EUROfusion

TSVV4 Update and Future plans

D. Told

Thrust 1 Meeting #03 — May 03, 2023

MAX-PLANCK-INSTITUT
FÜR PLASMAPHYSIK

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Outline

- Key deliverables / Project structure
- Report on 2022 activities
- Selected highlights

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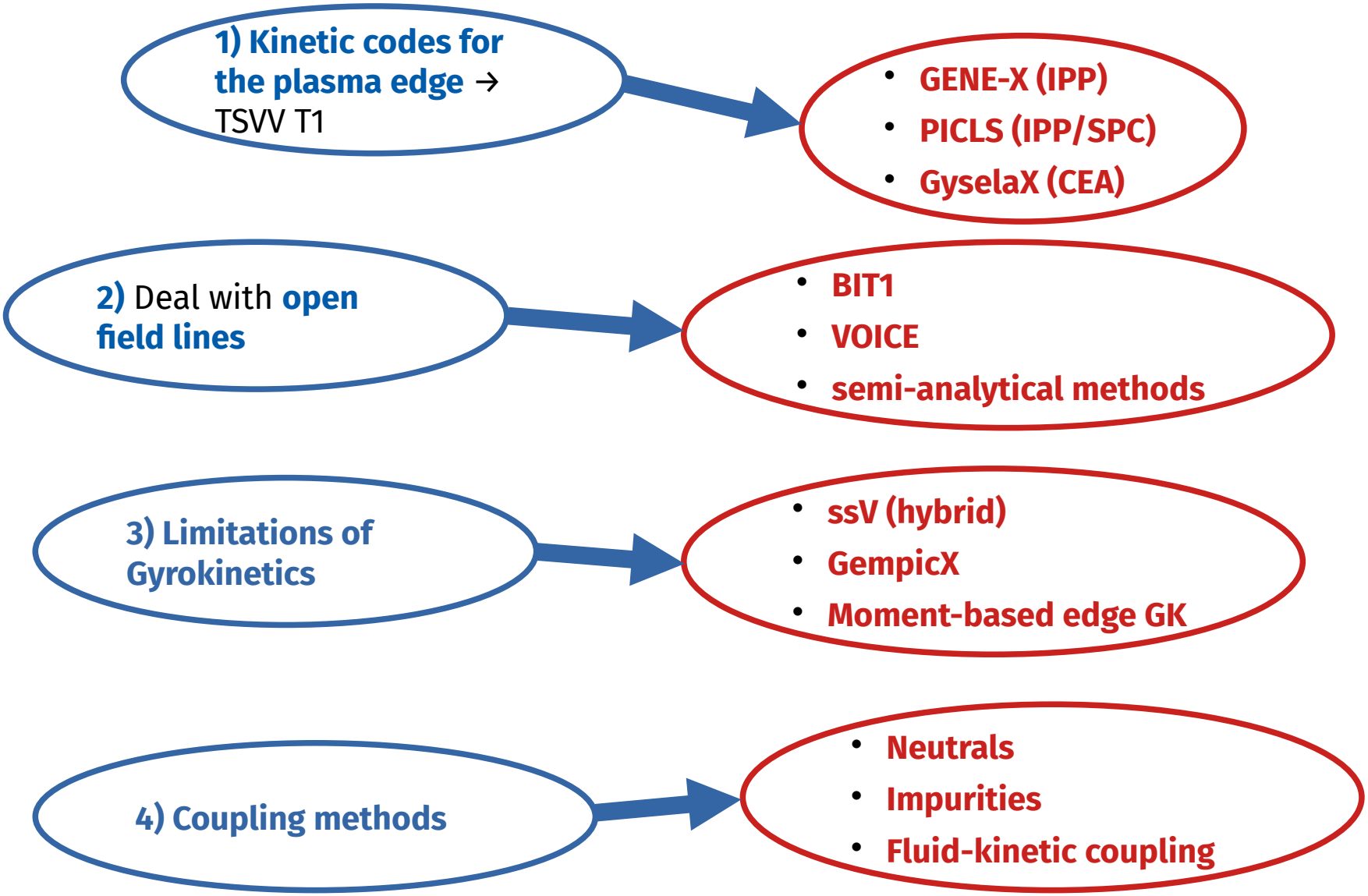
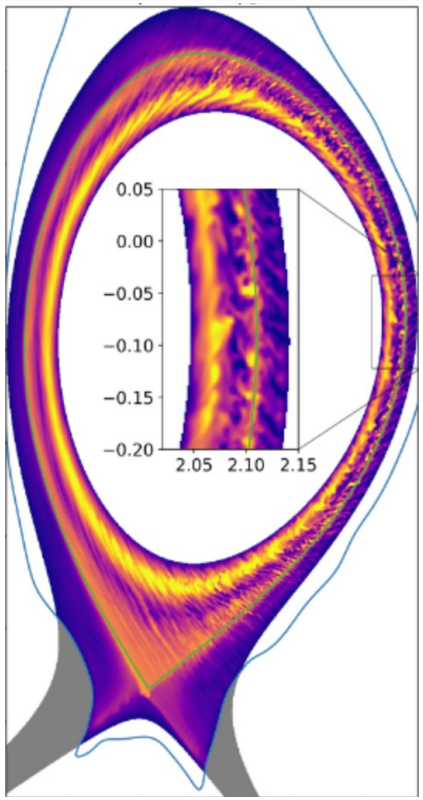
Setup of TSVV Task 4

