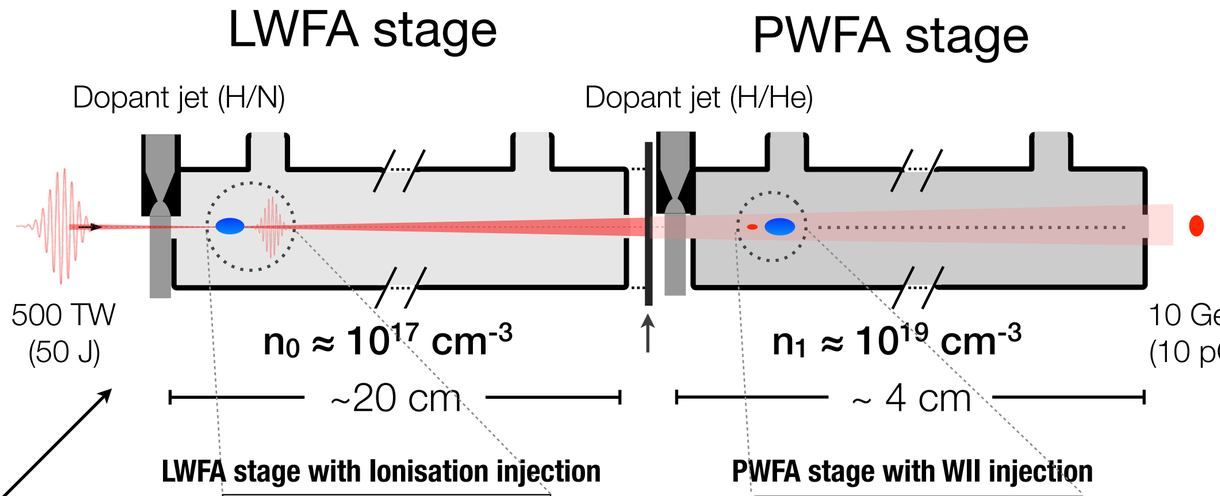
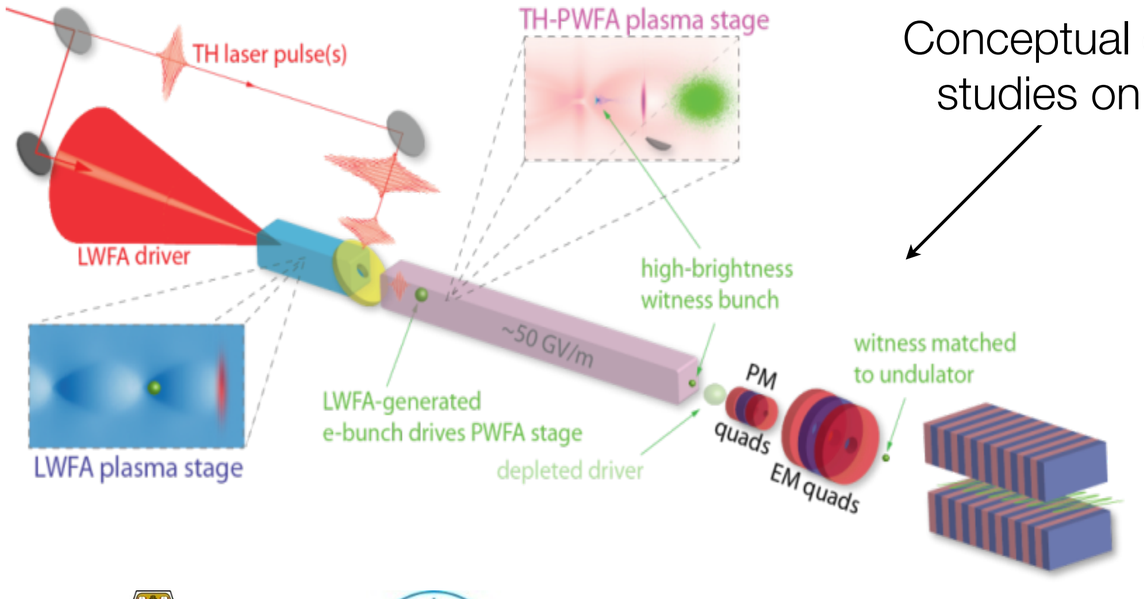
WP14 Hybrid Laser-Electron-Beam Driven Acceleration: Conceptual designs

Goals:

- Production of stable, high-current (≳10kA), GeV-class electron beams from LWFA at low densities. (but not necessarily high-quality)
- Demonstration of injection and acceleration of high-quality electron beams in a PWFA stage driven by the LWFA beam.



