# Pseudo-decoupler approach to error-field correction in RFX-mod

P. Piovesan

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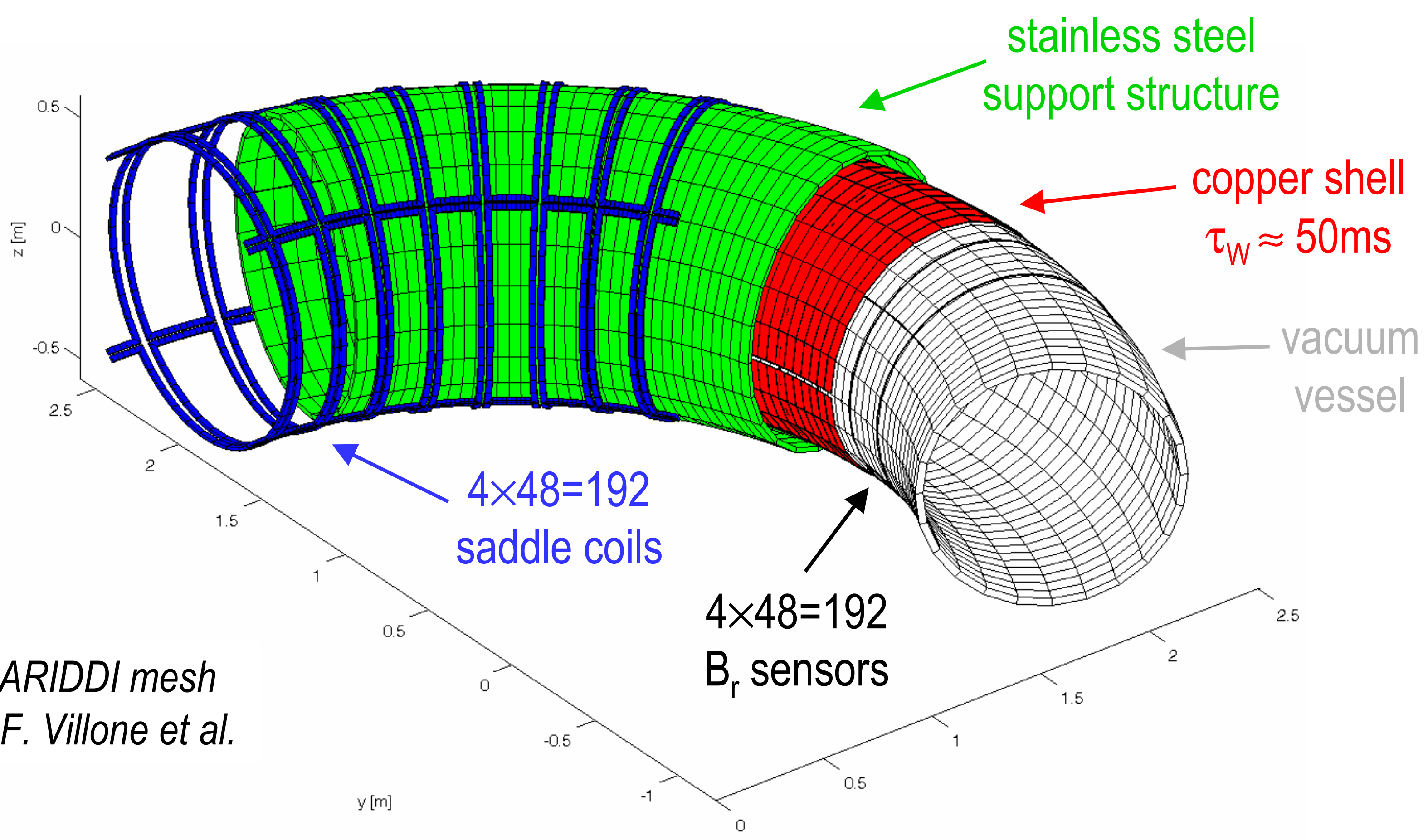
14th WORKSHOP ON MHD STABILITY CONTROL

Princeton, NJ, USA - November 9-11th 2009

# RFX-mod wall + feedback coils

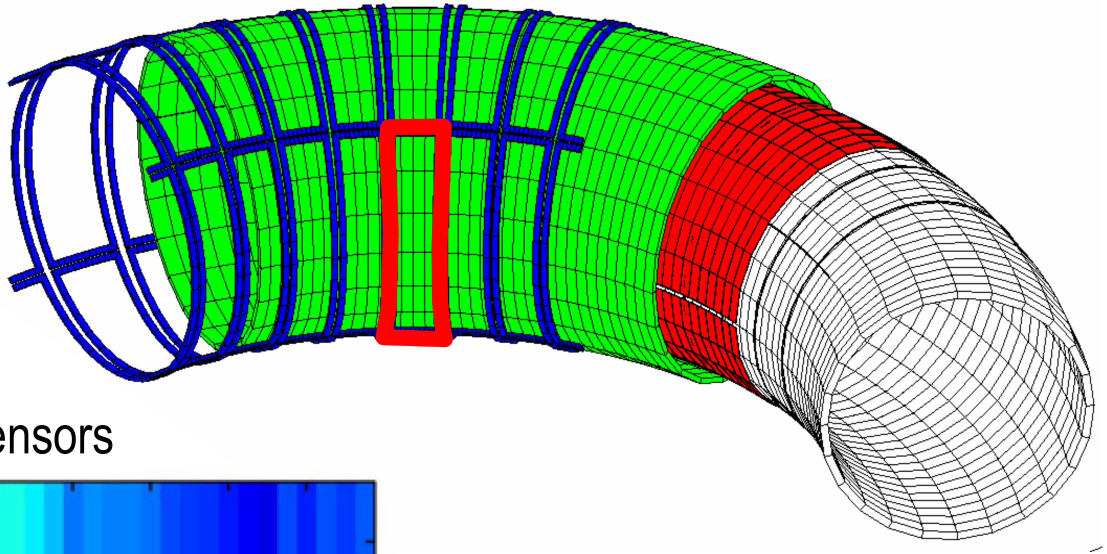
- 192 feedback coils independently driven and 192 $B_r$, $B_\phi$, $B_\theta$ sensors
- Wall not uniform: 1 poloidal gap, 2 toroidal gaps, portholes, …



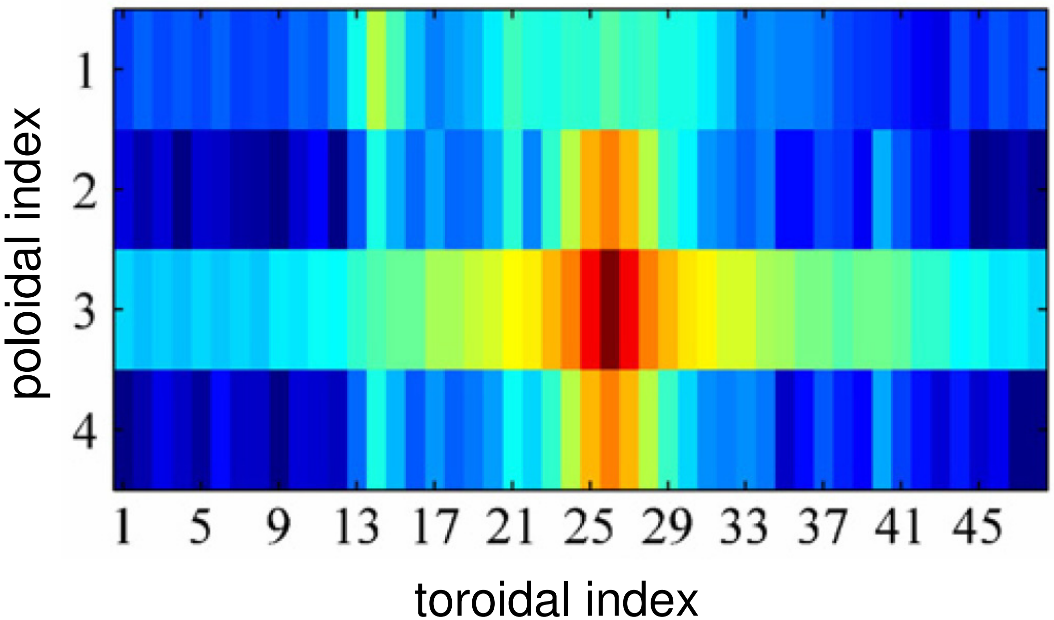

*CARIDDI mesh by F. Villone et al.*

# 3D structure of the wall

- Vacuum shot with one active coil driven at 20Hz
- 3D structures causing the main e.m. couplings are in this way highlighted



$B_r$ at the 4×48 sensors



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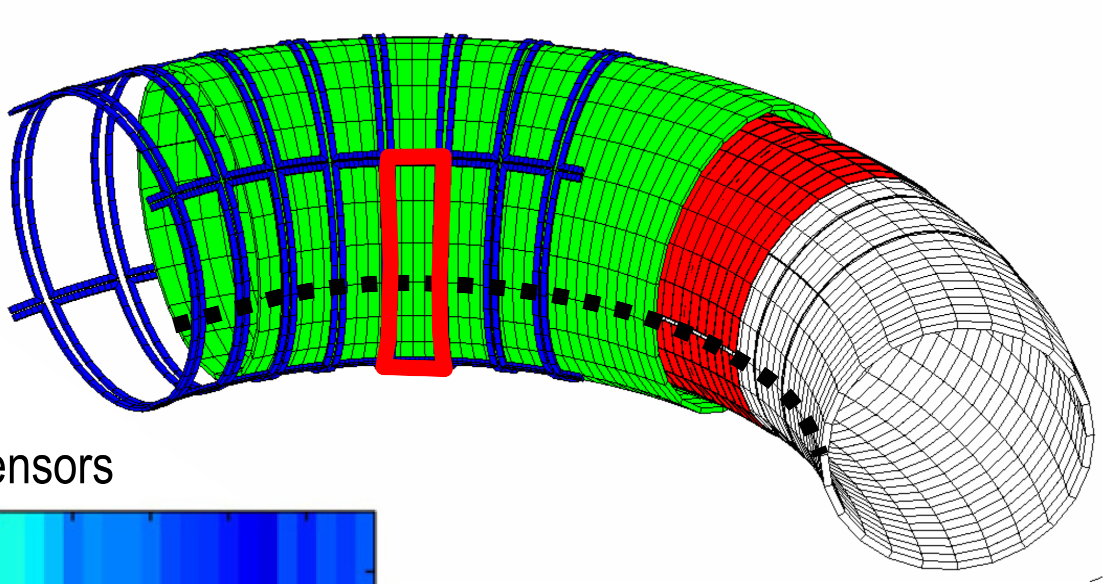

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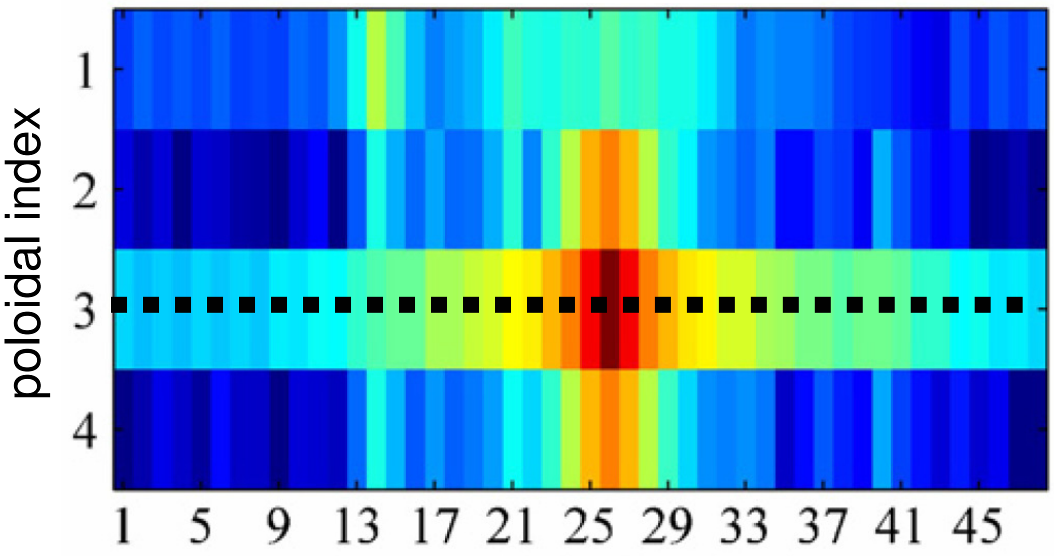


