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Ricerca Formazione Innovazione

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The role of plasma flow on quasi-helical states in reversed-field pinches

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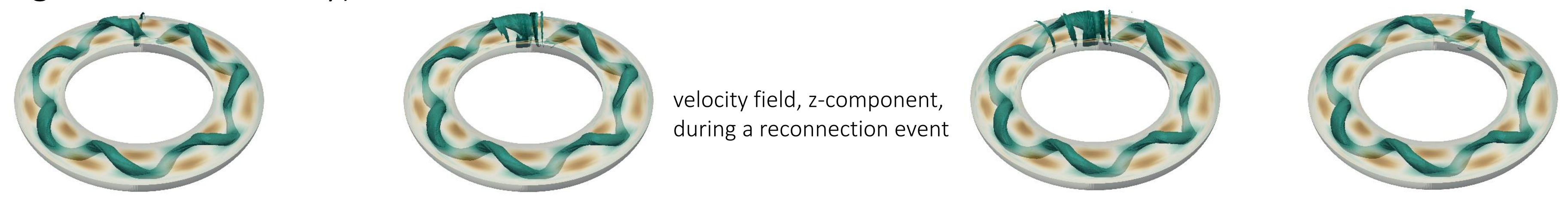
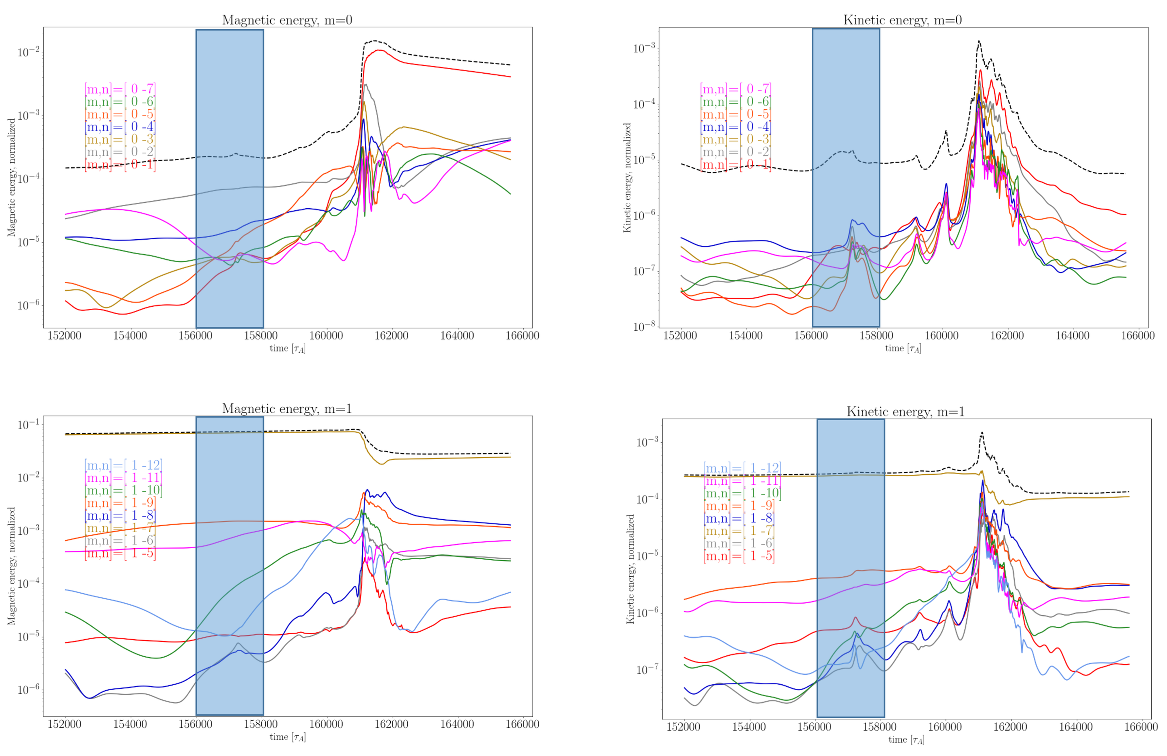
INTRODUCTION: Magnetic reconnection [1] involves changes in the connections of magnetic field lines, leading to modifications in the magnetic field topology. This phenomenon is common in both space and laboratory plasmas, such as solar flares [2], planetary magnetospheres, and laboratory experiments involving laser-plasma interactions. Magnetic reconnection is characterized by the release of magnetic energy, which is converted into kinetic and thermal energy within the plasma. It results in the acceleration of particles to non-thermal velocities [3] and the generation of waves and turbulence. Current sheets are often observed as a signature of reconnection.
Between the many configurations used to confine hot plasmas, both the RFP and the tokamaks exhibit a tendency to develop kink-like deformations, with RFPs forming a global helical configuration characterized by the quasi-single helicity (QSH) state [4, 5], interrupted by events which exhibit the signatures of magnetic reconnection [6]. These events have been referred to by various names in the RFP literature, including "dynamo relaxation events," "RFP sawtoothing," "discrete dynamo activity," and "localized reconnection events."

