EUROfusion

Thermal Quench and its diagnostics in JET

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1. WHY IS THE DYNAMIC/DURATION OF THERMAL QUENCH (TQ) IMPORTANT?

- **TQ is the first phase (in general, but not always!) of disruption and is critical to understanding the disruptions.**
- **For ITER and subsequent devices, high thermal loads during short TQ on the PFC should be predicted**.

2. TQ DIAGNOSTICS ON JET: MAGNETICS, ECE and SXR

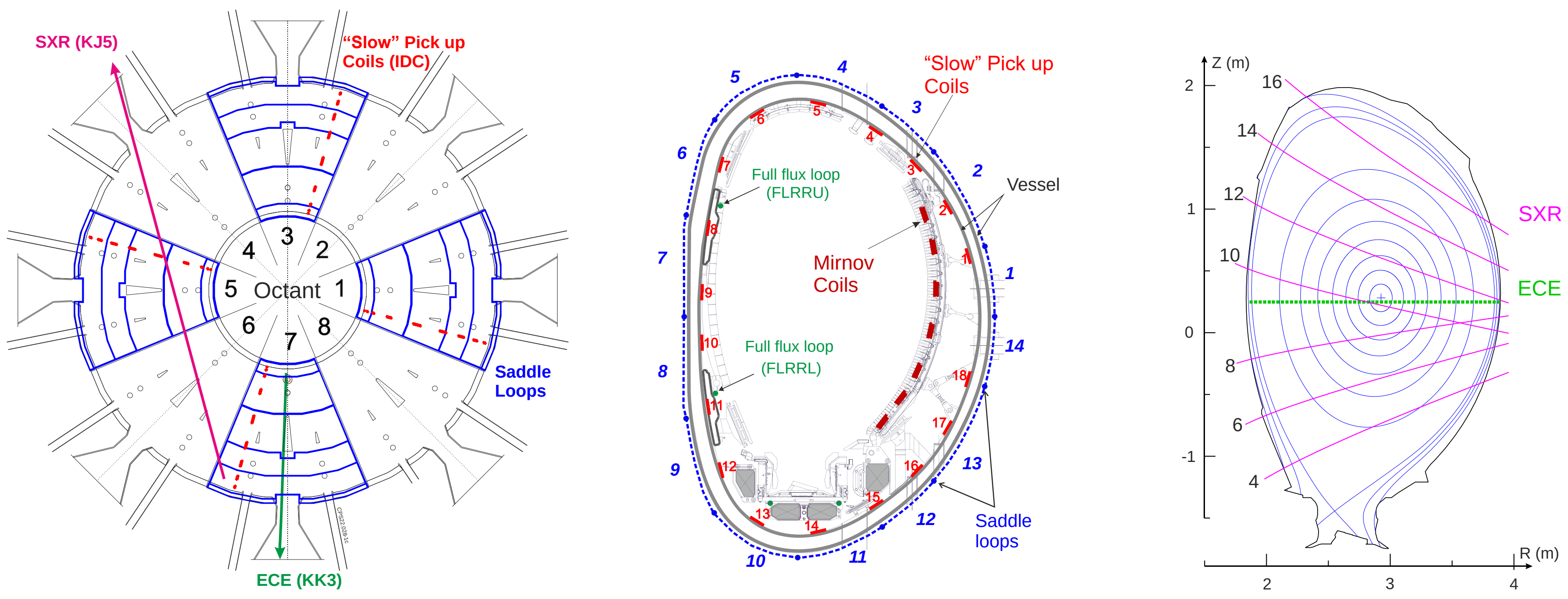

Fig.1. From left to right: top view, magnetics and ECE&SXR in poloidal cross-section.

Mirnov Coils:

- the frequency response **> 100 kHz**,
- sampling rate is **1 MHz** from #62752 (2004)

"Slow" Pick up Coils (IDC):

- the frequency response has a 3dB point of **8-9 kHz**
  - sampling rate is **5 kHz**
- Coils #16 are used to create amplitude modes n=1 (G101) and n=2 (G102). Analog signal processing includes amplification, summing, rectification, and **6 Hz (!)** low-band filtering
  - sampling rate is **10 kHz** starting from #70999 (2008)

ECE:

- sampling rate is **200 kHz (KK3F)** from #81093 (2011)
- noisy signal, need to smooth, e.g. +/- 100 µs filter
- ECE may suffer from cut-off due to high density

SXR:

- DA/C1M-S40XX sampled at **1 MHz**, (from #72711)
  - then smoothed (rectangular smoothed, +/- 50 µs, and down sampled to **25 kHz**, SXR/HXX)
- DD/J5-RTVS<S4:0XX **250 kHz** with a time window of 0.5 s
- **Be 250 µm** foil cuts off low energy photons

