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Recent results on RWM research on RFX-mod

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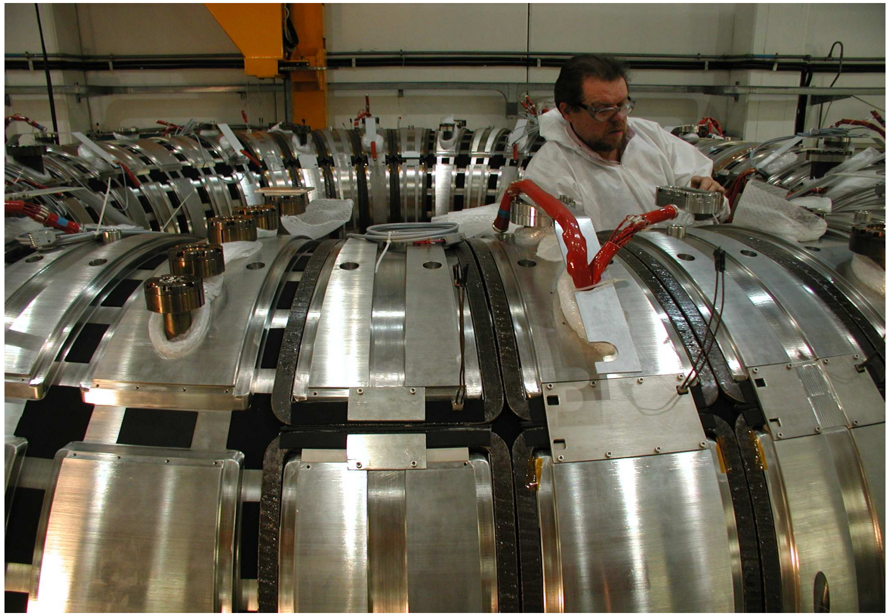
Outline

- Ø Introduction
- Ø Statistical investigation of RWM growth rates on RFX-mod
- Ø RWM active rotation: experimental issues
- Ø RWM active rotation: first (not fully validated) results
- Ø Conclusions and future work

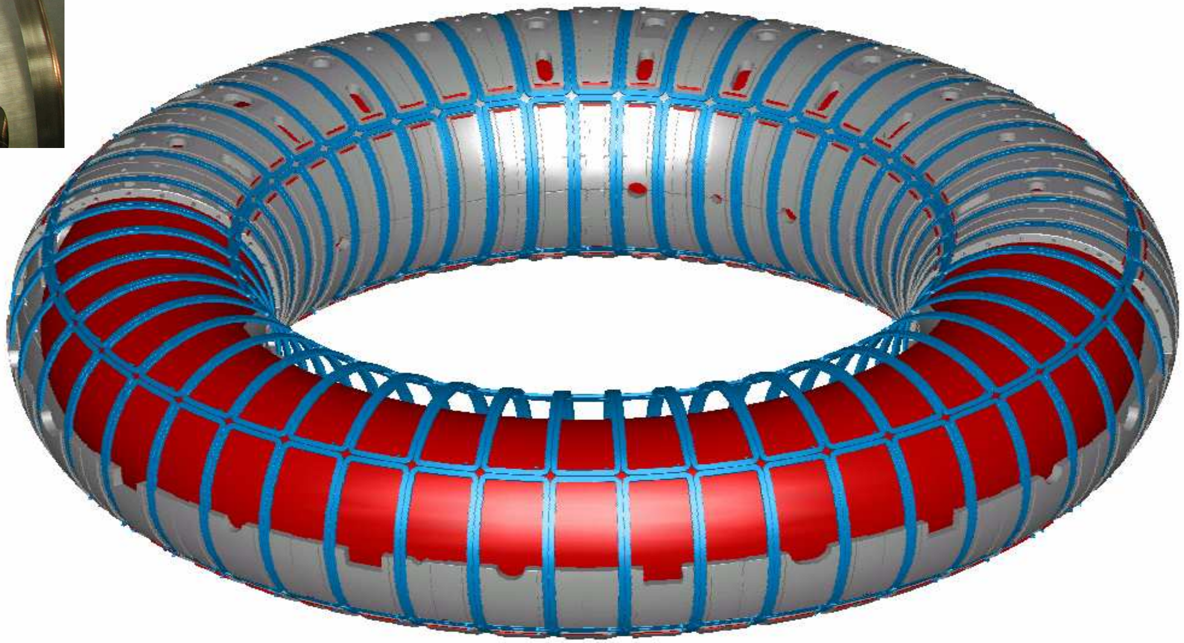
MHD active control in RFX-mod



Total of 192 active coils.

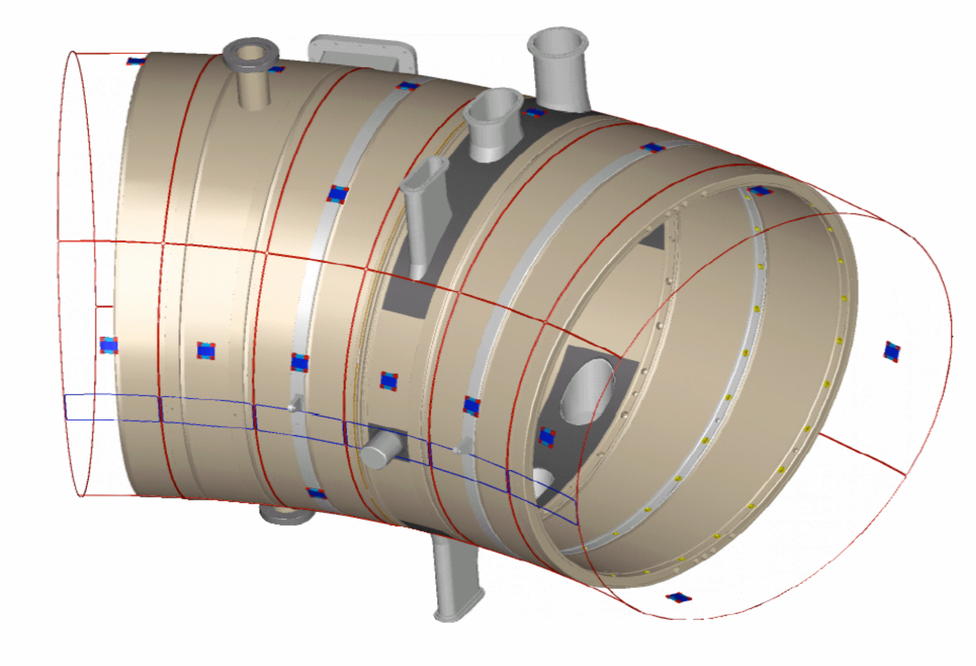
100% coverage of the mechanical structure external surface.

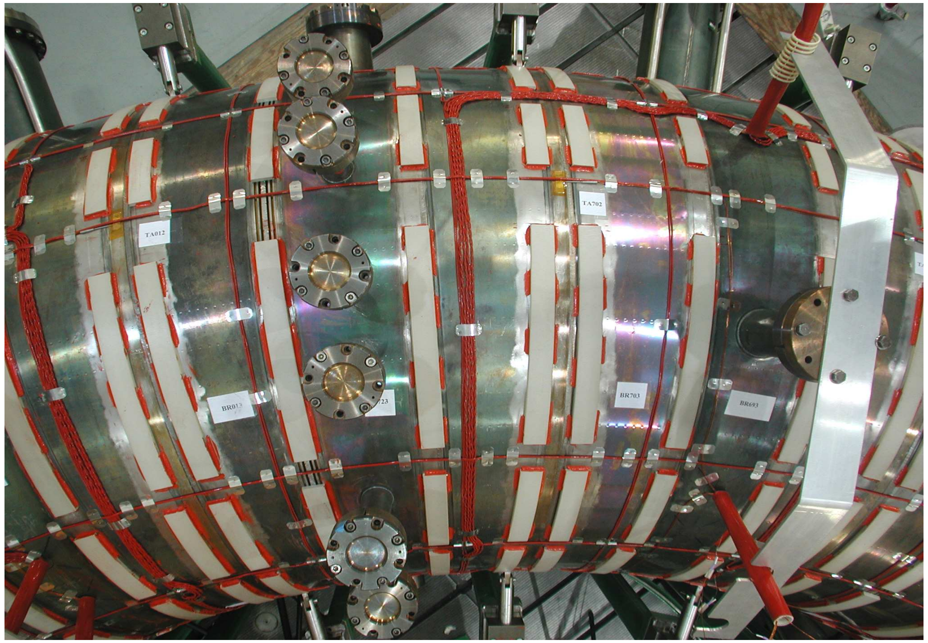
Each saddle coil is fed with its own power supply.



