20th IAEA Fusion Energy Conference
1-6 November 2004, Vilamoura, Portugal

EX/2-1

Energy loss for grassy ELMs and effects of plasma rotation on the ELM characteristics in JT-60U

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Introduction

ELMy H-mode (type I ELM)

Standard operational scenario for ITER

- ☺ High confinement
- ☺ Wide database for reliable prediction
- ☹ Material limits of divertor target
  - -Acceptable divertor lifetime (>10^6ELMs) requires tolerable $\Delta W_{ELM}/W_{ped} \leq 6\%$ (6MJ / ELMs)

Mitigation technique or **alternative scenario** are important!

Compatibility with ITER plasma parameter: $\nu_e^* \sim 0.05$

Attractive operational modes ($\nu_e^* \leq 0.15$) in JT-60U

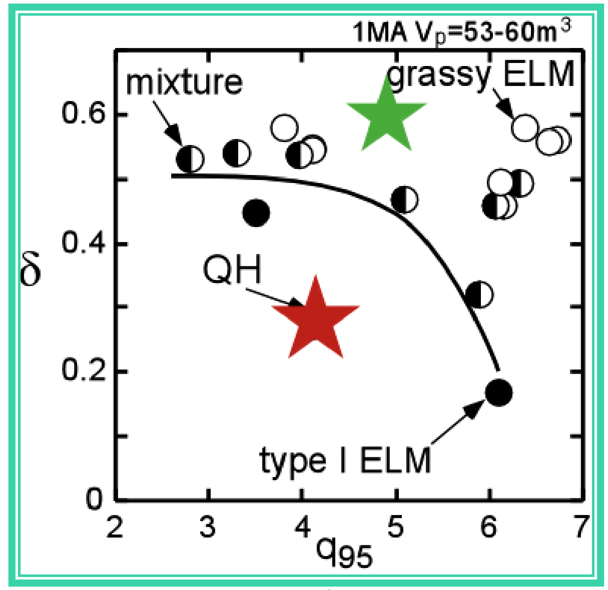
- Grassy ELM regime (small ELM)
- QH-mode regime (steady ELM free)

