WG5) for **Active Plasma Lenses**

See talk **J. Osterhoff** (WG1/WG8) for FLASHForward overview

FLASHForward in the FLASH2 tunnel (phase I)



Electron beamline installation status

> The beamline is installed up to a few meters upstream of the target chamber
→ **magnets**
→ **diagnostics** (beam position monitors, screen stations, beam loss monitors, charge monitors)
→ **beam pipe** and vacuum chambers
→ **vacuum system** (pumps, shutters, pressure sensors)

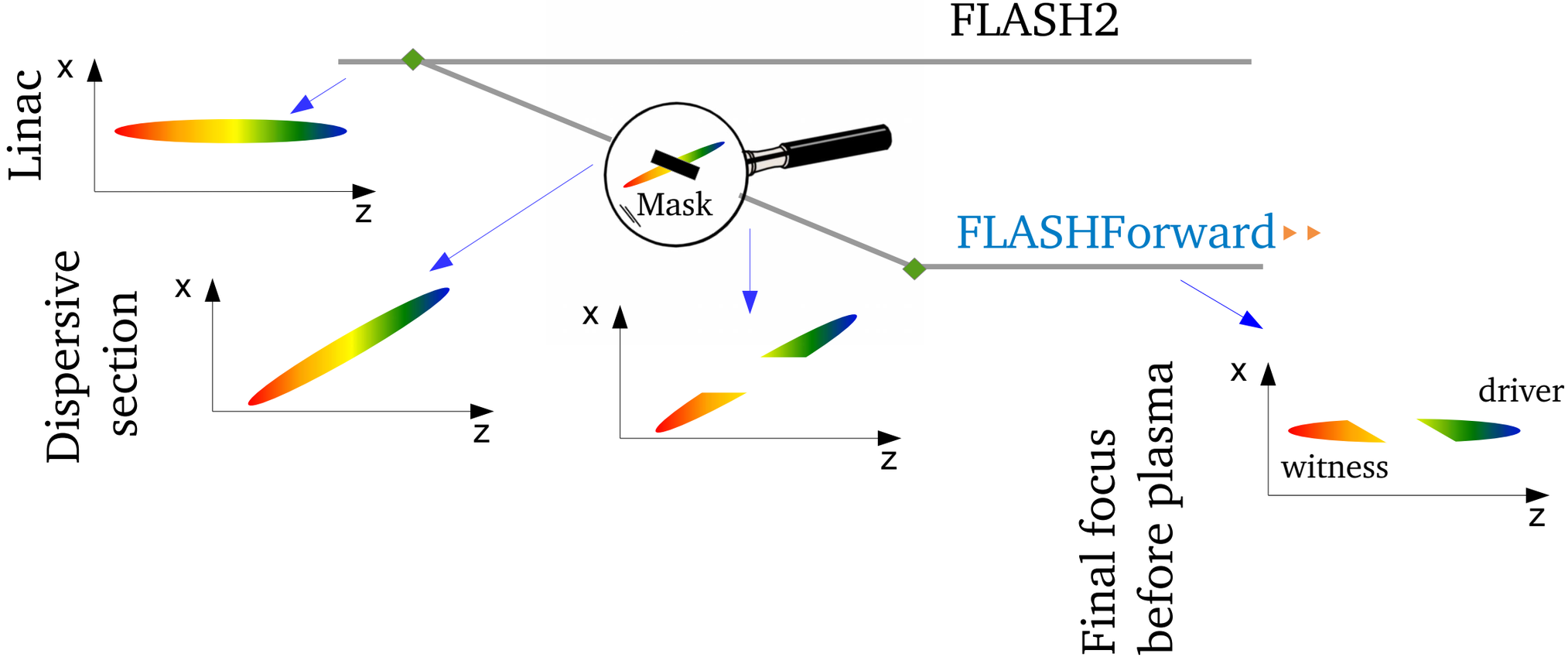
> Installations will be finalised in January 2018

> First **commissioning** shifts took place in August/September 2017

Double bunch generation - principle

P. Muggli et al.,
PRSTAB **13**, 052803 (2010)

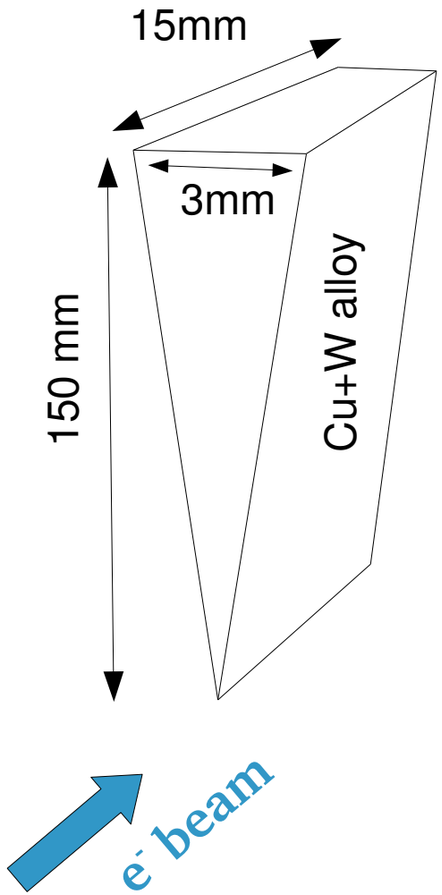
> An energy chirp (**z-E** correlation) is imposed in order to compress beams in the magnetic chicanes
> This leads to a **z-x** correlation in the dispersive section of FLASHForward
> A **transverse mask (scraper)** can therefore be used to split the bunch longitudinally
→ additional **side blocks** allow further tuning of the drive/witness pair longitudinal shape



