Detection of Turbulence Driven Magnetic Islands in Tokamaks: Towards Neural Network?

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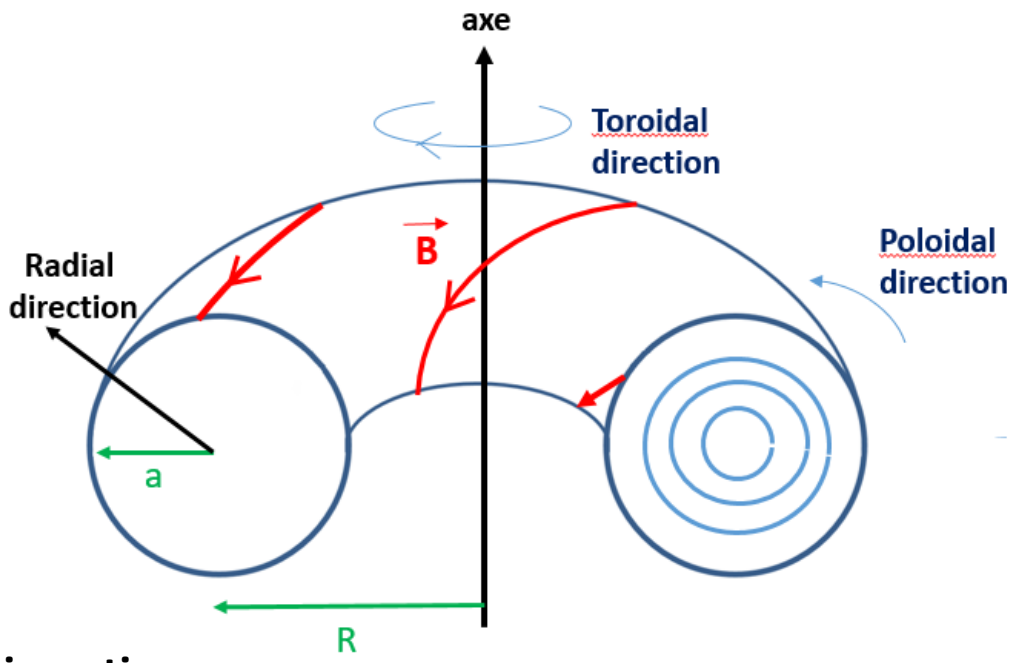
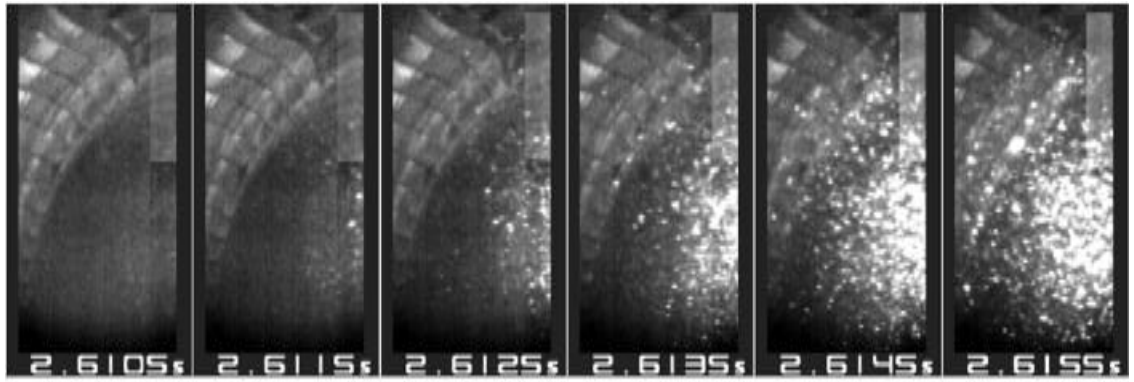
A basic picture of a Tokamak



Disruption:

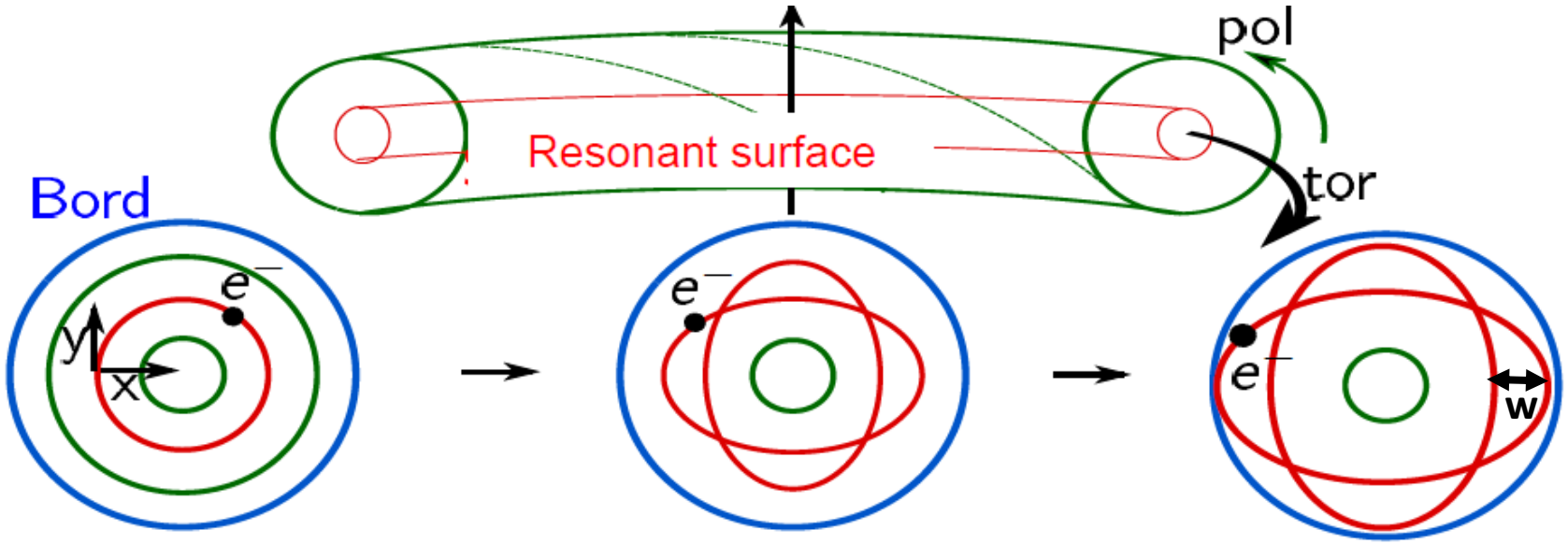


Tokamak

Magnetic field fluctuations → **Current gradient** → **MHD instabilities (cm~ m)/NTMs** → **Disruption (sudden stop)** → **Damage on devices**

Hot core and cool walls → **N, T, P gradient** → **Microscopic instabilities (μm~ mm)** → **Turbulence** → **Confinement loss**

What is magnetic reconnection?



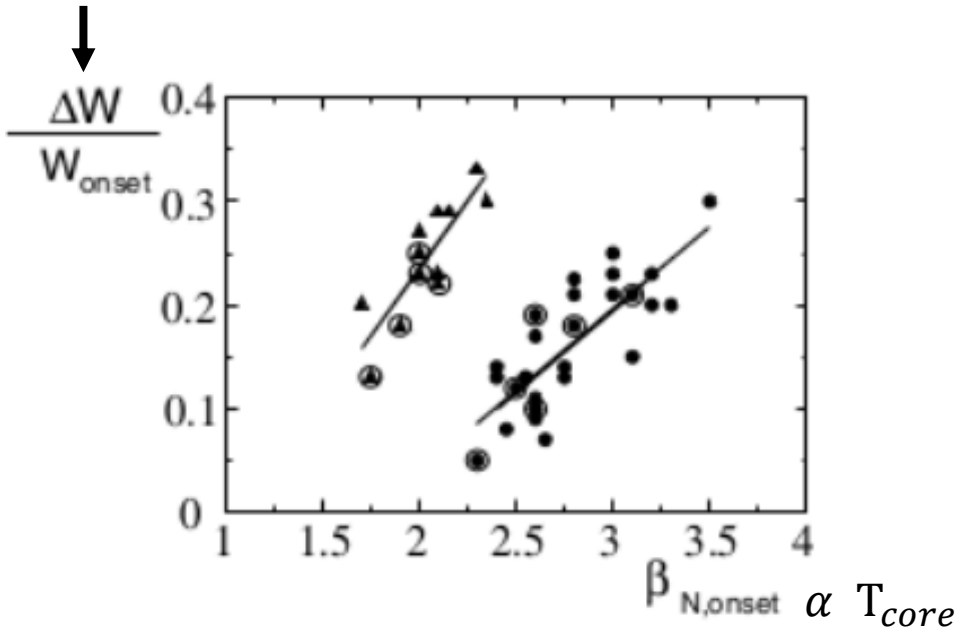
- Equilibrium

- Tearing instability
- Reconnection of magnetic field lines
- Generation of magnetic islands

