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

JT-60U

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

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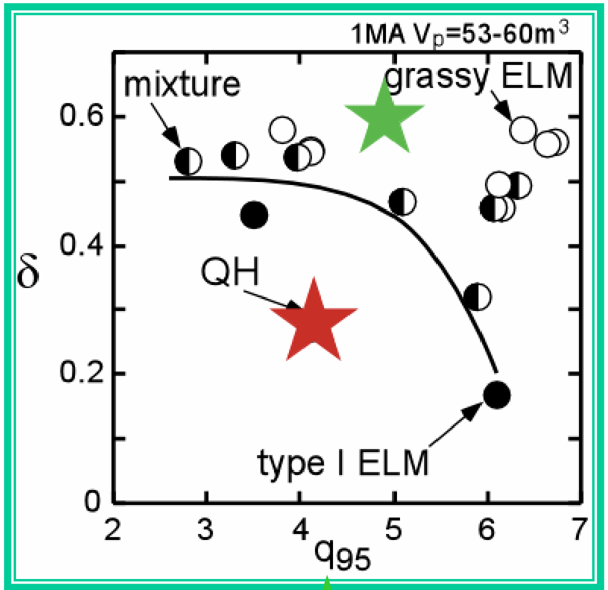

1. Introduction

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

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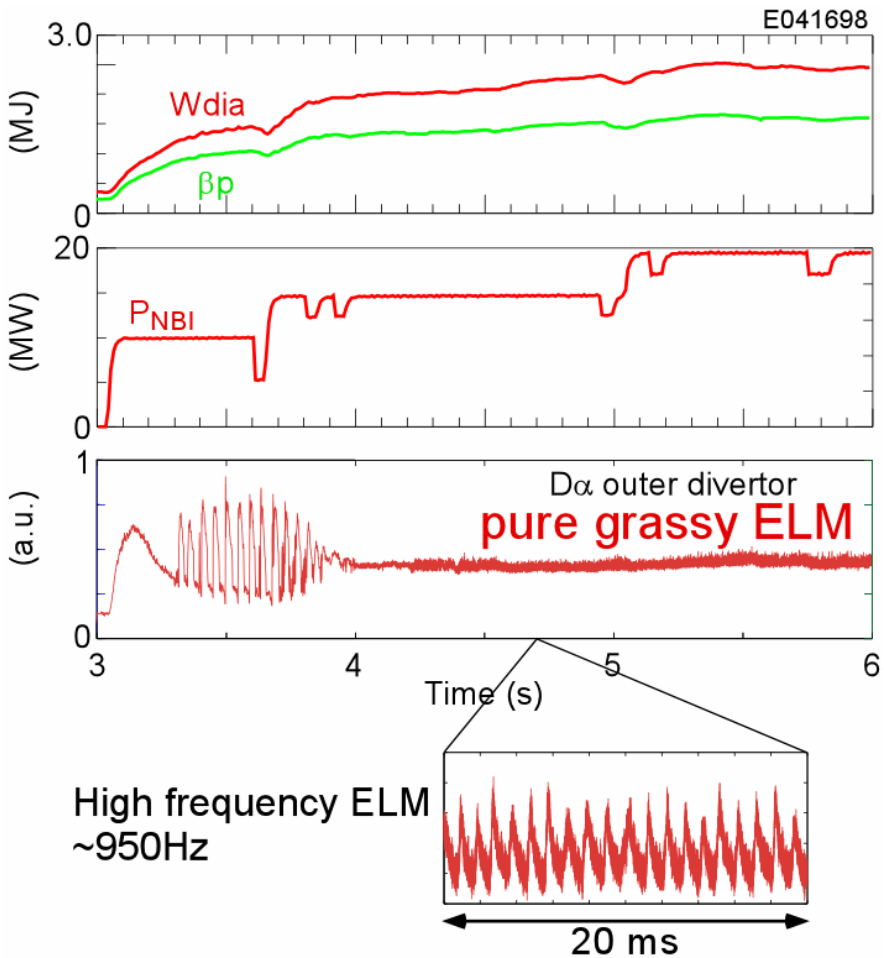
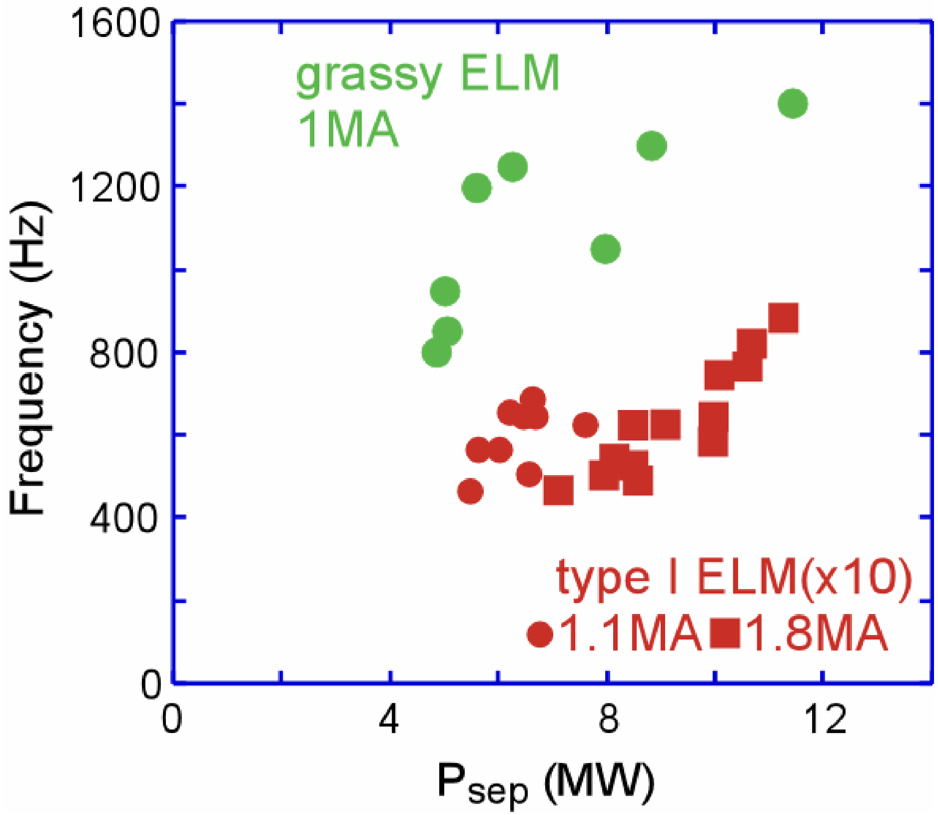
- Large ELM was replaced by high frequency ELMs. (Definition)
- Similar frequency dependence to type I ELM. $f_{ELM} \propto P_{sep}$





