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Single and Multiple helicity states revisited in 3D MHD dynamical simulations , related magnetic diffusion properties.

Presented by

S. Cappello,

in collaboration with:

D. Escande , F. D'Angelo, R. Paccagnella and C. Marchetto

Istituto Gas Ionizzati CNR- CONSORZIO RFX- ITALY

Outline

- MOTIVATION;

- ACCESSIBILITY OF SH-QSH STATES and IMPORTANT PARAMETERS OF VISCO-RESISTIVE MHD:

  - SENSITIVITY TO PINCH PARAMETER Θ ,

  - MH-SH TRANSITION AS A FUNCTION OF THE DISSIPATIVE COEFFICIENTS;

- SEPARATRIX EXPULSION AND CHAOS HEALING;

- SUMMARY and OPEN QUESTIONS.

Our recent theoretical-computational work:

Cappello,D'angelo,Escande,Paccagnella,Benisti, *Proc. EPS* '99

Martin,Buffa,Cappello,et.al. to appear in *Phys. Plasmas* (2000)

Motivated by:

- recent experimental observations in **RFX**:

Martin, *PPCF* <- EPS '99

Martini,et al. *PPCF* <- EPS '99

Cappello, Escande, Marrelli, Martin, et. al. *Proc.EPS* '99

Martin,Buffa,Cappello, et.al. to appear in *Phys. Plasmas* (2000)

- and other experiments:

TPE RM20	Brunsell, Yagi,Hirano, et. al. *Phys. Fluids* (1993)
T1	Nordlund, Mazur, *Phys. Plasmas*, (1994)
TPERM20	Hirano, Yagi, et al., *Plasma Phys. Contr. Fus.* **39**, A393, (1997)
MST	Sarff, et al., *Phys. Rev. Lett.* **78**, 62, (1997)

Previous theoretical-computational work:
NUMERICAL VISCO-RESISTIVE 3D MHD MODELS, EQUILIBRIUM PROBLEM SOLUTION

Cappello,Paccagnella , Varenna ‘90

Cappello,Paccagnella , Phys.Fluids ‘92

Finn,Nebel,Bathke , Phys.Fluids ‘92

- QSH <-> viscosity

- Sensitivity to initial conditions

- Ohmic helical equilibria

Cappello,Biskamp, Nucl. Fusion ‘96

- QSH <-> resistivity

- Intermittent behaviour: laminar-turbulent dynamo

How does the accessibility of SH states scale with important parameters of visco-resistive MHD: $\eta(\tau_A / \tau_R)$, $\nu(\tau_A/\tau_v)$, Θ ?

Dimensionless equations:

$$\frac{\partial B}{\partial t} = \nabla \wedge (v \wedge B) - \nabla \wedge (\eta J)$$

