RECENT HIGH DENSITY EXPERIMENTS IN OPEN AND CLOSED DIVERTORS IN DIII–D

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We examine several important characteristics of high density H-mode performance (e.g., detachment, H-L density limit, energy confinement, and heat flux reduction) in "open" vs "closed" divertor geometry. We find little difference in either the line-averaged or the edge pedestal densities near the H-L back transition density when comparing unpumped open and closed divertor cases. "Closing" the divertor in unpumped high density discharges also does not change the weak dependence of the H-L density limit on power input observed in open geometries. For closed divertors, changing the location of the outer strike point (OSP) in the divertor slot has little impact on the highest densities achievable in H-mode. In the closed divertor cases we observe no clear difference in the H-L back transition density between actively pumped and unpumped discharges. When gas puffing at high density in the closed geometry, we observe strong pumping by the outer divertor pump, even when the OSP is far from the pump entrance.

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234-00 jy

Abstract Submitted
for the DPP00 Meeting of
The American Physical Society

Sorting Category: 6.2.2 (Experimental)

Recent High Density Experiments in Open and Closed Divertors in DIII-D[1] T.W. PETRIE, A.W. LEONARD, M.A. MAHDAVI, T.H. OSBORNE, GA, M.E. FENSTERMACHER, C.J. LASNIER, LLNL, W.M. STACEY, Georgia Tech, J.G. WATKINS, SNL —

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[1]Work supported by US DOE Contract Nos. DE-AC03-99ER54463, W-7405-ENG-48, and DE-AC04-94AL85000.

☐ Prefer Oral Session
☒ Prefer Poster Session

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Special instructions: 1st poster in Divertor Session (before Boedo)

Date submitted: July 12, 2000

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MAIN QUESTIONS TO BE ADDRESSED BY THIS STUDY

- **How does "closing" the divertor affect discharge performance during elming H–mode operation?**
  - with respect to DETACHMENT, MARFE FORMATION AND THE H–MODE DENSITY LIMIT
  - with respect to FUELING and ENERGY CONFINEMENT AT HIGH DENSITY
- **Does active particle pumping improve discharge performance during elming H–mode operation?**
  - with respect to THE H–MODE DENSITY LIMIT
  - with respect to ENERGY CONFINEMENT AT HIGH DENSITY
  - RELATED QUESTION: DOES THE LOCATION OF THE DIVERTOR PUMPING HAVE A SIGNIFICANT EFFECT ON OVERALL PUMPING AND HEAT FLUX REDUCTION?

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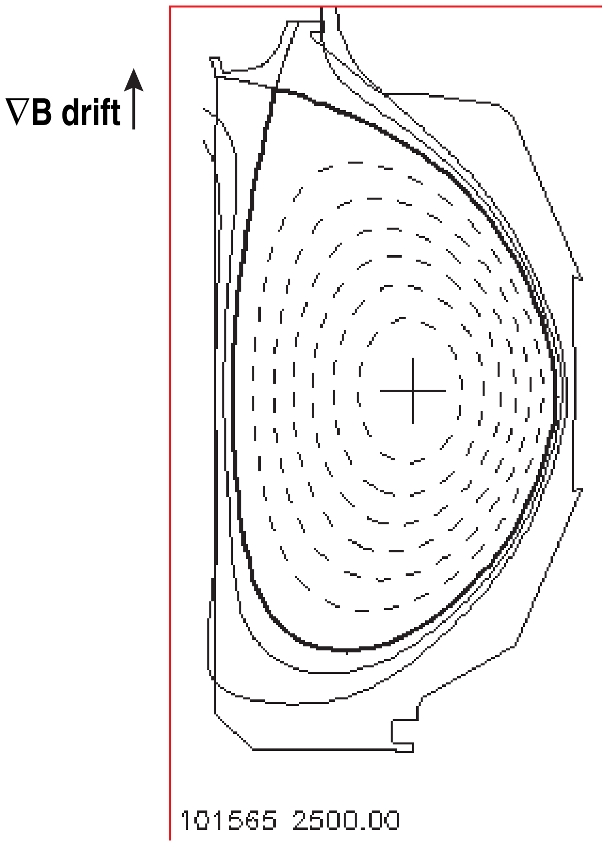
THE "OPEN" AND "CLOSED" CONFIGURATIONS USED IN THIS STUDY HAVE SIMILAR SHAPING PARAMETERS

