# THE EFFECTS OF OPEN AND CLOSED DIVERTOR GEOMETRIES ON PLASMA BEHAVIOR IN DIII–D

## OVERVIEW

- Some effects of divertor closure on divertor detachment, fueling rate, and impurity content of high triangularity, ELMy H–mode plasmas are examined. We find that:
  - Open versus closed geometry does not appear to play a major role in the evolution of several characteristic plasma parameters during gas puffing, such as stored energy and the pedestal and separatrix densities at the onset of detachment
  - However, the deuterium core fueling was modestly lower in the closed divertor configuration, and the core plasma with the closed divertor had less carbon than the open divertor for the same line-averaged density and power input

# INTRODUCTION

- Reduction in both pedestal and line-averaged densities in DIII–D is essential to reaching lower density “advanced tokamak” regimes
  - Baffled (“closed”) divertors are designed to accomplish this by reducing the chance of recycling neutrals from leaking into the core plasma
  - demonstrated the effectiveness of baffled divertor at low density

**Question:**

How would baffling affect the behavior of discharges under higher density, $D_2$ gas puffed conditions?

- Only unpumped, high triangularity plasmas are considered

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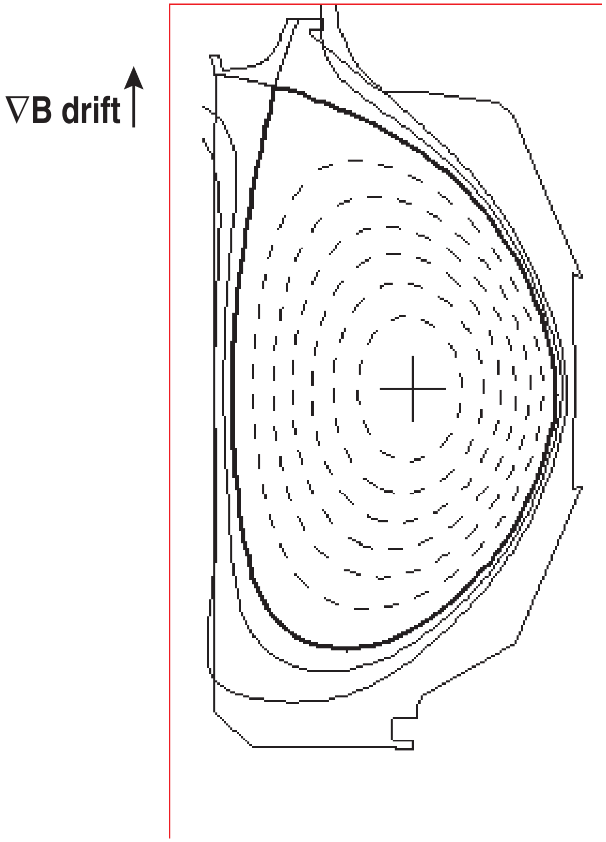
# THE "OPEN" AND "CLOSED" CONFIGURATIONS USED IN THIS STUDY HAVE SIMILAR SHAPING PARAMETERS

