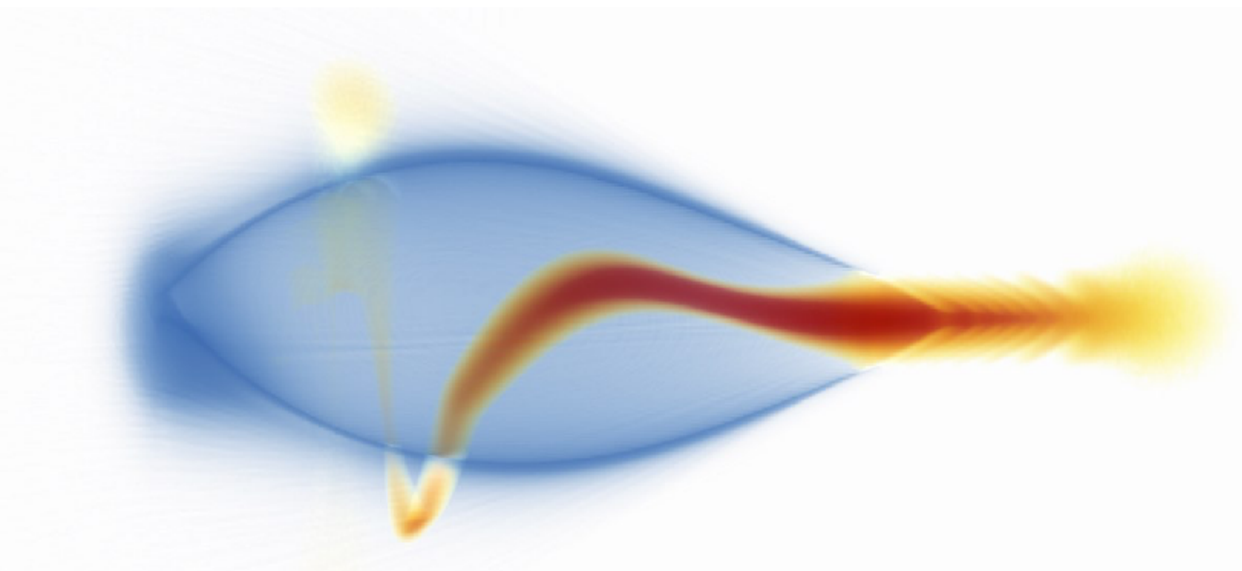

OSIRIS USAGE AT DESY

Full start-to-end PWFA simulations for FLASHFORWARD

Jens Osterhoff

FLASHFORWARD Project Leader | Head, Research Group for Plasma Wakefield Accelerators
Deutsches Elektronen-Synchrotron DESY, Particle Physics Division, Hamburg, Germany

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Andrej Schleiermacher

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Zeng Ming
Pardis Niknejadi
Kristjan Põder
Lucas Schaper
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Maria Weikum
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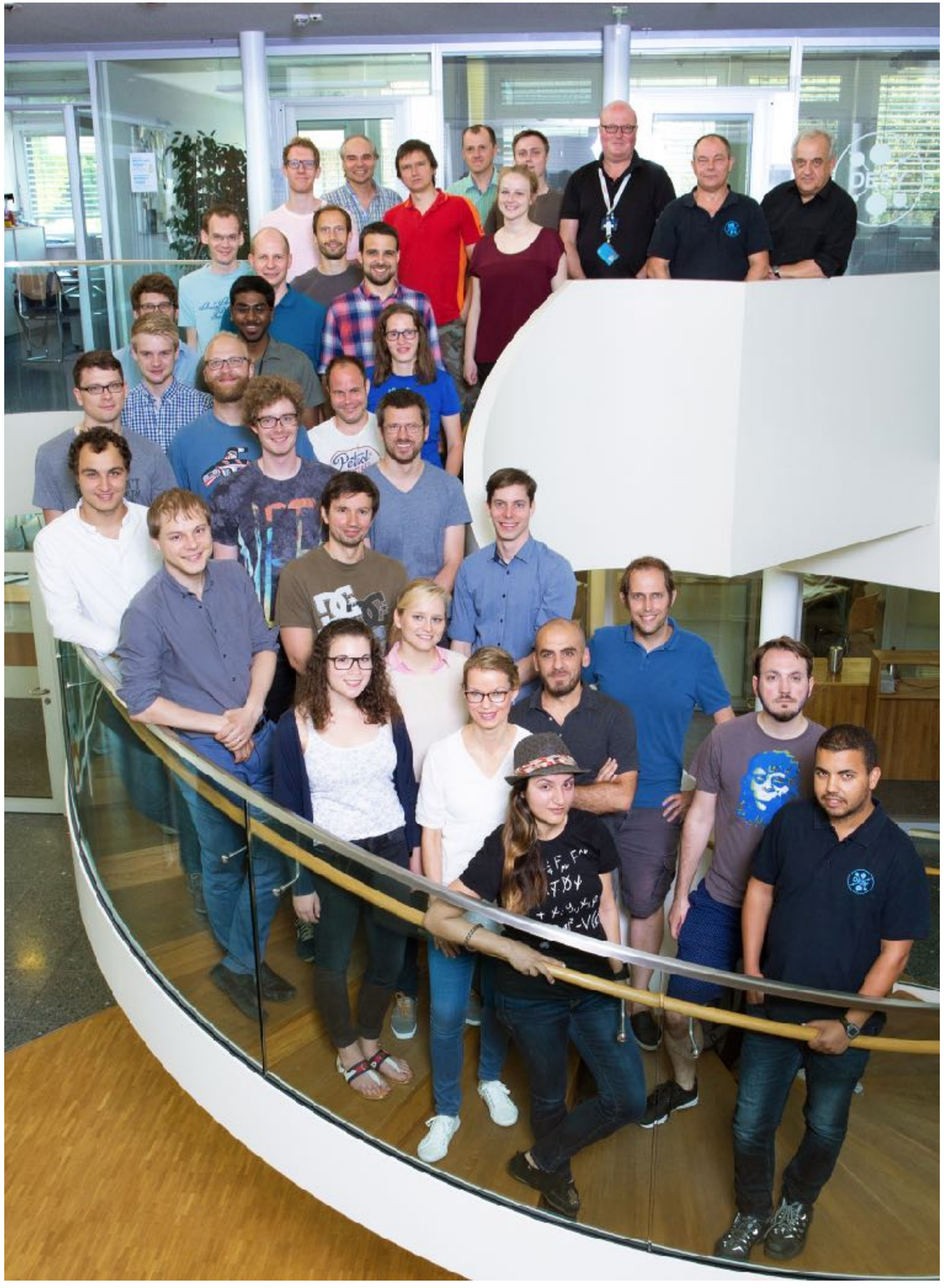

