Effect of B-field Direction and Core Torque Input on SOL Flows of Carbon Ions and Deuterons in USN Plasmas on DIII-D

by

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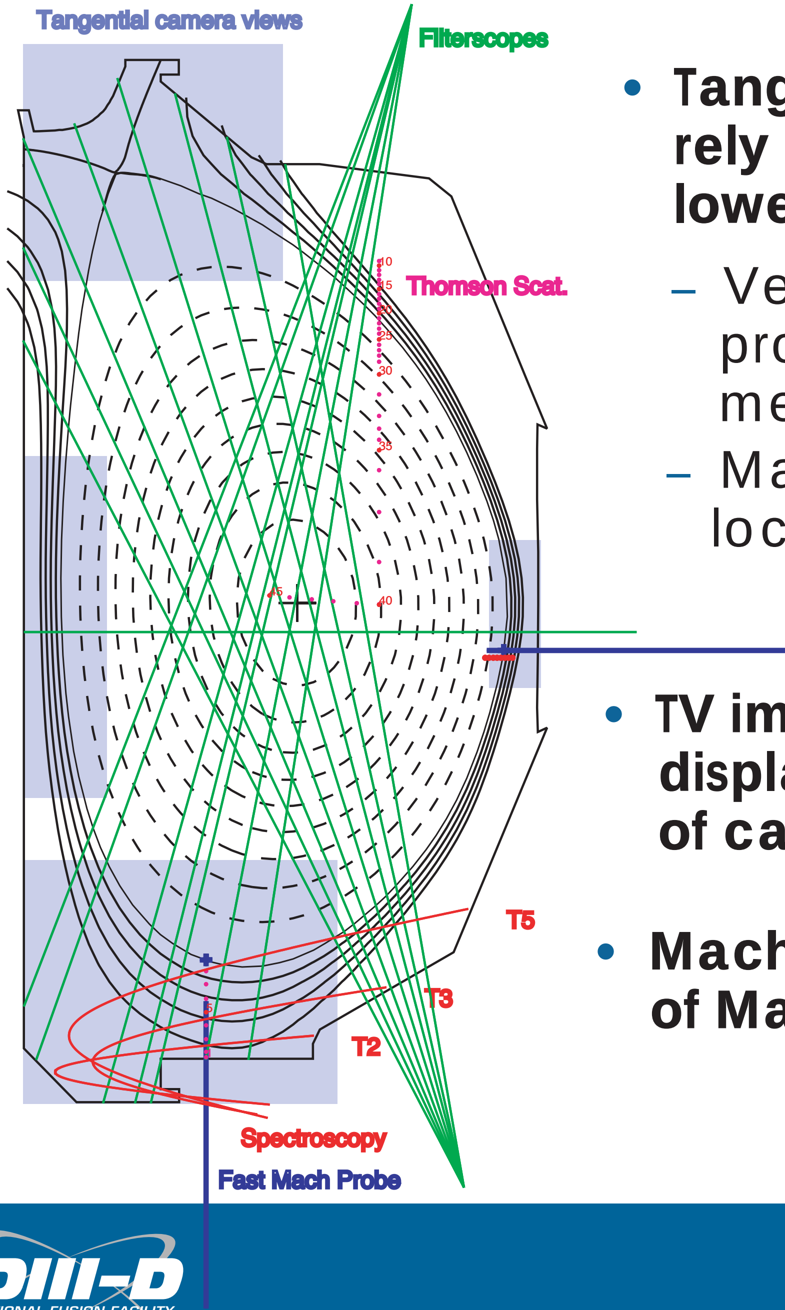
GENERAL ATOMICS

Goal and motivation: test effect on SOL flow of varying three externally controllable parameters

- **B_t direction**
  - **B**x∇B drift into x-point in 2006; out of x-point in 2008
- **Torque input at fixed power**
  - Co (beams), Counter (beams), none (ECH)
  - Switch from Co to Cnt on successive shots; reverse midway through shot
- **∇p in SOL, between outer midplane and divertor target**
  - Inner leg pumped, versus unpumped

- **Put model of SOL dominance of core rotation to experimental test**
- **Caveat: Are SOLs in DIII-D and C-Mod in similar regime?**
  - plasma collisionality
  - influence of bursty transport

Tangential spectroscopy, TV imaging and scanning Mach probe permit independent measurements of SOL flow in crown of USN plasma



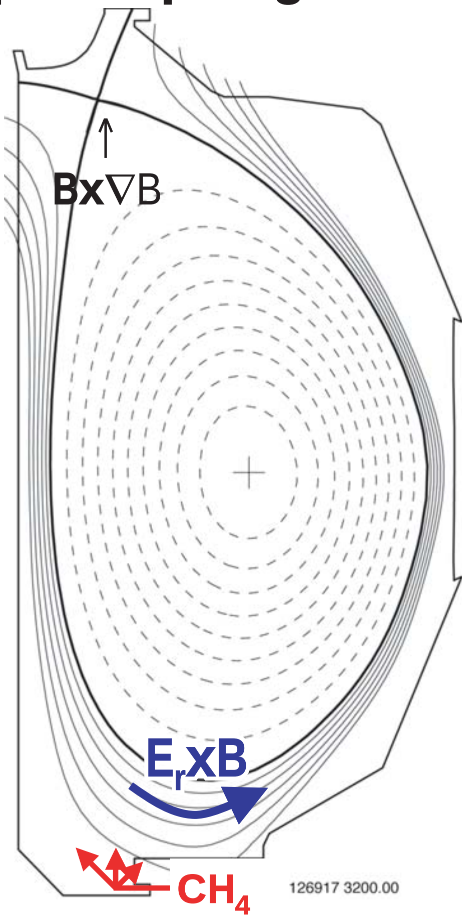
- **Tangential views of high-resolution spectrometer rely on in-vessel telescopes mounted under lower "divertor" shelf**
  - Vertical chords through plasma crown provide wavelength fiducial for measuring Doppler shift
  - Magnetic splitting of spectral lines permits localization of emssion along chordal path

