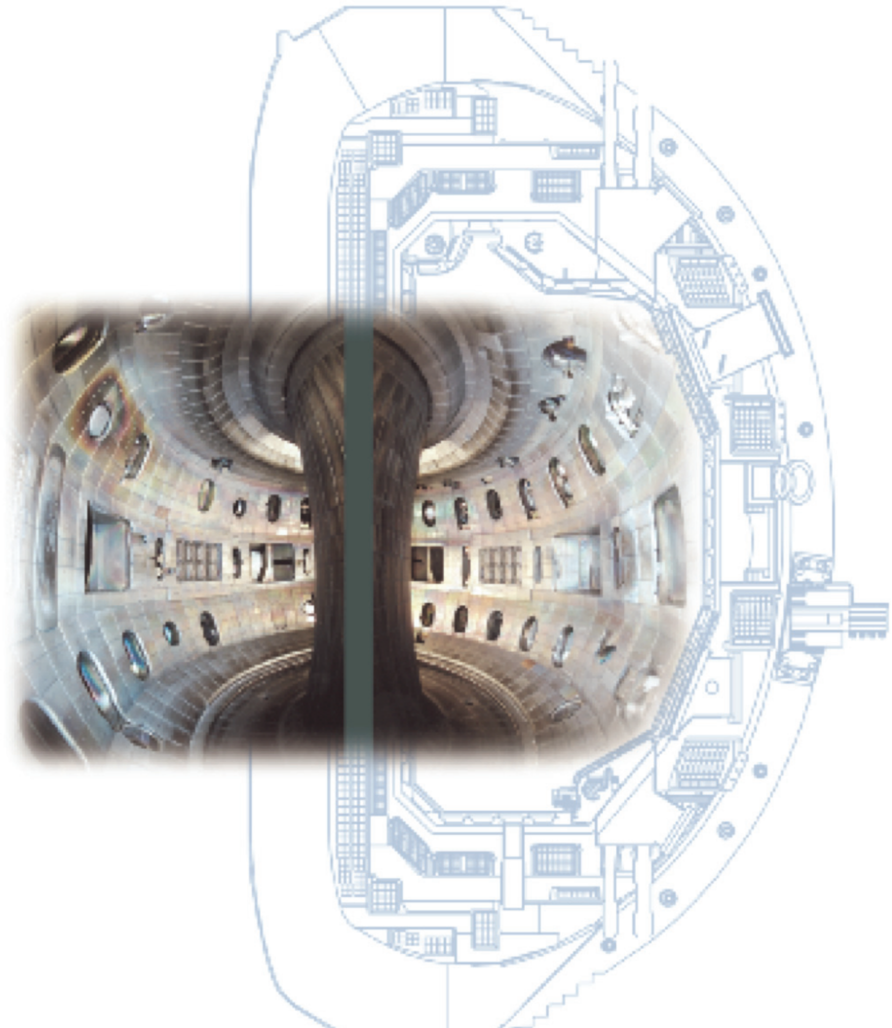
Fuel Retention and Removal in DIII-D Discharges

by

E.A. Unterberg[1]

with S.L. Allen[2], N.H. Brooks[3], C. Chrobak[3], J.W. Davis[4], B.W.N. Fitzpatrick[4], A.A. Haaz[4], G.L. Jackson[3], A.W. Leonard[3], M.A. Mahdavi[3], C.K. Tsui[4], P.C. Stangeby[4], K.R. Umstadter[5], W.P. West[3], D.G. Whyte[6] and the DIII-D Team

[1]Oak Ridge Institute for Science and Education
[2]Lawrence Livermore National Laboratory, Livermore
[3]General Atomics
[4]University of Toronto
[5]University of California -San Diego
[6]Massachusetts Institute of Technology



Presented at the
52nd Annual Meeting of the
APS Division of Plasma Physics
Chicago, Illinois

