Recent Results About Helical States in RFX

Presented by

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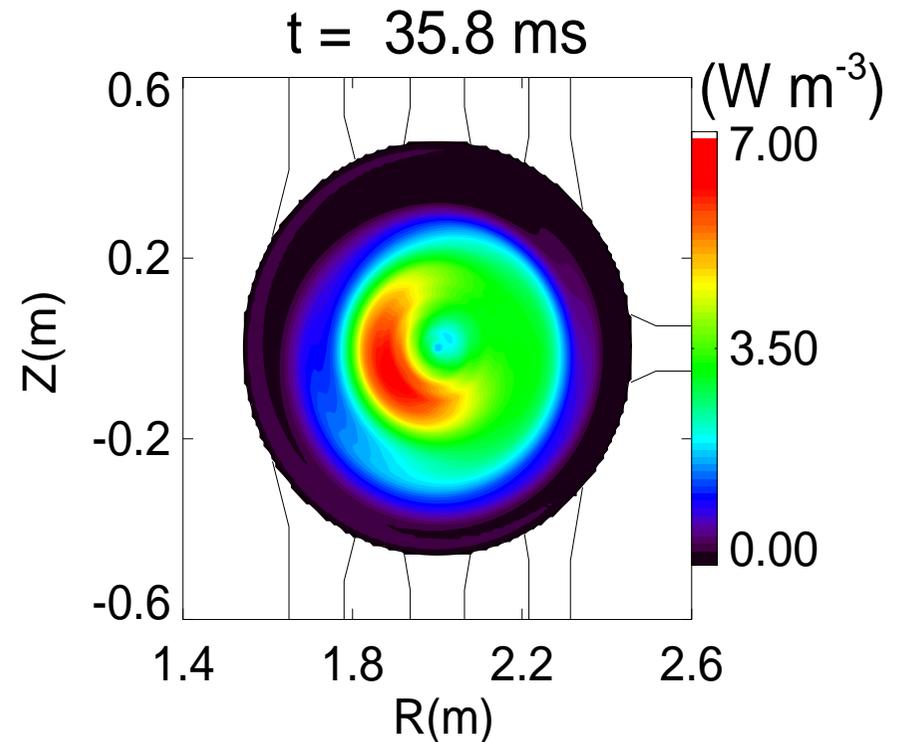
OUTLINE

- Some experimental results on helical states in RFX

- Helical states as ohmic equilibrium states

EXPERIMENTAL EVIDENCES

- **TPE (Japan)** Brunsell et. al. (1993) : high Θ quasi single helicity states

- **T1 (Sweden)** Nordlund&Mazur (1994)

-**RFX (Italy)** : tomographic reconstruction of magnetic islands , Martin et. al. (1999)

t = 35.8 ms

QSH states in RFX

- **QSH states are obtained in RFX**

  - **spontaneously**
    - **transient (similar in TPE-1RM20 - Improved High Theta Mode)**
    - **stationary**

  - **as a result of Pulsed Poloidal Current Drive (PPCD)**
  - **as a result of Oscillating Poloidal Current Drive (OPCD)**

