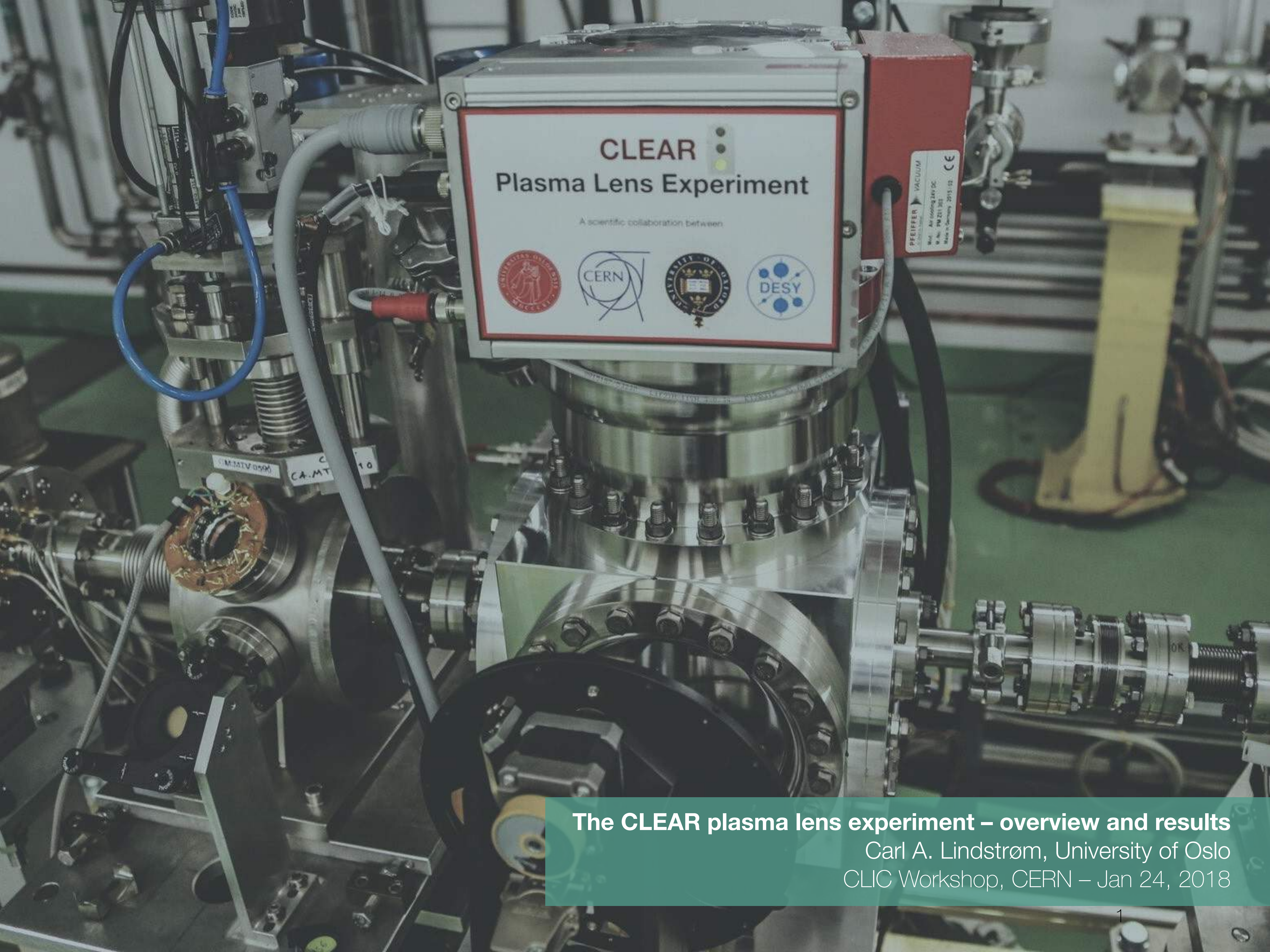


The CLEAR plasma lens experiment – overview and results

Carl A. Lindstrøm, University of Oslo

CLIC Workshop, CERN – Jan 24, 2018

The CLEAR plasma lens experiment
– overview and results

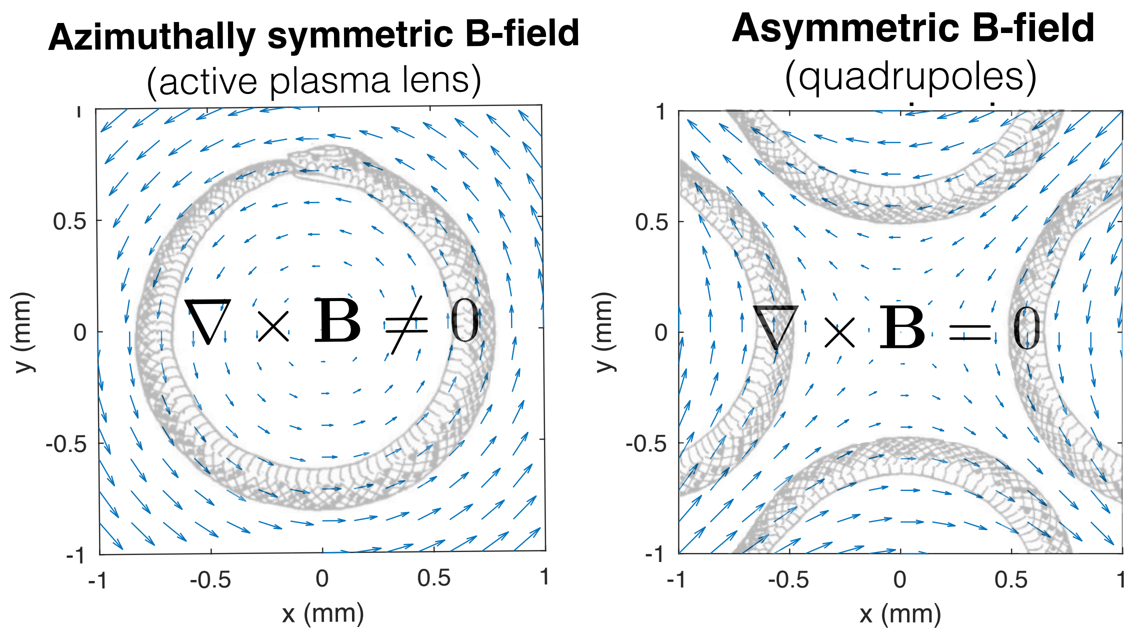
CLIC Workshop – Jan 24, 2018

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

Active plasma lenses

What is an active plasma lens?

- **Focusing in both planes simultaneously.**
- Maxwell equations require a **longitudinal current density** to have azimuthal focusing.
- We can use a plasma to conduct a large current parallel to the beam as it passes.
  => **Uniform current density** = an ideal/linear lens
- Can be up to 100 times stronger than conventional quadrupoles! (3500 T/m vs ~30 T/m)



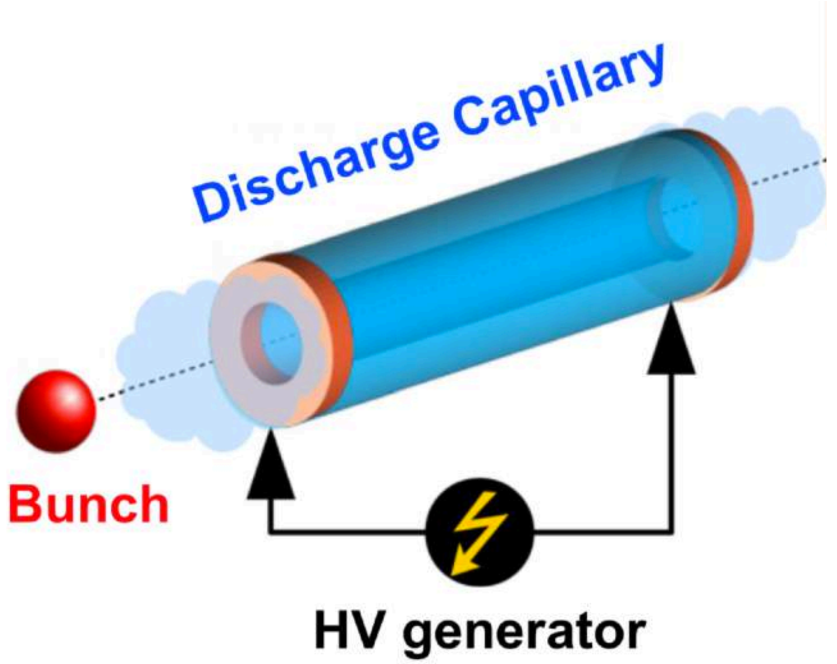


Image source: R. Pompili et al., **Appl. Phys. Lett. 110, 104101 (2017)**

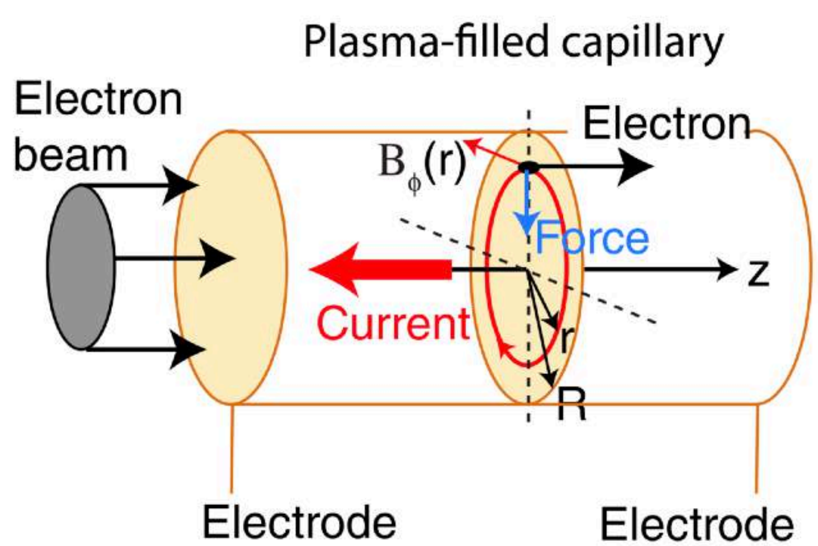
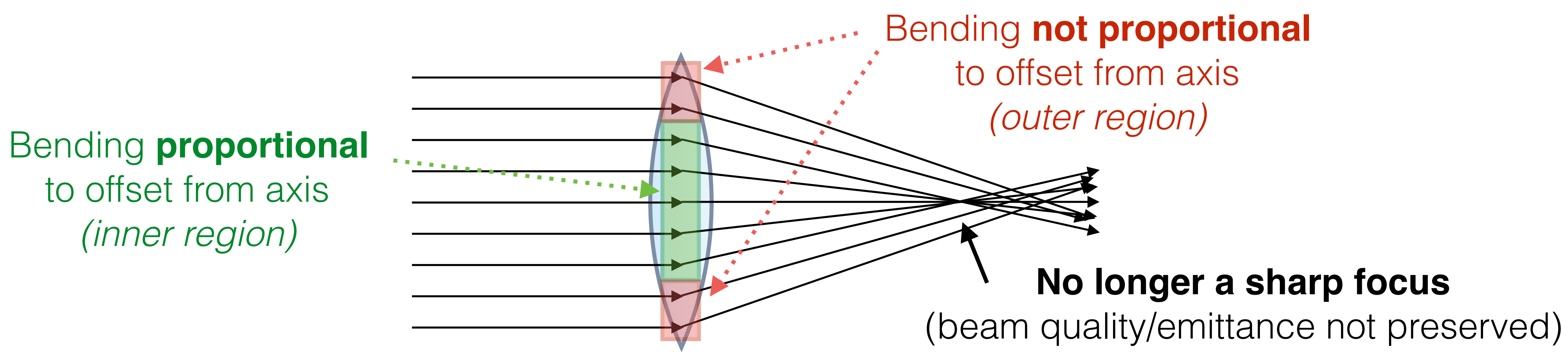


Image source: J. van Tilborg et al., **Phys. Rev. Lett. 115, 184802 (2015)**

Aberrations and emittance growth



1. Uneven plasma heating

=> Non-uniform current density

- Large currents heat the plasma, but unevenly (colder close to the walls).
- High temperature plasma conducts current better => more current in the center.