- Disruption

Impact of NTMs, the magnetic islands in high β tokamak regimes

Thermal energy variation



[S. Gunter et al. Phys. Rev. Lett. (2001)]

- Experimentally:

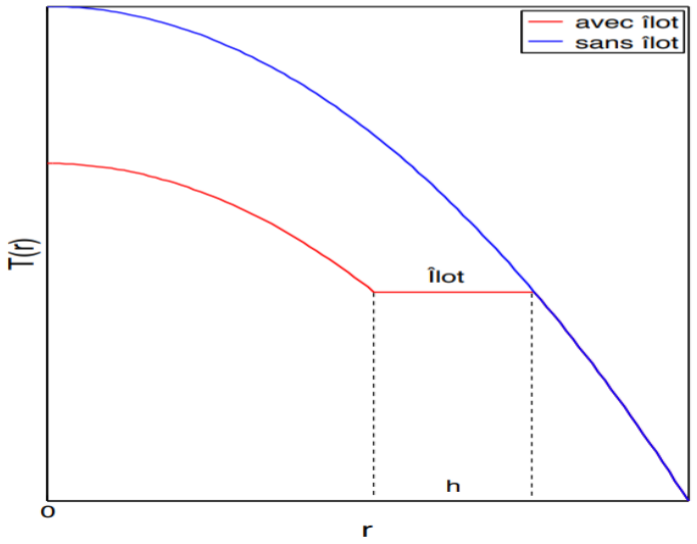
  Degradation of the energy confinement → mesurement of the thermal energy variation

- Reduction of the energy confinement due to the formation of magnetic islands on ASDEX Upgrade

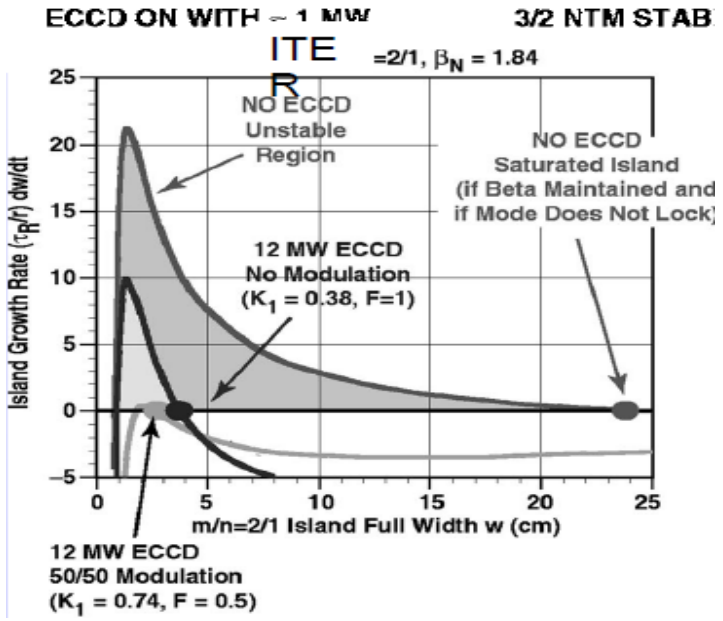
- LINEARITY between deconfiment induced by the island and β (α island size)

