7th Annual Theory and Simulation of Disruptions Workshop
Princeton Plasma Physics Laboratory, Princeton, New Jersey
August 5-7, 2019

EUROfusion

# Locked mode dynamics prior to disruptions in high performance JET-ILW plasmas

**Lidia Piron**

with thanks to T. C. Hender, E. Joffrin, F. Auriemma, P. Buratti, R. Paccagnella, P. Zanca, C. Challis, M. Fontana, S. Gerasimov, R. Henriques, L. Marrelli, P. Lomas, G. Pucella, F. Rimini, D. Terranova and JET Contributors

JET

Università degli Studi di Padova

CONSORZIO RFX
Ricerca Formazione Innovazione

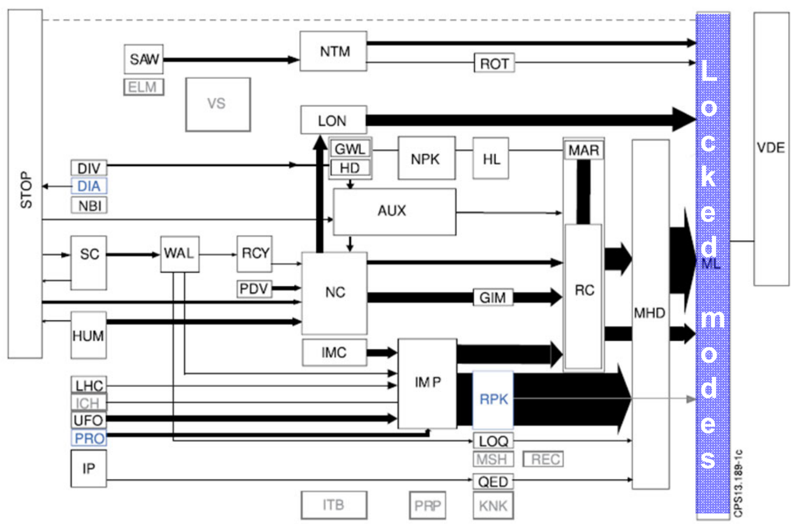
This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

# Motivation

- Nearly all JET disruptions eventually exhibit non-rotating modes, a.k.a. Locked Modes (LM).

***Survey of disruption causes at JET***

[P.C. de Vries et al 2014 PoP 21 056101]




**The reason of mode locking and a possible control strategy to avoid the associated disruptions are presented for JET-ILW plasmas.**

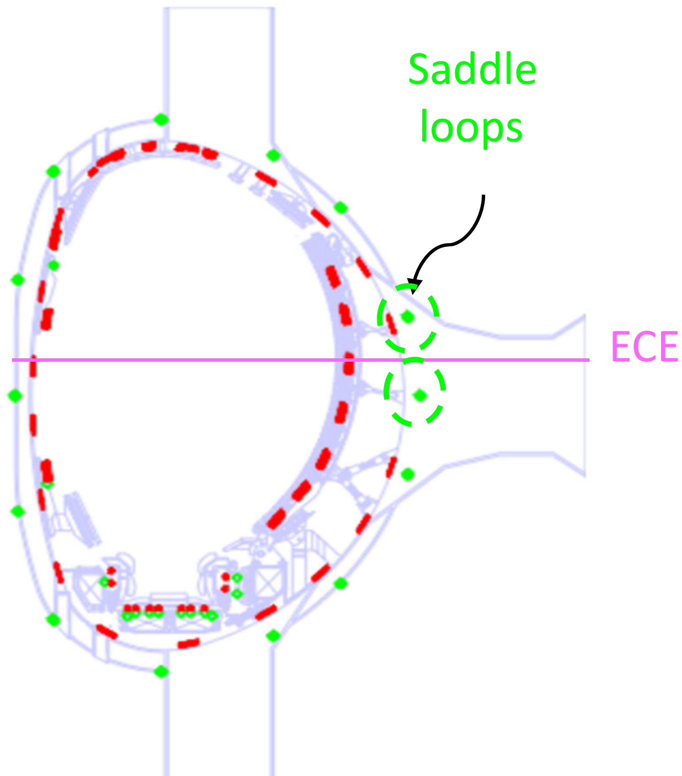
# Outline

1. Locked mode dynamics in JET-ILW plasmas
2. Mode triggering mechanism
3. Statistics of locked mode dynamics
4. Error field correction studies
5. Conclusions and future work

# Framework of the study

- JET-ILW plasmas suffer for the presence of LMs which cause the intervention of the Disruption Mitigation Valve (DMV) in ~ 6% of discharges in the plasma current ramp-up phase, and in ~ 60% of discharges during H-mode termination phase.

- LM dynamics has been investigated by analysing saddle loop and Electron Cyclotron Emission (ECE) signals.

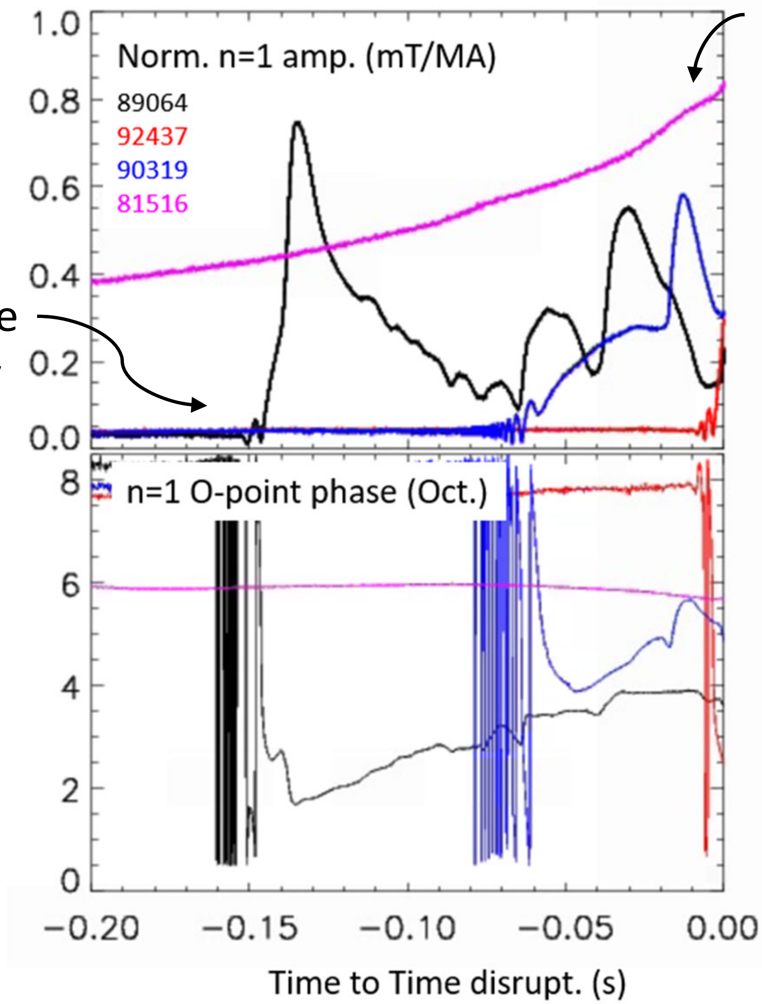


# A glance at LM dynamics in JET-ILW plasmas

- LMs exhibit various behaviours:

