Effects of a tri-dimensional boundary on Resistive Wall Mode stability

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with:

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OUTLINE

Presentation OUTLINE :

- general remarks about **RWMs** in tokamaks and RPFs
- brief description of the **CarMa** code (MARFS-F **+** Cariddi)
- results for RFX-mod and comparison with experimental data

F. Villone et. al. Phys. Rev. Lett ***100****, 255005 (2008))*

Physics open questions

- RWMs represent the **most stringent limiting** factor for high beta operation in ITER advanced scenarios

OPEN Physics ISSUES are:

- role of **dissipation/rotation** in stabilization
- role of **field errors** / realistic **3D wall** on mode stability
- feedback stabilization vs. **Sensors/actuators architecture**

The numerical approach: CarMa code

The CarMa code is the **union** of two codes:

MARS-F :

- **single fluid resistive MHD equations**
- eigenvalue and also initial value calculation (single n)
- Feedback coils (Fourier represented)
- Plasma rotation and damping models included
  - *Thin wall approximation*

and

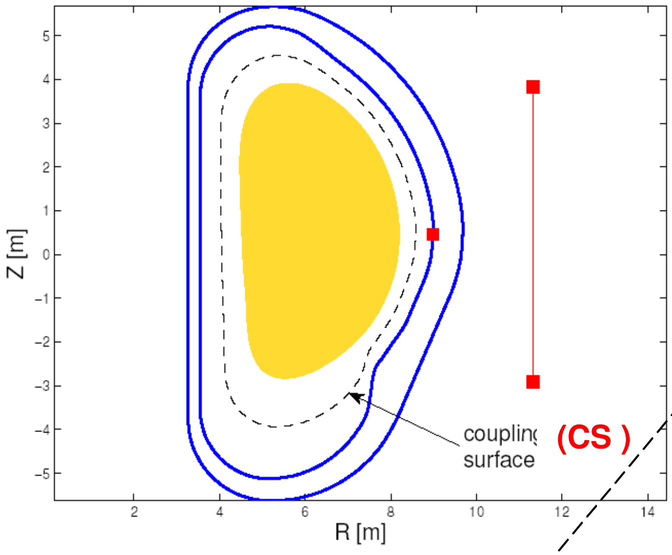
Carriddi:

- **3D electromagnetic code** (coils, passive conductors):

Solves eddy currents equations in time and frequency domain
3D integral formulation (only conductors are discretized))

Recently updated for RFP RWM calculations

The strategy of the CarMa code



- Mars-F calculates the plasma solution within **CS**

Plasma **mass is neglected**:
⇒the plasma response is static (Alfven time << wall time)
⇒and characterized by a response matrix to unit normal field on **CS**

- CARIDDI set a mesh of the passive structures and describes **CS** with a set of current filaments
  - surface currents on **CS** are considered to match the plasma magnetic field
  - the plasma/wall coupling is computed by CARIDDI via **CS** equivalent currents

b_{norm} on CS for each m with b_m=1 and $b_{m'}$=0 for all $m' \neq m$

+

γ is assumed to be very low
(but results independent on this choice)

CarMa is applied to RFX-mod

- RWMs in RFPs are very reproducible current-driven modes: their growth rates can be reliably compared with theory

