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Paper Rehearsal:

Fast ion confinement in the presence of core magnetic islands in Wendelstein 7-X

Plasma Phys. Control. Fusion

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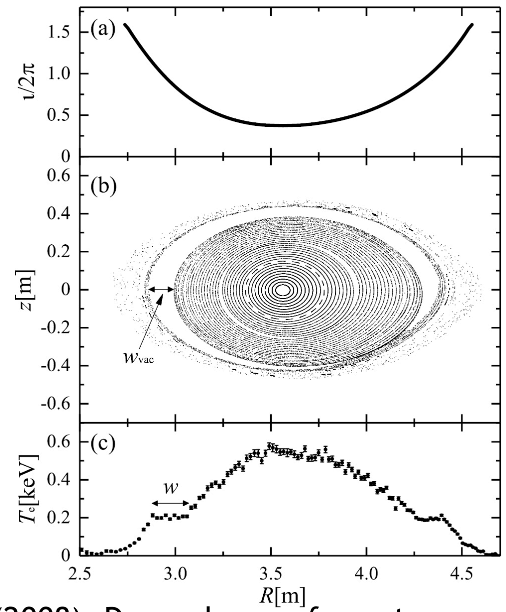
This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

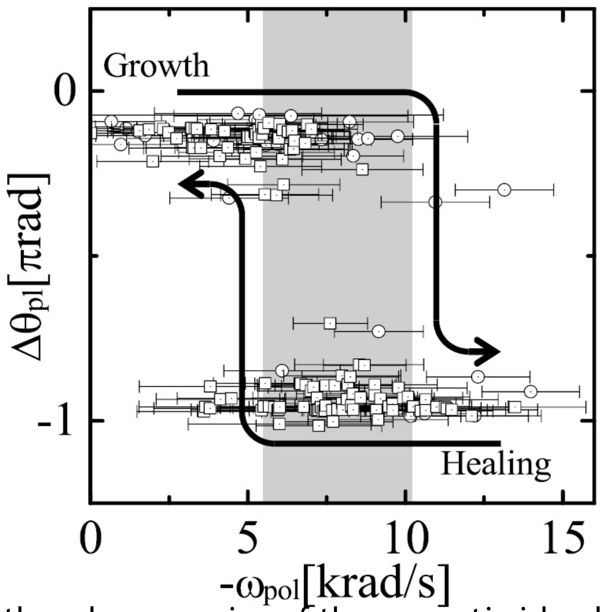
Abstract

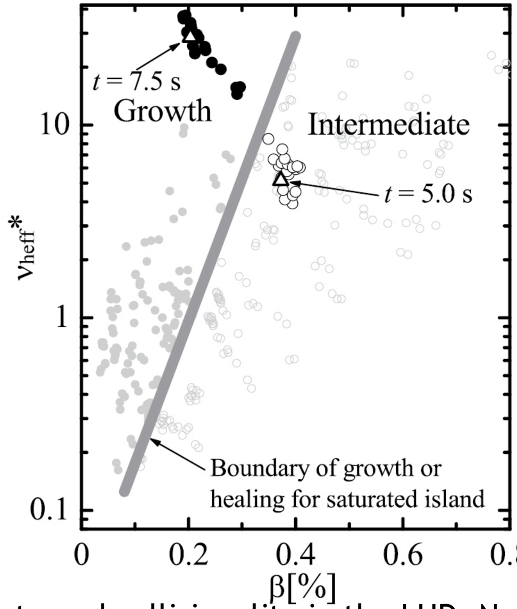
The effect of magnetic islands in the core region of Wendelstein 7-X (W7-X) on fast ion confinement is explored through simulations with the BEAMS3D code. A magnetic configuration where the n/m = 5/5 island chain is shifted to r/a ~ 0.7 allows the exploration of core island physics in W7-X. The control coil system on W7-X allows the tuning of the island size either increasing the island width or decreasing it. A coupling of the BEAMS3D code to the FIELDLINES code provides a versatile mechanism for incorporating magnetic islands and stochastic regions into the BEAMS3D code. Collisionless simulations suggest that the presence of core islands degrade the confinement of passing particles in the region of the island chain. Full neutral beam simulations of W7-X show a similar behavior with confinement decreasing as the island width is increased. Comparisons between a vacuum magnetic field and low beta HINT2 simulation are made showing similar fast ion behavior. Measurements of lost fast ions in W7-X confirm this trend with the control coil suppressed island configuration showing lower losses than that with no control coils applied. Simulations of fast ion wall loads are performed suggesting no drastic change in loss pattern and a slight reduction in losses with minimized islands.

Some background on islands in stellarators

- **The presence (or elimination) of core islands from stellarators has been a longstanding focus of stellarator optimization**
- **Experimental evidence (TJ-II and LHD) suggest that core islands can be 'healed' in the presence of flows.**
- **This is explained through neoclassical effects, analogue to mode penetration in tokamaks**