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



Parameters

$I_p = 1.37$ MA

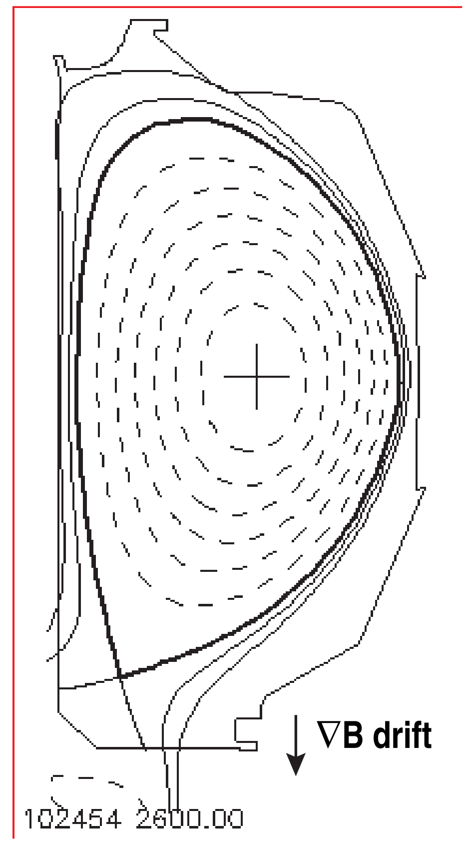
$|B_T| = 2$ T

$q_{95} \approx 4$

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

$P_{INJ} = 2.4\text{-}7.0$ MW

$\Gamma_{D2} \lesssim 700 \frac{\text{torr}}{\ell s}$



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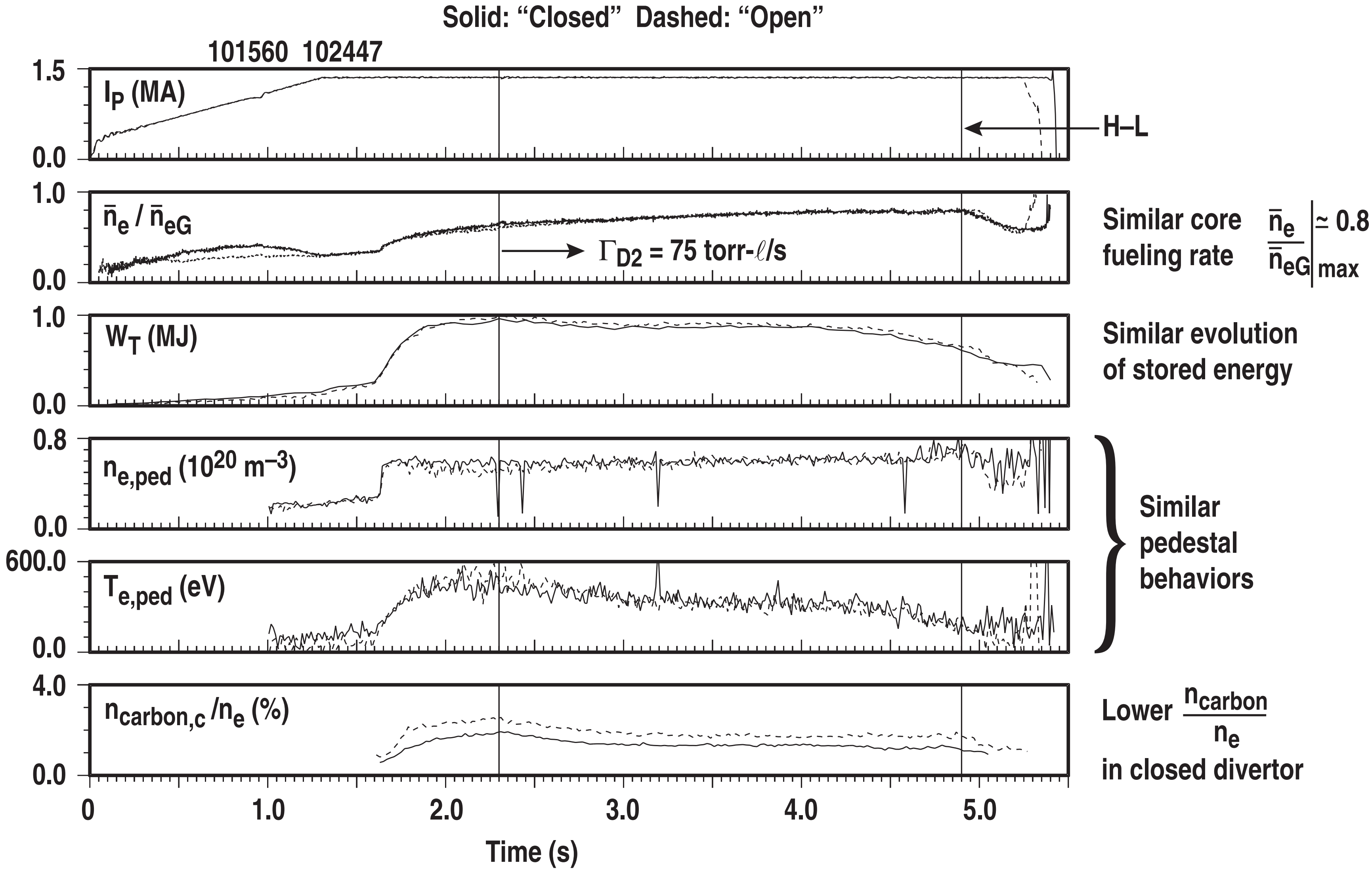
— UNPUMPED DIVERTOR DISCHARGES —

THE PLASMA EVOLVES SIMILARLY IN COMPARABLY-PREPARED "OPEN" AND "CLOSED" DIVERTORS



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THE SIMILAR DEUTERIUM FUELING RATE AND DIFFERENT CARBON IMPURITY CONCENTRATION IN THE CORE ARE CONSISTENT WITH PREDICTIONS FROM UEDGE MODELING

- **Deuterium core fueling rates are similar for unpumped, higher density divertor plasma in OPEN and CLOSED configurations**
  - Recycling current is much higher in closed divertor (~2X)
  - The efficiency of the recycled particles returning to fuel the core is much less in the closed divertor $\left(\sim \frac{1}{2}X\right)$
  - The product of these two factors is roughly constant ⇒ Dome in Divertor 2000 appears to play an important role.

- **Lower carbon concentration in the closed divertor**
  - Higher deuterium neutrals concentration below the Xpoint of the open divertor ⇒ More sputtering of carbon there ⇒ Easier carbon diffusion into the core both through the Xpoint and midplane regions
  - Highly complicated story

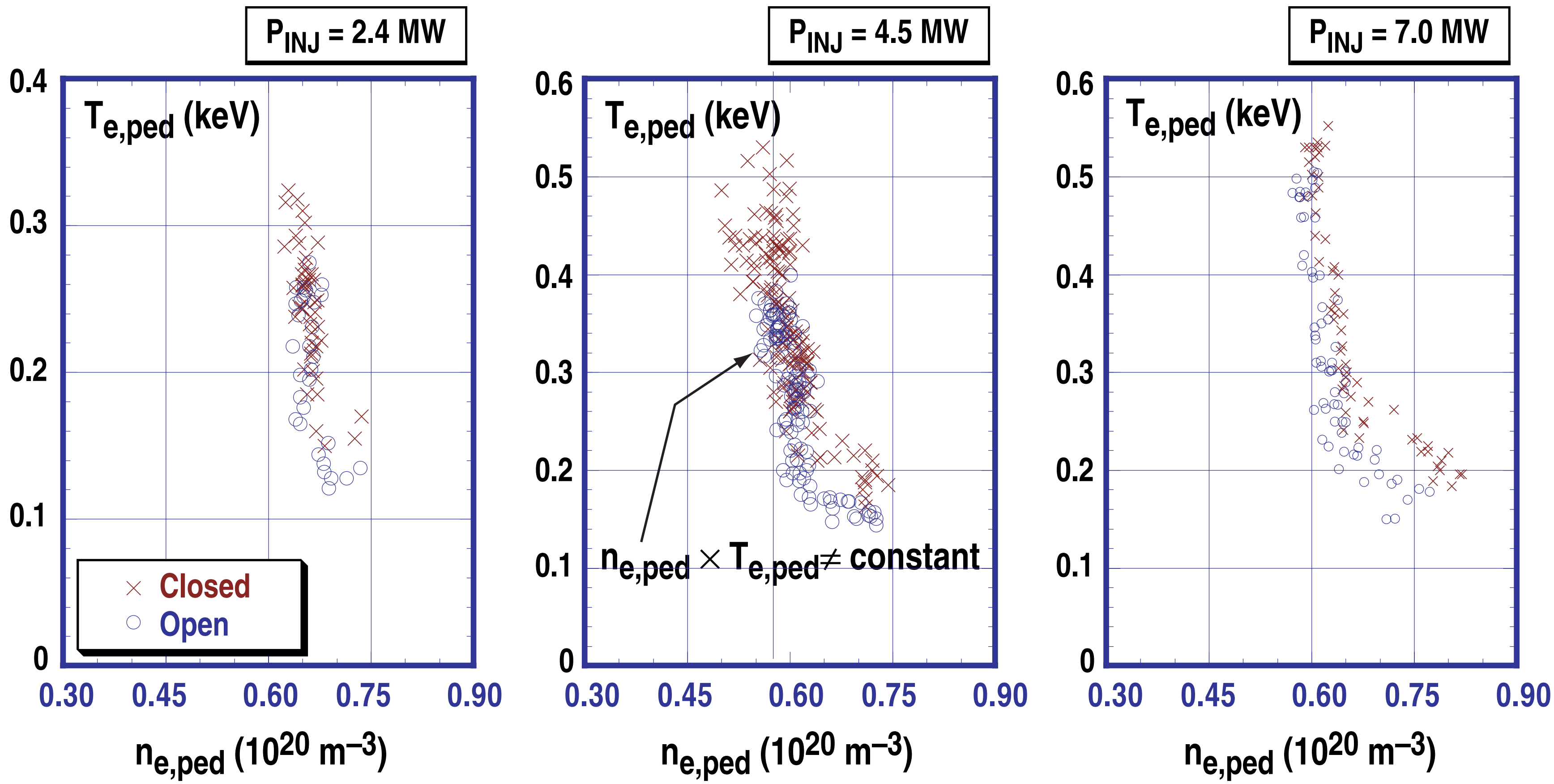
See poster by N. Wolfe (GP1.139)

