Neutral particle density and transport studies based on imaging X-ray spectroscopy

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T. Schlummer, O. Marchuk, G. Bertschinger, W. Biel, D. Reiter und das TEXTOR-Team

Institute of Energy and Climate Research - Plasma Physics, Forschungszentrum Jülich GmbH,
Association EURATOM-FZJ, Partner in the Trilateral Euregio Cluster, Jülich, Germany

Outline

- Imaging Bragg-spectrometer for W7–X at TEXTOR

- K_α – spectrum of He-like Argon
  - The spectral lines
  - Discussion/Contradictions in literature
  - Radial scan of the K_α – spectrum

- K_α – spectroscopy as diagnostic for the neutral gas density in the plasma and for the radial transport.

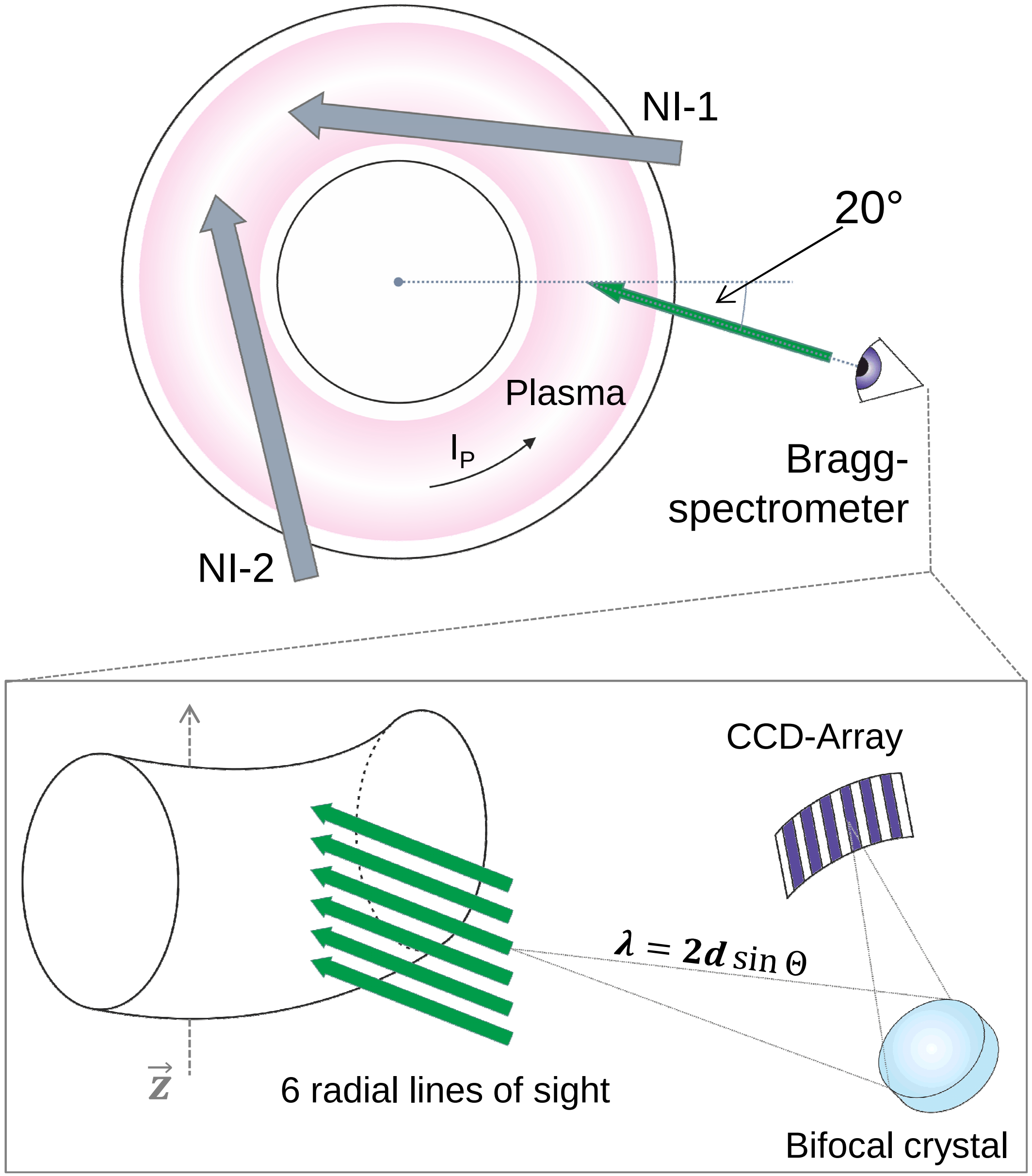
- Experimental results: $n_0(r)$, $D_\perp(r)$, $Ar_{tot}(r)$

- Conclusion

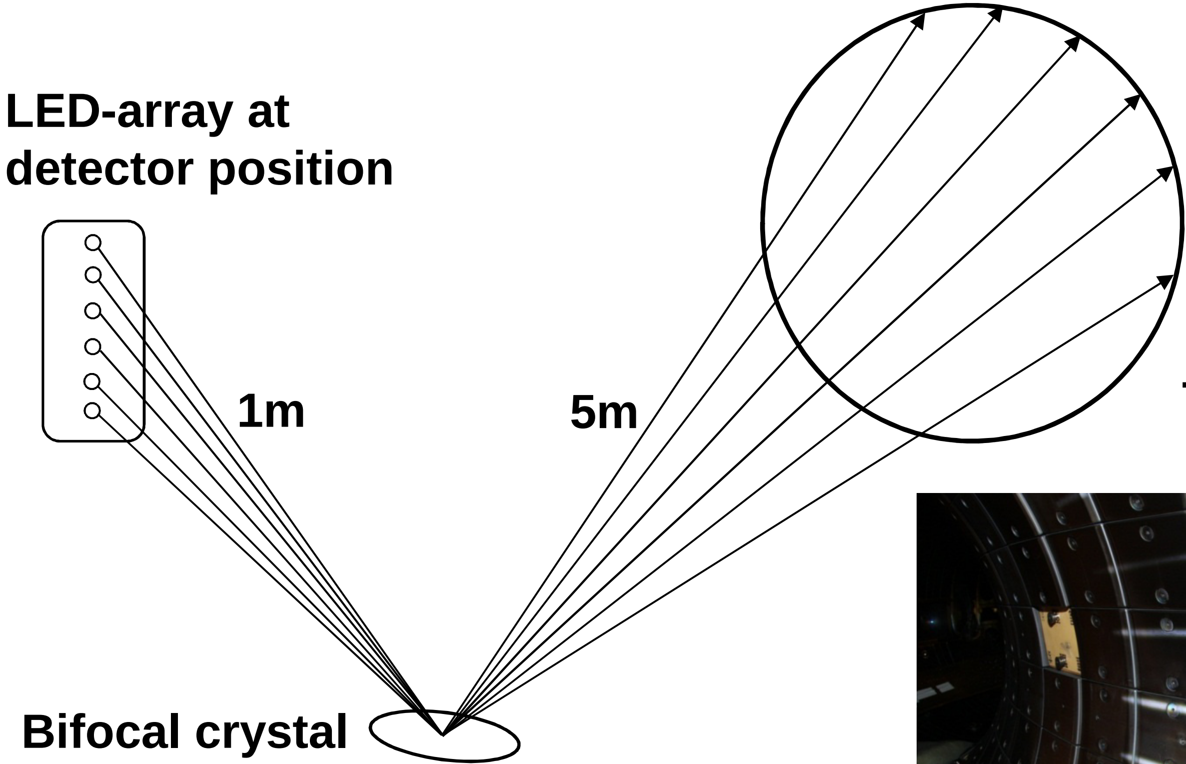
Multi channel Bragg-spectrometer for W7–X at TEXTOR

