Magnetic Reconnection in tokamaks: from theoretical fundations to solutions for fusion energy

T-RECS ENR

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From ENEA (Italy) : D. Grasso, D. Borgogno and C. Marchetto

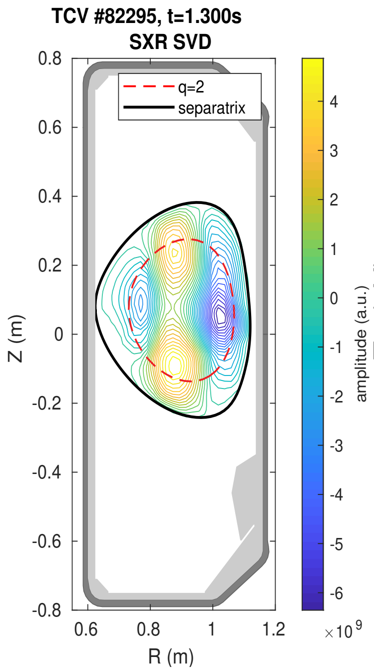
From DIFFER (The Netherlands) : M.J. Pueschel and T. Jitsuk

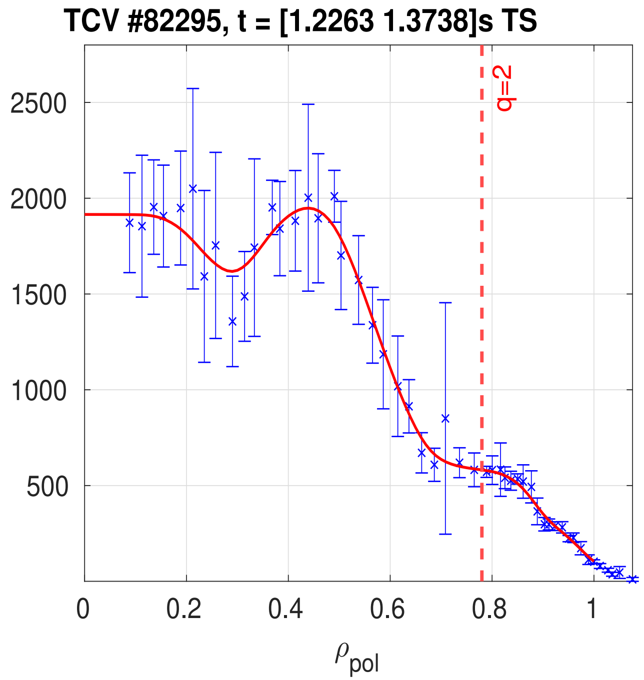
From IPP (Germany) : E. Poli, Q. Yu, A. Mishchenko, F. Widmer and J. Ren

From EPFL (Switzerland) : M. Kong, O. Sauter, A. Franck, L. Porte and S. Coda

Magnetic Reconnection (MR) is at the heart of open issues in fusion plasmas

Observation of Magnetic Island (MI) on TCV :





Open questions :

- Control of NTM(s),
- Role of MR in sawtooth crashes,
- Impact of MR on RE,
- Transport in presence of MI
- …

ENR main objective :

Improvement of magnetic reconnection fundamental knowledge for fusion plasmas.

Tools :

Combine modeling efforts using complementary models (GK & MHD) and codes (AMON, SCOPE 3D, GYSELA, GENE ORB5)

Main outcome :

Identification of mechanisms relevant for experimentalists

I. Relevant models of magnetic reconnection (MR) for fusion plasmas

II. Magnetic reconnection (MR) in fusion plasma turbulence and disruptive processes

III. Magnetic reconnection (MR) impact on turbulence, transport and confinement

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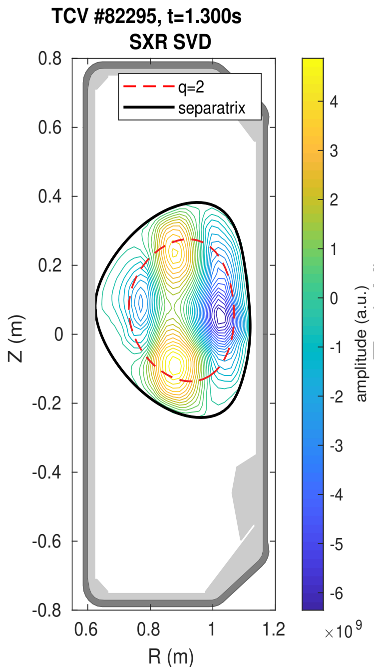
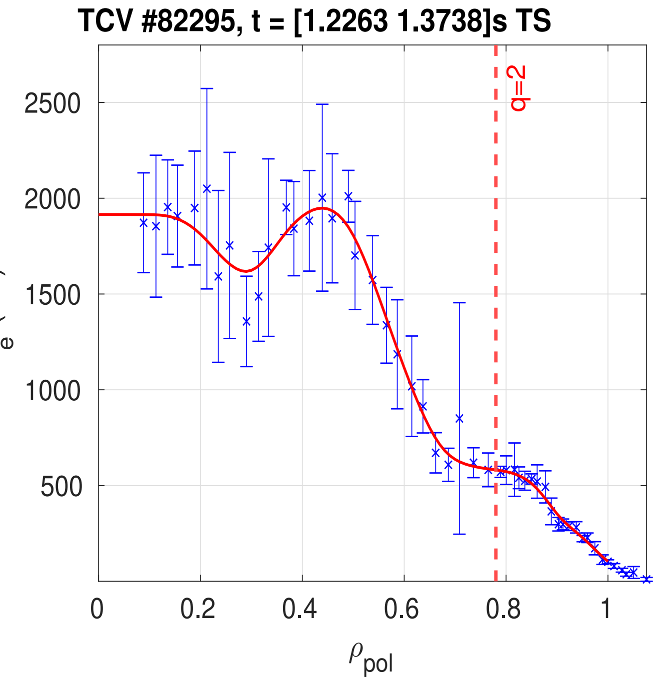




I. Relevant models of magnetic reconnection (MR) for fusion plasmas

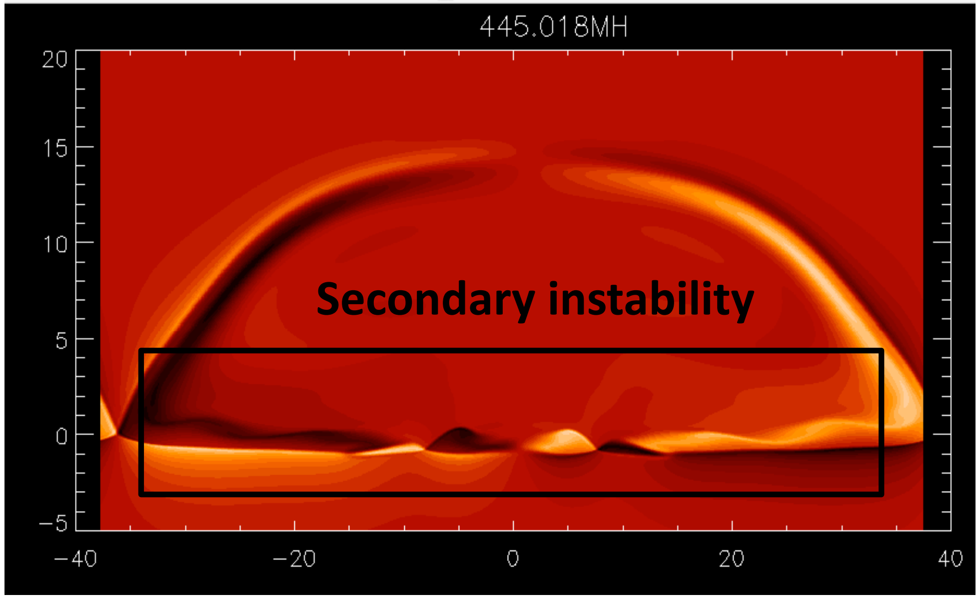
=> Understand the nonlinear structures (stochasticity generation and MI size) due to MR

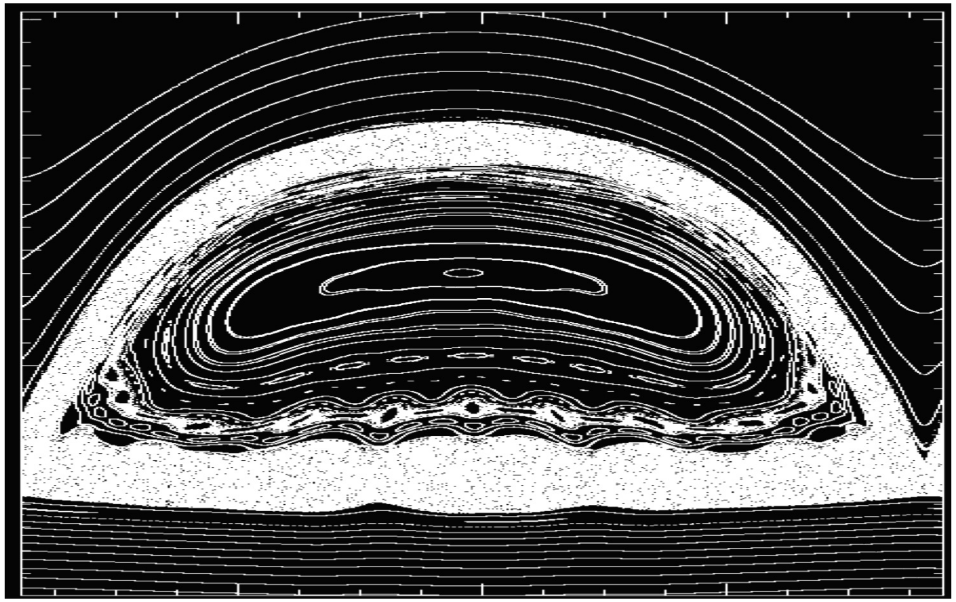
Open questions :

- Control of NTM(s),
- Role of MR in sawtooth crashes,
- Impact of MR on RE,
- Transport in presence of MI
- …

I. Relevant models of MR for fusion plasmas

- **Evolution of an 3D collisionless asymmetric Tearing Mode in presence of multiple helicities**
  Investigated by C. Marchetto et al. with SCOPE 3D





- **Main result :** With multiple helicities, chaos anticipates secondary instability appearance changing its features while the reconnected flux remains unchanged

D.1.1.1 reached « Kelvin-Helmoltz instability driven by asymmetry effects in chaotic magnetic configuration » on EUROfusion pinboard

=> Loss of DATA on Marconi : Some simulations have to be re-run !!!!

- **Ongoing work :** Understand the interplay between the secondary instability and the formation of chaos due to the magnetic field lines stochasticity.

I. Relevant models of MR for fusion plasmas

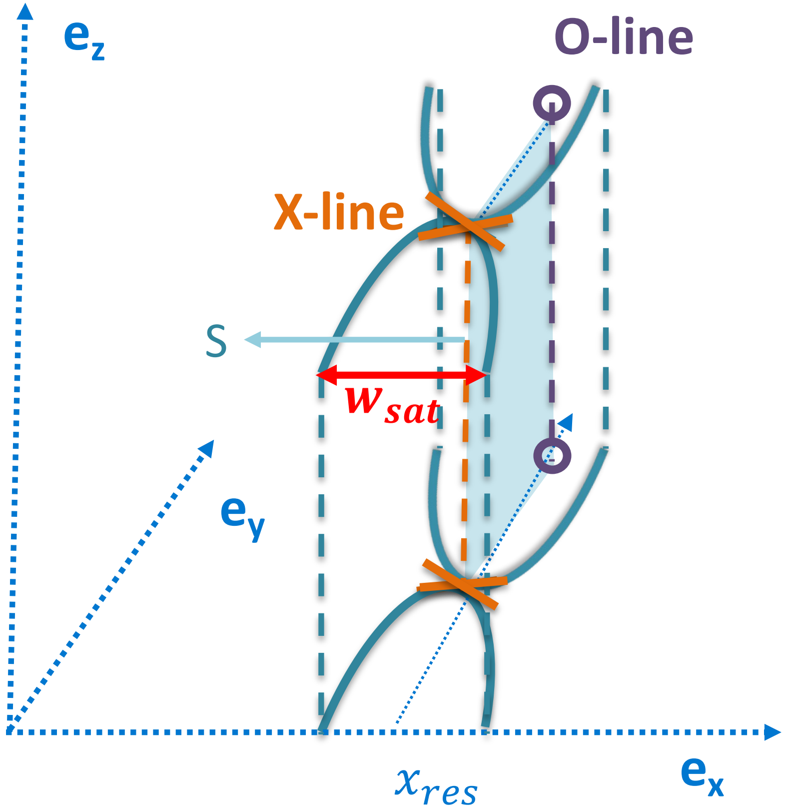
❖ Improvement of Rutherford-like model for the prediction of saturated island size

Investigated by M. Muraglia et al. with AMON **[M. Muraglia et al. JPP 91 (2025)]**

Magnetic island structure in SLAB geometry with strong guide field

$\boldsymbol{B} = B_z \boldsymbol{e_z} + \nabla \times \psi \boldsymbol{e_z}$

at the equilibrium, $B_y(x_{res}) = 0$



- **Hypothesis 1**

Definition from one Fourier mode $w \propto \sqrt{\psi_1(x_{res})}$

Definition from topology [D. Escande, B. Momo, RMPP, 2024]

$$w \propto \sqrt{\psi_X - \psi_O}$$

- **Hypothesis 2**

=> At saturation: $\partial_t(\psi_X - \psi_O) = 0$

(Instead of $\partial_t \psi(x, y) = 0$)

