Development of Steady-state Operation Scenarios with Full Tungsten Limiter/Divertor in ITER-Relevant Configuration on EAST

J. Huang[1,*], X. Gong[1], A. Loarte[2] , R.A. Pitts[2] , T. Wauters[2], J. Qian[1], R. Ding[1], G. Zuo[1], Y. Sun[1], L. Zeng[3], Z. Wang[3], A. Ekedahl[4], M. Jia[1], X. Zhang[1], B. Zhang[1], W. Liu[1], L. Xu[1], M. Li[1], C. Pan[1], Z. Zhang[1], T. Jia[1], X. Jian[1], Y. Hu[1], P. Li[1], Y. Wang[1], L. Zhang[1], Y. Guan[1], B. Wan[1] and EAST team[1]

*Email : juan.huang@ipp.ac.cn

[1]Institute of Plasma Physics, Chinese Academy of Sciences, Hefei, China [2]ITER Organization, CS 90 046, 13067, St. Paul Lez Durance Cedex, France
[3]Department of Engineering Physics, Tsinghua University, Beijing, China [4]CEA, IRFM, F-13108 Saint Paul-lez-Durance, France

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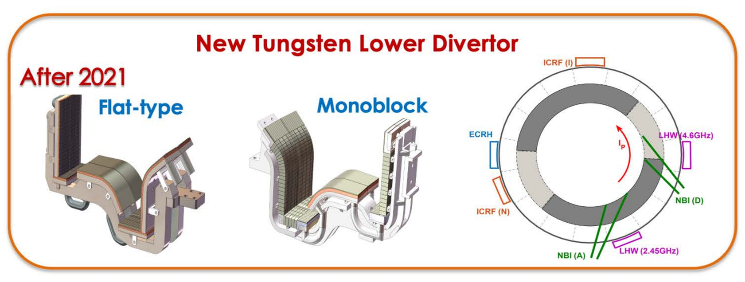
Motivation: New ITER Baseline Brings New Challenges Require More R&D and Support from Current Experiments

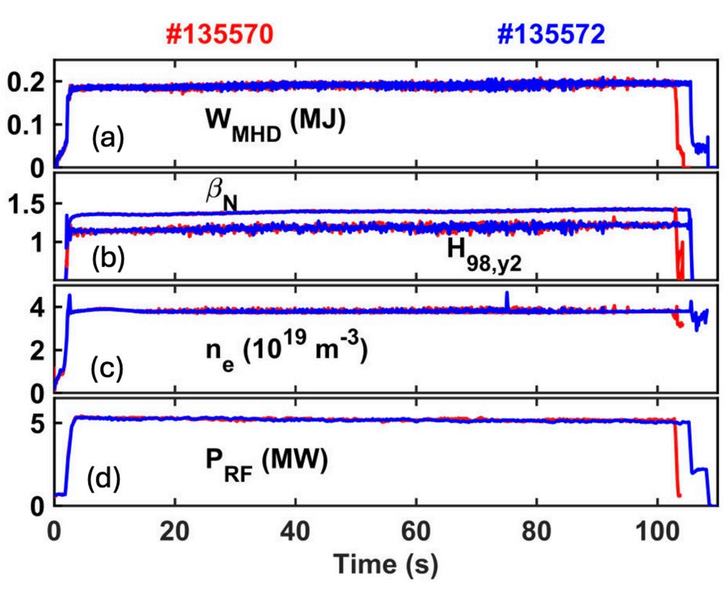
- EAST experiments with full W-limiter and W-divertors
  - Boronization studies (T. Wauters)
  - W Limiter start-up experiments (R.A. Pitts)
  - H-mode operation with W wall (A. Loarte)

