Working group 5

High-gradient plasma structures and Advanced beam diagnostics

Bernhard Schmidt, DESY

Olle Lundh, Lund University

EAAC 2017

Contributions

19 talks + 20 posters

Summaries from:

Thomas Audet (LPGP)
Simon Bohlen (DESY/UHH)
Fabrizio Bisesto (INFN)
Thomas Feurer (Uni Bern)
Spencer Gessner (CERN)
Mozhgan Hayati (Uni Bern)

Manuel Kirchen (DESY)
Carl Lindström (Oslo Univ)
Daniel Marx (DESY)
Erdem Oz (MPP)
Jan H Röckemann (DESY)
Paul Scherkl (Strathclyde Univ)

Robert Shalloo (Oxford Univ)
Roxana Tarkeshian (Bern Univ)
Roman Walczak (Oxford Univ)
Maria Weikum (DESY)
Omid Zarani (HZDR)

Topics

- **Advanced beam diagnostics**
- High-gradient structures and components
- Plasma lenses and laser waveguides

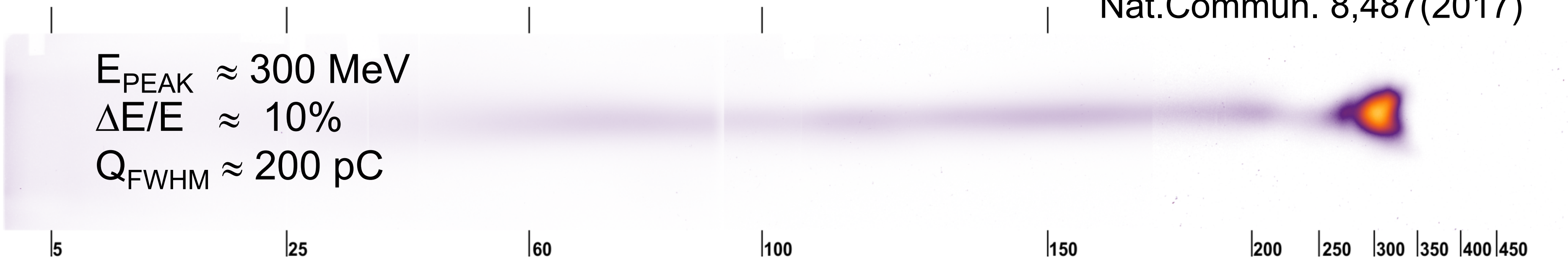
EAAC 2017

CTR based bunch length measurements

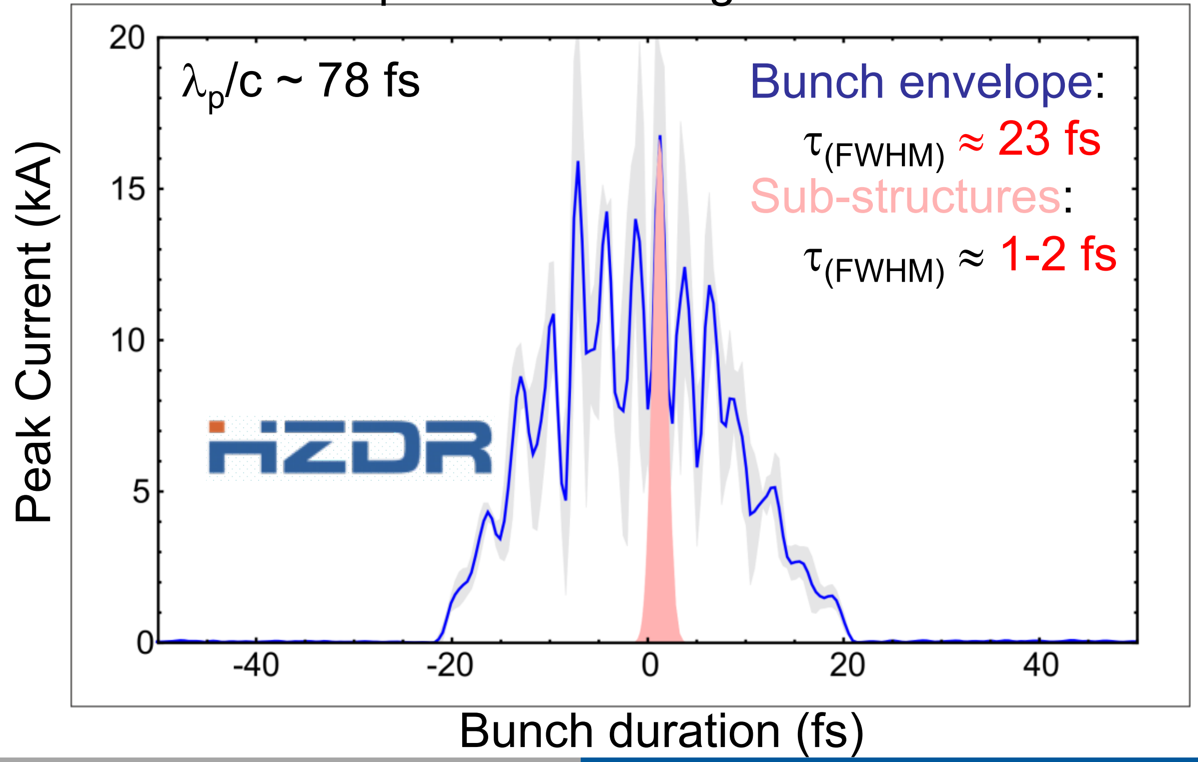
Electron spectrum

Omid Zarini, Monday, WG5

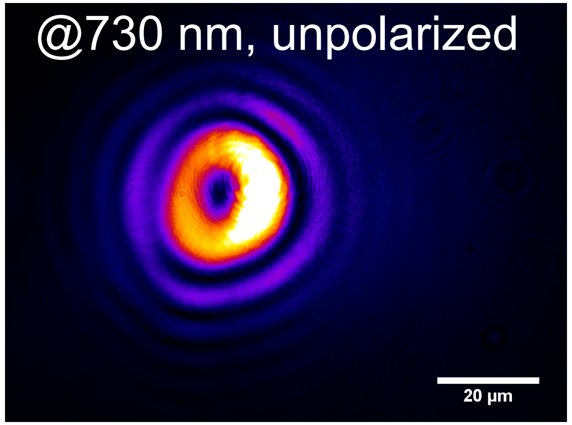
Couperus, *et al.*, Nat.Commun. 8,487(2017)



1st attempt for bunch length reconstruction

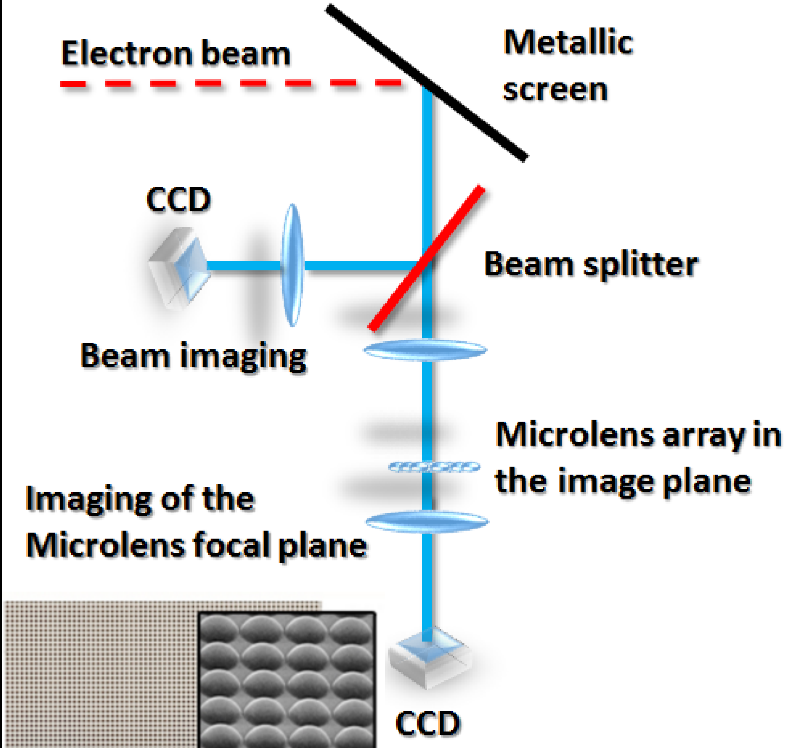


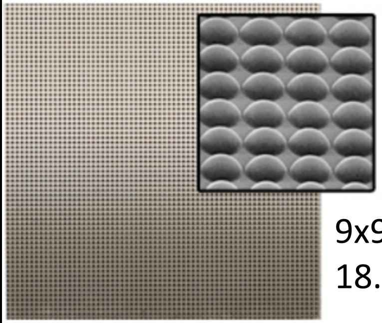
Observation of Point Spread Function



Single shot emittance measurements based on incoherent OTR

Experimental setup @ SPARC_LAB



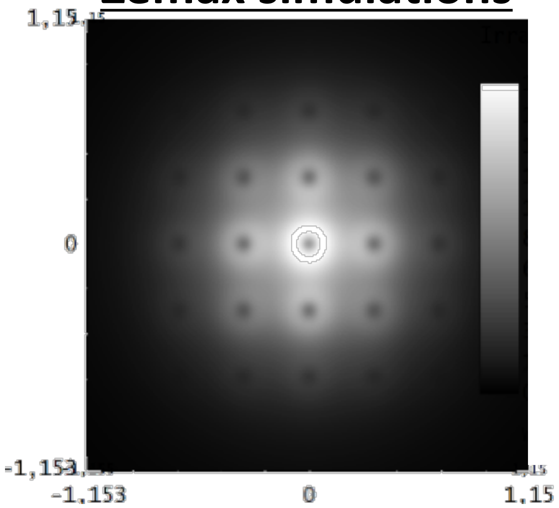


9x9mm array, 300um pitch, 18.5mm focal length

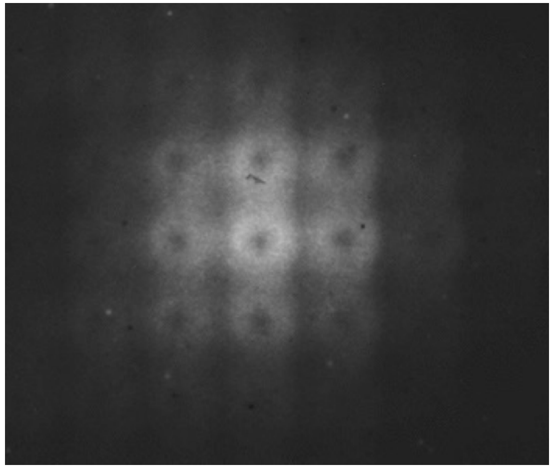
Motivations

- Single shot diagnostics on plasma accelerated electrons are needed to properly tune the source.
- We are studying a single shot emittance measurement based on incoherent optical transition radiation, exploiting its sensibility to beam divergence. In particular, the correlation term is reconstructed by using a microlens array.
- Zemax simulations have been perfomed and are in agreement with results.

