A plasma lens experiment at CLEAR

Carl A. Lindstrøm and Erik Adli

Dep. of Physics, University of Oslo, Norway and CERN

The experiment is prepared in collaboration with DESY and Oxford.

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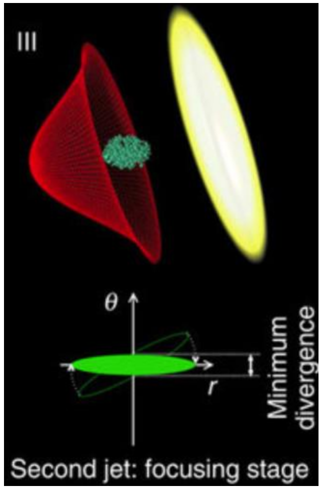
What are plasma lenses

Several principles :

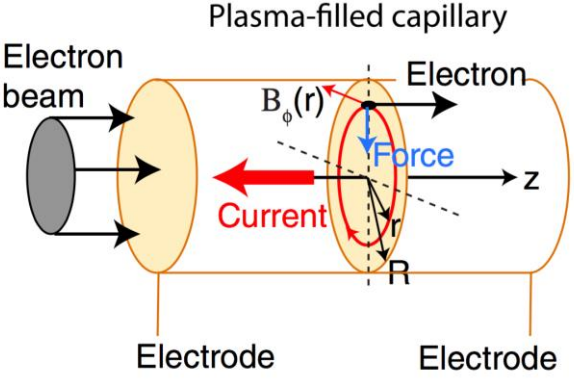
- **Wakefield plasma lenses**: drive a strong wake in plasma (with beam or laser driver), ion column focuses beam. Can give **strong, linear r-focusing** (both planes)
- **Active plasma lenses:** drive strong current through a plasma; current expected to be uniformly distributed out to a certain r ➔ Can give **strong, linear r-focusing** (both planes)

This talk, and our experiment, concerns active plasma lenses.



C. Thaury et al.,

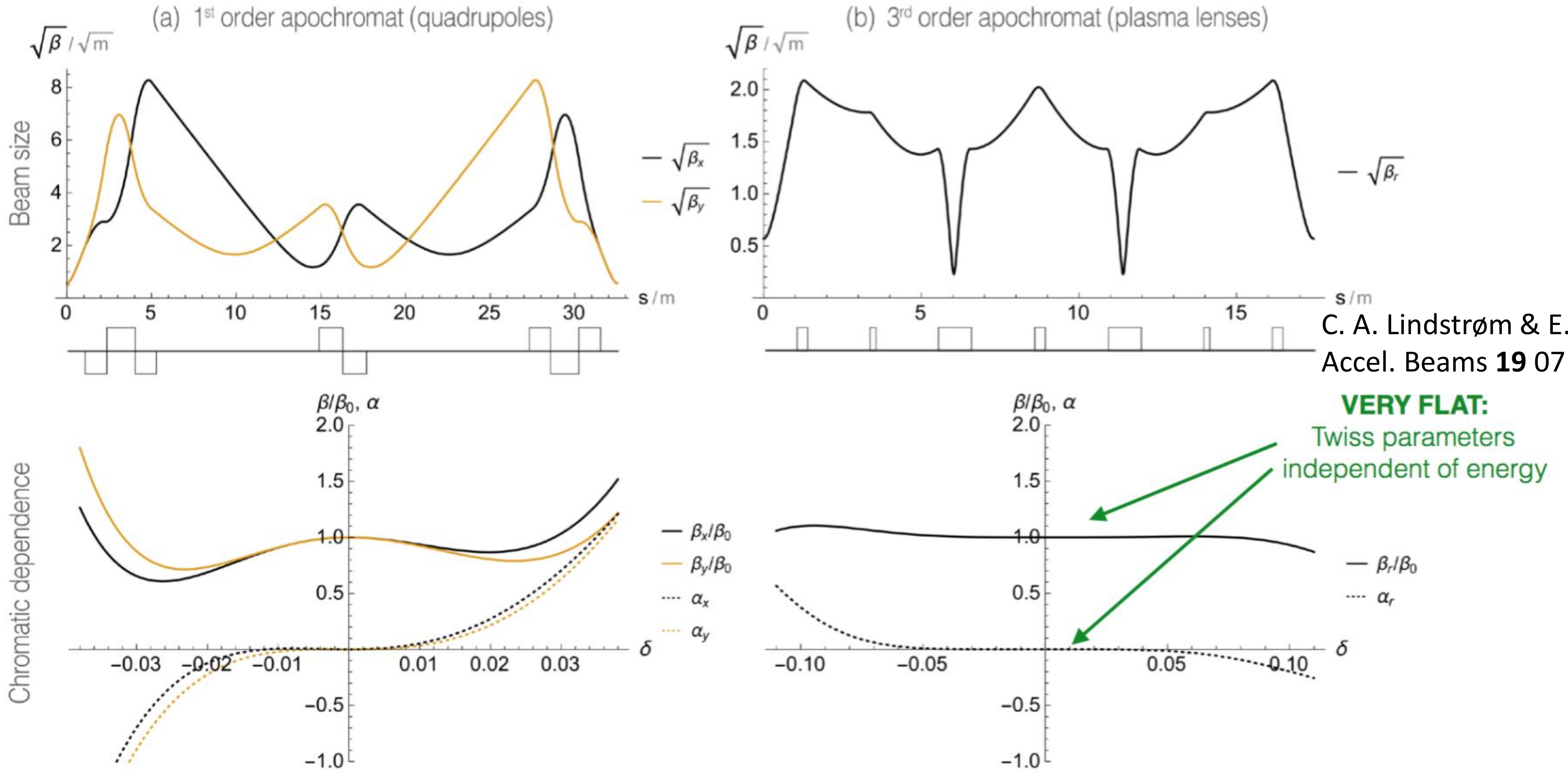
Nature Communications 6, 6860 (2015)



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

Interest of plasma lenses?