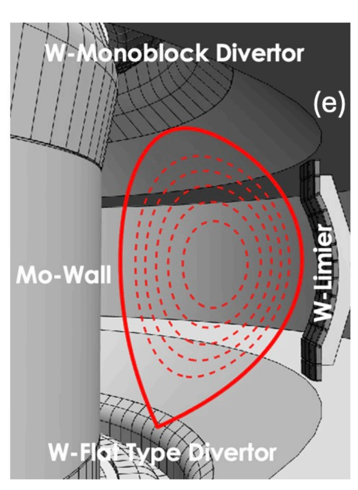


W-Limiter on EAST

- ITER First Wall Beryllium ➔ Tungsten
- Open issues with impact of W wall on ITER Q ≥ 10 and Q ≥ 5 SSO

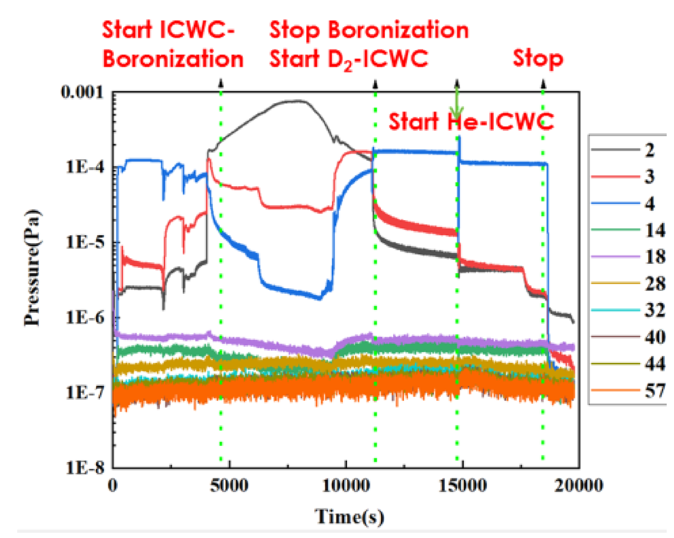
- **Demonstrate ~100s H-mode plasmas with Boronization**

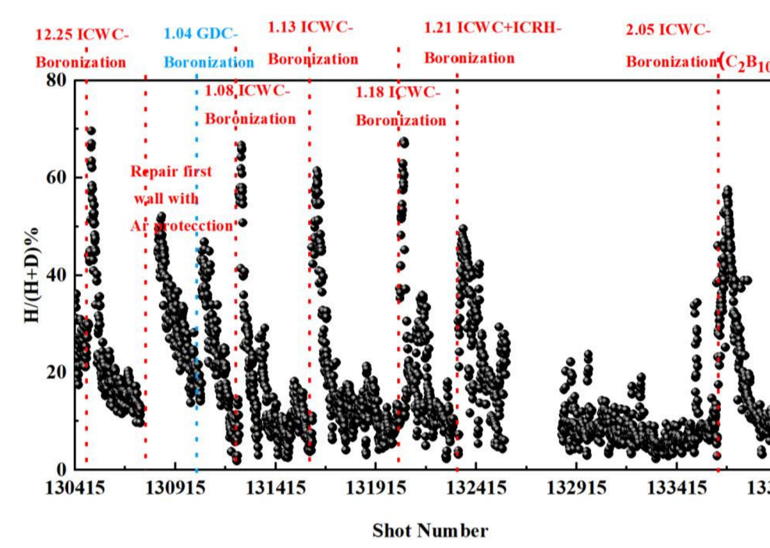




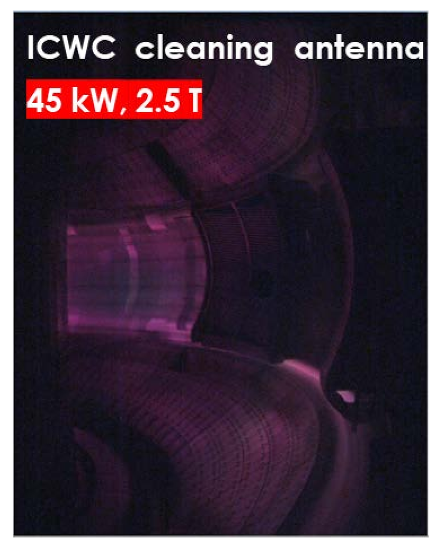
- q_{95}~6.0, H_{98y2}~1.1
- P_{EC}~ 3.0MW, P_{LH}~2.2MW
- Optimized H&CD coupling
- Well controlled high Z impurities

