Measurement of Limiter Particle Fluxes and Carbon Erosion in the Helical Scrape-Off layer of Startup Plasmas at W7-X

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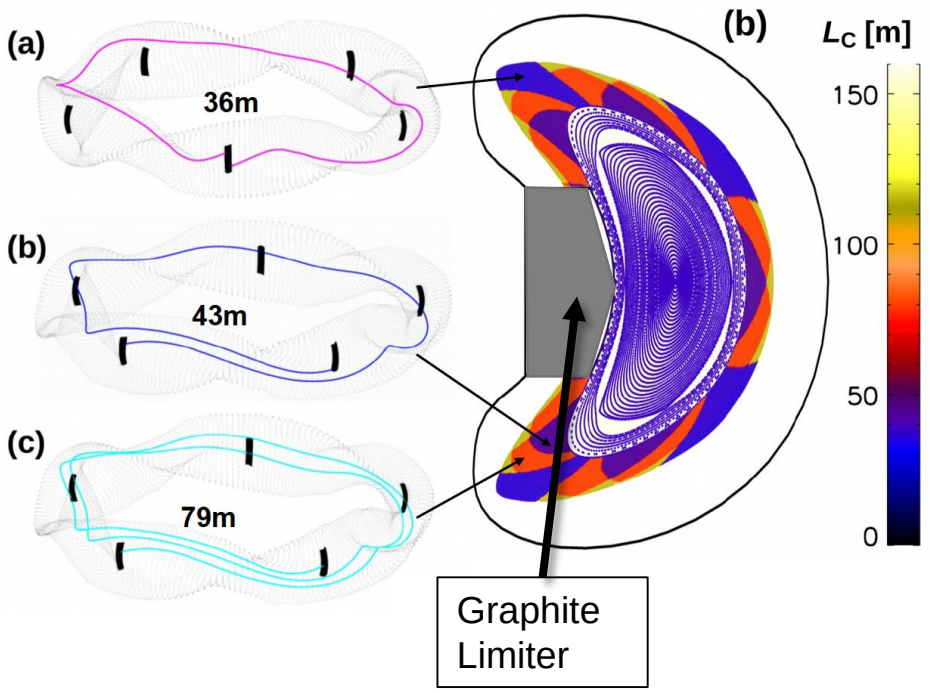
Motivation: carbon erosion affects plasma performance

- **Carbon erosion and transport** in W7-X is important for plasma performance

- Erosion/Deposition pattern provides information on the **3D aspects of PWI in optimized stellarators**

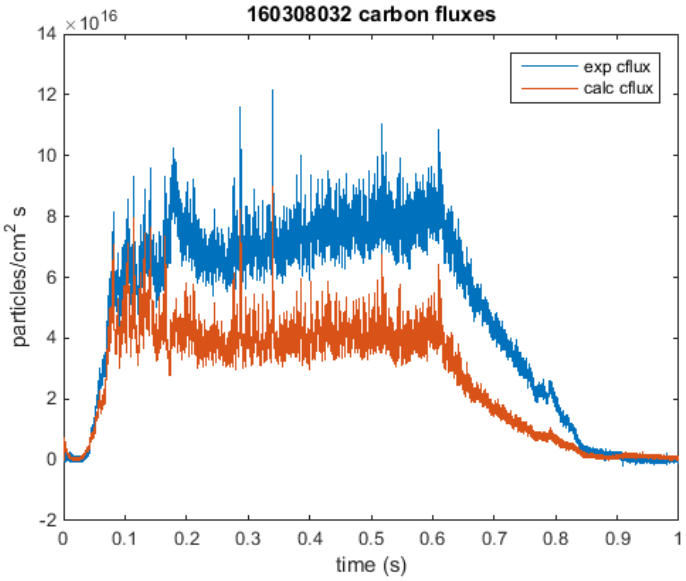
- This topic is tackled both with modelling and experimental techniques:
  - EMC3-EIRENE/ERO and Materials Analysis (collab with FZ Jülich)
  - Filterscopes (Oak Ridge)
  - Visible/IR camera (Los Alamos)
  - STRAHL and LBO (IPP)