$$\frac{dv}{dt} = J \wedge B + \upsilon \nabla^2 v$$

$$\rho \equiv 1, p \equiv 0$$

$\eta = \tau_A / \tau_R$

Lundquist number: $S = \eta^{-1}$

$\nu = \tau_A/\tau_v$

Prandtl number: $P = \nu/\eta$

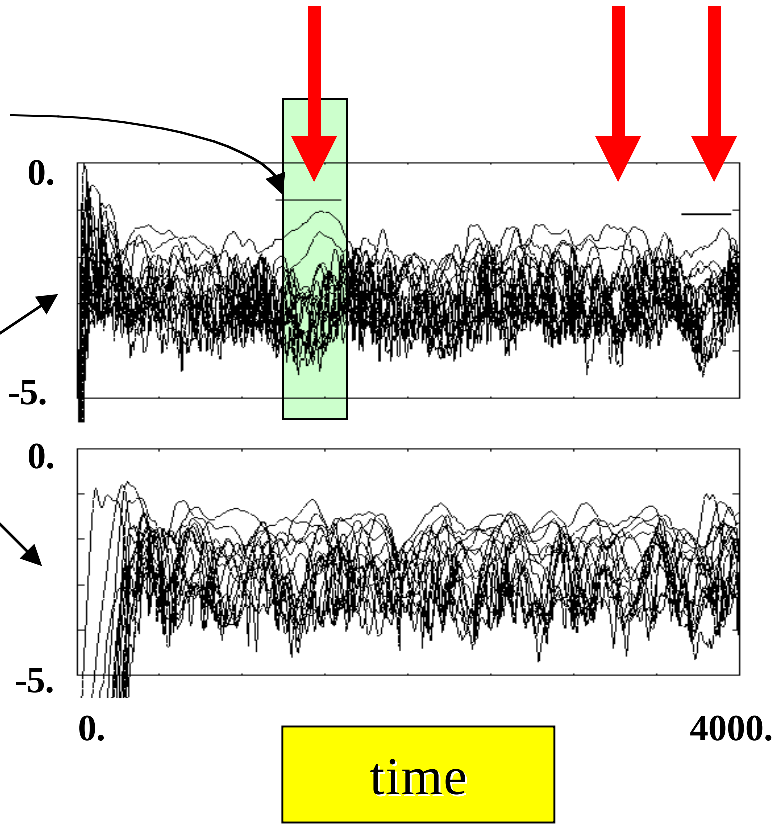
INTERMITTENT QSH at high Θ

$S = 3 \times 10^4$

(δt -> 400 τ_A => 60-160μs)

Cappello,D'angelo,Escande, et.al. EPS99

Log $E_{m=1}$



Θ=1.9

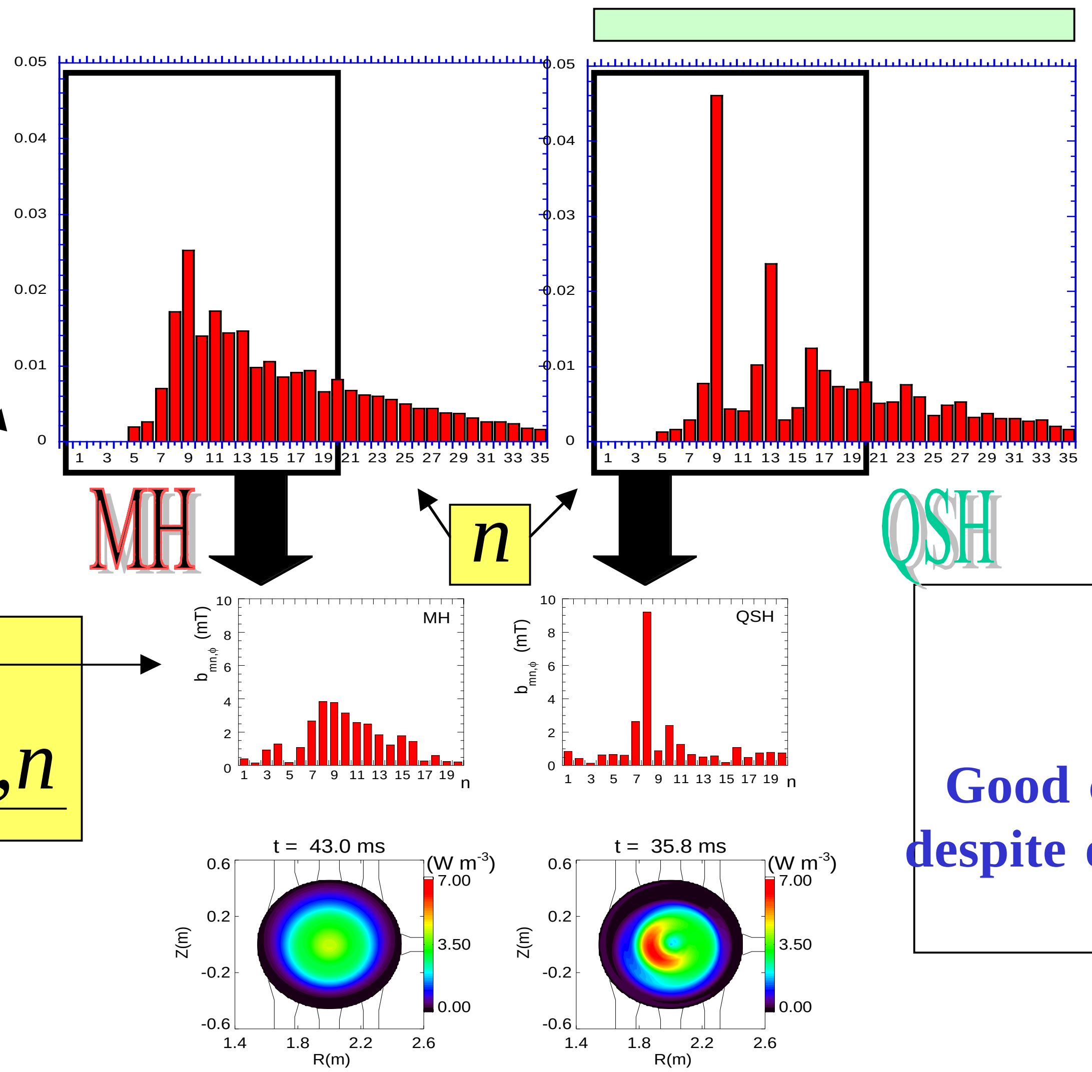
(R/a=4)

