Third Technical Meeting on Plasma Disruptions and their Mitigation
Saint-Paul-Lez-Durance, France, 3-6 Sept. 2024

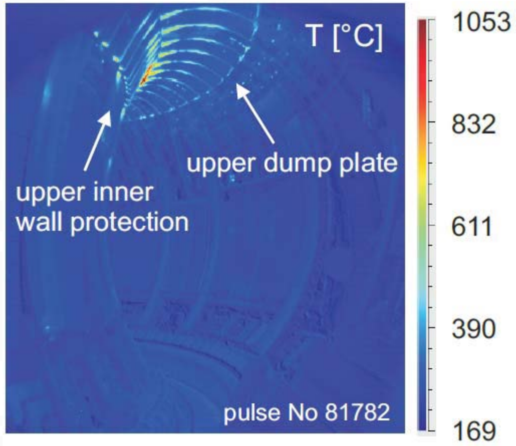
Characteristics of the thermal-quench process in the EAST disruptions and its interpretive MHD modelling with JOREK

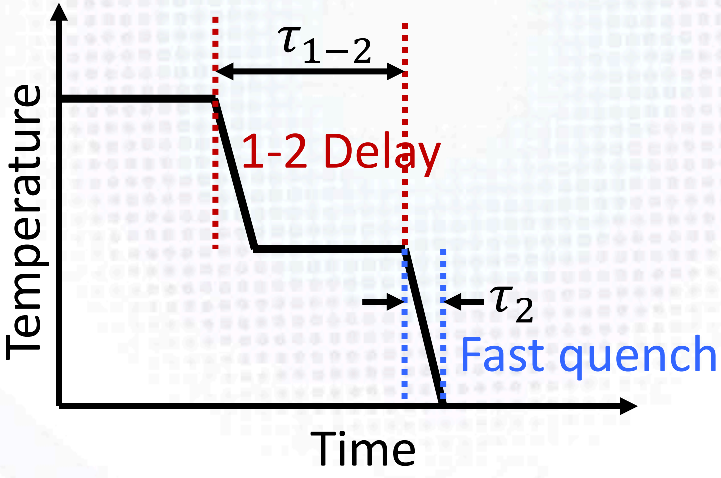
L. Zeng, W. Xia, T. Tang, D. Hu, D. Chen, Y. Duan, L. Xu, X. Zhu, X. Gao, Z. Gao and the JOREK team*

Department of Engineering Physics, Tsinghua University, Beijing 100084, China
Institute of Plasma Physics, Chinese Academy of Sciences, Hefei 230031, China
University of Science and Technology of China, Hefei 230031, China
School of Physics, Beihang University, Beijing 100191, China
Advanced Energy Research Center, Shenzhen University, Shenzhen 518060, China
***See Hoelzl et al 2021 (https://doi.org/10.1088/1741-4326/abf99f) for the JOREK Team**

Thermal quench pose serious threat to PFCs

- **Thermal quench (TQ) process can cause unacceptable heat load on PFCs in ITER.**
  - **The stored thermal energy at TQ**
  - **The duration of TQ**

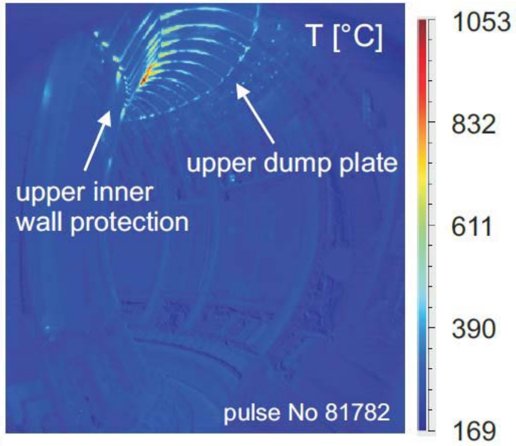




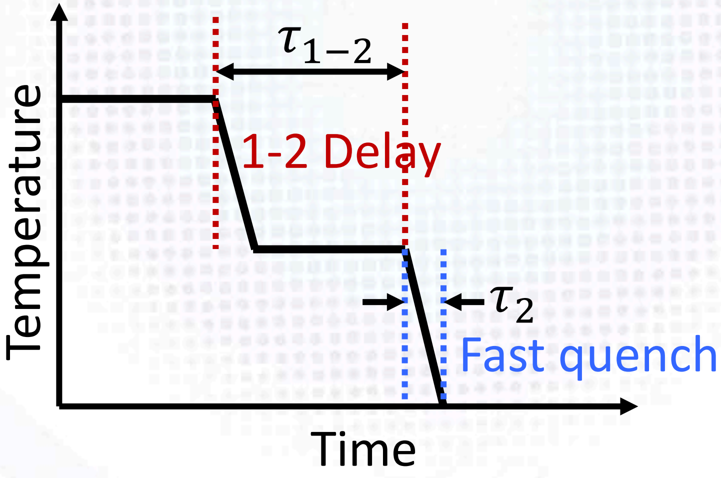
S. Jachmich, IIS(2017)

Thermal quench pose serious threat to PFCs

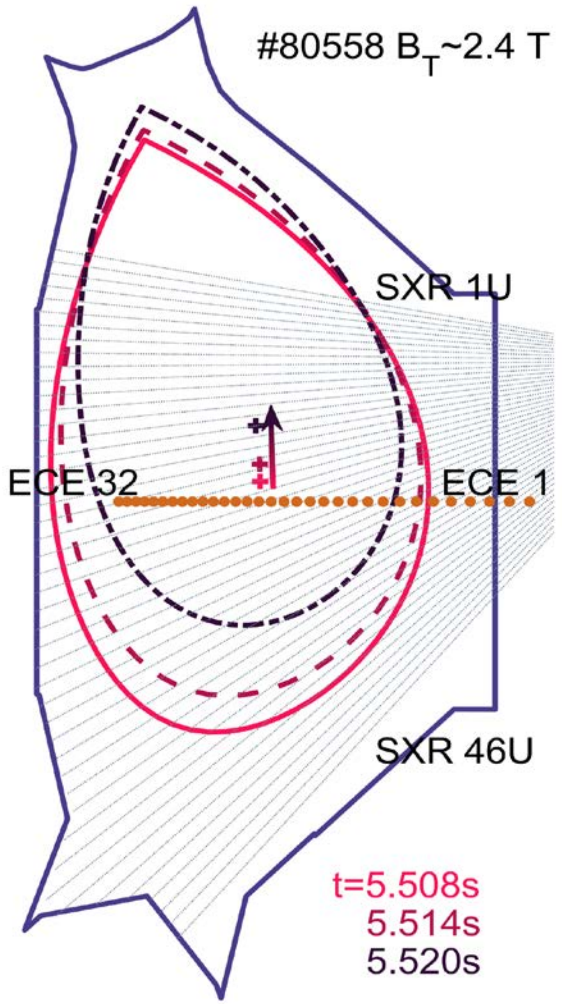
- **Thermal quench (TQ) process can cause unacceptable heat load on PFCs in ITER.**
  - **The stored thermal energy at TQ**
  - **The duration of TQ**



- **Talk presents results for the:**
  - **Timescale of the TQ process in EAST**
  - **The interpretive MHD modelling with JOREK**



Experimental Setup



Plasma configuration fitted by PEFIT

ECE: measure electron temperature

— spatial resolution ~1.0cm
— temporal resolution ~2.5μs

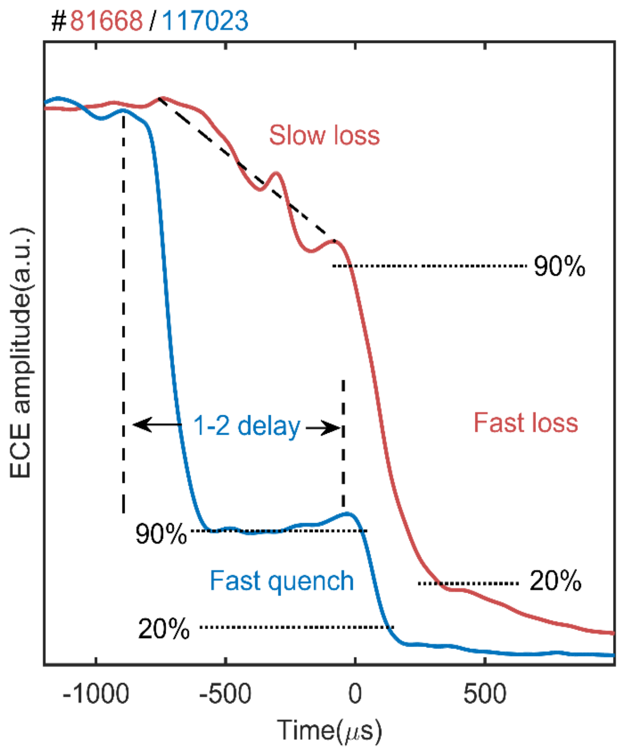
SXR: serving as an assisted measurement

Difficulties:

- For hot VDEs, TQ duration can't be measured accurately
- For ECE, plasma may **not be optically thick**; **non-Maxwellian electrons** driven by LHW during TQ