- Strong, linear r-focusing lenses may make optics for strongly focused beams more compact and less chromatic. Example :



C. A. Lindstrøm & E. Adli, Phys. Rev. Accel. Beams **19** 071002 (2016)

- Could potentially be a tool for **making linear collider final focus more compact and less chromatic**. Will also be studies in the frame of the Novel Accelerator Technology working group.

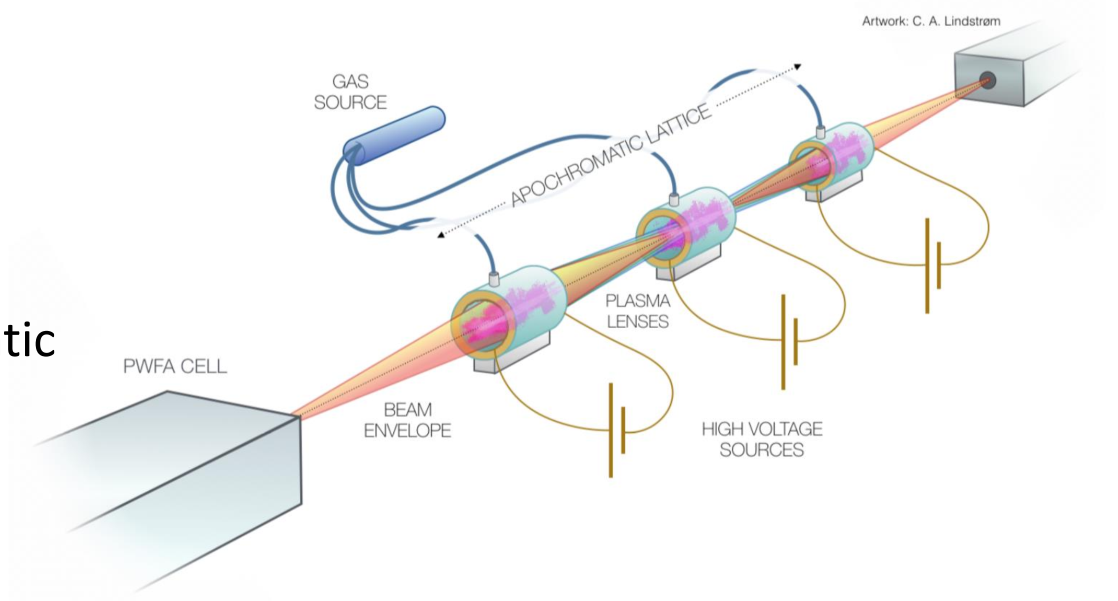
Context and future Oslo work

In Europe also DESY and INFN Frascati has activities on plasma lens tests.   Uniqueness of the Oslo-CLEAR tests :

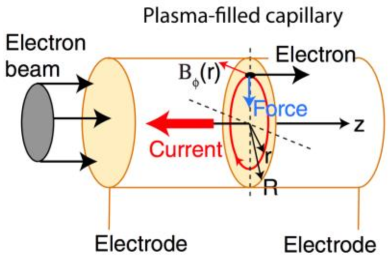
- Will develop and **investigate lattices of plasma lenses,** for example plasma interstages, final focus systems.
- CLEAR parameters allows for study of **influence of plasma wake** for high beam densities

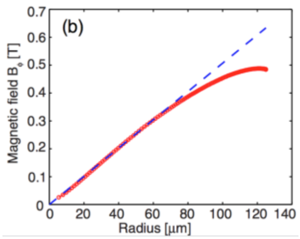
Long-term plans :

2017: single lens tests in CLEAR
2018:+ multiple lens (pending response from funding agencies)
2018:+ demonstration of achromatic plasma lens lattices (pending response)



Implementation of active plasma lenses





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

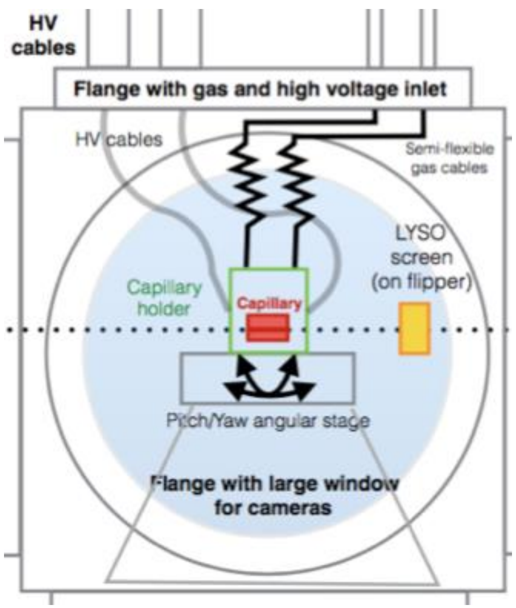
Goal: drive a current through a uniform plasma. The magnetic field leads to linear focusing. Plasma is created by a high-voltage discharge in the gas.