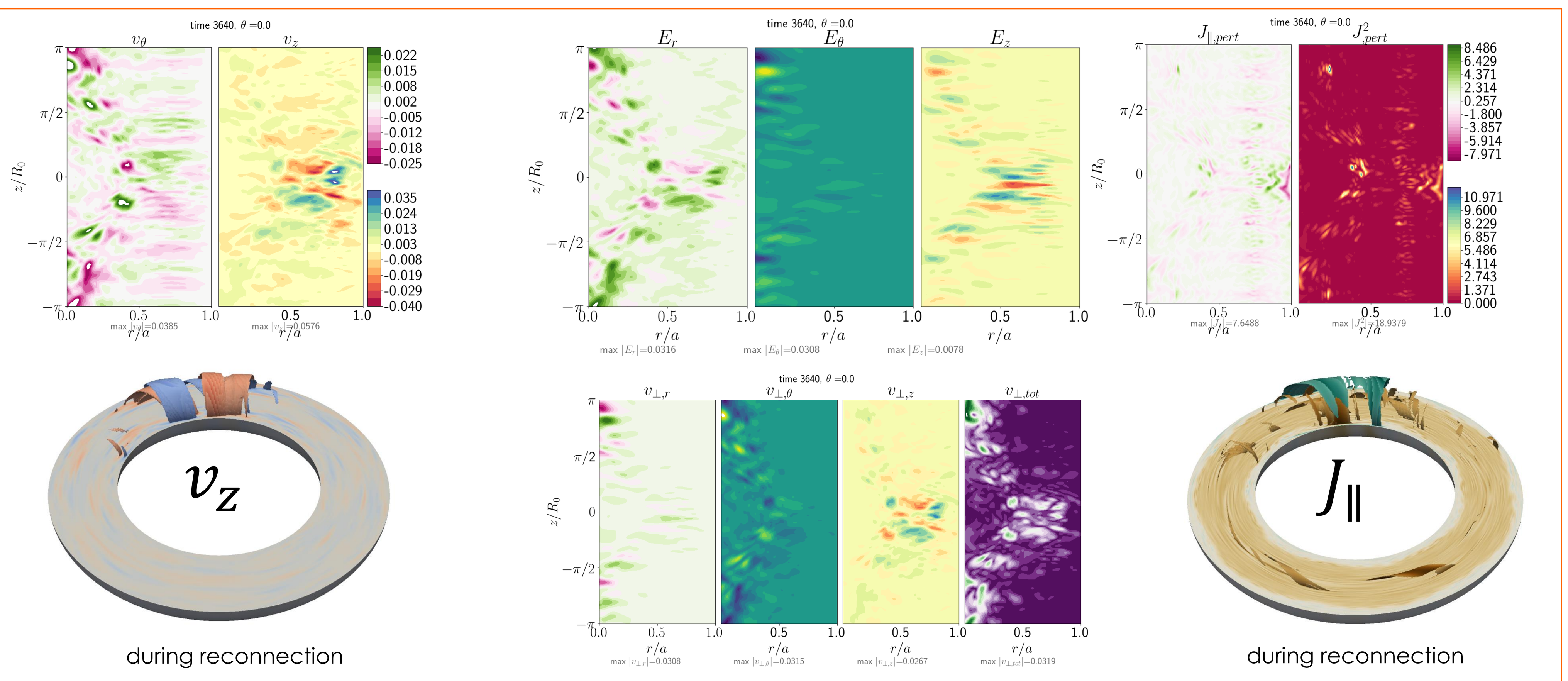
AIM: answer the question: "what is the cause of the relaxation / reconnections events in the RFP?"
TOOLS: 3D nonlinear visco-resistive MHD modelling, and a wide set of diagnostics for the physical quantities like magnetic field, velocity field, current density field, electric field
RESULTING INDICATION: The reconnection event is caused by the phenomenon of "collapse of the helixes", meaning that localized imperfections of the quasi-helical structure of the magnetic and velocity fields result in localized asymmetries in the plasma current density helical distribution. And given that co-currents tend to attract each others, a partial or total collapse of the structure is bound to happen. In this work we study both minor and major collapses of the RFP helical backbone. We focus on small/incomplete reconnection events, because the behaviour of the plasma is easier to observe than in the major events (which generate current sheets, high magnetic stochasticity).