Low density born-locked mode

Rotating tearing mode which finally locks



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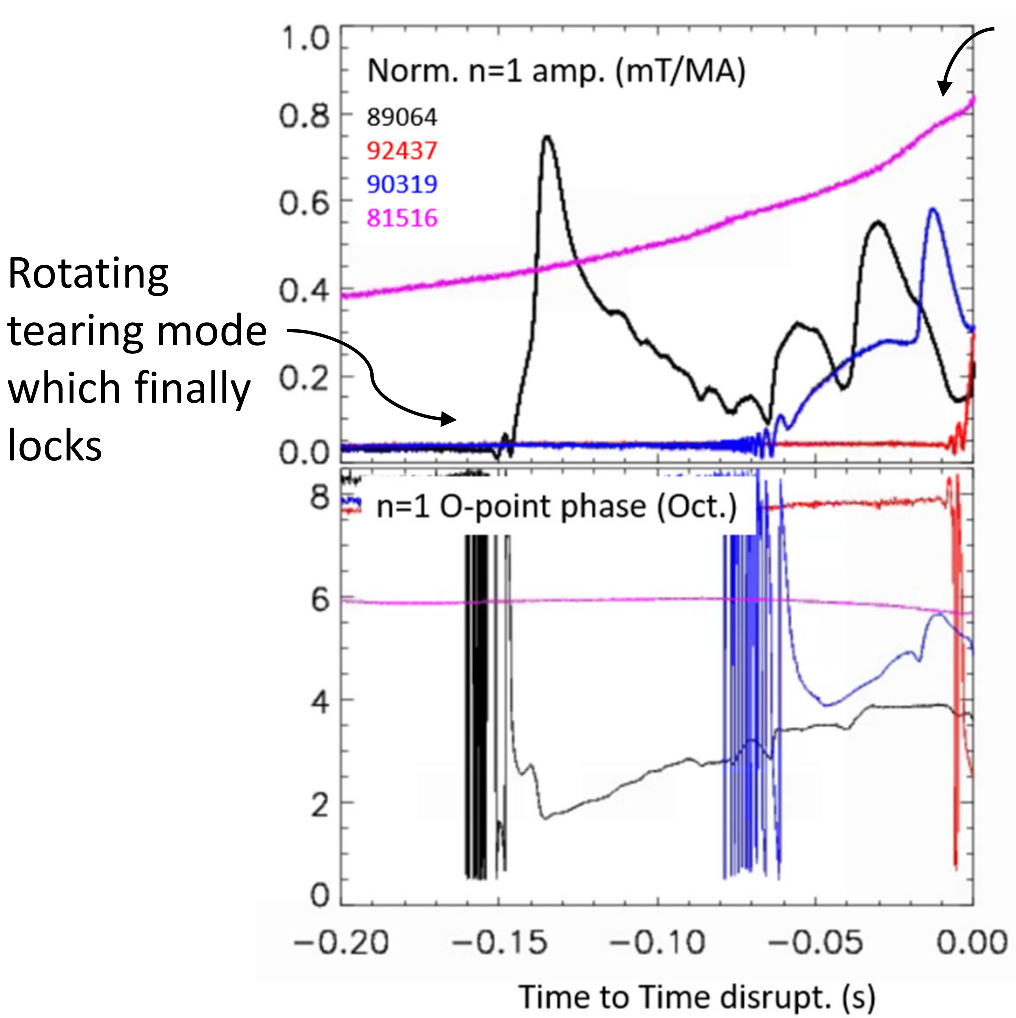
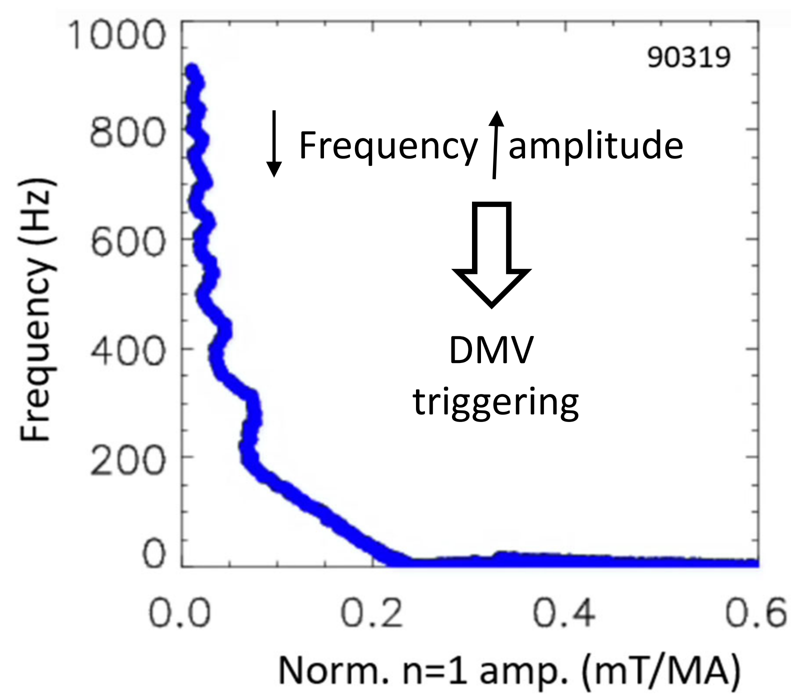
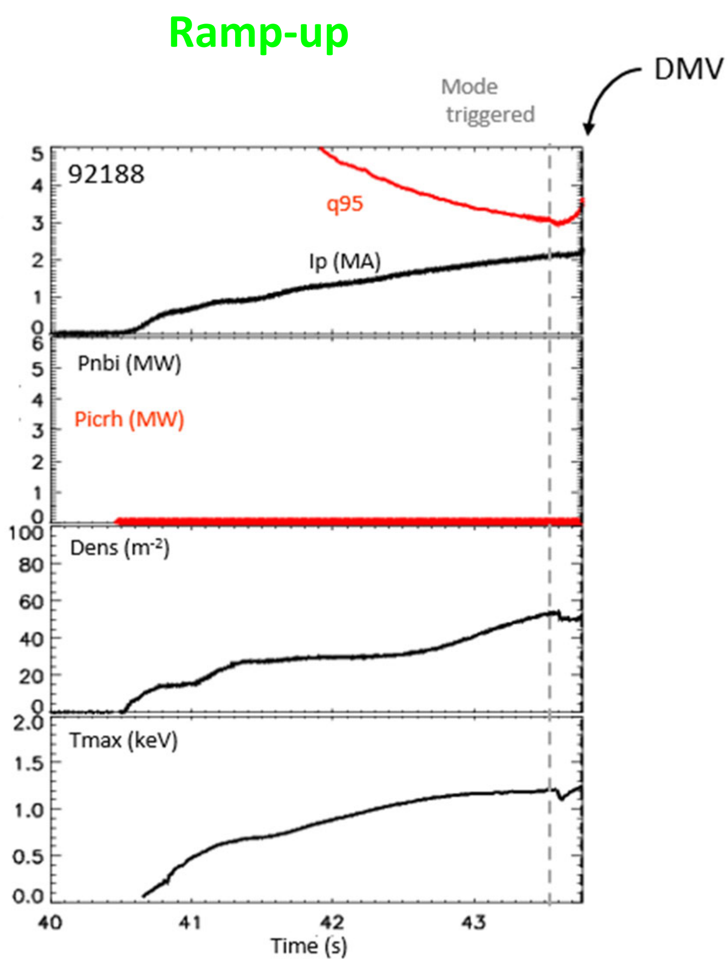
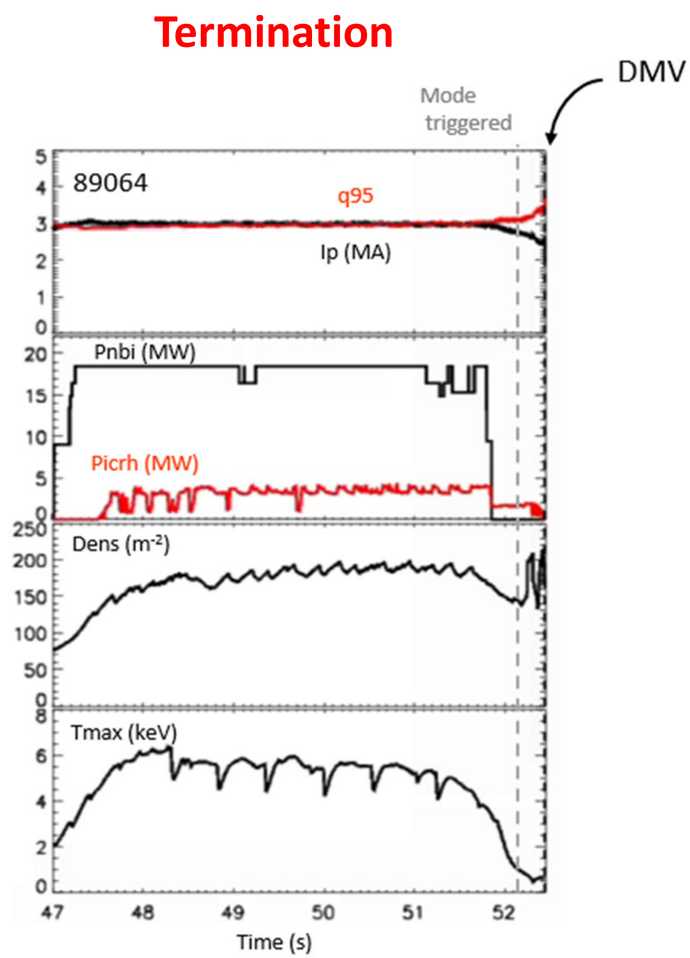


# LM dynamics in JET-ILW plasmas

- LM can be observed during the current ramp-up and also during the H-mode termination phase in JET-ILW plasmas.