Zemax simulations



Results

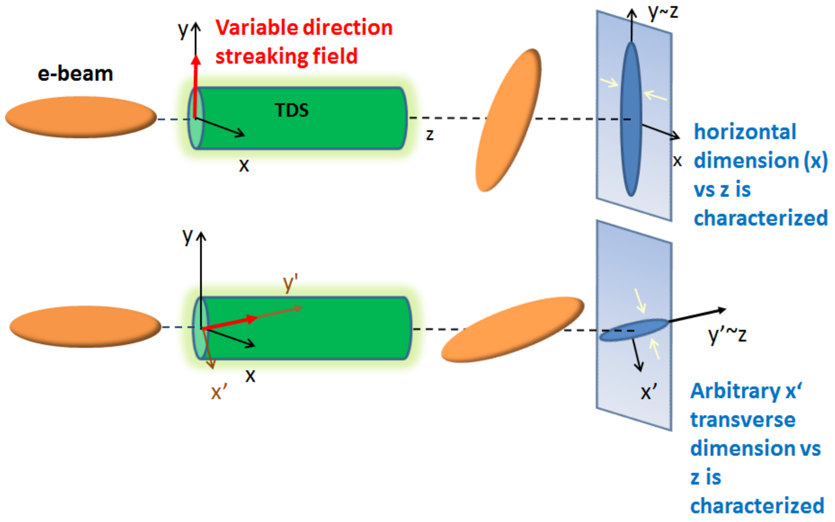


Cianchi, A., Bisesto, F. et al. " Transverse emittance diagnostics for high brightness electron beams." NIMA (2016)

Bisesto, F. G., et al. *SPIE Optics+ Optoelectronics*. International Society for Optics and Photonics, 2017.

Novel X-band TDS with variable polarization

- New X-band TDS with variable polarization to be installed at several DESY and PSI facilities, incl. at SINBAD
- Variable polarization allows bunch to be streaked in any transverse direction
- Allows following measurements:
  - Bunch length
  - 3D charge density profile using tomographic reconstruction (real space)
  - Slice emittance measurement (transverse phase space)
  - Slice energy measurement using dipole (longitudinal phase space)

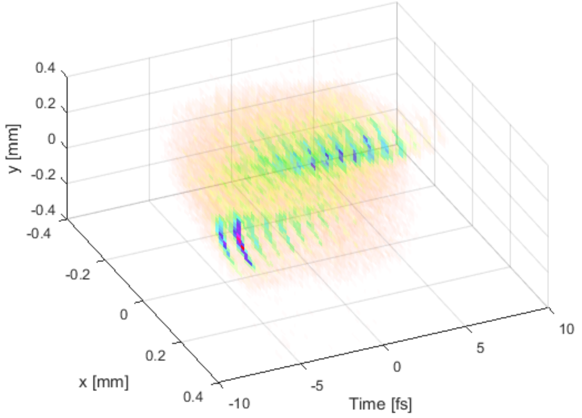


6D phase space characterization

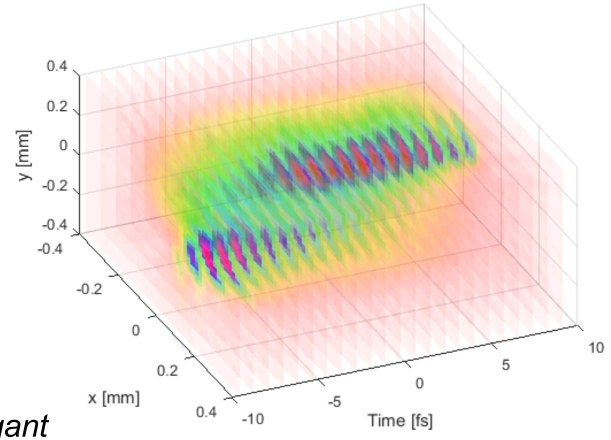
Charge density reconstruction

- Streak bunches at 16 transverse angles
- Combine profiles using tomographic techniques to reconstruct the 3D charge profile distribution

Actual distribution at screen with TDS off



Reconstruction

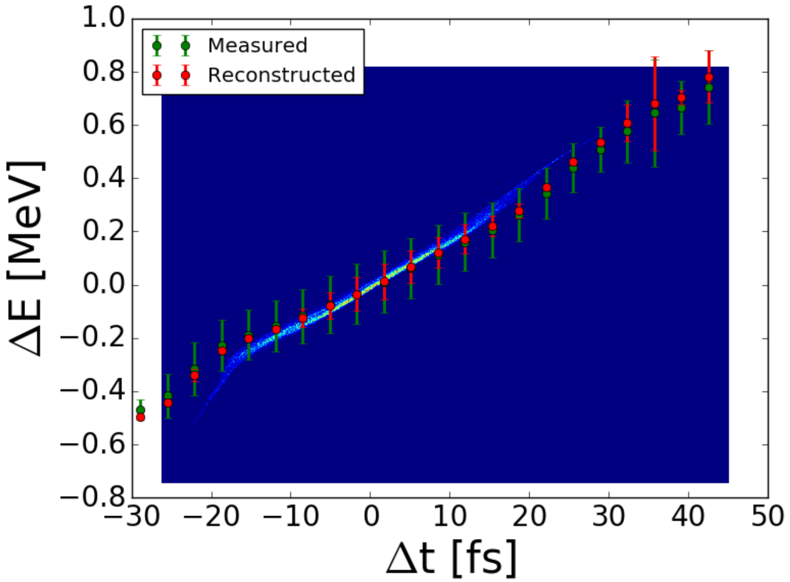


Simulations in *elegant*

D Marx *et al* 2017 *J. Phys.: Conf. Ser.* **874** 012077

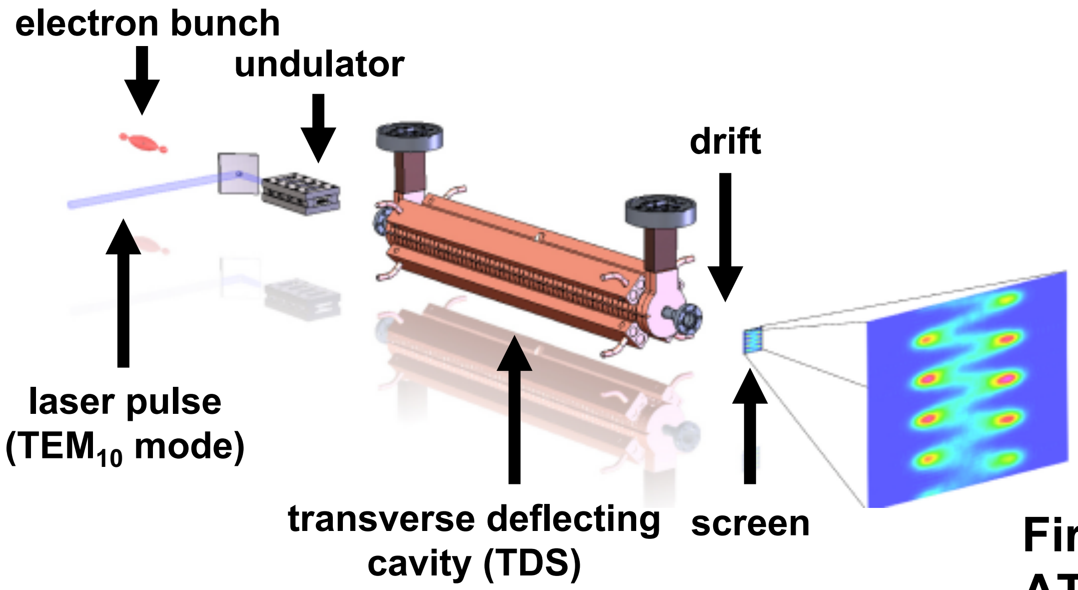
Bunch energy measurement

- Combine TDS with dipole for slice energy measurement
- Energy spread is induced in TDS
- Can calculate and remove but this is very difficult for short (fs-scale) bunches



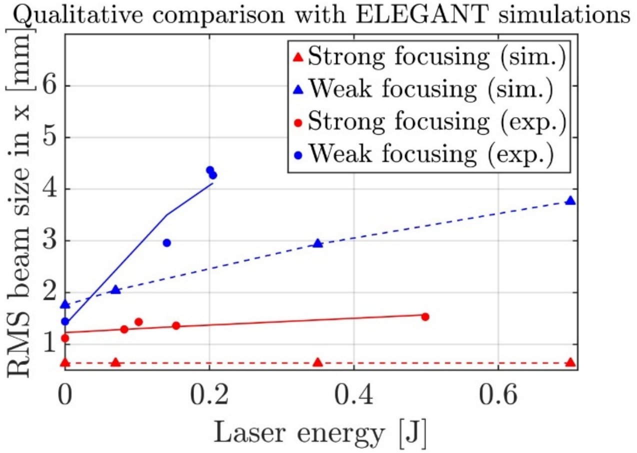
Simulations in *elegant*
Generated bunch for illustration

