Velocity-space tomography from synthetic FIDA measurements at EAST

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Abstract

In the Experimental Advanced Superconducting Tokamak (EAST), a vertically and a tangentially viewing fast-ion D-alpha (FIDA) diagnostics have been installed in order to investigate fast-ion dynamics. This is done by measuring the Doppler-shifted D-alpha light arising due to charge exchange between a neutral beam and the fast ions. By combining measurements from both FIDA instruments, the fast-ion velocity distribution can be obtained by velocity-space tomography. To explore the possibilities and limitations of velocity-space tomography in studying the fast-ion distribution in EAST, we present reconstructions of the fast-ion velocity distribution from synthetic FIDA measurements.

Introduction

In magnetic fusion devices, knowledge about the central fast-ion distribution is crucial in order to account for plasma heating and instabilities [1]. Information about the distribution can be obtained by measuring the Doppler-shifted Balmer-alpha radiation from neutralized deuterium ions [2, 3]. Two such fast-ion D-alpha (FIDA) instruments have been installed in EAST with tangential and vertical views relative to the magnetic field, respectively [4, 5, 6, 7]. Here, we test the possibilities and limitations for fast-ion velocity-space tomography [8, 9, 10] from these FIDA measurements in two views. We use synthetic FIDA measurements based on the conditions during the MHD-quiescent EAST discharge # 55408 studied in [5].

The fast-ion velocity distribution F^* is related to the observed FIDA signal S through the so-called transfer matrix W by

$$WF^* = S. \tag{1}$$

The transfer matrix consists of weight functions that depend strongly on the instrument viewing geometry and the measurement wavelength interval [11]. Examples of weight functions computed with the simulation code FIDASIM [12, 13] for the two views installed in EAST are shown in Fig. 1b-c in energy-pitch-space where the pitch $p = -v_{\parallel}/v$ is negative in the magnetic field direction. Here $v_{\parallel}$ is the velocity component along the magnetic field and v is the speed.

In order to obtain stable reconstructions F^* of the distribution, we regularize the solution using the zeroth-order Tikhonov method [14] that in its basic form gives the solution

$$F^* = \arg\min_F \left\| \begin{pmatrix} W \\ \lambda_0 L_0 \end{pmatrix} F - \begin{pmatrix} S \\ 0 \end{pmatrix} \right\|_2 \tag{2}$$

where L_0 is the identity matrix, and λ_0 is the regularization parameter chosen such that the solution error is minimized. Regularized solutions might, however, still contain artifacts that can be suppressed by including prior information in the inversions. We make use of non-negativity, null-measurements, and known peak locations [15, 16, 17].

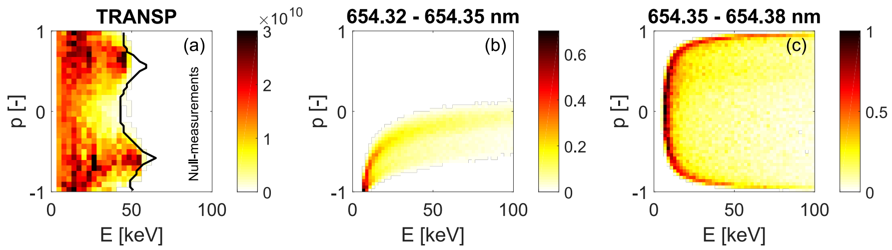

Figure 1: *(a) Simulated TRANSP fast-ion velocity distribution for shot #55804 at $R = 186$ cm, and examples of normalized weight functions for the corresponding (b) toroidal and (c) vertical views.*

Synthetic spectra

The synthetic spectra from the tangential and vertical views are, in accordance with Eq. 1, constructed by multiplying the FIDASIM weight functions with the TRANSP/NUBEAM [18] distribution function (Fig. 1a) using discharge # 55408 conditions including both counter- and co-current neutral beam injectors (NBI) with beam energies of 55 and 47 keV, respectively. We choose a central set of chords at $R = 186$ cm. In order to mimic measurement conditions that will be encountered in future tomographic studies, we choose a wavelength resolution of 0.03 nm and a noise level of about 10% [5]. The synthetic signals are shown as red dots in Fig. 2 together with FIDASIM simulations of other contributions to the total instrument signals. From these it is evident that the central part of the spectra with small Doppler-shifts from the unshifted D-alpha line at 656.1 nm are dominated by the halo and beam emissions [3]. Hence, only the high-energy wings of the FIDA signals are experimentally accessible. This is illustrated by light grey-shaded areas in the figure. The dark grey areas mark the null-measurements [15] that relate to the scarcely populated region to the right of the black line in Fig. 1a.

