The Effect of Divertor Magnetic Balance on H-mode Performance in DIII-D

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The "magnetic balance" between divertors affects the behavior of core- and scrapeoff layer plasmas in several ways. For this presentation, we discuss:

- Heat flux ratios between divertors
- Particle flux ratios between divertors
- H-L density limit
- Response to gas puffing

⇒⇒⇒ ***No Active Particle Exhaust*** ⇐⇐⇐

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The Effect of Divertor Magnetic Balance on H-mode Performance in DIII-D[1] T.W. PETRIE, C.M. GREENFIELD, R.J. GROEBNER, A.W. HYATT, R.J. LA HAYE, A.W. LEONARD, A.M. MAHDAVI, T.H. OSBORNE, D.M. THOMAS, General Atomics, S.L. ALLEN, M.E. FENSTERMACHER, C.J. LASNIER, G.D. PORTER, N.S. WOLF, Lawrence Livermore National Laboratory, J.G. WATKINS, Sandia National Laboratories, AND THE DIII-D TEAM — We report on recent experiments for which the magnetic balance of Elming H–mode plasmas was systematically varied. We define "magnetic balance" in terms of DRSEP, which is the radial distance between the upper and lower divertor separatrices at the outboard midplane. The direction of the grad-B drift is toward the lower divertor. Near-steady behavior in energy confinement, density, and ELMing is observed over wide ranges in DRSEP, except near magnatic balance (*i.e.*, DRSEP $\simeq 0$), where changes in ELMing and higher energy confinement time are observed. While the highest density in H–mode ($n_{\mathrm{e,max}}$) is constant between DRSEP of –4 cm (*i.e.*, lower SN) and 0, $n_{\mathrm{e,max}}$ is 15%–10% lower for DRSEP > 1.5 cm. Heat flux sharing between the divertors is a strong function of DRSEP between –1.0 cm and +1.0 cm.

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[X] Prefer Oral Session
[ ] Prefer Poster Session

Special instructions: DIII-D Contributed Oral Session, immediately following TN Carlstrom

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MAIN POINTS

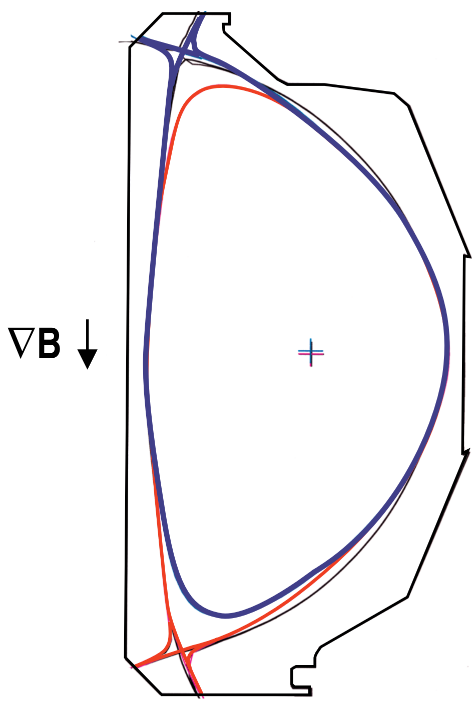
We find that changing the "magnetic balance" between divertors may result in:

- **Significant changes to the peak heat flux in each divertor**
- **Moderate changes to the peak particle flux in each divertor**
- **Variation in the H–L density limit**
- **Similar degradation in confinement with gas injection**

⇒⇒⇒ No active particle exhaust ⇐⇐⇐

SEPARATRIX CONFIGURATIONS ARE VARIED FROM LSN→DN→USN IN THIS STUDY

Upper divertor



Lower divertor

Common Parameters:

$I_p = 1.37$ MA

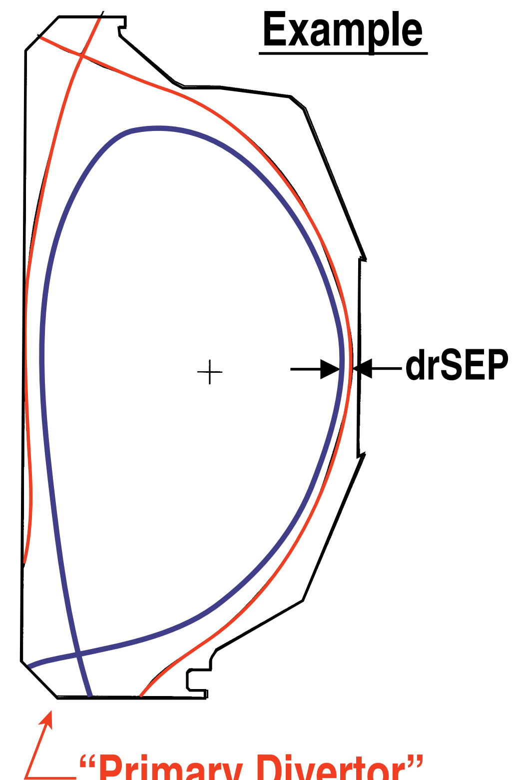
$B_t = 2.0$ T

$P_{in} = 4 - 8$ MW

$q_{95} \approx 4.5$

$\delta_{avg} = 0.8$ (DN)

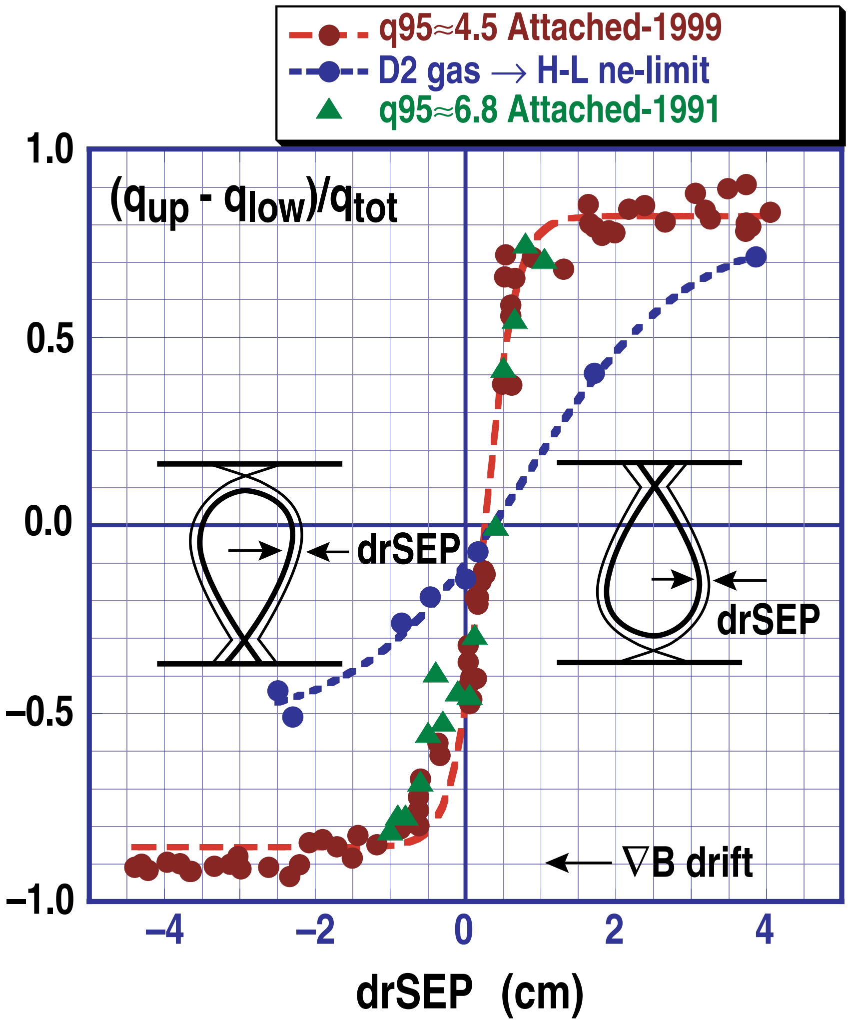
$\delta_{avg} = 0.6$ (SN)



drSEP > 0 (USN)
drSEP = 0 (DN)
drSEP < 0 (LSN)