Θ=1.5

MH and QSH: magnetic perturbation amplitude measured at the plasma edge: simulations and experiment.

3D MHD

Specyl



RFX

$$\tilde{b}_{m=1,n}$$

- Θ
- b.c.

Good comparison despite differences in

0.5%

- **SXR imaging reveals an helical structure in the plasma core during QSH states.**

3D MHD numerical simulations

-> parameters used for the study of the MH-SH transition diagram:

Exp: $10^4 \to 10^7$

(T1,TPE,MST,RFX)

$\Theta = 1.9$

$S \Rightarrow 3.3 \times 10^3 - 3. \times 10^4$

$P \Rightarrow 2/3 : 5 \times 10^3$

Exp:

RFX: $P^{//cl.} \to 10^6$, $P_{perp,cl.} \to 1$

MST estimate: $\upsilon_\perp^{exp} \approx 50 \cdot \upsilon_\perp^{cl.}$

$R/a = 4$

(RFX)

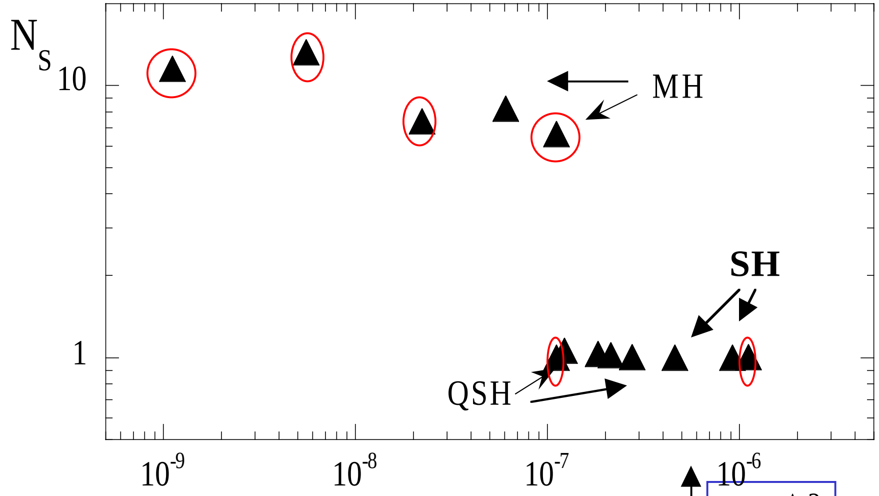
Phase transition diagram 1:
Spectral width(m=1) *Ns* vs. *P/S²*

