FLASHForward X-1

High-quality electron beams from a plasma cathode

A. Knetsch [1], S. Bohlen [1] ,J. Dale [1], R. D'Arcy [1], J.-H. Röckemann [1], B. Hidding[2], Z. Hu [1], V. Libov [3], T. Mehrling[1], P. Niknejadi[1], A. M. de la Ossa [1], K. Poder [1], L. Schaper [1], B. Sheeran[1], M. Streeter[1], G.Tauscher[1], M. Quast [1], J. Zemella [1], J. Osterhoff [1]

[1] Deutsches Elektronen Synchrotron, DESY
[2] University of Strathclyde, SCAPA, SUPA,
[3] Institute of Experimental Physics, University of Hamburg

HELMHOLTZ ASSOCIATION

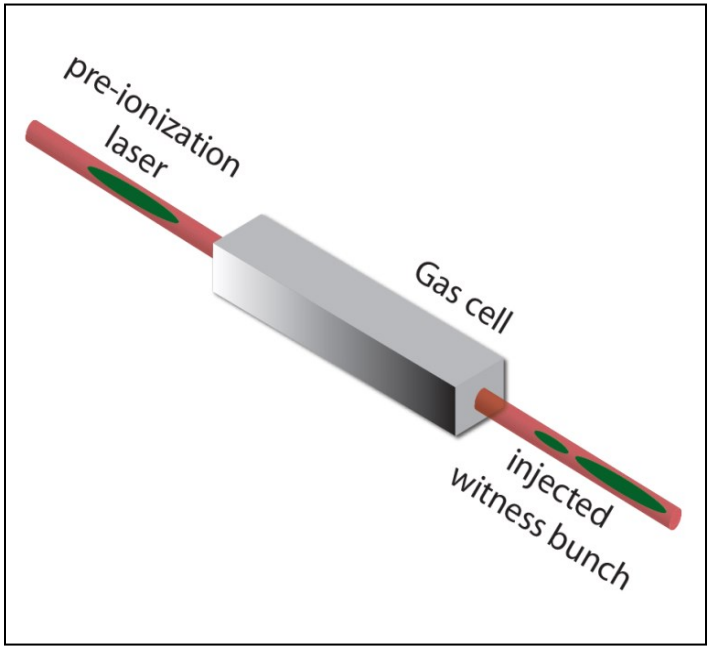
MT ARD MATTER AND TECHNOLOGIES ACCELERATOR RESEARCH AND DEVELOPMENT

FLASHForward

DESY

X-1: The Plasma Cathode

Target witness bunch properties	
Energy	> 1 GeV
Bunch length	1 - 20 µm
Emittance	< 1 µm
ΔE/E	~ 1 %



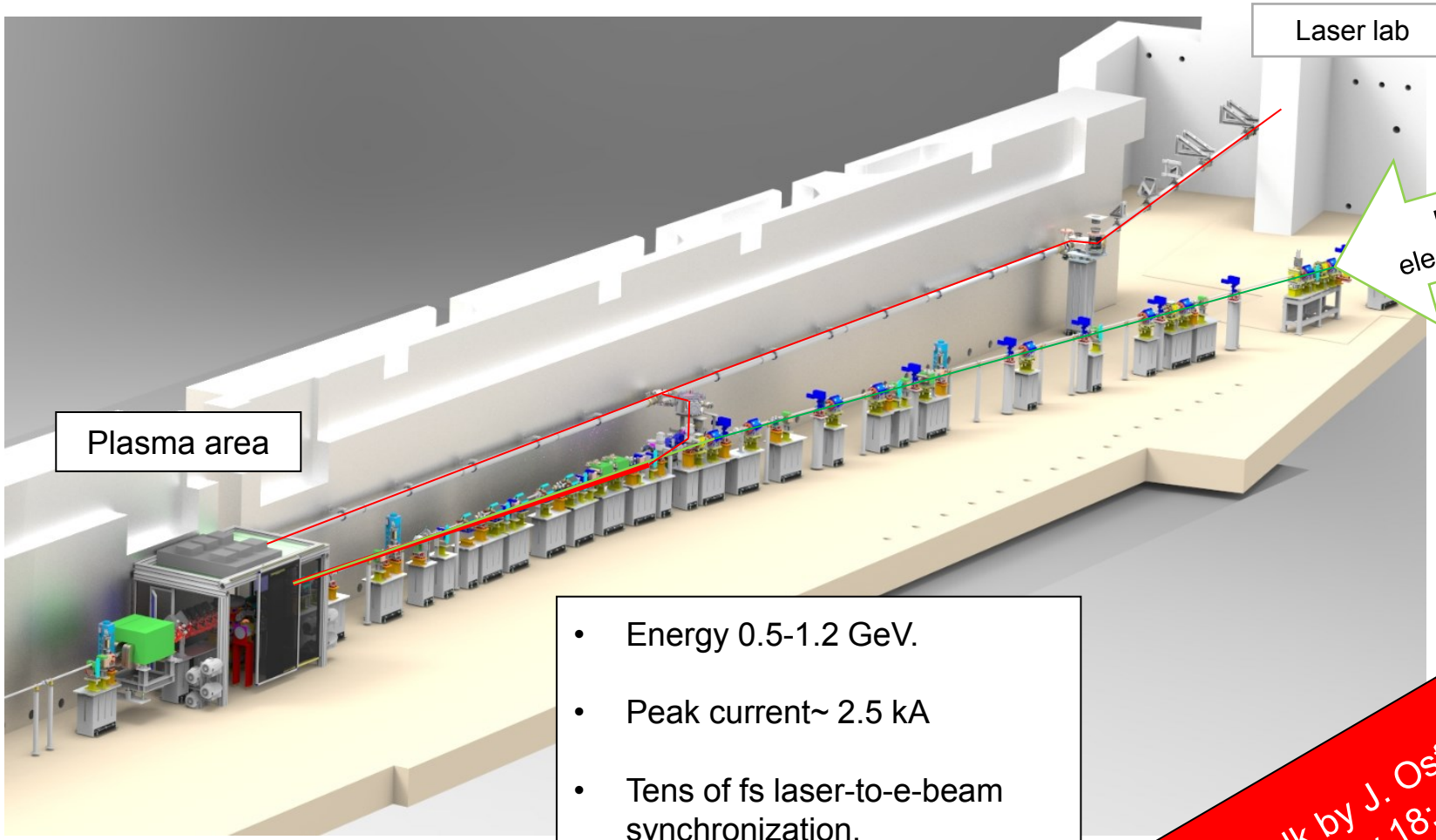
- Trojan Horse injection
- Laser-triggered Density downramp injection “Plasma Torch”

BMBF Verbundforschung:

- University of Düsseldorf
- University of Hamburg
- University of Jena
- University of Strathclyde

