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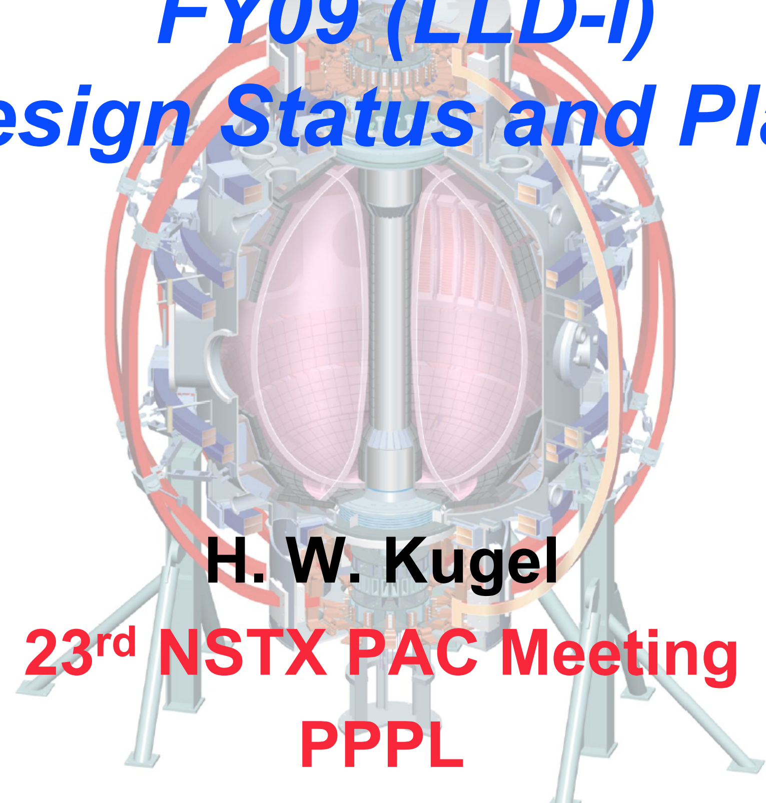
NSTX

Liquid Lithium Divertor FY09 (LLD-I) Design Status and Plans



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H. W. Kugel

23rd NSTX PAC Meeting

PPPL

Jan. 22-24, 2008

PPPL Princeton Plasma Physics Laboratory

Outline of Liquid Lithium Divertor FY09 (LLD-I) Design Status and Plans

- NSTX Implemented PAC-21 Recommended Analysis
- Motivation for Near Term and Longer Term Lithium Research
- Physics Design Requirements for LLD-I
- Analysis Approach for LLD-I
- The Planned Work and Time Line
- Summary

NSTX Implemented PAC-21 Recommended Analysis

- PAC21-16: Balance
  - Clarify the overall balance and cohesion among the several lithium approaches; develop a prioritized strategy for using these approaches (slide 4)
  - Work toward understanding the specific role of lithium (slides 4, 7,19)
  - Determine an explicit path for deciding the location lithium divertor; consider implementing an intermediate step such as a small test section of the liquid lithium divertor (slide 14,19)
- PAC21-43: LLD compatibility with ST work
  - Make a presentation of a detailed plan concerning compatibility of the lithium divertor with the advancement of ST research (slides 4, 8,12), including toward component testing (slide 14,19)

Motivation for Near Term NSTX Lithium Research

- NSTX near term research with *solid* and soon *liquid lithium* is initially aimed towards using liquid lithium to control density and impurity influxes in H-mode plasmas.

- The 3 Phase NSTX Lithium Plan for Particle Control and Power Handling is moving aggressively toward the 3rd Phase:

I. Lithium Pellet Injector (2005-2008)

- Li pellet injection: 2-5 mg, on graphite divertor (2005)
- Li powder tests: on graphite divertor (2007-2008)

II. Lithium EvaporatoR [LITER] (2006-2009)

- 1 LITER: deposition on graphite divertor (2006-2007)
- 2 LITER: deposition on graphite divertor (2008)
- 2 LITER: deposition on graphite and LLD-I (2009-2010)

III. Liquid Lithium Divertor (2009-2013)

- *LLD-I (FY09) : Li evaporated on thin Mo/SS on Cu baseplate*
- *LLD-II (FY10): Li evaporated + Li flow technique to load TDB surface*
- *LLD-III (FY11-13): a long pulse power handling surface for high power*

- ***This phased approach is***
  - ***- compatible with non-lithium related ST research***
  - ***- allowing NSTX operations, diagnostics, and research to be adapted to lithium wall conditions***

Motivation for Longer Term NSTX Lithium Research

• Over the longer term, NSTX will investigate if Liquid Lithium can help integrate 4 important potential benefits for fusion:

a. Divertor pumping over large surface area to be compatible with high flux expansion solutions for power exhaust

A major question for cryo-pump solutions is whether efficient pumping can be achieved with the potentially large flux expansions needed to achieve acceptable heat flux. More work is needed to assess this, and we have started with NHTX work with Maingi and Canik.

b. Improved confinement (indications seen in FY07)

c. ELM reduction/elimination (indications seen in FY07)

d. High-heat flux handling (via flowing Li and/or evaporative cooling)

Liquid Lithium Divertor Physics Design Goals

- Design Goals

1) LLD-I: Achieve density control for inductionless current drive capability in the range (from recent simulations):
   - $n_e \sim 5 \times 10^{19}$ m^{-3} at Ip = 700 kA, (15-25% n_e decrease from present exps)
   - highest non-inductive fraction discharges presently often evolve toward $n_e/n_{GW} \longrightarrow 1$

2) LLD-II: Enable n_e scan capability in long pulse H-mode (e.g.,~ x2) by varying lithium thickness
   - Increase filling rate to a TDB surface
   - Test ability to operate at significantly lower density
     - NHTX (n_e/n_{GW} = 0.5) and ST-CTF (n_e/n_{GW} = 0.25)

3) LLD-III: Investigate power handling with long-pulse LLD-III for high heat-flux

NSTX Design Presentations for Arriving at the LLD-I Physics Goals and Design Specifications

- **Partial List of PAC-21 Motivated LLD-I Design Presentations**

1) Basic Scope of Sandia Effort - R. Nygren, 2/27/07
2) NSTX , SNL, UCSD LLD Collaboration - H. Kugel, 2/27/07
3) Progress Toward Design Goals and the Process - H. Kugel, 3/09/07
4) Physics Considerations for the Design of the LLD for NSTX - R. Maingi (ORNL), 3/9/07
5) Liquid Lithium Divertor 0-D Pumping Projections and Sensitivities - R.Maingi (ORNL), 4/03/07
6) Near Term Plans - H. Kugel, 4/24/07
7) Particle Flux and Recycling Analysis in NSTX - V. Soukhanovskii (LLNL), 4/24/07
8) Lithium Chemistry in NSTX - J. R. Timberlake, 4/24/07
9) Fast Ion Loss to NSTX Divertor Region and Implications for the LLD - D. Darrow, 5/02/07
10) Recycling and Particle Fluxes in NBI H-mode Plasmas - V. Soukhanovskii (LLNL), 5/02/07
11) LLD Update - H. Kugel, 5/10/07
12) Liquid Lithium Divertor CHI Implications - R. Raman (U. Washington), 5/10/07
13) A Very Short Summary of CDX-U Lithium Regimes - R. Majeski, 5/10/07
14) Thermal Regime of LLD - L. Zakharov, 5/10/07
15) Edge Physics - ETG review of a candidate radius and width - NSTX Edge Physics ETG Meeting H. Kugel, 5/22/07
16) Rev of Results from the NSTX Edge Physics meeting on Adoption of the LLD Radius and Width - H. Kugel, NSTX Physics Meeting , 5/29/07
17) PPPL Effort on NSTX Liquid Lithium Divertor - Status, Plans, and Issues - H. Kugel, PFC Meeting, 6/6/07
18) LLD Eddy Currents - A. Brooks, 9/20/07
19) Summary of Planning for LLD CDR and FY08 Installation - H.Kugel, R. Ellis III, R. Nygren, 12/18/07

LLD-I, 15 cm Wide on the Outer Divertor, 5 cm Outboard of the CHI-gap Meets NSTX Requirements and Has the Lowest Risk

NSTX

Issues Investigated	Risk Level Inner Divertor	Risk Level Outer Divertor	Comments
Research Program			• If Outer Divertor LLD-I malfunctions could operate inboard in the high δ region almost unchanged without vent
Pumping Effectiveness	-	+	• Similar in both locations, but Outer Divertor location will pump both low and high δ
Maximum Operating Temperature			• About the same (200-400°C)
Installation Complexity			• Outer Divertor has convenient access to feedthrus and allows easiest modification of instrumentation
Lithium Filling & Temperature Control			• Outer Divertor location allows the most flexibility for lithium fill options
Diagnostic Perturbations			• In-vessel Instrumentation easier to modify on Outer Divertor
Power Handling			• TBD by experimental plan
Return to present configuration	-	+	• 6 week recovery time - remove LLD, reinstall graphite, cleanup, restart

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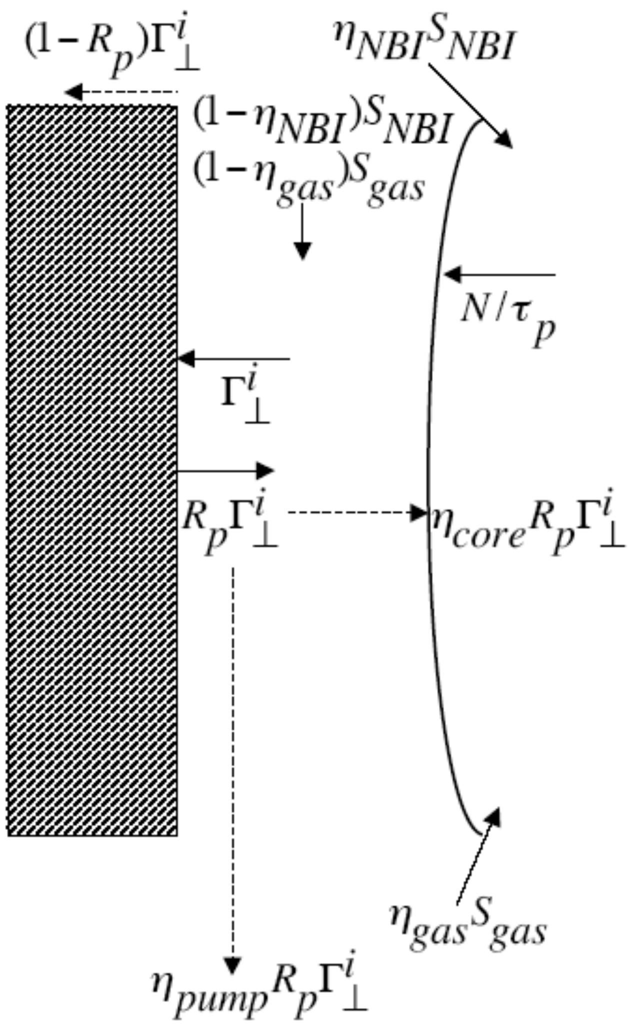
Particle Balance and Recycling Model Used to Estimate 0-D LLD-I Pumping Projections and Sensitivities



- Core and SOL particle equations

$$\frac{dN}{dt} = \eta_{NBI}S_{NBI} + \eta_{gas}S_{gas} - \frac{N}{\tau_p} + \eta_{core}R_p\Gamma^i_\perp$$

$$\frac{dN_i^{SOL}}{dt} + \frac{dN_0^{SOL}}{dt} = (1-\eta_{NBI})S_{NBI} + (1-\eta_{gas})S_{gas} + \frac{N}{\tau_p} - (1-R_p)\Gamma^i_\perp - R_p\Gamma^i_\perp(\eta_{pump} + \eta_{core})$$

- Normal assumptions applied to obtain N(t)
- Γ obtained experimentally (V. Soukhanovskii, LLNL)
- η_{pump} parameterized using divertor plasma data and pump geometry

R. Maingi

0-D Pump Probability Parameterized Using NSTX Divertor Plasma Data and LLD-I Geometry

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Li surface particle sticking probability - 0.85

In/out particle flux ratio - 0.8

(LLD) Tray toroidal coverage - 0.9

$$\eta_{pump} \cong \gamma_{Li}^{sticking} \frac{\int_{R_{min,tray}}^{R_{max,tray}} \Gamma_\perp(R) R dR}{\int_{R_{min}}^{R_{max}} \Gamma_\perp(R) R dR} \left(\frac{\Gamma_{out}}{\Gamma_{in}+\Gamma_{out}}\right)\left(\frac{\Gamma_{down}}{\Gamma_{up}+\Gamma_{down}}\right) f_\phi$$