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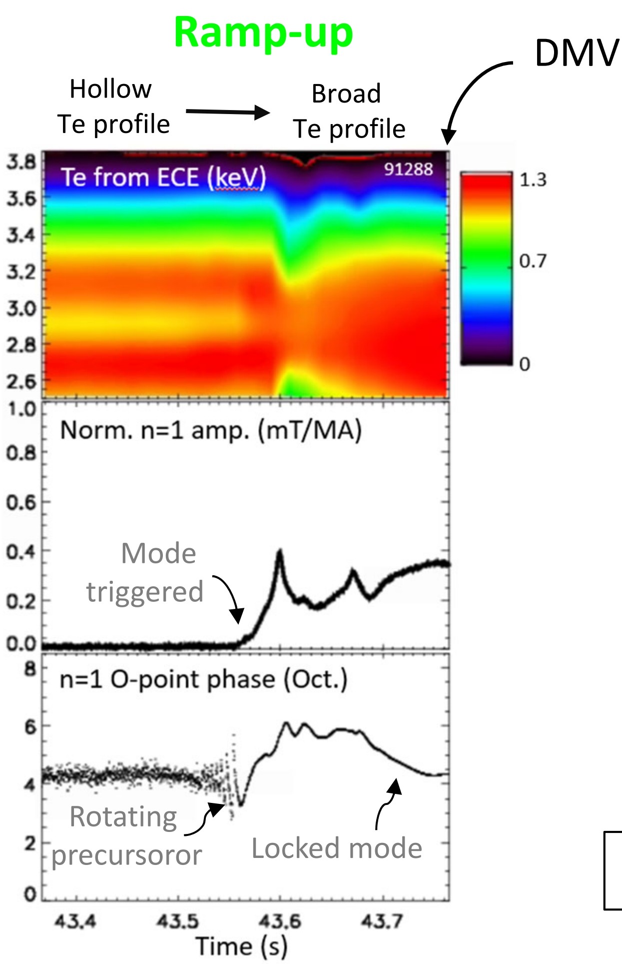
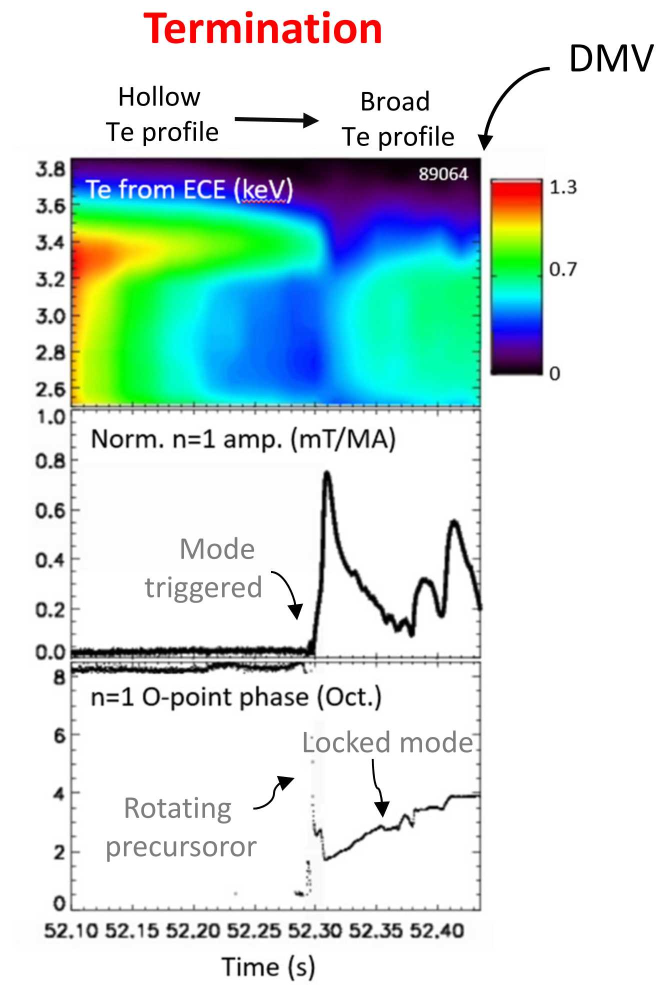



Impurity accumulation
↓
Te cooling
↓
Hollow Te profiles
↓
**LM triggered**
↓
**DMV triggering**



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# Mode driving mechanism

- The change of current density gradient, $\nabla j$, at q=2, associated with the formation of hollow $T_e$ profiles, is the drive of tearing mode instability.

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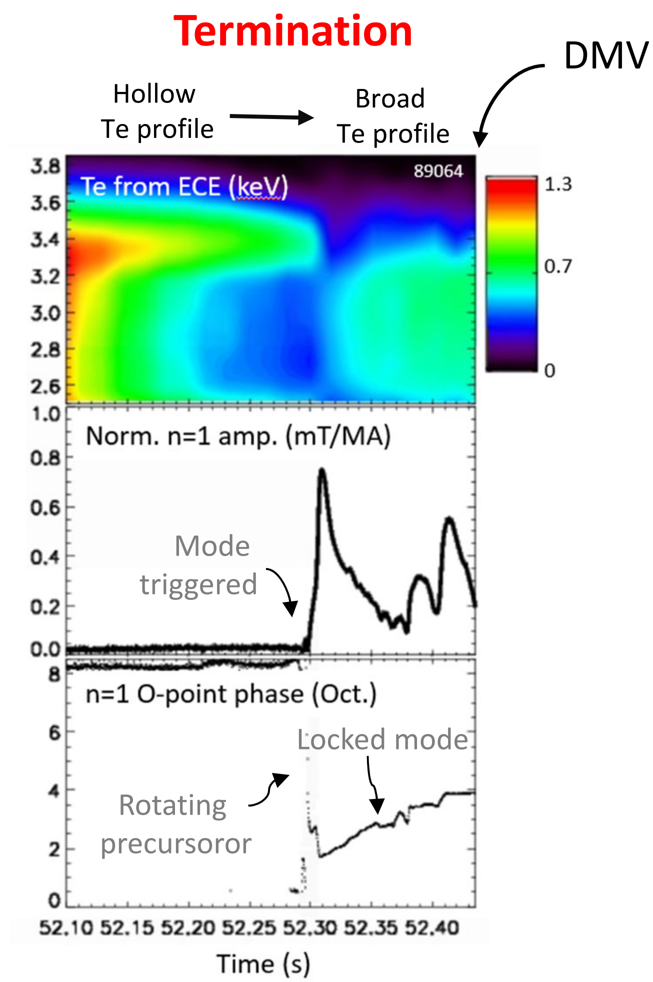

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[Furth H.P. et al. 1973 Phys. Fluids 16 1054]