1 poloidal gap inboard side $\Rightarrow$ coupling of m harmonics

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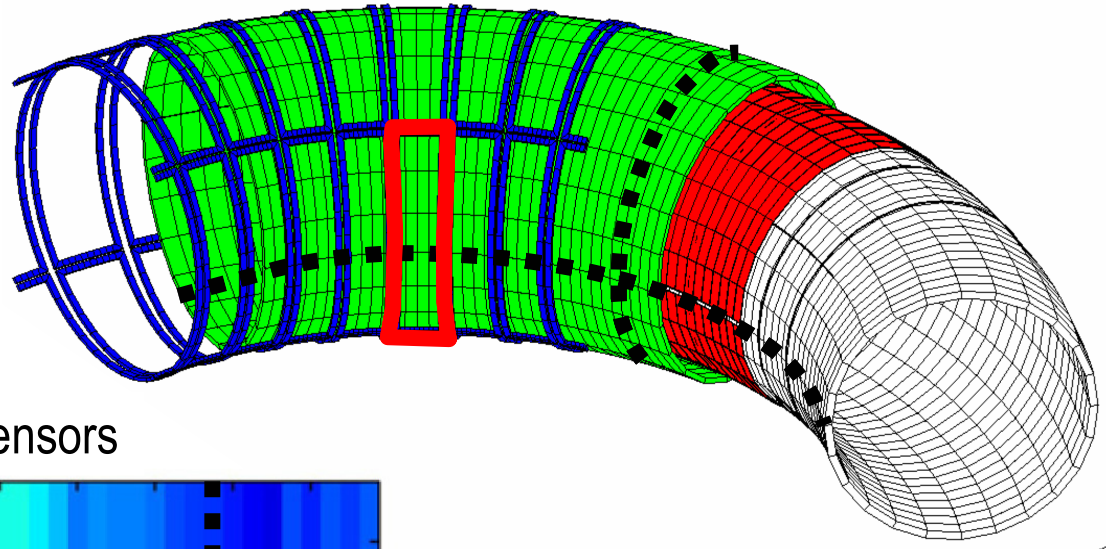

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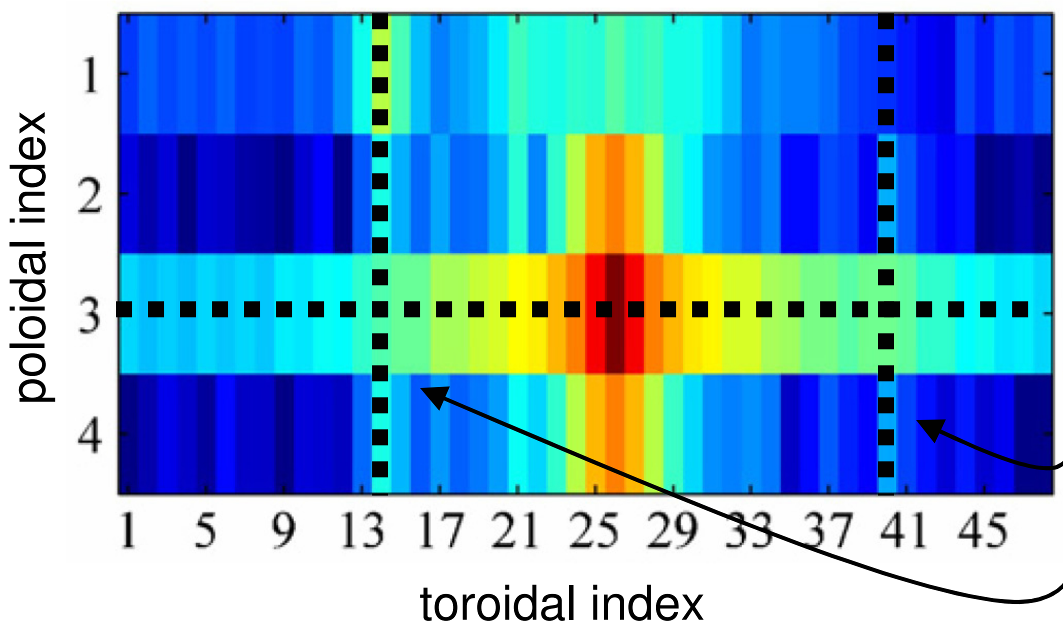
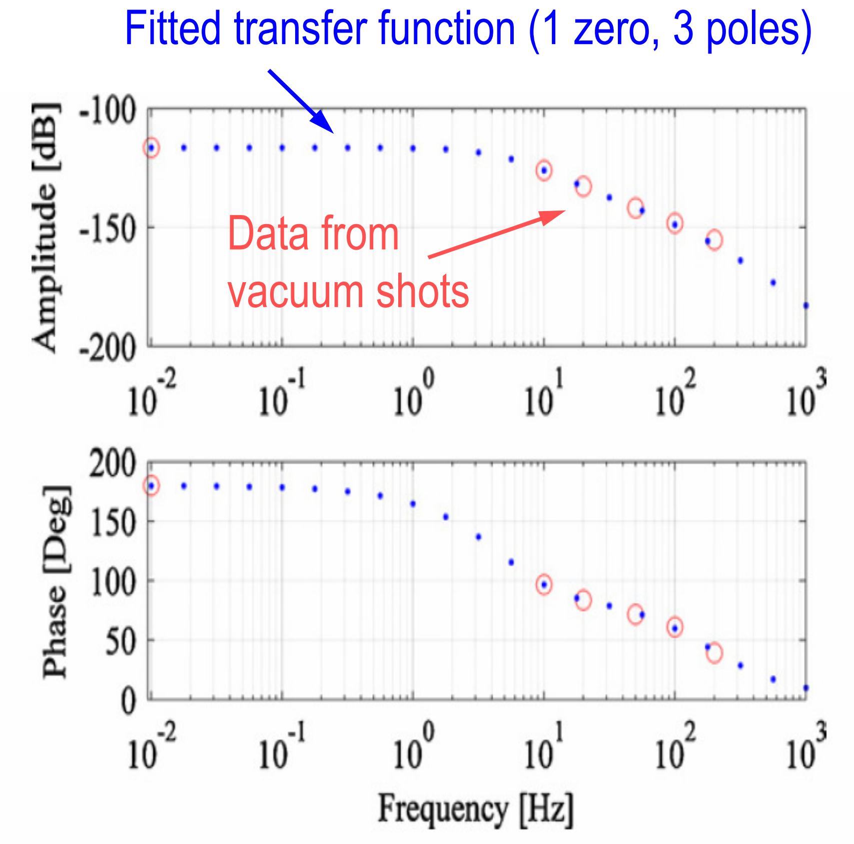



1 poloidal gap inboard side ⇒ coupling of m harmonics

2 toroidal gaps 180° apart ⇒ coupling of n harmonics

# Dynamic pseudo – decoupler

- All the e.m. couplings in the system are represented by a matrix of transfer functions between the 192 active coils and the 192 $B_r$ sensors



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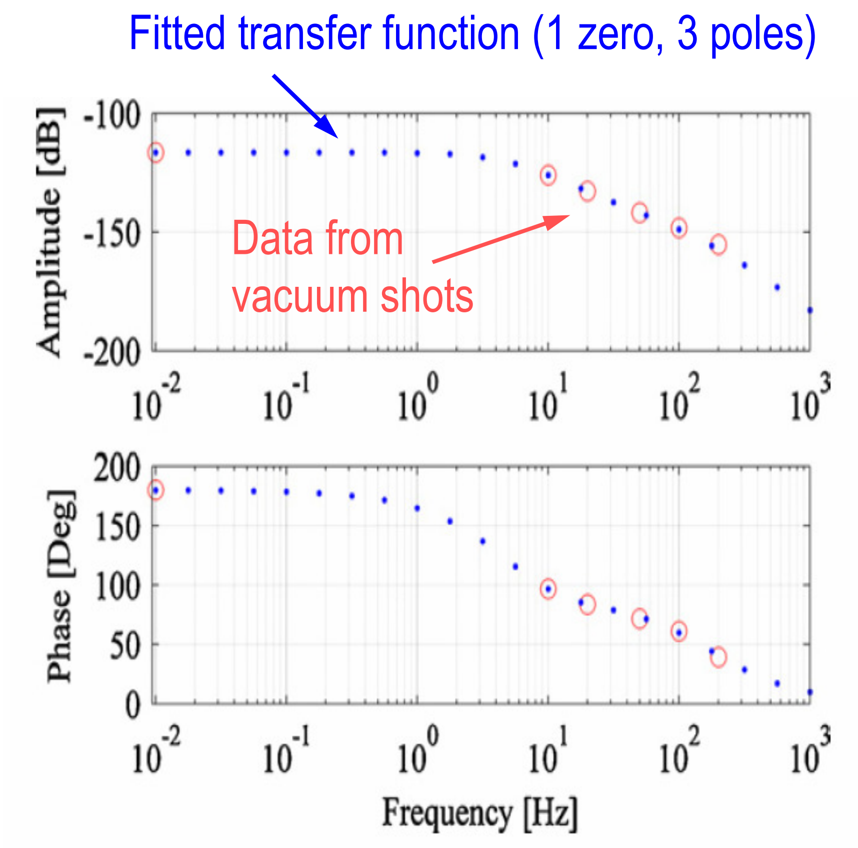
- All the e.m. couplings in the system are represented by a matrix of transfer functions between the 192 active coils and the 192 $B_r$ sensors
- The $B_r$ at the sensors produced by arbitrary currents in the active coils can be thus computed:

$$I_c^{i,j} \rightarrow M(f) \rightarrow b_r^{i,j}$$

i = 1 to 4; j = 1 to 48



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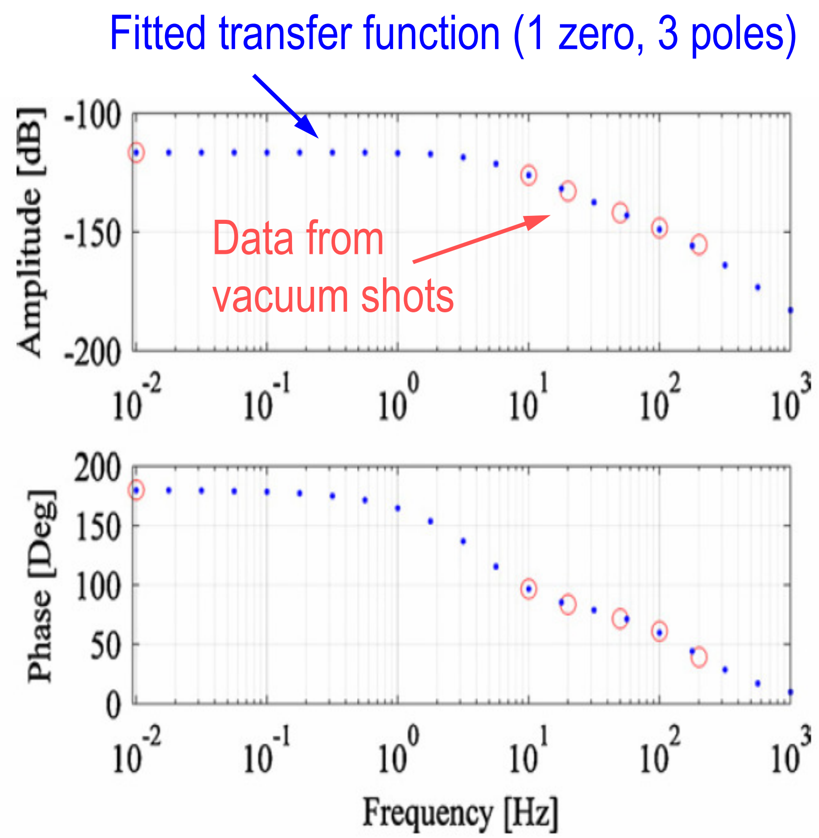
- A dynamic pseudo-decoupler has been built by inverting the M matrix with SVD and pseudo-inversion techniques:

$$b_r^{i,j} \rightarrow \tilde{M}^{-1}(f) \rightarrow I_c^{i,j}$$



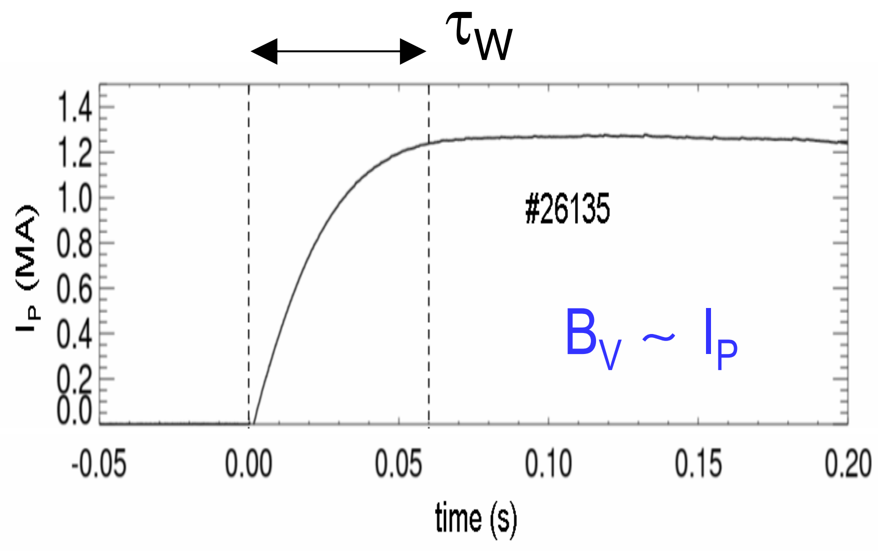

A. Soppelsa *et al.*, Fusion Eng. Des. **83**, 224 (2008)

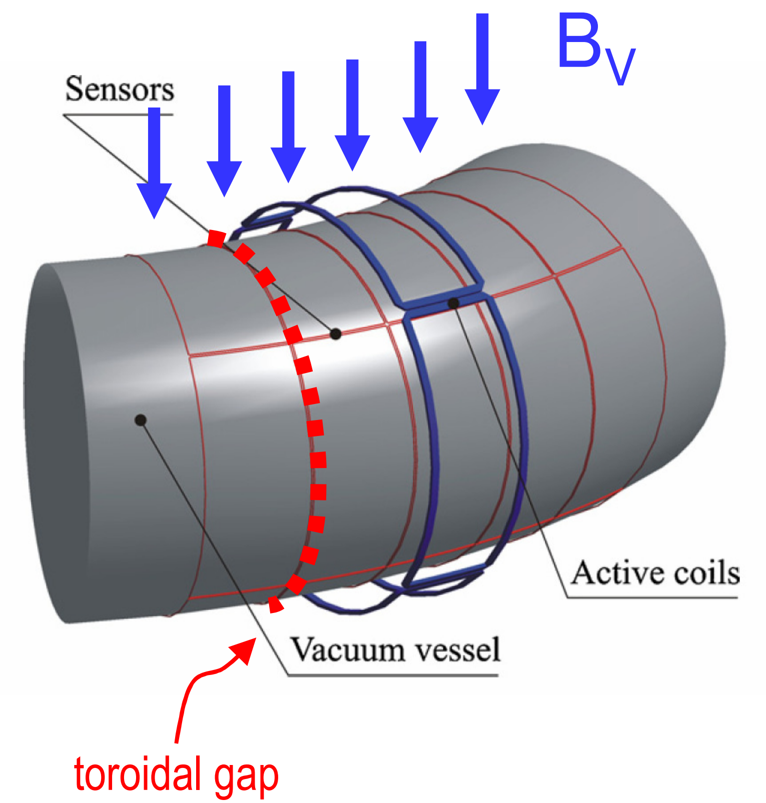
# 1. ERROR FIELD CONTROL

# 2. MODE CONTROL

# Main error field in RFX-mod

- Our main EF comes from the fact that the vertical field $B_V$ during the current ramp-up penetrates faster through the two toroidal gaps



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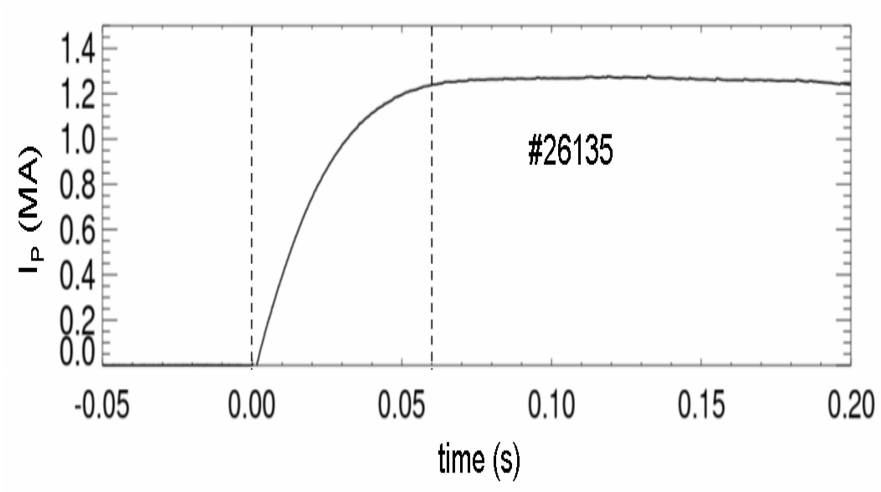

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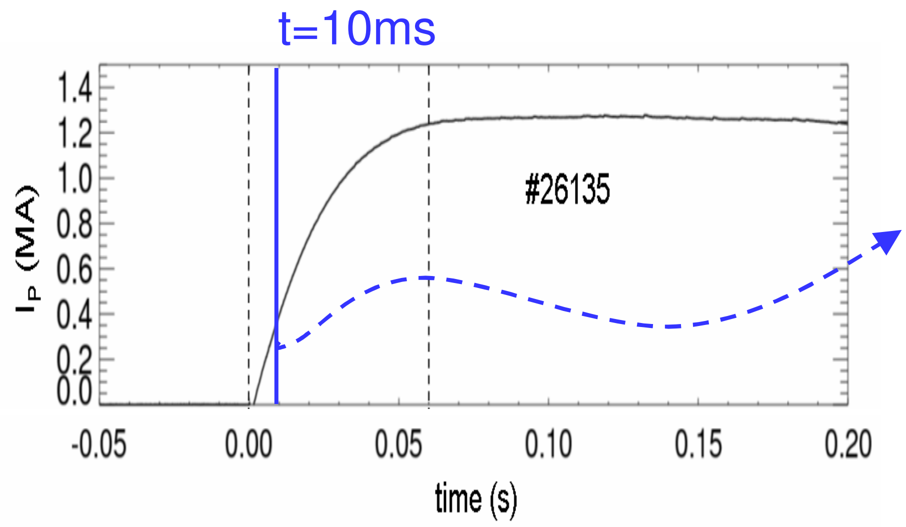


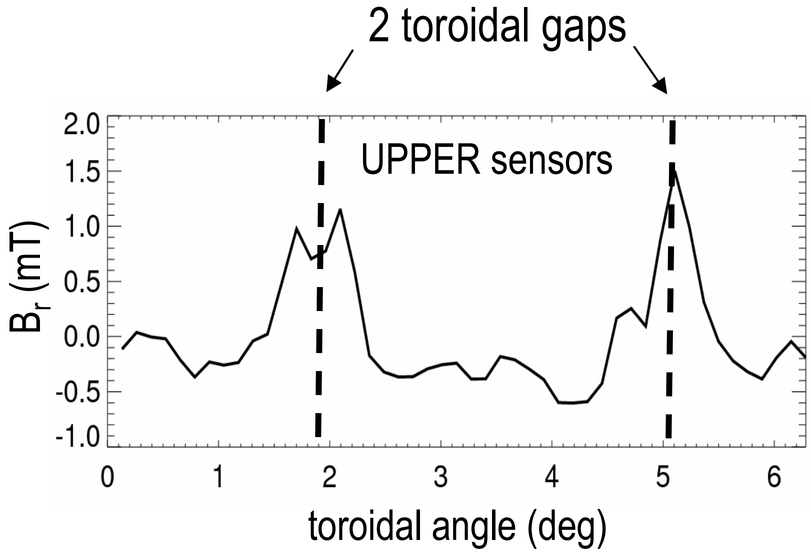

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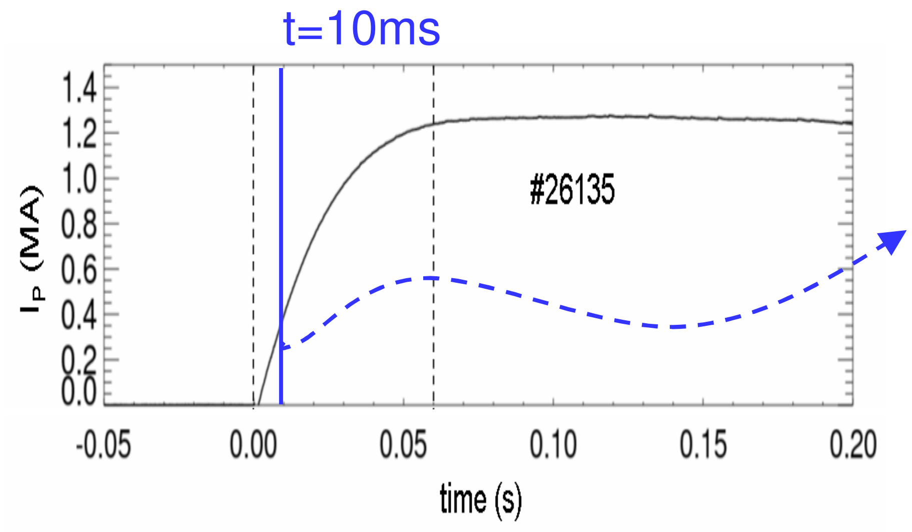