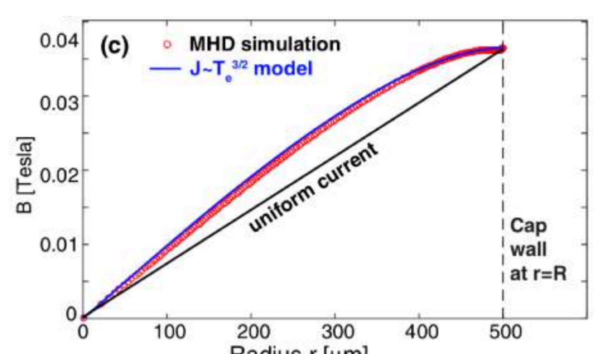
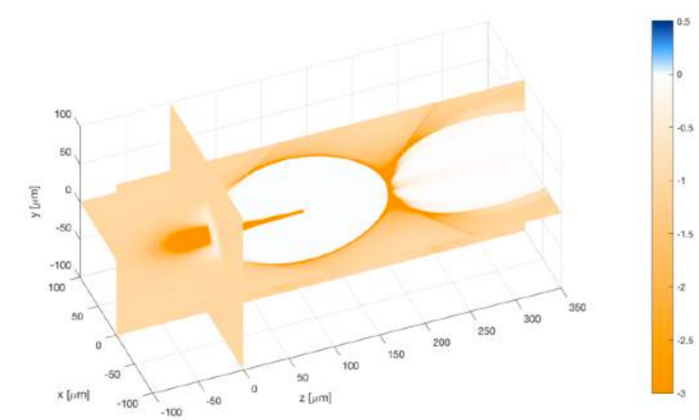


Image source: J. van Tilborg et al., **PRAB 20, 032803 (2017)**

2. "Passive" plasma lensing

=> Additional beam self-focusing

- Typically the beam transverse size is much larger in the lens than in the PWFA cell.
- However, if the electron beam is too intense, there will be a strong plasma wakefield.

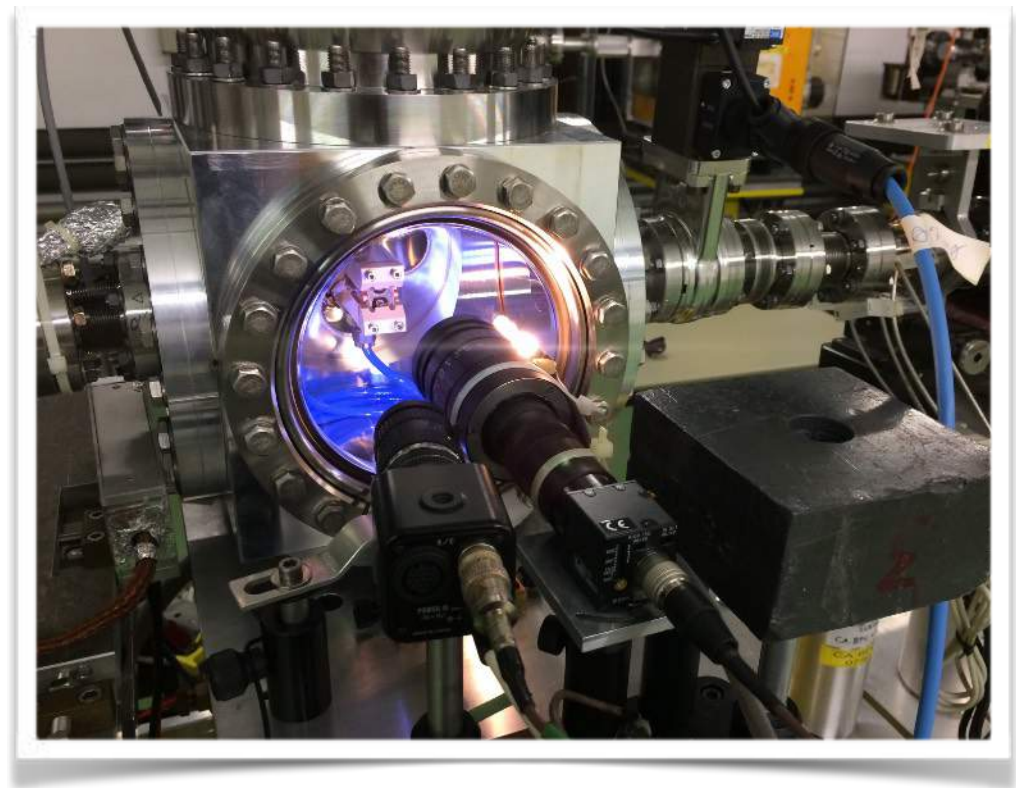


The CLEAR* plasma lens experiment†

- Several groups worldwide are investigating the active plasma lens (LBNL, INFN, DESY and CERN)

- We† are conducting an experiment at the CLEAR* user facility at CERN.

- Three experimental goals:
  - Demonstrate successful lensing with a new "low-cost" design*
  - Measure directly any spherical aberration from plasma heating
  - Probe limits set by plasma wakefields

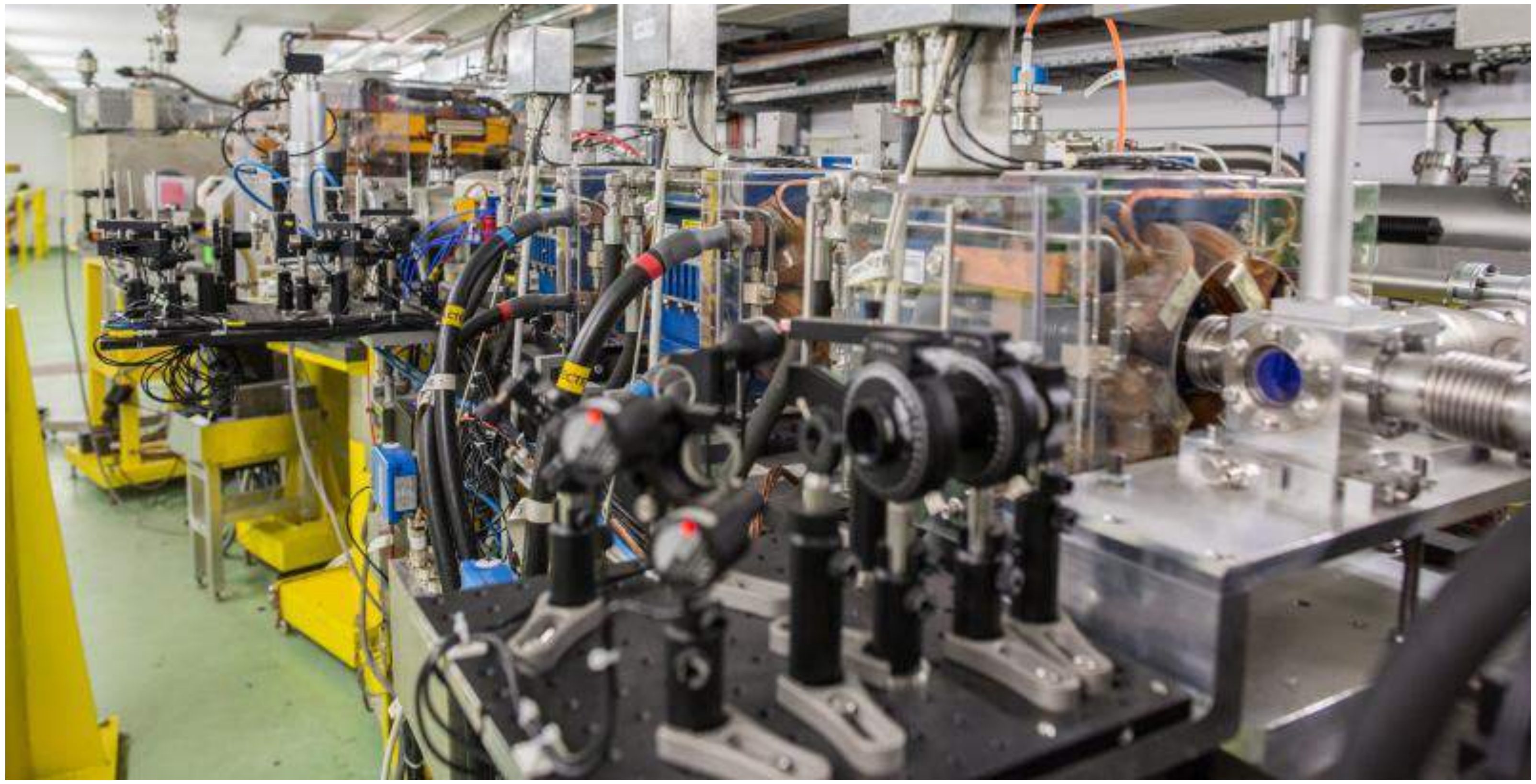


* *CERN Linear Electron Accelerator for Research*

† *C. A. Lindstrøm, K. N. Sjøbæk, E. Adli (PI) from the University of Oslo and CERN (W. Farabolini, D. Gamba, R. Corsini), with collaborators from DESY (J.-H. Röckemann, L. Schaper, J. Osterhoff) and Uni Oxford (A. Dyson, S. Hooker)*

Experimental setup

The CLEAR user facility at CERN



- Photocathode with S-band RF structures
- Previously used as the CTF3 witness injector
- Provides a tightly focused beam to the plasma lens experiment.

