Controlled injection of plasma electrons into a laser-driven wakefield using a variable length gas target

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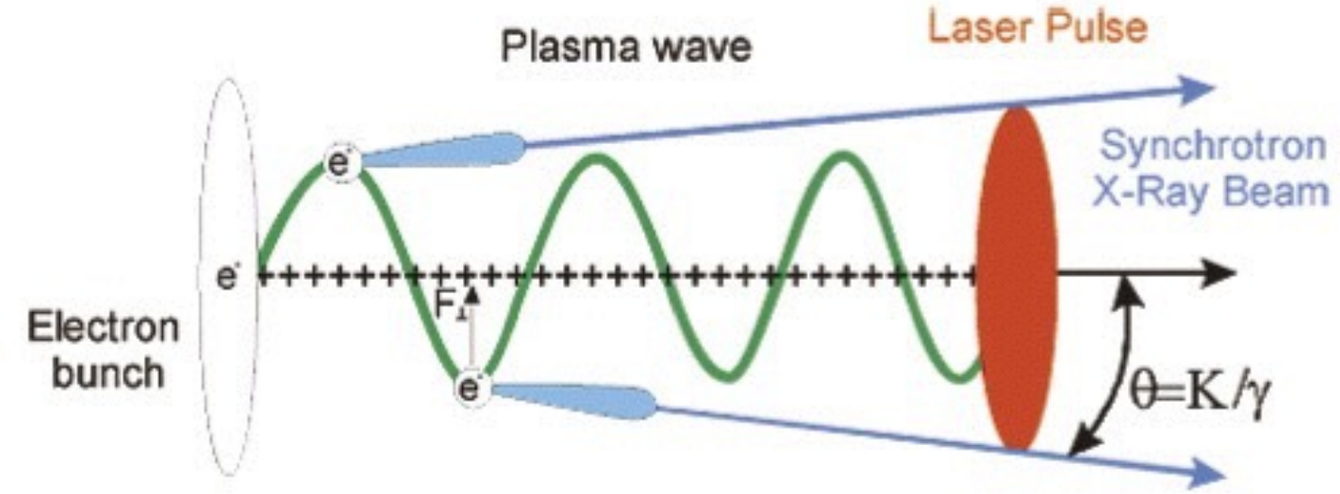
4 - Queen's University Belfast, North Ireland

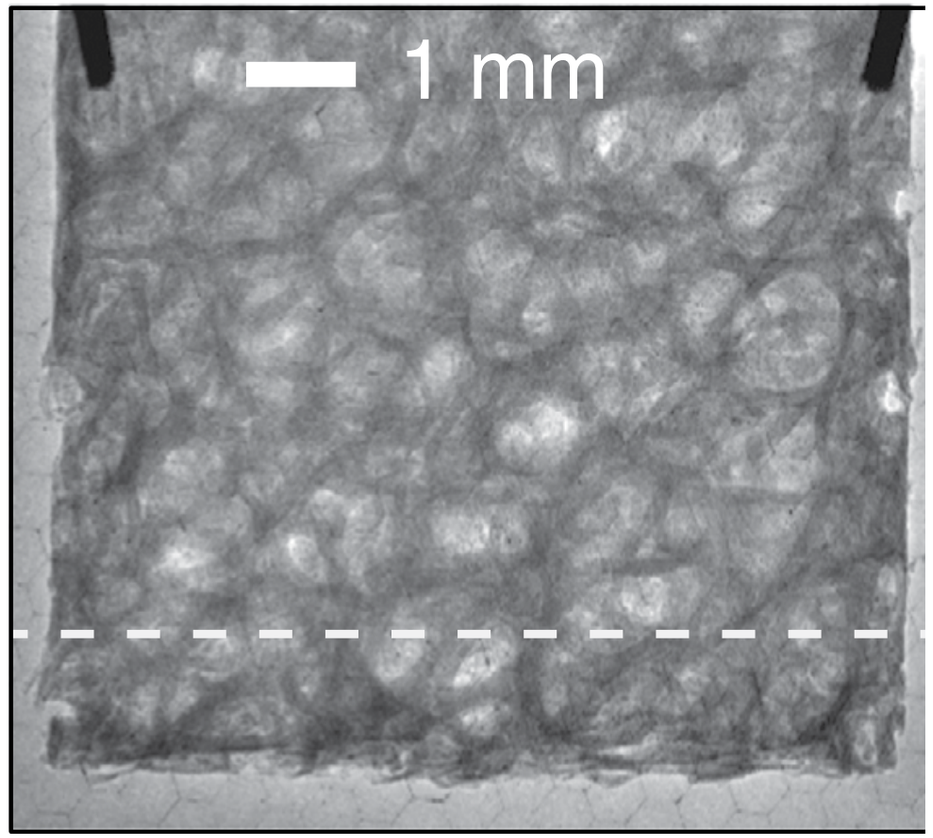
Deutsches Elektronen-Synchrotron

goals of the experiment

Plasma wakefield accelerator as an x-ray source for phase contrast imaging:



- micron resolution point-projection imaging
- high brightness, allowed single shot acquisition



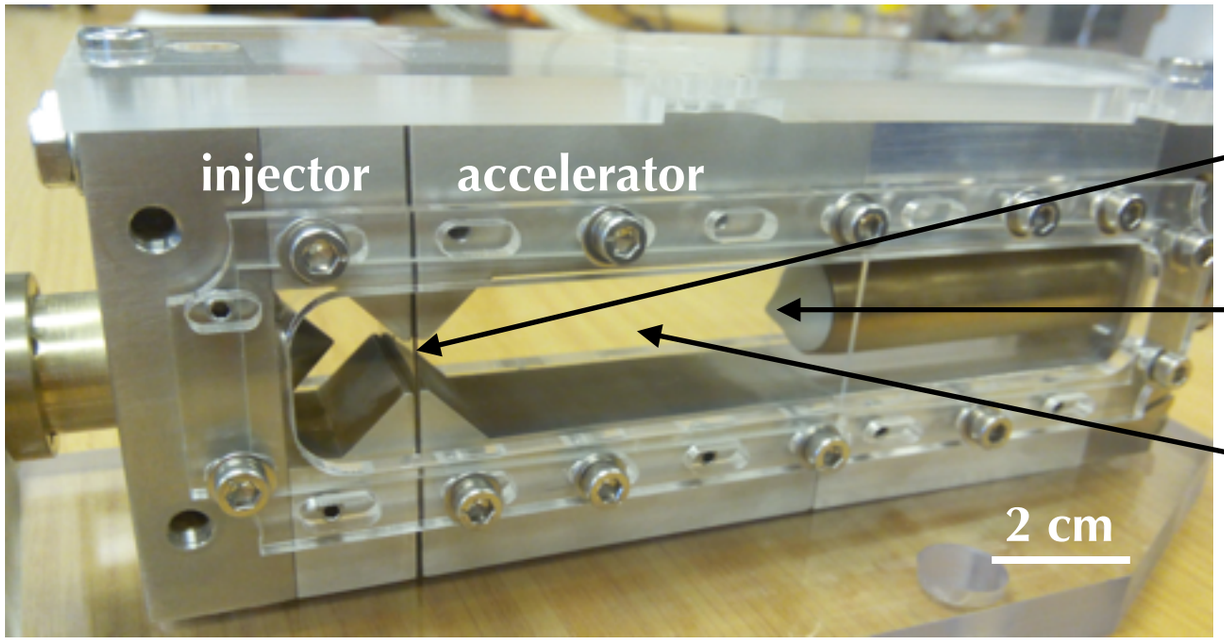
A single-shot radiograph of cylindrical femoral bone sample [1]

less absorption of the x-rays by biological sample. → Higher energy of x-rays → high electron energies are required

