CHALMERS

9th Workshop on MHD Stability Control, Princeton
21-23 November 2004

CONSORZIO RFX
Ricerca Formazione Innovazione

Comparisons with MHD Simulations of Feedback Experiments in EXTRAP-T2R

presented by R. Paccagnella

J.R. Drake 1), P.R. Brunsell 1), D. Yadikin 1), M. Cecconello 1), J.A. Malmberg 1), D. Gregoratto 2), T. Bolzonella 2), G. Manduchi 2), L. Marrelli 2), S. Ortolani 2), G. Spizzo 2), P. Zanca 2), A. Bondeson 3), Y.Q. Liu 3)

1) Alfvén Laboratory, KTH, EURATOM VR Association, Stockholm, Sweden
2) Consorzio RFX, EURATOM ENEA Association, Padova, Italy
3) Consiglio Nazionale delle Ricerche (CNR), Roma, Italy
4) Dept. of Electromagnetics, CTH, EURATOM Association VR, Gothenburg, Sweden

Outline

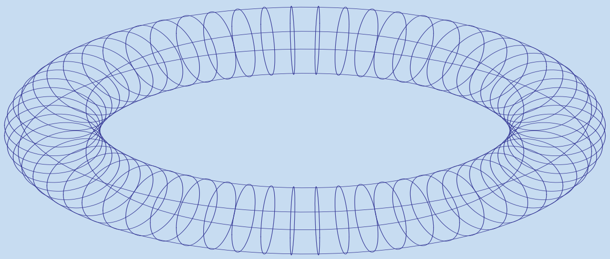
- Control system in T2R
- Theoretical Models
- RWM spectrum
- Closed-loop experiments
  - -Intelligent shell
  - -Mode control
- Conclusions

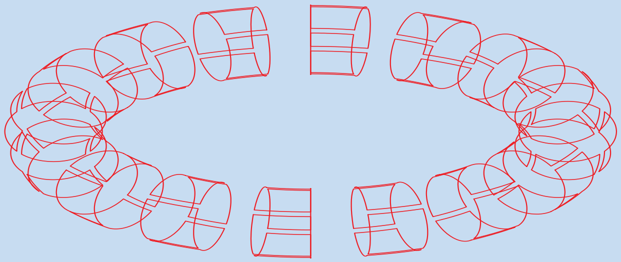
CHALMERS

Control system in T2R

SENSORS

COILS





Sensor coil array: 64x4=256 saddle coils Each coil has 90° poloidal, 360/64=5.125° toroidal extent

32X4=128 evenly spaced ”m=1” pair-connected coils, 32x2=64 input sensor signals

Active coil array: 16x4=64 saddle coils Each coil has 90° poloidal, 360/32=11.25° toroidal extent

Total surface coverage is 50%

Coils are ”m=1” pair connected into 16x2=32 independently driven coils

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

Theoretical Models

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

CHALMERS

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)

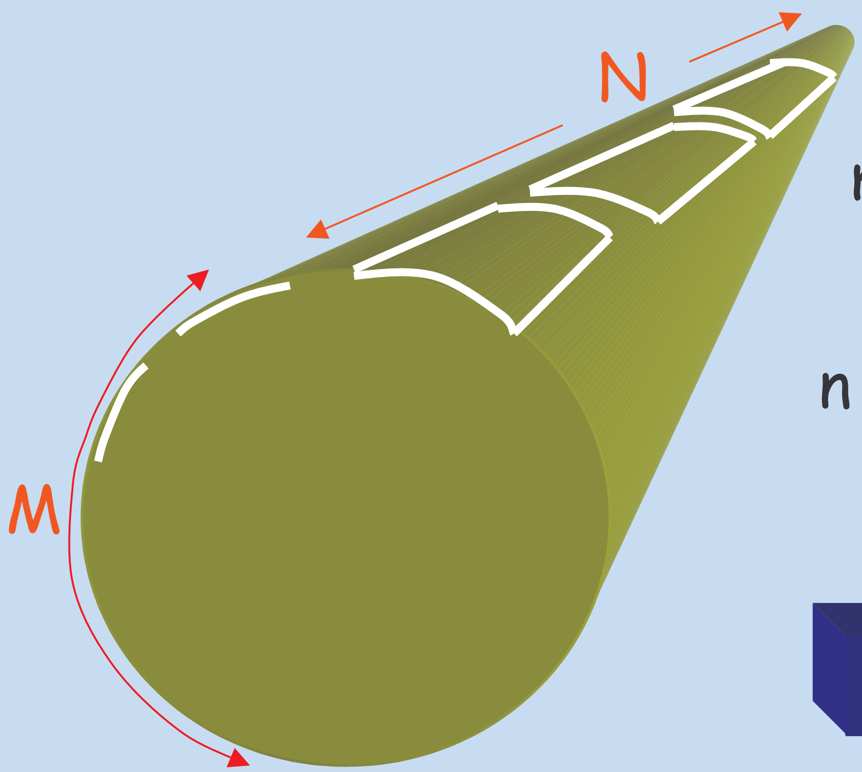
R. Paccagnella, D. Schnack, M. Chu, Phys. of Plasmas 9 (2002) 234