— OUTBOARD DIVERTOR —

THE VARIATION IN HEAT FLUX SHARING IS LARGE FOR SMALL CHANGES IN drSEP NEAR DN



ATTACHED

- Heat flux "domination" shifts from one divertor to the other within ≈ 1 cm
- Peak heat flux balance at drSEP ≃ 0.25 cm
- Balance DN: $q^p_{low} \simeq 2 \times q^p_{up}$

DETACHED

- Transition is broader at high density (e.g., $n_e \simeq n_{e,H\text{–}L}$)
  — $q^p_{low} \simeq 1.2 \times q^p_{up}$

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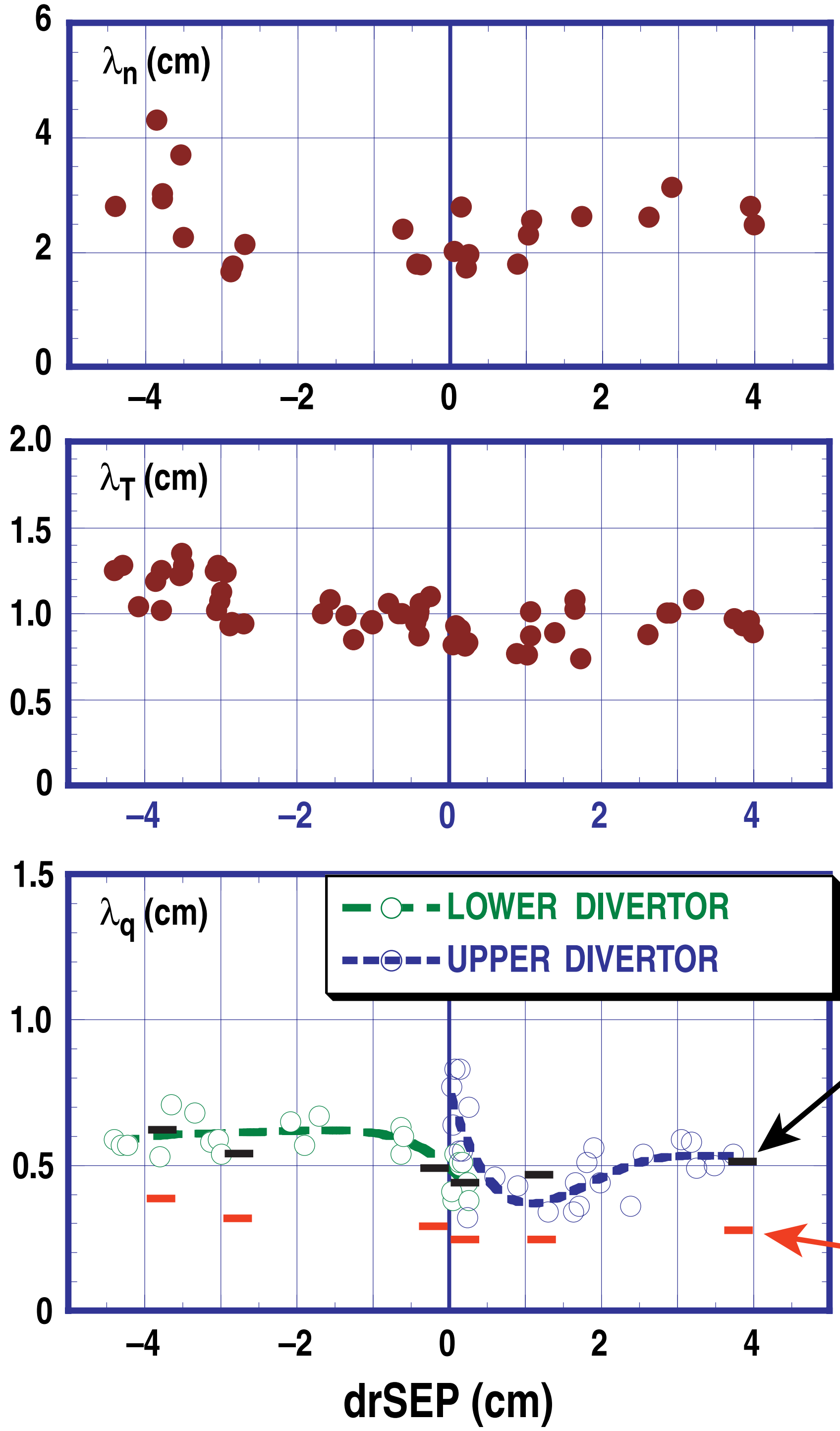
THE SCRAPE-OFF LENGTH OF THE PARALLEL DIVERTOR HEAT FLUX (λ_q) IS INSENSITIVE TO drSEP IN ATTACHED PLASMAS



