U.S. DEPARTMENT OF ENERGY | Office of Science

NSTX-U

UEDGE modeling of divertor geometry effects in NSTX

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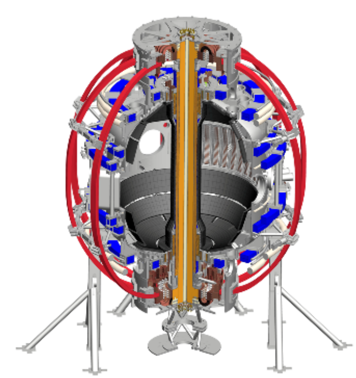

LLNL-POST-679321

Abstract

We report efforts toward the modeling of divertor geometry effects using the fluid code UEDGE and NSTX experimental equilibrium with different X-point heights. A variation of the geometry generates a competition between the poloidal magnetic flux expansion, which reduces the peak of the deposited heat flux and homogenizes its profile at divertor plates, and the proximity of the X-point to the divertor plates, which decreases the connection length and increases the peak heat flux. Our simulations use fixed fraction of carbon impurity, poloidally and radially constant transport coefficients, and high recycling boundary conditions, with a scan of density and pressure boundary conditions, and impurity fraction. Our simulations support the experimental observation that the poloidal flux expansion dominates the deposit heat flux over the parallel connection length effect. In opposite to experimental observation, detachment seems independent to the elevation. Improvement of the model is required.

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Outline

1 - Motivations

Advances divertors, NSTX observations,
Flux expansion vs. parallel connection length

2 - NSTX-like Divertor Simulations

UEDGE simulations vs. experimental tendencies

3 - Recovering the experimental tendencies

Impurity Fixed Fraction Scans

Particles Diffusion & Heat Transport Scans

4 - Selected 2D (post-analyses) Plots: P_{rad}, T_e, q_{plates}

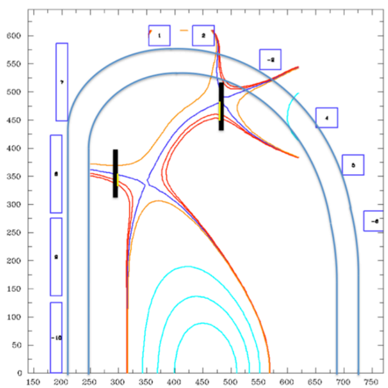
5 - Discussion on Geometric Effects

1 - Motivation of Advanced Divertors

Soukhanovskii, Edge Coordinating Committee Fall 2014 Technical Meeting

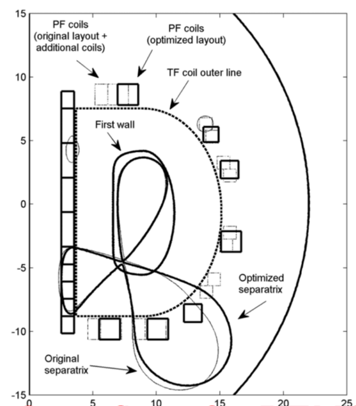
Goals:
Long life divertor components, cost efficiency, real time control, advanced confinement

Many pre-DEMO and DEMO designs include snowflake and Super-X configurations



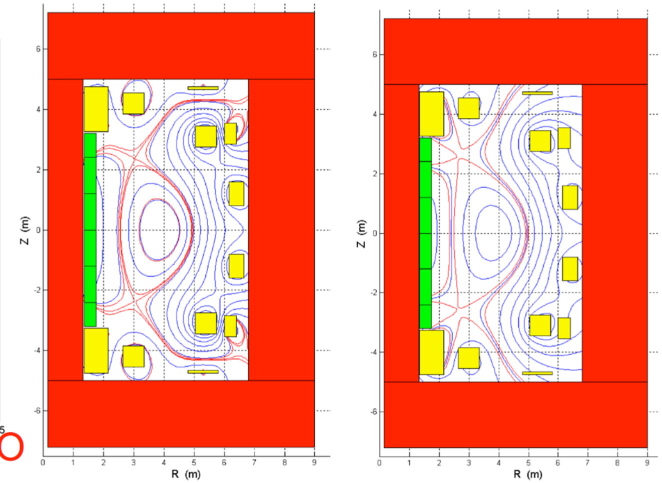
Super-X for Aries Slim CS

M. Kotschenreuther et. al, ARIES Workshop 2010



Snowflake for DEMO

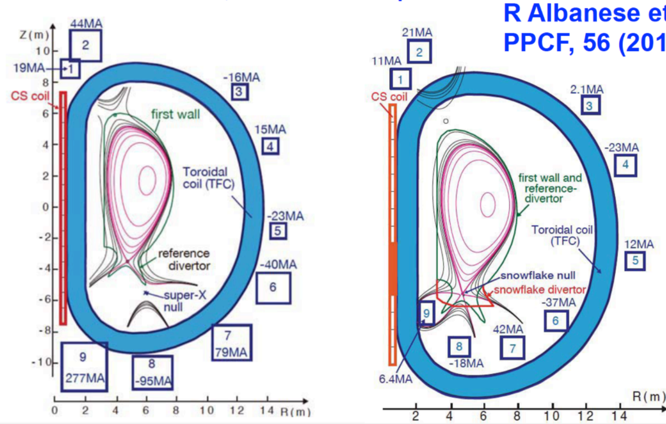
R Albanese et. al, PPCF, 56 (2014) 035008



China Fusion Experimental Reactor

Y. Wan, SOFE 2013

Z. Luo et.al, IEEE TRANSACTIONS ON PLASMA SCIENCE, V42, 2014, 1021



Super-X and Snowflake for DEMO

N. Asakura et.al, Trans. Fus. Sci. Tech. 63, 2013, 70.

1 - NSTX Experiments with Different X-pt Heights

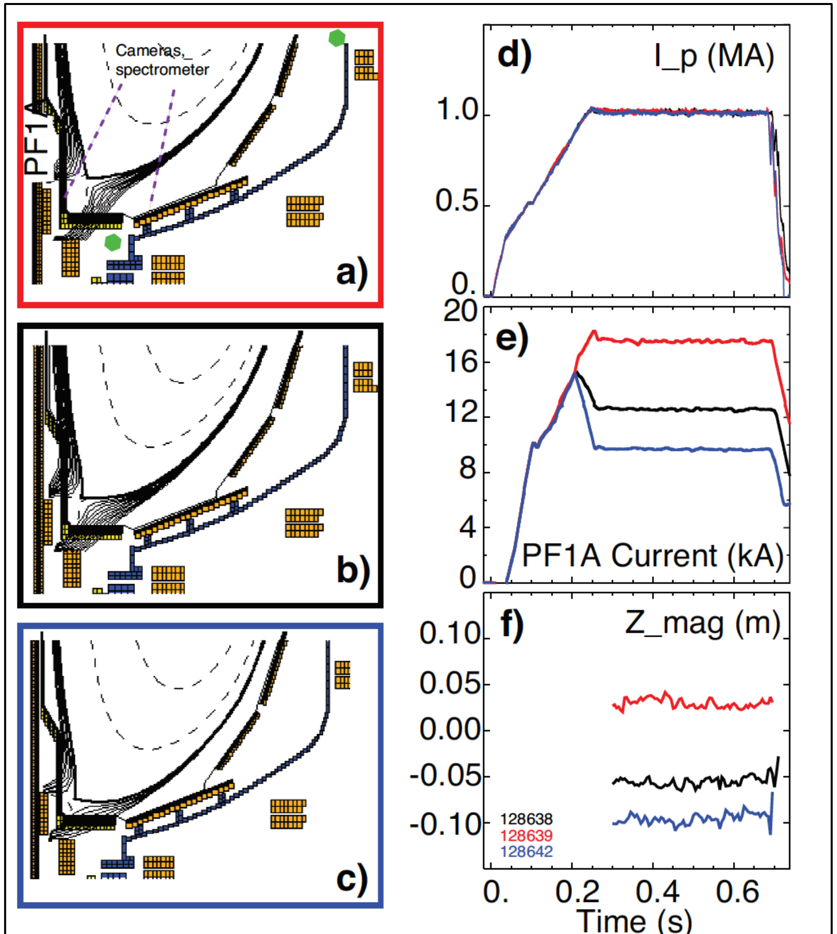


Figure 1: *Divertor equilibria for* $h_X = 18 - 22$ *cm (a),* $h_X = 8 - 12$ *cm (b),* $h_X = 3 - 6$ *cm (c). The shown flux surfaces are separated by 1 mm radial distance in the midplane, and show a full extent of the divertor SOL for each configuration. The associated (color-coded with same color) traces of plasma current (d), divertor PF1A coil current (e), and plasma magnetic axis vertical position (f).*

Soukhanovskii *et al.*, 36th EPS (2009) P2.178, Sofia

- Experimental observation in NSTX of the competition between the poloidal flux expansion and the parallel connection length, by increasing high of the X-point.