Radial field at 24 kAt	* (mT)*
DC	50
@10Hz	35
@50Hz	12
@100Hz (I=16 kAt)	3.5

MHD diagnostics: external probes

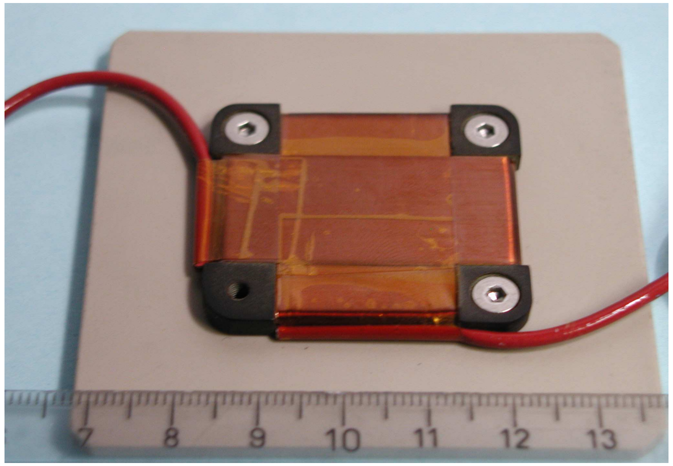




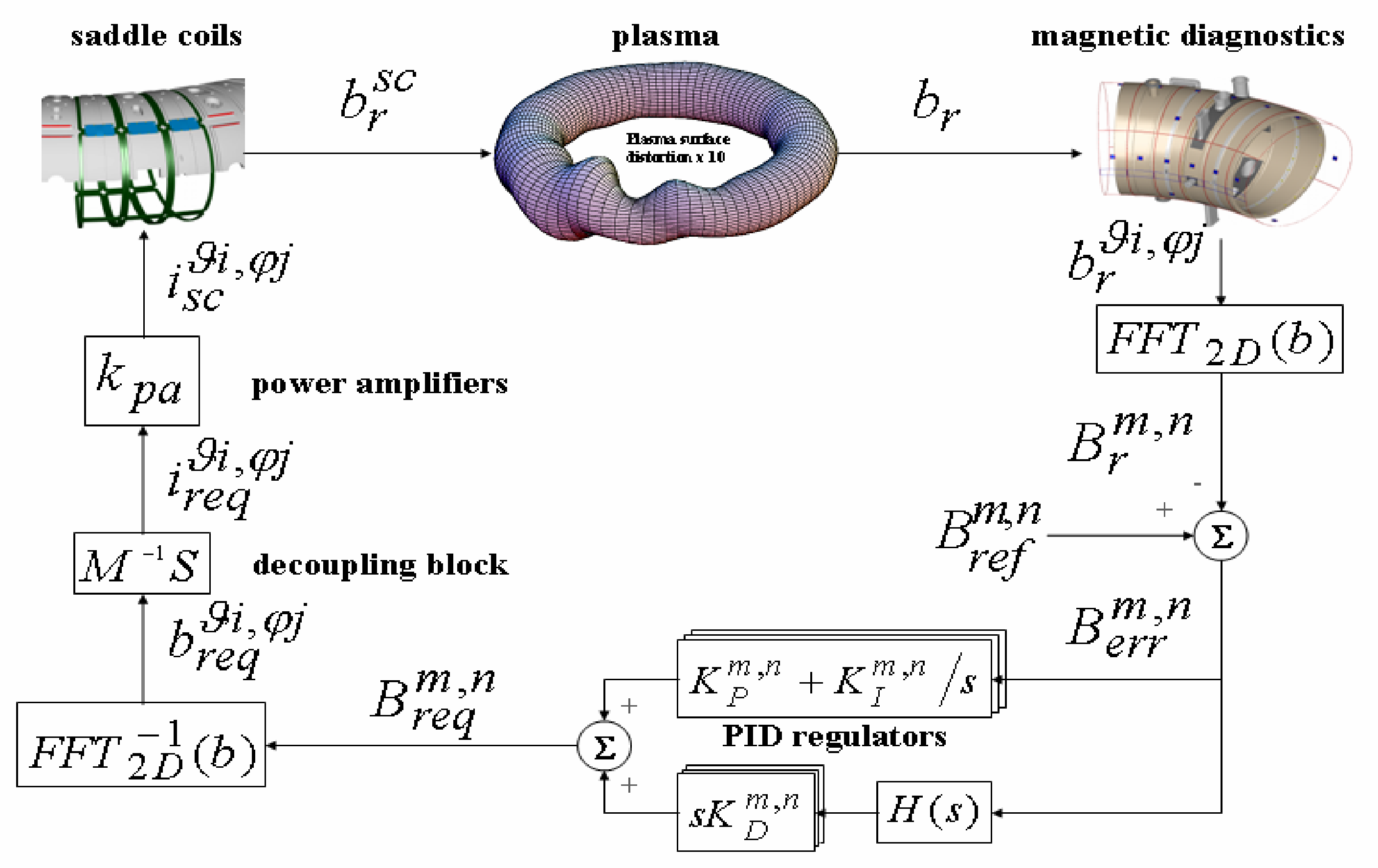
48 x 4 = 192 Br saddle probes
48 x 4 = 192 Bt and Bp pick up probes

+ other probes for toroidal and poloidal Vloop, plasma current, halo current measurements

TOTAL ≈ 650 probes



MHD control scenarios: Mode Control

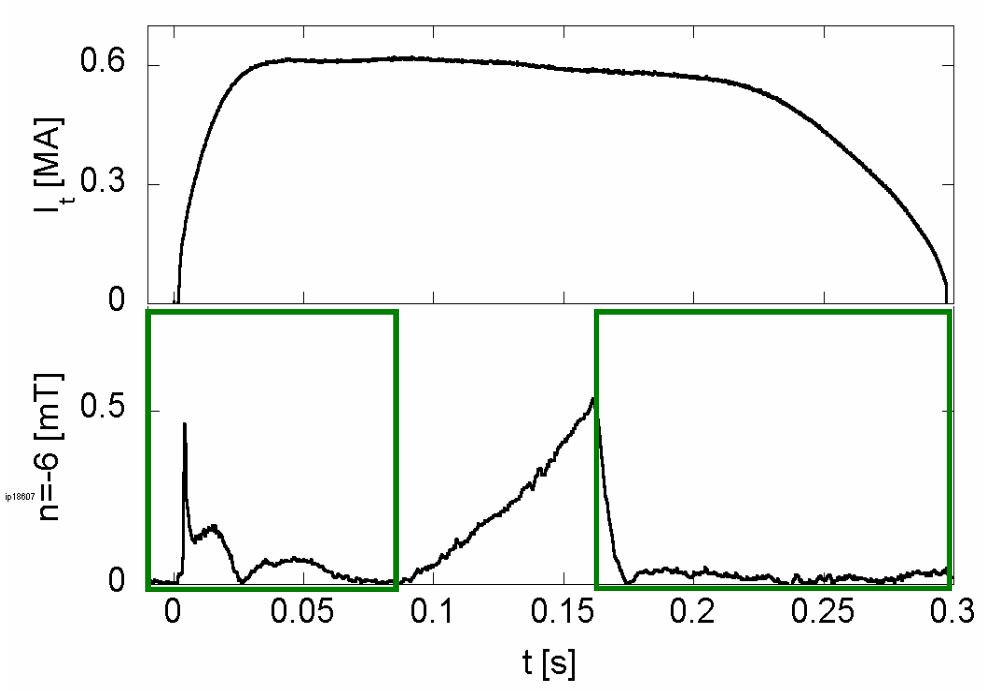


- ***Mode Control (MC)***: controls single modes or groups of modes (from 1 to all)
  each mode is assigned its own regulator.
  derivative control to compensate for radial field penetration delay due to the passive structures (delay depends on mode number)
  1-pole Butterworth filter to smooth the derivative action.

