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Comparisons with MHD Simulations of Feedback Experiments in EXTRAP-T2R

presented by R. Paccagnella

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Outline

- Theoretical Models
- Control system in T2R
- RWM spectrum
- Closed-loop experiments
  - -Intelligent shell
  - -Mode control
- Conclusions

Theoretical Models

- ***3D MHD studies using (modified) DEBS code***
- ***Linear cylindrical model with a discrete coil system***

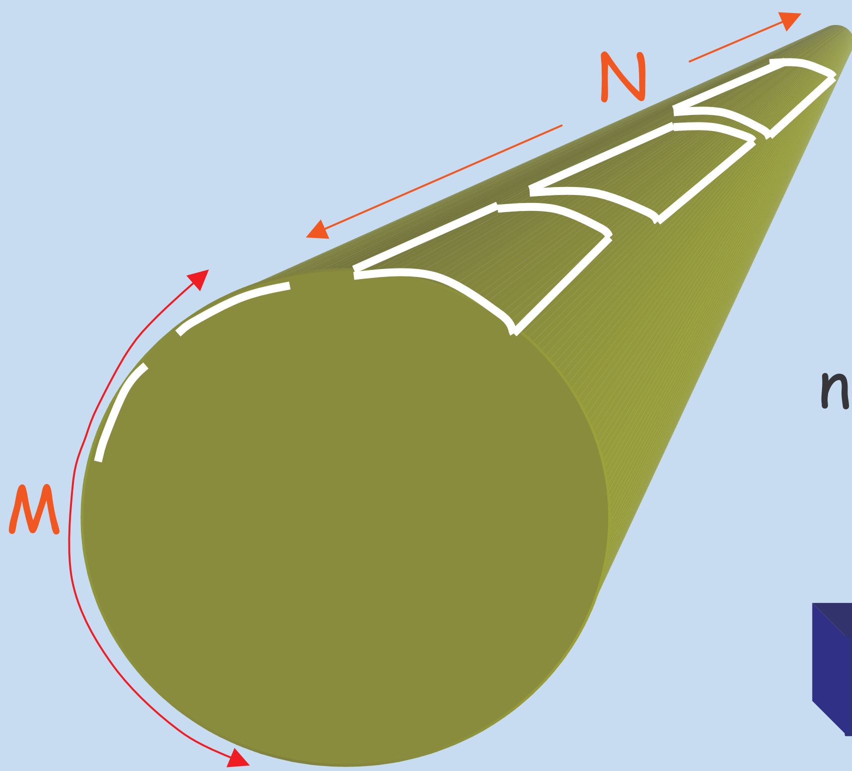
3D DEBS code:

- *Nonlinear visco-resistive MHD*
- *cylindrical geometry*
- *finite difference in radius, Fourier* in θ *and* ϕ *(pseudo-spectral)*
- *up to 2 "thin" resistive walls*
- *jump conditions on the external coils for each m,n (coils produce "clean" harmonics)*

R. Paccagnella, D. Schnack, M. Chu, Phys. of Plasmas 9 (2002) 234

Linear feedback stabilization model

Discretized coils system



m → m+ j M

(j=+/-1, +/-2 ..)

n → n+ k N

(k=+/-1, +/-2 ..)

Aliasing effect

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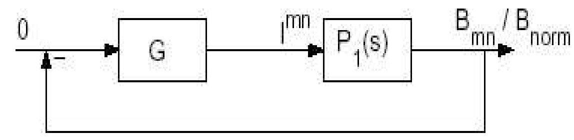
Linear feedback stabilization model



$$P_1 = \frac{b^{sens}_{mn}}{I_{mn}} = \sum_{m'=m+lM} \sum_{n'=n+pN} F_{m'n'} S_{m'n'} M_{m'n'}$$

Forms factor of coils and sensors

$$M_{m,n} = -\frac{\pi n^2 \varepsilon_a \varepsilon_f}{2\tau_w (s-\gamma^{m,n})} \left(1+\frac{m^2}{n^2 \varepsilon_w^2}\right) \frac{K'_m(n\varepsilon_f)}{(K'_m(n\varepsilon_w))}$$