"Upstream" λ_n & λ_T are mapped to the outer midplane

- $\lambda_n \approx$ 2-4 cm
- $\lambda_T \approx$ 0.8-1.3 cm

$\rightarrow \lambda_n \approx (2\text{-}3) \times \lambda_T$

Divertor heat flux is mapped from the primary divertor to the outer midplane

- Flux Limited Regime:

$$\lambda_q = \frac{1}{\frac{1}{\lambda_n} + \frac{1.5}{\lambda_T}}$$

Conduction Regime

$$\lambda_q = \frac{2}{7} \times \lambda_T$$

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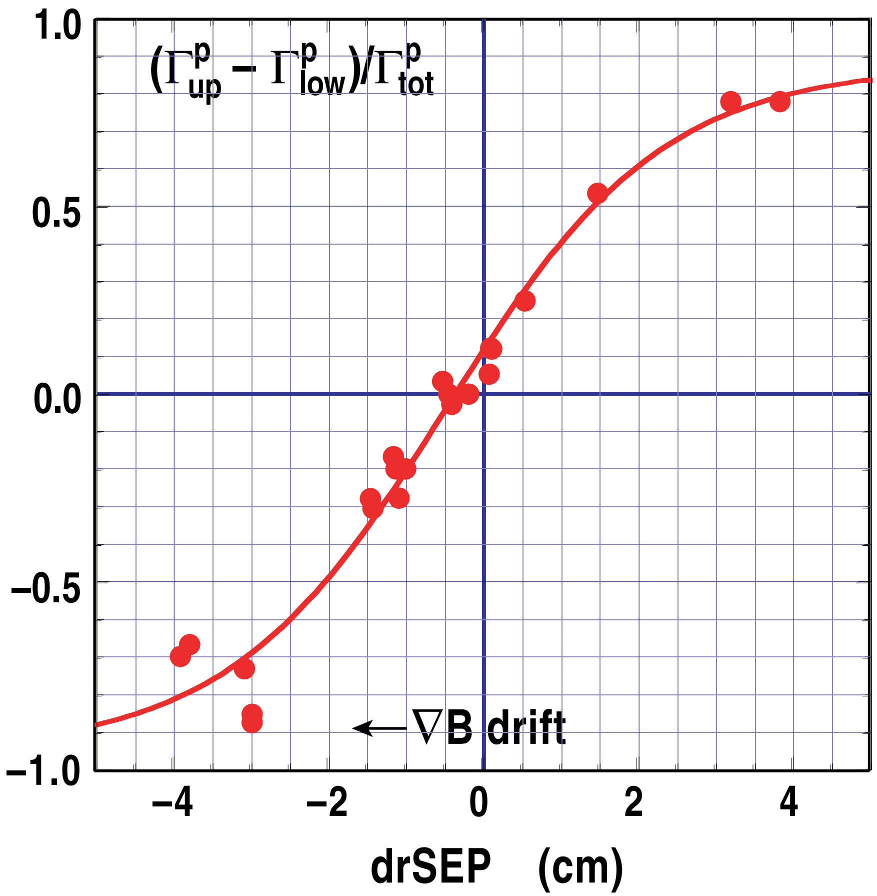
— OUTBOARD DIVERTOR —