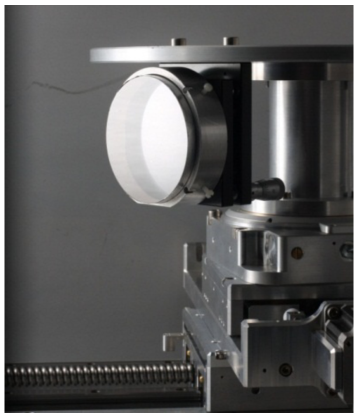
- Optimized for the K_α – spectrum (n=2 → n=1) of He-like Argon (ca. 4 Å)
- 6 Channels vertically distributed over the minor radius
- Radial profiles of
  - Ion temperature
  - Electron temperature
  - Toroidal plasma rotation
  - Argon ion ratios

    (H-like : He-like, Li-like : He-like)

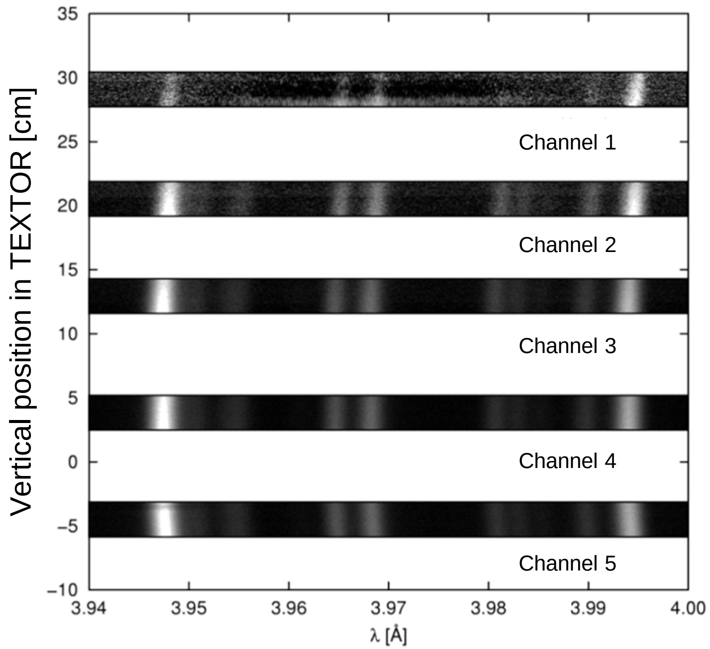


Vertical position of the lines of sight

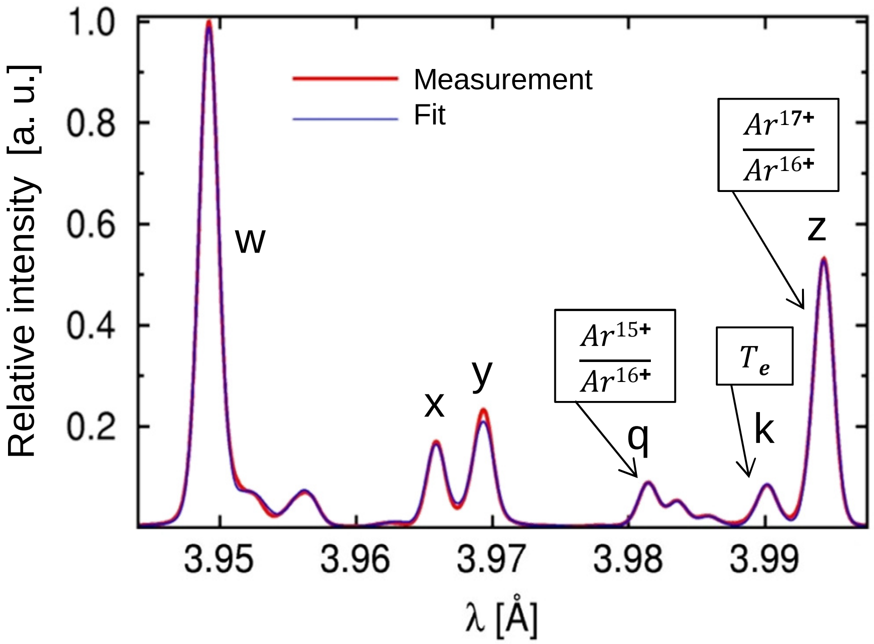


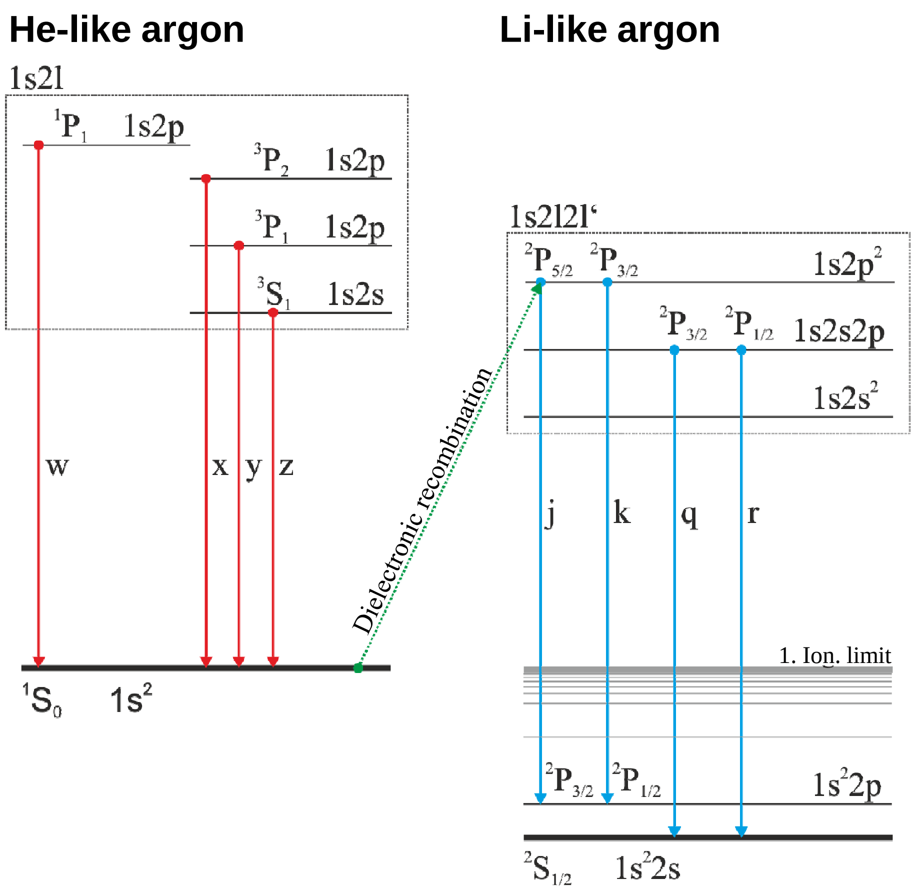


2-D spectral images



The 1s2l-1s² spectrum of He-like Argon

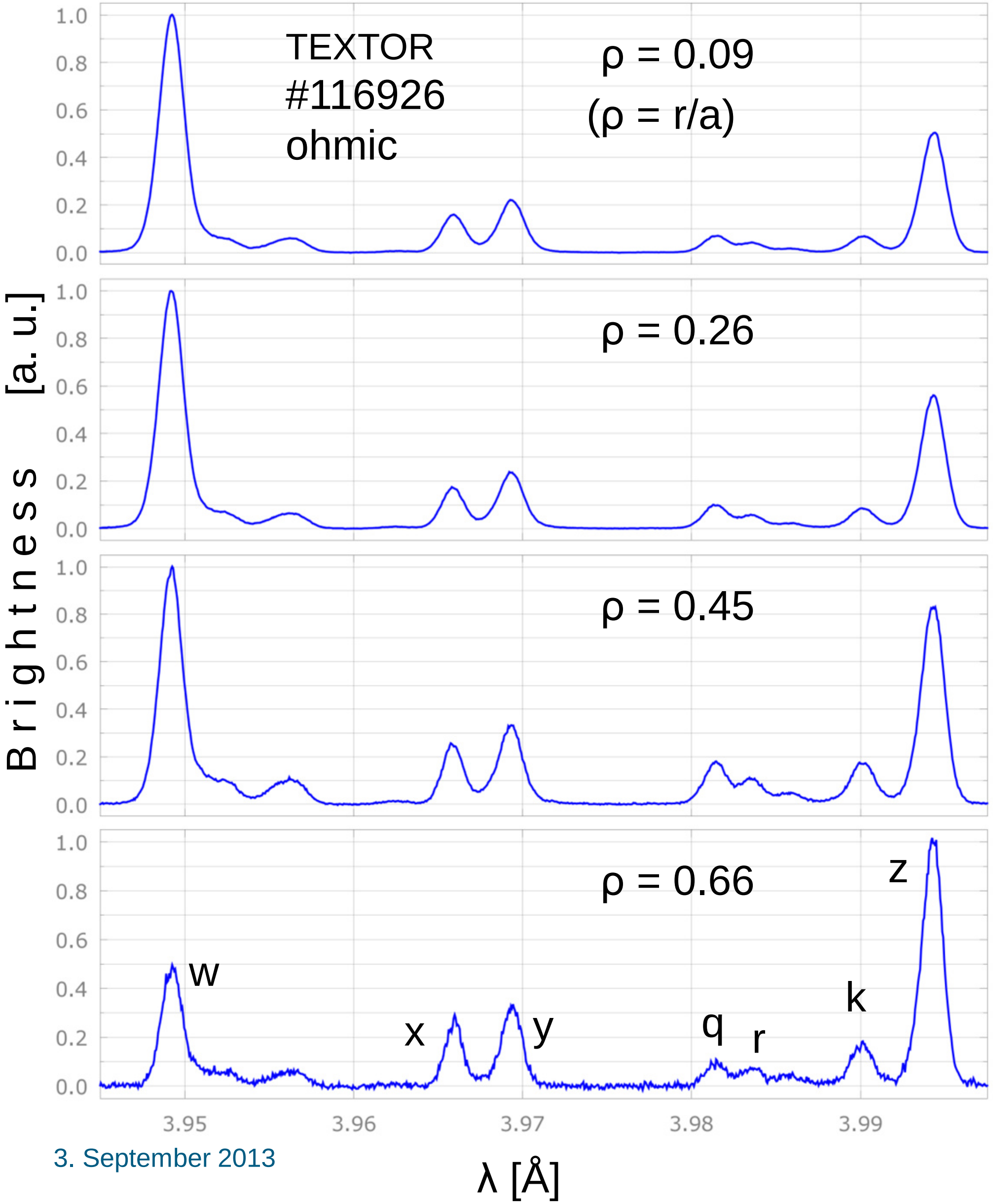




Atomic processes:

- Collisional excitation
- Radiative recombination
