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MHD Issues in Low-A RFP Machine RELAX

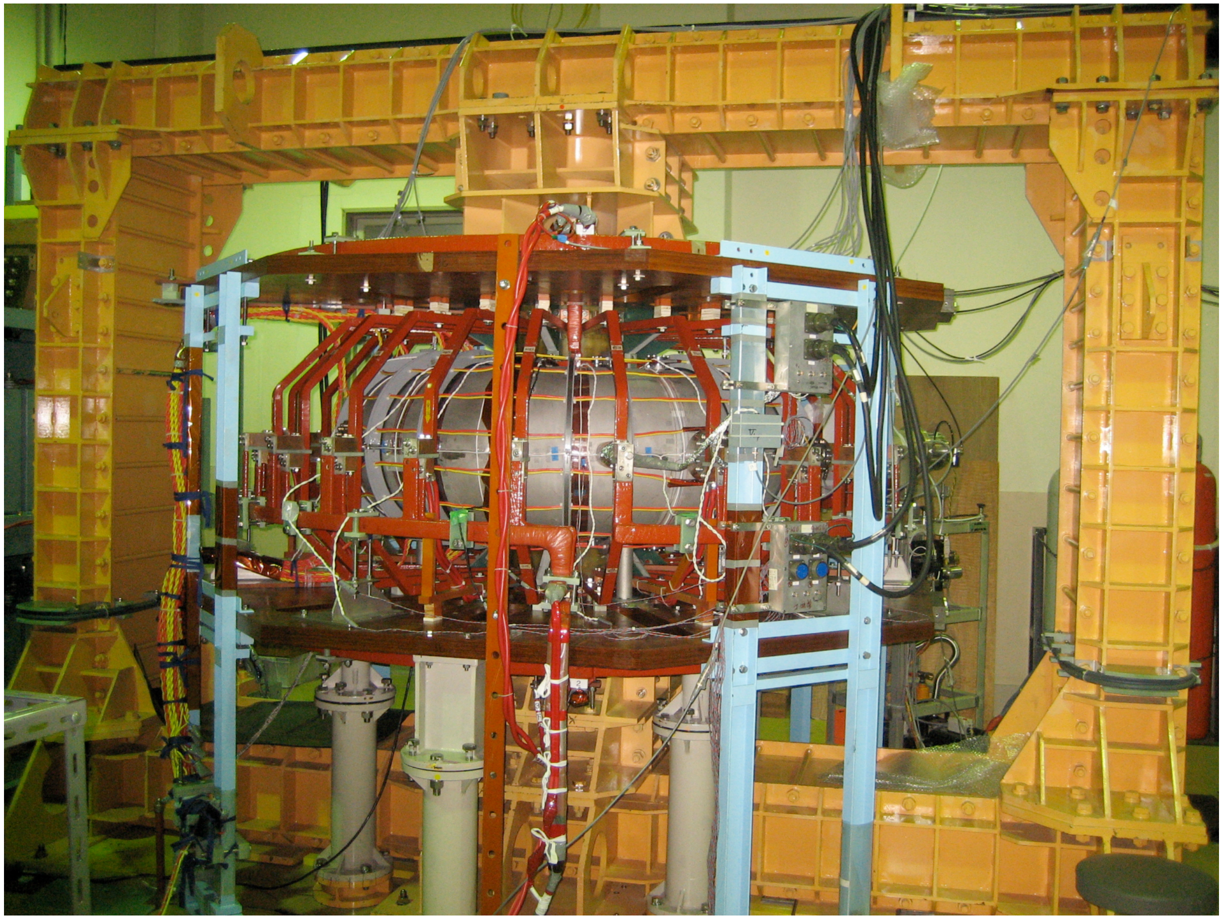
S.Masamune, A.Sanpei, R.Ikezoe, T. Onchi, K.Oki, T.Yamashita, H.Shimazu, H. Himura, N.Nishino[1)], R.Paccagnella[2)]

