SOLPS-ITER Predictions for a Highly Radiating Lithium Vapor Box Divertor in NSTX-U

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PPPL

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Lithium Vapor Box

- The lithium vapor box seeks to detach via lithium evaporation near the target, and condensation further upstream

- Past work has shown that the lithium vapor box could function with a completely open divertor

- In this presentation I am using SOLPS-ITER to examine an open diverter lithium evaporation scheme and compare with a baffled configuration

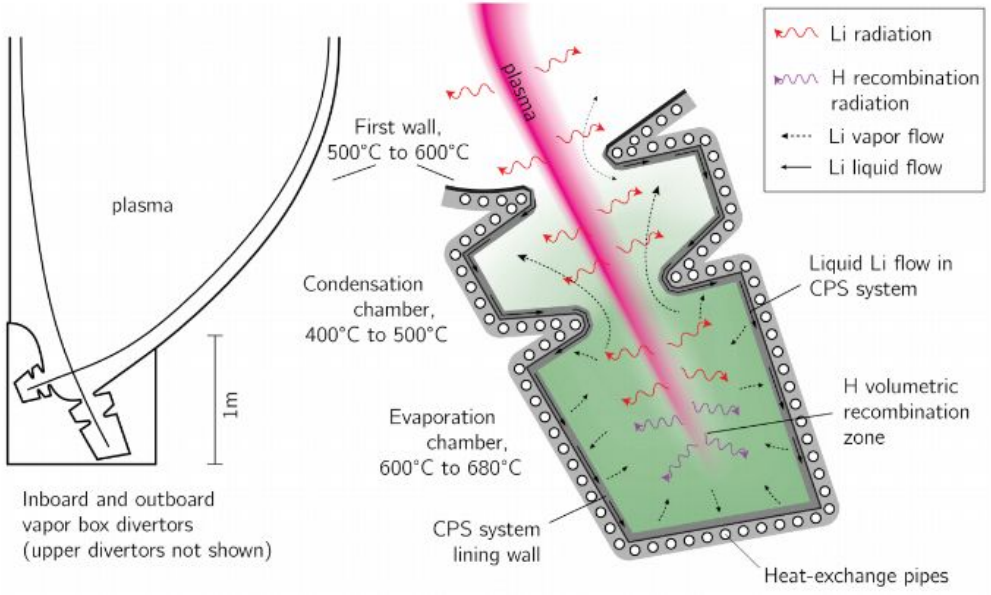


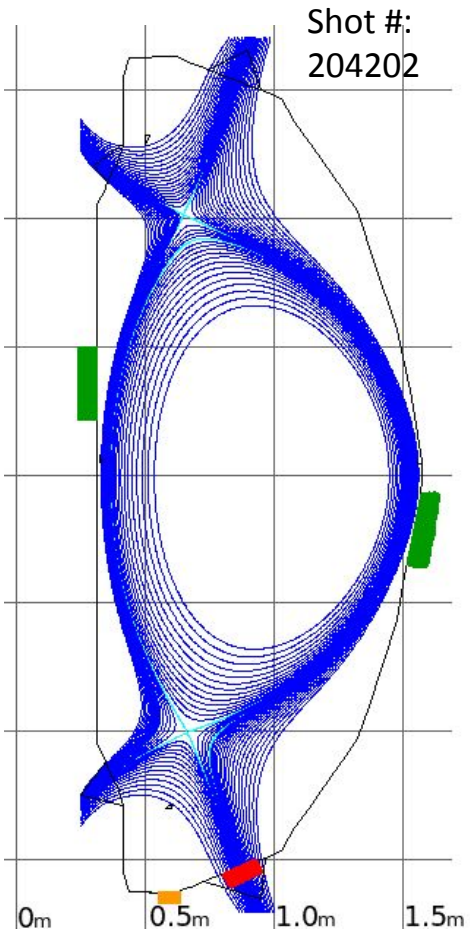
Diagram Credit: Jacob Schwartz

SOLPS-ITER

- High density of neutrals in divertor region requires Monte-Carlo modeling
- SOLPS-ITER uses the fluid code B2.5 coupled with the Monte-Carlo code EIRENE
- B2.5 solves Braginskii-type parallel momentum balance equation
  - Newer friction and thermal force models given in Sytova et al. CPP (2018)
- No drifts turned on for now
- Coupling of these two codes allows for accurate predictions in both the divertor region and the upstream plasma