November 8-12, 2010

DIII-D NATIONAL FUSION FACILITY

OAK RIDGE National Laboratory

Outline: Retention Processes in Graphite PFC

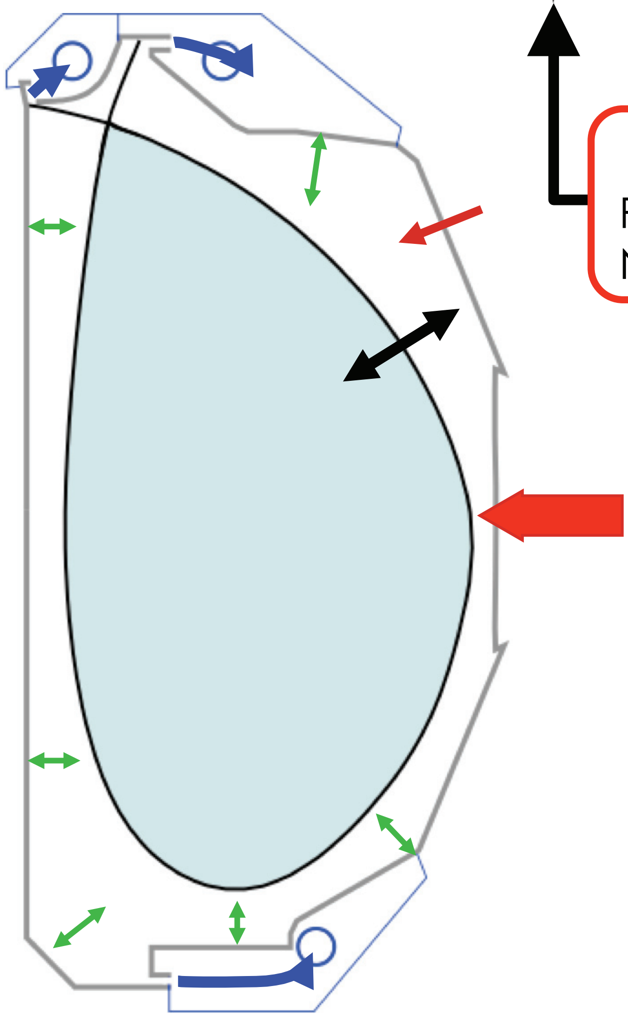
- **Level of saturable fuel measured via particle balance**
  - Accurately determine contribution from different phases
    - Dynamic ⇒ time-resolved balance
    - Static ⇒ shot-integrated balance
  - ~20% retention in ramp-up; ~0% in steady-state H-mode

- **Majority of fuel recovered during vessel bake**

- **Co-desposit removal via thermo-oxidation wall conditioning**
  - Developed for DIII-D at Univ. Toronto
  - Quick recovery of high performance discharges

Dynamic Particle Balance Calculation Based on Measured Quantities

$$\Gamma_{wall}(t) = \Gamma_{gas}(t) + \Gamma_{NBI}(t) - \left[Q_{pump}(t) + \frac{dN_0(t)}{dt} + \frac{dN_{core}(t)}{dt} \right]$$



Particle sources
Puff values ⇒ *flowmeter*
NBI ⇒ P_{NBI} & V_{NBI}

Particles exhausted
(cryo-pumps)
Fast ion gauge

Un-pumped neutrals
Fast ion gauge

Core particle #
CO_2 *interferometer*

In Steady-state H-mode, Dynamic Balance Reduces to a Few Terms

Main terms in NBI discharges

$$\Gamma_{wall}(t) = \cancelto{0}{\Gamma_{gas}(t)} + \boxed{\Gamma_{NBI}(t) - \left[Q_{pump}(t)\right.} + \cancelto{\sim 0}{dN_0(t)/dt} + \left.\cancelto{\sim 0}{dN_{core}(t)/dt}\right]$$

– Γ_{NBI} is derived & has uncertainty ~20%

– Q_{pump} is measured directly; low uncertainty (~5%)

