Development of High Poloidal Beta, Steady-state Scenario with ITER-like Tungsten Divertor on EAST

by

A.M. Garofalo

with

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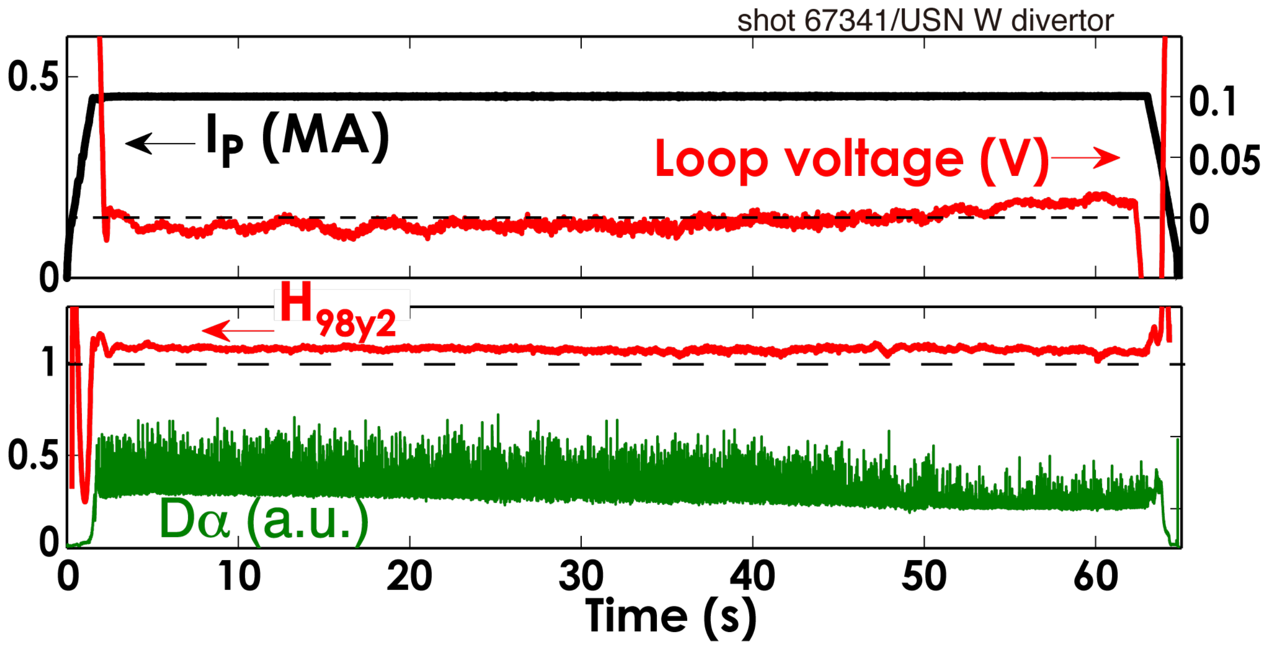
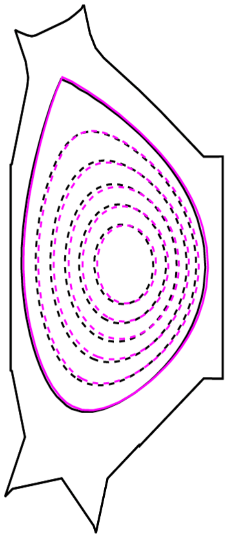
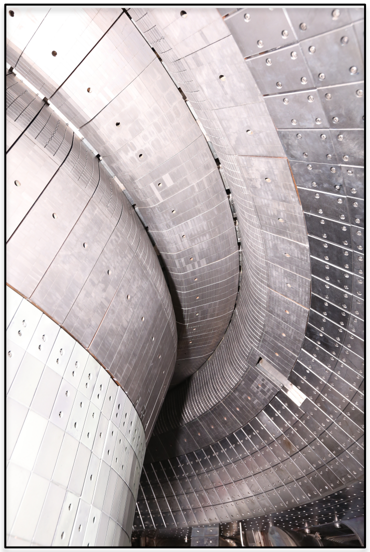
Experiments on EAST Achieve First Long Pulse H-mode Operation with Tungsten Divertor

- **Up to 65 s, sustained with loop voltage ~ 0**
- **~4 MW RF heating**
- **H_{98y2} ~1.1**







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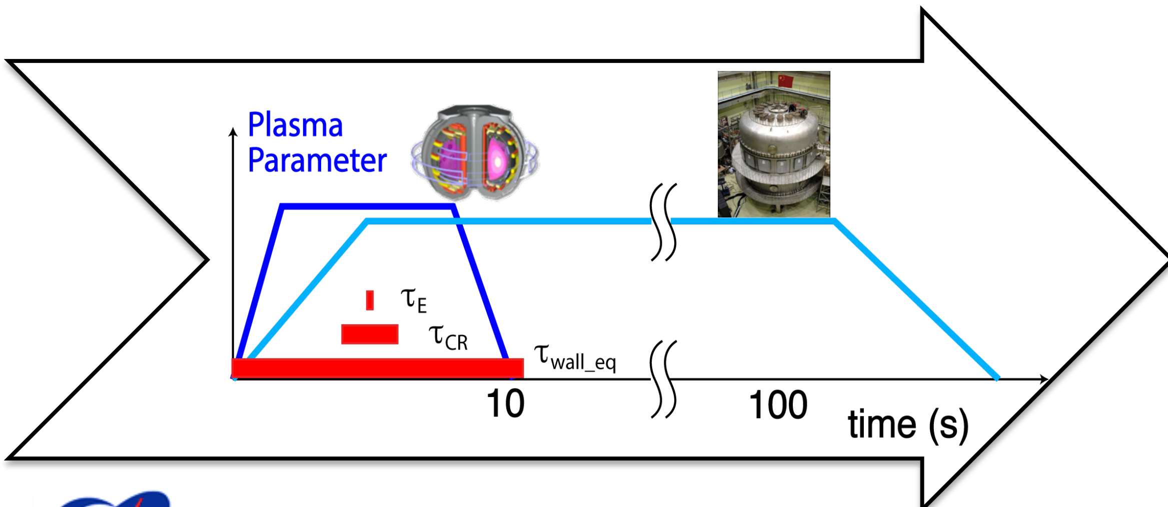
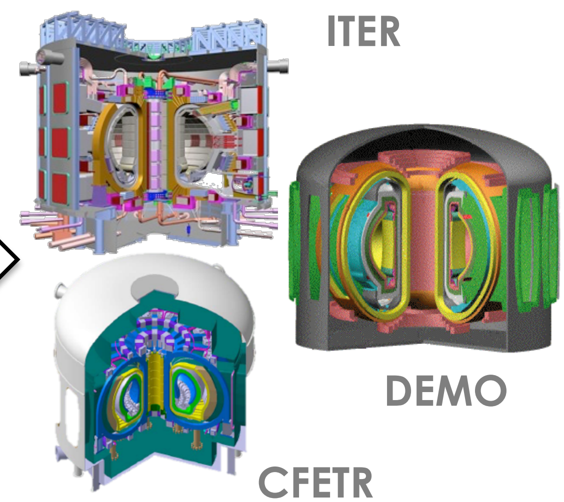
EAST/DIII-D Partnership: Sharing of Resources Accelerates Progress toward Fusion Energy

- **Fully non-inductive high bootstrap scenario on DIII-D achieves performance attractive for fusion reactor**
  - Broad current profile + high β_P → large-radius ITB, excellent confinement also without rotation
- **Key challenges: long pulse, compatibility with tungsten wall**

Long Pulse Initiative: extend high performance DIII-D discharges to true steady-state on superconducting EAST





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Demonstrate long pulse H-mode operation with tungsten divertor

Gain access to ITB

Develop tools to optimize q-profile, broaden ITB

Increase β_P toward DIII-D performance

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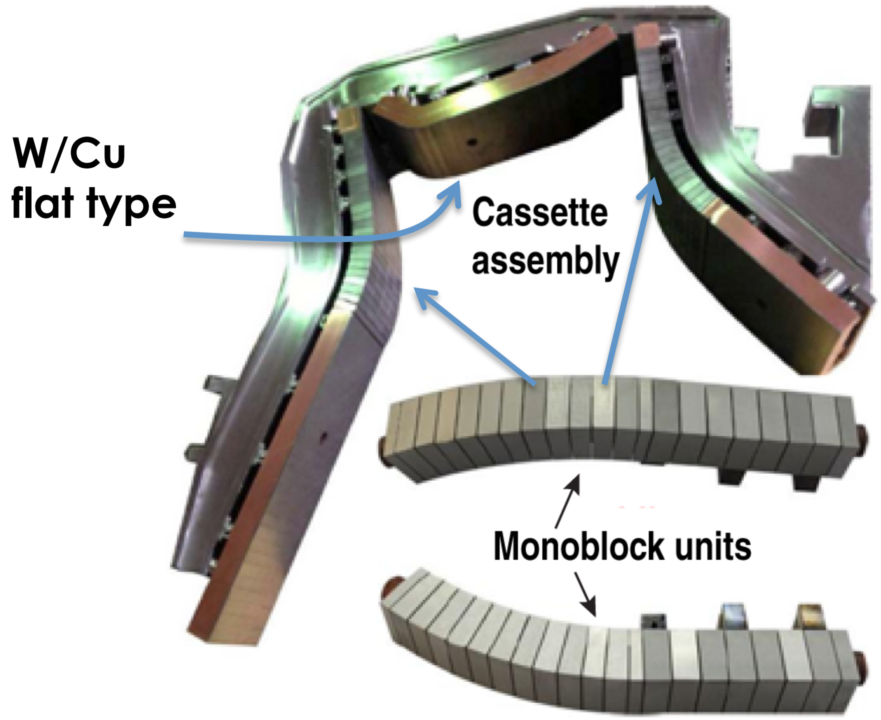
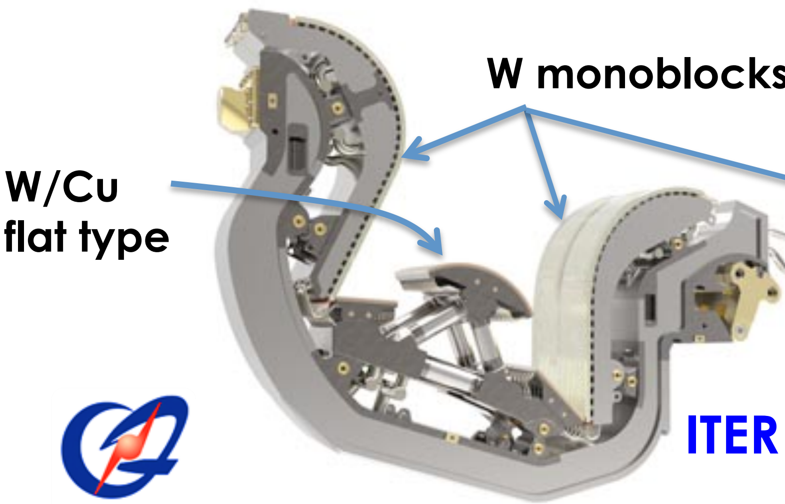
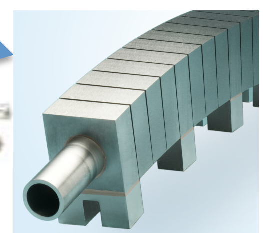
Upper Divertor on EAST Is Prototyping a Water-cooled Tungsten Divertor for ITER

- **Based on cassette technology**
- **ITER-like W monoblocks**
  - Divertor targets (10 MW/m^2)
- **ITER-like W/Cu flat type PFCs**
  - Divertor dome and baffles (~20 MW/m^2)