The 2- and 4 cm flux surfaces in the SOL are shown



**Parameters**

$I_p = 1.37$ MA

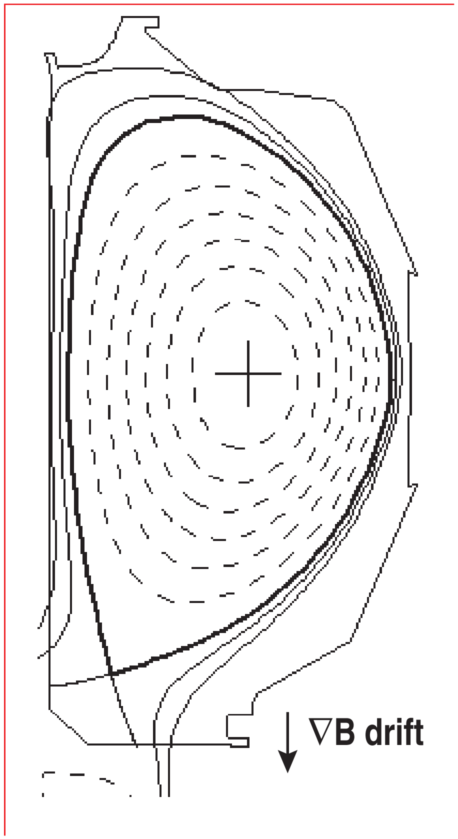
$|B_T| = 2$ T

$q_{95} \approx 4$

$\delta_{T,\,xpt} \simeq 0.74$

$P_{INJ} = 3.0\text{-}7.5$ MW

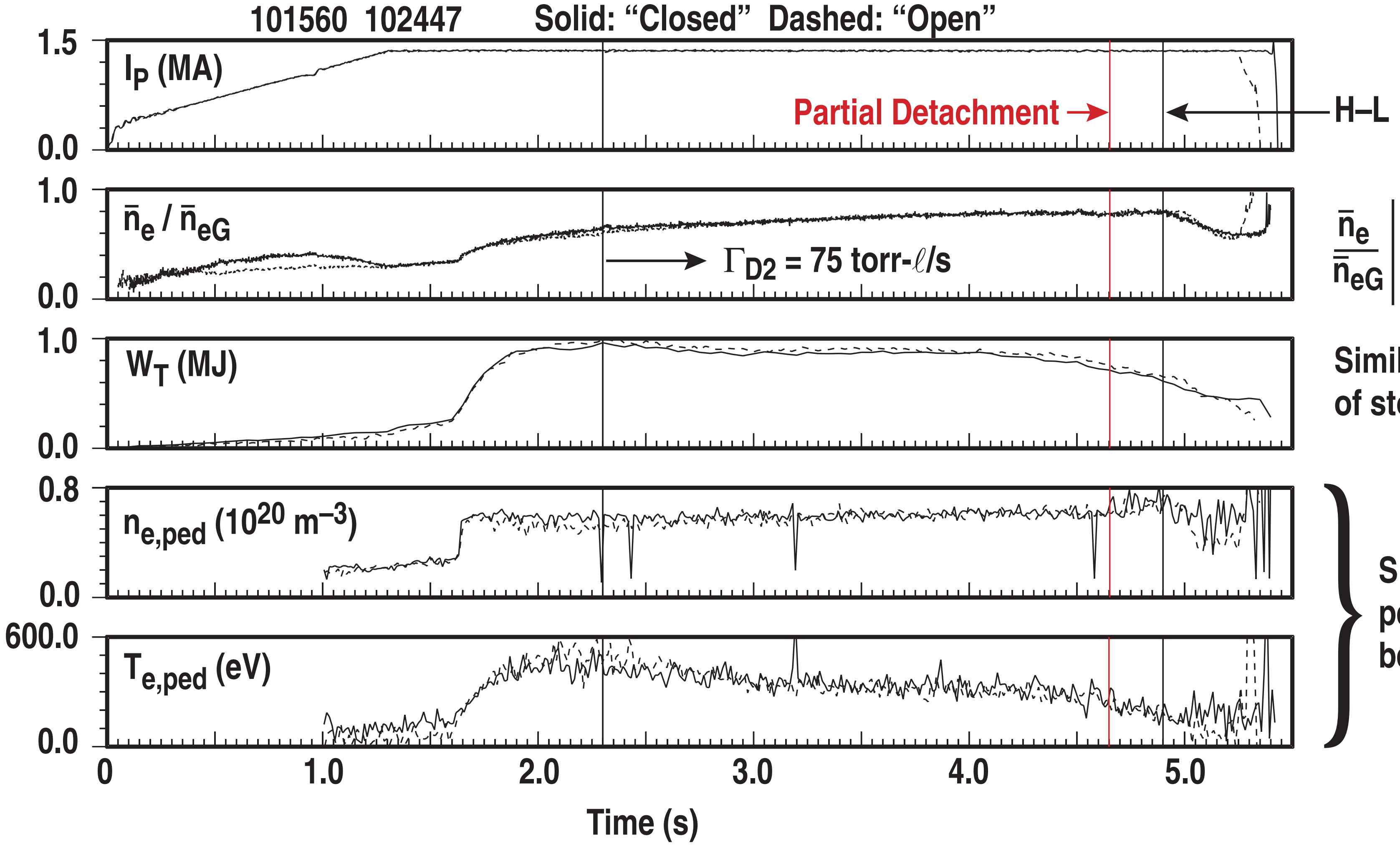
$\Gamma_{D2} \lesssim 150\ \dfrac{\text{torr}}{\ell\text{s}}$



- Since the pump geometrics are different in the two divertors, we limit this study to *unpumped*, high density, H–mode plasmas

# THE PLASMA EVOLVES SIMILARLY IN COMPARABLY-PREPARED “OPEN” AND “CLOSED” DIVERTORS

- Partial detachment is defined here as zero particle flux at the outer separatrix target (between ELM and/or sawtooth pulses

