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ATEP Progress meeting

27.1.2023

ATEP team

MAX-PLANCK-INSTITUT FÜR PLASMAPHYSIK

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

Center for Nonlinear Plasma Science CNPS Since 2020

iter china eu india japan korea russia usa

This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

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agenda

Friday 27 Jan 2023, 14:00 → 16:30 Europe/Berlin

Zoom

Description https://eu01web.zoom.us/j/66123338291?pwd=VUVOOFdUUVlGSkh4ZUpSS3g1S2c0Zz09

14:00 → 16:30 **ENR ATEP Progress Meeting**

14:00	**Introduction** Speaker: Philipp Lauber (IPP)	10m
14:10	**ATEP 3D -a neoclassical solver for the transport equations of phase space zonal structures** Speaker: Dr Guo Meng (MPG/IPP)	30m
14:40	**Constants of motion and non-linear dynamics** Speaker: Fulvio Zonca (ENEA)	30m
15:10	**Updates regarding the WP 3.1** Speaker: Dr Nakia Carlevaro (ENEA)	20m
15:30	**ATEP: recent developments** Speaker: Philipp Lauber (IPP)	25m
15:55	**updates on other WPs** Speaker: Philipp Lauber (IPP)	30m

news

- ATEP 2022 report submitted, signed Dec 2022; no feedback so far
- 8th Feb: monitoring of the progress made by projects in 2022 by E-TASC Scientific Board (20 mins)
- conferences: Matteo, Xin invited talks at EPS
- IAEA FEC synopses to be prepared; ATEP related: Philipp, Fulvio, Matteo, Gregorio, Guo, Thomas, Xin, Alessandro, others?
- travel plans in 2023
- need to grow closer connections to TSVV11 - e.g. integration of models into transport codes

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ATEP code: updates

Ph. Lauber

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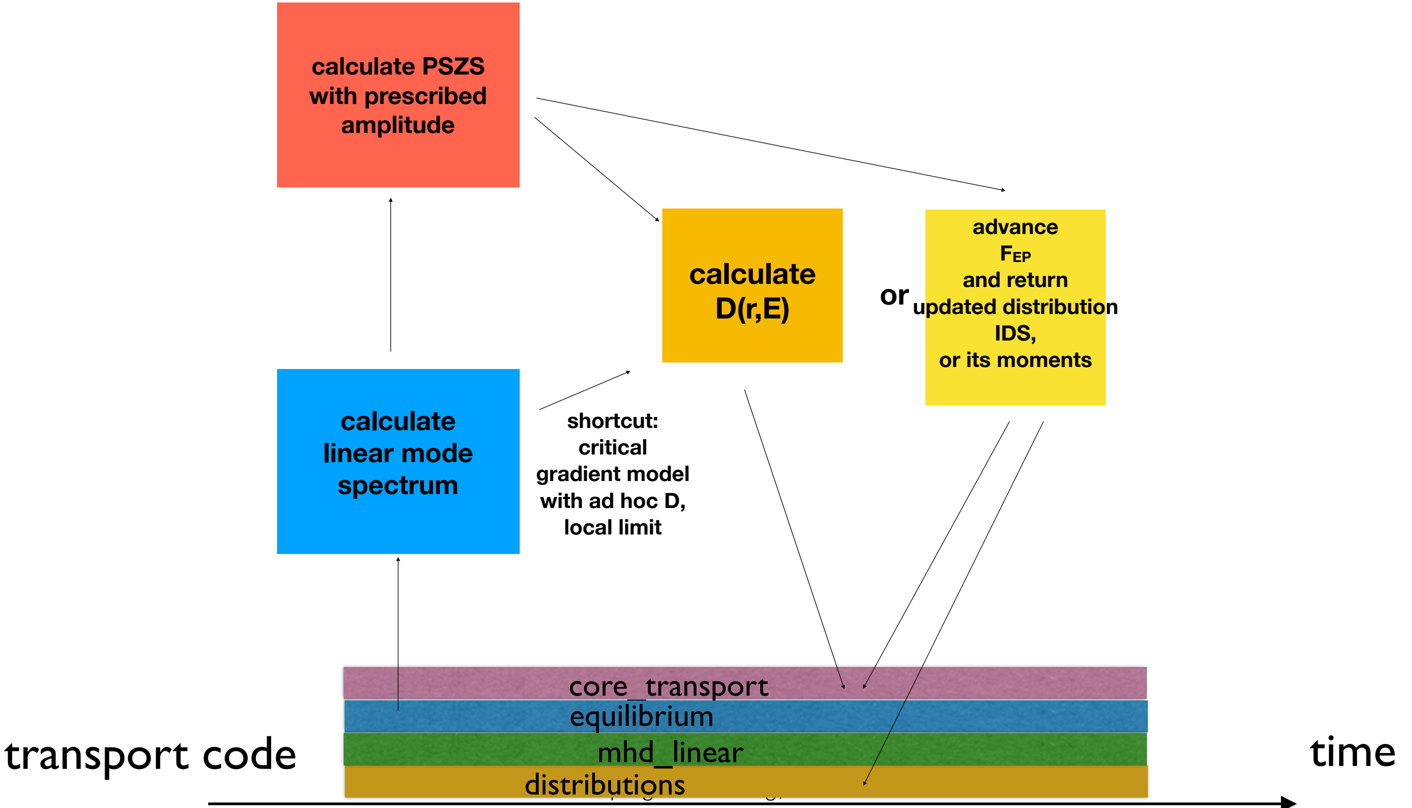
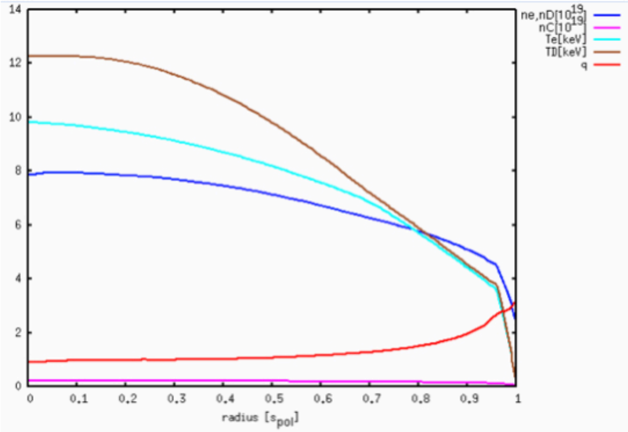
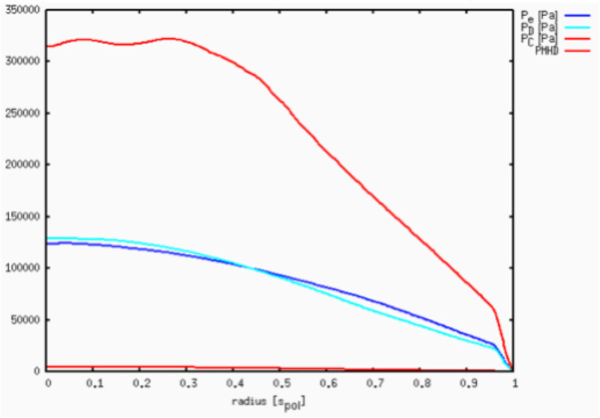
new ATEP results using the kick-model limit

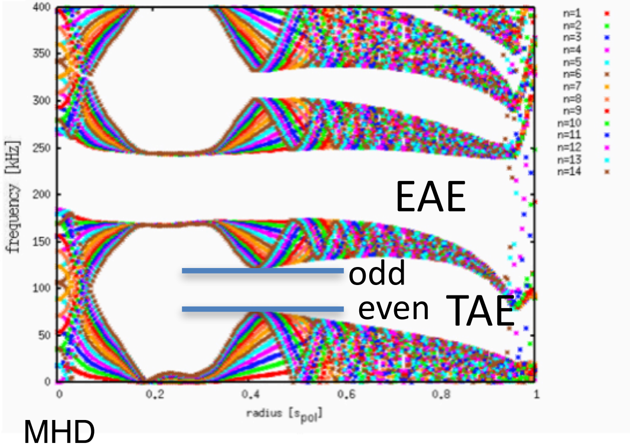


JT-60SA: successful coupling of EP WF and ATEP to JINTRAC output (scenario 2, 70000,419) [L Garzotti]

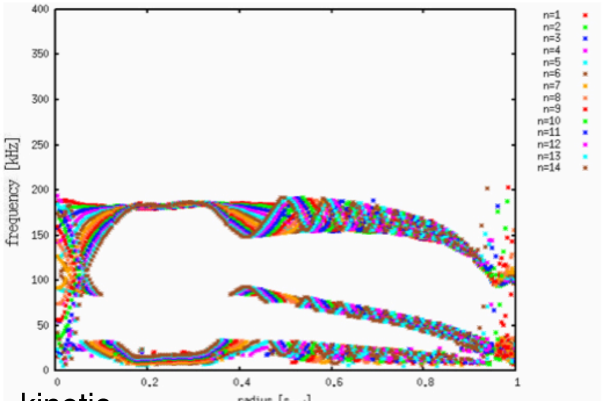
available on gateway







MHD



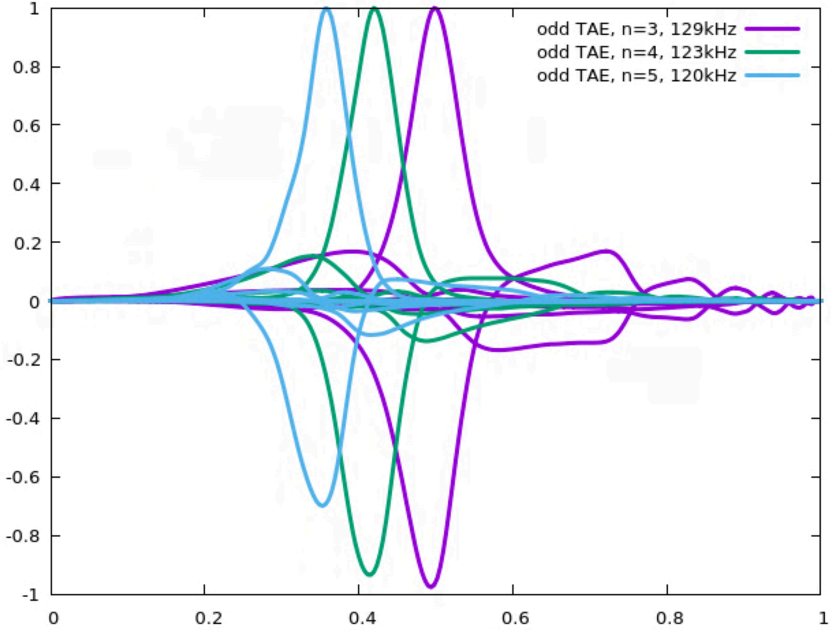
kinetic

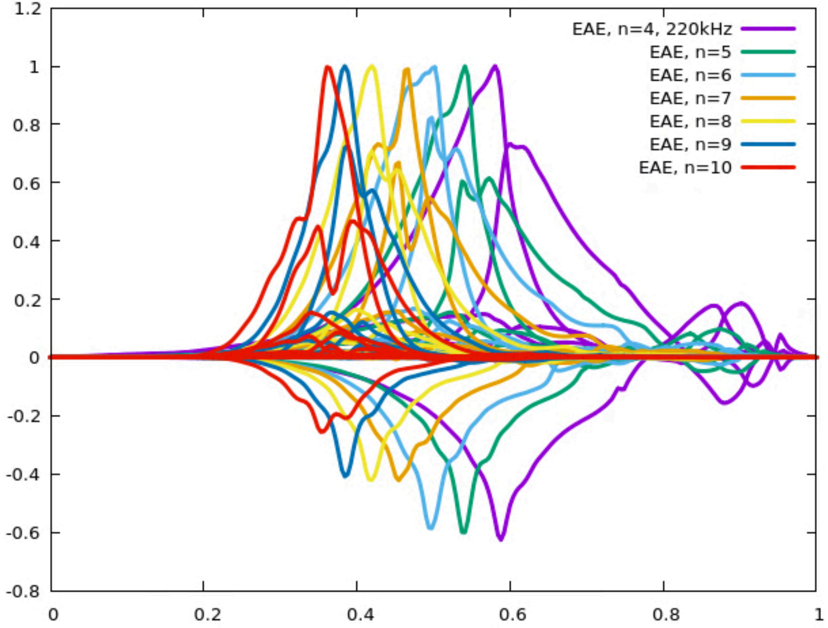
even TAEs strongly damped

odd TAEs and EAEs at higher frequency are weakly damped

[WPSA Deliverable SA-SE.CM.M.04-T002-D001, Dec. Lauber 2022]

