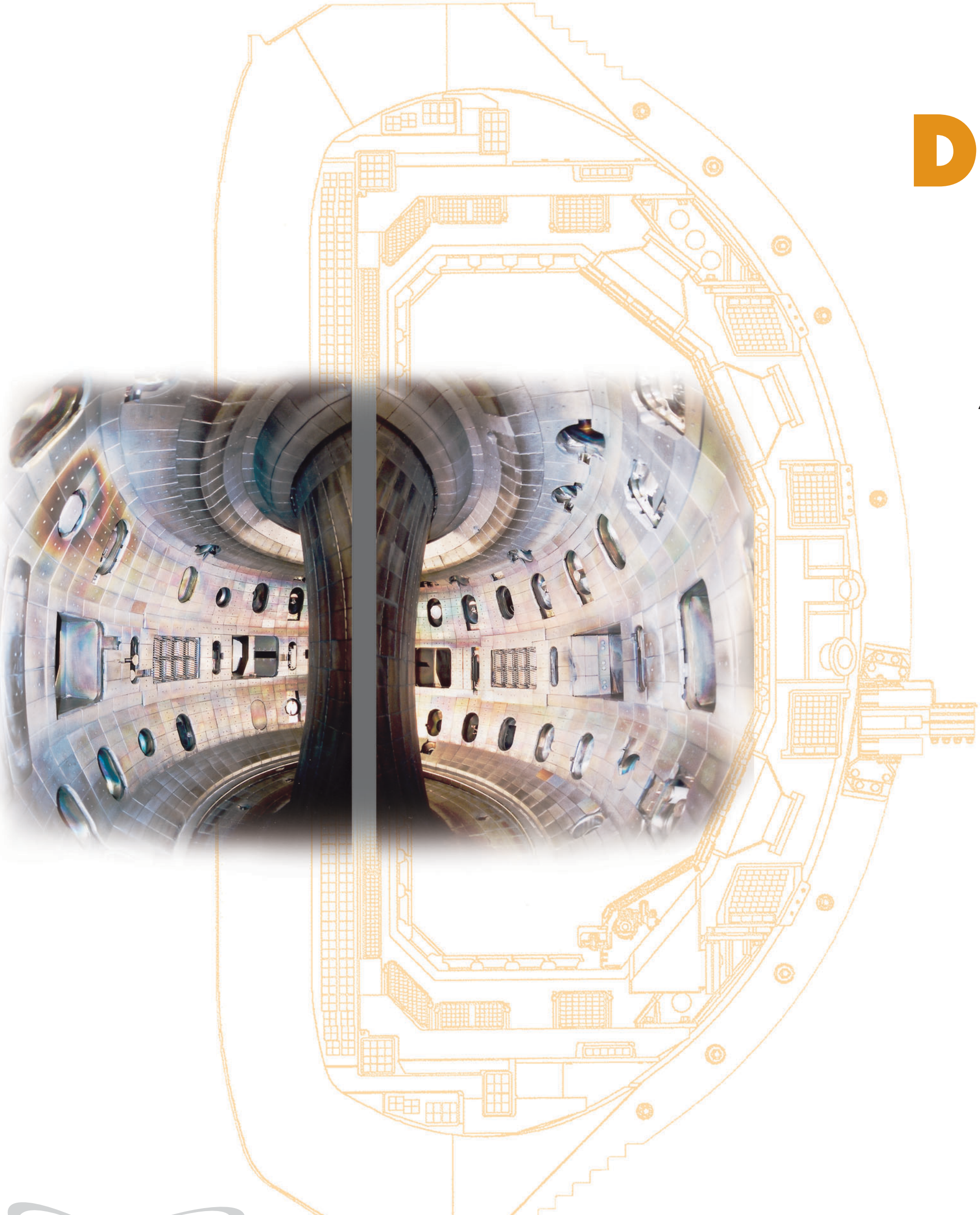
Carbon Transport Studies in the Edge and Divertor of DIII–D



by

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in collaboration with

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DIII–D
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Summary

- Tritium retention in divertor tokamaks appears to be governed by fast parallel flow in the SOL, conveying wall-released carbon to the inner divertor where tritium co-deposits build up, without saturation.

- Extrapolation to ITER indicates that the permitted in-vessel tritium inventory could be reached in a small number of shots.

- Such fast SOL flow - far from the divertor - was unexpected. The experimental evidence for it is still quite limited and a theoretical explanation has not yet been found.

- To better quantify this effect, $^{13}CH_4$ was injected toroidally-symmetrically at the top of lower single null discharges in DIII-D.

- The toroidal symmetry was key, greatly facilitating diagnosis and modeling, while minimizing the disturbance to local plasma conditions.

Summary (Cont'd)

- The CII and CIII emissions were recorded by toroidally-viewing cameras. The 2D reconstructed camera images provided direct, qualitative visual evidence of fast SOL flow toward the inside.