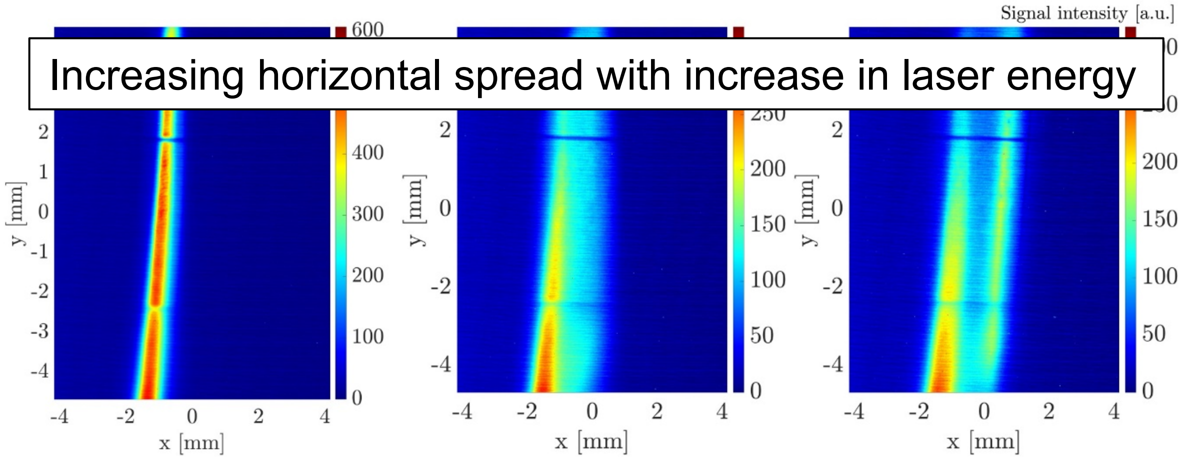
Proof-of-principle experiment for a sub-femtosecond electron bunch length diagnostic (M. Weikum et al.)



- Diagnostic device: laser modulator + RF deflecting cavity
- Strong horizontal streaking with laser modulator
- Vertical streaking to resolve streaking effect over full beam length

First proof-of-concept experiment at ATF (Brookhaven National Lab)





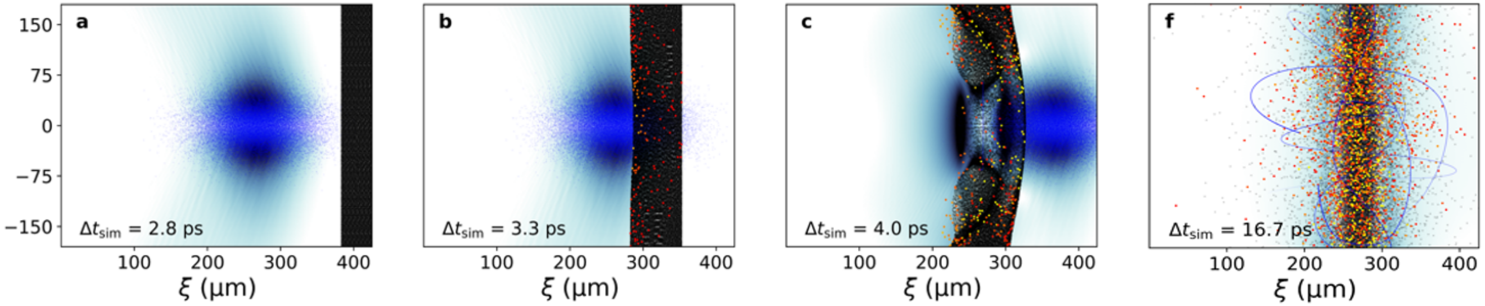
Increasing horizontal spread with increase in laser energy

HELMHOLTZ ASSOCIATION · erc · AXSIS · EuPRAXIA · SUPA · UCLA · University of Strathclyde Glasgow · DESY · radiabeam TECHNOLOGIES · BROOKHAVEN NATIONAL LABORATORY

Plasma-based spatiotemporal synchronization and alignment of electron and laser beams

Paul Scherkl, et al., EAAC 26-09-2017, WG5

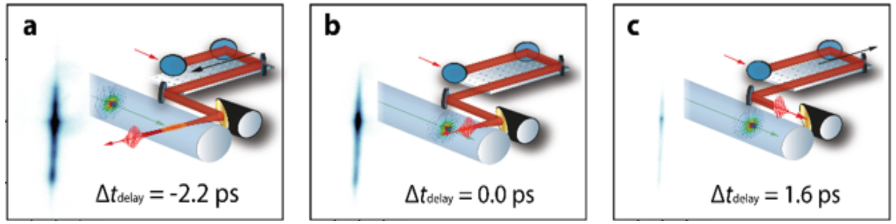
SLAC · radiabeam TECHNOLOGIES · SUPA · Physics Scotland · University of Strathclyde · FACET · UCLA · SCAPA · TECH-X · radiasoft · UH · DESY



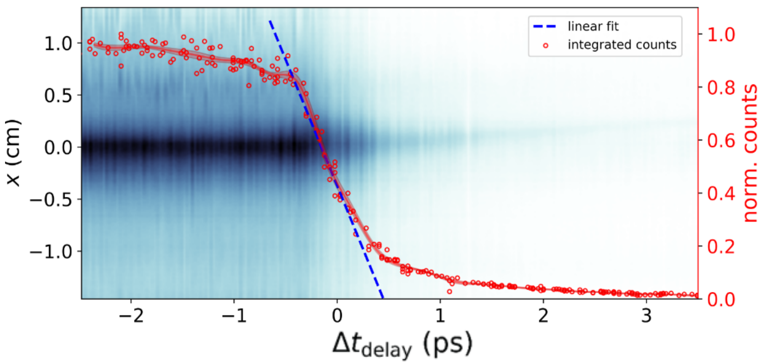
Interaction of e-beam and confined plasma

- transfers energy into plasma
- ions remain and build up localized attracting potential
- continuous heating, excitation, impact ionization
- additional relaxation/recombination light

e-beam – laser time-of-arrival scan



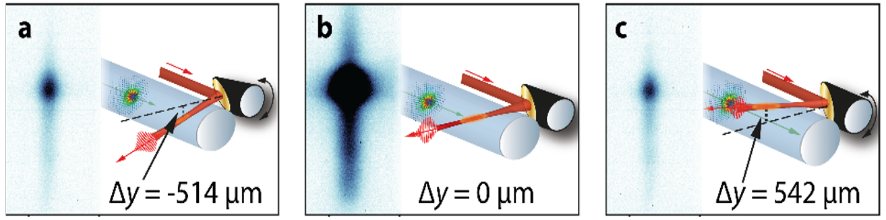
laser first T0 e-beam first



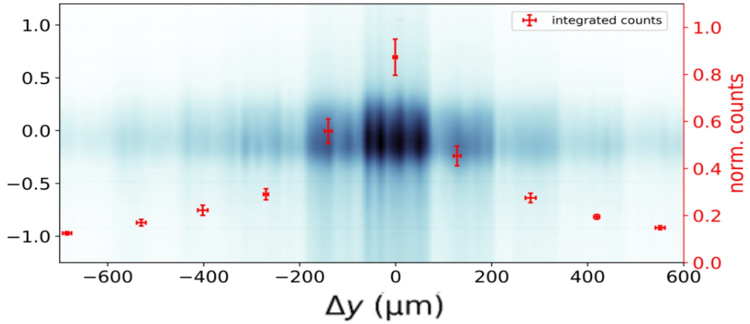
Temporal transition

- factor ~50 change in integrated counts
- r.m.s width ~470 fs
- slope ~ 1 fs / 0.1% change in intensity
- sensitive & robust beam arrival monitor

laser/plasma-alignment scan



on-axis



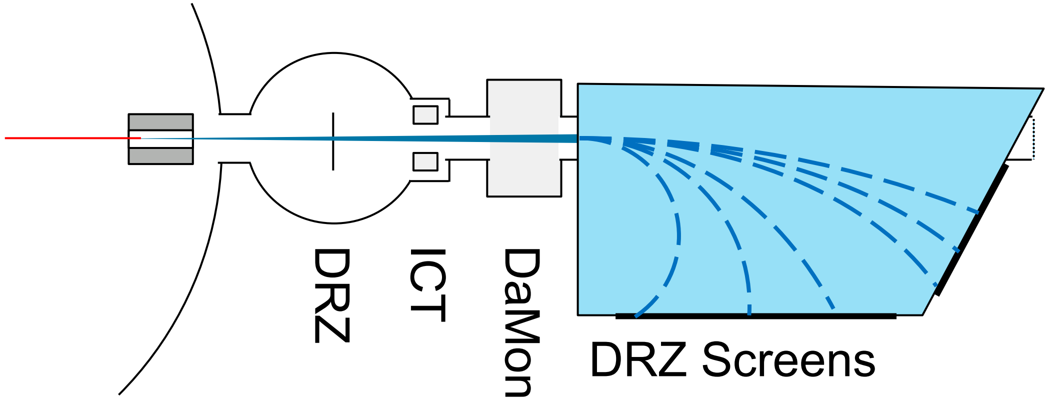
Spatial transition

- factor ~50 change in integrated counts
- r.m.s width ~58 μm
- response even for > 400 μm distance
- beam position monitor
- non-invasive