3. FROM THE "ITER PHYSICS BASIS" 1999 [1] & 2007 [2]

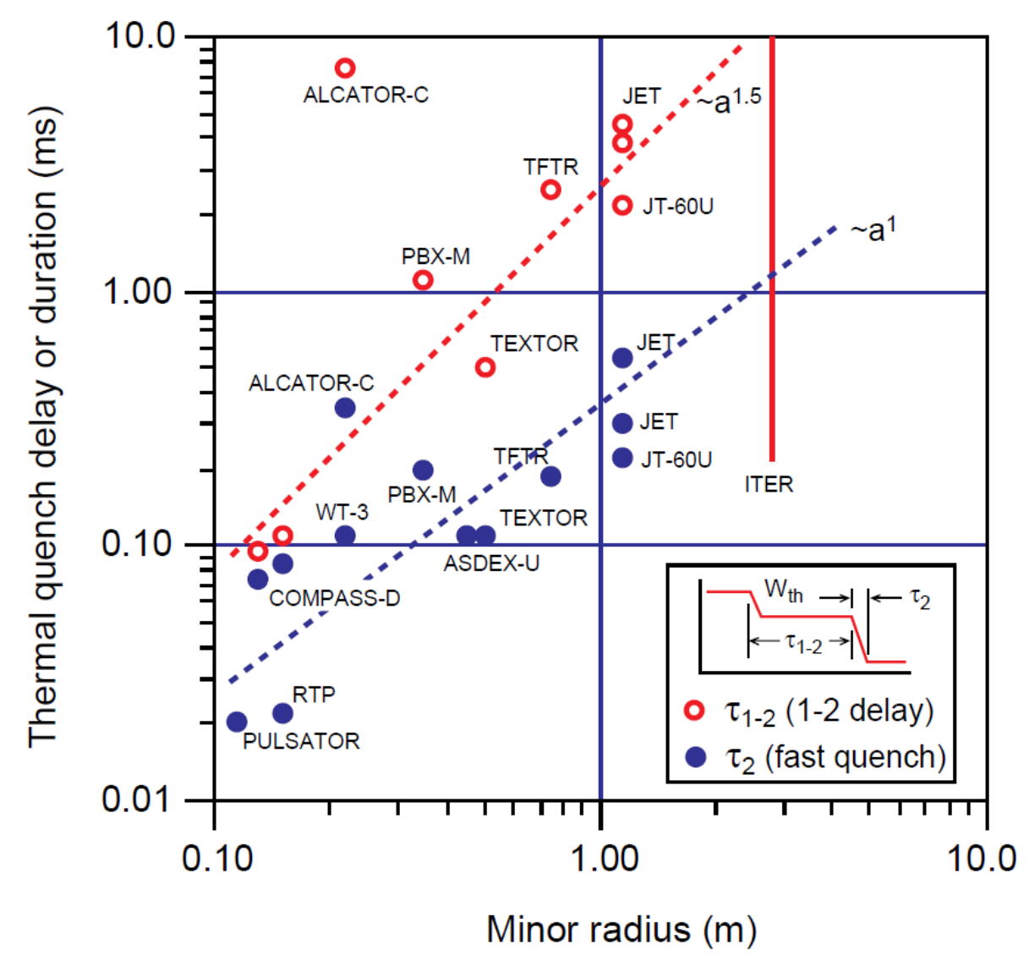

Figure 54 from [1] . *TQ times $\tau_{1\text{-}2}$ (delay between initial and final quench) and τ_2 (fast quench) for various tokamaks, plotted as a function of plasma minor radius. Extrapolation to ITER yields $\tau_{1\text{-}2}$ ≈20 ms and τ_2 ≈1 ms.*

- "The initial delay time, $\tau_{1\text{-}2}$, and the final fast quench time, τ_2, both increase roughly in proportion to plasma minor radius (with respective size scalings $\sim a^{1.5}$ and $\sim a^1$), and the ratio $\tau_{1\text{-}2}/\tau_2$ is typically about 10 [1].
- The TQ duration measurements are derived from plasma temperature or pressure or SXR measurements [1].
- It should be noted that in some cases the initial delay time phase, $\tau_{1\text{-}2}$, and fast quench time, $\tau_{1\text{-}2}$, effectively merge [2].