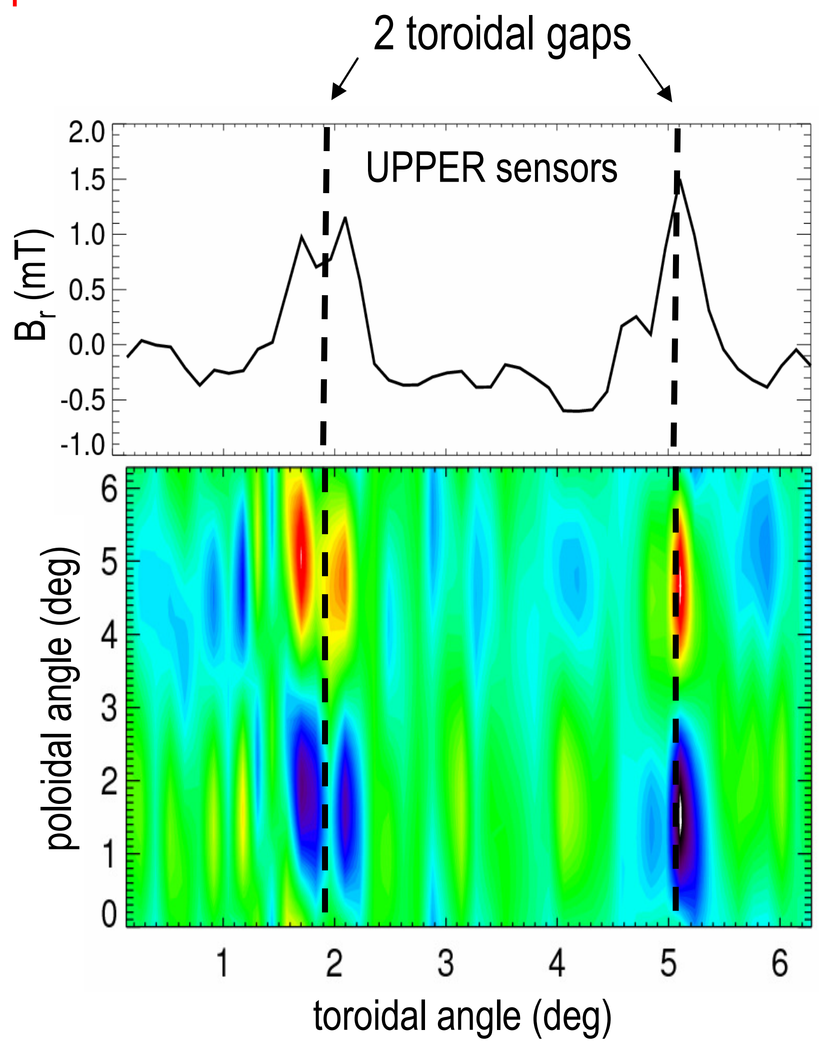

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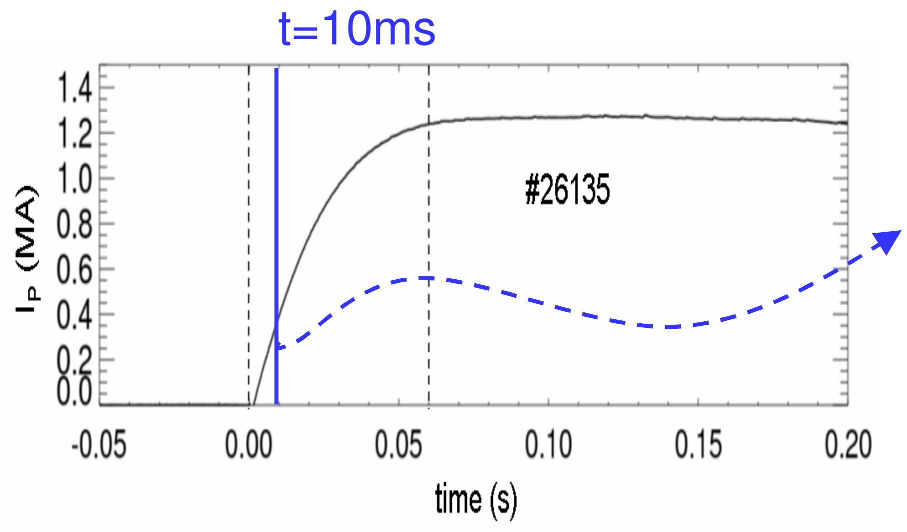


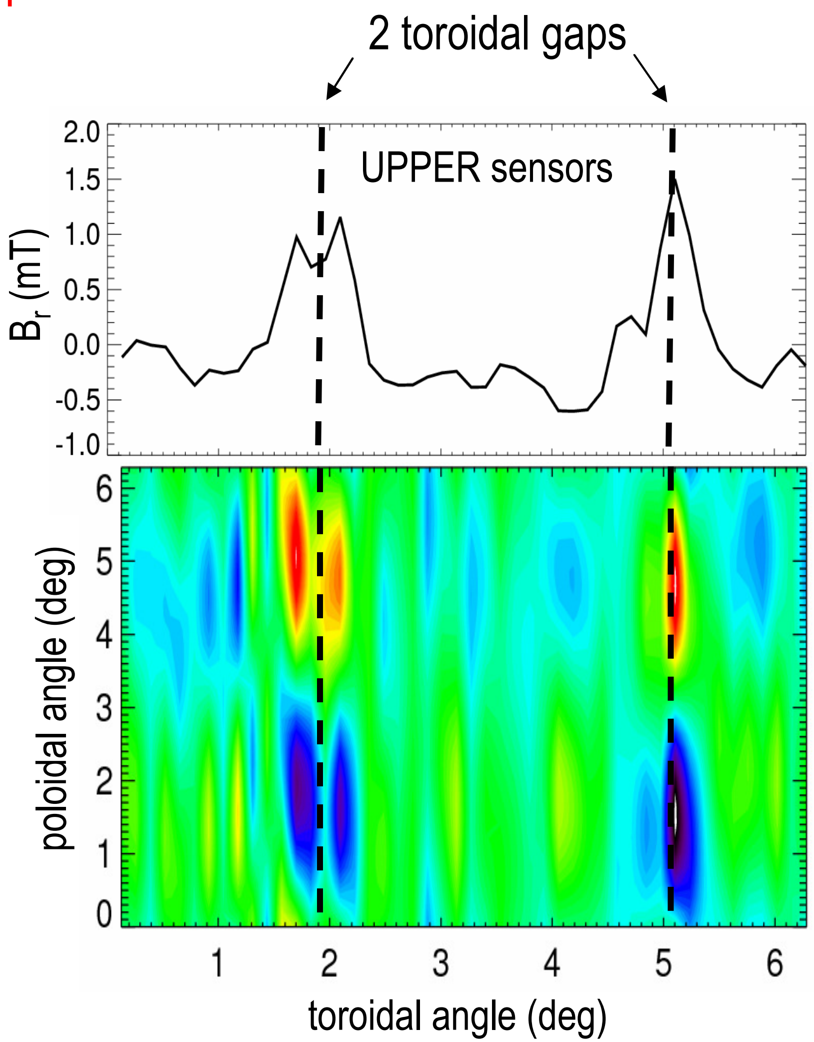


Main EF Fourier harmonics:

m = 1, n = ±2, ±4, ±6

resonant with RWMs

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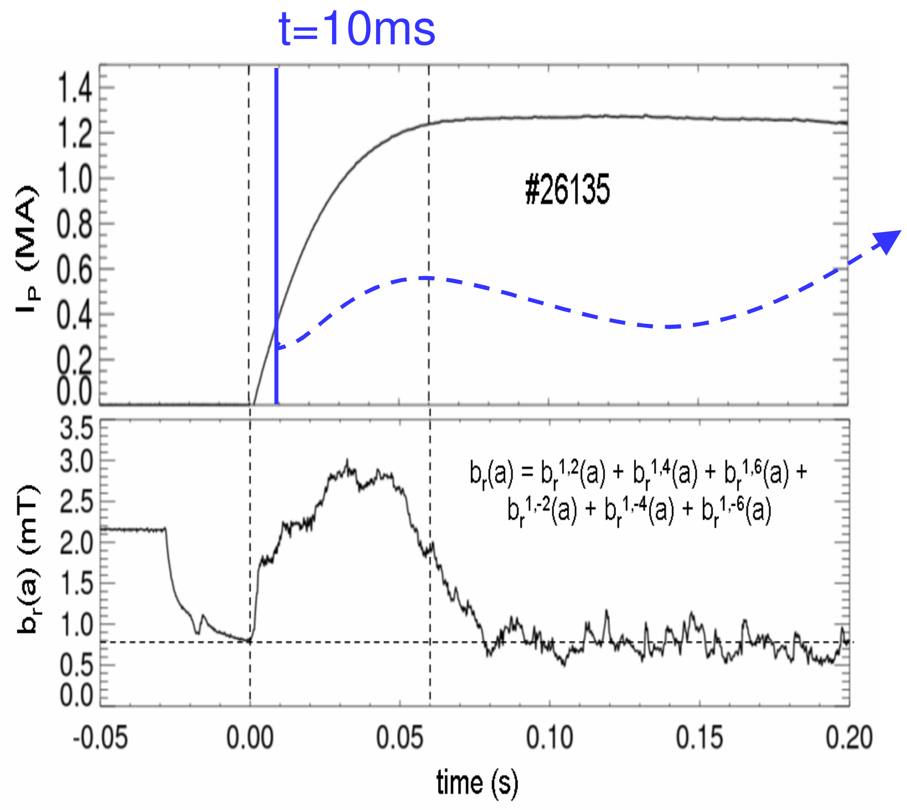
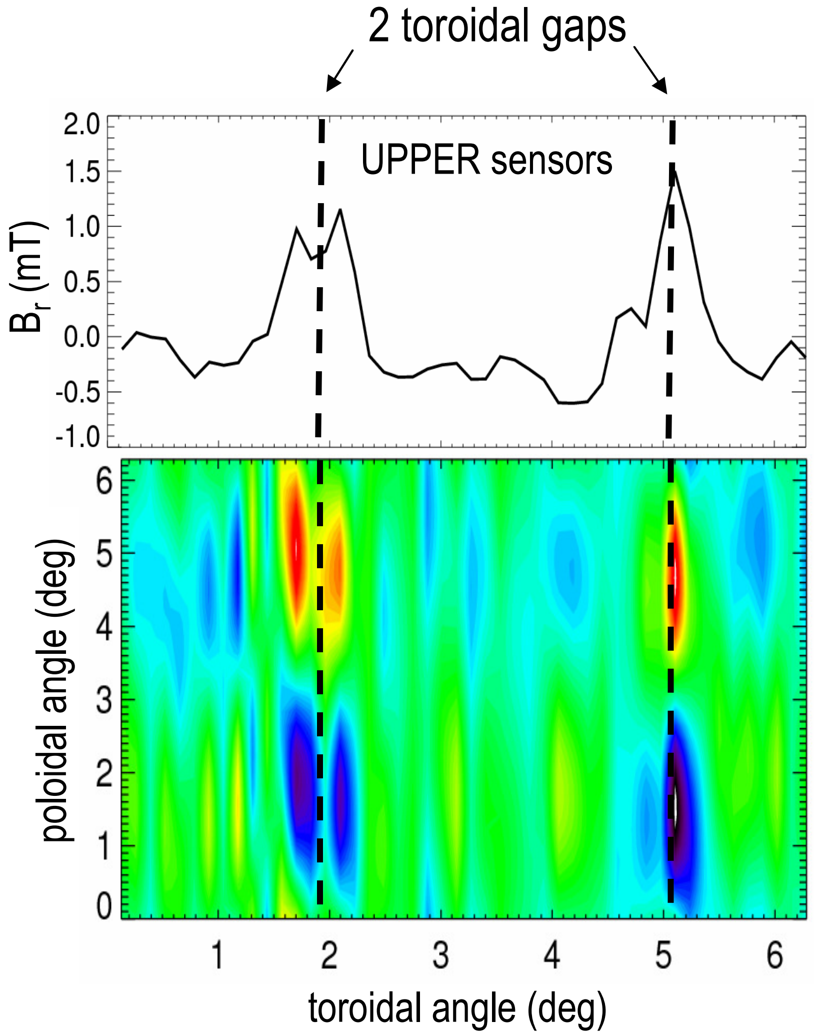
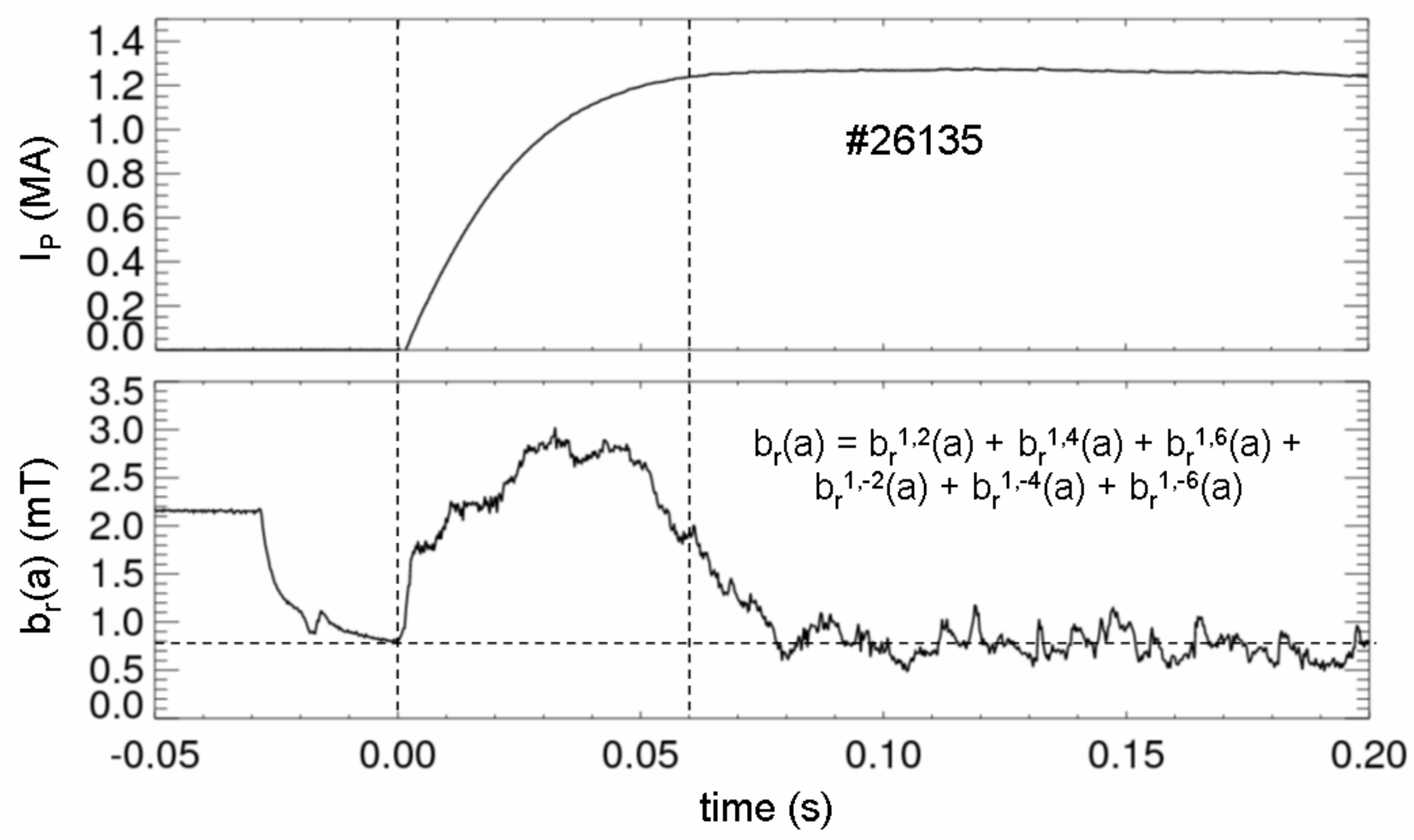


