Localised ionisation-induced trapping in a laser wakefield accelerator using a density down-ramp

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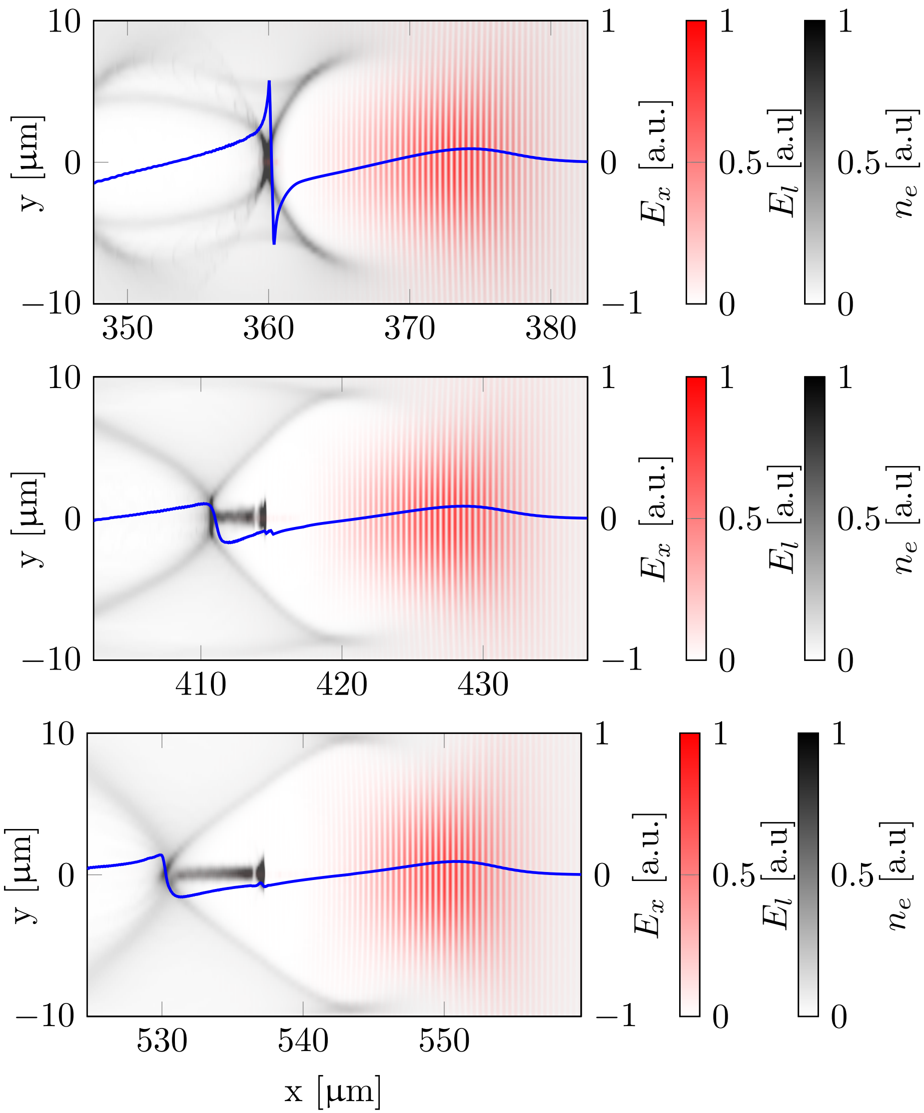
Density down-ramp injection



- Bubble expands in density down-ramp
- Background electrons trapped and accelerated

✓ Shock-front injection: Sharp density gradients (~λ_p)

✓ **Long density gradients (~10λ_p)**

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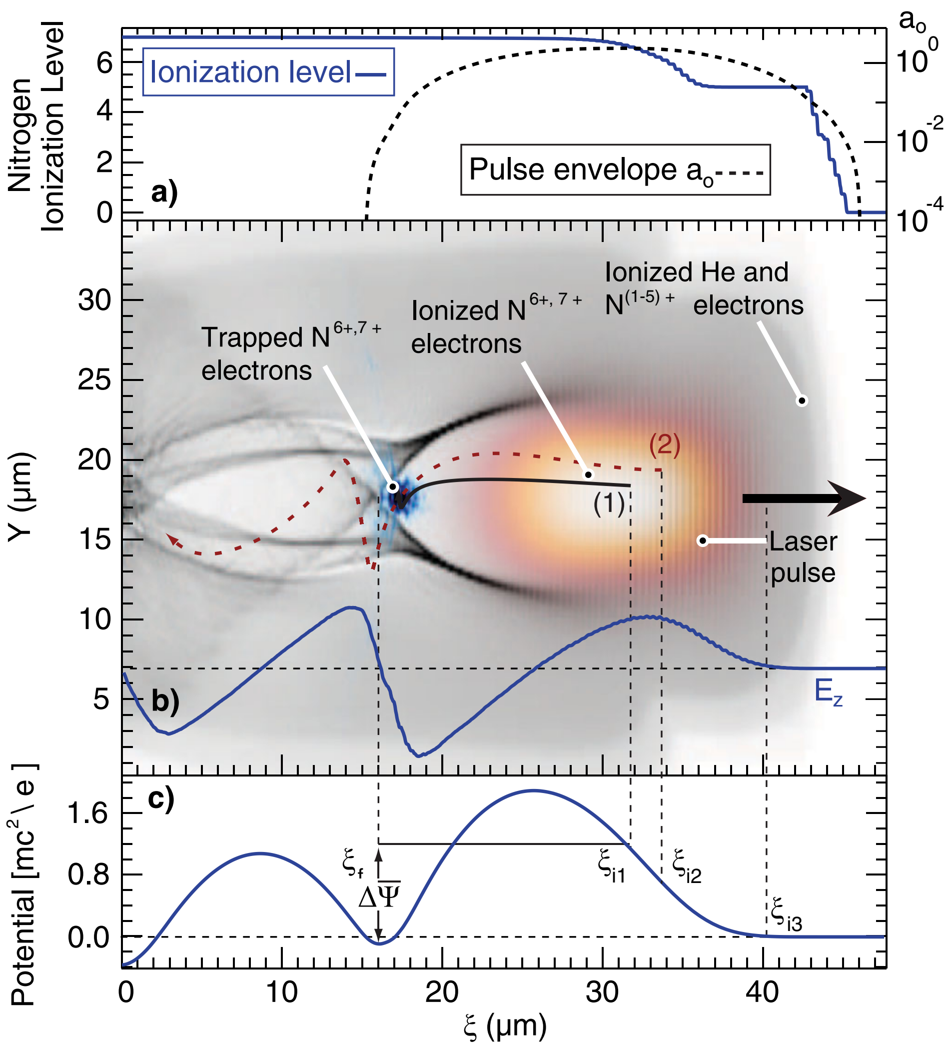
Ionisation-induced trapping



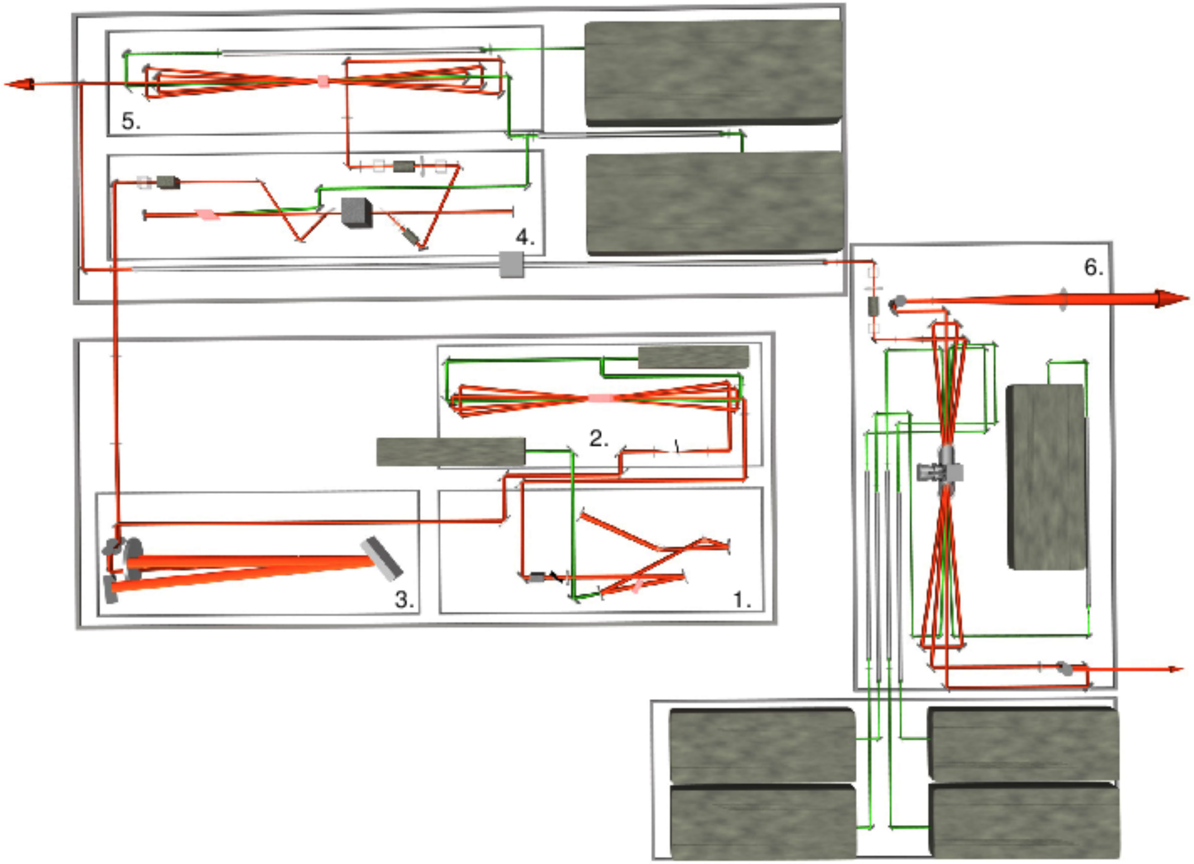
- Background plasma created by front edge of the laser pulse
- Core e- ionized close to laser peak are trapped and accelerated by in bubble
- High charge possible
- Not localised, lead to continuous spectrum

Illustration: A. Pak et al., Phys. Rev. Lett. 104, 025003 (2010)

Outline

- Interferometric characterisation of a gas cell
- Study of ionisation injection in a variable length gas cell
- Ionisation induced trapping in a density gradient

