Activity Report

2013

INTRODUCTION AND KEY RESULTS

EXPERIMENTAL PHYSICS PROGRAM

NBI DEVELOPMENT

ITER

THEORY AND MODELING

DIAGNOSTICS

BROADER APPROACH

DEMO

EDUCATION TRAINING AND INFORMATION TO THE PUBLIC

PUBBLICATION LIST

INTRODUCTION AND KEY RESULTS

The 2013 Activity Programme of Consorzio RFX was presented and evaluated at the 29th meeting of the RFX Scientific-Technical Committee on the 4th December 2012 and afterward it was finally approved, with adaptation to the available resources, in the Consorzio RFX Member meeting, the 3rd September 2013.

The long time required for the approval of 2013 Program and Budget is a clear signal of the difficulties encountered to combine the very rich experimental program on RFX, foreseen in 2013, and the very intensive activity necessary for PRIMA facility realization with the available financial resources. The initial foreseen programme was substantially confirmed and executed with a slight reduction on the actual available experimental time in RFX-mod for cost containment.

The approved programme remained focused on the two main research lines of Consorzio RFX: the realization of the NBI Facility and the exploitation of the RFX-mod, both with experimental and theoretical studies. Other accompanying activities were related to the development of diagnostic systems including the ITER magnetic measurements, the studies on the neutral beam and its plasma interaction, the Broader Approach program, the studies related to the fusion reactor, the public information and the education and training.

Key Consorzio results are related to:

- the tests on the prototypes of tungsten coated tiles, in view of the change of the first wall
- the density profile modification due to Li deposition on the first wall utilizing different techniques,
- improvement in the MHD control system by reducing the latency time,
- the sawtooth stabilization with external perturbations of low q Tokamak configuration in DIII-D and RFX-mod;
- the relevant progress in the PRIMA building construction which allows the start of the experimental plant installation;
- the completion of the tender specification of MITICA vessel and the progress in the realization of the SPIDER components, all under construction by the suppliers;

- an innovative magnetic configuration (non-continuous Halbach configuration;) was considered and studied thoroughly, which has now become the reference solution for the ion source;
- the completion of the construction of the ion source for NIO1;
- Progress of the Broader Approach activities which are perfectly on schedule.

Activities on diagnostics have suffered from the lack of adequate funds; anyhow improvements in a few RFX-mod diagnostics (SXR, arcless power supplies, room temperature pellet injector, multipellet lithium injector, fast camera for edge turbulence analysis, neutron spectrometer) have been made with an overall increase of measurement capability.

EXPERIMENTAL PHYSICS PROGRAMME

Experimental activity related to the study of the effect of a metallic first wall

Tests of metallic in place of graphite Plasma Facing Components (PFC) for RFX have been carried out: prototypes of tungsten coated tiles (similar to those successfully tested on AUG and JET) have been exposed to the plasma. The tiles have been produced by the National Institute for Laser, Plasma and Radiation Physics, Bucharest, Romania; they are covered by a 15 μm tungsten layer by the Combined Magnetron Sputtering and Ion Implantation (CMSII) technique. The tiles have been exposed to RFX plasmas around an equatorial access. Inspections by a CCD camera show several signs of arcs (see fig. 1). Such damages raise the issue if metal layers with thickness of the order of tens of microns are a suitable PFC for high current RFP plasmas, so that new experiments, involving materials with thicker layer depositions (obtained by different techniques) or bold metals are necessary in the next months. However, no macroscopic impact of tungsten has been observed on the plasma, though several W lines are detected by the

Fig. 1: image of W deposited tiles after about 450 plasma discharges

spectrometers. This is consistent with the transport analysis after W LBO experiments showing that W does not penetrate the plasma core.

In addition, smaller samples have been exposed to the plasma, on the one hand aiming at: characterizing different depositions and comparing the effective recycling of different material. On the other hand, such experiments are of general interest for fusion devices, since the samples in RFX can be tested with localized power loads up to 100 MW/m^2. Two series of samples, one produced by the CMSII technique in Bucharest and the other one by High Power Impulse Magnetron Sputtering technique at CNR-IENI, Padova with W layers of 10 and 20 μm have been exposed and compared. Both series showed damages (arc traces and delamination at the edges). Work is in progress to optimize the depositions and test new techniques.

A modeling activity aimed to improve the description of plasma edge in presence of a metallic wall and to simulate the impact of a low recycling wall on plasma scenarios has been pursued.

The NeNe code has been used to evaluate the effect of a W wall on neutral penetration, showing that at low density a W wall corresponds to a more internal source and therefore more peaked density profile

The effect of different wall recycling values has been included in the simulations by the ORBIT code to correctly evaluate ion and electron fluxes (and therefore radial electric field). In particular, such simulations allowed to understand how, due to the edge magnetic topology, small electron imbalance can trigger major density accumulation leading to the development of MARFE-like poloidal structures. Similar analysis have been carried out in collaboration with the TEXTOR team, showing that in TEXTOR edge plasma electrons are trapped at the O-points of the remnant islands. Indeed, in order to draw a unified picture of particle transport, in the RFP and tokamak RMPs, test particle transport simulations have been done on TEXTOR with the same tool ORBIT used in RFX-mod, allowing for an initial estimate of the radial electric field Er.

Collaboration with Tokamak laboratories on the interaction between plasma and W PFCs has been reinforced. Two experimental sessions have been performed at JET with injection of metal impurities. Molybdenum has been proven the most efficient element for impurity transport studies. Two additional experimental sessions have been postponed to 2014 after a major fault has stopped the JET operations. Analysis work of impurity transport on JET has continued in collaboration with IPP Garching and IFP Milan.

Experimental activity related to a modification of the RFX-mod magnetic front-end

Modeling by using the electromagnetic code RFXLOCKING to qualify the operative scenarios in different configurations with different positions and characteristics of the conductive shell has been performed. The result is that bringing the conductive shell closer to the plasma would lead to a significant reduction of the plasma deformation (i.e. of plasma-wall interaction), both in terms of the scrape-off layer width due to m=1 modes and of the scrape-off layer width due to sidebands. In this respect, feasibility studies are in progress to assess the possibility of removing the vacuum vessel keeping the present position of the shell thus improving plasma-shell proximity.

Activity related to the beam tangential injection

The installation of the AIST beam on RFX was further postponed due to the lack of adequate funds. Extra TRANSP runs carried out at Madison, Wisconsin, to assess the disadvantage of a perpendicular injection with respect to a parallel one have shown that the beam heating on electrons is about three times larger in the tangential NBI scenario, while the neutral beam current drive is seven time larger (in any case modest). All others quantities however, and in particular the fast particle density, are similar, with difference less than 25% thus confirming fast ion physics studies would not be severely affected in a scenario with perpendicular injection.

