Latest Developments at GSI Experiment at TU Munich's Tandem

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Experiment at TU Munich's Tandem performed in collaboration with:

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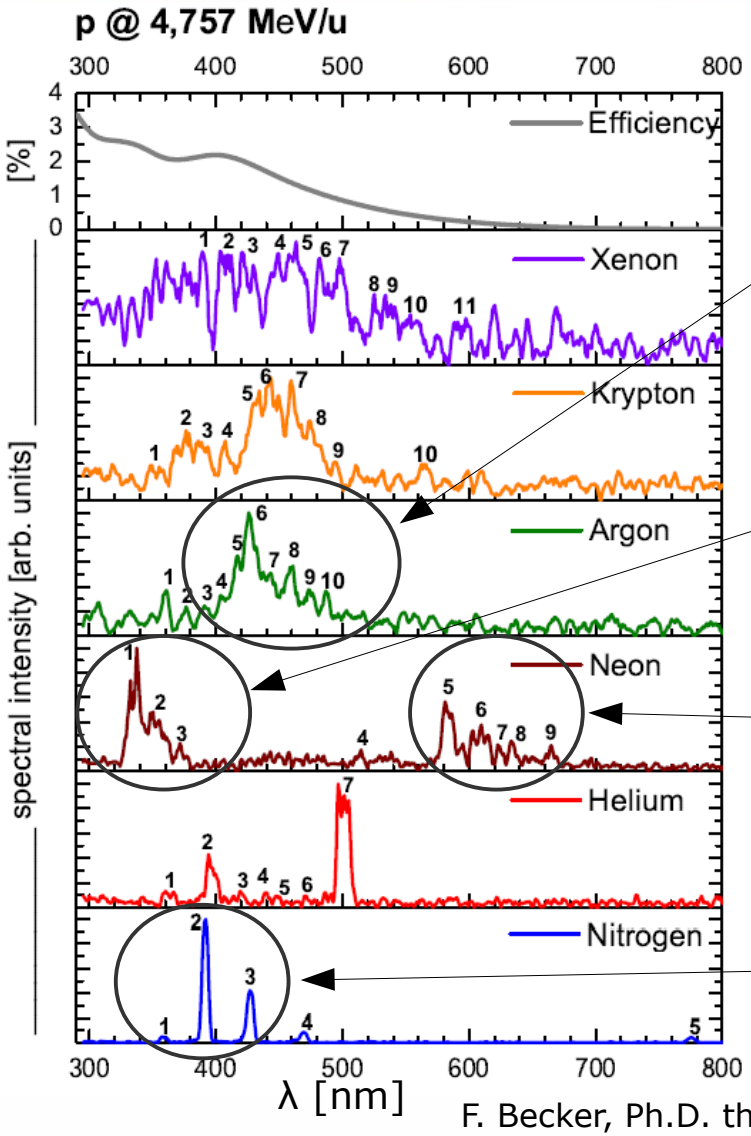
Outline

- Working gases
- Update on Argon cross sections and integration times
- Experimental setup at the TU Munich's Tandem
- Data processing for signal to noise ratio improvement
- Comparison between N_2 and Ne

Fluorescence of different gases



Strongest emission from Ar^+ blue/ green lines mainly corresponding to different $[3s^2 3p^4(^3P)]4p \rightarrow 4s$ transitions with life times of 10-20 ns.

Several Ne^+ UV lines mainly corresponding to different $[2s^2 2p^4(^3P)]3p \rightarrow 3s$ transitions with life times below 10 ns.

Several Ne yellow/red lines mainly corresponding to different $[2s^2 2p^5(^2P)]3p \rightarrow 3s$ transitions with life times of about 20 ns.

The strong UV/blue lines correspond to the $B^2\Sigma_u^+ \rightarrow X^2\Sigma_g^+$ electronic transition band of N_2^+, life times are of about 60 ns.

F. Becker, Ph.D. thesis, T.U. Darmstadt, Germany, 2009

Ar as working gas: excitation and emission

$Ar + p/e^- \rightarrow (Ar^+)^* + e^- + p/e^- \rightarrow Ar^+ + \gamma + e^- + p/e^-$

Leads to several $[3s^2 3p^4(^3P)]4p \rightarrow 4s$ transitions of the Ar^+ ion with wavelengths between 400 and 500 nm. The transitions in the table below have lifetimes of 10-20 ns. **Remark: presently cross section data available just up to 1keV for e^- impact! Upper levels are also populated by cascades but their contribution is small, approx. 5%.**

