# Particle Exhaust & SOL Conditions During ELM Suppression Using Resonant Magnetic Perturbations (RMPs) on DIII-D


Present by

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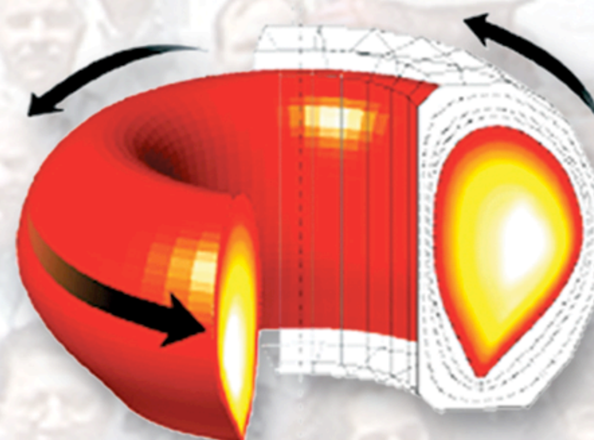

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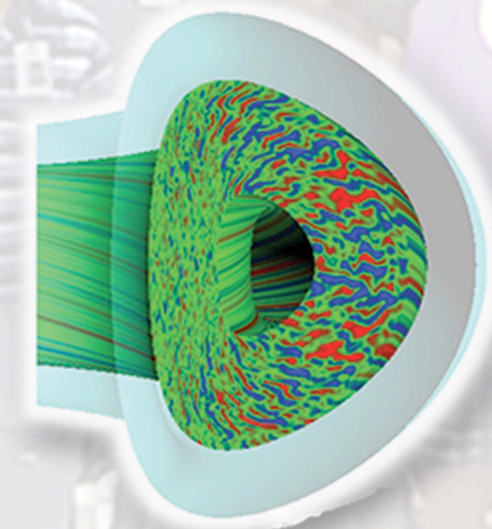
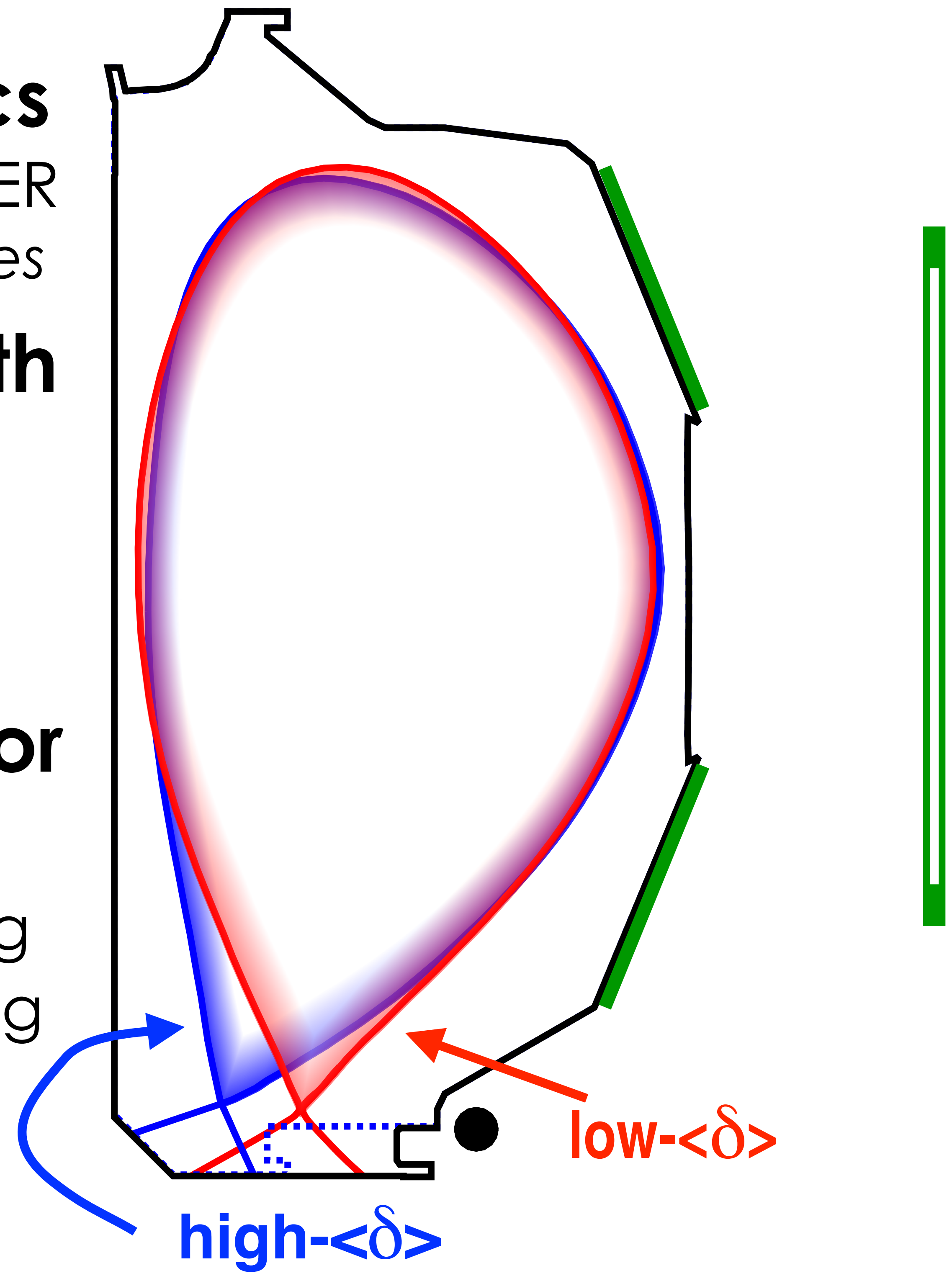


DIII-D NATIONAL FUSION FACILITY

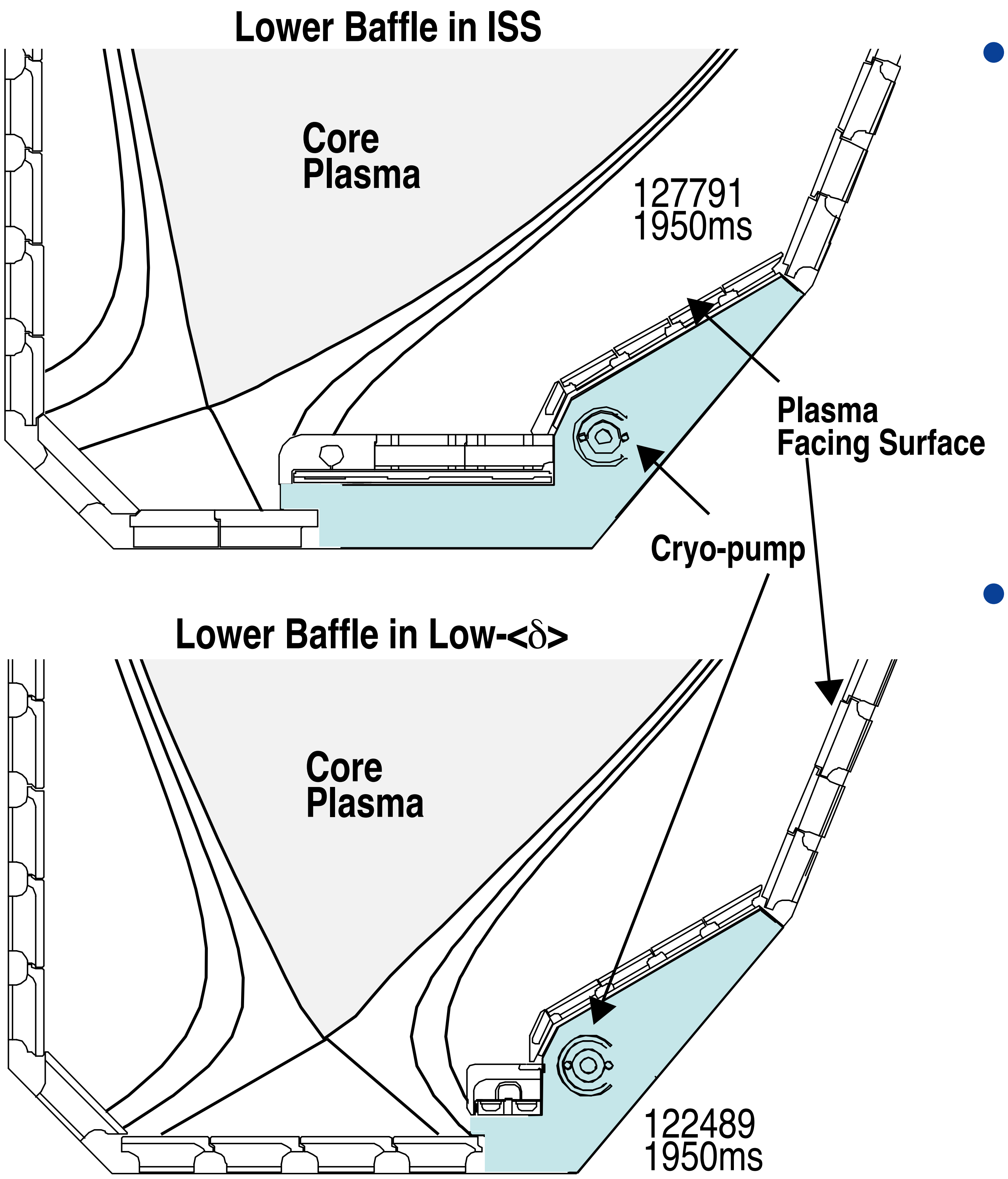
OAK RIDGE National Laboratory

# Overview: Particle Exhaust & SOL Conditions Are Significantly Effected by Divertor Geometry + RMP

- **RMP experiments in DIII-D have variety of boundary characteristics**
  - Similar shape (<δ>) and pedestal-$\nu^*_e$ to ITER
    - *Termed ITER Similar Shaped (ISS) discharges*
- **Particle exhaust characterized with global particle balance**
  - Graphite walls are significant at low-<δ>
  - Cryo-pumps dominant at hi-<δ>
- **Exhaust depends on RMP & divertor geometry details**
  - Edge plasma conditions ⇒ Cryo-pumping
  - Magnetic geometry ⇒ Strikepoint splitting
  - Main ion species ⇒ RMPs in helium discharges



# Upgraded Lower Baffle Gives Closed Divertor Geometry




- **Lower baffle structure extended in 2005**
  - Allows pumping on ISS discharges
  - Minimal effect on $S_{pump}$ & baffle conductance
- **More 'closed divertor' in ISS geometry**
  - Allows SOL plasma acts as 'plug' for exhausted neutrals

