Preliminary plasma core transport analysis of optimized internal inductance steady-state H-mode discharges in EAST

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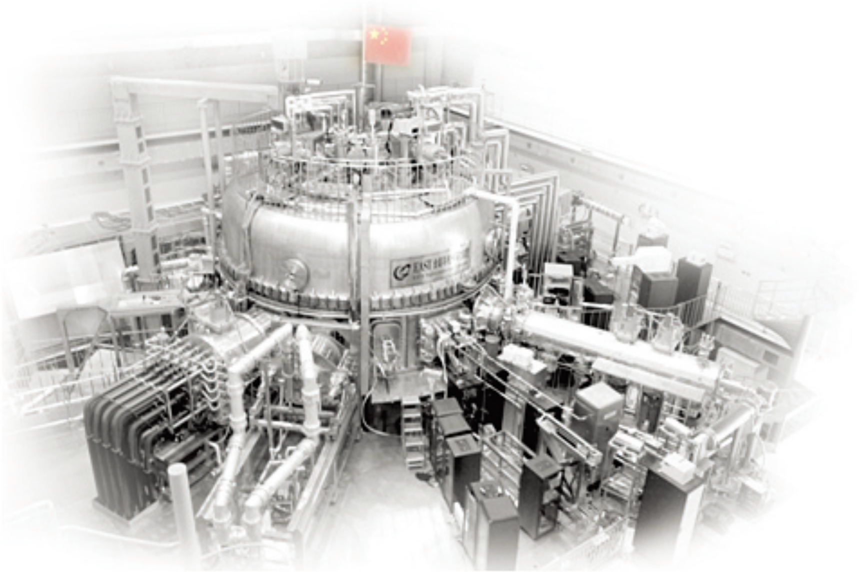

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Outline

- Motivation
- Moderate internal inductance steady-state H-mode discharges in EAST
  - ✓ eITB feature of EAST long pulse discharges
  - ✓ Stored energy reduction after ECW turn off
- TRANSP power balance analysis
  - ✓ LHW heating and current drive
  - ✓ Electron thermal diffusion
  - ✓ Plasma current evolution
  - ✓ Poloidal magnetic field and magnetic shear
  - ✓ Electron temperature gradient behavior
- Gyrokinetic Simulations
- Summary

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Motivation

Study of confinement improvement in high internal inductance (li) plasmas[1-5]

- **Transiently**

✓ Current ramp down (Tore Supra, JET, JT-60U, DIII-D), L-mode and H-mode
✓ Elongation ramp up (DIII-D), H-mode
✓ Core inductive current density peak 'frozen' inside $\rho = 0.4$ by ECCD (DIII-D), H-mode

- **Steady-state**

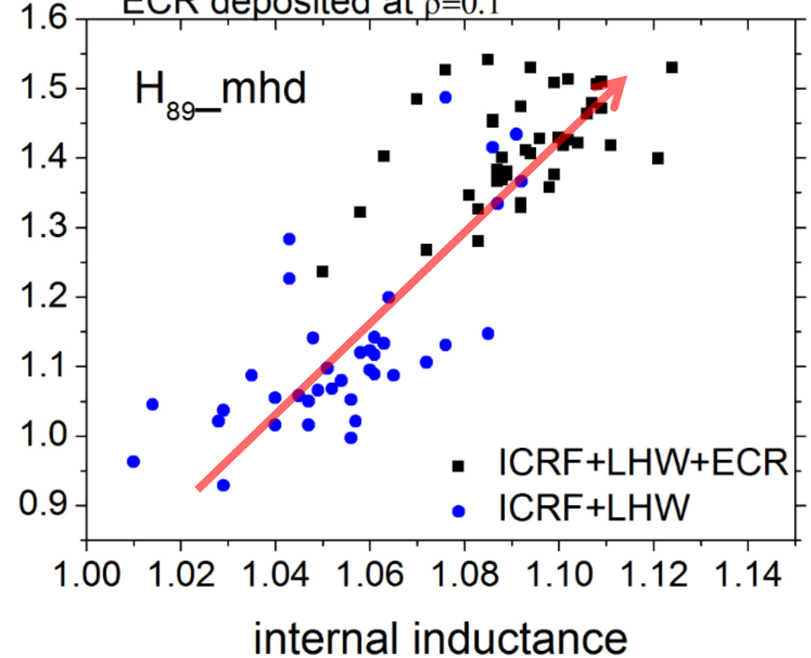
✓ LHCD just before current ramp down (Tore Supra), L-mode

Optimized internal inductance advanced tokamak scenario[5,6]

- Moderate li (~1.1)
- High bootstrap current fraction (~50%)
- MHD stability ($q_0 \geq 1$)
- Strong cross-section shaping

[1] Hoang G T et al 1994 Nucl. Fusion 34 75
[2] Lao L L et al 1993 Physical Review Letters 70 3435
[3] Challis C D et al 1992 Nucl. Fusion 32 2217
[4] Urano Y et al 2009 Nucl. Fusion 49 095006
[5] Ferron J R et al 2015 Nucl. Fusion 55 073030
[6] Lin-Liu Y R et al 1999 Phys. Plasmas 6 3934

Ip~420kA, ne~3*1019m-3, Vloop~0v,
ECR deposited at ρ=0.1



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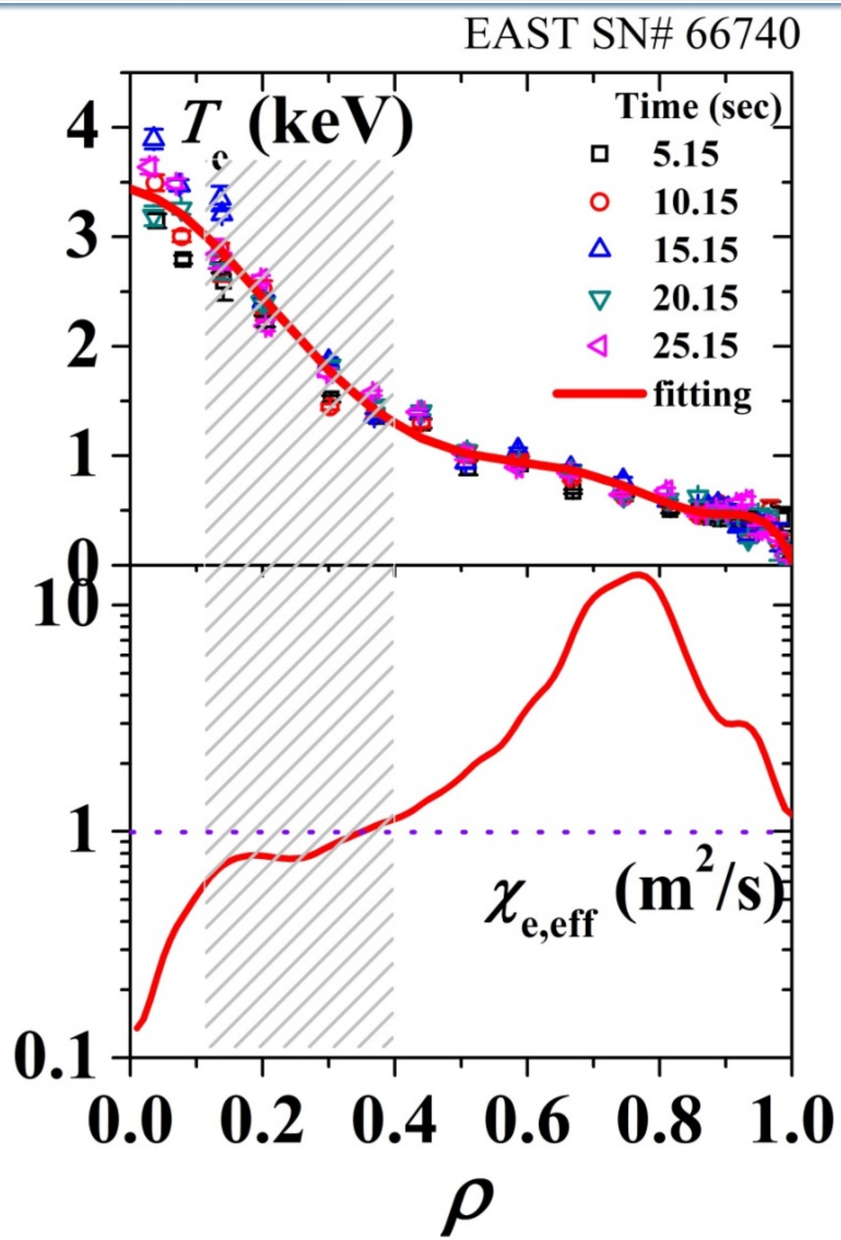
eITB feature of EAST long pulse discharges

