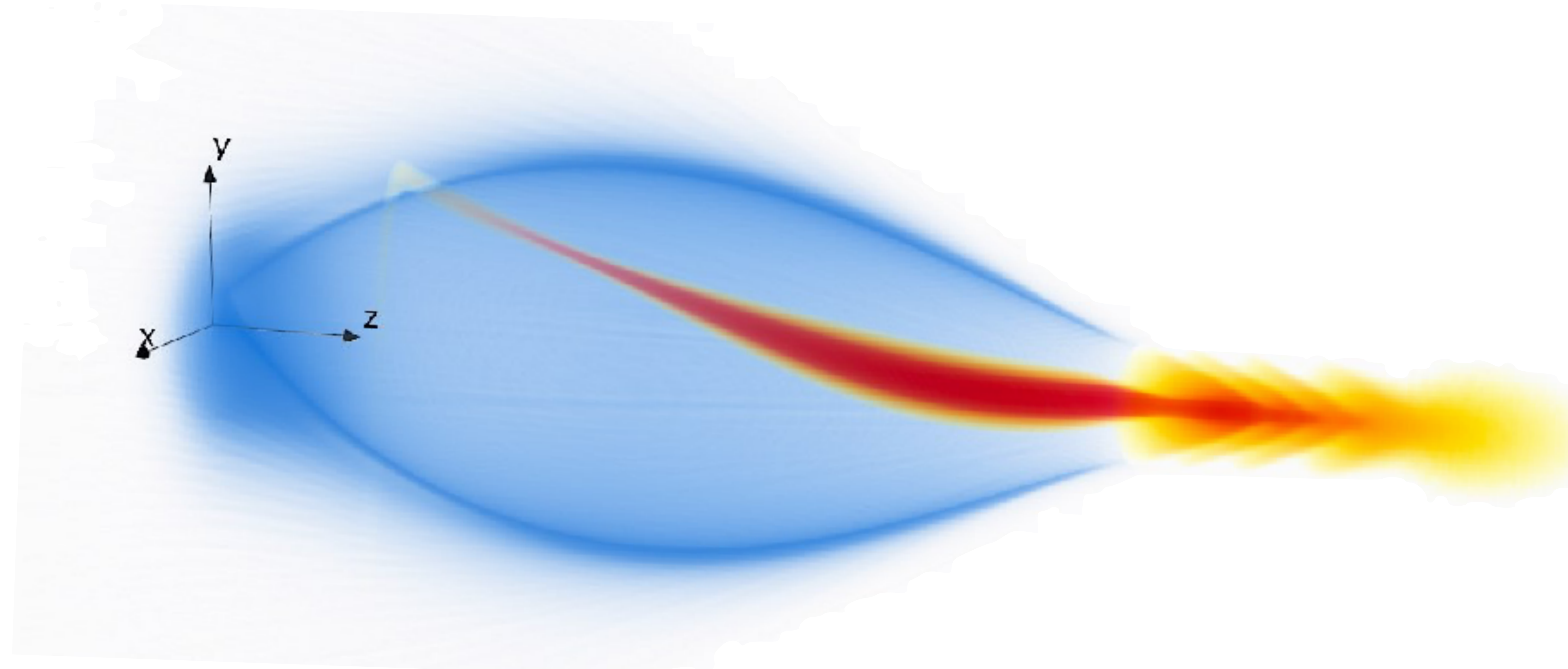
Beschleuniger-Betriebsseminar
Travemünde | February 20th, 2018



FLASHForward▸▸

Progress and plans for beam-driven plasma accelerator research at FLASH

Jens Osterhoff

Research Group for Plasma Wakefield Accelerators
Deutsches Elektronen-Synchrotron DESY, Particle Physics Division, Hamburg, Germany

Accelerator Research and Development, Matter and Technologies
Helmholtz Association of German Research Centres, Berlin, Germany

FLASHForward▸▸ contributors

> Core FLASHForward team

Engineers and technicians

Maik Dinter
Sven Karstensen
Kai Ludwig
Frank Marutzky
Amir Rahali
Andrej Schleiermacher

Postdocs

Gregory Boyle
Theresa Brümmer
Alexander Knetsch
Peng Kuang
Vladyslav Libov
Alberto Martinez de la Ossa
Zeng Ming
Pardis Niknejadi
Kristjan Põder
Lucas Schaper
Stephan Wesch

Scientists

Richard D'Arcy
Jens Osterhoff
Bernhard Schmidt

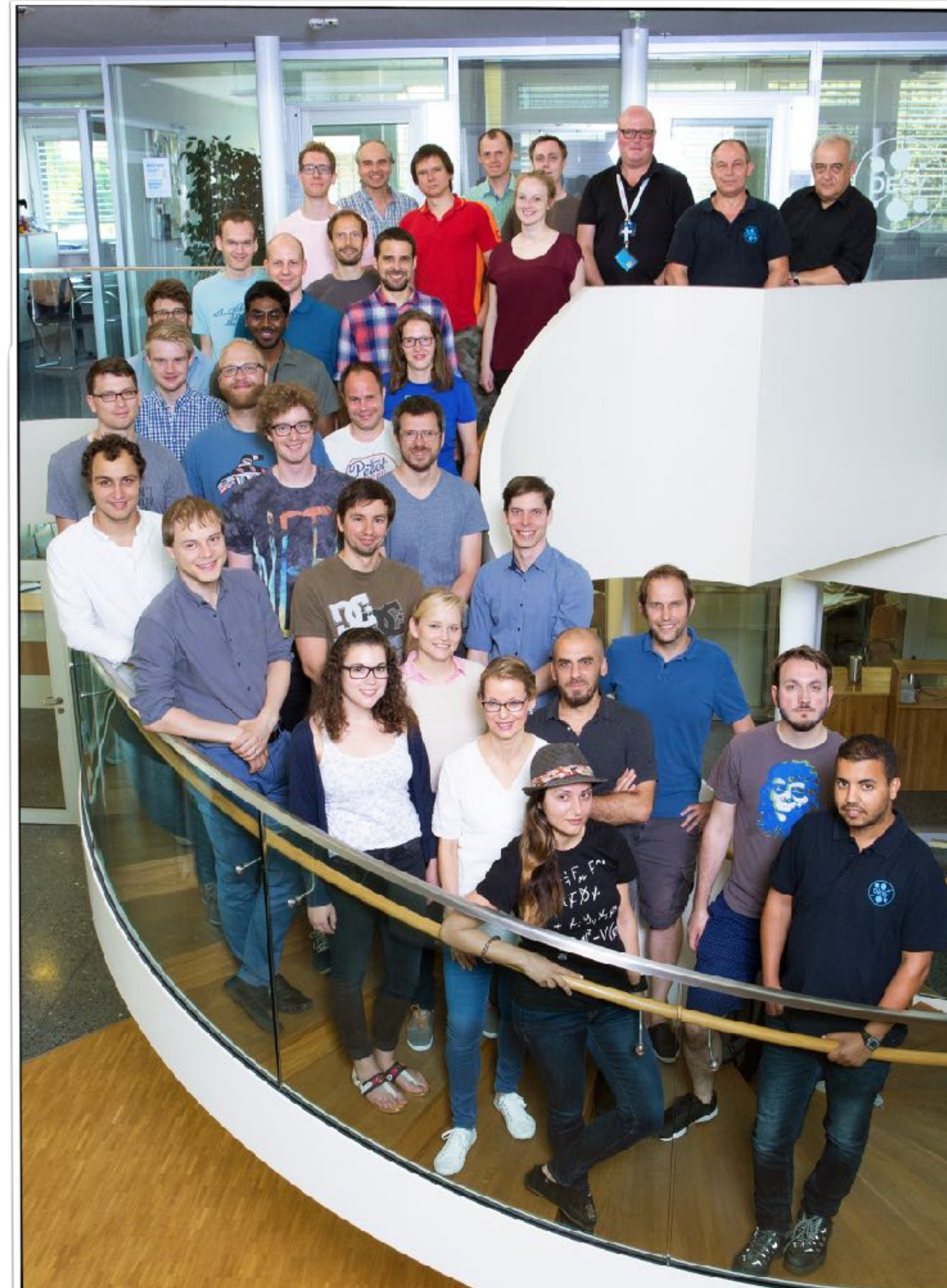
PhD students

Alexander Aschikhin
Simon Bohlen
Lars Goldberg
Pau Gonzalez
Jan-Hendrik Röckemann
Sarah Schröder
Jan-Patrick Schwinkendorf
Bridget Sheeran
Gabriele Tauscher
Paul Winkler

Students

Severin Diederichs
Artemis Kontogoula
Martin Meisel
Paul Pourmoussavi
Martin Quast
Arathi Ramesh

> The DESY engineering & technical groups



FLASHFORWARD▸▸ collaboration partners

Helmholtz

HZDR

HELMHOLTZ
Helmholtz-Institut Jena

Networks

MT ARD

HELMHOLTZ ASSOCIATION
VIRTUAL INSTITUTE
VH-VI-503

EuPRAXIA

Universities

National labs

BERKELEY LAB

BROOKHAVEN NATIONAL LABORATORY

SLAC

PAUL SCHERRER INSTITUT PSI

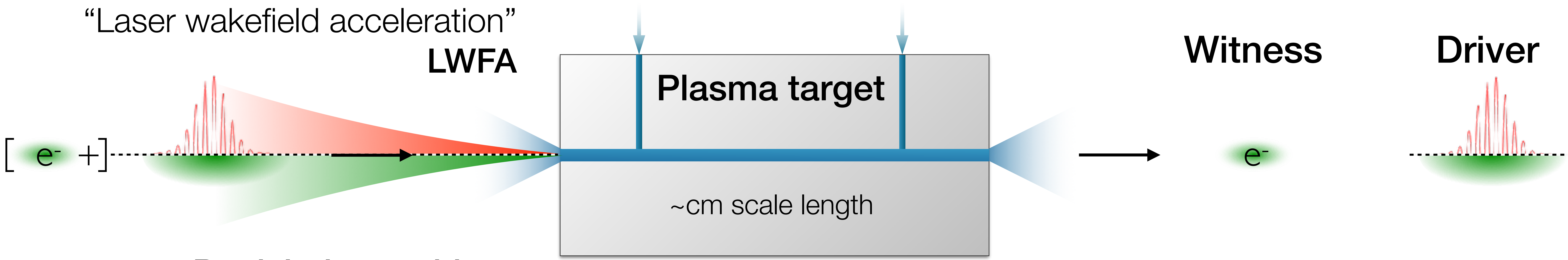
CERN

Science & Technology Facilities Council

eli beamlines

Plasma wakefield acceleration in a nutshell

Laser-pulse driven
"Laser wakefield acceleration"
LWFA



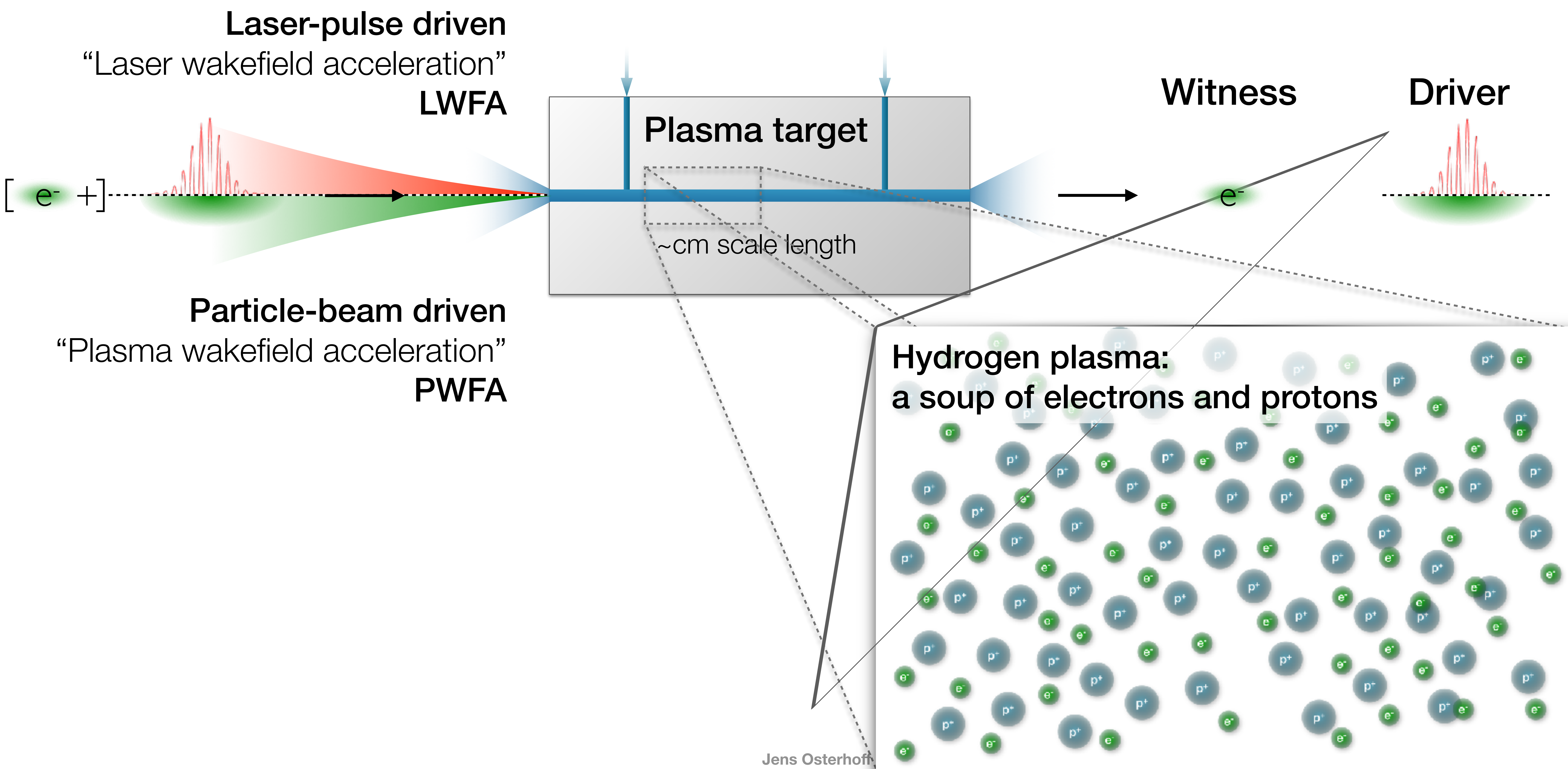
Particle-beam driven
"Plasma wakefield acceleration"

PWFA vs. LWFA

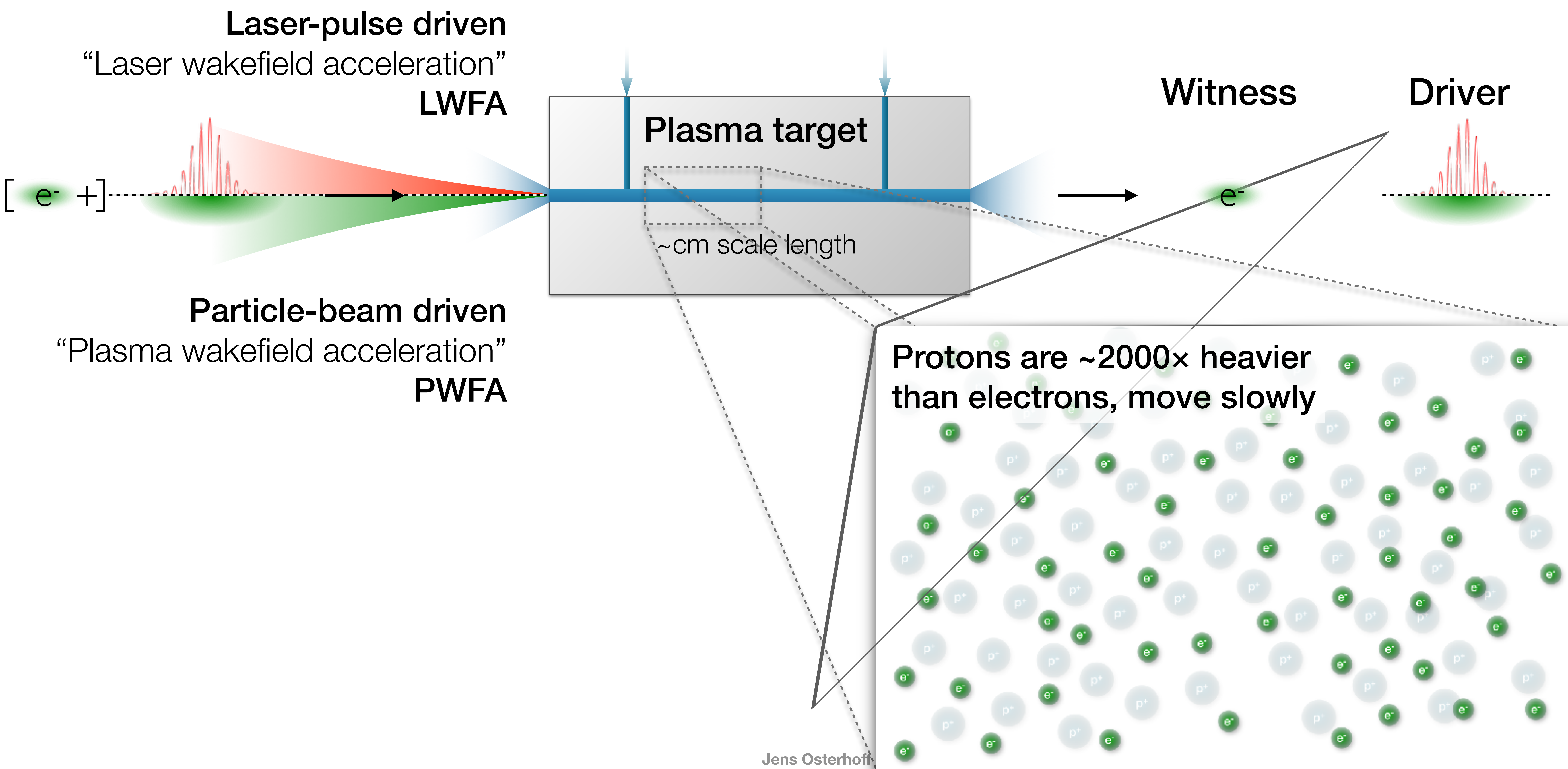
- average power of up to MW (vs. ~100 W)
- wall-plug efficiency of ~10% (vs. < 0.1%)

→ beam-driven wakes (currently) the only viable solution for high-average-power applications

