Annual report of the ITPA Topical Group on Energetic Particle Physics

For the period Nov 2010 to Oct 2011

The EP Topical Group held two meetings (its 6th and 7th) during the reporting period – at ENEA in Frascati on April 11-13, 2011 and at the University of Texas in Austin on September 12-13, 2011 right after the IAEA TM on energetic particles .
Minutes of these meetings and viewgraphs presented are available at the ITPA website, therefore only a summary of the main results is given here.

In addition to JEX activities, the work of the group is concentrated mainly on the following topics:

- ***Benchmark effort for the linear codes of Alfvén eigenmode***
- ***Benchmark effort for the non-linear codes of Alfvén eigenmode***
- ***Evaluation of fast ion losses induced by 3D effects (ELM control coils) and MHD***
- ***Energetic particle diagnostics for ITER***

Benchmark effort for the linear codes of Alfvén eigenmode
A prediction of the occurrence of fast particle driven instabilities in ITER will be supported by a linear code. As a first step, a common benchmark effort was carried out using a well-diagnosed JET discharges with measured damping rates for TAEs has been used. The experimental result was successfully reproduced by several codes. The results were summarized by S. Günter in IAEA FEC Daejeon.
After sucessfully comparing the damping rates, the benchmarking of the finite Larmor radius and finite orbit width effects in a large aspect ratio tokamak (n=6) was successfully carried out in 2011. Then, the group is about to start to focus its activity on ITER stability boundary studies for AEs. This exercise is a challenge for many codes, especially the kinetic codes, due to the following reasons: for the damping, the background ion Larmor radius has to be resolved ($rho_* \sim 500$) together with rational surfaces at the plasma edge. Furthermore, the most unstable modes will have higher toroidal mode numbers (5-15), what requires a higher poloidal resolution (or number of Fourier harmonics). The drive is a combination of alpha-particle drive and NBI heating requiring detailed and expensive modeling. Finally, a large number of modes (TAEs, RSAEs, BAEs, EAEs) have to be investigated.
Plans for further work: First results concerning scenario 4 are expected mid of 2012. In addition to this case, a JET DT case can be another target of the benchmark. A long-term goal is to support the design of the operation scenarios.

Benchmark effort for the non-linear codes of Alfvén eigenmode
It was found this activity needed several milestones in the activity in 2010. The first milestone was set to the benchmark of the linear stability of the mode. A benchmark case on an n=6 TAE mode was provided by A. Könies for this purpose. At the 6th meeting in Frascati, the results of linear growth rate for different energetic particle temperature were reported from both linear codes (CAS3D-K, CKA-EUTERPE, AE3D-K, GYGLES, LIGKA) as well as nonlinear codes (HMGC, MEGA, TAEFL). Comparisons were made for the cases with or without energetic particle finite Larmor radius effects. The important finding was that the results are sensitive to the details of the physics condition such as the cutoff velocity of the energetic particle distribution, particle recycling at the plasma boundary, and the treatment of the inconsistency of the initial energetic particle distribution. At the 7th meeting in Austin, new results from another linear code (VENUS) and revised results from both linear codes

(LIGKA, AE3D-K) and nonlinear codes (HMGC, MEGA, TAEFL) were presented. Better agreements were found among the codes for the mode structure and growth rate dependence on energy. Initial nonlinear regime results for this n=6 TAE mode case were also reported from HMGC code at the 7th meeting.
Plans for further work: This benchmark case for the linear stability as the first milestone will be closed, resolving the reaming issue, at the next meeting. The joint paper will be prepared for the next IAEA FEC to show the current status of this joint activity. Results concerning the nonlinear evolution of the n=6 TAE mode case will be collected for the next meeting, in order to evaluate the possibility of presenting a joint paper on this subject too.

