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Open-Minded

An Experimental Setup for Ultra-Short Ion Pulses - Generation of 400 ps Ion Pulses

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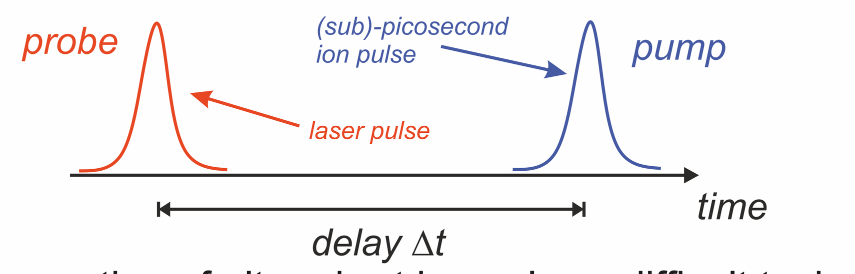
Motivation

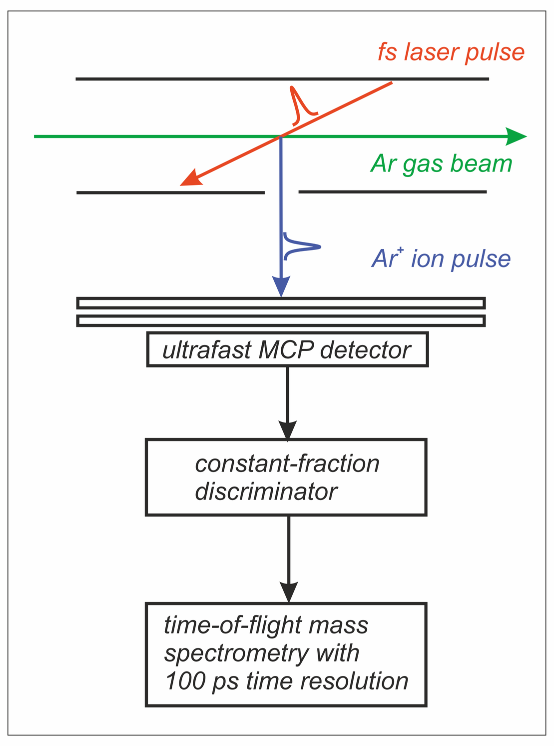
- generation of highly localized non-equilibrium states via ion impact onto a surface
- observation of dynamics on a (sub-) picosecond timescale via pump-probe technique



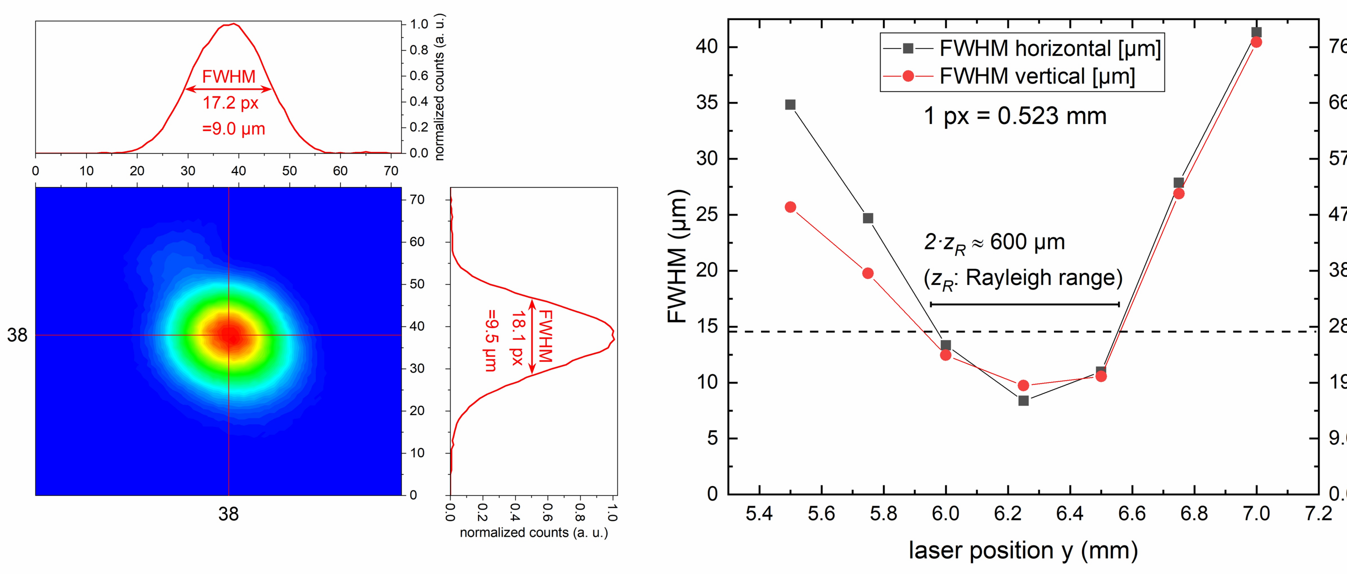
- generation of ultra-short ion pulses: difficult task due to space-charge broadening and velocity distribution of ions at a given temperature