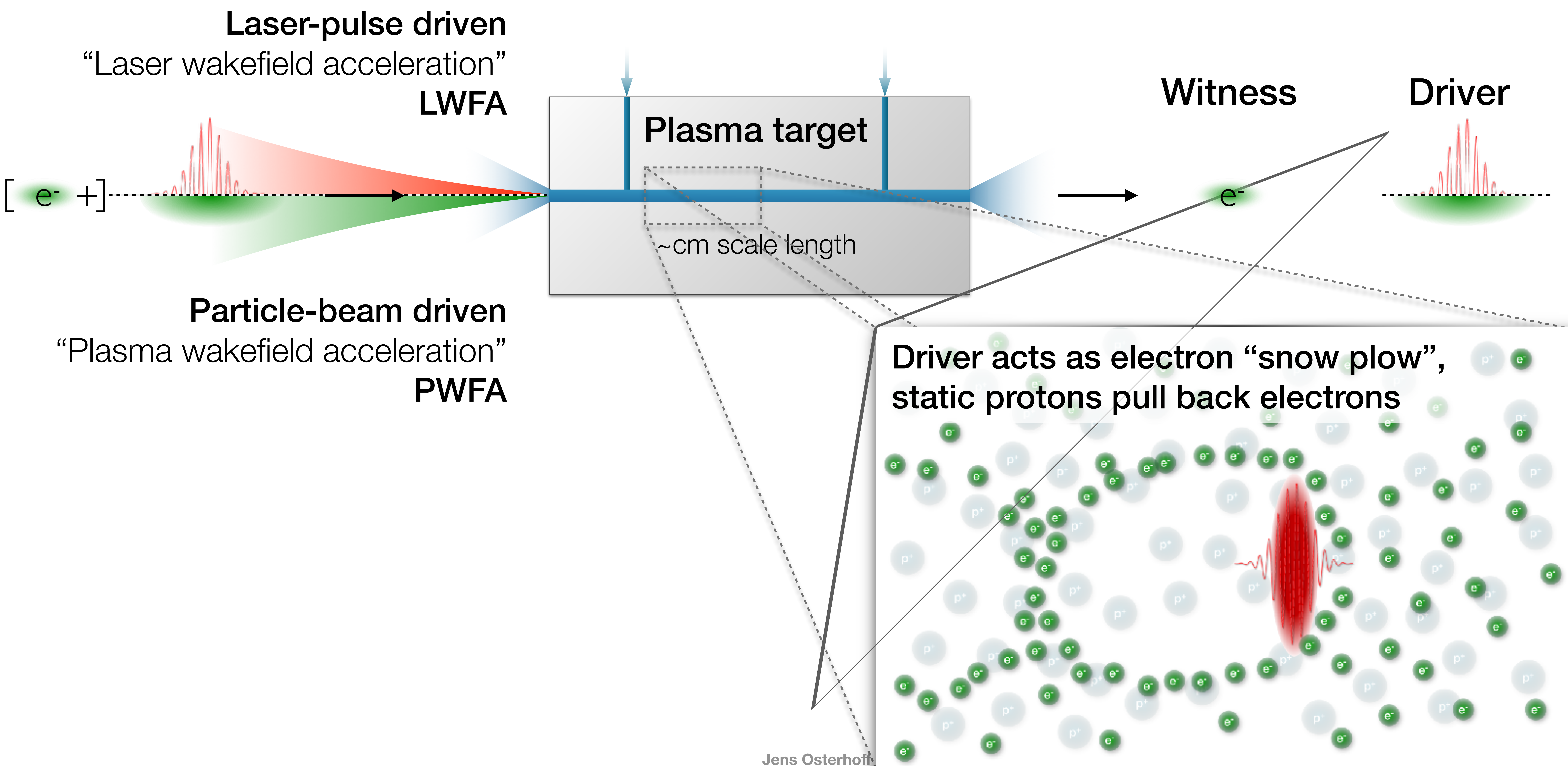
Plasma wakefield acceleration in a nutshell



Plasma wakefield acceleration in a nutshell



Plasma wakefield acceleration in a nutshell



Jens Osterhoff

Plasma wakefield acceleration ir

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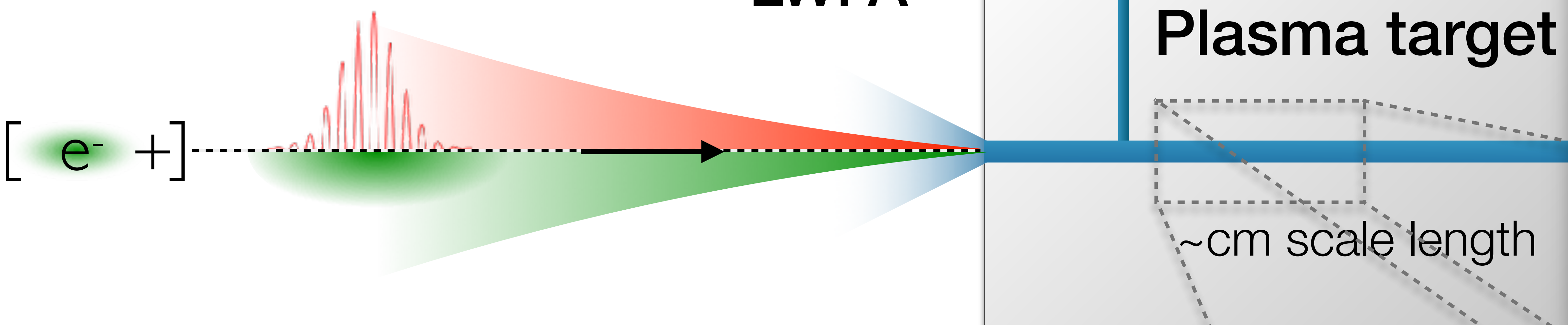

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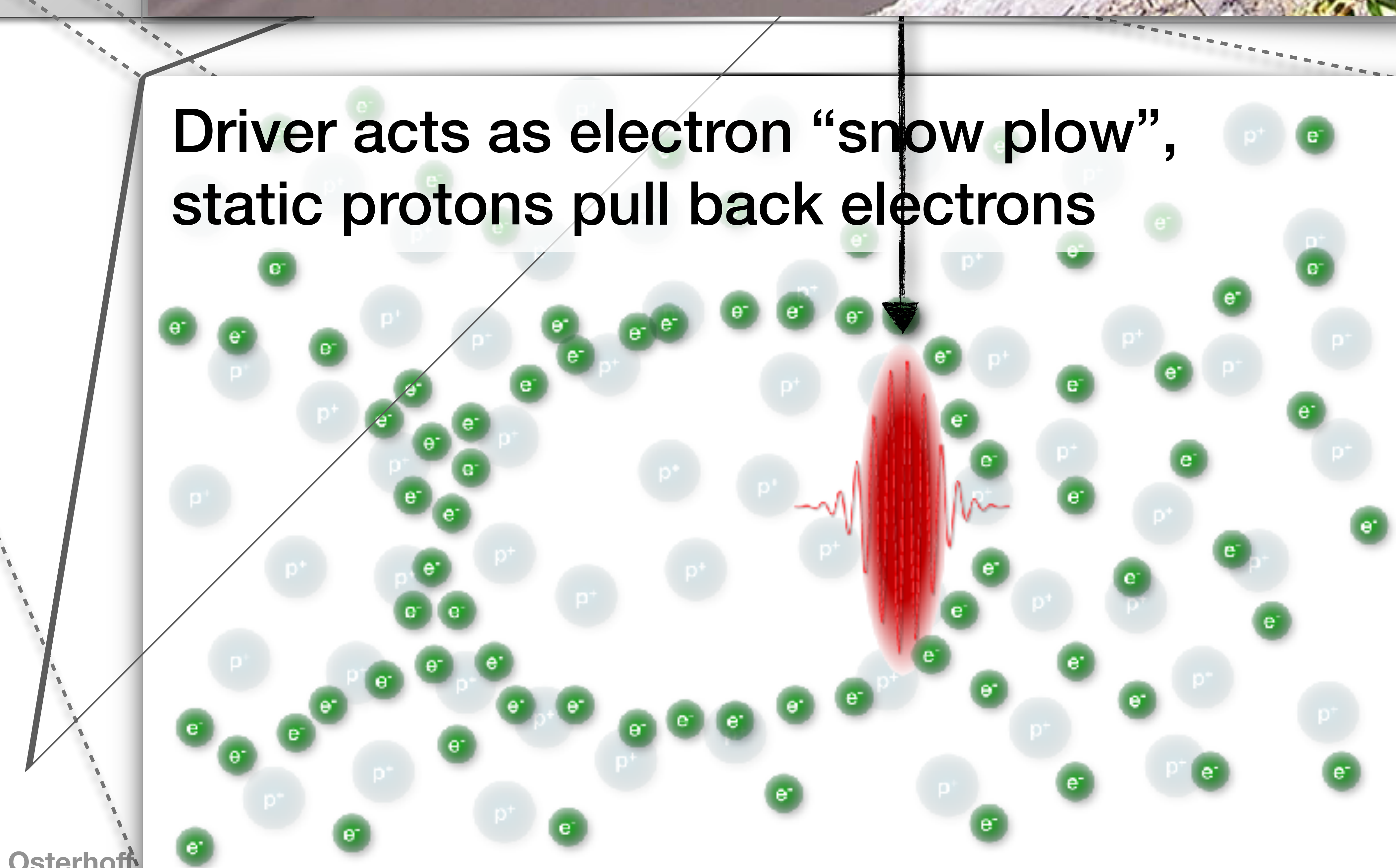
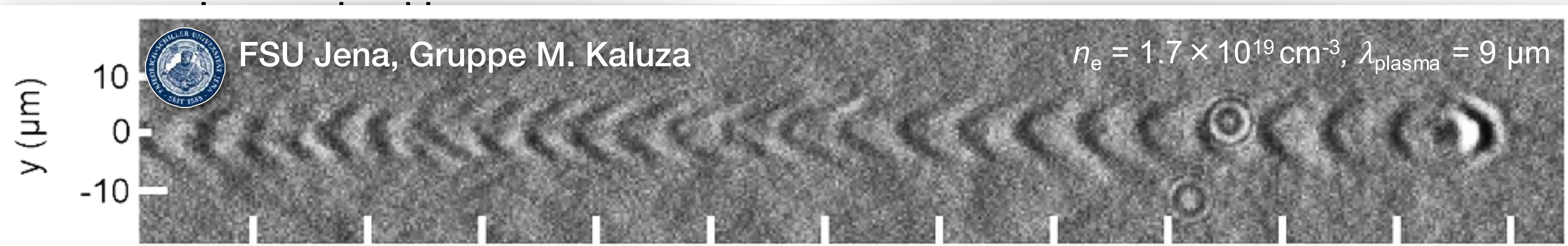


Plasma wakefield acceleration in a nutshell



M. Schnell *et al.*, Nat. Comm. 4, 2421 (2013)

Particle-beam driven
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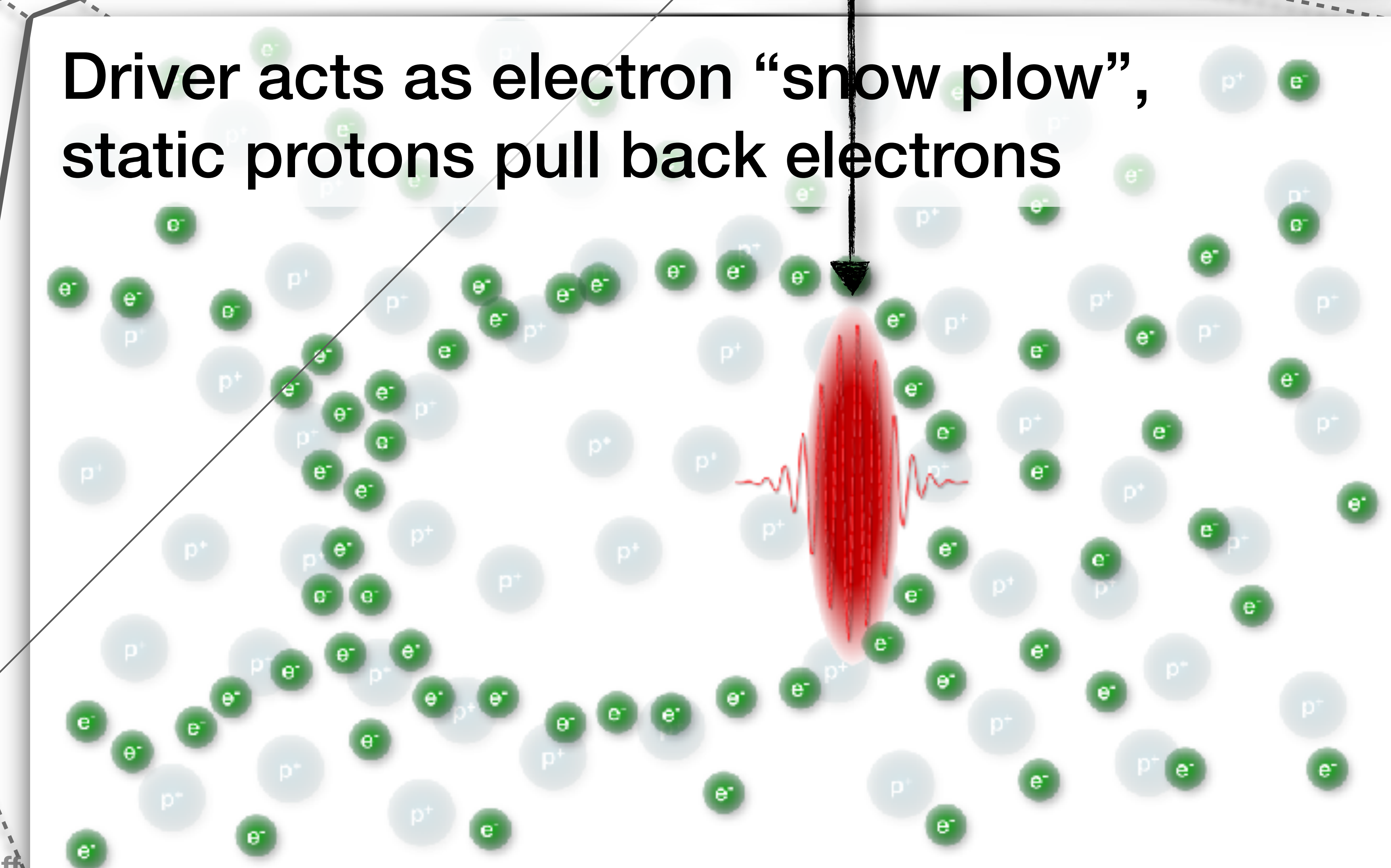
PWFA

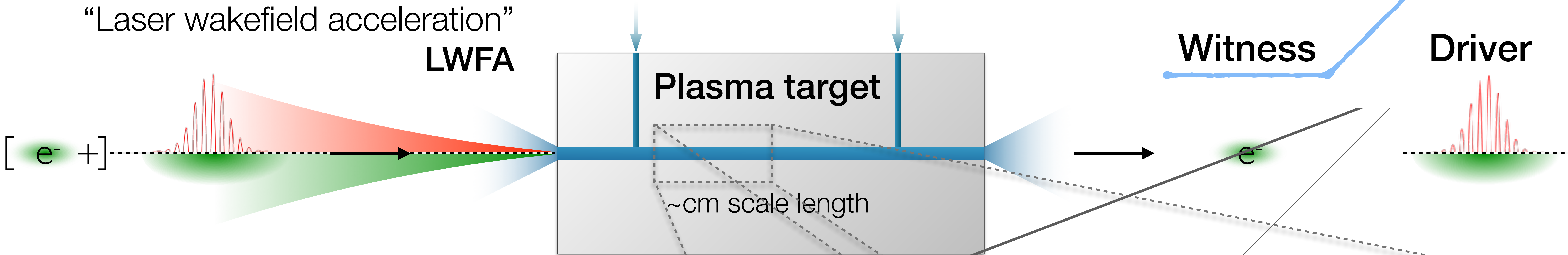


Plasma wakefield acceleration in a nutshell

Interesting for applications

~GeV energy < µm emittance
~fs duration ~kA current

Laser-pulse driven
"Laser wakefield acceleration"
LWFA



Particle-beam driven
"Plasma wakefield acceleration"
PWFA

Bunch duration: fs

→ O. Lundh *et al.*, Nature Physics 7, 219 (2011)

→ A. Buck *et al.*, Nature Physics 7, 543 (2011)

GeV energy gain over cm

→ W.P. Leemans *et al.*, Nature Physics 2, 696 (2006)

Size of structure

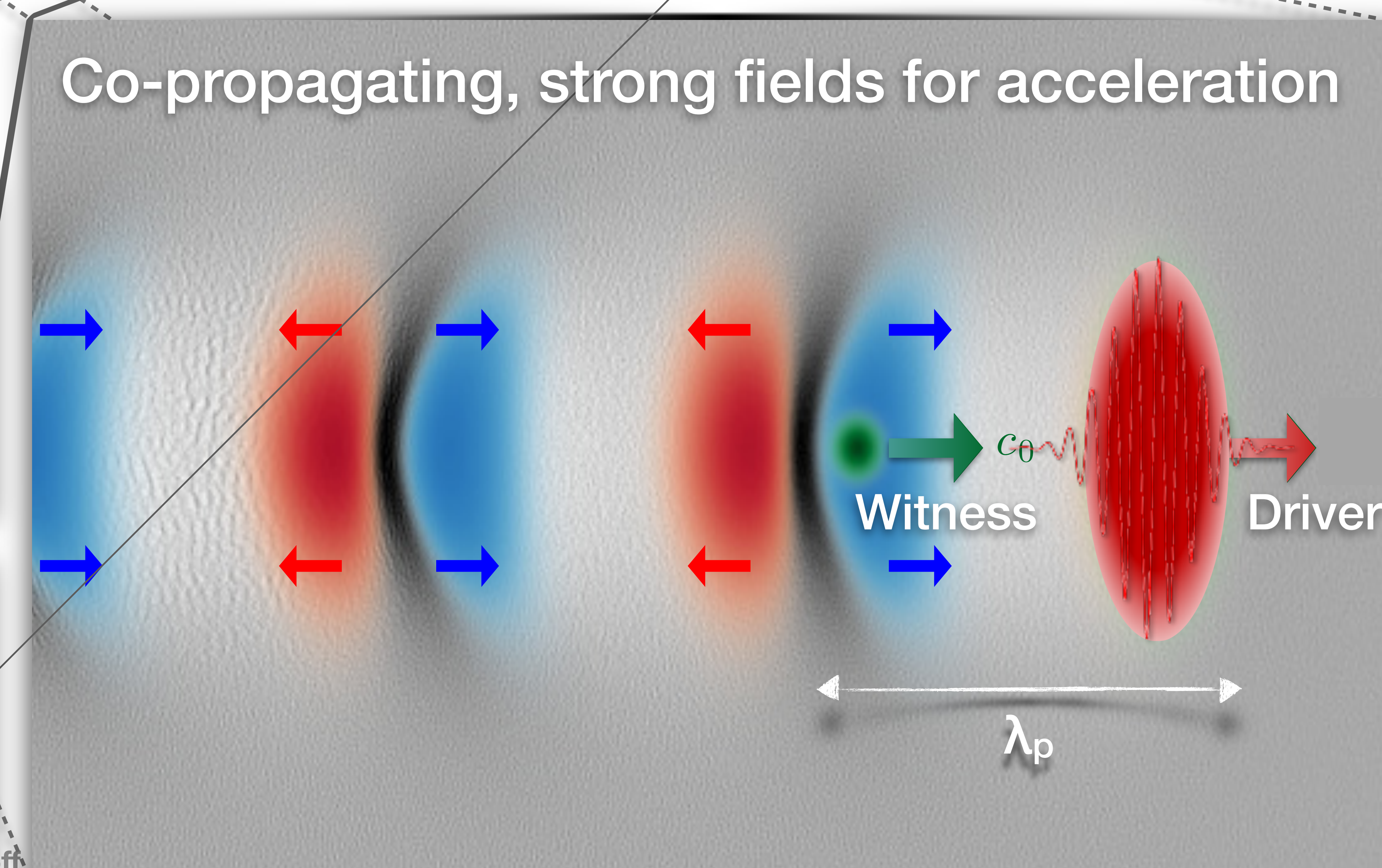
$$\lambda_p \approx \frac{2\pi c}{\omega_p} \approx (33\ \mathrm{km})\sqrt{n_e^{-1}[\mathrm{cm}^{-3}]}$$

typically $\lambda_p \approx 100\ \mu m$ (for $n_e \approx 10^{17}\ cm^{-3}$)

Electric field strength

$$E \approx \frac{mc\omega_p}{e} \approx (96\ \mathrm{V/m})\sqrt{n_e[\mathrm{cm}^{-3}]}$$

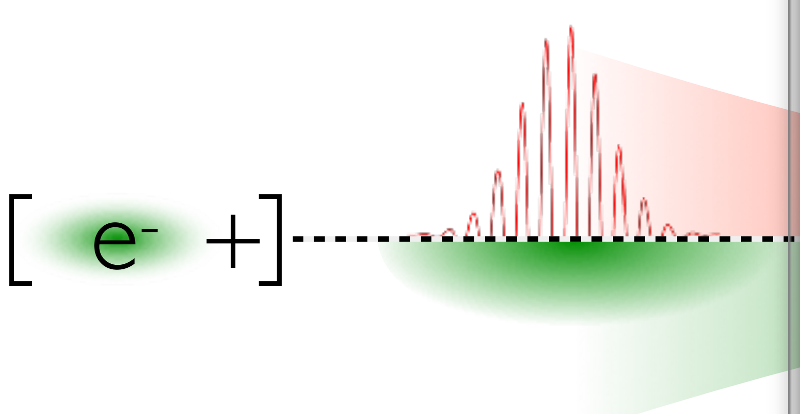
typically $E \approx 33\ GV/m$ (for $n_e \approx 10^{17}\ cm^{-3}$)



