Fuel Retention Studies in Present-Day Devices and the Relevance to ITER and Beyond

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"stationed" at DIII-D

presented at

ARIES Town Hall Meeting on Edge Plasma Physics and Plasma Material Interactions

May 20-21, 2010

Contributions from many boundary folks

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DIII-D NATIONAL FUSION FACILITY

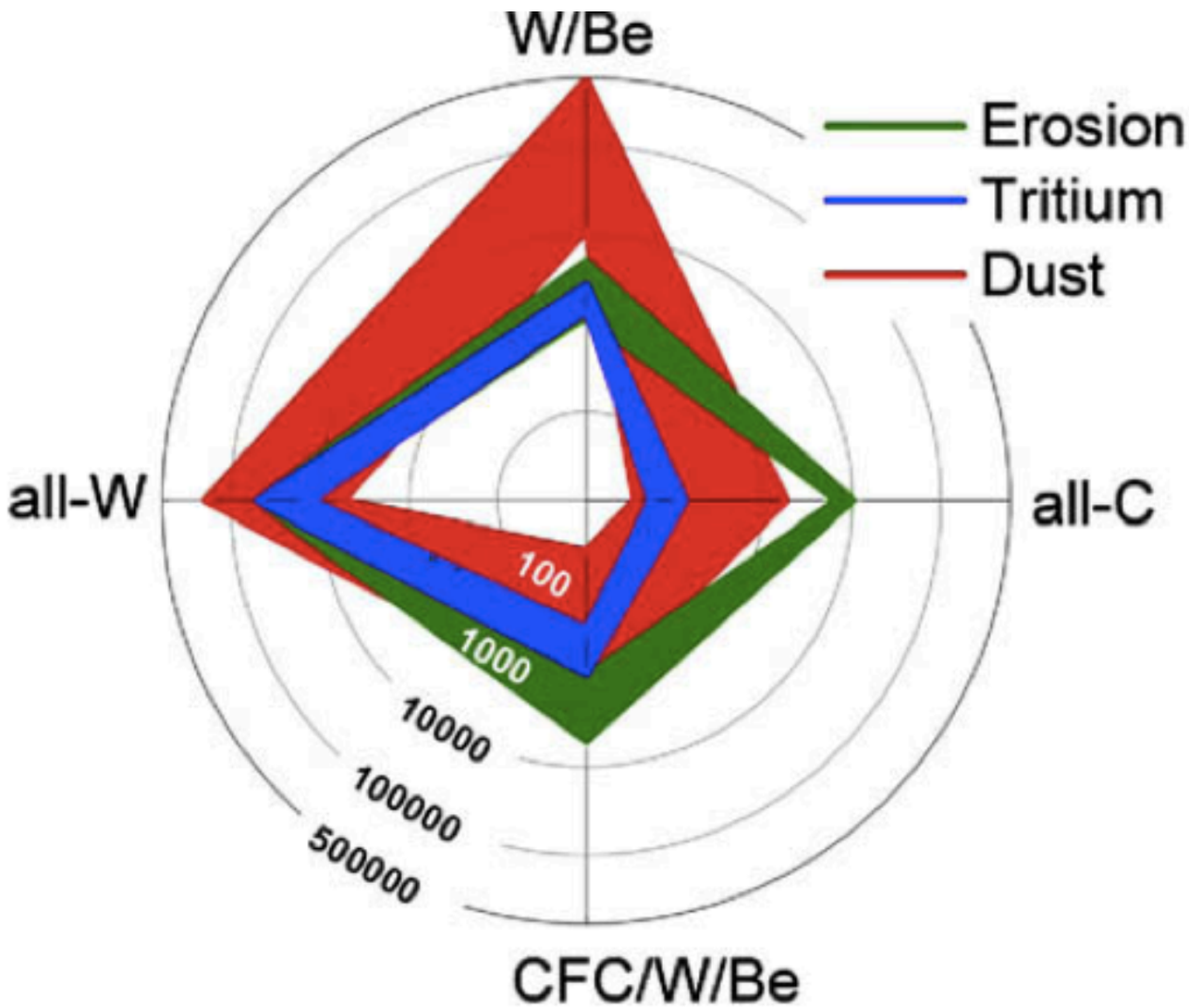
Alcator C-Mod

NSTX

Background: Plasma Facing Components (PFCs) have Implications for Tritium Fuel Cycle

- **Today's device PFC need:**
  - Mechanical strength
  - Resistance to large T transients
  - Favorable erosion/ radiation characteristics toward core plasma
- **To date, largely met by carbon PFC**
- **Carbon not (necessarily) in plans for future device PFCs**

discharges to reach safety limit in ITER



J. Roth et al., JNM (2009)

Outline

- **Introductory material**
- **2009 DoE Joint Facilities Milestone (JFM-09): Hydrogenic Retention in PFCs***
  - DIII-D, C-MOD, NSTX
  - Similar particle balance methods compared
  - Variety in configurations
    - divertor pumping (CMOD, DIIID) & un-pumped (NSTX)
    - PCF material: CMOD=Mo/W; DIII-D=C; NSTX=C + Li
    - Heating methods: RF; NBI; ohmic-only
- **Relation to future devices**
  - Any physics that extrapolates?

*http://www.science.doe.gov/ofes/performancetargets.shtml

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Overview: What We Know from Slurry of Studies

- **Research conducted on most tokamaks**
  - ToreSupra, JET, JT-60U, TFTR, TRIAM1, CMOD, DIII-D, ASDEX-U, NSTX, TEXTOR, etc.
  - Materials: graphite, W, Li, Be, others
  - Detailed results on:
    - *erosion rates, retention mechanisms, particle balances, etc.*
- **But still a "hot topic"**
  - 30+ presentations on retention issues at PSI-2010 next week
  - (2) invited talks on material in this presentation
- **Why? It's complicated…**

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Overview: Retention mechanisms in current devices

- **Retention mechanisms broken into (2) main groups**
  - Shot-term: reversible, saturating; loosely bound
  - Long-term: non-reversible, non-saturating, tightly bound
- **Short-term mechanisms**
  - Implantation, surface absorption (temp. dependent)
  - Usually out-gasses after discharge (~ up to days-weeks)
- **Long-term mechanisms**
  - Co-deposition
  - Deep implantation (in main chamber; usually small)
  - Does not come out without effort (i.e. very high T, disruption cleaning, etc.)

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Main Findings of DoE JFM-09 (1/2)

- **Direct comparison of <u>time-average</u> (dynamic) vs <u>shot-integrated</u> (static) particle balance method**
  - Allows accurate comparisons
- **Strongly pumped devices show near zero retention in steady-state (current/density flattop) phase**
  - Both CMOD (metallic PFC) & DIII-D (carbon PFC)
  - NSTX without active pumping saw different results
- **In ohmic discharges, results trended with divertor ion flux over all 3 machines**
  - ~1-2% retention/total ion flux in CMOD; ~ 2-4% in DIII-D; ~ 4-6% in NSTX from OSP only

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Main findings of DoE JFM-09 (2/2)

- **Mix of confinement regimes and heating sources were studied**
  - Results mixed:
    - DIII-D: consistently low retention in H-mode phase
    - CMOD: low retention in steady-state unaffected by confinement/ heating
    - NSTX: showed increasing retention independent of confin. or heating
- **Also addressed:**
  - *ex-situ* analysis; long-term retention; disruptions
- **Many, many details - see report if interested***
- **Details are DIII-D "heavy"**