Water-cooled W divertor on EAST



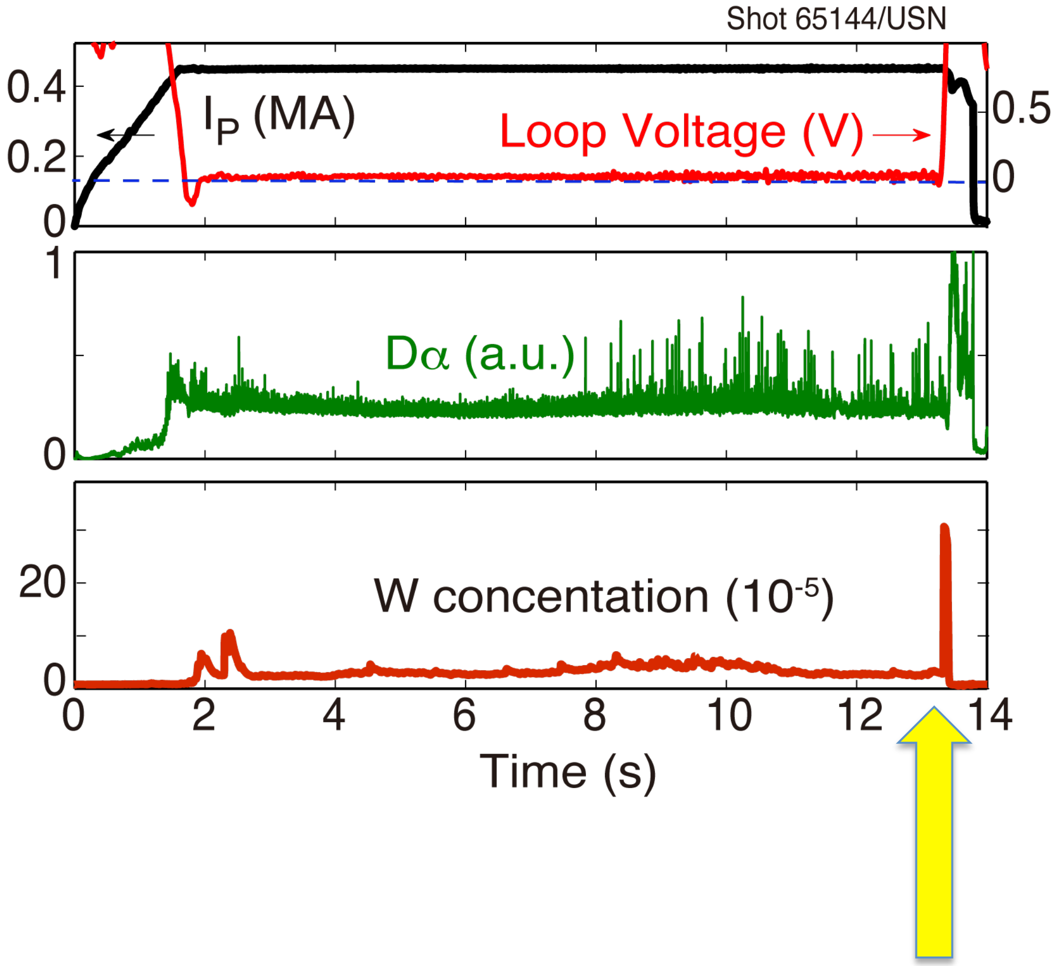




ITER divertor

See also
G.-N. Luo, MPT/1-2Ra

Previous Long Pulse H-modes Limited by Strong Influxes of Tungsten



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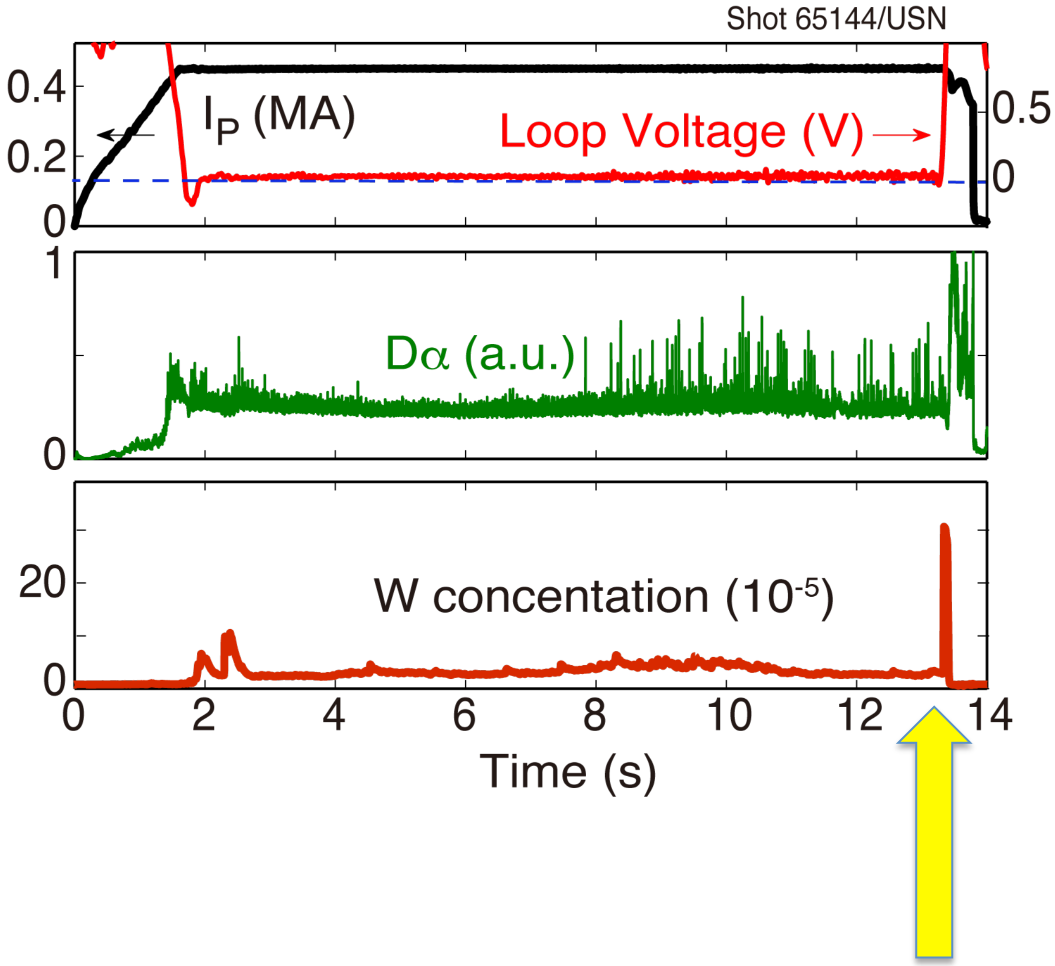
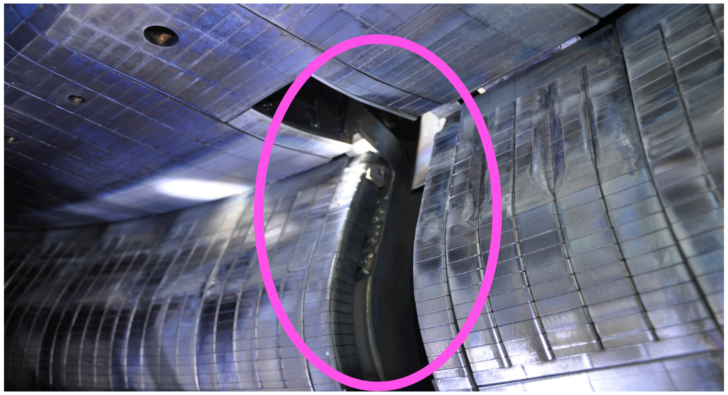


- **In one of two special locations, some armors were connected by mechanical joint (instead of Hot Isostatic Pressing)**



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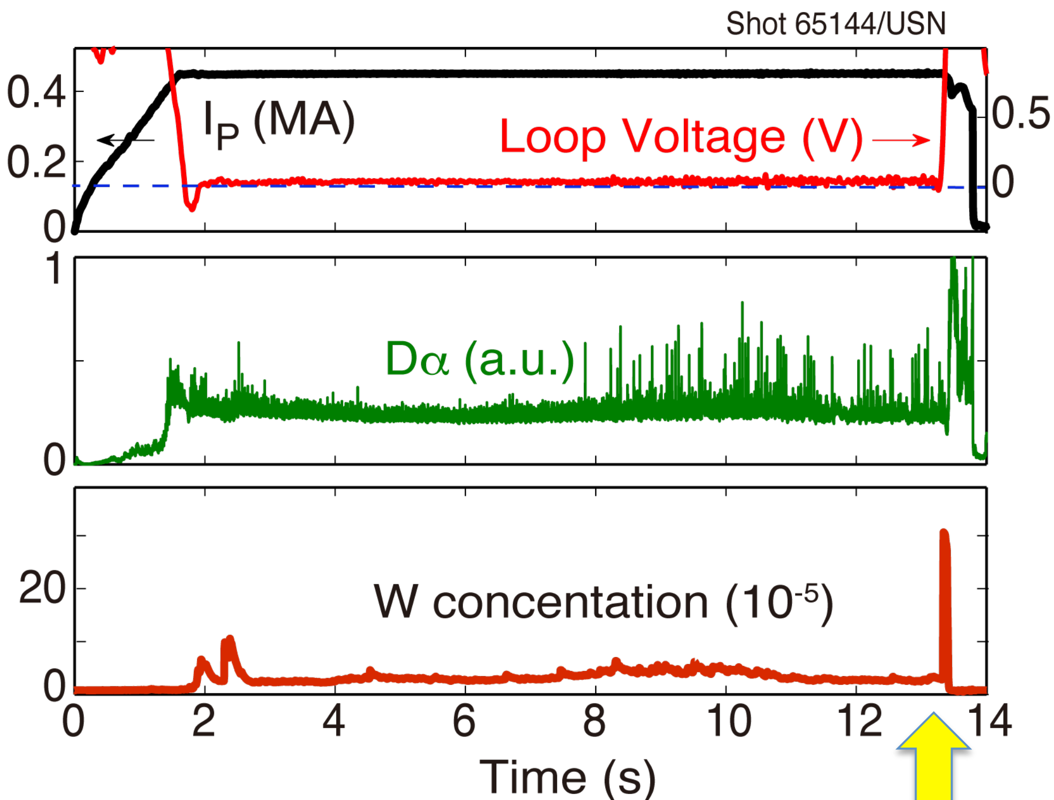
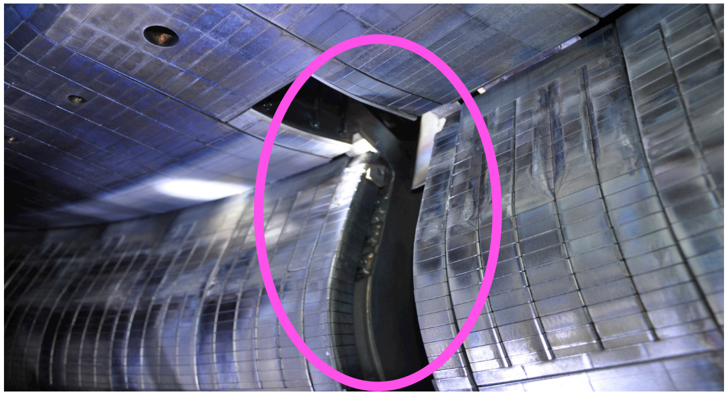


- Larger thermal contact resistance

- In one of two special locations, some armors were connected by mechanical joint (instead of Hot Isostatic Pressing)



