NSTX snowflake transport analysis

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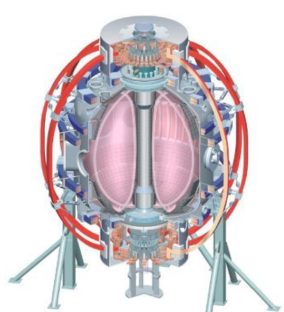

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Outline

- Snowflake motivation and overview
- UEDGE simulation setup
- NSTX modeling and analysis
- Conclusions

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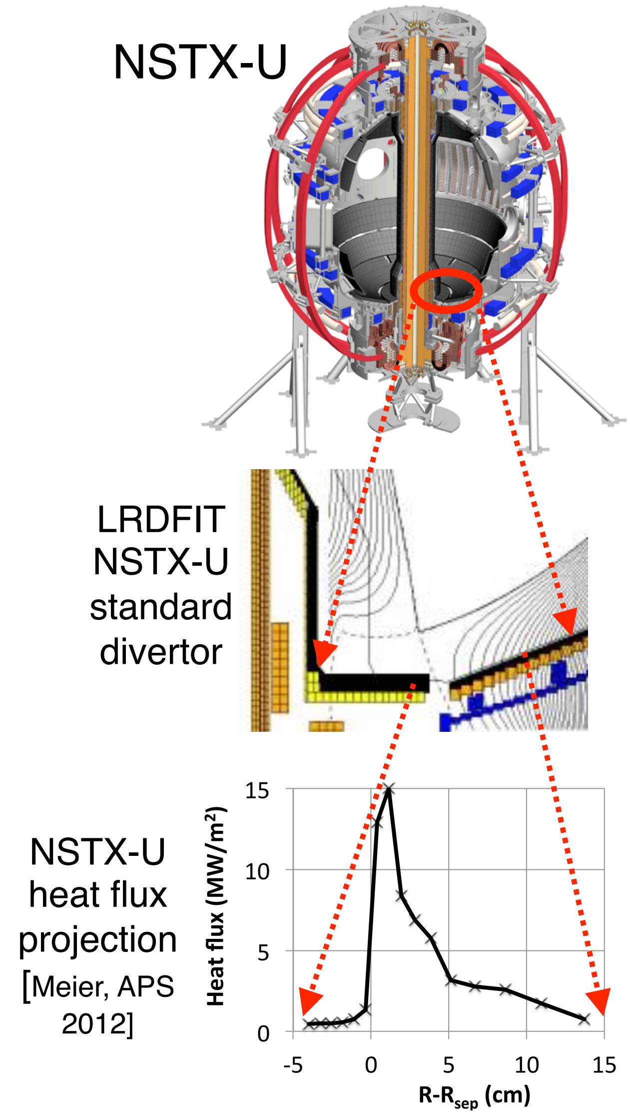
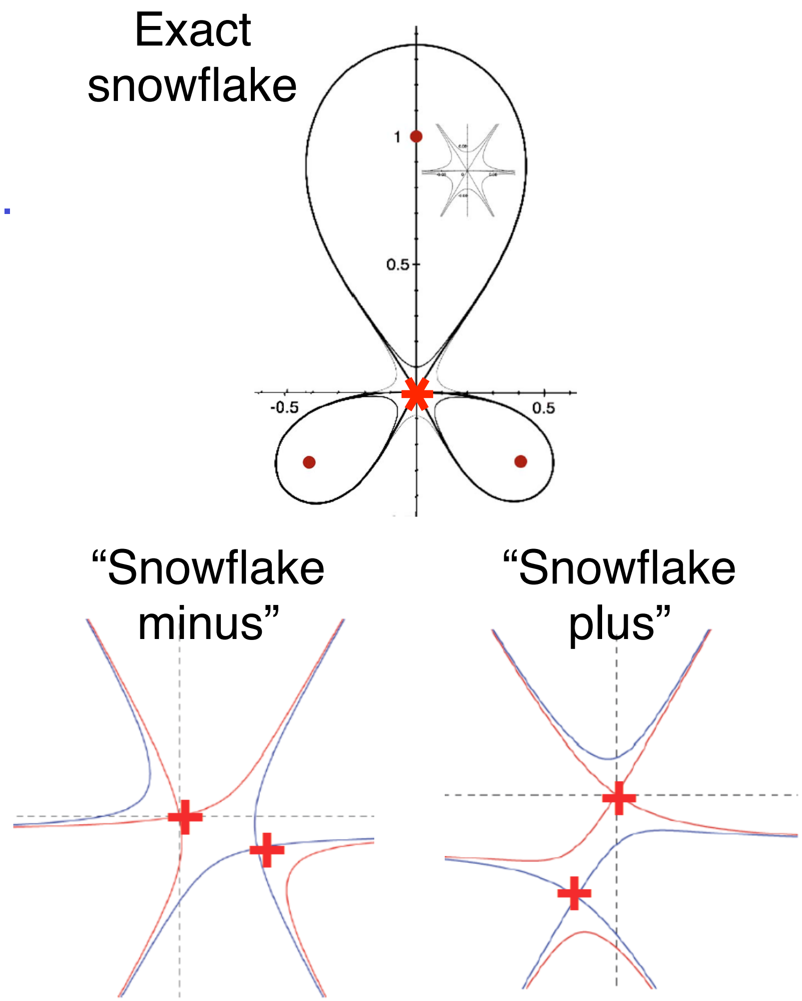
NSTX compact divertor offers high heat flux environment

- Compact divertor of NSTX offers high heat flux environment even in relatively low power machine.
- In NSTX, λ_q depends inversely on plasma current (I_p): $\lambda_q \sim I_p^{-1.6}$
- In NSTX-U standard divertor, we expect (midplane) λ_q=2-4 mm (approx. 3x reduction from NSTX)



Snowflake divertor configuration offers improved power handling

- The “snowflake” magnetic configuration leads to:
  - Large flux expansion near strike point.
  - Longer connection lengths.
  - Improved power handling; increased λ_q.
- Snowflake experiments on NSTX have shown promising results.