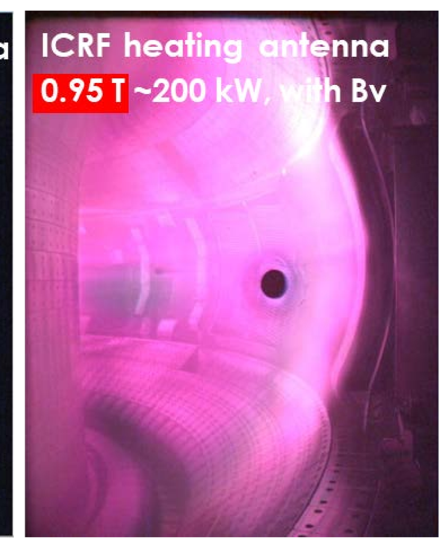
Boronization Technology Developed with Full Metal Wall

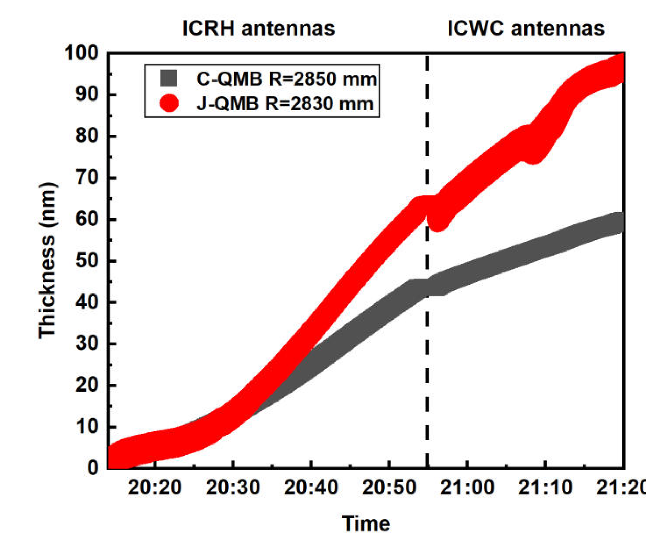




- $C_2B_{10}H_{12}$ for boronization
- D/He cleaning applied for 30-120 min to remove H in film