X-2: See talk by V. Libov Tuesday 18:36 WG1

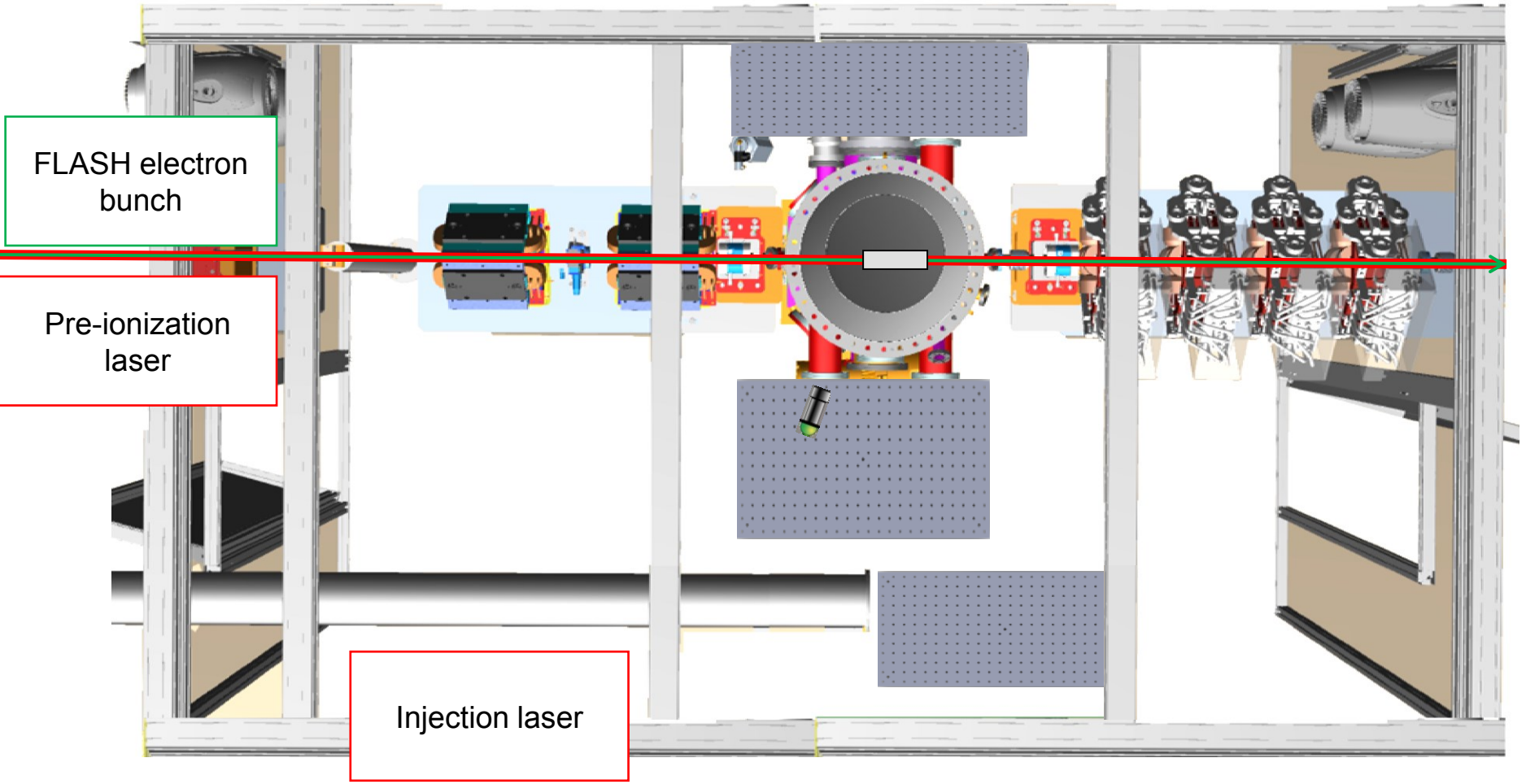
The FLASHForward PWFA facility



- Energy 0.5-1.2 GeV.
- Peak current~ 2.5 kA
- Tens of fs laser-to-e-beam synchronization.
- Control over longitudinal bunch shape.

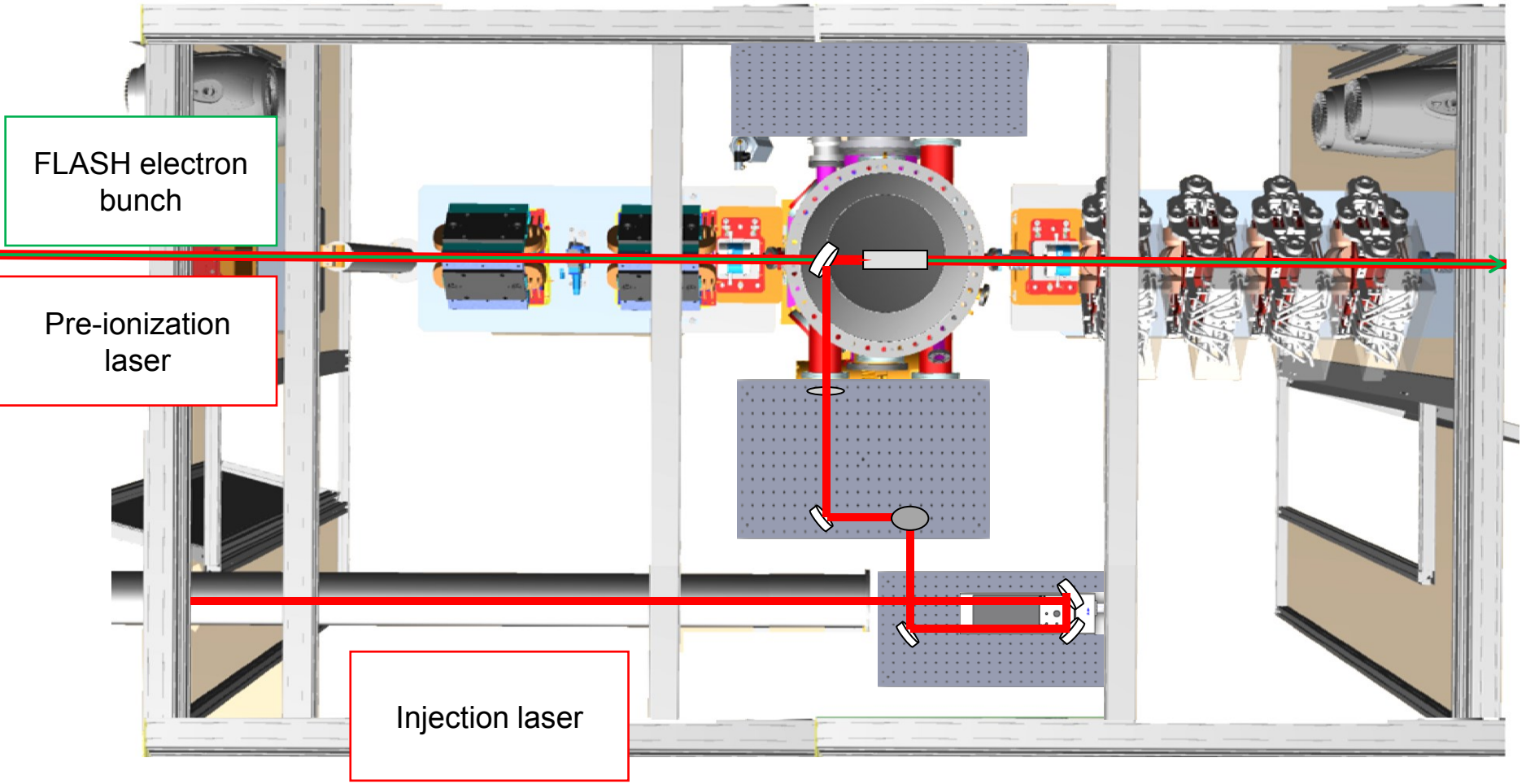
See talk by J. Osterhoff
Wednesday 18:45 WG1