I. Relevant models of MR for fusion plasmas

Improvement of Rutherford-like model for the prediction of saturated island size

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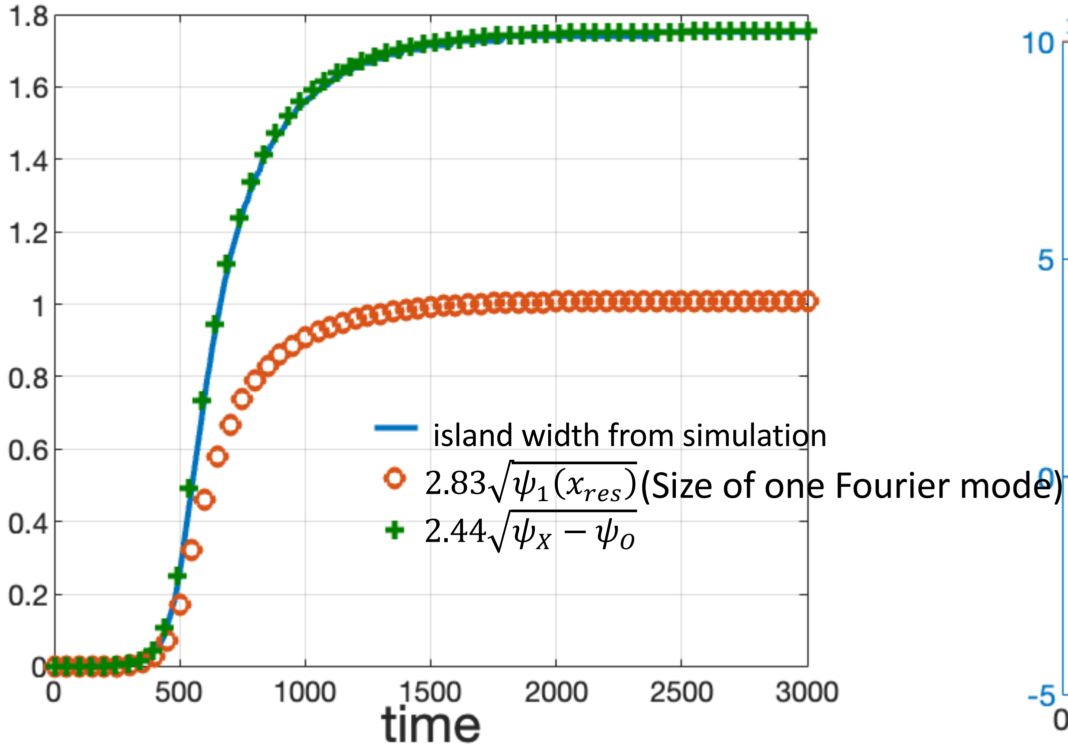
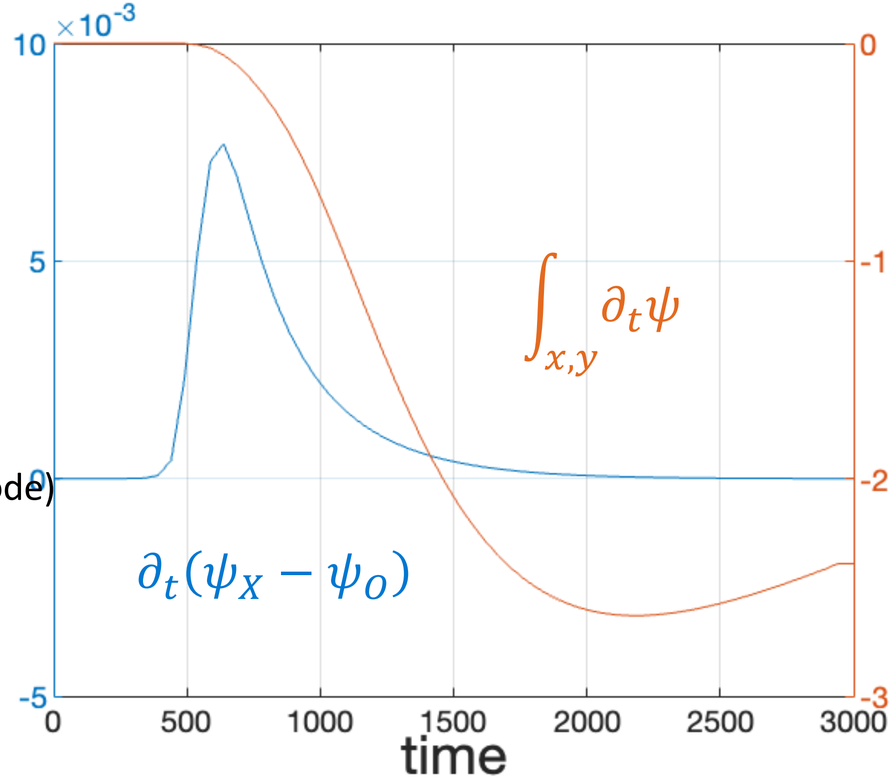




Main results :

- Island size can be computed from topology constraints $w \propto \sqrt{\psi_X - \psi_O}$
- Saturation can be computed from $\partial_t(\psi_X - \psi_O) = 0$

Ongoing work :

- Derivation of a new model has that will be tested on TCV discharges (see part II)
- What is the difference between resistive and inertial saturation mechanism?
- Do kinetic effects affect the saturation ?

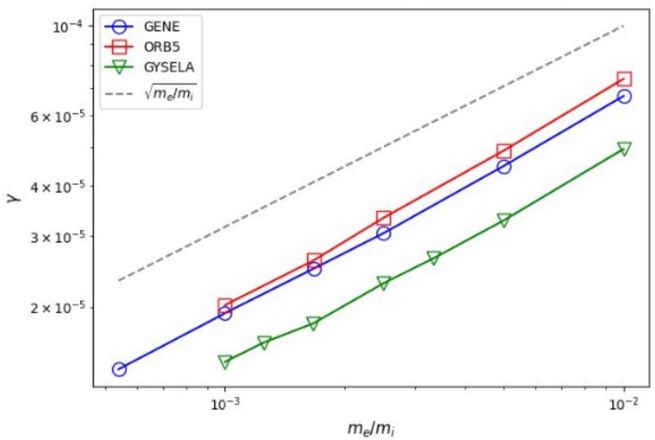
I. Relevant models of MR for fusion plasmas

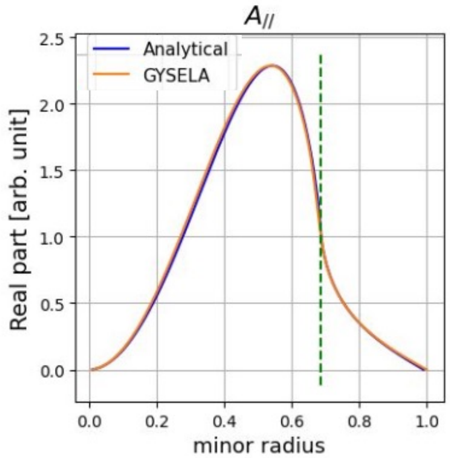
Gyrokinetic modeling of large-scale tearing mode

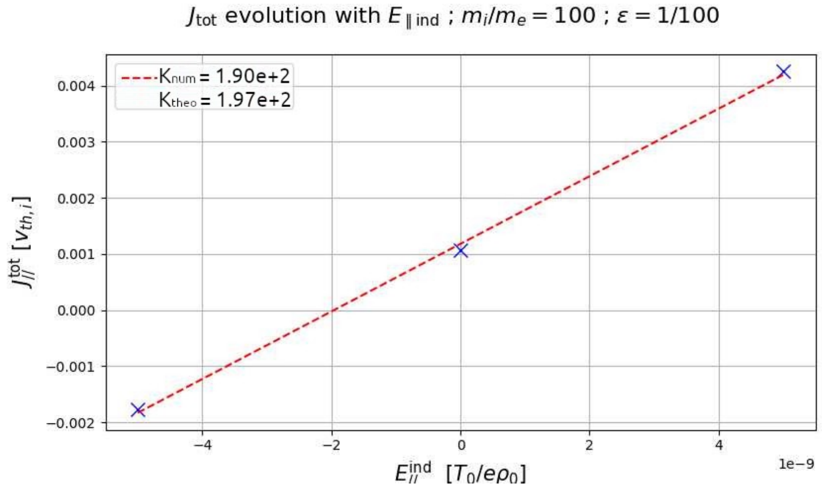
Investigated by R. Bigué et al. with GYSELA code

$$\hat{J}_{\|}^{\text{tot}} = K \;.\; \hat{E}_{\|}^{\text{ind}} \;.\; \nu^{*-1}$$

Successfull benchmark of GENE & ORB5
[T. Jitsuk et al, NF 24]







Main results

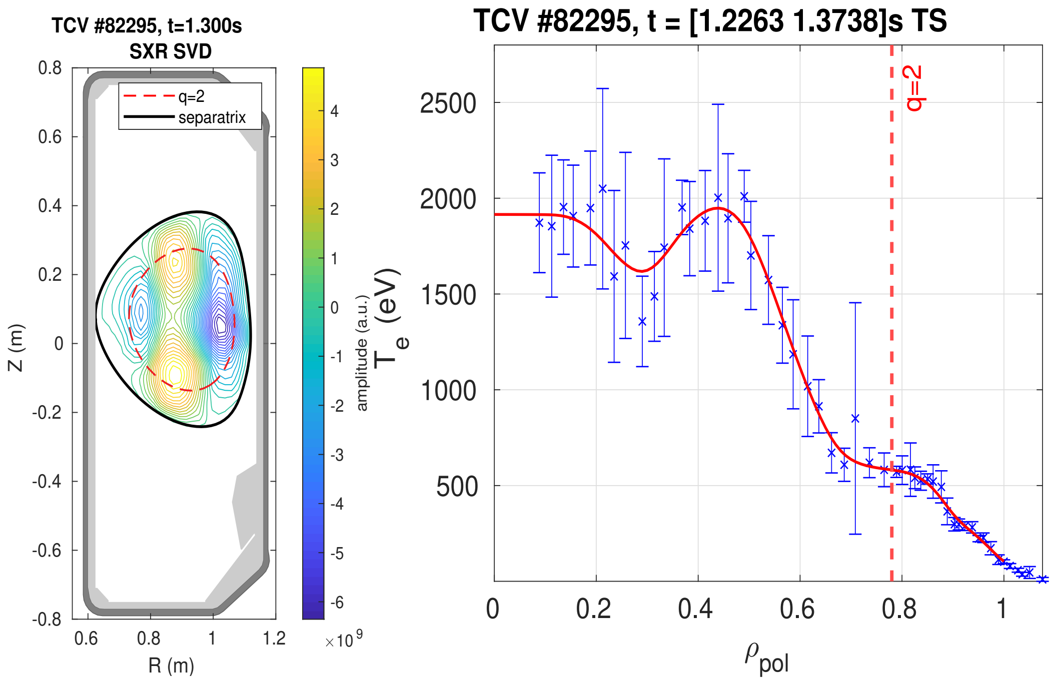
- First simulations in the linear phase of a (2,1) unstable collisionless tearing mode with GYSELA
- Linear growth has a correct scaling but still presents a discrepency with other GK codes
- Eigen functions of the mode are in agreement with theory
- Benchmark of electron-ion coll. operator in view of comparing collisional vs. collisionless saturation of tearing mode => Validation with theory of the Spitzer parallel resistivity

Ongoing work

- Developement and validation of an upgraded Ampère solver has to be done
- Benchmark of electron-ion coll. operator in view of comparing collisional vs. collisionless saturation of tearing mode => Validation with theory of the bootstrap current

Magnetic Reconnection (MR) is at the heart of open issues in fusion plasmas

Observation of Magnetic Island (MI) on TCV :



II. Magnetic reconnection (MR) in fusion plasma turbulence and disruptive processes

=> How does MR interact with other processes (turbulence and runaway electrons) in fusion plasma ?

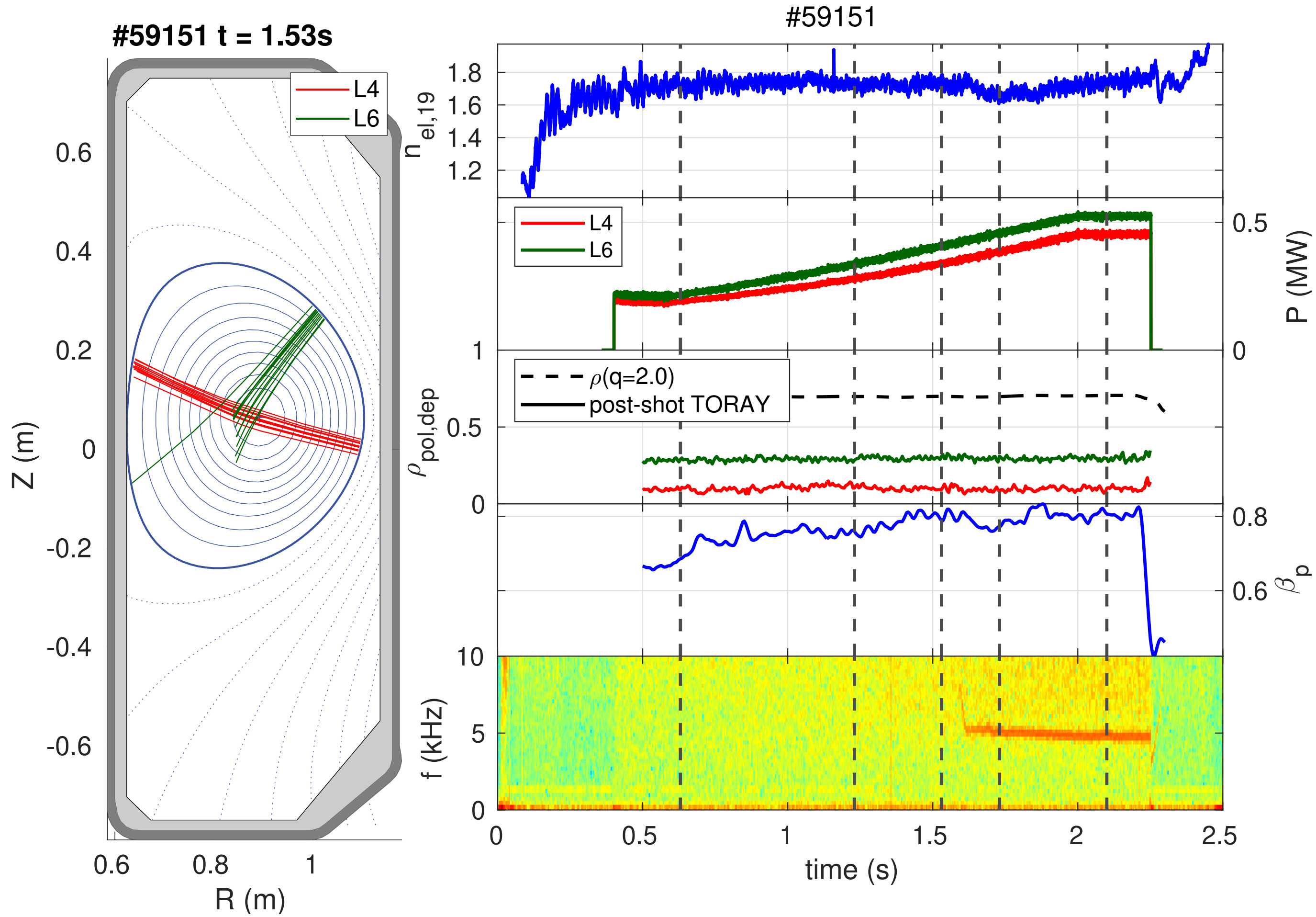
Open questions :

- Control of NTM(s),
- Role of MR in sawtooth crashes,
- Impact of MR on RE,
- Transport in presence of MI
- …