Martin,Buffa,Cappello,et.al. to appear in Phys. Plasmas

$$Ns \equiv \sum_n \left[\left(Wn_\phi / \sum_n Wn_\phi \right)^2 \right]^{-1}$$

m=1

○ : S=3x10⁴



PS^-2

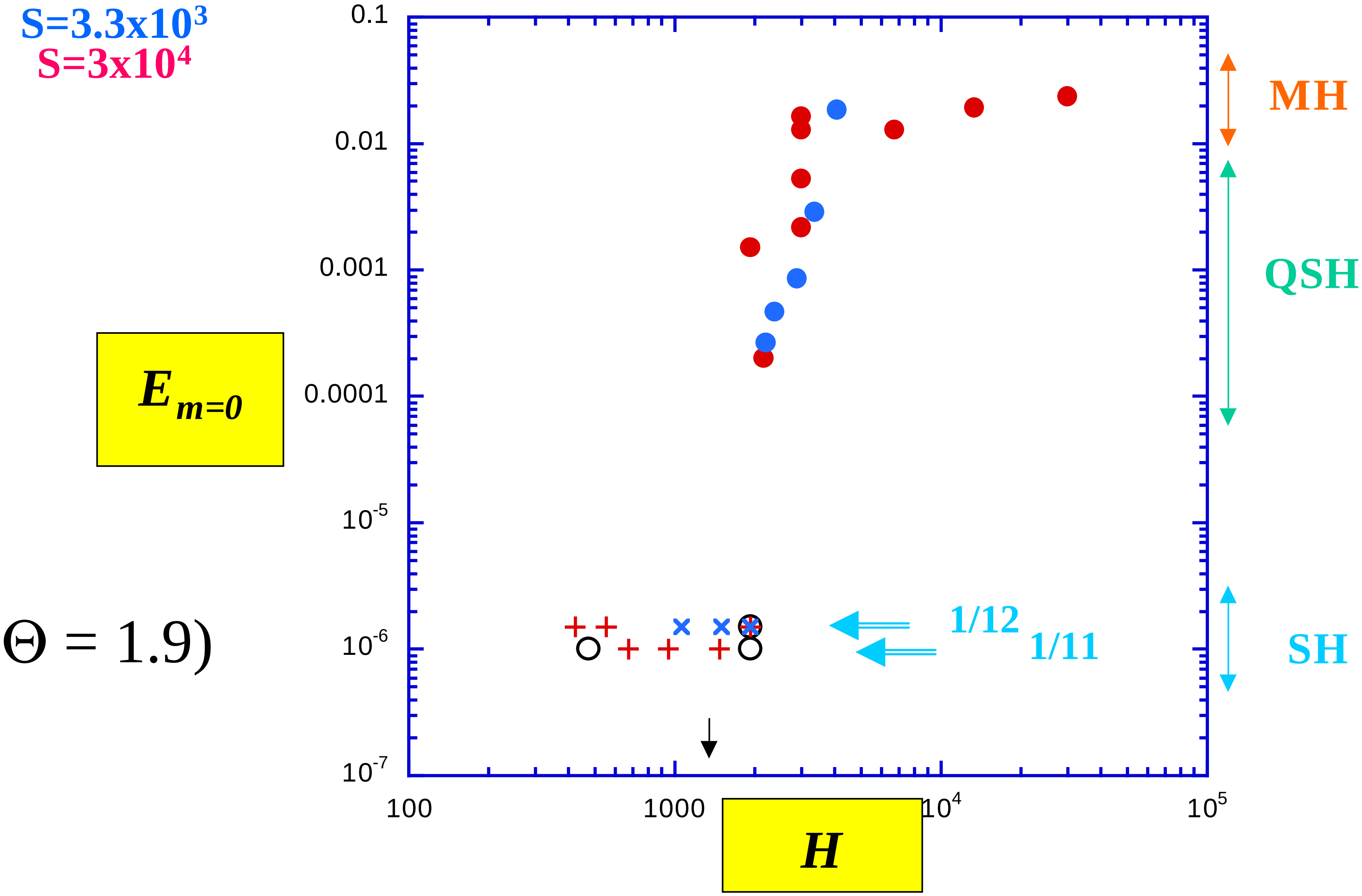
P/S^2 = H^{-2}

H ≐ $\nu\,\eta^{-1/2}$

(Hartmann number)