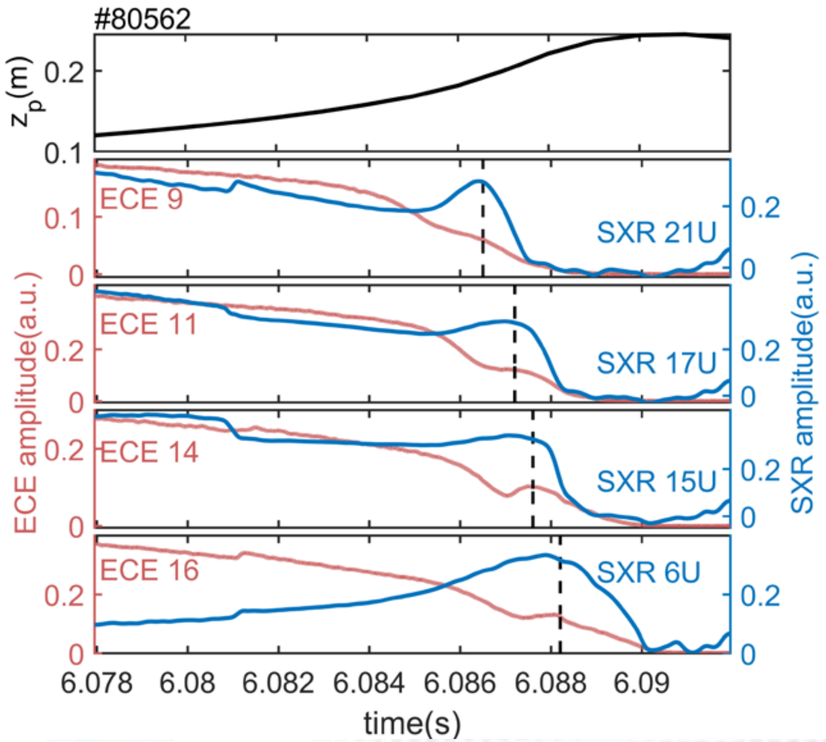
Typical TQ process in the EAST disruptions

MDs:



TQ duration
The time intervals between 90%-20%

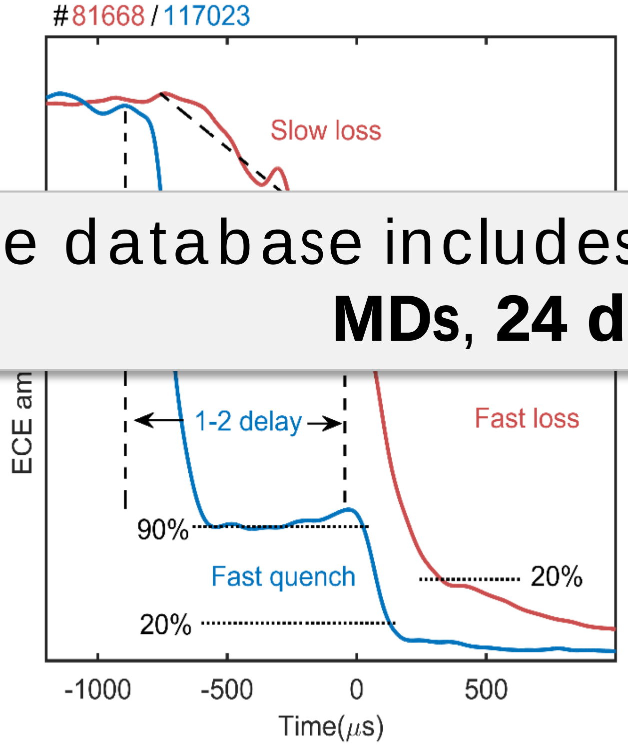
Hot VDEs:



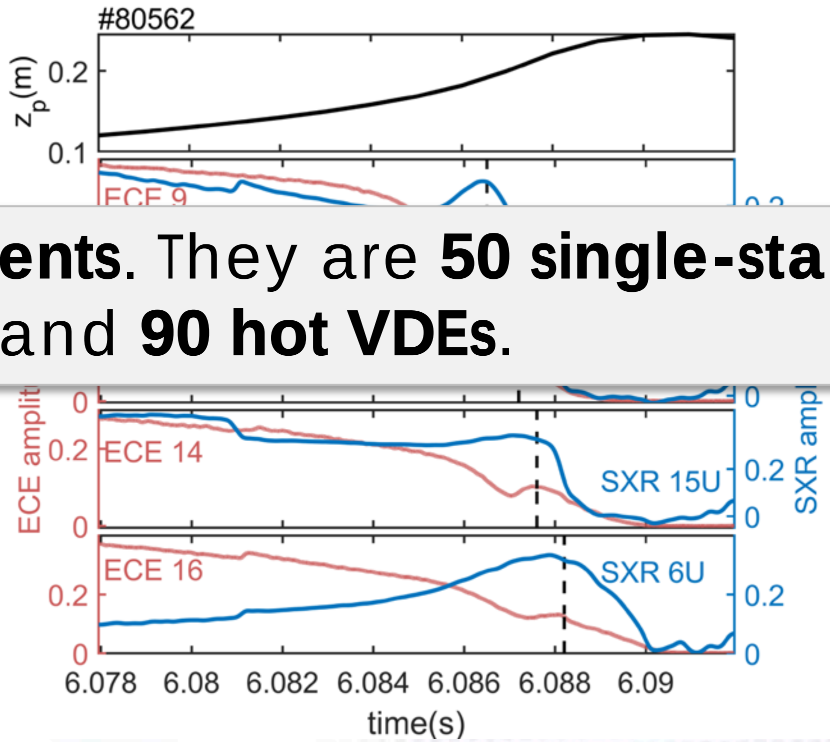
The last spike on ECE signals is believed as **the TQ start** in hot VDEs.

Typical TQ process in the EAST disruptions

MDs:



Hot VDEs:



The database includes **164 typical TQ events**. They are **50 single-stage MDs**, **24 double-stage MDs**, and **90 hot VDEs**.

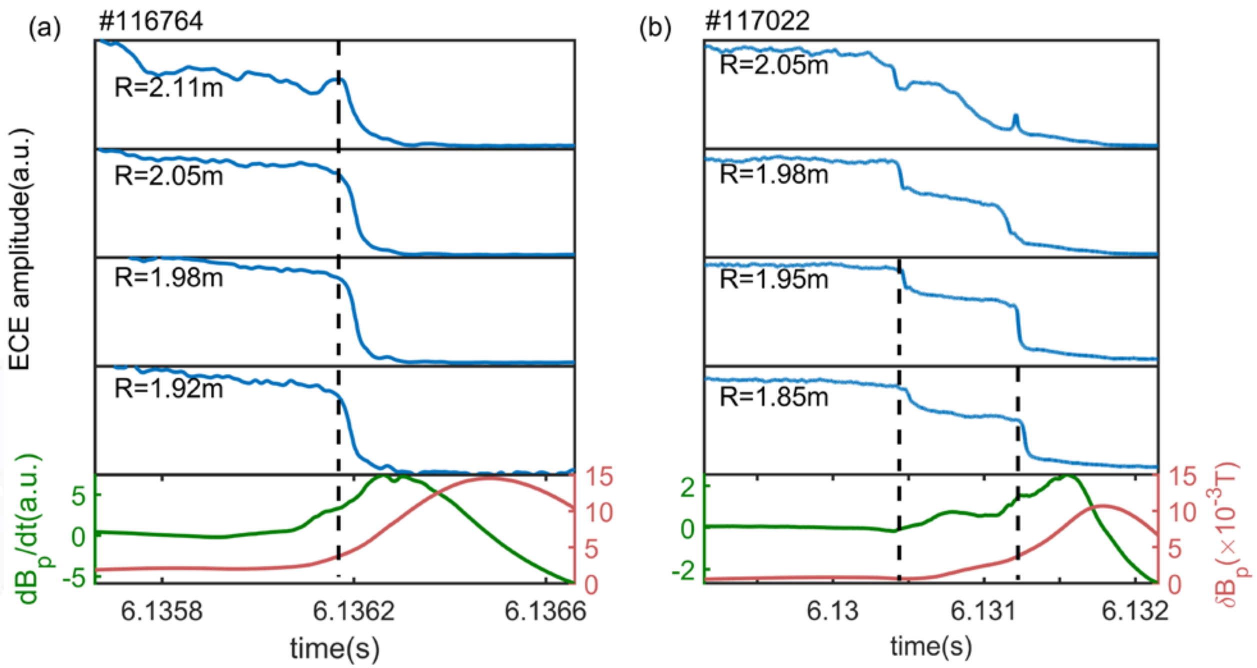
TQ duration

The time intervals between 90%-20%

The latest spike on ECE signals is believed as **the TQ start** in hot VDEs.

