Magnetic reconnection in fusion plasmas: the case of the Reversed-field Pinch

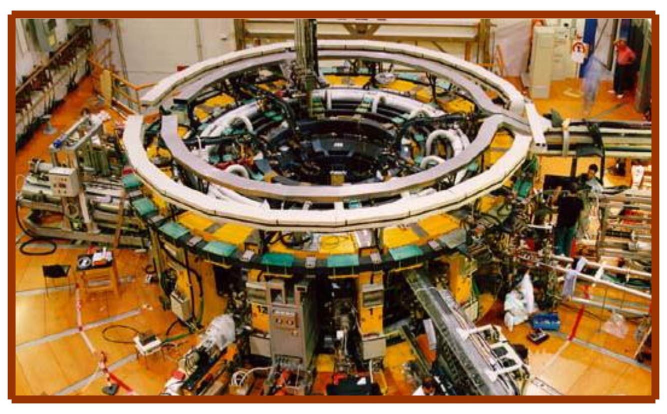
Luigi Cordaro, Matteo Zuin, Emilio Martines

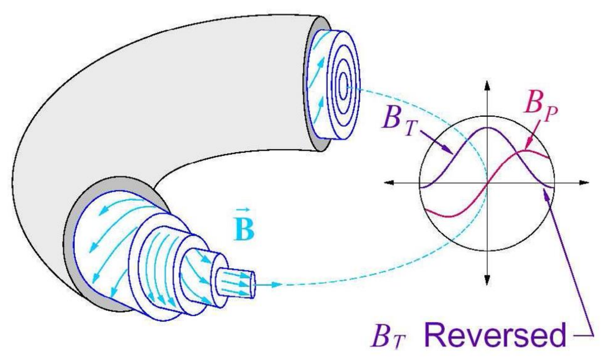
Joint Doctorate and Network in Fusion Science and Engineering
Consorzio RFX, Corso Stati Uniti 4, I-35127 Padova, Italy

luigi.cordaro@igi.cnr.it

RFX-mod experiment

R/a = 2 m/ 0.459 m





Plasma current: 0.1÷1.8 MA

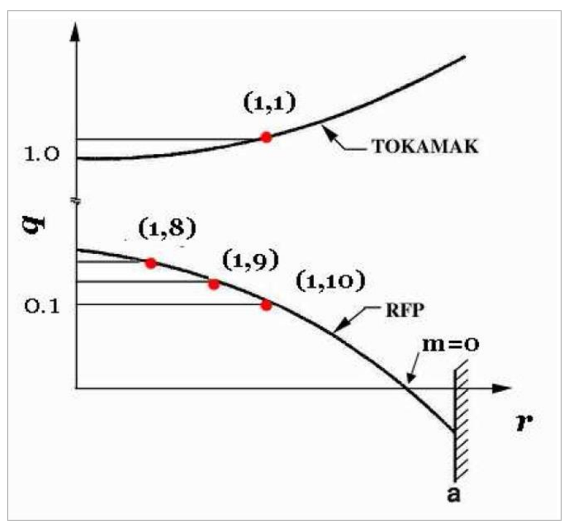
Summary

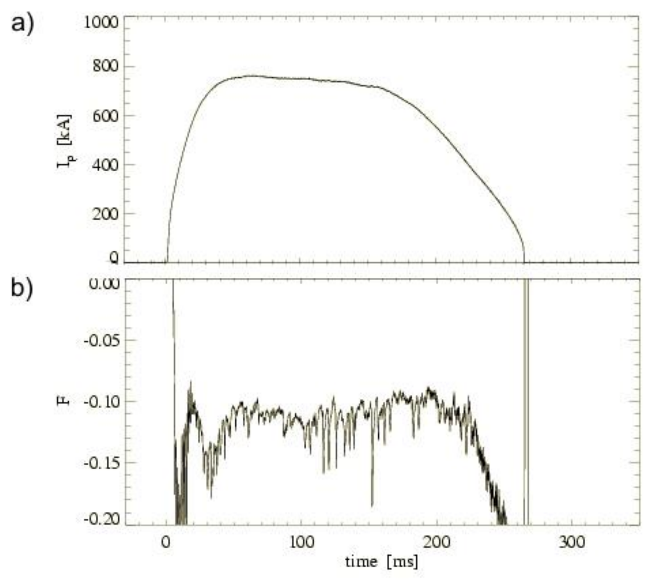
- **Magnetic reconnection, in which magnetic field lines break and reconnect to change their topology, occurs throughout the universe. The essential feature of reconnection is that it energizes plasma particles by converting magnetic energy.**
- **Recent simulations have shown that fragmented current sheets are efficient accelerators for electrons and ions.**
- **An analysis of plasma dynamics during impulsive magnetic reconnection events in the RFX-mod reversed field pinch (RFP) is performed by means of a large set of magnetic in-vessel coils.**

Introduction

In a RFP discharge, relaxation events, both continuous and discrete, are related with self-organized processes. Along with the action of the continuous dynamo process, discrete quasi-cyclic relaxation events, associated with re-arrangement of magnetic topology through reconnection phenomena, have been seen in RFP plasmas.