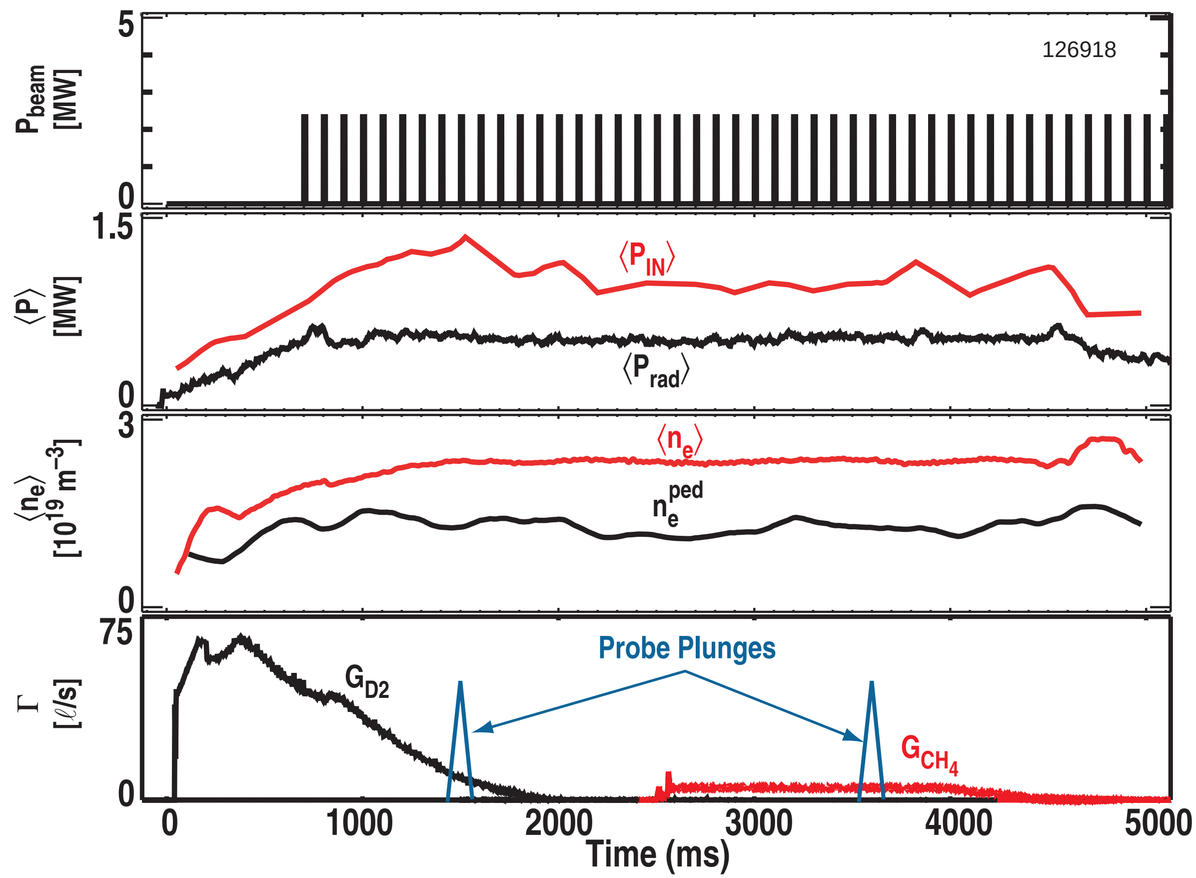
- **TV imaging of puffed methane show poloidal displacement in burnthrough charge states of carbon**

- **Mach probes in floor and midplane provide scans of Mach no. and plasma parameters**

Compare SOL flow in low-density, L-mode plasmas with ion B×∇B drift into, and out of X-point

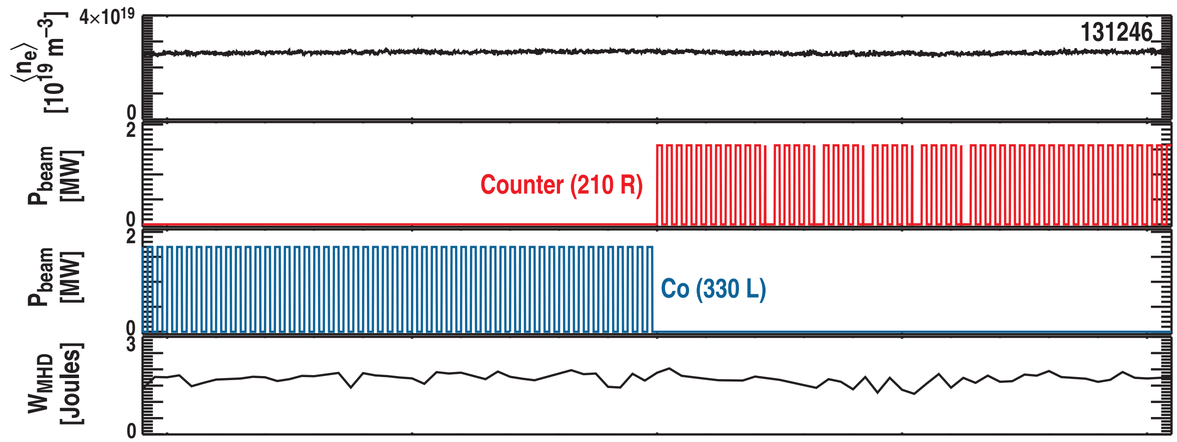
- **$\langle n_e \rangle \sim 2.5 \times 10^{19}\ m^{-3}$ => $n/n_{GW} \sim 25\%$; $f_{rad} \sim 65\%$**
  - B_t = 2 T forward & reverse; I_p = 1.1 MA
- **probe plunge 2x/shot; spectroscopy throughout**



