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

Youngmu Jeon[1,2], Hyunseok Kim[1], Jimin Lee[1,2], Youngho Lee[1], and many collaborators

[1]KFE, [2]UST (Korea)

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MOTIVATION AND HIGHLIGHT

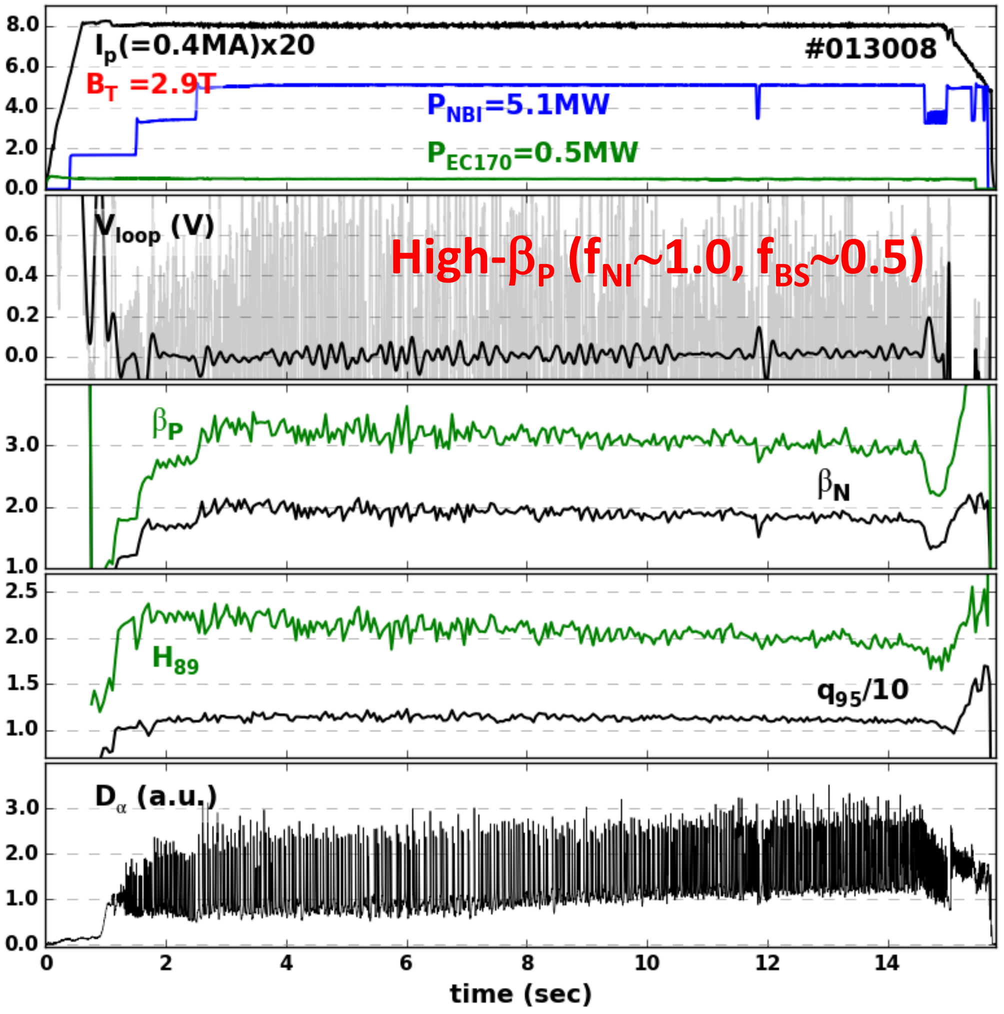
- **Recently, KSTAR successfully demonstrated a 100-second high-performance long-pulse operation based on the high poloidal beta scenario, following the Tungsten divertor upgrade**

- **Building on this, high poloidal beta scenario combined with a large-radius ITB has been developed through DIII-D/KSTAR collaboration for reactor-relevant long-pulse operation, showing encouraging initial results.**

Contents of This Talk

- **Characteristics of KSTAR high-β_P scenario used for long-pulse operations**
- **A joint activity between DIII-D and KSTAR for reactor-relevant, high-β_P scenario development**
  - (DIII-D) Establish a high-β_P scenario with KSTAR-like constraints
  - (KSTAR) Implement the new scenario under W-divertor
- **Summary and Discussion**

KSTAR High-β_P Scenario Successfully Demonstrated ~100 s High Performance Long-Pulse Operation with W-Divertor



- ➢ **KSTAR high-β_P scenario is suitable for long pulse applications, although no ITB forms**

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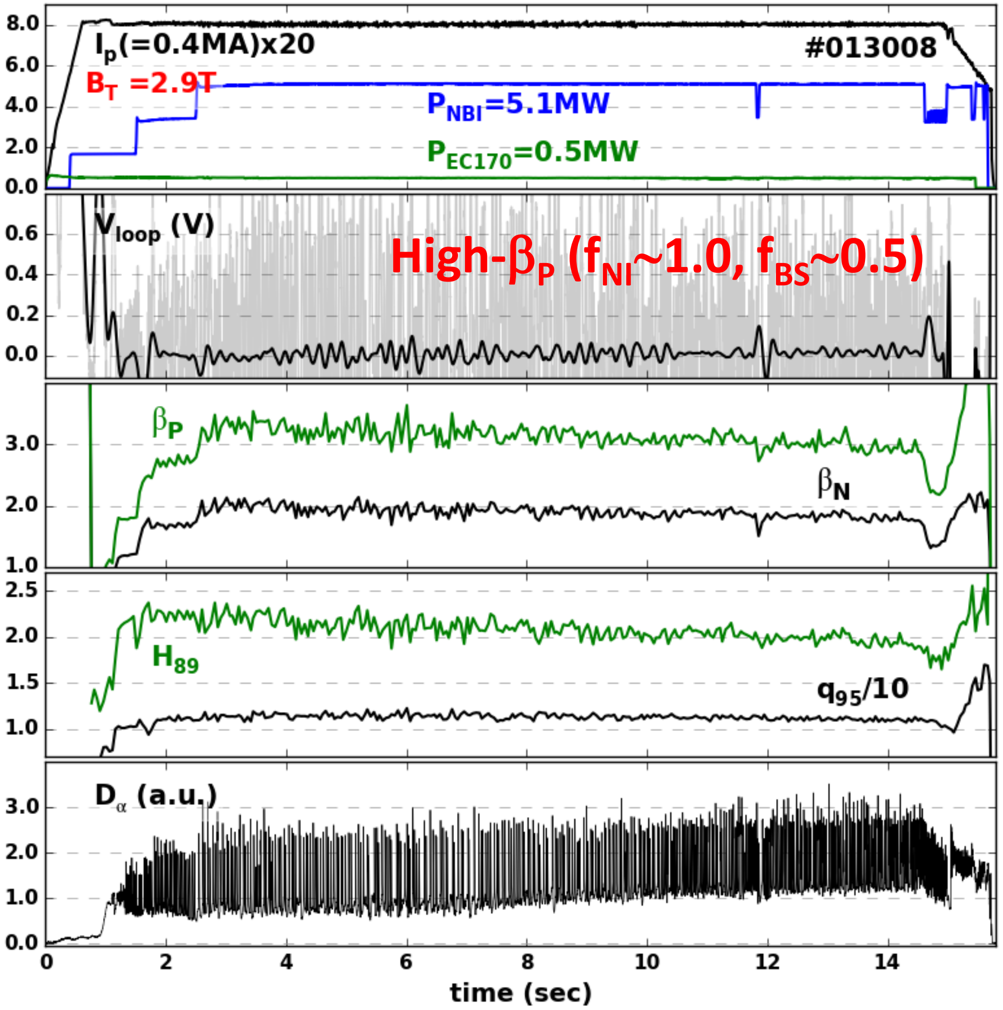
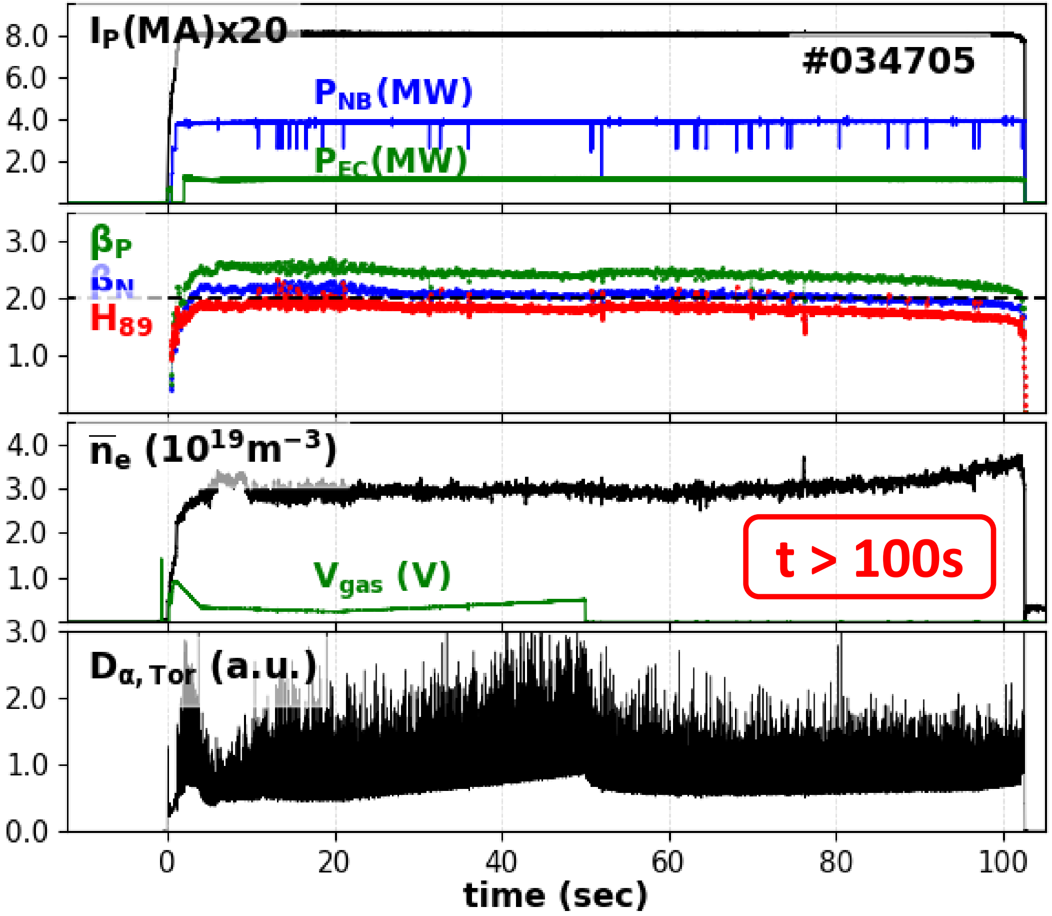