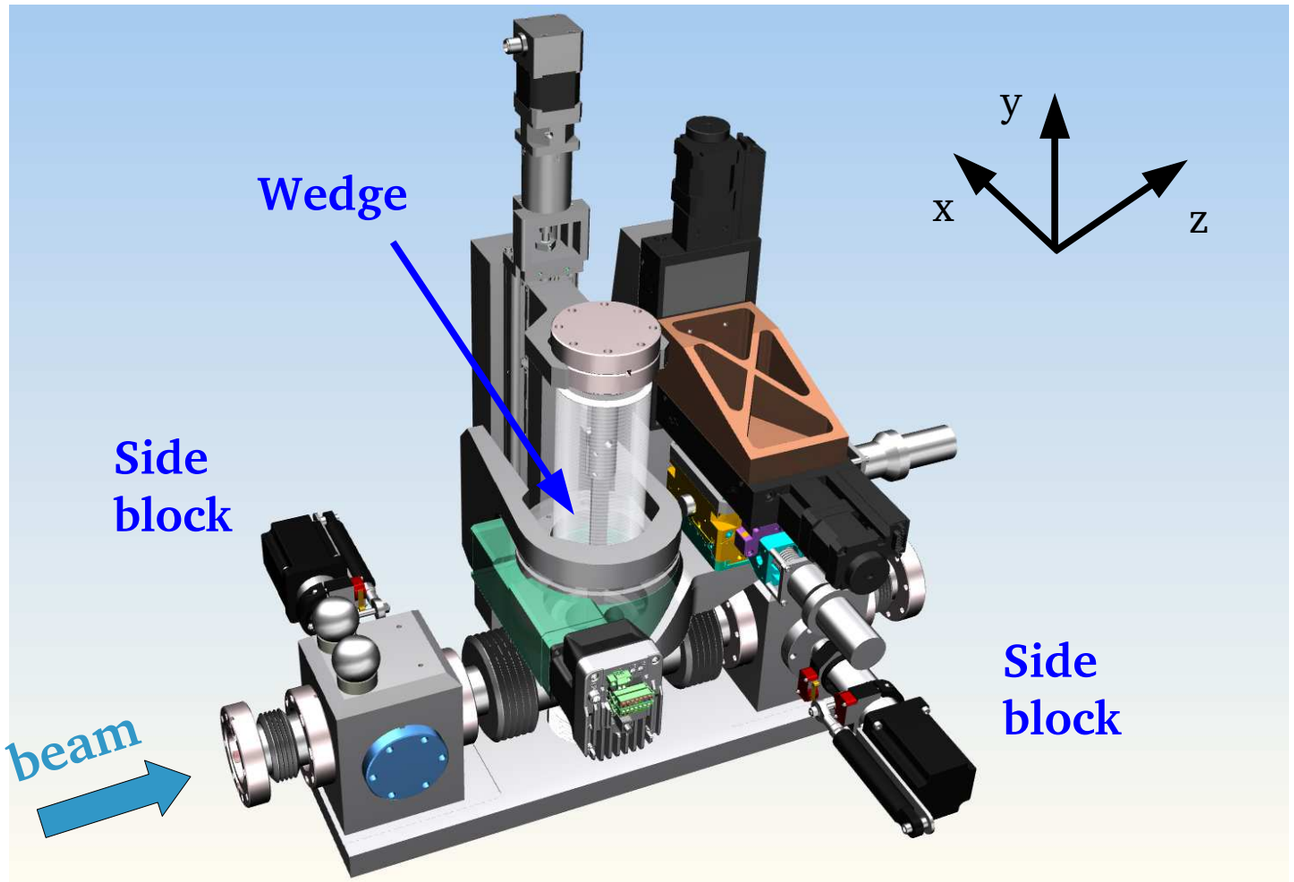
Double bunch generation – scraper design

> **A wedge-shaped scraper design was chosen to allows stepless** tuning of the driver-witness separation

Geometry:



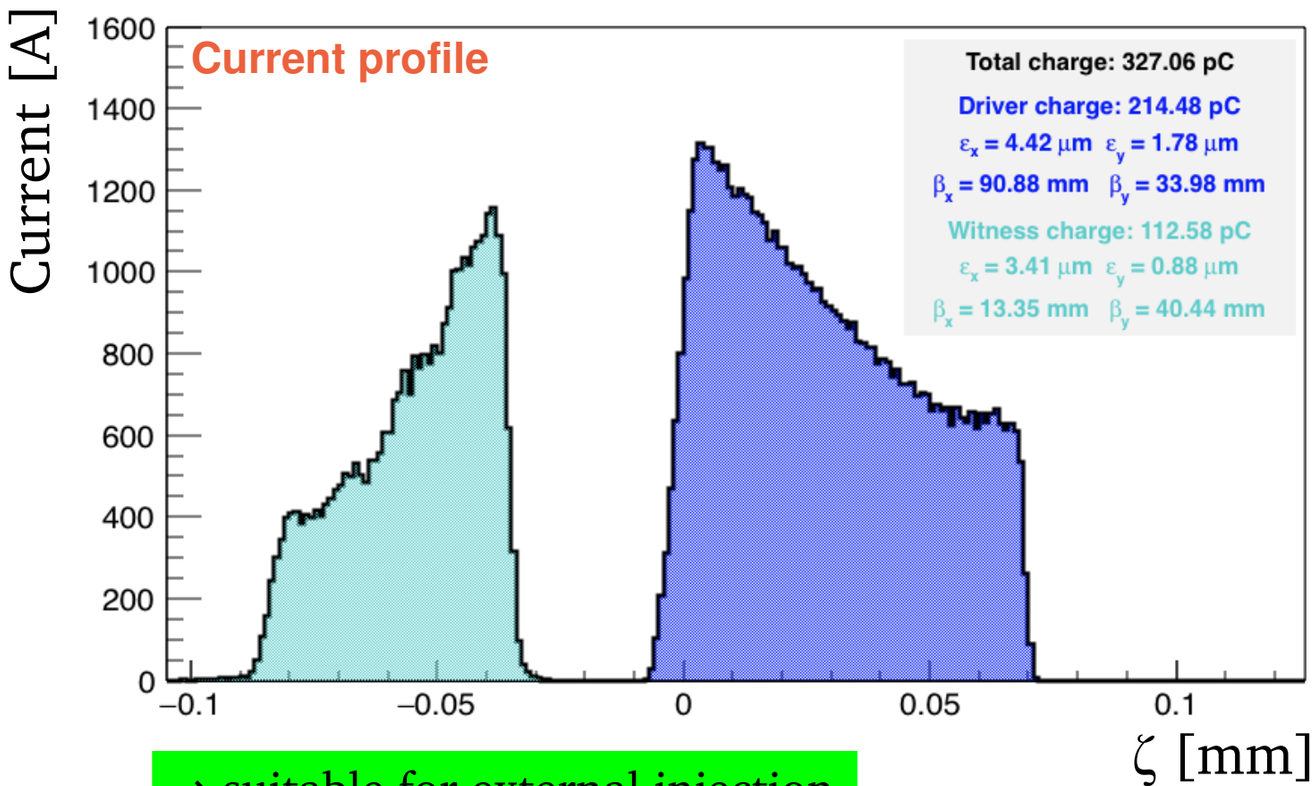
Example:



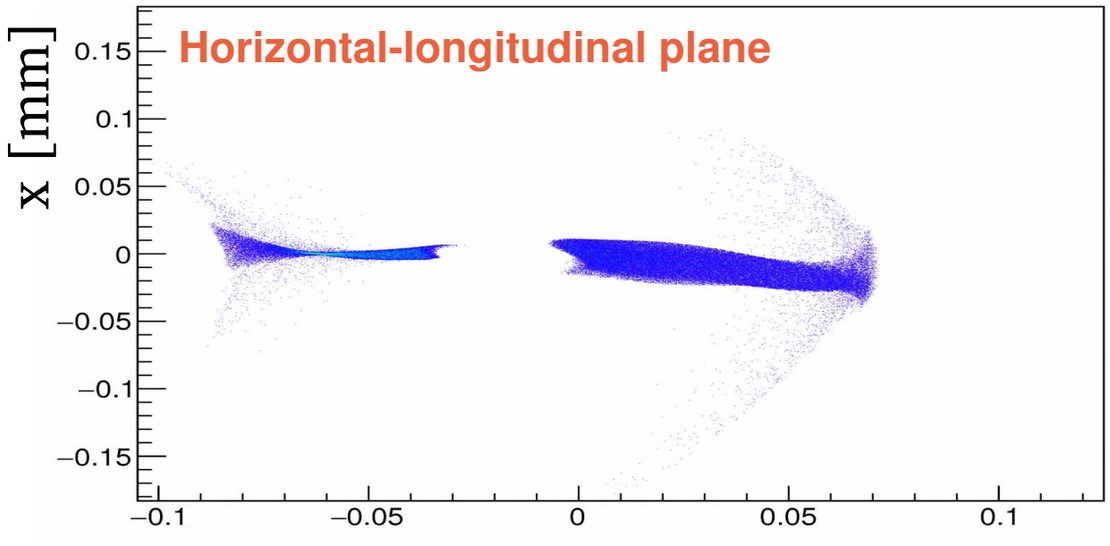
> Design of the mover system in progress
> x/y motion, and rotation around y are foreseen
> Installation planned for the **summer 2018** shutdown

Double bunch generation – beam-dynamics simulations

- Detailed **start-to-end simulations** are used to assess feasibility of driver-witness generation suitable for external injection
- **Centroid offsets** due to CSR effects must be minimised to avoid the hose instability
- **Tools**: *ASTRA* (FLASH injector), *elegant* (FLASH linac, FLASHForward beamline), *CSRTrack* (bends), *Geant4* (scraper)



