Integrated Operation of Steady-state Long Pulse H-mode in EAST

by X. Gong[1]

With

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27th IAEA Fusion Energy Conference

22-27 October 2018, Ahmedabad, India

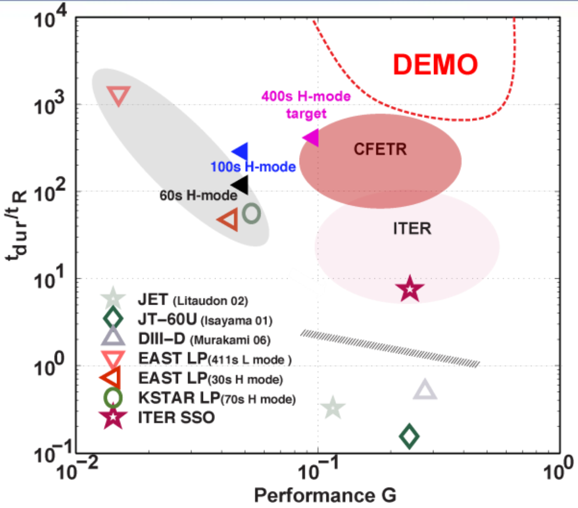
Acknowledgement

Great Progress on EAST Is Benefit from Broad Domestic and Wide International Collaboration!

ASIPP

Strategies to Establish the Scientific Basis for Long Pulse Operation in Support of ITER and CFETR

S1: Enhance H/CD efficiency and relevant to fundamental physics and key diagnostics



NBI 4+4 MW（Co/Ctr ~80 kV)

ECRH 2+2 MW（140GHz)

ICRH 6+6 MW（25-75MHz)

LHCD 4+6 MW（2.45/4.6GHZ)

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Strategies to Establish the Scientific Basis for Long Pulse Operation in Support of ITER and CFETR

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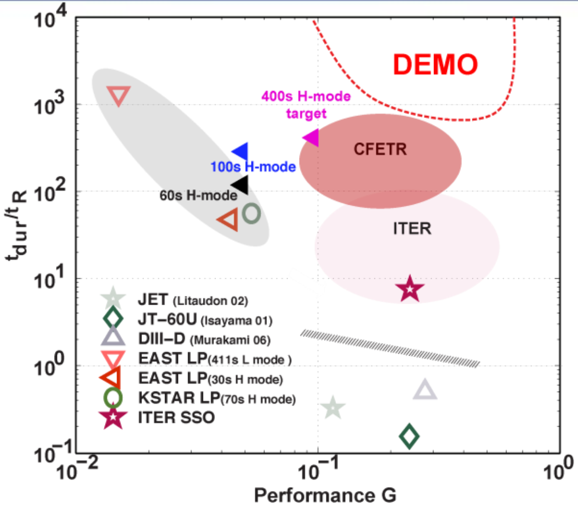
S2: Demonstrate long-pulse (≥100s) H-mode plasmas and develop fully non-inductive high-β scenarios



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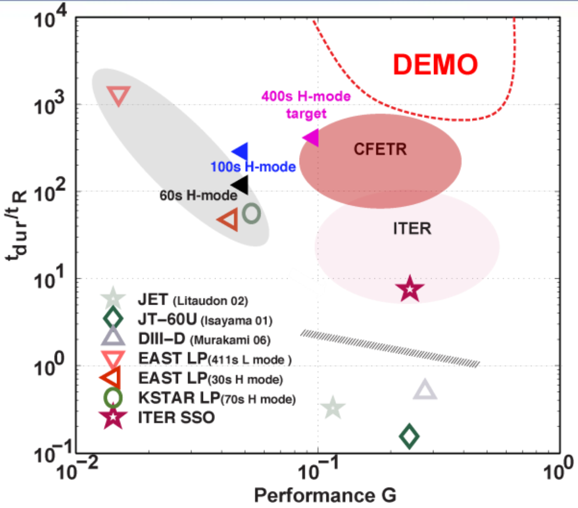
S3: Extend EAST operation regime to demonstrate steady-state high performance plasmas and deliver relevant physics for ITER and CFETR



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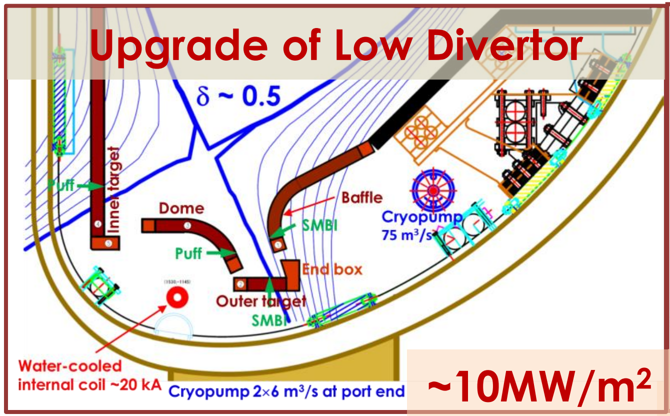
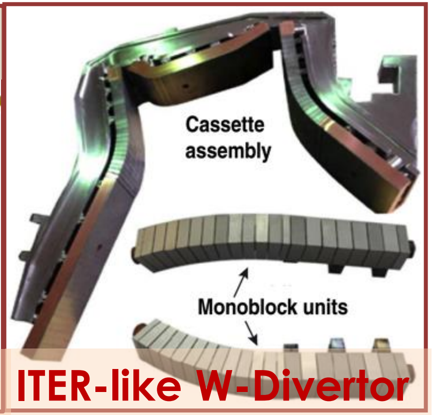
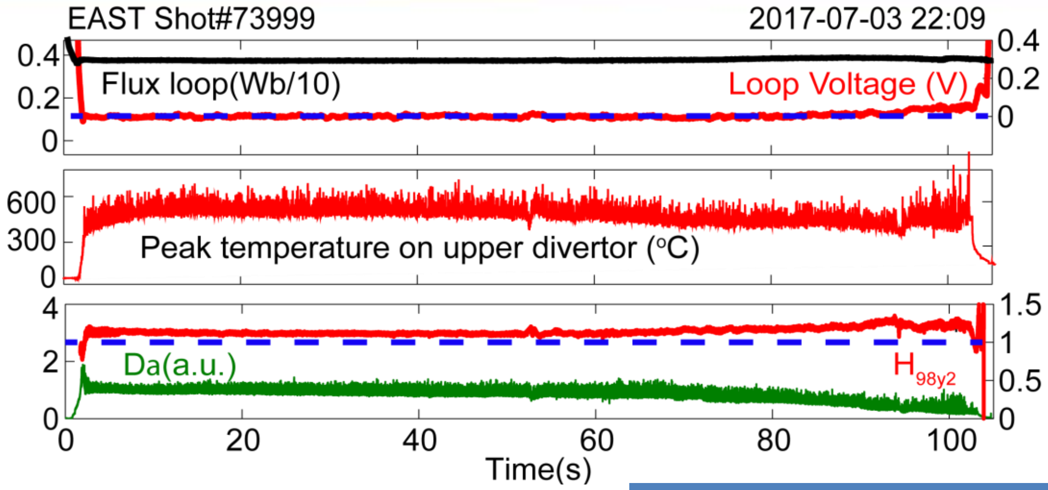
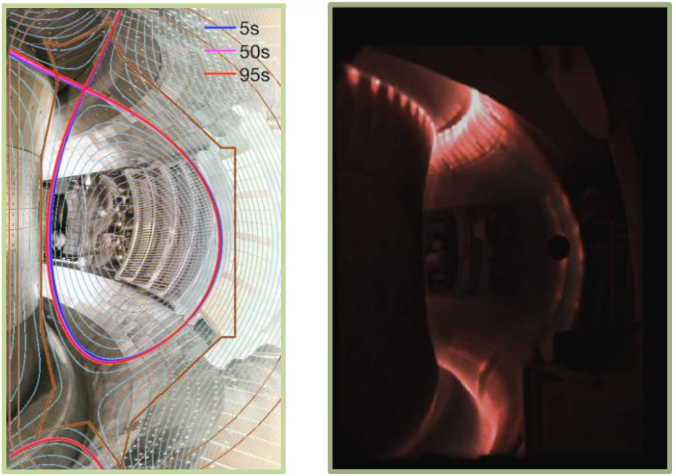
B.N. Wan, IAEA FEC (2018) OV/2-2