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

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

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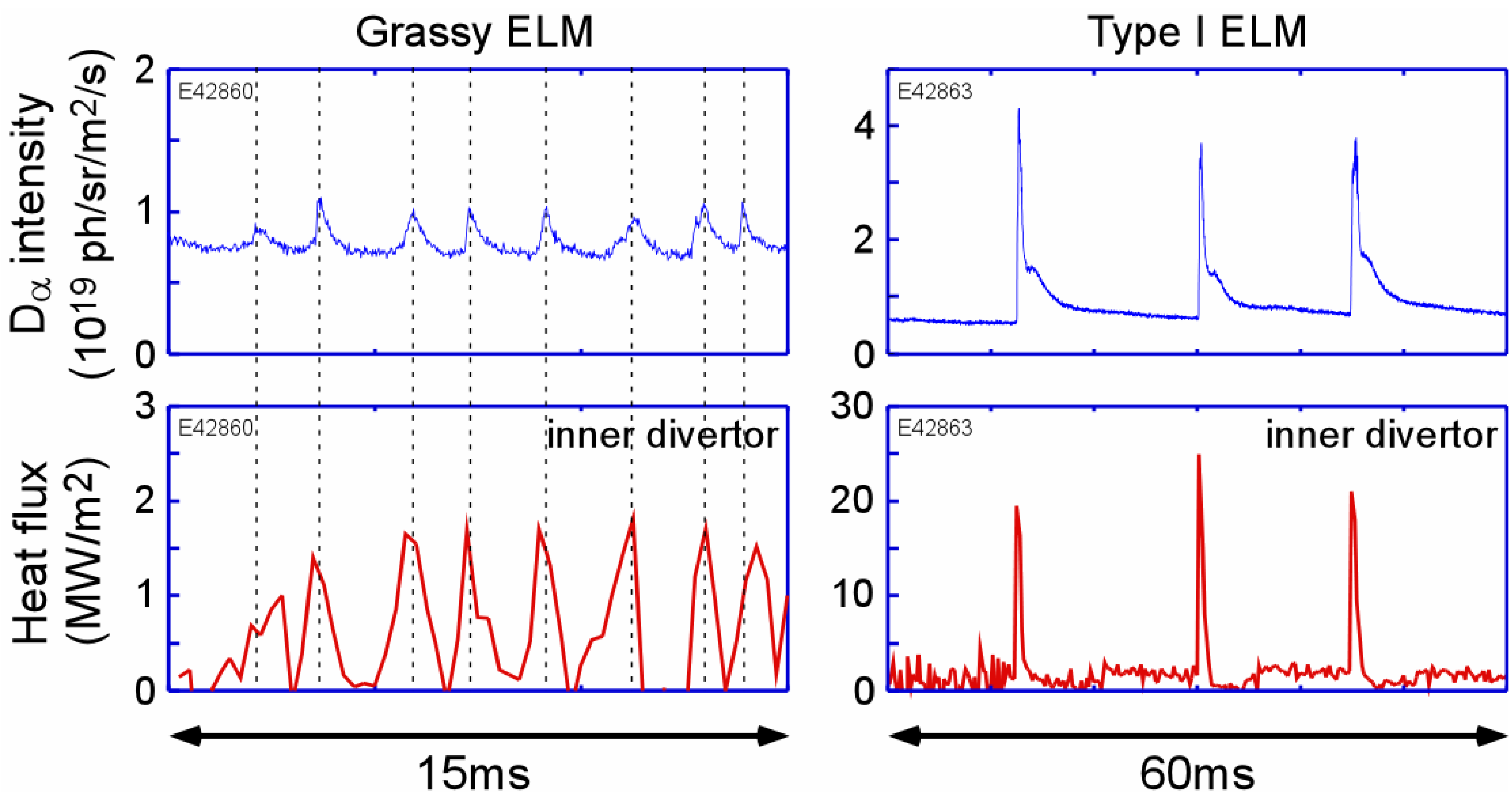
- ELM frequency Grassy : 533Hz Type I: 50Hz
- Divertor heat flux Grassy : ~1.7MW/m^2 Type I: ~21MW/m^2
- Peak heat flux is almost inversely proportional to f_{ELM}.



