UEDGE Simulations of the NSTX Liquid Lithium Divertor Module*

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NSTX

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NSTX Investigating Use of Lithium as a Plasma Facing Material

- For density control,
- Reducing impurity influxes,
- Heat flux handling,
- Improved plasma performance.
- NSTX lithium program proceeding in stages:
  - Li pellets (FY 2005 - 2009)
  - Li evaporator (FY 2006 - 2009)
  - Liquid lithium divertor (FY 2009 - 2012)
  - In parallel, LTX will examine efficacy of Li as the primary PFC.

Developing a Liquid Lithium Divertor (LLD) to Provide More Pumping & Better Density Control

- Evaporated Li in NSTX has yielded positive results,
  - L-mode density reduced 50% & H-mode density reduced 15%,
  - Along with improved τ_E and ELM control.
- But, density still increases monotonically during shot.
- $\Rightarrow$ Taking next step towards more aggressive use of Li as a PFC.
- Tokamak programs have relied on modeling in designing cryopumps,
  - Likewise, using modeling to aid in determination of LLD parameters.
  - Distinction is that Li pumps plasma & atoms
    $\Rightarrow$ describing plasma + neutral gas modeling here.
  - Programmatic & practical considerations also enter.

The Liquid Lithium Divertor Is a Joint Collaboration Between Sandia, UCSD, and NSTX

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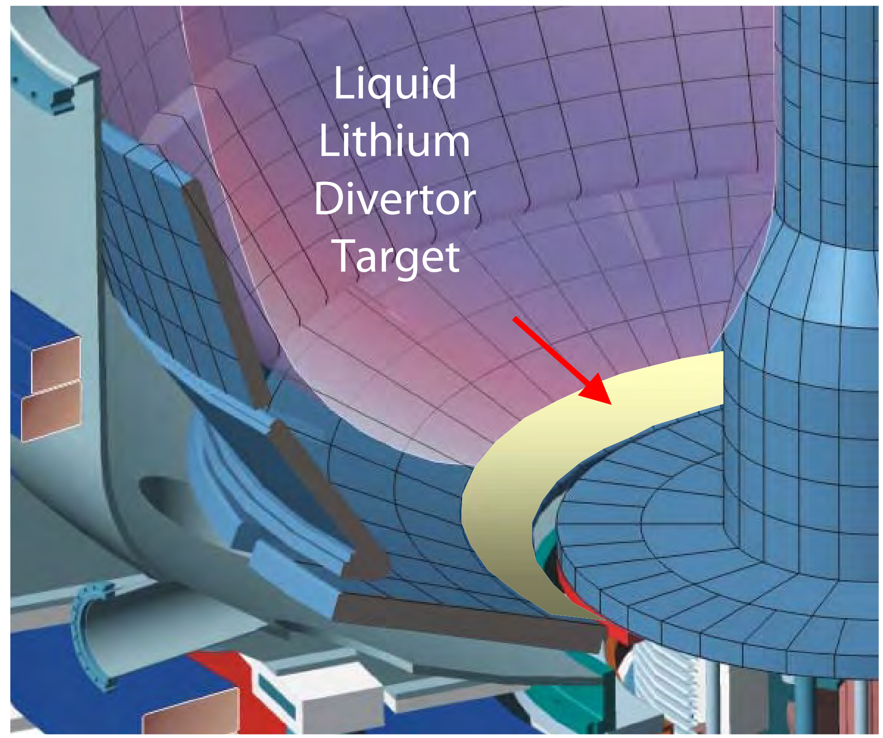
● The LLD collaboration is the result of a DoE funded proposal led by Sandia National Laboratory (R. Nygren, PI).

● The basic concept is of a toroidally extended lithium containing tray that would serve as a target for the outer strike point or divertor.

- E.g., a "boat" containing a Li-soaked Mo sponge.