MAIN FEATURES of huge reconnection events in the reversed-field pinch

- release of magnetic energy, converted into kinetic and thermal internal energy of the plasma [1]
- presence of so-called current sheets [7, 8]
- acceleration of particles to non-thermal velocities [3],
- generation of waves and turbulence [9]





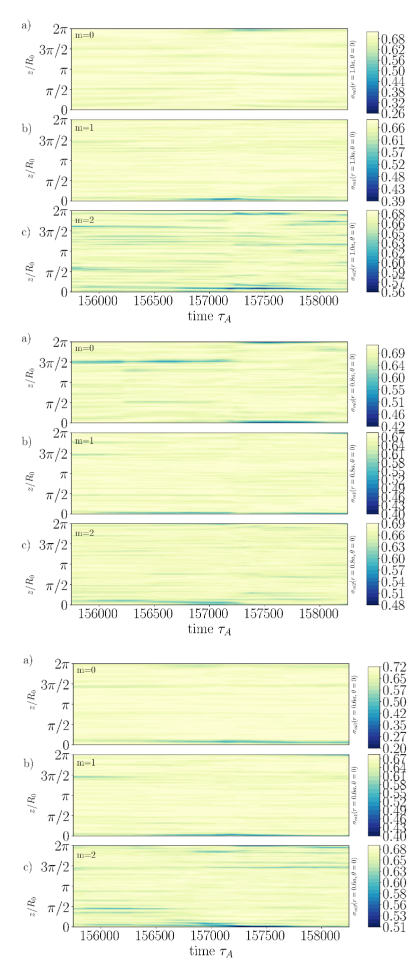
why study minor reconnection events

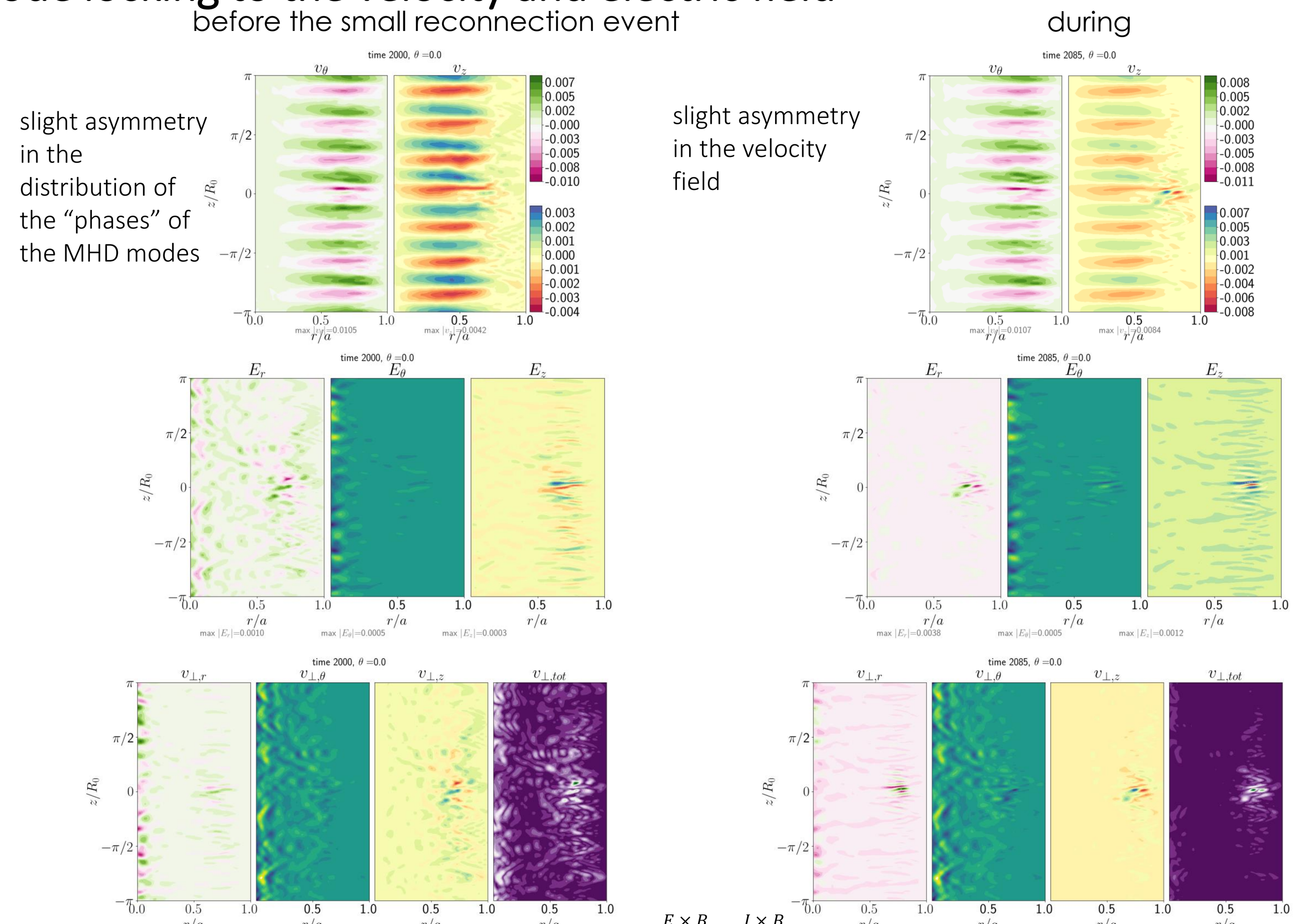
so-called "minor crash", i.e. a crash that does not destroy the helical state.
This allows avoiding the outburst of MHD modes and velocity associated with the main relaxation events, that obscures some of the features of the process.
In extreme synthesis:

- around the position of strong mode locking one can observe irregularities in the spatial distribution of the velocity field with respect to a quasi-helical structure.
- The locking provokes an outburst of velocity that aims at decreasing the locking itself
- a generation of localized electric field, perpendicular velocity, intense plasma current spikes around the position of high locking.

