Simulations of divertor target material composition during tokamak plasma operation with continuous boron powder injection

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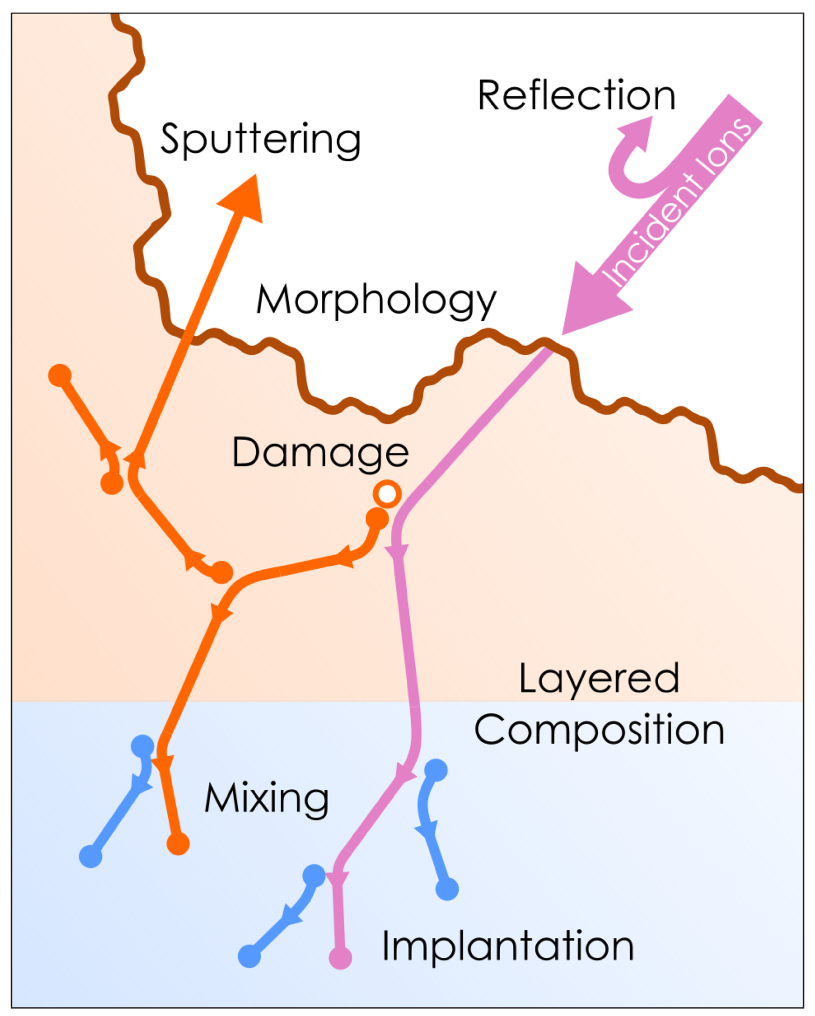
Abstract