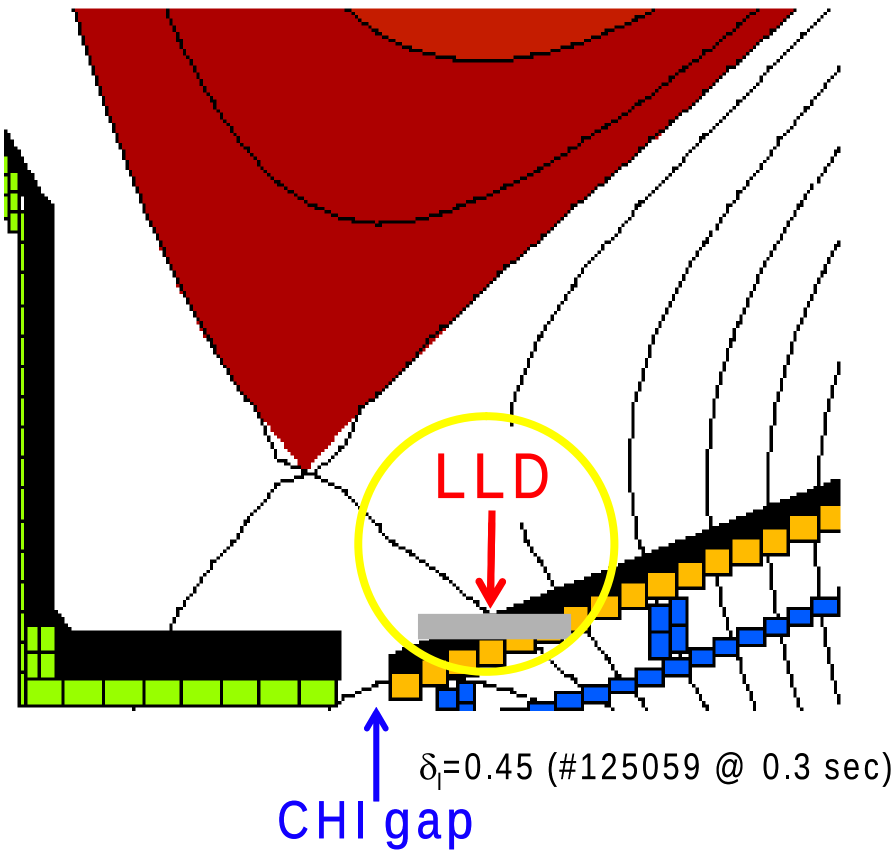


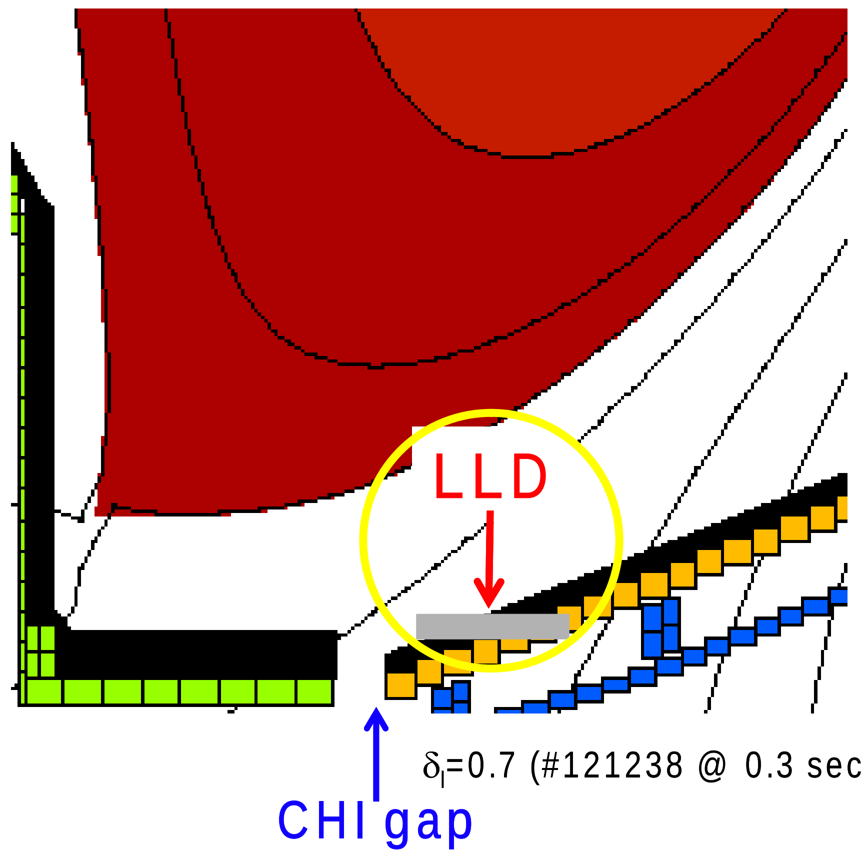
NSTX, Sandia, and UCSD Will Work Together to Design the LLD

- NSTX and SNL will work together to:
  - Arrive at a detailed design for the LLD,
    - ∗ The work described in this poster is part of this.
  - Decide on responsibilities and operational plans,
  - Install and test the LLD,
  - Carry out LLD experiments.
- UCSD will provide systems for filling the LLD with Li.

Goal of LLD is to Provide Density Control in Both Low & High Triangularity Shapes

NSTX





- For low triangularity, goal is 50% reduction in n_e.
- For high triangularity, 25%.
- Amount of pumping & density control will depend on distance of strike point from tray.

Key LLD Parameters to be Determined Based on Pumping Effectiveness and Practical Considerations

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- Need to estimate dependence of pumping effectiveness on:
  - Tray width w_t,
  - Tray major radius R_t,
    - Including location relative to CHI gap.

- Other aspects determined by NSTX engineering & SNL experiments:
  - Number of tray segments, gap between segments, "clocking" of segments.
  - Horizontal or sloped.

0-D Particle Balance Model Provides Initial Insight into Dependence of Pumping on LLD Parameters