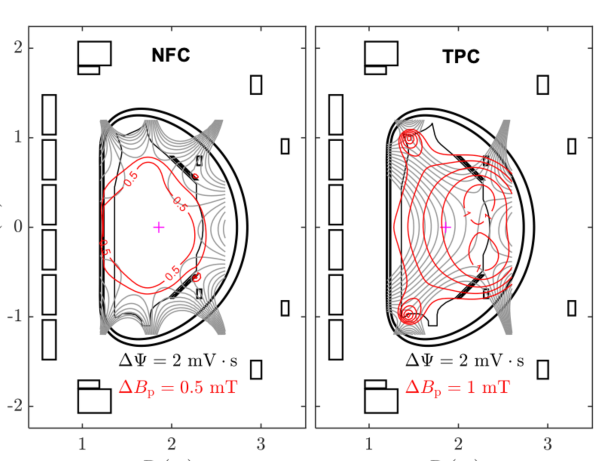


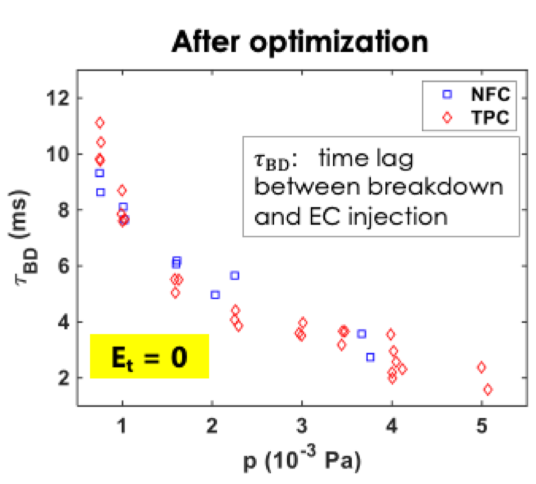


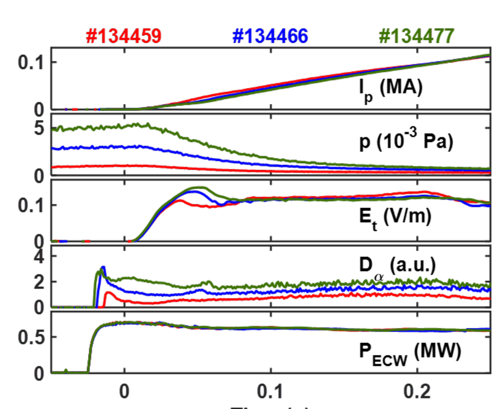


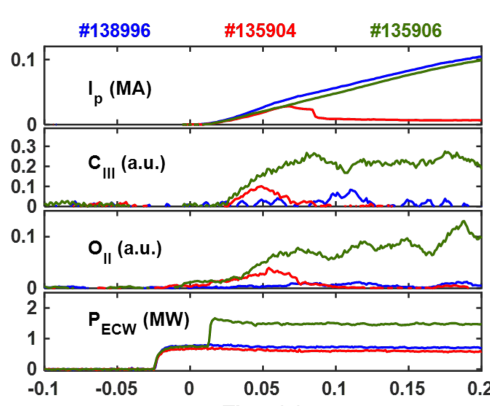
- Improved plasma uniformity and boron deposition rate obtained by ICRF heating antenna

Robust Breakdown and Plasma Startup with ECW Assistance



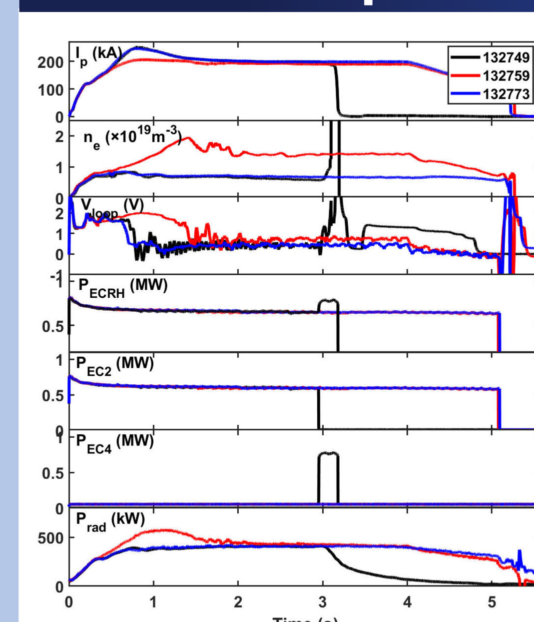


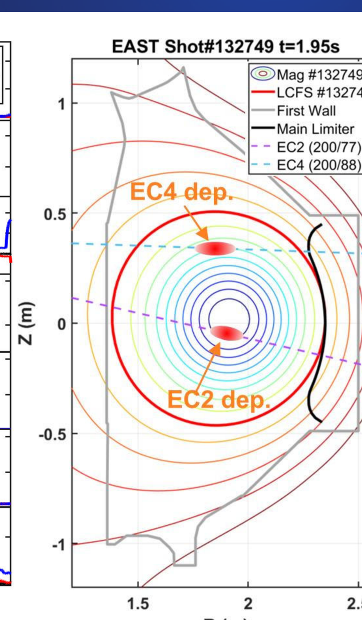




- Non-inductive breakdown (E_t = 0) with optimized NFC and TPC
- Low-E_t (< 0.15 V/m) burn-through and Ip ramp up with ECW assistance (ECH & ECCD)