The FLASHForward Plasma area



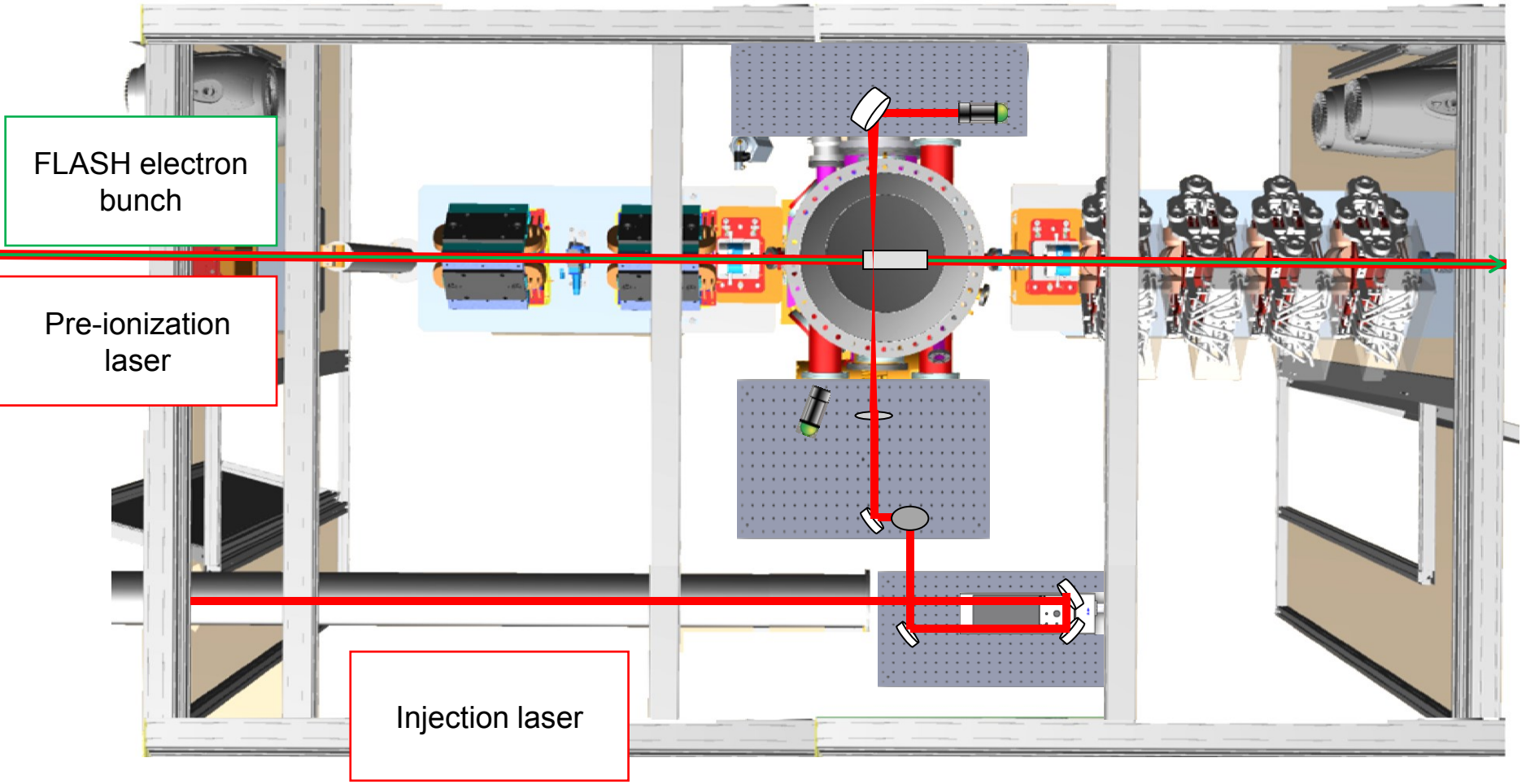
Courtesy F. Marutzky

Setup for Trojan Horse injection



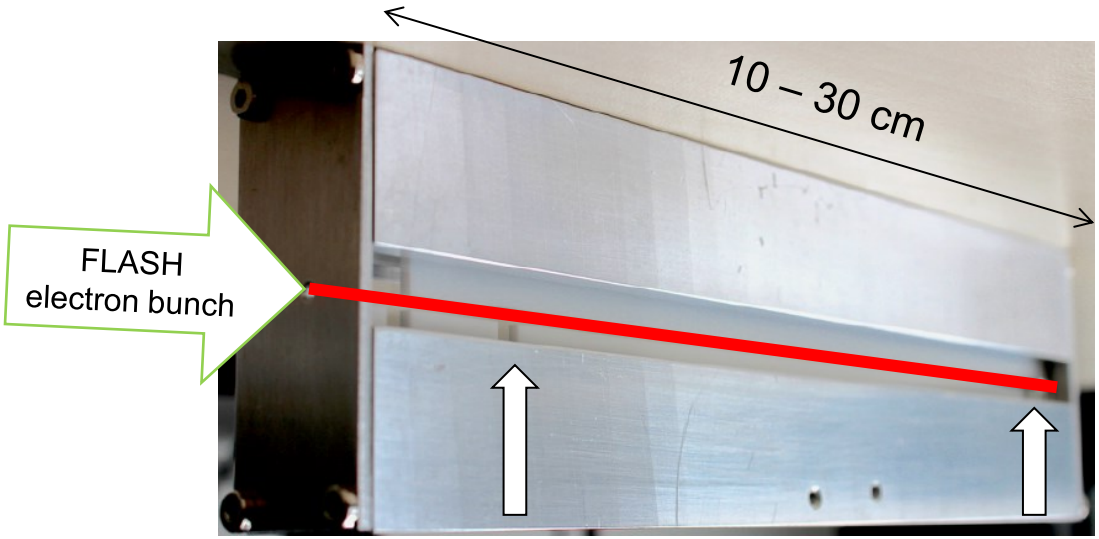
Courtesy F. Marutzky

Setup for Density-Downramp injection



Courtesy F. Marutzky

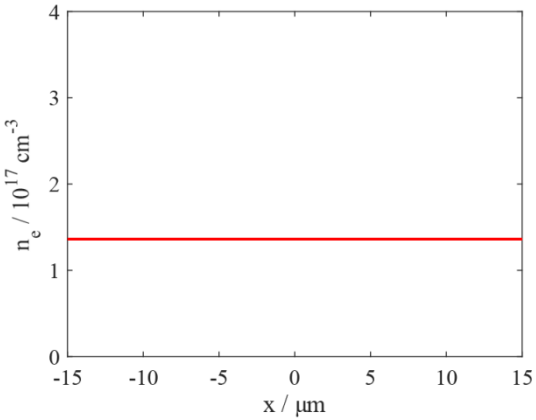
The gas cell



Gas inlets with H_2/He gas

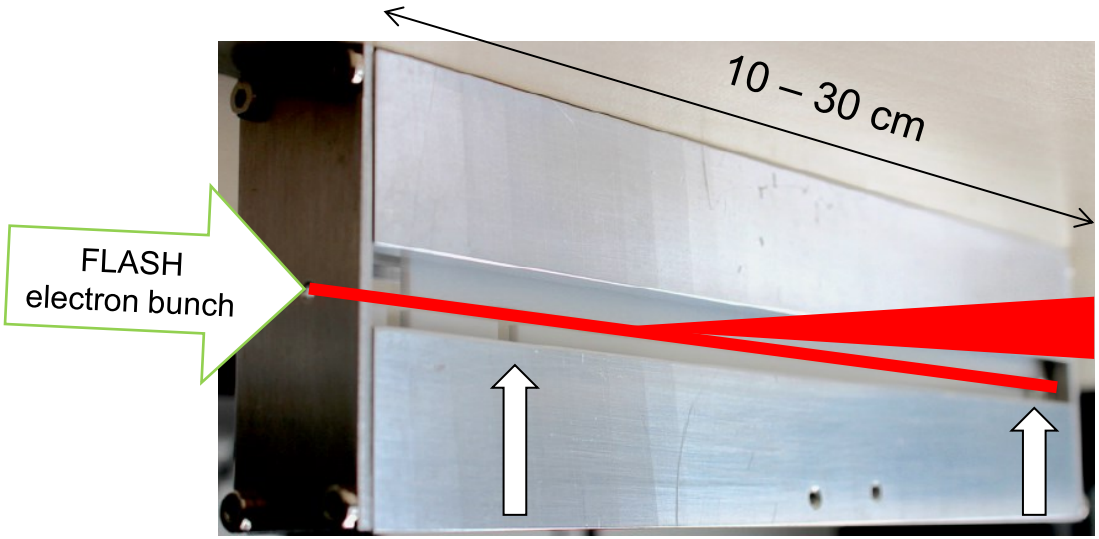