→ suitable for external injection

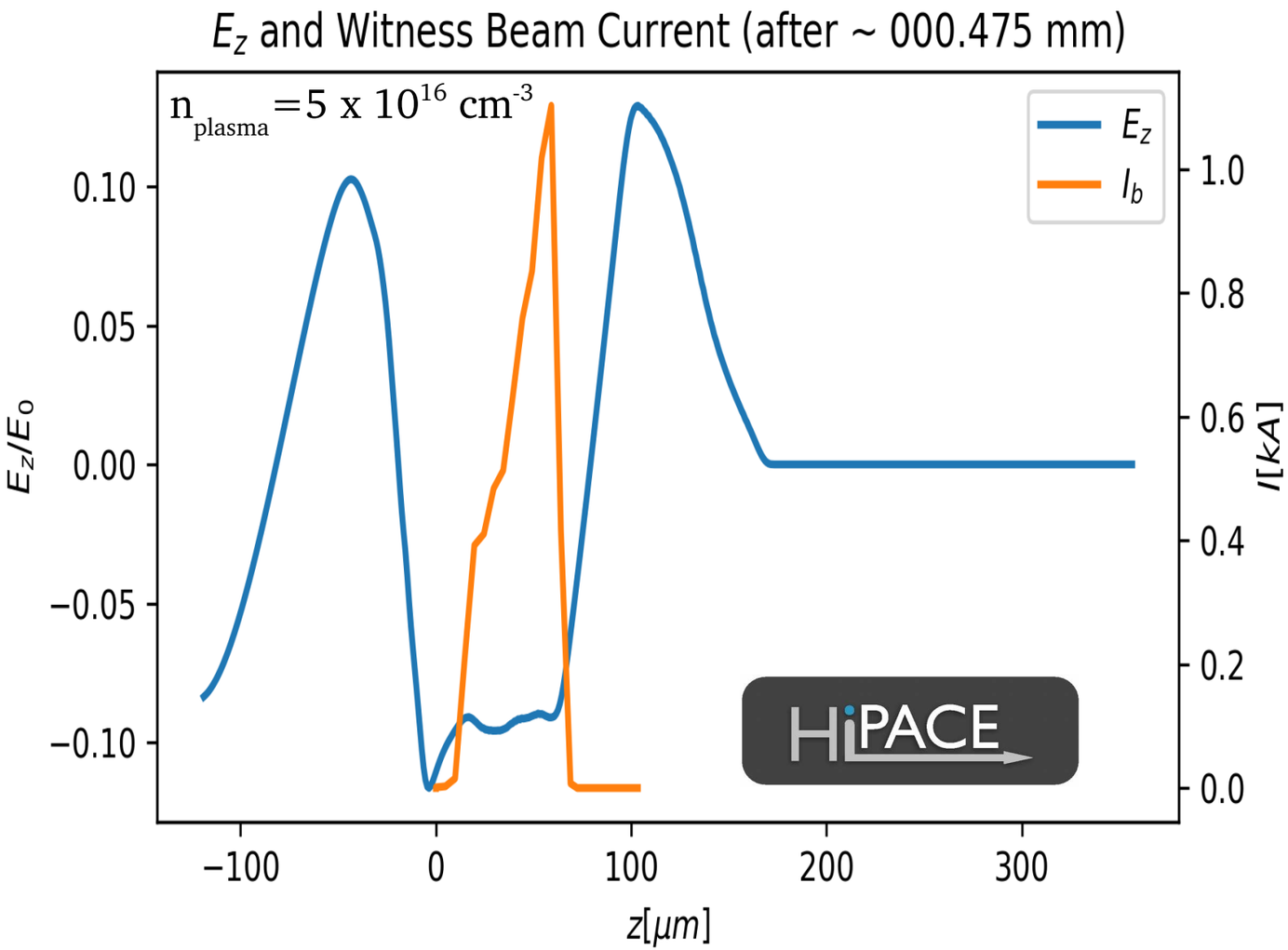


- Transverse offsets due to CSR evident

See plenary talk **T. Merhling** (Wed) for Hosing Instability Mitigation

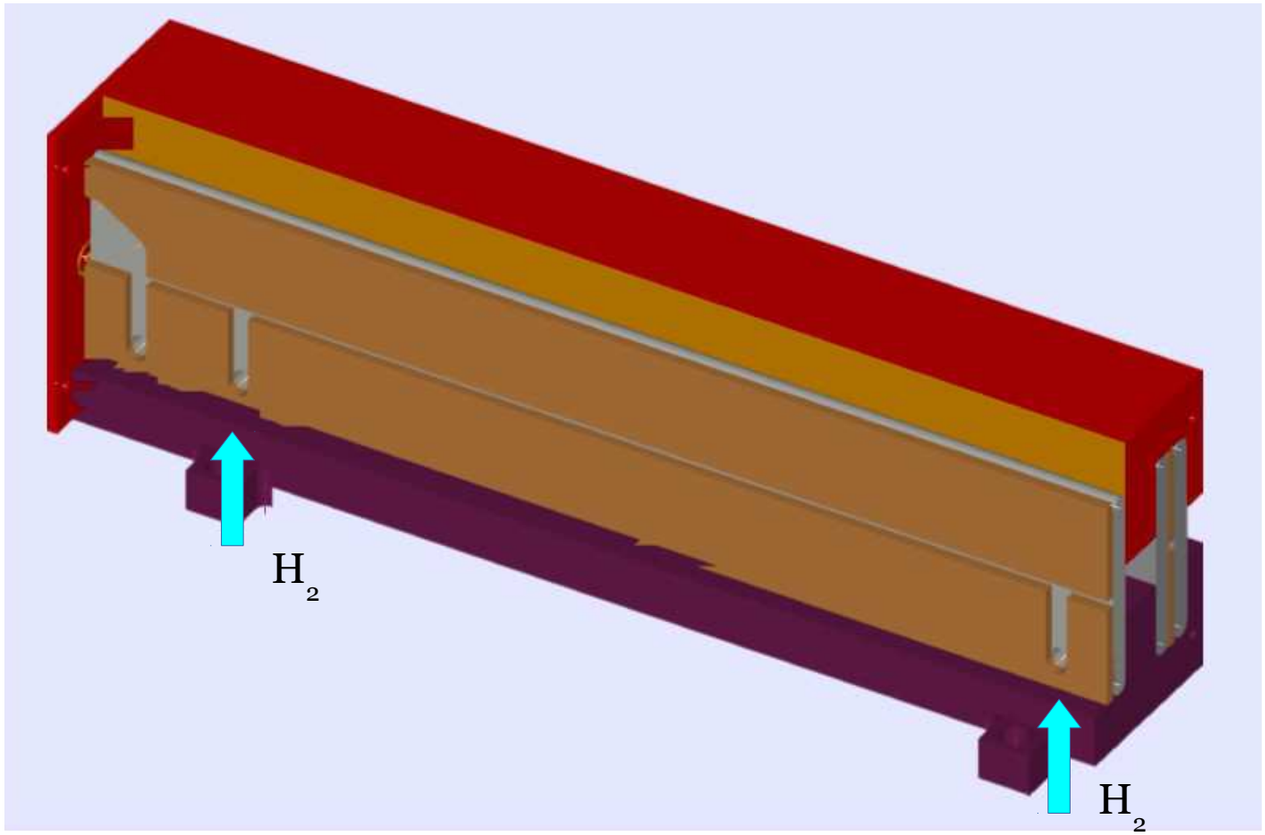
Particle-in-Cell simulations