⇨ supersonic gas expansion - control over number density and temperature distribution

- characterization of such a supersonic gas expansion of Argon via Excimer laser



Characterization of fs laser system via CCD camera



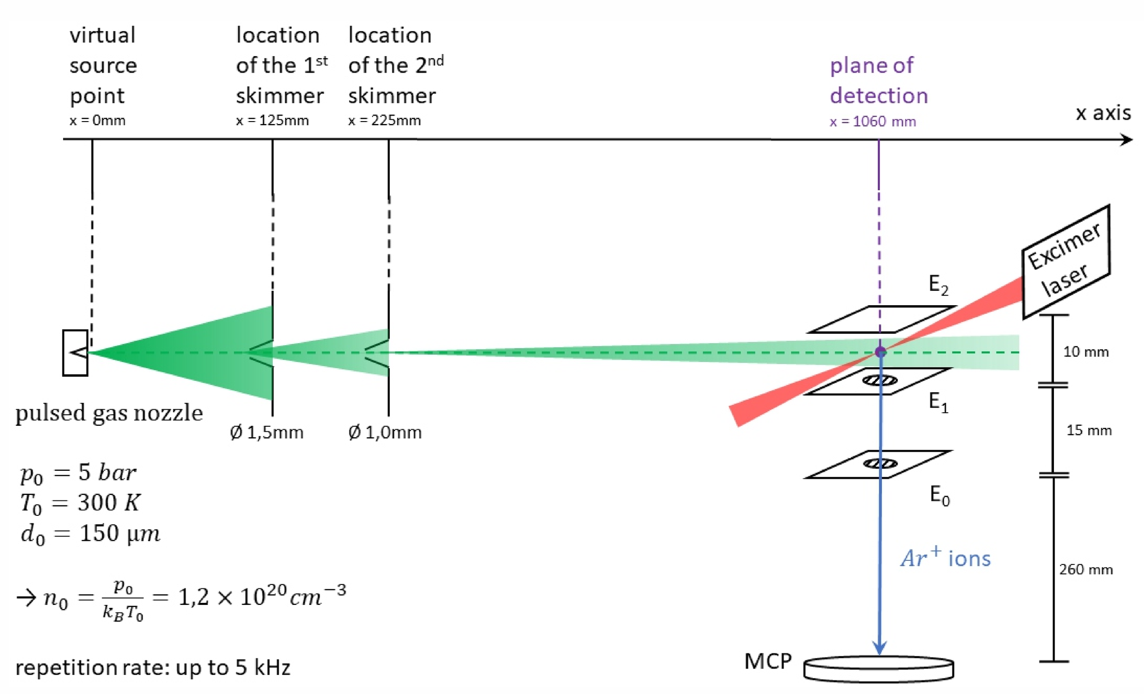
beam properties:

800 nm
50 fs
1.5 mJ
1 kHz

- nearly symmetrical laser spot profile with diameter < 10 µm and Rayleigh range of $z_R \approx 300$ µm
- measured spot profile leads to a peak intensity $I_0 \approx 4.0\times10^{16}$ W/cm^2

⇨ intensity allows in principle to create Ar^{q+} with charge state q = 1,..., 6

Experimental setup



beam properties:

157 nm
5 ns
3.0 mJ
up to 200 Hz

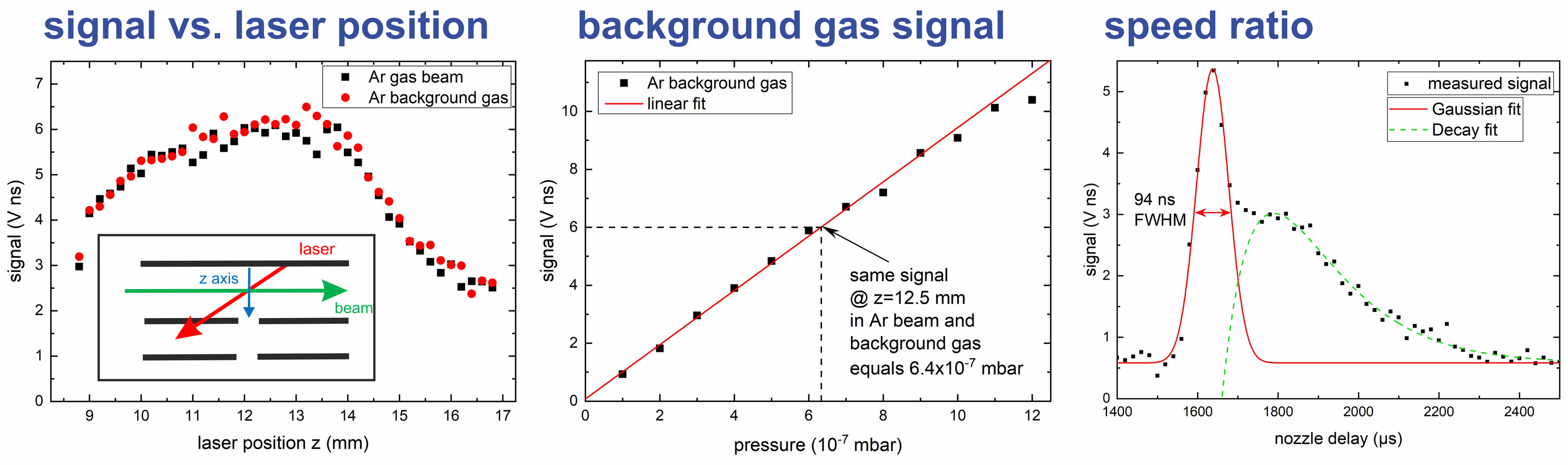
exit profile:
3 mm x 6 mm

lens focus:
384 mm

focal profile:
400 µm x 800 µm

Measurement of beam density

signal vs. laser position | background gas signal | speed ratio

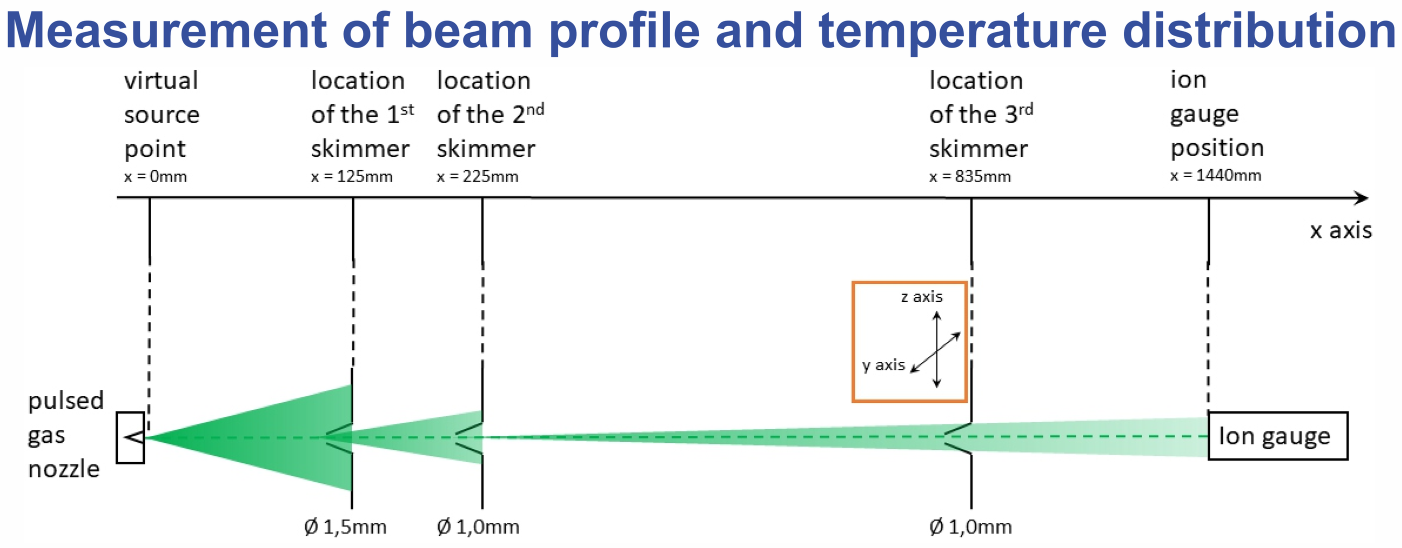


- measured ion pulses generated by **laser induced photoelectrons** in ionization volume!
- flight time yields a terminal parallel velocity of $v_{\parallel,\infty} = \frac{\Delta x}{\Delta t} = \frac{1060\ mm}{1640\ \mu s} = 646\ \frac{m}{s}$
- FWHM of 94 µs yields a (deconvoluted) standard deviation of $\sigma_t = 37$ µs