Challenge: Control of magnetic islands growth

Island Detection and control in Tokamak



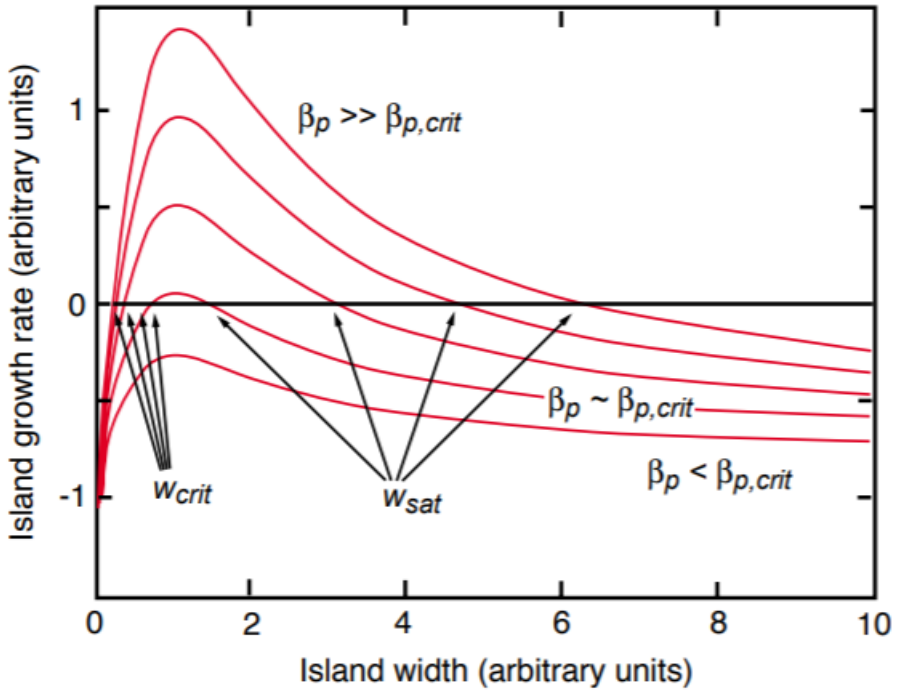
- Experimental measure of density profile by reflectrometry (Tore Supra) [L. Vermare et al PPCF 47 (2005)]
- Island presence detected electron temperature profile flattening



- Stabilization of a NTM by current injection(ECCD) on ASDEX Upgrade
- What's about ITER?
- ECCD should allow a control of NTM [R. J. La Haye POP 13 (2006)]
- Problems: - current injection is expansive and could be ineffective
  - can lead to an amplification of the NTM size

Understand the origin of NTM is an important challenge for ITER

Origin of NTMs

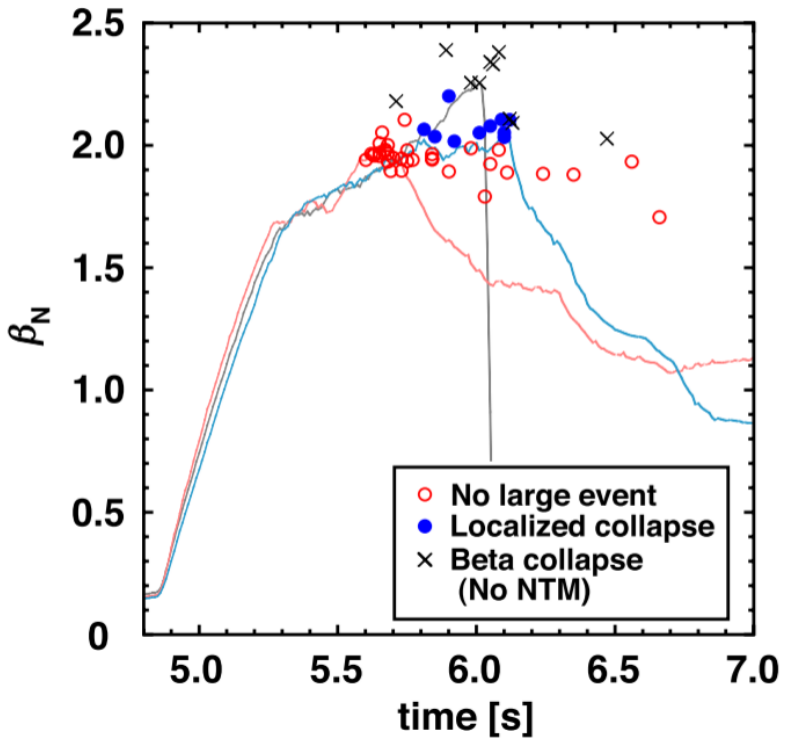


- Seed islands $(w_{crit} \leq w)$ ⇒ The onset of the seed islands is still open
- $w \geq w_{crit}$ ⇒ Radially extended islands or NTMs
- $\beta_p \leq \beta_{p,crit}$ ⇒ No NTM
- $\beta_p \geq \beta_{p,crit}$ ⇒ $(w_{crit} \leq w)$ ⇒ Saturation of the islands

[T.C. Hender et al, chap. 3: MHD stability, operational limits and disruptions]

What is the origin of the seed islands?

Origin of seed islands ($w \leq w_{crit}$)



[A. Isayama et al. Plasma and Fusion Research (2013)]

- NTMs precursors :

  MHD events (large scales)
  - Sawtooth oscillations
  - Edge localized modes
  - …..