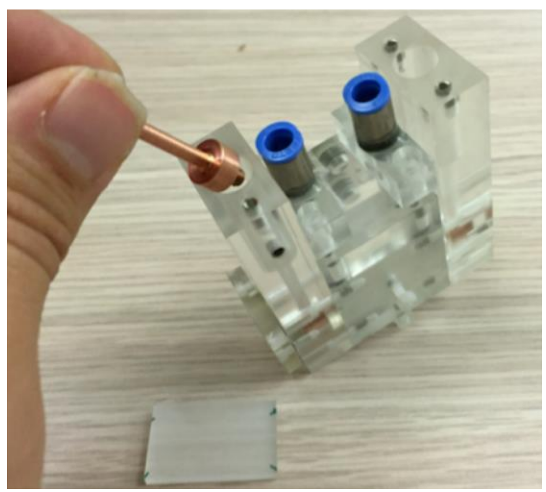
Requirements :
- capillary for (transverse) gas confinement
- gas delivery system (approx. 1 – 50 mbar)
- HV discharge unit (order 10 kV, few 100 A)
- vacuum system
- timing system
- alignment system

(Details on next slides)

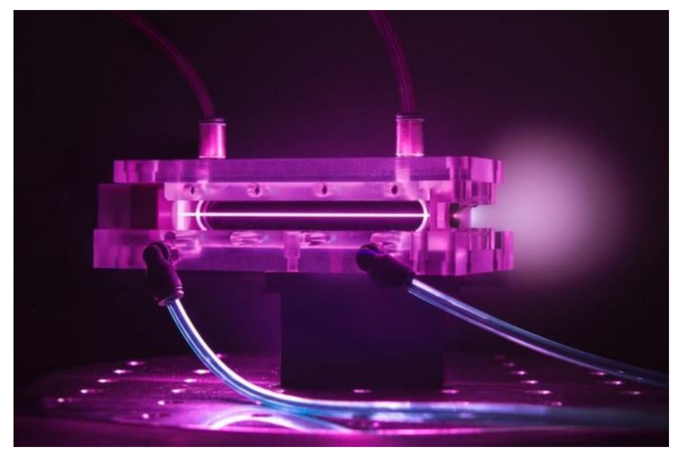
20 kV, 500 A

1 - 50 mbar





Picture from Clarendon Lab. Oxford.



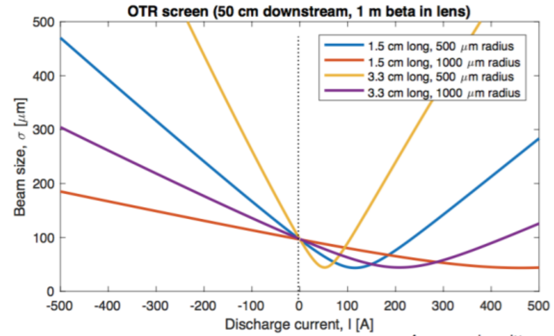
J. van Tilborg et al., Phys. Rev. Lett. **115,** 184802 (2015)

Planned measurements

Main measurement: OTR screen ca. 50 downstream of plasma lens. Complementary measurement: downstream BPM.

Focal length measurements :

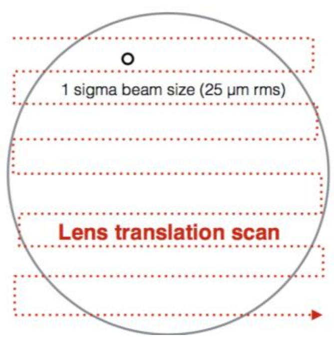
"Far" OTR screen (50 cm)



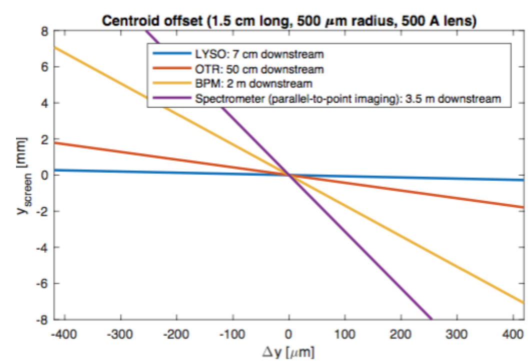
Assumed emittance: 3 mm mrad

Effect of beam jitter also studied (not shown here).

