Theory and simulations chapter

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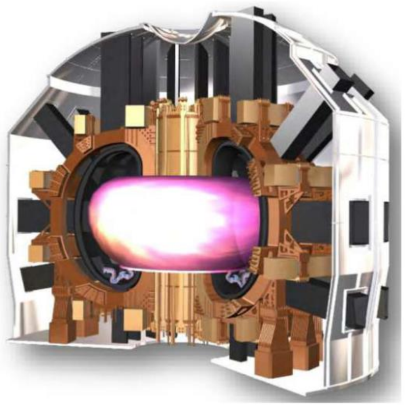
Outline

- Rationale
- Table of contents
- Summary of Chapter 8
- Status of the writing

Rationale of Chap 8

Divertor Tokamak Test (DTT) facility



- One of the key issues towards demonstration of fusion energy is Power & Particle EXhaust (PPEX)
  - Mission for DTT
- Integration of various physics and technology aspects is crucial
  - Clear impact on plasma performance and operation

From ICPP 2022 FZ&DTT Team

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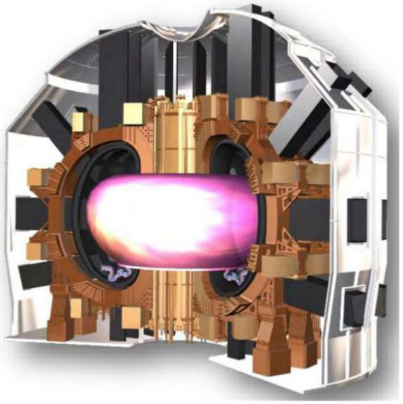
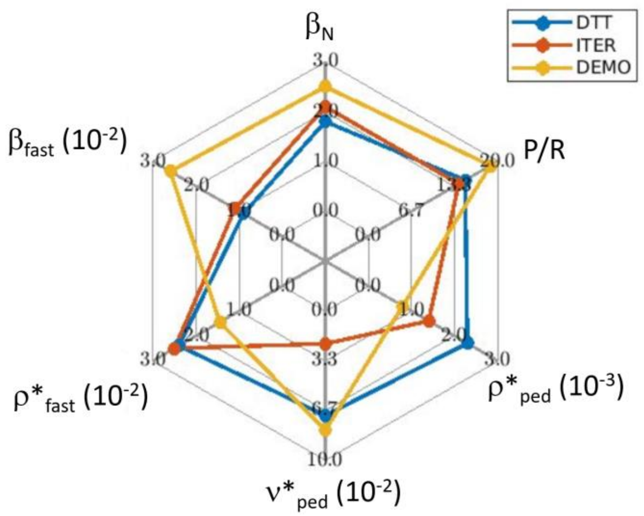


- One of the key issues towards demonstration of fusion energy is Power & Particle EXhaust (PPEX)
  - Mission for DTT
- Integration of various physics and technology aspects is crucial
  - Clear impact on plasma performance and operation
    - Here: focus on physics integration (in general)
  - Need for reliable predictive capability
  - Integrated Modeling crucial for turbulent transport
  - Need for novel approaches and physics understanding: fusion is not a mere engineering and technology problem

From ICPP 2022 FZ&DTT Team

Rationale of Chap 8



– DTT has been designed to describe the physics of reactor-relevant fusion plasmas;

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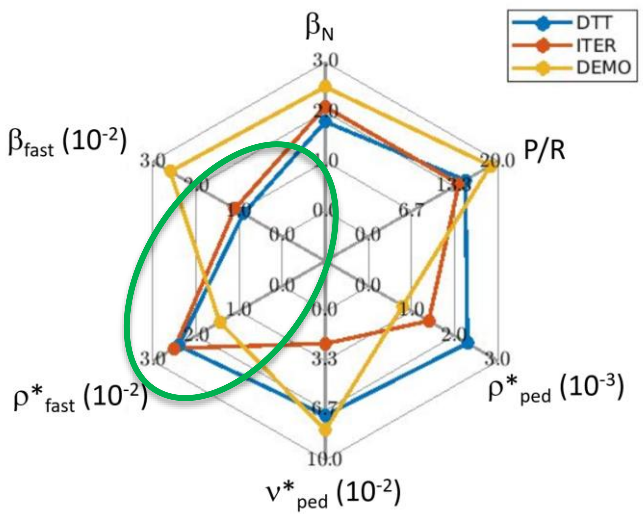