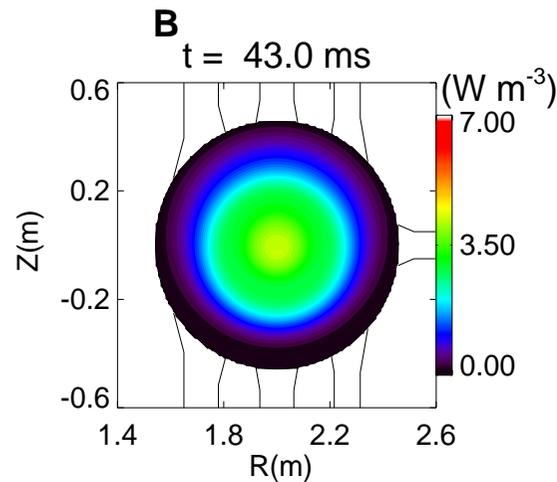**Techniques to control the edge poloidal electric field**
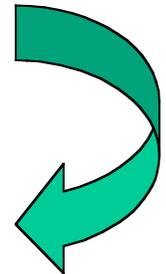
MH vs. QSH
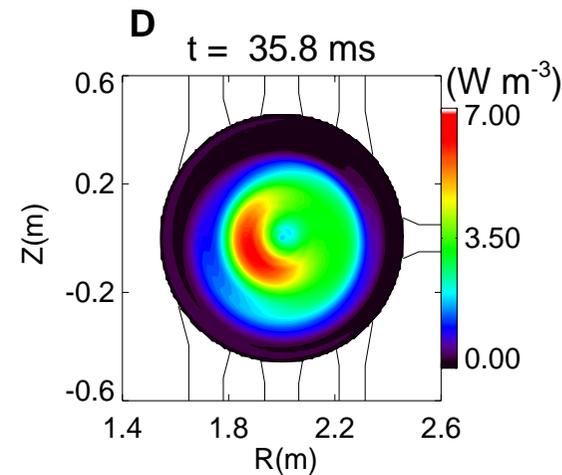
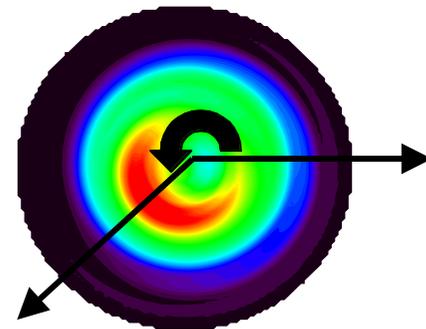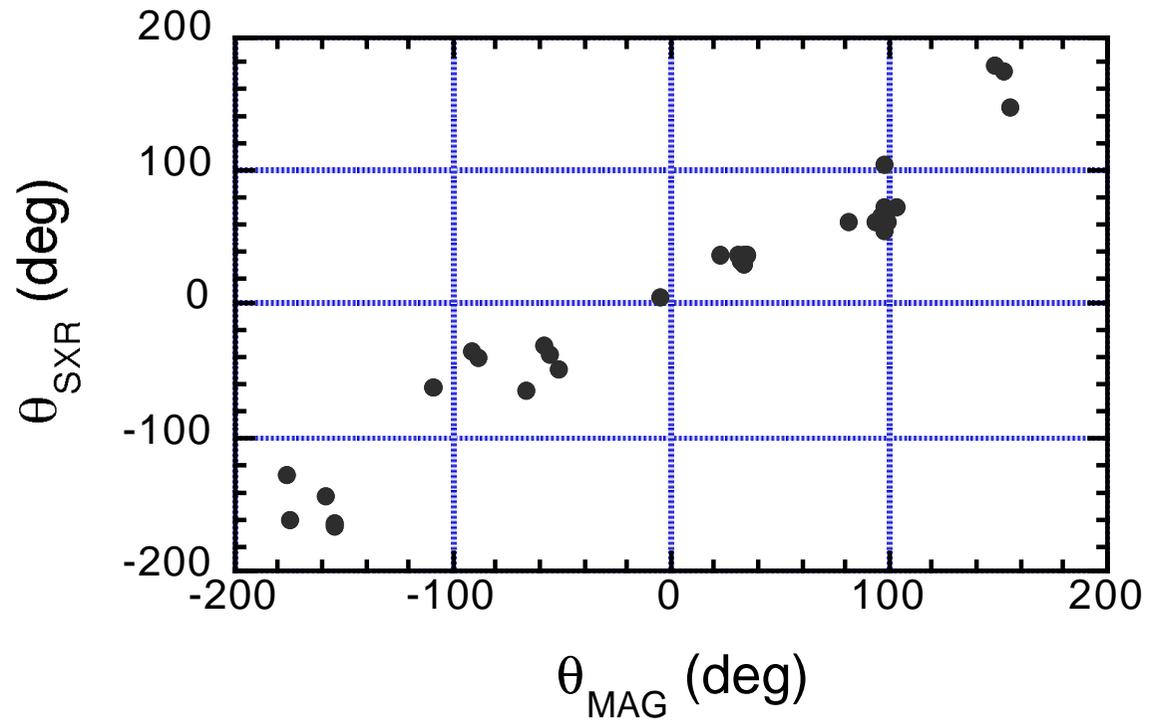- **SXR imaging reveals an helical structure in the plasma core during QSH states**
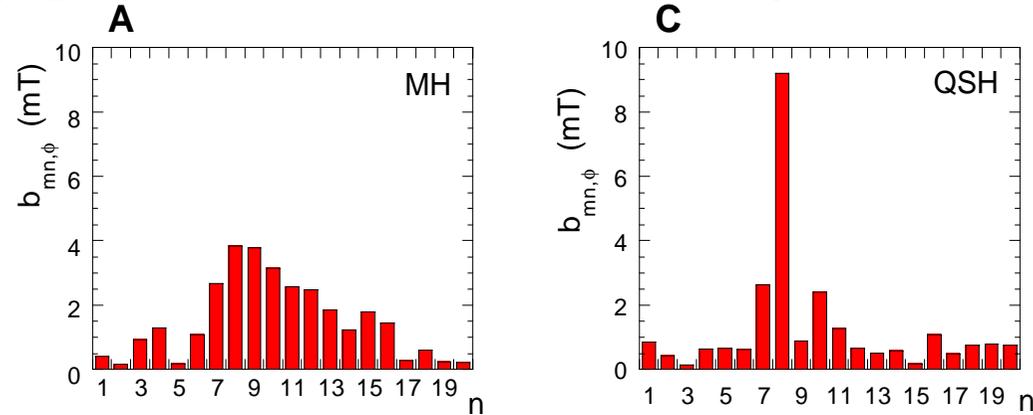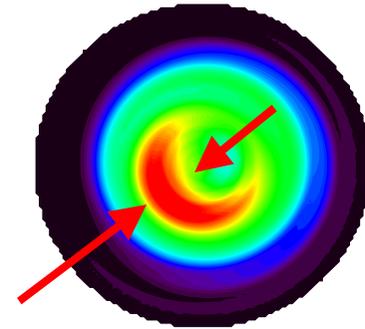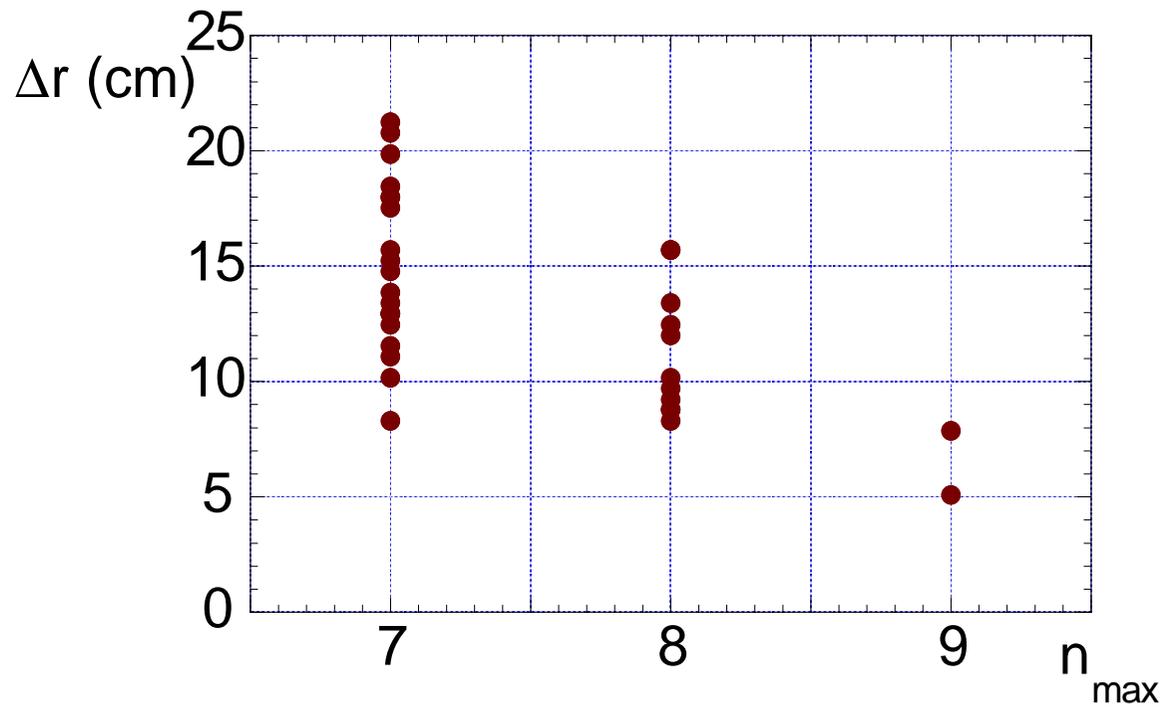