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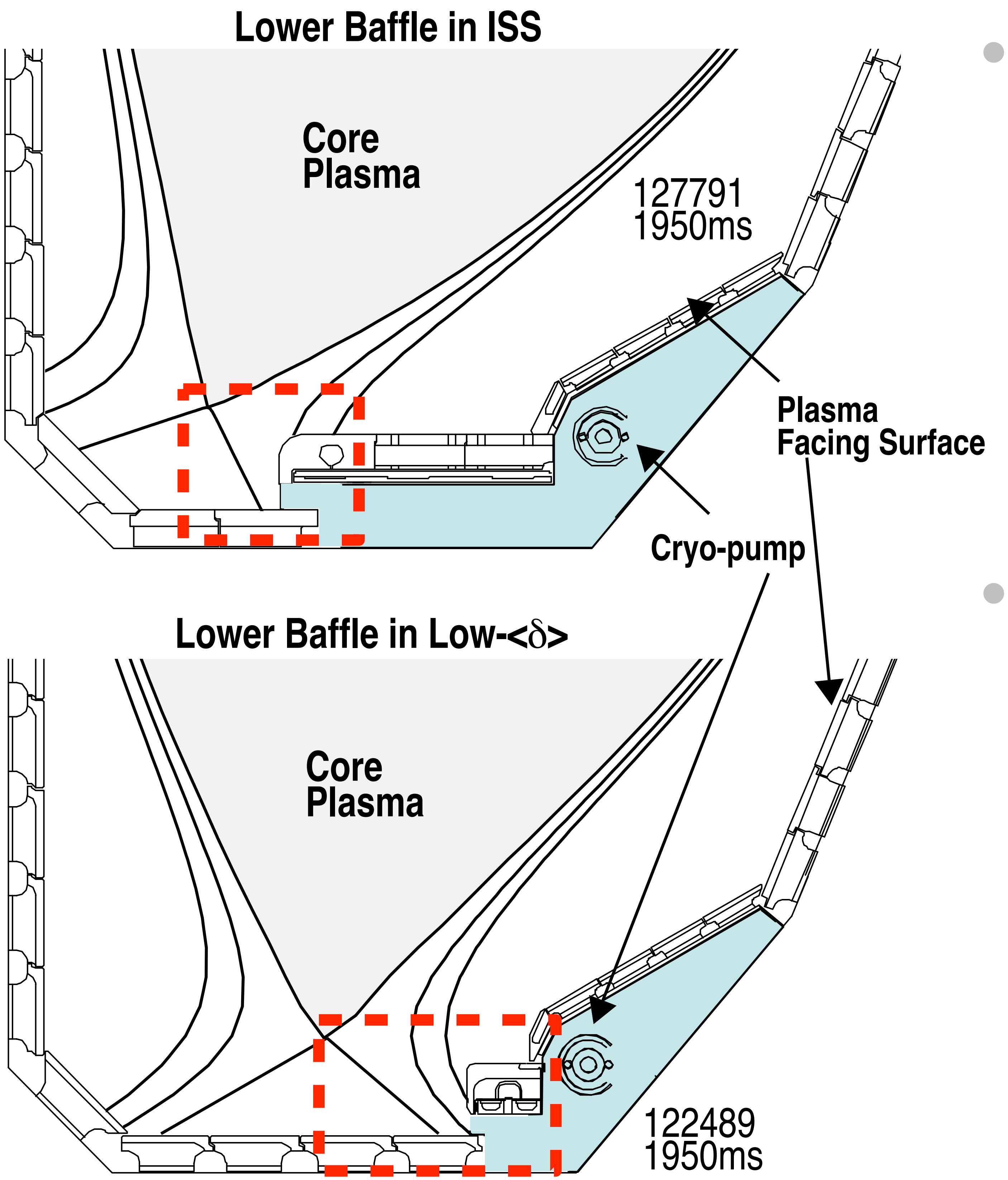


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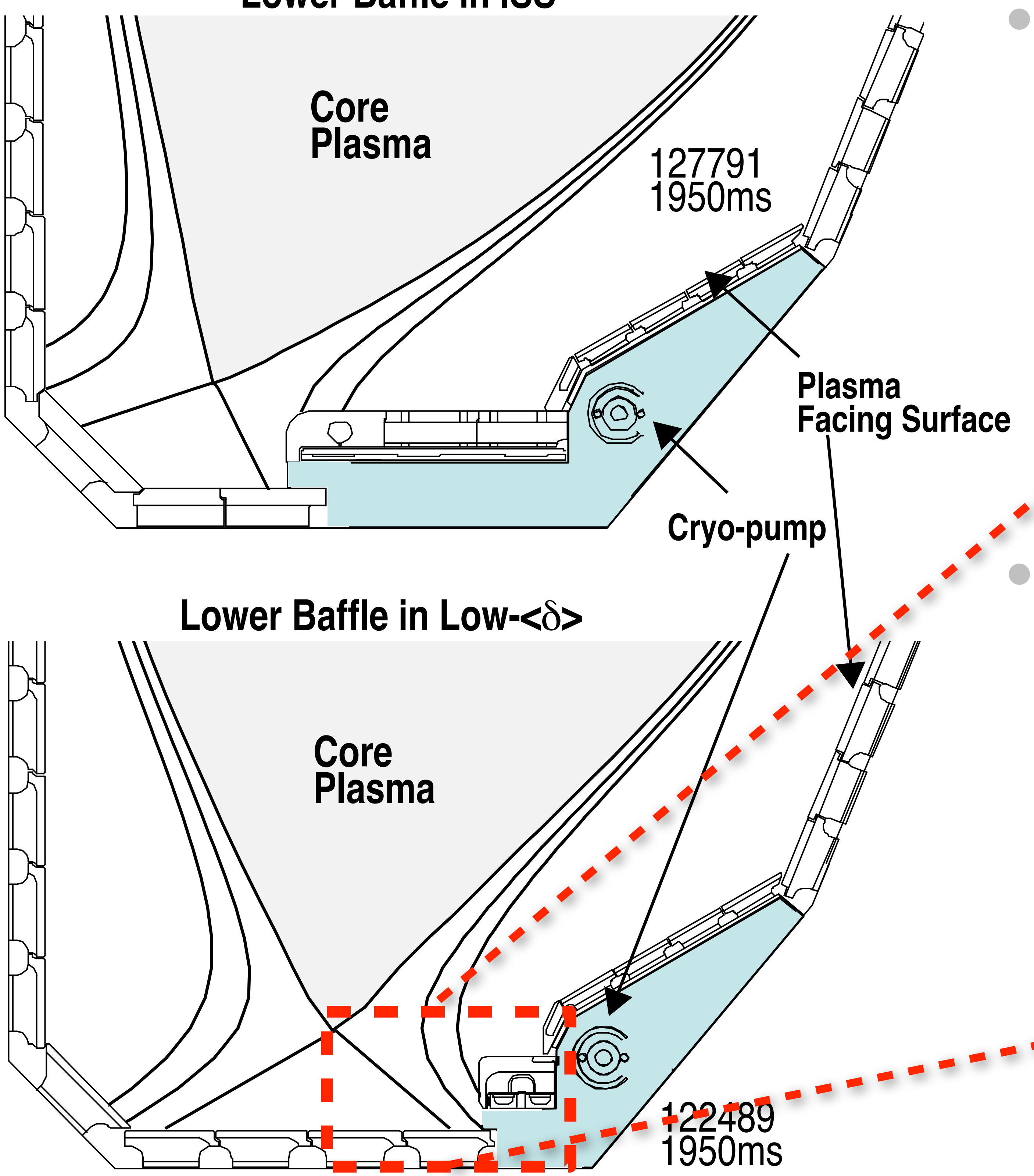