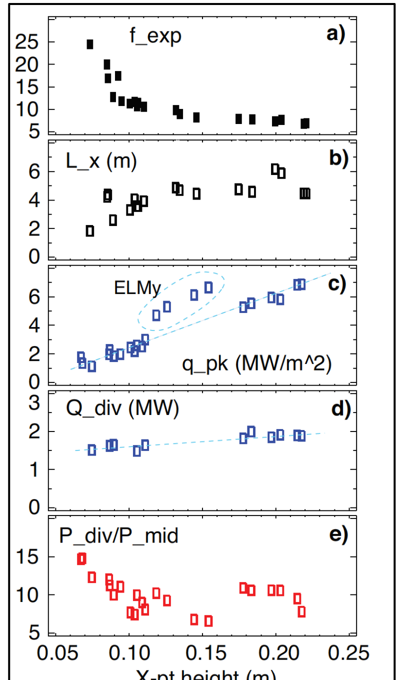
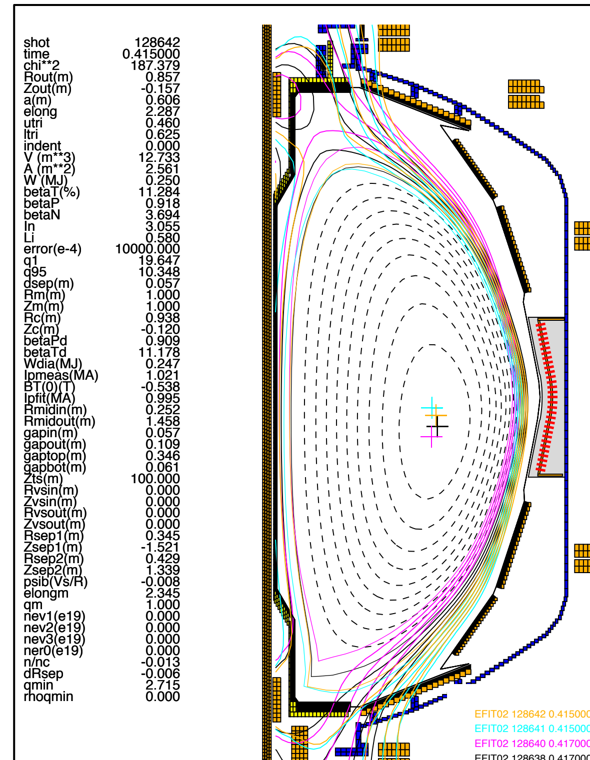


Figure 4: *Divertor geometry and plasma parameters as functions of* h_X*: (a) flux expansion, (b) X-point connection length, (c) peak divertor heat flux, (d) peak divertor heating power, (c) divertor deuterium compression.*



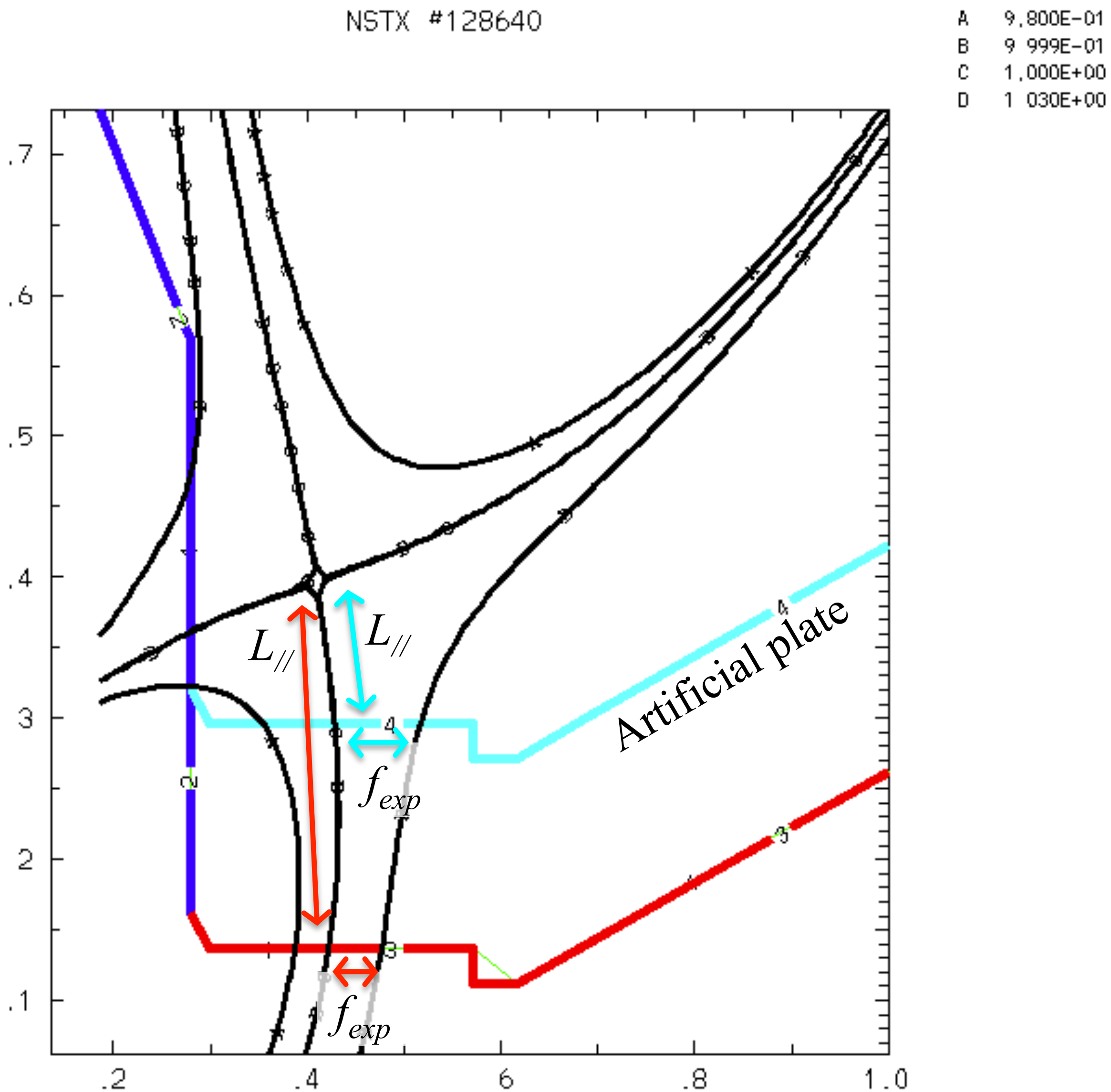
1 - X-pt Height Determines Flux Expansion and Parallel Connection Length

Goal of this work:

Detachment and radiation validations require to understand the competition between <u>flux expansion</u> f_{exp} and <u>parallel connection length</u> $L_{//}$

For 2 outer plate heights:

- (cyan) larger f_{exp}, smaller $L_{//}$
- (red) smaller f_{exp}, larger $L_{//}$



2 - State-of-the-art on Divertor Simulations

Advantages vs. Disadvantages of ≠ codes

UEDGE:
2D, Braginskii's equations, drift (on-off), fluid or kinetic neutrals, Impurity fixed fraction or charge exchange, SN/DN/Snowflakes grid already simulated

SOLPS-EIRENE:
2D, kinetic neutrals, drift (on-off), ITER Org's choice, Snowflakes grid already simulated

EMC3-EIRENE:
3D, No drifts, kinetic neutrals, Snowflakes grid already simulated

XGC-1 (and other versions):
Gyrokinetic equations (include kinetic effects),
No published results to date…

etc.