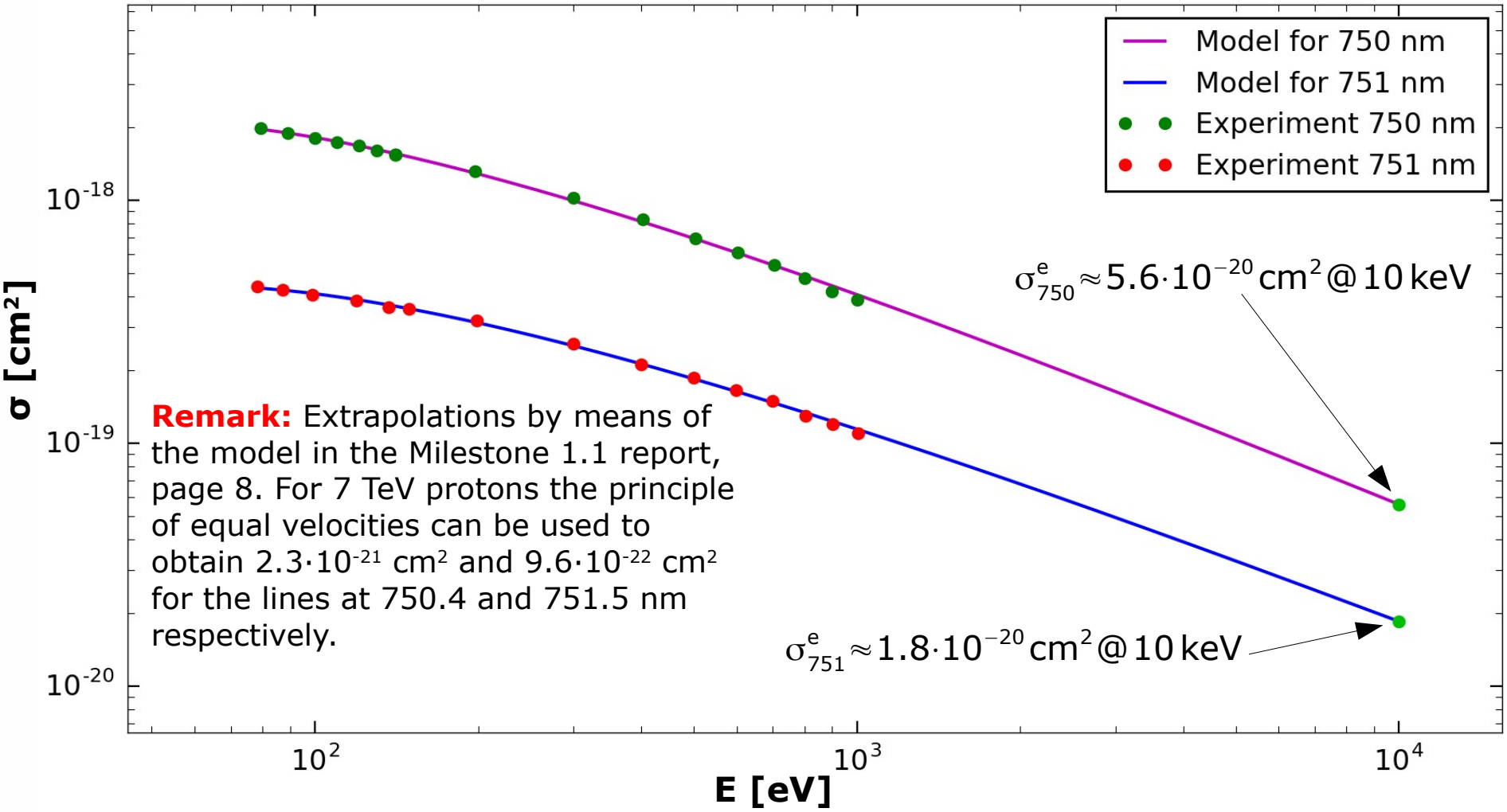
$[3s^2 3p^4(^3P)]4p$	$[2s^2 2p^4(^3P)]4s$	λ [nm]	
$^2P^o_{3/2}$	$^2P_{3/2}$	454.5	**significant branch**
$^2P^o_{3/2}$	**$^2P_{1/2}$**	**476.5**	**strongest line**

$Ar + p/e^- \rightarrow (Ar)^* + p/e^- \rightarrow Ar + \gamma + p/e^-$

Drives several $[3s^2 3p^5(^2P)]4p \rightarrow 4s$ transitions of Ar with the strongest at wavelengths above 700 nm. The upper levels from the table have lifetimes of 20-40 ns. **Remark: presently cross section data available just up to 1keV for e^- impact! No significant branching, cascades are not expected to lead to relevant distorsions.**

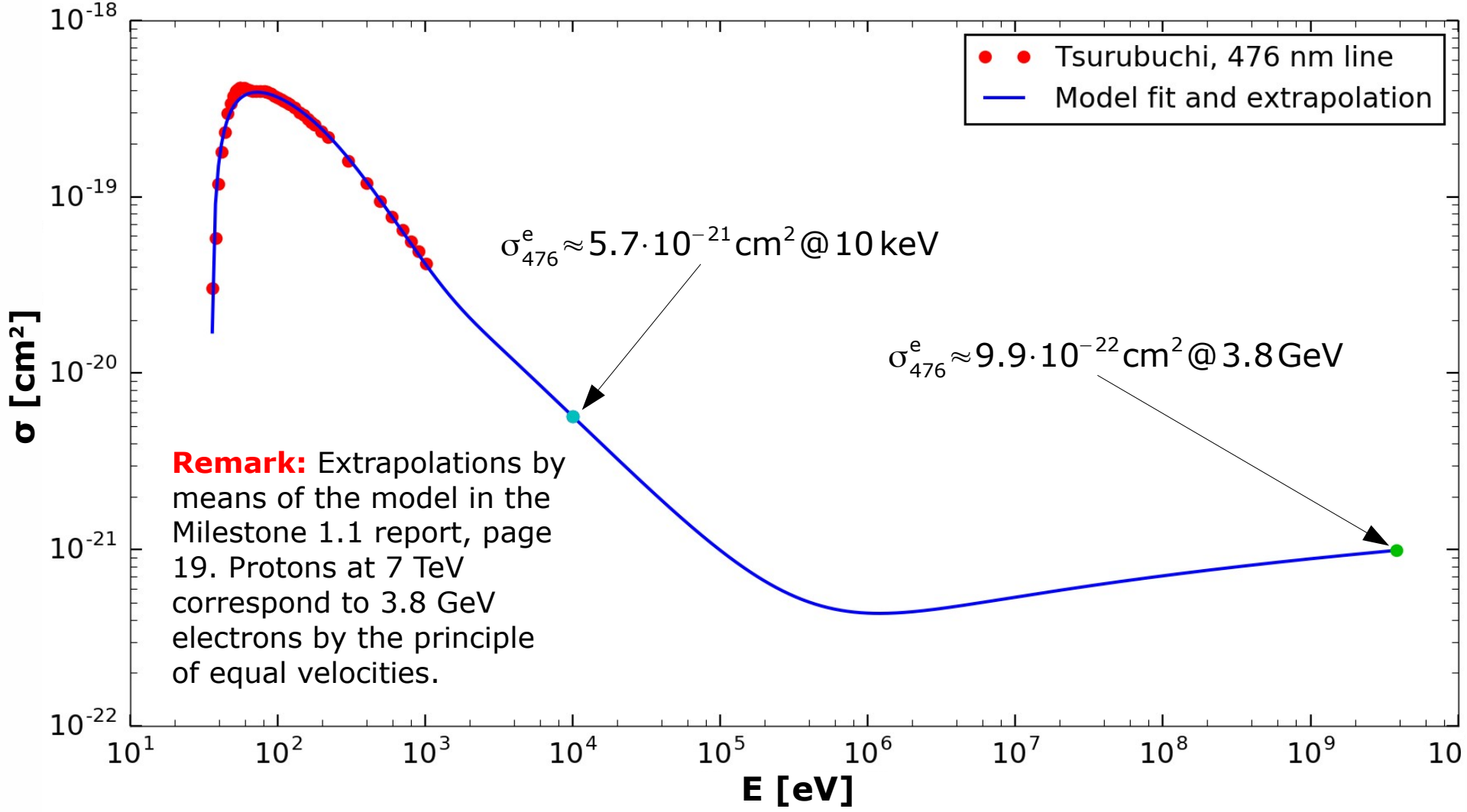
$[3s^2 3p^5(^2P)]4p$	$[3s^2 3p^5(^2P)]4s$	λ [nm]	
$2p_1$	**$1s_2$**	**750.4**	**strongest line**
$2p_5$	$1s_4$	751.5	