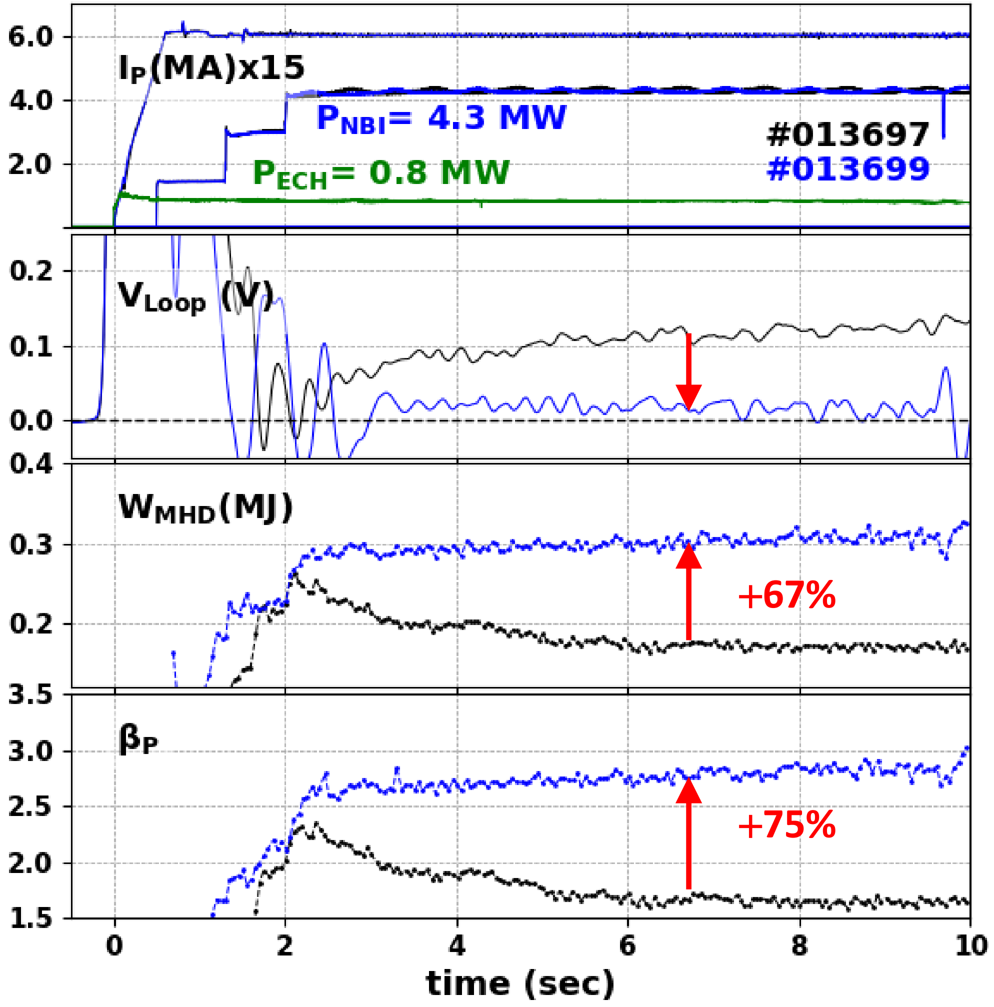


(Revised) [H.S. Kim, et al, 2nd IAEA-TM on Long-Pulse Operation of Fusion Devices, Vienna, October 2024]

➢ **KSTAR high-β_P scenario is suitable for long pulse applications, although no ITB forms**

