Effect of separatrix density on ELM instability in long-pulse H-mode plasmas on EAST

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Outline

- 1. Background
- 2. ELMs in minute-scale long-pulse H-mode plasmas on EAST
- 3. Large ELM mitigation by changing strike point location
- 4. Summary

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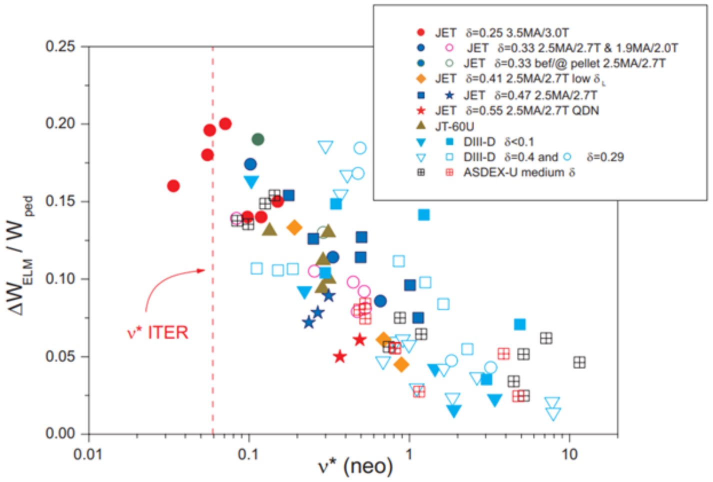
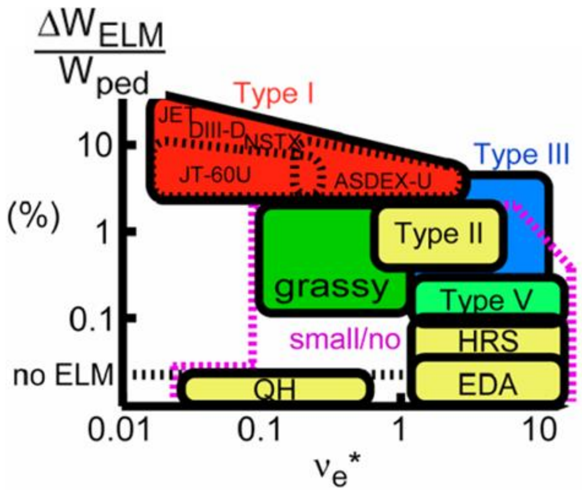
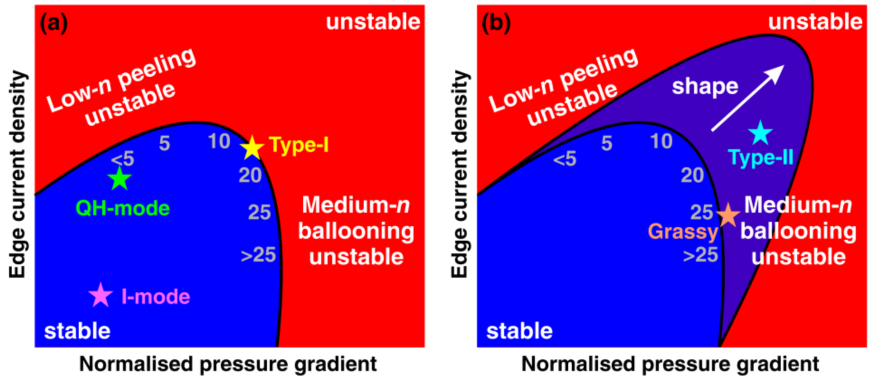
Stationary small/no ELM regime with good confinement is a solution to large ELMs for long-pulse operation of future fusion reactors



[A. Loarte et al., 2003, PPCF]



[K. Kamiya et al., 2007, PPCF]



[E. Viezzer et al., 2018, NF]

- **Type-I ELMs at low ν_e^* would be intolerable for long-pulse operation of future fusion reactors.**
- **Several small/no ELM regimes with good confinement have been developed so far.**
- **PBM has been widely recognized as the main stability limit of pedestal region.**

A detailed physics understanding of these regimes is necessary for extrapolation to future devices.

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The importance of pedestal density profile is highlighted in recent studies on small/no ELM H-mode regimes

- **EAST natural grassy ELM regime** *[G.S. Xu et al., 2019, PRL]*
  - Characterized by a wide pedestal with low ∇n_e
- **EAST low-recycling no-ELM H-mode regime** *[Y. Ye et al., 2019, NF]*
  - Low pedestal foot density plays a key role in achieving this regime.
- **DIII-D RMP grassy ELM regime** *[R. Nazikian et al., 2018, NF]*
  - Strongly correlated with RMP-induced density pumpout
- **DIII-D natural grassy ELM regime** *[Y.F. Wang et al., 2021, NF]*
  - Characterized by high $n_{e,sep}/n_{e,ped}$ and low ∇n_e
- **AUG small ELM regime** *[G.F. Harrer et al., 2018, NF]*
  - Higher $n_{e,sep}$ with stronger gas fueling appears to facilitate access to this regime.