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> DESY engineering and support groups

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Bundesministerium für Bildung und Forschung
Verbundforschung

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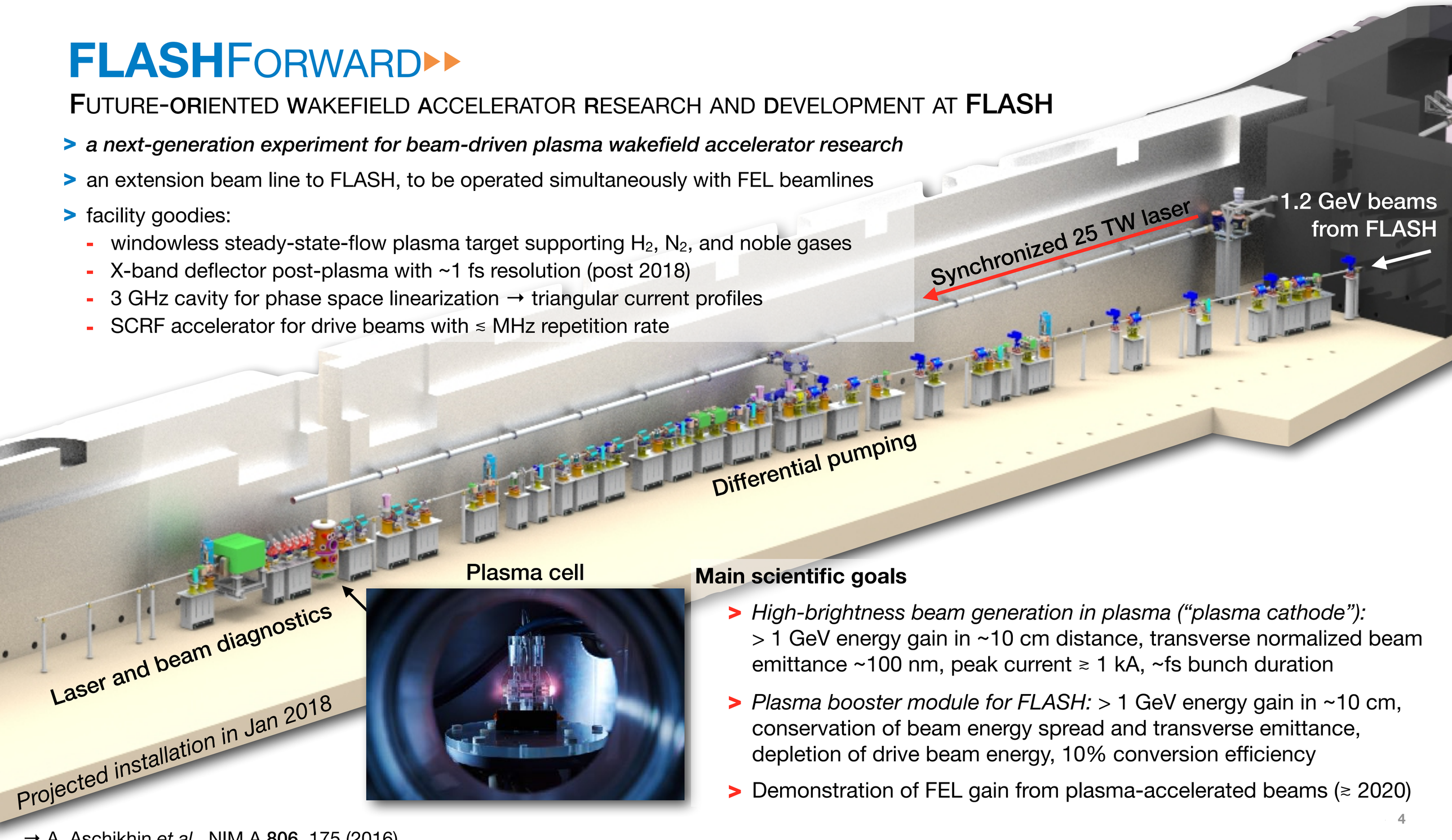
Heinrich-Heine-Universität Düsseldorf, Germany

FLASHFORWARD

FUTURE-ORIENTED WAKEFIELD ACCELERATOR RESEARCH AND DEVELOPMENT AT FLASH

- ***a next-generation experiment for beam-driven plasma wakefield accelerator research***
- an extension beam line to FLASH, to be operated simultaneously with FEL beamlines
- facility goodies:
  - windowless steady-state-flow plasma target supporting H_2, N_2, and noble gases
  - X-band deflector post-plasma with ~1 fs resolution (post 2018)
  - 3 GHz cavity for phase space linearization → triangular current profiles
  - SCRF accelerator for drive beams with ≲ MHz repetition rate