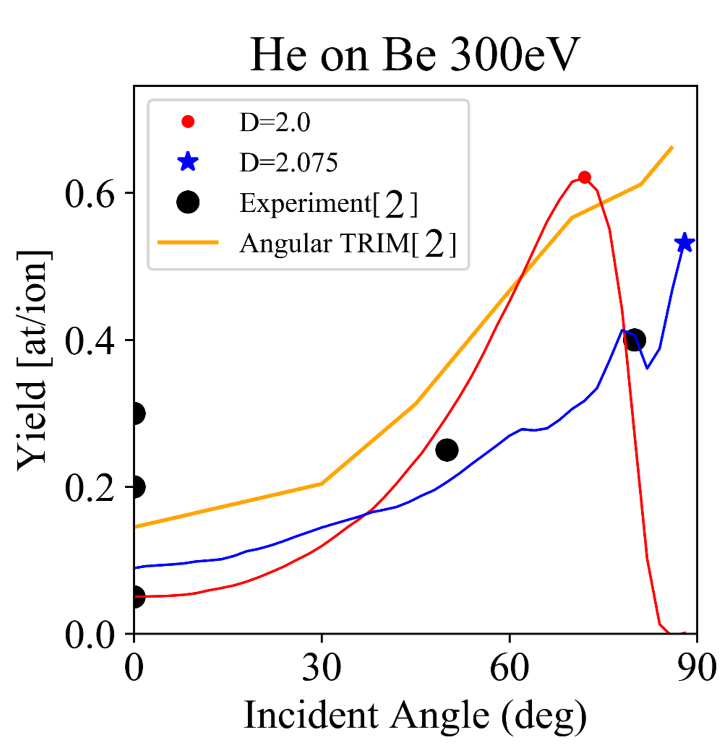
Powder injection may be an effective method to continuously condition fusion device walls during operation. A key scientific question regarding real-time wall conditioning is the feasibility of maintaining a surface layer of injected material (e.g., boron) on a PFC substrate (e.g., carbon or tungsten) while it is undergoing erosion and redeposition. To address this issue, experiments with real-time wall conditioning by boron powder injection have recently been performed in DIII-D [1], which will be interpreted by means of multi-scale numerical simulations. Detailed calculations of the plasma sheath and surface composition resulting from the boron impurity flux on a divertor target will be presented. Impurity fluxes are calculated using the coupled codes UEDGE and DUSTT for plasma edge and dust physics, respectively. The particle-in-cell code hPIC is coupled to the binary collision approximation code F-TRIDYN[2][3] to determine the surface response and the impurity flux implantation. Simulated material composition of the target after real-time boronization will be presented.

Fractal TRIDYN (F-TRIDYN)

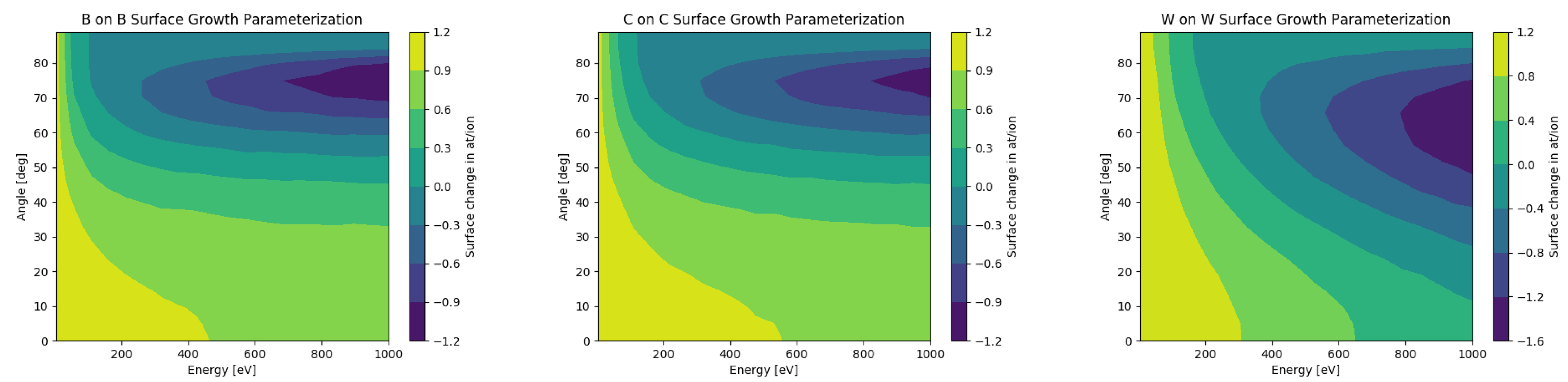
Fractal TRIDYN (F-TRIDYN) is a Monte Carlo, BCA code for ion surface interactions including surface morphology. F-TRIDYN calculates the detailed surface response of complex materials, including sputtering, reflection, and implantation.