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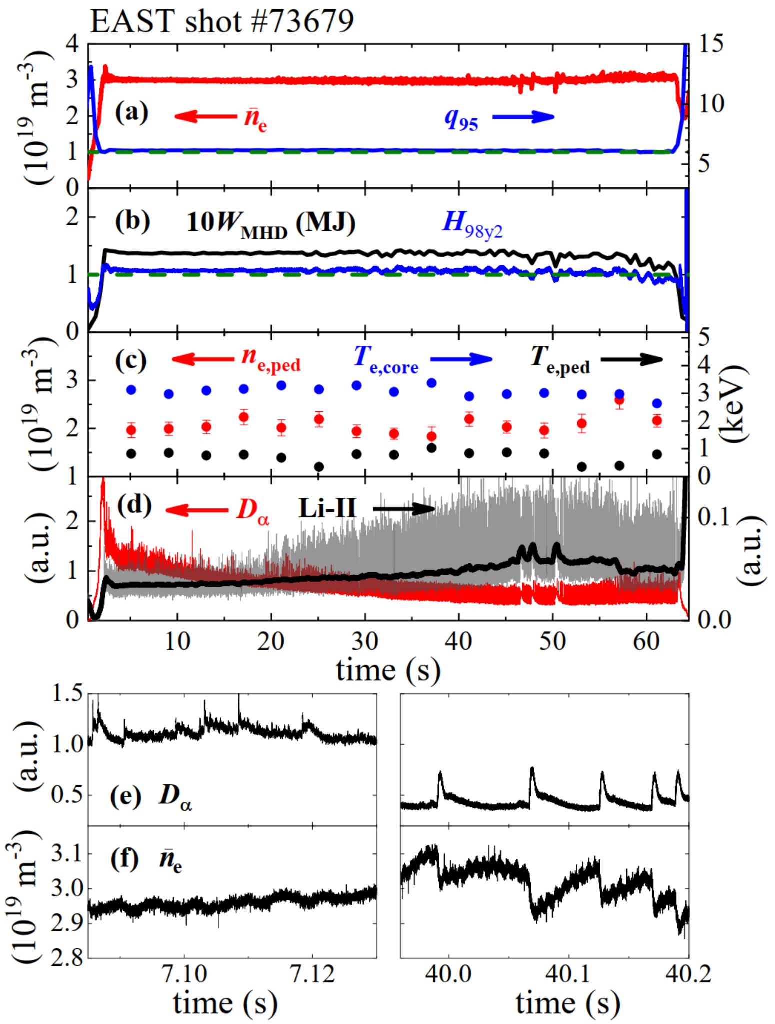
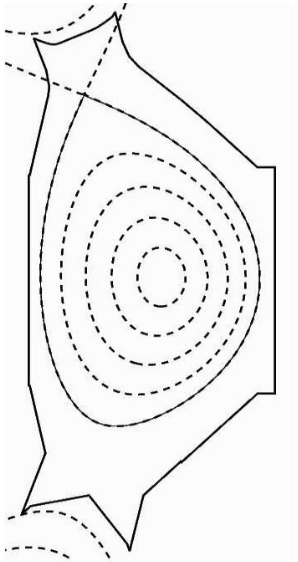
Large-amplitude ELMs appear in minute-scale long-pulse H-mode discharges on EAST



- **Typical discharge information:**
  - I_P ~ 450kA, unfav. B_T, USN
  - q_{95} ~ 6.1
  - n_e ~ $3.0\times10^{19}m^{-3}$
  - H_{98y2} ~ 1.06
  - P_{aux} ~ 3.4MW (RF-only)



- **Global plasma parameters remain unchanged during the H-mode phase, such as I_P, n_e, W_{MHD} and H_{98y2}, as well as $T_{e,core}$, $n_{e,ped}$ and $T_{e,ped}$.**
- **Li-II signal intensity increases and D_α signal intensity decreases gradually with time.**
- **Small ELMs are replaced by large ELMs.**

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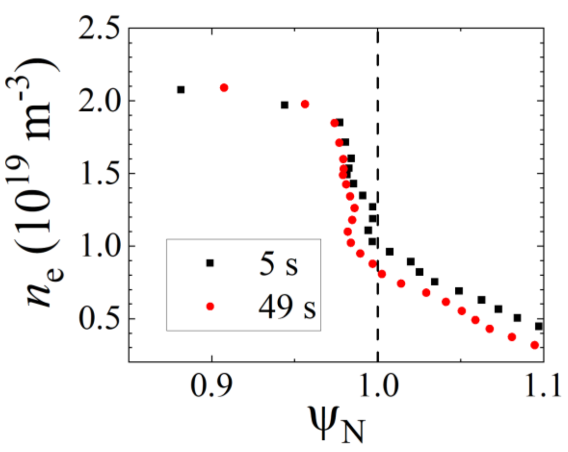
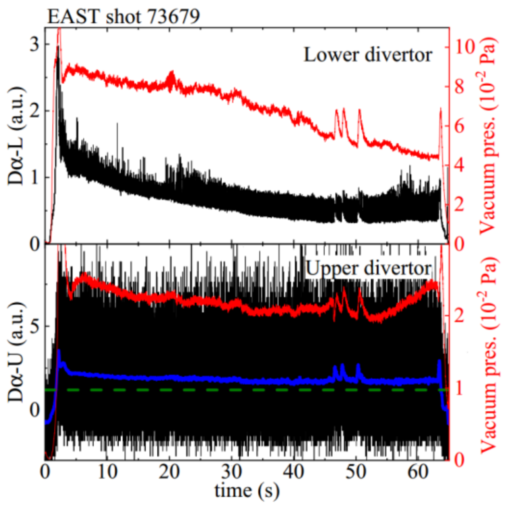
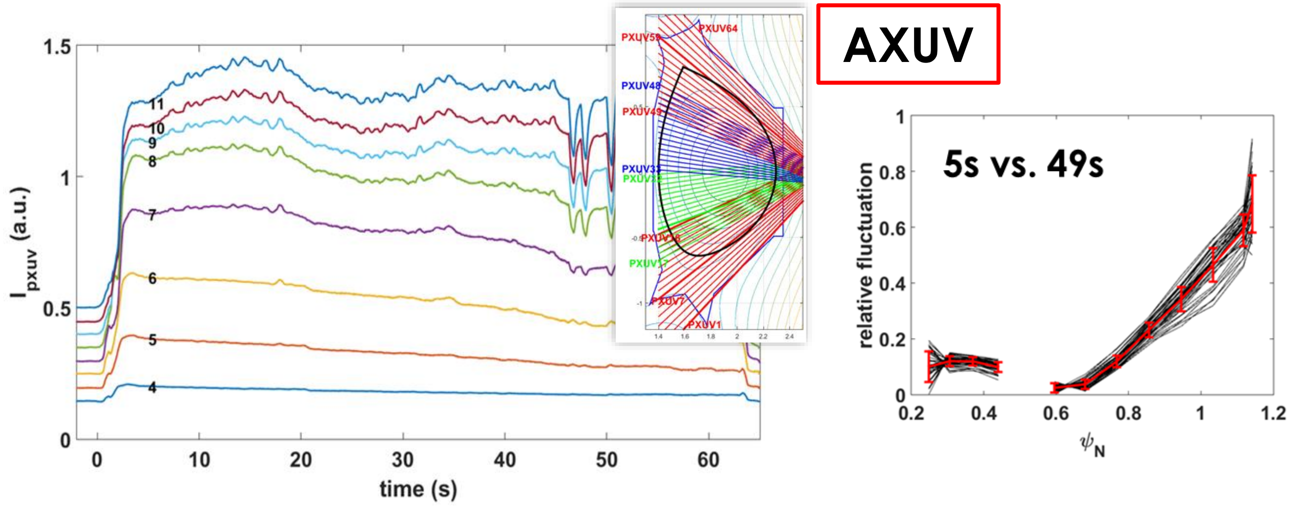
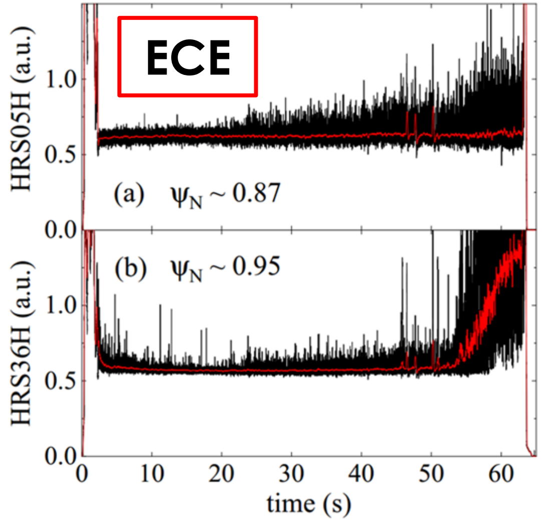
Separatrix density appears to decrease with the decrease in edge fuel recycling in the H-mode phase