2 - UEDGE Introduction

UEDGE overview:
Fluid transport code, grid generator included (single/multiple X-pt, ortho/non ortho mesh), read EFIT/LRDFIT magnetic equilibrium reconstruction, Braginskii equations, drift on/off, fluid (or kinetic) neutrals, multi-species impurities, boundary constraints (core, plates, wall)

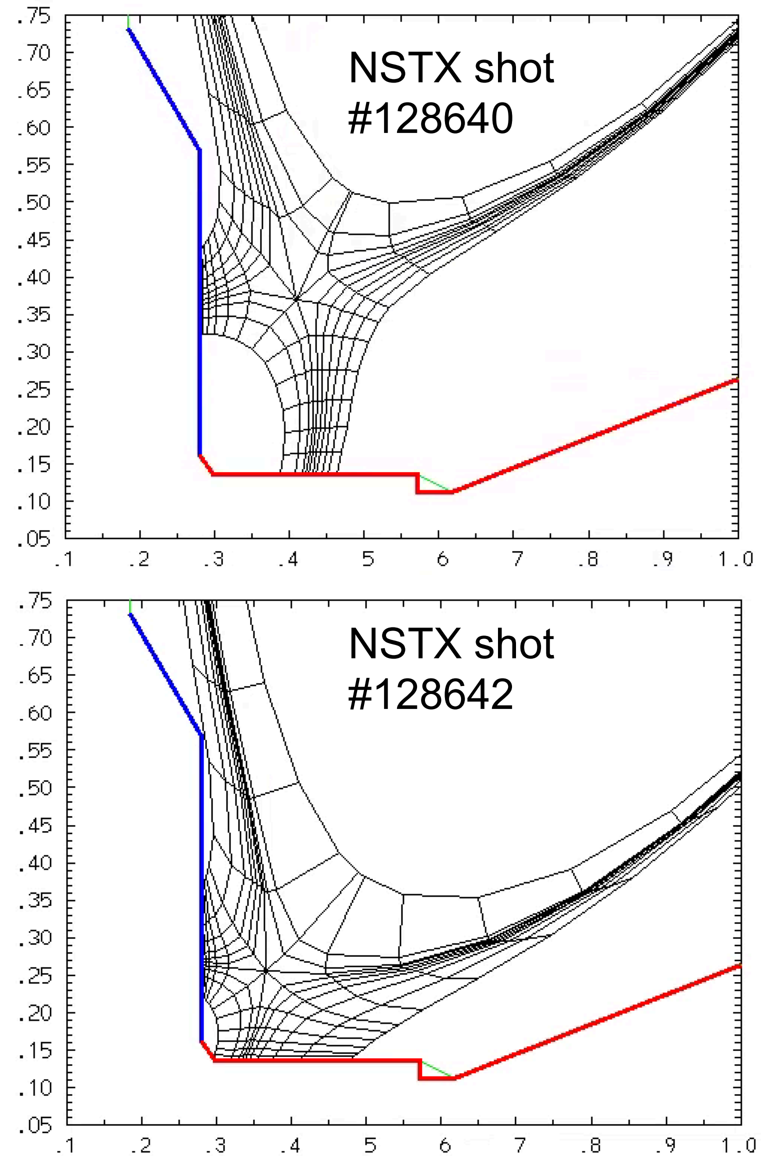
NSTX-like simulations:

Boundary conditions:
- ncore in [1e19 ; 4e19] m^{-3}
- pcoree=pcorei in [1 ; 6] MW

High recycling:
- Wall: recycw=100%
- Plates: recycp=99%

Transport coefficients: (poloidal and radial const.)
- difni in [0.1 ; 1] m^2/s
- kye=kyi in [1.5 ; 6] m^2/s

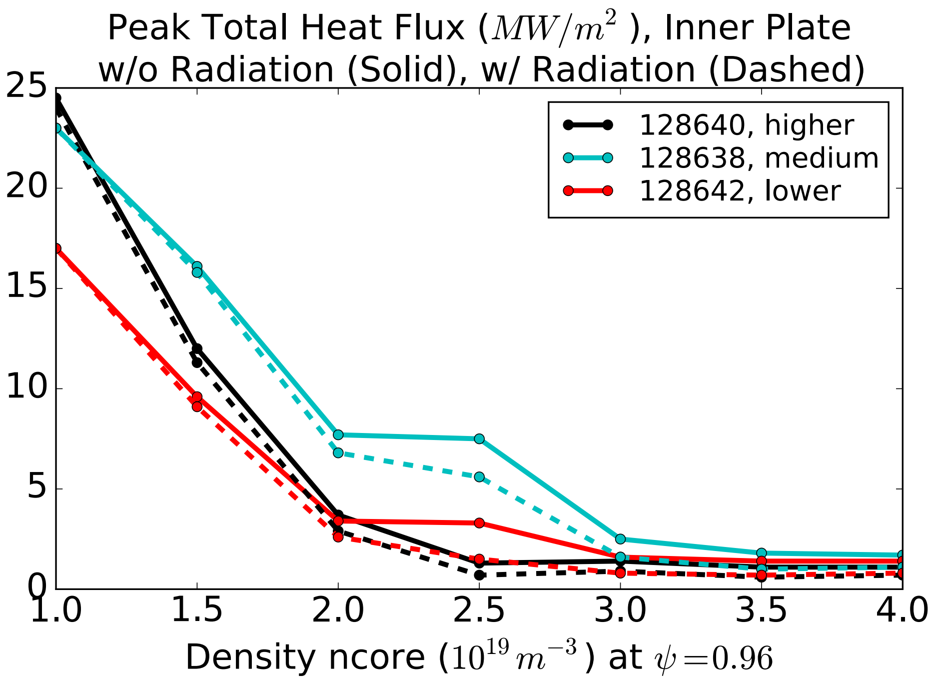
Impurity fixed fraction: (carbon)
- afracs in [1 ; 10]%