> Beams from the start-to-end linac simulations are imported into a PiC simulation to evaluate their suitability and to predict their properties after the plasma



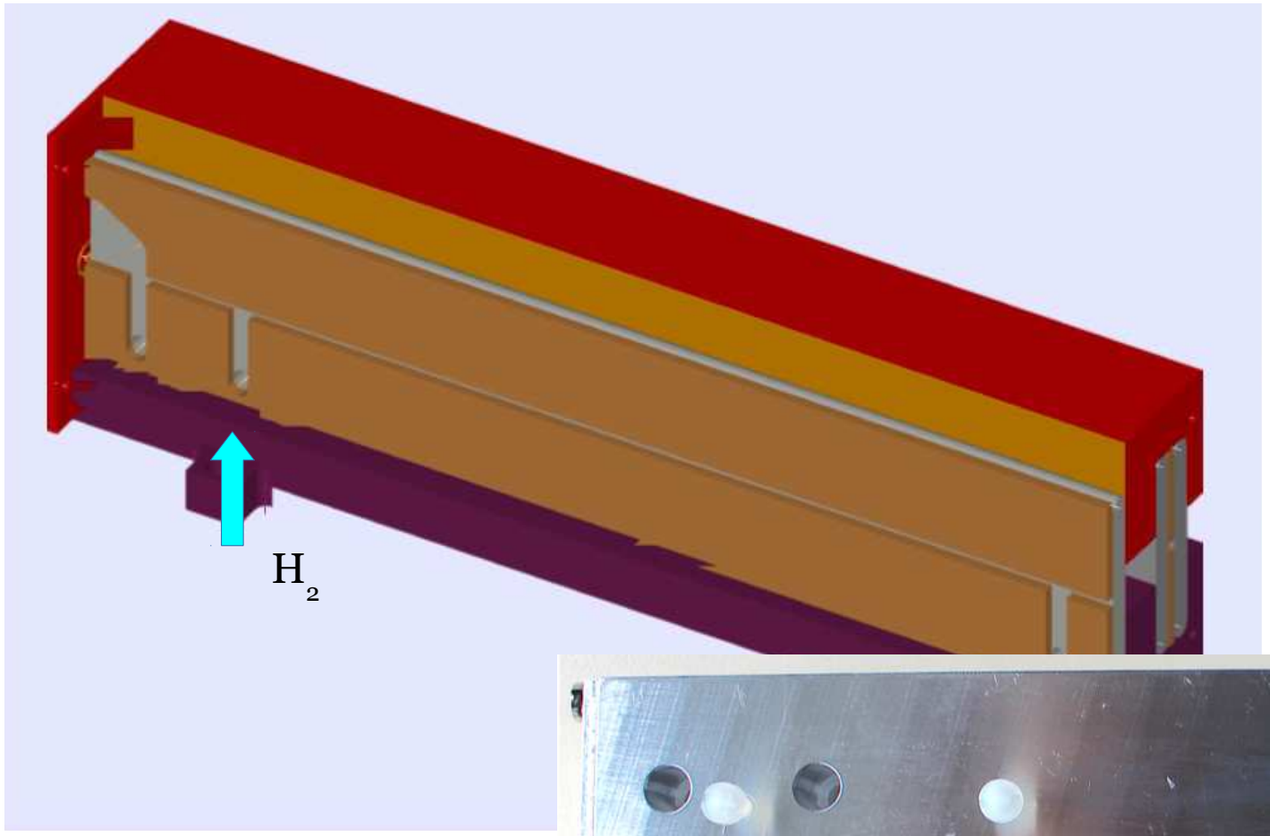
Optimising the longitudinal witness profile allows beam-loading of the wake