JT-60SA - used mode spectrum: odd TAEs and EAEs

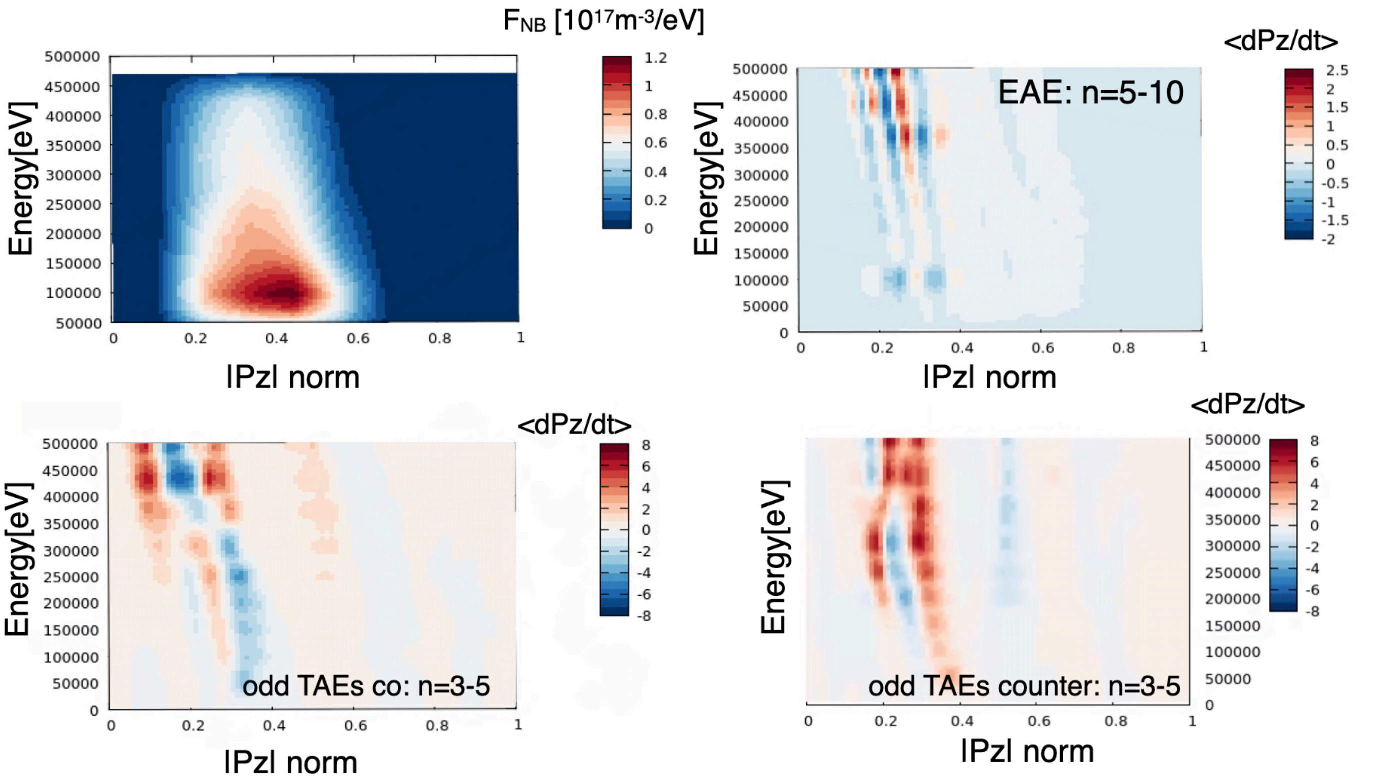




EP-WF has been adopted to cope with co- and counter propagating modes

PSZS for EAEs and odd TAEs

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

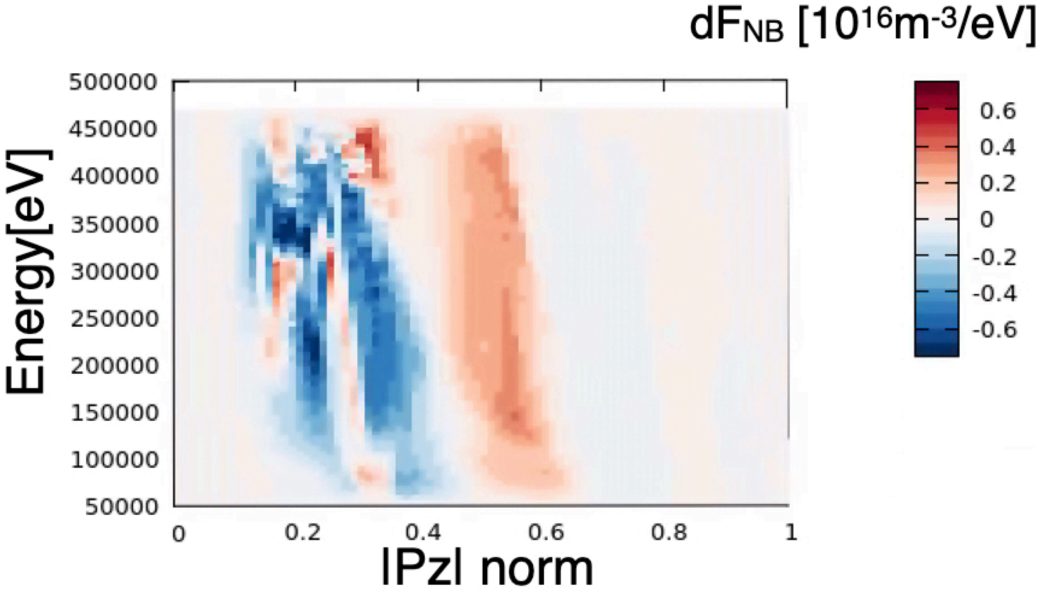


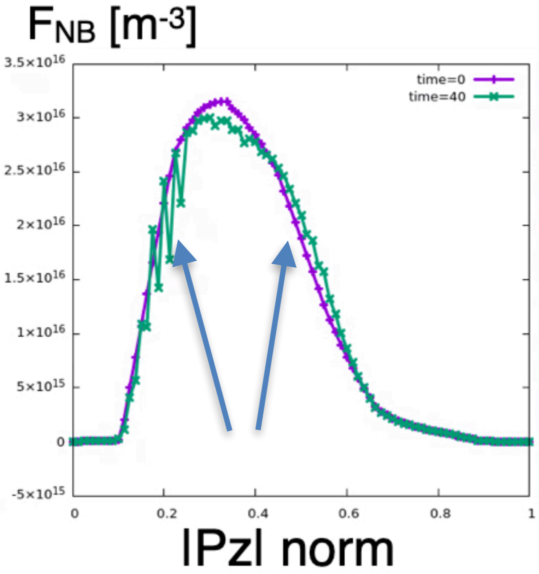
all plots for $\Lambda=\mu B_0/E=0.24$

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

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

δF(t)=F(t=40)-F(t=0) in COM space (Λ=μB_0/E=0.24) for the set of odd co and counter propagating TAEs

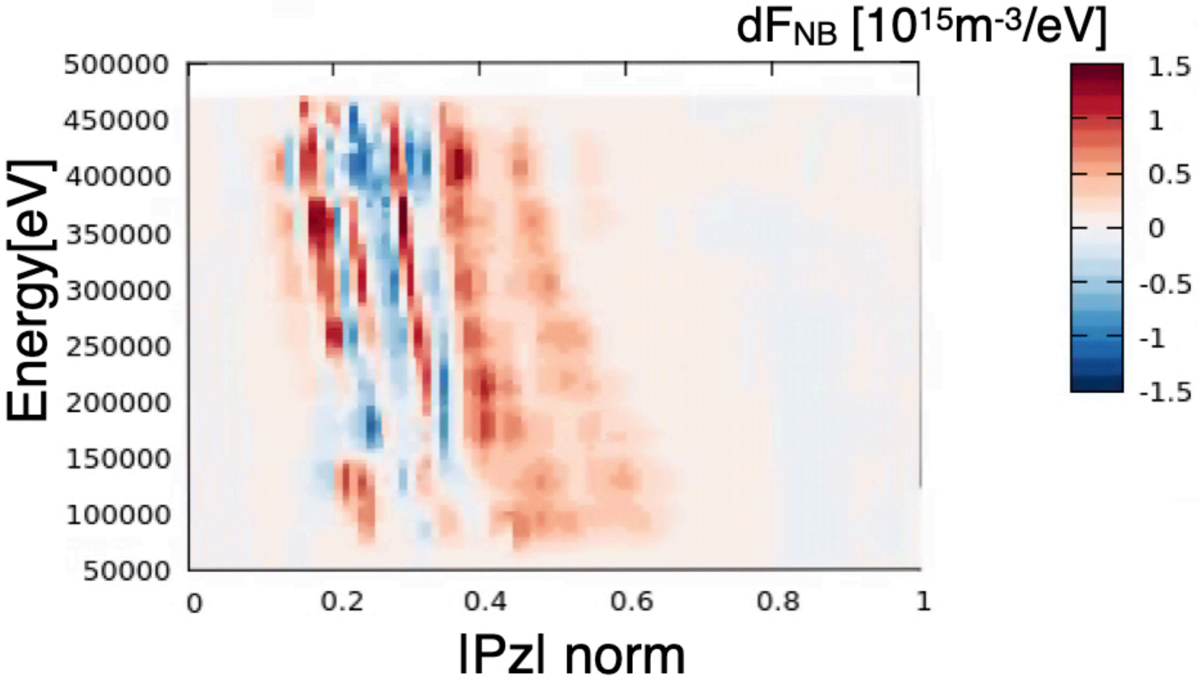


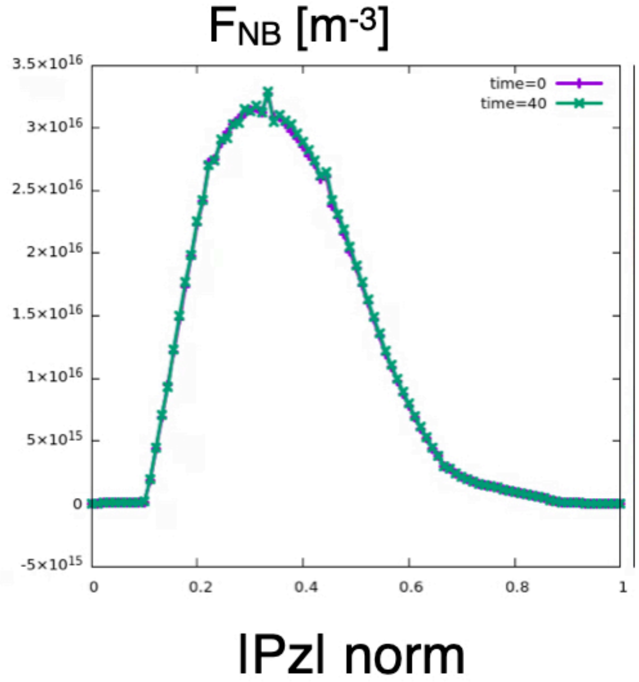


both gradients are depleted

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

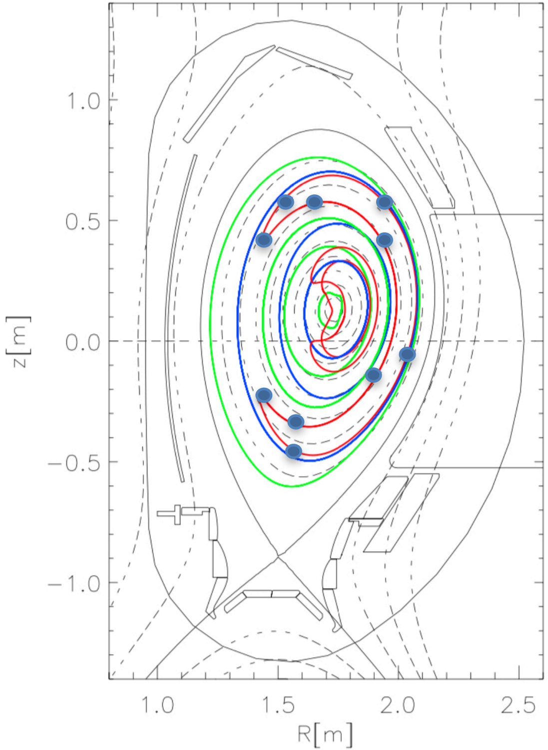
$\delta F(t)=F(t=40)-F(t=0)$ in COM space ($\Lambda=\mu B_0/E=0.24$) for the set of co and counter propagating EAEs





much smaller EP transport (4 times smaller) that odd TAEs (using the same saturation rule $\gamma \sim A^2$)
next: how do these modes affect the current deposition? mapping back and take moments…

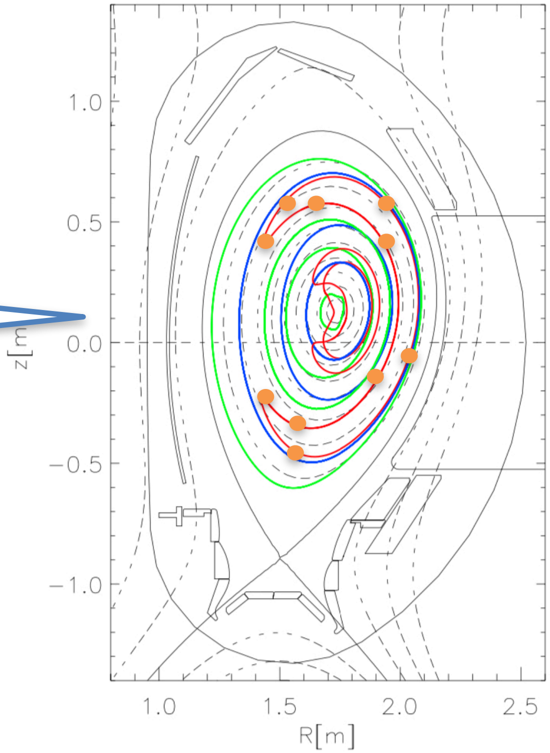
mapping from marker space to COM space and back



bin all markers on same orbit to (Pz,E,Λ)- grid and sum over weights to obtain density in COM space F(Pz,E,Λ)

evolve PSZS
transport equation
i.e. update $F_u(Pz,E,\Lambda)$

$$\frac{\partial F_{EP}}{\partial t} = \frac{\partial Pz}{\partial t}\frac{\partial F_{EP}}{\partial P_z} + \frac{\partial E}{\partial t}\frac{\partial F_{EP}}{\partial E}$$



distribute new weight proportional to original weights, i.e. scale all marker weights of certain bin by $F_u(Pz,E,\Lambda)/F(Pz,E,\Lambda)$