The transfer function has a pole for MHD unstable modes

$\gamma^{m,n}$ → complex
(to allow slow rotation)

R. Paccagnella, D. Gregoratto, A. Bondeson, Nucl. Fusion **42**(2002) 1102.

Control system in T2R

4 x 32 radial flux sensors

4 x 16 coils

→

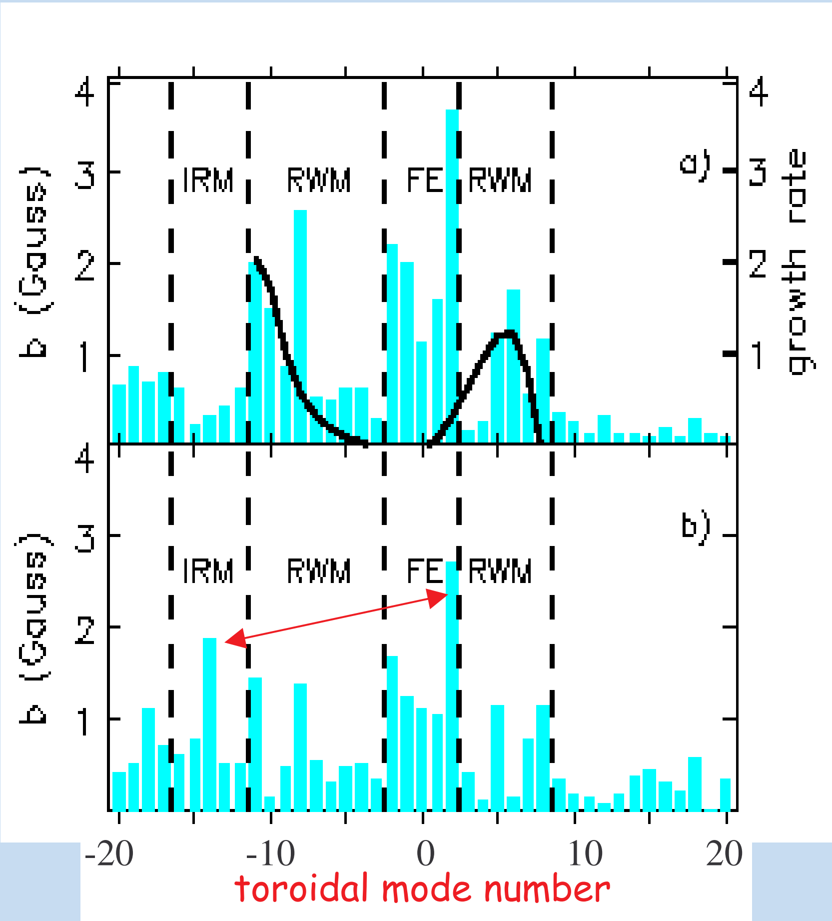
Measured mode harmonics:
$m = 1, \quad -16 < n < +15$

Control harmonics:
$m = 1, \quad -8 < n < +7$

Digital controller: "Virtual" IS, Mode control

Magnetic sensors-> FFT-> harmonics -> $\text{gains}_{m,n}$-> invFFT -> coils response

Intelligent shell



a) MHD spectrum (no feedb.):
RWMs are non-resonant & current driven modes
(no effect of plasma rotation velocity)

$-2 \leq n \leq +2$ → Field errors (FE)

b) With IS feedback

Coupling of FE mode (n=2) **and tearing mode** (n=-14)
(sideband effect)