Impact of R_{tray}, Δ_{tray}, (R_{OSP}- R_{tray})
(*Γ available from Vlad*)

Up/down particle flux ratio 0.5 (δ_r^{sep} important)

*Red items to be estimated from Vlad's CCD camera data
(V. Soukhanovskii, LLNL)

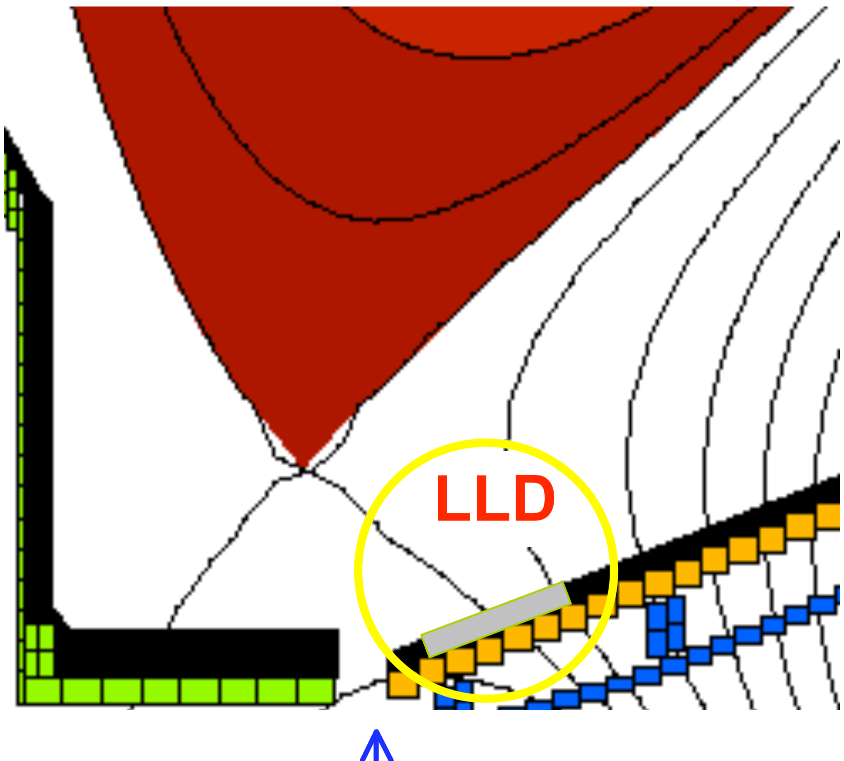
Iterative Procedure

- Convert measured Dα luminosity to particle flux using 20 ionizations per photon
- Estimate LLD-I flux intercept fraction from data for a given R_{LLD}, W_{LLD}, etc. for a given time slice
- Vary R_{LLD} in steps of 1 cm
- Repeat for different W_{LLD}, R_P η_{CORE} and other input parameters

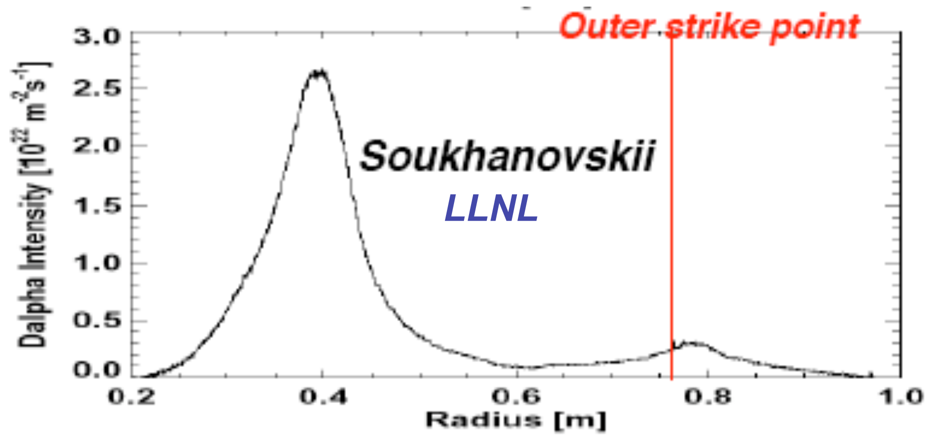
- **0-D model assumptions to be checked with UEDGE**

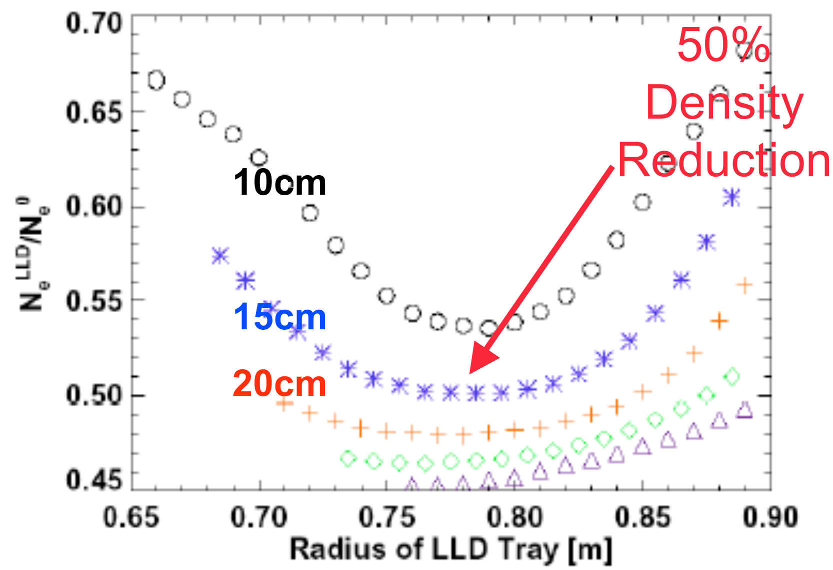
NSTX Data Used to Enable Analysis of Expected Performance of LLD for Low δ Plasmas

Low δ : reduce n_e by 50%



CHI gap





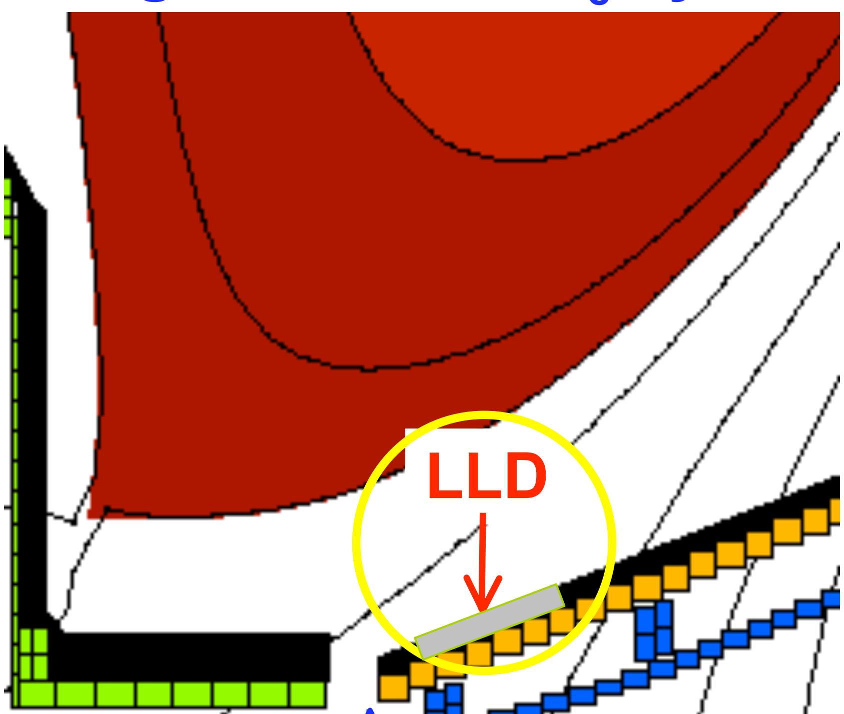
Shown for different LLD-I widths

R. Maingi

Pumping by an LLD-I 15 cm Wide on Outer Divertor Will Provide Density Control for Inner Divertor Broad SOL Dα Profile High δ Plasmas

- Density reduction will depend on proximity of outer strike point to LLD-I

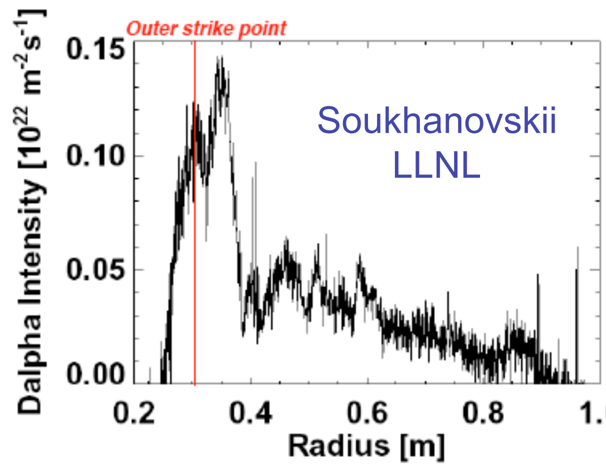
High δ : reduce n_e by 25%



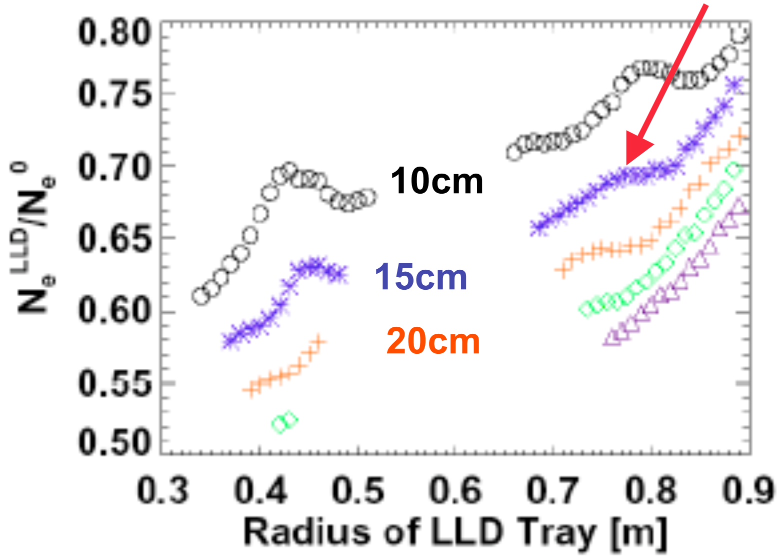
CHI gap

R. Maingi

#121238 @ 0.3 sec



25% Density Reduction



Shown for different LLD-I widths

Candidate Surfaces We Have Considered for LLD-I

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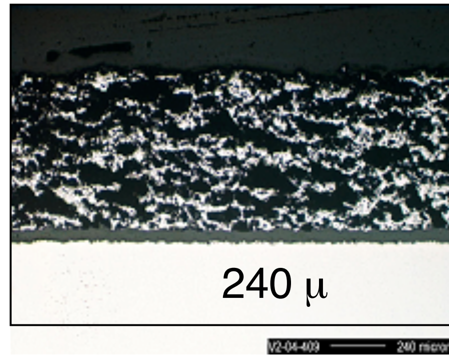
- Two candidate Li surfaces have been under investigation

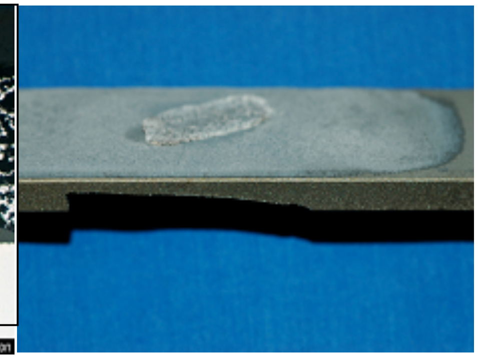
  1) Thin flame sprayed Mo, on thin SS on thick Cu baseplate

  - LTX style plate (tested offline)
    (prepared by Plasma Processes Inc)

  - High-Z *plate with thin Lithium film is highest confidence initial approach*



Micrograph of highly porous moly



Successful lithium wetting test on porous moly

  2) Chemical vapor deposited Mo on vitreous carbon mesh

  - under investigation at SNL (not tested)
    (prepared by Ultramet Inc.)