II. Interplay between magnetic island(s) and turbulence

❖ Selection of TCV discharges #59151 exhibiting a 2/1 NTM from a resistive unstable tearing mode

Selected by M. Kong et al. [NF 60 (2020)]



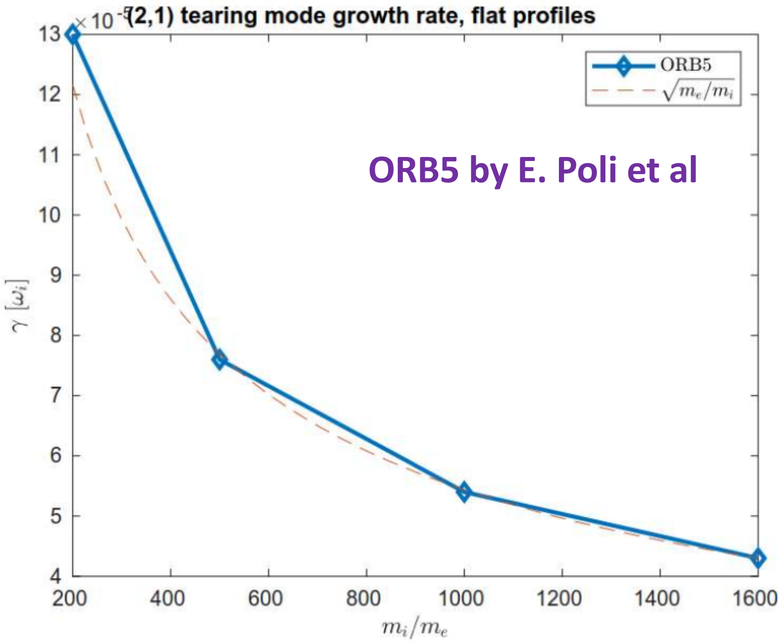
❖ Plasma parameters

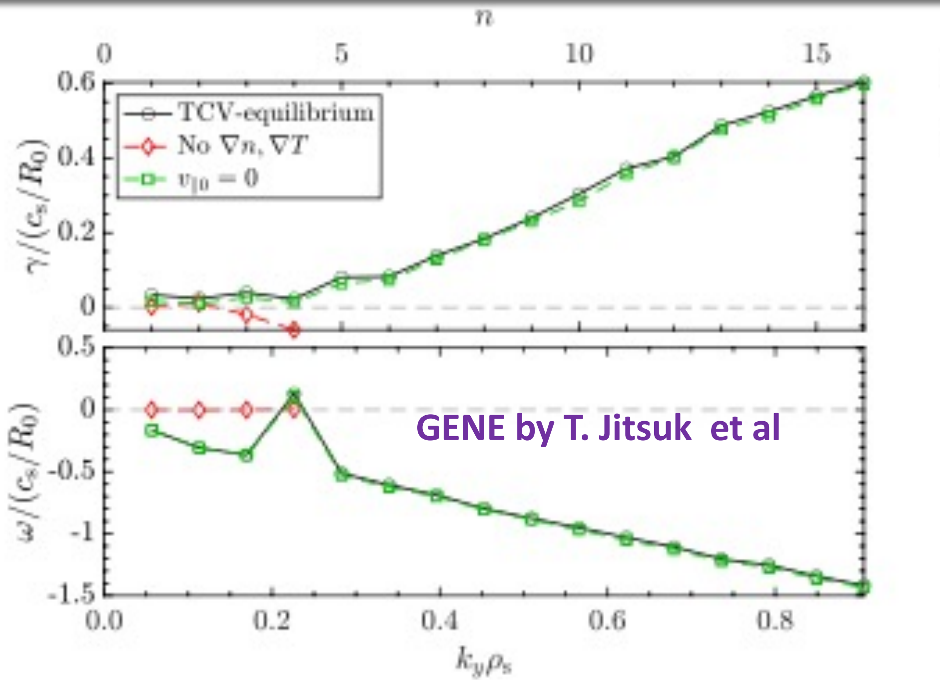
- $\beta_e = \frac{8\pi n_e(r_0) T_e(r_0)}{B_0^2} = 0.61\%$
- $\rho^* = \frac{\rho_s}{a} = 0.014$
- $\varepsilon_a = \frac{a}{R_0} = 0.317$
- $R_0 = 0.88m$
- $m_e/m_D = 2.73\times10^{-4}$
- $\nu_{ei} = 0.074 c_s/R_0$ with Landau coll. op.
- $Z_{eff} = 1$
- $J_{//} = J_{//e}$

II. Interplay between magnetic island(s) and turbulence

Linear stability of TCV discharge

Investigated by T. Jitsuk et al. with GENE code





n	$\nabla P = 0$	$J_{\|0} = 0$	all gradients
1	TM	MTM	TM-MTM
2	TM	MTM	MTM
3	stable TM	MTM	MTM
≥4	stable	ETG	ETG

Main results

- Combine effort analysis with ORB5 & GENE in the modeling of TCV discharge
- Detailed linear analysis (growth rate & frequency) of the linear spectra with the identification of the modes nature of the TCV discharge with GENE code

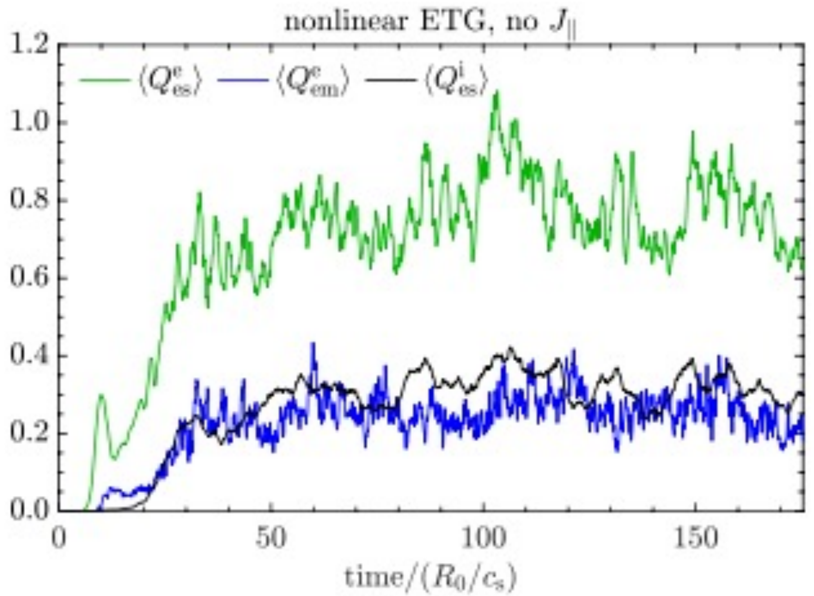
Ongoing work

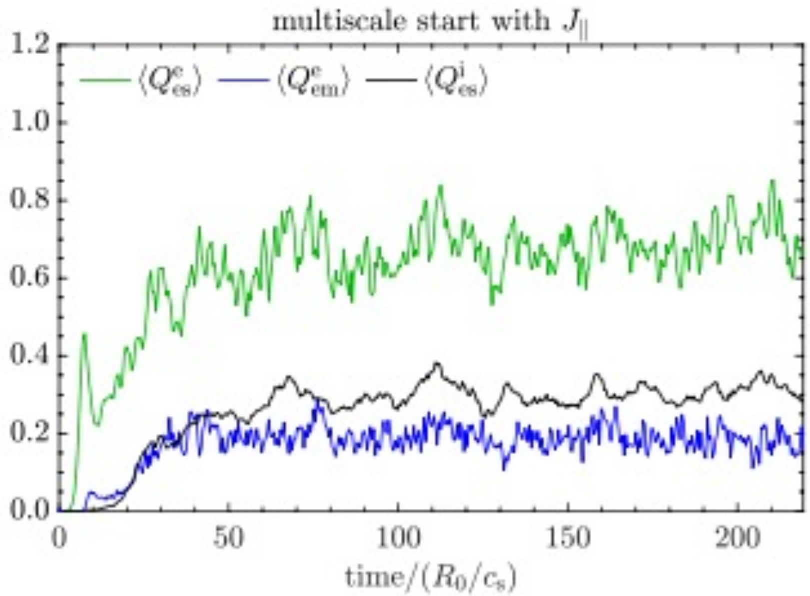
- Linear analysis is ongoing with GYSELA and AMON codes

II. Interplay between magnetic island(s) and turbulence

NL MTM-ETG (wo $J_{||}$) and multiscale TM-MTM-ETG in GK framework

Investigated in 2024 by T. Jitsuk et al. with GENE code





Main results

- Similar flux levels between the two models (with or wo $j_{||}$)
- MTMs and ETGs are nonlinear coupled

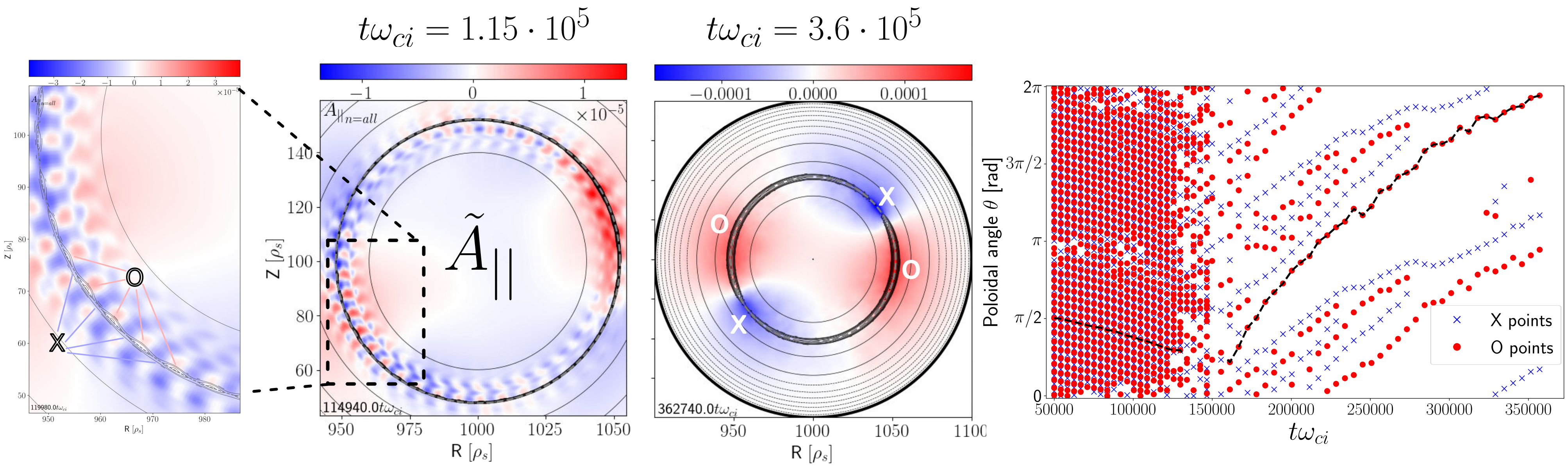
Ongoing work

- Activity of tearing mode does not rise at given time -> require longer simulation for TMs to come up ?
- Compare with other models (collionless/resistive, GK/MHD, …) to complete the analysis

II. Interplay between magnetic island(s) and turbulence

Investigation of Turbulent Driven Magnetic Island dynamic with ORB5

Investigated in 2024 by F. Widmer et al. with ORB5 code



Main results

- Large scale magnetic island non-linearly generated from micro-instability (MTM) at small-scale
  => TDMI generation
- Small scales islands rotating in the electron direction merge during the quasi-linear into a large magnetic island that rotates in the opposite direction

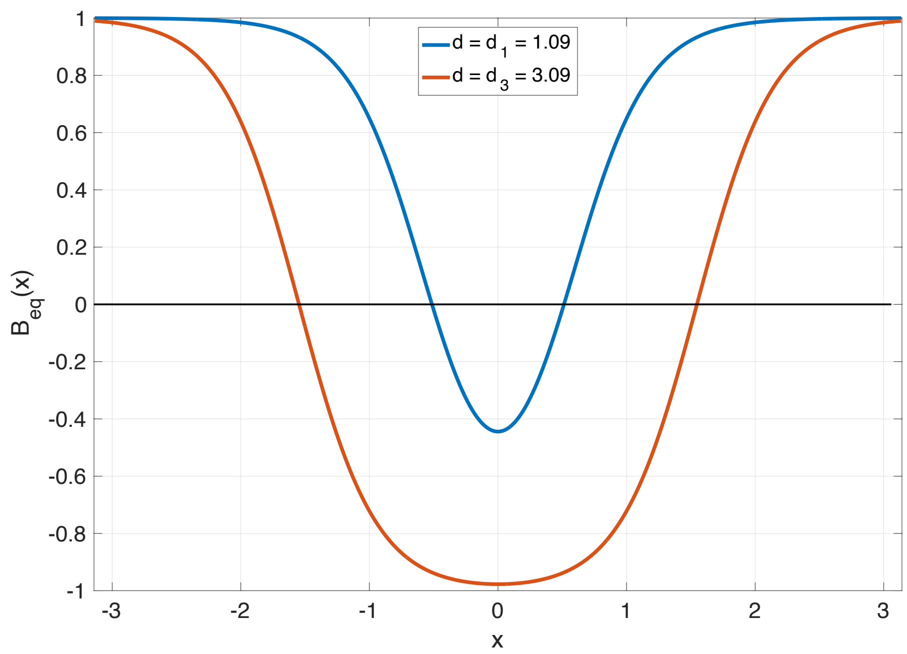
Ongoing work

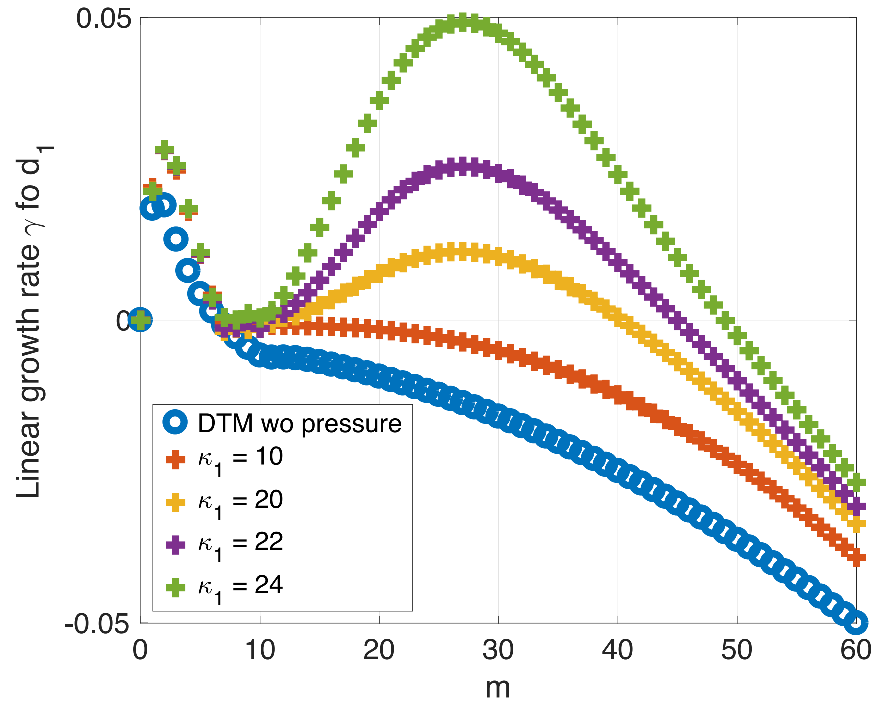
- Characterize the physics of the merging
- Role of the different instabilities in TDMI process
- Determine the amount of temperature and density profile flattening (complementary to Task III)

