FLASHForward

Future-oriented wakefield-accelerator research and development at FLASH

Jens Osterhoff

Project coordinator, Deutsches Elektronen-Synchrotron DESY

representing the

LAOLA. collaboration

Outline

- Planned FLASHForward beamline and goals
- Science case
  - Injection techniques
  - Transformer ratio studies
  - Overview scientific programme
- Project schedule
- Network
- Summary

FLASHForward

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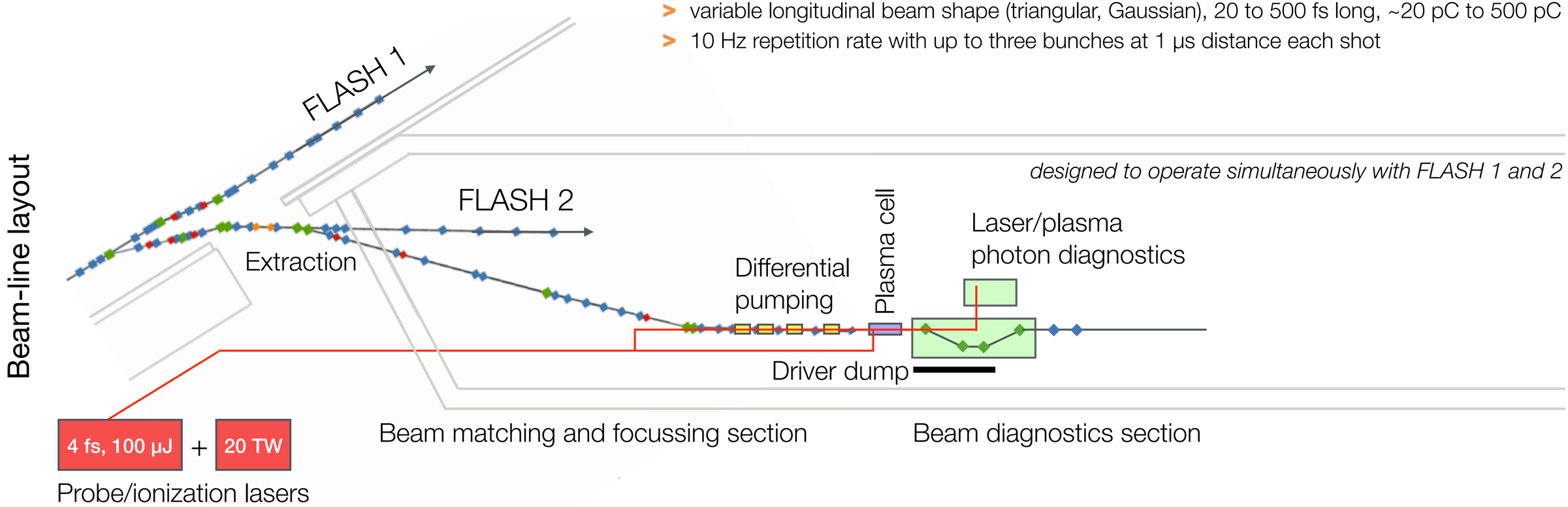
Driver-beam parameters

- FEL quality, ≤ 1.6 GeV, 0.1% energy spread, 1 µm transverse emittance
- variable longitudinal beam shape (triangular, Gaussian), 20 to 500 fs long, ~20 pC to 500 pC
- 10 Hz repetition rate with up to three bunches at 1 µs distance each shot



Experiments to start in 2016, run for 4 years+

Status: conceptual design in progress, to be concluded 12/2013

Phase I (2016 - 2018)

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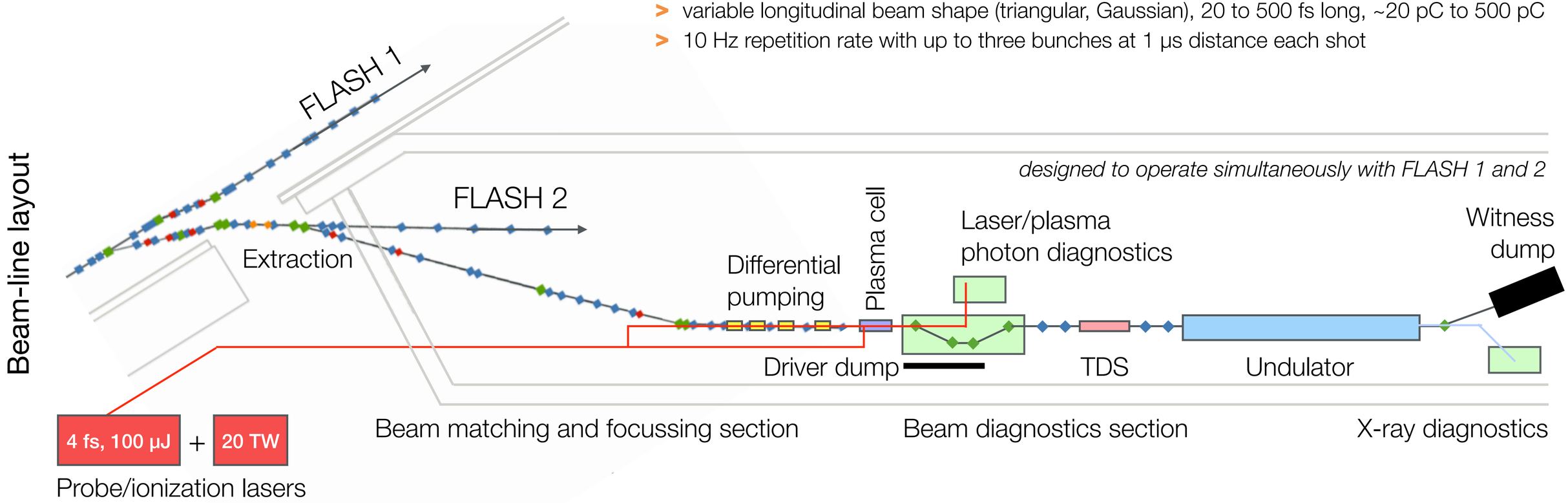

Experiments to start in 2016, run for 4 years+

Status: conceptual design in progress, to be concluded 12/2013

Phase II (2018 - 2020)

+ TDS
optional

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Scientific mission

FF▸▸ aims at advancing beam-driven novel-accelerator science by exploring

- *external injection* and *in-plasma beam-generation* and acceleration techniques to provide high-energy (1.5 to 4+ GeV), low transverse emittance (~100 nm), ultrashort (~ fs), and high current (> 1 kA) electron bunches
- *transformer ratios* beyond 2
- the application of such beams to assess their potential for *free-electron laser gain* at photon energies inside and beyond the water window

In addition, the beamline will be well equipped to study a plethora of scientific problems in novel and conventional accelerator R&D (e.g. acceleration in dielectric structures, Thomson scattering, …)