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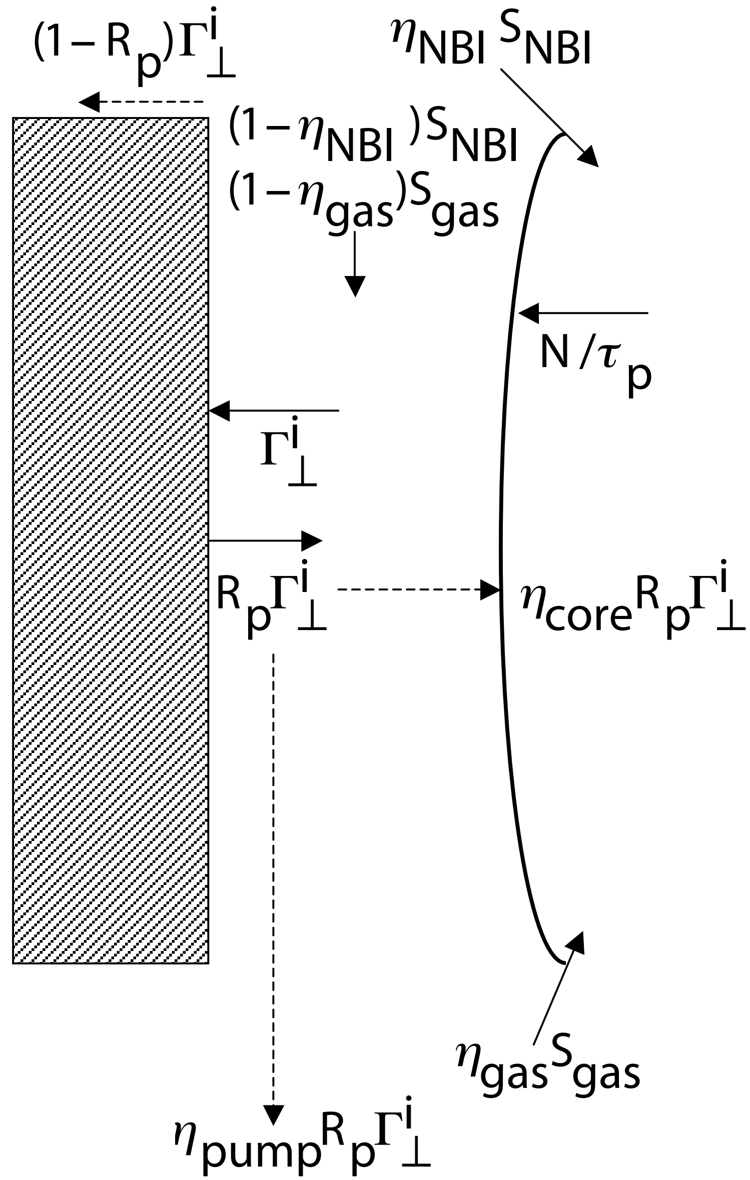
- Set up coupled equations for:
  - Number of core ions N,
  - Number of SOL ions + atoms.
- Include:
  - Source due to NBI S_{NBI},
  - Source due to gas puffing S_{gas},
    - Fractions deposited in core η_{NBI} & η_{gas}.
  - Divertor recycling coefficient R_p,
    - Fraction of recycled gas reaching core η_{core}.
    - Fraction that is pumped by Li η_{pump}.
- Solve for $N(\eta_{\mathrm{pump}} > 0)/N(\eta_{\mathrm{pump}} = 0)$.



0-D Pumping Probability η_{pump} Estimated Using Plasma & LLD Parameters

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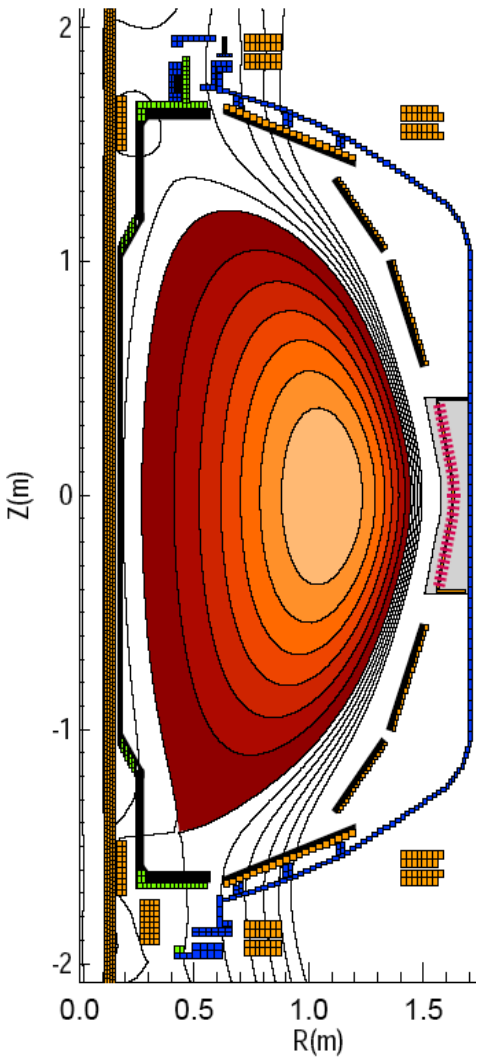
- Factor in:
  - LLD tray width & radius,
  - Distance of tray from outer strike point,
  - Up / down & in / out divertor particle flux ratios (from CCD camera),
  - An 85% sticking probability for a D atom striking tray.
- Examine shots with different strike point location & flux expansion.
- Conclude: 15 - 20 cm wide tray just outside CHI gap will provide $\sim 30 - 50\%$ density reduction.
- Objective of UEDGE modeling is to put these results on firmer footing.