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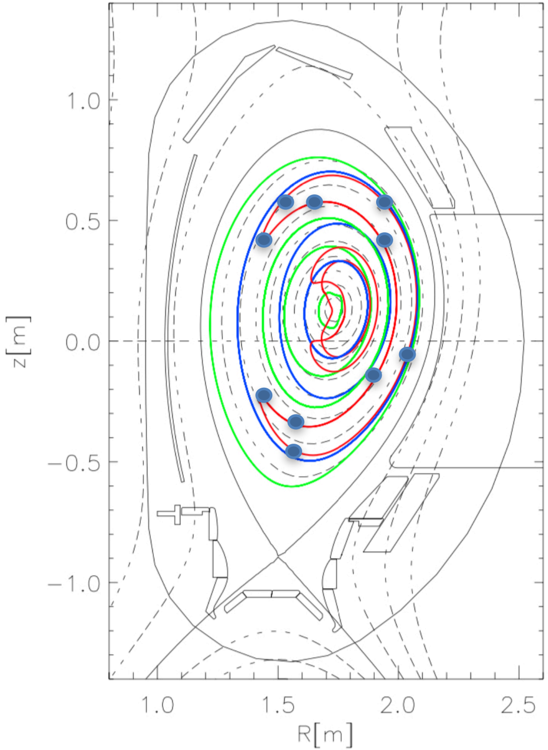
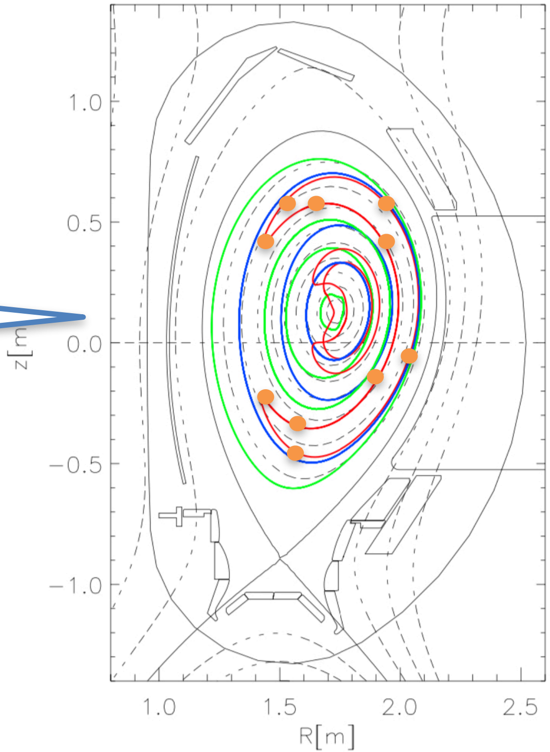
mapping from marker space to COM space and back



bin all markers on same orbit to (Pz,E,Λ)- grid and sum over weights to obtain density in COM space F(Pz,E,Λ)

evolve PSZS
transport equation
i.e. update $F_u(Pz,E,\Lambda)$

$$\frac{\partial F_{EP}}{\partial t} = \frac{\partial Pz}{\partial t}\frac{\partial F_{EP}}{\partial P_z} + \frac{\partial E}{\partial t}\frac{\partial F_{EP}}{\partial E}$$



then calculate moments and/or transport coefficients to be used in connected codes

next step: QL limit and beyond

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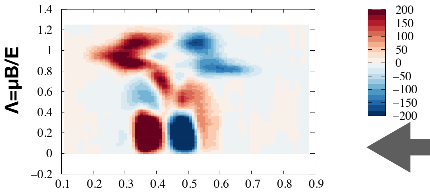
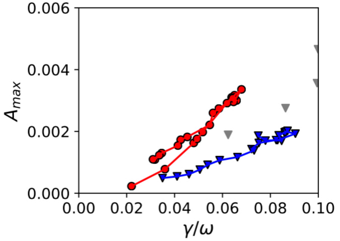
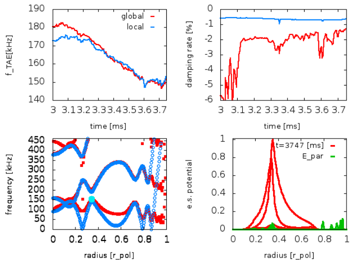
orbit+zonal averaging



saturation rule: HAGIS or ORB5



EP WF (LIGKA)



calculate PSZS

use NL code/model for intensity closure

calculate linear mode spectrum

calculate D(r,E)

or

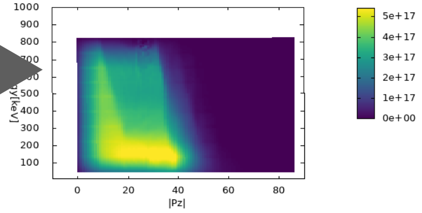
advance F_{EP} and return updated distribution IDS, or its moments

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

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

[M. Falessi 2017-2022]

ATEP code [Ph. Lauber, 2022]



can be extended to include zonal structures driven by turbulence and their mutual interaction

t

t+1

core_transport

equilibrium

mhd_linear

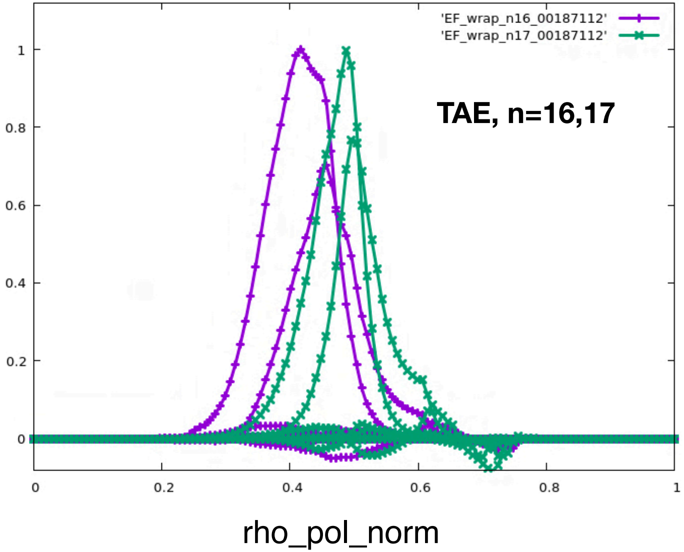
distributions

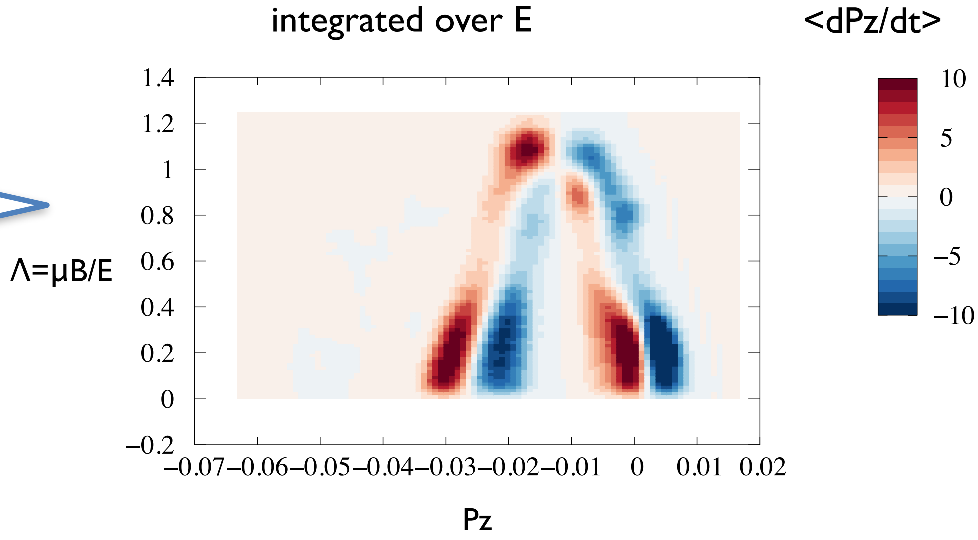
transport code

time

towards multi-mode, QL implementation: investigate two-mode system

- calculate <dPz/dt> , <dE/dt> for given fixed mode structures - here: scan amplitudes in 2 mode system

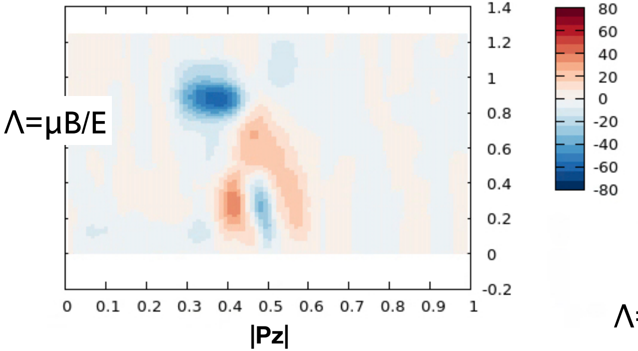




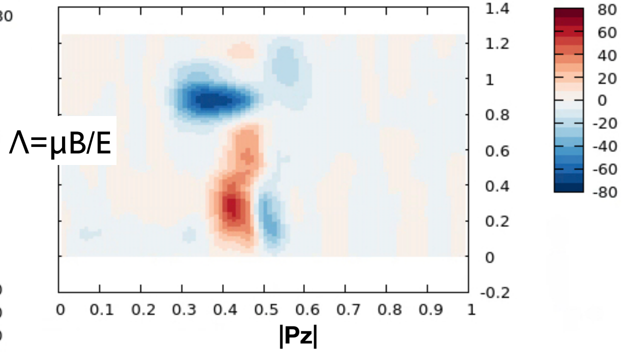
typical grid: (Pz,E,Λ) (128x40x40)