Witness-bunch production paramount problem of PWFA

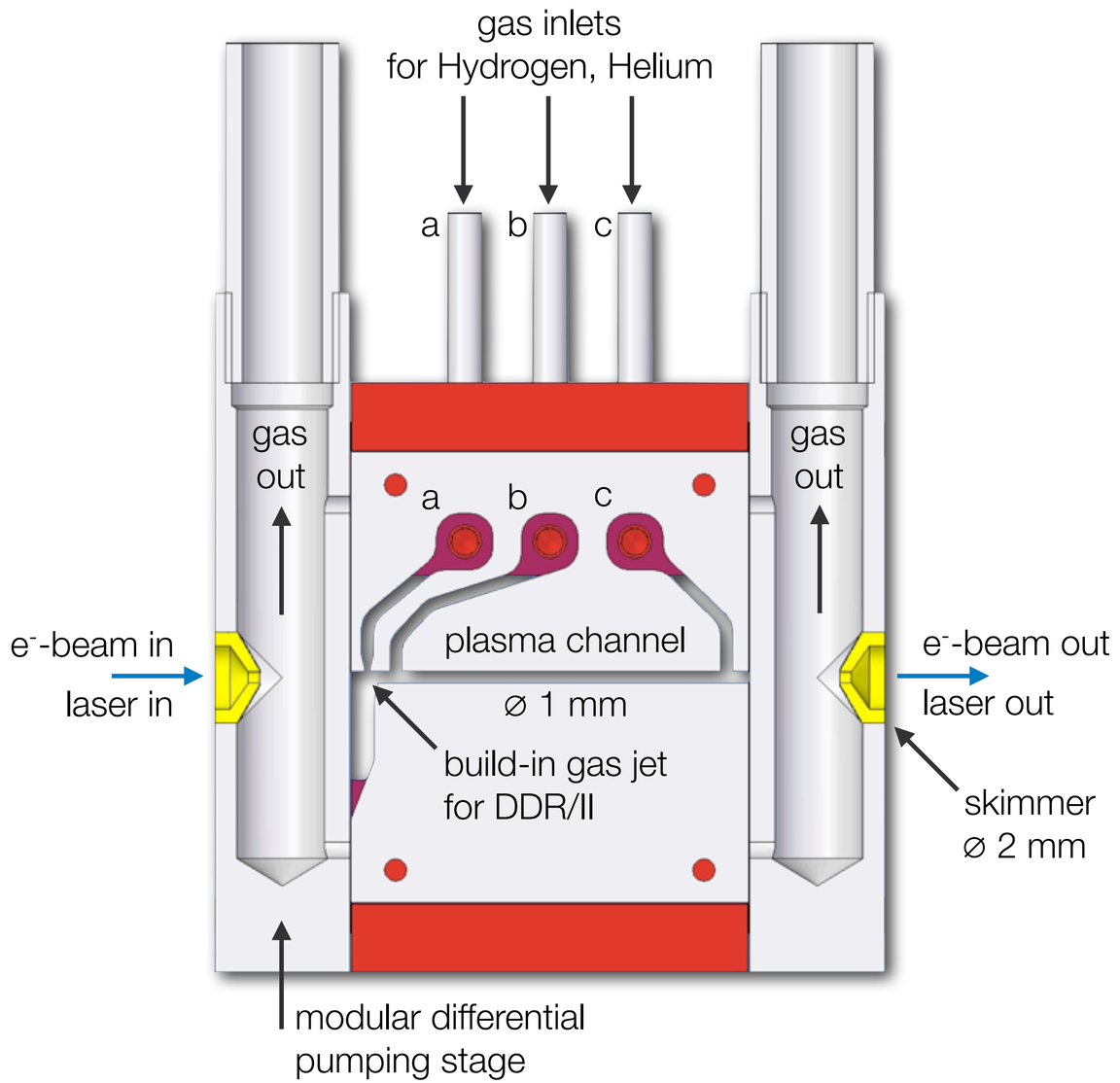
- Quality of accelerated beam strongly linked to control over initial population of wake-phase space at injection

Plasma experiments at FLASHForward offer various paths for witness-bunch generation

- *External:* witness generation at photo gun by second laser pulse and transport through accelerator to plasma cell
- *Internal:* laser-triggered ionization injection (“Trojan Horse”) with fs-scale synchronized injection laser
  → idea by B. Hidding *et al.*, Phys. Rev. Lett. **108**, 035001 (2012)
- *Internal:* wake-triggered ionization injection
  → new scheme, idea by A. Martinez de la Ossa (DESY), paper submitted
- *Internal:* density-down-ramp injection
  → possible at FLASHForward owing to utilized plasma-cell technology

New plasma-cell design supports novel PWFA-injection schemes

> Concept: *L.Schaper, N.Delbos (UHH)*



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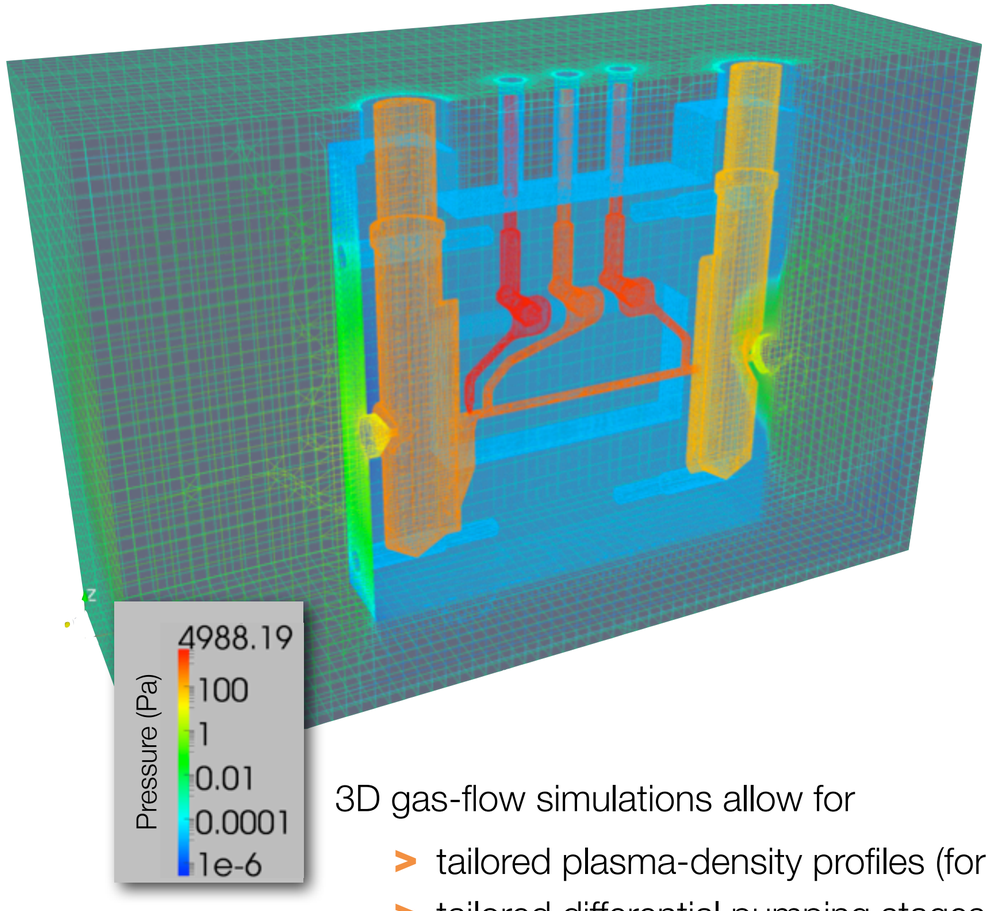
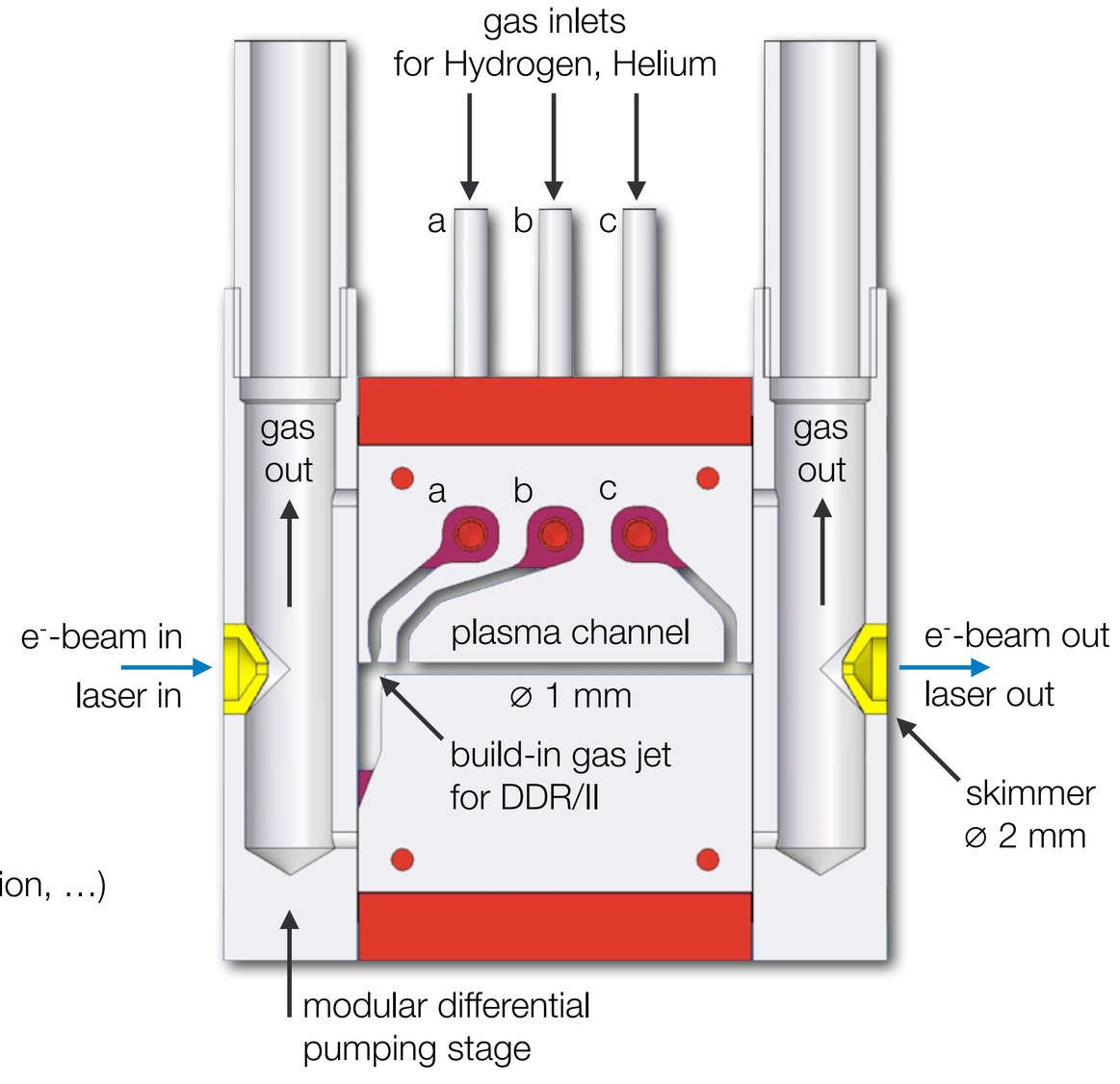