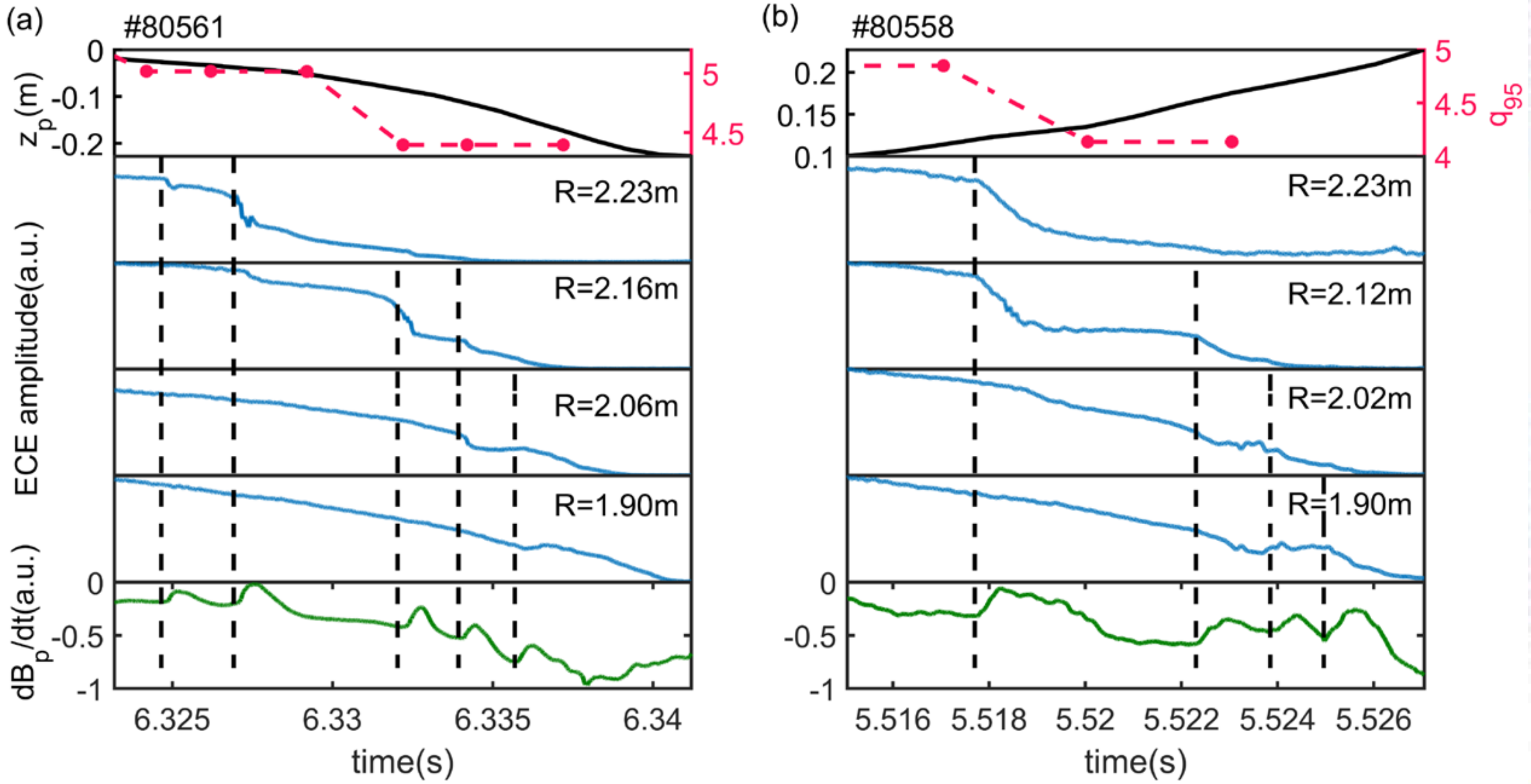
Characteristics of TQ in MDs

- **Single-stage TQ**
  - The temperature collapses simultaneously across the radial position
  - At the onset of temperature collapse, the n=1 **δB_p** reaches **4.3×10^{-3} T**
  - The **growth rate** of magnetic perturbation is **$1.5\times10^{-2}\mu s^{-1}$**
- **Double-stage TQ**
  - Two temperature collapses corresponding to two fast heat transport events.
  - **δB_p ~3.6×10^{-3}T**
  - **γ ~$5.3\times10^{-3}\mu s^{-1}$**



TQ evolutions in hot VDEs

- Electron temperature collapses **step by step from the edge to the core**.
- A slight burst in magnetic perturbation corresponds to each collapse event.
- The growth rates γ in VDEs ≲ γ in double-stage TQ.

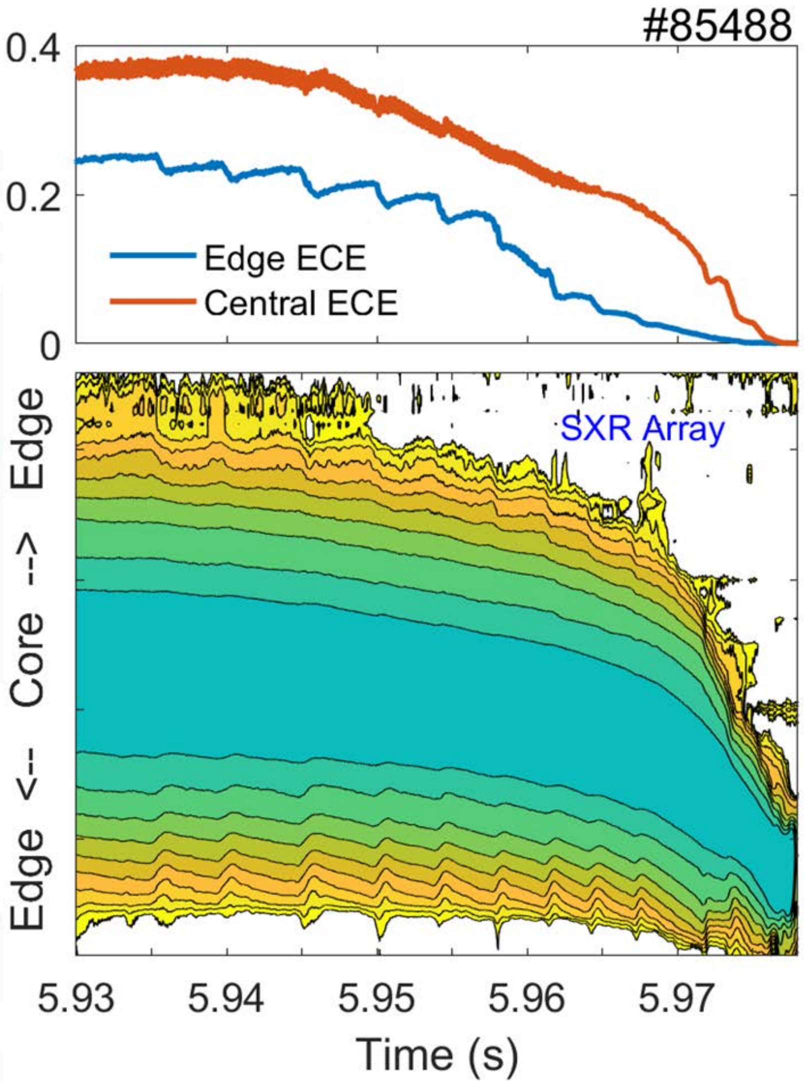


TQ evolutions in hot VDEs

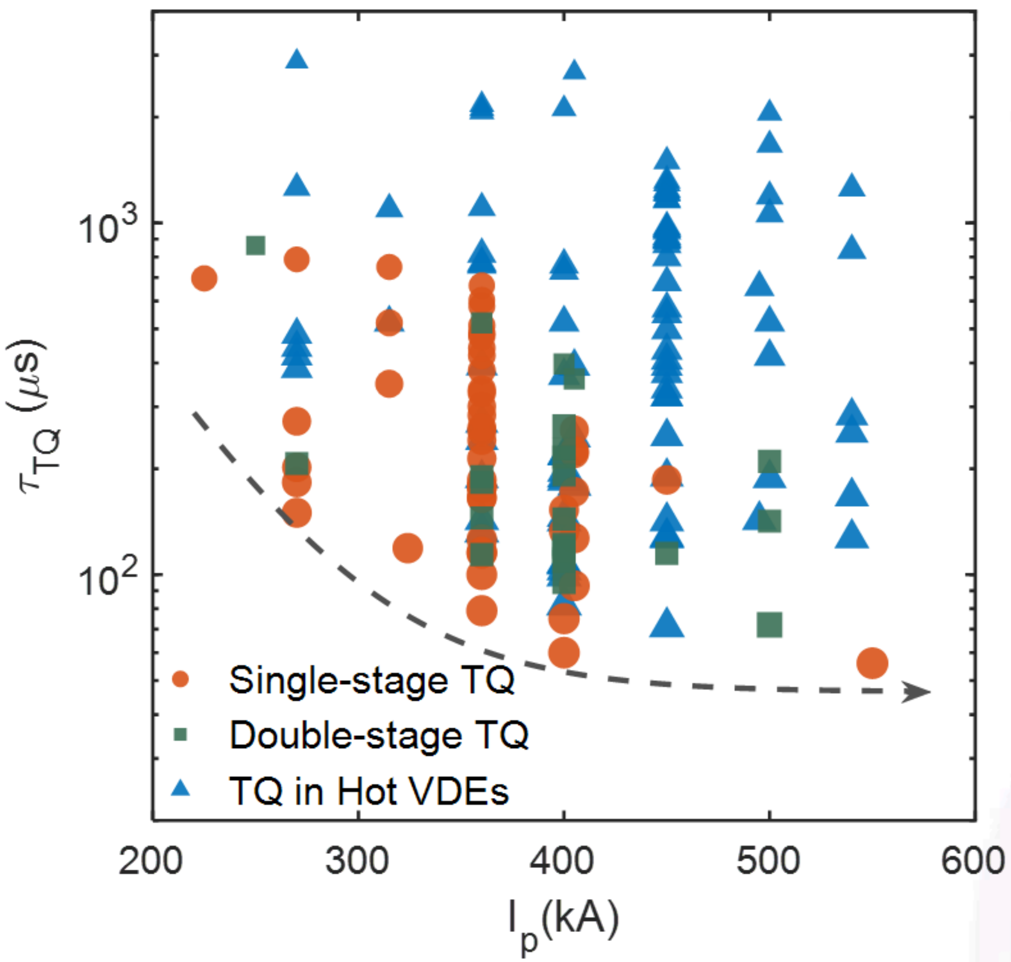
- Collapses in the amplitudes of the ECE signals appear at **different radial locations and time**, which is confirmed from the SXR arrays.