Lund Multi-Terawatt Laser



30 TW

30 fs

50 mm beam

10 Hz

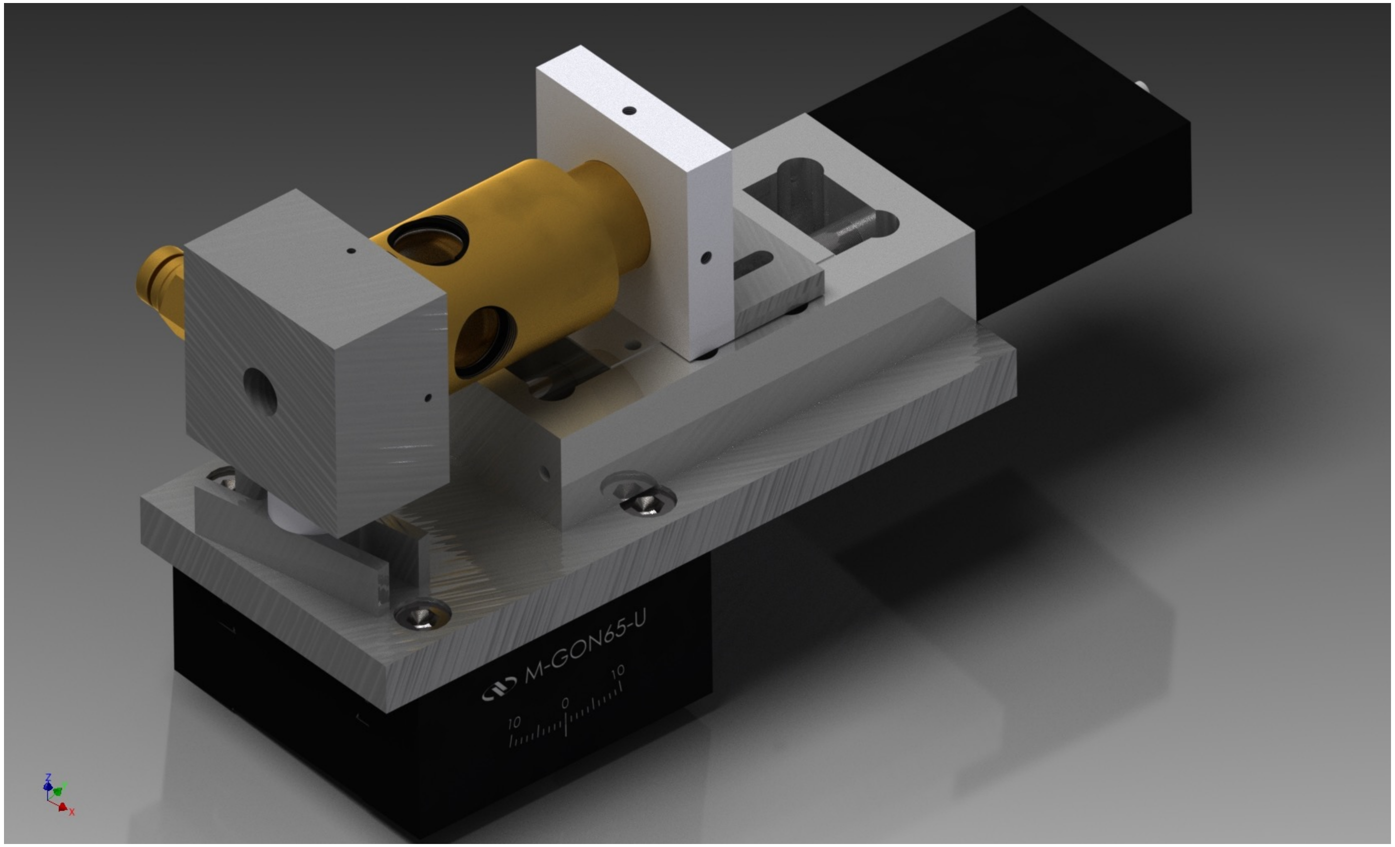
10^{19} W/m^2

10^9 contrast

Adaptive optics

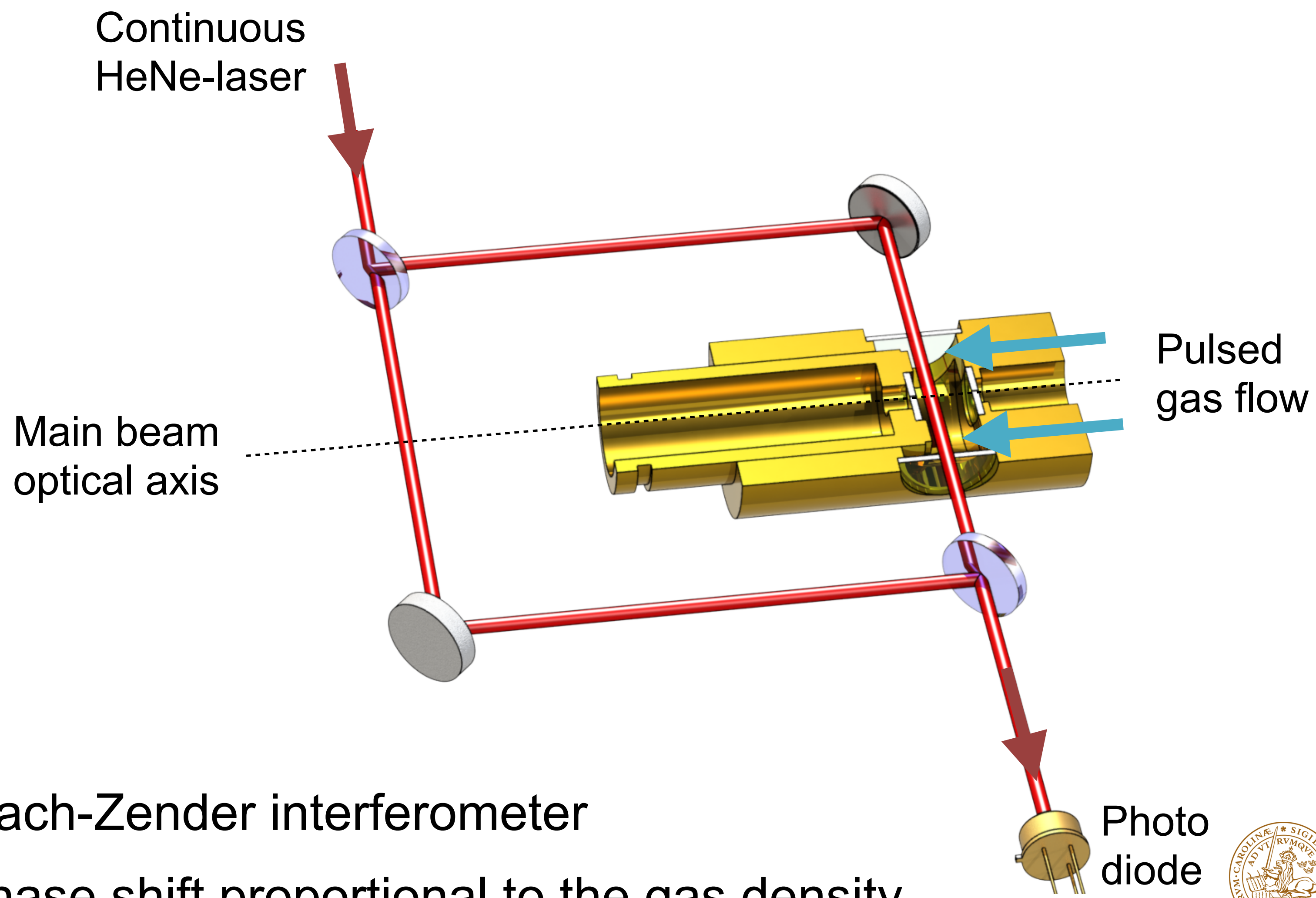
Pointing stabilization

Gas cell



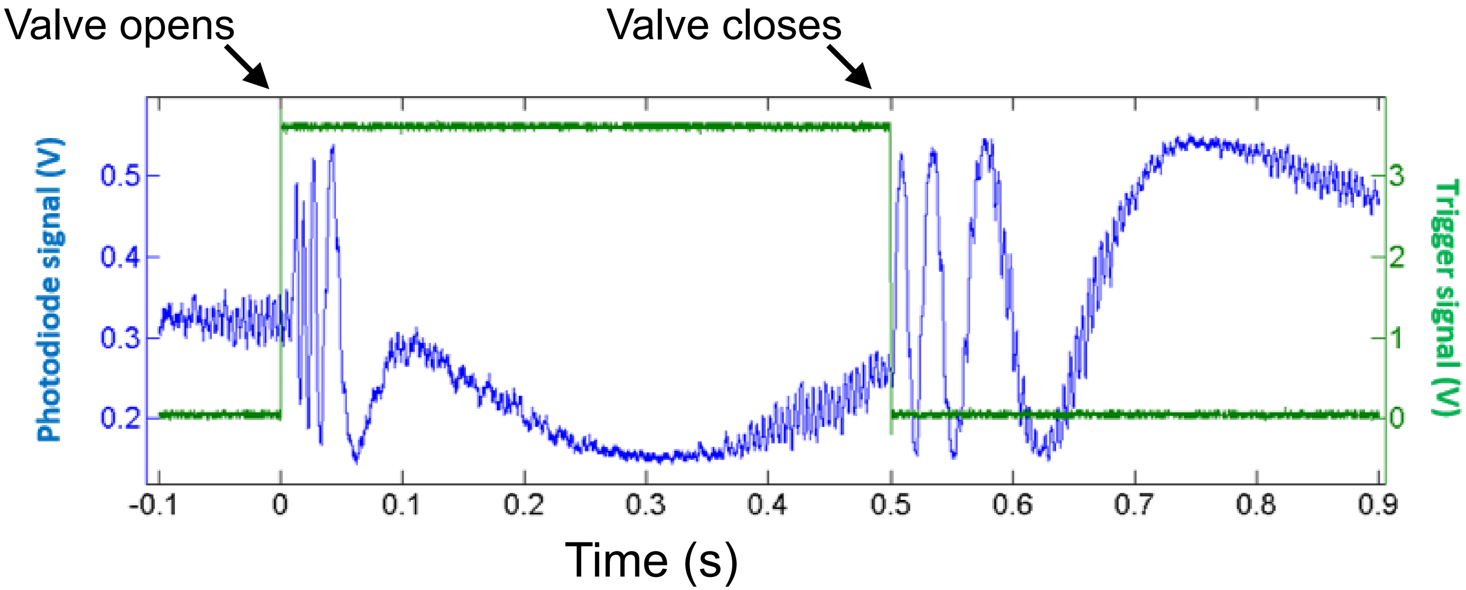
- Variable length 0 - 15 mm
- Optical windows for diagnostics and interferometry

Measurement of the gas density



- Mach-Zender interferometer
- Phase shift proportional to the gas density

Measurement of the gas density



- Valve opens: Gas flows into the cell
- Equilibrium: Inflow equals outflow (100 µm pinholes)
- Valve closes: Cell is evacuated