- Charge exchange
- Inner shell excitation
- Dielectronic recombination

Radially resolved argon spectrum

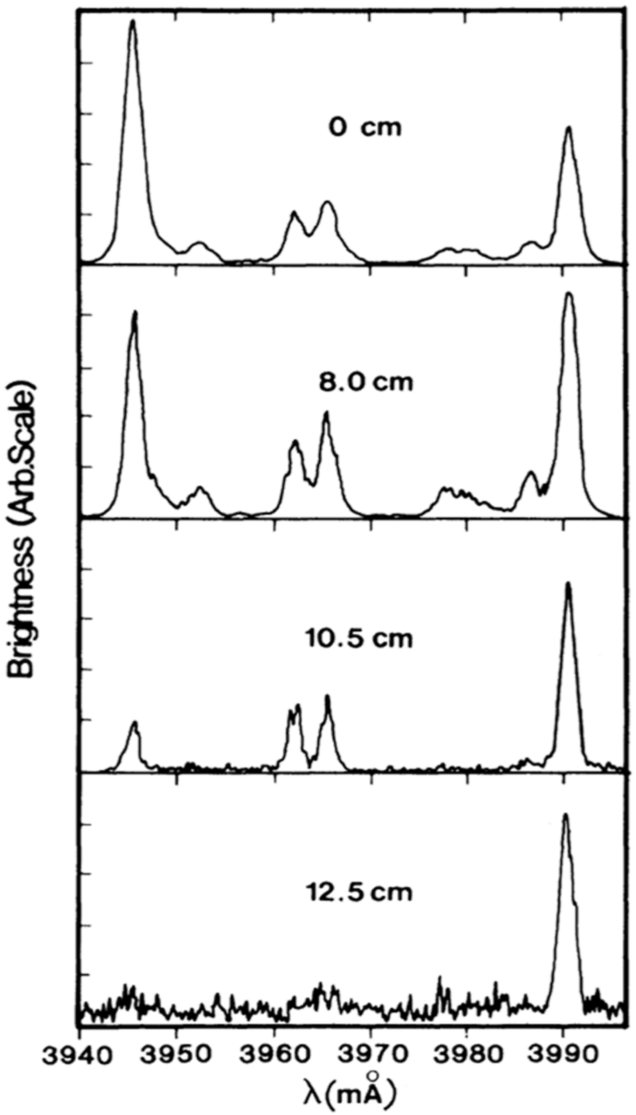


- Imaging X-ray spectrometry reveals increasing z-line towards the edge.
- Reason unresolved !
- Today two possible mechanisms are considered:
  - Charge exchange with neutral hydrogen

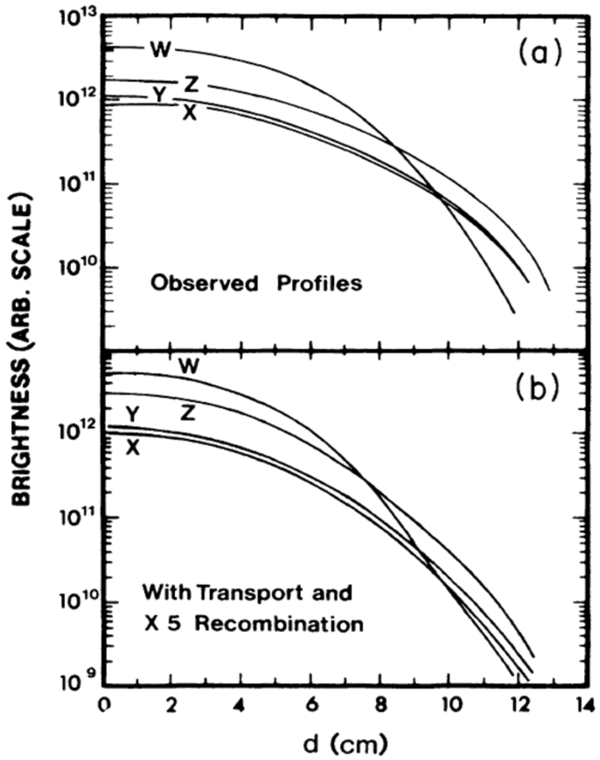
    $Ar^{17+} + H^{0} \rightarrow Ar^{16+} + H^{+}$

    At lower T_e Ar^{17+} should not be abundant.
  - Transport

K_α – spectra from ALCATOR-C



- [Rice – Phys. Rev. A, Vol. 35, No. 7, 1987]
- Rice could approximately describe the spectra with increased radiative recombination rates by factor of **five**.