3D gas-flow simulations allow for

- > tailored plasma-density profiles (for DDR injection, …)
- > tailored differential pumping stages

→ done with Open∇FOAM

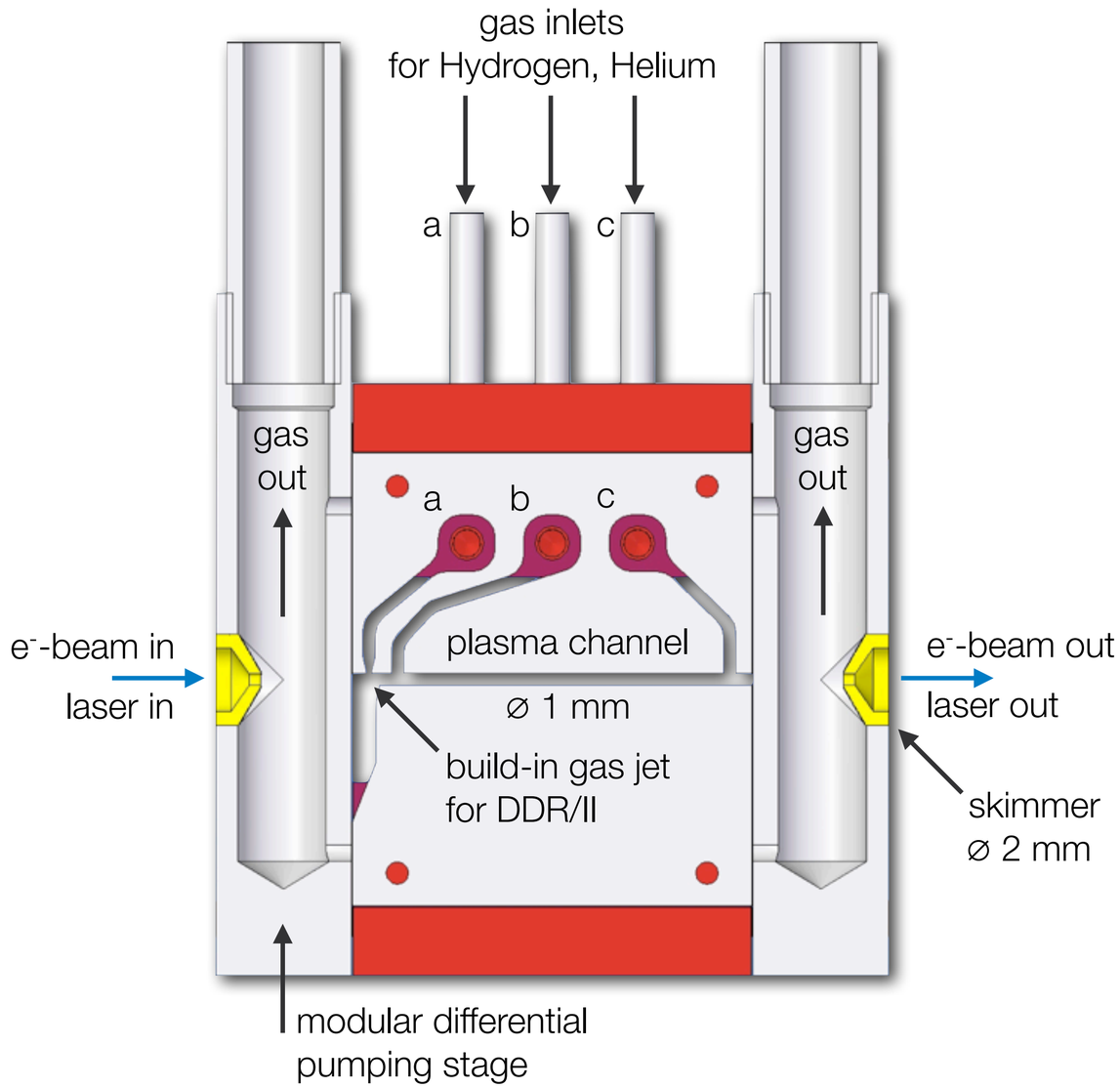


New plasma-cell design supports novel PWFA-injection schemes

> Concept: *L.Schaper, N.Delbos (UHH)*

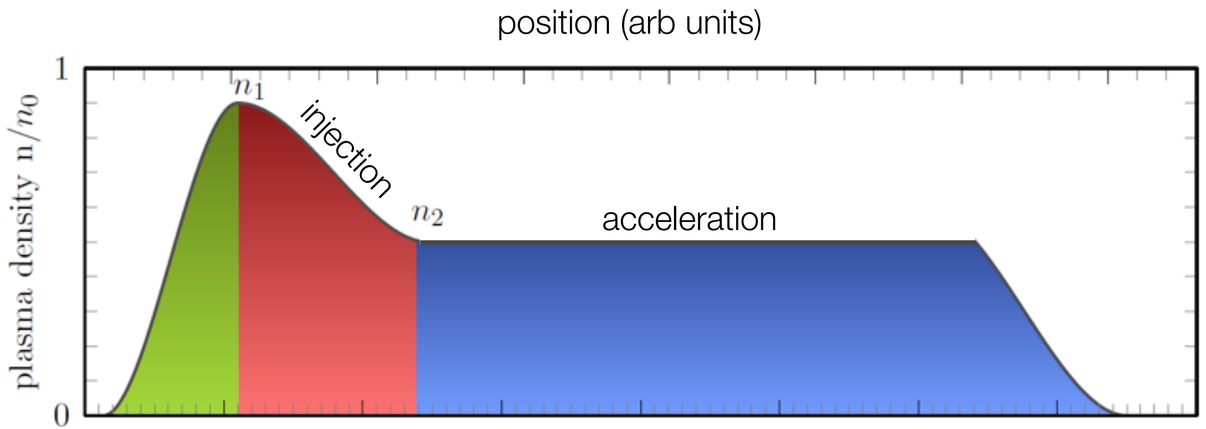
Innovative design

- window-less to avoid emittance growth
- compatible with laser and discharge plasma creation
- transverse laser probing possible
- redundant installation in vacuum chamber possible
- exchange during an 8h maintenance shift possible
- gas release into vacuum requires differential pumping, DESY experience exists
- FLASH protected from gas-system failure by fast shutter 40 m upstream



