Magnetic feedback optimization by including the dynamic response of the wall in RFX-mod and DIII-D

Lidia Piron, Consorzio RFX

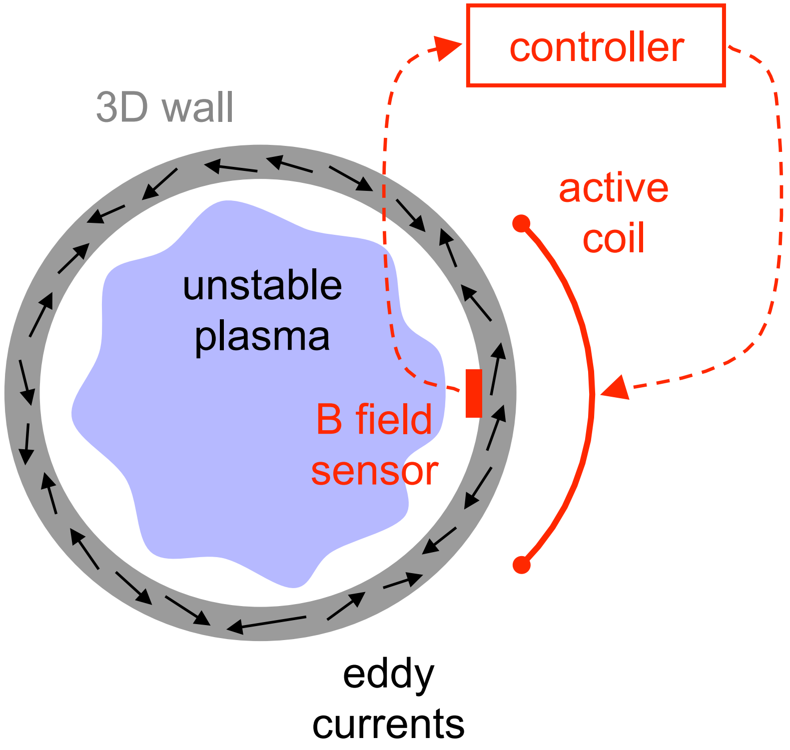
in collaboration with L. Marrelli, P. Martin, P. Piovesan, A. Soppelsa for RFX-mod and J. Hanson, Y. In, M. Okabayashi, E.J. Strait, H. Reimerdes for DIII-D

15TH WORKSHOP ON MHD STABILITY CONTROL

Madison, WI, USA, November 15th-17th, 2010

Background and motivation

- Any realistic wall has complicated 3D conducting structures that modify its dynamic response (eddy currents) to any time-varying magnetic field, produced by the plasma or by any external source, such as feedback and axisymmetric coils



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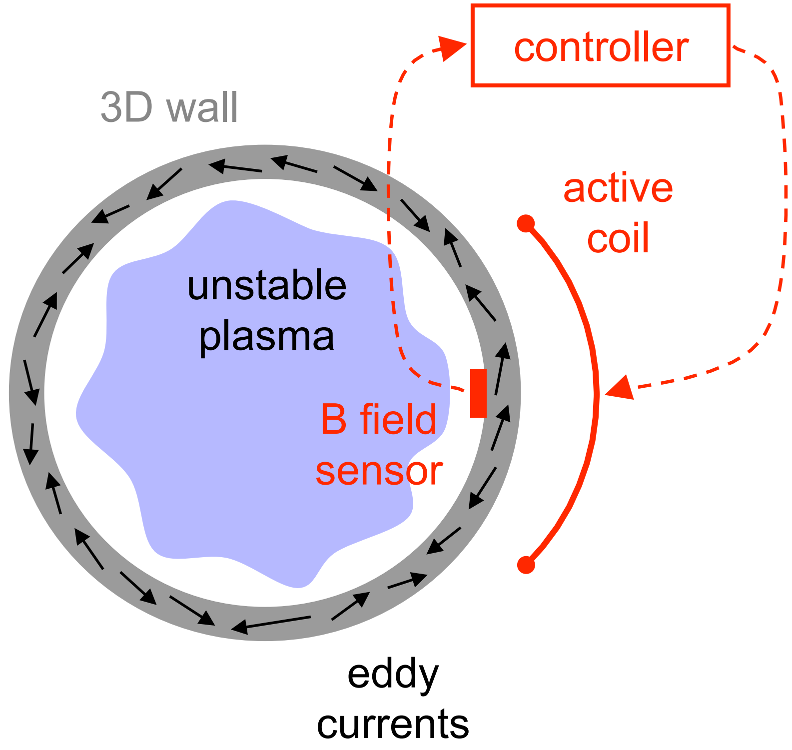

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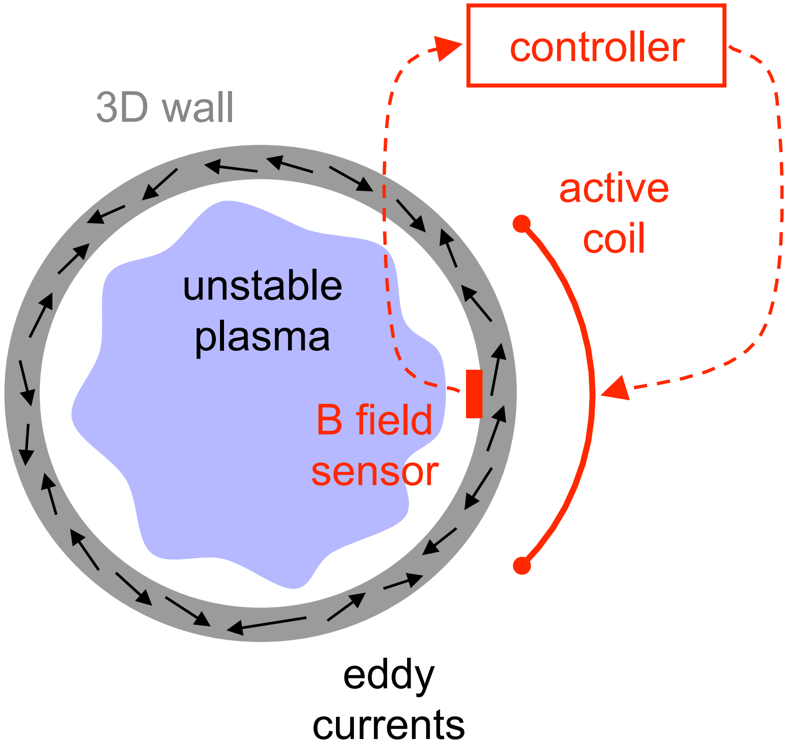
  - the magnetic field produced by the active coils inside the wall can be modified by the wall response → *error fields may be thus produced*



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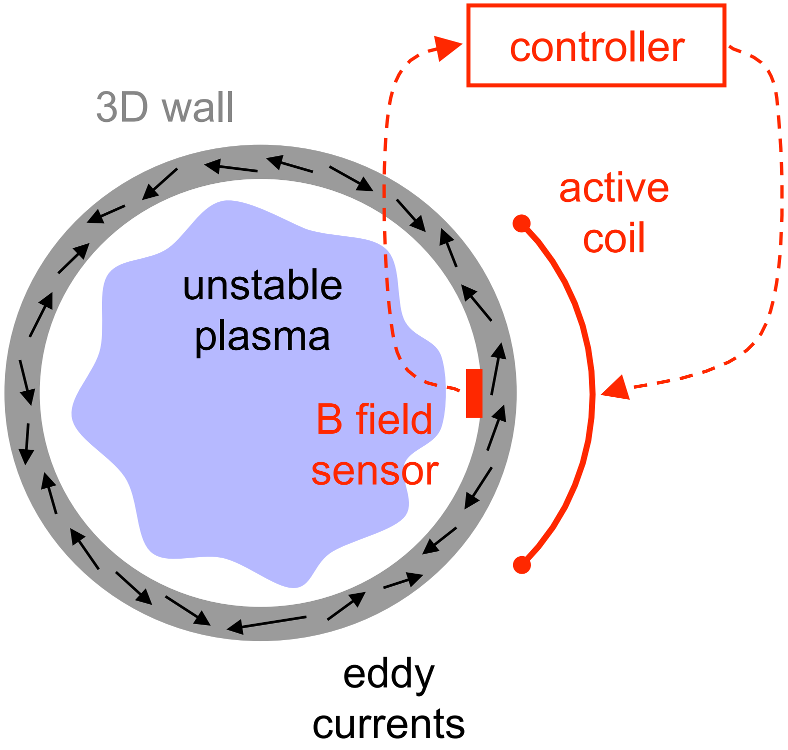
  - the magnetic field produced by the active coils inside the wall can be modified by the wall response → *error fields may be thus produced*
  - the sensors measure contributions from the plasma and from all external magnetic field sources, but also from the time-dependent eddy currents induced in the wall → *possible need of AC compensation schemes*



Outline

- Two different examples of how the frequency-dependent response of a 3D wall can affect magnetic feedback in a real experiment will be presented, along with strategies to compensate for such effects by including in the feedback algorithm information on the wall response:

RFX-mod

– control of a helical RFP equilibria by imposing helical boundary conditions

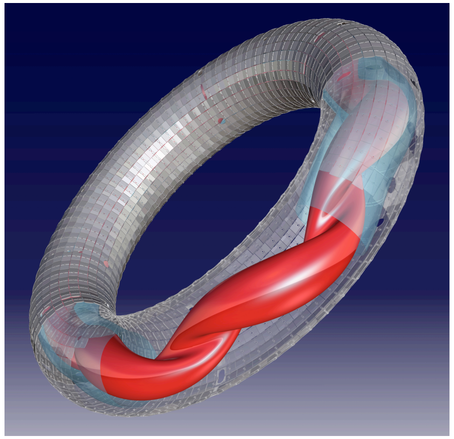
DIII-D

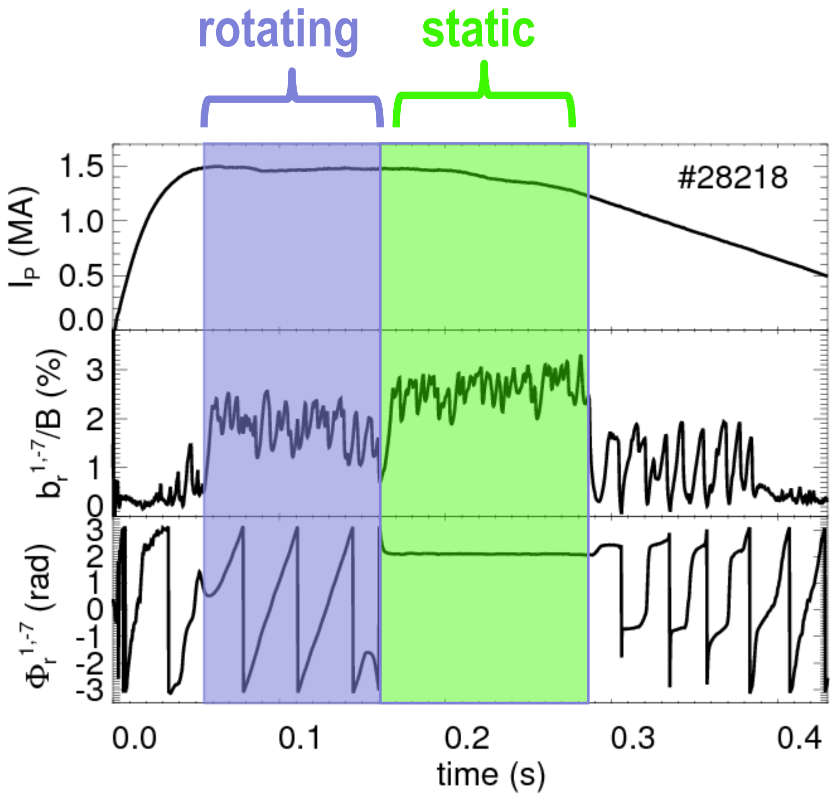
– DC vs AC compensation of sensor signals for n=1 RWM suppression both in Ohmic and high-β discharges

RFX-mod

Control of helical equilibria in RFX-mod

- Helical RFP equilibria can be sustained at high I_P by imposing m=1, n=-7 helical boundary conditions through magnetic feedback → *more in P. Piovesan's talk*





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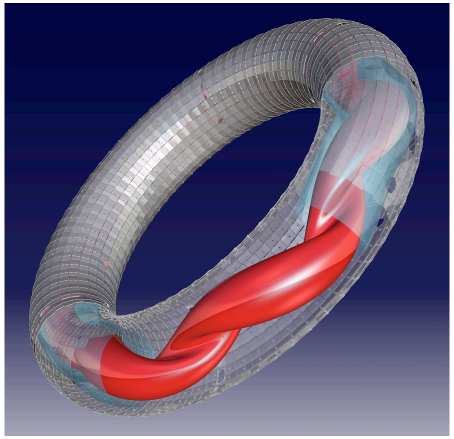
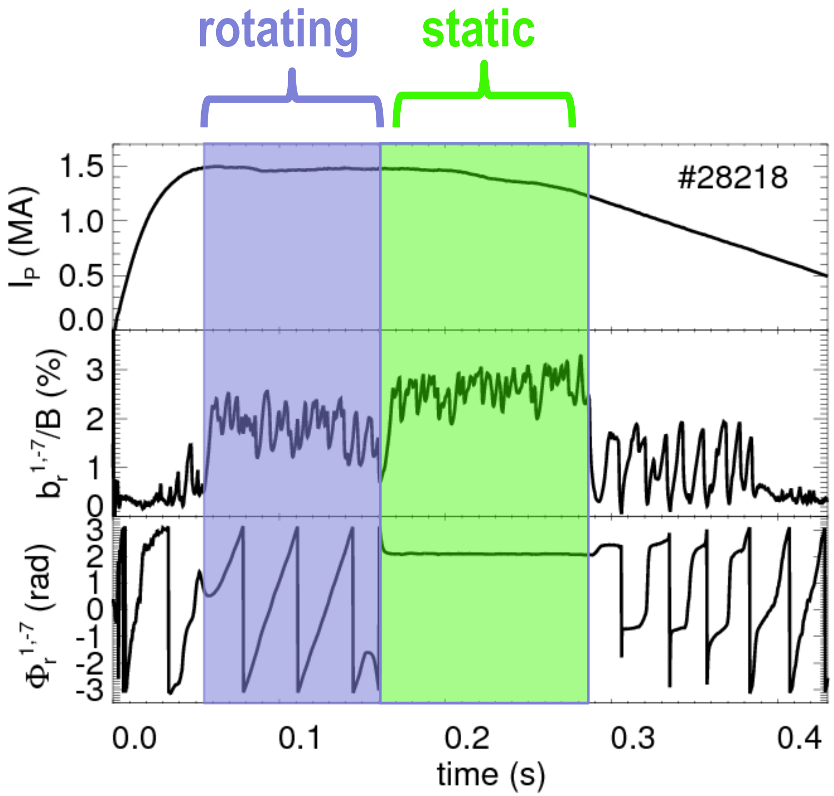
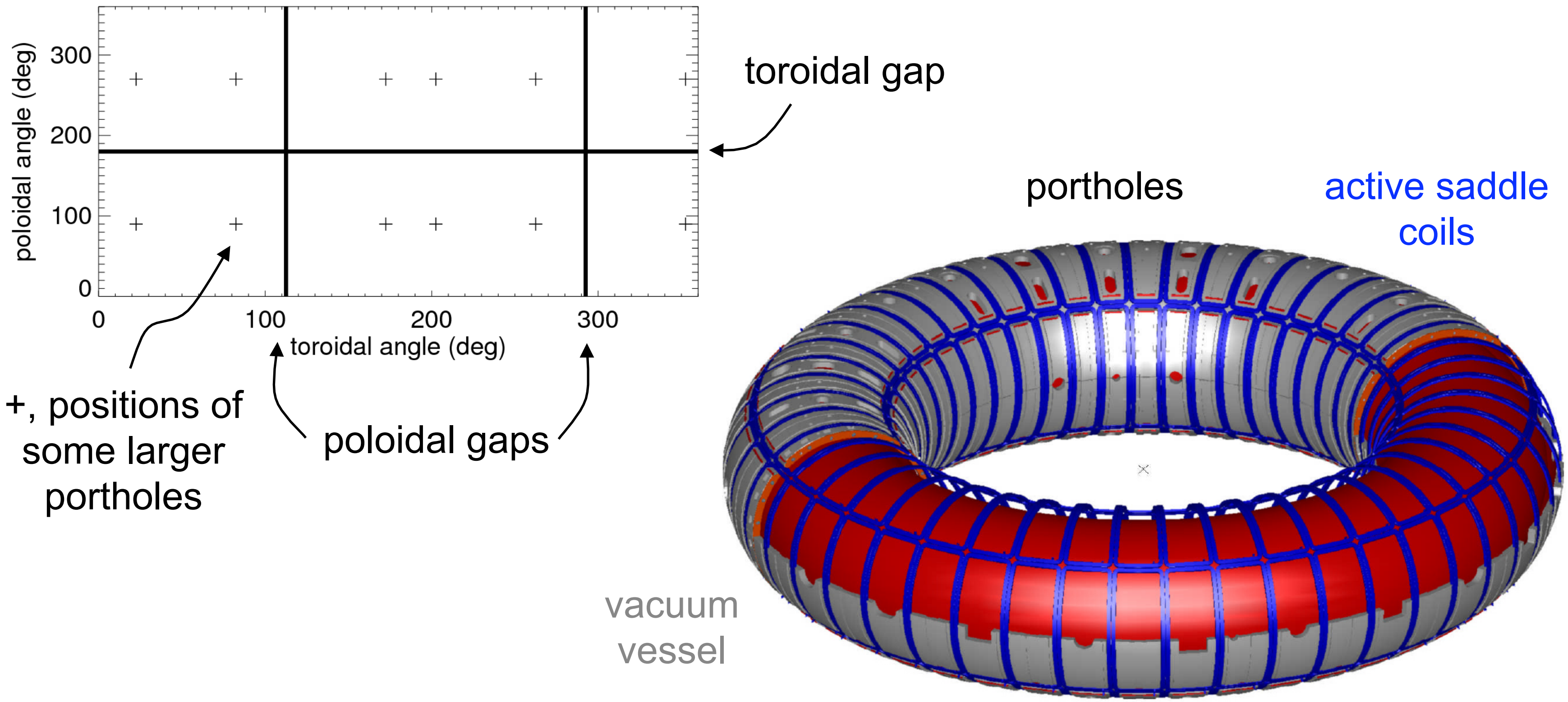




- Error fields due to 3D wall structure may excite secondary instabilities and affect this improved confinement regime

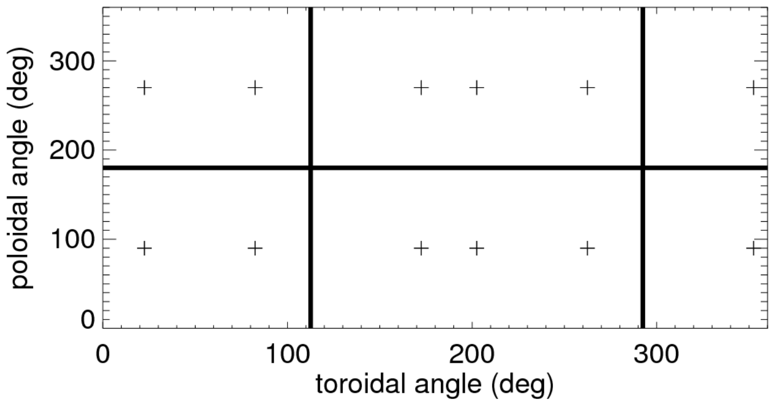
RFX-mod wall layout & control coils scheme

