EUROfusion

ENR ATEP 2022 review

ATEP team:

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MAX-PLANCK-INSTITUT FÜR PLASMAPHYSIK

ENEA ITALIAN NATIONAL AGENCY FOR NEW TECHNOLOGIES, ENERGY AND SUSTAINABLE ECONOMIC DEVELOPMENT

CNPS Center for Nonlinear Plasma Science Since 2020

iter china eu india japan korea russia usa

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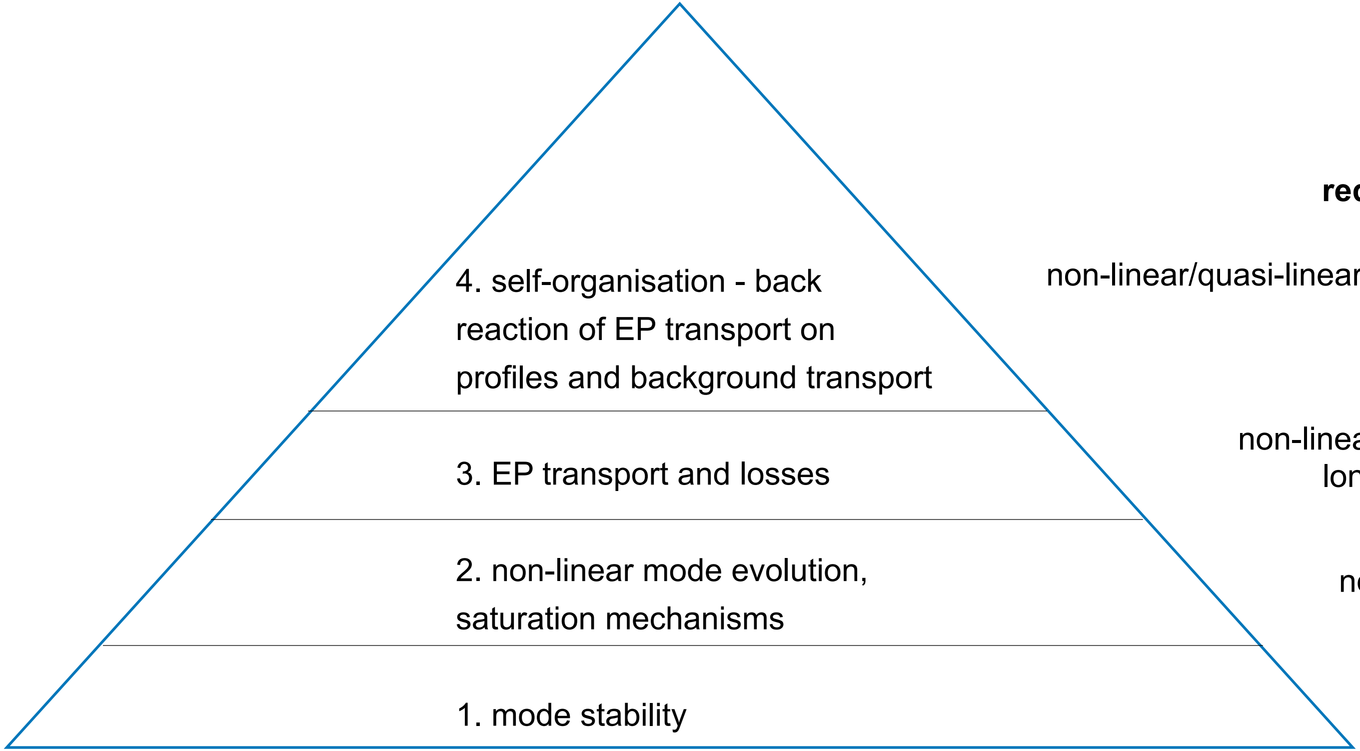
ATEP's goal: add reduced EP transport models to presently available tools:

needed for scaling from TCV-AUG-JET, W7X… to JT-60SA-DTT-ITER-DEMO, in particular burning plasmas



required models:

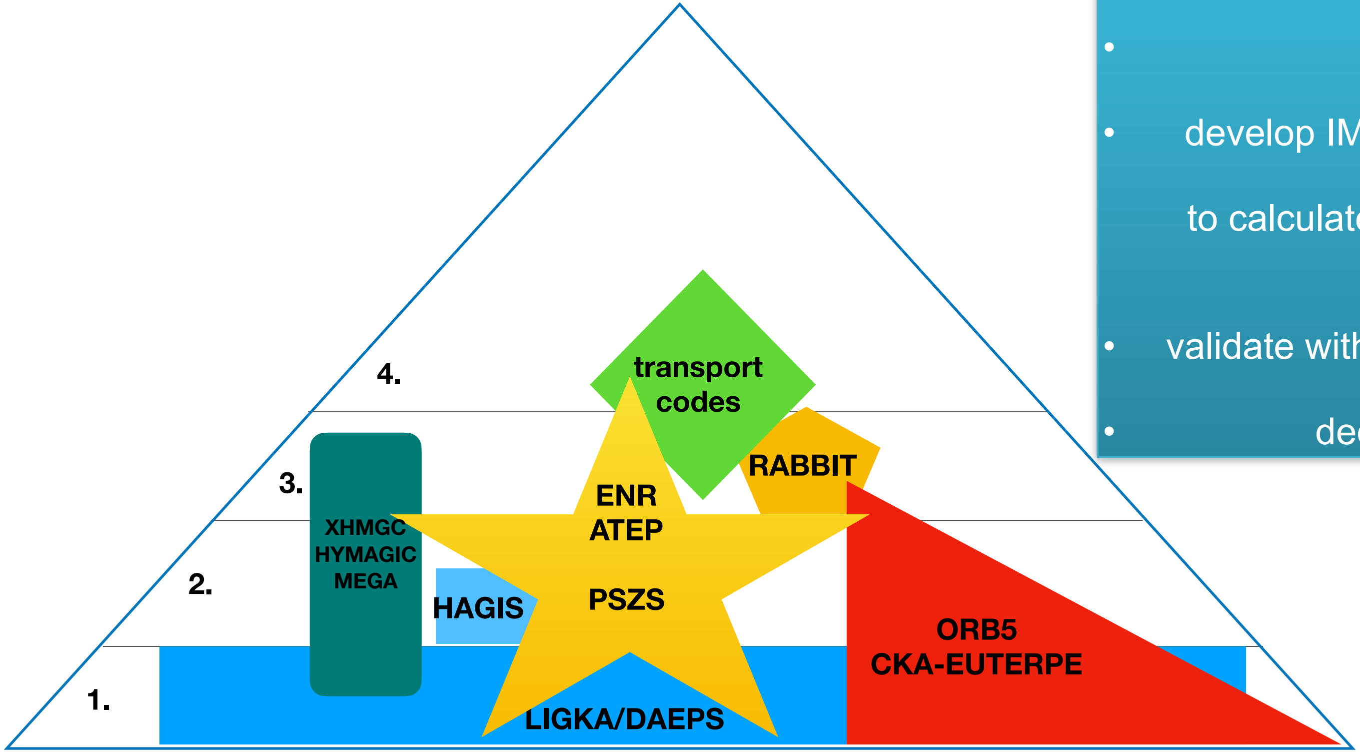
non-linear/quasi-linear global kinetic e.m.+ background transport

non-linear/quasi-linear global kinetic e.m. + long time scales (source +sink)

non-linear global kinetic e.m.

linear global kinetic e.m.