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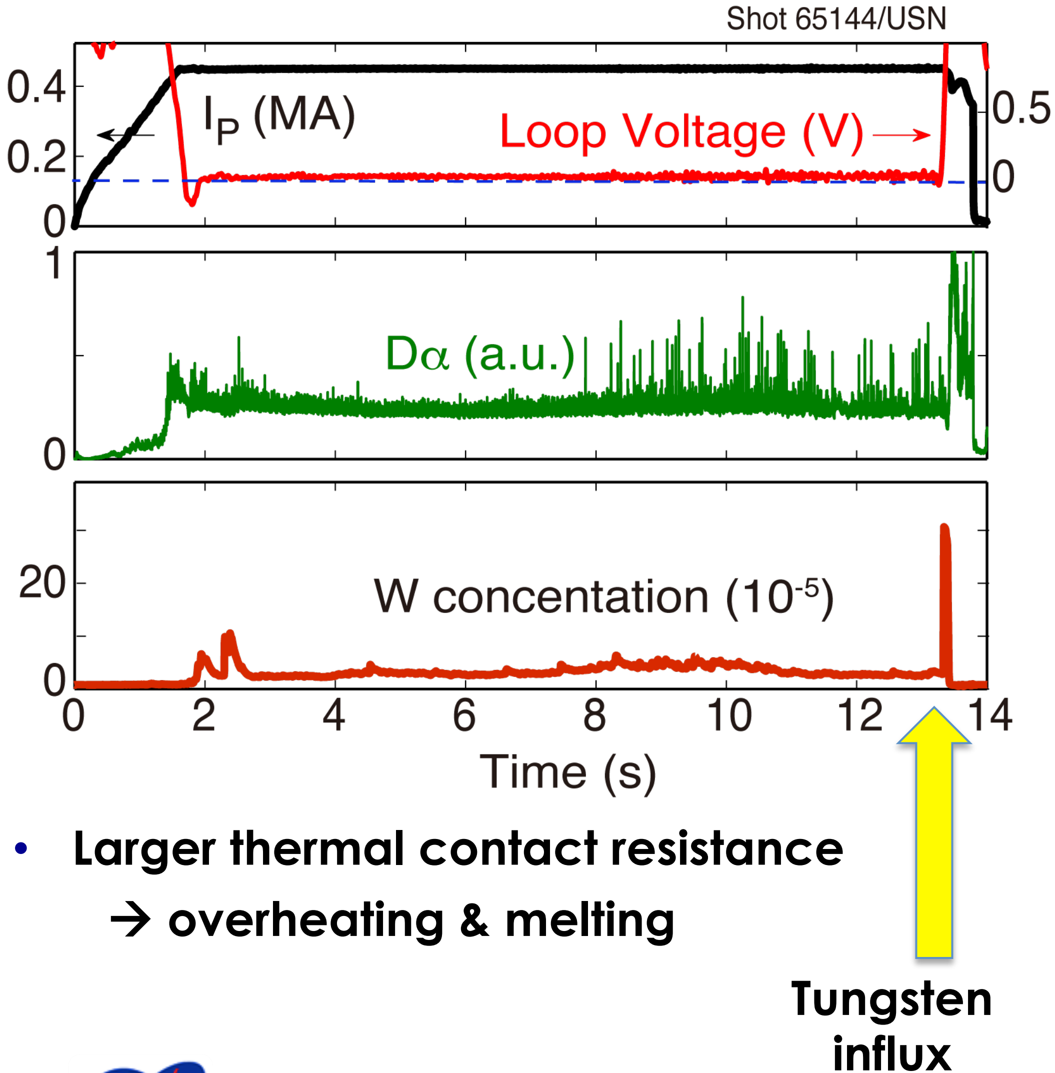
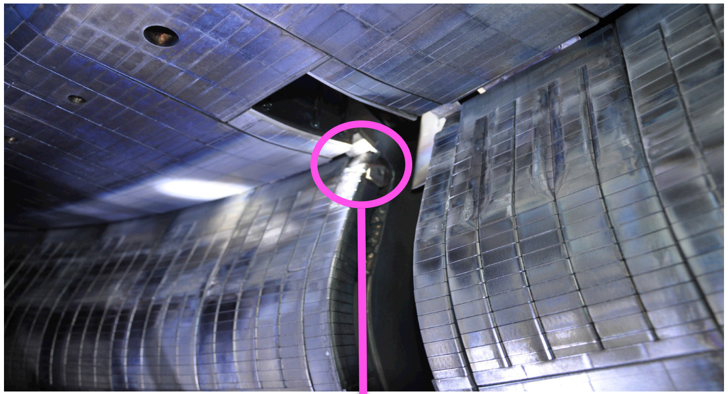
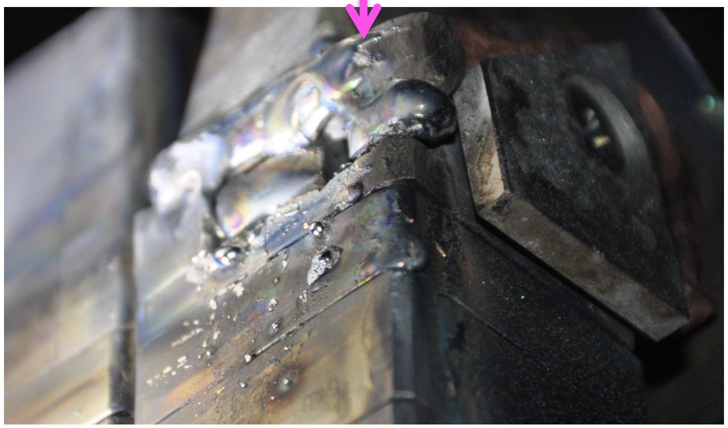


- Larger thermal contact resistance
  → overheating & melting

- In one of two special locations, some armors were connected by mechanical joint (instead of Hot Isostatic Pressing)





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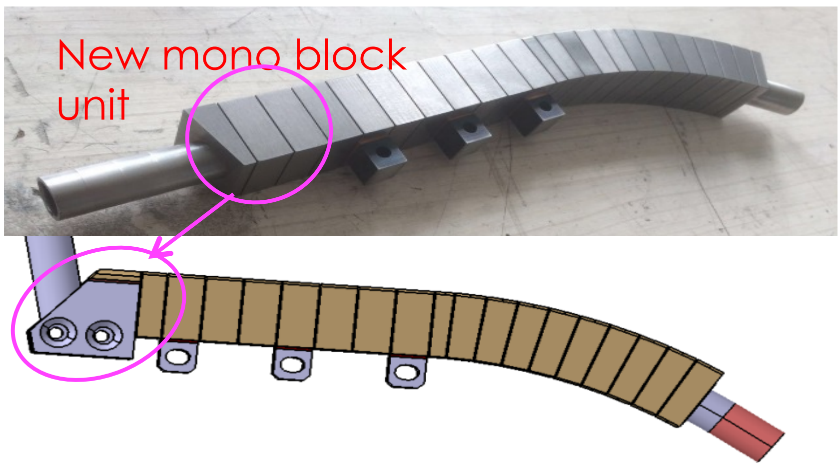
Redesigned Monoblock Units with Improved Heat Transfer

- **New monoblock units with three standard tungsten armors to replace U-shape armor have been developed and installed**



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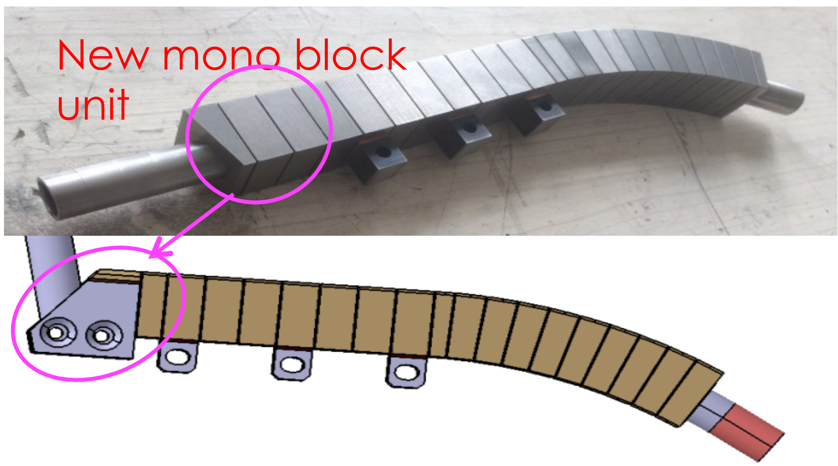

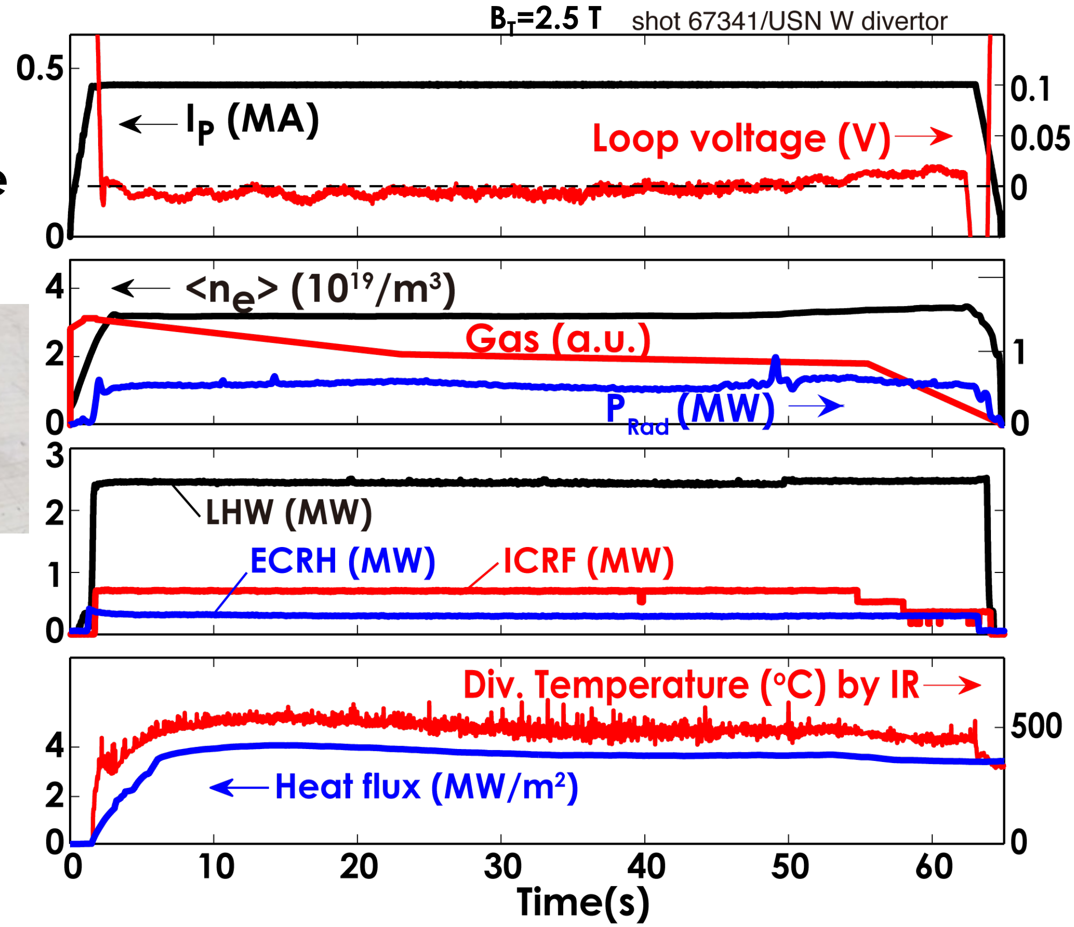

- **Duration not limited by machine capability**
- **Excellent particle exhaust**
- **Stationary W divertor temperature**