- H_2 ionization: Total gas density determines electron density.

Courtesy L. Schaper

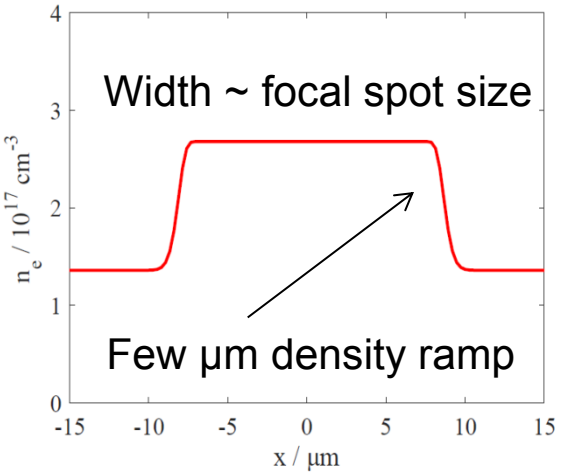


The plasma cell

Key parameters



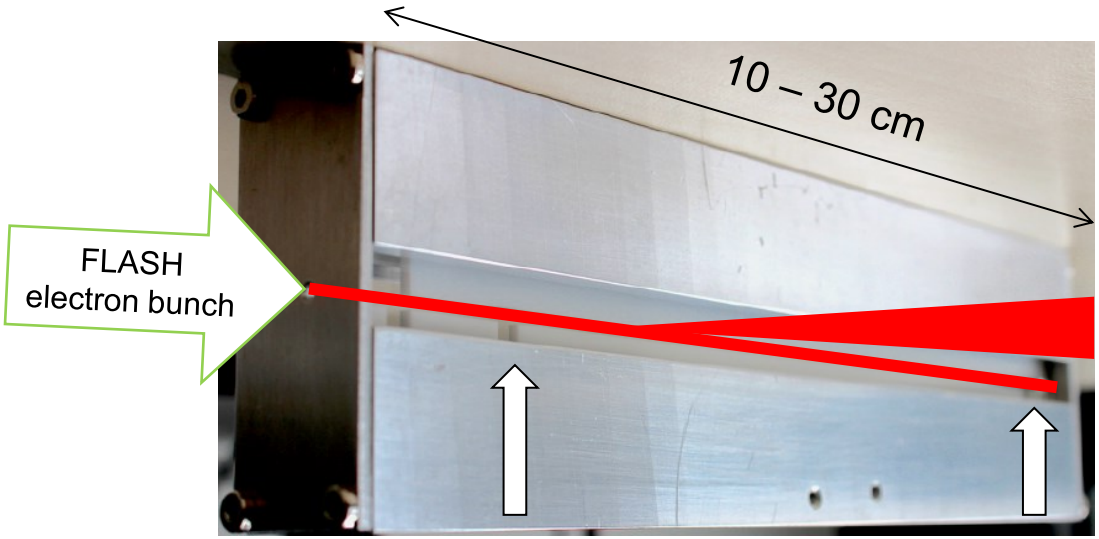
Gas inlets with H_2/He gas



- H_2 ionization: Total gas density determines electron density.
- Focussing determines slope and width of density spike.
- Adaptive optics to shape precisely plasma shape.