Kyoto Institute of technology, Kyoto, Japan

[1)]*Hiroshima University, Higashi-hiroshima, Japan*

[2)]*Consorzio RFX, Padova, Italy*

REversed field pinch of Low-Aspect-ratio eXperiment



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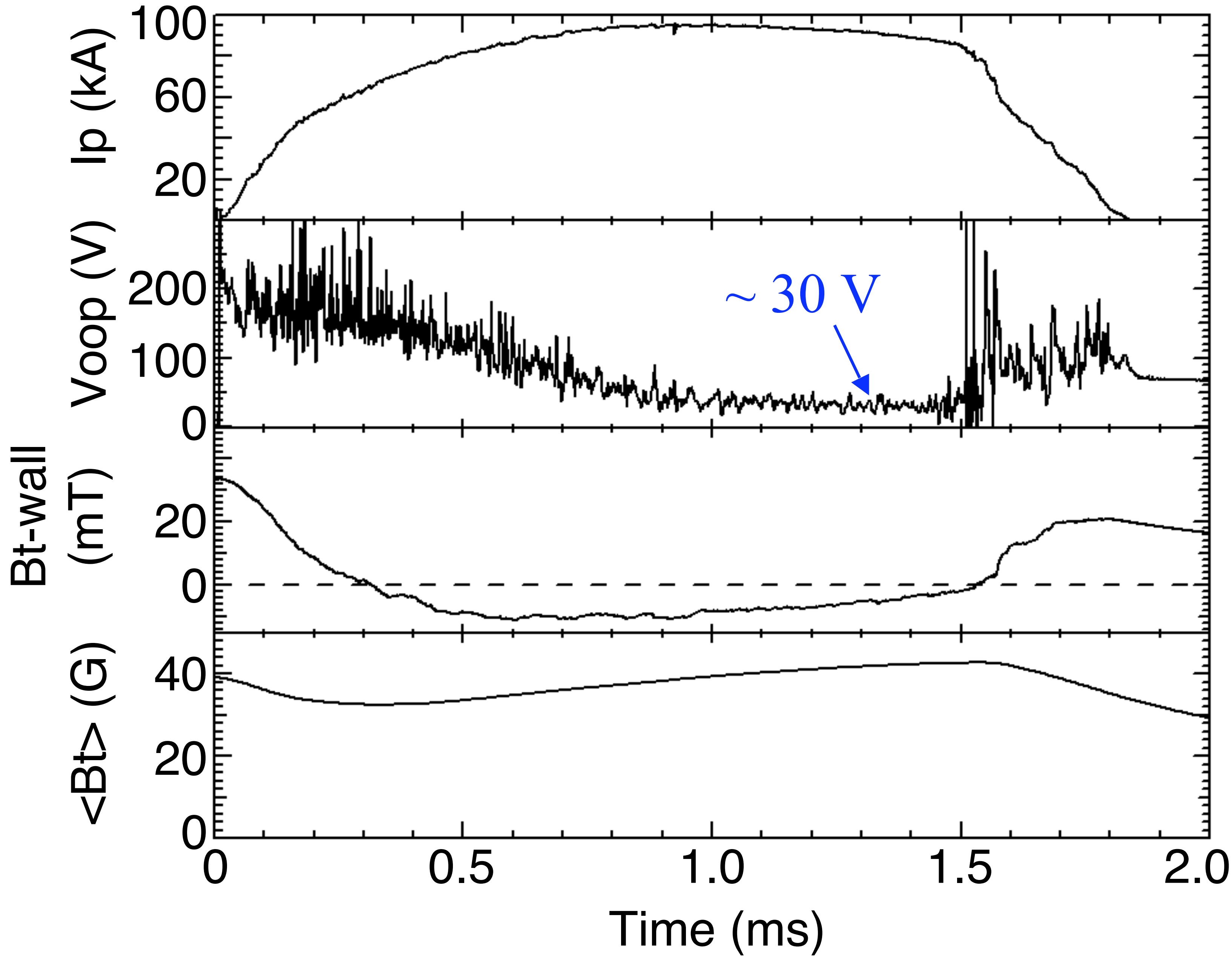
- $R/a = A = 2$ (51 cm/25 cm)
- Optimization in progress

Normal RFP discharges established



Goal of RELAX experiment

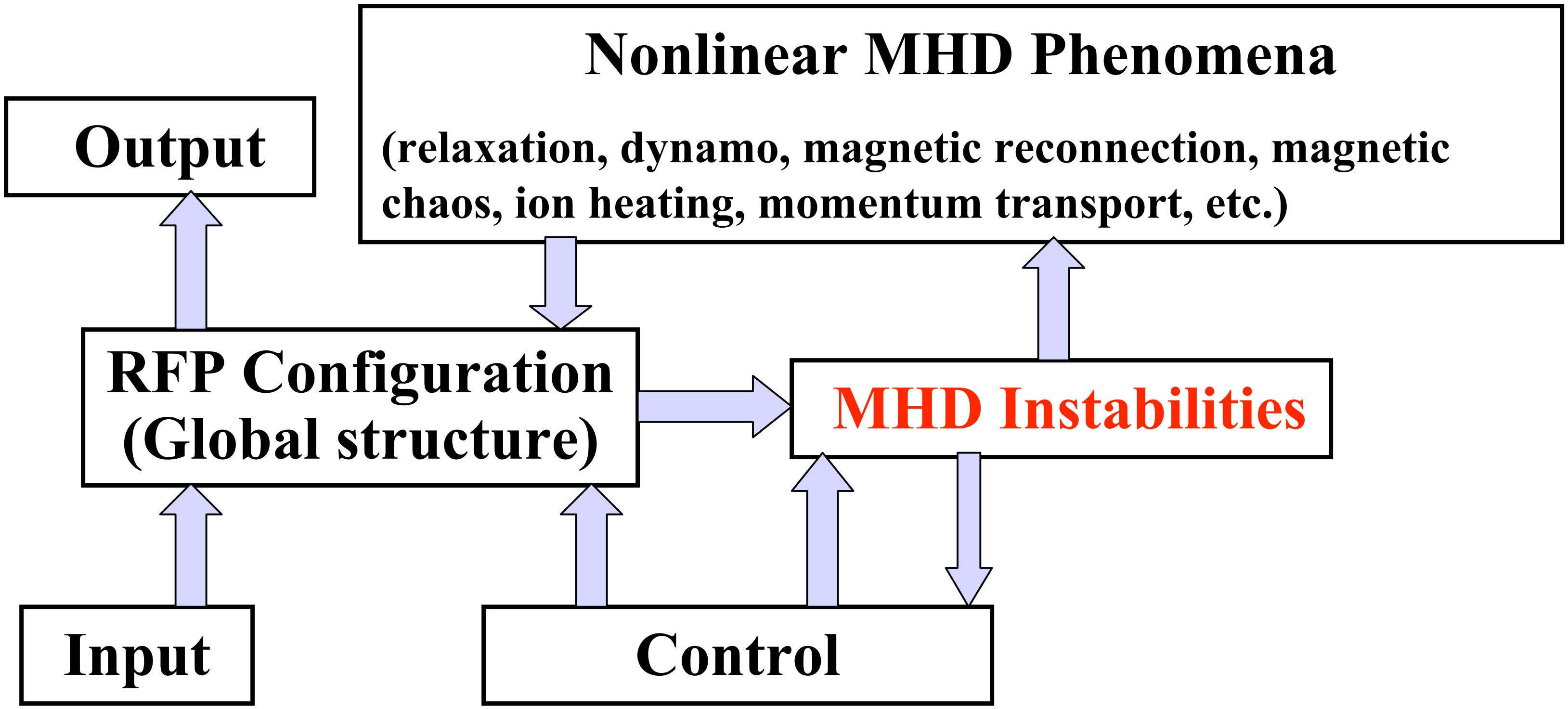
- Experimental study on advantages of low-*A* RFP configuration