Beam parameter	**Range**
Energy	50–220 MeV
Bunch charge	1–1500 pC
Norm. emittance	~3 μm (for 50 pC), ~20 μm (for 400 pC)
Bunch length	300–1200 μm

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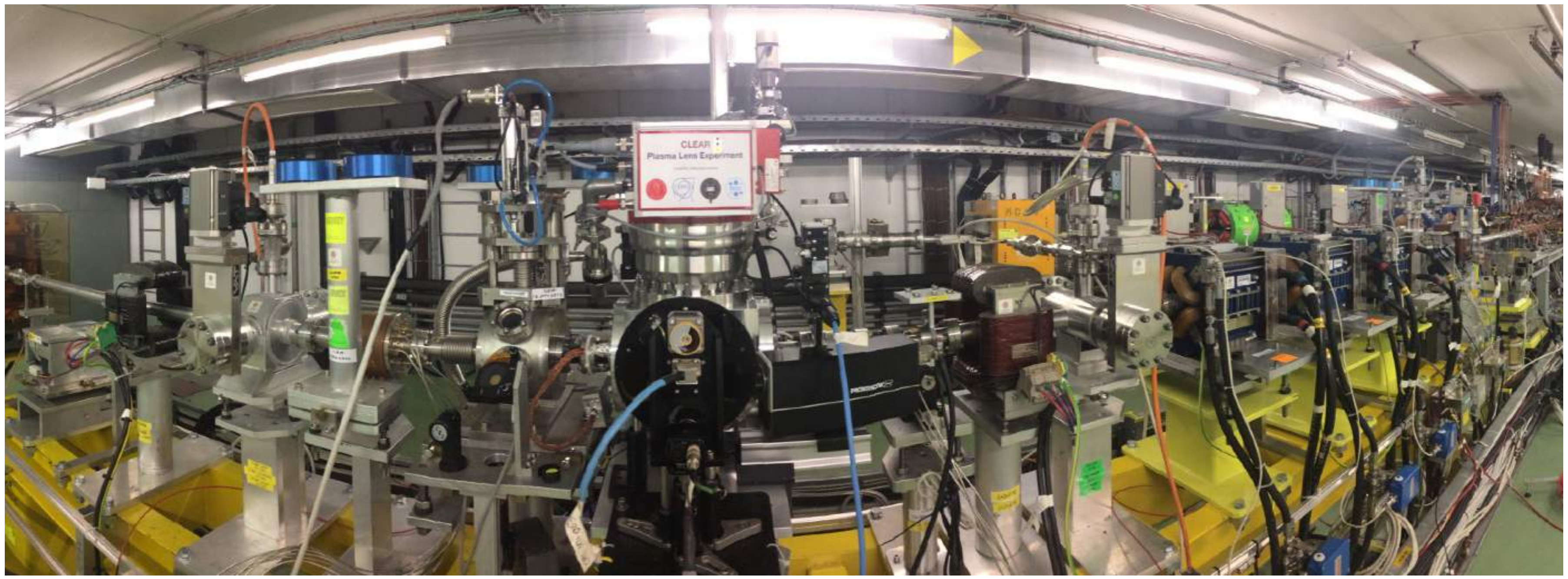
Small size, but many subsystems

Beam direction ←



← *Beam direction*

5 subsystems:

Capillary and mount — provided by DESY

Gas flow

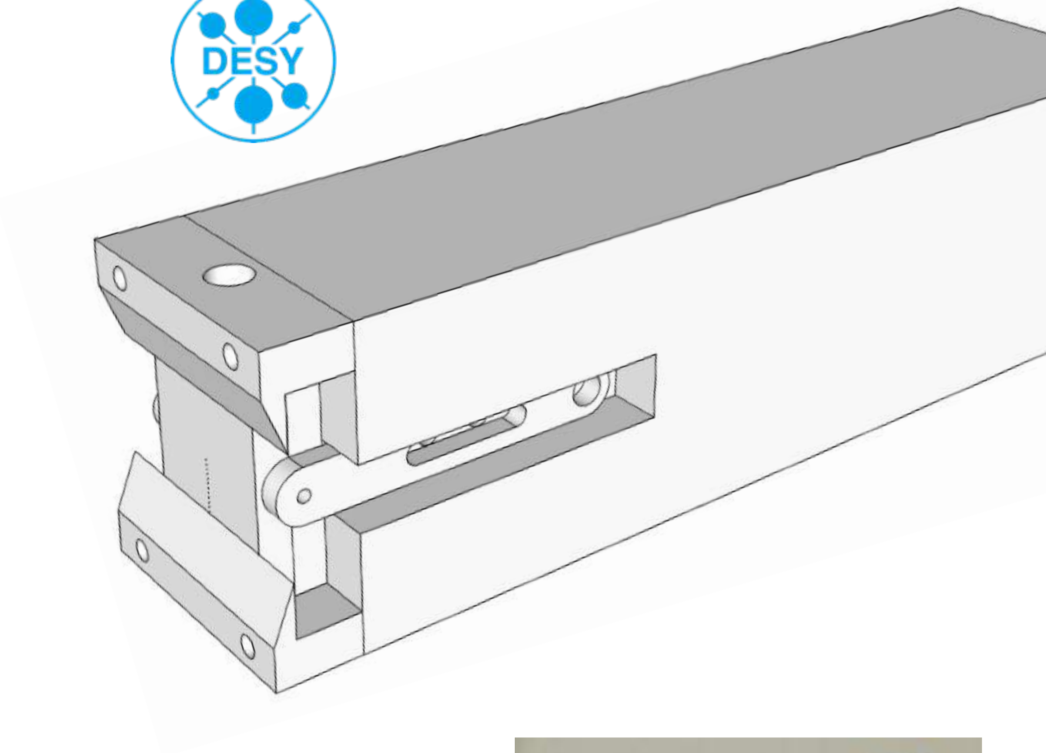
Vacuum and beam windows

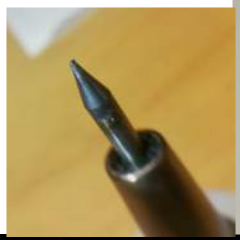
High voltage source — provided by University of Oxford

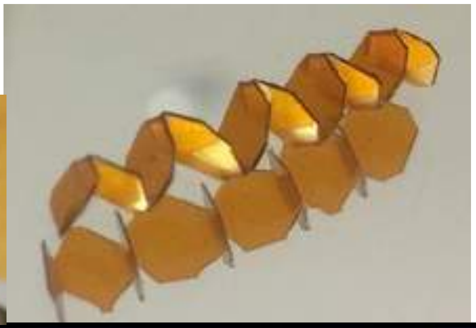
Beam diagnostics

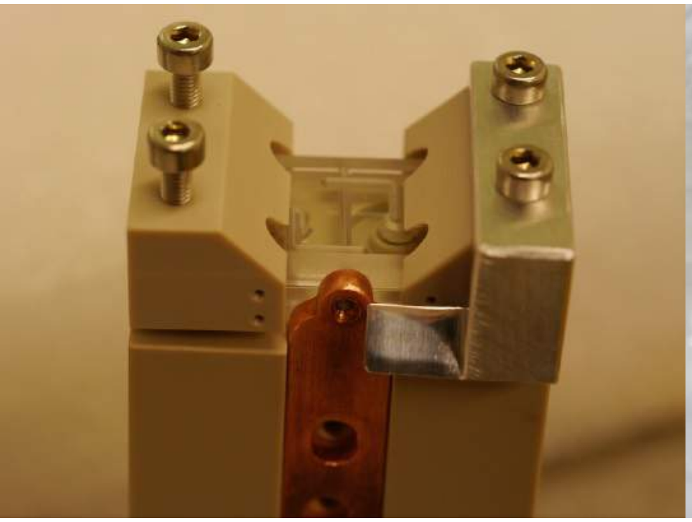
Sapphire capillary and mount

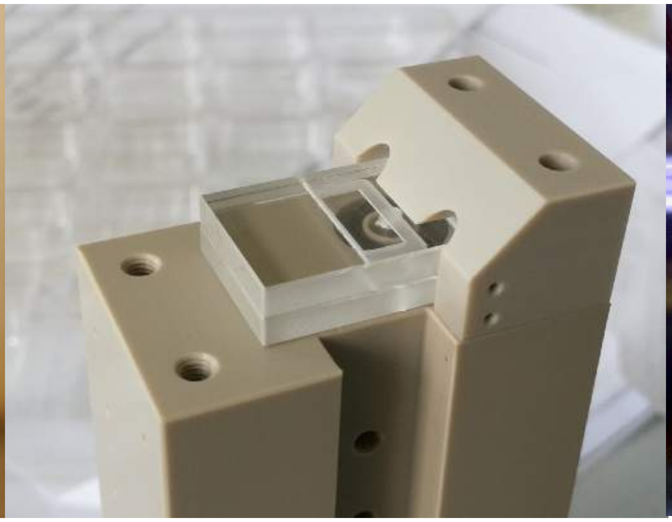
- 1 mm diameter half-tubes milled from two blocks of sapphire ($3 \times 15 \times 20$ mm^3)
- Polyether ether ketone (PEEK) UVH compatible, insulating plastic used for mount.
- Rubber gaskets for leak-tight internal gas flow.
- Folded Kapton-sheet inside the gas inlet to stop internal discharging.
- Copper electrodes connected to HV source.