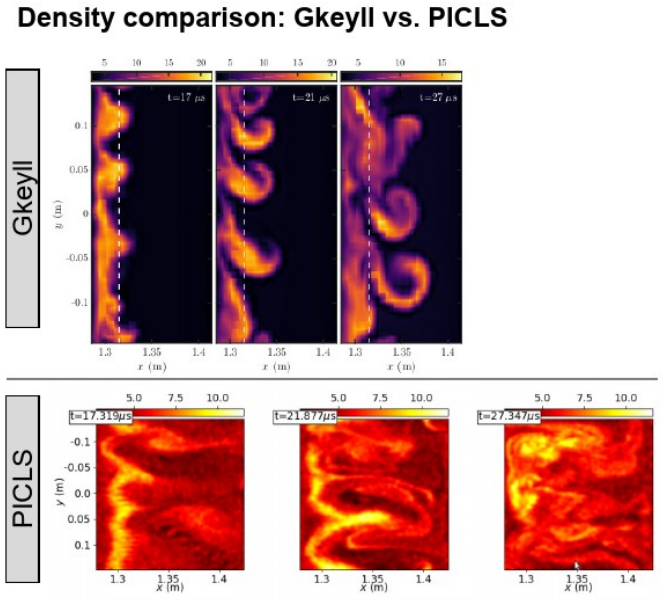


Aim: GK codes for Edge + SOL

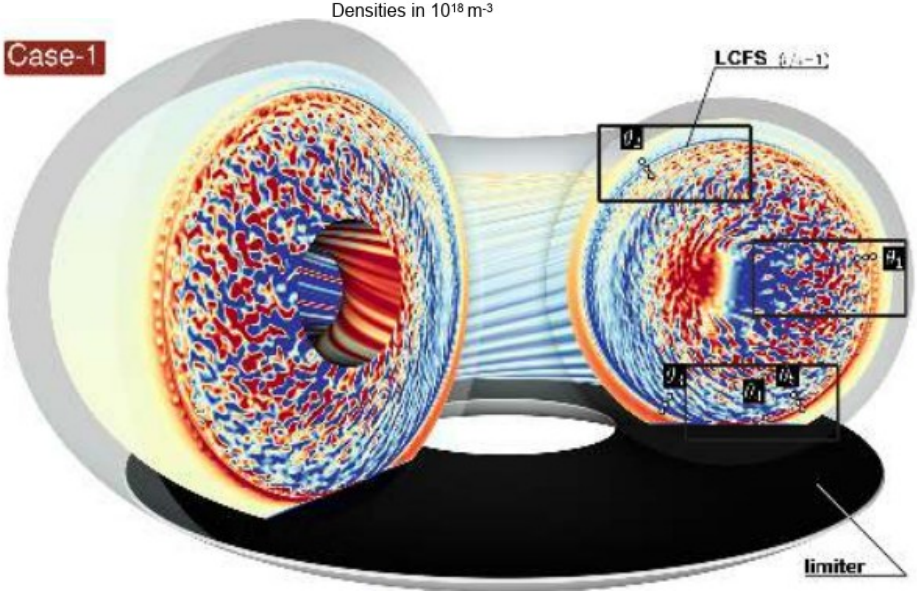


GENE-X /
D. Michels et al.,
Phys. Plasmas 2022

PICLS /
A. Bottino
2021



GyselaX /
G. Dif-Pradalier,
Commun. Phys.
2022



Milestone report for 2022 /1

- Done
- In progress/ modified
- Delayed

GENE-X

- Implementation of a **nonlinear quasi-neutrality** equation

  Crucial ingredient for SOL due to large density variations – implemented and tested via MMS

GyselaX

- Experimentally relevant **heat sources**

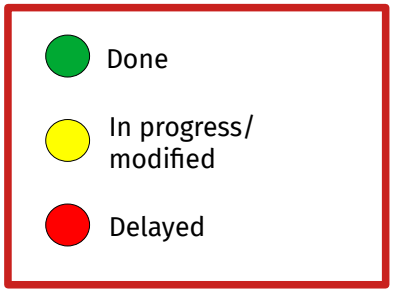
  Delayed due to continued focus on immersed sheath boundary condition – fully kinetic studies with VOICE

PICLS

- **Delta-f to full-f transition** studies, open vs-closed field line regions in simple geometry

  Transition studies have been carried out in ORB5, with open/closed field line applications soon to follow

Milestone report for 2022 /2



Ab-initio sheath studies

- Performing **new simulations for ITER SOL** and providing the boundary conditions → **see highlights**
- First simulation of **full DEMO SOL** with fully resolved sheath

