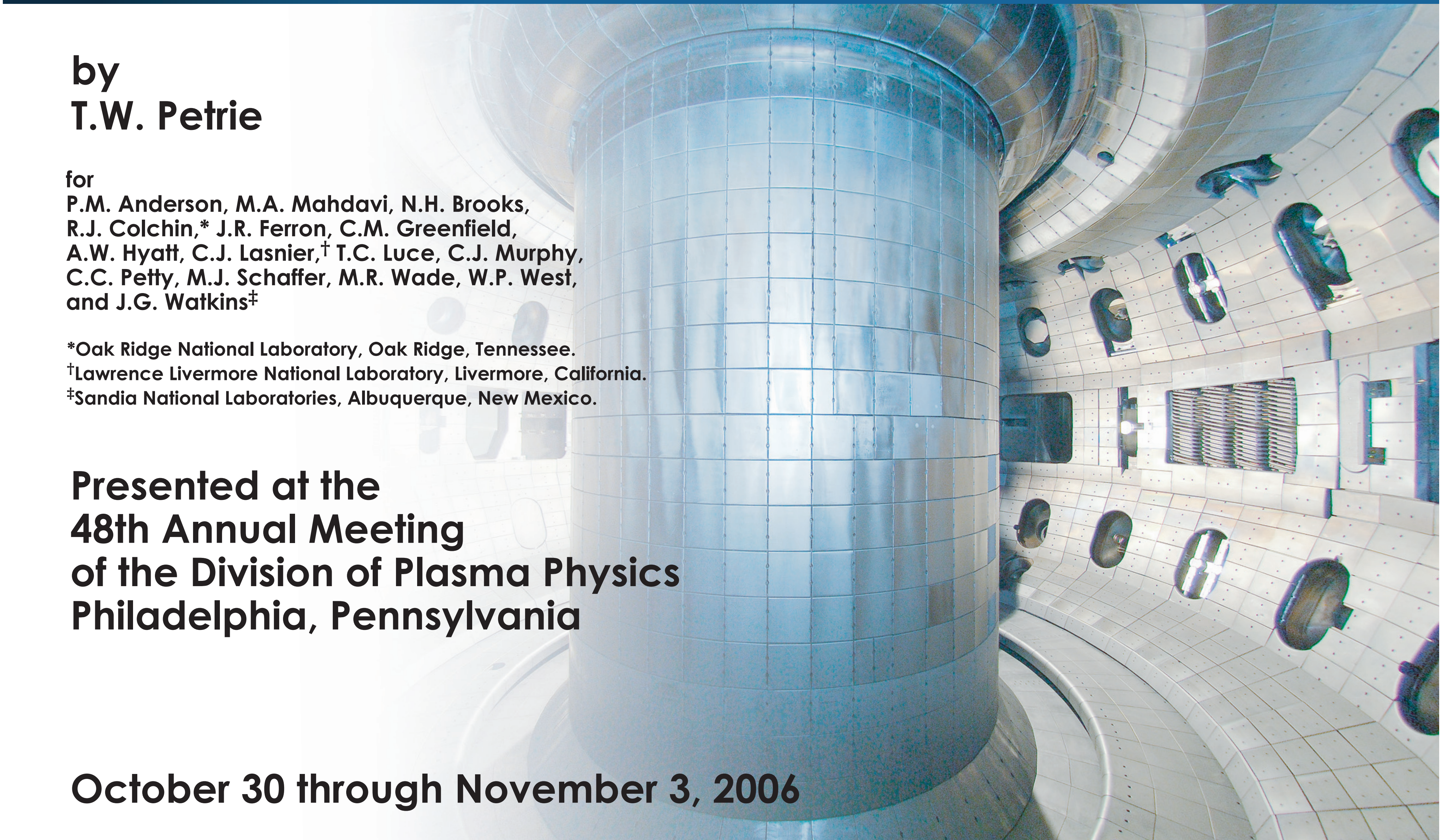
# Density Control Using the New Divertor Pumping Configuration in DIII-D




by
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for
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GENERAL ATOMICS

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# The Changes to the Pumping Configuration Were Driven by the DIII–D Advanced Tokamak Program

- **High performance “AT” plasmas benefit from:**
  – High triangularity ($\delta$), double-null (DN) shaping → higher $f_{bs}$ and $\beta_N$
  – Application of ECCD ($\propto 1/n_e$)
    → Shape/maintain favorable current density profiles
    → Achieve 100% non-inductive current

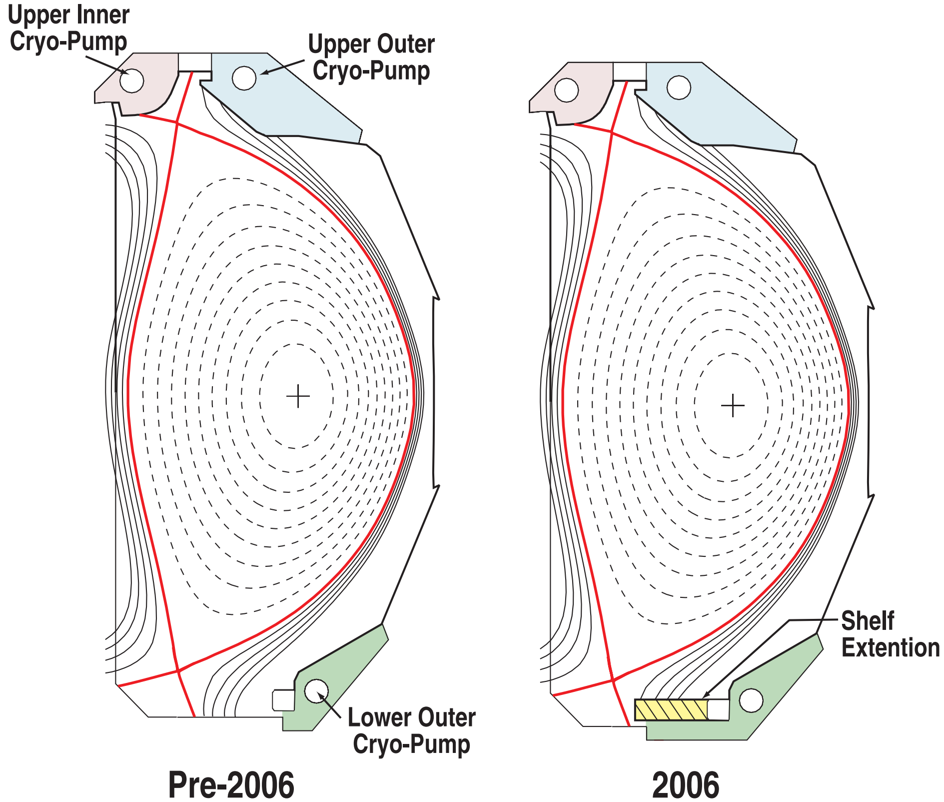
- **Density control in a high-$\delta$ DN shape is difficult to maintain if active particle exhaust is limited to only one divertor (pre-2006)**
    → Solution: Modify hardware for pumping high $\delta$, DNs from both divertors