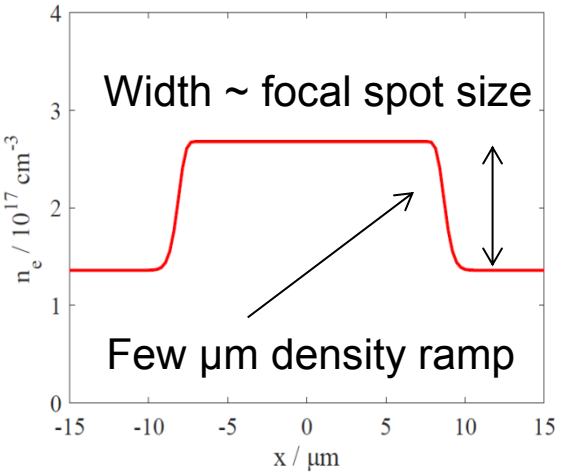
The plasma cell

Key parameters



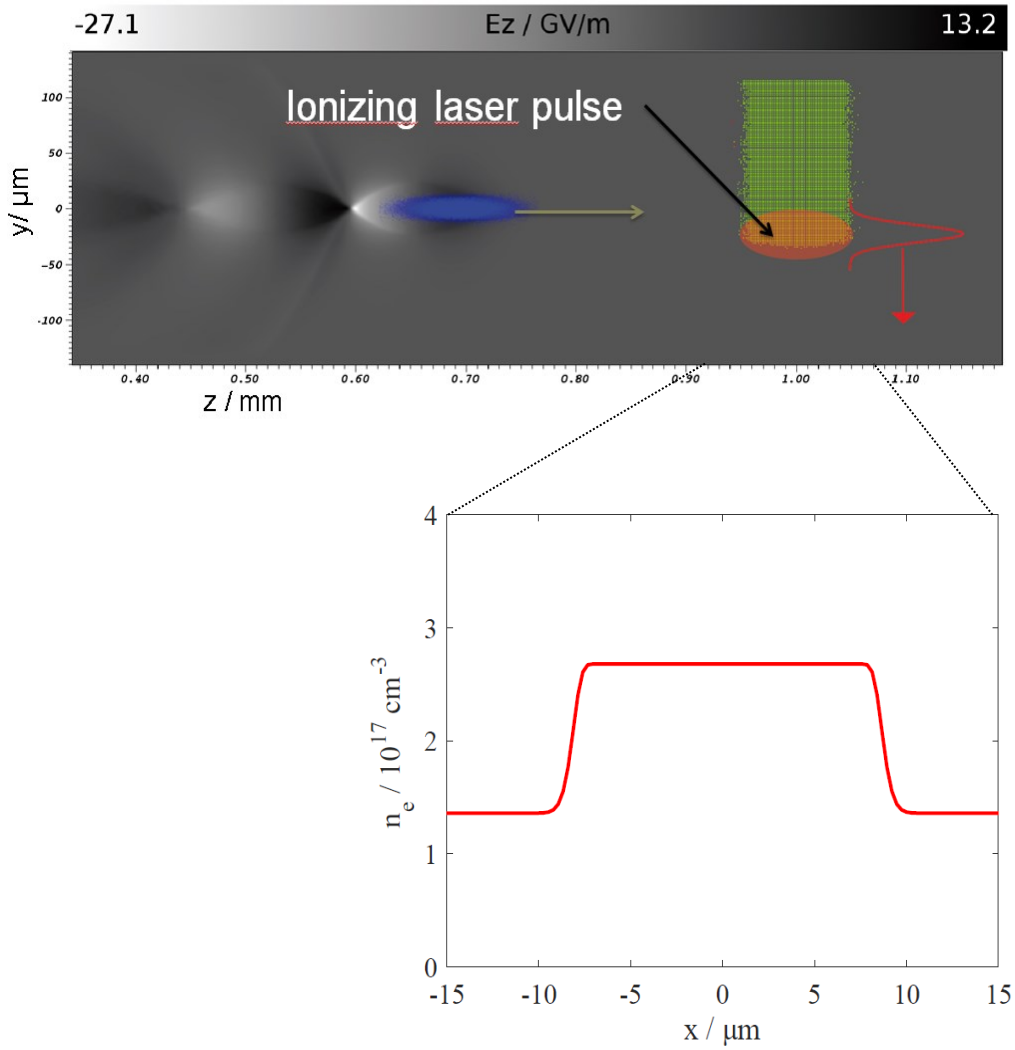
Gas inlets with H_2/He gas

- H_2 ionization: Total gas density determines electron density.
- Focussing determines slope and width of density spike.
- Adaptive optics to shape precisely plasma shape.
- Total gas density and H_2/He ratio determine upper-plateau electron density.



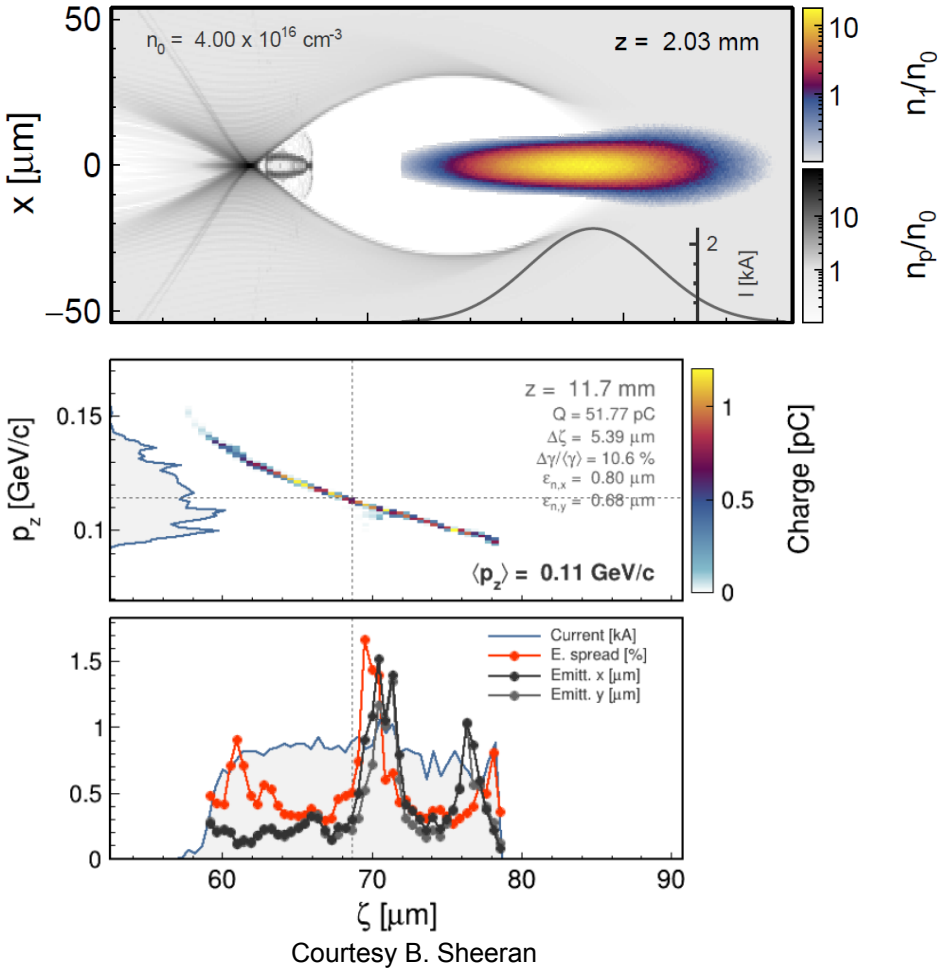
Variable gas densities

The principle of laser-triggered DDR injection



- Decreasing plasma density causes expansion of plasma wake .
- Density downramp leads to decrease phase velocity of plasma wake.
- Decreased phase velocity enables injection of sheath electrons.