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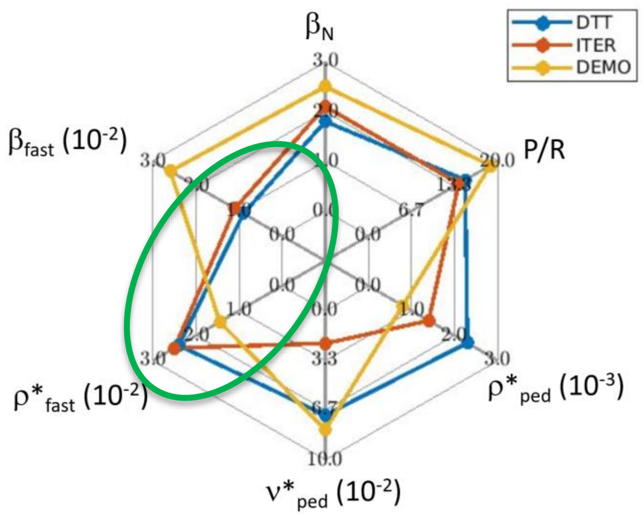

– DTT has been designed to describe the physics of reactor-relevant fusion plasmas;
– reactor-relevant plasmas are a complex system;
– as a result, it gives rise to challenges in the theoretical description of the physics processes;

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What makes DTT unique?

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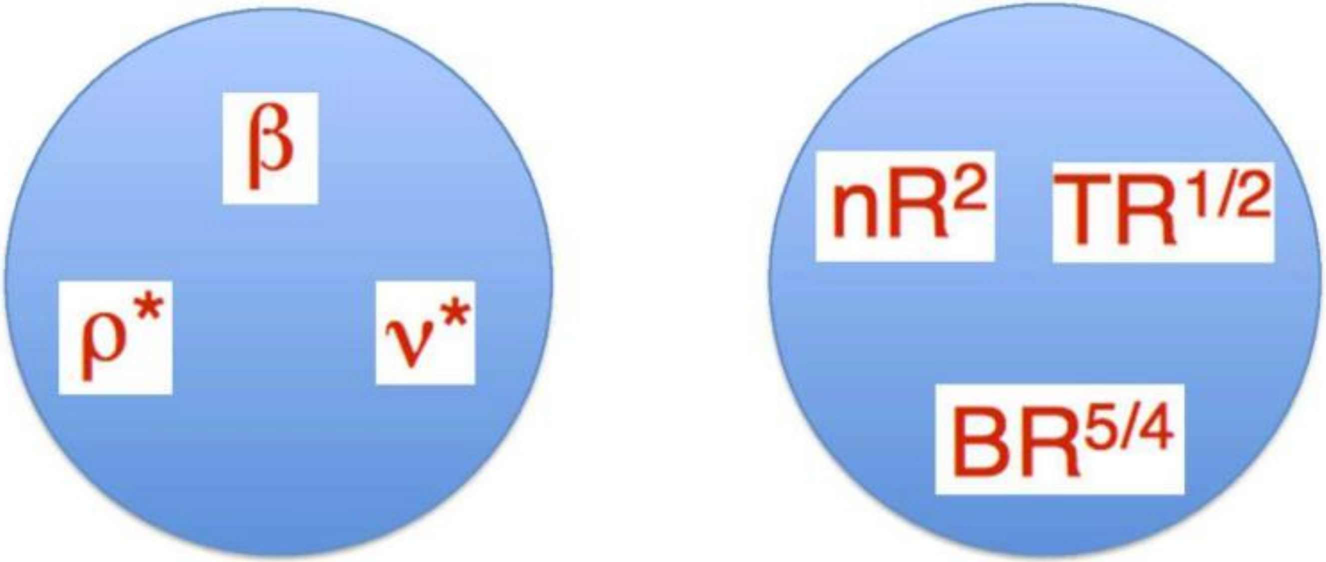
Theoretical challenges in describing the physics of DTT

8.1 Weak similarity scaling & DTT

- The operation space of quasi-neutral, collisional, finite-β plasmas



There exist three dimensionless parameters in the governing equations [Kadomtsev 75]

Three engineering (dimensional) parameters, with R left to vary [Lackner 90]

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8.1 Weak similarity scaling & DTT

- Weak Kadomtsev scaling [Pizzuto et al NF2010]:
  ➔ fix $\rho_* R^\epsilon$, β, ν_*
  - Weak scaling of $\rho_* R^\epsilon$
    - Cross-scale coupling (micro-meso scales) is preserved;
    - Preserve ρ_{*EP}/ρ_* set by T_{EP}/T , given by condition of dominant electron heating