Former measurements at TEXTOR

X-ray spectroscopy (1-dimensional, plasma center)

- Rosmej et al.:

  Deviations from corona values:

  - mainly charge exchange with neutral hydrogen
  - low transport coefficients needed

[Rosmej et al. – Plasma Phys. Control. Fusion, 41 (1999)]

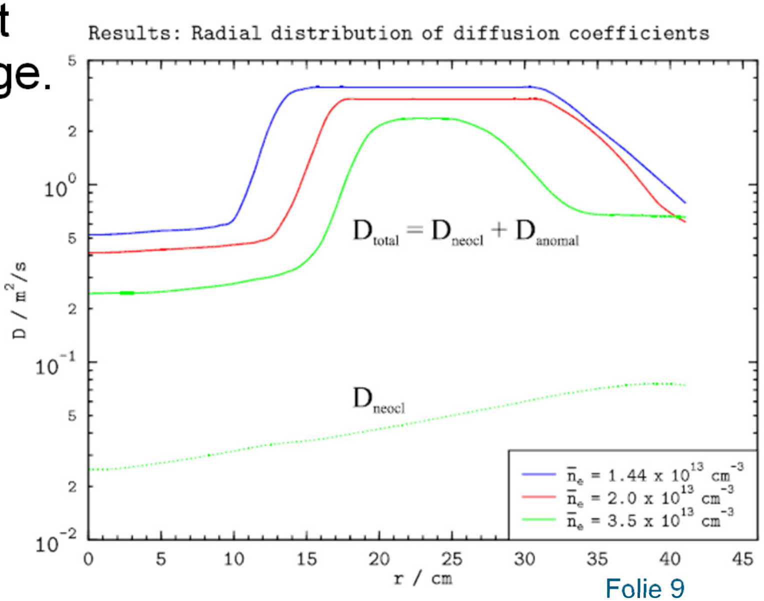
VUV – spectroscopy (1-dimensional, plasma center)

- Biel et al. could not describe VUV-spectra without high transport despite respecting charge exchange.
  [Biel, *ECA Vol. 25 A (2001)*]

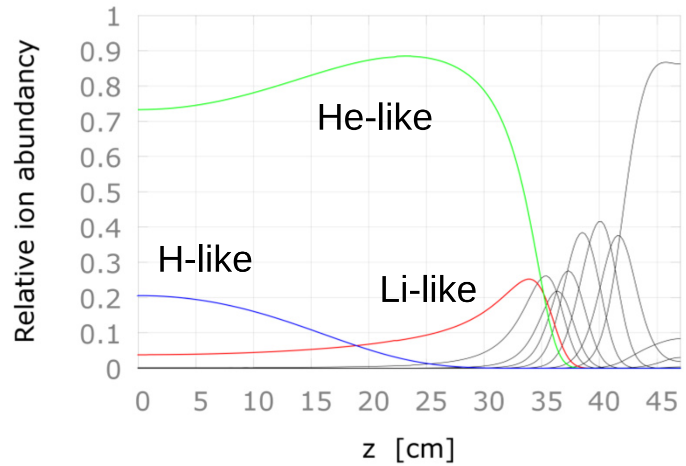
- High transport zone with very high diffusion coefficients was needed.

- Similar findings at Jet (L-mode) by Mattioli et al.
  [Mattioli et al. - Nucl. Fusion 38 (1998)]

→ **Contradicting results!**



Fitting the K_α – spectrum



- For the interpretation of the K_α – spectra only the H-, He-, and Li-like argon states are considered.

- For the intensity of each line the following general equation applies:

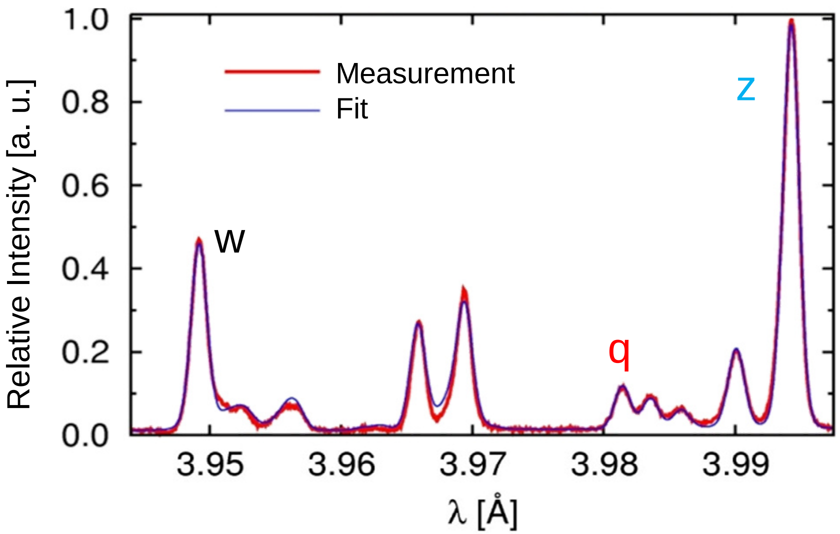
$$I(\lambda) \propto \int_0^1 n_e \cdot ArHe \cdot \left(\alpha_{He}(\varrho) + \left(\alpha_{H(\varrho)} + \alpha_{cx(\varrho)} \cdot \frac{n_0}{n_e} \right) \cdot \frac{Ar_H}{Ar_{He}} + \alpha_{Li}(\varrho) \cdot \frac{Ar_{Li}}{Ar_{He}} \right) d\varrho$$

- Theoretical description of the spectra is based on the theoretical cross sections for the atomic processes.

- Fit parameter: T_e, T_i, n_0, $Ar_H : Ar_{He}$ and $Ar_{Li} : Ar_{He}$

- To respect the line integrated signals, the fit routine integrates over the radial profiles for plasma density, temperature and neutral gas density given as input data. (→ **Emission profiles**)

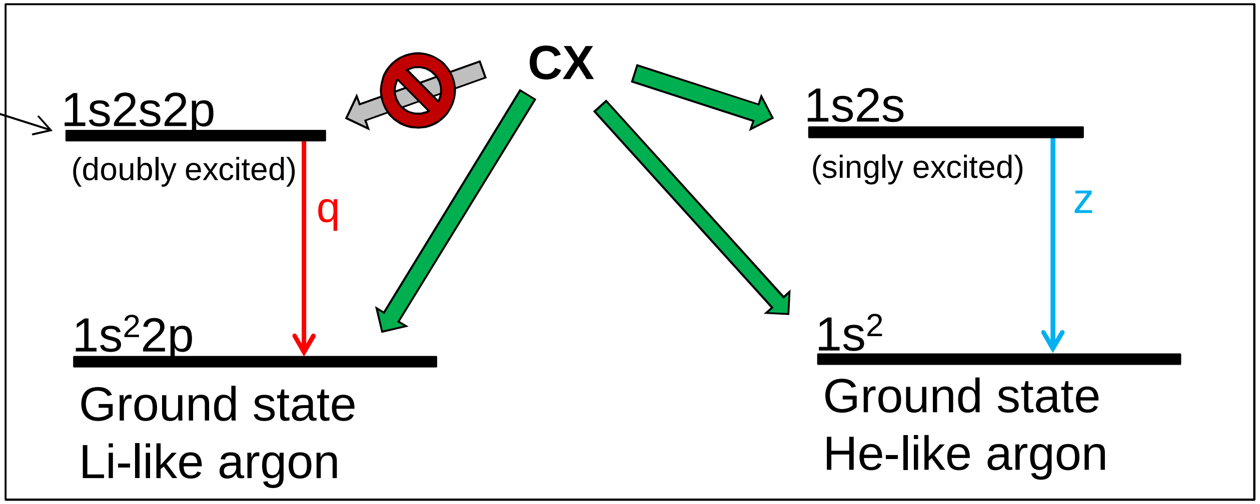
Distinguishing between transport and CX



- Transport only affects the ground states of the argon ions.
- The z-line is affected by CX in two ways:
  - Cascade contributions
  - Ground state
- The q-satellite is affected by CX only via the ground state. (low density limit)

→ Transport and charge exchange are discriminable !