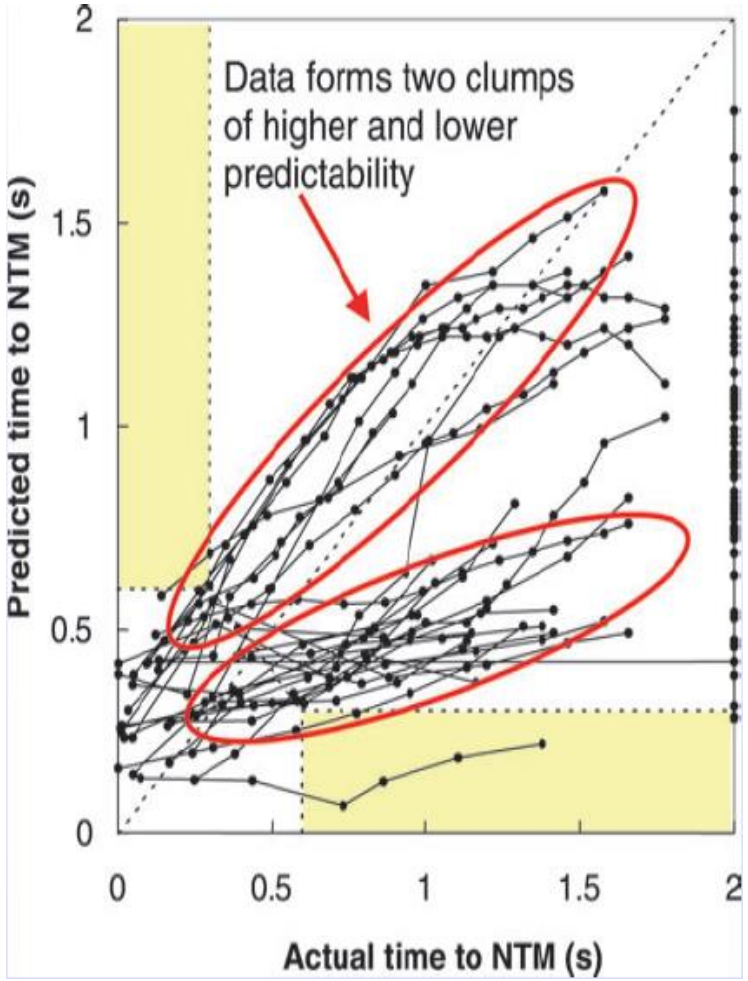
- Onset of NTMs in high β discharges in JT60U Tokamak

- In about 80% of the discharges, NTM appear without any noticeable triggering event

Projet

- Creation of a JET, ASDEX Upgrade data base
- Determination of seed Islands origins (Turbulence)
  - Huge space of parameters
- Prediction of the island saturated size
- Prediction of disruptions induced by NTMs

Neural Network used in the NTM onset prediction with JET data base



- Dicharges when MHD events have been detected before NTM onset

40 parameters

3 parameters discharges are revelent to predict NTM onset:

- ✓ β parameter
- ✓ ρ_i ionic larmor radius
- ✓ Sawtooth (MHD event) period

What's about discharges without MHD event?
What's about TDMI detection?

[R. J. Buttery et al., NF 44, 678 (2004)]

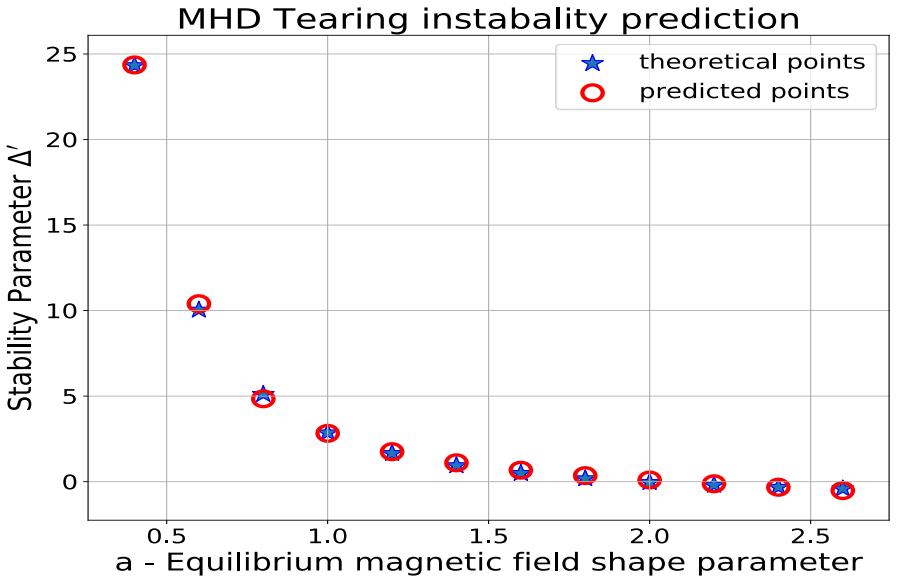
Neural Netwark used to predict a MHD instability threshold