OPEN vs CLOSED DIVERTORS – NO ACTIVE PUMPING

EDGE PLASMA PRESSURE EVOLVES ALONG SIMILAR TRAJECTORIES DURING ELMING H–MODE OPS

— "EDGE" DENSITY LIMIT FOR THE ELMING H–MODE DEPENDS WEAKLY ON POWER —

— CONSISTENT WITH CONSTANT $n_{e,ped} \times T_{e,ped}$ FOLLOWING $T_{e,ped}$ FALL-OFF —



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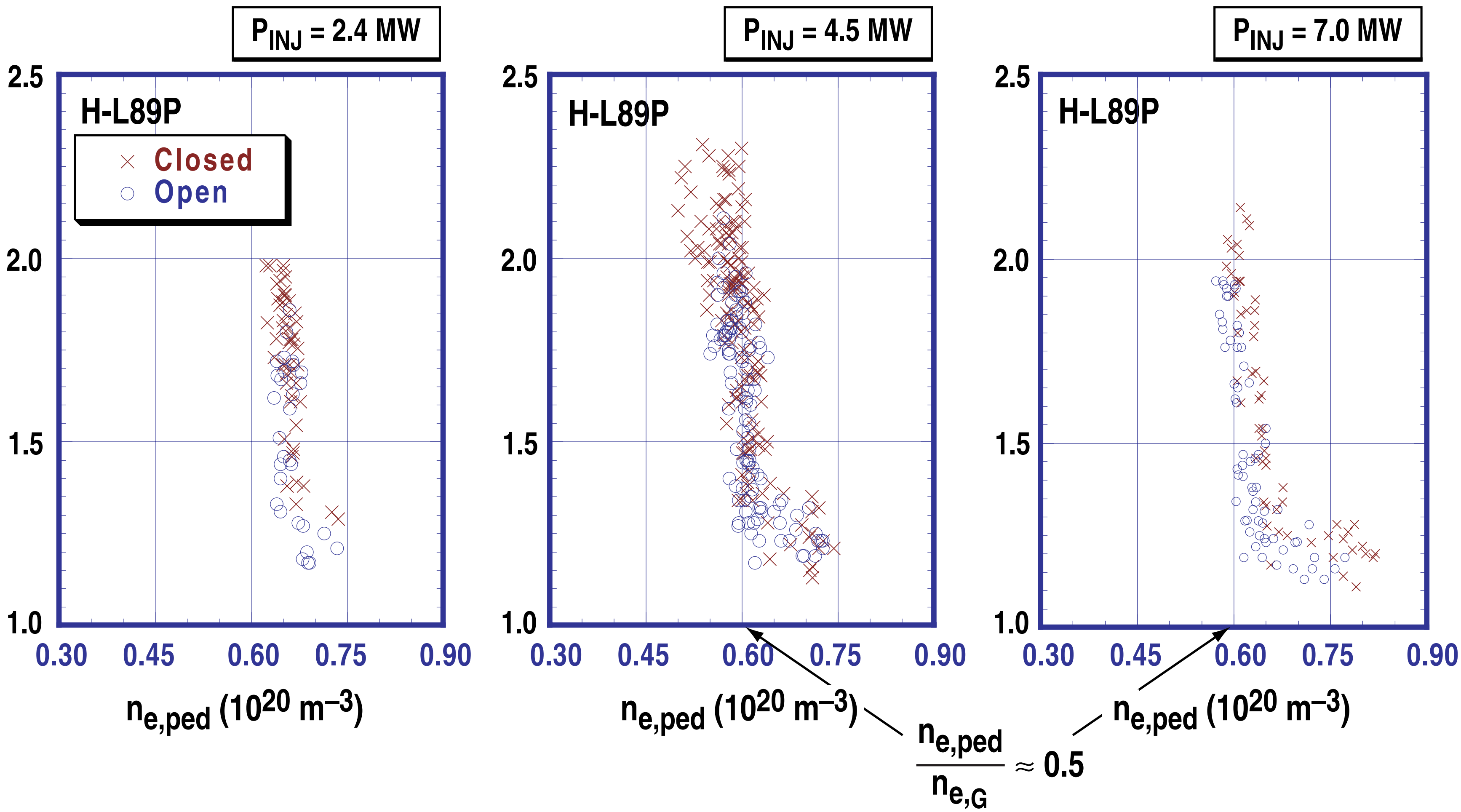
"OPEN" vs "CLOSED" DIVERTORS – NO ACTIVE PUMPING