Plasma w ell

Lase

“Laser wakefiel



Interesting for applications

~GeV energy < μm emittance
~fs duration ~kA current

Witness **Driver**

Particle-beam driven

“Plasma wakefield acceleration”

PWFA

Bunch duration: fs

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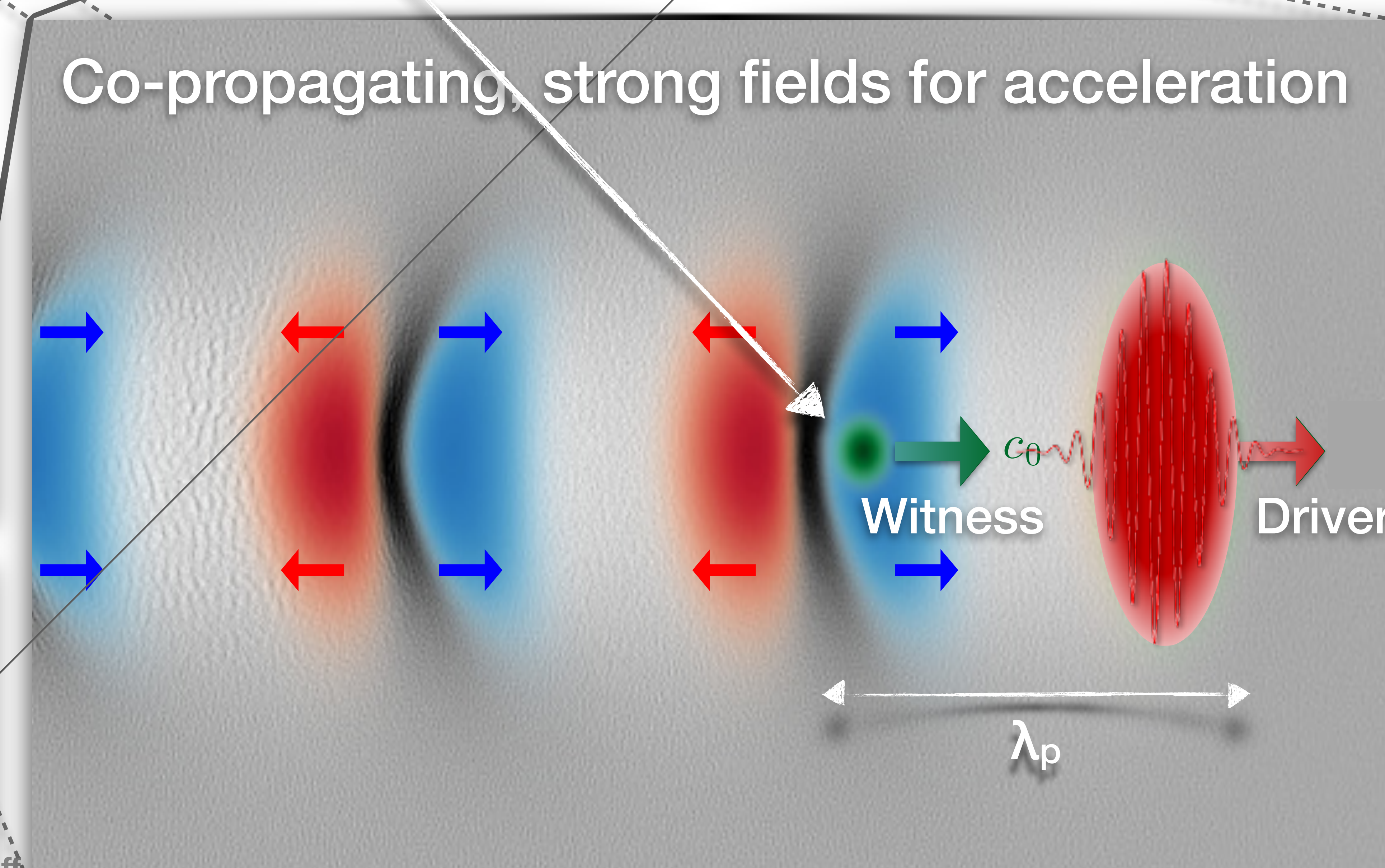
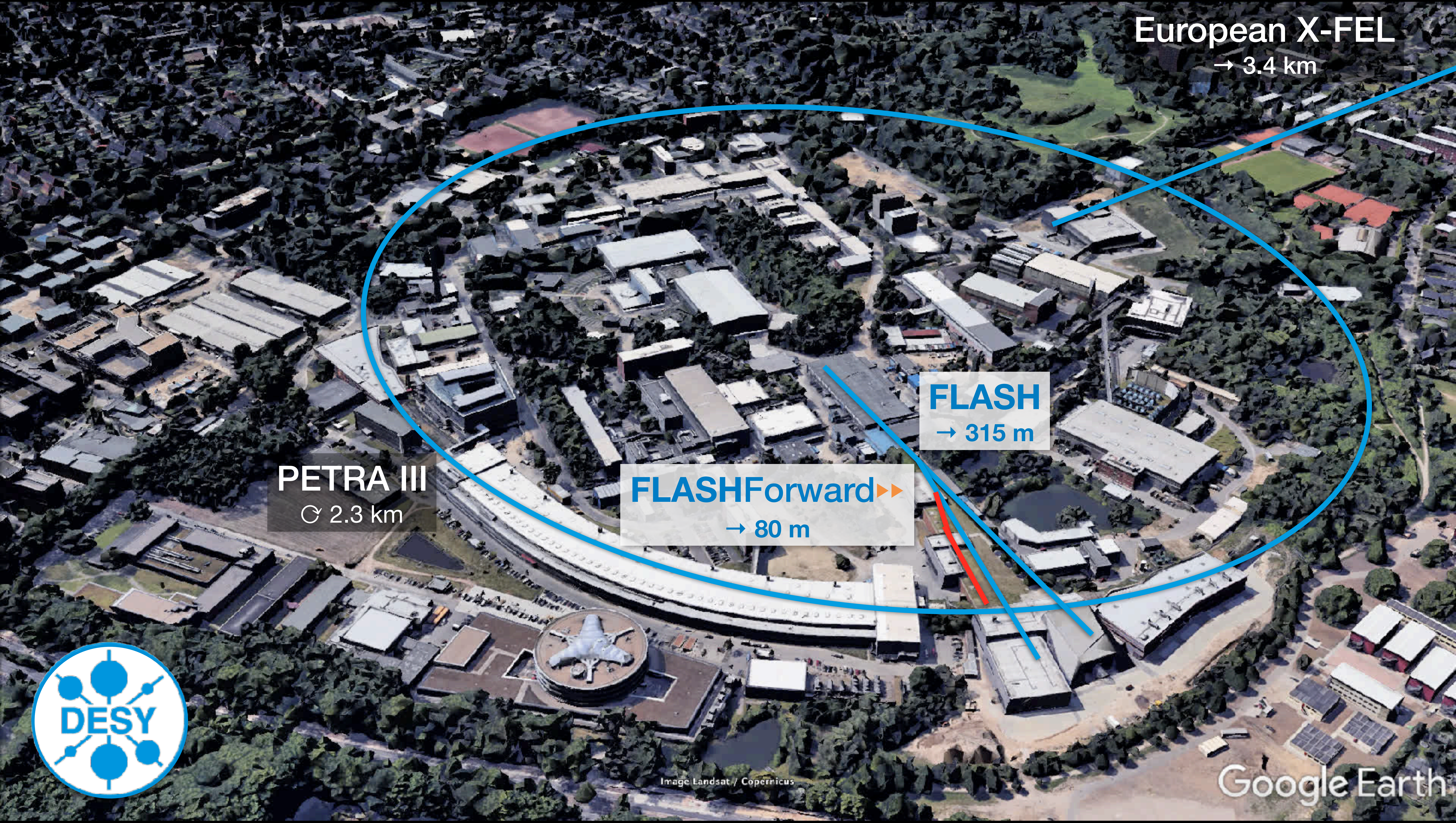
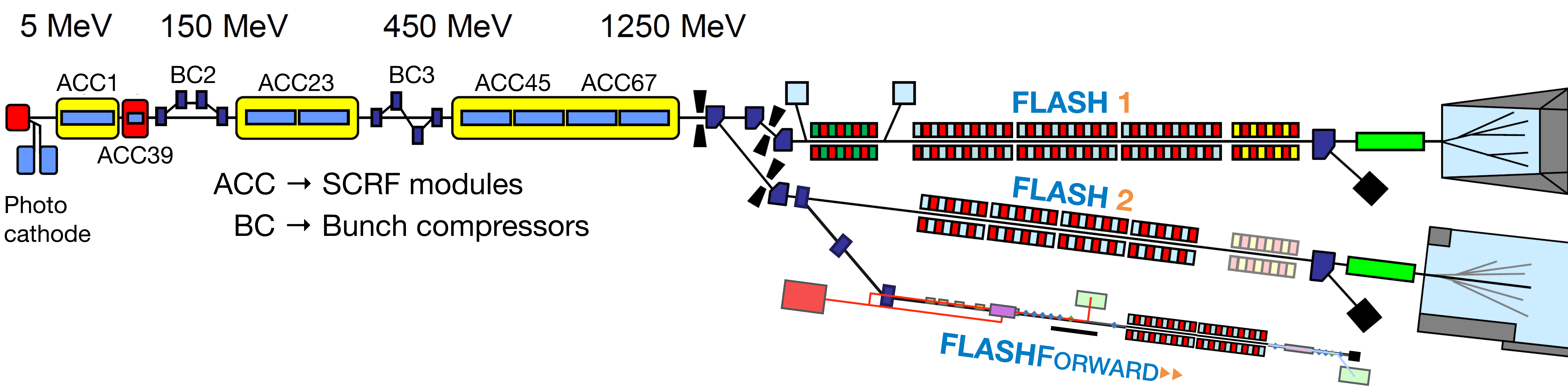



European X-FEL
→ 3.4 km
FLASH
→ 315 m
PETRA III
2.3 km
FLASHForward
→ 80 m
DESY
Image Landsat / Copernicus
Google Earth

FLASH drives free-electron laser and accelerator research

SUPERCONDUCTING SYSTEM FEEDS MULTIPLE BEAM LINES SIMULTANEOUSLY



> **FLASH** is an FEL user facility

> **FLASHForward▸▸** is a beam line for PWFA research

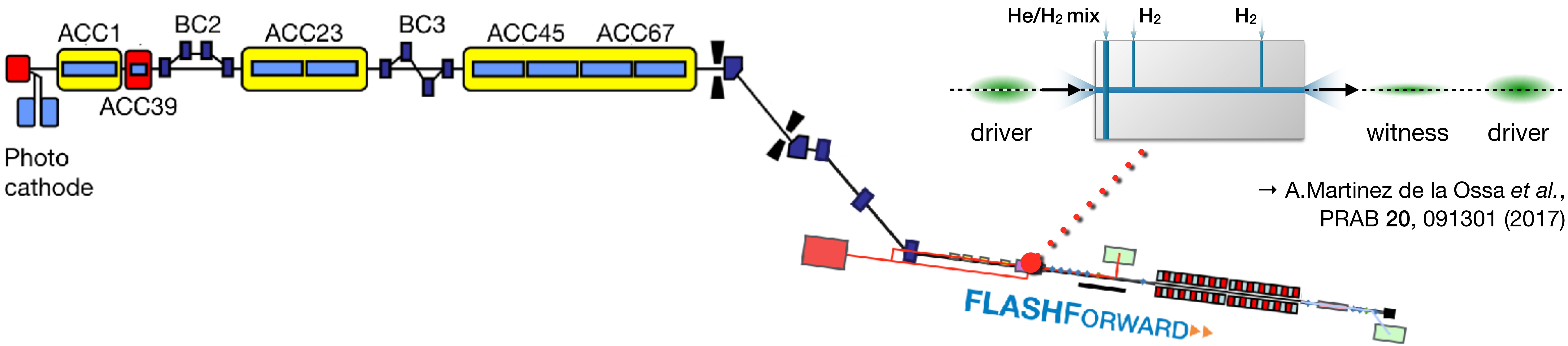
> **Both share the same superconducting accelerator front-end. Typical electron beam parameters:**

- ≲ 1.25 GeV energy with a few 100 pC at ~100 fs rms bunch duration
- ~2 μm trans. norm. emittance
- up to 800 bunches (≲ MHz spacing) at 10 Hz macro-pulse repetition rate, up to 30 kW average beam power

FLASHFORWARD

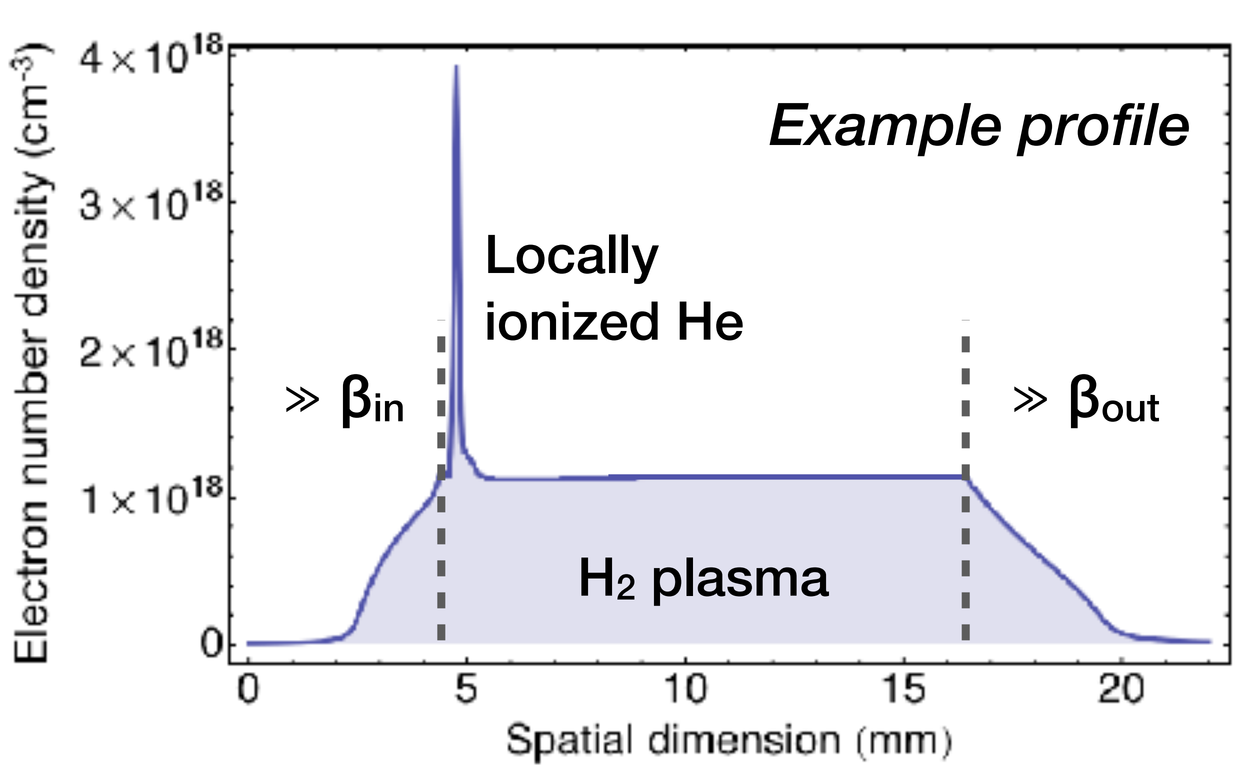
MAIN GOALS: HIGH BEAM BRIGHTNESS

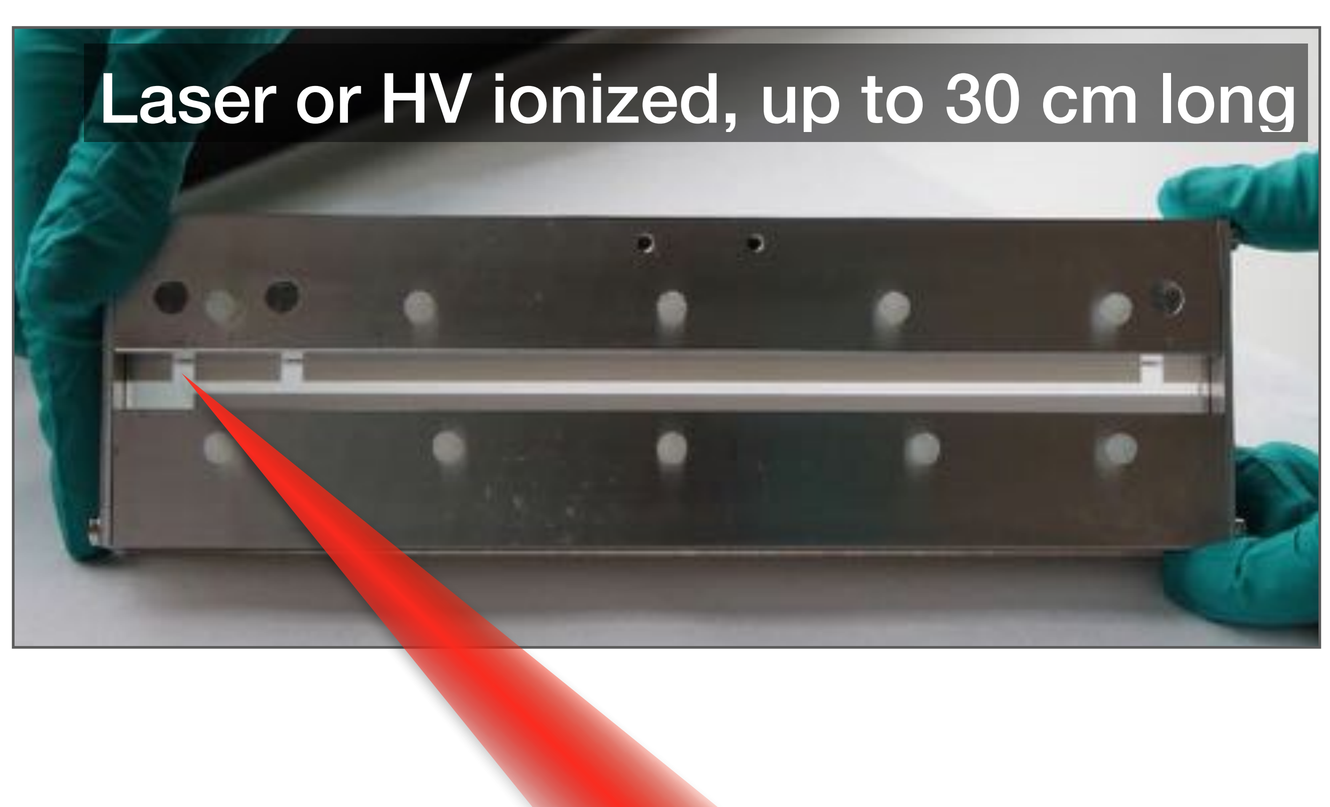
X-1 **Plasma Cathode**
- **PI:** A. Knetsch (DESY)



→ A.Martinez de la Ossa *et al.*, PRAB **20**, 091301 (2017)

- **X-1 Plasma Cathode:** beam-brightness converter (→ photon science)
  > 1.25 GeV energy, trans. norm. emittance ~100 nm, current ≳ 1 kA, ~fs bunch duration