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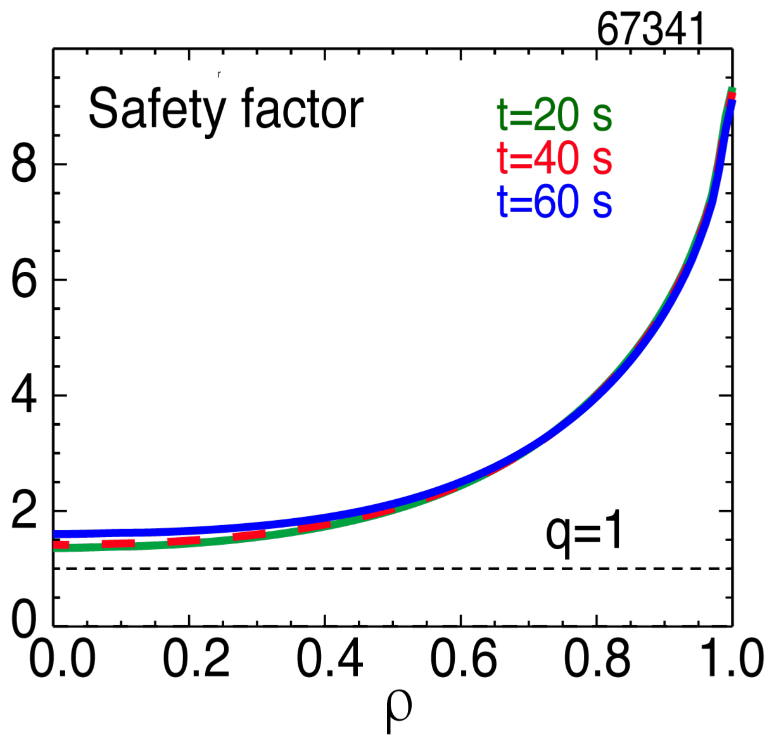
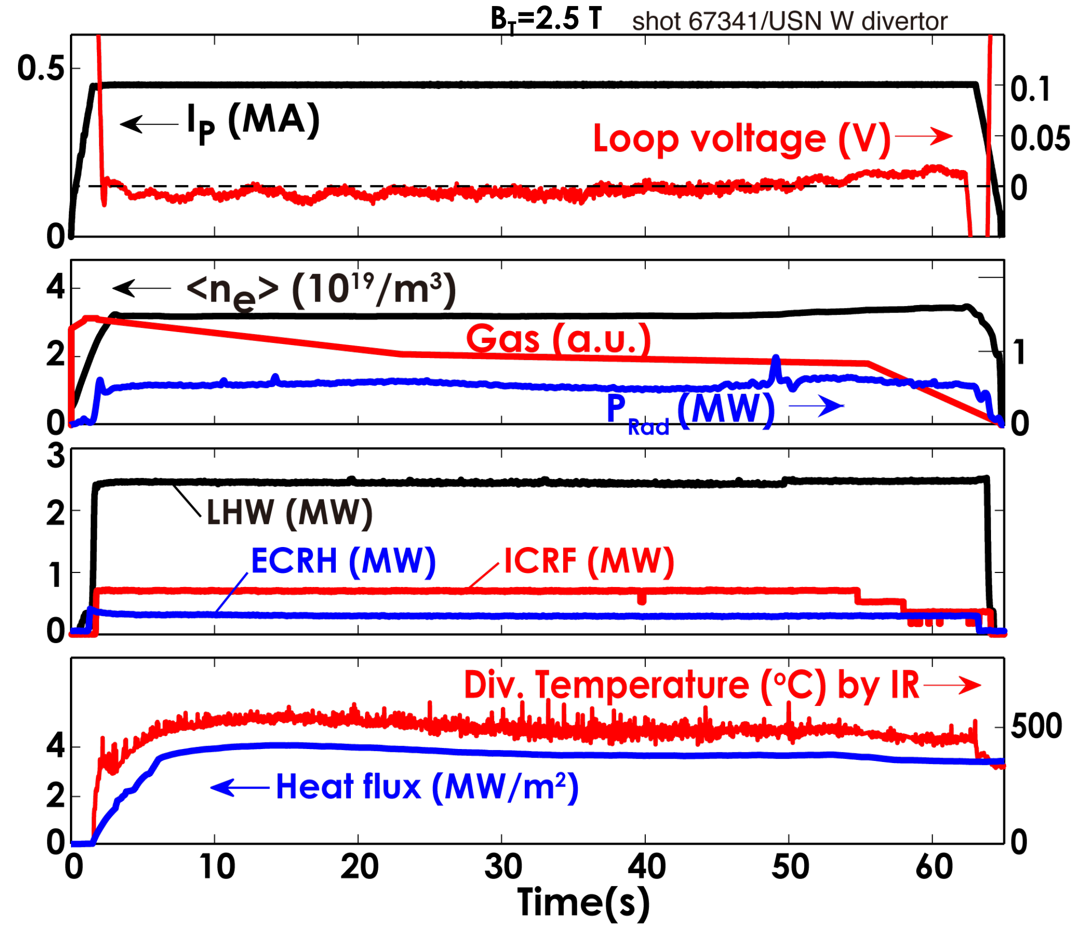


- **Stationary current profile with q_{min}~1.5**



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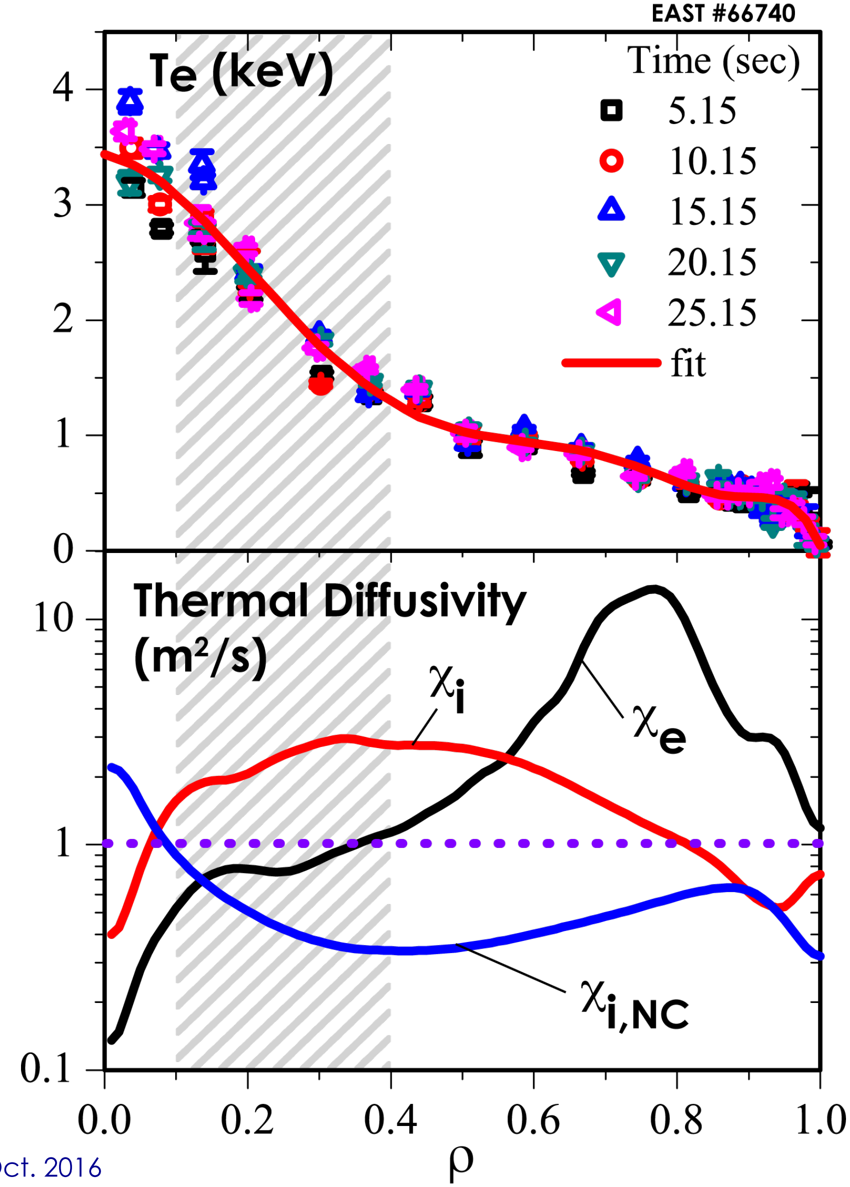
Steady-state eITB Features (H_{98y2}~1.1) Observed in Long Pulse H-mode Discharges

- **Peaked T_e profile and improved confinement are stationary (tens of seconds)**
- **Power balance analysis shows significantly reduced χ_e in plasma core**
- **Core T_e profile meets ITB criterion**
  - $\rho^*_{Te}(max)=0.02 > \rho^*_{ITB}\sim 0.014$

    [Tresset, NF 2002]



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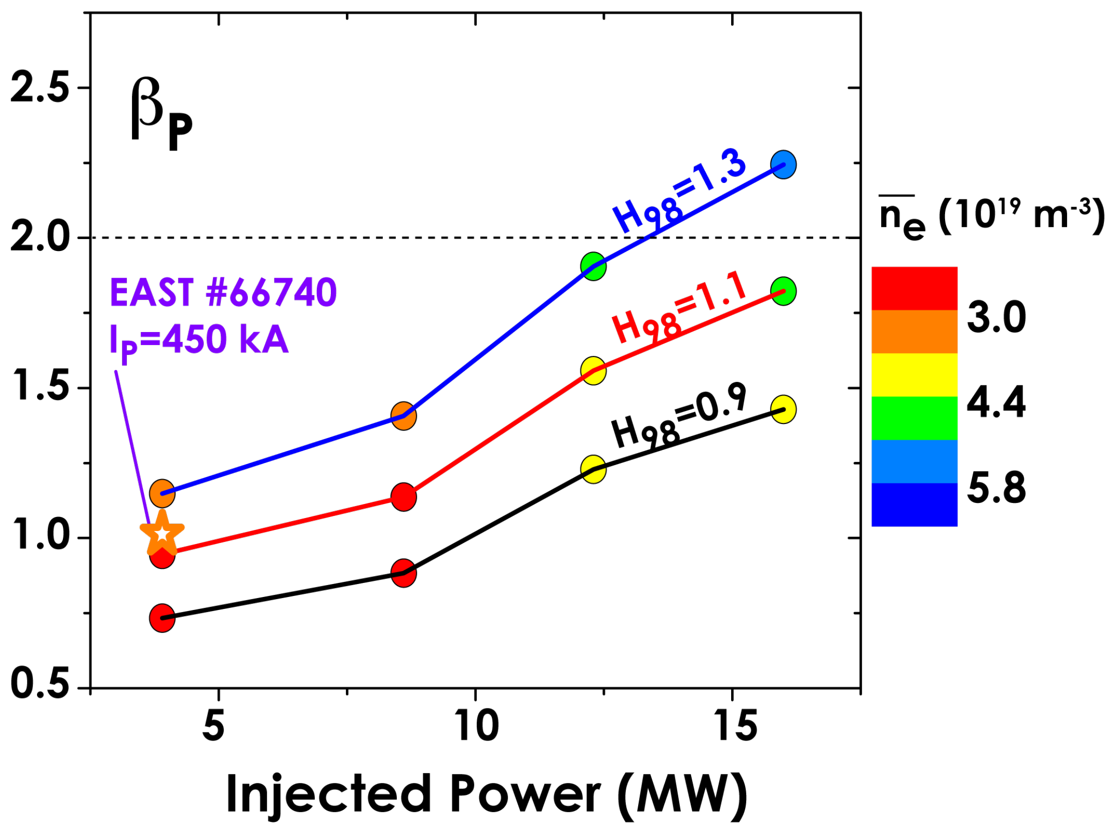
Steady-state at High Performance Requires Increased Injected Power and Improved Confinement (H_{98y2}≥1.3)



- 0D modeling of steady-state solutions at I_P= 450 kA
- Up to 16 MW of steady-state injected power to become available in near future
- β_P>2 with higher density and higher injected power, if H_{98y2}≥1.3

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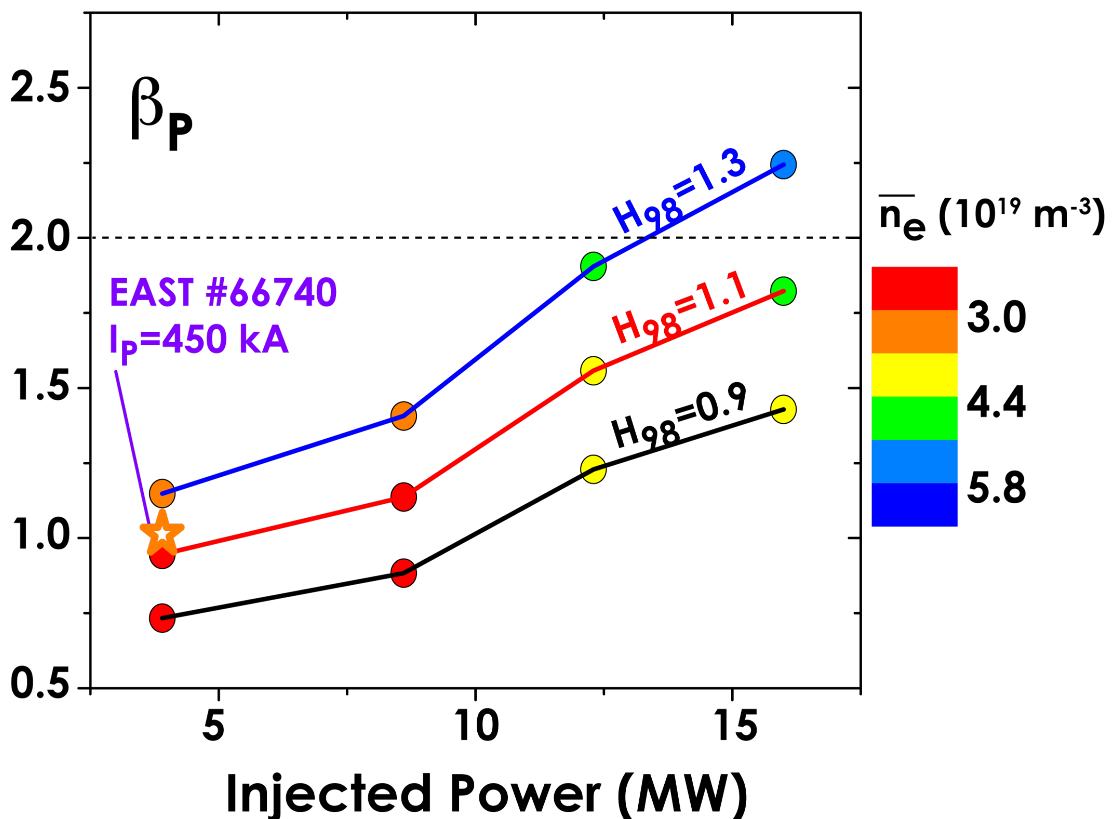