PIC simulations



Courtesy B. Sheeran

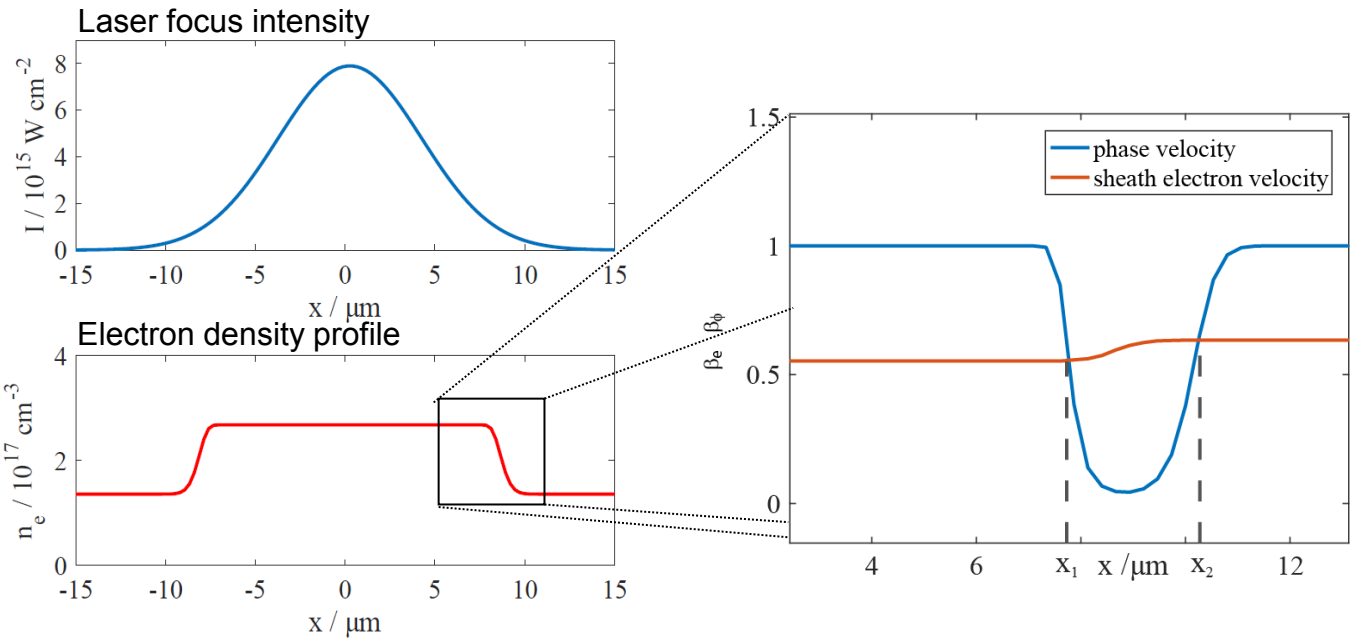
- Density-downramp injection in PWFA can generate electron bunches with few kA current sub-µm emittances and few-percent energy spread [2].
- Simulations with realistic parameters are promising.
- Transverse normalized emittance < µm.
- 4D Brightness ~ 6x10^{15} A m^{-2} rad^2.

See poster by B. Sheeran
Monday 19:30

[2] AM de la Ossa et al., PRAB 2017

Engineering scaling law

Effective model for injected charge



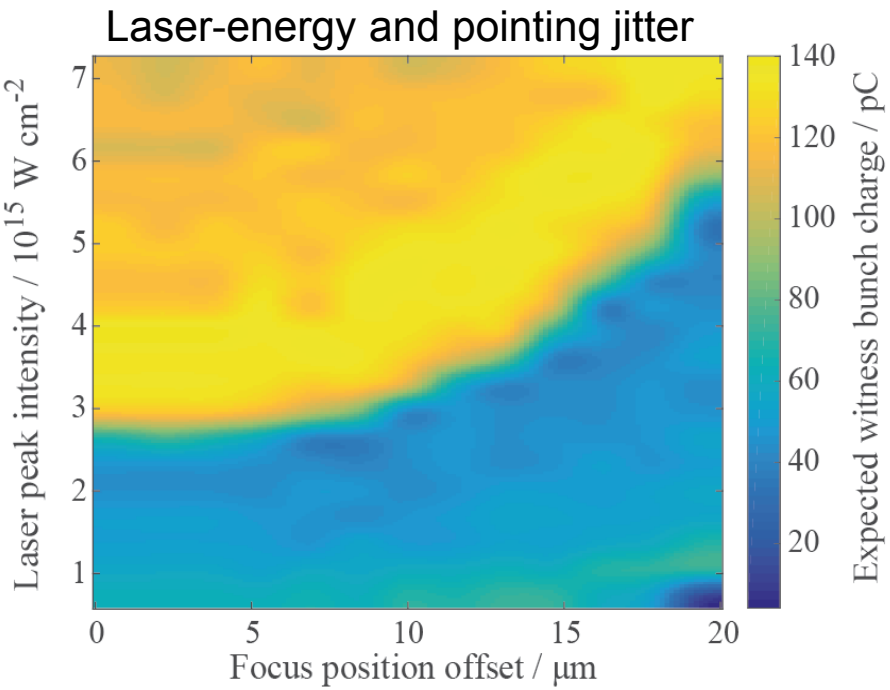
1. Calculate focal spot.
2. Calculate He ionization with ADK.
3. Density gradient → phase velocity
   - Injection criteria: $v_\phi < v_e$

$$v_\phi(\xi, z) = \frac{c}{\frac{1}{2n_e}\frac{\partial n_e}{\partial z}\xi + 1}$$

4. Charge estimate fitted from sim. parameter study: $Q \propto \int_{x_1}^{x_2} k_p^3 n_e(x) dx$

Stabilization studies

Expected injected charge

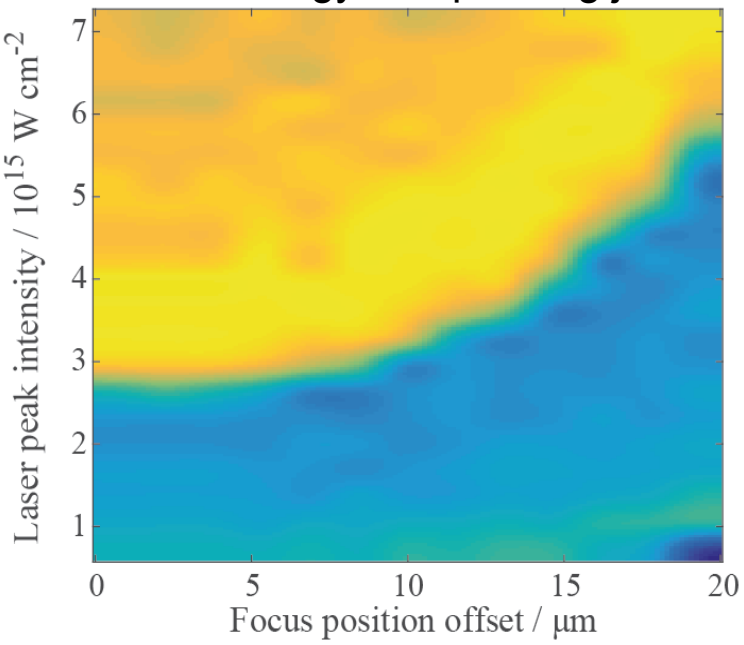


- Pointing and energy jitter show a large parameter space with constant charge.