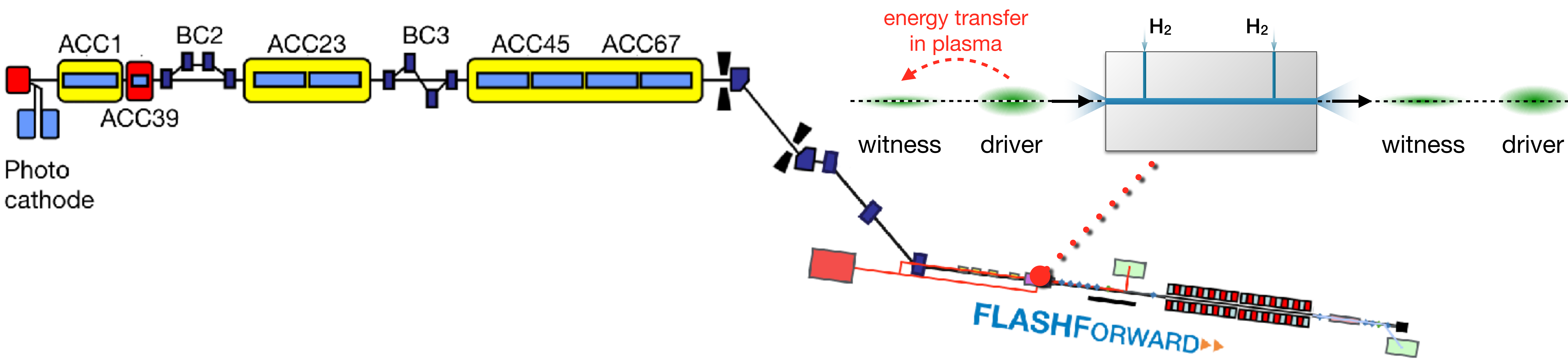




FLASHFORWARD▸▸

MAIN GOALS: HIGH BEAM ENERGY

X-2 Plasma Booster
- **PI:** V. Libov (U Hamburg)

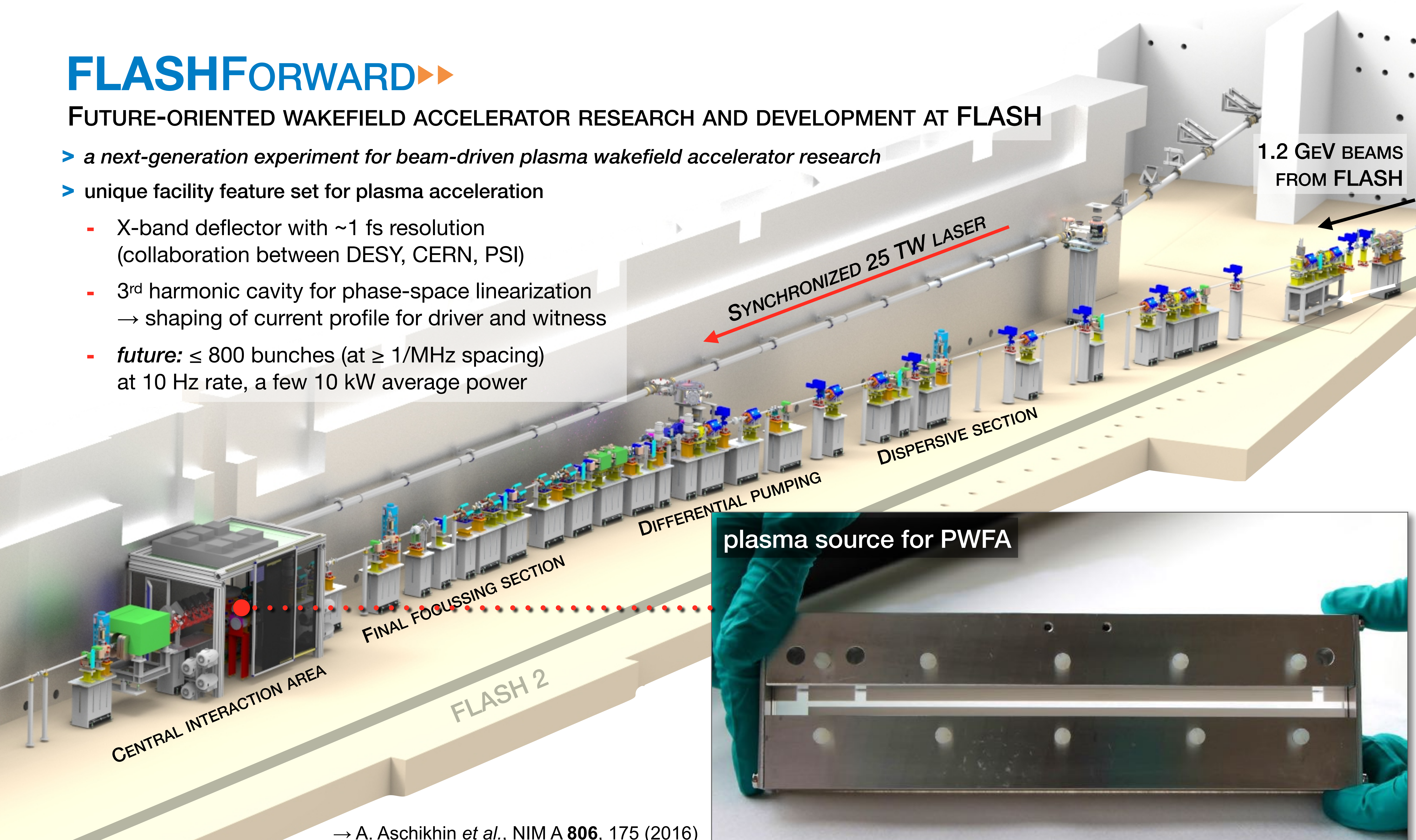


> **X-2 Plasma Booster:** post acceleration (→ photon science + high-energy physics)
energy doubling, energy spread & emittance preservation, drive depletion (> 10% efficiency)

FLASHFORWARD▸▸

FUTURE-ORIENTED WAKEFIELD ACCELERATOR RESEARCH AND DEVELOPMENT AT FLASH

- *a next-generation experiment for beam-driven plasma wakefield accelerator research*
- unique facility feature set for plasma acceleration
  - X-band deflector with ~1 fs resolution (collaboration between DESY, CERN, PSI)
  - 3rd harmonic cavity for phase-space linearization → shaping of current profile for driver and witness
  - *future:* ≤ 800 bunches (at ≥ 1/MHz spacing) at 10 Hz rate, a few 10 kW average power

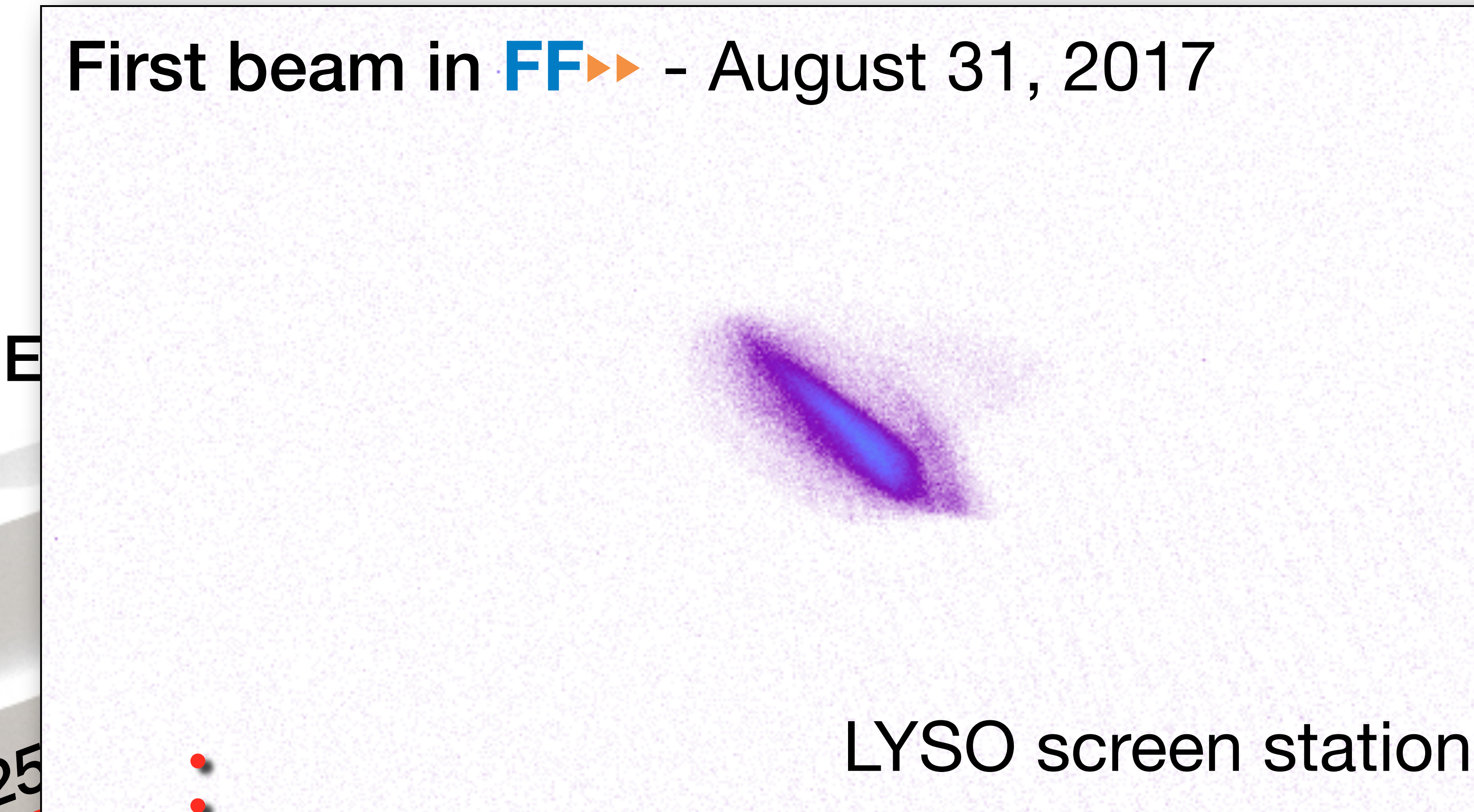


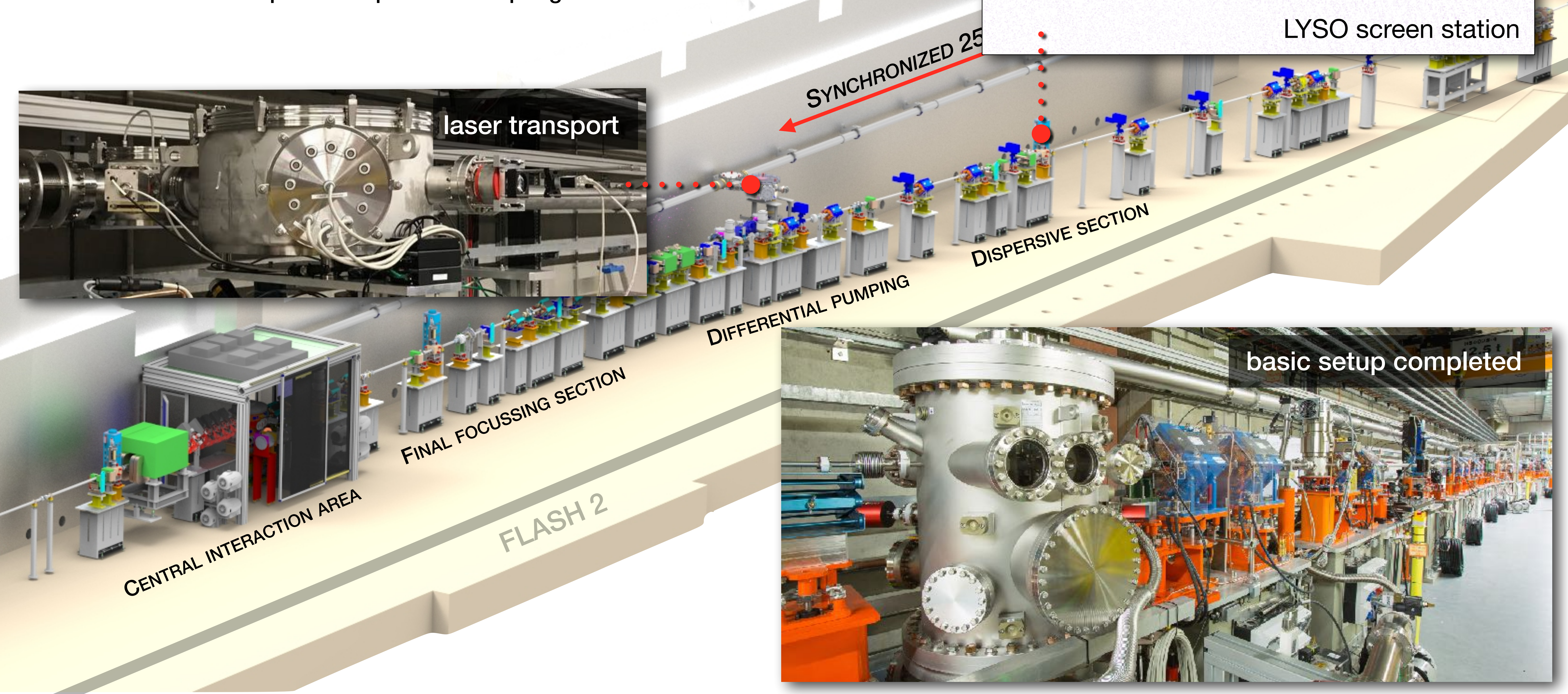
→ A. Aschikhin *et al.*, NIM A **806**, 175 (2016)

FLASHFORWARD▸▸

FUTURE-ORIENTED WAKEFIELD ACCELERATOR RESEARCH AND DEVELOPME

- beamline hardware installation ready for experiments
- commissioning to be concluded soon,
  first studies with plasma expected this spring

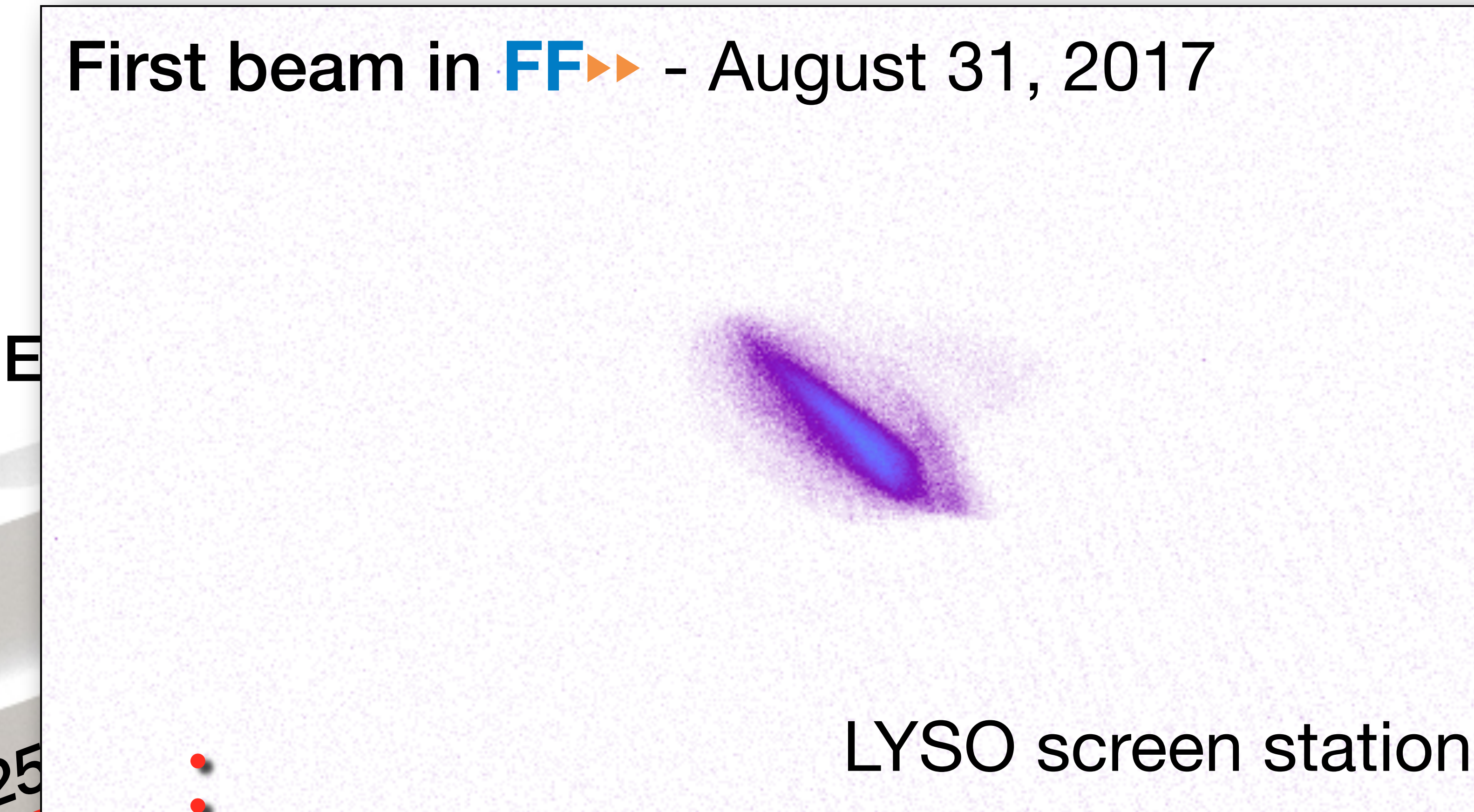


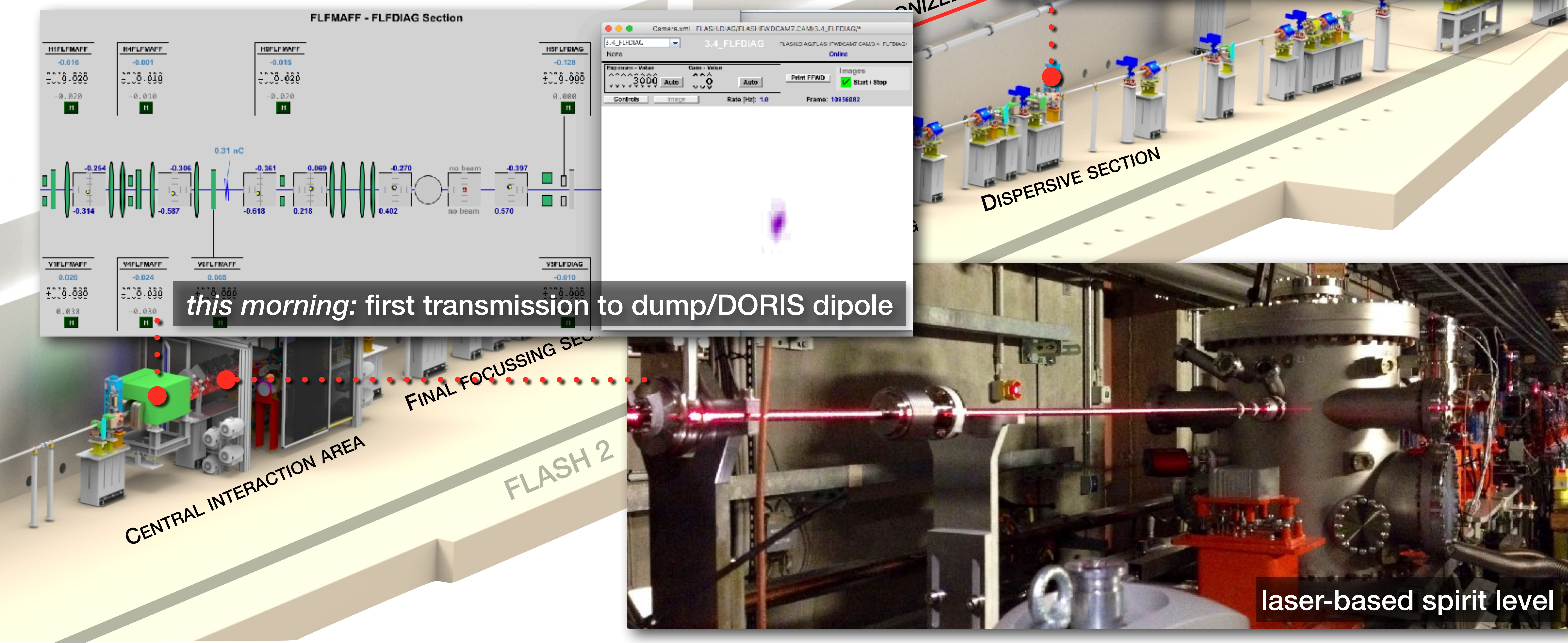


FLASHForward▸▸

Future-oriented wakefield accelerator research and developme[nt]