→ Applicability to ITER

I. suppression mechanism of type I ELMs

II. stabilizing effects of the plasma rotation

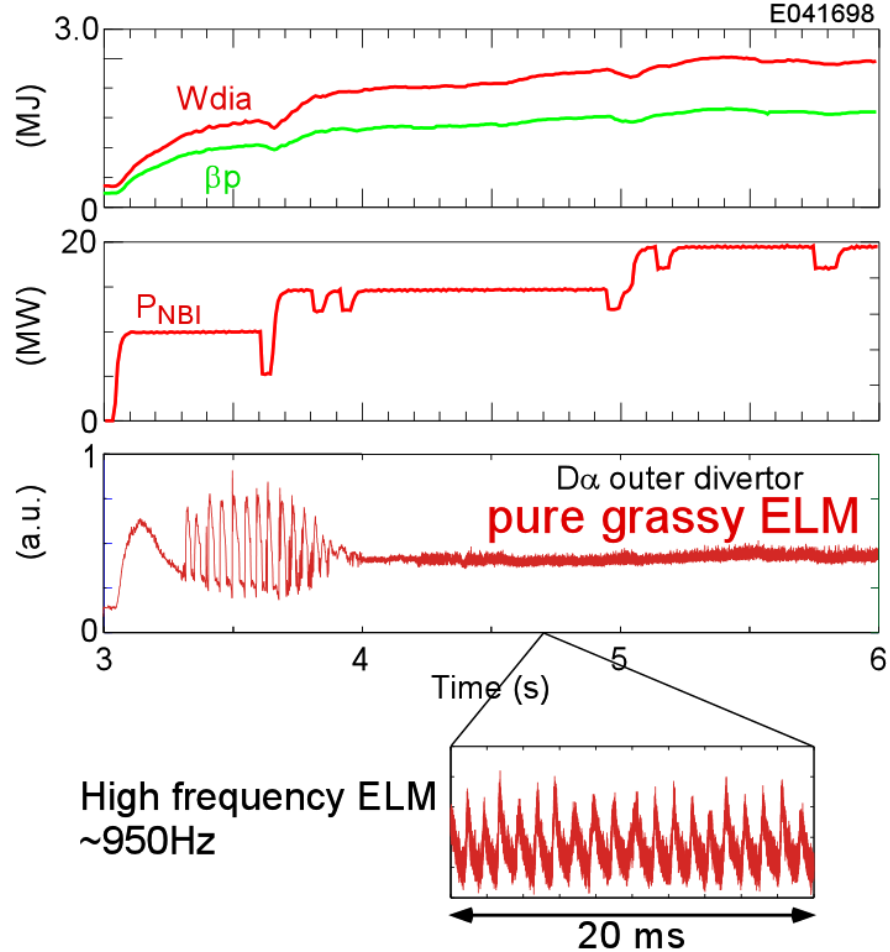
Outline

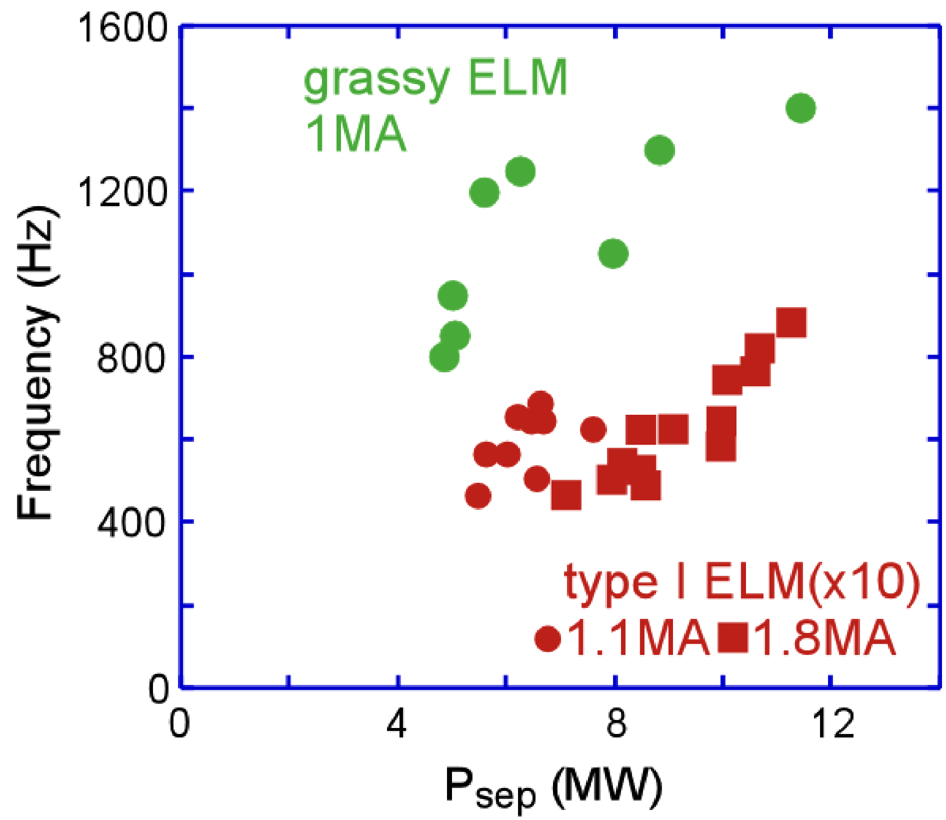


1. Introduction
2. Grassy ELM regime (higher δ)
   - Frequency dependence
   - Divertor heat flux
   - Collapse of T_e pedestal
   - ELM control by toroidal rotation (at ★)
3. QH-mode regime (lower δ, ★)
   - Pedestal characteristics
   - Fluctuation properties
   - Requirement of counter NBI
4. Summary

Grassy ELM frequency is ~15 times higher than type I ELM frequency

- Large ELM was replaced by high frequency ELMs. (Definition)
- Similar frequency dependence to type I ELM. $f_{ELM} \propto P_{sep}$