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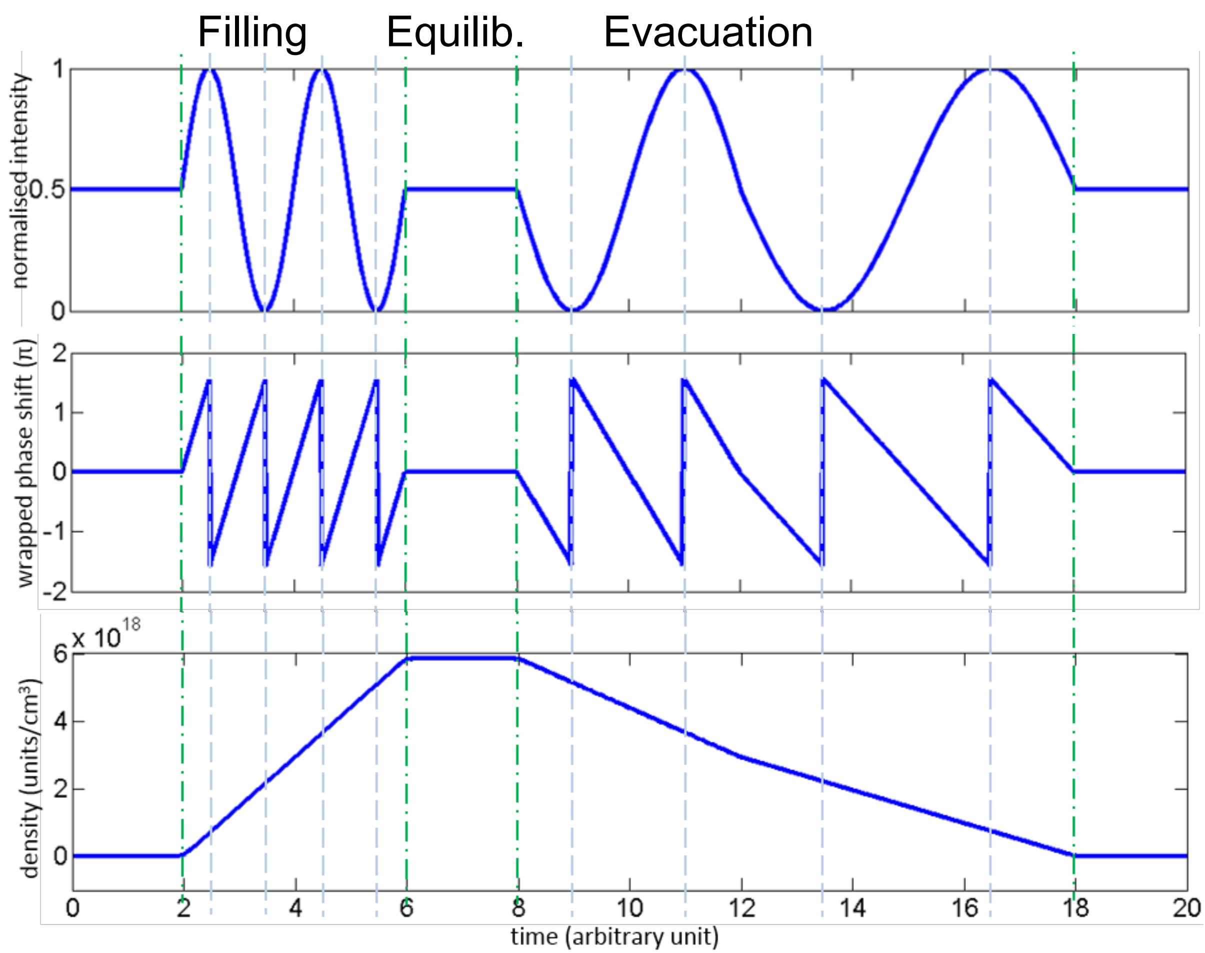
Retrieving the density



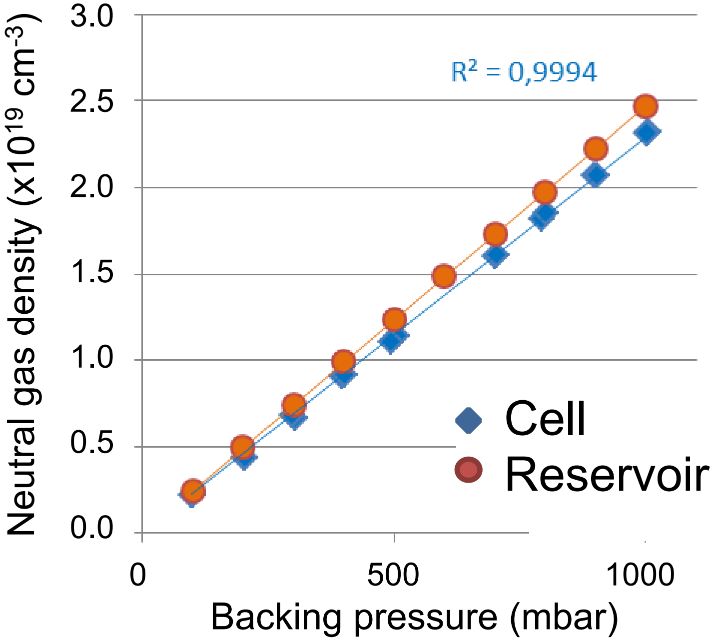
Diode signal

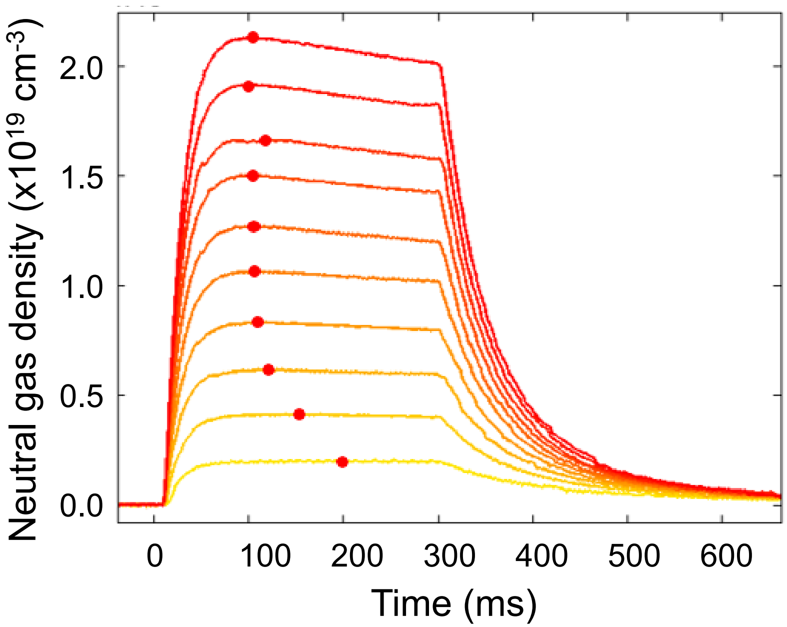
Wrapped phase

Unwrapped density

Schematic illustration

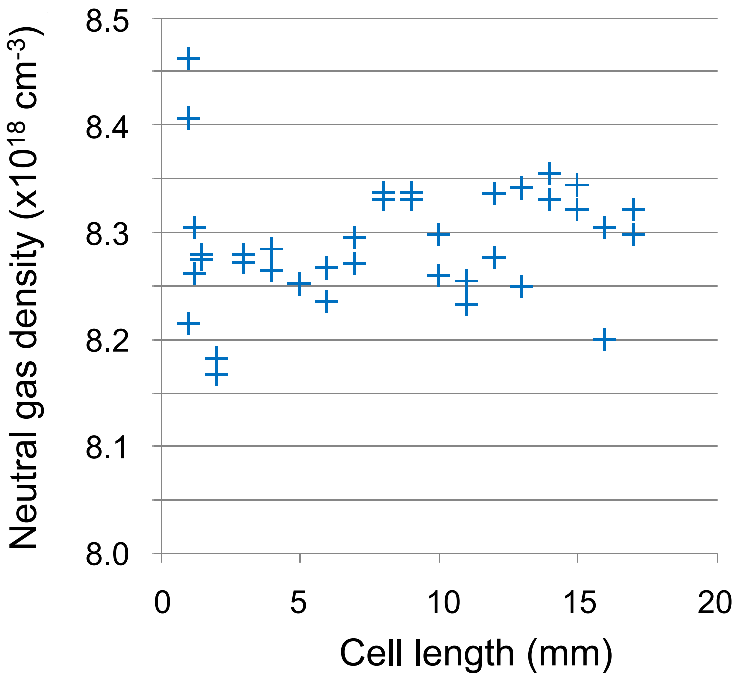
Influence of the backing pressure

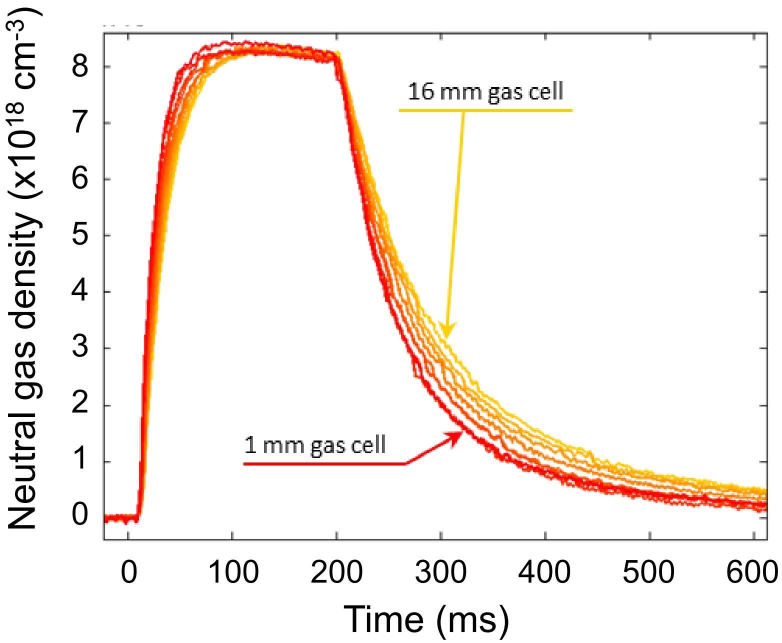




- Linear dependence on backing pressure
- ~90% of static reservoir density measured in cell
- 100-200 ms filling time to maximum pressure