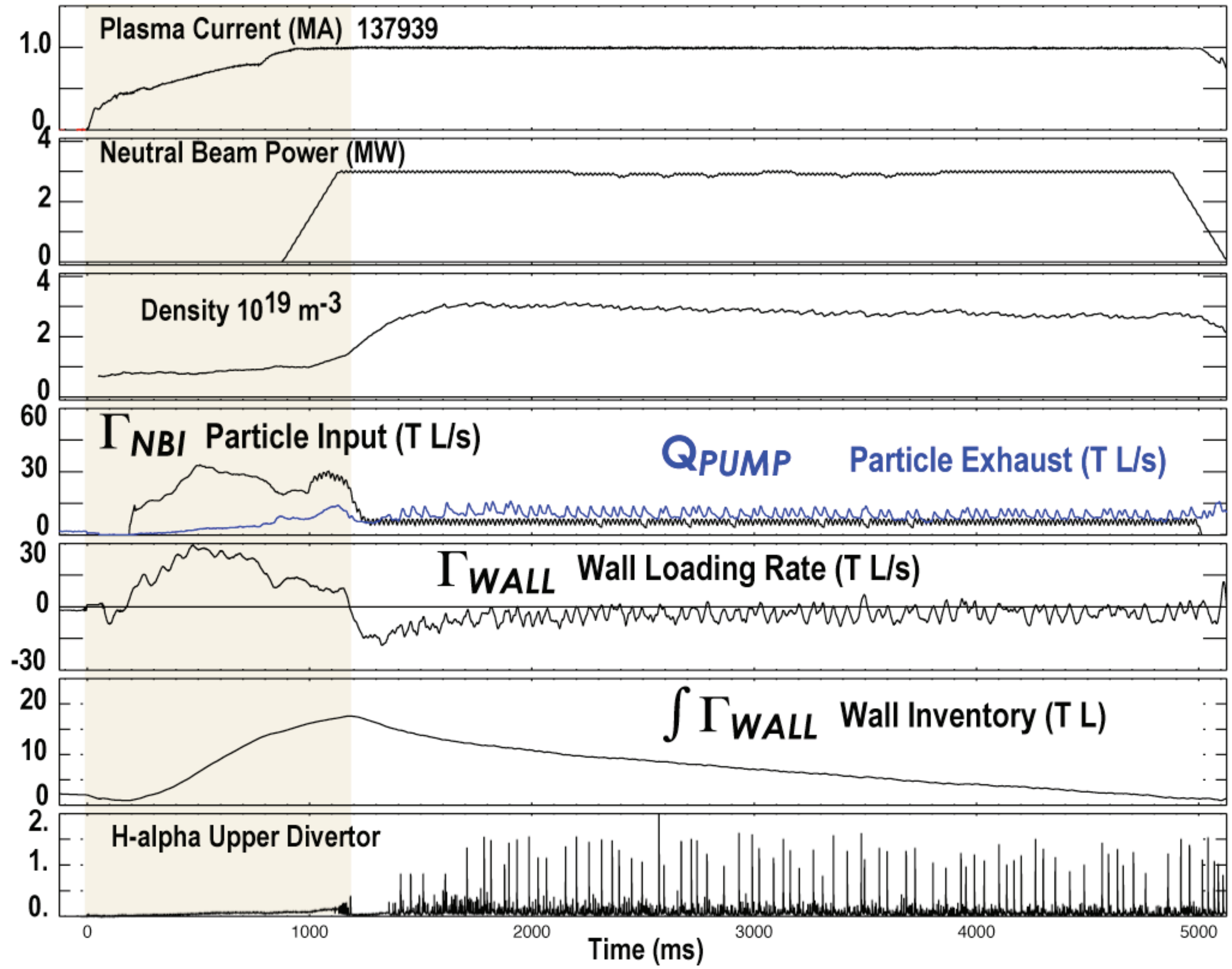
Main terms in ECH discharges

$$\Gamma_{wall}(t) = \boxed{\Gamma_{gas}(t)} + \cancelto{0}{\Gamma_{NBI}(t)} - \boxed{Q_{pump}(t)} + \cancelto{\sim 0}{dN_0(t)/dt} + \left.\cancelto{\sim 0}{dN_{core}(t)/dt}\right]$$

– Considered more accurate due to well calibrated quantities

Dynamic Particle Balance Shows No Retention in H-mode

- **High retention in ramp-up phase**



EA Unterberg/APS/November 2010

Dynamic Particle Balance Shows No Retention in H-mode

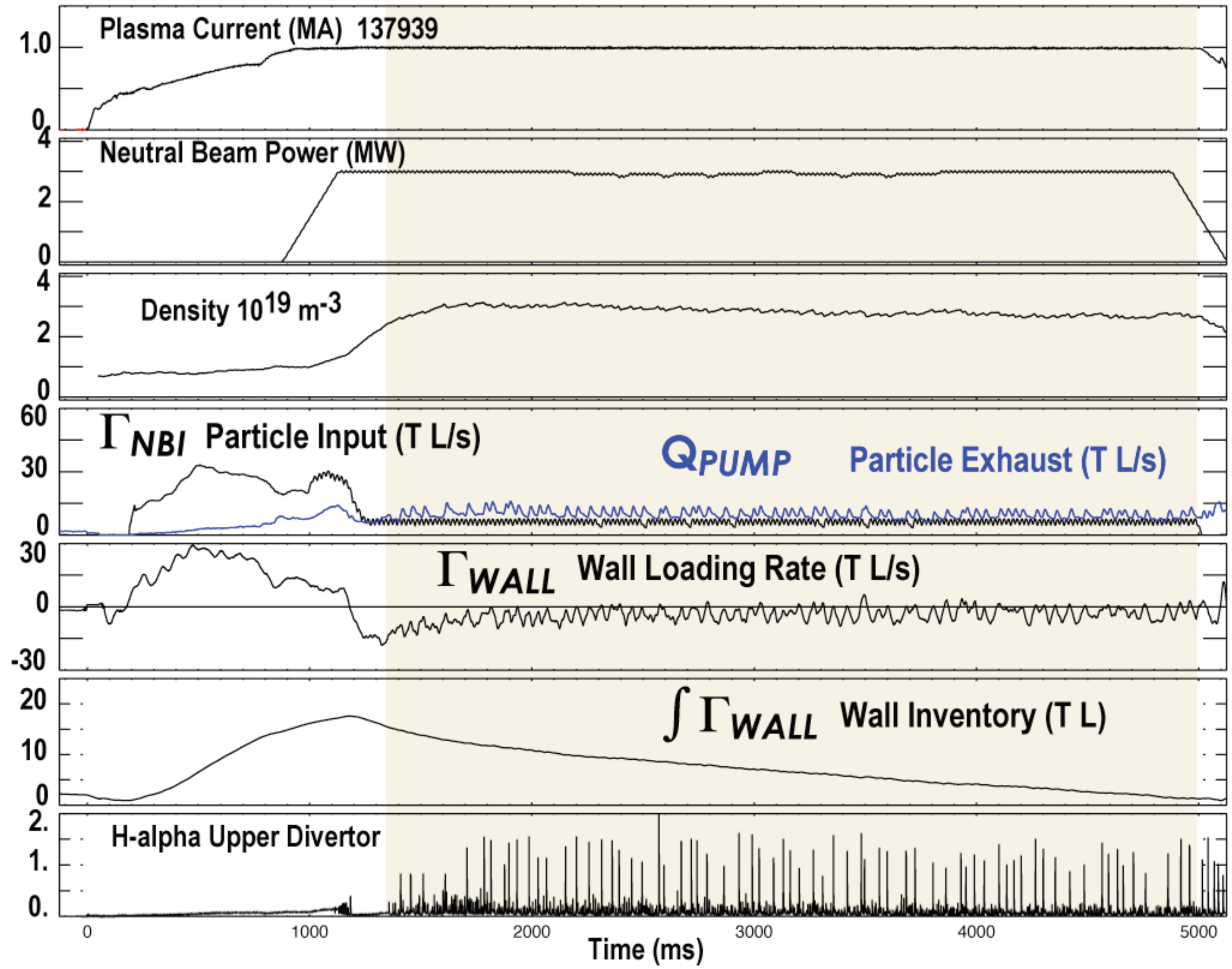
- **High retention in ramp-up phase**
- **H-mode removes fuel**