F-TRIDYN compares favorably to alternative surface-morphology BCA codes and to the available experimental data of sputtering from rough surfaces.



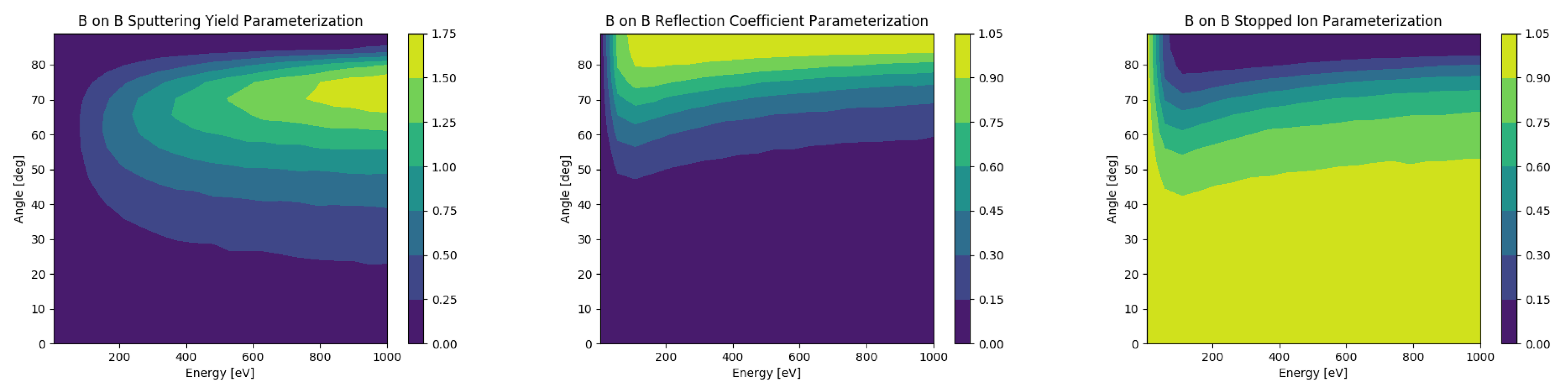
Parameterization of Self-Eroded Atoms per Ion



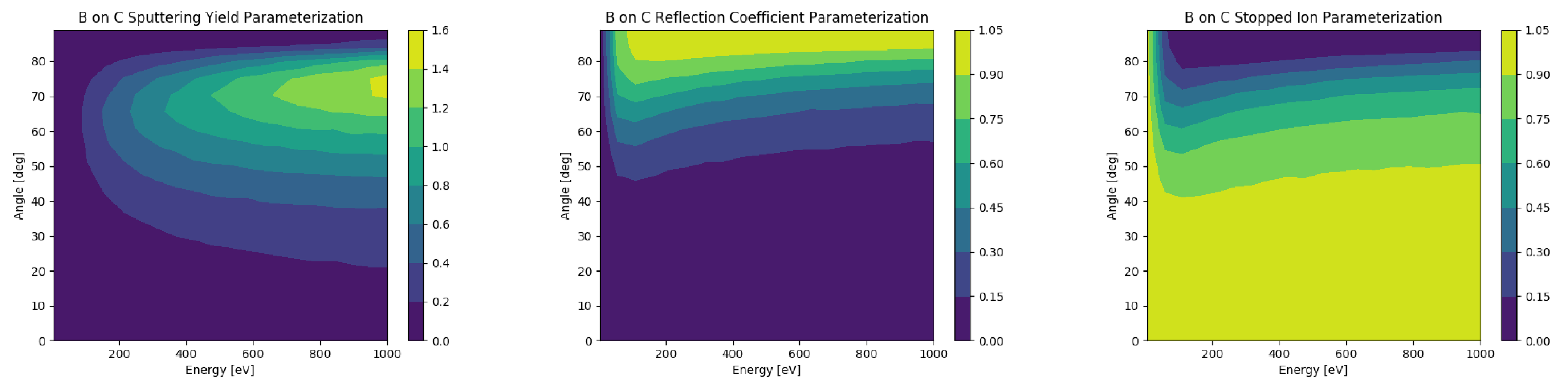
This figure shows the predicted surface change in surface layer atoms for three relevant plasma-facing surface materials. For all three materials, surface growth occurs at low energies and low angles. For complex materials, such as the multilayered, multi-composition surfaces of actual divertors, with multi-species incident flux, full integrated simulations would need to be run.