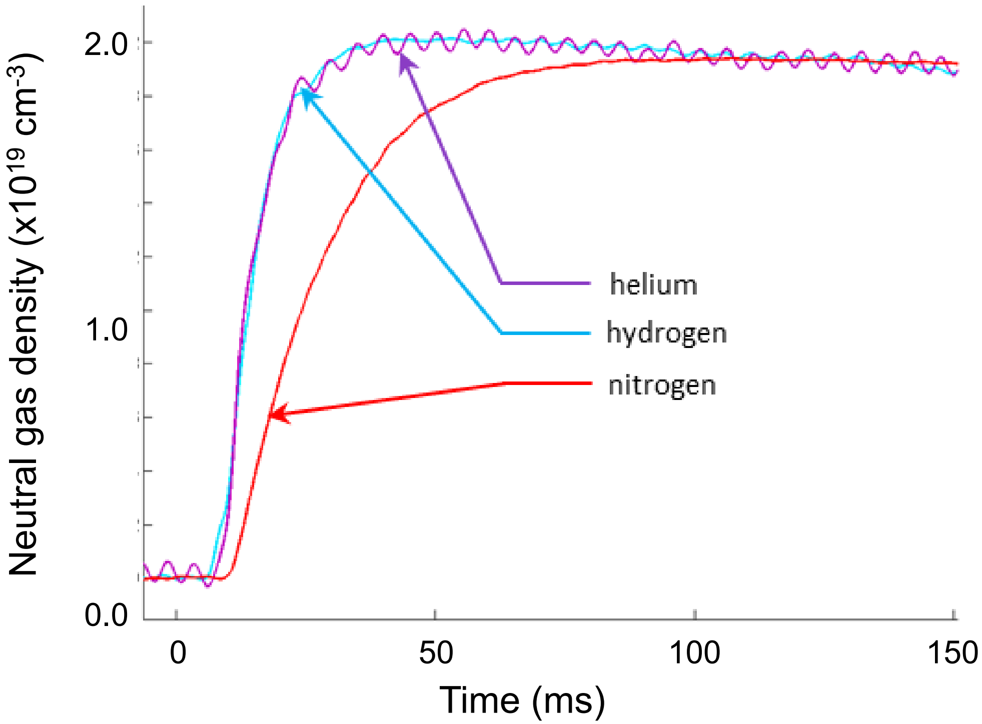
Influence of the cell length





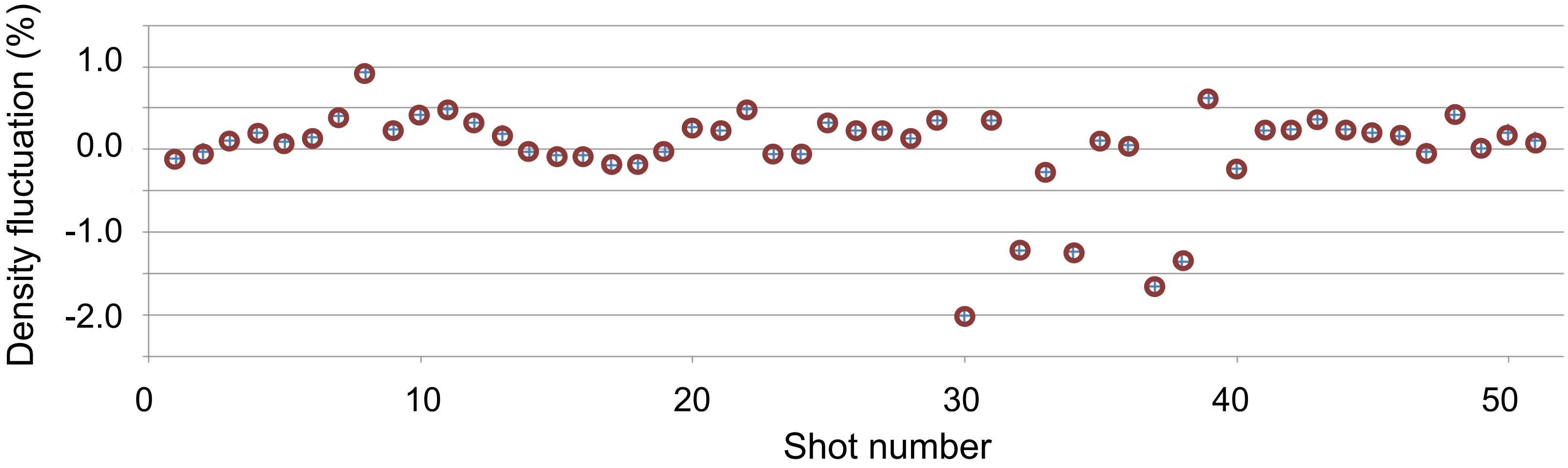
- Maximum density is the same for all cell lengths
- Longer filling time for longer cells

Influence of the gas medium



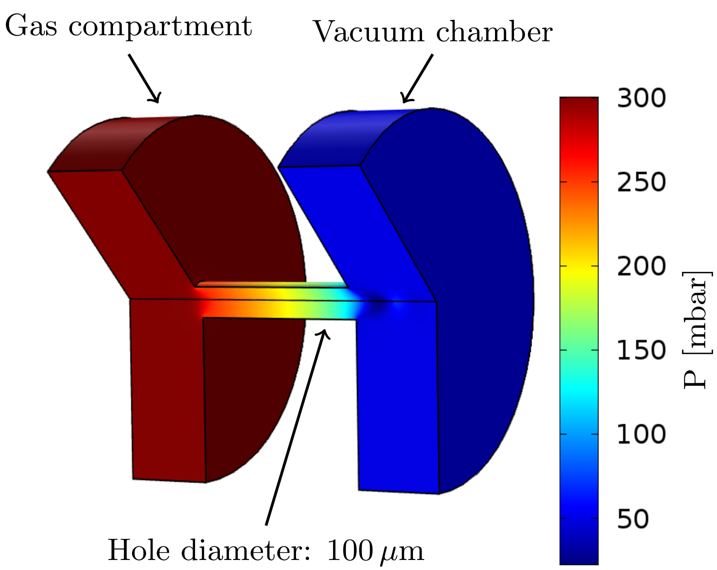
- H_2, He: ~50 ms filling time
- N_2: ~100 ms filling time

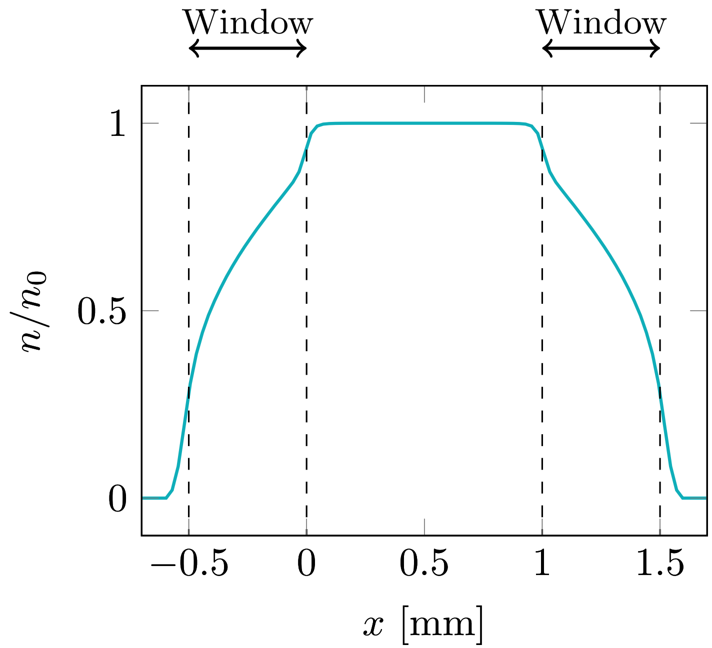
Reproducibility



- 240 mbar N_2 , Length 5 mm
- ±0.55% RMS density fluctuation

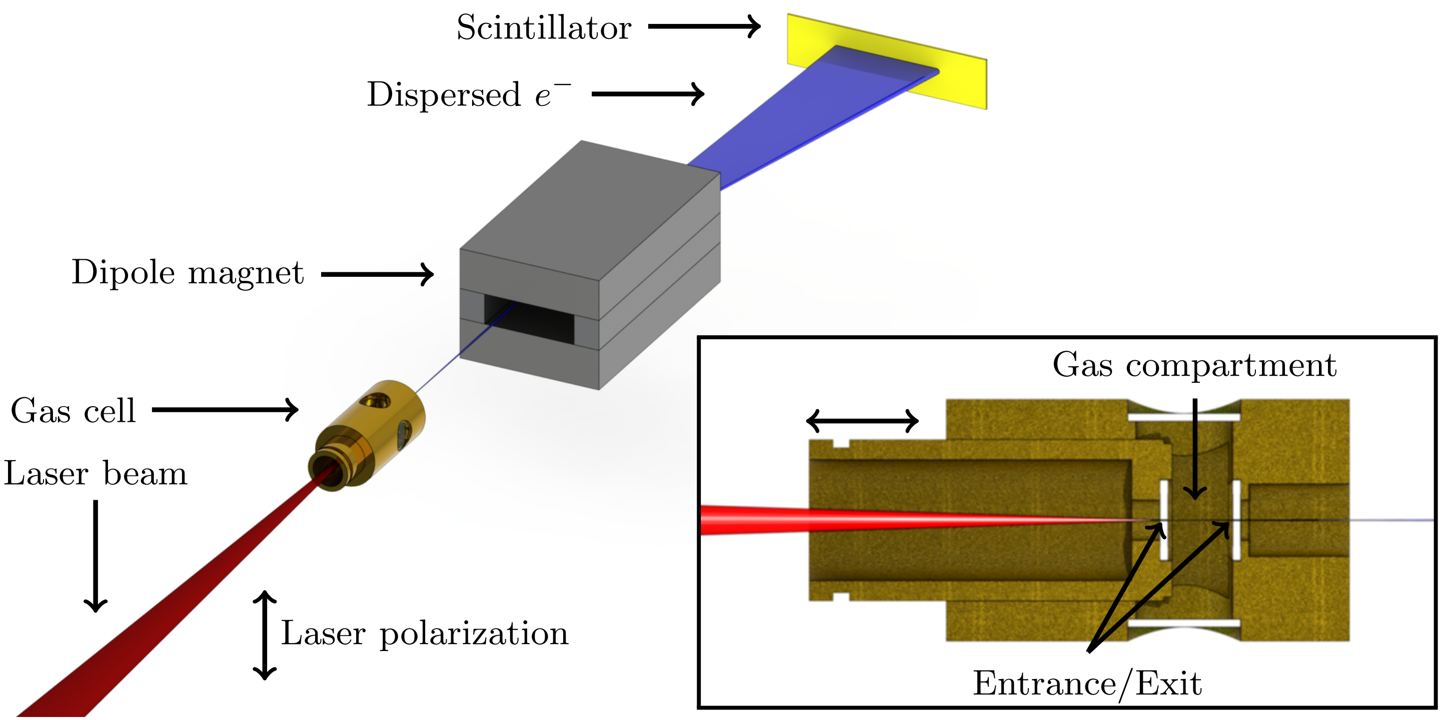
Entrance gradients





- Density gradients estimated using computational fluid dynamics
- Plateau density measured using interferometry