*http://www.science.doe.gov/ofes/performancetargets.shtml

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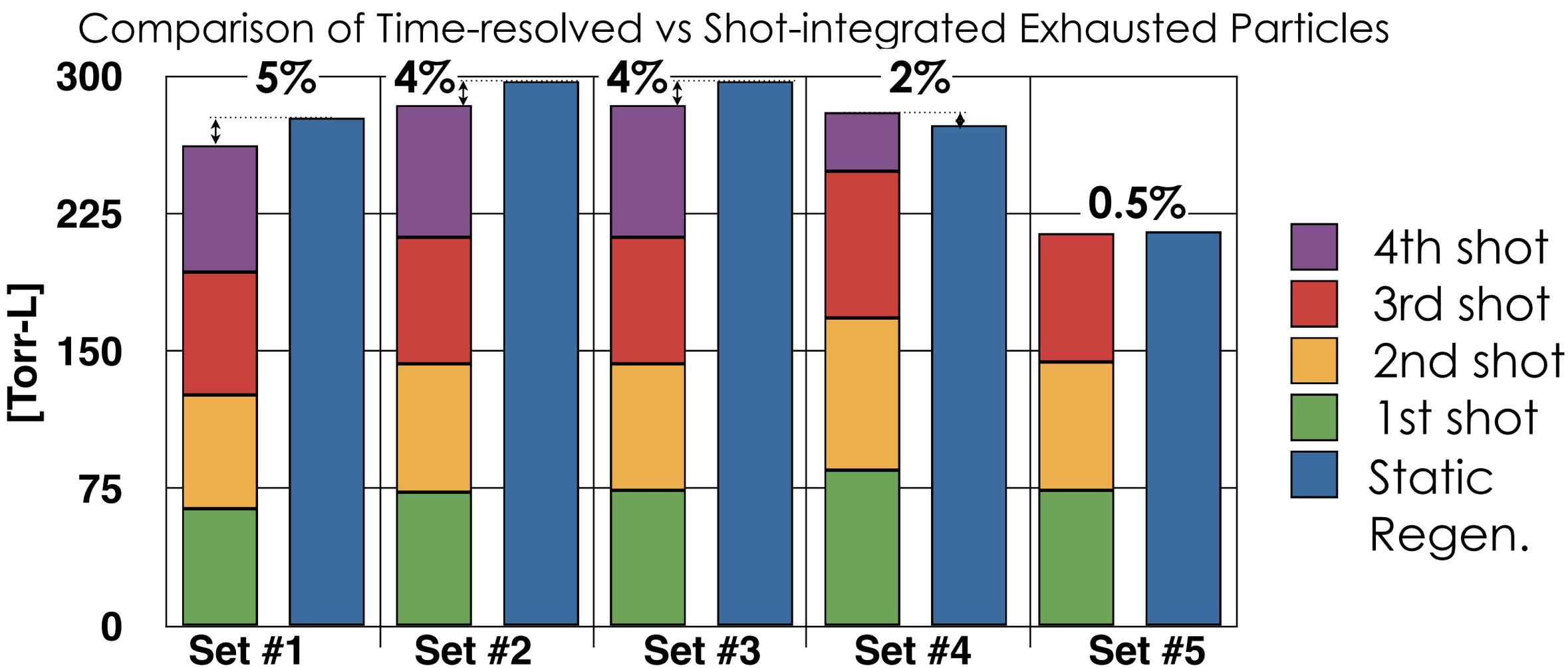
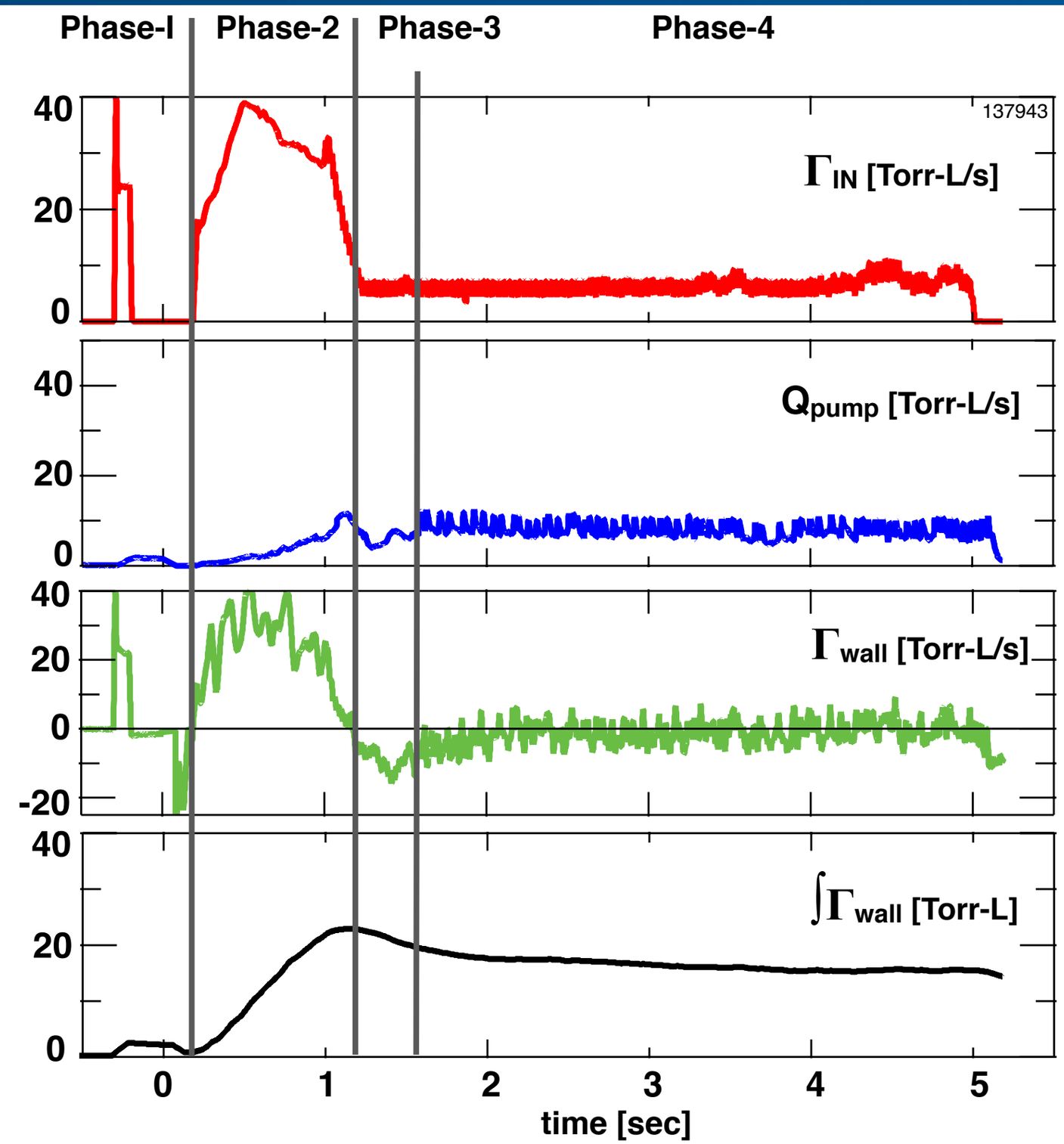
Dynamic and Static Balances Directly Compared

- **In DIII-D:**
  - Careful calibration of dynamic balance diagnostics completed
  - Multiple shots used for better accuracy in static balance
  - Allows confidence in dynamic balance results



Typical Dynamic Balance has Phases of Retention

- **Phase-I:Pre-fill & Startup**
  - No net retention
- **Phase-2: L-mode**
  - Large wall uptake
  - Dominated by puffing
- **Phase-3: early H-mode**
  - ELM-free; $\overline{n}_e$ build-up
  - Net wall release
- **Phase-4: H-mode steady-state**
  - No measurable net retention