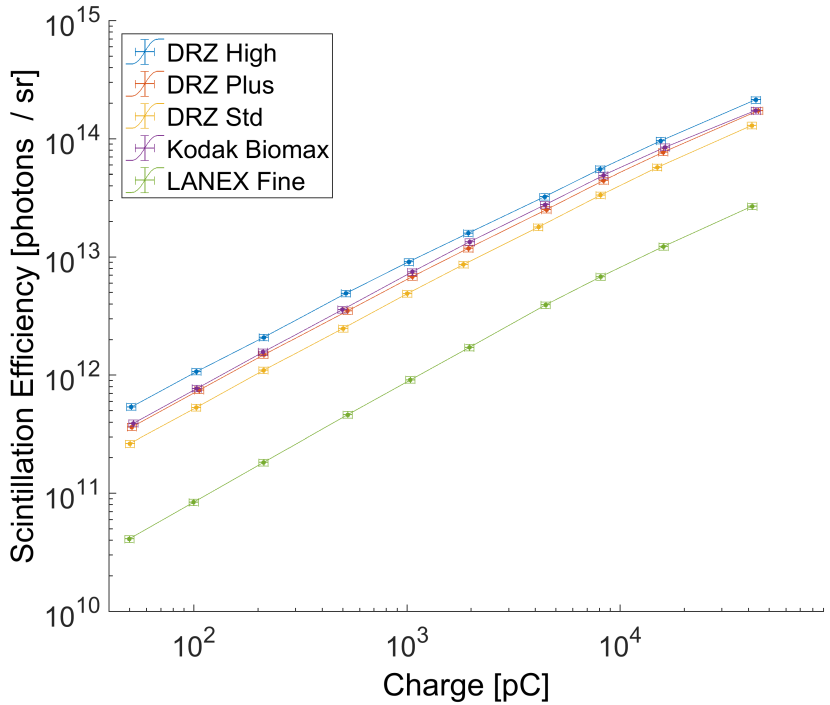
P. Scherkl[1,2], A. Knetsch[2], T. Heinemann[1,2,3,4], A. Sutherland[1,2,5], A. F. Habib[1,2], O. Karger[3], D. Ullmann[1,2], A. Beaton[1,2], G. G. Manahan[1,2], Y. Xi[6], A. Deng[6], M. D. Litos[7], B. O'Shea[5], S. Z. Green[5], C. I. Clarke[5], G. Andonian[8], R. Assmann[4], D.A. Jaroszynski[1,2], D. L. Bruhwiler[8], J. Smith[9], J.R. Cary[7,9], M. J. Hogan[5], V. Yakimenko[5], J. B. Rosenzweig[6], and B. Hidding[1,2]

Calibration of Charge Diagnostics using LWFA Electrons

- Three different types of charge diagnostics installed for LWFA experiments at FLASHForward:
  - DRZ screens
  - DaMon
  - ICT

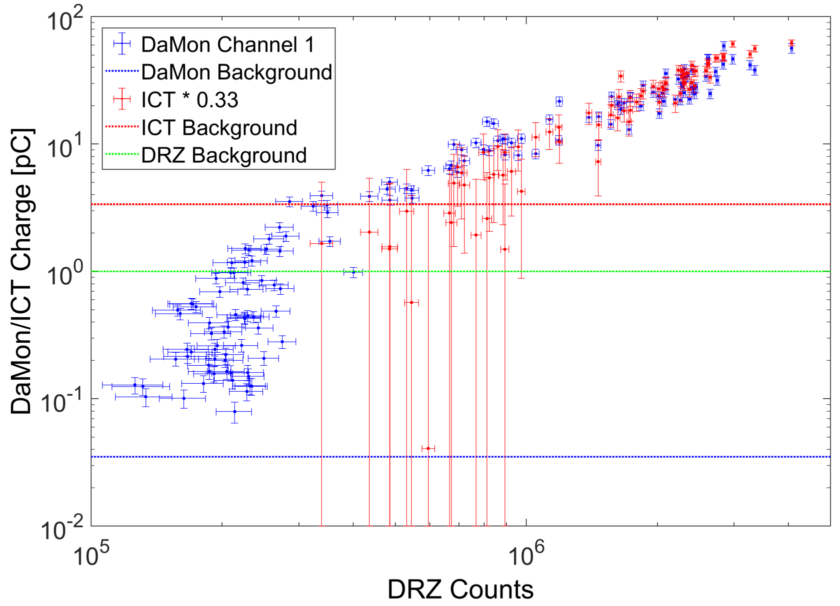


- Absolute calibration of DRZ screens was performed at ELBE:
  - DRZ High was measured to have a very high light output of 1.05×10^{10} photons / (sr * pC)
  - Factor of 13 more light yield compared to LANEX Fine

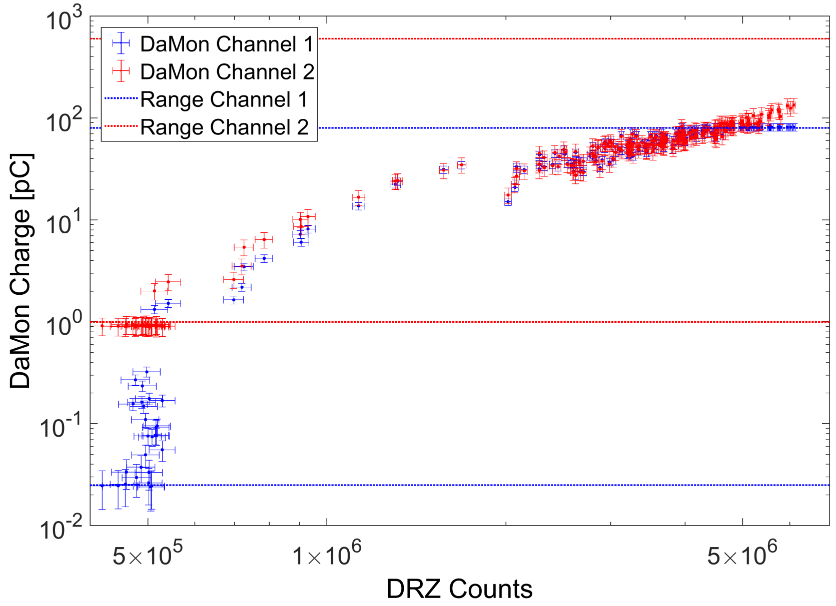


Calibration of Charge Diagnostics using LWFA Electrons

- ICT was tested in noisy environment:
  - Charge scaling factor of 0.33 required at our setup
  - Noise restricting measurement to charges above a few pC
  - Non-destructive measurement



- DaMon was first tested in LWFA setup:
  - Stainless steel cavity used as passive resonator
  - Amplitude of TM01 mode used for charge measurement
  - High dynamic range from ~ 10 fC up to 100 nC
  - Insensitive to electromagnetic noise from plasma
  - Non-destructive measurement



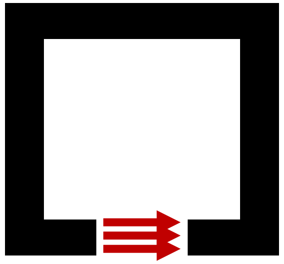
Topics

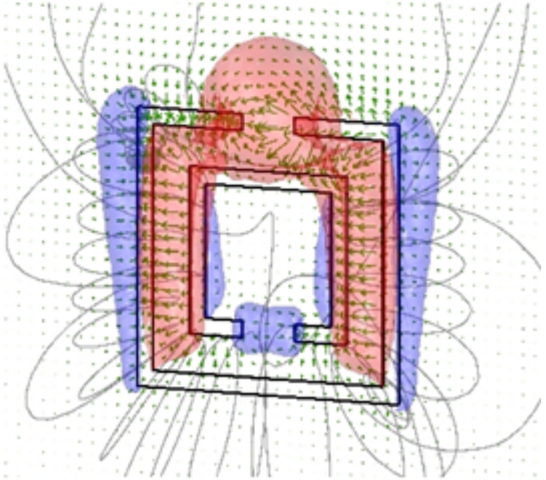
- Advanced beam diagnostics
- **High-gradient structures and components**
- Plasma lenses and laser waveguides

THz Field Enhancement Structures for Accelerators

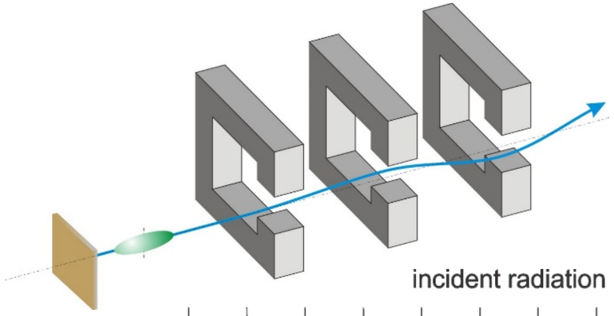
See also talk by Mozhgan Hayati WG 5

Resonant THz electric or magnetic field enhancement structures

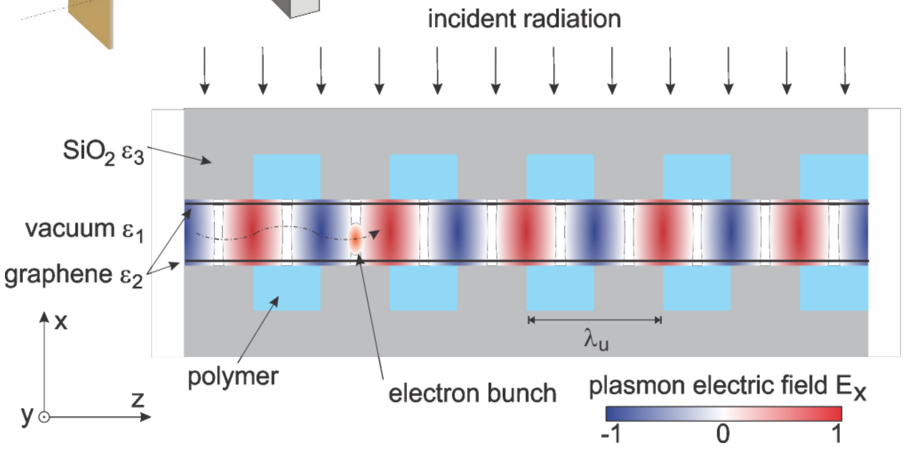




- Electron streaking – single and multi-element structures
- Electron acceleration
- Electric field driven undulators