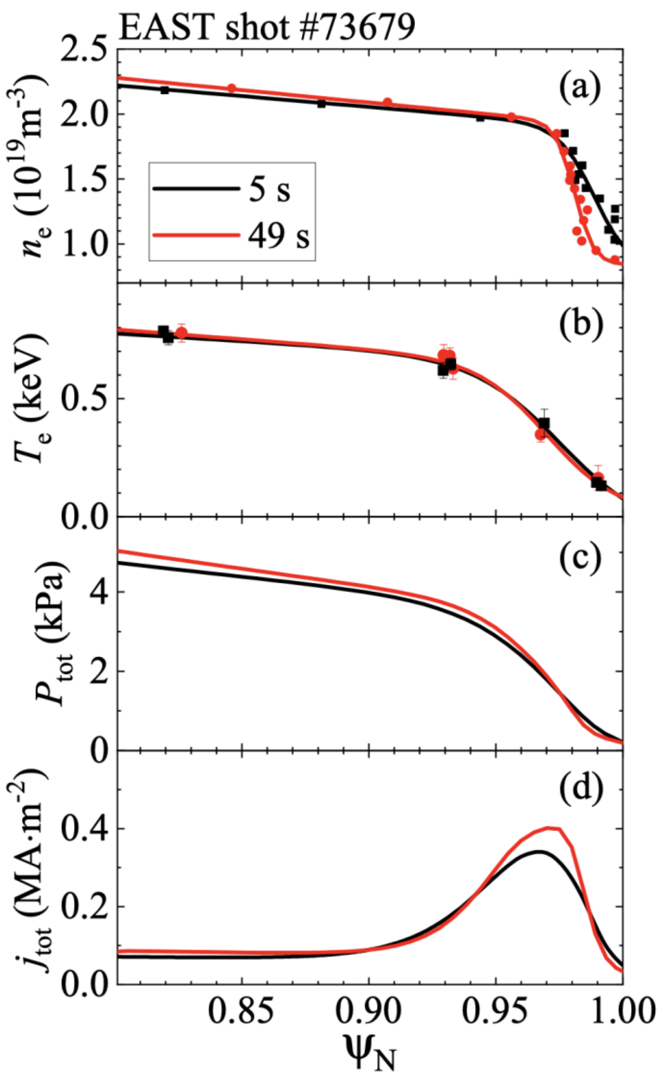


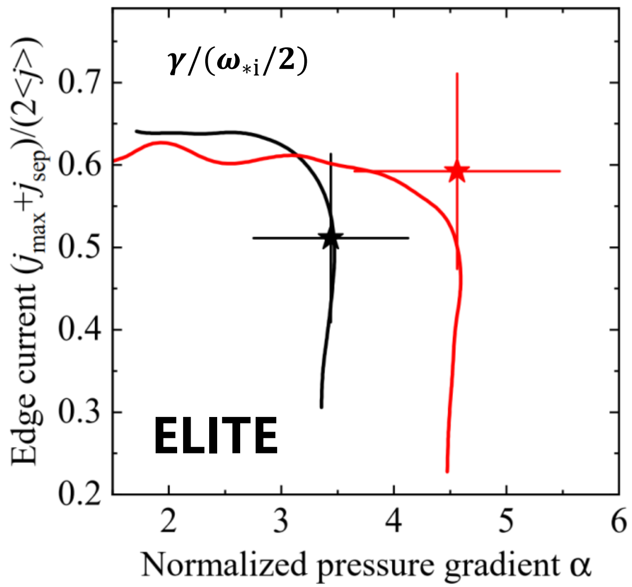


- The electron density near separatrix is observed to decrease during the H-mode phase, as well as D_α background intensity and divertor vacuum neutral pressure.
- The AXUV signal intensity in the edge region shows a gradual decrease.
- The ECE background intensity near pedestal top region remains unchanged.