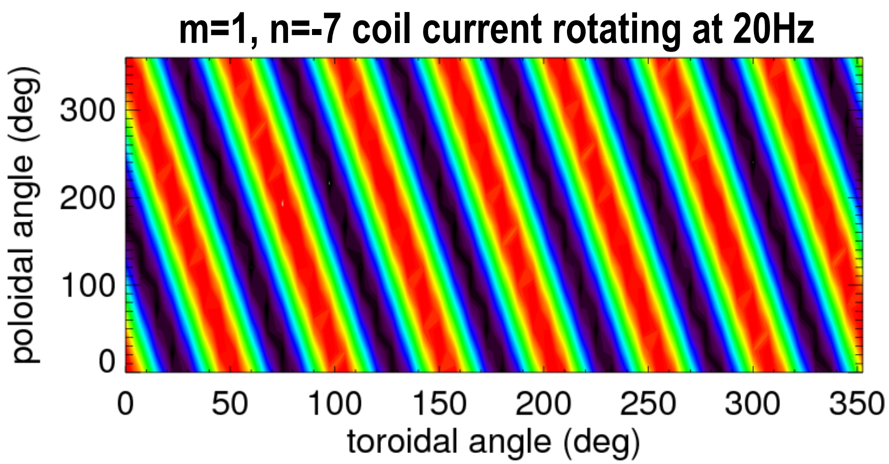
- The RFX-mod wall has two poloidal gaps and one toroidal gap, plus some large portholes that significantly affect its dynamic response to external magnetic fields
- 48×4=192 active coils (external) and respective sensors (internal) fully cover the torus



Error fields due to the equatorial gap

- The radial magnetic field produced inside the wall by a rotating m=1, n=-7 current in the active coils is affected mostly by the presence of the toroidal gap





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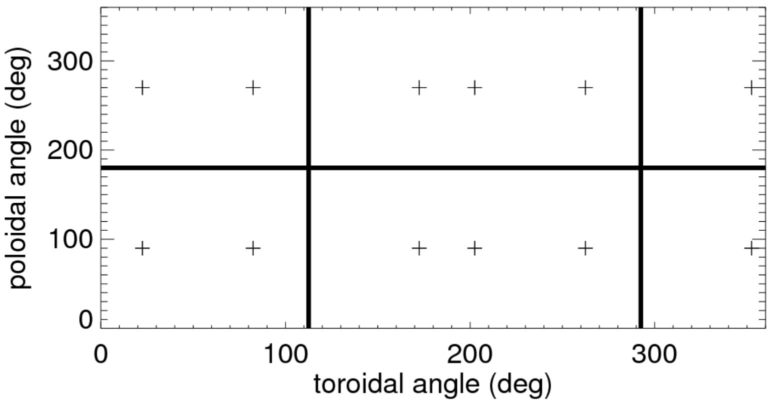
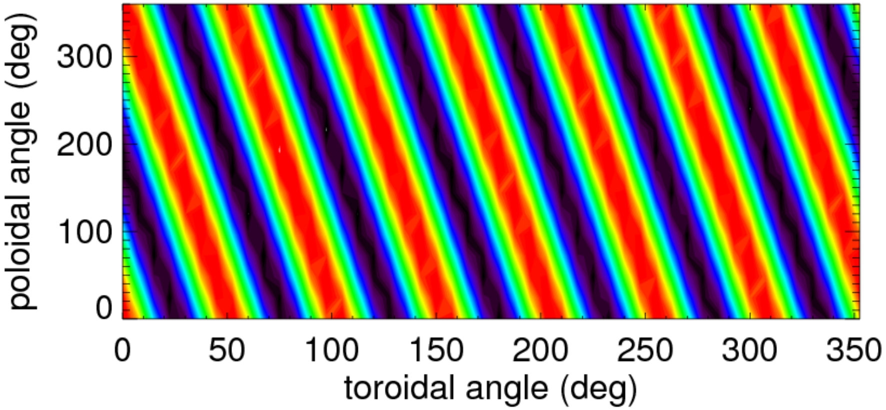
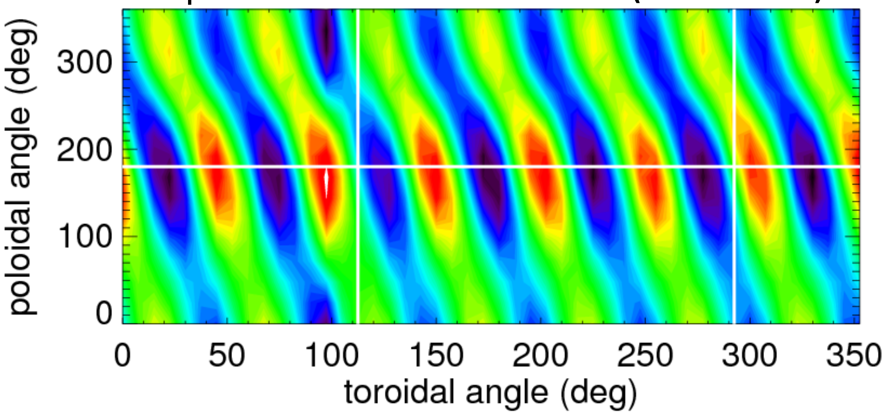


m=1, n=-7 coil current rotating at 20Hz



B_r measured inside the wall (in vacuum)



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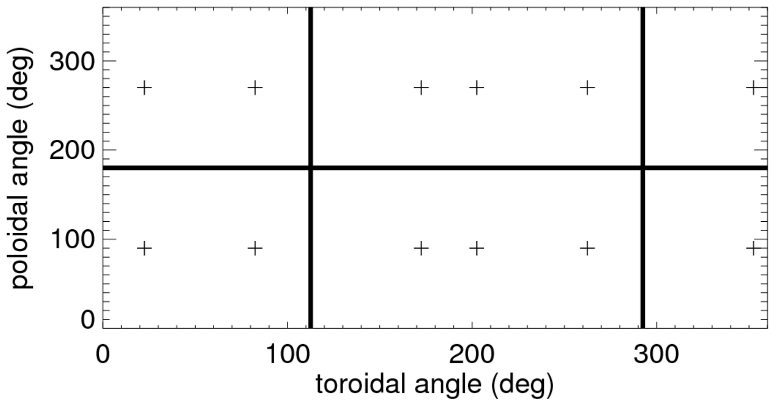
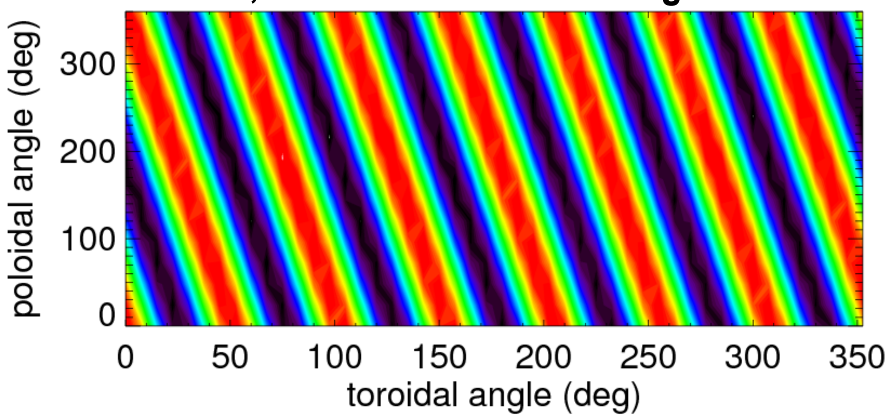
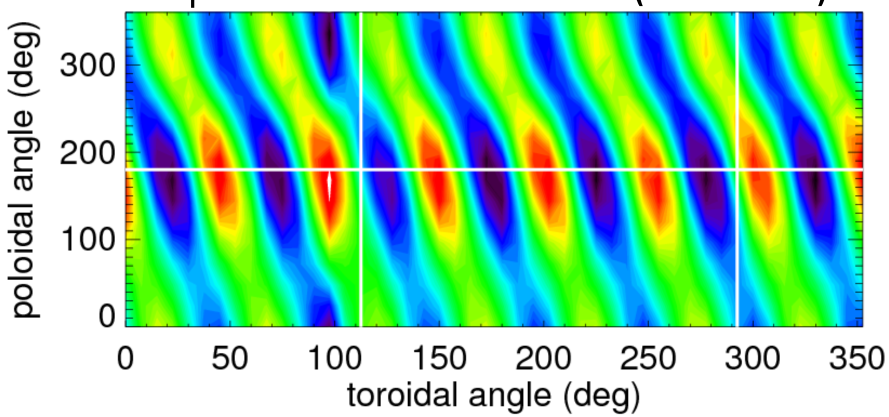