ASIPP

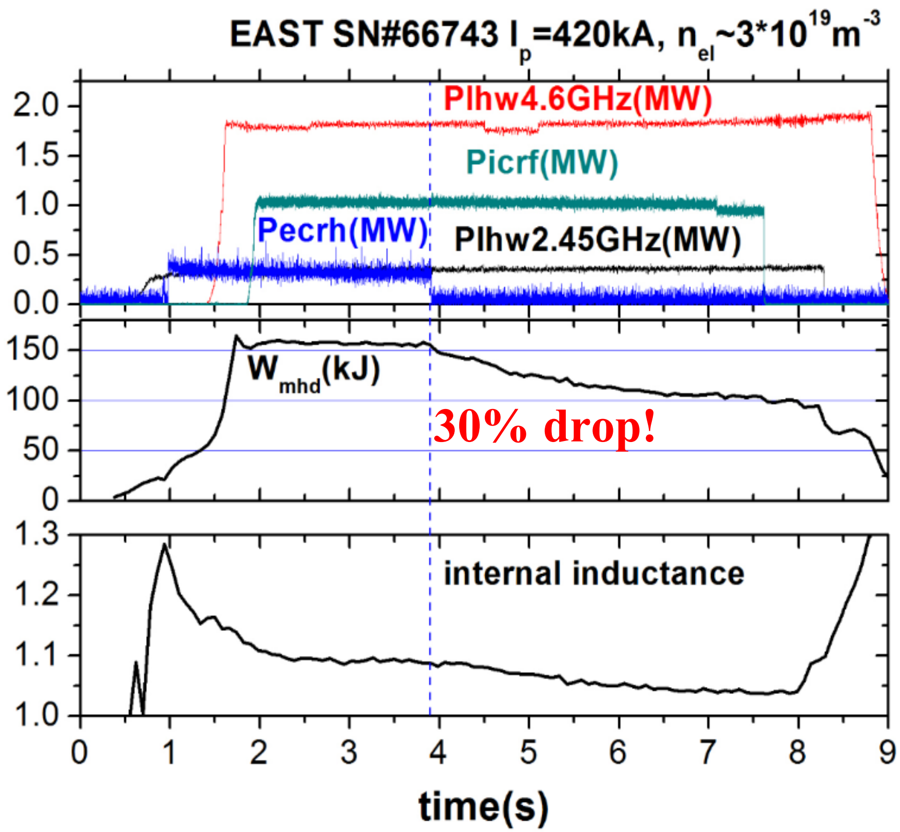


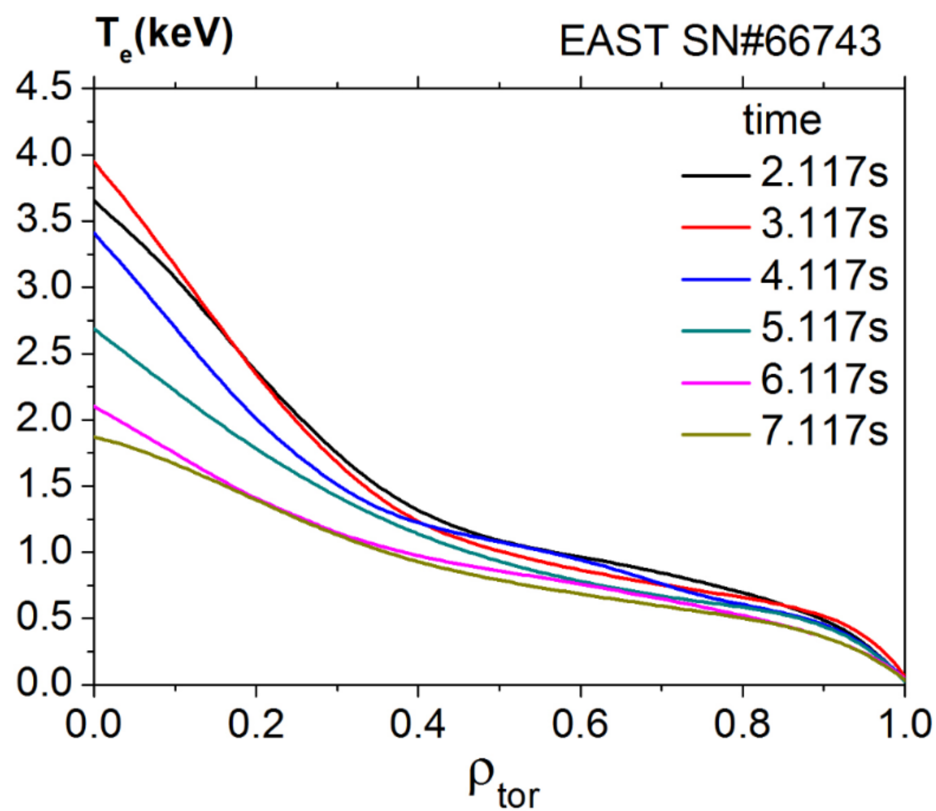
- In the last EAST campaign, long pulse steady-state H-mode plasmas with moderate li (~1.1) have been achieved with LHCD and ECCD
- Peaked T_e profile and good confinement are stationary
- Power balance analysis by TRANSP shows a low χ_e in plasma core region
- Core T_e profile meets the ITB criterion
  - $\rho^*_{Te}(\max) = 0.02 > \rho^*_{ITB} \sim 0.014$

