Reconstruction of hydrogenic ion temperature profiles for ohmic plasmas on TCV tokamak

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Aim

- simulate the **radial origin** of the charge-exchange flux measured by the Compact NPA on TCV
- link **energy spectrum** of the CX-flux to the **birth place** of the neutrals
- relate the CNPA **ion temperature** measurement to a restricted **range of plasma radii**
- reconstruct CNPA hydrogenic **ion temperature profiles** by fitting the CX spectrum at different energies and using pseudo chord measurements

TCV Compact Neutral Particle Analyser

- **Compact NPA** from Ioffe Institute [1]
- **horizontal view line**, at the midplane, perpendicular to the magnetic axis (figure 7)
- **simultaneous** measurement of **two species** by mass separation
- **wide energy range** (H: 11 channels 0.6..50 keV, D: 17 channels 0.5..34 keV)

Charge exchange spectrum and CNPA temperature

- CNPA measures $F_{CX}^{CNPA}(E)$, the **neutral particle flux**
- **charge exchange spectrum** $\frac{F_{CX}^{CNPA}}{\sigma_{CX} E}$ (figure 1)
- inferred **CNPA ion temperature**

$$T_i^{CNPA}(E) \approx -\left(\frac{d}{dE}\ln\left|\frac{F_{CX}^{CNPA}}{\sigma_{CX}E}\right|\right)^{-1} \quad (1)$$

- which **radial position** gives the **maximum contribution to the flux** of energy E? Does the CNPA T_i coincide with the ion temperature profile at this position?

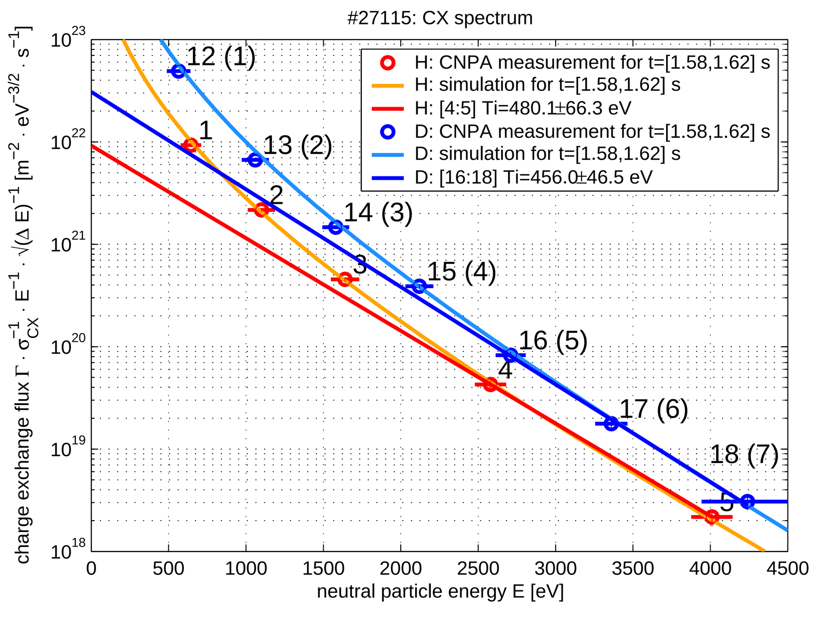


Figure 1: CNPA charge exchange spectrum with temperature fits to channels 4 & 5 and 16-18 for hydrogen and deuterium respectively.