from magnetic field mode locking to the velocity and electric field

before the small reconnection event — during

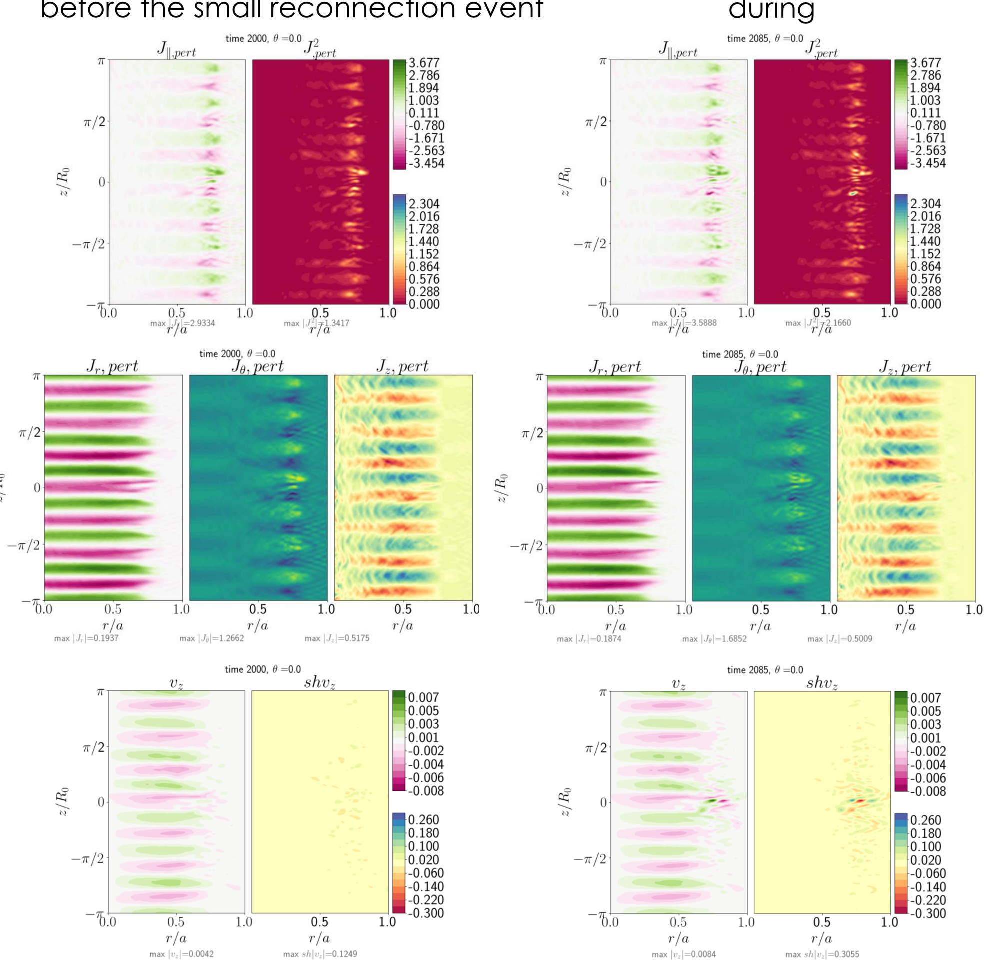




$$v_\perp = \frac{E\times B}{B^2} - \eta\frac{J\times B}{B^2}$$

plasma current density features

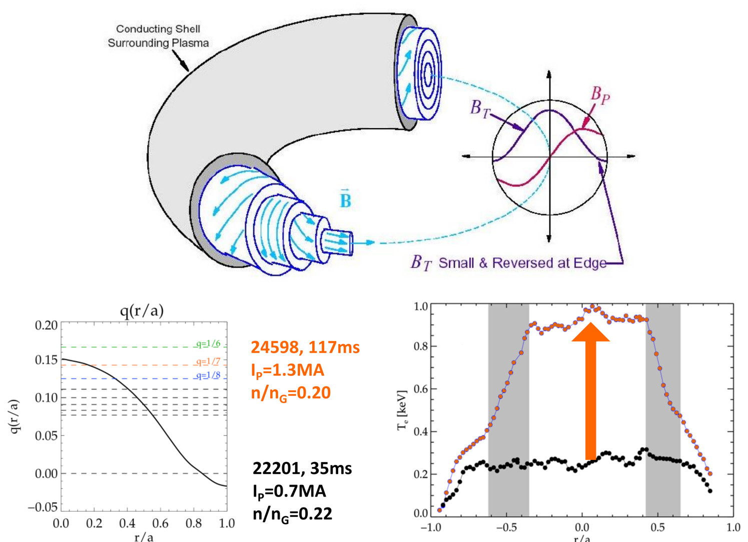
before the small reconnection event — during