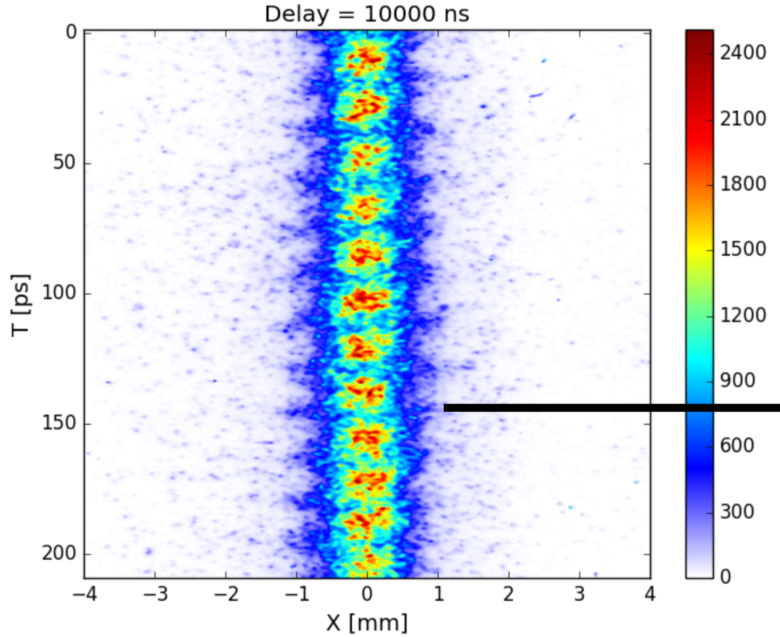
Split ring resonator based device



Graphene plasmon based device

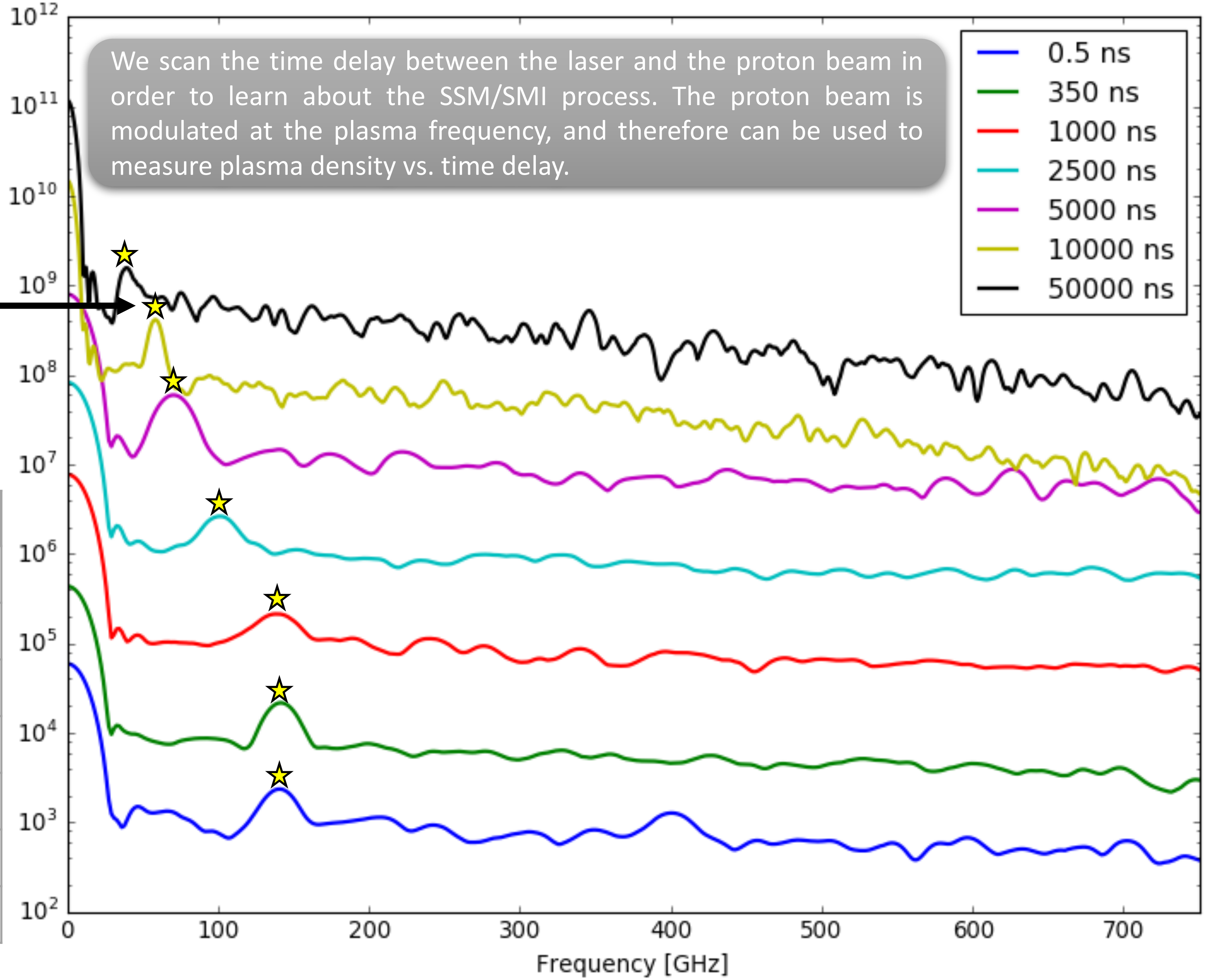
Time Delay Scan Fourier Analysis

Spencer Gessner (AWAKE @ CERN)



Delay [ns]	FFT Peak [GHz]	Equivalent n [$\times 10^{14}$ cm^{-3}]
0.5	141.2	2.47
350	141.2	2.47
1000	139.5	2.41
2500	101.6	1.28
5000	70.6	0.62
10000	58.5	0.42
50000	39.2	0.19

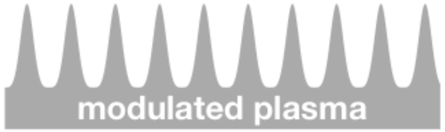
We scan the time delay between the laser and the proton beam in order to learn about the SSM/SMI process. The proton beam is modulated at the plasma frequency, and therefore can be used to measure plasma density vs. time delay.



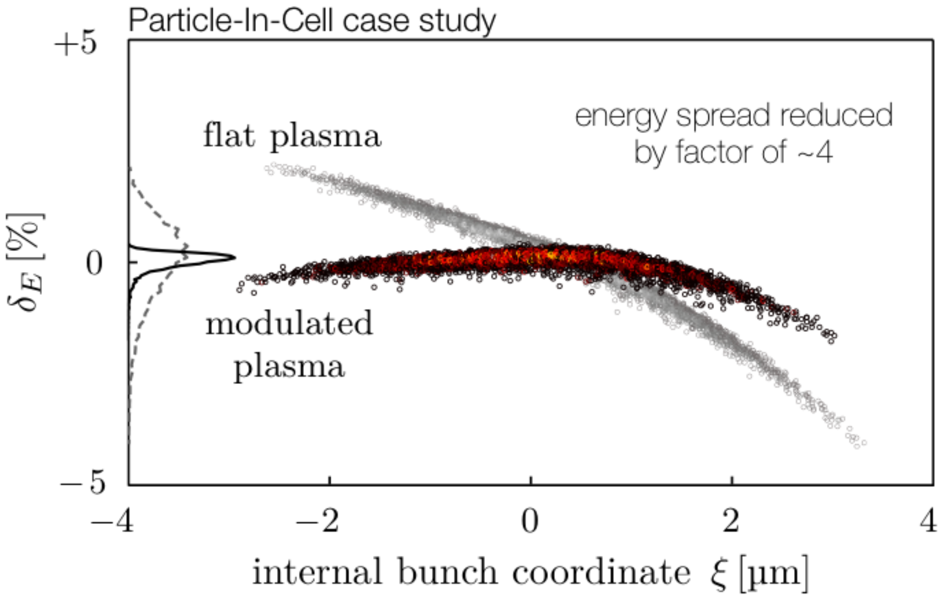
Chirp Mitigation of Plasma-Accelerated Beams by a Modulated Plasma Density

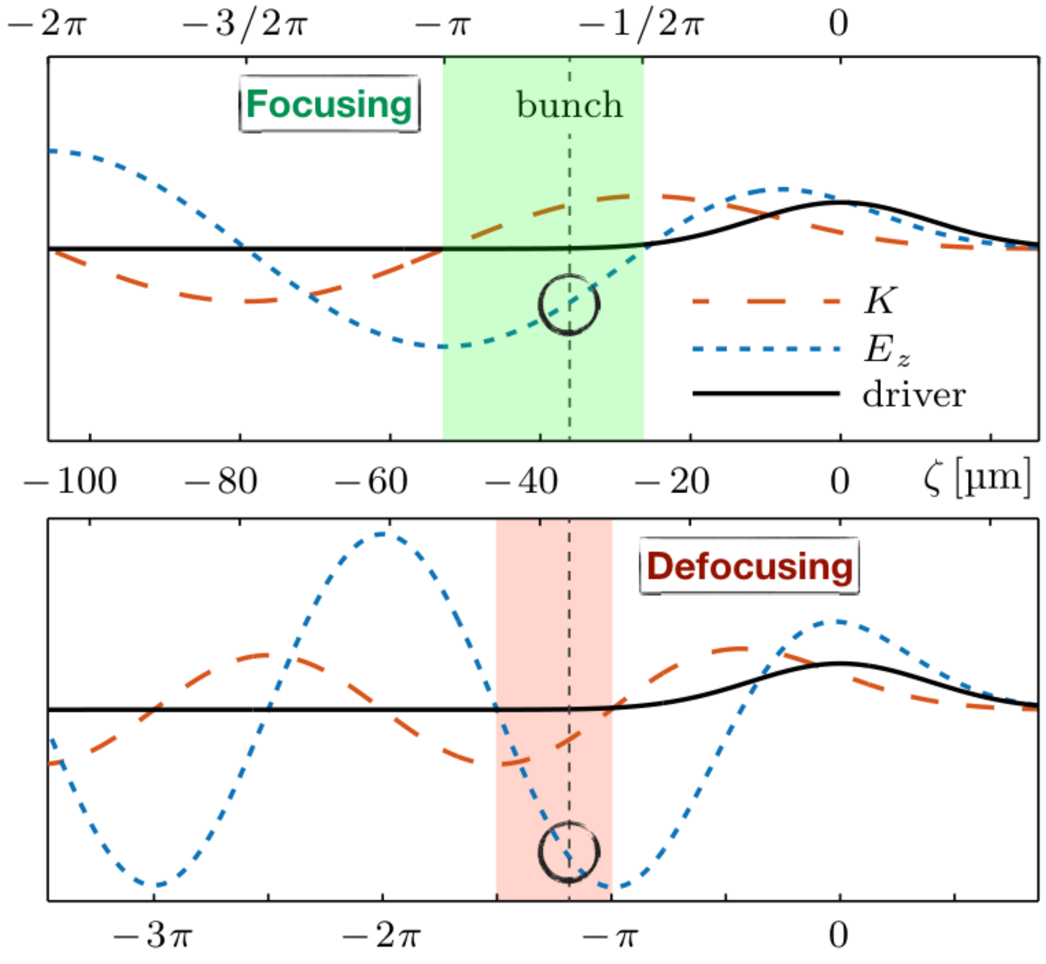
R. Brinkmann et al.
Phys. Rev. Lett. 118, 214801 (2017)