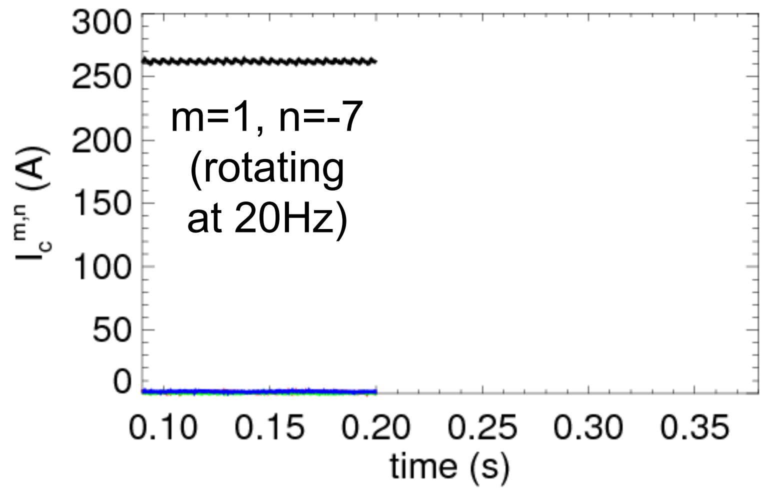


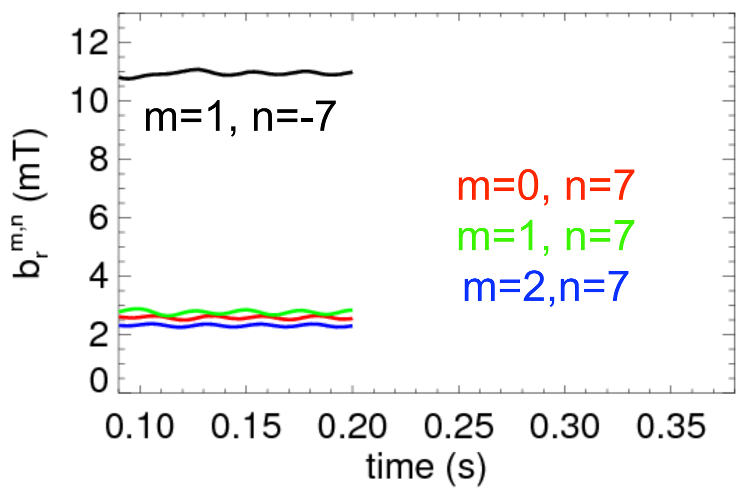
- As a result, the radial magnetic field as a dominant m=1, n=-7 harmonic, plus m=0,1,2, n=-7 harmonics to represent the radial field perturbation localized at the toroidal gap



Coupling of different n=7 poloidal harmonics

- The toroidal gap introduces a coupling between different poloidal harmonics that can be represented by complex transfer functions, which have been measured in vacuum



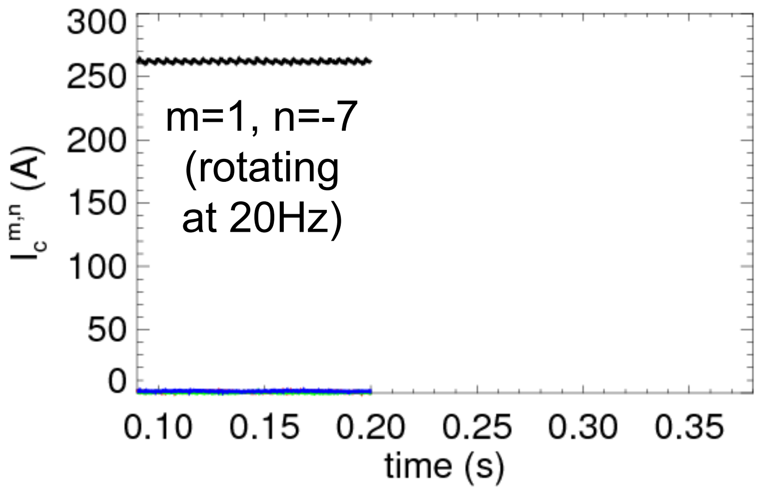


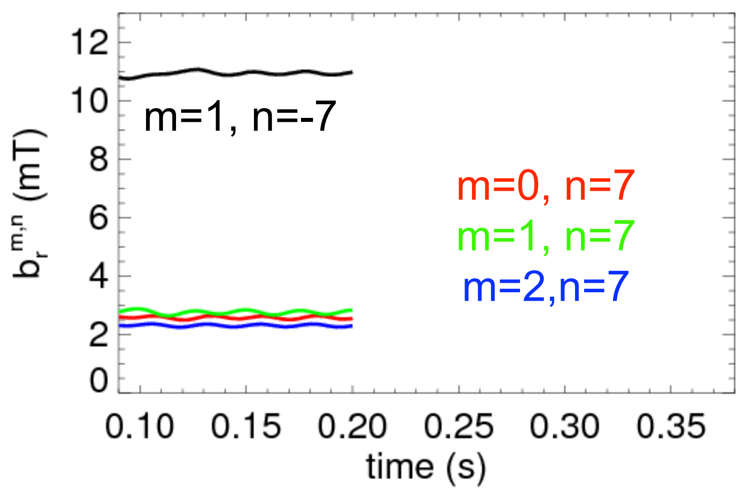
Transfer function matrix

$$\begin{bmatrix} M_{1,-7}^{1,-7} & M_{0,7}^{1,-7} & M_{1,7}^{1,-7} & M_{2,7}^{1,-7} \\ M_{1,-7}^{0,7} & M_{0,7}^{0,7} & M_{1,7}^{0,7} & M_{2,7}^{0,7} \\ M_{1,-7}^{1,7} & M_{0,7}^{1,7} & M_{1,7}^{1,7} & M_{2,7}^{1,7} \\ M_{1,-7}^{2,7} & M_{0,7}^{2,7} & M_{1,7}^{2,7} & M_{2,7}^{2,7} \end{bmatrix} \cdot \begin{bmatrix} I_c^{m=1,n=-7} \\ 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} b_r^{m=1,n=-7} \\ b_r^{m=0,n=7} \\ b_r^{m=1,n=7} \\ b_r^{m=2,n=7} \end{bmatrix}$$

Dynamic decoupler for the n=7 harmonic

- A dynamic decoupler for the n=7 mode was built, by inverting the transfer function matrix, to compute the current distribution that generates a pure 1/-7 B_r inside the wall





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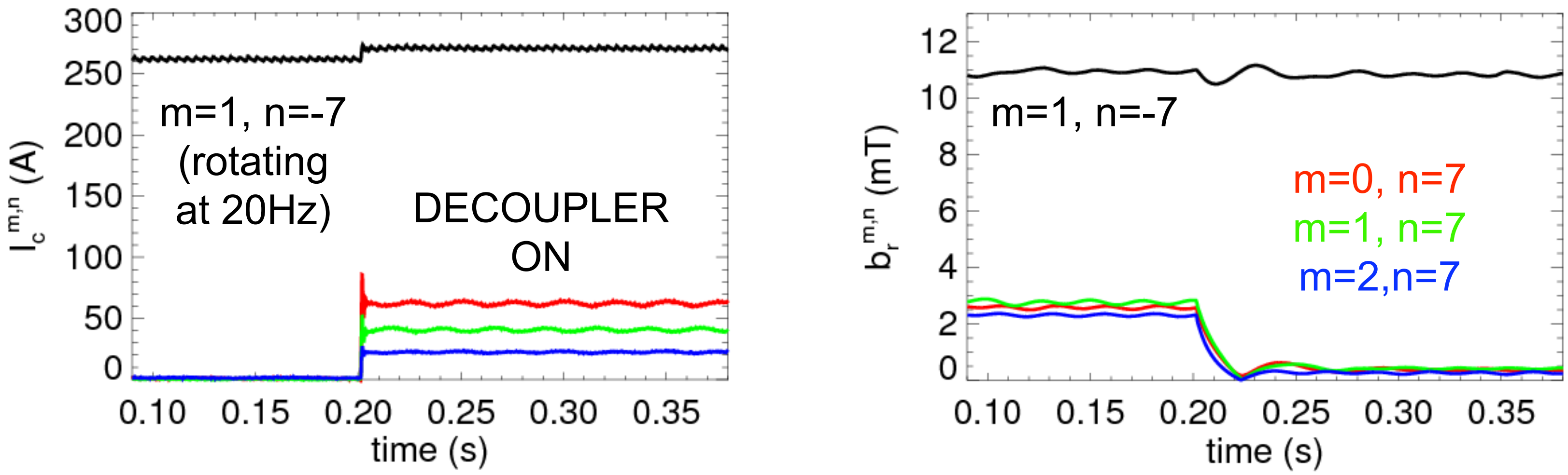

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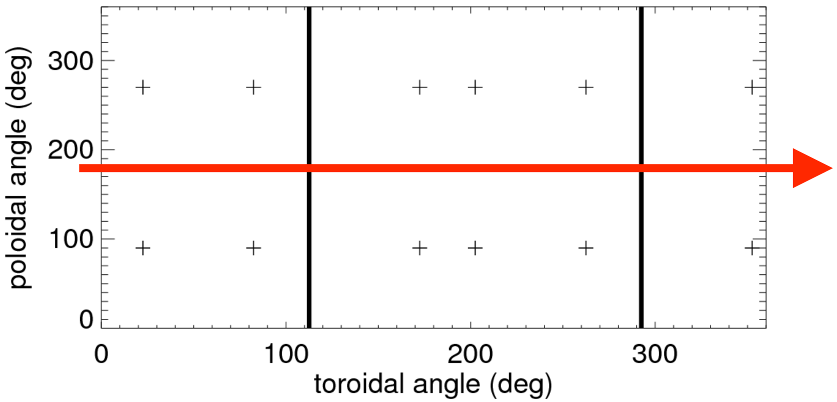
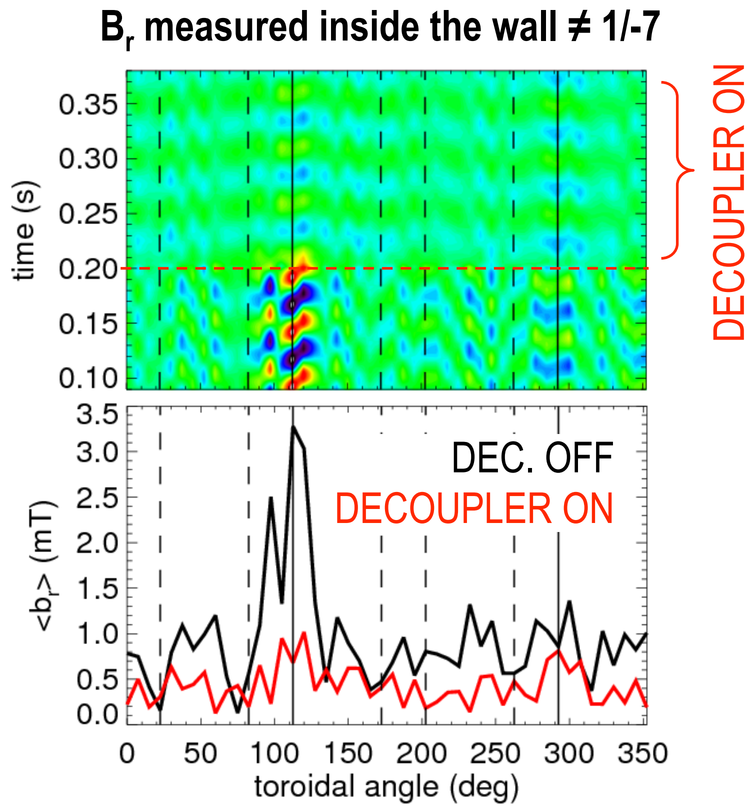
Other error fields due to poloidal gaps and portholes

