# Modeling Fast Ion Losses in JET Deuterium Plasmas Supported by Measurement

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## Faraday Cup Fast Ion Loss Detector Array

JET contains an array of Faraday cup fast ion losss detectors (FILDs) capable of providing energy and spatially resolved energetic particle losses.[1] The array consists of five strucures,

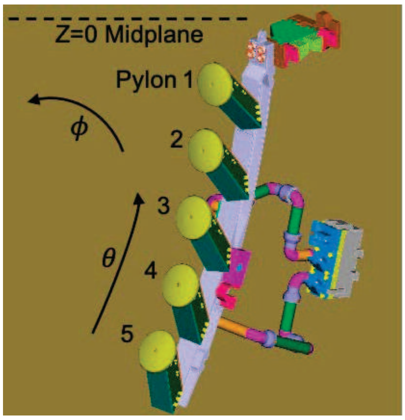


Figure 1: Faraday cup detector array with labeled "Pylon" structures containing 3 radial Faraday cups each. Toroidal, $\phi$, and poloidal, $\theta$, directions are given for reference.

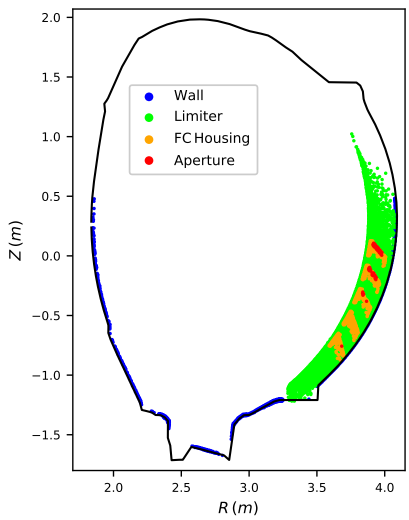


Figure 2: Modeled lost ion positions with finite Larmor radius effects in ORBIT.

previously referred to as "pylons", each containing up to three Faraday cups. The detector structure is shown in Figure 1. Each Faraday cup is composed of conductive Ni foils separated by insulating mica layers. This establishes an energy resolution for an incident ion depending on its penetration depth. The Faraday cup array has undergone recent improvements to its data acquisition system that have resulted in enhanced, and new, measurements as well as improved analysis techniques.[2] In particular, losses due to low frequency MHD activity are particularly well resolved which are aptly suited for numerical transport studies. By synergistically combining experiment and modeling, more information can be garnered from the physical scenario than with just measurement or computational simulation alone.

**An Integrated Model for Fast ion Transport and Synthetic Losses**

An integrated energetic particle transport model has been constructed capable of reproducing realistic losses in JET plasmas. The model has been designed to replicate measurements

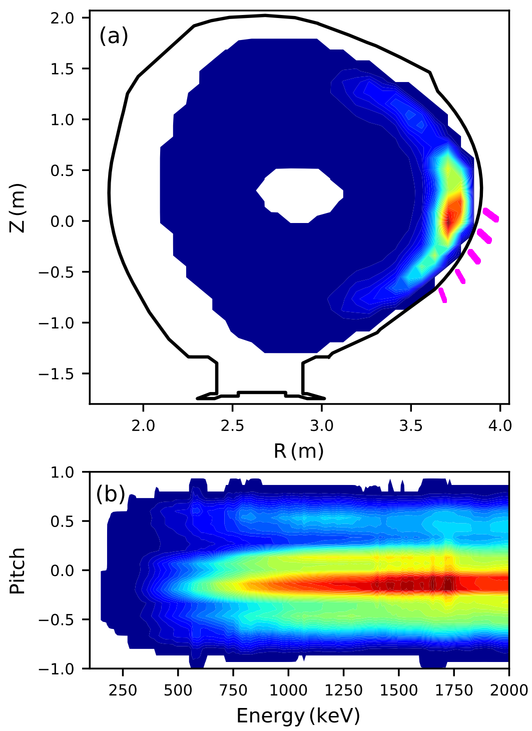


Figure 3: Intensity of the exact loss distribution produced from reverse integratinig orbit trajecctories from the Faraday cup apertures into the plasma region in (R,Z), (a), and (E,pitch), (b).

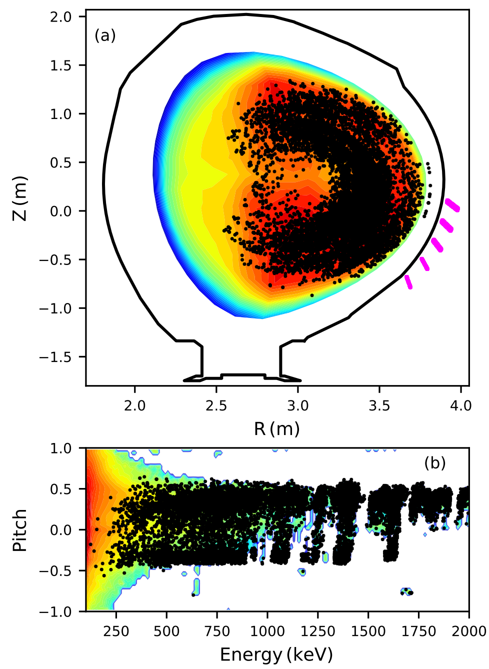


Figure 4: Initialized particles used in ORBIT biased against the reverse integrated loss distribution overplotted on the TRANSP calculated energetic particle distribution in (R,Z), (a), and (E,pitch), (b). Faraday cup apertures are shown in magenta for reference.

from JET's thin-foil Faraday cup fast ion loss detector array. The loss model is composed of the TRANSP[3] and ORBIT-kick[4] codes with enhanced features for producing the synthetic diagnostic. Extensions to the ORBIT code allow a full-orbit representation within the vacuum region that can map particles directly to the detector geometry such as that shown in Figure 2.