Linear pedestal stability analysis before and after the decrease in separatrix density $n_{e,sep}$





- **The decrease in separatrix density results in an increase in both pedestal pressure gradient and edge current density.**

- **The ballooning stability boundary also expands due to the enhanced ion diamagnetic stabilizing effect.**
  - ion diamagnetic frequency $\omega_{*i} \sim \nabla p_e / n_e$

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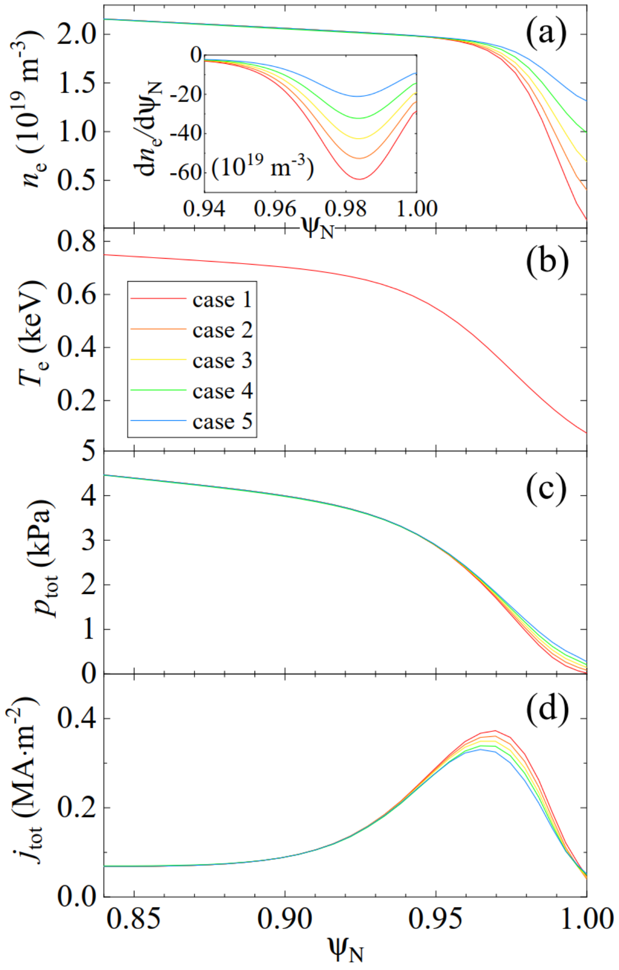
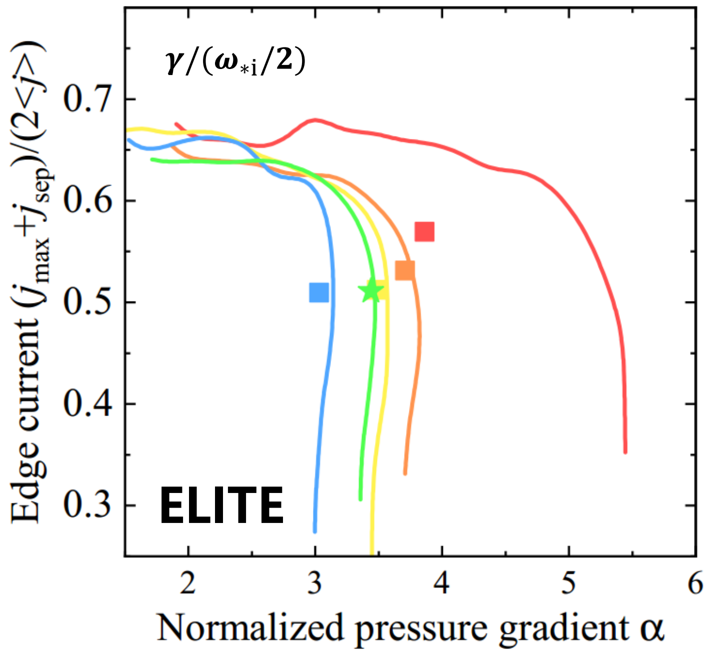
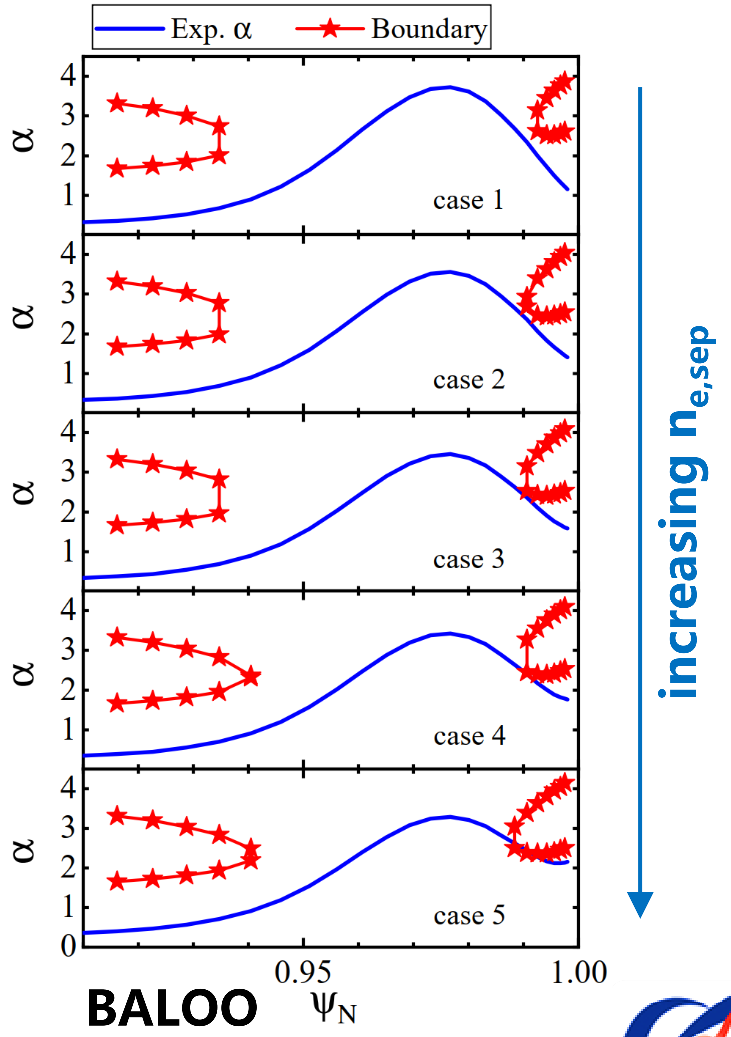
The operational point moves from near the ballooning boundary to near the peeling boundary as $n_{e,sep}$ decreases