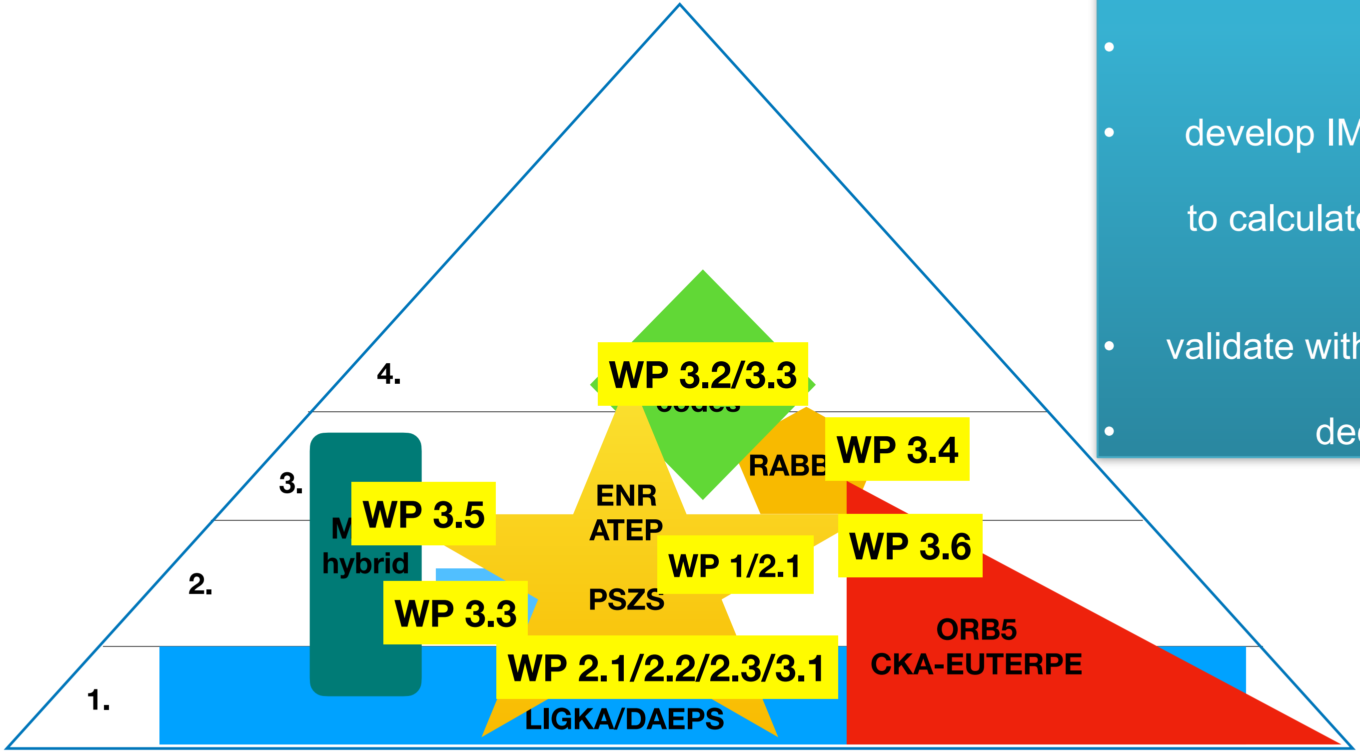
modelling hierarchy for plasmas with significant energetic particle pressure



ENR ATEP aim:

- advance theory
&
- develop IMAS based models of various fidelity and cost
to calculate electromagnetic, global EP transport
&
- validate with more comprehensive codes
&
- dedicated experiments

modelling hierarchy for plasmas with significant energetic particle pressure



ENR ATEP aim:

- advance theory (WP 1)
  &
- develop IMAS based models of various fidelity and cost (WP 2)
  to calculate electromagnetic, global EP transport
  & (WP 3)
- validate with more comprehensive codes
  &
- dedicated experiments (WP4)

2022 Deliverables 1/2

3. Scientific deliverables

Scientific deliverable *(annual scientific deliverables as specified in the Task Agreement)*		**Achieved: Fully/Partly/Not**	**Evidence for achievement, brief reason for partial or non-achievement**
WP1-D2	Explicit expressions of phase space fluxes as input for WP2	fully	ID 33607; Explicit expressions have been presented in an invited talk at the Varenna Theory Conference and submitted for publication to PPCF in the corresponding manuscript
WP2.1-D2	Reduced EP transport model in tokamaks	fully	ID 33607; From WP1-D2 it has been shown that turbulent fluxes consistent with nonlinear gyrokinetic codes can be recovered and reduced to the DSM as well as to the quasi-linear limits
WP2.2-D1	Fast analytical LIGKA version including trapped particles/ Generalize fast analytical LIGKA version to non-Maxwellian distribution functions, in particular slowing down	partly	ID 31591; the personnel changes discussed above lead to a re-ordering of the deliverables/milestones. The further development of LIGKA-fast has been started with the inclusion of generalised distribution functions. Trapped particles models are postponed to 2023. See mid-term report: https://wiki.euro-fusion.org/wiki/Project_No10
WP3.1-D1	Validated 1D reduced model for EP transport in ITER/DTT	fully	ID 32056 , ID 30899 **Prediction of avalanches (non-diffusive transport) triggered by EPs**
WP3.2-D1	Insights into short- and long-time relaxation dynamics of a non-thermal plasma with intense energetic particle component	fully	Milovanov et al 2022, paper in preparation See also mid-term report: https://wiki.euro-fusion.org/wiki/Project_No10

2022 Deliverables 2/2

WP3.3-D1	Availability of validated reduced phase space transport model based on LIGKA/HAGIS/RABBIT within IMAS framework	partly	This deliverable, planned for the end of the project has been anticipated: kick-model limit for the ATEP code is already now available; PSZS IMAS interfaces were defined and are already in use. See mid-term report: https://wiki.euro-fusion.org/wiki/Project_No10
WP3.4-D1	Validated version of RABBIT including model for fluctuation-induced radial transport of EPs/ use RABBIT input for reduced transport model	partly	After setting up the first version of the ATEP code it turned out that using RABBIT as source for ATEP is mode convenient than the other way around. Orbit averaged deposition information given by RABBIT instead can be straightforwardly used by ATEP. A neoclassical module with sources and sinks is presently under development.
WP3.5-D1	Hybrid kinetic-MHD results for V&V of transport models: with generalized distributions functions and collisions for AUG, ITER, DDT.	Fully/partly	IDs: 33267, 33536
WP3.6-D1	Deliver quantitative criteria for transitions between different transport regimes w/o turbulence and ZF/ZSs in experimentally relevant regimes	Fully/partly	IDs :33267, 33147. 32694
WP4-D1	Availability of reference scenarios (ITER, AUG, DTT) for application of transport models	fully	ID 31591, Invited talk S.D. Pinched, EPS 2022

Milestones 2022 1/2

3 WP2.1-M1 Benchmark of DAEPS in general toroidal geometry against reduced local LIGKA analysis for trapped particles, mid 2022