1. **Modulate plasma** wavelength (density)…



2. …thereby **oscillate between positive and negative slopes** of the accelerating field…
3. …while **alternately focusing and defocusing** the bunch for stable beam transport.





On average: Stable *virtual* on-crest acceleration
Compensation of energy chirp

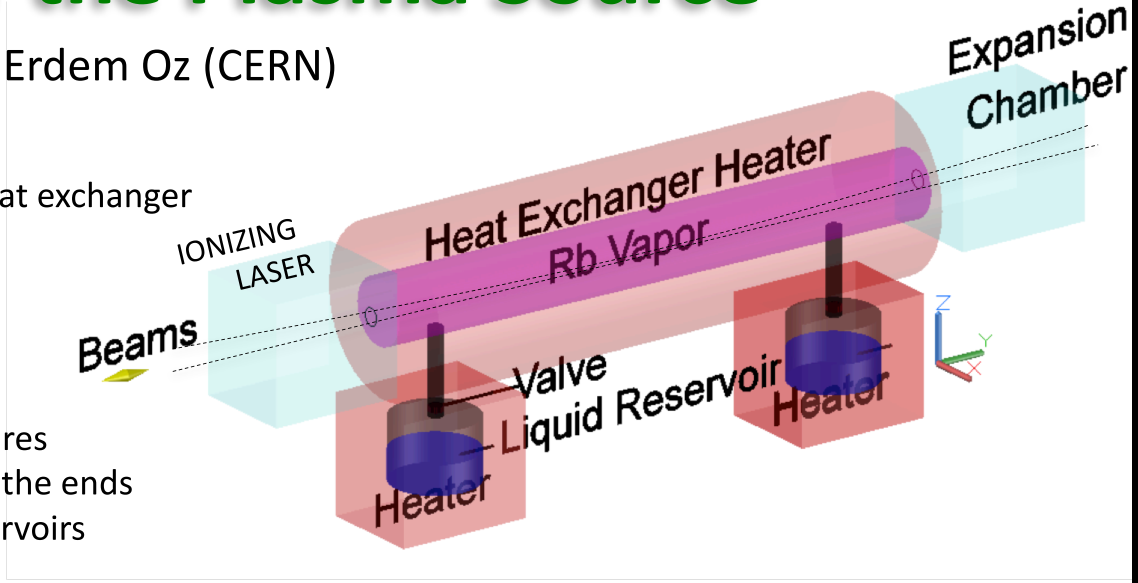
Overview of the Plasma Source

Erdem Oz (CERN)

Consists of 3 main sections

- a 10 m long 4 cm diameter liquid (Galden) heat exchanger
- 2 Rb reservoirs at the ends
- 2 Rb expansion chambers (buffer zones)

for Rb collection



- Rb continuously flows through the system

and exits the ends through 1 cm diameter apertures
condenses in the expansion chambers located at the ends

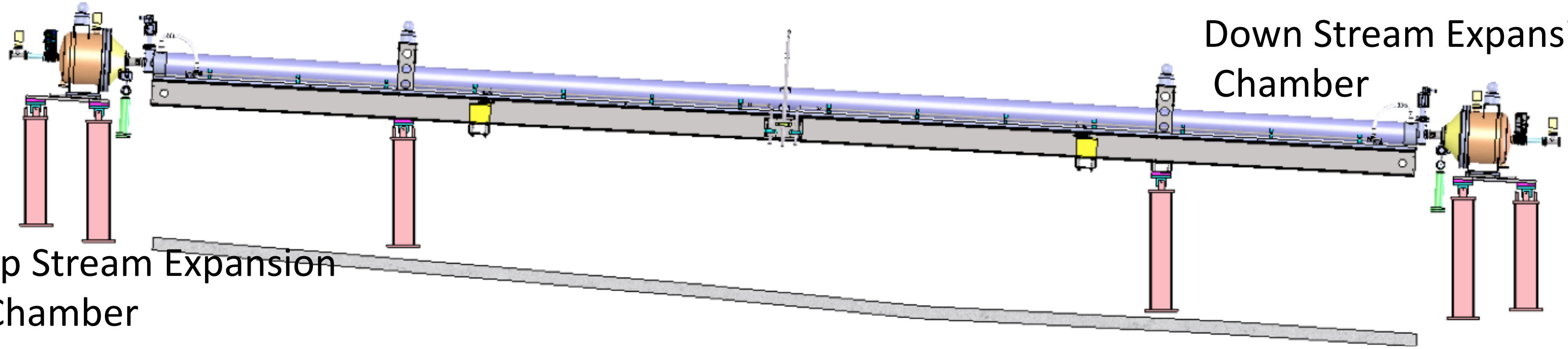
- Density profile is adjusted by setting the reservoirs temperatures

- Plasma formed by laser ionization of Rubidium (Rb) Vapor. Above threshold (~10^12 W/cm^2) we ionize % 100

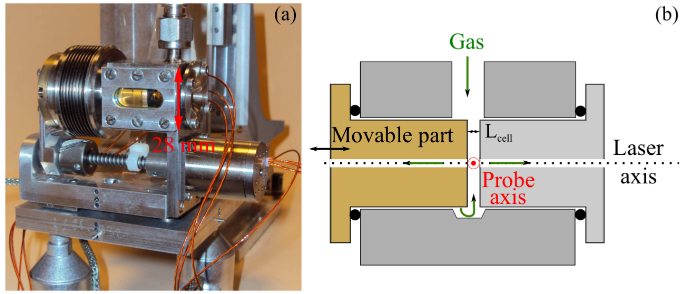
Plasma density = Vapor Density (n)

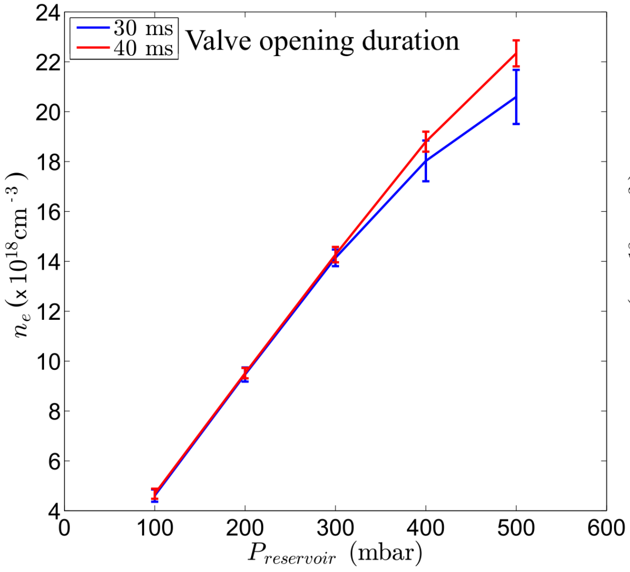
Plasma density uniformity = Vapor Density uniformity

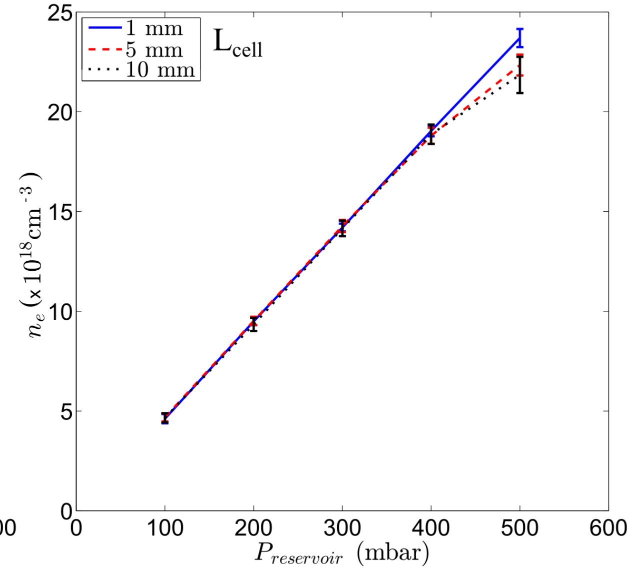
- Density is measured at both ends with a Mach-Zehnder interferometer 0.1 % accuracy

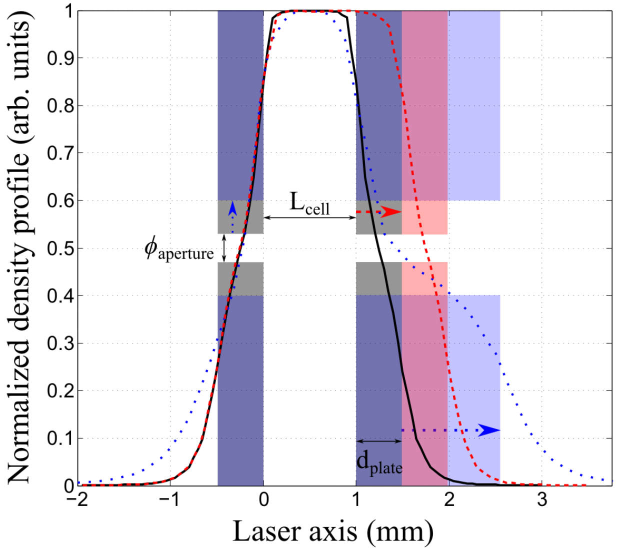


Summary of density control in the ELISA variable parameters gas cell









Interferometric measurements of the mean density insite the cell for various parameters

Fluid simulations with OpenFOAM : determination & control of the density profile along the laser axis.