Simulation Set-Up

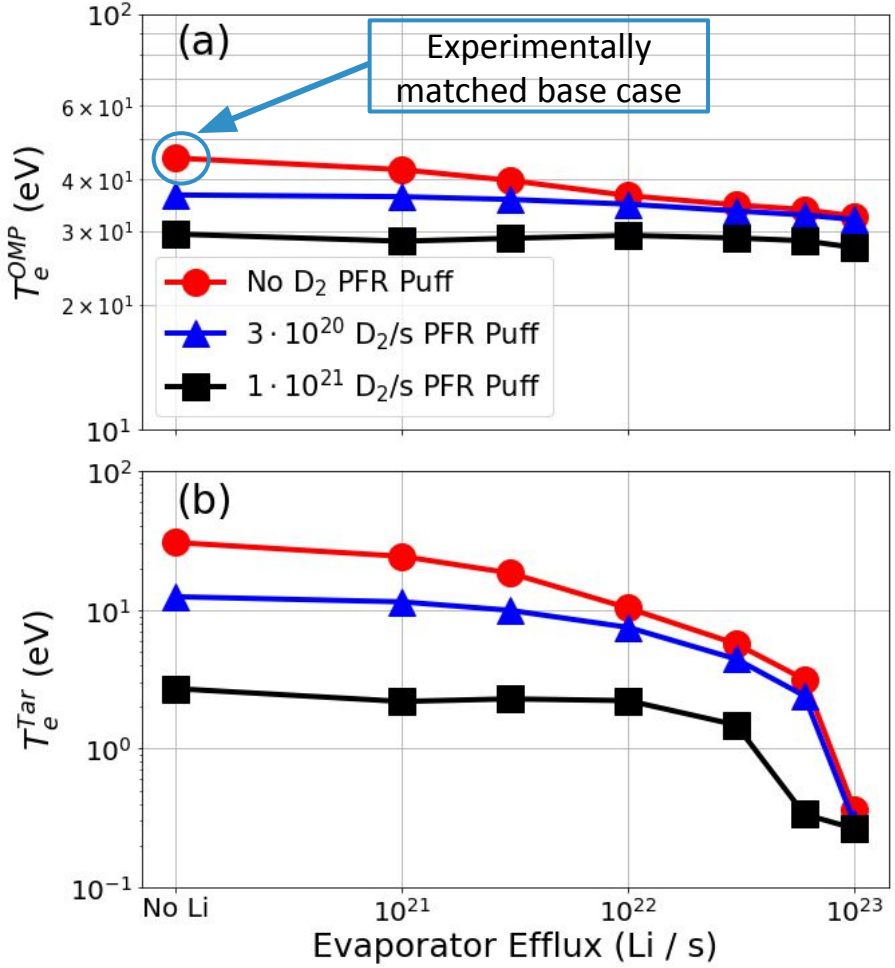
- Used experimental magnetic equilibrium
- D_2 gas puff locations shown in green and orange
  - Green locations are in experiment and used in profile matching
  - Orange is added in Private Flux Region (PFR) for predictive simulations
- Lithium evaporator location in red
- 2MW of input power
- 1.5×10^{19} m^{-3} core density B.C



Effects on T_e

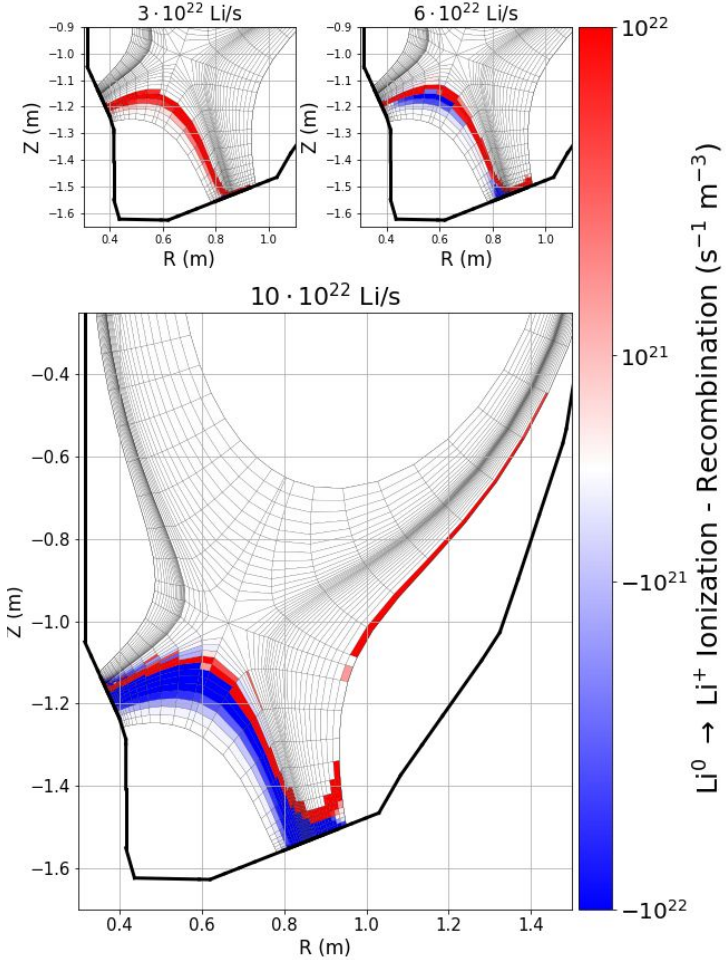
- SOLPS separatrix electron temperatures at the (a) outer midplane and (b) lower outer target for a variety of PFR D_2 puff intensities and Li evaporator effluxes shown to the right