(2) Phases Are of Most Interest

- **Phase-I:Pre-fill & Startup**
  - No net retention
- **Phase-2: L-mode**
  - Large wall uptake
  - Dominated by puffing
- **Phase-3: early H-mode**
  - ELM-free; $\overline{n}_e$ build-up
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- **Phase-4: H-mode steady-state**
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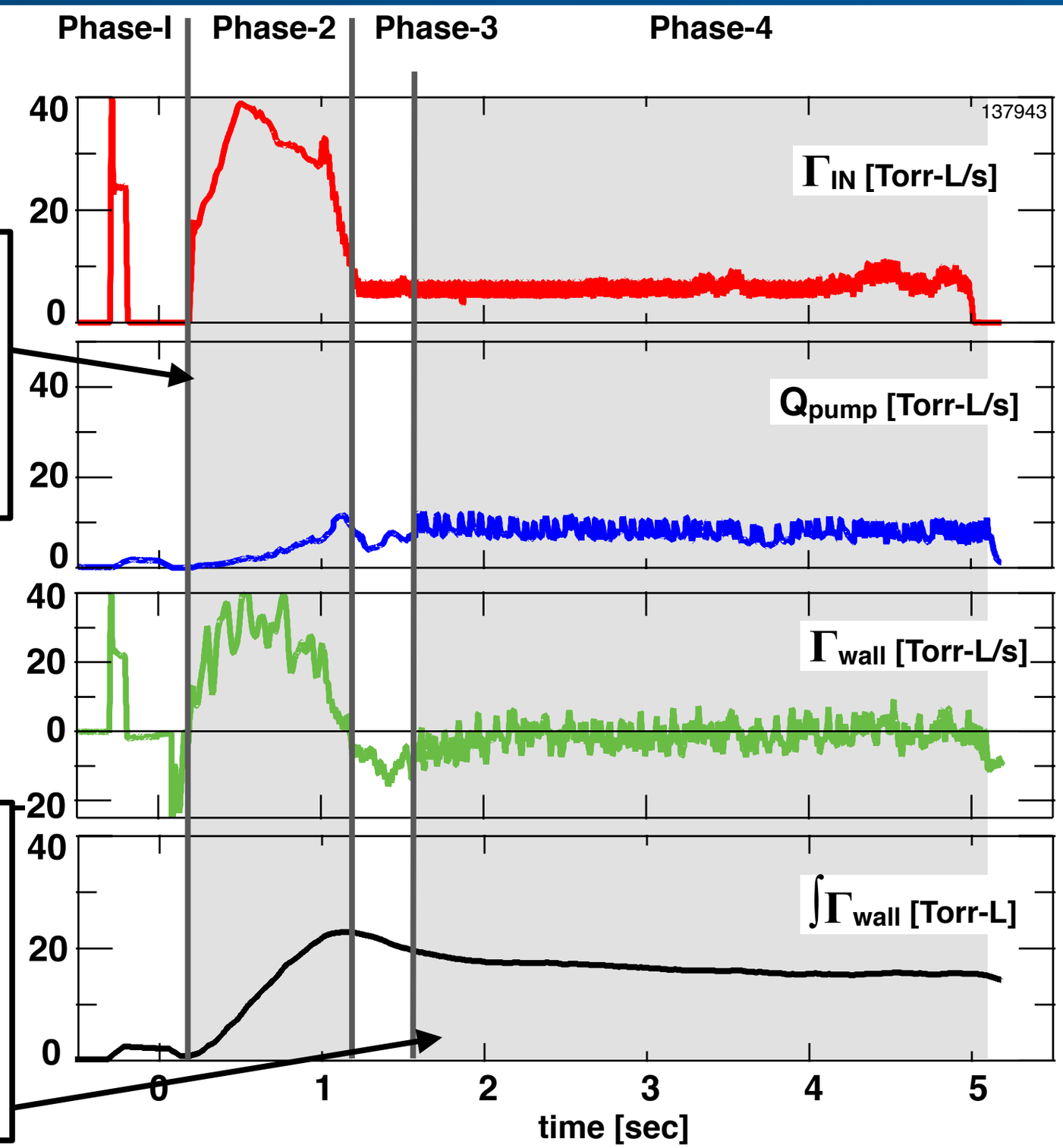
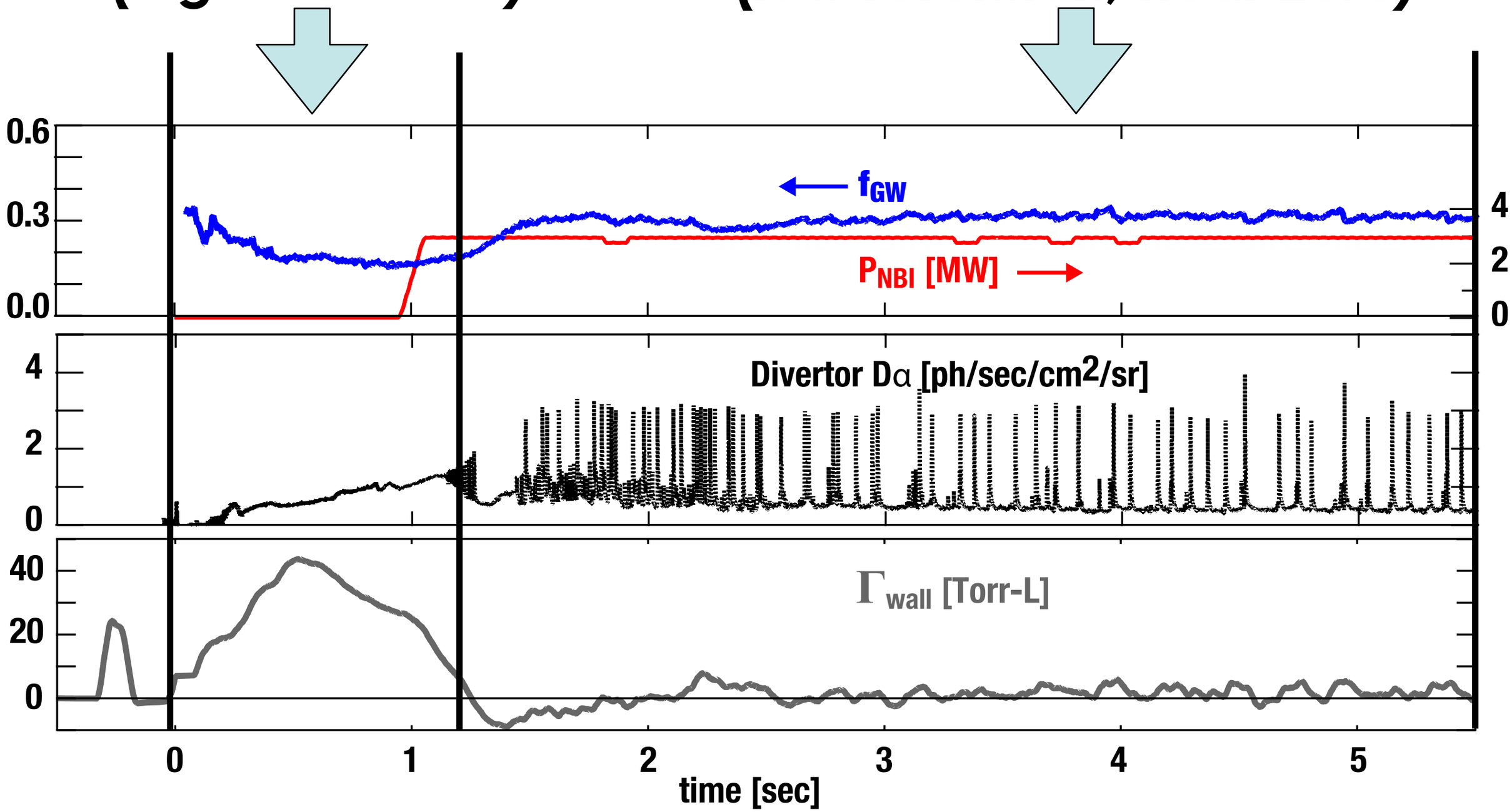


DIII-D Discharges had Low-n_e/n_{GW}; Med. Aux. Power

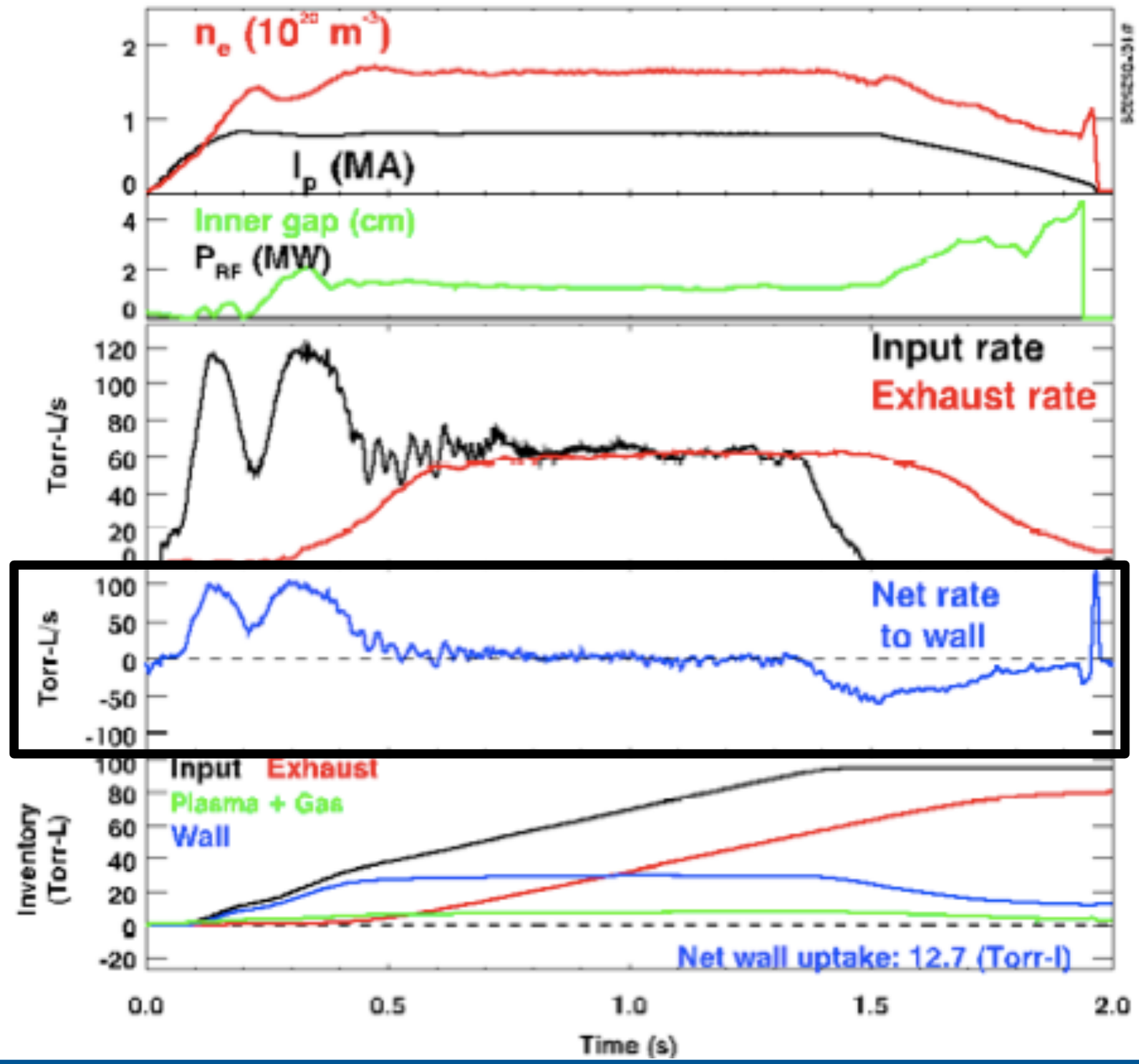
Ohmic/L-mode phase
(high retention)