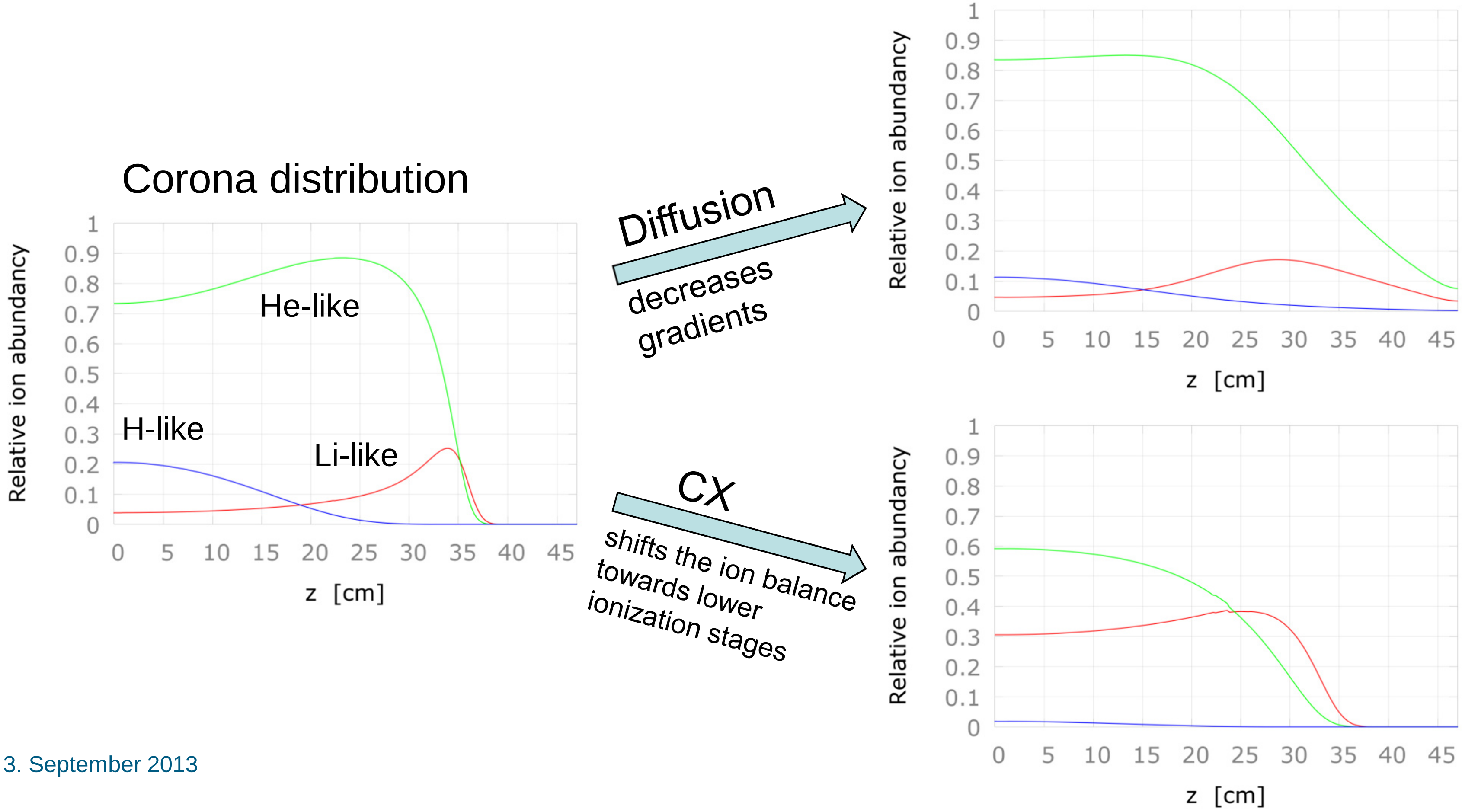
The q-satellite is not directly affected by CX !



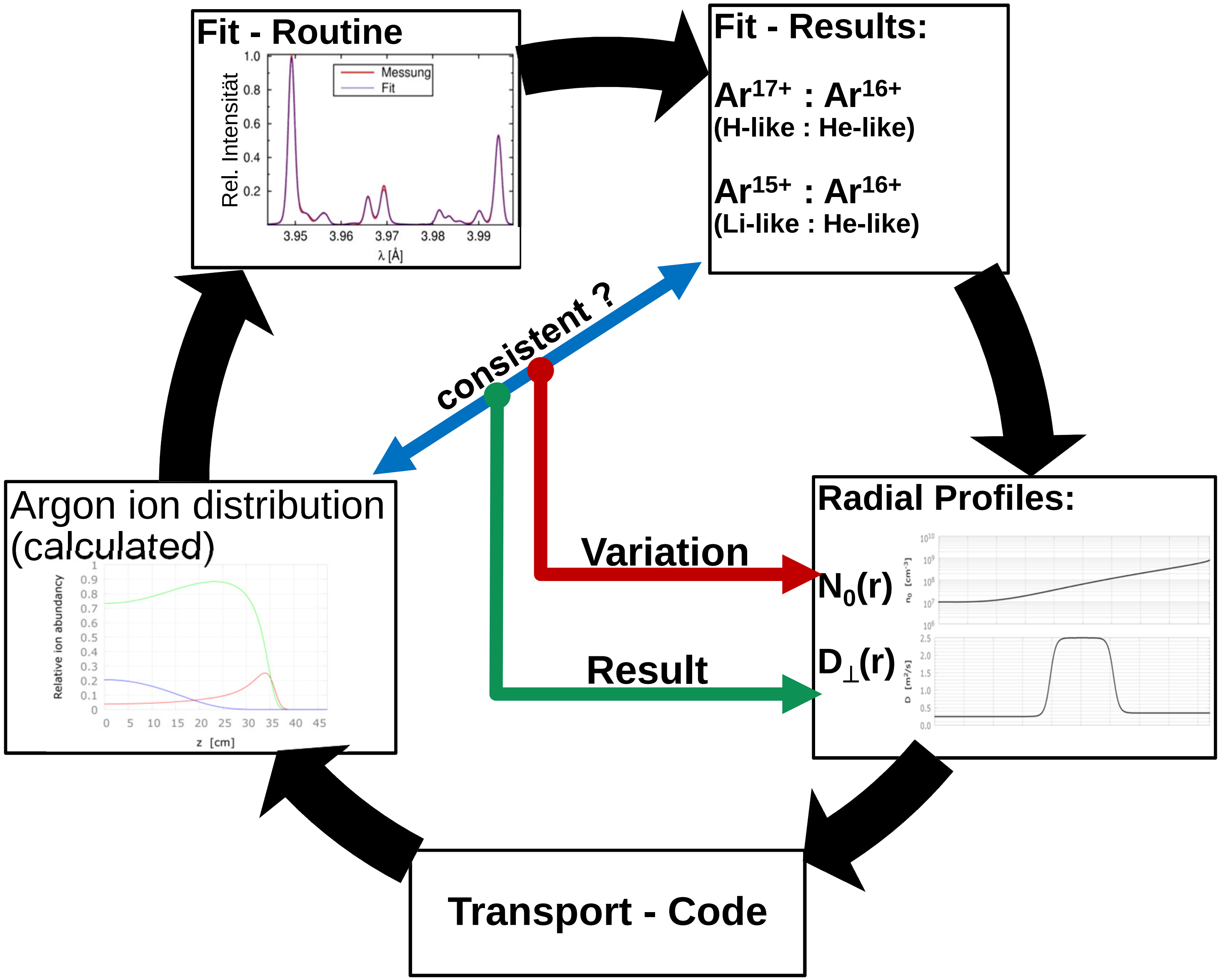
Including transport and charge exchange

- The fit routine uses radial profiles of the argon ions given as input data.
- To include transport and charge exchange a simple transport code is used solving the system of steady state transport equations for Ar^{0} – Ar^{18+}.