4 WP2.1-M2 Computation of nonlinear coupling coefficients in the nonlinear envelope equation and of EP fluxes in phase space, end 2022

fully
partly
not started

6 WP2.2-M1 Develop (semi-)analytical trapped particle model for LIGKA, mid 2022

8 WP2.2-M3 Generalize fast analytical LIGKA version to non-Maxwellian distribution functions, in particular slowing down End 2023 (Master Project started - first results); swapped with milestone 6

9 WP2.3-M1 Derive equations for local LIGKA-like version in 3D Mid 2022 (slightly delayed - mid 2023)

12 WP3.1-M2 Interface of the 1D "mapping" in the ITER/IMAS workflow; End 2022 (partly)

13 WP3.2-M1 Probability density function of the radial displacements of tracer particles deduced from EP transport models Mid 2022

Milestones 2022 2/2

15 WP3.3-M1 Extend unperturbed orbit integration routines and averaging procedures in order to calculate phase space fluxes in HAGIS mid 2022 (fully)

17 WP3.3-M3 Finish reduced EP transport workflow based in LIGKA/HAGIS within IMAS

mid 2024 (anticipated) - new ATEP3D conceptually finished (matlab version)

18 WP3.4-M1 Develop and implement radial diffusion model to RABBIT End 2022 (postponed to 2023) - (the sub-project will be started mid 2023, based on ATEP3D results)

replaced by COM neoclassical solver (ATEP 3D), developed by G. Meng

19 WP3.4-M1 Apply extended RABBIT model to transient events, e.g. EP evolution during sawtooth cycles mid 2024 (the sub-project will be started end 2023, based on ATEP3D results)

21 WP3.5-M2 Implementation of generic EP distributions into XHMGC, HYMAGYK and MEGA; add drift-kinetic model to STRUPHY; couple to GVEC 3D equilibrium solver for application to tokamaks and stellarators

23 WP3.6-M2 Calculate particle and heat transport in the presence of turbulence with ORB5 for validation of the reduced models End 2022

24 WP4-M1 Plan and conduct AUG experiments in the view of clear and well-diagnosed transitions between EP transport regimes End 2021/22

fully
partly
not started

4. Publications/presentations

First Author	Initials	Title of work	Journal / Conference	Doc. Type	DOI or status of paper	Pinboard ID
Lauber	Ph.	Energetic particle driven instabilities during the L-H transition in ASDEX Upgrade	Proceedings 48th EPS Conference on Plasma Physics (EPS), Maastricht, Netherlands, 2022	Poster, paper	published	31591
Pinches	S.D.	Role of Energetic Ions in the ITER Research Plan	Plenary talk at 48th EPS Conference on Plasma Physics (EPS), Maastricht, Netherlands, 2022	Plenary talk	N/A	N/A
Wang	X.		THEORY OF FUSION PLASMAS JOINT VARENNA - LAUSANNE INTERNATIONAL WORKSHOP, Varenna, Italy, 12th September 2022.	Invited talk		
Wang	X.	Nonlinear dynamics of nonadiabatic chirping-frequency energetic particle mode in Tokamak plasmas	28th ITPA Topical Group Meeting on Energetic Particle Physics, Caradache, France, 21st November 2022.	talk	N/A	33267
Wang	T.	Excitation of toroidal Alfvén eigenmode by barely circulating energetic electrons in low density plasmas	Plasma Physics and Controlled Fusion	paper	submitted	33536
Hayward-Schneider	T.	Global electromagnetic gyrokinetic simulations of Energetic Particle driven instabilities in ITER and ASDEX Upgrade	6th Asia Pacific Conference on Plasma Physics (AAPPS-DPP2022), online , 9th October 2022.	invited	N/A	33120
Carlevaro	N.	Energetic particle transport: diffusion vs convection and phase-space barriers	48th EPS Conference on Plasma Physics (EPS), Maastricht, Netherlands, 27th June 2022.	poster	published	32056
Biancalani	A.	Interaction of Alfvénic modes and turbulence via the nonlinear modification of the equilibrium profiles	48th EPS Conference on Plasma Physics (EPS), Maastricht, Netherlands, 27th June 2022.	Poster/paper	published	31903
Sama	J.N	Effect of temperature anisotropy on the dynamics of geodesic acoustic modes	Journal of Plasma Physics, 2022	paper	submitted	33147
Zocco	A.	Nonlinear drift-wave and energetic-particle transport in stellarators: solution of the kinetic problem.	Journal of Plasma Physics,2022	paper	submitted	33166
Koenies	A.	A numerical	Physics of Plasmas	paper	10.1063/5.01	32404

First Author	Initials	Title of work	Journal / Conference	Doc. Type	DOI or status of paper	Pinboard ID
		approach to the calculation of the Alfven continuum in the presence of magnetic islands			02239	
Falessi	M. V.	Energetic particle nonlinear equilibria and transport processes in burning plasmas	6th Asia Pacific Conference on Plasma Physics (AAPPS-DPP2022), online , 9th October 2022.	invited	N/A	33199
Wei	S.	Core localized alpha-channeling via low frequency Alfvén mode generation in reversed shear scenarios	Nuclear Fusion	paper	10.1088/1741-4326/ac968f	33016
Chen	L.	On scattering and damping of Toroidal Alfvén eigenmode by drift wave turbulence	Nuclear Fusion	paper	10.1088/1741-4326/ac7cf9	32705
Bottino	A.	Time evolution and finite element representation of phase space zonal structures in ORB5	THEORY OF FUSION PLASMAS JOINT VARENNA - LAUSANNE INTERNATIONAL WORKSHOP, Varenna, Italy, 12th September 2022.	poster, paper	accepted	32694
Wu	Y.	Nonlinear electron phase-space dynamics in spontaneous excitation of falling-tone chorus	:Geophysical Research Letters	paper	10.1029/2022GL100046	32688
Chen	L.	Parity-breaking parametric decay instability of kinetic Alfvén waves in a nonuniform plasma	Physics of Plasmas	paper	10.1063/5.0091057	32397
Li	Y.Y.	Kinetic Structure of Low Frequency Continuous Spectrum in General Tokamak Geometry	48th EPS Conference on Plasma Physics (EPS), Maastricht, Netherlands, 27th June 2022.	Poster/paper	published	31816
Falessi	M. V.	Energetic particle nonlinear equilibria and transport processes in burning plasmas	48th EPS Conference on Plasma Physics (EPS), Maastricht, Netherlands, 27th June 2022.	Poster/paper	published	31766
Ma	R.R.	Theoretical studies of low-frequency Alfvén modes in tokamak plasmas	Plasma Physics and Controlled Fusion	paper	10.1088/1361-6587/ac434a	31657
Li	Y.Y.	Physics of drift Alfvén instabilities and energetic particles in fusion plasmas	THEORY OF FUSION PLASMAS JOINT VARENNA - LAUSANNE INTERNATIONAL WORKSHOP, Varenna, Italy, 12th September 2022.	Invited/paper	To be submitted	33607