- Other error fields with lower amplitude are produced by the rotating 1/-7 perturbation near the two poloidal gaps and some large portholes
- A more general decoupler that inverts the matrix of transfer functions among all 192 active coils and 192 B_r sensors was used to compensate for these error fields





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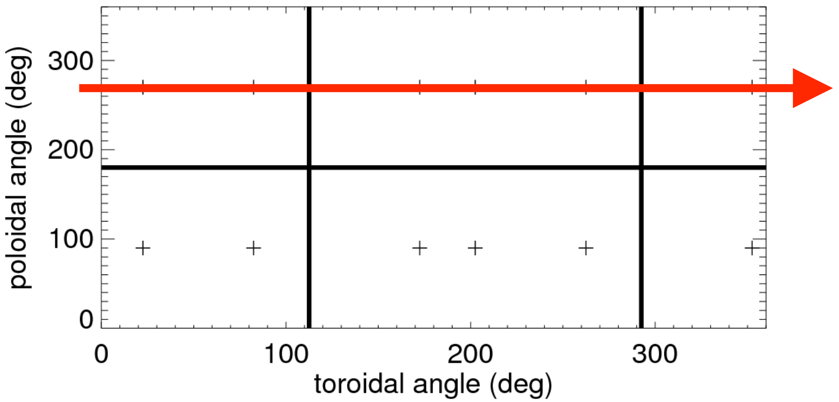
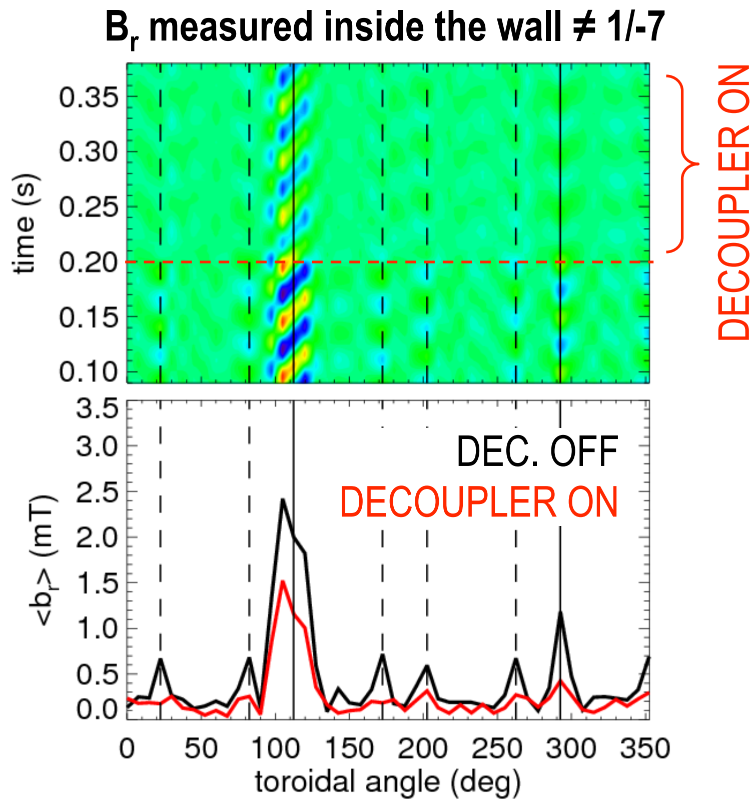
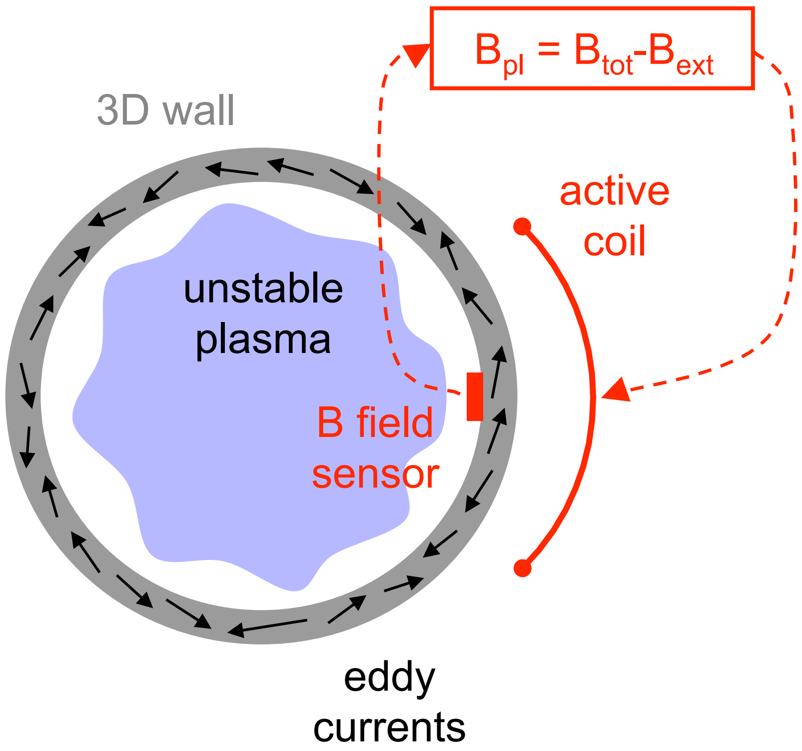




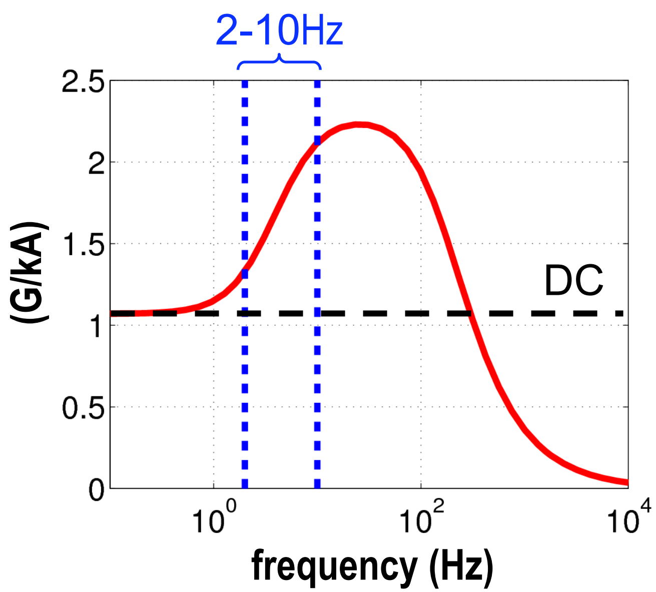
DIII-D

DC *vs* AC sensor signal compensation in DIII-D

- To suppress a n=1 RWM, or the plasma response to n=1 error fields, the measured magnetic field must be compensated for spurious n=1 fields produced by other sources, such as the active coils, slightly misplaced axisymmetric coils, or by eddy currents induced in the 3D wall structures by any magnetic field varying in time