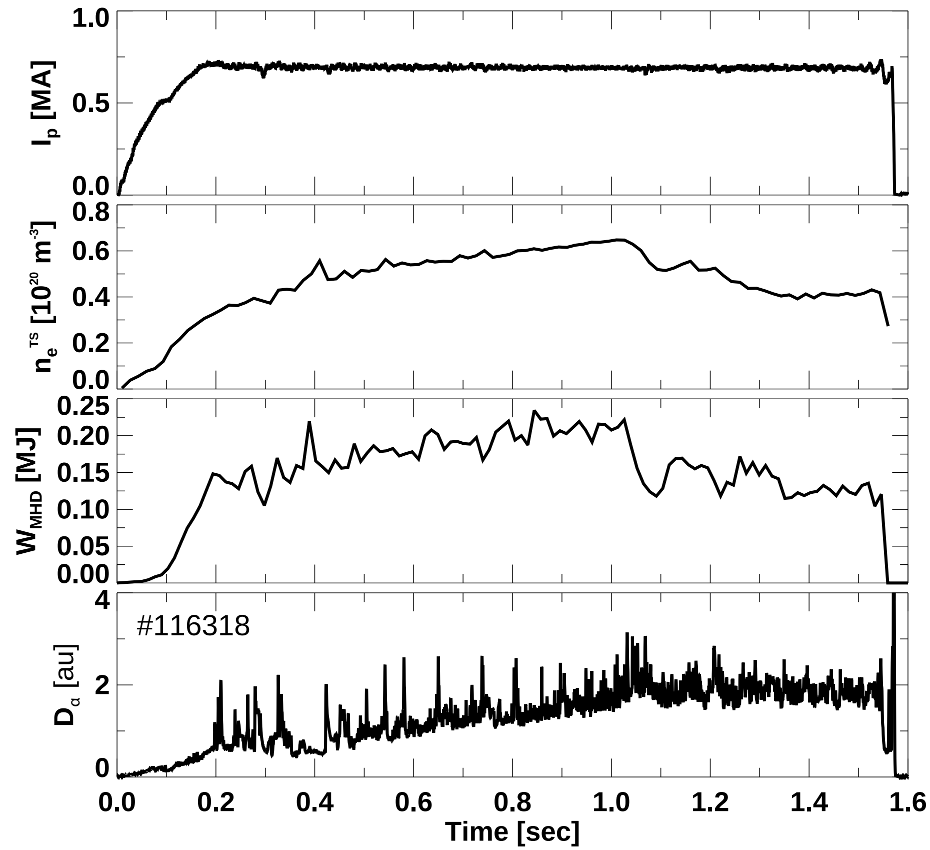
Shot 116318 Has Intermediate Triangularity, Inner Divertor Strike Point, Narrow SOL

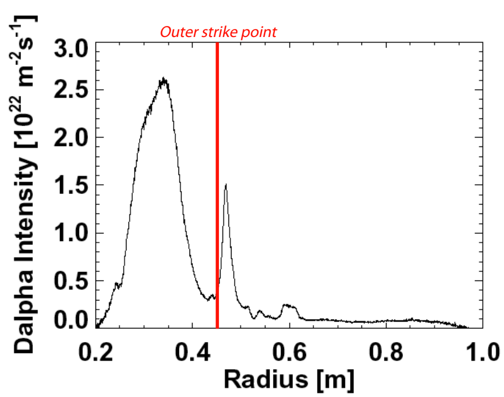
Existing #116313

$\kappa = 2.3, \ \delta_{X\text{-}L} = 0.75$

$\delta R_{SEP} = -1\text{cm}$







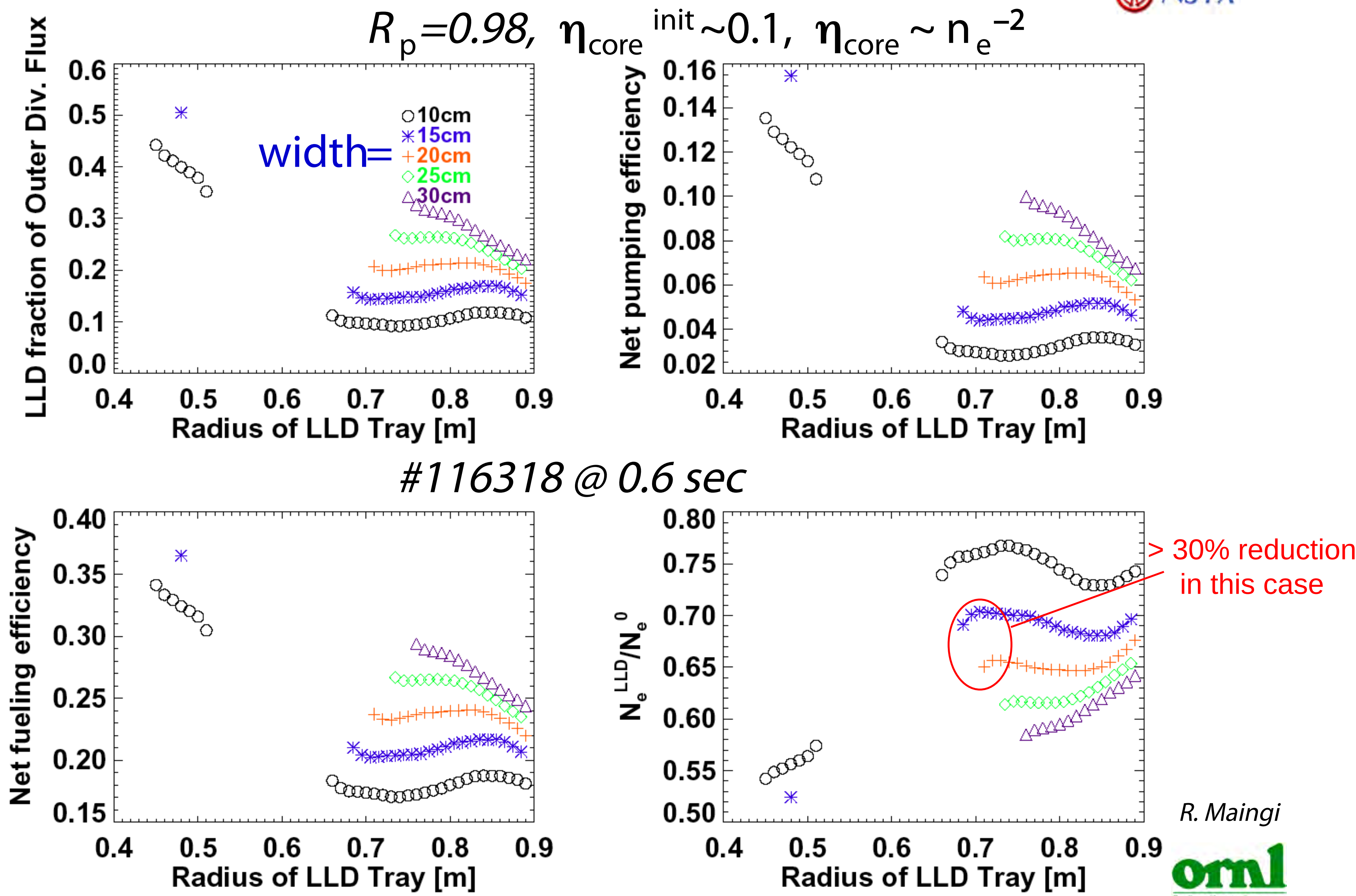
#116318 @ 0.6 sec

(no data on #116313)