These cooling processes are closely linked **to some MHD activities**.

The evolution of q profile can affect original MHD activities.



TQ duration vs plasma current



- The lower bound of the duration of TQ decreases significantly and robustly with the plasma current increasing.
  - *At Ip = 550 kA,* ***the duration reaches a minimum value, with*** $\boldsymbol{\tau_{TQ}}$ ***= 56 μs****.*
  - *The TQ duration of the hot VDEs range from ~0.1 to ~3 ms , which is slightly longer than MDs.*

The dependance on temperature

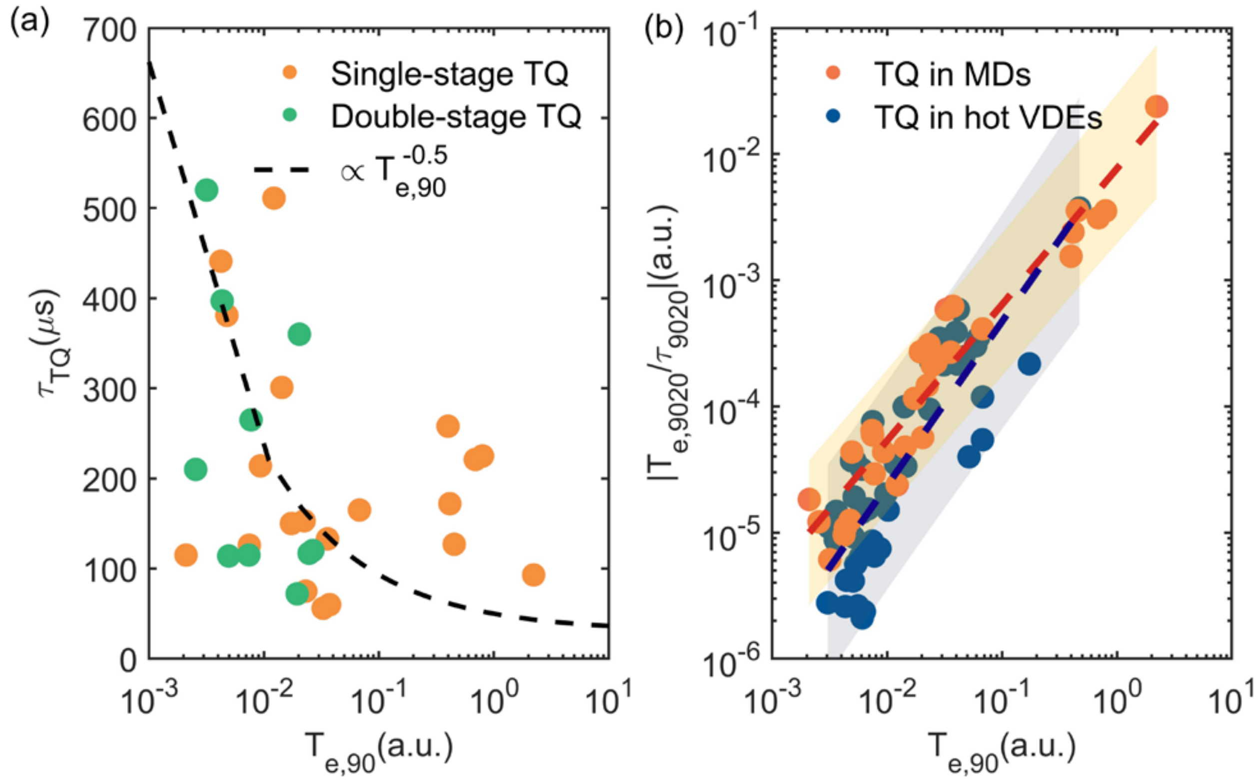
Operated at B_T=2.4T

- A large range at the low temperature and small TQ durations at high temperature, not fully consistent with $T_e^{-0.5}$.

MDs: $\left|\frac{T_{e,9020}}{\tau_{9020}}\right| = 10^{-2.12} T_{e,90}^{\ 1.08}$ **$\tau_{TQ} \propto T_e^{-0.08}$**

Hot VDEs: $\left|\frac{T_{e,9020}}{\tau_{9020}}\right| = 10^{-2.03} T_{e,90}^{\ 1.30}$ **$\tau_{TQ} \propto T_e^{-0.30}$**

Simplified TQ duration **$\tau_{TQ} \propto T_e^{-0.5}$**
(the heat conduction equation in free-streaming regime)

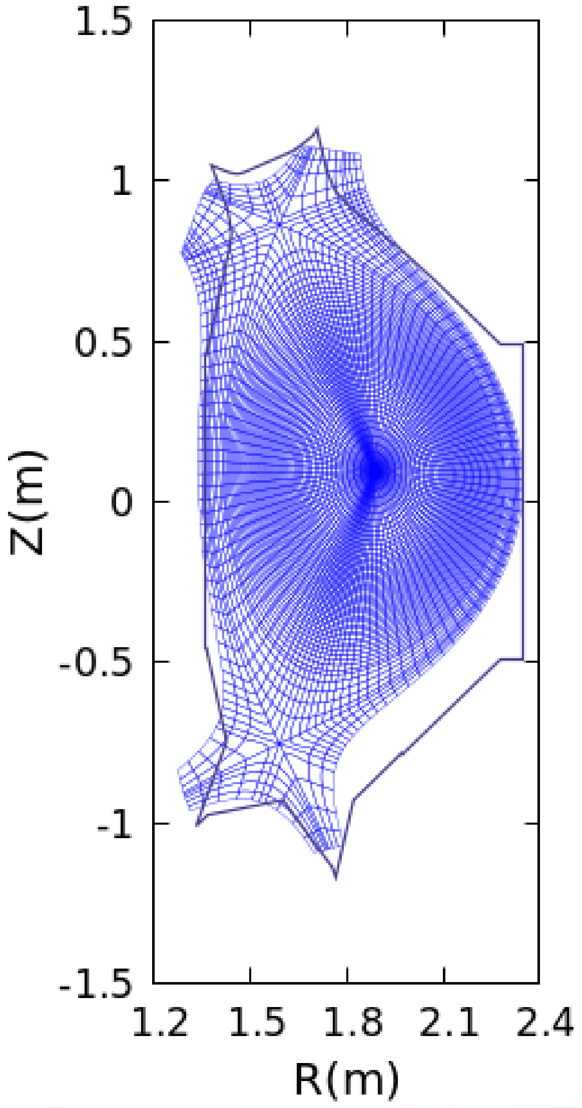


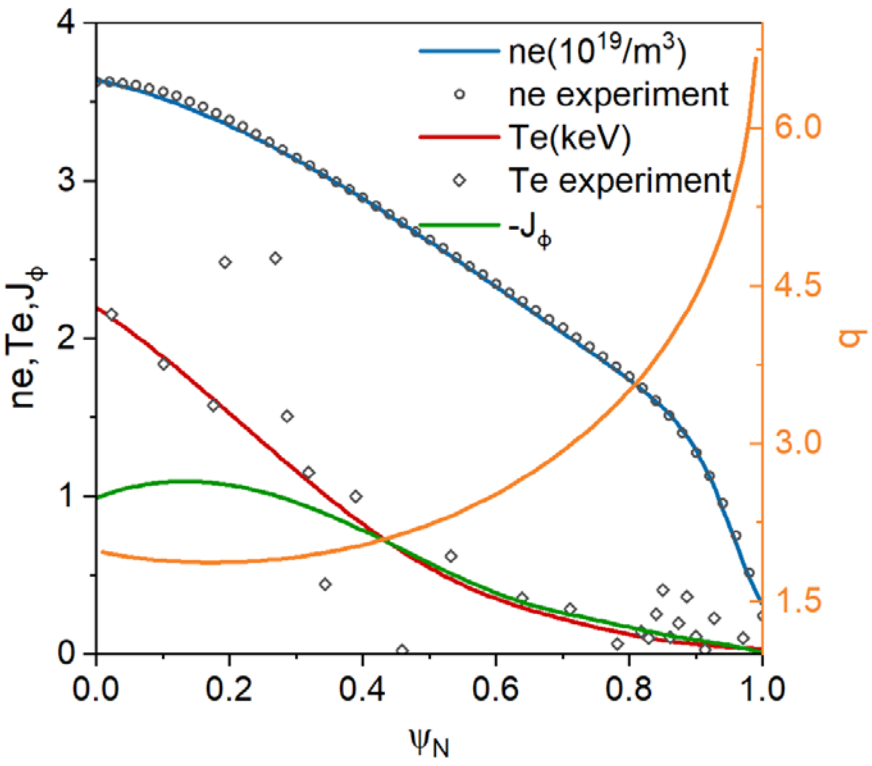
W. Xia, PPCF(2023)

Simulation setup by JOREK

The JOREK non-linear extended MHD code

- A reduced MHD model (model 307) with single-fluid extensions,
- An treatment for collisional-radiative non-equilibrium impurity particles and the model for MGI

