DTT Research Plan Chapter 7: Energetic Particle Physics

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DTT Research Plan Team Meeting

Frascati, May 06-08, 2024

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Chapter 5: MHD, disruptions and control
Chapter 7: Energetic particle physics
Chapter 8: Theory and Simulation

Summary

Chapter 7: Energetic Particle Physics

(note: *Energetic* instead of *Fast*)

Table of Content:

Total pages: 12

Rationale of Chapter 7.

- This chapter discusses the role that DTT can play in studying the energetic particle physics in the frame of “core-edge integration” while considering different plasma shapes at ITER and DEMO relevant plasma parameters.
- The peculiar role of energetic particles as mediators of cross scale couplings in reactor relevant burning plasmas is briefly introduced.
- Brief summary of test particle approach (NNBI and test particle transport: prompt and ripple losses of energetic particles).
- Self-consistent simulations for Energetic Particle (short review on past and recent activity performed and future envisaged work).
- Diagnostics: DTT as a testbed for energetic particle diagnostics
    - relevant to future reactors
    - in relation to turbulence and instabilities.
- Headlines of the research programme for energetic particles.
- *List of Codes for Energetic Particles now in Appendix H.*

Chapter 7

- Title changed to “Energetic Particle Physics”
  (title of Ch. 7 in RP version presented at Padua (2023.12.13-15) was “Fast Particle Physics”)

Section 7.1 Introduction

- Text unchanged w.r.t. the RP presented at Padua (2023.12.13-15) meeting

Section 7.2 NNBI and test particle transport

- Text expanded w.r.t. the RP presented at the Padua (2023.12.13-15) meeting:
    - add details on the computation and already published results;
    - add details on future work on the effects of electromagnetic perturbed fields (e.g., TAEs) on single particle dynamics;
    - add a new figure on prompt losses and ripple-resonant losses vs the pitch $\lambda=v_{\|}/v$;
    - add a new figure on the map of the power load in the plane ($R\zeta$, L) ($R\zeta$: distance along the toroidal direction on the equatorial plane, L: distance along the separatrix from the mid-plane toward the X-point and $R=R_0+r$, r being the radius of the LCFS)

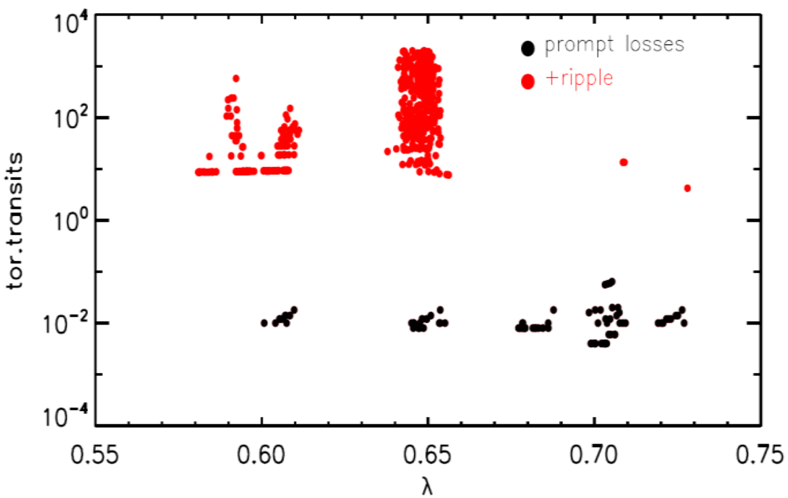

Fig.7.1: Loss times of ions with 510 keV energy as a function of pitch $\lambda = v_{\|}/v$, Run with $N_p = 10^6$ particles and toroidal turns N_{tor} = 2000. Red dots are losses occurring only in simulations with ripple, black dots also in those without ripple (prompt losses).