Helical Scrape-off Layer Geometry

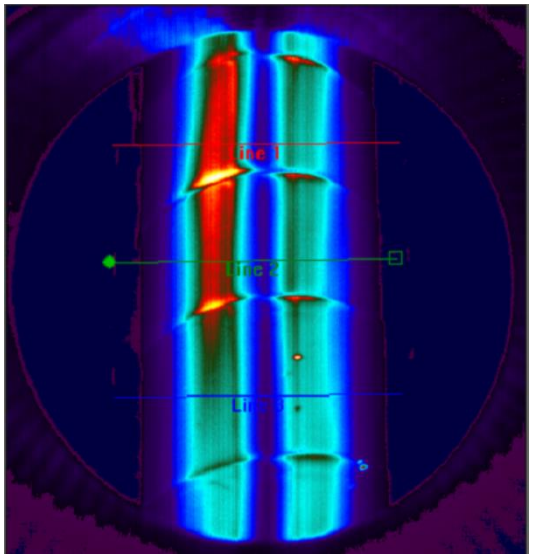


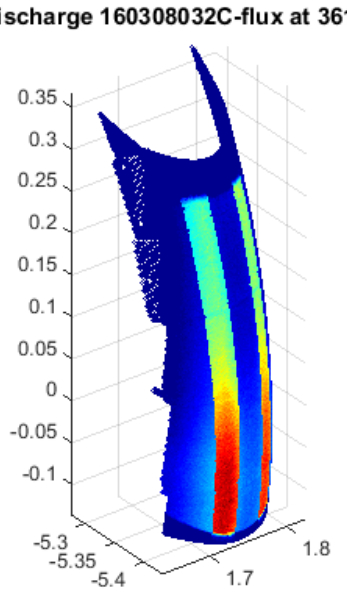
F. Effenberg. IAEA FEC 2016

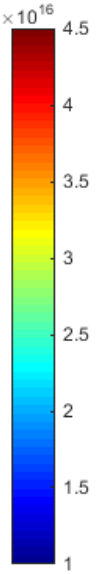
In-Situ measurements provide a first estimate of the impurity source from carbon



160308032 IR Image

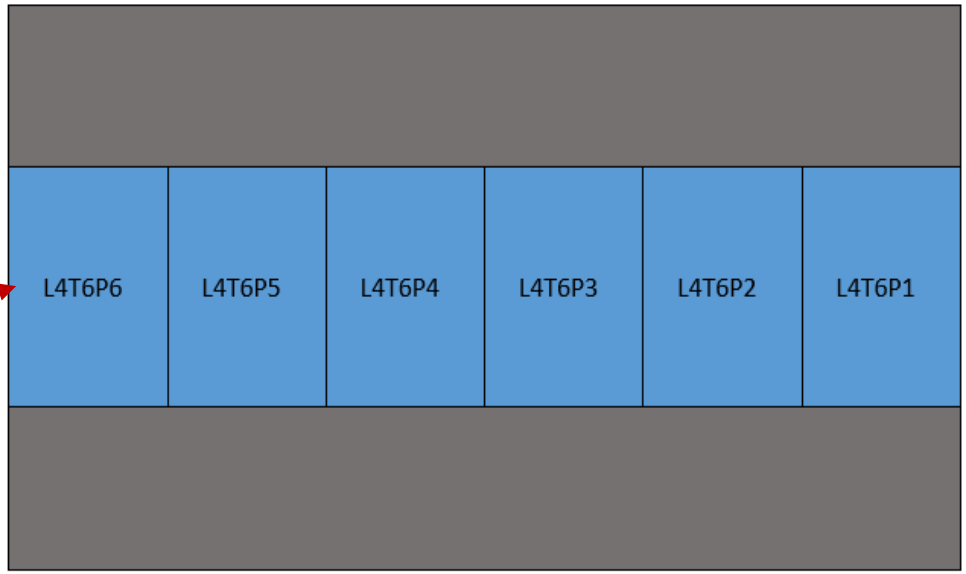






- Calculated C-flux from H-Alpha measurement (SXB conversion + Roth formula + Physical sputtering from TRIM) matches to results found experimentally
- Suggests majority of erosion happens in high heat flux regions: confirm with post-mortem analysis