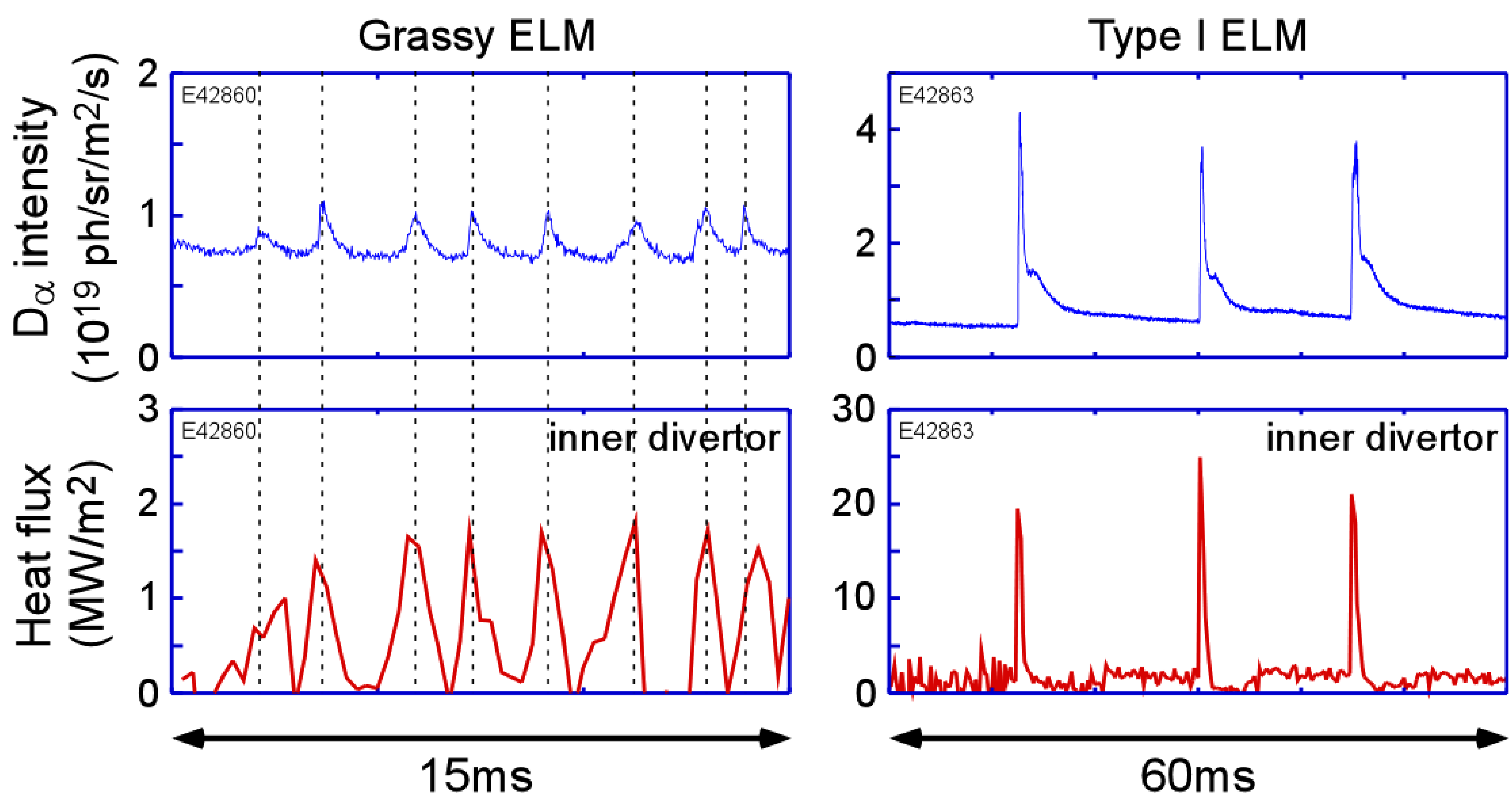


$P_{sep}=P_{abs}-dW/dt-P_{rad}$

Divertor peak heat flux was less than 10% of that in type I ELMs

JT-60U

- ELM frequency   Grassy : 533Hz   Type I: 50Hz
- Divertor heat flux   Grassy : ~1.7MW/m^2 Type I: ~21MW/m^2
- **Peak heat flux is almost inversely proportional to f_{ELM}.**



Narrower radial extent in grassy ELM

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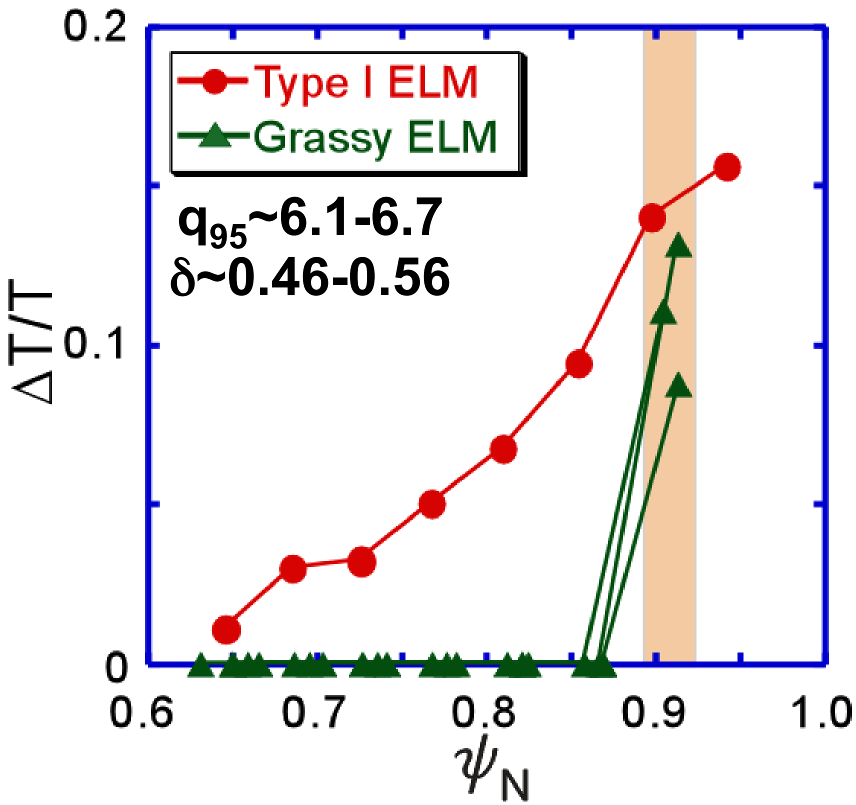
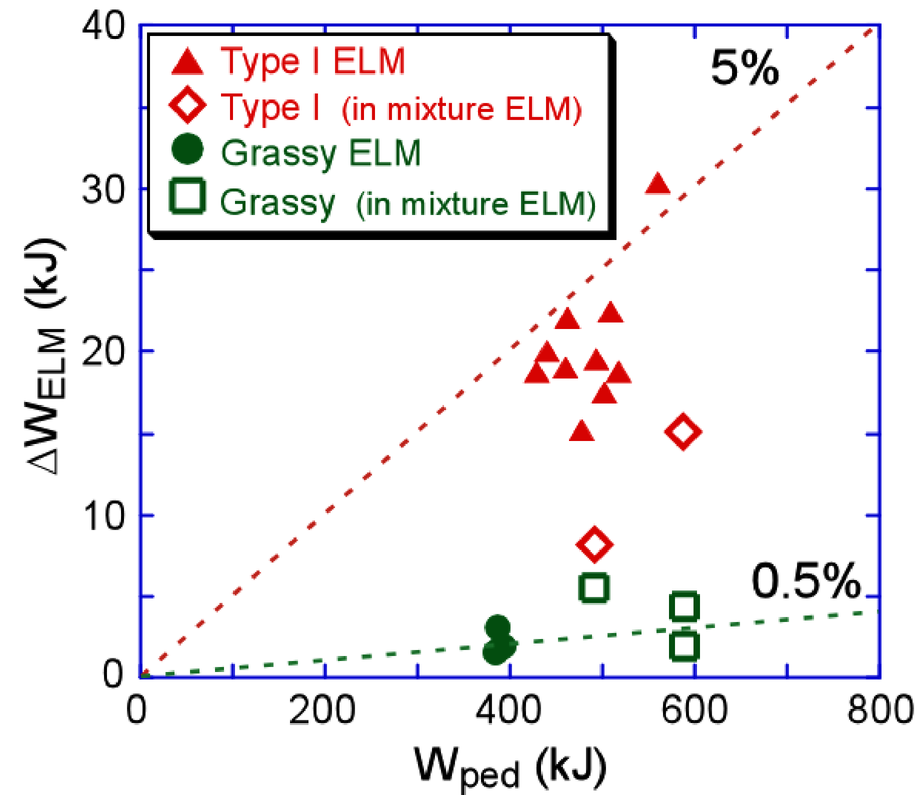
● $\Delta T_e/T_e$ was similar to that in type I ELM, but much narrower.