G. Tresset, Nucl. Fusion, 42(2002)520

Stored energy reduction after ECR turn off

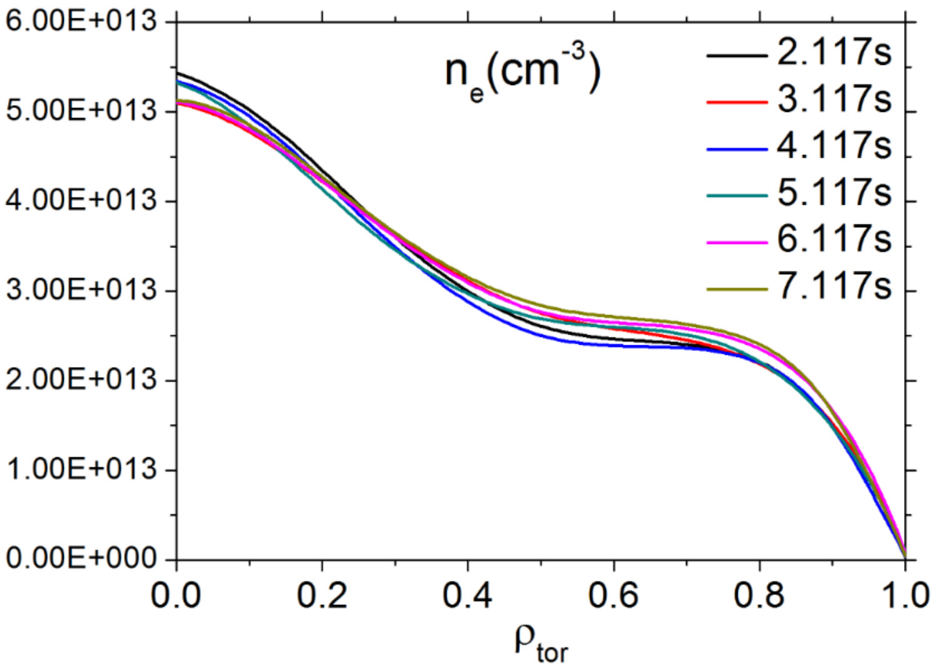
- **Stored energy reduction after ECW turn off may correlated with**
  - ✓ Lose of Synergy effect of LHW and ECW in both heating and current drive
  - ✓ Lose of moderately high li (peaked current profile)
- The reduction lasts for about 2.5 seconds, which is a time scale of current evolution under high electron temperature.(Increase of Te in the core results in increase in τ_R, **that is why stored energy decreases slowly.)**

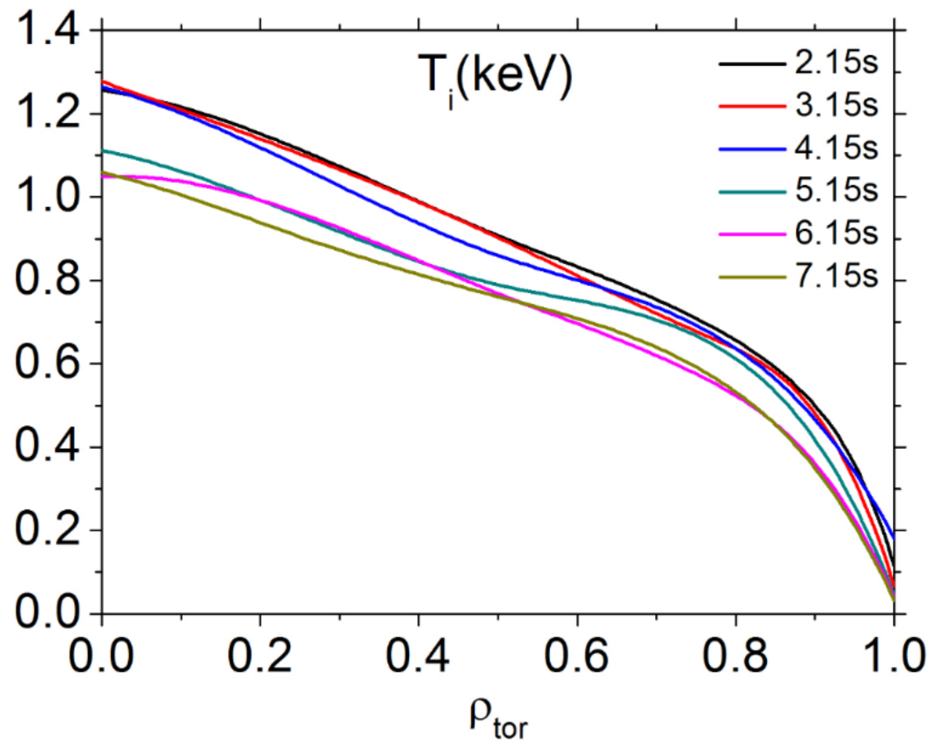




Stored energy reduction after ECR turn off

- The electron density is kept almost stationary by feedback control
- The ion temperature profile drop is due to **electron-ion thermal coupling.**
- So the drop of stored energy is mainly due to electron temperature profile drop both at core and large radii.





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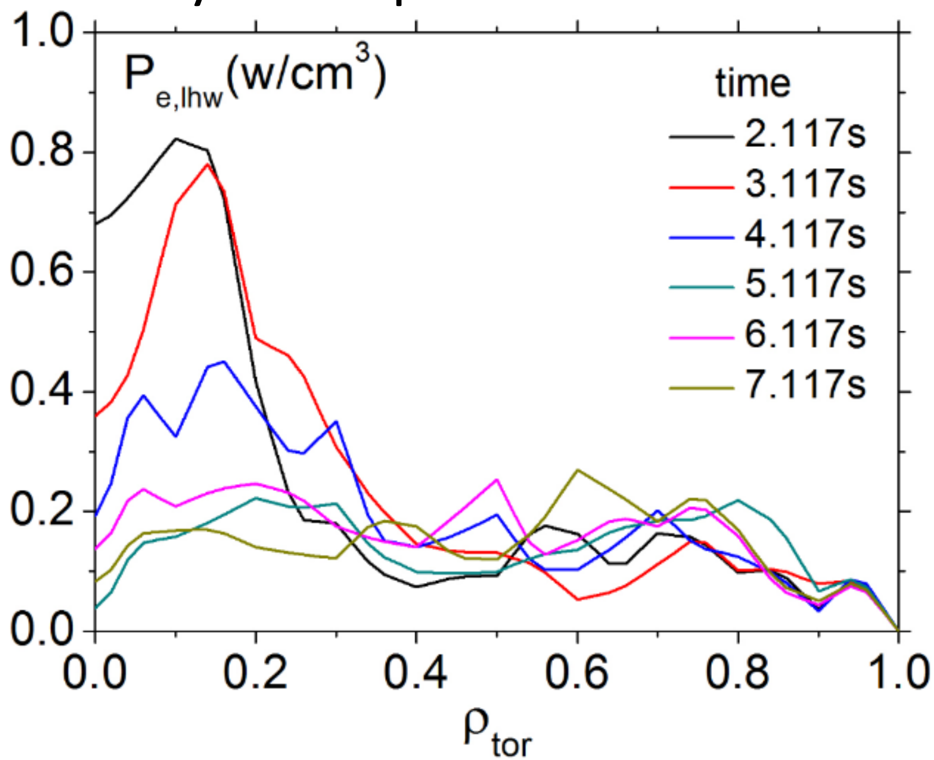
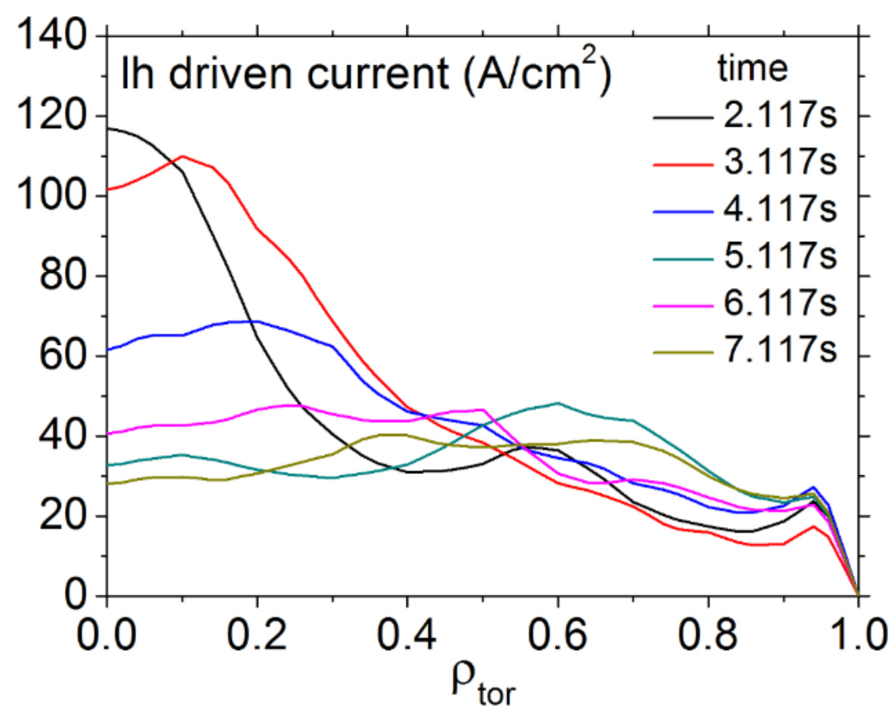
LHW heating and current drive

- LHW heating profile and current density profile is calculated by **GENRAY+CQL3D** with LHW power absorption coefficient 0.75 and fast electron diffusivity 0.8 m^2/s.
- After ECW turn off (3.9s), **electrons lose core heating gradually and also the LHW driven current moves from core to large radii**, that is why Te drops at core and the internal inductance drops.