RFP experiments with Deuterium

The licensing procedure for operation with deuterium as filling gas has been successfully concluded and first experiments with deuterium performed at the end of 2013. A new neutron diagnostic has been installed in collaboration with University of Padova, Physics Department: very preliminary results show a correlation between neutron emission and MHD activity, with bursts of neutrons following magnetic reconnection events. A first survey scanning the main plasma parameters (current, density, edge field reversal) has been carried out with deuterium as filling gas. First results are encouraging: the pureness and duration of the improved helical states increases. At the same density and secondary mode amplitude, electron temperature increases as well, both in the core and at r/a=0.66 (fig. 2). Though deuterium discharges have not been optimized yet (for

example, the wall was not conditioned by boronisation), the electron energy confinement time increases by about 25%.

Injection of 50 keV neutral deuterium by means of the diagnostic neutral beam injector into a deuterium plasma has shown the possibility to use the neutron detector for experiments of fast ions transport, based on the decay time of the neutron signal after the end of the beam pulse.

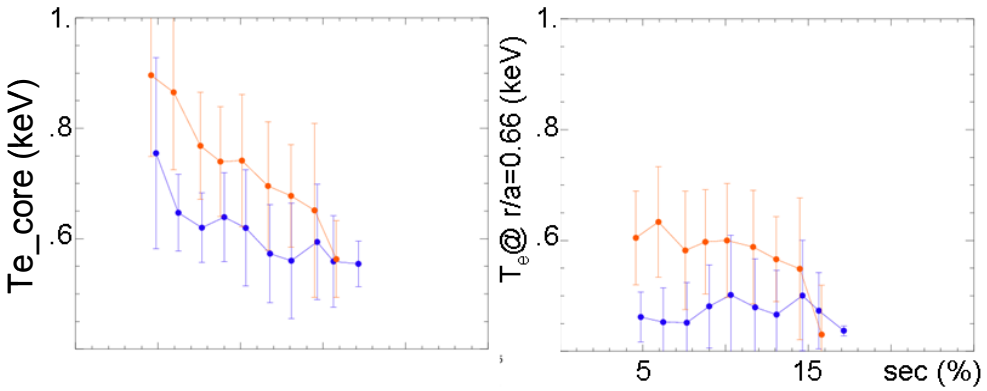

Fig.2: electron temperature in the core (left) and at r/a=0.66 (right) as a function of the secondary mode amplitude normalized to the poloidal field. Red: deuterium discharges; blue: hydrogen discharges. Average values in discharges with Greenwald fraction ranging between 0.08 and 0.18.

Density control at high plasma current

In order to obtain a Li deposition on the wall more uniform than with one evaporator, a multi-pellet injector developed in collaboration with PPPL has been applied. In a first version of the device the pellet velocity was too low to penetrate the plasma. The injector has been upgraded increasing pellet frequency and velocity. Though the uniformity of Li deposition has improved, the velocity and the amount of injected Li in a high current discharge is still not sufficient to guarantee a uniform coverage of the plasma wall, and a further modification of the injector and increase of Li spheres diameter is under consideration.

Fuelling of the plasma core has been performed by H pellet injection at high current with low recycling wall. It has been found that the application of pellets on Li covered wall produced a modification of the density profile comparable to what observed with carbon wall: density peaks at low density.

MHD control experiments with the upgraded control system

The upgraded control system has allowed the latency to be decreased (from 1.5 to 1 ms) and, more important, the computing power to be increased. As a result, the sideband correction has been extended to *n*=24 and *m*=0,1,2 by applying clean virtual shell and switching from a modal control to a position control. Experiments based on Clean Mode Control algorithm at sensor radius have been completed and the results presented at the EPS conference.

In addition, in Tokamak configuration the control algorithms based on the so called plasma response have been tested.

Studies of MHD control with reconfigured system including lower numbers of coils, already started with the former control system, have been transposed to the new one, and the benchmarck with electromagnetic codes used for ITER (CARMA) has been performed.

Transport studies and 3D physics

The mechanism leading to the crash of QSH and the relation between magnetic SHAx and thermal barrier has been investigated and the results reported in several EPS contributions and in a dedicated PPCF paper. The VMEC and V3FIT codes have been applied for the reconstruction of helical equilibria and the results reported at the joint RFP-Stellarator workshop.

Magnetic equilibria have been reconstructed using diagnostic information as constraints by the V3FIT code with VMEC as equilibrium solver. The used diagnostic are both magnetic (Mirnov coils, flux loops, saddle coils, total of 626 measurements) and kinetic (electron temperature and density, SXR emissivity, total of 150 signals). An example is

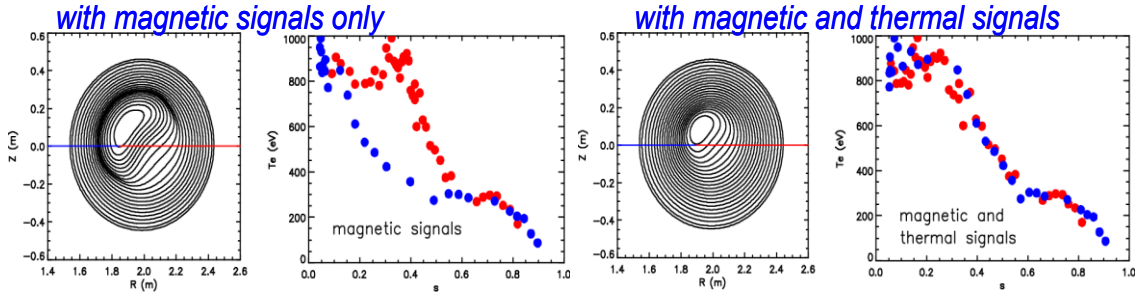

Fig.3: comparison of helical magnetic equilibrium and temperature profile reconstruction by the V3FIT + VMEC code, with magnetic diagnostic only (left) and with magnetic and thermal diagnostics (right)

given in fig.3, showing that pressure profile is important to reduce the degeneracy of the helical equilibrium.

Experiments, aiming at characterizing the kinetic of the *m*=0 islands developing at the edge and the effect of collisionality on the phase relation between radial electric field and the magnetic perturbation have been performed and the results included in invited talks at EPS and APS and in dedicated contributions. A main outcome is that the edge magnetic topology related to the *m=0* island amplitude and phase is crucial in determining two density tresholds: the first, at $n/n_G \approx 0.3$ related to the achievement of the helical states, the other one, at $n/n_G \approx 0.6$, corresponding to the radiation high density limit.