- **Changes to the lower divertor pumping configuration were made during the 2005-2006 vent to implement this solution**

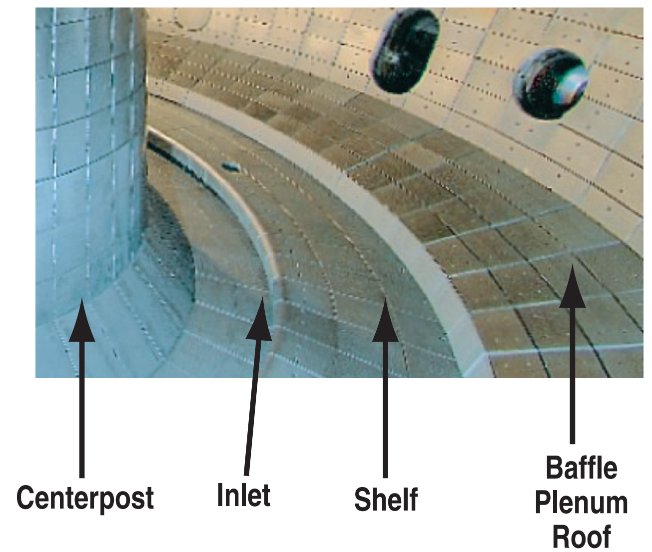
- **The new pumping configuration has improved density control in DN and near-DN shapes**

# Recent Modifications to the Lower Divertor Makes it Possible to Pump High-δ DN Plasmas from Both Divertors

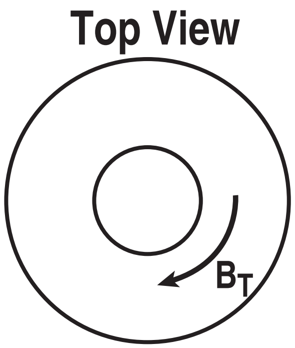
- Prior to 2006, the lower divertor cryopump was poorly situated for removing recycled neutral particles from high δ, symmetric DNs
- A shelf extension was installed in 2006 to serve as a conduit for neutrals between the lower outer divertor target and the pumping plenum