4.1 TQ IN HIGH ENERGY, W_P ≈ 6.5 MJ, DISRUPTION, JET C-WALL [3]

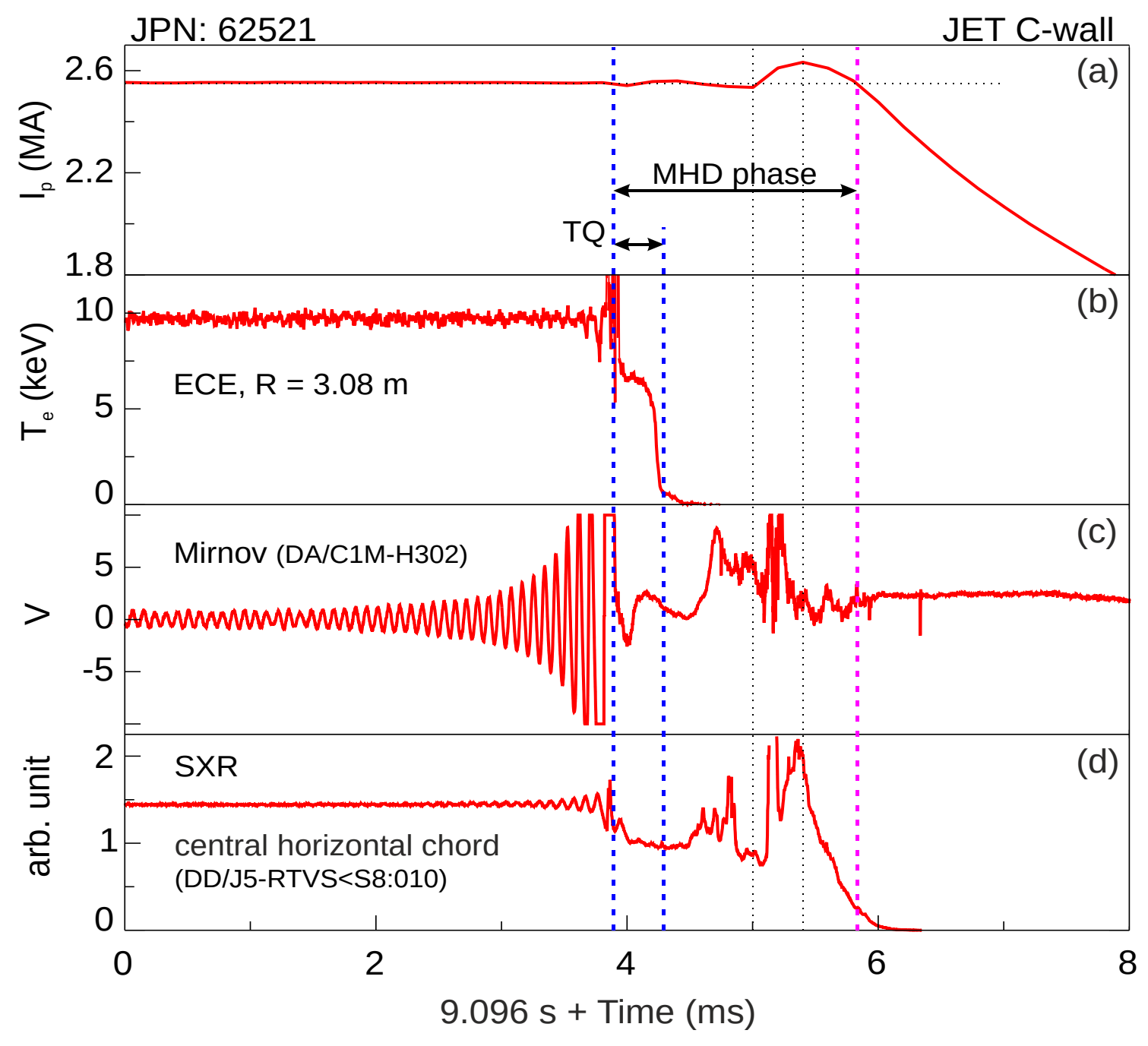

Fig.2. (a) Plasma current, (b) ECE Te at plasma centre, (c) MHD Mirnov, (d) SXR central chord.