Density down-ramp injection produces low-transverse-emittance witness beams

> Simulations: *J.Grebenyuk (FLA)*



> demonstrated to work in LWFA, new concept for PWFA

> simple: no injection laser necessary, just tailored plasma target

> injection occurs on density down-slope

S. Bulanov *et al.*, Phys. Rev. E **58**, R5257 (1998)

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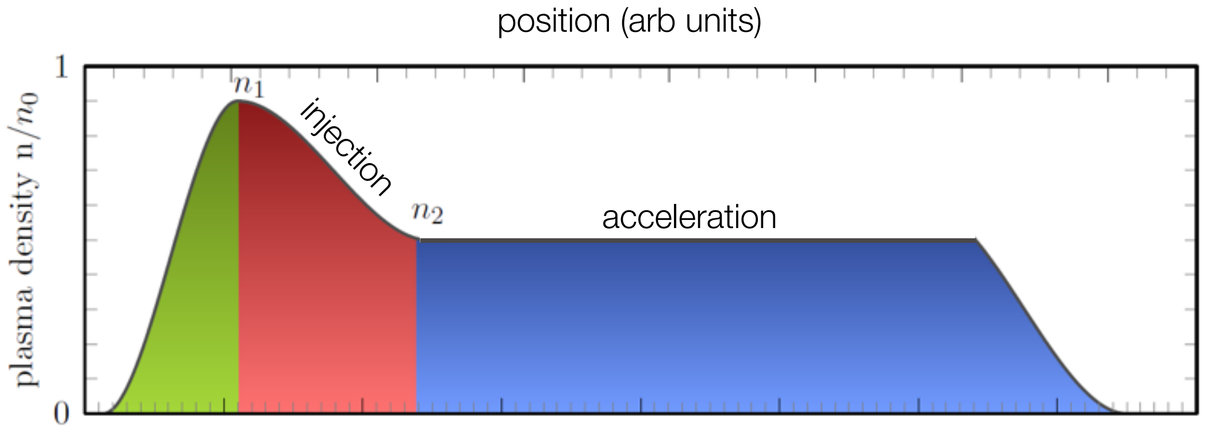

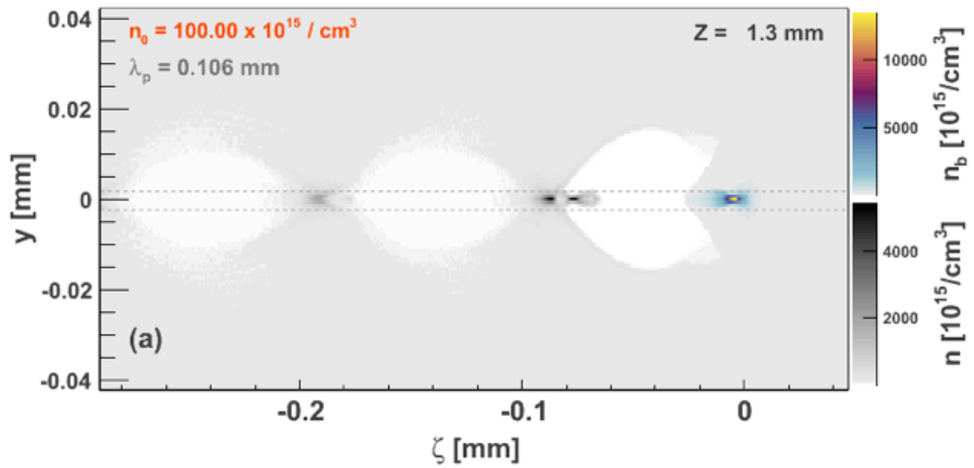

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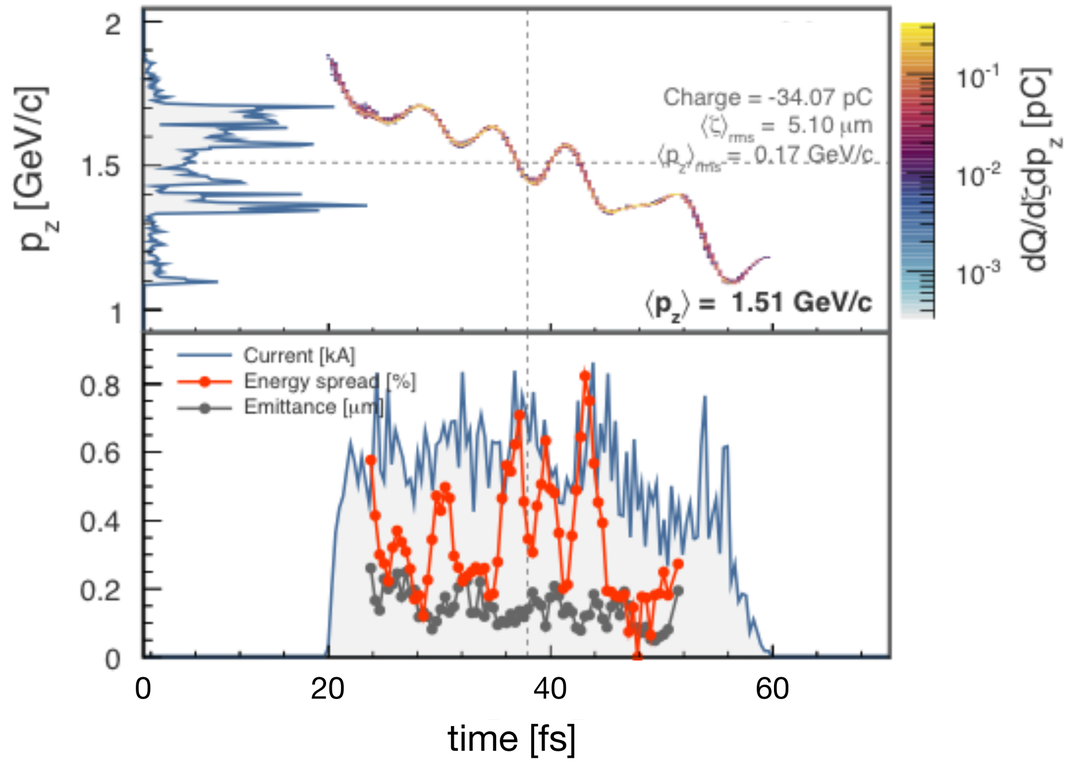
Witness-beam parameters after 140 mm of propagation ⟶

- beam at 1.5 GeV with 1.0 GeV driver
- further acceleration to ~2.0 GeV possible
- projected normalized transverse emittance < 0.5 μm
- strong longitudinal correlation

Can such beams drive an FEL?