Narrower radial extent in grassy ELM

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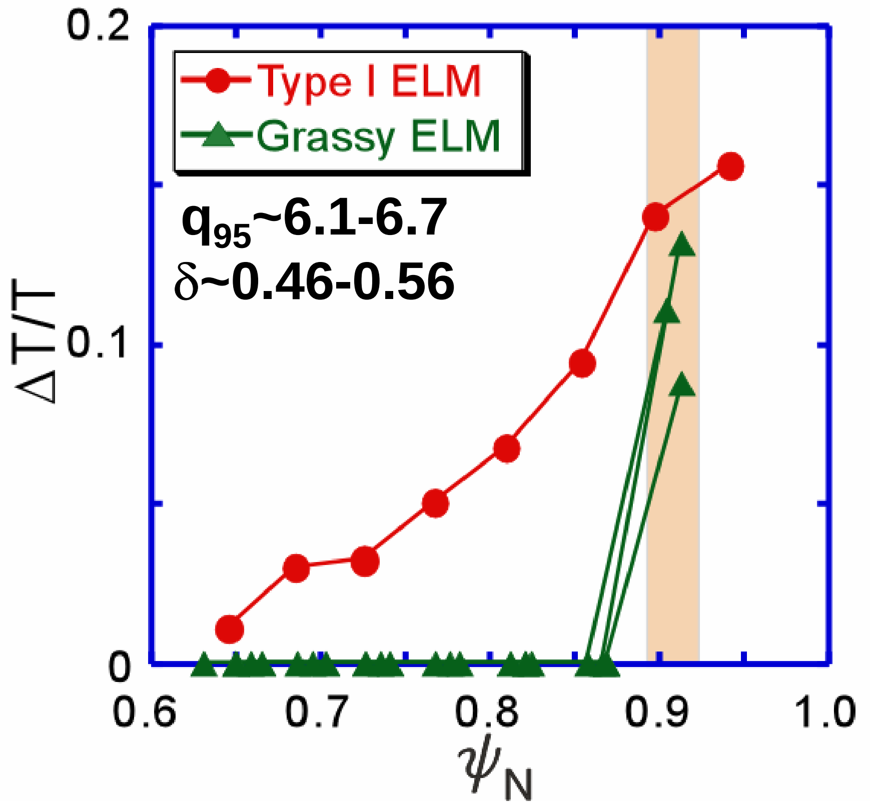
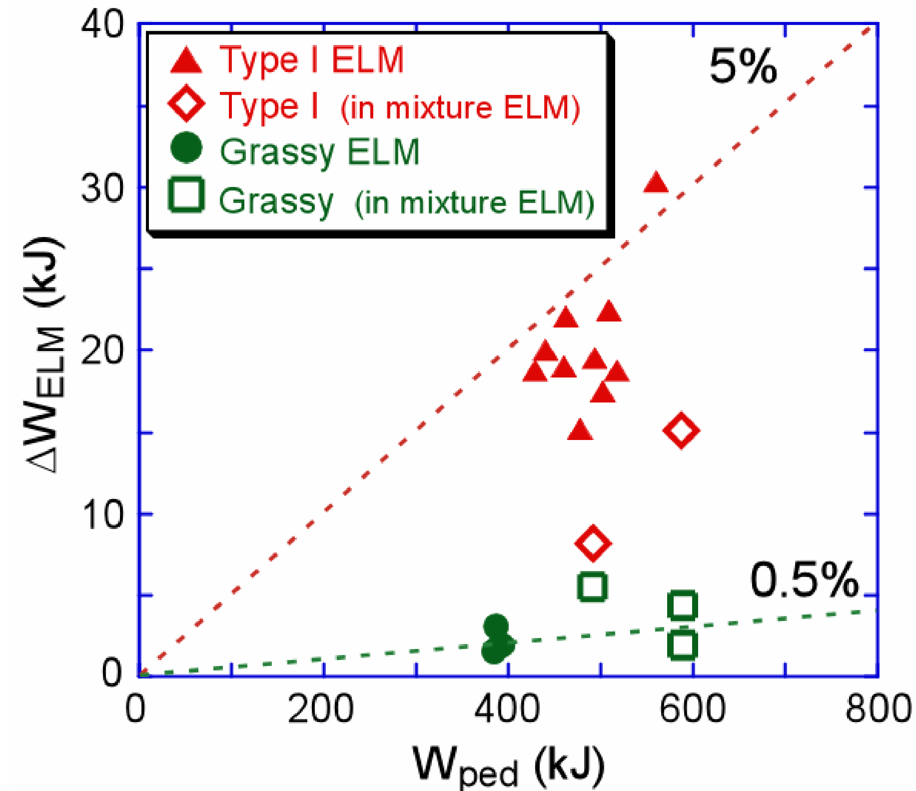
- $\Delta T_e/T_e$ was similar to that in type I ELM, but much narrower.