Central ECH Plays A Key Role for the Access of High-β_P

- $B_T \sim 2.9T$ ($q_{95} \sim 11.0$) with 170GHz ECH



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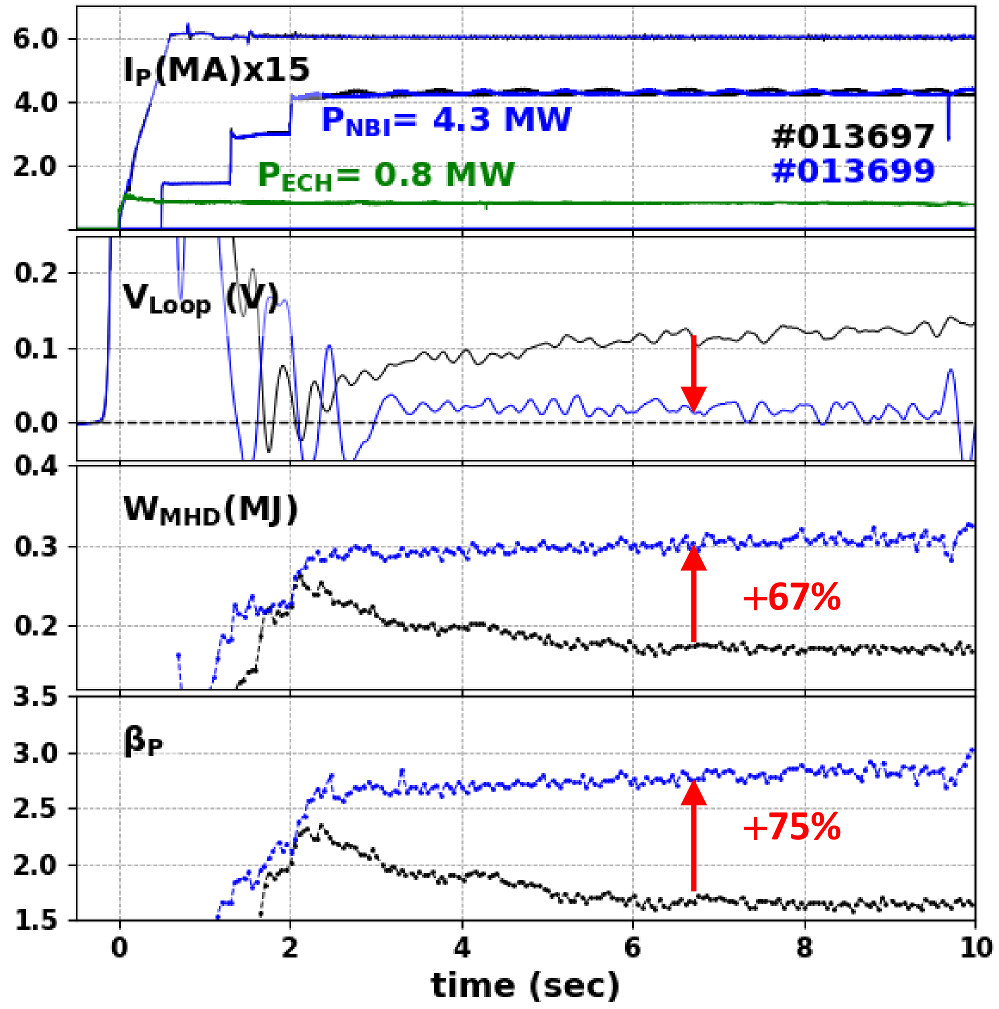
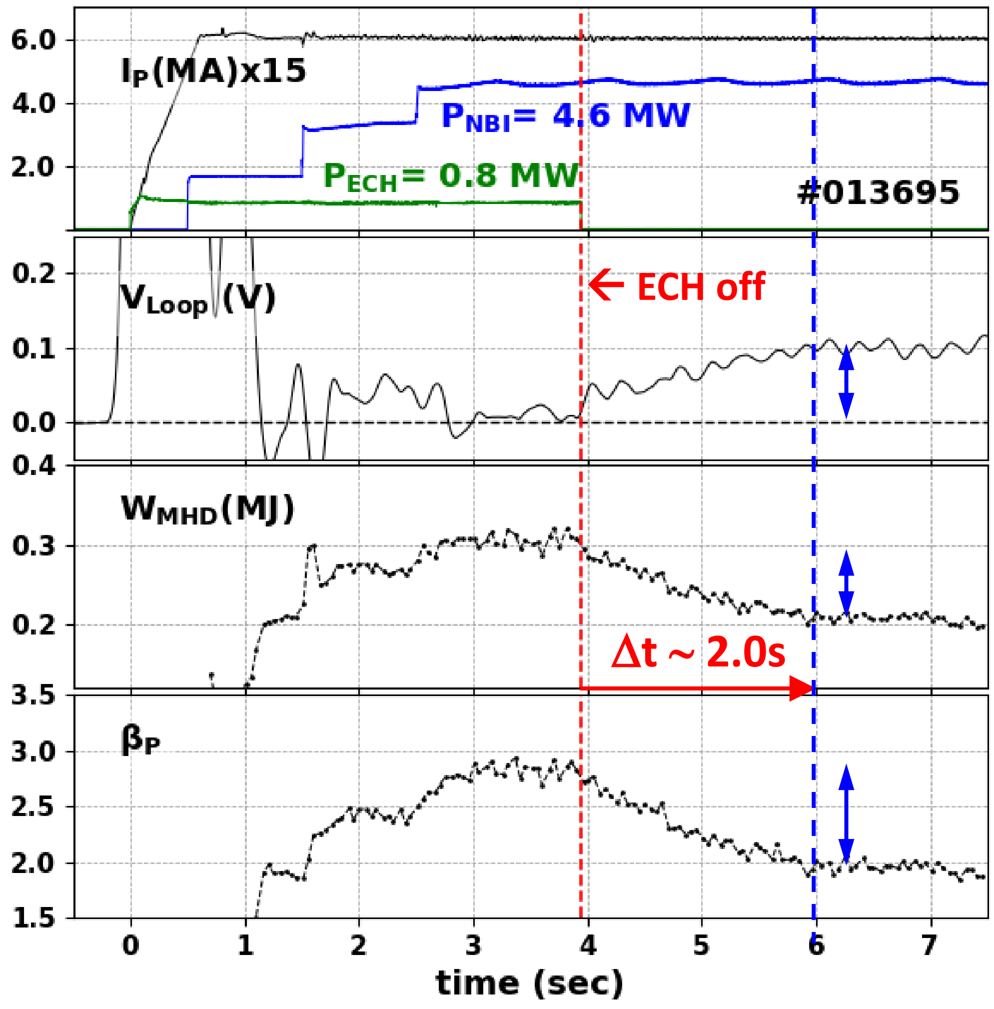
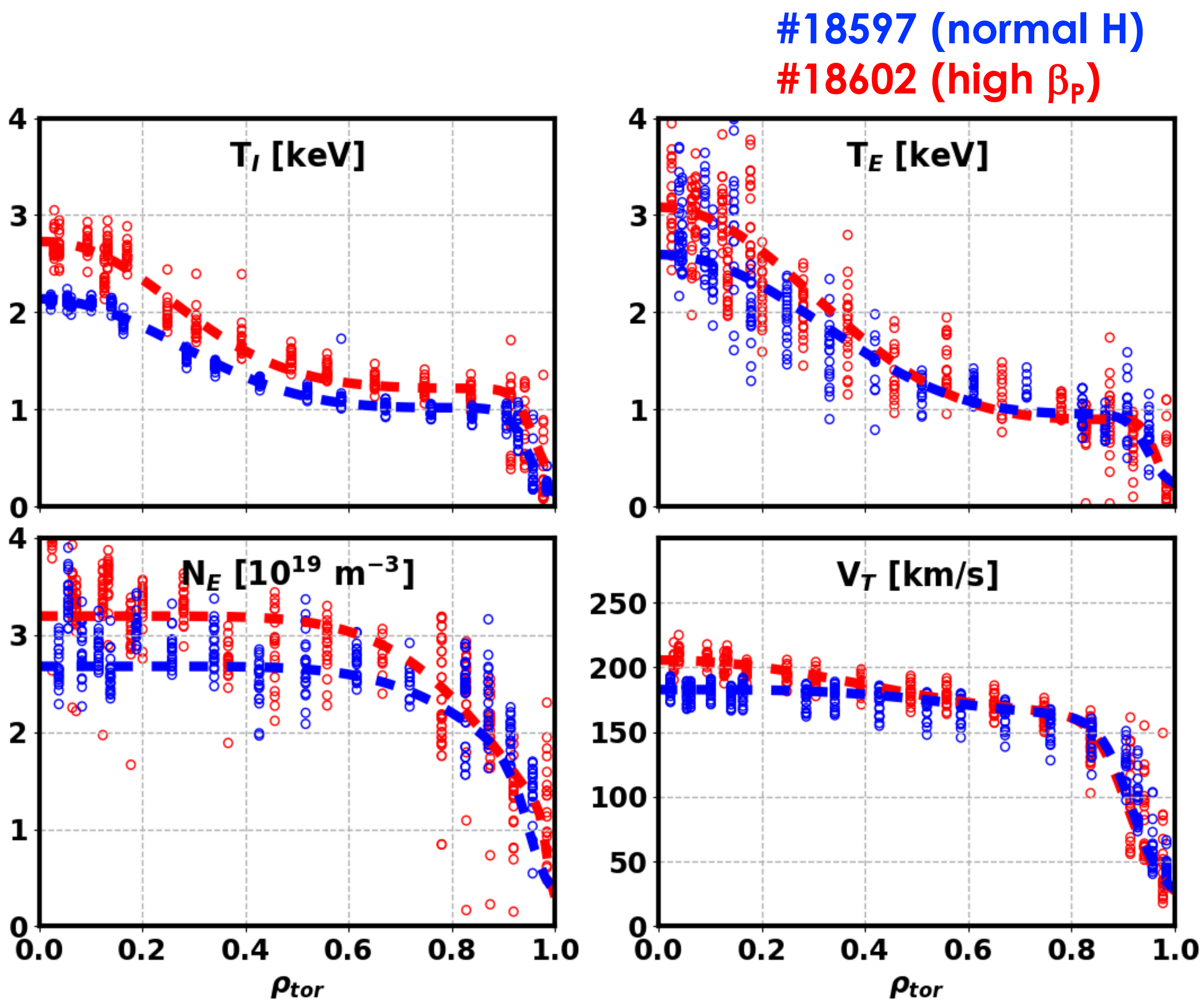