The poloidal position of the island coincides with the poloidal phase angle of the dominant mode
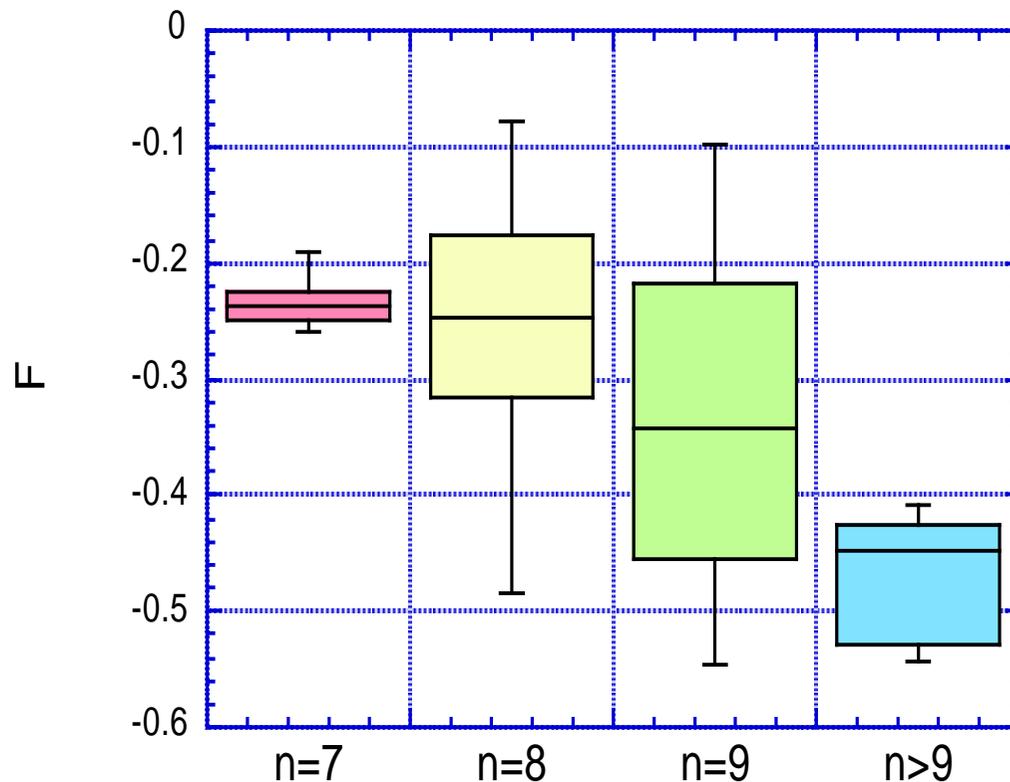
Poloidal position of the island

radial width of the helical structure vs. n_{max}

For lower n the radial width of the island increases

Dominant *n* depends on *F*

The level of the edge toroidal field reversal plays a role in determining which mode emerges in a QSH state.

A deeper reversal corresponds in fact to a lower on-axis safety factor; this can therefore eliminate the resonance of the lowest n numbers (n=7 with RFX aspect ratio).

A relationship between nmax and the reversal parameter F, defined as $F=B_t(a)/<B_t>$ is indeed experimentally observed.

The core helical structure heats up

- **Spontaneous QSH**
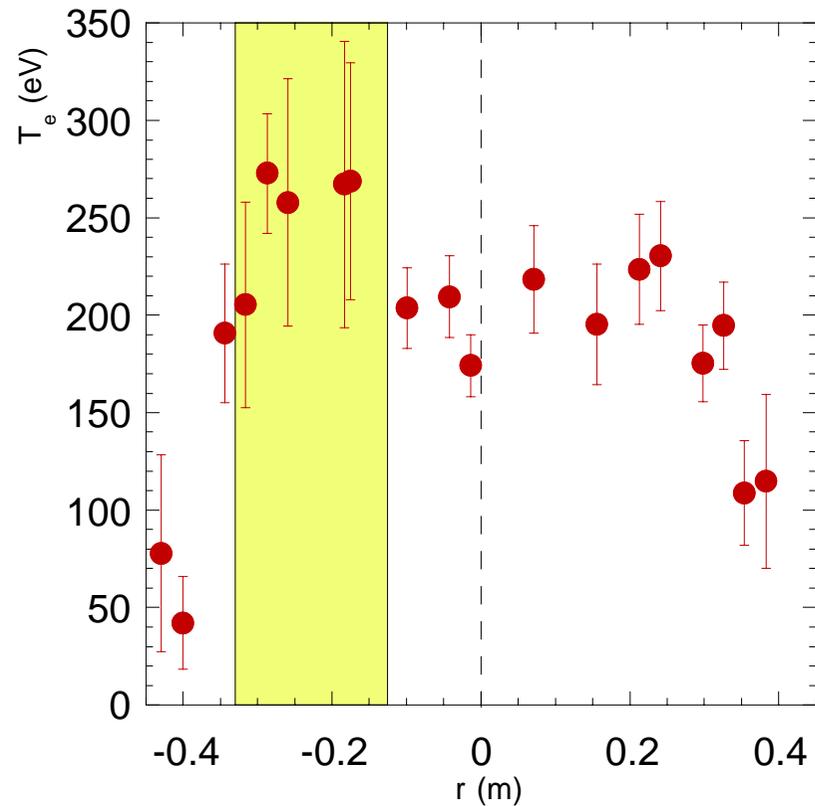
Electron temperature profile
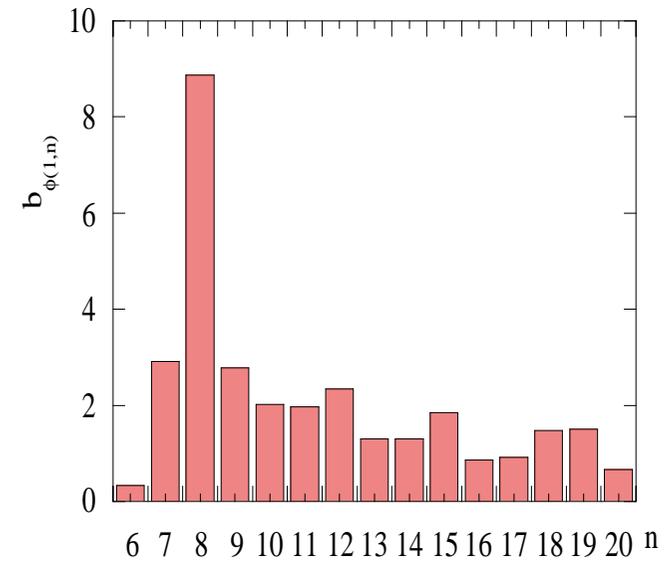
m=1 toroidal spectrum