- Detachment levels of target electron temperature reached for $6x10^{22}$ Li/s and greater



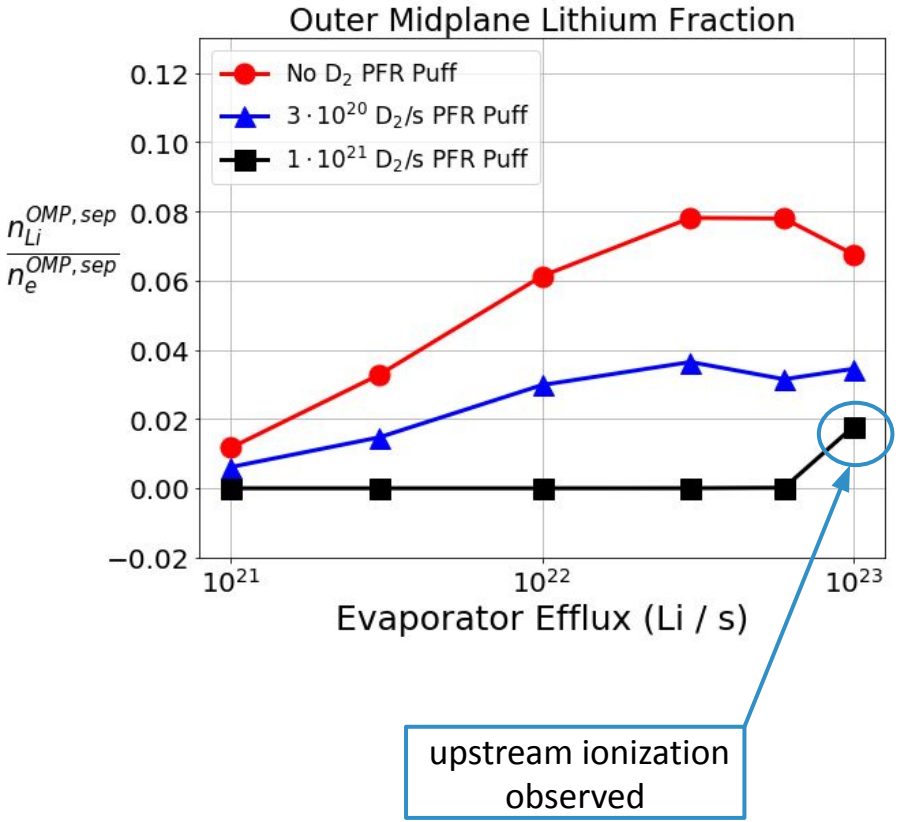
Detachment

- Poloidal cross-section of the volumetric ionization rate for three cases with 1x10^{21} D_2/s in the PFR.
- At 1x10^{23} Li/s the ionization front lifts fully off the target, indicating full detachment.
  - Upstream ionization observed with full detachment
  - Causes upstream lithium contamination