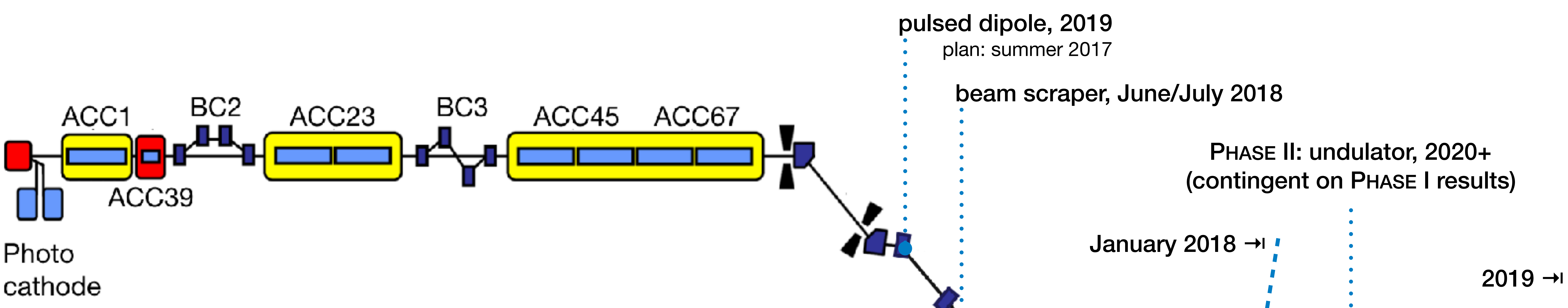
- recent struggles with elastically bent beam pipe (⌀ 10 mm) in two locations
- corrected alignment last week with “laser spirit level”
  → thanks to MEA and MVS for support!
- transmission to DORIS dipole achieved this morning

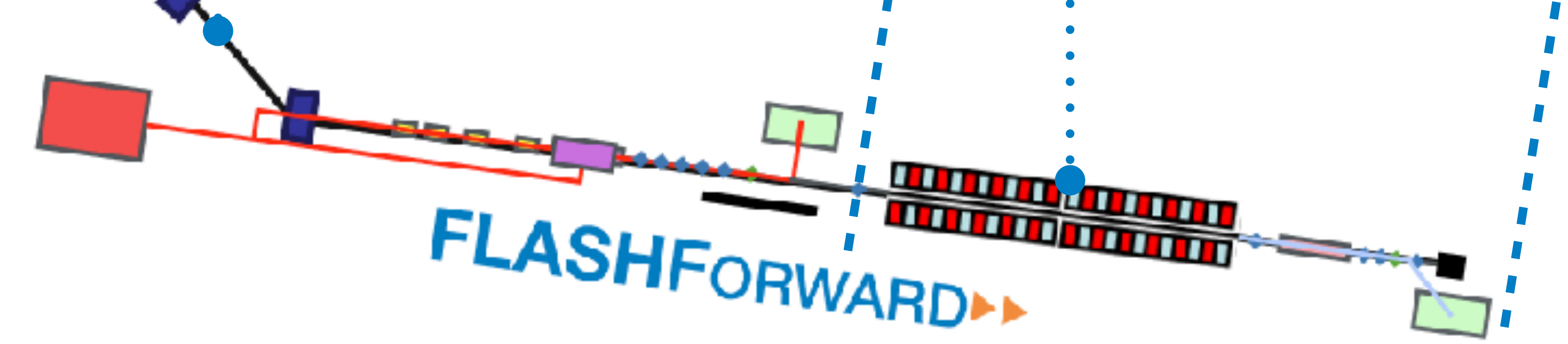




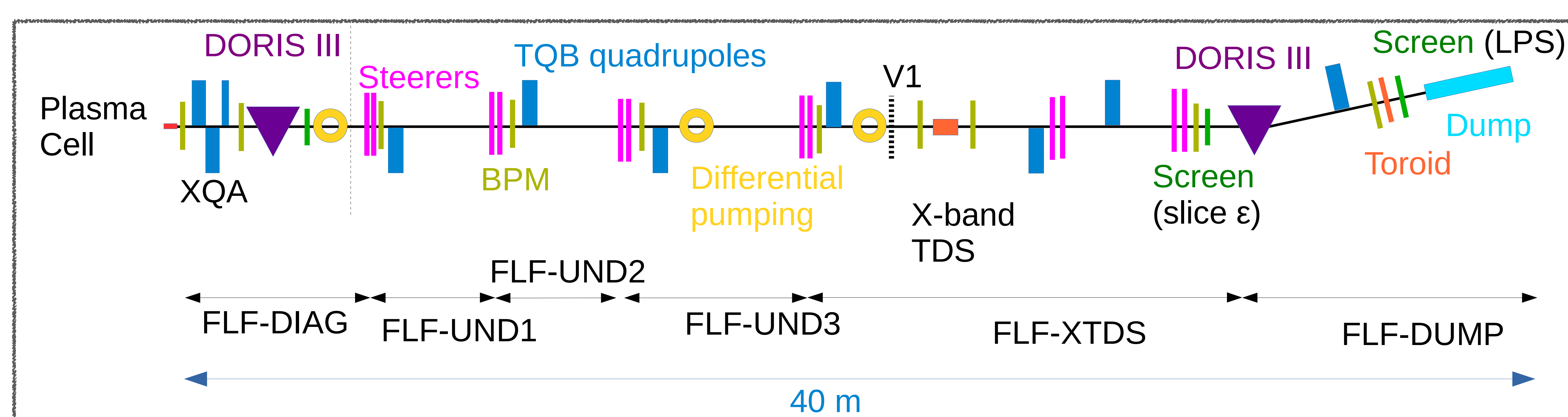
FLASHFORWARD▸▸ follows a staggered installation plan

PROJECT PHASE I: PLASMA WAKEFIELD BEAMLINE AND DIAGNOSTICS — PHASE II: UNDULATOR INTEGRATION



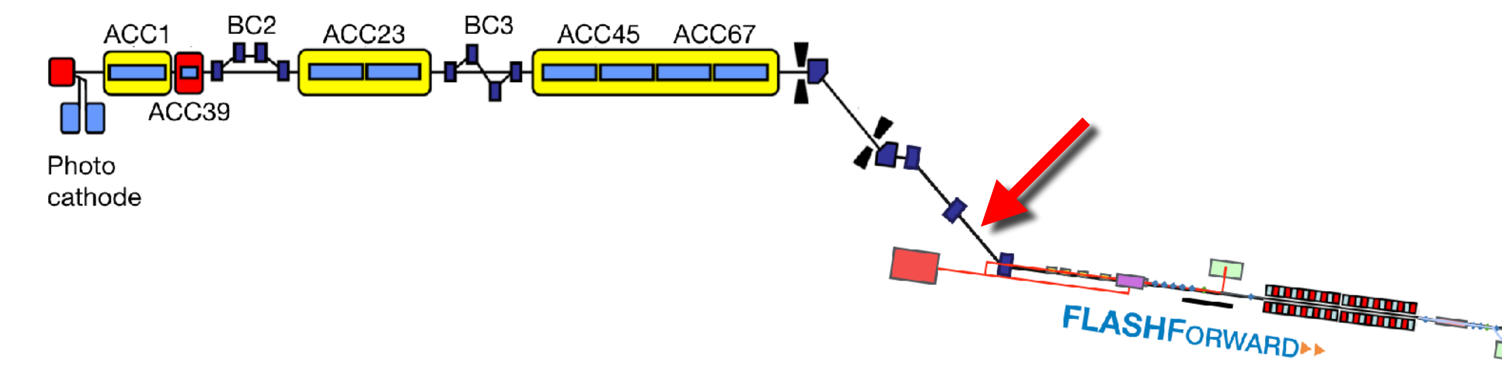


> installation proceeds in FLASH shutdowns

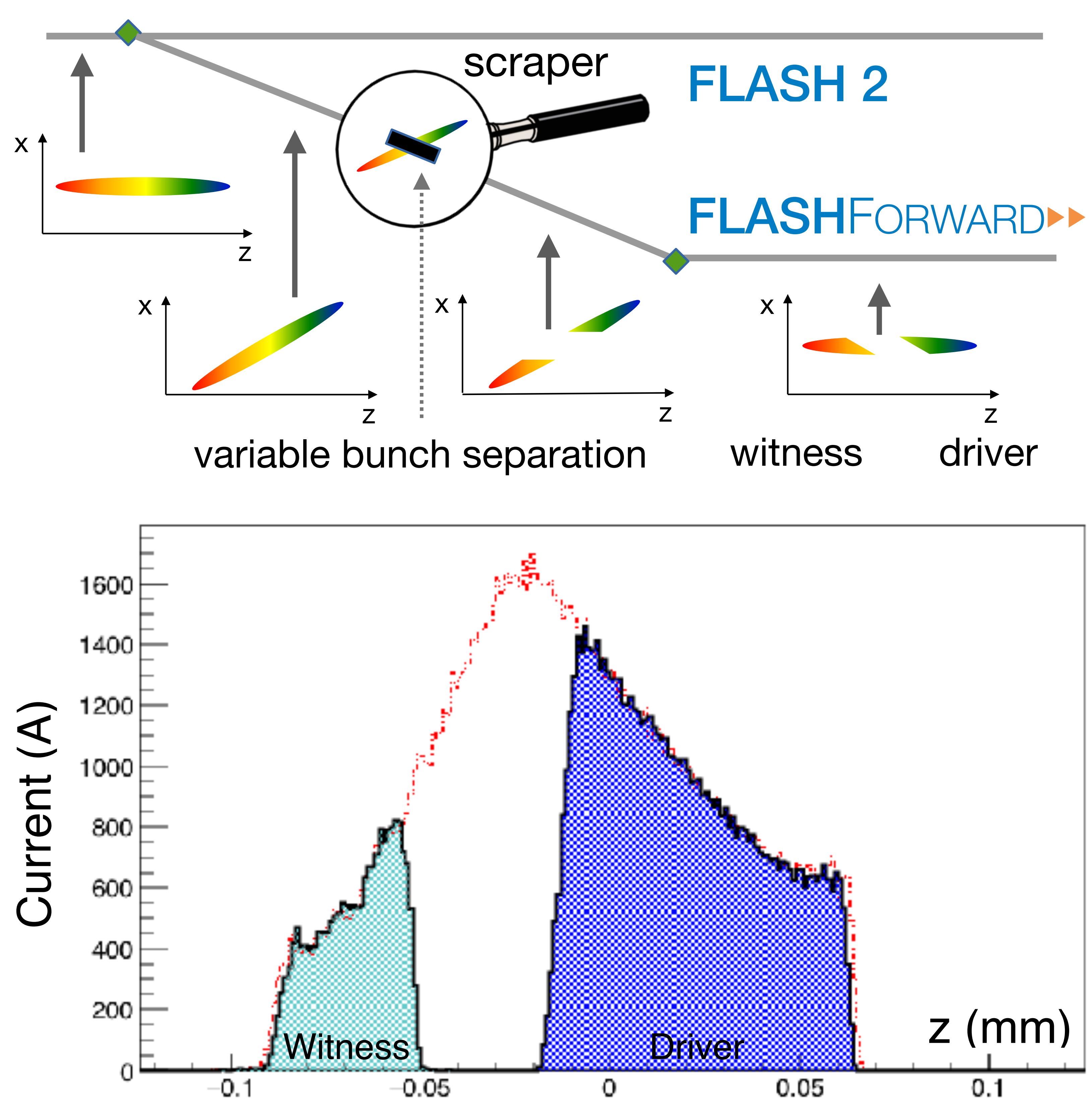


Driver/witness-pair creation in dispersive section by variable mask

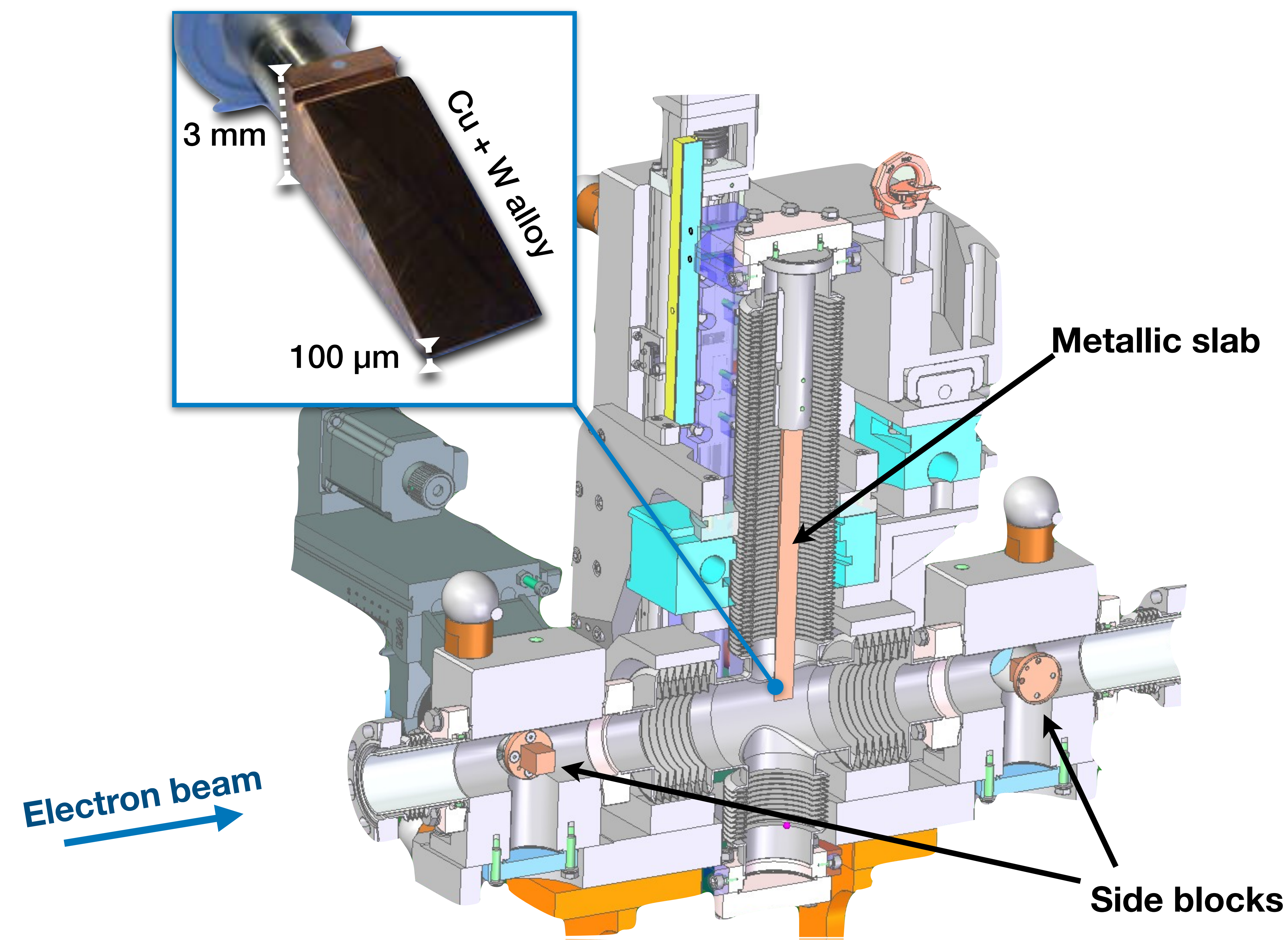
TECHNICAL INNOVATIONS AT FF▸▸ TO FACE CHALLENGES IN PWFA



BEAM SCRAPER FOR DRIVER/WITNESS-PAIR CREATION



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



X-2	Plasma Booster
	▸ **PI:** V. Libov (U Hamburg)

Driver/witness-pair creation in dispersive section by variable mask

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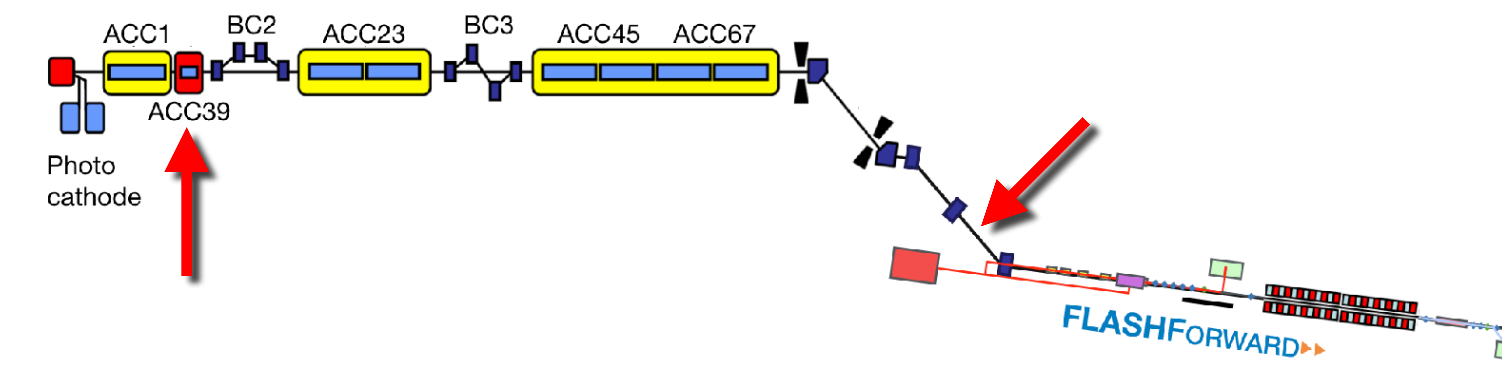