Lower n islands are hotter

- **Core temperature vs. n_{dom} for QSH plasmas**

Transient QSH state (during PPCD)

- Plasma makes transitions to states with a much narrower $m=1$ modes spectrum

MODE AMPLITUDES — SHOT N.11392 — odd m — BT

Toroidal mode number **n**

PPCD

time

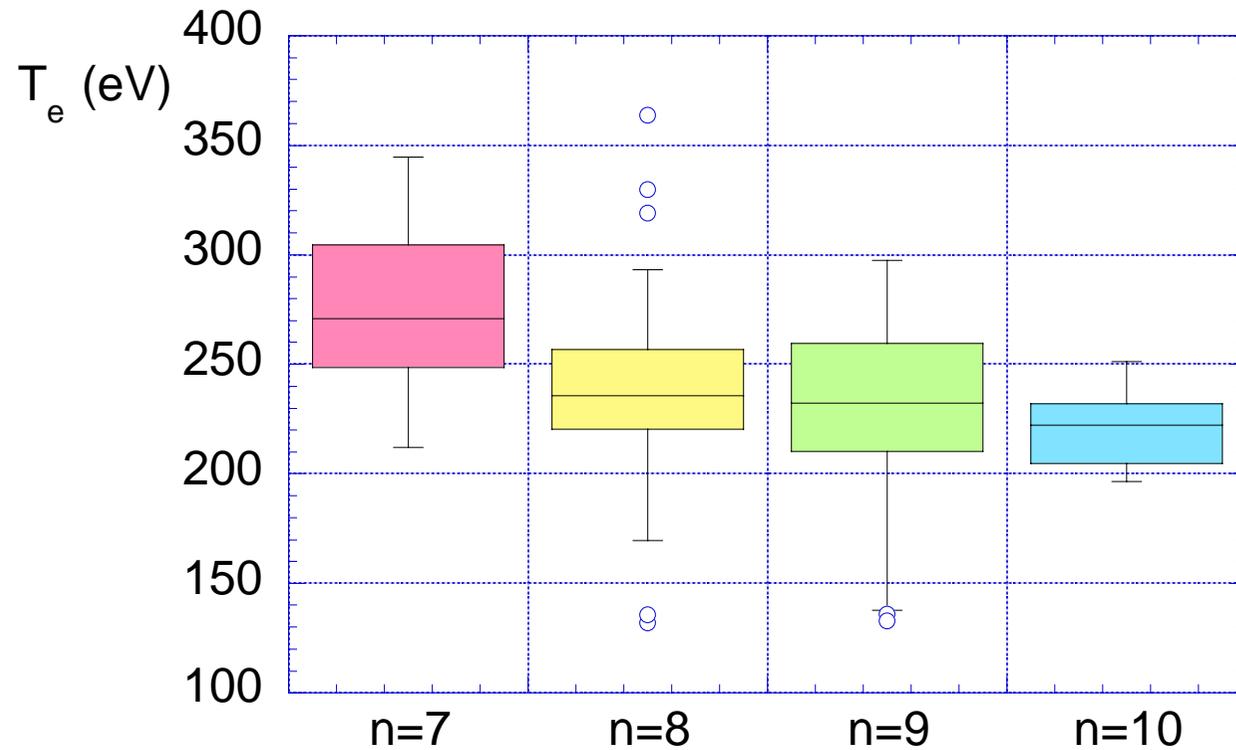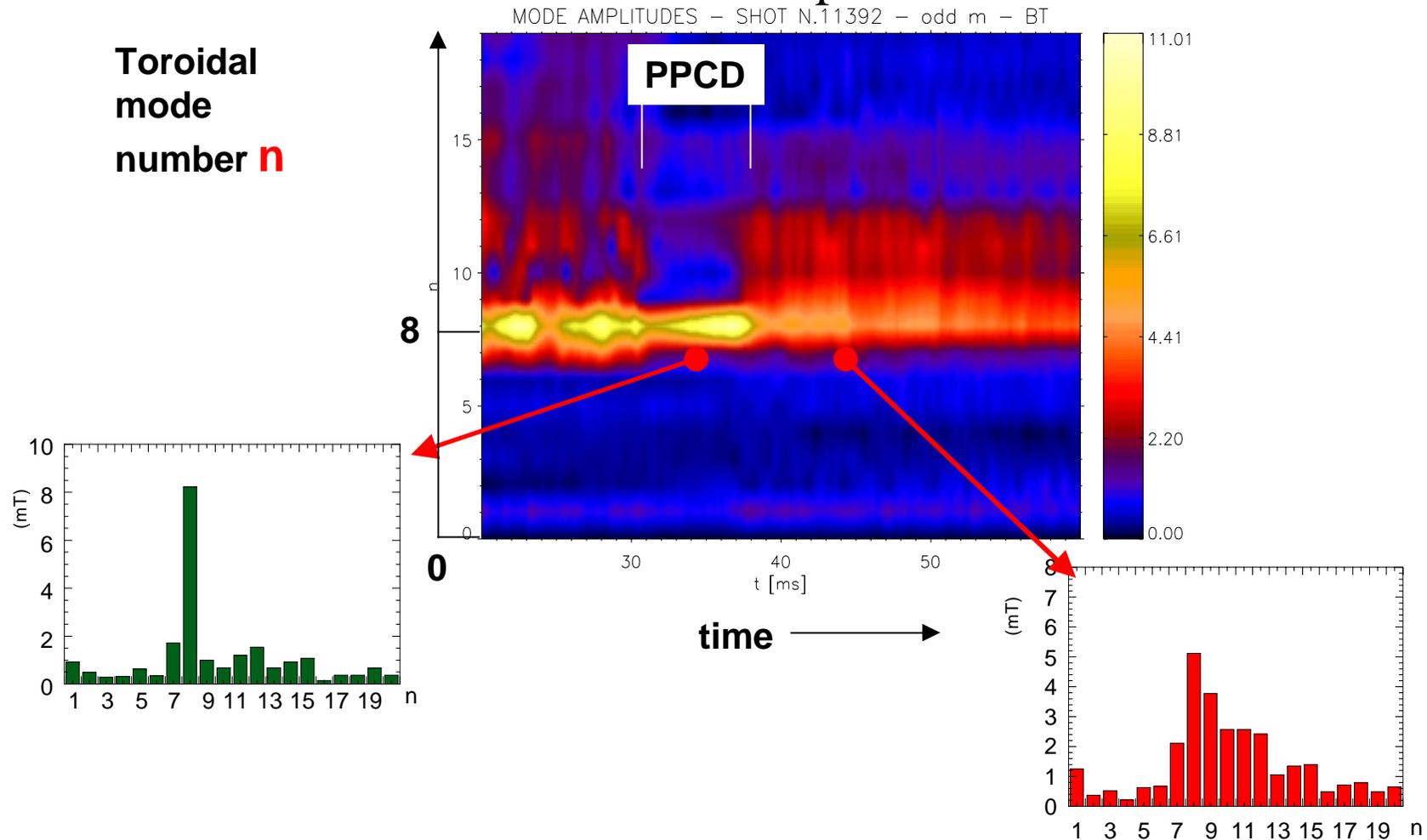# Fluctuations and dynamo