Recent developments and outlook 2023

WP1: theoretical framework, implementation in DAEPS WP2

derived explicit analytical expressions for fluxes, implemented in DAEPS

$$\partial_t \left(\overline{e^{iQ_z} \bar{F}_0} + \overline{e^{iQ_z} \delta F_z} \right) = - \frac{1}{\tau_b} \frac{\partial}{\partial \psi} \left[\tau_b \overline{e^{iQ_z} \delta \dot{\psi} \delta F} \right]_z - \frac{1}{\tau_b} \frac{\partial}{\partial \mathcal{E}} \left[\tau_b \overline{e^{iQ_z} \delta \dot{\mathcal{E}} \delta F} \right]_z$$

phase space flux

$$\begin{aligned} \tau_t \overline{\delta \dot{\bar{r}} \delta F} = & \frac{\pi |A|^2}{\omega_{Ts} \bar{x}} F_s \mathrm{Re} \left(i \omega_{ds}^T \right) \int d\vartheta \frac{\mathfrak{r}^{3/2}}{\sqrt{\mathfrak{r} - \lambda}} e^{inq2\pi l} J_{0s} (\vartheta) \bar{\phi}^\star (\vartheta) \bar{\phi} (\vartheta - 2\pi l) \\ + & \frac{\pi |A|^2}{\omega_{Ts} \bar{x}} F_s \mathrm{Re} \frac{\hat{\sigma} \bar{x} \omega_{ds}^T}{\bar{\omega}^\star} \int d\vartheta e^{inq2\pi l} J_{0s} (\vartheta) \partial_\vartheta \bar{\psi}^\star (\vartheta) \bar{\phi} (\vartheta - 2\pi l) \\ + & \frac{\pi |A|^2}{\omega_{Ts} \bar{x}} \mathrm{Re} \left(i \omega_{ds}^T \right) \left(-1 + \frac{\omega_{*ns}^T}{\omega} - \frac{3}{2} \frac{\omega_{*Ts}^T}{\omega} + \frac{\omega_{*Ts}^T}{\omega} \bar{\mathcal{E}} \right) F_s \int d\vartheta \frac{\mathfrak{r}^{3/2}}{\sqrt{\mathfrak{r} - \lambda}} e^{inq2\pi l} J_{0s} (\vartheta) \bar{\phi}^\star (\vartheta) \bar{\psi} (\vartheta - 2\pi l) \\ + & \frac{\pi |A|^2}{\omega_{Ts} \bar{x}} \mathrm{Re} \frac{\hat{\sigma} \bar{x} \omega_{ds}^T}{\bar{\omega}^\star} \left(-1 + \frac{\omega_{*ns}^T}{\omega} - \frac{3}{2} \frac{\omega_{*Ts}^T}{\omega} + \frac{\omega_{*Ts}^T}{\omega} \bar{\mathcal{E}} \right) F_s \int d\vartheta e^{inq2\pi l} J_{0s} (\vartheta) \partial_\vartheta \bar{\psi}^\star (\vartheta) \bar{\psi} (\vartheta - 2\pi l) \\ - & \frac{\pi |A|^2}{\omega_{Ts} \bar{x}} \mathrm{Re} \left(i \omega_{ds}^T \right) \int d\vartheta \frac{\mathfrak{r}^{3/2}}{\sqrt{\mathfrak{r} - \lambda}} e^{inq2\pi l} J_{0s} (\vartheta) \bar{\phi}^\star (\vartheta) K_s (\vartheta - 2\pi l) \\ - & \frac{\pi |A|^2}{\omega_{Ts} \bar{x}} \mathrm{Re} \frac{\hat{\sigma} \bar{x} \omega_{ds}^T}{\bar{\omega}^\star} \int d\vartheta e^{inq2\pi l} J_{0s} (\vartheta) \partial_\vartheta \bar{\psi}^\star (\vartheta) K_s (\vartheta - 2\pi l) \end{aligned}$$

[Y.Y. Li et al, invited talk Varenna Theory meeting 2022,
PPCF paper, submitted]
[M.V. Falessi et al, EPS 2023, invited talk]
[M.V. Falessi et al, IAEA FEC 2023]

+ 3D version of PSZS equation [A. Zocco et al, in review process]

2023 outlook: Yang Li will replace Y.-Y. Li (left mid 2022); start in March/April 2023

WP1-D3 (mid 2024) Self-consistent description of EPM repeated burst dynamics using the PSZS theoretical framework
[F. Zonca et al, IAEA FEC 2023]

WP2: new neoclassical building block for ATEP 3D [G Meng, Ph. Lauber]

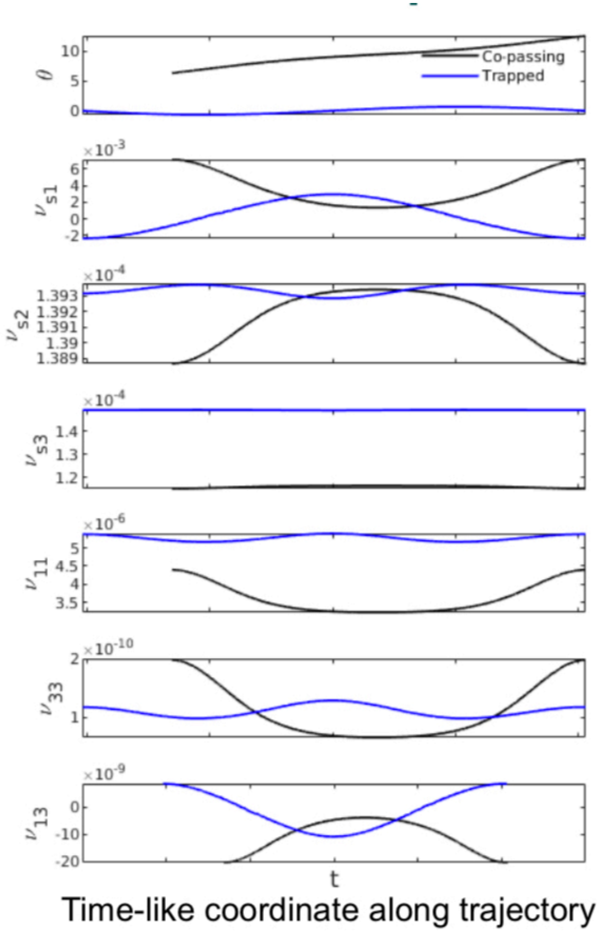
$$\frac{\partial}{\partial t}\overline{F_{z0}} + \frac{1}{\tau_b}\left[\frac{\partial}{\partial P_\phi}\overline{\left(\tau_b \delta \dot{P}_\phi \delta F\right)}_z + \frac{\partial}{\partial \mathcal{E}}\overline{\left(\tau_b \delta \dot{\mathcal{E}} \delta F\right)}_z\right]_S = \overline{\left(\sum_b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

- original plan: use RABBIT
- but: COM formulation is not compatible with RABBIT model

- instead:
- use already available, well tested collision operator in HAGIS code [A. Bergmann]
- calculate orbit averaged collision-coefficients

$$\frac{\partial f}{\partial t} = C(f) + \gamma f + S$$

$$C(f) = \frac{\partial}{\partial P_\zeta}(\nu_{s1} f) + \frac{\partial}{\partial E}(\nu_{s2} f) + \frac{\partial}{\partial \mu}(\nu_{s3} f) + \frac{1}{2}\frac{\partial^2}{\partial P_\zeta^2}(\nu_{11} f) + \frac{1}{2}\frac{\partial^2}{\partial E^2}(\nu_{22} f) + \frac{1}{2}\frac{\partial^2}{\partial \mu^2}(\nu_{33} f) + \frac{\partial^2}{\partial P_\zeta \partial \mu}(\nu_{13} f) + \frac{\partial^2}{\partial P_\zeta \partial E}(\nu_{12} f) + \frac{\partial^2}{\partial E \partial \mu}(\nu_{23} f),$$