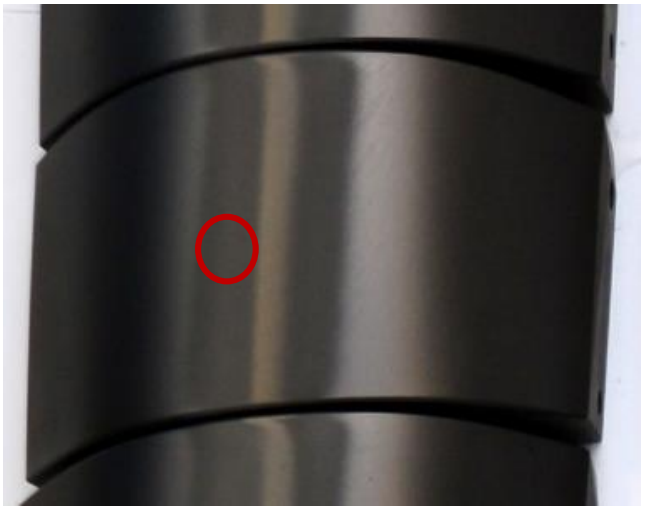
Post mortem analysis (SEM, FIB, EDX) is being done in collaboration with FZ Jülich

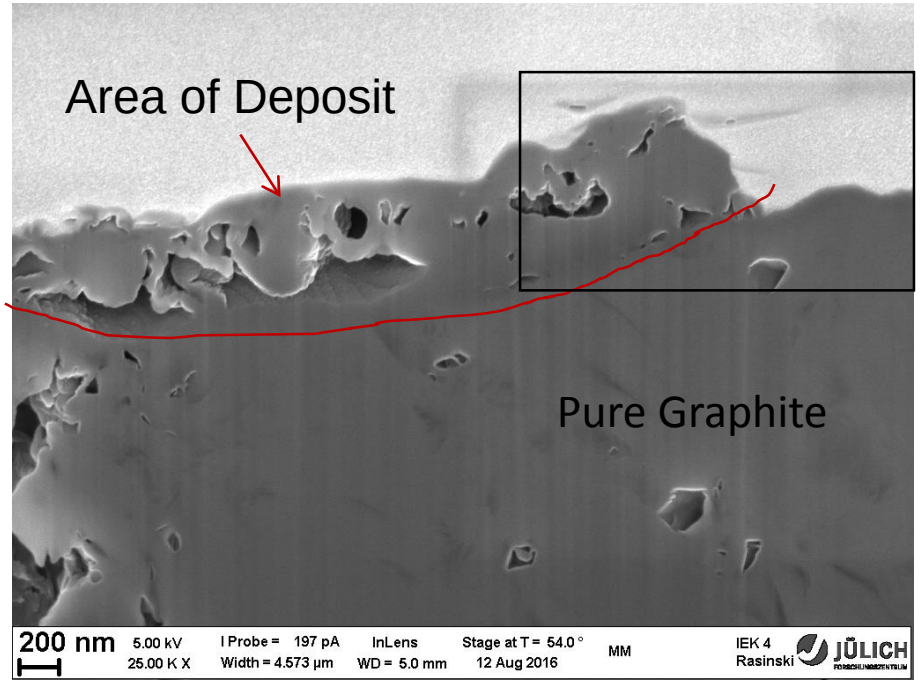


- Tile surface morphology left-right symmetric
- All deposits contain O with trace amounts of S, Cl, and Cu

FIB cutting on Piece 4 (rough stripe region) and Piece 6 (edge region) to determine depth of deposits

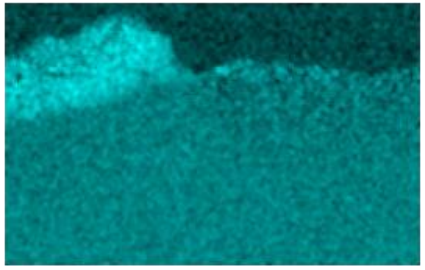
Rough stripe region of tile appears to have both erosion and redeposition



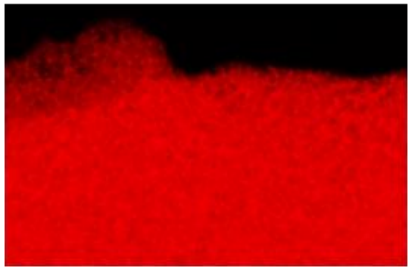


- Deposition not uniformly distributed in this region
- Deposit is rough and porous-possible signature of local plasma effects