ENERGY CONFINEMENT FOLLOWS SIMILAR TRAJECTORIES DURING GAS PUFFING

— "PLATEAU" BEHAVIOR IN ENERGY CONFINEMENT COMMON TO ALL CASES —

— PREVIOUS ONETWO ANALYSIS INDICATES τ_E DROP DUE PRIMARILY TO INCREASED LOSSES IN ION CHANNEL —



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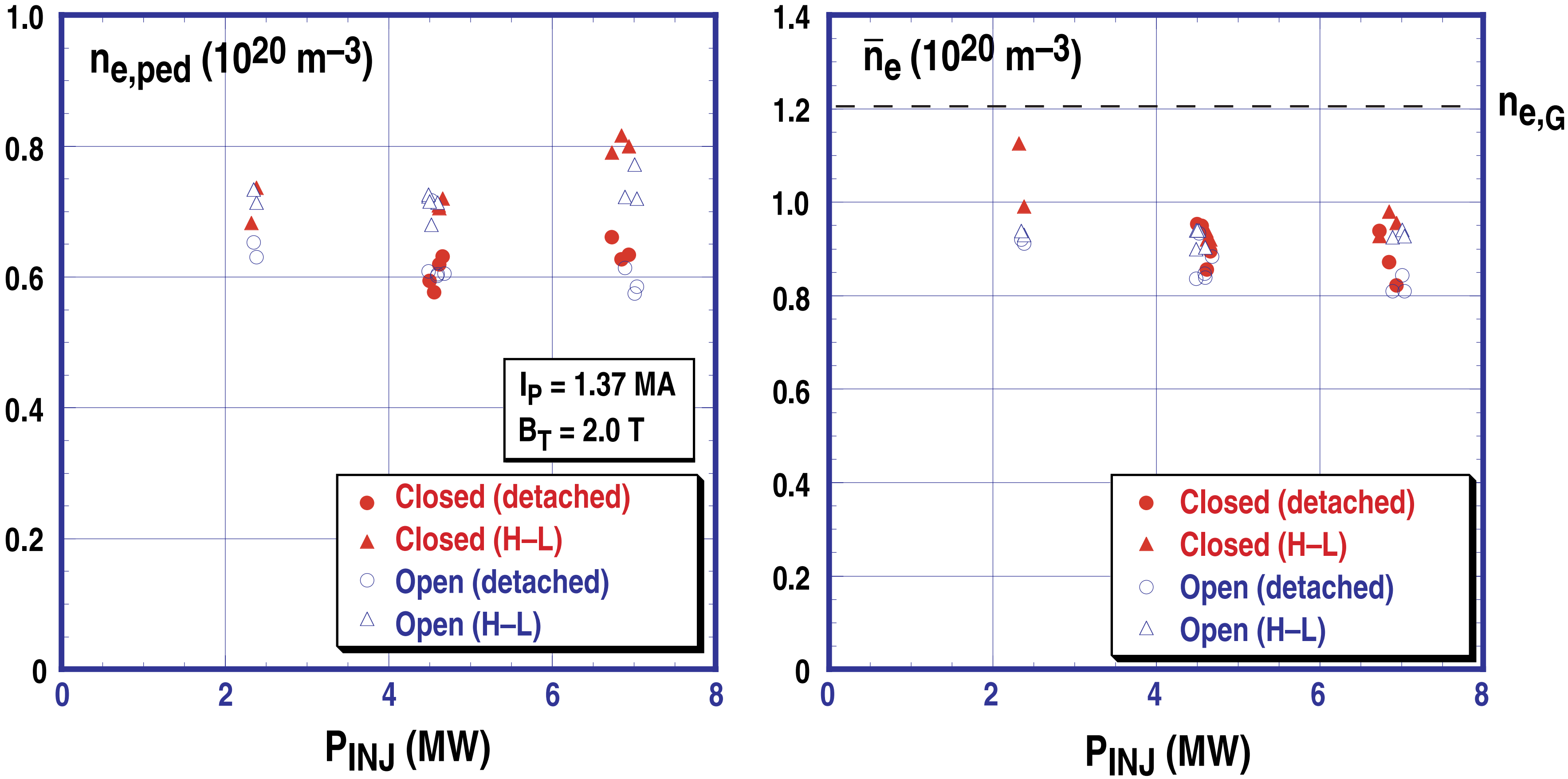
BOTH "DETACHMENT" AND THE H–L BACK TRANSITION DEPEND WEAKLY ON P_{INJ} IN THE OPEN AND CLOSED DIVERTOR CONFIGURATIONS

- "Detachment": the particle flux at the outer separatrix becomes less than the particle flux at the divertor on the 0.8-cm midplane flux surface



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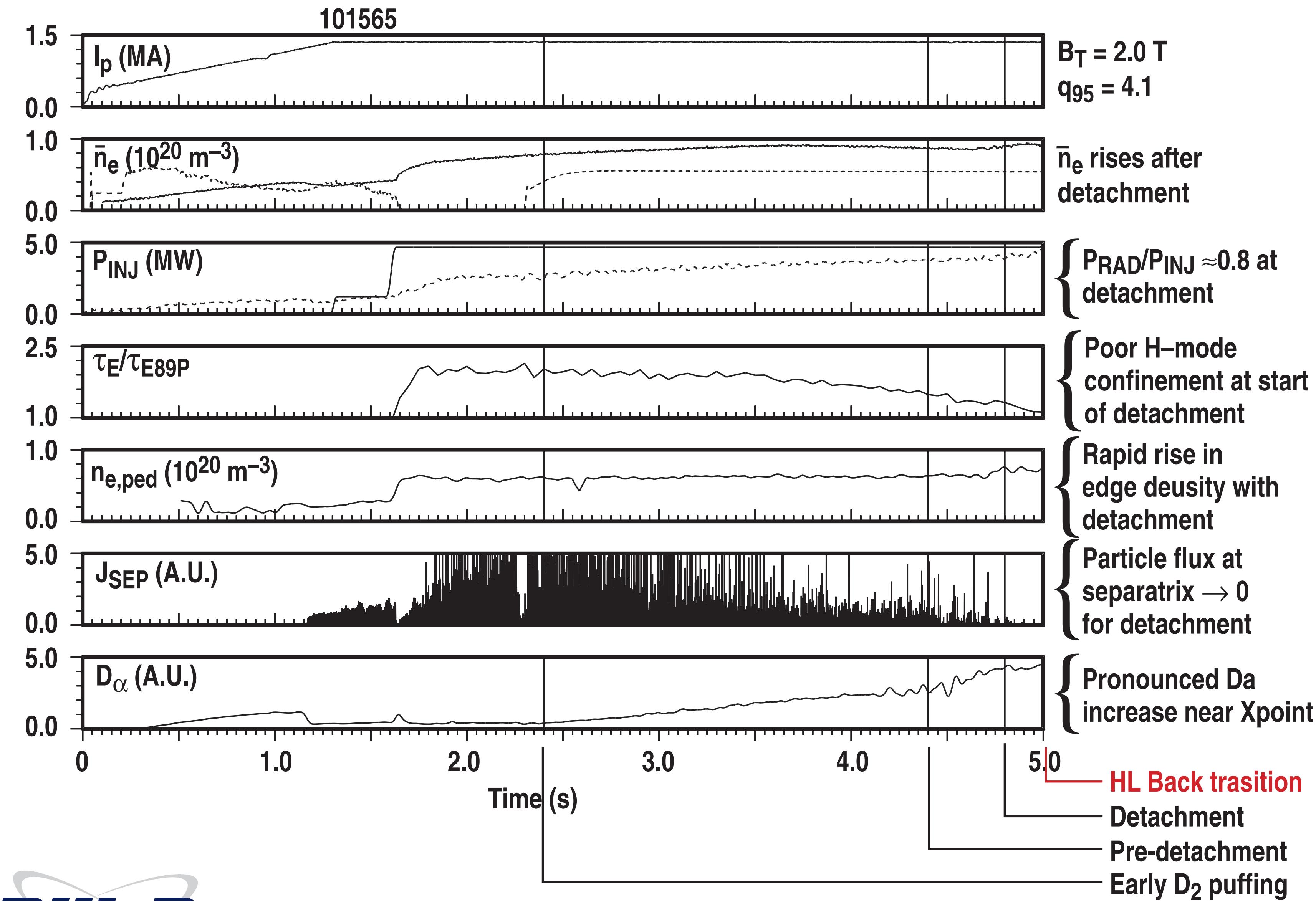
SIGNATURES OF MARFE FORMATION AND DETACHMENT IN THE CLOSED DIVERTOR ARE OBSERVED IN THIS HIGH TRIAGULARITY, GAS PUFFED DISCHARGE



