E-324: Optical visualization of beam-driven plasma wakefield accelerators

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+ FACET-II collaborators: M. Litos (UC-Boulder) & students, C. Joshi, K. Marsh (UCLA) & others
+ computational collaborators: T. Silva, J. Vieira (IST); K. Lotov & students (Budker Inst.)

Science Goals

Goal 1 (*6months-1year*) Long-time dynamics of post-wake plasma (with and without pre-ionization).
- delays from 0 to ~4ns (optical delay line - high temporal resolution)
- delays from 0 to ~μs or ~ms (coarser electronic delay up to full recovery of the medium)

Goal 2 (*1-1.5 years*) Medium-time dynamics (0 to ~100ps) of post-wake plasma .
- Formation and evolution of ion wake (including central density peak and its decay into a channel)

Goal 3 (*2 -3 years*) Short-time dynamics – plasma wake structure behind the electron driver
- Unloaded plasma wake structure with and without pre-ionization

Goal 4 (*2 -3 years*) short and long time dynamics (with and without pre-ionization).
- loaded and unloaded wake structure
- structure of electron wake formed within the evolved ion wake
- magnetic field detection and mapping

Definition of success

Minimum: Goal 1 - These results would form an important extension of FACET-I results.

Ideal: Goals 1 – 4.

Experimental Timeline

Experimental design: ***DONE***
- A mock setup is currently being constructed and tested in UT.

Installation plan: ***DONE***
- CAD drawings of setup supplied.
- Simple single-camera/lens for testing phase; multi-camera/lens for science experiments.

Ready for Experimental safety review: ***YES***

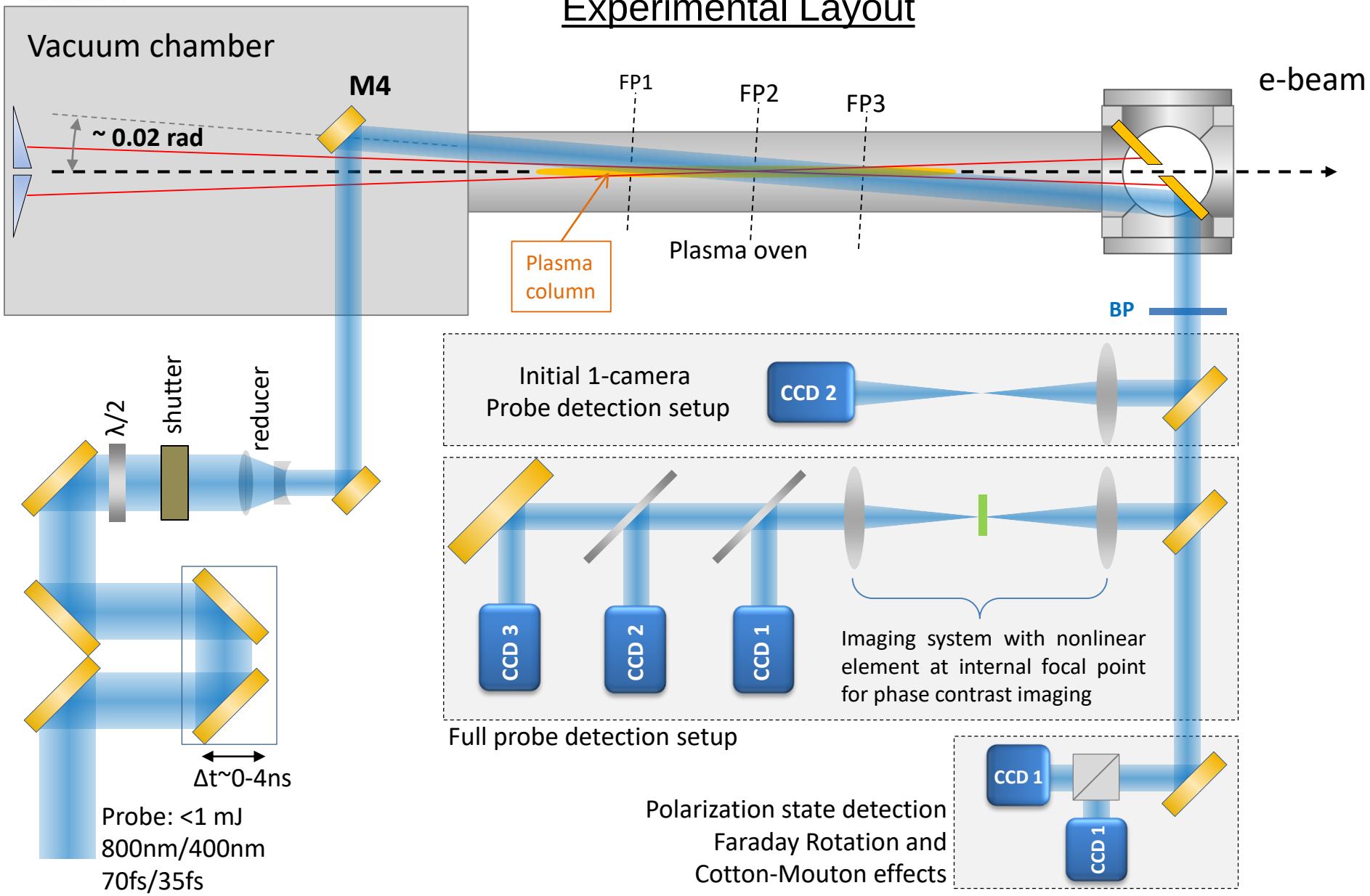
Ready for installation: ***Dec.2020 – Jan.2021***
- next few weeks for beta-testing at UT desirable