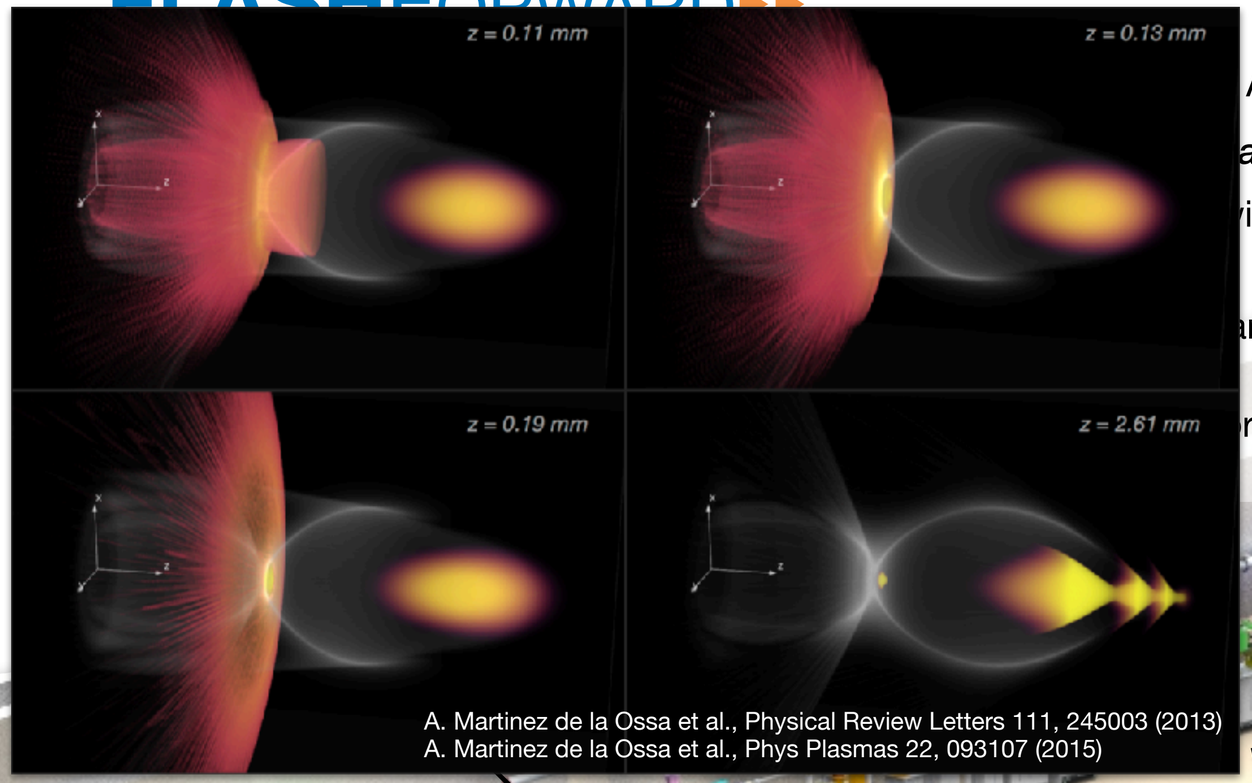


Main scientific goals

- *High-brightness beam generation in plasma ("plasma cathode"):* > 1 GeV energy gain in ~10 cm distance, transverse normalized beam emittance ~100 nm, peak current ≳ 1 kA, ~fs bunch duration
- *Plasma booster module for FLASH:* > 1 GeV energy gain in ~10 cm, conservation of beam energy spread and transverse emittance, depletion of drive beam energy, 10% conversion efficiency
- Demonstration of FEL gain from plasma-accelerated beams (≳ 2020)

→ A. Aschikhin *et al.*, NIM A **806**, 175 (2016)

FLASHFORWARD



A. Martinez de la Ossa et al., Physical Review Letters 111, 245003 (2013)
A. Martinez de la Ossa et al., Phys Plasmas 22, 093107 (2015)

AND DEVELOPMENT AT **FLASH**

accelerator research

ith FEL beamlines

nd noble gases

rofiles

Main scientific goals

- *High-brightness beam generation in plasma ("plasma cathode"):* > 1 GeV energy gain in ~10 cm distance, transverse normalized beam emittance ~100 nm, peak current ≳ 1 kA, ~fs bunch duration
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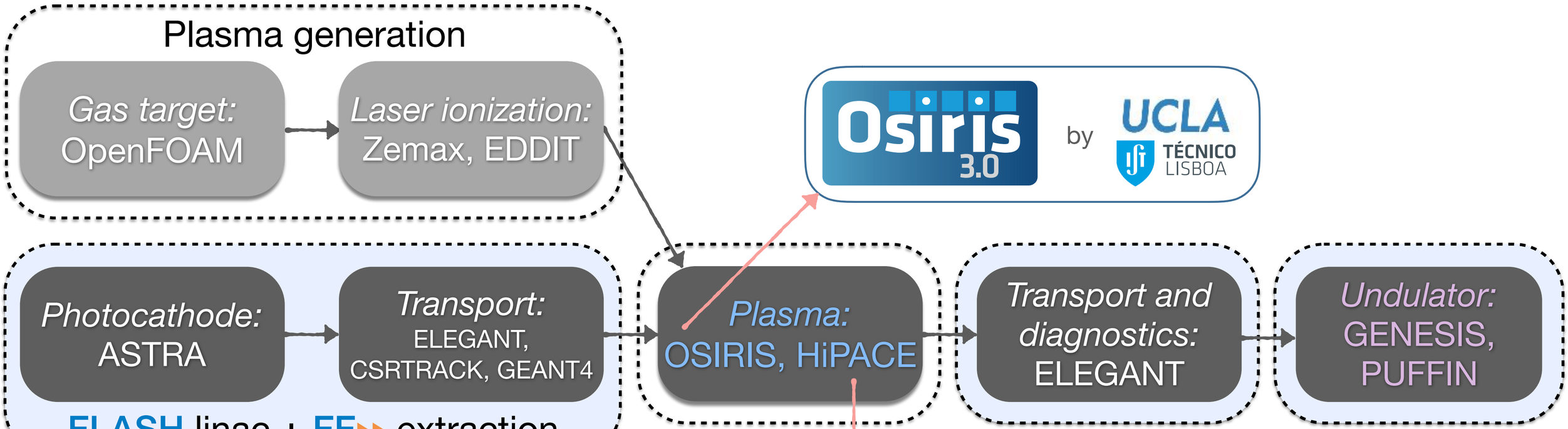
Full start-to-end simulations implemented including CSR, space charge, and wakefield effects



HiPACE

HiPACE - a highly efficient plasma accelerator emulation

- > **3D quasi-static, relativistic, fully electromagnetic PIC code**
- > **fully parallelized** and well scalable (tested up to 1024 cores)
- > dynamic time-step adjustment
- > **orders-of-magnitude speedup** vs. full PIC
- > **interfaces** seamlessly with OSIRIS and tracking codes