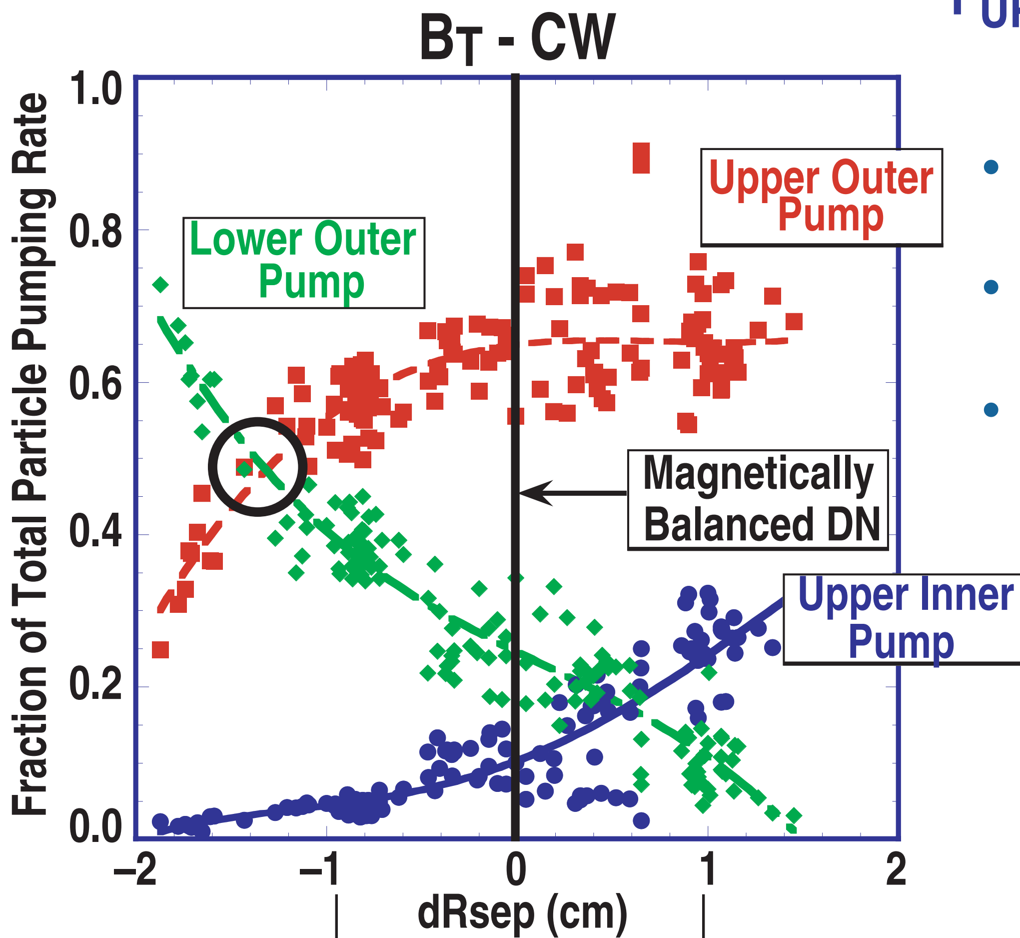


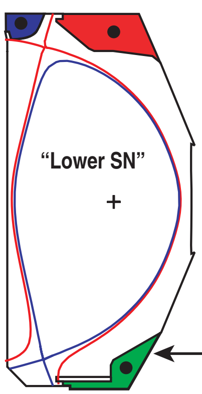

Lower Divertor (2006)

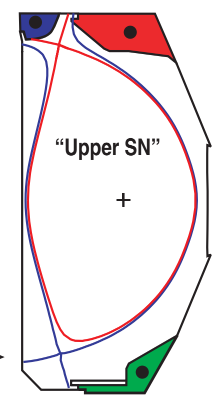


# The Fractional Contribution of Each Cryopump to the Total Particle Exhaust Rate Depends on the Magnetic Balance



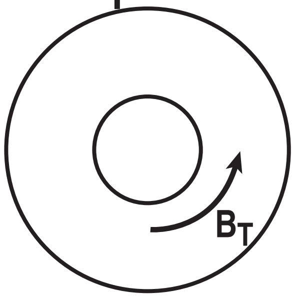



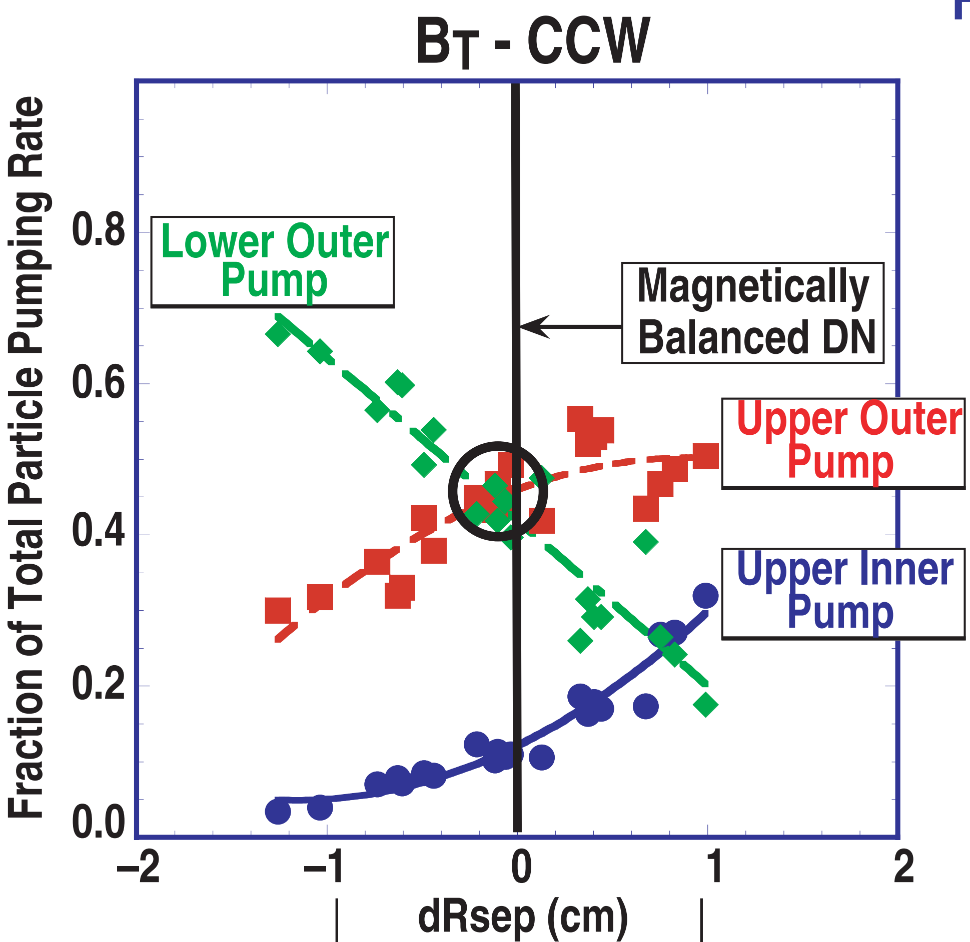

$F_{UP\text{-}IN} + F_{UP\text{-}OUT} + F_{LO\text{-}OUT} = 1$

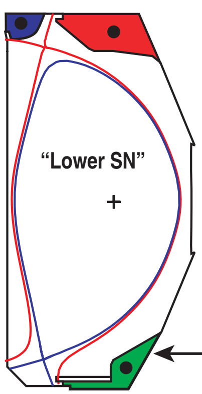
- DN: $F_{UP\text{-}OUT} > F_{UP\text{-}IN}$ & $F_{LO\text{-}OUT}$
- DN: $\dfrac{F_{UP\text{-}OUT}}{F_{LO\text{-}OUT}} \simeq 2.5$
- DN: $F_{UP\text{-}IN}$ removes ≈10% of total pumped particles

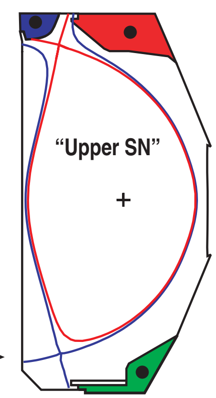
# Reversing the Direction of $B_T$ Significantly Affects the Fractional Contributions of the Two Outer Pumps