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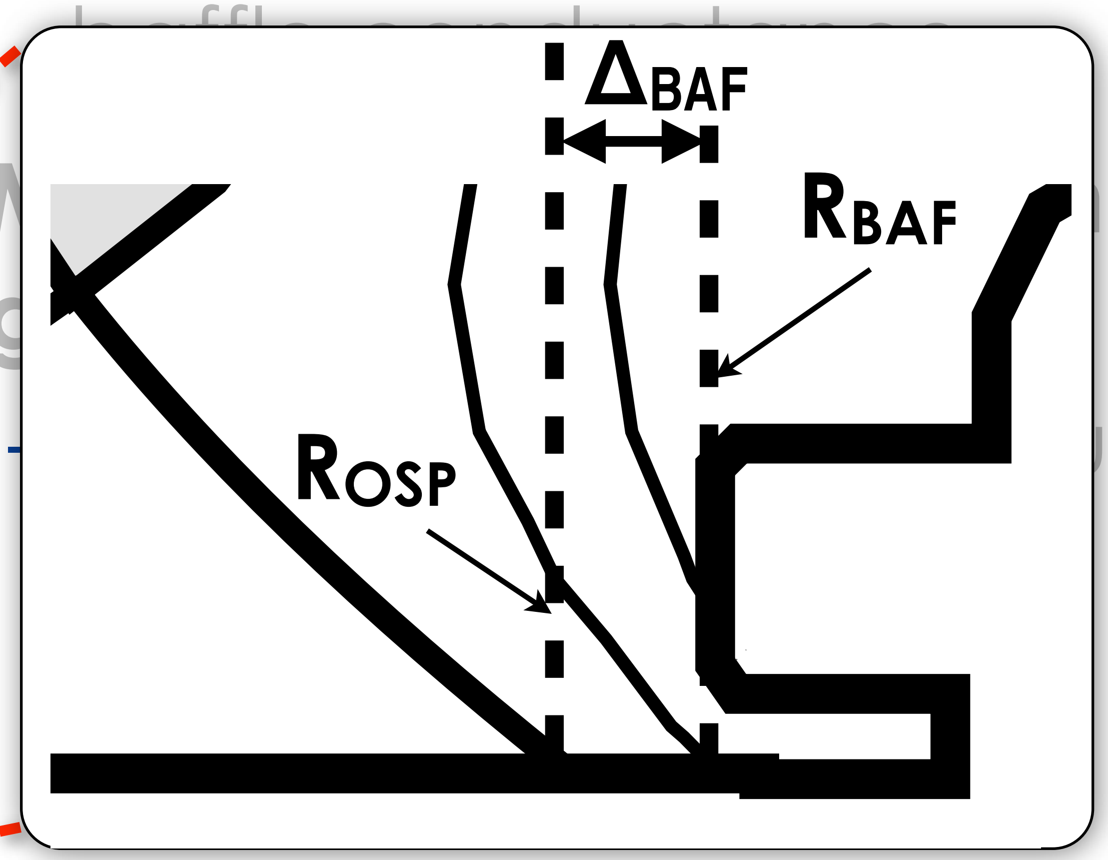
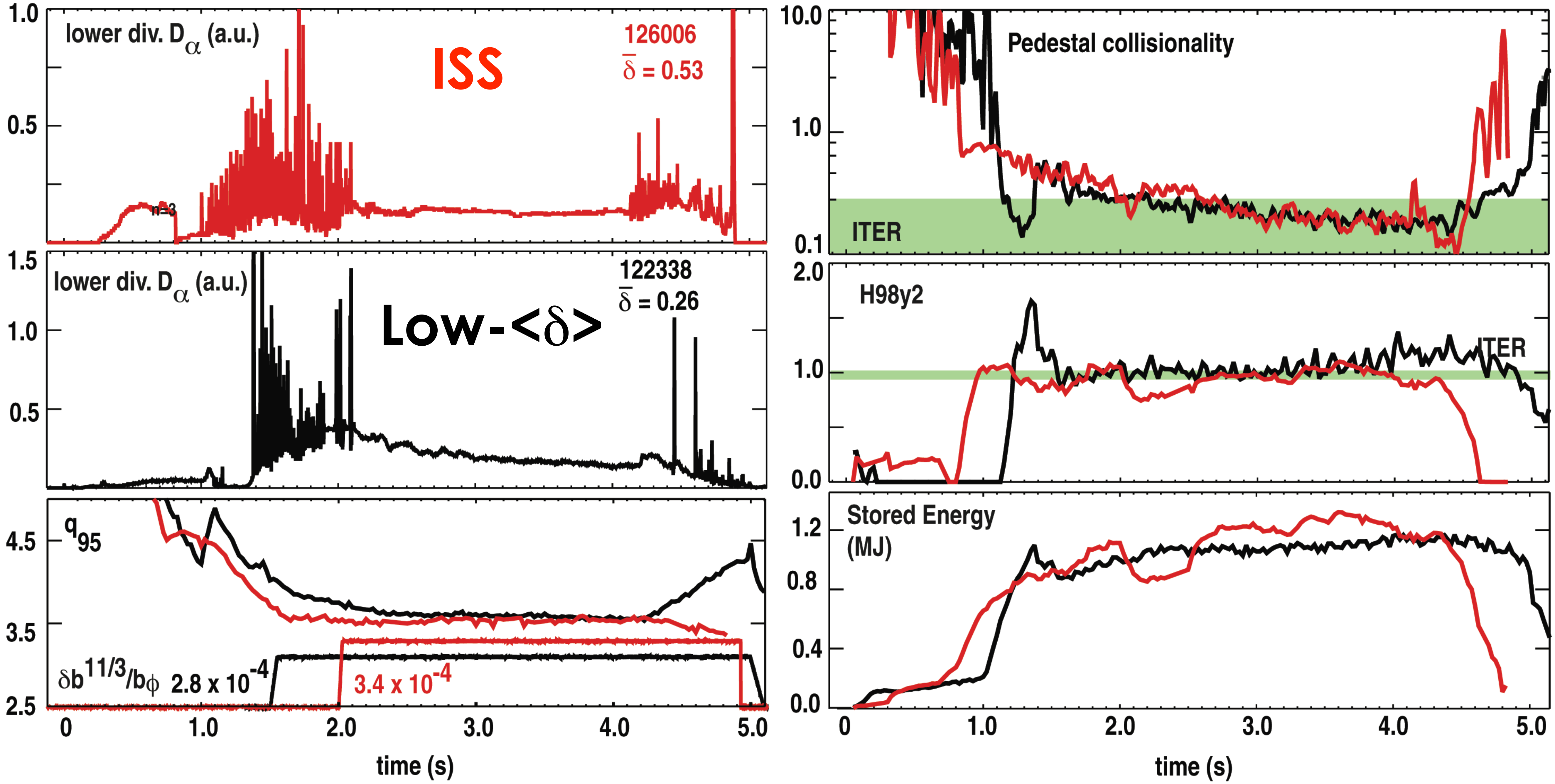


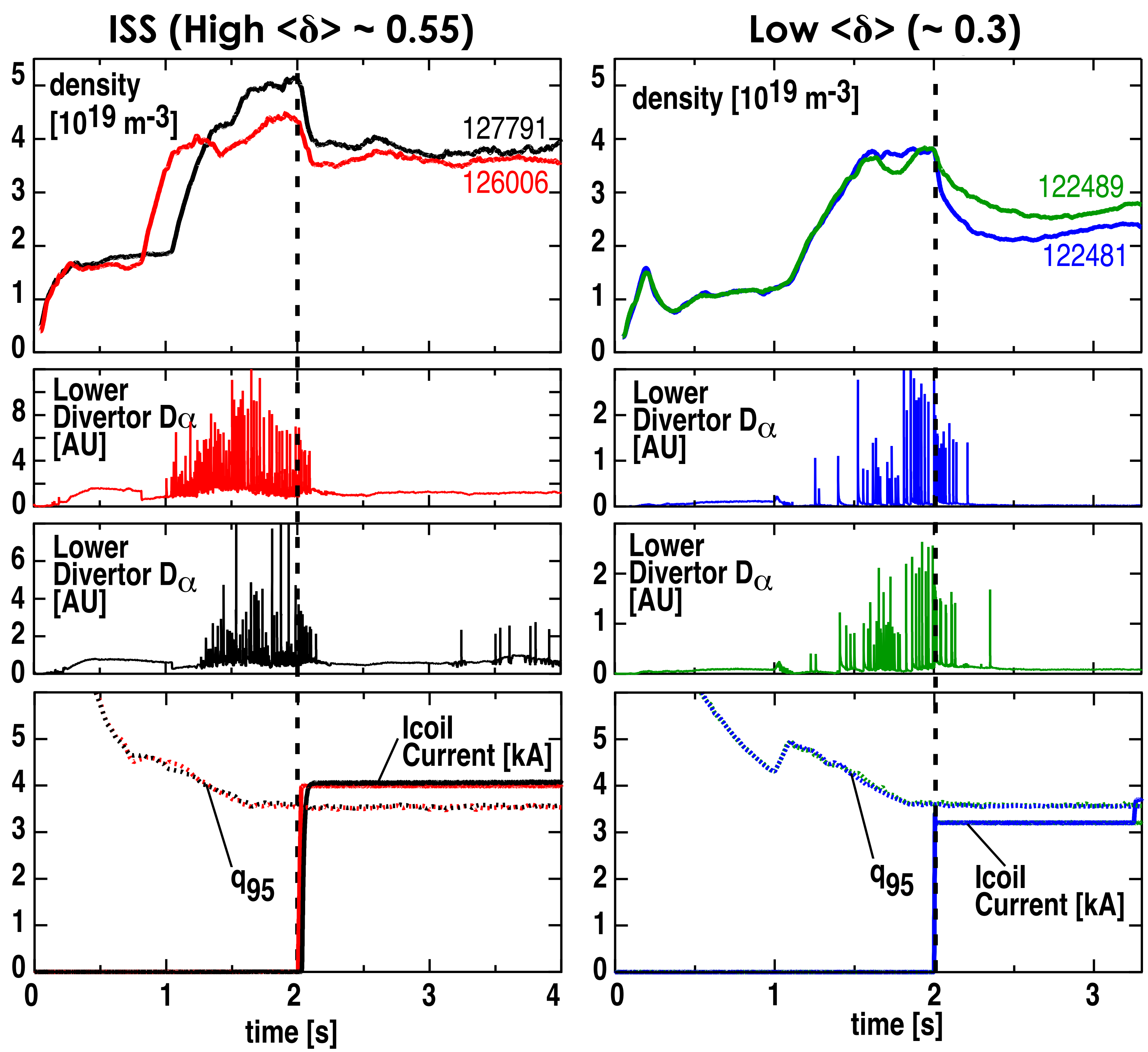
# ELM Suppression Seen in ITER Relevant Discharge Conditions




- **ITER shape requires 20% more RMP amplitude for ELM suppression compared to low triangularity (δ) shapes**

# Density Pumpout (PO) Independent of $q_{95}$ and $I_{coil}$ Current

- **At low-$\nu^*$, variable PO with similar $q_{95}$ & $I_{coil}$**
  - PO precedes ELM suppression
- **PO magnitude varies**
  - Different $n_e$ before RMP; similar $n_e$ during RMP
  - Same $n_e$ before; lower $n_e$ during RMP
- **No apparent shape dependence to observation**



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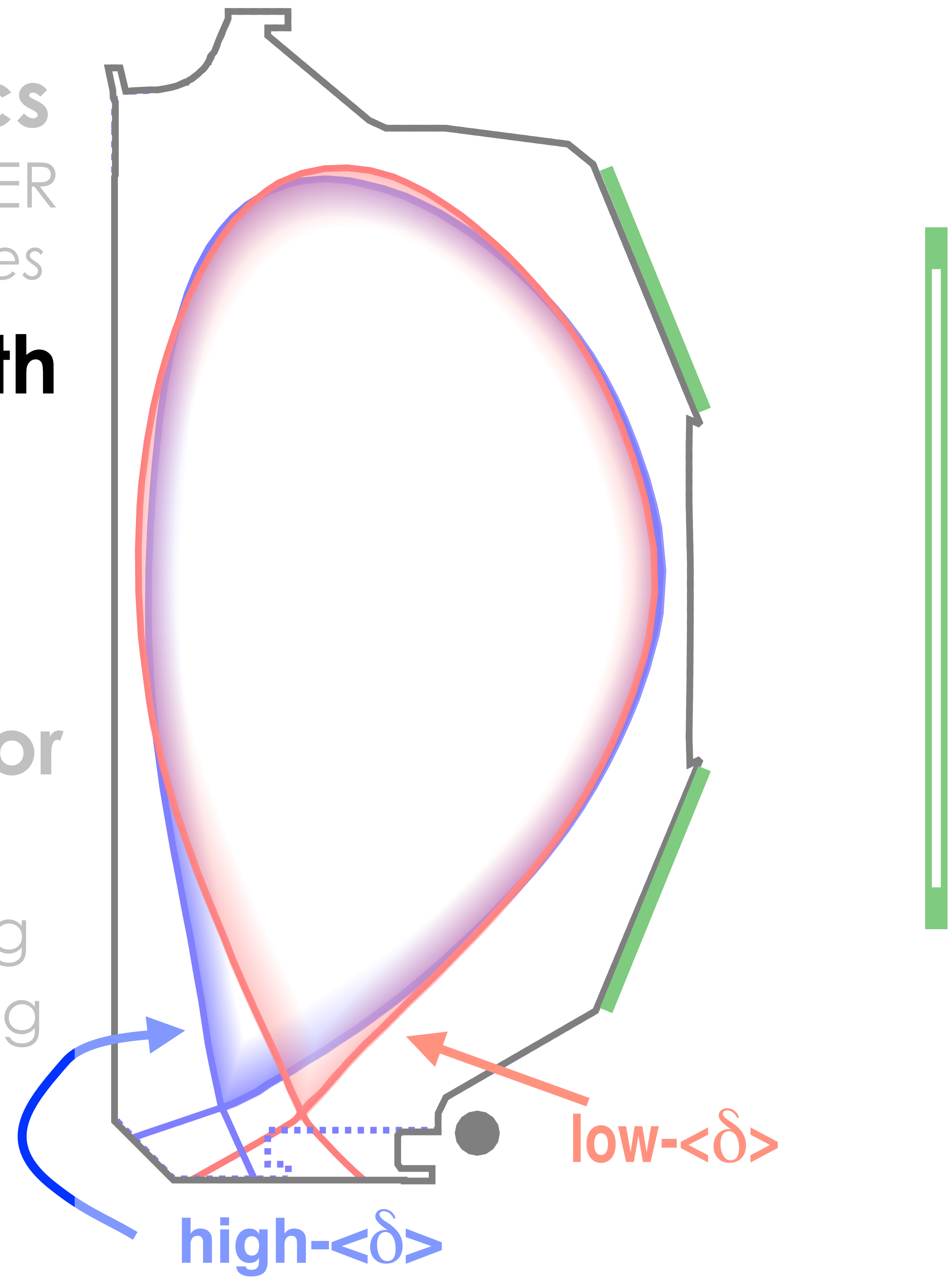