$$Q_{PUMP} > \Gamma_{NBI}$$

$$\Gamma_{WALL} < 0$$

$\int \Gamma_{WALL}$ **Decreasing**

- **High retention in ramp-up phase**



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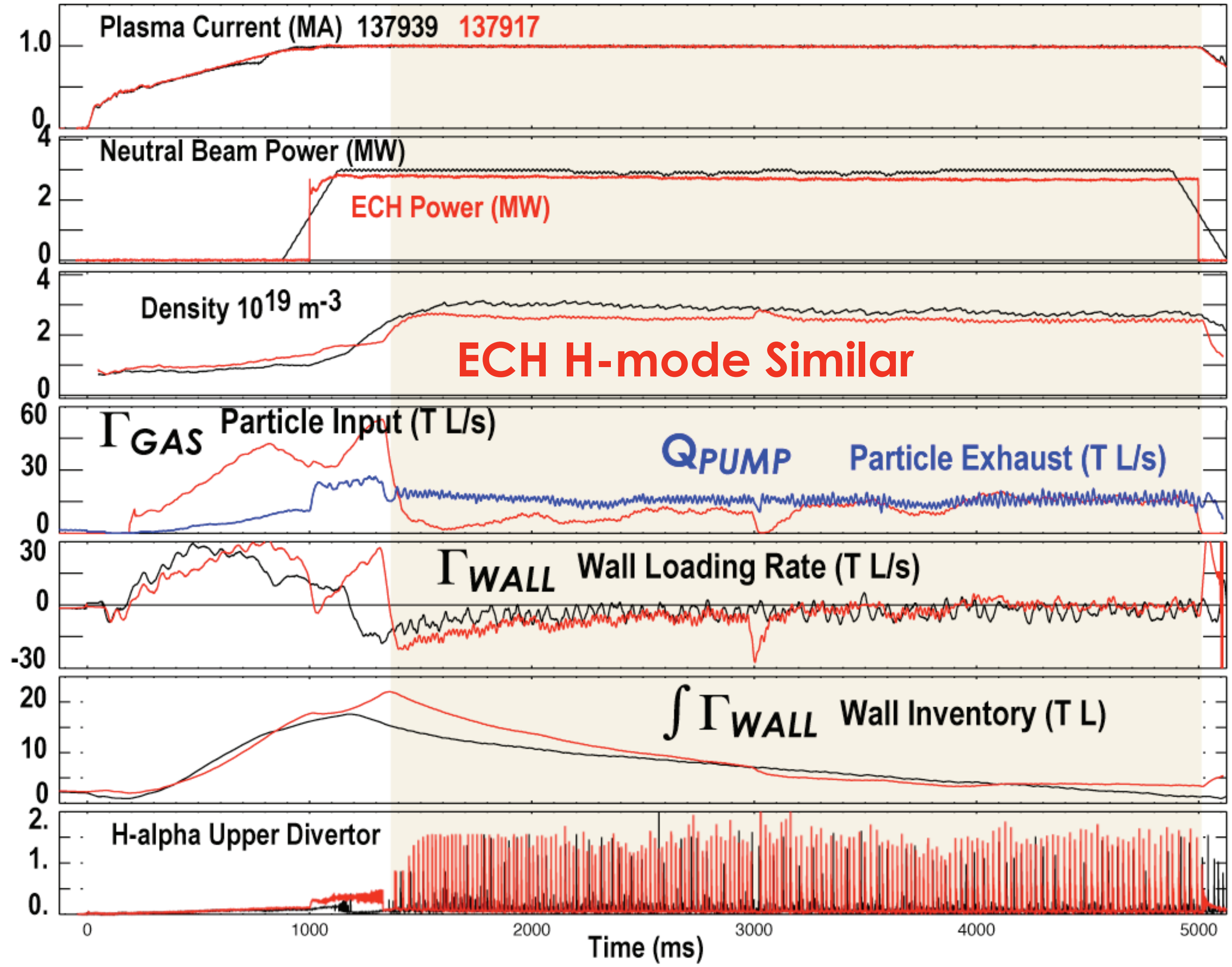
Dynamic Particle Balance Shows No Retention in H-mode