Ryutov, Phys. Plasmas, 2007

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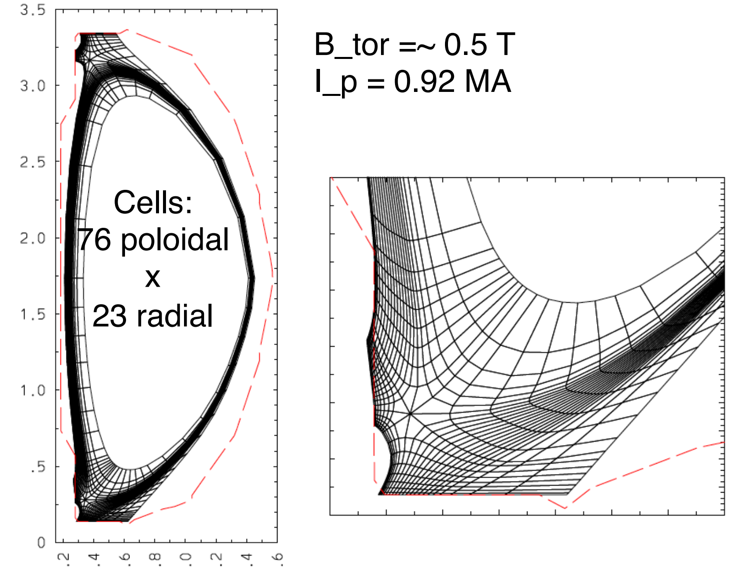
UEDGE is used to compare snowflake divertor (SFD) and standard divertor (STD) physics

UEDGE Settings	
Carbon impurity	Fixed fraction, 7% (non-coronal)
Anomalous perpendicular transport	Constrained by outer midplane data • Thomson: T_e, n_e • Charge-exchange recombination spectroscopy: n_{C6+}, T_{C6+}
Target recycling	97% • Some pumping to model Li conditioning
Scrape-off-layer power	3 MW • Discharge 141240 has 4 MW neutral beam power • Assume 25% fast ion + radiation losses.
n_{D+} BC at core-edge interface	Fixed D^+ flux • 60 atom amps (3.7e20 s^{-1}) for STD simulation corresp. to particle injection from 4 MW neutral beam. • 90 atom amps (5.6e20 s^{-1} for SNF simulation
Drift effects	No

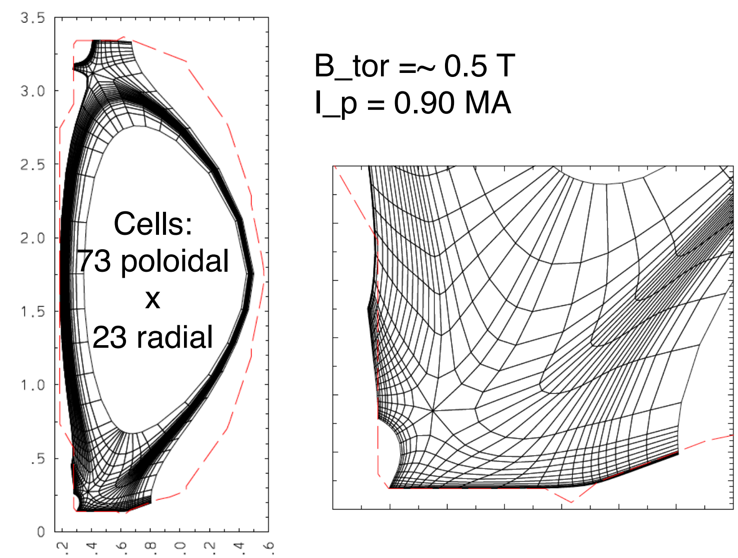
To capture 1+ cm SOL, double-null grids are used for NSTX modeling

- NSTX grids are based on LRDFIT equilibria at 439 ms (**STD**), and 905 ms (**SNF**).
  - Both grids capture psi=0.9 to 1.1.
  - Outer midplane SOL thicknesses are 2.03 cm and 2.44 cm for the standard and snowflake grids, resp.