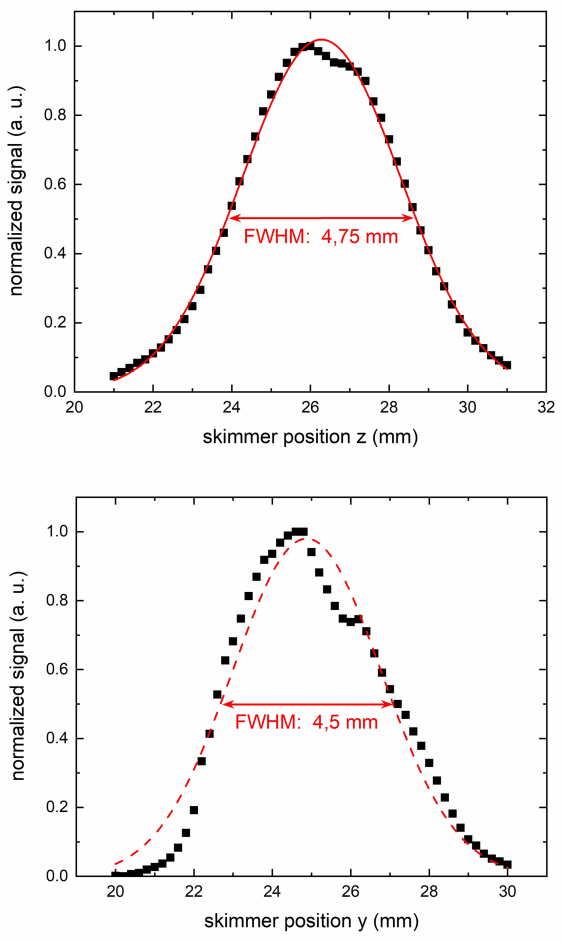
⇨ resulting speed ratio of $S = 44$ leads to parallel temperature of $T_{\parallel,\infty}$ **= 512 mK**

⇨ combines to a spatial standard deviation of $\sigma_x = 24$ cm along flight direction

Measurement of beam profile and temperature distribution



Beam profile and temperature distribution



- allows to quantify the center beam density with condition

$$N_{Bulk} = N_{Beam} = \iiint \rho_0 f_x(x) f_y(y) f_z(z)\ dV,$$

$$f_x(x) \cong 1,\ f_y(y) = e^{-\frac{y^2}{2\sigma_y^2}},\ f_z(z) = e^{-\frac{z^2}{2\sigma_z^2}}$$