- **A resistive, steady state, axisymmetric reversed toroidal field equilibrium is not possible**

- **RFP "dynamo" has to satisfy Cowling's theorem:**

  - *"axisymmetric magnetic fields cannot be maintained by any symmetric fluid motion"*

  - **MHD fluctuations can provide the poloidal electric field => turbulent MHD dynamo**

  - **non-axysimmetric ohmic equilibrium states**

MHD Equilibrium

$$\nabla p = \mathbf{J} \times \mathbf{B}$$

Helical Grad-Shafranov Equation

$$\Delta_h \chi = \frac{1}{f}\frac{\partial}{\partial r}\left(f\frac{\partial \chi}{\partial r}\right) + \frac{1}{rf}\frac{\partial^2 \chi}{\partial u^2} = \left(c - \frac{dg}{d\chi}\right)g(\chi) - \frac{dp}{d\chi}(m^2 + k^2 r^2)$$

where χ is the helical flux function
$u = m\,\theta + k\,z$ is the helical angle, g is the helical magnetic field and p is the pressure profile
$f = r/(m^2 + (k\,r)^2)$, $c = -2\,k\,m/(m^2 + (k\,r)^2)$
$\lambda(\chi) = \mathbf{J}\,\mathbf{B}/\mathbf{B}^2 = (dg/d\chi + g/B^2\,dp/d\chi)$
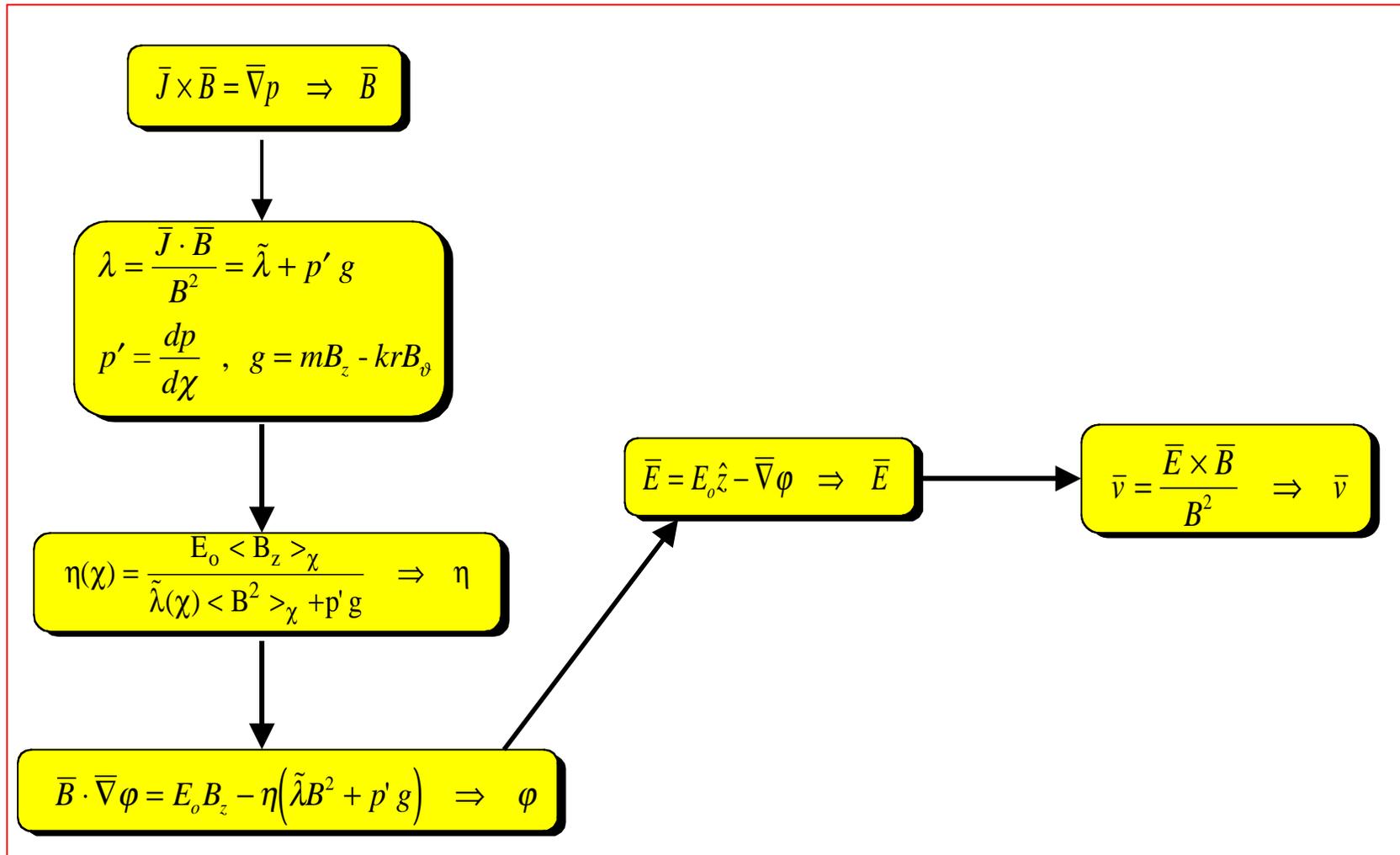
OHM's Law