Top View



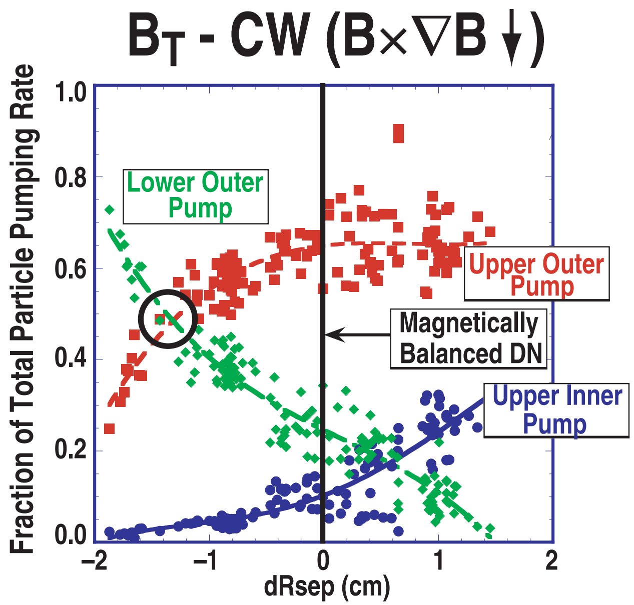



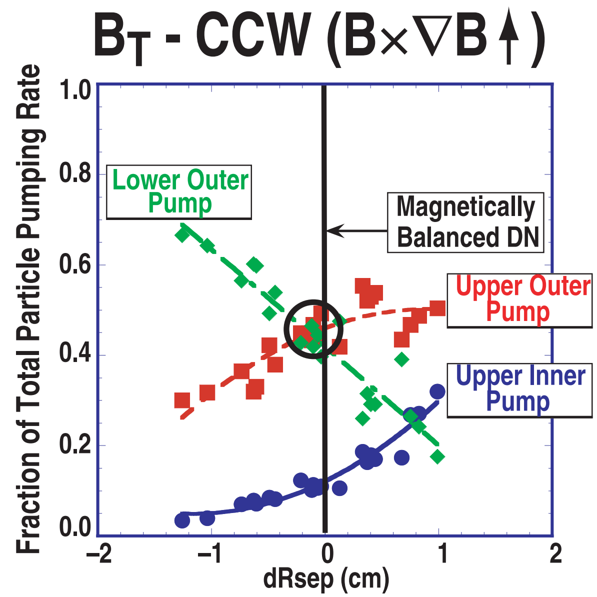



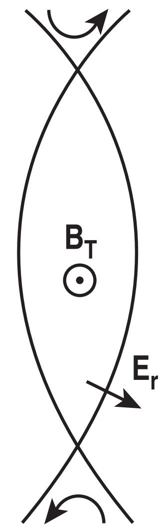

$F_{UP\text{-}IN} + F_{UP\text{-}OUT} + F_{LO\text{-}OUT} = 1$

- DN: $F_{UP\text{-}OUT} \simeq F_{LO\text{-}OUT}$ near DN
- DN: $F_{UP\text{-}IN}$ is still ≈10%

# Both Particle Drifts and Divertor Geometry Appear to be Important Factors in Pumping Behavior



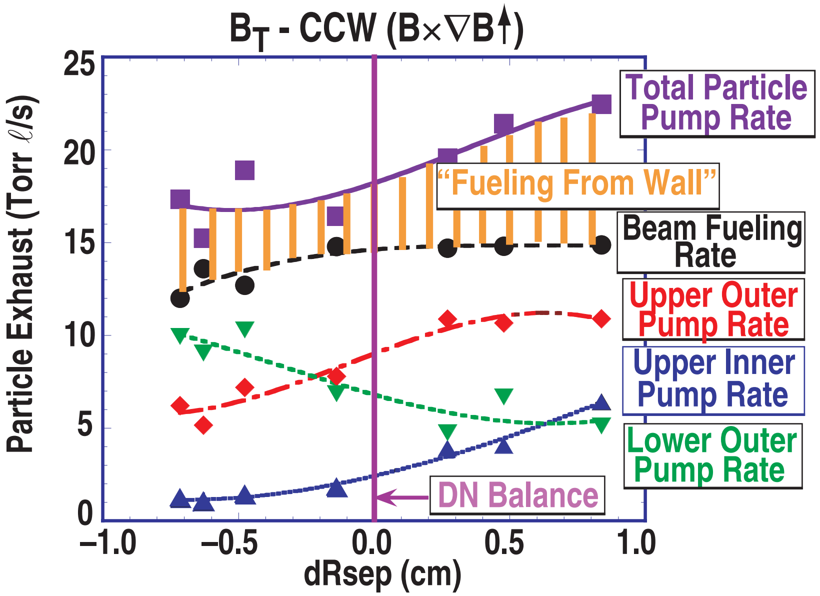



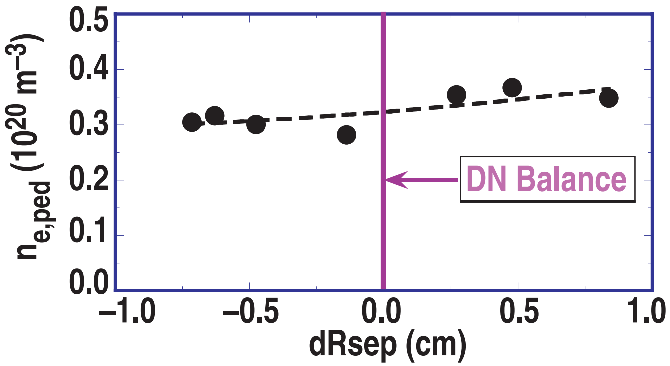

- **The difference in pumping "crossover" locations in the CW and CCW cases is qualitatively consistent with the roles of particle drifts in the SOL and divertor***
  - $B_T$ - CW → B×∇B↓, $B_T$ - CCW → B×∇B↑