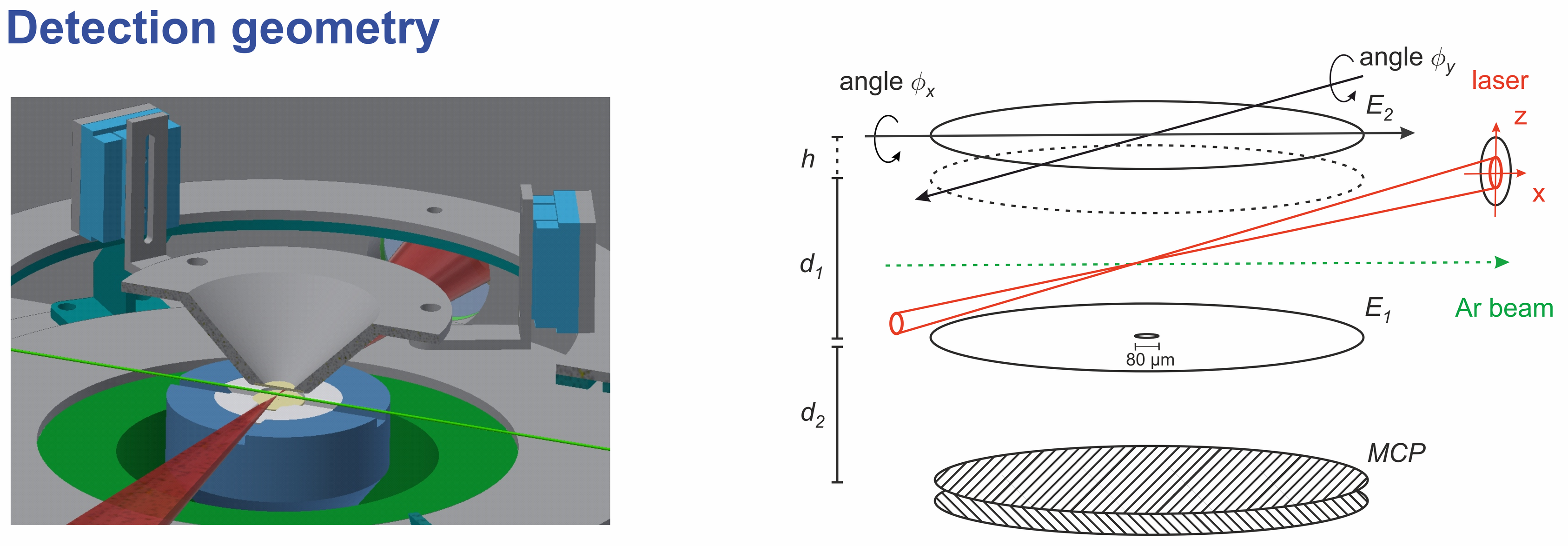
- yields a center line density of $\rho_0 = (6.0 \pm 0.12)\times10^{10}$cm^{-3}
- difference to theoretical prediction of an order of magnitude due to the presence of skimmers blocking the central intensity of the beam
- estimation of the velocity distribution perpendicular to the beam according to

$$e^{-\frac{m v_\perp^2}{2 k_B T_\perp}} = e^{-\frac{z^2}{2\sigma_z^2}} \quad \text{with the geometric relation} \quad \frac{v_\perp}{v_{\parallel,\infty}} = \frac{z}{\Delta x}$$

- for laser with an estimated Rayleigh range of ≈ 400 µm and distance Δx = 380 mm between skimmer 3 and plane of detection: $v_\perp \leq 1$ m/s → $T_\perp$ **≤ 2.3 mK**
- upper limit of 10 mK in simulations already leads to a time resolution of sub-picoseconds → <u>unproblematic</u>

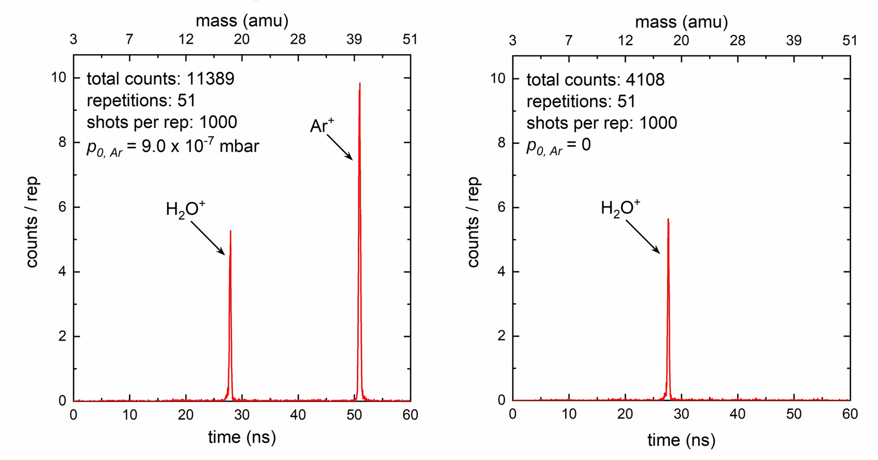
Characterization of geometry: Argon background gas

Detection geometry



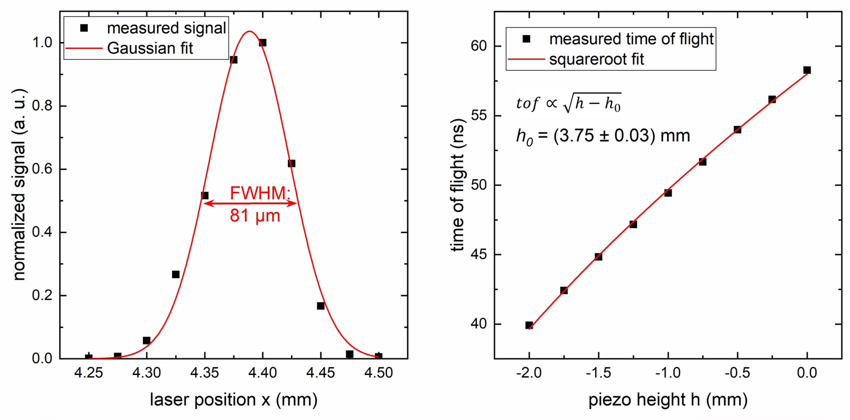
- 3 piezo motors allow to move the upper electrode twofold: absolute height h and angular tilt $\phi_{x,y}$
- vacuum chamber filled with Argon background gas at $p_0 = 9.0\times10^{-7}$ mbar