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    - Preserve ρ_{*EP}/ρ_* set by T_{EP}/T , given by condition of dominant electron heating
  - Fix β and stability
    - Preserve temporal scale hierarchy: frequency ordering of meso- to macro-scale fluctuations
  - Fix collisionality parameter ν_*
    - Preserve edge physics and PWI (PPEX)
    - Preserve supra-thermal particle content in the core

From ICPP 2022 FZ&DTT Team

8.2 Plasma as a complex system: nonlinear equilibria and self-organization

- ❑ Integrated simulations ➔ must address burning plasmas as complex self-organized systems

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CNPS

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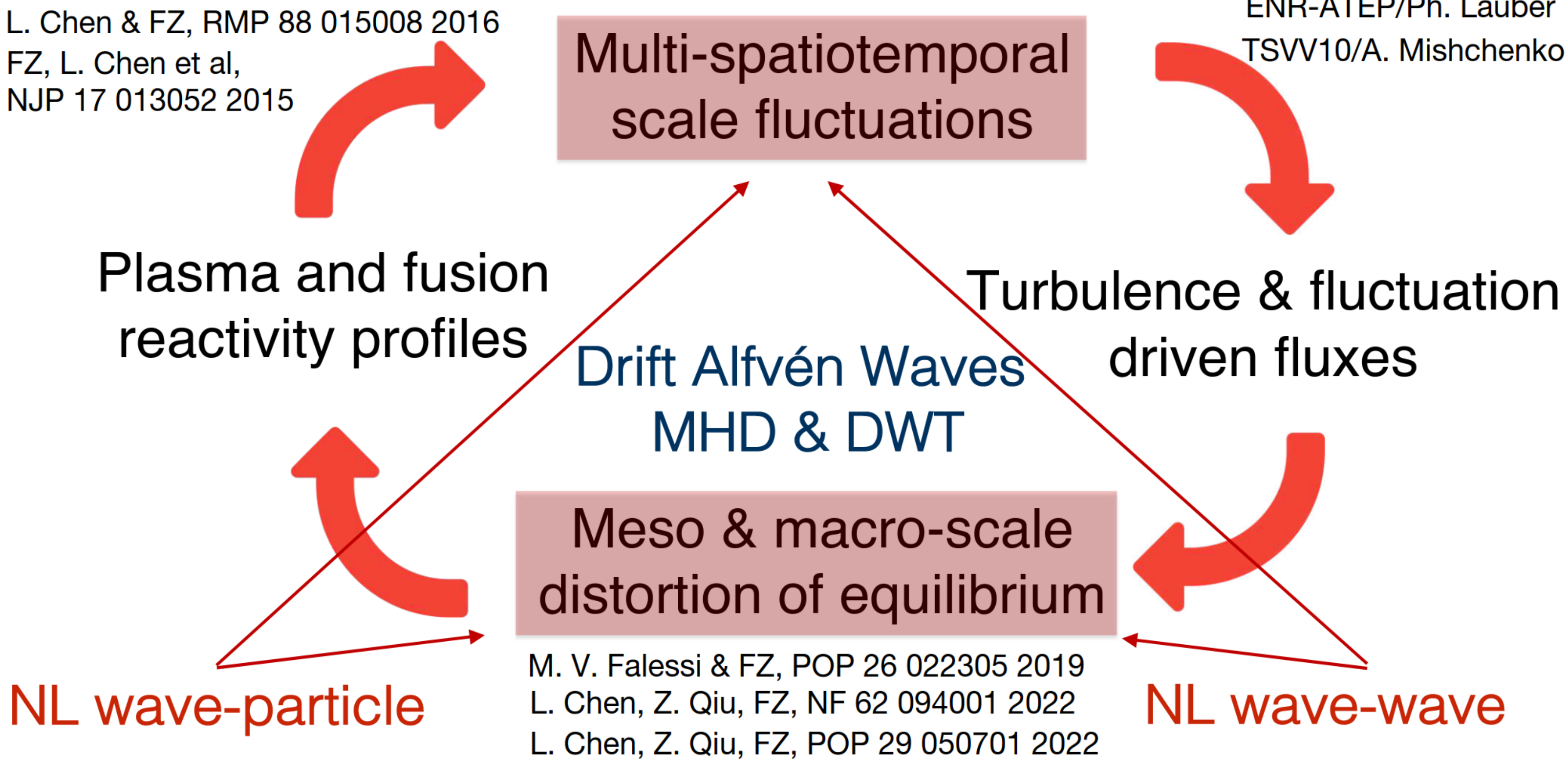
EUROfusion projects
ENR-ATEP/Ph. Lauber
TSVV10/A. Mishchenko