Plasma target



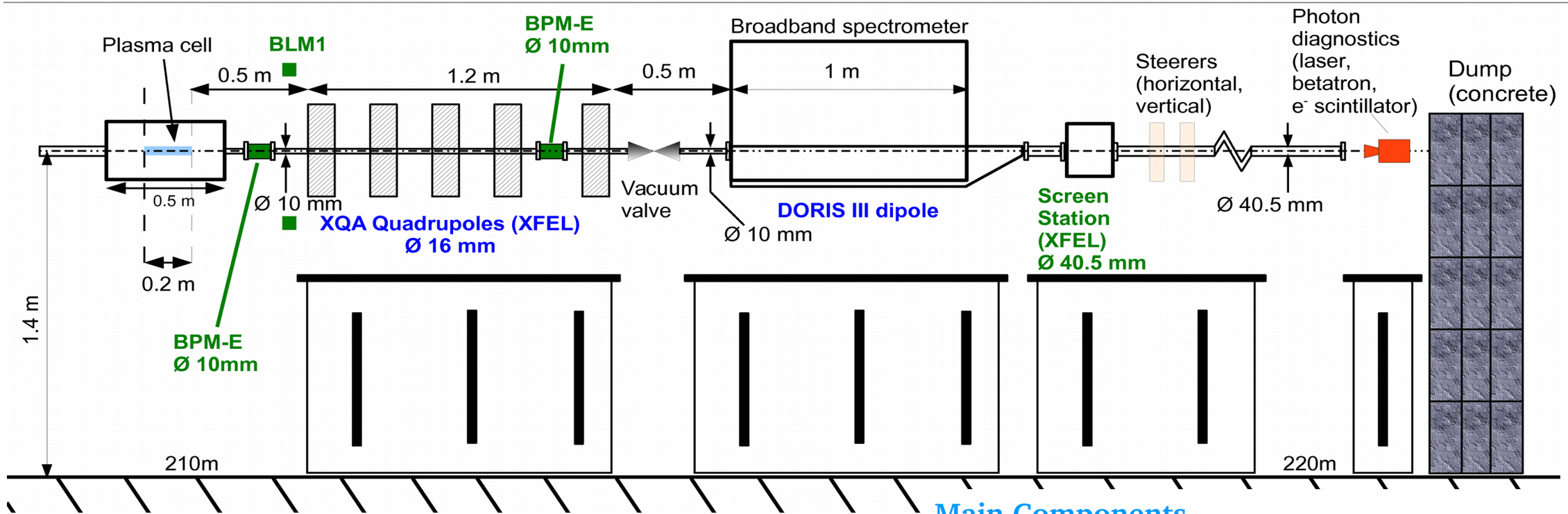
- Windowless design
  → emittance conservation
- Lengths up to 250 mm
  → driver energy depletion
- Densities up to 5 x 10^{17} cm^{-3}

Plasma target



- Windowless design
  → emittance conservation
- Lengths up to 250 mm
  → driver energy depletion
- Densities up to 5 x 10^{17} cm^{-3}

Diagnostics beamline – phase I



Side-view

A basic suite to observe PWFA
→ **capturing** and **transport** of the witness beam
→ measurement of the **charge**, **energy**, **transverse profile**, **position** of drive and witness beams

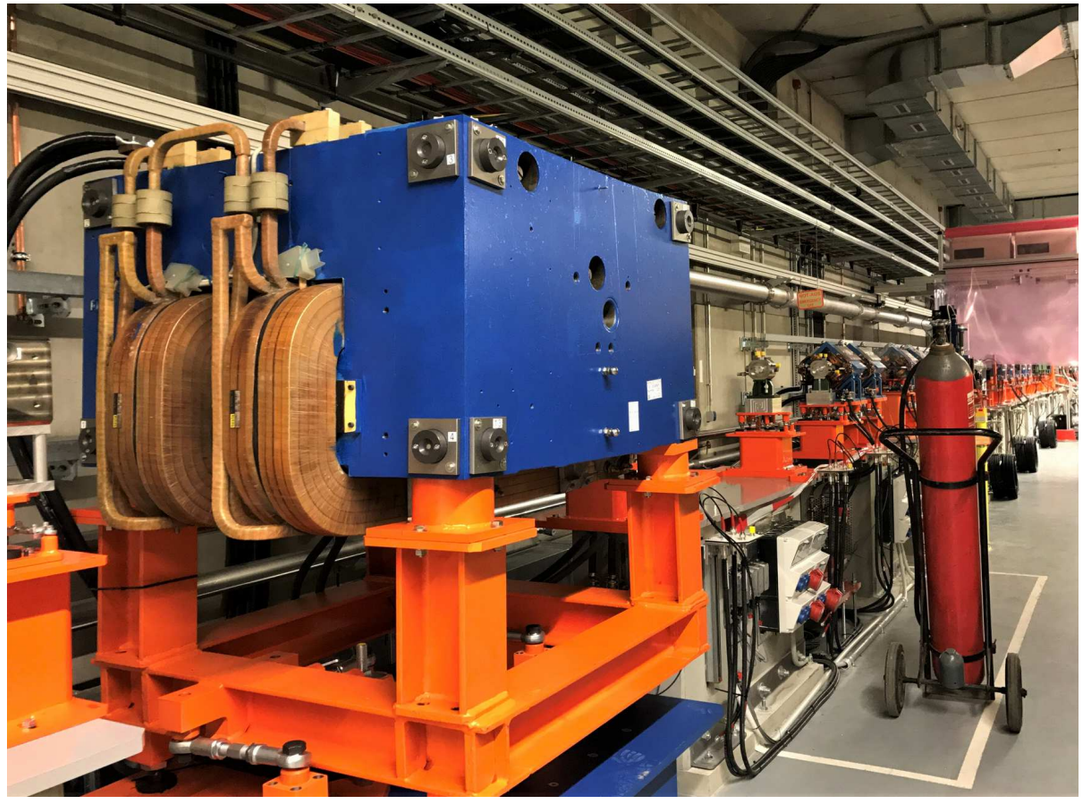
Extension (phase II) will include
→ **Transverse-deflecting structure** for full longitudinal diagnostics
→ **High-resolution** narrow-band electron spectrometer