STD



SFD

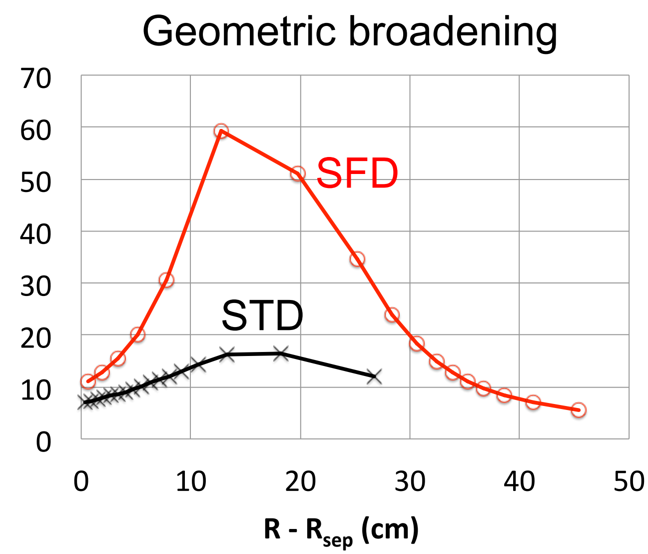


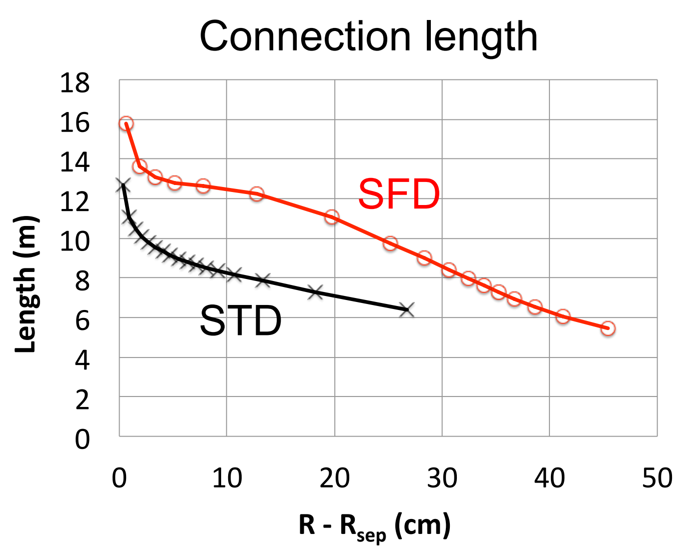
SFD → increased wetted area and greater connection lengths

- Increased wetted area allows a geometric reduction of heat flux.
- Longer connection lengths lead to reduced target temperatures [Stangeby, 2000]:

$$T_t \propto q_{\|}^{10/7} / L^{4/7} n_u^2$$ (assuming conduction only)

  – Lower T_t → More radiation?





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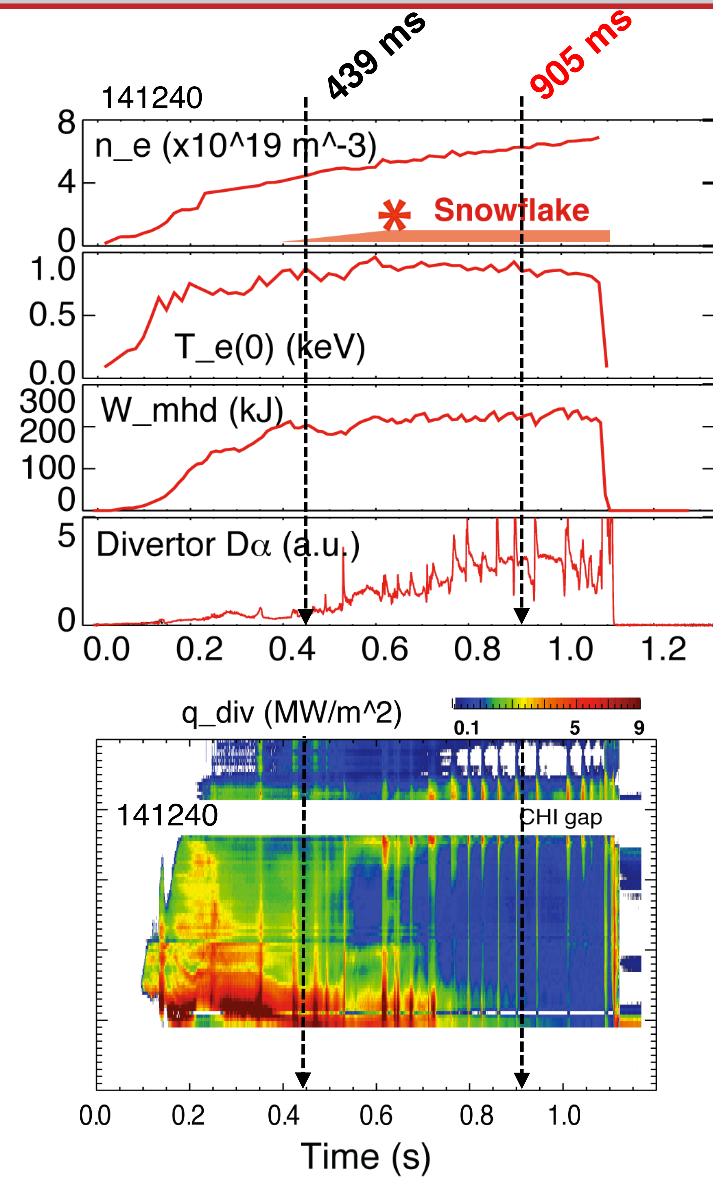
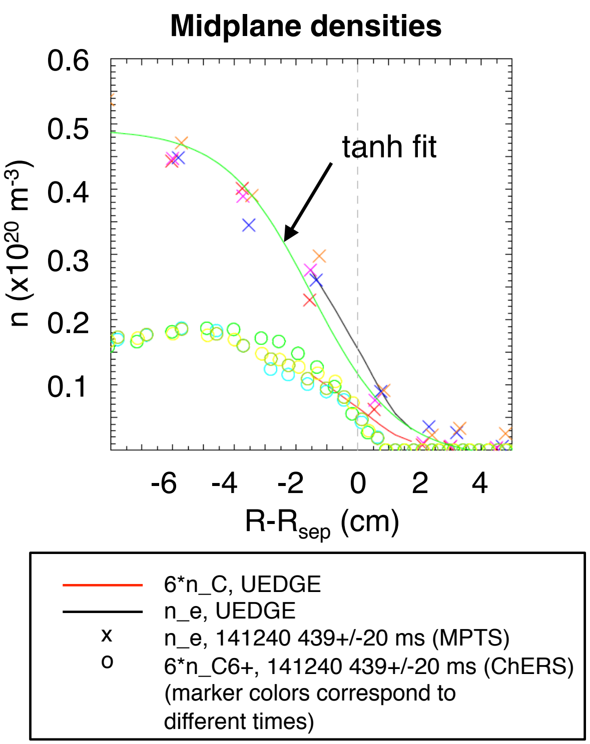
Snowflake divertor (SFD) configuration yields partial detachment and large heat flux reduction