Simulation of neutral profile and charge exchange flux

- **line integrated CNPA measurement** cannot unfold the place of birth
- **neutral source function**

$$S(\rho, E) = f_i(E)\sigma_{CX}(E)v_i(E)n_0(\rho) \quad (2)$$

- **attenuation** of the flux outwards the plasma

$$\alpha(\rho, E) = \frac{1}{v_i(E)}\{\sigma_{ei}(E)n_e(\rho) + [\sigma_{ii}(E) + \sigma_{CX}(E)]\, n_i(\rho)\} \quad (3)$$

- **neutral emissivity** profile

$$\varepsilon(\rho, E)\exp\left(-\int_\rho^{\rho_{a_{LFS}}} \alpha(\rho', E)d\rho'\right) S(\rho, E) \quad (4)$$

- n_0 cannot be measured ⇒ **simulation** using **KN1D** [2], [3]

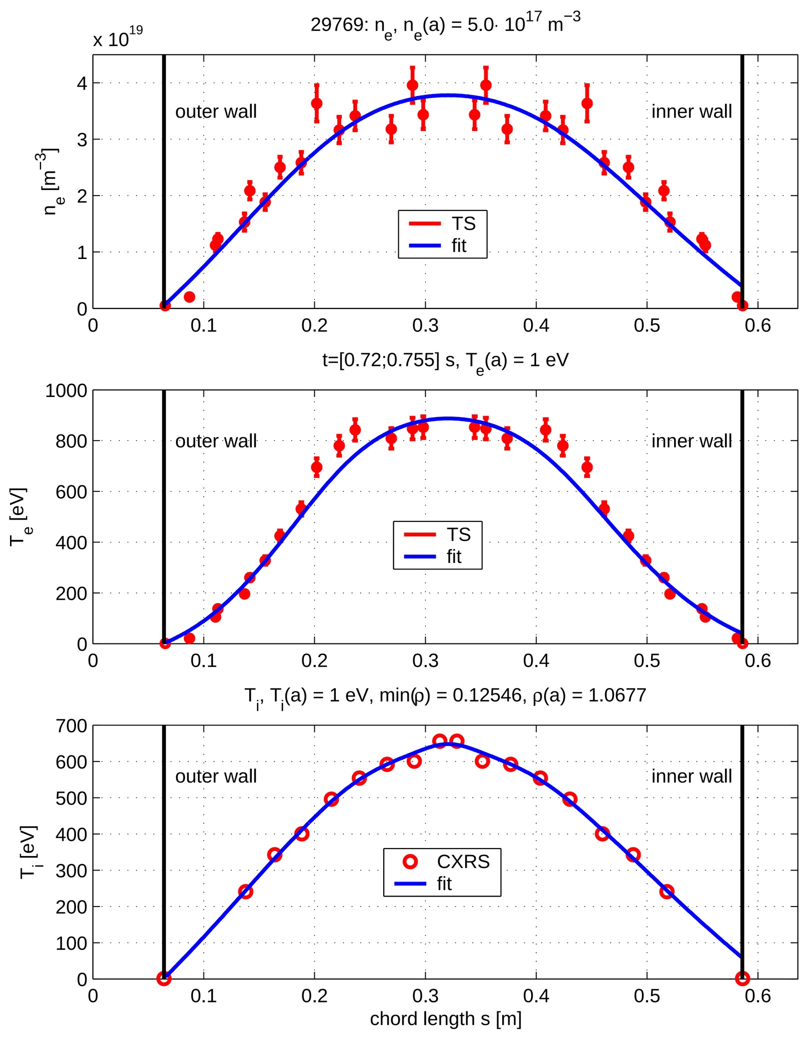
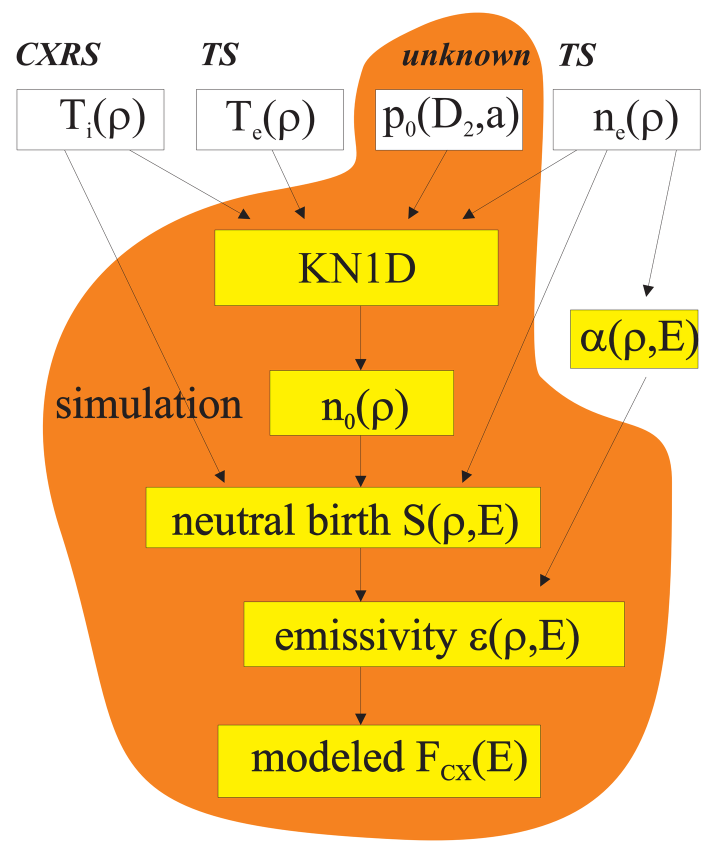