- **But still not symmetric around dRsep=0: May be due to differences in geometry between upper and lower divertors (e.g., neutral particle trapping)**

***T.W. Petrie, et al., Nucl. Fusion <u>46</u> (2006) 57**

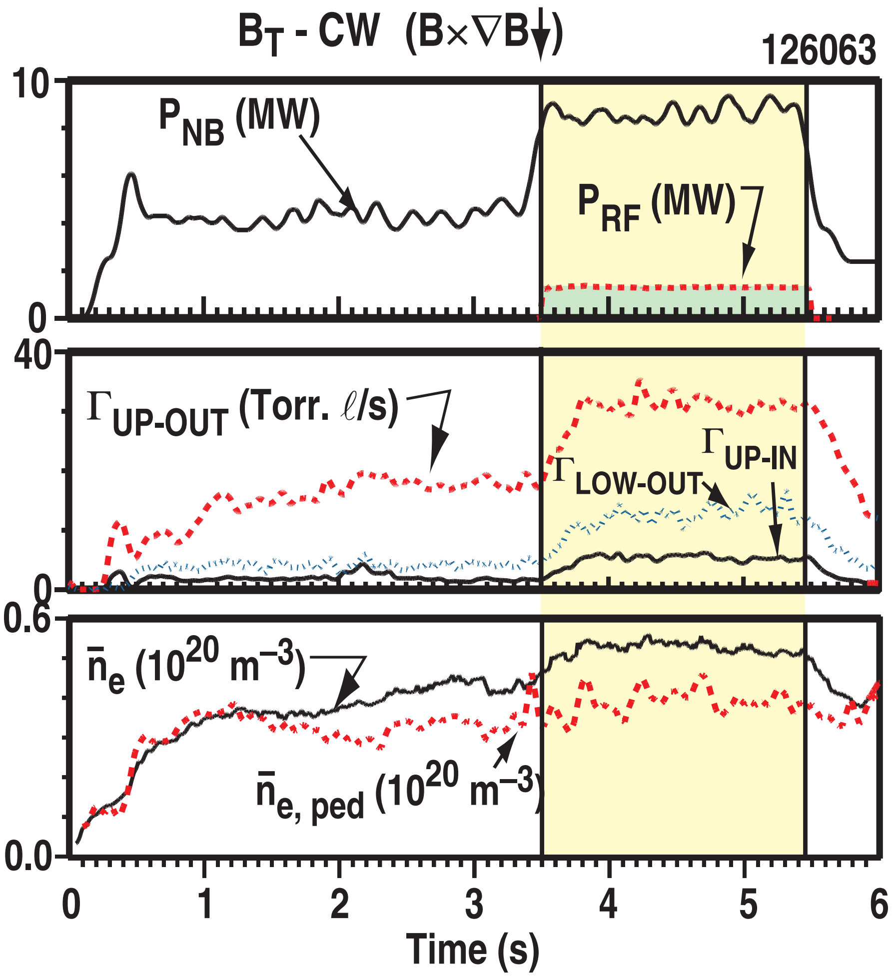
# Particle Pumping and Low Plasma Density Can Be Maintained in Both Upwardly Biased and Downwardly-Biased DN Shapes