II. Interplay between magnetic island(s) and turbulence

❖ Interaction of Double Tearing Mode (DTM) and turbulence in MHD framework

Investigated in 2024 by M. Muraglia et al. with AMON code





❖ Main results

- ➢ Nonlinear simuations with AMON code of double tearing mode without turbulence for nearby and distant islands => explosive dynamic and total reconnection is observed for nearby island **[M. Janvier at al NF 51 2011]**
- ➢ Investigation of parameters space to find linear spectrum with unstable DTM and turbulence

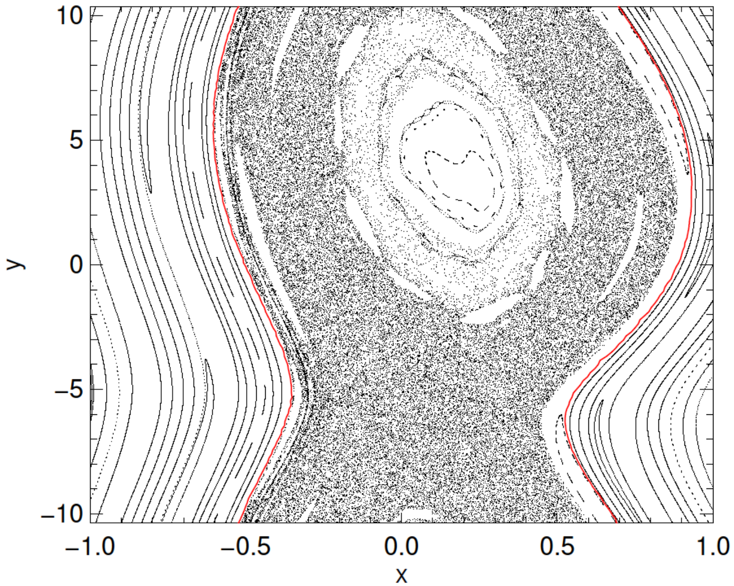
❖ Ongoing work

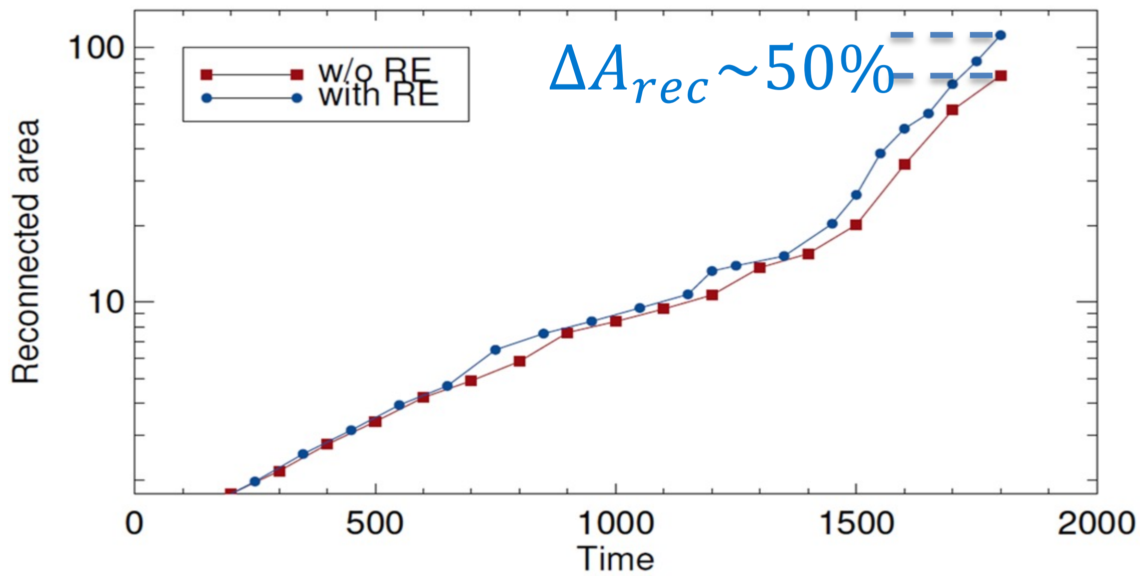
- ➢ Toward first nonlinear simulation of DTM in presence of turbulence

II. Mutual interplay between MR and Runaway Electrons

❖ Nonlinear MHD simulations of multiple helicities in 3D configuration

Investigated by D. Borgogno et al. with SCOPE3D code





❖ Main results:

- ➢ Chaos leads to explosive magnetic reconnection processes
- ➢ Runaway electrons increase 50% of the reconnected area
- ➢ REs current decreases and is uniformly distributed in the chaotic region

❖ Ongoing work

- ➢ Final submission of D.2.2.1 if Marconi's problem will be fixed (recover data or new simulations ?)
- ➢ Implementation of RE on JOREK module : Nonlinear validation is in ongoing

II. Mutual interplay between MR and Runaway Electrons

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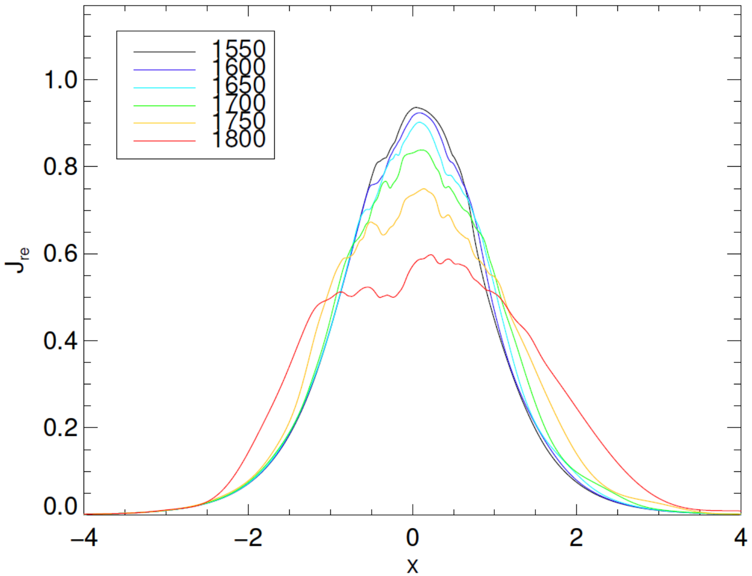

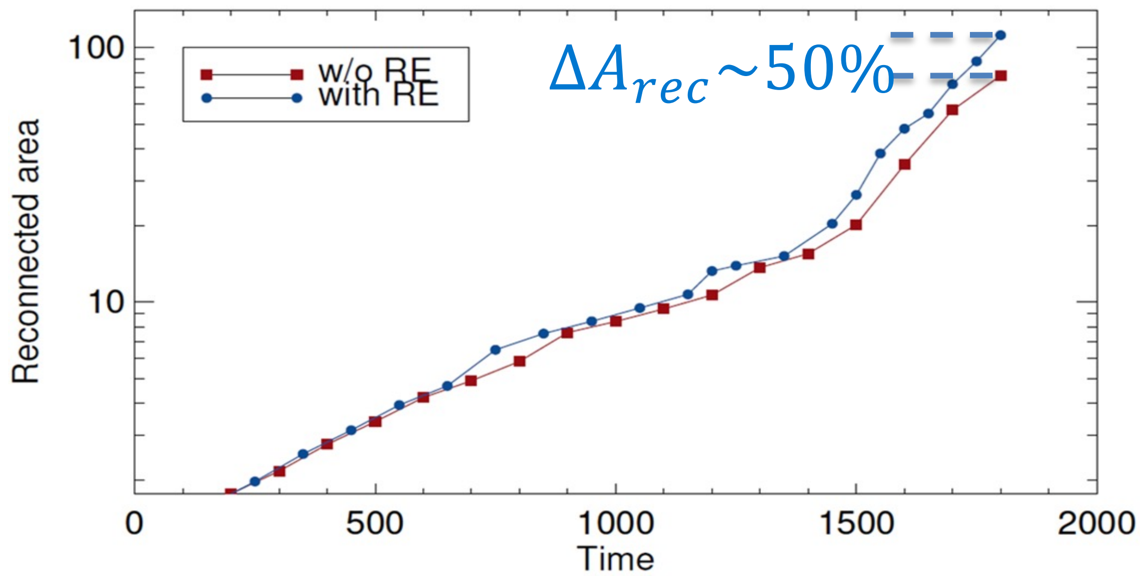

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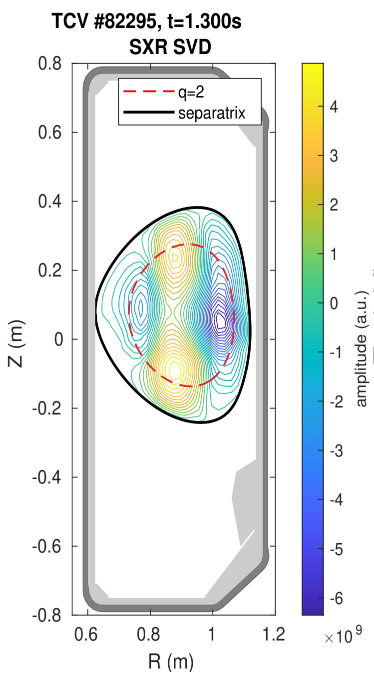

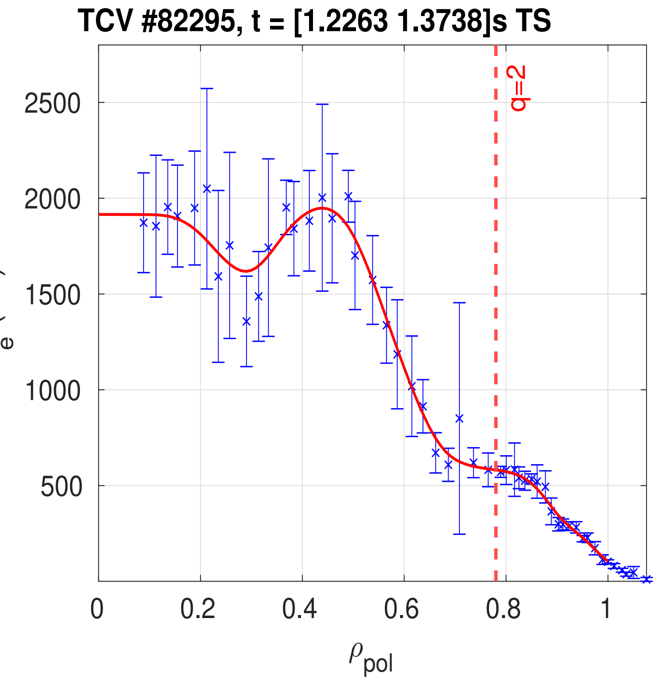

III. Magnetic reconnection (MR) impact on turbulence, transport and confinement

=> How does MR impact profiles ?

Open questions :

- Control of NTM(s),
- Role of MR in sawtooth crashes,
- Impact of MR on RE,
- Transport in presence of MI
- …

III. GK modeling of the impact of MI on turbulence

Gyrokinetic modeling of mutual interplay between MI and turbulence

Investigated by R. Bigué et al. with GYSELA code

- Static magnetic island was planned to be implemented in GYSELA
- Self-consistence tearing instability is under implementation in GYSELA (as already presented)
- Deliverables have been changed to investigate directly and self-consistently the mutual interplay between MI and turbulence

T3.1	**Impact of MHD instability on ion-scale micro-instabilities/turbulence** **M.J. Pueschel**, P. Donnel, X. Garbet, O. Agullo, and M. Muraglia	
No	Milestones - Description	Exp. Date
M.1	~~Modification of the GYSELA code to simulate a static magnetic island (modified particle trajectory equations)~~	01/05/24
M.2	~~Impact of a static magnetic island on ITG turbulence (adiabatic electron response) with GYSELA~~	01/09/24
M.3	~~Impact of a static magnetic island on ITG/TEM turbulence (hybrid electrons) with GYSELA~~	01/12/24
Deliverables - Description		Year
D.3.1.1	~~Report on the impact of a static magnetic island on flux driven electrostatic turbulence with GYSELA~~	2025