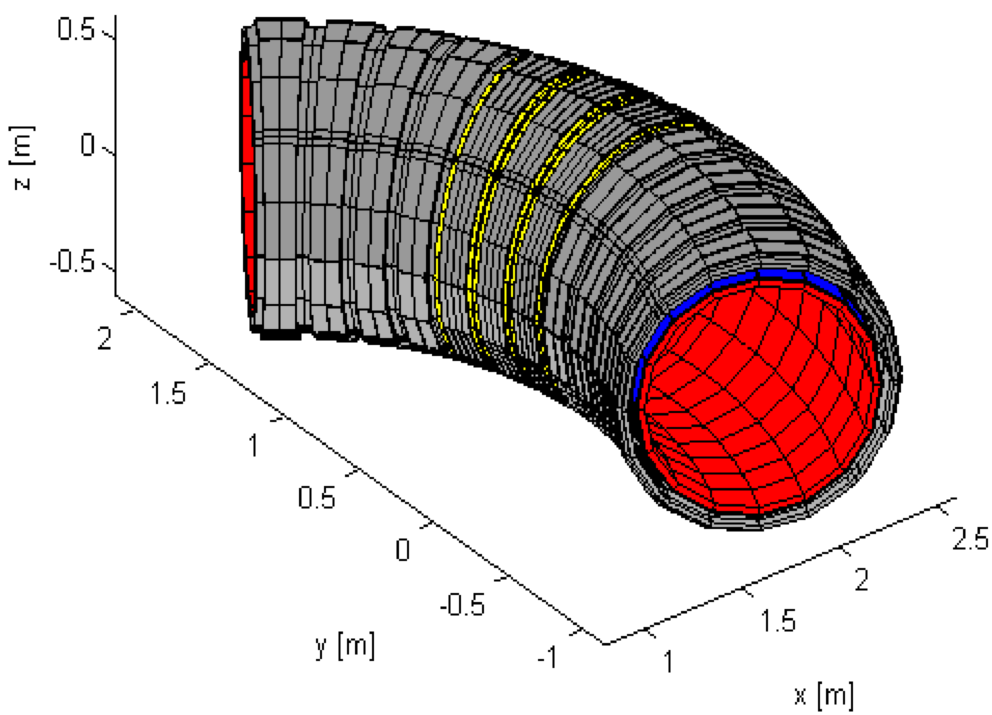
- 3D effects/error fields are likely to influence the growth rates

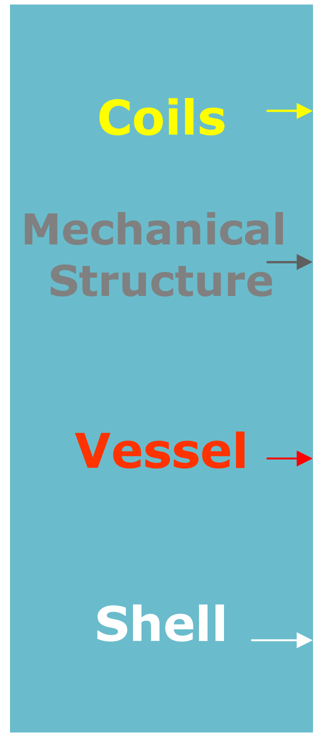
- CarMa results can be compared with experimental data so that RFP can serve as a sort of benchmark of the code in view of ITER apllications
(beside an answer to the previous points can be obtained)

- CarMa electromagnetic model of RFX-mod can also be used for future studies on the general feedback problem (not only RWM but also tearing modes control)

RFX-mod passive structures

Typical discretization:
> 20000 elements > 57000 nodes





- **Coils** → on the shell ext.
- **Mechanical Structure** → $b/a > 1.2$, $\tau_{wall} \cong 20$ ms
- **Vessel** → $b/a \cong 1.08$, $\tau_{wall} \cong 1 - 2$ ms
- **Shell** → $b/a \cong 1.11$, $\tau_{wall} \cong 50 - 60$ ms