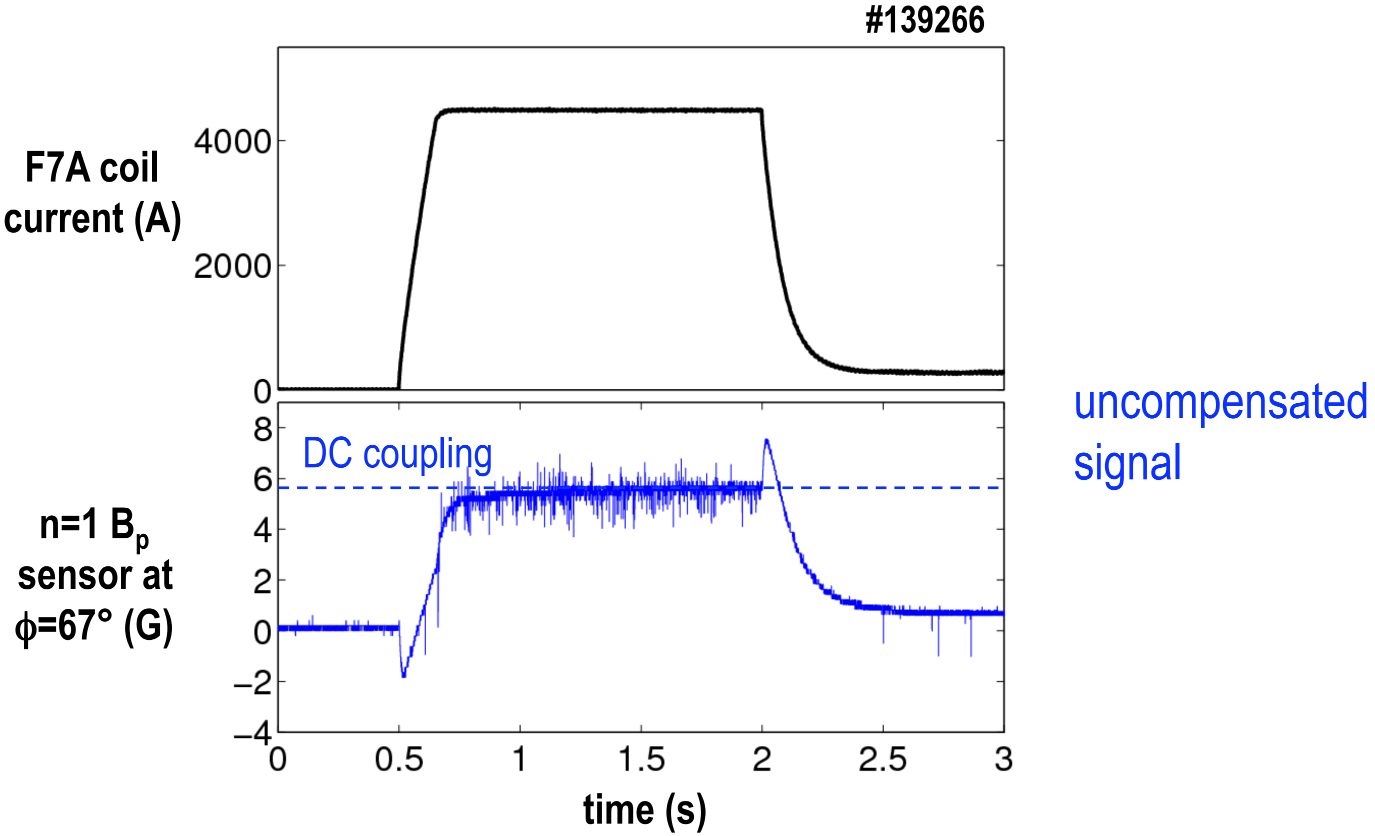


Transfer function among a field shaping coil (F7A) and a n=1 B_p sensor at ϕ=67°



Example: spurious n=1 B_p fields from the F coils

- The field shaping coils produce spurious contributions to the n=1 B_p signal used for feedback, which need to be compensated for in real-time. This is usually done with a DC compensation scheme based on vacuum measurements of the DC couplings



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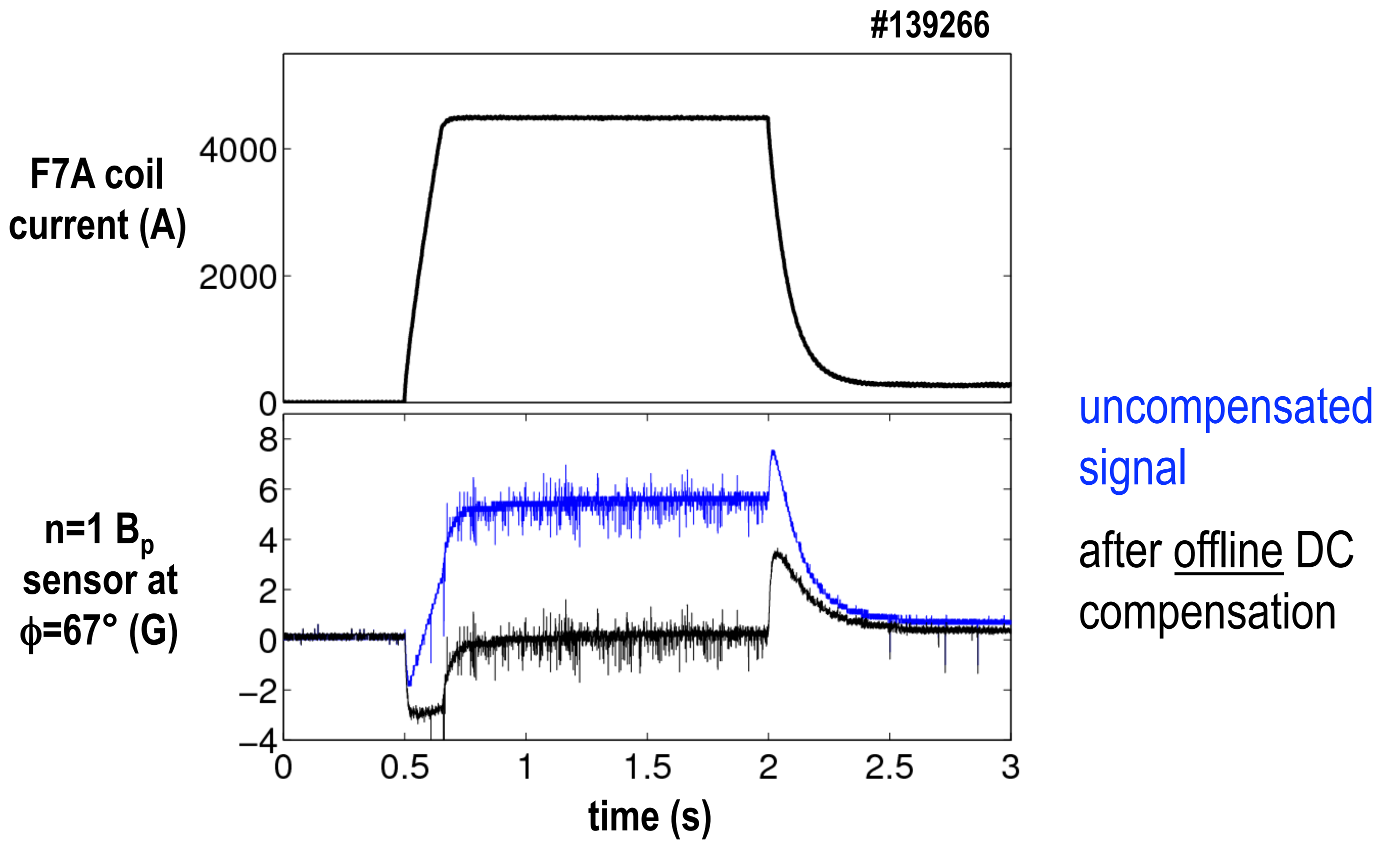
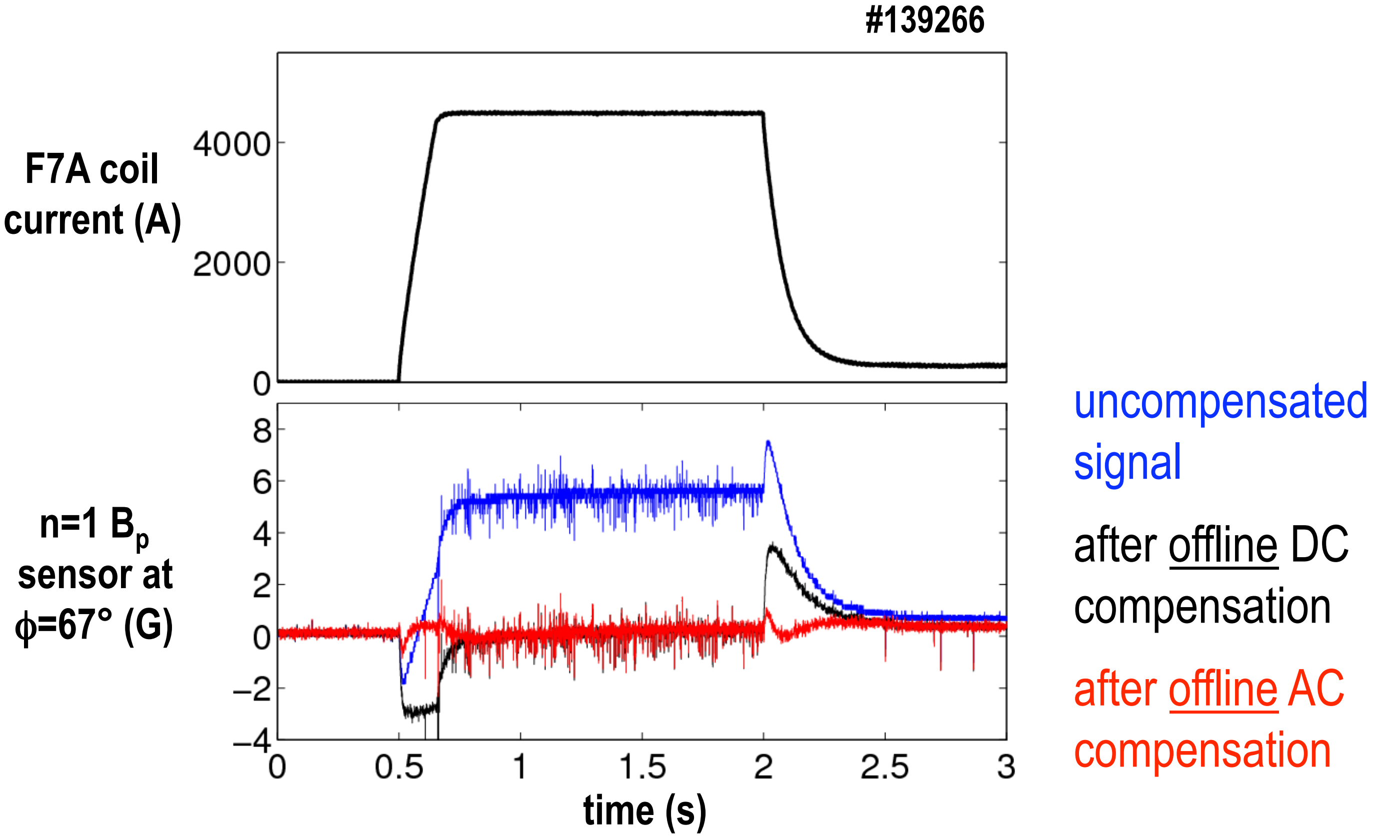


