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Edge Fast Ion Distribution – benchmarking ASCOT against experimental NPA data on ASDEX Upgrade

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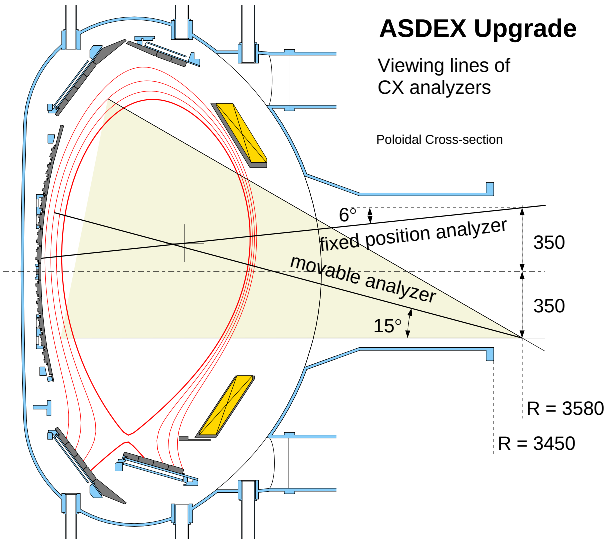
Introduction The Monte Carlo -based orbit-following code ASCOT [1] can evaluate the fast ion population in a tokamak plasma in the presence of collisions, magnetic ripple and radial electric field. But to have confidence in numerically obtained results, the ASCOT-calculated distributions have to be quantitatively benchmarked against experimentally accessible data. ASCOT includes a model for the Neutral Particle Analyzer (NPA), and in February 2005 six ASDEX Upgrade discharges (shots #19912–19917) were dedicated to benchmarking ASCOT against NPA measurements. In this paper we report the results from the benchmark effort by comparing the measured and simulated neutralfluxes. The experimental fluxes were obtained from the high energy channels of the movable CX-analyzer.

Experimental results The geometry of the movable CX-analyzer in AUG is displayed in figure 1. Complete data was obtained for shots 19913, 19915 and 1997, corresponding to detector settings with vertical tilting angle $\alpha_{\text{vert}} = 13^\circ$, 27° and 13° and horizontal angle $\beta_{\text{hor}} = 10^\circ$, 3° and 18°, respectively. Figure 2 indicates what parts of plasma these sightlines are able to monitor, together with the particle pitch range accessible. Sightlines with $\alpha_{\text{vert}} = 13^\circ$ are central: they can collect signal all through the plasma. The two central sightlines differ in that with $\beta_{\text{hor}} = 18^\circ$ the detector picks up mostly passing particles and will be referred to as *toroidal* sightline, while $\beta_{\text{hor}} = 10^\circ$ can collect signal from both passing and trapped ions and is called *central*. The sightline with $\alpha_{\text{vert}} = 27^\circ$ collecting signal only from the edge region, mostly above the horizontal midplane, is called the *edge* sightline, and it detects mostly trapped particles with small pitch values.

In each discharge the beams were stepped in a sequence half a second long, which supposedly is long enough for a slowing down distribution to build up. The CX-data were collected towards the end of each beam step. All shots were carried out in standard configuration and had identical global parameters: $B_T = 2.0\,\text{T}$, $I_p = 0.8\,\text{MA}$ and, with the 2.5 MW NBI heating, the plasmas displayed typical H-mode profiles with central electron temperature of about 2 keV and central electron density of $5 \times 10^{19}\,\text{m}^{-3}$. There were six beams available: sources 1, 3 and 4 from injector-1 with 60 keV nominal energy, and sources 6, 7 and 8 from injector-2 with 93 keV



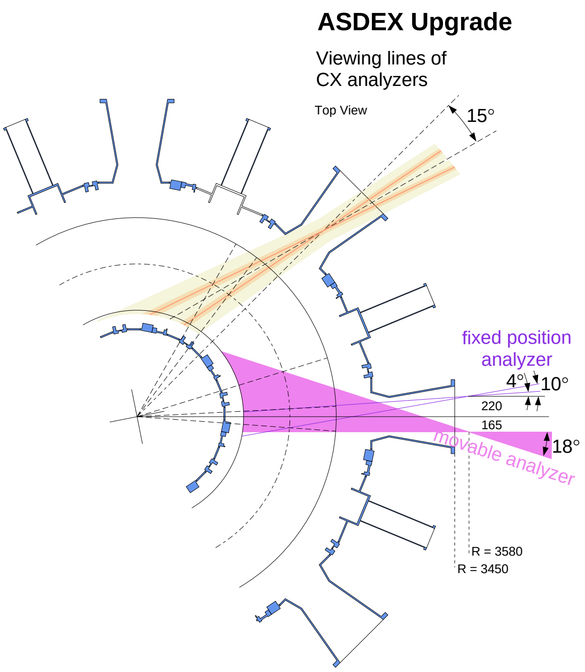


Figure 1: The vertical (above) and the horizontal (on the right) cross-sections of the CX-analyzer geometry in AUG. Horizontally the movable analyzer looks in the beam injection direction.