CHALMERS

Linear feedback stabilization model (cylindrical)

CONSORZIO RFX
Ricerca Formazione Innovazione

Discretized coils system



m → m+ j M

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

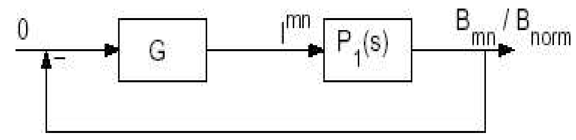
n → n+ k N

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

Aliasing effect

CHALMERS

Linear feedback stabilization model



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

Forms factor of coils and sensors

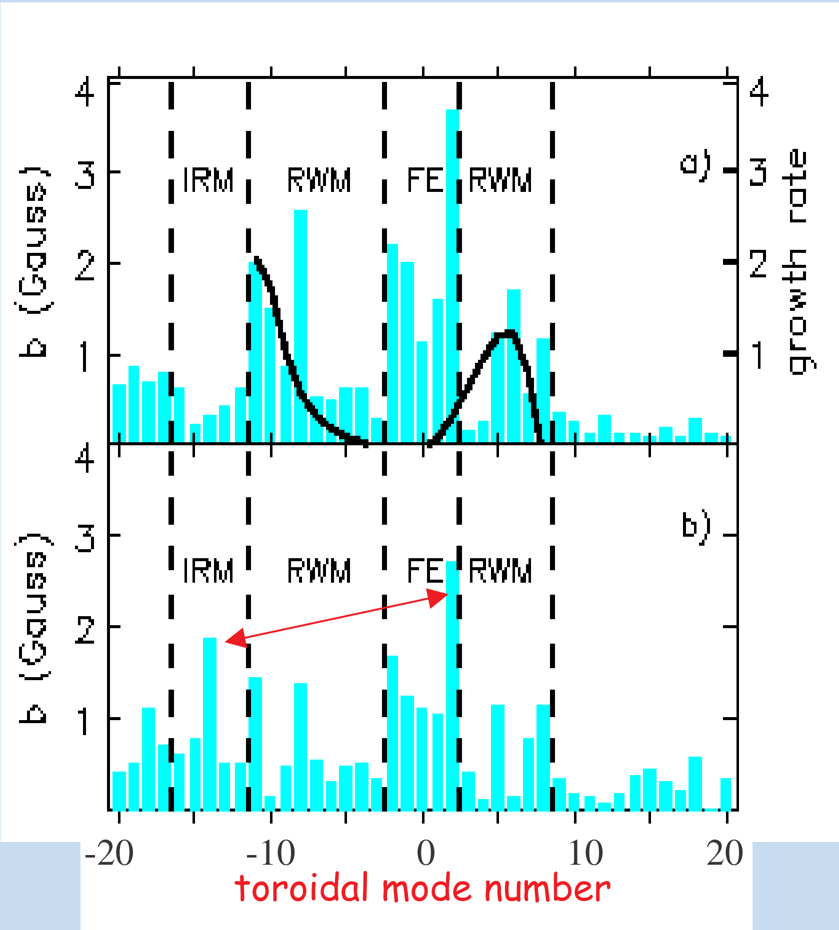
$$M_{m,n} = -\frac{\pi n^2 \varepsilon_a \varepsilon_f}{2\tau_w (s - \gamma^{m,n})} \left(1 + \frac{m^2}{n^2 \varepsilon_w^2}\right) \frac{K_m'(n\varepsilon_f)}{(K_m'(n\varepsilon_w))}$$

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.