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

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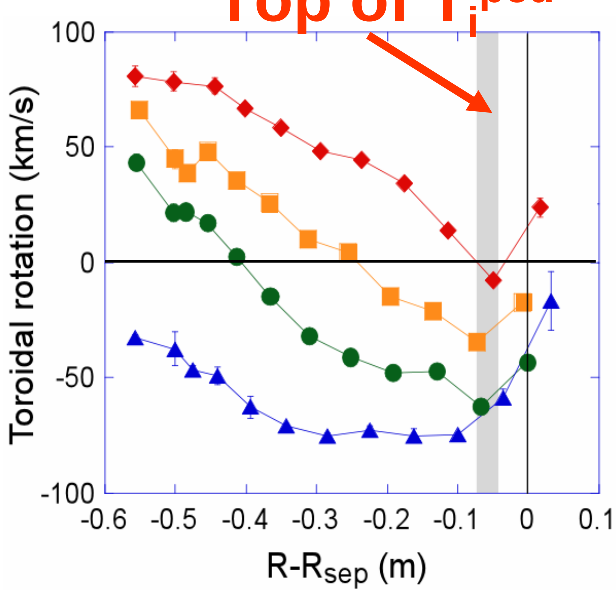
- Larger counter rotation leads to smaller ELM and higher f_{ELM}.
- New parameter for access to grassy ELM regime.

  absolute value? or sign?

- No edge fluctuations were observed even in larger counter rotation phase.