Cross sections for neutral Ar



Data from: J.B. Boffard, B. Chiaro, T. Weber, C.C. Lin, Atomic Data and Nuclear Data Tables, **93**, p. 831, 2007
S. Tsurubuchi, T. Miyazaki, K. Motohashi, J. Phys. B: At. Mol. Opt. Phys., **29**, p. 1785, 1996.

Cross sections for Ar^+



Data from: S. Tsurubuchi, J. Phys. Soc. Japan, **66**, p. 3070, 1997.

Photon rate estimations

$$N_\gamma = \sigma \cdot \frac{I \cdot \Delta t}{e} \cdot n \cdot d \cdot \frac{\Omega}{4\pi} \cdot T \cdot T_f \cdot \eta_{pc} \cdot \eta_{MCP}$$

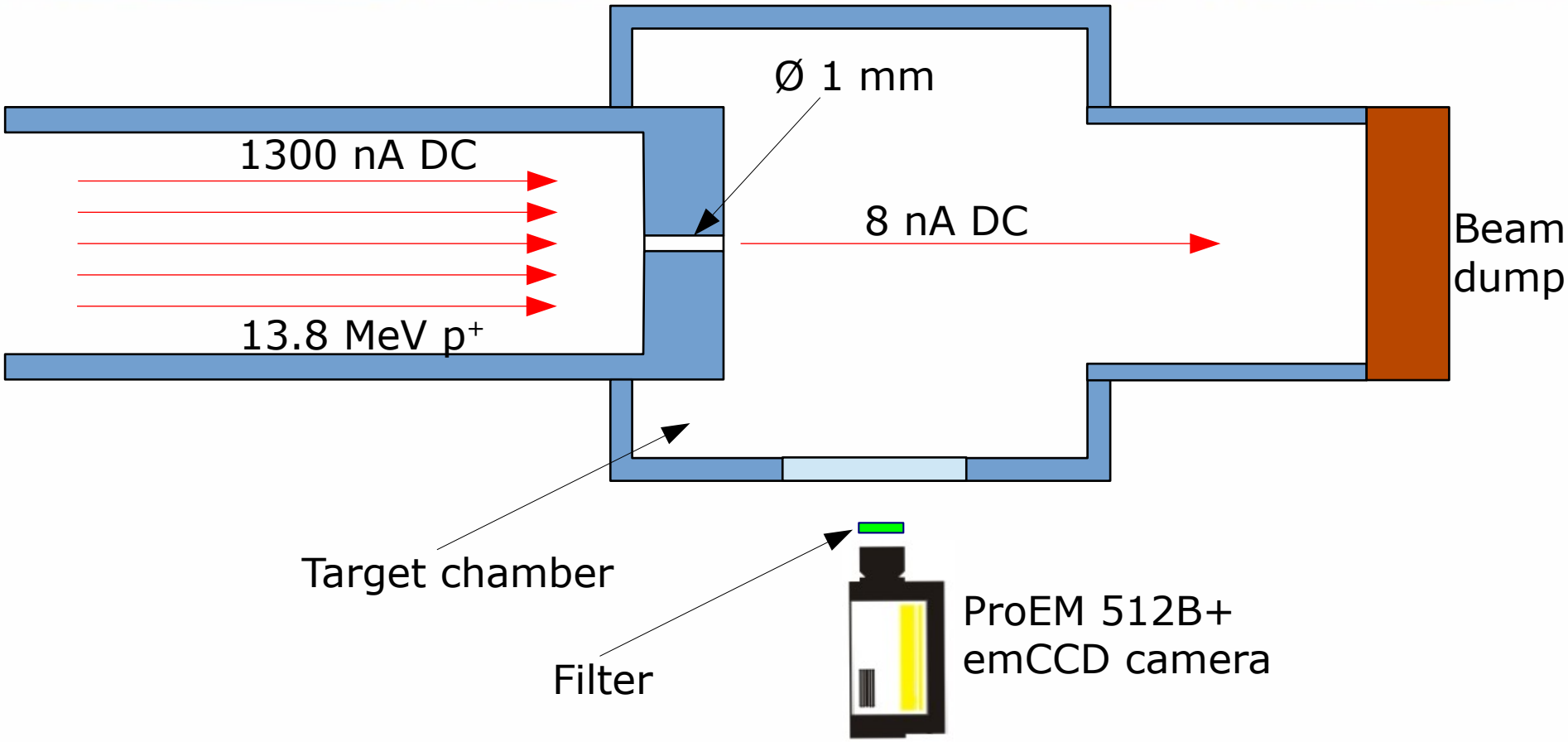
n = **2.5 · 10¹⁰ cm⁻³** (Still not there!)
d = 5 · 10⁻² cm
Ω = **40π · 10⁻⁴ sr** (Scheimpflug!?)
T = 85%
T_f = 80%
η_{MCP} = 75%