detailed insight into multi-mode cases: amplitude scan: **dB/B=0.5 *10^-3**

n=16 single

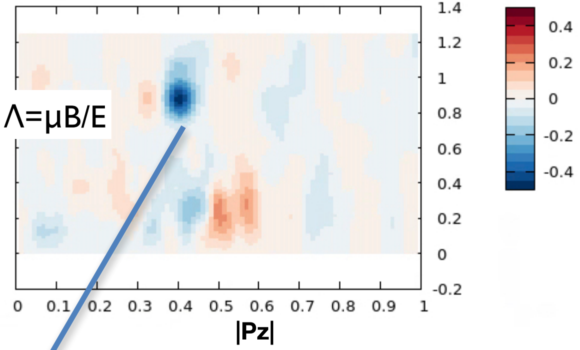


n=16+17 both

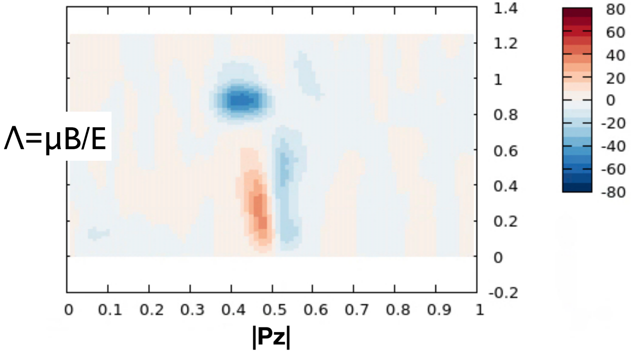


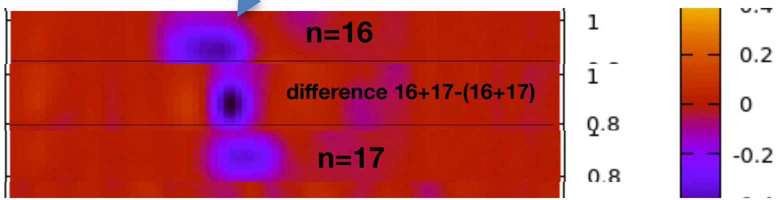
relative difference

$$\frac{(P16+P17)-P(16+17)}{P(16+17)max}$$



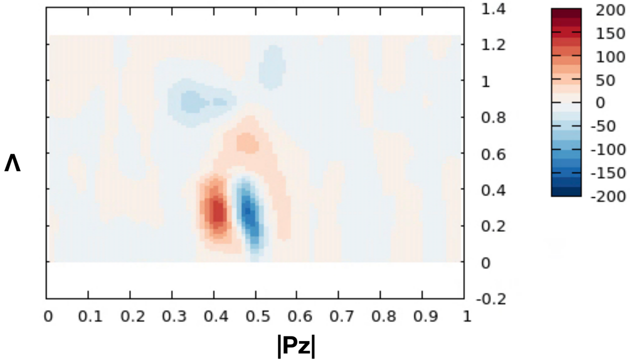
n=17 single



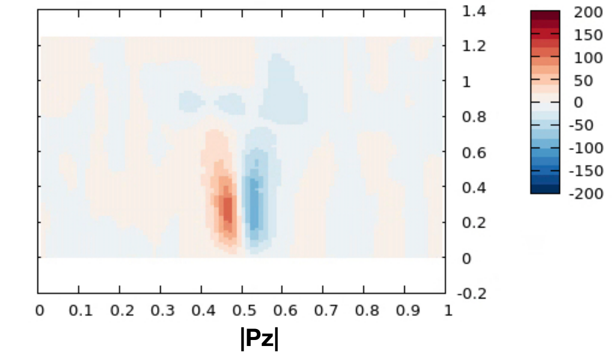


detailed insight into multi-mode cases: amplitude scan: **dB/B=1 *10^{-3}**

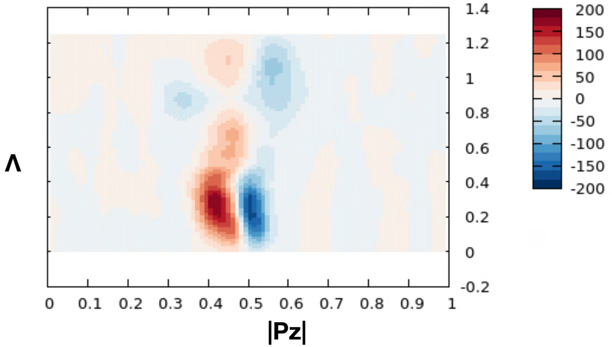
n=16 **single**



n=17 **single**

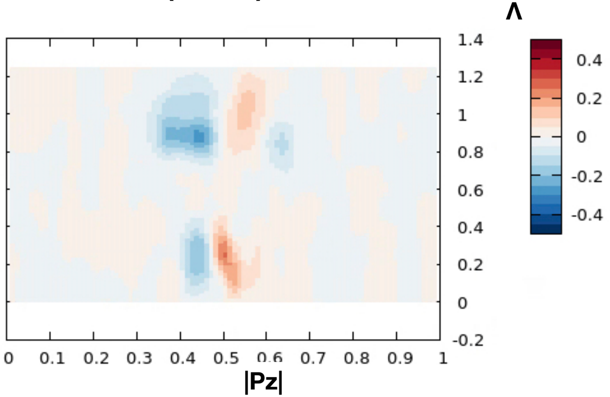


n=16+17 **both**



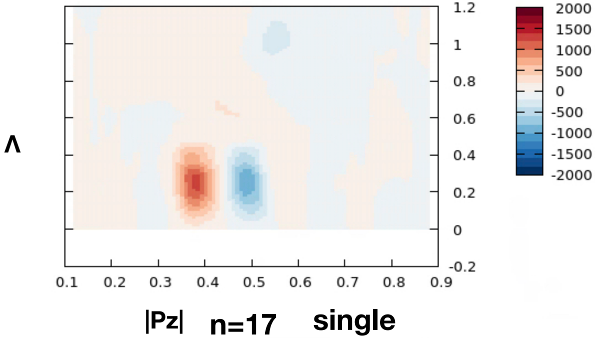
relative difference

$$\frac{P16+P17-P(16+17)}{P(16+17)max}$$

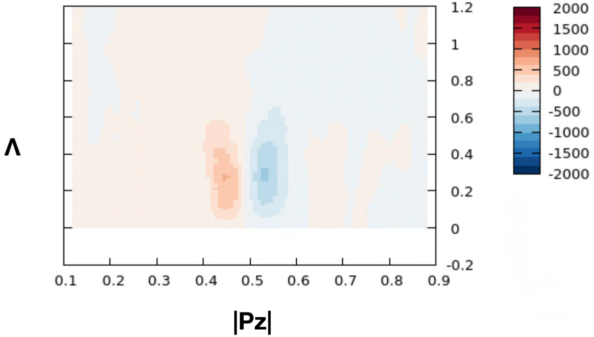


detailed insight into multi-mode cases: amplitude scan: **dB/B=5 *10^{-3}**

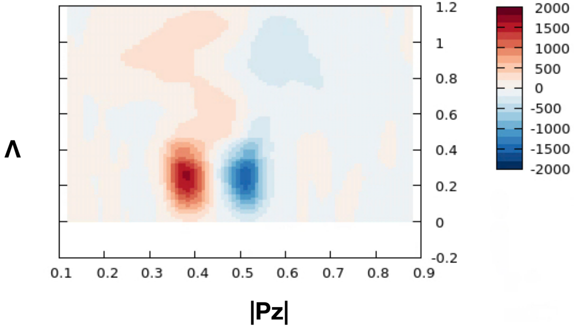
n=16 single



n=17 single

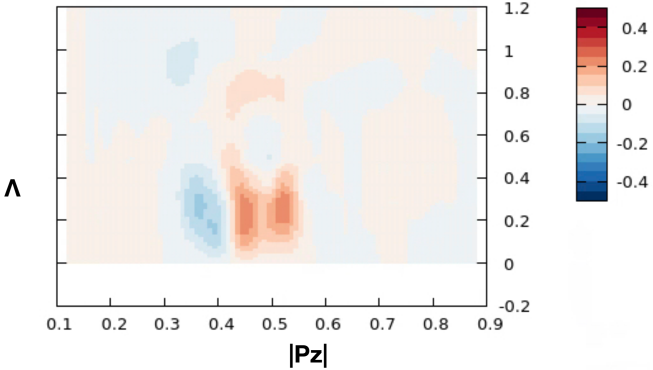


n=16+17 both



relative difference

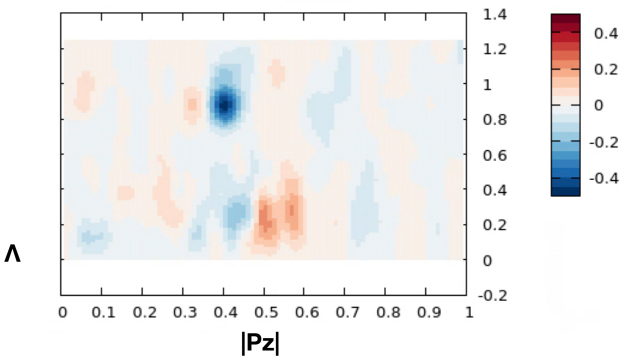
$$\frac{P16+P17-P(16+17)}{P(16+17)max}$$



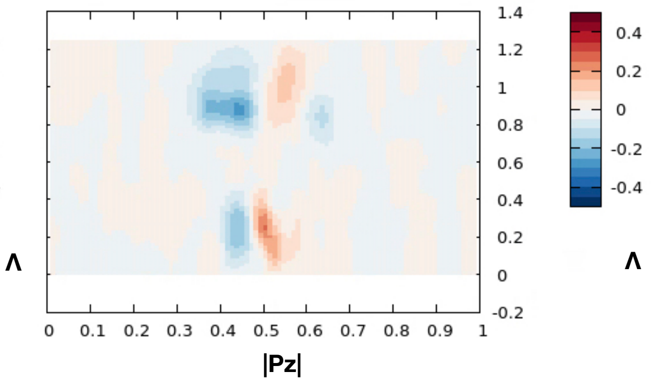
start to investigate multi-mode cases: amplitude scan

relative difference $\frac{\mathbf{(P16+P17)-P(16+17)}}{\mathbf{P(16+17)max}}$

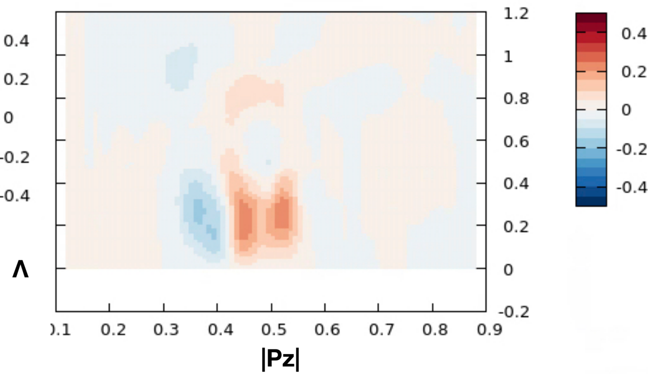
dB/B=0.5 *10^-3



dB/B=1 *10^-3

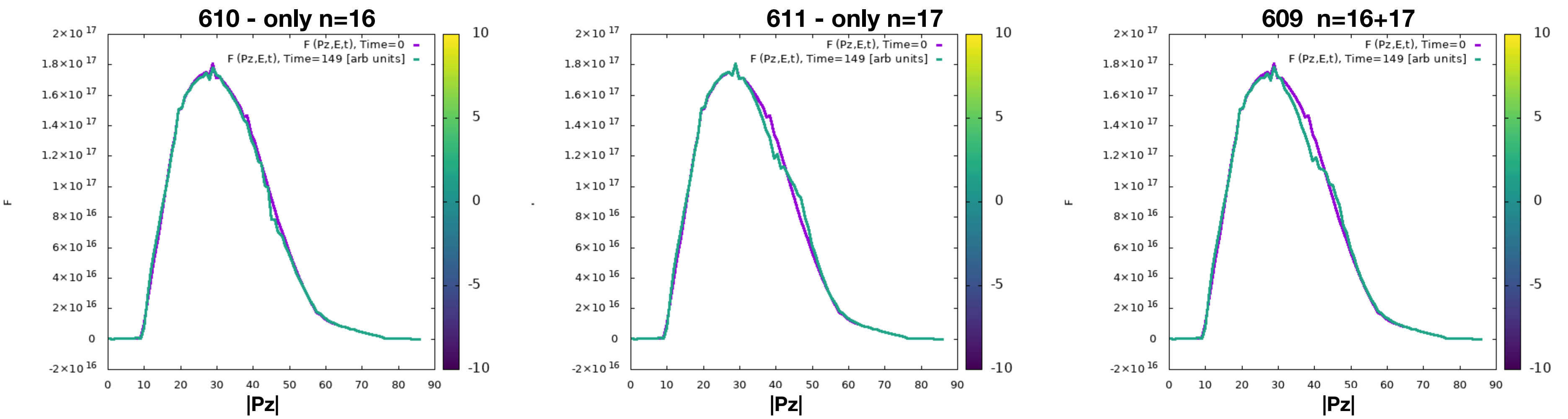


dB/B=5 *10^-3



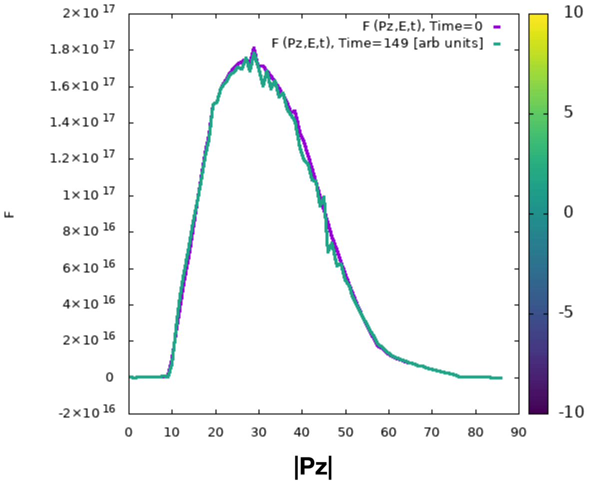
- multi-mode systems need careful treatment when going from isolated mode case to resonance-overlap (diffusive) regime:
- depending on amplitude, trapped and passing particles show different relative importance for causing resonance overlap (FOW vs resonance width) - **consistent treatment of resonance broadening is needed**