H-mode phase
(low retention; near zero)



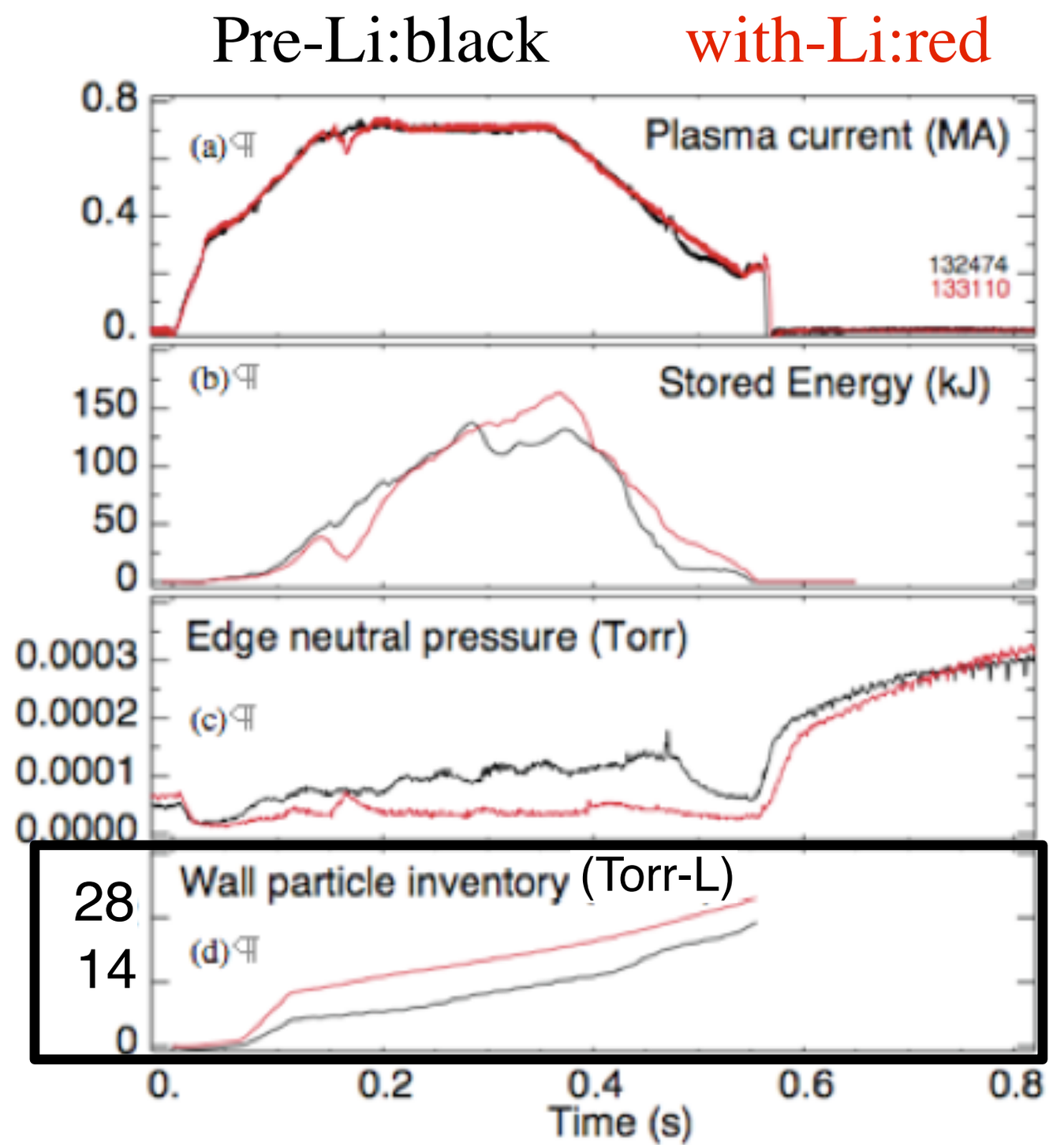
C-MOD Found the Wall Uptake rate ~ 0 in Steady State Phase

- **Similar f_{GW} ~ 0.3**
- **Most diverted tokamaks see similar results**
  - AUG (W PFC)
  - JET @ low fueling
  - JT-60U @ low fueling
- **In this regime is SOL self-equilibrating?**



NSTX Results Markly Different w/o "Active" Pumping

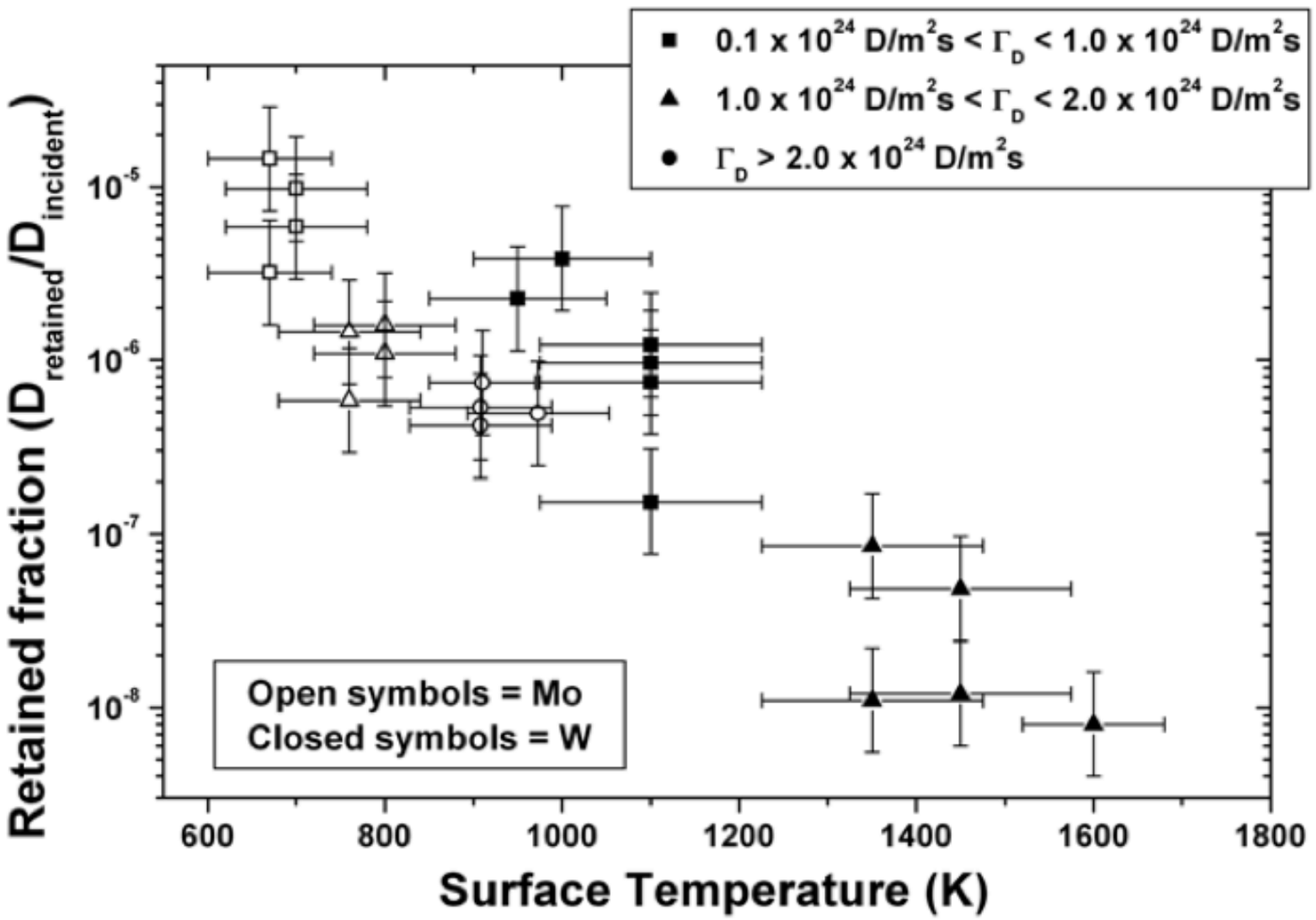
- **Li-coating had significant effect on particle balance**
- ***in-vacuo* PMI probe used to characterize Li-coating retention**
- **Unlike, DIII-D & CMOD, wall inventory increases continuously**
- **Key finding: surface analysis of Li-D bonding**