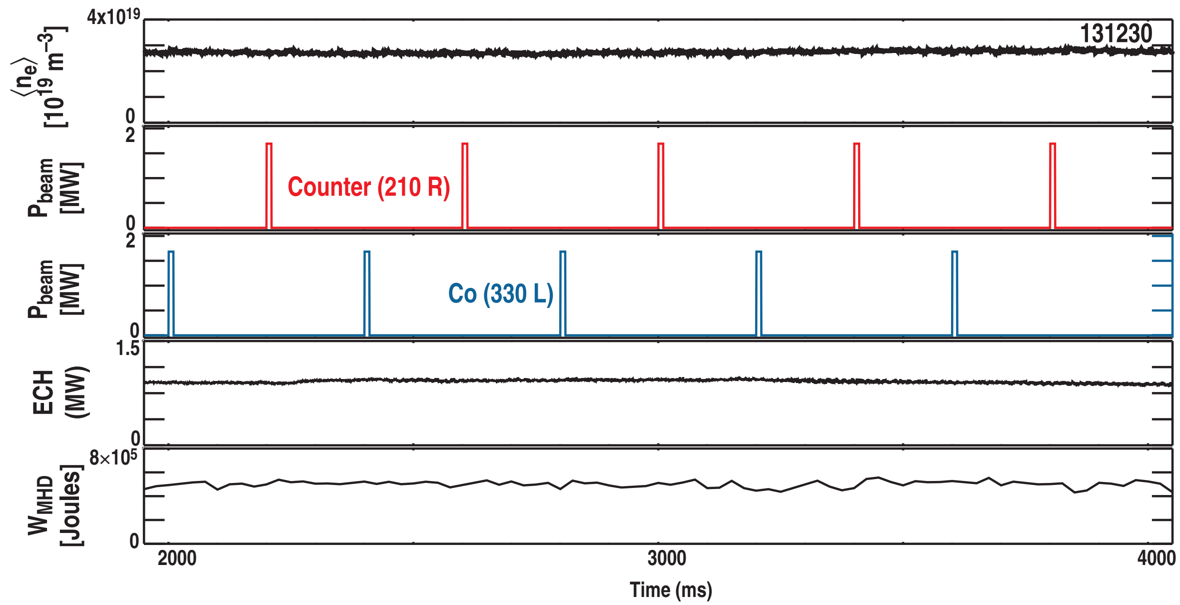


Torque Input Varied at Fixed Power with Bx∇B ↓ Co (beam), Counter (beam), None (ECH)

- **Beam modulated for CXRS measurement**
  – Torque changed within shot and shot to shot



- **During shots with ECH, beam blips alternated to cancel torque input**



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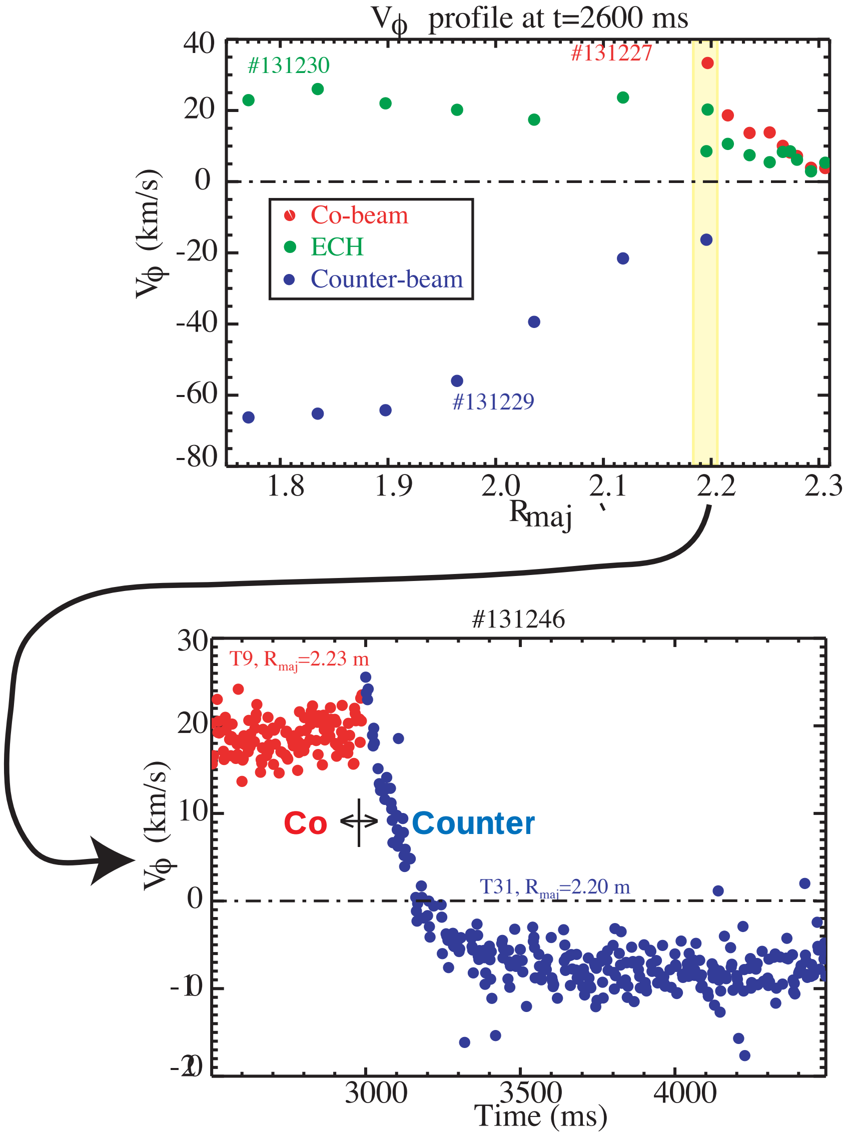
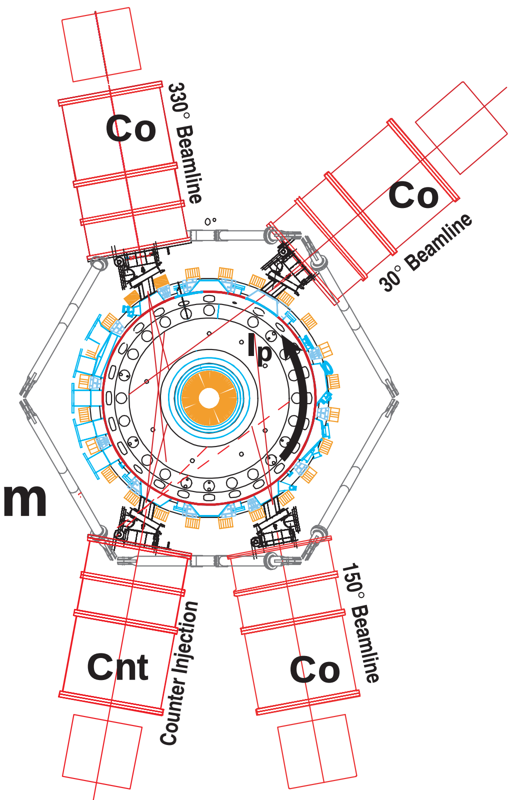
V_ϕ profile of C^{6+} ions, measured with CXRS, shows response of plasma core to external torque input