Turbulence studies

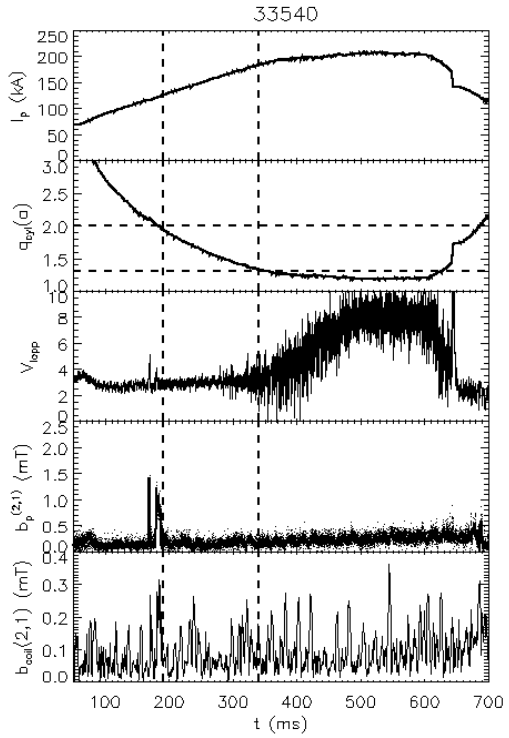

Fig.4: RFX-mod tokamak discharge. From top to bottom: plasma current, edge q, loop voltage, (2,1) mode amplitude, (2,1) coil current

To improve the understanding of the stability of all the micro-turbulent modes in helical states a version of the GENE code using the equilibrium calculated by VMEC will has been adapted to the RFP in collaboration with IPP Greifswald and the results have been reported in several papers. Small scale electromagnetic turbulence driven by strong electron temperature gradients has been experimentally observed and characterized by means of high-frequency in-vessel magnetic diagnostics. A Neutral Particle Analyzer, has been installed to measure the ion temperature for studies of fast ion in relation with alfvenic drift modes. Experiments at low plasma current with 3D external fields have been performed to produce helical states where turbulence has been studied by means of insertable probes: effects of helical magnetic perturbation on turbulent intermittent structure, on long-range correlation and on spectral properties has

been carried out. Investigations are in progress to address the different transport properties in relationship with the local magnetic topology.

Operation in Tokamak configuration

Experiment in tokamak configuration with q(a)<2 or q(a) slightly greater than 2 have been performed with the control done by means of B_θ sensors (without Clean Mode Control) instead of B_r sensors with CMC as done previously.

As an example, figure 4 shows an RFX Tokamak discharge where q(a) =1.3 has been reached and controlled.

The effect of a reduced numbers of coils has been experimentally studied.

External 3D fields have been applied to complete the experiments involving sawthooth control by means of external perturbation fields and to study the relation between RMP, edge flow and turbulence.. Experiments on sawtooh stabilization with external perturbations have been replicated on DIII-D (Torkil Jensen award 2013), and the results have been presented at the last APS conference. In the framework of a joint experiment (ITPA) to study the control of runaway electrons, preliminary experiments have been carried out

With the objective of producing a double/single null Tokamak plasma and induce the L-H transition to exploit the RFX control system for studies on ELM control via magnetic perturbation application, a shape feedback control scheme has been designed and successfully implemented. Elongated plasma discharges have been produced in an accurate and repeatable way, thus demonstrating the possibility of a stable feedback controlled operation with an elongated plasma. On this topic, the collaboration with the DIII-D team has shown active and will continue for 2014 experiments.

JT60SA: Participation to EFDA/F4E activities in preparation of JT-60SA exploitation

All the programmed activities advanced in 2013 and met most of their targets:

- the coordination of European MHD activities is finalizing EU MHD contributions to version 3.1 of the JT-60SA Research Plan;
- diagnostic system optimization continued focusing on the Thomson Scattering diagnostic optics and on the polarimeter design;

- Resistive Wall Mode stability calculations done including the effect of plasma flow;
- Consorzio RFX contributed to the activities of the Data Working Group with one of the four European members: the Working Group wrote the final activity report in October 2013;
- predictive scenario simulations including the modeling of heating and current drive sources suffered the lack of dedicated manpower and did not advance significantly;
- following the suggestions of the Scientific-Technical Committee of Consorzio RFX, a new activity aiming at RWM control modeling studies with 3D boundary conditions started in 2013.

NBI DEVELOPMENT

PRIMA

The PRIMA buildings are progressing as scheduled, in the first semester the underground works have been completed and the erection of the large buildings started in June 2013. Two of the main plant systems, “Cooling plant” and “Vacuum, gas injection and storage plant” entered into the manufacturing phase in conjunction with the presentation and approval of the detailed design. An extended activity has been carried out in 2013, in support to the integration of the construction of the buildings with the development of the detailed design of the plants and components. The work for the integration of the different plant systems and injector components in the PRIMA buildings has continued and an update of the SPIDER and MITICA assembly and commissioning sequences has been performed.

All the interfaces between buildings and Plant Systems and between different plants Systems have been checked and in meantime an Interface Management System is under preparation as support to this activity. A complex organization is required to coordinate in safety conditions and in according to Italian law, the site activities performed simultaneously by more suppliers referring to different customers. During 2013 the set up of this organization that will be operational in the early months of 2014 when the first installations will begin in the Site was started.

SPIDER

The main contracts for the procurement and installation of all the components and plant systems have been placed. The manufacturing of them is progressing in agreement with the schedule for all the procurement contracts. The preparatory works for the definition of the agreements between F4E and Consorzio RFX for the development of control and diagnostics have been progressed. In particular, at the beginning of the second semester the official call for proposal for the control/interlock/safety systems has been issued by F4E to Consorzio RFX, RFX answered to the call and the signature of this Framework is expected by the beginning of 2014. At the same time definition of the diagnostic contract has been progressed; the signing of this contract is expected by mid-2014. Management of the interfaces and integration of components to be supplied by INDA is progressed to guarantee the coherence of the plant manufacturing phase and its integration in the buildings and with the other interfaced plant systems.

In 2013 it has started the work for the preparation of the sequences and for the preparation of the content of the Commissioning of Facilities Plant up to the integrated tests of PS and up to the overall integrated tests of the experimental test beds in conjunction with the progress of the design and construction activities components and plant systems made available by Consorzio RFX, F4E, IO and the other DAs.