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8.2 Plasma as a complex system: nonlinear equilibria and self-organization

CNPS

- In collisionless burning plasmas
  - Power balance is dominated by EP
  - Fluctuation induced transport may cause significant deviation from local thermodynamic equilibrium
    ➔ importance of phase space transport
  - EP are mediators of cross-scale couplings (C&Z RMP16)

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- Recent progress in two areas of theory and simulation:
  - Interaction of Alfvén Eigenmodes (AE) and drift wave turbulence (DWT) (Chen et al. 2021-22)
  - Gyrokinetic theory of phase space transport (Falessi et al. 2019-21-23) ➔ phase space zonal structures (PSZS)

8.3 Gyrokinetic transport theory: general approach & reduced models

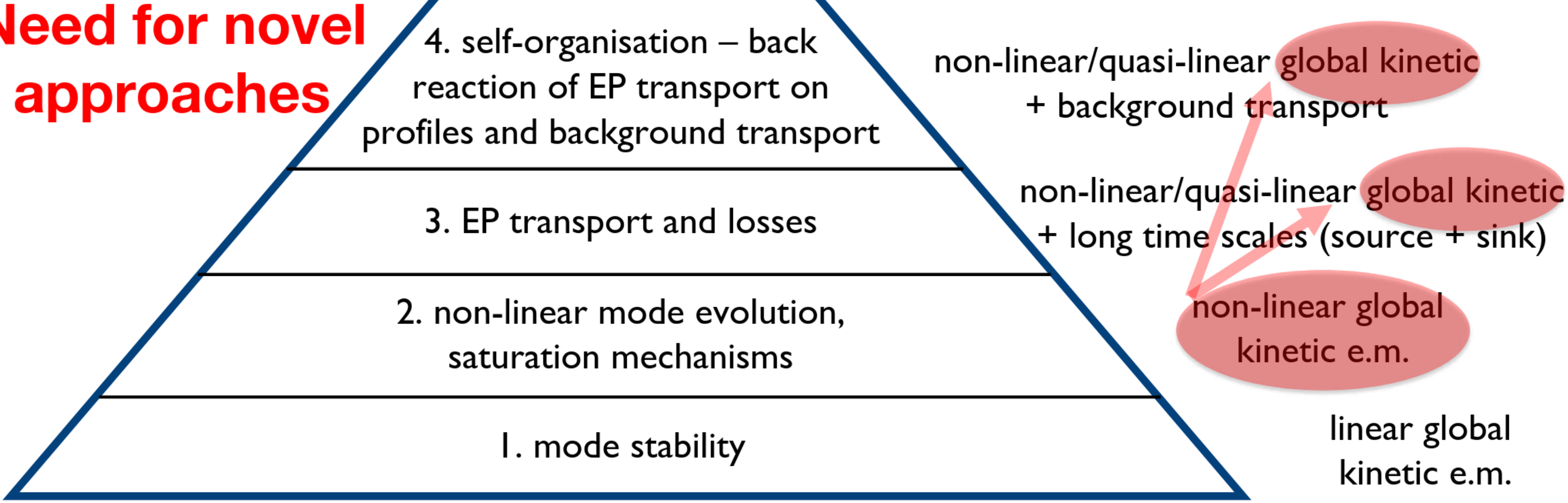
- Integrated simulation hierarchy for plasmas with significant EP energy density ➔ **Drift Alfvén Waves & DWT**

EUROfusion projects

ENR-ATEP/Ph. Lauber
TSVV10/A. Mishchenko

Courtesy of Ph. Lauber
3.rd Trilateral International Workshop on EP Physics, Nov 7-10, 2022