Linearity measurement using kick measurements :

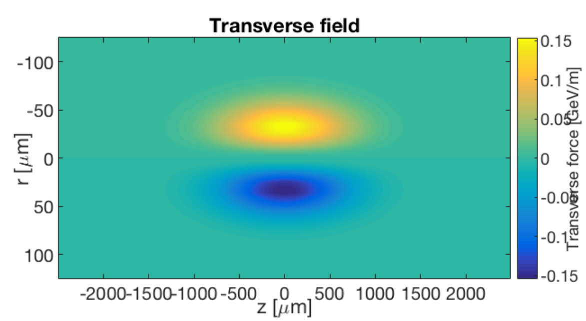


500 μm radius



Effect of plasma wake on field linearity :

- uniqueness of CLEAR with respect to earlier experiments
- challenging to get negligible effect

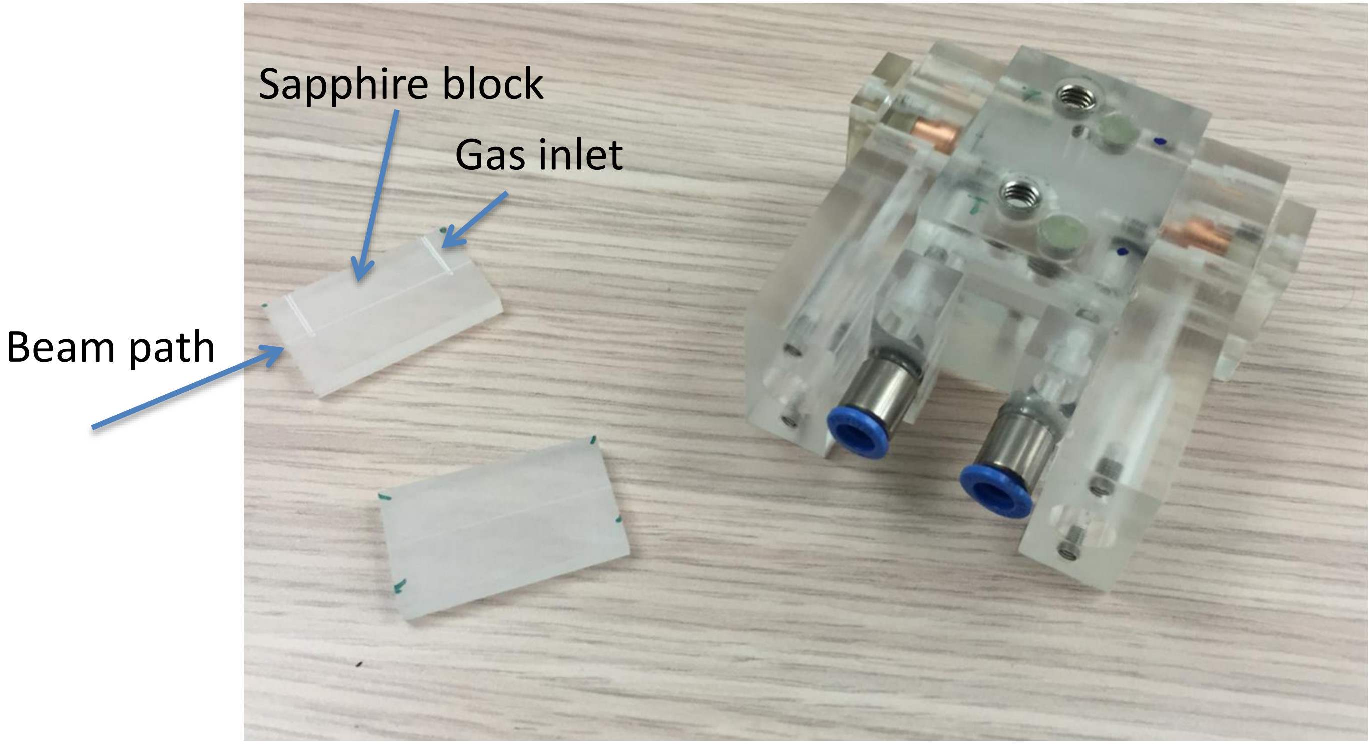


$$g_{max} \sim \frac{Q}{\sigma_z \sigma_x \sigma_y}$$

$Q = 10$ pC, $\sigma_z = 5$ mm $\Rightarrow$ max 6 T/m

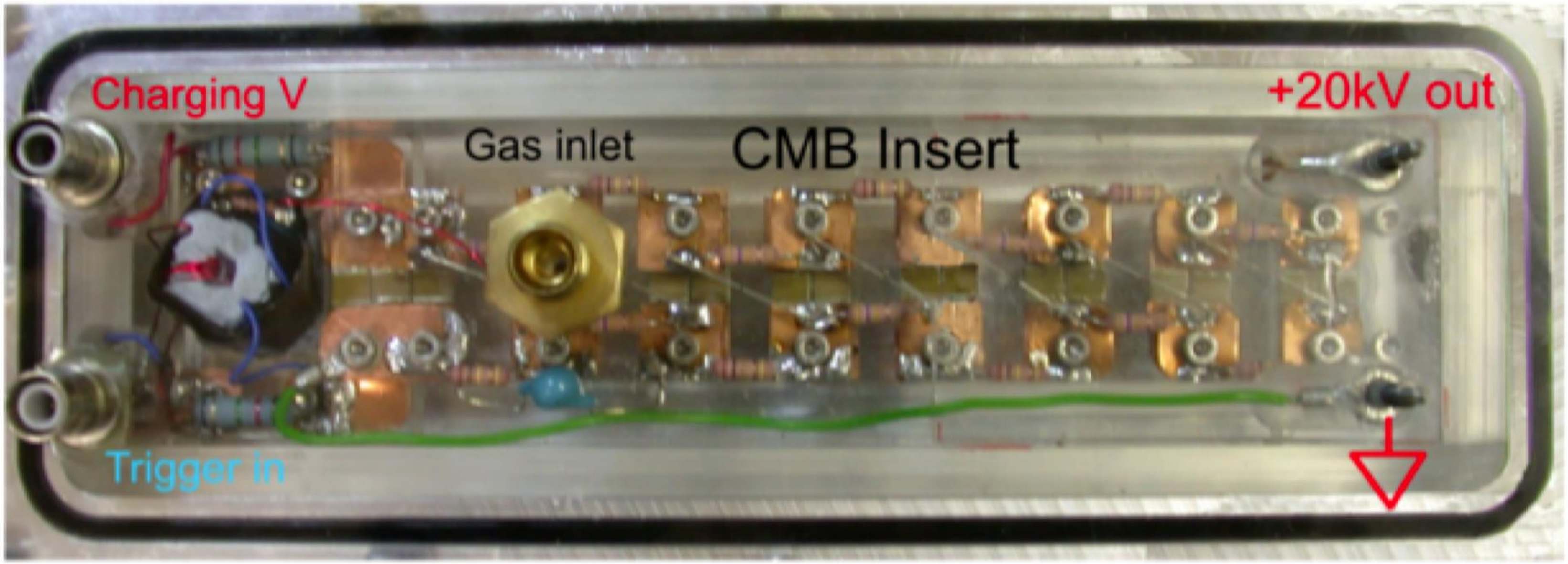
Capillary

- Capillary: cylindrical tube R ~ 100 um – 1 mm, L ~ 1 cm – few cm. Could be made of a Sapphire block, with laser-etched/drilled gas channels. **CLEAR experiment: Drilled Sapphire block, R=500 um / R = 1000 um, L=1.5 cm** – provided by DESY**.**
- R=500 um, with a current of 500 A (next slide) gives magnetic field gradient of **400 T/m**
- Holder made of UHV PEEK-plastic – provided by DESY.



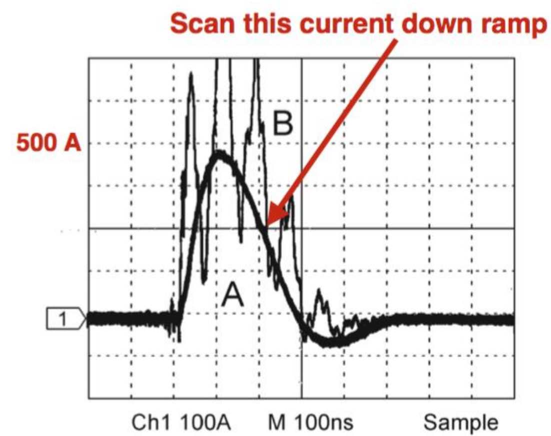
Picture from Clarendon Lab. Oxford. Technology is well known from LWFA-experiments, where plasma is used to guide the laser pulse driving a plasma wake. See e.g. D. J. Spence and S. M. Hooker, Phys. Rev. E, **63**, 015401R (2000) .

Discharge unit: compact Marx bank