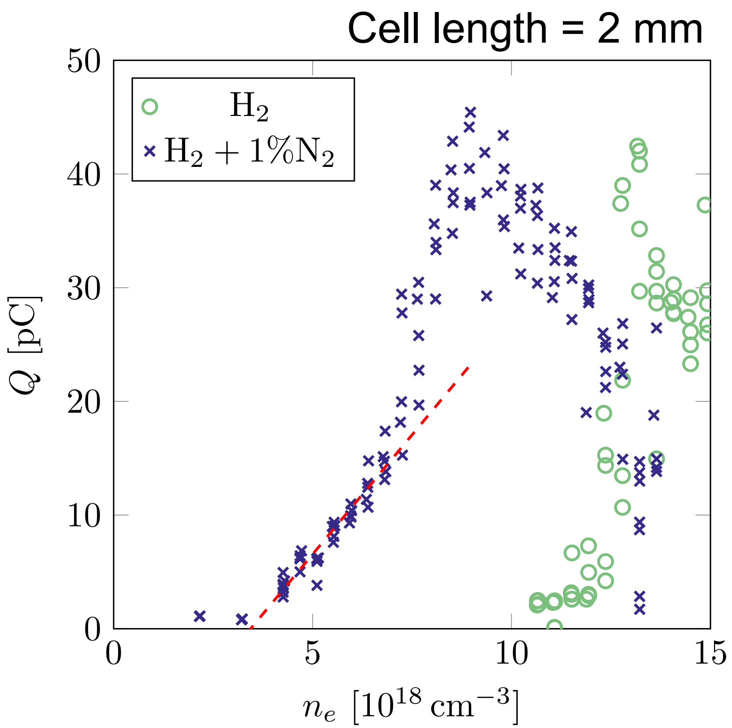
Experimental setup



Target parameters
- L = 0.5 – 4 mm
- H_2 or H_2 + 1%N_2
- P = 100 – 300 mbar

Laser pulse parameters
- E = 600 mJ
- T_{FWHM} = 37 fs
- D_{FWHM} = 17 µm
- $I_{peak} = 4 \cdot 10^{18}$ W/cm^2
- a_0 = 1.2

Density dependence



Mixture H2+1%N2

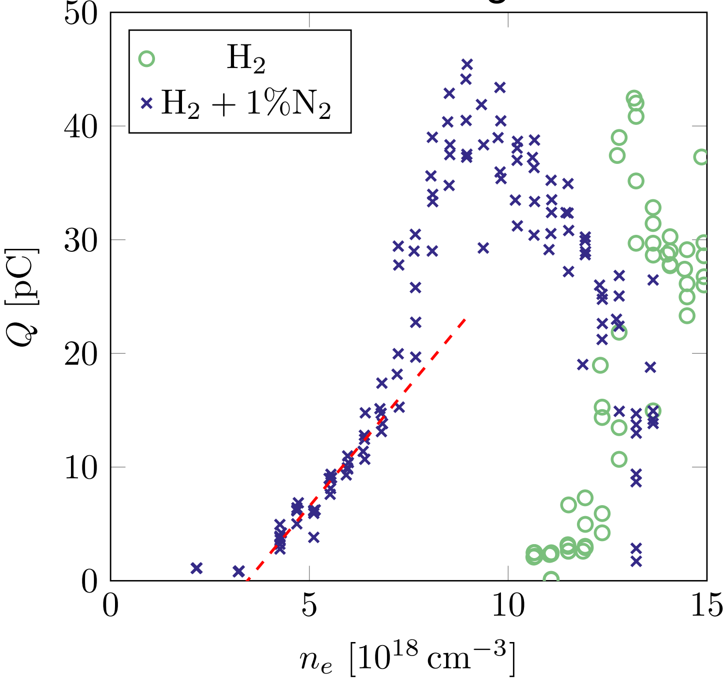
- Threshold ≈ $3 \cdot 10^{18}$ cm^{-3}
- Broad energy spectrum
- Stable

Pure H2

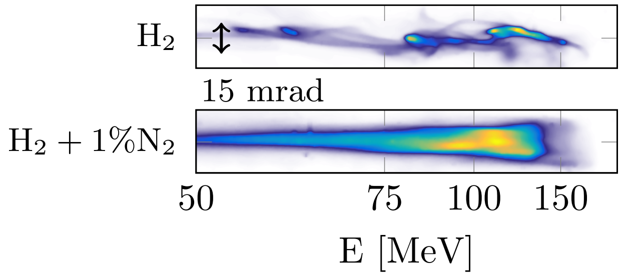
- Threshold ≈ $1 \cdot 10^{19}$ cm^{-3}
- Narrow spectral features
- Fluctuations

Density dependence

Cell length = 2 mm

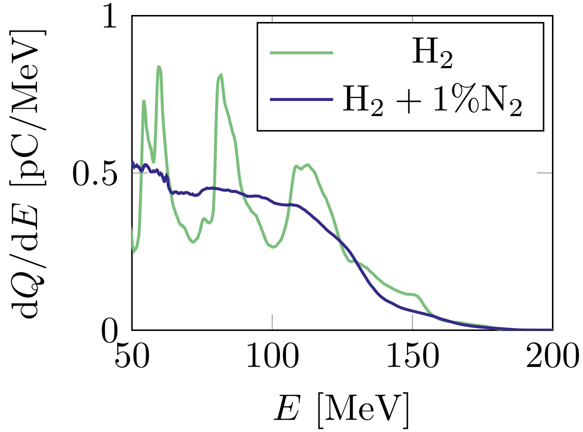


Typical beams with Q ≈ 40 pC



$13 \cdot 10^{18}$ cm^{-3}

$9 \cdot 10^{18}$ cm^{-3}



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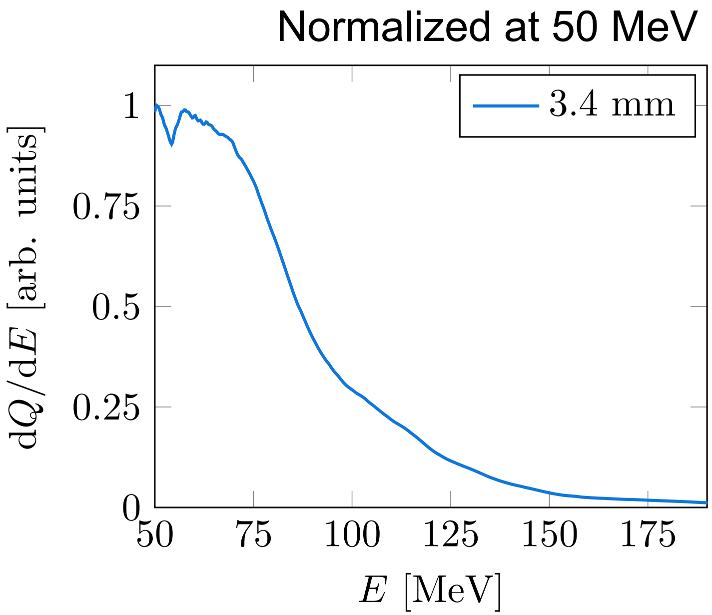
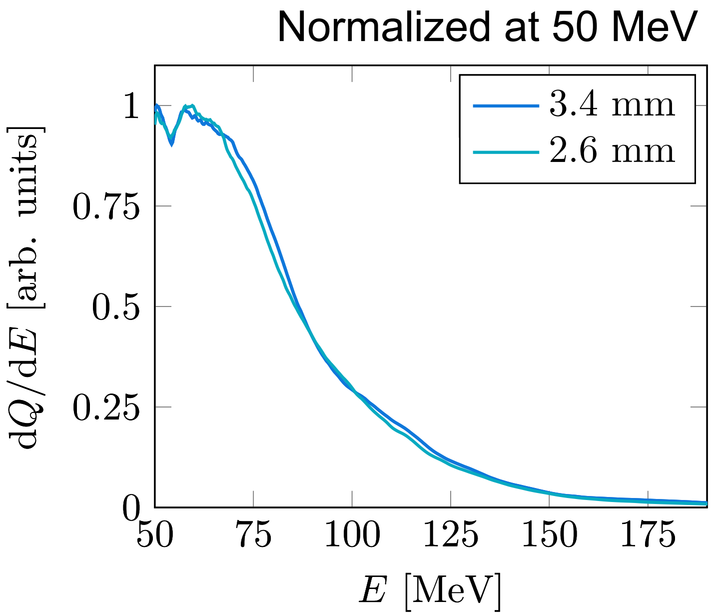
Evolution of the energy spectrum



- 250 mbar H_2 + 1%N_2

Evolution of the energy spectrum



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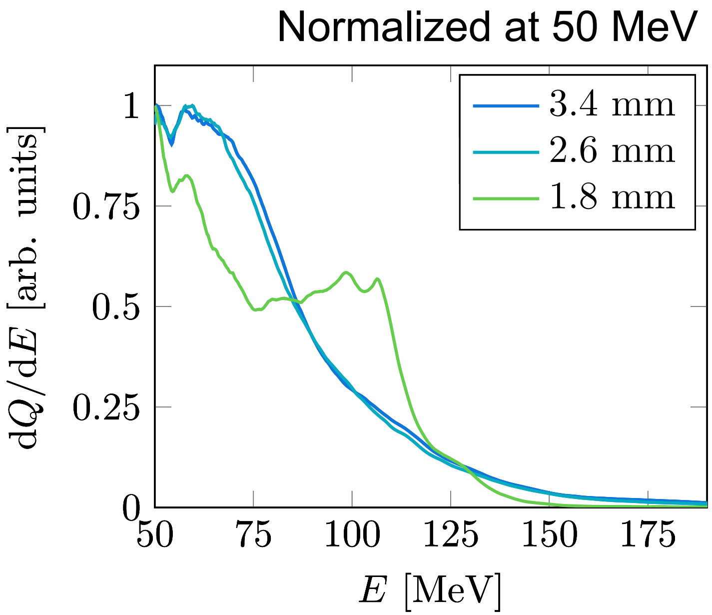

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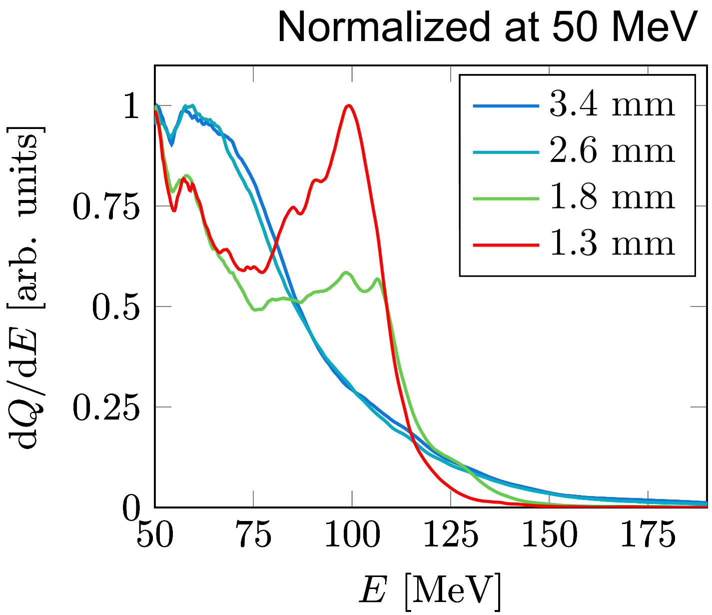