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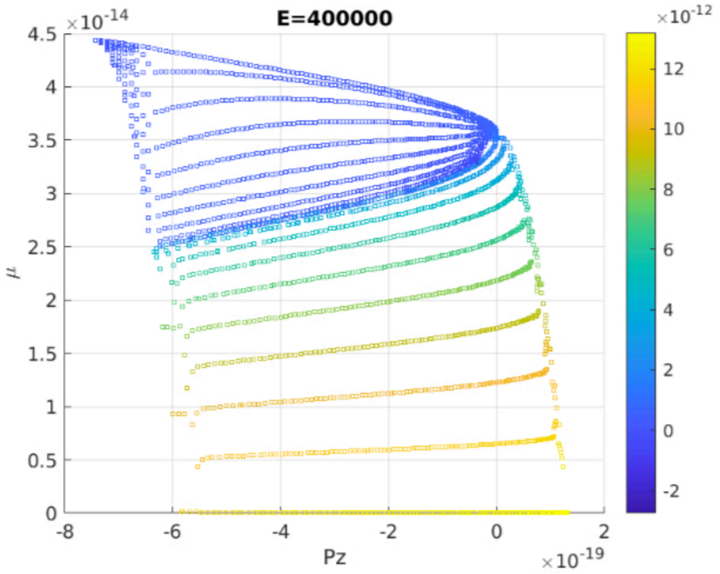
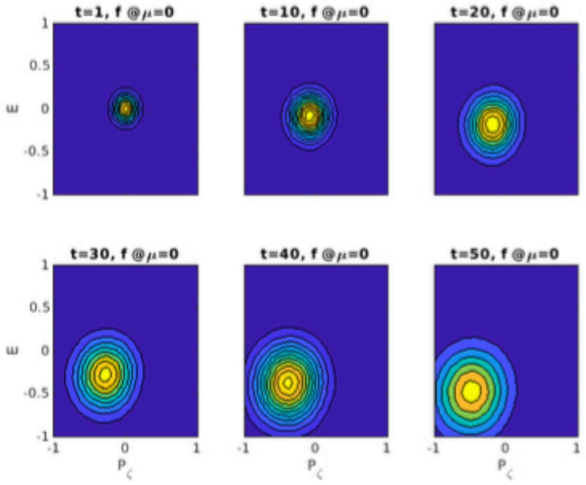
$$+ \frac{1}{2}\frac{\partial^2}{\partial P_\zeta^2}(\nu_{11} f) + \frac{1}{2}\frac{\partial^2}{\partial E^2}(\nu_{22} f) + \frac{1}{2}\frac{\partial^2}{\partial \mu^2}(\nu$$
$$+ \frac{\partial^2}{\partial P_\zeta \partial \mu}(\nu_{13} f) + \frac{\partial^2}{\partial P_\zeta \partial E}(\nu_{12} f) + \frac{\partial^2}{\partial E \partial \mu}(\nu_{23} f),$$

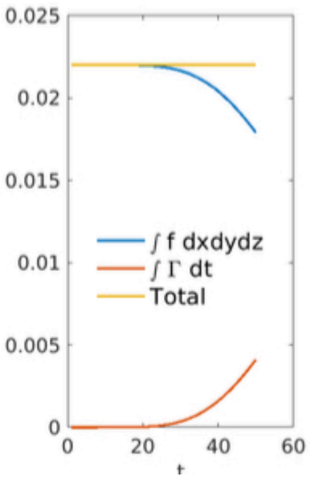
ν_{s1}



$$\frac{\partial f}{\partial t} = \sum_{\alpha,\beta} \frac{\partial}{\partial x_\alpha} \left(D^\alpha f + D^{\alpha\beta} \frac{\partial f}{\partial x_\beta} \right) + S$$

- finite volume method on Pz,E,μ grid
- spatial discretisation: linear centered scheme
- Crank-Nicolson time stepper
- open boundary conditions to allow for losses and slowing down to thermal distribution

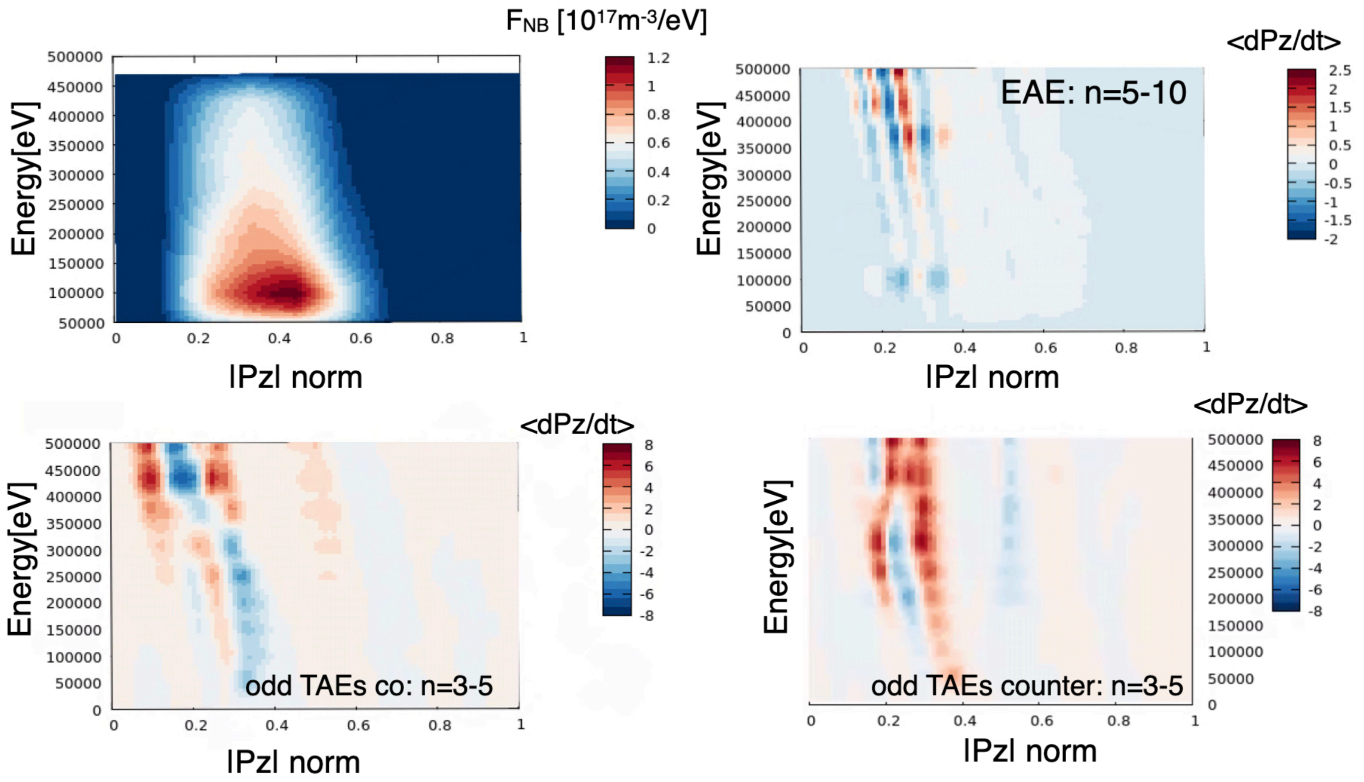




ready for combination with PSZS transport!