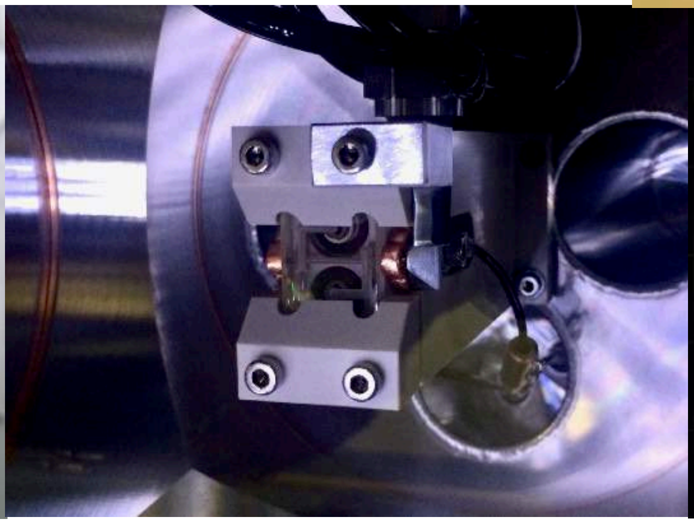


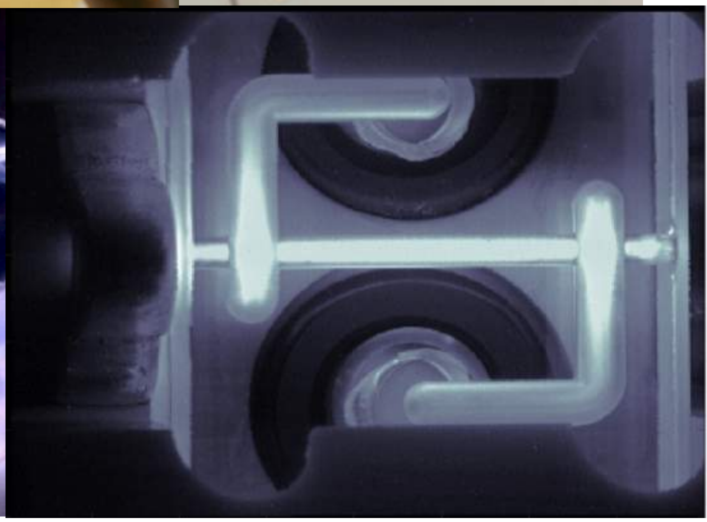






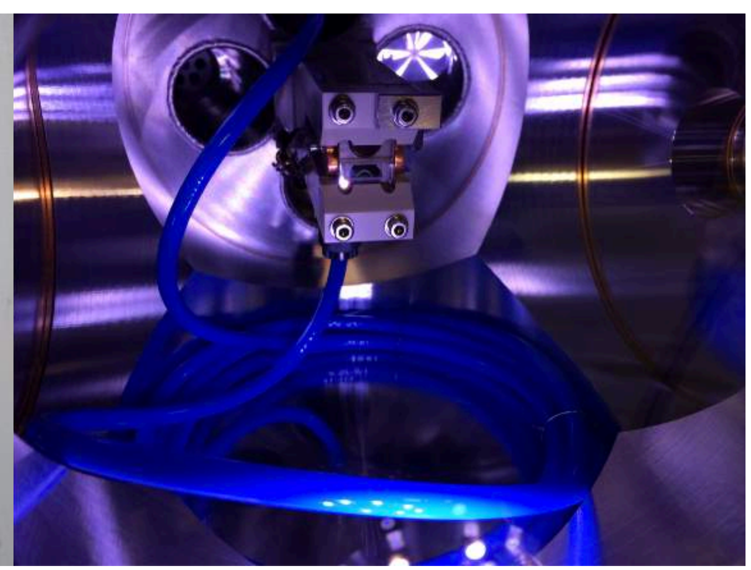






Gas flow

- Argon/helium bottles outside the accelerator hall.
- Remotely controlled needle valve (1-1000 mbar):
  – typically operated at 5-30 mbar capillary pressure
- Buffer volume with pressure gauge in feedback loop.
- Long (2 m) polyurethane pipe inside vacuum for electrical insulation (to avoid spark to ground).

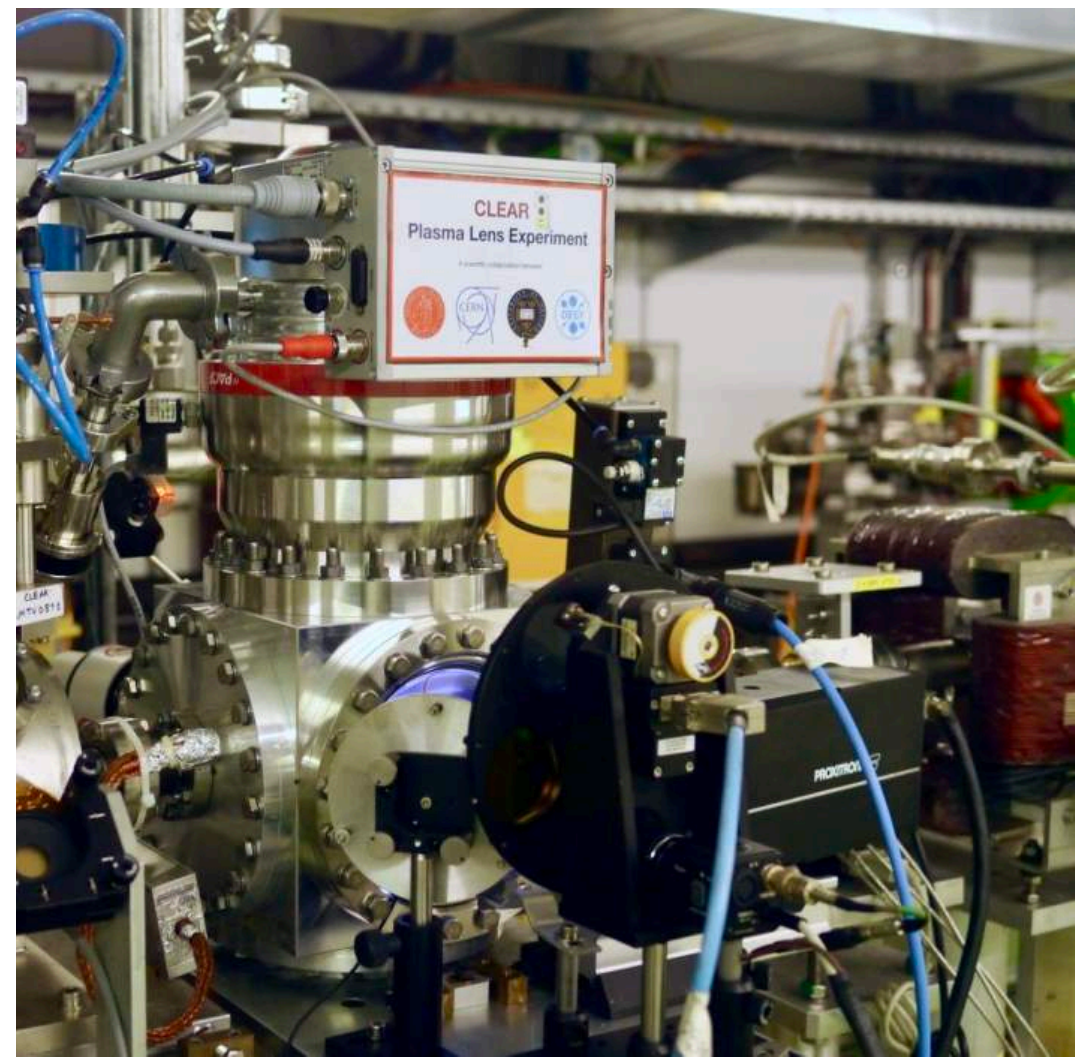


Vacuum and beam windows

- A large turbo pump (700 l/s) installed on top of the chamber. Usually achieves a vacuum of 10^{-8} mbar.

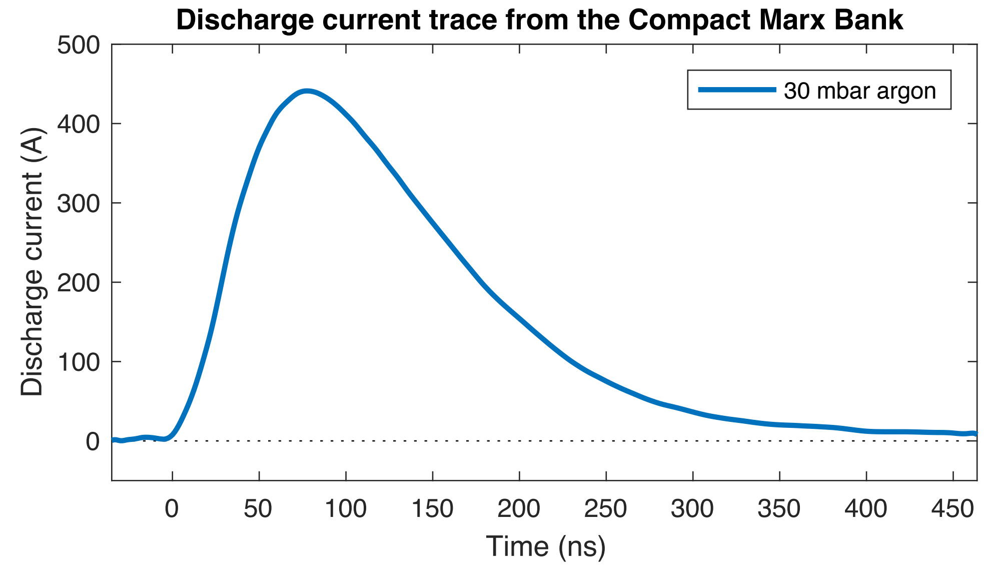
- A scroll pump is connected in series to keep a fore vacuum of 0.1 mbar.

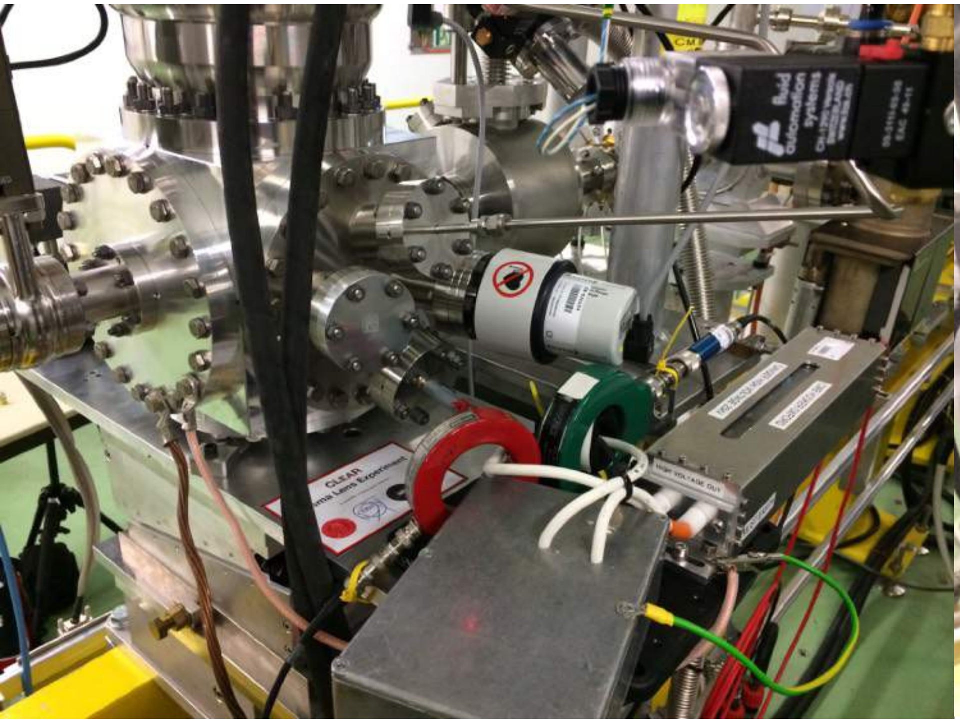
- 8 µm polymer foil (Kapton) installed in an insertable gate valve just upstream (20 cm) to spare the photocathode.