Intelligent shell



a) MHD spectrum (no feedb.):

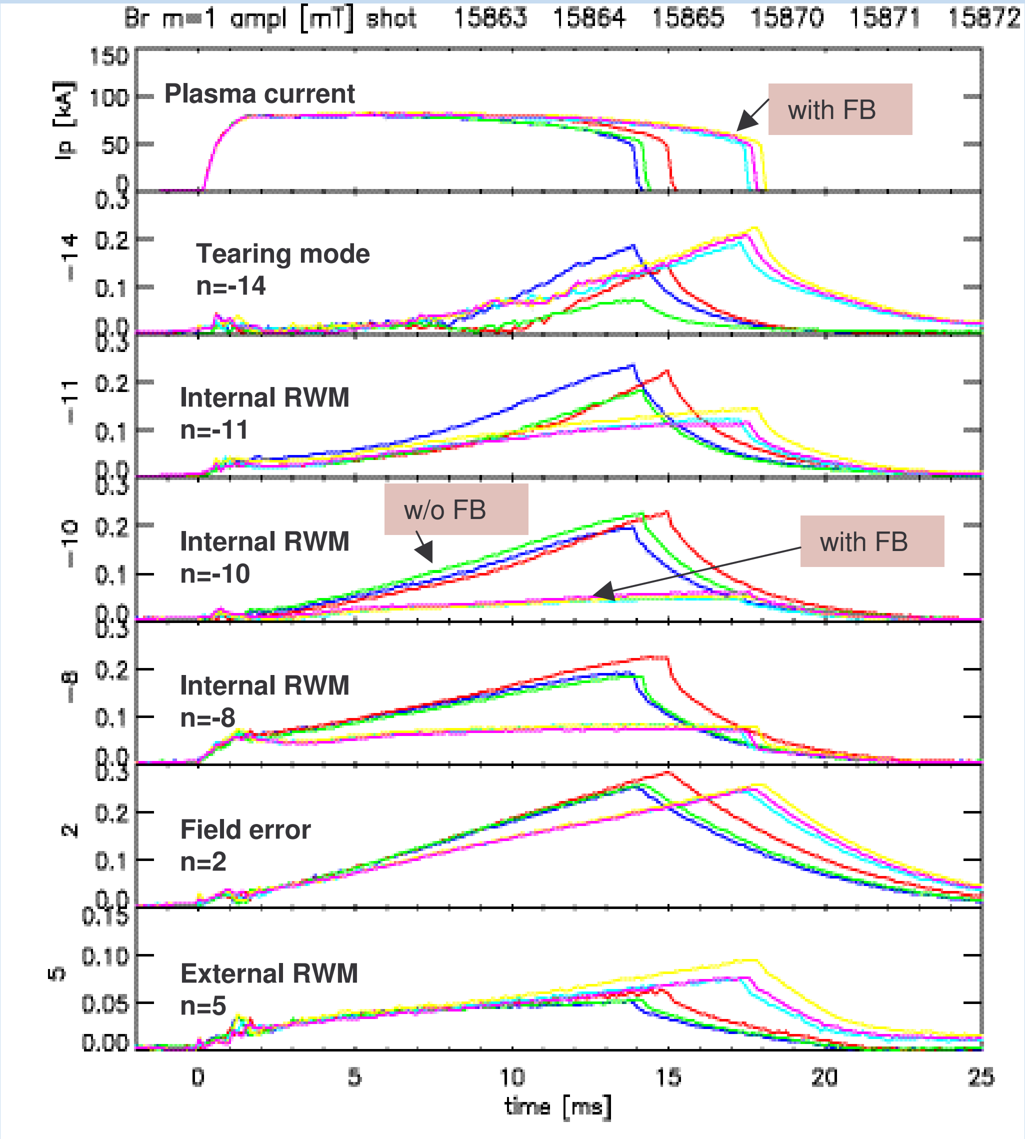
RWMs are non-resonant & current driven modes (no effect of plasma rotation velocity)