- Key properties for an acceptable LLD-1 lithium surface
  - wetting capability
  - minimize temperature rate of rise of Li --> rapid heat transfer from Li to baseplate

Evolution of NSTX-Sandia Lab Collaboration

Proposed FY07 work: Mo mesh design, thermal analyses, Mo wetting tests
Status: late start, concept modifications, design/analysis/testing (not completed)

A. Mo mesh in tray – not in FY08

Install LLD, pump&bake	**Liquid Li fill (ala CDXU)** *4 ports, 4-5 d*	*Keep Li liquid (no cleaning)* ***Unacceptable risk*** →	**LLD expmts**

Rethink: 1. Li supply/wetting; 2. Li contamination/cleaning
Schedule-driven solution – simplest, heat removal not great

B. Mo coated plate – FY09 Operation

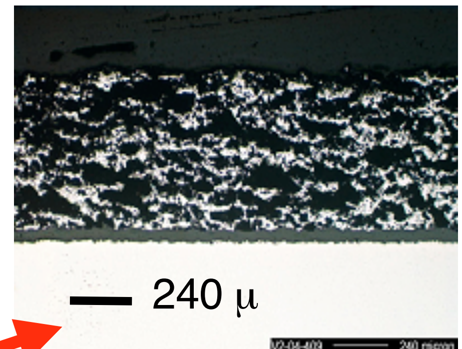
Install LLD, pump&bake	**evaporate Li (improved)**	***contaminate (low sputter)*** →	**recoat Li**	**LLD expmts**

C. Filled Mo mesh – development for FY10/NHTX

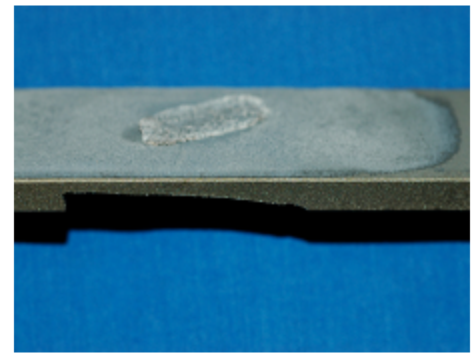
More complex, more development time, better heat removal

LTX R&D has aided in performance projections and design of NSTX LLD aimed at achieving density control at low n_e/n_{GW}

- LTX can begin lithium ops early summer 08
  - Recycling on liquid lithium at more relevant edge parameters than CDX-U
  - Test plasma fueling w/ gas puffing, jets when recycling particle source is small
  - Examine lithium sputtering w/ hotter edge



Micrograph of highly porous moly



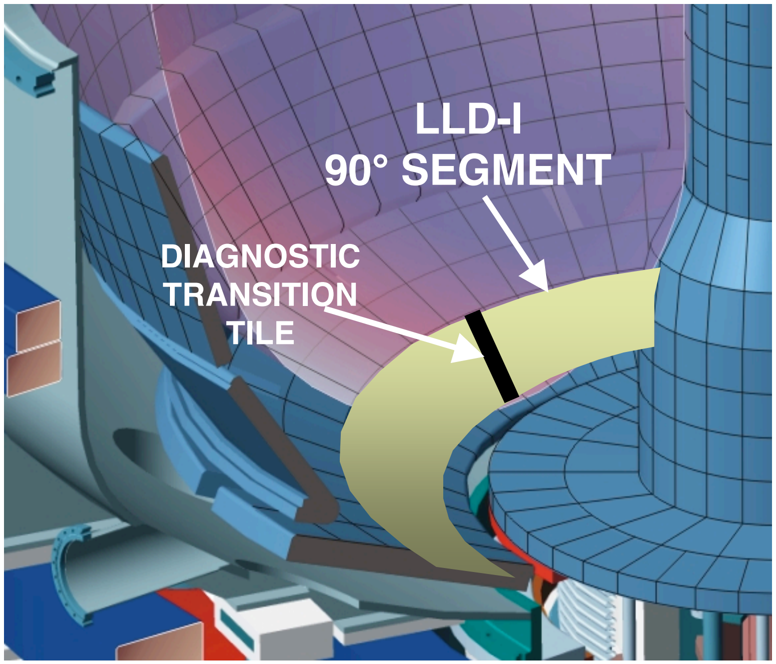
Successful lithium wetting test on porous moly

- LLD-relevant lithium wall implementations developed for LTX
  - Continue LLD development support in 08
  - NSTX & LTX have been working closely with Sandia to determine LLD-I design for ops in FY09

- Candidate LLD-I porous molybdenum surface -
  - Originally developed for 2nd LTX shell (Phase II SBIR w/ Plasma Processes, Inc.)

The LLD-I Plate Design With Thin Lithium Film on High-Z Bonded to Copper is Highest Confidence Approach

NSTX



- *3 rows of graphite tiles to be removed to storage*
- *6 week time to remove LLD-I, restore graphite, return to operation*

- Location - lower outer divertor in four 90°sections
- Width -15 cm starting 5 cm outboard of CHI gap
- Shape - replaces present graphite tiles
- Structure - thin Mo flame-sprayed on 0.02 cm SS brazed to 1.9 cm Cu containing resistive heaters and cooling lines for maintaining 200-400°C
- Lithium Loading - 2 lithium evaporators

- Each toroidal section electrically grounded to vessel at one mid-segment location to control eddy currents (A. Brooks simulations)

- Each toroidal section fastened at its 4 corners to existing divertor copper baseplate with fasteners providing structural support, electrical isolation, and accommodate thermal expansion

- Narrow graphite tile transition regions between sections contain thermocouples, an array of Langmuir probes, and magnetic & current sensors

LLD-I Lithium Surface Will Be Supplied Using 2 LITER Units

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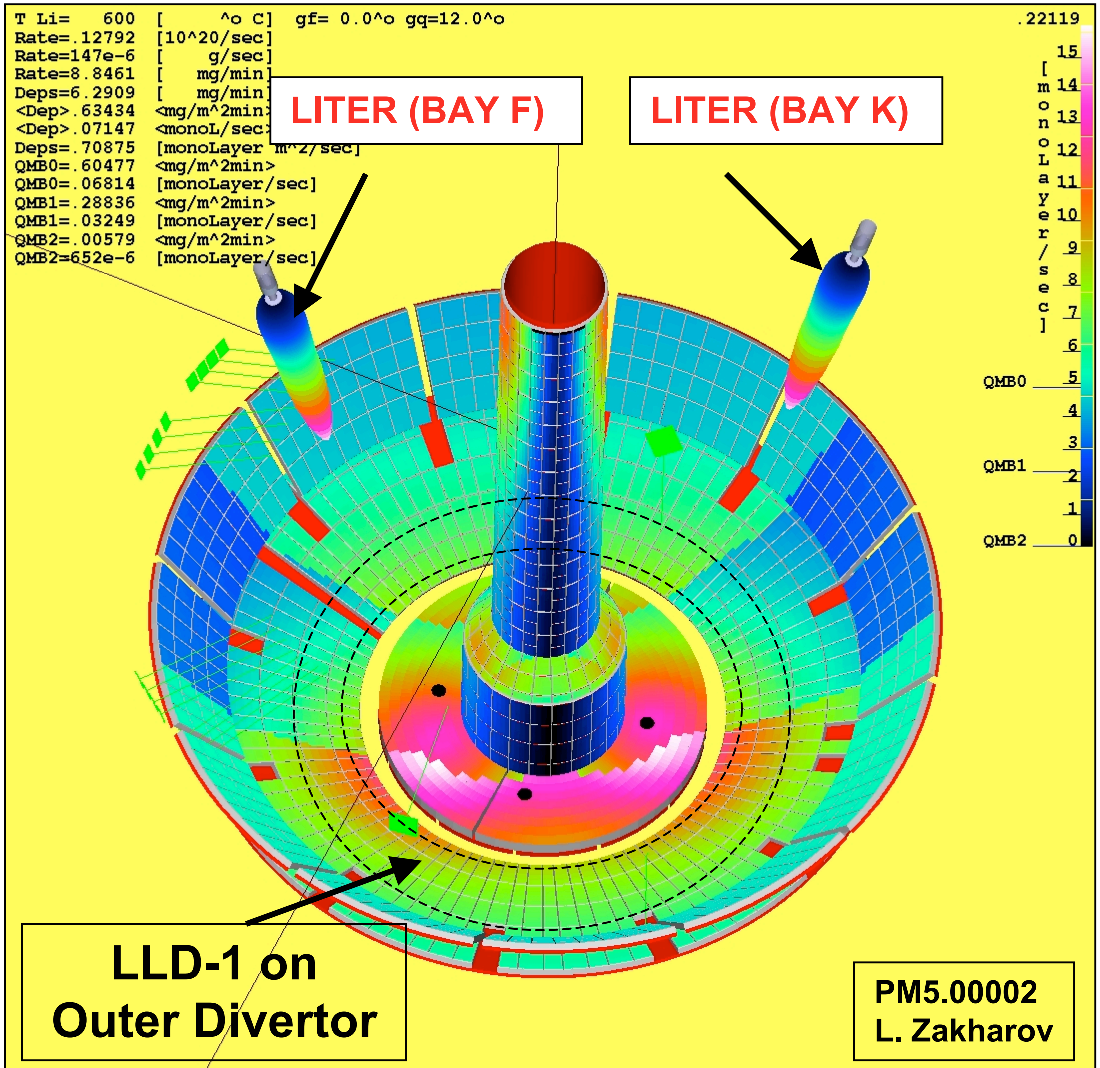
- *Installing 2nd LITER for FY08; Both with Li shutters*
  -no deposition when diagnostic shutters open



- <u>**LITER Deposition Capability**</u>

- for LLD-I to pump NSTX plasma from 7×10^{13} cm^{-3} --> 5×10^{13} cm^{-3} will require the absorption of 2.4×10^{20} D particles, every particle confinement time (~ 50 ms), for 1000 ms, for a total of 4.8×10^{21} D particles absorbed.

- for a 1:1 D/Li ratio requires at least 5.5×10^{-2} g of lithium (2 μm).

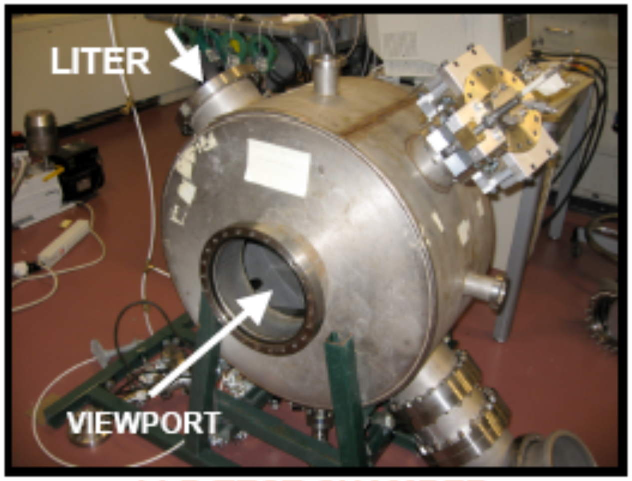
- present LITER deposition efficiency on to LLD ~ 7% of it total output, then the total lithium need is 0.79 g.

- using two evaporators at 30 mg /min (FY07 typ) will require about 13 min to coat the LLD-I.

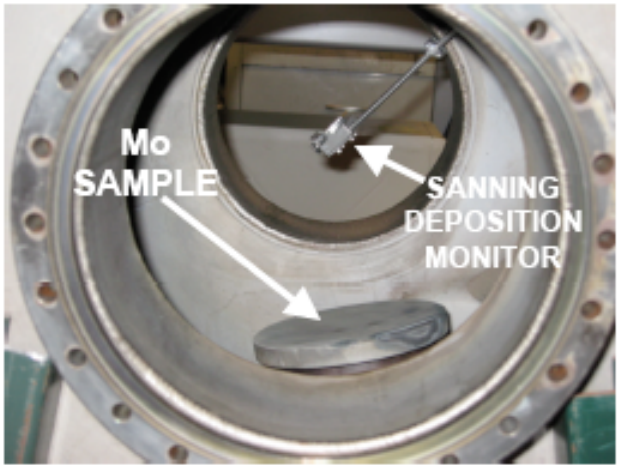
- if lower concentration ratio 0.1D/Li is required, then need 7.9 g of lithium (20 μm), or 4 g per LITER, operating at 100 mg/min for 40 min.