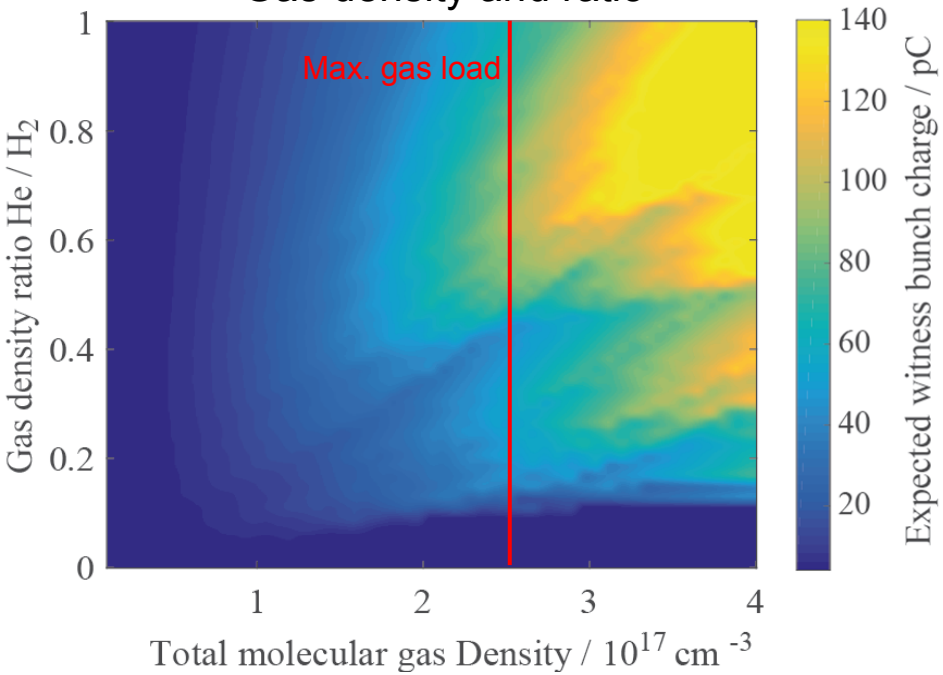
Stabilization studies

Expected injected charge

Laser-energy and pointing jitter



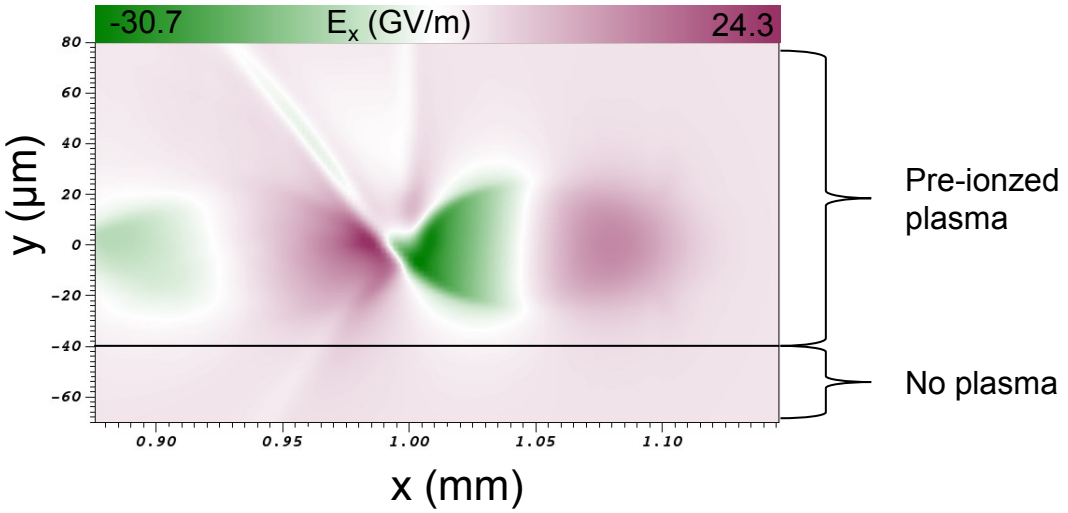
Gas density and ratio



- Pointing and energy jitter show a large parameter space with constant charge.
- Gas density and He/H_2 ratio calculations indicates ~ 50:50 mixture.

Dark Current mitigation

Ensure density-downramp is source of injection

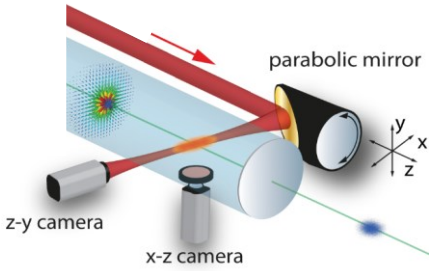


Witness bunch parameters	
charge	111.7 pC
rms bunch length	18.1 mu
emittance	1e-5 m rad
peak current	1.3 kA
Divergence	65 mrad

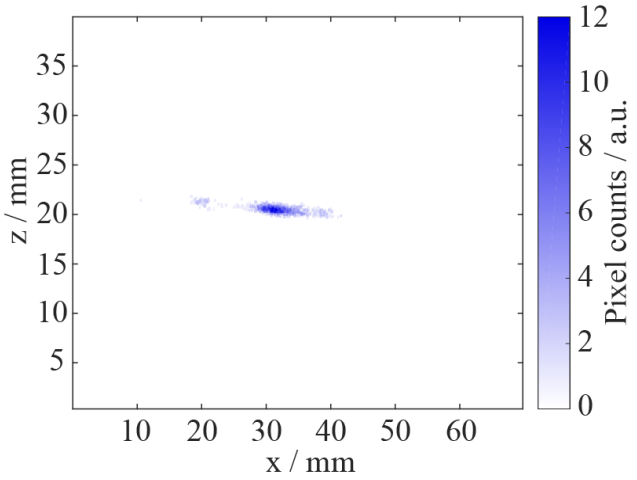
- Ionization injection → Expected fields too low.
- Deformed blowout near plasma edge (40 µm)
  - → Injection at density spike.
- Low-quality witness bunch injected.
- Need for wide plasma channel and good alignment.

