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Velocity-space tomography using many-view CTS or FIDA systems

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Introduction

Here we investigate what can be gained by installing additional FIDA views on ASDEX Upgrade. Fast-ion D_α (FIDA) [1–7] and collective Thomson scattering (CTS) [8–11] diagnostics can measure 1D functions, g, of the fast-ion velocity-space distribution function, f, in small measurement volumes. The viewing directions are chosen through geometric arrangement of the experiment. An ion with a given parallel and perpendicular velocity with respect to the magnetic field elicits a response in CTS or FIDA receivers at several frequency shifts. This opens up the possibility to compute velocity-space tomographies from simultaneous CTS or FIDA measurements in the same measurement volume [12]. Previously, theoretical tomographies using up to four synthetic views have been investigated [13, 14]. Here we go up to twelve synthetic FIDA views and study the effect of noise. The use of synthetic diagnostics allows us to compare the tomography with the original 2D velocity distribution used to compute the synthetic measurements. A five-view FIDA system may be available at ASDEX Upgrade from 2014 as two additional FIDA views are planned to be installed. This would give a total of seven views since the five FIDA views could be combined with up to two CTS views in joint tomographies [14]. Furthermore, two FIDA views are available both at MAST [6] and NSTX [2] and are being planned at EAST, and three FIDA views are available at DIII-D [7].

Tomography from synthetic FIDA measurements

Figure 1 shows a 2D fast-ion velocity distribution as function of parallel and perpendicular ion velocities simulated with TRANSP/NUBEAM [15]. This is a typical ion velocity distribution caused by the injection of fast particles using the 60 keV neutral beam injector S3 at ASDEX Upgrade. The distribution function and the tomographic reconstructions are discretised on a 45×22 grid in $(v_\parallel, v_\perp)$. The velocity-space tomography method is described in [12–14]. For each view, the part of the spectrum that would be obscured in a real experiment due to beam emission and halo emission is omitted. Each synthetic FIDA view has a wavelength resolution of 0.1 nm. This corresponds to about 100 wavelength bins per view. Figure 2 shows tomographic reconstructions of the distribution function from synthetic measurements. In the left column ((a), (d), (g)) we assume no noise in the synthetic FIDA measurements and calculate tomographic reconstructions from four, eight and twelve views, respectively. In the middle column ((b), (e), (h)) we assume a noise-level of 5%. In the right column ((c), (f), (i)) we assume 10% noise. Figure 2(a) shows a tomography using four FIDA views without noise in the measurements. The viewing angles, ϕ, of the four views are 11°, 32°, 57° and 83°. The viewing angle is the angle between the magnetic field and the line-of-sight of the FIDA view. The tomography from four views has the same overall shape and the same locations of the two beam injection maxima at 60 keV and 30 keV as the original distribution. Figures 2(d) and 2(g) show that the tomographies using eight views and twelve views without noise in the measurements are almost identical to the original function. For eight views, the viewing angles are 11°, 22°, 32°, 47°, 57°, 63°, 73°, and 83°. For twelve views, they are 6°, 11°, 16°, 22°, 32°, 37°, 47°, 57°, 63°, 73°, 83°, and 88°.

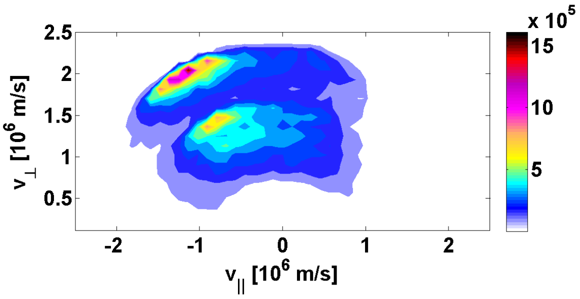
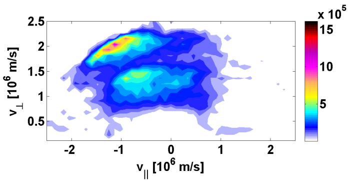


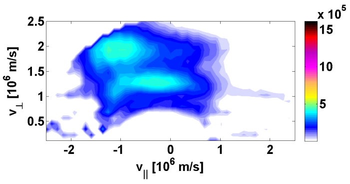
Figure 1: Velocity distribution function [s^2/m^5] simulated using TRANSP/NUBEAM. The distribution is a central fast-ion velocity distribution, typical to an ASDEX Upgrade low density plasma with no mode-activity heated by the neutral beam S3.