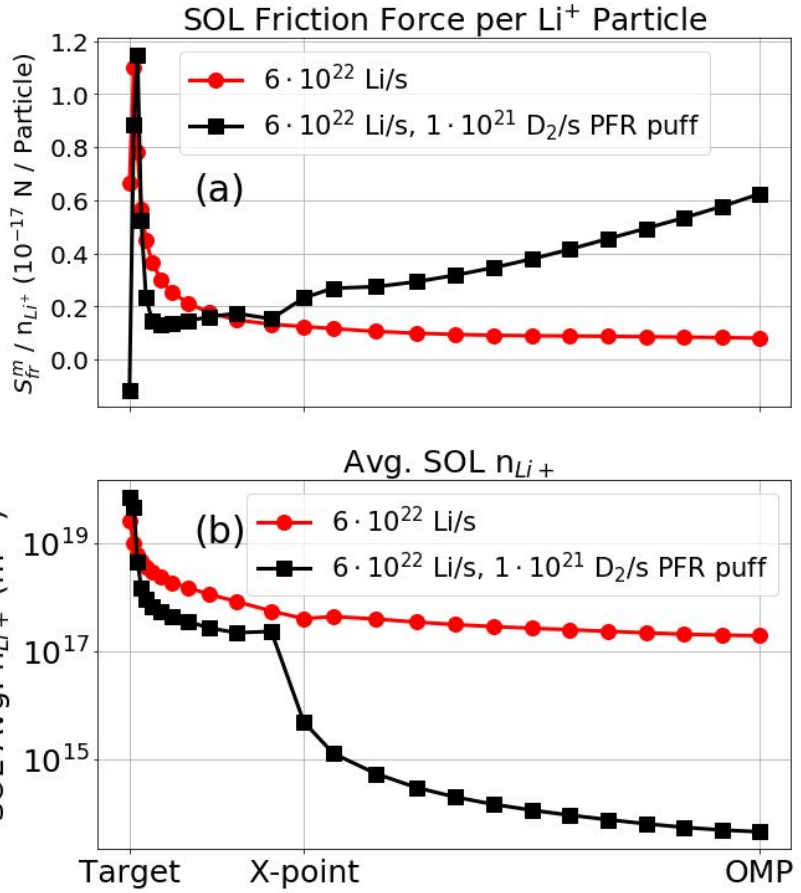
Lithium Fraction

- Predicted lithium fractions at the outer midplane for different evaporator effluxes and D_2 puff intensities.
- The lithium fraction is strongly dependent on the amount of D_2 puffed in, allowing the lithium fraction to be effectively controlled.
- Upstream ionizations caused the fully detached case to have non-negligible lithium at the OMP, regardless of D_2 puff



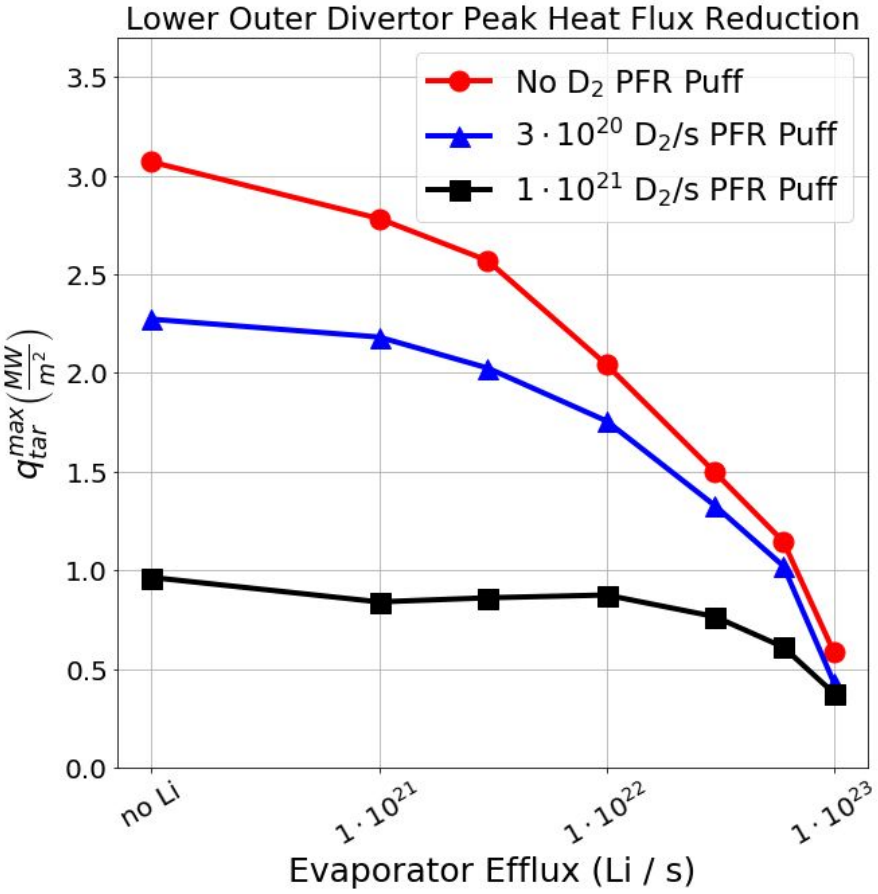
Friction decreases upstream lithium

- Addition of D_2 puffing increases friction acting on Li+
- Results in much less lithium upstream with especially sharp drop below X-point