Need for novel approaches



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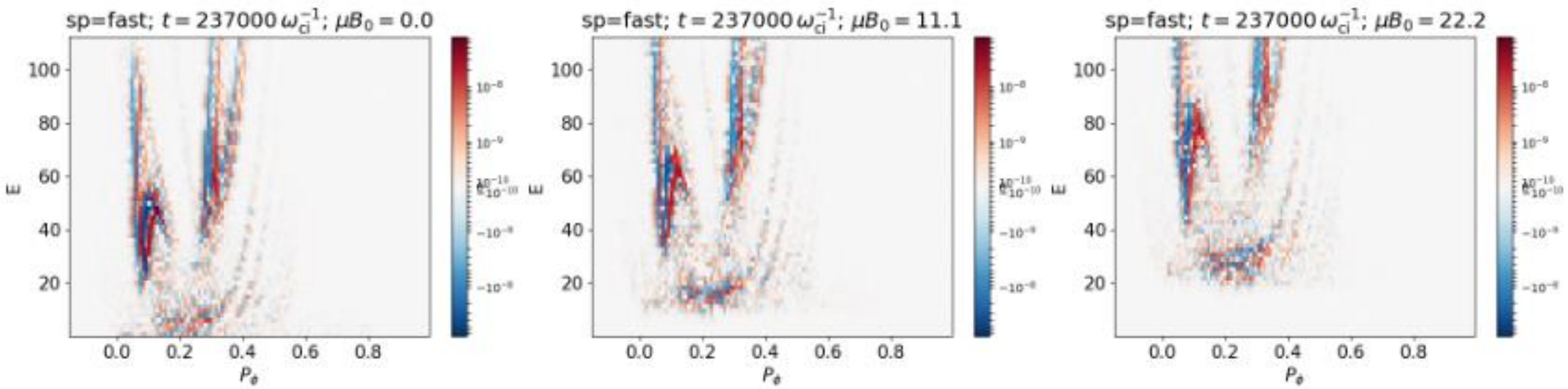
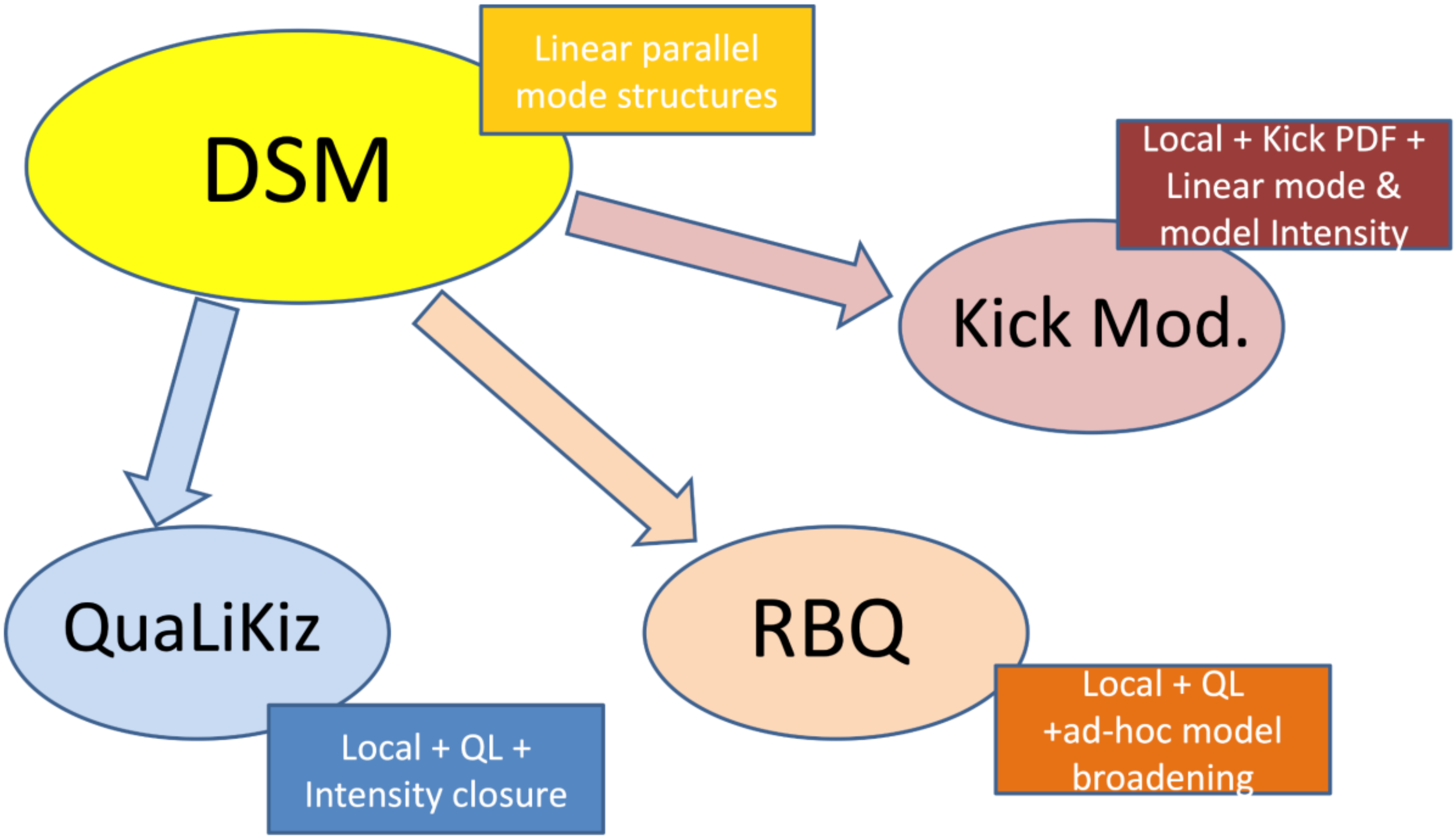
8.3 Gyrokinetic transport theory: general approach & reduced models