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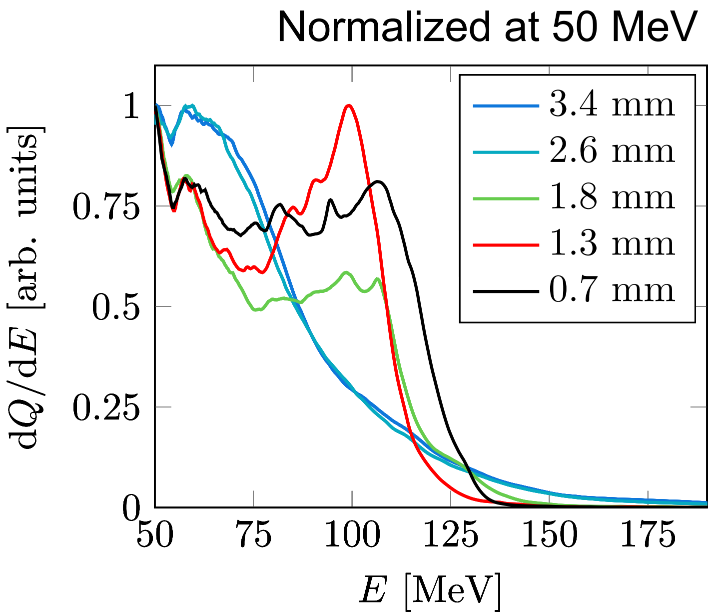

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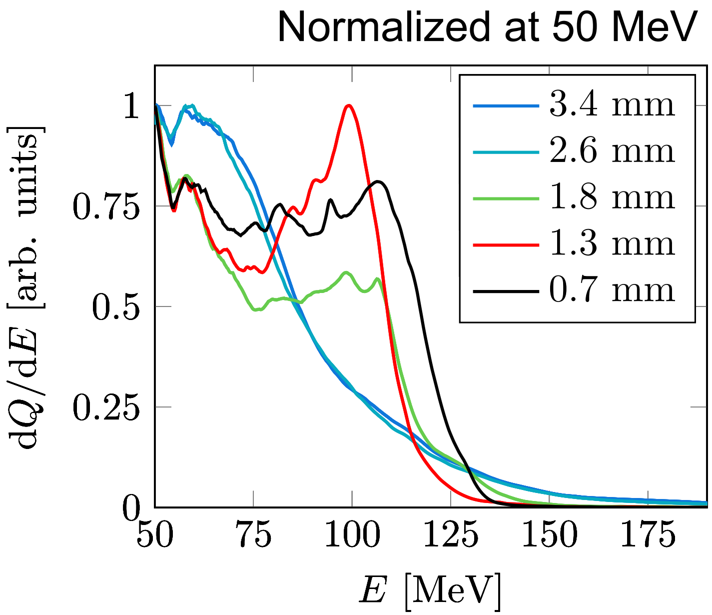
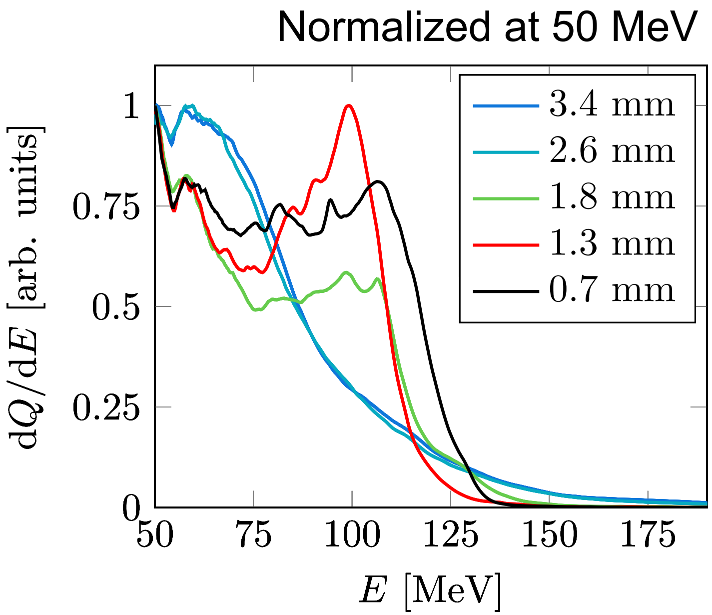
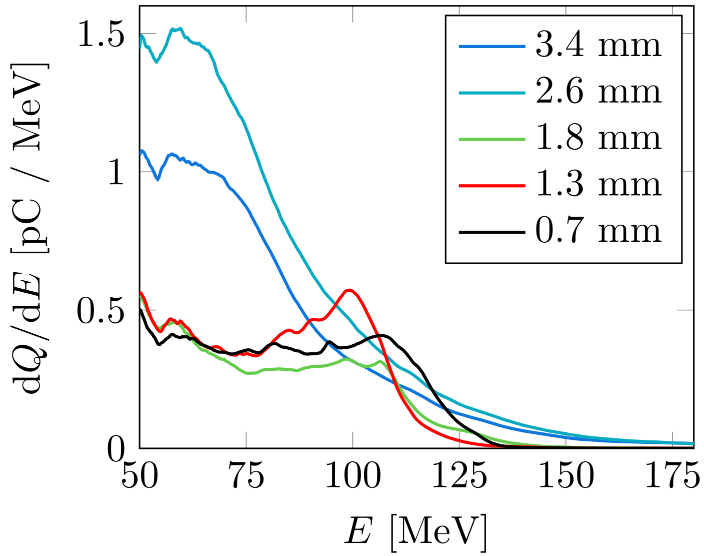


- 250 mbar H_2 + 1% N_2
- Peaked features at optimum length
- Energy of peak essentially constant

Evolution of the energy spectrum





- 250 mbar H_2 + 1% N_2
- Peaked features at optimum length
- Energy of peak essentially constant
- Wide part of spectrum dominates over peak for longer cells

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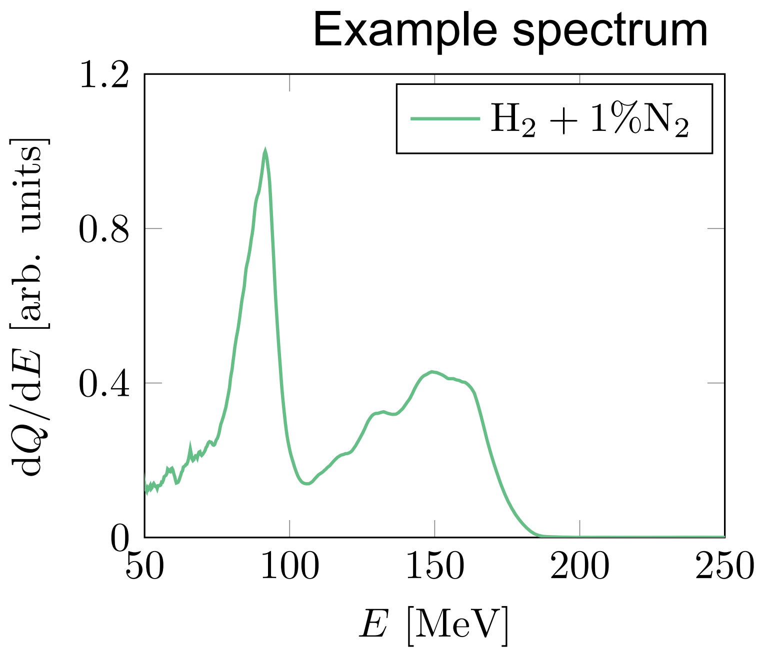
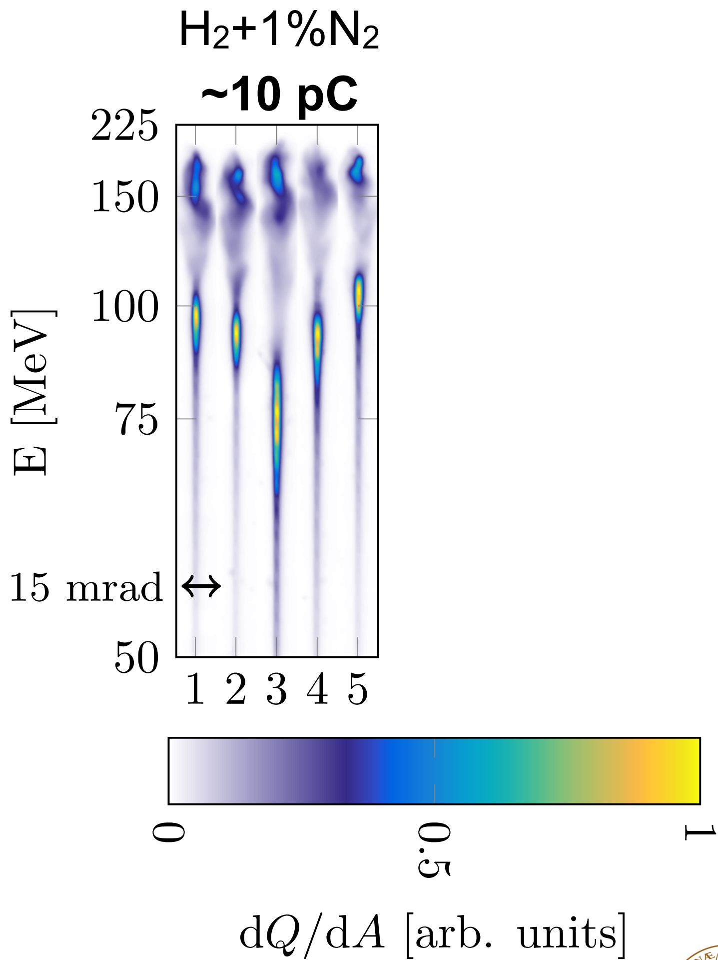
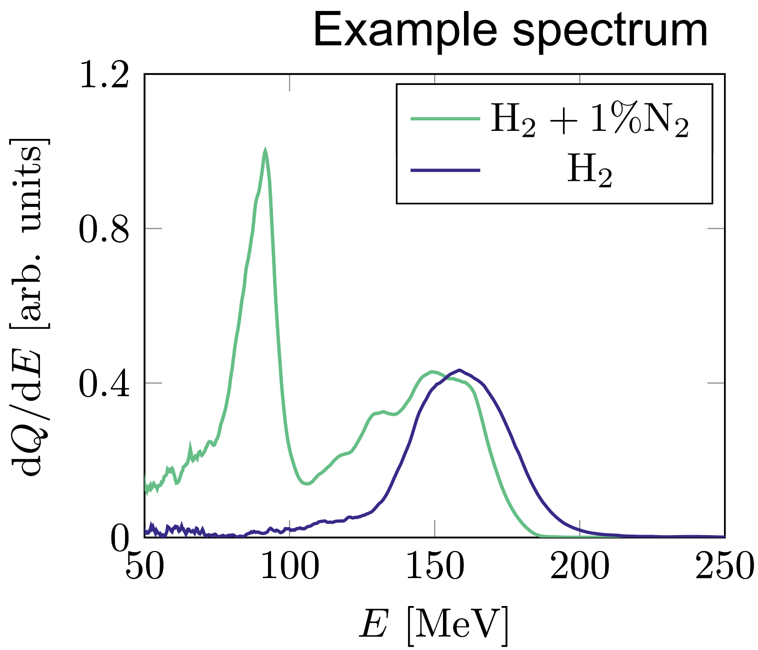
Reproducible beam characteristics