A novel reverse integrated biasing scheme has been implemented to enhance the loss statistics often plagued by synthetic loss detectors and boost computational efficiency.[5] An ad-hoc, full orbit, reverse integration code is used to construct an exact loss distribution, shown in Figure 3, that is biased against the TRANSP distribution skewing the particle sampling toward loss detection as shown in Figure 4. This methodology discards strongly confined orbits unlikely to be lost and favors those that do, thus allowing for a lower number of simulated particles to be used for improved computational efficiency.

The TRANSP calculated energetic particle density is taken as marker weights for the particles which are tracked to a realistic Faraday cup FILD geometry in ORBIT as a result of some supplied perturbation. The marker weights are ensembled across all ion species of interest and foil energy ranges to produce the final synthetic lost ion flux. The Faraday cup FILD is not absolutely calibrated, so only a relative flux can be produced.

**Model Results**

The model has been verified against a JET deuterium discharge with modest NBI and ICRH power. The JET pulse exhibits robust kink mode induced losses. The kink modes are modeled

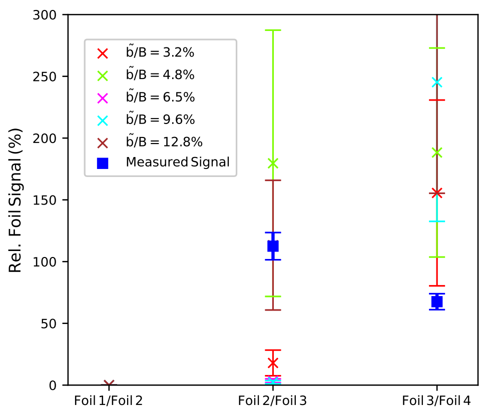


Figure 5: Relative lost ion signals from experiment (squares) and synthetic loss model (crosses) for various kink mode amplitudes. Note that Foil 1 of experiment is discarded due to noise.

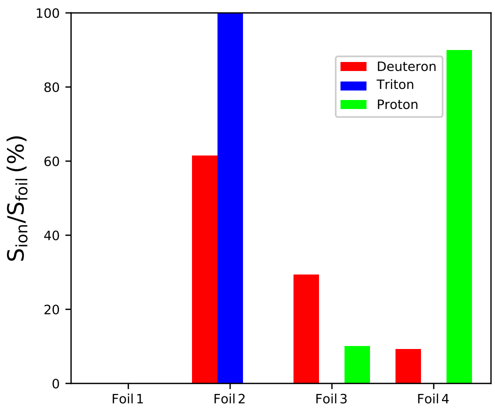


Figure 6: Distributionn of loss signal by ion species found from the synthetic loss model for $\tilde{b}/B$=5%. Note that the triton birth energy is detectable by Foil 2 while the proton birth energy is observed in the slowing portion within Foils 3 and 4.

with an analytical form constrained by experiment.[6] The experimental loss measurements are compared to the model output and found to be in general agreement, shown in Figure 5, across a variety of mode amplitudes. Furthermore, a breakdown of the foil signals by ion species, displayed in Figure 6, demonstrates the model's capability to provide information absent in experiment. Interestingly, no synthetic signal was observed in Foil 1 which could bolster its experimental use in noise correction.[2]

The species dependence of the foils is in qualitative agreement with experiemtal expectation while the total synthetic lost ion flux is slightly overestimated. The model is sesitive to the mode amplitude and holes in the NUBEAM distribution (see Figure 4) which cannot be obtained directly from experiement. Current efforts seek to better describe the NUBEAM distribution and constrain the mode amplitude.

**Conclusion and Ongoing Work**

An energetic particle transport model capable of producing loss signals consistent with experimental measurements from JET's Faraday cup FILD has been constructed. The model is built on the TRANSP and ORBIT code frameworks with newly added features. The TRANSP computed energetic particle distribution is taken as marker weights for the particles which are tracked to a realistic Faraday cup FILD geometry in ORBIT as a result of a supplied perturbation. The marker weights are ensembled across all ion species of interest and foil energy ranges to produce the final synthetic lost ion flux. The model utilizes forward and backward integration techniques in which forward modeled particles are weighted against those tracked backward from the detector. The model was successfully deployed on a JET discharge with kink modes and found to qualitatively agree with measurement with slight uncertainty in the mode amplitude.

Ongoing work includes further expanding ORBIT to calculate reverse integrated particles with a full orbit representation. This would eliminate the need for any biasing as every particle would be detectable upon initialization. Perturbative effects should remain time-invariant, and marker weights summed across the backward calculated paths.

**Acknowledgements**

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Fusion Energy Sciences, under contract number DE-AC02-09CH11466. This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and traiining programme 2014-2018 and 2019-2020 under grant N0 633053. The views and opiinions expresssed herein do not necessarily reflect those of the European Commission.

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