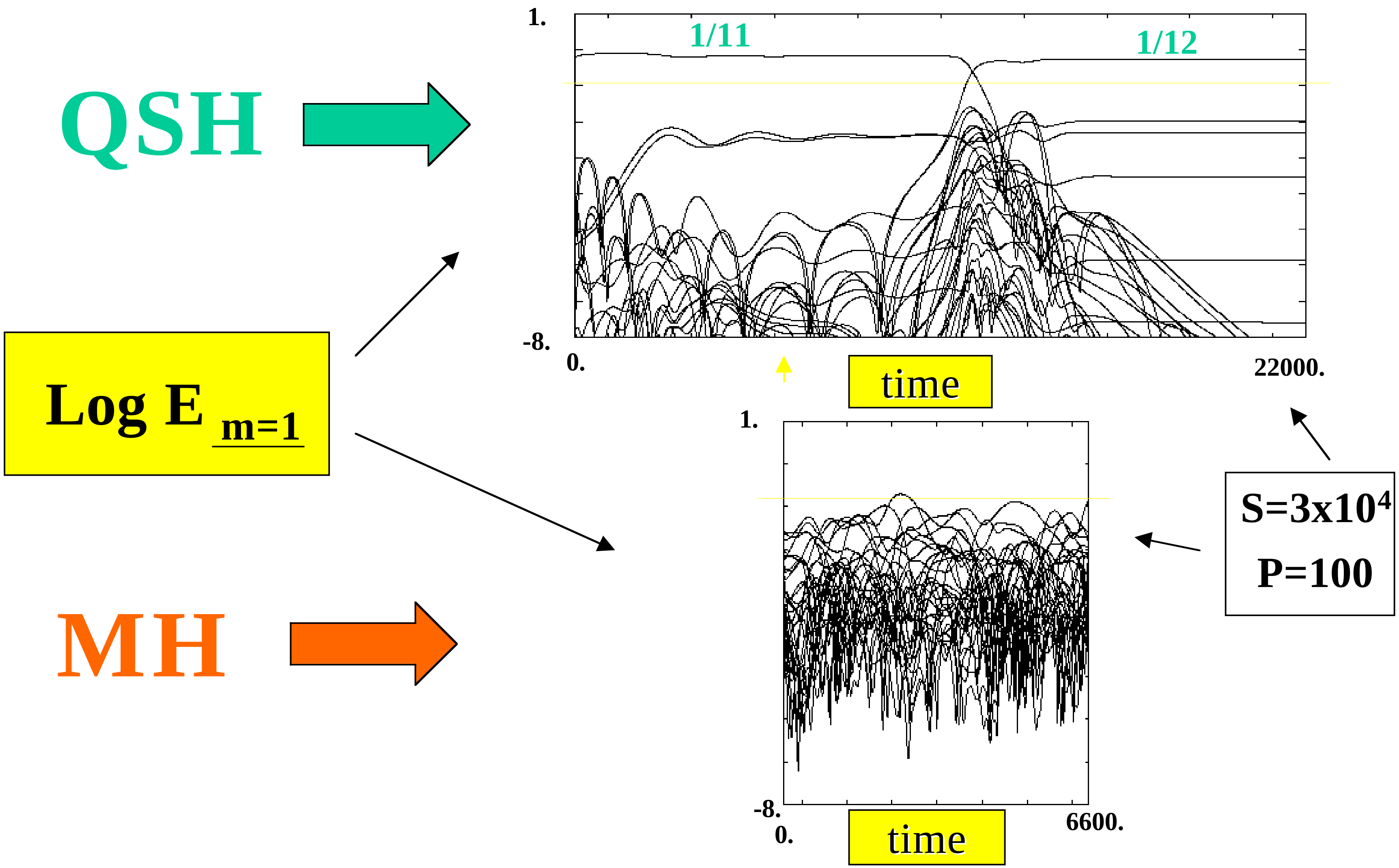
LINEAR STABILITY
SLAB → **Tebaldi,Ottaviani Jour.Plas.Phys. 1999**
TOKAMAK → **Montgomery Plas.Phys.Contr.Fus. 1992**

Phase transition diagram 2:
m=0 modes $\underline{E}_{\underline{m=0}}$ vs. $\underline{H}$artmann



(Θ = 1.9)

Close to the transition threshold some helicities can persist as QSH for long time intervals:



Summary and open questions (1)

Physical parameters:

The Hartmann number *H*,
which is a suitable combination of Lundquist and magnetic Prandtl (P/S^2),
seems to be
the important parameter of visco-resistive nonlinear MHD,

Stability,robustness and accessibility of QSH-SH regimes depend basically on **H**,
(besides of geometry and boundary)

More accurate modeling of the stress tensor (->viscous term in momentum equation) might be important (as well as inclusion of anomalous terms). (Experimental estimate!)