THE SLOWER VARIATION OF PARTICLE FLUX WITH drSEP IS LIKELY DUE TO DIVERTOR PROCESSES



- Determined using Langmuir probes + strike point sweeping
- Balanced DN: $\Gamma^p_{up} \approx 1.2 \times \Gamma^p_{low}$
- Might expect a slower variation of λ_Γ with drSEP than λ_q
  - $\Gamma \propto n\sqrt{T}, \rightarrow \lambda_\Gamma \simeq 1$ cm
  - Figure implies: $\lambda_\Gamma \simeq 3$ cm

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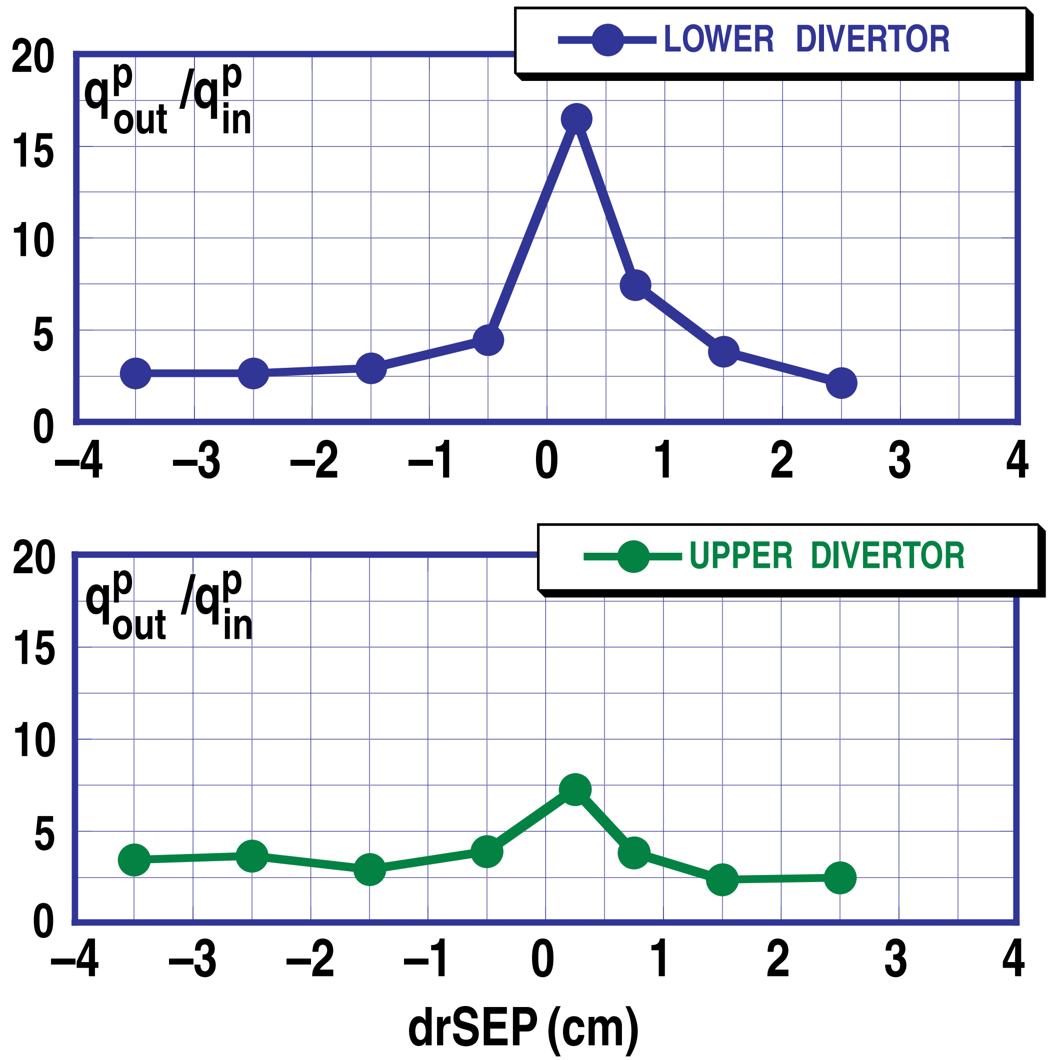
(See Watkins, JPI.06)

