Update on the DTT Research Plan Chapter 7: Fast Particle Physics

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Chapter 5: MHD, disruptions and control
Chapter 7: Fast particle physics
Chapter 8: Theory and simulation for preparation of experiments

Summary

Chapter 7: Fast Particle Physics (FPP)

- 7.1 Specificities of DTT related to FPP
- 7.2 NNBI and test particle transport
- 7.3 Simulation activity for FPP
- 7.4 FPP experiments and diagnostics
- 7.5 Codes available/required
- 7.6 Others...

Section 7.1 Specificities of DTT related to FPP

- As stated in the Technical and Scientific Committee (CTS) of DTT on 11-12 July 2022 "the first priority of the DTT research mission is to study and establish the "core-edge integration" with different plasma shapes at ITER/DEMO relevant parameter regimes";
- in these conditions, energetic ions (as generated in DTT by NNBI and ICRH) are expected to mutually interact with Alfvén waves (TAE, EPM, etc.);
- these supra-thermal ions are characterized by typical dimensionless orbit widths (characteristic Larmor radius or magnetic drift orbit size normalized to the machine size) similar to those expected in burning fusion plasmas => generally smaller than in present day devices;
- the ratio of ion speed to the Alfvén speed in DTT is similar to that expected in ITER/DEMO (the strength of Energetic Particle (EP) drive of Alfvénic fluctuations via wave-EP resonant interactions is preserved);
- => integrated physics behaviors of DTT plasmas similar to those expected in ITER
- Alfvénic fluctuation spectrum resonantly excited by EPs is expected to be characterized by toroidal mode numbers $n \sim O(10)$ (similarly to ITER plasmas) because of similarities of dimensionless parameters.

T. Wang et al., Physics of Plasmas **25**, 062509 (2018);
T. Wang et al., Physics of Plasmas **26**, 012504 (2019)

7.2 NNBI and test particle transport

In the past years, activities in the field of energetic particle physics have been carried out within the DTT Physics Theory tasks (leaded by F. Zonca) and continued at present (leaded by M. Falessi); part of these activities should be continued for the different plasma scenarios developed within the RP:

- Optimization of NNBI energy and geometry (with important fall-out on machine and scenario design): resonance structures by NNBI ions in DTT;
- Test particle transport: prompt and ripple losses and Resonant Magnetic Perturbation coils effect;
  => strong dependence of ripple losses on NNBI energy and angle of injection.

Simulations:

- Existing: Analyses on full power scenario (R_0=2.14m (old), R_0=2.19m)
- Ongoing/planned for near future: Analyses on full power scenario (R_0=2.19m) including EP driven modes
- To be done as preparation to experiments: for each scenario in presence of NNBI
- To be done in support to experiments (e.g., for interpretation):
- Existing codes and necessary developments: CHEASE (high resolution equilibrium), ORBIT, ASCOT, METIS, FAFNER, TRANSP, JINTRAC, MARS, HYMAGYC

Diagnostics:

- Already planned:
- To be considered:

7.3 Simulation activity for FPP - 1

Preliminary studies of Energetic Particle driven Alfvénic modes using the hybrid MHD-Gyrokinetic codes HMGC and HYMAGYC have been performed showing the evidence of excitation of Alfvénic type modes (T. Wang et al., ibid.). Linear simulations for ITER-like Energetic Particle pressure profiles have shown the presence of a broad spectrum of oscillations, with linearly unstable modes for toroidal mode numbers at least up to *n*=20 (the max. toroidal mode number checked...) (G. Vlad et al., MET-ENR final Workshop, 2021).

=> availability of reliable scenarios: on-axis q values unrealistically too low (now $q_0 \approx 0.6$...);
=> availability of realistic EP distribution functions (NNBI, ICRH)...

- repeat these studies for up-to-date scenarios, considering ICRH/NNBI generated energetic ions;
- scans while varying the characteristics energetic particle parameters (as, e.g., v_H/v_A, ϱ_H/a, n_H/n_i, radial profiles of safety factor, bulk and energetic particle density profiles, etc.) should be investigated to illustrate the stability of the energetic particle driven Alfvénic modes in the accessible parameter space of DTT (computationally highly demanding, HPC resources?);
- high-β scenario at low toroidal field during the initial phases of the operation of DTT could be considered (could DTT supplement JT-60SA results...(?));
- actual transport models (e.g., JINTRAC/JETTO, ETS,...) typically do not include eventual EP transport induced by EP driven Alfvénic modes (nonlinear saturation, mutual interaction between Alfvén waves and energetic particles, which could give rise to radial transport of the EP themselves);
- determination of the typical spectrum of oscillations driven by energetic particles in the range of Alfvénic modes: required to compute nonlinear fluxes in the phase space (see Phase Space Zonal Structures (PSZS) theory, and their implications on transport)