MITICA

The Final Design Review of the Vacuum Vessel has been performed and the preparation of the documentation for the Call for Tender to be issued by F4E has been completed by the end of 2013. The Preliminary Design Review for the Beam Source and the Beam Line Components (Neutralizer, Electrostatic Residual Ion Dump Calorimeter) has been performed. The Final Design Review for the Beam Source and for the Beam Line Components (Neutralizer and Electron Dump, Electrostatic Residual Ion Dump, Calorimeter), originally planned in September 2013, has been rescheduled in January 2014 due to reduced resources devoted to these activities. In fact, the more effort that it was necessary to follow the contracts already signed led to a redistribution of resources with consequent suffering of these activities. The Final Design review for the cryogenic pump was in November 2013, but the Consorzio RFX involvement in the design development of this component has been marginal as the design is done directly by the ITER staff. The bidding phase for the cryogenic plant procurement has been

postponed by F4E in 2014 and therefore the Consorzio RFX activities have been suspended in the first semester. In the second part of the year, this activity was restored and brought forward with the contribution of KIT. The finalization of the tender documentation for the CfT is scheduled for the Spring 2014.
For the Acceleration Grid Power Supplies (AGPS-conversion system) and the ground level power supplies the call for tender documentations have progressed. The technical specifications have been completed and sent to F4E in April. Then it began the phase of the joint review that should be completed in early 2014 when it will launch the Call for Tender phase was iniziated.
A big effort in support to the development of the design of the AGPS high voltage part and the 1 MV insulated transmission line, procured by JA Domestic Agency, has been carried out. All this mainly aimed to guarantee the coherence of all the interfaces with all the other plant systems and components, the integration with the PRIMA buildings and to ensure full compliance with Italian regulations.

R&D activities

Thermo- mechanical R&D - In 2013, different mechanical R&D activities in support to the design of the mechanical components of the MITICA Injectors were carried out. Almost all of these activities were a continuation of activities initiated in previous years, plus one that has consisted in the development of SIC feedthrough prototypes to be applied to the MITICA Vessel.

Radiofrequency R&D - These activities were in support of component design and procurement and in support of the consequent commissioning and operation of RF generators and relevant equipment. They include develop of a resonant circuit for tests of RF voltage holding in vacuum, frequency control for impedance matching and training of Consorzio RFX personnel's at IPP laboratory following the commissioning of the RF Power Supply of ELISE experiment.

Physics Modeling

The modeling activities have progressed substantially with the investigation of new concepts in many aspects of the beam generation. In more detail the main areas of activity were:

- the model for the computation of the neutral particle profile inside the accelerator and along the beam line progressed substantially, including new phenomena; the model was also adopted to interpret experimental results particularly regarding the MANITU data
- the generation of the magnetostatic field, primarily devoted to deflect the secondary electrons co-extracted from the plasma source, was optimized; advanced concepts (non-continuous Halbach configuration; patent documents have been filed) were proposed for the compensation of the undesired deflection of negative ions due to the same magnetic field; this configuration has now become the reference solution
- the electrostatic configuration of MITICA accelerator, including aiming of the beam and compensation of the space charge repulsion, was identified; all aspects of the MITICA accelerator have been studied and for almost all of them the final solution was adopted; for the remaining one (aiming of beamlets) several solutions were studied
- data were provided for the thermo-mechanical design of the plasma source and the accelerator system
- the thermo-hydraulic and thermo-mechanical modeling of the cooling circuits of the different parts of the source and of the accelerator grids was improved
- progress towards the finalization of the electrostatic configuration in the most critical areas of the source and between the source and the vessel at ground potential
- some support was also given to the follow-up of the construction of SPIDER accelerator
- new considerations were proposed for the interpretation of the observed beam optics
- a first version of a new model for the beam evolution along the beam line was realised, taking into account electric and magnetic fields and the production of secondary particles
- The collaboration with the Bari group proceeded and a model based on molecular dynamics was developed to interpret the mechanisms of caesium deposition on copper and molybdenum. Main features of the resulting layer were deduced.

NBI accompanying activities

High Voltage studies - The 2013 activities at HVPTF were focused to study the surface treatments to improve the voltage holding in vacuum at pressures lower than 10^{-6} mbar, moreover a dedicated experimental campaign was carried out to study the magnetic field effect on the left side of the H_2 Paschen curve. A clean room has been implemented to control the environmental powders concentrations in the laboratory; this effort is aimed to reduce the deposition of external contaminants inside the vacuum chamber during the electrode substitution.

Construction of an ion source with extraction system (NIO1) - Site adaptation has proceeded; the vessel supporting structure, the source supporting structure and the mains cabinet were realised. The ion source was received from the supplier and initial vacuum tests were performed; some leaks were fixed. Several items were purchased (e.g. alternative sets of magnets; electrical fence for the transformer; pump, heat exchanger and other items for the cooling system) and the detailed design of the cooling system is in progress.
Construction of the high voltage deck is in progress. The BES model was used for the design the NIO spectroscopy diagnostic.

Participation to operation of Ion sources and Neutral beam injectors at other facilities - Personnel of Consorzio RFX participated in the operation of the BATMAN facility at IPP (Garching) and tested prototype diagnostics produced at RFX. Thorough analysis was performed of the data of spectroscopy diagnostics in BATMAN according to the developed diagnostic model. For STRIKE, two types of analysis codes were developed and applied to the data collected in 2012. Modeling of STRIKE and beam emission spectroscopy diagnostics gave indications of the expected performances of the diagnostics and the possibilities of exploitation. Personnel of Consorzio RFX participated in ELISE commissioning with caesium at IPP (Garching) and visited NIFS to prepare for joint experimental campaigns on NIFS NBI Test stand.

Beam-Plasma interaction - This line suffered the lack of dedicated manpower and did not advance significantly in 2013. A new PhD project on beam-plasma interaction started in 2013 to fill this gap.

ITER DIAGNOSTICS

ITER Magnetic Diagnostics

During 2013 the activities related to the design of electro-magnetic sensors for ITER have been progressing with the involvement of Consorzio RFX in two Grants supported by Fusion for Energy.

With reference to the first Grant (F4E-2009-GRT-047), carried out in collaboration with CREATE, ENEA (UTFUS) and CCFE, the activity was focused on the completion of the evaluation of performance and the optimization of the halo current diagnostic system for ITER, by using simulation and reconstruction algorithms developed in the previous phases of the project. A performance evaluation was carried out on the present layout and on 3 alternative distributions of sensors in order to assess the capability of the diagnostic system to reconstruct the halo current pattern on the first wall with a wide set of representative test cases. The results presented in the Final Report [Bettini2013] demonstrated that the system meets the measurement functional specifications with each of the 4 layouts; nonetheless a significant better performance could be obtained with a redistribution and slight increment of sensors (10 out of 215).

As far as the second Grant is concerned (F4E-2010-GRT-155) the activity was mainly concentrated on the development of the preliminary design of the mechanical and electrical connection system for the in-vessel magnetic sensors. Proper FEM thermo-mechanical analyses were carried out to assess that the stress and deformation due to the welding to the VV are acceptable to guarantee a sound installation and a suitable thermal contact of the sensor assembly to the VV during operating conditions [Gonzalez2013]. Moreover suitable CAD studies were carried out to meet the Remote Handling compatibility requirements. The Preliminary Design Review of the diagnostic system is planed within 2014.