Courtesy of Thomas Hayward-Schneider



$$\frac{\partial}{\partial t}\overline{F_{z0}} + \frac{1}{\tau_b}\left[\frac{\partial}{\partial P_\phi}\overline{\left(\tau_b \delta \dot{P}_\phi \delta F\right)_z} + \frac{\partial}{\partial \mathcal{E}}\overline{\left(\tau_b \delta \dot{\mathcal{E}} \delta F\right)_z}\right]_S = 0$$

8.3 Gyrokinetic transport theory: general approach & reduced models



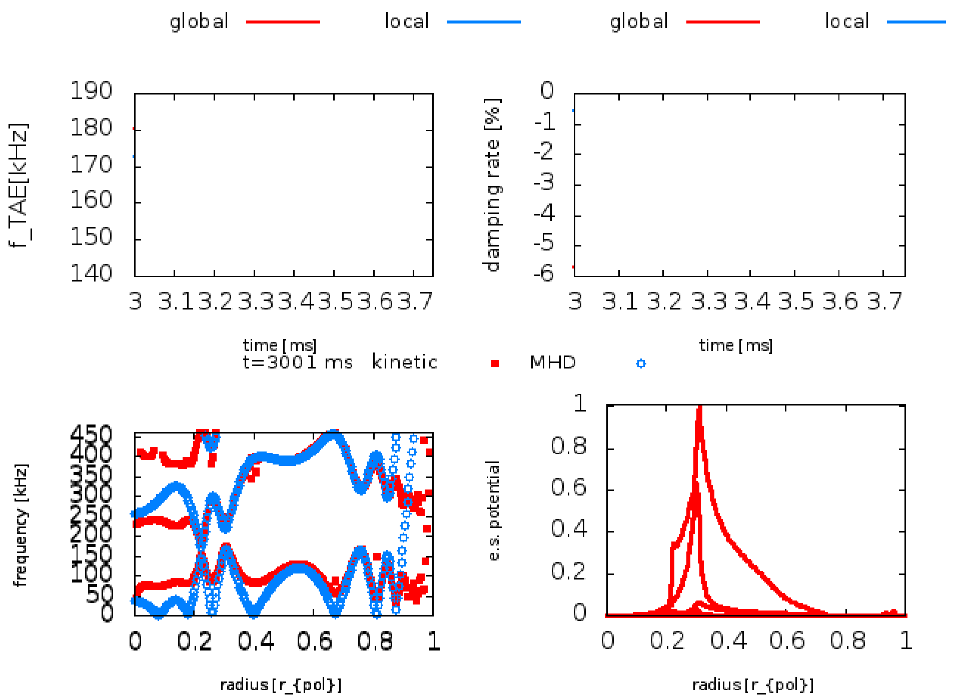
From FZ CNPS-DTT MHD&TH Seminar Dec 2021

Additional topics:

- improvement of current transport approaches;
- Moment based hybrid/kinetic models;
- need of truly global, electromagnetic, Gyrokinetic analyses;

8.4 Integration of theory, simulation and experiments

- Importance of building an infrastructure to verify and validate reduced models on DTT;
- role of IMAS infrastructure;
- Ligka-Hagis EP workflow, synthetic diagnostics;



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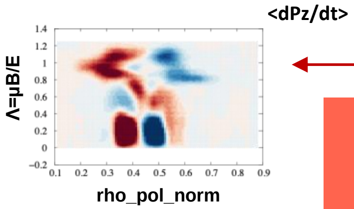
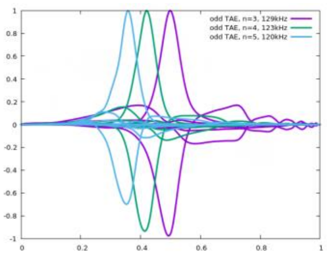