$-2 \le n \le +2$ → Field errors (FE)

b) With IS feedback

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

Intelligent shell

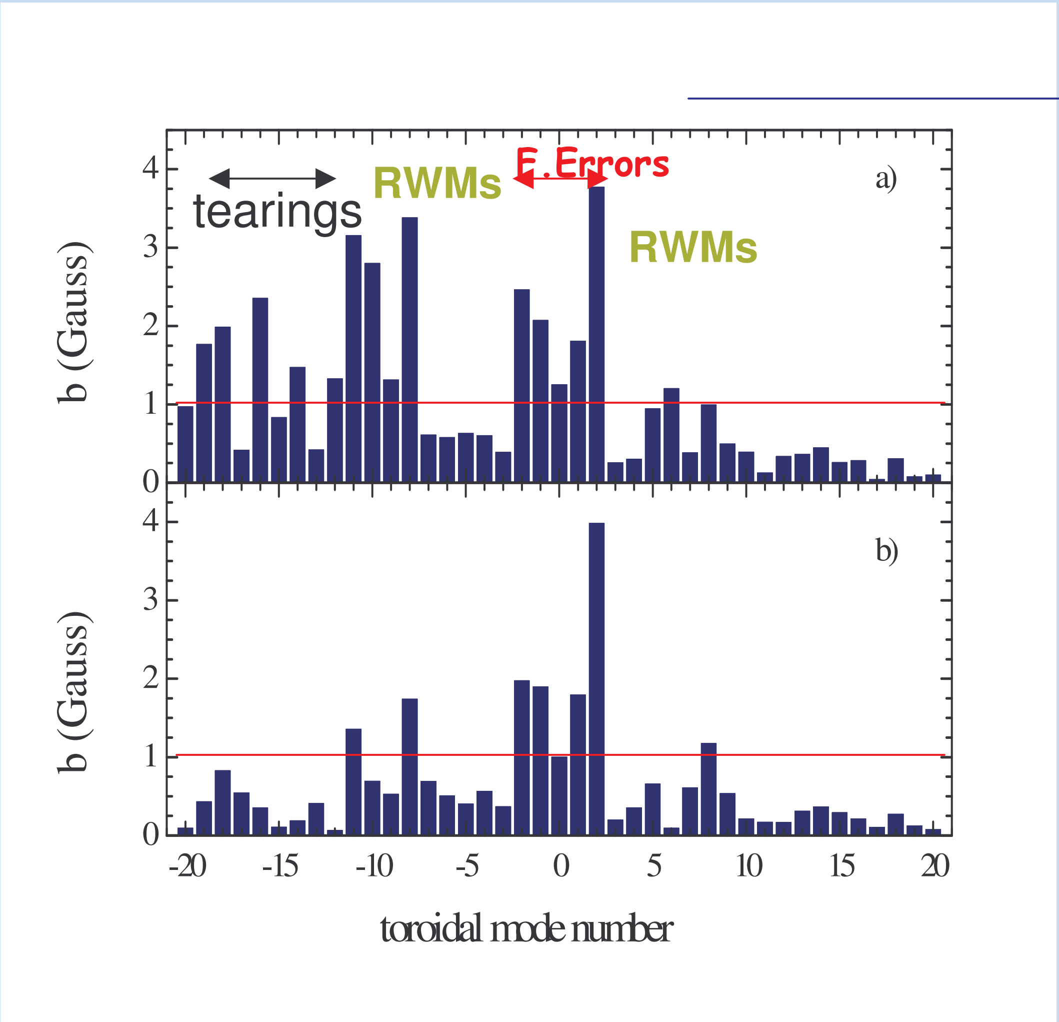


- Mitigation of RWMs (difficulties with sidebands)