Temperature Dependence on Retention is also Stressed

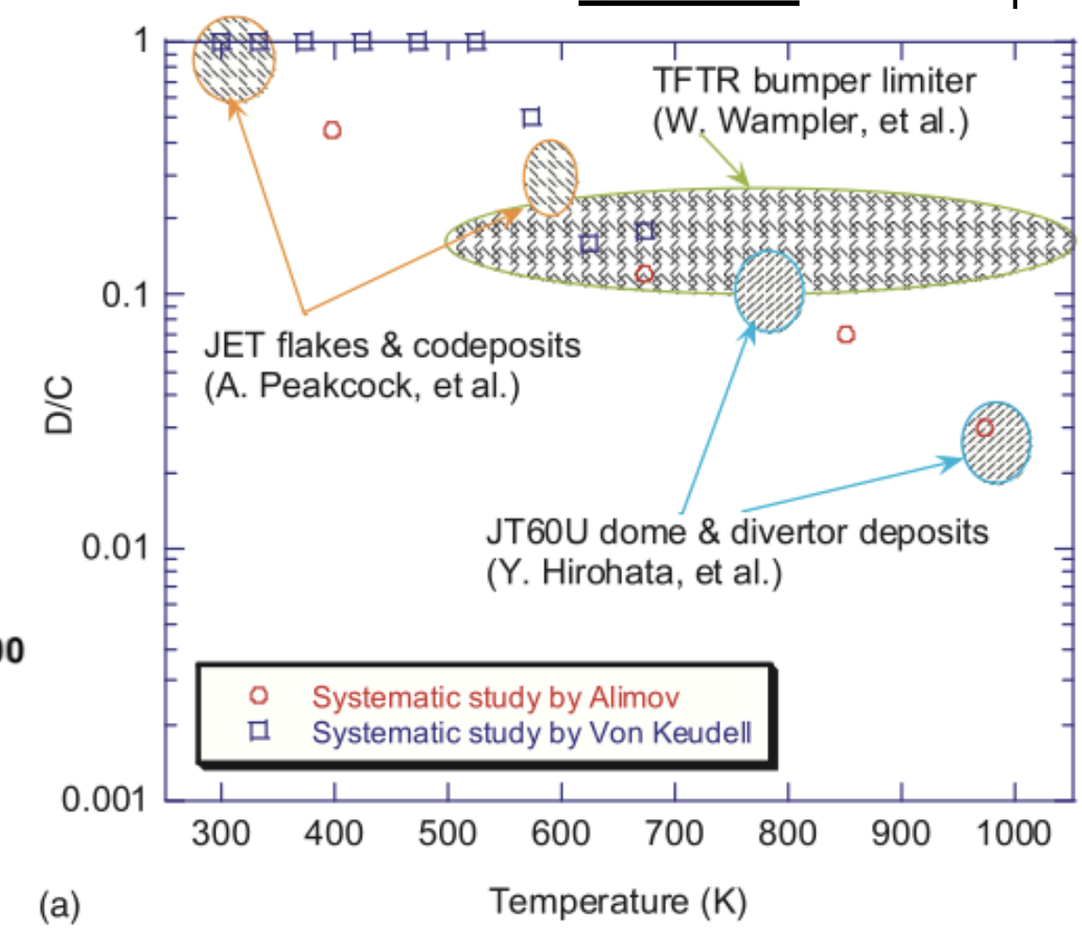
- **Higher ΔT for long pulse & higher ambient T in reactor**

Retention in **High-Z** vs Temp.



G.M. Wright et al., Nucl. Fusion (2010)

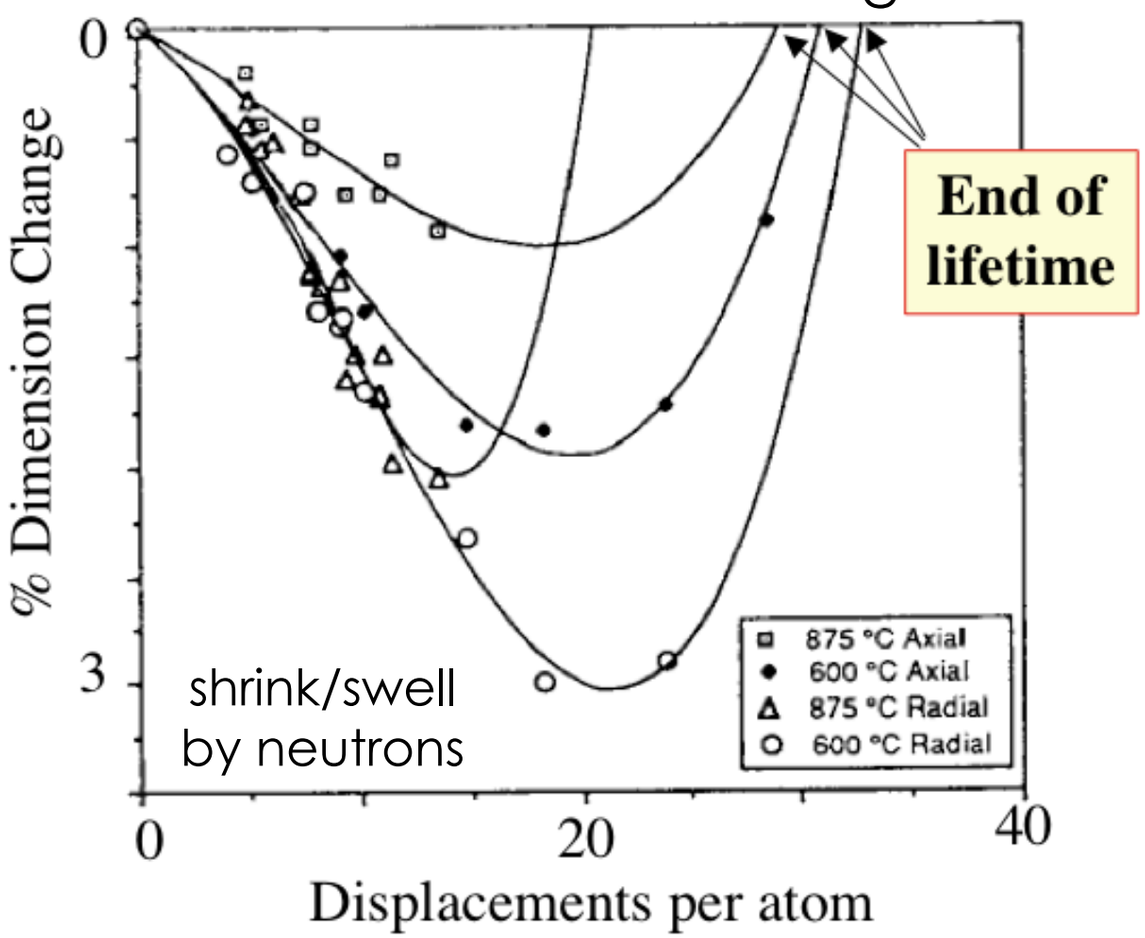
Retention in **Carbon** vs Temp.



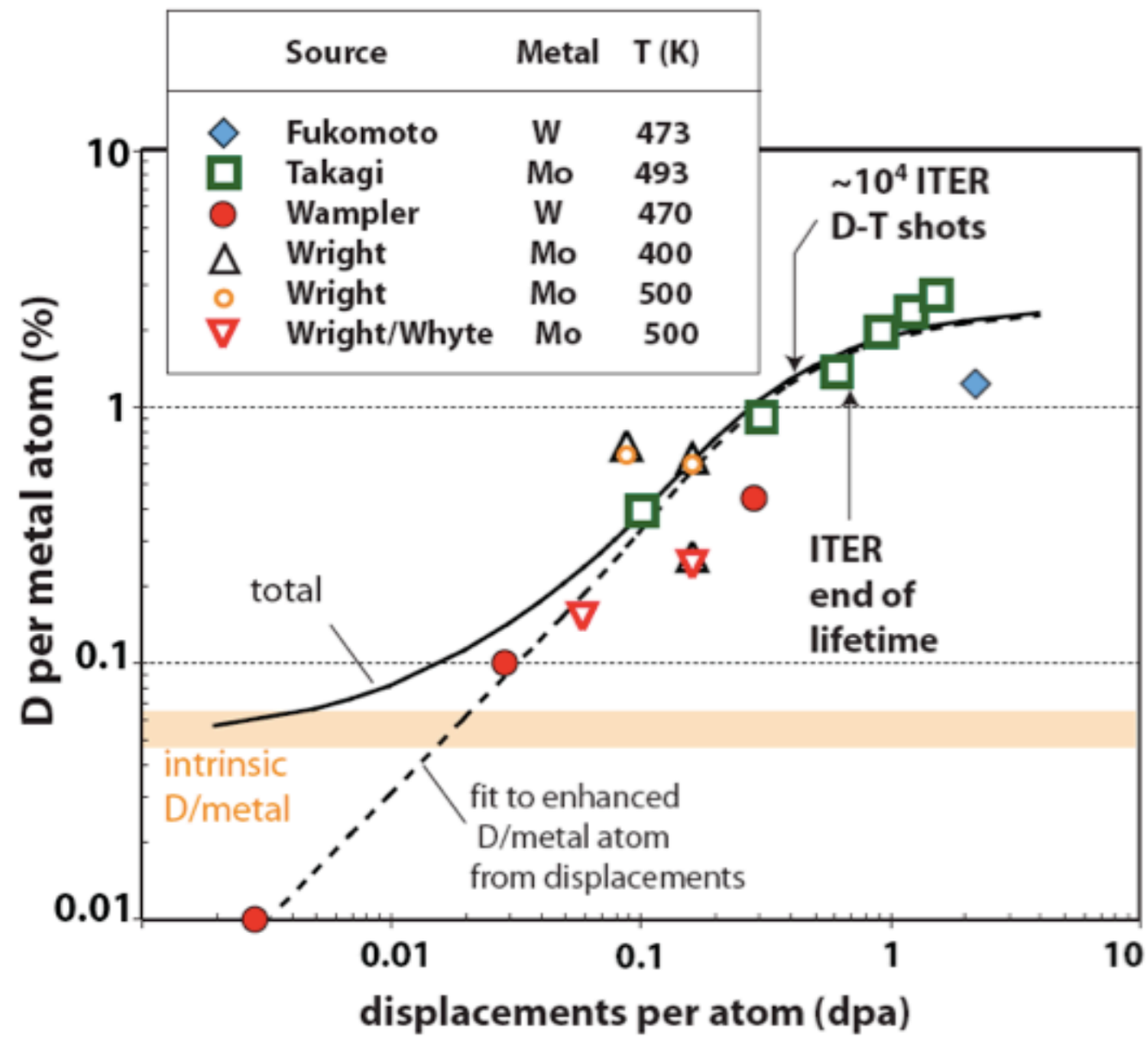
R.J. Doerner et al., Nucl. Fusion (2009)