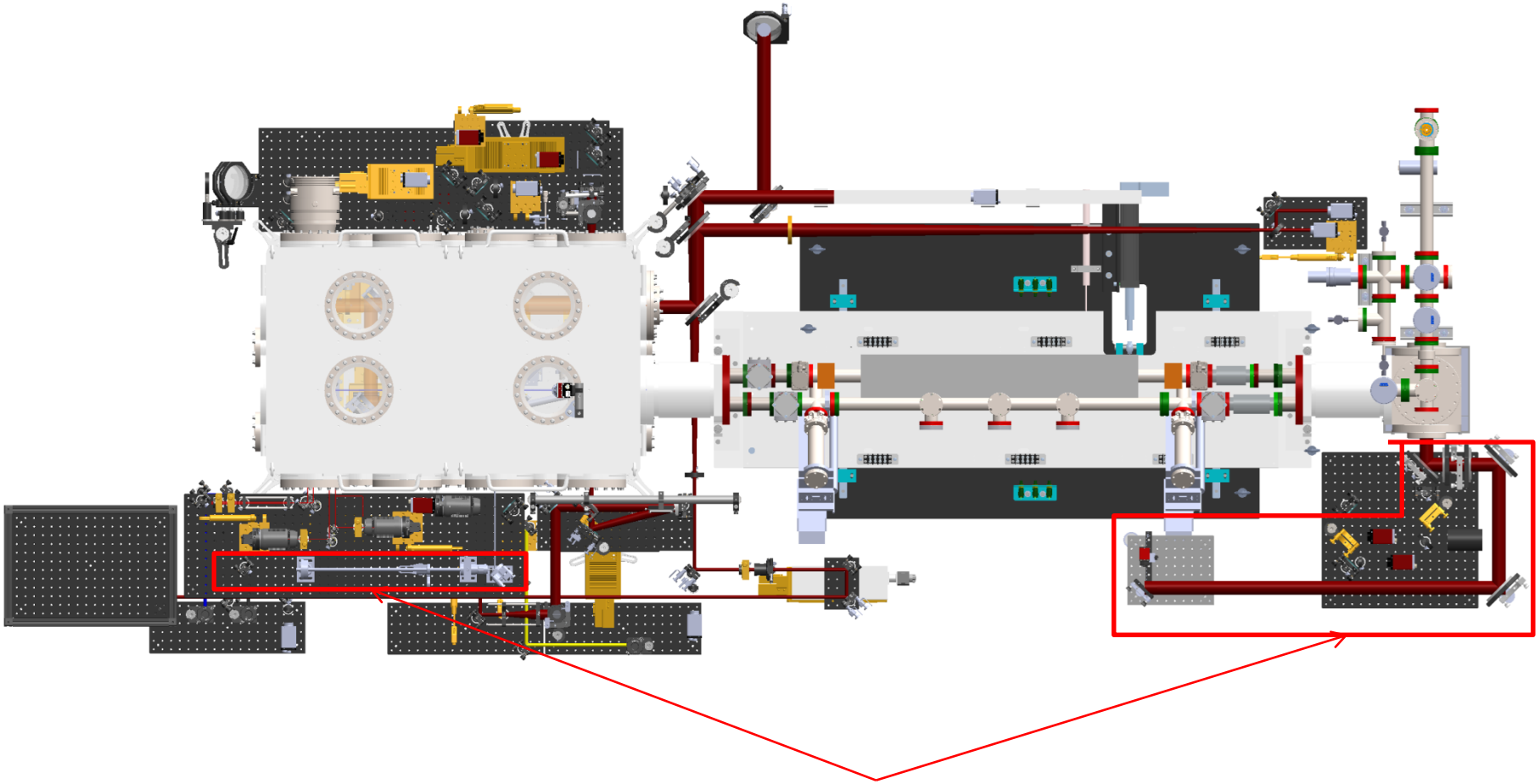
Ready for commissioning: ***Jan.2021***
- Commissioning of optical setup requires only laser probe beam.
- Both the probe beam and low power main beam required for full setup.