Conceptual designs studies on going

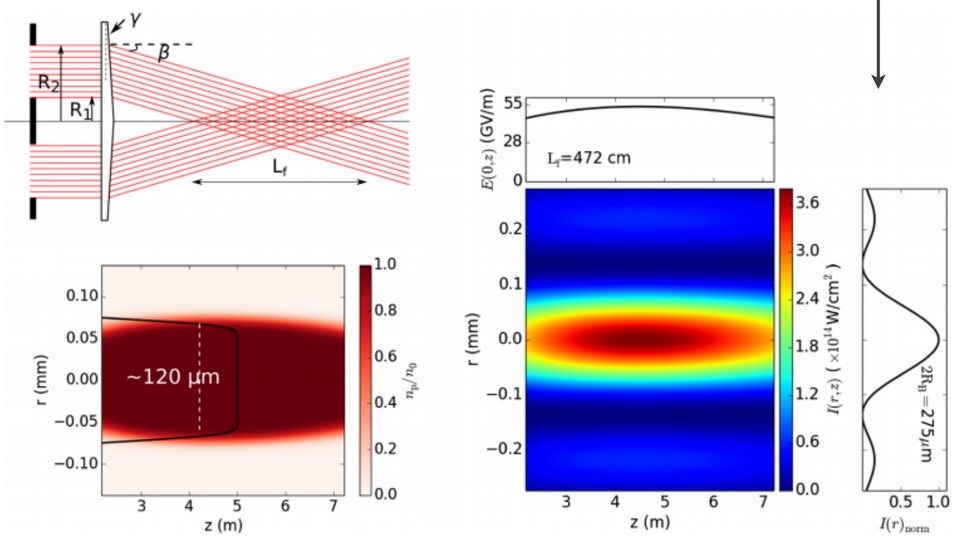


B. Hidding et al., Phys. Rev. Lett. 104, 195002 (2010).
B. Hidding et al., Phys. Rev. Lett. 108, 035001 (2012).
A. Martinez de la Ossa et al., Phys. Rev. Lett. 111, 245003 (2013).
A. Martinez de la Ossa et al., Phys. Plasmas 22, 093107 (2015).

Energy and quality booster for the production of multi-GeV FEL capable beams

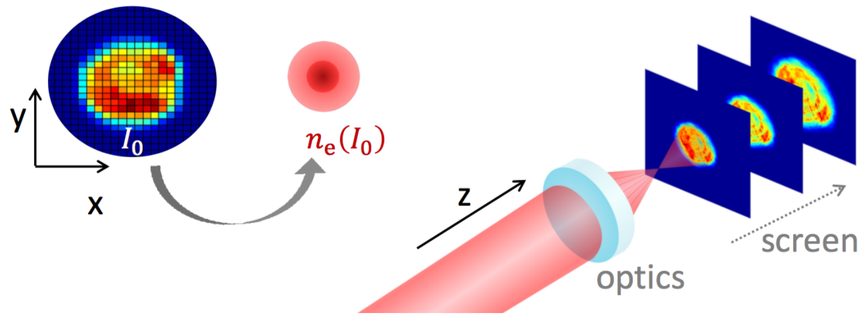
WP14 Hybrid Laser-Electron-Beam Driven Acceleration: Tasks and deliverables

- **Task 14.1.** Selective ionization of plasma components.
  - ↳ Experimental determination of ionisation rates triggered by a laser.
  - ↳ Selection of most promising species for internal injection in both LWFA and PWFA modules.
  - ↳ **Deliverable 14.1.** Design of an optimized plasma ionization module.