N_γ = average number of photons detected during time Δt
σ = cross section of the photon generation process
I = electron or proton current (electrical)
e = elementary charge
n = gas density
d = distance traveled through gas (curtain thickness)
Ω = solid angle of the optics
T = transmittance of the optical system
T_f = transmittance of the optical filter
η_{pc} = quatum efficiency of the photocathode
η_{MCP} = detection efficiency of the MCP

Projectile	Emitter	λ [nm]	σ [cm²]	I [A]	η_{pc}	N_γ [s⁻¹]	$1/N_\gamma$ [s]
electron	Ar	750.4 & 751.5	$7.4 \cdot 10^{-20}$	5	0.02	$2.9 \cdot 10^{4}$	$3.4 \cdot 10^{-5}$
proton	Ar	750.4 & 751.5	$3.3 \cdot 10^{-21}$	1	0.02	$2.6 \cdot 10^{2}$	$3.8 \cdot 10^{-3}$
electron	Ar^+	454.5 & 476.5	$9.9 \cdot 10^{-21}$	5	0.2	$4.0 \cdot 10^{4}$	$2.5 \cdot 10^{-5}$
proton	Ar^+	454.5 & 476.5	$1.7 \cdot 10^{-21}$	1	0.2	$1.4 \cdot 10^{3}$	$7.4 \cdot 10^{-4}$

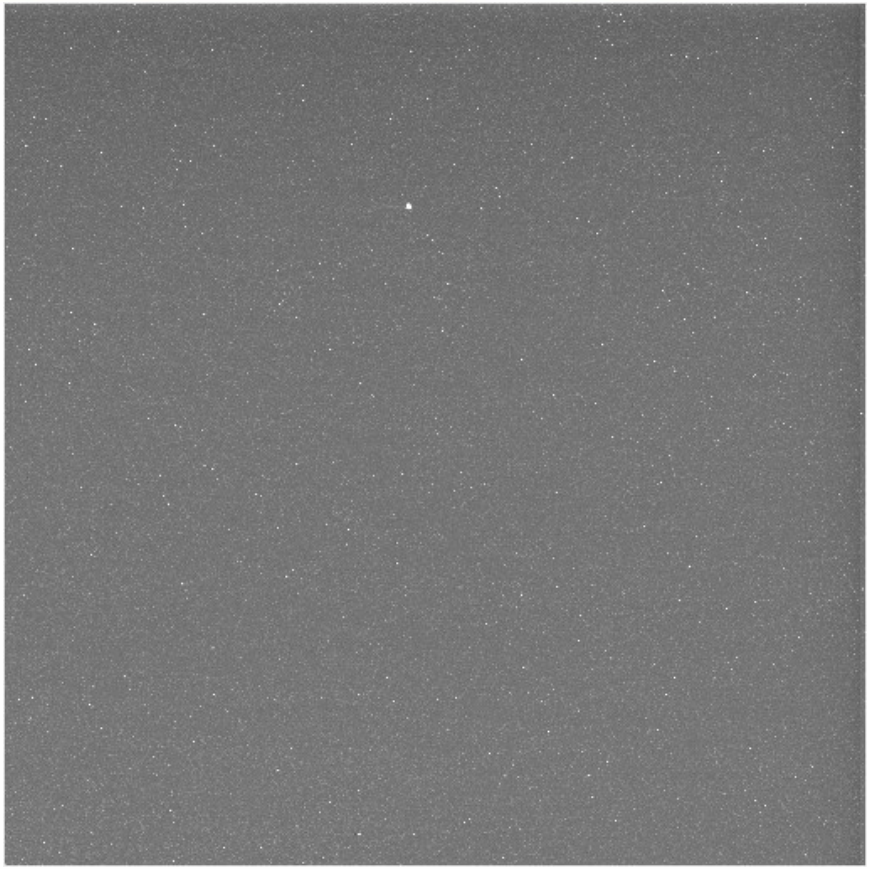
Remark: The Ar^+ cross section can be significantly increased by integrating over 400 < λ < 500 nm