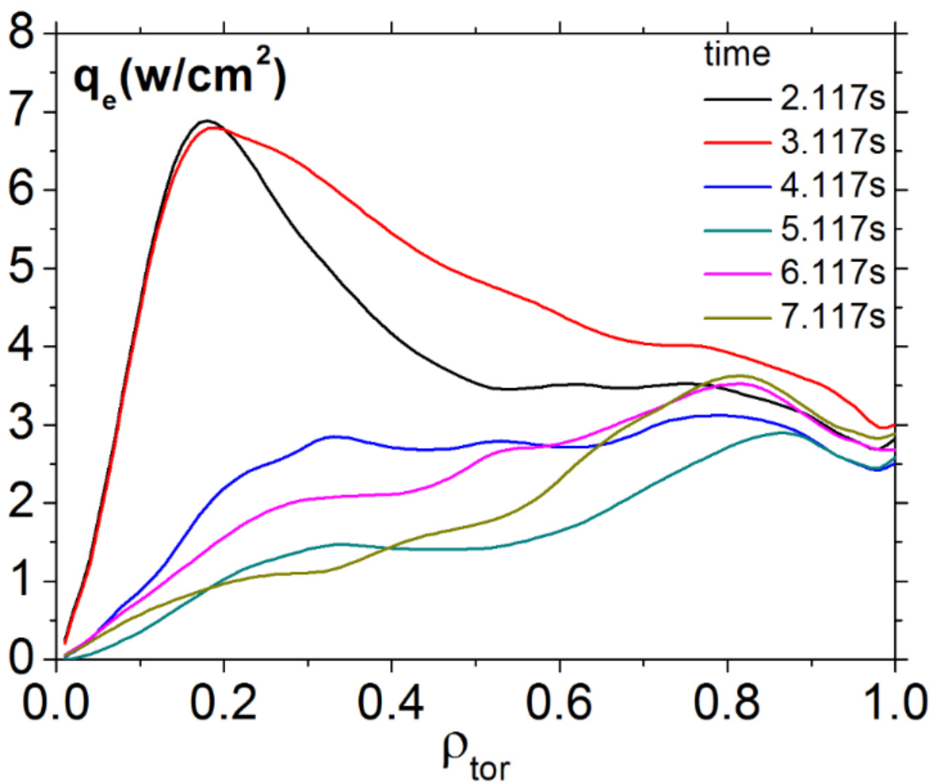


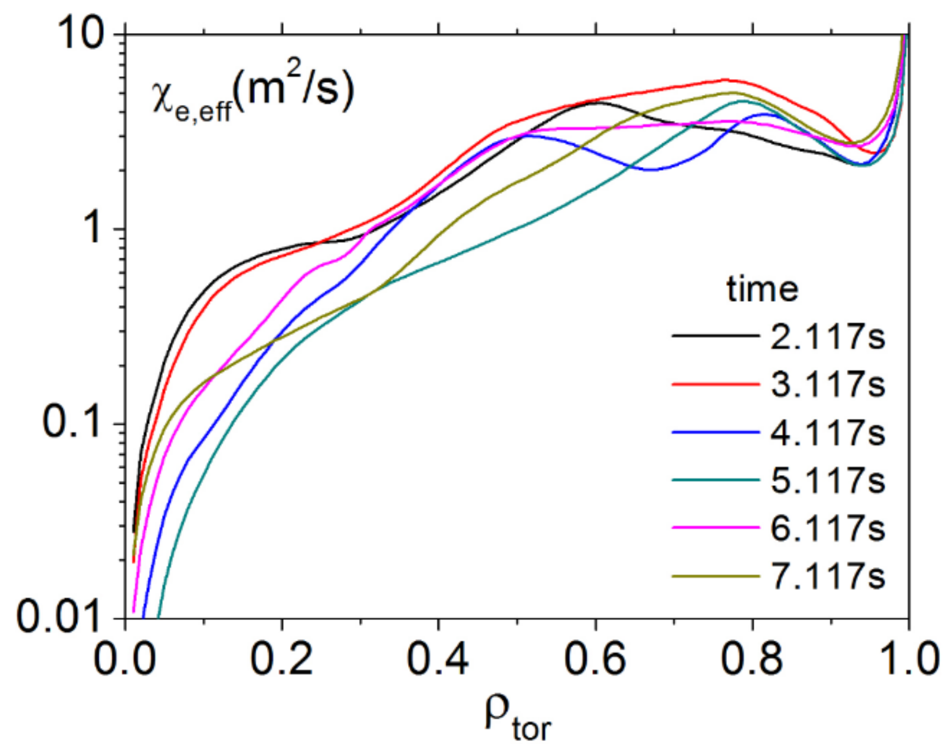


Electron thermal diffusion

- **Inputs:** LHW heating profile and current density profile calculated by GENRAY+CQL3D; EFIT reconstructed equilibria; T_e, T_i, n_e and radiation profiles;
- ECW current drive and heating calculated by TORAY
- ICW heating calculated by TORIC (mainly H minority heating)

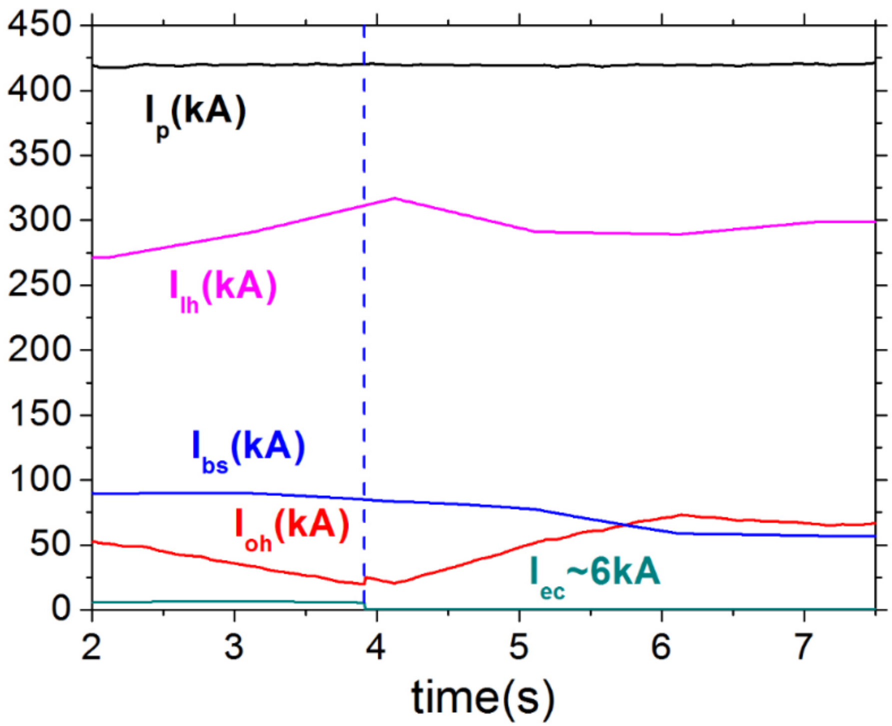
After ECW turn off, the $\chi_{e,eff}$ does not increase, the reduction of W_{mhd} is due to lose of peaked electron core heating rather than enhanced transport.