- Improved confinement with QSH for achieving high beta

- Experimental identification of bootstrap current

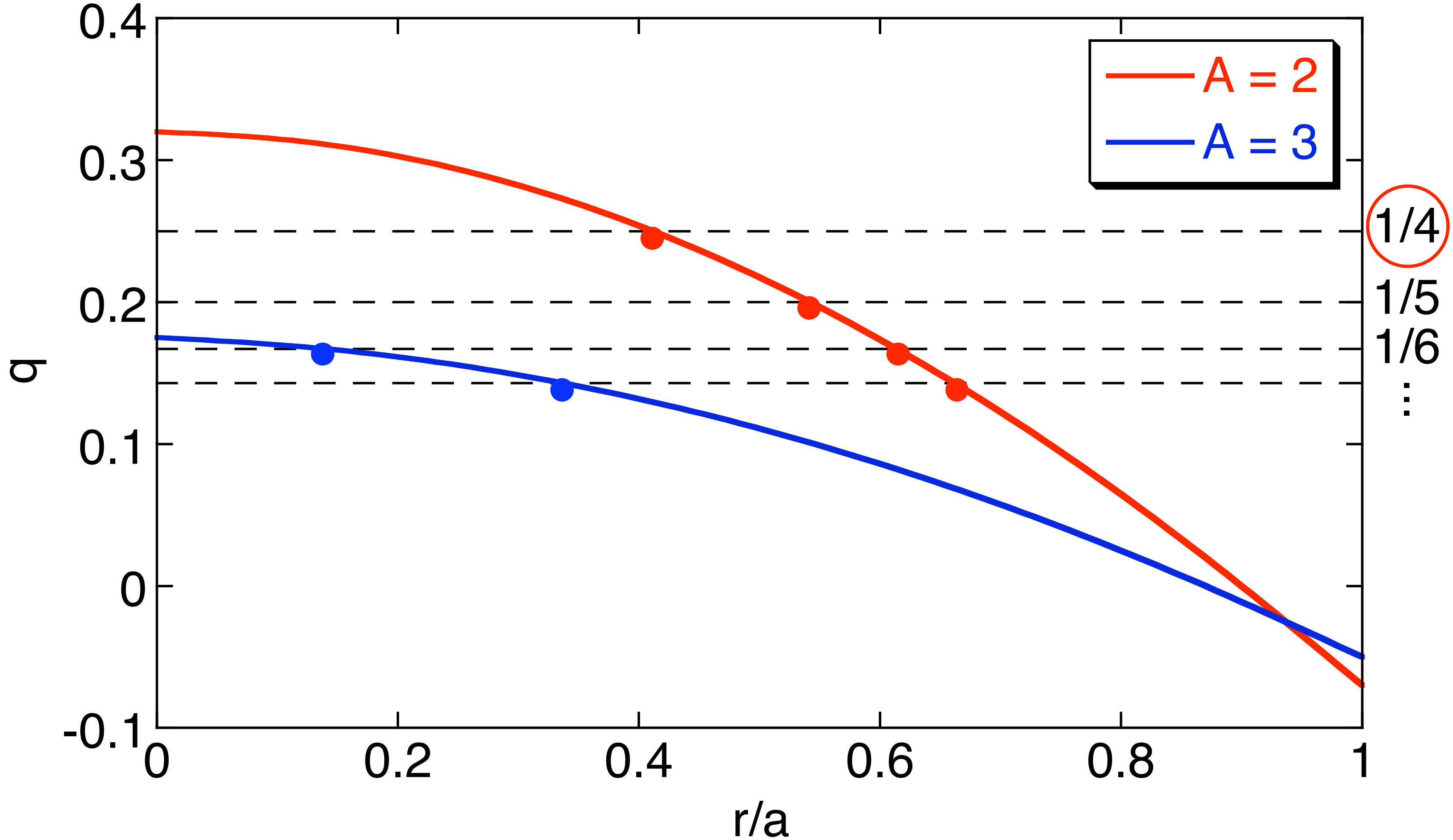
(targer parameters: Te~300eV, n_e~4x10^{19}m^{-3} at Ip~100kA)