A. Luchetta et al., IAEA conference, Chengdu (2006)

Main achievements on RWM

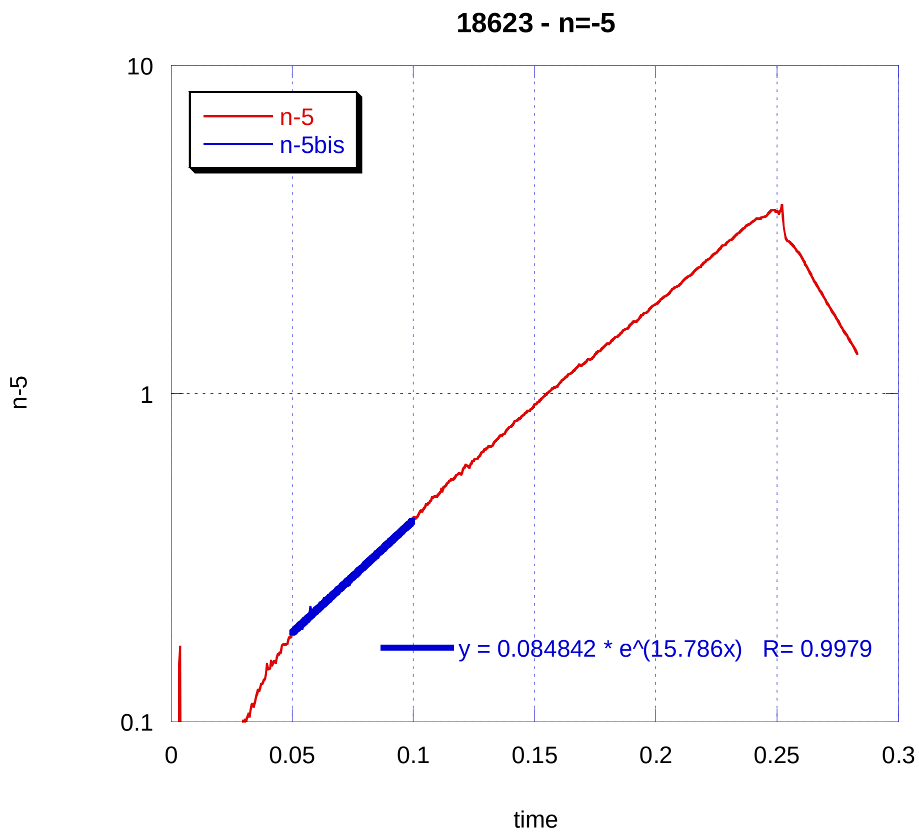
- Full control of the RWM spectrum (multiple RWMs are always unstable)
- Identification of RWM growth in discharges with partial (selective) mode control
- Test of RWM control after some time of free growth
- Controlled growth of different combinations of unstable RWM and TM
- First RFA studies