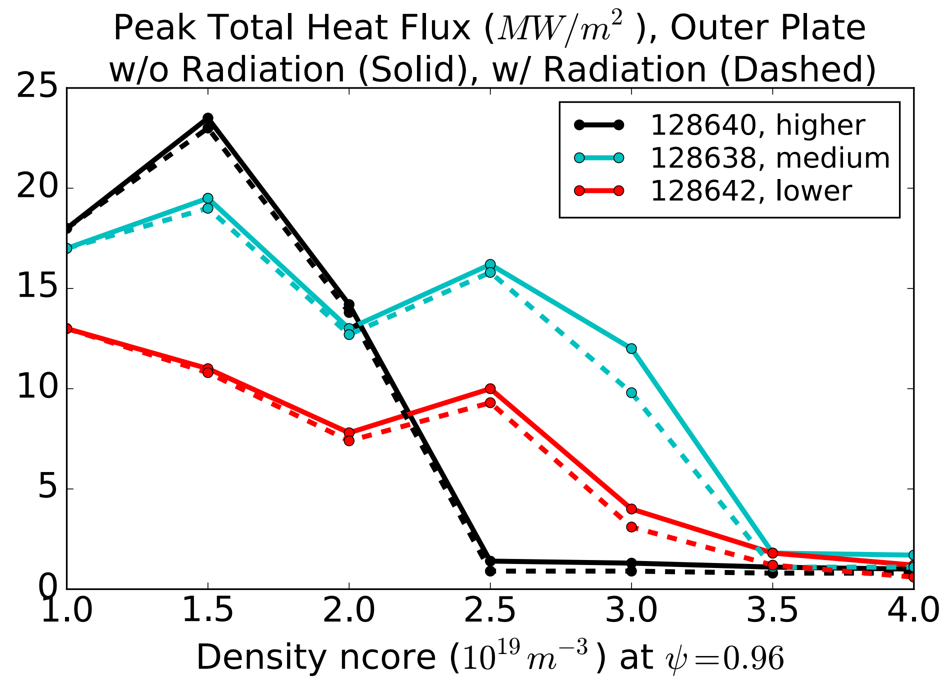


2 - UEDGE Simulations of NSTX divertor

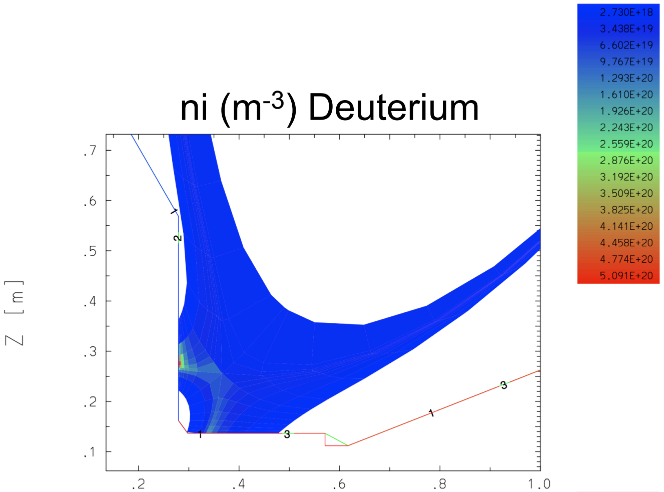
Our UEDGE simulations recover the dominance of the flux expansion (which reduces peak heat flux) over the parallel connection length (which increase peak heat flux) for low (≤ 2e19m^{-3}) density boundary condition!

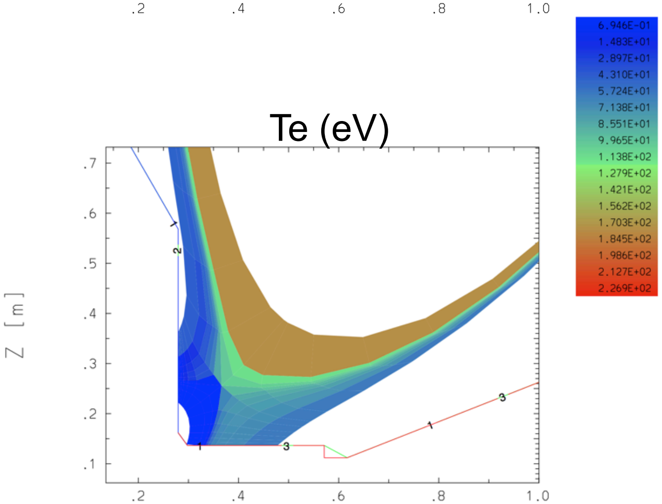
However, contradiction for higher (≥ 2.5e19m^{-3}) density boundary condition





2 - Detachment Discrepancy between UEDGE Simulations & NSTX Observations





R [m]

<u>Lower X-pt:</u>

NSTX shot #128642

<u>Higher X-pt:</u>

NSTX shot #128640

NSTX-like simulations:

<u>Boundary conditions:</u>

ncore=2.5e19 m^{-3}

pcoree=pcorei=2.0 MW

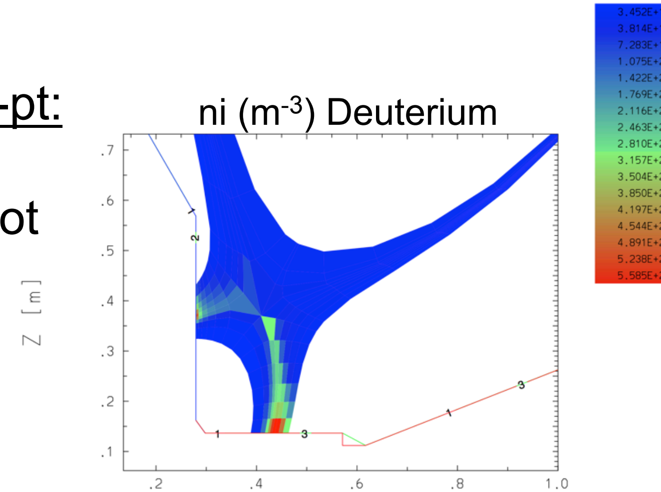
<u>Transport:</u>

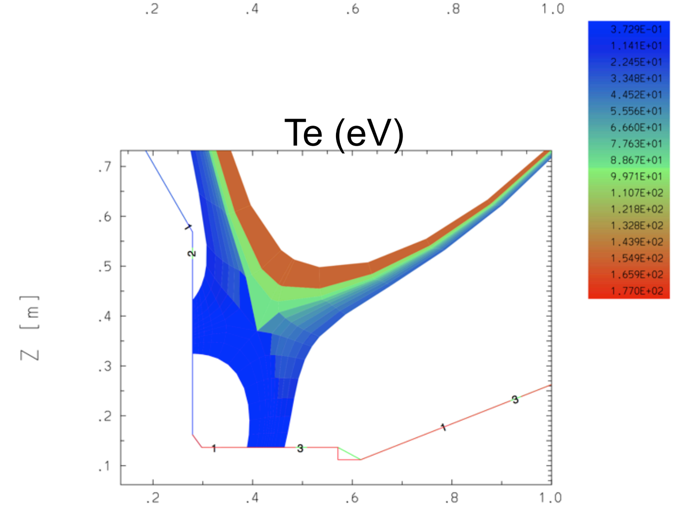
difni=0.5 m^2/s

kye=kyi=1.5 m^2/s

<u>Impurity fixed fraction:</u>

afracs=5%

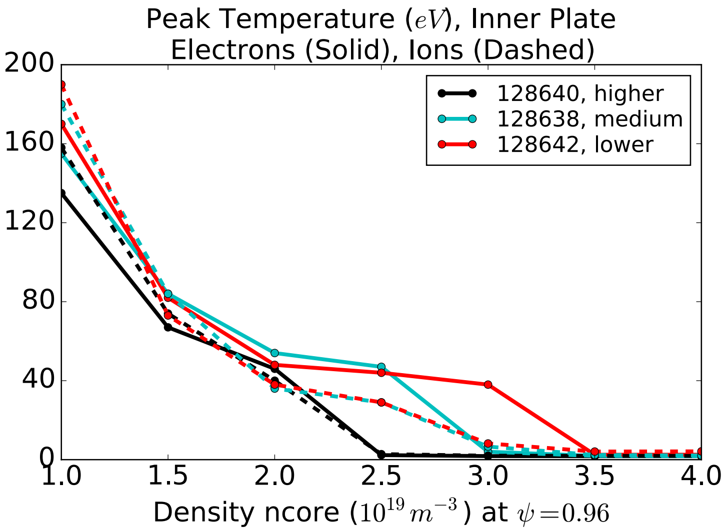


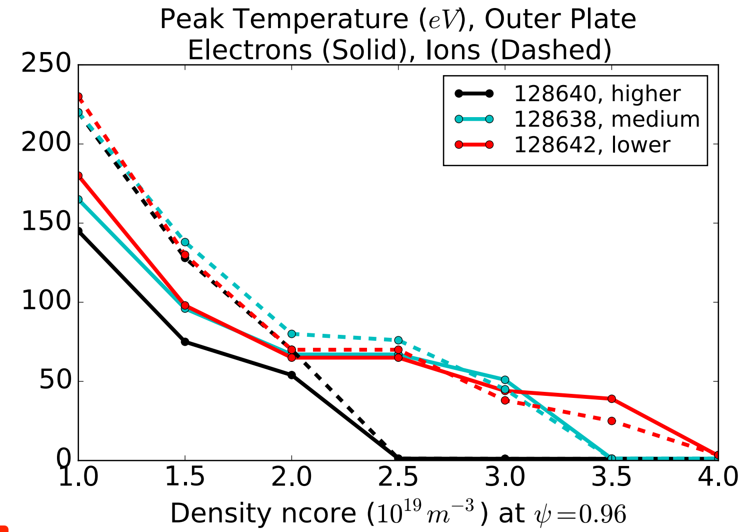


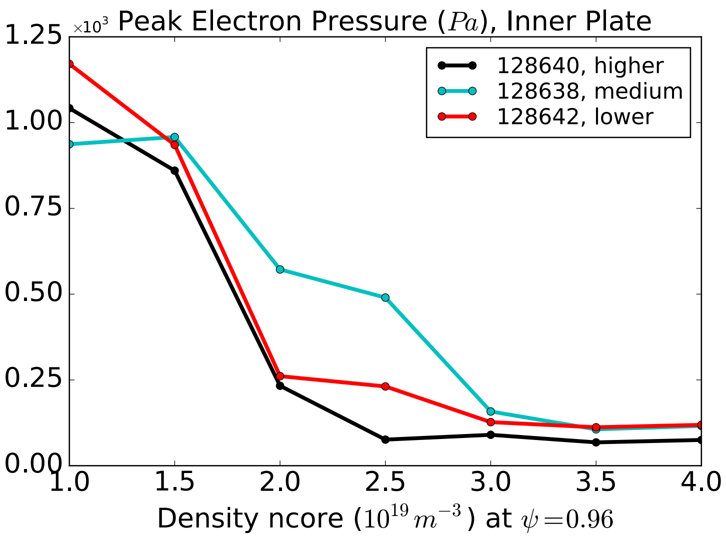
R [m]