Synchronization and alignment

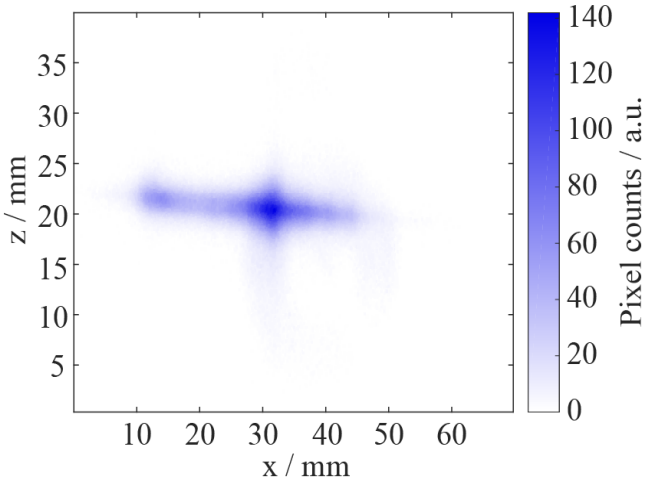
Observation of light-emission from plasma



Laser-ionization only



Electron-beam heated plasma



- Plasma heating from electron beam leads to additional ionization and largely enhanced recombination light signal.
- Method allows for fs-timescale synchronization and μm alignment [1] .

[1] P. Scherkl, A. Knetsch, ,T. Heinemann et al., in submission.
Poster by P. Scherkl

Summary

- X-1 aims at low-emittance electron bunches generated in an PWFA.
- Density-Downramp injection is capable of fullfilling set goals.
  - Emittance < 1 µm
  - Peak current > 1 kA
  - Brightness $>10^{15}$ A m^{-2} rad^2
- Dark Current mitigation properly prepared.
- Experimental setup nearly finished.

Summary

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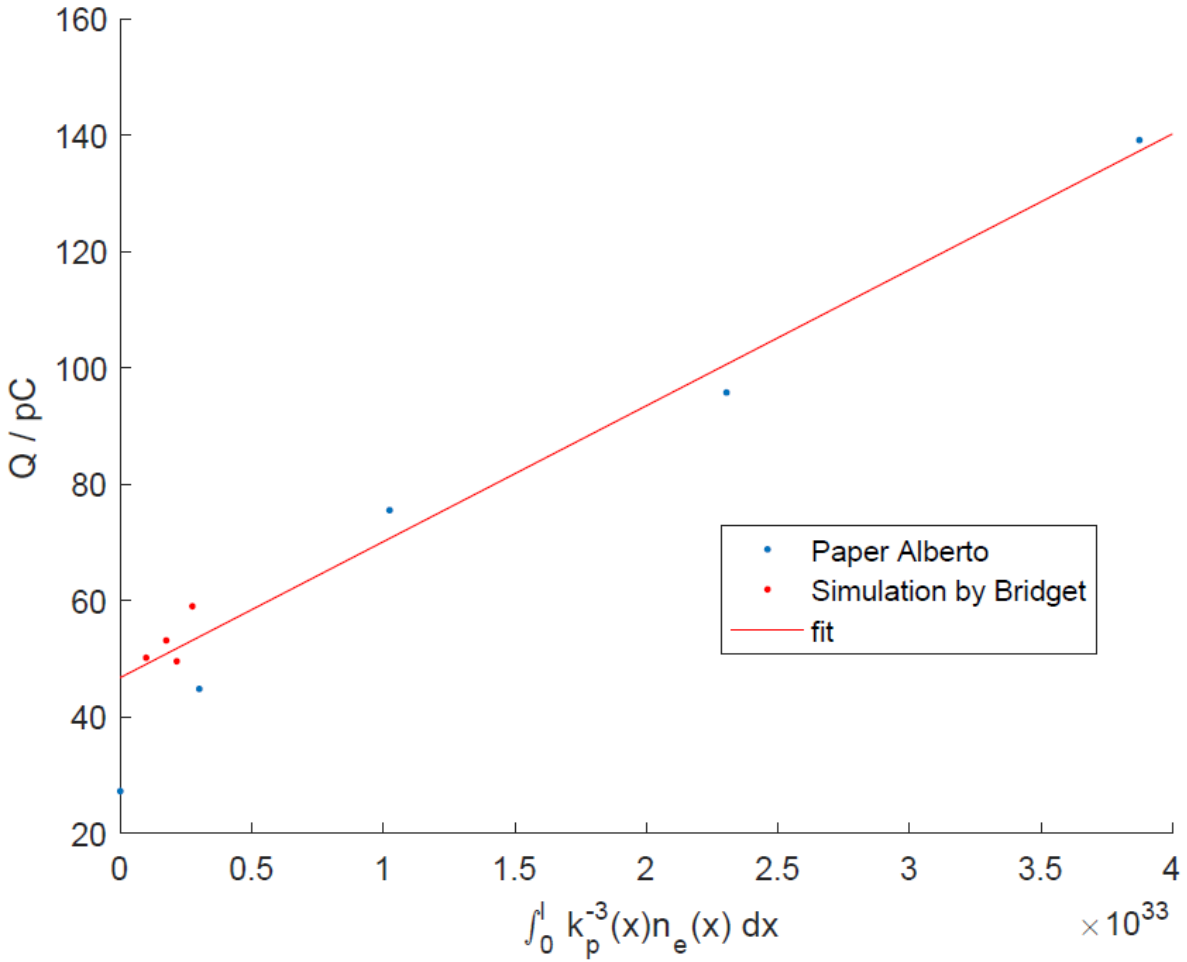
Next AAC: Report Injection

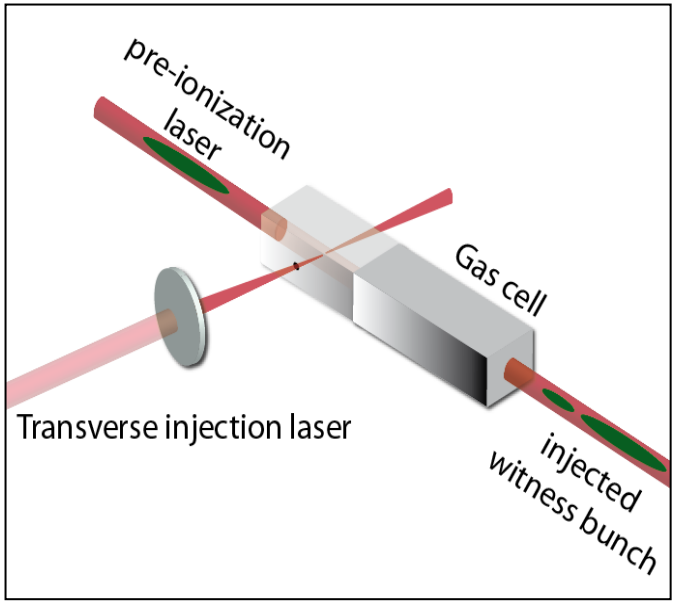
Annex

Calibration effective theory



Laser-triggered density downramp injection

- H_2 / He gas mixture
- Pre-ionization laser ionizes a wide H_2 plasma
- Injection laser-arm ionizes small He plasma with steep ramps
- Injection by density-downramp injection



FLASHForward at DESY