- **High retention in ramp-up phase**
- **H-mode removes fuel**

$$Q_{PUMP} > \Gamma_{GAS}$$

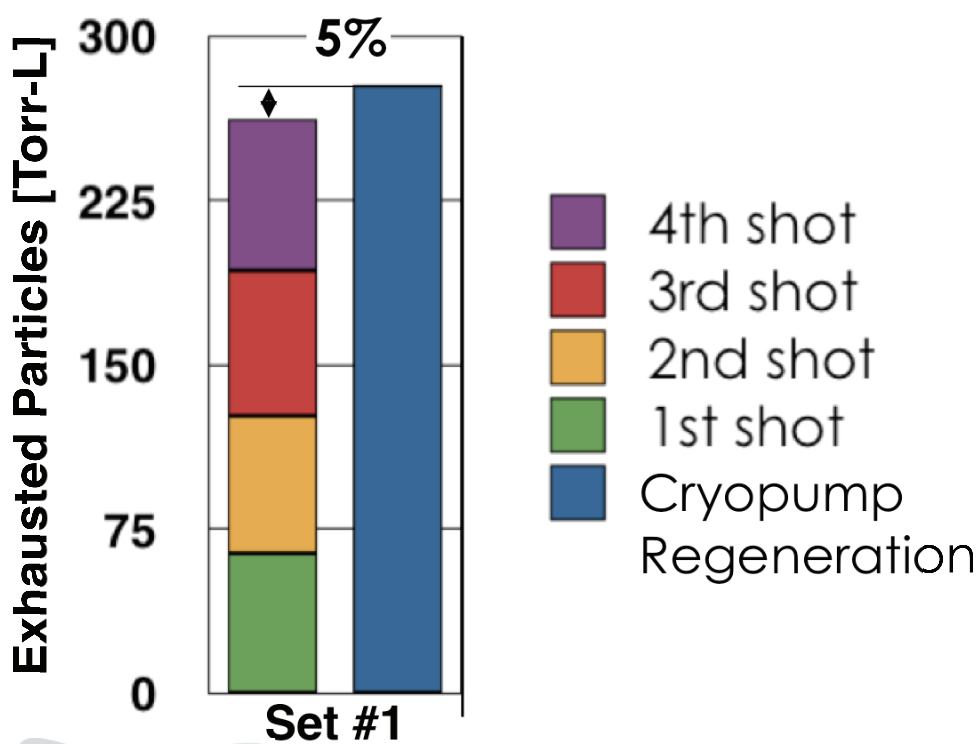
$$\Gamma_{WALL} < 0$$

$\int \Gamma_{WALL}$ **Decreasing**



Validation of Dynamic Exhaust with Integrated Gas Balance

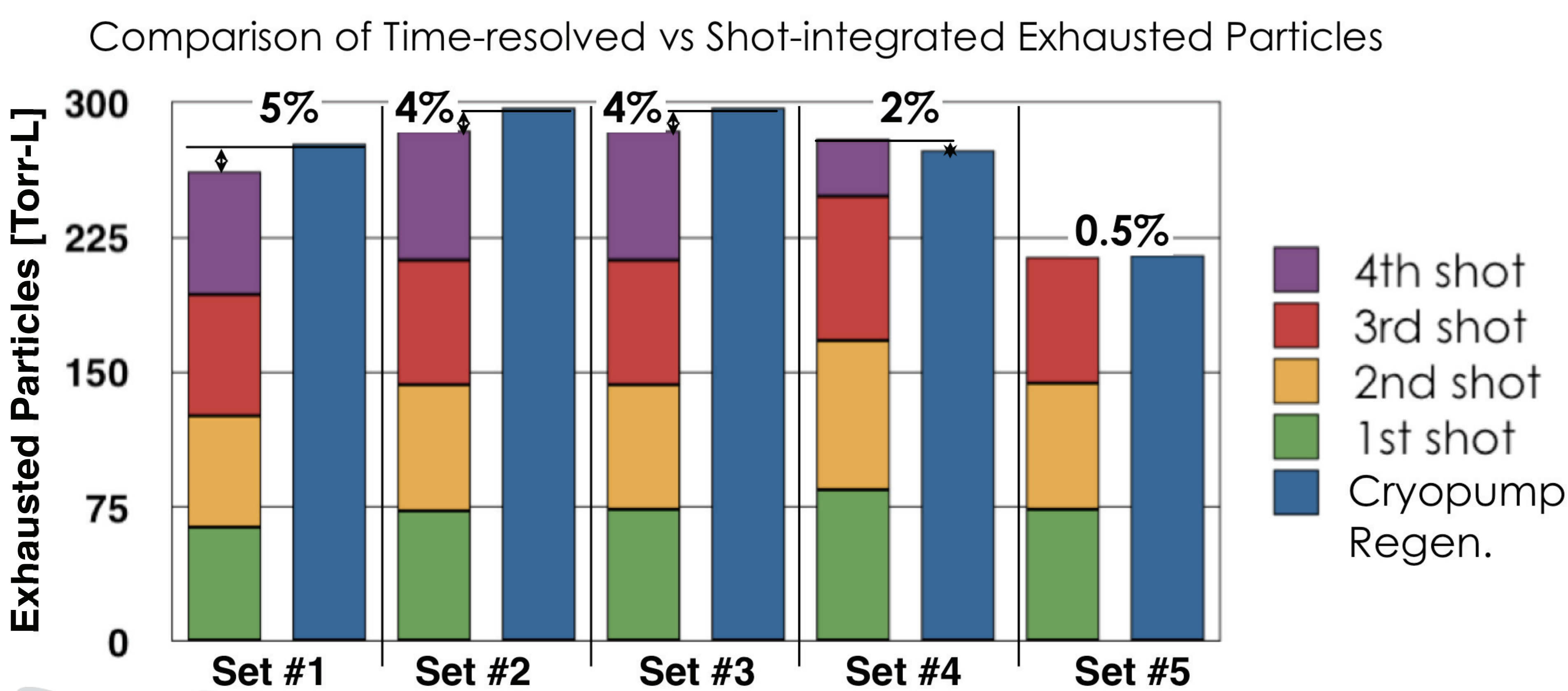
- **ECH balance used**
  - $\Gamma_{wall}(t) = \Gamma_{gas}(t) - Q_{pump}(t)$
- **After several shots ⇒ Cyropumps regenerated; Measure vessel pressure ⇒Compare with dynamic exhaust**