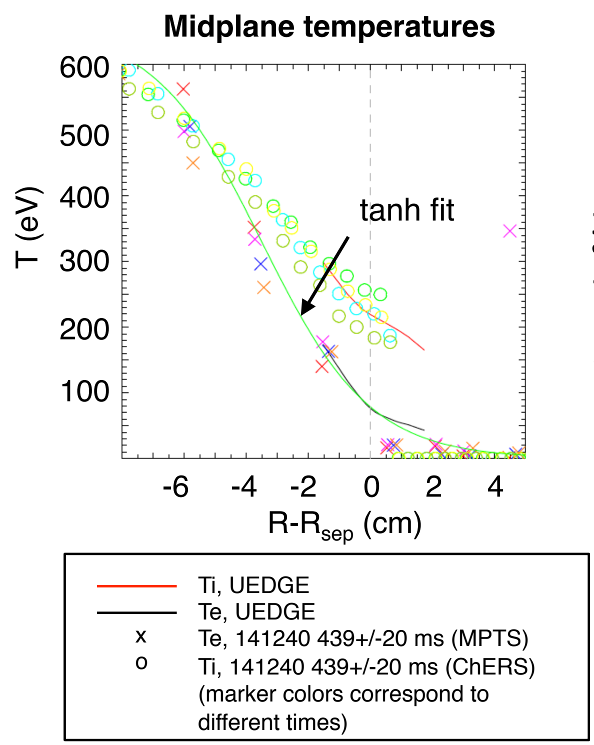
- SFD is established at ~600 ms*.
  - Core plasma retains desirable properties.
  - Outer divertor partially detaches, and ELMs are present.
  - Peak heat flux is reduced from ~8 MW/m^2 to ~1 MW/m^2.
- **Simulations are conducted for 439 ms (STD) and 905 ms (SFD).**