O Wt%



C Wt%



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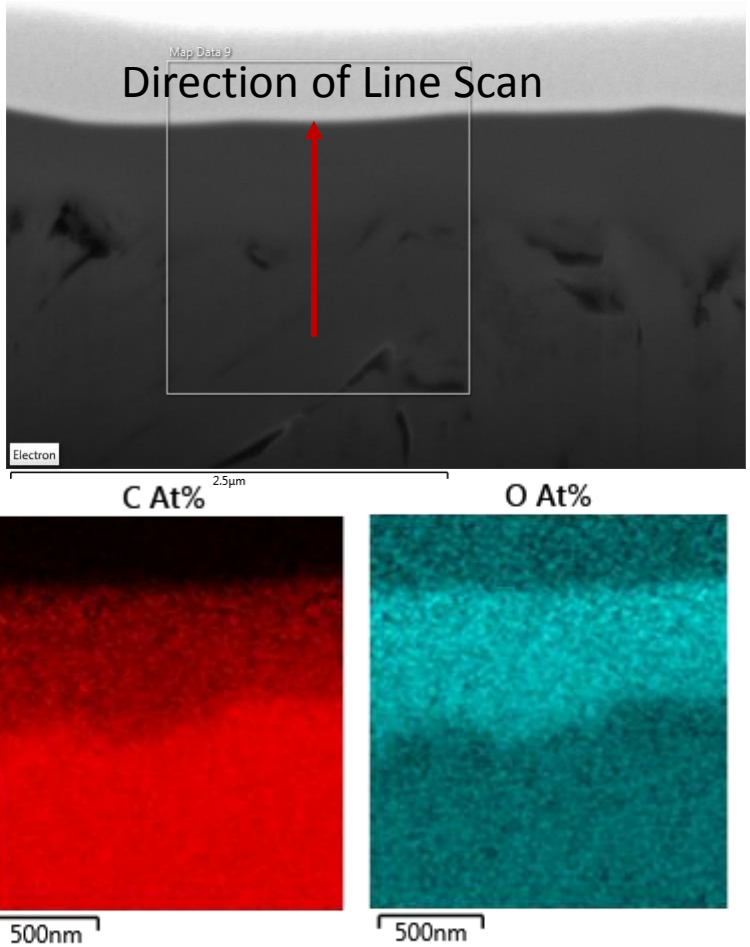
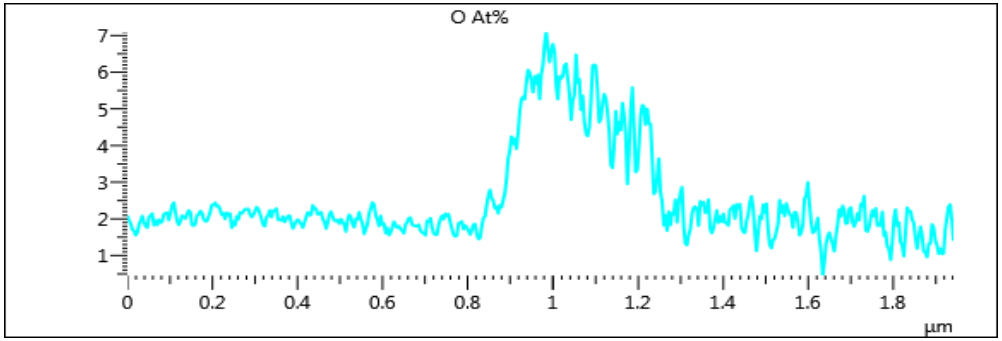
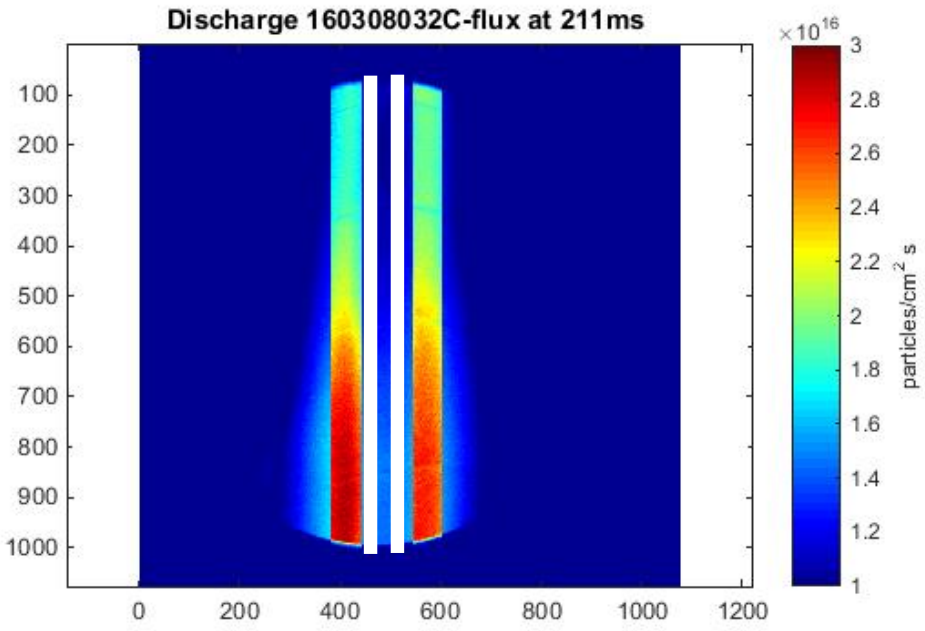
Edge region of tile shows uniform deposition