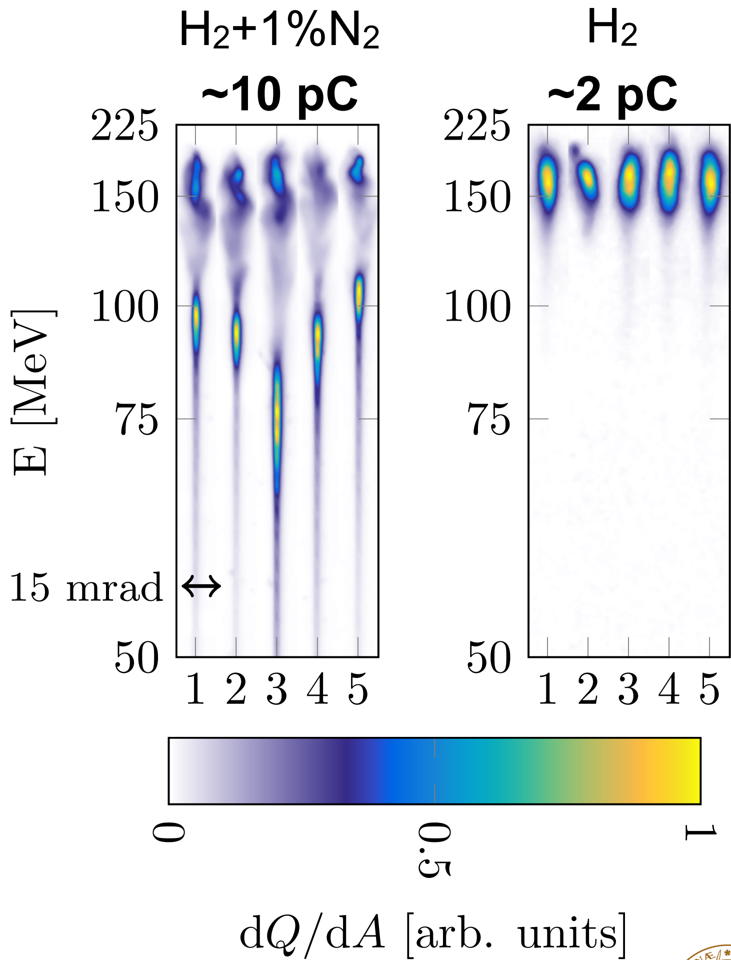




- Cell length 0.7 mm
- Pressure 250 mbar

Reproducible beam characteristics





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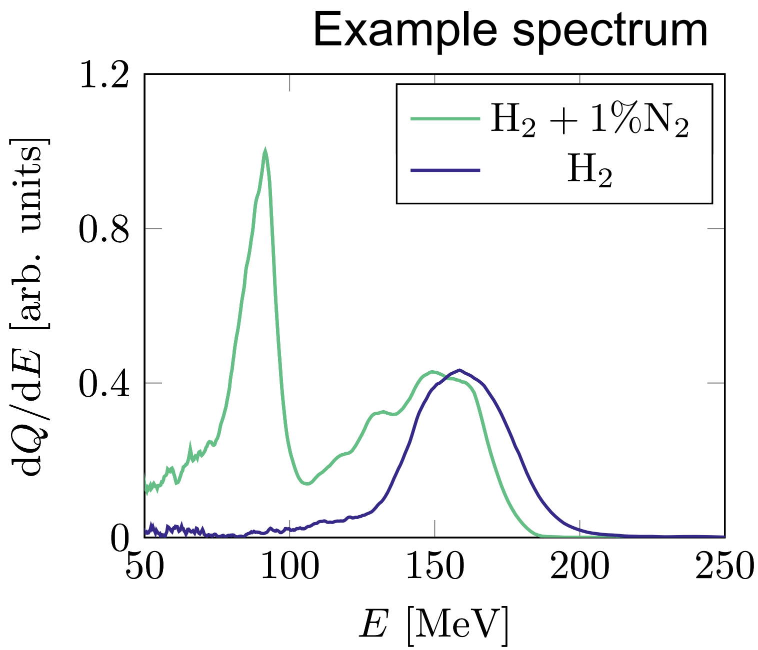
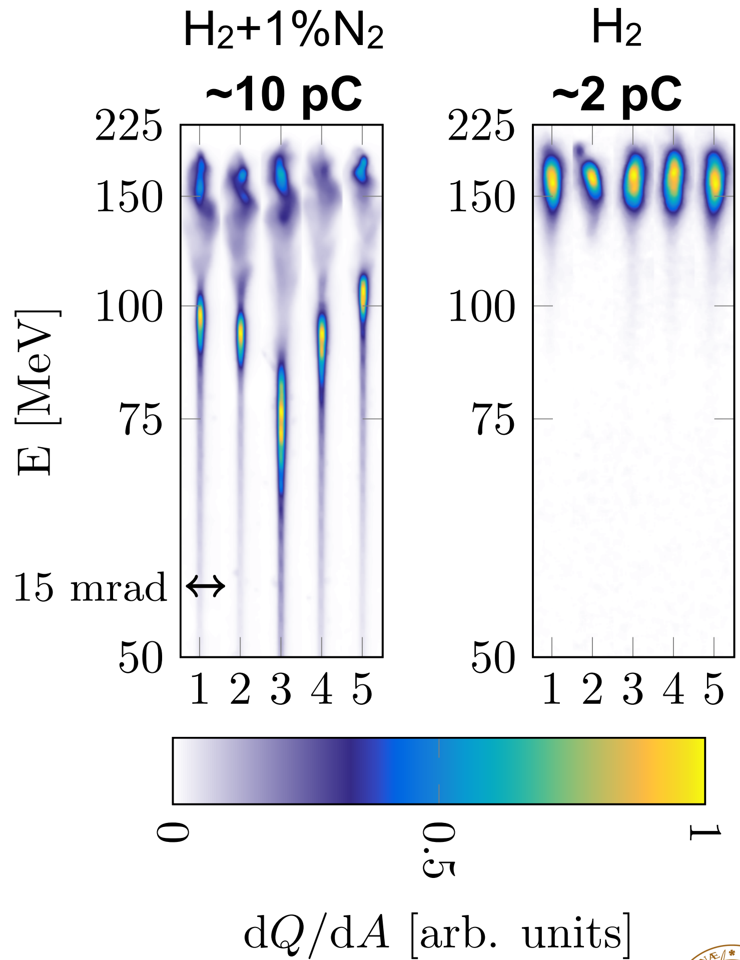


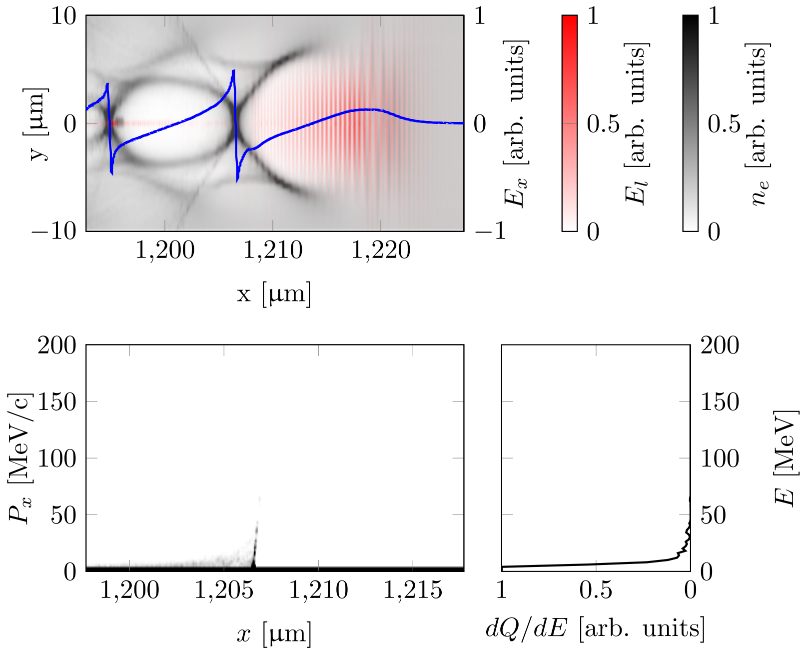


- Cell length 0.7 mm
- Pressure 250 mbar

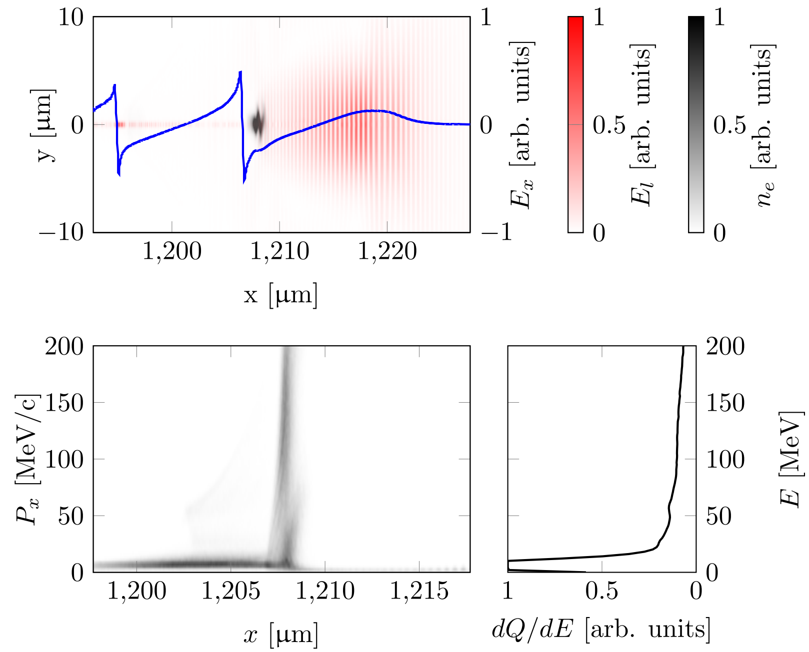
Two spectral components — Two injection mechanisms?