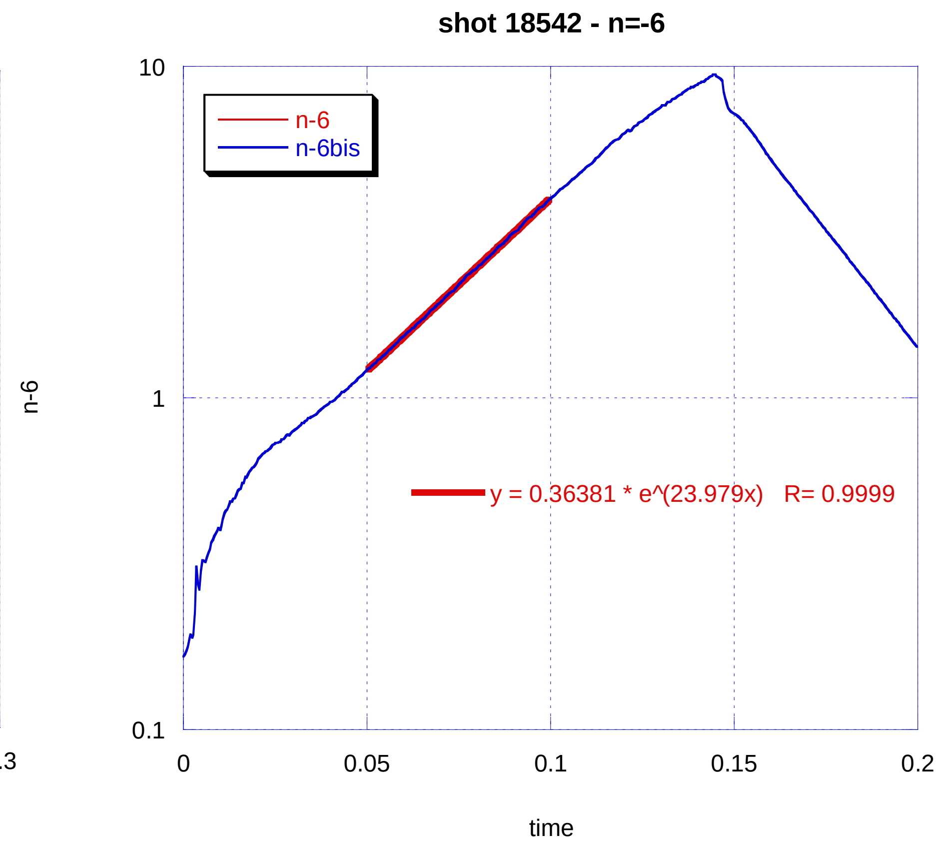


First part

- Statistical investigation of RWM growth rates on RFX-mod

Very precise determination of RWM exp. growth

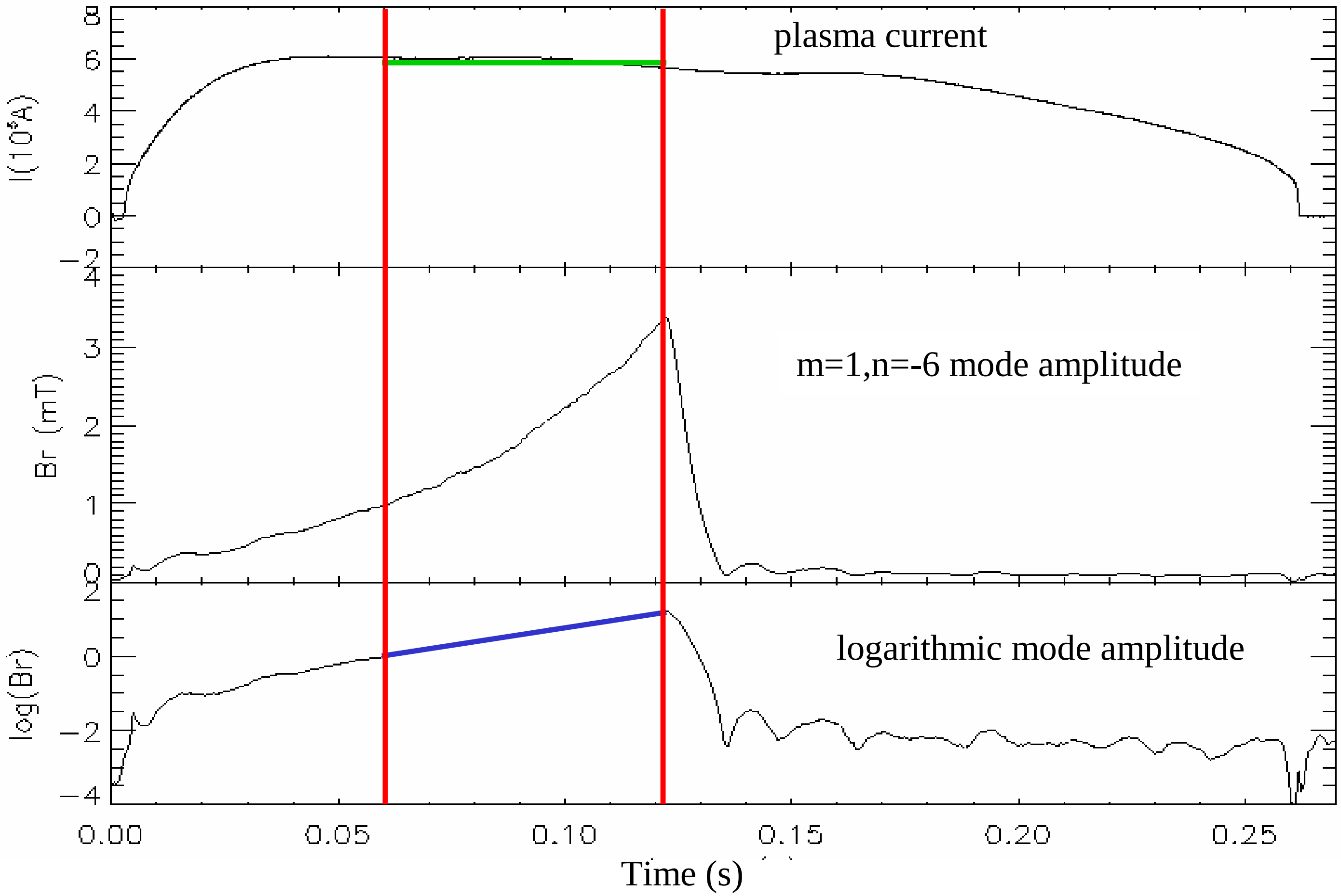




RWM experimental growth rates: (m=1, n=-5) and (m=1, n=-6); F=-0.07

Calculation of each RWM growth rate

An authomatic procedure finds the interval with the best exponential fit
("true RWM growth")



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RFX-mod relevance for a statistical analysis

RFX-mod has unique capabilities to explore low (<0.3 MA) to high (up to 1.5 MA reached at present) plasma currents

RFX-mod is also equipped with a complete set of diagnostics to characterize the backgroud plasma (not only an extensive set of magnetics, but also density and temperature profiles, spectroscopic measurements, etc.)

Parameters chosen for the study:

- plasma current: 350 kA<I<700 kA
- F parameter: -0.4<F<-0.05
- plasma density: $1\ 10^{19}\ m^{-3} < n_e < 3\ 10^{19}\ m^{-3}$
- electronic poloidal beta: $0.01 < \beta_{p,e} < 0.04$

total of 234 points

N.B. Preliminary study: non independent parameters!

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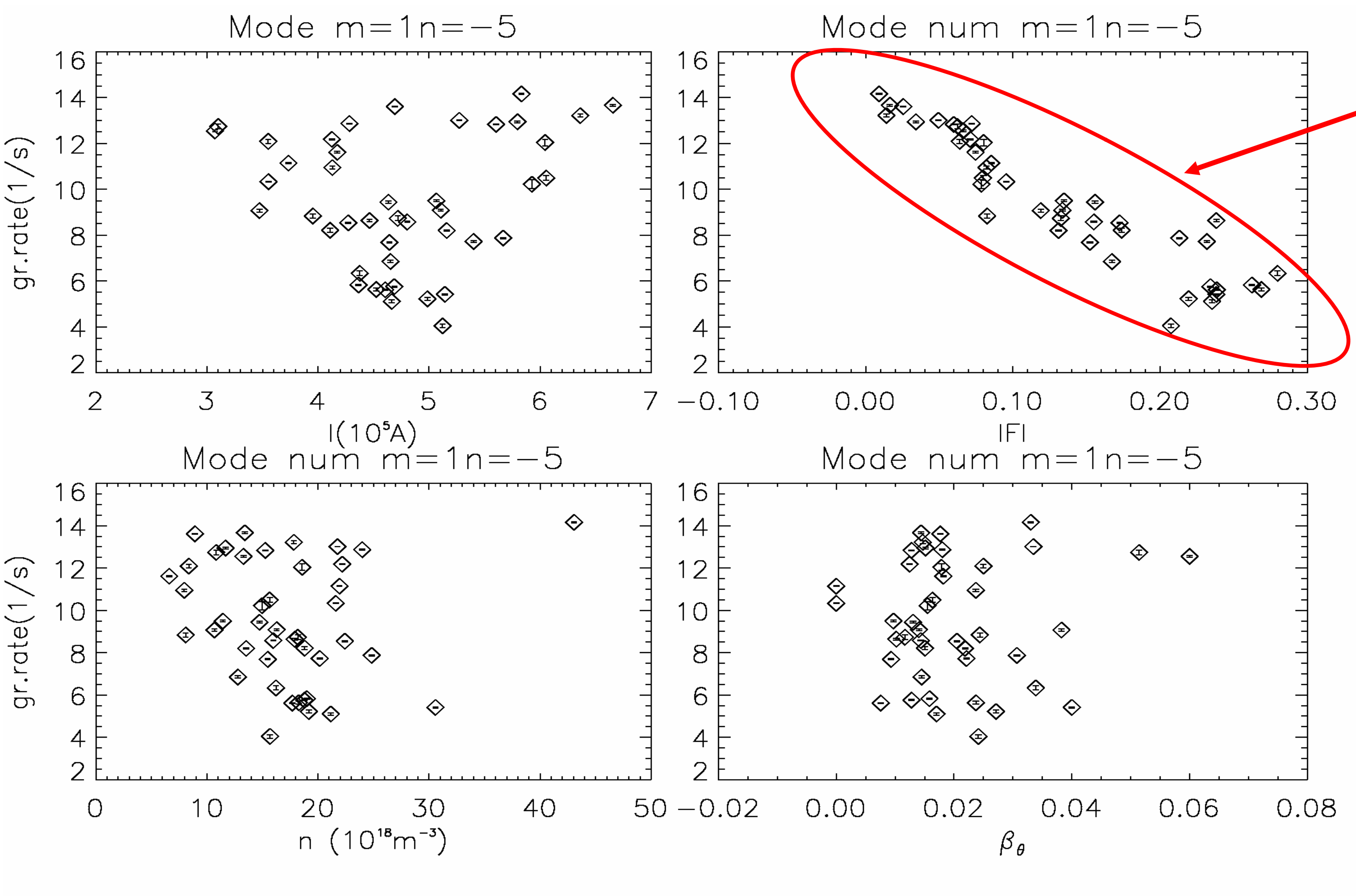
Statistical analysis for n=-5