[1] Cole J M *et al* 2015 Scientific reports 5 13244

target design

independent control over length, pressure and gas species of both stages



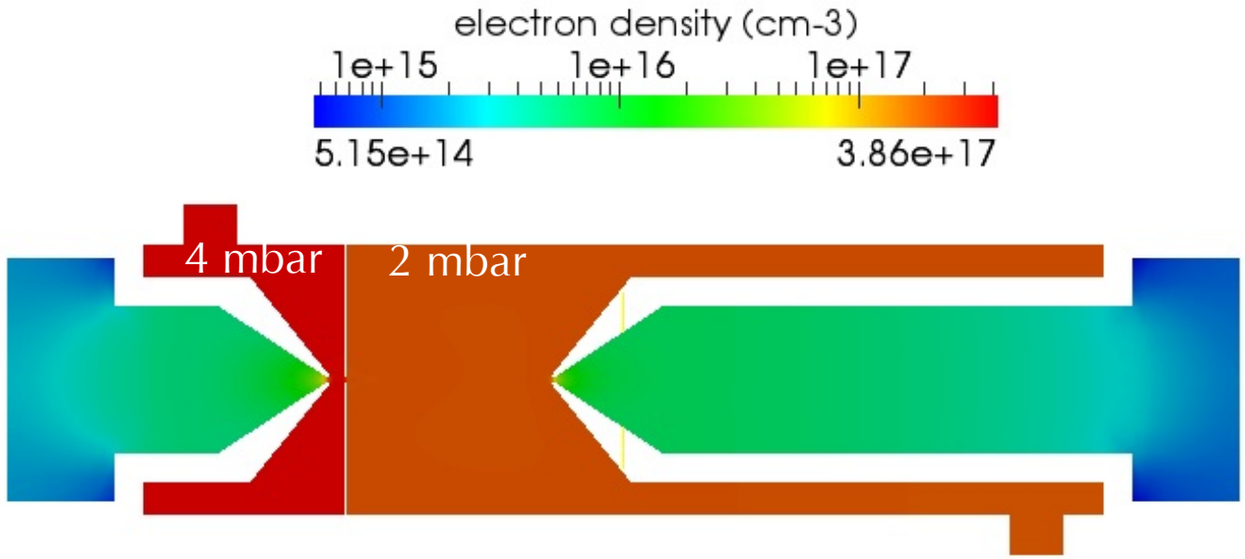
An Imperial College group's variable length gas target, developed by N.Lopes

- removable 100 μm aluminium middle inlet
- 8mm inner diameter cylinder with plastic/aluminium cone tips
- 2 cm height 10 cm long side windows

minimal length	~2 mm of both compartments
maximal length	42 mm
aperture diameter	300 microns - ~ 1mm (defined by laser damage)
pressure range	0 - 500 mbar
gases available	He, N (1,2,5%), CO_2 (1,2,5%)

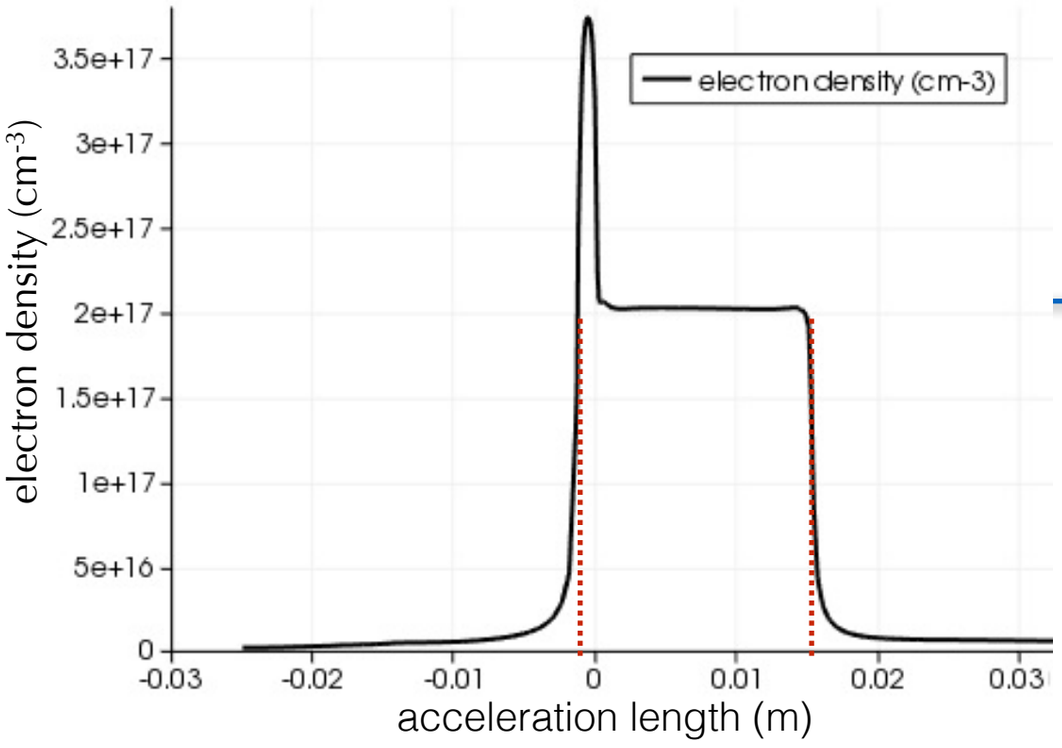
2D hydrodynamic simulations

Solver: sonicFoam, suitable for high gradients



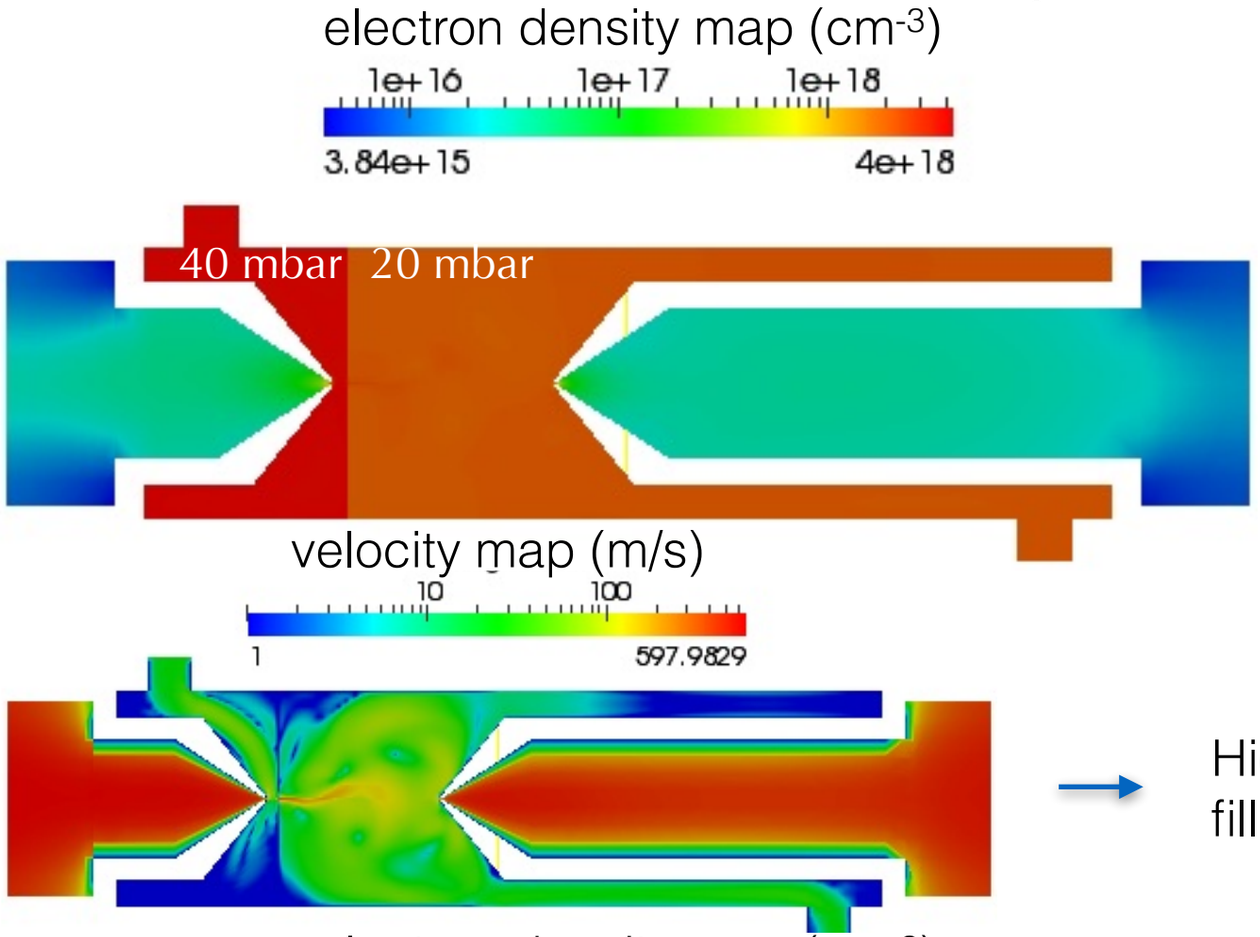
300 µm aperture diameter
1 mm and 10/15 mm compartment lengths
He at 4 (40/400) and 2 (20/200) mbar
43 µm transverce & 33 µm longitudinal resolution
5 ms with a timestep of 10^{-7} (10^{-8}/10^{-10})s