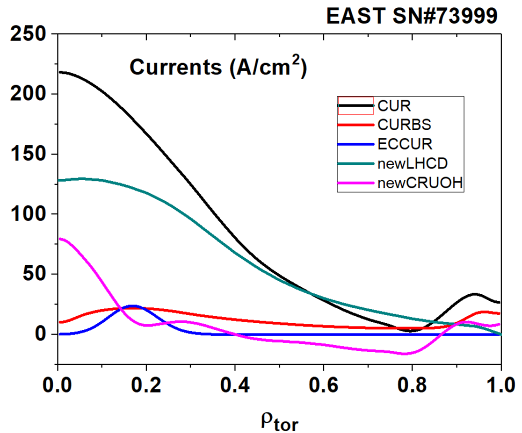
The Longest Pulse Fully Non-inductive H-mode Operation Achieved with Tungsten Divertor on EAST





X. Gong, APS DPP (2017)

USN @ W/Cu Divertor



- Up to **101.2s** sustained with v_{Loop}~ 0
- Saturated W-Div. surface temperature
- Good confinement (LHW+ICRF+ECH)
  - H_{98y2} ~1.1-1.2
- Low bootstrap current fraction: f_{BS}~23%

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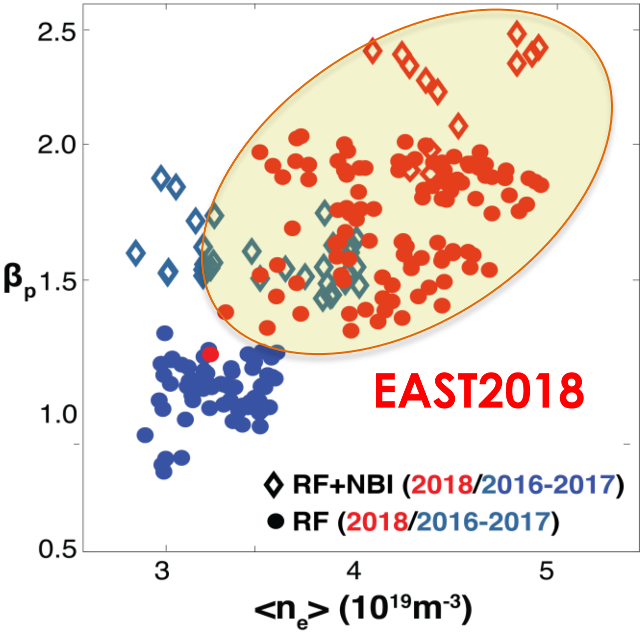
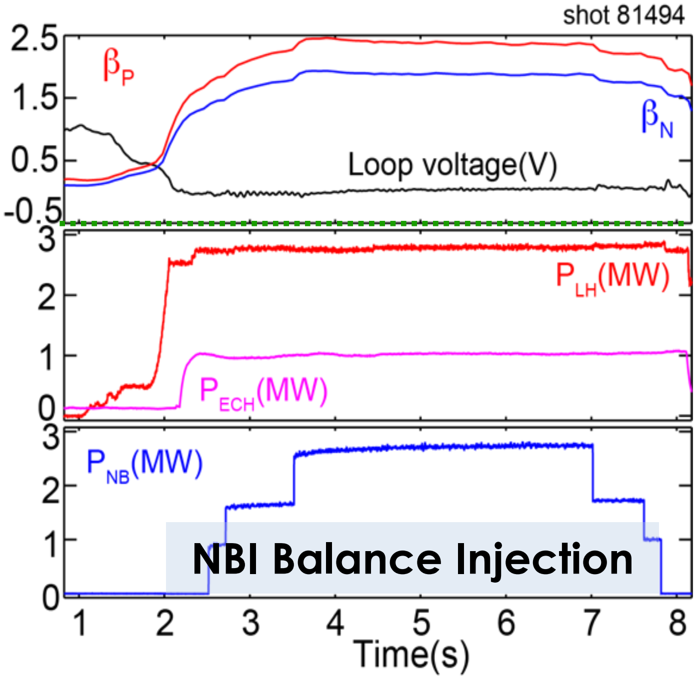
Recent Experiments Demonstrated Steady-state Fully Non-inductive Scenarios with Extension of Operational Regime



- High β_P ~2.5/β_N ~2.0 with H_{98y2} ~1.25 and f_{BS}~47% at f_{Gr}~0.8 by RF+NBI



– High f_{BS}~40-50% with H_{98y2}>1.0 at f_{Gr}~0.6-0.8

– Broad q-profile, Shafranov shift and e-ITB

J. Huang, IAEA FEC (2018) EX/P2-15

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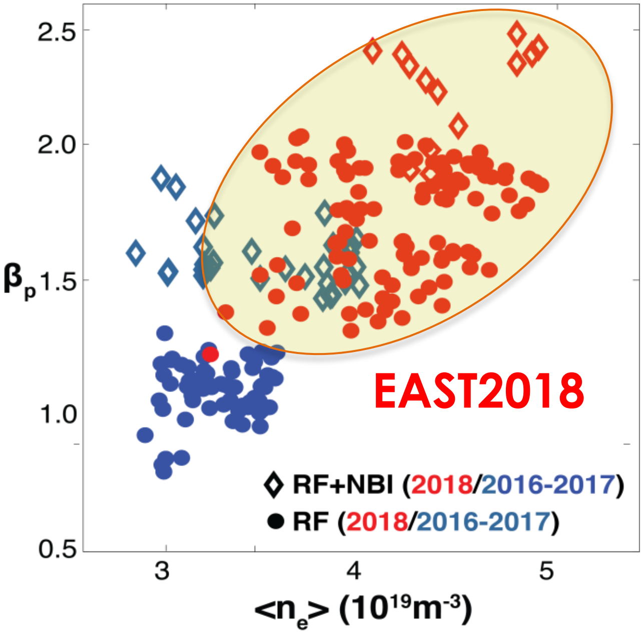

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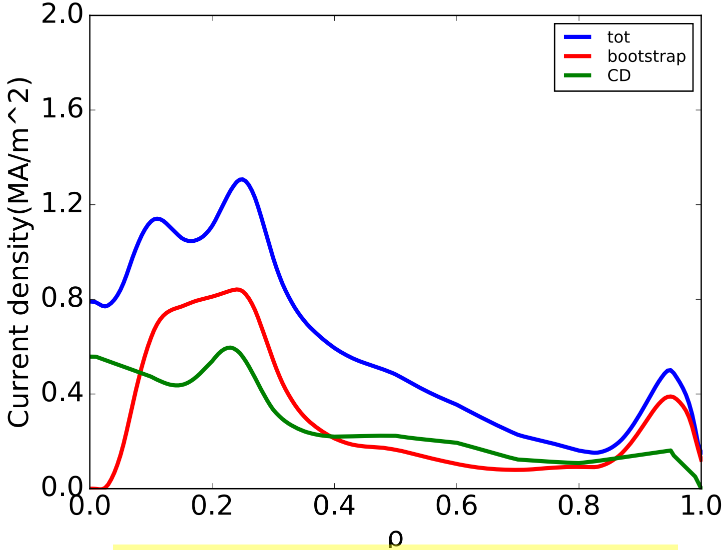