➢ **Numerical scan of separatrix density $n_{e,sep}$**

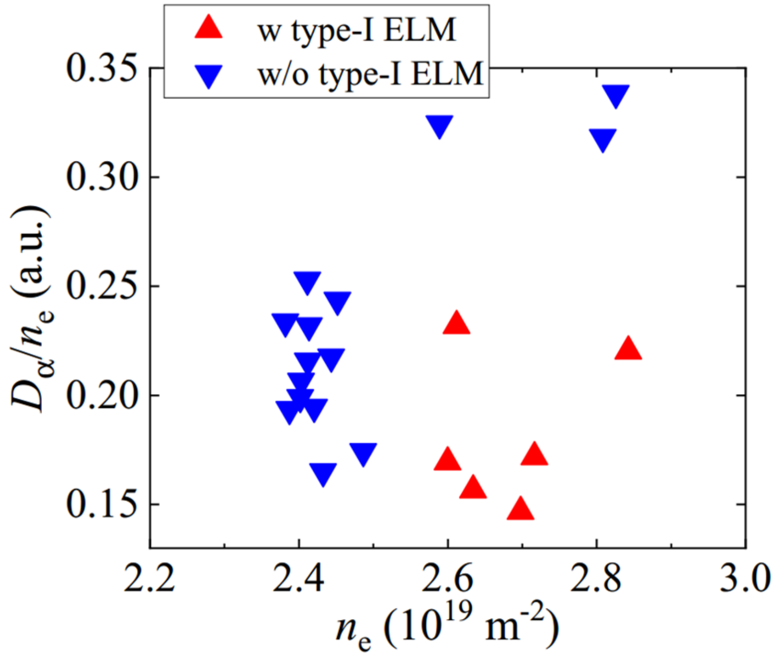


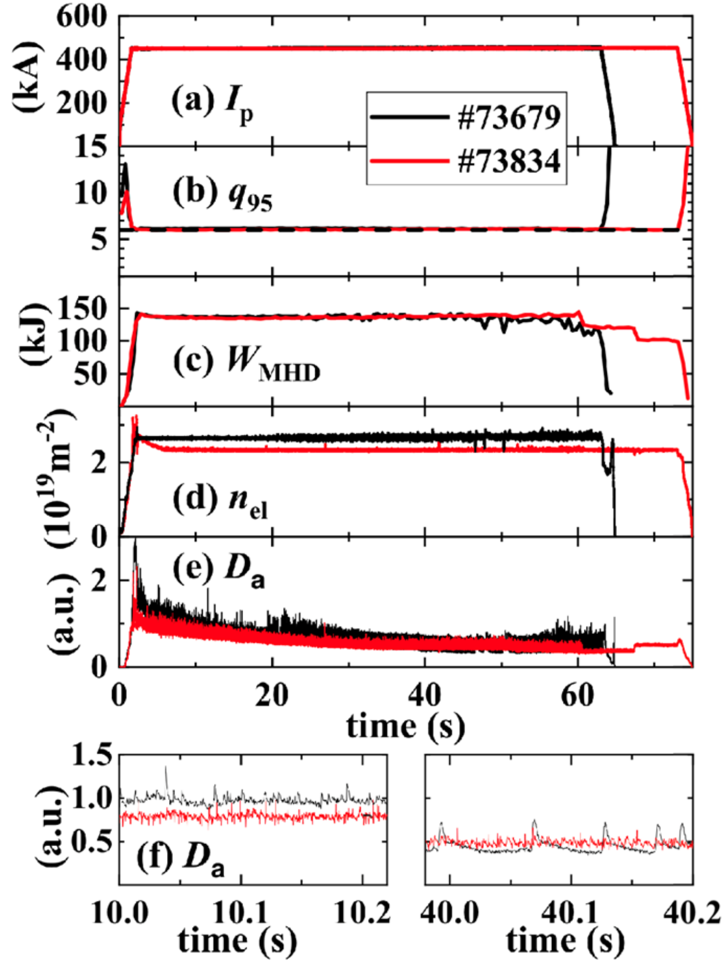




- **The ballooning mode at pedestal foot region may help drive particles and heat transport, preventing larger ELM bursts.**

Lower plasma density at low edge recycling appears to facilitate small ELMs in minute-scale long-pulse H-mode discharges on EAST





- The experimental data in minute-scale long-pulse H-mode discharges in 2017 campaign has been collected.
- With lower plasma density, no large ELMs appear even with a decrease in D_α signal.