Fast ion losses induced by 3D effects (TBMs, ELM control coils) and MHD
The assessment of the effect of the 3D effects and MHD using codes that follow drift particle orbits in three-dimensional magnetic field configurations has been one of our main activities. The joint effort till 2010 was published in K. Shinohara et al. NF 51 (2011) 063028.
An investigation of the effect of the ELM mitigation coils on the fast ion loss has been started. Results on the ITER 15MA scenario by F3D-OFMC have been reported. Incremental losses were observed for beam ions than for alpha particles. Heat load increases were present in the divertor region, but the level ($< 0.3 Mw/m^2$) should be manageable. The calculations were also carried out by ASCOT and F3D-OFMC for the AUG RMP coils to support EP-6.
The simulation under perturbations by MHD activity, energetic particle driven modes and plasma turbulence besides the 3d effects of the equilibrium fields is an important topic. ASCOT has been upgraded to include magnetic islands due to neoclassical tearing instabilities and applied to beam ion redistribution in ASDEX and ITER. For ITER it was found that beam current drive is not affected much by the islands due to their non-alignment with the current drive region for Scenario 2.
Plans for further work: The effect of ELM mitigation coils on the fast ion loss is not negligible in the ITER 15 MA scenario. The check will be carried out by other codes. The assessment of the effect of perturbations by MHD activity will be continued. A long-term goal is to include fast ion redistribution caused by energetic particle driven modes as calculated by non-linear codes.

Energetic particle diagnostics for ITER
In collaboration with the MHG-TG a discussion on diagnostic needs in light of control techniques for ITER has been organized as WG4. The AE diagnostics needs were described in the final report of the WG4 report. In this final report, the most of the diagnostics and actuator requirement are proposed for the physics studies, considering the identification of the modes, their location and profile changes that could remove the drive or increase damping.
Given that the main physics objective for ITER is the investigation of thermonuclear self-heating and alpha-particle physics, concern was raised that most of the fast ion related diagnostics is not credited for ITER. One of important diagnostics is the fast ion collective scattering (CTS) system. Currently, only the Low-Field-Side-Back-Scattering (LFS-BS) system has been approved. This implies near parallel fast ions with energies > 3 MeV cannot be measured (the LFS system can primarily only measure energetic trapped ions). The EP TG unanimously endorsed adding the High-FS-Forward-Scattrering diagnostic to ITER diagnostic set.

Others:
Data base for energetic particle physics on ITER
A data base with the relevant ITER data for simulations with respect to energetic particles physics has been updated. It allows in particular detailed investigations of localized heat loads onto the three dimensional wall structures.