Top of T_i^{ped}

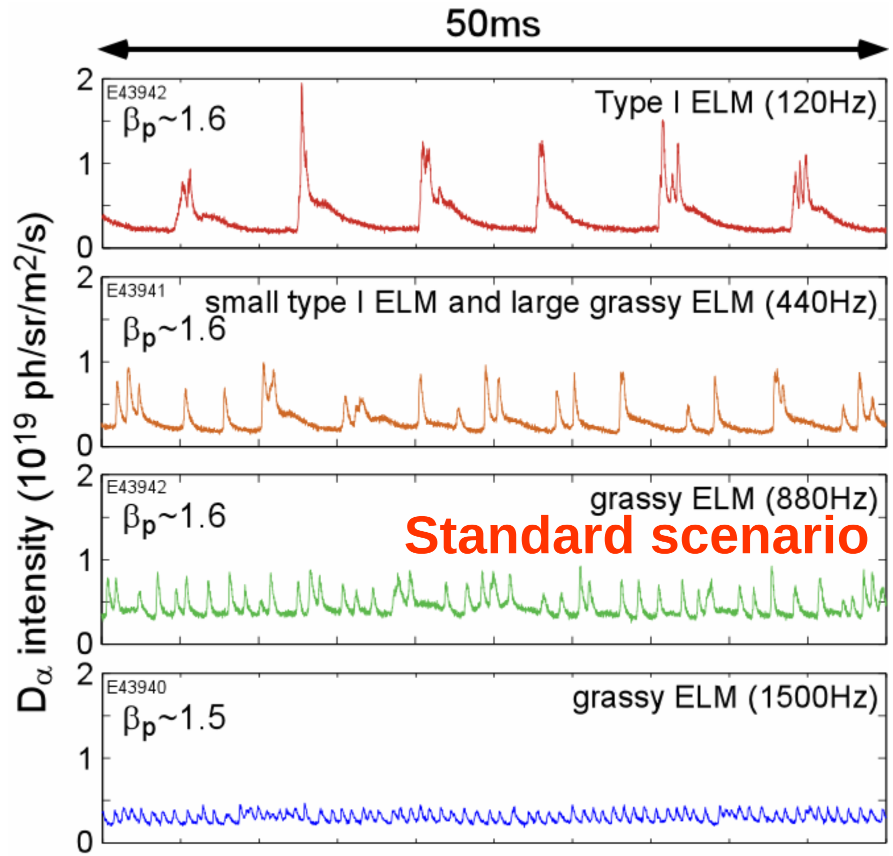


Toroidal rotation profile

(q_{95}~4.9, δ~0.6)