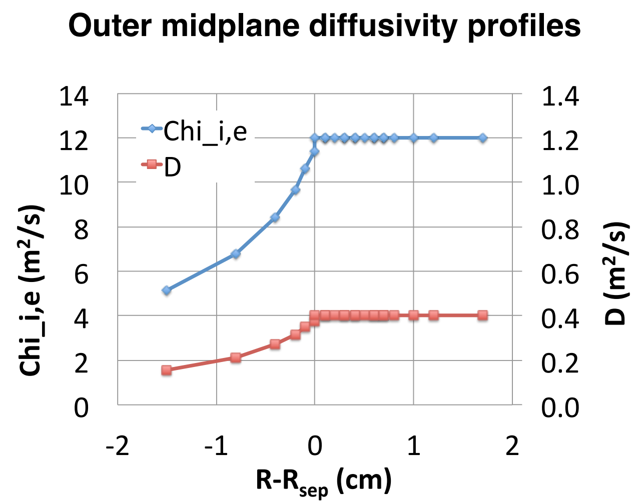


* Soukhanovskii et al., Phys. Plasmas, 2012

STD simulation matches midplane MPTS and ChERS data…







- Diffusivities in the core region vary as radius cubed and are uniform in the SOL and PF regions.
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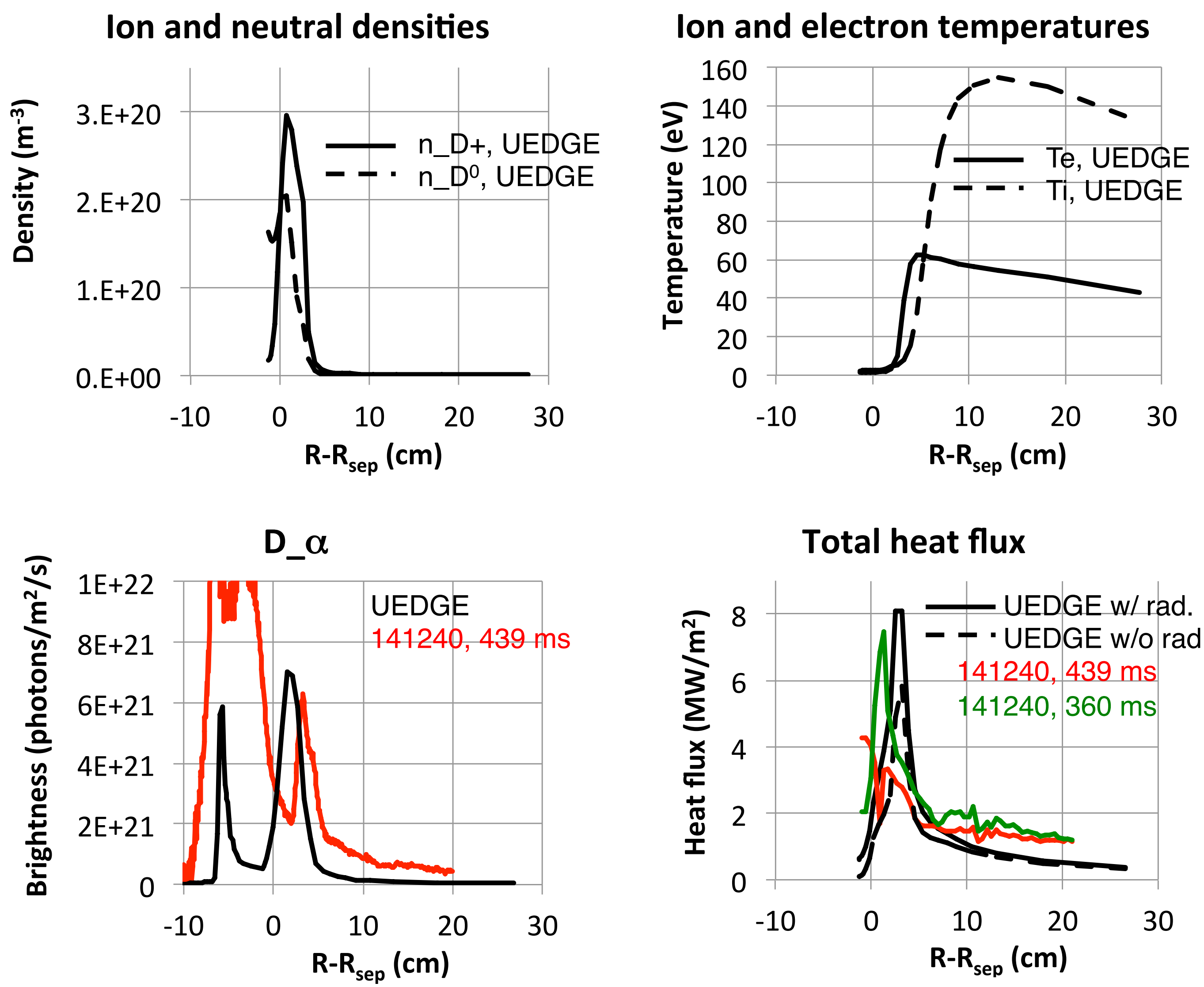
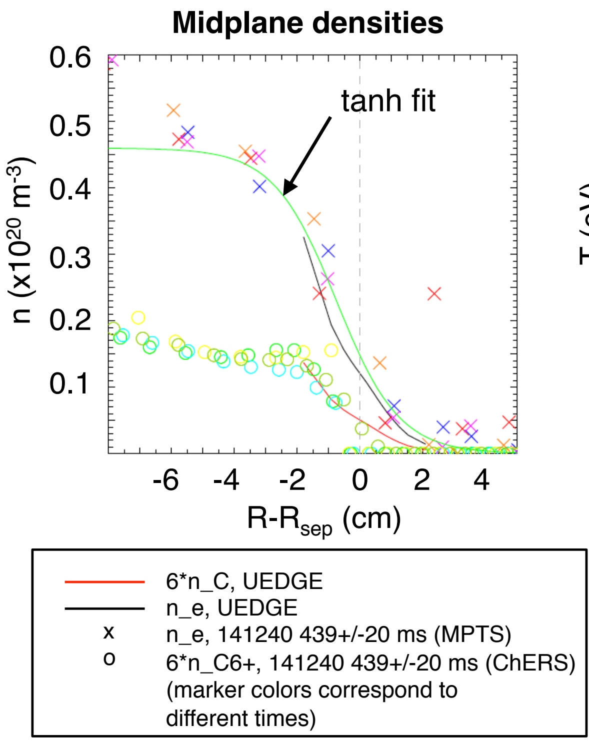
- Hyperbolic tangent functions are generated following Porter [G.D. Porter et al., PoP, 1998].
- The experimental data is shifted outboard 1.5 cm with respect to the LRDFIT equilibrium.

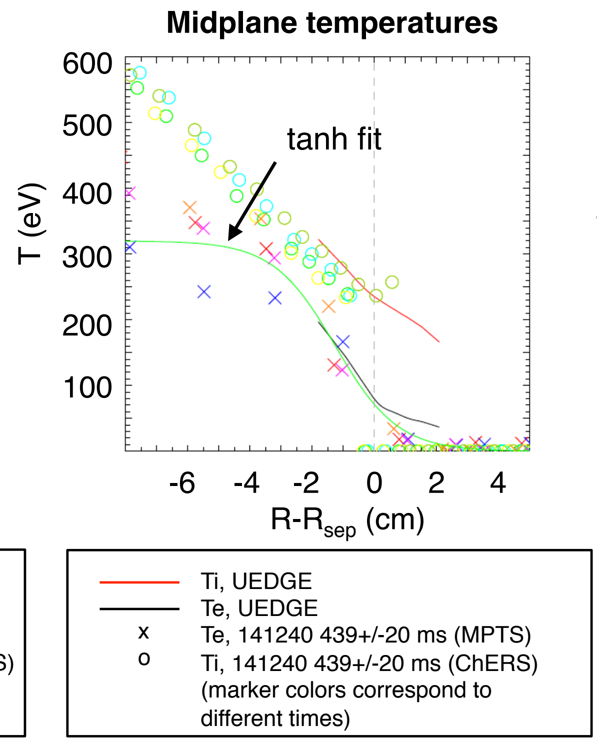
…and the lower/outer divertor heat flux and D_α data

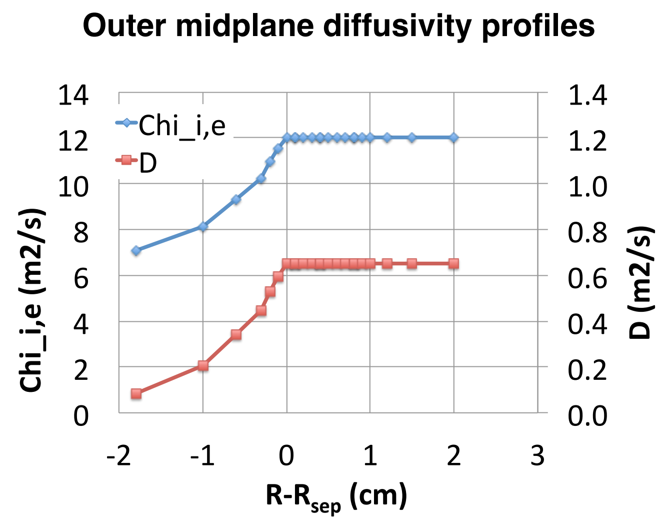
- D_α measurements are from filtered cameras.
- Heat flux is based on dual-band IR thermography.