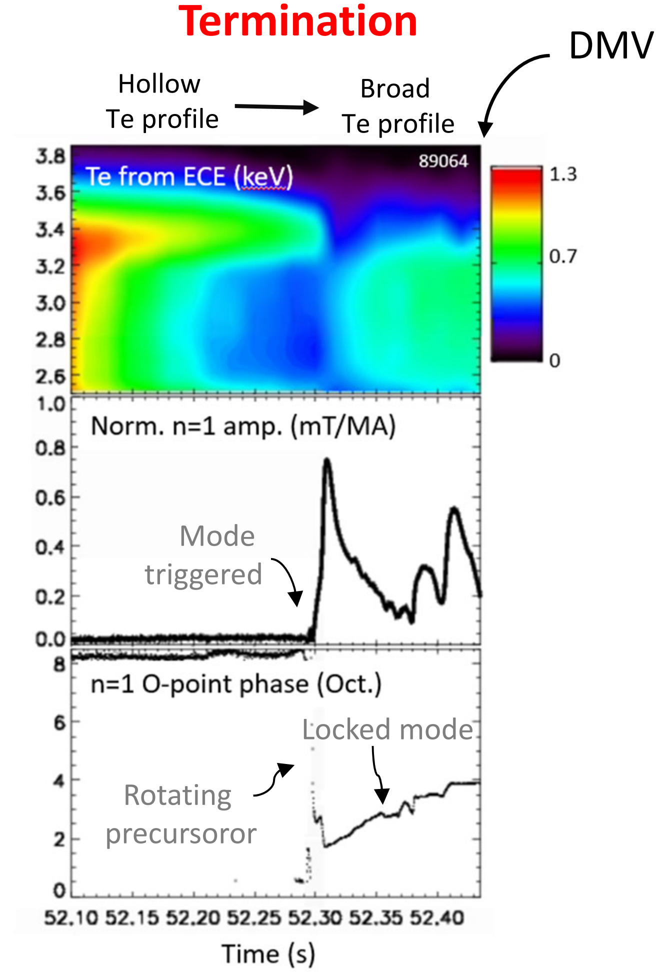
**Local tearing instability parameter:**

$$\lambda = -\frac{1}{2}\frac{r_s R \mu_0}{n s B_T}\frac{dj}{dr}$$

*Computed from EFIT++ (magnetics & pressure constrains) and TRANSP outputs*

Impurity accumulation → $T_e$ cooling → Hollow $T_e$ profiles → **LM triggered** → **DMV triggering**

**Termination**



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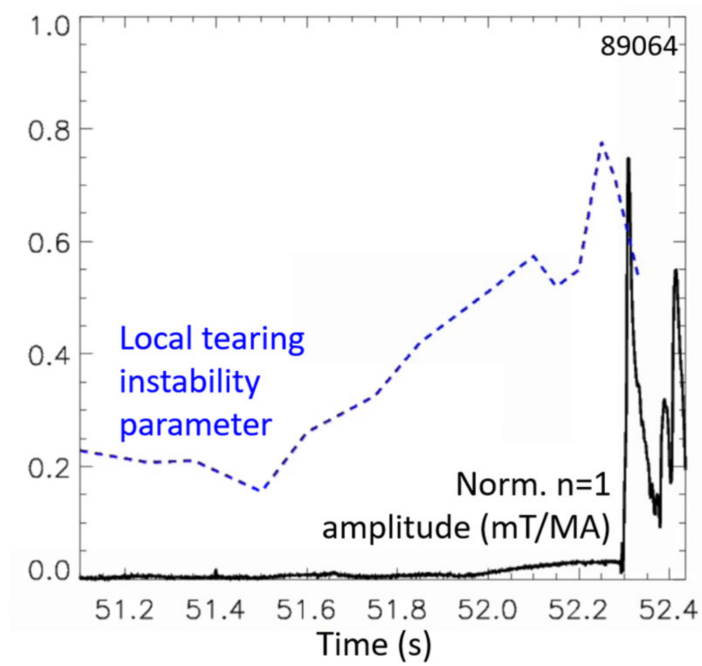

# Should we always use $\lambda$ as parameter for mode destabilization?

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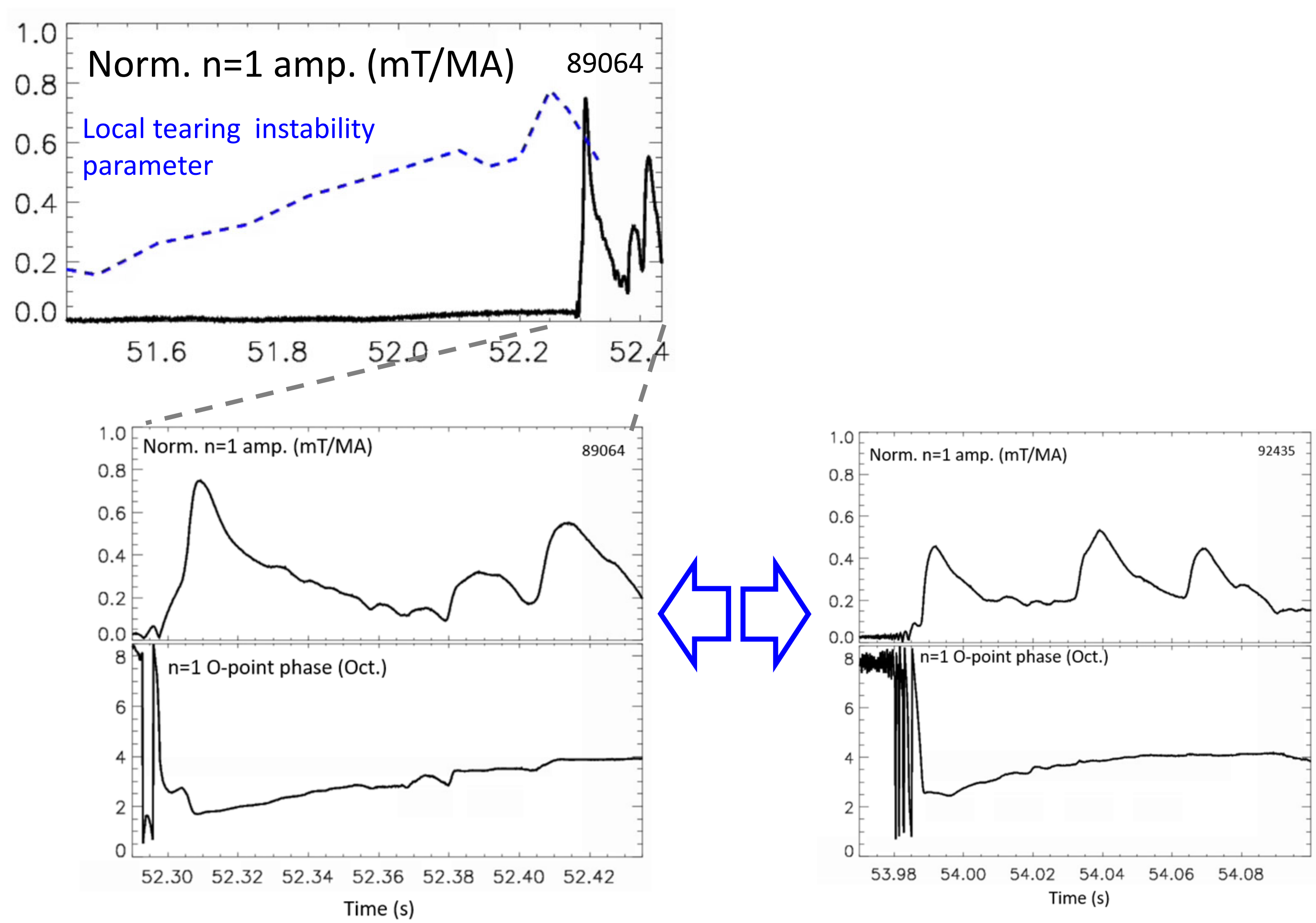