$$\vec{E} + \vec{v} \times \vec{B} = \eta\, \vec{j}$$
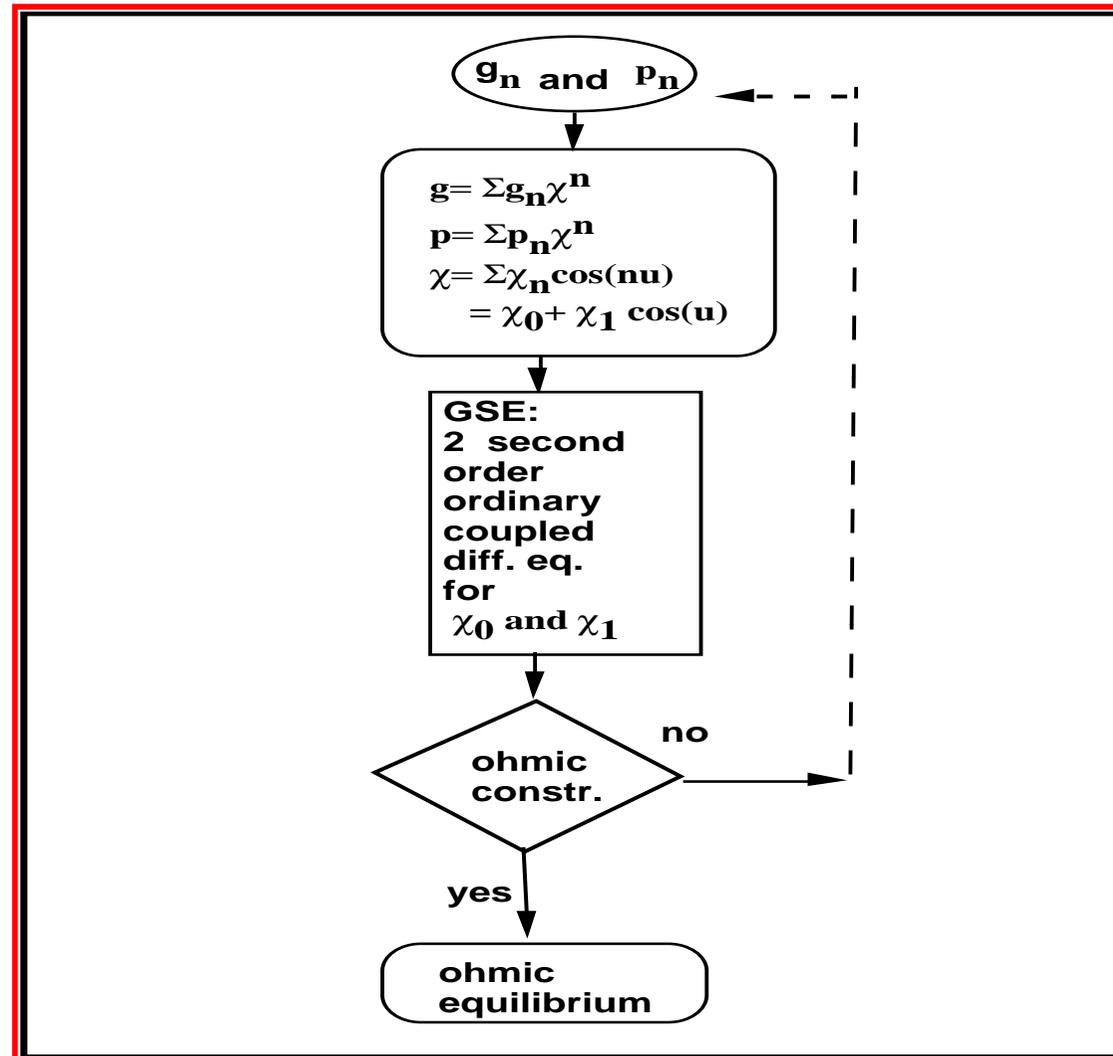
in helical symmetry
(parallel component)

$$E_o < B_z >_\chi = \eta(\chi)\left(\tilde{\lambda}(\chi) < B^2 >_\chi + g\frac{dp}{d\chi} \right)$$