- Quantitative interpretation of 4 different measurements, using OEDGE code-modeling, each indicated $M_{||SOL} \sim 0.4$:

1. **The most direct indication was the poloidal distributions of the CII and CIII 'clouds', and particularly their relative shift.**
2. **Also direct: the CIII poloidal distribution measured by the absolutely-calibrated, poloidal-array filterscopes.**
3. **Less direct: the injection-induced increment to the core C-ion content, as measured by CER spectroscopy.**
4. **Less direct: the deposition pattern of ^{13}C measured in the inner divertor.**

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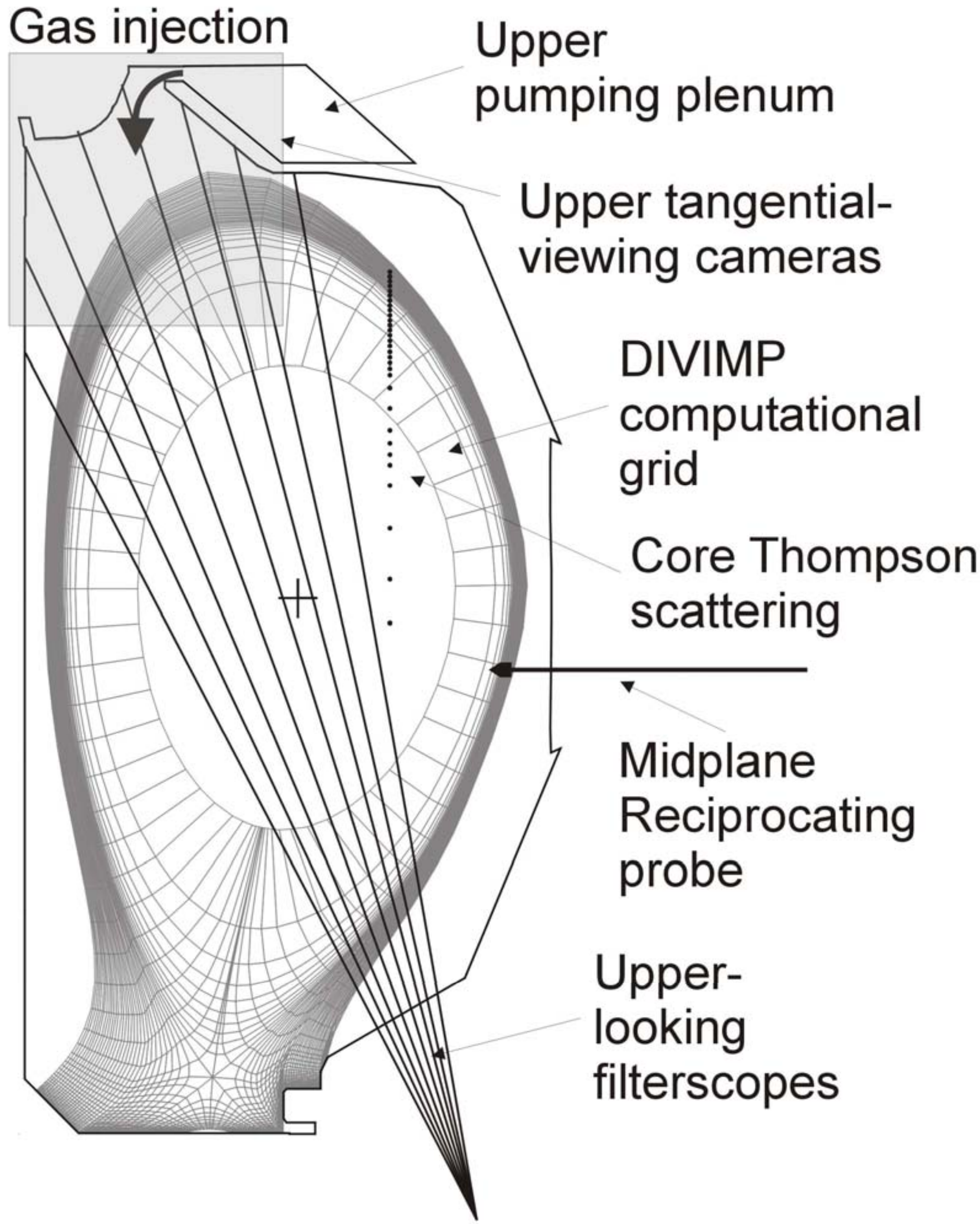
- $^{13}CH_4$ injected into the vessel via the toroidally-symmetrical cryo pumping plenum at top (pumps off).

- Injection region (shaded) observed by tangential-viewing camera (CII, CIII) and poloidal array of absolutely-calibrated filterscopes (CIII).