Neutron Damage to PFC Must be Considered

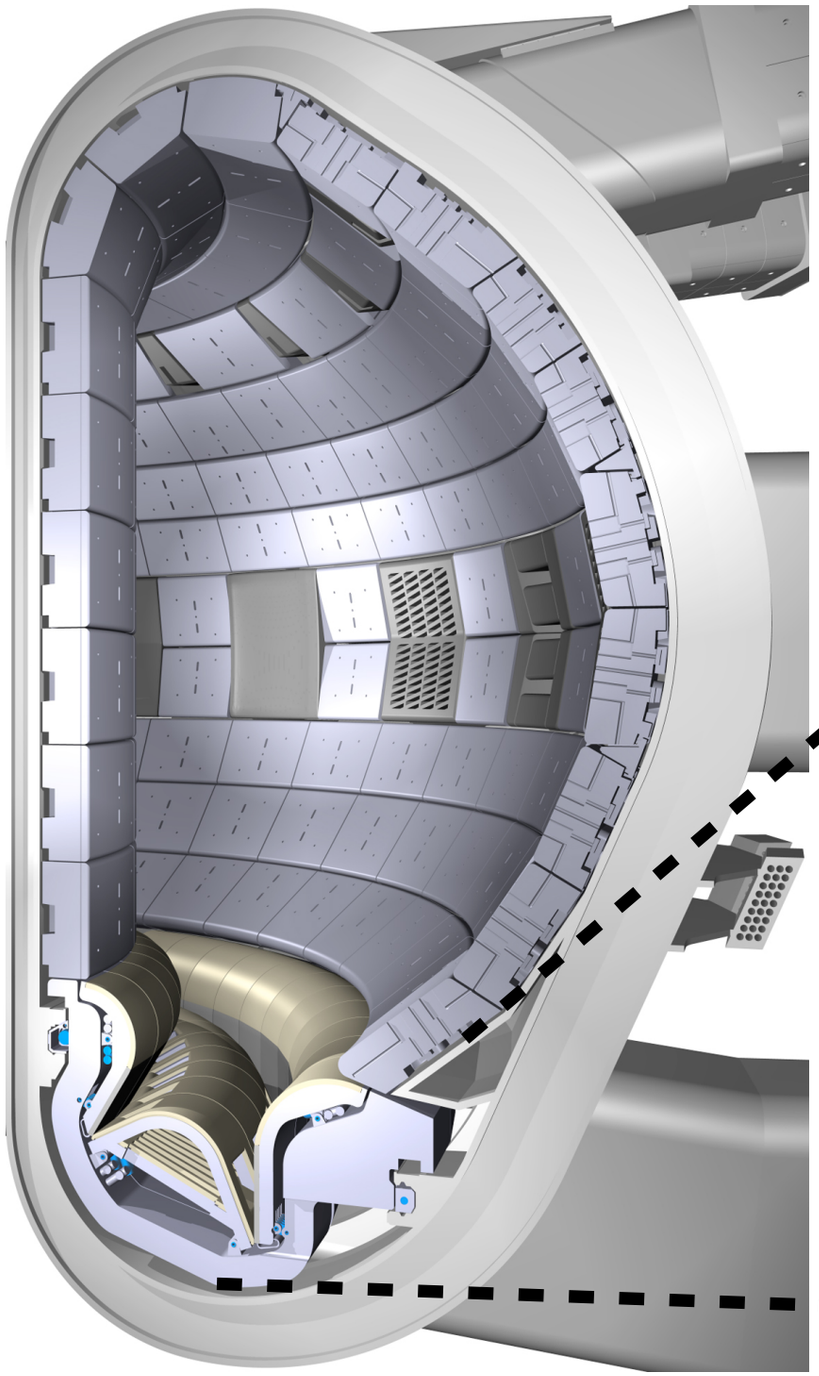
Lifetime limit set on graphite due to neutron damage