# Global Particle Balance Used During RMP Discharges for Source/Sink Calculation

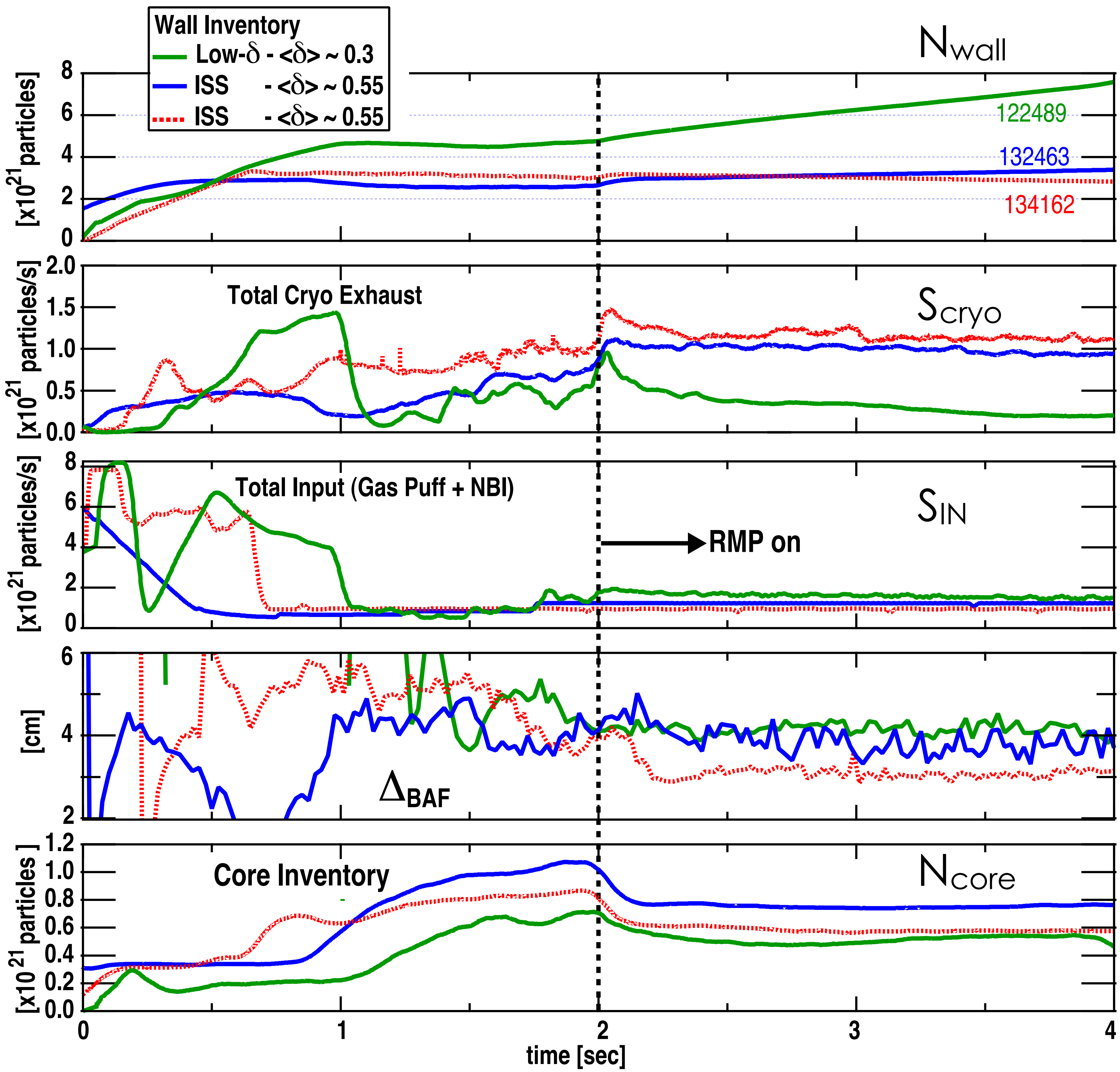
- **Global particle balance calculated based on past DIII-D work***

$$S_{wall} = S_{gas} + S_{NBI} - \left[ Q_{cryo} + {dN_{neutral}}/{dt} + {dN_{core}}/{dt} \right]$$

  - Right and side terms are all measured quantities on DIII-D
  - $N_{wall} = \int_0^t S_{wall} \, dt'$
- **Balance neglects impurities and SOL & divertor effects**
  - Originally, quantify dynamic wall changes within discharge
- **Give macroscopic dynamic evaluation of sources and sinks**

*Maingi et al., NF (1996)

# Wall Retention Decreased with New Divertor Geometry



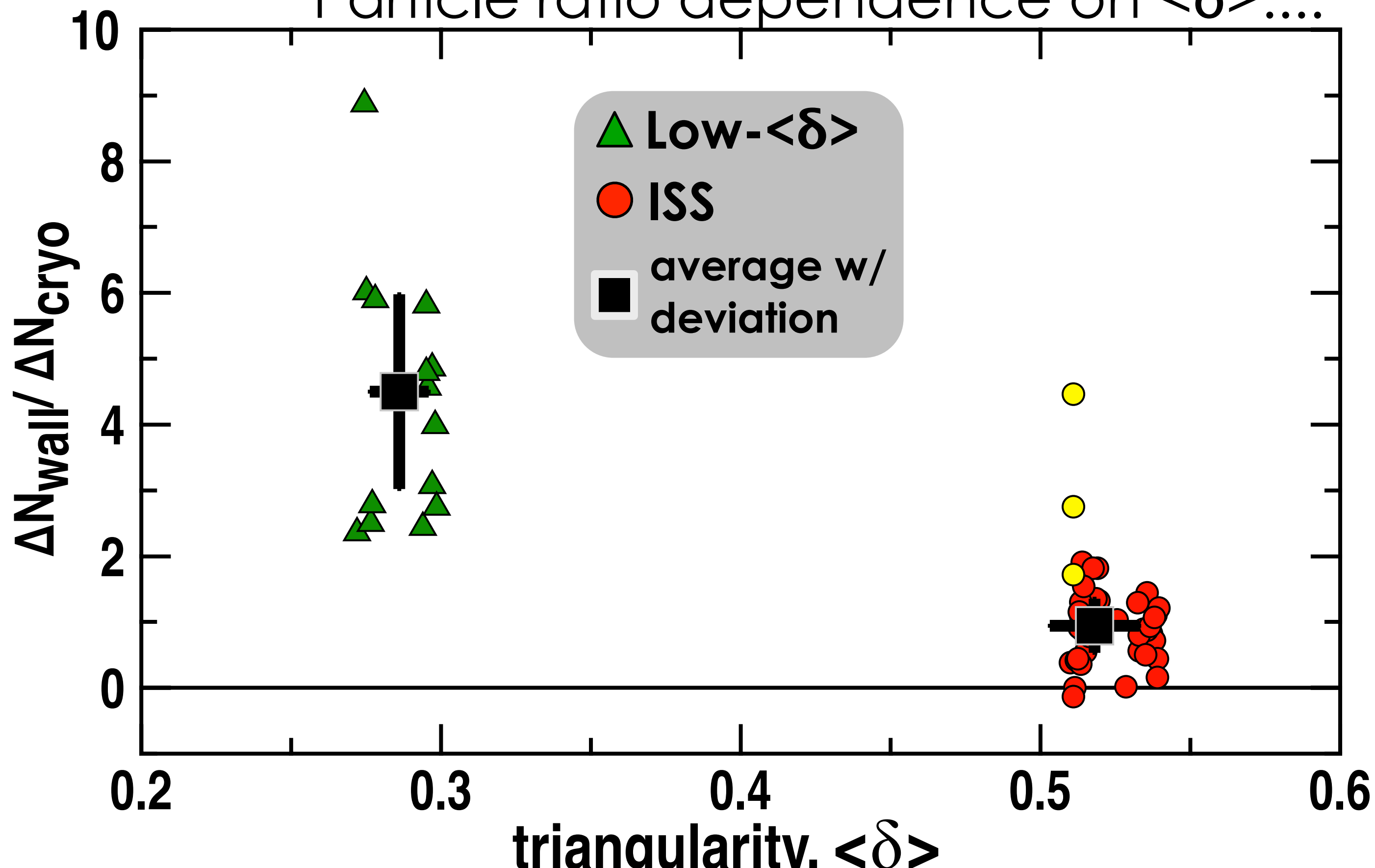

- During RMP, $N_{wall}$ increases in low-$\langle\delta\rangle$ discharge, but not in ISS case
- ISS case, cryo-pump exhaust ~ 2X higher
- Similar ISS exhaust at same $\Delta_{BAF}$ as low-$\langle\delta\rangle$

Unterberg, et al., *NF* (2009)