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Alignment of Bootstrap Current and total current

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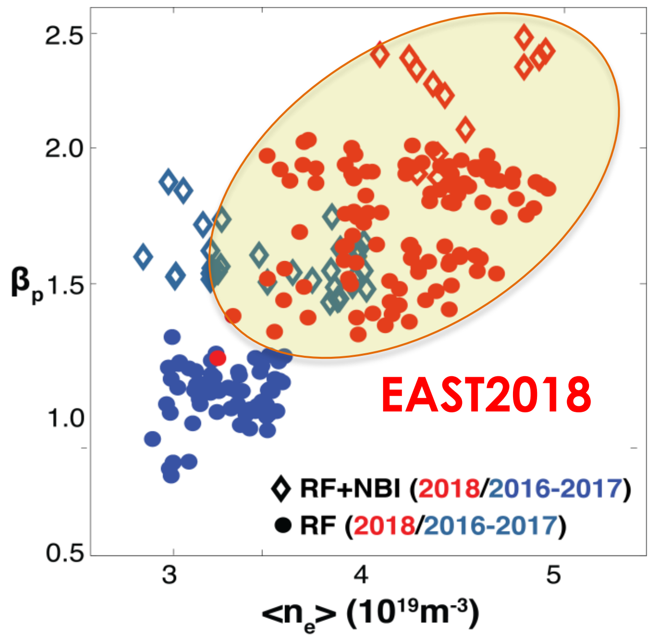

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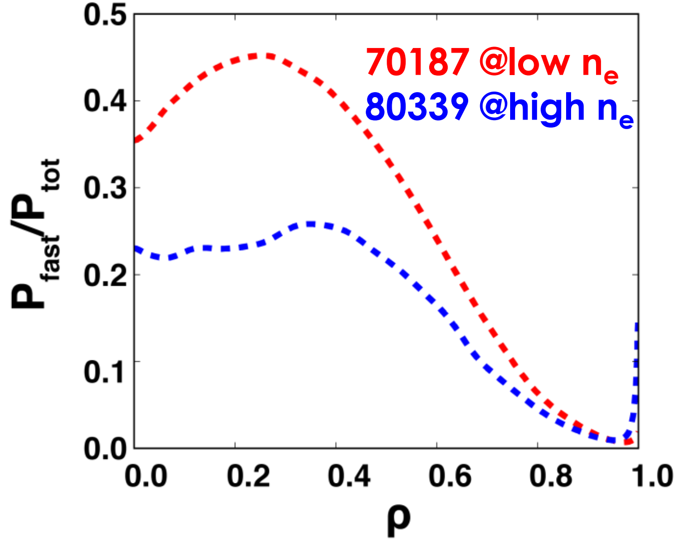

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Dramatically decreased for Fast-ion pressure at high-ne /low beam energy

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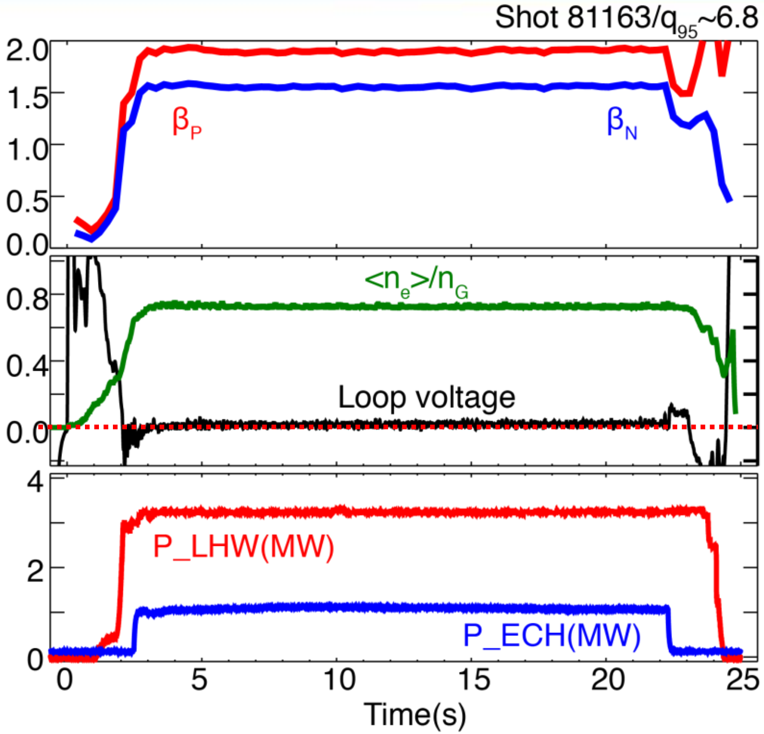
Long Pulse Fully Non-inductive High-β_p up to 21s Achieved by RF-only on EAST with Metal Walls



- **Good confinement $H_{98,y2}$~1.2**
  - β_p~1.95/β_N~1.6, f_{Gr}~0.78, f_{BS}~45%, V_{loop}~0

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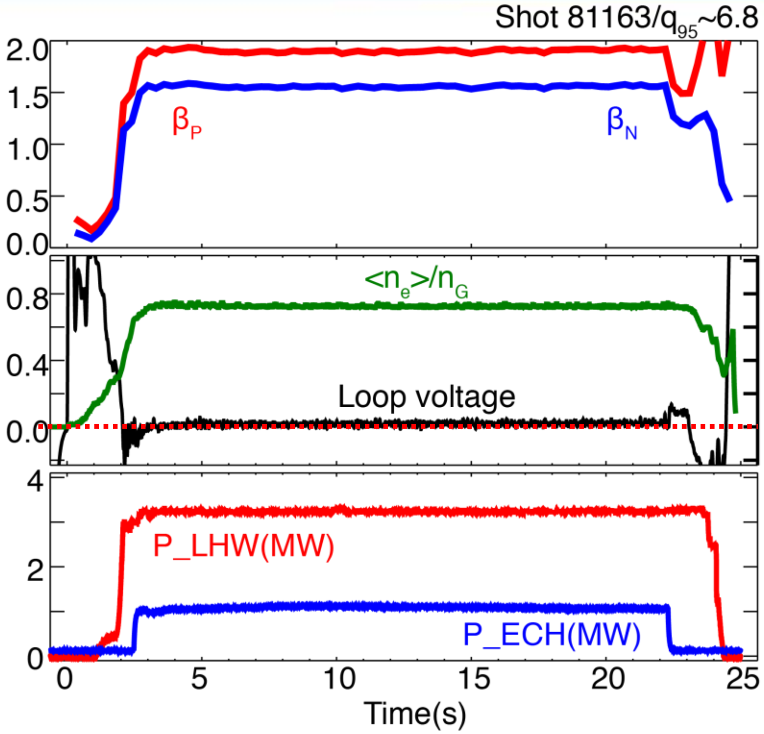