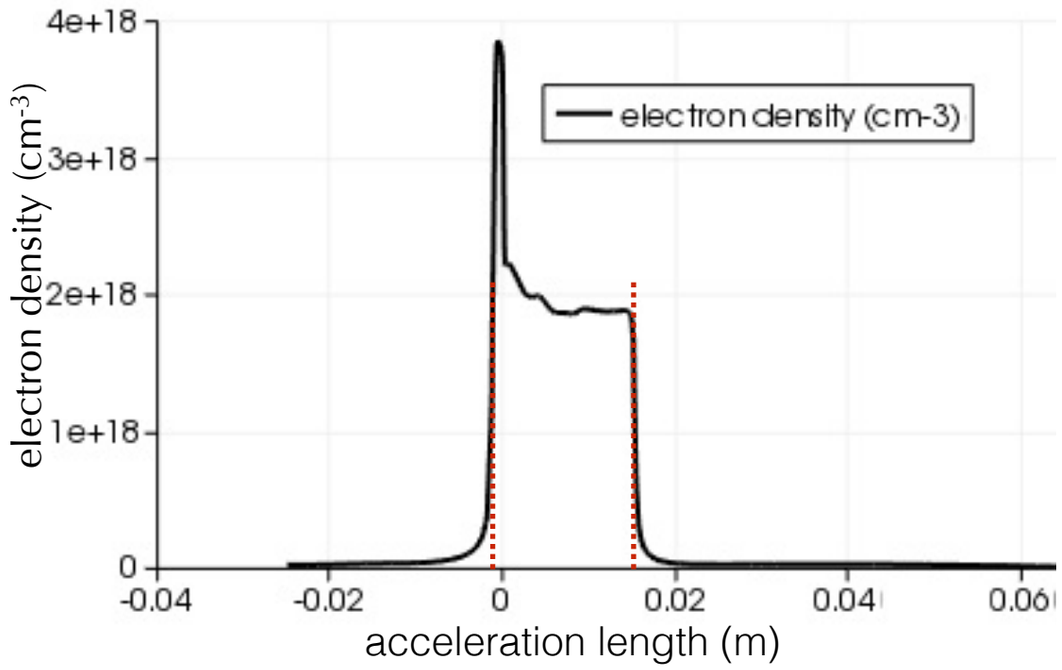
$$C = \frac{u\,\Delta t}{\Delta x} < 0.8$$ - courant number



- flat-top profile for low pressure reached within 5 ms in 2D
- density downramp from peak to plato regions ~ 400 µm
- density down ramp ~ 2 mm after exits of the gas cell
- still 2 - 5% of plateau density tail outside injection & acceleration gas volume