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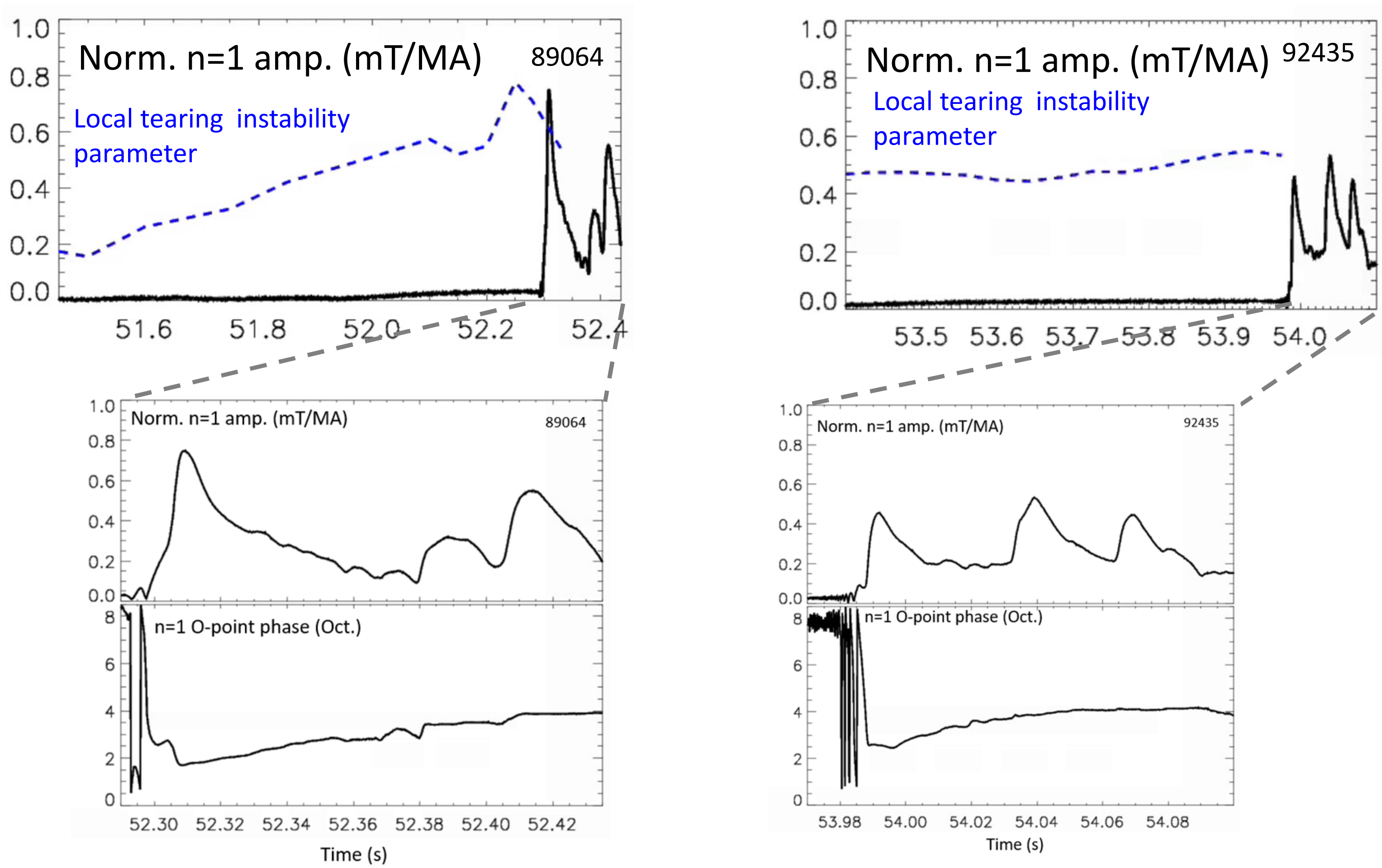
- λ, the local tearing instability parameter, is not suitable for predicting the mode destabilization without edge cooling.



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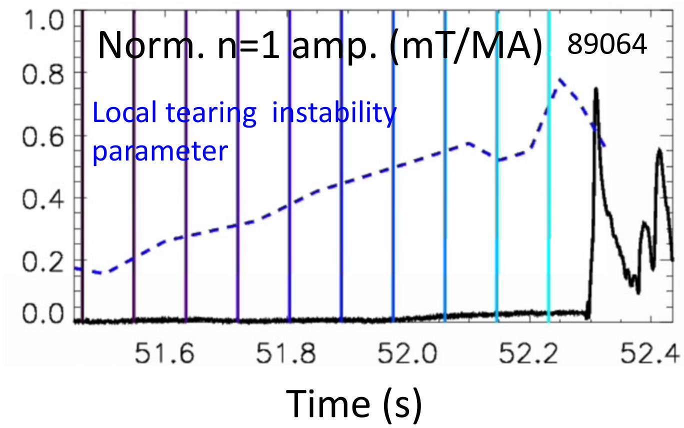


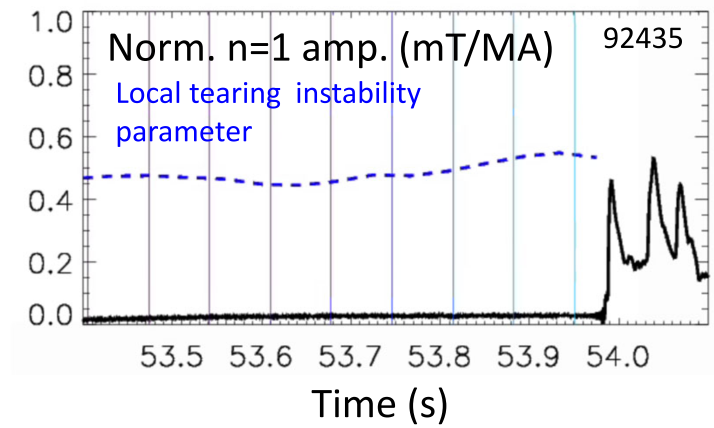


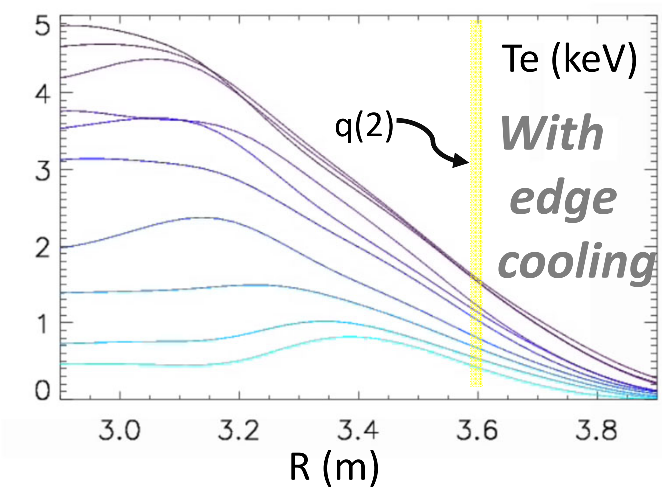


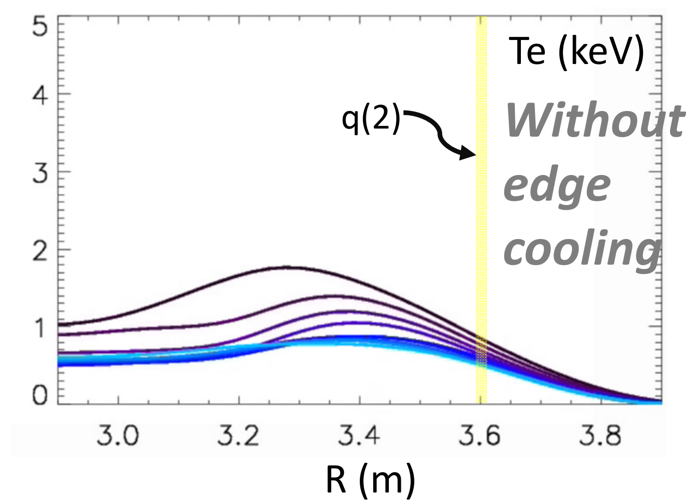

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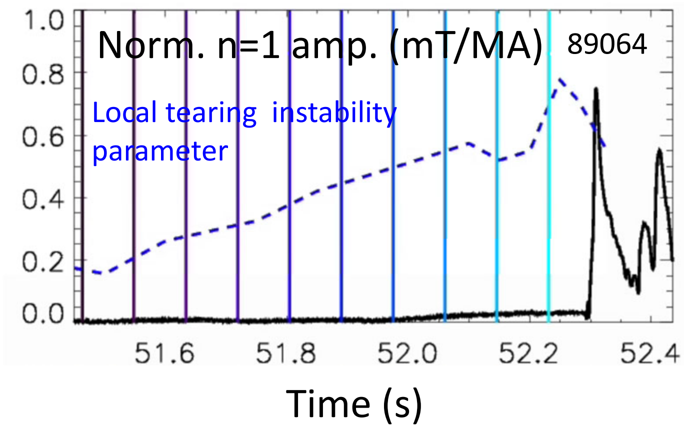
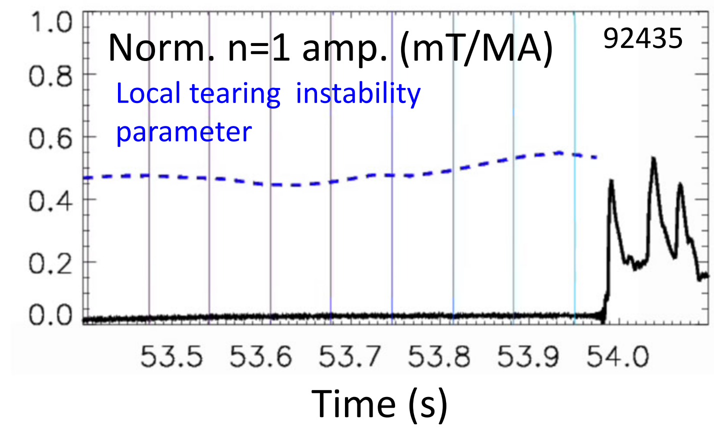