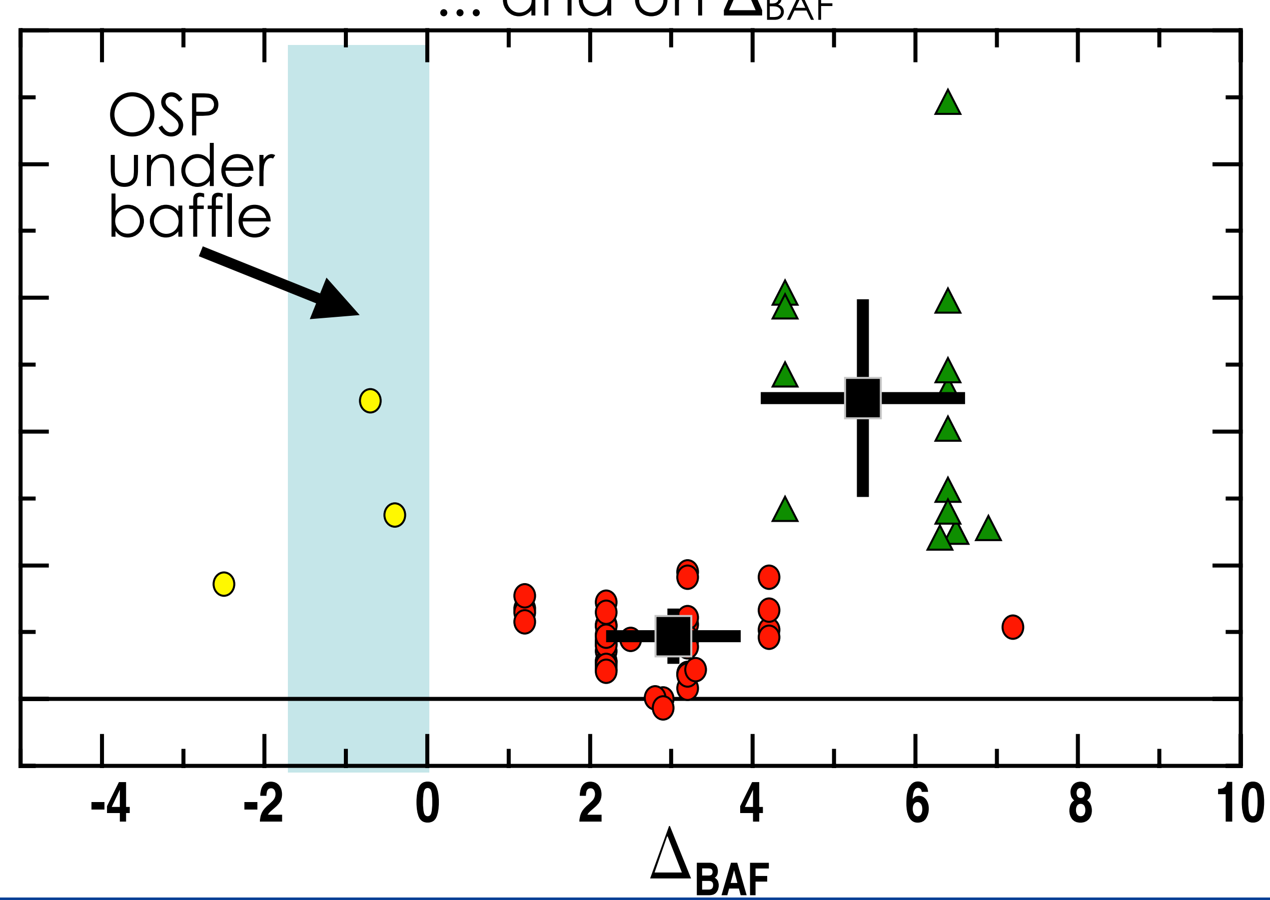
# More Particles to Pumps in ISS Seen in Multiple Discharges

- **$\Delta N_{wall}/\Delta N_{cryo} \equiv$ change in particle content to wall &/or cyro-pumps during RMP ELM suppression phase**
  - High $\Delta N_{wall}/\Delta N_{cryo}$ implies wall uptake high
  - Low $\Delta N_{wall}/\Delta N_{cryo}$ suggests cryo-pumping dominant during RMP
- **Database includes most fully suppressed RMP shots in DIII-D**
- **Large variation in ratio seen at low-<δ> and versus $\Delta_{BAF}$**
  - Indicative of more complex structure than axisymmetric OSP

Particle ratio dependence on <δ>....




... and on $\Delta_{BAF}$



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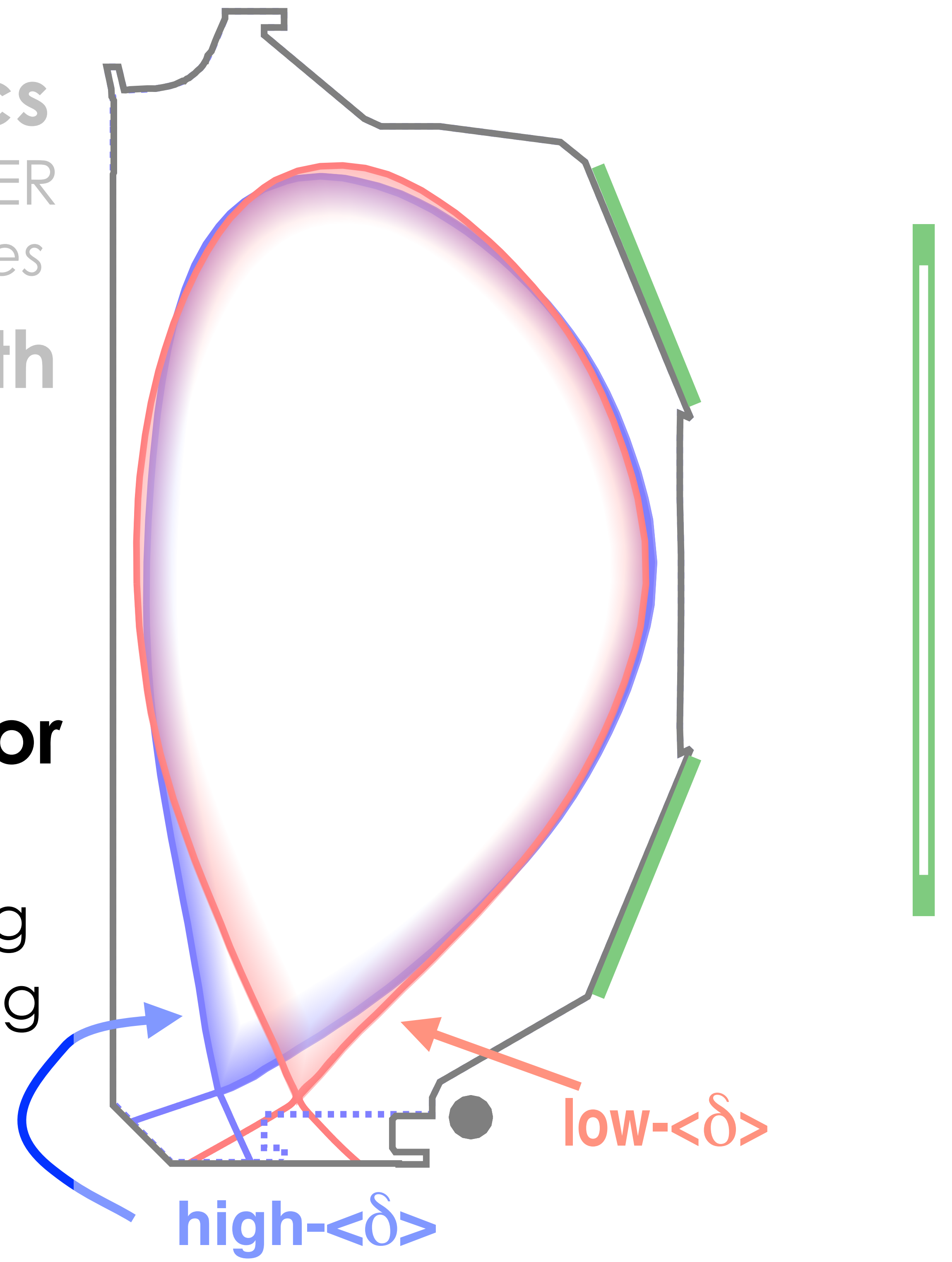
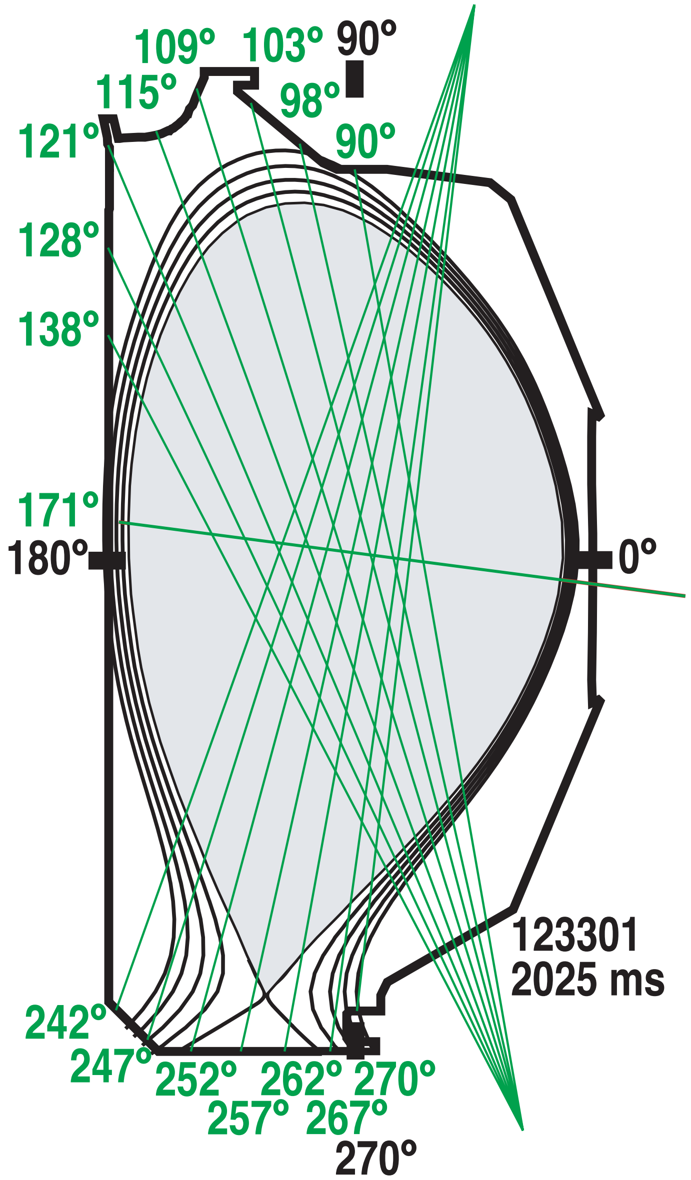
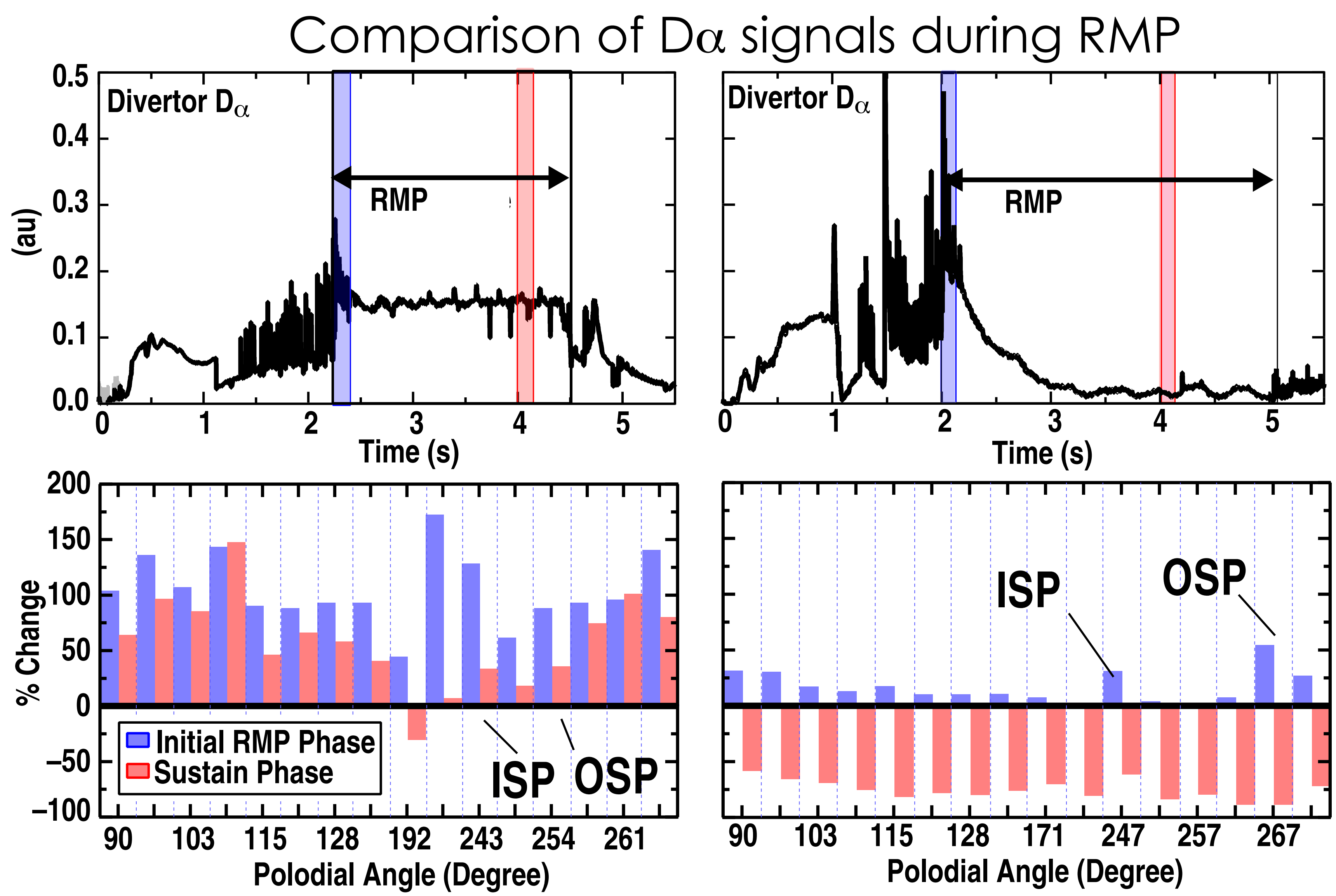