Experimental setup at TU Munich's Tandem

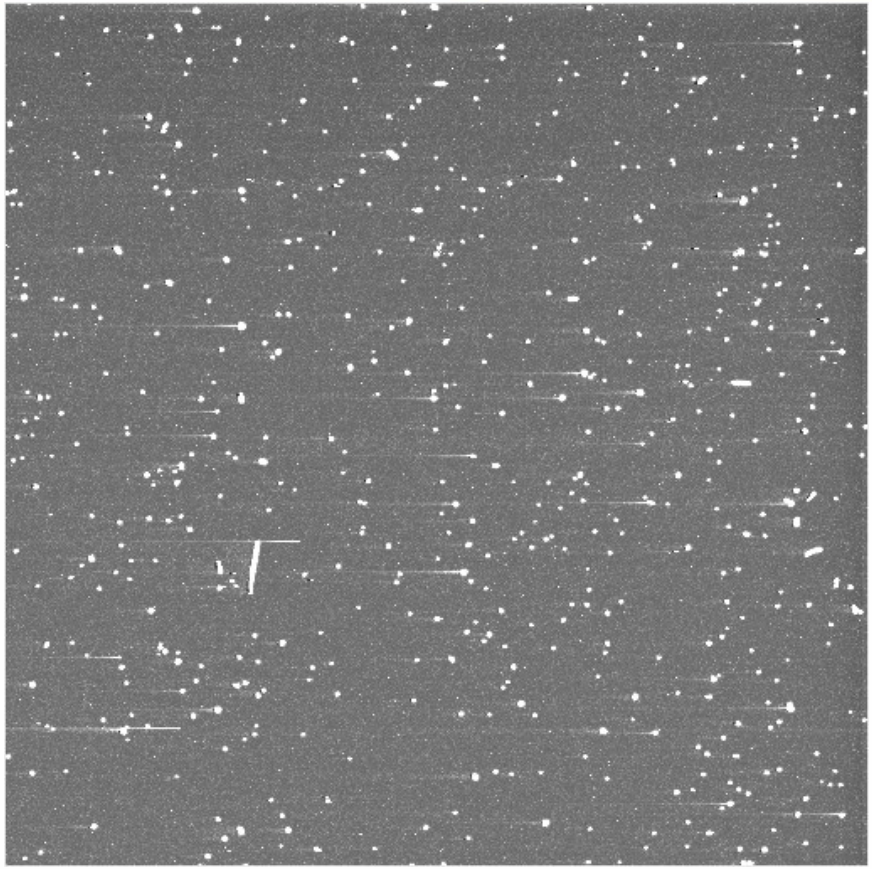


Measurements have been performed for N_2, Ne and Ar at pressures between $2 \cdot 10^{-4}$ and 0.3 mbar. Depending on gas different filters have been used. According to the principle of equal velocities 13.8 MeV p^+ should be equivalent to 7.5 keV e^-.

Raw data



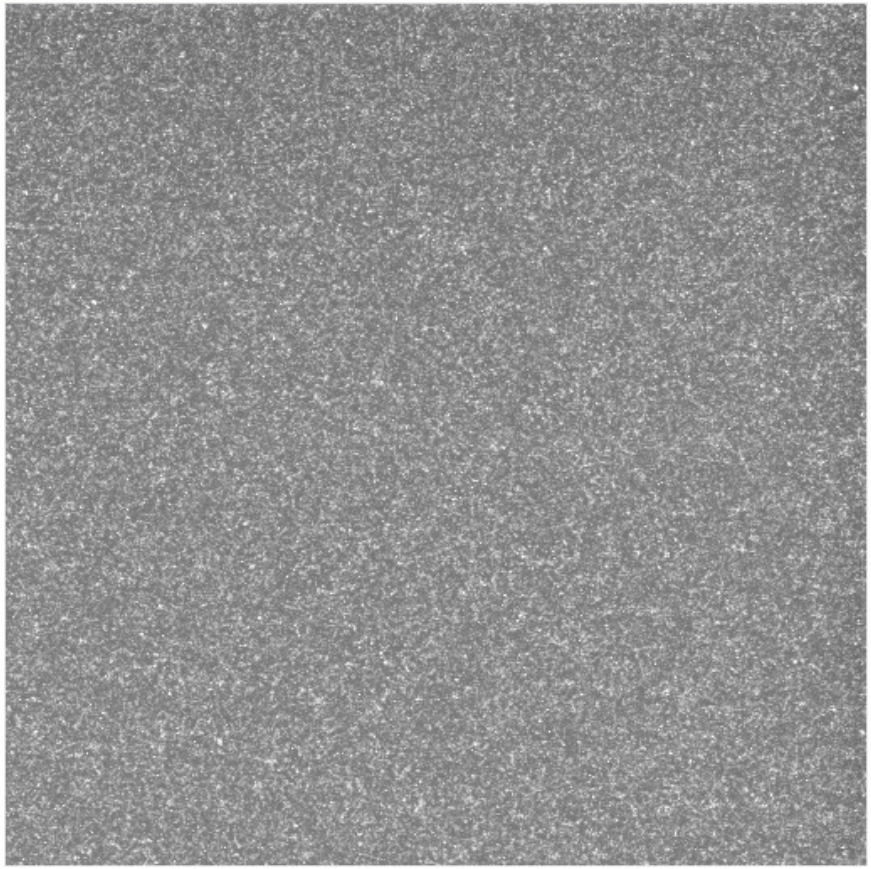
Typical background single shot image, 10 s exposure



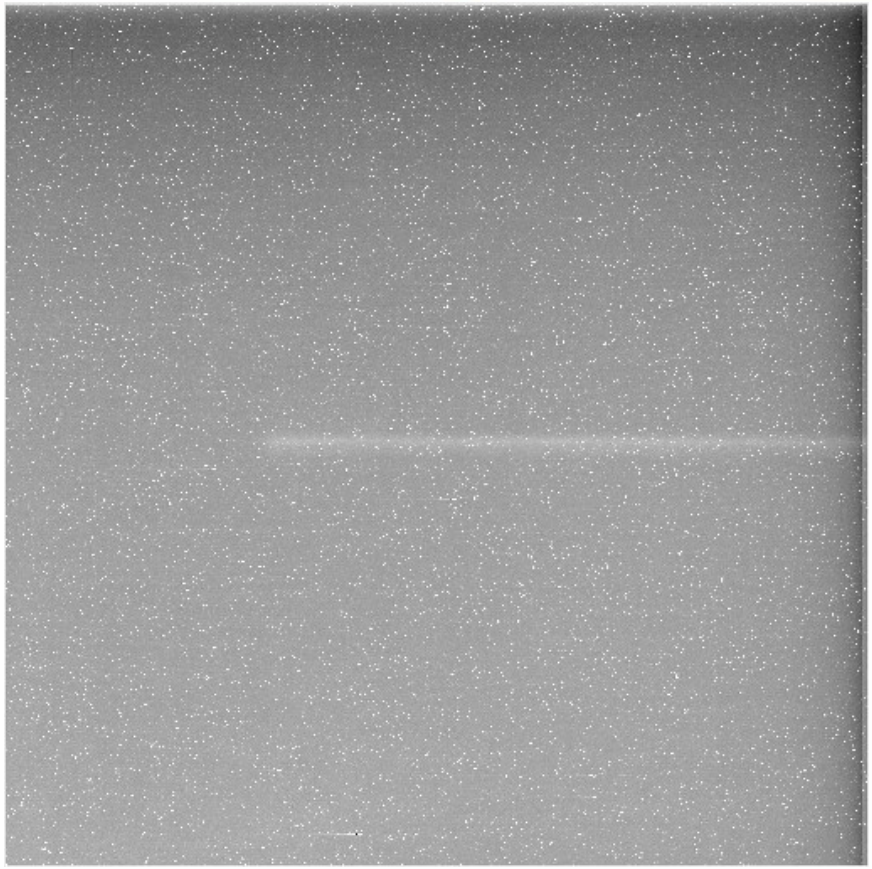
Typical single shot image with beam on, 10 s exposure

