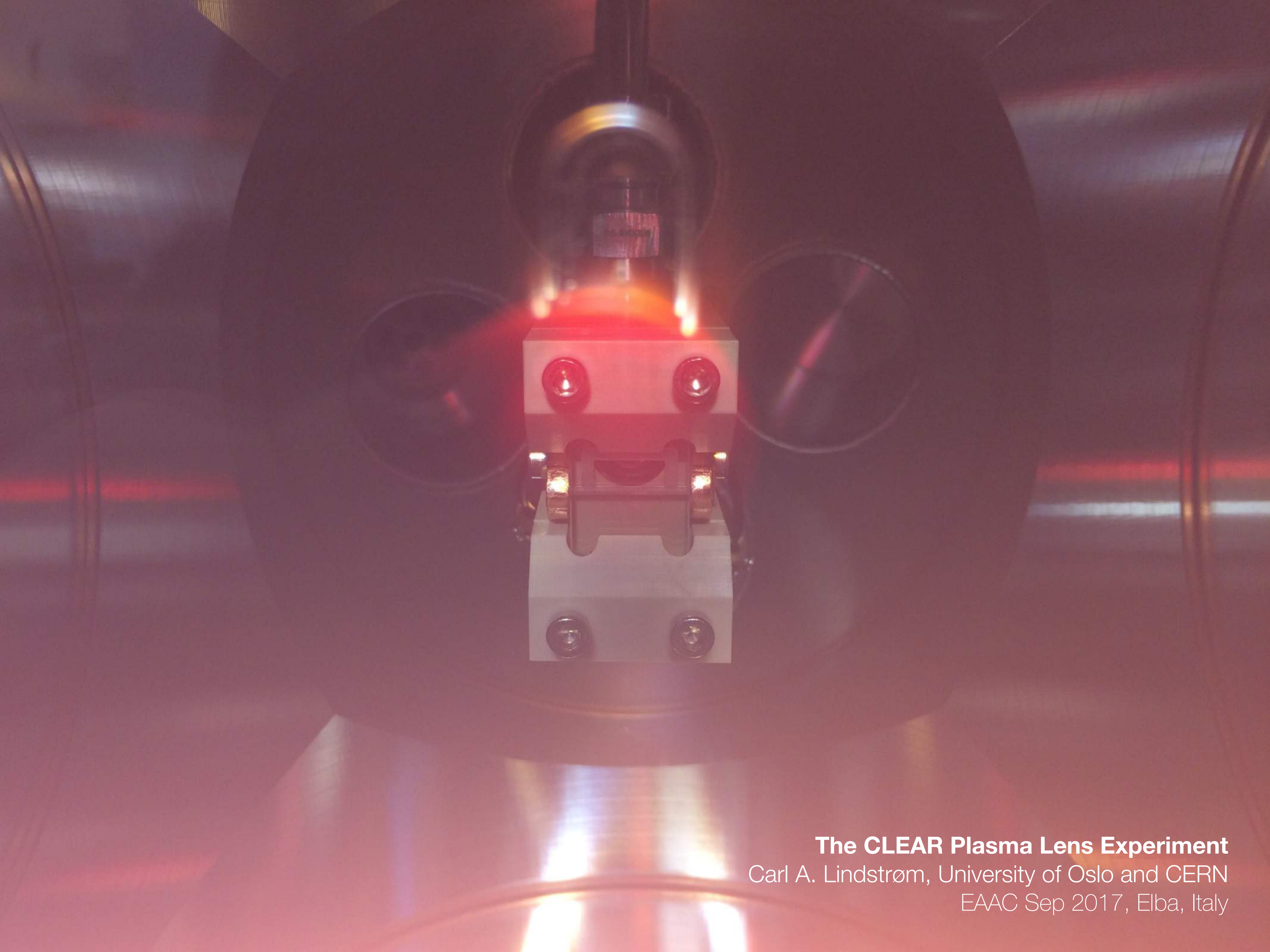

The CLEAR Plasma Lens Experiment

Carl A. Lindstrøm, University of Oslo and CERN

EAAC Sep 2017, Elba, Italy

The CLEAR Plasma Lens Experiment

EAAC 2017 – Elba, Italy – Sep 26, 2017

Carl A. Lindstrøm
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Supervisor: **Erik Adli**

Outline

Why? (motivation for the plasma lens experiment)

Where? (introducing the CLEAR Test Facility at CERN)

What? (experimental goals)

How? (experimental setup)

When? (current progress and plans)

The grander problem: Staging

- Staging of PWFA cells is a significant hurdle to reaching the TeV scale required for linear colliders

- Staging needs to
  – be compact
  – preserve emittance

- BELLA @ LBNL and others have started using discharge capillary *active* plasma lenses to solve this problem.

- Chromaticity: a serious problem due to a combination of
  – large energy spreads from plasma accelerators
  – strong focusing in plasma

- **University of Oslo has proposed using multi-lens *apochromatic* lattices to partly cancel chromaticity.**

- Note: plasma ramps will likely also be necessary (effectively reducing the plasma focusing strength)

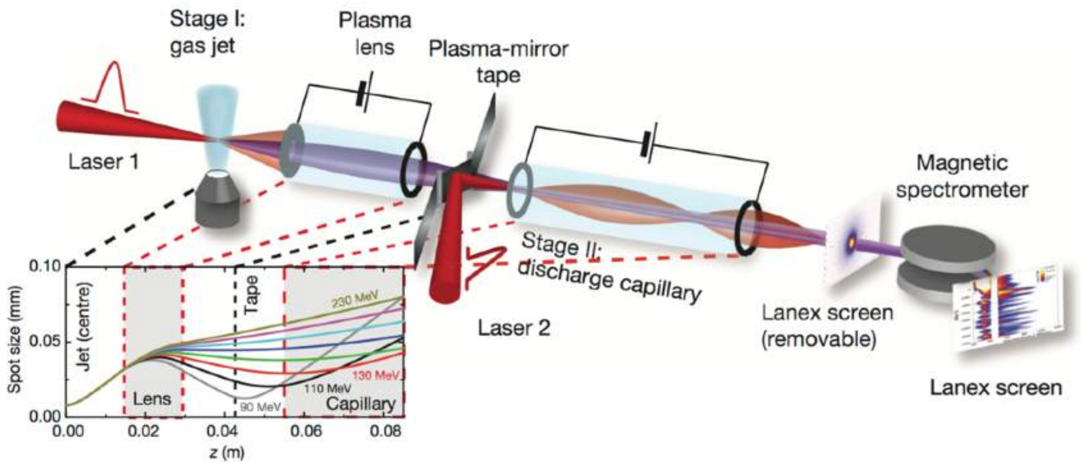


Image source: Steinke et al., Nature (2016)
"Multistage coupling of independent laser-plasma accelerators"

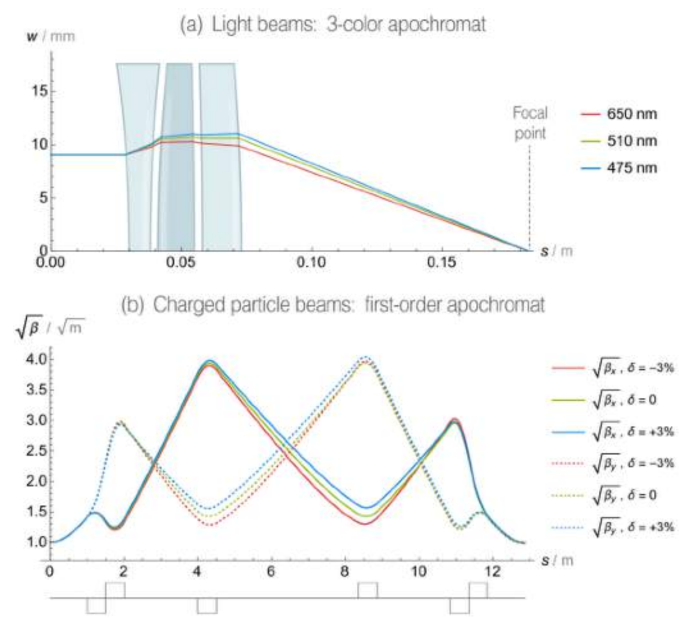
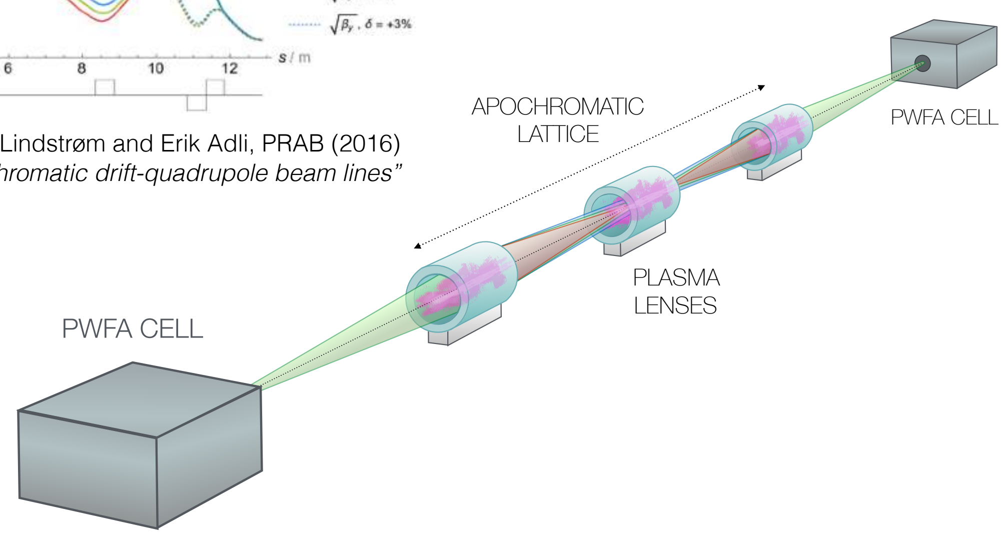


Image source: C. A. Lindstrøm and Erik Adli, PRAB (2016)
"Design of general apochromatic drift-quadrupole beam lines"



Discharge capillary plasma lenses

- Operating principle:
  - Use high voltage to break down a gas inside a cylindrical capillary
  - Pass a high current through, which sets up a ~uniform longitudinal current density
  - The radially linear increase in azimuthal B-field will strongly focus a beam

- Potential problems (leading to emittance growth)
  - Radially non-uniform temperature affects the uniformity of the current density
  - Very intense beams will also experience non-uniform plasma wakefields

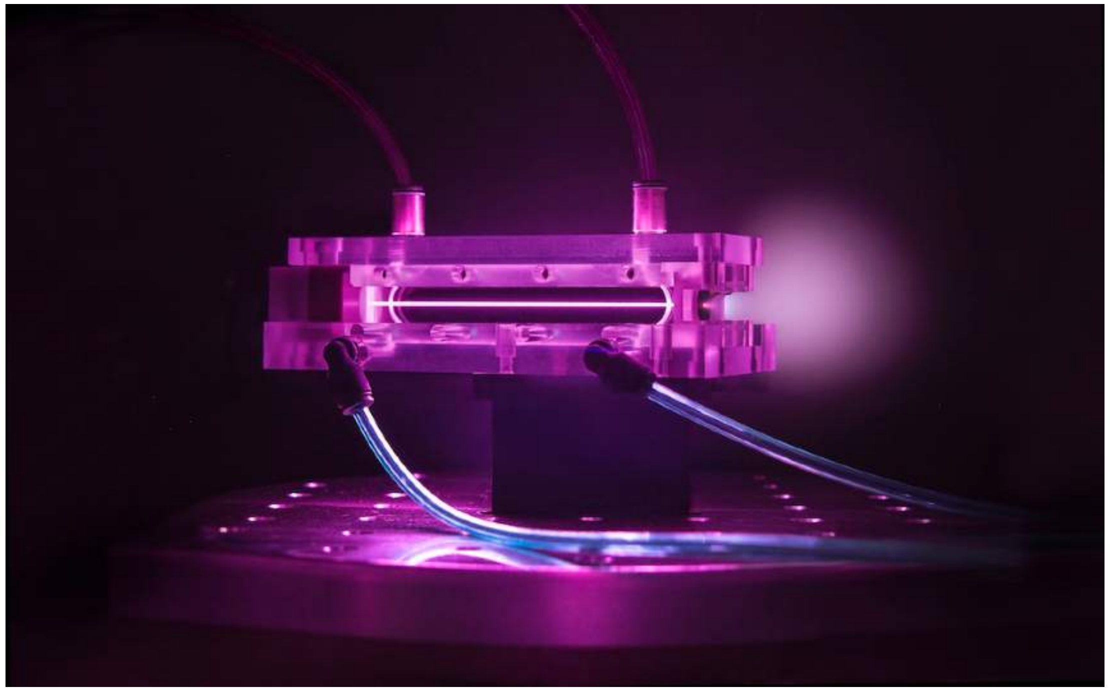
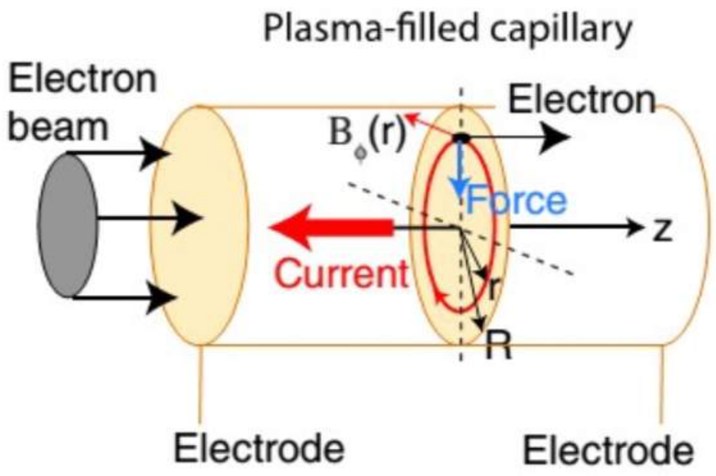
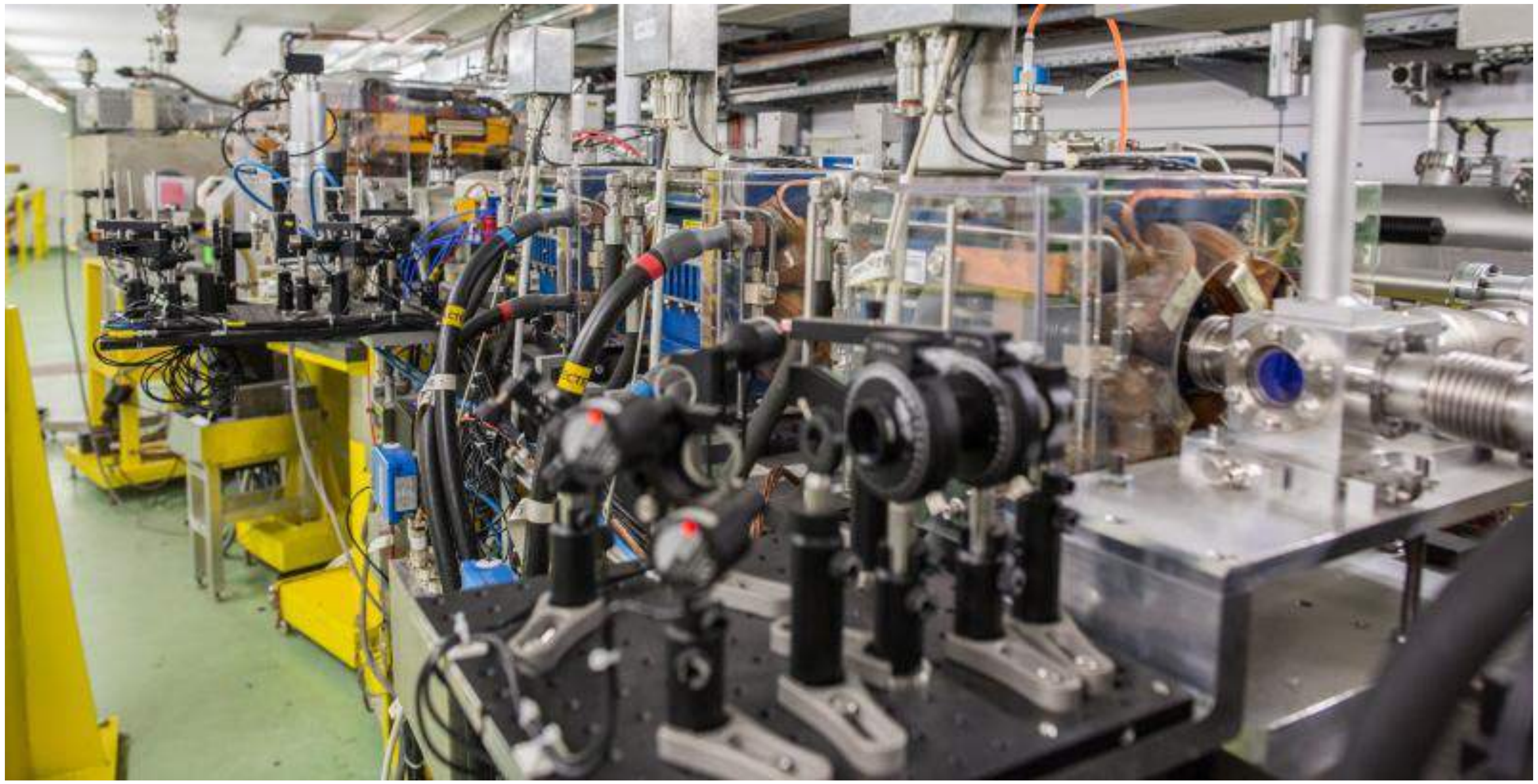


Image source: LBNL



Van Tilborg, J., et al. "Active plasma lensing for relativistic laser-plasma-accelerated electron beams." Physical review letters 115.18 (2015): 184802.

The CLEAR Test Facility at CERN



- Photocathode with S-band RF structures
- Previously used as the witness injector for the CLIC Test Facility

Beam parameter	**Range**
Energy	130–220 MeV
Bunch charge	10–500 pC
Norm. emittance	~3 μm (for 50 pC), ~20 μm (for 400 pC)
Bunch length	500–1200 μm

We have 3 main experimental goals:

1

Successfully operate a single discharge plasma lens

(first step in long term plan of using a lattice)

2

Measure the radial uniformity of the magnetic field gradient

(for different gases, pressures and currents)

3

Probe the limits set by plasma wakefields

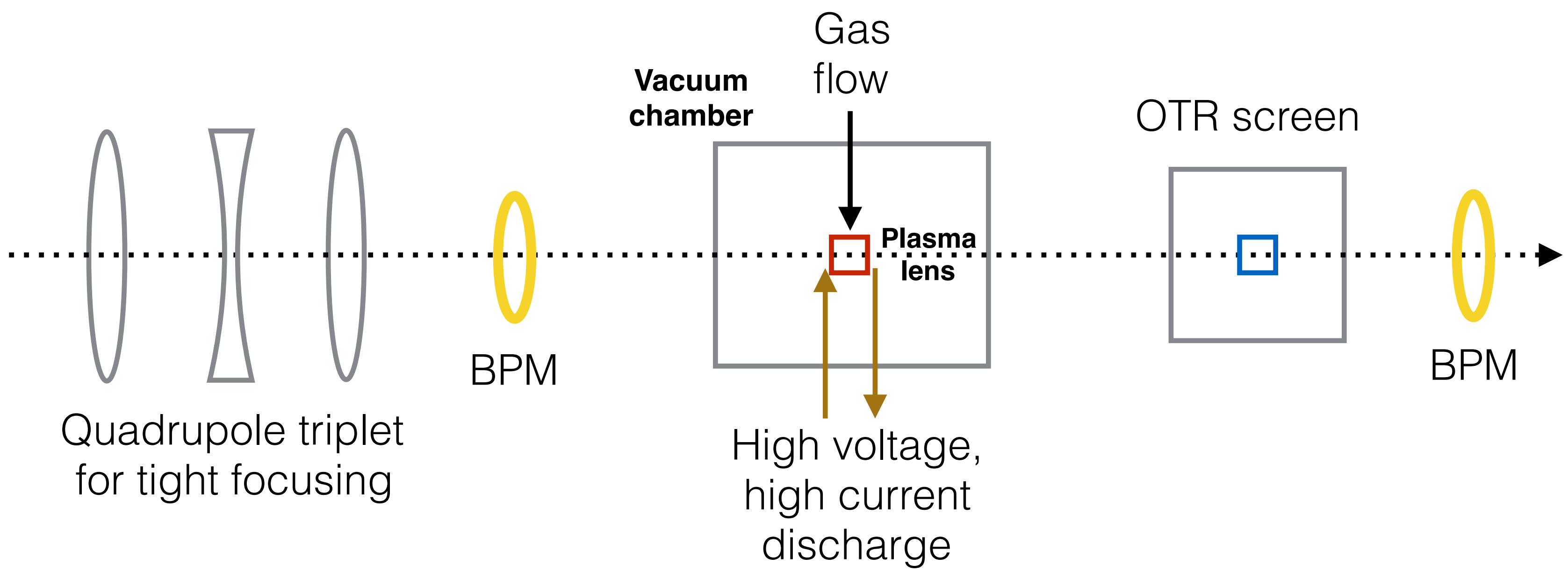
(by observing self-lensing in the plasma)

1

Successfully operate a single discharge plasma lens

(first step in long term plan of using a lattice)

Conceptual setup



- Peak discharge current: $I \approx 500$ A
  Capillary radius: R = 0.5 mm
  Expected gradient: g ≈ 400 T/m

Linear model

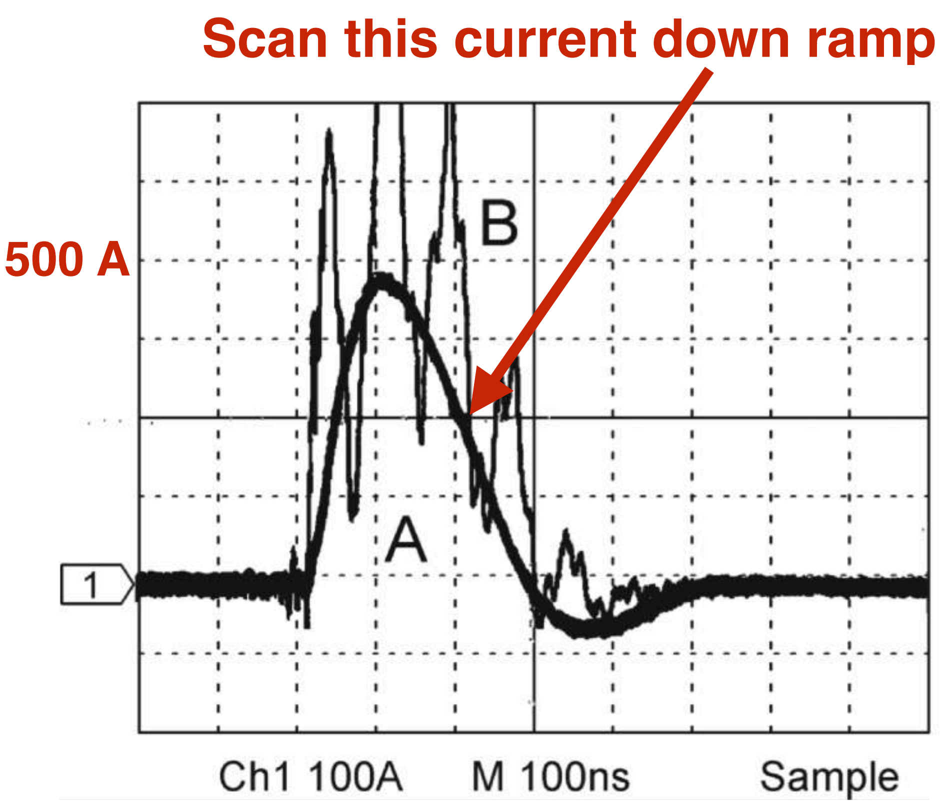
$$\frac{\partial B_\phi}{\partial r} = \frac{\mu_0 I}{2\pi R^2}$$

- Will be measured using beam size on downstream OTR, and from dipole kick when the beam is offset in lens.

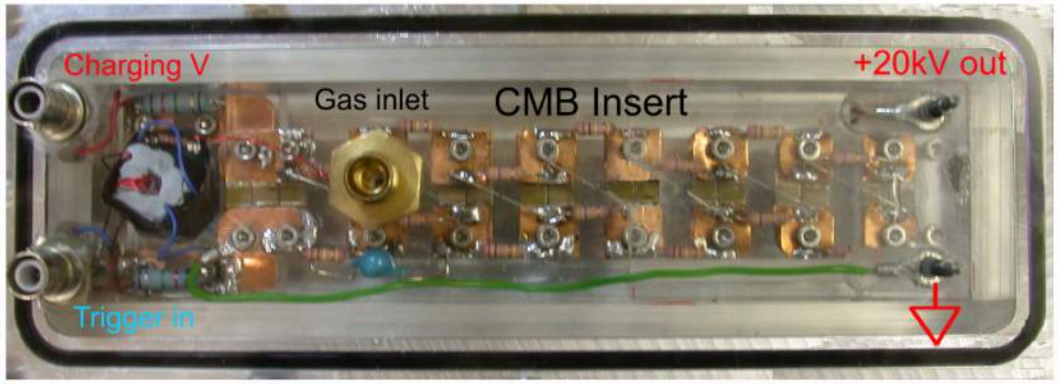
Changing gradient

- Will be using a Marx Bank as a HV/HC source:
  – Extremely stable and reproducible
  – Not easily tuned

- Method of varying magnetic field strength:
  timing within pulse



Smooth current profile of the Marx Bank pulse using short cables (A) or long coaxial cables (B) to connect to the load.
Image source: A. E. Dyson et al., "Compact, low cost Marx bank for generating capillary discharge plasmas", Rev Sci Inst 87 093302 (2016)



(Compact) Marx Bank, by Anthony Dyson (Uni Oxford)

2

Measure the radial uniformity of the magnetic field gradient

(for different gases, pressures and currents)

Measuring the radial magnetic field profile

- A new paper from LBNL models the radial magnetic field in an active plasma lens with simulations and an analytic model.
- J. van Tilborg, Phys. Rev. Accel. Beams **20**, 032803 (2017), *"Nonuniform discharge currents in active plasma lenses".*
- An additional enhancement factor of ~1.35 is expected due to non-linearities (400 T/m –> 550 T/m).
- We will compare this directly to measurement of dipole kicks with a tightly focused beam (sampling a small transverse region).

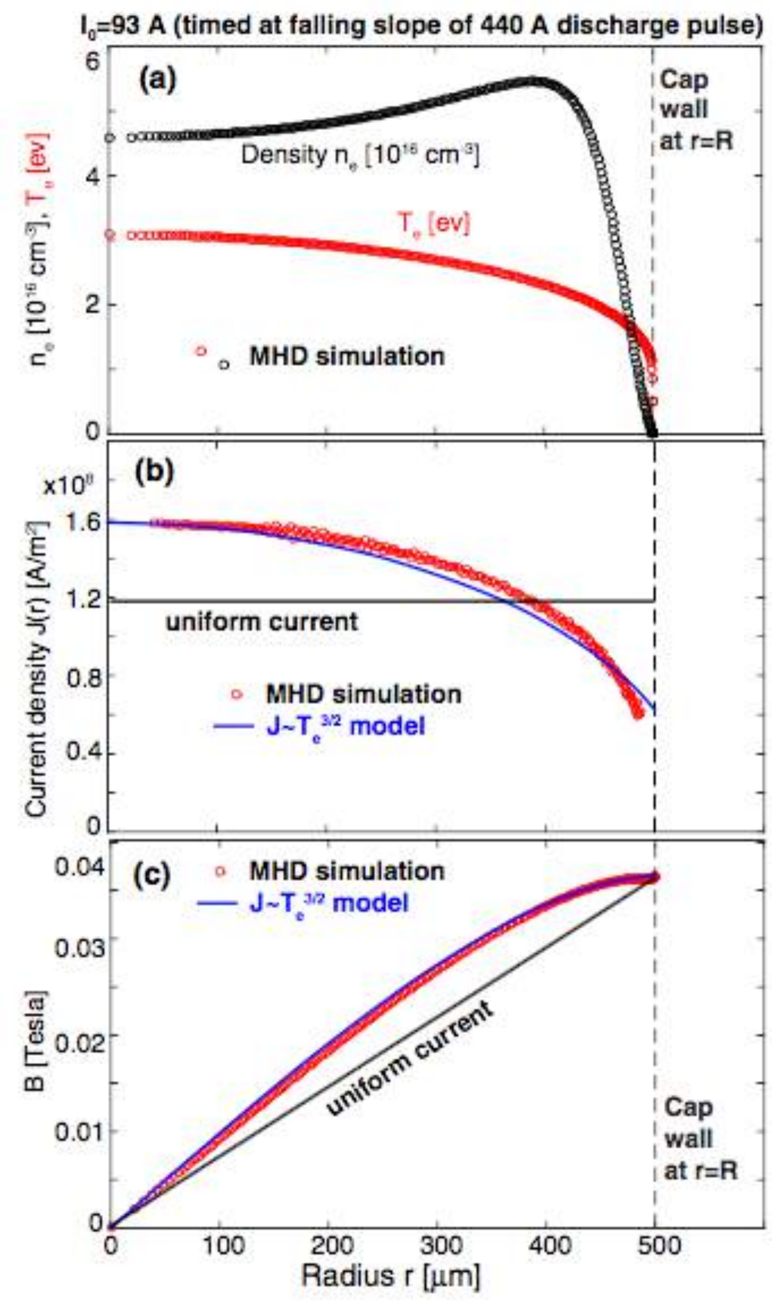
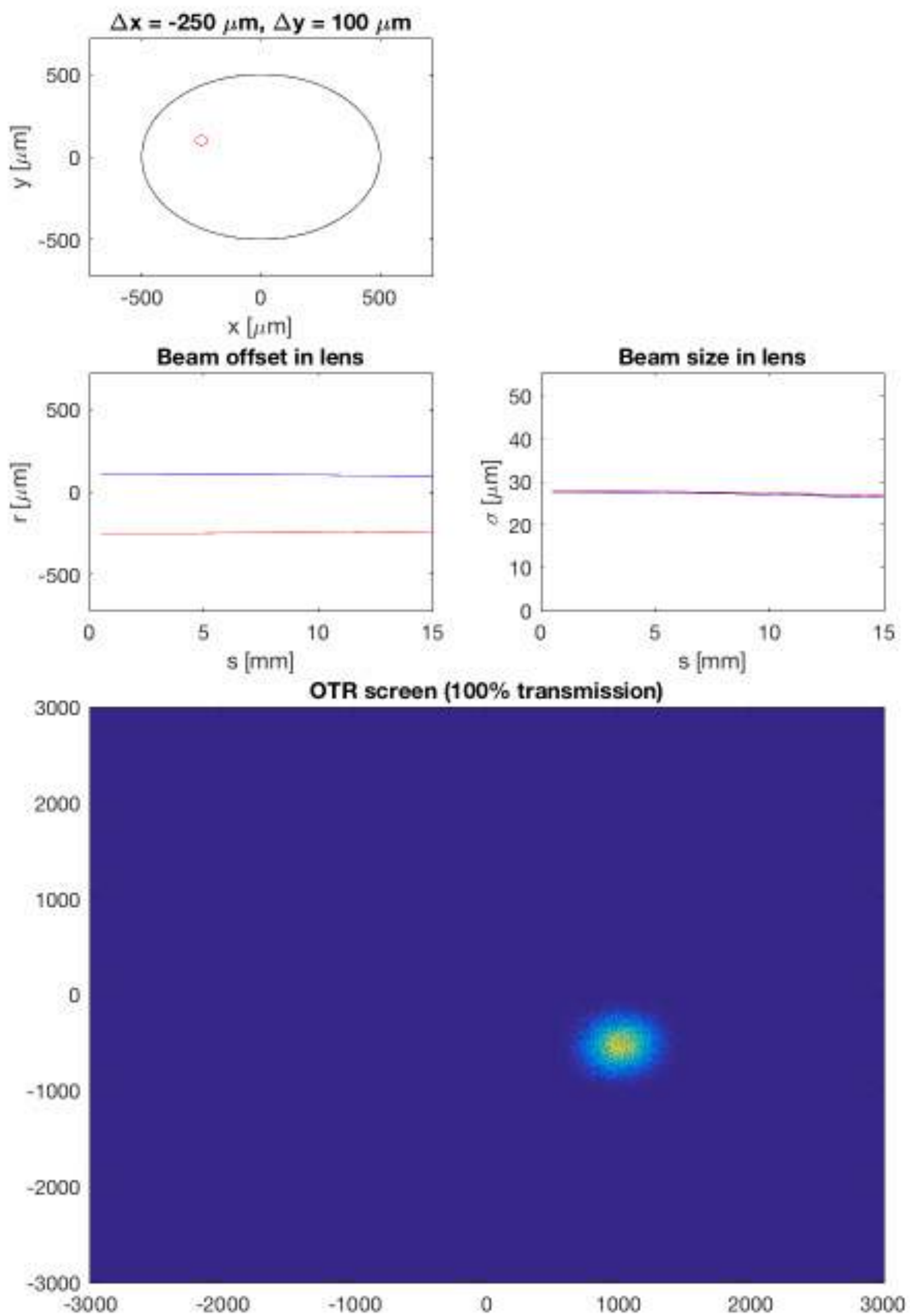
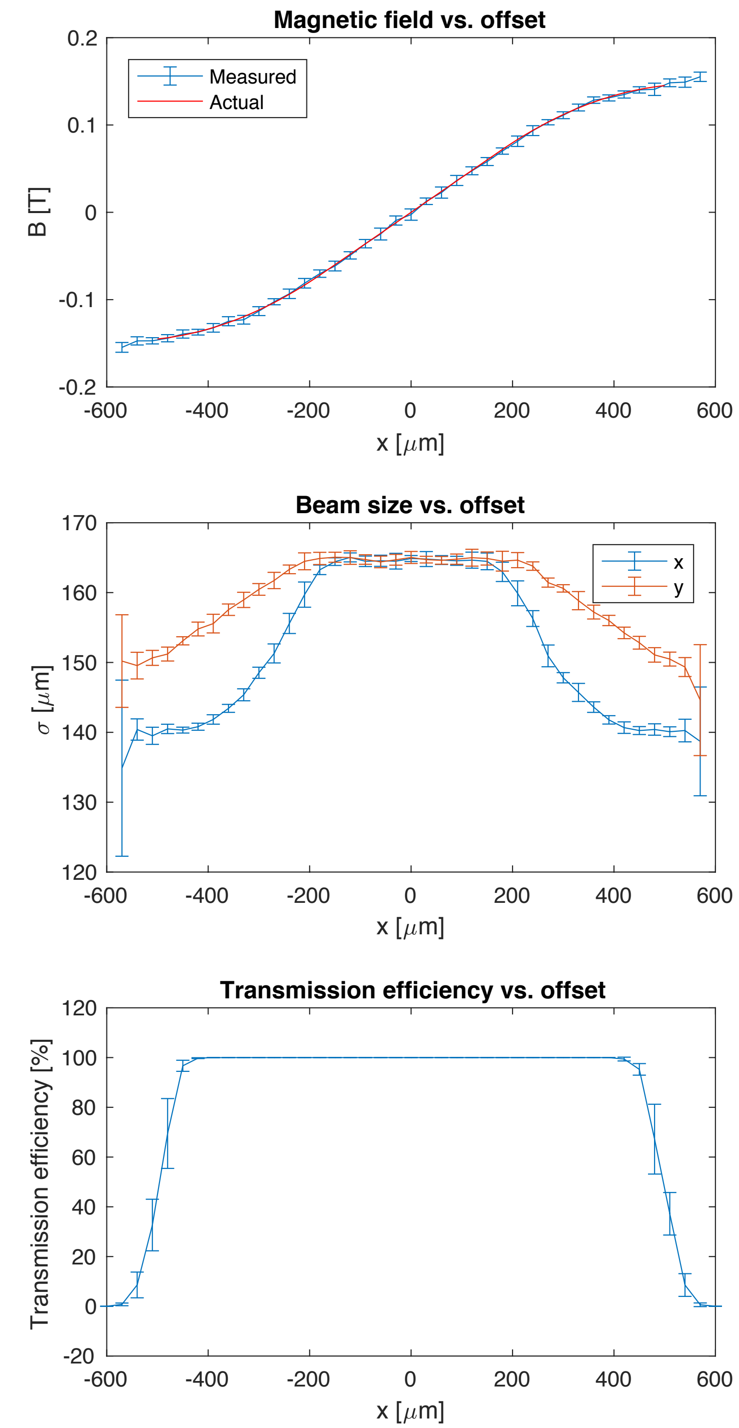


Image source: J. van Tilborg, PRAB (2017)
Nonuniform discharge currents in active plasma lenses



Simulated transverse offset experiment
(with realistic jitters)



Expected 1D results

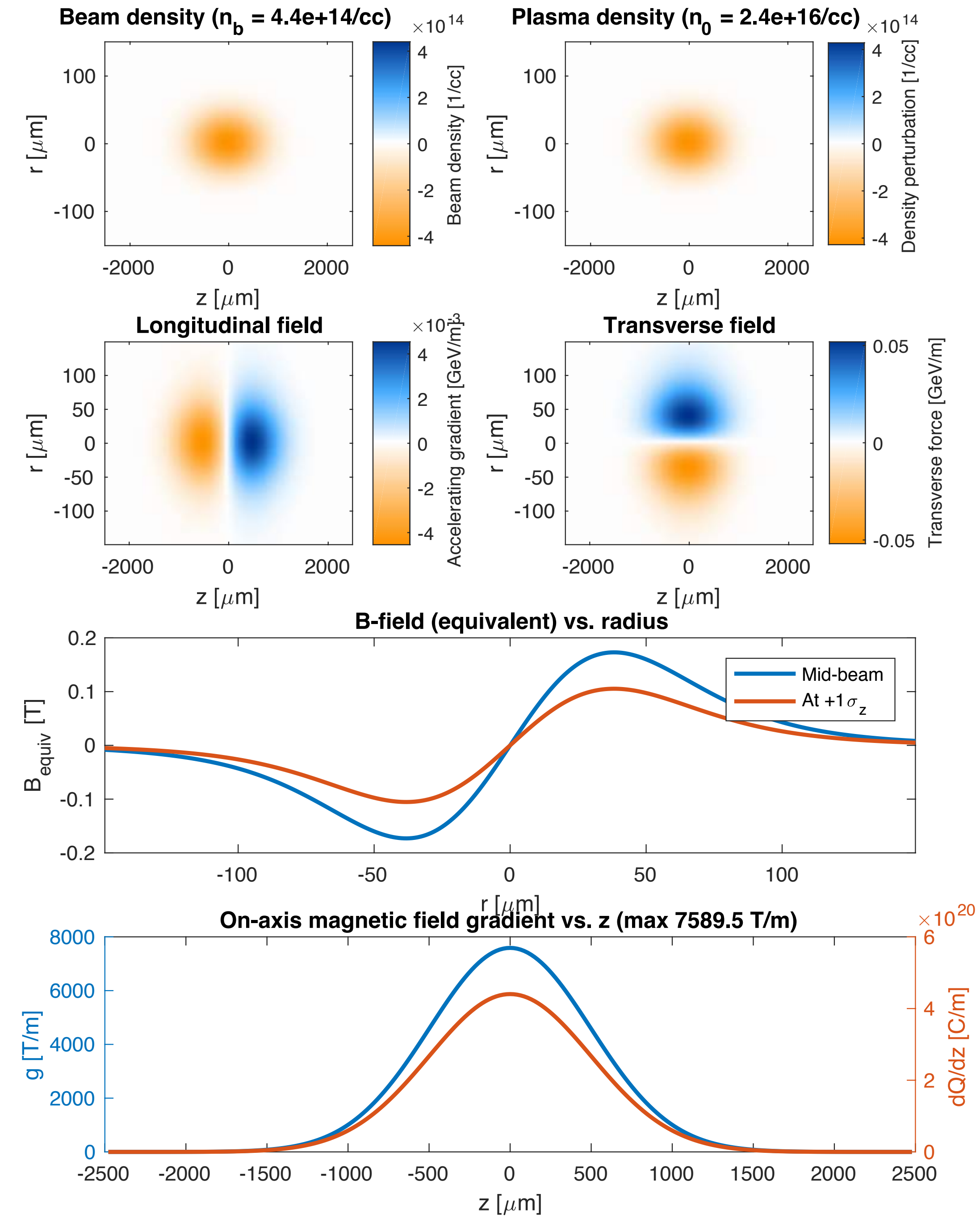
3

Probe the limits set by plasma wakefields

(by observing self-lensing in the plasma)

Plasma wakes

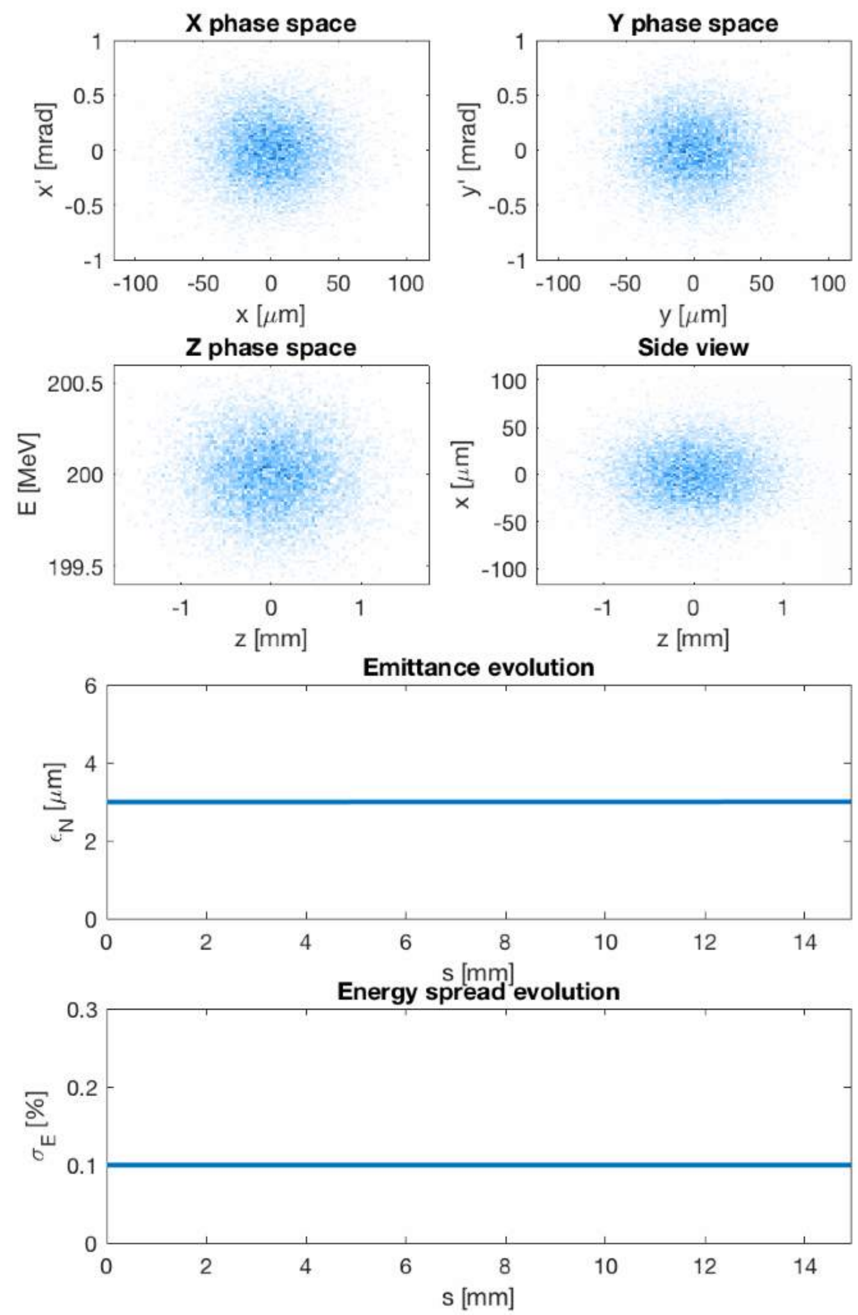
- It is important to determine where plasma wakefield focusing (transversely nonuniform) begin to interfere with the active plasma lens focusing (transversely uniform, ideally).
- For long beams: linear PWFA regime.
- Can be measured by observing focusing of an offset beam which varies separately from the dipole kick (from the active lens).



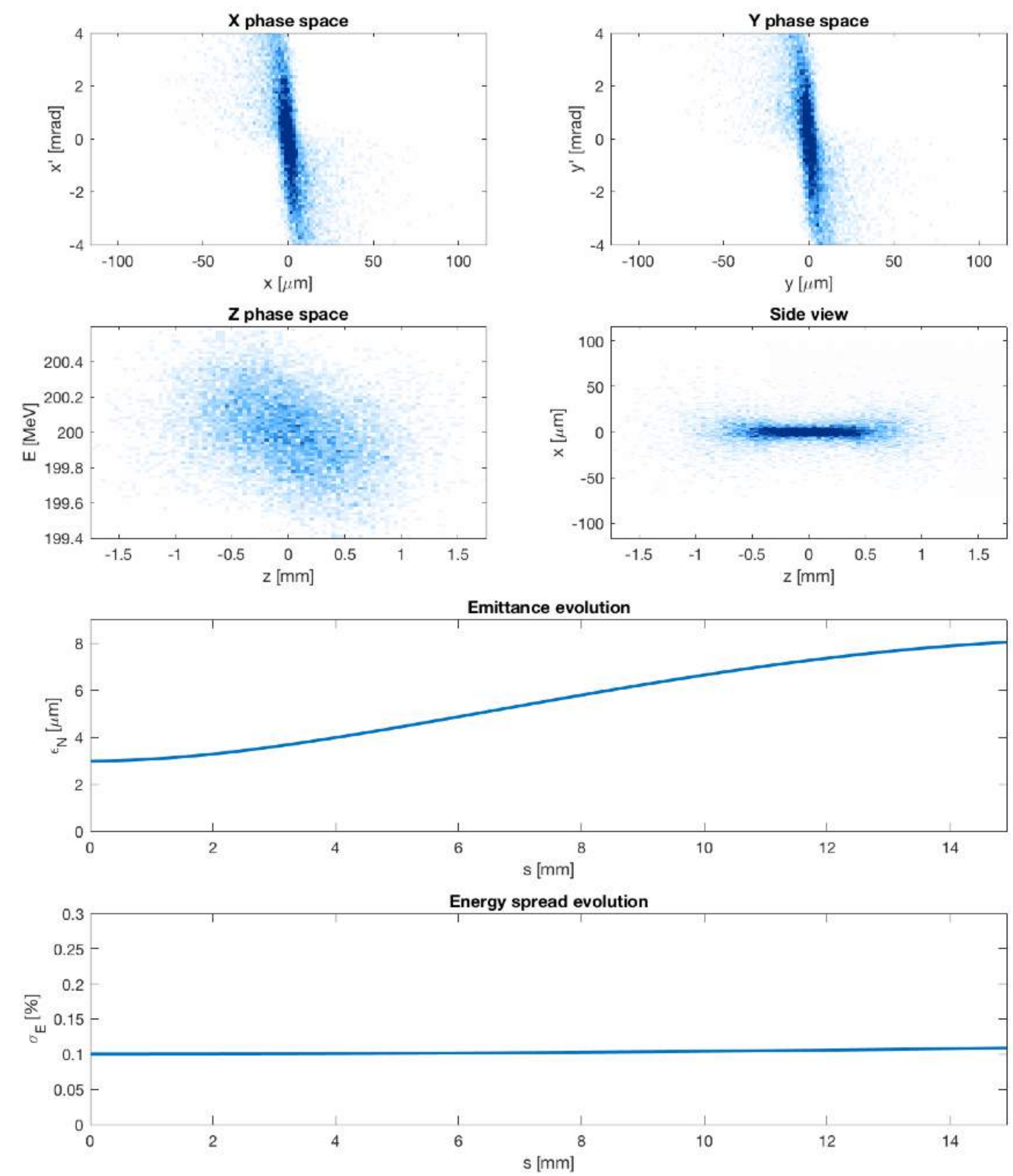
Simulations run in QuickPIC

Probing the lens with varying beam intensity

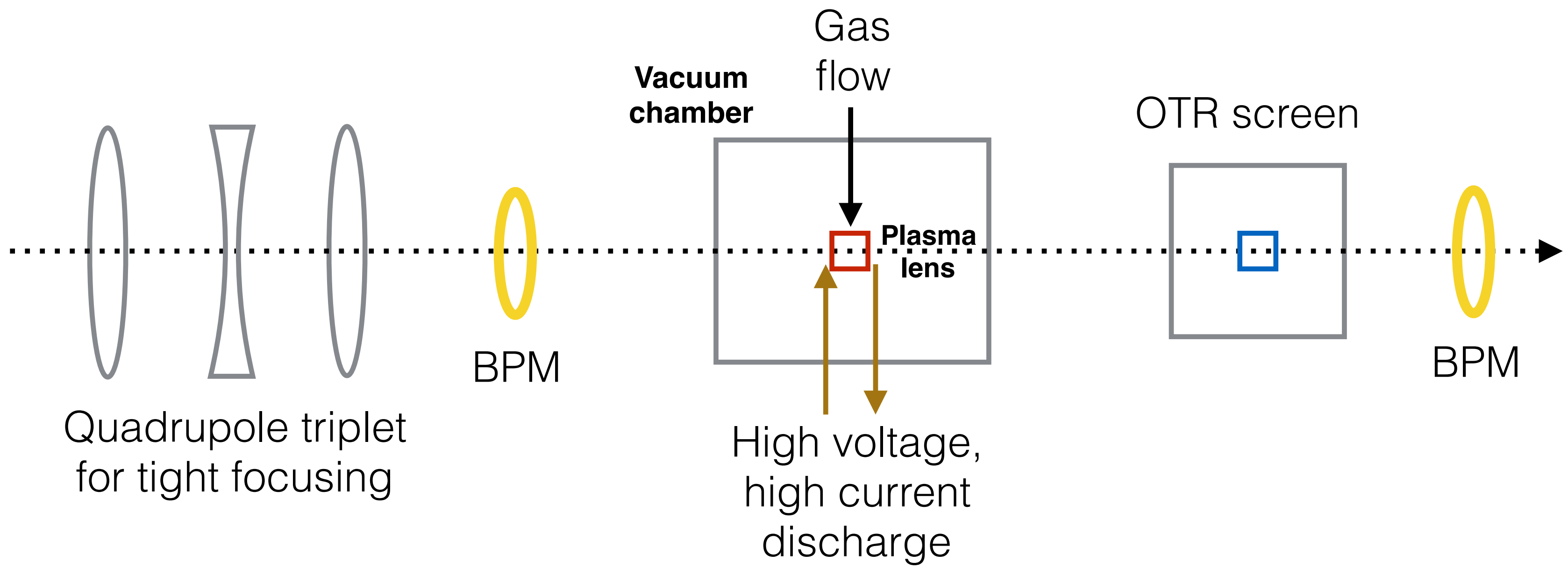
Low beam density:
10 pC, 500 μm rms bunch length, ~40 μm rms beam size



High beam density:
500 pC, 500 μm rms bunch length, ~30 μm rms beam size



Experimental setup



Subsystems

Capillary and mount

Sapphire capillary

PEEK mount
(internal gas line)

Gas flow and vacuum

Flow regulator

Turbo pump

Beam window

Vacuum chamber

High voltage discharge source

Marx Bank

Triggering and charging system

Diagnostics

OTR screen

Gas system pressure gauge

Vacuum chamber pressure gauge

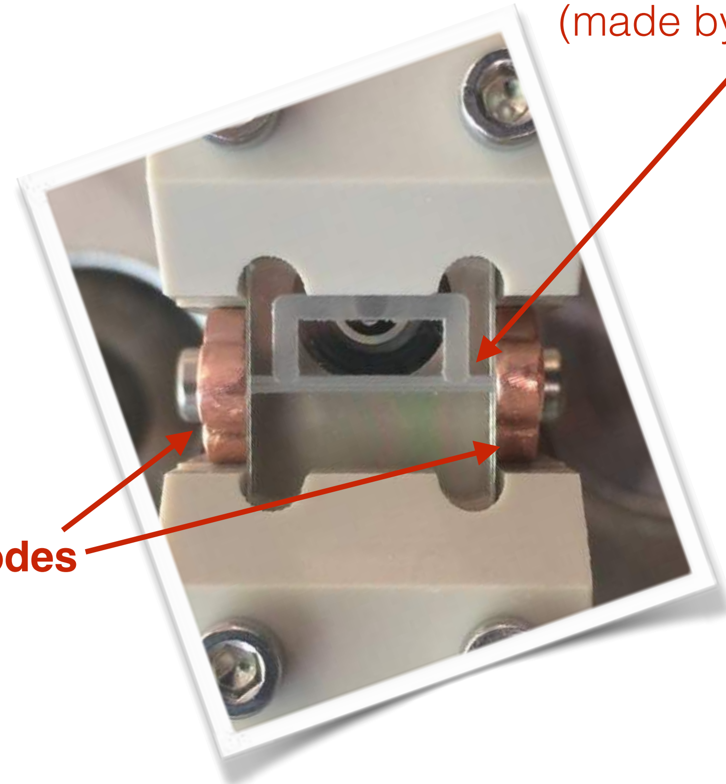
Inductive and cavity BPMs

Experimental setup

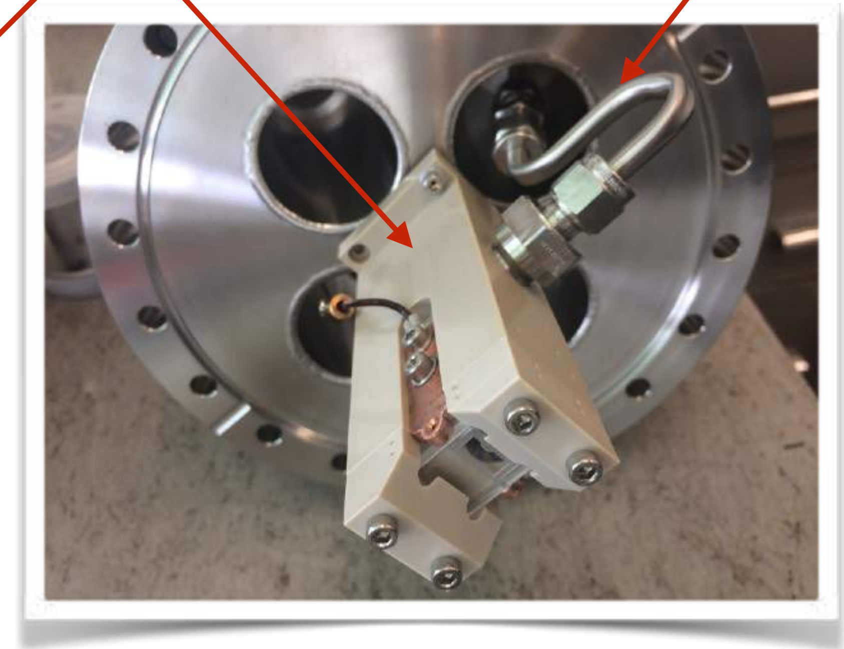
Sapphire capillary
(made by Jan-H. Röckemann, DESY)

PEEK mount
(made by Jan-H. Röckemann, DESY)

Gas line from outside



Electrodes



Subsystems

Capillary and mount

Sapphire capillary

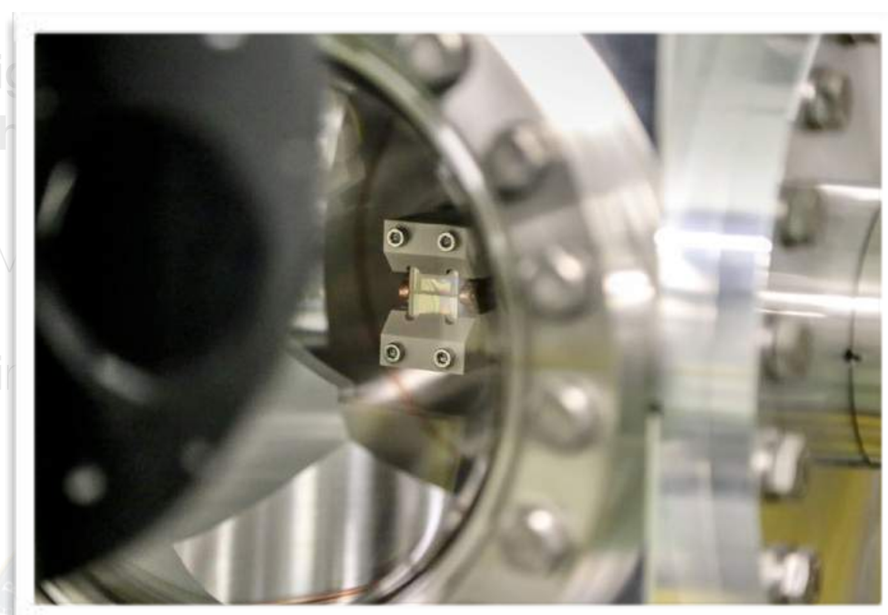
PEEK mount
(internal gas line)

Gas flow and vacuum

Flow regulator

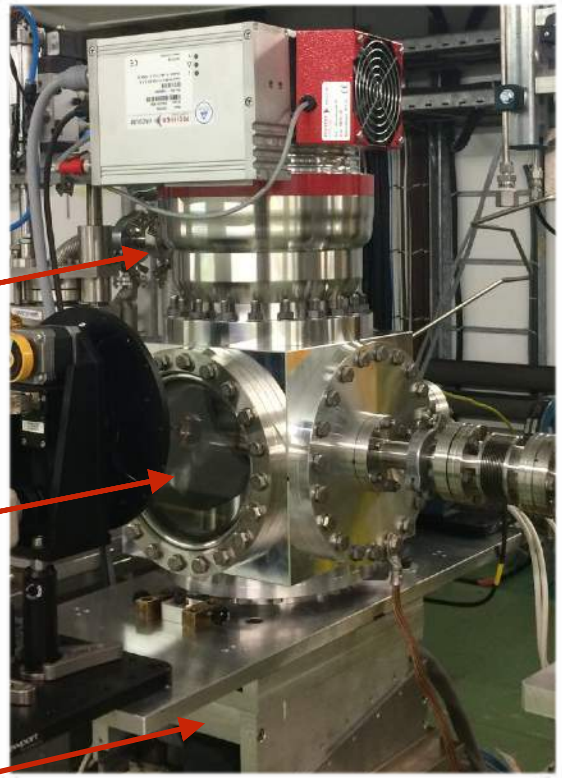
Turbo pump

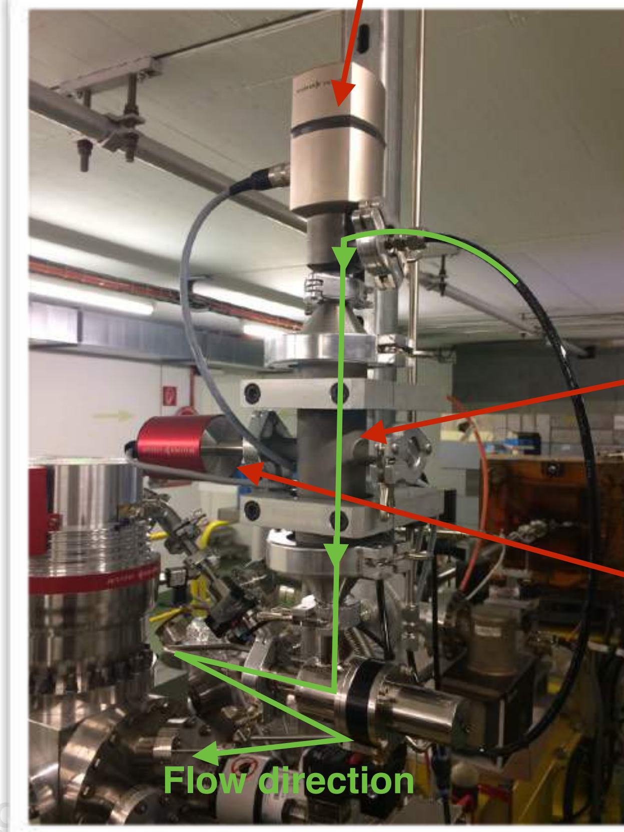
Beam window



DESY collaborators:
Jan-H. Röckemann
Lucas Schaper
Jens Osterhoff

Experimental setup





Subsystems

Capillary and mount

Sapphire capillary

PEEK mount (internal gas line)

Gas flow and vacuum

Flow regulator

Turbo pump

Beam window

Vacuum chamber

High voltage discharge source

Marx Bank

Triggering and charging system

Diagnostics

OTR screen

Gas system pressure gauge

Vacuum chamber pressure gauge

Inductive and cavity BPMs

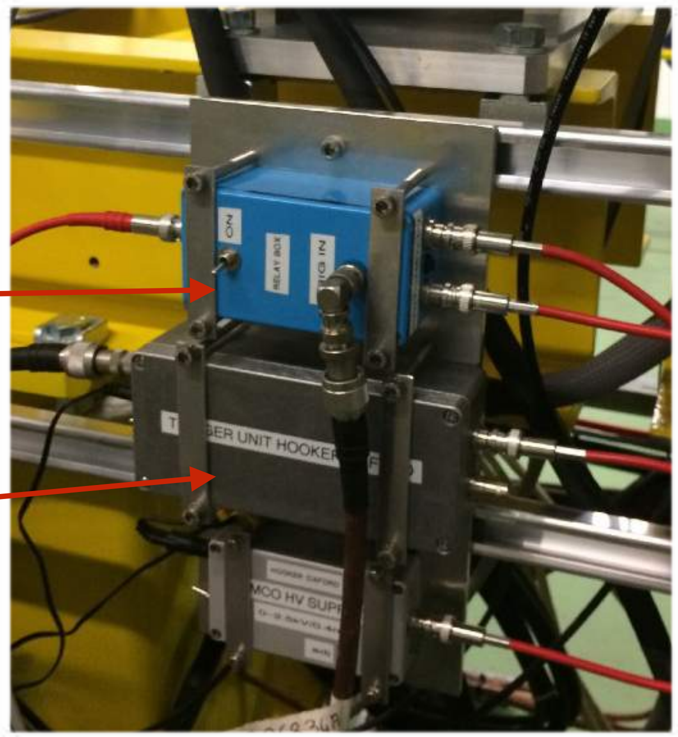
We will use gases: **Helium** and **Argon**

Experimental setup

Charging relay

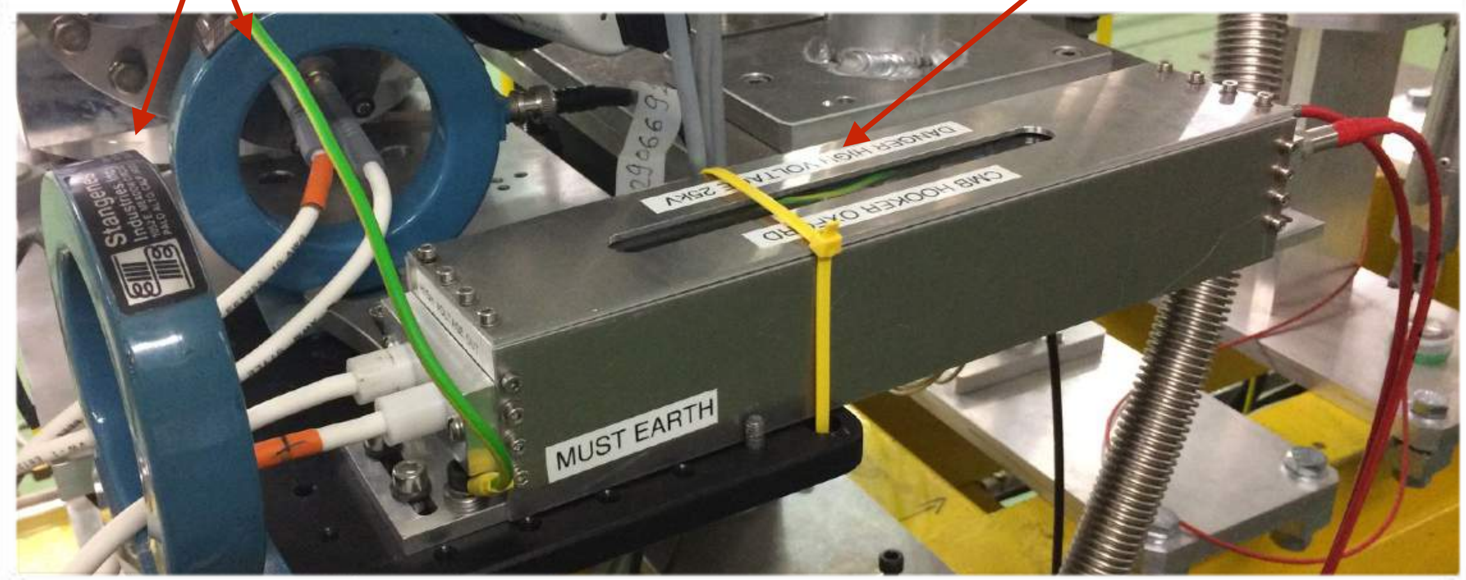
HV trigger pulse generator

All made by Anthony Dyson, Uni Oxford



Current pulse transformers

Compact Marx Bank
(made by Anthony Dyson, Uni Oxford)



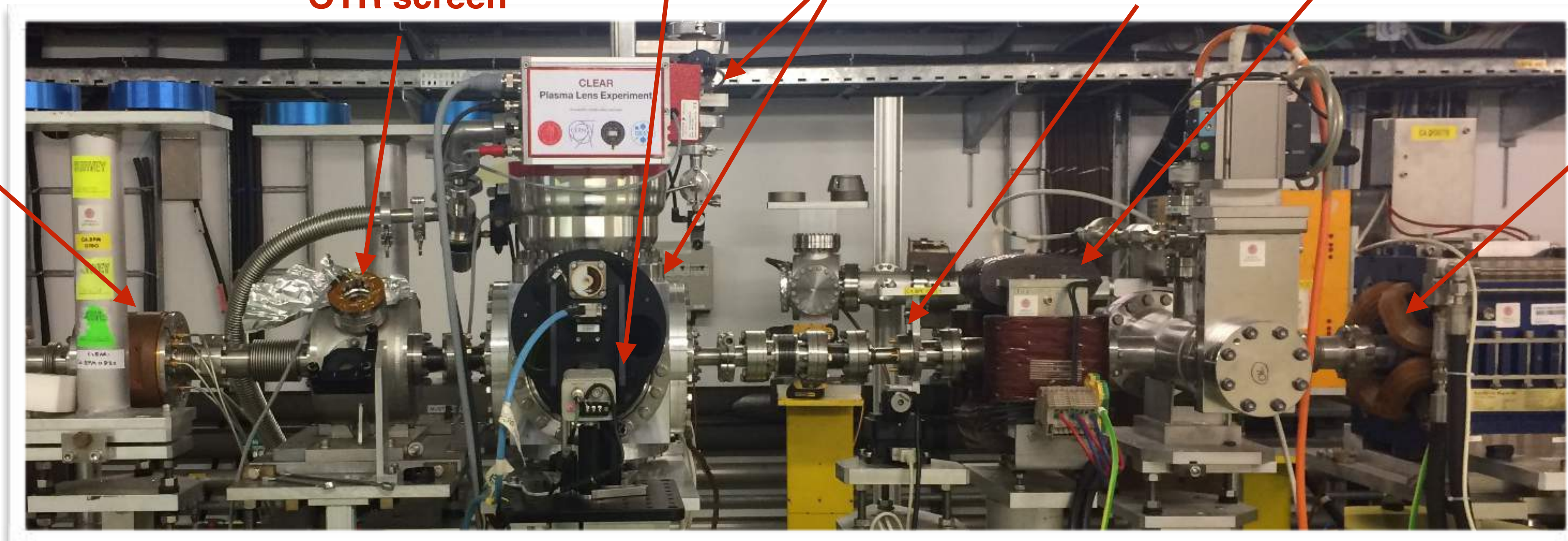
Current pulse: **~500 A peak**, 150 ns pulse

Subsystems

Capillary and mount	Gas flow and vacuum	High voltage discharge source	Diagnostics
Sapphire capillary	Flow regulator	Marx Bank	OTR screen
PEEK mount (internal gas line)	Turbo pump	Triggering and charging system	Gas system pressure gauge
	Beam window		Vacuum chamber pressure gauge
	Vacuum chamber		Inductive and cavity BPMs

Uni Oxford collaborators:
Anthony Dyson
Simon Hooker

Experimental setup



Subsystems

High voltage discharge source

Marx Bank

Triggering and charging system

Diagnostics

OTR screen

Gas system pressure gauge

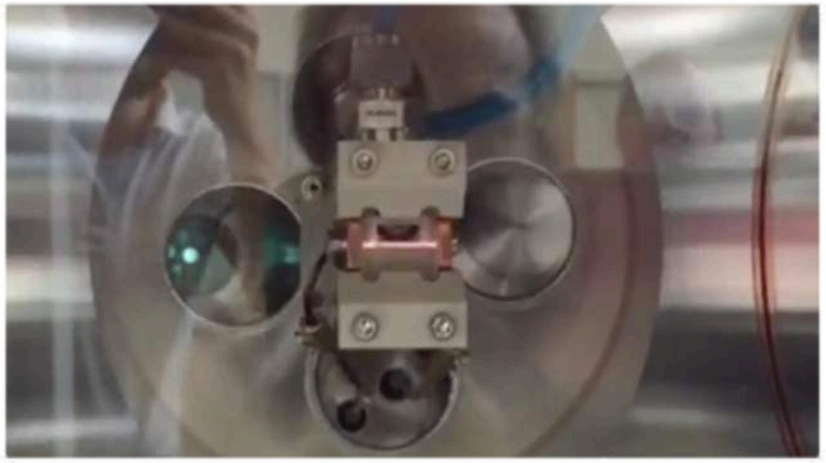
Vacuum chamber pressure gauge

Inductive and cavity BPMs

HV test: Successful demonstration of plasma

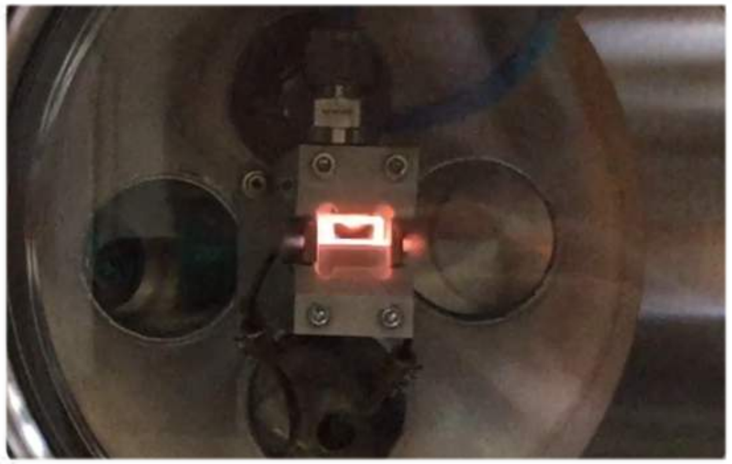
- Conducted Aug 2017 at CERN with collaborators from DESY and Uni Oxford present

DC power supply

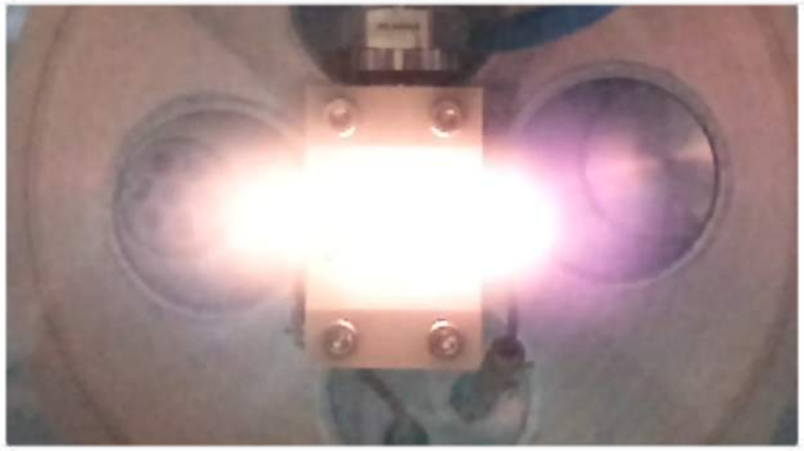


In the reflection:
Erik Adli (principal investigator, Uni Oslo)

CMB pulse



CMB pulse (very high pressure)



Gianfranco Ravida (CERN, left)
and **Anthony Dyson** (Uni Oxford, right)

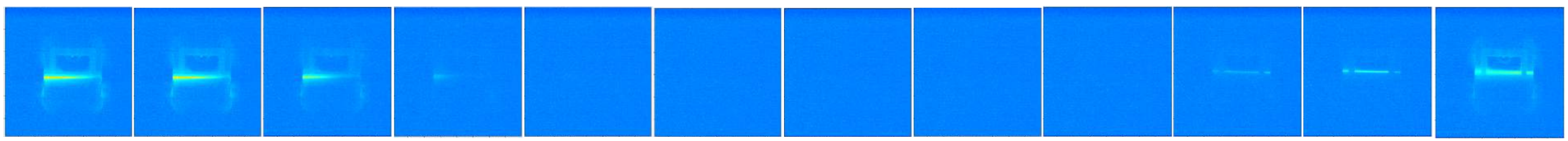
Carl A. Lindstrøm (Uni Oslo, left)
and **Jan-Hendrik Röckemann** (DESY, right)

Beam test: Sent a beam through the capillary

- Conducted Sep 2017 in the CLEAR test facility at CERN.

*Installation and experiments conducted with help from **Davide Gamba** (CERN, left) and **Wilfrid Farabolini** (CERN, right).*

Vertical offset scan (beam scintillates in the sapphire)

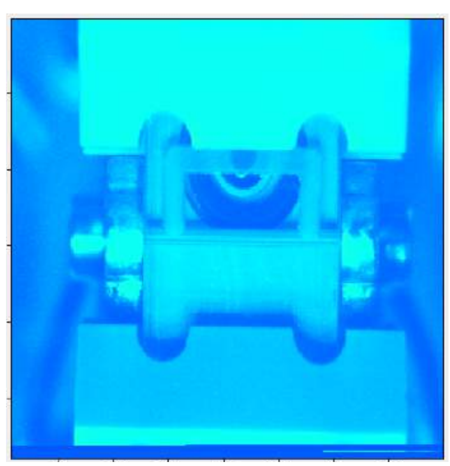


← Scintillates below → ← **Beam passes through cleanly** → ← Scintillates above →

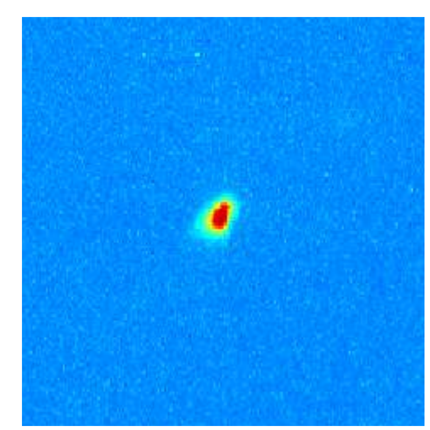
(750 μm range)

20 pC charge (single bunch)
Beam size ≤ 100 μm rms

Capillary with **chamber light on**

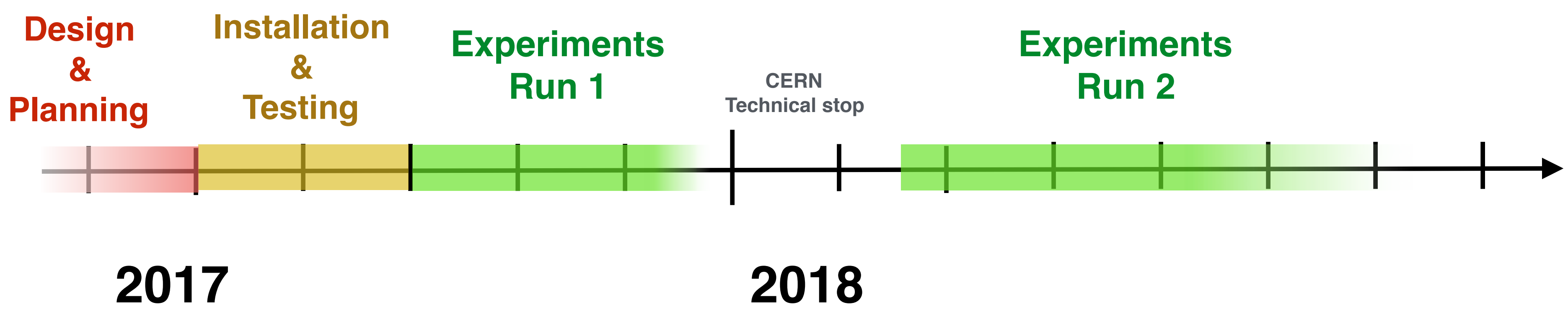


Beam at dump window after passing through the capillary



The way forward

- Experiments with beam and an active plasma lens planned to start in Oct 2017.
- Further experiments will be performed until ~mid 2018.



Thanks for your attention!