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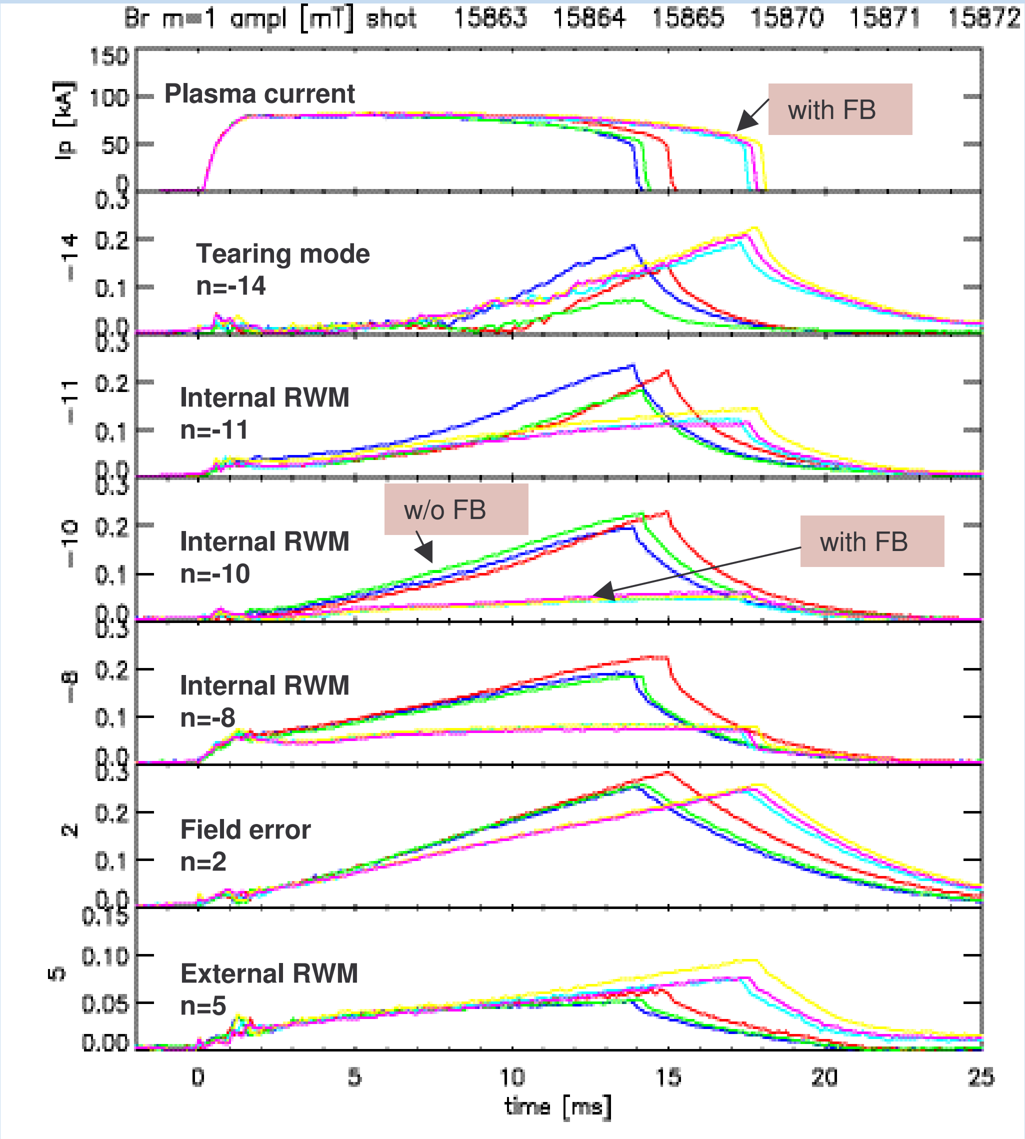
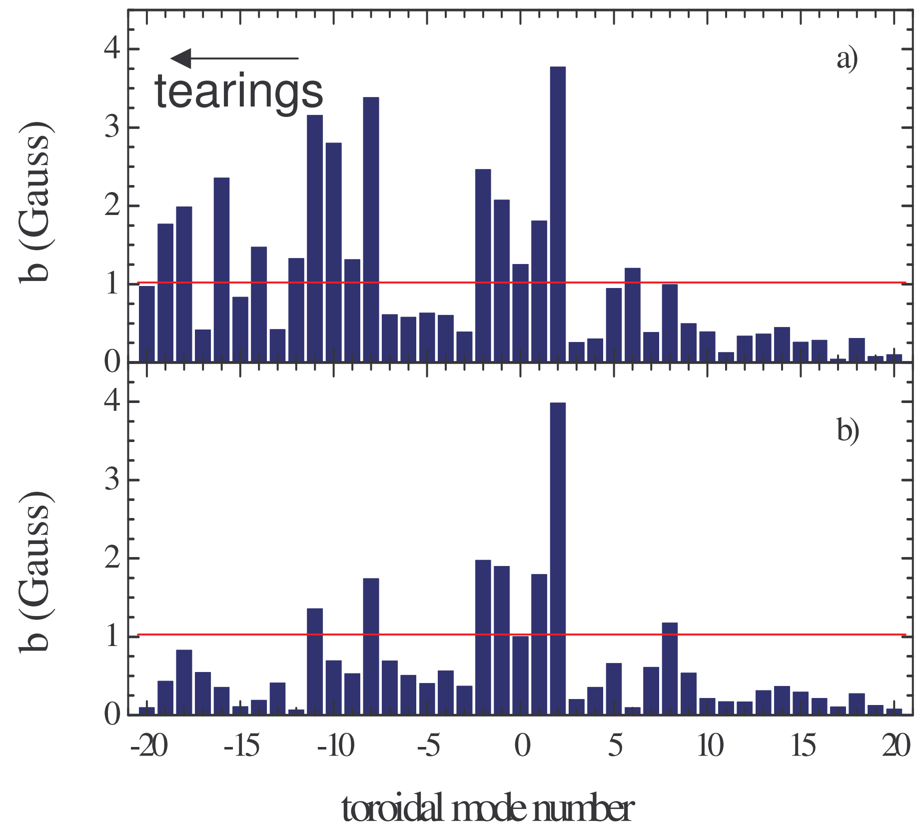
Intelligent shell