- **Substantial confinement improvements made by central ECH in a long time scale**

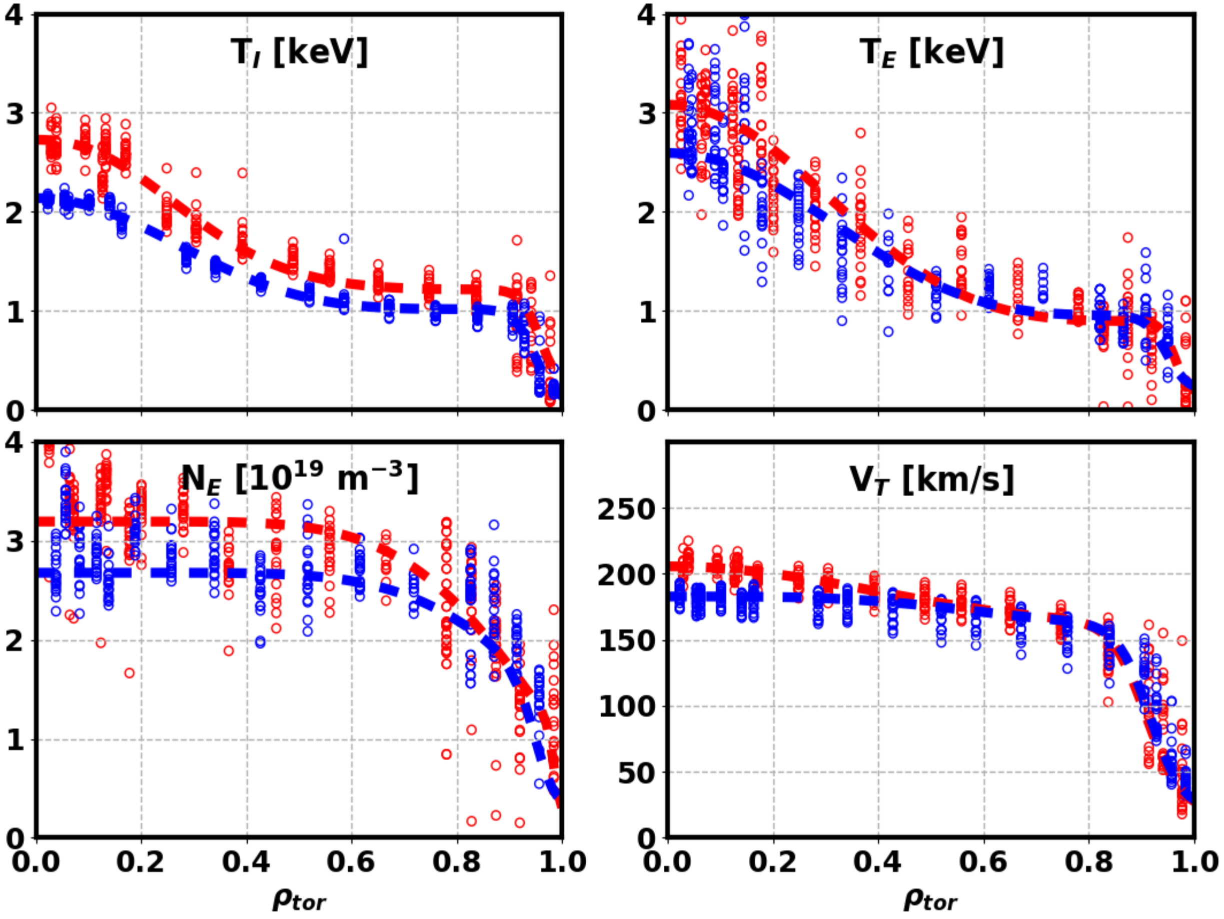
Improvement of Fast Ion Confinement Is A Main Change



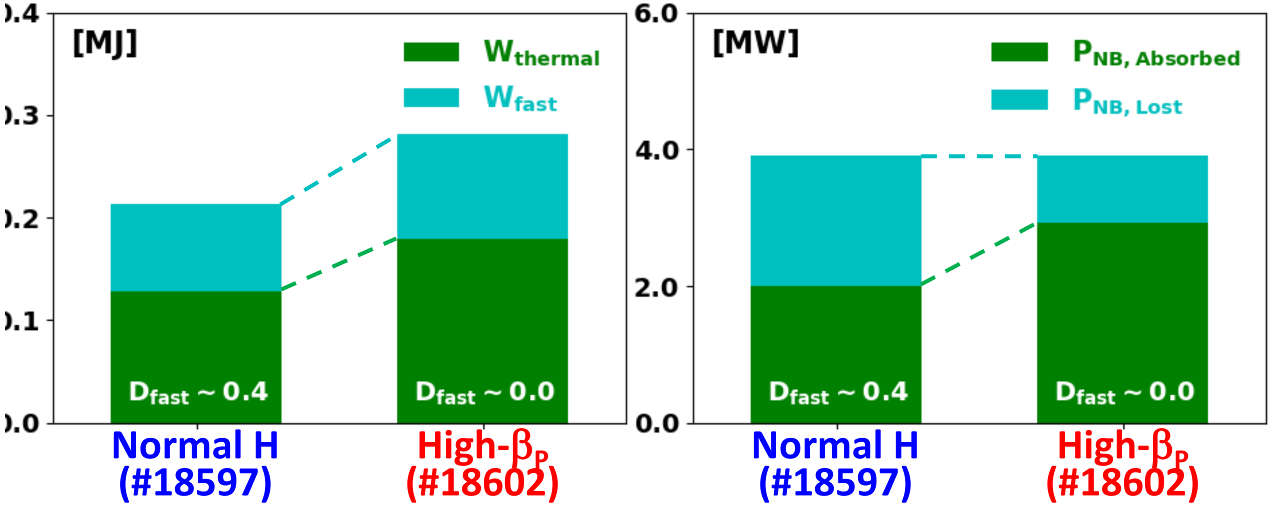
- **No ITB observed in KSTAR high-β_P**

Improvement of Fast Ion Confinement Is A Main Change

#18597 (normal H)
#18602 (high β_P)