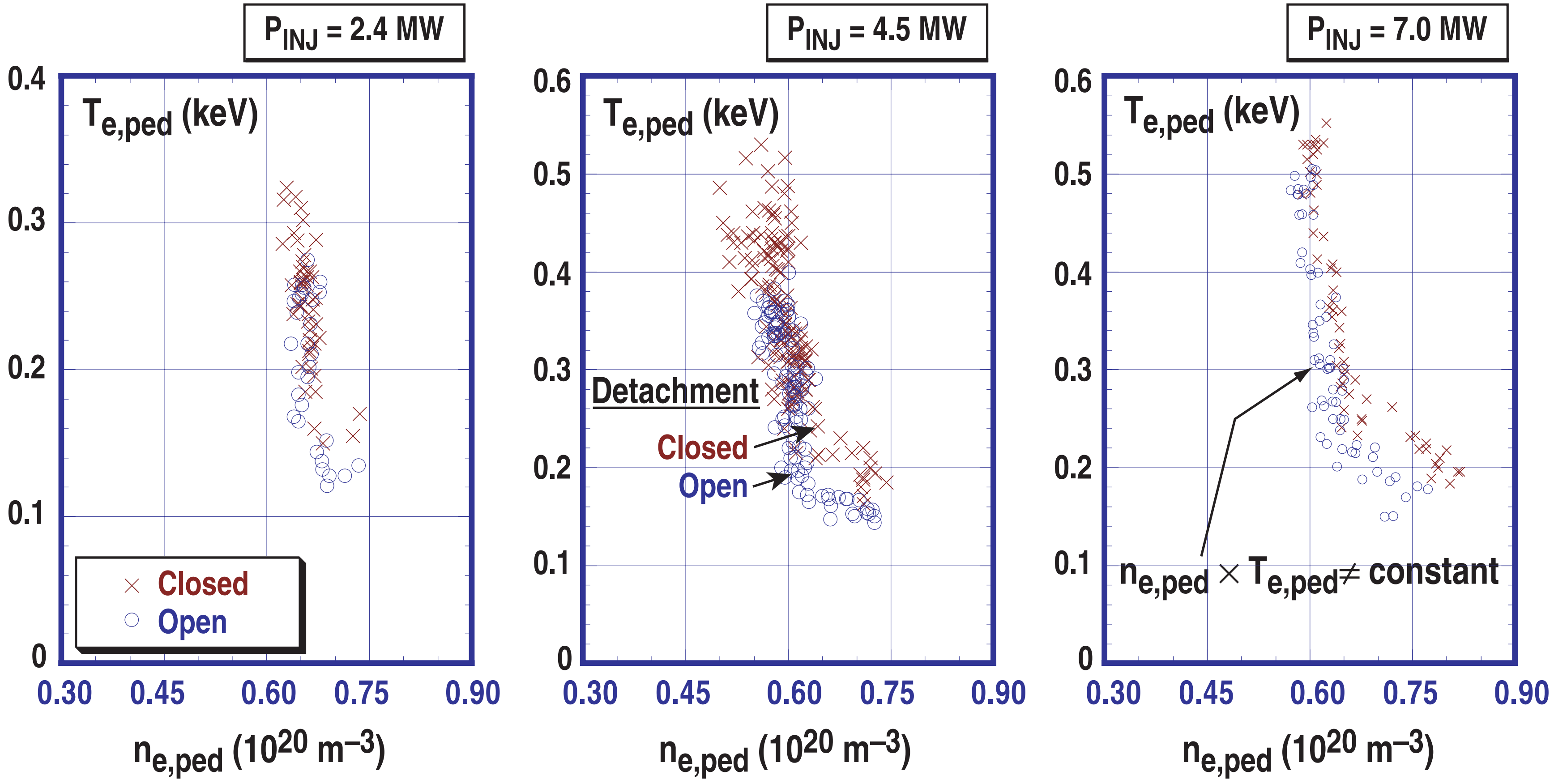


$\left.\frac{\bar{n}_e}{\bar{n}_{eG}}\right|_{max} \simeq 0.8$

Similar evolution of stored energy

Similar pedestal behaviors

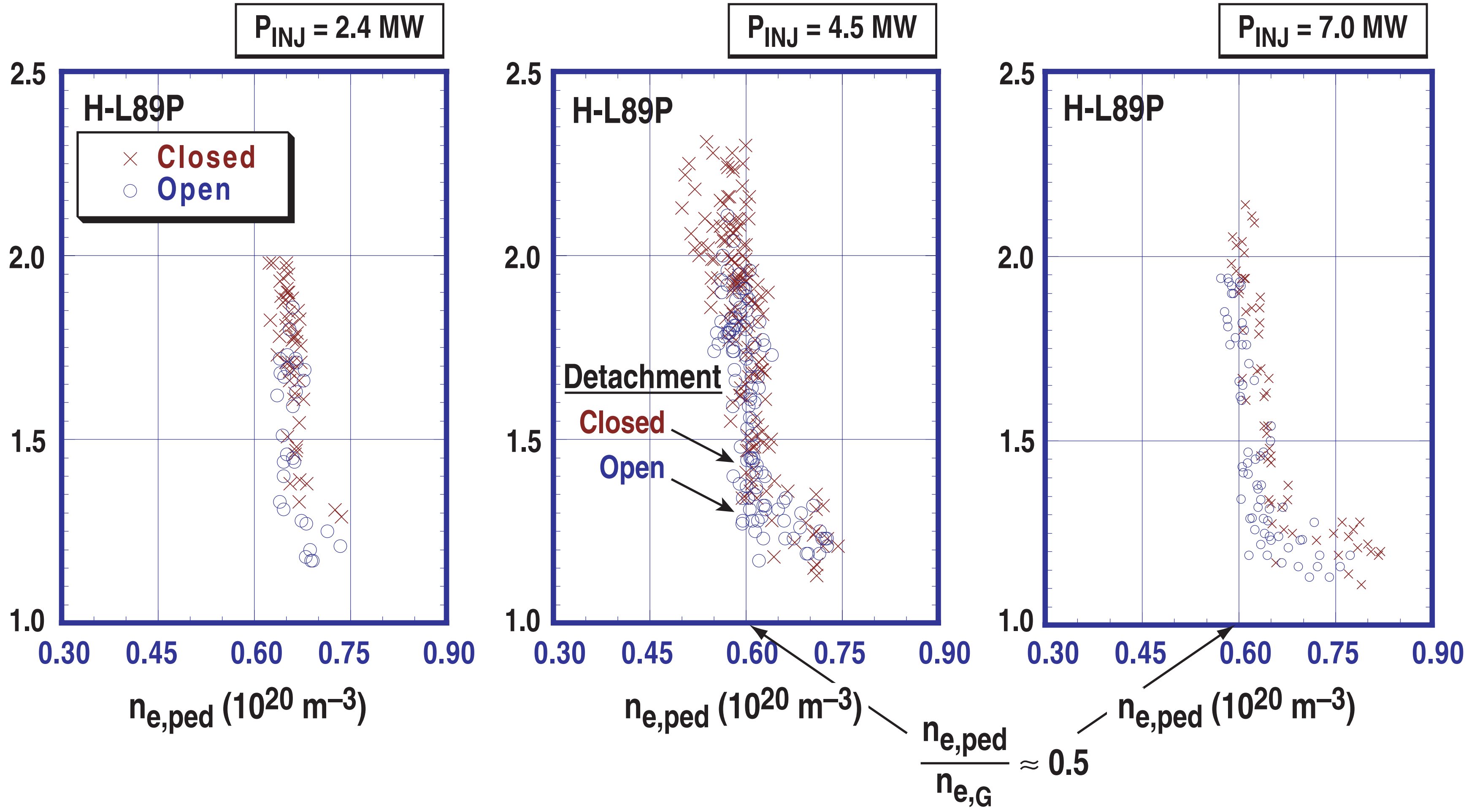
# THE RELATIONSHIP BETWEEN $n_{e,ped}$ AND $T_{e,ped}$ WAS INSENSITIVE TO DIVERTOR CLOSURE