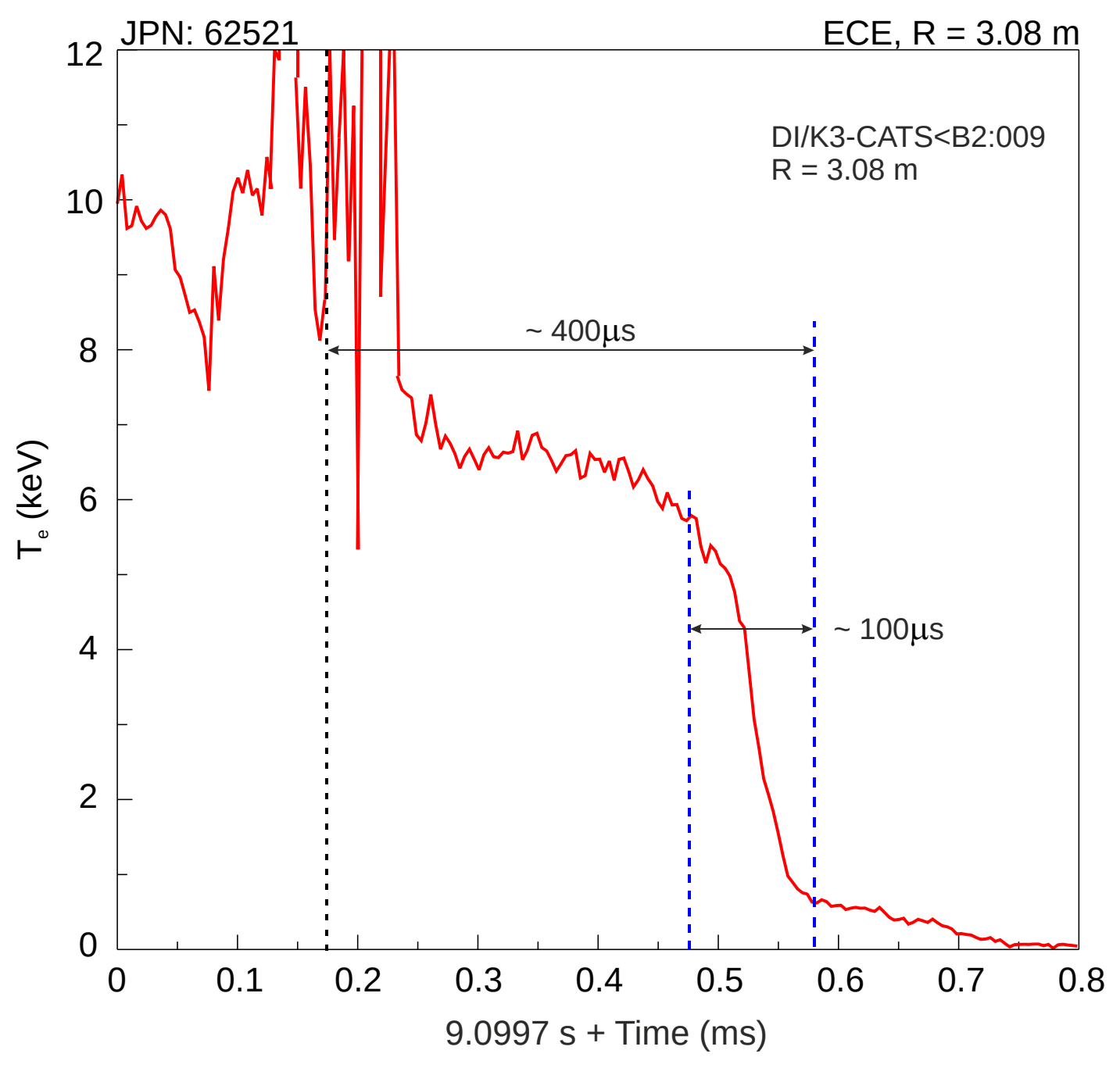

Fig.3. TQ: ECE Te at plasma centre.

- **ECE shows the duration of TQ**
- **SXR** can sometimes be misleading, perhaps these are photons emitted from the wall during the MHD phase

- **Two fast phases of TQ, but both short, namely only hundreds of microseconds**

[1] ITER Physics Basis Editors 1999 Nucl. Fusion 39 2251
[2] ITER Physics Basis Editors 2007 Nucl. Fusion 47 S128
[3] Riccardo and Loarte Nucl. Fusion 45 (2005) 1427–1438
[4] Arnoux et.al. Nucl. Fusion 49 (2009) 085038
[5] Gerasimov et.al. Phys. Scr. 99 (2024) 075615.

4.2 TQ IN LOW ENERGY, W_P < 0.5 MJ, DENSITY LIMIT DISRUPTION, JET C-WALL [4]

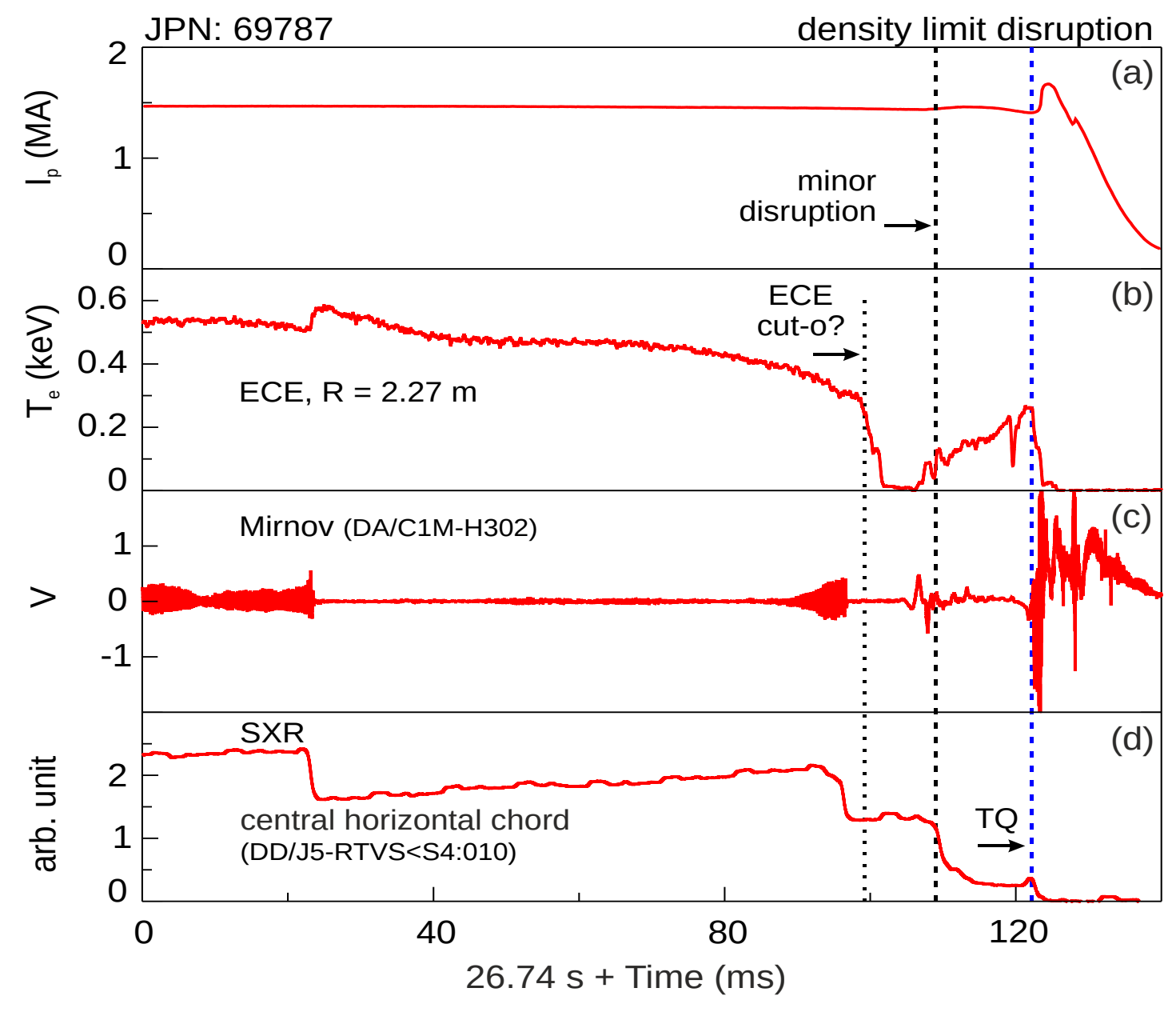

Fig.4. (a) Plasma current, (b) Te in the region of high B_T, (c) MHD Mirnov, (d) SXR central chord.