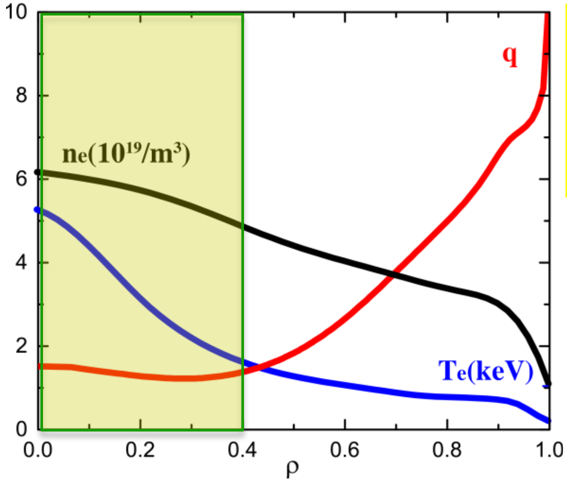

Broaden current profile and e-ITB is key to high performance

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- **High LHCD efficiency at high density**
  - On-axis ECH /Low recycling wall /Integrated active control

- **Small/no ELM is essential for SSO**

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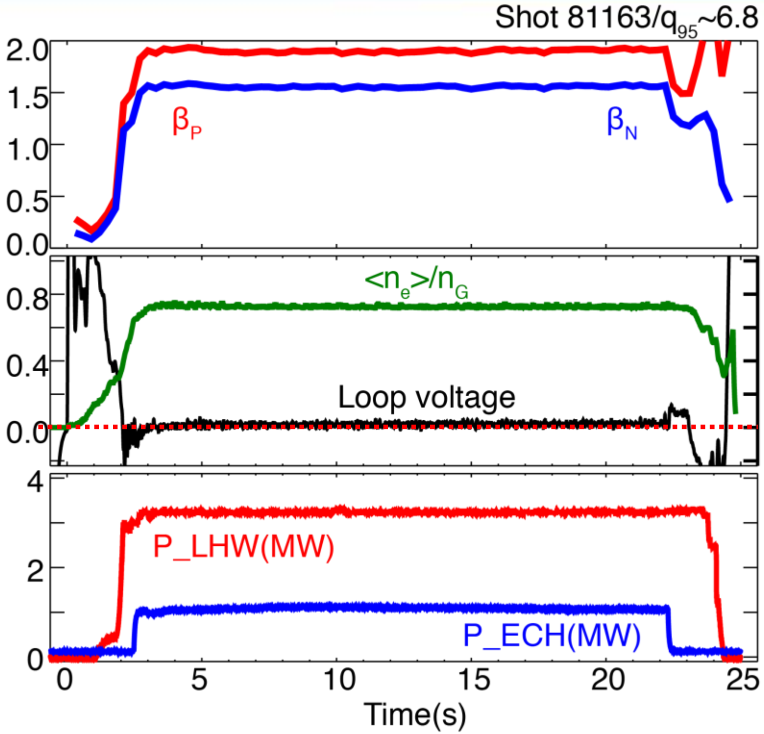

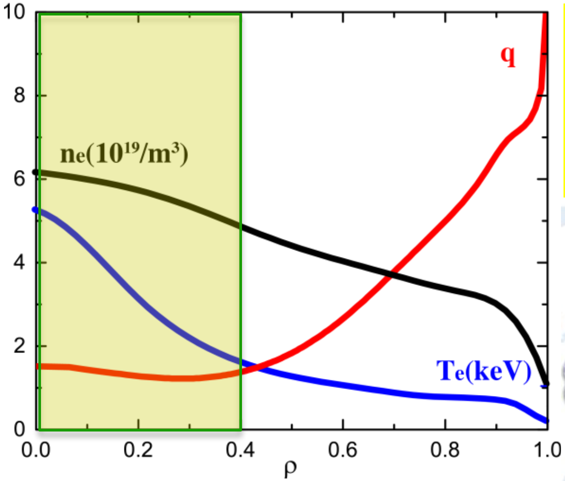

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Joint EAST/DIII-D Task Force

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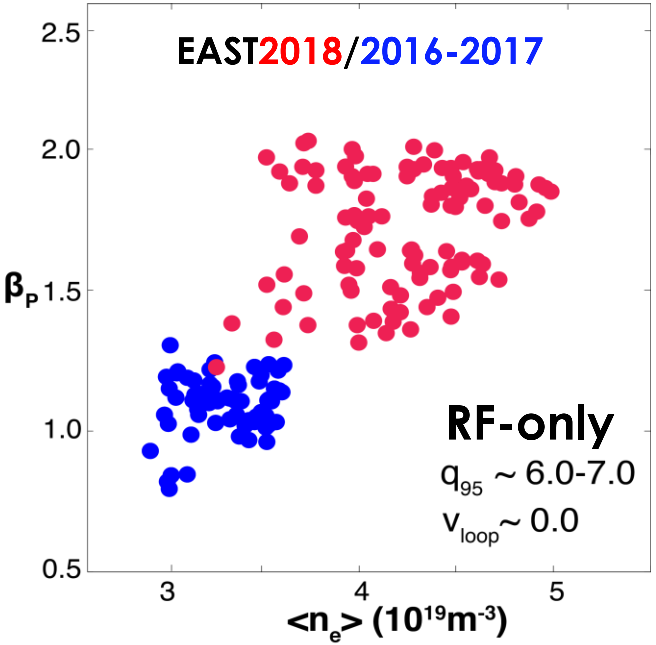
Fully Non-inductive High-β_p Scenarios Extends to High Density Regime Demonstrated on EAST



Zero or low torque experiments on EAST may contribute to ITER

- **With new guide limiter of LHW and the 2nd ECH**
  - β_p~2.0/β_N~1.6 using **RF-only**
  - V_{loop}~ 0, f_{BS}~40-50% with f_{Gr}~0.6-0.8

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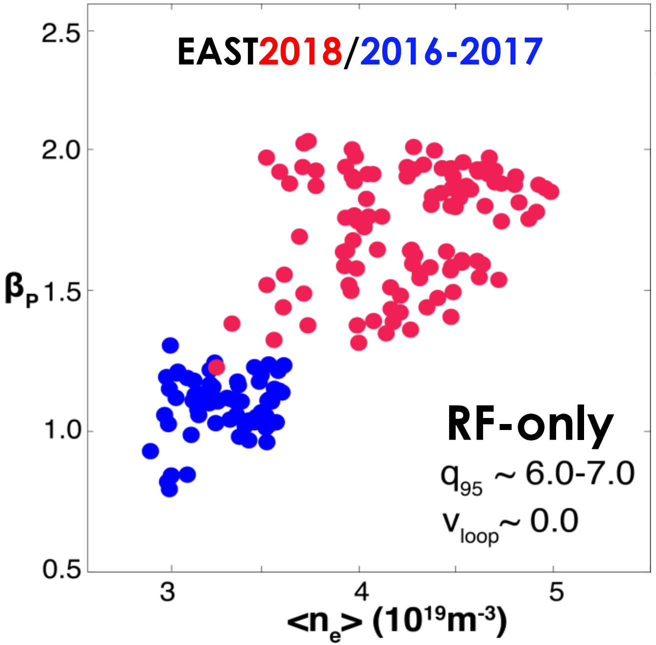