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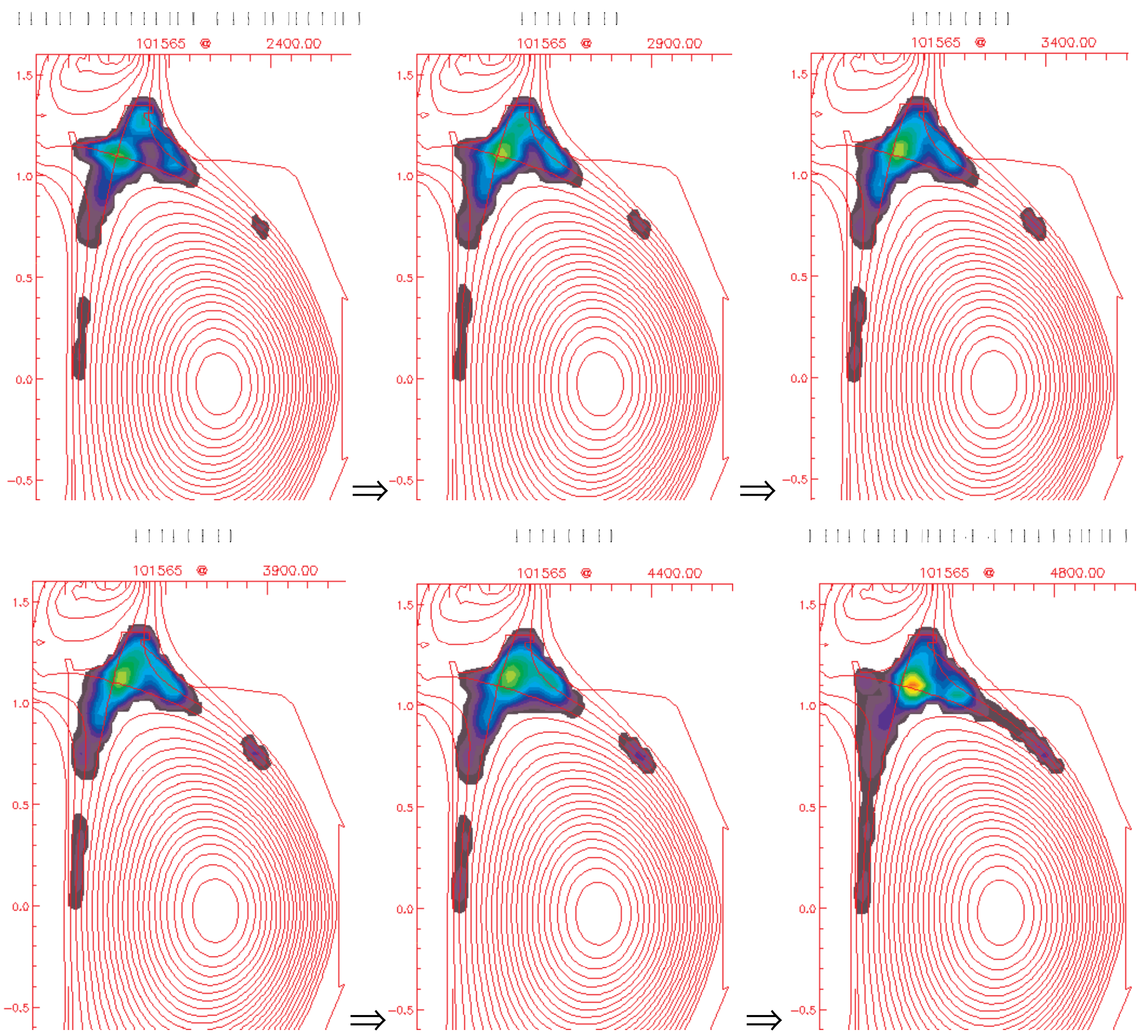
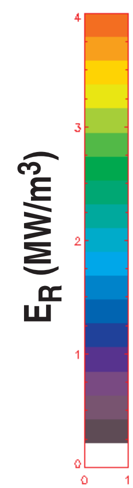
RADIATED POWER INCREASES SLOWLY DURING THE ATTACHED PHASE, BUT RISES SHARPLY AT THE XPOINT FOLLOWING DETACHMENT



I_p = 1.4 MA
B_T = 2.1 T
q_{95} = 4.1
P_{INJ} = 4.7 MW



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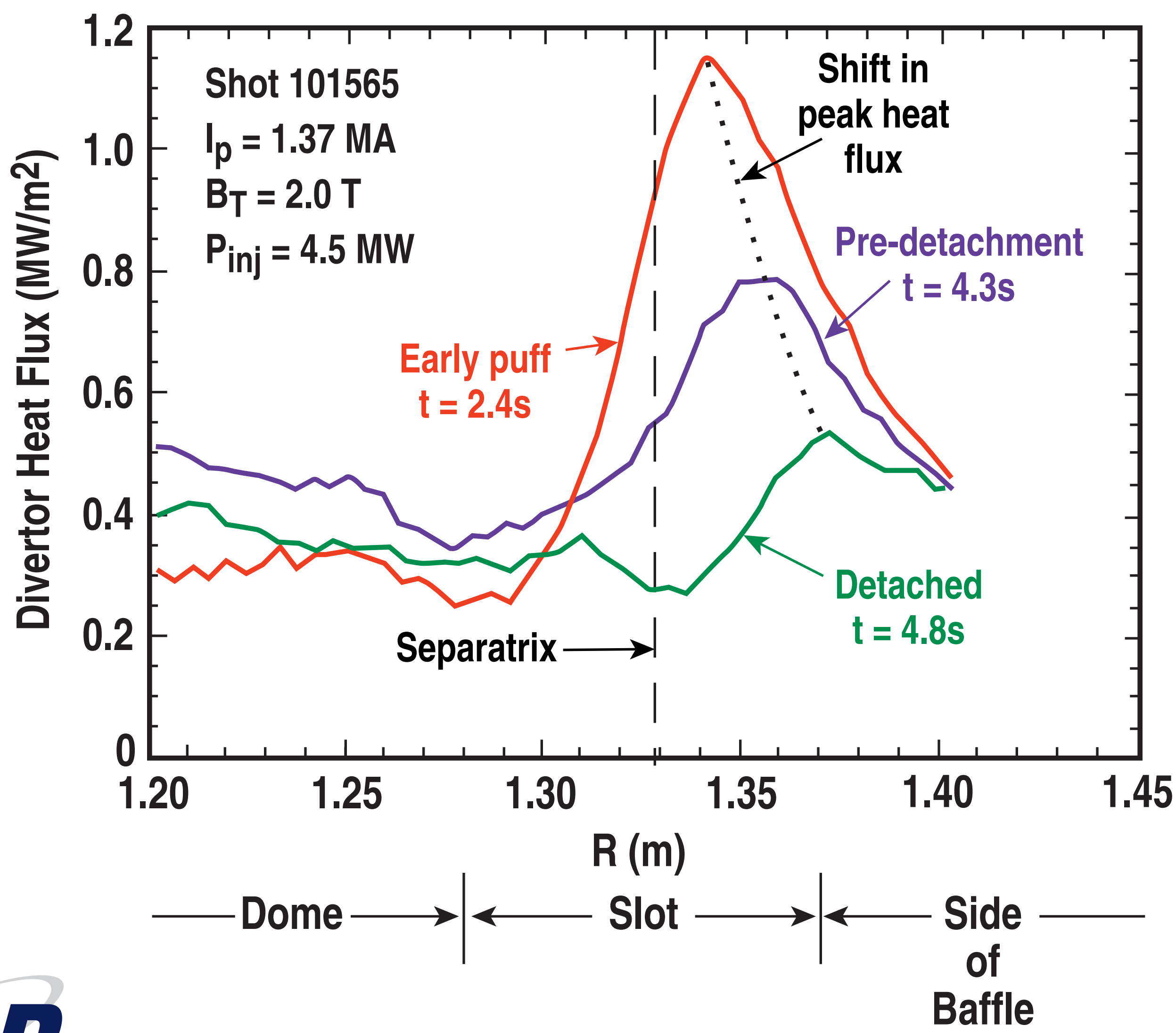
THE PEAK IN THE HEAT FLUX PROFILE MOVES AWAY FROM THE SEPARATRIX STRIKE POINT DURING D_2 GAS INJECTION