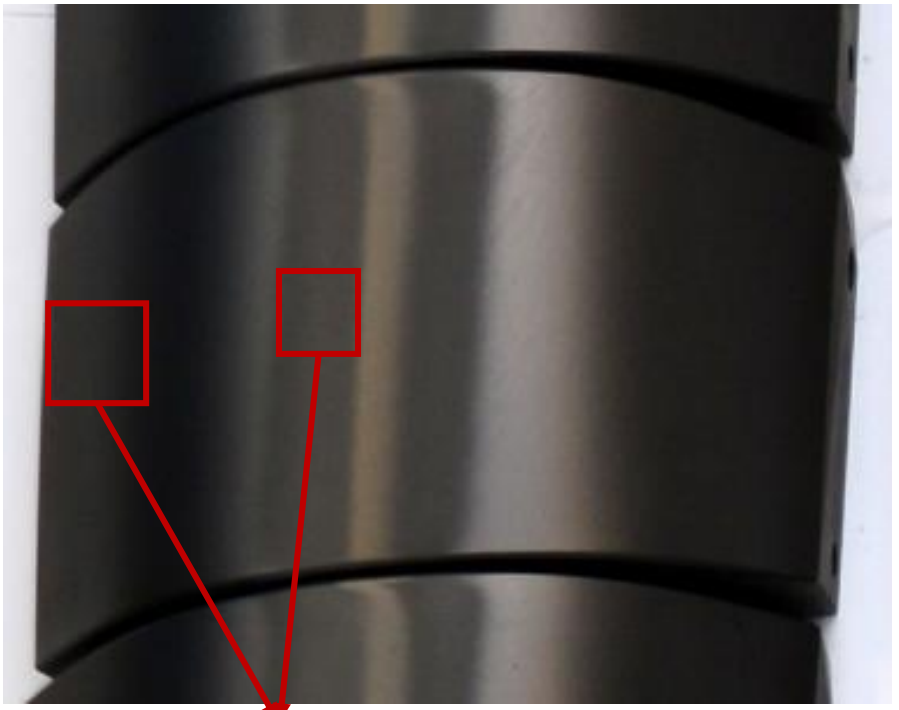


- Deposits between 350nm up to 1µm
- Smooth and dense on the surface - possible signature of background plasma effects