Offline Tasks to Obtain Operational Experience for LLD-I on Maintaining an Active Lithium surface

- Off-Line Experiments in the PPPL Lithium Test Facility (LTF):
  - Wetting tests of heated candidate substrate with LITER
    - Angular distribution measurements during evaporation
  - Passivate Li surface by absorption of impurities
    - Optimize reactivation of surface with LITER
    - Vary amount of time for passivation
  - Exploration of loading options
    - Lithium powder, boat evaporator, reservoir,…
  - Glow discharge cleaning
    - Test helium GDC as option for Li cleaning
  - Recovery from carbon dust contamination



LLD TEST CHAMBER



- LTF Diagnostics and facility requirements
  - Heaters and thermocouples
  - Quartz deposition monitor
  - Visible reflectometry
  - Residual Gas Analyzer

NSTX Will Test the Potential Benefits of Liquid Lithium Divertor for Integrating High Plasma and PMI Performance

- FY09
  - *LLD-I: The Outer Divertor is lowest technical and programmatic risk location for the LLD-I to the high performance, high δ, ST research program*
    - LLD-I, 15cm wide pumping on Outer Divertor provides reduction in density for high performance Inductionless Current Drive Milestone
      (may be possible to test Private Flux region pumping)
- FY10
  - *LLD-II*: Enable n_e scan capability in long pulse H-mode
    - Increase filling rate to a TDB surface
    - Test ability to operate at significantly lower density (NHTX, CTF)
- FY11-FY13
  - *LLD-III*: Investigate power handling for long-pulse with high heat-flux
    - Long pulse, high power surface
    - Higher lithium fill rate
- Near Term Time Line
  - Engineering analysis in progress for Conceptual Design Review in Feb 2008
  - Hardware ready for installation in Sept 2008
  - Installation completed by Nov 2008

Backup

Liquid Lithium Divertor 0-D Pumping Projections and Sensitivities

R. Maingi, ORNL

*With Acknowledgement to
V.A. Soukhanovskii for Lower Divertor D_α data

Liquid lithium divertor physics design discussion

Princeton, NJ
April 3, 2007

Motivation and Technique

- Desire predictive models for effect of pumping on NSTX edge plasma
  - Provide means for comparing density control schemes, e.g. different Lithium tray design parameters (or even in-vessel cryopumping)
  - Should be compared with other experiments and more details calculations
- Consider simple recycling model to evaluate examples of each scheme
  - DIII-D data from first cryopump in 1993
  - CDX-U data from liquid Lithium
- Goal: Predict range of reduction in edge density in H-mode

Pumping calculations will help specify the LLD design parameters

NSTX

- ***0-D calculations presented in this talk:***
  - ***Parameterized as ratio of pump to core fueling probabilities***
  - ***Requires an assumed relation between pump probability and lithium surface area***
- 1-D calculations
  - Onion-skin OEDGE type, *requires assessment for NSTX*
- 2-D fluid calculations (model)
  - T. Rognlien did NSTX calculations in the past for ALPS/APEX
- 2-D fluid + lithium transport calculations (model)
  - T. Rognlien/J. Brooks did NSTX calcs in the past for ALPS/APEX
- 2-D fluid plasma (data-constrained base case)
  - G. Porter, L. Owen, and R. Maingi have done these for DIII-D
- 2-D fluid plasma + kinetic neutrals (data-constrained base case)
  - L. Owen, M. Rensink, and R. Maingi have done these for DIII-D

ornl

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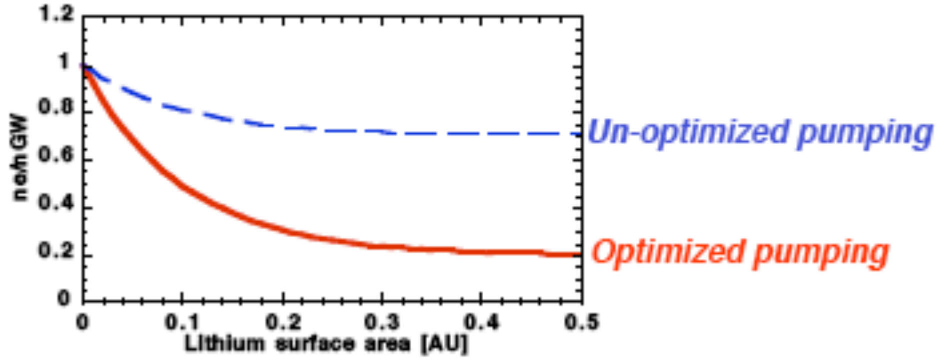
Calculations needed for LLD Tray Design Specification

- The following LLD design parameters need to be specified (target: April 15, 2007):
  1) Tray Width
  2) Tray Major Radius R_{tray}
  3) Number of tray segments, gap size(s) between segments, and clocking of segments (ϕ_{min}–ϕ_{max})
- Minimum density will depend on tray-OSP distance

Large distance between OSP and LLD radius



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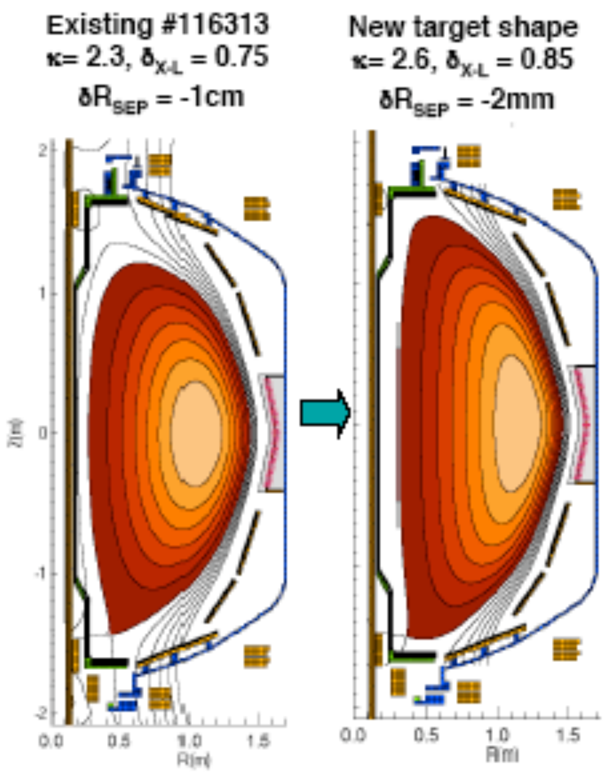
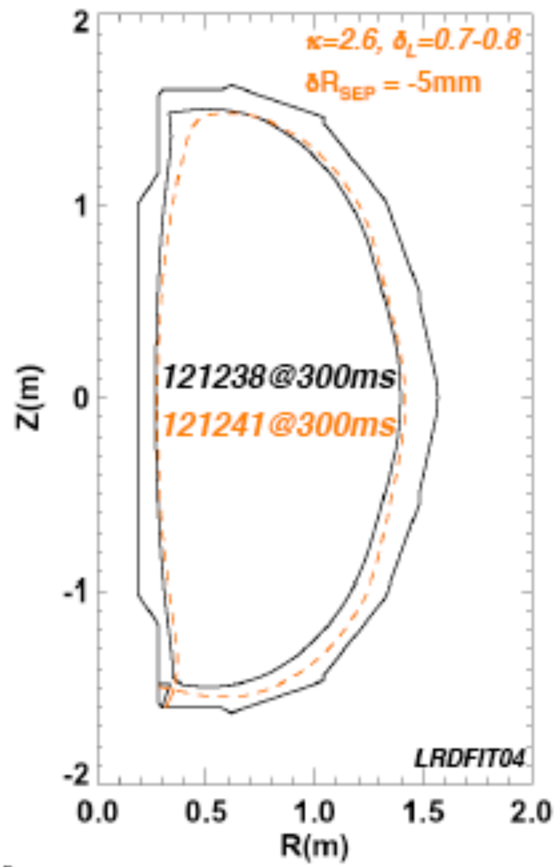
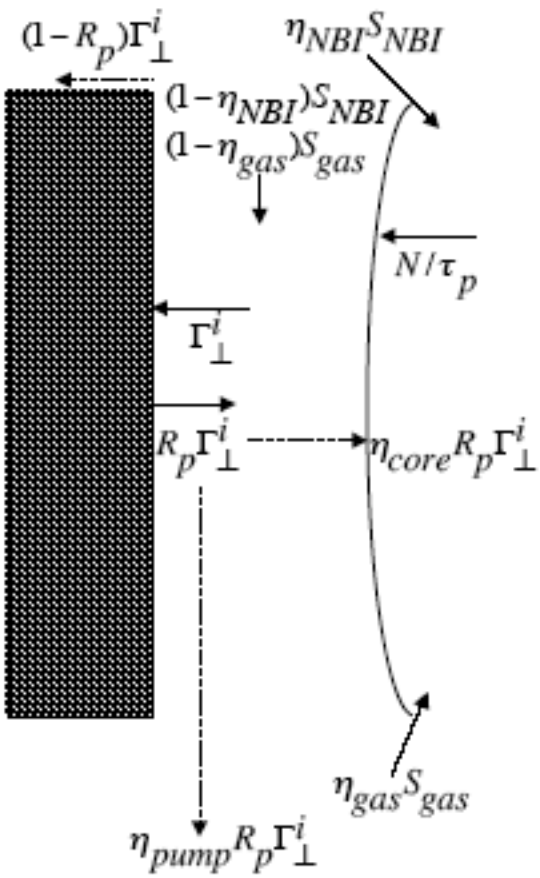
Discharges #116318 @ 0.6 sec and #121238 @ 0.3 sec used for design calculations





Particle Balance and Recycling Model



- Consider core and SOL particle content equations

$$\frac{dN}{dt} = \eta_{NBI} S_{NBI} + \eta_{gas} S_{gas} - \frac{N}{\tau_p} + \eta_{core} R_p \Gamma_\perp^i$$

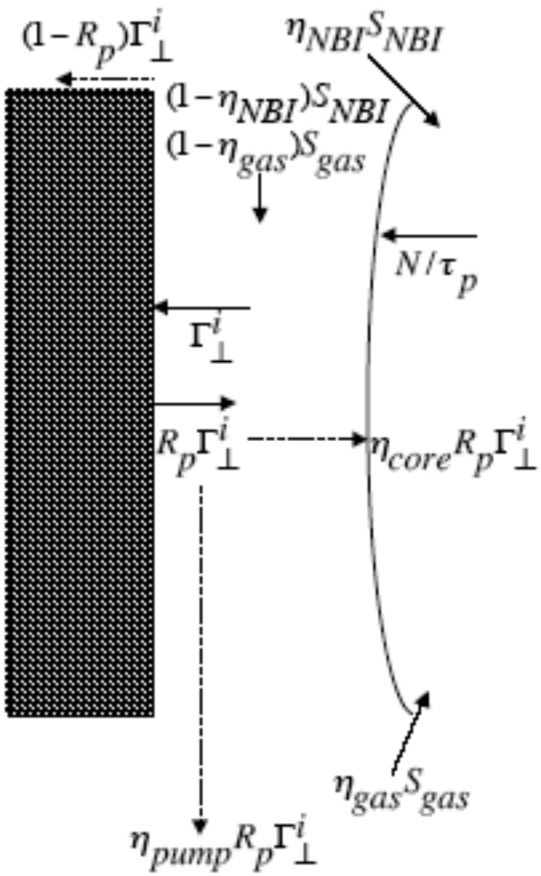
$$\frac{dN_i^{SOL}}{dt} + \frac{dN_0^{SOL}}{dt} = (1-\eta_{NBI}) S_{NBI} + (1-\eta_{gas}) S_{gas} + \frac{N}{\tau_p} - (1-R_p)\Gamma_\perp^i - R_p \Gamma_\perp^i (\eta_{pump} + \eta_{core})$$

- Assume SOL neutral and ion density in steady state

$$\frac{dN}{dt} = (1+\beta-\beta\eta_{NBI})\eta_{NBI} S_{NBI} + (1+\beta-\beta\eta_{gas})\eta_{gas} S_{gas} - \frac{N(1-\beta)}{\tau_p}, \text{ where}$$

$$\beta \equiv R_p \eta_{core} / \left[(1-R_p) + R_p(\eta_{pump} + \eta_{core})\right]$$

Simplified Particle Balance and Recycling Model



- Define $\tau_p^* = \tau_p/(1-\beta)$
  - Steady state: $\tau_p^* = N/(S_{NBI}+S_{gas})$
- Normal assumptions:
  - $\eta_{NBI} \sim 1$
  - $R_p(\eta_{pump} + \eta_{core}) >> (1-R_p)$
  - η_{pump}, η_{core} independent of time
- Particle balance equation becomes:

$$\frac{dN}{dt} = S_{NBI} + (1+\beta(1-\eta_{gas}))\eta_{gas}S_{gas} - \frac{N}{\tau_p^*}$$