Note: Strongly exposed spots of several pixels due to secondary particles; stripes starting at such spots most likely due to smearing.

Improving signal to noise



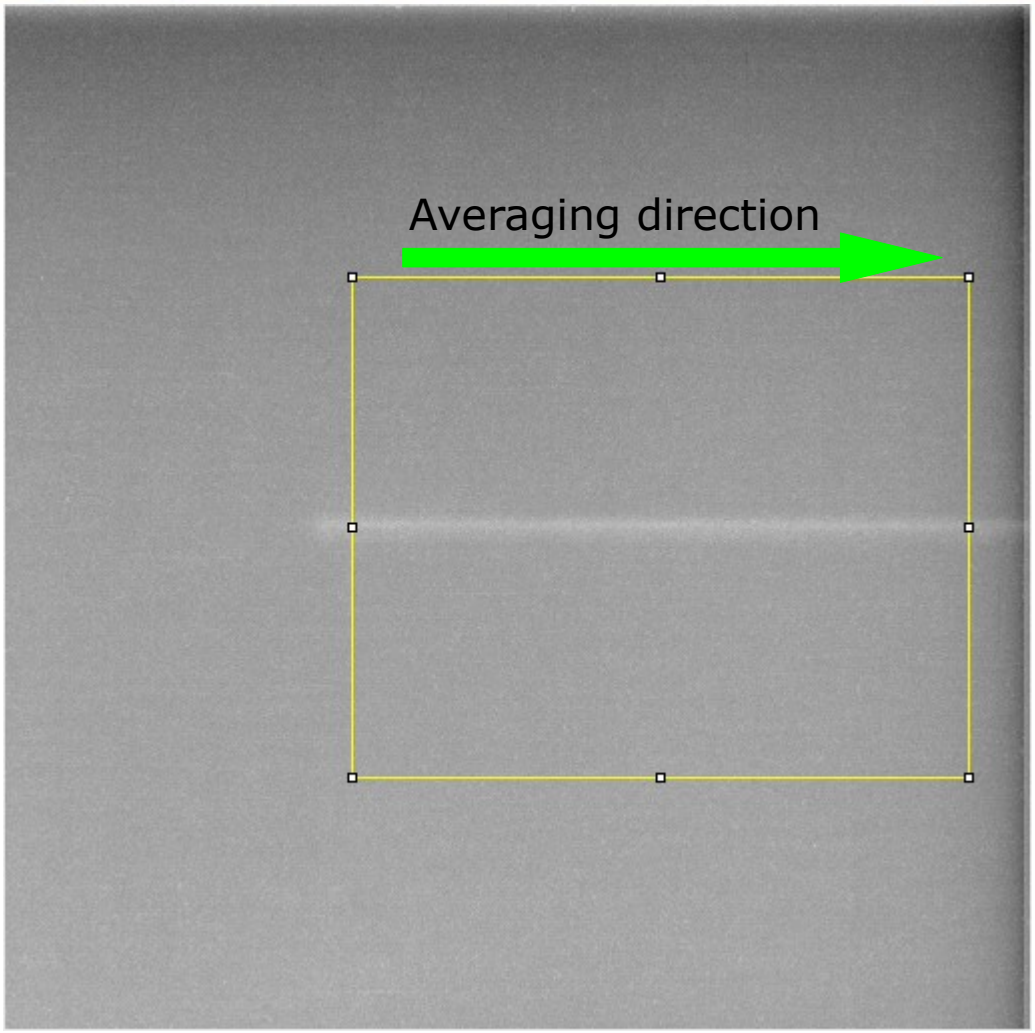
Averaging over a few 100 images doesn't help