nominal energy. Beams 1 and 4 are the most radial ones, while 6 and 7 are the most tangential ones, sometimes referred to as the CD (current drive) beams.

The experimental neutral spectra for different sightlines are shown in figure 3 for shot 19913, in figure 4 for shot 19915, and in figure 5 for shot 19917. The spectra corresponding to the different injectors and, correspondingly, different initial energies, are given in separate plots. Signal from injector-2 is always lower than from injector-1 simply because, for the same heating power, injector-1 ejects more particles. Of the three detector settings it is the edge sightline that gives the highest signal levels. This does not necessarily imply a high concentration of fast ions in the very edge but, rather, it results from the neutral density dropping very rapidly as one moves inward from the separatrix thus enhancing the CX-signal from the edge region.

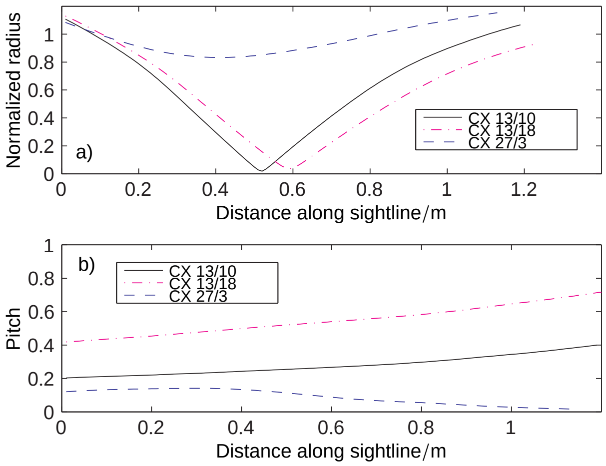


Figure 2: The detector sightlines: (a) The radial regions probed by the sightline. (b) The particle pitch range contributing to the CX-signal.

Also the beam injection angle clearly plays a role in determining the signal strength: From injector-1 the radial beams 1 and 4 typically give similar signal strengths while the more tangen-

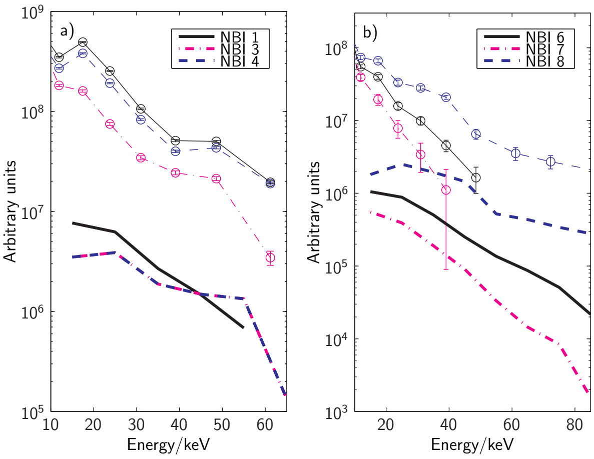


Figure 3: The measured (thin lines with open circles and error bars) and simulated (thick lines) neutral spectra for central sightline (shot 19913). Only reliable measurements have been included in the experimental spectra. The signal from the simulations was not in physical units and so, to facilitate the qualitative comparison to experimental spectra, the simulated spectra have been multiplied by an overall factor to bring them to the same scale. (a) 60 keV *beams from injector-1. (b)* 93 keV *beams from injector-2.*