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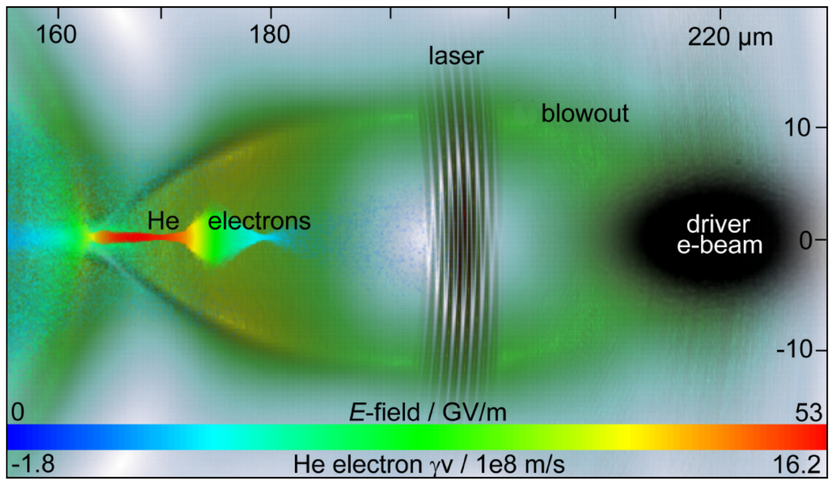
Laser-triggered ionization injection for controlling electron trapping

> Simulations: *A.Martinez de la Ossa (FLA), B.Hidding (UHH)*



from B. Hidding, Phys. Rev. Lett. 108, 035001 (2012)

- laser triggers ionization and injection of electrons from He
- first experiments by B.Hidding planned at FACET E-210
  → lessons learned will help to optimize experiment at FLASH
- laser-to-beam synchronization crucial

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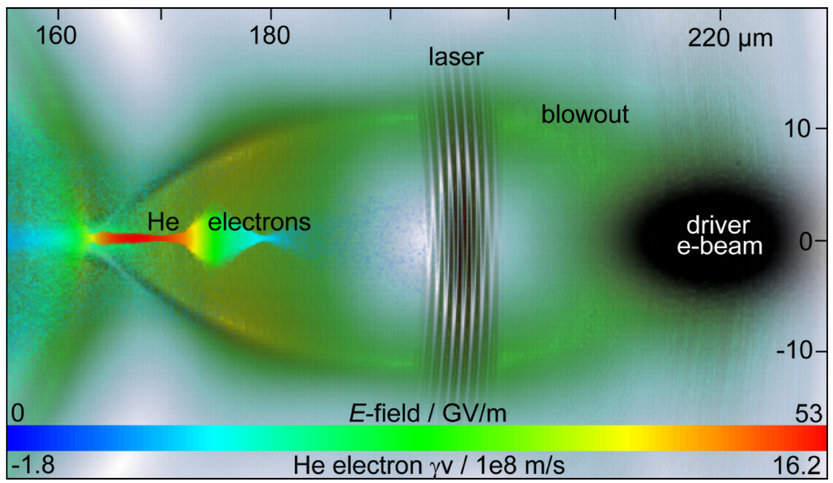

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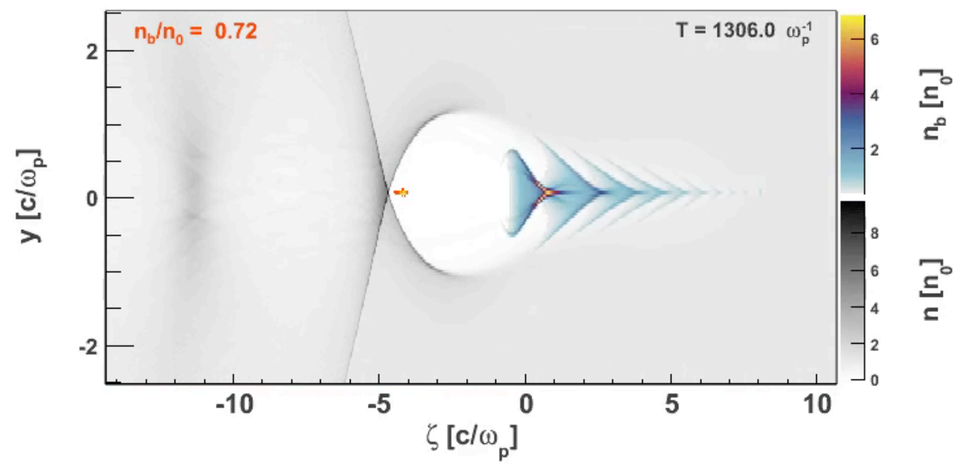
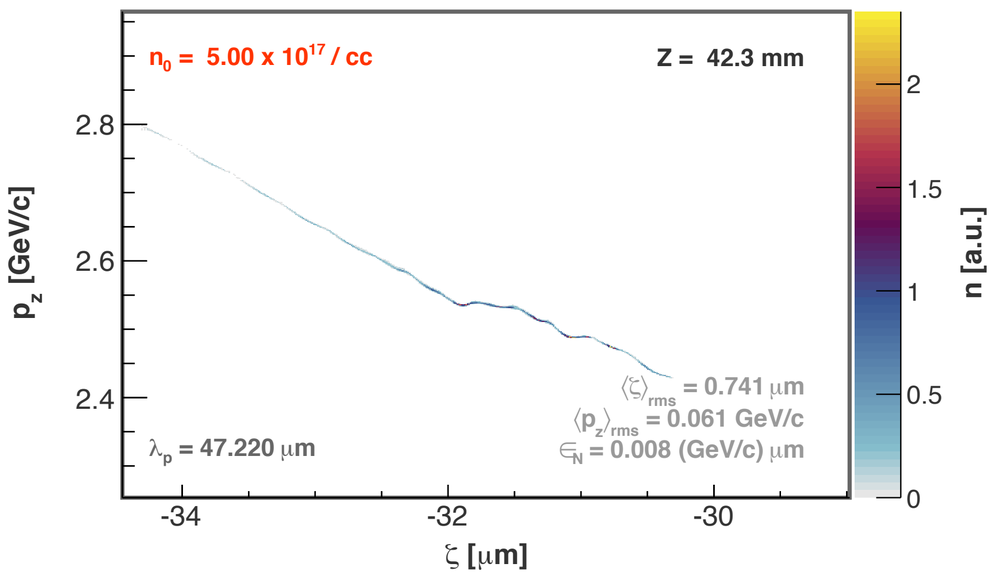
Witness-beam parameters after 42 mm of propagation ⟶

- beam at 2.5 GeV with 1.0 GeV driver
- small sliced energy spread (~‰ level), emittance (~100 nm), ~kA current
- strong longitudinal correlation