Soukhanovskii

R. Maingi

Pumping by 15 - 20 cm Wide LLD on Outer Divertor Will Reduce Density by 30 - 50%



R. Maingi

UEDGE Is a 2-D Edge Plasma Transport Code

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- Mesh based on experimental equilibrium with one coordinate following flux surfaces.

- Second coordinate orthogonal except near divertor surfaces.

- Solve equations for n_i, T_e, T_i, $u_{\|}$, ϕ,

  – Classical transport along field lines $+$ flux limits,

  – Anomalous transport across flux surfaces.

  – Not solving ϕ equation and ignoring $\mathbf{E} \times \mathbf{B}$ & $\boldsymbol{\nabla} B$ drifts here.

- Multi-species impurities can be simulated.

- Built-in fluid model for neutral atoms,

  – Can be coupled to Monte Carlo neutral transport model like DEGAS 2.

Use UEDGE to Estimate LLD Density Reduction Based on Simulation of Existing Shot

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- Fix n_e, T_e, and T_i at core boundary using Thomson scattering & CHERS data,

- Adjust D, χ, R_p, etc. to match midplane profiles & divertor measurements,

- Switch to equivalent particle & power flux boundary conditions at core.

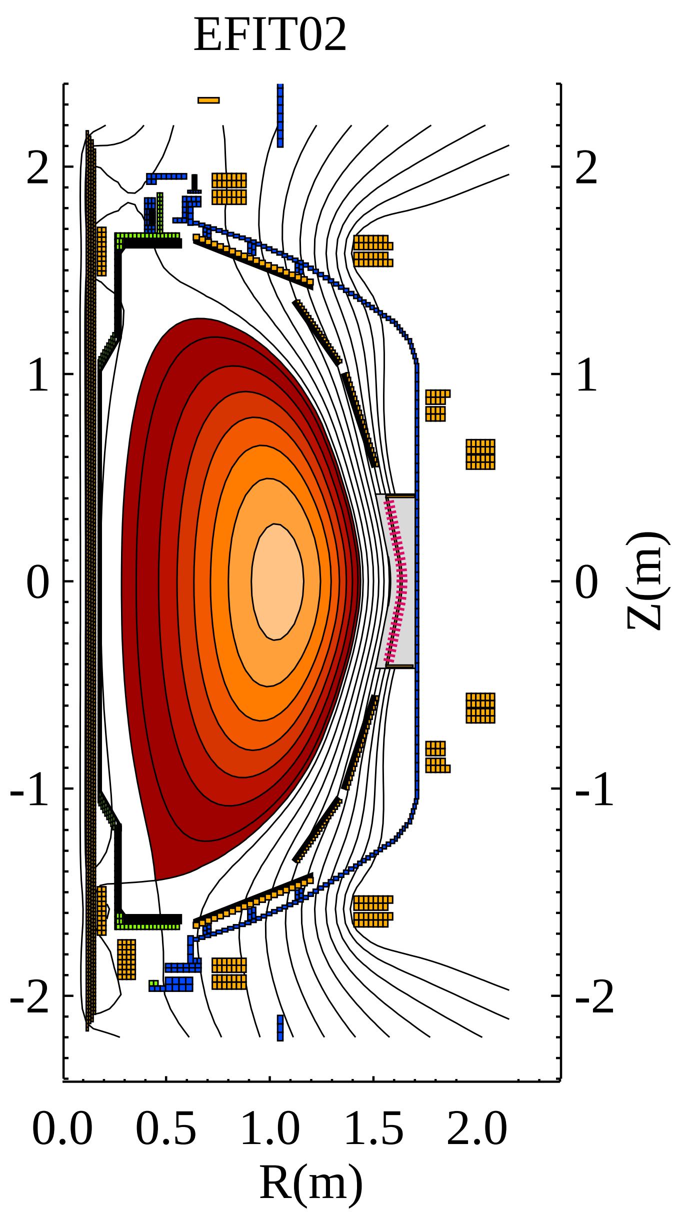
- Simulate tray as region of reduced recycling along divertor plate, holding all other parameters fixed,