EC Assist Required for Successful Start-up on W-Limiter

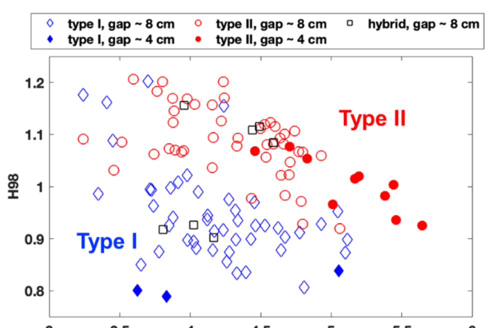


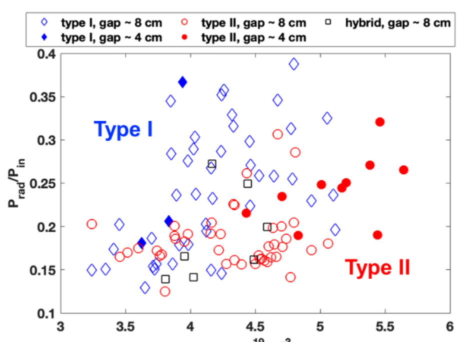


132773, low f_{GW} ~0.15
132759, high f_{GW} ~0.35
132749, off-axis ECH

- W-limiter start-up experiments required for code validation aiming at ITER limiter phase

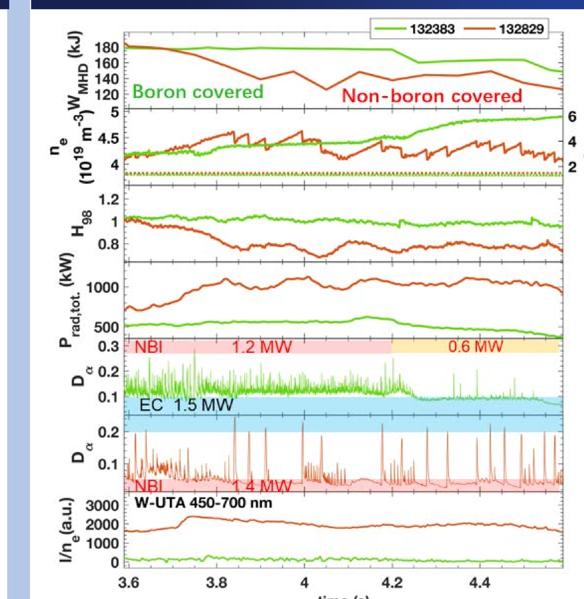
Impact of W as First Wall Material on H-mode Performance





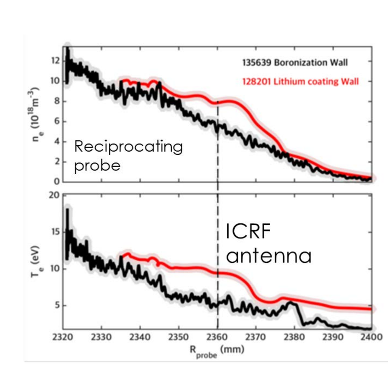
- Assessed for low/no B coverage at q_{95} ~ 6 DN plasmas with B_t ~ 2.45 T (central ECH)
- Type II ELMs provide higher confinement, lower impact of the separatrix-limiter gap and lower plasma radiation than Type I ELMs