A. E. Dyson, C. Thornton, and S. M. Hooker, Rev. Sci. Instrum. **87**, 093302 (2016)

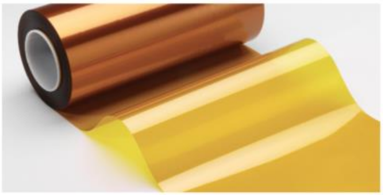
Current version of Marx bank: current variation requires few ns-precision timing scan of beam-discharge interval.



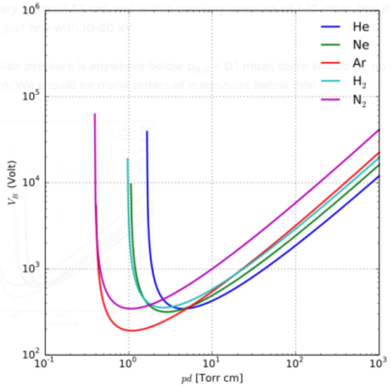
- A compact, low cost Marx bank (spark gaps): 20 kV, 500 A. Can be placed close to capillary (avoiding long cables). Cost of components plus charging supplies <~ 1000 EUR. Can easily be mass-manifactured.
- CLEAR experiment, we'll have access to a custom made Marx Bank, provided by Oxford.
- Could also be used : thyratrons/kicker voltage sources. Potential problems with impedance matching and long path length, leading to current bounce.

Vacuum

Upstream beam vacuum must be protected from gas flow (ion pumps, photocathode). Will use **upstream vacuum window** (selected material: Kapton tape, based on PITZ experimence). Gives acceptable scattering.



Another main concerns: gas discharge does not go through the inside of the capillary, but takes outside path, or, goes towards chamber. Requires good vacuum level to avoid. But, hard to calculate exactly. Estimated required pressure: <= **1e-3 mbar**.