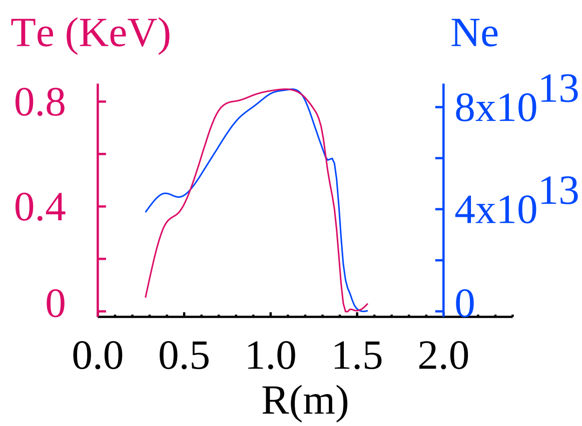
- Obtain N_e^{LLD}/N_e^0,

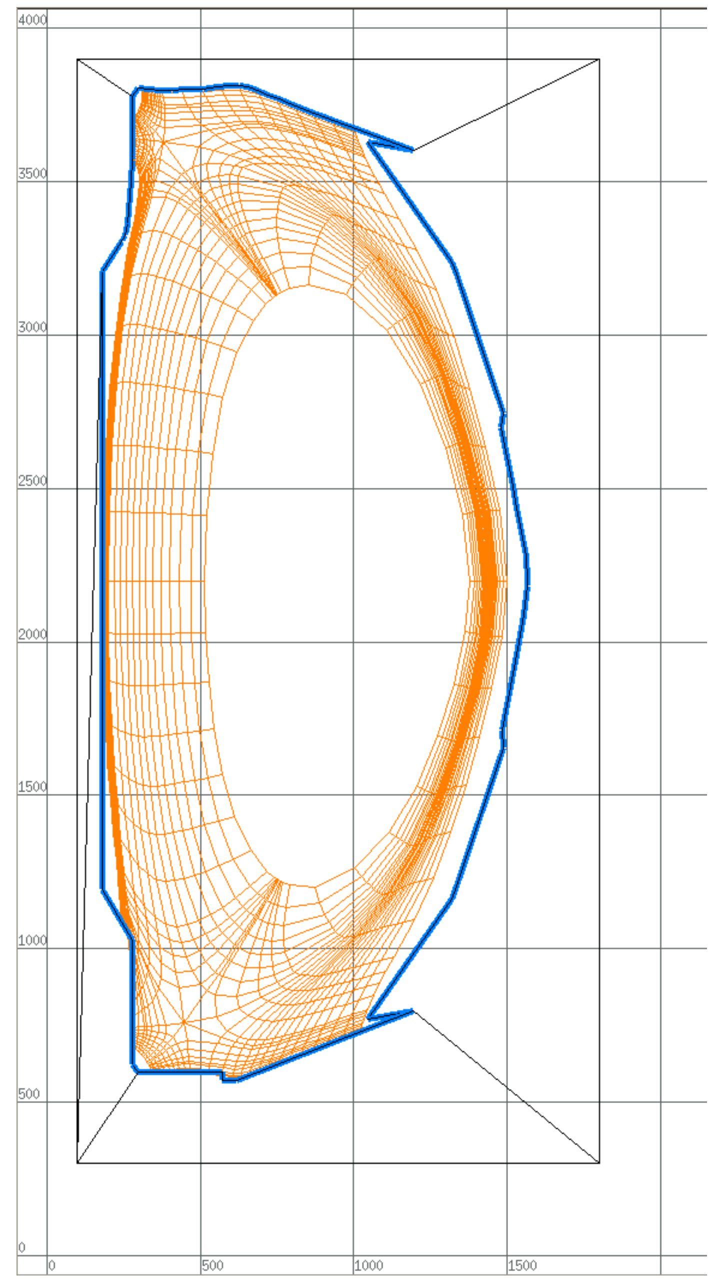
  – Vary tray major radius and width
    $\Rightarrow$ curves analogous to those from 0-D model.

- Can also assess validity of assumptions and parameter values entering into 0-D model.