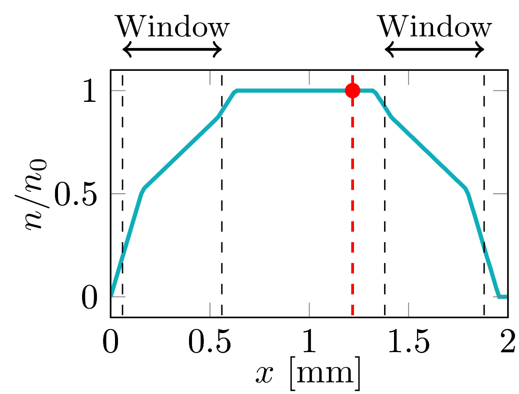
Simulations with CALDER-Circ

Background plasma



e- from ionised from $N^{5+,6+}$





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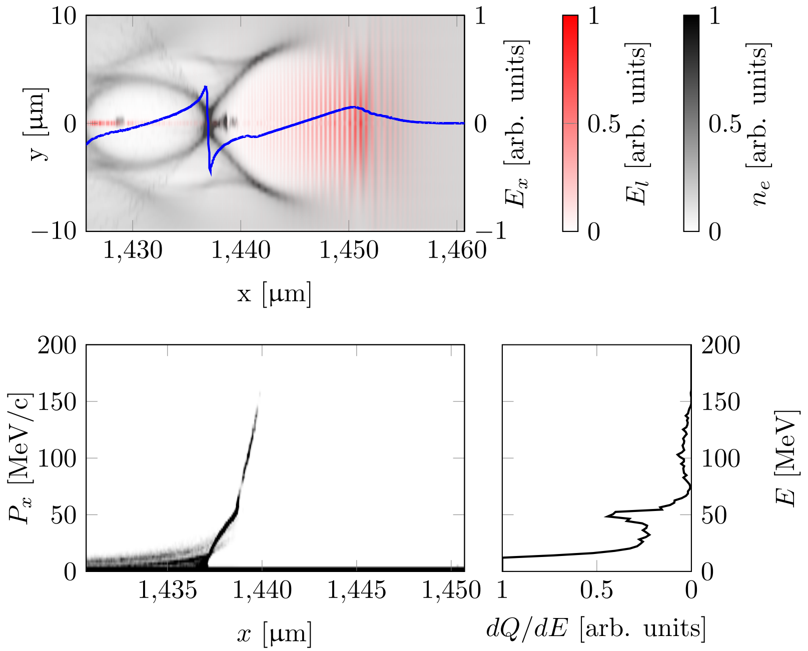

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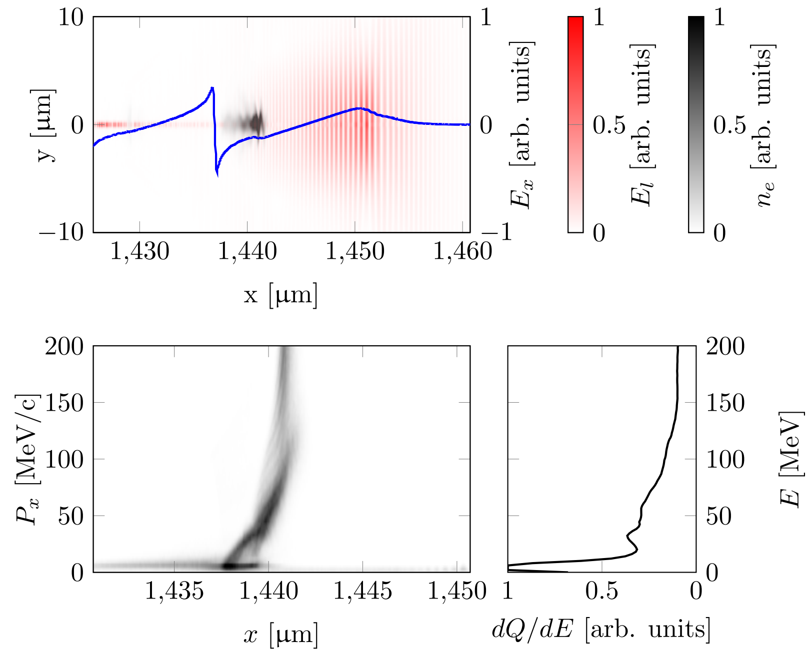
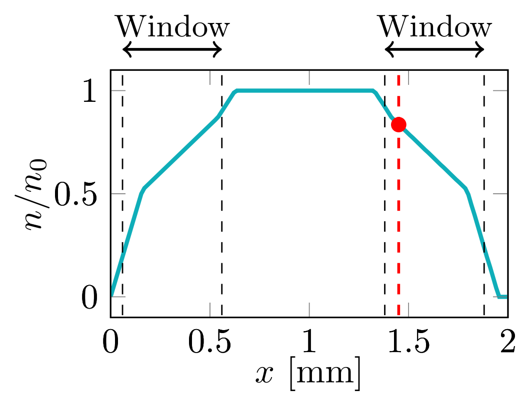
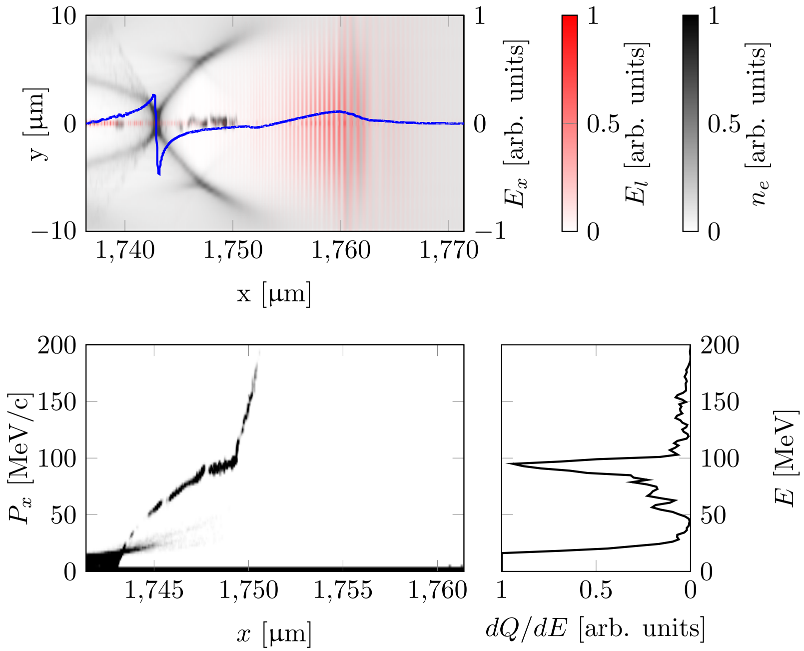


- Increased injection from $N^{5+,6+}$ in downramp



Simulations with CALDER-Circ

Background plasma



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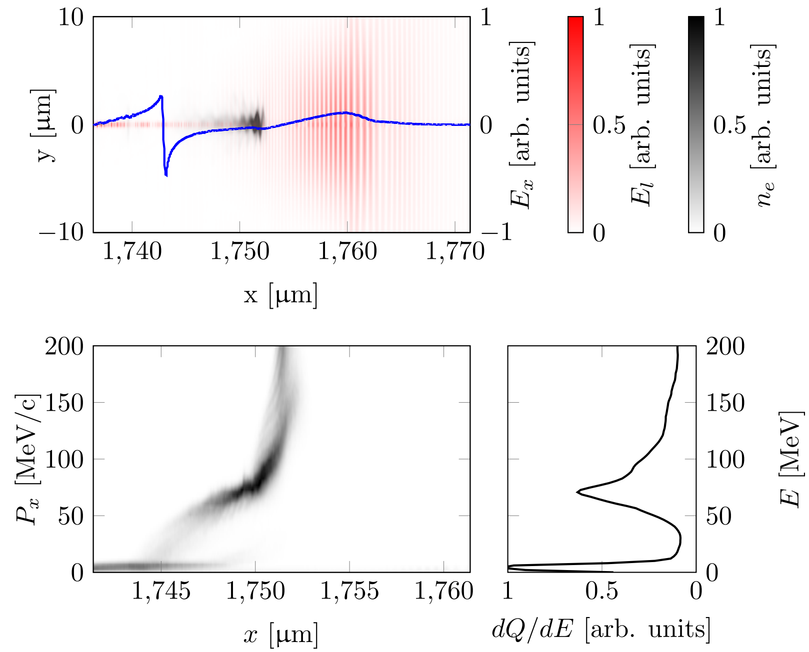
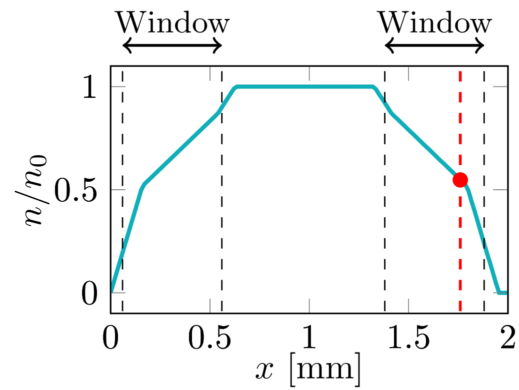
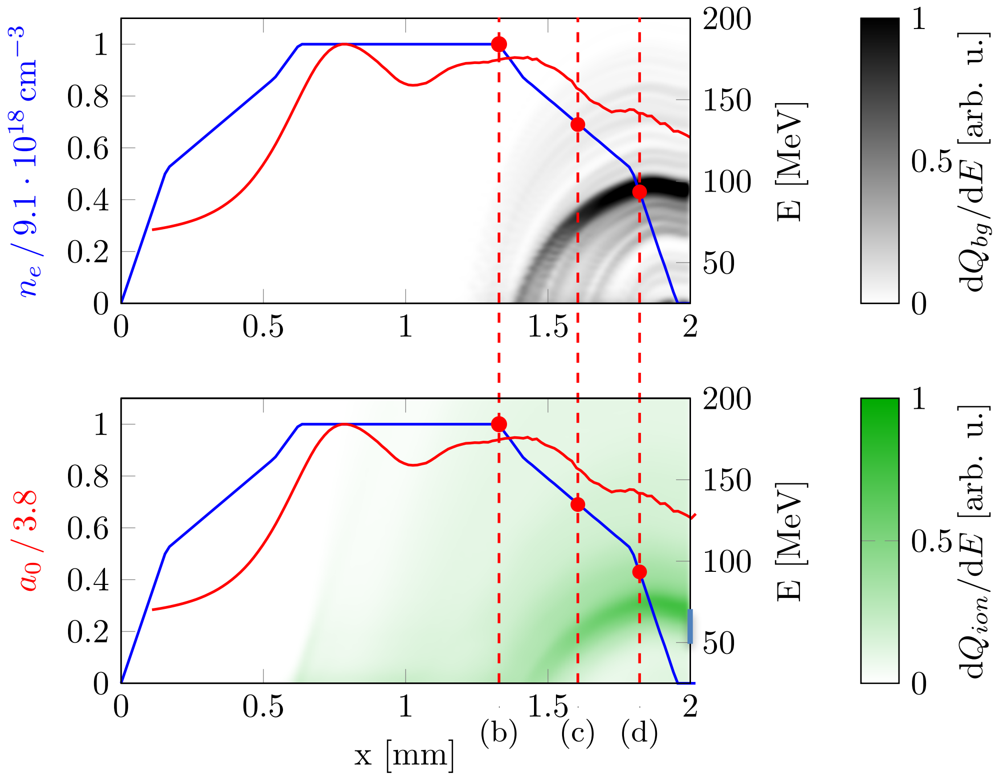


- Increased injection from $N^{5+,6+}$ in downramp
- Longitudinal extent allows phase-space rotation
- Two separate peaks in electron energy spectrum



Simulations with CALDER-Circ



Background plasma
E_{peak} = 90 MeV

e- ionised from N$^{5,6+}$
E_{peak} = 75 MeV

- Increased injection from N5,6+ in the density ramp
- Longitudinal extent allows phase-space rotation
- Two separate peaks in electron energy spectrum

Summary

- Interferometric characterisation of a variable length gas cell
- Combined ionisation- and density down-ramp injection
- Peaked spectra by localisation and phase-rotation
- Reproducible beam structures

Talk in WG1 Wednesday (tomorrow) by Martin Hansson

Controlled injection using
Two gas jets: Density down-ramp injection
Two laser beams: Colliding pulse injection

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Thank you for the attention!

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