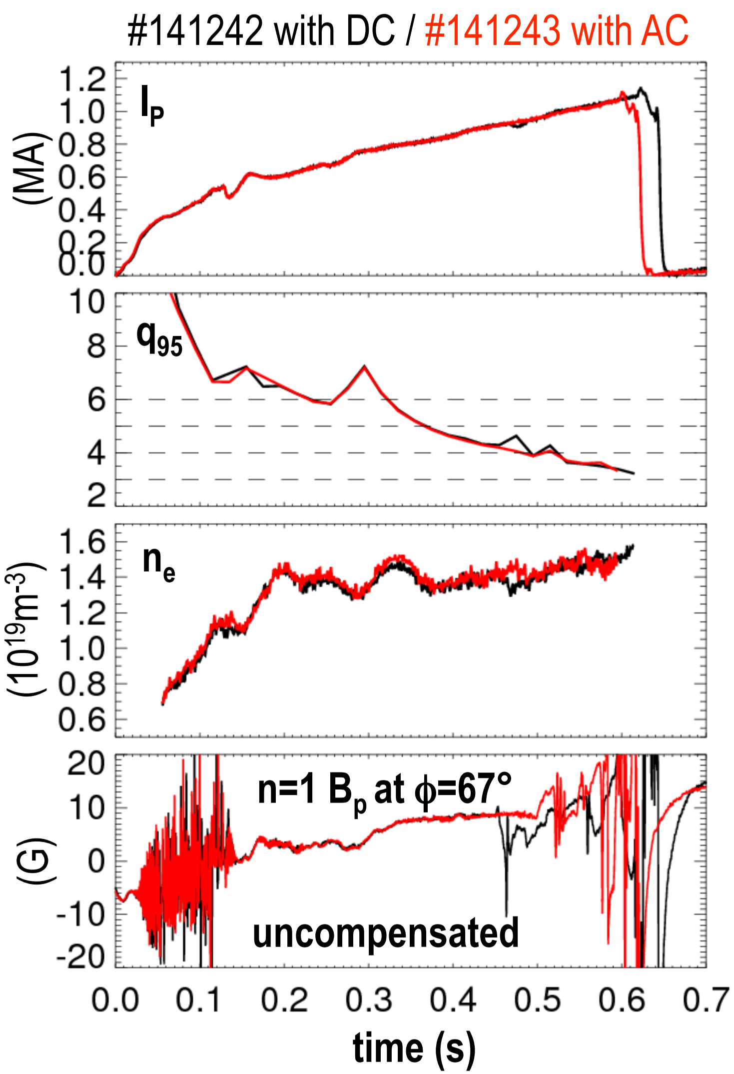
First tests of AC compensation in vacuum

- During transients, the eddy currents induced in the wall produce a significant effect on the n=1 B_p signal, which can be compensated with a scheme recently implemented in real-time in DIII-D, based on transfer functions measured in vacuum



Test of AC compensation in Ohmic plasmas

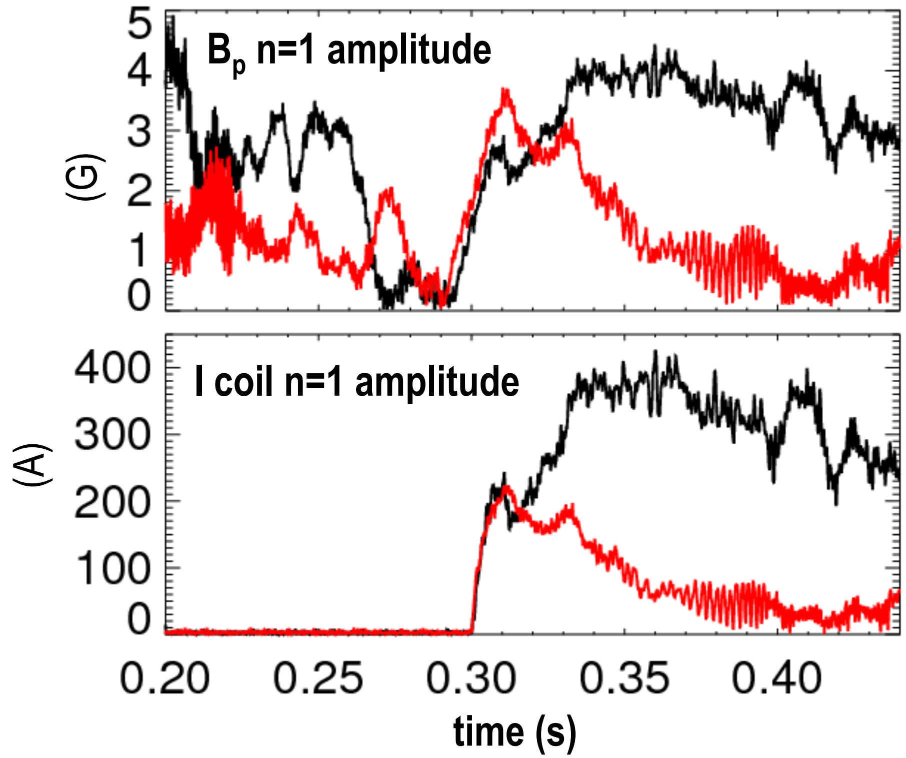
- DC and AC compensation have been compared in two very similar Ohmic discharges
- A fast current ramp was programmed to destabilize current-driven RWMs, but unfortunately the targeted n=1 mode at q_{95}=4 turned out not to be unstable
- Nonetheless, we could compare the effect of DC and AC compensation on dynamic error field correction



Test of AC compensation in Ohmic plasmas

- In these cases, the largest AC effects are associated with the variation of the F coil currents during the current ramp-up
- The n=1 B_p amplitude estimated with AC compensation is significantly smaller than with DC compensation. This is completely due to the different algorithm, not to different plasma parameters
- As a consequence, the I coil current is significantly reduced and the production of additional error fields avoided

#141242 with DC / #141243 with AC



Possible relevance for high-β plasmas

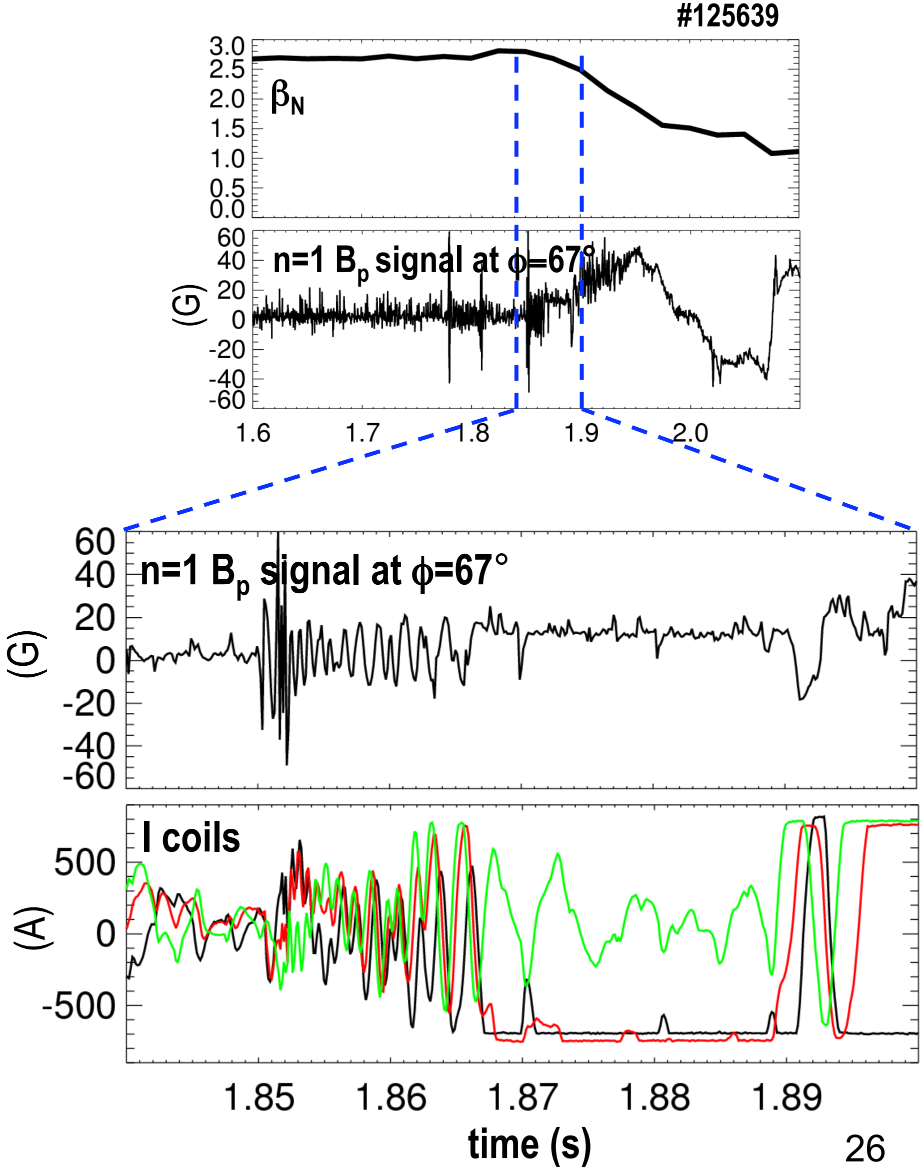
- In high-β plasmas, fast feedback is quite effective in suppressing ELM or fishbone-driven RWMs

  [M. Okabayashi *et al.*, Nucl. Fusion **49**, 125003 (2009)]

- In some cases a residual oscillation remains, causing the I coil currents to increase and saturate, which brings to a β collapse