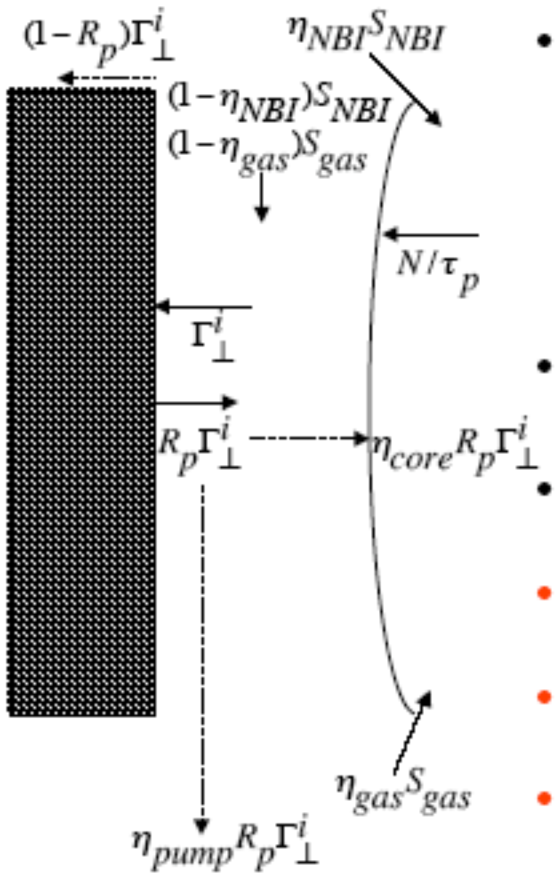
Let $S = S_{NBI} + (1+\beta(1-\eta_{gas}))\eta_{gas}S_{gas}$

Solution:

$$N(t) = S\tau_p^{*,1} + S(\tau_p^{*,2} - \tau_p^{*,1})\exp-(t/\tau_p^{*,2})$$

- Has been used to model step change in τ_p (L-H) and pumping ($\eta_{pump}>0$)

Simplified Particle Balance and Recycling Model



- Density reduction factor

  $n_e^{red} = \tau_{p,pump}^* \,/\, \tau_{p,nopump}^*$

  $= (1-\beta)_{noLi} / (1-\beta)_{Li}$ {constant τ_p}

- $\beta_{noLi} = \eta_{core} R_p / ((1-R_p) + R_p^* \eta_{core})$

- $\beta_{Li} = \eta_{core} R_p / ((1-R_p) + R_p^* (\eta_{core} + \eta_{pump})$

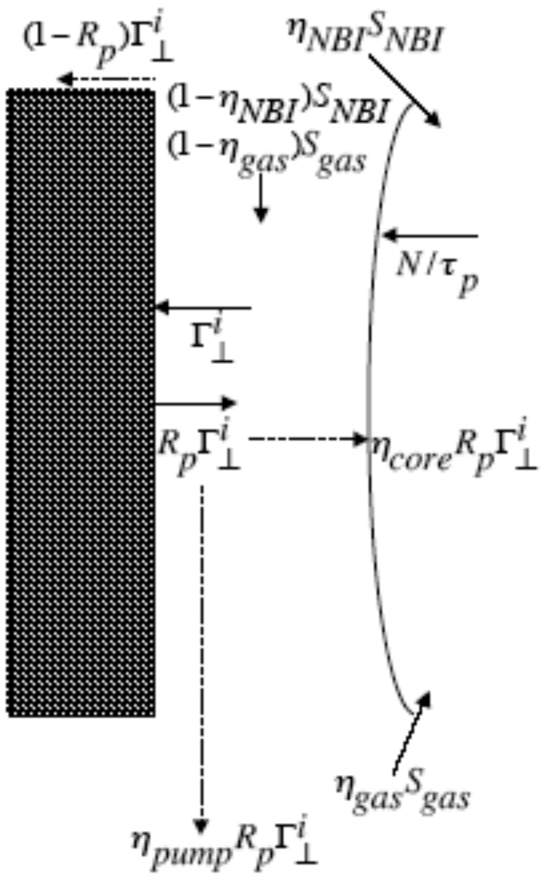
- **Need prescription to estimate η_{Li}**

- **Is η_{core} really independent of n_e?**

- **Is τ_p really independent of n_e?**

8

Limits of Particle Balance and Recycling Model



- Note $\tau_p^*/\tau_p = 1/(1-\beta)$
- Pump off: $\tau_p^*/\tau_p \sim 1 + \eta_{core}R_p/(1-R_p)$
  - $\tau_p^*/\tau_p \sim 6$
- Pump on: $\tau_p^*/\tau_p \sim (\eta_{core}+\eta_{pump})/\eta_{pump}$
  - $\tau_p^*/\tau_p \sim 2$

➢ n_e should go down by 2/3 w/pumping

⇒Smaller n_e reduction observed, maybe due to increased core fueling probability at low n_e

- Input data (from DIII-D studies):
  - $R_p \sim 0.98$ for carbon (reference?)
  - $\eta_{core} \sim 0.1$ (Rensink, PoF B 1993)
  - $\eta_{pump} \sim 0.1$ (Maingi, NF 1999)

9

Method to Relate 0-D Pump Probability to Divertor Plasma and Lithium tray parameters

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Li surface particle sticking probability - 0.85

In/out particle flux ratio - 0.8

Tray toroidal coverage - 0.9

$$\eta_{pump} \cong \gamma_{Li}^{sticking} \frac{\int_{R_{\min,tray}}^{R_{\max,tray}} \Gamma_{\perp}(R) R dR}{\int_{R_{\min}}^{R_{\max}} \Gamma_{\perp}(R) R dR} \left(\frac{\Gamma_{out}}{\Gamma_{in} + \Gamma_{out}} \right) \left(\frac{\Gamma_{down}}{\Gamma_{up} + \Gamma_{down}} \right) f_{\phi}$$

Impact of R_{tray}, Δ_{tray}, $(R_{OSP} - R_{tray})$
(Γ available from Vlad)

Up/down particle flux ratio 0.5 (δ_r^{sep} important)

*Red items to be estimated from Vlad's CCD camera data

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Procedure

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- Convert D_α to particle flux with magic number of 20 ionizations per photon
- Estimate LLD flux intercept fraction from data for a given R_{tray}, W_{tray}, etc. for a given time slice
  - Vary R_{tray} 1 cm at a time
    - R_{tray} starting point a few cm inside of the outer strike point; avoids interpretation of partially detached inner region
    - Avoid covering CHI gap with tray
  - Iterate on $\eta_{core} \sim 1/n_e^\alpha$ (default: α=2)
- Repeat for different W_{tray}, R_p, and other input parameters
- Repeat calculations for different shots with different poloidal flux expansion

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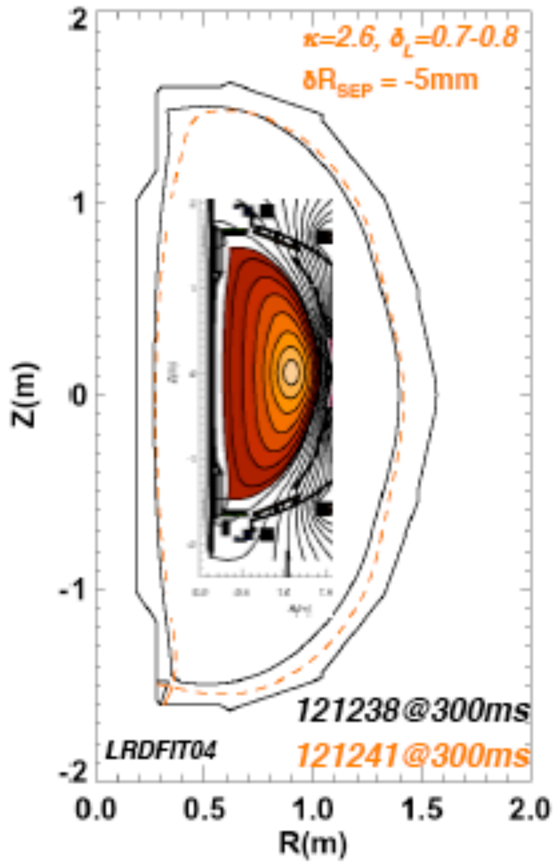
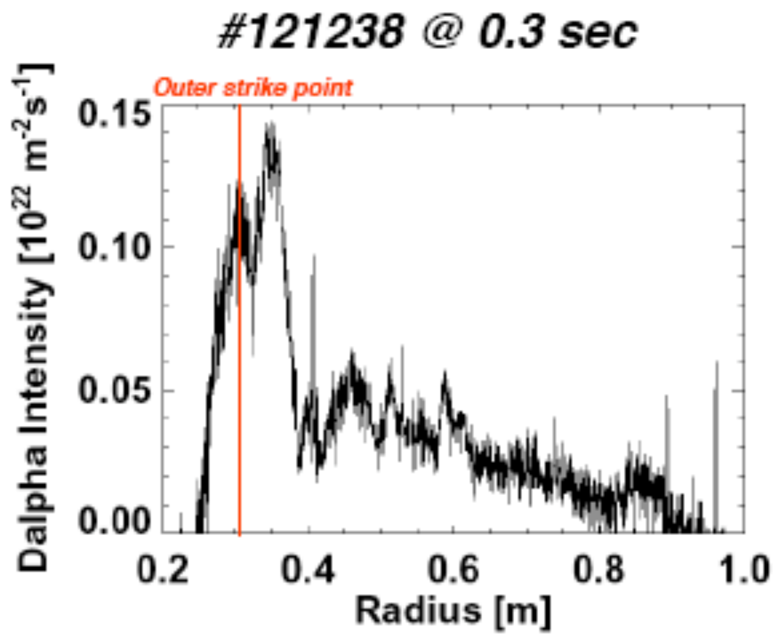
Broad SOL D_α profile in high δ (pf1a) #121238