Immersed boundary sheath studies

- **Impact of non-Maxwellianity** of Fws **on SOL properties** in VOICE

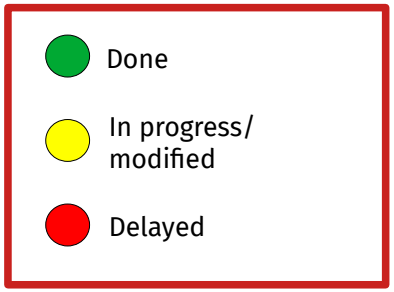
  Additionally: Studied role of source/sink terms + collisions on sheath potential and heat transmission

Analytical sheath studies for gyrokinetic systems

- Extension of sheath model for treatment of **multiple ion species**

  Additionally: auxiliary code for **non-grazing magnetic field** (due 12/24) completed

Milestone report for 2022 /3



Exploring the limits of Gyrokinetics

- Evaluate **high-frequency behavior** of hybrid kinetic driftkinetic system, determine time step requirements for tokamak edge parameters (ssV)

  Lower-hybrid wave important for timestep → $\Omega_{ci} \cdot \sqrt{(m_i/m_e)}$

- Introduce **tokamak geometry** capability (ssV)

  Delayed due to additional work required on numerical schemes (see highlights) – first steps taken, but interfaces still missing

- Implementation of **drift-kinetic electrons** (GempicX)
- Implementation of customizable **sources and sinks** of particles, momentum and energy (GempicX)