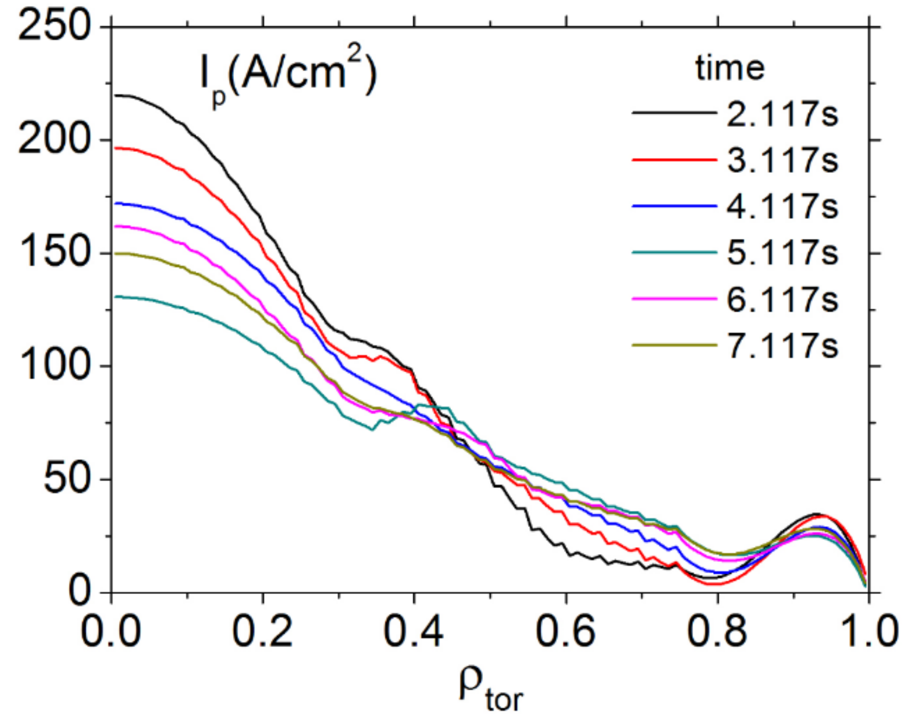




Plasma Current evolution

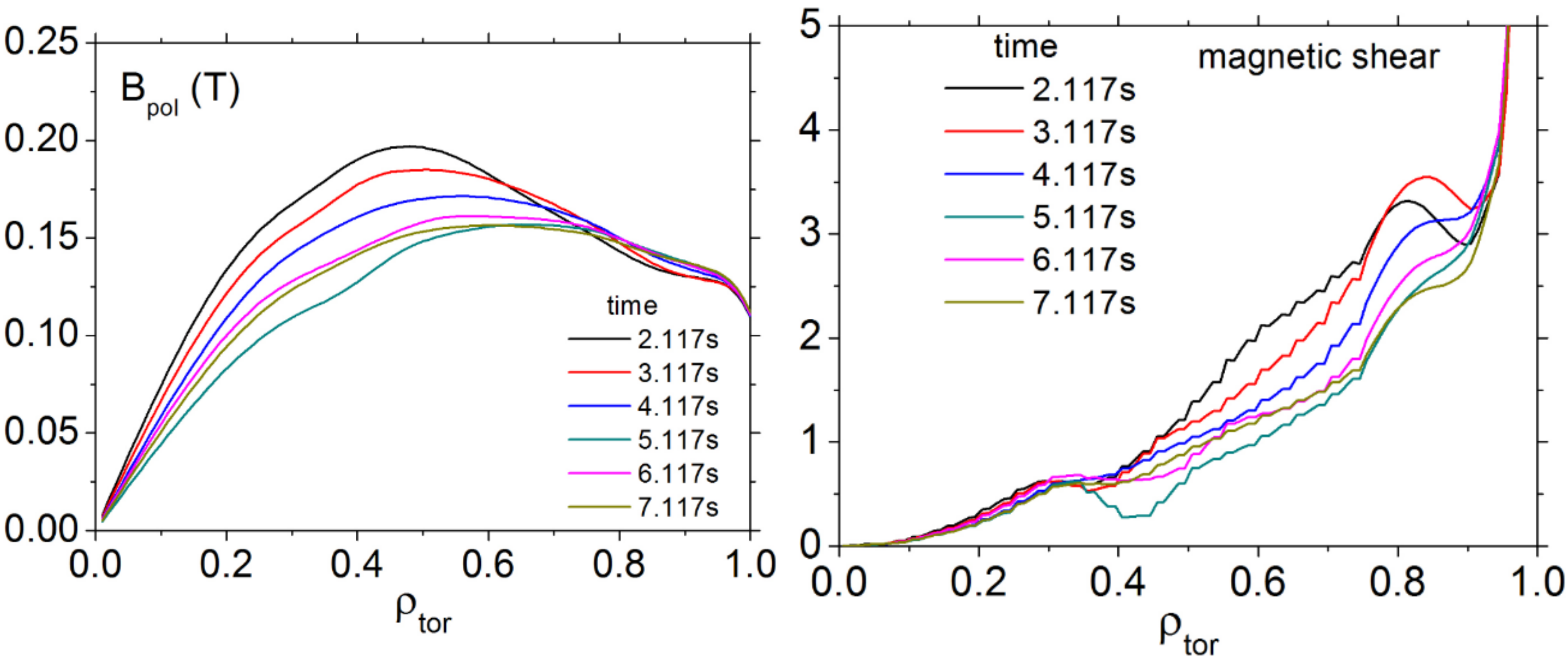
- Before ECW turn off, LHW driven current increases, which may be due to **synergy effect of ECW and 2 LHWs**. And this synergy effect does not develop to a stationary state before ECW turn off.
- Then, the ohmic current goes up is due to decrease of bootstrap current, which results from decrease of pressure gradient.
- The evolution of total plasma current density profile has the same trend with LHW driven current profile.