III. GK modeling of the impact of MI on turbulence

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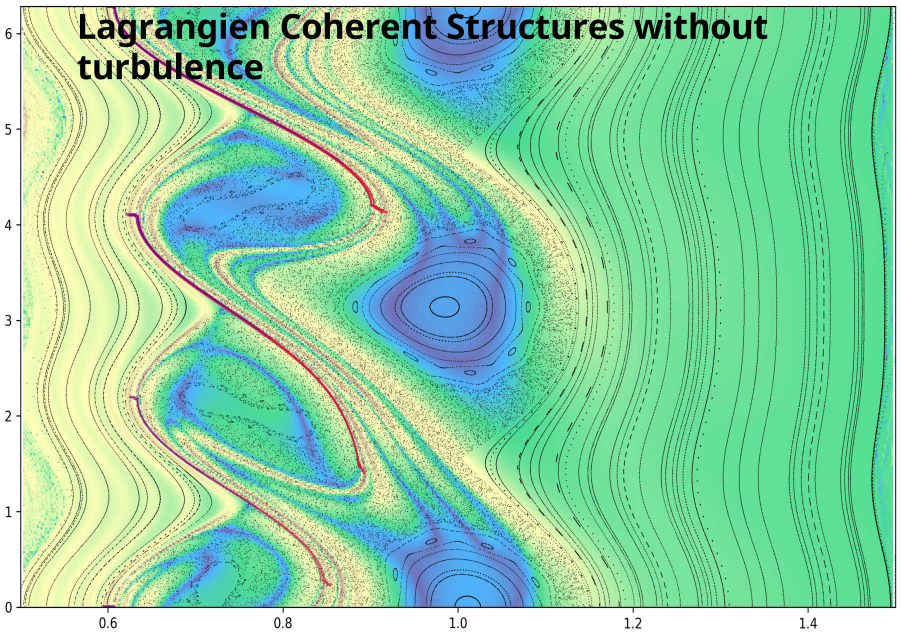
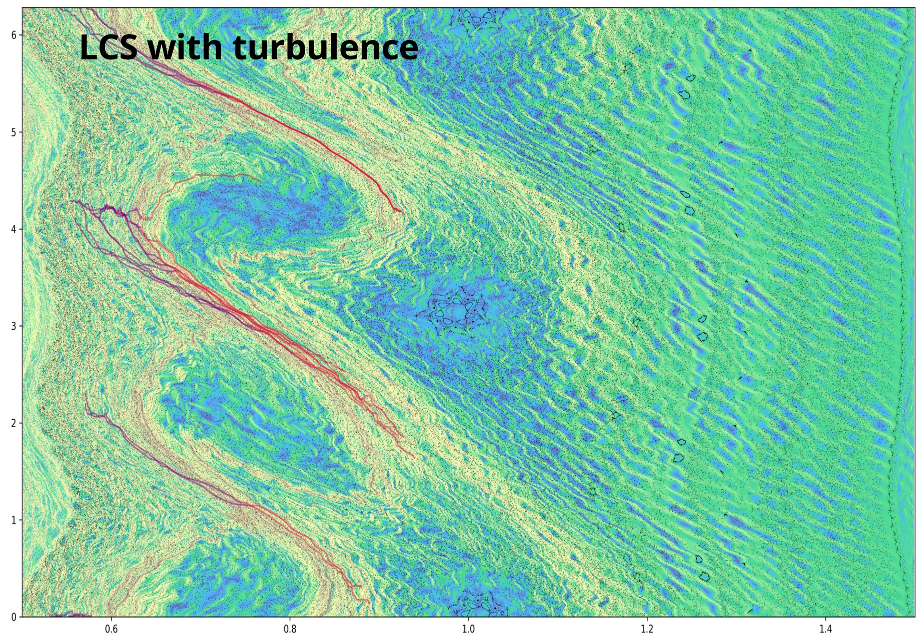
No	Milestones - Description	Exp. Date
M.1	Modification of the GYSELA code to simulate nonlinear tearing mode in the collisional regime and including a magnetic equilibrium solution of Grad-Shafranov equation	In progress
M.2	Implementation of the collision operator in GYSELA	In progress
M.3	First simulation with GYSELA of tearing mode in presence of gradients (pressure and electronic temperature)	Current 2025
Deliverables - Description		Year
D.3.1.1	Report on the kinetic drift-tearing mode with GYSELA	2025

III. Transport in Magnetic Island(s)

Stochastic field lines due to MI and transport

Investigated by N. Dubuit et al. with AMON code





Main results

- Lagrangien Coherent Structures are resilient to small-scales turbulence
- Transport barriers resulting from magnetic field stochasticity are still present with turbulence

D.3.2.1 reached « Structure of MIs in presence of small-scales stochastic turbulence » on EUROfusion pinboard

Ongoing work

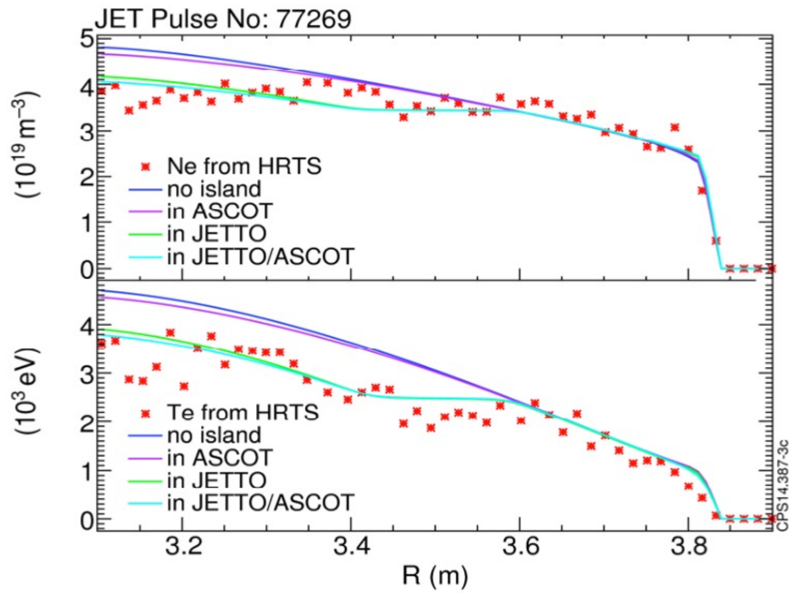
- Comparison with MHD simulations without and with turbulence and evaluation of transport

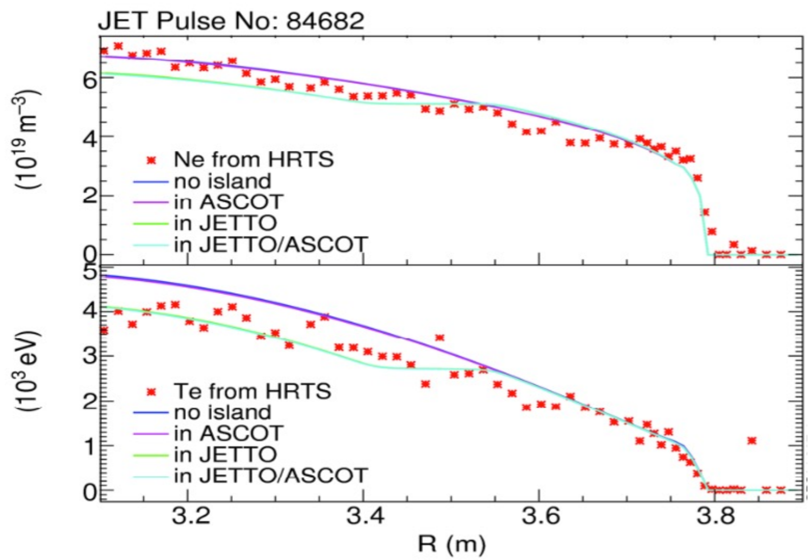
III. Transport in Magnetic Island(s)

Computing transport inside islands/NTMs : 1D model

Investigated by C. Marchetto et al.

- Starting from a simple model of island (virtually infinite, flat transport coefficients) implemented in JETTO & ASTRA (ongoing comparison with experiments to be completed in 2025 in WPTE)





[C. Marchetto et al., EPS 2014]

Ongoing work

- Random-walk-like calculation to improve the model (flat or shaped coefficients? which value? which coefficient affected?)
- Comparison with experiments (also in WPTE and TSVV11)

Conclusions

- 2024 milestones have been fully achieved

- Stop of Marconi has delayed the deliverable D.2.2.1 and should delay some milestones and deliverables in 2025

  - Strong impact of data loss and Marconi outage on project progress
  - LEONARDO's drawbacks : new achitecture and submission file, share with other

- 2024 meetings

  - Online meetings in January and May
  - Face to face workshop at Marseille in September

- 2025 meetings

  - Online meetings in March and in December
  - Face to face meetings : In June at Turin, In September at Marseille

- T-RECS network and visibility

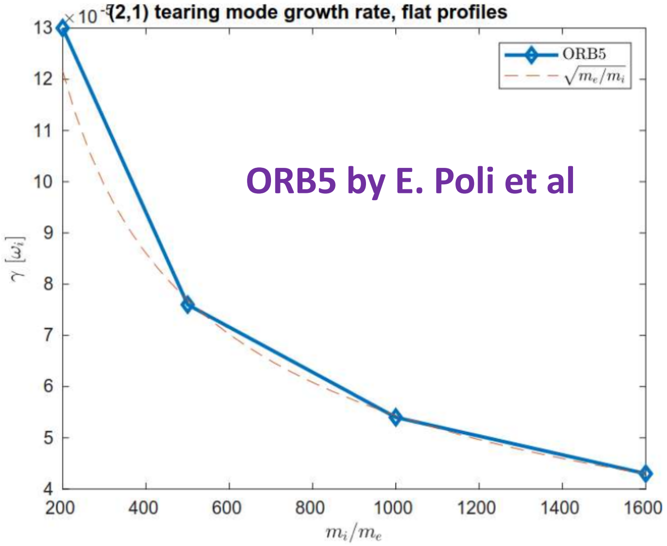
  - Organisation of the next ECMRP at Turin in June 2025

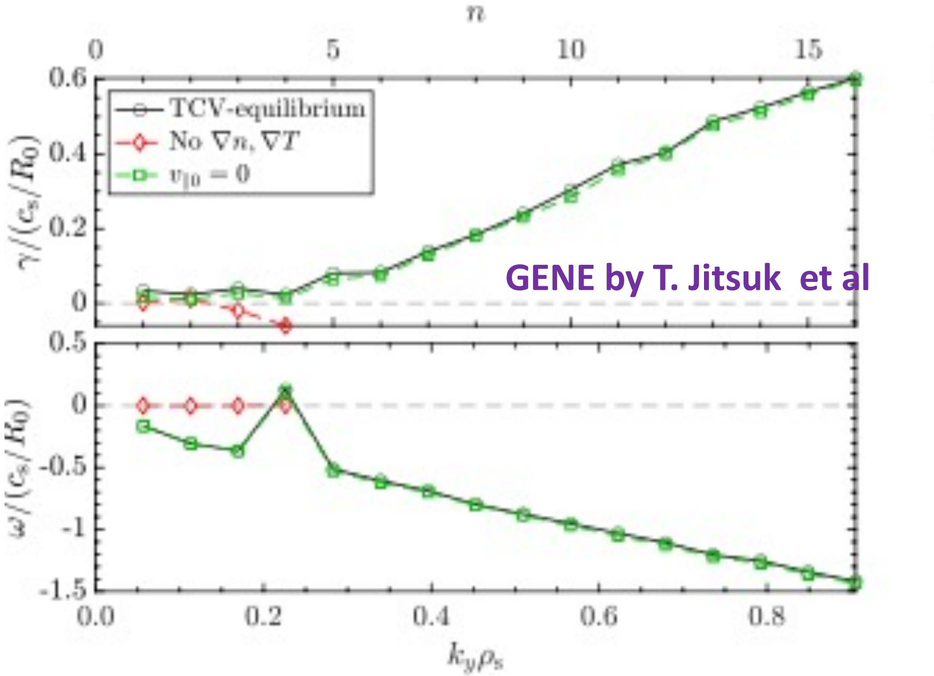
Thank you

II. Interplay between magnetic island(s) and turbulence

Linear stability of TCV discharges

Investigated in 2024 by T. Jitsuk et al. with GENE code





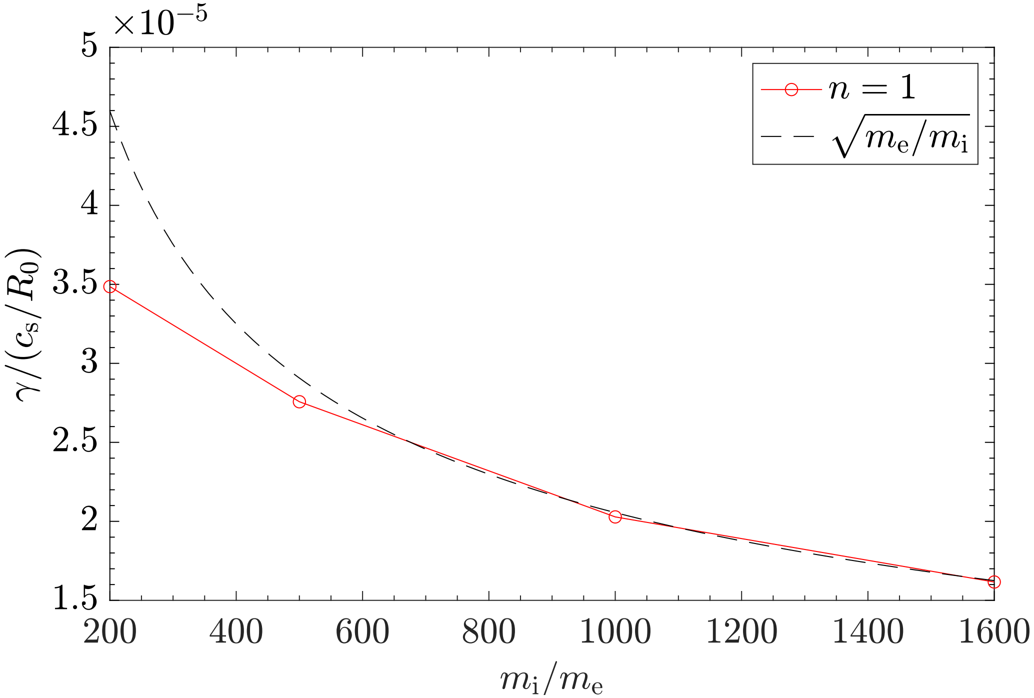
n	$\nabla P = 0$	$J_{\|0} = 0$	all gradients
1	TM	MTM	TM-MTM
2	TM	MTM	MTM
3	stable TM	MTM	MTM
$\geq$4	stable	ETG	ETG

II. Interplay between magnetic island(s) and turbulence

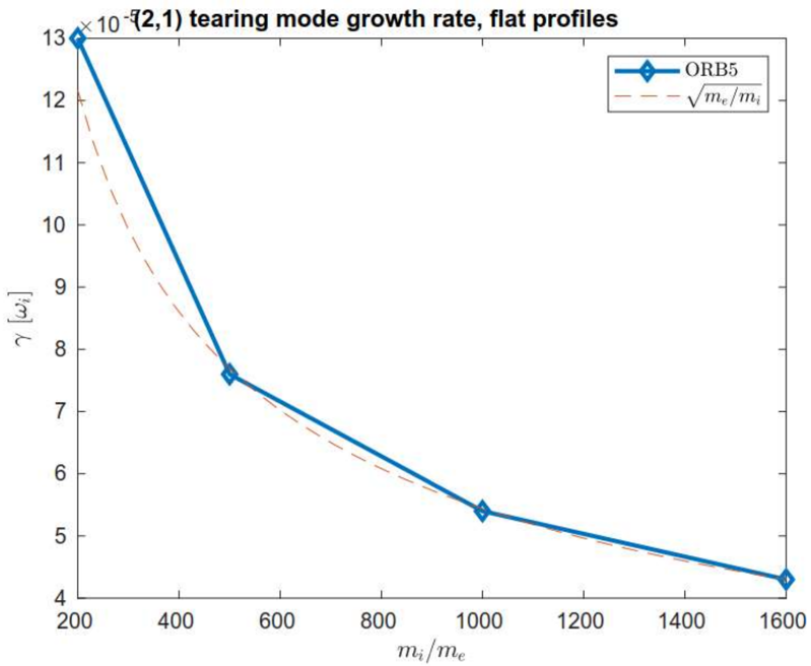
First simulations of TCV discharges using GK framework

Combine (GK and MHD) modeling efforts on multi-scale interaction between magnetic reconnection and turbulence in order to give qualitative explanation of observations in TCV.