- Mitigation of RWMs (difficulties with sidebands)

- The pulse length is only slightly extended
from t =14-15 ms to t =17-18 ms
(due to n=2 /n=-14 sidebands)

Mode control: "wise shell"
(real gains)



No control of
$-2 \leq n \leq +2$

- Control affects also tearing mode amplitudes
- allows sustainment of tearing mode rotation

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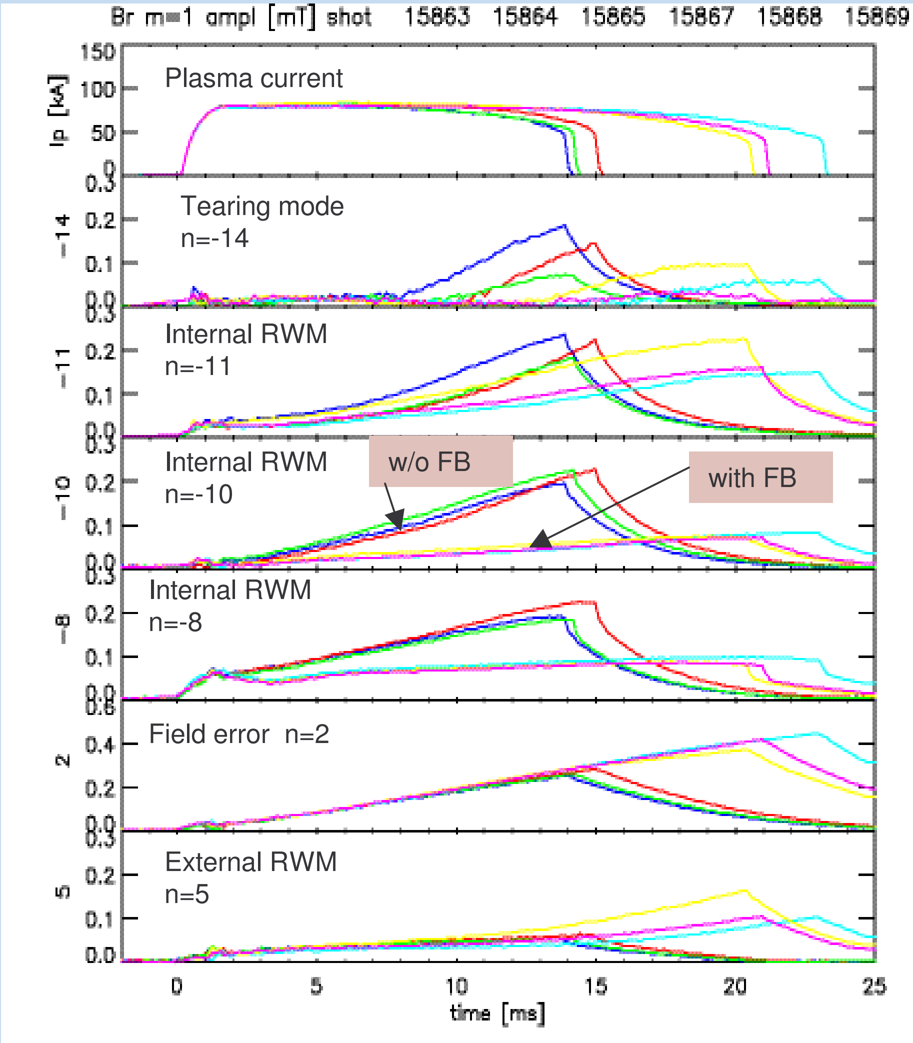
Mode control: "wise shell"