Tearing and RWM play important roles in the RFP

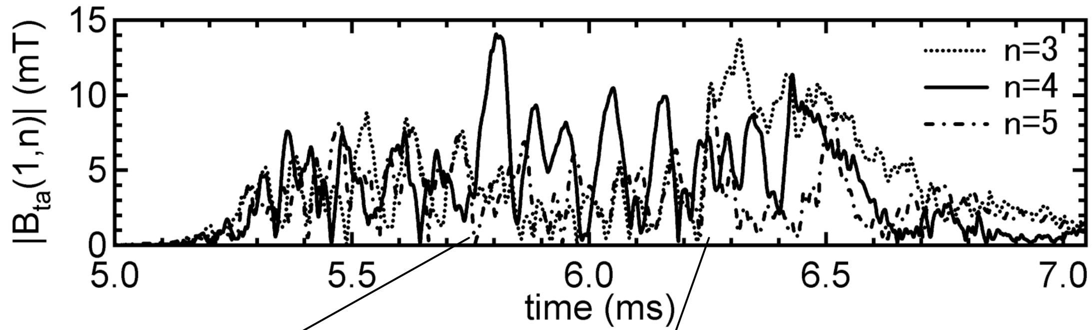


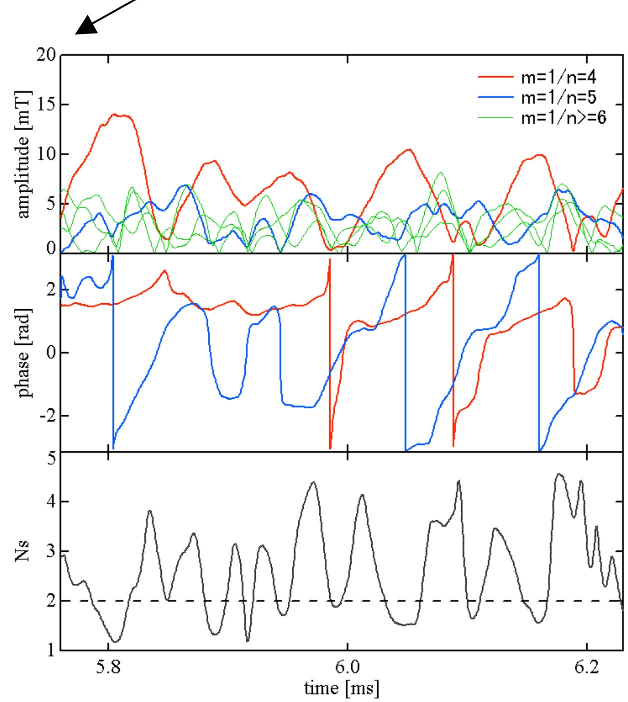
- formation and sustainment of the configuration through nonlinear MHD
- of general interest as a control problem of highly nonlinear system

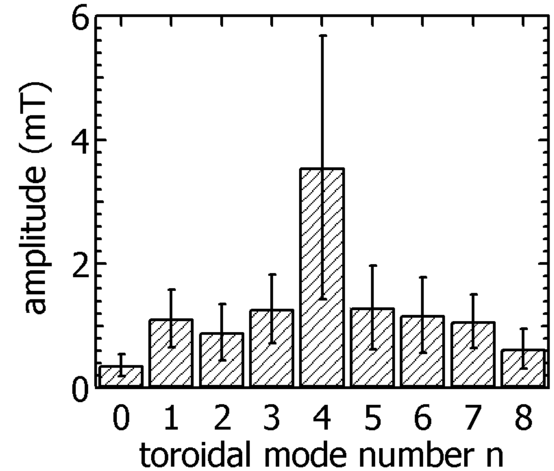
Lower A means lower n for dominant m = 1 modes



Quasi-periodic growth of a single dominant helical mode (m=1/n=4)





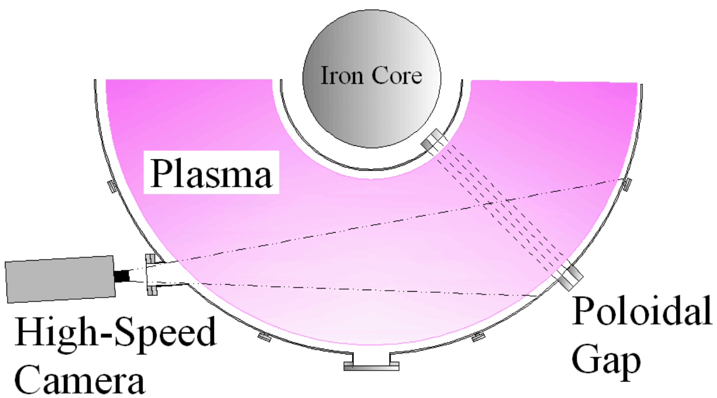


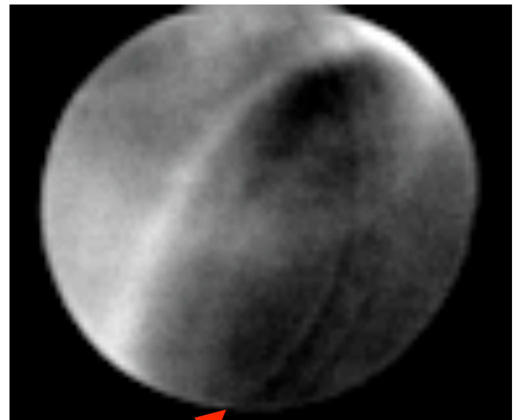
Spectral index N_s

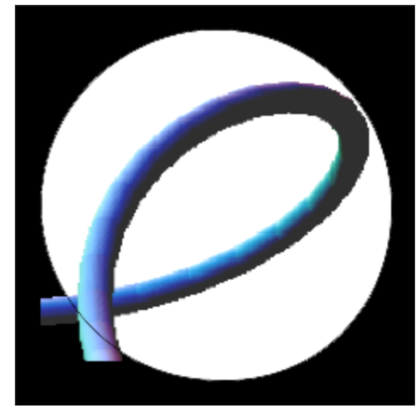
$$N_s = \left[\sum_{n=n_{min}}^{n_{max}} \left(\frac{b^2_{1,n}}{\sum_n b^2_{1,n}} \right)^2 \right]^{-1}$$

Characteristic of the QSH RFP state: lower dominant mode number (mostly n = 4) and higher amplitudes than in other RFPs.

