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Development of High Poloidal Beta Scenario for Long-Pulse Operation in Collaboration between DIII-D and KSTAR

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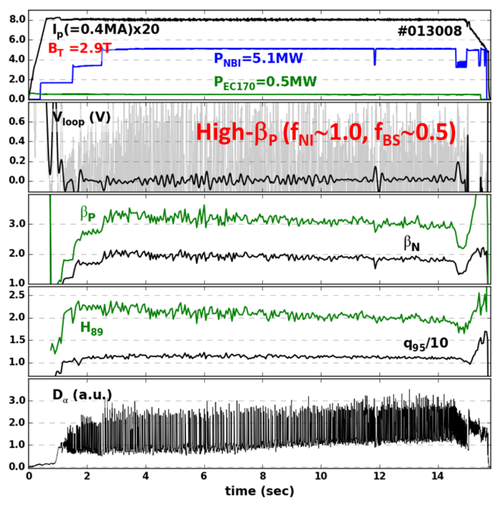
1. ABSTRACT / HIGHLIGHT

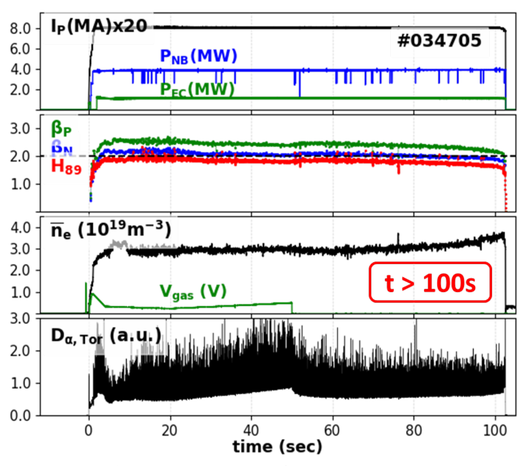
Development of High-β_p Scenarios for Reactor-Relevant Steady-State Operation

- **High-confinement long-pulse operation (>100 s)** has been achieved in **KSTAR** with a **tungsten divertor**, based on its **high-β_p scenario**.
- To advance toward K-DEMO, the **DIII-D–type high-β_p scenario** with a **large-radius ITB** was adopted.
- A **joint DIII-D/KSTAR effort established this scenario on DIII-D** under KSTAR-like conditions, achieving H_{98}~1.5, $\beta_p \geq 3.0$, $f_{BS} \geq 0.5$, and a large-radius ITB ($\rho \geq 0.5$).
- **Initial KSTAR tests showed promising results**—a weak ion ITB with ~30% performance gain, despite tungsten accumulation and limited NBI power.

2. High-β_P Scenario Used for KSTAR Long-Pulse Operations

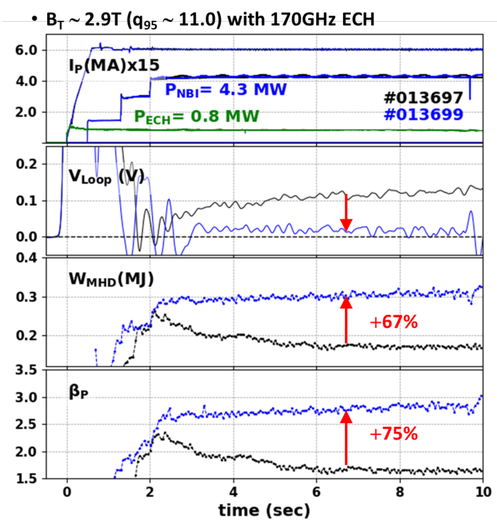
- **A ~100 s high performance long-pulse operation demonstrated based on high-β_P scenario with W-Divertor.**