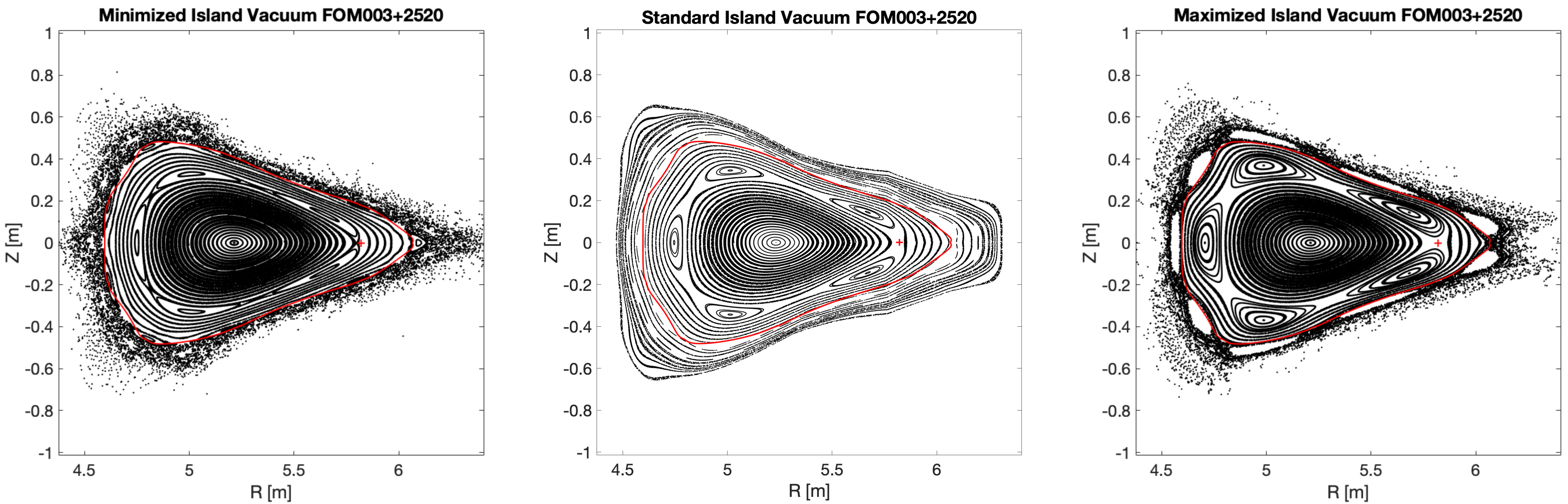


Narushima, Y., et al. (2008). Dependence of spontaneous growth and suppression of the magnetic island on beta and collisionality in the LHD. Nuclear Fusion, 48(7), 075010. http://doi.org/10.1088/0029-5515/48/7/075010

Narushima, Y., et al. (2017). Observations of sustained phase shifted magnetic islands from externally imposed m/n = 1/1 RMP in LHD. *Nuclear Fusion*, *57*(7), 076024. http://doi.org/10.1088/1741-4326/aa6dce

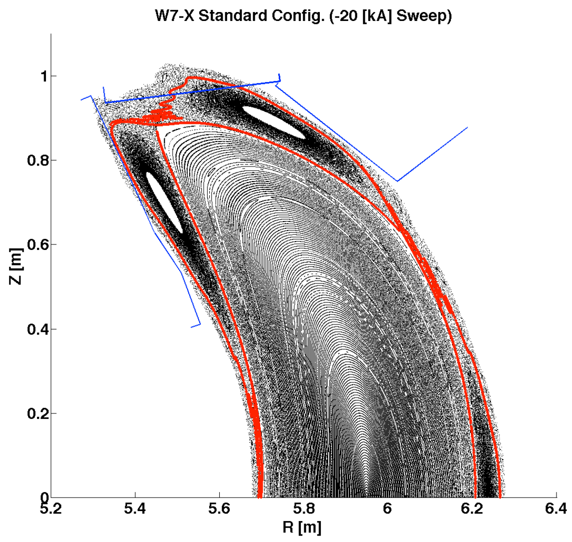
Introduction

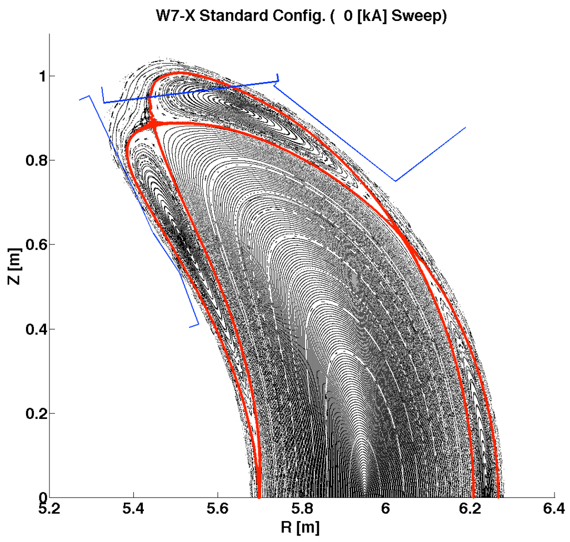
- Fast ion confinement is explored with BEAMS3D in Wendelstein 7-X (W7-X) for the case of core islands (FOM magnetic configuration)
- Leverages new capability to include vacuum and HINT2 equilibria in addition to VMEC
- Small island (VMEC, vac), nominal island (HINT2, vac), and large island (vac) cases
    - Island size controlled in vacuum by control coils
- Collisionless test-particle and NBI simulations performed
- Confinement is compared to measurements made with NIFS-FILD in OP2.1

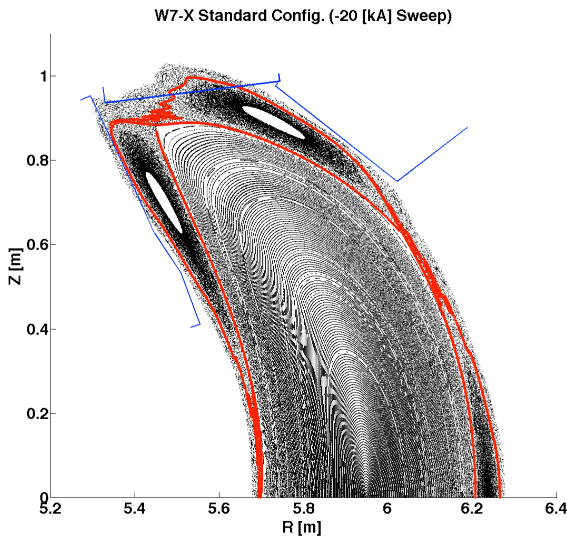


Given magnetic field alone we can now construct background coordinates

- B-Field is required for tracing particles but not background grids (rho, theta).
- A general interface would generate background grids from equilibrium B-field
- FIELDLINES code was modified for this purpose (predecessor of BEAMS3D)
  - Pseudo-return map used for calculating periodic orbits -> finds magnetic axis
  - Field lines are followed to ‘fill’ simulation space
- BEAMS3D uses the field lines to construct minor radius coordinate and create background grid