Spectroscopy and materials analysis results show good agreement with one another



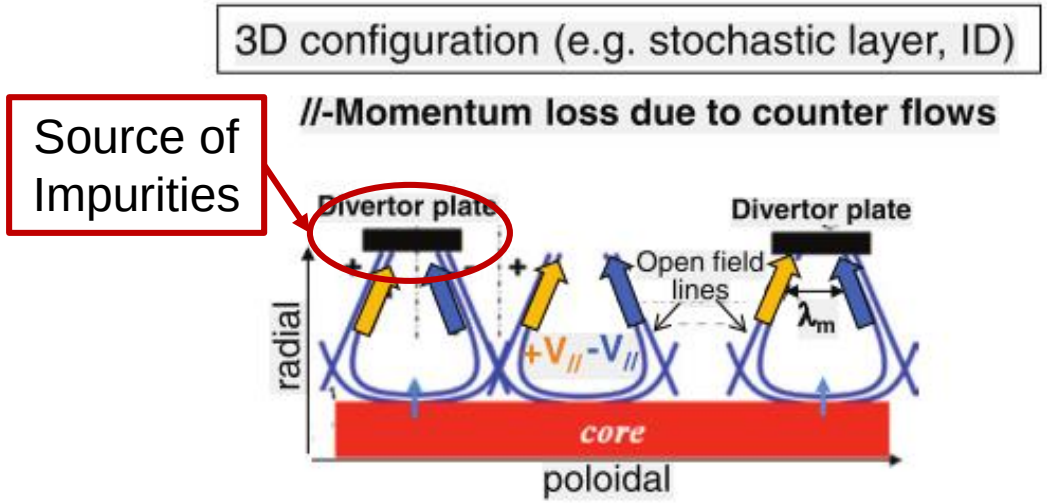
Overlayed white lines correspond to rough stripe locations



FIB analyzed samples where deposits were found

- Areas found without deposits were located within the high heat flux regions as well as the very middle of the limiter
- Insight to why Limiter 1 lacks the rough stripe regions: higher heat flux could have eroded them away

Moving forward in OP1.2: linking material physics and edge impurity transport



[1] M. Kobayashi *et al.*, "3D effects of edge magnetic field configuration on divertor/scrape-off layer transport and optimization possibilities for a future reactor," *Nucl. Fusion*, vol. 55, p. 22, 2015.

- Impurity source linked to level of erosion/deposition in divertor region as well as ability to transport through the island divertor
- Use In-Situ spectroscopy to measure source amount coming from divertor/scraper element
- Use calibrated sources of different energies (gas puffing, LBO), to measure how impurities penetrate and transport through the island divertor
- Compare experimental results to modeling (STRAHL, ERO, EMC3-EIRENE)

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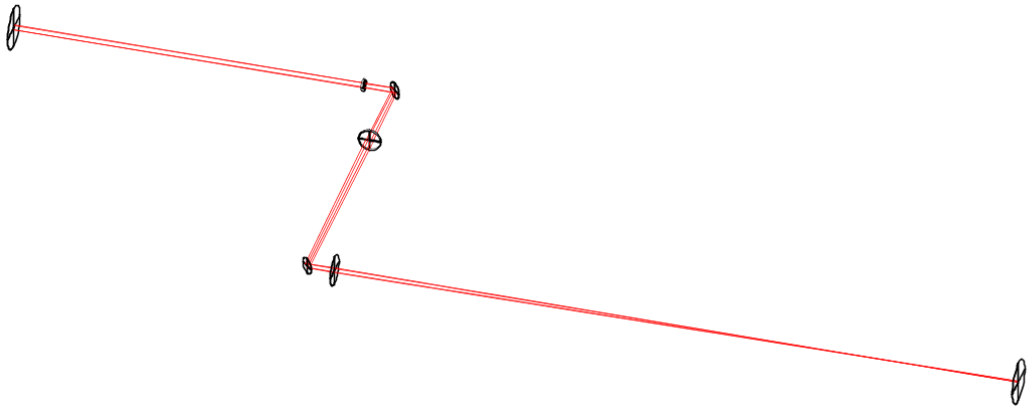
Calibrated source for fast impurities: LBO System



- Calibration of targets will take place at UW Madison
- Idea to try to manufacture a:C-H targets to introduce fast impurity branch
  - Compare this source to eroded source/gas puffing
- See T. Wegner's talk on more details of the LBO system

Conclusions and future work

Conclusions

- In-situ spectroscopy has been shown to be able to predict qualitatively the erosion/deposition pattern on the W7-X limiters

- The rough stripes located near the center of the limiter show rough, porous deposits, which could be a signature of local erosion/redeposition plasma effects

- The edge of the limiter show smooth, dense deposits which could be a signature of background plasma deposition

Future Work

- Analyze other limiter tiles to look for possible toroidal/poloidal dependencies

- Begin ERO analysis for information on how carbon locally transports around limiter

Goal: Define 3-D impurity source and explore penetration through the island divertor: Deliver impurity influx characteristics to neoclassical domain