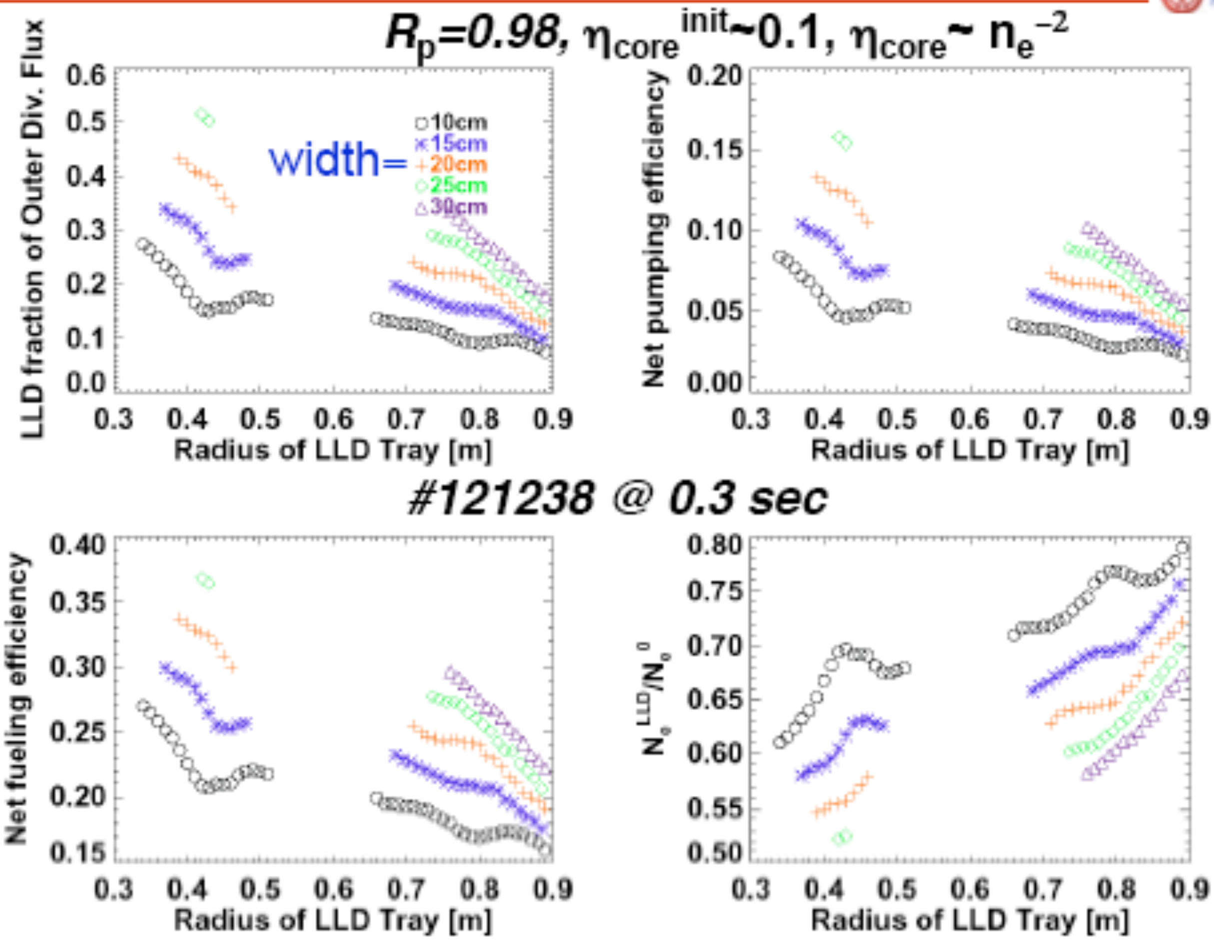




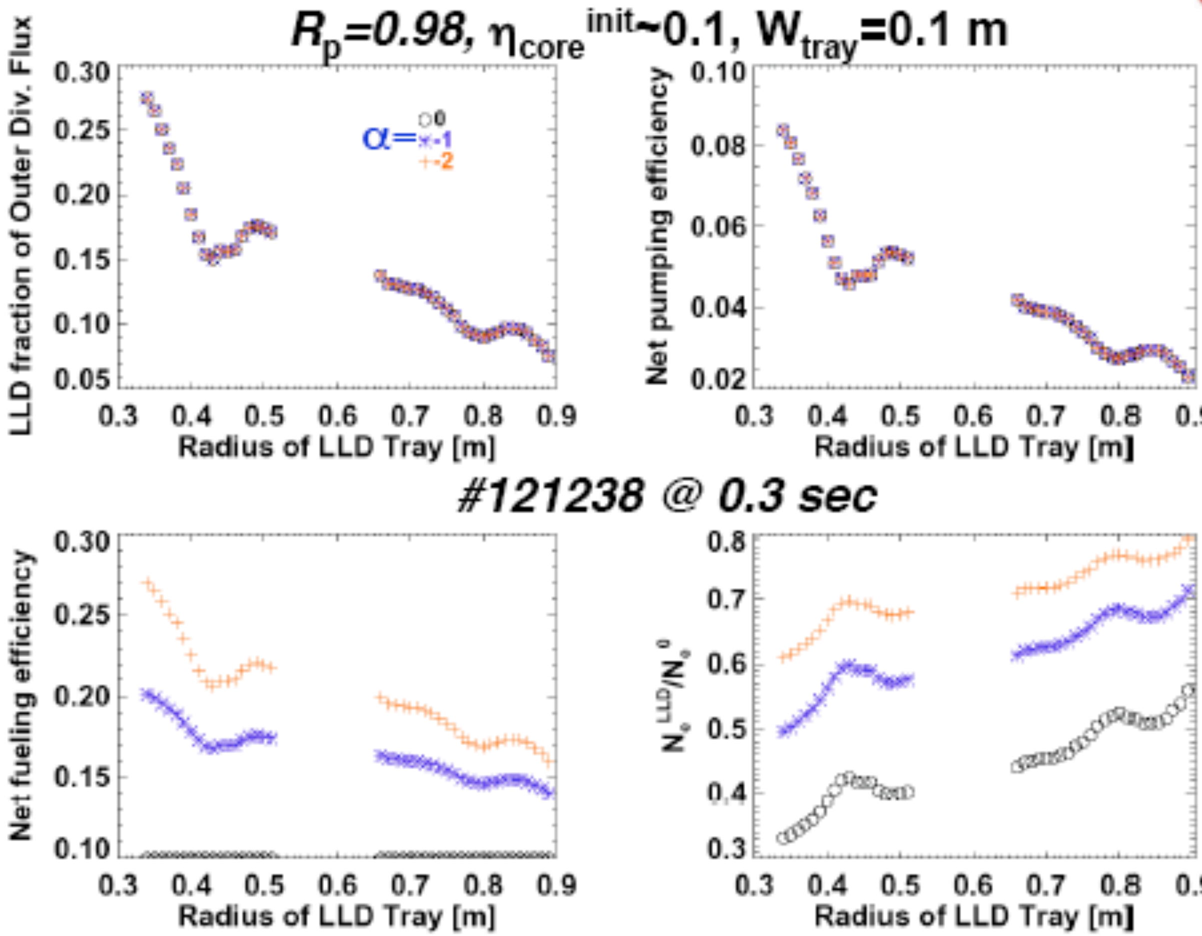
Soukhanovskii

12

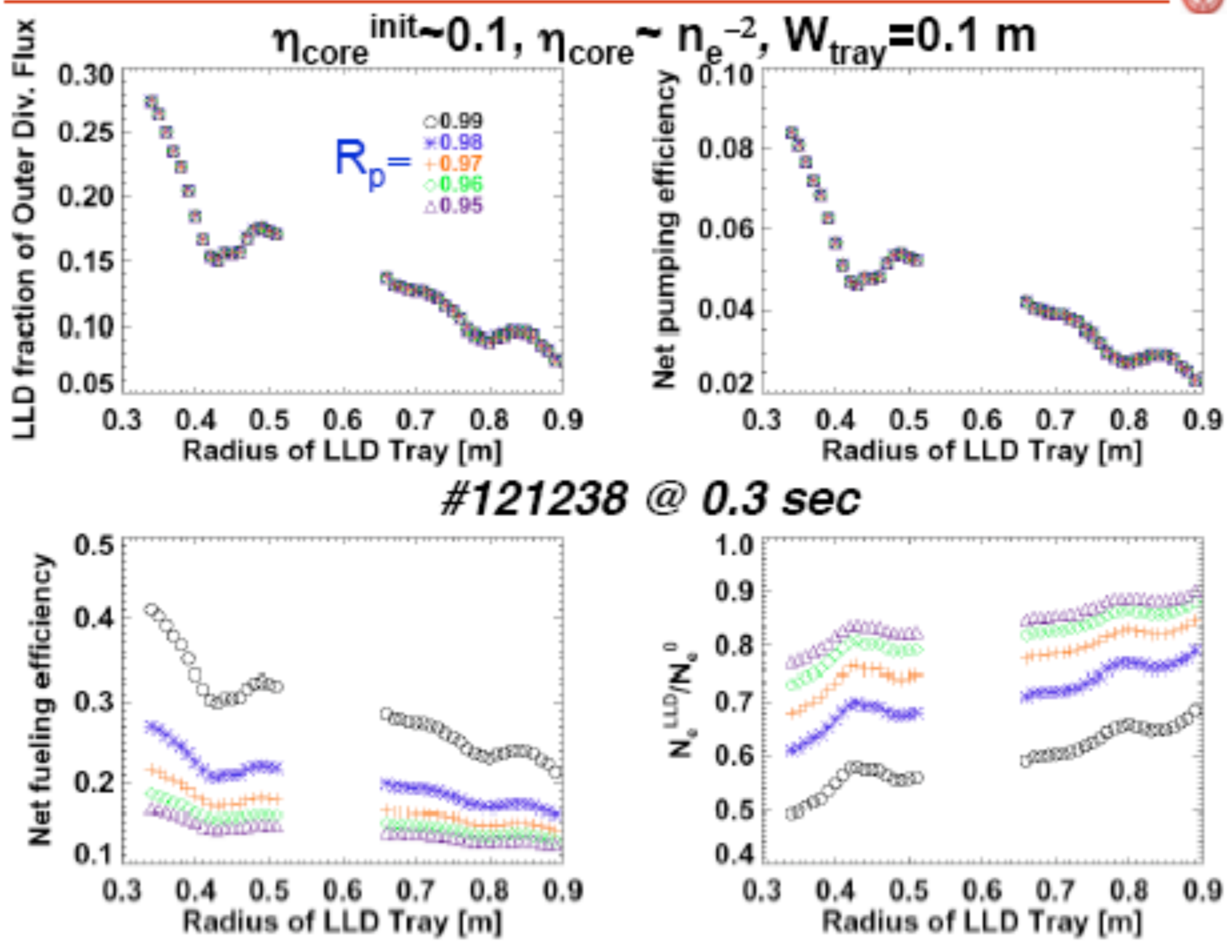
Achievable edge density reduction depends on tray radius and width



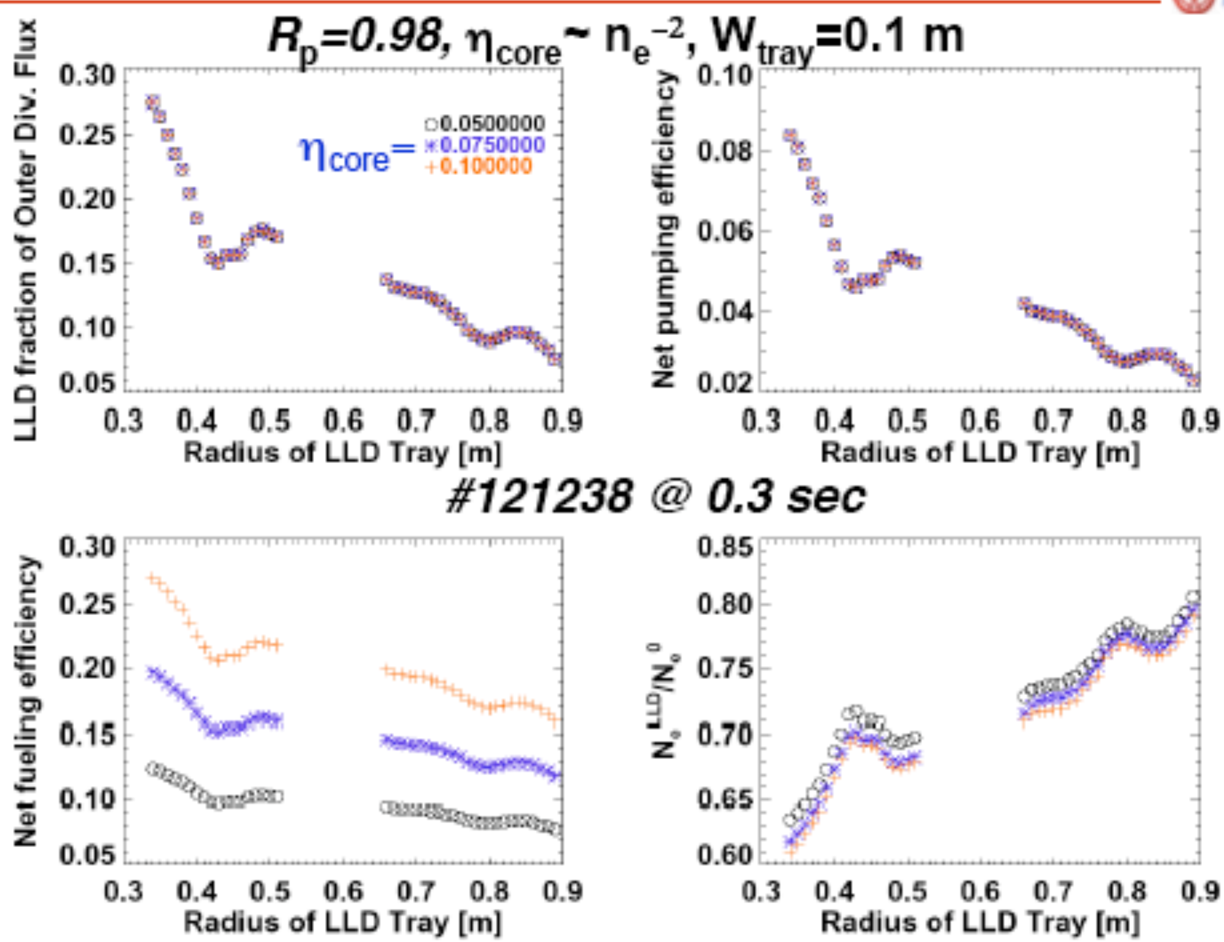
Achievable edge density reduction is reduced if core fueling efficiency $\eta_{core} \sim n_e^{\alpha}$



Achievable edge density reduction decreases with assumed initial wall recycling coefficient, R_p

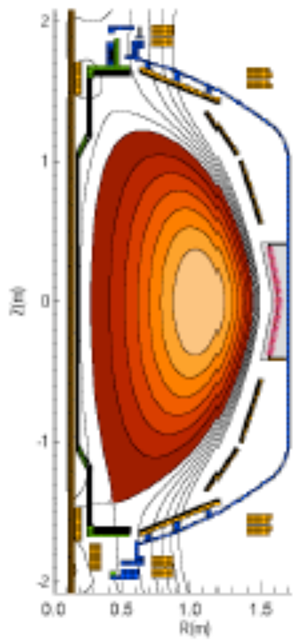


Achievable edge density reduction nearly independent of initial core fueling probability, η_{core}