- V_ϕ **profiles shown for three shots with different torque inputs at fixed power**
  - Case with ECH has an intrinsic rotation in Co direction
- V_ϕ **tends toward zero on chords near LCFS (2.28m)**
- **Rotation reverses when counter beam substituted for Co**



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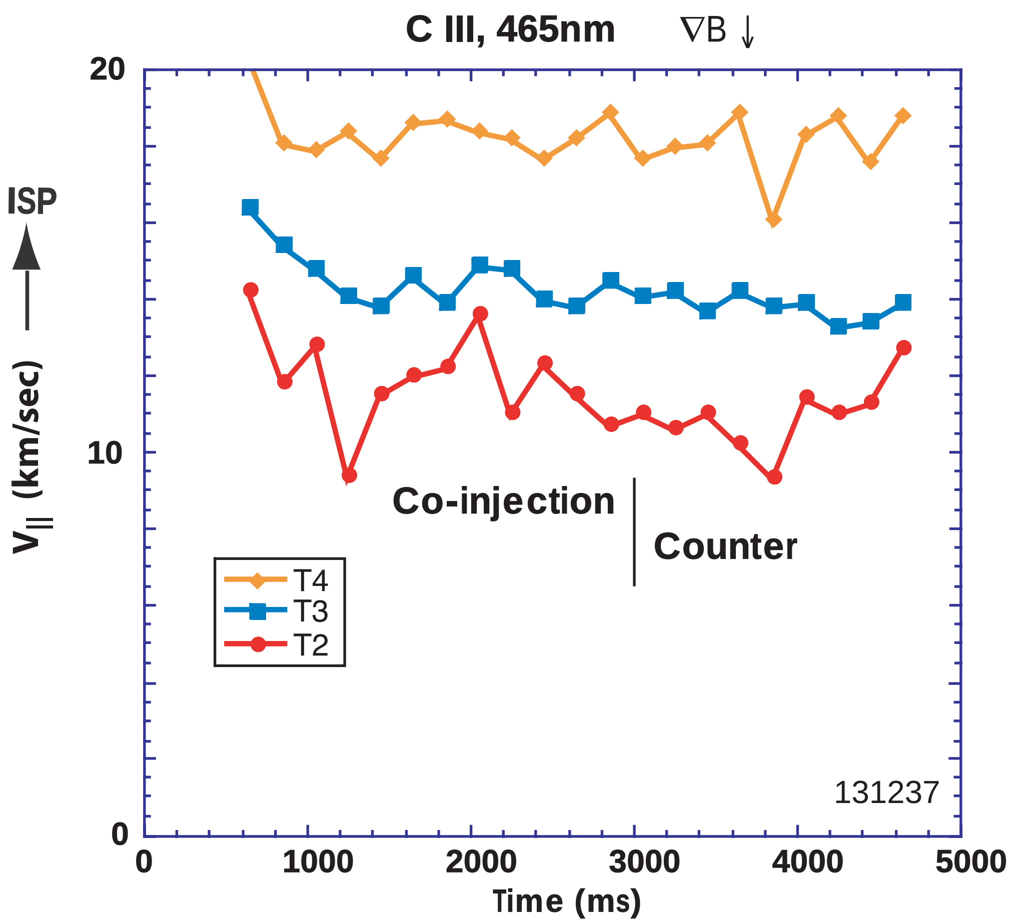
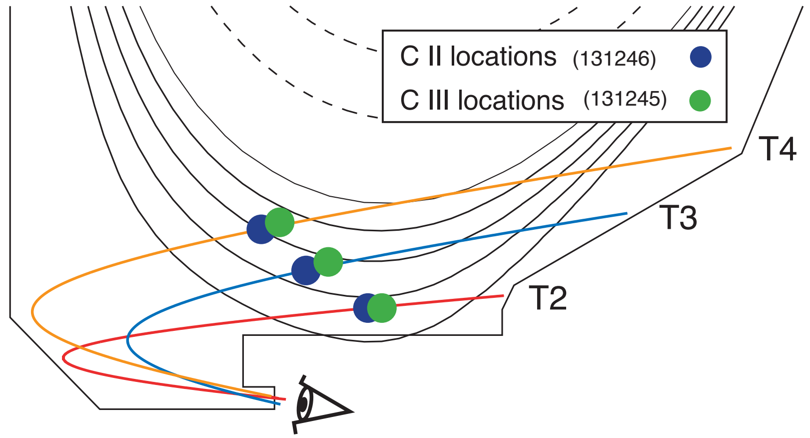
Carbon flow along B_{tot} shows no change with beam direction; speed increases with proximity to LCFS