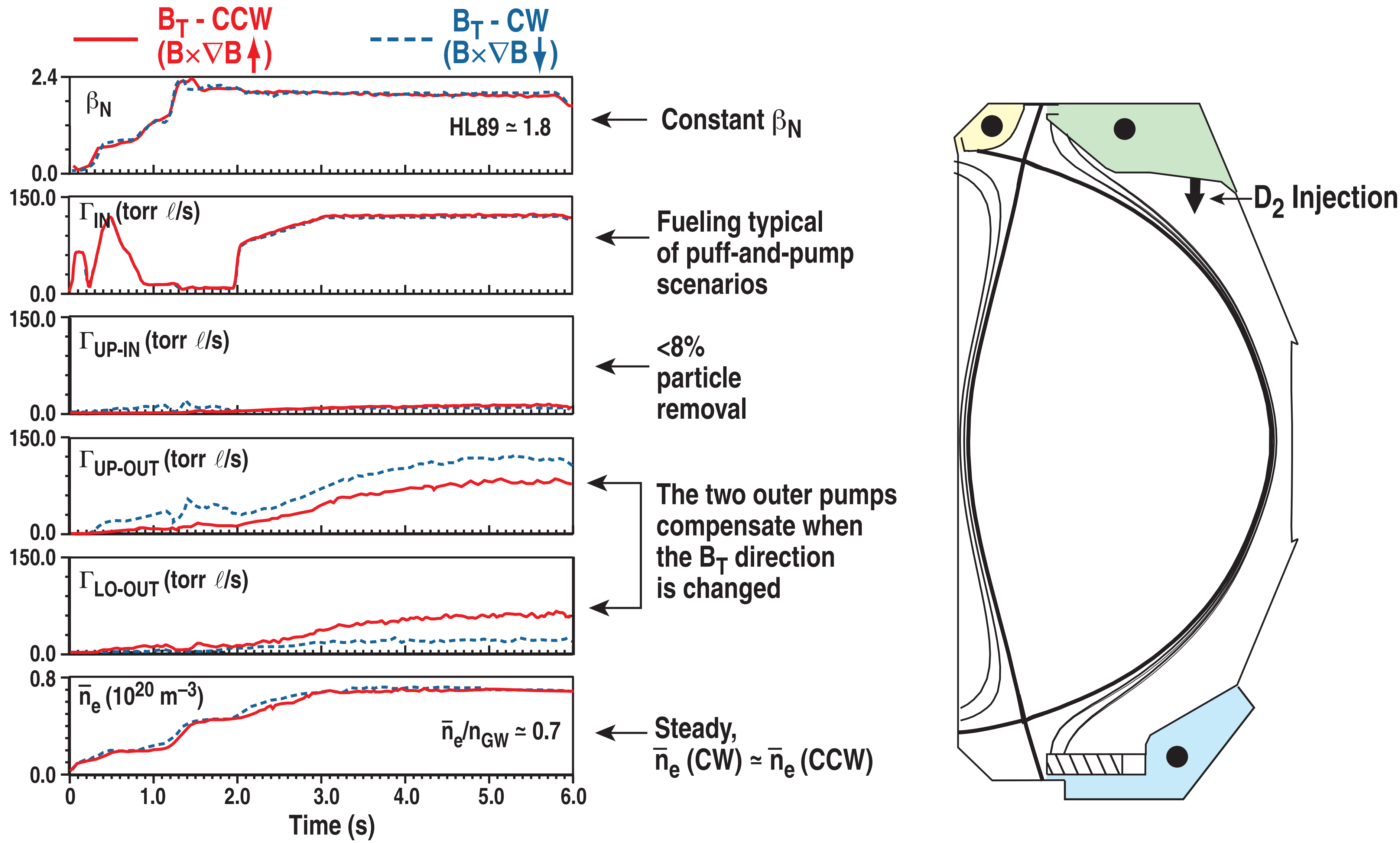

- The total particle pumping rate was greater than the particle fueling rate from the beams
  - ⇒ The "wall" was a source of particles at the time of measurement
- The combined particle exhaust of the two outer pumps remained nearly constant as dRsep was changed near DN
- The pedestal density was fairly insensitive to changes in magnetic balance

# Initial Results at Controlling Density in DN AT Plasmas are Encouraging




- → $\beta_N \simeq 3.6$, HL89 = 2.6 during the high power phase
- Lower outer pump makes an important (≈30%) contribution to particle control
- $\bar{n}_e$ and $n_{e,ped}$ are steady, and they are ≈20% lower than previous DN densities with upper pumps only

# The Modified Pumping Configuration Makes it Possible to do Experiments involving High Gas Throughput in High-$\delta$ DN Plasmas for Both $B_T$ Directions



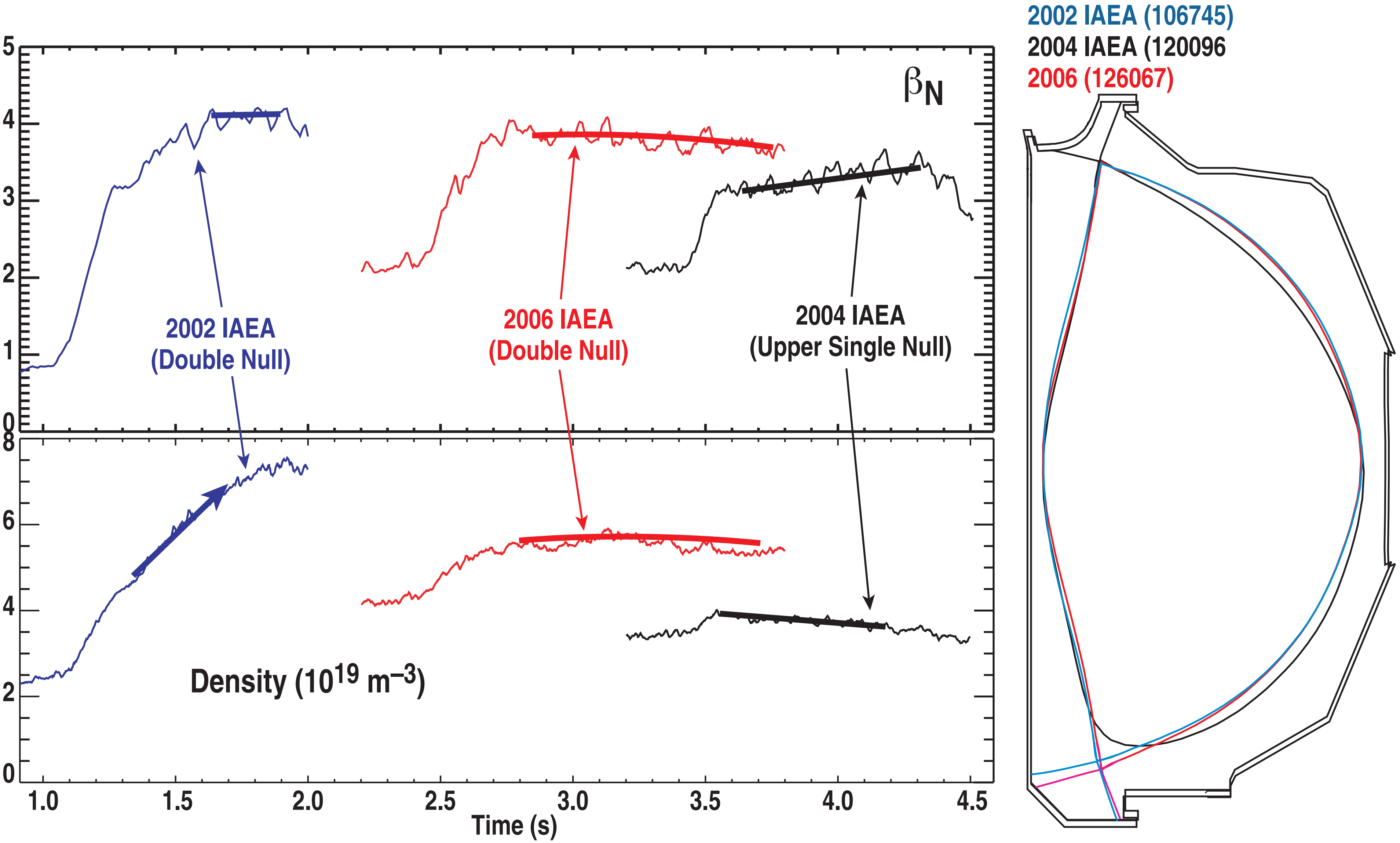
# Summary and Conclusion

- **Simultaneous particle pumping from both upper and lower divertors of high triangularity, DN plasmas is now possible in DIII–D**
  – Characterized pumping WRT two key parameters: dRsep and $B_T$ - direction
  – Demonstrated density control in high performance AT plasmas