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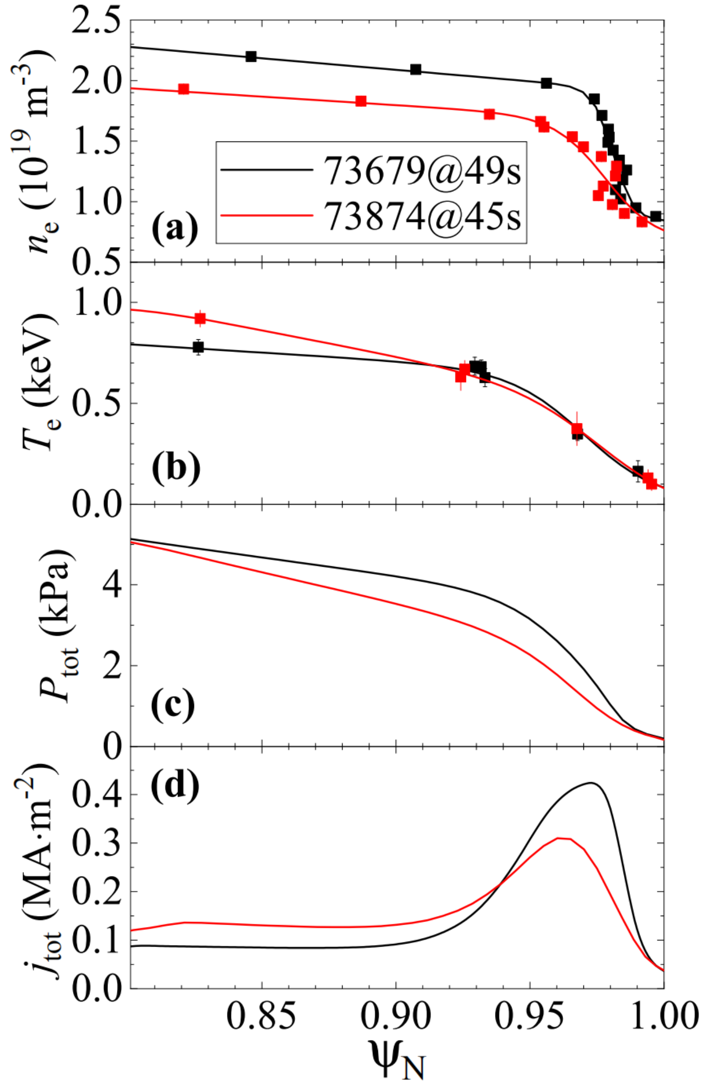
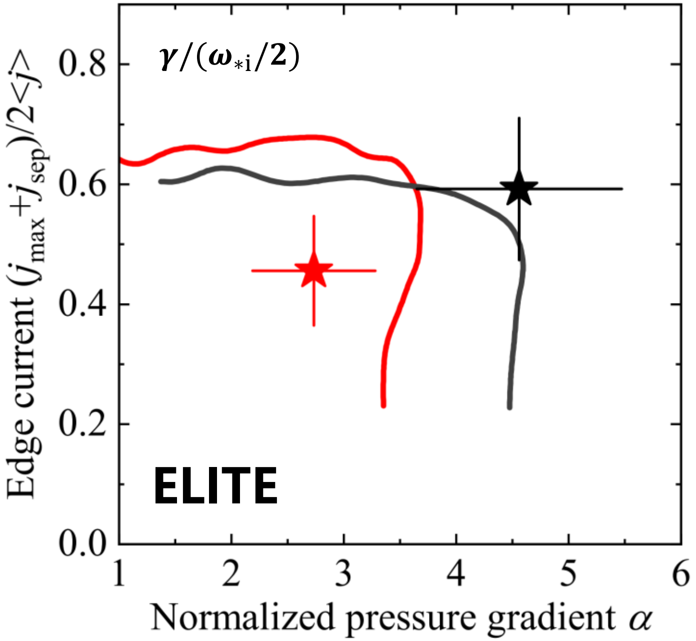
Pedestal stability analysis of ELMs with different plasma density





- **Lower plasma density and thus lower pedestal top density lead to lower ∇p and j, making PBMs more stable.**

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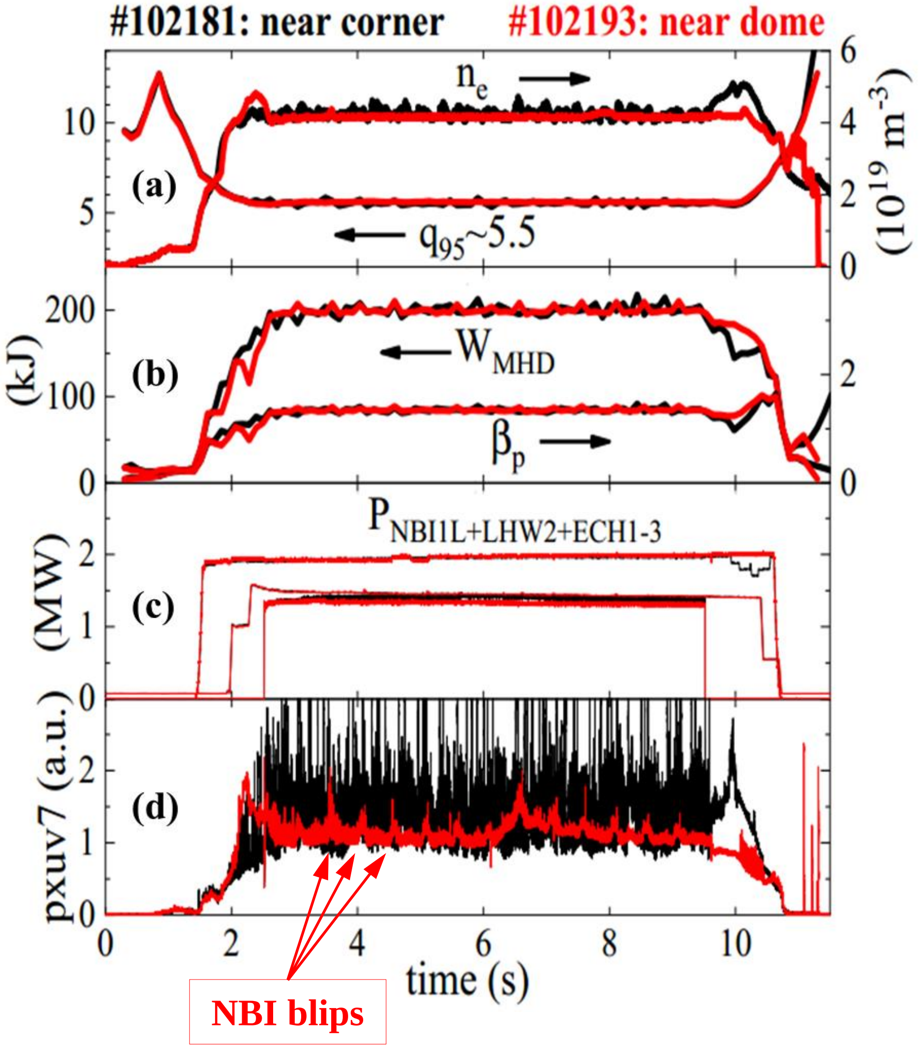
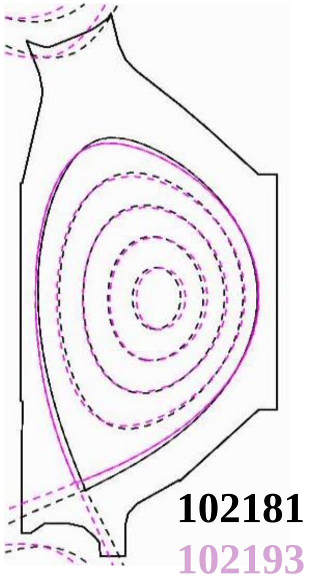
Large ELMs are mitigated by changing strike point location



