The CLEAR Plasma Lens Experiment
Carl A. Lindstrøm, University of Oslo and CERN
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The CLEAR Plasma Lens Experiment

Carl A. Lindstrøm
PhD Student
University of Oslo, Department of Physics

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)
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

The CLEAR Test Facility at CERN

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

<table>
<thead>
<tr>
<th>Beam parameter</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>130–220 MeV</td>
</tr>
<tr>
<td>Bunch charge</td>
<td>10–500 pC</td>
</tr>
<tr>
<td>Norm. emittance</td>
<td>~3 µm (for 50 pC), ~20 µm (for 400 pC)</td>
</tr>
<tr>
<td>Bunch length</td>
<td>500–1200 µm</td>
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</tbody>
</table>
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)
Successfully operate a single discharge plasma lens
(first step in long term plan of using a lattice)
Conceptual setup

- Peak discharge current: $I \approx 500 \text{ A}$
- Capillary radius: $R = 0.5 \text{ mm}$

**Expected gradient:** $g \approx 400 \text{ T/m}$

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

Linear model:

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

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.


- 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).
Simulated transverse offset experiment
(with realistic jitters)
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

Subsystems

Capillary and mount

Sapphire capillary

PEEK mount (internal gas line)

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

Gas line from outside

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

Gas flow and vacuum

Flow regulator

Turbo pump

Beam window

Electrodes

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

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

Subsystems

Gas flow and vacuum
- Flow regulator
- Turbo pump
- Beam window
- Vacuum chamber

We will use gases: Helium and Argon

Kapton foil (8 µm) holding Δp = 1 bar

Gas flow regulator

Buffer volume

Gas pressure gauge

Flow direction

Turbo pump

Vacuum chamber

Chamber mover (± 5 mm in x/y)

Sapphire capillary

PEEK mount (internal gas line)

Capillary and mount

High voltage discharge source

Marx Bank

Triggering and charging system

Vacuum chamber pressure gauge

Inductive and cavity BPMs

OTR screen

Gas system pressure gauge
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

- **Gas flow and vacuum**
  - Flow regulator
  - Turbo pump
  - Beam window

- **Capillary and mount**
  - Sapphire capillary
  - PEEK mount (internal gas line)

- **HV trigger pulse generator**

- **Current pulse transformers**

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

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

All made by Anthony Dyson, Uni Oxford

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

CMB pulse

CMB pulse (very high pressure)

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

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.

Vertical offset scan (beam scintillates in the sapphire)

- Scintillates below
- Beam passes through cleanly (750 µm range)
- Scintillates above

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

Capillary with chamber light on

Beam at dump window after passing through the capillary

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