# Feedback on the main EF harmonics

- Turn on feedback with proportional gains on main EF harmonics: m=1, n=±2, ±4, ±6
- Feedback on total $B_r$ → equivalent to virtual shell. Not yet on the plasma response, as is usually done for example in DIII-D



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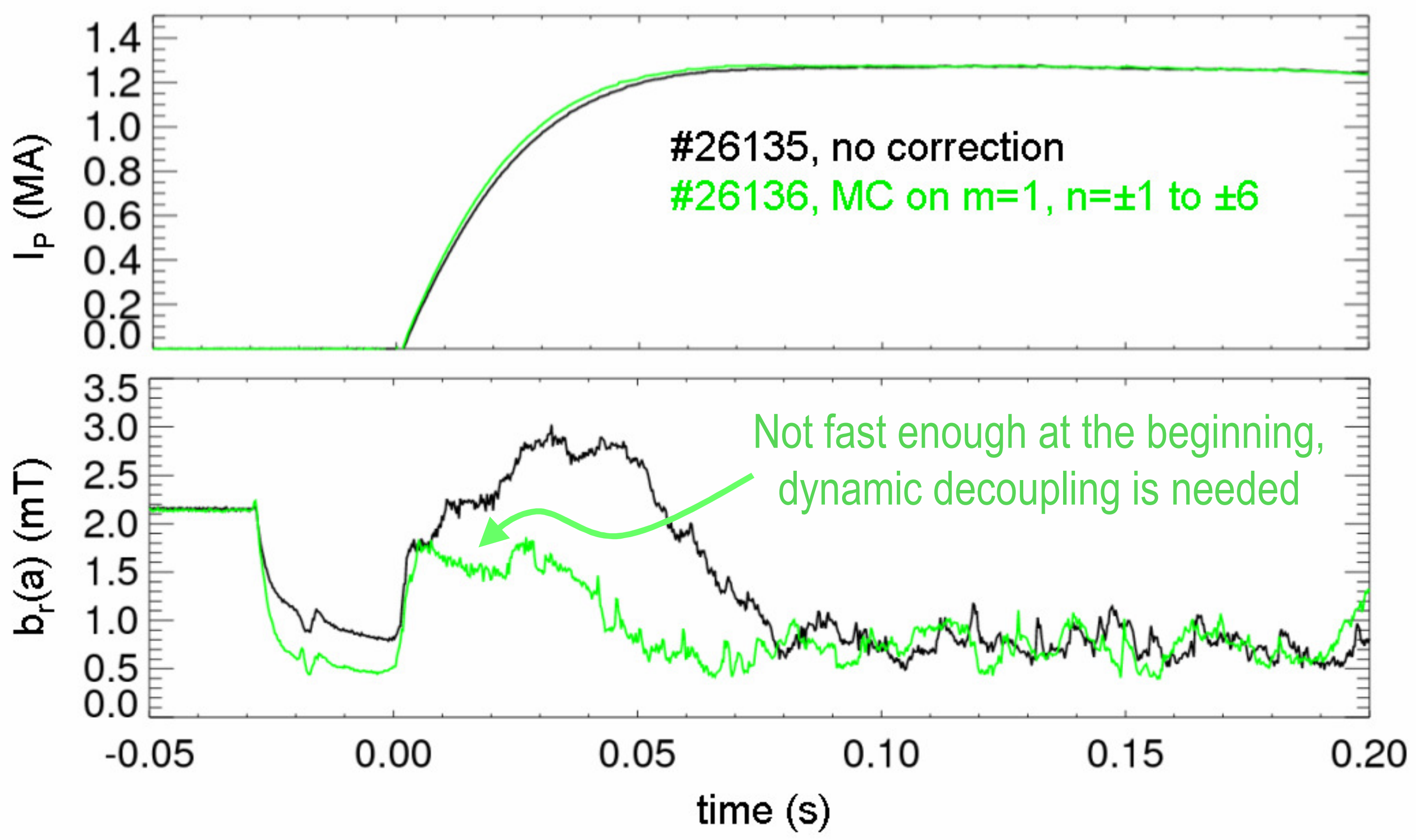
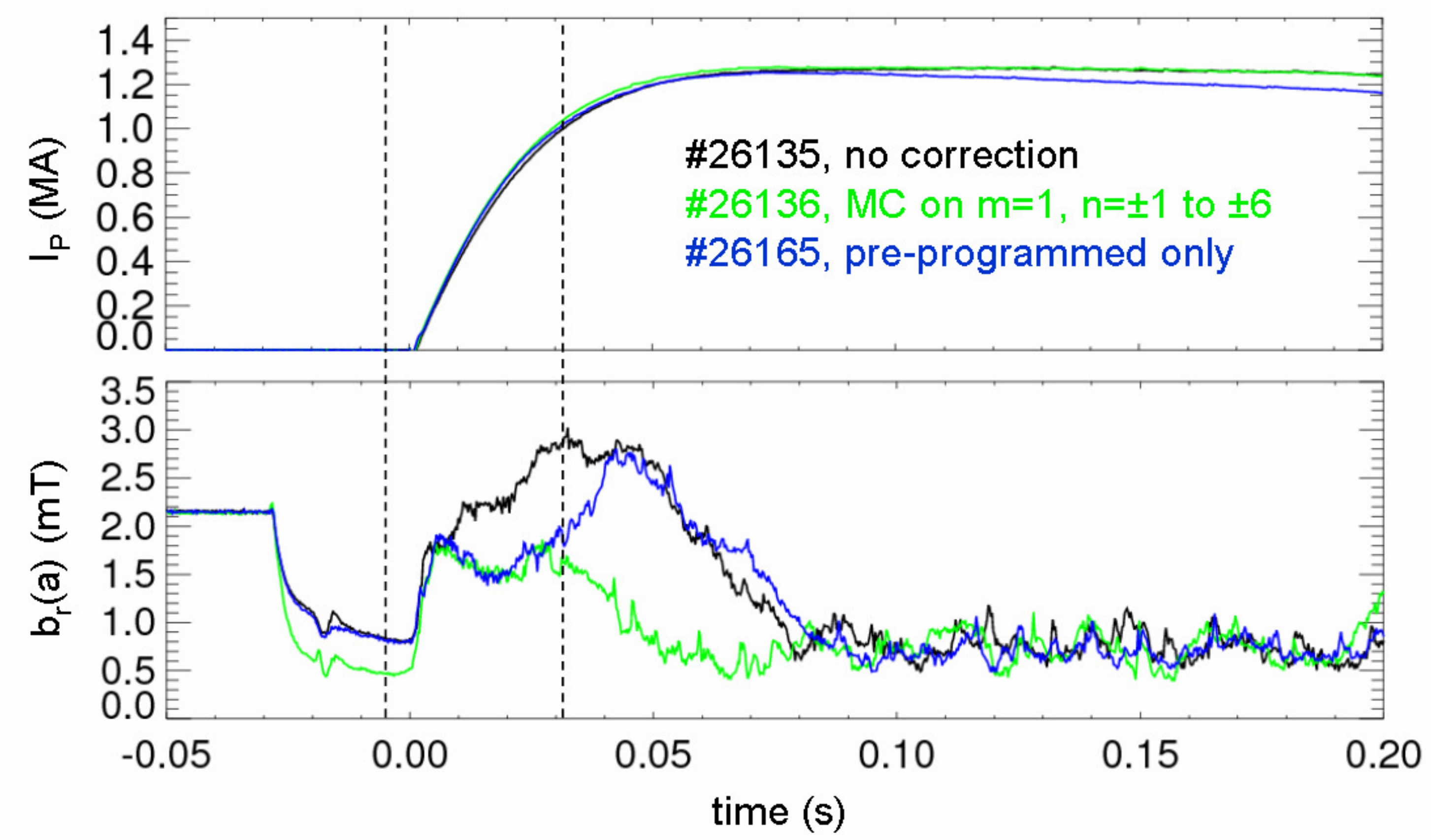