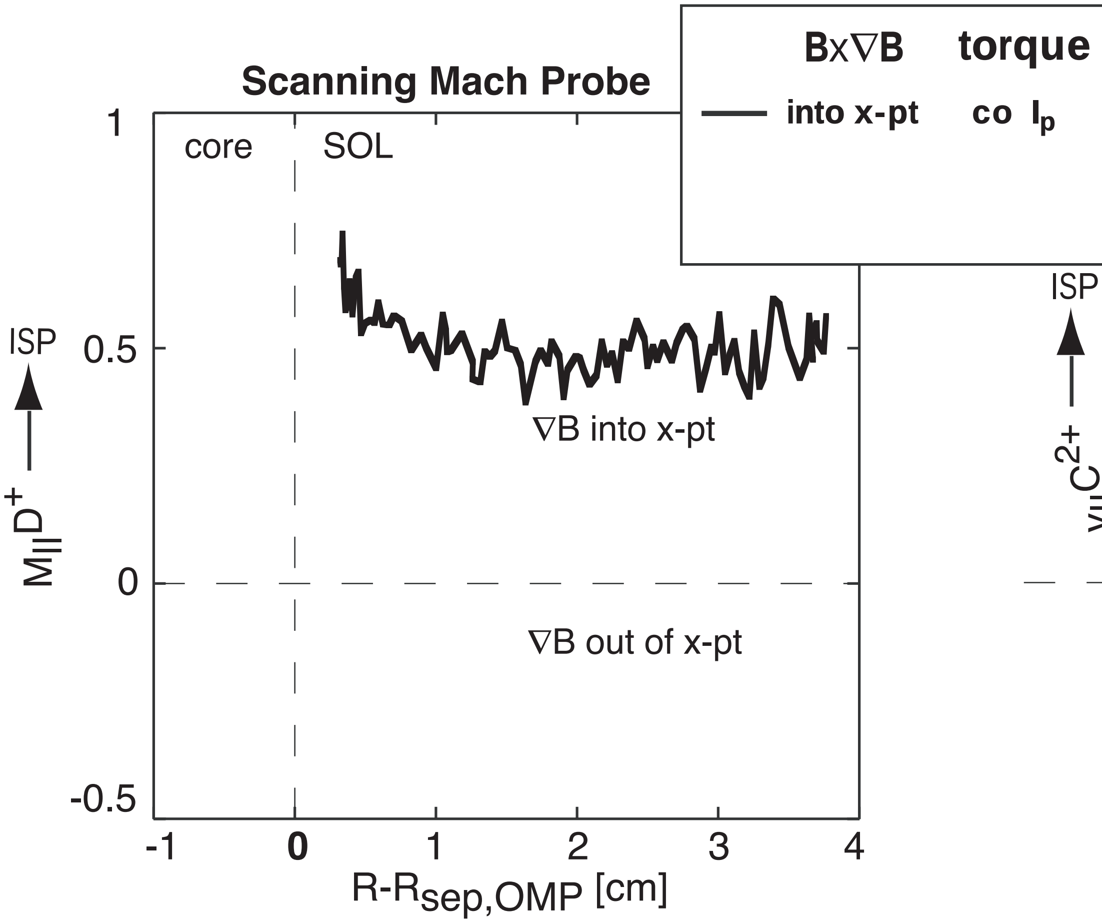


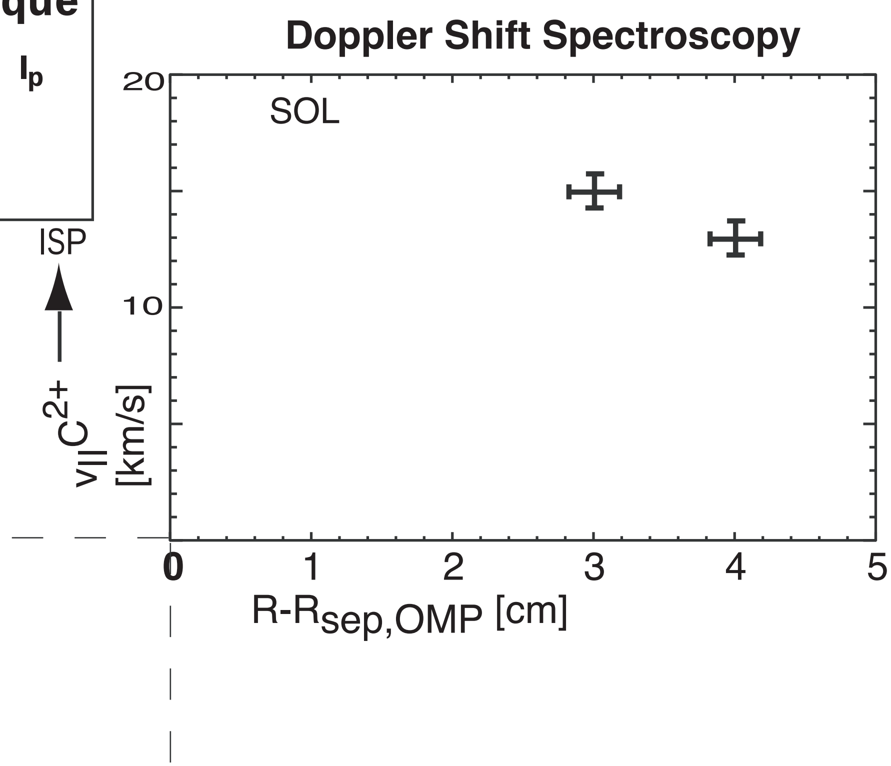
- C III velocities are higher than CII (not plotted here)
- Approximate locations (below) deduced from magnetic splitting



SOL Profiles of D+ Mach Number and C++ Velocity

- D+ and C++ flows agree, consistent with entrainment of C ions in streaming plasma