SFD simulation also matches midplane data…





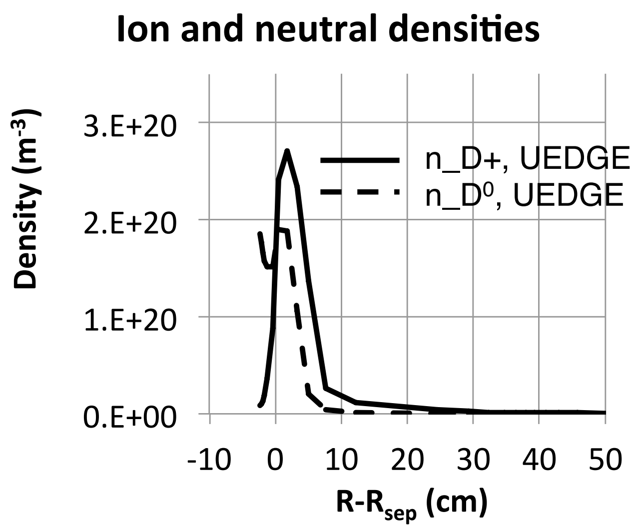


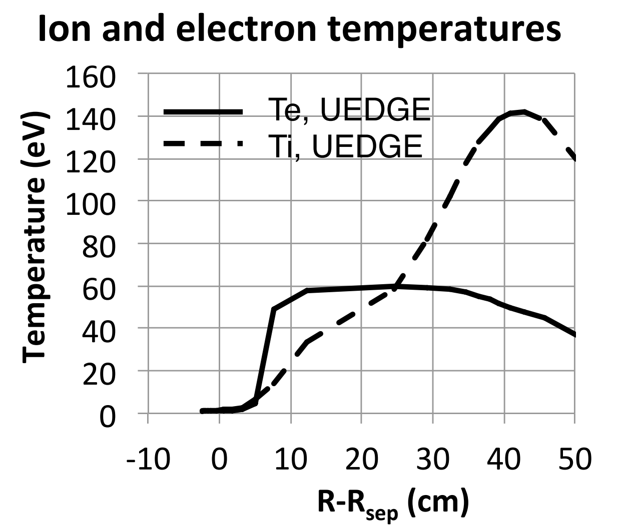
- Diffusivities in the core region vary as radius cubed and are uniform in the SOL and PF regions

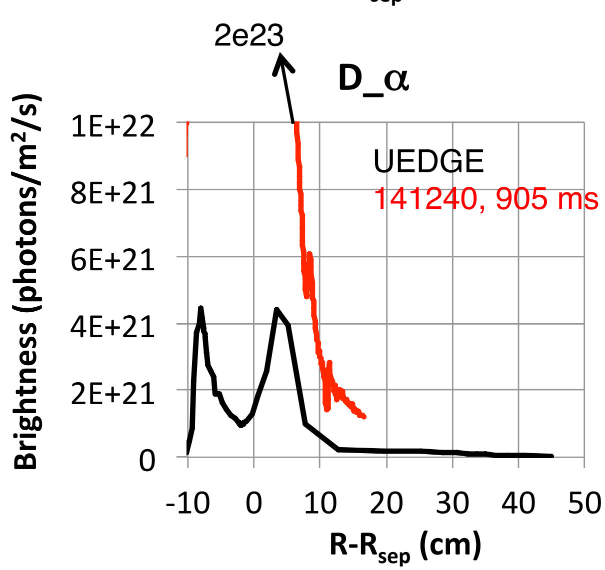
- Hyperbolic tangent functions are generated following Porter [G.D. Porter et al., PoP, 1998].
- The experimental data is shifted outboard 1.75 cm with respect to the LRDFIT equilibrium.

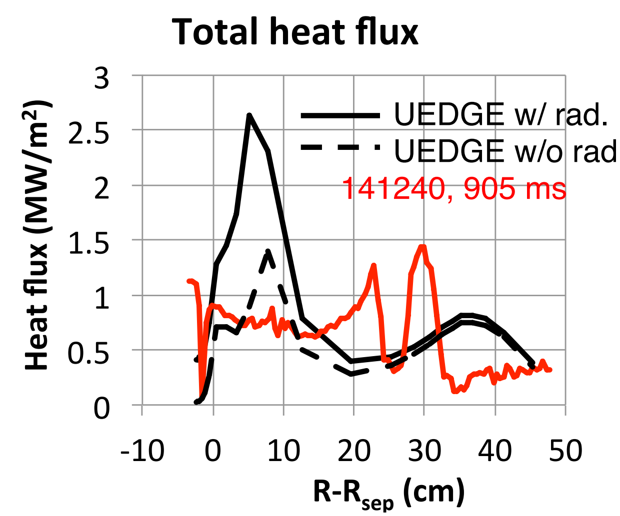
…but deviates from lower/outer divertor data, especially D_{α} light

- Simulated heat flux is reduced as in the experiment, but detailed profile is not captured.
- D_{α} discrepancy is significant.
  - Cause of discrepancy is unclear.
- Partially detached divertor solution is found.
  - Te and Ti are ~1.5 eV from 0 to 7 cm from the SP.