MOST OF THE HEAT FLUX GOES TO THE OUTBOARD DIVERTOR LEGS IN A BALANCED DN DIVERTOR



- $q^p_{out}/q^p_{in} \approx 2.5$ over most of drSEP in both upper and lower divertors.
- $q^p_{out} >> q^p_{in}$ for drSEP ≈ 0 in both upper and lower divertors.
  - Difference in the peaks believed due to E×B poloidal drift effects (Boedo, this session)
- Hypothesis:
  - Peak near drSEP = 0 is due to q^p_{in} becoming small via isolation of the inboard leg.

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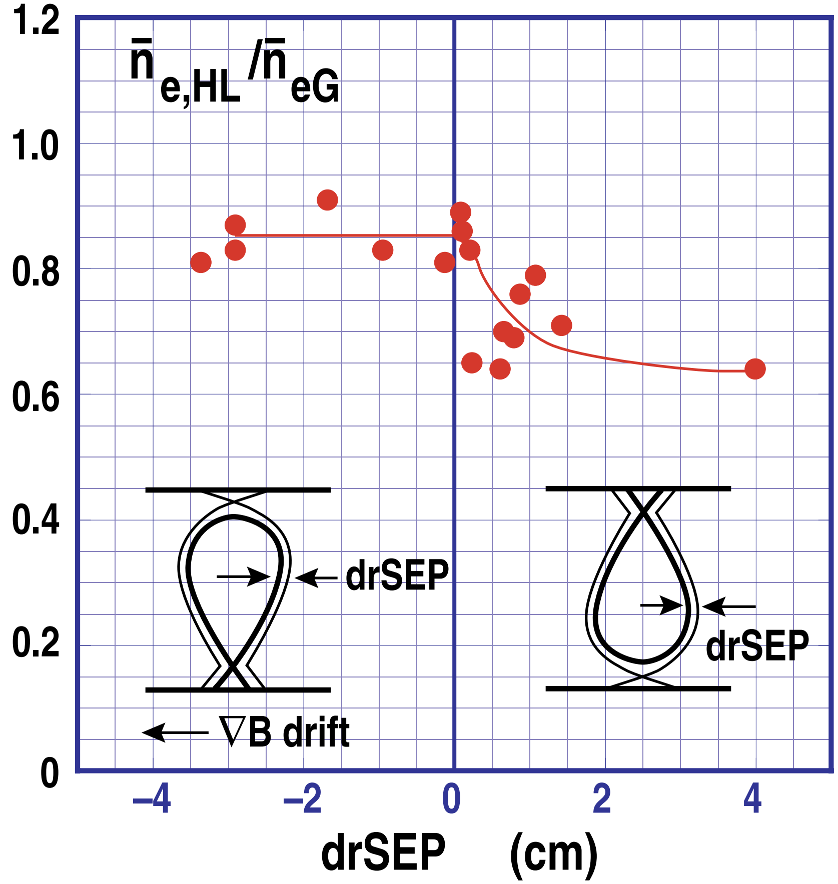
THE DENSITY AT THE H–L BACK TRANSITION IS LOWER FOR UNBALANCED DN BIASED AWAY FROM THE ∇B-DIRECTION



- $n_{e,HL}/n_{e,G}$ falls off between drSEP = 0 and +1 cm for moderate q_{95} (=4.5) case.
- Adequate control of drSEP for "high density" DN operation must be considered.