Change of Te

↓

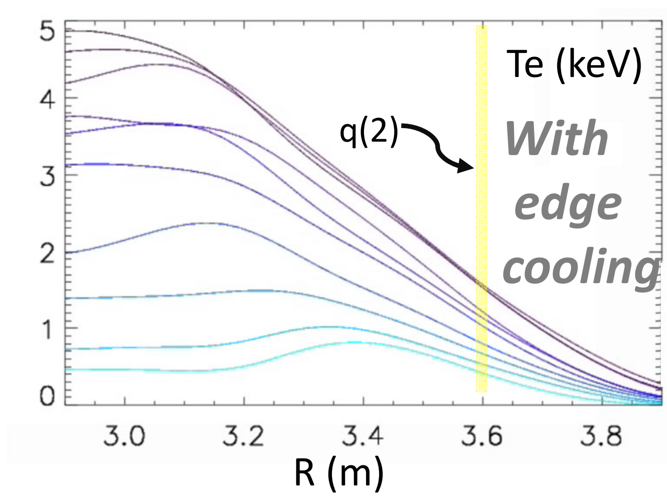
Plasma resistivity

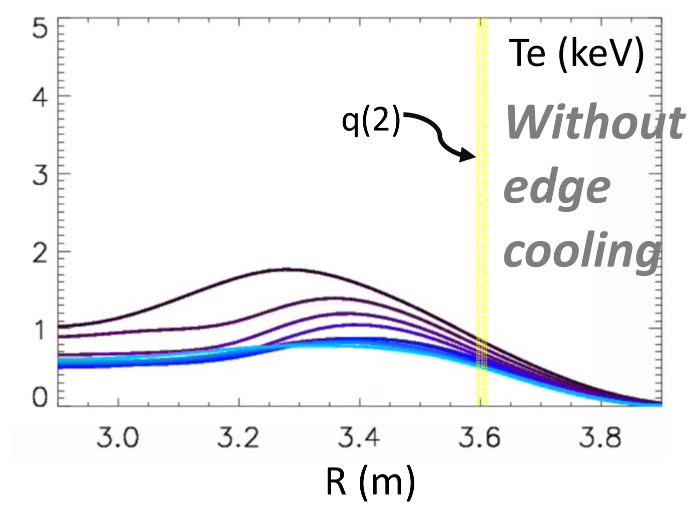
↓

Current diffusion

↓

$$\lambda = -\frac{1}{2}\frac{r_s R \mu_0}{n s B_T}\frac{dj}{dr}$$



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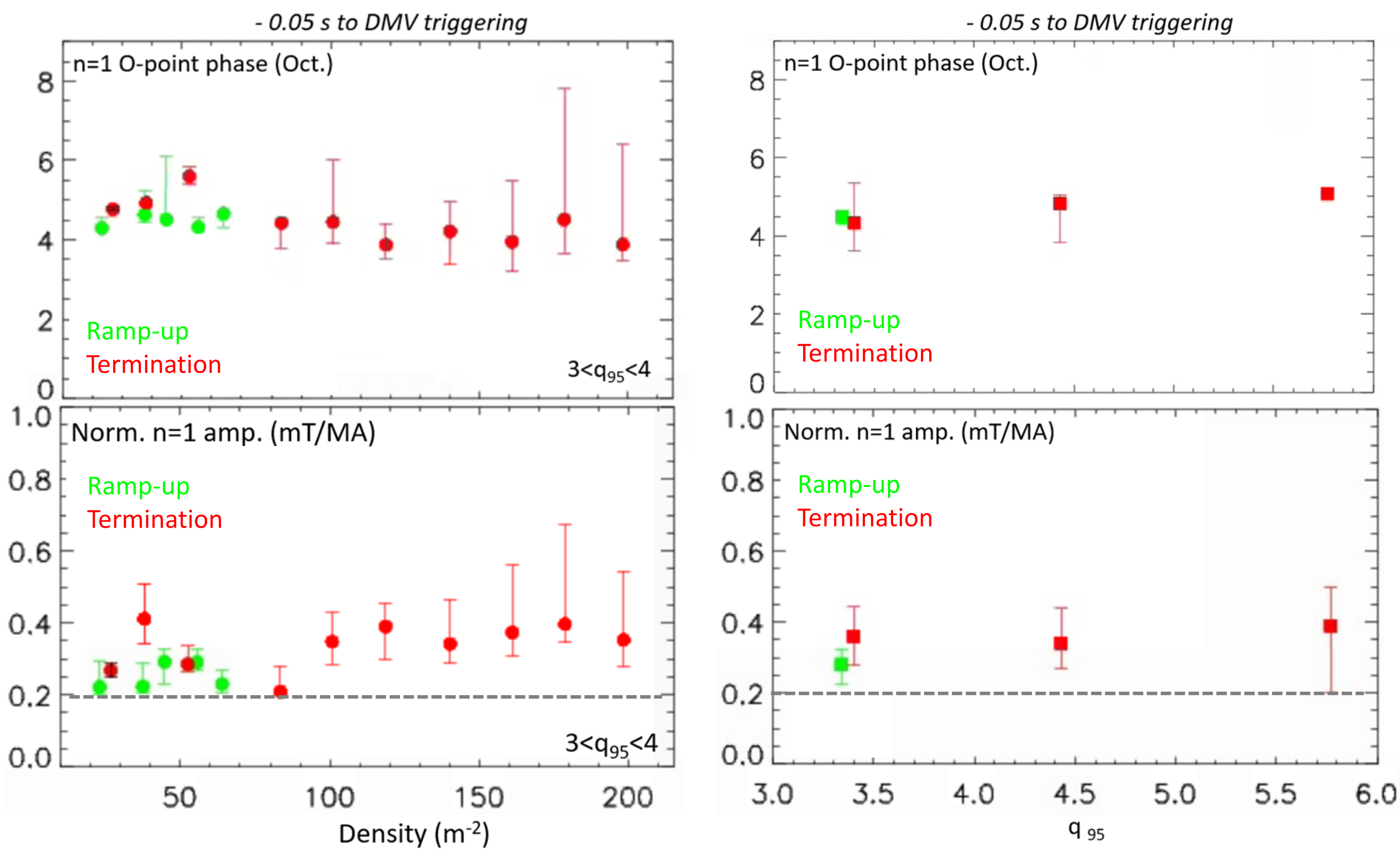
# Statistics of LM dynamics

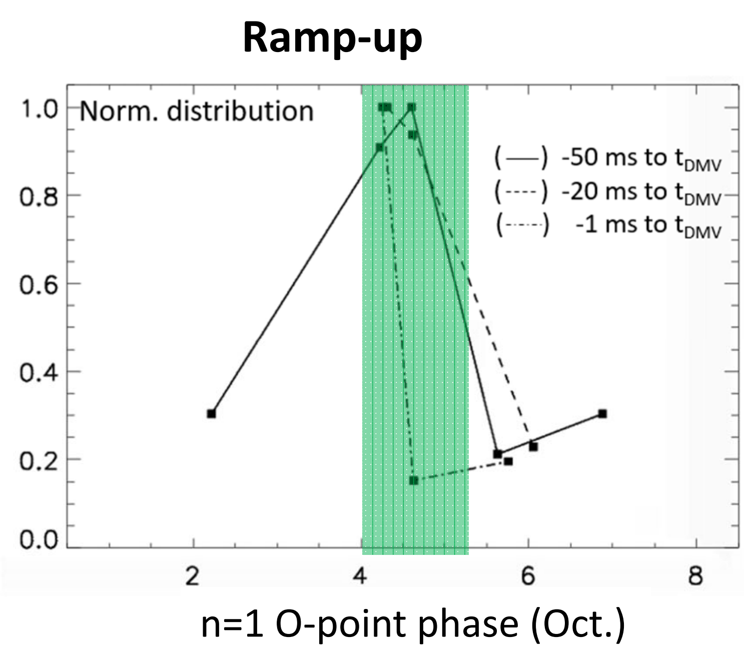
- The normalized n=1 amplitude and the n=1 O-point phase do not depend on density and q95.