UEDGE Simulation Based on Shot 116318 @ 0.970 s



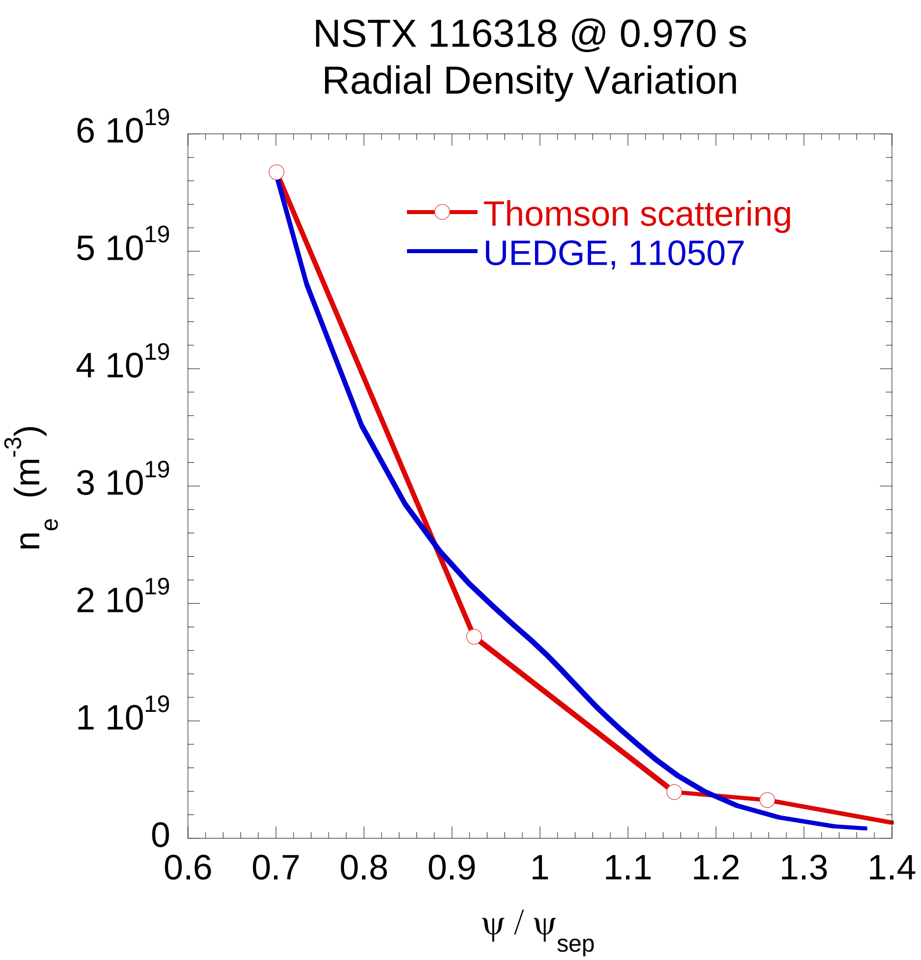


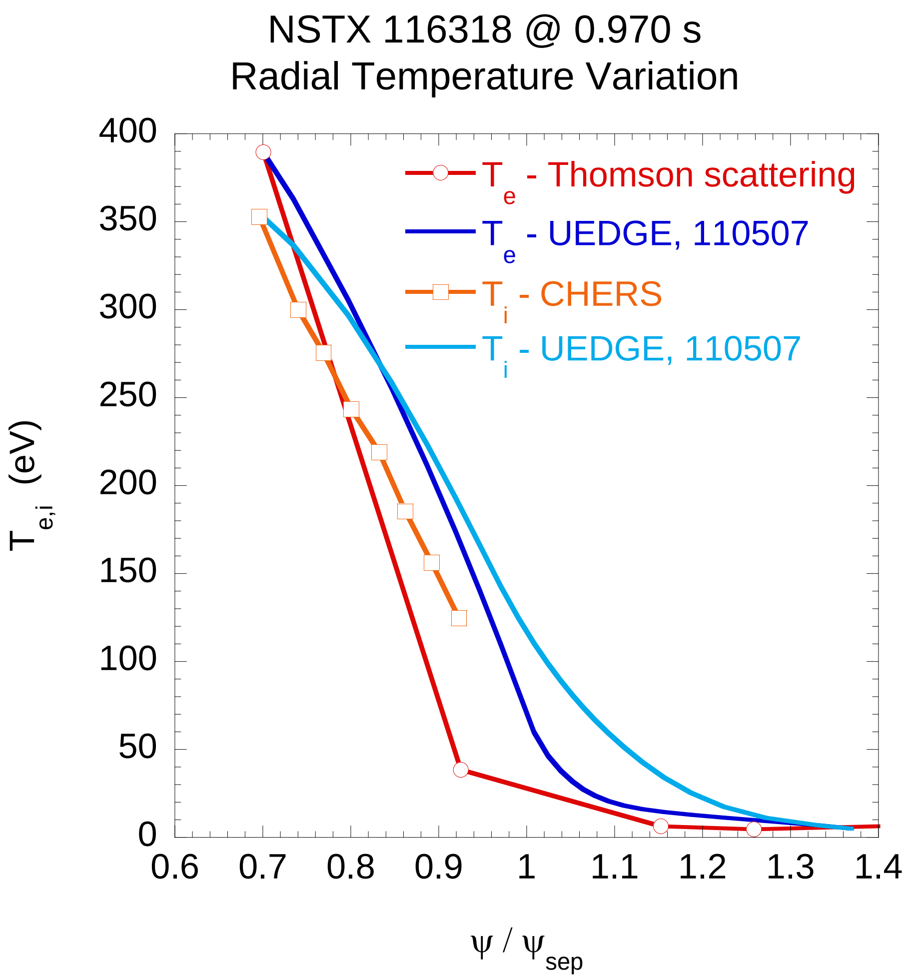


Adjust Transport Coefficients & Impurity Fraction to Match Midplane Profiles and Power into SOL

- $D = 1.2$ m^2/s,
- v increases with ψ_n from -20 m/s at core to $+60$ m/s at outer edge,
- Similarly, χ_e increases from 5.5 to 6.5 m^2/s,
- $\chi_i = 4.5$ m^2/s.
- Set impurity fraction to reproduce estimated 4.1 MW flowing into SOL,
  - Using global impurity fraction of 0.018.
  - With an impurity lifetime of 1 ms.
  - Radiation computed via coronal non-equilibrium MIST model (Hulse & Post).

Simulated UEDGE Midplane Profiles Close to Those Measured





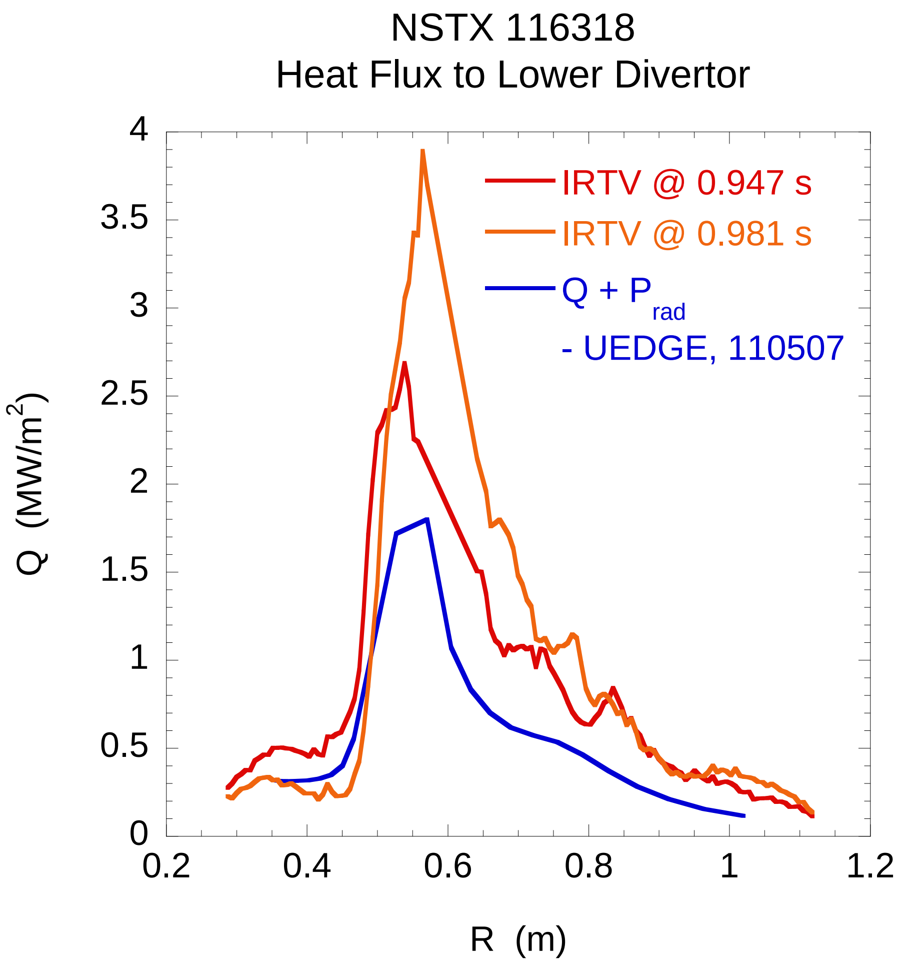
Adjust Remaining Parameters to Match Divertor Signals