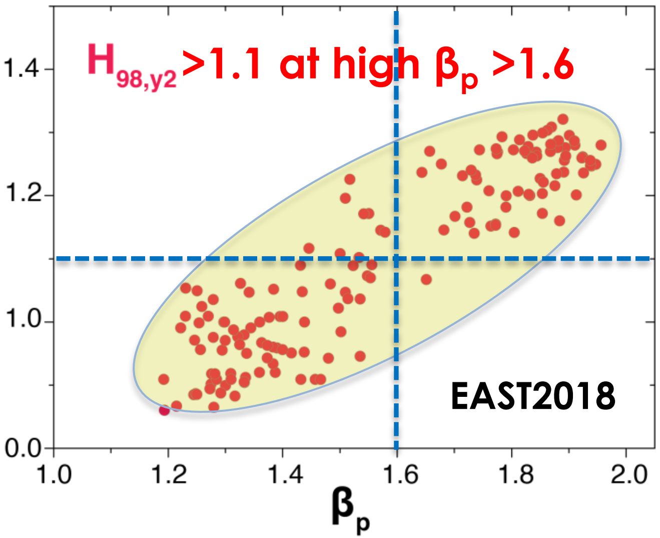

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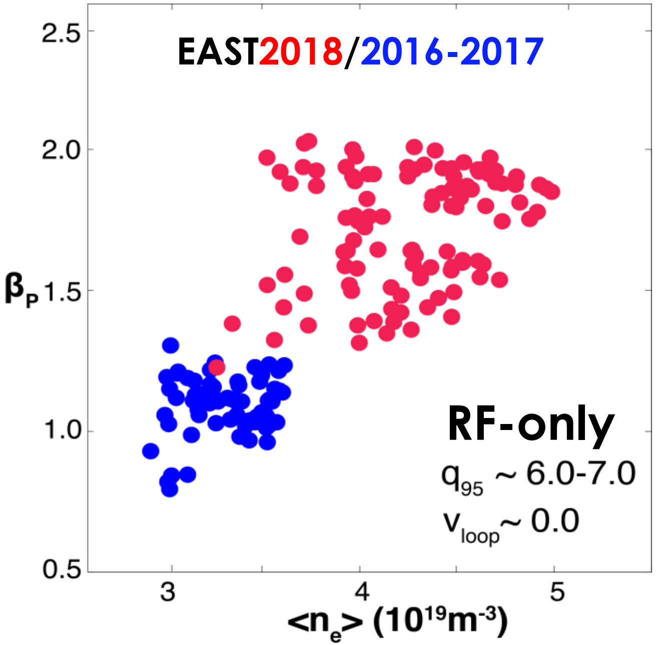
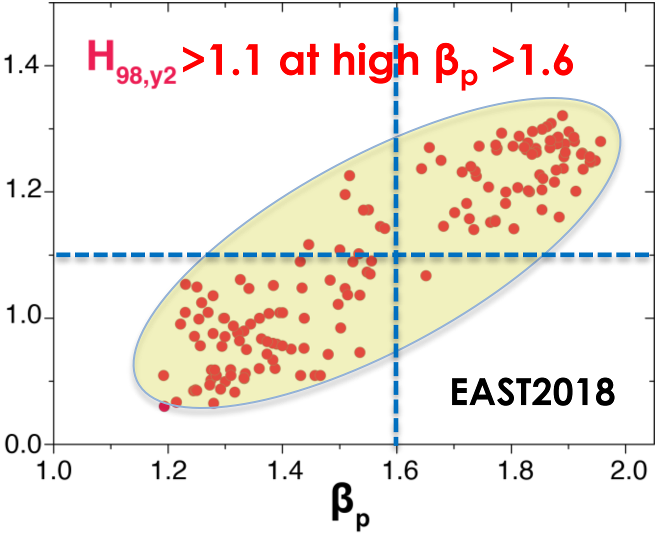
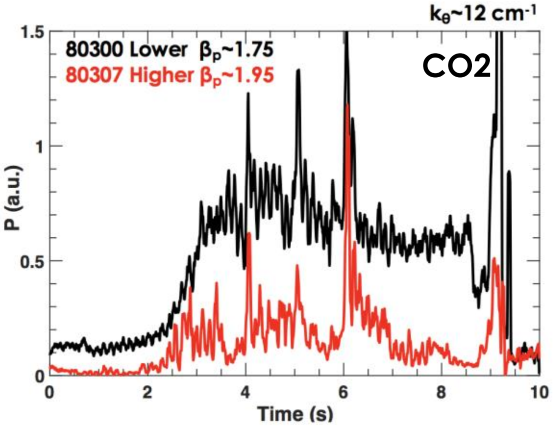




Shafranov shift effect on turbulence suppression at high β_p



Zero or low torque experiments on EAST may contribute to ITER

- More effective heating is required to raise β_N
- Active kinetics control for stabilities

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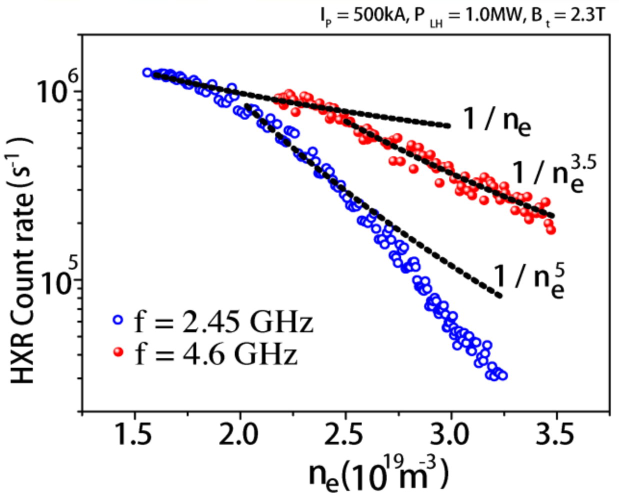
Higher LHW Frequency and Lower Recycling Wall Allows High LHCD Efficiency at High Density

- **4.6GHz LHCD**
  - **Weaker non-linear effect lead**
    - Higher current drive efficiency
    - Better confinement
    - Higher rotation driving



A. Ekedah, IAEA FEC (2018) EX/P2-15

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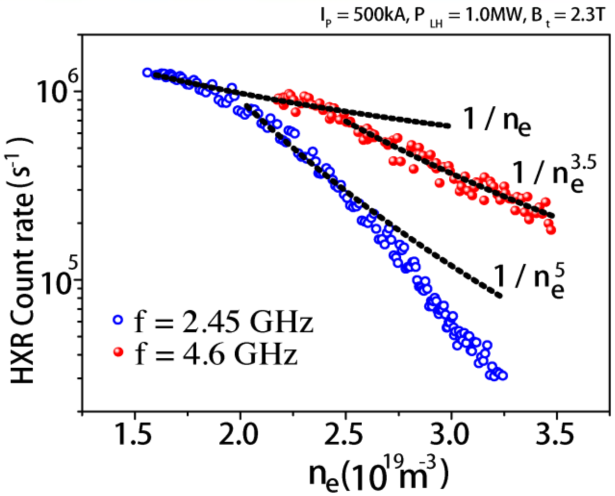