Axicon setup: *G. G. Manahan et al. (PRAB 19, 011303 (2016)*

G. Tauscher. Master thesis.

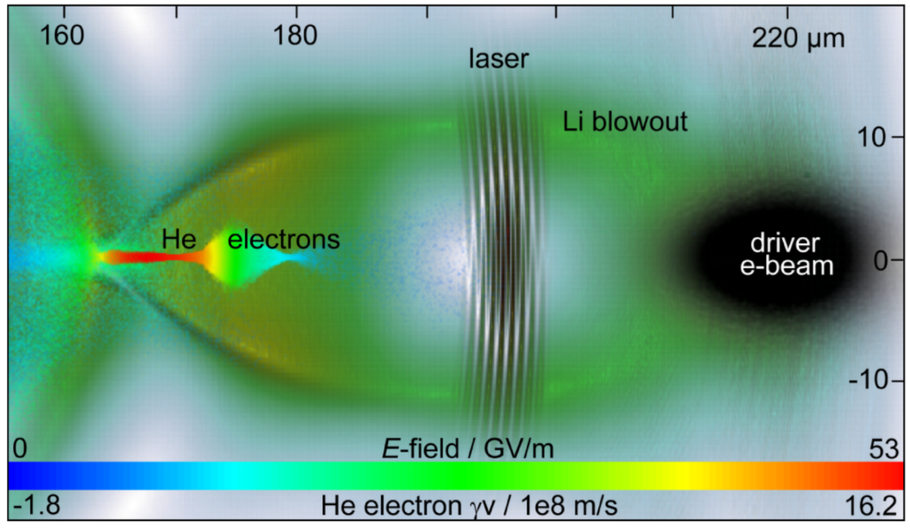


- ➤ Inferring plasma density profiles from measured laser intensity propagation.
- ➤ Understanding of ionisation process: Atomic vs molecular behaviour

Towards realistic LWFA PIC simulations for the design of a reliable LWFA stage

WP14 Hybrid Laser-Electron-Beam Driven Acceleration: Tasks and deliverables

- **Task 14.2.** Trojan Horse underdense photocathode witness bunch generation.
  ↳ Deliverable 14.2: Underdense plasma photocathode design report.
  B. Hidding et al., Phys. Rev. Lett. 108, 035001 (2012).
  A. Knetsch et al., arXiv:1412.4844v1 [physics.acc-ph].



Potential production of ultra low emittance beams

- ➤ Study on the requirements for the implementation of Trojan horse scheme in PWFA scenarios with LWFA produced electron beams.
- ➤ Determination of laser/beam synchronisation levels for certain target design capabilities.

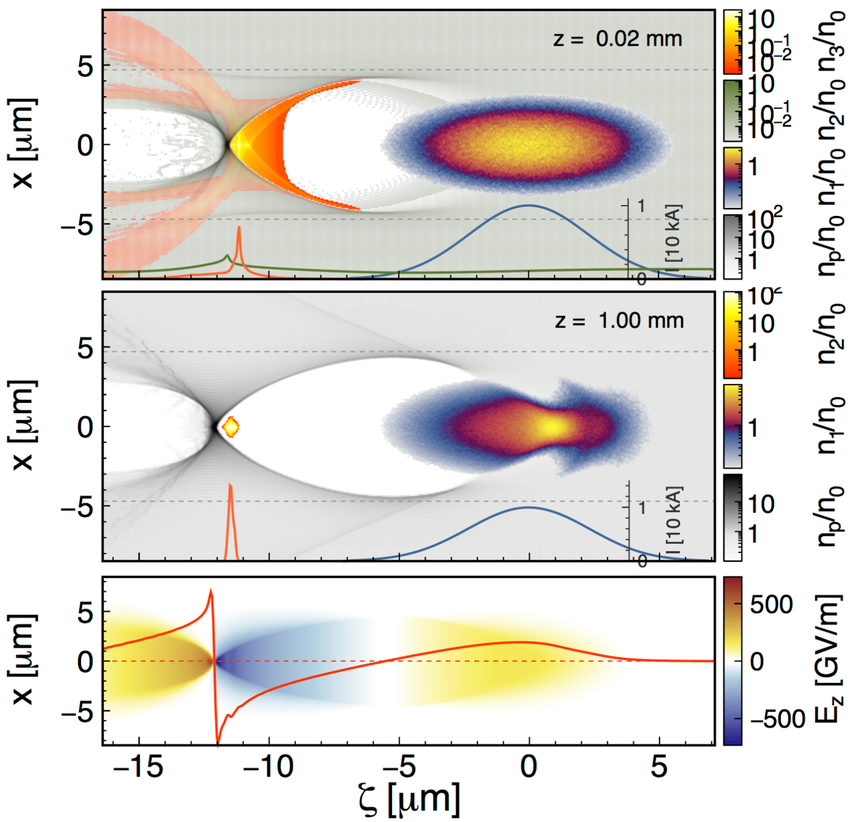
Extensive datamining of E210
“Trojan Horse PWFA“ multiyear collaboration at SLAC FACET (where preionization was a major bottleneck) in progress

Key experience gained through E210 experiment[1]!