[G. Meng IAEA FEC 2023]

WP3 Application of ATEP: PSZS for EAEs and odd TAEs



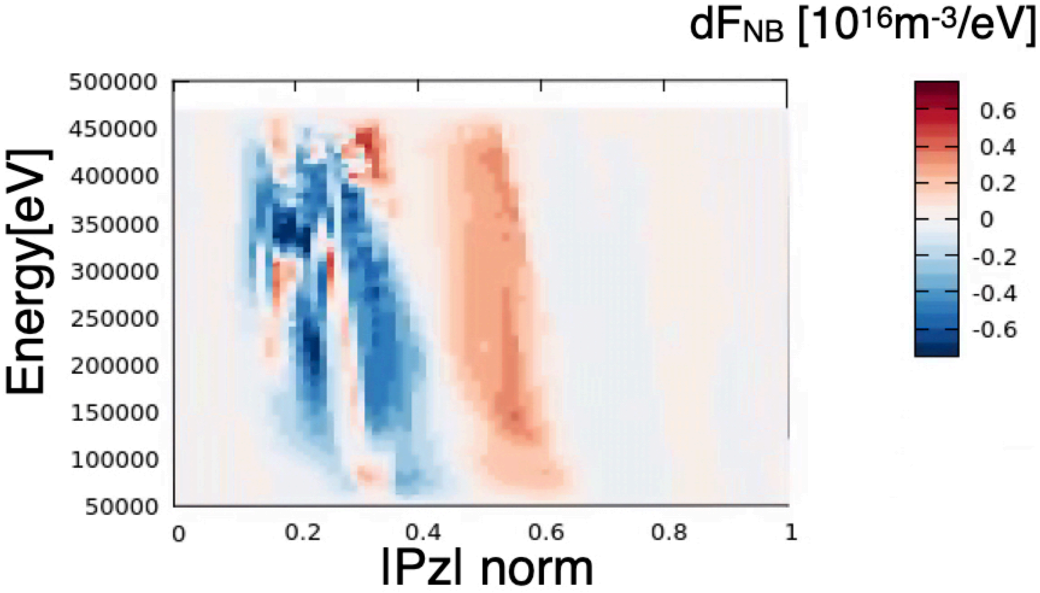
$\delta B/B$ =[1.0-7.0 10^{-4}]

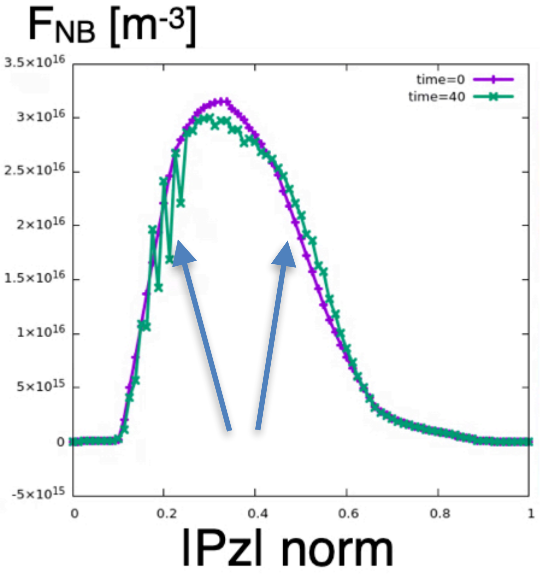
all plots for $\Lambda=\mu B_0/E=0.24$

resonances with both positive and negative gradients of F_{EP} possible

solving the PSZS equation (kick-model limit): TAEs

$\delta F(t)=F(t=40)-F(t=0)$ in COM space ($\Lambda=\mu B_0/E=0.24$) for the set of odd co and counter propagating TAEs

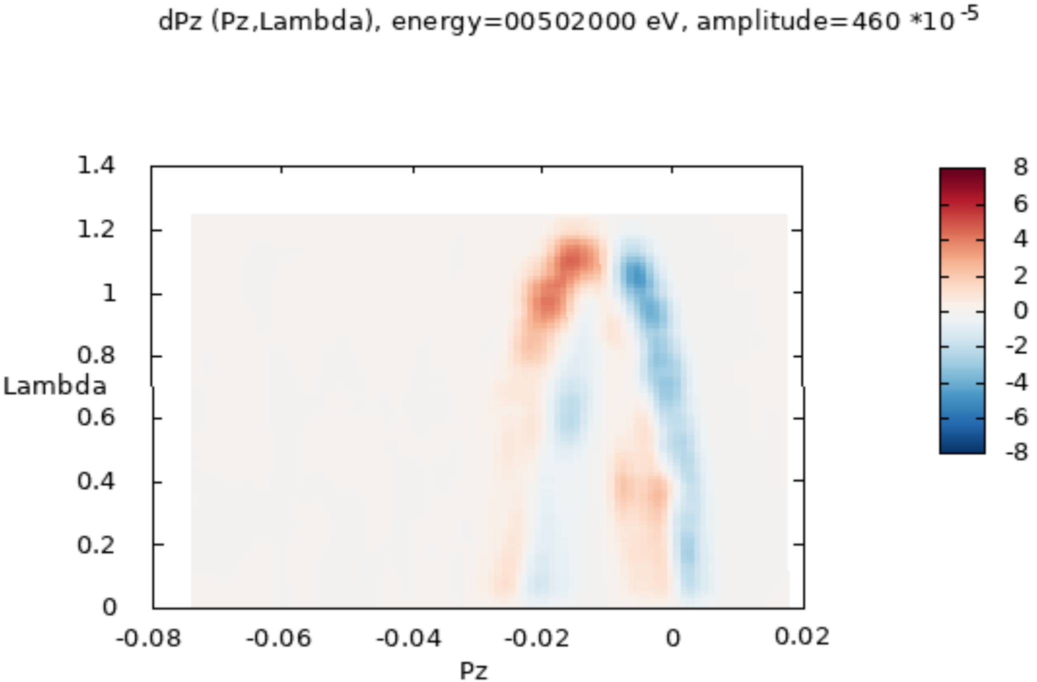




both gradients are depleted

amplitude closure needed for QL model & for tackling resonance overlap problem:

construct 4D PSZS: Pz,E,Λ,δB/B (=amplitude)