- **Basic discharge information:**
  - I_P ~ 500kA, fav. B_T
  - q_{95} ~ 5.5
  - n_e ~ $4.2 \times 10^{19} m^{-3}$
  - P_{aux} ~ 4.5MW
  - β_p ~ 1.35, W_{MHD} ~ 200kJ



- **By moving the strike point on the horizontal target plate away from divertor corner region, large ELMs are successfully mitigated.**
- **At the same time, plasma energy confinement performance remains unchanged.**

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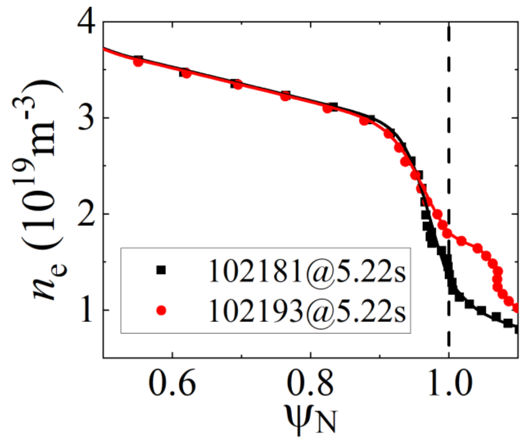
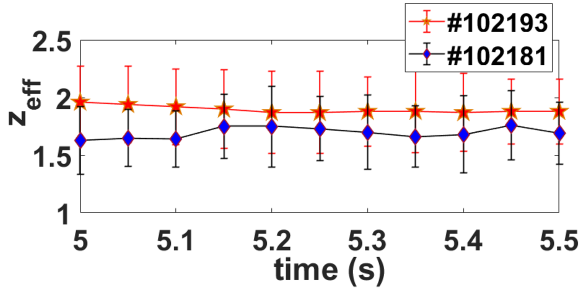
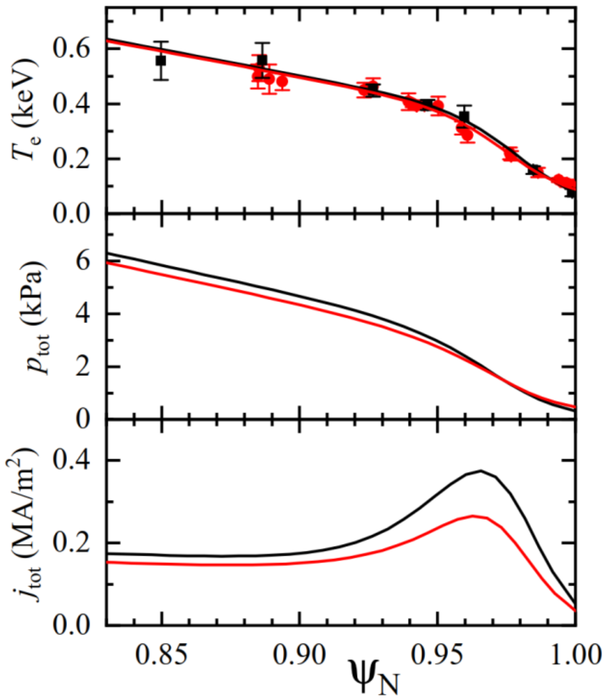
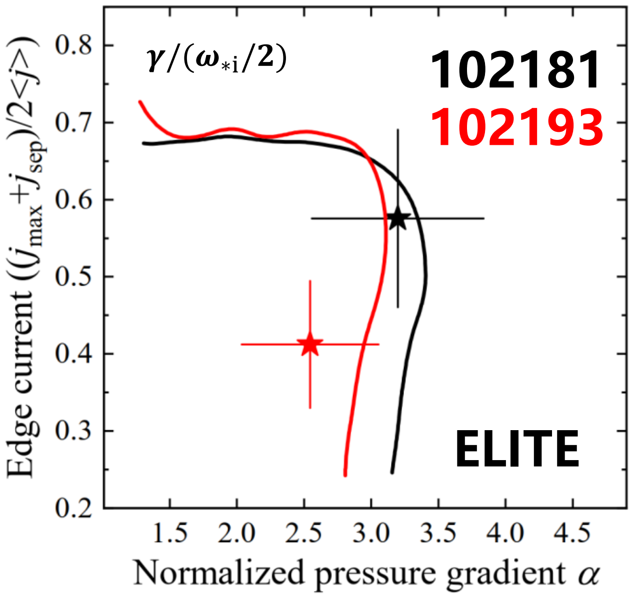
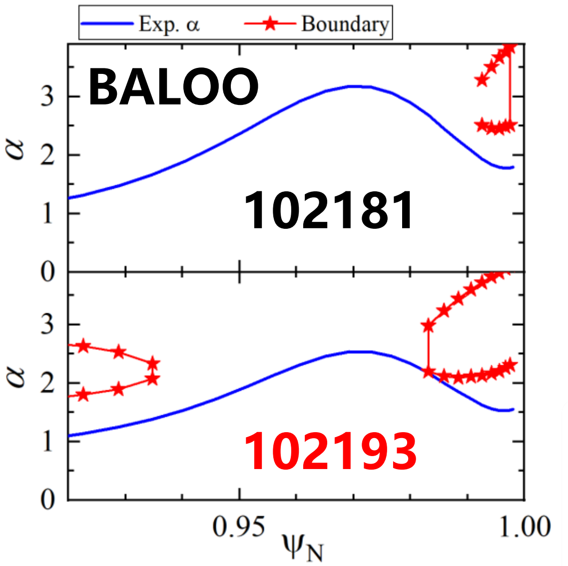
The enhanced separatrix density is thought to be an important reason for the large ELMs mitigation











- The $n_{e,sep}$ is enhanced when the SP moves away from the divertor corner region.
- The operational point moves to near the ballooning boundary, with the ideal ballooning mode marginally unstable at the pedestal foot region.