High voltage, high current source

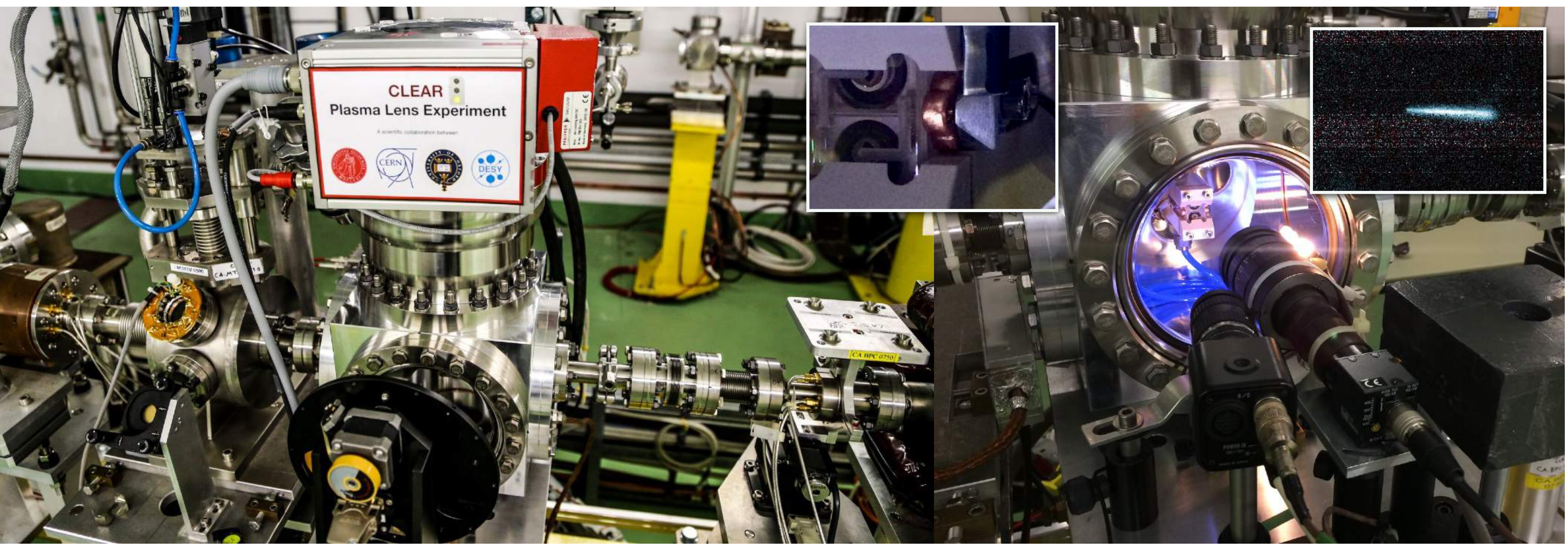
- Compact Marx Bank, provided by collaborators at Uni Oxford.
- 10 rungs of 45 nF capacitors, discharging via spark gaps.
- Supplies a ~300 ns pulse of ~20 kV and ~500 A.
- Current ingoing and outgoing measured using two current pulse transformer (Pearson probes)

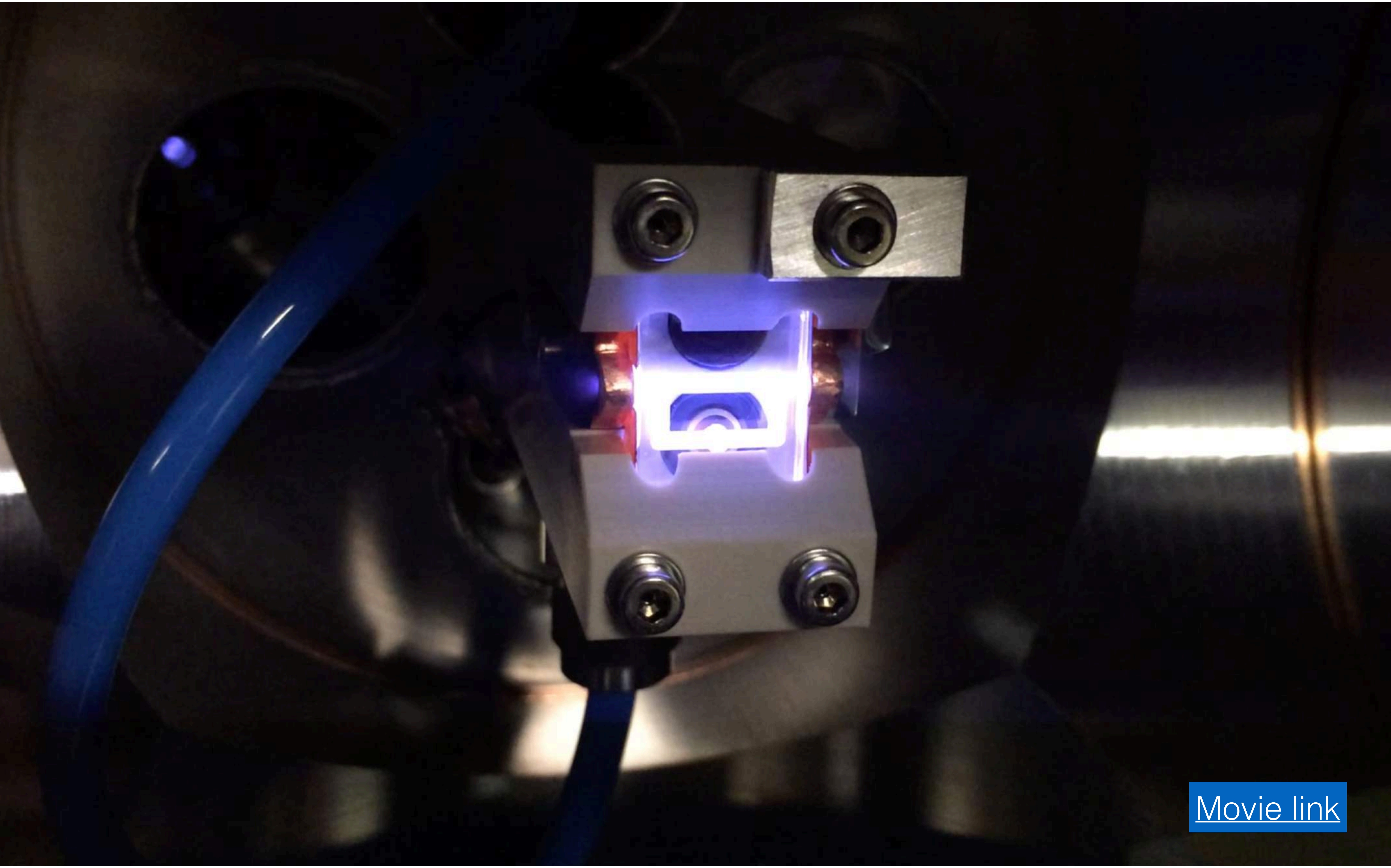




Beam diagnostics

- OTR screen downstream (30 cm) to measure beam size and offset, with blinder foil to stop plasma light.
- Mini-OTR wedge mounted on capillary to measure incoming beam size (destructive measurement).
- YAG screen just before the dump (~3 m downstream), as well as BPMs upstream and downstream.