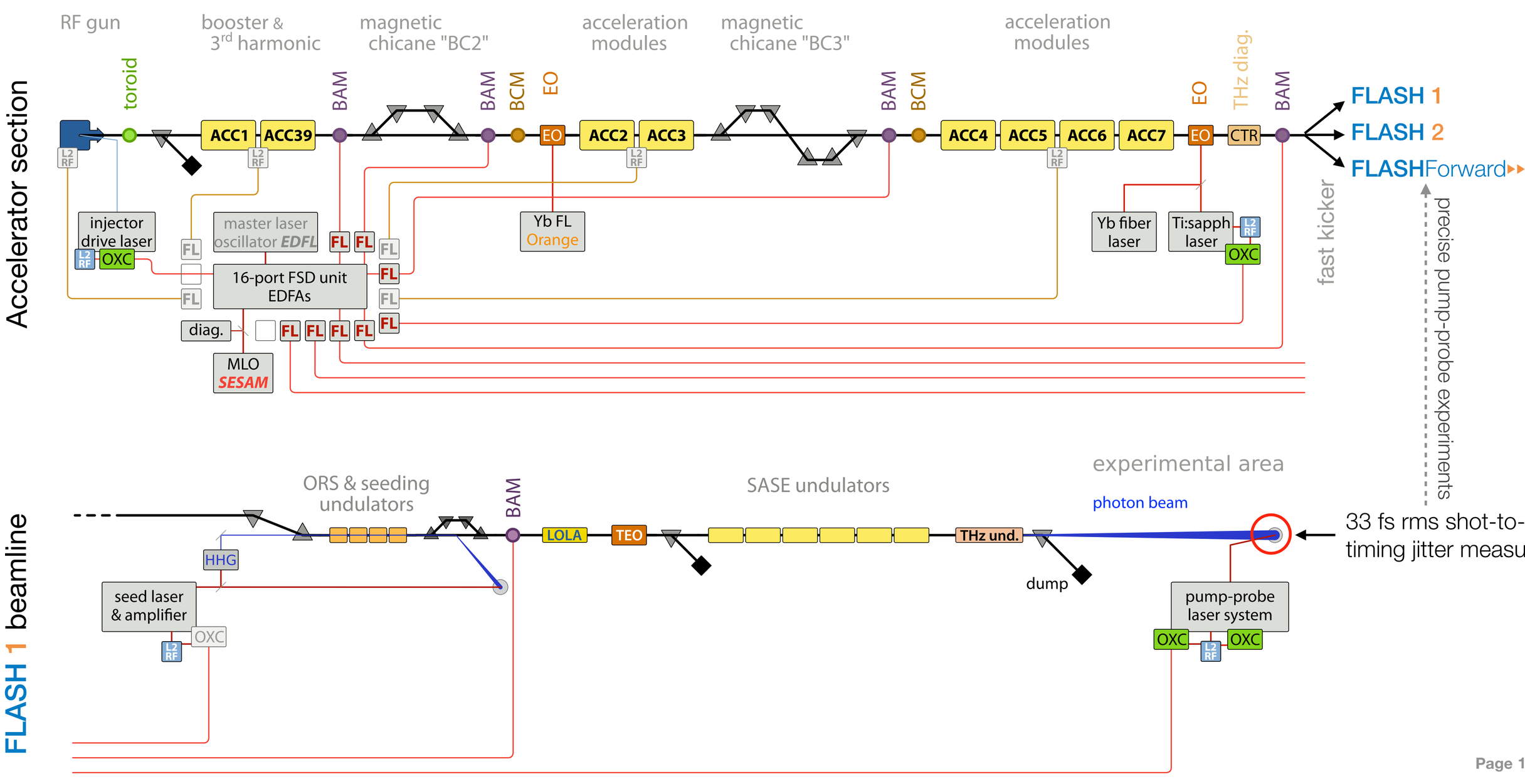
With FLASH parameters





FLASH timing system allows for beam-to-laser synchronization of ~30 fs rms

> Concept: *H.Schlarb (MSK)*



FLASH offers versatile, FEL-quality, electron beams for PWFA

Two operation modes

Standard mode: *symmetric beams for FLASH FEL operation.*

- model: Gaussian current profile, 20 to 500 fs long,
  10 µm rms focus size, ~1.2 GeV, 0.1% energy spread,
  1 µm emittance, < 2.5 kA peak current
- mode useable in parallel with FLASH 1/2 operation
  - FEL and PWFA have similar demands on beam quality:
    high current, short beams, low emittance

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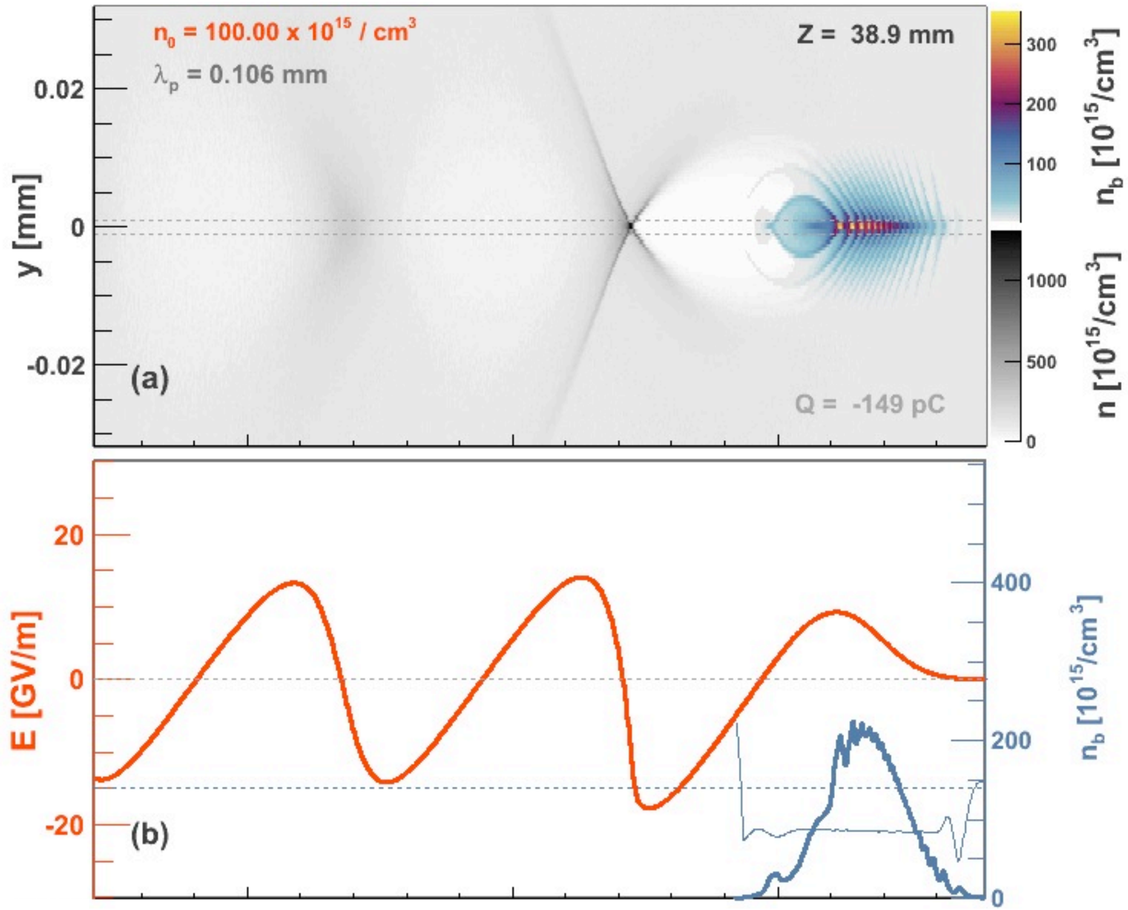


From OSIRIS 3D PIC simulations

- transformer ratio of ~2 is confirmed
- 17 GV/m peak field strength
- doubling of FLASH energy within
  less than 10 cm seems possible
- most of the physics programme can
  be investigated in this mode

osiris v2.0 — *3D particle-in-cell (PIC) simulation*

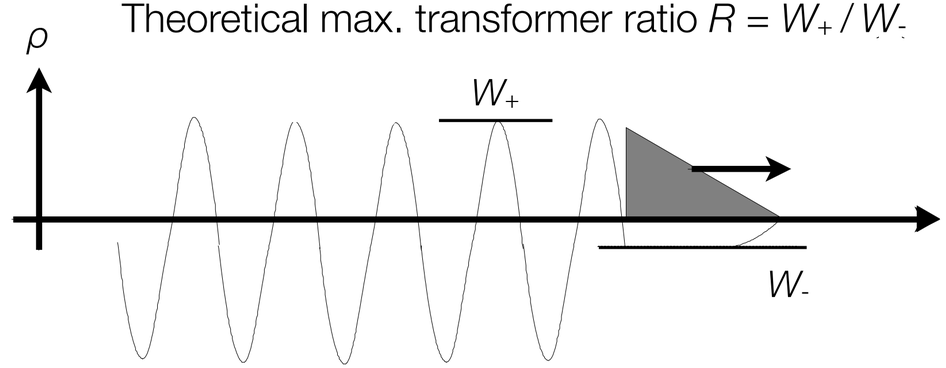
FLASH offers versatile, FEL-quality, electron beams for PWFA

Two operation modes

Shaped mode: *tailored triangular beams for PWFA*

- model: triangular current profile, 60 to 200 µm long, 10 µm rms focus size, ~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)

Theoretical max. transformer ratio $R = W_+ / W_-$



from J.G.Power *et al.*, PAC Proceedings 115 (2001)