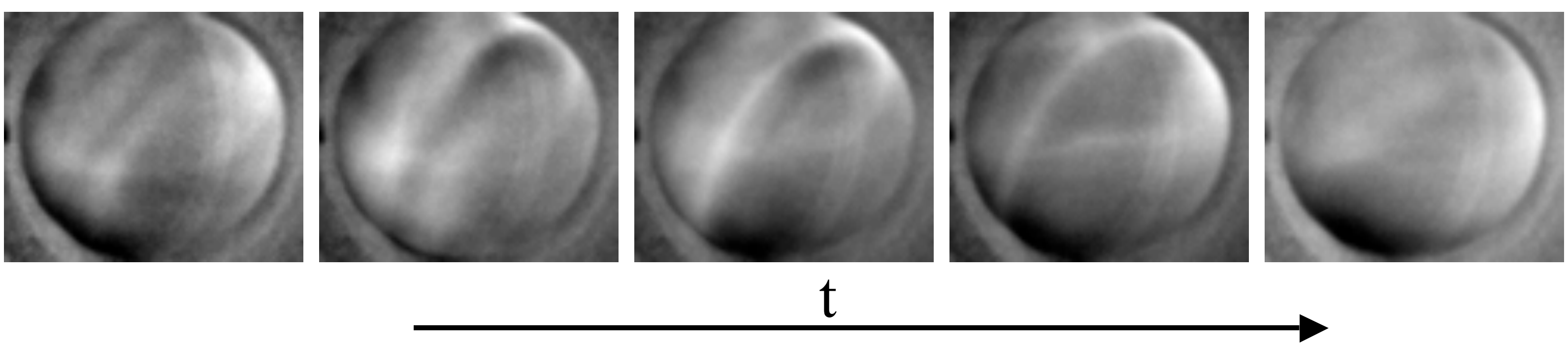
Dominant helical structure observed with high-speed camera







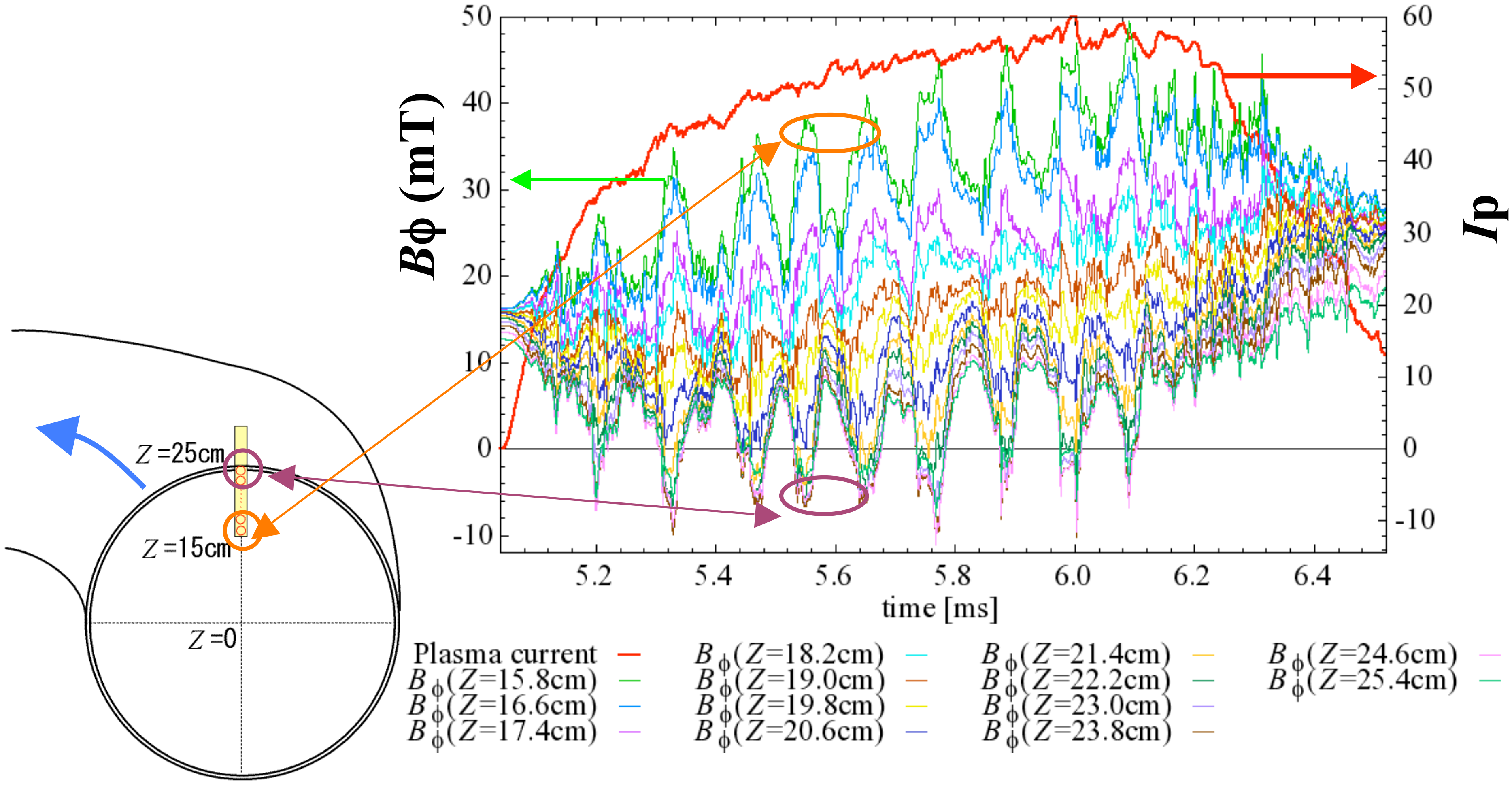
Simulated helix with m=1/n=4



Filament structure indicates simple structure of plasma parameters → effect of lowering *A*

Possibility of rotating Helical Ohmic Equilibrium state
- A large-scale magnetic field profile change -

- **Quasi-periodic oscillation between reversed and non-reversed states**
- **Similar large-scale oscillatory behavior in B_r and B_θ**