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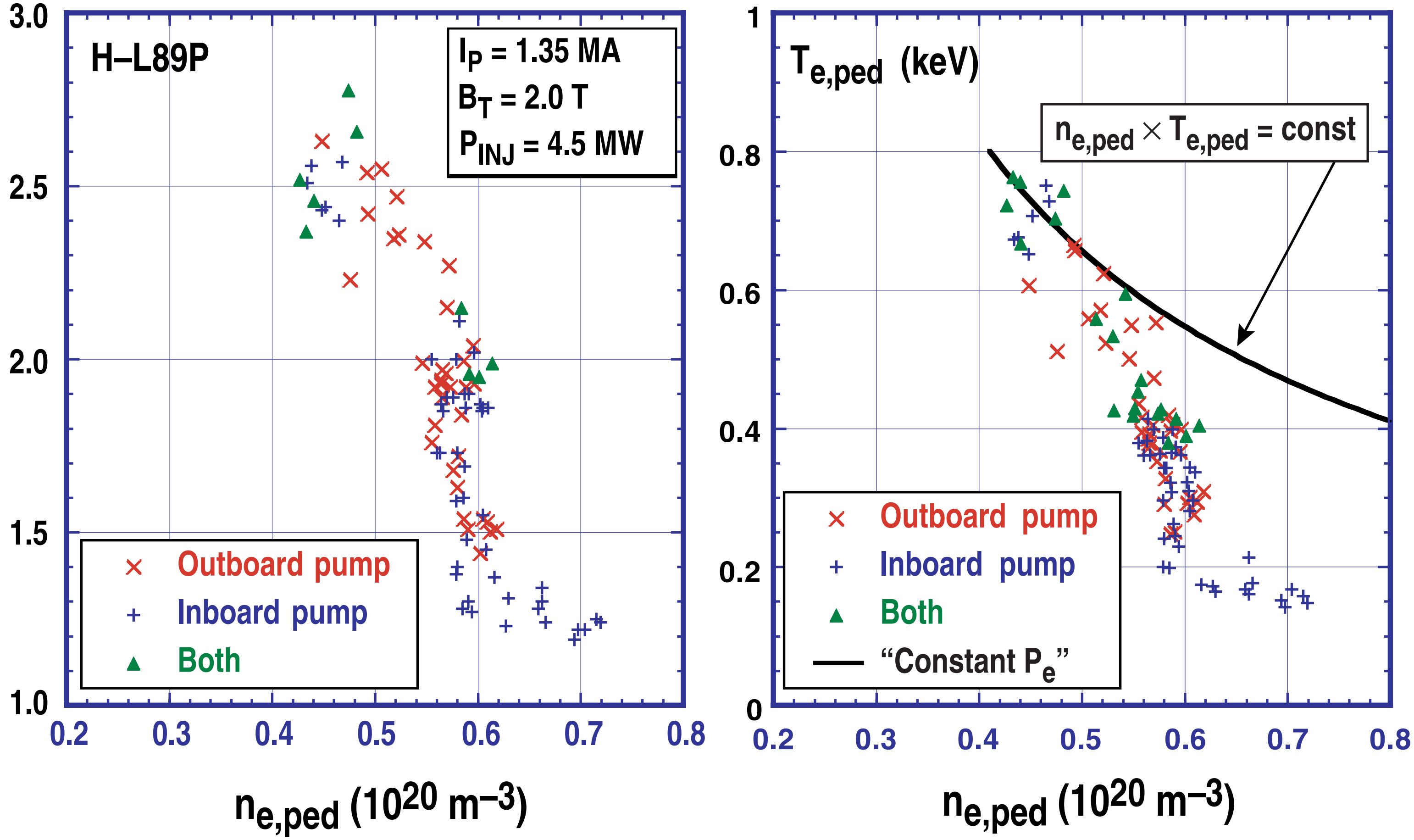
— PUMPED DISCHARGES IN THE CLOSED DIVERTOR —

ENERGY CONFINEMENT DECREASES WITH GAS PUFFING, REGARDLESS OF PUMPING LOCATION

— Degradation in τ_E occurs at $n_{e,ped} \approx n_{e,G}$



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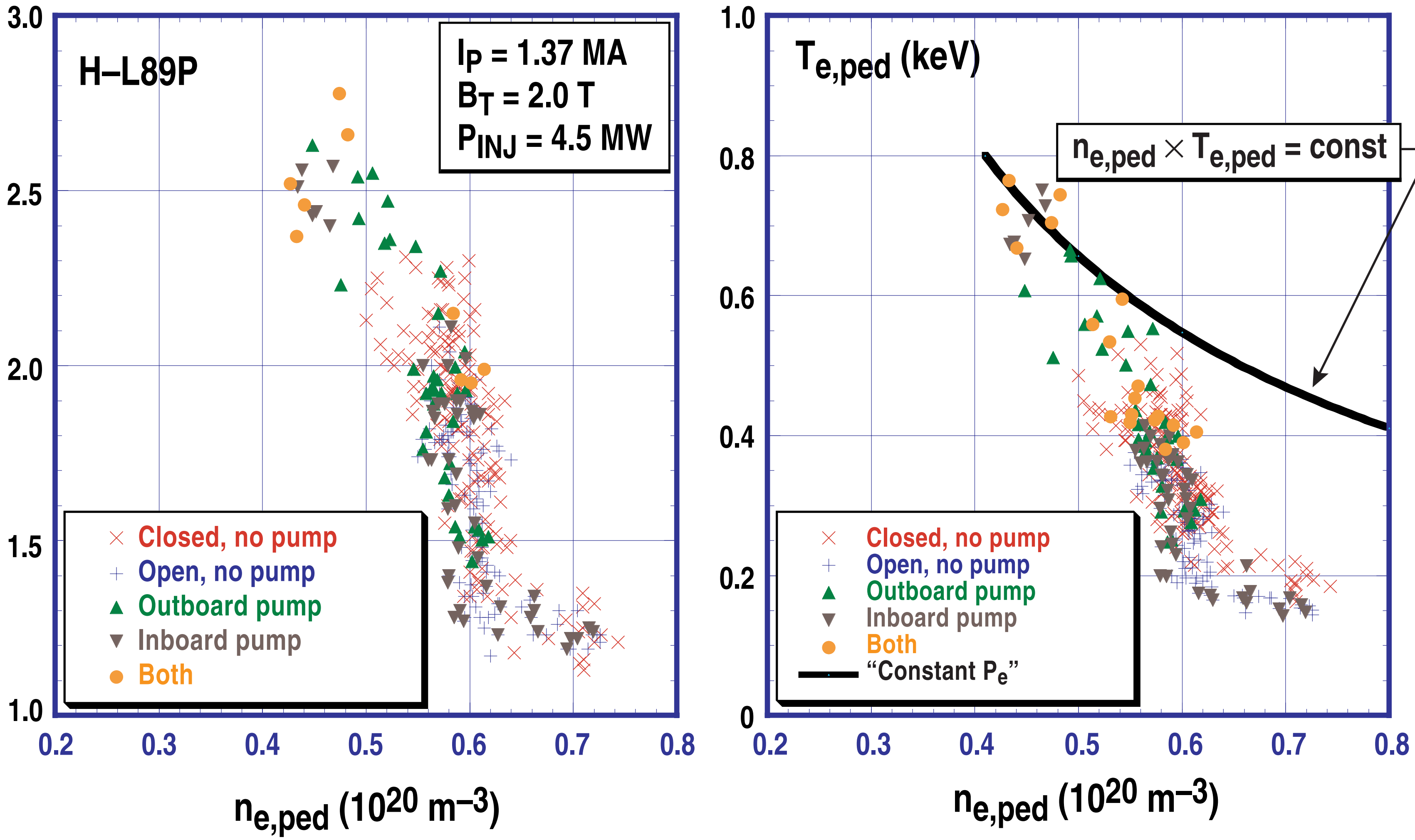
— PUMPING VS NON–PUMPING —