ITPA Topical Group Publication list 2008-2010

Group	Year	list
EP	2008	**Presentations at the 2008 IAEA Fusion Energy Conference, Korea** S. Günter, M. García-Muñoz, K. Lackner, Ph. Lauber, P. Merkel, M. Sempf, E. Strumberger, D. Tekle and the ASDEX Upgrade team, *Three Dimensional Effects in Tokamaks – How Tokamaks Can Benefit From Stellarator Research,* Paper TH/P9-10 M. García-Muñoz, H.-U. Fahrbach, V. Bobkov, M. Brudgam, M. Gobbin, S. Günter, V. Igochine, Ph. Lauber, M. J.Mantsinen, M.Maraschek, L.Marrelli, P.Martin, S.D. Pinches, P. Piovesan, E. Poli, K. Sassenberg, H. Zohm and the ASDEX Upgrade Team, *MHD induced Fast-Ion Losses on ASDEX Upgrade,* Paper EX/6-1 **Publications in peer-reviewed journals** S Günter, Ph Lauber, P Merkel, M Sempf, E Strumberger, D Tekle and K Lackner, *Three-dimensional effects in tokamaks,* Plasma Phys. Control. Fusion **50** 124004 (2008) M. García-Muñoz, H.-U. Fahrbach, S. Günter, V. Igochine, M. J. Mantsinen, M. Maraschek, P. Martin, P. Piovesan, K. Sassenberg, and H. Zohm, *Fast Ion Losses due to High Frequency MHD Modes in the ASDEX Upgrade tokamak,* Phys. Rev. Lett. **100** 055005 (2008) E. Poli, M. García-Muñoz, H.-U. Fahrbach, S. Günter and ASDEX Upgrade Team, *Observation and modelling of fast trapped ion losses due to Neoclassical Tearing Modes,* Phys. Plasmas **15** 032501 (2008) Ph. Lauber and S. Günter, *Damping and drive of low-frequency modes in tokamak plasmas,* Nucl. Fusion **48** 084002 (2008)
EP	2009	**Publications in peer-reviewed journals** M. García-Muñoz, H.-U. Fahrbach, S. D. Pinches, V. Bobkov, M. Bruedgam, M. Gobbin, S. Günter, V. Igochine, Ph. Lauber, M. J. Mantsinen, M. Maraschek, L. Marrelli, P. Martin, P. Piovesan, E. Poli, K. Sassenberg, G. Tardini, H. Zohm and the ASDEX Upgrade Team, *MHD induced fast-ion losses on ASDEX Upgrade,* Nucl. Fusion **49** 085014 (2009) M. García-Muñoz, H.-U. Fahrbach and H. Zohm, *Scintillator based detector for fast-ion losses induced by magnetohydrodynamic instabilities in the ASDEX Upgrade tokamak,* Rev. Sci. Instrum. **80** 053503 (2009) Ph. Lauber, M. Bruedgam, D. Curran, V. Igochine, S. Günter, M. Marascheck, K. Sassenberg, M. García-Muñoz and N. Hicks, *Kinetic Alfven Eigenmodes in ASDEX Upgrade. Plasma Phys. Control. Fusion* **51** 124009 (2009) K. Shinohara, T. Oikawa, H. Urano, N. Oyama, J. Lonnroth, G. Saibene, V. Parail, Y. Kamada, *Effects of ferromagnetic components on energetic ion confinement in ITER*, Fusion Eng. Des. 84 (2009) 24 K. Sassenberg, M. Maraschek, P. J. Mc Carthy, H. Zohm, R. Bilato, W. Bobkov, S. Da Graca, A. Flaws, M. García-Muñoz, S. Günter et al, *Stability of toroidicity induced shear Alfven eigenmodes in ASDEX Upgrade,* Plasma Phys. Control. Fusion **51** 065003 (2009) M. Gobbin, L. Marrelli, H. U. Fahrbach, M. García-Muñoz, S. Günter, P. Martin, R. B. White and the ASDEX Upgrade Team, *Numerical simulations of fast ions losses induced by MHD magnetic islands in the ASDEX-Upgrade tokamak*, Nucl. Fusion **49** 095021 (2009)
EP.	2010	**Presentations at the 2010 IAEA Fusion Energy Conference, Korea** ITPA Group on Energetic: D. Borba, A. Fasoli, N.N. Gorelenkov, S. Günter, Ph. Lauber, N. Mellet, R. Nazikian, T. Panis, S.D. Pinches, D. Spong, D. Testa and JET-EFDA contributors, *The Influence of Plasma Shaping on the Damping of Toroidal Alfvén Eigenmodes*, THW/P7-08 M. García-Muñoz, I.G.J. Classen, B. Geiger, W.W. Heidbrink, M.A. Van Zeeland, S. Akaslompolo, R. Bilato, V. Bobkov, M. Brambilla, S. da Graca, V. Igochine, Ph. Lauber, M. Maraschek, F. Meo, M. Schneller, G. Tardini and the ASDEX Upgrade Team, *Fast-Ion*