1 toroidal and
2 poloidal (1 overlapped)
gaps are modelled

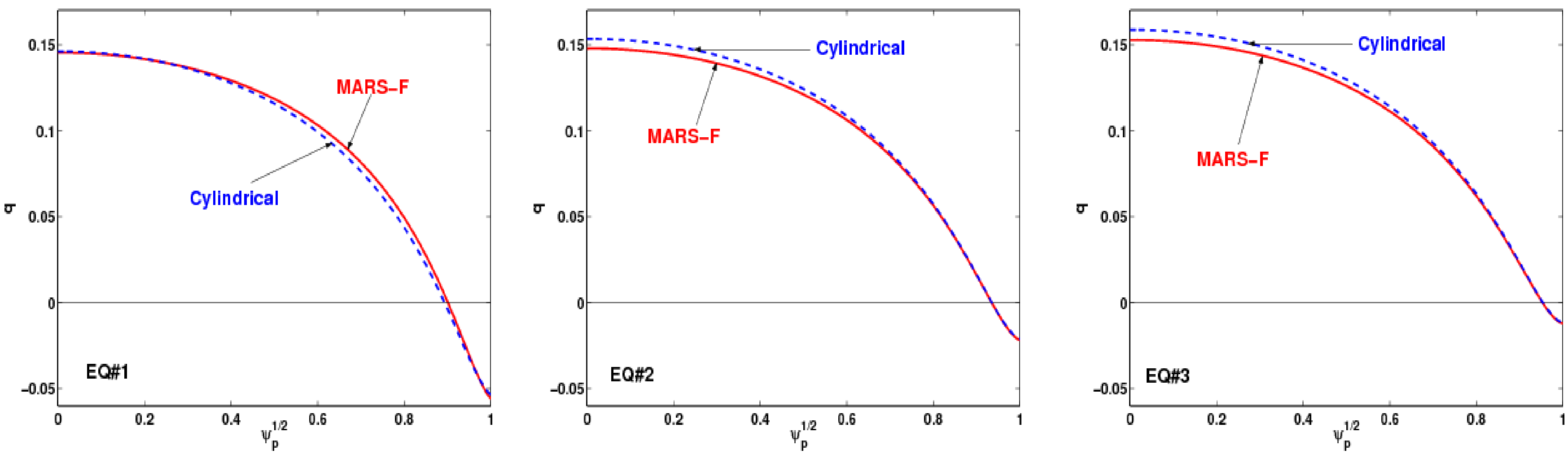
RWMs growth rates comparison: MARS-F and ETAW toroidal vs. cylindrical

- MARS-F (Chease) has been modified for toroidal RFP equilibria
- No big differences in growth rates were expected *(cylinder vs. torus)*

  R.Paccagnella et. al. NF ***31*** *(1991) 1899*
- 3 Equilibria with different F's have been considered (mu&p model)