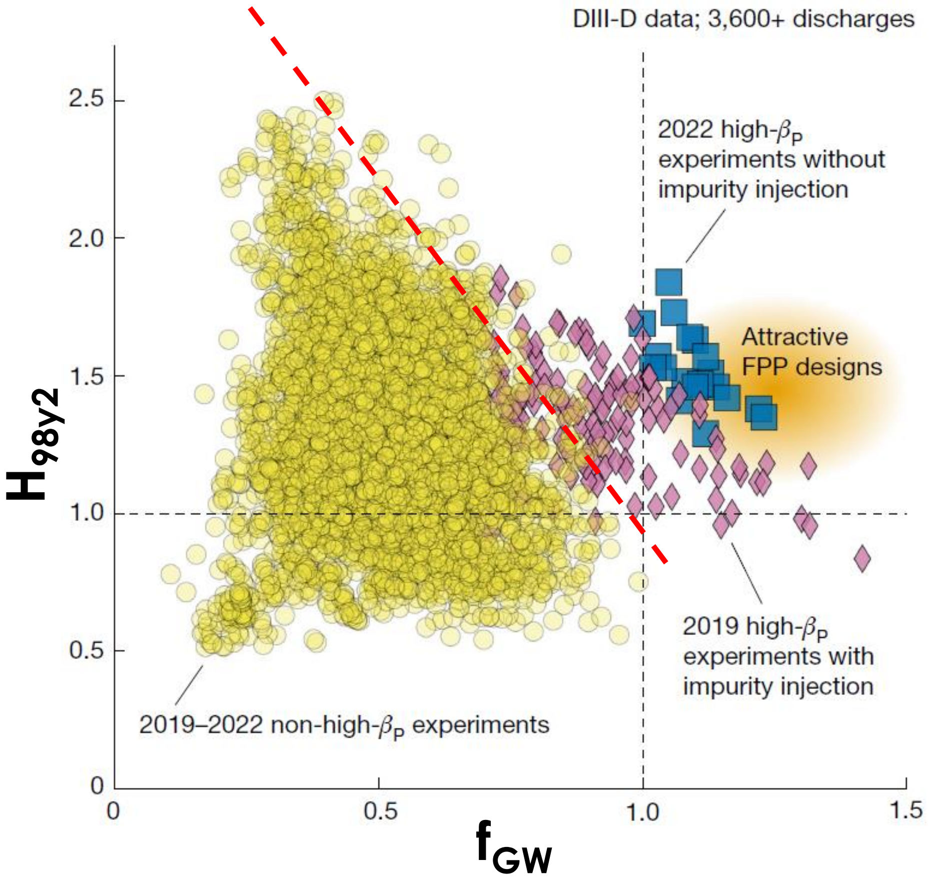
- **No ITB** observed in KSTAR high-β_P
- **Suppressed anomalous transport** of fast ion (done **by central ECH**)
- **Beam absorption** was greatly enhanced



EFIT/TRANSP analysis

Further Improvements Needed for DEMO and FPP. One Promising Path Is the DIII-D High-β_p Mode, Characterized by A Large-Radius ITB

DIII-D High-β_P Scenario with Large Radius ITB Is A Promising Candidate for DEMO and FPP



Database of H_{98y2} and f_{Gr} for DIII-D discharges [S. Ding, et al., Nature, 629, pp.555–560 (2024)]

- **Excellent energy confinement (H_{98y2}≥1.5) in high density operation (even for f_{GW}>1.0)**
  - Candidate for DEMO and beyond
  - beneficial for core-edge integration

A Joint Activity between DIII-D and KSTAR Was Initiated to Maximize the Synergy between the Two Devices

- **Maximizing synergy**
  - **DIII-D**: A leading facility in high-β_P scenario research
    - → **Establish a scenario with KSTAR-like constraints**
  - **KSTAR**: Long-pulse capability with W-wall
    - → **Verify the scenario and extend in a long pulse**

DIII-D NATIONAL FUSION FACILITY

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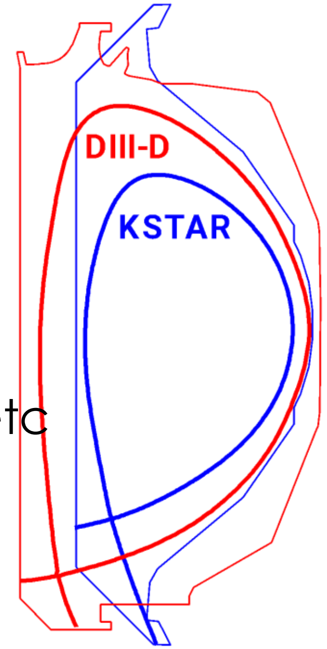
➢ KSTAR-like constraints

– 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



DIII-D High-β_P Scenario Was Successfully Established with KSTAR-Like Constraints (f_{BS}~0.6, H_{98y2}≥1.5, f_{GW}~0.9)

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  - **DIII-D**: A leading facility in high-β_P scenario research
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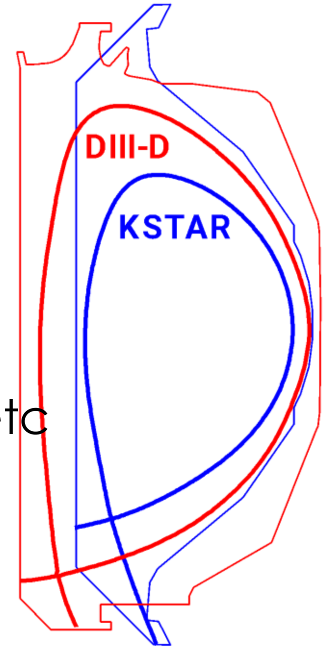
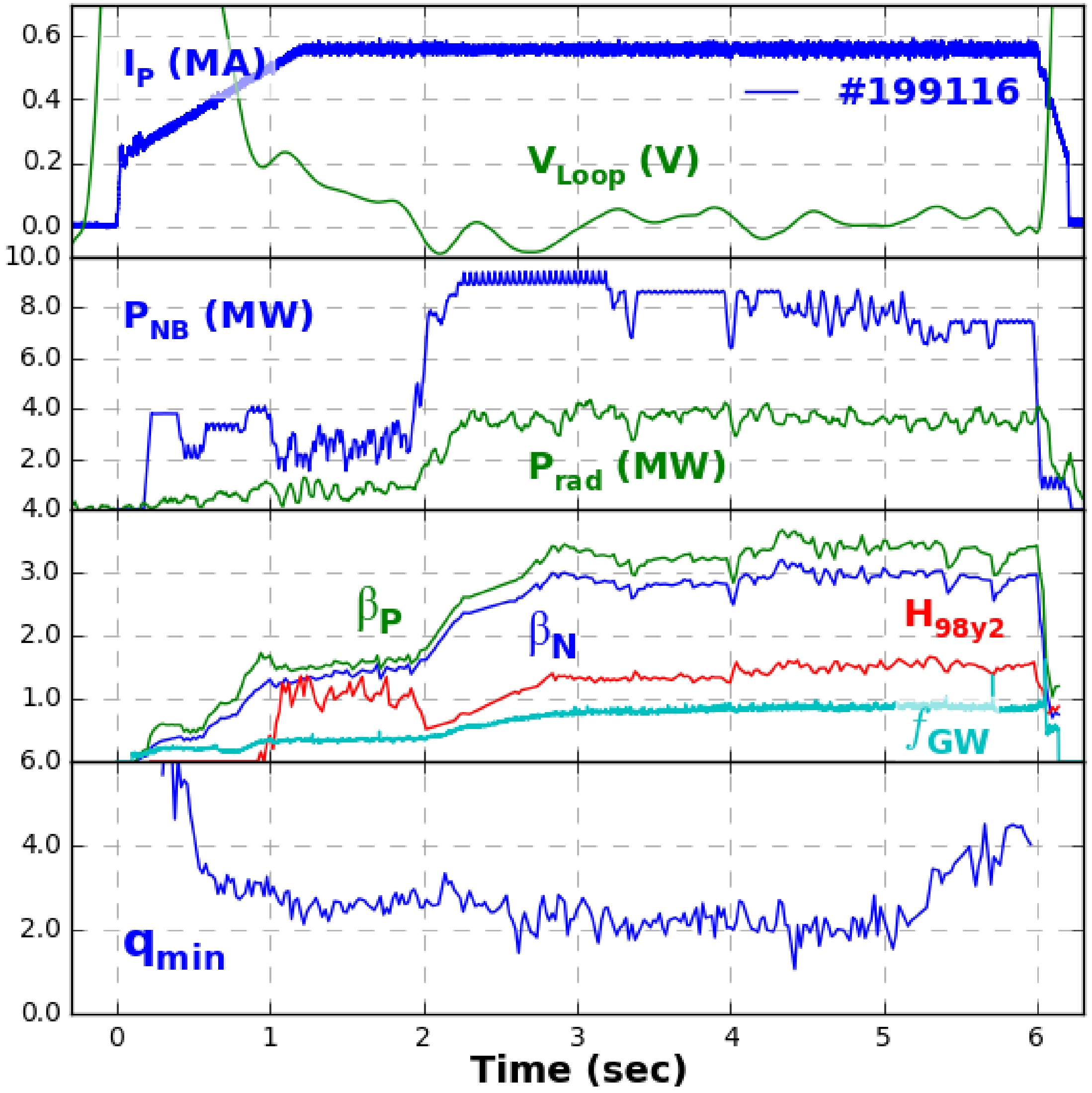
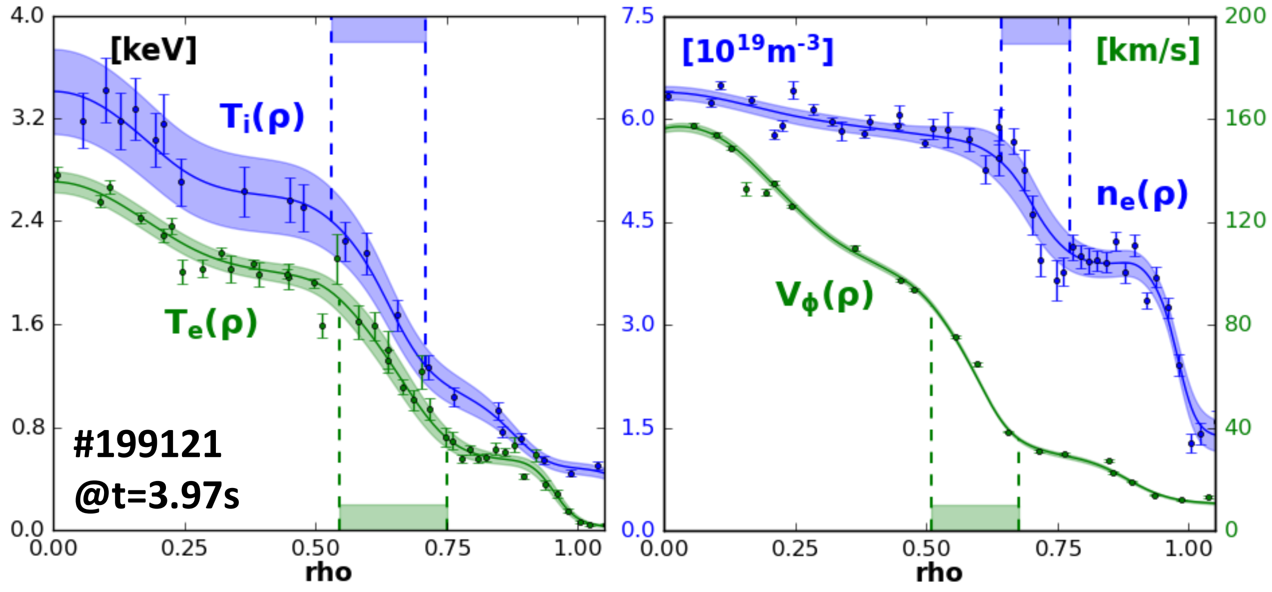