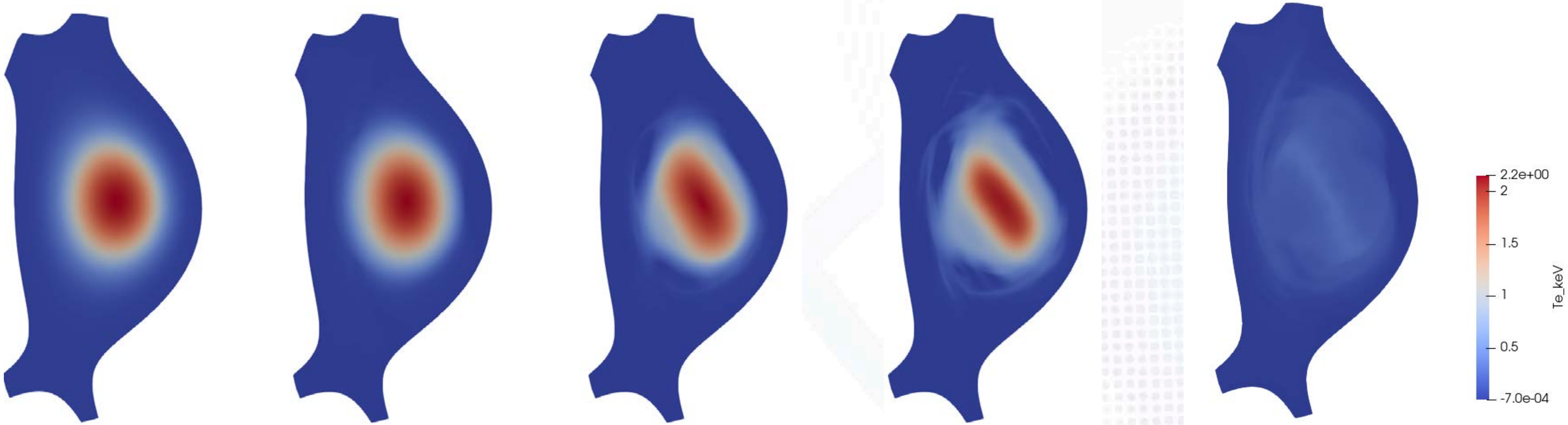




- Simulation setup: A typical L-mode plasma with $I_P \sim 0.4$ MA and $\mathbf{q_{min}}$ **~ 1.6 in the core.**
  - *The initial core T_e is ~2.2 keV, electron and ion temperatures are assumed to be equal, and the core n_e is ~3.6×10^{19} m^{-3}.*
  - *MGI triggered*

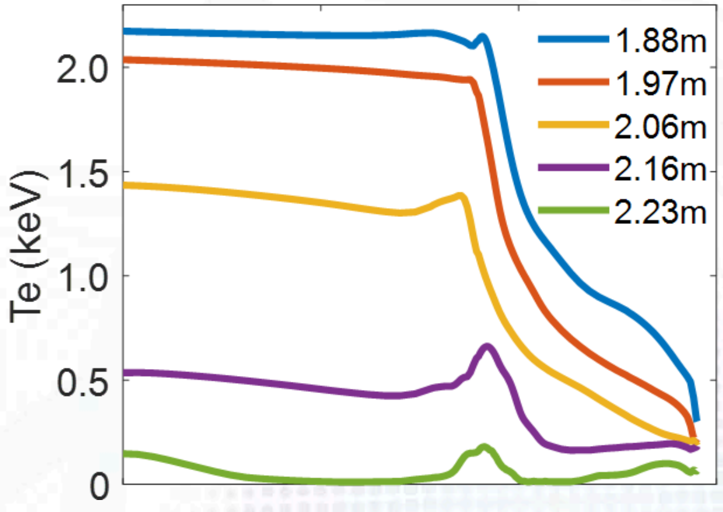
Te evolution during TQ process

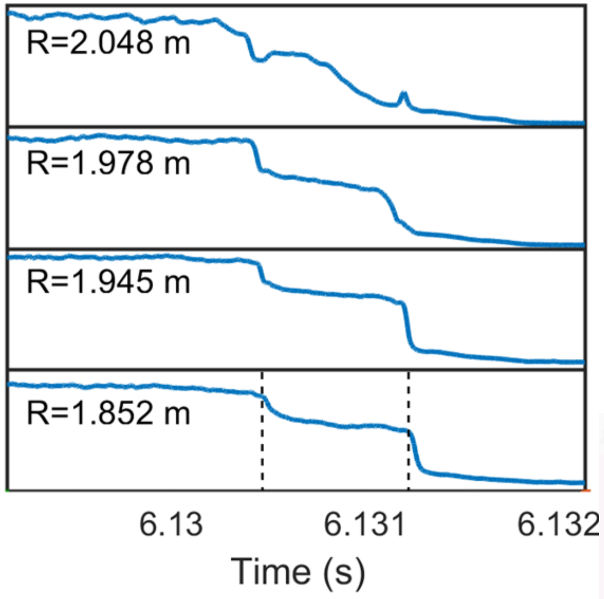
Edge cooling → **Poloidal rotation** → **Island Increase** → **Stochasticity**

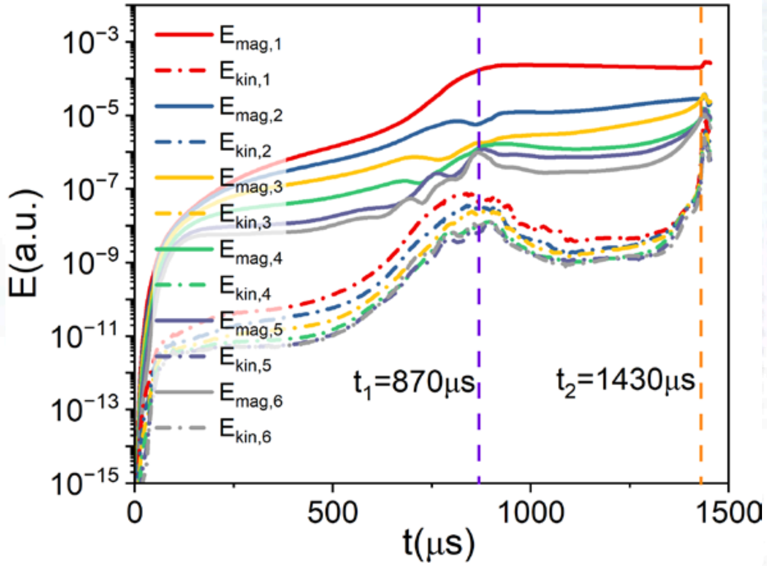


Te evolution during TQ process

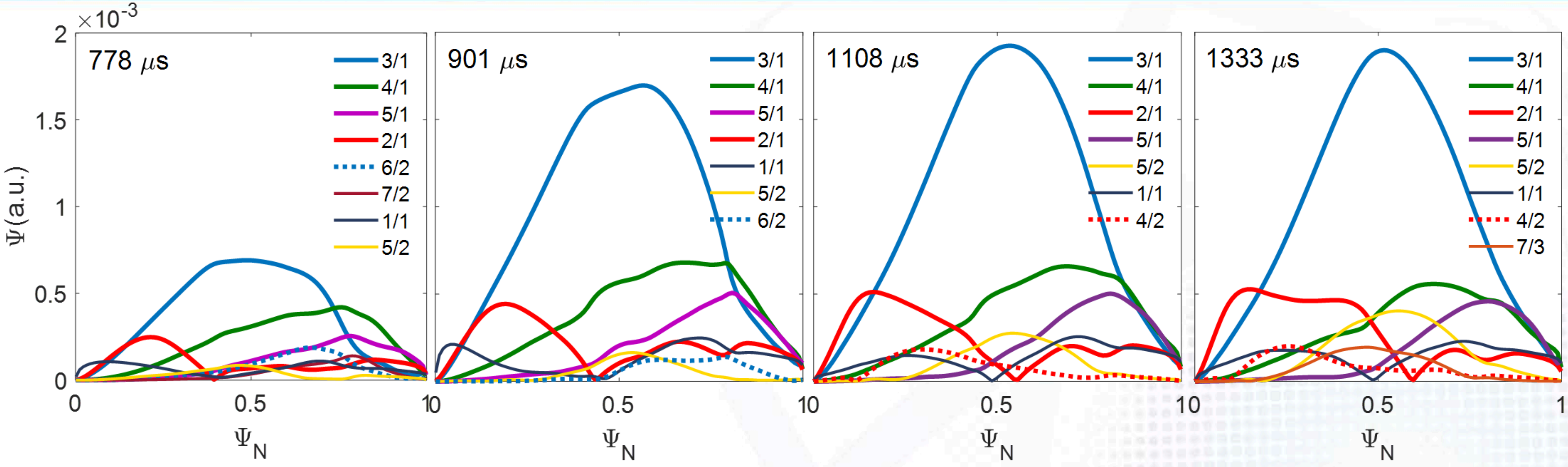
- The process of a double-stage TQ has been represented with neon MGI, consistent with the experimental observation.