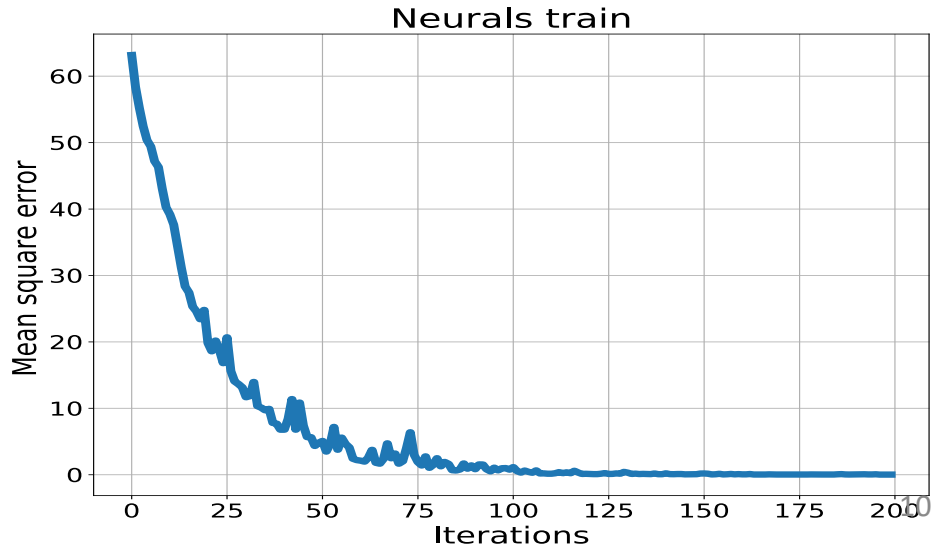
- MagnetoHydroDynamic (MHD) instability leading to magnetic island formation : **Tearing instability**
- Theoretical calculation : **Δ' = f(a)**