- 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
$-2 \leq n \leq +2$

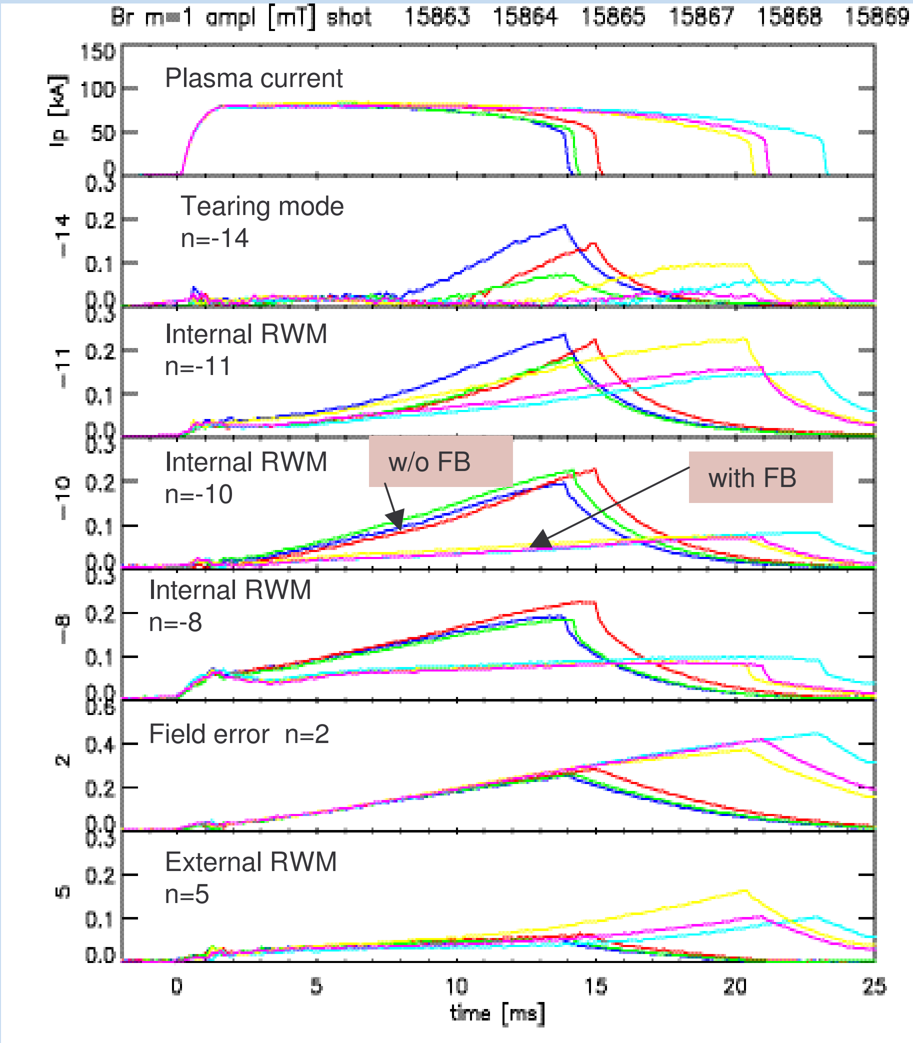
•Control affects also tearing mode amplitudes:

allows sustainment of tearing mode rotation

CHALMERS

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

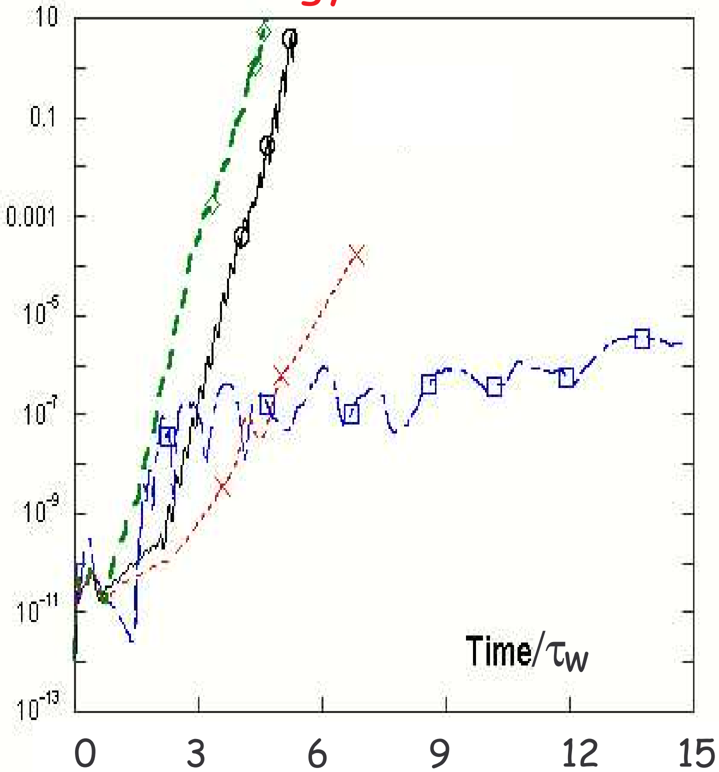
Mode control : complex gains

3D nonlinear simulations with DEBS code

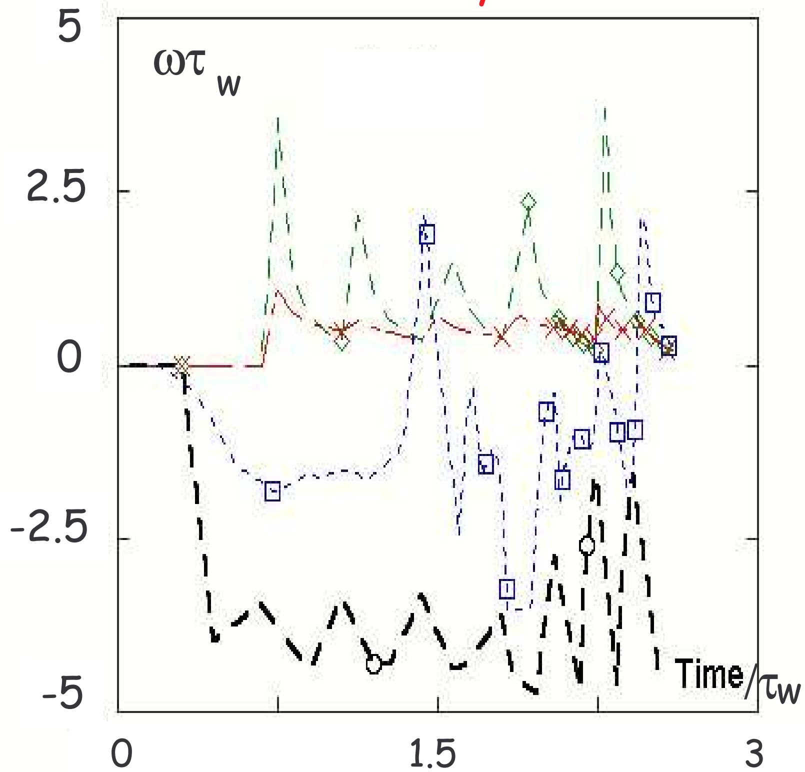
- Complex gains induce mode rotation

n=5