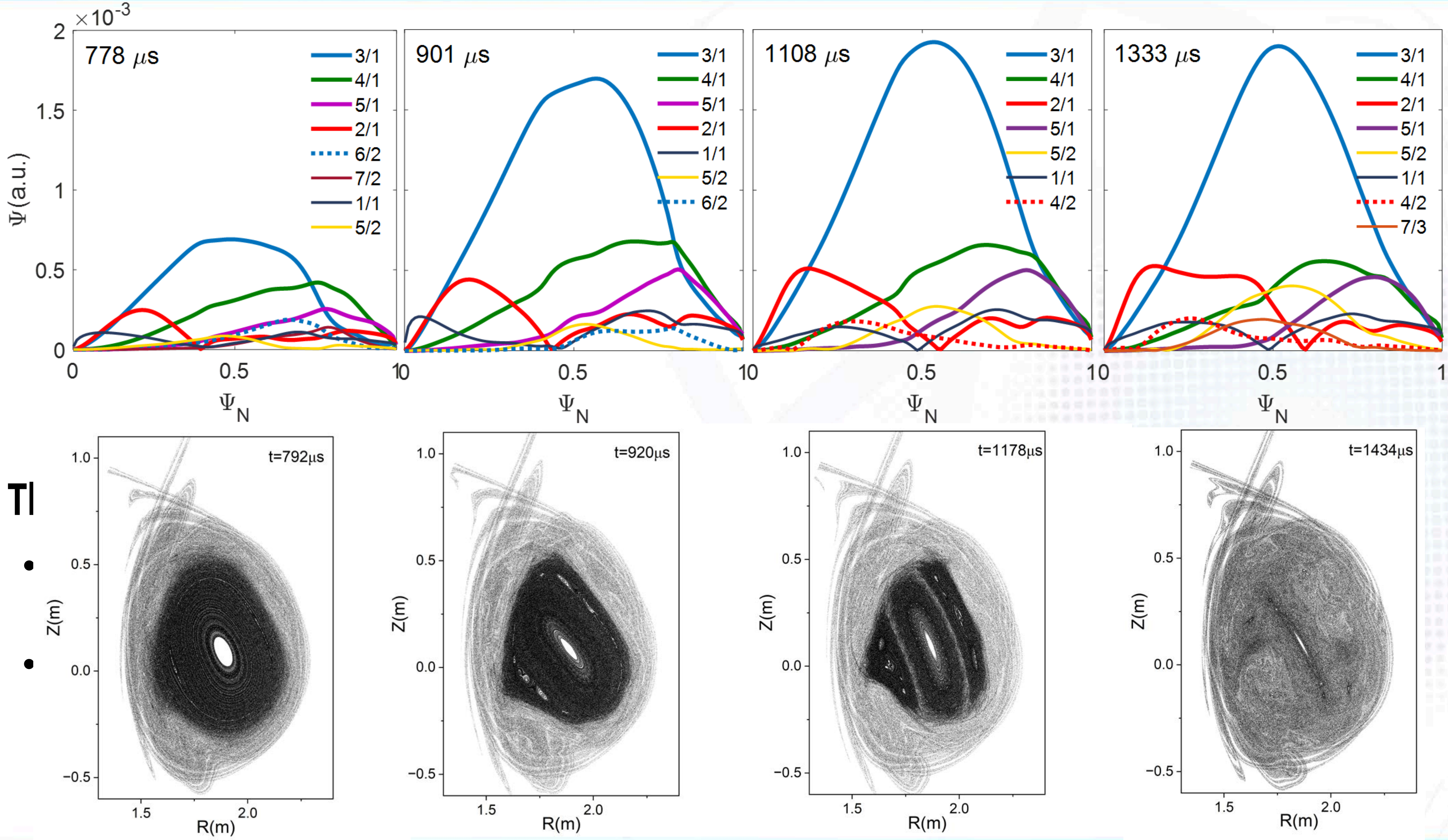
MHD evolution during TQ process



➢ **The 3/1 mode is dominant** in the whole collapse process.

- ***First collapse*** *is from the outer region (q>2) and the coupling between 3/1 and 4/1 is the main reason.*
- ***Second collapse****: The coupling among 2/1, 3/1 and higher harmonic mode 4/2 is dominant in the final collapse.*

MHD evolution during TQ process

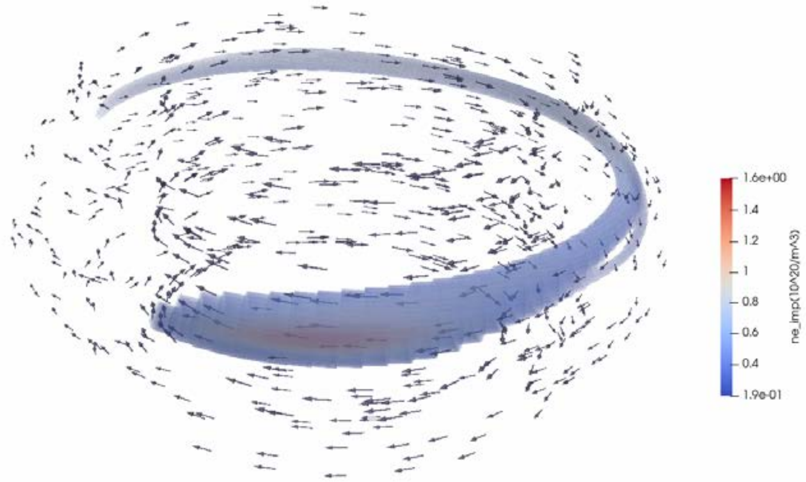


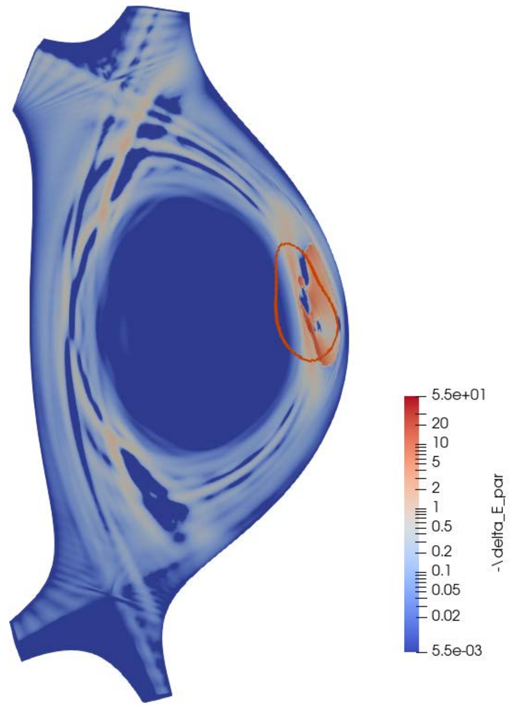
- Tl
  -
  -

Impurity evolution during TQ process

- The neutral impurity particles move inward along minor radius due to the initial injection velocity, and eventually stopping near the plasma edge.

- The ionized particles drift non-axisymmetrically in both the toroidal and poloidal directions.
  - Toroidal: The ionized particles move along the Ip direction
  - Poloidal: The ionized particles extend counterclockwise

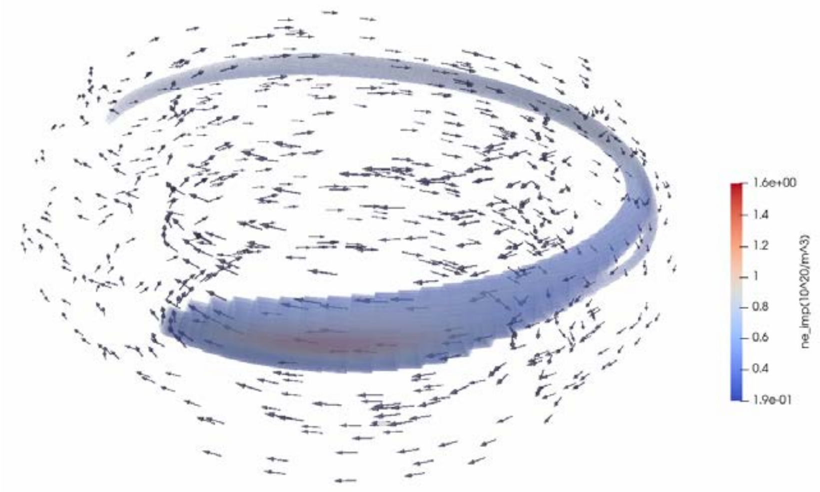


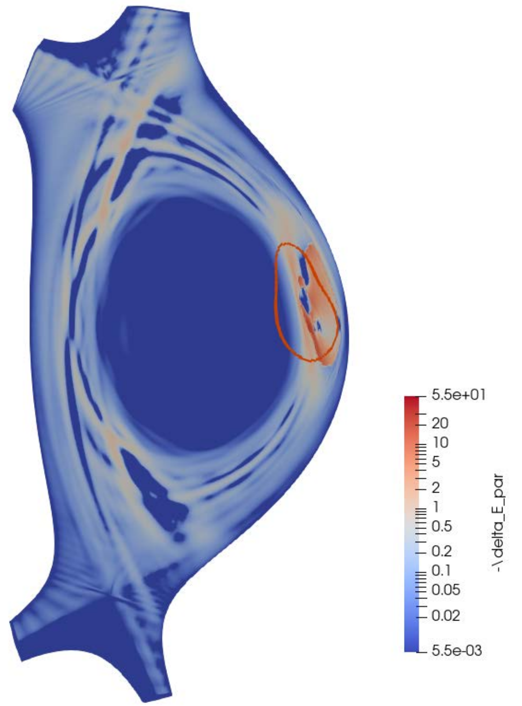


Impurity evolution during TQ process

- The neutral impurity particles move inward along minor radius due to the initial injection velocity, and eventually stopping near the plasma edge.