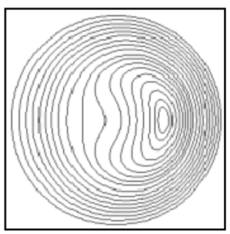


Measured field profile agrees well with Helical Ohmic Equilibrium state with closed helical flux surfaces

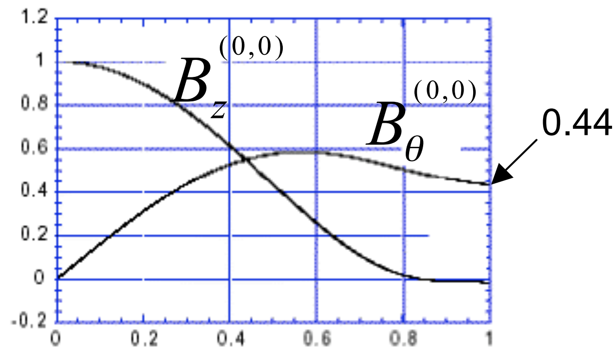
$$B = B^{(0,0)} + b$$

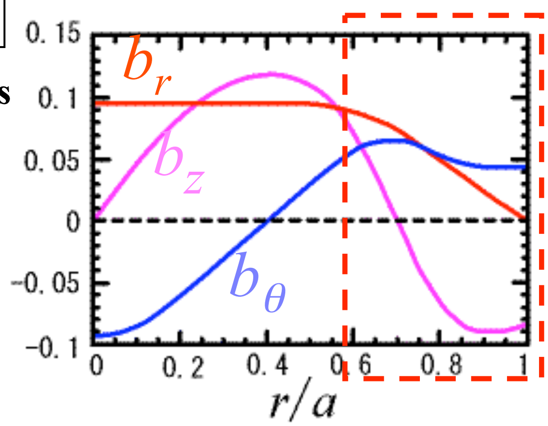
Theory

Numerical solution of Helically symmetric RFP equilibrium



Flux surfaces recovered!





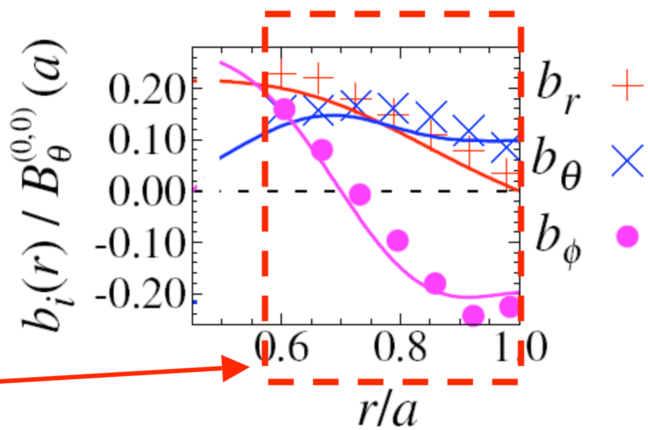
R. Paccagnella, IEA / RFP Workshop 2000

Experiments

$B^{(0,0)}$: **Low-frequency (*f*<2kHz) component**

b : $b = B - B^{(0,0)}$

Radial profiles (0.6<*r/a*<1.0)



Excellent agreement may be an indication of rotating Helical Ohmic Equilibrium state

3D MHD simulation can reproduce major MHD characteristics of RELAX plasmas

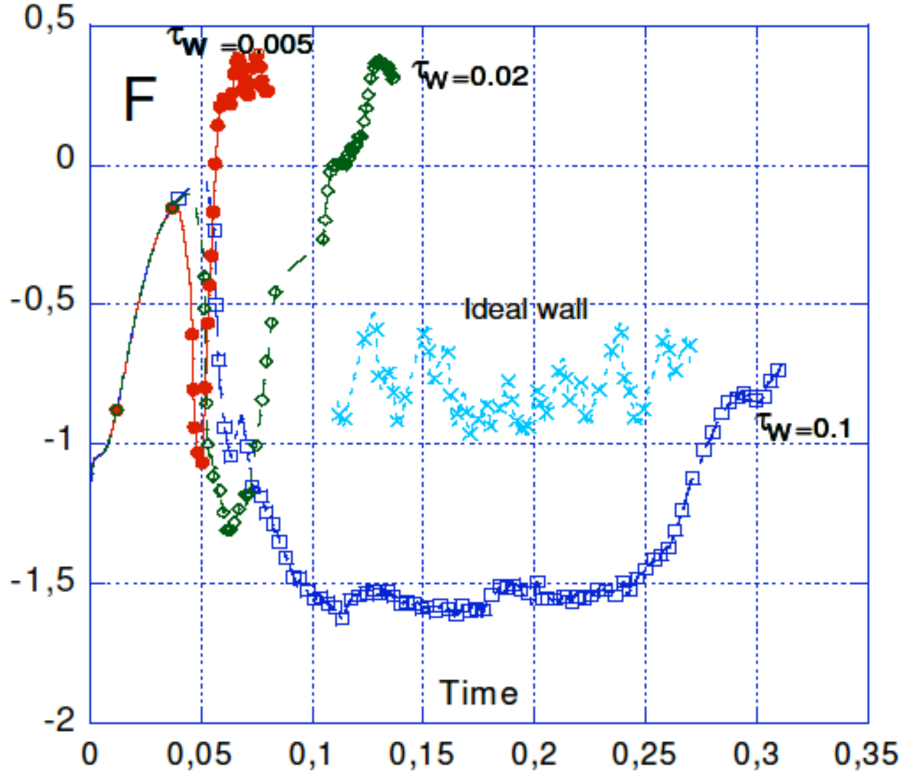


Fig.1: F vs. time, light blue curve refers to the ideal wall while the other curves are the resistive wall cases.