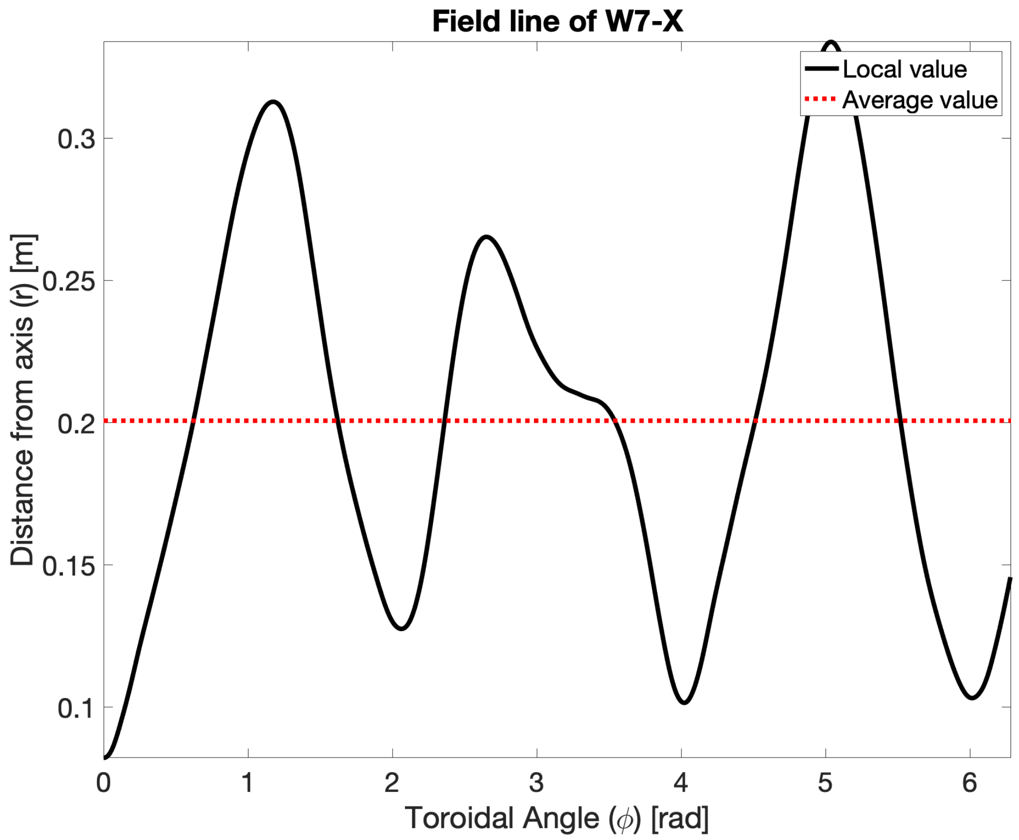


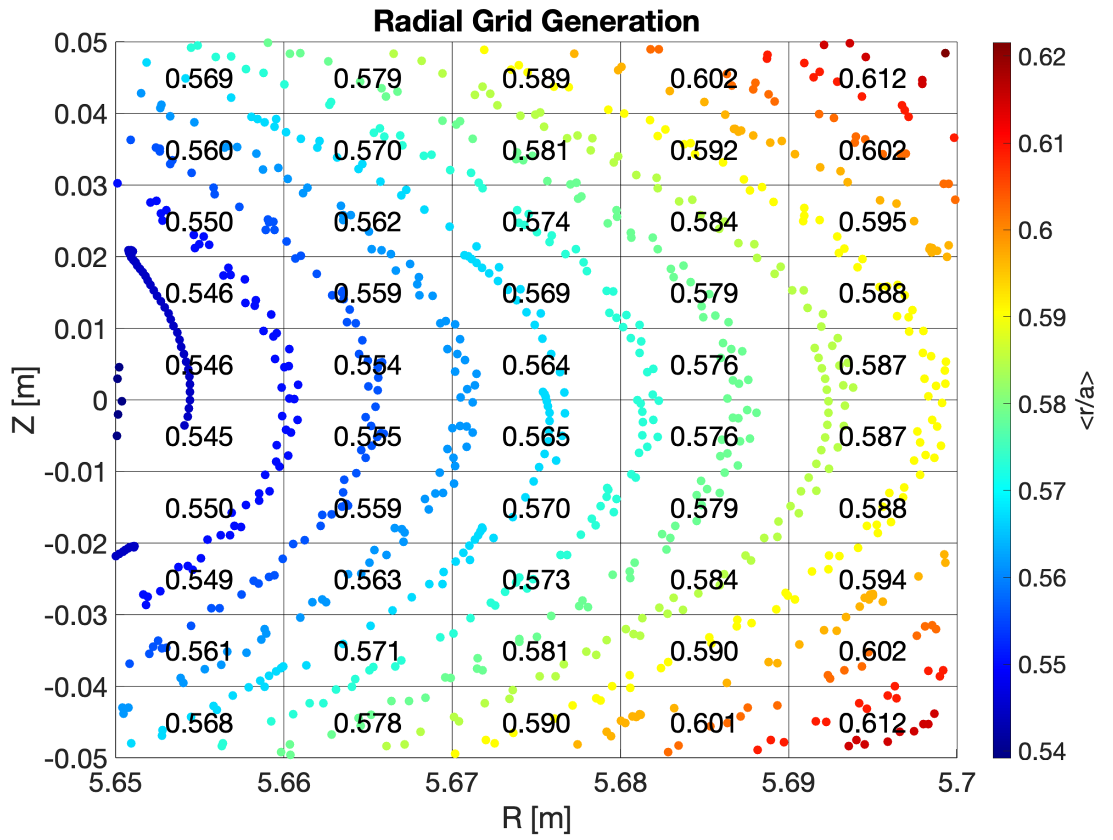




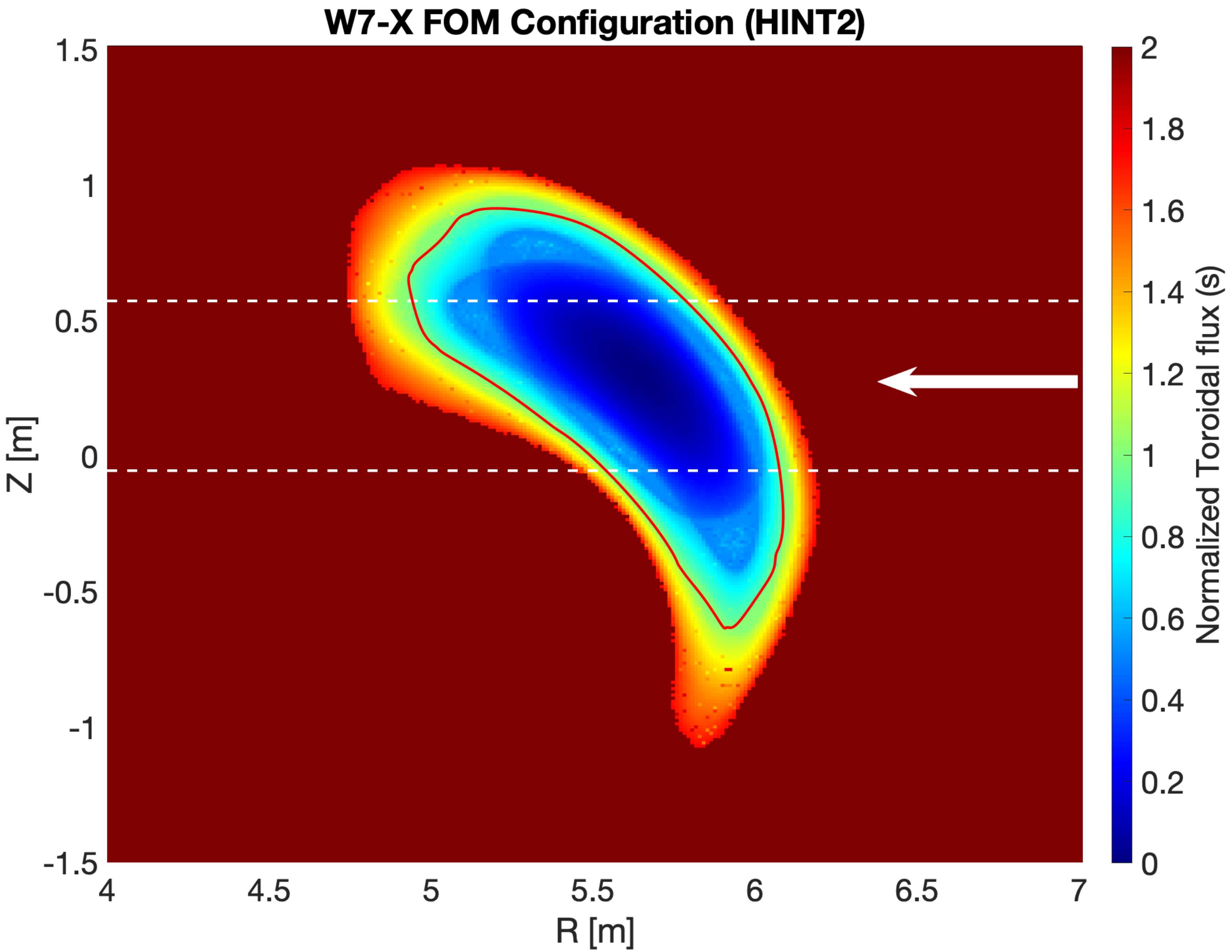
Field line tracing is used to construct background coordinates

- Calculate distance to magnetic axis, use average r/a to label field lines
- Then average value of <r/a> in region of a grid cell.