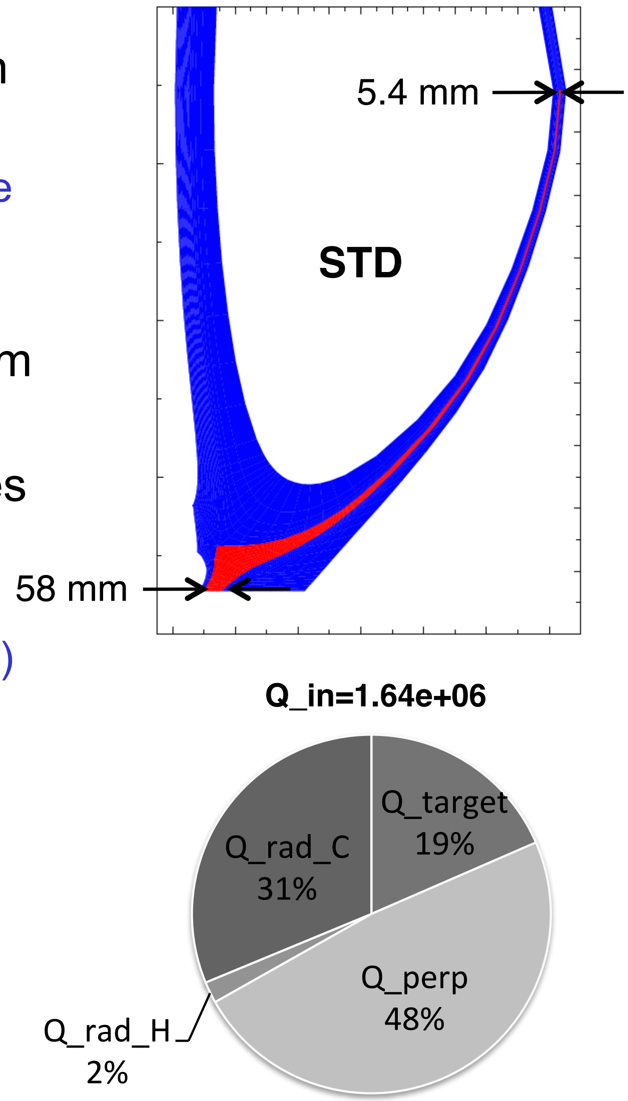


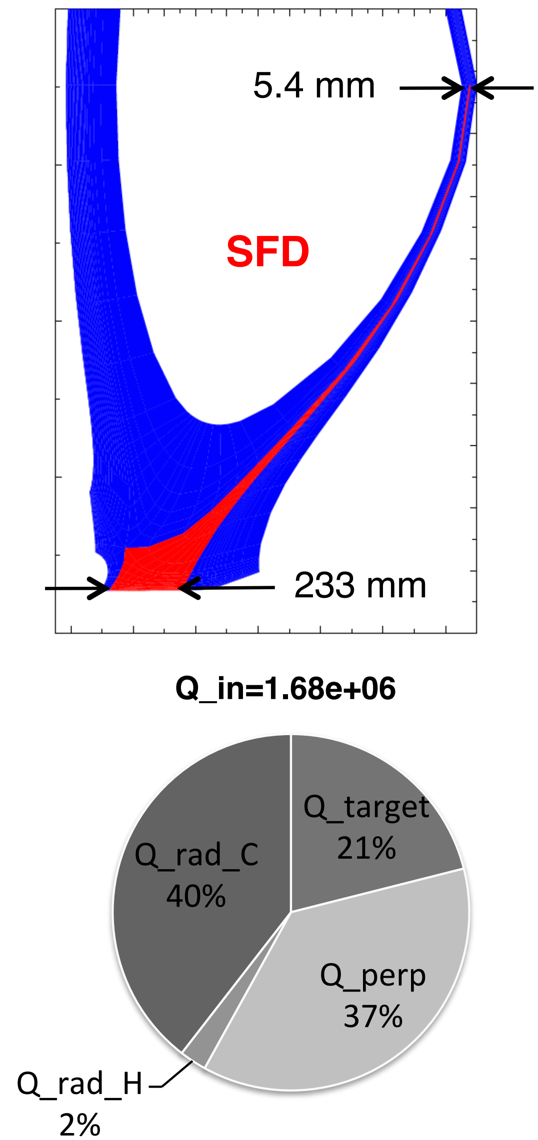




Radiation is stronger in SFD, but primary heat flux reduction is due to geometric profile broadening