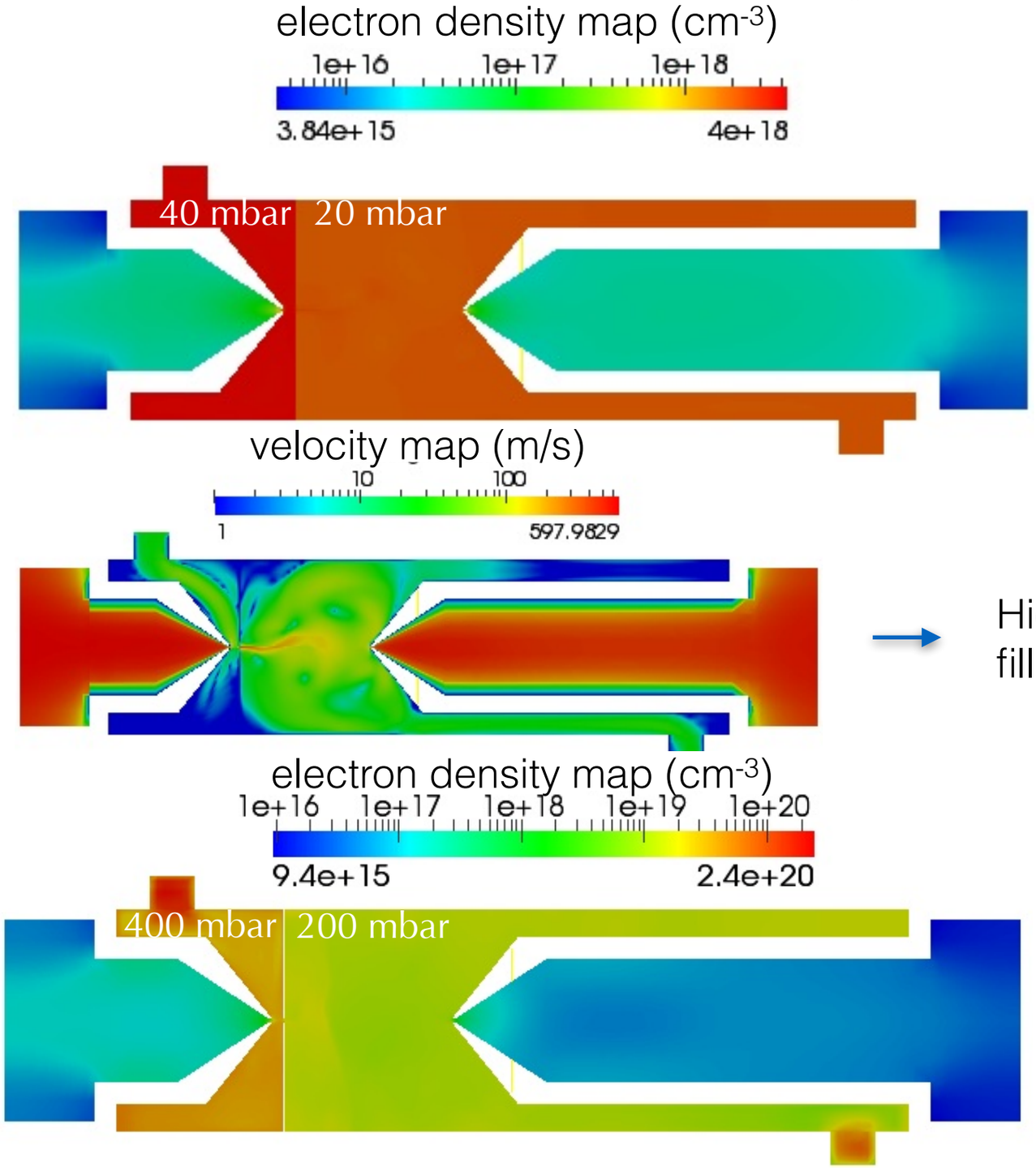
2D hydrodynamic simulations

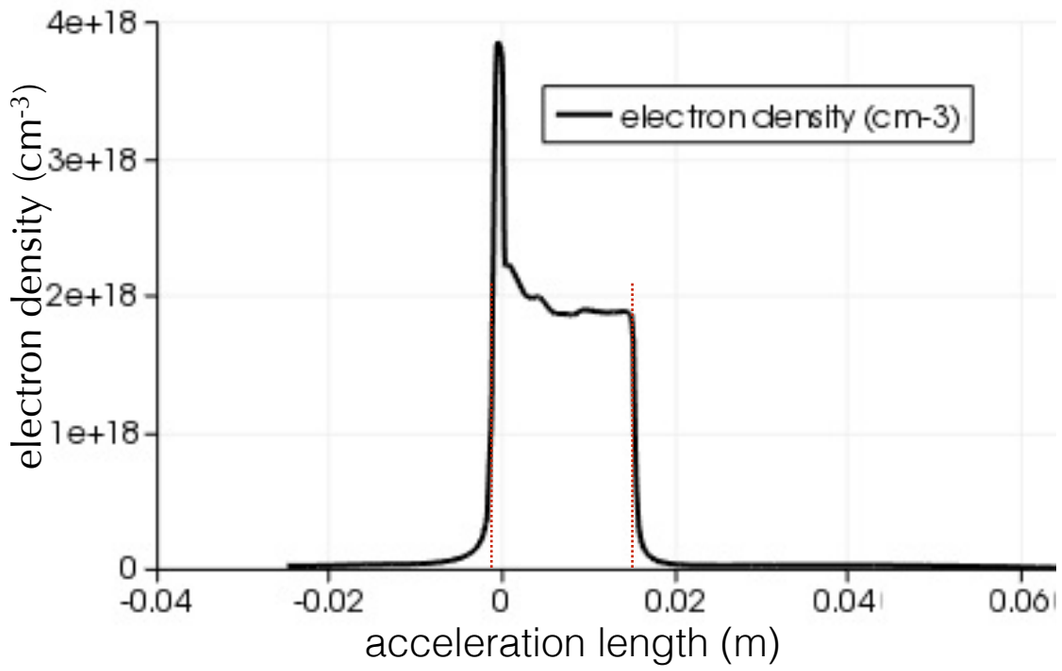




High turbulence and inhomogeneous filling for higher pressure

2D hydrodynamic simulations





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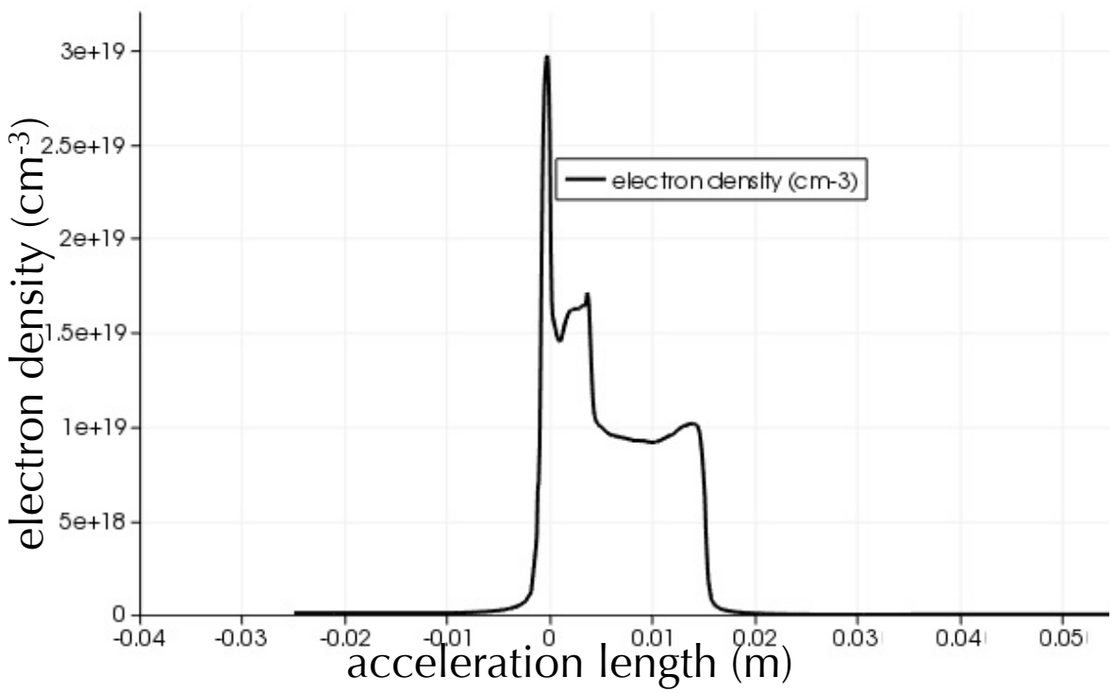
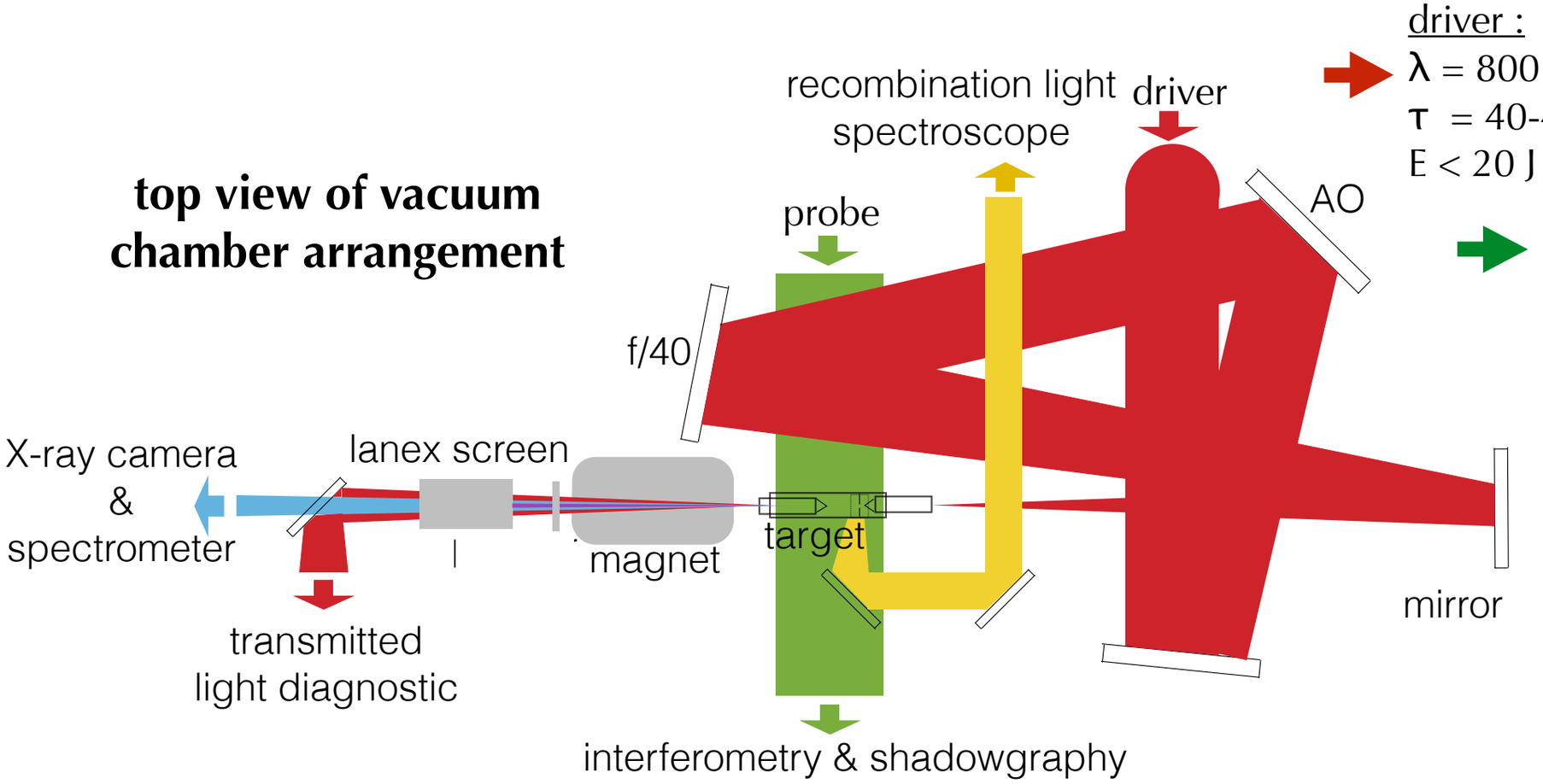


non-flat-top profile while pressuring the gas cell might lead to the high shot-to-shot fluctuations in density profile

experimental setup

experiment ongoing Astra Gemini laser, lead by Imperial College London

top view of vacuum chamber arrangement



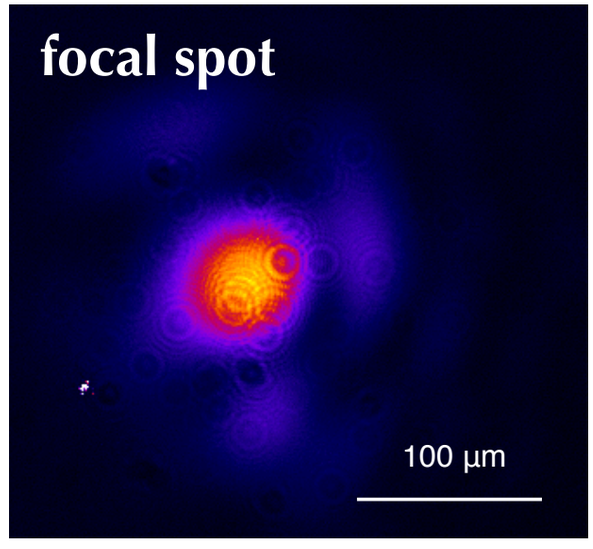
driver :
λ = 800 nm
τ = 40-45 fs
E < 20 J before compressor