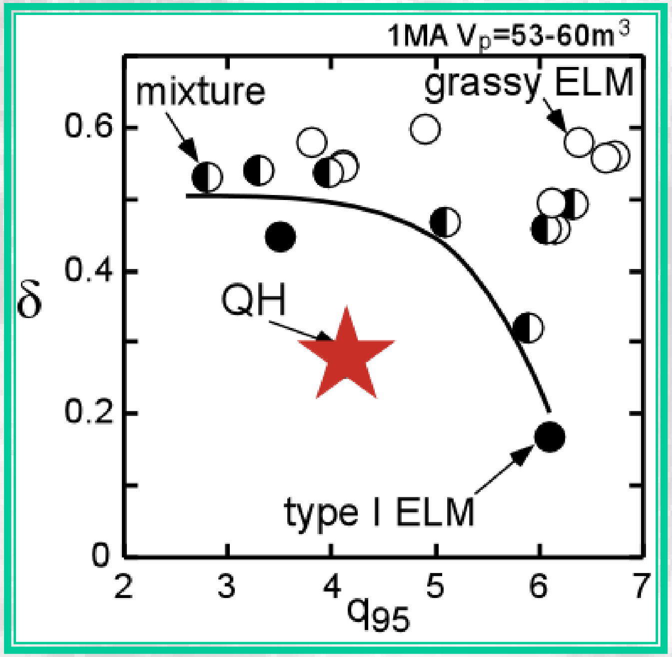
small CTR-V_T

large CTR-V_T



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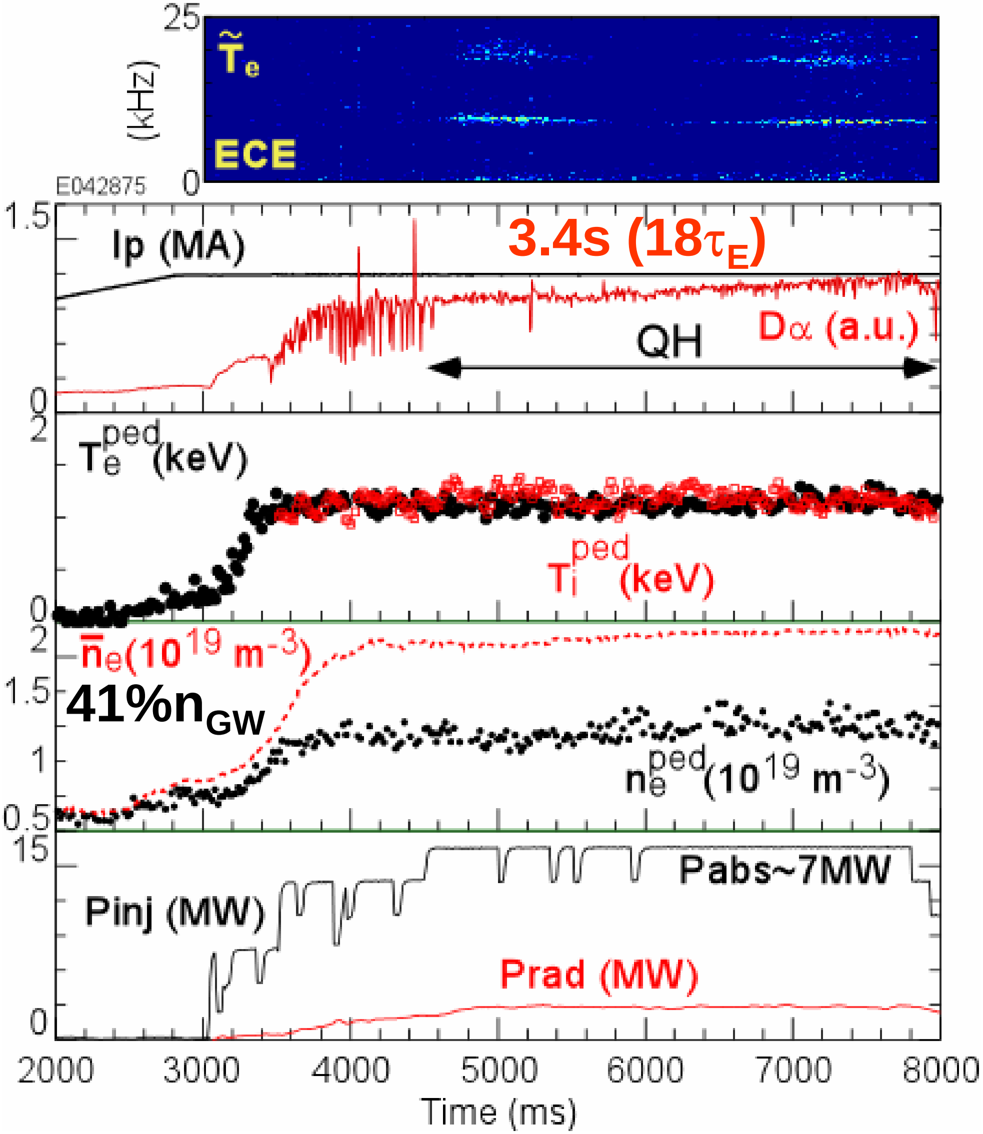
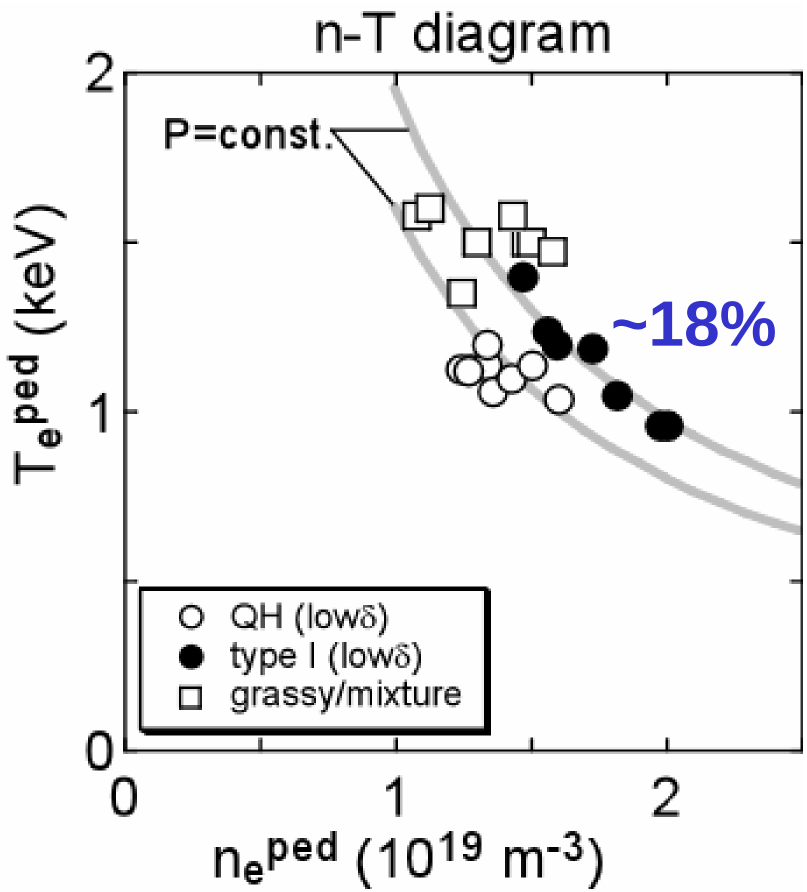
- **Pedestal parameters were almost constant during QH phase.**