Clear IFI dependence, agreement with theory

No other clear dependencies

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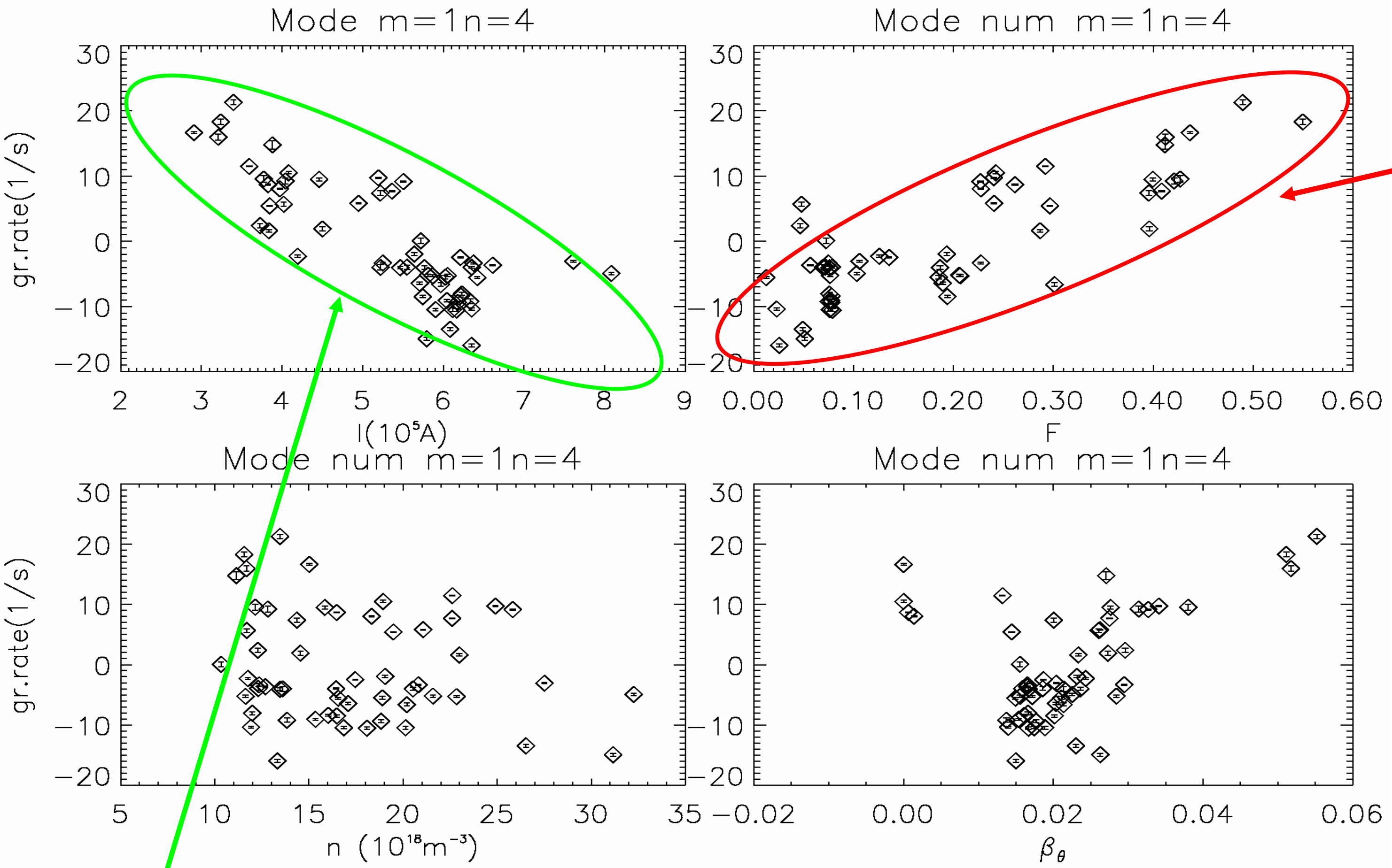
Statistical analysis for n=+4



Clear IFI dependence, agreement with theory

No other clear dependencies

Plasma current dependence appears?

Possible explanations? Error field influence should grow with I.

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Second part

- RWM active rotation experiments

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How to rotate a RWM?

Open loop rotation

Main advantage: external perturbation amplitude and phase perfectly under control

Disadvantages: long trials and errors procedure

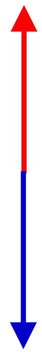
Feedback rotation

Main advantage: the system "self-adjust" itself to the best possible mode control configuration (amplitude)

Disadvantage: amplitude and phase of plasma and perturbation not trivial to calculate

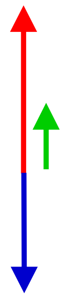
The idea (feedback control)

Perfect control



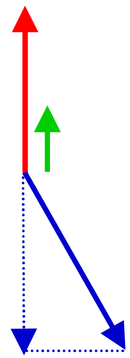
Plasma field
Total field=0
External field

Incomplete control



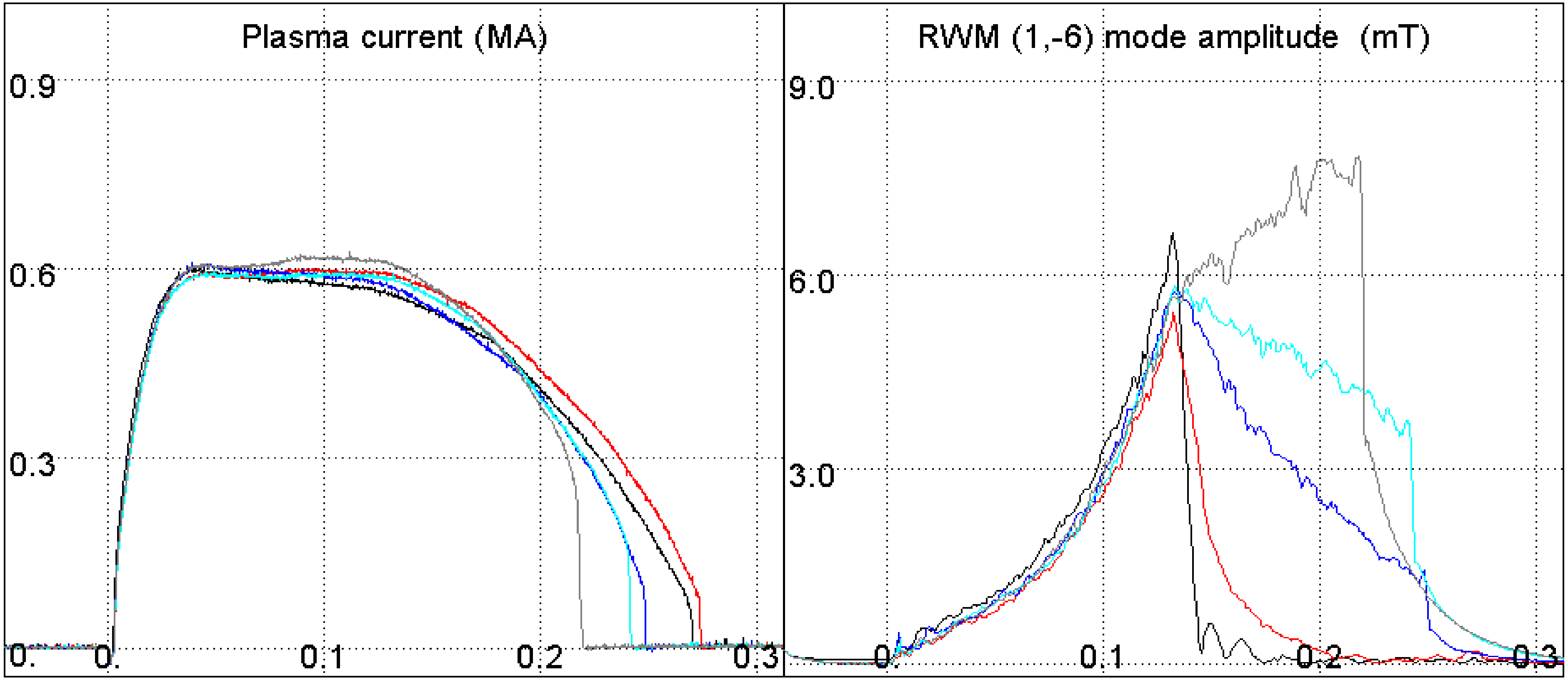
Plasma field
Total field≠0
External field

Incomplete control
with phase shift
(torque on the mode?)