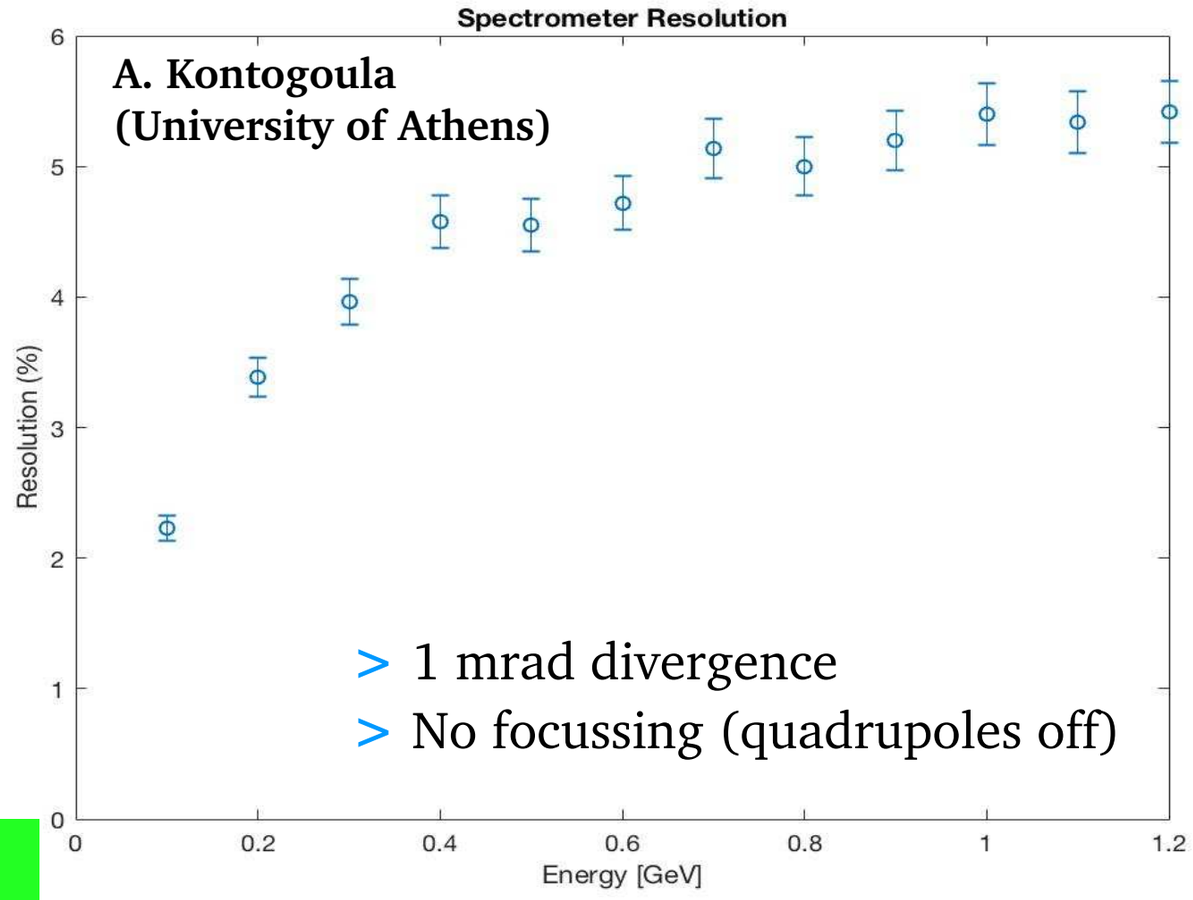
Main Components

> 100 T/m quadrupole "triplet" (paired)
> 1.4 T broadband electron spectrometer
> Cavity beam position monitors (μm-level resolution, low sensitivity to electromagnetic noise and halo electrons)
> Scintillator screen station (10 μm resolution)
> Betatron/laser diagnostics (in-air)
> 10 m long to reduce the laser intensity
  > Also allows focussing the witness beam
> Space is foreseen after the exit window for laser, betatron, and electron (scintillating screen) diagnostics