(real gains)



No control of
$-2 \leq n \leq +2$

- **good suppression of RWMs**
- **The pulse length is significantly extended** from t=14-15 ms to t=21-24 ms.

Problem: simultaneous stabilisation of two unstable modes

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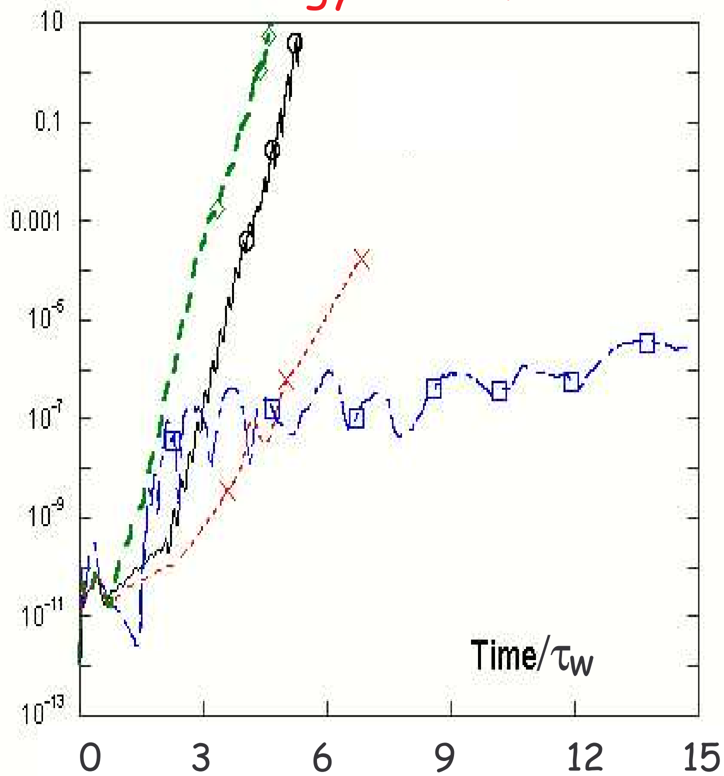
Mode control : complex gains