MHD simulation reproduces quasi-periodic oscillation of the dominant m=1/n=4 mode

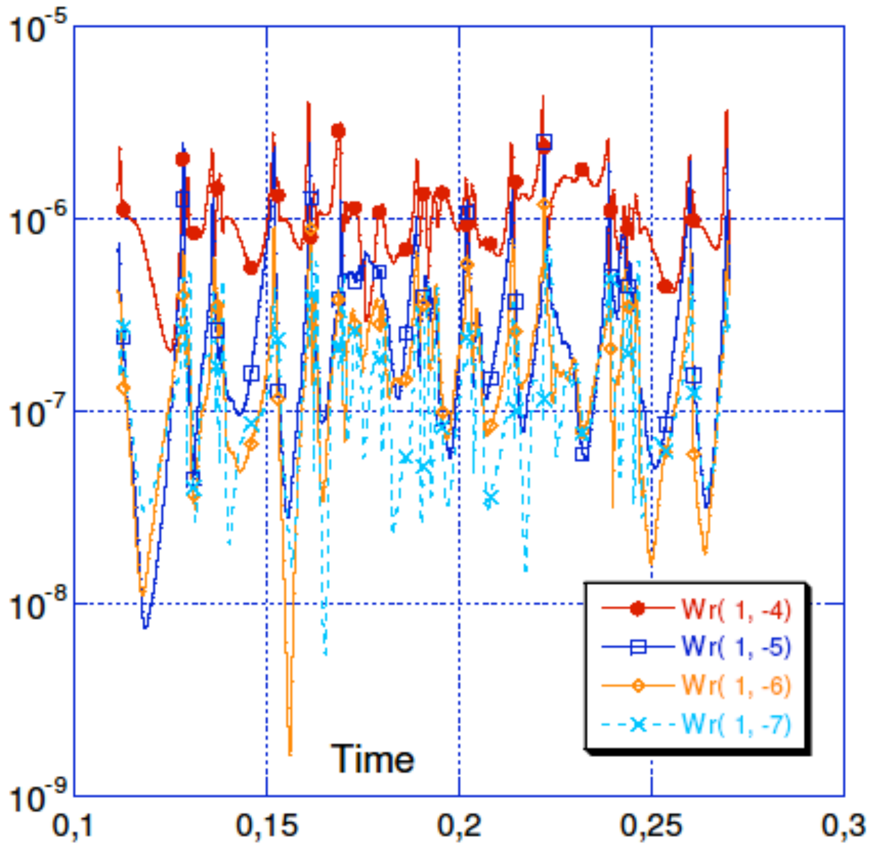


Fig.2: Radial mode energy vs. time for the ideal wall simulation.

Oscillating behavior of the tearing part of the spectrum (m=1/n=4,5,..) in RELAX can be compared with 3D MHD simulation with ideal wall boundary condition.