The F parameter is characterized by a series of abrupt, almost periodic fluctuations at different scale lengths (both in time and space), the largest of which are associated with local magnetic perturbations which move in the toroidal direction and associated with the generation of current-sheets.

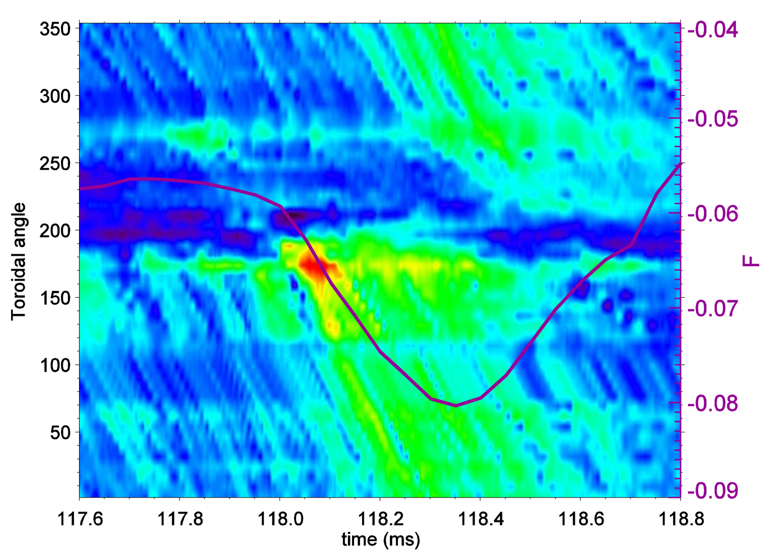




$$F = \frac{B_\Phi(a)}{< B_\Phi >}$$

Reversal Parameter

The presence of a localized perturbation is due to the interaction of m=1 dynamo modes that reaches its maximum value in a toroidally localized region around a position dubbed as Φ_{lock} (the process is dubbed as locking in phase). The abrupt decreasing (crash) in the magnitude of these modes is associated with an increase in the magnitude of the m=0 modes. This energy transfer could be caused by magnetic reconnection processes. The m = 0 activity begins at the lock position and then moves with the plasma in a direction opposite to the toroidal current, that is towards decreasing toroidal angles (according to the RFX-mod reference system). The perturbation seems to show a fragmented aspect.