# Poloidal Variation of Wall Recycling During RMP Seen in Both Configurations

- Change in $D_\alpha$ intensity compared at 2 times during RMP
- At ISS, initial & 'sustain' phase have ~ 75-100% increase in signal
- At low-<$\delta$>, initial rise followed by decay to << pre-RMP value

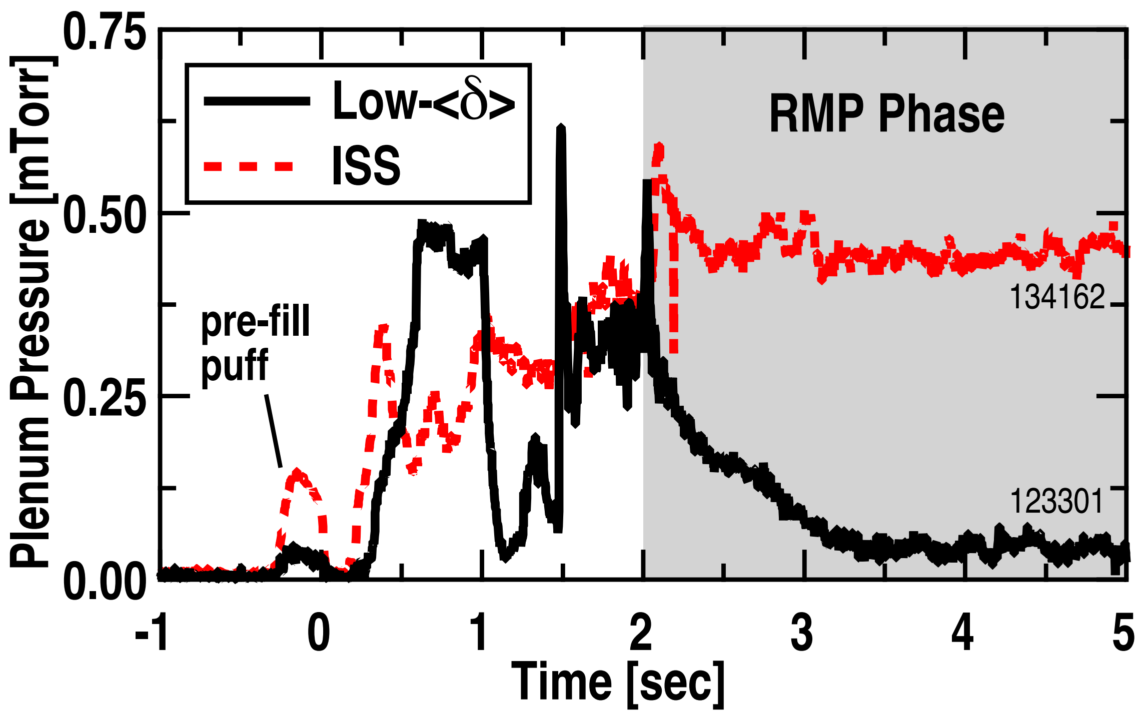


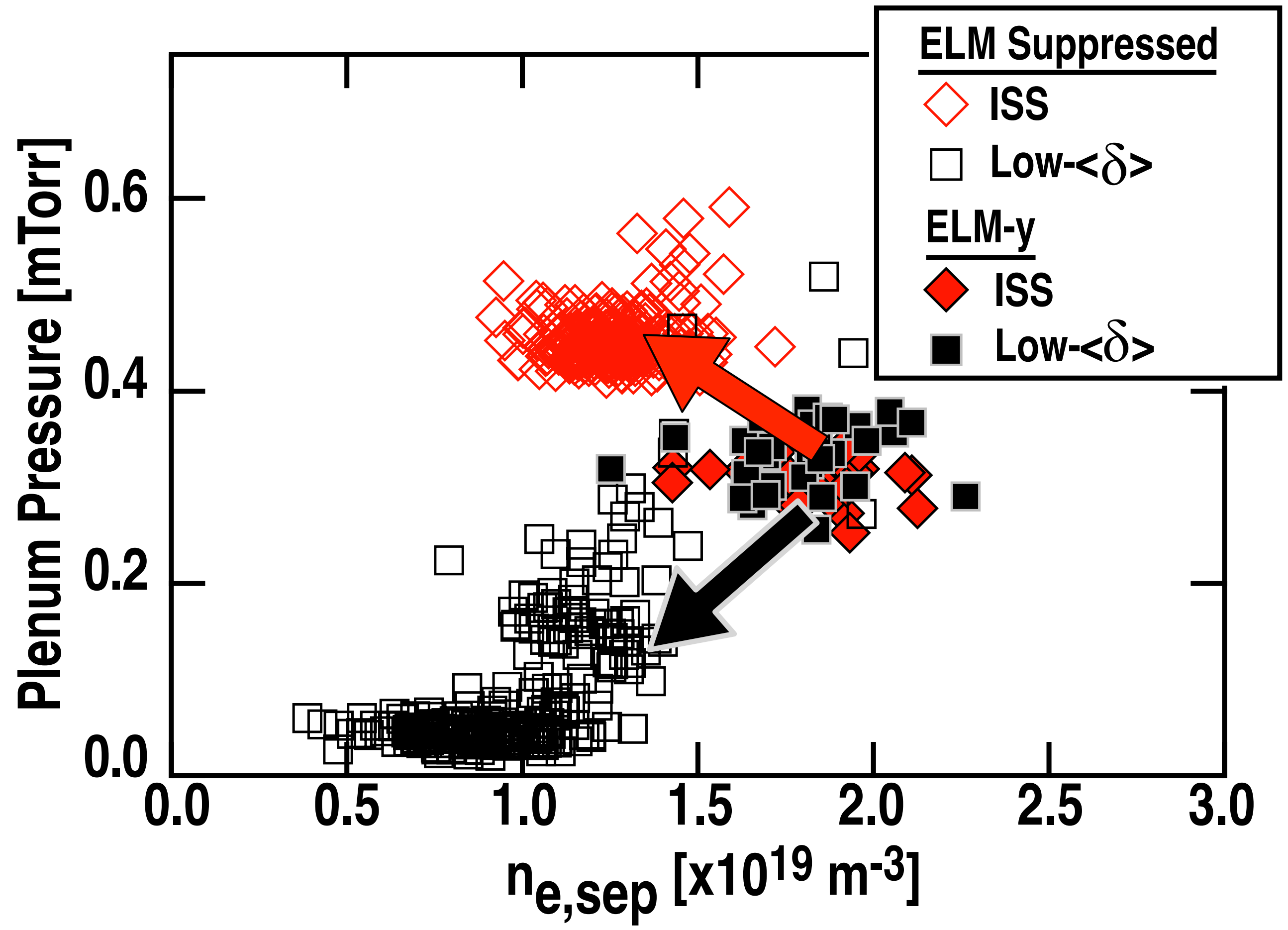
# Shape Difference Leads to Bifurcation in Divertor Pumping