  Delayed due to unexpected loss of personnel

Milestone report for 2022 /4

- Done
- In progress/ modified
- Delayed

Coupling to neutral and impurity physics

- Implement a constant-in-time **particle source** featuring the minimal properties of the one expected from neutrals
- Selection of existing test cases for a **realistic guess of neutral particle sources**
- Identify **bottlenecks** of main code implementations **regarding impurity physics**

Exploring the gyrokinetic moment hierarchy

- Implement **full nonlinear model** in a two-dimensional simple geometry (Z-pinch or linear machine)

Further activities

Dissemination (as of AR 2022):

- 4(+2) papers, 3 invited talks, several talks + poster presentations

ACH:

- **GyselaX** project underway at EPFL hub
- **GENE-X** project underway at BSC hub
- Applied math project at EPFL hub (gyro-moment code)

Meetings:

- Monthly member meetings
- Dedicated **sheath subgroup** meets every few weeks
- Visit by A. Geraldini to IPP on sheath physics
- Second annual **in-person meeting** in Garching planned for mid-June – will have shared session(s) with TSVV3

Milestones for 2023

GENE-X

- Implementation of electromagnetic effects

GyselaX

- Solving Poisson in 2D (target = arbitrary geom.)

PICLS

- EM effects and improved edge GK

Ab-initio sheath studies

- Finishing all proposed DEMO SOL simulation cases

Immersed boundary sheath studies

- Implementation of immersed boundary with kinetic electrons in GyselaX

Analytical sheath studies for gyrokinetic systems

- Investigation of turbulent gradient effects on sheath physics

Exploring the limits of Gyrokinetics

- Introduce nonlinear solvers for field equations (ssV)
- Implementation of advanced boundary conditions: logical BC, and EM waves source at the boundary (GempicX)

Coupling to neutral and impurity physics

- Implementation and testing of neutral physics source terms in at least one code
- Enable internal impurity species treatment in main codes

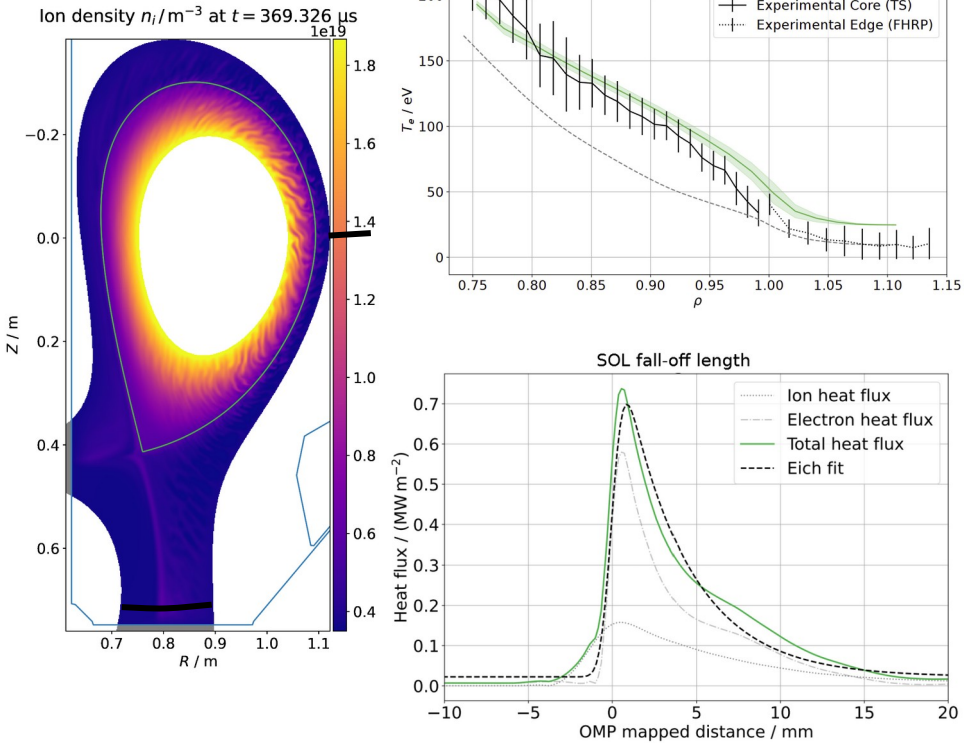
Exploring the gyrokinetic moment hierarchy

- Generalization to a 3d geometry (linear or with constant curvature, such as in the simple magnetized toroidal plasma configuration).