Attached ← **IN OPPOSITION TO EXPERIMENTAL TENDENCIES** → **Detached**

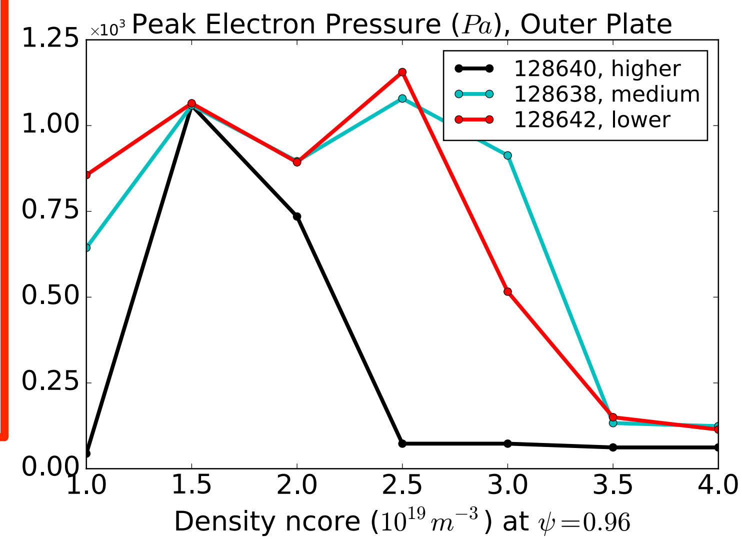
2 – Peak Temperatures & Pressures Profiles as fct. of Core Density







DETACHMENT SIMULATIONS IN OPPOSITION TO NSTX EXPERIMENTS: Need simulation improvements!



2 – Try to Move Closer to Experimental Observations

Issue:

Failure to recover the experimental observations of detachment at high core density

How can we fix it?

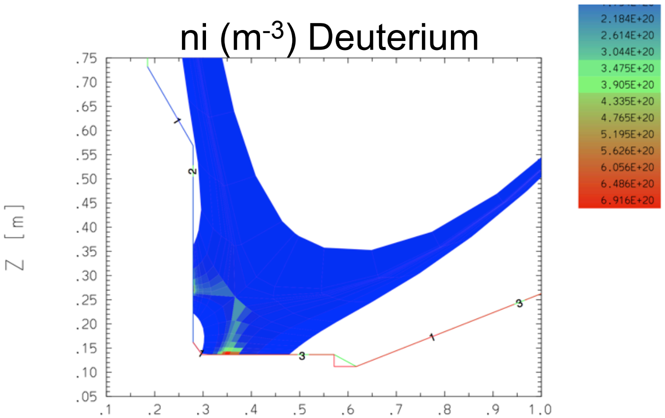
- understand if this discrepancy is related to radiation
- what are the impacts of transport coefficients (particle diffusion and heat conduction)

=> Indeed, usually people match experimental profiles by using 1D or 2D transport coefficient profiles with different (fixed fraction or charge exchange) impurity densities

However, before using the most advanced “magical” technique, we need to understand if there is a solution with minimal modifications

3 - Higher Impurity Fixed Fraction Needed to Detach (Partially) the Lower X-pt

<u>Solution 1:</u> Scan of impurity fixed fraction

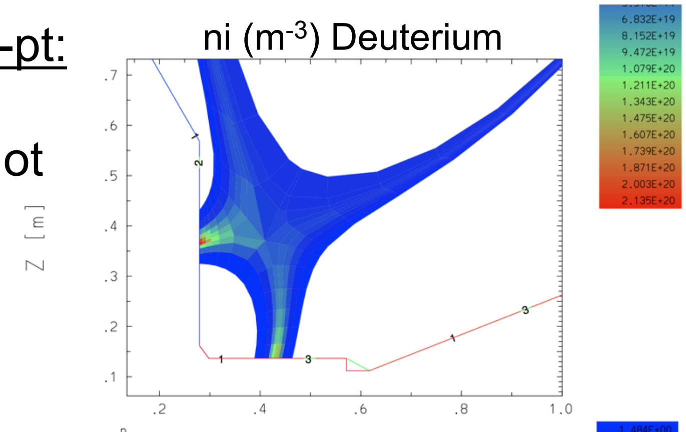


<u>Lower X-pt:</u>

NSTX shot #128642

<u>Higher X-pt:</u>

NSTX shot #128640

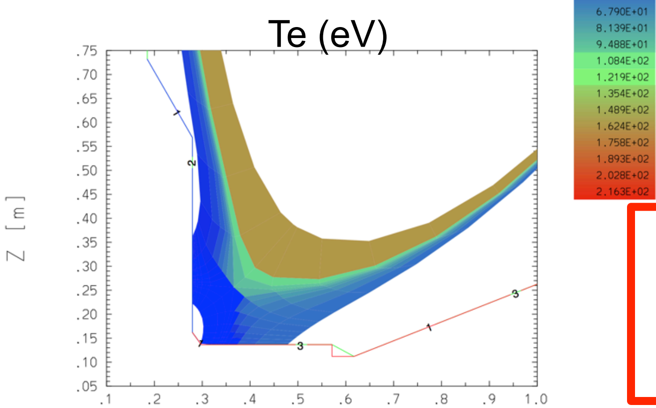


(Partially) Detached

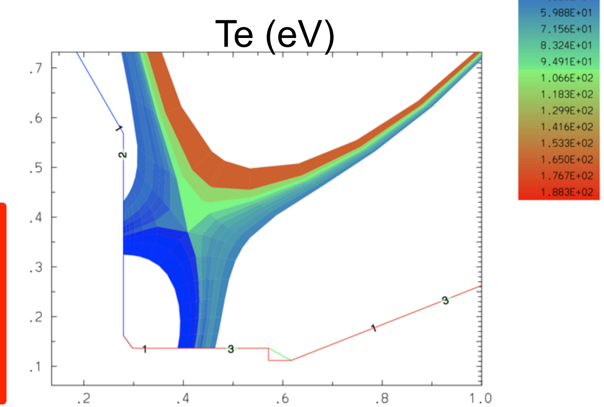
Attached

NSTX-like simulations:
<u>Impurity fixed fraction:</u>

afracs=10% | afracs=1%



RECOVERS DETACHMENT SIMILAR TO NSTX EXPERIMENTS



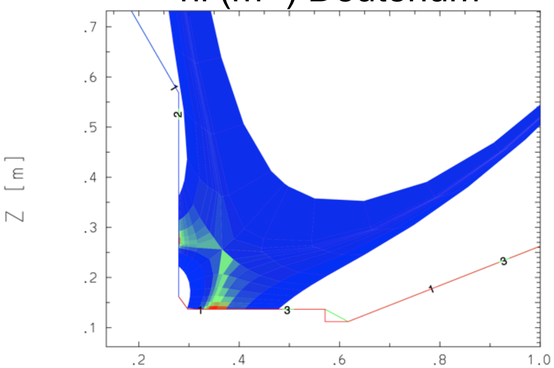
<u>Problem:</u> How to motivate 10% vs. 1% of impurity?