ATEP code: solve transport equation for PSZS with sources and collisions, Lauber 2022

$$\frac{\partial}{\partial t}\overline{F_{z0}} + \frac{1}{\tau_b}\left[\frac{\partial}{\partial P_\phi}\overline{\left(\tau_b \delta\dot{P}_\phi \delta F\right)}_z + \frac{\partial}{\partial \mathcal{E}}\overline{\left(\tau_b\delta\dot{\mathcal{E}}\delta F\right)}_z\right]_S = \overline{\left(\sum_b C_b^g\left[F,F_b\right]+\mathcal{S}\right)}_{z\,S}$$

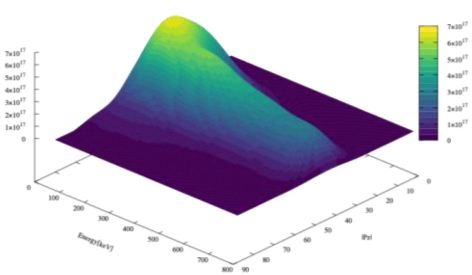
calculate PSZS fluxes with prescribed amplitude

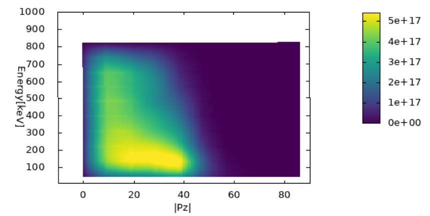
advance F_{EP} and return updated F_{EP} into IDS, or its moments