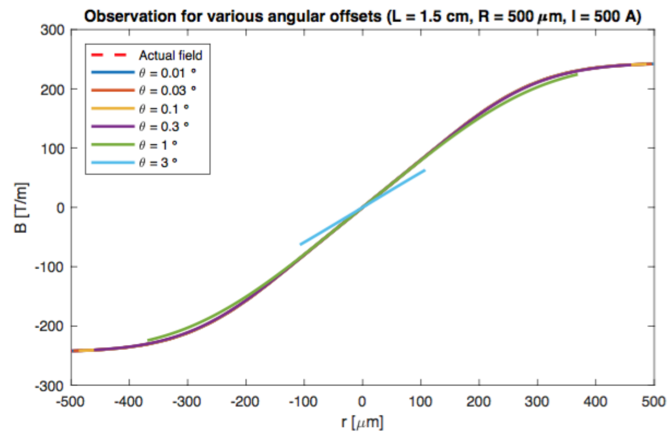


Experiment gas pressure (worst case) : 50 mbar (constant, in the periods we run the experiment).
Best case pumping: turbo pump running constantly. Mounted directly on chamber (assuming perfect conductance) we estimate a **steady-state pressure level of 5e-4 mbar** using a 200 l/s pump.

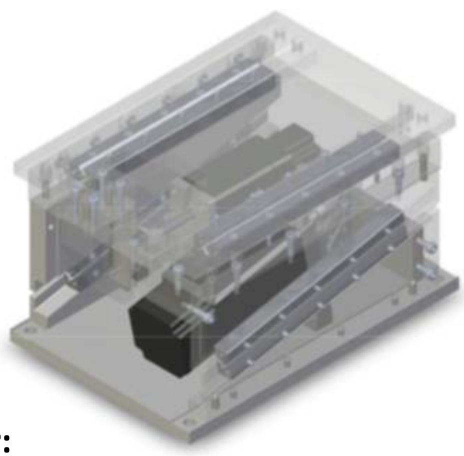
Keeping an adequate vacuum level seems to be a main constraints in deciding on the set up; a turbo pump directly onto chamber seems preferred.

Alignment

- Remote control of X, Y needed for kick measurements.
- With short capillaries and angular pre-alignment better than 1 deg, remote control not strictly needed on angular DOF.



Two options studied for alignment : **TBL-mover** and smaller, **movers mounted inside.**



TBL mover:

- Exists, and controls already integrated
- X-Y motion, range specified to +/- 4 mm
- Large; must be outside vacuum chamber
- Specified for 50 kg load

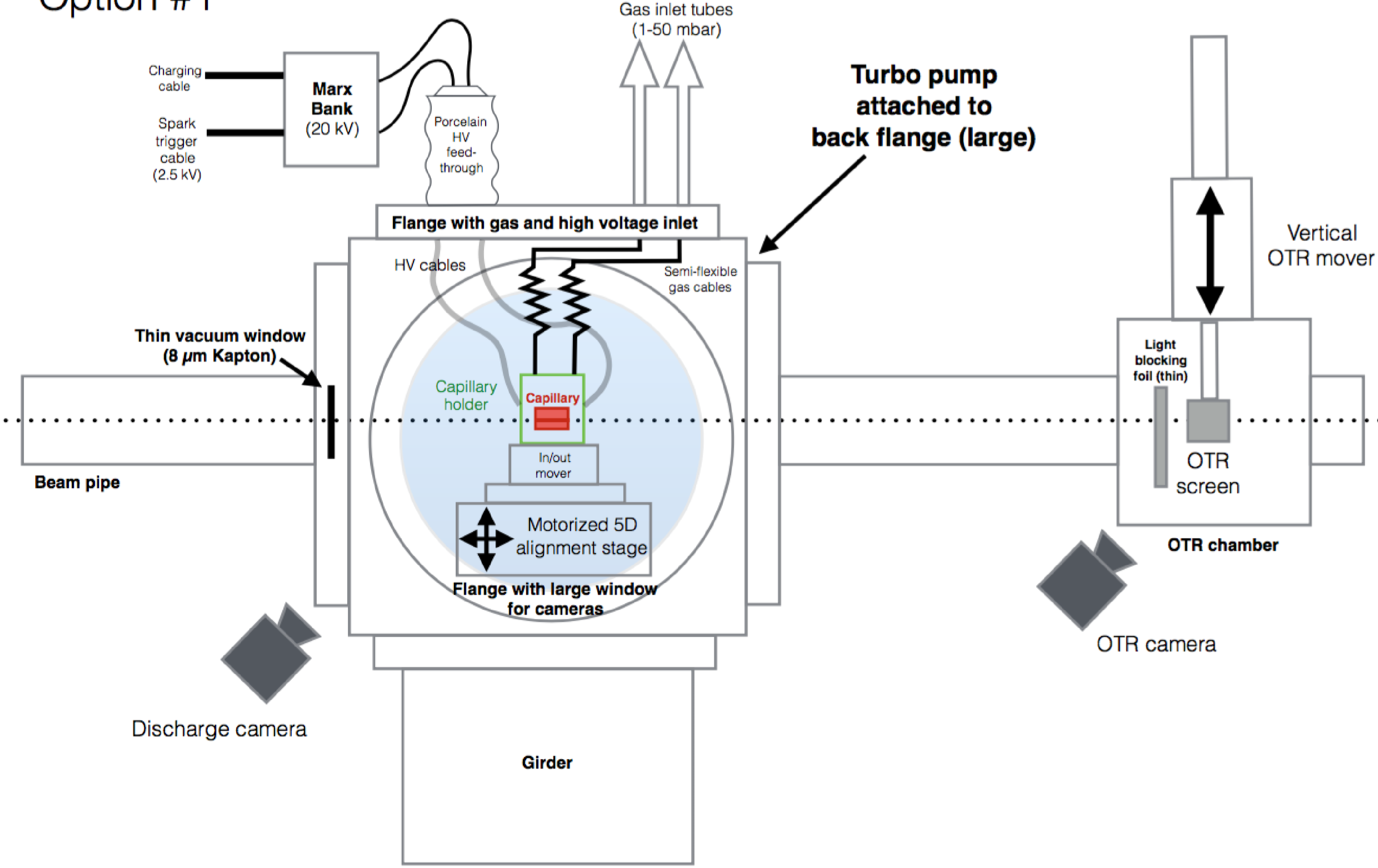
Movers mounted inside :