R [m] R [m]

3 - Higher Heat Conductivity Needed to Detach (Partially) the Lower X-pt

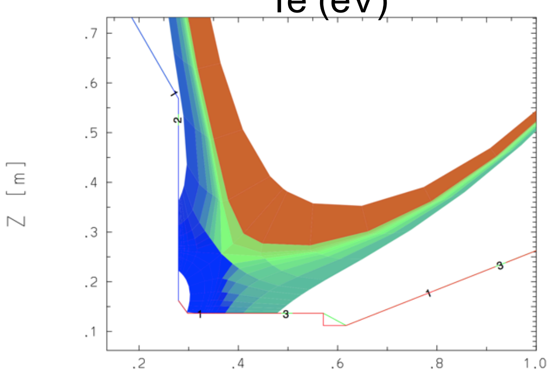
❌ **Solution 2:** Scan of heat conductivity

ni (m^{-3}) Deuterium



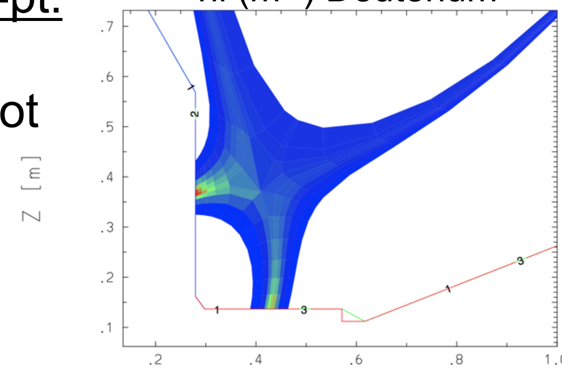
(Partially) Detached

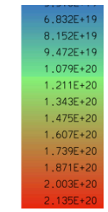
Te (eV)



Lower X-pt:	Higher X-pt:
NSTX shot #128642	NSTX shot #128640

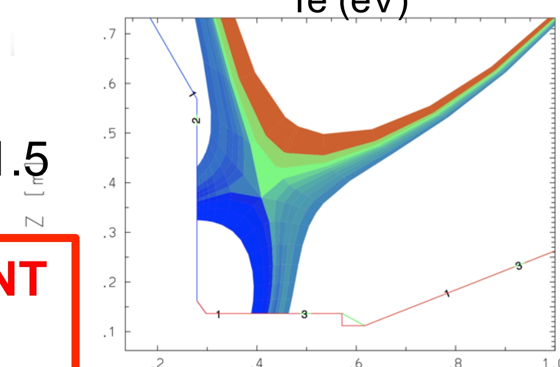
ni (m^{-3}) Deuterium





Attached

Te (eV)



NSTX-like simulations:

Boundary conditions:

ncore=2.0e19 m^{-3}

Particle diffusion:

difni=0.4

Heat conduction:

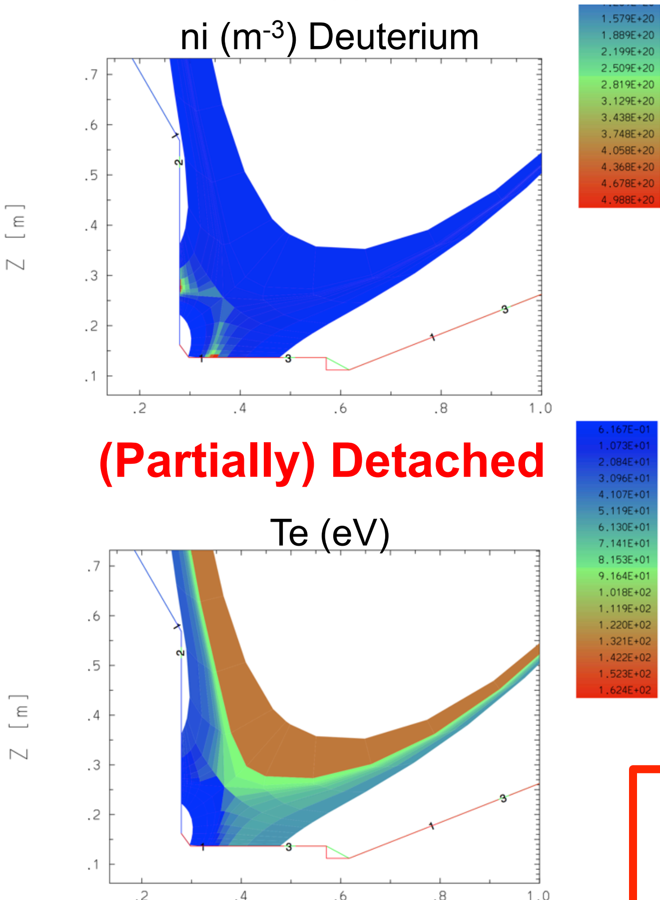
kye=kyi=6 | kye=kyi=1.5

RECOVERS DETACHMENT SIMILAR TO NSTX EXPERIMENTS

Heat conductivity differences at ≠ X-pt heights

3 - Higher Particle Diffusion Needed to Detach (Partially) the Lower X-pt

Solution 3: Scan of particle diffusion



Lower X-pt:	Higher X-pt:
NSTX shot #128642	NSTX shot #128640

NSTX-like simulations:

Boundary conditions:

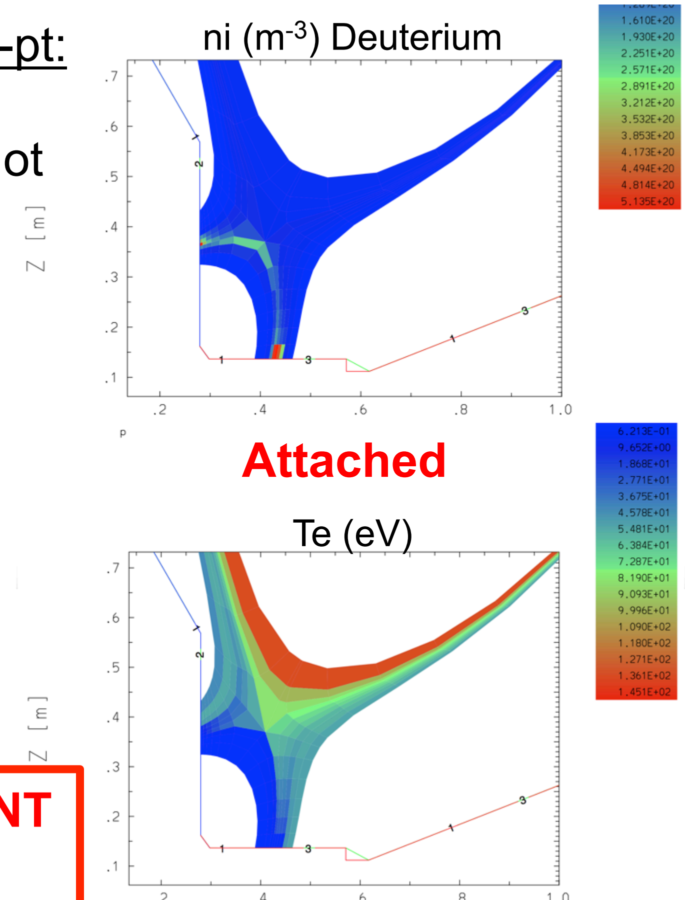
ncore=2.5e19 m^{-3}

Heat conduction:

kye=kyi=2.5

Particle diffusion:

difni=0.4 | difni=0.1

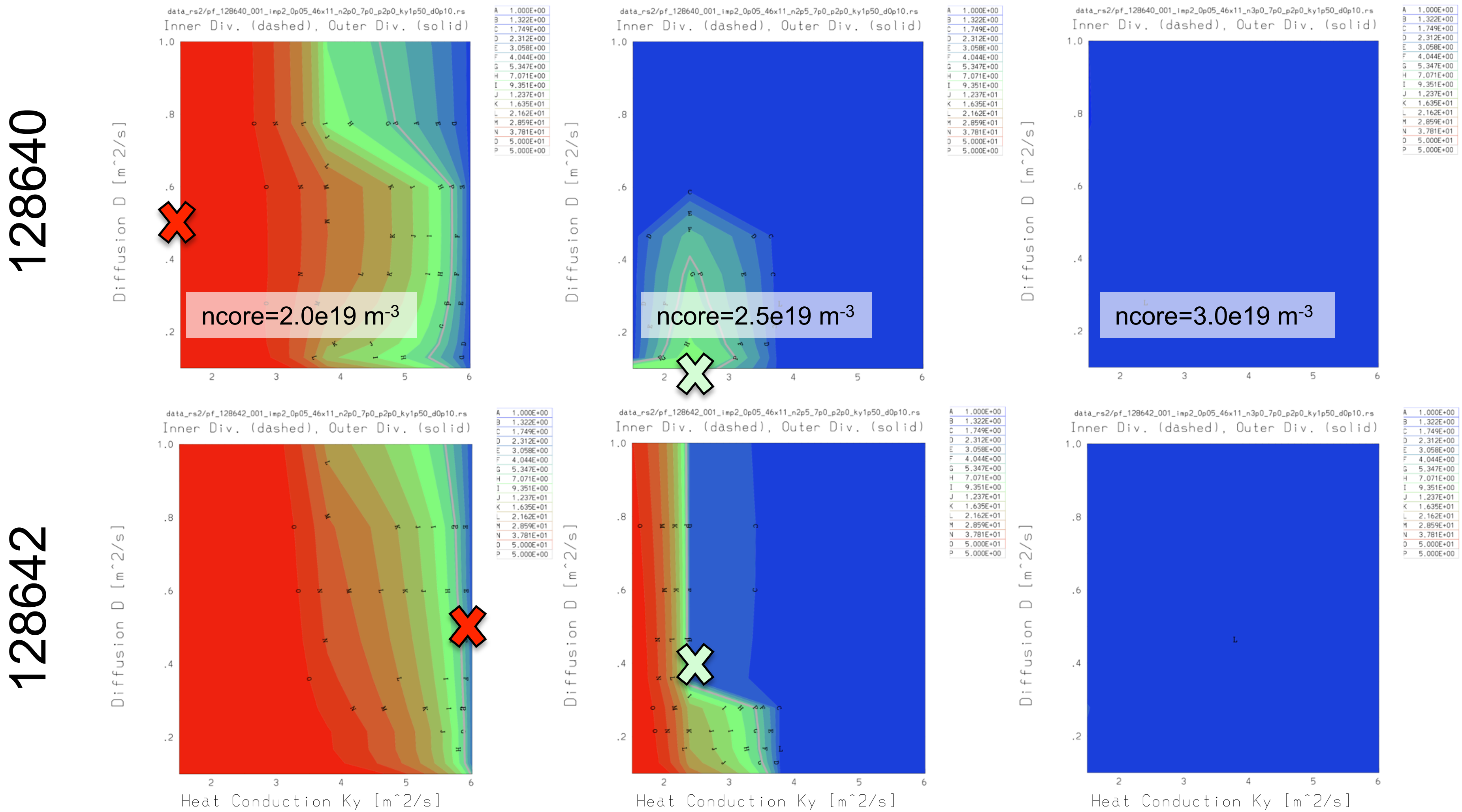


RECOVERS DETACHMENT SIMILAR TO NSTX EXPERIMENTS

Particle diffusion differences at ≠ X-pt heights

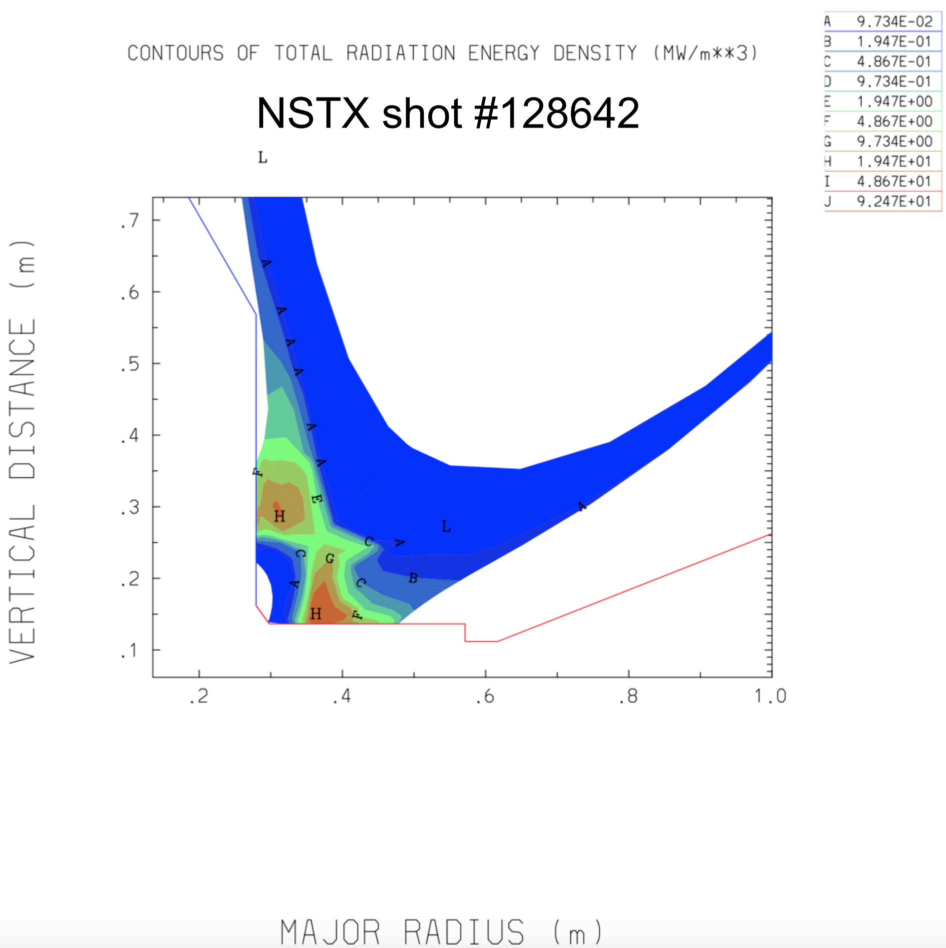
3 – 2D Map of Detachment for 2 NSTX shots at 3 densities

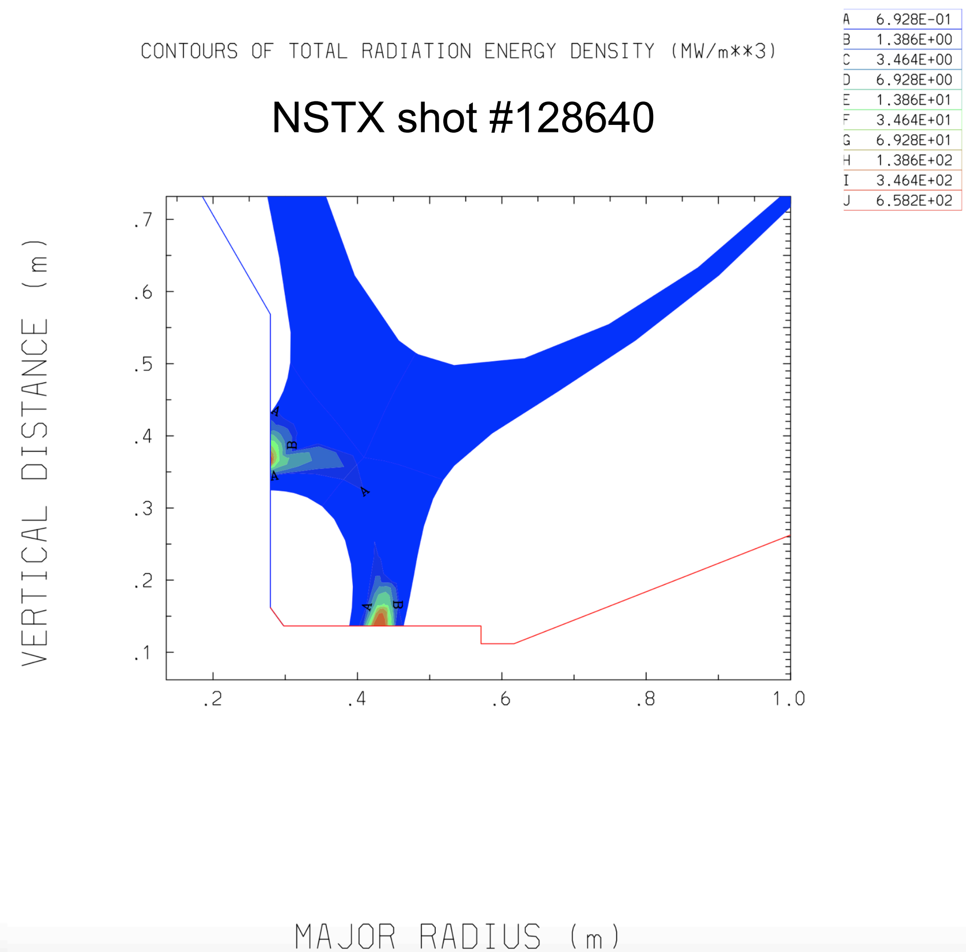
Map $T_e\,(D,K_y)$ of detach. ("def." by $T_{e,out\text{-}plate} \leq 5$eV on R in [0,2]cm):