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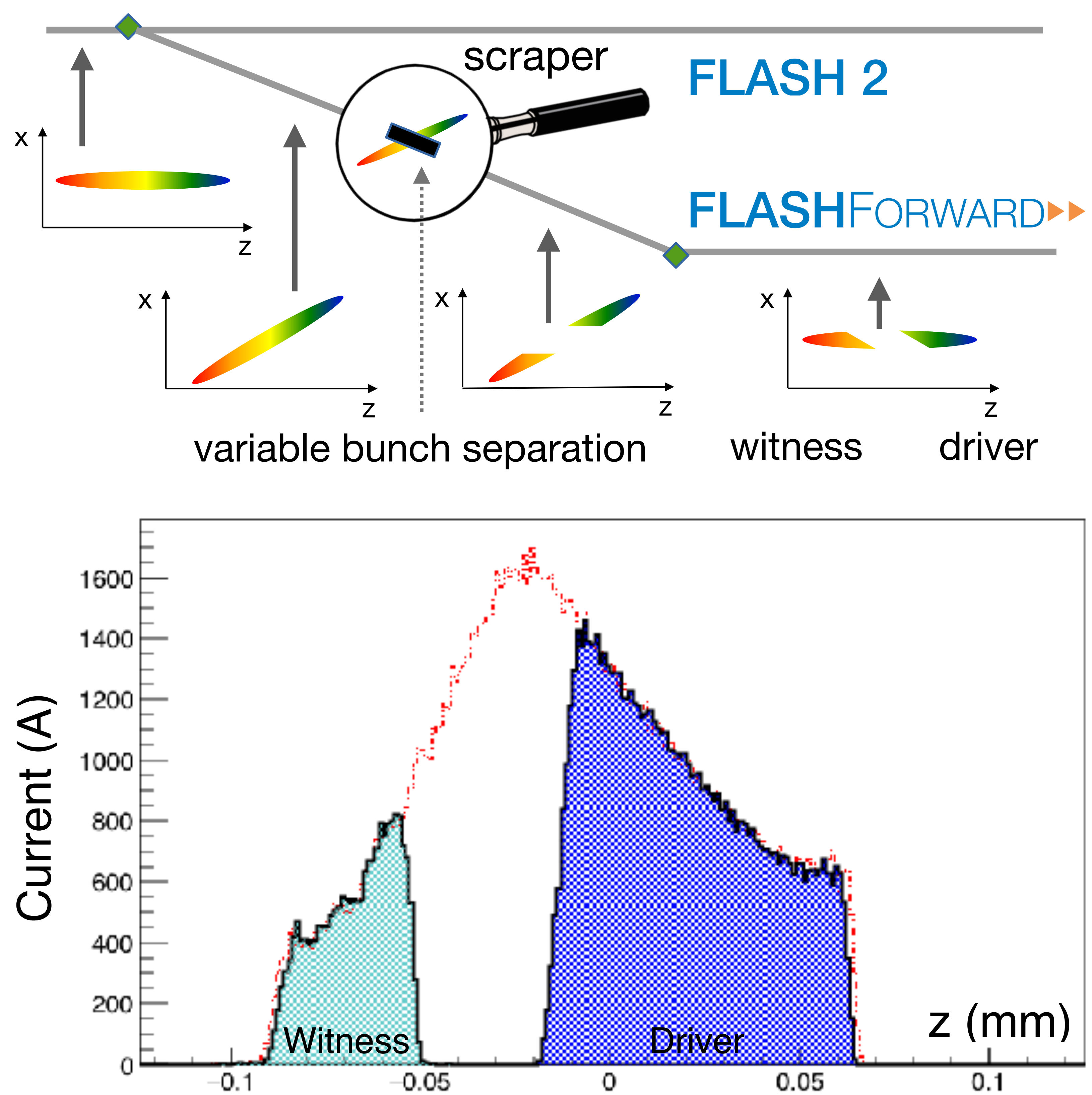
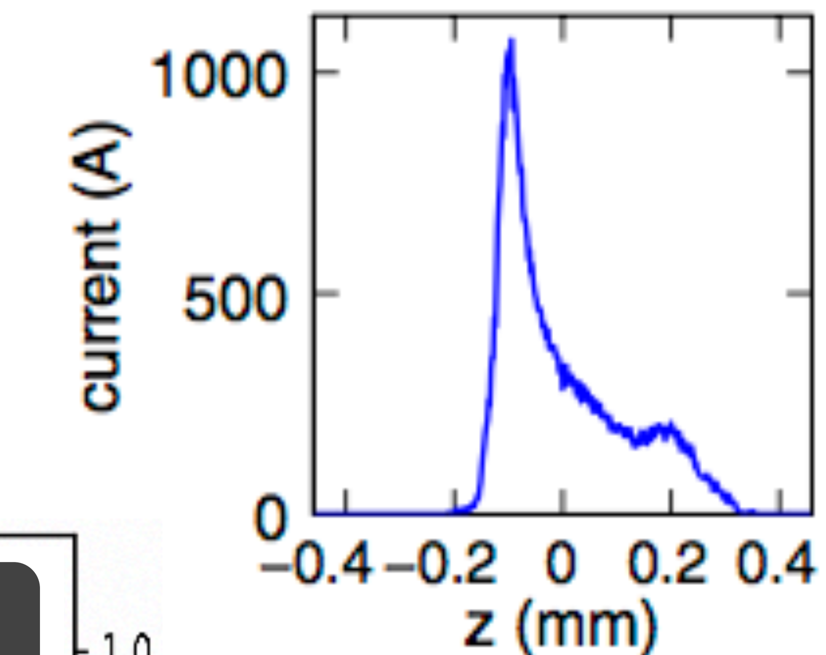


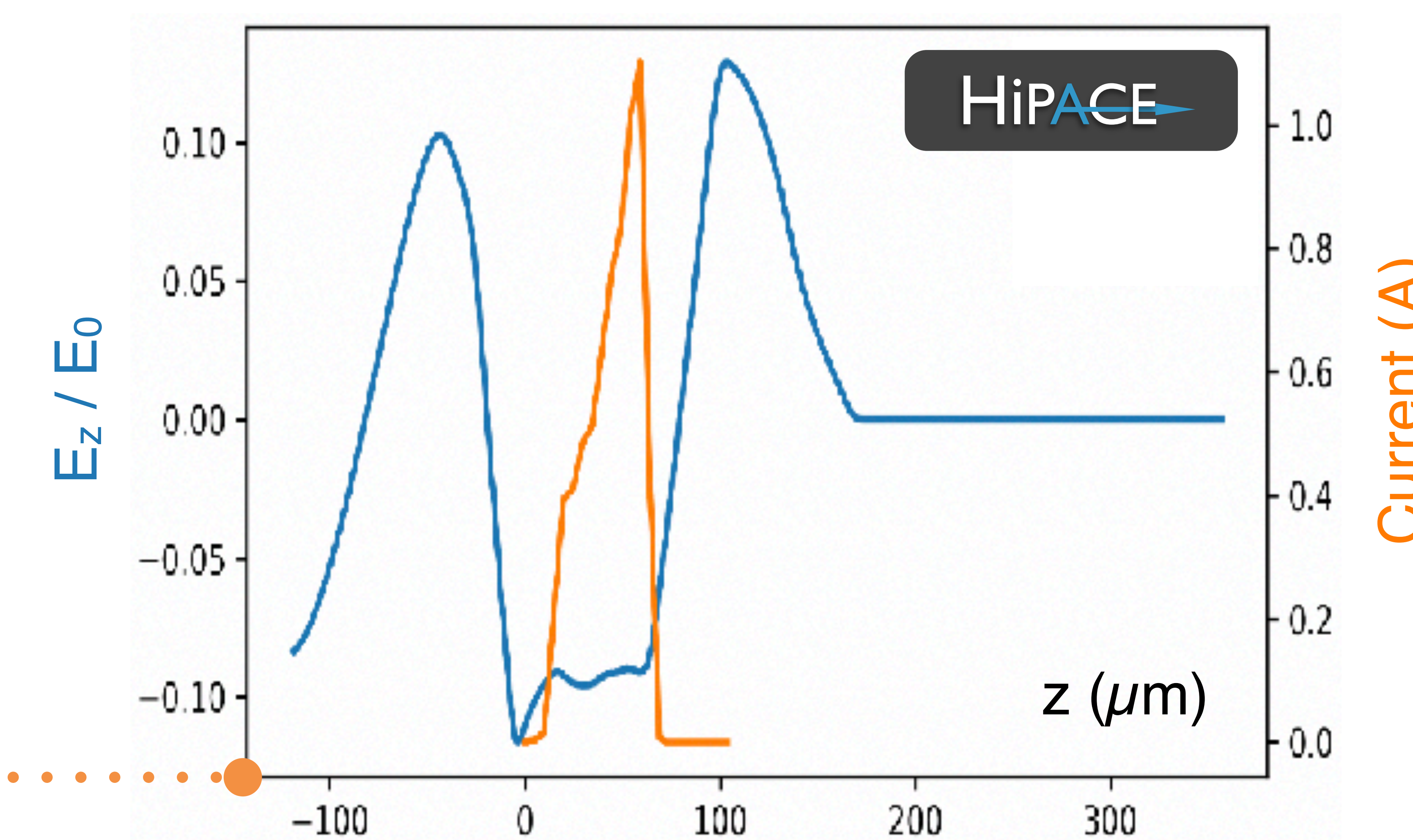
BEAM SHAPING FOR BEAM LOADING/TRANSFORMER RATIO CONTROL

> 3.9 GHz cavity and compressors for beam shaping

> Triangular current profile for uniform electric fields



Piot *et al.*, PRL **108**, 034801 (2012)

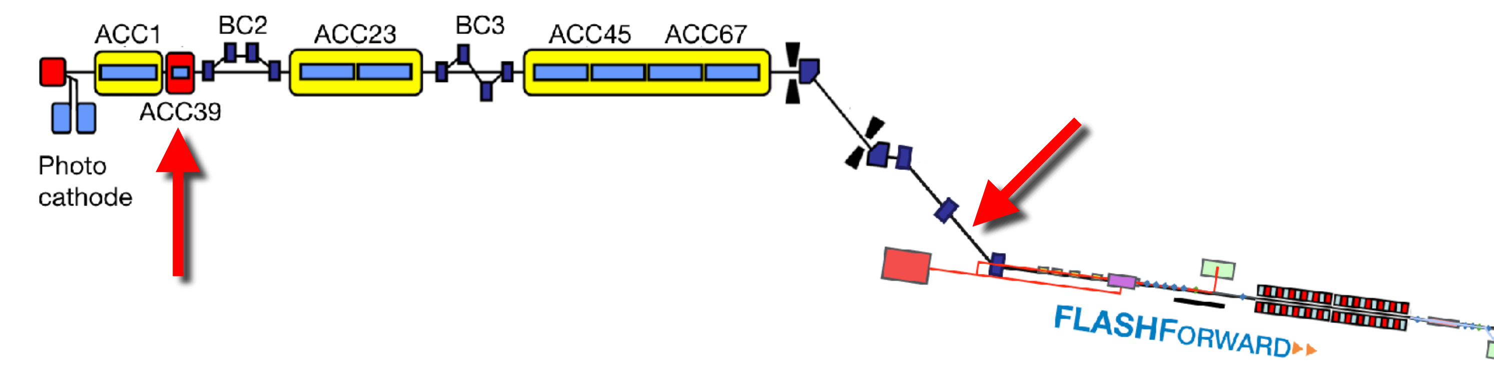


> Triangular witness profile for energy spread conservation

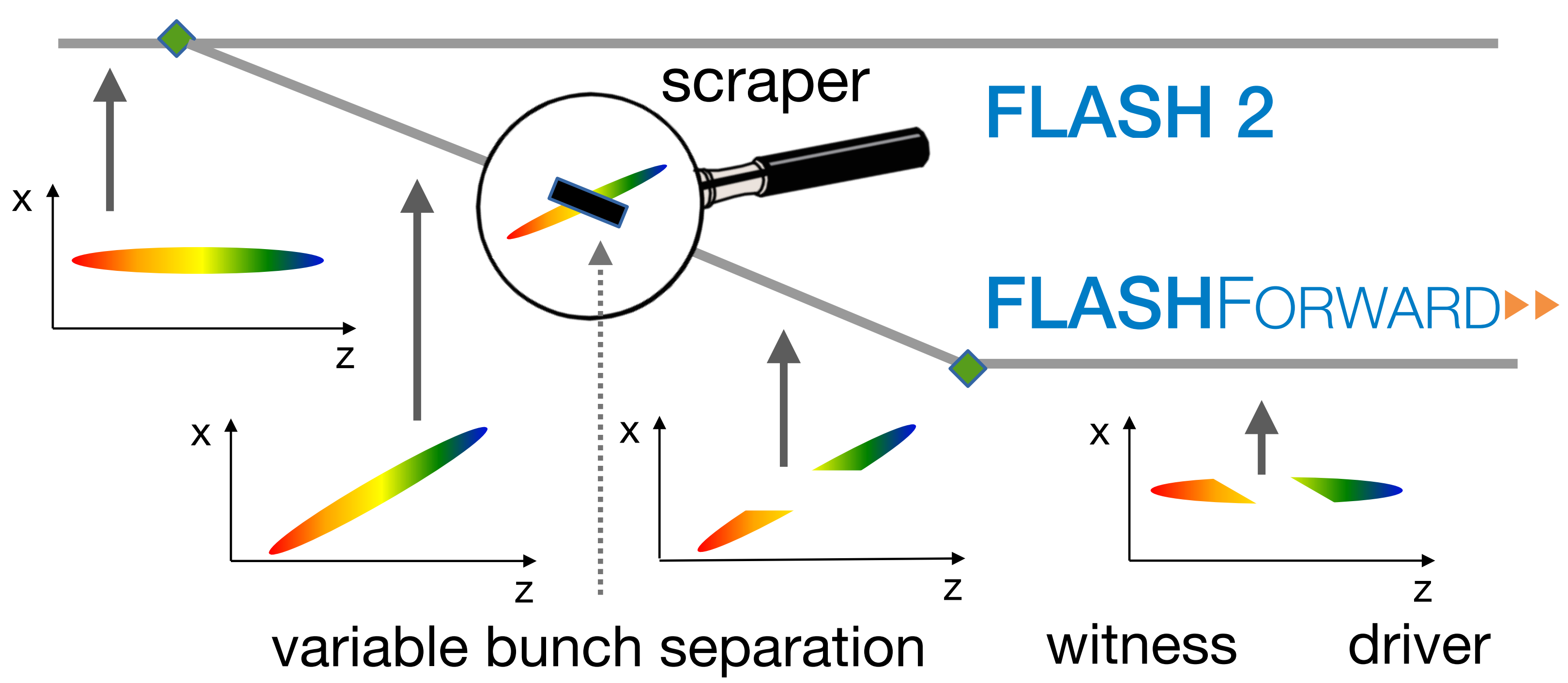
X-2 **Plasma Booster**
- **PI:** V. Libov (U Hamburg)

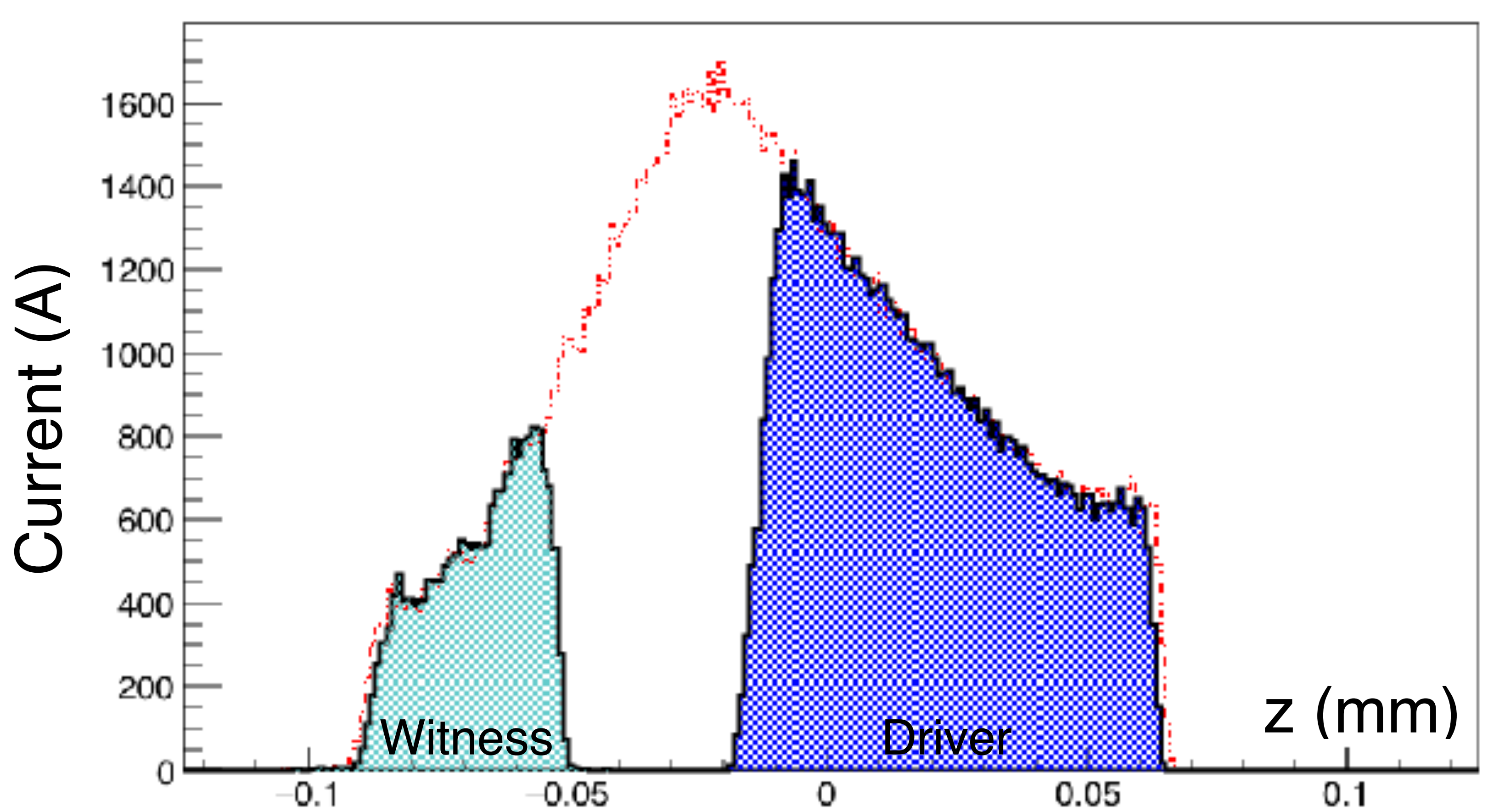
Driver/witness-pair creation in dispersive section by variable mask

TECHNICAL INNOVATIONS AT FF▸▸ TO FACE CHALLENGES IN PWFA



BEAM SCRAPER FOR DRIVER/WITNESS-PAIR CREATION





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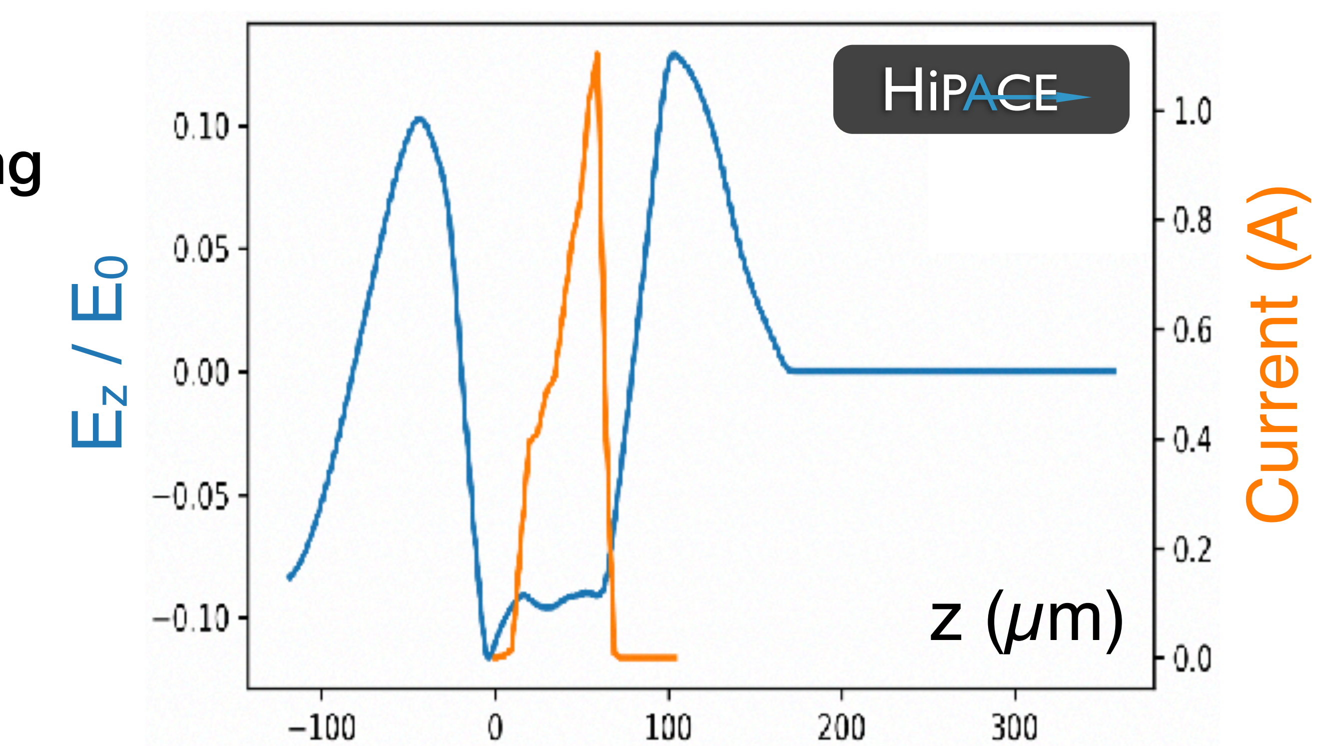
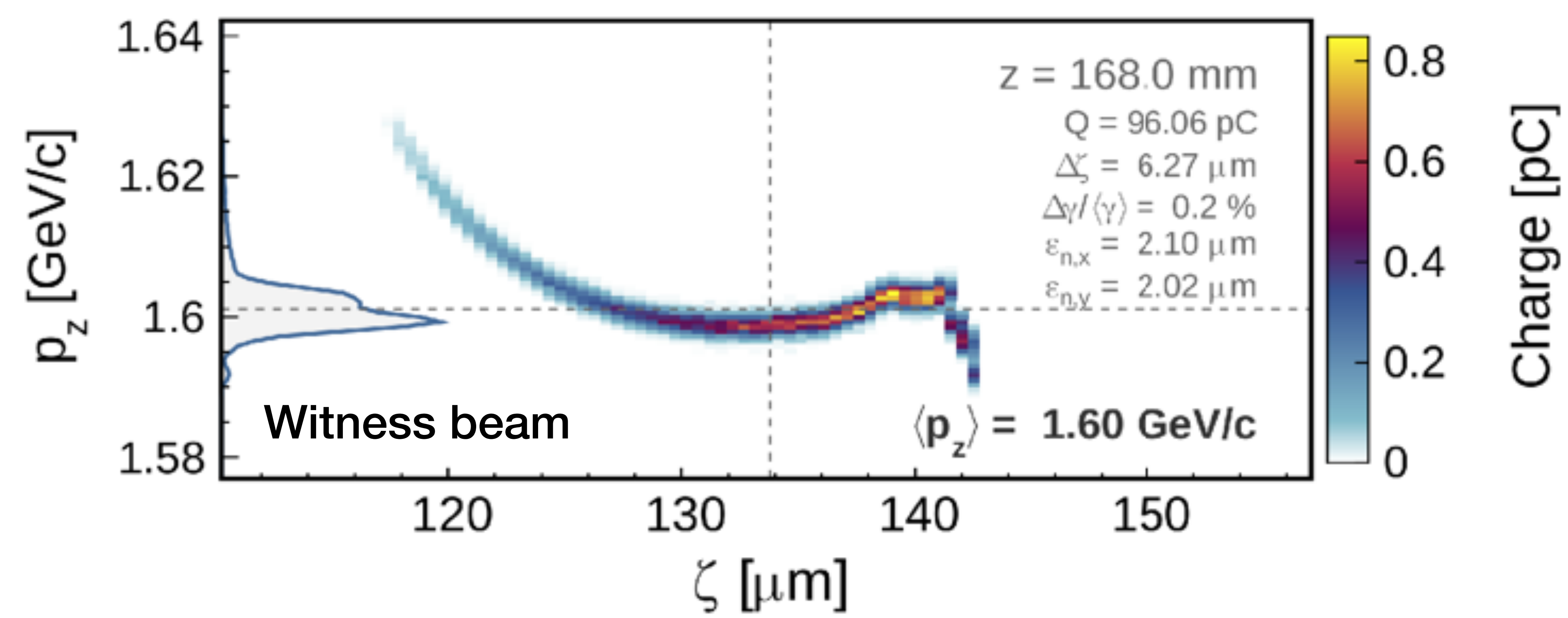