3D nonlinear simulations with DEBS code

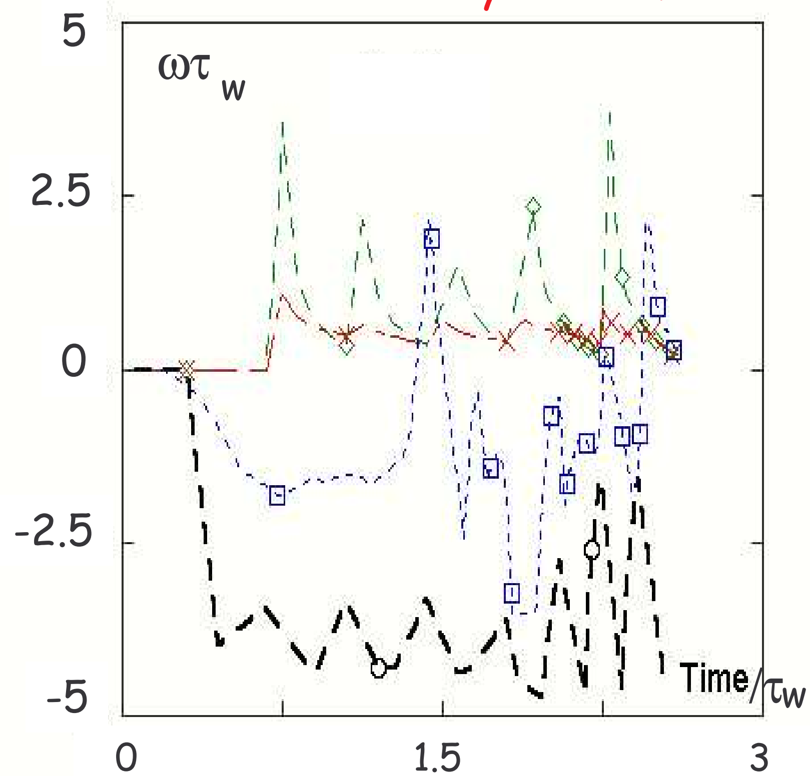
- Complex gains induce mode rotation

n=5

Energy vs. Time



Phase velocity vs. time

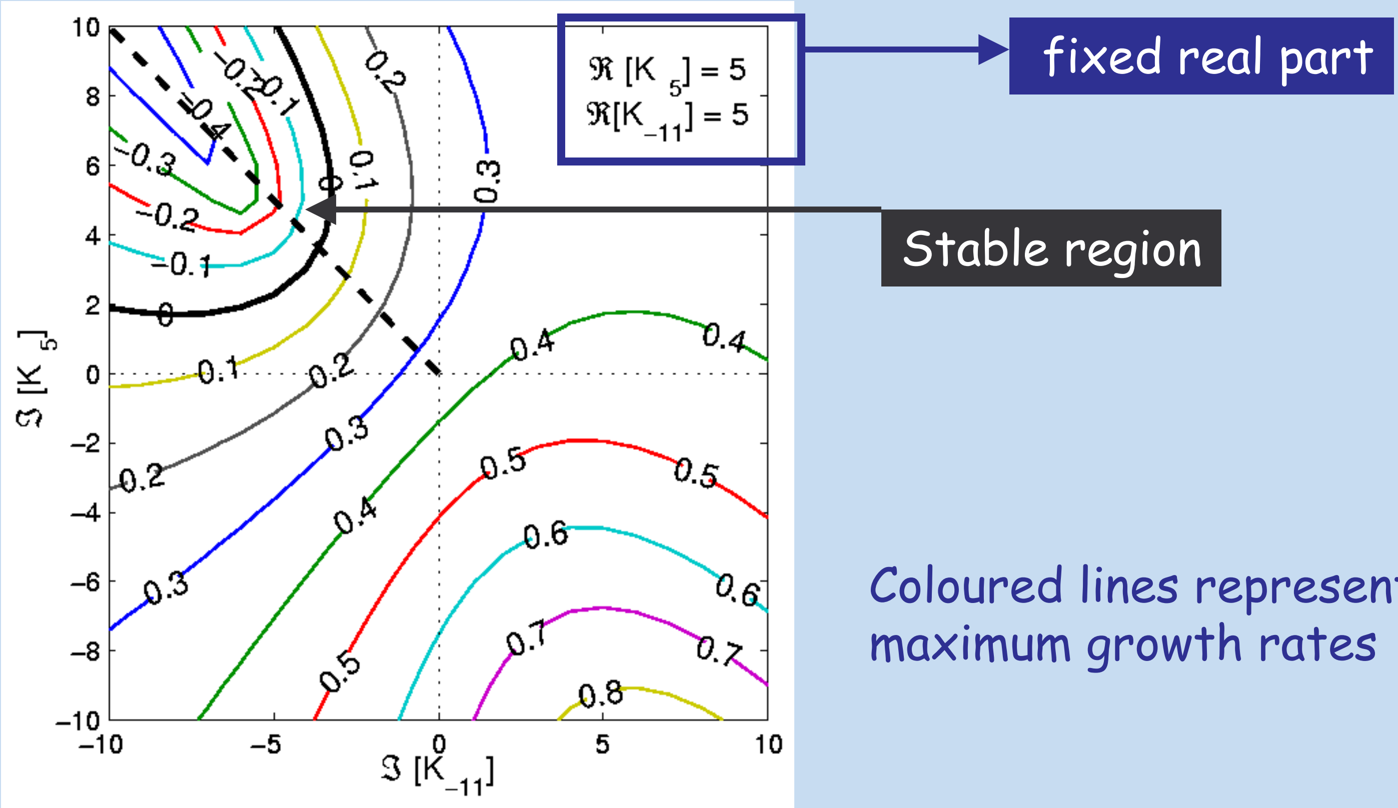


Mode control : complex gains

Linear Model