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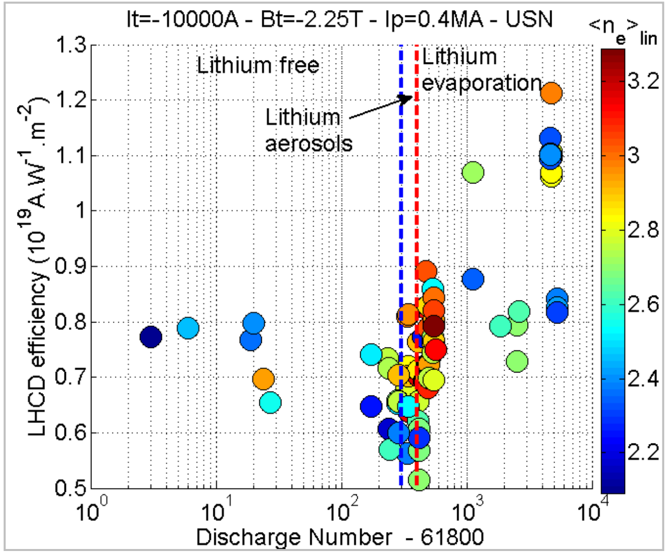

- **Higher CD efficiency due to lower Z_{eff}: $\eta_{LH} \sim 1/(5+Z_{Eff})$**
- **Reduced edge neutral density improves accessibility (weaken non-linear effect)**

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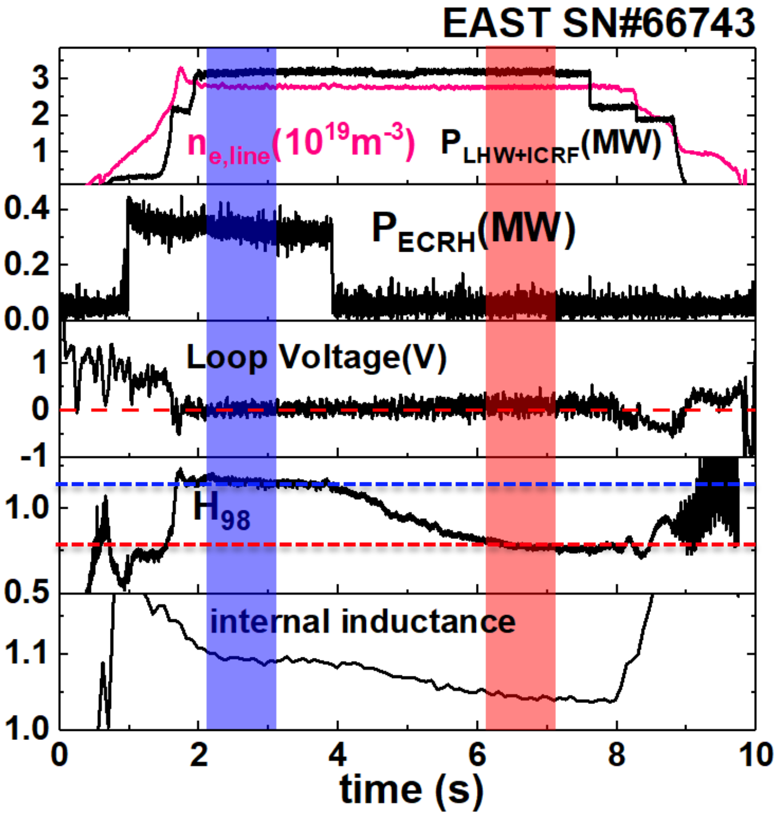
Synergy of ECH and LHCD also Helps Improvement Confinement and Enabling Higher Performance

- **RF discharges**
  - P_{LHW}~2.0MW, P_{ICRF}~1.0MW
    P_{ECH} ~0.4MW @ on-axis
  - Confinement decreased from **H_{98y2} ~1.15 to 0.75** when ECH turned off

H.F. Du et al., Nucl. Fusion 58, 066011 (2018)



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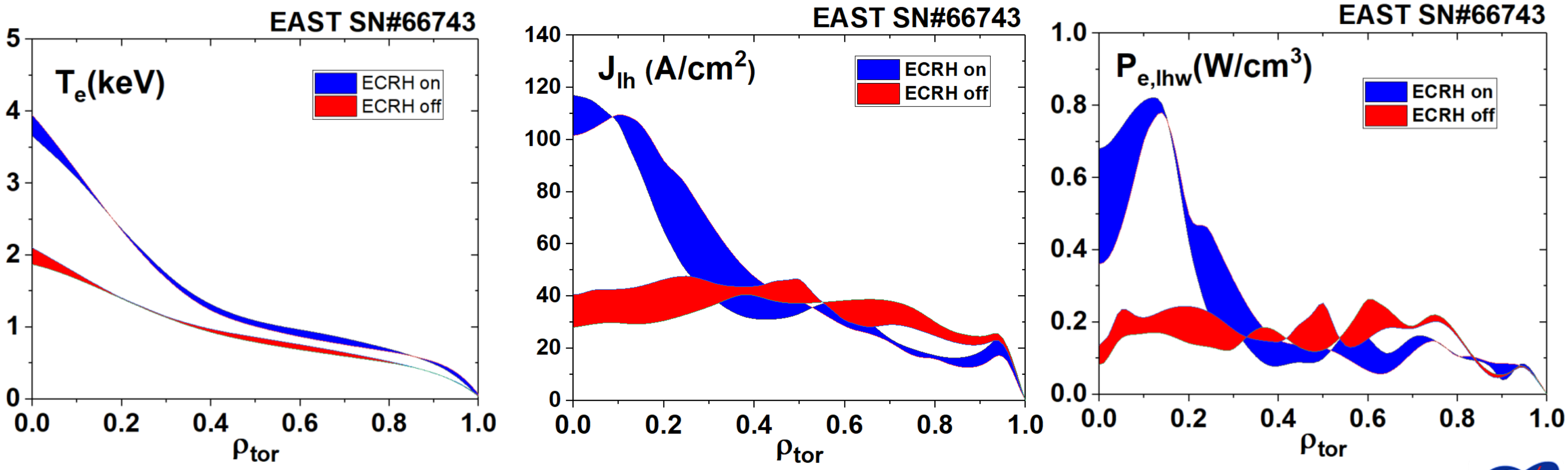
Synergy of ECH and LHCD also Helps Improvement Confinement and Enabling Higher Performance

- **Shift of LHW H&CD, GENRAY+CQL3D shows**
  - More efficient electron heating and current driving by LHW at core with on-axis ECRH



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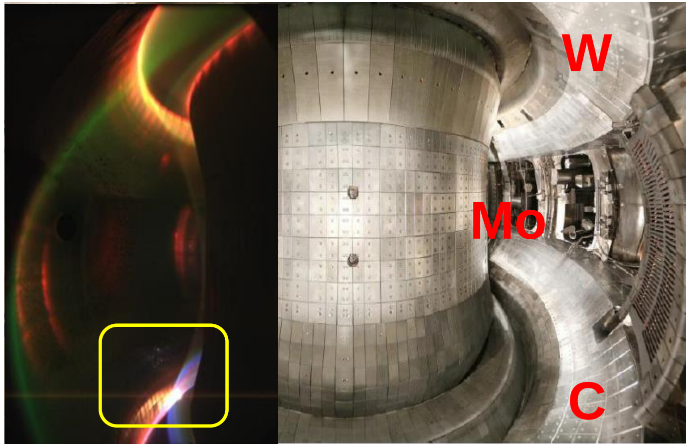
Demonstration of Effective Particle and Heat Load Exhaust
Low Impurity Concentration/Recycling Control



- **Actively water-cooled W/Cu Divertor** ~10MW/m^2
- **Inner Cryopump @ Divertors** ~75,000l/s for D_2 (@ LHe)
- **Real-time Wall conditioning**