PUMPING ACCESSES LOWER DENSITY WITH GOOD CONFINEMENT, BUT IS LESS EFFECTIVE AT HIGH DENSITY



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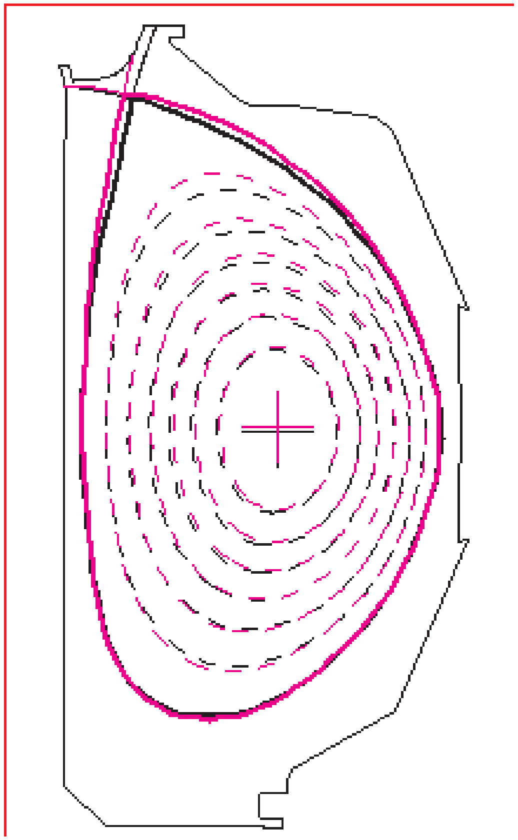
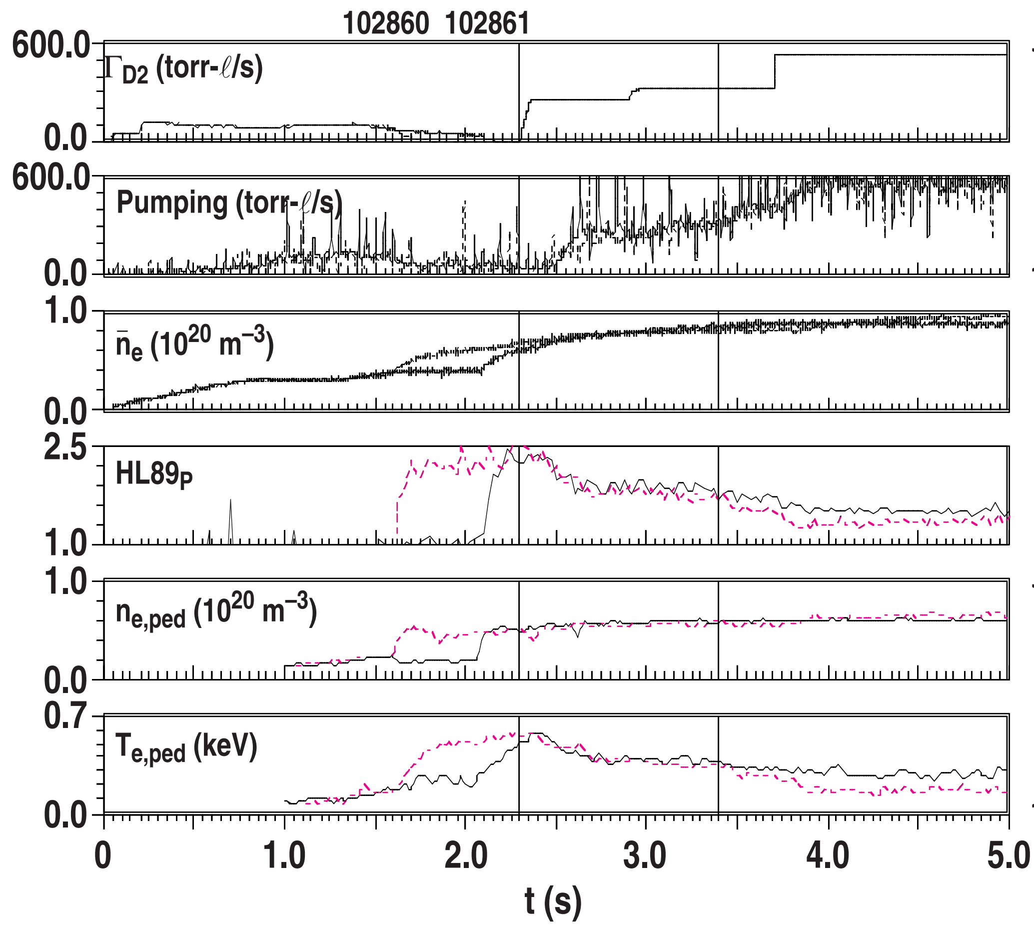
— WITH OUTBOARD PUMPING ONLY —

PUMPING IS FEASIBLE AT HIGH DENSITY DURING ELMING H–MODE OPERATION EVEN WHEN THE OUTER STRIKE POINT IS WELL AWAY FROM THE PUMPING DUCT