4 - 2D Radiation at Low Density

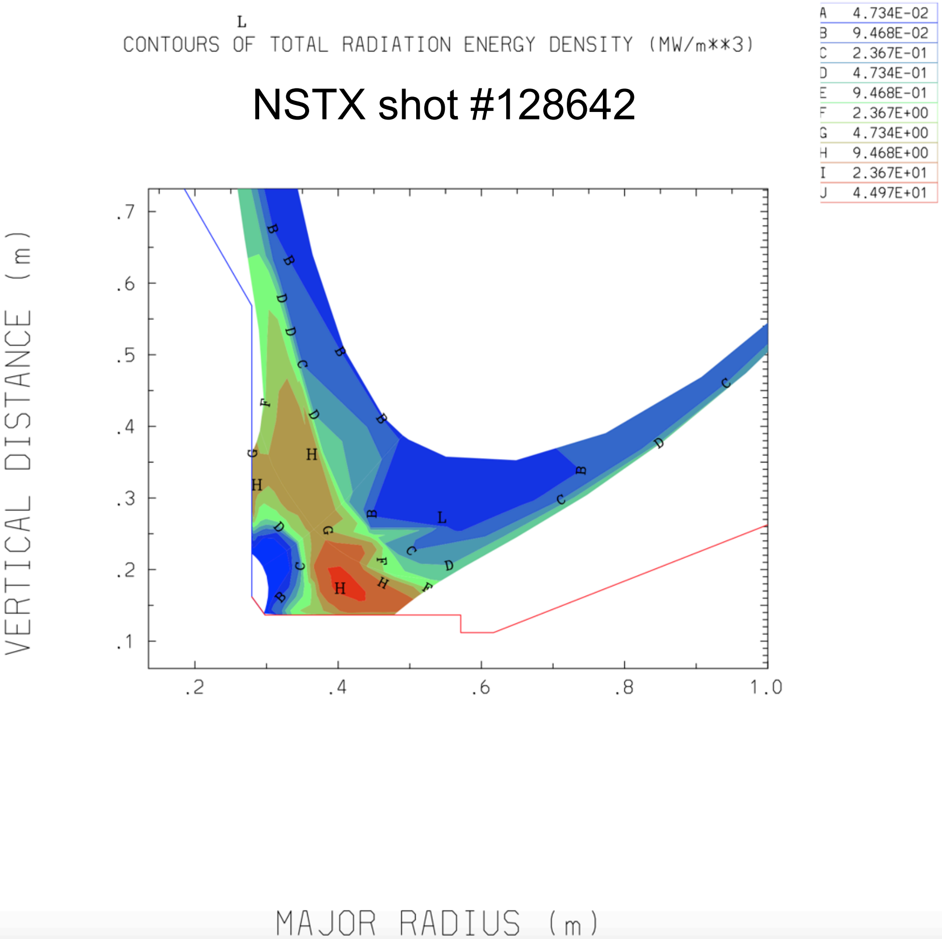
As commonly observed, increasing *D* increases radiation (see ✗, solution 2a)

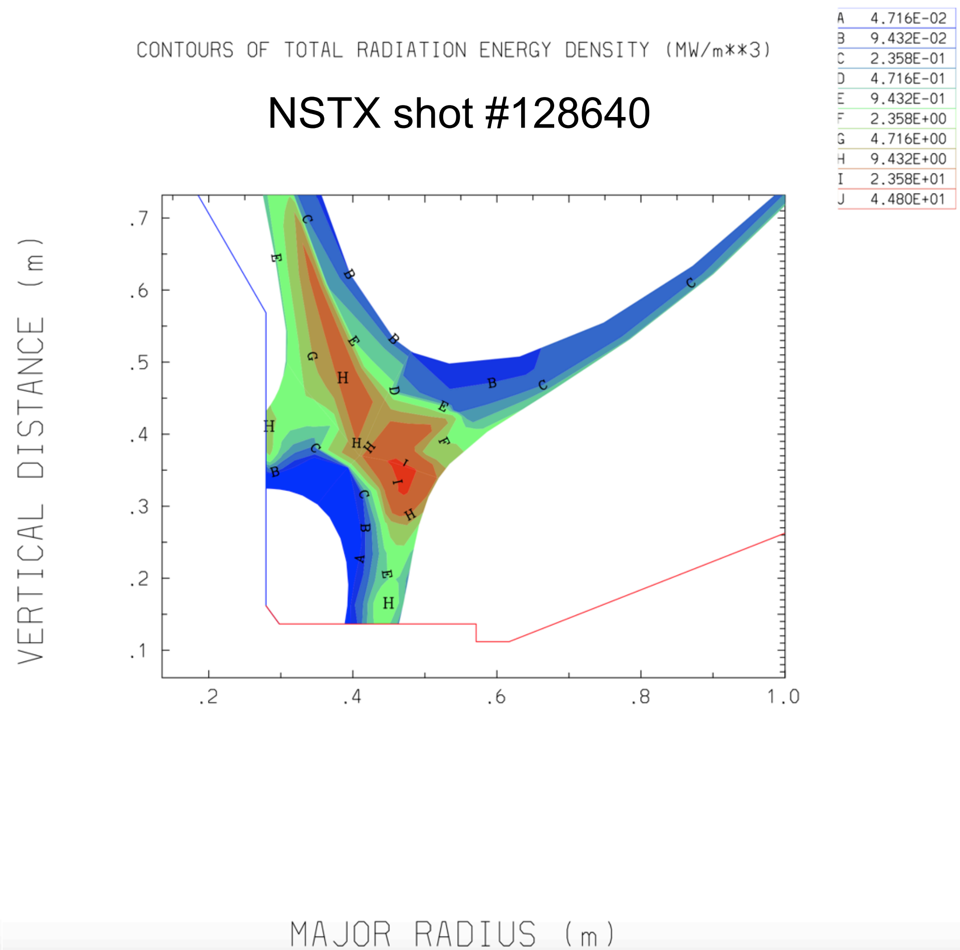




4 - 2D Radiation at High Density

Both legs fully detached, increasing *D* does not change the radiation





5 - Discussion

Results of our UEDGE simulations:

Higher X-pt has higher heat flux at low density (attached) than for lower X-pt
=> same than experimental observation!

Higher X-pt has lower heat flux at high density (detached) than for lower X-pt
=> but detachment was not well simulated!

Lower X-pt detaches at lower density than for higher X-pt with higher transport coefficients or with more radiation (more impurities)
=> experimental correspondence, but need to evolve impurities (charge exchange) and to add more impurity species

Radiation contributes to the detachment
=> need to include more impurity species

Radiation does not change with transport for a fully detached plasma
=> but radiation enters in the core for higher X-pt

5 - Perspectives

- **Validation between UEDGE simulations and NSTX data:**

Need to adapt the transport coefficients (radial & poloidal profiles), to use charge exchange impurities or a mix of them to match experimental profiles

- **Snowflakes simulations in UEDGE:**

NSTX snowflakes have been already performed. Need to validate UEDGE simulations against DIII-D snowflakes experiments. Can we find the best divertor configuration? (open, close, inclinations, baffles, etc.)

- **Explanation of required transport coefficient profiles to match profiles between UEDGE simulations and experimental data:**

Are transport coefficient profiles linked to kinetic effects? Stay tuned for the answer…