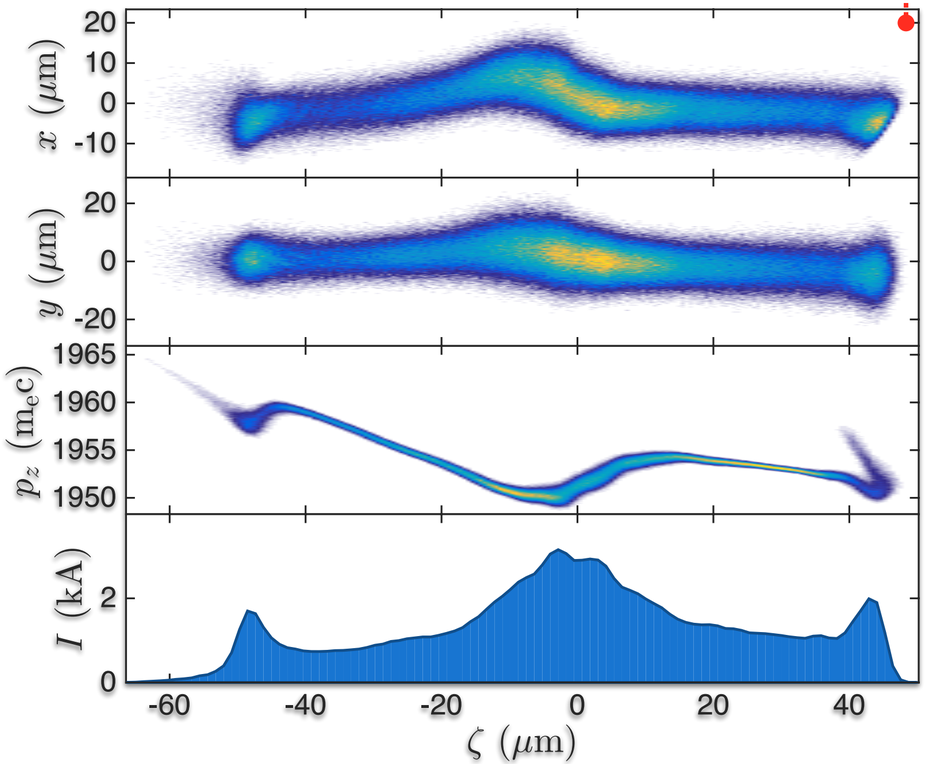
DESY

BERKELEY LAB

developed in collaboration between DESY and LBNL

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

Full start-to-end simulations implemented including CSR, space charge, and wakefield effects



Realistic beam distribution from tracking codes incl. nonlinear transport effects

→ Not Gaussian!

Full start-to-end simulations implemented including CSR, space charge, and wakefield effects

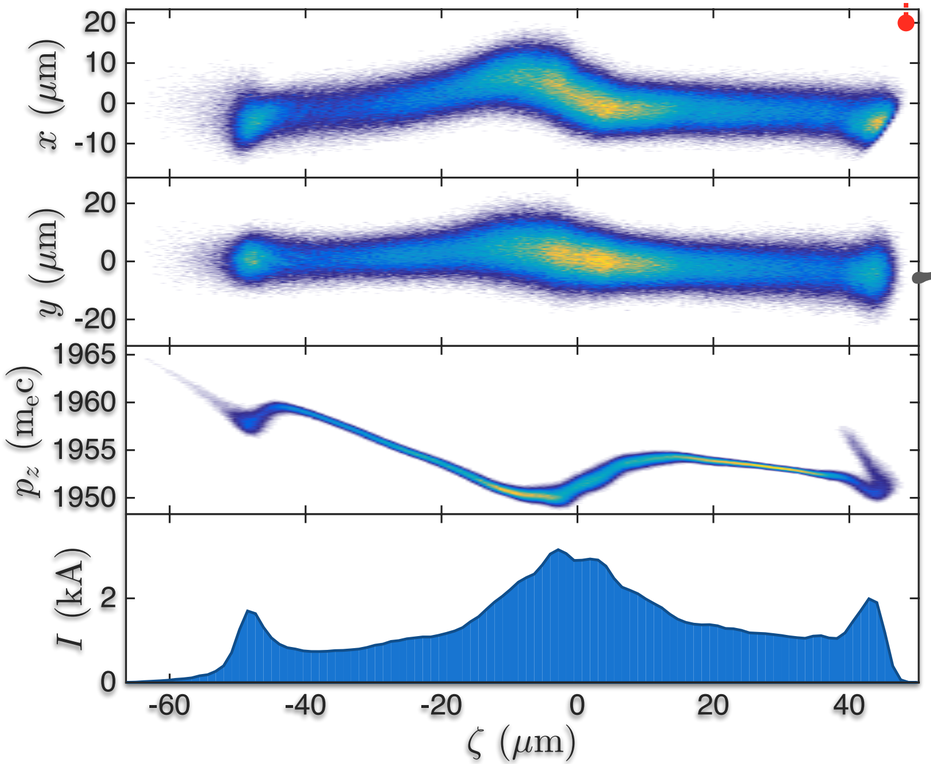
Photocathode: ASTRA → *Transport:* ELEGANT, CSRTRACK, GEANT4