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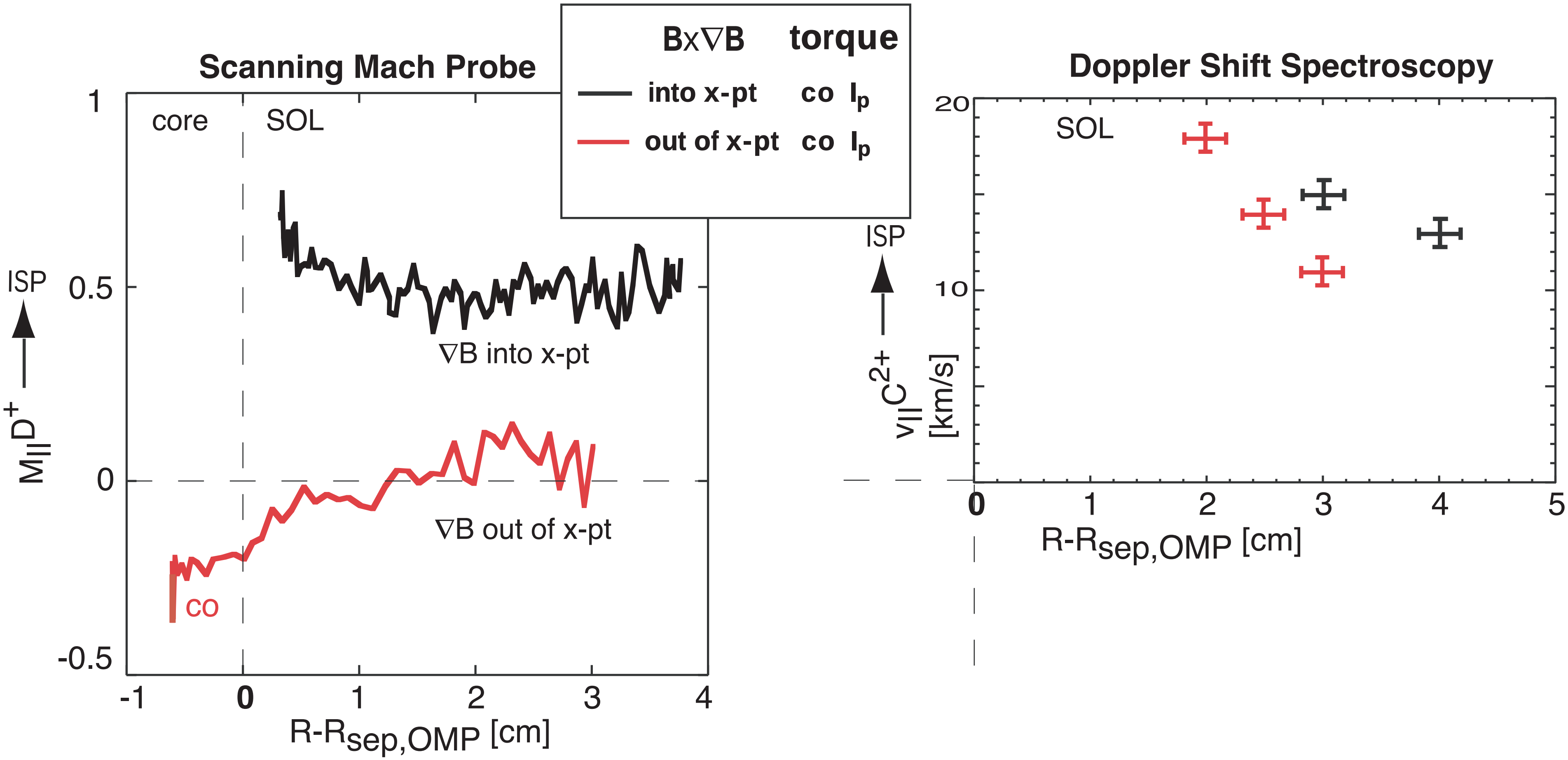
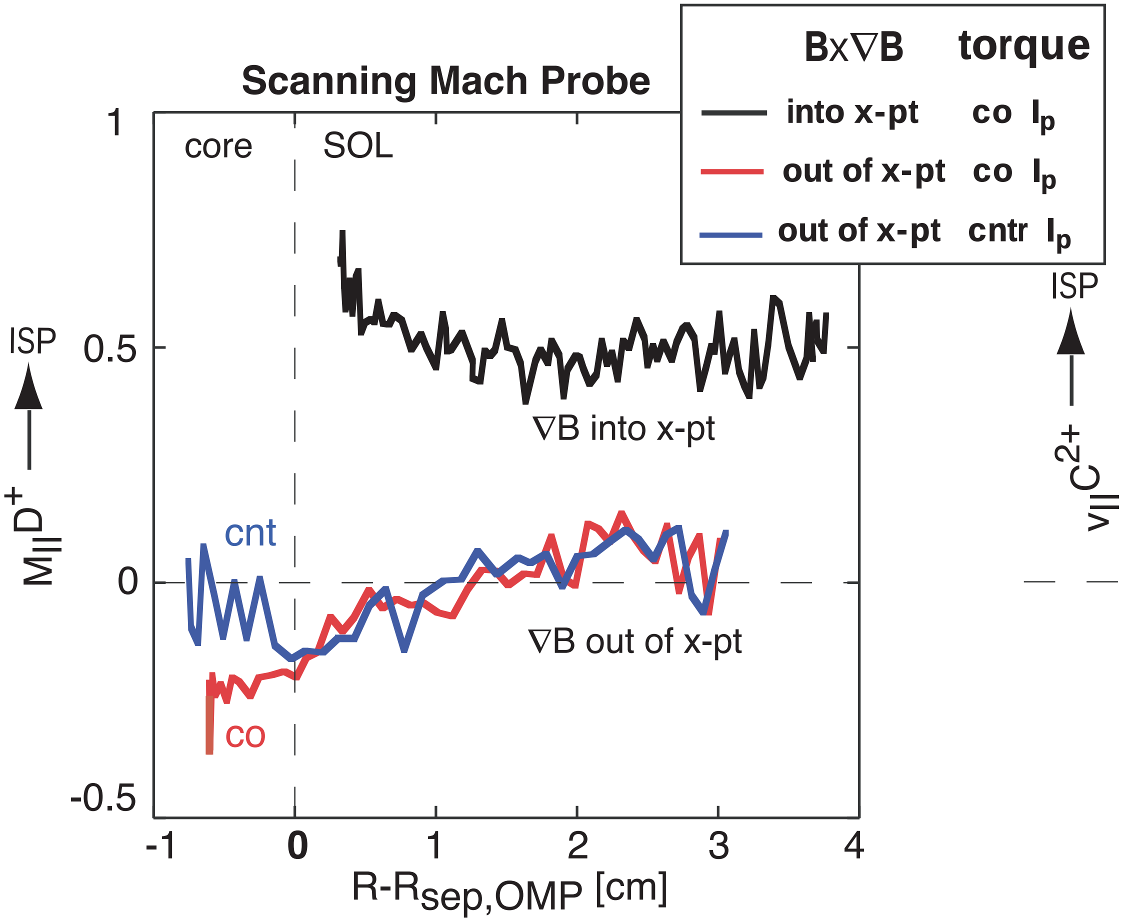
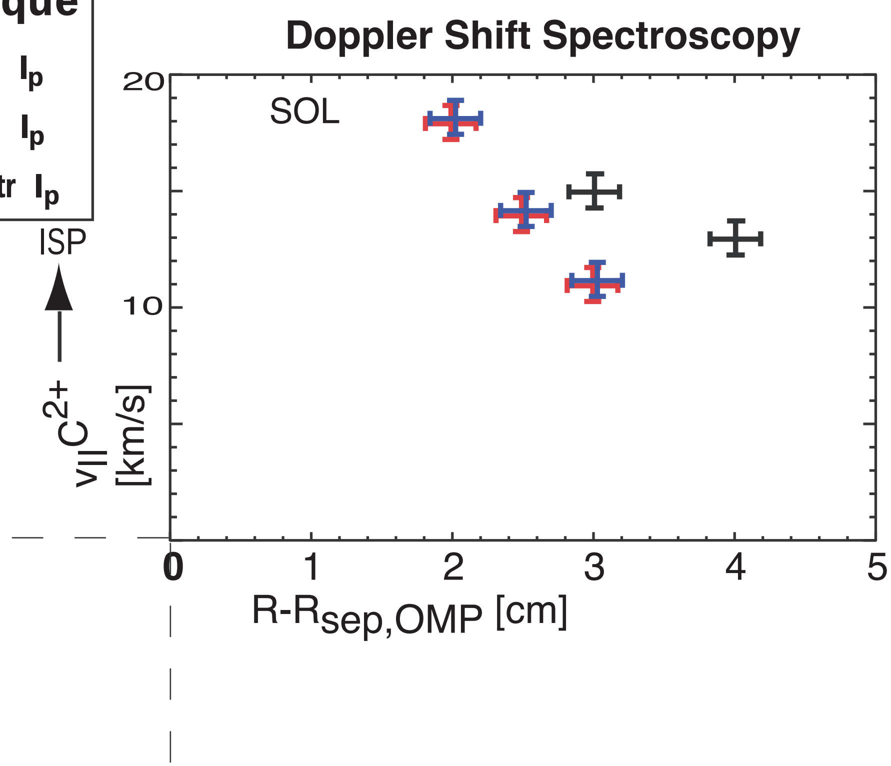
- D+ shows strong dependence on B×∇B direction, but C++ unchanged