Figure 2: Plasma input profiles against CNPA chord coordinate. Diagnostics measurements (⊙) and fitted profiles (—) for n_e (top), T_e (middle) and T_i (bottom).



- $p_{D_2^0}(r=a)$ experimentally not known but **iterated** to **match** the **modeled** neutral particle flux

$$F_{j,sim}^{CX}(E_j)dE_j = \mu_j(A\Omega)\int_{\rho_{a_{HFS}}}^{\rho_{a_{LFS}}} \varepsilon(\rho, E_j)\, d\rho$$

to the CNPA **measurement** $F_{j,CNPA}^{CX}$

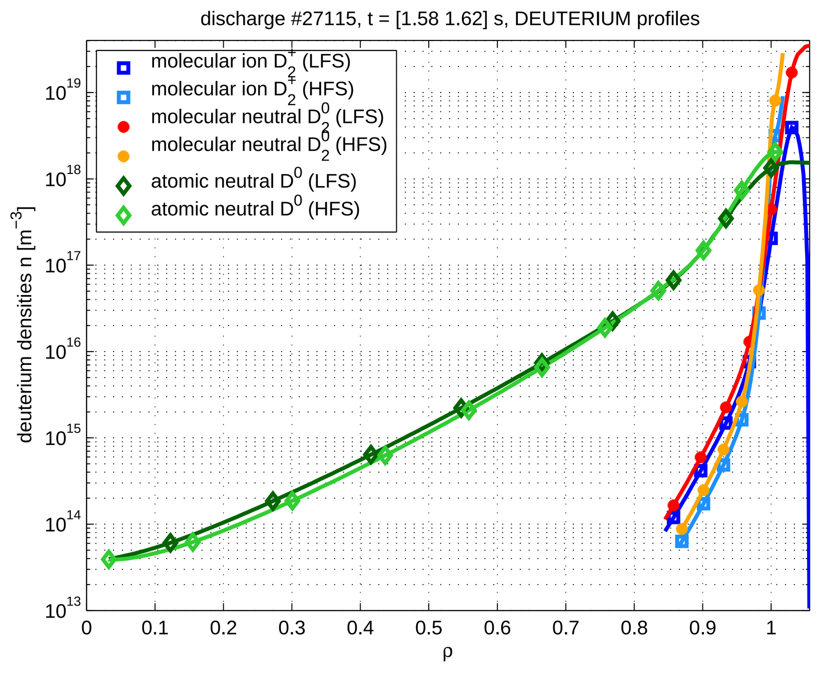


Figure 3: Simulated profiles ●● neutral molecular D_2^0, □□ molecular ion D_2^+ ◇◇ atomic neutral D^0 densities.