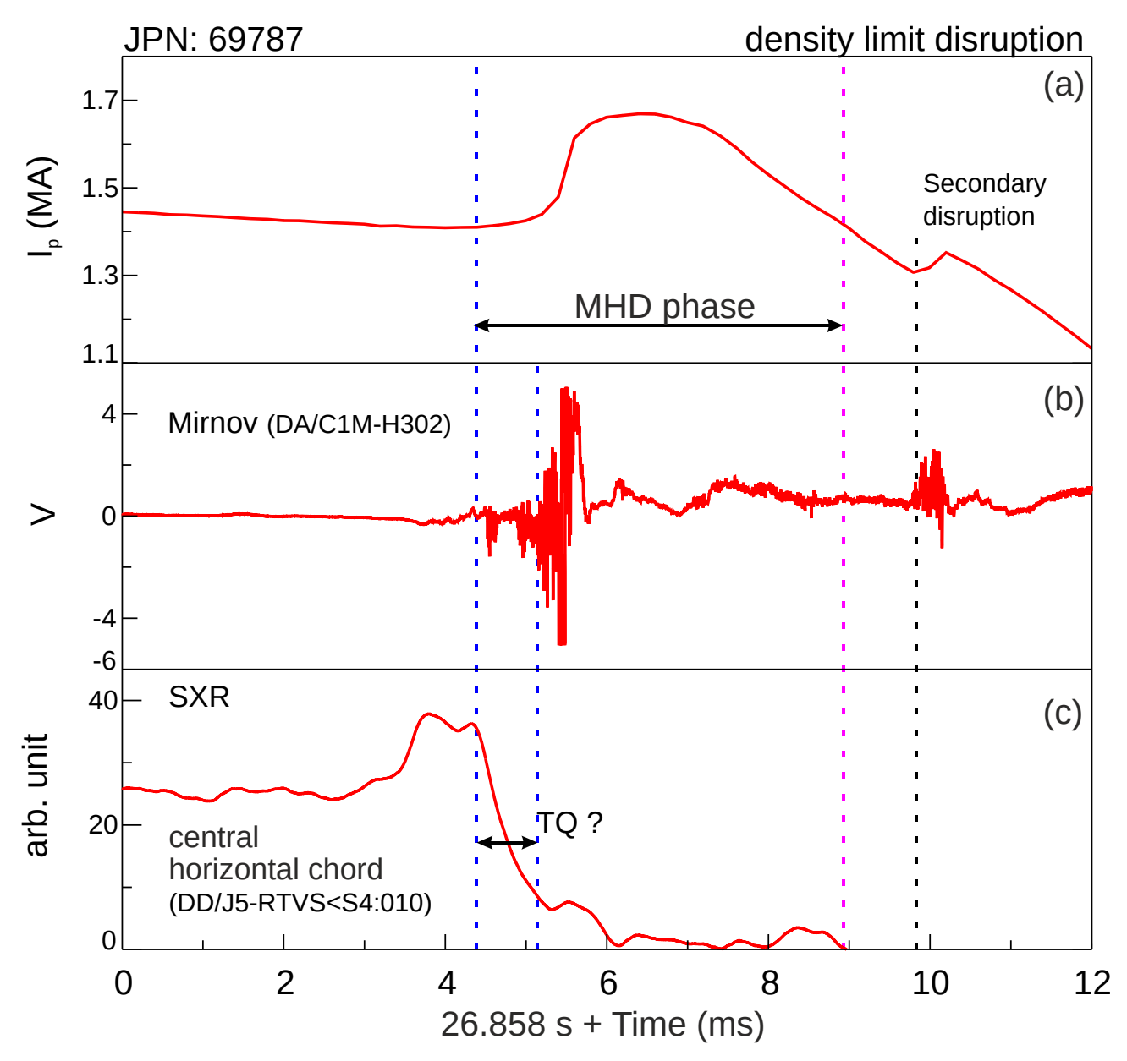

Fig.5. Zoomed Fig.2. (a) Plasma current, (b) MHD Mirnov, (d) SXR central chord.

- ECE cut-off for high density plasma (and low B_T).
- Diagnosing TQ is challenging, especially for low-energy plasmas.