- Divertor plenum pressure used as metric
- Conditions similar in both configurations before RMP
- Divertor conditions change substantially at low-<δ>
- Evidence of ‘plugging’ in ISS divertor

Time history of divertor pump pressure



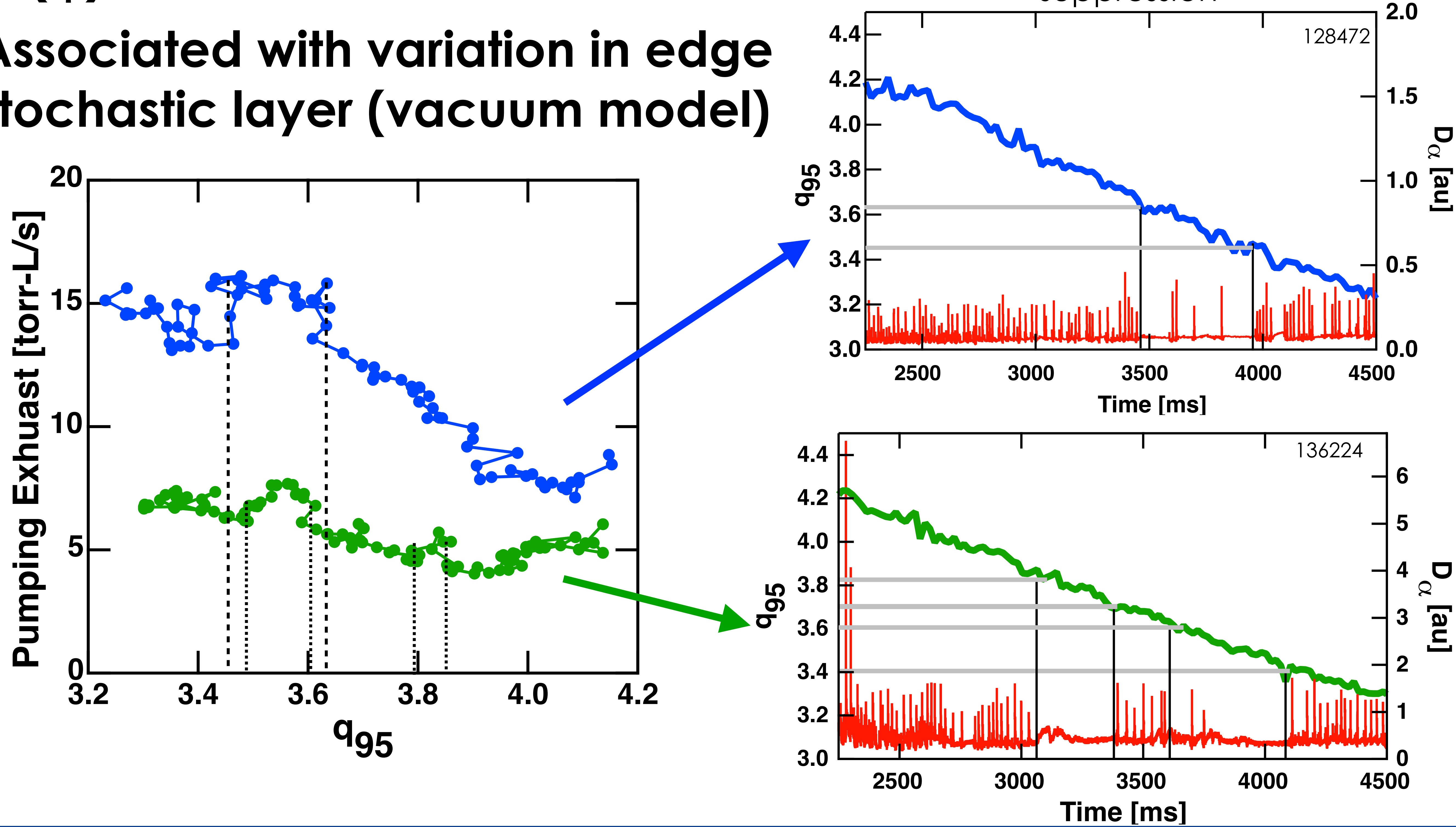

LCFS density dependence on shape



# Safety Factor Determines Particle Exhaust Changes When RMP is Applied

- **Modulation with $q_{95}$ also seen in $p_e(\psi)$***
- **Associated with variation in edge stochastic layer (vacuum model)**

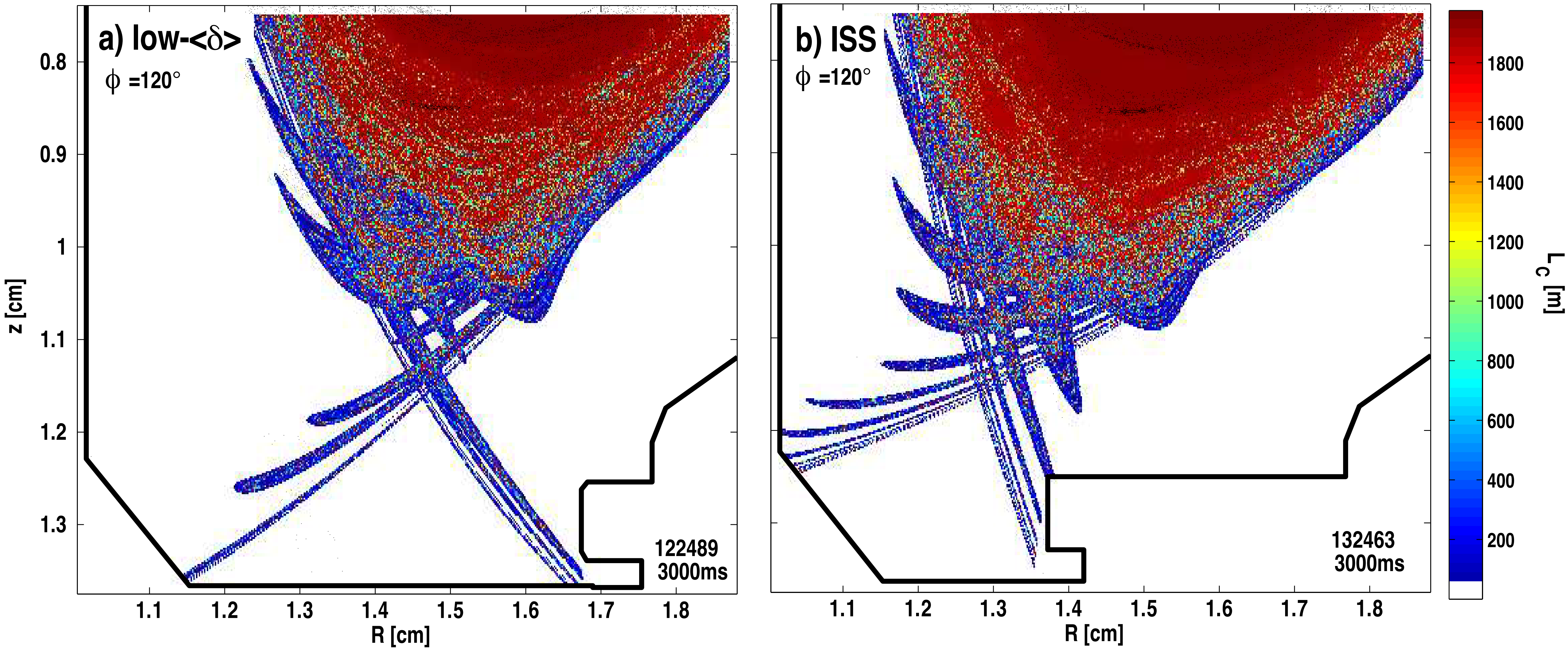
Increases in exhaust correlated to ELM suppression




*O. Schmitz et al., PRL (2008); M. Jacubowski et al., last talk

# Field Line Tracing Shows the Perturbed Separatrix Changes with <δ>

- **TRIP3D (vacuum model) calculates field lines of perturbed strikepoints***
- **Poloidal cut gives general overview of projected 3D geometry**
- **Shows in ISS case 'plugging' of divertor region**

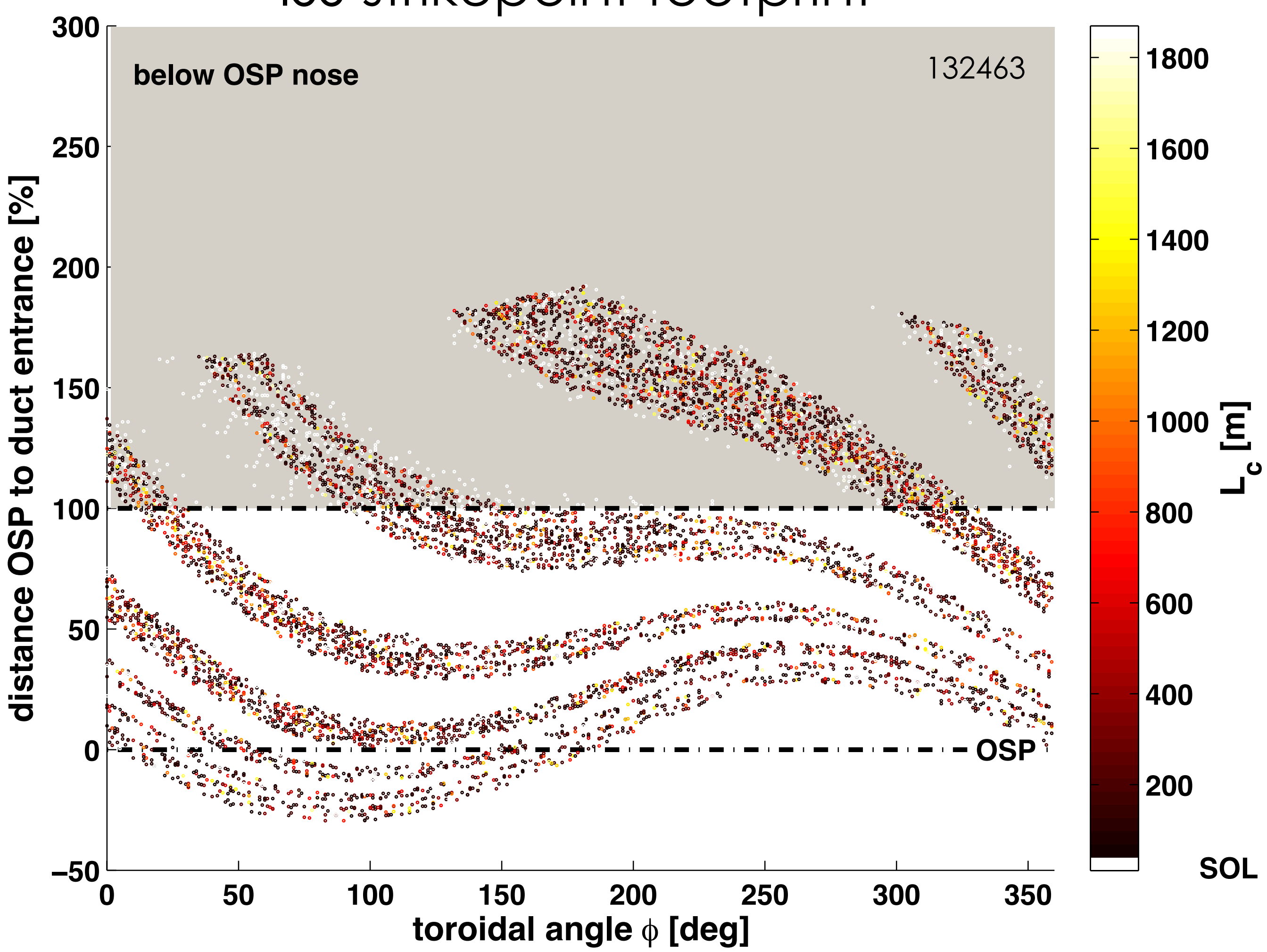



*O. Schmitz et al., PPCF (2008)