ELM energy loss for grassy ELMs was 0.4%-1.0% of W_{ped}

Evaluation by using change of kinetic energy from ΔT_e.

$$\Delta W_{ELM} = \frac{3}{2}\int\left(1+\frac{7-Z_{eff}}{6}\right)n_e^{ped}\Delta T_e dV$$

, assuming $\Delta T_e = \Delta T_i$

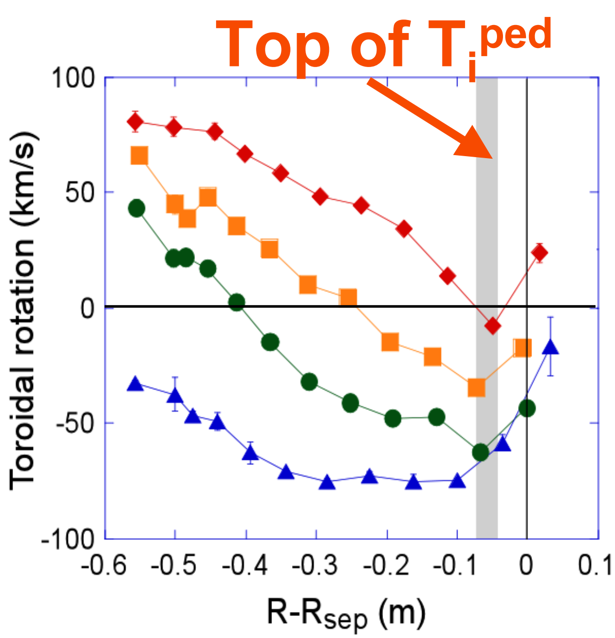
Δn_e was small.

ELM amplitude and frequency can be changed by toroidal rotation

JT-60U

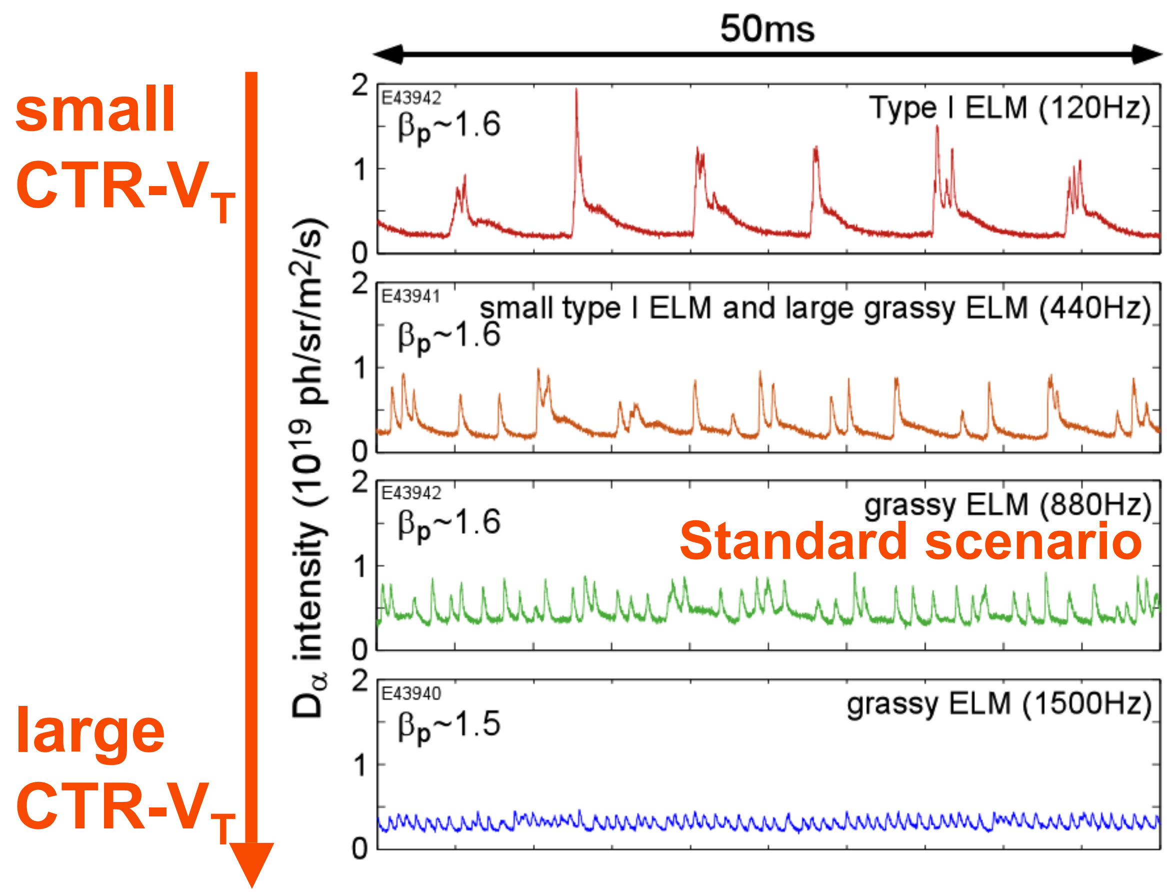
- Larger counter rotation leads to smaller ELM and higher f_{ELM}.
- New parameter for access to grassy ELM regime.