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Broaden the current profile to expand ITB radius and increase H, similar to DIII-D experiments

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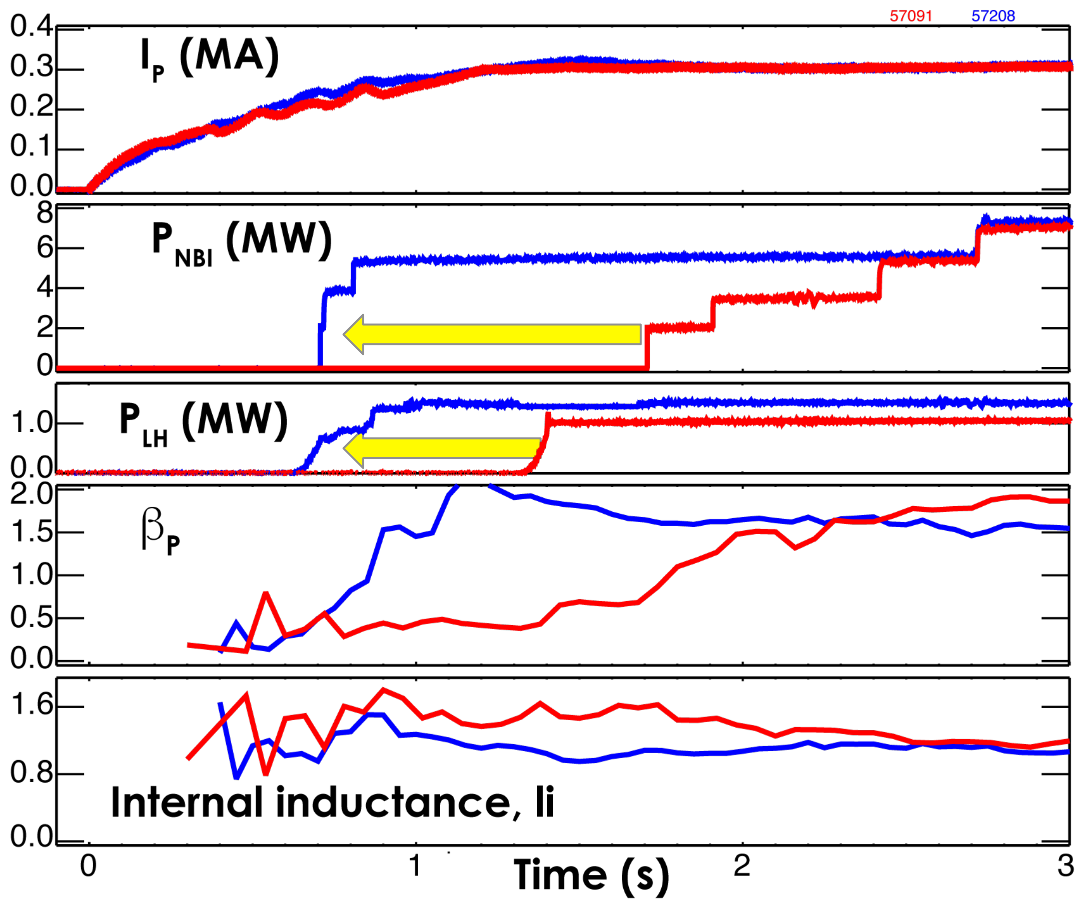
Standard Techniques to Broaden the Current Profile Only Work Transiently

- **Application of early heating power (with/without early H-mode transition) affects early ℓ_i evolution, but leads to same final state**
  - Current relaxation time, τ_{CR} ~0.4 s << pulse length



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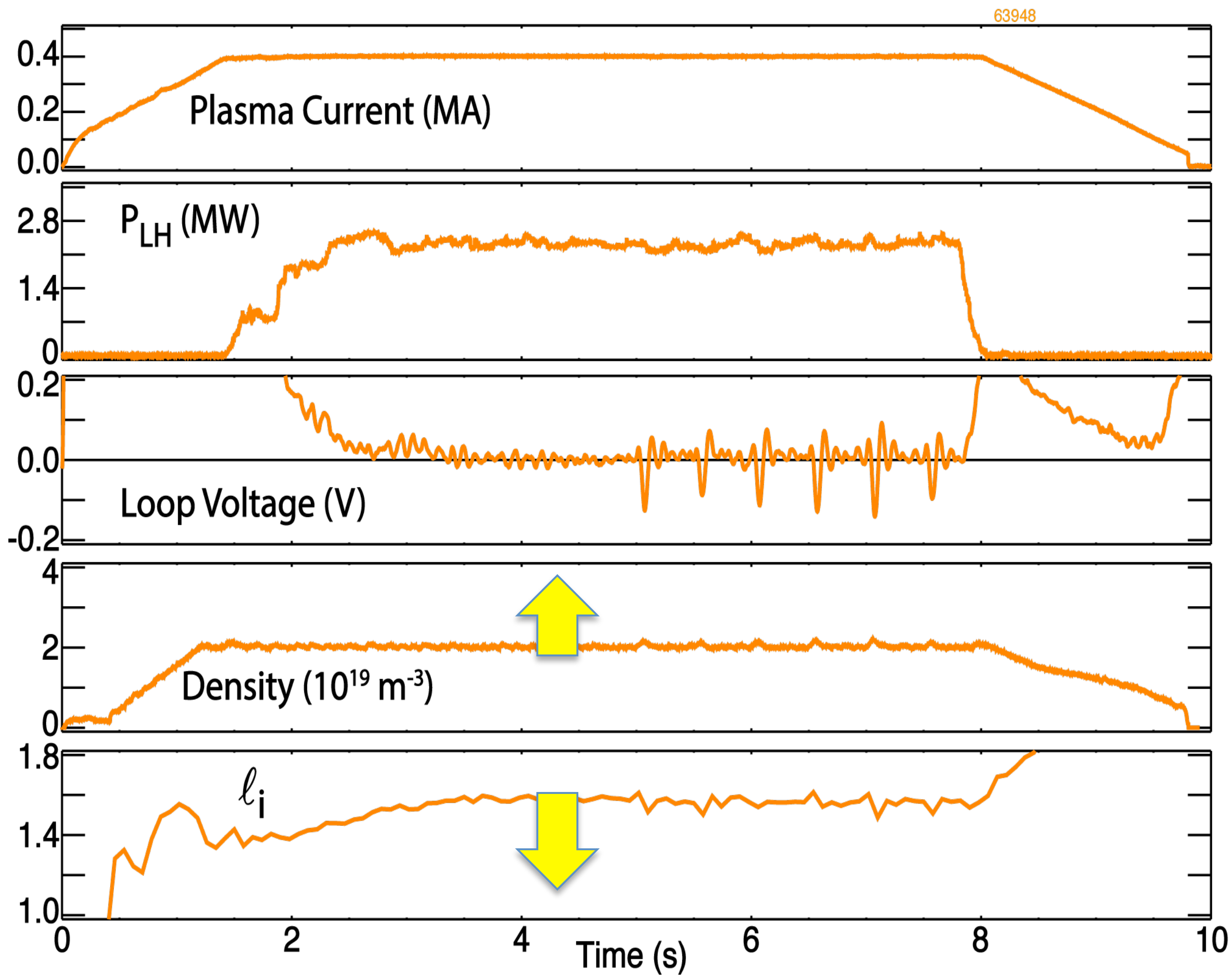
Stationary, Lower ℓ_i Achieved by Increasing Density in LH Current-driven Plasmas

- **L-mode discharges**
- **Radial penetration of LH wave slower at higher density**
  - Expect wave to be fully absorbed closer to plasma edge
- **Loop voltage ~ 0**



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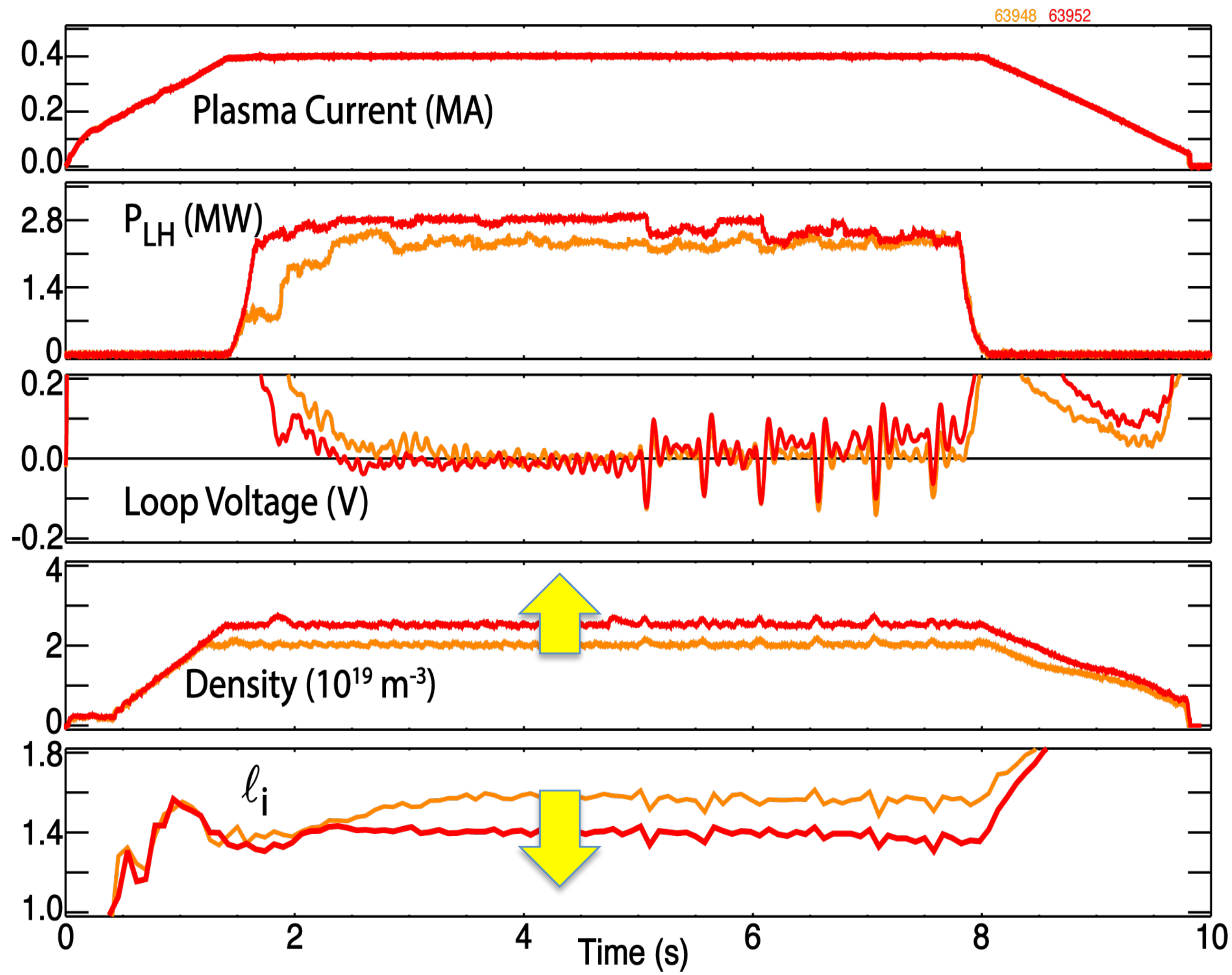