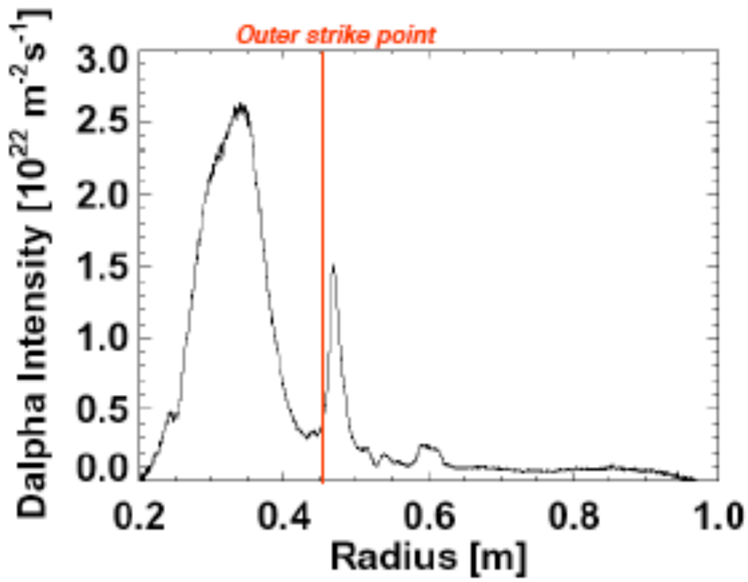
Narrow SOL D_α profile in medium δ (pf1b) #116318

Existing #116313
$\kappa = 2.3$, $\delta_{X\text{-}L} = 0.75$
$\delta R_{SEP} = -1$cm



#116318 @ 0.6 sec

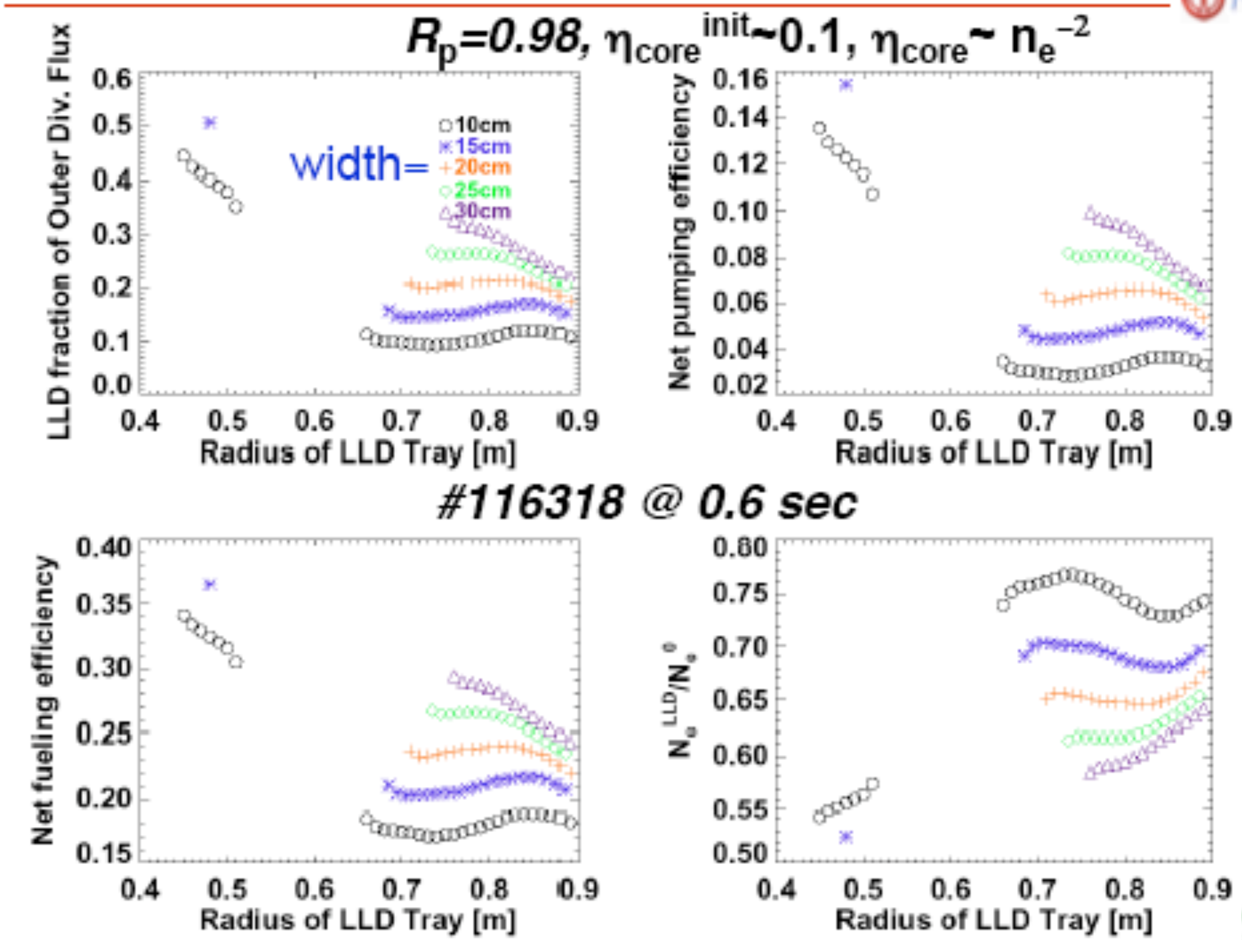
(no data on #116313)



Soukhanovskii

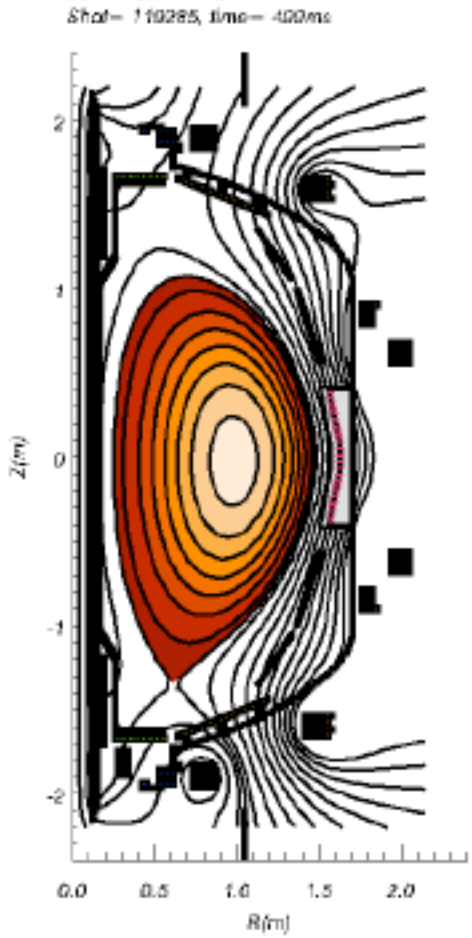
17

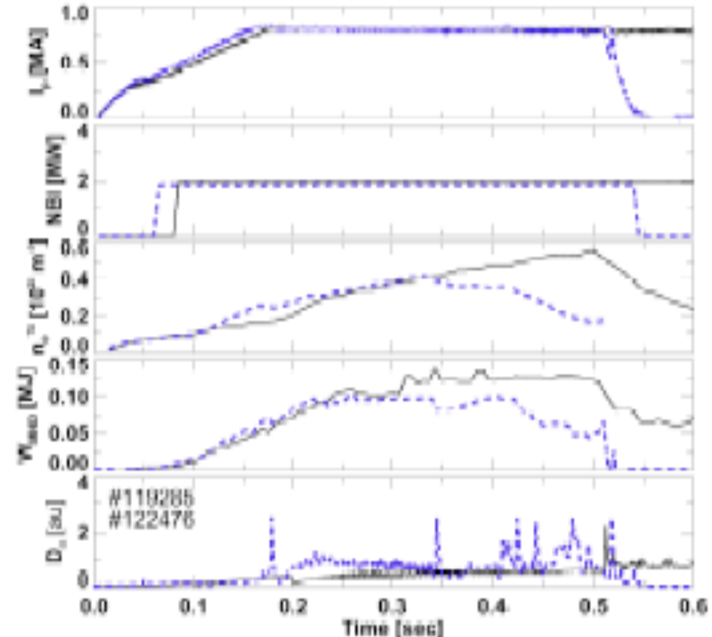
Achievable edge density reduction depends on tray radius and width

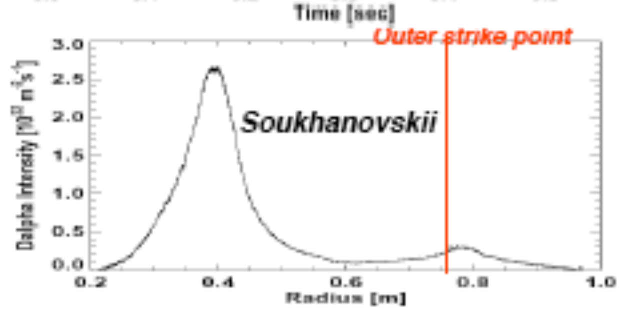


Narrow SOL D_α profile in low δ (pf2) #119285

NSTX







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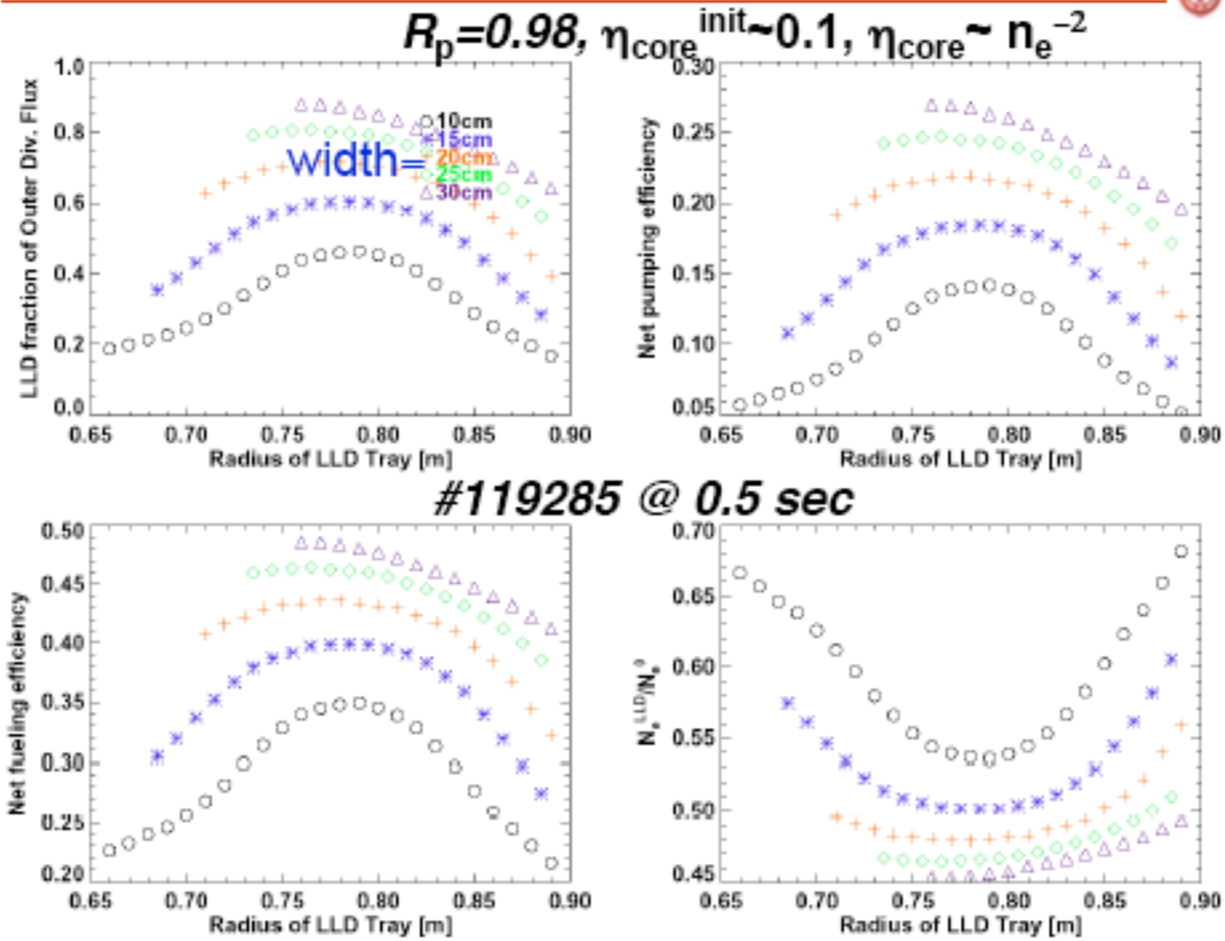
Achievable edge density reduction depends on tray radius and width



Discussion and Conclusions

- 20cm wide tray just outboard of the CHI gap likely to provide sufficient density reduction as required for long pulse high non-inductive fraction reported at the Dec. 2006 research forum
- To get a full 50% density reduction will probably require a tray near the outer strike point
  - Inboard of CHI gap for high δ discharges
  - Outboard of CHI gap for low δ discharges
- Actual density reduction factor depend strongly on how quickly core fueling efficiency increases with decreasing density, and the pre-Li global wall recycling coefficient
- Intend to compare with UEDGE calculations, when available

Summary of Analysis of Experimental Program Impact on High Performance high δ Discharges, If LLD Component Failure Occurs

NSTX

• Simplest Gedanken: Assume an LLD whose pumping speed is independent of radius, it functions for a few weeks, and then has a component failure.