FLASH linac + **FF**▸▸ extraction

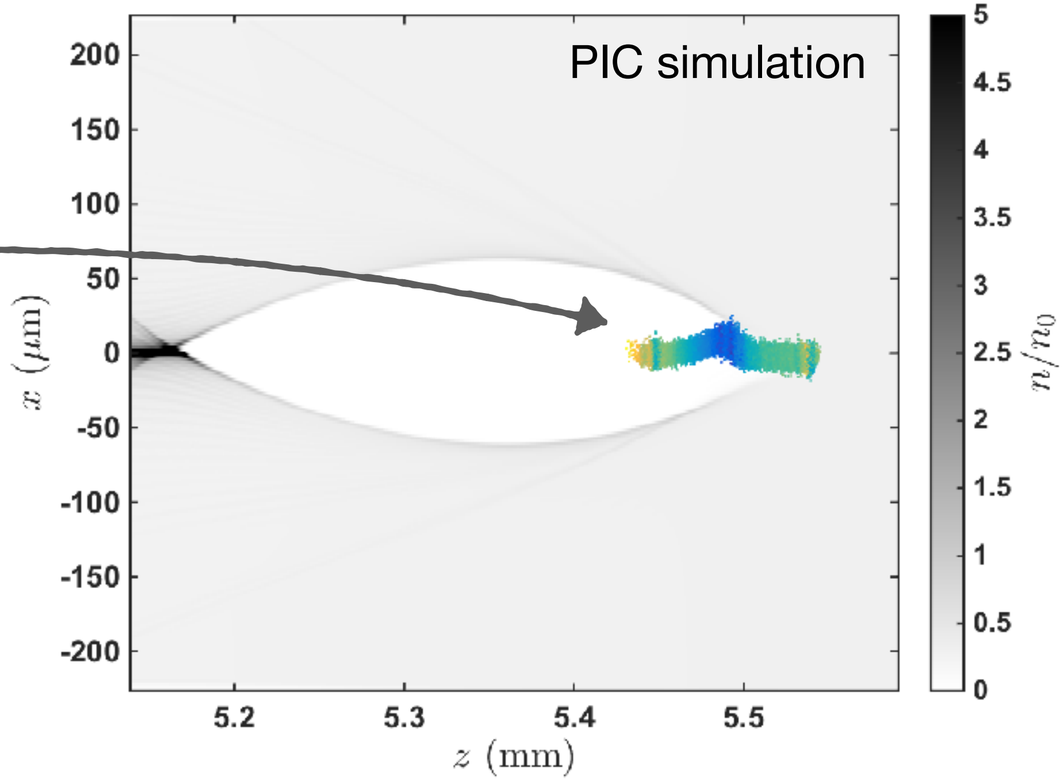
Plasma: OSIRIS, HiPACE

Transport and diagnostics: ELEGANT

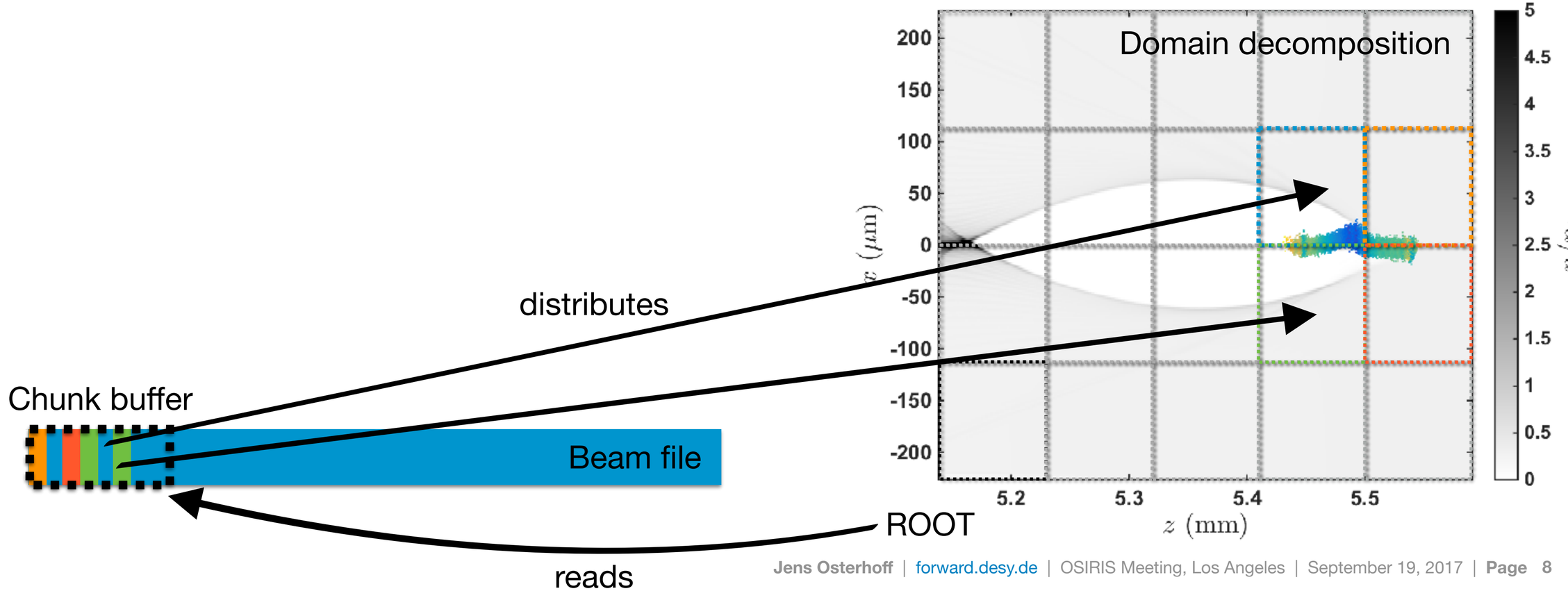
Undulator: GENESIS, PUFFIN



- New interface enables import of 6D beam data into OSIRIS 3.0
- Read in from text / HDF5 file implemented



Full start-to-end simulations implemented including CSR, space charge, and wakefield effects

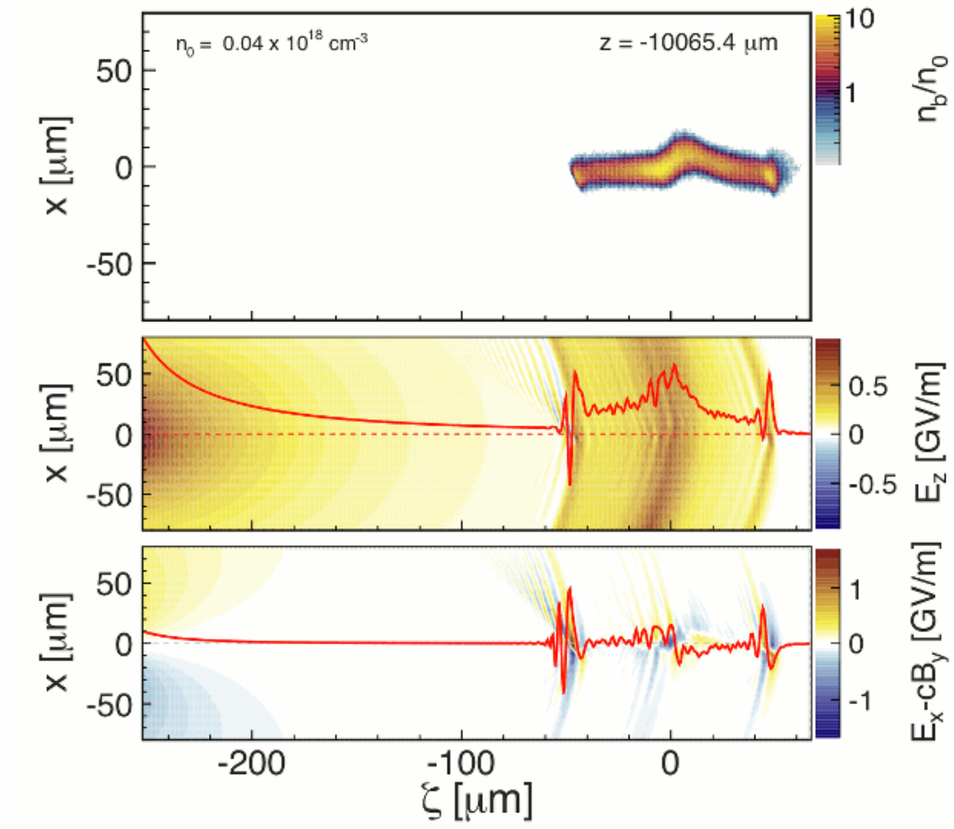


Full start-to-end simulations implemented including CSR, space charge, and wakefield effects