- **Difference in calculated vs measure exhaust within measurement error**

Validation of Dynamic Exhaust with Integrated Gas Balance

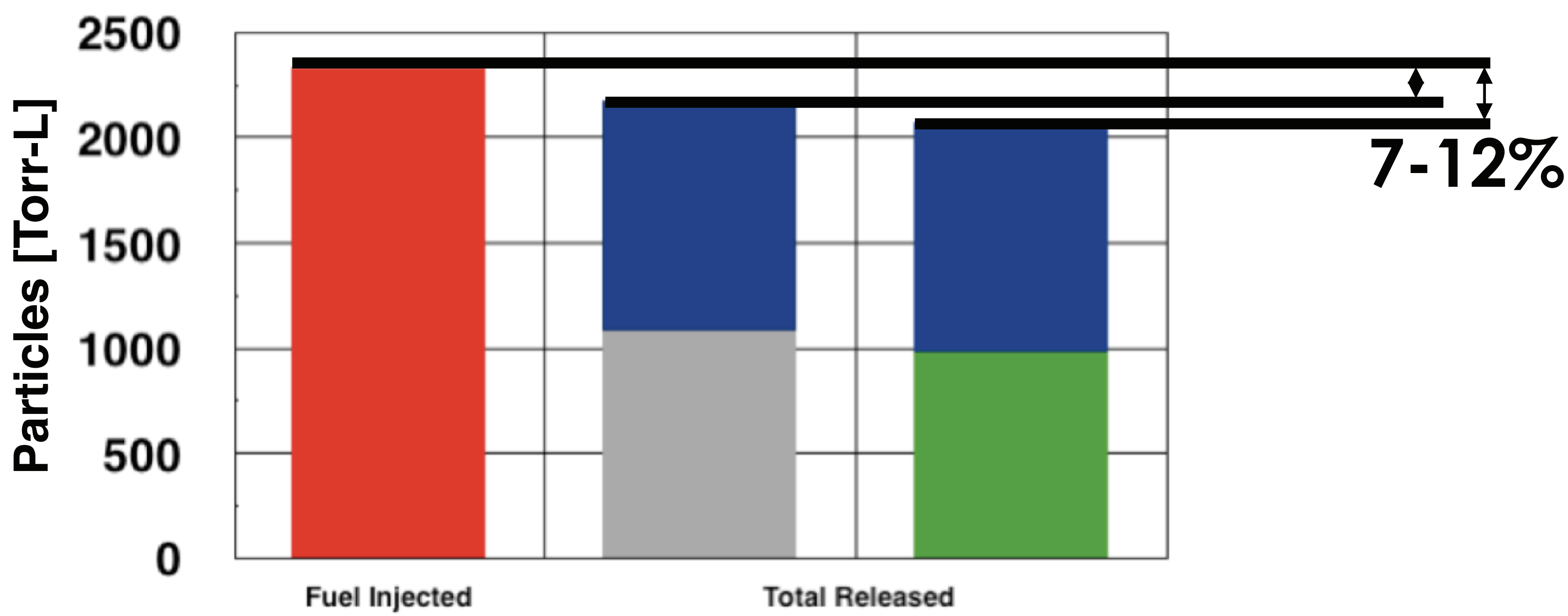
- **ECH balance used**
  - $\Gamma_{wall}(t) = \Gamma_{gas}(t) - Q_{pump}(t)$
- **Aggreement gives confidence in dynamic balance**