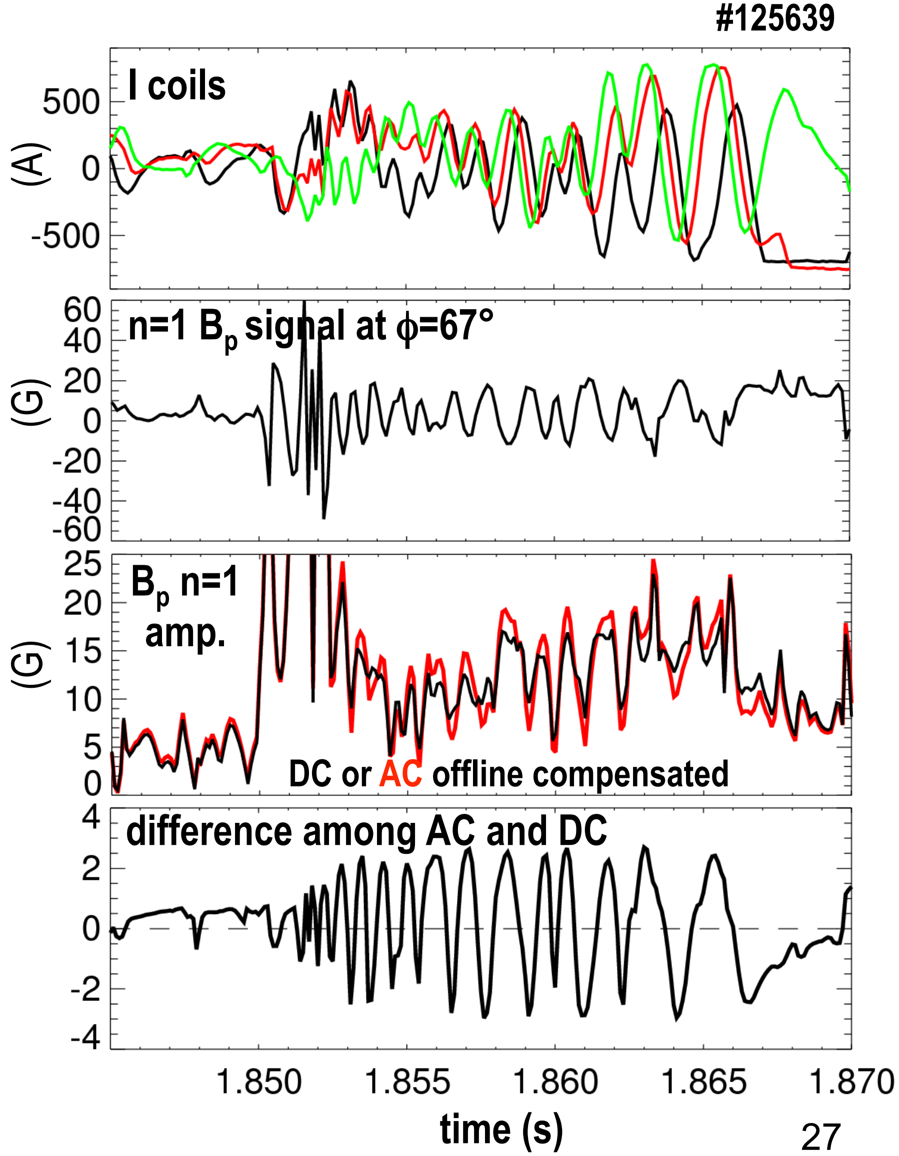
- The residual oscillation stops as the I coil currents saturate. This may indicate that this is not an instability, but possibly amplification of the field produced by the I coils.

- But why does this oscillation persists?



Error fields due to AC effects may be destabilizing

- The n=1 mode amplitude computed including AC effects differs from that with DC compensation by an error that oscillates in time
- At some times the feedback overcorrects the mode, adding a small error field; while at others it undercorrects it
- In high-β plasmas, such errors can be amplified and may induce the residual oscillation responsible for the saturation of the I coils and the β collapse



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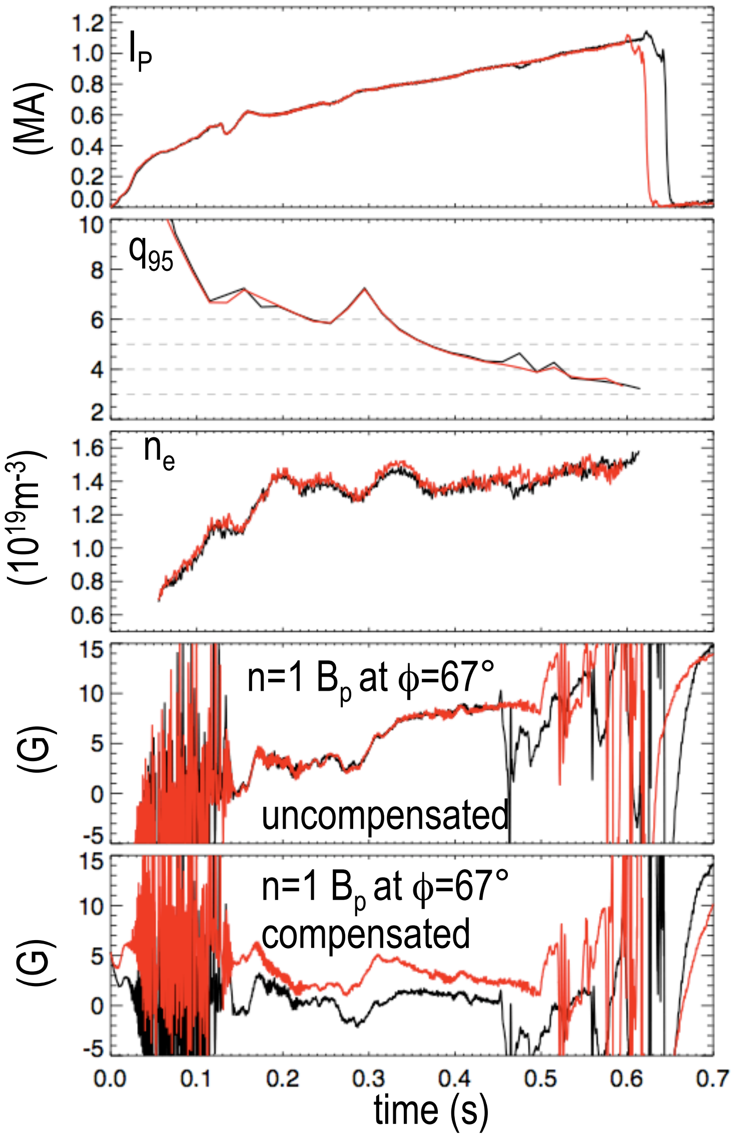
    → *Future work*: the new AC compensation scheme, or upgraded versions of it, may be tested more extensively in high-β plasmas, to assess their relevance in terms of performance improvement

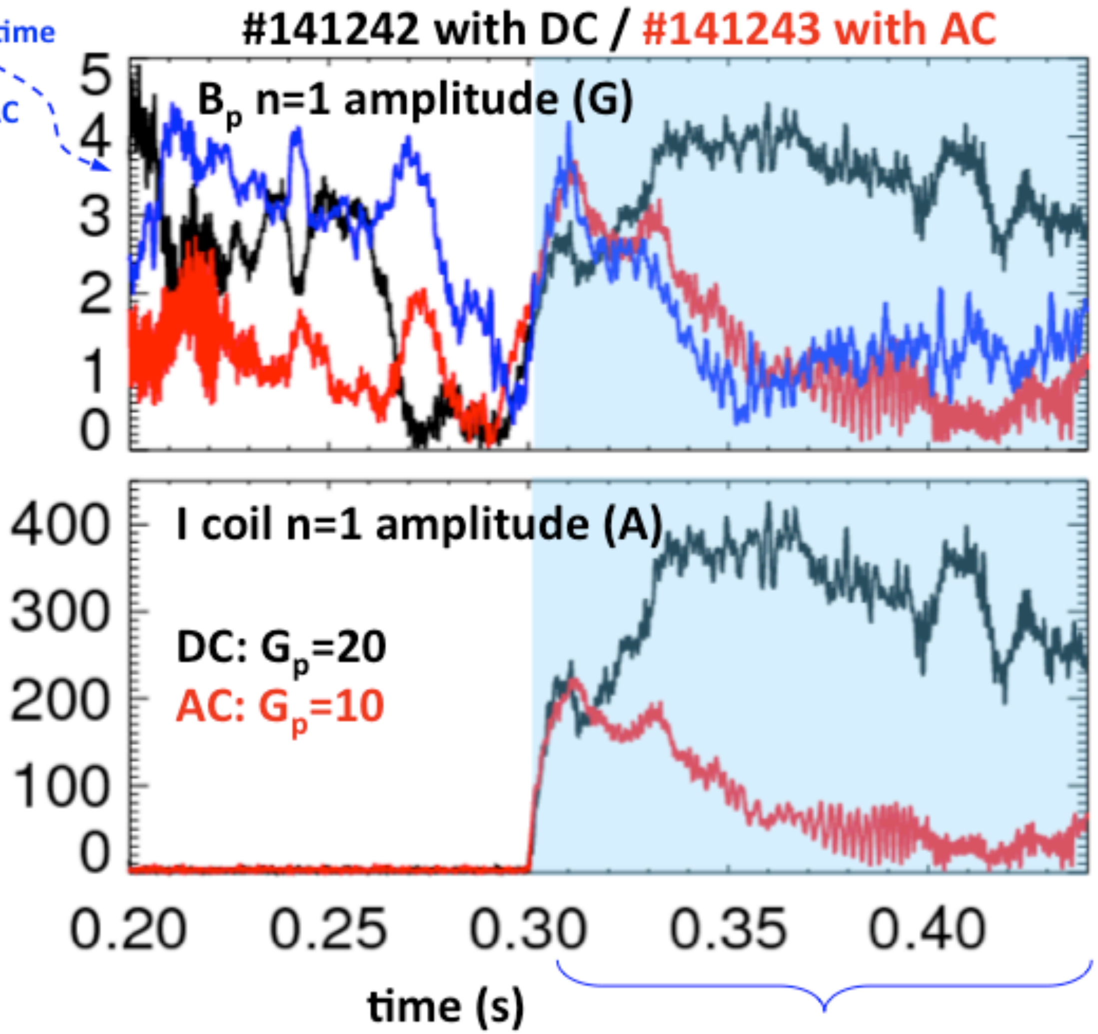
Thank you for your attention

Spare slides

#141242 with DC / #141243 with AC



Case with real-time DC comp. compensated AC OFFLINE.



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