- Must be procured, controls need to be integrated
- Up to 5D motion, ranges varying
- Must be small; will be inside vacuum chamber
- Load not a concern (inside chamber)

Possible layout: internal mover

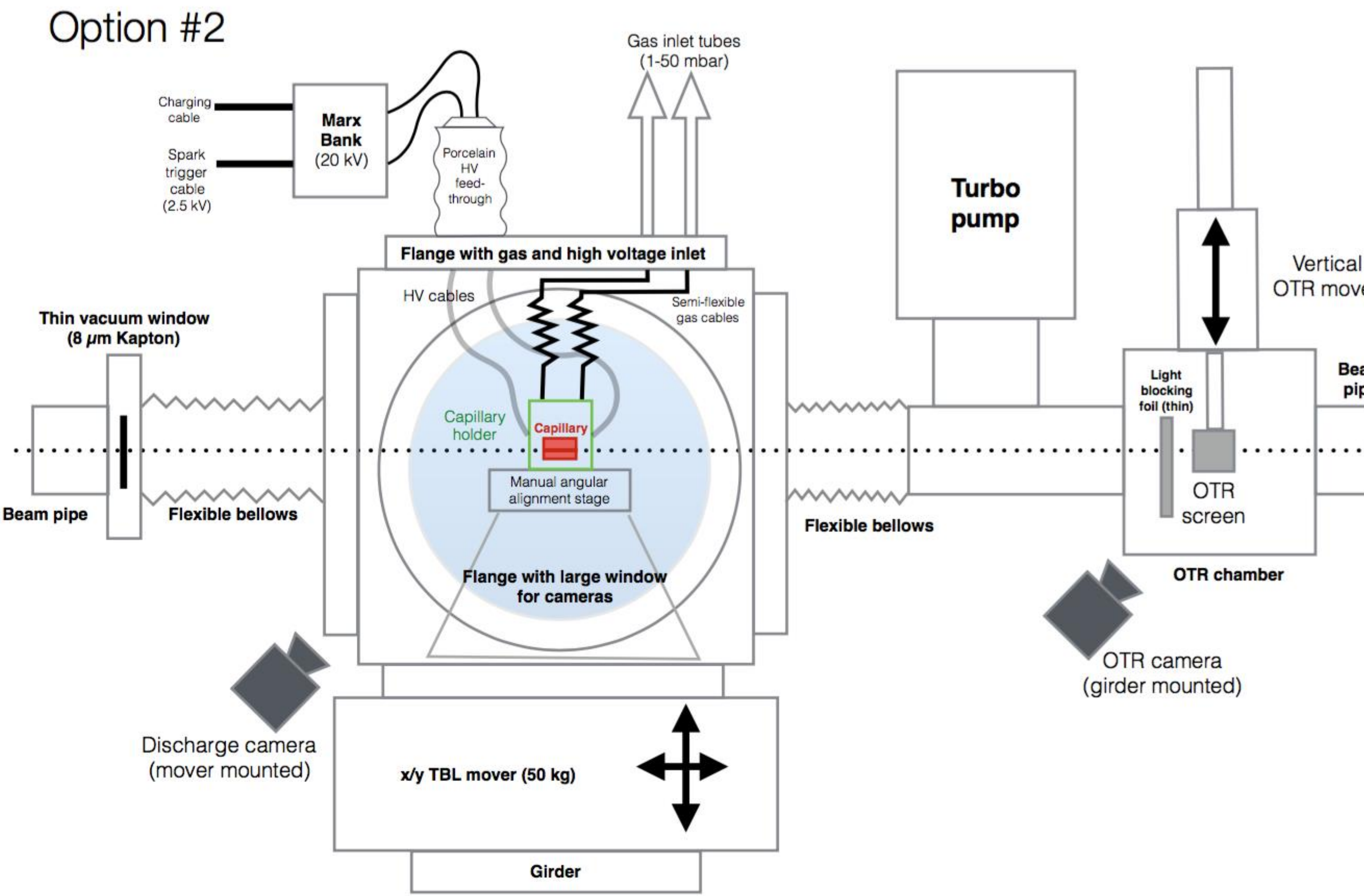
Requires flexible HV and gas gables (has been done before)