∇B PARTICLE DRIFT ⇑



I_P = 1.37 MA, B_T = 2.0 T, P_{INJ} = 4.6 MW



D2 puffing and pumping in approximate balance

Comparable $\bar{n}_e$

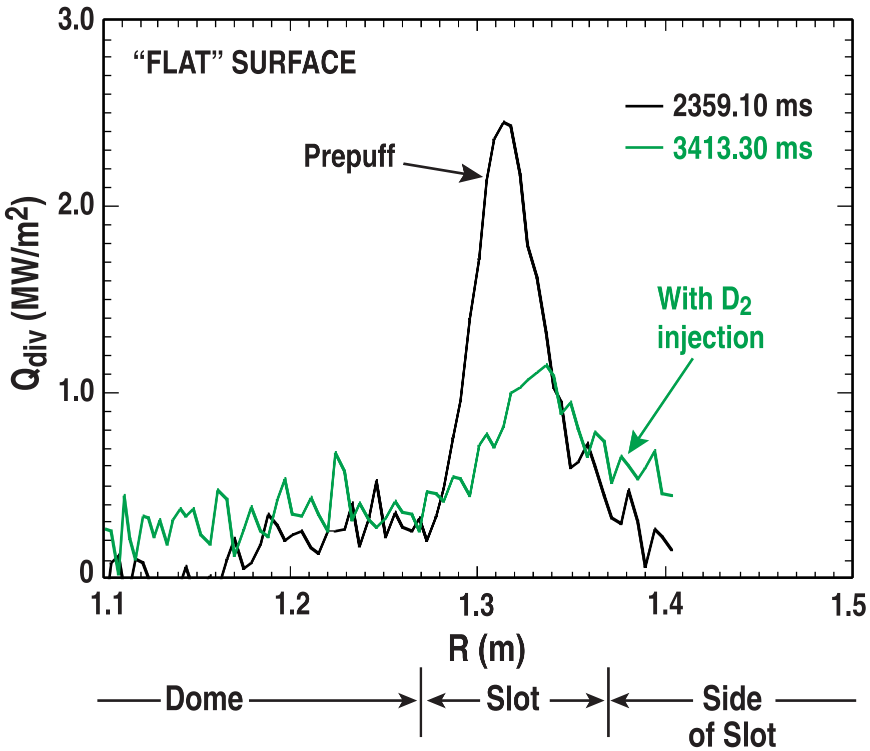
"Dome" confinement decreases first

Comparable $n_{e,ped}$ and $T_{e,ped}$ at $t \simeq 3.4$ s

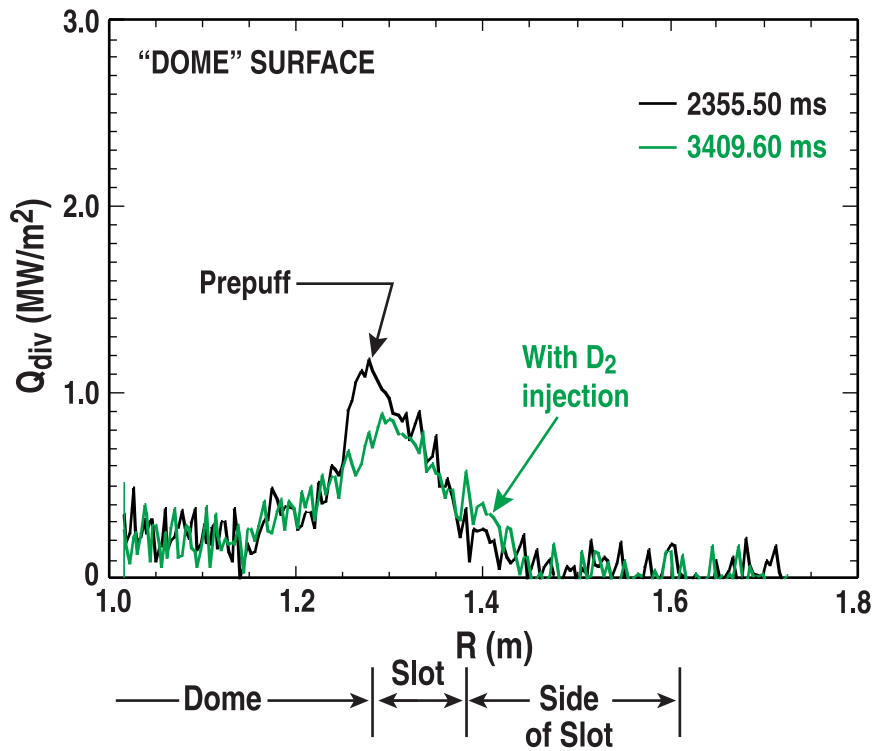
STEEPLY INCLINED DIVERTOR SURFACES ARE EFFECTIVE IN REDUCING HEAT FLUX IN LOW DENSITY, ATTACHED PLASMAS

- But "contouring" is of much less value for high density, detached plasmas.

Camera 6298 Pass 1 Shot 102860 Pol. Cut Line #141 Time 2359 ms



Camera 6298 Pass 1 Shot 102861 Pol. Cut Line #141 Time 2355 ms



$$Q_{div,S} \approx \frac{P_{heat} \times (1 - f_{rad}) \times f_{outboard/total} \times (1 - f_{pfr}) \times \sin(\alpha)}{2\pi \times R_S \times f_{exp} \times \lambda_{q||}}$$

where P_{heat} = 4.6 MW, R_S = 1.25 m, $f_{exp} \approx 5$, $f_{outboard/total} \approx 0.6$, $f_{pfr} \approx 0.1$, $\lambda_{q||} \approx 0.007$ m

FLAT CASE: $\alpha \approx 60°$, $f_{rad*} \approx 0.6 \rightarrow Q_{div,S} \approx 2.1$ MW/m^2

DOME CASE: $\alpha \approx 15°$, $f_{rad*} \approx 0.5 \rightarrow Q_{div,S} \approx 0.8$ MW/m^2

SUMMARY AND CONCLUSIONS

Without pumping

- Important performance measures in H–mode, such as the energy confinement time, core fueling, detachment density, and maximum density, are little changed by whether the divertor is OPEN or CLOSED
  - Detachment density and maximum H–mode density are weakly dependent on power input and either OPEN and CLOSED divertors
  - The higher recycling in the divertor but lower probability of neutrals leaking into the core plasma for the CLOSED plasma ⇒ similar fueling of the core plasma in OPEN and CLOSED divertors for these cases

- MARFE activity has been inferred in the high triangularity, baffled (CLOSED) divertor

  ⇒ Expect much of the physical understanding of Marfes and detachment from previous studies in the OPEN divertor to still apply here

SUMMARY AND CONCLUSIONS (Continued)

With pumping

- The evolution of $T_{e,ped}$ and τ_E with $n_{e,ped}$ during gas injection at high density is virtually identical with non-pumped cases

  ⇒ **Pumping was no more effective in achieving high density with good confinement than comparable discharges without pumping**

- Strong pumping is feasible in a high density, closed divertor even when the outer separatrix strike point is well away (and upstream) of the pumping duct

  ⇒ **Precise control over the strike point location is less of an issue than for lower density, attached plasmas**

- Sloped (or "contoured") divertor surfaces which spread out heat loading in the divertor are effective in reducing heat flux for lower density attached plasmas but much less effective at higher density

  ⇒ **The decision to make the effort and expense to contour the divertor structure may depend very much on the operating regime**