probe:
apodised to rectangular shape
25mm x 100 mm

accelerated electron beam

plasma recombination light

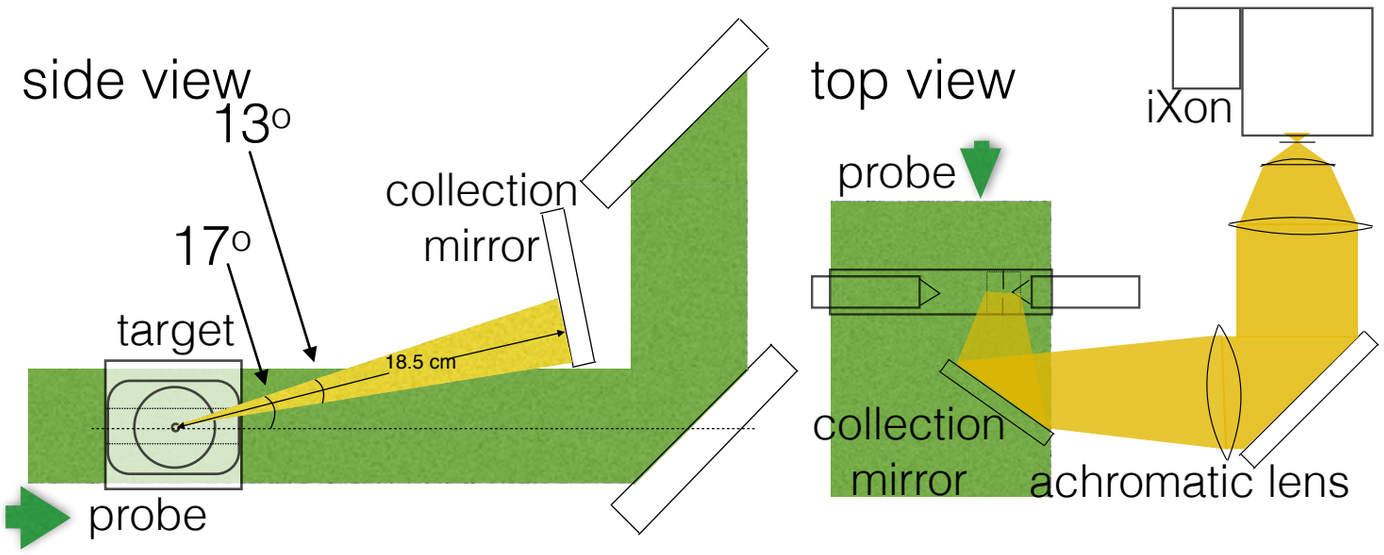
x-ray beam

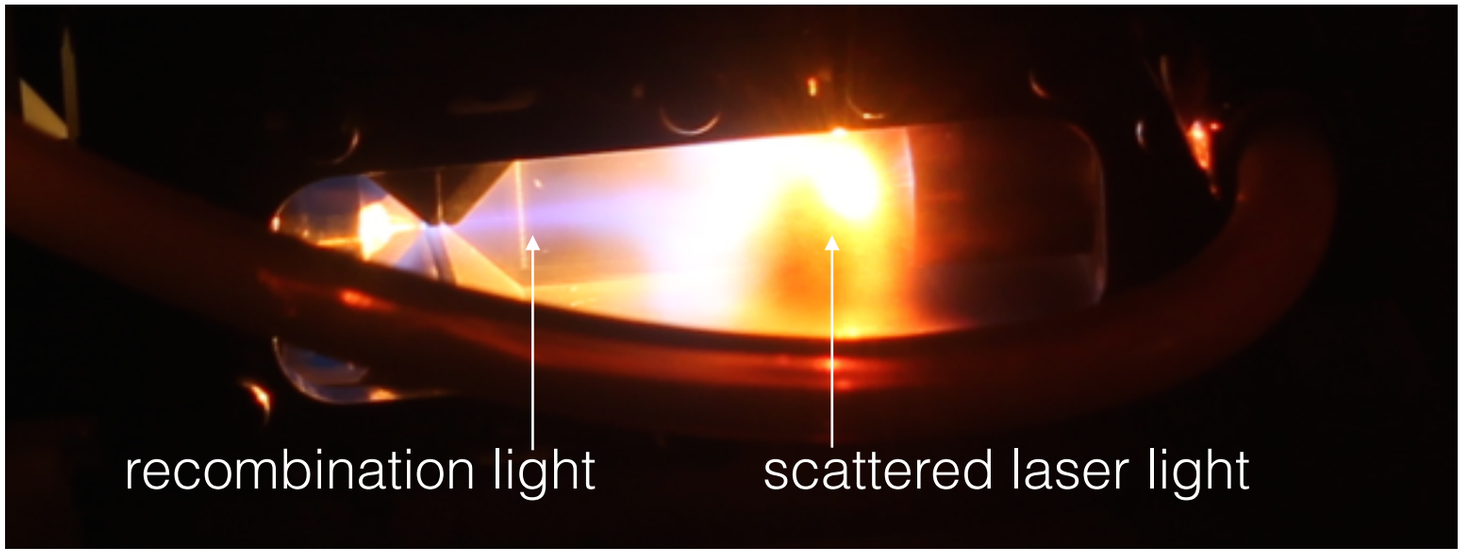


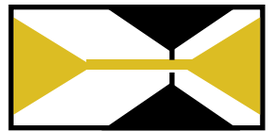
- f/40 parabola focuses beam to spot with r_{FWHM} of ~22 µm and Rayleigh length of ~5 mm
- electron spectrometer using double lane screen detection
- wedge with a hole to reflect the transmitted light and transmit the x-ray beam

plasma recombination light

after ionisation by laser plasma starts to recombine → each ion type emits a photon of a particular wavelength → spatially resolved spectra of photons from the dopant gas can provide an estimation of the location of the potential injection region (see talk of L.Schaper)







imaging the channel onto the slit

SETUP

- light collected at 13° and to the horizontal plane
- shortpass filter before slit entrance with transmission of more than 80% for 420 - 650 nm
- spectral resolution ~ 0.2 nm

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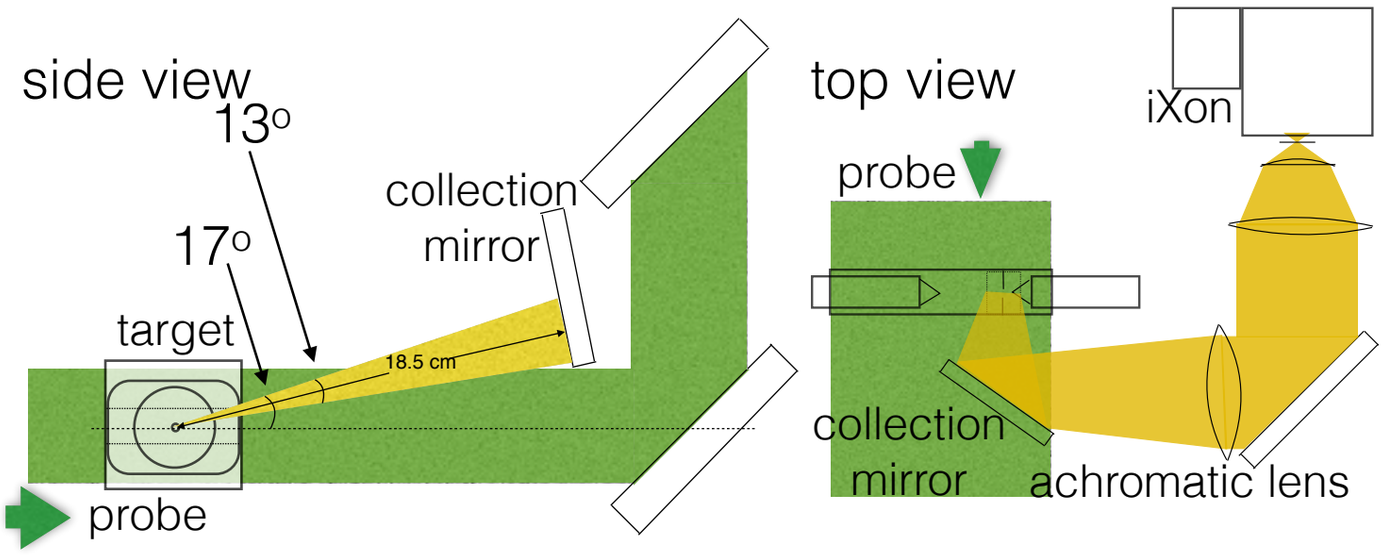