a : equilibrium magnetic field shape parameter

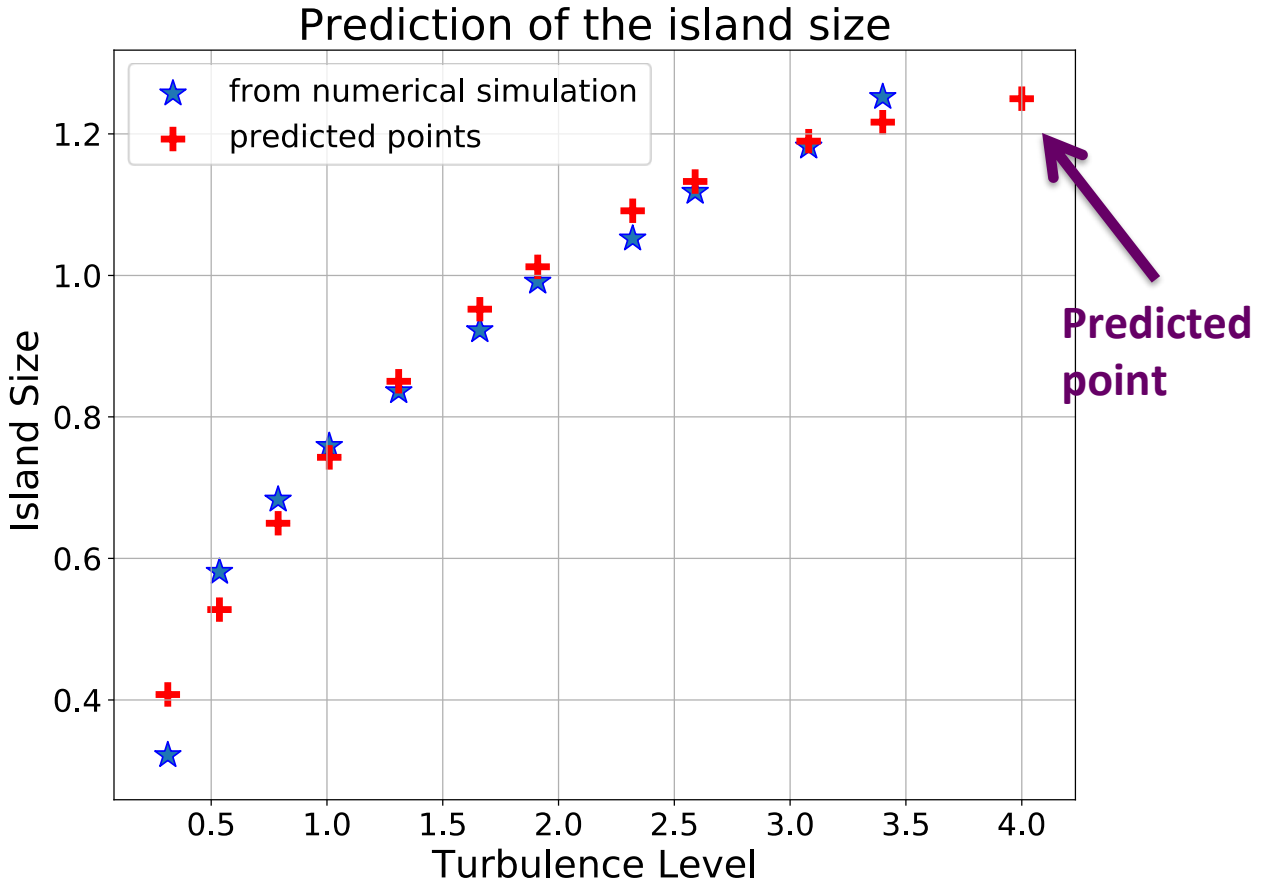
Δ' : tearing index stability parameter

Δ' < 0 : Tearing mode stable
Δ' > 0 : Tearing mode UNSTABLE





Neural Netwark used to redict Island size in presence of turbulence



- Nonlinear simulations including **turbulence** used to train a neural network
- **Prediction of island size for a given turbulence level (to be continued …)**

Conclusion

- Magnetic island growth, in particular, NTM growth will degrade confinement in fusion devices and in ITER. NTM control is a challenge.

- NTM could be controlled by current injection. However it could fail.

Improve the understanding of the origin of seed islands required to the NTM growth to improve NTM control.

Projet :

- Creation of JET, ASDEX- Upgrade data base
- Prediction of the seed islands
- Determination of the islands saturated size, disruption

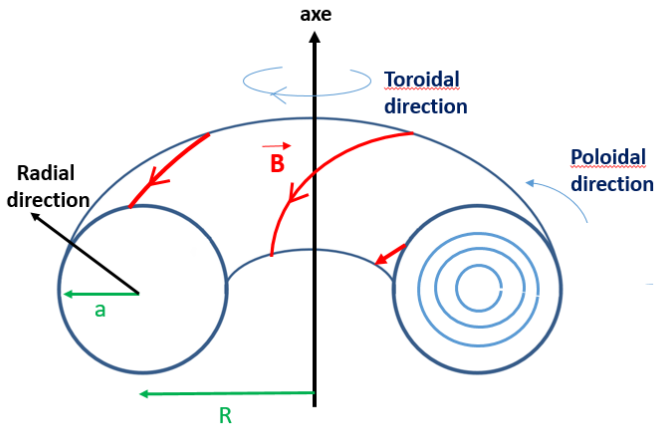
Turbulence driven magnetic islands (TDMI)?

Tokamak

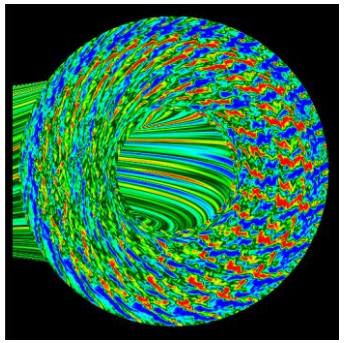
Magnetic field variation → Current gradient → MHD instabilities (cm~ m)/NTMs

Hot core and cool walls → N, T, P gradient → Microscopic instabilities (μm ~mm)