two mode system (n=16,17, see above): dB/B=0.5 *10-3

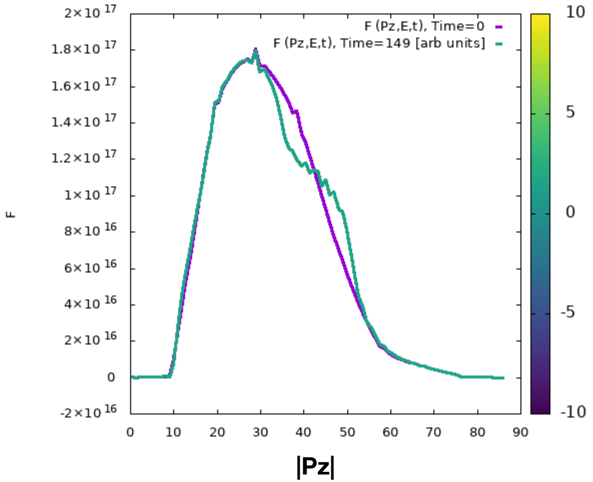


two mode system (n=16,17, see above): dB/B=1 *10^{-3}

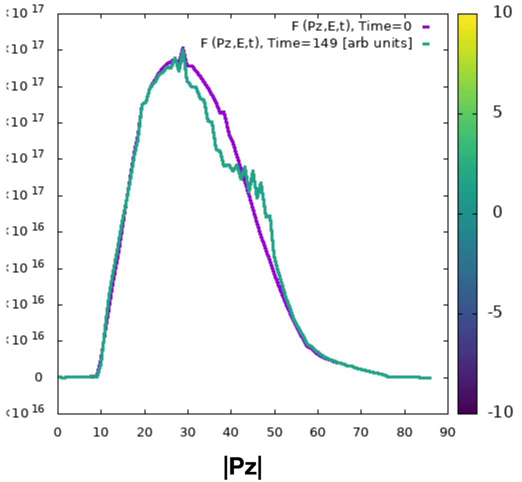
603 - only n=16



605 - only n=17

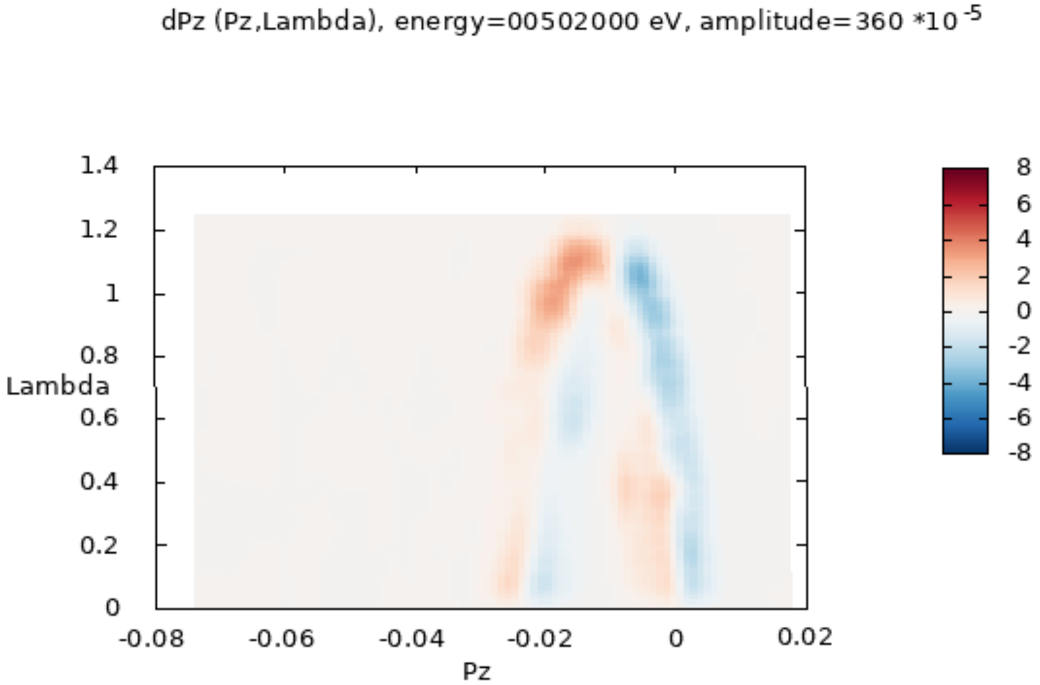


604 n=16+17



4D PSZS: Pz,E,Λ,$\delta B/B$ (=amplitude)

- run previously developed WF for calculating PSZS (FINDER/HAGIS) and store in difference IDS occurrences
- import into ATEP code (typically 3-5 different amplitudes $\delta B/B = 10^{-5}, 10^{-4}, 10^{-3}, 10^{-2}$)
- interpolate in COM space, then construct 4D object



- this 'map' will be used when saturation rules are applied (closure of QL model)
- it includes resonance broadening and transitions from isolated to overlapping modes
- it is NOT yet self-consistent, i.e. ratio of mode amplitudes is fixed

- use E-conservation considerations of PSZS transport equation to determine energy transfer to mode and change mode amplitude(s) accordingly

- in case of multi-mode system use a rule, e.g. ratio of linear growth rates $\gamma^2 \sim A$, to 'distribute' free energy to mode amplitude

- powerful but also 'expensive' object - various ideas to speed up its calculation outlook:

- combine all elements - neoclassics (Guo), QL mode, and back-mapping
- start to think how to include zonal field as given from non-linear simulations, i.e. rules how to infer radial structure and amplitude scaling (e.g. forced driven cases)

in parallel: benchmarking and validation

- follow up on agreed test cases: attach to non-linear AUG NLED case benchmark effort (Gregorio)
- work on latest ITER ‘flagship’ 15 MA simulation - help from JINTRAC group, M. Schneider needed

2023 outlook

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)

- 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

Milestones 1

1 WP1-M1 2D and 3D formulation of Phase Space Zonal Structures transport equations, and definition of Zonal State with corresponding equations for Zonal Field Structures governing equations with separated dependences from nonlinear radial envelope and parallel mode structures, end 2021

2 WP1-M2 study of EPM dynamics in the presence of linearized collision integral and source terms, end 2022

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

5 WP2.1-M3 Benchmark of DAEPS in general stellarator geometry (jointly with WP2.3), end 2023

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

7 WP2.2-M2 Test and tune analytical global mode structure model for LIGKA/HAGIS, end 2022

fully
partly
not started

Milestones 2

8 WP2.2-M3 Generalize fast analytical LIGKA version to non-Maxwellian distribution functions, in particular slowing down End 2023 (Master Project started - Riccardo Stucchi)

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

10 WP2.3-M2 Local eigenvalue code in 3D (LIGKA) including passing particles End 2023

11 WP3.1-M1 Implementation of the 1D “mapping” in general geometry End 2021

12 WP3.1-M2 Interface of the 1D “mapping” in the ITER/IMAS workflow; Investigation of the influence of turbulence on the 1D "mapping" End 2022

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

14 WP3.2-M2 The hypothesis of super-diffusive spreading of tracer particles on Lévy flights tested in simulations, hybrid flight- convective model complete mid 2023

fully
partly
not started

Milestones 3

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

16 WP3.3-M2 Explore methodology and possibly implement RABBIT as EP source into HAGIS End 2023 (ongoing)

17 WP3.3-M3 Finish reduced EP transport workflow based in LIGKA/HAGIS within IMAS mid 2024 (ongoing)

18 WP3.4-M1 Develop and implement radial diffusion model to RABBIT End 2022 (postponed to 2023)

19 WP3.4-M1 Apply extended RABBIT model to transient events, e.g. EP evolution during sawtooth cycles End 2023

fully
partly
not started

Milestones 4

20 WP3.5-M1 Flux calculations for frequency-chirping modes, compared to fixed frequency modes; add magnetic axis to STRUPHY End 2021

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

22 WP3.6-M1 Calculate zonal structures in the presence of turbulence with ORB5 for validation of the reduced models End 2021

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

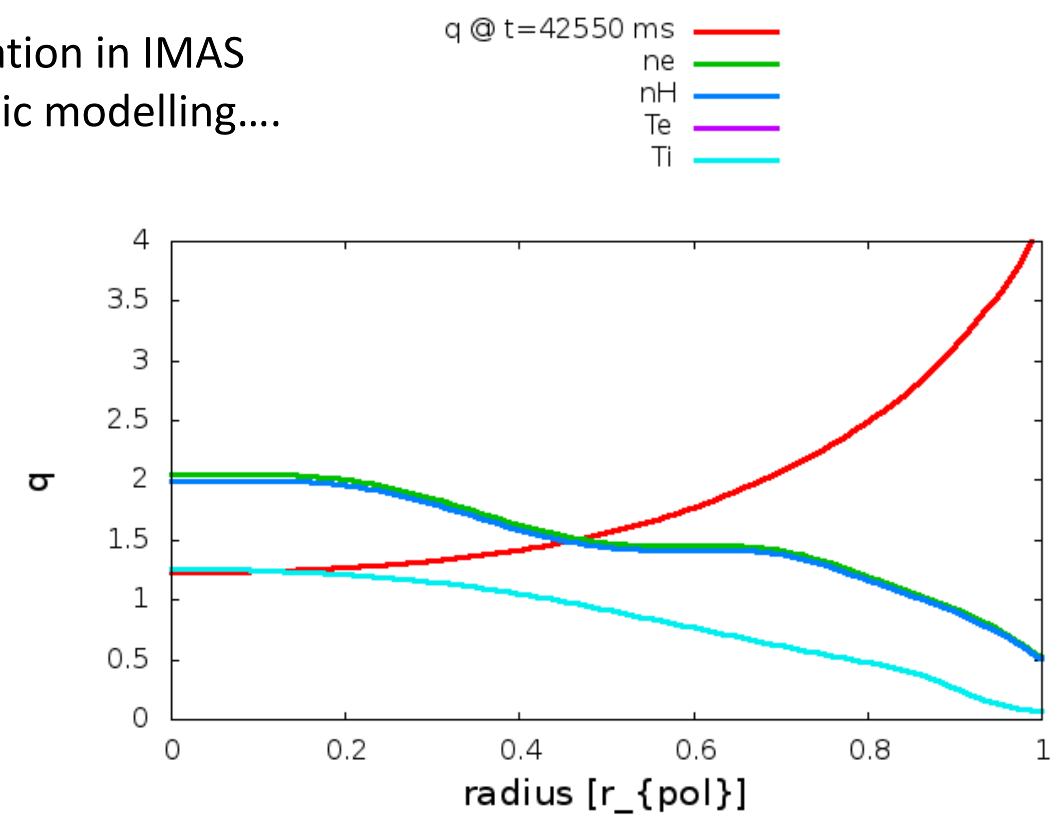
24 WP4-M1 Plan and conduct AUG experiments in the view of clear and well-diagnosed transitions between EP transport regimes End 2021/22

fully
partly
not started

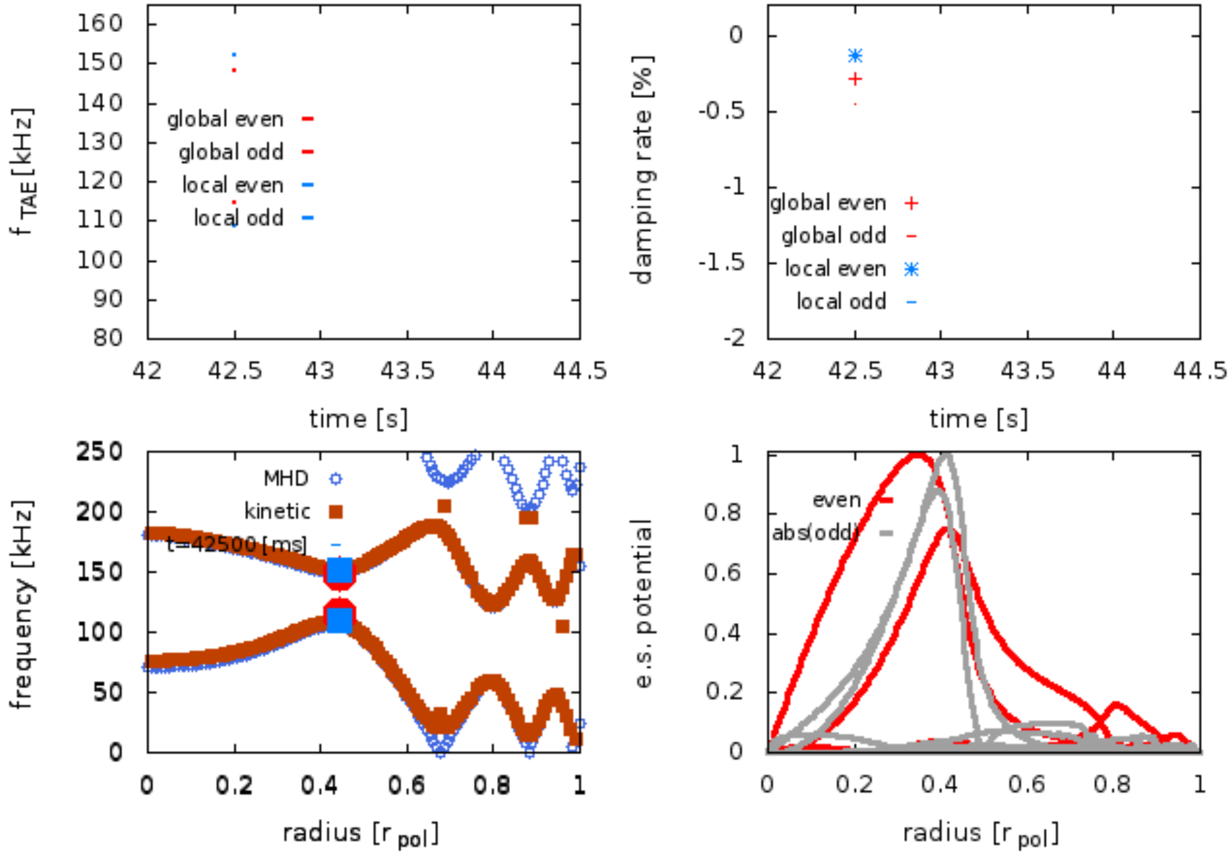
started to model JET TAE damping rates as measured by TAE antenna