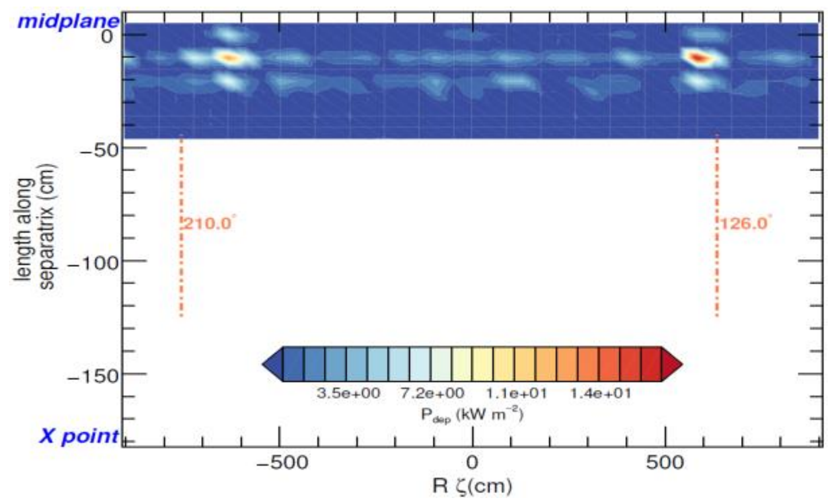

Fig.7.2: Map of the power load (in kW/m²) calculated with a 40 × 10 binning. In panel (b) the two vertical, dashed lines mark the injection and exit angles, ζ_{inj} = 126° and ζ_{out} = 210°.

Section 7.3 Simulation activity for EP physics

- Figure 7.4 updated:

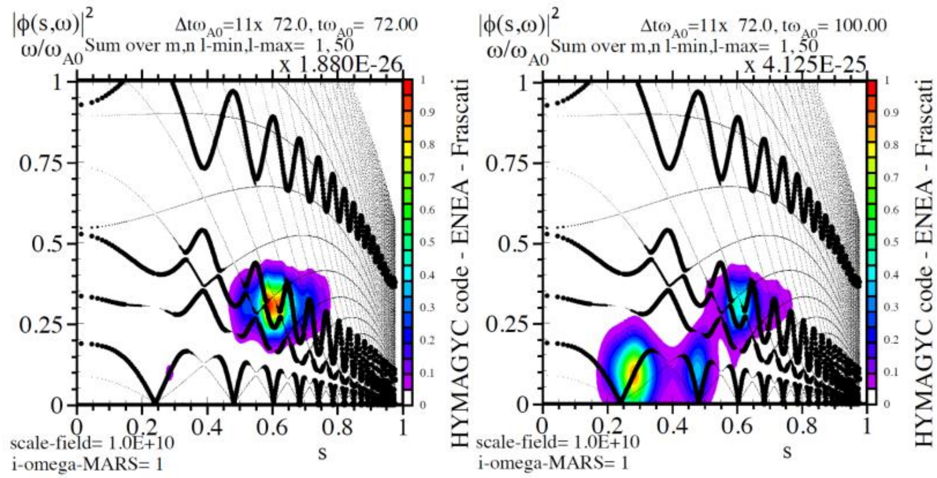

Fig. 7.4: Frequency spectra of the electrostatic potential in the plane (s,ω) as obtained by a linear HYMAGYC simulation with mode number n=10. Coloured structures refer to an energetic particle driven mode (left, $t\omega_{A0}$ =72) and to the appearance of the infernal-like mode (right, $t\omega_{A0}$ =100). Dots refer to Shear Alfvén and magneto/acoustic continua, as calculated by FALCON code; larger and darker symbols refer to Alfvénic oscillations, while smaller and lighter ones to ion sound waves.

- Added some sentences on the requirement for HPC resources for using Hybrid MHD-Gyrokinetic (PIC) codes (IMAS infrastructure and workflows relevance now in Ch. 8)
- Added a comment on the opportunity to investigate the possibility to begin Energetic particle studies on DTT during phase 1 scenario B (half current/half toroidal field).

Original Diagnostic Section split now in two separate sections:

Section 7.4 DTT as a testbed for reactor-relevant EP diagnostics

Section 7.5 Diagnostics for Fast Ions vs instabilities & turbulence

- Add a brief subsection related to diagnostics for “Direct observation of phase-space transport”

Add new Section 7.6 Headlines of the research programme for energetic particles

Headlines Number	Headlines contents	Priority (+, ++, +++)	ITER	DEMO
Construction Phase 2022-2029				
C.7.1	Verification of linear stability of EP driven modes on available scenarios with NNBI and ICRH using global gyrokinetic codes	++	*	*
C.7.2	Nonlinear simulations of EP driven modes on available scenarios with NNBI and ICRH using global gyrokinetic codes	++	*	*
C.7.3	Numerical study of the EP distribution function in phase space (NNBI, ICRH, NNBI & ICRH)	++	*	
C.7.4	Numerical study of EP test particle losses induced by magnetic field ripple and in presence of global Alfvén eigenmodes.	++	*	*
C.7.5	Set up IMAS infrastructure and dedicated workflows	+++		

Continue Section 7.6 ...