ITER core LIDAR Thomson Scattering (TSCL)

RFX is a member of the ITER Thomson scattering (TS) Consortium, a collaboration between several EU fusion laboratories involved in the design and the development of this important ITER diagnostic. In 2013 a pre-CDR steering panel was held by IO to provide expert advice to help the TS design team determine the best approach for the diagnostic. RFX contributed providing a preliminary assessment of performance of a convention TS approach, and a comparison with the previous LIDAR one. A report was

issued by IO in which many technical aspects of the two design approaches were examined, but a definitive conclusion in favour of one of the two solutions was not made. Subsequently F4E launched a Call for Proposals F4E-FPA-409 (DG) for the development of this diagnostic. RFX contributed together with other members of the core TS Consortium, offering expertise in the fields of diagnostic performance modelling, development of NIR detectors and definition of advanced calibration methods. Unfortunately the Consortium members were not able to provide resources sufficient to present an offer for the complete preliminary design and eventually no offer was presented to F4E. Recently F4E has issued a market survey with the goal to verify which parties in Europe would be interested in contributing to this diagnostic, with the aim of increasing the amount of resources available. RFX has confirmed its interest and the amount of resources already offered for the FPA call (4 ppy in 4 years). In addition in 2013 a detailed study of the feasibility of dual laser calibrations in ITER as well as in RFX has been carried out. In particular this study has shown that the dual laser calibration technique is feasible also in RFX-mod and a proposal of a test of the method in the experiemntal campaignof 2014 ha been prepared.

THEORY AND MODELING

Use of the extended MHD code PIXIE3D on the Helios supercomputer (Japan)

The code was installed in the Japanese supercomputer managed in the Broader Approach framework and a one-year project with dedicated CPU time (allocated after a call-for-proposals) started on November 2013

Study of toroidal effects for the RFP

An extensive set of 3D simulations of the RFP with toroidal geometry with PIXIE3D is in progress. First simulations at close to realistic dissipation parameters with helical perturbation of the magnetic boundary are being performed.

Study of the coupling with transport for the RFP

The study on the capability of PIXIE3D to solve the temperature equation in a self-consistent way with the other MHD equations is in progress. First 1D (axisymmetric) and 2D (helical) tests with Spitzer resistivity have been performed with isotropic heat

diffusivity and both RFP and tokamak configurations.

Study of the chaos healing properties of quasi helical RFP states.

An extensive study of the conditions for chaos healing in quasi helical RFP states is in progress. A large helical perturbation amplitude is shown to be beneficial for the broadening of the core region where the q profile is rather flat and conserved magnetic surfaces are found.

Kinetic-MHD hybrid toroidal stability model

A kinetic-MHD hybrid toroidal stability code MARS-K for plasma shaping effects on MHD instabilities in the RFP was completed and the effect of energetic particles on Resistive Wall Modes and ideal kink (fishbone like) modes in RFP plasmas is being performed.

Assessment of transport coefficients from modulation experiments

Results of perturbative experiments using a time-modulated source have been modelled on tokamaks to reconstruct corresponding transport coefficients. Similar work on RFX-mod is in progress.

A mixed diffusive-MHD model has been developed to interpret fast heat pulse dynamics in tokamaks and tested successfully over a large number of experimental data.

An invited review paper collecting the whole expertise on perturbative transport experiments accumulated throughout these last years is being written.

Turbulence modelling with gyrokinetic codes

Benchmark of linear results obtained with GS2 and GENE in axisymmetric geometries is in progress. The GS2 code has been used to continue the work on electromagnetic instabilities.

The study of the effect of trapped electron dynamics on drift instabilities, in particular Trapped Electron Modes in RFP plasmas by using the integral gyrokinetic equation solver HD7, is almost finished.

Helical equilibria

A preliminary investigation of the effect of current density profile on the safety factor of

helical states reveals that a purely ohmic mu profile is not compatible with the experimental reversal parameter. This suggests that either the achieved equilibrium is not stationary or a dynamo contribution to Ohm's law, due to the secondary modes, is still present.
Work is in progress on the derivation of transformation rules for MHD spectra from machine to helical coordinates.

Simulation of the m=2, n=1 tearing mode in Tokamak configuration

A modification of the RFXlocking code to study the feedback on a single tearing mode including the Rutherford equation for the island amplitude evolution has been developed. The Fitzpatrick-Rossi saturation model (Phys. Plasmas 8 (2001) 2760) turns out to be inadequate, since no saturation of the island width is predicted for the typical tokamak equilibrium of RFX-mod. Instead, the Arcis-Escande-Ottaviani saturation model (Phys. Plasmas 14 (2007) 032308) provides edge amplitudes and feedback induced frequencies during the wall-locked phase in fair agreement with the experimental data. In addition, two further effects related to the pressure gradient, the Green-Glasser-Johnson term (stabilizing) and the boostrap-current term (destabilizing) have been included in the Rutherford equation, but not tested against the experimental data yet.

Tearing mode simulations with the RFXlocking code

Simulations of the low current discharges (I_p<150kA) of RFX-mod, where spontaneous rotation of tearing modes is observed, have required the inclusion of the diamagnetic frequency to reproduce well the experimental observations.
For standard discharges, a study of configurations considering a vacuum-tight mechanical structure replacing the present vacuum vessel has been carried out, analyzing the different options for the stabilizing shell location from the tearing mode control and sidebands production point of view.

Stability of pressure driven modes in helical states

The COBRA code has been applied to several experimental RFX-mod helical equilibria and the corresponding grow rates for ballooning/interchange ideal modes have been computed. For all the cases analyzed the growth rates are found to be negative which means these modes are stable. Up to now we have used COBRA only in the ITB region

but it is currently being updated in order to deal with the reversal of the toroidal magnetic field at the plasma edge.

Edge ambipolar field

In the RFP edge the measured transport and flows are strongly influenced by magnetic islands and associated ripple. For several years a model using the ORBIT code has been used to compute the electrostatic potential at the edge. This potential has been modeled for a m/n=0/1 magnetic island in the multiple helicity state, according to an analytic form which can be inserted in the mono-energetic, ion and electron runs. The model correctly accounts for the amplitude and symmetry of the measured plasma potential, while the phase is 180 degree-shifted with respect to measurements in RFX-mod.

In 2013 the model has been modified by accounting for a whole Maxwellian population of electrons and ions, interacting with a background of electrons, ions and C4+ impurities via an energy-exchanging, full profile Coulomb scattering operator, in the MonteCarlo approach. Furthermore, the numerical diagnostics used for RFX-mod have been adapted to the 12/4 and 3/1 configurations of the resonant magnetic perturbations produced by the Dynamic Ergodic Divertor (DED) in the TEXTOR tokamak. The results on the electrostatic potential in TEXTOR show that the phase shift, present in RFX-mod, disappears in the tokamak case.