— Gas puffing for either open or closed divertors resulted in a pronounced drop in $T_{e,ped}$ (and $P_{e,ped}$)

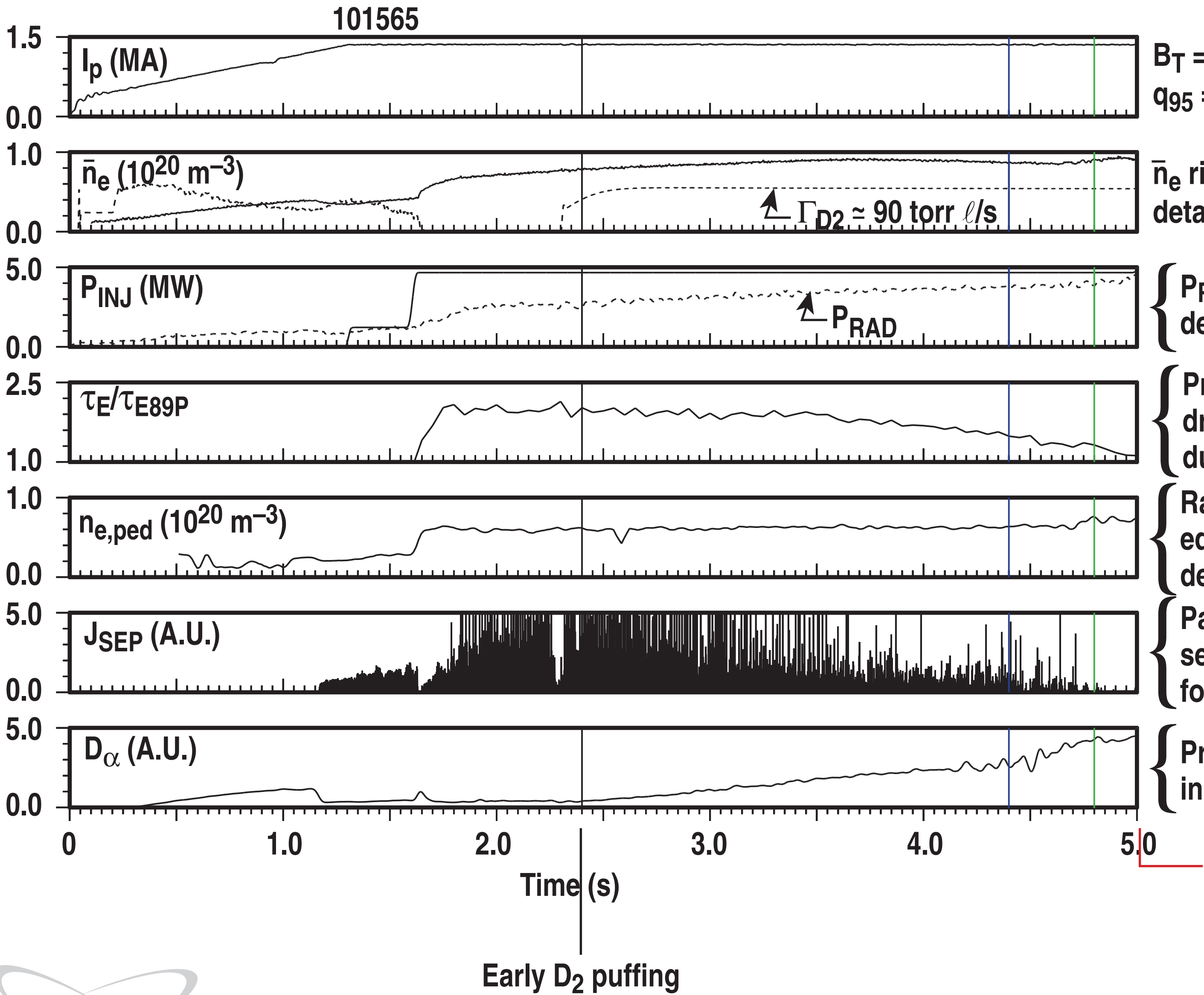
— Signficant reduction in Te, ped observed prior to “partial detachment.”