  absolute value? or sign?
- No edge fluctuations were observed even in larger counter rotation phase.



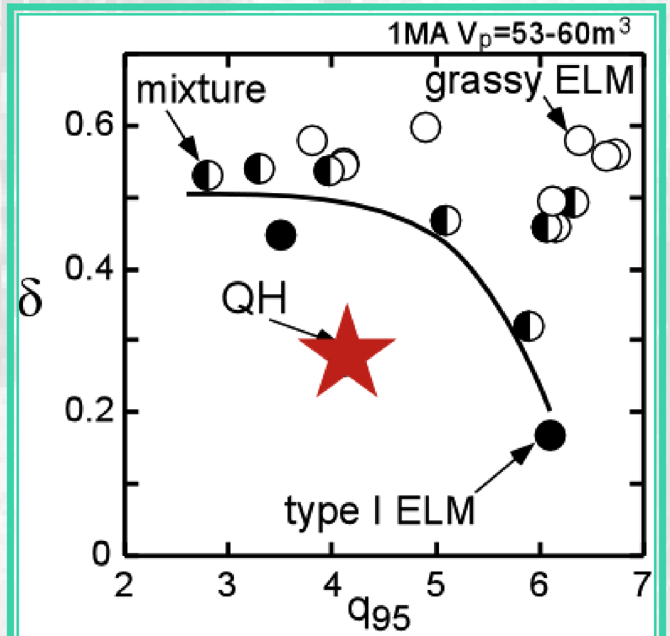
Toroidal rotation profile

(q_{95}~4.9, δ~0.6)



QH-mode regime

- Pedestal characteristics
- Fluctuation properties
- Requirement of counter NBI



Pedestal pressure in QH phase is smaller than in ELMy phase

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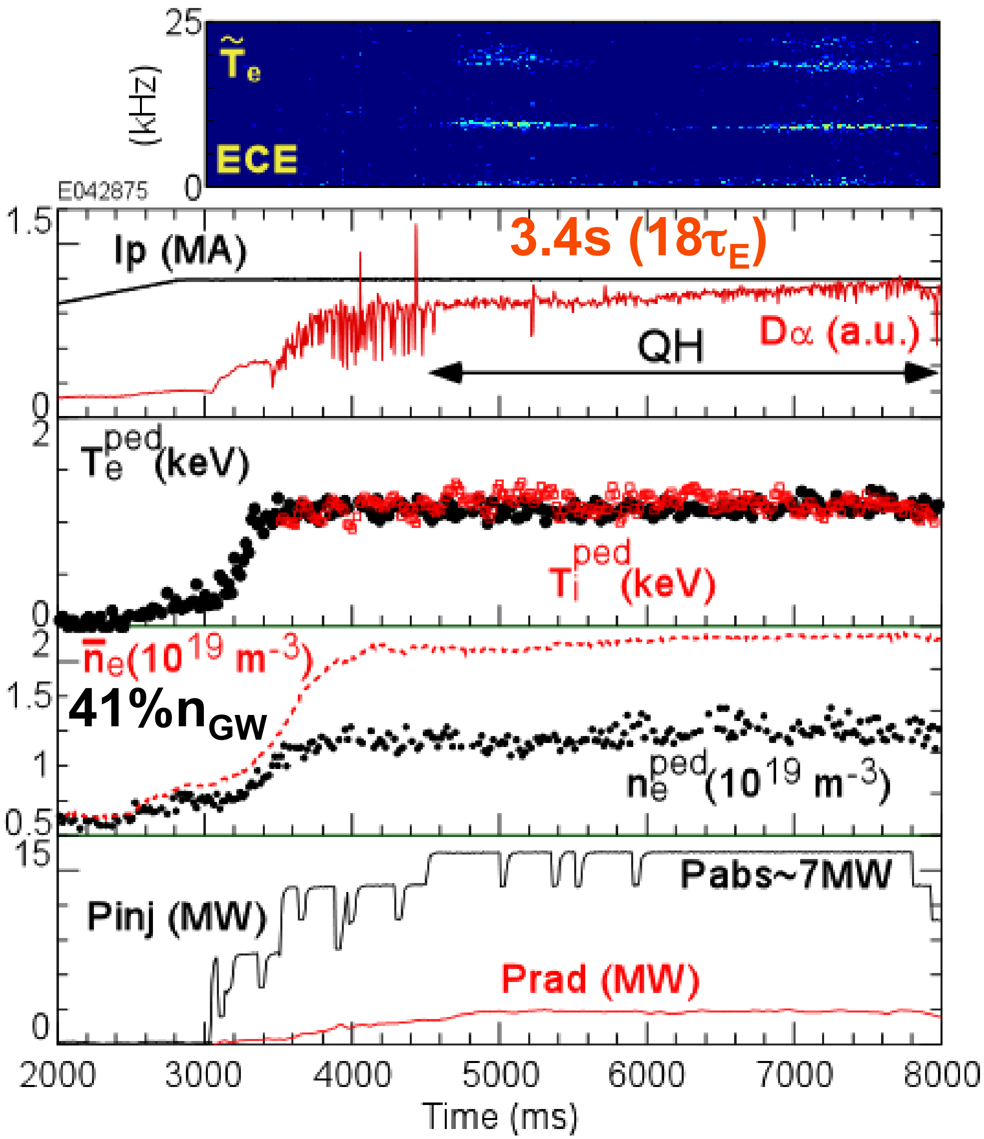
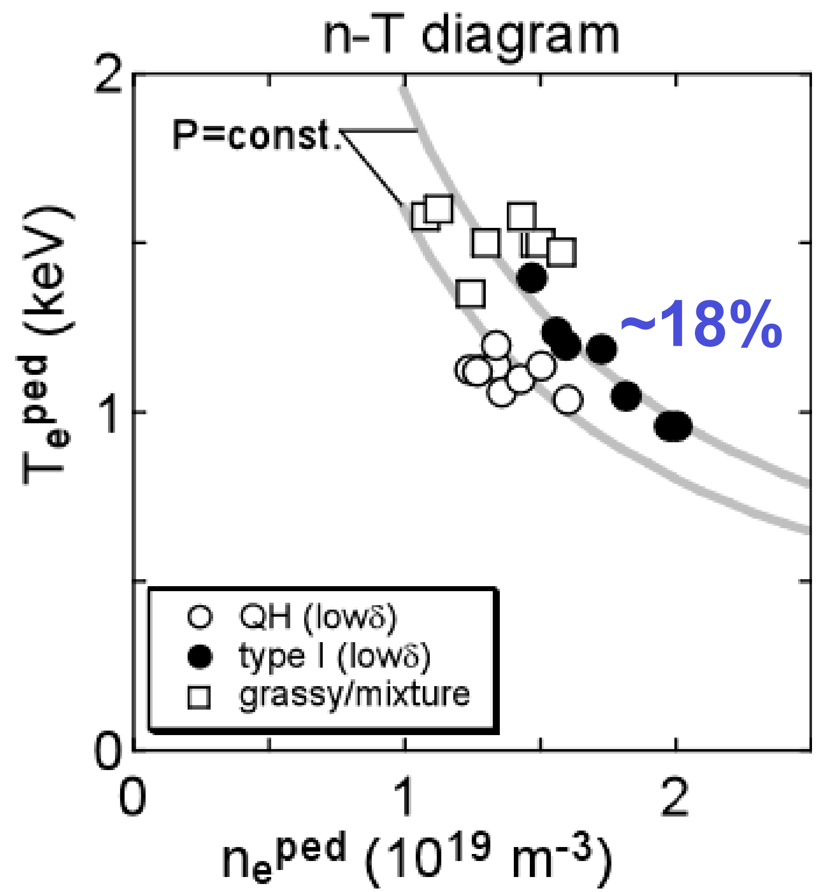
- **Pedestal parameters were almost constant during QH phase.**

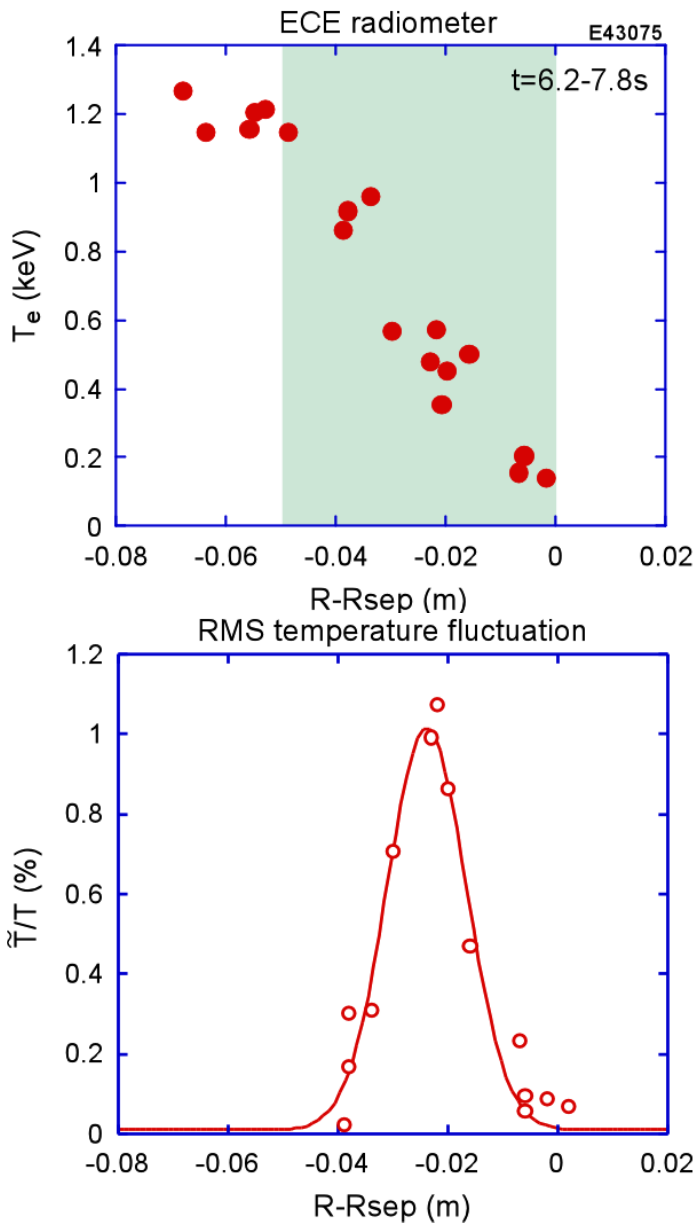




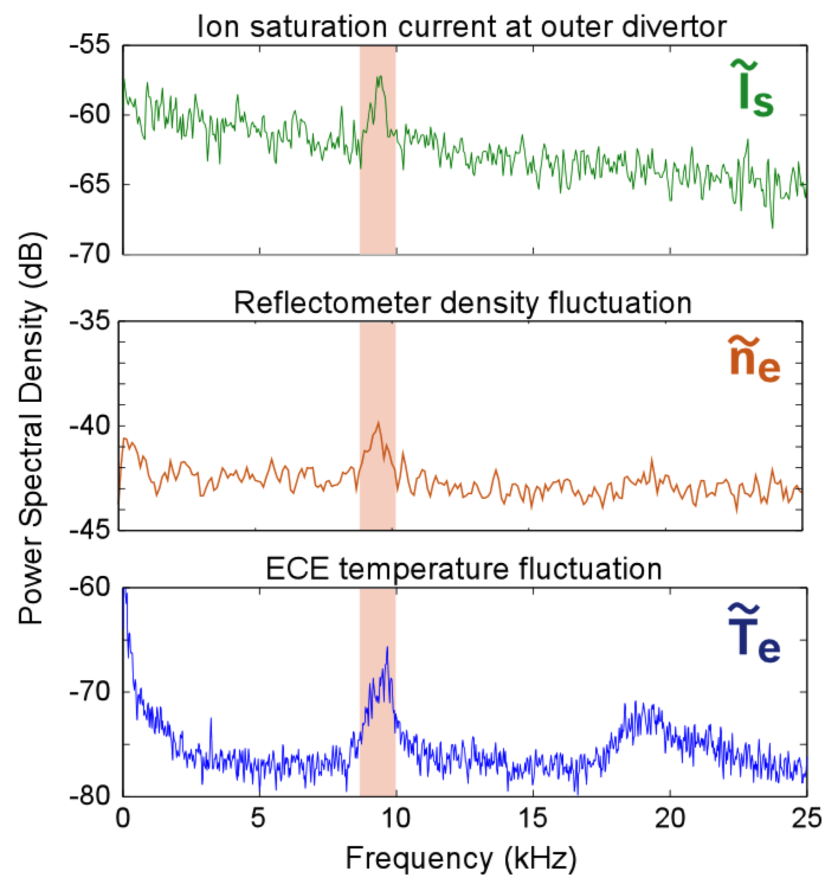
T_i^{ped} was also smaller in QH phase

Edge fluctuations may play an important role to reduce the pedestal pressure.

JT-60U



- Maximum amplitude of ~1% was observed at ~2cm inside separatrix.
- Ion saturation current at divertor target and edge density at outer mid-plane are also modulated with same frequency.



Partial QH phase was observed at almost no edge rotation with co-NB injection

JT-60U

QH phase with co-NBIs

😐 same edge fluctuations ($f_{fluct} \propto V_T$)

☺ better confinement

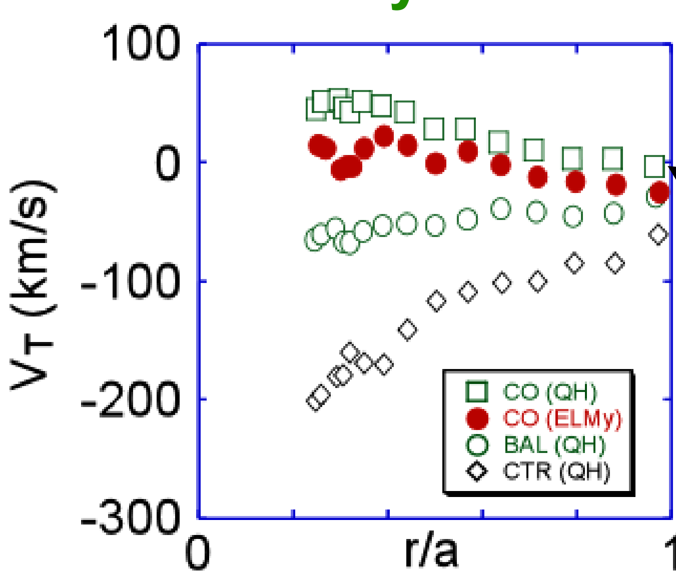
H_{89}~1.7(⇐~1.5)

☺ smaller P_{rad} ~0.8MW (⇐~1.5MW)

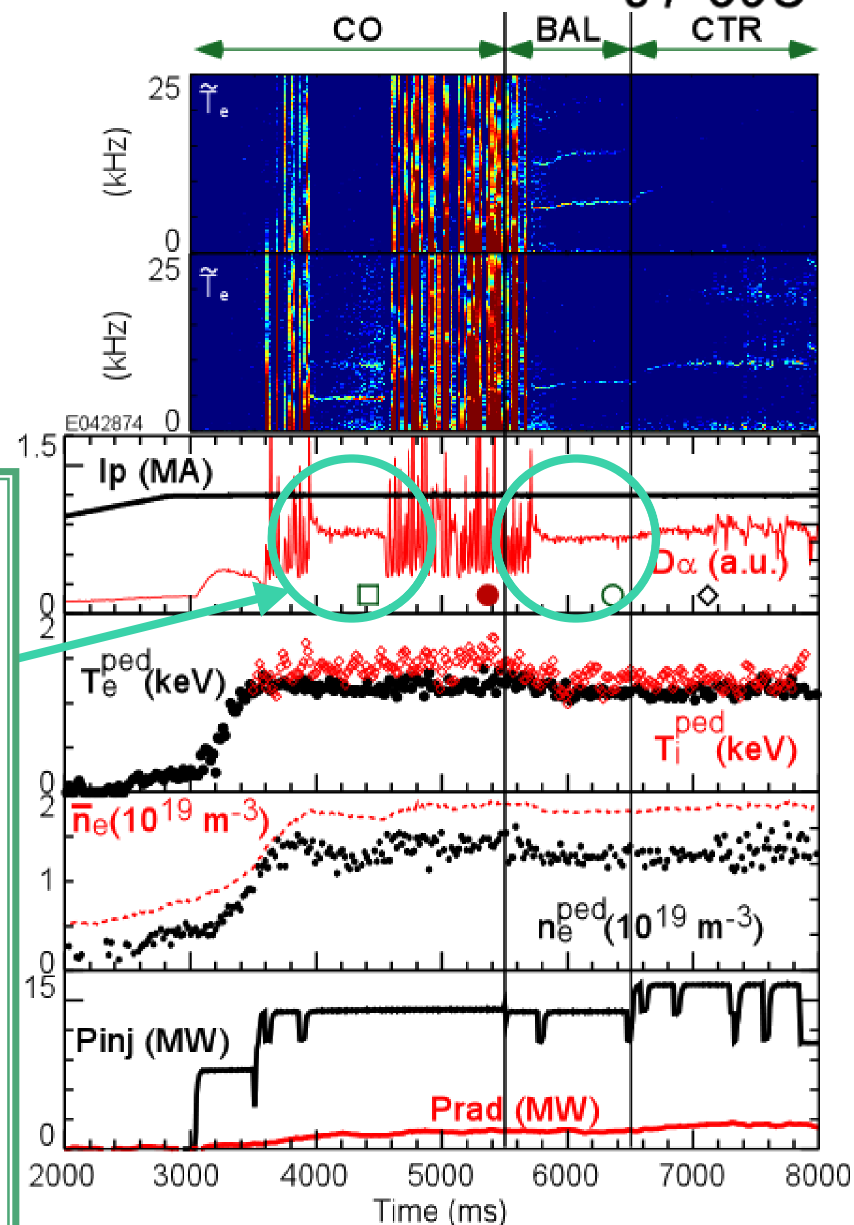
Z_{eff} ~2.8 (⇐~3.3)

than QH phase with ctr-NBIs

=> CTR rotation & CTR NBIs are not necessary conditions!



No toroidal rotation with co-NBI



Summary

We have investigated type I ELM suppression mechanisms and effects of plasma rotation in attractive operational modes with low-collisionality regime ($\nu_e^* \leq 0.15$) at JT-60U

	Energy loss	Rotation effects
Grassy regime	Narrow collapse area ● f_{ELM} (~15 × f_{ELM}^{typeI}) ● ΔW_{ELM} (~0.1 × ΔW_{ELM}^{typeI}) ● $\Delta W_{ELM}/W_{ped}$~0.4-1%	CTR V_T: same q, δ, β_p Type I -> grassy ● f_{ELM} up, ΔW_{ELM} down
QH regime	Higher base D_α Edge fluctuations ● R-R_{sep} ~2cm ($\tilde{T}_e$) ● Lower P_{ped} Linkage with other parameters?	CTR V_T: Long QH (3.4s) Small V_T: partial QH ● better confinement ● smaller P_{rad} and Z_{eff} than QH with CTR-NBIs