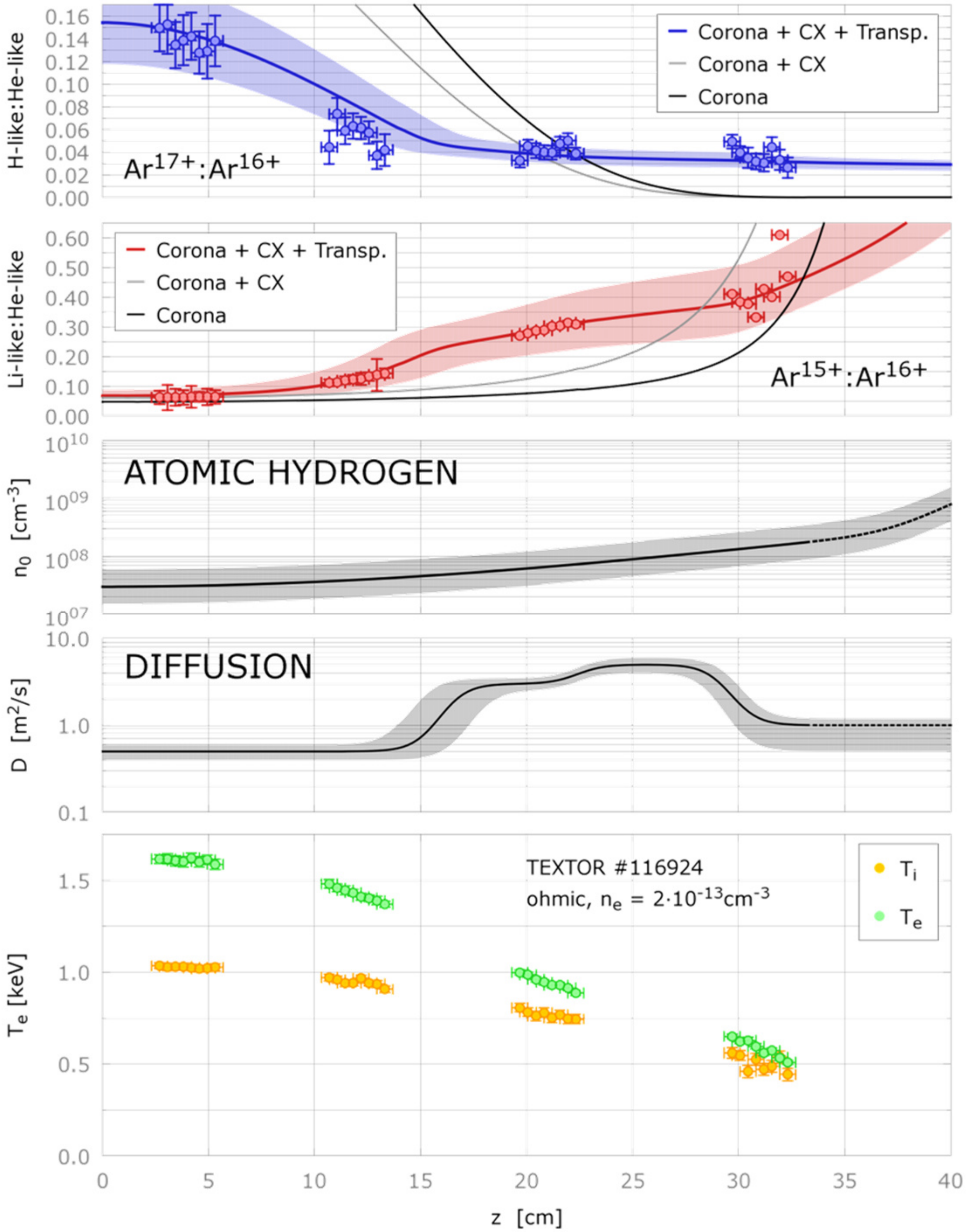
  [Tokar – Plasma Phys. and Contr. Fusion, Vol. 36, No. 11, 1994]
  [Dux – STRAHL – Code user manual]



Selfconsistency



Experimental neutral gas density profiles from TEXTOR



- TEXTOR discharge #116924
  ($n_{e,la} = 2.0 \cdot 10^{13} cm^{-3}$, ohmic)

Results:

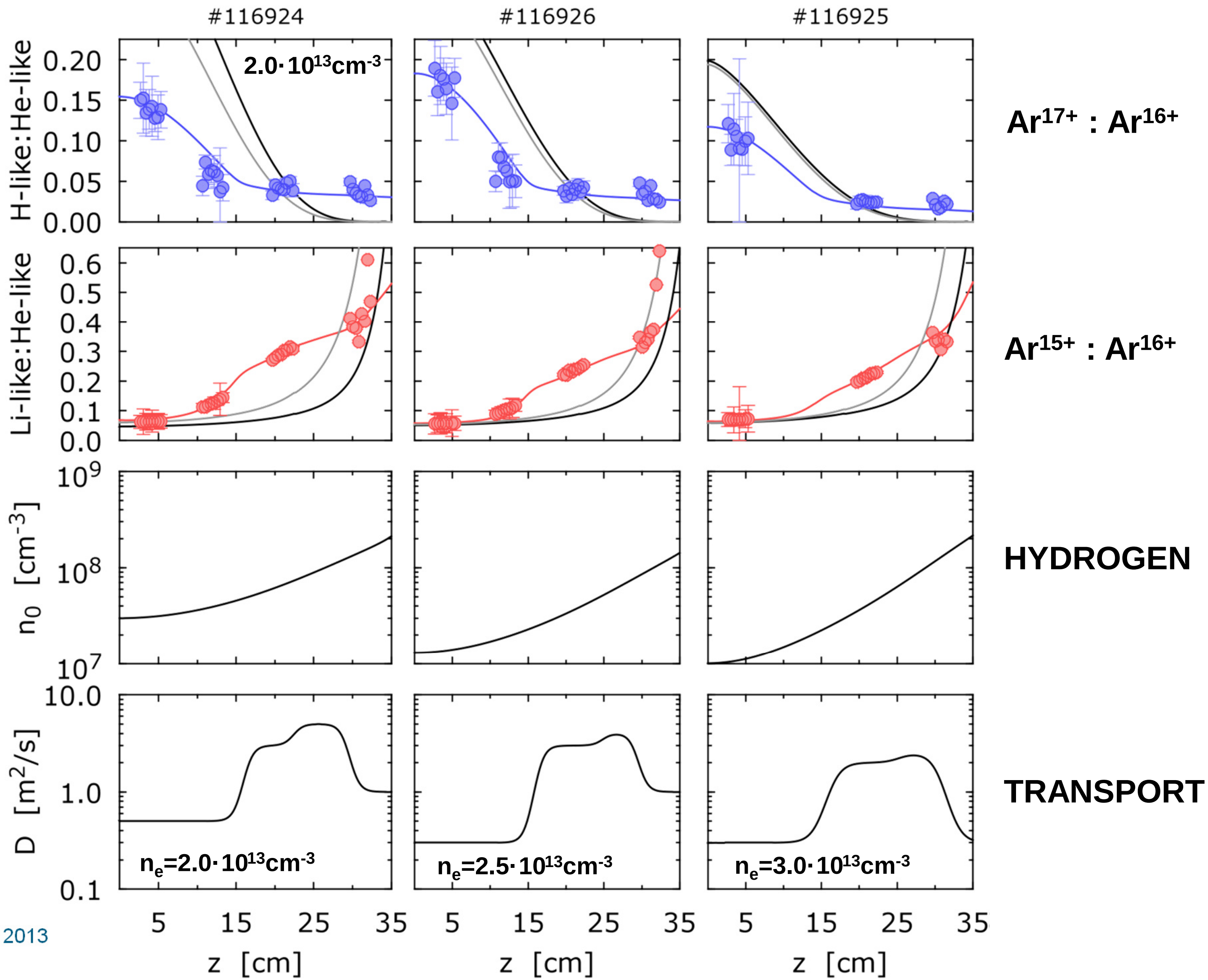
- No consistent description of all channels without a high transport region !
- Neutrals are needed to describe Li-like and H-like argon consistently !
- Transport is the dominant mechanism !