SOL Profiles of D+ Mach Number and C++ Velocity

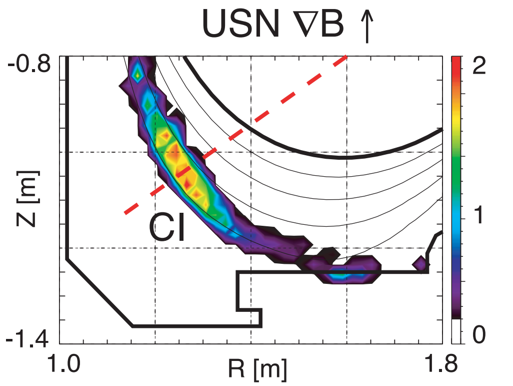
- D+ and C++ flows agree, consistent with entrainment of C ions in streaming plasma
- D+ shows strong dependence on B×∇B direction, but C++ unchanged
- In far SOL, neither D+ nor C++ respond to reversal of beam torque

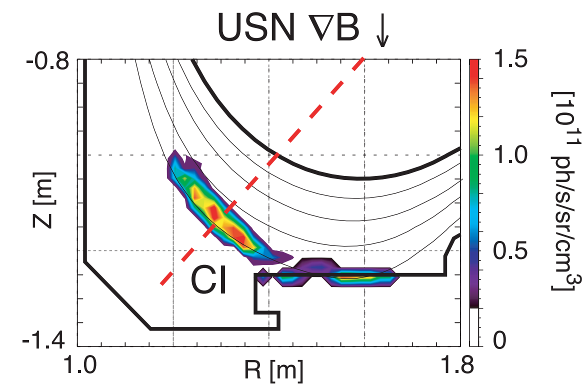


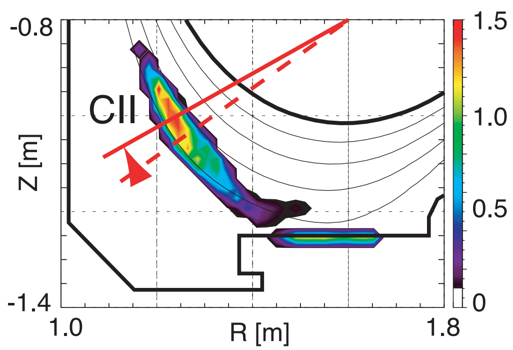


Poloidal shift in burnthrough clouds of methane-sourced carbon is 3x greater with $\nabla B \downarrow$ than with $\nabla B \uparrow$

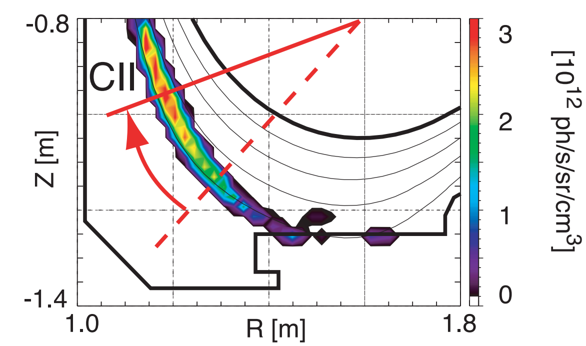
- **Centroid of C II 515nm emission profile displaced CW relative to C I 910**
  - Poloidal shift can arise from flow || B and poloidal drifts
  - Excess shift in $\nabla B \downarrow$ case in direction of E_rxB