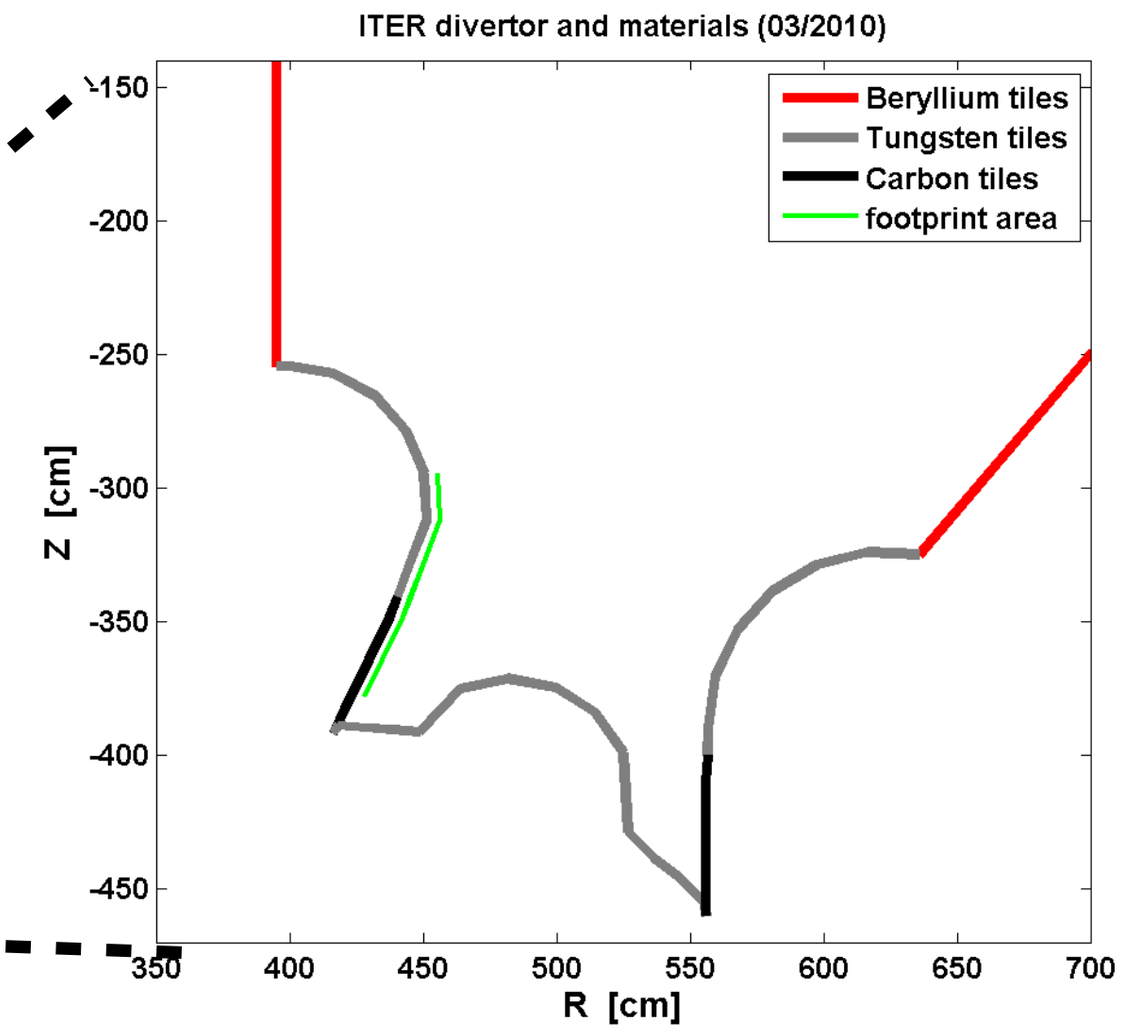
retention in **High-Z** vs DPA



Common Threads from Today's Research to Future Machines - 3D Field Effects

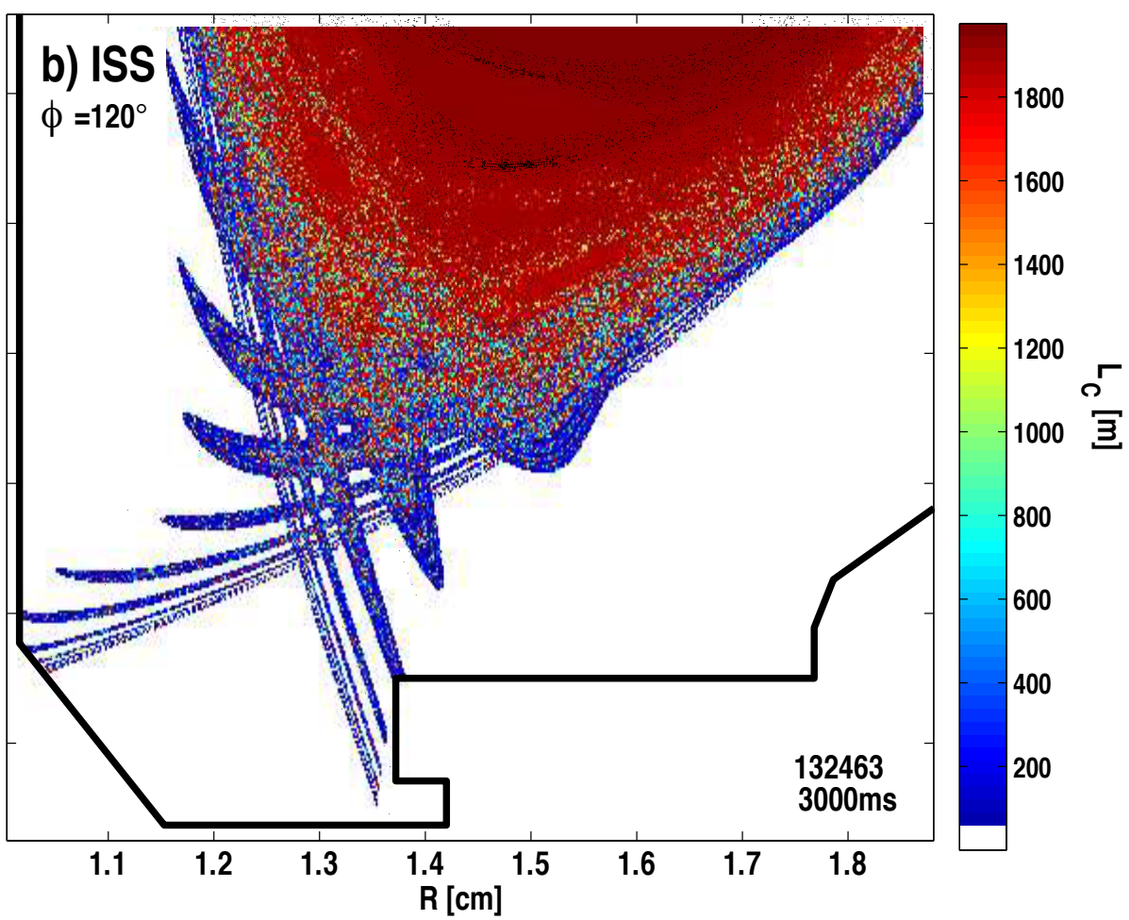


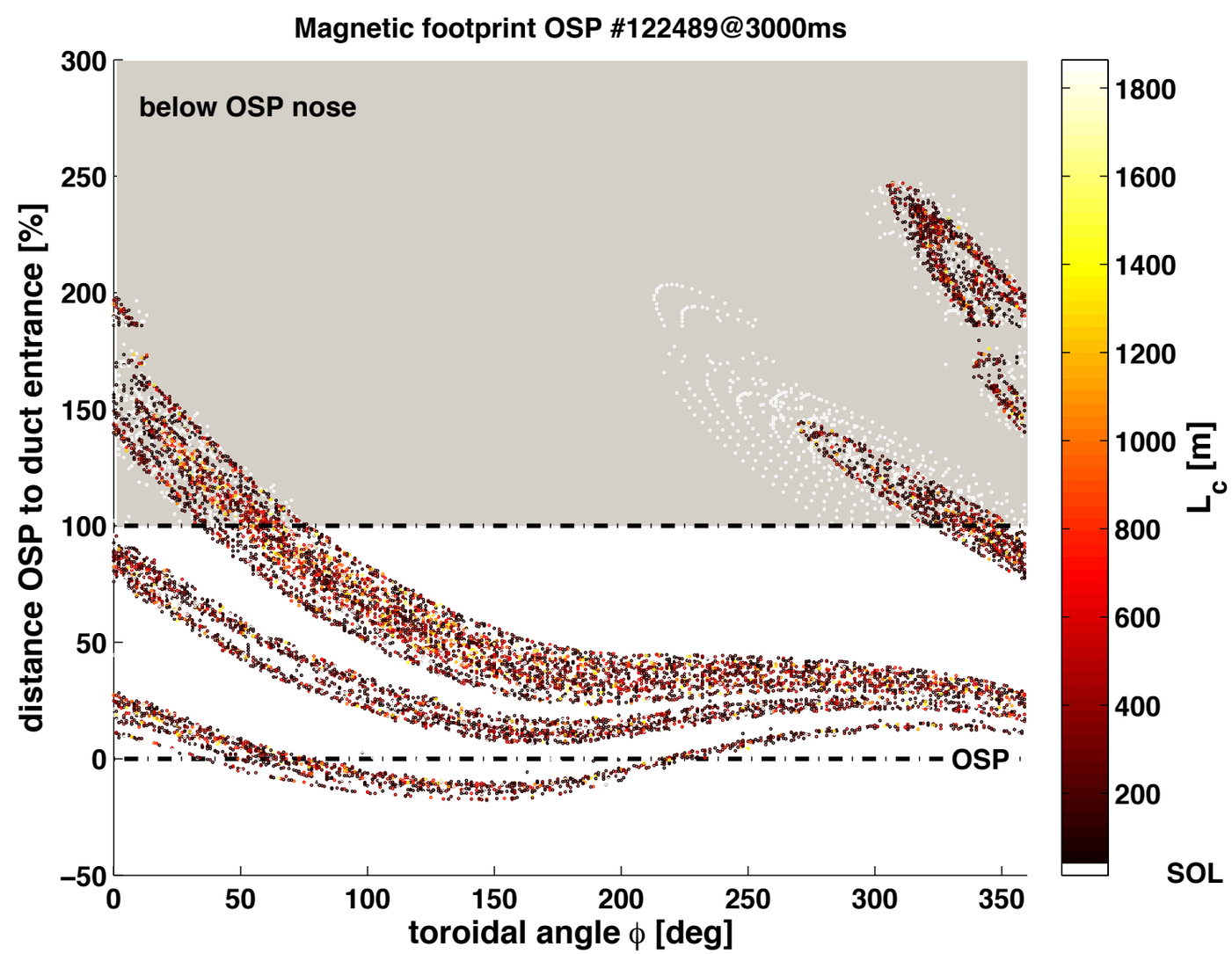
- **Plasma-Wall Interactions (PWI) due to magnetic topology**
- **Deformed by 3D asymmetries**



Extensive Work Done on 3D PWI at TEXTOR and DIII-D*

- **Interaction of applied 3D perturbation on seperatrix causes predicted strikepoint pattern (the footprint)**