Energy vs. Time



Phase velocity vs. time



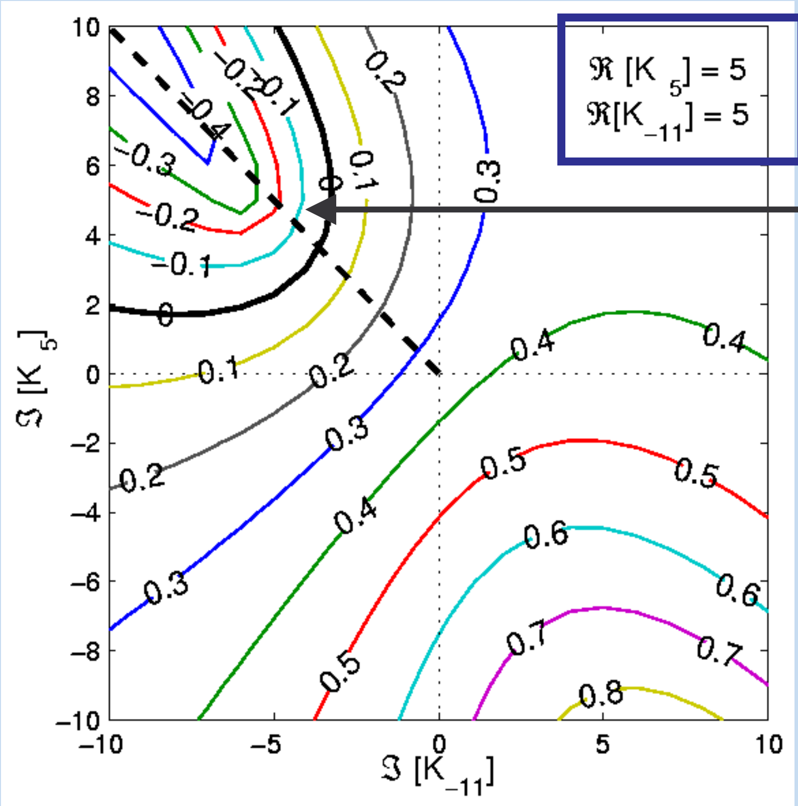
CHALMERS

Mode control : complex gains

Linear Model

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

Complex gains stabilization diagram



fixed real part

Stable region

Coloured lines represent iso-contours of maximum growth rates