Parameterization of Surface Response

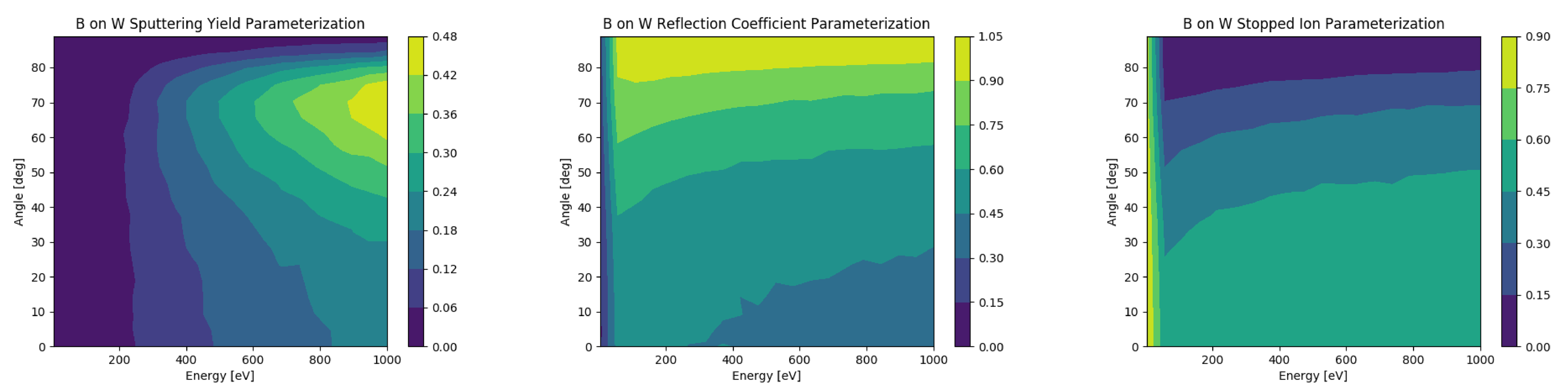
Boron on Boron



Boron on Carbon

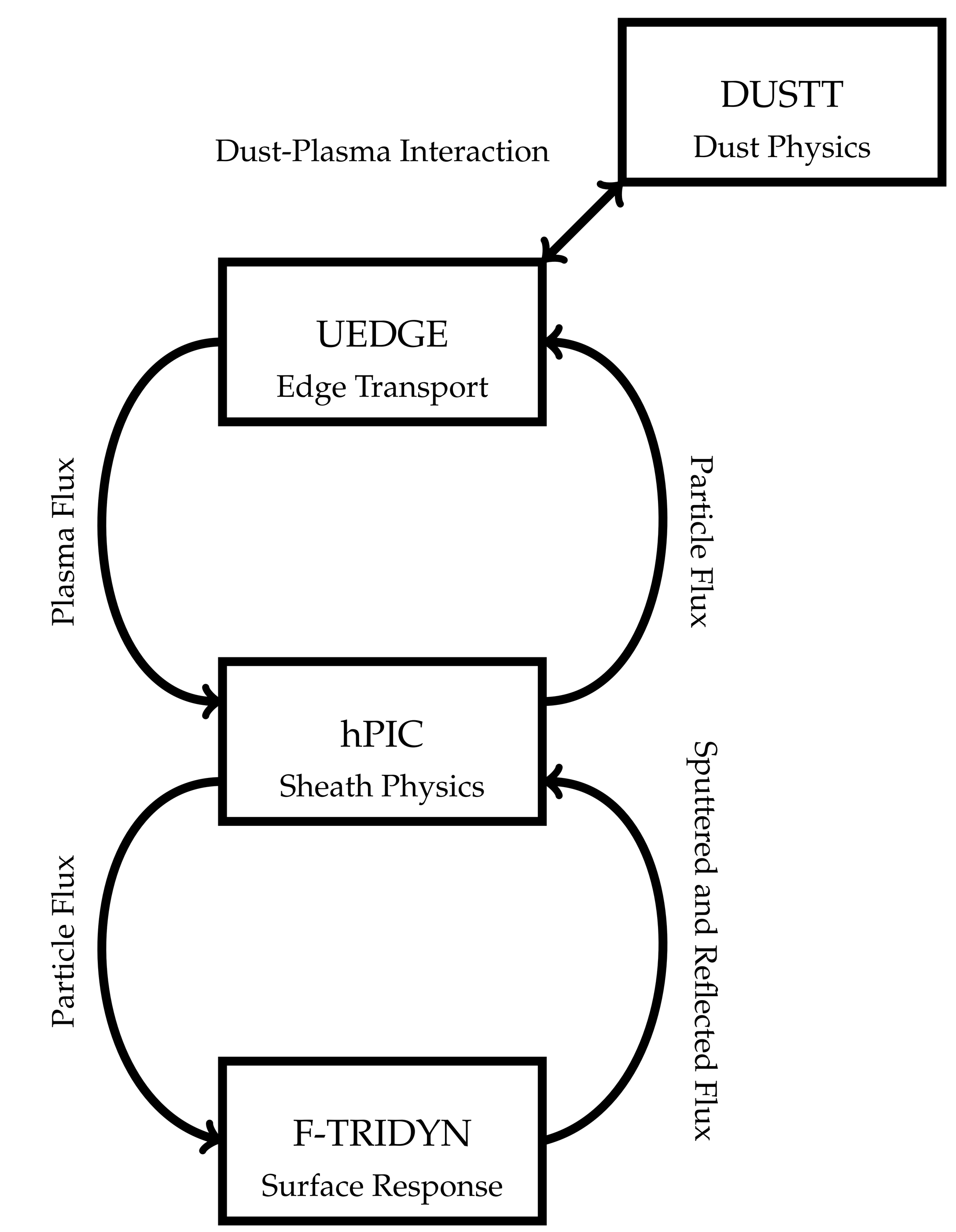


Boron on Tungsten



F-TRIDYN provides a detailed model of the surface response. Incident ions with a particular energy angle distribution will be tracked as they interact with the material of the divertor. Sputtering yields, reflection coefficients, and implantation distributions are used as inputs to other codes. The net erosion can be calculated from the combination of particles gained via deposition and those lost via sputtering. By conducting a parametric sweep from 1.0 to 1000.0 eV for angles between normal incidence and grazing incidence, F-TRIDYN can produce net erosion calculations.

Proposed Workflow



A proposed workflow for simulating the divertor composition is shown above. UEDGE[5] and DUSTT[6] are coupled to provide plasma edge transport and dust physics. Dust particles are tracked until they degrade completely and provide a source of boron particle flux to the plasma. UEDGE solves for the physics of the plasma edge and provides resultant fluxes to hPIC[7] to model the plasma sheath.

hPIC is a particle-in-cell code designed for high performance computing. hPIC takes incident plasma fluxes and calculates the physics of the plasma sheath, including the resulting fluxes on the plasma-facing mateirals.

F-TRIDYN is a BCA code that takes incident ion energy angle distributions and solves for the surface response, including reflection, implantation, and sputtering. Energy angle distributions of particles leaving the surface are provided back to hPIC.

This workflow provides an integrated multiphysics suite for predicting the thickness and quality of boron layer thickness after continous powder injection.

References and Acknowledgements

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