- **In addition to its value to the AT program, the new pumping capability is able to handle high gas throughput scenarios in DN and near-DN shapes, e.g, Puff and Pump in DN***

***T.W. Petrie, IAEA FEC 2006**

# New Lower Divertor Has Enabled Improved Density Control in High β, Double Null Plasmas

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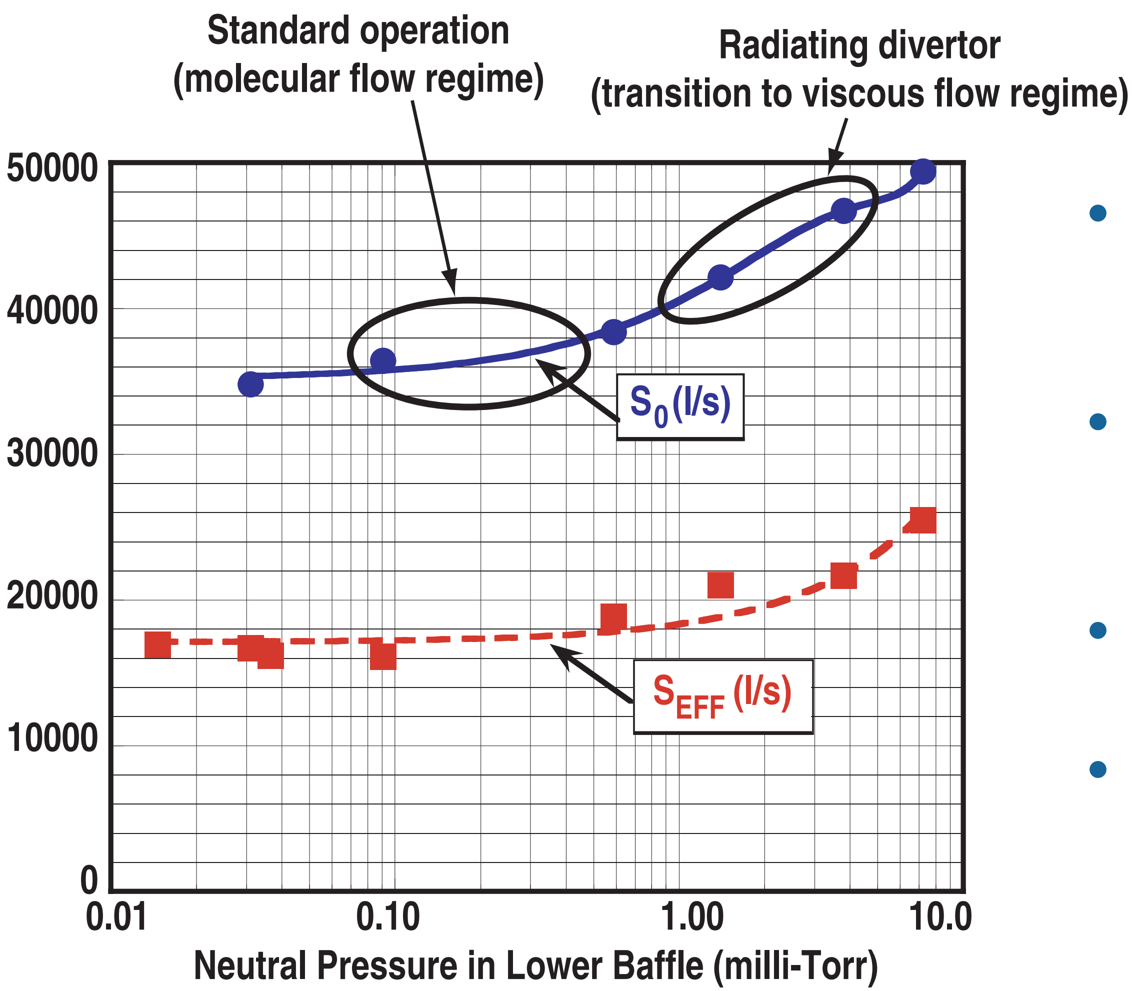
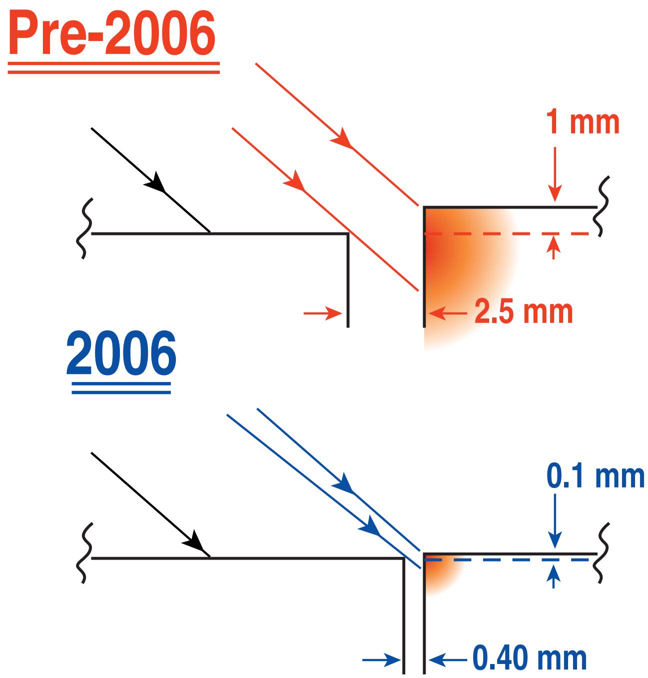
271-06/MW/jy