7.3 Simulation activity for FPP - 2

DTT research activities and EUROfusion theory and simulation initiatives (TSVVs, ENRs):

- CfP-FSD-AWP21-ENR-03 (ATEP: Advanced Energetic Particle transport models): DTT reference scenario already available for benchmarking and testing (but old parameters, e.g., R_0=2.08m, must be updated...);
- TSVV Task 10: Physics of Burning Plasmas;
- TSVV Task 2: Physics Properties of Strongly Shaped Configurations (NT).
- other EUROfusion initiatives (e.g., WPs (WPTE, WPSA, WPPrIO, etc.) and International Collaborations, e.g., China, the Center for Nonlinear Plasma Science (CNPS), etc.).

Simulations:

- Existing: Analyses on full power scenario (R_0=2.08m (old)), Energetic Particle radial density profiles as for ITER baseline scenario, *n*=1,...,20
- Ongoing/planned for near future: some activity simulations to compare Positive Triangularity vs. Negative Triangularity scenarios within TSVV#2 project
- To be done as preparation to experiments:
- To be done in support to experiments (e.g., for interpretation):
- Existing codes and necessary developments: CHEASE (high resolution equilibrium), FALCON, EQUIPE, DAEPS, JINTRAC, ETS(?), MARS, HYMAGYC, Energetic Particle IMAS Workflow (Ph. Lauber, ENR ATEP, TSVV#10)

7.4 FPP experiments and diagnostics

- Which experiments could be of interest to validate the FPP we expect from the codes?
- Synthetic diagnostics to understand how much the physics related to Energetic Particles can be "observed" by diagnostics...
- Contribution from experimentalist experts (M. Nocente, D. Testa, ...)

7.5 Codes available/required

Name	Description	Availability	Owners/users
FALCON	semi-analytical tool to study various aspects of linear physics of the Energetic Particles	Available (ENEA)	M. Falessi et al.
EQUIPE	Equilibrium post processing	Available (ENEA)	M. Falessi et al.
DAEPS	Drift Alfvén Energetic Particle Stability code	Available (ENEA)	
CHEASE	high resolution equilibrium code	Available (ENEA)	G. Vlad/V. Fusco
MARS	linear MHD solver	Available (ENEA)	G. Vlad/V. Fusco
HMGC	hybrid MHD-Gyrokinetic code (visco-resistive, non-linear reduced $O(\varepsilon^3)$ MHD; $k_\perp \varrho_H$<<1 Gyrokinetic equation (guiding center limit) for Energetic Particles)	Available (ENEA)	G. Vlad/V. Fusco/S. Briguglio
HYMAGYC	hybrid MHD-Gyrokinetic code (resistive, linear full MHD in curvilinear geometry; k_perp _rho_H ~O(1) Gyrokinetic equation for Energetic Particles)	Available (ENEA)	G. Vlad/V. Fusco/S. Briguglio
Hamitonian mapping	analysis tool	Available (ENEA)	V. Fusco/S. Briguglio
JOREK	Non-linear MHD, suited for edge studies (include x-point, scrape-off layer, divertor region, resistive wall effects, two-fluid effects and neoclassical flows, kinetic particle models, and further extensions. Main physics applications are the physics and control of disruptions and edge localized modes (ELMs)	Available (RFX)	D. Bonfiglio, ...
ORBIT	single particle guiding center code	Available (RFX)	G. Spizzo, M. Gobbin.
ASCOT	"Accelerated Simulation of Charged Particle Orbits in Toroidal devices" is a Monte Carlo orbit-following code developed in collaboration with VTT Technical Research Centre of Finland since 1991	Available (RFX)	P. Vincenzi
NBI distribution function	...	...	...
heating codes	...	...	...
Integrated Workflow for Energetic Particle Stability (IMAS)	automated time-dependent workflow for energetic particles stability analysis within the Integrated Modelling & Analysis Suite (IMAS) (Python-based), Not available at present, but ENEA-Frascati participate actively in the ENR project which developed this tool	Available (IPP, EU)	Ph. Lauber (ENR ATEP project)

7.6 Connections with other EGs

- Phase space fluxes from DAEPS: using the Phase Space Zonal Structures (PSZS) theory and linear results allow to compute the non-linear fluxes in the phase space ↔ implications on transport (should be addressed in Ch. 8, Theory?)
- Energetic Particles and their effects on bulk plasma transport (→ EG-3 "Plasma scenarios and associated modelling") (should be addressed in Ch. 8, Theory?)
- Equilibrium and stability of MHD modes (EG-5, Ch. 5)