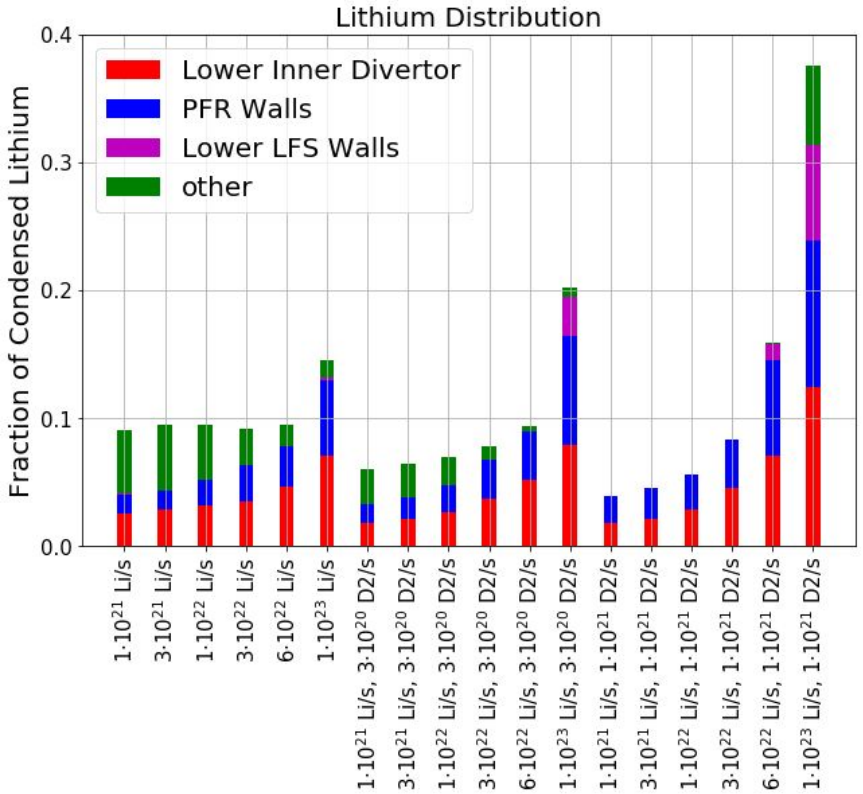
Target Heat Flux

- Heat flux drops significantly with neutral injection
- Heat flux able to be reduced by 80% from the experimentally matched base case
- q^{max}_{target}<0.5 MW/m^2 evidence of detachment



Lithium Condensation Locations

- The distribution of where the lithium ends up for each of the lithium cases, other than the lower outer divertor target.
  - The “other” category primarily consists of flux to the upper outer divertor but also contains some lithium ending up at the higher LFS walls.
- Since no fraction is greater than 0.4, lower outer divertor lithium condensation is always >60% (and typically >80%) of total condensation