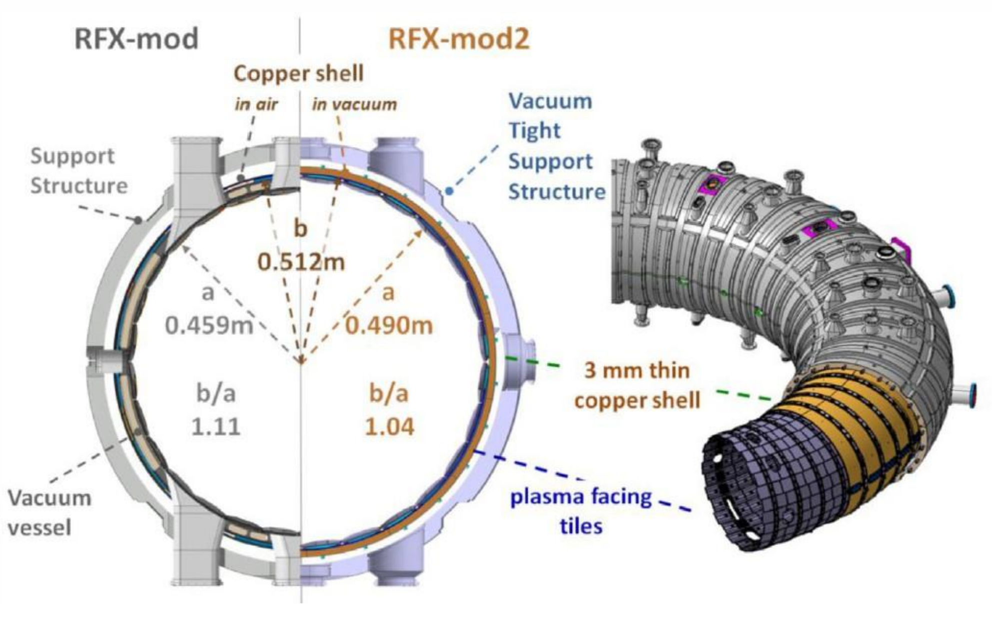
THE REVERSED-FIELD PINCH: similar to the tokamak but 10x stronger plasma current (with same B_ϕ)

consequences:

i) the current produces most of the confining magnetic field;
ii) toroidal field coils need to produce just the small reversed field -> simplicity
iii) high current can heat the plasma



RFX-MOD2 NEW MAGNETIC LAYOUT



The highly resistive vessel will be removed, graphite tiles will be attached to the copper stabilizing shell and the stainless steel support structure will be modified in order to be vacuum tight. In RFX-mod2, the shell-plasma proximity passes from b/a = 1.11 to b/a = 1.04 and copper, instead of Inconel, will be the continuous conducting structure nearest to the plasma [10].

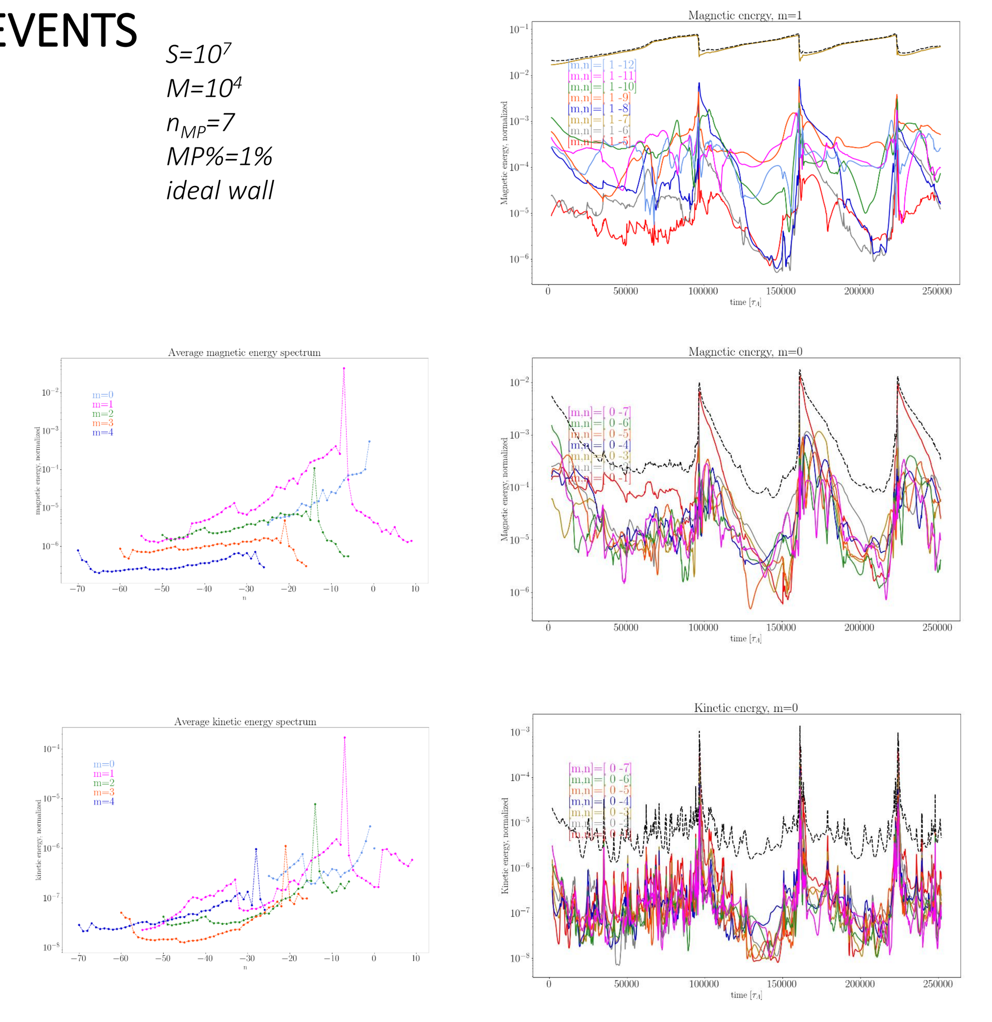
MHD DESCRIPTION OF RECONNECTION EVENTS

3D nonlinear viscoresistive MHD modelling gives a description of mode locking similar to the one coming from the experimental measurements previously described.
Peculiarity: the phase of growth of the helical state is often disturbed by the growth of secondary perturbations not having the necessary strength to destroy the helical state.
One can observe the quasi-periodical emergence of a QSH state, interrupted by violent eruption observed as a sharp increase of the kinetic energy.

$S=10^7$
$M=10^4$
$n_{MP}=7$
MP%=1%
ideal wall

$$\partial_t \boldsymbol{v} + \boldsymbol{v}\cdot\nabla\boldsymbol{v} = \boldsymbol{J}\times\boldsymbol{B} + \frac{1}{M}\nabla^2\boldsymbol{v} + \frac{1}{Q}\boldsymbol{S}_M$$
$$\partial_t \boldsymbol{B} = \nabla\times\left(\boldsymbol{v}\times\boldsymbol{B} - \frac{1}{S}\boldsymbol{J}\right)$$
$$\nabla\times\boldsymbol{B} = \boldsymbol{J}$$
$$\nabla\cdot\boldsymbol{B} = 0$$

$$\sigma_m = 1/N_{tot}\sum_{j=1}^{n_{max}-1}\sum_{k=j+1}^{n_{max}}\left|\sin\left(\frac{\phi_{m,j}-\phi_{m,k}}{2}\right)\right|$$



solved by SpeCyl [10]
Physical approximations:

- $\rho = cost, p = 0$;

some definitions:

- cylindrical geometry: periodical boundary conditions on θ and z;
- resistivity: $\eta_0 = \frac{\tau_A}{\tau_R} = S^{-1}$ (inverse Lundquist number).
- viscosity $\nu_0 = \frac{\tau_A}{\tau_\nu} = M^{-1}$(inverse viscous Lundquist number).
- Dissipation coefficients radial profile: $\eta(r,t) = \eta_0(1+20r^{10})$; $\nu(r,t) = \nu_0$

- S_M represents an ad-hoc momentum source
- Edge MP is imposed at $r = a$ with amplitude given by the quantity $MP\% = \frac{B_r(a)}{B(a)}\%$
- Edge MP is a single helical modulation of the radial component of the field, typically with m=1.

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