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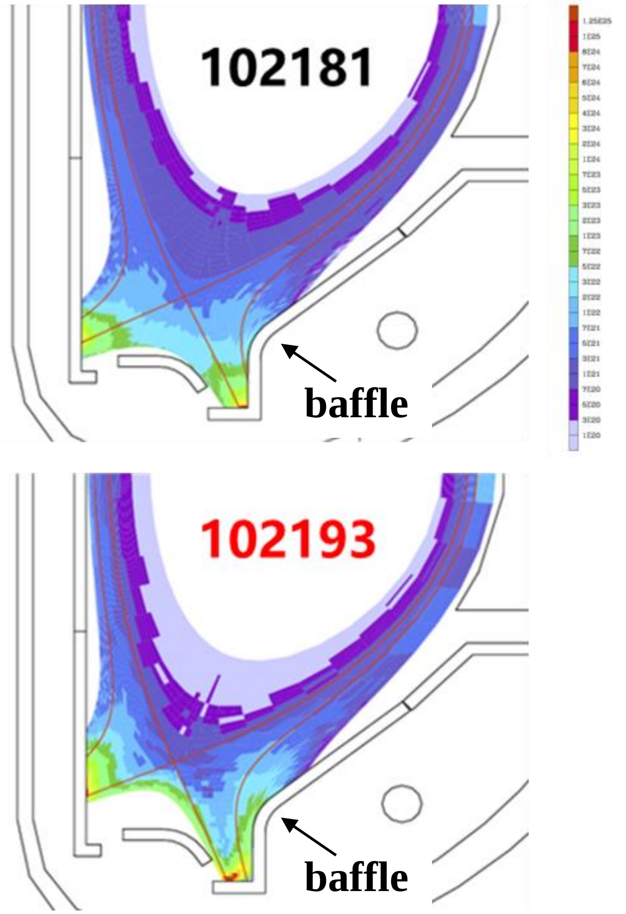
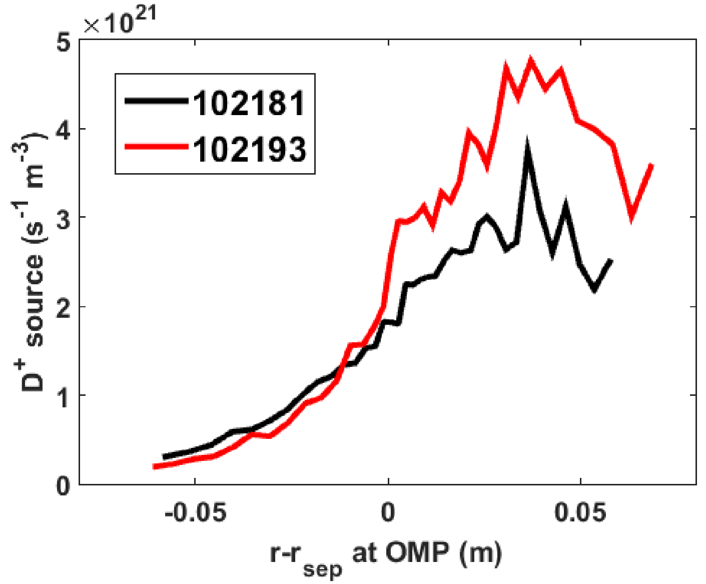
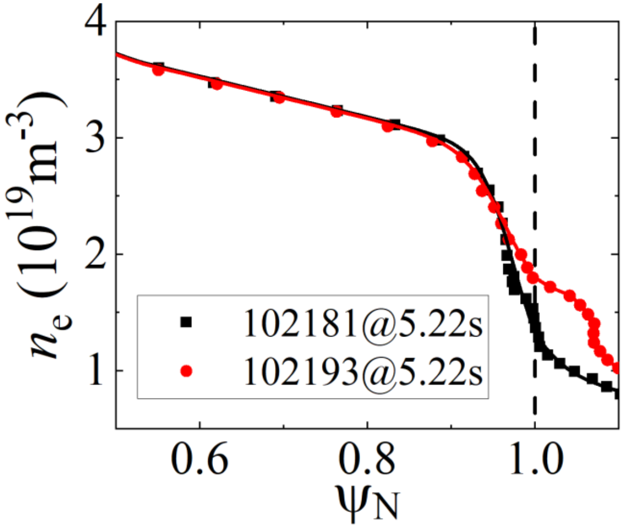
SOLPS-ITER simulation suggests a higher ionization source exists in the SOL region when the strike point moves away from the divertor corner



2D distribution of D⁺ source
(40% of full drift effect)





- **SOLPS-ITER simulation for different strike point locations**
- **When the strike point moves away from the divertor corner region, there is a higher ionization source in the SOL region, providing fueling near separatrix and thus enhancing separatrix density.**

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Summary

- **It has been repetitively observed that small ELMs could be replaced by large ELMs in the minute-scale long-pulse H-mode discharges on EAST.**
  - Correlated with decrease in edge fuel recycling and $n_{e,sep}$
- **Pedestal linear stability analysis suggests that the decrease in $n_{e,sep}$ plays an important role in triggering the large ELMs.**
  - Operational point moves from near ballooning boundary to near corner of the PBM boundary.
- **Lower plasma density at low edge recycling level appears to facilitate small ELMs in minute-scale long-pulse H-mode discharges on EAST.**
  - Lower $n_{e,ped}$ leads to lower ∇p and j, preventing large ELM bursts.
- **Large ELM mitigation has been achieved by changing the strike point location on the horizontal target plate of lower tungsten divertor on EAST.**
  - Accompanied by significantly enhanced $n_{e,sep}$
- **SOLPS-ITER simulation suggests that a high ionization source exists in the SOL region when the strike point is located away from the divertor corner.**
  - Providing fueling near separatrix and enhancing $n_{e,sep}$

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Thank You