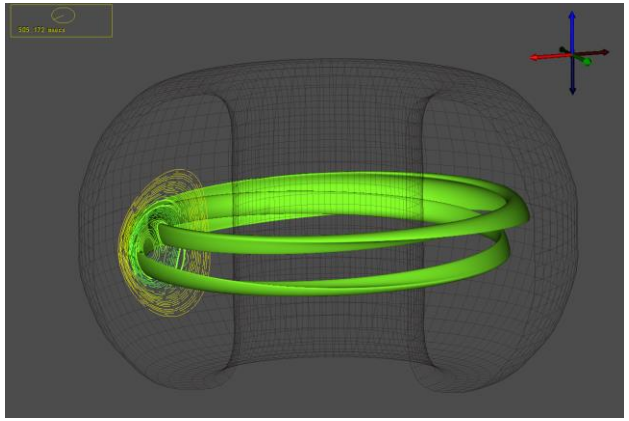
CREATE



Equilibrium



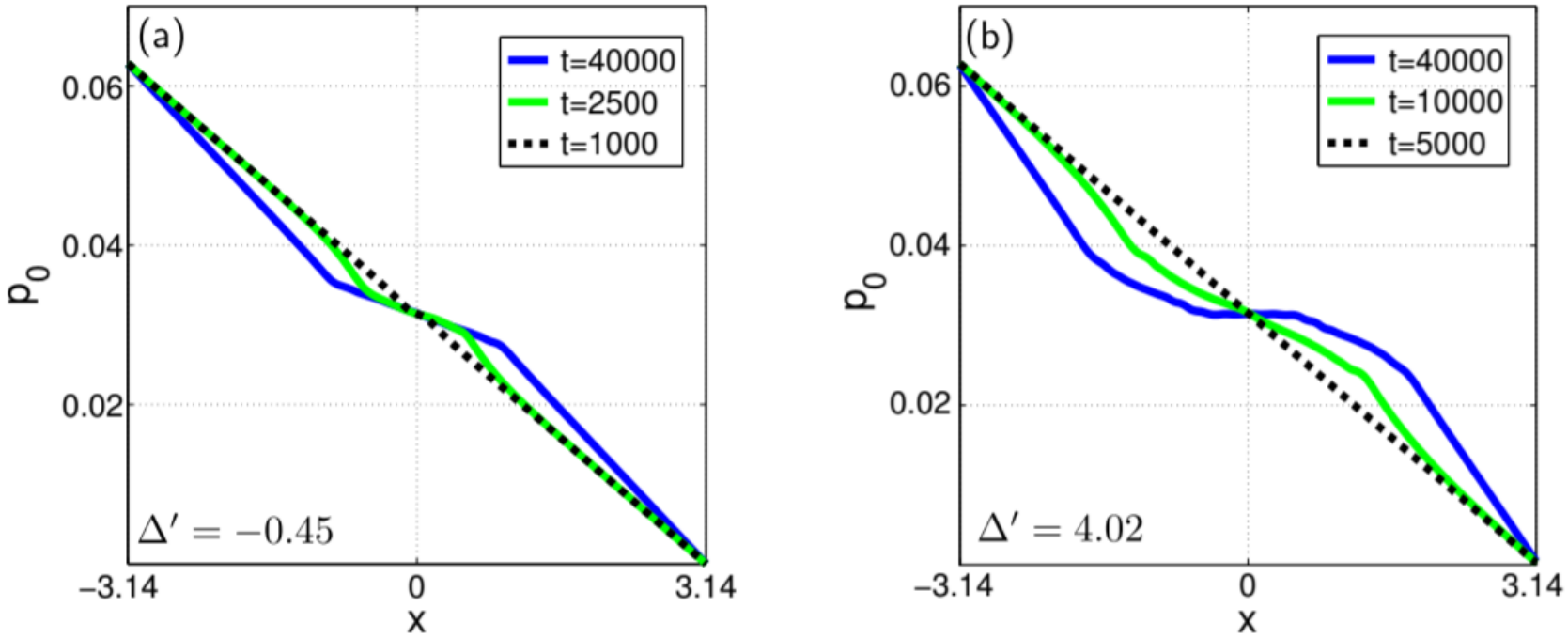
Turbulence



Turbulence Driven Magnetic Islands

Signature of TDMIs: Pressure profile exhibits a partial flattening

- Pressure profiles at different times:



TDMI:

- Partial flattering of both density and T_e, in conditions where it should not be partial (Fritzpatrick criterium), have been already observed