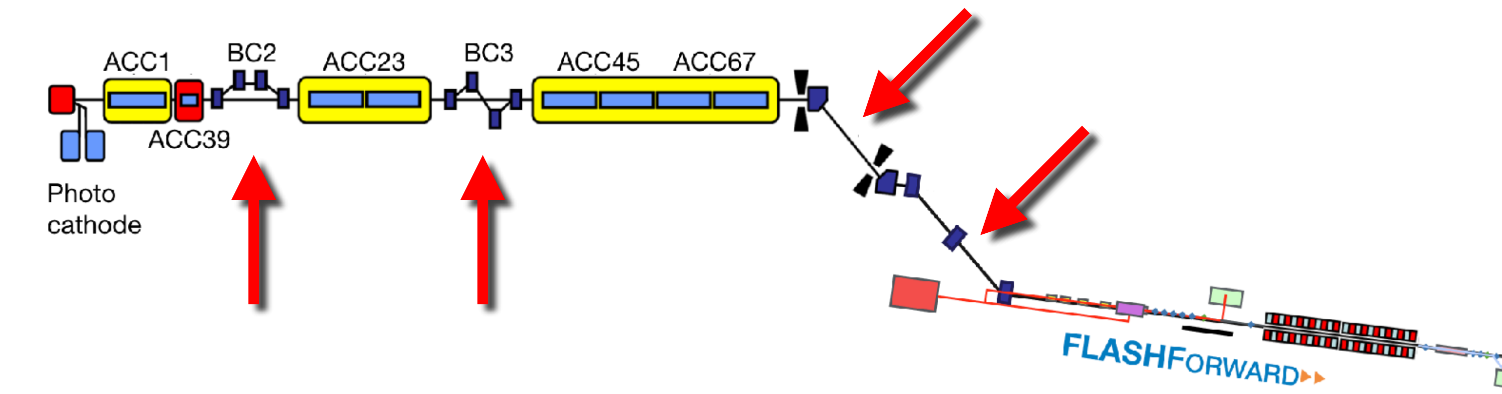


> Initial norm. emittance 2.0 μm, energy spread 0.2%, energy 1.0 GeV

X-2 Plasma Booster
- PI: V. Libov (U Hamburg)

Driver/witness-pair creation in dispersive section by variable mask

TECHNICAL INNOVATIONS AT FF▸▸ TO FACE CHALLENGES IN PWFA



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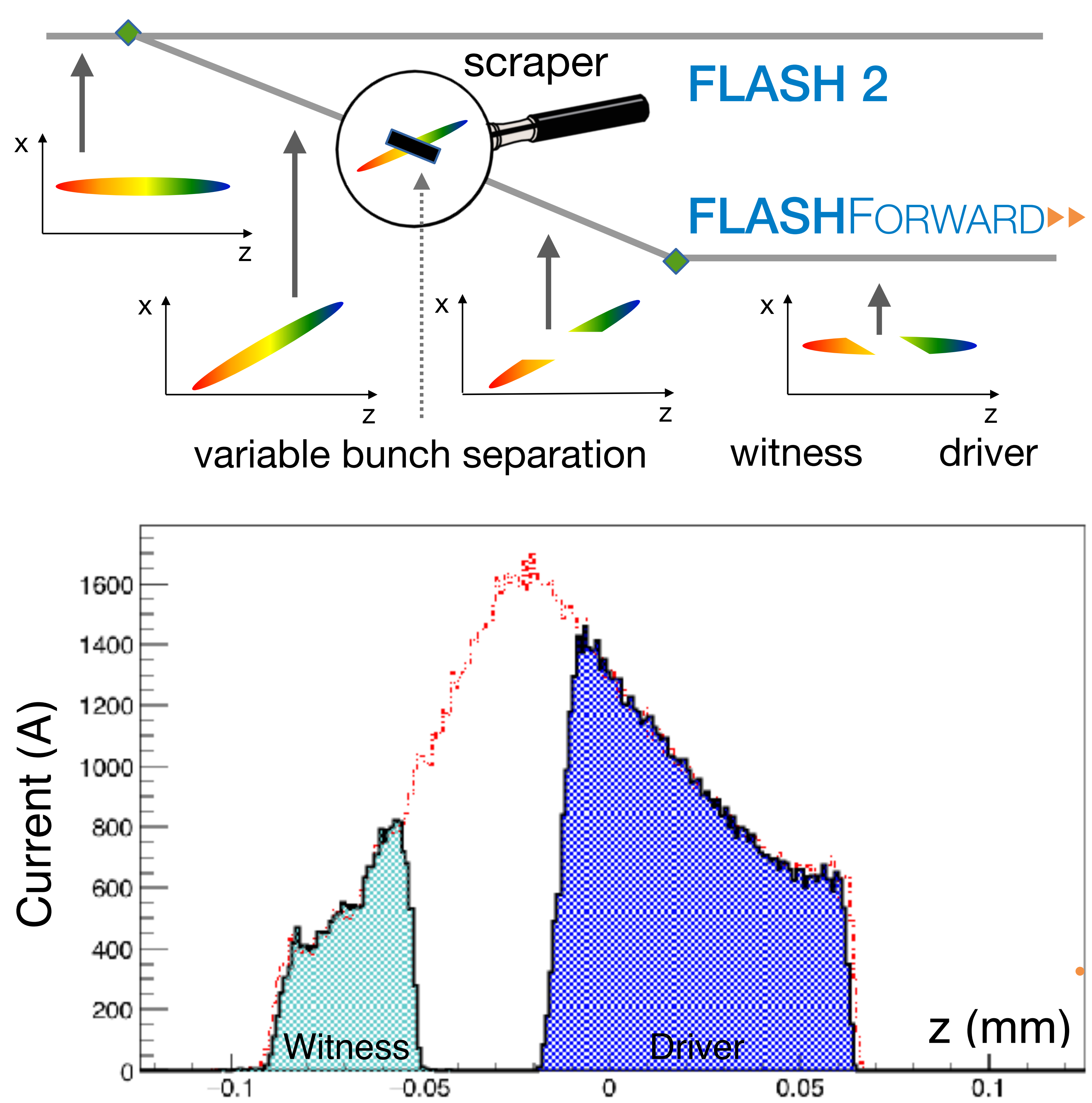
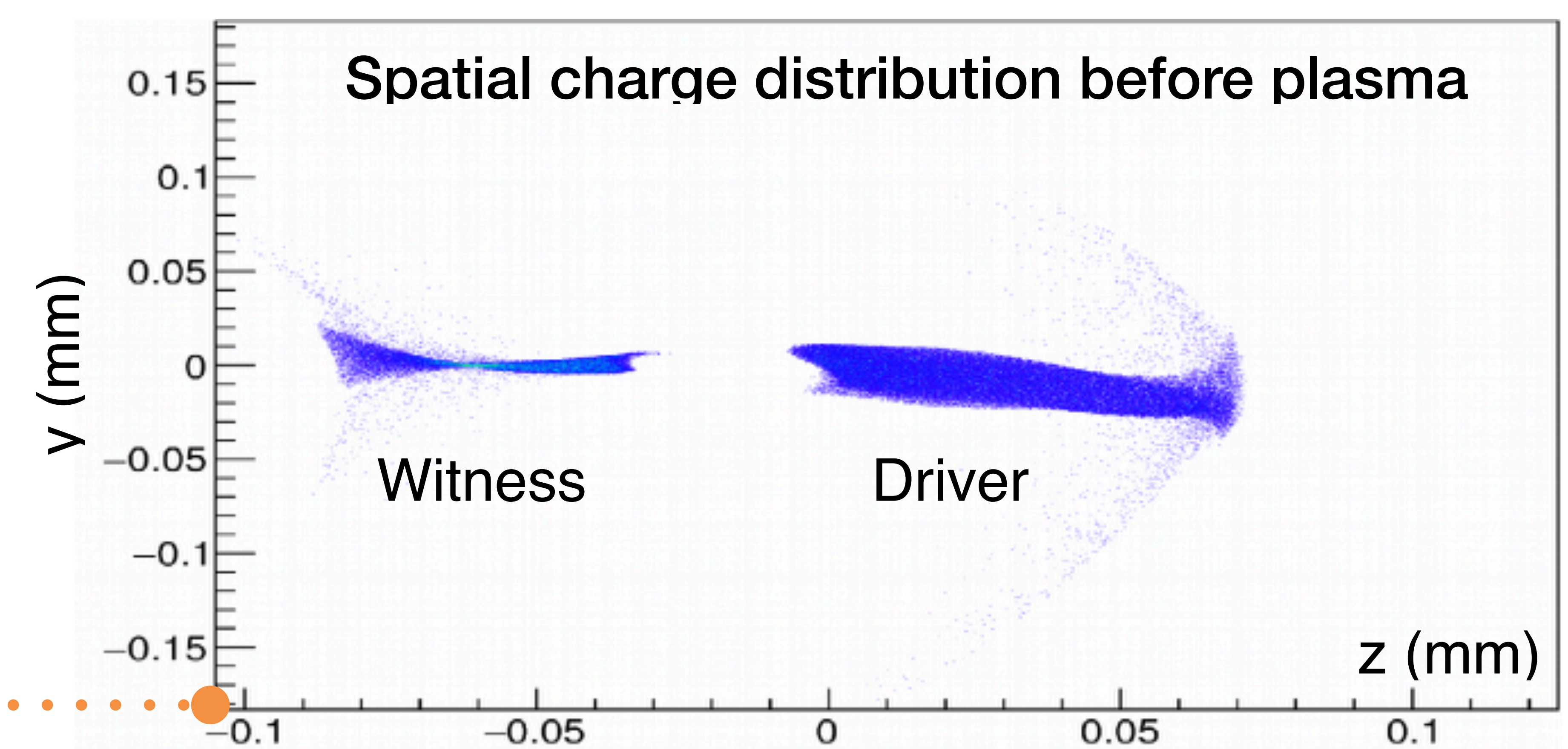




- Asymmetries in charge distribution seed the hosing instability
- Asymmetries caused by coupler kicks and CSR in bends

X-2 **Plasma Booster**
- **PI:** V. Libov (U Hamburg)

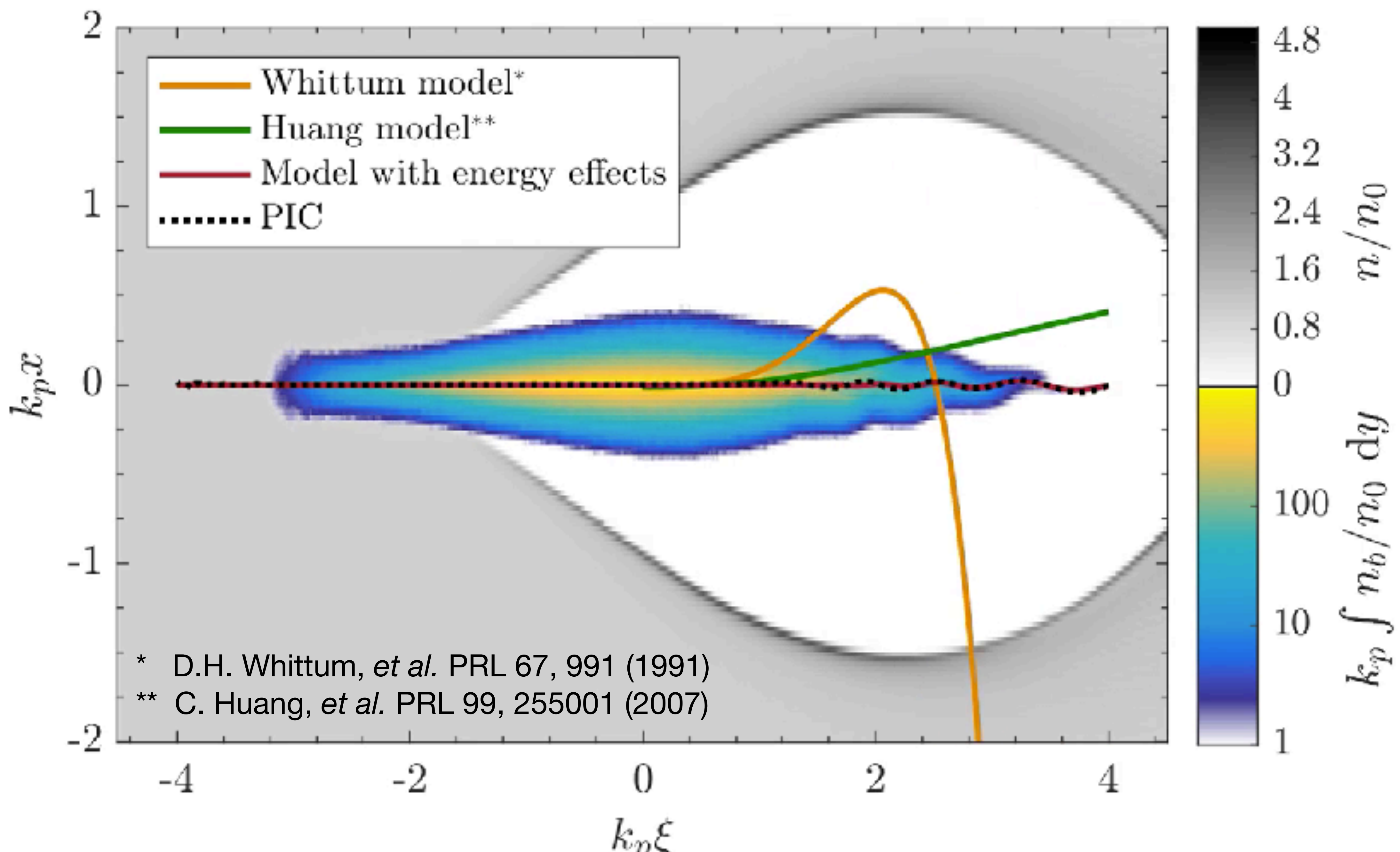
Advanced theory predicts hosing saturation

FF▸▸ SCIENCE HIGHLIGHTS

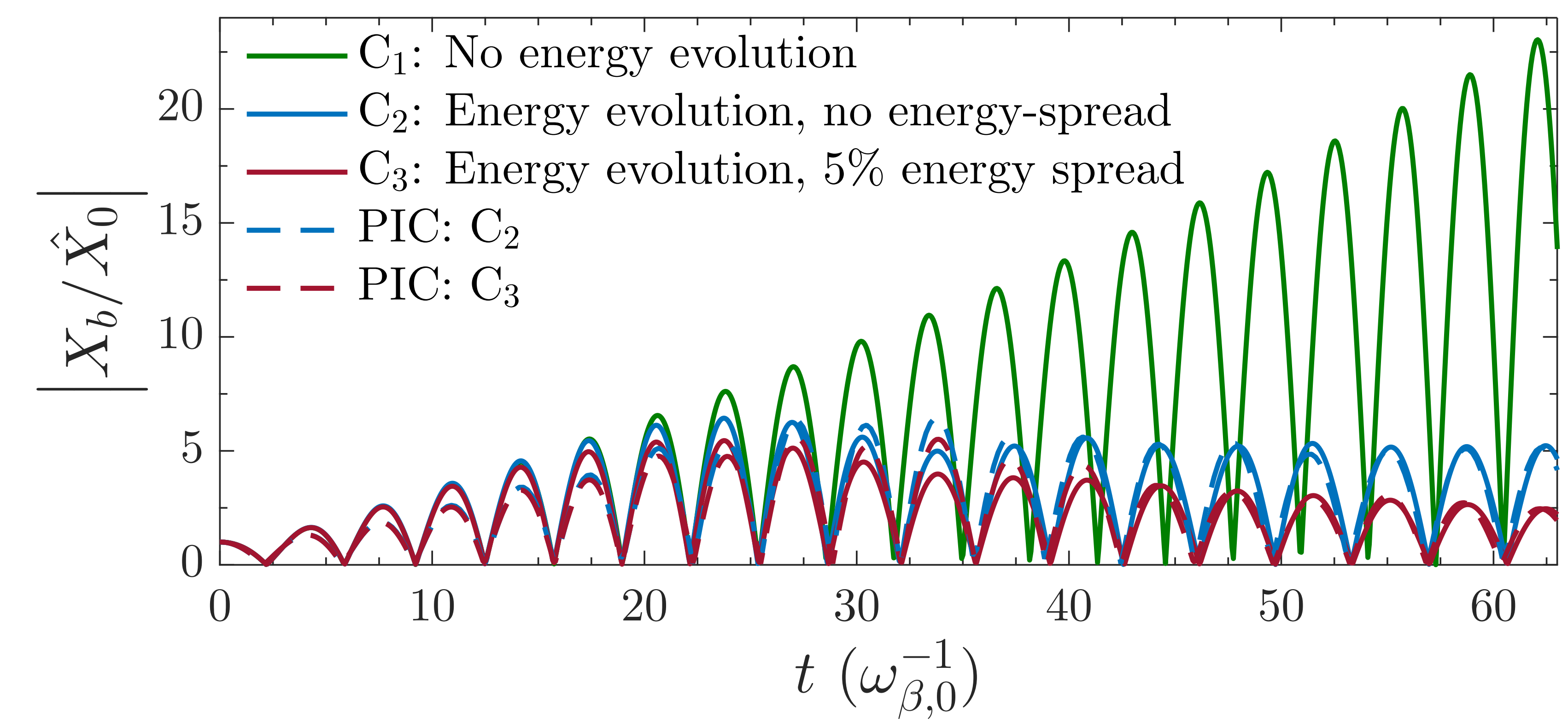
collaboration between
U Hamburg and IST Lisbon