GENE **[Courtesy T. Jitsuk et al]**



ORB5 **[Courtesy E.Poli et al]**

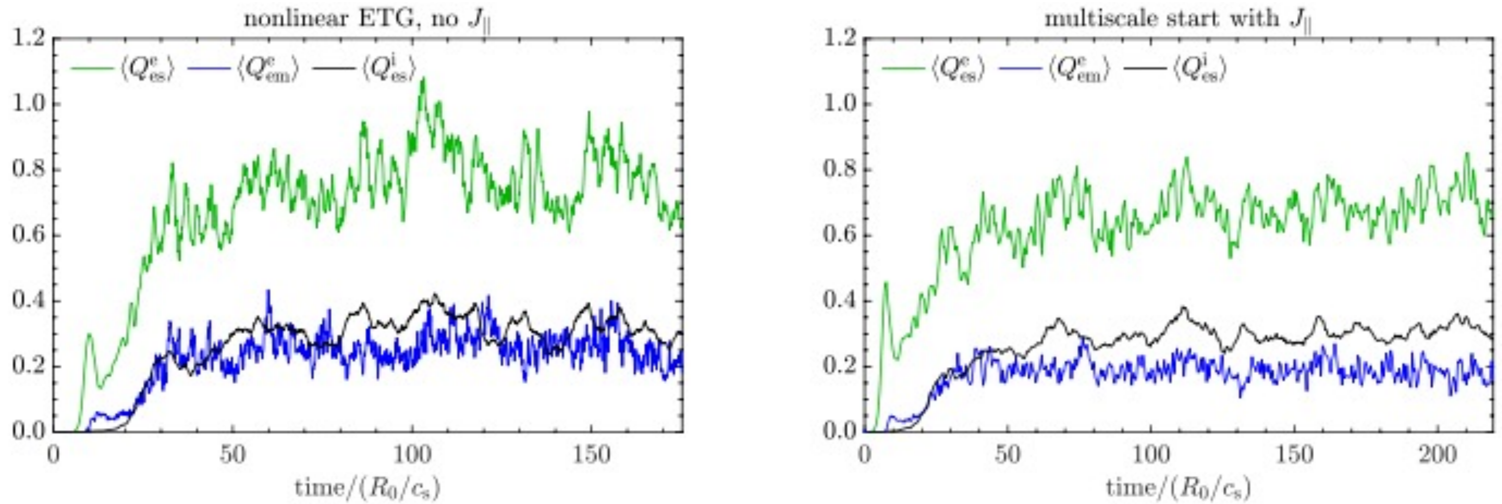


- Unstable tearing mode is observed in simulations
- Collisionless or resistive tearing mode ?

II. Interplay between magnetic island(s) and turbulence

- **NL MTM-ETG (wo $J_{||}$) and multiscale TM-MTM-ETG in GK framework**

  Investigated in 2024 by T. Jitsuk et al. with GENE code

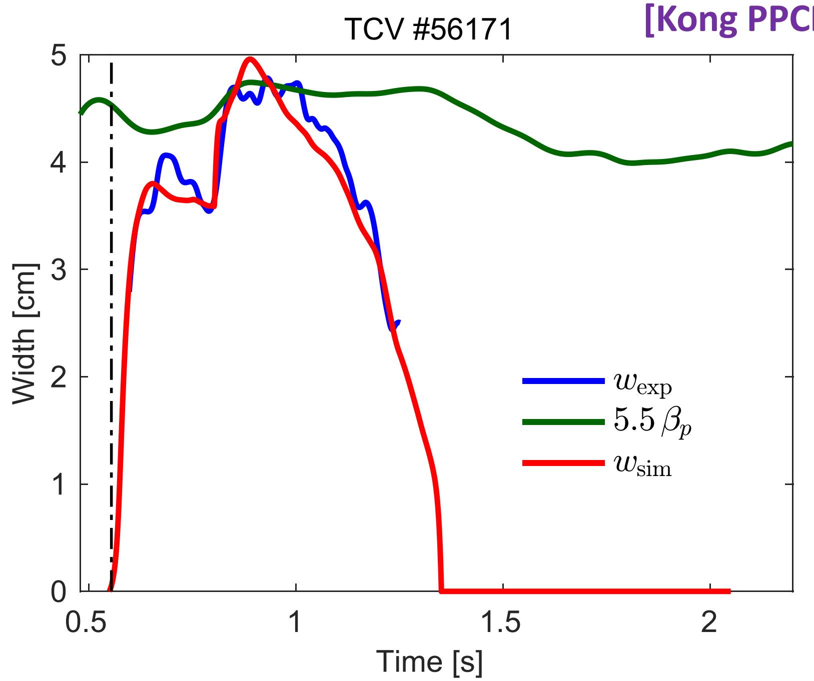


fluxes	nonlinear MTM-ETG only	multiscale TM-MTM-ETG
$\langle Q^{e}_{em}\rangle_{50\leq t\leq 170}$	0.25 ± 0.05	0.19 ± 0.03
$\langle Q^{e}_{es}\rangle_{50\leq t\leq 170}$	0.78 ± 0.09	0.67 ± 0.06
$\langle Q^{i}_{es}\rangle_{50\leq t\leq 170}$	0.32 ± 0.04	0.29 ± 0.03

- Similar flux levels between two systems
- MTMs and ETGs are nonlinearly coupled $\rightarrow Q^{e}_{em}$ and Q^{e}_{es}
- Subdominant ITGs also involve in nonlinear coupling $\rightarrow Q^{i}_{es}$
- Activity of TM does not rise at given time $\rightarrow$ require longer simulation for TMs to come up

1. Relevant models of magnetic reconnection for fusion plasmas

[Kong PPCF 2022]

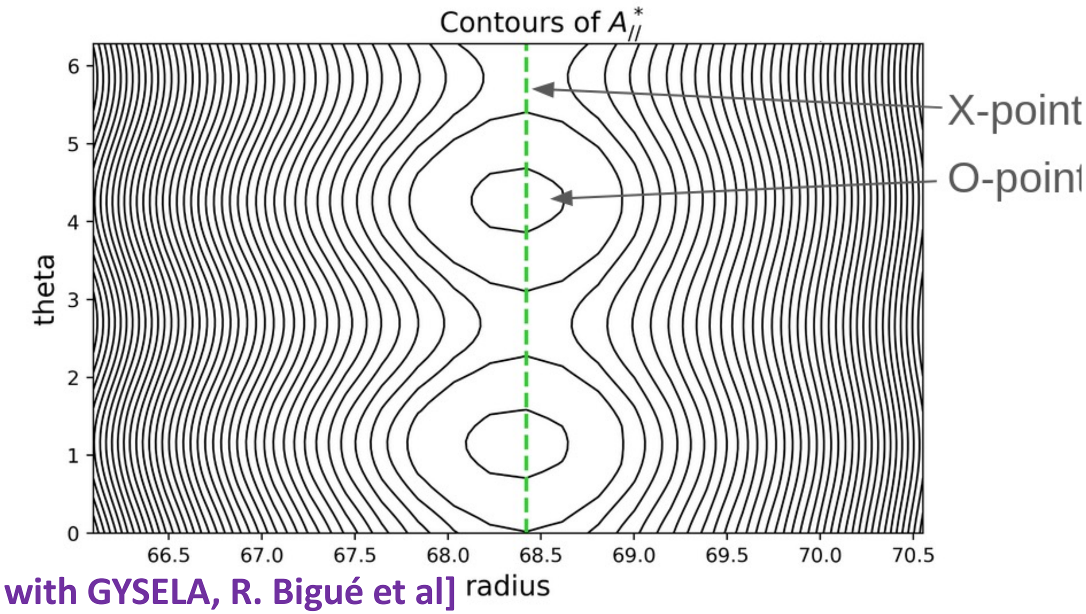


- Prediction of the evolution of magnetic island size by **fluid and gyrokinetic frameworks**

  => Results analyzed in light of TCV experimental results.

=> New ideas to reduce/control the negative impact of magnetic reconnection in fusion plasmas.

- Investigate the difference between inertial and resistive saturation mechanisms



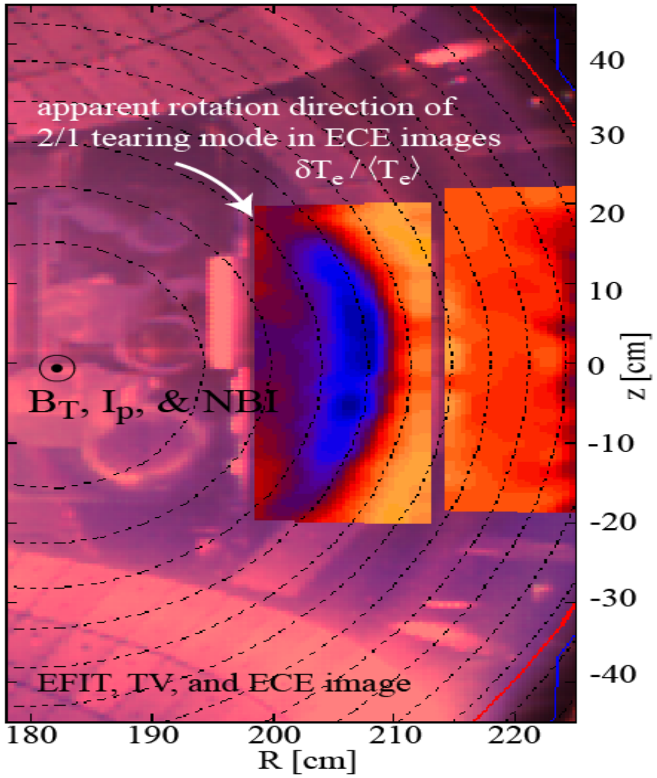
[Magnetic island with GYSELA, R. Bigué et al]

Magnetic reconnection is at the heart of open issues in fusion plasmas

- Control of large magnetic island(s) called NTM(s) [Kong PPCF 2022]
- Magnetic reconnection is observed in sawtooth crashes [Yu NF 2022]
- Runaway electrons can drive magnetic reconnection [Grasso JPCS 2022]
- Magnetic island(s) can transport impurities [Hender NF 2016]
- Magnetic reconnection will play a role in compact high fields tokamaks which requires high beta plasma. What is the scientific relevance of such configurations ? [Guo Nat. Comm. 2015]

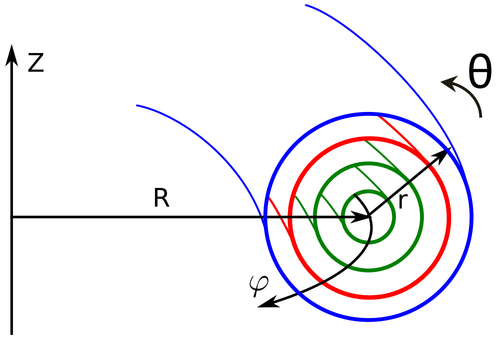
Large magnetic island in KSTAR

[Minjun J. Choi, Nature Communications 2021]



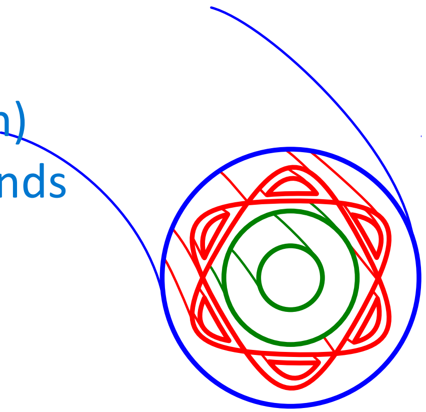
Magnetic reconnection is ubiquitous in plasmas

Magnetic reconnection describes topology magnetic field changes due to non-ideal effects.



« Tearing » - like instabilities:
Magnetic field lines are torn then reconnected on resonant surfaces (in red)

Large (few cm) magnetic islands

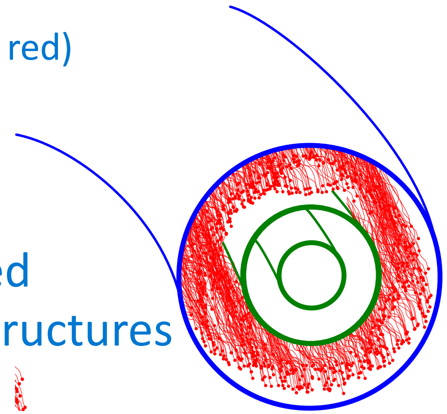


1. Prediction of the saturated island size ?
[O. Sauter et al. POP 1997]

+ Turbulence

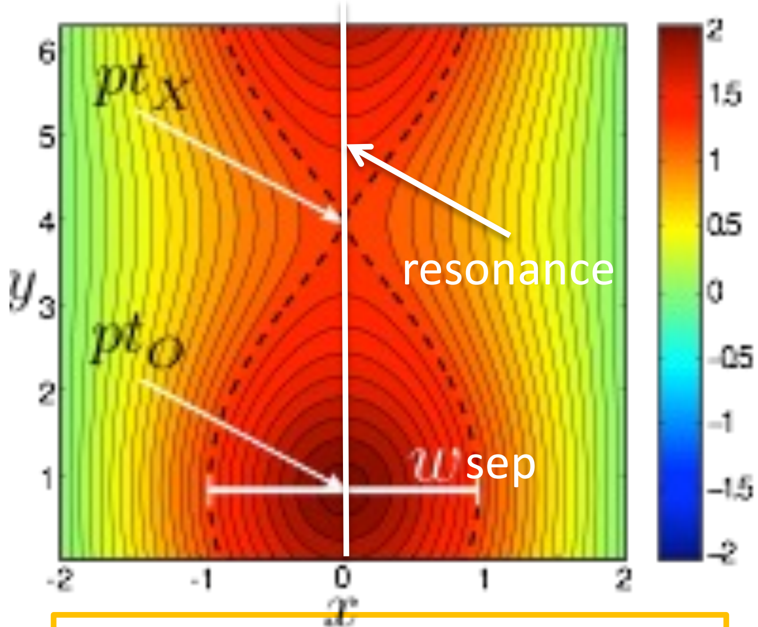
2. Generation of island by turbulence ?
[M. Muraglia PRL 2011]
[Thèse de D. Villa (PIIM)]
[D. Villa et al, sub. to POP]