# THE ENERGY CONFINEMENT TRAJECTORIES WERE INSENSITIVE TO DIVERTOR CLOSURE DURING GAS PUFFING



- Decrease in H–L89P coincided with drop-off in $T_{e,ped}$ (and $P_{e,ped}$), consistent with “stiff” temperature profiles
- Significant energy confinement loss was observed prior to “partial detachment” for both open and closed divertor cases

# "SLOW" PARTIAL DETACHMENT WAS OBSERVED IN HIGH TRIANGULARITY DISCHARGES, WHETHER OPEN OR CLOSED



$B_T = 2.0$ T
$q_{95} = 4.1$

$\bar{n}_e$ rises during detachment

$P_{RAD}/P_{INJ} \approx 0.8$ at detachment

Pronounced drop in confinment during detachment

Rapid rise in edge density with detachment

Particle flux at separatrix → 0 for detachment

Pronounced Da increase near Xpoint

HL Back transition

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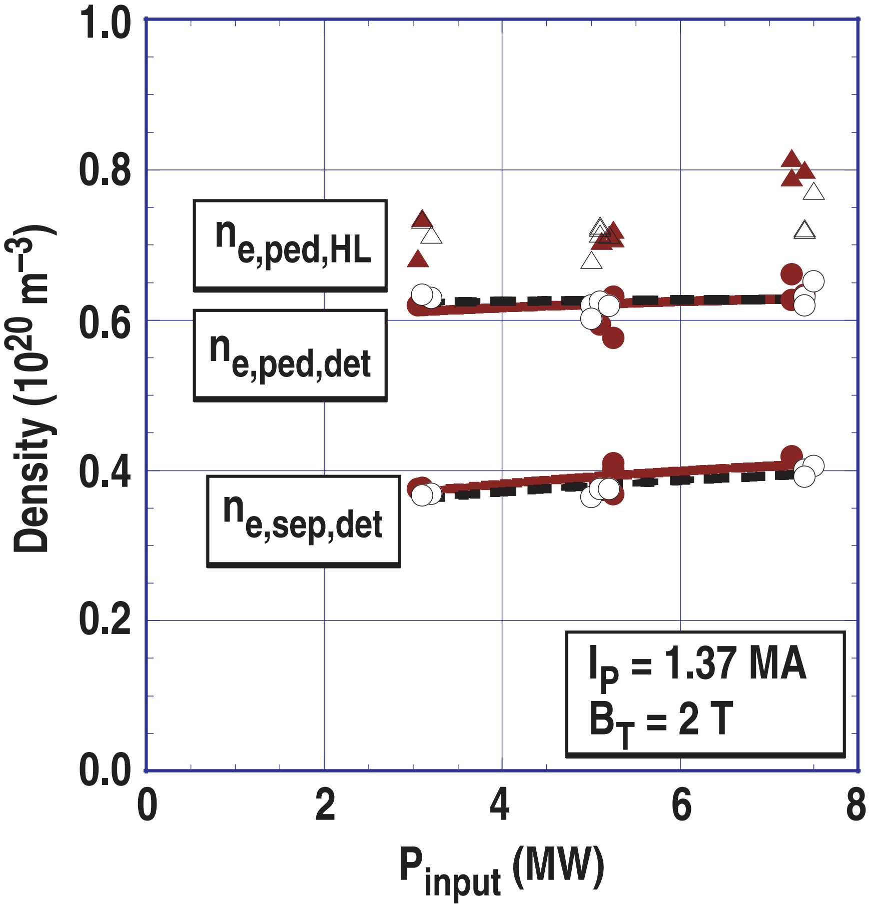
# BOTH PEDESTAL DENSITY AND SEPARATRIX DENSITY AT PARTIAL DETACHMENT WERE INSENSITIVE TO DIVERTOR CLOSURE



- Since $\frac{n_{e,\,ped,\,det}}{n_{e,\,sep,\,det}}$ was essentially unchanged for open and closed diverted discharges
  - Significant core fueling for both cases might be expected in the same general poloidal location(s)*
  - Supported by UEDGE simulations

- The pedestal density at the HL back transition ($n_{e,ped}$, HL) was ≈ 20% over $n_{e,ped,det}$

*M.A. Mahdavi et al., “High Density H–mode Plasmas at Densities Above the Greenwald Limit,” accepted fo publication in Nucl. Fusion

# COMPARISON OF PARTIAL DETACHMENT BEHAVIOR WITH PREVIOUS, LOW TRIANGULARITY (“OPEN DIVERTOR”) PLASMAS

- Partial detachment is defined here as zero particle flux at the outer separatrix target (between ELM and/or sawtooth pulses)

- Comparison of partial detachment between low- and high triangularity

| | | Low $\delta_{TRI}$ | High $\delta_{TRI}$ |
|---|---|---|---|
| Initial detachment | ⇒ | at separatrix | at separatrix |
| Divertor Marfe | ⇒ | yes | consistent with Marfe<br>(not measured directly) |
| Transition to detachment | ⇒ | sudden<br>(~100 ms) | gradual<br>(occurred in both OPEN and CLOSED div cases)<br>(~1000-2000 ms) |