# Preprogrammed currents

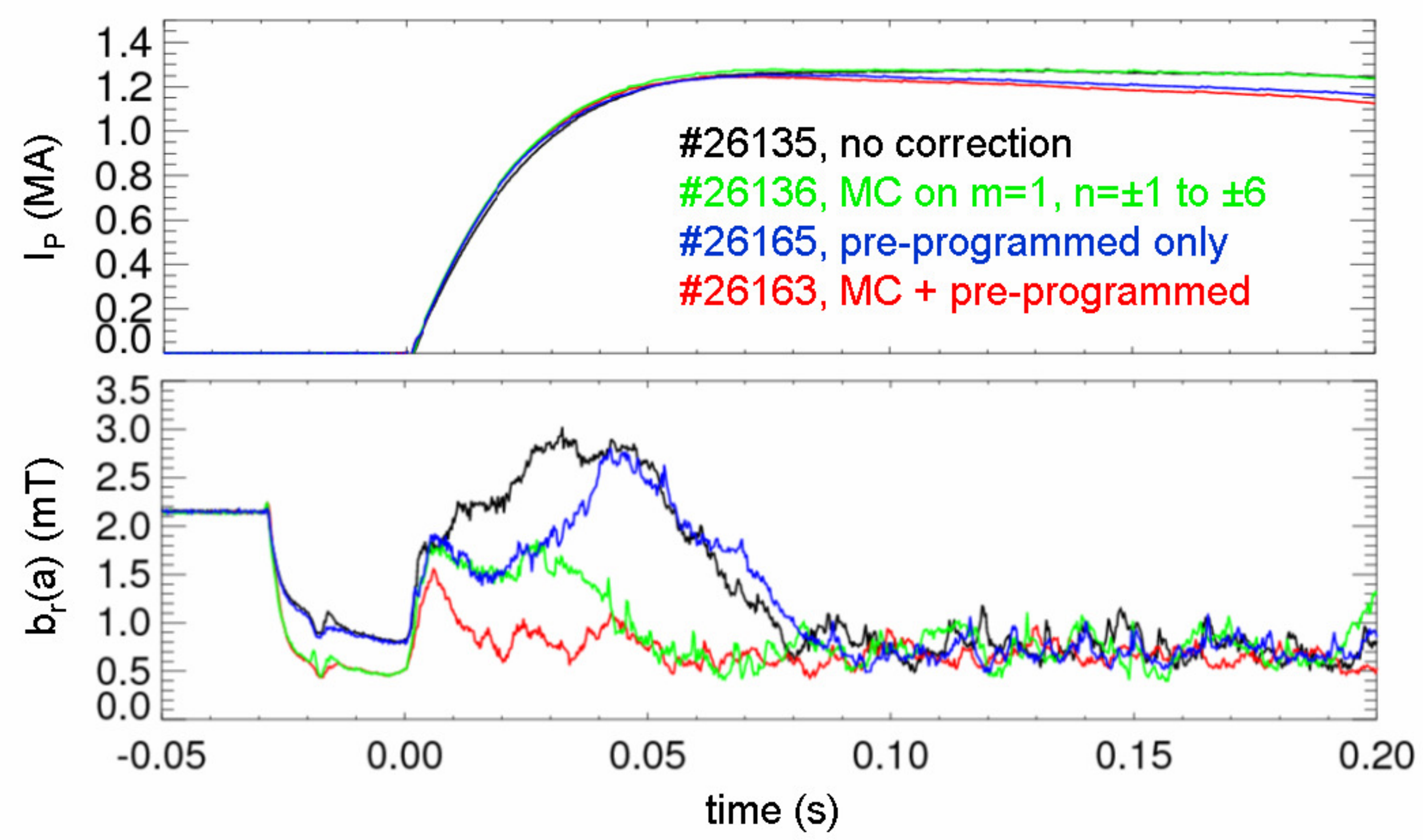
- Compute offline with the dynamic decoupler the currents needed to correct the EF

$$b_r^{EF} \longrightarrow \tilde{M}^{-1}(f) \longrightarrow I^{i,j}$$



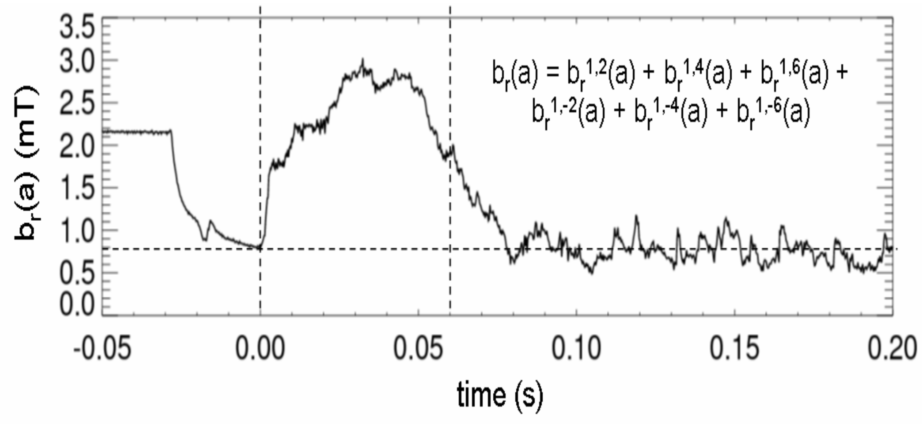
# Feedback + preprogrammed currents

- The combination of feedback and pre-programmed currents is rather succesful, but there is still room for improvements: approximations in the decoupler, uncertainties in the experimental TFs, small shot-to-shot variations, plasma response, ...



# Plasma response

- The plasma response from multiple RWMs resonant with the main EF harmonics is indeed important. We may have to feedback on it, as is done in tokamaks
- Radial eigenfunction from the Newcomb equation



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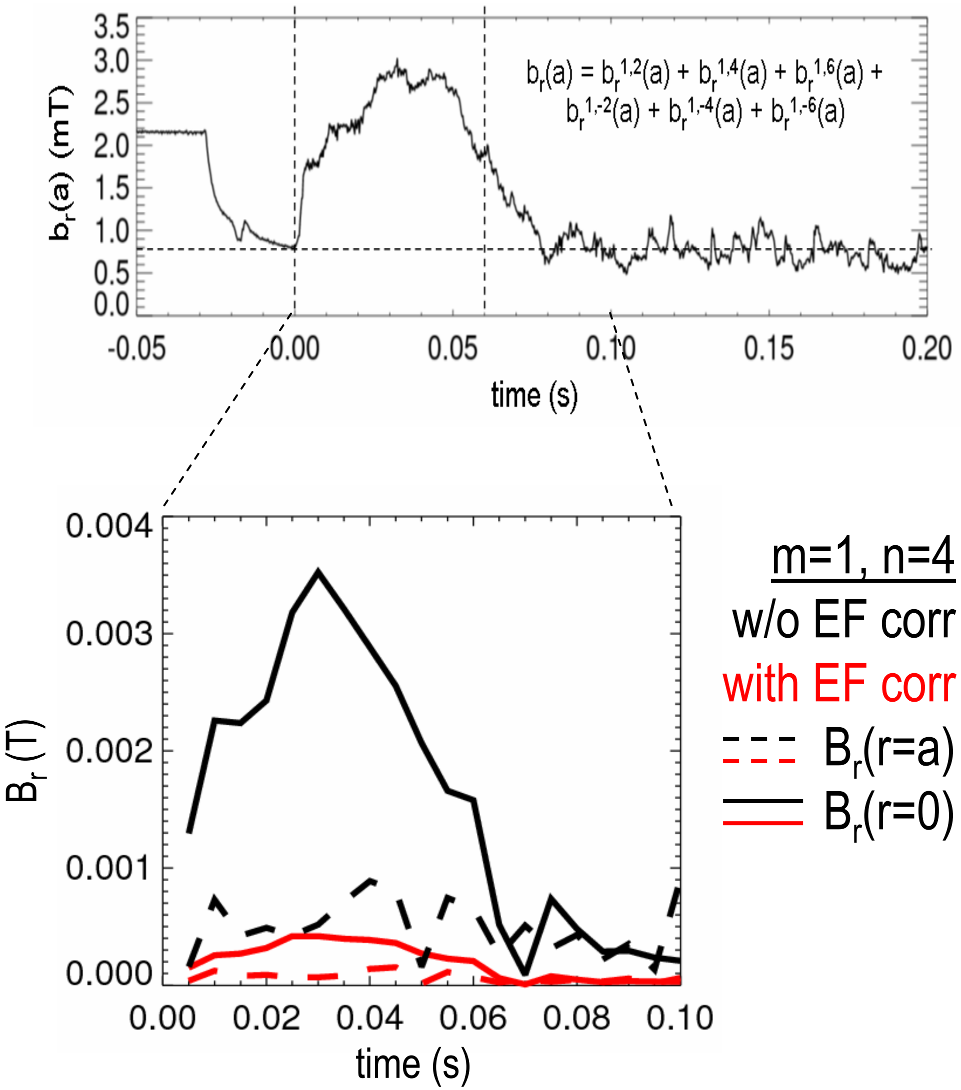

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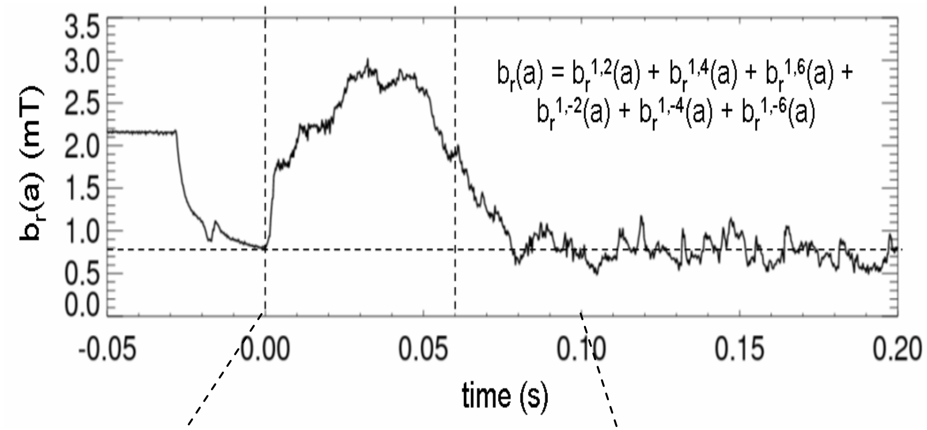
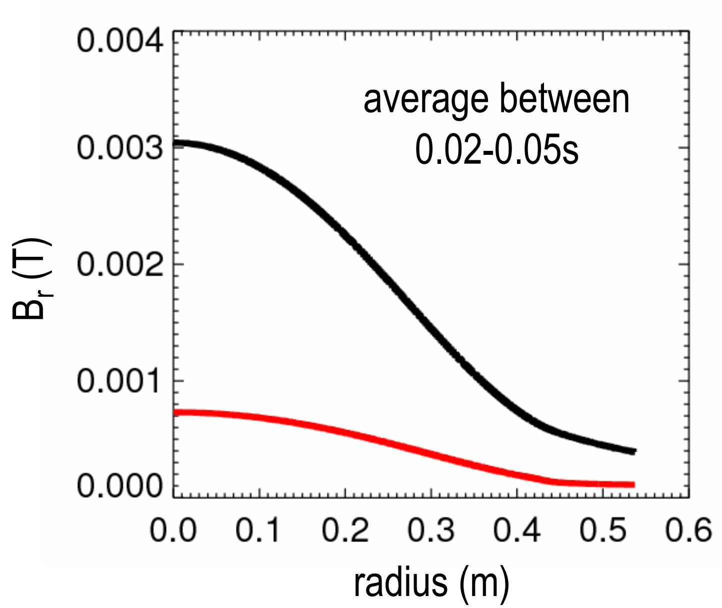
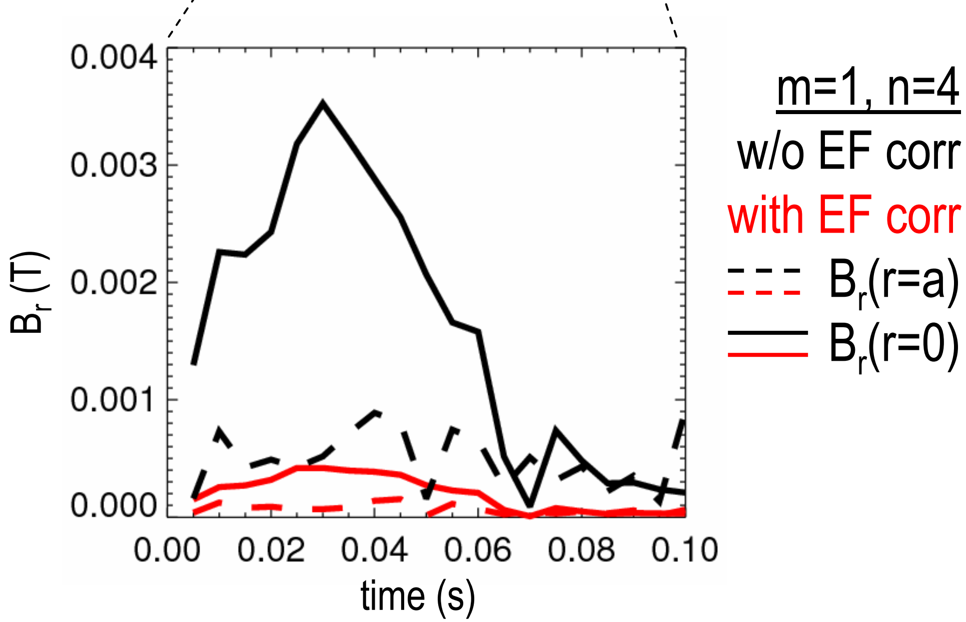