Large-Radius ITBs (ρ_{Tor} = 0.50~0.75) Formed in All Channels. Divertor Detachment Also Achieved by Neon Seeding



- ITBs formed in all channels at ρ_{Tor}= 0.50~0.75
- The strongest ITB in electron density

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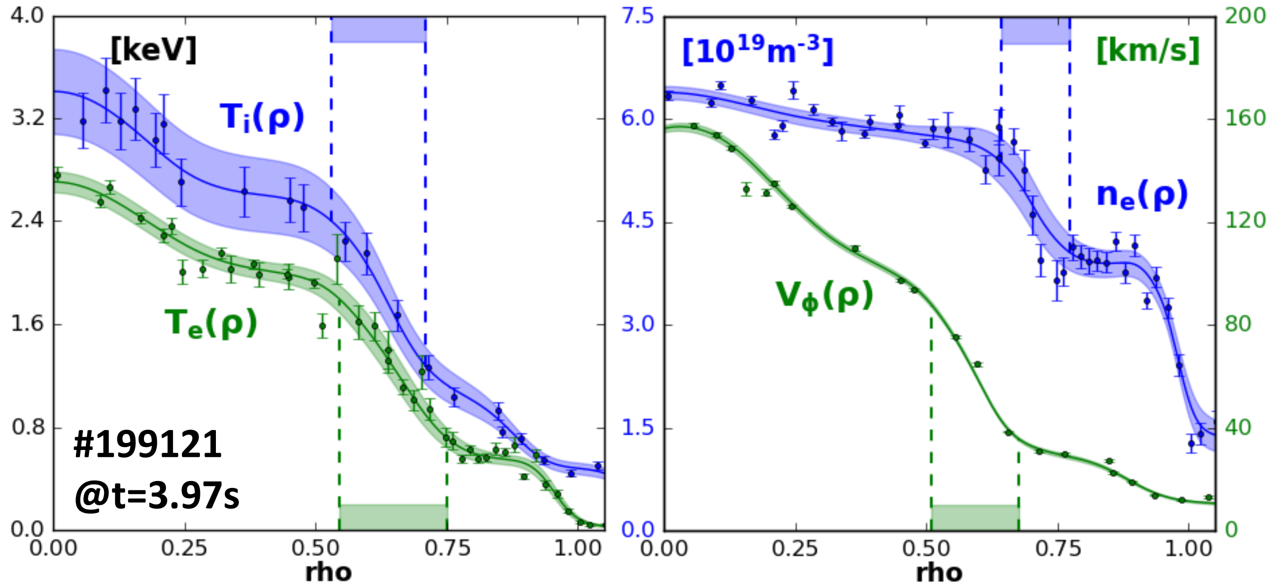

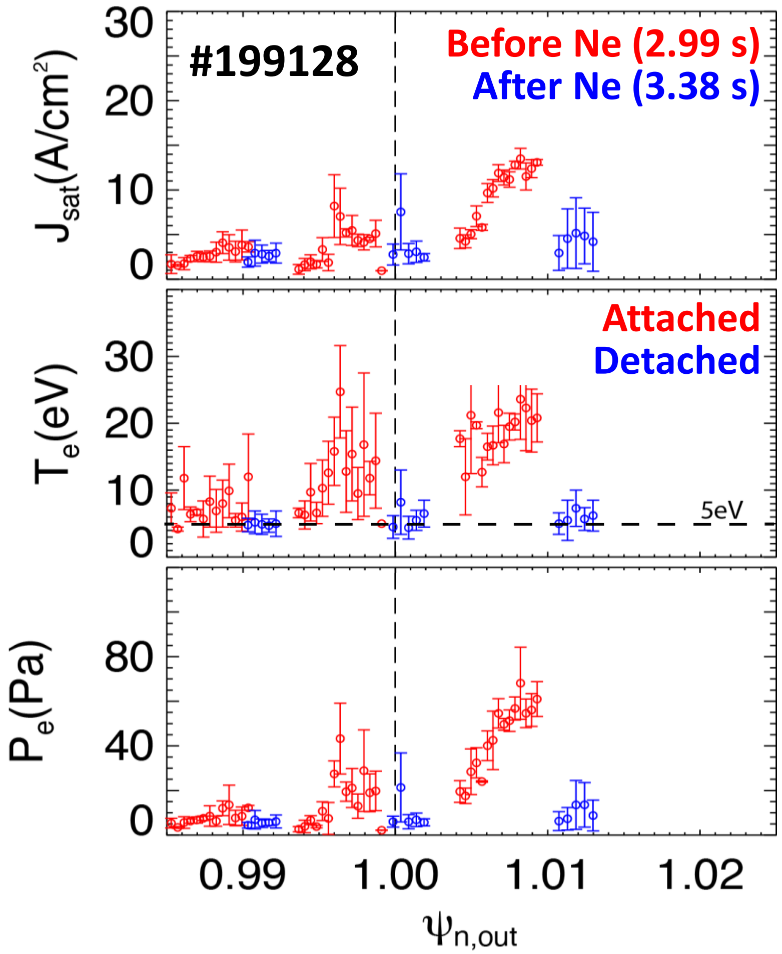

Detached divertor profiles

- ITBs formed in all channels at ρ_{Tor}= 0.50~0.75
- The strongest ITB in electron density