Extension of hosing theory → T. J. Mehrling et al., Phys. Rev. Lett. 118,174801 (2017)

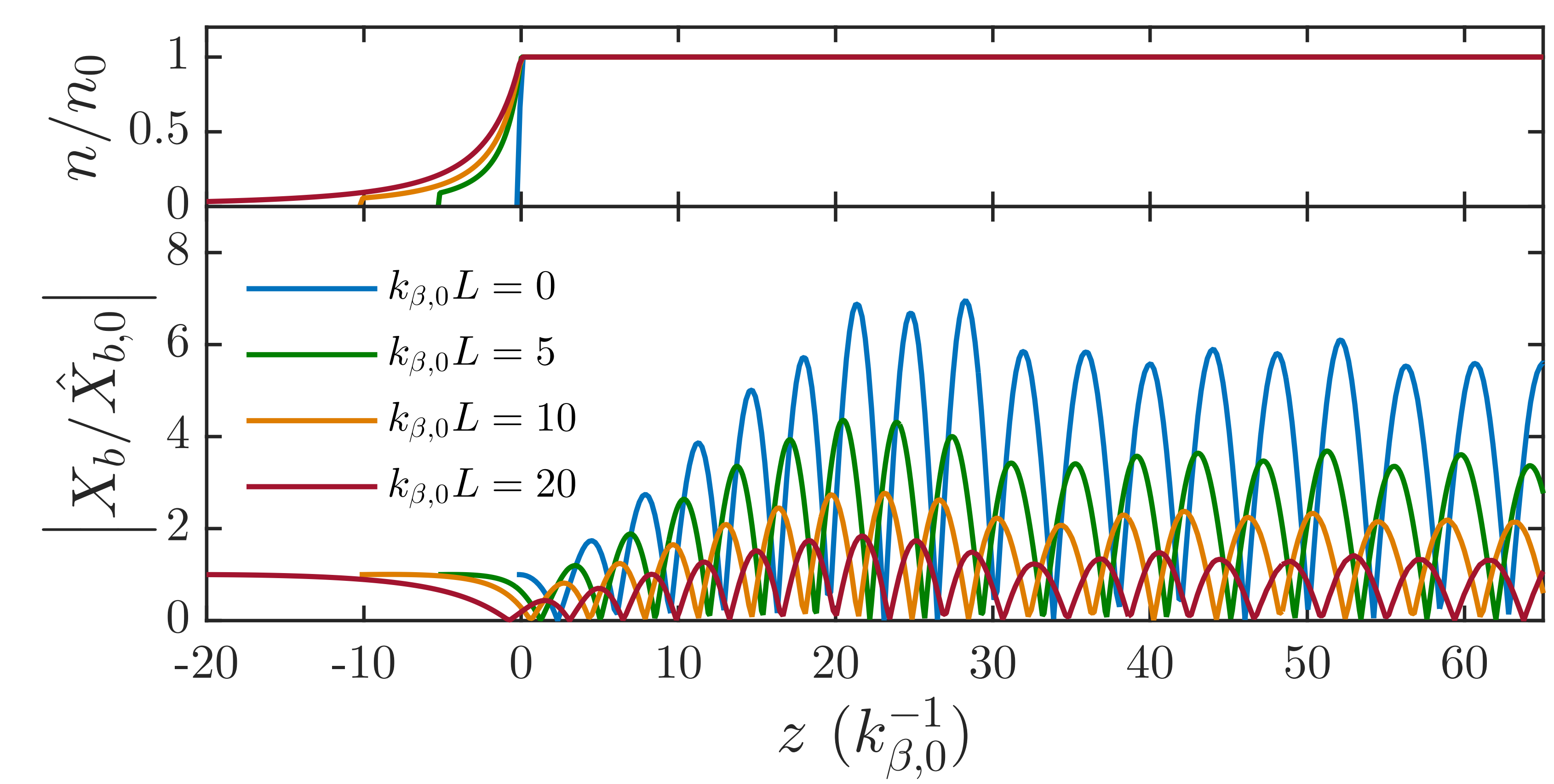
> includes energy spread and evolution, predicts saturation and damping (similar to BNS damping)



Betatron decoherence



Seed reduction



Advanced theory predicts hosing saturation

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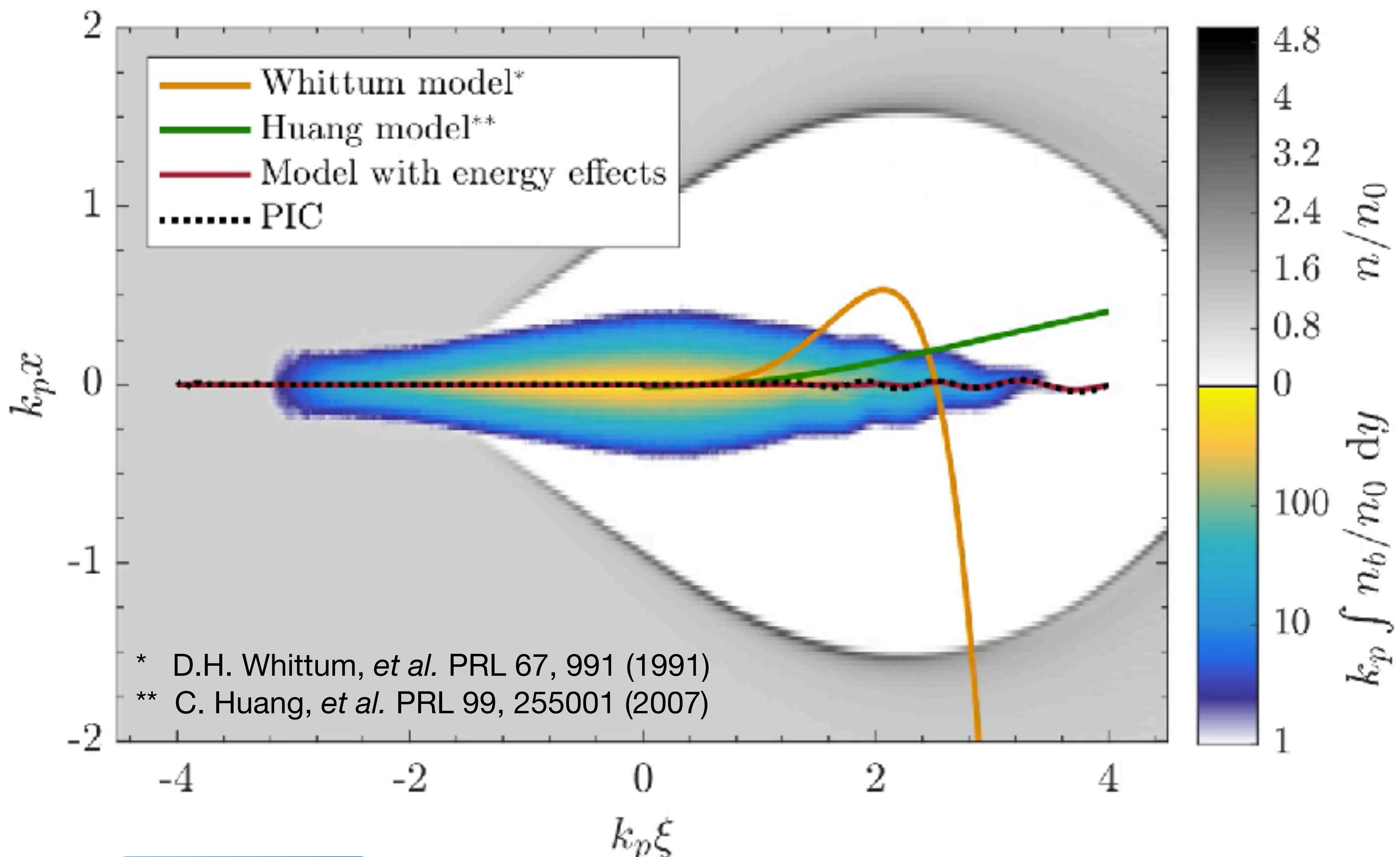
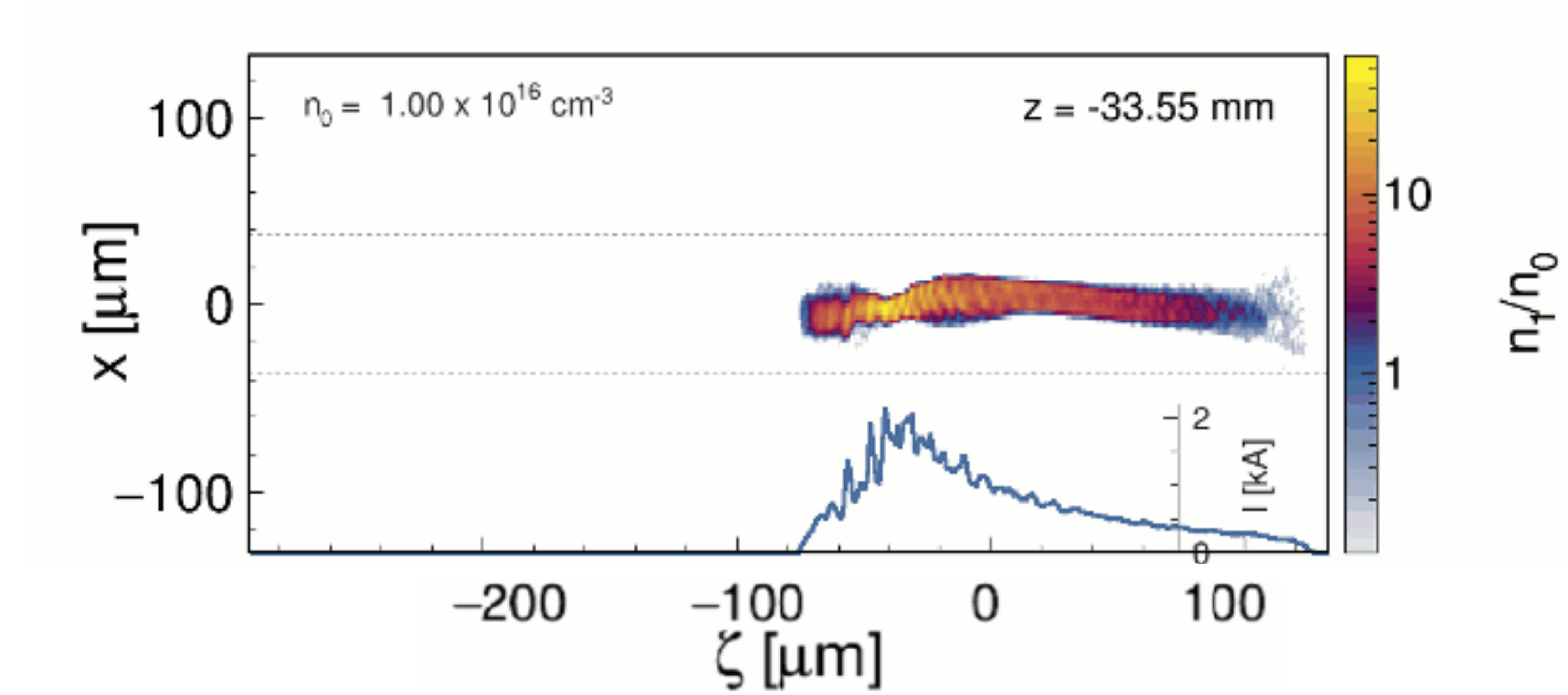




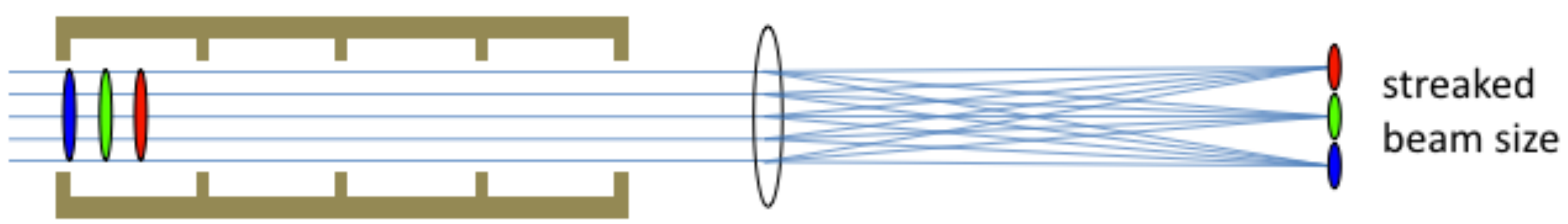
> Full start-to-end simulations incl. CSR confirm hosing modes can be excited

> Measurement of growth rates & hosing saturation vs. beam parameters one of first steps at FLASHForward

X-band transverse deflector for femtosecond phase-space characterization

TECHNICAL INNOVATIONS AT FF▸▸ TO FACE CHALLENGES IN PWFA

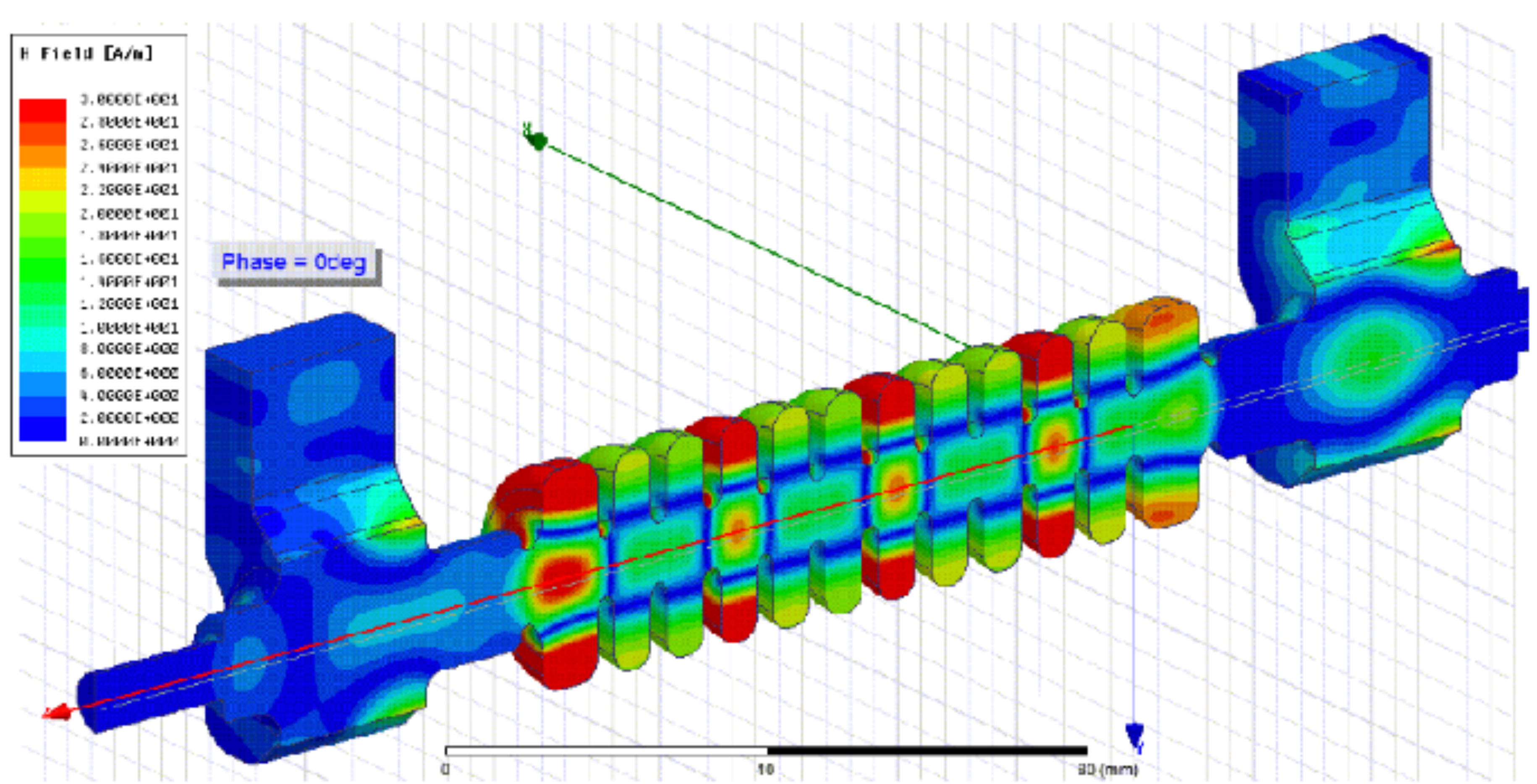
▸ DESY coordinator: **B. Marchetti**



Courtesy of Klaus Flöttmann

> A collaboration between DESY, CERN, and PSI to share expertise and develop X-band technology

> A novel dual-polarisation RF deflecting cavity → tomographic reconstruction of phase space



Courtesy of Alexej Grudiev, CERN

> Resolutions witness* and driver** beam working points:

$$R_z = \frac{\sigma_y}{S} = \sqrt{\frac{\varepsilon_y(s)}{\beta_y(s_0)}}\,\frac{1}{|\sin\mu_y|}\,\frac{E}{eVk}$$

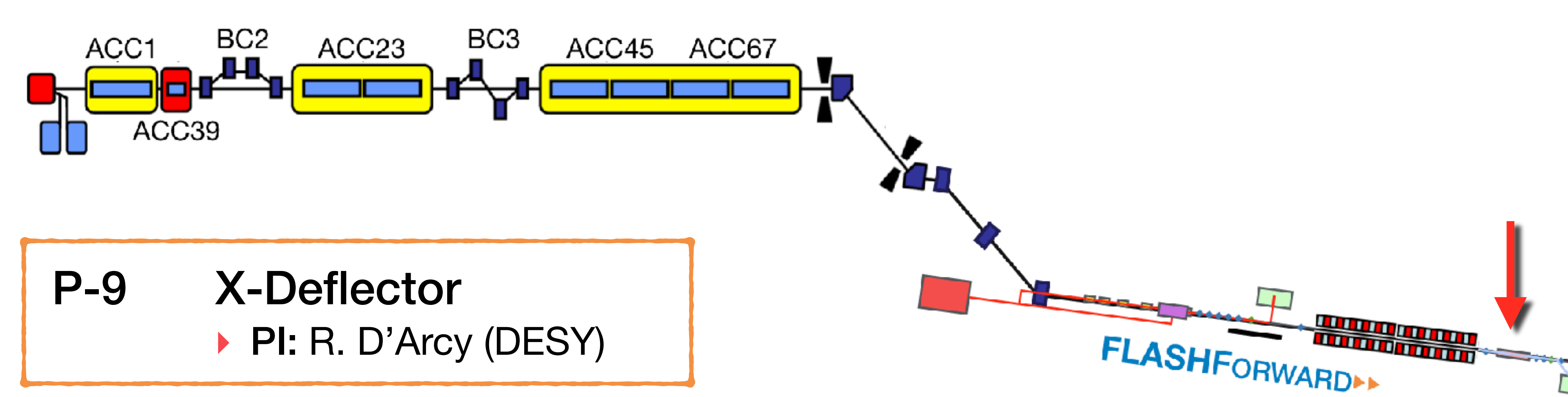
$R_t > 0.9$ fs (witness)
$R_t > 1.5$ fs (driver)

$$R_\delta = \frac{\sigma_x}{|D_x|} = \sqrt{\varepsilon_x}\,\frac{\sqrt{\beta_x}}{|D_x|}$$

$R_\delta > 2\text{x}10^{-4}$ (witness)
$R_\delta > 1\text{x}10^{-4}$ (driver)

*E = 1.5 GeV, ε = 0.5 μm **E = 1.0 GeV, ε = 2.0 μm

> Prototype to be commissioned at FLASHForward in 2019



P-9 **X-Deflector**
▸ **PI:** R. D'Arcy (DESY)

Summary

- Plasma wakefield acceleration is an intriguing technology to miniaturized particle accelerators.
- FLASHForward▸▸ is a unique next-generation experiment for plasma accelerator research.
- Beamline commissioning is under way.
- Experiments with plasma should start this spring. *Exciting times are ahead!*
- M-groups have done a fantastic job supporting the project.
  Thanks to MBB, MCS, MDI, MEA, MFL, MIN, MKK, MPS, MPY, MSK, MVS!