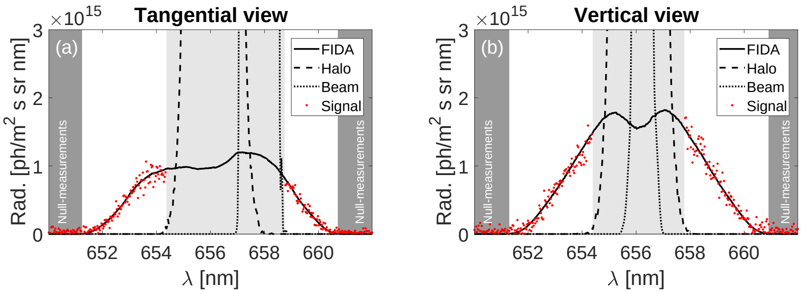

Figure 2: *FIDASIM simulations of the spectra observed by the (a) tangential and (b) vertical views for the TRANSP distribution in Fig. 1a. The light grey areas mark the wavelength regions where either the halo or beam emissions dominate the FIDA signal. The dark grey areas indicate null-measurements.*

Reconstructing the fast-ion distribution

Reconstructions of the fast-ion velocity distribution from the synthetic spectra in Fig. 2 are shown in Fig. 3 together with their pixel error relative to the true solution (Fig. 1a). The recon-

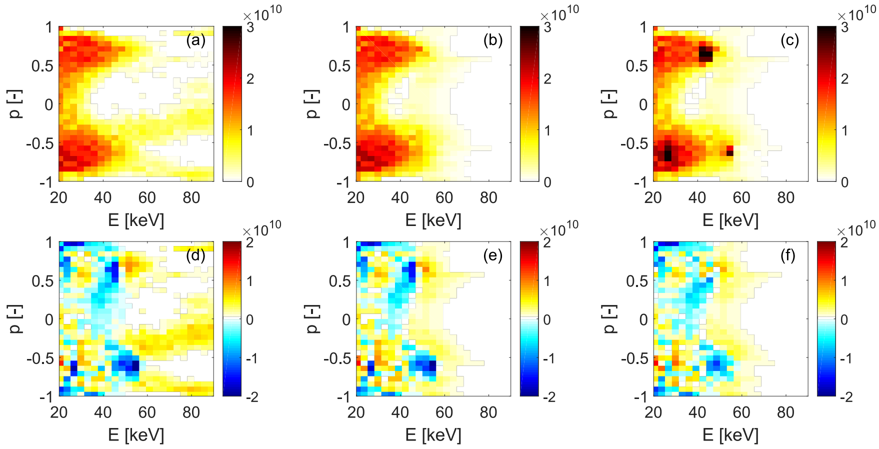

Figure 3: *Reconstructions of the fast-ion velocity distribution from the synthetic signals in Fig. 2 using (a) non-negativity, (b) non-negativity and null-measurements, and (c) non-negativity, null-measurements and known peak locations as prior information. Panels d-f give the pixel errors of panels a-c relative to the true solution in Fig. 1a.*

struction using only non-negativity (panel a) as prior information captures well the shape of the true distribution but is plagued by artifacts at high energies. These are suppressed when including null-measurements in the reconstruction (panel b). However, still the peaks at the injection energies are not captured. This can be overcome by penalizing the solution norms less at the known peak locations (panel c). With this method, the true distribution is well-reconstructed over all pitches in the energy range $20-65$ keV yielding that changes in both the passing and trapped fast-ion population can be reliably investigated by tomographic inversions using the dual-view FIDA diagnostics at EAST.

Conclusion

Using synthetic measurements, we have demonstrated the possibility of doing fast-ion velocity-space tomography from the dual-view FIDA diagnostics installed at EAST. We show that the inclusion of prior information in the zeroth-order Tikhonov inversion method is necessary in order to suppress clear artifacts in the solution. Combining non-negativity, null-measurements, and known peak locations results in a reconstruction that captures the structure of the true distribution well. Velocity-space tomography based on real FIDA measurements at EAST will be demonstrated in the near future.

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