Topics

- Advanced beam diagnostics
- High-gradient structures and components
- **Plasma lenses and laser waveguides**

Carl A. Lindstrøm, University of Oslo and CLEAR, CERN

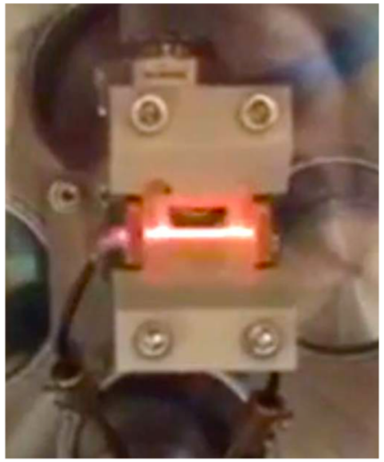
The CLEAR Plasma Lens Experiment - Summary

A scientific collaboration between:

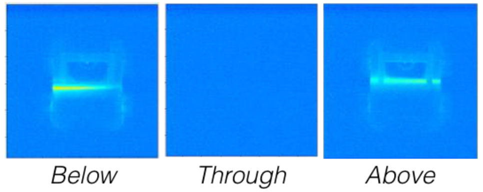
- **Active plasma lens experiment** at the CLEAR Test Facility at **CERN**.
  - 15 mm long, 1 mm diameter **sapphire capillary** (made by DESY)
  - Compact **Marx Bank** HV short-pulse discharge source of peak current ~500 A (made by Uni Oxford)

- Experimental goals:
  - Successful operation: **First step towards a multi-plasma lens apochromatic lattice** for a emittance preserving PWFA/LWFA staging
  - **Measurement of radial field non-uniformity** with high resolution (small beam)
  - **Probing limits set by plasma wakefields** using short, intense particle beams

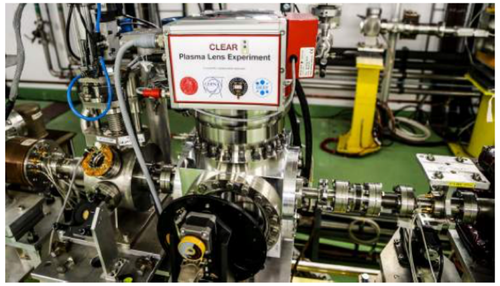
- Current progress and plans:
  - **Successfully tested plasma discharge** (no beam, Aug 2017)
  - **Successfully transported beam through capillary** (no discharge, Sep 2017)
  - Experiments Oct 2017 - mid 2018.



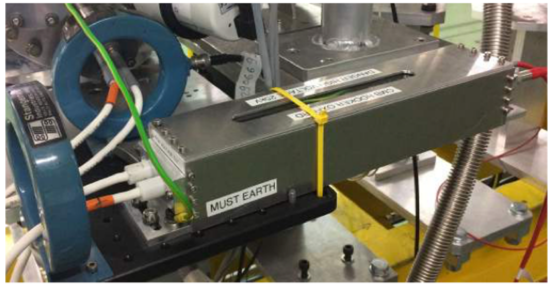
Bench test of the capillary (Aug 2017)



Scan of vertical capillary offset.
Beam sent through capillary (Sep 2017)



Experimental setup installed into CLEAR



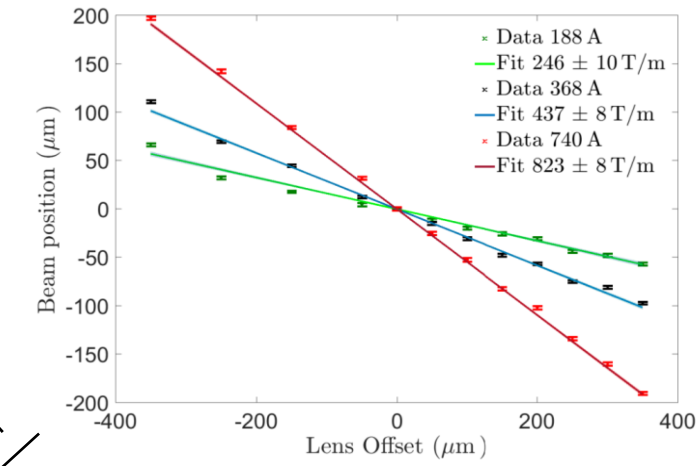
The HV discharge source (Compact Marx Bank)

Mapping active plasma lenses

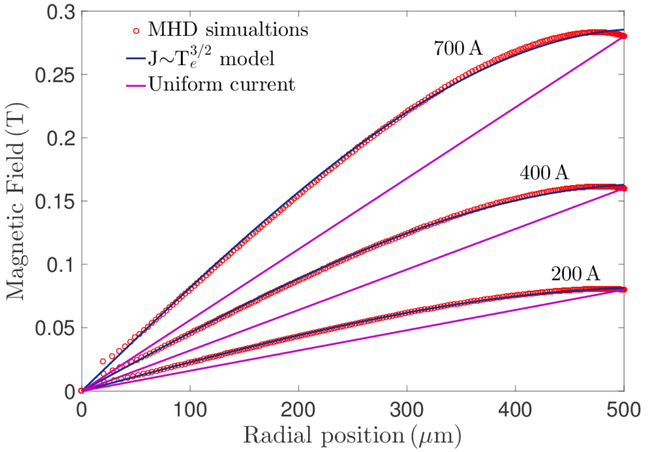
Direct detection of linear and nonlinear focusing fields

- Plasma lens experiment at Mainz Microtron (855 MeV; 1.5 mm mrad)
- No pointing or orbit stability degradation through plasma lens
- Direct magnetic field gradient measurements performed
- Emittance measured after plasma lens interaction
- Results confirm predictions from MHD and particle tracking sims
- Future studies will focus on reducing gradient nonlinearity

Magnetic field scans



Field scan



Modeling: N. A. Bobrova et al., Phys. Rev. E , 65 (2001), J. van Tilborg et al., Phys. Rev. Accel. Beams, 20 (2017)

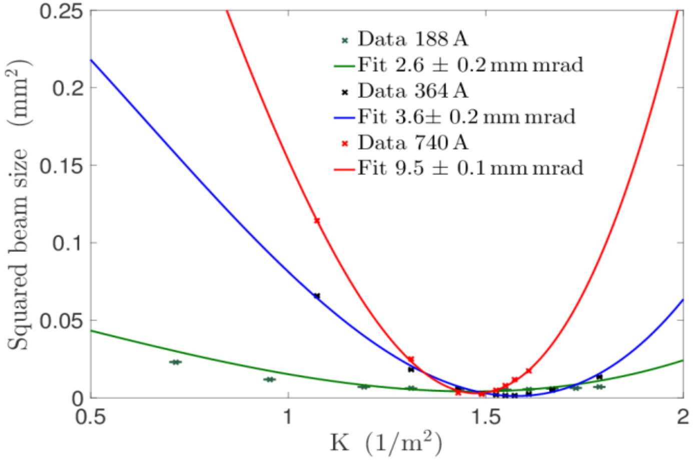
Model

$$B_\varphi(r) = \frac{\mu_0}{2}(a_1 + a_3 \cdot r^2)r$$

Tracking

Current [A]	Simulated Norm. Emitt. [mm mrad]
188	3.3 ± 0.3
368	4.7 ± 0.1
740	7.4 ± 0.2