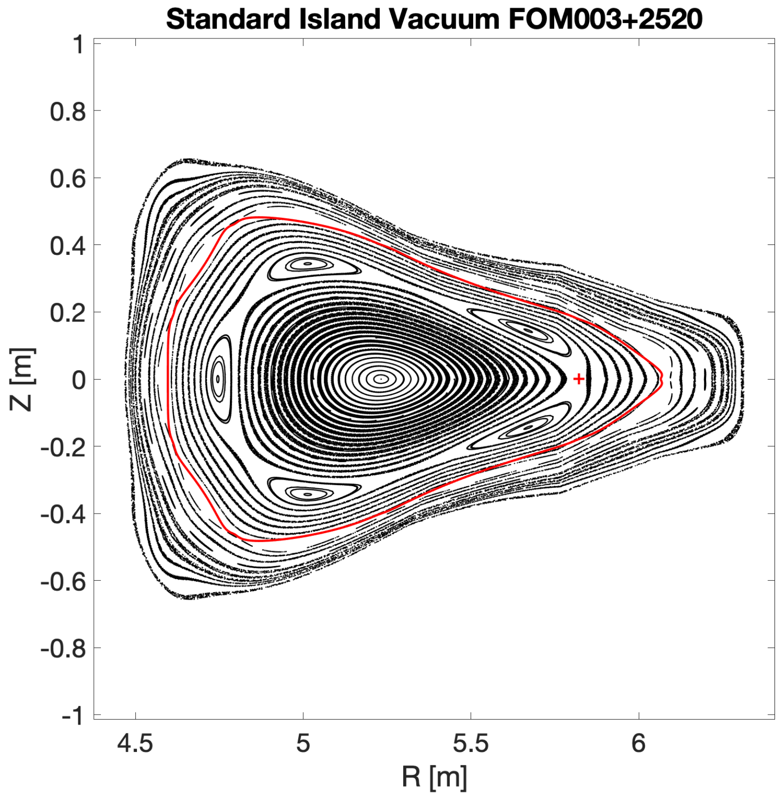


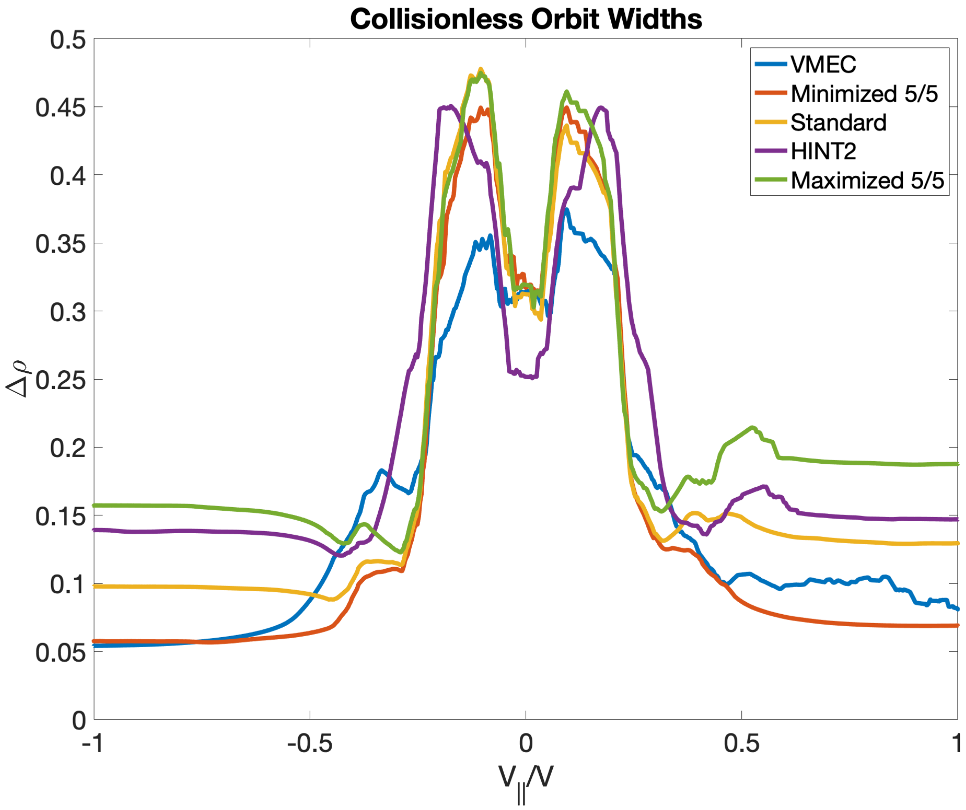
<r/a> grid generated show presence of island



Collisionless orbits are traced with the BEAMS3D code

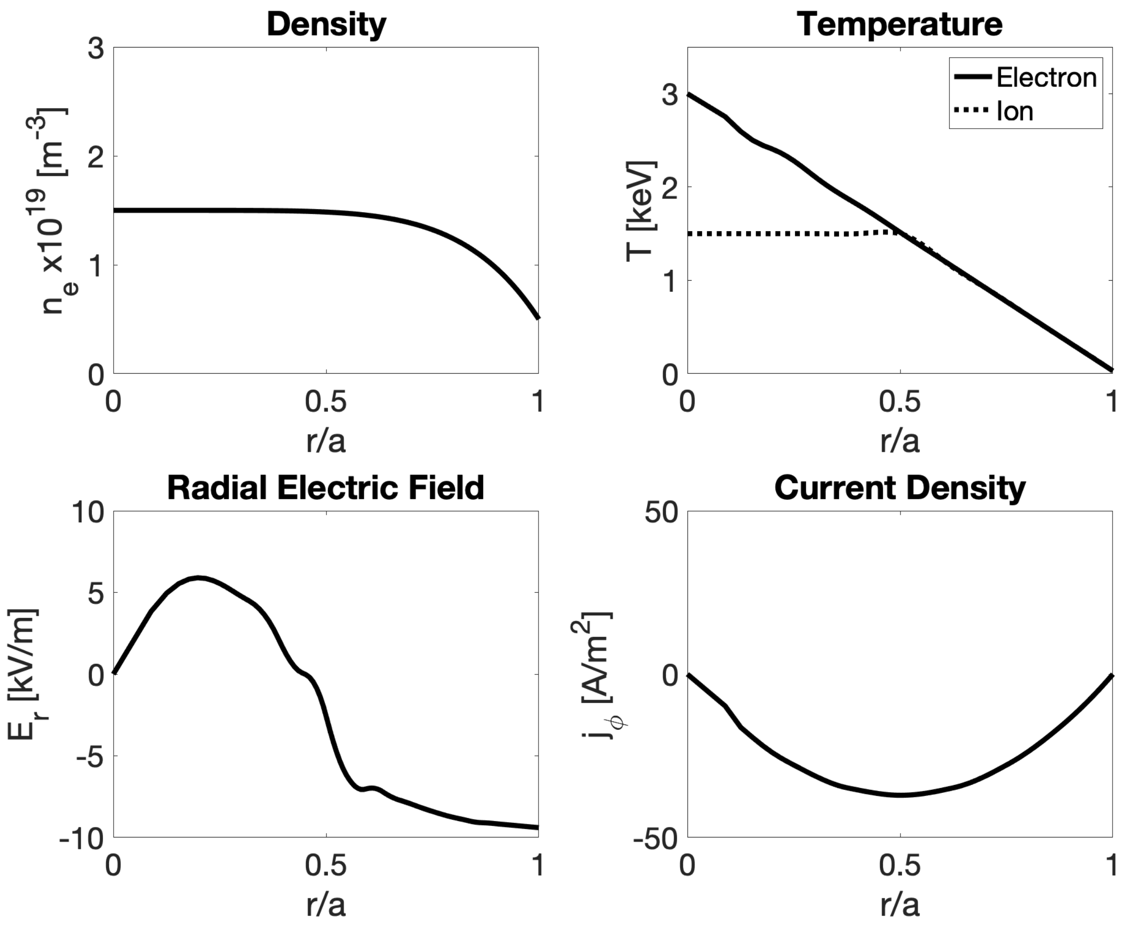
- An array of particles are launched from inside the 5/5 island chain scanning pitch
- Passing particles show scaling of orbit with with island size
- Trapped particles show little sensitivity to island width