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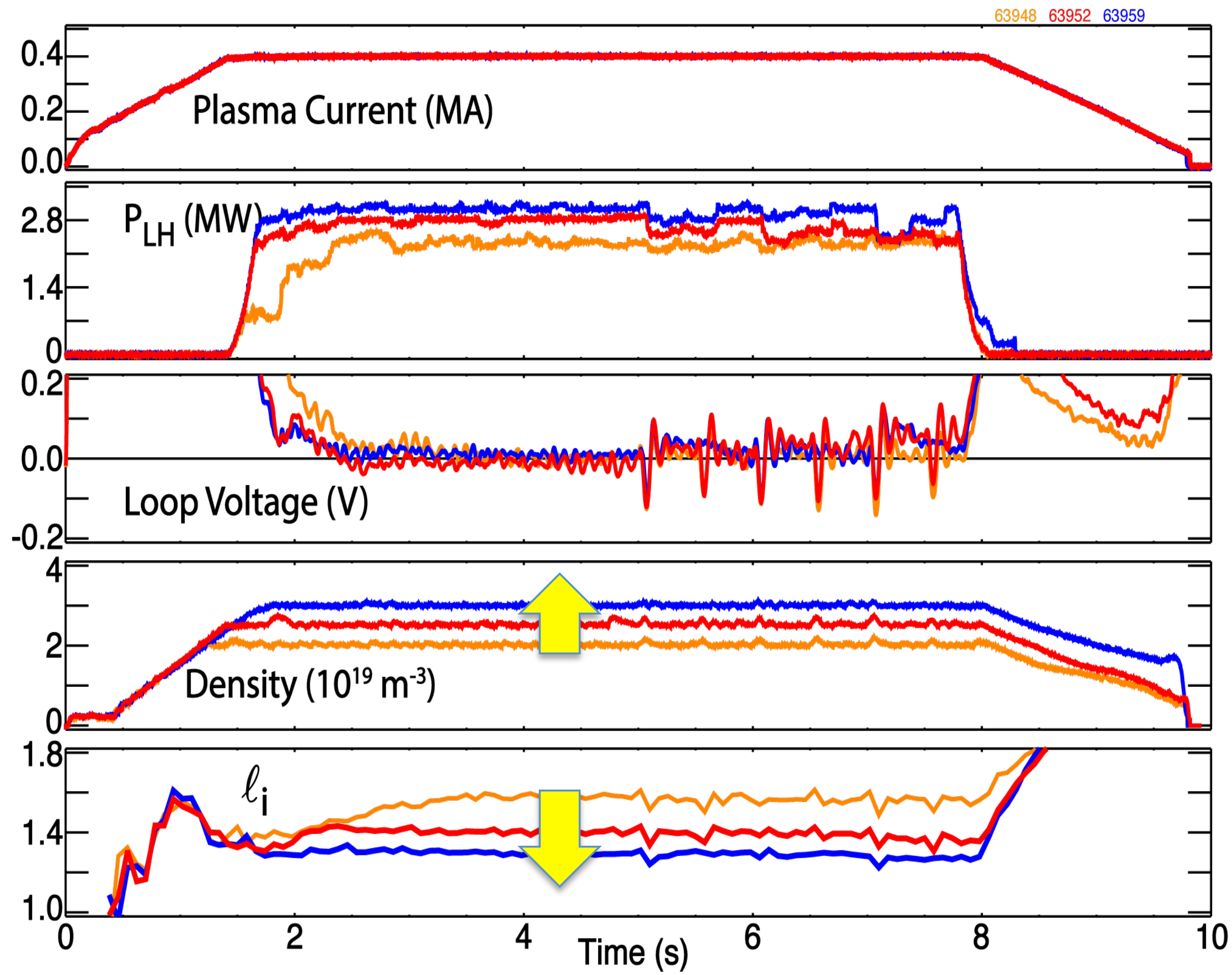

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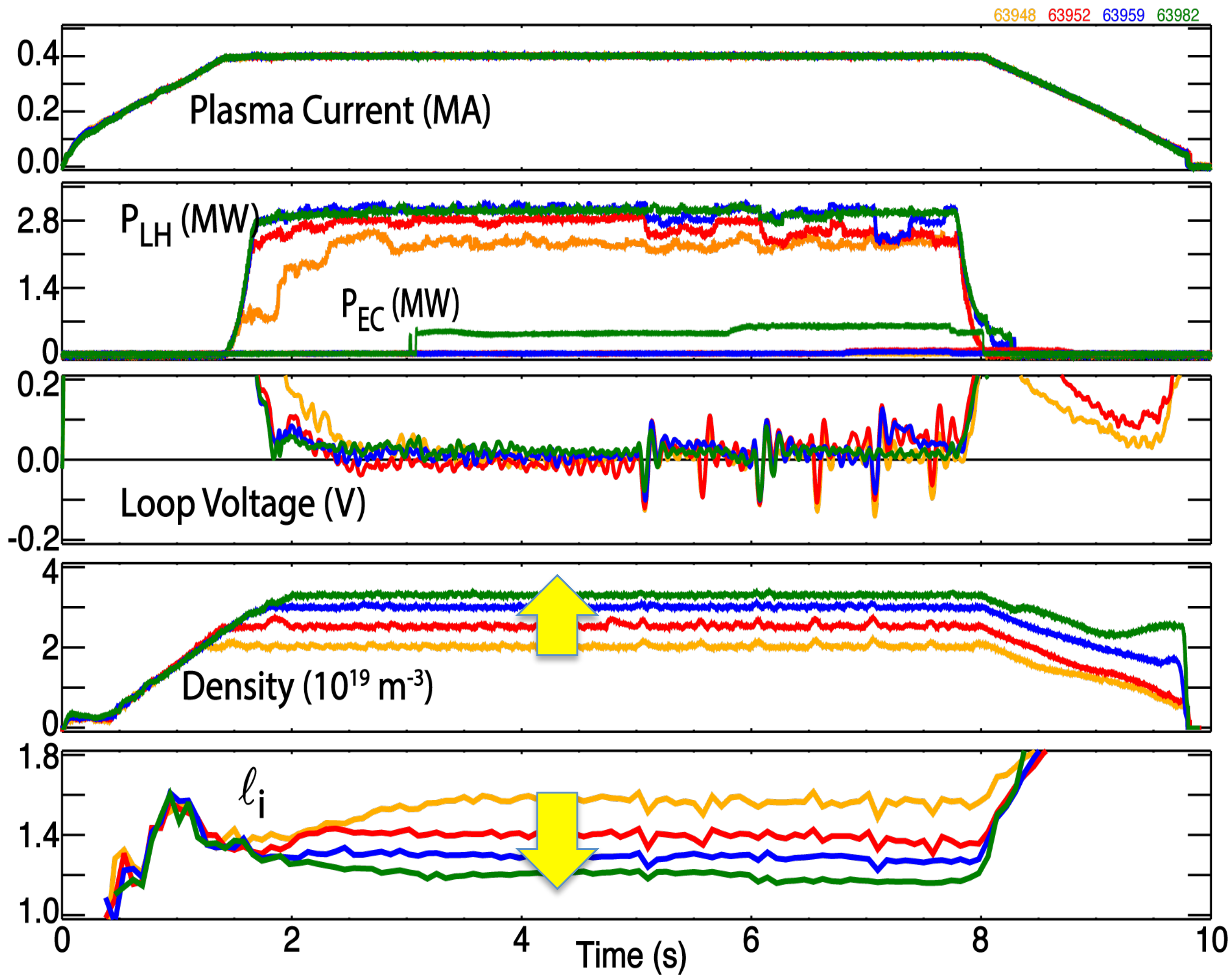

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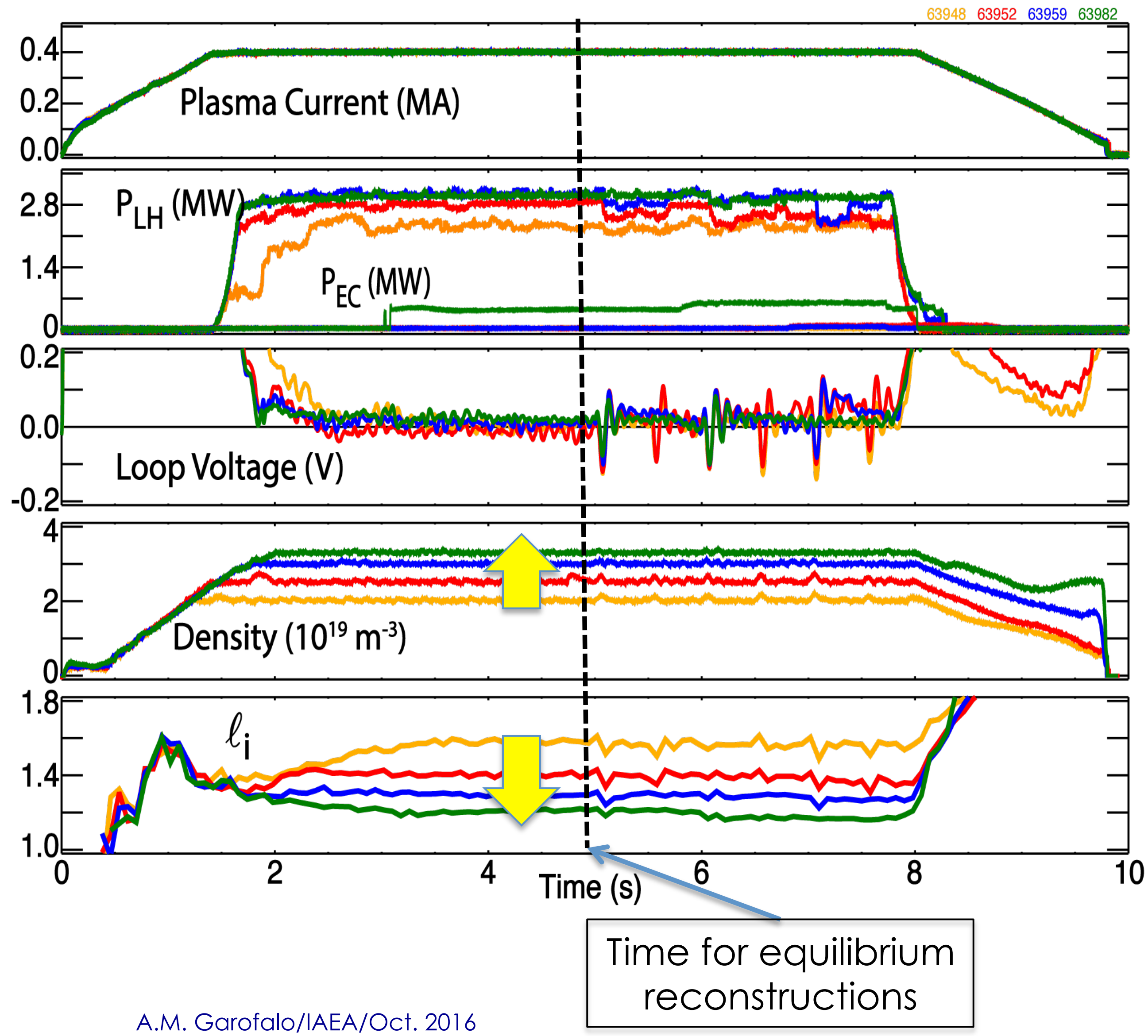
- **Time of analysis is after >5τ_{CR} of operation at ~zero loop voltage**
  - Negligible Ohmic current