T_i^{ped} was also smaller in QH phase

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

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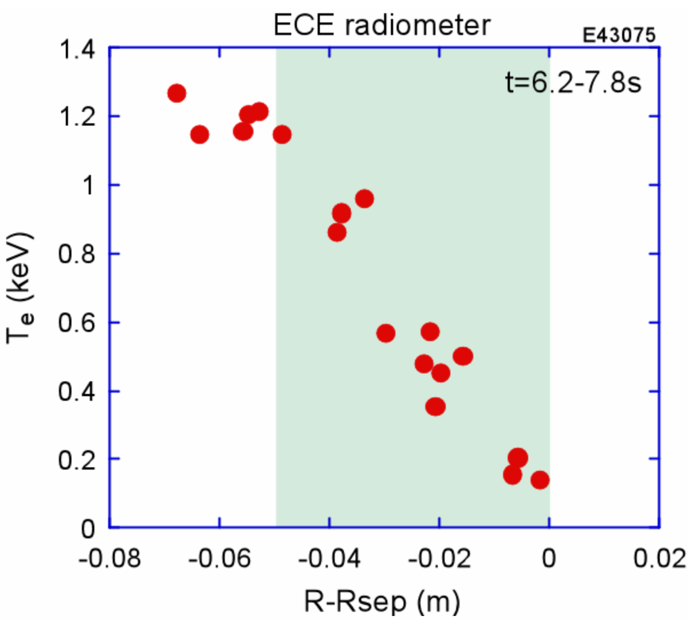
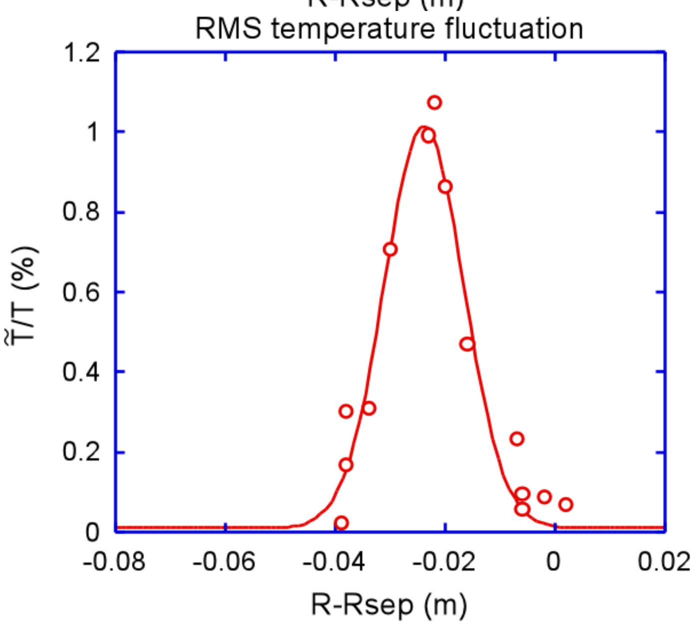
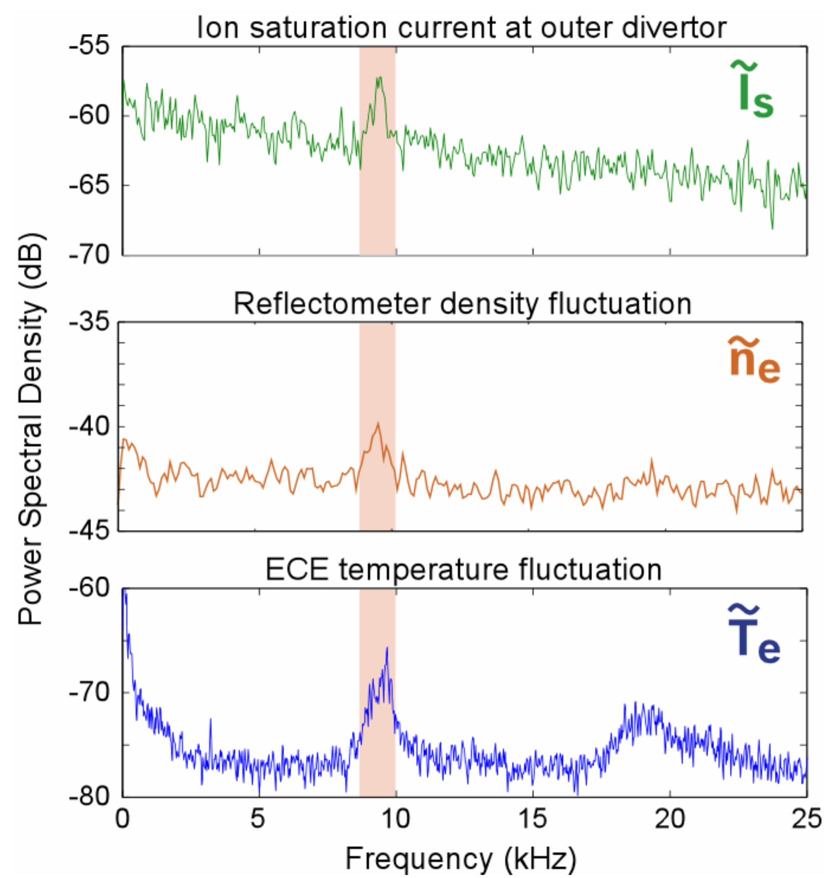




- **Maximum amplitude of ~1% was observed at ~2cm inside separatrix.**
- **Ion saturation current at divertor target and edge density at outer mid-plane are also modulated with same frequency.**