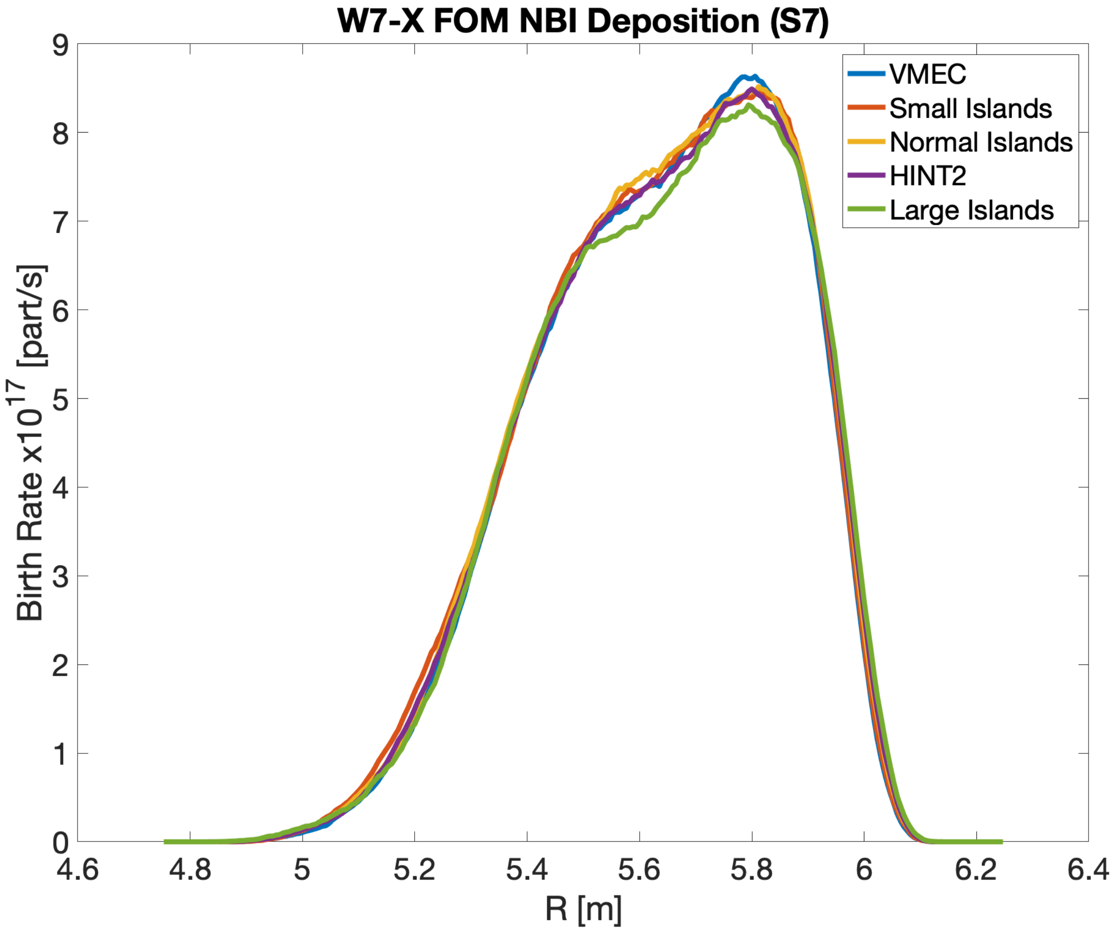




Neutral beam simulations with BEAMS3D

- **BEAMS3D simulations performed with experimentally relevant profiles / sources (S4+S7)**
- **NBI generates predominantly passing particles so island effect should occur.**