Feedback law : $I_{+5} = -K_{-11} b_{-11} - K_{+5} b_{+5}$

Complex gains stabilization diagram



Coloured lines represent iso-contours of maximum growth rates

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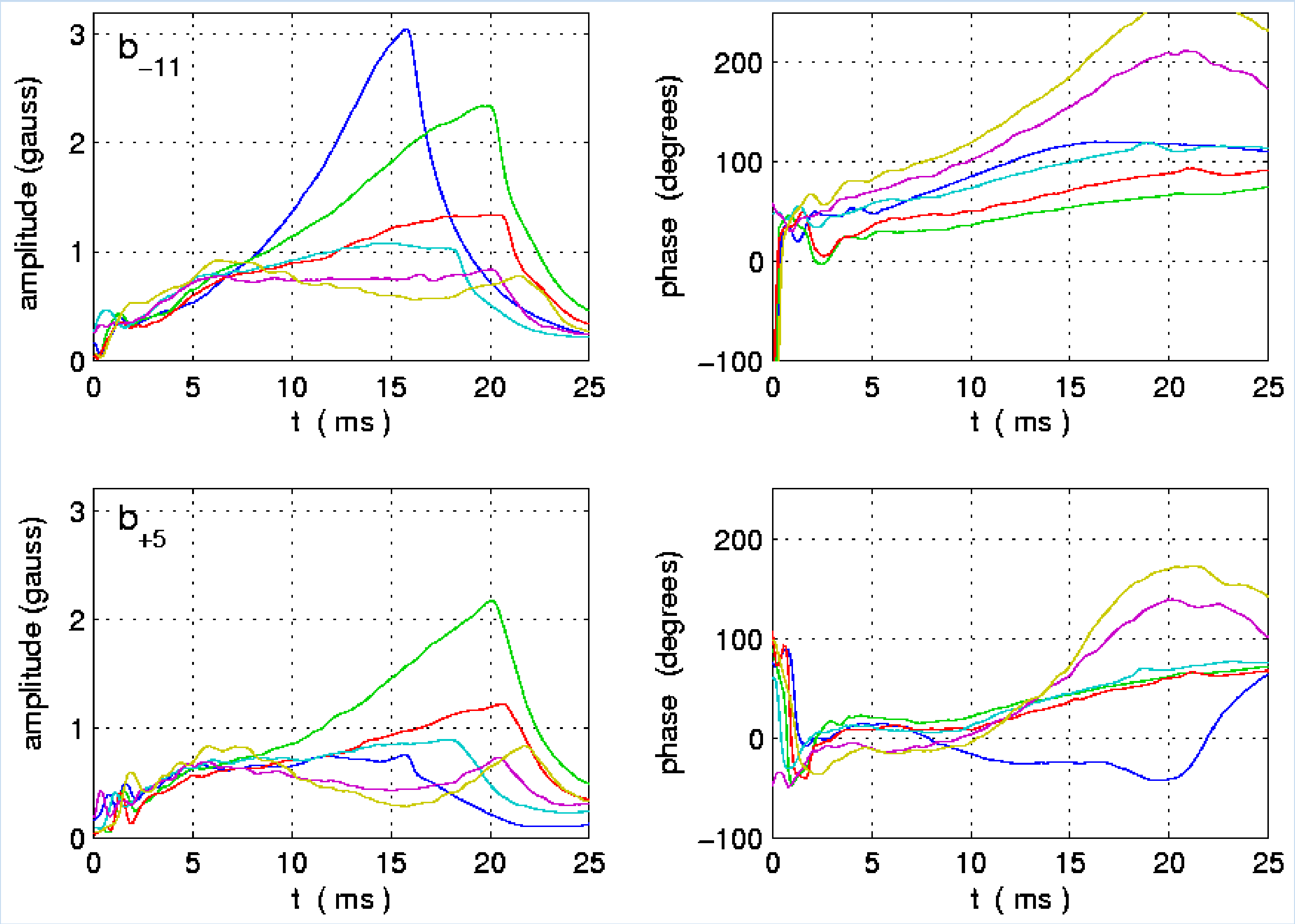
Mode control : complex gains