4.3 TQ IN SPI INSTIGATED DISRUPTIONS [5]

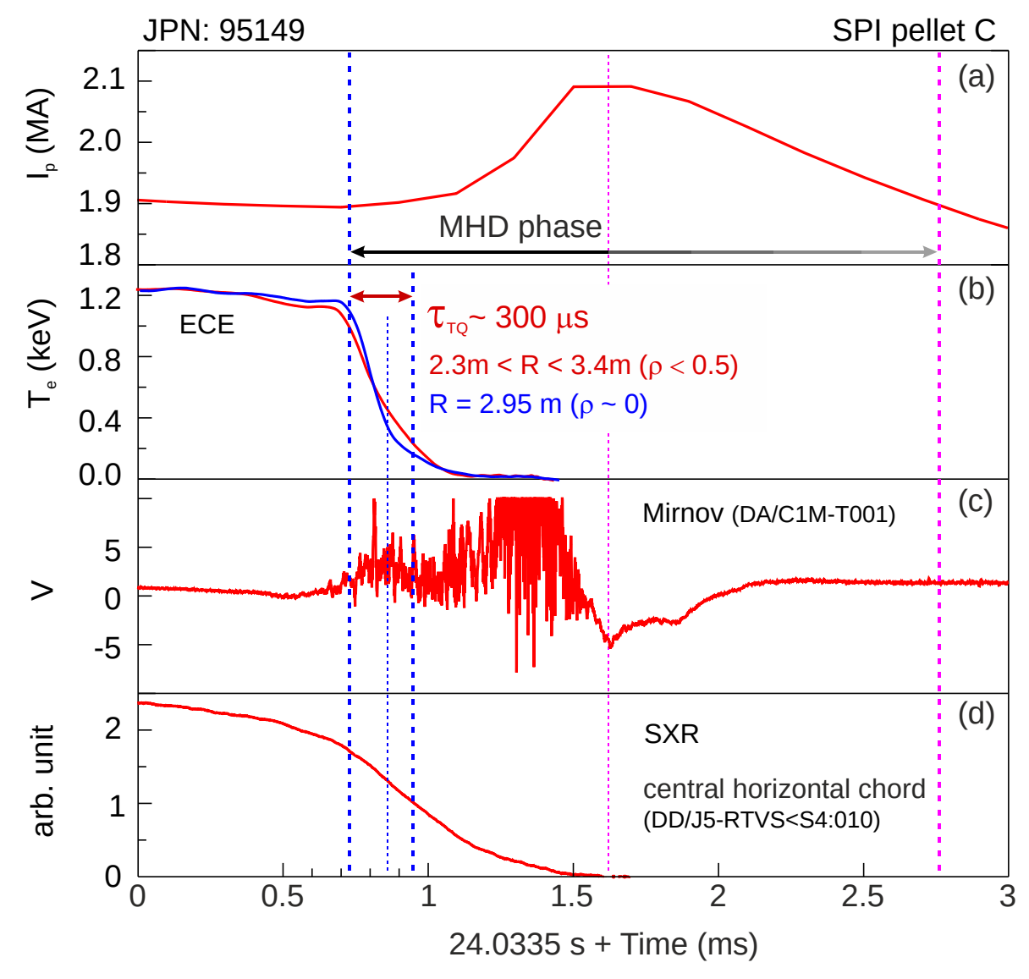

Fig.6. (a) Plasma current, (b) average Te at ρ < 0.5 and at the plasma centre, (c) MHD Mirnov, (d) SXR central chord.