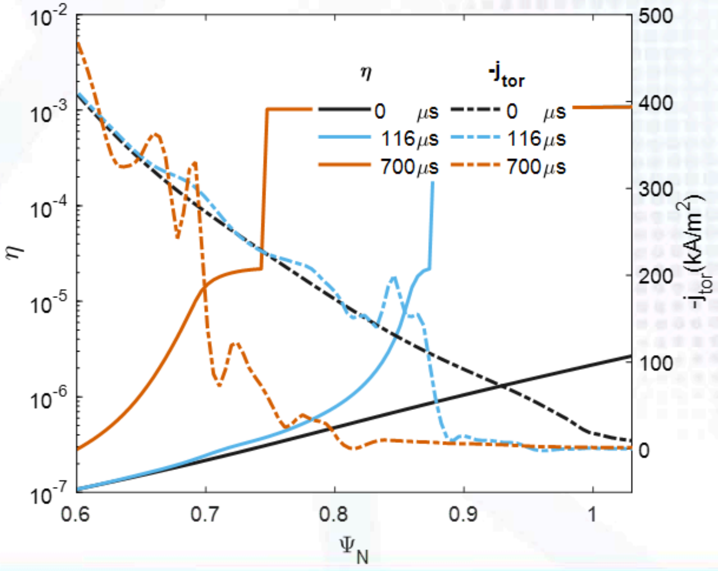
- The current distribution become more peak according to the inward movement of particles.
  - The resistivity increase rapidly in a short moment.

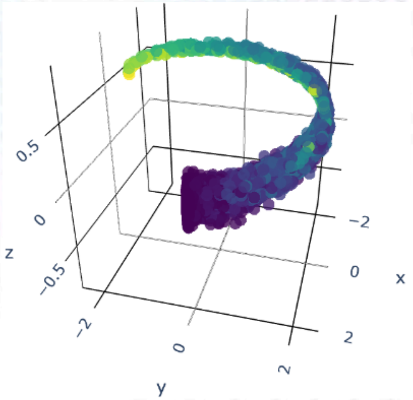




Current relaxation time > resistivity increase time

$$E_{||} = \eta(T_e, Z_{eff}) j_{tor}$$

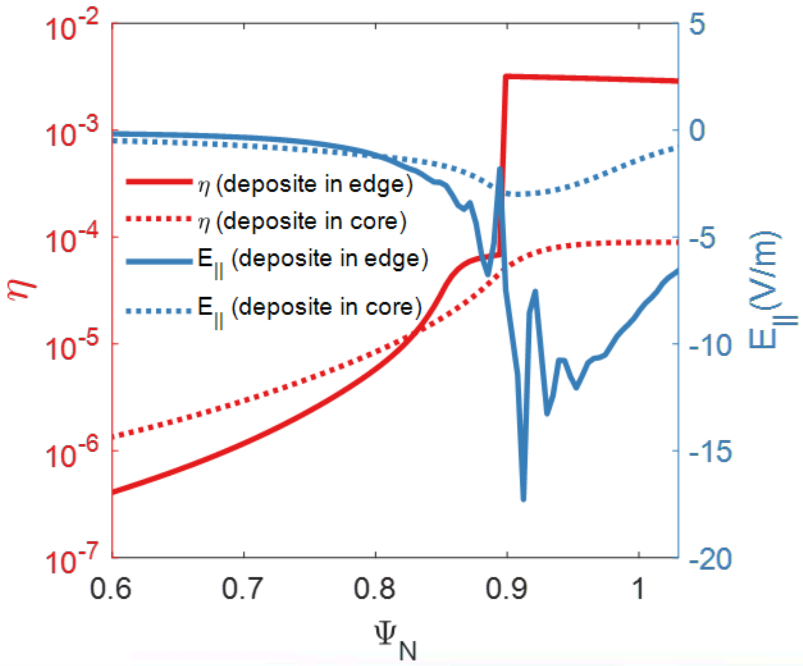


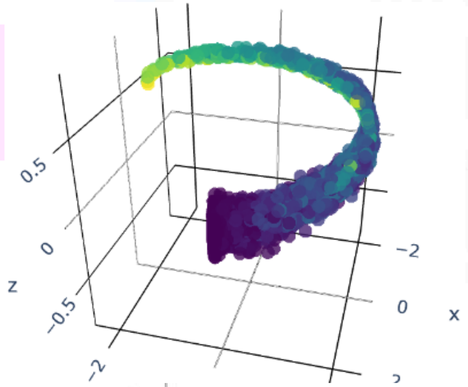


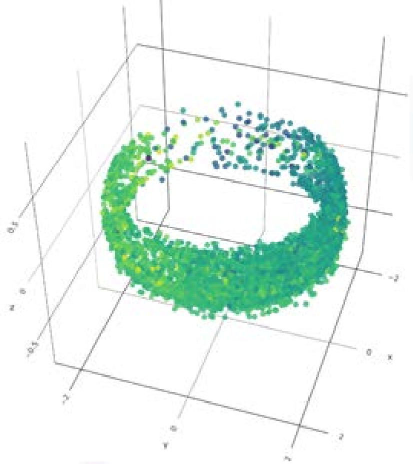
Toroidal electrical-field evolution during TQ process

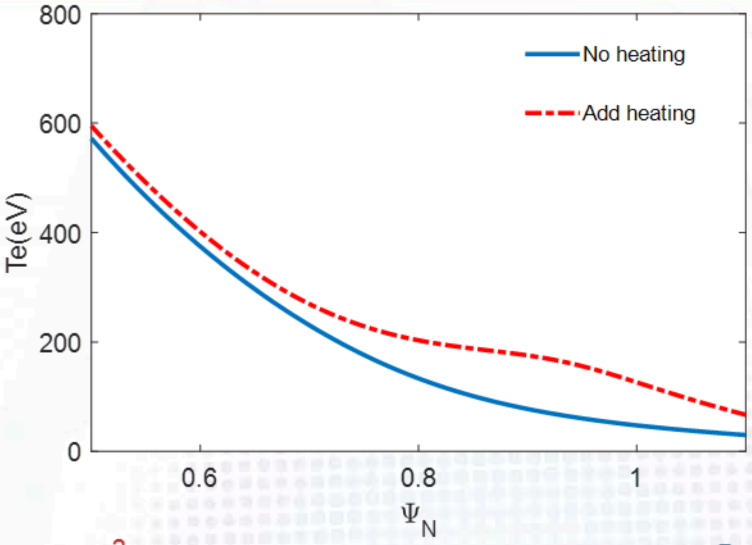
- Two numerical experiment tested
  - **Change the deposition position** of the impurities
  - **Increase the edge temperature**

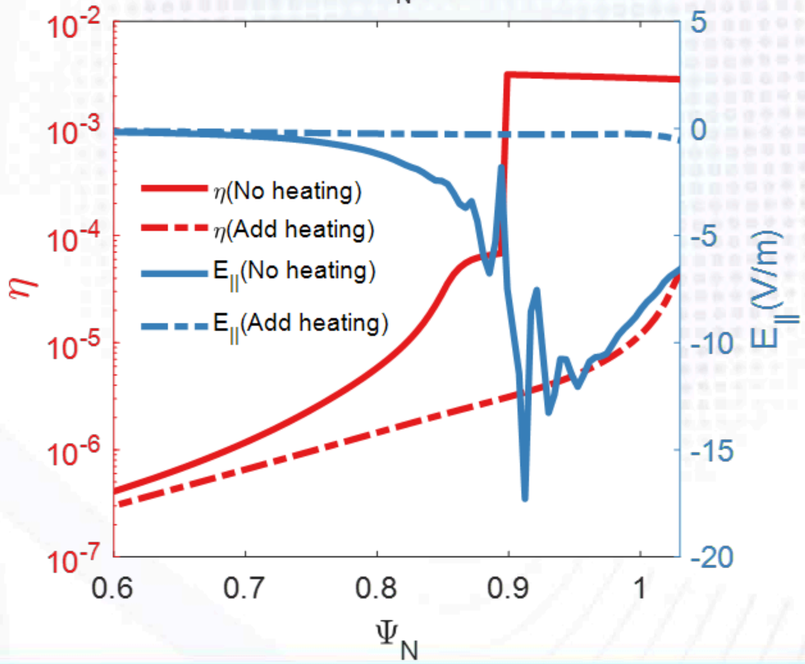
Toroidal electric field decreased and also the asymmetrical distribution





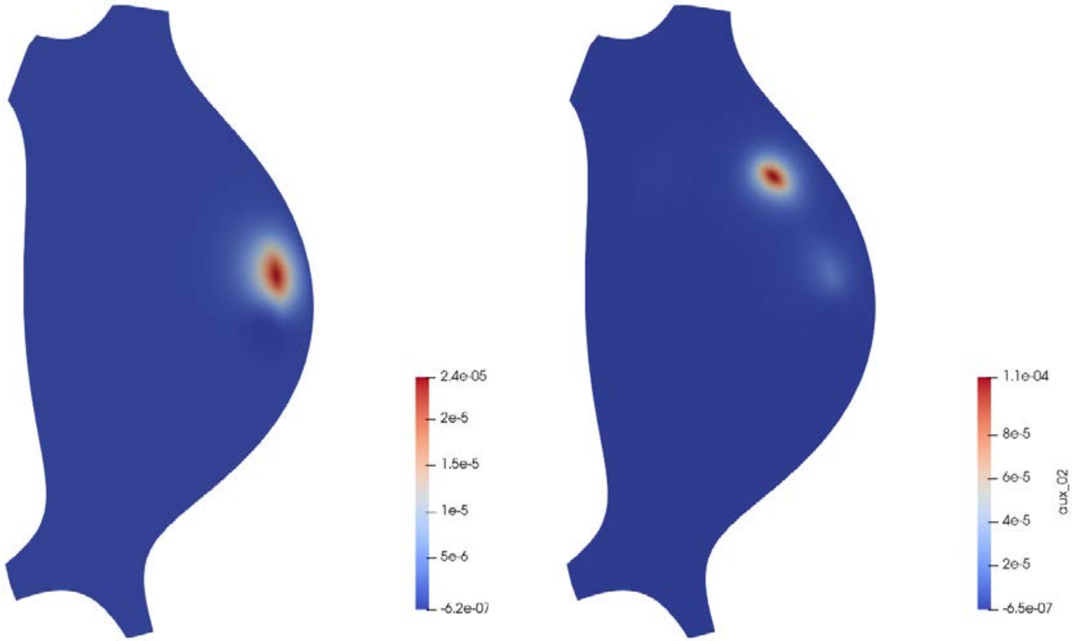






Impurity evolution during TQ process

- **The obvious poloidal rotation of impurity** is found in the radiation density configuration.