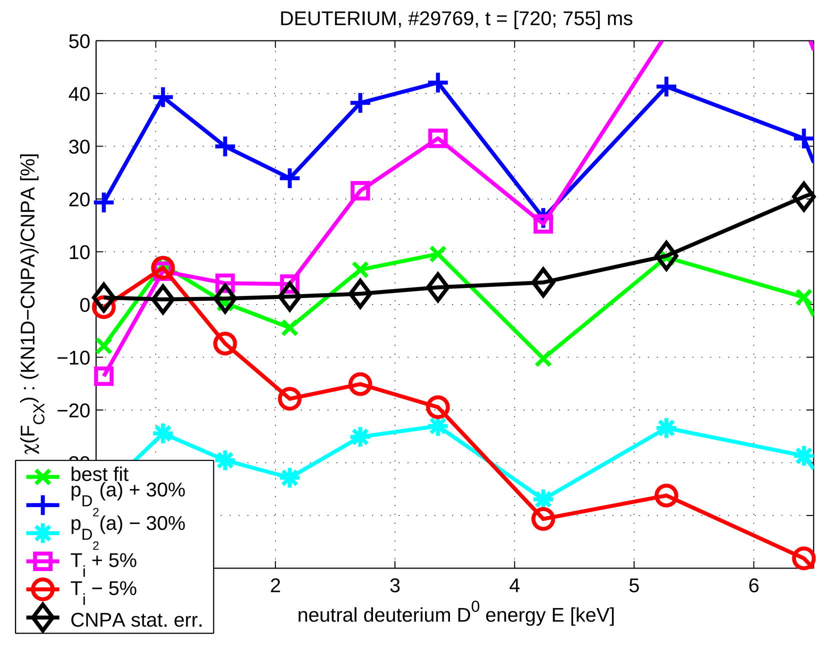


Figure 4: Relative fit error. Best fit for $p_{D_2^0}(r=a) = 0.57$ mTorr and $T_i = T_{i,C}^{CXRS}$ (×), $p(a) \pm 30\%$ (+, ∗) and $T_i \pm 5\%$ (□, ⊙).

- most important contribution to the CX flux ⇔ where is $\varepsilon(\rho, E)$ maximum ?
- $p_{D_2^0}(r=a)$ is **linear** in the resulting atomic neutral profile (figure 3)
- **relative error** χ (figure 4) < 10 % for $E = 500$ .. 6500 eV.
- **statistical error** of channels at higher energies is > 50 %

Recovery of the neutral birth place

- maxima of emissivities **separated** in space (figure 5)
- finite CNPA energy channel width ⇒ channel centre energy needs a **correction** (figure 6)
- the **slope** of the **CX spectrum fitted** to H channels 4, 5 and D channels 16-18 **matches** the **slope** of the **simulated CX spectrum** at $E = 3.5$ keV (figure 2) whose **emissivity is maximum** at $\rho = 0.5$ for both species.
- $T_{i,H(4:5)}^{CNPA}$ = 480 eV and $T_{i,D(16:18)}^{CNPA}$ = 460 eV, $T_{i,C}^{CXRS}(\rho = 0.5)$ = 450 eV
- the ions are **thermalised**