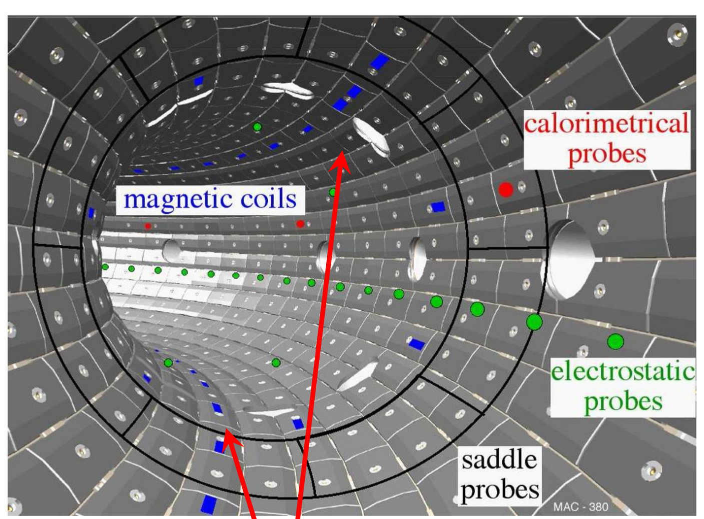
Diagnostics

MAGNETIC DIAGNOSTIC

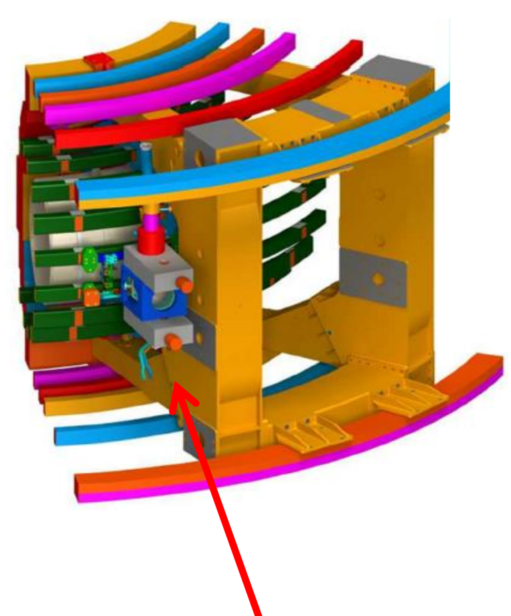
The data analysis here presented refers only to the toroidal magnetic field measurements collected by **ISIS** (Integrated System of Internal Sensors), whose magnetic sensors (pickup coils) are placed just below the graphite first-wall (r = 1.03a), forming two arrays at diametrically opposite positions (θ=70, θ=250). These sensors allow the magnetic field measurement at the edge of the plasma column.

NEUTRON DIAGNOSTIC

The diagnostic system makes use of a 51 mm diameter, 51 mm thick EJ-301 liquid scintillator cell and of a calibrated crystal NaI(Tl) larger scintillator coupled to H8500 flat-panel photomultipliers. The liquid scintillator is sensitive to neutron and gamma radiation, signals being classified on the basis of a pulse shape discrimination (PSD) process.



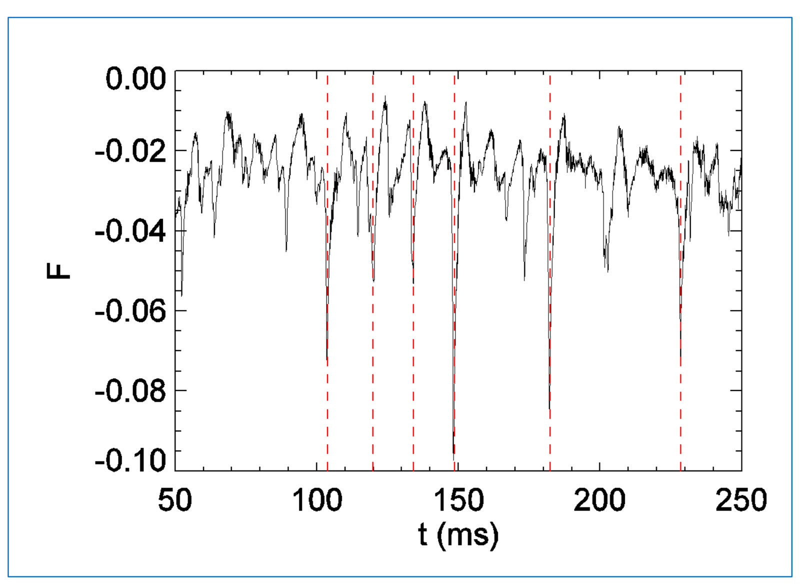
Two arrays of 48 magnetic sensors uniformly distributed along the toroidal direction



Neutron detectors

Intermittent structures recognition
Wavelet based Method

A method, based on the Wavelet Transform, able to recognize the signals' intermittent structures, was used in order to study the evolution of the current sheets associated with magnetic reconnection processes in a statistical way.



$$C(\tau,s) = \frac{1}{\sqrt{s}}\int f(t)\Psi\left(\frac{t-\tau}{s}\right)dt$$

Wavelet

$$I(\tau,s) = \frac{C(\tau,s)^2}{< C(\tau,s)^2 >}$$

Local intermittency measure

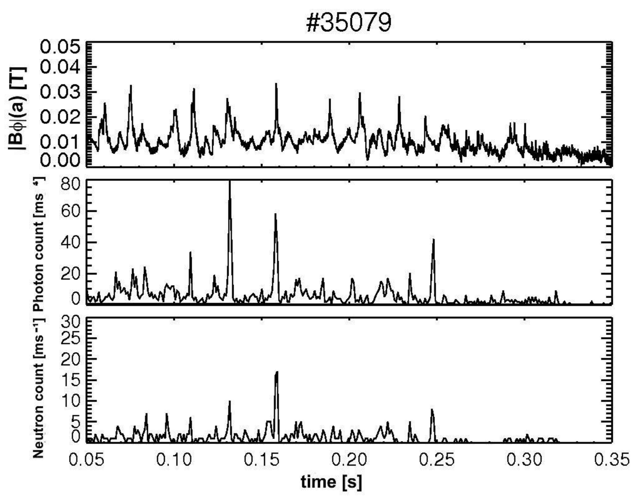
$$F(s) = \frac{< C(\tau,s)^4 >}{< C(\tau,s)^2 >^2}$$