Figures 2(b), 2(e) and 2(h) show tomographies using the same four, eight and twelve views as before but with 5% noise in the synthetic measurements. The noise significantly reduces the number of singular values that can be used in the singular value decomposition. For four views, the overall shape of the tomography still corresponds approximately to that of the original distribution, and two maxima can be seen. However, the location of the 30 keV maximum is further to the right in the tomography compared with the simulation. For eight views, the two maxima can clearly be identified, and they are almost at the same locations as in the simulation. For twelve views, the beam maxima are even more pronounced and their locations are now as in the simulation. When increasing the number of views from four to eight and from eight to twelve, the tomographic reconstructions improve firstly because more measurements are available, and secondly because more views are available and thus a better probing of velocity-space is possible.

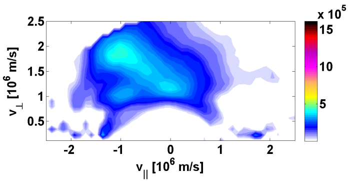
Figures 2(c), 2(f) and 2(i) show tomographies using the same four, eight and twelve views but with 10% noise in the measurements. For four views, the overall shape resembles the simulation, but only one maximum appears. For eight views, the two maxima can be identified, but the location of the 30 keV maximum is again placed further to the right compared with the simulation. For twelve views, the two maxima are clearly seen and their locations are as in the simulation.



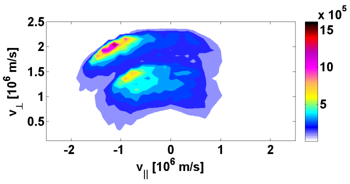
(a) Four views, no noise.



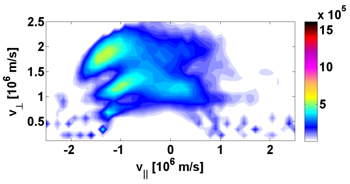
(b) Four views, 5% noise.



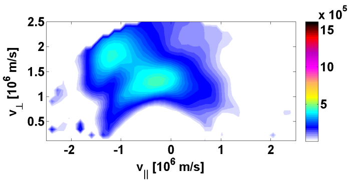
(c) Four views, 10% noise.



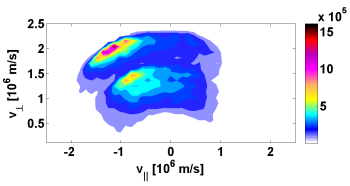
(d) Eight views, no noise.



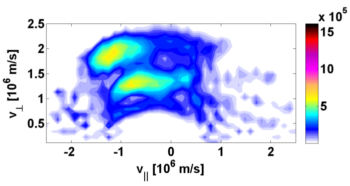
(e) Eight views, 5% noise.



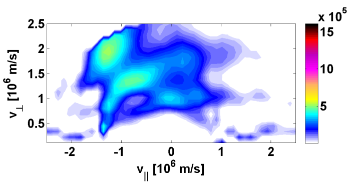
(f) Eight views, 10% noise.



(g) Twelve views, no noise.



(h) Twelve views, 5% noise.



(i) Twelve views, 10% noise.

Figure 2: Tomographic reconstructions from synthetic measurements in an increasing number of views with and without Gaussian noise. The unit of the colorbar is [s^2/m^5].

Conclusions

Tomographic reconstructions are calculated from synthetic FIDA measurements in up to twelve views with and without noise. For noise-free synthetic measurements, salient features of the original fast-ion velocity-space distribution function appear in the tomography using only four views. An almost perfect reconstruction on a grid with 45×22 points is possible if eight views are available. When noise is added to the measurements, the tomographic reconstructions become more blurred, as expected. The overall shape of the velocity distribution function in a tomographic reconstruction using four views resembles the simulation. When using eight views, the locations of the two beam maxima at full and half beam injection energy are clearly defined for noise levels of 5% and 10%. Both the 30 keV and the 60 keV maxima are even more sharply defined if twelve views are available for noise levels of 5% and 10%. We conclude that the resemblance of the tomographic reconstruction and the original function improves with the number of views for up to twelve FIDA views, even for a noise level of 10%.

Acknowledgements

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