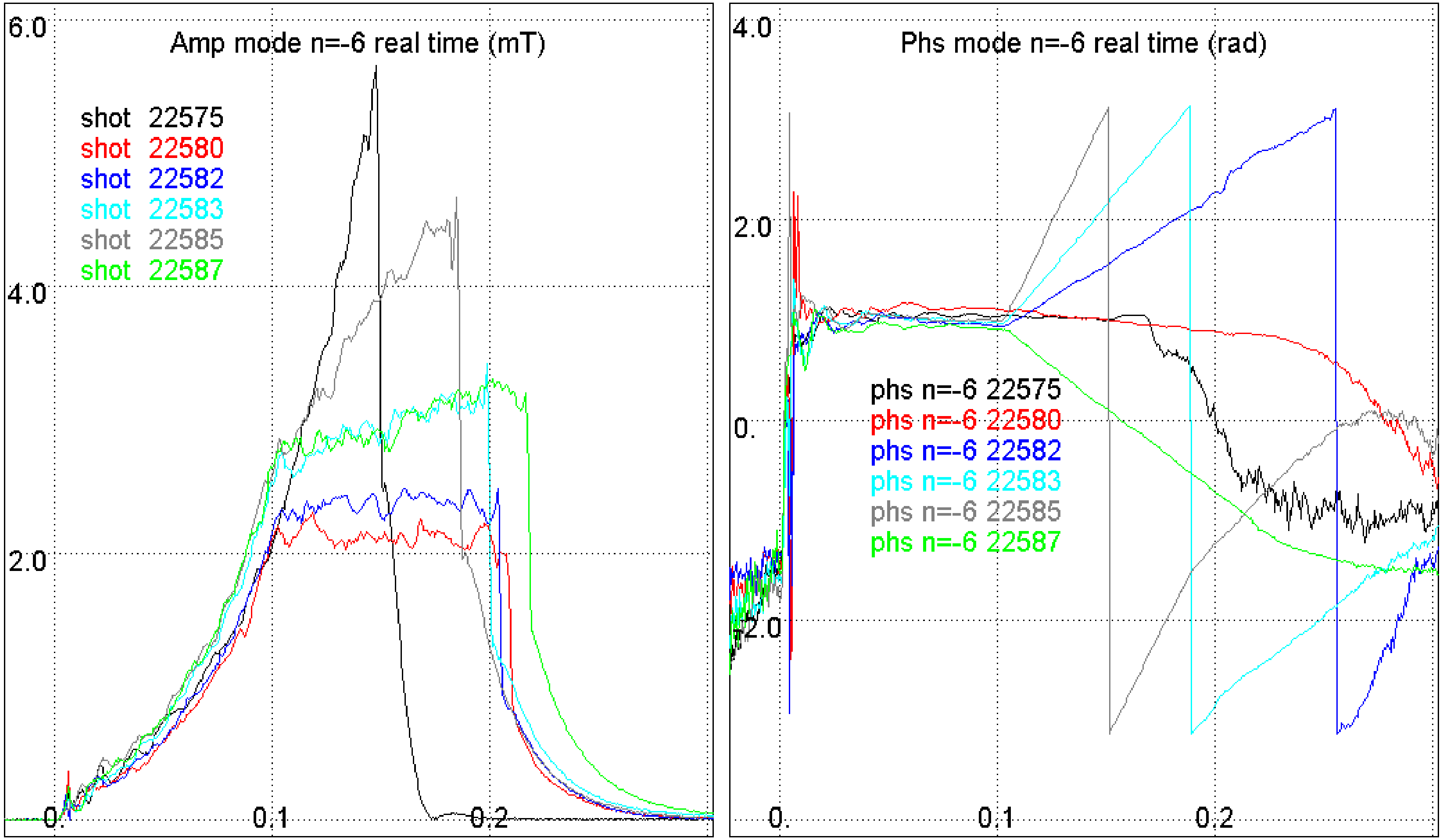
Plasma field
Total field≠0
External field

Incomplete (1,-6) control – 0 phase diff.