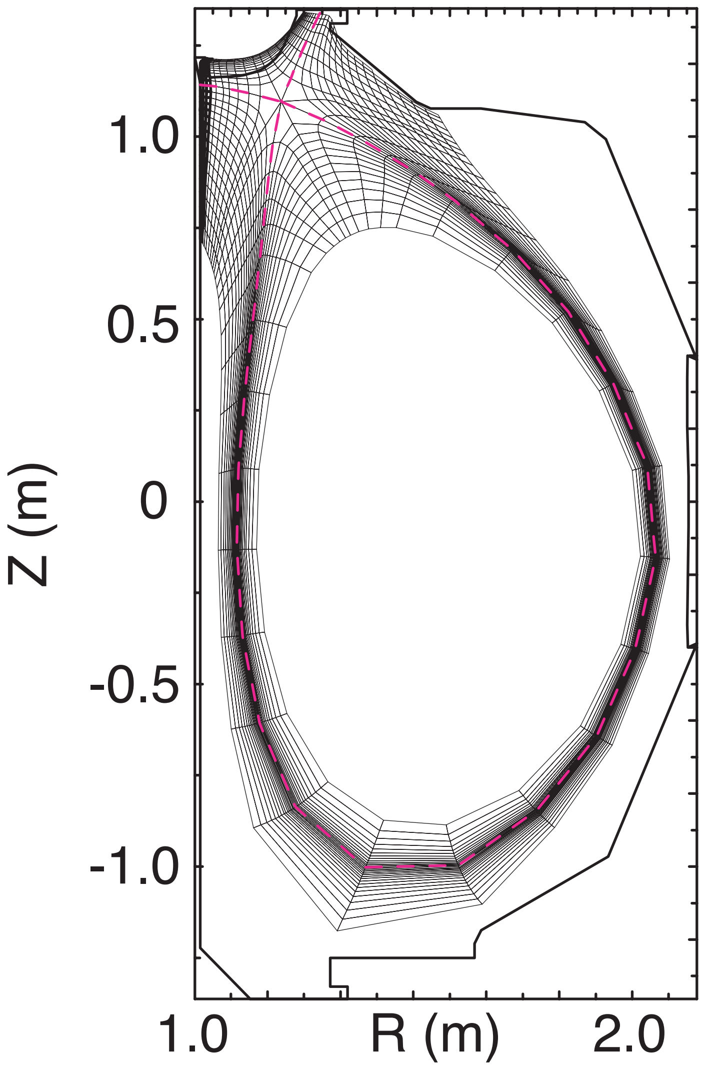


(However, in far SOL, UEDGE fluid modeling predicts only a small E_rxB drift)



Scrape-off layer modeling with the edge-fluid code UEDGE, including cross-field drifts $_B$ $B \times \nabla B \downarrow$ case only

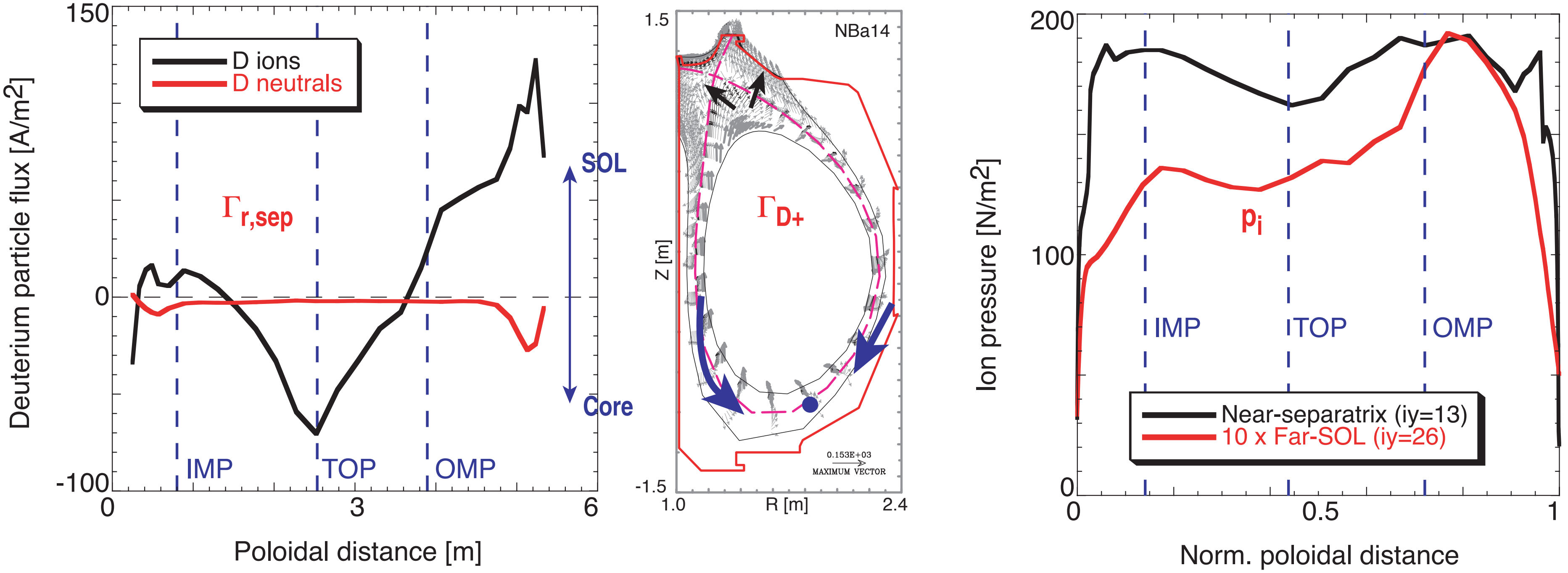
48x28 cells: $0.9 \leq \Psi_N \leq 1.09$



- **UEDGE fluid code with 'fluid' D neutrals**
- **Parallel transport modeled using Bragiinski equations and kinetic 'corrections' (flux limits)**
- **Cross-field particle drifts due to ExB and $B \times \nabla B$**
- **UEDGE base case:**
  - Radial transport diffusive, adjusted to match core Thomson n_e and T_e, and outer midplane T_i:

    $\Rightarrow$ Radially varying $D_\perp$, poloidally constant χ_e, χ_i
  - Ions fully recycle at plate and walls
  - Neutral pumping at plate = 2%, and wall = 5%

Predicted poloidal deuteron flow is mainly driven by the pressure imbalance between the X-point and the crown



- **Ion Bx∇B drift produces core inflow at the crown, outflow at the X-point region**

  ⇒ SOL poloidal flow becomes stagnant near crown just outside LCFS

- **E_rxB flow contribution insignificant in far SOL**
- **APS06: as inner divertor detaches, plasma pressure below inner midplane increase ⇒ entire SOL becomes stagnant at the crown**

Summary

- **Externally controllable parameters varied and SOL flow measured**
  - ion ∇B drift direction, torque input, ∇p in SOL

- **SOL flow of D^+ shows strong dependence on Bx**∇B **direction**, **C^{++} does not**
- **With** ∇B ↓ ,**changing core rotation has no discernible effect on SOL flow**
  - ∇p: halving divertor neutral pressure had no effect on SOL flow

- **UEDGE modeling with drifts available for one case only:** ∇B ↑
  - Predicted SOL flow direction opposite to that observed
  - large E_rxB drift predicted in near SOL (C V ion) only

- **All experiments performed in low-n_e, L-mode plasmas**
  - Do same physics mechanisms dominate in in DIII-D and C-Mod, with differing collisionalities of SOL layer and levels of bursty transport ?