- Sophisticated start-to-end simulations for PWFA
- Hose instability may severely affect quality and stability of **low-emittance** beams
- Analysis and mitigation of hose-instability may be crucial for FLASHForward and FACET-II to reach next level of performance
- Continue work on hosing models/mitigation strategies: **T. Mehrling et al., Phys. Rev. Lett. 118,174801 (2017)**

- **Missing feature:** elegant initialization of self-consisted fields in 3D
- Standard PWFA beam initialization workaround being used so far

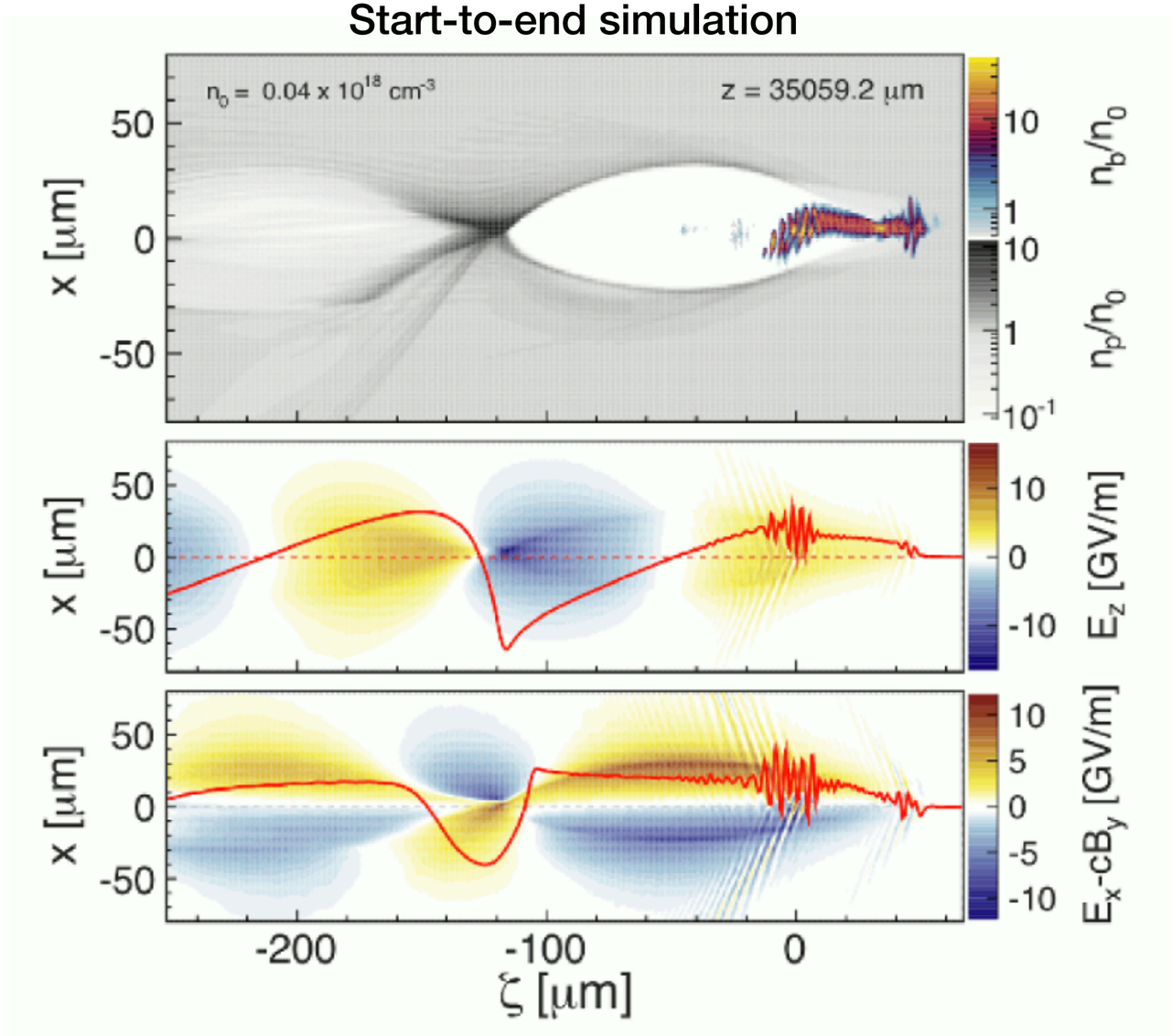
solved in OSIRIS 4.0



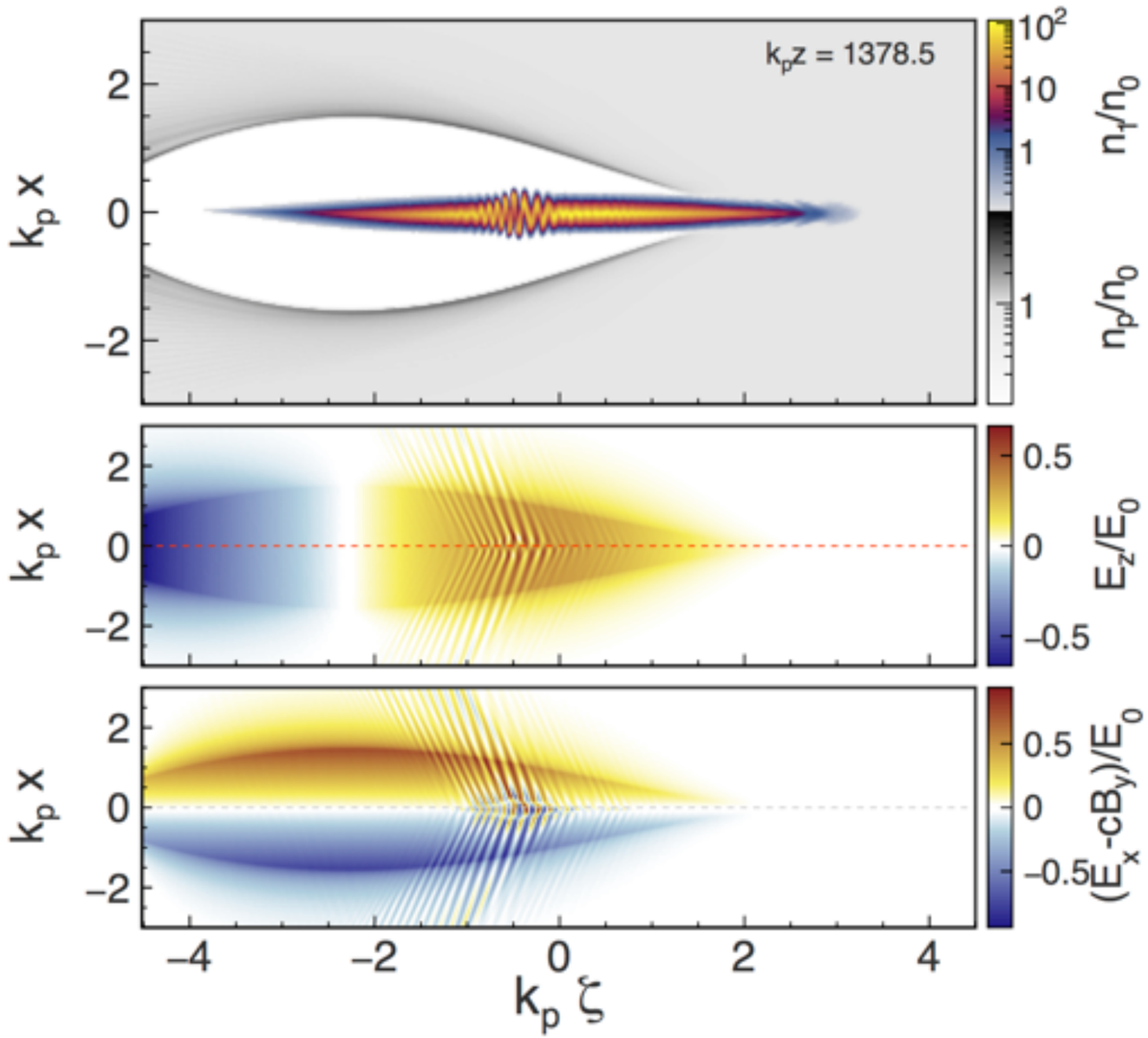
Numerical Cherenkov radiation needs careful treatment