- maximum energy of a witness beam $E_W = R \times E_D$

FLASH offers versatile, FEL-quality, electron beams for PWFA

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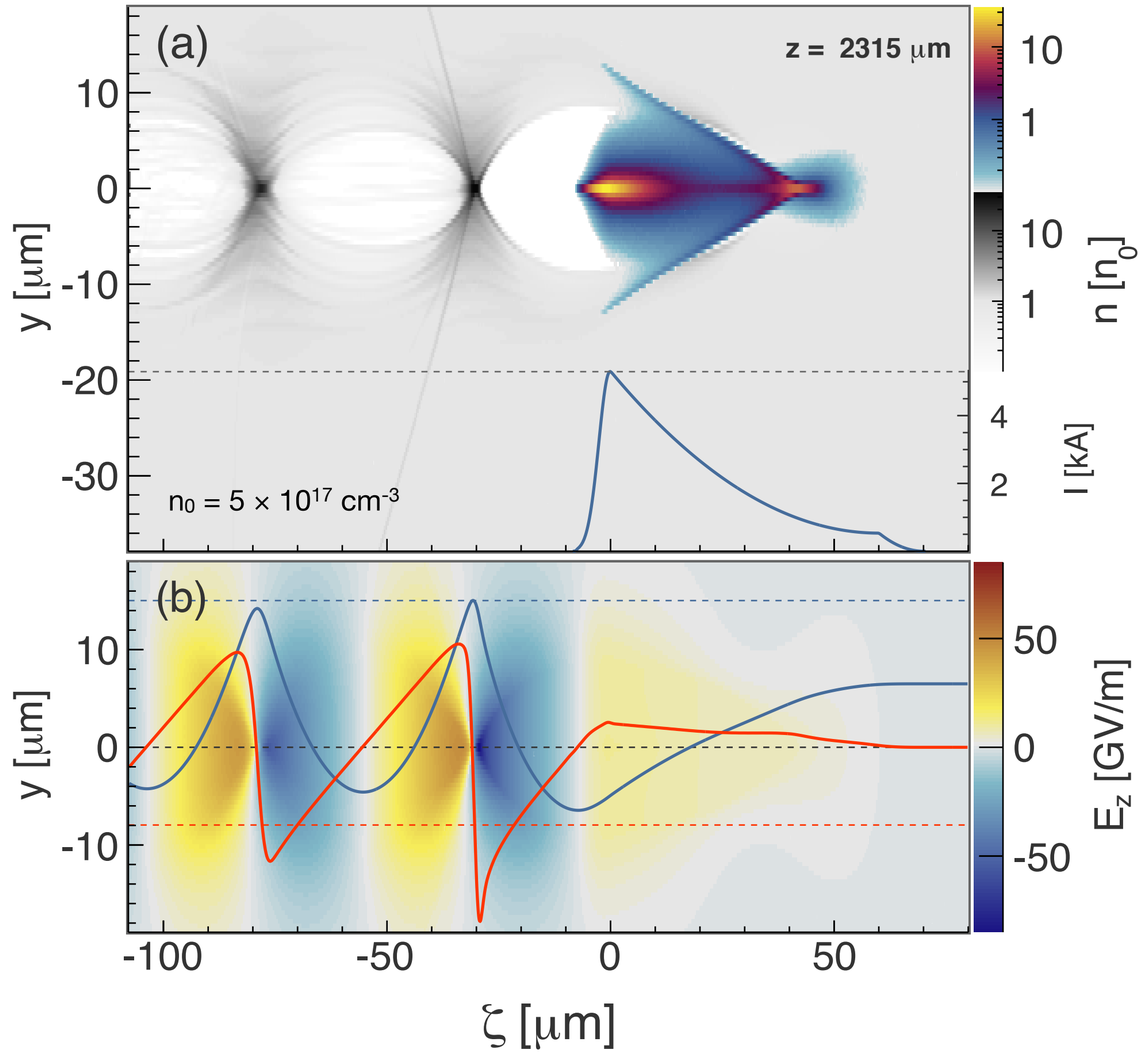

From OSIRIS 3D PIC simulations

- transformer ratio of ~**6** is confirmed
- **50 GV/m** peak field strength
- boosting the energy of a witness beam to ~5 GeV in less than 10 cm seems feasible

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Broad scientific programme for novel acceleration techniques

FLASHForward▸▸ *core studies*

> novel types of witness-bunch generation for unprecedented PWFA beam quality
- laser-triggered ionization injection
- wake-triggered ionization injection
- density down-ramp injection
- two pulses from photo gun

> transformer ratios of 2 and beyond
- boost beams to ~2 GeV
- boost beams to ~4+ GeV Triangular

> acceleration in dielectric structures

> demonstrate FEL gain

> bunch-quality for photon-science applications
- emittance, current, duration measurements
- first measurement of slice parameters *(with TDS)*

> stability/reproducibility of the process
- beam- and plasma-parameter influence on stability

In addition, Thomson scattering, novel diagnostic and timing schemes, component tests…

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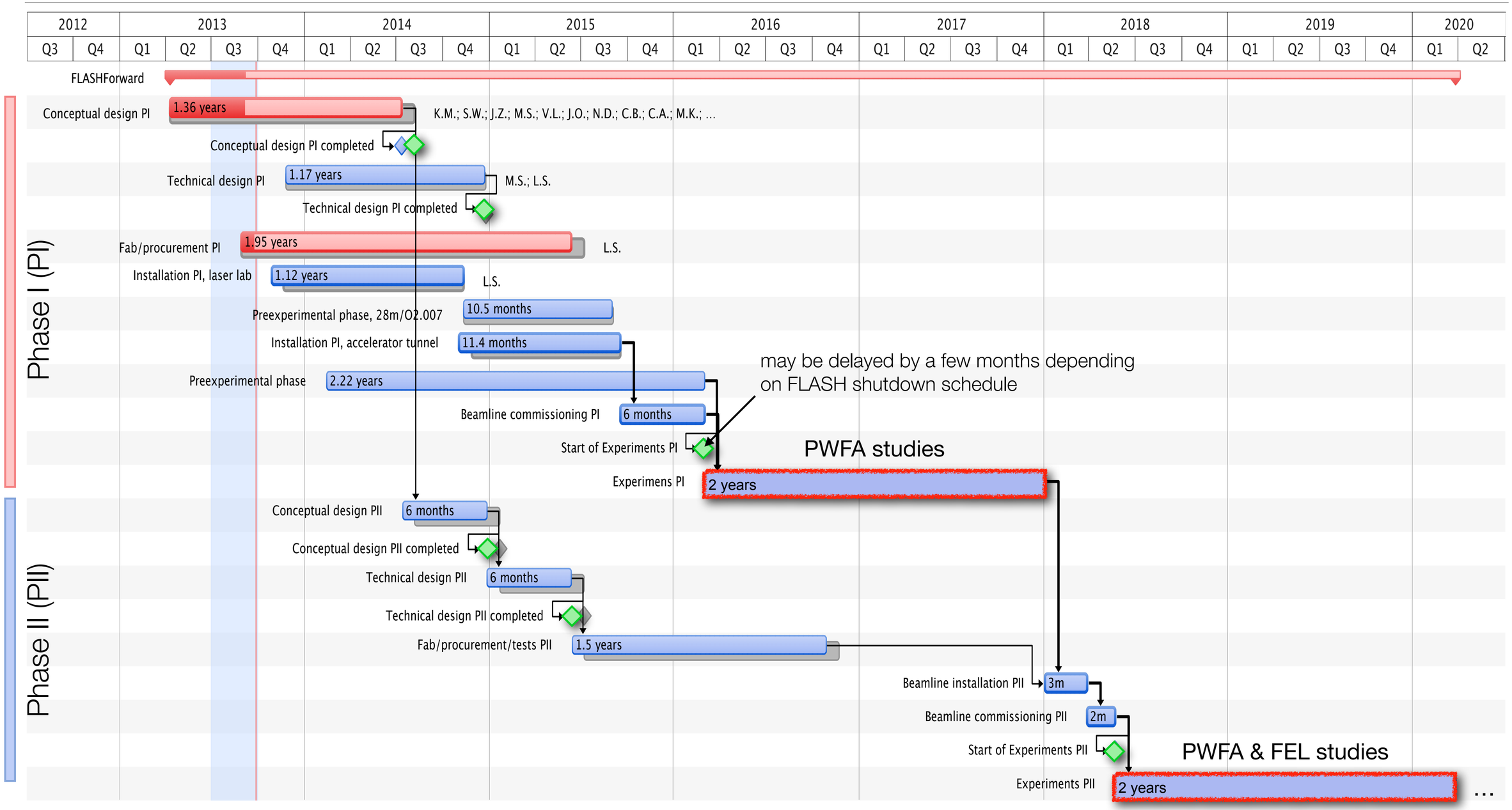
Experiments to start in 2016, run for 4 years+