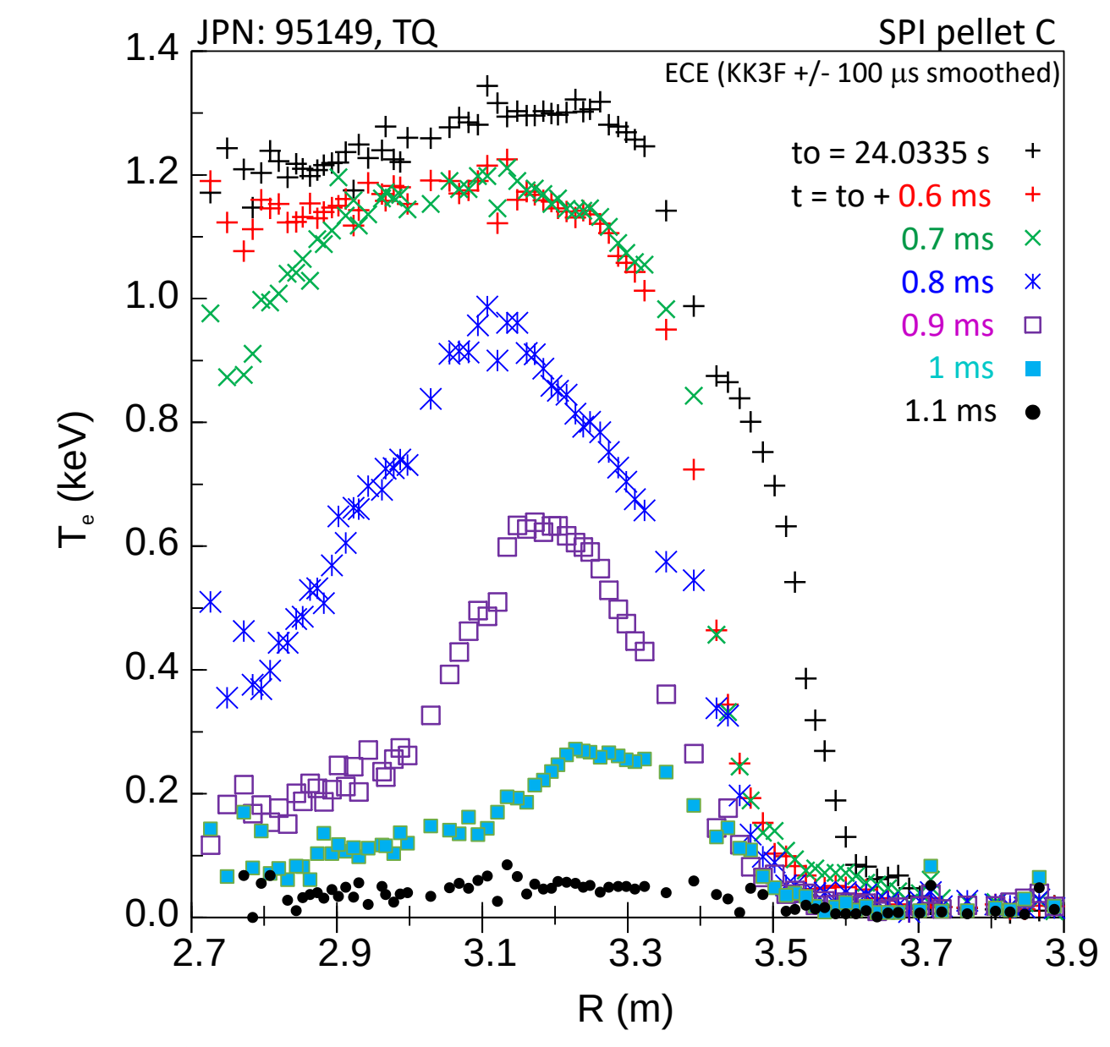

Fig.6. Te profiles during TQ, TQ duration is about 300 µs.

- Small pellet, no ECE cut-off
- A very fast, only about 300 µs, collapse of electron temperature in the plasma core
- SXR does not reflect fast drop of the Te, however it's better corelated with MHD

4.4 TQ IN NATURAL DISRUPTION, WP = 4.2→1.1 MJ

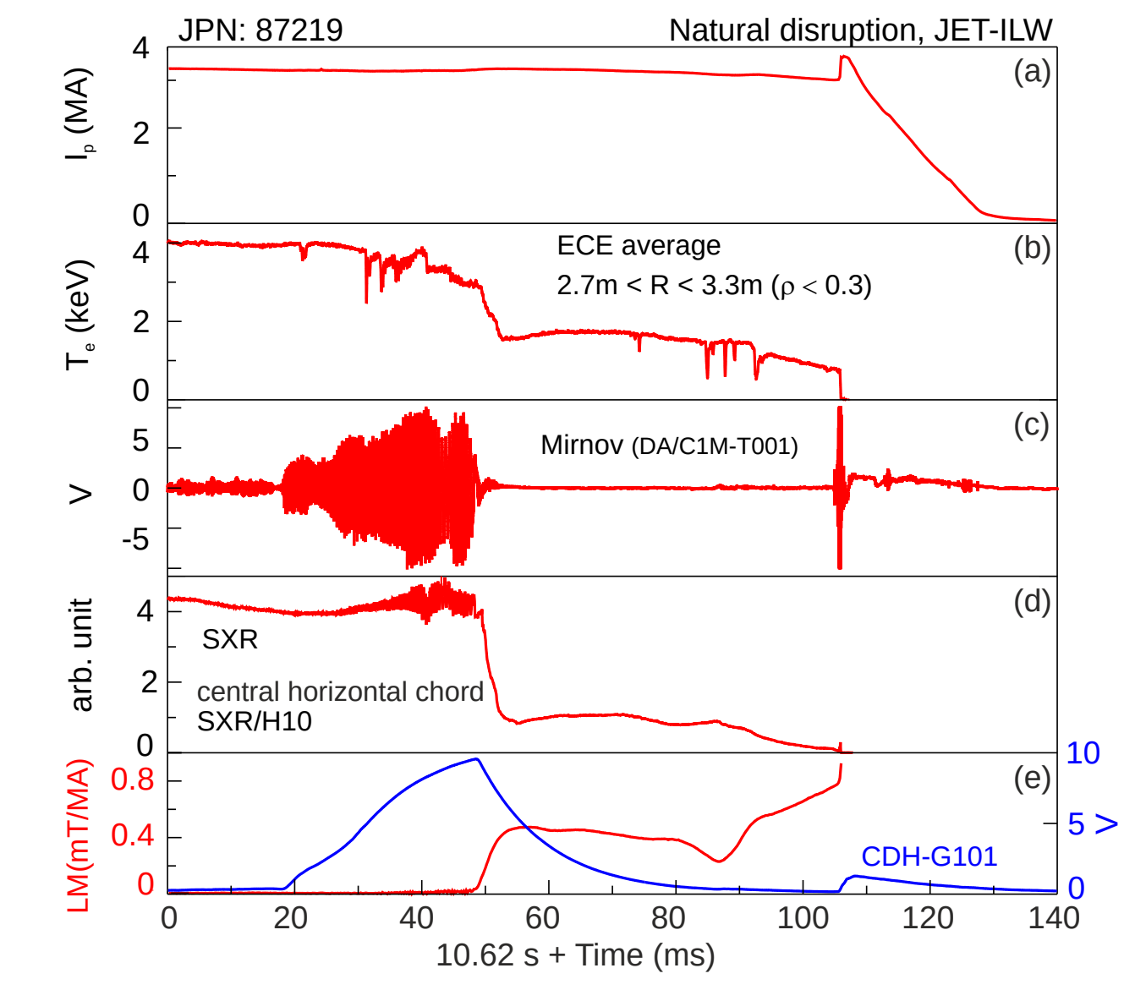

Fig.7. (a) Plasma current, (b) average Te at ρ < 0.3, (c) MHD Mirnov, (d) SXR central chord, (e) Locked and rotating mode amplitude.