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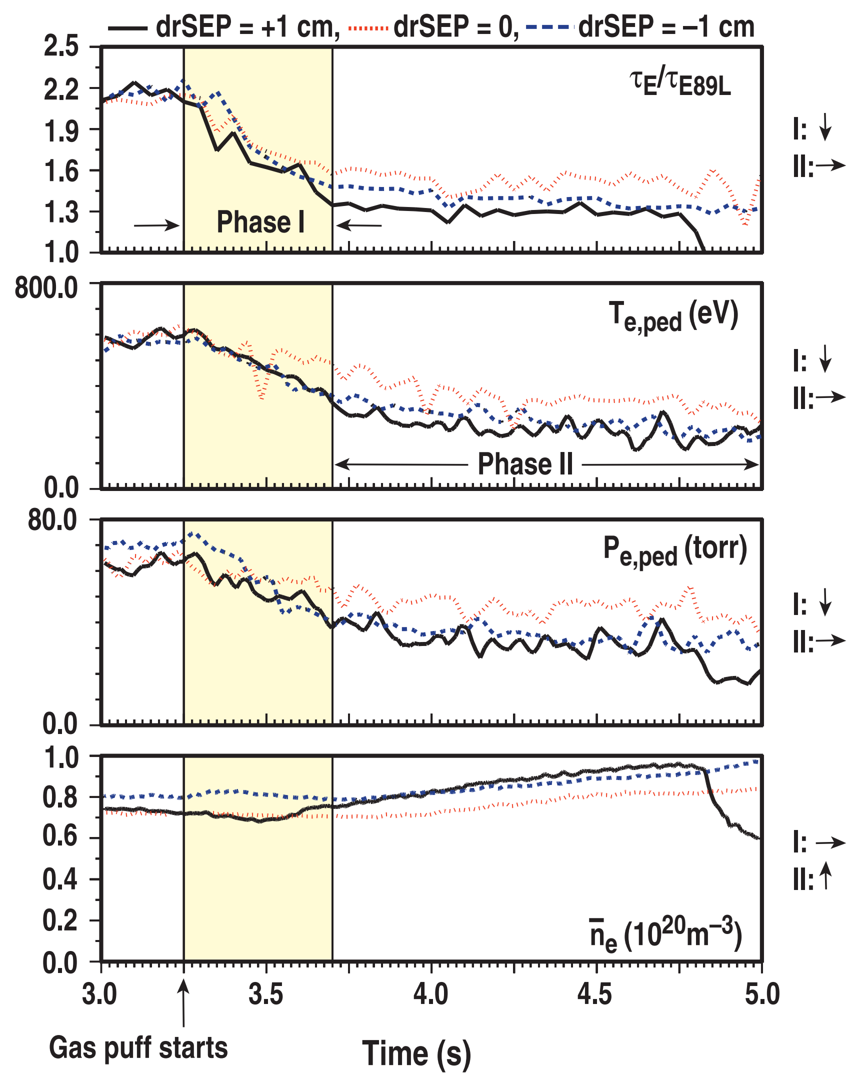
CONFINEMENT AND PEDESTAL CHARACTERISTICS DEGRADE WITH GAS PUFFING AT ALL VALUES OF drSEP

- For drSEP = –1cm (LSN), 0 (DN), +1 cm (USN)
  - ★ τ_E/τ_{E89p}, $T_{e,ped}$, and $P_{e,ped}$ decrease together after gas injection [Phase I]
  - ★ τ_E/τ_{E89p} $P_{e,ped}$ are essentially unchanged during Phase II
  - ★ Density does not increase until Phase II



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CONCLUSIONS

- Peak heat flux balance (up/down, in/out) is highly sensitive to variation in magnetic balance near DN in attached plasmas
  - Less sensitivity in magnetic balance for detached plasmas
- H$\rightarrow$L density limit drops 15-20% between DN and drSEP = +1 cm (USN)

  $\Rightarrow$ Adequate control over the magnetic balance DN may be important at high density
- Similar degradation of τ_E with gas injection was seen for all drSEP values
  - These are unpumped plasmas but pumping may allow high density with good confinement (Osborne, this session)
- Particle flux to the outboard divertors is less sensitive to changes in magnetic balance

  $\Rightarrow$ Magnetic balance control may be less critical to particle pumping