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# ESTIMATE OF THE CORE FUELING RATE

$$S_f \approx \frac{dN}{dt} + \frac{N}{\tau_P} - S_{NBI}$$

$S_f$ → Non-beam core fueling rate, $S_{NBI}$ → Beam fueling of the core

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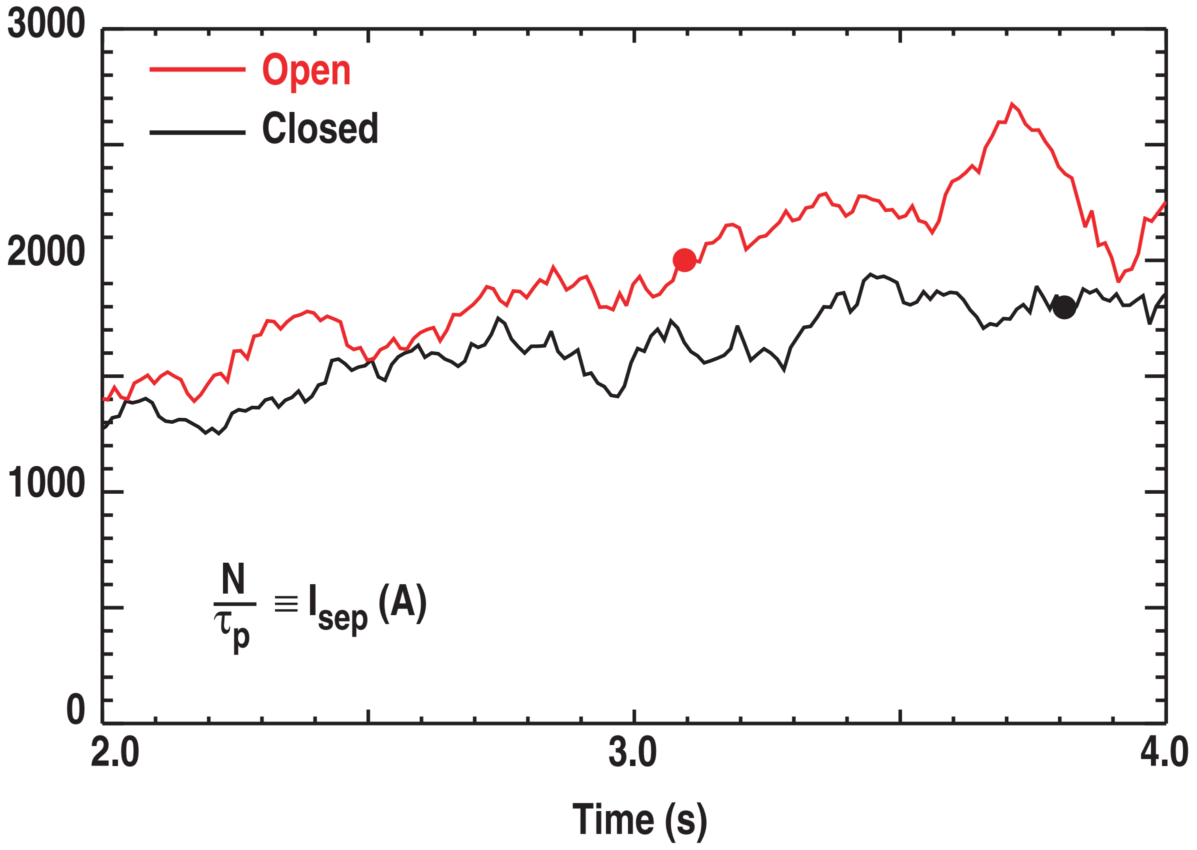
$\frac{N}{\tau_P}$ → Ion loss rate from the core plasma

$[N/\tau_P]$ is estimated by first finding a self-consistent pair $\chi_{eff}$ and $\alpha$, where $\chi_{eff}$ is the anomalous perpendicular diffusivity for thermal energy, $\alpha = 2.5 \times [D_\perp] / [\chi_{eff}]$, where $D_\perp$ is the anomalous perpendicular diffusivity for particles. We follow Porter's approach*, using the measured gradients in density and separatrix and the estimated power across the separatrix,

* G.D. Porter, et al., Phys. Plasmas, Vol 5 (1998) 4311.

# ESTIMATED CORE FUELING RATE IS ≈10-15% LOWER IN THE CLOSED DIVERTOR CASE

- Example: Open (#102447) and closed (#101560) comparison cases shown previously
- The timeslices selected (denoted by the black and red dots in the figure) have the same $\tau_E$, $n_e$, $\Gamma_{D2}$, $n_{e,ped}$, and $T_{e,ped}$ for 102447 and 101560



| | Closed | Open |
|---|---|---|
| $\frac{dN}{dt}$ (A) | 23 | 41 |
| $S_{NBI}$ (A) | 90 | 90 |
| $\frac{N}{\tau_p}$ (A) | 1810 | 2010 |
| $S_f$ (A) | 1743 | 1961 |