Flatness

Experimental analysis

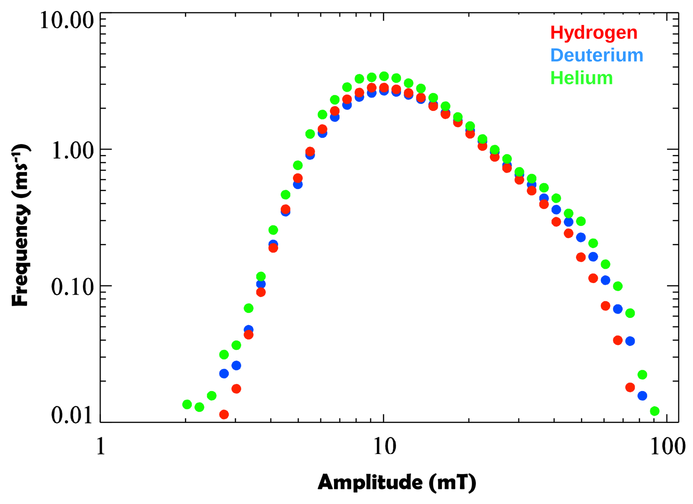
Particle acceleration

- Bursty generation of D-D fusion neutrons and γ rays are observed, which appear to be time correlated with the rapid variation of the magnetic field at the edge of the plasma
- This effect could be compatible with particle acceleration by magnetic reconnection processes occurring in plasma.



Statistical distribution

The recognition analysis was performed on every magnetic signal (relative to a single ISIS sensors array) for each pulse, in order to calculate the distribution function, which is the total count of events in a plasma shot as function of amplitude.

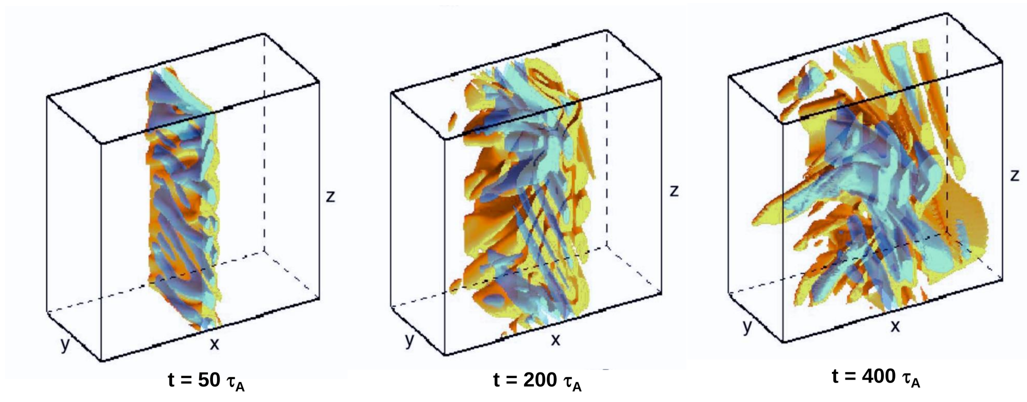


- Distributions show a dependence on the ion masses.
- At medium amplitudes (15mT< $\vec{B}$ <30mT) distributions appear superimposed. Power law trend.

- Possible dependence on the ion Larmor radius?
- Is the two-fluid MHD model mandatory for the study of magnetic reconnection phenomena?

Current sheet analysis

Onofri, Isliker, Vlahos, 'Stochastic Acceleration in Turbulent Electric Fields Generated by 3D Reconnection', Physical Review Letters, 2006