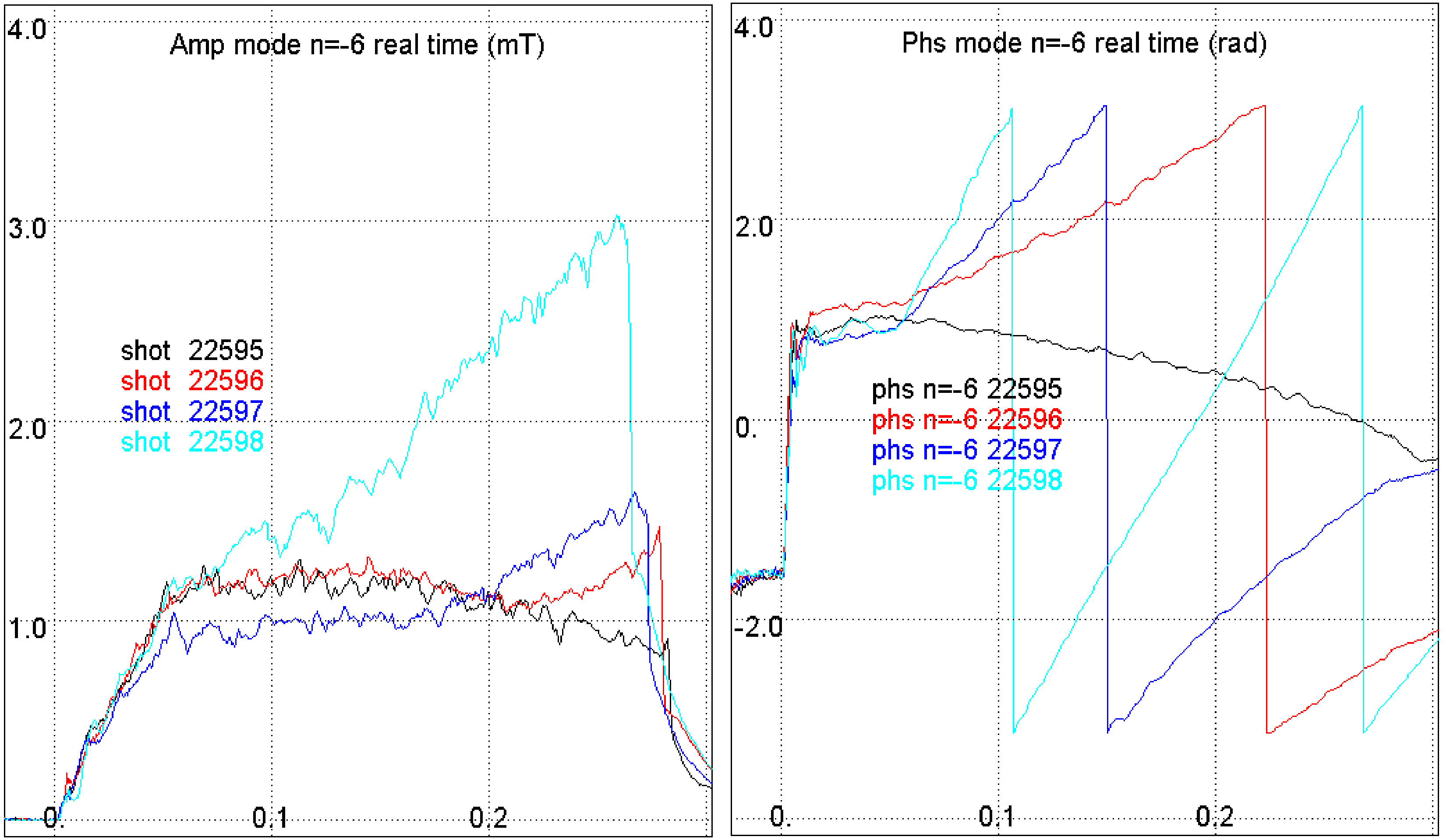
Control from 130 ms

Phase scan at fixed (normal) Gp. I=400 kA



Phase velocity depends on pre-programmed phase difference

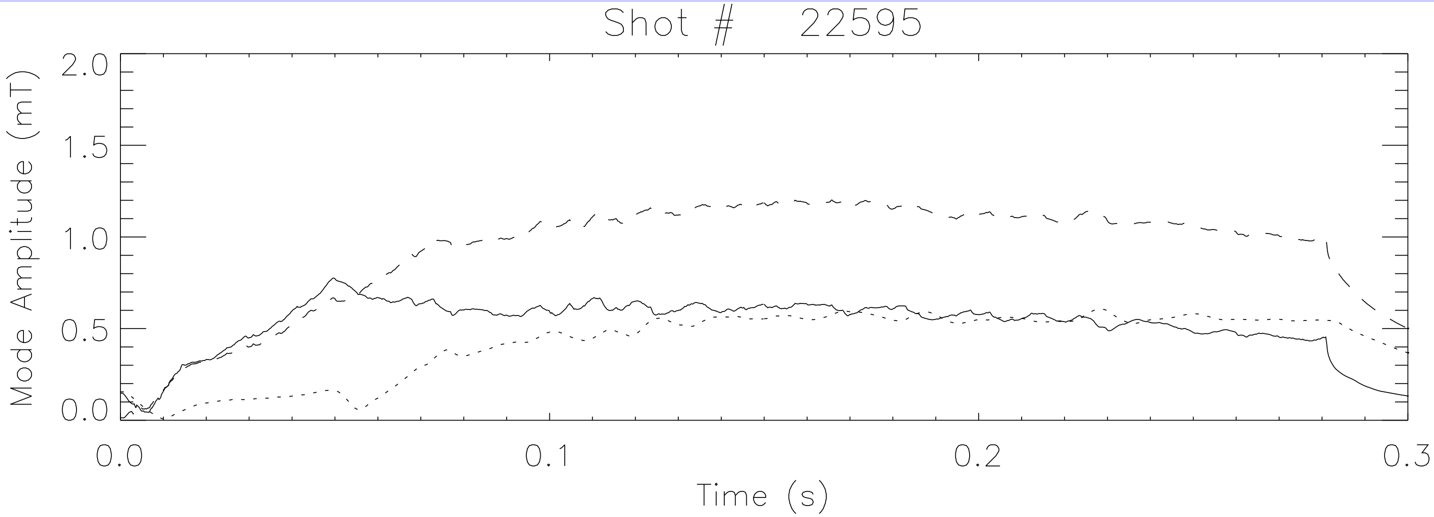
Phase scan at fixed (normal) Gp. I=600 kA

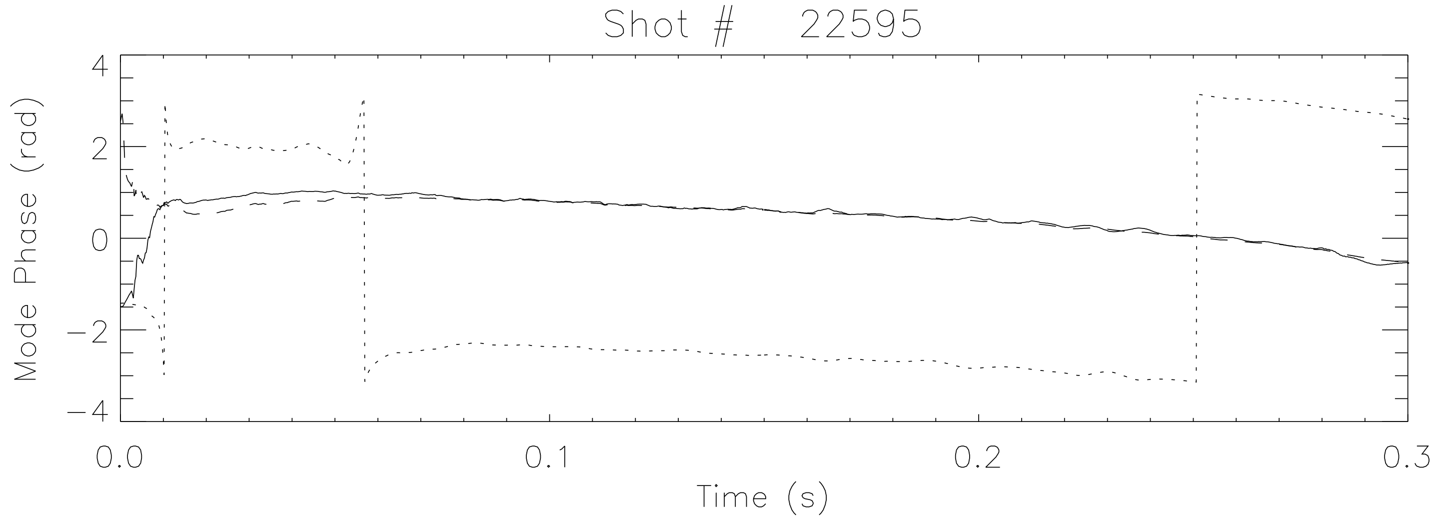


Induced rotation data analysis

- From total br measurements to plasma vs external fields
- External br field at the measurement radius obtained from coil currents (including mutual inductances and machine structure). **Model developped by G. Marchiori**
- Plasma br field by subtraction
- Time evolution of external and plasma harmonics (amplitude and phase)
- If the experiment is successful (torque balance):
  - constant rotation
  - constant phase difference
  - torque calculation and comparison with models