- **Toroidal symmetry necessary for both measurements.**

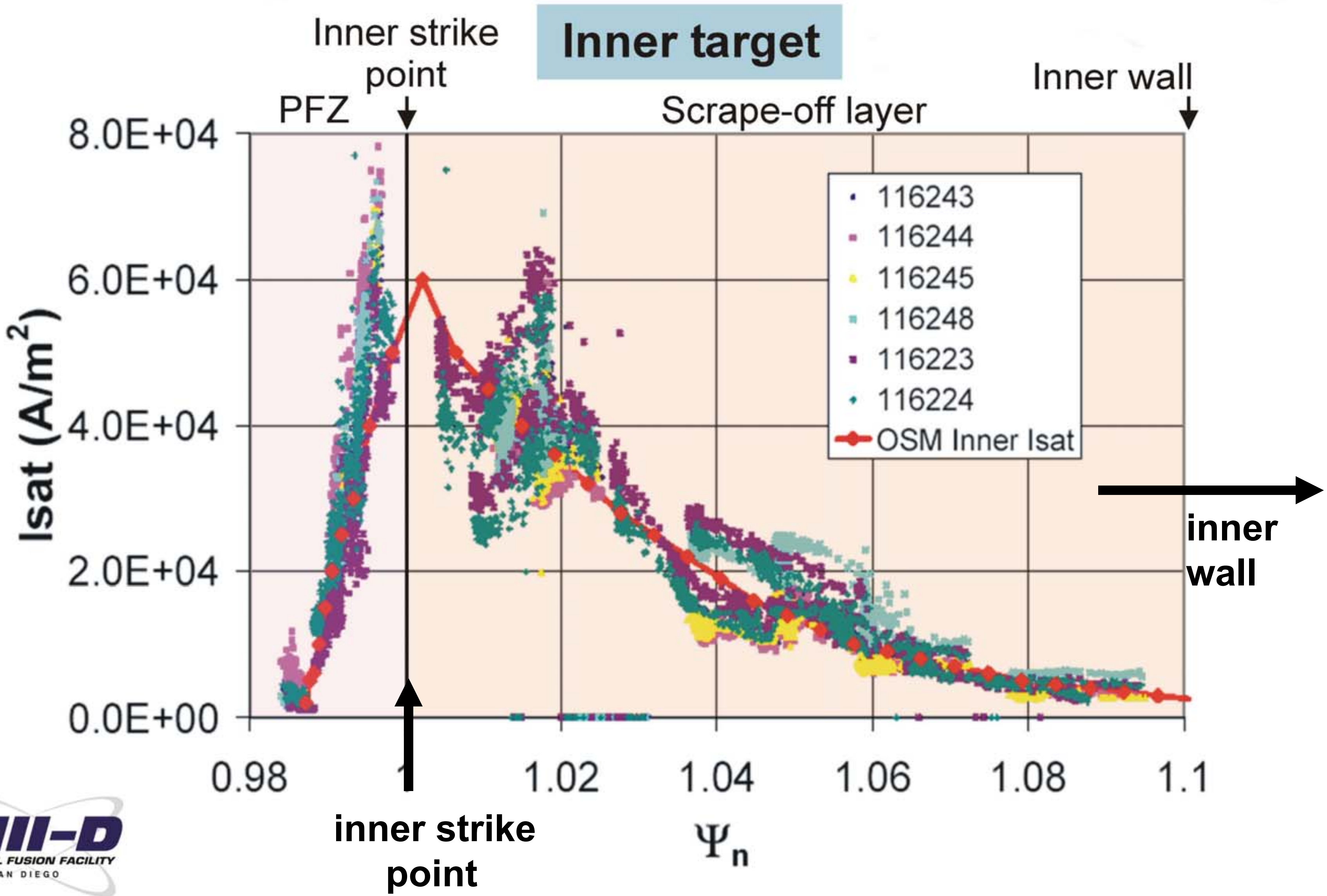


DIII-D

OEDGE Interpretive Edge Code

- OEDGE = Onion-Skin Modeling (OSM) + EIRENE + DIVIMP for edge analysis
- Monte Carlo, MC, codes are used to make most of the comparisons with experimental data.
- EIRENE is a neutral hydrogen MC code.
- DIVIMP is an impurity neutral & ion MC sputtering & transport code that includes methane-breakup kinetics.
- The MC codes require a “plasma background” into which to launch particles – provided by OSM.
- OSM: a *semi-empirical* approach to 2D edge modeling. As much as possible, experimental data is used as input.