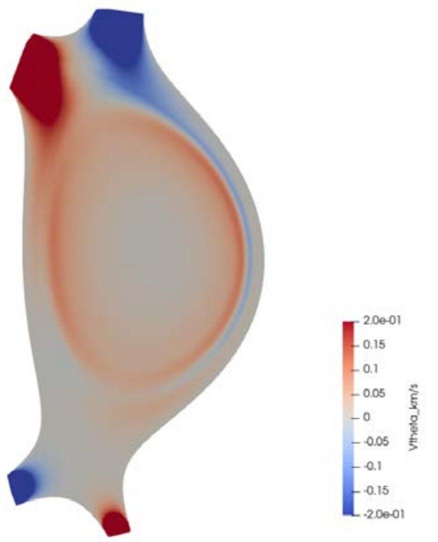


The phenomenon may relate to $E \times B$ **drift**

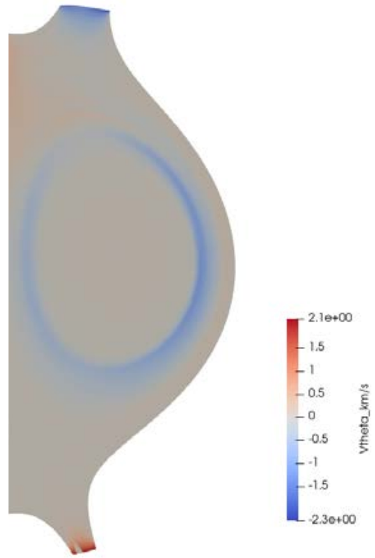
$\propto \nabla_{\perp} T$

Radial electrical-field evolution during TQ process

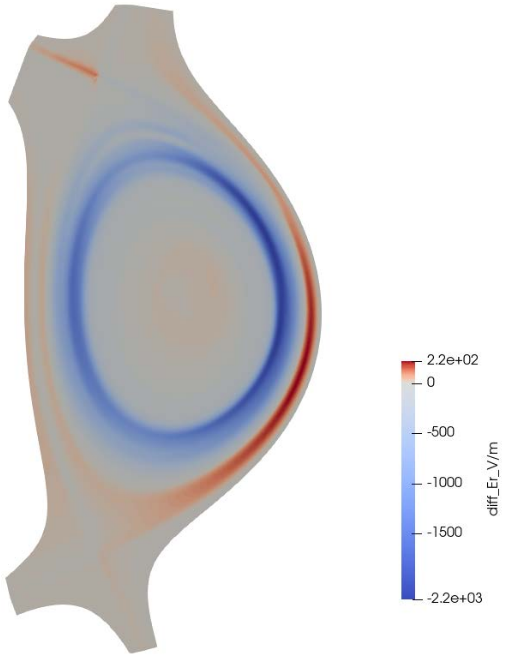
- Before injection: The poloidal velocity is positive and weak. **(~+150m/s)**
- After injection: The poloidal velocity is negative and strong. **(~-1000m/s)**



Before injection

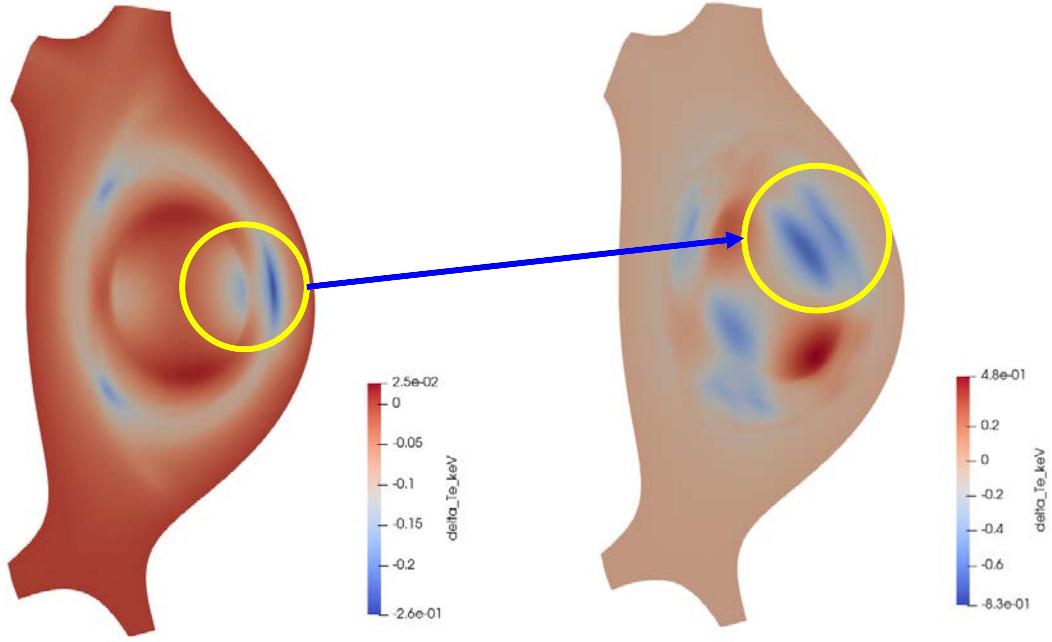


After injection

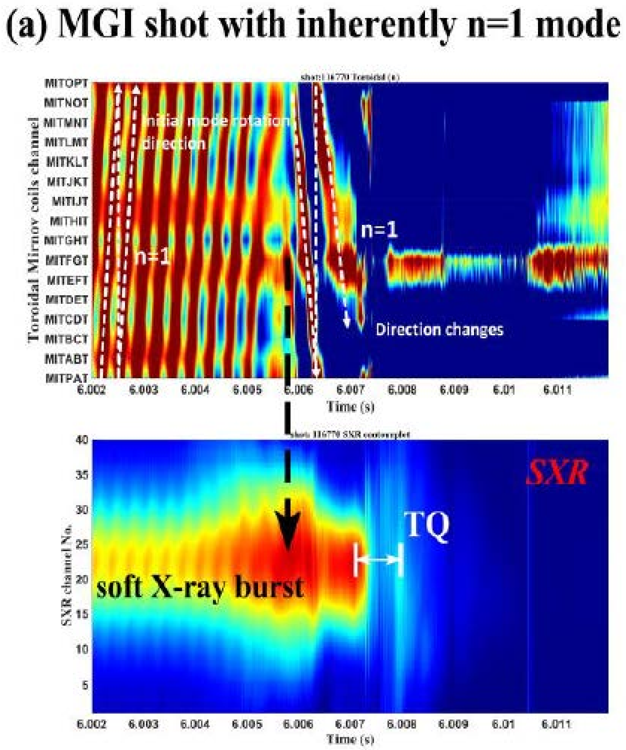


This radial electrical field exhibits a significant reverse increase near the plasma edge, contributing to the reverse poloidal rotation

Impurity evolution during TQ process



rotate 45° ~ 270 μs



S. Zhao, submitted to Nucl. Fusion

- In simulation, the 2/1 island rotation has been observed , which indicate the frequency of probes is **~920 Hz**.
- This result is **qualitatively consistent with the experimental result (~1000 Hz)**.

Summary

- **The detailed description of the TQ database on EAST, including both major disruptions (MDs) and hot vertical displacement events (VDEs), are presented.**
  - The TQ duration of MDs is within 60~800 μs, and the value of VDEs is approximately in the range of 100~3000 μs.

- **First simulations of neon MGI into an EAST L-mode plasma with the JOREK MHD code have been done.**
  - The effect of several parameters, including amounts of injected particles, deposition position and deposition width, on MHD activity and TQ dynamics is studied.
  - The evolution of electric field (toroidal and radial) cause The ionized particles drift asymmetrically.

Summary

- **The detailed description of the TQ database on EAST, including both major disruptions (MDs) and hot vertical displacement events (VDEs), are presented.**
  - The TQ duration of MDs is within 60~800 μs, and the value of VDEs is approximately in the range of 100~3000 μs.

- **First simulations of neon MGI into an EAST L-mode plasma with the JOREK MHD code have been done.**
  - The effect of several parameters, including amounts of injected particles, deposition position and deposition width, on MHD activity and TQ dynamics is studied.
  - The evolution of electric field (toroidal and radial) cause The ionized particles drift asymmetrically.

Thanks!