Option #1



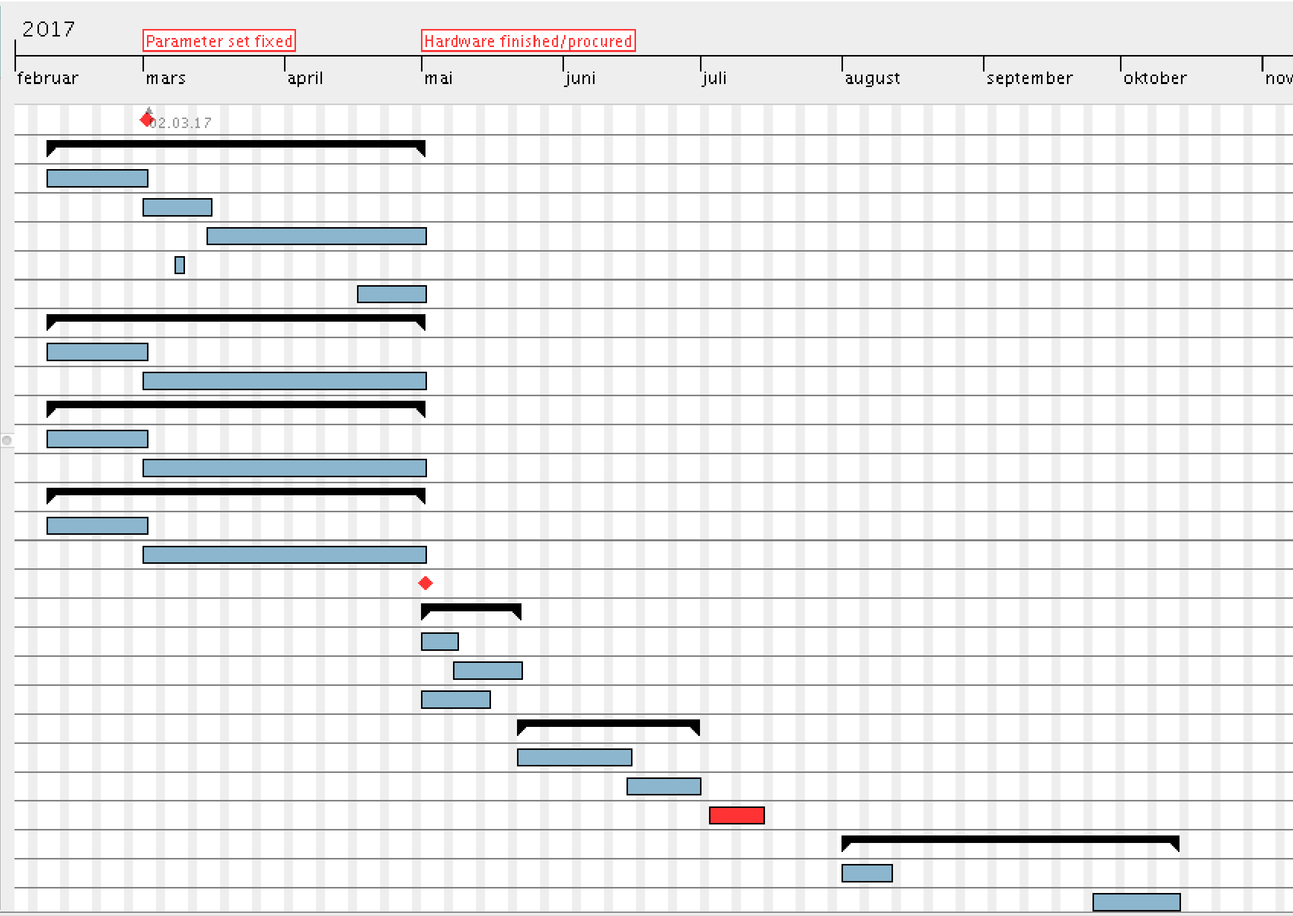
Possible layout: external mover

Requires large bellows



Draft schedule

Navn	Startdato	Sluttdato
Parameter set fixed	01.03.17	01.03.17
Discharge source (def. Marx bank)	08.02.17	01.05.17
Decide parameters [All]	08.02.17	01.03.17
Design [Oxford, Oslo]	01.03.17	15.03.17
Build [Oxford, Oslo]	15.03.17	01.05.17
Carl visit Oxford [Oslo]	08.03.17	09.03.17
Tests [Oxford]	17.04.17	01.05.17
Gas system	08.02.17	01.05.17
Decide concept / parameters	08.02.17	01.03.17
Assemble	01.03.17	01.05.17
Capillary	08.02.17	01.05.17
Decide parameters	08.02.17	01.03.17
Machine	01.03.17	01.05.17
Alignement system	08.02.17	01.05.17
Decide parameters	08.02.17	01.03.17
Procure, if needed	01.03.17	01.05.17
Hardware finished/procured	01.05.17	01.05.17
Integration tests [w/o beam]	01.05.17	22.05.17
Test Marx bank at CERN	01.05.17	08.05.17
Generate plasma	08.05.17	22.05.17
Test of aligment systems	01.05.17	15.05.17
Integration into vacuum chamber	22.05.17	30.06.17
Generate plasma in chamber	22.05.17	15.06.17
Pre-alignment	15.06.17	30.06.17
Installation into beamline	03.07.17	14.07.17
Experimental runs	01.08.17	13.10.17
Run I	01.08.17	11.08.17
Run II	25.09.17	13.10.17



* parameters fixed **by start March**
* production and procurement done by **start May**
* Test and integration without beam **May 1 - July 1** (capillary, gas system, discharge source, alignment system)
* **Installation in beam line start July** (2 weeks dedicated)
* First experiments following installation

Summary

- Plasma lens experiment planned for this summer; progress in the planning is good
- Adds several interesting challenges to CLEAR (gas/vacuum, HV...)
- Single lens-tests first step towards developing lattices of plasma lenses