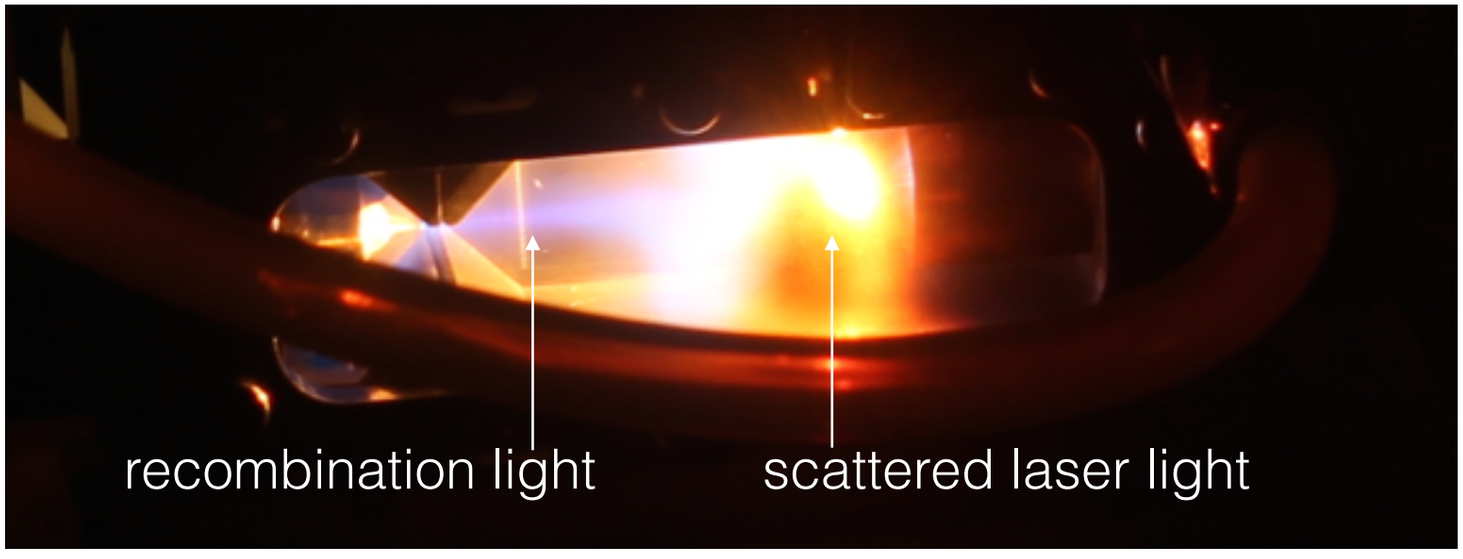

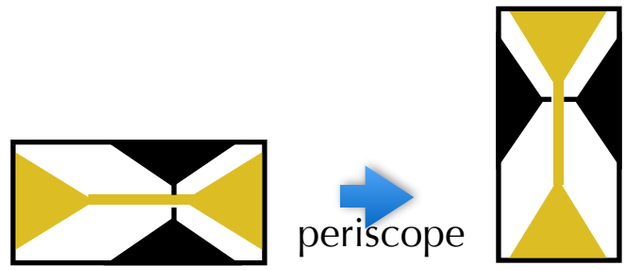

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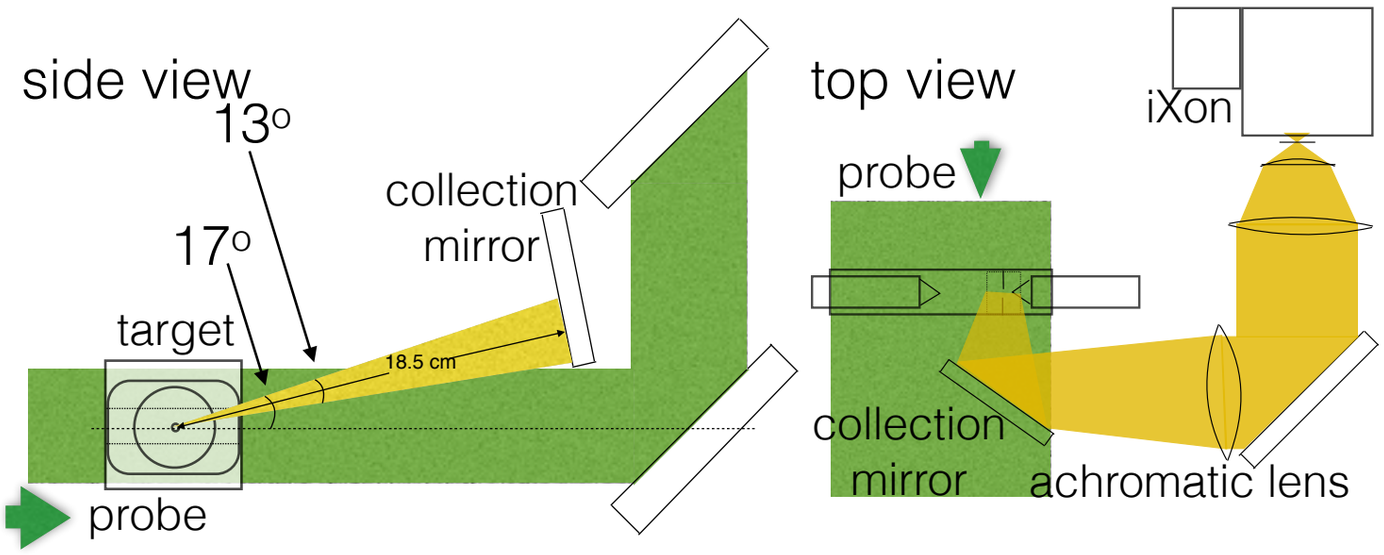