Phase 1 2029-2034				
1.7.1	Optimization of experimental scenarios to observe EP driven modes on Phase 1 scenarios	++	*	*
1.7.2	Validation of linear and nonlinear EP dynamics simulation on Phase1 experiments.	++	*	*
1.7.3	Validation of EP distribution function experimental reconstruction on Phase1 experiments.	++	*	*
1.7.4	Validation of EP test particle losses simulations with experimental observations.	++	*	*
Phase 2 2034-2038				
2.7.1-2.7.4	Same as 1.1-1.4 on Phase 2 scenarios 1.7.1-1.7.4	++	*	*
Phase 3 2038-...				
3.7.1-3.7.4	Same as 1.1-1.4 on Phase 3 scenarios 1.7.1-1.7.4	++	*	*

Observations, questions raised, etc...

- Van Eester:

Because of the weak Kadomtsev scaling approach considered in designing the device (see Chapter 1 and Chapter 8), the supra-thermal ions in DTT are characterized by typical dimensionless orbit widths, which are expected to be similar to those of burning fusion plasmas and are generally smaller than in present-day devices (the dimensionless orbit width of the supra-thermal ions is defined as the characteristic Larmor radius

is this true for a machine of the size of DTT??

- Pietro Vincenzi, minor corrections/suggestions:
  - ITER acronym;
  - add references to Ch. 6;
  - mention to ICRH EP;
  - repetition with diagnostic for NBI (and ICRH) in Ch. 6

Typos, corrections in Ch. 7 (version DTT-RP draft_v6.pdf)

- at p. 112 (Section 7.2): "*Toroidal Alfven Eigenmodes (TAE)*" Alfven => Alfvén

- First bullet at p. 112 (Section 7.2):
  "• *Studying the resonance structures created by NNBI ions in the DTT plasma on the various scenarios considered for DTT.*"

- Headlines: headlines numbering to be updated "*1.1-1.4*" =>1.7.1-1.7.4

Phase 2 2034-2038				
2.7.1-2.7.4	Same as 1.1-1.4 on Phase 2 scenarios 1.7.1-1.7.4	++	*	*
Phase 3 2038-...				
3.7.1-3.7.4	Same as 1.1-1.4 on Phase 3 scenarios 1.7.1-1.7.4	++	*	*

Next versions of Chapter 7: Energetic Particle Physics-1

- As a general comment:
  - I think there is the need for a greater involvement of the DTT physics group (e.g., the participants to the “Call for Services”) in the Research Plan group.

- Section 7.2 NNBI and test particle transport
  - Studying the resonance structures created by NNBI ions in the DTT plasma on the various scenarios considered for DTT (only full power scenario has been investigated for now...)
  - Test particle transport: investigating prompt and ripple losses of energetic particles and understanding the effects of Resonant Magnetic Perturbation (RMP) coils.
  - Simulations also including electromagnetic perturbations generated by the energetic particles themselves (EP driven modes) are envisaged.

Next versions of Chapter 7: Energetic Particle Physics-2

- Section 7.3 Simulation activity for EP physics
  - To properly simulate EP physics in DTT, it is essential to have realistic scenarios with on-axis q values that are not unrealistically low;
  - and it would be desirable to have equilibria optimized with respect to medium to high-n ballooning modes stability;
  - The availability of realistic EP distribution functions generated by ICRH and NNBI is crucial for accurate simulations, the behaviour of the EP-driven Alfvénic modes possibly being strongly dependent on the details of the EP distribution function in phase space;
  - at present, EP studies in DTT have been focused only on full power scenarios, considering an EP population generated by NNBI;
  - in earlier phases of DTT, a moderate ICRH would be already present (e.g., scenario B during phase 1, at half current and half toroidal field, I_p(MA)/B_T(T)=2/3 and P_{ECRH}(MW)/P_{ICRH}(MW)=16/4), see Table 2.1): EP effects in this scenario should be investigated in the near future;
  - comparing DTT results with existing results from other devices like JT-60SA may offer further validation and understanding.

Thank you for your attention!