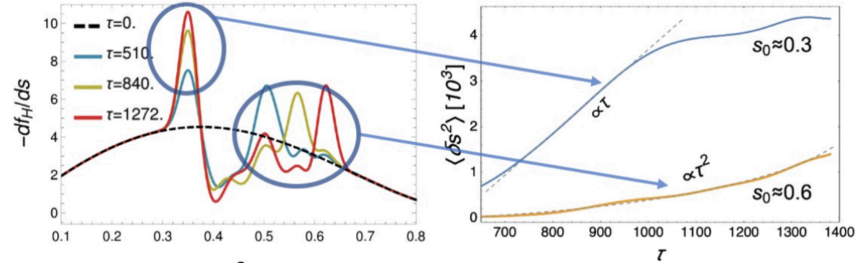


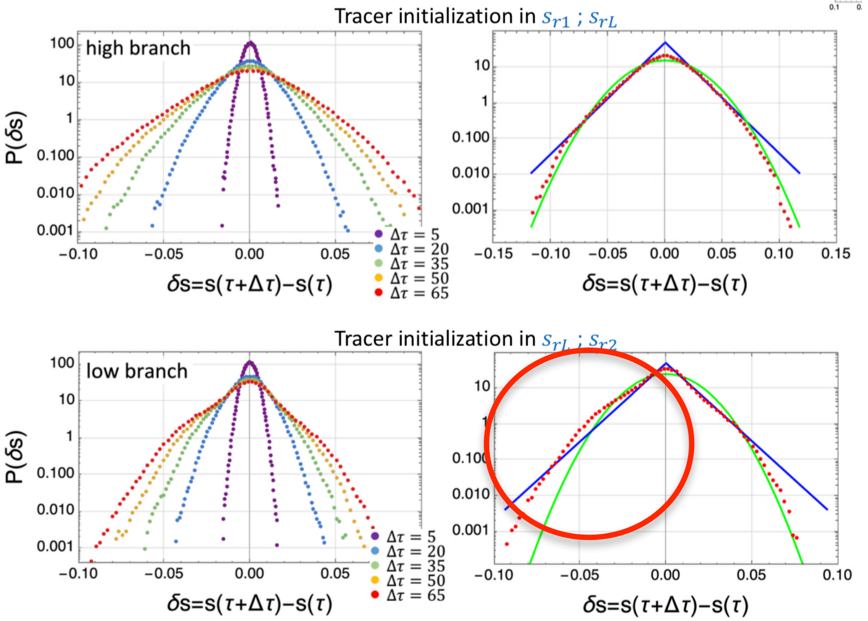
- this 'map' in COM space includes resonance broadening and transitions from isolated to overlapping modes as function of modes' amplitudes
- use E-conservation considerations of PSZS transport equation to determine energy transfer to mode and change mode amplitude(s) accordingly
- powerful but also 'expensive' object - various ideas to speed up its calculation

[Ph. Lauber IAEA FEC 2023]

WP3: develop reduced models

N. Carlevaro, G. Montani, M.V. Falessi, Ph. Lauber, EPS22, P5a.113 ID : 32056





previously: ITER 15MA case

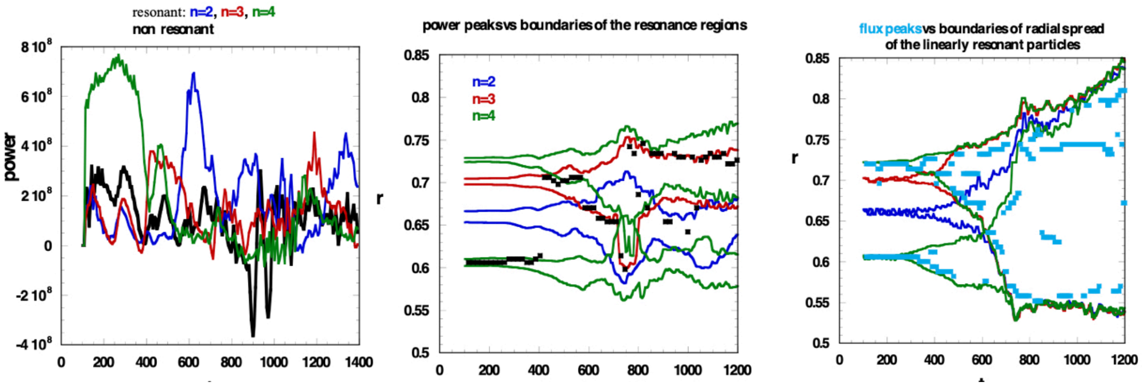
determined diffusive (τ) vs. convective (τ²) scalings

- WP3.2-M: Probability density function of the radial displacements of tracer particles deduced from EP transport models
- Comparison w/ **QLT (diffusive model)**
  -> trajectories defined by random walk
  -> PDF expected to be a **normal distribution** with expected value $\mu = 0$ and variance $\sigma = 2D\tau$
- 2023: IMAS interface, broad series of test cases, comparison with other ATEP model(s)

WP3.5: MHD-kinetic hybrid models

WP 3.5: together with TSVV10: non-linear benchmark for NLED AUG case has been started [G.Vlad, IAEA FEC 2023]

- in particular: PSZS will be part of non-linear analysis -> compare to reduced models
- generalisation and (IMAS) interfaces for general distribution functions ongoing
- new diagnostics developed, especially for multi-mode studies



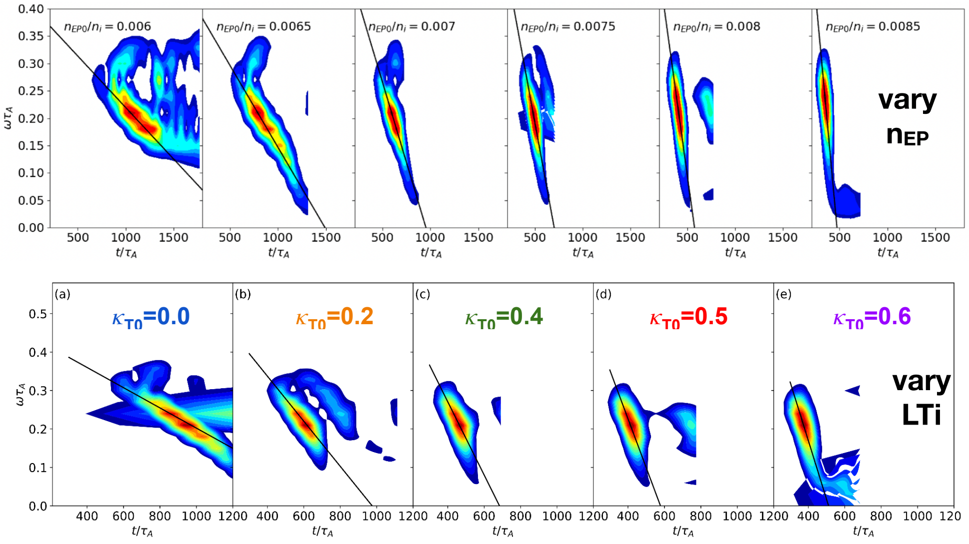
STRUPHY:

- add drift-kinetic model to STRUPHY: finished, ongoing tests
- coupling to GVEC 3D equilibrium solver for application to tokamaks and stellarators finished
- ready for tackling physics cases, join common benchmarks

WP3.6: Non-linear GK simulations

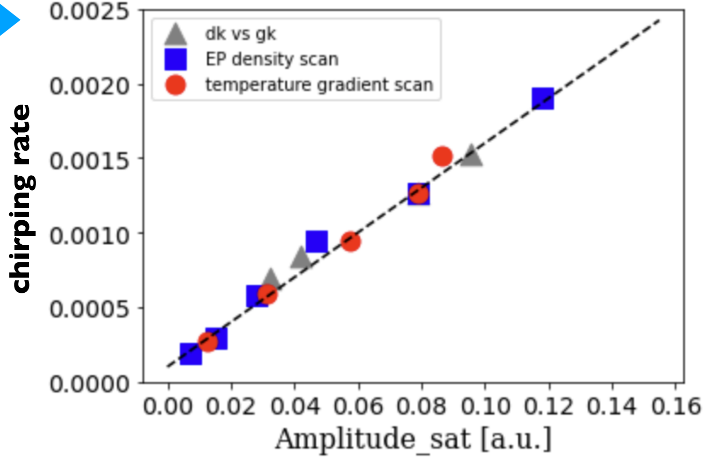
WP 3.6: scaling of chirping rate obtained with comprehensive AE + ZF studies + turbulence (ORB5)