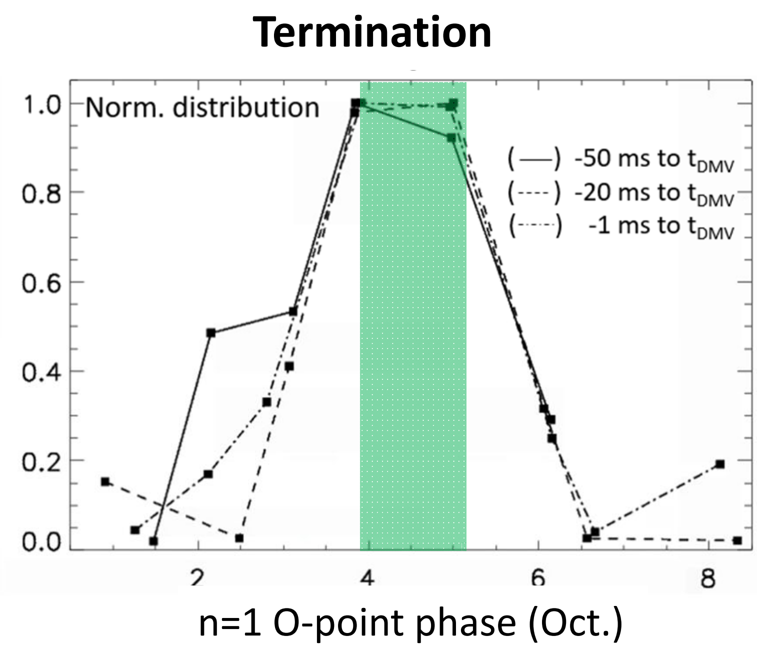


# LM dwells at JET intrinsic error field position

- The rotating tearing mode slows down due to wall image currents and then finally locks, dwelling at certain toroidal locations, i.e. octants 4-5
  → Intrinsic Error Field (EF) position.

[Fishpool G.M. et al 1994 NF 34 109]



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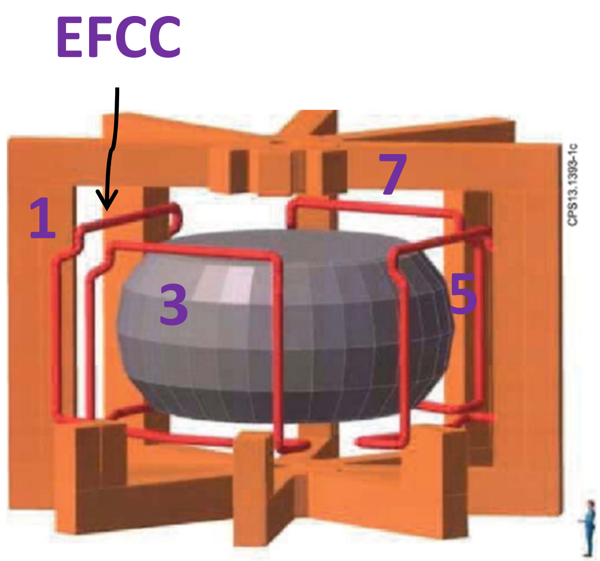
# EF correction strategy

- JET is equipped with 4 ex-vessel EF Correction Coils (EFCC).
- The intrinsic EF is associated with the current distribution in poloidal field coils. [Buttery J. et al 2000 NF 4 807]
- To identify the intrinsic EF and deduce the EFCC currents for EF compensation, the compass scan method has been applied in the past (2006):
  - performed in high-triangularity shape 1.6T/1.5MA plasmas,
  - ramped up the current in one pair of the EFCCs until a locked mode is formed,
  - repeated with four phases of applied field.



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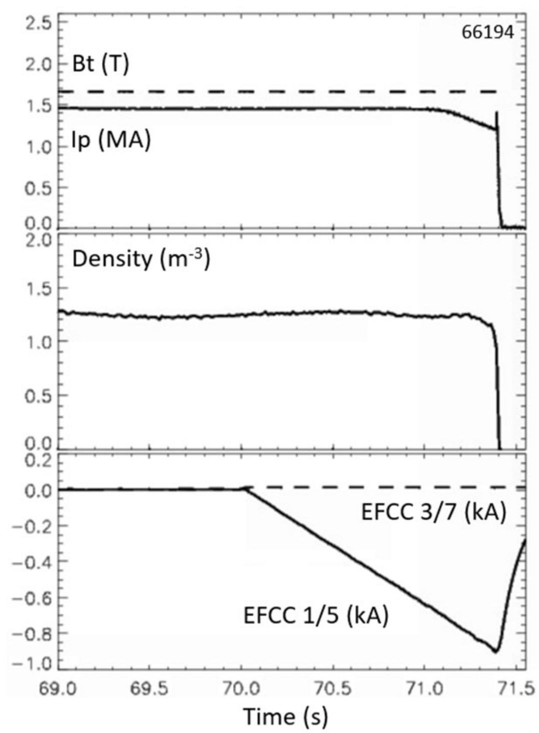
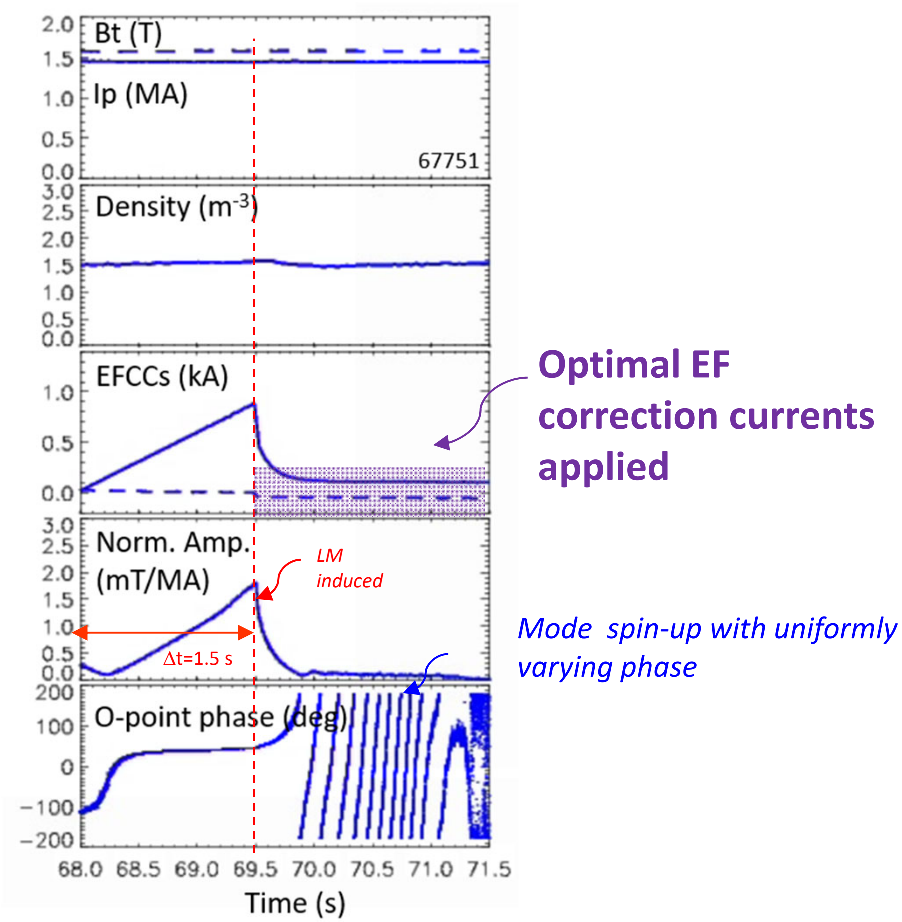
→ Deduced EFCC currents:
EFCC 3/7 =160 A &EFCC 1/5=-40 A