Time-of-Flight mass spectra



- detection of ionized Argon via Time-of-Flight mass spectrometry (ToF)
- allows to quantify absolute flight time, pulse height and pulse width for each mass species

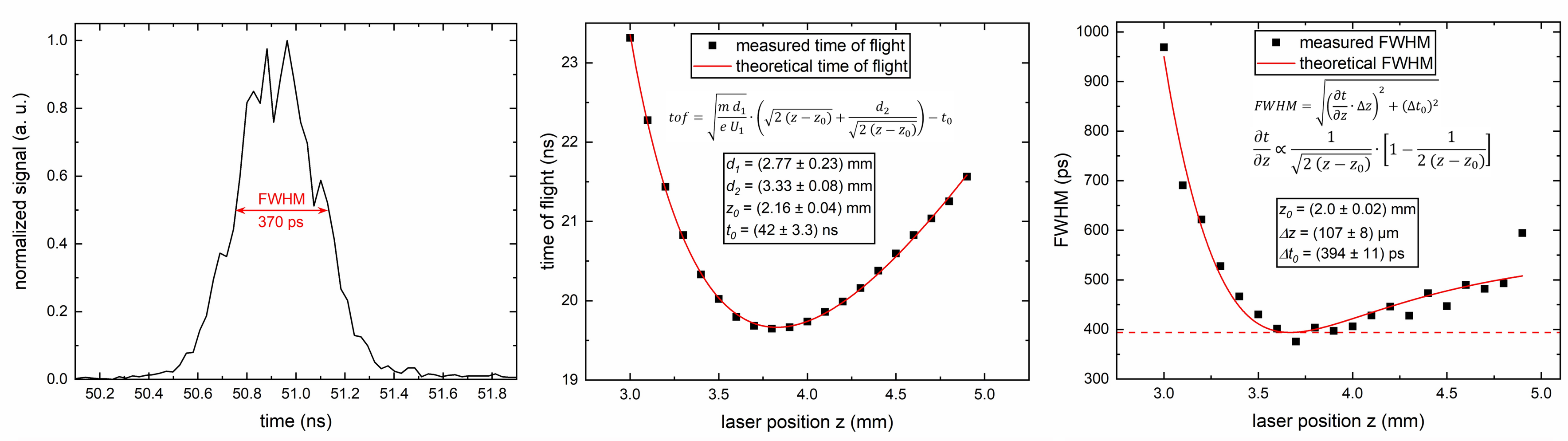
geometric boundaries



- x-scan of laser allows to image the transmitting hole in electrode E_1
- time of flight as function of height h of electrode E_2 yields starting height h_0 = 3.75 mm

Time-of-Flight focus and sub-400 ps ion pulses

pulse shape | ToF vs. laser position | FWHM vs. laser position



- the shortest pulse duration yields a FWHM of **370 ps** for the Ar^+ pulse of the bulk gas
- time of flight as a function of laser position matches the theoretically expected behaviour

⇨ allows to extract distances d_1, d_2 and z_0 in geometric arrangement

- FWHM of Argon ion pulse is minimized at the Time-of-Flight minimum → $\Delta t_{min} \approx 0.25$ ps

⇨ offset Δt_0 must originate from:

  - thermal starting velocity spread → ≈ 200 ps at T = 300 K
  - temporal measurement jitter / detector time resolution

- FWHM allows to estimate the starting width $\Delta z \approx 100$ µm → expanded laser focus

Current status

- distance d_1 can be reduced without altering detection characteristic
- adjusting the laser focus to diameter < 10 µm

⇨ reduces the behaviour of the FWHM by an order of magnitude

⇨ produces charge states for Ar^{q+} for $q > 1$ in mass spectra

- crossing the gas and laser beam for ion signal from gas beam

⇨ <u>reducing thermal broadening to shorten pulse width even further!</u>