L. Wang, IAEA FEC (2018) EX/P2-8

ASIPP

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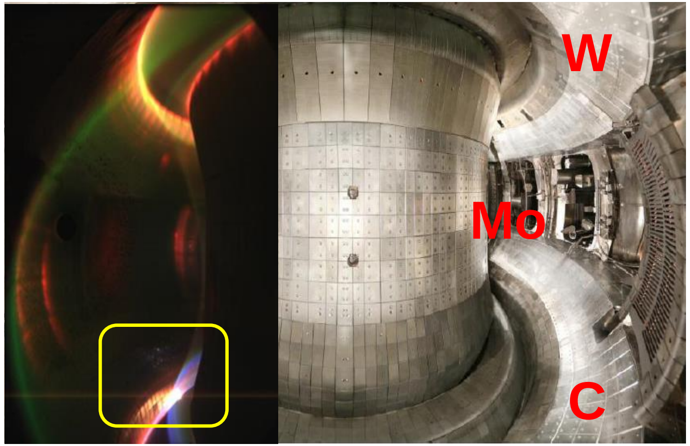

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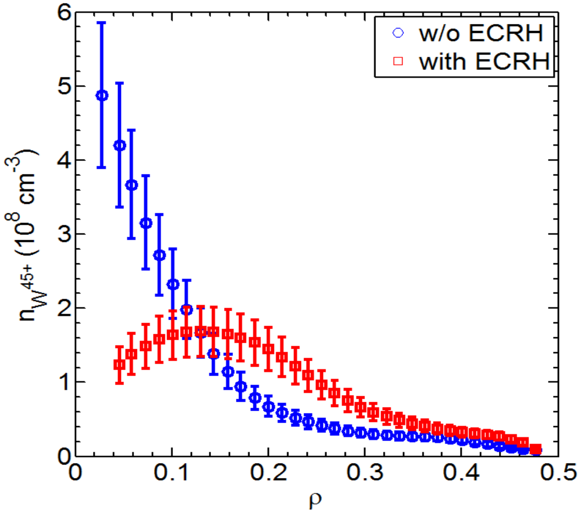
L. Wang, IAEA FEC (2018) EX/P2-8



L. Zhang, IAEA FEC (2018) EX/P2-3

- **On-axis ECH pump out high Z impurities from core plasma**

ASIPP

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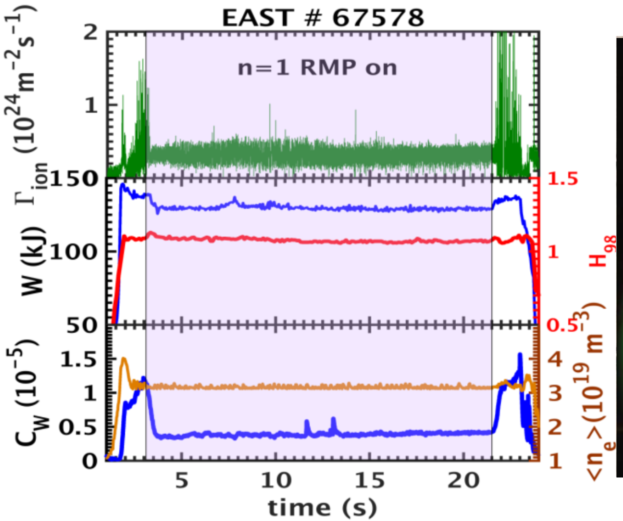
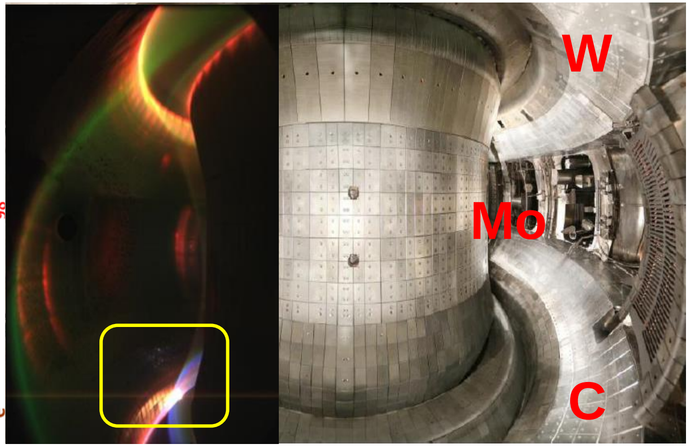


- ELM control by n=1 and rotating n=2 and static n=3 RMP in low rotating plasmas
- W-impurities pump-out and heat flux reduced

Y. Sun, IAEA FEC (2018) EX/7-2



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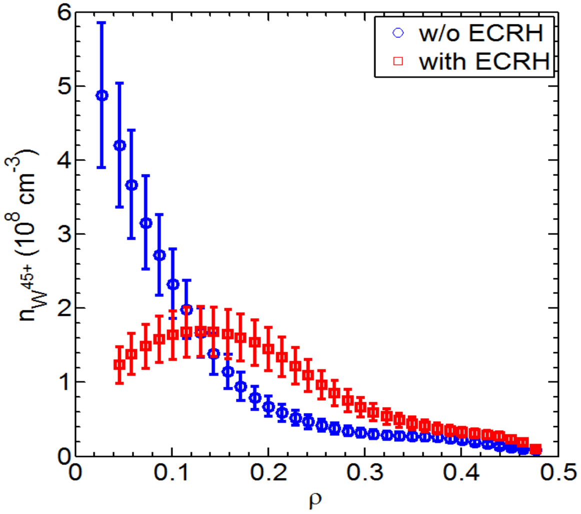
L. Wang, IAEA FEC (2018) EX/P2-8



L. Zhang, IAEA FEC (2018) EX/P2-3

- On-axis ECH pump out high Z impurities from core plasma

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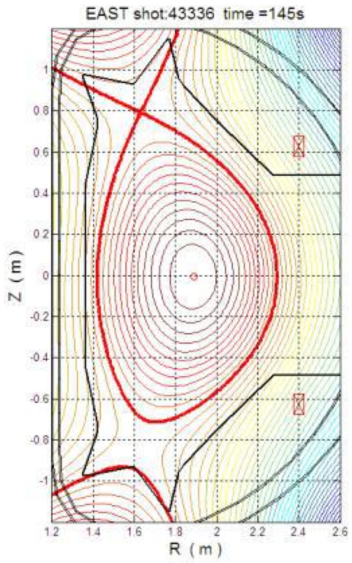
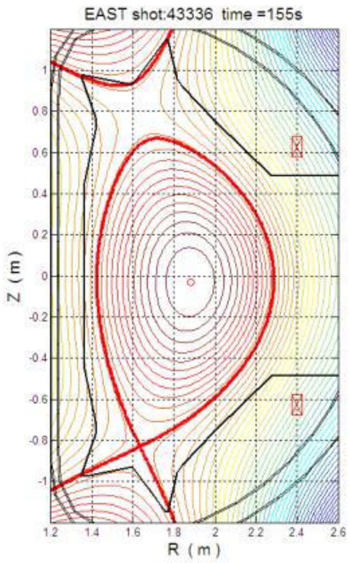
Integrated Plasma Control for Long Pulse Operation

- **Plasma Configuration for RF-coupling**
  - Outer/inner gap and X-point, Gas-puffing at RF antenna
- **Divertor Heat flux and Particle Exhaust**
  - Sweep of X point
  - Strike point for pumping