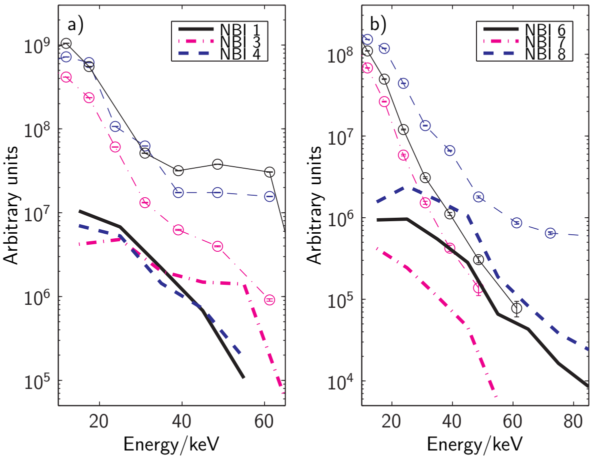


Figure 4: The measured and simulated neutral spectra for edge sightline (shot 19915). (a) 60 keV *beams, (b)* 93 keV *beams.*

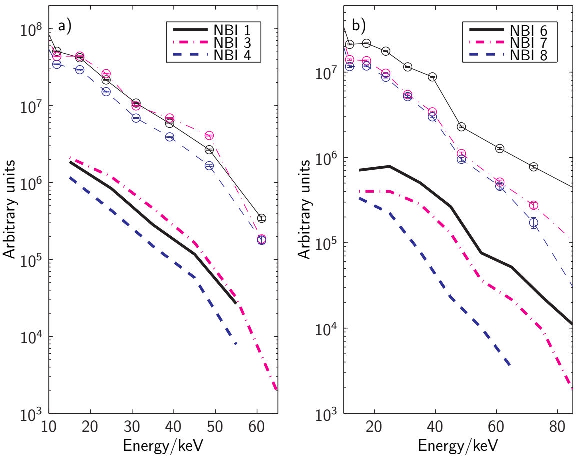


Figure 5: The measured and simulated neutral spectra for toroidal sightline (shot 19917). (a) 60 keV *beams, (b)* 93 keV *beams.*

tial beam 3 gives lower signal except, understandably, for the toroidal sightline. From injector-2 the CD beams 6 and 7 generally give lower signal than the more radial beam 8 (which actually is even more radial than beam 3). Surprisingly, for the toroidal sightline the signal from beam 7 does not resemble the signal from its partner beam 6 but, rather, beam 8 which has a very different injection angle.

Simulation results ASCOTs NPA model, constructed according to the AUG geometry, collects signal according to the local charge exchange probability and takes into account signal attenuation along the sightline. All three discharges were simulated with ASCOT using the experimental plasma background. For the ion temperature, since only one beam was on at a time, $T_\mathrm{i} = T_\mathrm{e}$ was generally assumed, and T_i-measurements carried out for one of the shots justified this. The neutral density, needed for the NPA-simulations in ASCOT, was obtained with the Eirene analysis, and the birth profiles for test ions from FAFNER [2] calculations.

The simulated spectra are also shown in figures 3, 4 and 5. Generally, the overall features observed for the experimental spectra are reproduced by the simulations, but there are several notable differences: For the *central* sightline (shot 19913), it is very strange that the spectrum from beam 4 overlaps with that of beam 3 which has very different injection angle. Also the crossing of the spectra is something not observed experimentally. The order of the spectra for the 93 keV beams 6, 7 and 8 is correct. Additionally, the agreement between measured and simulated spectra for beam 8 is very good. Unfortunately, because of the steep slope and unfavourable aperture setting, the signals from beam 6 and 7 fall below the detection limit at 40 keV and 50 keV. Also for the *edge* sightline (shot 19915) the spectrum from beam 3 manifestly differs from the experimental one, and even for beams 1 and 4 the high end of the spectra is qualitatively different. It is interesting and, so far, not understood, why beam 3 gives the plateau structure measured for beams 1 and 4 at high energies. Of the CD beams, the beam 7 has larger parallel velocity and its signal drops fastest. However, it is strange that its counterpart, beam 6, gives signal that is qualitatively closer to beam 8 than beam 7. This is also in contrast to the experimental spectra. Finally, for the *toroidal* sightline (shot 19917), the best agreement is observed: the order of the spectra as well as the fall-off rates are quite similar experimentally and from the simulations.

Conclusions While many of the gross features of the measured neutral particle spectra were reproduced in the ASCOT simulations, there are significant enough differences to warrant a complete review of the numerical NPA-model. In particular, it was found that in the model the effective detector aperture depends on particles' distance from the detector. This leads to overemphasizing signal from deep inside the plasma and even from the high field side. However, this mistake is somewhat offset by the exponential decay of the signal. The model will also be upgraded to give the fluxes in same physical units as experimentally: $\mathrm{eV}^{-1} \cdot \mathrm{ster}^{-1} \cdot \mathrm{cm}^{-2} \cdot \mathrm{s}^{-1}$.

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References

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