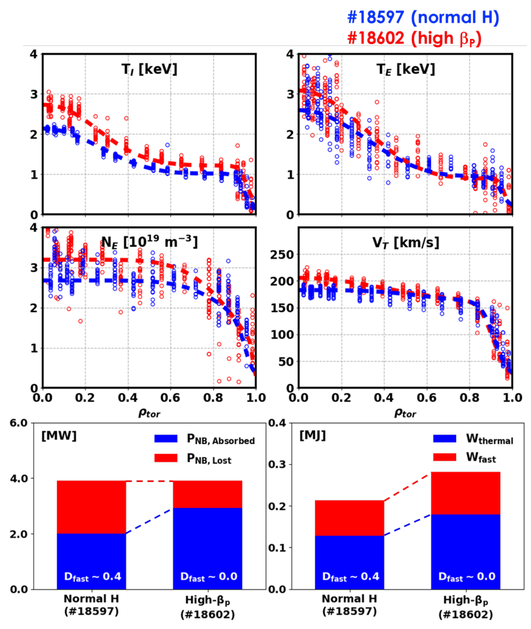




(Revised) [1]H.S. Kim, et al., 2nd IAEA-TM on Long-Pulse Operation of Fusion Devices, Vienna, Octorber (2024)

- **Central ECH plays a key role on the access of high-β_P, by suppressing anomalous transports of fast ion**





EFIT/TRANSP analysis

3. Further Improvements ➔ High-β_P with Large-Radius ITB

- **DIII-D high-β_P scenario with large-radius ITB is a promising candidate for DEMO and FPP.**
  - Excellent energy confinement ($H_{98y2} \geq 1.5$) in high density (even for f_{GW}>1.0)

H_{98y2} vs density for DIII-D discharges
[2]S. Ding, et al., Nature, 629, pp.555–560 (2024)

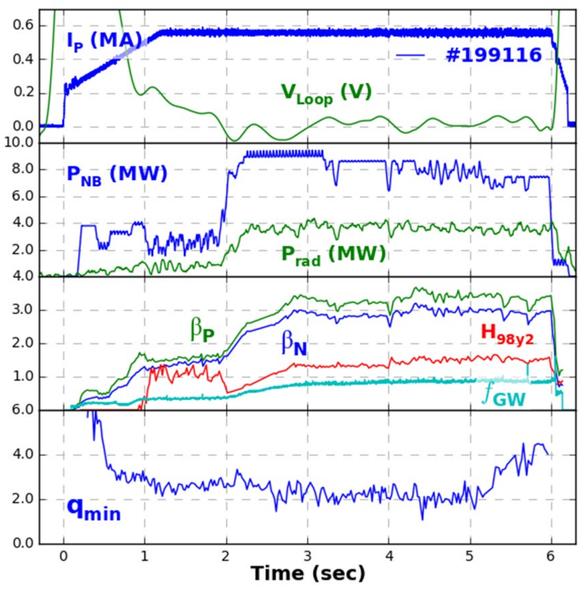
H_{98y2} vs density in different modes
[3]S. Ding, et al, Phys. Plasmas 32, 022502 (2025)

4. New High-β_P Scenario Established on DIII-D with KSTAR Constraints

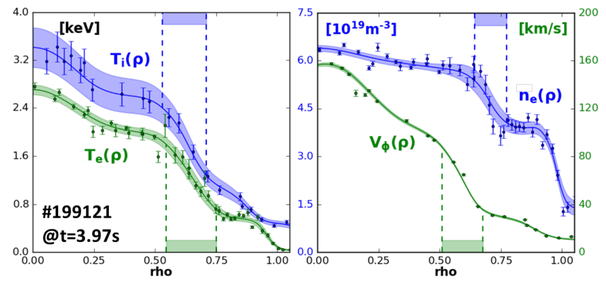
- **Maximizing synergy through collaborative research**
  - DIII-D : A leading facility in high-β_P scenario research
  - KSTAR : Long-pulse capability with tungsten wall

- **KSTAR constraints**
  - KSTAR specific shape
  - **Delayed shaping time**: ~0.5 s (KSTAR)
  - **Slow I_p ramp rate**: ~0.3 MA/s (KSTAR)
  - NB heating limitations: power, on-time, etc
  - Tungsten impurity issue