- due to mode rotation

- due to short discharge duration

MHD simulation predicts RWM will be problematic for longer pulse operation

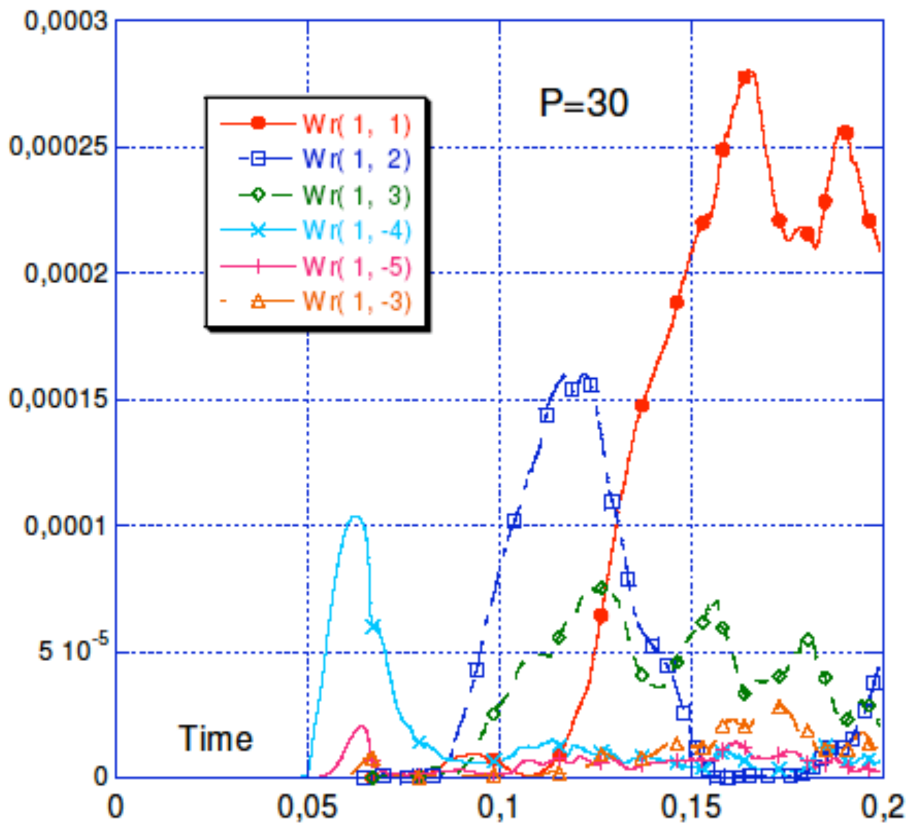
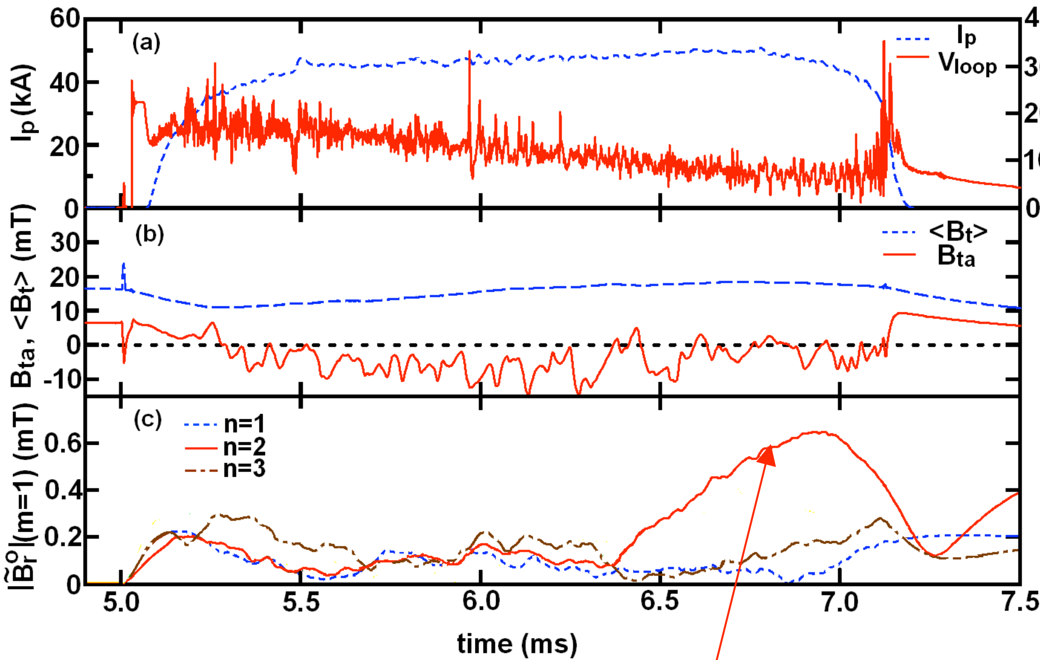
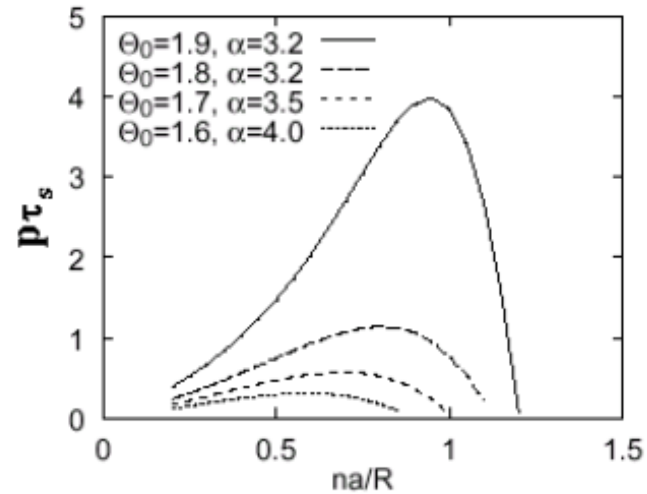


Fig.6: Radial mode energy vs. time for the RW simulation with $\tau_w = 0.02$ (P=30, S=3 10^4).

Experimental implication of RWM in RELAX



Br (m=1/n=2) measured on the outer surface of the vacuum vessel



Growth rate vs. n*a*/*R* of external kink modes for α-Θ_0 model profiles

$$\tilde{B}_r(a)/B_p(a) \approx 1-1.5\%$$

=> I_p starts decreasing

MHD control plans in RELAX

- Discharge performance improvement:
  - Ip~100kA, τ: ~2ms => 5ms (within present capability)
  - Static helical perturbation

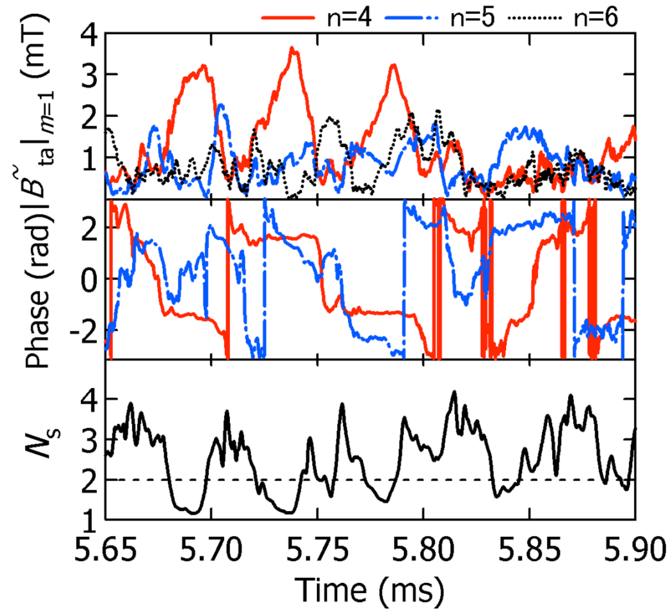
  Further improvement will require improved magnetic boundary:
  - feedback control system

Another means for confinement improvement (current profile control, e.g.) may be necessary

Conclusion

- RFP plasma with MHD properties characteristic to low-*A* configuration attained in RELAX
- Dominant mode with lower n realized
- Simple helical structure observed
- Possible Helical Ohmic Equilibrium state demonstrated
- 3D MHD simulation could reproduce most of the characteristics

Growth of dominant mode is related to mode rotation



m=1/n=4 mode behavior:

- ➢Longer QSH period for slower rotation
- ➢Shorter QSH period with higher spectral index *N*s for faster rotation