DIAGNOSTICS

Substantial budget cuts limited also the completion of the 2013 Diagnostic development plan. Among the most successful realizations one can mention the new arcless power supply for ion saturation current measurements, the completion of the microwave reflectometer, which now is a three-band system as designed, the improvement of the multi pellet lithium injector, the use of the fast CMOS camera on loan from Princeton laboratory, and the installation a neutron spectrometer in collaboration with the Physics Department of Padova University. In the following we report the work done maintaining the structure of the activity plan. For this reason some paragraphs will be empty.

FIR Polarimeter

The planned activities to further improve the measurement quality and to extend time and spatial resolution have been postponed.

Soft X-Ray (SXR) diagnostics

Modified Vertical SXR camera - The DSXC Multichord diagnostic has been installed at the toroidal location of the main SXR tomography. 10 points T_e profiles have been obtained, but after a few months of operation the pinholes of the diagnostic have been partially obscured by tiny debris of unknown origin: this made the collected data not reliable. A different design, capable of avoiding debris accumulation over the pinholes, is being developed.

SXR Multifilter - The tests of logarithmic amplifiers, instead of the Femto linear ones, in order to increase the operational range of the diagnostic, and the replacement of the Be foils among the photodiodes in order to always have a pair of diodes optimized for any operation range of RFX-Mod were postponed.

SXR Photodiodes - The test of a new SXR photodiode “shielded” to electromagnetic noise in collaboration with the MST group stopped at design level. The very small diode size (due to mechanical constraints) would have resulted in higher signal to noise ratio and would not have improved the data quality. In particular, electromagnetic pickup noise, whose reduction was the aim of the study, was expected to be overwhelmed by the larger noise level.

Neutral Particle Analyzer

The optimization of the 11-channel Neutral Particle Analyzer on loan from IPP-Greifswald, operational since 2010, by adding a shield for the external magnetic field and the remote control of the voltages applied to the diagnostic from SIGMA was postponed.

Fast Reciprocating Manipulator (FARM)

The construction of the Fast Reciprocating Manipulator was postponed.

Arcless power supply for ion saturation current measurements

The final engineering for the arcless power supply rack has been finalized, including board circuits, rack design and cabling.

Revamping of the shot-to-shot probe insertion systems

The replacement of the old PLC based control system (no longer repairable) with a new simplified has been completed

Edge Thomson Scattering

The procurement of a new collection optical system made by mirrors instead of lenses stopped at design level. The new vacuum interface was designed, but the mirror could not be optimized with the ZEMAX code and the development of dedicated software is required.

Diagnostic Neutral Beam Injector

Charge exchange measurements of impurity T_i were performed in Tokamak discharges. Further improvements of the signal-to-noise ratio by increasing the pumping speed in the duct leading to the RFX vessel or more significant hardware upgrades, such as a new set of acceleration grids to lower beam were not possible due to limited financial resources.

Microwave Reflectometer

The three-band system is installed and operational, but the substitution of the old IMPATT microwave sources, which are no longer available on the market and are therefore a critical item, could not be done because of lack of financial resources.

CO2 multi-chord interferometer

Due to the failure of the mid infrared He-Ne laser during the 2012 and the present commercial unavailability of reliable infrared He-Ne lasers, we planned to test the use Quantum Cascade Laser as mid infrared source for interferometric measurements. The commercial availability of such sources was assessed, but they could not be purchased because of lack of financial resources.

The realization a new digital control panel started, some delay in the orders of new components forced the postponement of its completion

Pellet injectors

Cryogenic pellet injector - The development of a new control system should was postponed

Room temperature pellet injector - A detailed redesign of some components of the room temperature injector to improve its ability to inject the smaller pellets required for impurity transport studies was carried out.

New mechanical components were realized by the RFX workshop and they are ready to be installed.

Multi pellet lithium injector - The improvement of the multi pellet lithium injector on loan from Princeton Plasma Physics Laboratory (PPPL) has been completed. In particular the dropper was modified and RFX a new vacuum interface was designed and installed. The new system has been successfully tested on a brief experimental campaign with about a 3-fold increase of the effective injection rate.

Pellet tracker for trajectory reconstruction - The improvement of the tracker to solve the problems related to EMI interference of present pellet tracker was postponed because of insufficient financial resources.

Energetic X-rays and neutron detector

The collaboration with IFP Milano to install a detector capable of neutron gamma discrimination coupled to fast digital recorders has been started.

Lithium neutral beam diagnostic

The diagnostic aimed to measure density and its fluctuations in the region close to the edge was not done because of lack of financial resources.

R&D for a fast electron tracker

The activity to modifiy the old ruby laser to use it as a fast electron source, was started with the design and contruction of the necessary components to assemble a pulse

compressor.

Upgrade of the thermal Helium Beam Diagnostic (THB) with 3 new stations

The activity plan entailed the installation of three new stations of Helium injection and measurements at three different poloidal positions.

One new THB station has been installed at ϕ = 262°. It is operating and gives the time evolution of the electron density and temperature in the outboard equatorial midplane, at r/a about 0.98. All the hardware for the other two THB stations are ready to be installed in the next shut down.

Loan of fast camera for edge turbulence analysis

A new fast CMOS camera on loan from Princeton laboratory was on RFX-mod, complementary to the GPI diagnostic. The camera was used during the 2013 campaign for measuring the edge plasma turbulence. During the experimental campaign, the fast varying magnetic field causes some acquisition problems, and so it was possible to use it only at low plasma current (up to 800 kA), and it was not possible to mount it in the toroidal position of the pellet injector. However, it was used to measure the blobs propagation in the plasma edge, and it gave the first direct two-dimensional visualization of a blob in a RFP plasma.

New optical interface for Fast CMOS camera

To improve wall interaction studies by the fast CMOS camera we planned to modify its optical interface to install the camera at θ (poloidal position) -90°. However, in this position the camera would have been much nearer to the magnetic coils: since we have highlighted problems with the magnetic field (B) in a position with weaker B and weaker time variation of B, this activity had to be canceled.

Monitor for electromagnetic plasma instabilities

The construction of the new tri-axis magnetic coils measuring the fluctuation of the three components of the magnetic field has almost been completed (only the boron nitride caps still to be done). Also the final definition of the mounting position is still under way.

Local recycling diagnostic

The design and realization of the new Local recycling diagnostic was done. The diagnostic is ready for installing and commissioning. With this system plan to characterize the recycling behavior of the RFX graphite wall, in particular with reference to the test of wall conditioning techniques (e.g. Li and W coating), which is subject to thermal and particle fluxes much larger than those normally found in tokamaks and stellarators.

JT-60SA FIR Polarimeter/interferometer

We collaborated to the conceptual design of the JT-60SA polarimetry system, in particular we analyzed the availability of far-infrared quantum cascade laser as possible sources. Unfortunately it was found that, in the present developing phase, these lasers still have a too small power to be used on an interferometer/polarimeter. A study on the optimization of polarimeter lines of view in terms of number and position has been also started using the V3FIT code.