Probe I_{sat} Profile and Fit Used as Boundary Condition for OSM Modeling



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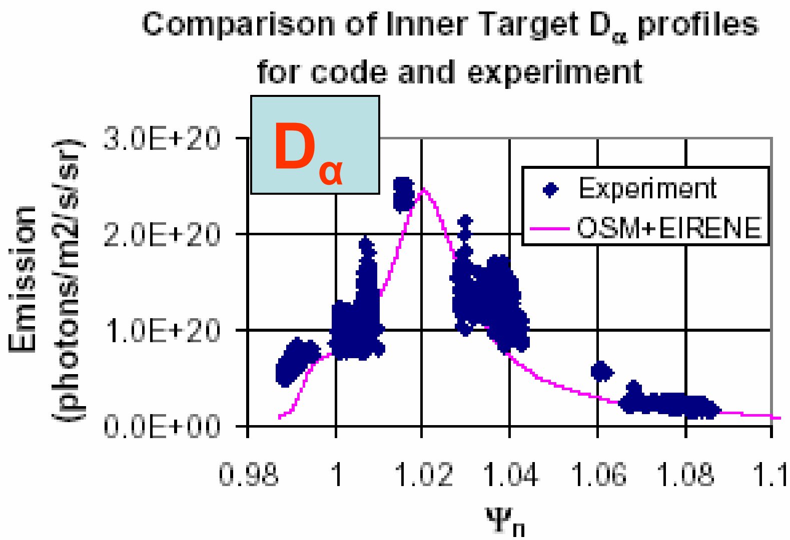
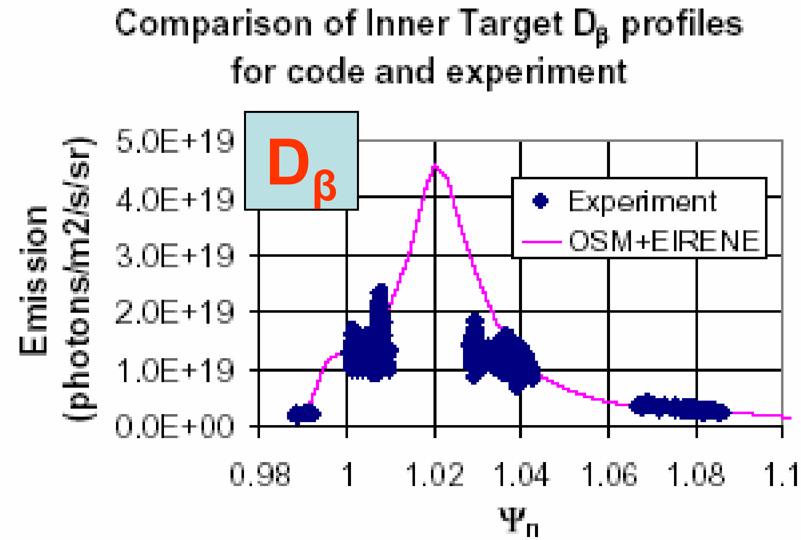
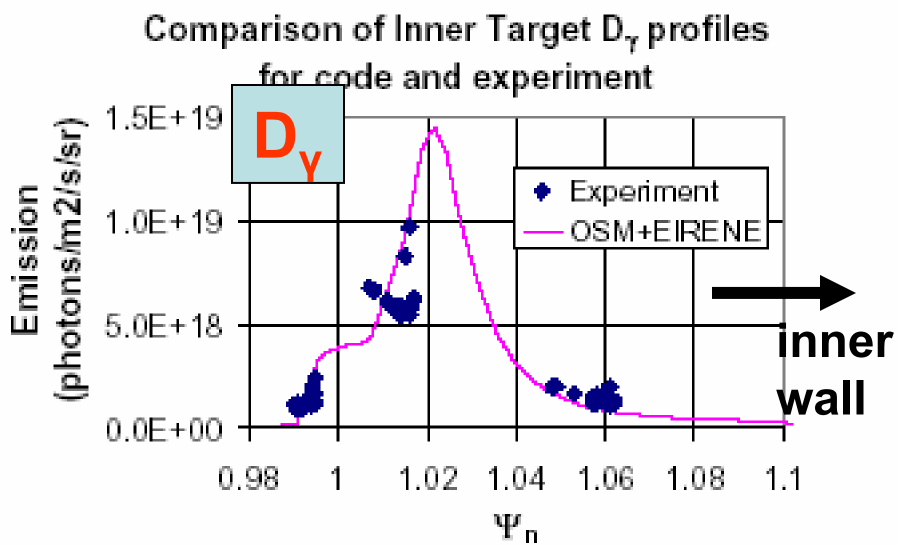
Comparison of Hydrogenic Spectra