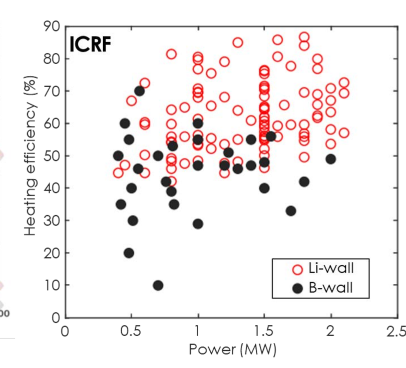
Impact of B Wall on H-mode Performance

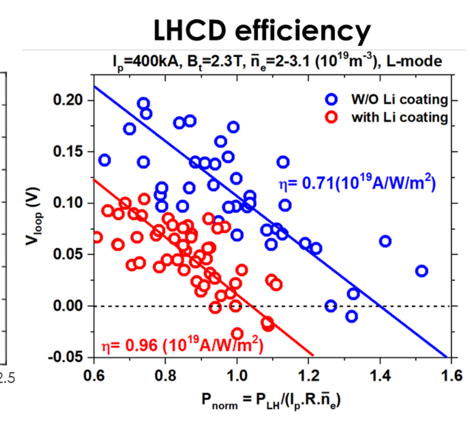


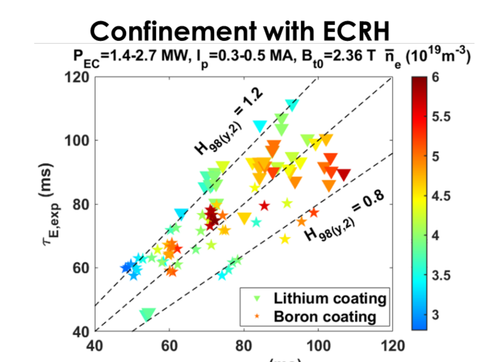
- B coverage significantly reduced the W density in core
- Achieve high confinement type II ELMs with lower P_{EC}~1.5MW, instead of low confinement type I ELMs with non-boron