$$\frac{S_{f,\ CLOSED}}{S_{f,\ OPEN}} \approx 0.89$$

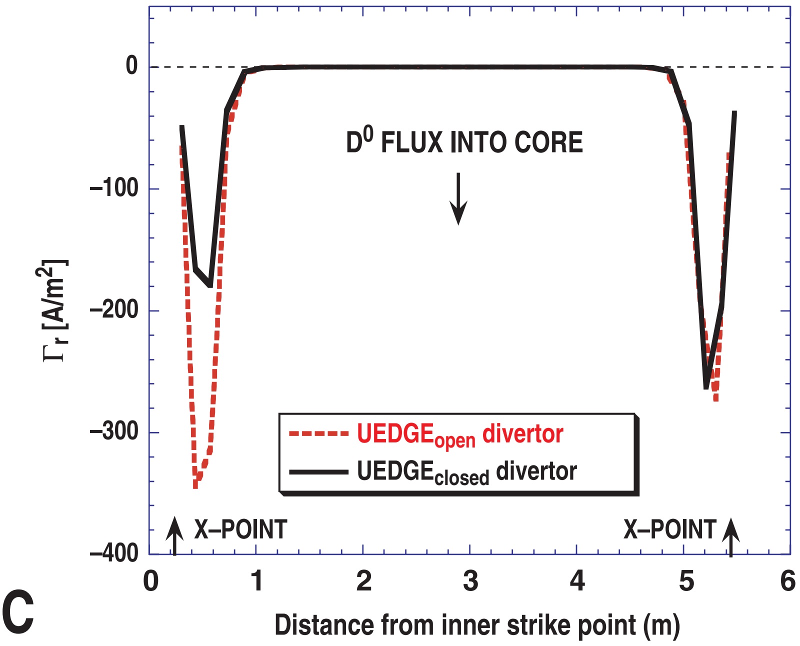
# LOWER CORE FUELING IN THE CLOSED DIVERTOR IS DUE TO IMPROVED NEUTRAL TRAPPING DESPITE HIGHER RECYCLING CURRENT

## UEDGE ANALYSIS

| | CLOSED | OPEN |
|---|---|---|
| ● $I_{RECYCL}$ [A] | 5142 | 2590 |
| ● $N/\tau_p$ [A] | 1680 | 2010 |
| ● $S_{NBI}$ [A] | 90 | 90 |
| ● $S_f$ [A] | 1590 | 1920 |
| ● $f_{REFUEL}$ | 0.33 | 0.78 |

$$N/t_p = S_f + S_{NBI} = f_{REFUEL} \times I_{RECYC}$$

$$\frac{S_f^{CLOSED}}{S_f^{OPEN}} \approx 0.83$$

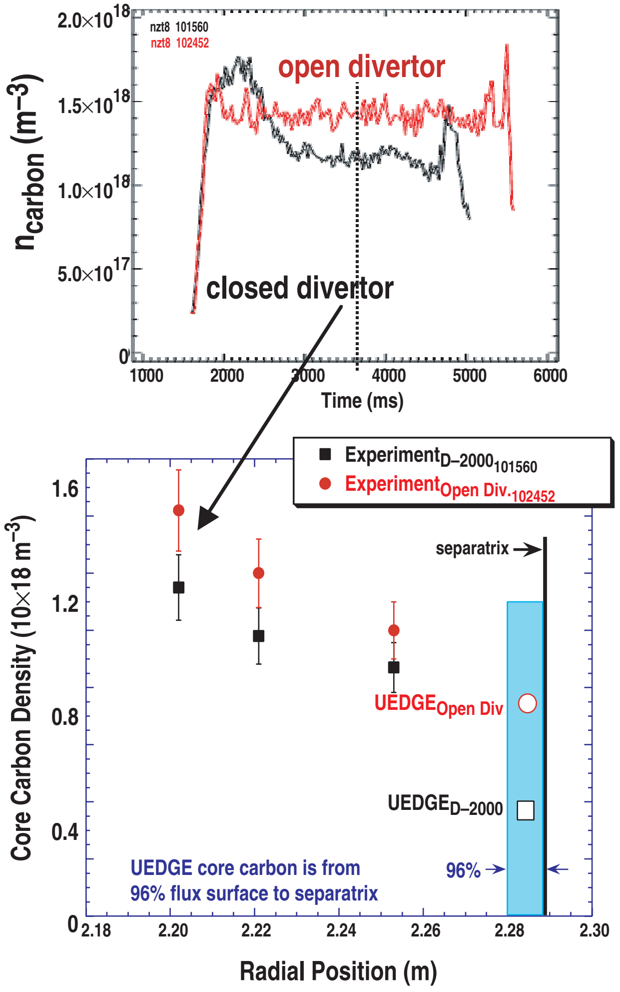


**For both open and closed cases, the peak in $D^0$ fueling is upstream from the X–point**

# CORE DENSITY WAS 15 - 25% LOWER WITH CLOSED DIVERTOR

- **EXPERIMENT:**
  - Results for comparable density and power input with $Z_{eff} \leq 1.6$ for core plasma
  - DIII–D carbon density is measured by CER and shown here for a time series and three core radii (@ 3700 ms)

- **SIMULATION:**
  - UEDGE gives approximate range of core carbon density (but a higher ratio for open to closed divertor than experimental results, perhaps because modeling is outside the 96% flux surface.