Vacuum Bake Before and After Single Run-day Returned Large Fraction of Retained Particles

- **Particle balance summary**
  - Total injected: 2400 [torr-L]
  - Exhausted: 1010-1140 [torr-L]
  - Bake released: 1090 [torr-L]
- **Post-bake retention/total injected**
  - 170-300 [torr-L]/2400 **~7-12%**

- **Bake "short" due to operational constraints**
- **Gives upper bound on co-deposits**



Co-deposited D Could Account for Remaining Fuel After Vacuum Bake

- **Can estimate D/C ratio via**
  - $\Gamma_{CoCep} = (D/C) \cdot \Gamma_C$
- **Assume constant co-deposition**
  - D left in machine after bake:
    170-300 Torr-L ⇒ 1.2-2.1x10²² D atoms
  - $\underline{\Gamma_{CoDep}} = \dfrac{1.2 - 2.1 \times 10^{22}}{\Delta t = 165\ s} = \underline{0.7 - 1.3 \times 10^{20}}$
- **Global net C re-deposition***
  - $\Gamma_C = 1.9 \times 10^{20}$ C/s

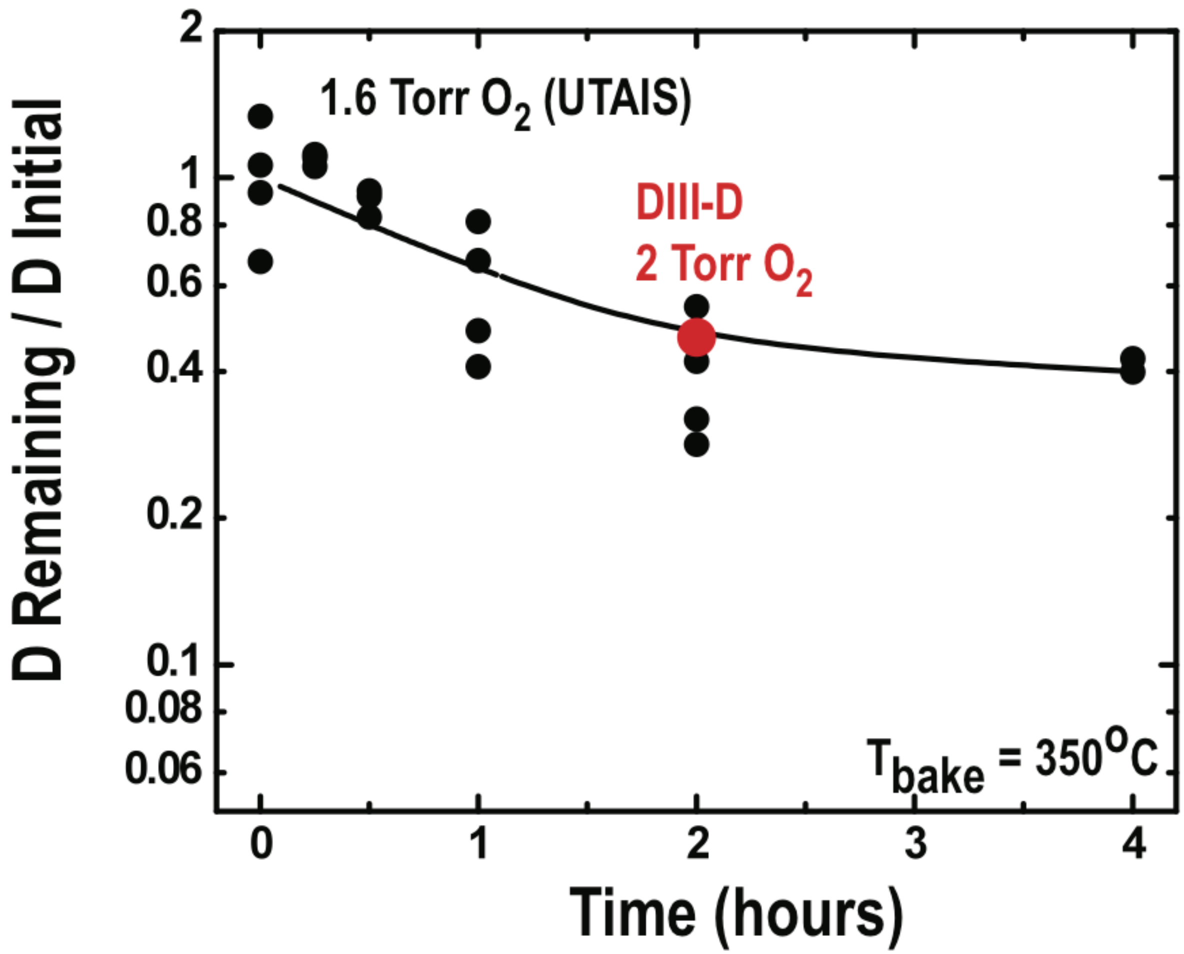
$$D/C = \Gamma_{CoDep} / \Gamma_C = 0.4 - 0.7$$