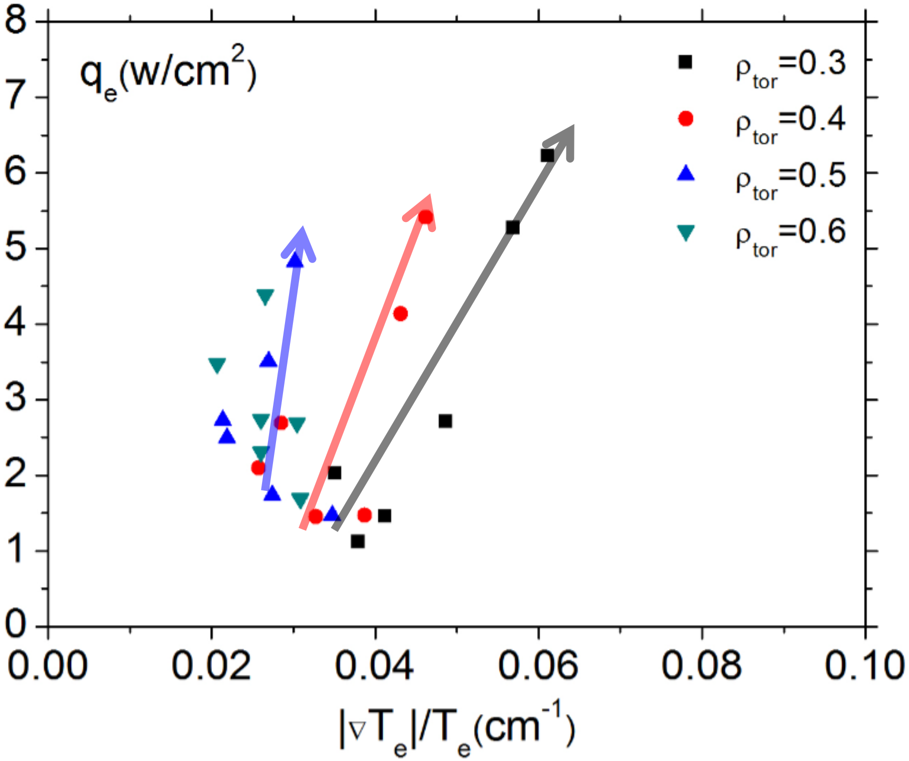
Poloidal magnetic field and magnetic shear

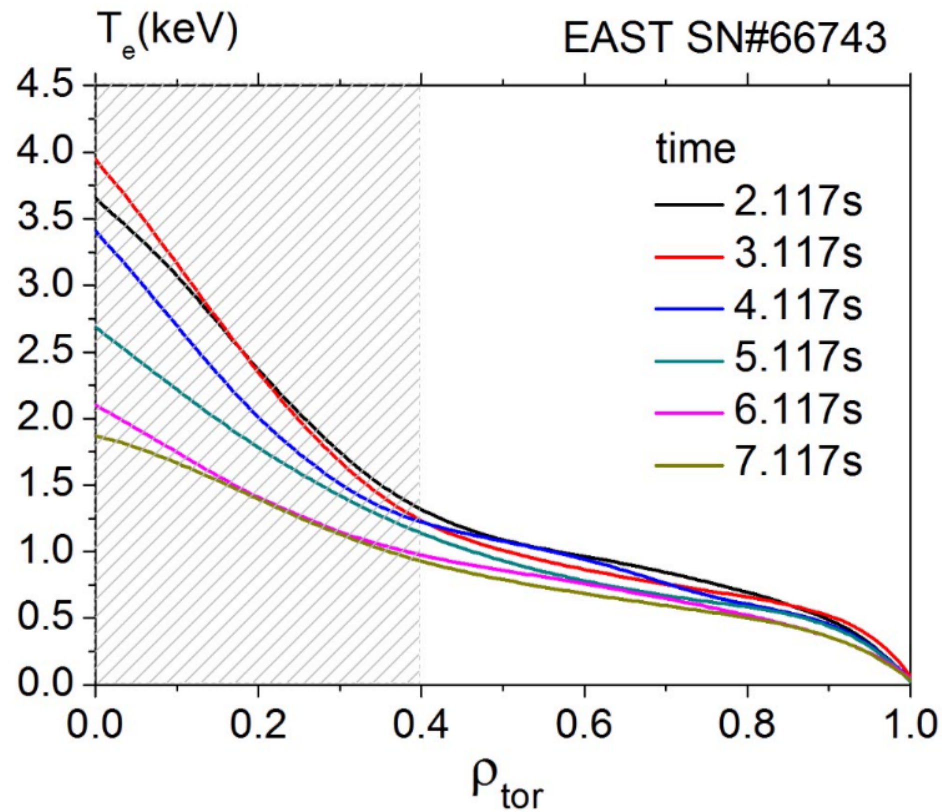
- Before ECW turn off, the plasma has the same features with that of prior high li performance enhancement studies.
  - ✓ **poloidal magnetic field is higher in the core**
  - ✓ **magnetic shear in the outer half of the plasma are larger**.



Electron temperature gradient behavior

- In the near axis region, electron temperature profile have **lower stiffness** and **higher threshold** than that in the region far from the axis.
- That is why **core heating can enhance the plasma performance**.





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Linear Gyrokinetic Simulations Indicate Decreasing Low-k Instability Growth Rate from Large to Small Radii, which Agrees with the Reduced $\chi_{e,eff}$

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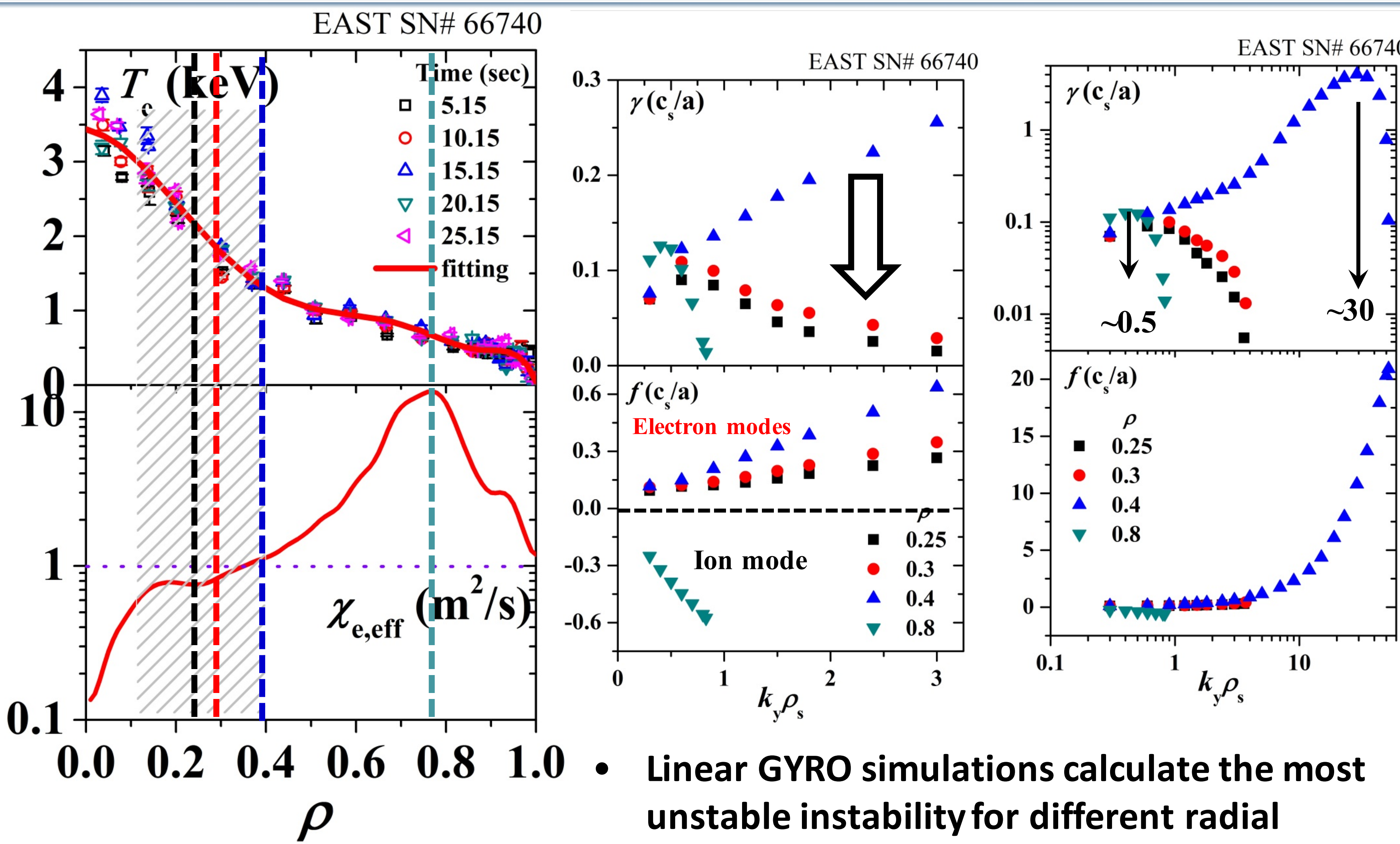