1. B. Hidding et al. Physics and Applications of HBB. March 30th, 2016, Cuba

WP14 Hybrid Laser-Electron-Beam Driven Acceleration: Tasks and deliverables

- **Task 14.3.** Wakefield-Induced ionisation injection .
  ↳ Deliverable 14.3: Design report with Wakefield induced ionisation technique.
  A. Martinez de la Ossa et al., Phys. Rev. Lett. 111, 245003 (2013).
  A. Martinez de la Ossa et al., Phys. Plasmas 22, 093107 (2015).



➤ Study on the requirements for the implementation of WII injection scheme in PWFA scenarios with LWFA produced electron beams.

Produced beams are intrinsically synchronised, low-emittance and accelerated at high transformer ratio

High transformer ratio
$\mathrm{R} = E_z^{\mathrm{wit}}/E_z^{\mathrm{dri}} \approx 3$

Low emittance beam
$k_p \epsilon_n \approx 0.1$

Experience from FLASHForward design studies and incoming experimental runs (summer 2017).

A. Aschikhin et al., Nucl. Instr. Meth. Phys. Res. A806, 175 (2016).

WP14 Hybrid Laser-Electron-Beam Driven Acceleration: Tasks and deliverables

- **Task 14.4.** Exploiting LWFA-generated electron bunches as drivers for PWFA.
  - ↳ Determination of a working point to enable internal injection in PWFA stage with LWFA produced beams.
  - ↳ Estimation of experimental tolerances: Laser jitter, laser asymmetries, bunch asymmetries, plasma fluctuations, dark current suppression, hosing mitigation, etc.
  - ↳ Studies on FEL gain capabilities with the generated bunches:
    Sufficient bunch length, and specially, sufficiently low energy spread are key features to achieve.
  - ↳ **Deliverable 14.4.** Conceptual design of optimized LWFA-source for PWFA-driver electron bunches.

Determination of a working point for EuPRAXIA design parameters[1,2]

Estimation of experimental tolerances through start-to-end simulations:

1. Close collaboration with WP2 (Physics and simulations):
   - Needs of expensive 3D simulations and more realistic laser profiles
   - 6D phase-space distributions (PSD) for PWFA injection studies.
   - Dedicated computing grant for EuPRAXIA ?
2. Continuous feedback with WP3 and WP4 -> LWFA and Laser design and optimisation.
3. PWFA physics considerations parallel to WP9 (Alternative e-beam driven plasma structure).
4. Close connection with WP6 (FEL pilot application) for target design parameters and applications.

1. A. M. de la Ossa et al., Physics and Applications of HBB. La Habana, March 30th, 2016.
2. A. M. de la Ossa et al., 5th LAOLA meeting, Wismar, June 22nd, 2016.

- **Task 14.4.** Exploiting LWFA-generated electron bunches as drivers for PWFA.
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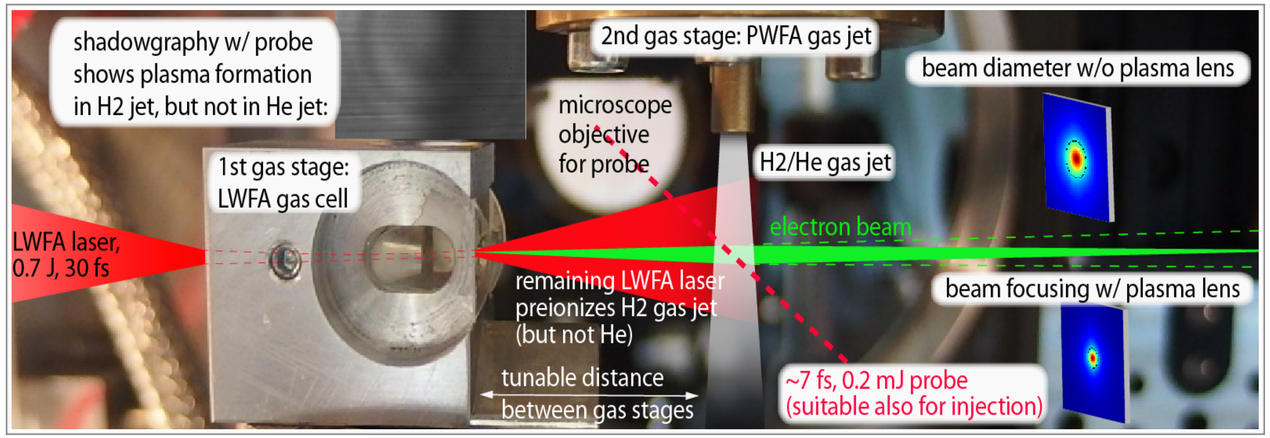
Estimation of experimental tolerances through existing facilities:

1. FACET
2. FLASHForward
3. Plasma lensing experiment FSU (JENA) ⟶
4. HZDR (Dresden)
5. LNF-INFN (Frascati)
6. …

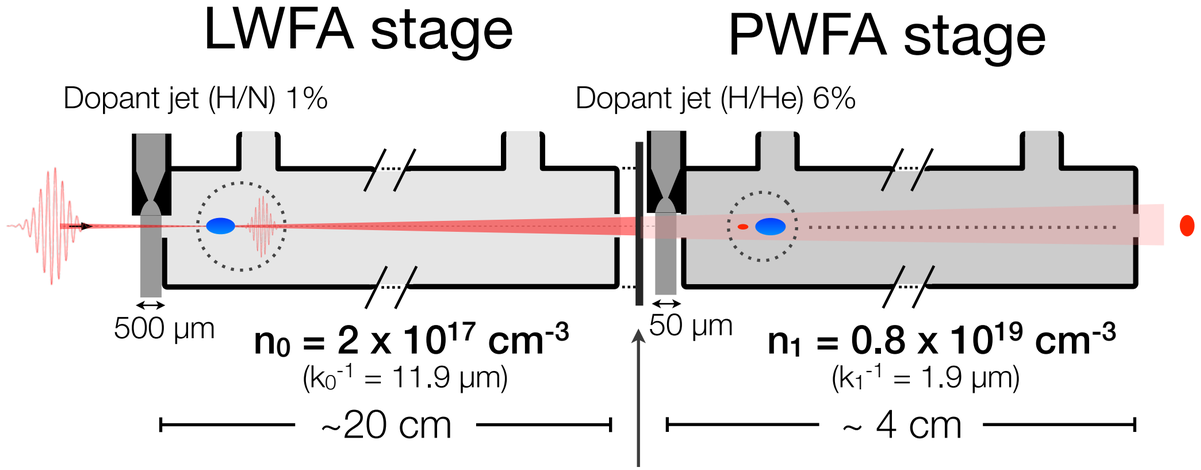


T. Heinemann et al.

WP14 Hybrid Laser-Electron-Beam Driven Acceleration: A working point (preliminary)

Laser beam

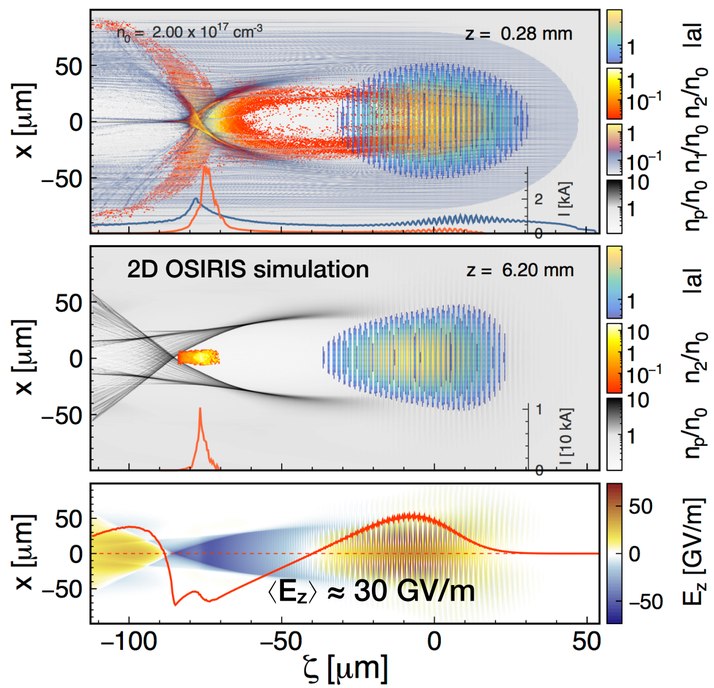
P_0 = 500 TW
λ_0 = 800 nm
w_0 = 41 μm
a_0 = 3
τ = 100 fs
Energy = 53 J



Electron beam

I_0 = 15 kA
ε_n = 130 nm
τ = 700 as
Ymc^2= 10 GeV
$\Delta Y/Y$ = 0.1 %
Charge = 10 pC

LWFA stage with Ionisation injection



Laser barrier

Attenuates the laser below He^+ ionisation levels.
Electron beam goes through.