Errors:

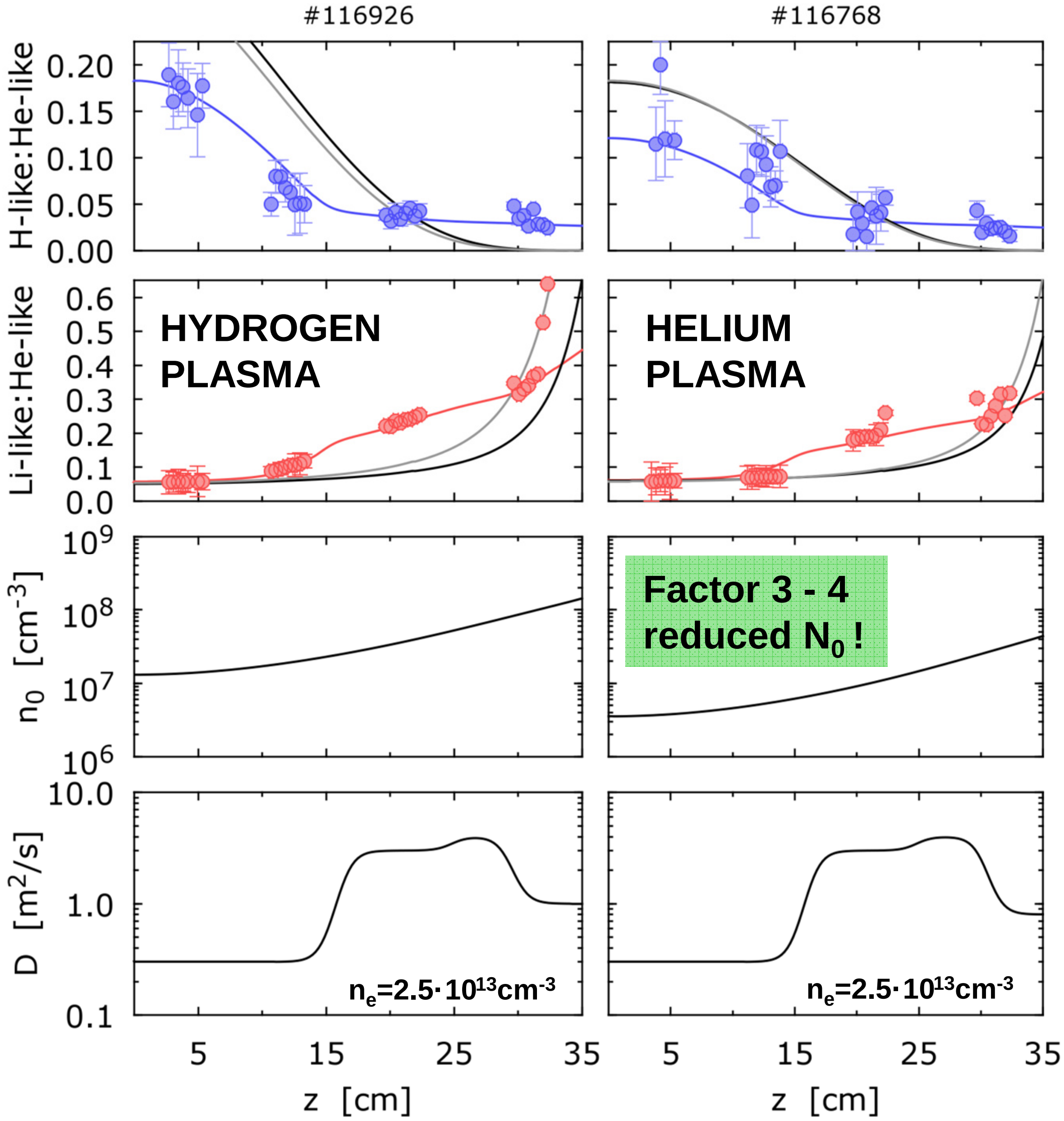
- The neutral particle density can be determined by about a factor of 2.
- Fragmentary radial coverage leads to uncertanties in position and steepness of the transport barriers.

→ Continous imaging with a one piece detector will significantly increase the accuracy.