Diagnostics beamline – broadband electron spectrometer

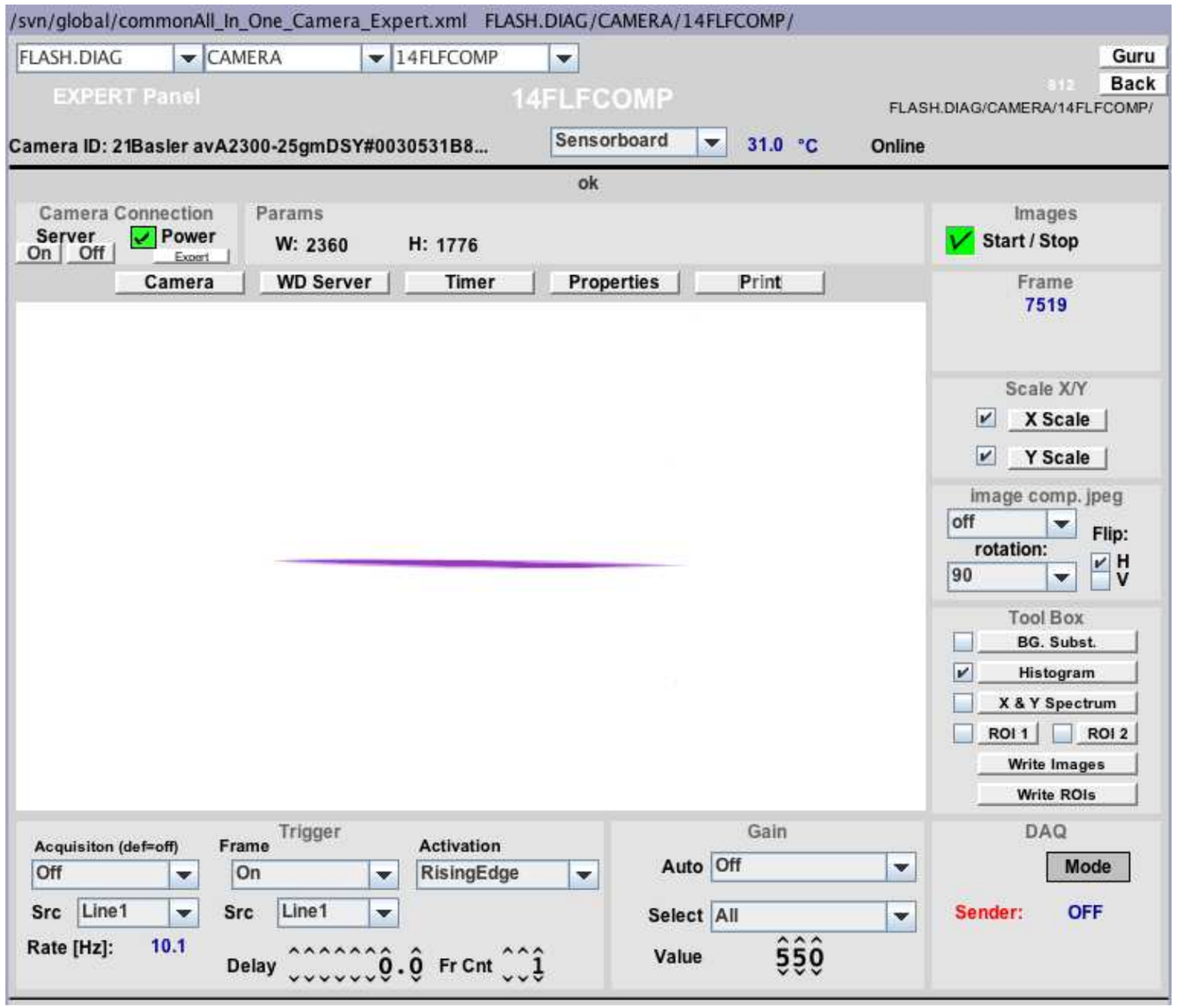
> Essential component to observe wakefield formation and witness acceleration
> Recycled 1.4 T dipole from the DORIS III ring
> Resolution was determined using the 3D map of magnetic field (measured at 950A)





Few-% resolution → sufficient for experiments
Can be improved for specific energy by using quadrupoles

First beam in FLASHForward!



> Commissioning started 30.8.2017
> First beam in the beamline was seen at 2am on 31.8.2017
→ scintillator profile screen in the dispersive section (therefore the shape)

Used around 40h of beam time to

> Successfully test
→ **magnet** polarities
→ **diagnostics**
→ **control system**
> Achieve **beam transmission** up to the vacuum safety valve
> Perform first measurement of the **orbit response matrix**

→ a test for correctness of the beamline model (and magnet installation/connection)

Summary and Outlook

- Beam **quality preservation** in a plasma booster is one of the key missing milestones towards application of plasma-based accelerators for high energies

- **FLASHForward** is a novel PWFA experiment to study all aspects of a plasma booster

- Electron beamline is partially **installed** and **commissioned**

- Detailed **start-to-end simulations** are performed together with **PiC simulations**
  → to optimise the driver/witness beam parameters
  → evaluate their evolution in plasma

- Dispersive section mask installation is foreseen to summer 2018
  → first external injection experiments!