Computing the median of the same images works

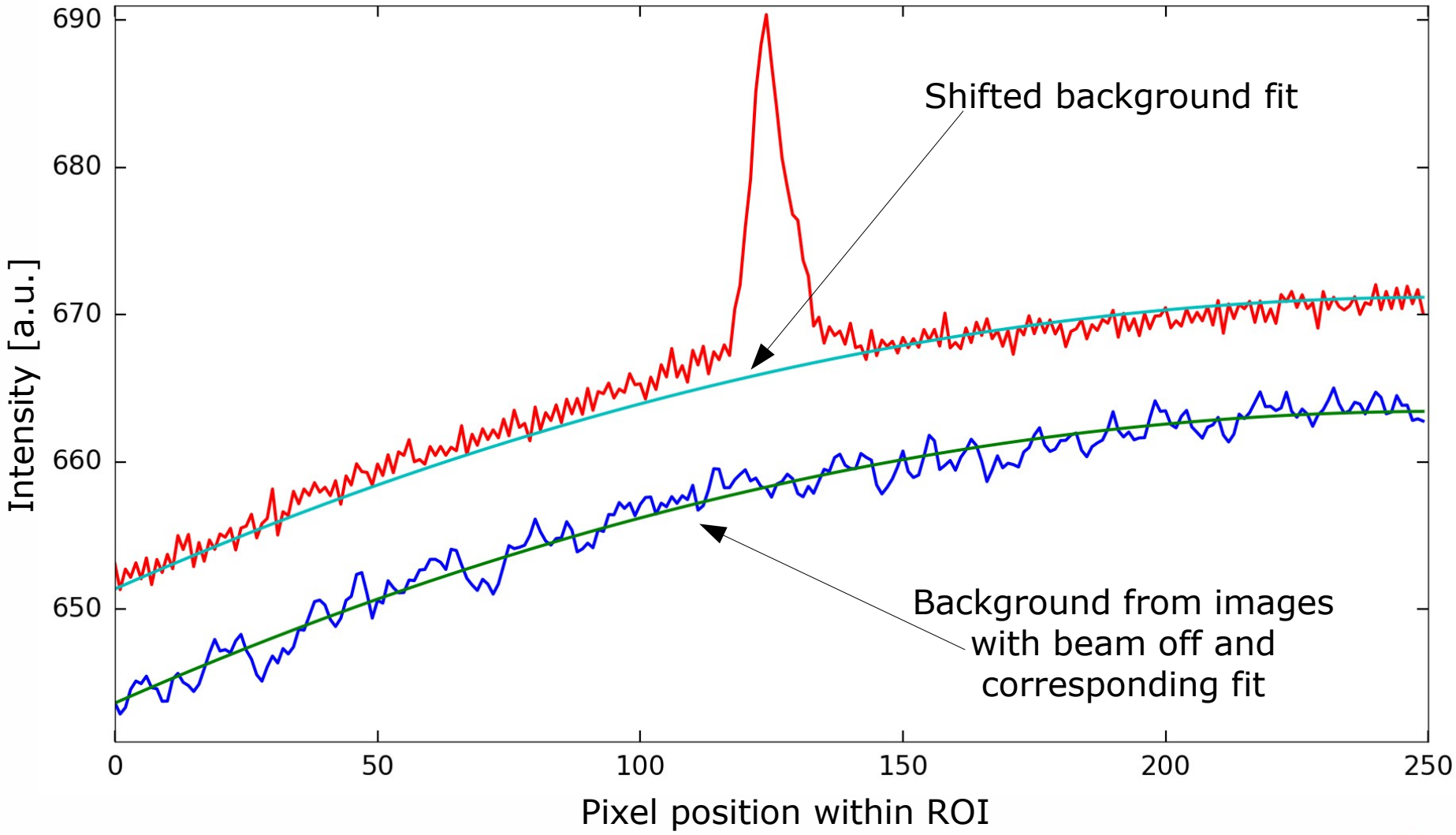
Note: The hot spots in the median image can be removed by a thresholded median filter applied to it (called "Remove Outliers" in ImageJ).