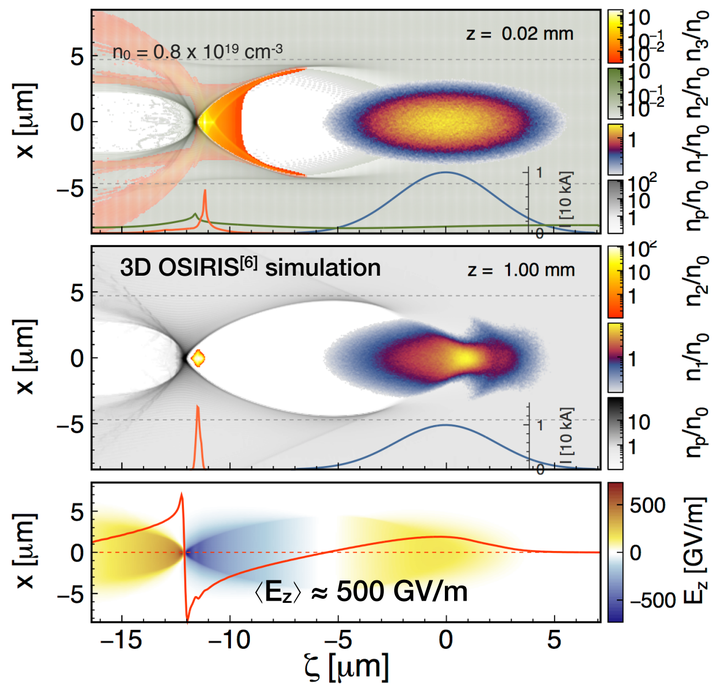
Electron driver

(from LWFA)

I_0 = 10 kA
ε_n = 10 μm
τ = 7 fs
Ymc^2= 5 GeV
$\Delta Y/Y$ = 10 %
Charge = 100 pC

Brightness booster $B \propto \frac{I_b}{\epsilon_n^2}$ x 10000

PWFA stage with WII injection



WP14 Hybrid Laser-Electron-Beam Driven Acceleration: Summary

- Conceptual designs on going.
- Key experience on PWFA injection techniques through E210 “Trojan Horse” at FACET (2016) and FLASHForward at DESY (2017).
- Promising approach for the production of multi-GeV, high-brightness bunches using a staged or hybrid LWFA + PWFA setup:
  ➢ Energy and quality booster by means of a PWFA stage with internal injection.
- Generated beams are naturally ultra-short (sub-micron length)
  ➢ Potential issue for FEL gain: bunches need to be longer than cooperation length.
- Generated beams needs low relative energy spread for sufficient FEL gain
  ➢ Preliminary estimations show a target value of 0.1% for GeV energy bunches.
- Generated beams feature high-current (tens of kA) for a reduction of the energy spread by means of beam loading.
  ➢ Stretching the bunch for longer interaction with FEL radiation.
  A. R. Maier et al., Phys. Rev. X 2, 031019 (2012)
- Other applications for multi-GeV class, ultra-short (< fs), high-brightness beams?

WP14 Hybrid Laser-Electron-Beam Driven Acceleration: Research personnel

Research personnel:

- Prof. Bernhard Hidding (Strathclyde). WP14 leader.
- Dr. Alberto Martinez de la Ossa (Hamburg/DESY). WP14 co-leader.
- Dr. Grace Manahan (Strathclyde).
- Thomas Heinemann (Strathclyde). PhD student.
- Paul Scherkl (Strathclyde). PhD student.
- Ángel Ferran Pousa (Hamburg/DESY). PhD student.
- Fahim Habib (Hamburg), Master student.
- Gabriele Tauscher (Hamburg/DESY) ?. PhD student.
- Olena Kononenko (Hamburg/DESY) ?. PhD student.
- …