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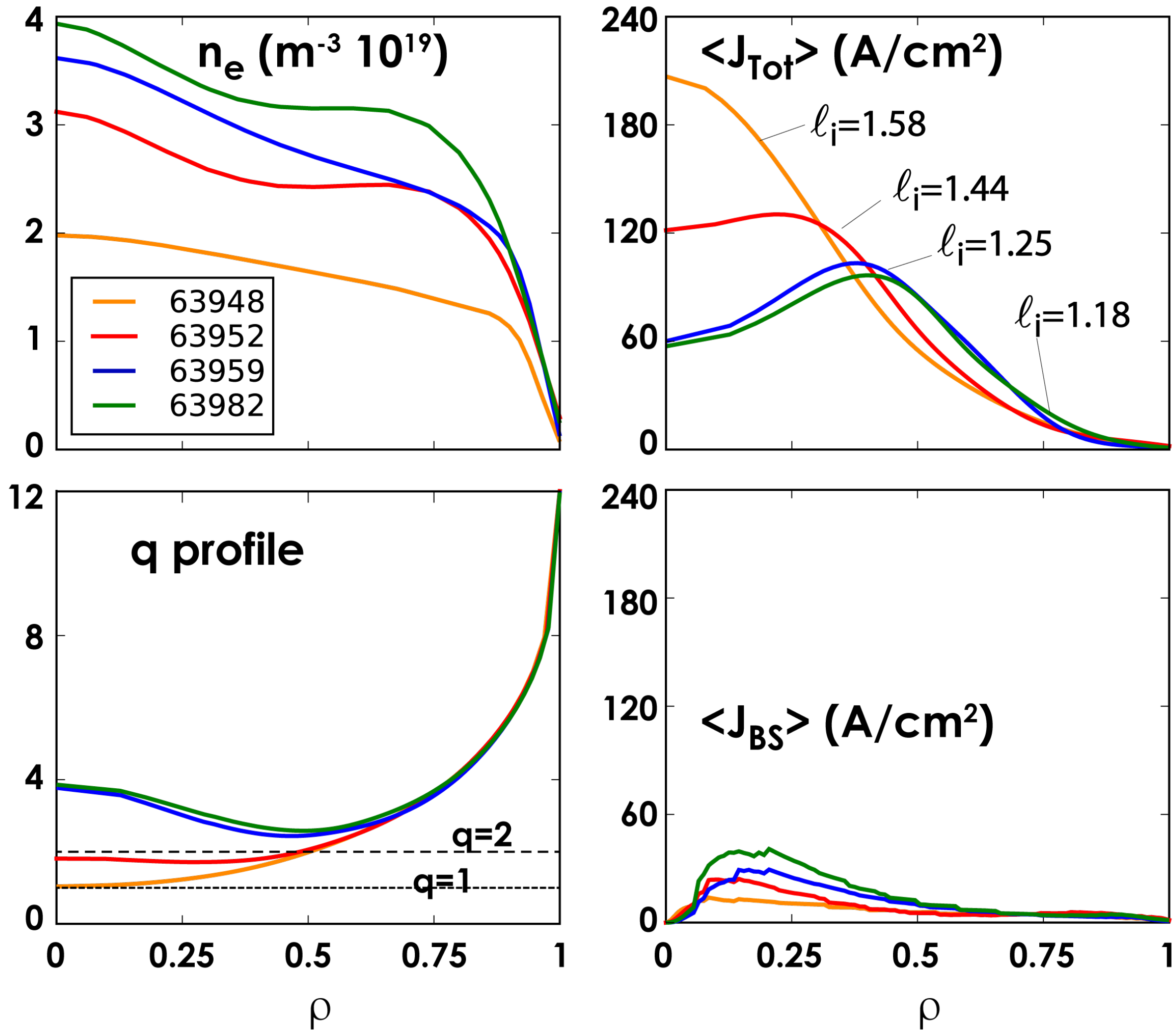
Equilibrium Reconstructions Confirm Broader Current Profile at Higher Density



- **Steady-state negative central shear obtained at high density**

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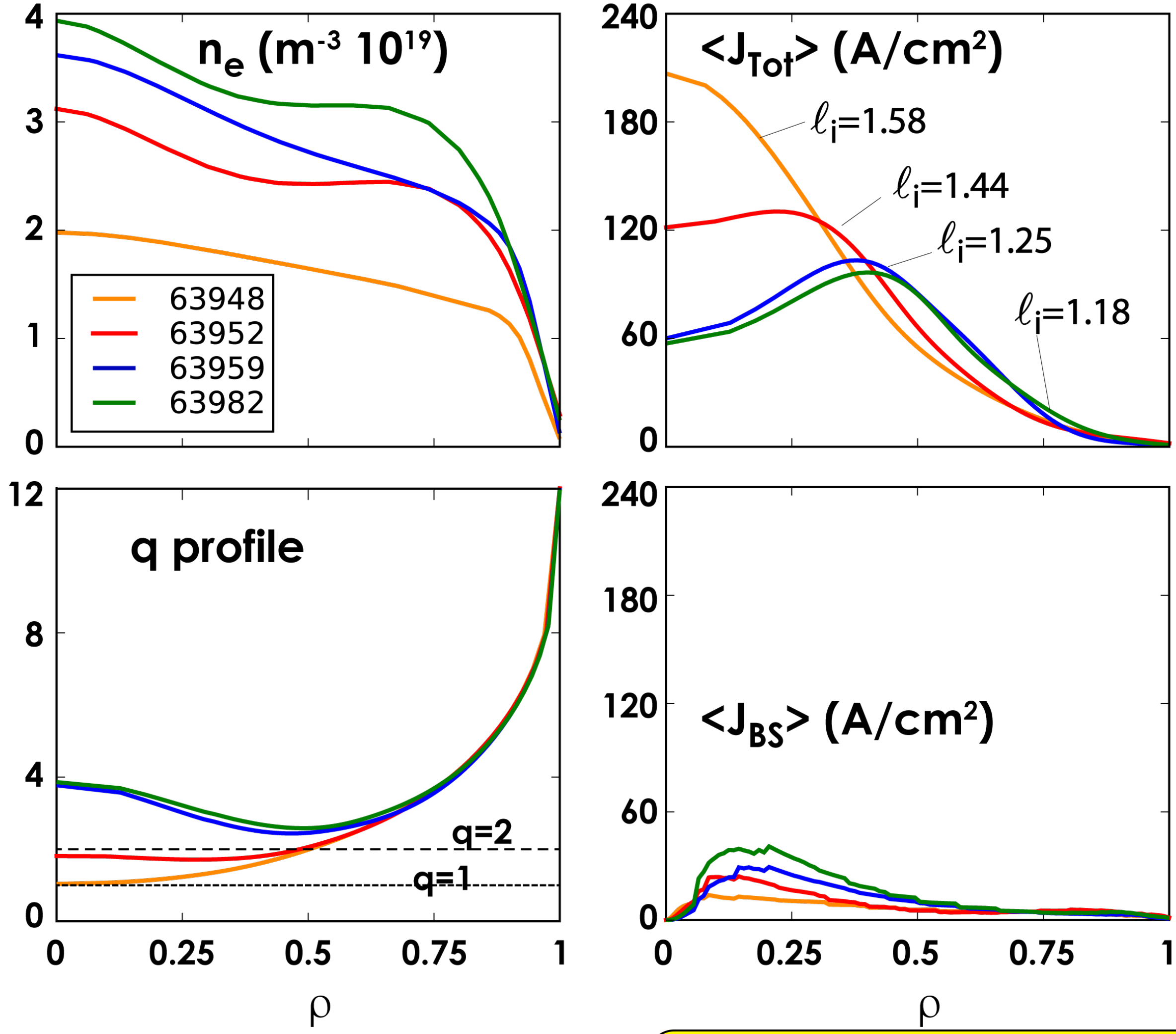

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"High performance synergy" between broad current profile and high density

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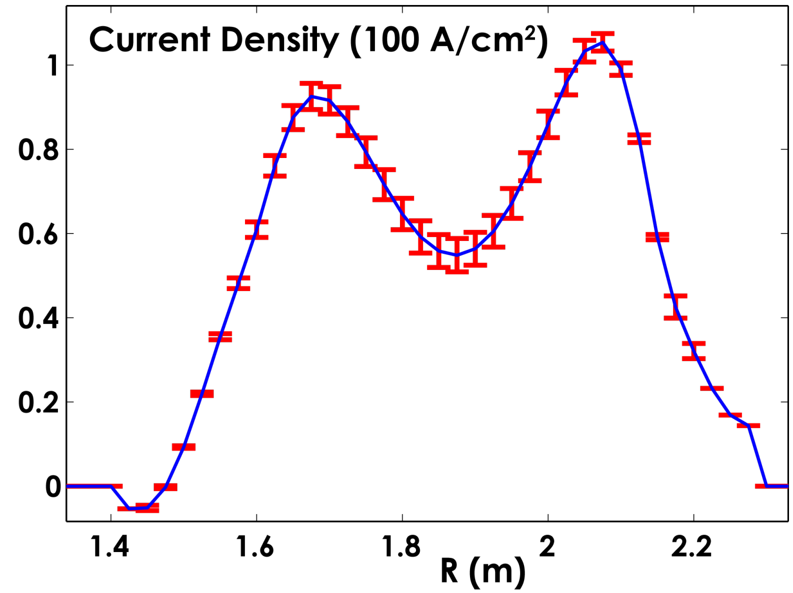
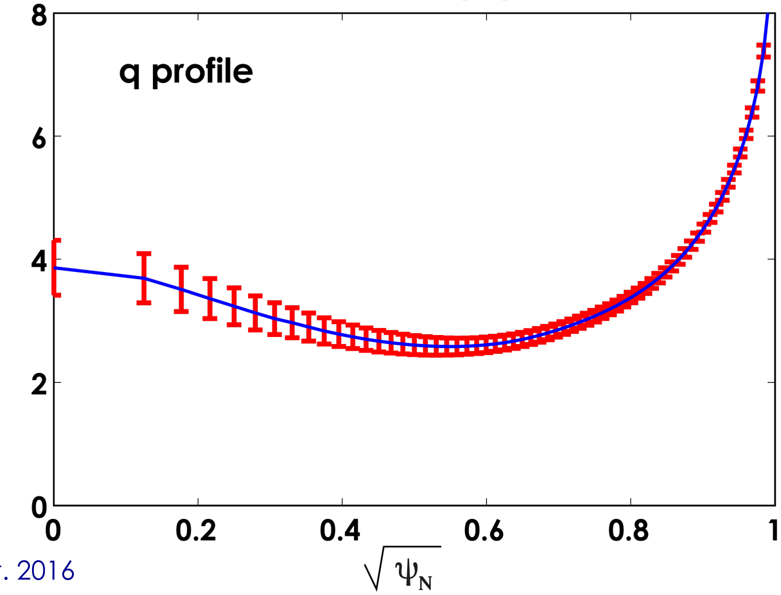
Current Profile Reconstruction Enhanced by New Polarimetry-Interferometry (POINT) Diagnostic

- **POINT → line-integrated measurements of internal magnetic field and plasma density**
- **Provides sufficient constraint to reveal hollow current profile**
  - Uncertainty estimate constructed by the Monte Carlo method of uncertainty propagation





See also
W.X. Ding, EX/P7-16

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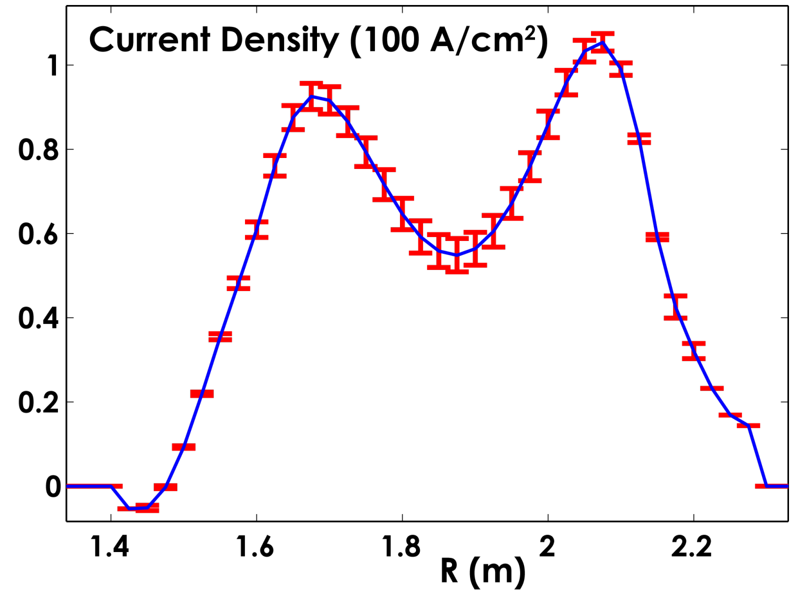
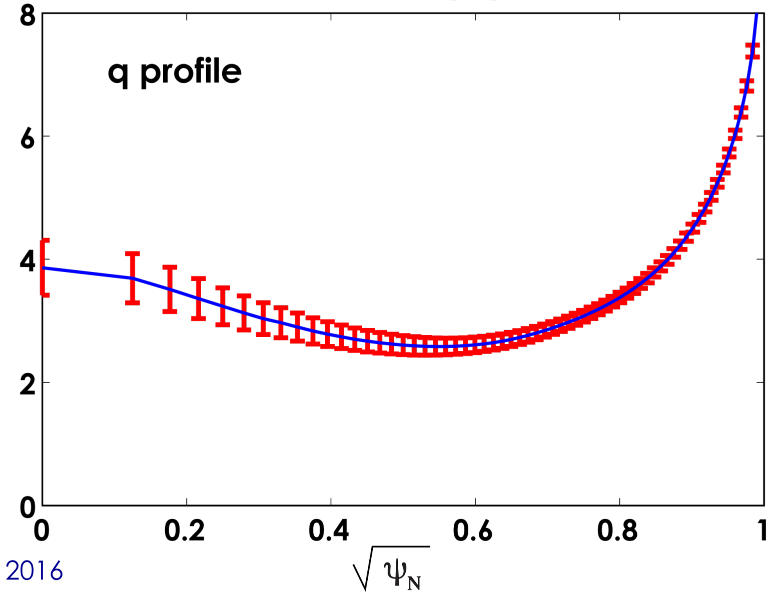
With no Ohmic current, profile of $J_{Tot}-J_{BS}$ can be compared directly to J_{LHCD} simulation