Validation of GENE-X in TCV

[Courtesy of P. Ulbl]

Simulations enable accurate reproduction of key experimental observables in TCV



Code validation vs. “TCV-X21“ open dataset

- Simulations reproduce key aspects of the experiment

  Left: **green** vs. **black** lines

- Divertor heat flux fall-off follows Eich-fit function, match improves with collisions

  SOL fall-off length λ_q: **Experiment 5.5 mm**

Fluid Models			GENE-X (Gyrokinetic)		
GRILLIX	1.1	mm	No Coll	1.34	mm
GBS	11.6	mm	Coll BGK	**4.68**	**mm**
TOKAM3X	0.1	mm	Coll LBD	**3.75**	**mm**

[P. Ulbl et al., APS invited talk (2022) + PoP (accepted), 2023]

Simulation of ITER inter-ELM SOL

[Courtesy of D. Tskhakaya]

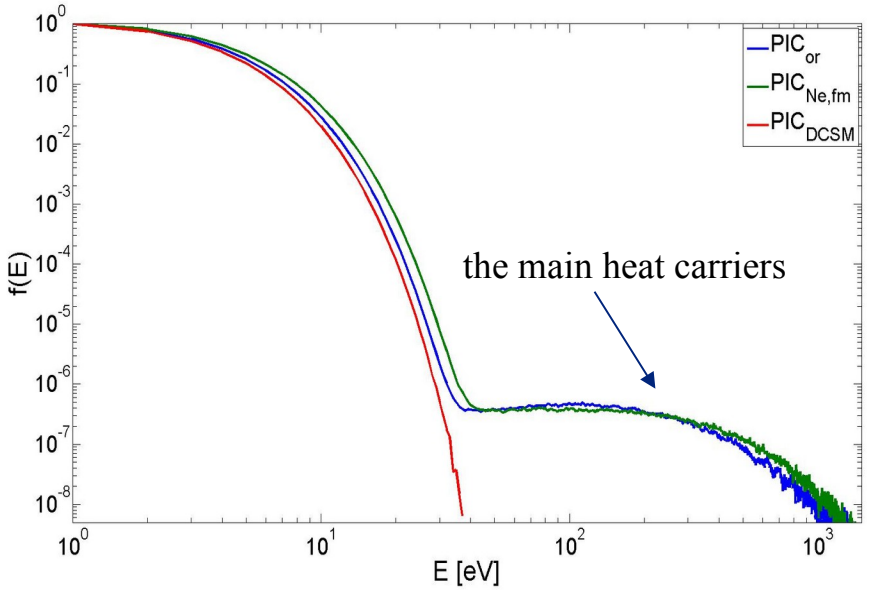
Two new sets of ITER SOL simulations have been performed:

- including higher ionized states of Ne^{+i} (up to i=6)
- including Dressed Cross-Section Model (DCSM). The DCSM [1] does not apply the coronal approximation and takes into the account millions of possible atomic transitions.

No significant influence of the applied model on the plasma profiles has been found, but on the electron power loads to the divertor

q_e [MW / m²]	Original	With $Ne^{+i<7}$	With DCSM
ID / OD	3.7 / 15.7	7,2 / 13.2	0.9 / 0.9

The explanation of these results is the following: the main heat carriers to the divertors are the super-thermal non-Maxwellian collisionless electrons originated from the upstream SOL, which **are absent in the DCSM**.