Impact of Wall Conditions on H&CD Efficiency



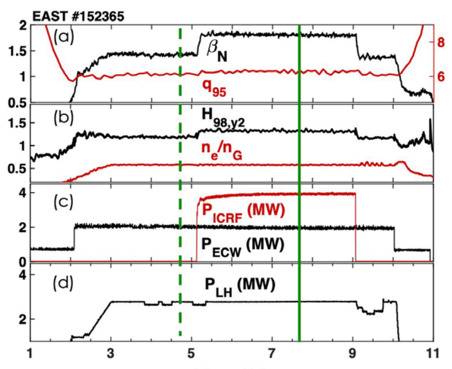


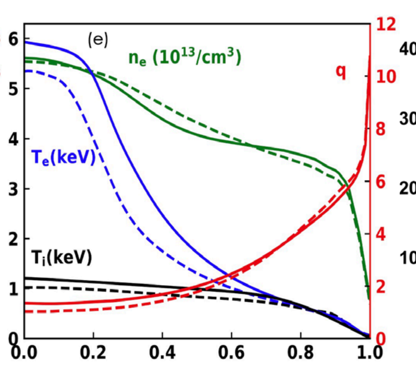


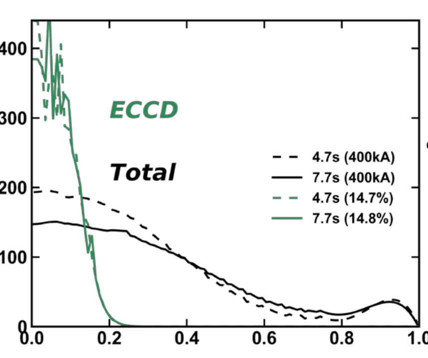


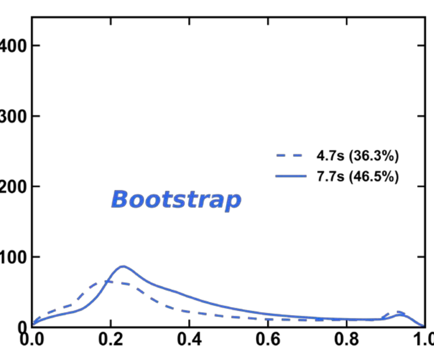
- Edge profiles changed with different wall conditions
- The reduced ICRF heating efficiency with Boron-coating compared with Li-coating
- LHCD efficiency increased by a factor of 1.35 with li-coating than non-coating
- ECRH plasma shows similar normalized confinement quality

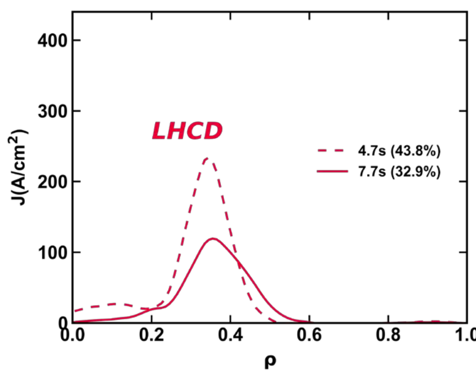
Development of High-β_P Scenario Development on Full Metal Wall