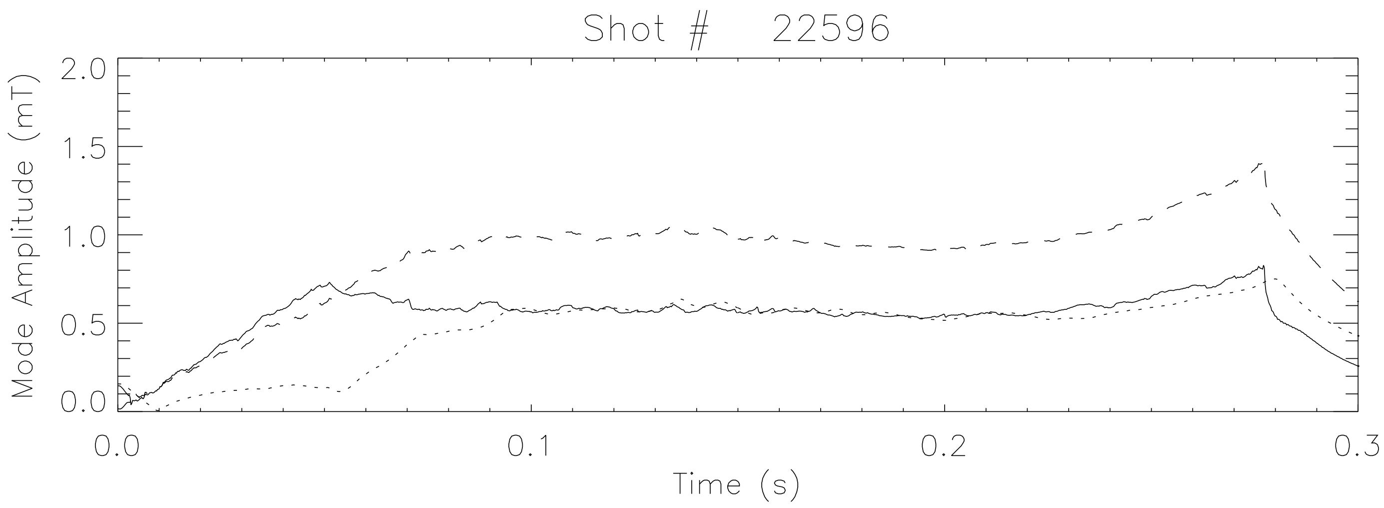
#22595 (reference): Kp=140; ϕ=0°

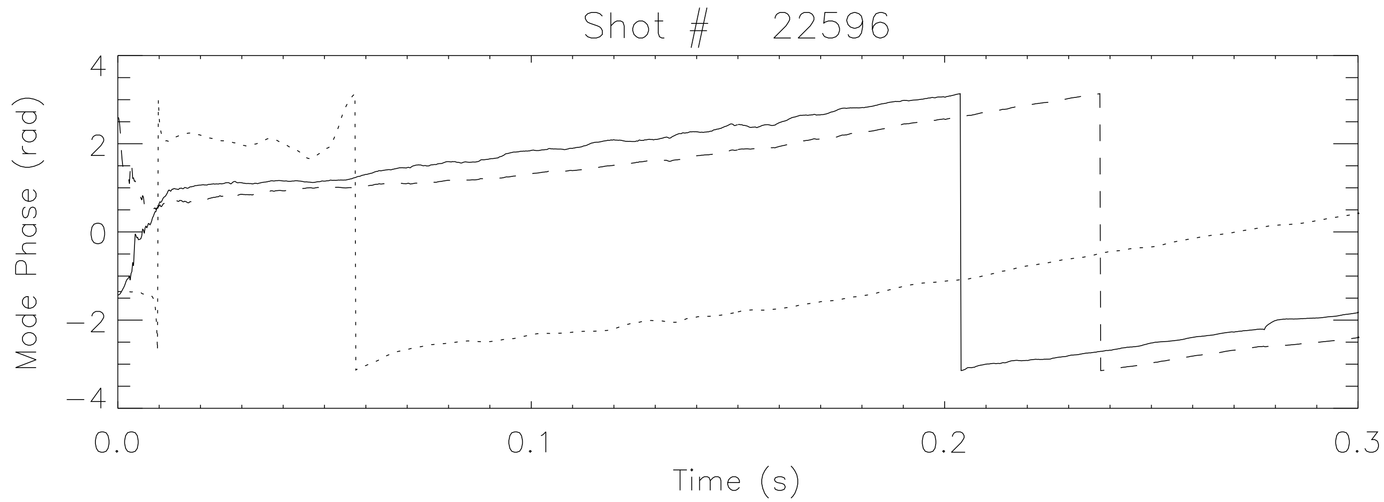




Full line: total br measurement. Dotted line: reconstructed "external" br. Dashed line: reconstructed "plasma" br. (NB non-fully validated run)

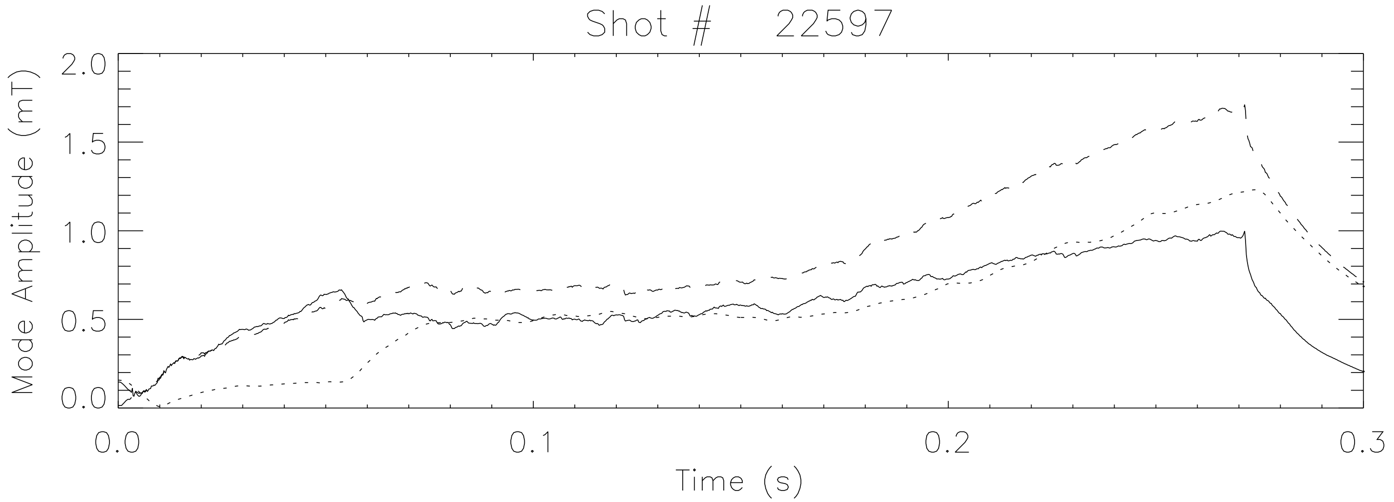
#22596: Kp=162; ϕ=30°

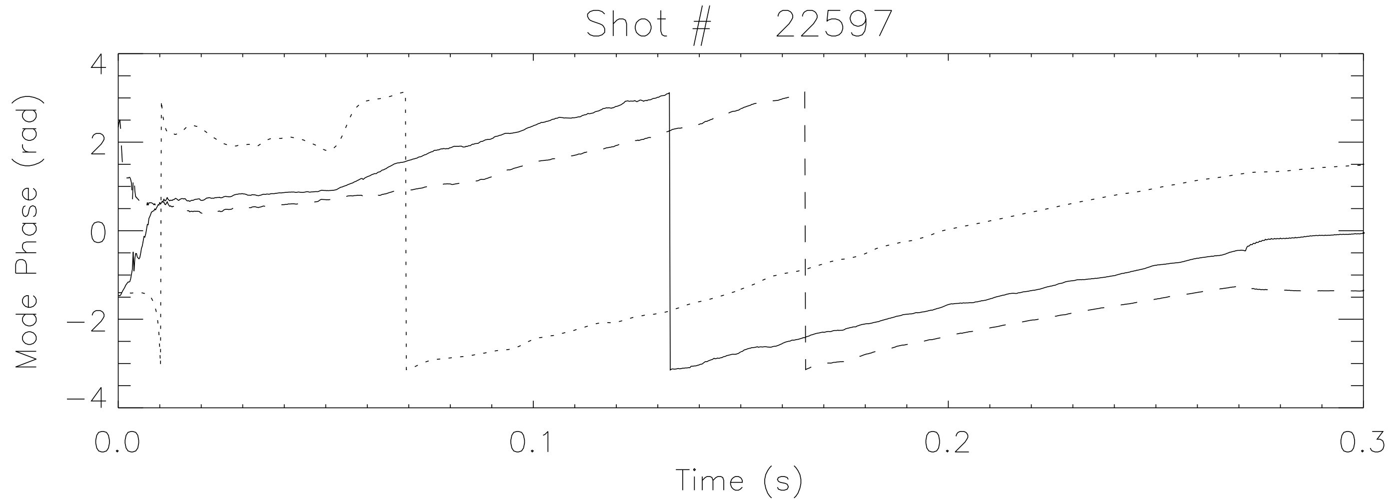




Full line: total br measurement. Dotted line: reconstructed "external" br.
Dashed line: reconstructed "plasma" br. (NB non-fully validated run)

#22597: Kp=198; ϕ=45°





Full line: total br measurement. Dotted line: reconstructed "external" br.
Dashed line: reconstructed "plasma" br. (NB non-fully validated run)

Future work

- ü Continuation of RWM characterization, fill the operational space, test plasma current influence, comparison with models.

- ü Feedback rotation successful for the first time!
  Continue with data analysis and further experiments (AUG collaboration)

- ü Experimental data are ready for comparison with numerical models in order to clarify the leading torque mechanisms.

- ü Play the "EF search" game: open loop EF correction at the beginning of the discharge; study the RWM phase dependencies; Resonant Field Amplification experiments

- ü Experiment vs theory-modelling main issues:
  - ü include all the relevant physics in the models(tokamak benchmarck)
  - ü go from "qualitative" to "quantitative" agreement at least for the simplest cases (RFP benchmarck)
  - ü quantitative comparison: quantification of real-wall effects on growth rates