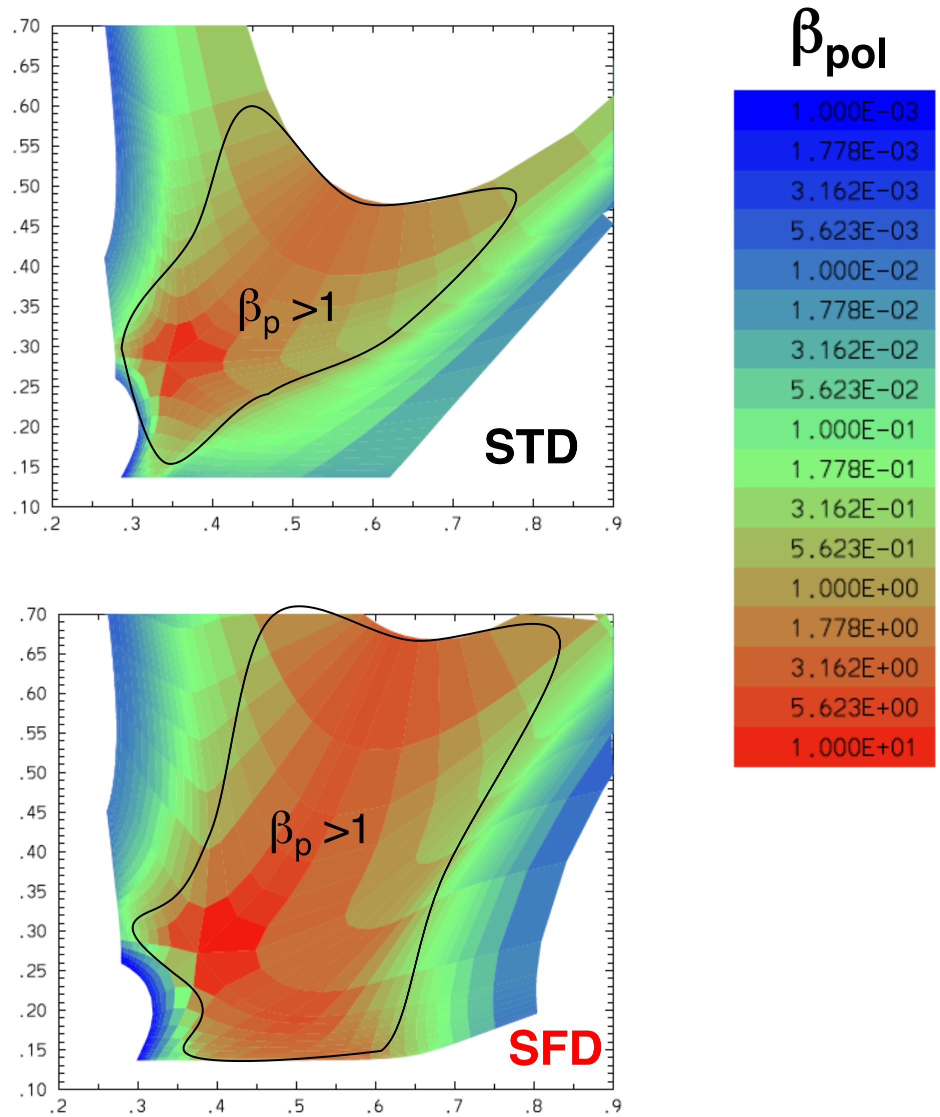
- Consider power balance in the red-shaded flux tubes.
  - At the outer midplane, the tubes enclose ~5 mm.
- Power enters primarily by perpendicular diffusion from the core (Q_in).
- Power leaves the flux tubes through four channels:
  - Convected+conducted power to target (Q_target)
  - Perpendicular diffusion (Q_perp)
  - Carbon radiation (Q_rad_C)
  - Hydrogenic radiation (Q_rad_H)





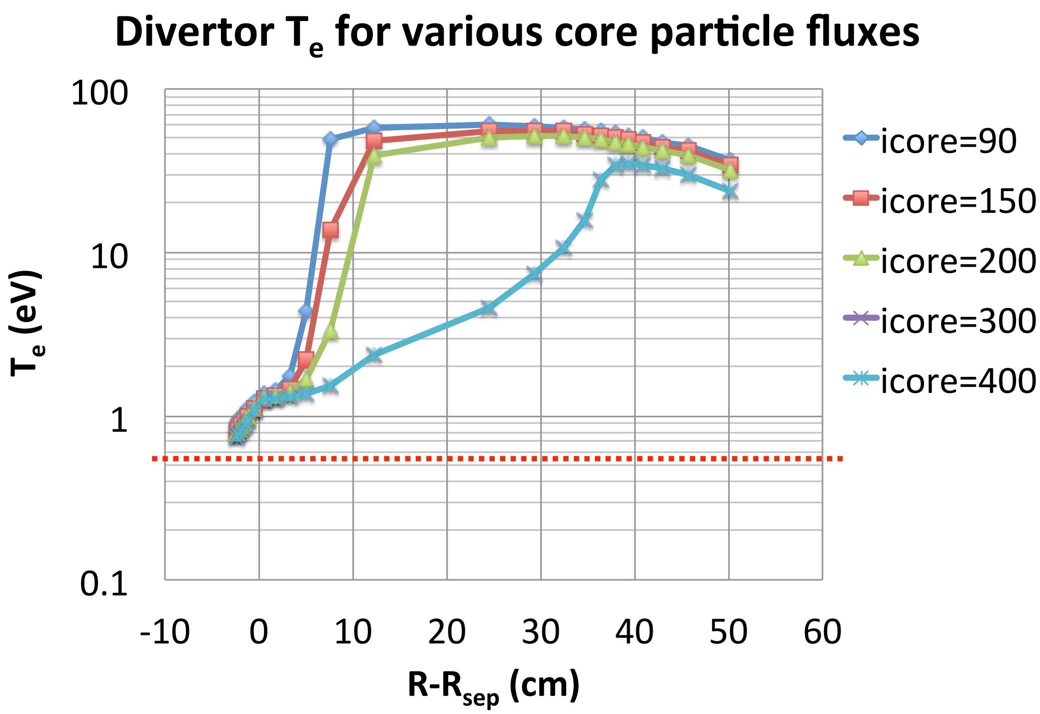
Zone of high poloidal beta (β_p>1) is larger in SFD, possibly offering improved ELM dissipation

- During ELM ejection, high β_p might lead to convective mixing and associated reduction of peak ELM heat fluxes [D.D. Ryutov et al., CPP, 2012].
- UEDGE simulations show relatively large high-beta regions (β_p>1) in the SFD configuration.



The simulation is "reluctant" to enter low-temperature (high-D_α) regime

- Emissivity calculations suggest that T_e below ~0.5 eV could yield the observed D_α.
- Large increasing core particle flux does not induce such low T_e.
  - Core density is more than doubled.
  - Ion "birth energy" seems to play a minimal role.
  - Could perpendicular or parallel transport be unphysically high?
  - Is "inter-ELM" simulation missing something important?



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- Anomalous perpendicular transport is found to be similar in the STD and SFD phases of the discharge.
- Total power to the outer divertor target is similar in STD and SFD.
  → Peak heat flux reduction is enabled by geometric profile broadening.
- Simulation of snowflake phase does not recreate the strong (highly radiative) detachment seen in the experiment.