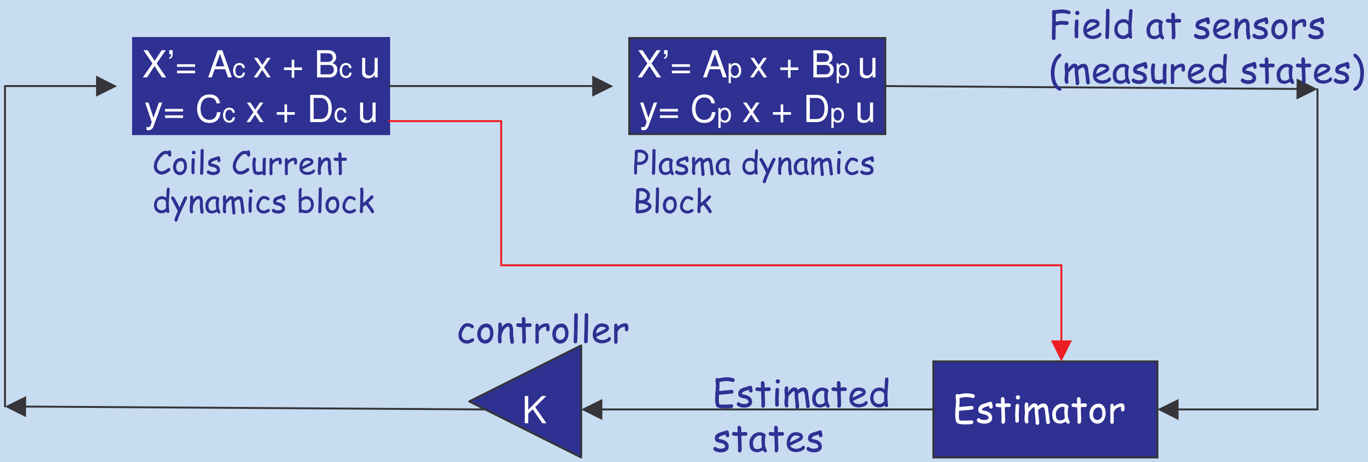
Experimental results

n=-11

n=5

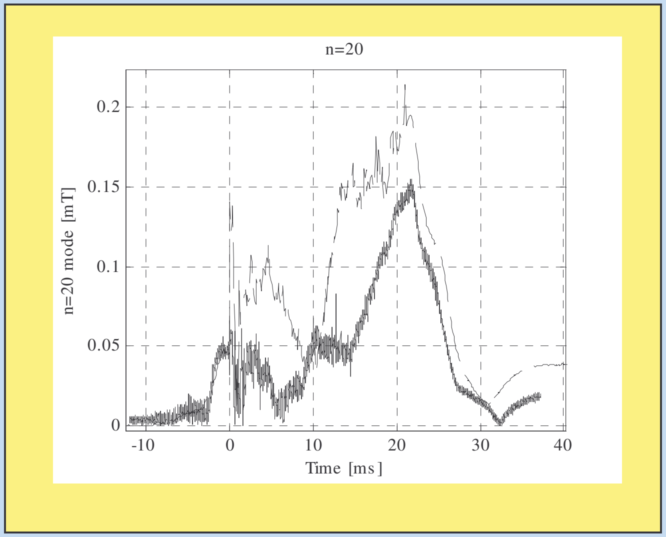


Control strategies: State variables representation



Initial attempt!

Estimated n=20 mode (dashed line) and measured (CAMAC) (plain line) in T2R



Cavinato et. al. SOFT 2004

Conclusions

- Testing of different feedback schemes
- Satisfactory Models Validation

- Simultaneous suppression of modes and increase of discharge duration

(a record duration of 30 msec= 5 τ_w achieved)

- Effective control of sidebands with complex gains (mode rotation observed)