Development of a probe for Scrape-Off Layer investigation on TCV

The collaboration with CRPP Institute, Lausanne for the development, installation and exploitation of an electromagnetic probe for a Reciprocating Manipulator on loan from PPPL has been postponed.

Neutron spectrometer

The collaboration with the Physics Department of Padova University, aimed at installing a neutron spectrometer on RFX-mod was successful. The spectrometer provided by the Physics Department was installed on RFX-mod and very interesting preliminary measurements were performed during the Fall 2013 deuterium campaign.

BROADER APPROACH

The contribution to the JT-60SA satellite tokamak project, in the framework of the Broader Approach agreement, has been continued in 2013 both with the activities related to the systems to be procured by CNR, acting through Consorzio RFX, and with the participation in the International Project Team (IPT) work. The two systems to be

procured are the Quench Protection Circuits (QPC) and the Power Supply (PS) system for RWM control.

Quench Protection Circuits

It is recalled that the function of the Quench Protection Circuits (QPC) consists in protecting the superconducting coils in case of quench, by a fast removal of the stored energy. QPC system is procured via a contract awarded to the company Nidec ASI (formerly Ansaldo Sistemi Industriali) in Dec. 2010. Three units will be provided for the toroidal circuit, capable of interrupting up to 25.7 kA and to sustain 2.8 kV reapplied voltage and ten units for the poloidal circuits (21 kA, 4.2 kV).

The design was completed and approved in summer 2011. It is based on a hybrid mechanical-static Circuit Breaker (CB); a pyrobreaker in series assures the backup protection. A full scale prototype has been manufactured and deeply qualified with specific type tests campaigns; this phase was concluded on time, with the approval of the “Factory Type Test Report” on PF and TF QPC prototype, second milestone of the Procurement Arrangement, in January 2013. The manufacturing of the first two units of QPC series production, one TF QPC and one PF QPC, started subsequently and has been completed with routine tests accomplishment on June 2013. An alternative pyrobreaker actuation system has been developed to reduce the risk of delays due to difficulties in the exportation of the explosives and firing circuit from Russia and to enhance the pyrobreaker availability, since two alternative systems will be suitable for the application; the qualification process of the new actuation system has been successfully completed in June 2013. The main achievements in the second semester have been the manufacturing and successful routine tests of the most part of the components of the series units.

The contract follow-up activities have proceeded in parallel to the company activities on all the topics in progress. The analyses to process the experimental data of the type test on the prototype have significantly progressed to complete the characterization of the QPC operation and the validation of the QPC electrical model developed during the design phase.

Power supplies for in-vessel sector coils for RWM control

Consorzio RFX has continued working on the design and procurement of the Power Supply system to control Resistive Wall Modes in JT-60SA and supporting JAEA in the design of overall system. After the definition of the new conceptual design of the RWM control coils proposed by JAEA in July 2012, the electrical characterization of the coils, feeders and cables has been updated with Finite Element analyses. The voltage induced in the coils and in the power supplies in case of fast transients of plasma current has been re-evaluated; these results have been compared with those of JAEA, founding a good agreement.

In parallel, considering the requirements for the PS system, very demanding in terms of dynamic response and latency, Consorzio RFX proposed to develop an inverter prototype to gain confidence on technical feasibility, availability of power switches and cost, with the aim to achieve significant risk mitigation. The Technical Specifications for the inverter prototype have been issued in February 2013 and approved by F4E and JAEA. Then, the call for tender has been performed and the contract has been signed in May 2013.

The prototype design progressed well in the second half of 2013. A provisional mock-up has been put in place by the industry to test the innovative power switches which have been chosen. The First Design Report has been delivered in September. The prototype should be delivered in March 2014 and the qualification tests are foreseen in March/April 2014 on a dummy load, under development in JAEA, reproducing the impedance of the real load in the frequencies of interests.

Analyses to verify the detailed design choices proposed by the company and the expected performance have been carried out in parallel to the development of the design and the results presently confirm the fulfillment of the requirements.

DEMO

Economic aspects of a fusion power plant

The FRESCO code revision started in 2012 has been accomplished and a comprehensive descriptive paper has been drawn up and published. Furthermore a new module has been included in the code to perform stochastic analyses based on the Monte Carlo method. This feature has been used to contribute to the EDFA activities

concerning the estimation of the cost of electricity from a fusion power plant. Specifically, the study focused on the effects of the uncertainties on the cost of electricity of a PPCS-like power plant. The FRESCO code is now enough flexible to include further modules about much more specific technical and physical aspects of both a DEMO reactor and a future commercial power plant.

Energy scenarios

The results of the stochastic analyses performed by FRESCO have been used in the framework of the EFDA SERF activities to set up new scenarios about the possible deployment of PPCS-like power plants. The results of the study have been presented at the ISFNT Satellite Meeting (Barcelona, September 2013) and the IEA ETSAP International Meeting (Seul, November 2013). In addition, a draft paper titled “Analysis of the contribution of fusion and renewable technologies in a future low carbon global electricity system” has been written in cooperation with the CIEMAT team.

Finally further work has been carried out to enhance the COMESE program so as to make it suitable to model both the national and the European energy system. The fusion technology has been also included in the code database and some exploratory scenarios have been developed. Moreover actions have been taken to transpose the code from MsExcel to the C++ environment to get a more flexible and powerful device.

EDUCATION TRAINING AND INFORMATION TO THE PUBLIC

All activities related to European Doctorate, GOT programme and University courses have been performed as scheduled. Concerning information to the public a specific campaign of on the NBTF project has been defined and actions are underway.

PUBBLICATION LIST

SUMMARY

International and national journals

1. Numerical verification of Orbit and Nemato codes for magnetic topology diagnosis
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Communications to National and International Workshops and Conferences

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4. P. Martin: "Advantages and Disadvantages of 3D Effects in Magnetically Controlled Fusion Plasmas", Invited, 531st Wilhelm and Else Heraeus Seminar - 3D versus 2D in Hot Plasmas, 30th April – 2nd May 2013, Physikzentrum Bad Honnef, Germany

5. M. Valisa: "Transport analysis of Tungsten and Beryllium in JET Hybrid Plasmas with the ITER-like Wall", oral, IAEA Technical Meeting SSO 2013, Aix en Provence, France, from 14-17 May 2013

ISPP 2013

6. R. Pasqualotto: "Diagnostics of the ITER neutral beam injector and test facility", invited, ISPP 2013 International Conference on Fusion Reactor Diagnostics, Villa Monastero, Varenna, Italy 9-13 sept. 2013

7. W. Gonzalez: "Thermo-mechanical analyses of ITER in-vessel magnetic sensor assembly**",** ISPP 2013 International Conference on Fusion Reactor Diagnostics, Villa Monastero, Varenna, Italy 9-13 sept. 2013