Worldwide network and collaborations

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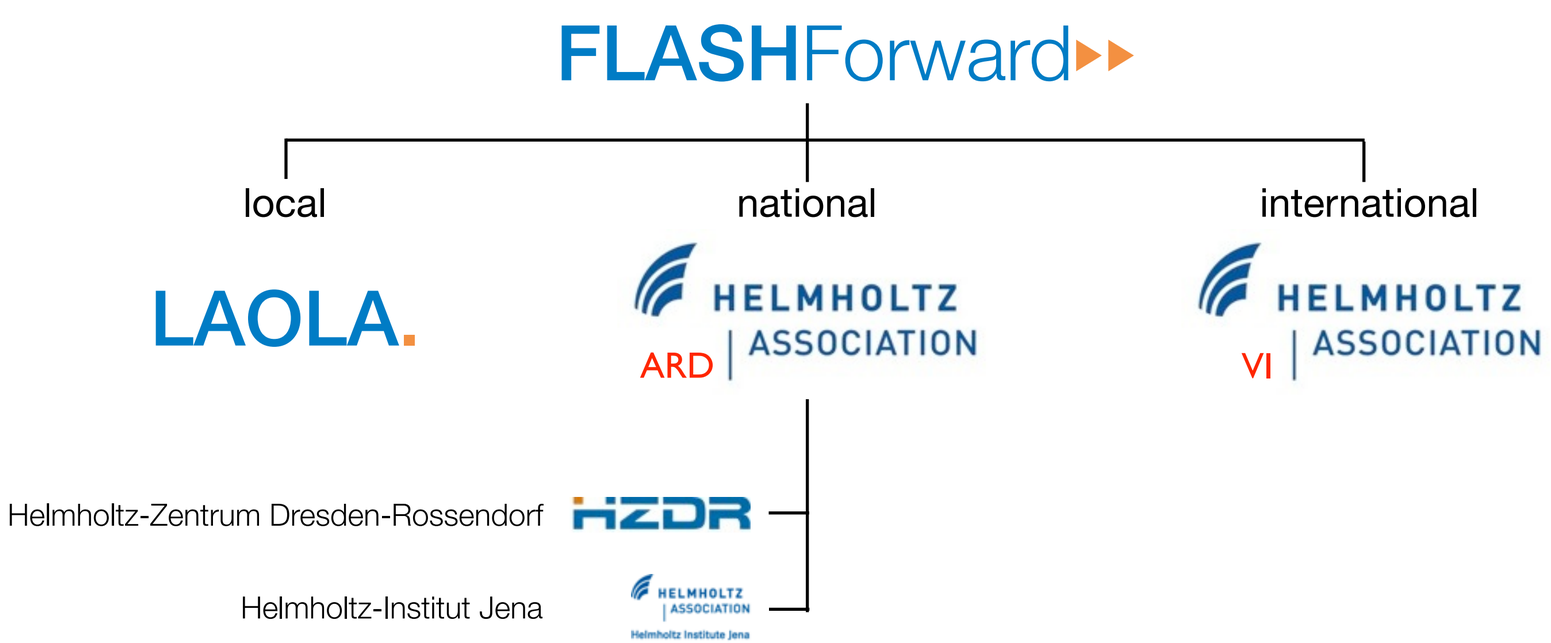

Worldwide network and collaborations

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local

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national

HELMHOLTZ ASSOCIATION ARD

Helmholtz-Zentrum Dresden-Rossendorf

Helmholtz-Institut Jena

international

HELMHOLTZ ASSOCIATION VI

John Adams Institute, UK

Lawrence Berkeley National Laboratory, US

Stanford Linear Accelerator Center, US

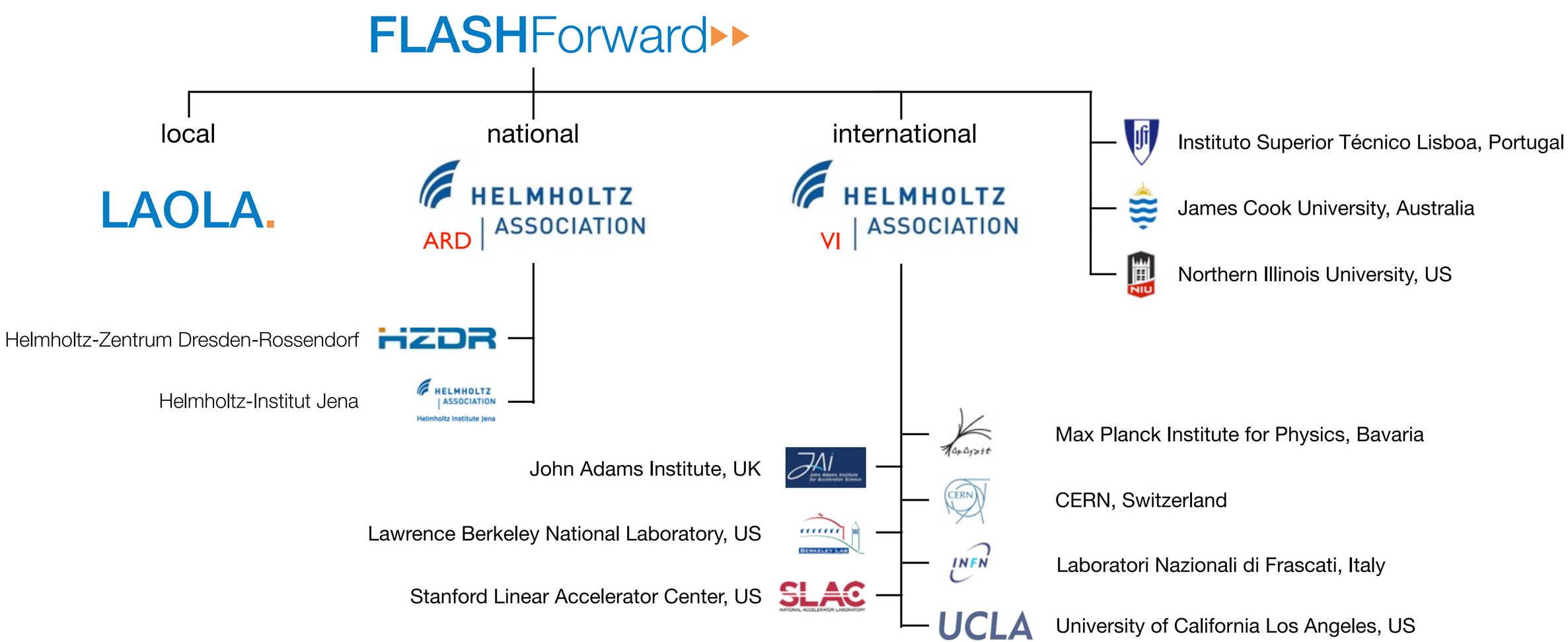
Max Planck Institute for Physics, Bavaria

CERN, Switzerland

Laboratori Nazionali di Frascati, Italy

University of California Los Angeles, US

Worldwide network and collaborations



Summary

- FLASHForward is a beamline for novel accelerator research and development
- Great chance to use a unique accelerator, ***FLASH***, for significant scientific contributions towards the field of PWFA
  - *external injection* and *in-plasma beam-generation* and acceleration techniques to provide high-energy (1.5 to 4+ GeV), low transverse emittance (~100 nm), ultrashort (~ fs), and high current (> 1 kA) electron bunches
  - *transformer ratios* beyond 2
  - the application of such beams to assess their potential for *free-electron laser gain* at photon energies inside and beyond the water window
- Numerous collaboration opportunities exists over the next 7+ years

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Opportunities for collaboration

- Resonant wake excitation by multiple beamlets → JAI
- Incoherent undulator radiation as beam diagnostic → JAI
- Dielectric wakefield acceleration
- e^--beam to laser timing jitter reconstruction
- Wakefield probing (e.g. frequency-domain holography, …)
- Hollow-core plasma waveguides
- FLASH beam current maximization
- Direct laser-e^--beam interaction
- External injection of FLASH beams into plasma-driven wakes
- Emittance characterization for nm beams
- Other beam diagnostics (Betatron diagnostics → JAI)
- Plasma target test with LWFA → JAI
- PIC Simulations
- …

Other ideas are welcome!

Let's discuss…