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

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QH phase with co-NBIs

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

☺ **better confinement**

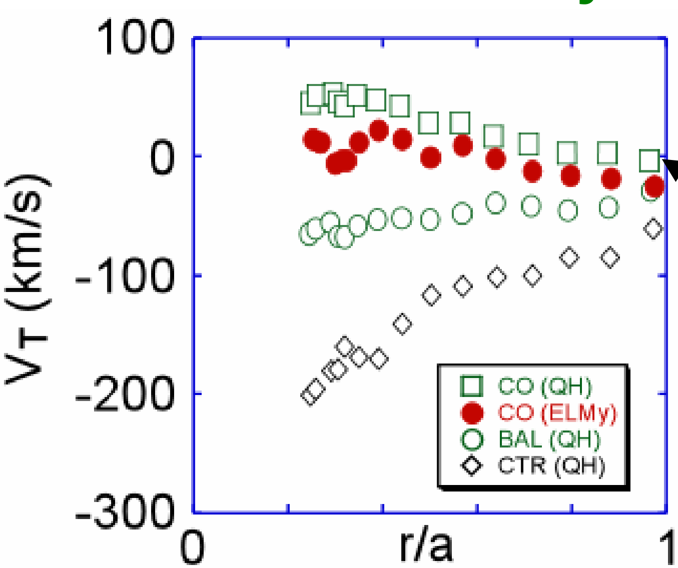
H_{89}~1.7 (⇐~1.5)

☺ **smaller P_{rad} ~0.8MW (⇐~1.5MW)**

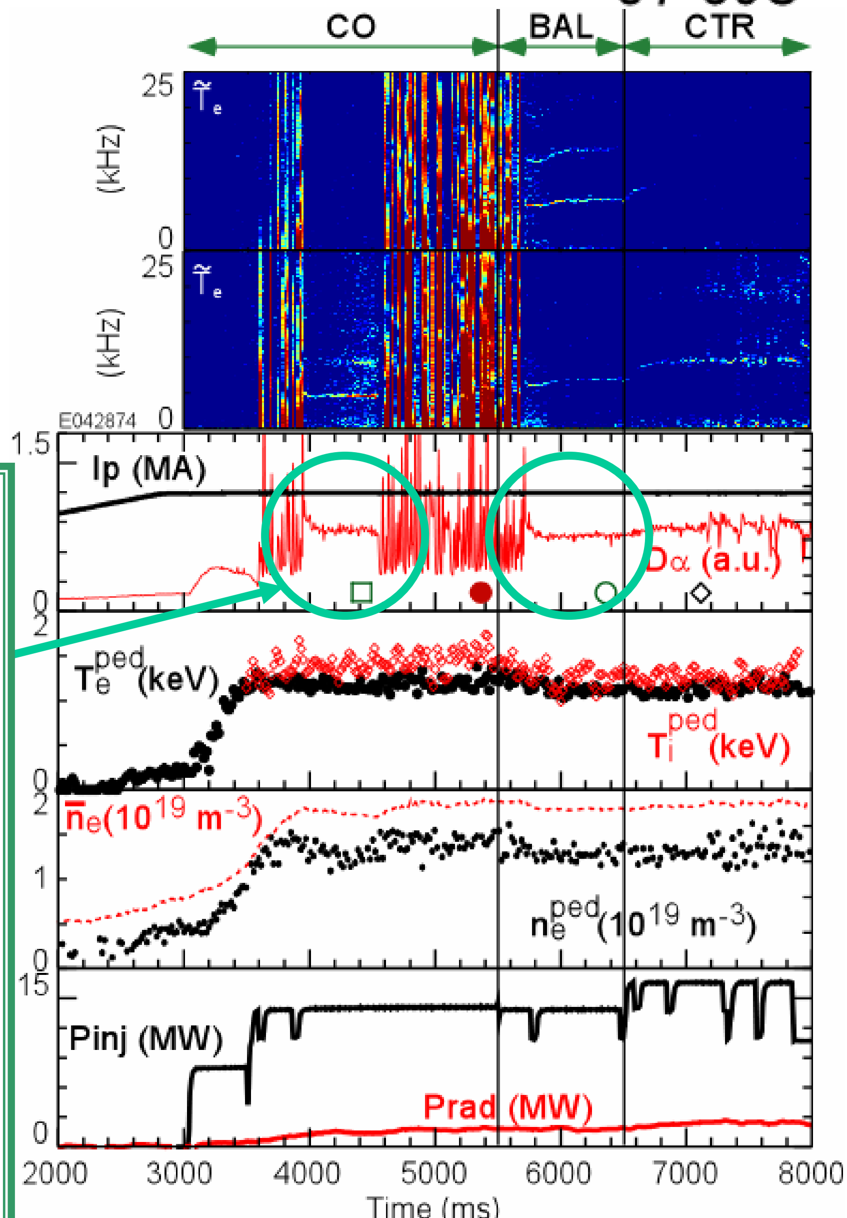
Z_{eff} ~2.8 (⇐~3.3)

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