RADIUS & WIDTH	PROGRAM RISK LEVEL	COMMENTS
Inner-half, Lower Inner Divertor	Highest	This is the high performance, high δ. If LLD malfunctions, necessary to stop the Run, vent, and fix malfunction
Outer-half, Lower Inner Divertor	Medium	If LLD malfunctions could maybe operate inboard if LLD is narrow, but flux expansion would overlap LLD
Lower Outer Divertor	Lowest	If LLD malfunctions could operate in the high performance, high δ region almost unchanged

• **Under the above assumptions, the lowest risk location for the LLD to high performance, high δ discharges is the Outer Divertor.**

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Summary of Analysis of LLD Radius Location and In- & Ex-vessel Technical Complexity

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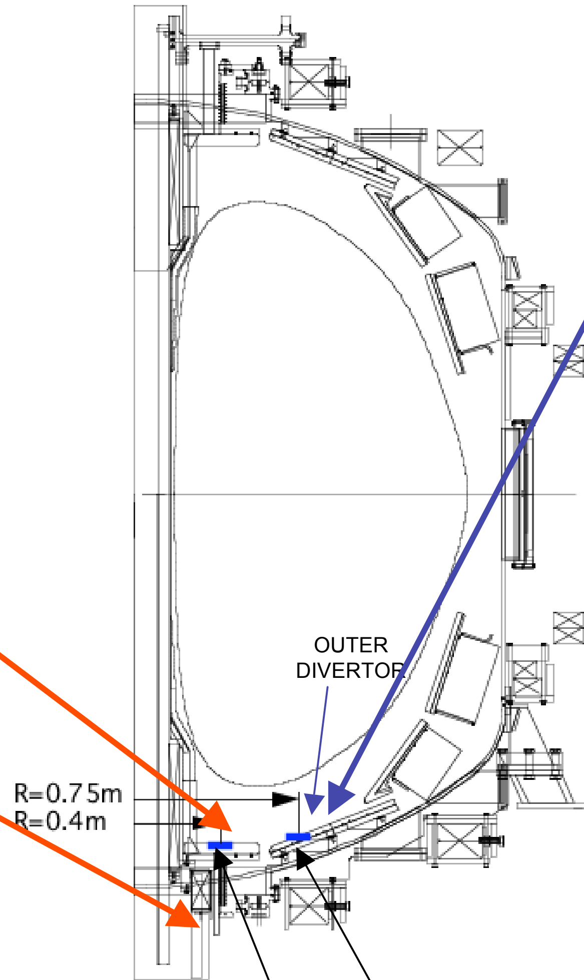
INNER DIVERTOR

- Interference with Lower Inner Divertor gas ports.

- Difficult to reach Inner Vessel feedthrus. Cannot be reached during operations.



- **Candidate locations for toroidal, LLD at Inner or Outer Divertor**

OUTER DIVERTOR

- **Either**
  - **- Flat installation on conical section**
- **Or**
  - **- Sloping conical installation on conical section more difficult**
- **Possible P-CHERS shielding issue**
- ***Convenient access to feedthrus and easiest modification of instrumentation***

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LLD Lithium-filling is Most Accessible from Horizontal Outer Divertor Ports

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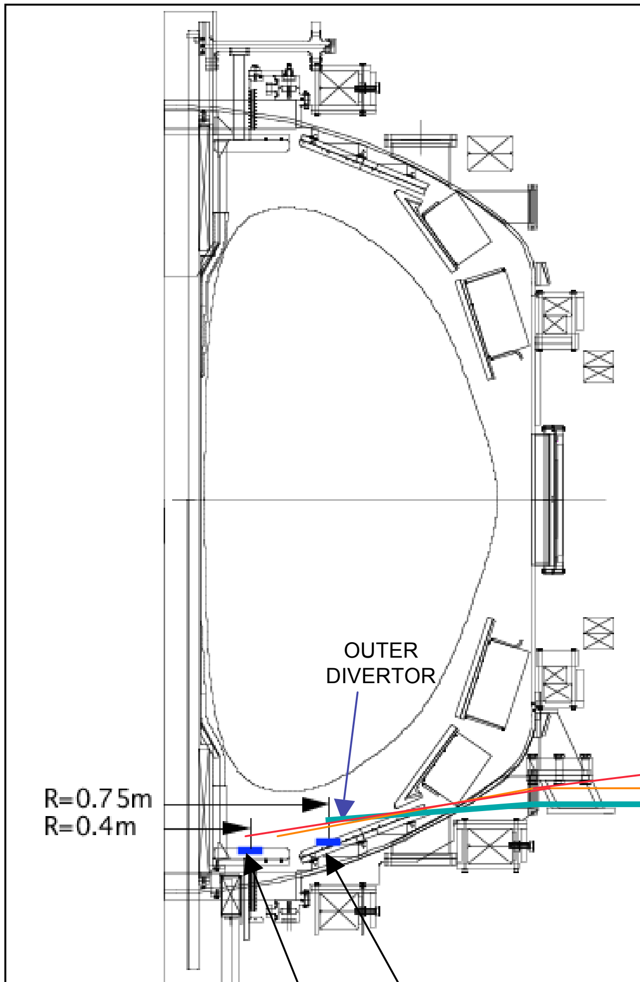

- Candidate locations for toroidal, LLD at Inner or Outer Divertor

INNER-HALF INNER DIVERTOR

- Li feed stroke ~137 cm from Horizontal Divertor Port

OUTER-HALF INNER DIVERTOR

- Li feed stroke ~117 cm from Horizontal Div Port

OUTER DIVERTOR

- Li feed stroke ~102 cm from Horizontal Divertor Port.
- *minimum feed stroke for outer divertor location*

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Summary of Analysis of LLD Diagnostic Issues

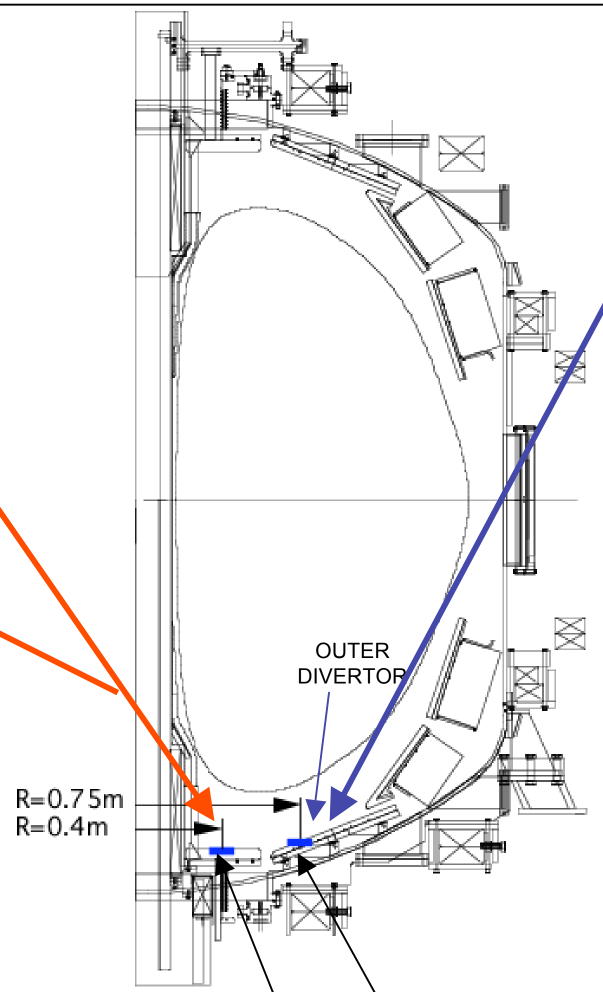
• *In-vessel Instrumentation Easier to Modify on Outer Divertor*

• INNER-HALF INNER DIVERTOR

- Loss of 1 or 2 Bz coils
- Loss of 2 Thermocouples
- Loss of 2 Langmuir Probes

• OUTER-HALF INNER DIVERTOR

- Loss of 1 or 2 Bz coils
- Loss of 2 Thermocouples
- Loss of 2 Langmuir Probes



• Candidate locations for toroidal, LLD at Inner or Outer Divertor

• OUTER DIVERTOR

- Loss of 2 Bz coils
- Loss of 2 Thermocouples
- Loss of 1 Langmuir Probe
- Flux Loops response changes
- Possible PCHERS shielding issue

• In-vessel Instrumentation easier to modify on outer divertor

NSTX

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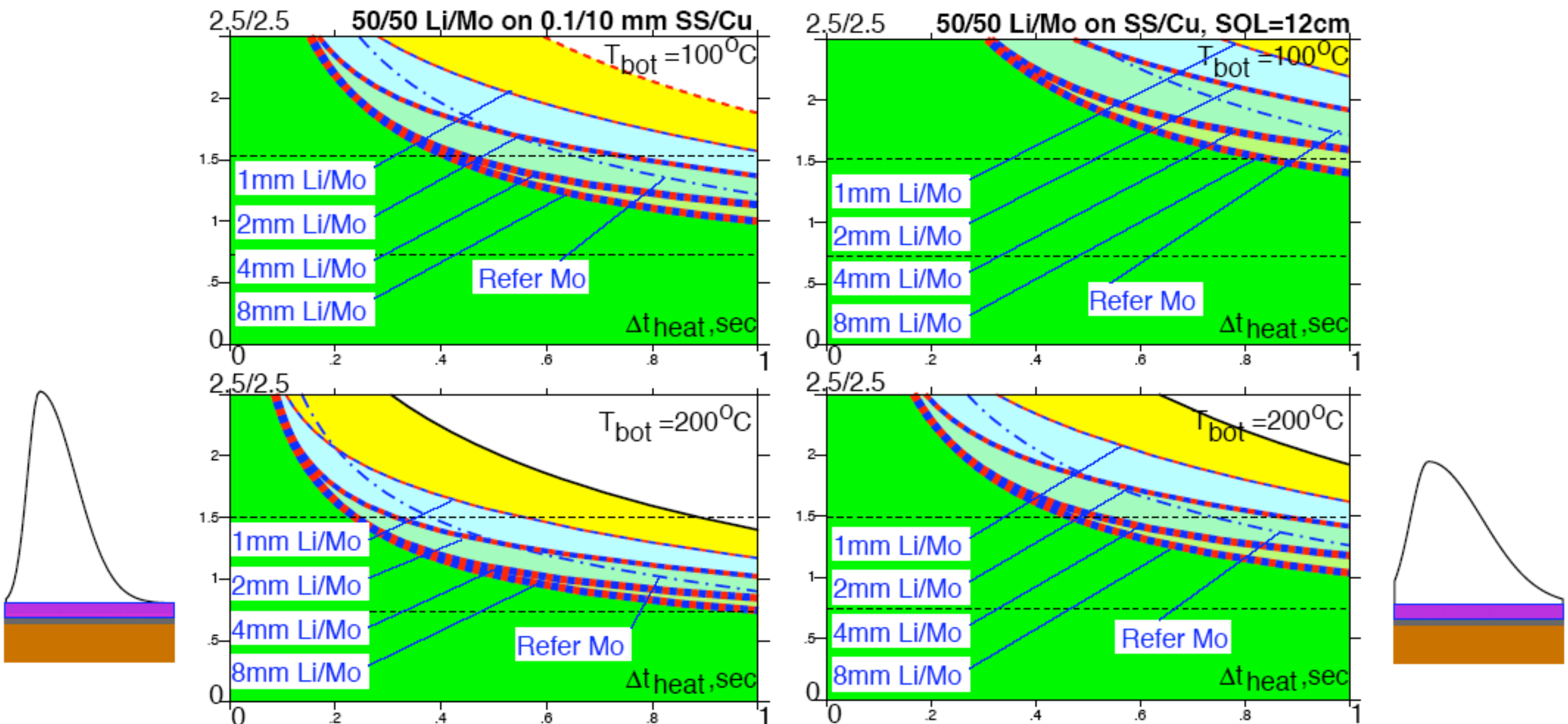
1 mm Li/Mo CPS on 0.1/10 mm SS/Cu plate is the best



$d_i = 2, d_e = 6$ cm $d_i = 3, d_e = 9$ cm

1 mm Li/Mo CPS on 0.1/10 mm SS/Cu is similar to T-11M,FTU