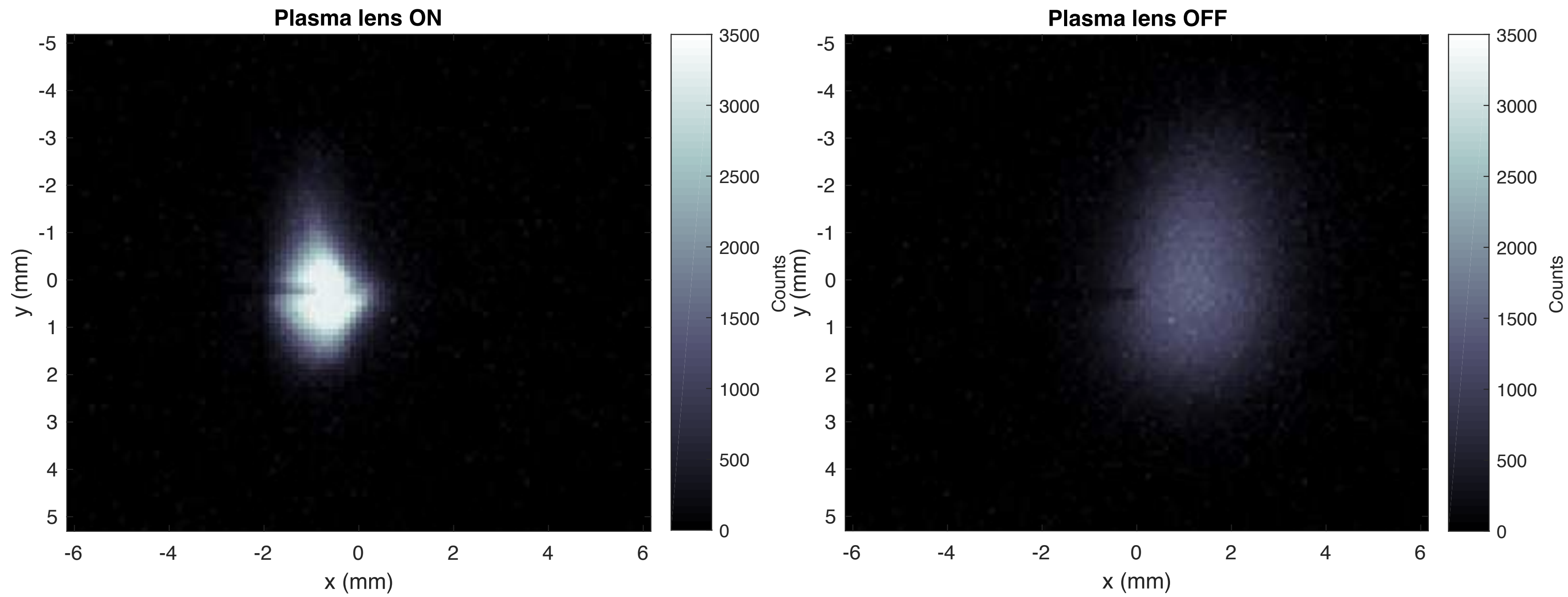



Movie link

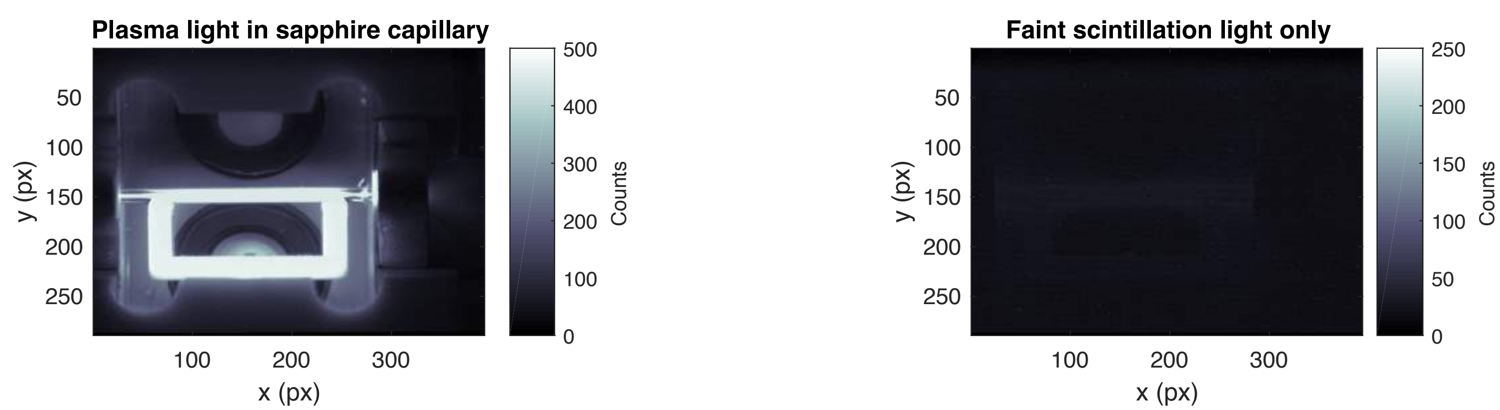
Experimental results

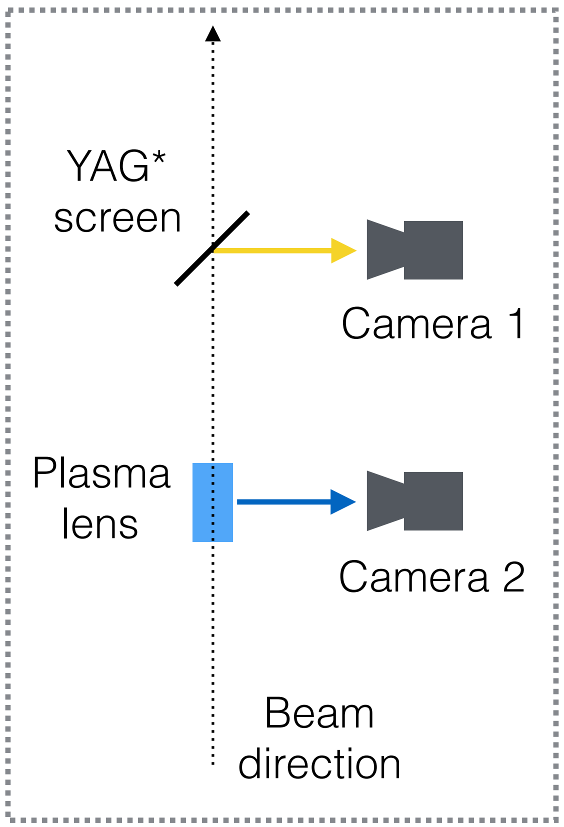
Successful lensing

Camera 1



Camera 2

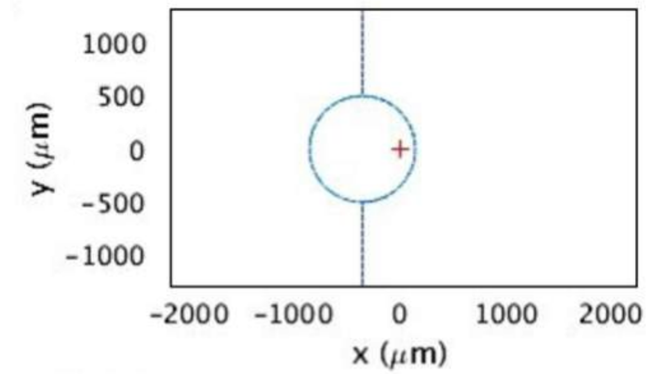




** yttrium aluminium garnet (crystal)*

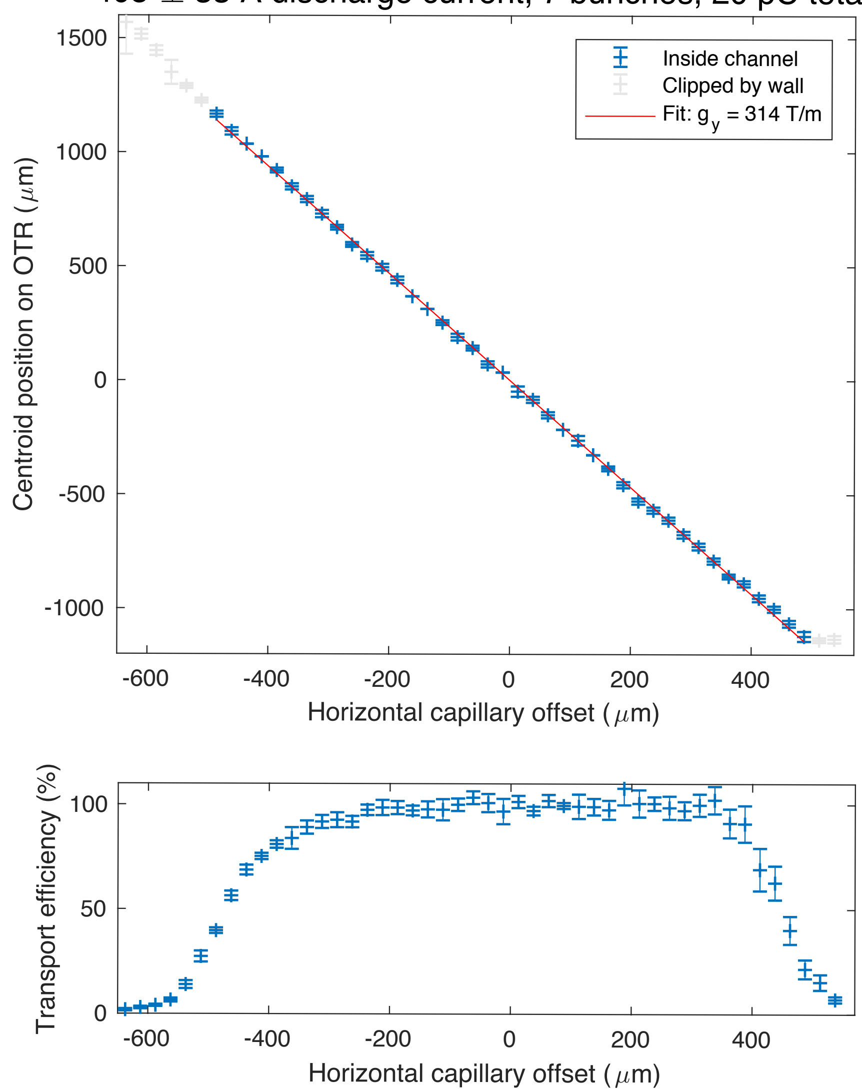
Measurement of local B-field for transverse offsets

No evidence for spherical aberration from uneven plasma heating!



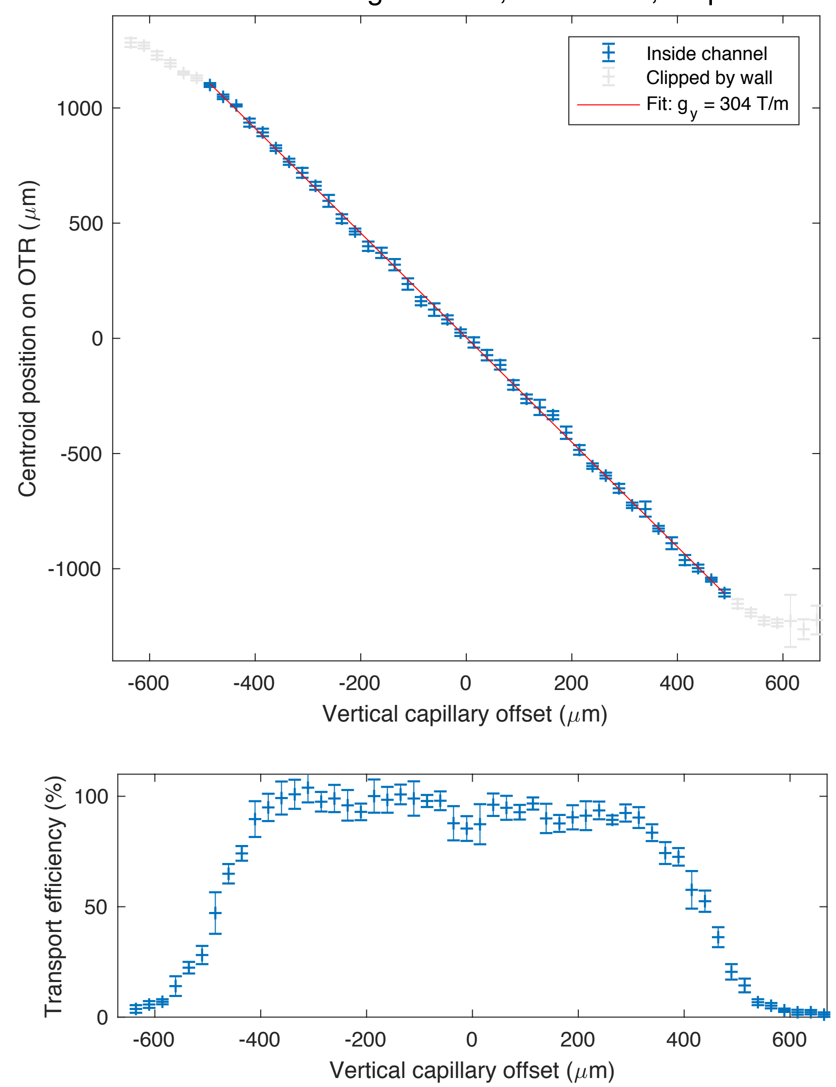
Horizontal offset scan

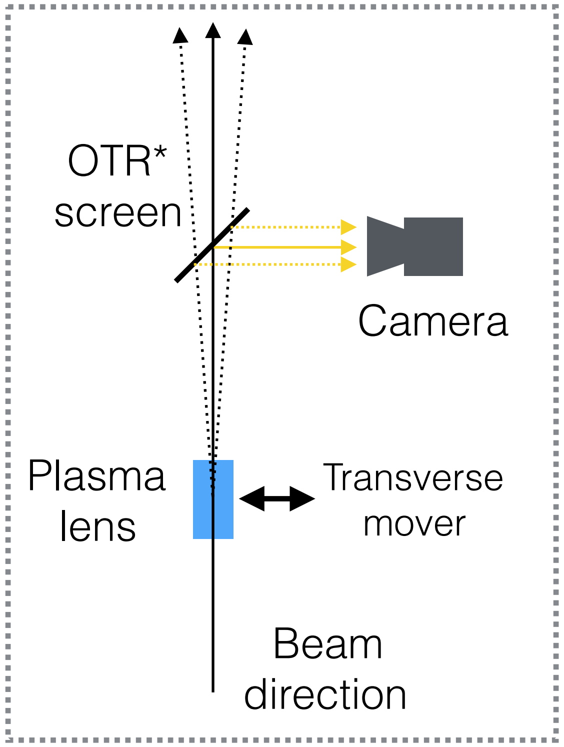
405 ± 33 A discharge current, 7 bunches, 20 pC total