# Proof of principle experiment for testing EF compensation

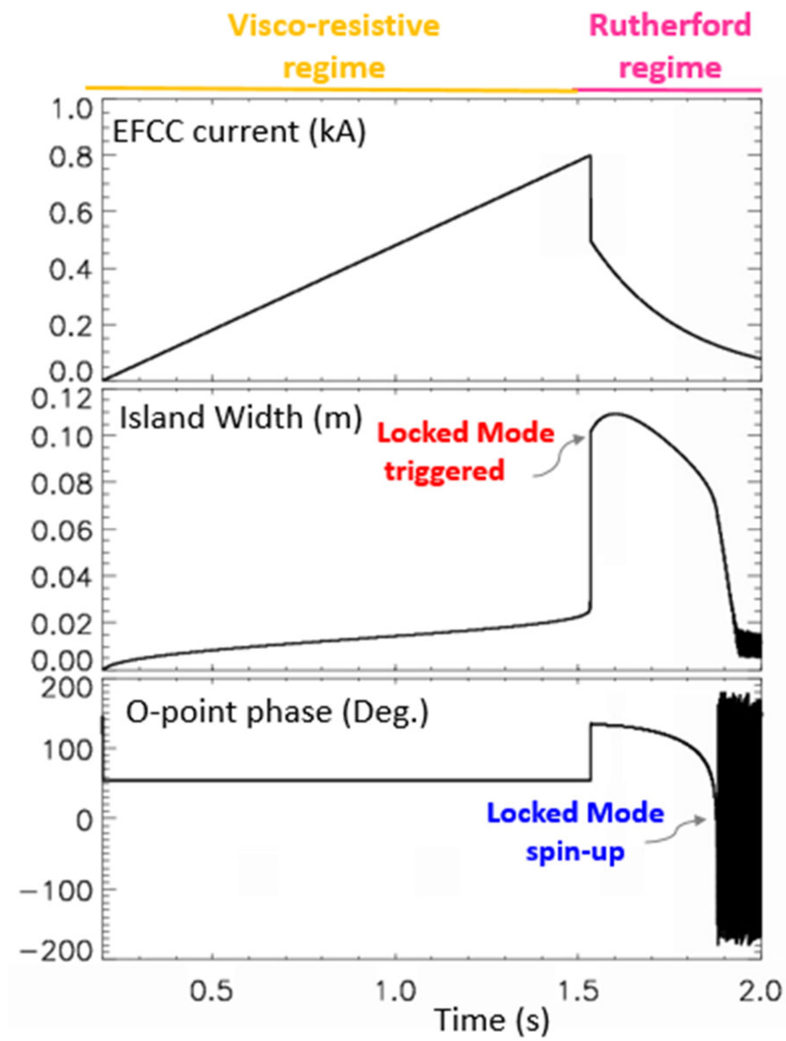
- An experiment has been performed using the EFCCs to induce a LM and afterwards to compensate the intrinsic EF.



# Modelling of mode spin-up mechanism

- The cylindrical RFXlocking code[1] has been adapted to JET tokamak configuration:
  - the visco-resistive regime has been applied to model the external magnetic field penetration and the LM formation[2]
  - the Rutherford regime is used to model the subsequent magnetic island evolution using several formulations [3-5]

- RFXlocking modelling shows that by reducing the external magnetic field (in the experiment this means EF correction), the mode starts to rotate, in agreement with experimental findings.




1 Zanca P. et al 2015 NF 55 043020, 2 Fitzpatrick R. et al 1993 NF 33 1049, 3 Wesson J., Tokamaks, Oxford University Press, 4 Militello F. et al 2006 PoP 13 112512, 5 Arcis N. et al 2007 PoP 14 032308

# Towards EF correction experiments

- The proof-of-principle experiment suggests that EF correction can spin a LM up and make the mode rotate with an uniformly varying phase.

- The EFCCs system could thus be exploited to maintain the mode rotating in the low frequency branch (about 10Hz), while keeping its amplitude finite. This can prevent the DMV triggering.

- An experimental proposal has been accepted by JET scientific committee which aims at avoiding the locked modes, and experiments will be performed in future JET experimental campaigns:

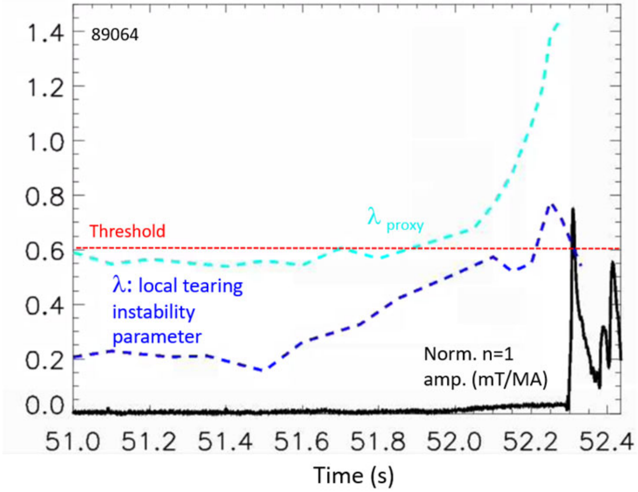
  - The frequency response of JET wall has not been affected by the change of PFC, i.e. from Carbon to Tungsten and Beryllium.
  - EF correction currents depend on the plasma shape. EFCC currents will need to be optimized for the plasma shapes used in the more recent JET campaigns, mostly low-triangularity plasmas.
  - Definition of EF control strategy.

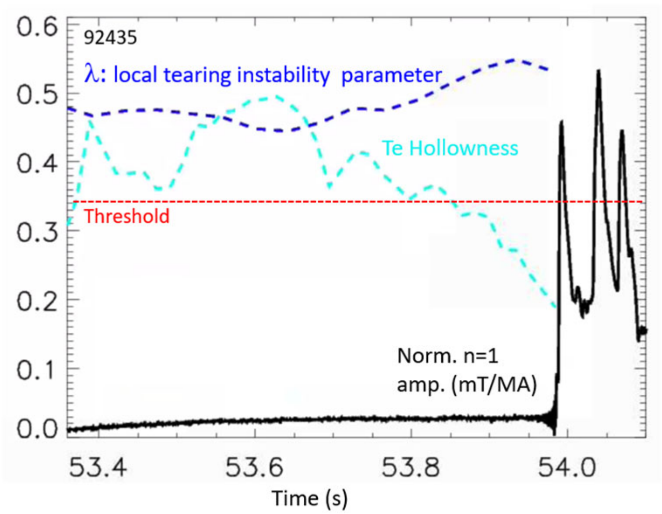
# EF control strategy

- Feedforward EFCC currents can be applied for the entire discharge duration or when proper indicators exceed a threshold value:

  - With edge cooling, a promising indicator is $\lambda_{proxy}$ which is based on a simplified version of $\lambda$, the local tearing instability parameter. $\lambda_{proxy}$ can be calculated in real-time considering Spitzer-like resistivity and flat $Z_{eff}$, i.e. $\nabla j \propto \nabla Te / Te$

  - Without edge cooling, $\lambda_{proxy}$ can not be used being $\nabla j$ constant. The Te hollowness parameter: $Te^{core} / Te^{max}$ will be adopted.



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# Conclusions and future work

- A systematic analysis of LM dynamics before DMV triggering has been carried out for JET-ILW plasmas in the plasma current ramp-up phase and during H-mode termination phase.
  - This study highlights the tendency of the mode to lock at the intrinsic EF position, i.e. octants 4-5.
  - Spin-up of induced LMs has been observed in 2006 when correcting the intrinsic EF by using EFCCs.

- Based on these experimental results, the exploitation of EFCC system is proposed to avoid disruptions induced by LM in future JET campaigns.
  - The compass scan method will be use to identify the EF correction strategy and dedicated experiments will be performed to test the effectiveness of the EF correction recipe in avoiding DMV triggering.

Future work:

- Modelling of tearing mode triggering mechanism without edge cooling.
- Plasma response modelling by MARS-F code.
- Compare JET EF studies with corresponding results obtained in AUG and COMPASS devices.