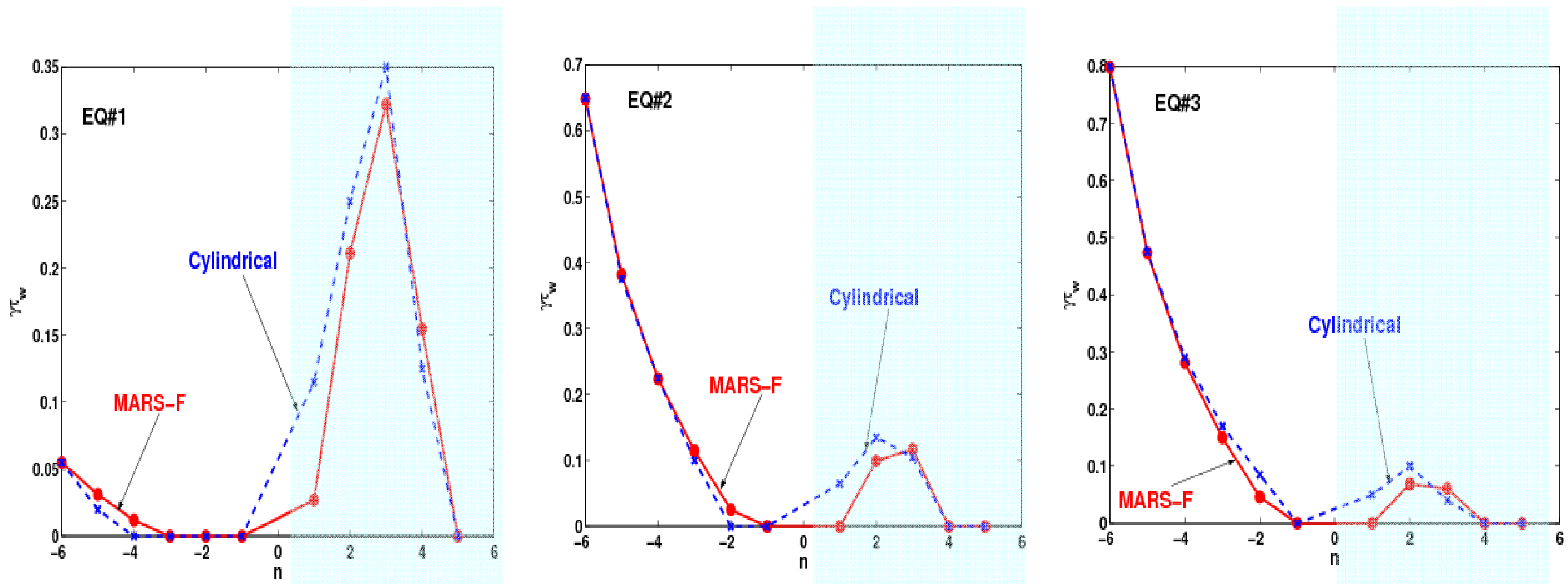
  $\mu(0)$, α

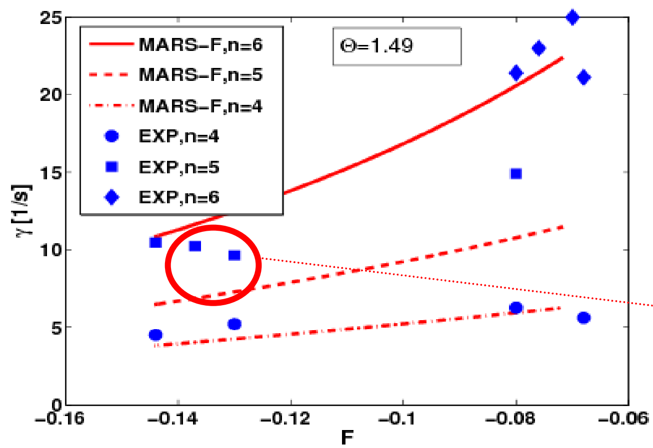
slightly different q profiles and F values due to toroidicity



F=-0.37 F=-0.15 F=-0.07

RWMs growth rates comparison:
MARS-F and ETAW toroidal vs. Cylindrical (2)





- Good agrement has been found of cylindrical vs. Toroidal vs. *Experimental* growth rates

some exceptions!
n=-5,-6

CONSORZIO RFX
Ricerca Formazione Innovazione

RWMs spectrum: ETAW, MARS-F , CarMa
cylindrical, toroidal and 3D

Cylinder:

m=1 → n, → -n are 2 distinct modes

Torus:

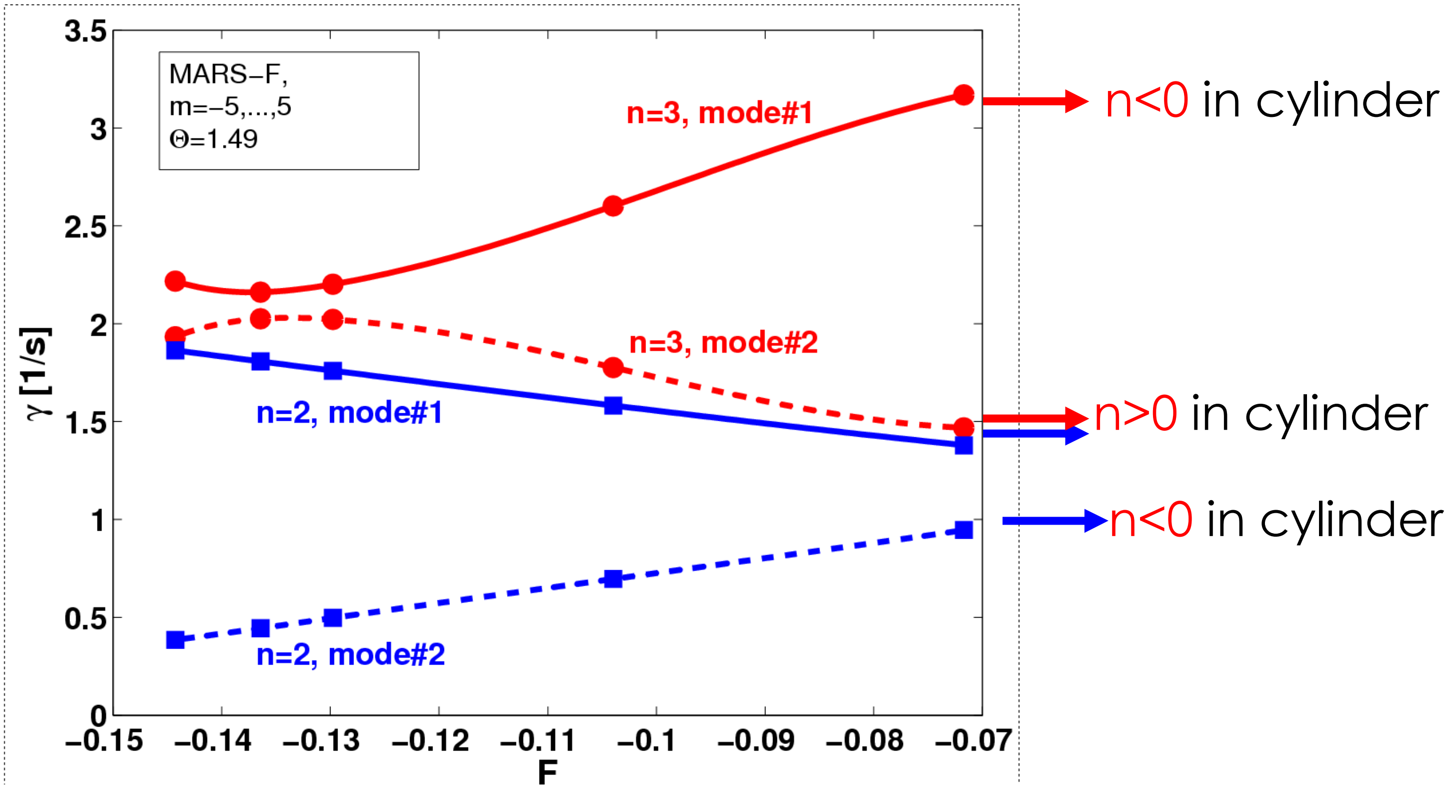
All m's coupled → can not distinguish (+/- n) → n →

→ but there are still **2 distinct global modes** with different m's spectral decomposition and different growth rates
→ (dominant m=+/-1)

for each of these modes there is another degenerate mode (same γ) with an eigenfunction shifted by (π /2 n) toroidally

→ **3D effects** (like gaps) can remove this degenerancy →

RWM spectrum: MARS-F results (toroidal coupling)



RWMs spectrum: 3D effects

CarMa → monomodal, multimodal — Identical for 2D axi-symmetric wall

With a 3D wall, monomodal and multimodal growth rates are different: modes with different n's are coupled due to 3D conducting structures

Similar result in : *R. Fitzpatrick, Phys. Plasmas* ***1****, 2931 (1994)*

To summarize 3D effects can:

- remove spectral degenerancy
- couple modes with different n's
- affect the growth rates