Vertical offset scan

397 ± 14 A discharge current, 7 bunches, 20 pC total





** optical transition radiation*

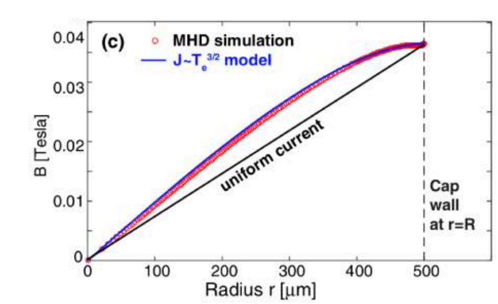


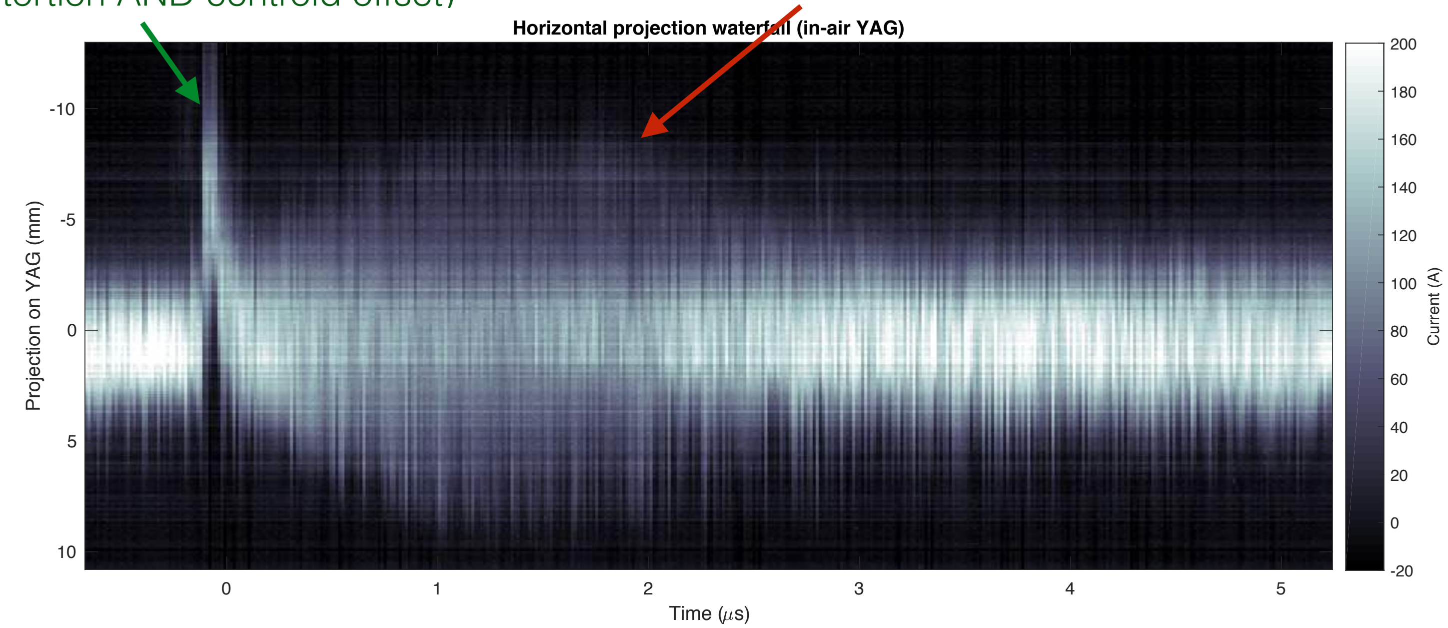
Image source: J. van Tilborg et al., **PRAB 20, 032803 (2017)**

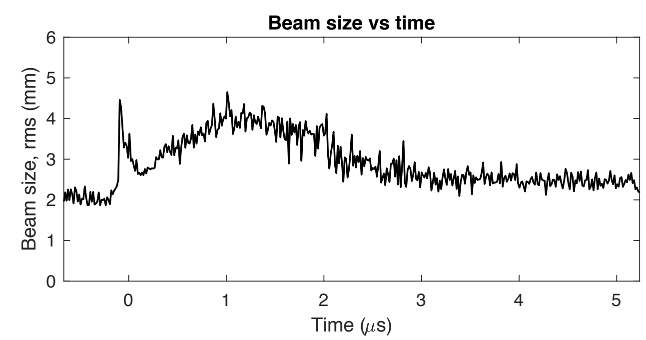
(preliminary data analysis)

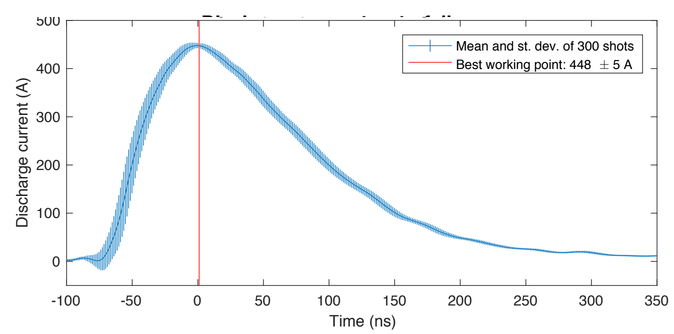
Evidence of passive plasma lensing

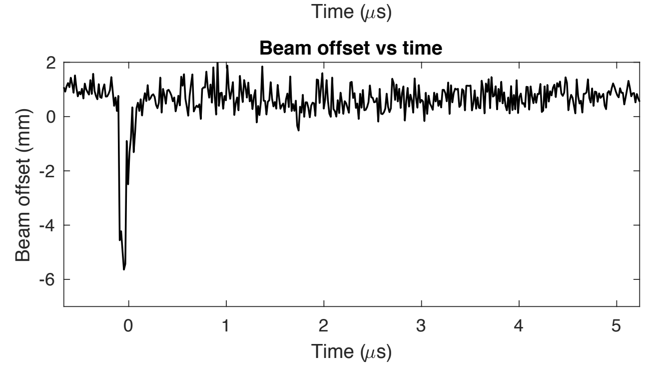
Normal active plasma lensing
(distortion AND centroid offset)

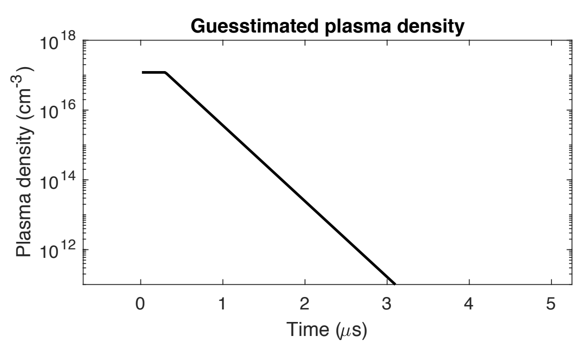
Beam-plasma self-focusing
(distortion, BUT NO centroid offset)

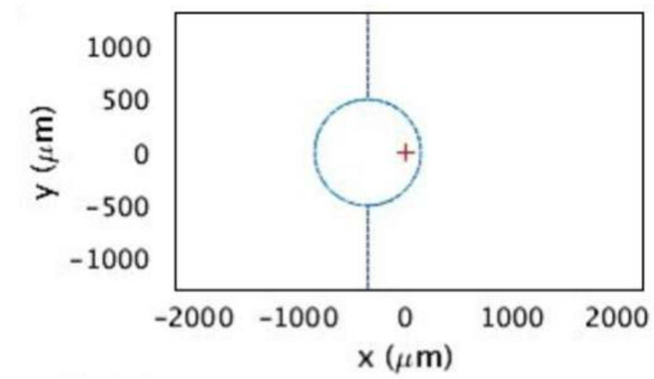




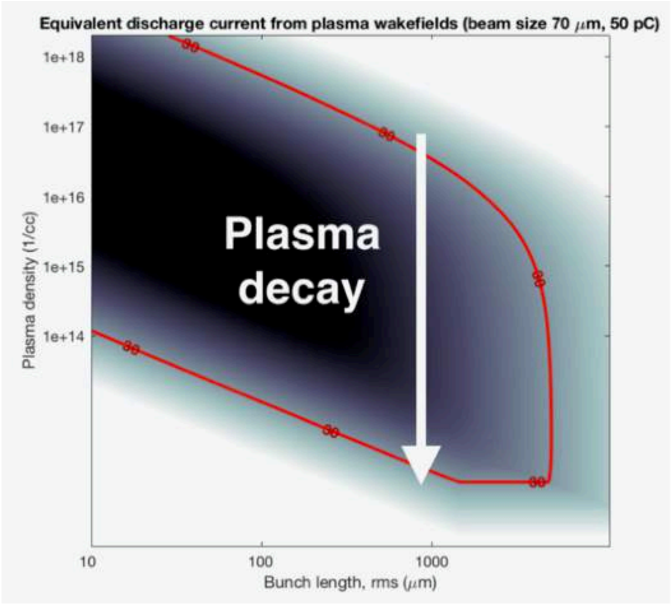








Used an offset beam in the lens to decouple passive and active plasma lensing



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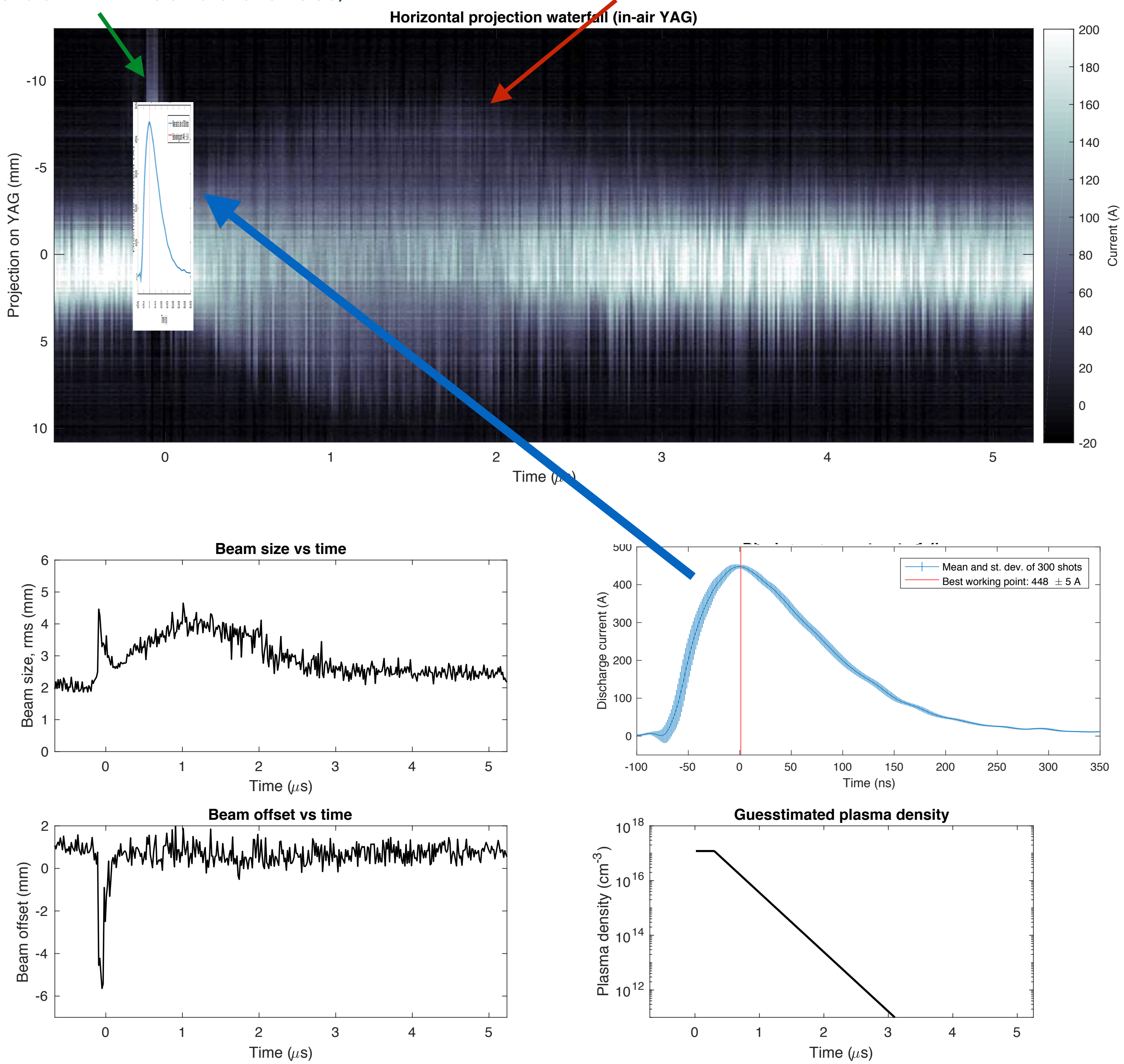