Emittance measurements



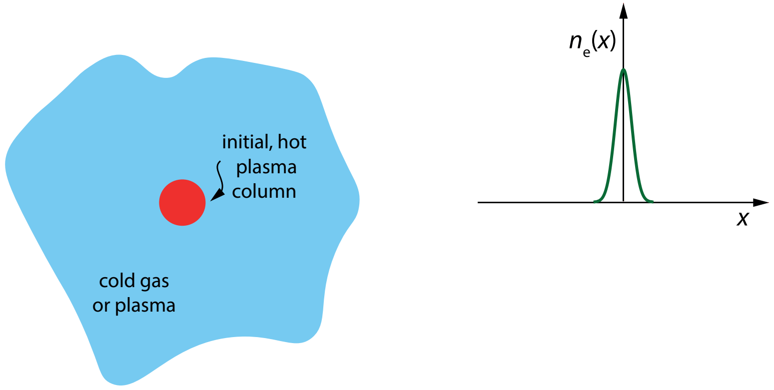
Collaboration by

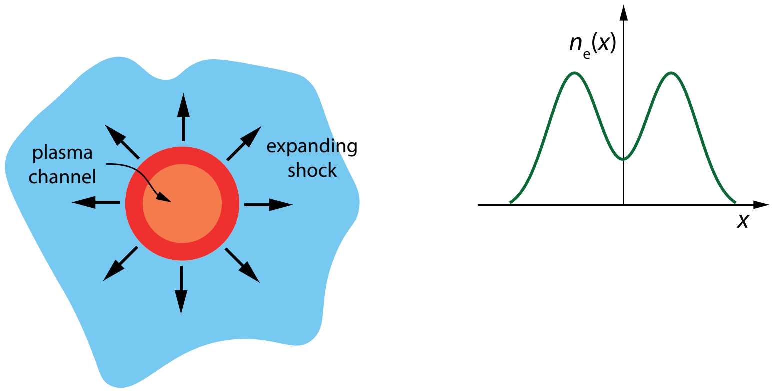
part of

Jan-Hendrik Röckemann (DESY) *et al.*
publication in preparation

Low-density plasma channels capable of high repetition rate operation

John Adams Institute for Accelerator Science



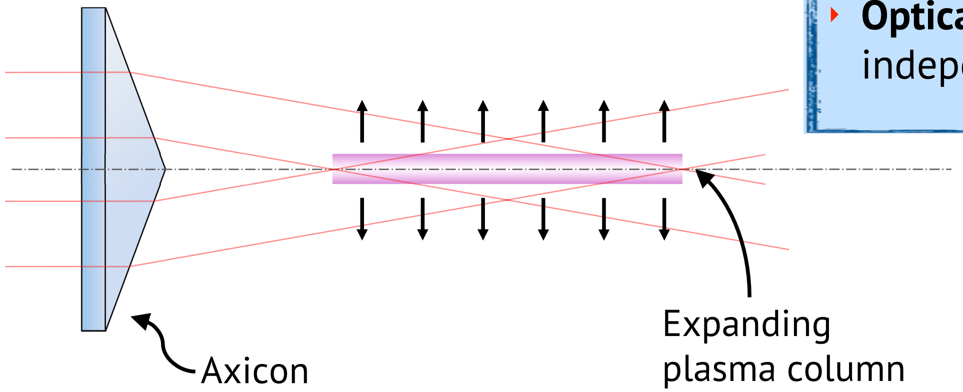


- Hydrodynamic expansion of plasma columns can generate channels suitable for guiding which:
  - Are capable of **multi-kHz operation**
  - Are **immune to damage**
  - Can be made **long** (several hundred mm)

- To date initial plasma columns have been heated collisionally
  - Requires high initial density for efficient heating
  - Thus limits on-axis density to > 1 x 10^{18} cm^{-3}

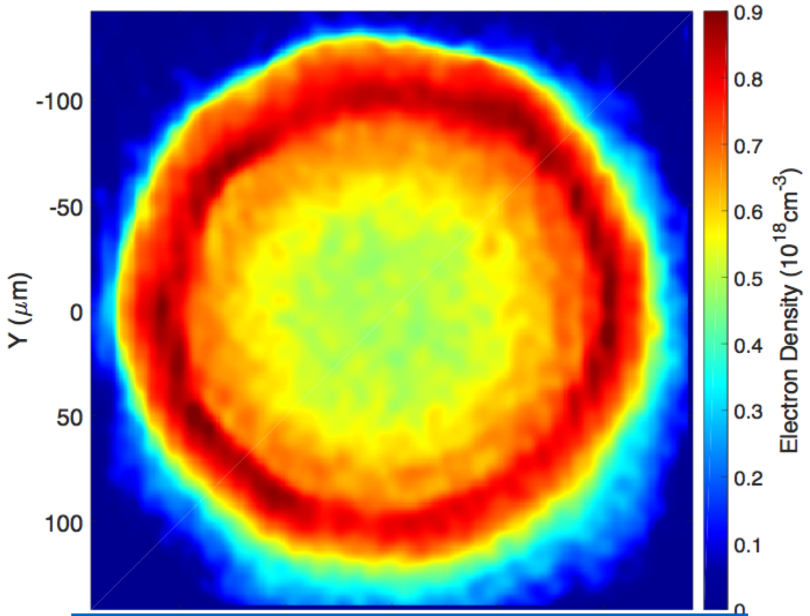
- Desirable to decrease on-axis density to ~ **10^{17} cm^{-3}** for ~ 10 GeV stages

- **Optical field ionization** can create hot electrons independent of initial density



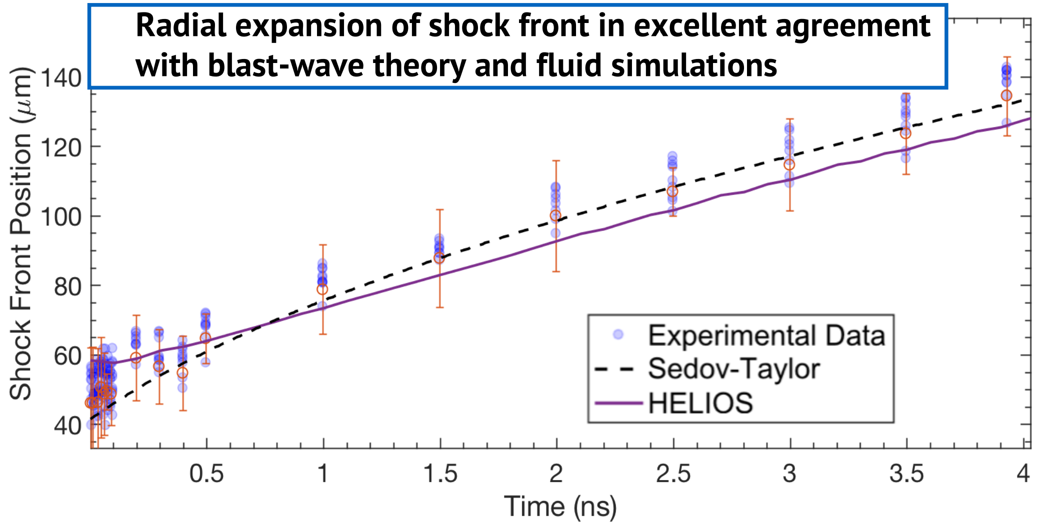
Low-density plasma channels capable of high repetition rate operation

- Experiments performed with 25mJ, 50fs laser. Interferometric measurements of OFI channels show:
  - On-axis densities as low as **$2x10^{17}$ cm^{-3}**
  - Matched spot sizes **35-55 μm**
  - Calculated **low-loss** guided mode
  - Attenuation length of order 900mm

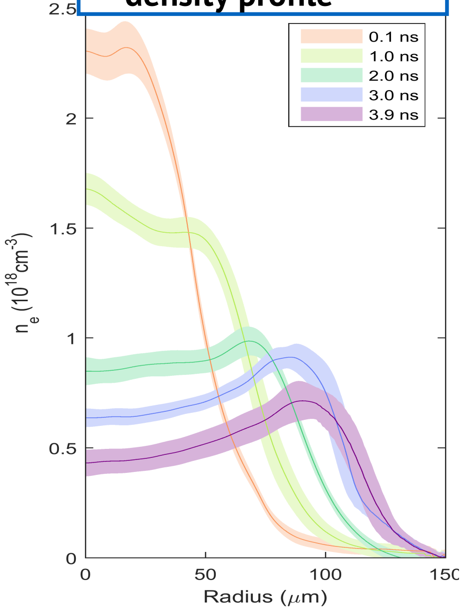


Example transverse electron density profile 3.9 ns after channel-forming pulse

Radial expansion of shock front in excellent agreement with blast-wave theory and fluid simulations



Example of evolution of transverse electron density profile



John Adams Institute for Accelerator Science

Propagation of trains of laser pulses in pre-formed plasma channels

R. Walczak et al.

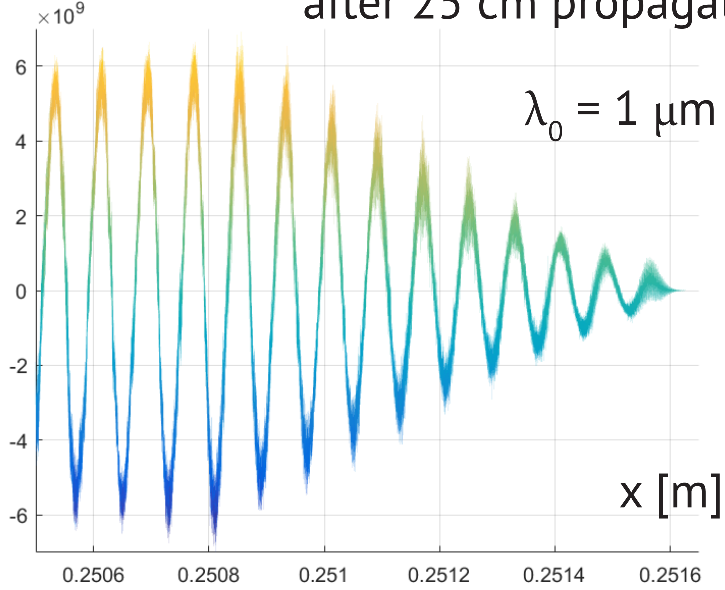
Summary

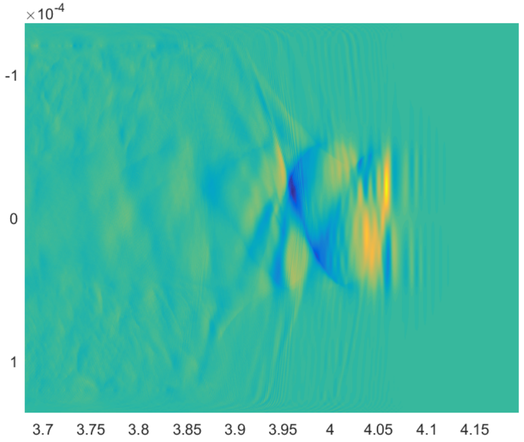
► Plasma channels ~r^{α} for α = 6 or larger are suitable for propagation of long trains of laser pulses. Matching spot size doesn't depend on α.

► A train of 10 laser pulses with total energy of 800 mJ @ 1 μ was propagated (EPOCH 2D PIC) over 25 cm in a plasma channel with α = 10 and the density on axis = 1.75×10^{17} cm^{-3} demonstrating that MP-LWFA accelerating electrons to GeV energies at low density in a plasma channel is possible.

► Red and blue frequency shifts are significant and eventually limit accelerator energy and amount of usable pump laser energy. This has been demonstrated at the pump wavelength increased to 8 μ. For a_0 = 3, possible accelerator length is about factor 2 shorter than the dephasing length.

E_x longitudinal electric field on axis in V/m after 25 cm propagation





λ_0 = 8 μm

Thanks!

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