CARMA results with a 3D shell with gaps : example of "line" splitting

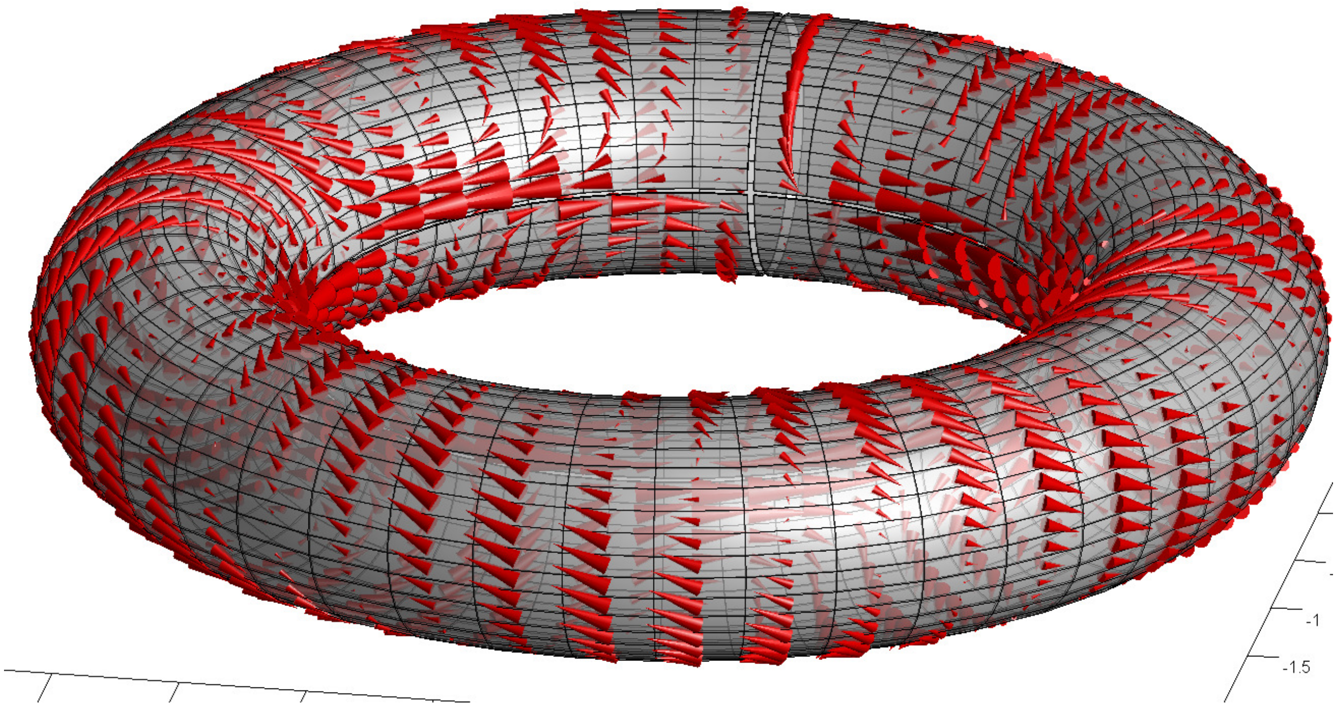
n value	monomodal	multimodal
1	<0	<0
2	0.447 } (-1,n) 0.459 } (1,-n) 2.40 } (1,+n) 2.48 } (-1,-n)	0.448 0.462 2.33 2.36
3	2.58 } 2.62 } 2.96 } 3.04 }	2.61 2.64 3.13 3.26
4	5.46 5.53	5.63 5.78
5	9.62 9.73	9.91 10.2
6	17.0 17.2	17.6 18.2

Equilibrium #2
F=-0.15

(in s^-1)

CarMa results

(Eq#1 with F=-0.37)



$\gamma\tau_{wall}$ = 0.32
MARS-F

$\gamma\tau_{wall}$ = 0.55
CarMa

Current pattern on the shell due to an n=3 unstable mode

CarMa results (2)

	Equilibrium #3 F=-0.07				Equilibrium #2 F=-0.15			
	ETAW	MARSF	CarMa	Exp.	ETAW	MARSF	CarMa	Exp.
n=1	0.909	<0	<0	<0	<0	<0	<0	<0
n=2	1.56	0.780	0.869 0.931	N.A.	<0	0.434	0.448 0.462	N.A.
	1.82	1.29	1.67 1.81		2.45	1.81	2.33 2.36	
n=3	0.727	1.10	1.37 1.40	N.A.	1.82	2.08	2.61 2.64	N.A.
	3.09	2.71	3.69 3.78		1.90	2.16	3.13 3.26	
n=4	5.27	5.07	7.30 7.48	≈6	4.09	4.04	5.63 5.78	≈4.5
n=5	8.63	8.55	12.8 13.1	≈12	6.81	6.89	9.91 10.2	≈8
n=6	14.5	14.4	22.6 23.4	≈22	11.8	11.7	17.6 18.2	≈17

(sec^-1)

CarMa compares better with experimental results in RFX-mod at least for some modes

CONCLUSION

• good comparison of CarMa with RFX RWM results

• realistic electromagnetic model can help also for future feedback studies on tearing modes in RFX

• assessment of CarMa reliability very important for ITER applications

for the near future:

• strengthen the comparison with RFX experimental data (new campaigns)

• build /test a complete electromagnetic model of the RFX machine for feedback studies and also for field errors reconstruction/recognition

• applications to other RFPs (T2R..) also possible