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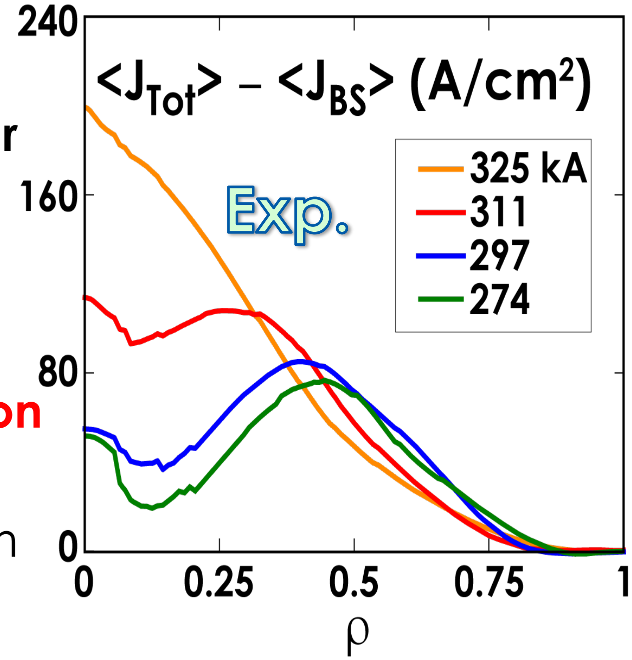
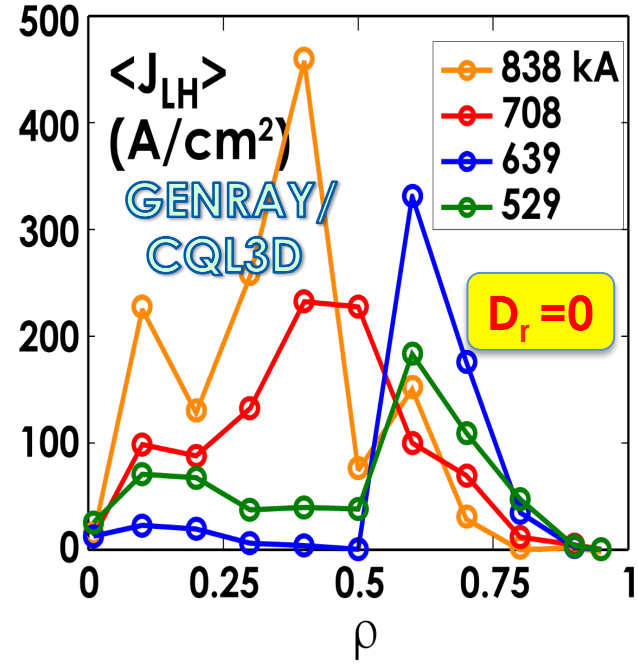
LHCD Modeling Reproduces Trend of Broader Profiles at Higher Density

- **GENRAY/CQL3D and C3PO/LUKE give similar results**
- **Matching experiment magnitude requires** **anomalous fast electron transport, $D_r > 0$**
  - Similar to results from other tokamaks





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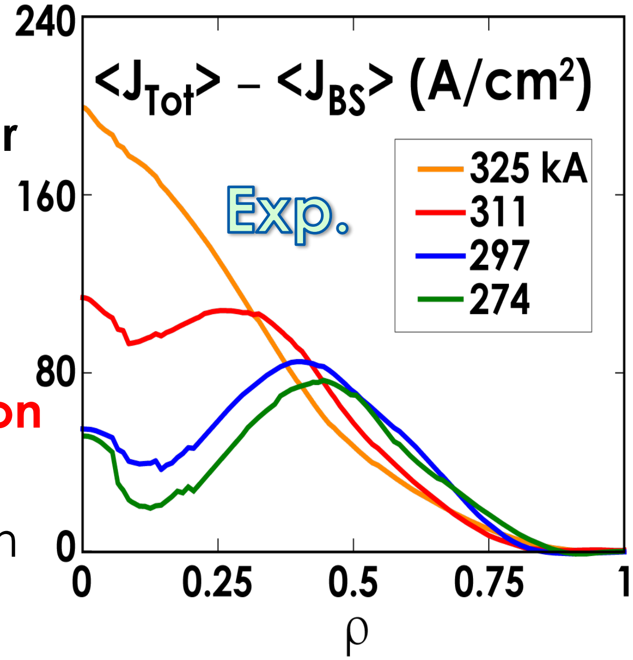

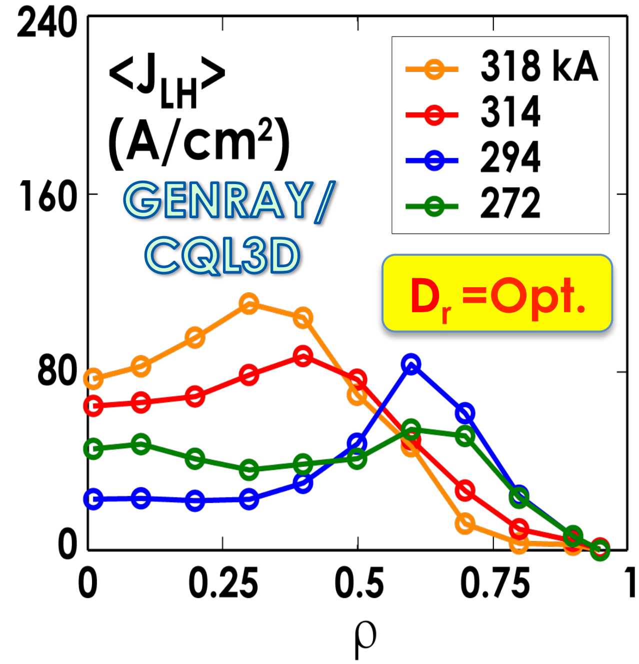

D_r (m^2/s)	1.15	1.3	0.8	0.8
n_e (10^{19} m^{-3})	2	2.5	3	3.3

- **Optimal D_r is smaller at higher density**

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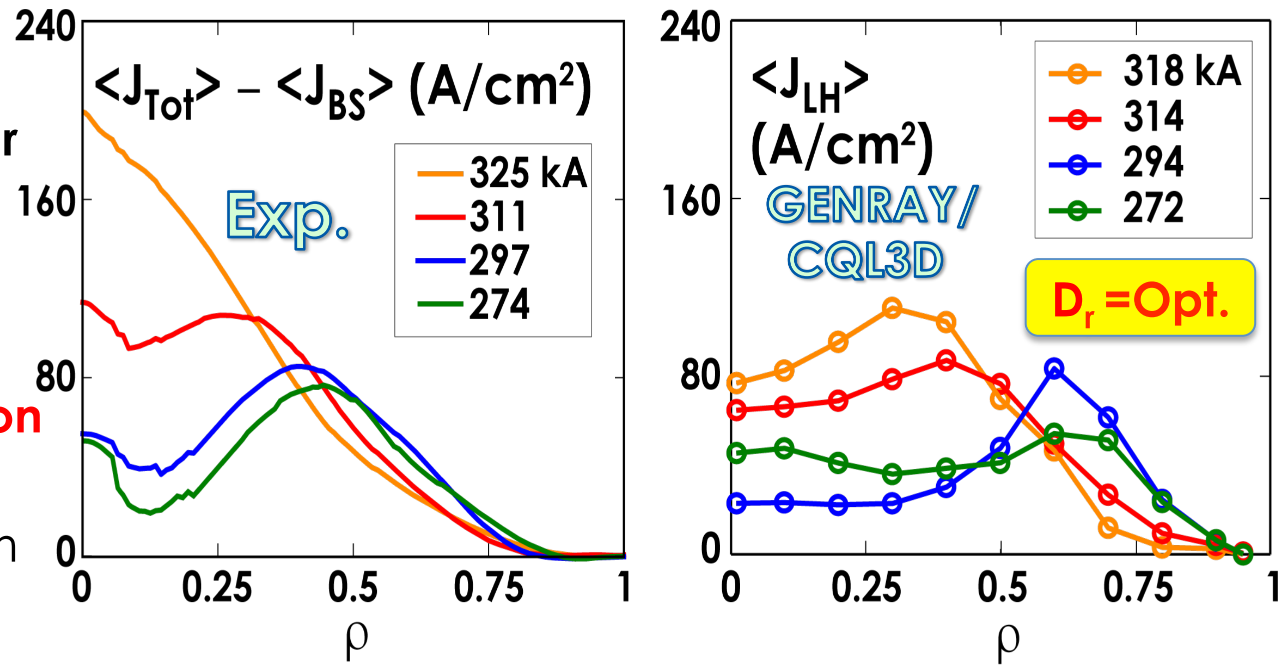

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  [Rechester-Rosenbluth, PRL 1978]

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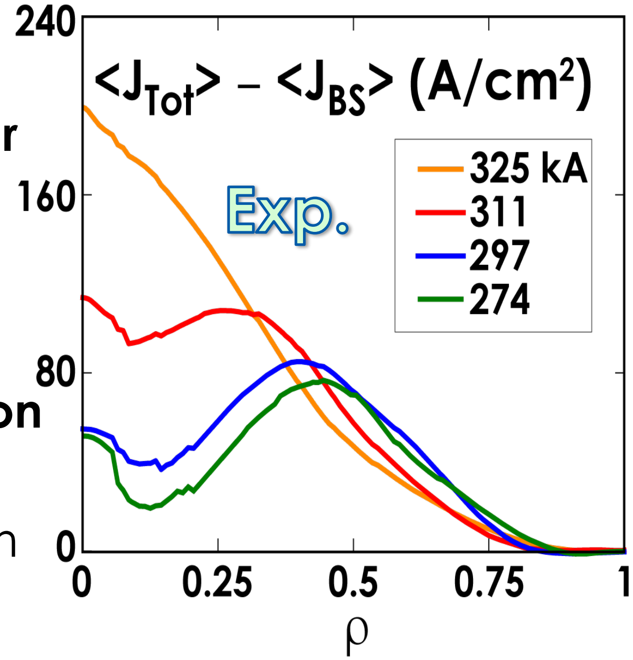

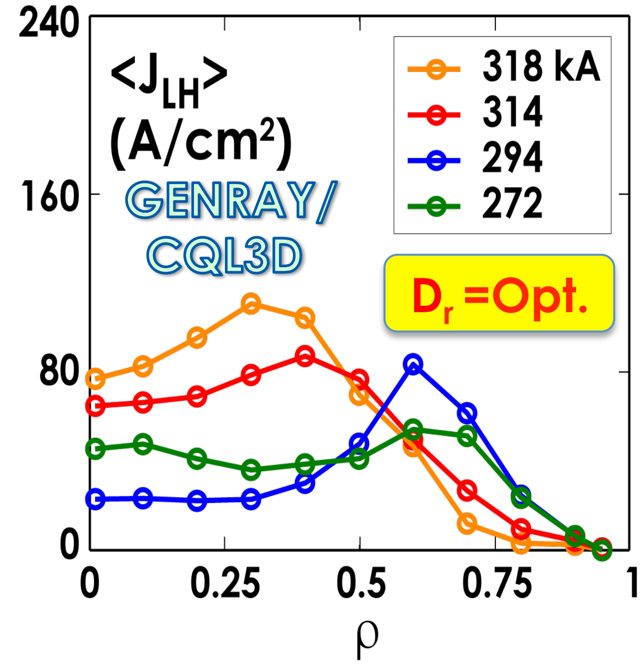

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- **Simulated profiles are systematically broader than experiment**
  → "Tail" model may yield better agreement

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➢ **Next step: Optimize ITB with higher β_P and broader current profile**