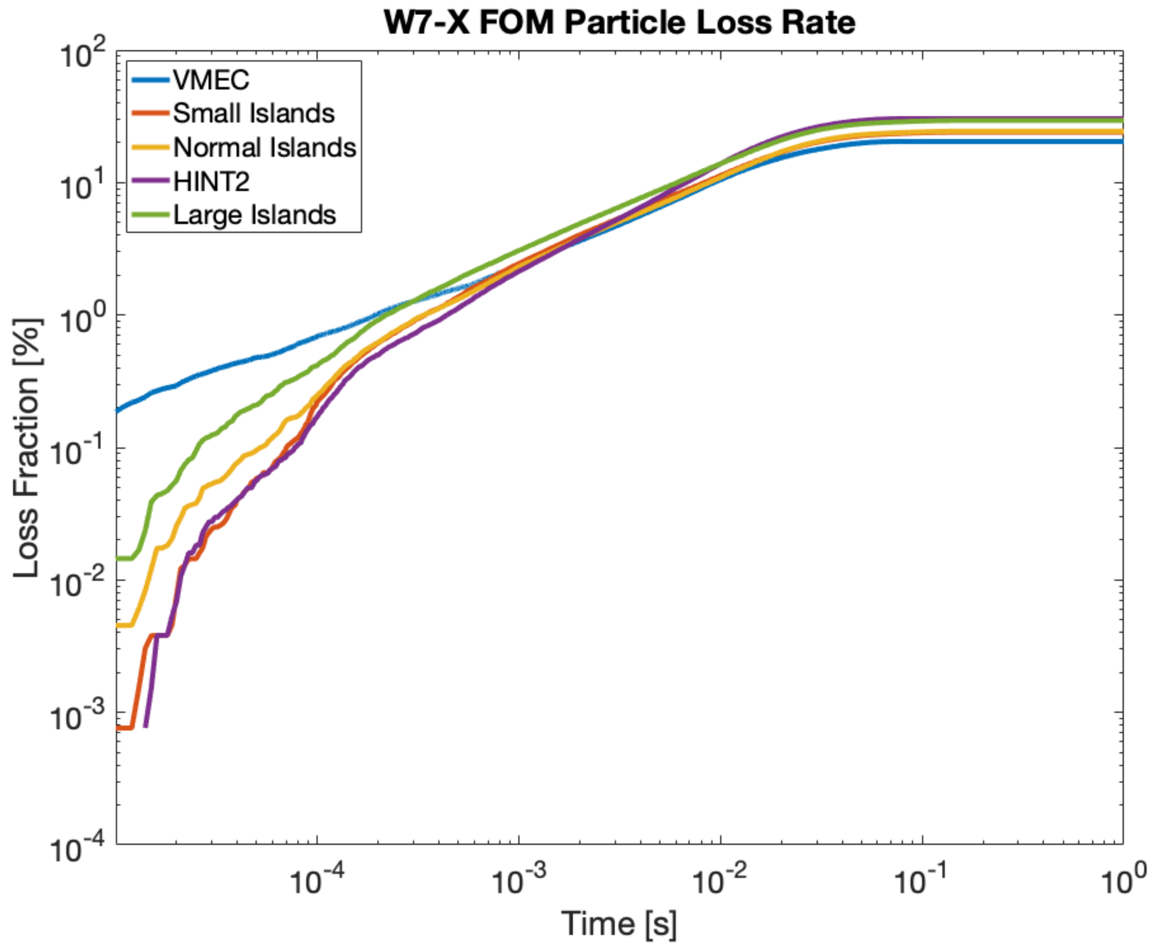




Losses scale with island size as expected from collisionless simulations

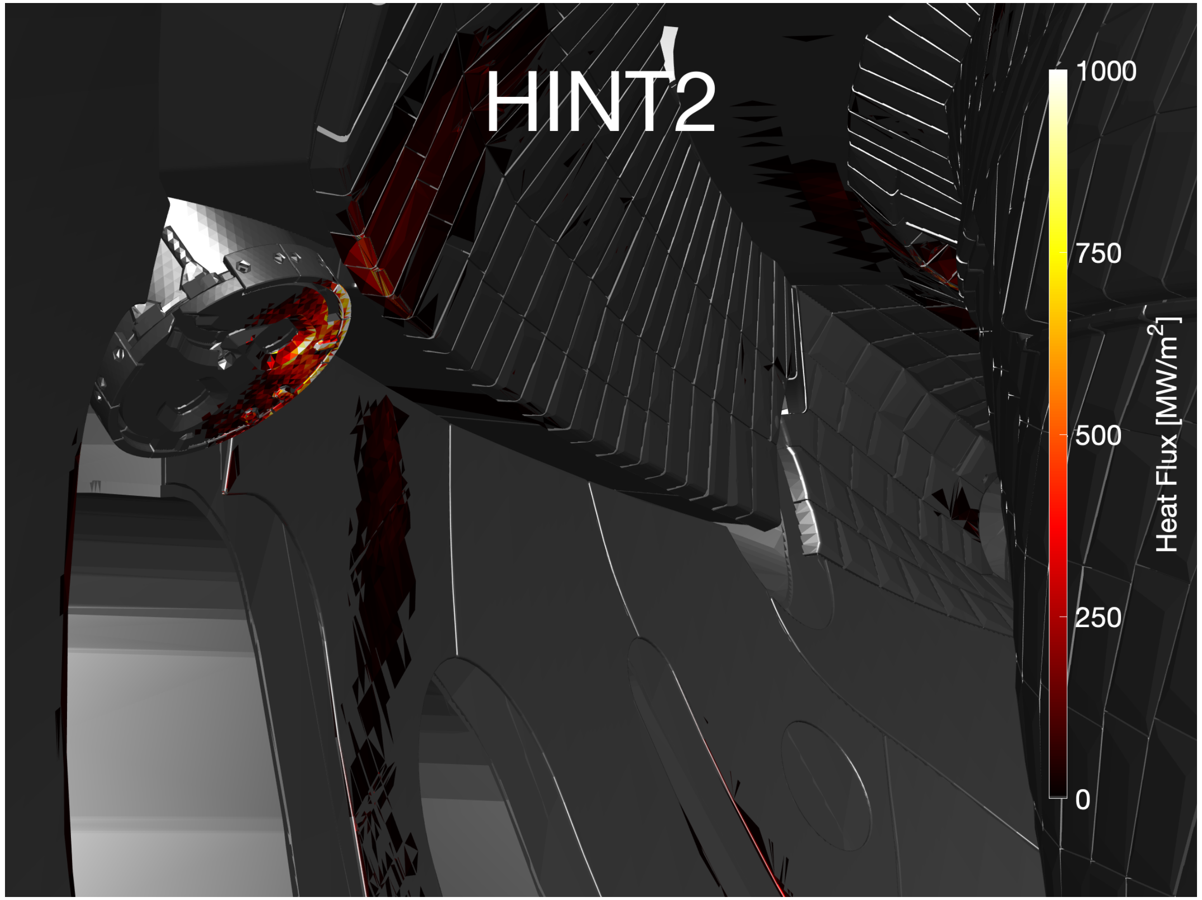
- Larger islands results in more losses.
- VMEC has largest prompt losses
- VMEC total loss tracks small island losses
- HINT2 shows largest losses