N.Viaello, IAEA FEC (2018) EX/3-2





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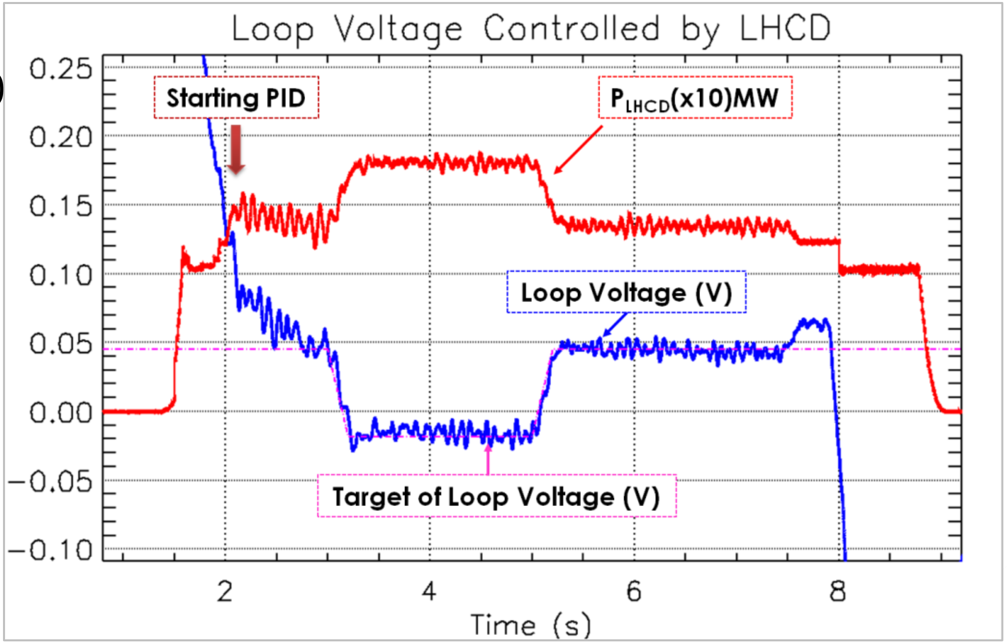
Integrated Plasma Control for Long Pulse Operation

- **Plasma Configuration for RF-coupling**
- **Divertor Heat flux and Particle Exhaust**
- **Loop Voltage Feedback Control by LHW**
  - True steady-state , I_{OH}~ 0
  - PF-coils Consumption



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Integrated Plasma Control for Long Pulse Operation

- **Plasma Configuration for RF-coupling**
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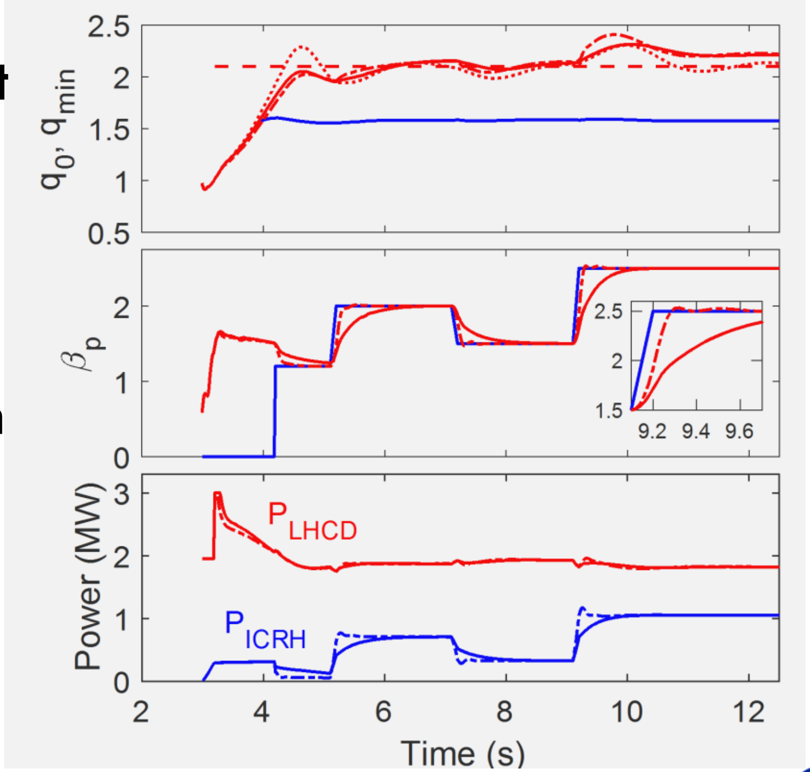
- **Loop Voltage Feedback Control by LHW**
- **Active Feedback Control**
  - Beta and j(r) for stationary SSO
- **Active Feedback Control of Radiation Power**
  - To reduce heat flux into SOL



D. Moreau, IAEA FEC (2018) EX/P2-26

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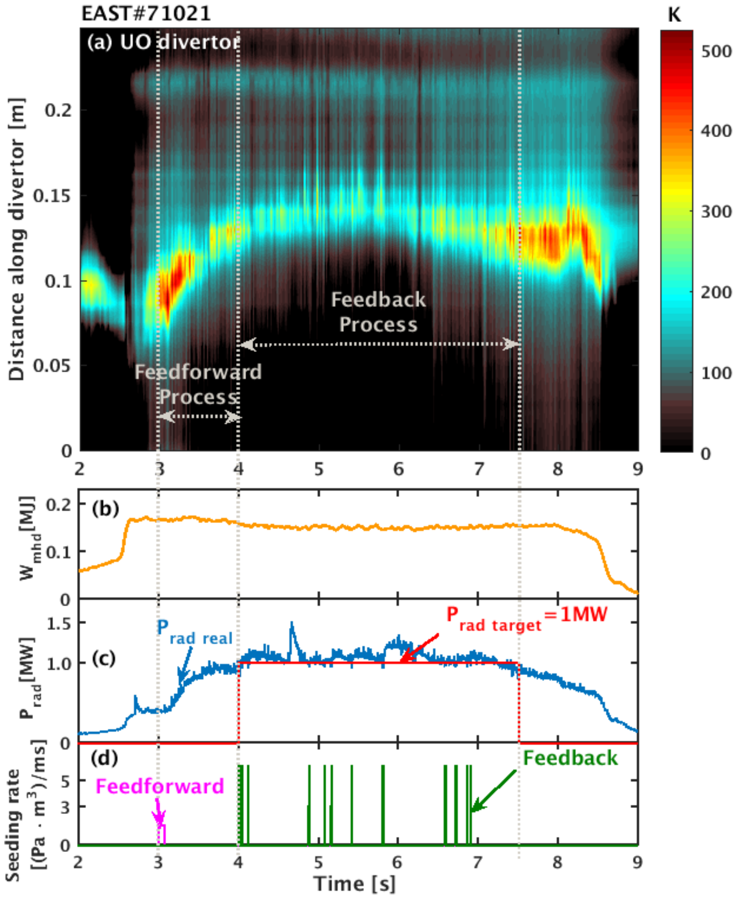

K. Wu et al., Nucl. Fusion 58, 056019 (2018)

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Summary

- **A world record discharge of 101.2 s H-mode achieved on EAST**
- **Steady-state fully non-inductive high-β_P scenarios demonstrated with extension of operational regime**
  - High LHCD efficiency at high density with on-axis ECH
  - High f_{BS}~40-50% with good confinement
  - Broad q-profile, Shafranov shift and e-ITB is key to high performance
  - Zero or low torque experiments on EAST may contribute to ITER
- **Further research on integration of core performance and edge-divertor plasma for scenarios development and resolving heat flux issues will try to extrapolate to reactor regime, essential for advanced steady-state operation**

Thank You For Your Attention
Your Suggestions and Comments Will Be Appreciated

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