matching D_α, D_β, D_γ, identifies T_e at inner target quite precisely

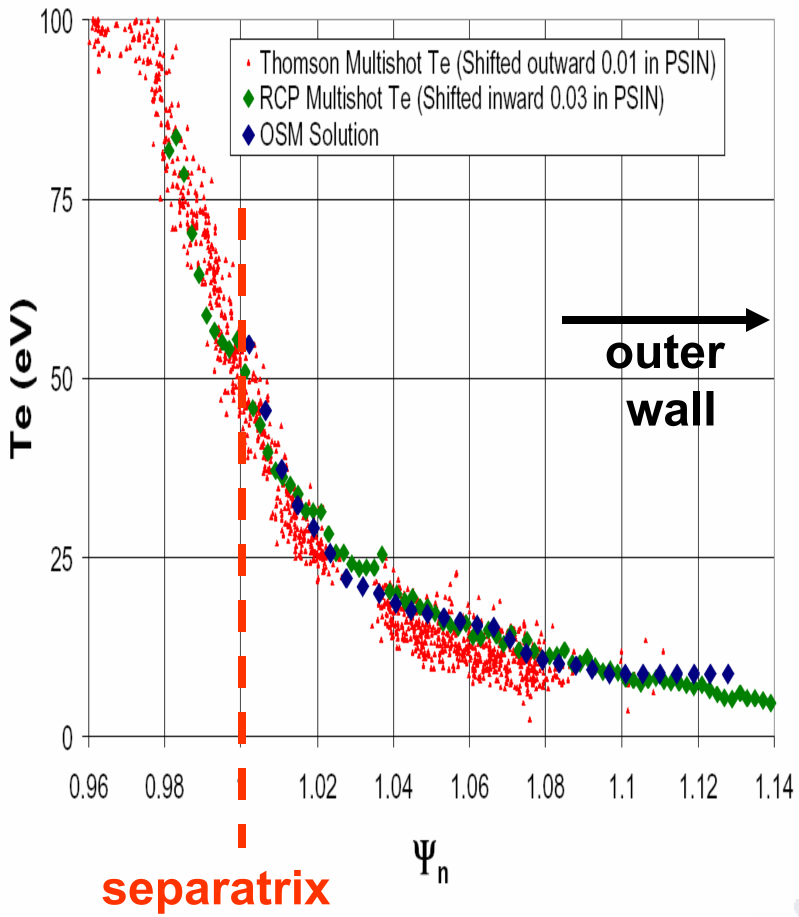


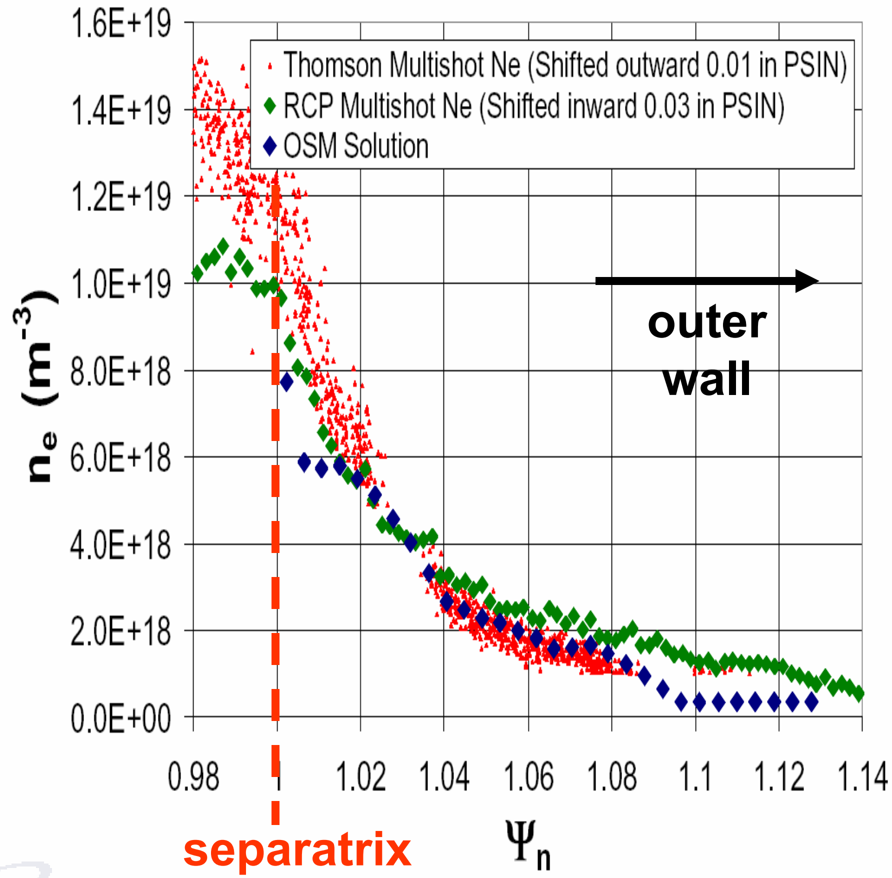




- Agreement with code calculated D_α, D_β and D_γ is good although more complete data would more fully constrain the OSM solution.

OSM solution using outer target probe data as input, matches well the n_e and T_e profiles measured in the outer main SOL by reciprocating probe, RCP, and Thomson – although requiring small shifts in separatrix location.





1.