		Transport Induced by Alfven Eigenmodes in ASDEX Upgrade, Paper EXW/P7-07 Ph. Lauber, M. Brudgam, D. Curran, M. Sempf, V. Igochine, S. Gunter, M. Maraschek, P. McCarthy, M. García-Muñoz and the ASDEX Upgrade Team, *Damping, Drive and Non-linear Effects of Kinetic Low-frequency Modes in Tokamaks,* Paper 1 THW/2-2Ra D.C. Pace, C.Z. Cheng, C.W. Domier, R.K. Fisher, M. García-Muñoz, W.W. Heidbrink, Z. Lin, N.C. Luhmann, Jr., G.R. McKee, M. Murakami, C.M. Muscatello, R. Nazikian, J.M. Park, C.C. Petty, T.L. Rhodes, D.A. Spong, G.M. Staebler, B. Tobias, M.A. Van Zeeland, R.E. Waltz, R.B. White, J.H. Yu, W. Zhang, and Y.B. Zhu, *Transport of Energetic Ions due to Microturbulence, Sawteeth, and Alfvén Eigenmodes,* Paper EXW/4-2 K. Shinohara, T. Kurki-Suonio, D. Spong, O. Asunta, K. Tani, E. Strumberger, S. Briguglio, T. Koskela, G. Vlad, S. Günter, G. Kramer, S. Putvinski, K. Hamamatsu, *3D Effect of Ferromagnetic Materials on Alpha Particle Power Loads on First Wall Structures and Equilibrium on ITER*, ITR/P1-36 **Publications in peer-reviewed journals** M. García-Muñoz, N. Hicks, R. van Voornveld, I.G.J. Classen, R. Bilato, V. Bobkov, M. Brambilla, M. Bruedgam, H.-U. Fahrbach, V. Igochine, S. Jaemsae, M. Maraschek, K. Sassenberg and the ASDEX Upgrade Team, *Fast-ion losses induced by ACs and TAEs in the ASDEX Upgrade Tokamak,* Nucl. Fusion **50** 084004 (2010) M. García-Muñoz, N. Hicks, R. van Voornveld, I. G. J. Classen, R. Bilato, V. Bobkov, M. Bruedgam, H.-U. Fahrbach, V. Igochine, S. Jaemsae, M. Maraschek, K. Sassenberg and the ASDEX Upgrade Team, *Convective and diffusive losses of energetic particles induced by Shear Alfven waves in the ASDEX Upgrade tokamak*, Phys. Rev. Lett. **104** 185002 (2010) K. Sassenberg, M. Maraschek, P.J. Mc Carthy, W. Bobkov, M. García-Muñoz, N. Hicks, V. Igochine, P. Lauber, S. Günter and ASDEX Upgrade Team, *ICRH Beatwave excited Alfven Eigenmodes in ASDEX Upgrade,* Nucl. Fusion **50** 052003 (2010) R.B. White, N. Gorelenkov, W.W. Heidbrink, and M.A. Van Zeeland, *Particle distribution modification by low amplitude modes*, Plasma Phys. Control. Fusion **52** (2010) 045012 R.B. White, N. Gorelenkov, W.W. Heidbrink, and M.A. Van Zeeland, *Beam distribution modification by Alfvén modes,* Phys. Plasmas **17** (2010) 056107 **Presentations** M.A. Van Zeeland, *Alfvén Eigenmodes and Fast Ion Loss in the DIII-D and ASDEX-Upgrade Tokamaks,* **Invited Talk,** 52nd Annual Meeting of the APS Division of Plasma Physics, Chicago, Illinois, USA, November 8–12, 2010
EP	2011	**Publications in peer-reviewed journals** M. García-Muñoz, I.G.J. Classen, B. Geiger, W.W. Heidbrink, M.A. Van Zeeland, S. Akaslompolo, R. Bilato, V. Bobkov, M. Brambilla, G.D. Conway, S. da Graca, V. Igochine, Ph. Lauber, N. Luhmann, M. Maraschek, F. Meo, H. Park, M. Schneller, G. Tardini and the ASDEX Upgrade Team, *Fast-ion transport induced by Alfven eigenmodes in the ASDEX Upgrade tokamak,* Nucl. Fusion **51** 103013 (2011) G.J. Kramer, B.V. Budny, R. Ellis, M. Gorelenkova, W.W. Heidbrink, T. Kurki-Suonio, R. Nazikian, A. Salmi, M.J. Schaffer, K. Shinohara, J.A. Snipes, D.A. Spong, T. Koskela, and M.A. Van Zeeland, *Fast-ion effects during test blanket module simulation experiments in DIII-D*, Nuclear Fusion, 51 (2011) 103029 T. Kurki-Suonio, O. Asunta, T. Koskela, A. Snicker, T. Hauff, F. Jenko, E. Poli, and S. Sipilä, *Fast Ion power loads on ITER First Wall Structures in the Presence of NTMs and microturbulence*, Nuclear Fusion **51**, (2011) 083041 K. Shinohara, T. Kurki-Suonio, D. Spong, O. Asunta, K. Tani, E. Strumberger, S. Briguglio, T. Koskela, G. Vlad, S. Günter, G. Kramer, S. Putvinski, K. Hamamatsu, ITPA Topical Group on Energetic Particles, *Effects of Complex Symmetry-breakings on Alpha Particle Power Loads on First*