Profile from image

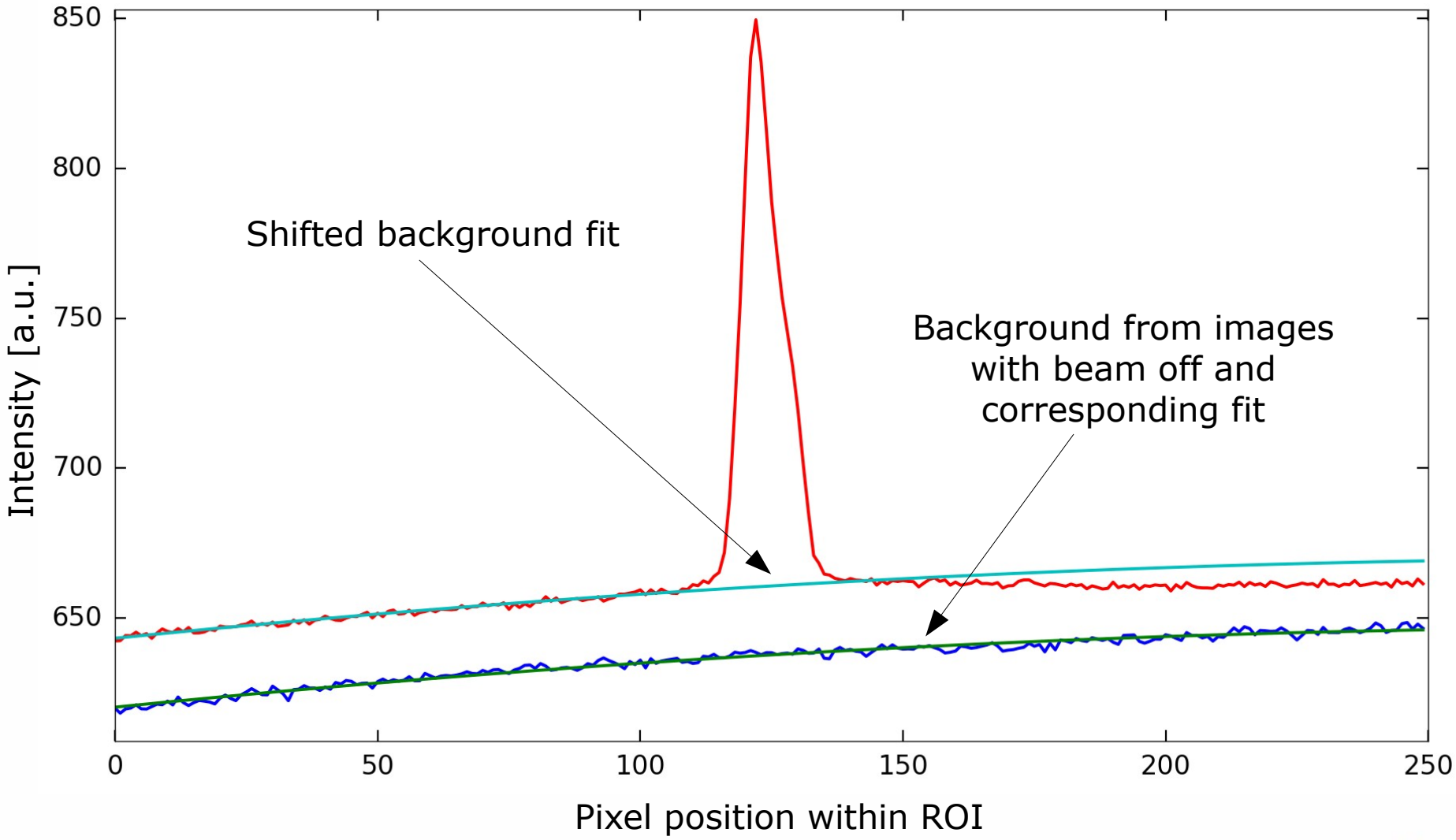


The average pixel value is computed for each row within the selected area.
This is done separately for images obtained with beam on and off.

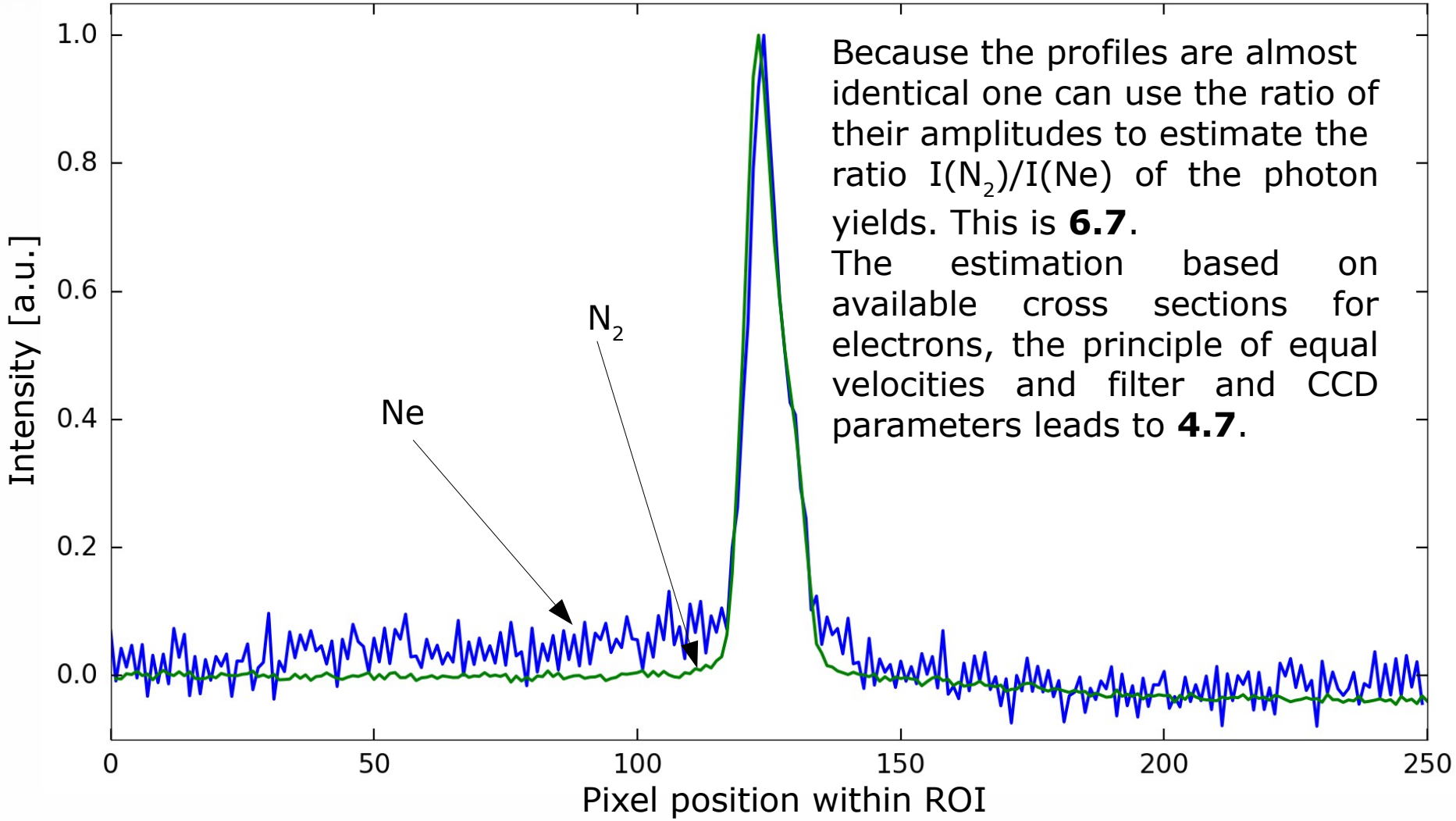
Ne profile @0.03 mbar and filter @585 nm



N_2 profile @0.03 mbar and filter @391 nm



Profile comparison



Because the profiles are almost identical one can use the ratio of their amplitudes to estimate the ratio $I(N_2)/I(Ne)$ of the photon yields. This is **6.7**.

The estimation based on available cross sections for electrons, the principle of equal velocities and filter and CCD parameters leads to **4.7**.

Note: The Ne profile shows some week wings which may need further investigations.

Conclusion

- due to additional data found in literature the knowledge of fluorescence cross sections for Ar has improved
- new estimates of integration times for Ar were possible
- several measurements have been performed with 13.8 MeV protons and N_2, Ne and Ar as target gases at the Tandem accelerator of TU Munich
- the experimental intensity ratio for Ne and N_2 compares well with the one predicted by extrapolation from available data.