- **Linear GYRO simulations calculate the most unstable instability for different radial positions**

Parametric Dependence Shows the Features of Dominant Modes

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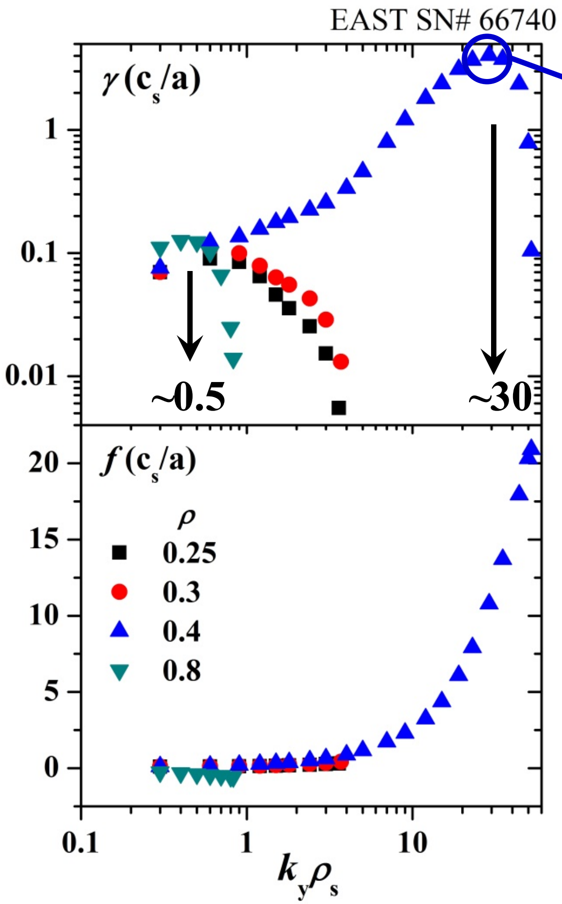

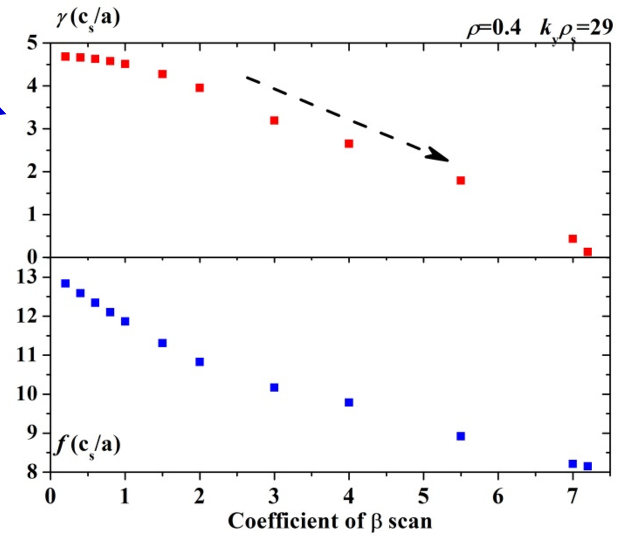

- **Small scale electron mode in core plasma can be stabilized by high β (ETG)**

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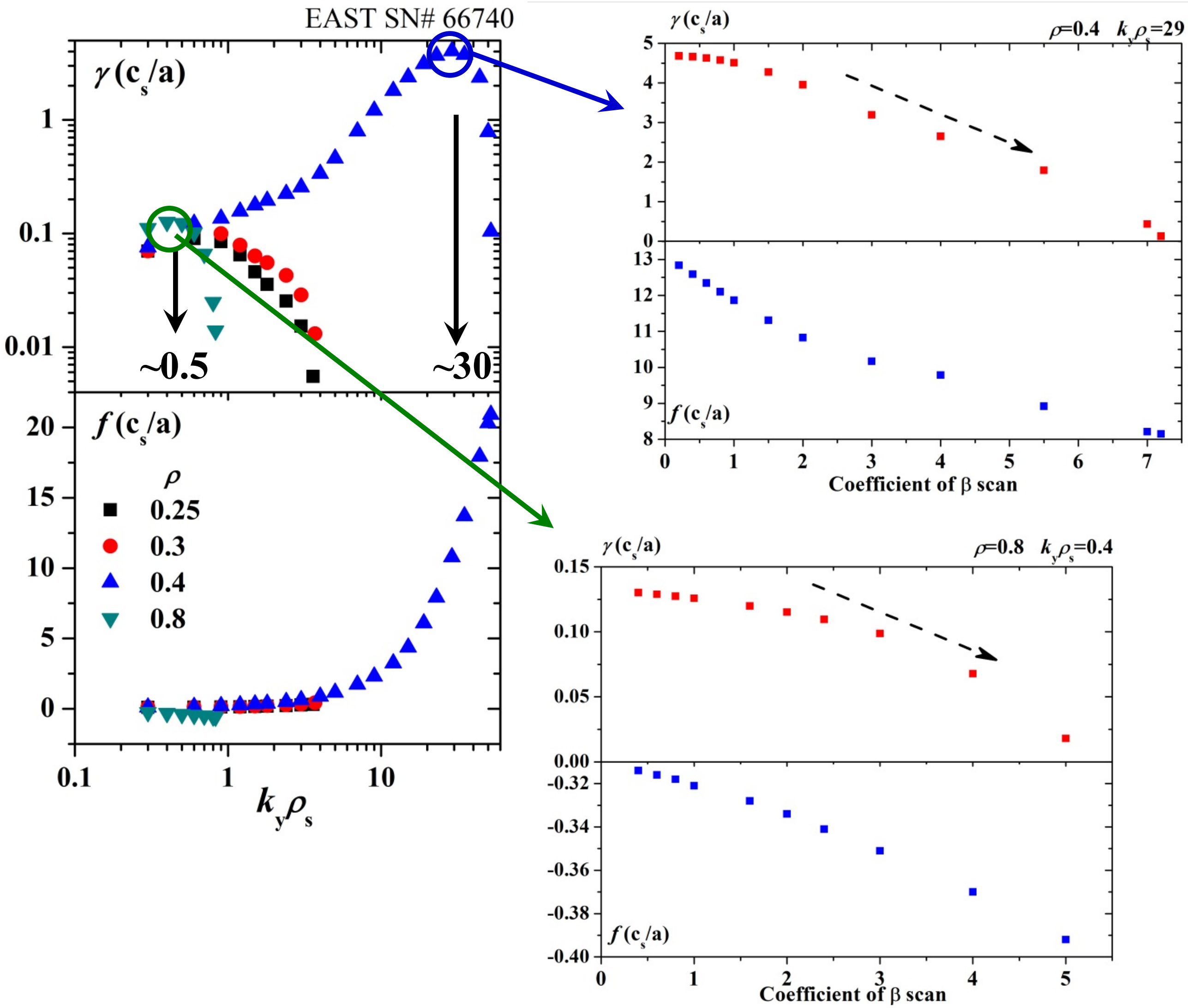

- Small scale electron mode in core plasma can be stabilized by high β (ETG)
- Ion mode near pedestal top can be stabilized by high β (ITG)