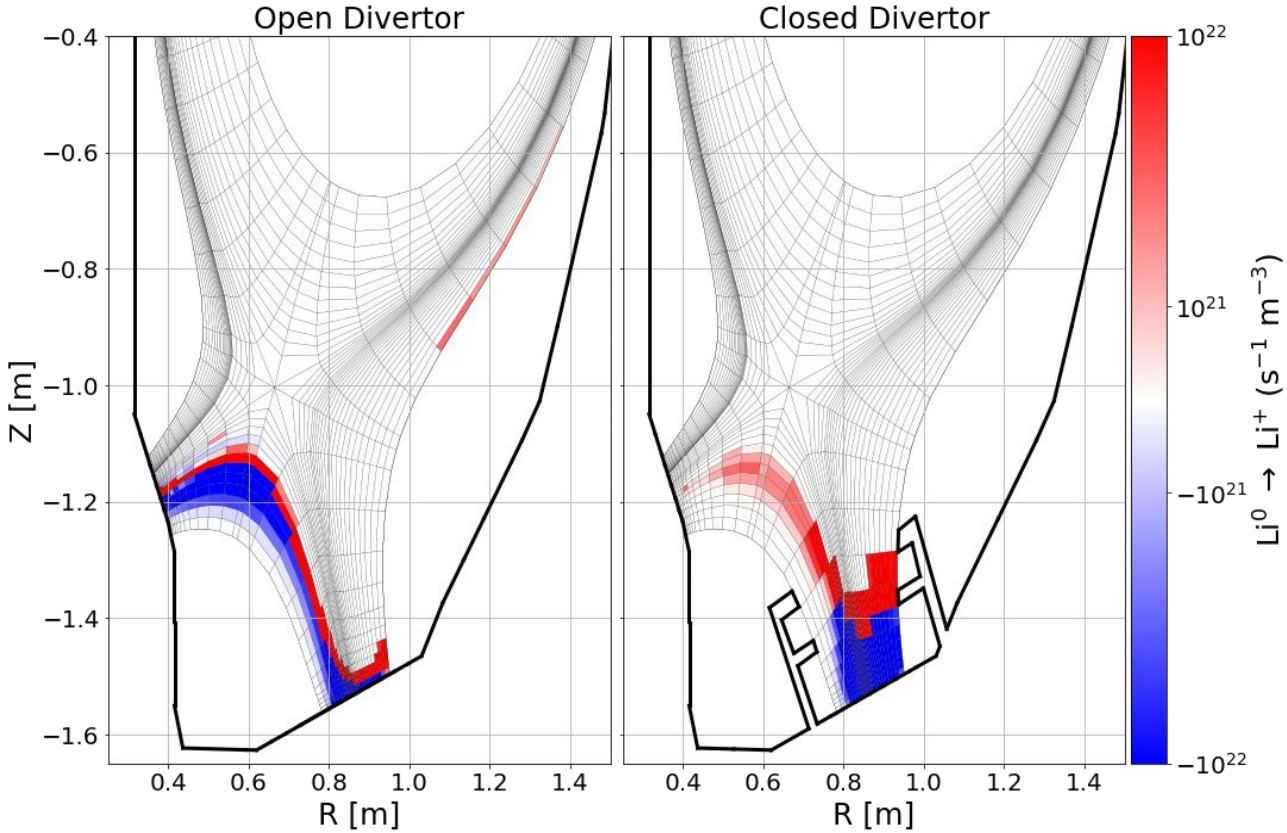


Lessons Learned

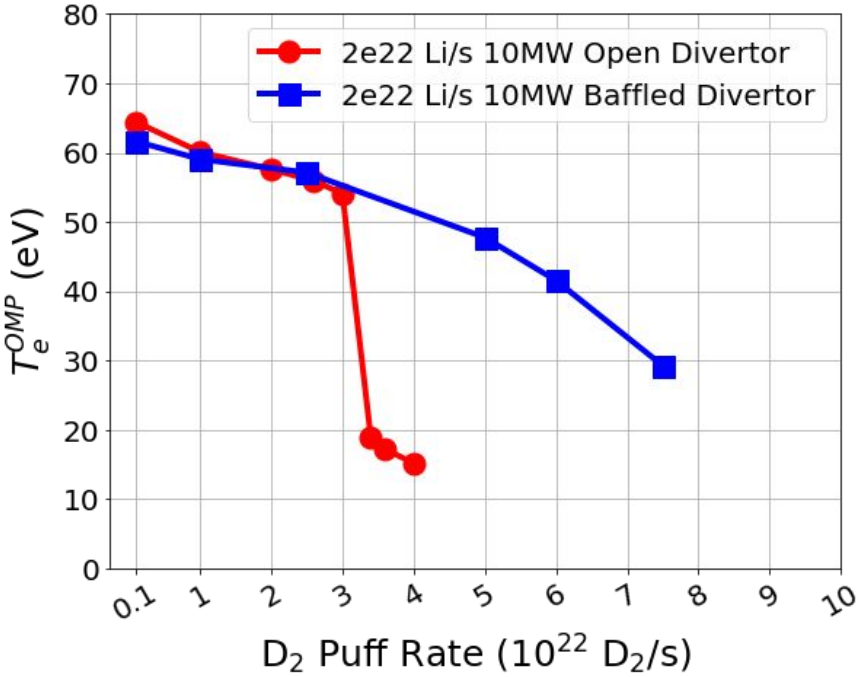
- Detachment possible with lithium vapor
- Deuterium puffing is a knob to control upstream lithium content
- Lithium distributes itself across the lower half of the tokamak with an open divertor

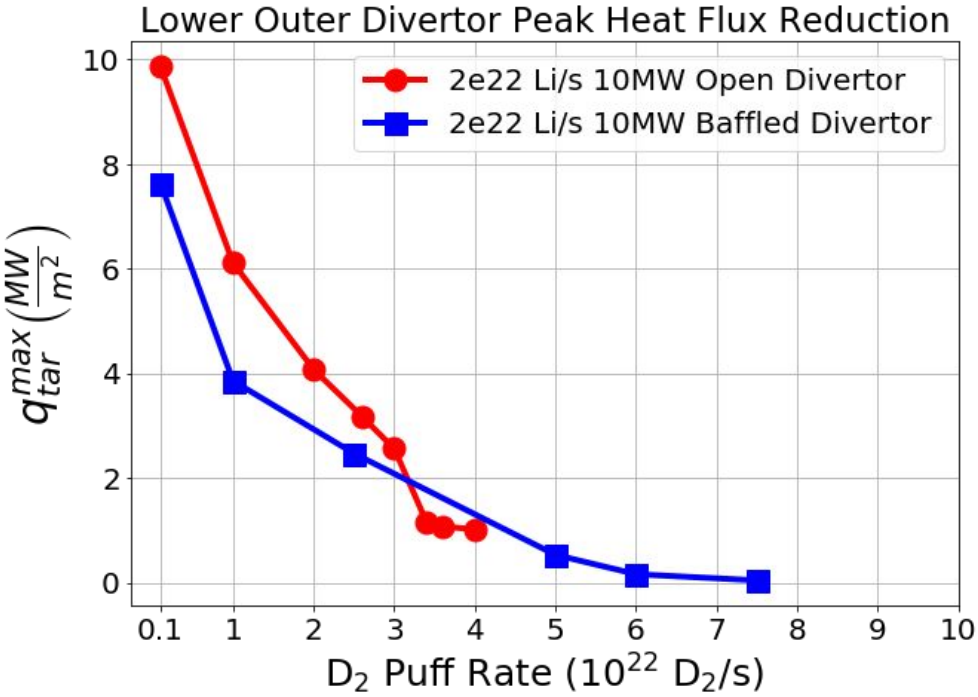
Divertor Closure

- Divertor closure fixes upstream ionization
- Does this translate to higher power?