- Divertor detachmenet achieved by neon seeding with 10~20% performance degradations

Preliminary Experiments Implementing DIII-D High-β_P Scenario on KSTAR Show Encouraging Results

Key Elements for Demonstrating DIII-D High-β_P Scenario on KSTAR

- Slow I_P ramp rate
- Delayed shaping/diverting
- Delayed NB on-time

➡ **Current profile peaking**

Key Elements for Demonstrating DIII-D High-β_P Scenario on KSTAR

- **Slow I_P ramp rate**
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→ **Current profile peaking**

1. **Broad current profile for ITB formation**
   - KSTAR has high li and low qmin (~1.0)
   - DIII-D has low li and high qmin (> 2.0)

Key Elements for Demonstrating DIII-D High-β_P Scenario on KSTAR

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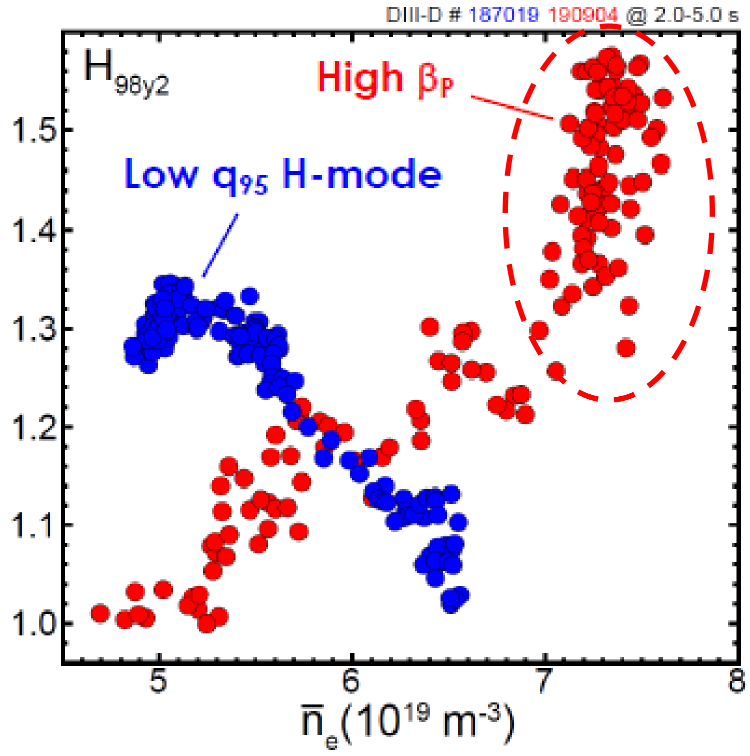
➡ **Current profile peaking**

1. Broad current profile for ITB formation

- KSTAR has high li and low qmin (~1.0)
- DIII-D has low li and high qmin (> 2.0)

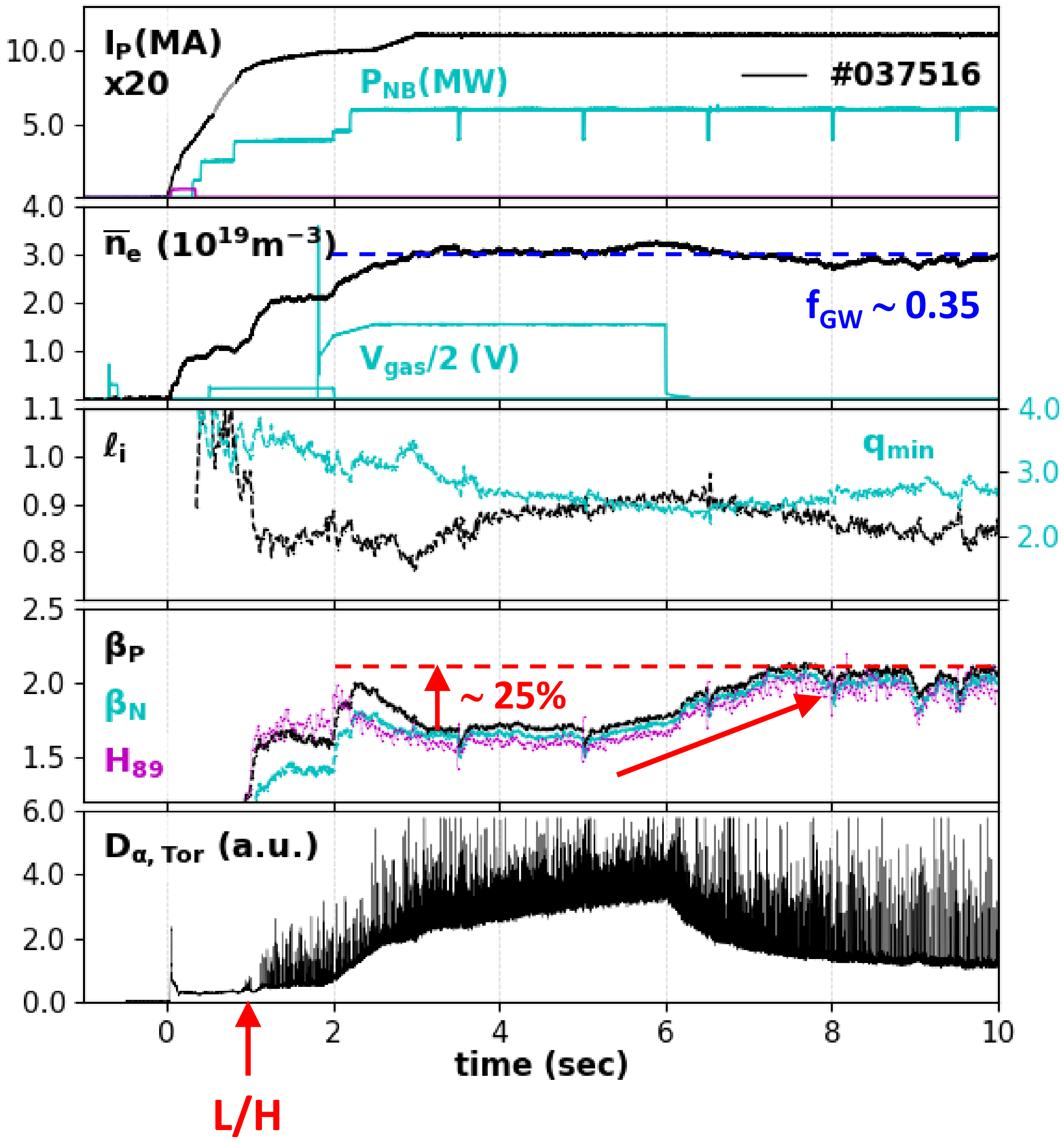
2. High density (pedestal)

- KSTAR usually operated in low density (**f_{GW} < 0.5**)
- DIII-D requires high density operation (**f_{GW} > 0.8**)