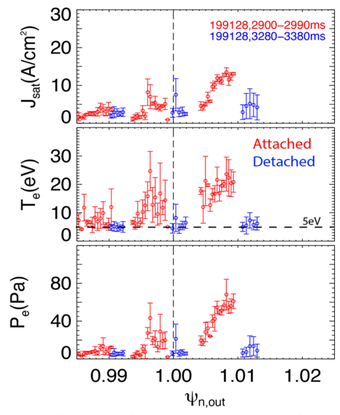
New high-β_P scenario with KSTAR constraints established on DIII-D
➔ **Demonstrate the new scenario (with ITB) on KSTAR**



Time evolutions of new high-β_P discharge on DIII-D with KSTAR constraints
($H_{98y2} \geq 1.5$, $\beta_P \geq 3.0$, f_{BS}~0.6, f_{GW}~0.9)



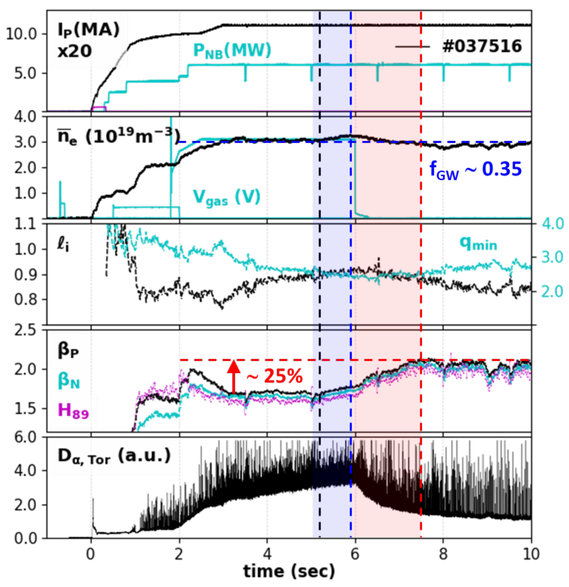
Large-radius ITBs formed in all channels

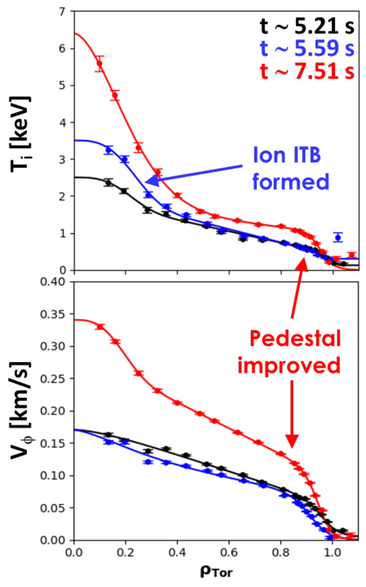


Divertor detachment achieved via neon seeding with 10~20% degradations

5. Demonstrate New High-β_P Scenario on KSTAR (Preliminary)

- **The first implementation shows encouraging results**
  - Marginal condition to trigger ITB
  - Several perturbations made weak ITB formed with ~25% performance gain





- A ~100 s long-pulse operation was successfully demonstrated in KSTAR using high-β_P scenario under a tungsten divertor environment.
- To pursue further improvements, a joint activity between DIII-D and KSTAR was initiated to establish DIII-D-type high-β_P scenario (i.e. with a large-radius ITB) on KSTAR.
- The first implementation of this scenario on KSTAR has shown encouraging outcomes; weak ion ITB with ~25% performance gain
- A dedicated experiment is planned for KSTAR 2025-2026 campaign

ACKNOWLEDGEMENTS / REFERENCES

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[1] H.S. Kim, et al., Proc. 2nd IAEA-TM on Long-Pulse Operation of Fusion Devices, Vienna, October 2024.
[2] S. Ding, et al., Nature, 629, pp. 555–560 (2024).
[3] S. Ding, et al., Phys. Plasmas, 32, 022502 (2025).