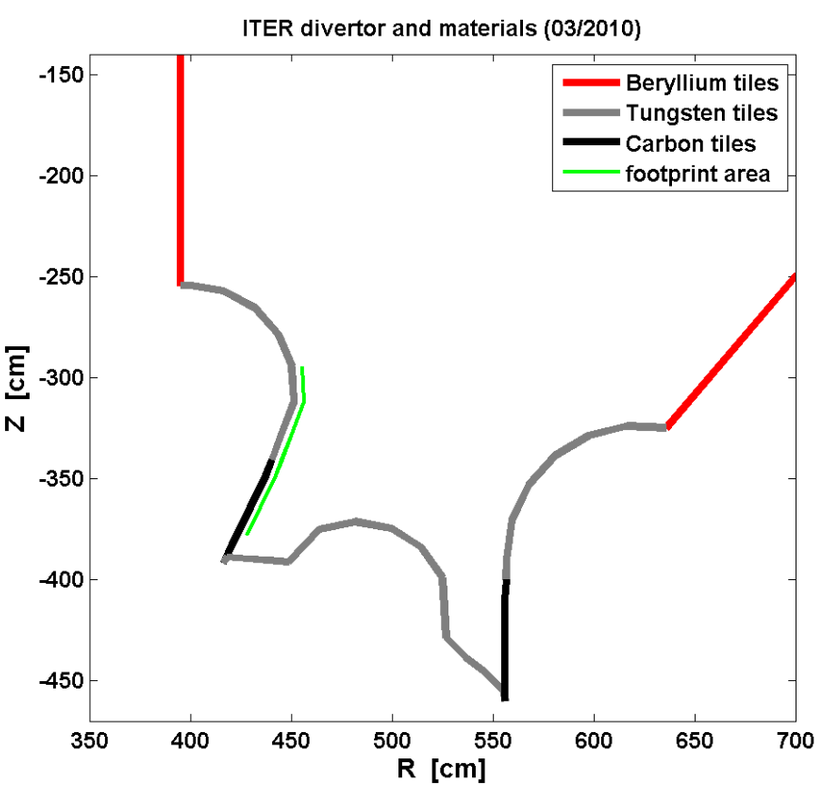


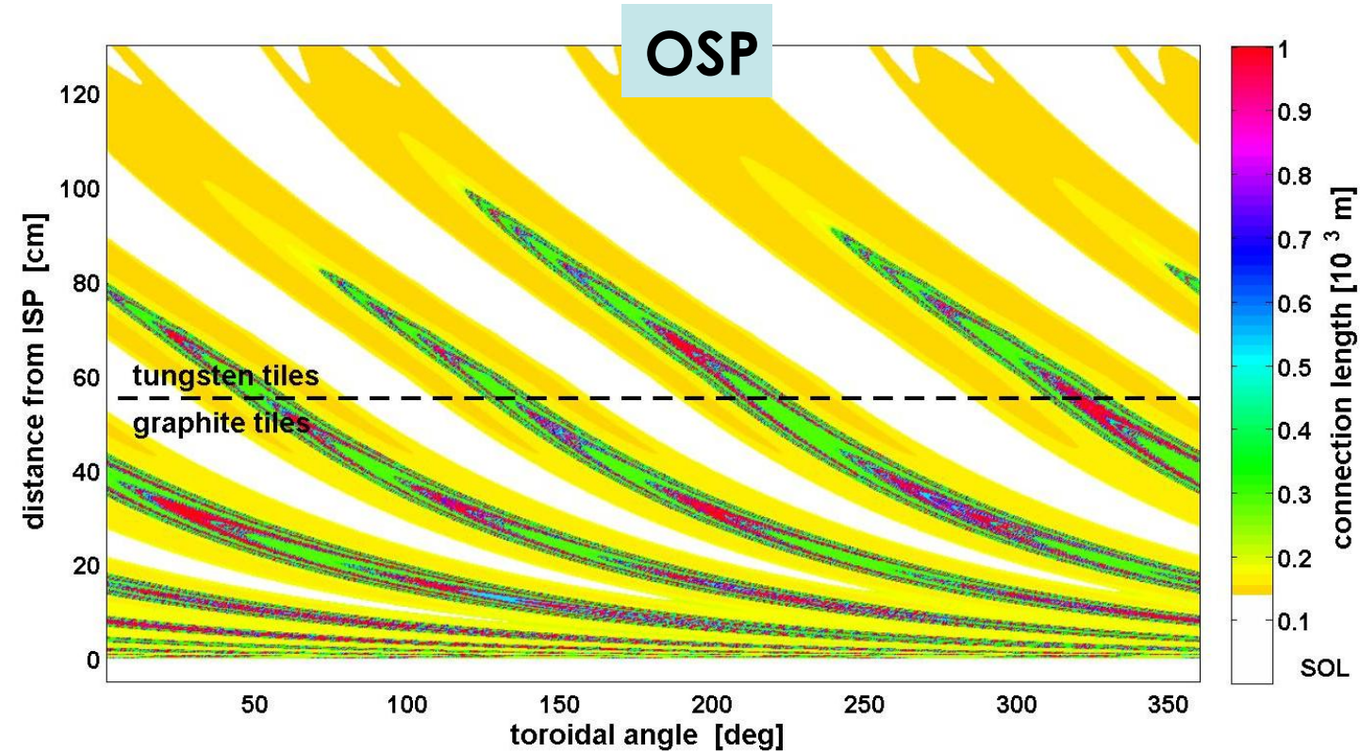


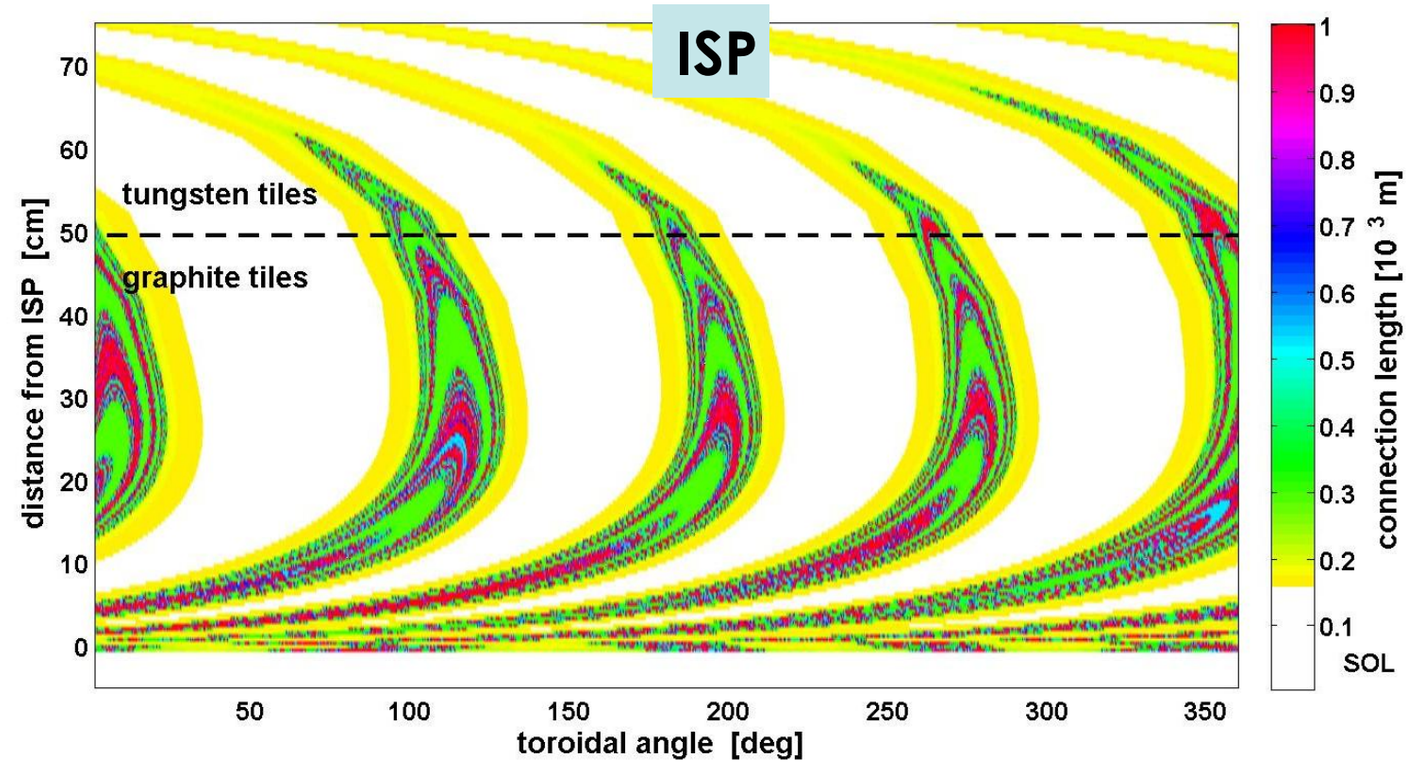
*O. Schmitz et al., PPCF 2008

Predictions for ITER RMP Coils Made*

- **Predicted footprint leads to large spreading of high flux (heat & particles)**







*O. Schmitz et al., Invited Talk at PSI-2010

In Summary

- **2009 DoE Joint Facilities Milestone (JFM-09): Hydrogenic Retention in PFCs***
  - Similar particle balance methods compared on all 3 machines
  - Consistent finding: Strong pumping plays role in global particle balance
    - *edge modeling beyond 0-D would help (i.e., 2D (3D?))*
- **Relation to future devices**
  - Temperature dependence
    - *Seems well understood, but no device runs at high T*
  - 3D field effects should be considered
    - *Erosion rates, particle exhaust, heat & particle profiles*

*http://www.science.doe.gov/ofes/performancetargets.shtml

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