S. Ding, et al, Phys. Plasmas 32, 022502 (2025)

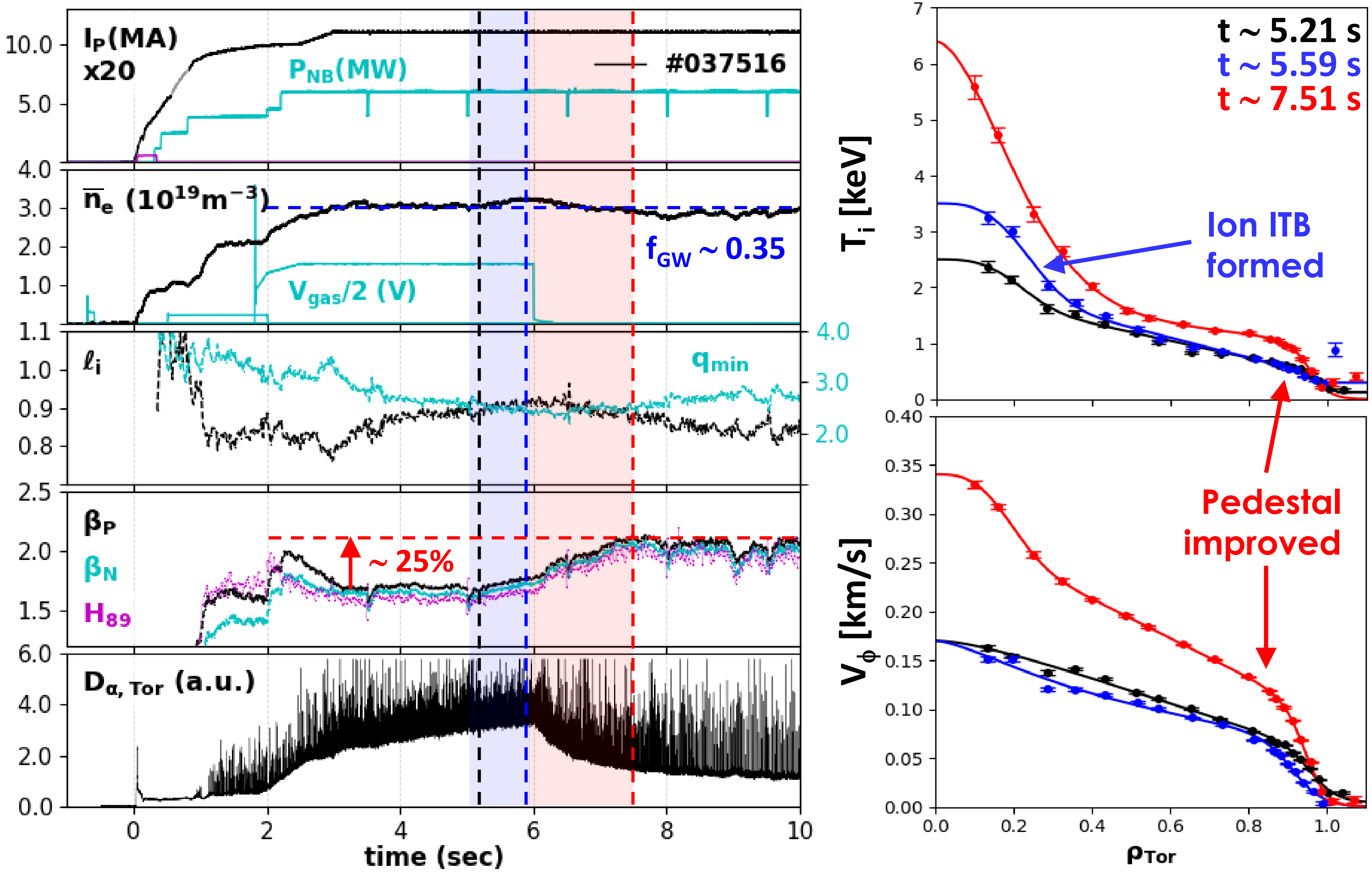
Preliminary Experiments Show the Difficulties of Controlling Density and Current Profiles as Expected



- **Differences from the reference**
  - Lower density (f_{GW}~0.35)
  - Rather high li
  - Rather lower confinement

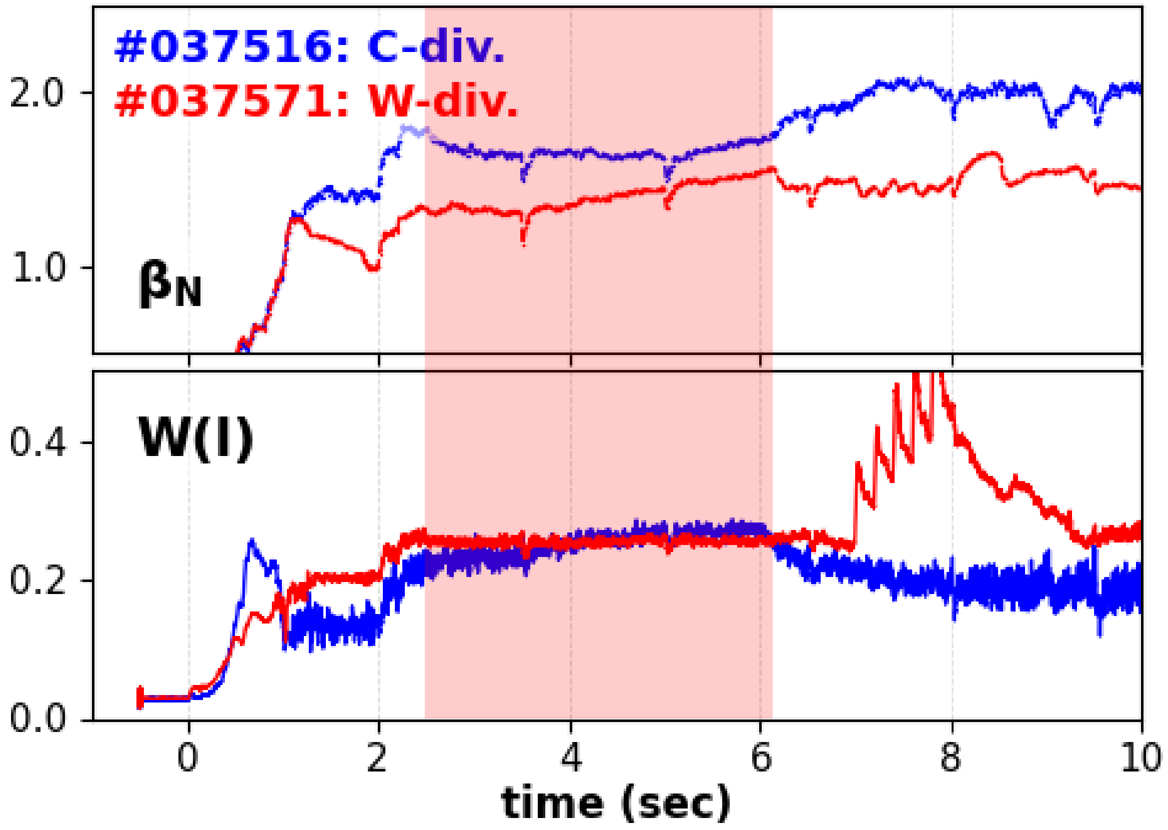
➔ **What made the large improvement in 5.0~8.0 sec?**

Weak Ion ITB Formed by A Beam Perturbation, Followed by A Large Improvement from Pedestal Enhancement



- **1st improvement (blue)**
  - Beam blip (t~5.21s) made ion-ITB formed
- **2nd improvement (red)**
  - Gas-off (t~6.0s) and another beam blip (t~6.5s) made edge pedestal improved together with a weak rotation ITB

(Preliminary) The Effect of ITB on Tungsten Accumulation



- **Not much variations of W during confinement/performance increased including ITB**

- **A sudden increase at t~7.0 s is under investigation**

➔ **Further experiments and analysis are on going**

Summary

- **A ~100 s long-pulse operation was successfully demonstrated in KSTAR by using high-β_P scenario under a tungsten divertor environment**
  - The key characteristics of KSTAR high-β_P scenario were discussed

- **To pursue further improvements toward DEMO and beyond, a joint activity between DIII-D and KSTAR was initiated, yielding promising preliminary results**
  - High-β_P scenario with a large-radius ITB was successfully established in DIII-D under KSTAR-like constraints

- **The first implementation of this scenario on KSTAR shows encouraging outcomes**
  - A weak ion ITB was obtained under marginal conditions through NBI perturbation.
  - Tungsten impurity showed clear influences on the performance

- **Further experiments and analysis are planned on the coming 2025-2026 campaign.**

Acknowledgement

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Thank you~!