-more general MHD model...

Summary and open questions (2)

Physical parameters:

→ Introducing the "m=0 energy" as "order parameter" we can build up a clear phase transition diagram: the results we obtain provide a possible **connection** between the RFP dynamical system and studies of modern nonlinear dynamics, in particular fluid dynamics;

Geometrical aspects :

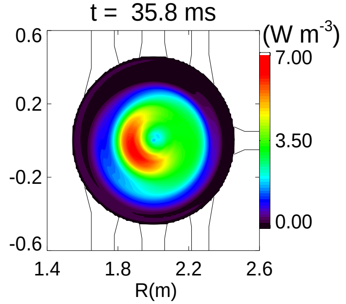
→ We have qualitative indications of **easier achievement of SH states at high Θ**.(3D MHD next future investigation),

→ Impact of aspect ratio R/a: should also be investigated: full toroidal geometry may be important (NIMROD);

Summary and open questions (last)

Magnetic chaos and transport:

Onset of QSH states with suitable (large!) amplitude of the dominant helicity may explain the observation of helical structures in SXR tomography in RFX, via a mechanism of **separatrix expulsion** -> **chaos healing** , (contrary to expectations in terms of the island overlapping picture),



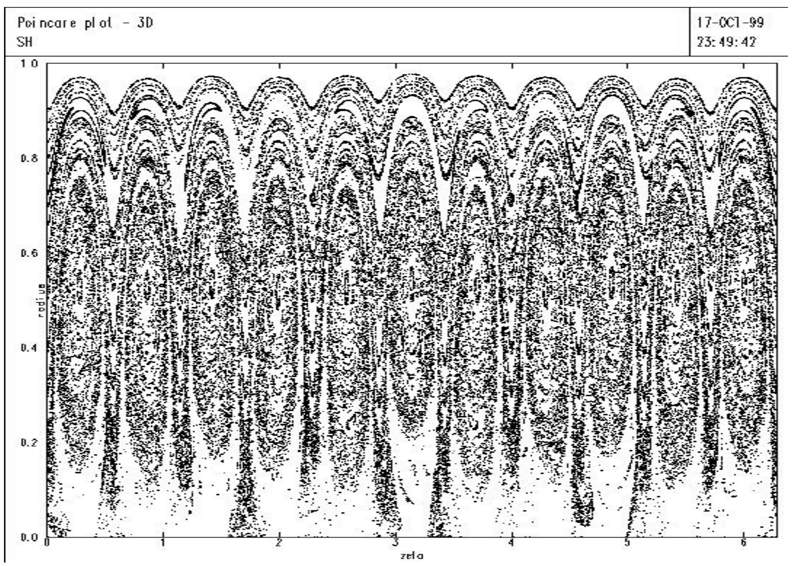
Still to clarify the requirements for full exploitation of confinement improvement by onset of QSH/SH regimes !