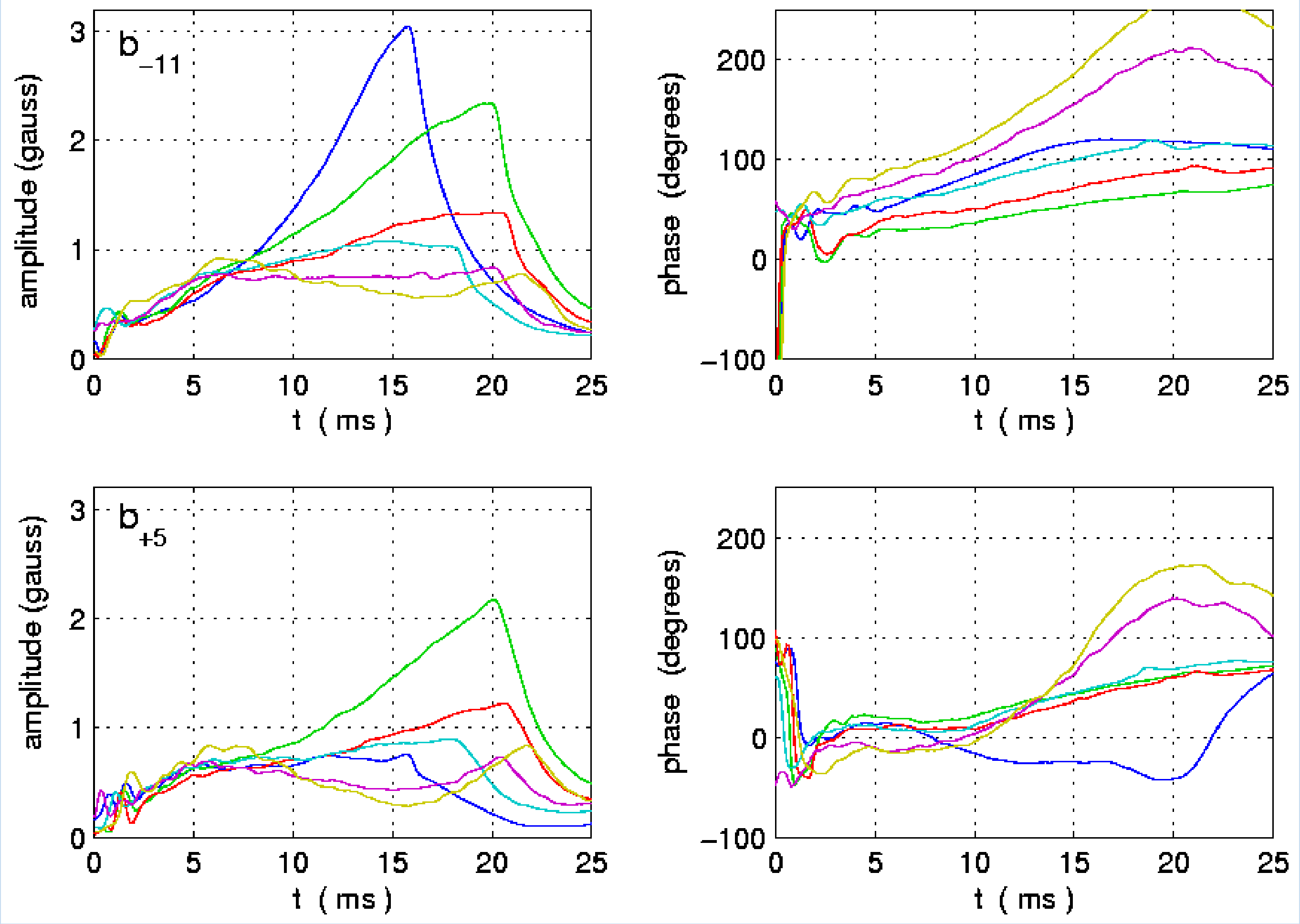
CHALMERS

Mode control : complex gains

Experimental results

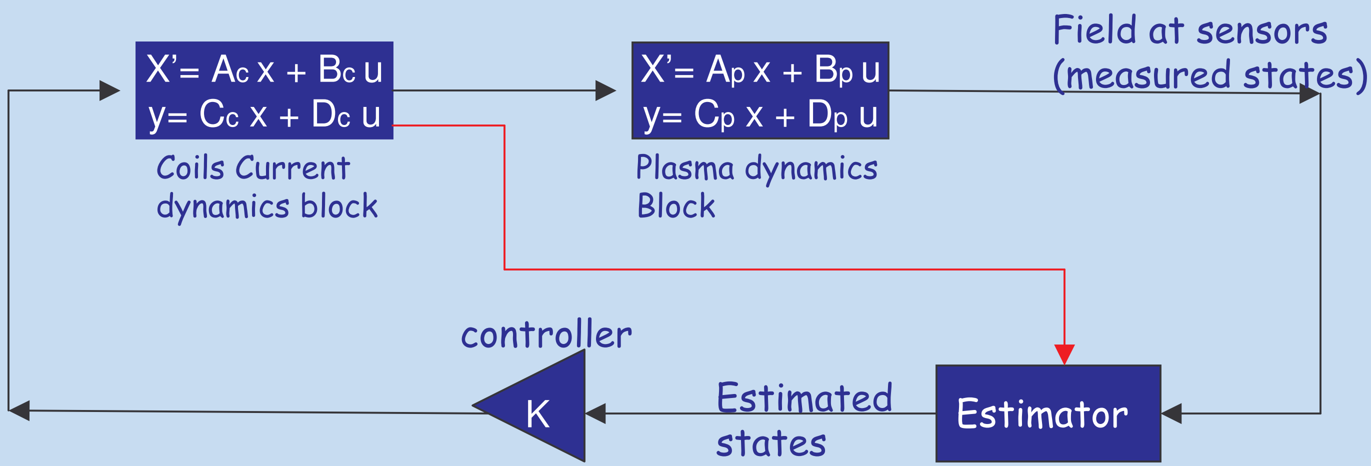
n=-11

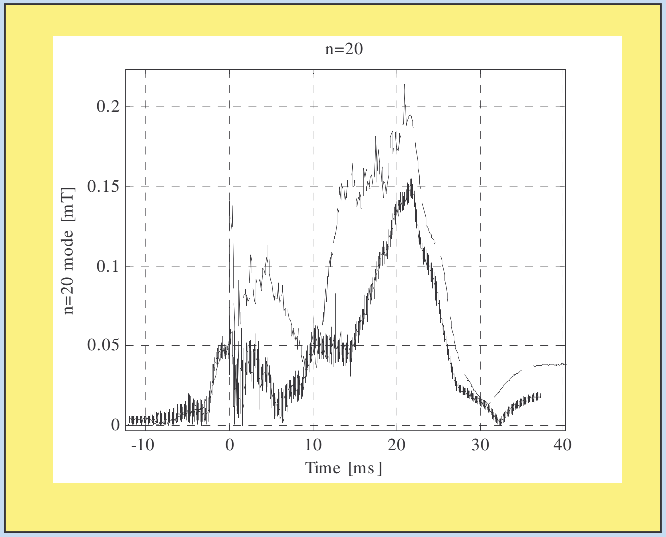
n=5



CONSORZIO RFX
Ricerca Formazione Innovazione

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 induced)