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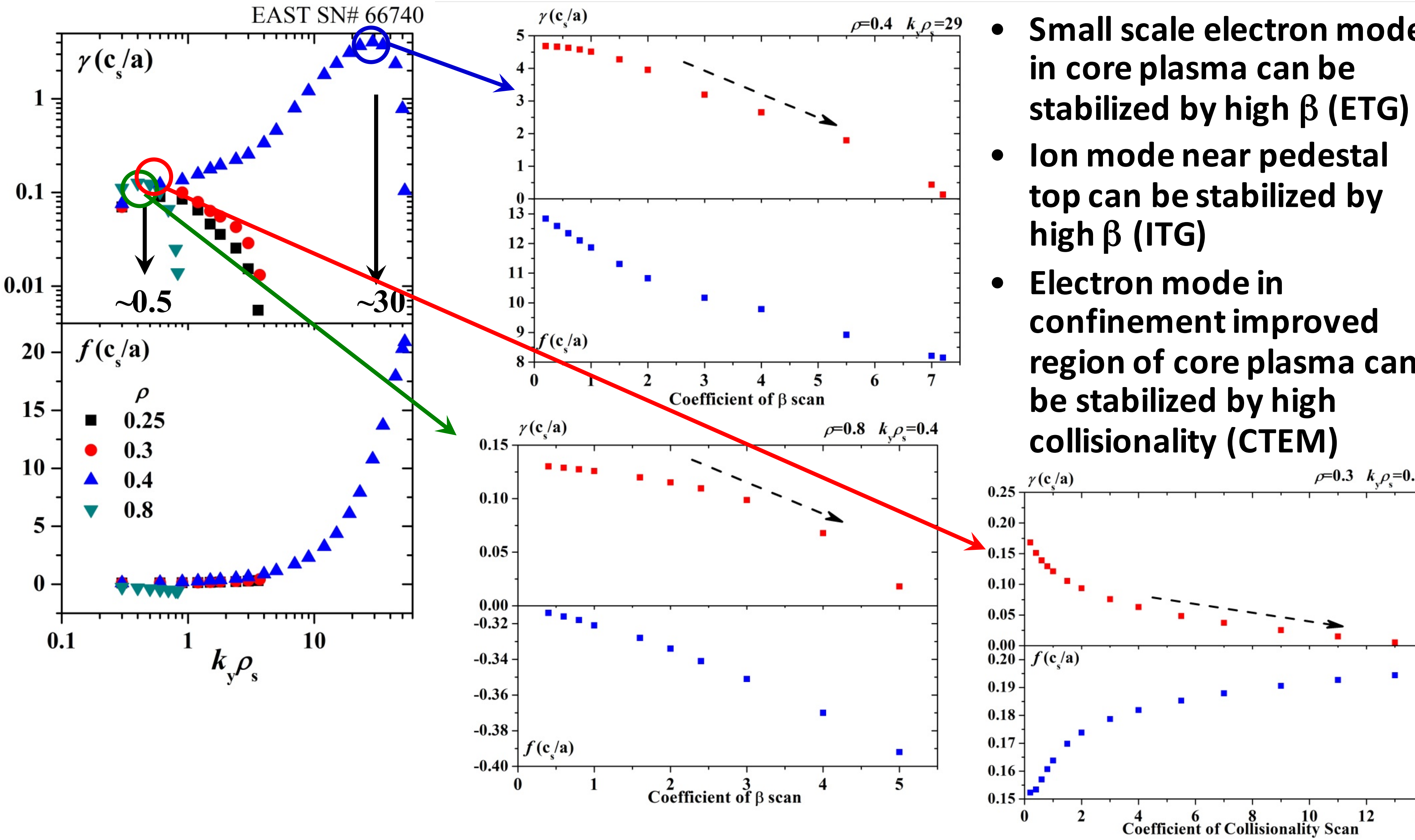

- Small scale electron mode in core plasma can be stabilized by high β (ETG)
- Ion mode near pedestal top can be stabilized by high β (ITG)
- Electron mode in confinement improved region of core plasma can be stabilized by high collisionality (CTEM)

<u>More details can be seen in Dr. Siye Ding's poster B-P2 "Gyrokinetic Simulations on the Optimized Internal Inductance Steady-State Plasmas on EAST", this conference.</u>

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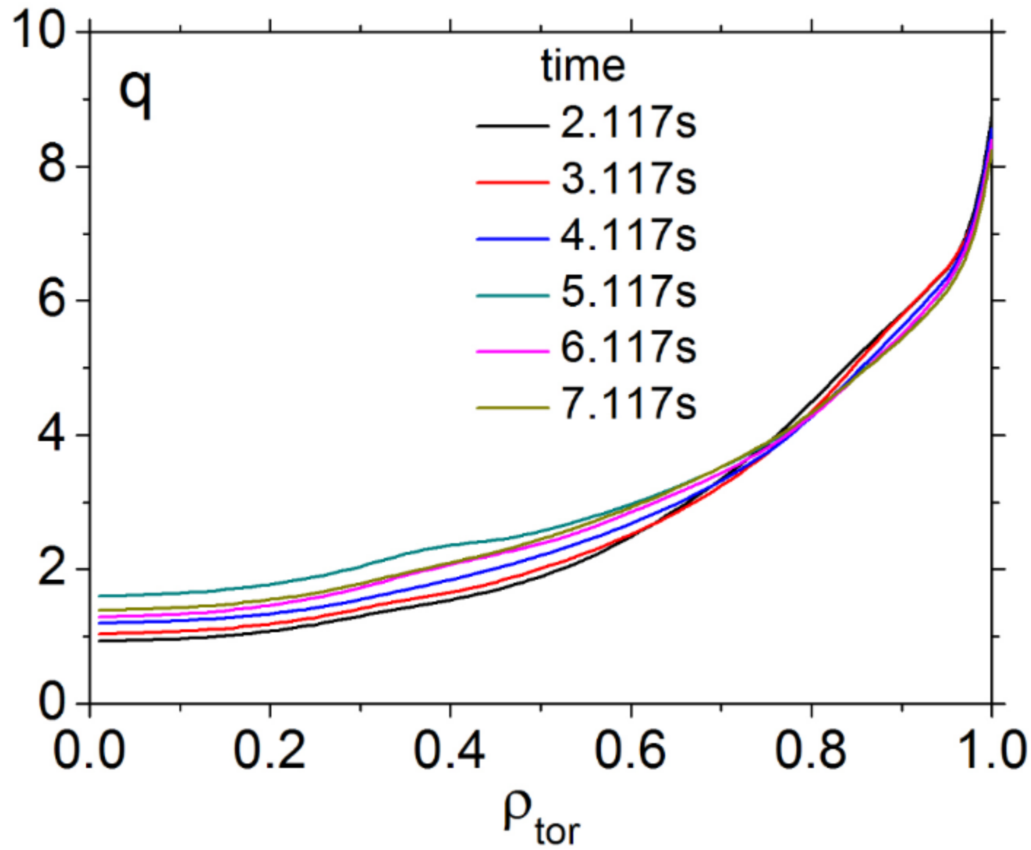
- **When the current density profile is more peaked, the poloidal magnetic field is higher in the core, and the magnetic shear in the outer half of the plasma are larger.**
- **Core ECW heating make LHW deposit more power in near axis region, where electron temperature profile have lower stiffness and higher threshold than that in the region far from the axis, therefore the plasma performance is enhanced.**
- **Gyrokinetic simulations suggest that the most unstable instability is CTEM in the confinement improved region in plasma core.**

Thank you !

Backup slides



q, Magnetic shear
Poloidal magnetic field,
turbulence supression

?

Te profile stiffness and threshold