QSH STATES IN 3D NUMERICAL SIMULATIONS

helical structure

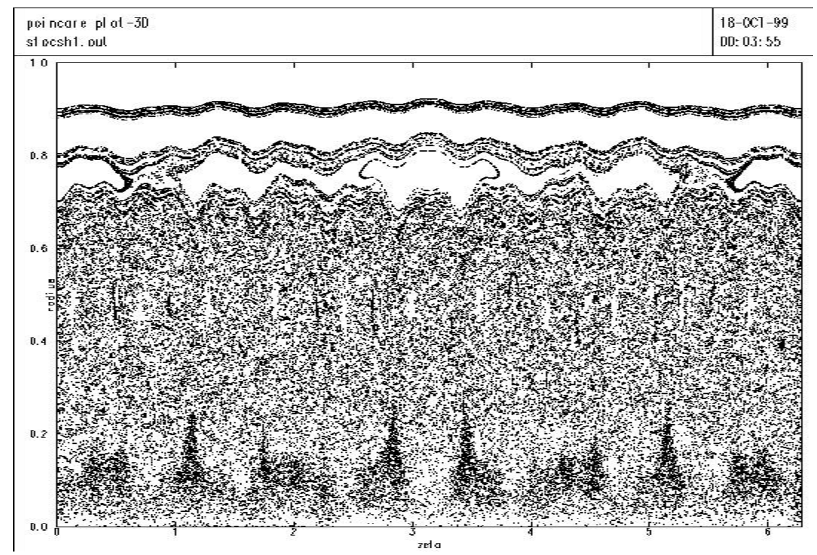
conserved **destroyed**

radius



Toroidal angle

radius

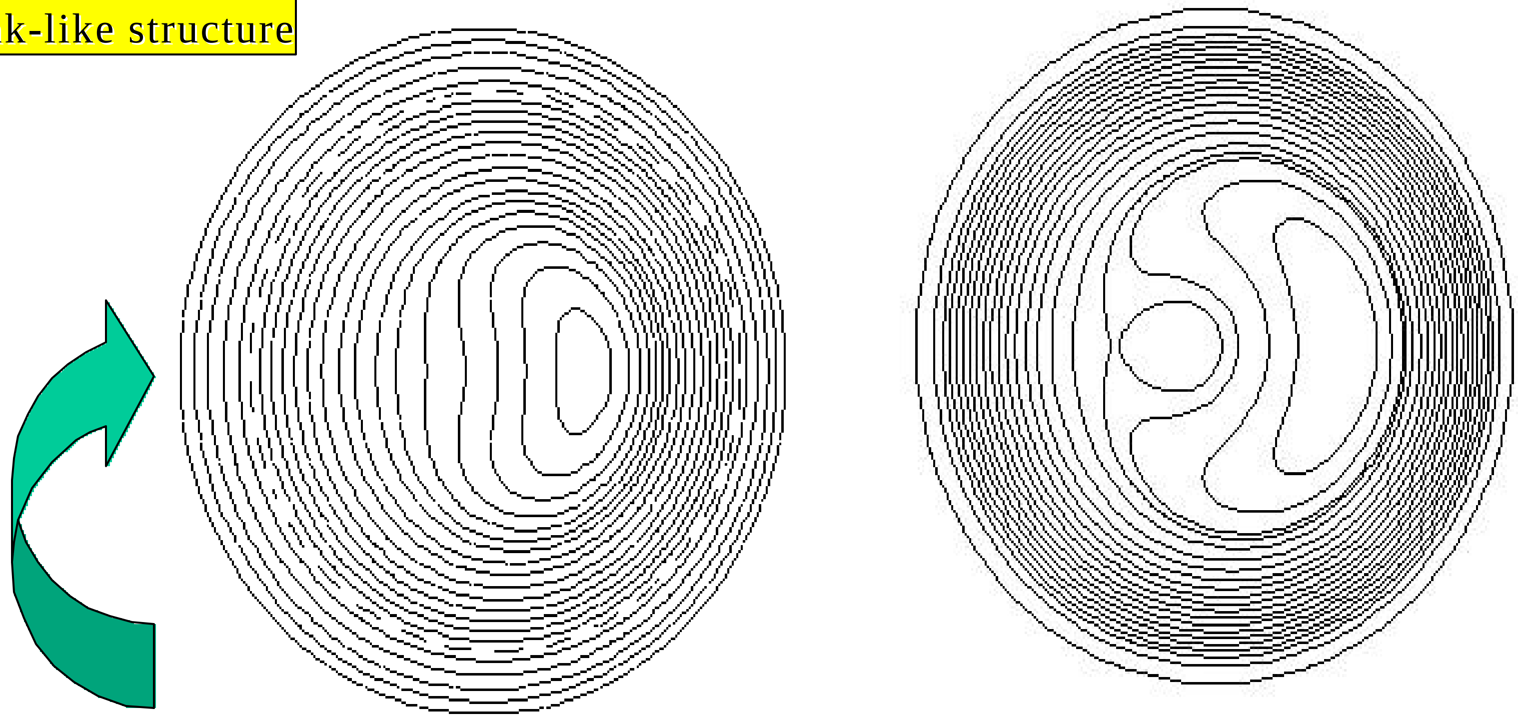


Toroidal angle

Poincare' plot
for QSH state

SEPARATRIX EXPULSION FOR SH STATES

Bean Shape
Kink-like structure



Increasing amplitude
of the dominant mode

SADDLE-NODE
BIFURCATION