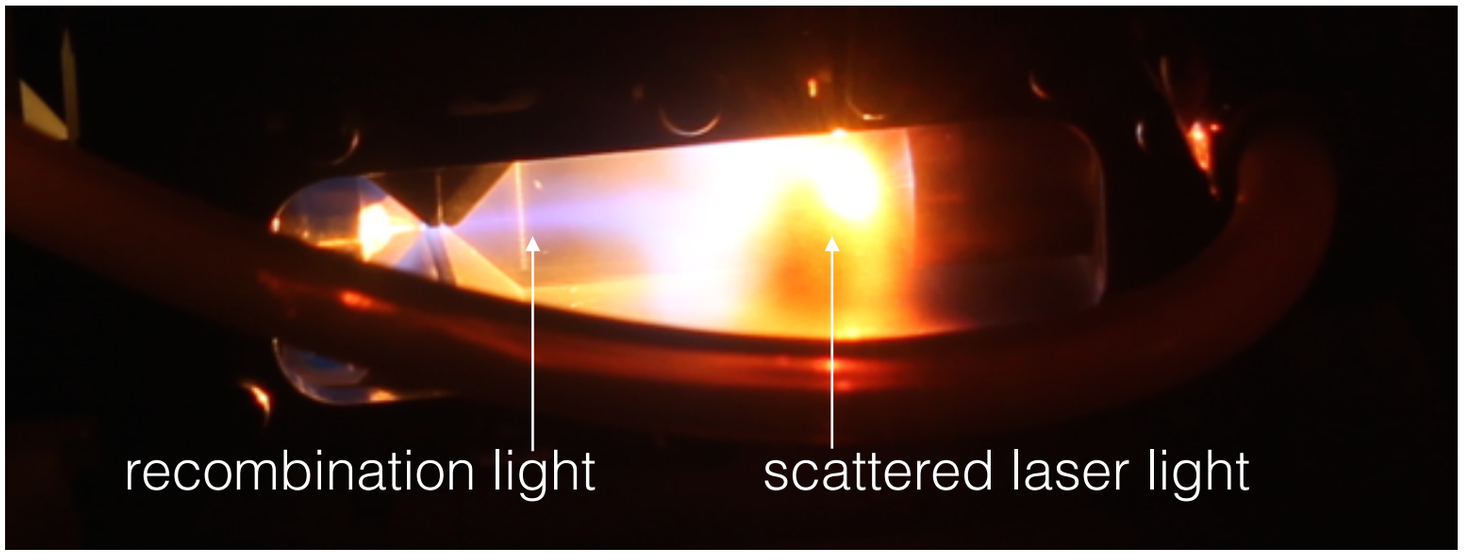

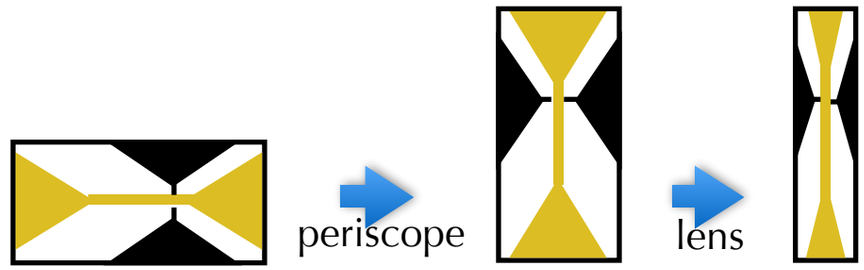

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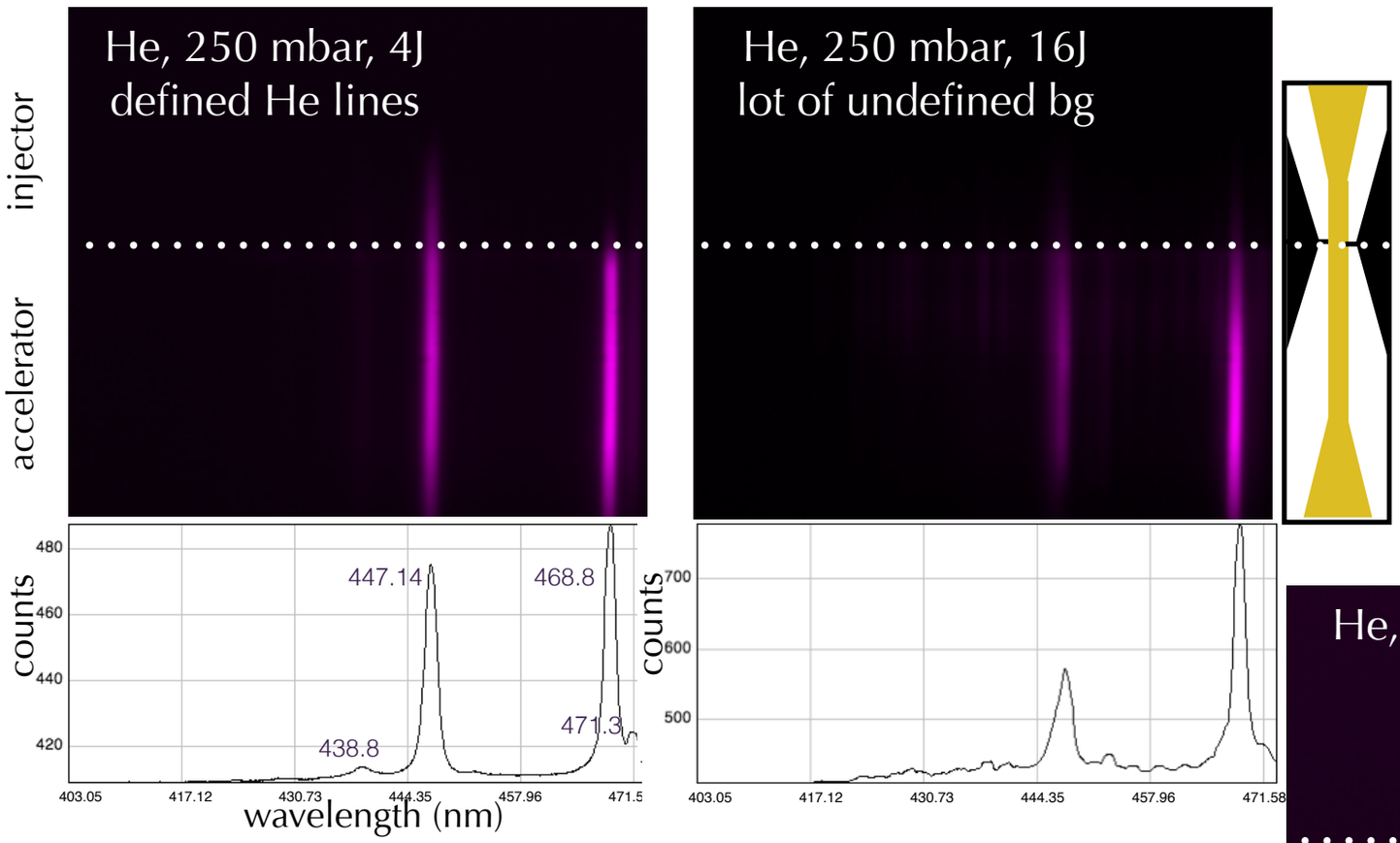
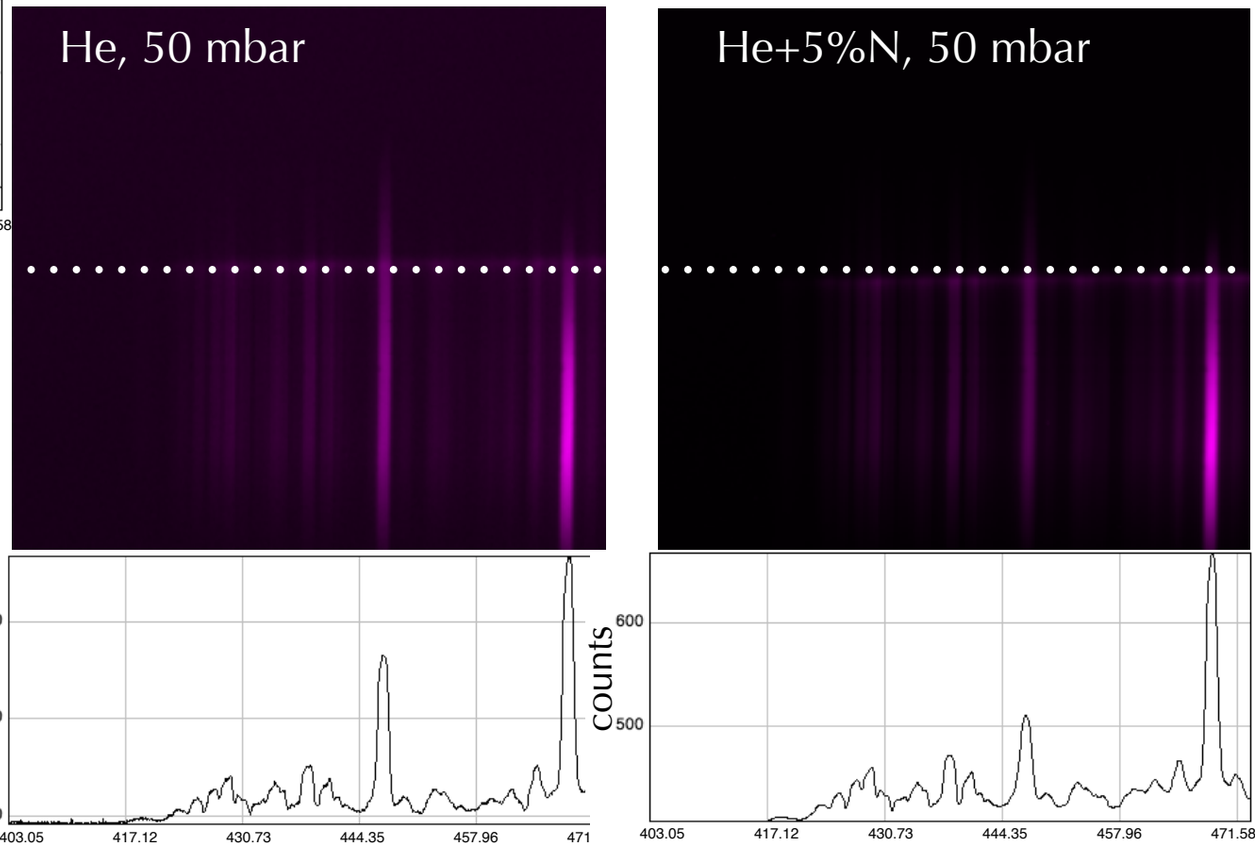
preliminary

preliminary results: recombination light spectra



- Four helium lines measured at different target parameters
- high background at full energy shots (~ 12 J on target) observed
- nitrogen lines (460 - 466 nm) are not observable in integrated spectra
- data collection is ongoing