Results for different plasma densities



Hydrogen plasma vs. Helium plasma



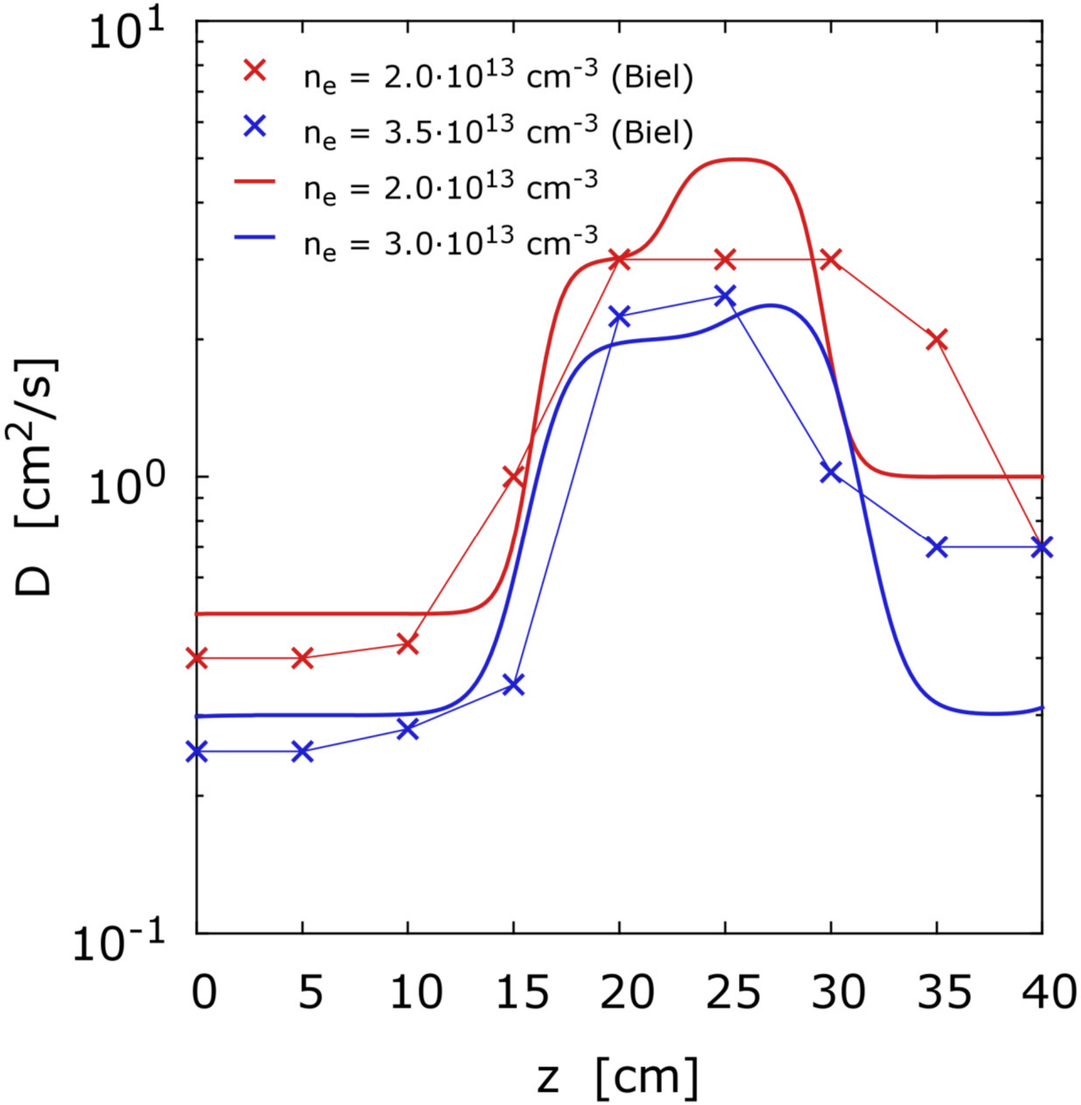
Ar^{17+} : Ar^{16+}

Ar^{15+} : Ar^{16+}

HYDROGEN

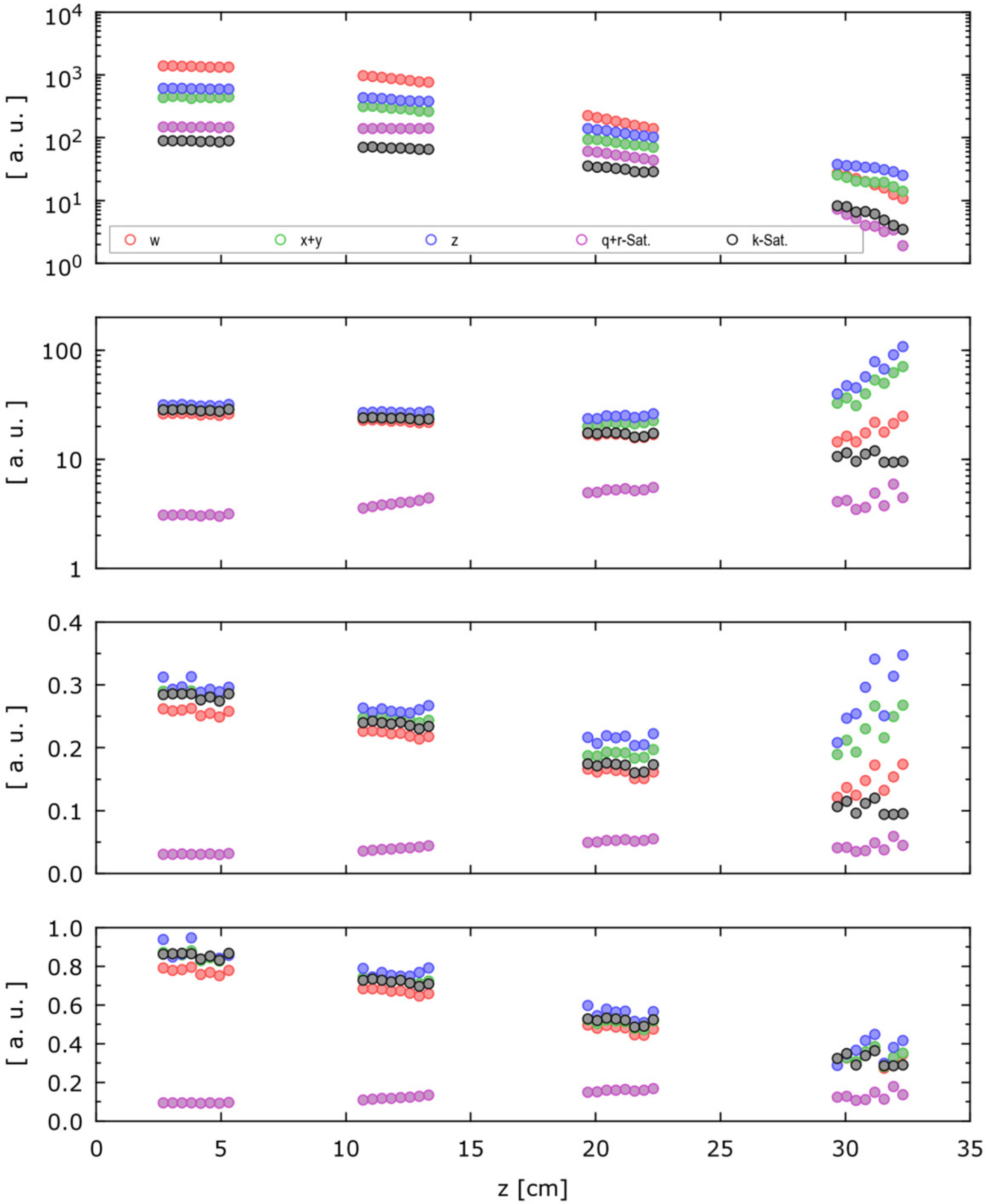
TRANSPORT

Diffusion coefficient



[Biel et al. - 28. EPS Conf. on Contr. Fusion and Plasma Phys., Funchal, 2001]

Absolute line intensities



Absolute line intensities

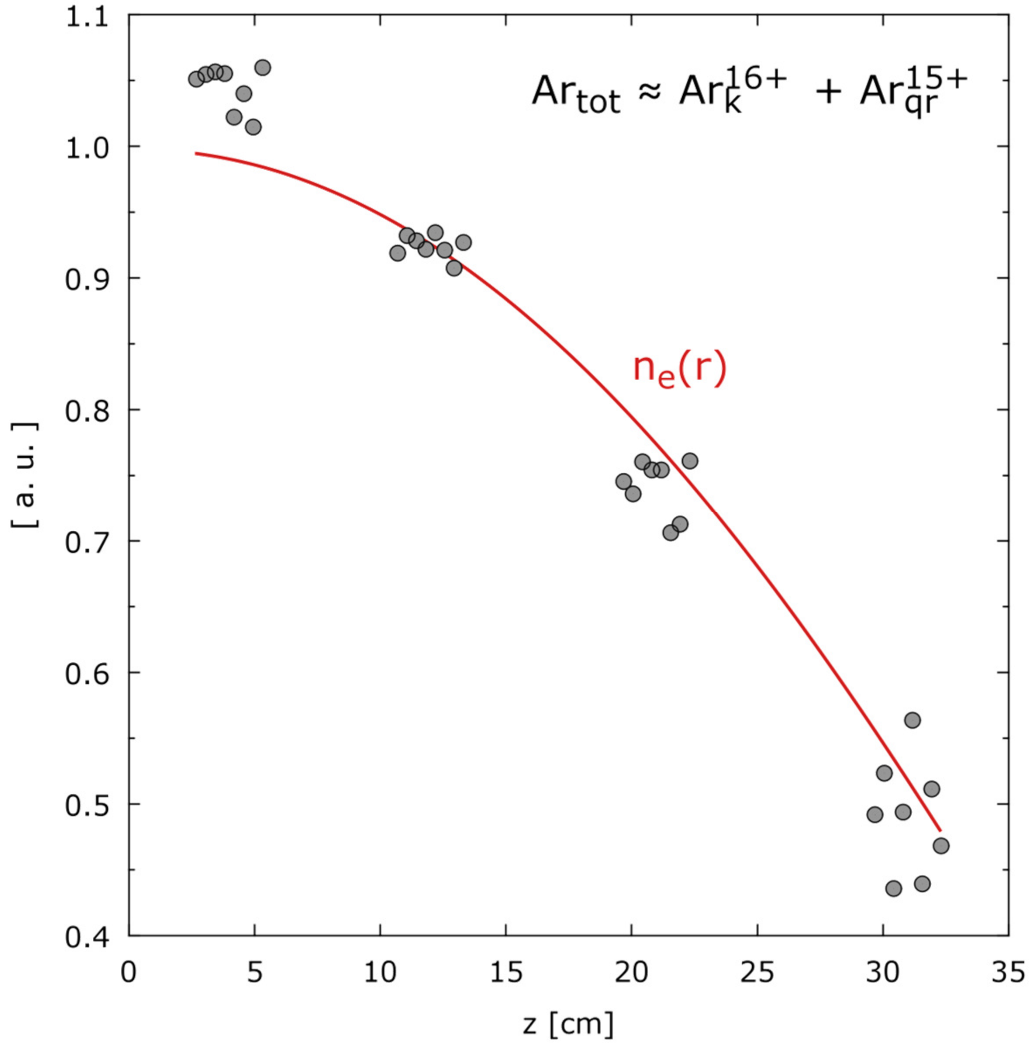
I

I / EXC

I / (EXC + RR)

I / (EXC + RR + CX)

Total argon density



- **Additional information in the absolute line intensities**
- **The total argon density can be approximated by:**

  Ar_{tot} ≈ He-like Ar + Li-like Ar

- **The total argon density Ar_{tot} is found to be proportional to the electron density $n_e(r)$.**

Conclusion

- Measurements of radially resolved spectra of He-like argon in TEXTOR using the new W7-X imaging X-ray-spectrometer.

- Study of charge exchange and transport effects on the argon ionization balance in TEXTOR based on these spectra.

  - **Clear distinction** between impact of **charge exchange** and **transport** on the line intensities.

  - **High transport** zone is essential for the reconstruction of the observed line ratios. [$D_\perp(r)$]

  - First measurement of the **neutral particle density** in a tokamak core plasma. [$n_0(r)$]

  - **Total argon density** is found to be proportional to the electron density.

- Introduction of imaging X-ray – spectroscopy as diagnostic for neutral particle density and for radial transport in fusion plasmas.

Thank you for your attention !