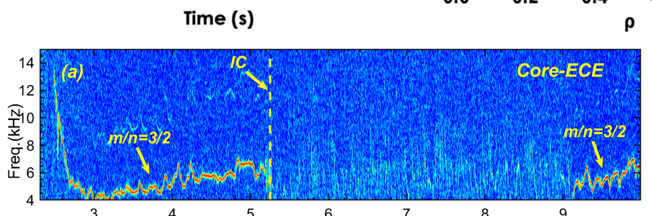


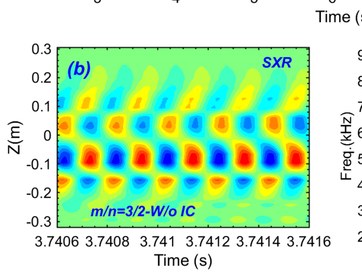


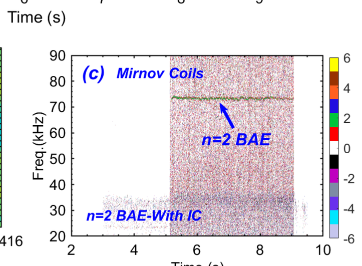




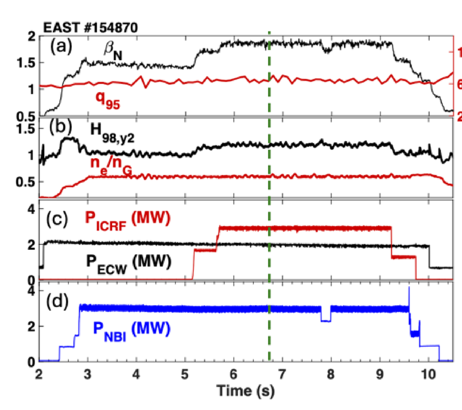


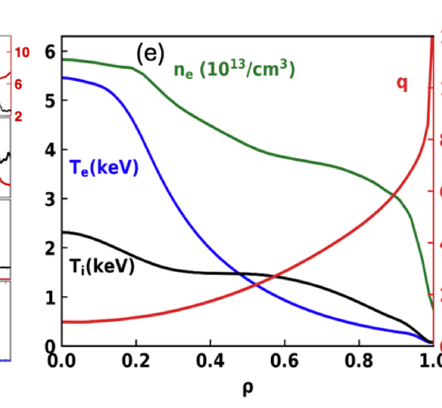


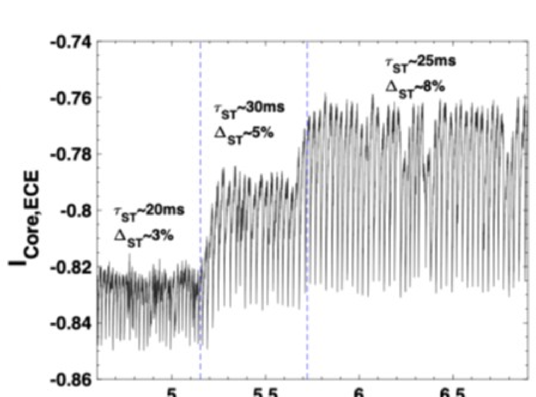




- **Improved performance during IC heating at high B_t~2.5T**
  - V_{loop}~0, P_{LHW}~2.7MW, P_{EC}~2.0MW, P_{IC}~4.0MW
  - n_{Gr}~0.65, β_P~2.1, β_N~1.85, H_{98y2} ~1.35, q_{95}~6.0
- **Improved performance attributed to flat and broader j(r)with on-axis q>1**
  - Broadening of j(r) with ICRF from increased BS due to effective ICRF heating
- **Features of core MHD instabilities**
  - m/n=3/2 tearing mode stabilized with ICRF
  - n=2 BAE triggered during ICRF

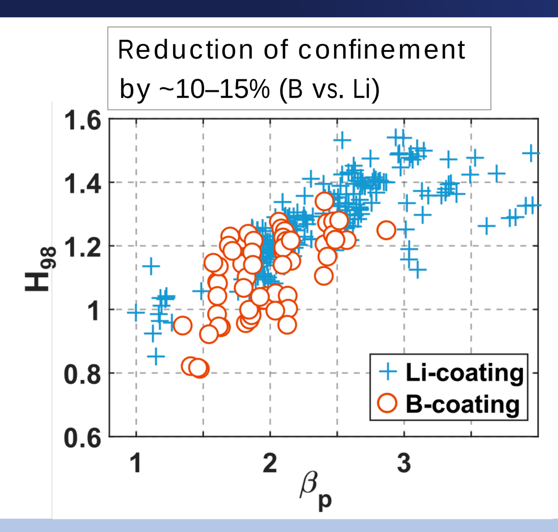






- **High-β_P plasmas w/o LHCD at high B_t~2.5T**
  - P_{NBI}~3.0MW, P_{EC}~2.0MW, P_{IC}~3.0MW
  - n_{Gr}~0.65, β_P~2.1, β_N~1.85, H_{98y2}~1.21, q_{95}~6
  - Higher T_i increased by 2, f_{NI}~65% with f_{bs}~38%, f_{EC}~13%, f_{NB}~14%
- **Sawtooth instability with peaked current profile and on-axis q below 1**
  - The period increased during ICRF
  - The crash amplitude enhanced with ICRF on-axis heating

Challenges for Development of High-β_P Plasmas with Boronization



Joint Experiments & Actives for ITPA IOS-3.2

- **Next step with enhanced capabilities on EAST towards more ITER-relevant configuration**
  - Optimize Boronization with ICRF and new B_2D_6
  - Explore high-β_P scenario at moderate q_{95} towards high-Q SSO
  - Broaden j(r) and active control to improve confinement
  - Improve T_i/T_e by effective ion heating to extend fusion performance
  - Account for ITER heating and current mix, etc.

Future Plan

- **With upgrade of inner components and H&CD capabilities**
  - Develop SSO scenario with ITER shaping (LSN) at moderate q95 ~5-6 in low aspect ratio
  - Develop SSO scenario in ITER-like heating scheme by enhancing H&CD capabilities
  - Investigate the impact of wall condition on scenario development
  - Extend plasma performance and improve confinement by broaden j(r) with q_{min}>2 aiming at NCS or weak shear to form ITB in all channels

➔ Demonstrate SSO with extended fusion performance at P_{in} ~ 15-20 MW

Acknowledgements

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