[X Wang, ITPA 2022]



from analytical theory:

$$(\Delta\omega/\Delta t)_{sat} \sim (\omega_{res}') \; A_{sat}$$

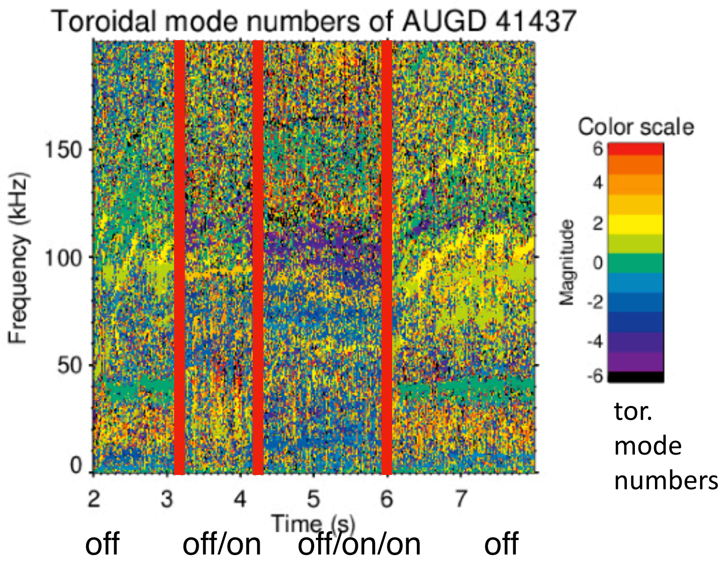


X. Wang [draft manuscript, EPS invited talk 2023]

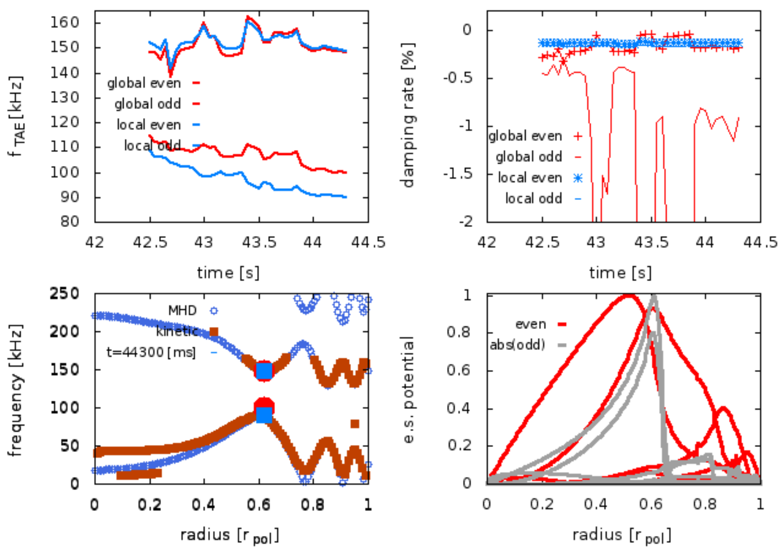
A. Biancalani [FEC 2023]

WP4: Reference cases

- more reference cases and scenarios collected and adapted to various WFs in 2022:
- AUG, ITER, JET, JT-60SA, TCV, DTT
- no new AUG experiments after Jul. 2022 (D beams in H plasma)
- unresolved difficulties with reliable automated equilibrium reconstruction at JET



JET TAE damping case



changes ATEP team in 2023

Yang Li will replace Y.-Y. Li (left mid 2022); start in March/April 2023

A. Cardinali retired - E. Giovanozzi will replace him.

summary, outlook, outreach

- most deliverables and milestones fully reached in 2022
- deviations/shifts/swaps motivated by personnel changes, decision points after in-depth analysis
- 2023 plans on track, all activities have been kicked off
- overall project goals to be reached by mid 2024 seems feasible
- established and enhanced contacts to transport modellers (ETS, JINTRAC) and EP source code developers (ASCOT/NEMO/SPOT)
- ATEP project presentation in TSVV 11 seminar
- contact person for TSVV 8 identified (X. Wang)
- ~9 ATEP related IAEA FEC contributions planned, dedicated ATEP overview poster

Deliverables 1

- End 2021 WP1-D1 Complete transport theory of Phase Space Zonal Structures and Zonal State separating its microscale structures from macro-/meso- scale components (last report)
- End 2022 WP1-D2 Explicit expressions of phase space fluxes as input for WP2
- mid 2024 WP1-D3 Self-consistent description of EPM repeated burst dynamics using the PSZS theoretical framework

- End 2021 WP2.1-D1 DAEPS in general tokamak geometry
- mid 2023 WP2.1-D2 Reduced EP transport model in tokamaks
- mid 2024 WP2.1-D3 DAEPS in general stellarator geometry

fully
partly
not started

- End 2022 WP2.2-D1 Fast analytical LIGKA version including trapped particles
- End 2023 WP2.2-D2 Fast analytical LIGKA model including guesses for global mode structures and non-Maxwellian distribution functions

- Mid 2022 WP2.3-D1 Explicit expressions for local eigenvalue code in 3D (ongoing, end October 2022)
- mid 2024 WP2.3-D2 Local eigenvalue code in 3D (LIGKA) including passing particles

- End 2022 WP3.1-D1 Validated 1D reduced model for EP transport in ITER/DTT
- mid 2024 WP3.1-D2 Systematic statistical analysis of test particle transport and assessment of diffusive vs. non diffusive behaviours - jointly with WP3.2

Deliverables 2

- End 2022 WP3.2-D1 Insights into short- and long-time relaxation dynamics of a non- thermal plasma with intense energetic particle component)
- mid 2024 WP3.2-D2 Practical basic understanding of convective radial transport of energetic particles versus the possible non-local transport regimes

- Mid 2024 WP3.3-D1 Availability of validated reduced phase space transport model based on LIGKA/HAGIS/RABBIT within IMAS framework (ATEP 3D)

- End 2022 WP3.4-D1 Validated version of RABBIT including model for fluctuation-induced radial transport of EPs (postponed to 2023) -> replaced by COM neoclassical solver (ATEP 3D), developed by G. Meng

- End 2022/23 WP3.5-D1 Hybrid kinetic-MHD results for V&V of transport models: with generalized distributions functions and collisions for AUG, ITER, DDT.
- mid 2024 WP3.5-D2 STRUPHY will deliver long time-scale simulations for V&V purposes (demonstrating conservation properties of advanced coupling scheme) based on the same equilibria as XHMGC, HYMAGYK, MEGA and ORB5

- End 2022/23 WP3.6-D1 Deliver quantitative criteria for transitions between different transport regimes w/o turbulence and ZF/ZSs using experimentally relevant parameters
- End 2022 WP4-D1 Availability of reference scenarios (ITER, AUG, DTT) for application of transport models