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B. Geiger, M. García-Muñoz, W. W. Heidbrink, R. M. McDermott, G. Tardini, R. Dux, R. Fischer, V. Igochine and the ASDEX Upgrade Team, *Fast-ion D-alpha measurements at ASDEX Upgrade,* Plasma Phys. Control. Fusion **53** 065010 (2011)

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Presentations

O. Asunta**,** S. Äkäslompolo, T. Kurki-Suonio, S. Sipilä, M. Garcia-Munoz, the ASDEX Upgrade team, *Fast ion wall loads in ASDEX Upgrade in the presence of magnetic perturbations due to ELM mitigation coils*, 38th EPS Conference on Plasma Physics, Strasbourg, France, June 27 - July 1, 2011, Europhysics Conference Abstracts (2011), P1.116 (2011)

O. Asunta, S. Äkäslompolo, T. Kurki-Suonio, T. Koskela, S. Sipilä, A. Snicker, M. Garcia-Munoz, the ASDEX Upgrade team, *Fast ion wall loads in AUG in the presence of magnetic perturbations due to ELM mitigation coils*, Proc. of 12th IAEA Technical Meeting on Energetic Particles in Magnetic Confinement Systems, September, 2011, Austin, O-15

M. Garcia-Munoz, I. G. J. Classen, B. Geiger, W. W. Heidbrink, M. A. Van Zeeland, S. Akaslompolo, J. Boom, A. Burckhart, G. D. Conway, S. da Graça, A. Gude, V. Igochine, T. Kurki-Suonio, Ph. Lauber, N. Lazányi, N. Luhmann, T. Lunt, M. Maraschek, H. Park, M. Schneller, G. Tardini, E. Viezzer, M. Willensdorfer, E. Wolfrum, and the ASDEX Upgrade Team, *MHD Induced Fast-Ion Redistribution & Loss in AUG*, Proc. of 12th IAEA Technical Meeting on Energetic Particles in Magnetic Confinement Systems, September, 2011, Austin, O-11

T. Kurki-Suonio, O. Asunta**,** T. Koskela, S. Sipilä, A. Snicker, S. Äkäslompolo, *Orbit-following fusion alpha wall load simulations for ITER including full orbit effects*, Proc. of 12th IAEA Technical Meeting on Energetic Particles in Magnetic Confinement Systems, September, 2011, Austin,, O-17

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K. Shinohara, K.Tani, S. Putvinski, *Effect of rippled field on energetic ion confinement in 15MA scenario in ITER*, P Proc. of 12th IAEA Technical Meeting on Energetic Particles in Magnetic Confinement Systems, September, 2011, Austin, P2-10