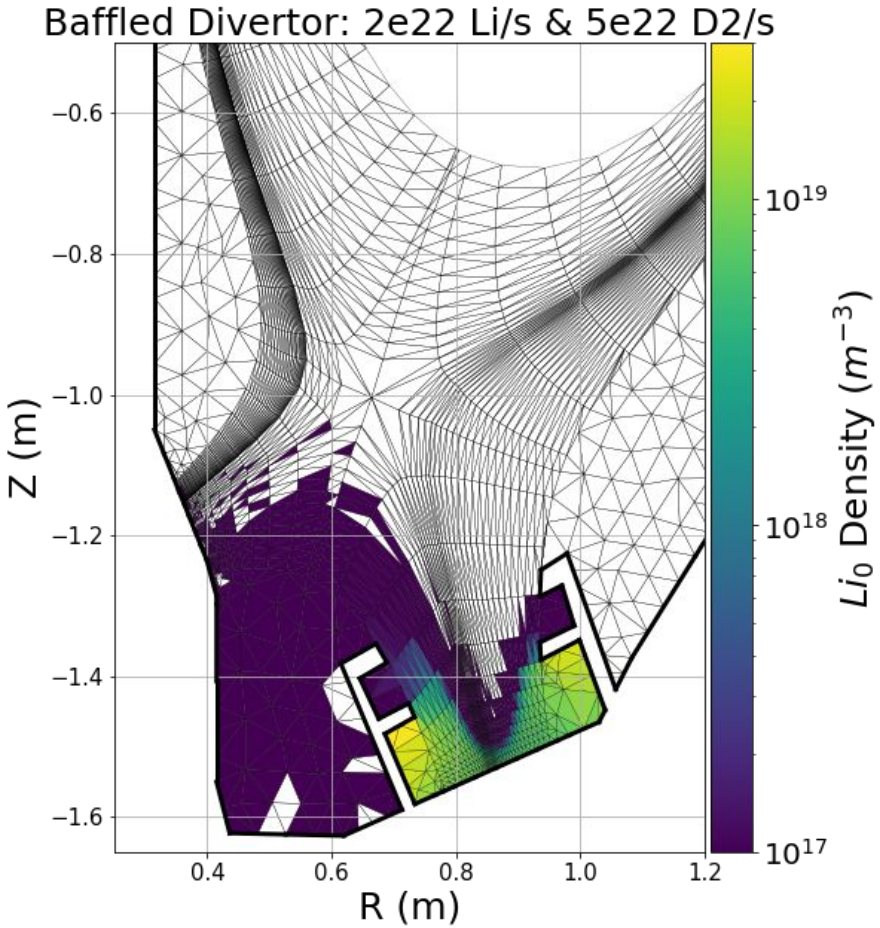
High Power Operation



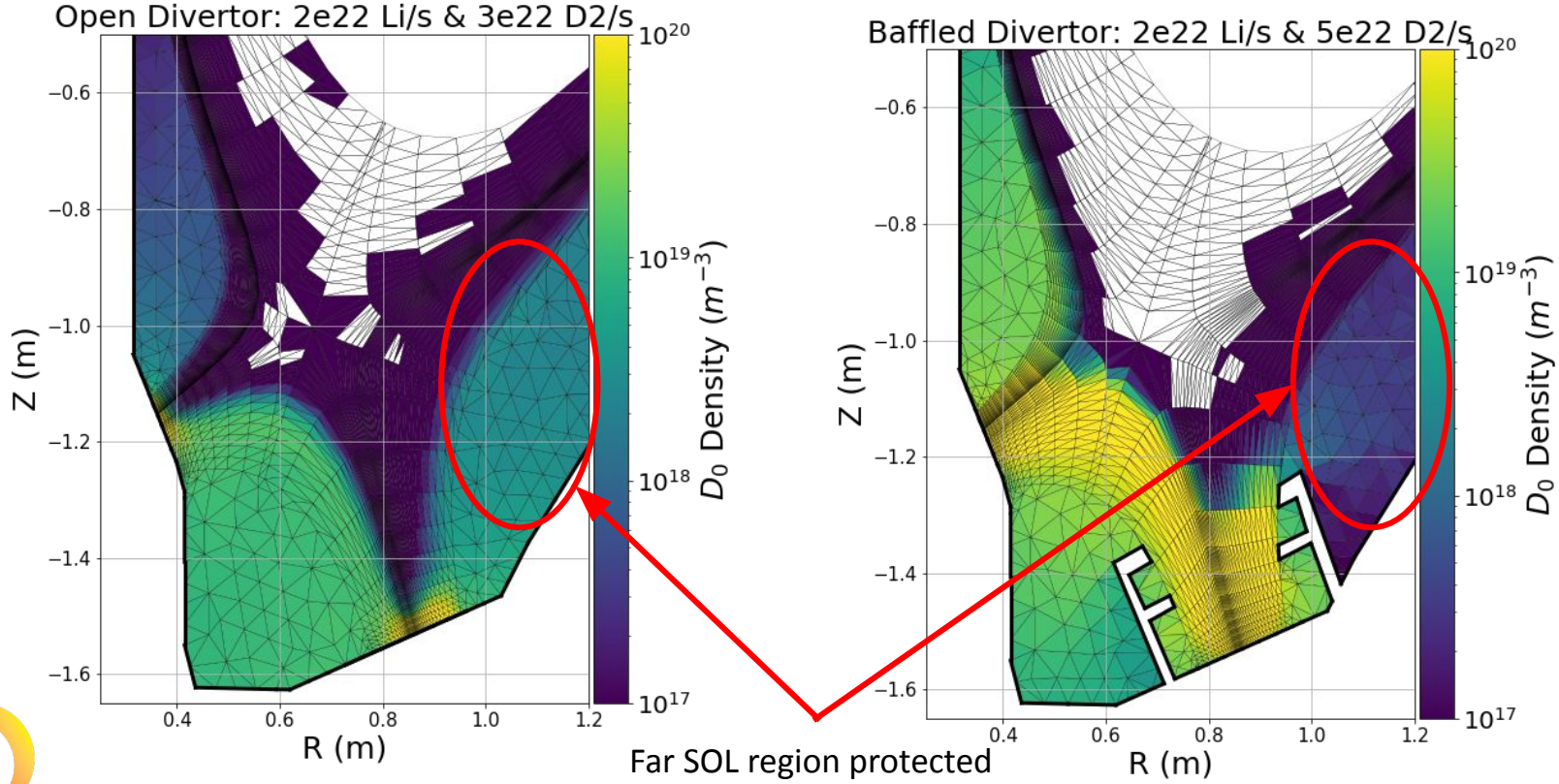


Divertor Closure

- ~99% of the lithium condenses inside the lithium vapor box system!
- Corresponds to less than 1mg/s to other locations (other divertors and PFR walls primarily)
- Lithium fraction upstream is practically negligible
  - $n^{OMP}_{Li}/n^{OMP}_{e} \sim 10^{-4}$



D0 Contained By Baffling



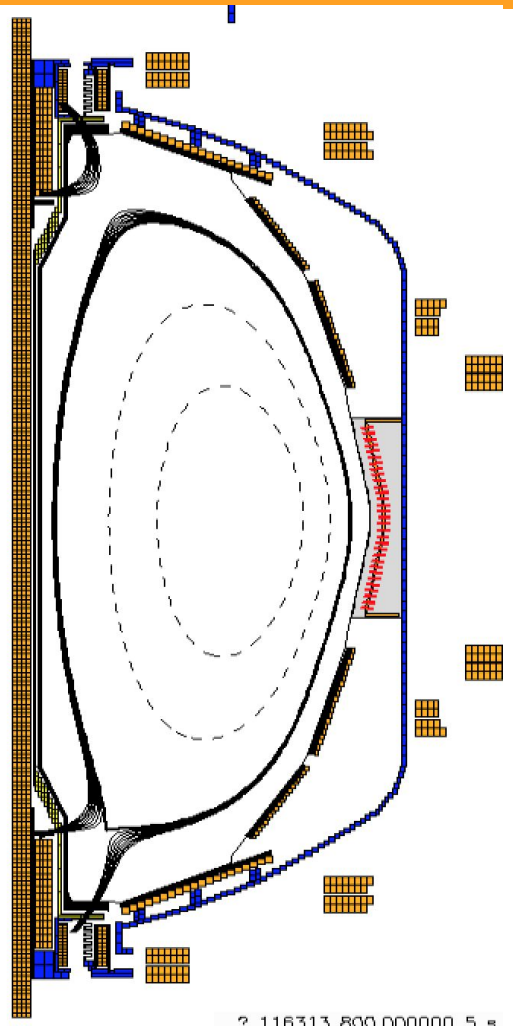
Far SOL region protected from neutrals by baffling

Summary

- Lithium Vapor Box divertor can cause full detachment in a completely open diverter at low powers but at high powers requires baffling (closure)
- ~99% of the lithium stays in the boxes with less than 1mg/s going elsewhere in a baffled divertor at 10MW
- Upstream ionization is an issue in a detached open divertor but not an issue for a detached closed divertor.
- Baffling/condensation contains not only the lithium but also the deuterium since deuterium is entrapped in colder liquid lithium.

Future Work

- Examine the effects of drifts on the simulations
- Can the LVB handle higher heat flux densities at the target?
  - Effects of H-mode?
  - Predictions of 96 MW/m^2 at target
- Simulate a lithium vapor box in a pilot plant to determine viability for a reactor-grade device



Back-Up Slides

Profile Matching

- Midplane parallel heat flux exponential fit shown to the right yielded λ_q=9.1 mm ±1.3 mm
- This is slightly narrower than experimental L-mode scaling from MAST using this shot's parameters (13.8 mm)
- Indicates reasonable NSTX-U transport coefficients