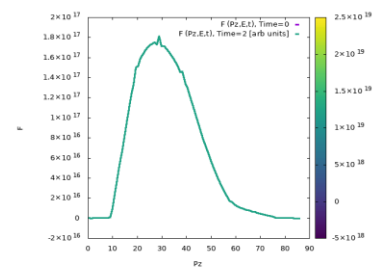


calculate linear mode spectrum

DAEPS and LIGKA Are interchangeable Thanks to IMAS



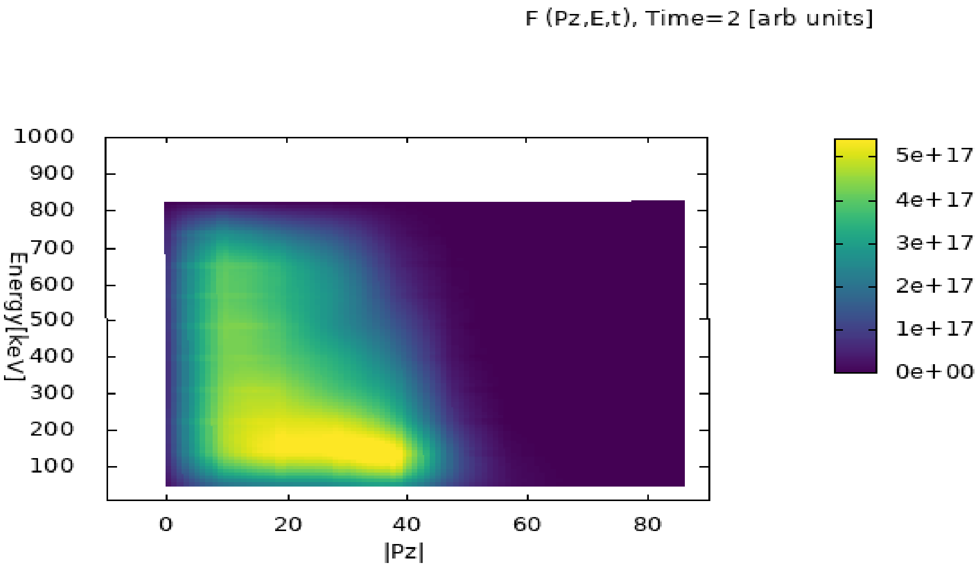


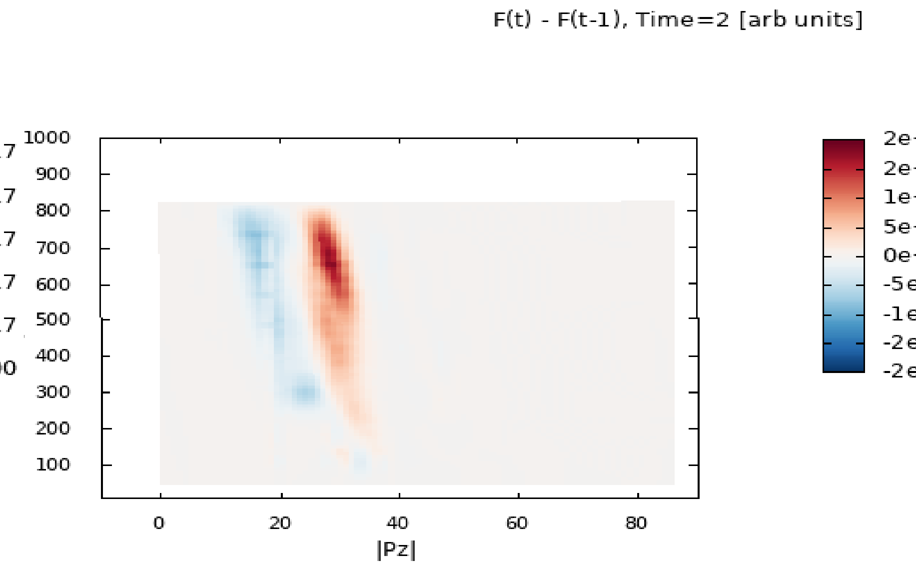


core_transport
equilibrium
mhd_linear
distributions

time

8.4 Integration of theory, simulation and experiments





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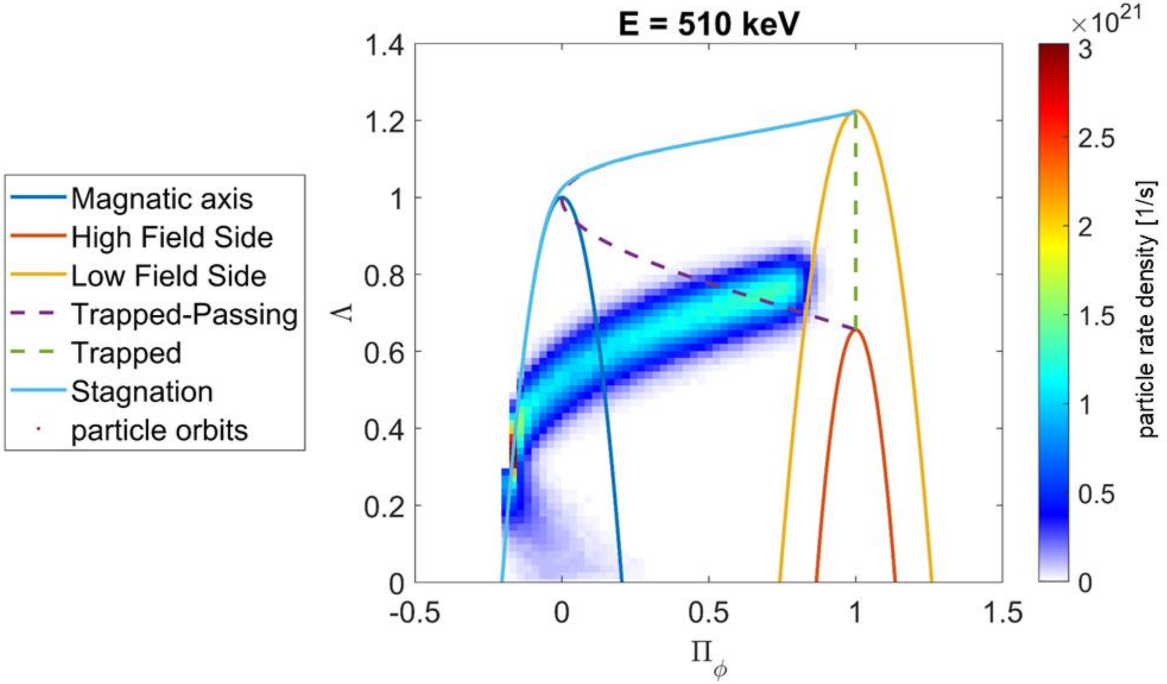

Courtesy of C. de Piccoli & P. Vincenzi

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8.5 Novel approaches and open problems

Some topics:

- nonlinear Gyrokinetics near plasma edge;
- fully nonlinear Gyrokinetic collision operators;
- Hierarchy of reduced models for edge physics (mid term priority);

What is missing

– The writing process is almost completed;

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- Interactions with Pietro Vincenzi and Chiara de Piccoli regarding EPs distribution functions;
- Interactions with Gloria Falchetto and others regarding integrated and edge physics;
- Interactions with Paola regarding the «transport workflow» and IMAS are foreseen;

Thank you for your attention!