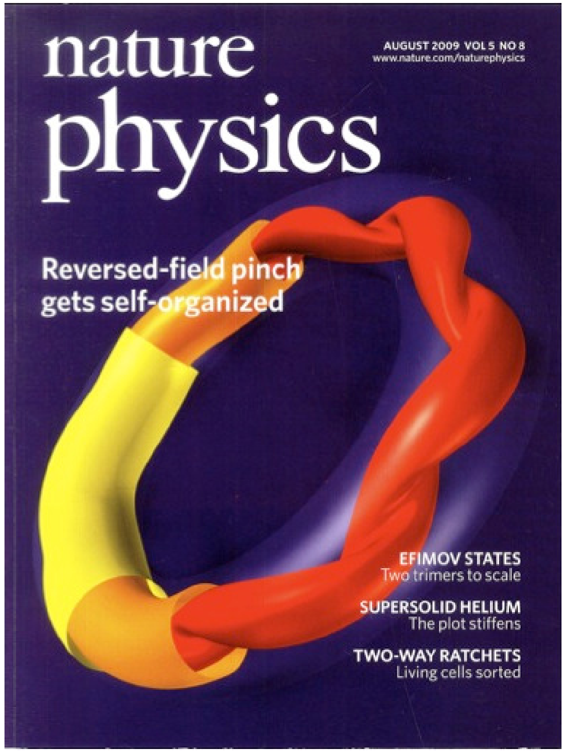



1. ERROR FIELD CONTROL

# 2. MODE CONTROL

# Mode control

- Mode control in RFX-mod is important both for error fields, RWMs, and tearing modes
- In particular, to obtain the high-$I_P$ helical states, it is key to control the edge $B_r$ of the 1/7 tearing mode at low amplitude and to maintain it into slow rotation

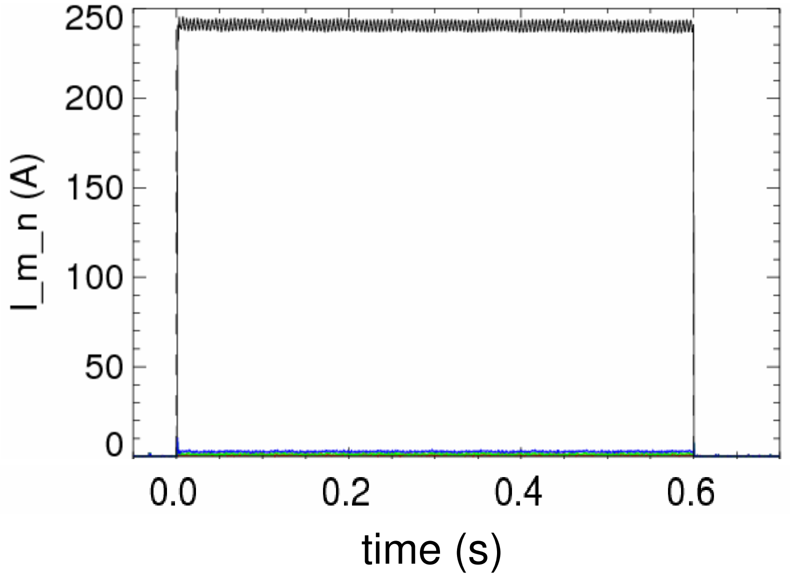



August 2009

# Mode control needs dynamic decoupling

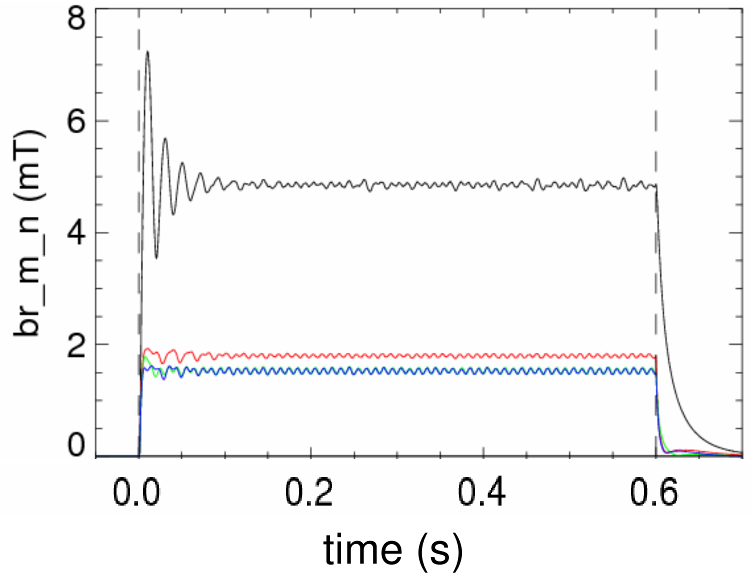
- A rotating perturbation in the coil currents with some helicity (m,n) produces a $B_r$ with a rich spectrum of m harmonics
- Mainly due to the coupling of m harmonics introduced by the poloidal gap

$I_c^{m=1,n=-7}$ rotating at 50Hz



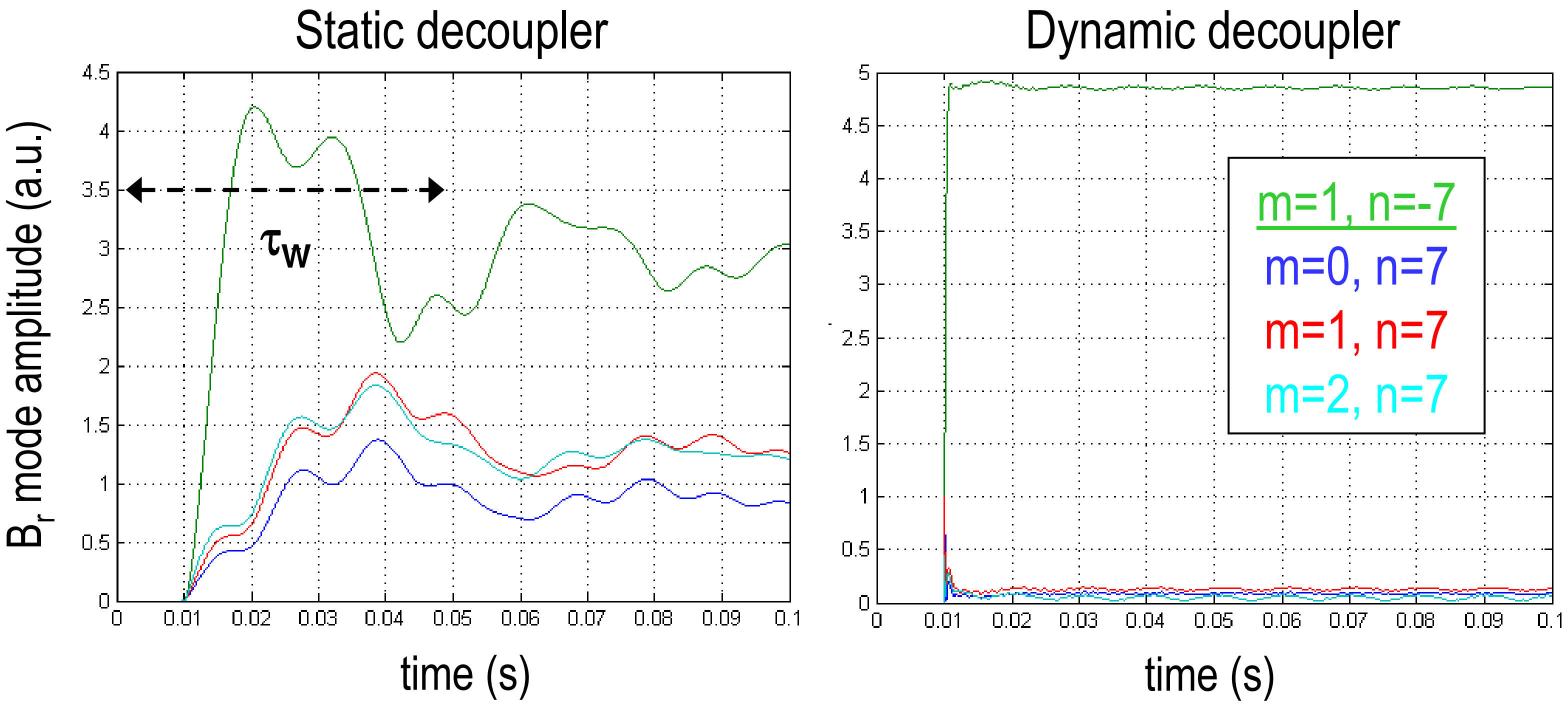

⇒

n = 7, m = -1, 0, 1, 2



# Mode control needs dynamic decoupling

- In these simulations the feedback is requested to generate a $B_r$ perturbation with fixed helicity, m=1, n=-7, rotating at 50Hz in vacuum
- Dynamic decoupling seems to be important for the mode control to be at the same time sufficiently clean and fast



# Dynamic “mode” decoupler

- If one needs to decouple a small number of modes, as it may be the case for RFX-mod or tokamaks, the dimensions of a full dynamic decoupler are excessive
- A dynamic “mode” decoupler acting on the dominant 1/7 mode is now being designed