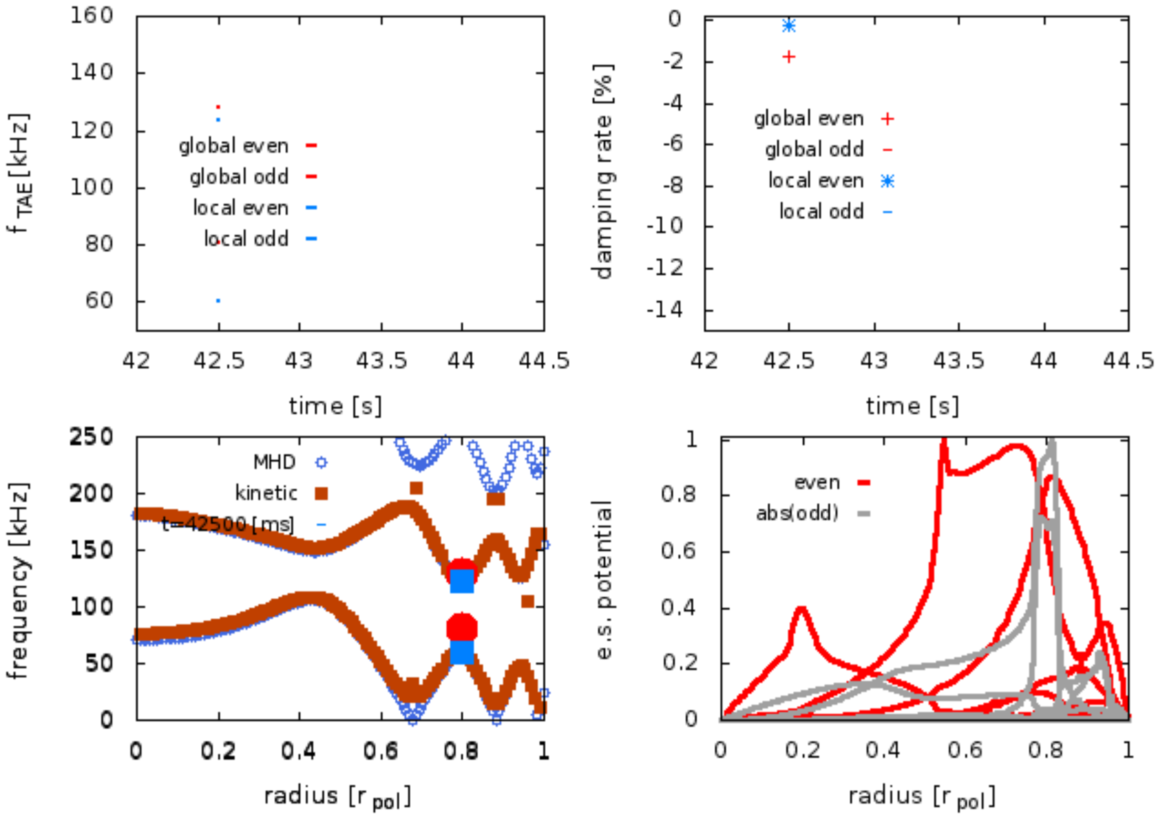
present equilibrium information in IMAS
is not sufficient for automatic modelling….

#96182
(thx to J Fereira)



damping rates - inner TAE gap




f TAE [kHz]
global even
global odd
local even
local odd
time [s]
damping rate [%]
global even
global odd
local even
local odd
time [s]
frequency [kHz]
MHD
kinetic
t=42500 [ms]
radius [r pol]
e.s. potential
even
abs(odd)
radius [r pol]

kick model/ quasi-linear diffusion model

typical quasi-linear scheme:

add effective collisions, sources

initial F_{EP}, amplitudes Φ mode structures → determine γ from F_{EP} → evolve Φ → calculate D from A → calculate F_{EP} using D

until γ=0, gradients exhausted, or γL=γD

$$\gamma_n = 2\pi^2 \frac{e^2}{m} \frac{v_n}{|k_n|} \frac{\partial f(v_n)}{\partial v}$$

$$\frac{\partial}{\partial t} W_n = 2\gamma_n W_n$$

$$W_n = \frac{|k_n \phi_{n0}|^2}{2\pi v_n}$$

$$D(v) = \frac{2\pi e^2}{m^2} \sum_n |k_n \phi_{n0}|^2 \delta(\Omega_n)$$

+self consistent resonance broadening

$$\frac{\partial f}{\partial t} = \hat{Q} f \equiv \frac{\partial}{\partial v}\left(D(v) \frac{\partial f}{\partial v}\right)$$

kick model scheme:

initial F_{EP}, prescribe amplitudes Φ, mode structures → calculate kick matrix → calculate F_{EP}

effective collisions, sources handled by collisional SD code

WP1: theoretical framework

derived explicit analytical expressions for fluxes:

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

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, in preparation]

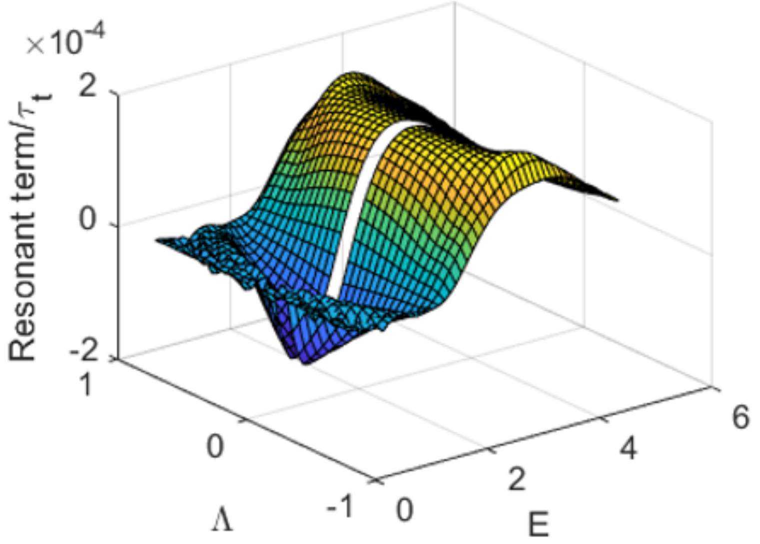
(WP1-D2 fully)

+ 3D version of PSZS equation [A. Zocco et al, draft Aug 2022, DTT Seminar Oct 2021]

WP2.1, WP3.3 explicit calculation of PSZSs

DAEPS

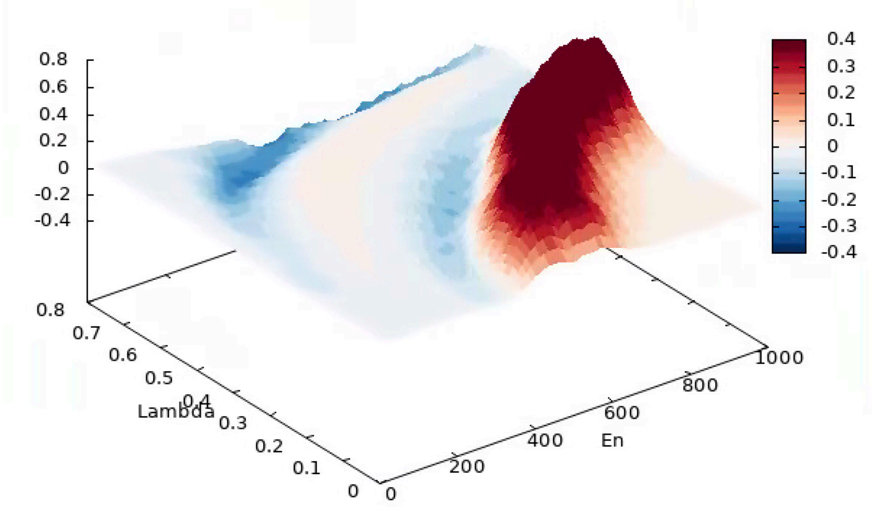
$$\left[\tau_b \overline{e^{iQ_z} \delta\dot{\psi}\delta F}\right]_z$$



DTT, TAE

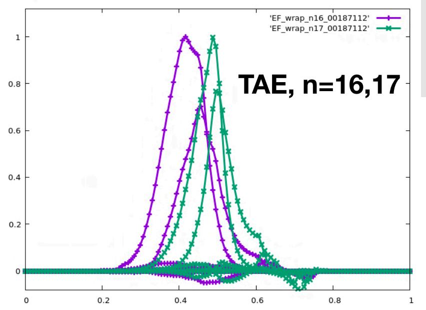
LIGKA/HAGIS

$$\left[\tau_b \overline{e^{iQ_z} \delta\dot{\psi}\delta F}\right]_z$$



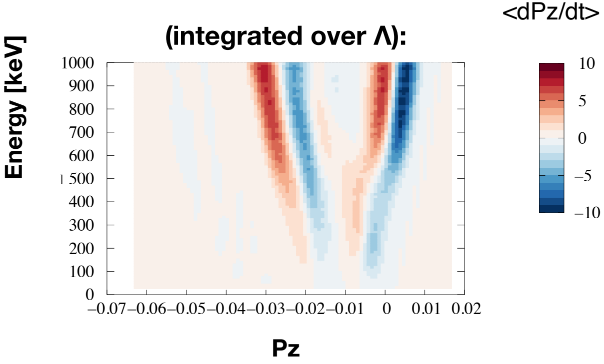
ITER, TAE

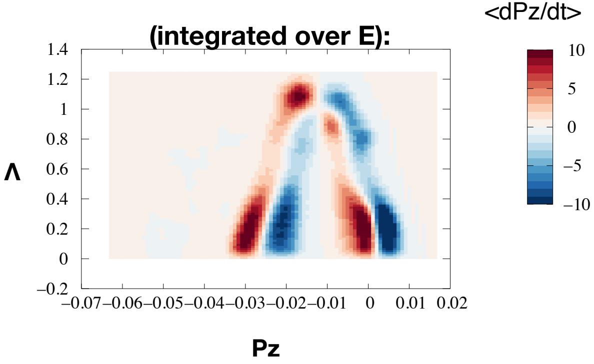
WP 3.3 Extend HAGIS/LIGKA framework to calculate EP fluxes

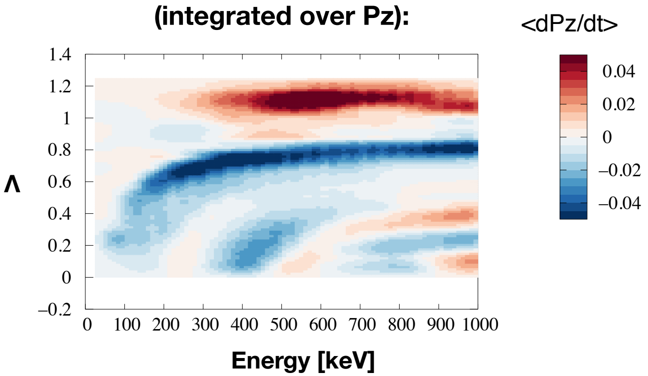


WP3.3-M1 Extend unperturbed orbit integration routines and averaging procedures in order to calculate phase space fluxes in HAGIS mid 2022 (fully)

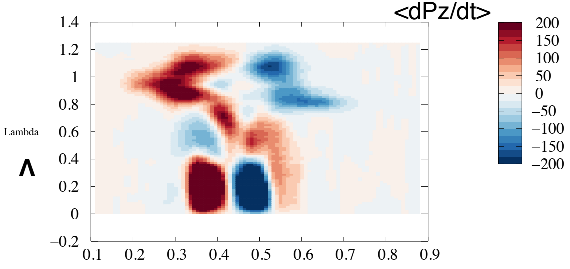
by zonal averaging of a representative particle ensemble, calculate <dPz/dt>, i.e. radial transport for given set of fixed mode structures at fixed amplitudes, write as IDS object in COM Pz,E,Λ [Lauber DTT seminar, 5/2022, Bierwage et al, ID: 30554]

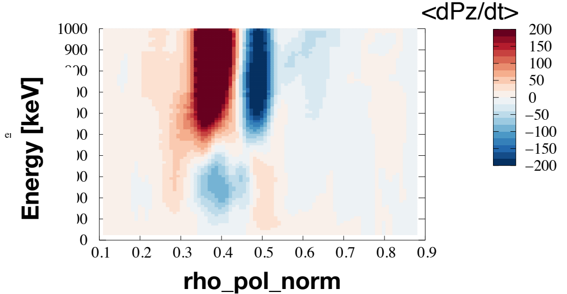






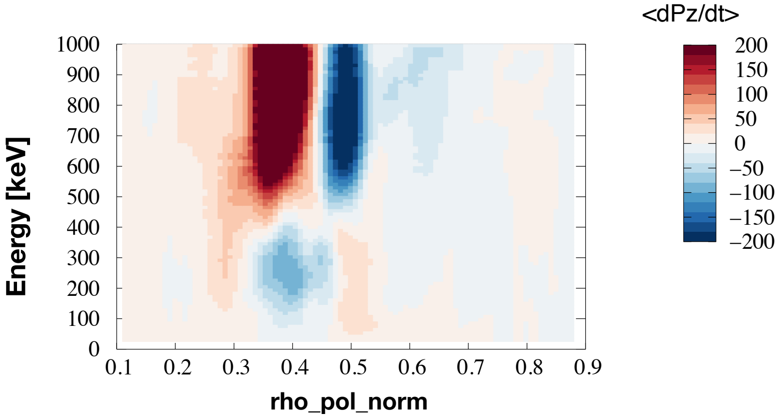
can be easily mapped to <s>:



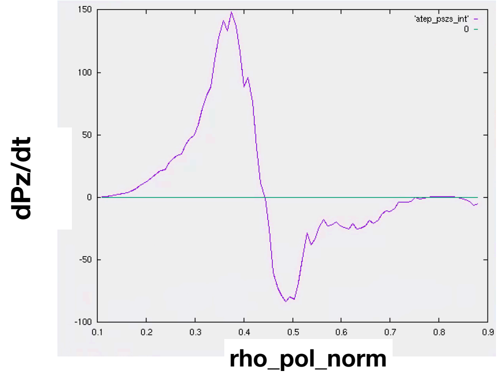


WP 3.3 Extend HAGIS/LIGKA framework to calculate EP fluxes

calculation of diffusions coefficients: D(s,E) and D(s)