*D.G. Whyte et al., Nucl. Fusion 1999

Deposition Pattern in Lower Divertor Region

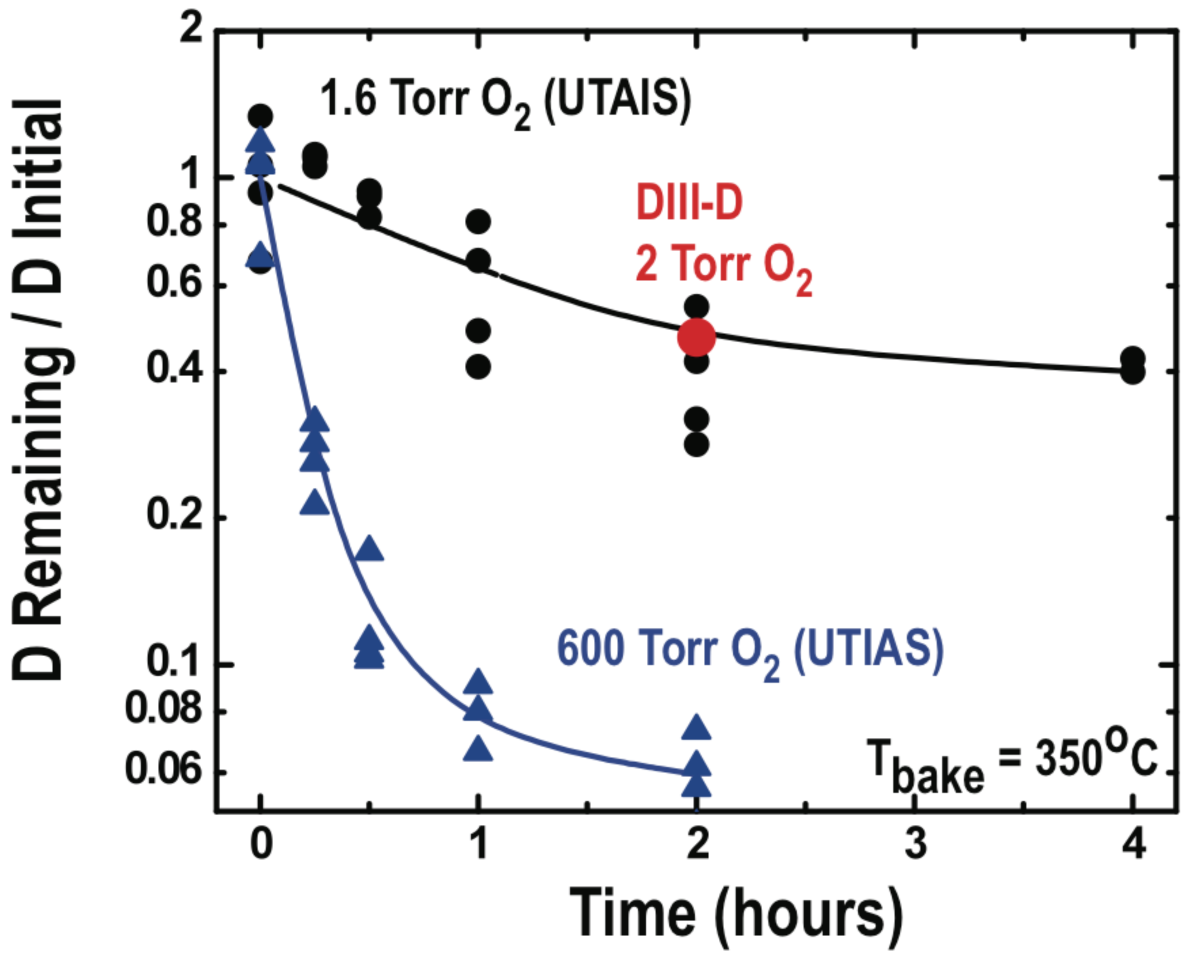
DIII-D "Full System" O_2 Bake Matches with Side Lab Test

- **Complete thermo-oxidation experiments at U. Toronto**
  - Used sample DIII-D tiles
- **DIII-D successfully tested method**
  - Full system: cryopumps, RF antenna, etc.



DIII-D "Full System" O_2 Bake Matches with Side Lab Test

- **More aggressive bake removes more D**



See C. Chrobak's Poster tomorrow AM, GP9.00062

Conclusions: Fuel Retention Rate is Phase Dependent and Large Fraction is Recovered by Baking

- **Level of saturable fuel measured via particle balance**
  - Dynamic balance is accurate method to determine contribution from phases
  - ~20% retention in ramp-up; ~0% in steady-state H-mode

- **Vessel bake recovers majority of injected fuel**
  - ~50/50 fuel removal from divertor pumping & bake
  - ~7%-12% total injected fuel 'retained' after bake
  - Potential upper bound on co-deposited D

- **Co-deposit removal via thermo-oxidation wall conditioning**
  - Developed and validated at Univ. Toronto for DIII-D