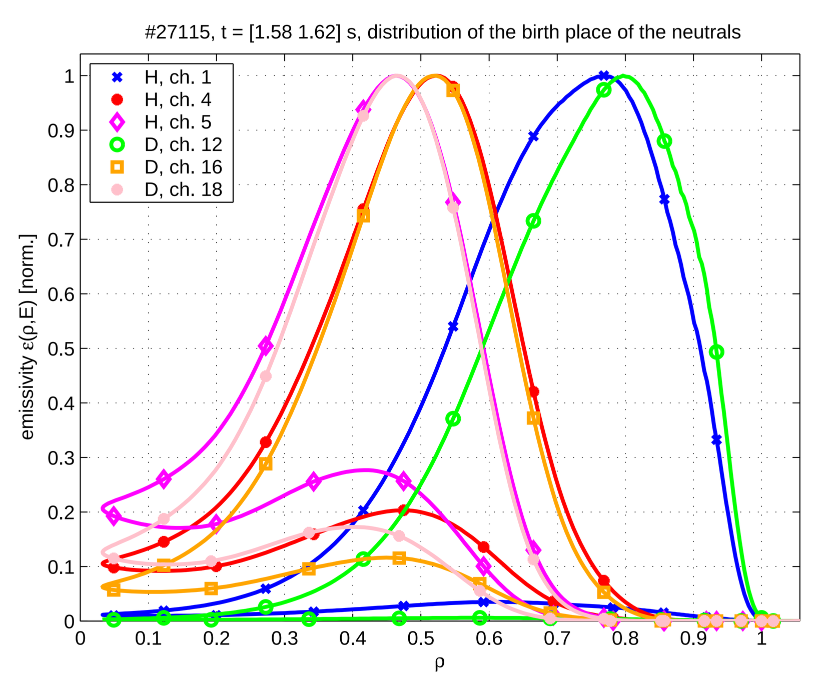


Figure 5: Origin of detected neutrals. Normalized neutral birth place (c.) as a convolution of neutral source function (a.) and plasma neutral transparency (b.).

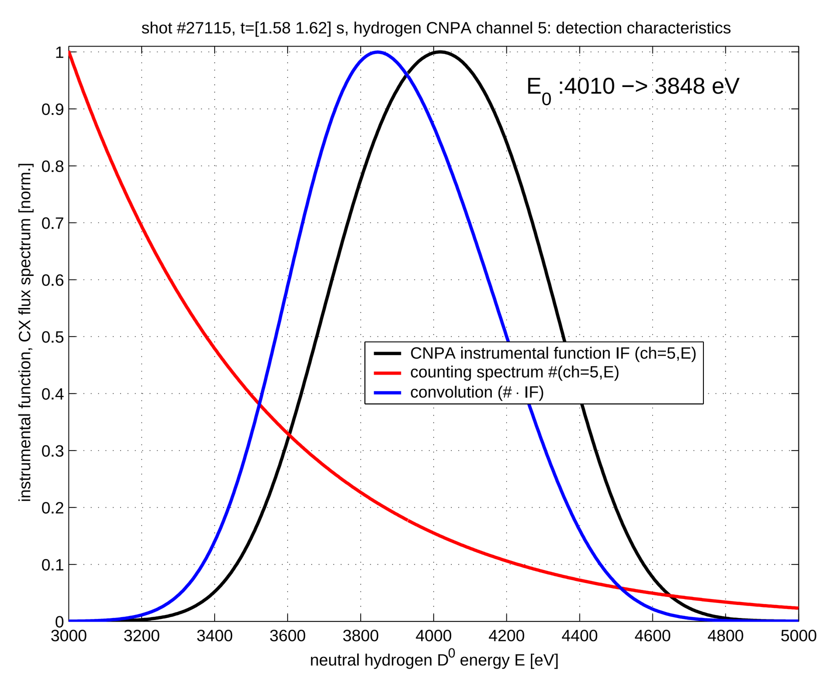


Figure 6: The convolution of the count spectrum for CNPA channel 5 (—) with the instrumental function (—) lowers the energy of the maximum of counted particles by 5 % (—).

Pseudo chord temperature measurements

- we **fit** the temperature **for all neighboring channels** in order to reconstruct **hydrogenic ion profiles**
- **pseudo chord measurements** (figure 7) using a plasma moving across the CNPA view line intercept the whole plasma cross section
- the **radial coverage** is as good as $\rho = 0.3$ .. 0.9 (figure 8)
- the **horizontal error bars** cover 50 % of the detected neutrals
- **CNPA** and **CXRS** ion profiles are in **agreement** within the error bars