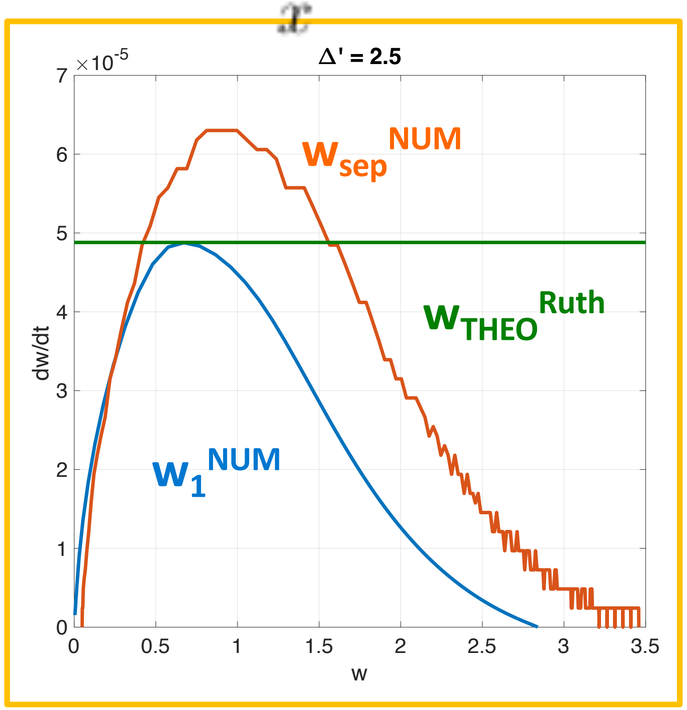
Small (mm) Reconnected magnetic structures



3. Impact on transport ?
[N. Dubuit et al JPCS 2022]

First models for island size saturation prediction





- **Definition and evolution of the island size?**

  An open question

- Evaluation of the island size/ radial witdth from poloidal mode 1 **[P.H. Rutherford POF 16 (1973)]**

$$w_{m=1} = 4\sqrt{2a\psi_1(x_{res})}$$

- Derivation of Rutherford model from the projection of the Ohm's law on m=1 mode and reduction the Grad-Shafranov equation: **[P.H. Rutherford POF 16 (1973)]**

$$\partial_t w^{Ruth} = \partial_t w_{m=1} = 1.22\eta\Delta'$$

- Saturation of the mode m = 1 => POEM model **[Escande and Ottaviani (2004) & Militello and Porcelli (2004)]**

$$\partial_t w^{POEM} = \partial_t w_{m=1} = 1.22\eta\Delta' - 1.22\eta\frac{0.41}{a^2}w$$

1) Valid only for m = 1 and small island
2) Valid only at the resonance => 0D model

I. Relevant models of MR for fusion plasmas

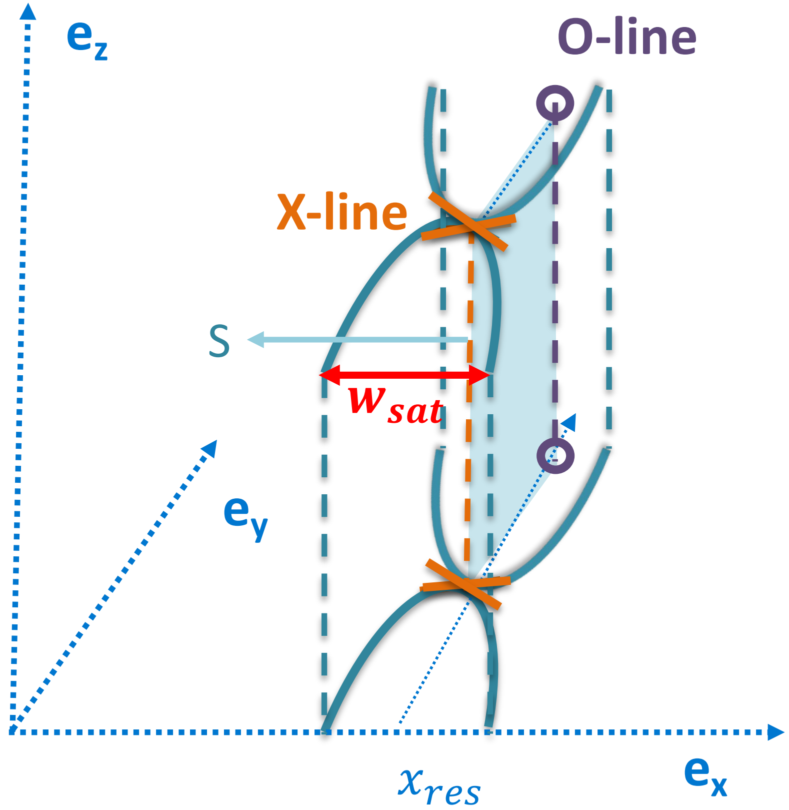
❖ Improvement of Rutherford-like model for the prediction of saturated island size

Investigated by M. Muraglia et al. with AMON **[M. Muraglia et al. JPP 91 (2025)]**

Magnetic island structure in SLAB geometry with strong guide field

$\boldsymbol{B} = B_z \boldsymbol{e_z} + \nabla \times \psi \boldsymbol{e_z}$

at the equilibrium, $B_y(x_{res}) = 0$



➢ Reconnection and annihilation rates

$$\left.\frac{d\phi}{dt}\right|_s = \frac{d}{dt}\iint_S \boldsymbol{B}.\boldsymbol{dS} = \int_{X-line} \eta j_z dz - \int_{O-line} \eta j_z dz$$

$$\mathrm{RR} = \left.\frac{d\phi}{dt}\right|_{RM} \qquad AN = \left.\frac{d\phi}{dt}\right|_{AN}$$

➢ Hypothesis 1

Growth of island: $\left.\frac{d\phi}{dt}\right|_{RM} > \left.\frac{d\phi}{dt}\right|_{AN}$

Saturation of island: $\left.\frac{d\phi}{dt}\right|_{RM} = \left.\frac{d\phi}{dt}\right|_{AN}$

➢ Hypothesis 2

New definition of island size [D. Escande, B. Momo, RMPP, 2024]

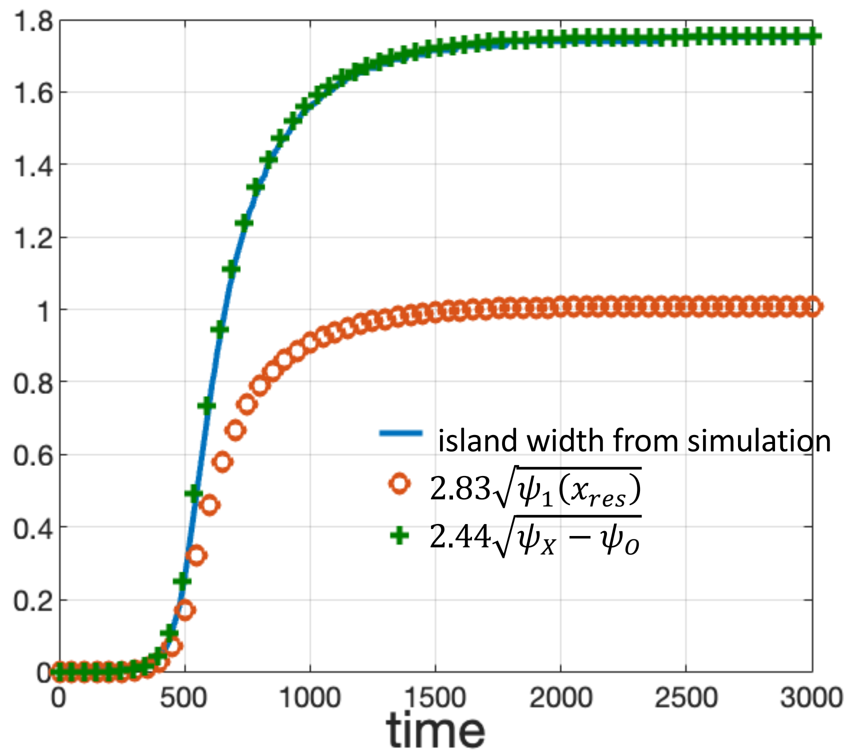
$w \propto \sqrt{\psi_X - \psi_O}$ (instead of $w \propto \sqrt{\psi_1(x_{res})}$)

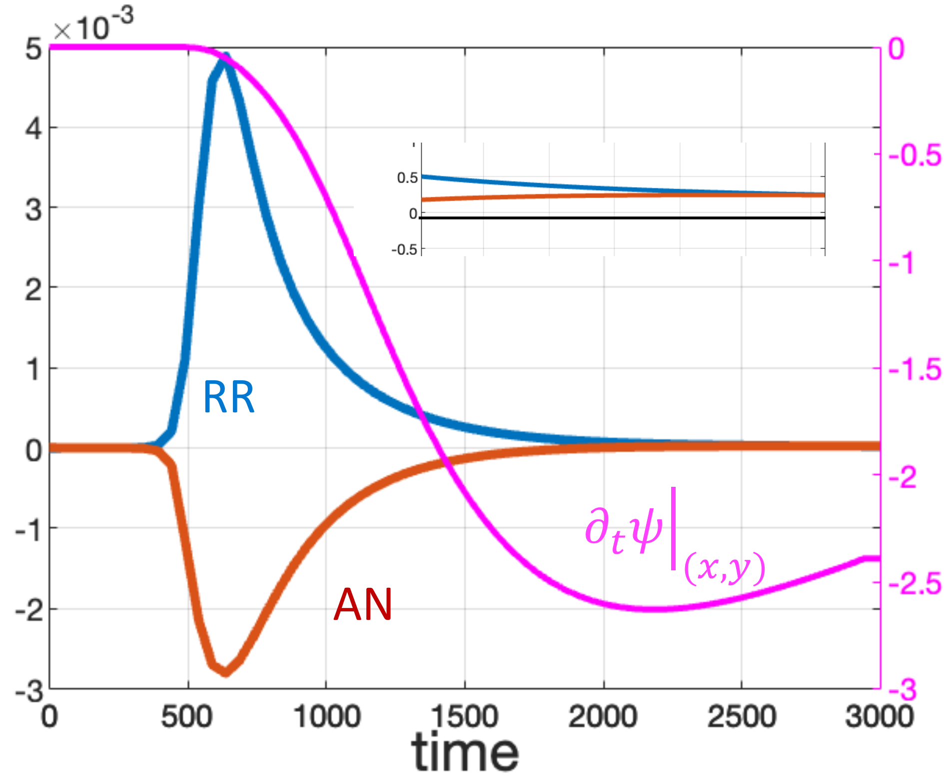
=> At saturation: $\partial_t(\psi_X - \psi_O) = 0$

I. Relevant models of MR for fusion plasmas

❖ Improvement of Rutherford-like model for the prediction of saturated island size

Investigated by M. Muraglia et al. with AMON





Main results :

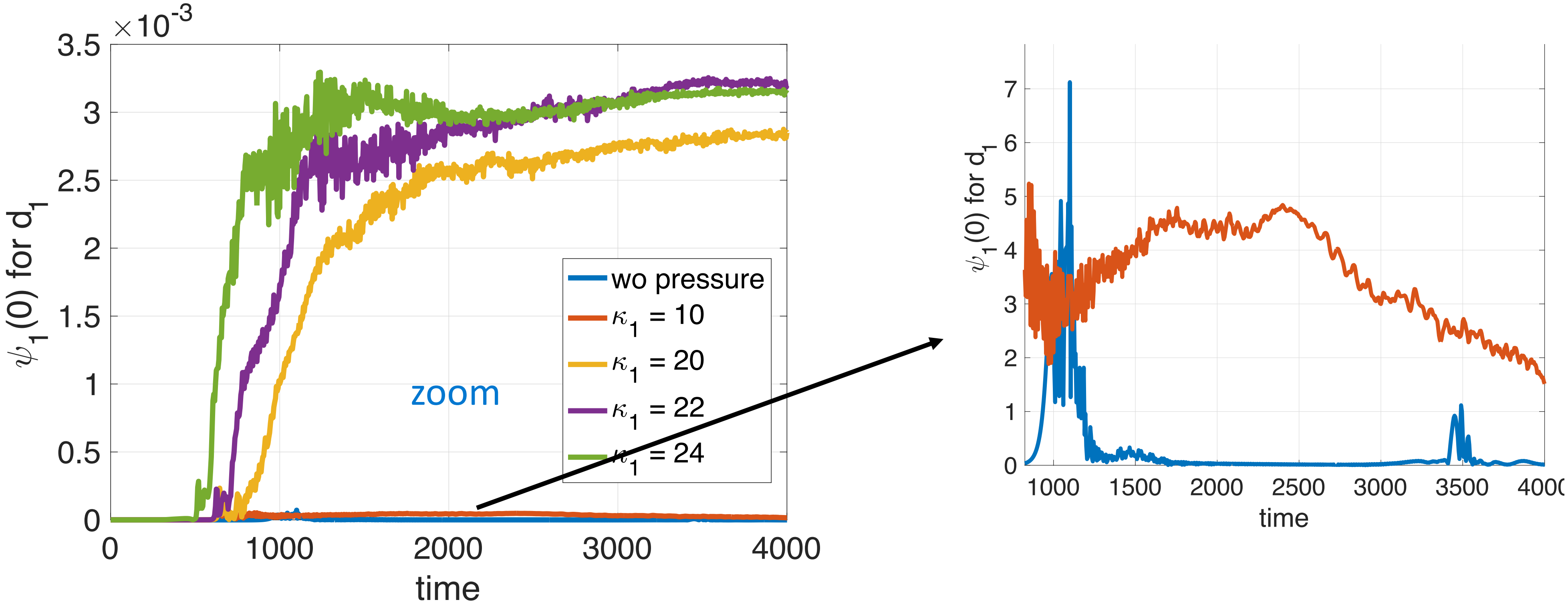
- For the first time, agreement between simulation and theoretical definition of island width
- Island growth RR > AN, Island width saturation RR = AA

Ongoing work : New theoretical model has to be derived from this two new features and application to TCV discharges (see part II)
What is the difference between resistive and inertial saturation ?
Do kinetic effects affect the saturation ?