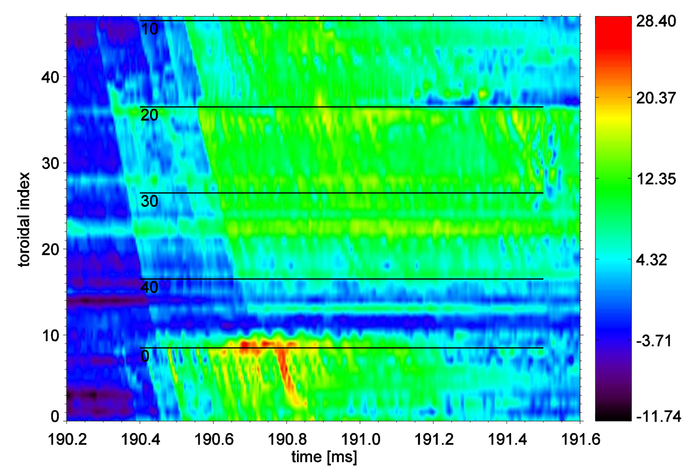
$$\tau_A = \frac{L}{v_a}$$

$$v_a = \frac{B}{\sqrt{\mu_0 \rho}}$$

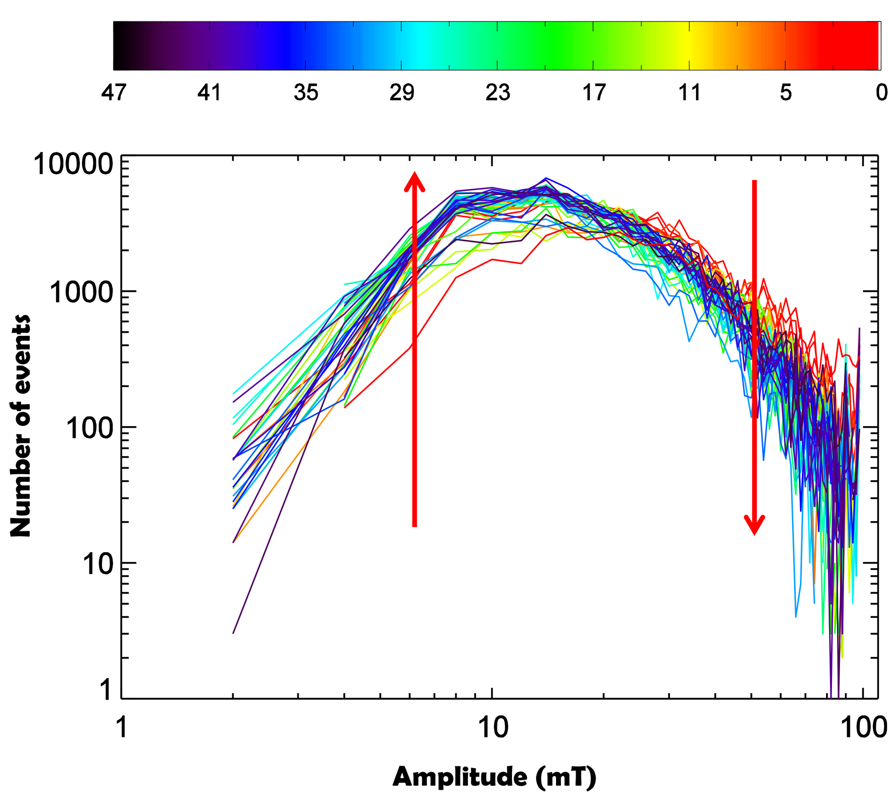
Current sheet evolution simulation

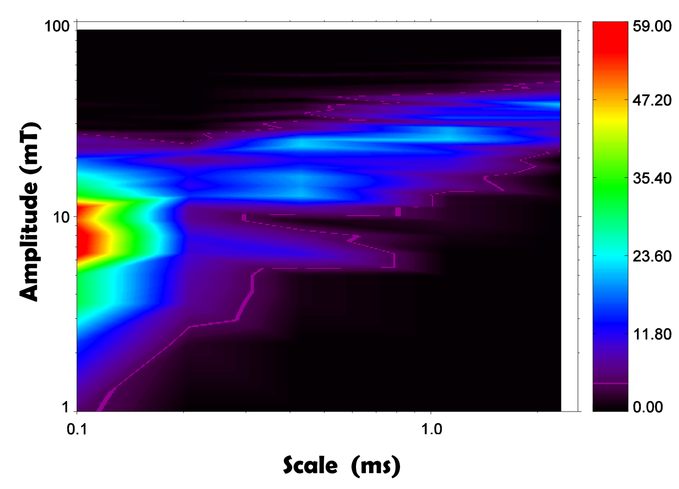
- Current sheet is fragmented in a quite short time
- Fragmented current sheet is a good ion and electron accelerator

Are there fragmented current sheets in the RFX-mod plasma?



- Identification of magnetic reconnection events corresponding to the crashes of the F parameter
- Recognition, for each crash temporal window, of the intermittent structures in the m=0 component of the magnetic field
- Identification of the toroidal index associated to the current sheet formation
- Creation of a new reference system
- The number of events is counted for each index





- $\vec{B}$ > 50 mT: the frequency of big recognized events decreases going from the 0 index (red curve) to higher ones.
- $\vec{B}$ < 20mT : the frequency of smaller events increases going to smaller scales.

- Current sheet fragmented
- Fragmentation time compatible with simulation

Conclusions and perspective

- **The statistical analysis here proposed shows that current sheets, associated with magnetic reconnection events in Reversed-field Pinch plasmas, exhibit fragmentation dynamics.**
- **Analysis will be done in order to understand how these fragmented structures can lead to the observed particle accelerations.**