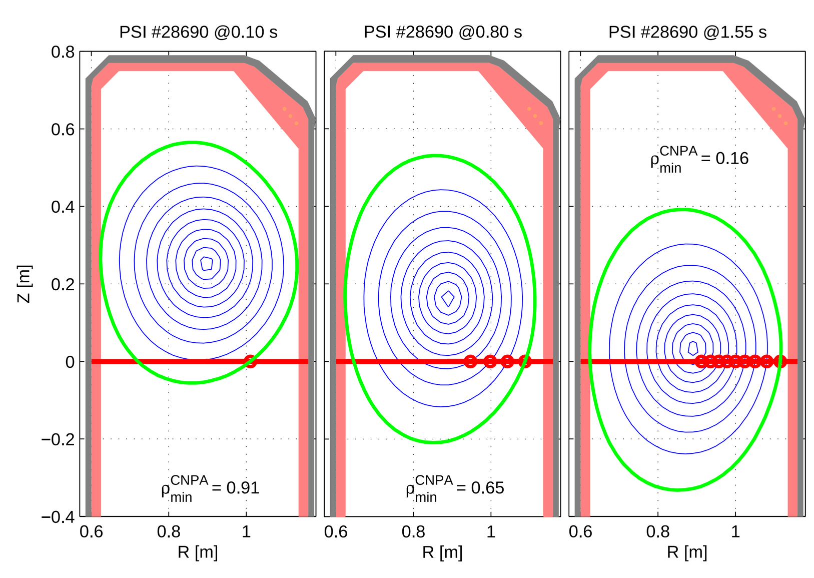


Figure 7: Magnetic topology with the horizontal CNPA line of sight at the midplane for t = 100, 800 and 1550 ms.

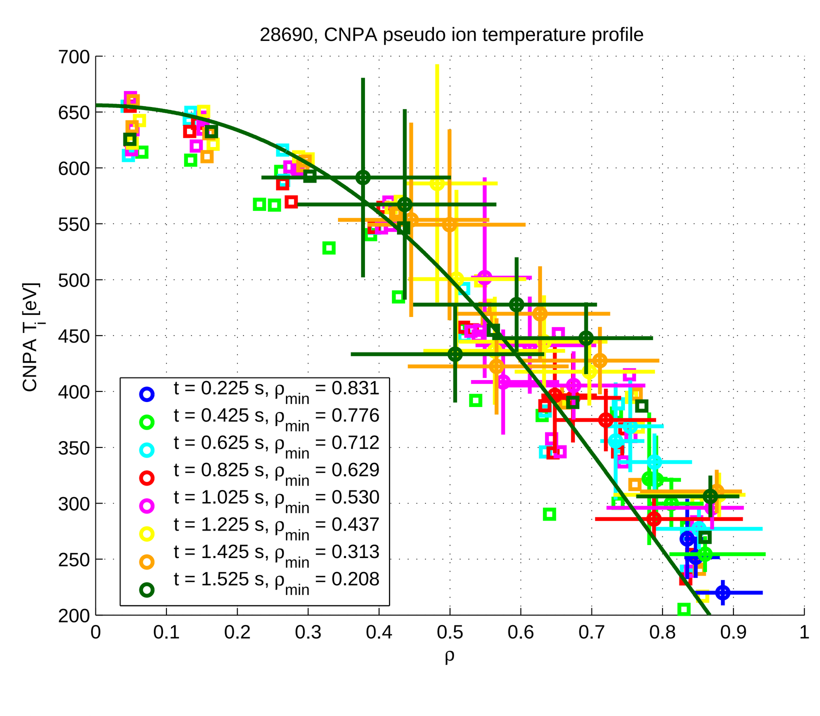


Figure 8: Reconstructed CNPA deuterium T_D profile (⊙) and carbon T_C (CXRS, measurement □, — fit for t=1.525 s).

References

[1] F. V. Chernyshev et al., Inst. Exp. Tech., **47** (2004) 214.
[2] A. N. Karpushov et al., 30^{th} EPS Conf. PCCF, London, P-2.152, ECA **28G** (2004)
[3] B. LaBombard, KN1D, PSFC/RR-01-9, MIT, Cambridge (2001).

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