Magnetic Field Source	Plasma Heating [kW]	Wall Losses [kW]
VMEC	960	160
Small Vacuum Islands	1020	100
Nominal Vacuum Islands	1020	100
HINT2	920	200
Large Vacuum Islands	980	140



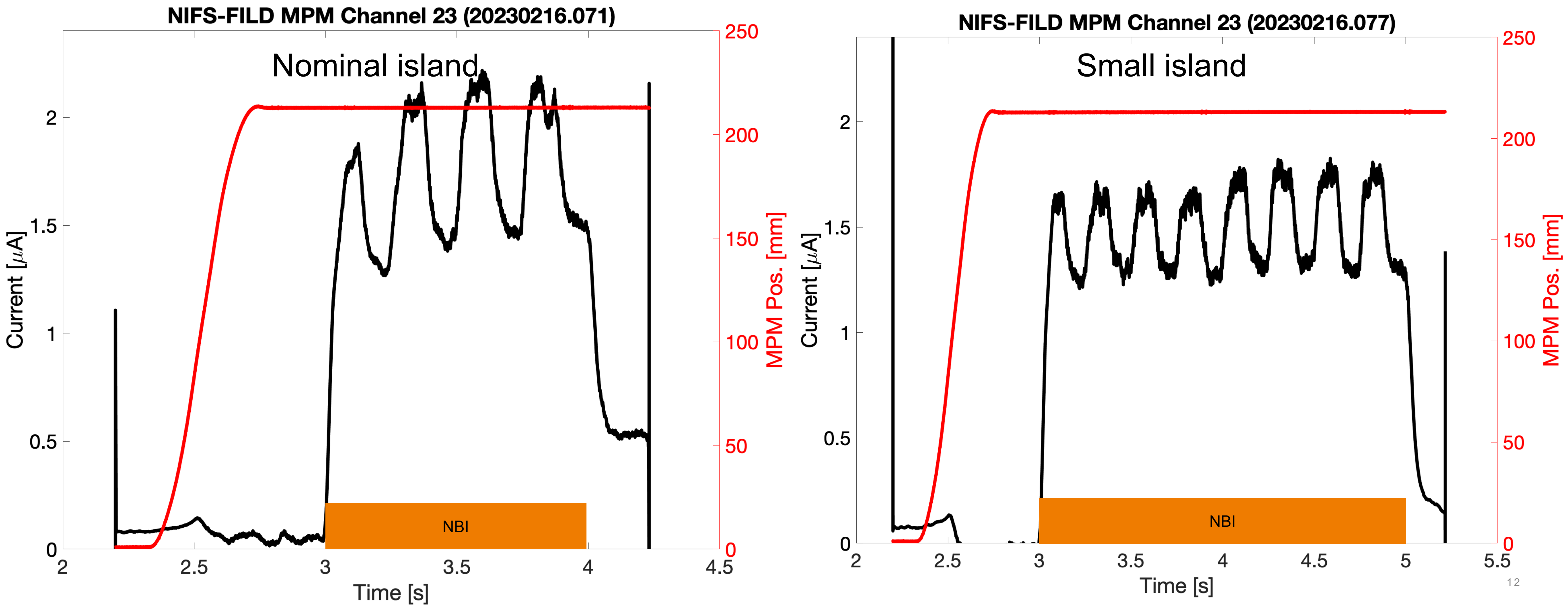
BEAMS3D Gyro orbit simulations performed to first wall

- Initialized for gyro center losses to r/a=1 surface.
- Island size does not show effect on loss pattern
- Local heat fluxes found consistent within numerical noise
- Loads to upper immersion tubes and baffles as in the standard configuration.



Experimental data from OP2.1 confirms scaling of losses with island width.

- S4 continuous, S7 blipped
- NIFS-FILD shows reduced losses with smaller island



Conclusions

- **A new generic interface between BEAMS3D and various magnetic field representations has been developed**
  - **Only requires magnetic field data**
- **Modeling of core islands in W7-X shows strong effect on passing particles.**
  - **Radial transport scales with island width**
  - **Neutral beam simulations confirm this behavior for NBI fast ions**
  - **Wall loss pattern shows no significant variation with island size**
- **Limited experimental data corroborates core islands affecting NBI fast ion confinement**