First science: beam requirements:
- no special beam requirements for the initial experiments.
- nominal FACET-II beam parameters. Single bunch – no witness bunch.

2 phases of the program:
- first phase ***Jan.2021*** : single camera shadowgraphy NEXT SLIDE
- second/third phase: multiple camera shadowgraphy for phase/polarization measurement NEXT SLIDE

Experimental Layout





CAD Model: Henrik Ekerfelt

Diagnostics and observables

- Lithium vapor density, bypass line diagnostics.
- Laser beam parameters: Energy, spectrum, intensity profile, phase profile, pointing data, delay between laser probe/ionizing pulse and electron beam. Bessel beam parameters when plasma is laser pre-ionized.
- Electron bunch parameters before and after the interaction point
- E324: probe shadowgraphic images, from single or multiple cameras, polarization state of probe all correlated with above laser and electron beam diagnostic data.

Potential Future Evolution of the Experiment beyond what was presented to PAC

- Transition from multi-shot to single shot plasma wake detection
- Transition from single to multiple probes
- Diagnostics of e-beam driven positron wakefield acceleration
- Radiographic probing of the plasma wave and bunch fields. Requires a laser wakefield generated electron probe – upgraded laser system.

Collaborations

The University of Texas at Austin, Austin, Texas, USA

Budker Institute of Nuclear Physics SB RAS, Novosibirsk, Russia

Novosibirsk State University, Novosibirsk, Russia

Insituto Superior Tecnico, Lisboa, Portugal

École Polytechnique Université Paris-Saclay

University of California Los Angeles

University of Colorado Boulder

University of Strathclyde Glasgow

SLAC National Accelerator Laboratory, Menlo Park, CA, USA

Desired Facility Upgrades

- Continued improvements of laser system stability, mode quality.
- 400nm optical probe pulses (in addition to the currently planned 800nm). This is to increase spatial resolution and provide additional information about dispersion of the plasma/neutral gas mixture.
- Increased transverse diameter of plasma source chamber to increase the maximum optical probing angle and to allow for smaller f/# imaging for increased resolution. Addition of side ports in this chamber to facilitate transverse probing.
- Positron source to enable optical probing studies of positron acceleration visualization.

Publications, Students

Deng, A., Karger, O.S., Heinemann, T. *et al.* Generation and acceleration of electron bunches from a plasma photocathode. *Nature Physiscs* **15,** 1156–1160 (2019). https://doi.org/10.1038/s41567-019-0610-9

Rafal Zgadzaj, T. Silva, V. K. Khudyakov, *et al.* Dissipation of electron-beam-driven plasma wakes. *Nature Communications* **11,** 4753 (2020). https://doi.org/10.1038/s41467-020-18490-w

University of Texas students participating in the FACET II campaign:

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