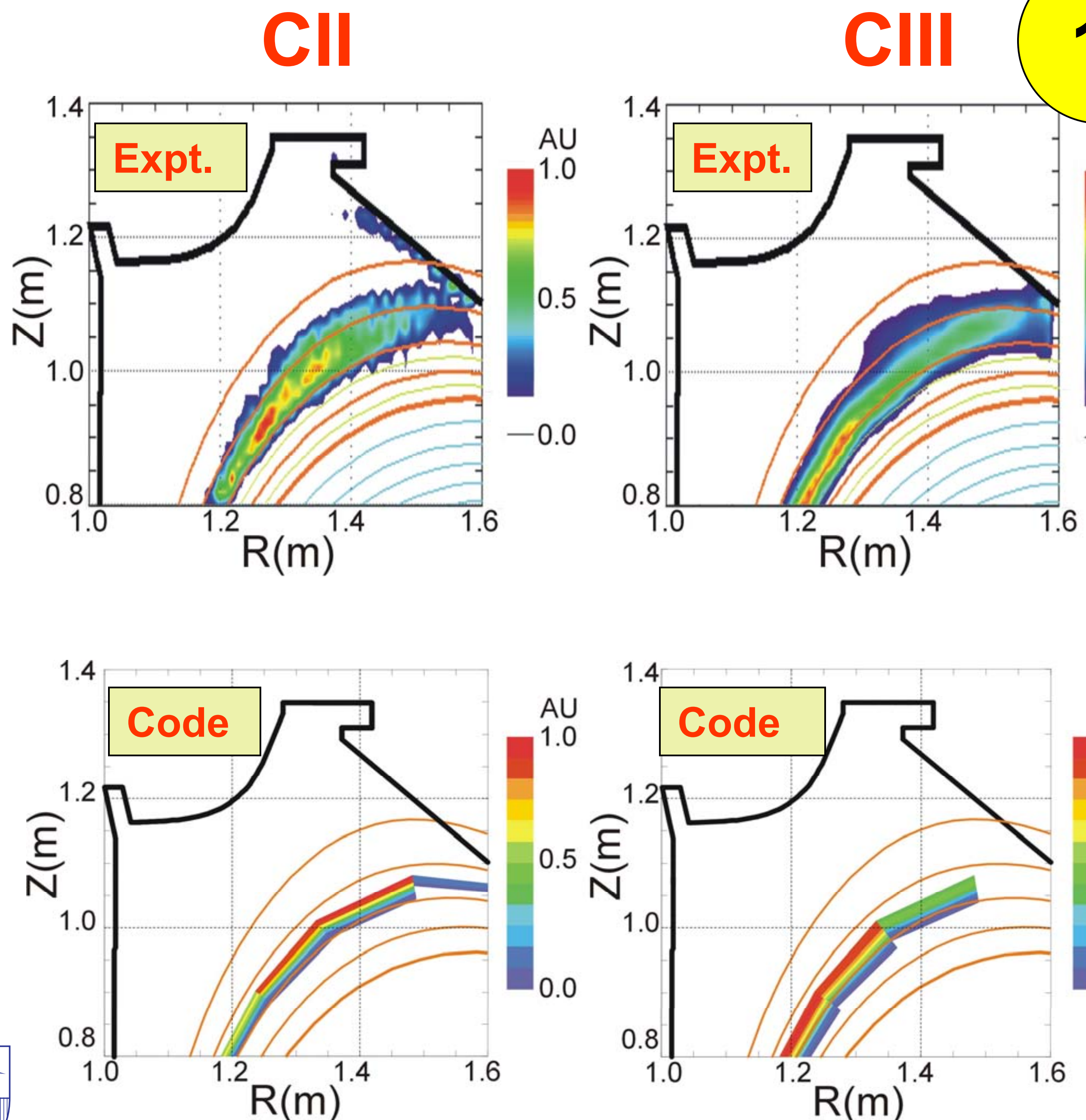
Top

2D reconstruction of CII and CIII images from toroidal-viewing cameras.

Bottom

code results assuming $M_{||} = 0.4$.

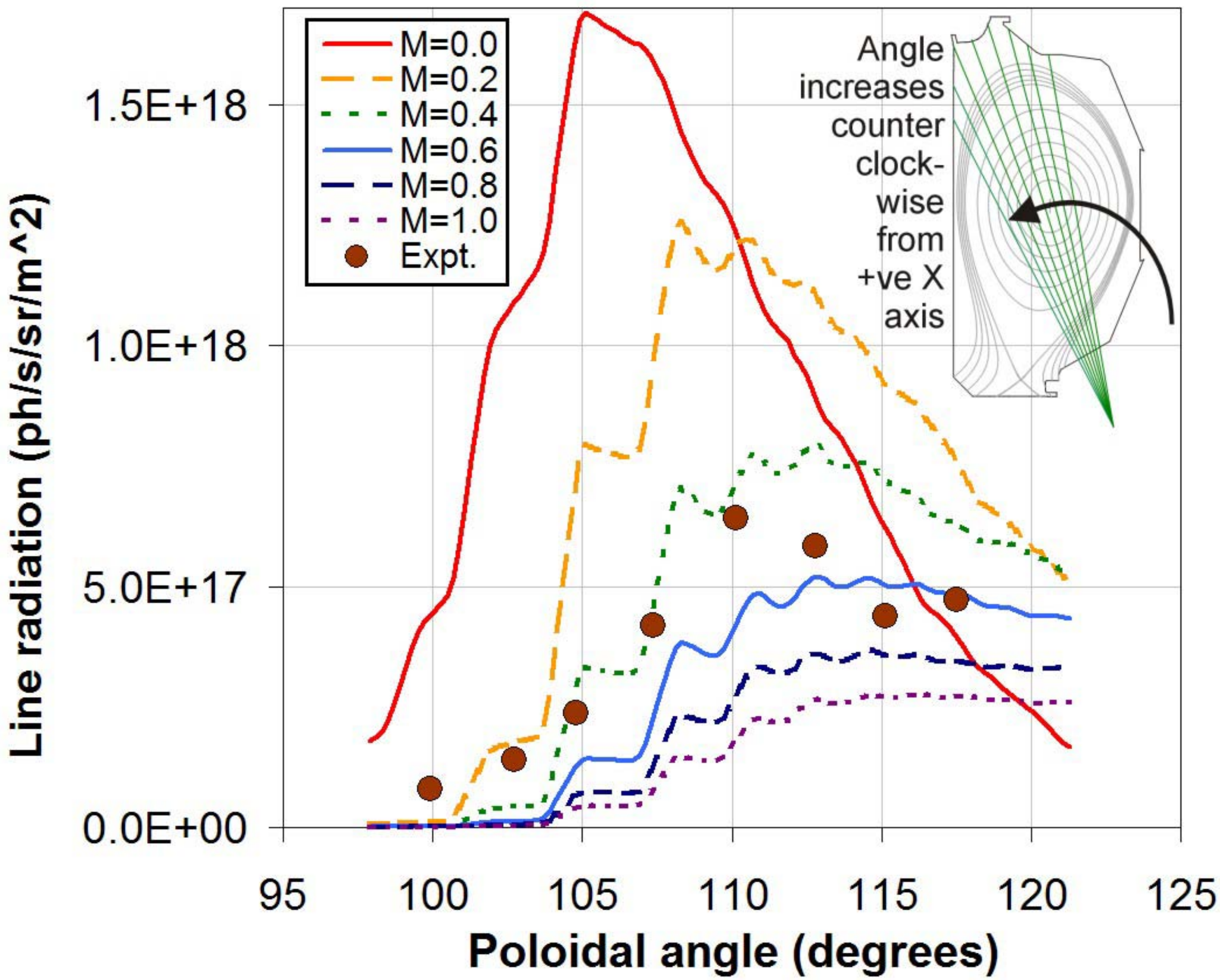
Relative poloidal shift of CIII cf. CII indicates fast transport toward inside.