II. Interplay between magnetic island(s) and turbulence

❖ **First nonlinear MHD simulation of DTM in presence of interchange turbulence**

Investigated in 2024 by M. Muraglia et al. with AMON code



➢ In presence of pressure, the reconnection persists after the explosion and the total reconnection

➢ Turbulence enhances reconnection (i. e. the production of magnetic flux)

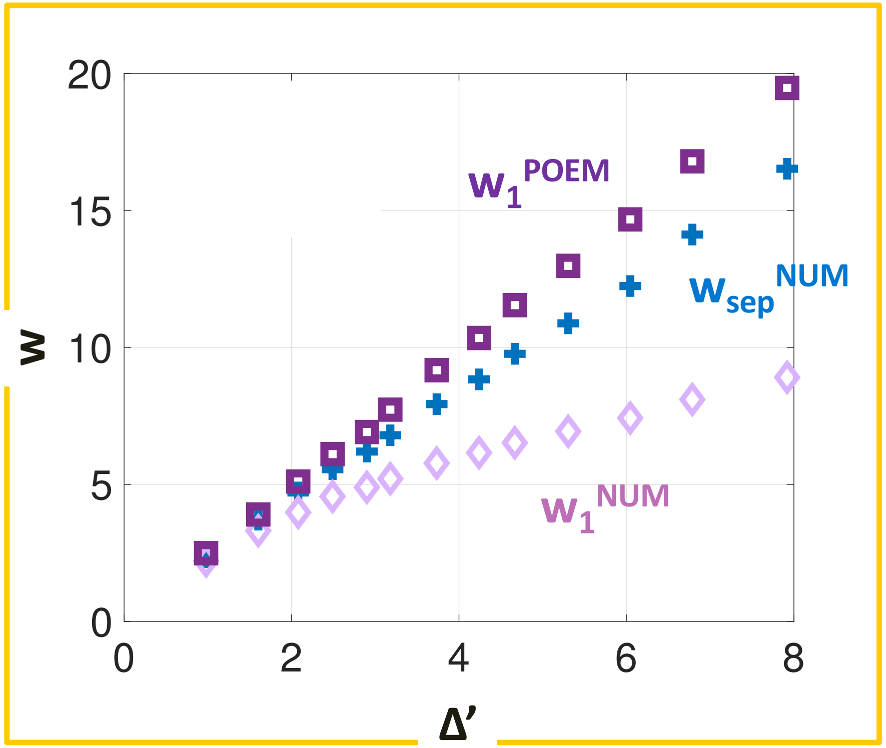
Systematic comparisons between theory and simulations

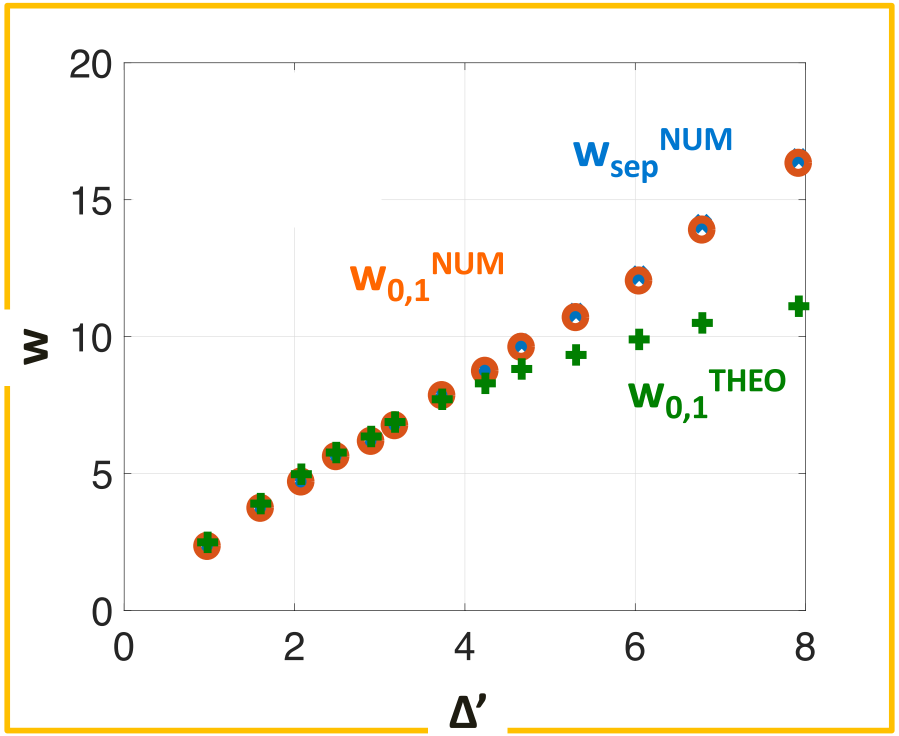
- **Saturation of the island taking into account modes 0 and 1**

[A. Smolyakov et al. POP 20 (2013)]

$$\partial_t w_{m=0,1} = 1.22\eta\Delta' - 1.22\eta \frac{0.41}{a^2} w \times \frac{1}{1-0.1678w^2/a^2}$$

=> Should be confronted to simulations





[M. Muraglia et al, PPCF (2021)]

=> Model fails to predict the complete dynamics

=> What's about NTM dynamics prediction by Rutherford-like models ?

T1.1

T1.1	**3D and asymmetric effects impacting magnetic structure** **C. Marchetto**, D. Grasso, D. Borgogno, P. Donnel, X. Garbet, M.J. Pueschel, O. Agullo and M. Muraglia	
No	Milestones - Description	Exp. Date
M.1	A first study of asymmetric mode with low stochasticity level around the separatrix in collisionless plasmas with SCOPE3D	31/12/24
M.2	Find relevant input parameters to investigate the linear stability of 2/1 TM in GYSELA using a tokamak q-profile	01/03/25
M.3	Linear collisionless and collisional simulations with GYSELA of 2/1 TM	01/06/25
M.4	Comparison of linear simulations with GYSELA to theoretical and MHD predictions	01/09/25
Deliverables - Description		Year
D.1.1.1	Report on the effect of magnetic chaos on nonlinear evolution of a 2/1 TM	2024
D.1.1.2	Validation of the linear TM implementation in GYSELA	2025
D.1.1.3	Report on the linear properties of the asymmetric TM instability in in the collisionless and collisional regimes	2025

T1.2

T1.2	**New 1D Rutherford-like model based on TCV experiments** **O. Agullo**, M. Kong, O. Sauter, E. Poli, P. Donnel, X. Garbet and M. Muraglia	
No	Milestones – Description	Exp. Date
M.1	Obtain input parameters from TCV experiment of 2/1 NTM	01/03/24
M.2	Run and analyze NL simulations with ORB5 and AMON of a simple 2/1 TM	01/12/24
M.3	Comparison of numerical results with theories and TCV measurements	01/06/25
Deliverables – Description		Year
D.1.2	New 1D Rutherford-like model to predict saturated island size (report)	2025

T2.1

T2.1	**Signatures of turbulence-driven magnetic islands** **E. Poli**, M. Kong, O. Sauter, M.J. Pueschel, Q. Yu, O. Agullo, N. Dubuit, X. Garbet, and M. Muraglia	
No	**Milestones - Description**	**Exp. Date**
M.1	Obtain input parameters from TCV experiment of 2/1 NTM with turbulence	01/03/24
M.2	Run and analyze linear simulations of double TM (DTM) together with turbulence using AMON	01/12/24
M.3	First comparison between ORB5, GENE, and AMON NL simulations (tearing + turbulence) of TCV	01/06/24
M.4	First round of comparison of simulations with TCV experimental data	01/12/24
M.5	Run and analyze NL simulations of DTM with turbulence with AMON	01/06/25
M.6	Final analysis and interpretation of the comparison of MHD and gyrokinetic simulations (tearing + turbulence) with TCV results	01/09/25
Deliverables - Description		**Year**
D.2.1.1	List of signatures of the mutual interaction between magnetic island and turbulence (report)	2025
D.2.1.2	Report comparing the impact of ITG and TEM turbulence regimes on the island, both at low (intact island) and high (stochasticized island) pressure	2025
D.2.1.3	First analysis of the interaction between turbulence and a DTM (report)	2025

T2.2

T2.2	**Magnetic reconnection driven by runaway current** **D. Grasso**, D. Borgogno, N. Dubuit, and M. Muraglia	
No	Milestones - Description	Exp. Date
M.1	Effect of electron mass on MR driven by runaway current	30/06/24
M.2	Comparison of our results with upgraded JOREK including runaways	30/06/25
Deliverables - Description		Year
D.2.2.1	Report on the simulation campaign on MR driven by runaways taking into account the electron mass	2024
D.2.2.2	Report on verification of the JOREK module including runaways	2025

T3.1

T3.1	**Impact of MHD instability on ion-scale micro-instabilities/turbulence** **M.J. Pueschel**, P. Donnel, X. Garbet, O. Agullo, and M. Muraglia	
No	**Milestones - Description**	**Exp. Date**
M.1	Modification of the GYSELA code to simulate nonlinear tearing mode in the collisional regime and including a magnetic equilibrium solution of Grad-Shafranov equation	In progress
M.2	Implementation of the collision operator in GYSELA	In progress
M.3	First simulation with GYSELA of tearing mode in presence of gradients (pressure and electronic temperature)	Current 2025
Deliverables - Description		**Year**
D.3.1.1	Report on the kinetic drift-tearing mode with GYSELA	2025
D.3.1.2	Report on how microturbulence reacts to different saturated tearing scenarios (based on GENE simulations)	2025

T3.2

T3.2	**Transport and confinement in the presence of reconnected structures** **N. Dubuit**, O. Agullo, C. Marchetto and O. Sauter	
No	Milestones - Description	Exp. Date
M.1	Investigation of the resilience of large-scale Lagrangian Coherent Structures (LCS) to small-scale fluctuations	31/12/24
M.2	Characterization of 2D transport in islands in the presence of interchange/ballooning turbulence	30/06/25
M.3	Calculation of transport coefficients for main plasma species, experimental validation	30/06/25
M.4	Calculation of transport coefficients for impurities, experimental validation	31/12/25
Deliverables - Description		Year
D.3.2.1	Report on the robustness of large-scale LCS in a turbulent plasma	2024
D.3.2.2	Model of transport coefficients in the presence of magnetic islands without turbulence	2025
D.3.2.3	Model of coefficient transports in the presence of magnetic islands with turbulence	2025

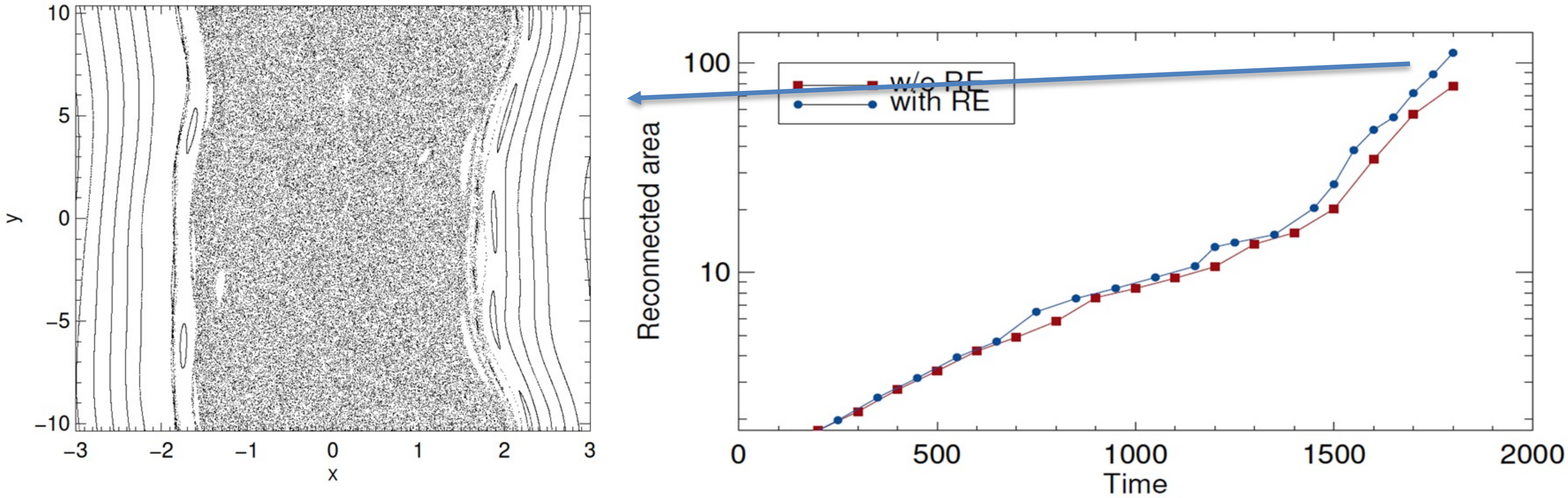
2024 Deliverables

Scientific deliverable *(annual scientific deliverables as specified in the Task Agreement)*	**Achieved: Fully/Partly/Not**	**Evidence for achievement, brief reason for partial or non-achievement**
Kelvin-Helmholtz instability driven by asymmetry effects in chaotic magnetic configurations D.1.1.1	Fully	EUROfusion pinboard number 3.ENR-05-CEA-01-new, 39265
Report on the simulation campaign on MR driven by runaways taking into account magnetic chaos D.2.2.1	Partially	The stop of Marconi has delayed the data analysis and the writing of the draft
Structure of magnetic islands in presence of small-scale stochastic turbulence D.3.2.1	Fully	EUROfusion pinboard number 3.ENR-05-CEA-01-new, 39287

II. Mutual interplay between MR and Runaway Electrons

Nonlinear MHD simulations of multiple helicities in 3D configuration

Investigated by D. Borgogno et al. with SCOPE3D code



Main results:

- Multiple helicities drive chaos and lead to stochastisation of magnetic field lines
- Chaos leads to explosive magnetic reconnection processes
- Runaway electrons increase 50% of the reconnected area
- REs current decreases and is uniformly distributed in the chaotic region

Ongoing work

- Final submission of D.2.2.1 if Marconi's problem will be fixed (recover data or new simulations ?)
- Regarding the linear evolution, the scaling law as a function of the resistivity was verified in JOREK, and the results agree with the theory derived from FKR. We are working at the comparison of the saturated islands.

Conclusions

- 2024 milestones have been fully achieved

- Stop of Marconi has delayed the deliverable D.2.2.1 and should delay some milestones and deliverables in 2025

- Strong impact of data loss and Marconi outage on project progress
- LEONARDO

  - (((((Some data are LOST for ever on marconi and are required to complete some tasks
  - CPU-time consuming simulation (in particular the multiscale nonlinear simulations) can not be done on medium-size computer centers (like mesocentre at Marseille) and marconi is needed.
  - Leonardo : new submission files, share with other community, …
  - STRONG impact of the achievement of the projet)))

- 2024 meetings

  - Online meetings in January and May
  - Face to face workshop at Marseille in September

- 2025 meetings

  - Online meetings in March and in December
  - Face to face meetings : In June at Turin, In September at Marseille

- T-RECS network and visibility