PRONOUNCED EFFECT IN HIGH-CURRENT PWFA SIMULATIONS

Start-to-end simulation

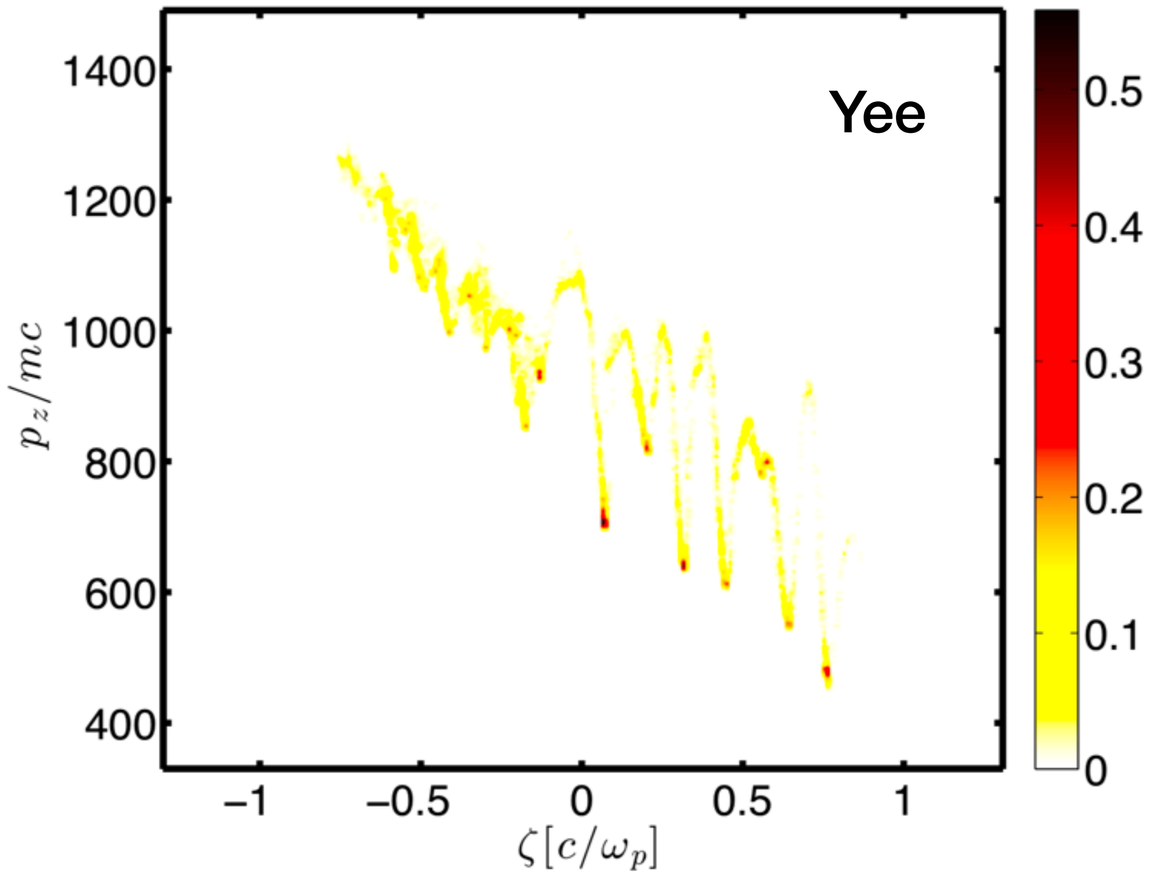


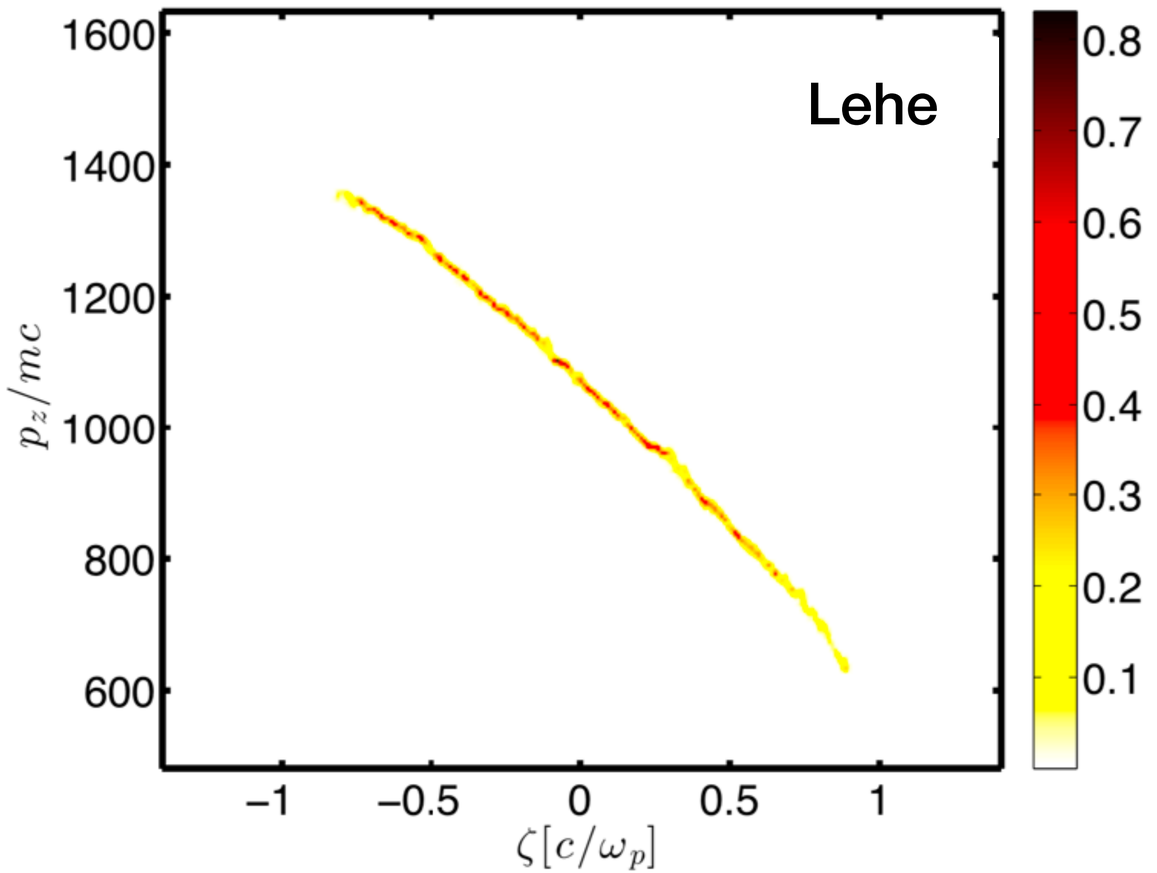
Idealized simulation



Numerical Cherenkov radiation needs careful treatment

Resulting bunch properties with Yee solver may show strong distortions





Numerical Cherenkov radiation needs careful treatment

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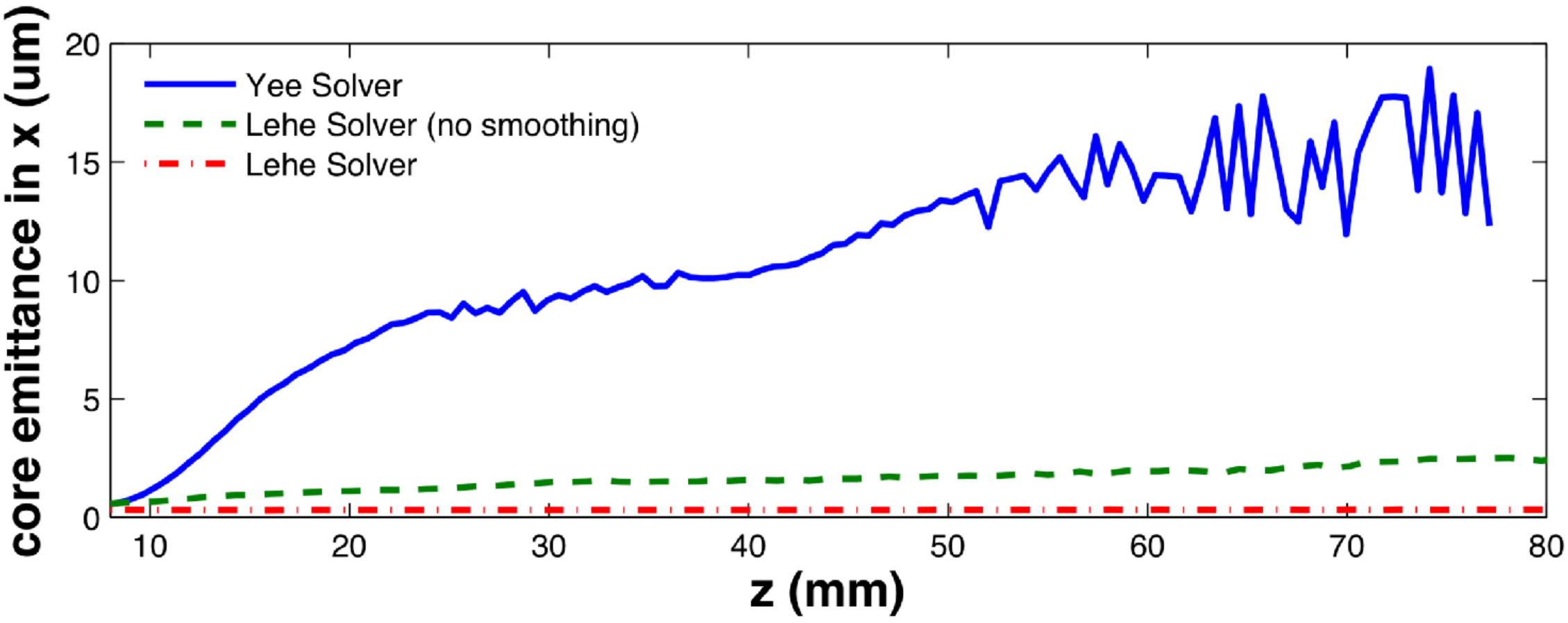

- Lehe solver yields more physical results than Yee (in this example), but has other issues (e.g. PML boundary conditions currently not working)
- Current workaround: start with OSIRIS (Yee or Lehe) and hand over to quasi-static code asap
- Need a full OSIRIS-based solution!

Summary

> **OSIRIS is an essential tool for the FLASHFORWARD▸▸ PWFA project at DESY (and beyond…)**
  - ~10 OSIRIS users at DESY
  - perform ~20 M core hour simulations per year (on JuQUEEN/JuROPA + local DESY cluster)

> **T. Mehrling has implemented an interface in OSIRIS 3.0 to read in arbitrary 6D phase-space distributions of beams**
  - more elegant initialization of self-consistent fields in 3D was missing / is implemented in OSIRIS 4.0

> **Numerical Cherenkov radiation needs satisfactory solution for high-fidelity LWFA and PWFA simulations**

A big thanks to the OSIRIS team!

OSIRIS has become an indispensable tool for all plasma-wakefield-related activities at DESY.

We would like to give back and help to improve it in the future.

Thank you for listening!