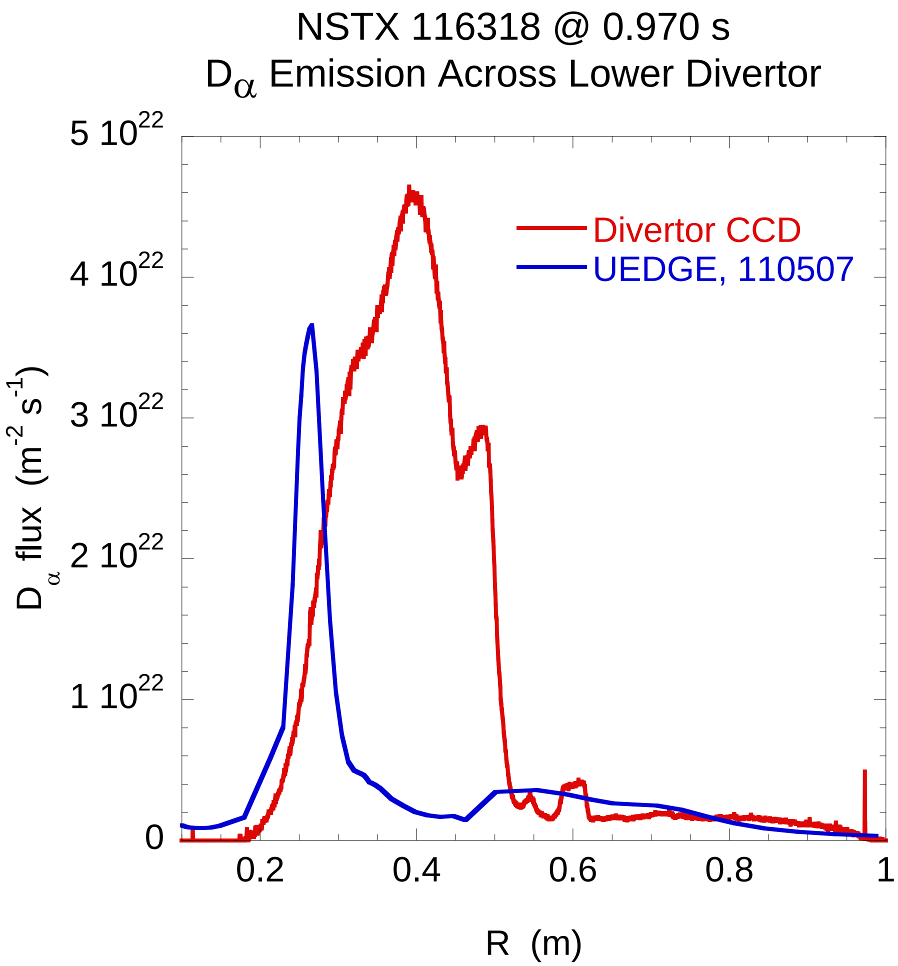
- 100% divertor recycling & 90% wall recycling.

- Simulated heat flux below IRTV data,
  - But roughly correct shape.
  - $\Rightarrow$ Not enough power into SOL?

- Simulated D_α emission far below that observed with divertor viewing CCD camera,
  - Due to recombination?
  - Trapping of Ly-α may also be important.

Comparison of Simulated Divertor Conditions with Measurements More Problematic





Miscellaneous Considerations

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- Use of disconnected double null configuration allows UEDGE mesh to span entire lower divertor,
  - Consistent with NSTX interest in high δ discharges.
- Need inner gap as large as possible to facilitate construction of UEDGE mesh.
- Core boundary at small enough ψ_n that neutral flux into core is negligible.
- Would like for simulations to self-consistently estimate lithium temperature,
  - And estimate resulting Li evaporation.
- Once carbon incorporated into UEDGE as an explicit species, will be interested in carbon ion flux striking LLD,
  - Concerned with sputtering and creation of LiC.

Summary

- 0-D particle balance model indicates that 15 - 20 cm wide tray just outside CHI gap provides $30 - 50\%$ density reduction in the 3 different discharges analyzed,
  - Remains to verify assumptions and results against UEDGE simulations.
- Further refinement of UEDGE simulation of 116318 required before that study can begin.
- Will need to assess sensitivity of UEDGE results to its input parameters,
  - In simulating existing shot 116318,
  - And in predictive simulations of LLD since transport coefficients, etc. may be modified by presence of LLD.