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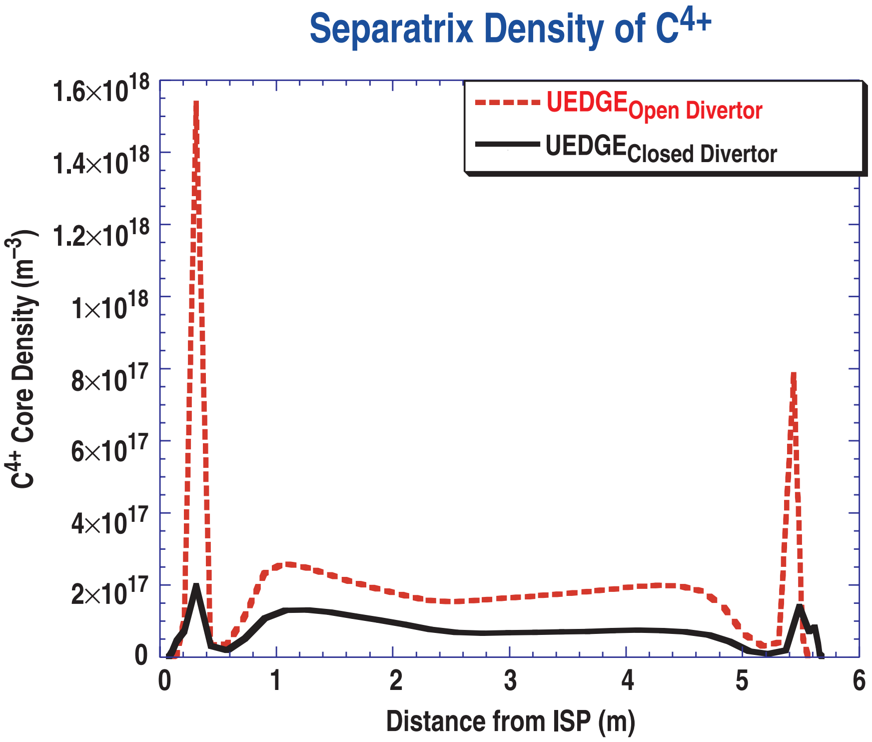
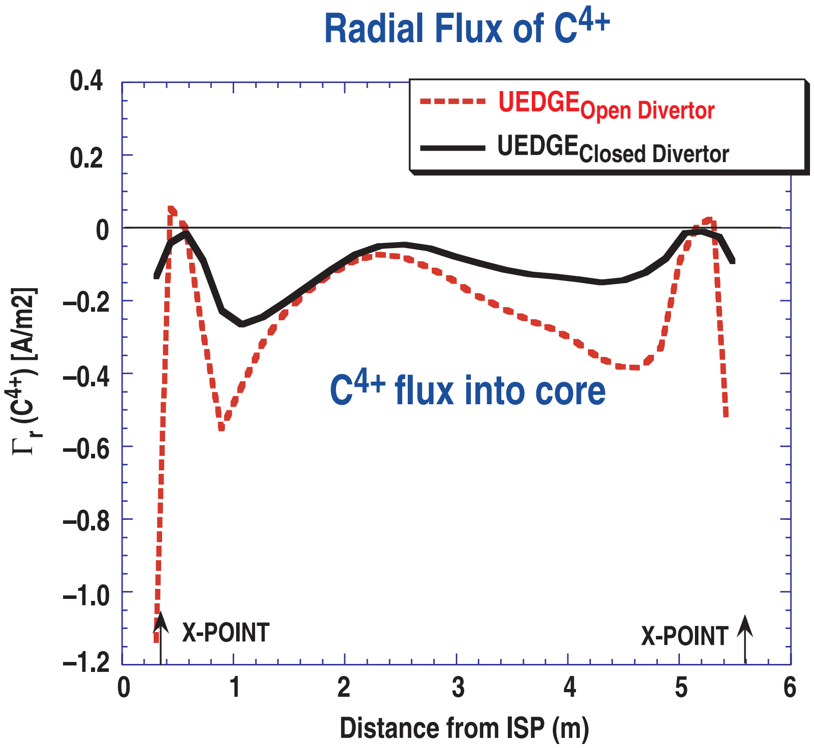
# LOWER $C^{4+}$ NEAR SEPARATRIX OF THE CLOSED DIVERTOR CONTRIBUTES TO REDUCED RADIAL FLUX, AND HENCE LESS CORE CARBON





- $C^{4+}$ was the main carbon ion along the separatrix flux surface (upstream $T_e$ was 50 - 100 eV)

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# SUMMARY OF UEDGE ANALYSIS

- In unpumped, non-detached, H–mode plasmas, the geometric effect of the closed divertor may decrease the core carbon density by:

  1. reducing neutral carbon density near the X–point region,
  2. reducing carbon ion flux along the SOL toward the midplane and hence decreasing the C4+ diffusing radially into core.

- This UEDGE analysis indicates that divertor geometry may be at least partially responsible for lower core carbon

# SUMMARY AND CONCLUSIONS

**Divertor closure in unpumped, H–mode plasmas with $D_2$ gas puffing:**

- Had little effect on several global and edge plasma properties, including energy confinement time and pedestal electron density and temperature
- Had little effect on midplane density and temperature at the onset of partial detachment
- Led to a modest decrease in the deuterium core fueling rate by reducing the neutrals diffusing into the core above the X–point (UEDGE support)
- Led to a modest decrease in the carbon impurity content of the core plasma by reducing the probability of sputtered carbon impurities escaping the divertor (UEDGE support)

**Impact of baffling of the outer divertor leg may be reduced by large fueling sources above the X–point, especially from high recycling near the (unbaffled) inboard leg for both open and closed cases**