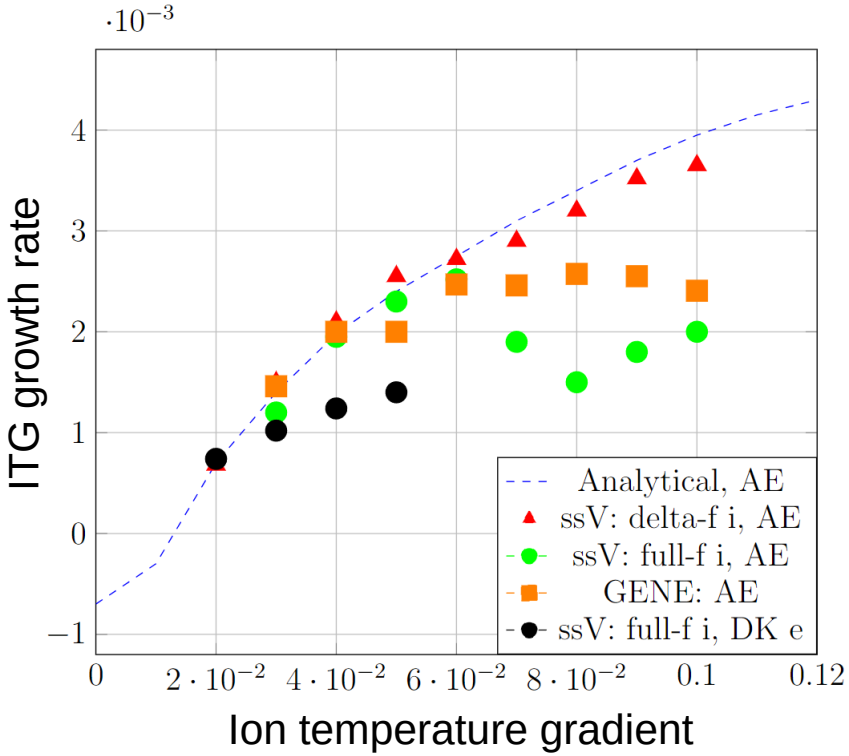


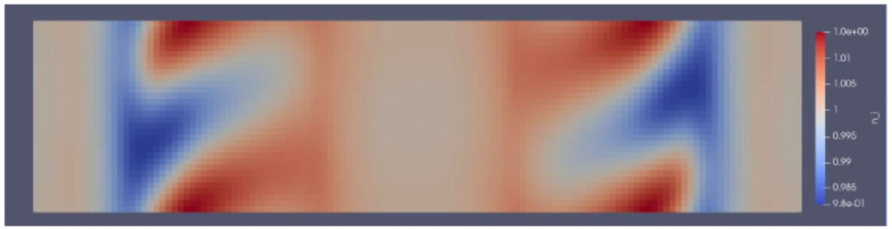
Electron energy distribution function at the ITER outer divertor sheath entrance from different SOL models. "or" denotes the original model including only up to the 5th ionized states of Ne

[1] D. Tskhakaya, Europ. J. Phys. D, submitted for publication (2023)

Full-f hybrid-kinetic ITG runs using ssV

- Challenge in simulating low-frequency physics with full kinetics: **Numerical dissipation**
- Settled on 5th order flux-conserving scheme with SLMPP limiter to allow ITG modes to develop
- Successfully **reproduced ITG physics in full-f** setting and found agreement with GENE (global slab)
- New challenge: are differences at higher gradients physical (=non-GK?) or numerical?





Ion density fluctuations in $\perp$ plane

Summary / Outlook

T4 codes making progress.

What about delivery to TSVV Task 1?

Specific questions can be studied already now, but some important physics still lacking:

- Correct sheath physics
- Neutrals

Also keep in mind: Edge/SOL studies will usually be global, nonlinear → expensive!

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Thank you for your attention!