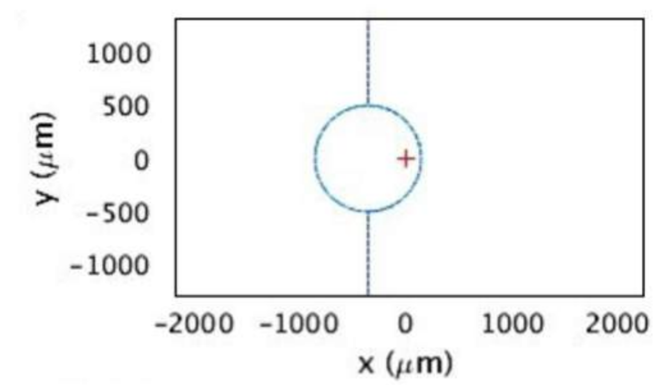

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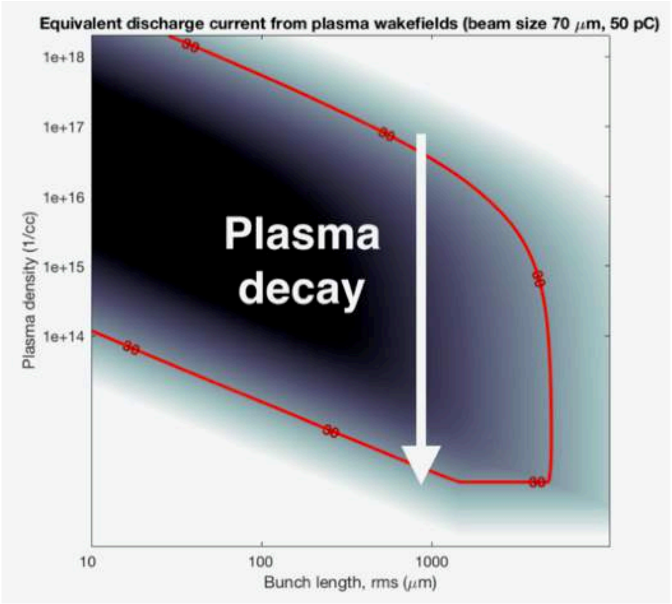
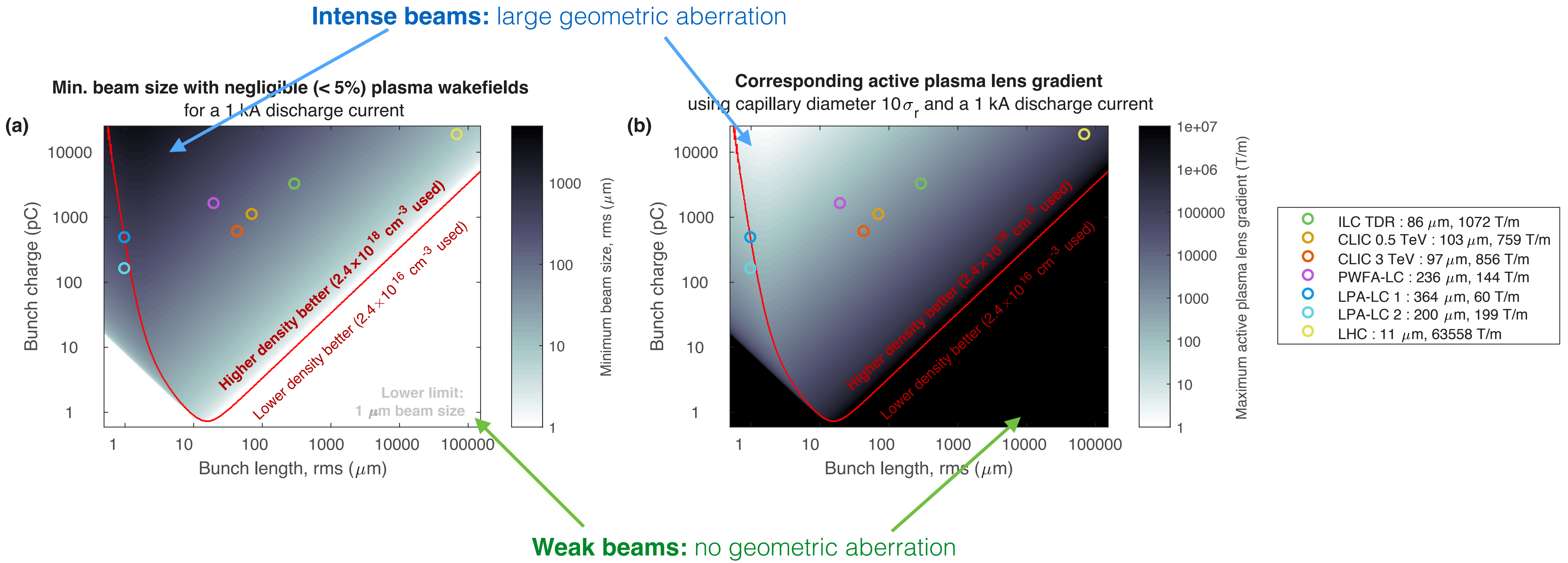


(preliminary data analysis)

Outlook and future work

Good news and bad news

- Good news: Less geometric aberration from plasma heating than feared.

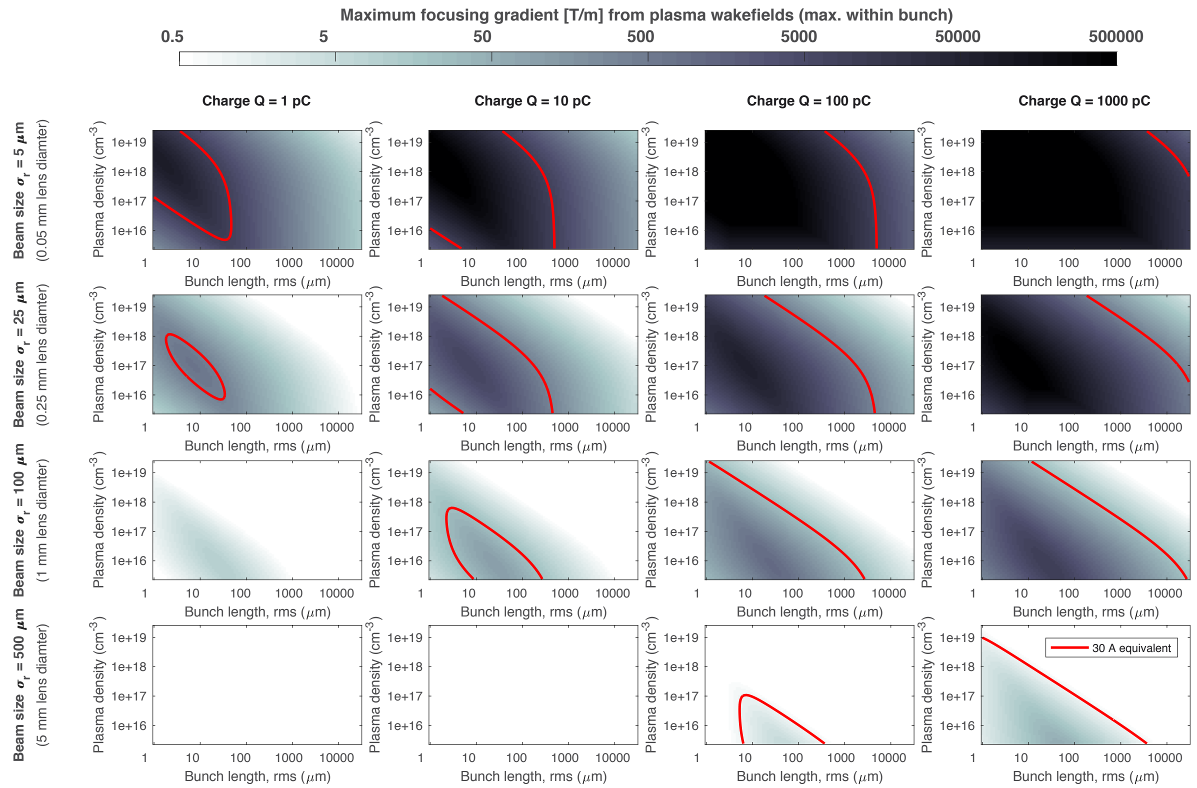


- Bad news: Plasma wakefields will distort intense beams – non-ideal for collider parameters.

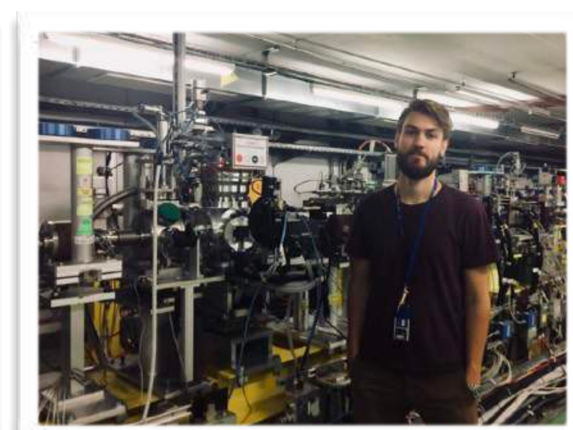
- However, OK if beam size is large enough (but low emittance implies huge beta functions of 10^4-10^6 m)
  ⇒ May (?) be used as an alternative for the final doublet with focusing in both planes, low chromaticity

Ongoing experiments in CLEAR (2018)

- The CLEAR beam line is currently being upgraded to allow new measurements
- **Goal #1:** verify negligible emittance growth with quad scans
- **Goal #2:** scan large parts of the beam/ plasma parameter space for wakefield distortion



“Full” 4D beam+plasma parameter space



In summary

- The promising active plasma lenses is under study at the CLEAR User Facility.
- Although small, a plasma lens requires several subsystems to work together.
- Preliminary results show no evidence of aberrations due to plasma heating, and clear evidence of plasma wakefield distortion.
- Further experiments at CLEAR in 2018 are underway.

Thanks for listening!