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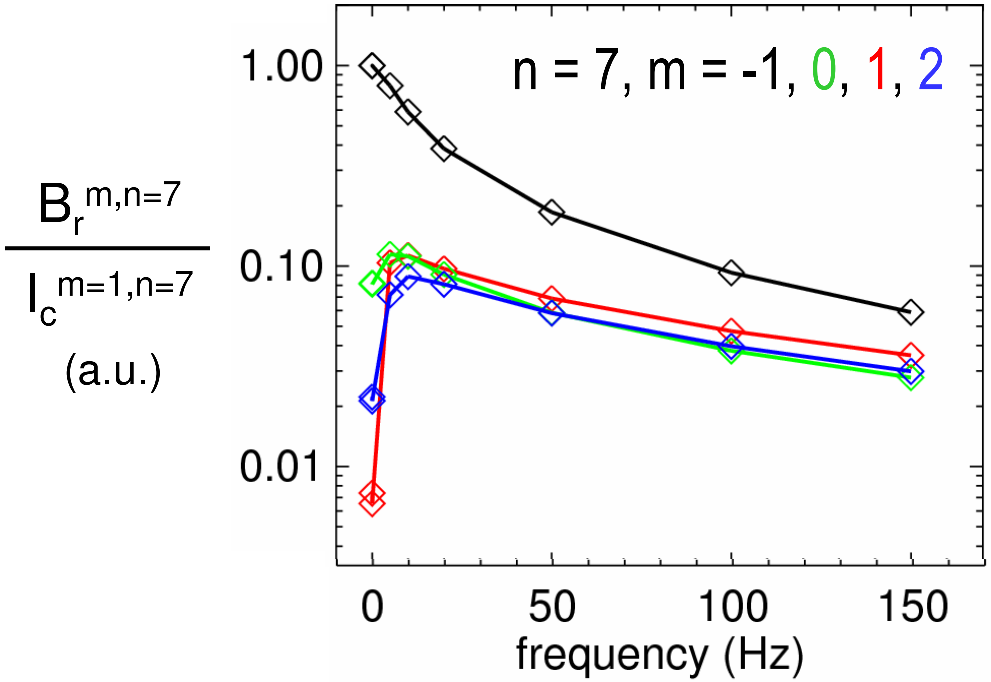
- A dynamic “mode” decoupler acting on the dominant 1/7 mode is now being designed
- This is based on the “mode” transfer functions between the m=-1,0,1,2, n=7 current harmonics and the same $B_r$ harmonics, recently measured in vacuum discharges
- The transfer function matrix is now 4×4 instead of 192×192, a great advantage for real-time implementation



# Conclusions and future work

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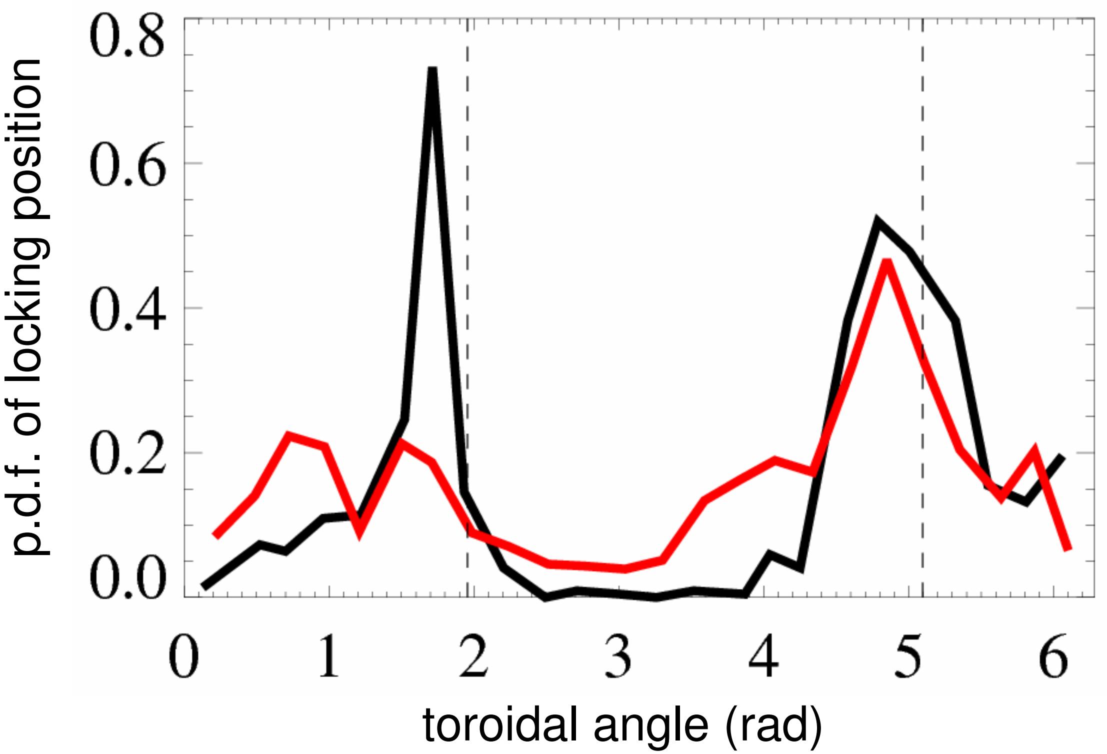
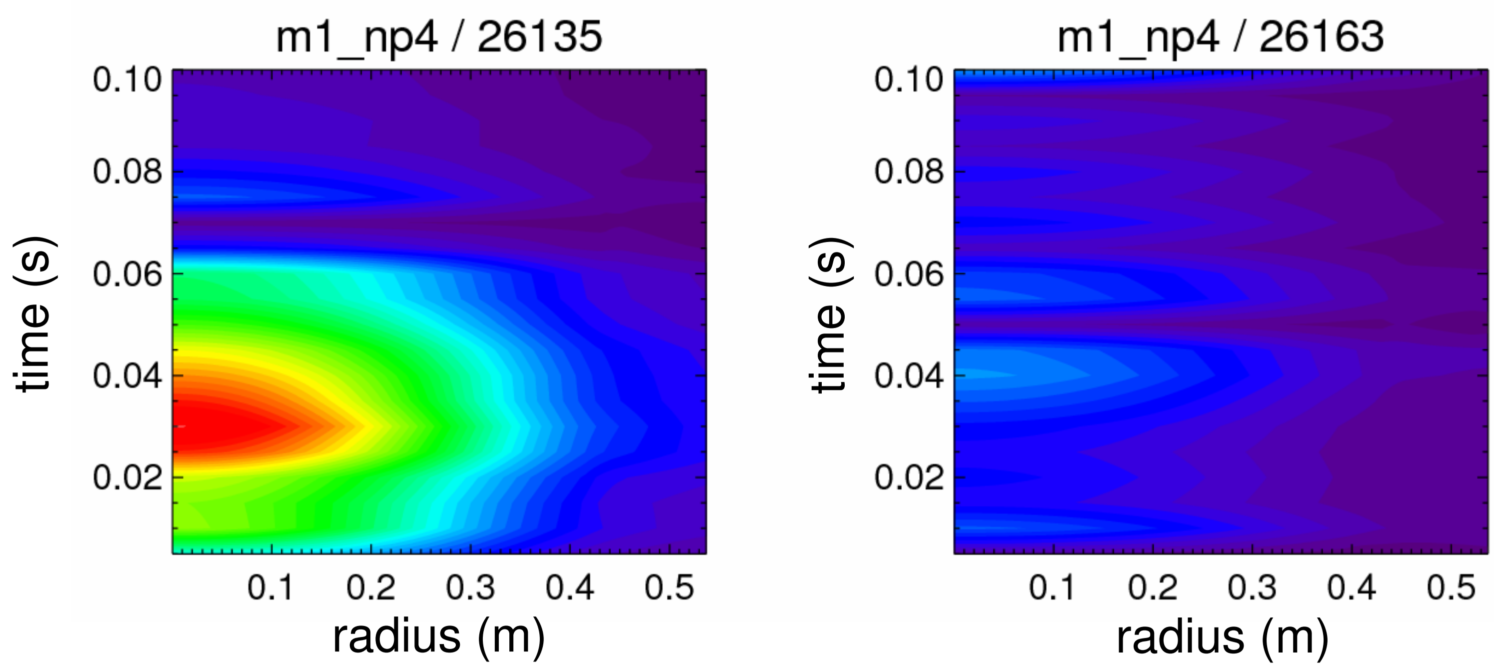
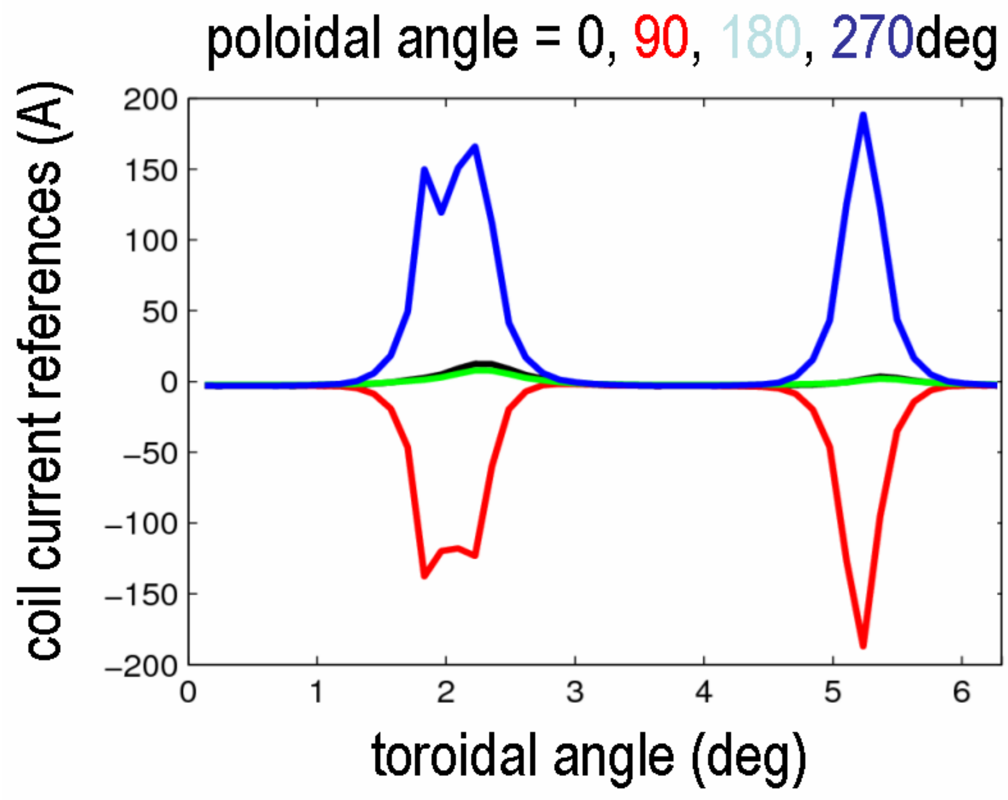
- Thanks to an extensive set of magnetic measurements, the main e.m. couplings of the wall in RFX-mod can be well characterized
- Decoupling in space and time is important for error field and mode control
- Plasma response is non included in the present approach, but it is important and should be considered in future work
- Real time implementation of the dynamic decoupler is ongoing
- Investigate similar dynamic effects in tokamaks and develop tools for dynamic decoupling. Collaboration with DIII-D recently started.

**with** and **w/o** EF correction



# $B_r(r,t)$


m1_np4 / 26135
0.10
0.08
0.06
0.04
0.02
time (s)
0.1
0.2
0.3
0.4
0.5
radius (m)
m1_np4 / 26163
0.10
0.08
0.06
0.04
0.02
time (s)
0.1
0.2
0.3
0.4
0.5
radius (m)



poloidal angle = 0, 90, 180, 270deg
coil current references (A)
200
150
100
50
0
−50
−100
−150
−200
0
1
2
3
4
5
6
toroidal angle (deg)