# DIII–D Plasma Operation Produces a Wide Range in Neutral Pressure Inside the Lower Divertor Baffle



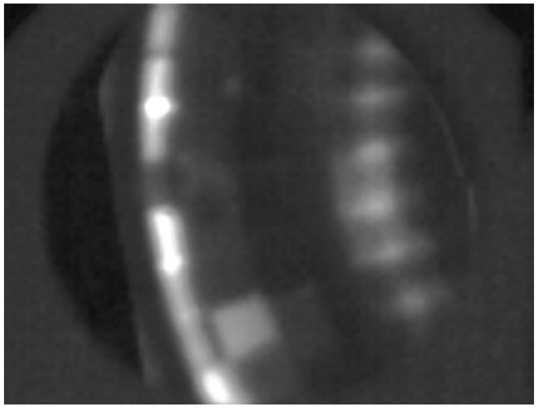

- $S_o \Rightarrow$ pumping speed of pump
- $S_{EFF} \Rightarrow$ effective pumping speed
- $S_{EFF} \simeq 0.5 \times S_o$
- Conductance is matched to $S_o$

# Divertor Tile Heating is Much More Uniform in the New Lower Divertor



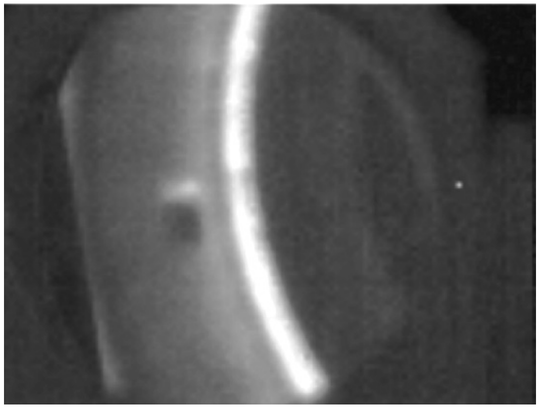

- Reduced tile gaps to ≈ 0.4 mm
- Alignment of tiles to $\lesssim$ 0.1 mm height differential

**Infrared Light**



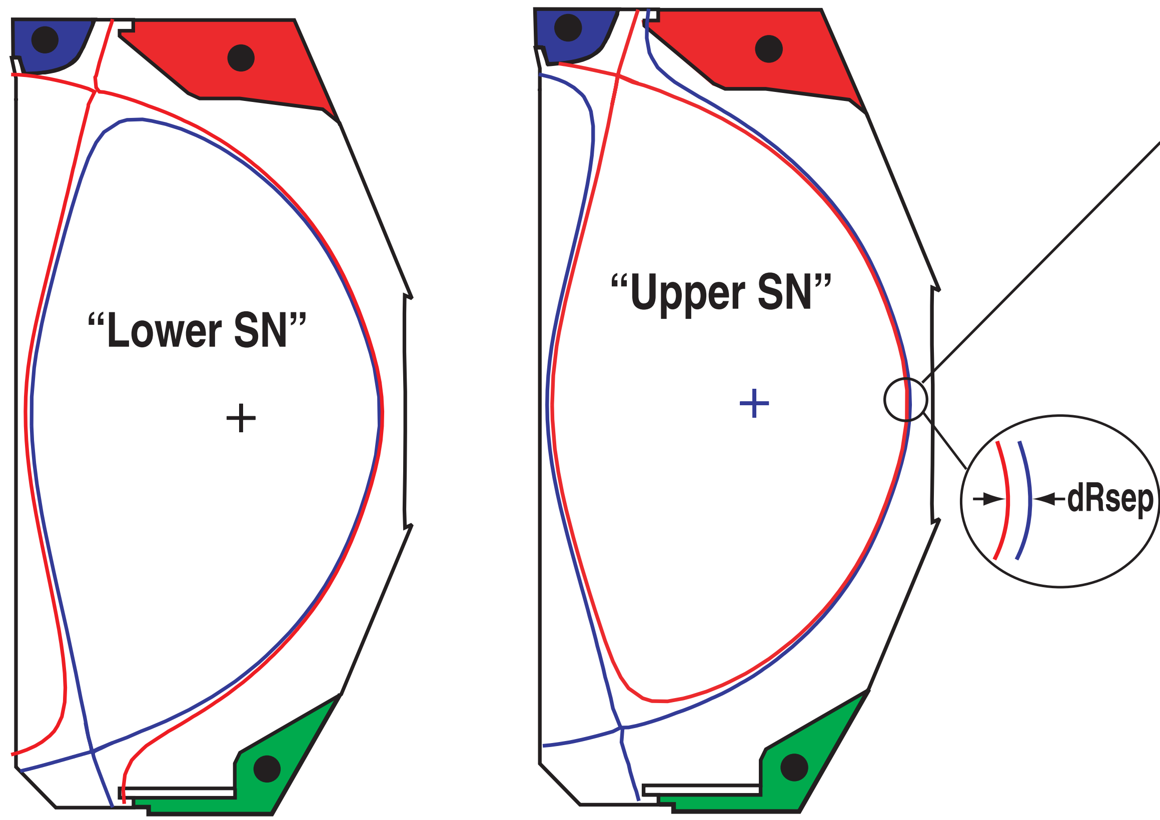
2005

Outer Strike Point   Inner Strike Point



2006

# Definition of Magnetic Balance




dRsep = –0.9 cm

dRsep = +0.9 cm

$dRsep = R_{LOW} - R_{UP}$

$R_{LOW}$ = major radius of the lower divertor separatrix flux surface at the outer midplane

$R_{UP}$ = major radius of the upper divertor separatrix flux surface at the outer midplane