Comparison of poloidal profile of CIII measured by the upward-looking filterscope - absolutely calibrated - compared with code results assuming various parallel $M_{||}$.

Poloidal profile of absolutely calibrated CIII (465 nm) emissivity

2.



$M_{||}$ ~ 0.4 - 0.6 indicated.

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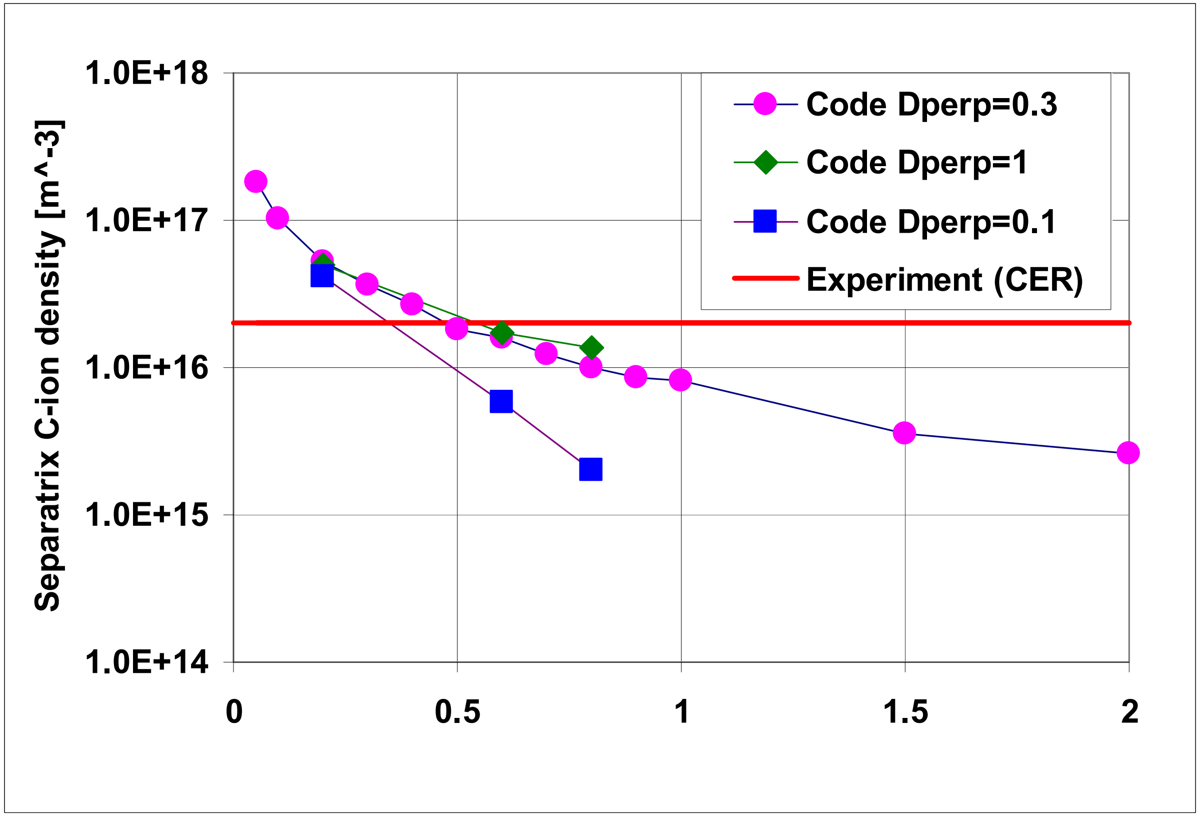
Faster SOL flow makes divertor sink-action stronger, reducing C-ion density in core

3.

The increment to the calculated C-ion density in the confined plasma is quite sensitive to the assumed value of $M_{||SOL}$ – and more than to D_{perp}.

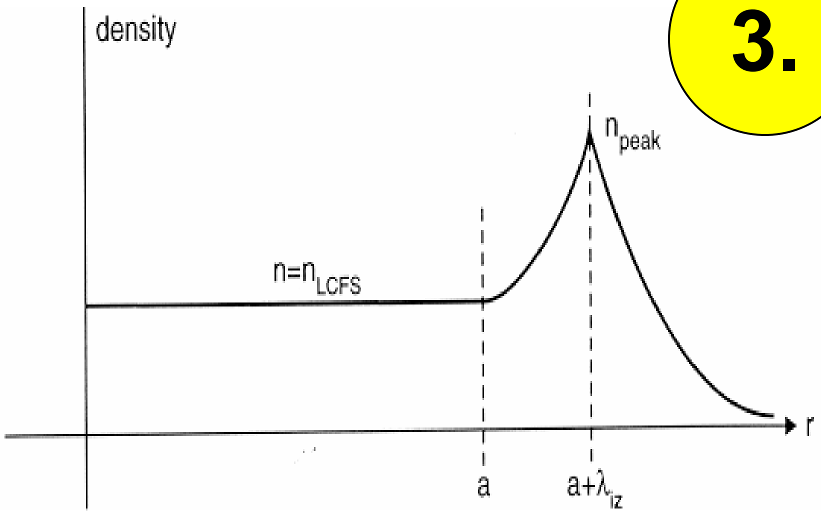
$M_{||}$ ~ 0.5 indicated

Increment in C-ion separatrix density



3.