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Joint 19th ISHW and 16th IEA-RFP workshop

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12. L. Carraro: “Impurity screening in RFX-mod RFP plasmas” (invited), Joint 19th ISHW and 16th IEA-RFP workshop, 16-20 Sept. 2013, Padova, Italy

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14. M. Gobbin: “eITBs dynamics in helical RFX-mod states by high time resolution Te measurements” (oral), Joint 19th ISHW and 16th IEA-RFP workshop, 16-20 Sept. 2013, Padova, Italy

15. D. Bonfiglio: “Impact of helical magnetic boundary in 3D nonlinear MHD physics of the helical RFP” (oral), Joint 19th ISHW and 16th IEA-RFP workshop, 16-20 Sept. 2013, Padova, Italy

16. L. Piron: “Tearing mode control in the RFX-mod device” (oral), Joint 19th ISHW and 16th IEA-RFP workshop, 16-20 Sept. 2013, Padova, Italy

17. P. Franz: “Te from SXR in Reversed Field Pinches: 2D imaging of 3D structures”, Joint 19th ISHW and 16th IEA-RFP workshop, 16-20 Sept. 2013, Padova, Italy

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24. C. Piron: “New real-time RFX-mod feedback control algorithms in the MARTe framework”, Joint 19th ISHW and 16th IEA-RFP workshop, 16-20 Sept. 2013, Padova, Italy

25. L. Chenguang: “The preliminary design of TMs’ feedback control in KTX based on simulation”, Joint 19th ISHW and 16th IEA-RFP workshop, 16-20 Sept. 2013, Padova, Italy

26. C. Finotti: “Improvement of the RFX-mod toroidal power supply to enhance the control of the toroidal magnetic field in the RFX-mod experiment”, Joint 19th ISHW and 16th IEA-RFP workshop, 16-20 Sept. 2013, Padova, Italy

27. M. Zuin: “Characterization of Microtearing Modes in the RFX-mod Reversed-Field Pinch Plasmas”, Joint 19th ISHW and 16th IEA-RFP workshop, 16-20 Sept. 2013, Padova, Italy

28. I. Predebon: “Gyrokinetic investigation of ion temperature gradient instability in helical RFPs”, Joint 19th ISHW and 16th IEA-RFP workshop, 16-20 Sept. 2013, Padova, Italy

29. S. C. Guo: “Trapped electron effects on the micro-drift instabilities in RFP plasmas”, Joint 19th ISHW and 16th IEA-RFP workshop, 16-20 Sept. 2013, Padova, Italy

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31. Fulvio Auriemma: “Particle influx studies and confinement properties in RFX-mod”, Joint 19th ISHW and 16th IEA-RFP workshop, 16-20 Sept. 2013, Padova, Italy

32. Rita Lorenzini: “Ion temperature measurements in RFX-mod”, Joint 19th ISHW and 16th IEA-RFP workshop, 16-20 Sept. 2013, Padova, Italy

33. G. Ciaccio: “Edge islands transport in tokamaks and RFPs”, Joint 19th ISHW and 16th IEA-RFP workshop, 16-20 Sept. 2013, Padova, Italy

34. L. Marrelli: “RFX-mod Overview”, Joint 19th ISHW and 16th IEA-RFP workshop, 16-20 Sept. 2013, Padova, Italy

1.1. LAPD 16

35. L. Giudicotti, R. Pasqualotto, A. Fassina: “A study for dual-laser Thomson scattering calibrations in RFX-MOD”, P21, 16th International Symposium Laser Aided Plasma Diagnostics, Madison, Wisconsin USA , September 22-26 2013

ISLA 2013

36. P. Innocente: “Lithization on RFX-mod reversed field pinch experiment”, 3rd International Symposium on Lithium Applications for Fusion Devices, Frascati, October 9-11, 2013

55th Annual Meeting APS

37. Edge ambipolar potential in toroidal fusion plasmas
G. Spizzo, (tentative list) S.Abdullaev, M.Agostini, G.Ciaccio, P.Scarin, O.Schmitz,N.Vianello, R.B. White, the RFX and TEXTOR teams – Invited, 55th Annual Meeting APS, November 11 – 15 2013, Denver Colorado USA

38. Characterization of particle confinement properties in RFX-mod at high Ip
    F. Auriemma Fulvio, M. Agostini, P. Franz, R. Lorenzini, P.Innocente, P. Scarin – Oral - , 55th Annual Meeting APS, November 11 – 15 2013, Denver Colorado USA

Poster:

39. A pressure-driven model for the quasi periodical oscillations of the Single Helical States in Rever
    R. Paccagnella, 55th Annual Meeting APS, November 11 – 15 2013, Denver Colorado USA

40. New MHD feedback control schemes using the MARTe framework in RFX-mod
    C. Piron, G.Manduchi, L.Marrelli, P.Piovesan, P.Zanca, , 55th Annual Meeting APS, November 11 – 15 2013, Denver Colorado USA

41. Overview of the RFX fusion science program
    P. Martin, Puiatti and the RFX-mod team, 55th Annual Meeting APS, November 11 – 15 2013, Denver Colorado USA

42. SXR Diagnosis of Electron Temperature Dynamics in Reversed-Field Pinches
    P. Franz, M.Gobbin, L.Marrelli, A.Ruzzon, F. Bonomo, A.Fassina, E. Martines, M.B. McGarry, D.J. Den Hartog, J.A. Goetz, J. Johnson, , 55th Annual Meeting APS, November 11 – 15 2013, Denver Colorado USA

43. Progress in nonlinear 3D MHD modeling of fusion plasmas with the PIXIE3D code
    D. Bonfiglio, S. Cappello, L. ChacÃ³n, D. F. Escande, M. Veranda, 55th Annual Meeting APS, November 11 – 15 2013, Denver Colorado USA

44. 3D Boundary behavior in RFX-mod: role of advected quantities
    P. Scarin, M. Agostini, L. Carraro, G. Spizzo, N. Vianello, 55th Annual Meeting APS, November 11 – 15 2013, Denver Colorado USA

45. Experimental characterization of microtearing modes in the RFX-mod reversed-field pinch plasmas
    M. Zuin, Spagnolo, Predebon, Sattin, Auriemma, Cavazzana, Fassina, Gobbin, Martines, Paccagnella, Spolaore, Vianello, 55th Annual Meeting APS, November 11 – 15 2013, Denver Colorado USA

46. Electron temperature profiles characterization and eITBs dynamics in the helical states of RFX-mod
    M. Gobbin, A.Fassina, P.Franz, L.Marrelli, B.Momo,I. Predebon, A.Ruzzon, R. Sanchez, D.Terranova, M.Zuin, , 55th Annual Meeting APS, November 11 – 15 2013, Denver Colorado USA