where $< >$ means flux surface average and $\tilde{\lambda} = \dfrac{dg}{d\chi} = \vec{J} \cdot \vec{B} / B^2 - \left(g\, \mathbf{dp/d\chi} \right) / B^2$
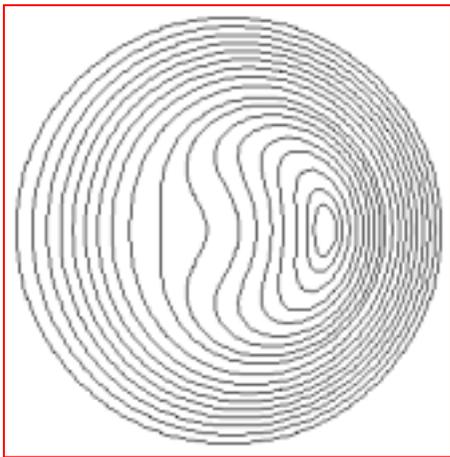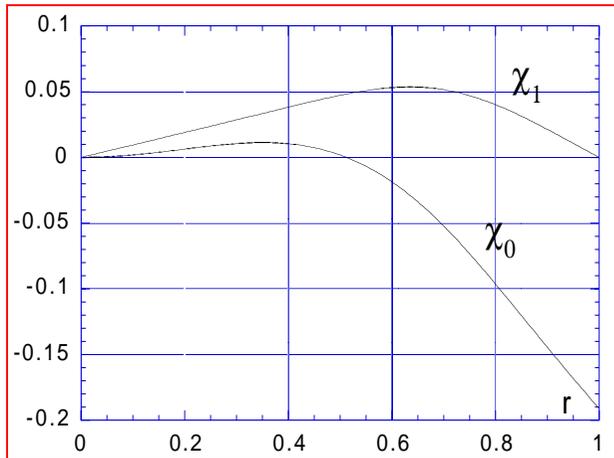
Finn-Nebel-Bathke (1992)

From the helical ohmic state to the calculation of the laminar velocity vector field.

$$\bar{J} \times \bar{B} = \bar{\bar{\nabla}} p \quad \Rightarrow \quad \bar{B}$$

$$\lambda = \frac{\bar{J} \cdot \bar{B}}{B^2} = \tilde{\lambda} + p' \, g$$

$$p' = \frac{dp}{d\chi} \quad , \quad g = mB_z - krB_\vartheta$$

$$\eta(\chi) = \frac{E_o < B_z >_\chi}{\tilde{\lambda}(\chi) < B^2 >_\chi + p' g} \quad \Rightarrow \quad \eta$$

$$\bar{B} \cdot \bar{\nabla} \varphi = E_o B_z - \eta \left(\tilde{\lambda} B^2 + p' g \right) \quad \Rightarrow \quad \varphi$$

$$\bar{E} = E_o \hat{z} - \bar{\nabla} \varphi \quad \Rightarrow \quad \bar{E}$$

$$\bar{v} = \frac{\bar{E} \times \bar{B}}{B^2} \quad \Rightarrow \quad \bar{v}$$

Ohmic Helical equilibrium using polynomial expansion
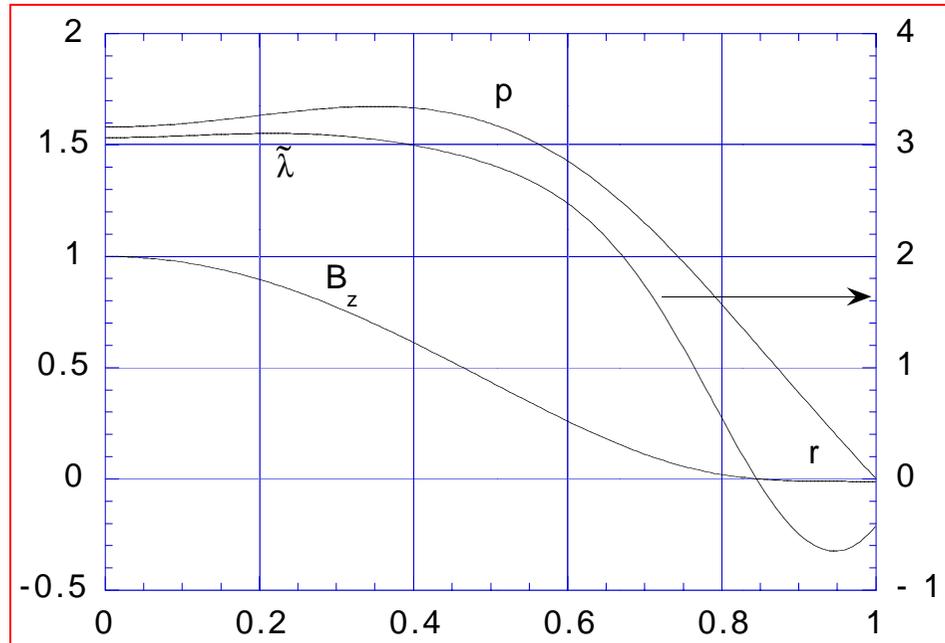
Ohmic helical equilibrium solution

Radial profiles

and

Helical flux contours

$\Theta=1.78$
$F=-0.06$
$\beta=0.1$
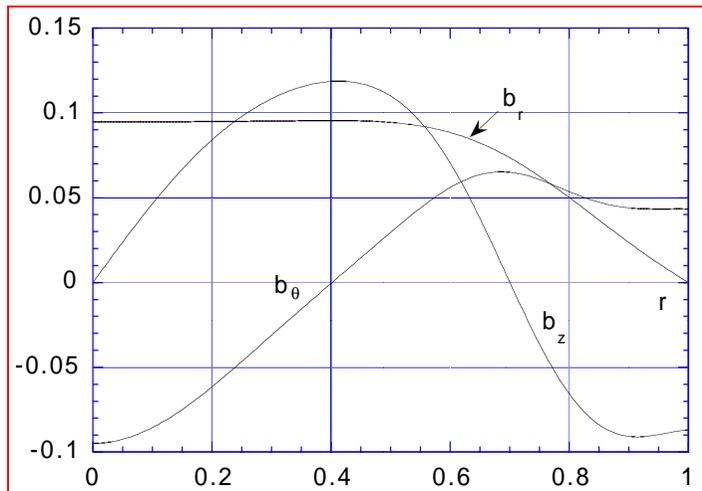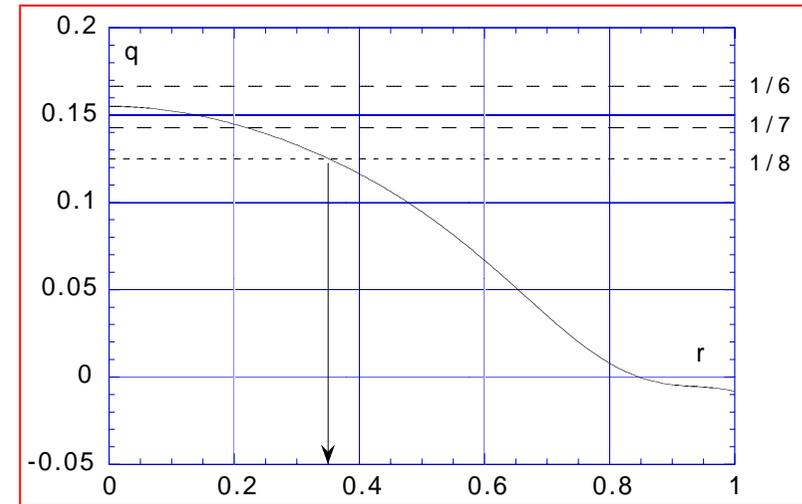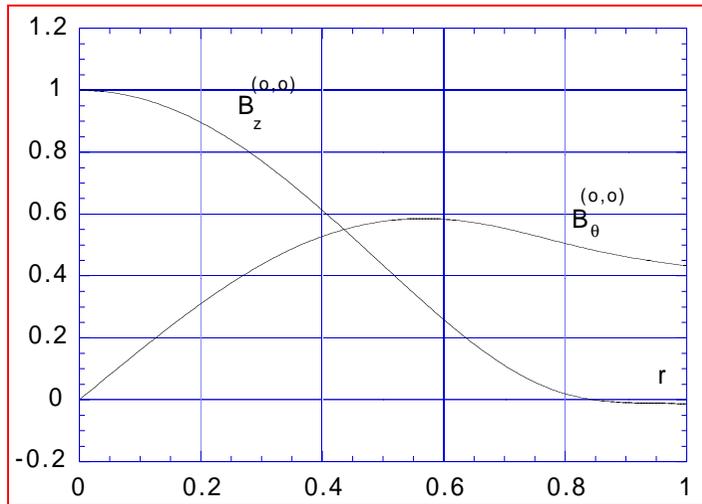
Ohmic helical equilibrium solution (continued)