The Engelhardt Model (1978) explains these trends



$$n_{sep} = \frac{\Gamma_{\perp}^{neutral} \lambda_n^{SOL}}{D_{\perp}} \exp(-\lambda_{iz} / \lambda_n^{SOL})$$

where $\lambda_n^{SOL} = \left(\tau_{\|} D_{\perp}\right)^{1/2}$ and $\tau_{\|} = L / v_{\|}$

thus $n_{sep} \propto v_{\|}^{-1/2} \exp(-v_{\|}^{1/2})$ 2 $v_{\|}$-terms re-enforcing

while $n_{sep} \propto D_{\perp}^{-1/2} \exp(-D_{\perp}^{-1/2})$ 2 D-terms off-setting

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Surprisingly, the 13C-deposition pattern on the inner target – both **shape and magnitude** – is a fairly sensitive indicator of $M_{||SOL}$

4.

….this despite:

(a) large distance between ^{13}C source and sink

(b) poorly known/understood plasma conditions in (detached) inner divertor

(c) unknown role of other forces on C-ions

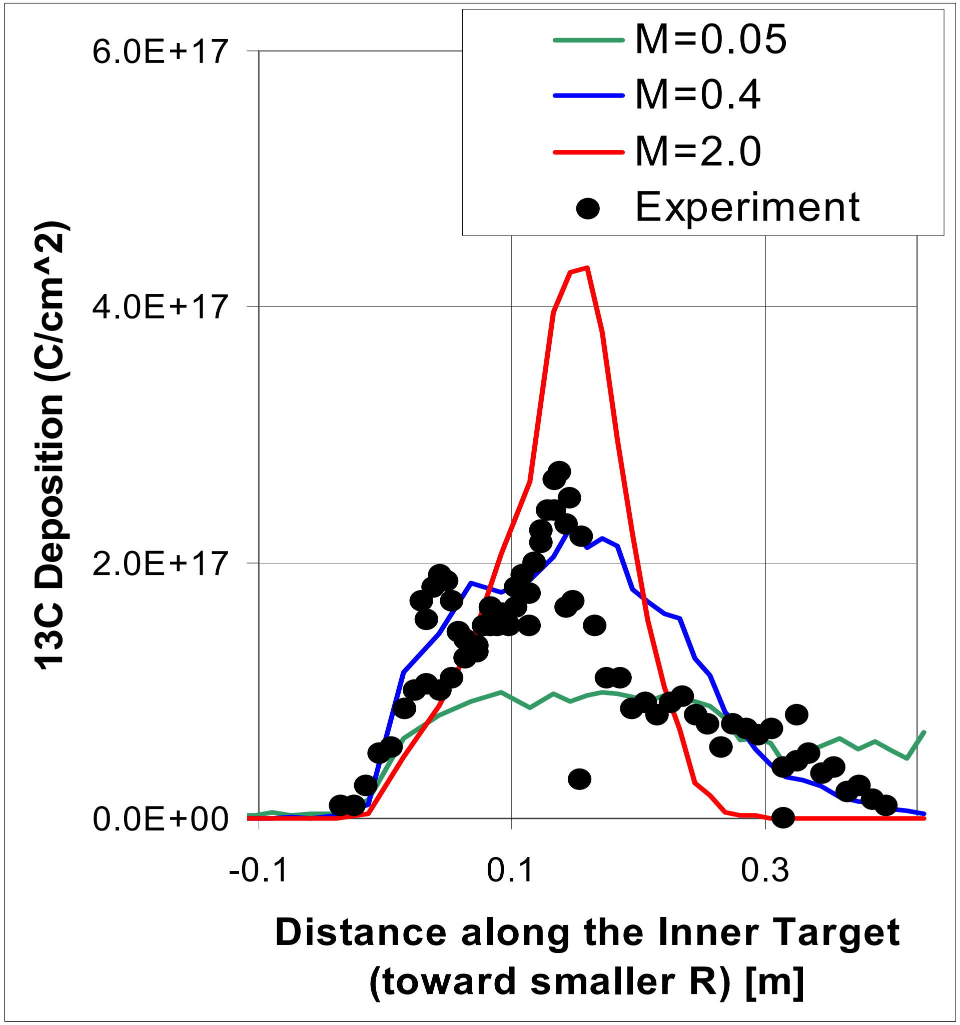
(d) re-distribution of ^{13}C-deposits by ongoing PSI at inner target

(e) assumption of constant $M_{||}$

- Re-distribution of deposits evidently not significant for low power L-mode used here

$M_{||}$ ~ 1/2 indicated.

^{13}C deposition on inner target



Conclusions

- Toroidally-symmetric injection of $^{13}CH_4$ at the top of DIII-D has provided the most direct and quantitative evidence to date for the existence of fast transport of C-ions along the SOL into the inner divertor.
- Only *net* deposition causes non-saturating build-up of tritium co-deposits.
- The observed SOL carbon transfer process is efficient, conveying much of the wall-released C to the inner divertor, causing substantial *net* deposition and rapid, non-saturating build-up of T co-deposits.