E integration →



to be done: transform from $\langle dPz\rangle^2/\langle dt\rangle$ to $D(s,E)=\langle ds\rangle^2/\langle dt\rangle$

and feed back to transport code

WP 3.3 ATEP code: advance transport equation

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

simple finite difference scheme to start with (final scheme to be decided when sources/collisions are implemented):

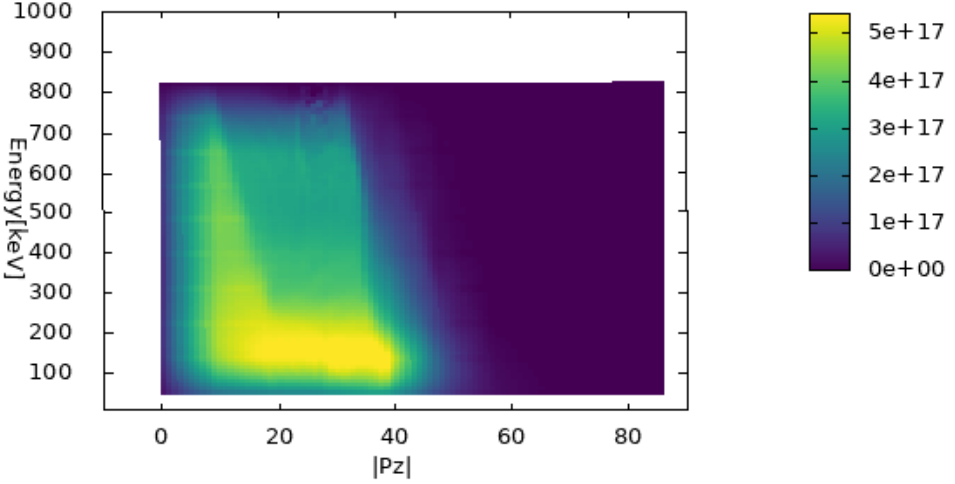
$$\frac{\partial F_{EP}}{\partial t} = \frac{\partial Pz}{\partial t}\frac{\partial F_{EP}}{\partial P_z} + \frac{\partial E}{\partial t}\frac{\partial F_{EP}}{\partial E}$$

note: $\frac{\partial^2 Pz}{\partial t \partial P_z} F_{EP}$ **term excluded so far: dPz/dt assumed constant -> kick model limit**

runtime: several seconds

F (Pz,E,t), Time=199 [arb units]

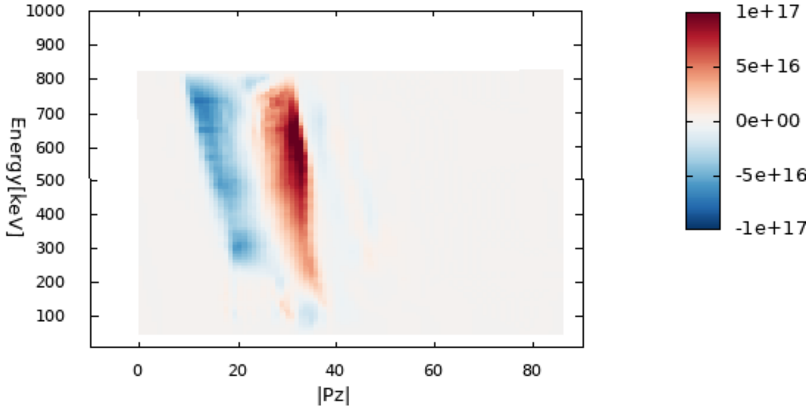
full F:



radial coordinate

F(t) - F(t=0), Time=147 [arb units]

delta F:



radial coordinate

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

WP 3.3 ATEP code: advance transport equation

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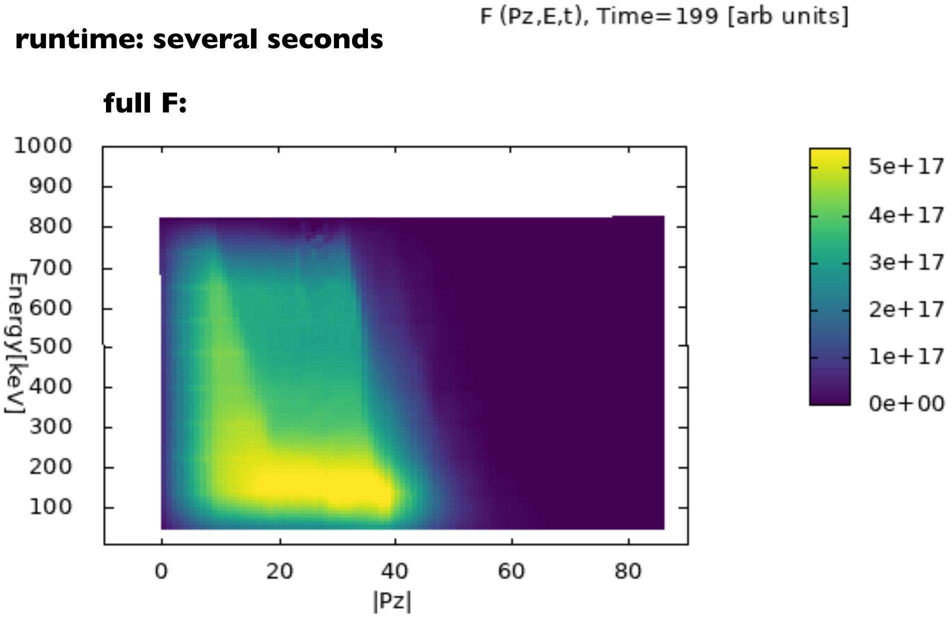
note: $\frac{\partial^2 Pz}{\partial t \partial P_z} F_{EP}$ **term excluded so far: dPz/dt assumed constant -> kick model limit**

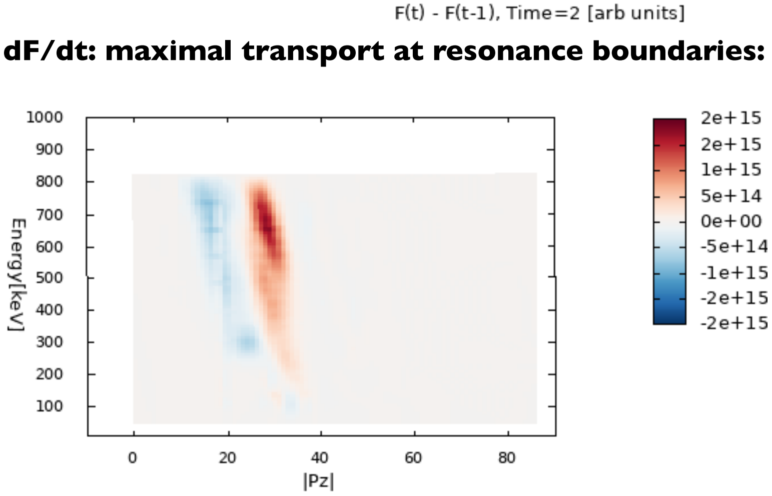
runtime: several seconds

full F:



radial coordinate

dF/dt: maximal transport at resonance boundaries:

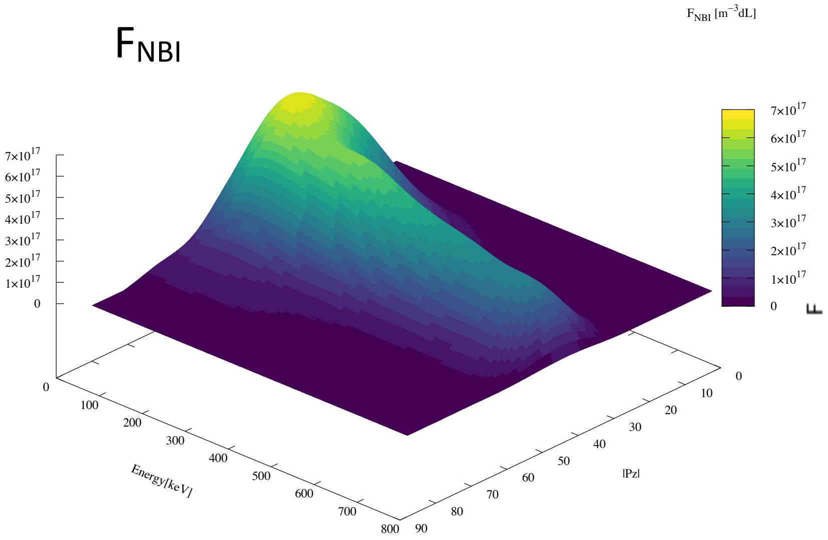


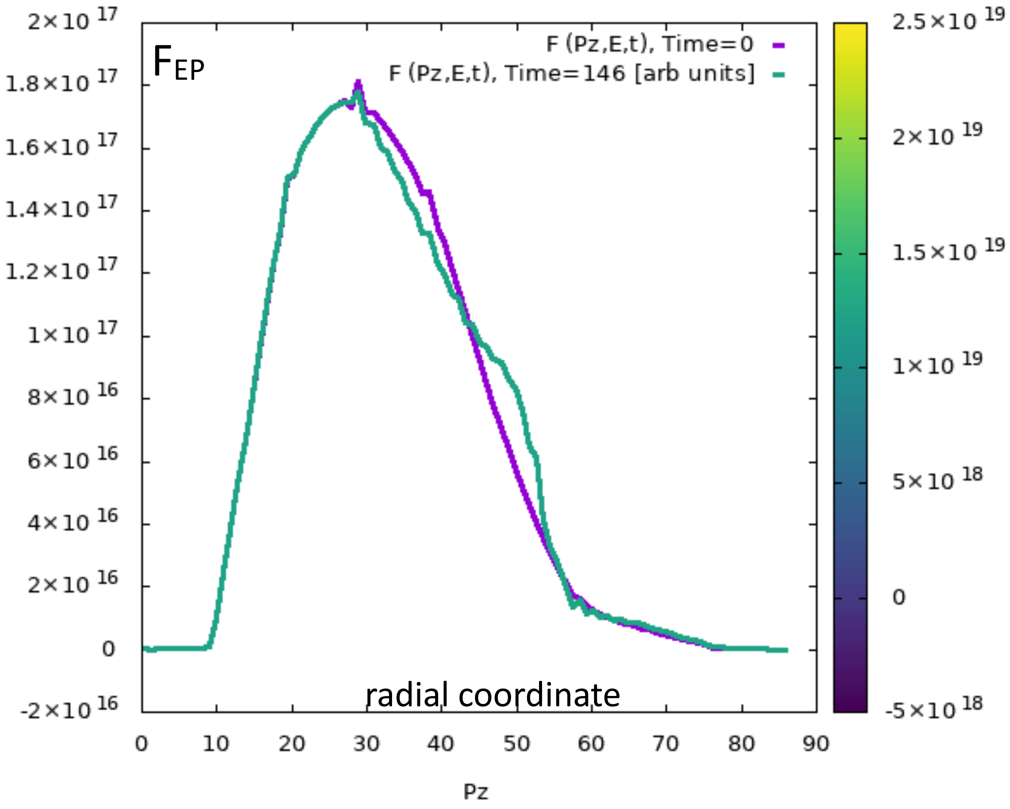
radial coordinate

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

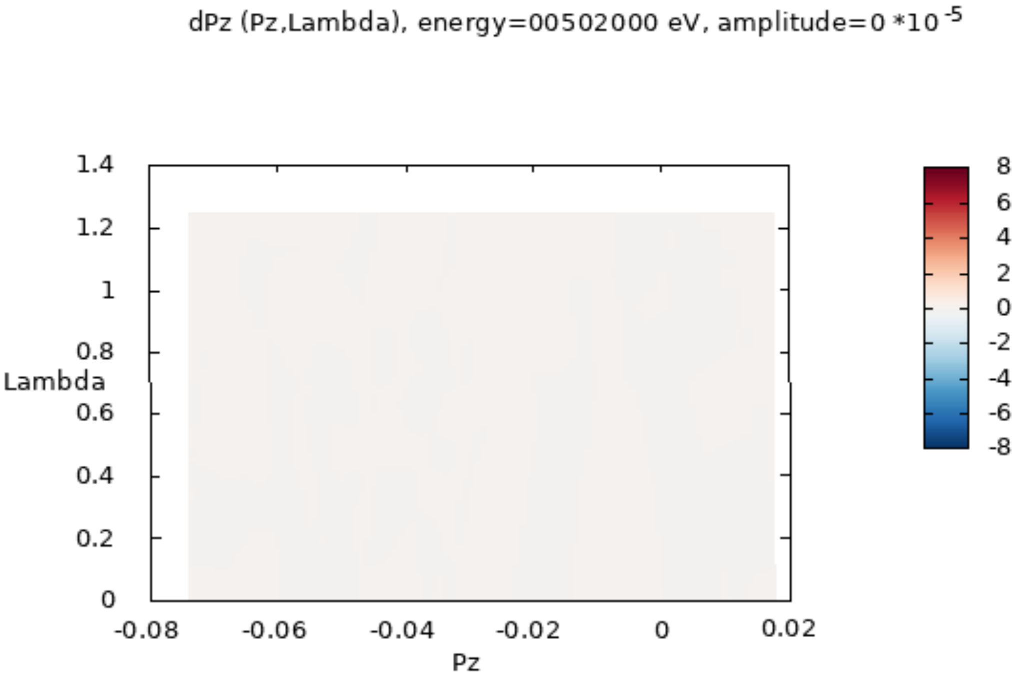
WP 3.3/3.4 Extend HAGIS/LIGKA framework to calculate EP fluxes