$$E_0 < B_z >_\chi = \eta(\chi)\left(\tilde{\lambda}(\chi) < B^2 >_\chi + g\frac{dp}{d\chi} \right)$$

with

$$\tilde{\lambda} = \frac{dg}{d\chi} = \vec{J} \cdot \vec{B} / B^2 - (g\, \mathbf{dp/d\chi}) / B^2$$
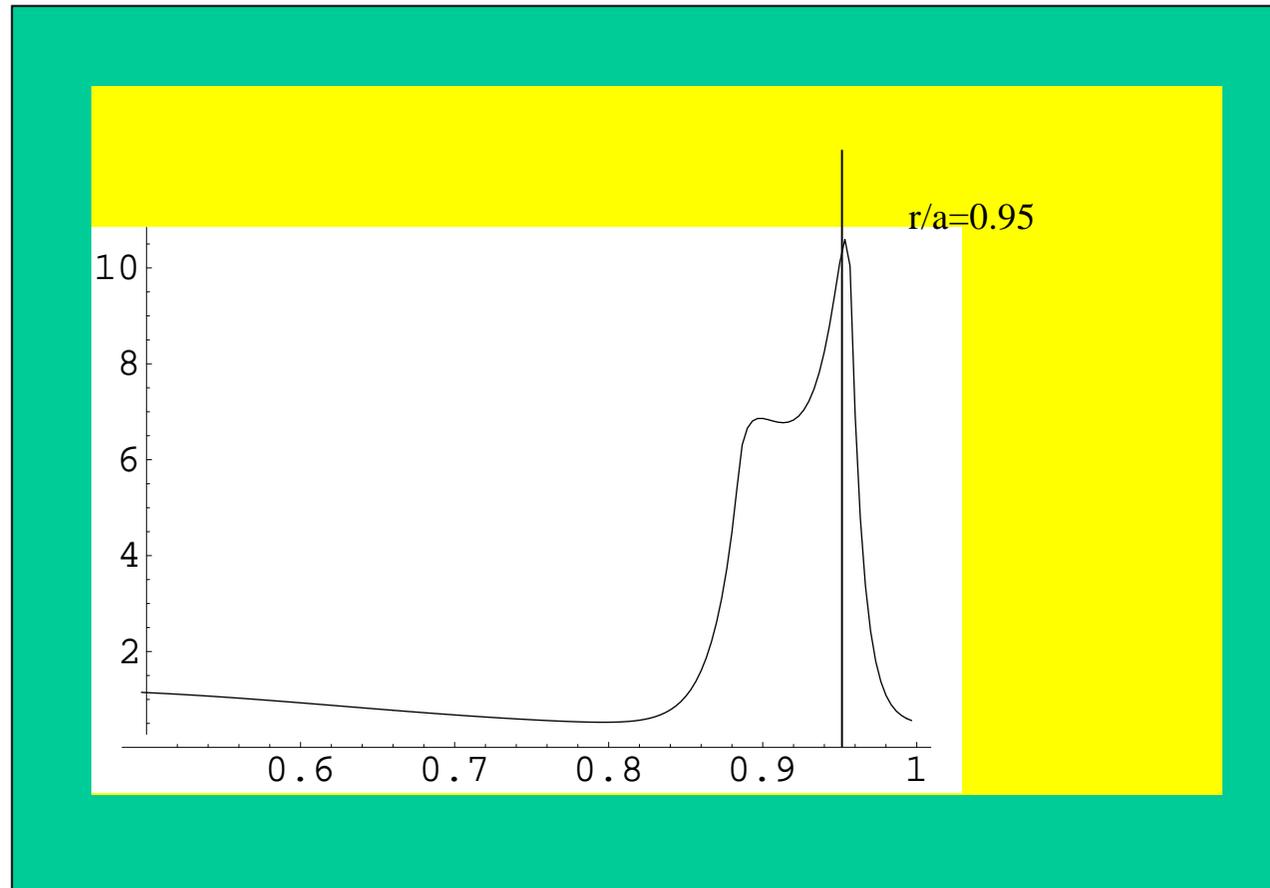
Ohmic helical equilibrium solution (continued)

Perturbation level

$$b_z(a)/B_\vartheta^{(o,o)}(a) \approx 20\%$$

Calculated resistivity profile

Summary

- Clear experimental evidences of helical structures in RFX

- Motivation to search ohmic helical symmetric equilibrium solutions

- Such solutions exist!

- Realistic η, b/B not too high (?)