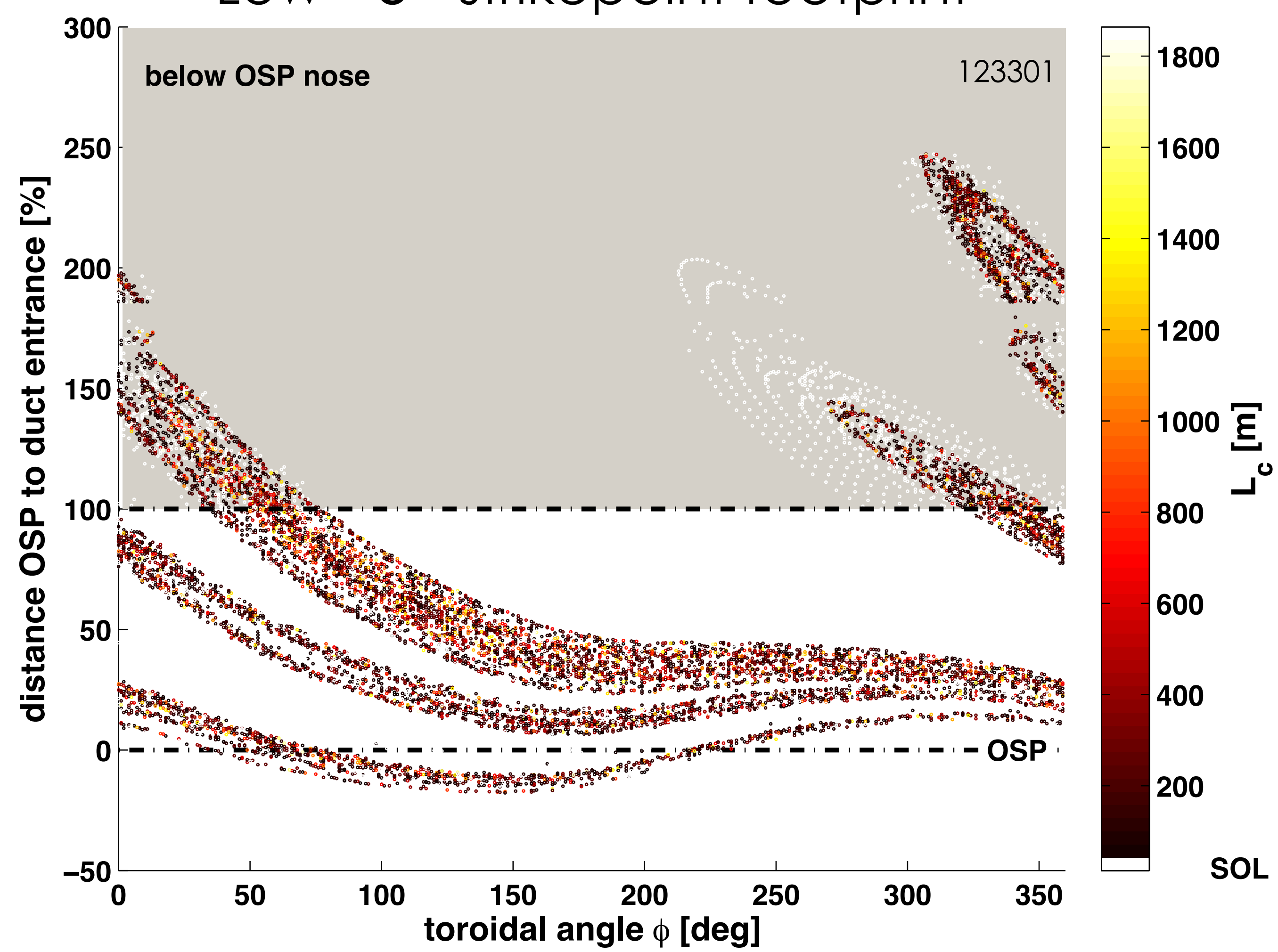
# Field Line Tracing Also Shows a More Closed Geometry in the ISS Cases

- **Field lines w/ short connection length ($L_C$) quickly bring hot plasma to wall**
- **ISS: Large area of short $L_C$ near baffle entrance**
  - ↑ neutral pressure in baffles ⇒ higher pumping rate
- **Low-<δ>: Perturbed strikepoint ⇒ less area near baffle**

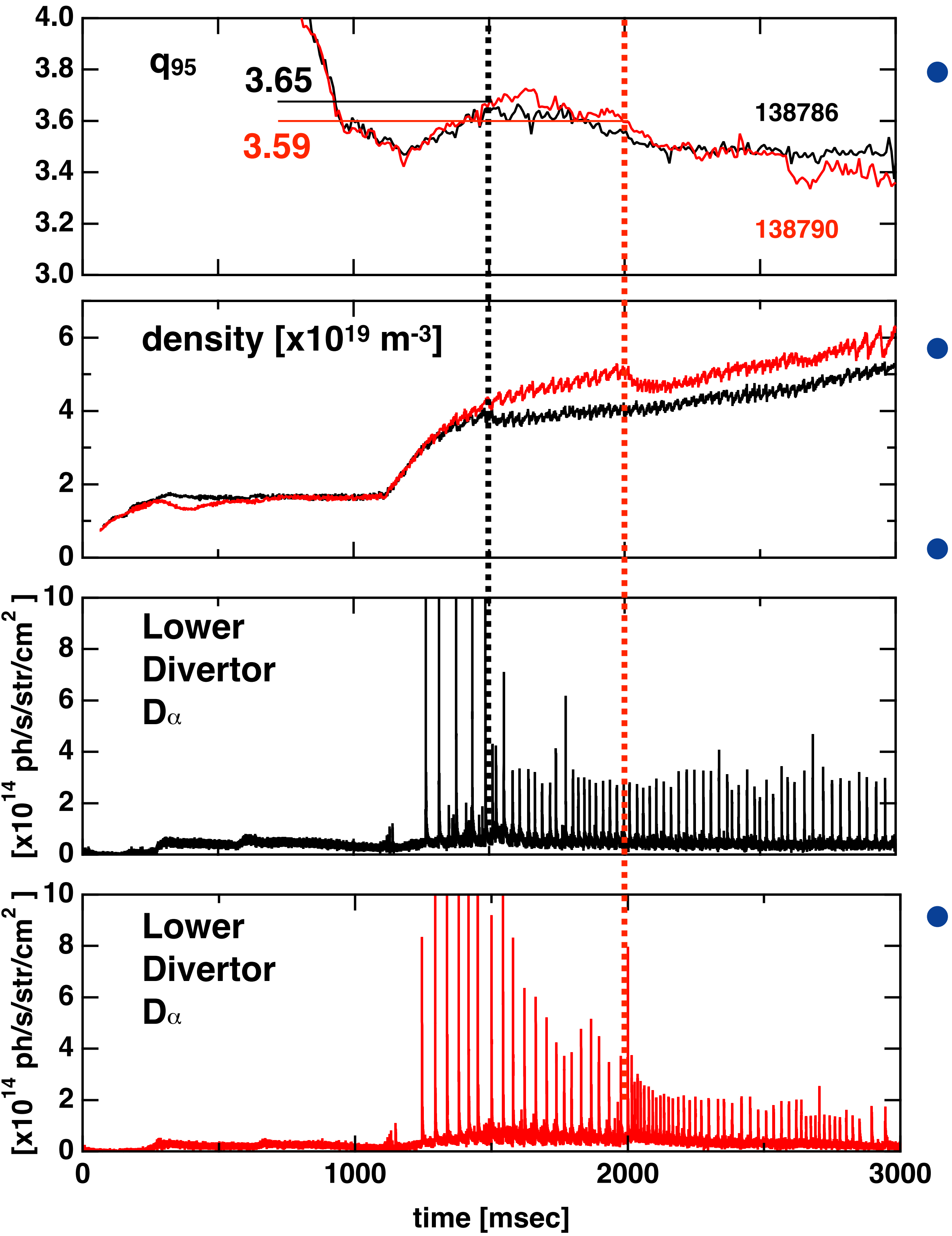
ISS strikepoint footprint




Low-<δ> strikepoint footprint



# In Helium Discharges, Pumpout Seen within Expected $q_{95}$ Range + ELM Mitigation




- **Motivated by ITER first campaign needs & source/ sink studies**
- **Effect seen at $3.55 < q_{95} < 3.65$**
  - Similar to RMP window in $D_2$
- **Density not controlled due to weak pumping**
  - Wall retention of helium very small
- **ELM magnitude & frequency changed with application of Icoil**

# Summary: With Closed Divertor, Pumping Exhaust is Main Sink of RMP Efflux

- **RMP experiments in DIII-D have variety of boundary characteristics**
  - *Divertor changes allow pumping with closed divertor configuration*
- **Particle exhaust controlled with more closed divertor**
  - *Graphite walls significant at low-<δ> ⇒ ~ 2X cryo pumping*
  - *Neutral pressure & $D_\alpha$ ↑ in main chamber with increased cryo exhaust*
  - *Edge density & $D_\alpha$ bifurcate during RMP in dependence with shape*
- **Exhaust increase depends on details of divertor conditions**
  - *More coupling to baffling with ISS strikepoint splitting*
  - *Observations suggest plasma 'plugging' in divertor*
  - Wall pumping does not hinder RMP pumpout effect
    - *Cryo-pumping isolated w/ helium discharges ⇒ saw pumpout*
    - *No cryo-pumping ⇒ pumpout + ELM suppression*