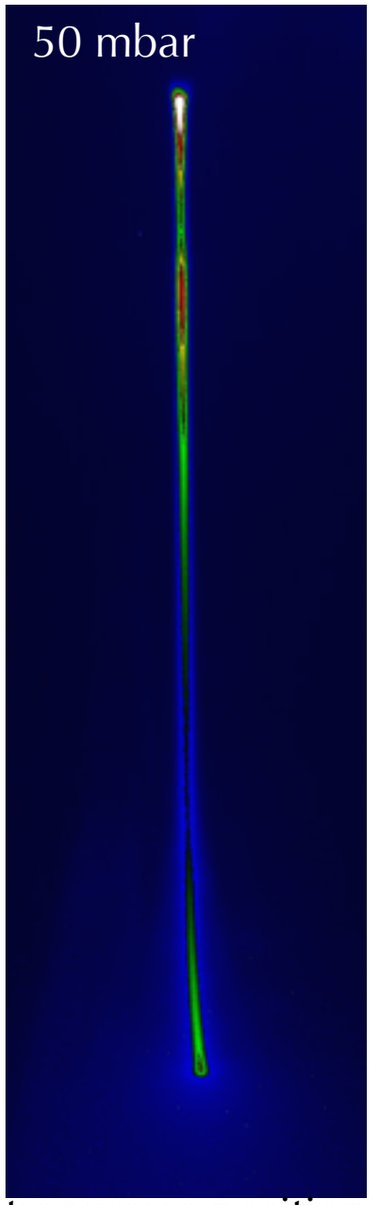
- ~~use bigger optics to collect more light~~
- ~~increase resolution by changing the grating~~
- ✓ intensity of lines scales with a density -> increase density
- ✓ measure spectra in different spectral regions -> e.g. at 567 - 587 nm [2]

[2] Pollock B B *et al* 2011 Phys. Rev. Lett. 107 045001

preliminary

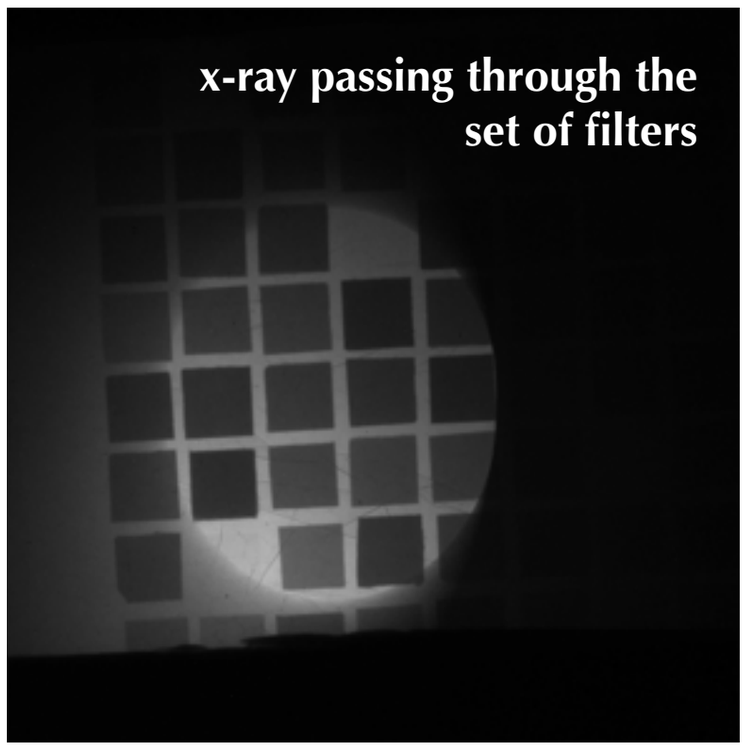
preliminary results: electrons and x-ray

Self injection
at 2 cm of He



- guiding over few Rayleigh distances observed
- Self injection and ionisation injection tested at:
  - different target length,
  - gas mixture,
  - electron densities and
  - laser energy pulse
- electron energy above 1 GeV achieved
- bright x-ray signal was measured

EXPERIMENT AND DATA ANALYSIS ARE ONGOING



Summary

- Novel multistage gas target for controlled injection and long acceleration length was used for successful LWFA

- OpenFOAM simulations of the target were performed. High turbulence at pressures 20/40 mbar and higher

- preliminary measurements with plasma recombination light diagnostic highlight difficulty of background

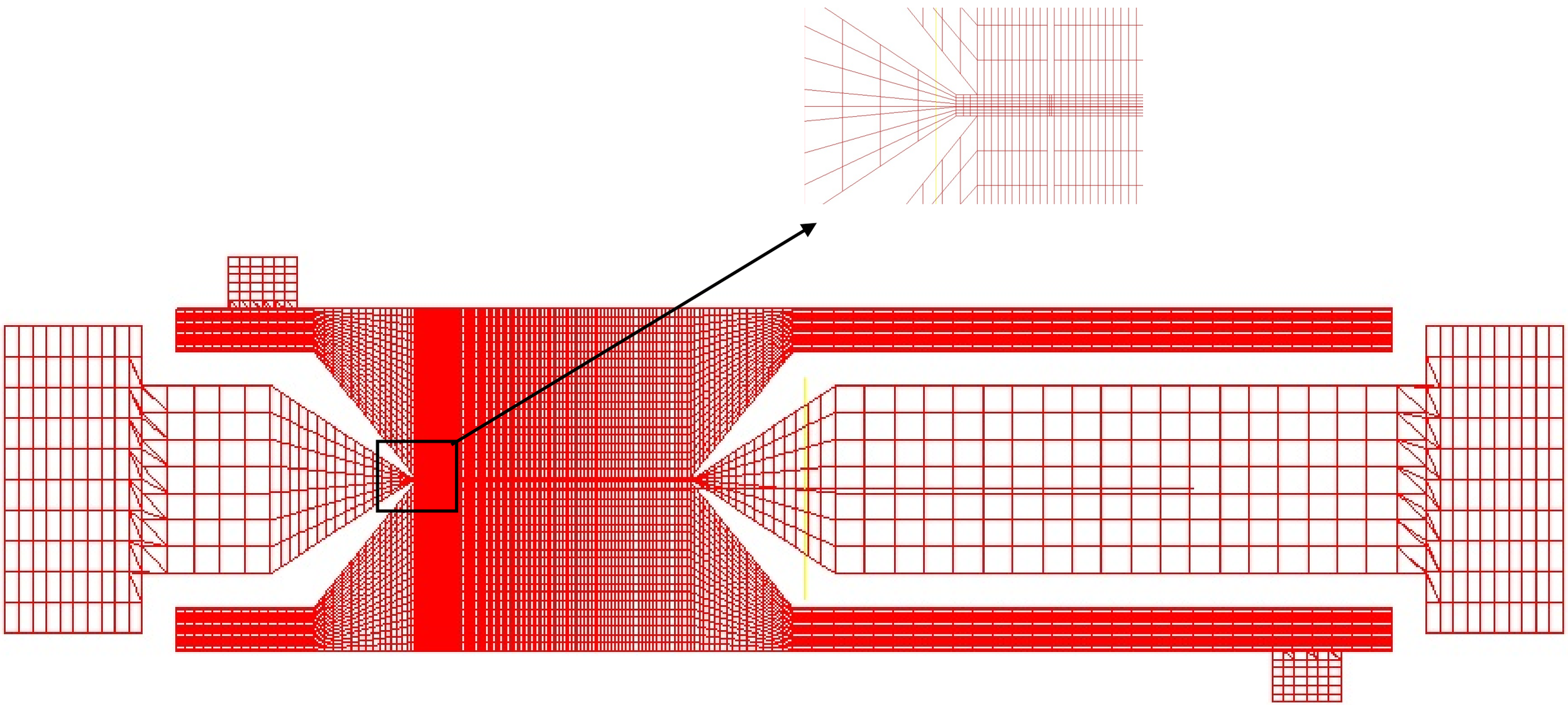
- Experiment ongoing

- Preliminary electrons and x-rays looks exciting

Thank you for your attention

backup slides

mesh resolution



spectral lines

Ion	wavelength (nm)
He^0	438.79; 443.75; 447.14; 471,3; 492.2; 501.57; 504.8; 587.56
He^{1+}	468.54 - 468.59
N^0	484.7; 491.5; 493.5;
N^{1+}	443.3; 444.7; 453.0; 460.15; 460.7; 461.4; 462.1; 463.4; 464.3; 478.8; 480.329; 489.5; 498.7 and many more
N^{2+}	433.9; 434.57; 437.9; 451.1; 451.5; 464.1; 485.9; 486.7
N^{3+}	460.63;
N4+	460.37; 462.0; 494.5