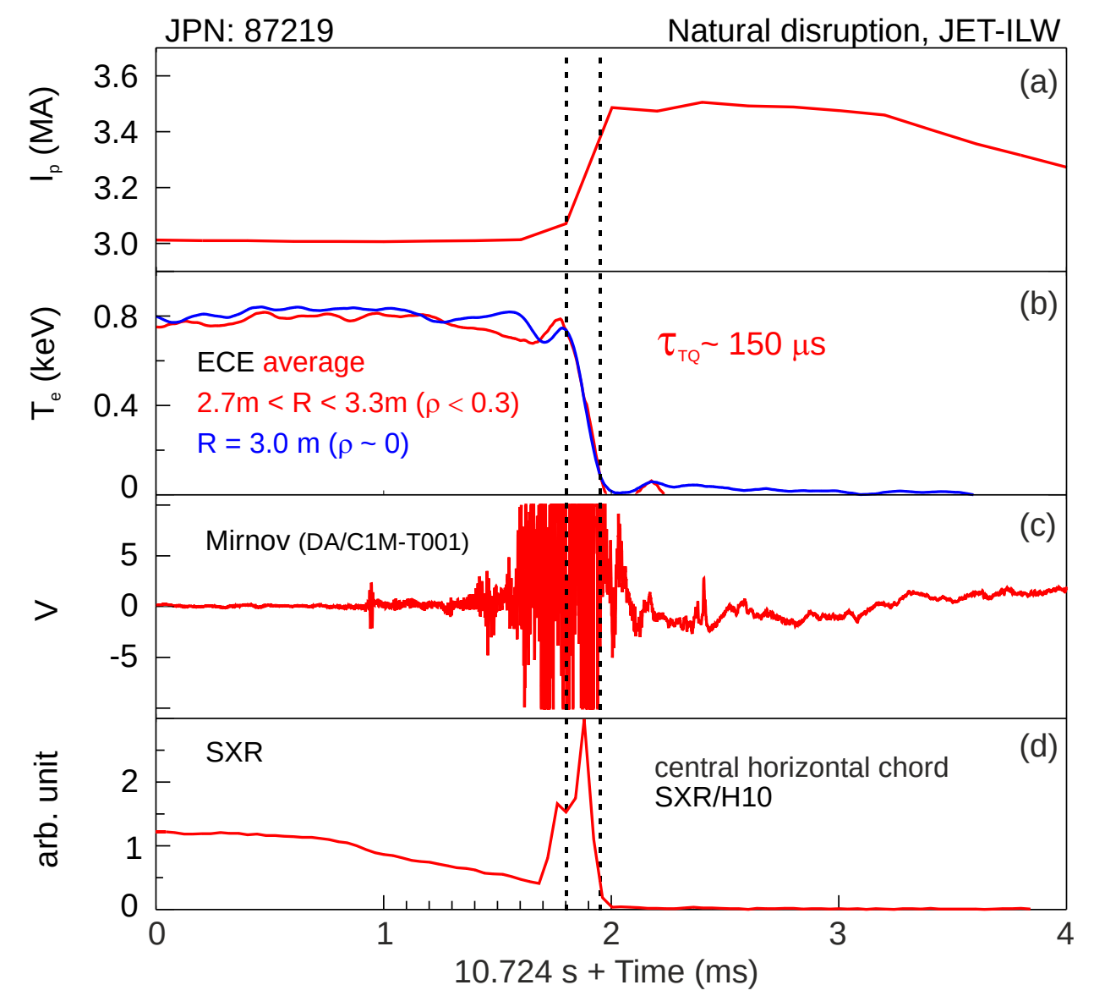

Fig.8. Zoomed Fig.7.

- Very fast TQ correlates with the leading edge of the Ip spike

- Soft stop (bolo-peaking 9.8s)): NBI (fast), ICRH (slow) stops
- Locking Rotating mode
- DMV2 was **late**, triggered at 10.72s on the LOCA signal

High performance baseline scenario, radiative collapse

SUMMARY

TQ diagnostics is challenging, especially for low thermal energy plasmas:

- ECE diagnostic (KK3F) is the main diagnostic for TQ
  - High time resolution and spatial resolution
  - However, ECE suffers from cut-off especially for MGI, SPI and other high plasma density disruptions
  - ECE(KK3F) signals are noisy and need to be smoothed with a filter e.g., +/- 100µs.
- MHD (Mirnov) correlates with TQ but usually extends beyond TQ
- SXR can be used with great care, but SXR can be misleading, possibly due to photons emitted by the wall
- Locked and n=1 (G101) amplitudes are slow and not suitable for this purpose
  - **Remarkably fast TQ, in the order of hundreds of 100 µs, were observed in various disruptions that were analysed**

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