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





using ITER NBI off-off axis configuration


dPz (Pz,Lambda), energy=00502000 eV, amplitude=0 *10 -5
1.4
1.2
1
0.8
Lambda
0.6
0.4
0.2
0
-0.08
-0.06
-0.04
-0.02
0
0.02
Pz
8
6
4
2
0
-2
-4
-6
-8

WP 4 - reference cases based on experimental scenarios

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

End 2022 WP4-D1 Availability of reference scenarios (ITER, AUG, DTT) for application of transport models

presently the following scenarios are available on ITER/Gateway (IMAS) and have been investigated with the EP stability WF:

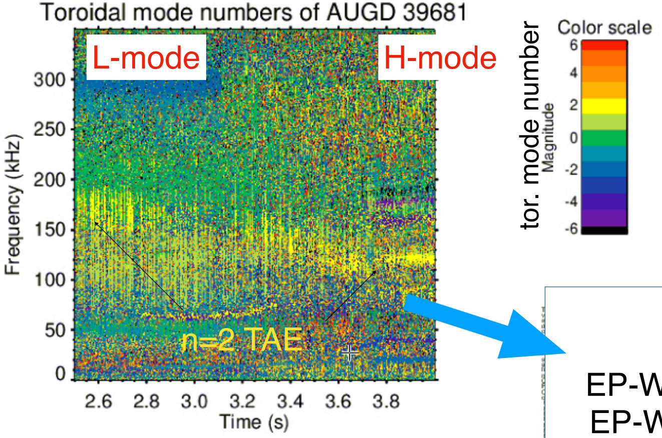
AUG*
TCV* [M. Vallar, subm NF, ID 33003]
JT-60SA
DTT (updated scenarios soon)*
ITER*: 15MA (various), PFPO2

*time dependent

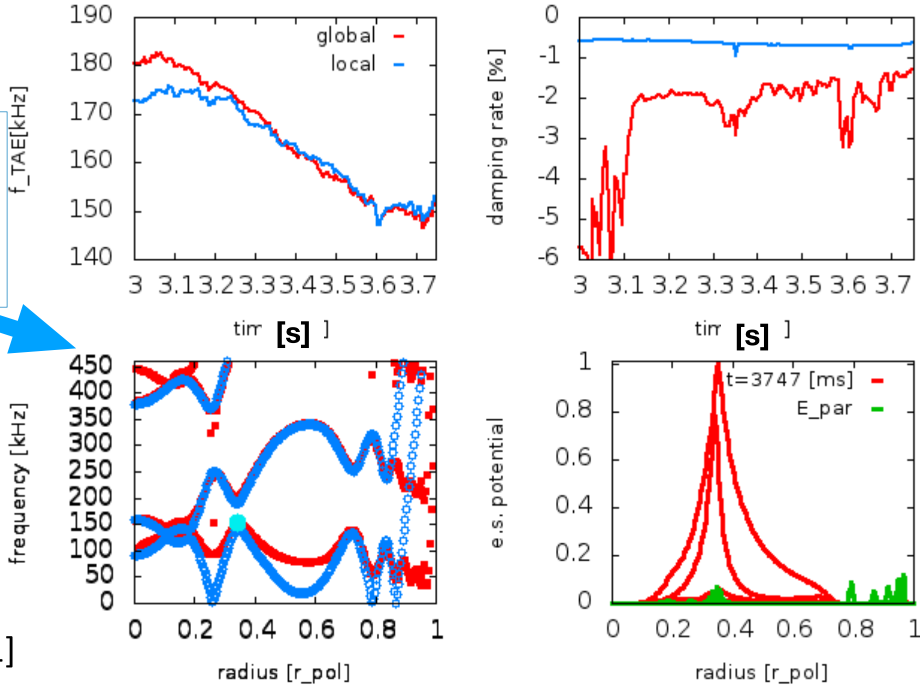
further needs: location for publicly available IMAS database for sharing on gateway, with standard for 'mandatory fields' in IDS

WP 4: AUG reference case: L-H transition in presence of TAEs

AUG EP ‘supershot’ scenarios: D NBI into D plasmas, D -> H and H-> H



IDA +
TRVIEW +
EP-WF: LIGKA local +
EP-WF: LIGKA global

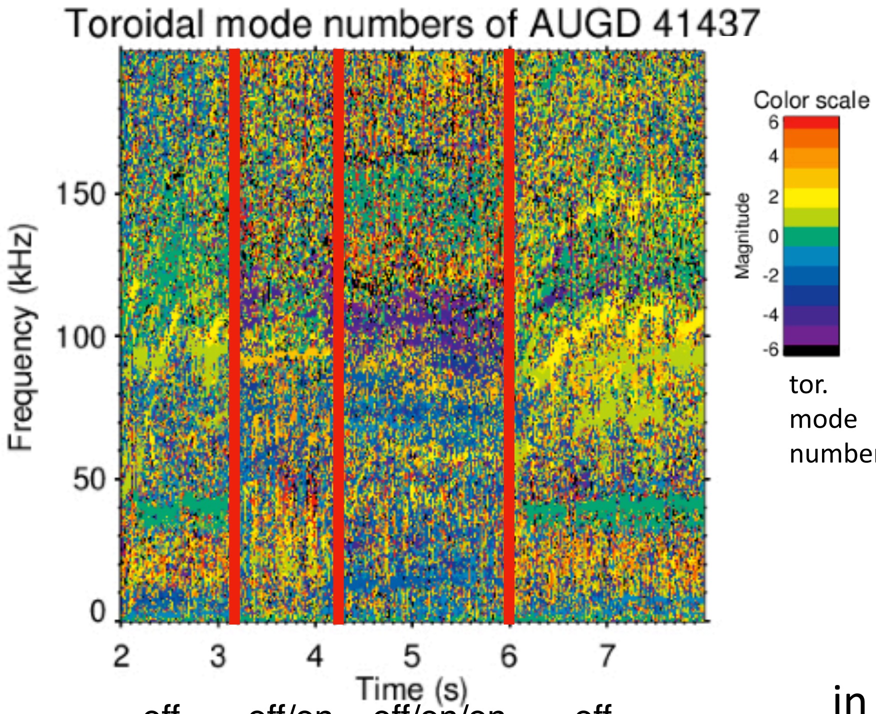


- analyse L-mode,H-mode and transition phase using
- systematic uncertainty quantification feasible
- bursty and steady-state phases visible, in agreement with damping analysis and drive - EP transport?
- speed up WF using ML methods [V.-A. Popa]

[Lauber, EPS 2022,ID 31591]

WP 4 - isotope scans

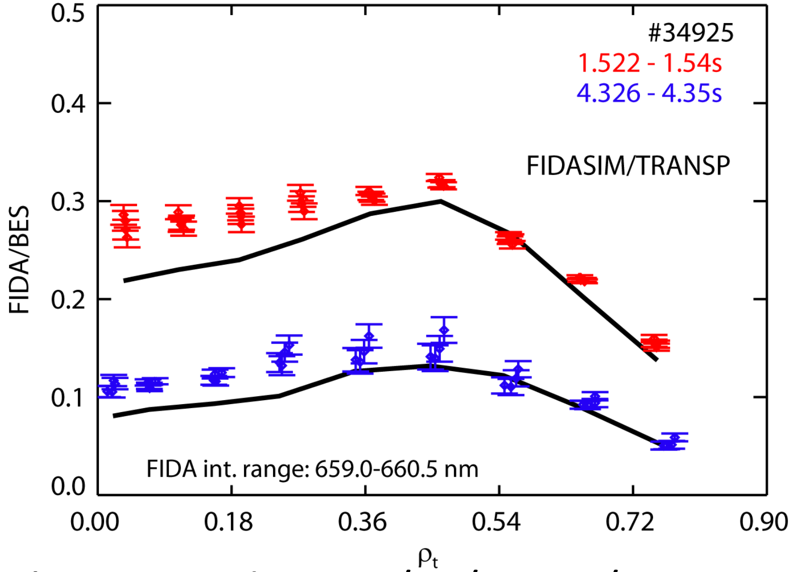
- July 2022: D NBI in He plasmas - ideal for numerical isotope studies, stability FOW/ FLR effects and EP transport under stationary conditions



tor. mode numbers

off off/on off/on/on off

for some shots: FIDA data available

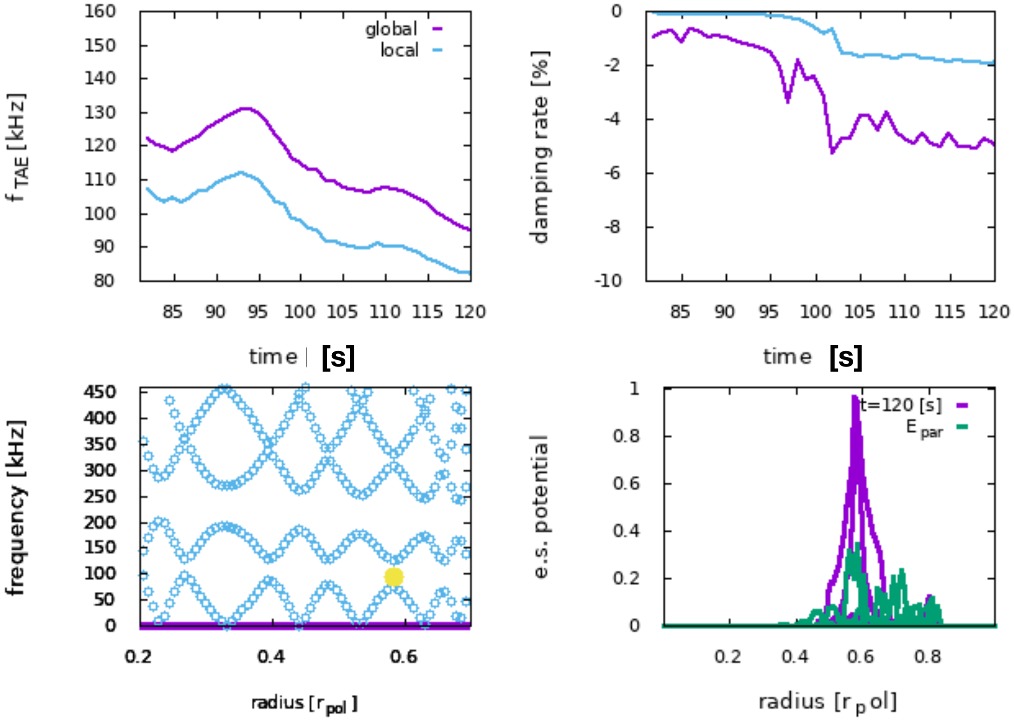


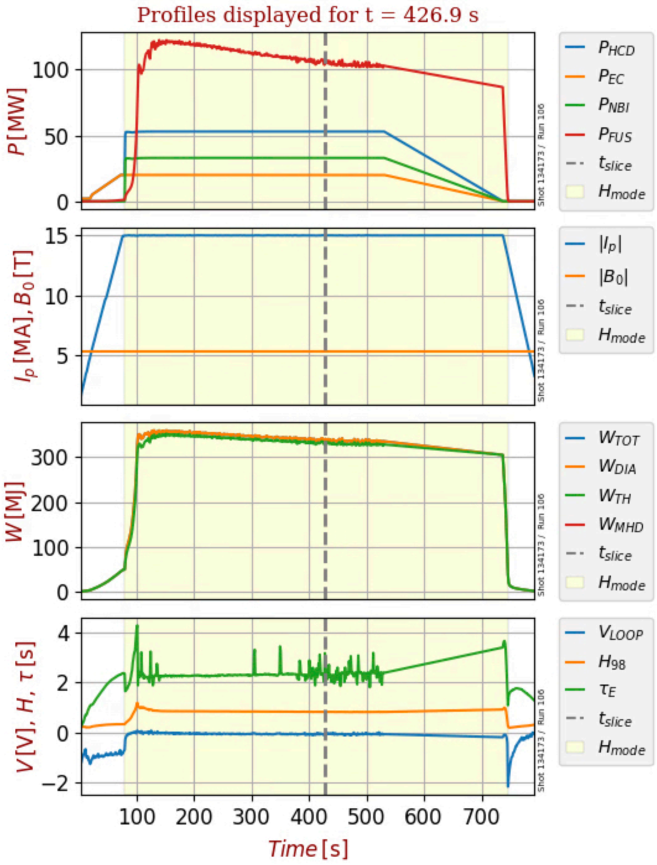
in depth analysis started 34924/25/39681/41437

WP 4 projected ITER scenarios (HFPS): #134173, 106

[S.D. Pinches, plenary EPS 2022]

TAE n=18





identified end of power ramp-up phases as most critical time points
for in-depth EP transport analyses

ATEP aims to 'enable' new routes to EP transport analysis and prediction via:

- new theoretical framework
- new common concept of connecting non-linear code results to reduced models (PSZS)
- new common EP (transport) code developments - explore speed up possibilities
- new analysis methods
- new IMAS based infrastructure

established and growing connections to other WPs: