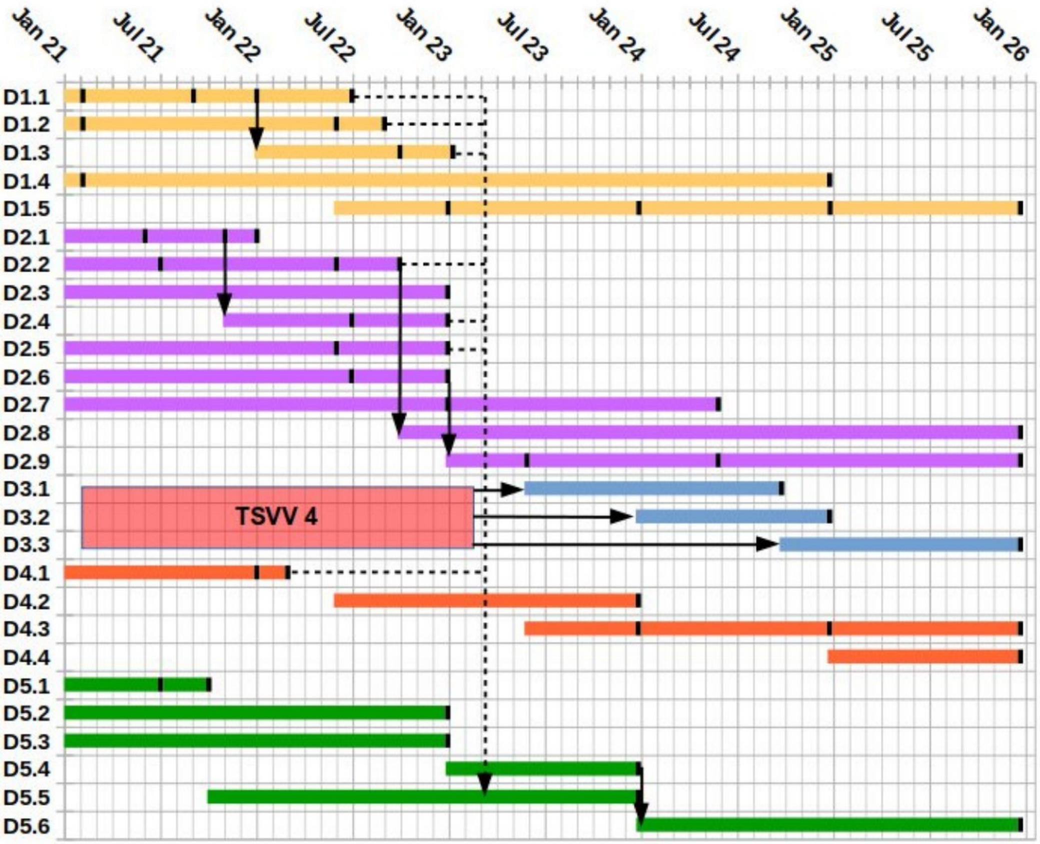
EUROfusion

TSVV1 “L-/H-transition and pedestal physics” – status

E-TASC thrust 1 meeting,
July 9, 2021

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Workplan (as originally proposed)



Validated local & global GK simulations of ion-/elect.-scale, & multi-scale turbulent transport in the H-, QH-, I-, and L-mode edge: IPP, SPC, CEA, DIFFER (GENE, ORB5, GYSELA)

Extensions to relevant macroscopic (MHD-like) instabilities (CCFE, IPP) and radial electric field development: also CEA, SPC (ion orbit losses, fluid codes, eventually GK)

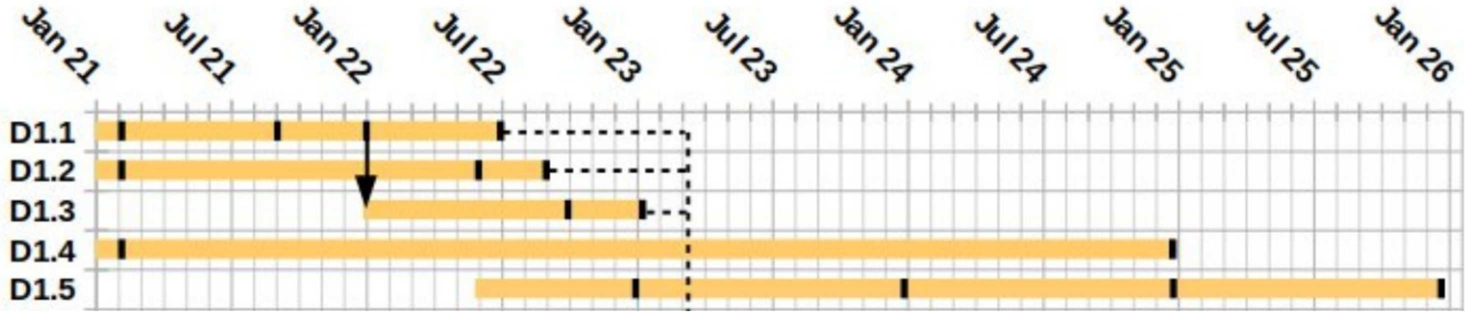
Consistent application of new Task 4 edge GK code: various partner 2022+

An interpretative and predictive capability of L-H transitions: from fluid codes (SOLEDGE2X, GBS) to TSVV4 code

Reduced transport models for the pedestal on the basis of GK simulations, involving electron-/ion-scale, and MHD-like instabilities: IPP, DIFFER (heuristic models to coupled QuaLiKiz profile predictions)

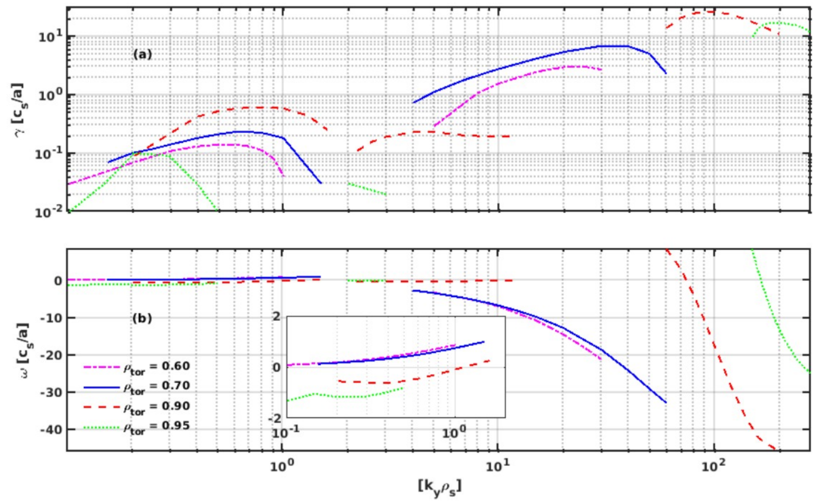
D1 goals for validated local & global GK sims.

- **Level of realism by first validation (delta-f, local) studies discussed, further need for more comprehensive simulations (global, multi-scale) and physics scenarios assessed (2022)**
- **ITB physics studied and key elements that could be transferred to edge transport barriers identified (2022)**
- **Assessment of the level of realism confirmed by advanced delta-f validation studies (e.g., global, multi-scale) (2022)**
- **Level of realism found in full-f simulations and coherency/agreement of the comparisons assessed (2024)**
- **Extension of previous studies, e.g., by covering new scenarios and/or diagnostics (2025)**

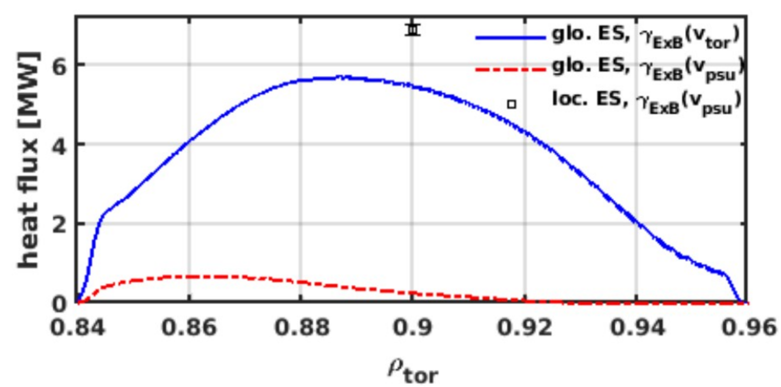


D1: Examples for launched GENE studies

- **Gyrokinetic study of EDA H-mode with Ar-seeding on ASDEX Upgrade**
  [K. Stimmel et al., to be subm. to PoP (2021)]
  - Pedestal instabilities: MTM but also hybrid modes (drift direction changes) found at ion-scales; ETG at electron scales
  - Nonlinearly, ETGs negligible, ion-scale turbulence in the right ballpark with global simulations (EM still needs to be performed)
  - Quasi-linearity & frequency spectra assessed as well



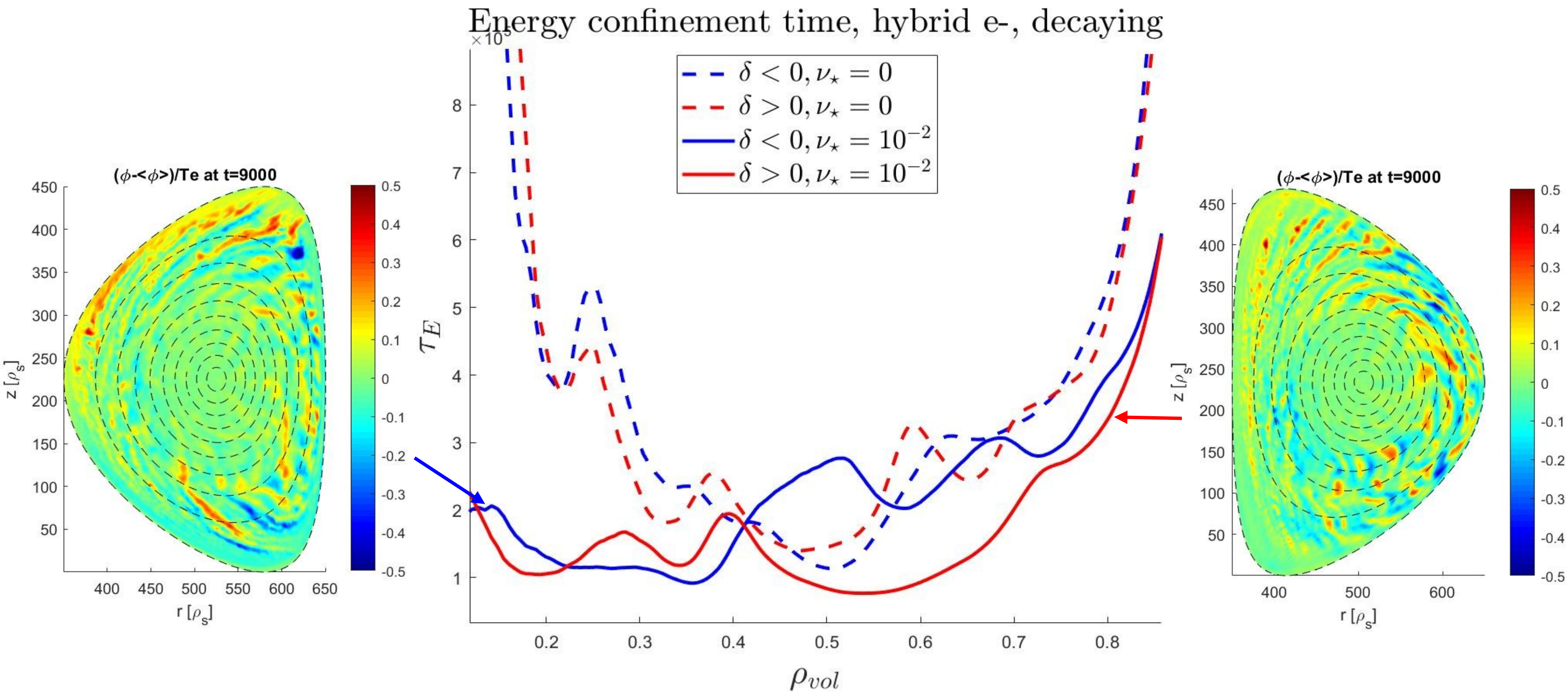
Heat Transport [MW]			ρ_i-scale						ρ_e-scale	neo.	Q_{sum}	
			e.s. channel			e.m. channel						
radial position	ρ_i mod.	v_{prof}	ion	e^-	Ar	ion	e^-	Ar	ρ_e sum		sim.	exp.
$\rho_{tor} = 0.60$	–	v_{tor}	2.11	0.82	–	-0.03	0.02	–	0.06*	0.48	3.46±0.14	3.36
	$\omega_{Ti} - 15\%$	v_{tor}	0.83	0.34	–	-0.01	0.00	–			1.70±0.00	
$\rho_{tor} = 0.70$	–	v_{tor}	4.32	1.96	–	-0.05	0.03	–	0.14*	0.56	6.96±0.01	3.44
	$\omega_{Ti} - 15\%$	v_{tor}	2.38	1.14	–	-0.02	0.02	–			4.22±0.14	
	+ Ar prof. 2	v_{tor}	3.19	1.43	0.01	-0.04	0.02	0.00			5.31±0.14	
$\rho_{tor} = 0.90$	–	v_{tor}	12.68	23.36	–	-0.14	1.40	–	0.03	0.60	37.93±1.29	2.75
	–	v_{psu}	5.48	9.34	–	0.20	0.92	–			16.57±0.76	
	$\beta_e = 0$	v_{psu}	2.38	4.53	–	–	–	–			6.91±0.14	
$\rho_{tor} = 0.95$	–	v_{tor}	1.88	3.15	–	0.00	0.15	–	0.00	0.88	6.06±0.18	2.22
ρ_{tor} = 0.84 - 0.96	$\beta_e \sim 0$	v_{tor}	1.38	2.40	–	–	–	–	–	–	3.77	–
ρ_{tor} = 0.84 - 0.96	$\beta_e \sim 0$	v_{psu}	0.04	0.08	–	–	–	–	–	–	0.12	–



D1: Examples for launched GENE studies

- **Further GENE studies:**
  - AUG H-mode pedestal ELM cycle [M Cavedon et al., PPCF'17, Viezzer et al., IAEA'18]
  - AUG L-mode edge validation – measurements completed, waiting for kinetic edge profiles while already performing core validation
  - ITB scenario: first step, idealized setup – low magnetic shear studies
  - Linear scans for JET parameters for QuaLiKiz comparison (→ D5)
  - Micro-tearing mode studies (→ D5)
  - Discussion with JET dep. TFL to study type-I ELM pedestals during isotope scans
  - Further AUG edge/pedestal studies by N. Bonanomi (permanent guest)
  - JET high/low power pedestal characterization by B. Chapman (permanent guest)

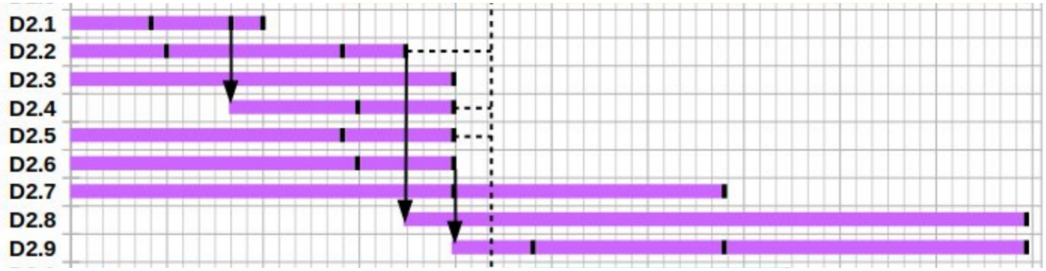
Hybrid electrons and collisions needed to qualitatively reproduce the improvement of confinement in δ<0 (TCV case)



Next steps : include ECRH [Donnel et al., PPCF 2021] source to have flux driven simulations → study the impact of boundary conditions on confinement

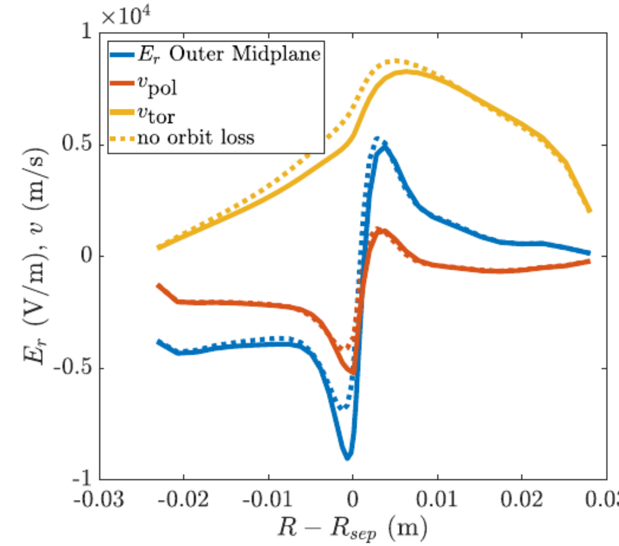
D2: MHD extensions & E_r development

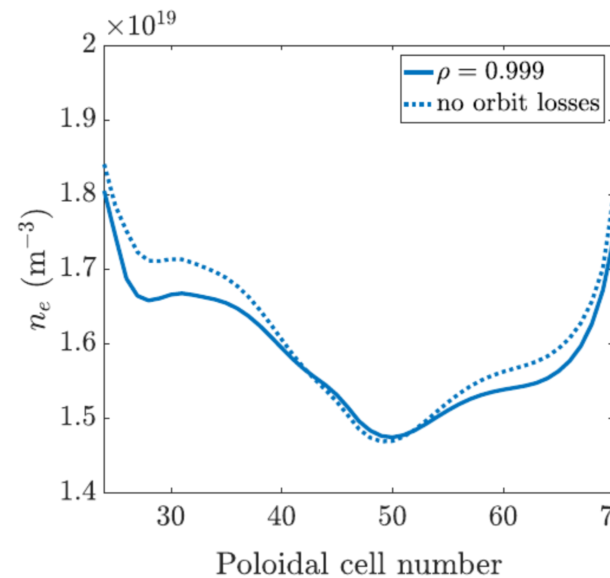
- **Simulation and analysis of the radial electric field development due to ion orbit loses in a fluid turbulence code with comparisons to SOLPS and assessments of ion orbit loss model (2021), interfacing to GK code (2022)**
- **GK simulations with MHD-terms added in at least one gyrokinetic code (2022); based on the outcome, coupling between MHD-dynamics and drift-mode physics and further refinements explored (2025)**
- **Development of full-f HAGIS code (2022) & subsequent neoclassic bootstrap current studies in support of GK simulations (2024)**
- **Report from global fluid & GK (full-f) simulations on the relative impact of separate ingredients playing a role in the electric field formation (orbit losses, ripple, turbulence, neutral, limiter …) (2022)**
- **EM fluctuations in GBS and large parameter scan (injected power, shaping, etc) conducted on Er development (2025)**



D2: Ion-orbit loss model

- **Preparing manuscripts for submission: steady-state orbit loss and SOLPS coupling**
  - Er affected by ion-orbit losses
  - Poloidal asymmetries are less strongly forced
- **Production of a stand-alone orbit loss model on-going**
- **Emphasis on clear documentation for stand-alone model that can be employed by GRILLIX (fluid code) and TSVV1 (and other) codes**
- **Identifying of responsible IPP staff for joint (with R. Brzozowski) maintenance, dissemination, and future development / coupling**

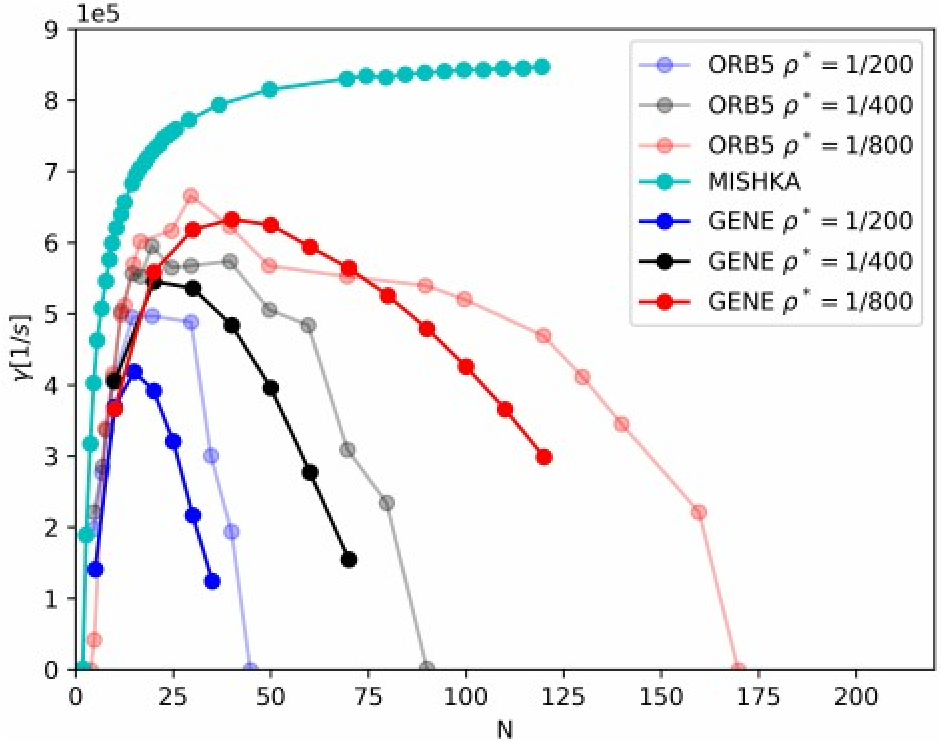




Courtesy: R. Brzozowski

D2: GK/MHD comparisons & extensions

- **GENE joined GK-MHD (ORB5/MISHKA) comparison**



- **One important ingredient to improve agreement a low-n: kink physics**
  - 2D parallel current density implemented in ORB5 during TSVV pilot phase; further test/refinements on-going
  - Implementation of a shifted Maxwellian for kink physics work-in-progress in GENE (together with US co-workers)

D2: Improved HAGIS code for NC predictions

- **Pedestal: steep density & temperature profiles, strong Er**
  higher collisionality

- **LH-TSVV pilot project: need for more accurate model for bootstrap current calculations shown**

- **Goal here:**
  - **Improve HAGIS collision model and run HAGIS as full-f code**
    (new initialisation procedure, procedure to stabilise the density and temperature profiles w/o turbulent transport in the simulation)

- *First step on-going: δf code with improved collisions and profile stabilisation*

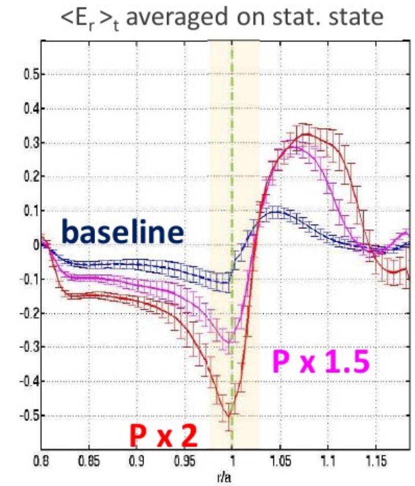
D2: TSVV L-H pilot – TOKAM3X outcomes: systematic spontaneous generation of inverse Er

TOKAM3X anisotherm drift-fluid turbulence simulations in a **limited circular plasma geometry**, encompassing both the closed field lines edge region and **SOL**.

➢ Systematic spontaneous generation of a reversed radial electric field in the proximity of the separatrix

Power scan (heating power increased at fixed core fueling) :

- **deepening of E_r well**, consistently with exp.
  - E_r systematically peaks at the separatrix
  - E_r shear max. at the outer midplane at few Larmor radii outside separatrix, in near SOL
- Steepening of the global plasma density and temperature profiles, creation of strong gradient in near SOL reminiscent of narrow λ_q
- Dynamic oscillatory behavior of E_r



G. Falchetto EPS 2021

D2: Next drift-fluid code steps in TSVV1

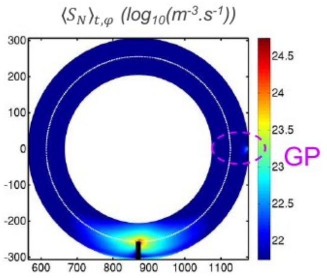
- ➢ Support to understanding E_r generation in more realistic flux-driven cases *Key D2*
- ➢ Explore a wide(r) parameter range, so to provide relevant regimes for GK investigation *Key D4*

❑ Move from **idealized cases (3D circular limited)** towards **more relevant edge plasma conditions**

- particle source at the limiter
- recycling neutrals
- divertor geometry
- realistic collisionality

Impact on transport *Tamain PSI 2018* *NME 2021*

R Tatali NF 2021



✓ 3D turbulence in **realistic X-point geometry** exhaustively studied with TOKAM3X
[Galassi NF 2017, Fluids 2019 ; Gallo PPCF 2017 ; Nespoli NF 2019, NF 2020]

❑ **TSVV1 2021-25**

- explore impact of :
  - neoclassical friction
  - favorable versus unfavorable magnetic drift configuration (WEST case)

➔ more recent code **SOLEDGE3X**

D2: GBS extensions for global fluid sims

EPFL

Investigation of turbulent transport in the plasma boundary and formation of a transport barrier by using GBS simulations

M. Giacomin

Description	Status	Date
Improve the GBS fluid turbulence code to avoid the Boussinesq approximation and to include electromagnetic effects	The GBS code has been extended to include the electromagnetic effects and avoid the Boussinesq approximation	12/2021
Improve the GBS fluid turbulence code to include the interaction with neutrals	Work in progress. No major issue so far	12/2022
Using the GBS code, two-fluid simulations that include electromagnetic fluctuations, neutral physics and avoid the Boussinesq approximation	To be addressed	06/2023

Simulations that avoid the Boussinesq approximation and include electromagnetic effects are currently running

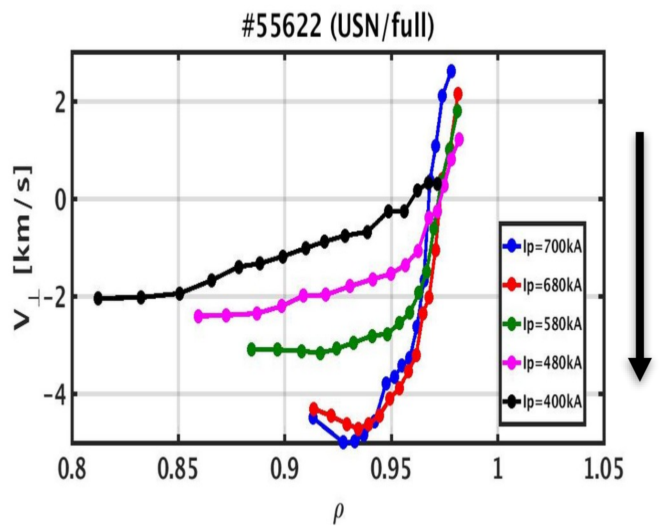
Swiss Plasma Center

D2: Full-f GK radial electric field studies

M2.9	Study the development of a radial electric field in response to key parameters such as injected power, collisionality and safety factor, using the GYSELA and ORB5 codes including simplified limiter/SOL - comparison with fluid code results	L. Vermare, X. Garbet, R. Varennes, P. Donnel	06/2022

- Evolution with the safety factor (through the plasma current)
- Experimental measurements on WEST plasmas
- Gyrokinetic simulations in progress …

<u>Experimental evidence of the influence of Ip in the Er profile</u>



Increase of Ip

D2: Full-f GK radial electric field studies II

D2.5	Report including statements on the relative impact of some separate ingredients playing a role in the radial electric field formation (orbit losses, ripple, turbulence, neutrals, limiter…)	report or paper submitted, conference contribution	X. Garbet, R. Varennes, L. Vermare, G. Falchetto, P. Donnel	12/2022

Impact of ripple on turbulence

Neoclassical predictions on toroidal velocity :

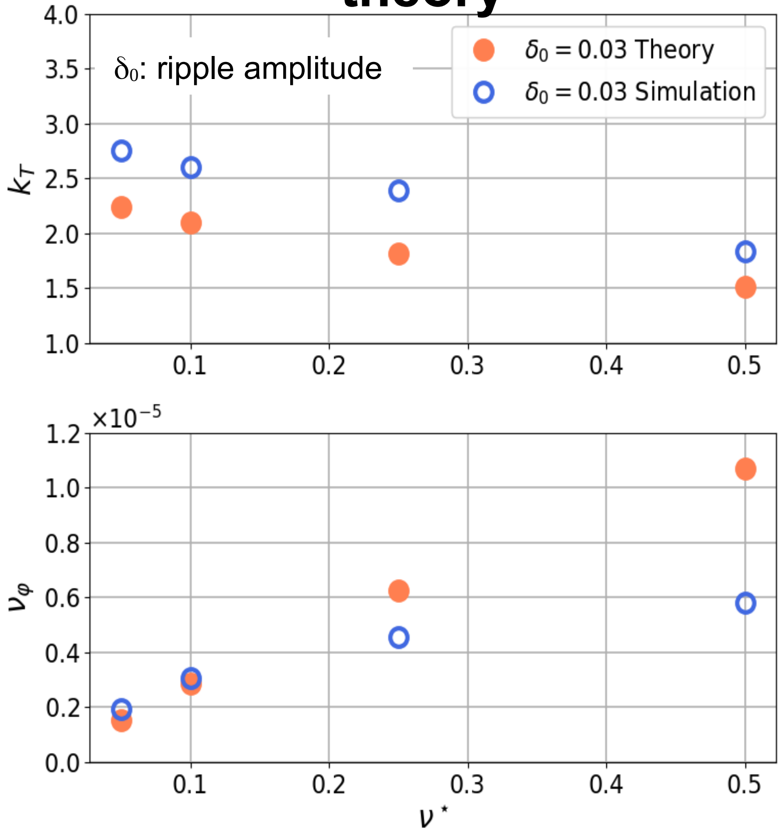
$$\frac{\partial V_T}{\partial t} = -\nu_\varphi \left(V_T - k_T \frac{\nabla T}{e B_P} \right)$$

Neoclassical friction (ν_φ)

Thermal drive (k_T)

Gyrokinetic code GYSELA compared successfully with neoclassical predictions

Comparison simulations / theory

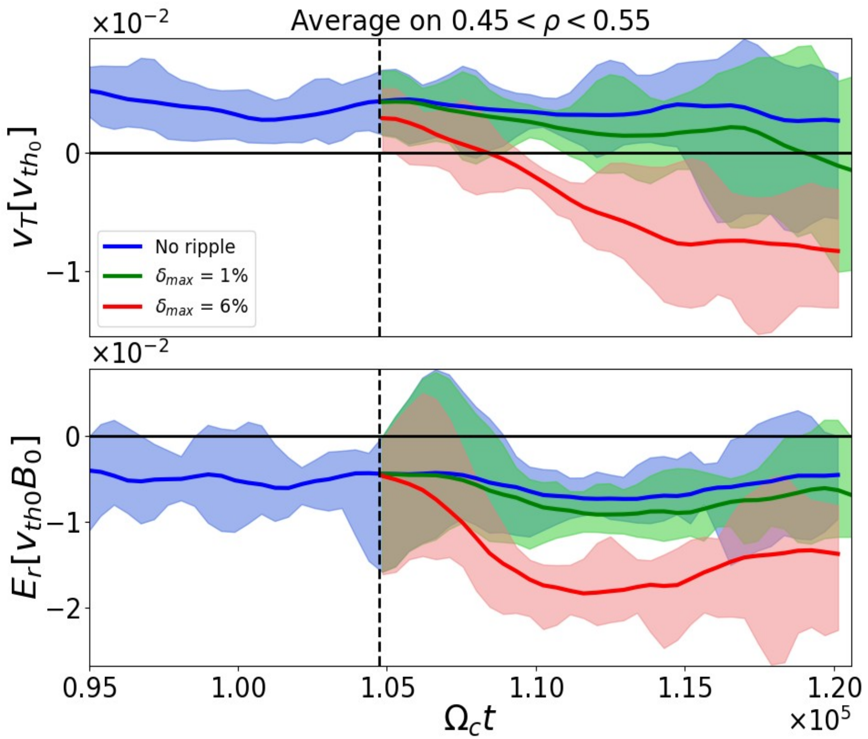


D2: Full-f GK radial electric field studies III

D2.5	Report including statements on the relative impact of some separate ingredients playing a role in the radial electric field formation (orbit losses, ripple, turbulence, neutrals, limiter…)	report or paper submitted, conference contribution	X. Garbet, R. Varennes, L. Vermare, G. Falchetto, P. Donnel	12/2022

Gyrokinetic simulations : ripple activated on top of a turbulent statistical equilibrium

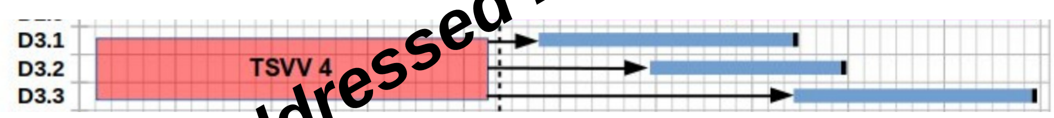
Gaussian ripple perturbation (maximum at mid-radius) to avoid mix-up with boundary conditions



D3: consistent TSVV4 code application

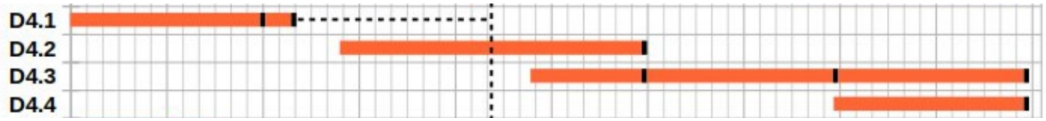
- **Comparative study between previous fluid / GK results and first TSVV Task 4 code results (2024)**
- **Report including statements regarding the level of realism of the edge conditions and the effect of the direction of the magnetic drift with respect to experimental measurements (2024)**
- **Comparative study with updated version of TSVV Task 4 code (assuming some evolution) (2025)**

to be addressed in the future



D4: interpretative & predictive capability of L-H transitions: from fluid codes to TSVV4 code

- **Quantification of ITB momentum drive from rational vs. irrational surfaces and comparisons to plasma edge (2022)**
- **Report on the SOLEDGE3X study of the effect of the direction of the magnetic drift and the level of realism of the edge conditions, with respect to experimental measurements (2023) → preparations, see D2**
- **Predictive capabilities of the edge turbulence regime transitions based on a large scan of GBS simulations, and validation with experimental results (2025) → preparations, see D2**
- **Assessment of comparison of fluid results with TSVV4 code (2025)**

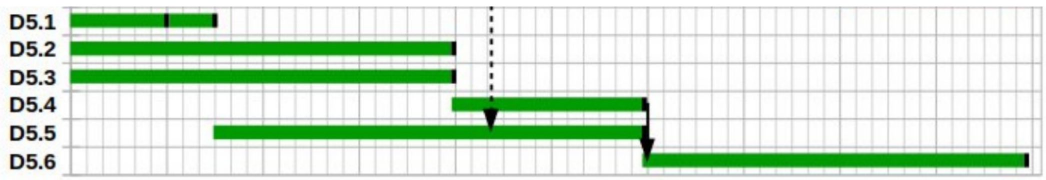


D5: Goals for red. transport model development for the pedestal on the basis of GK simulations

- Refined heuristic transport model ready for interfacing (2021) and updated versions based on TSVV1 findings (2023, 2025)

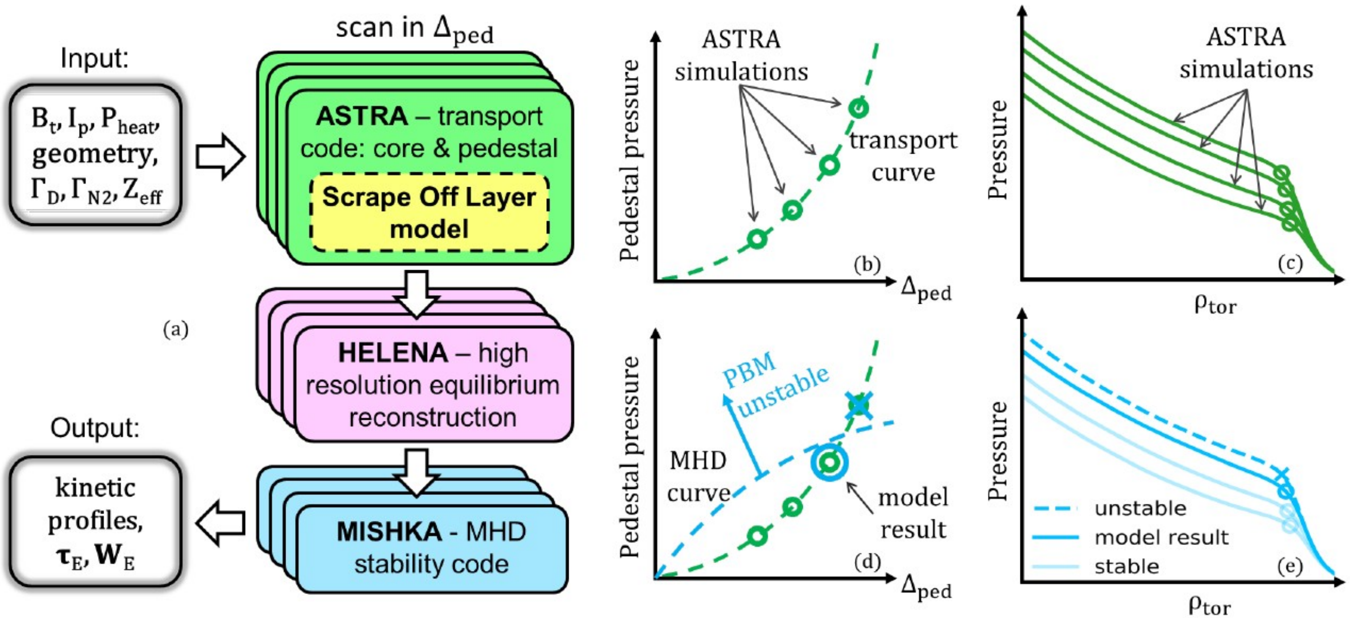
- Core-edge coupled flux-driven integrated modelling (QuaLiKiz-based) for L-H transition studies implemented with available reduced physics models (2022+updates)

- Reduced models for selected edge/pedestal modes (e.g., micro-tearing modes) developed (2022) and validated (2023)



D5: Heuristic pedestal transport model

Integrated Model based on Engineering Parameters (IMEP)



[T. Luda *et al* 2020 *NF*]
[T. Luda *et al* 2021 *NF* (to be submitted)]

- **Model:** $\chi_{e,ped}$ adjusted to $\frac{<\nabla T_e>}{T_{e,top}} = -0.5$ [1/cm]
- **Optimized to 50 AUG H-modes**
- **Currently extended to JET, C-MOD**

The model:
- ✓ is **more accurate** with respect to the IPB98(y,2) scaling law
- ✓ can accurately **capture the effect** of the different operational parameters

D5: QuaLiKiz-based modelling / reduced MTM model

- **Core-edge coupled flux-driven integrated modelling (QuaLiKiz-based) for L-H transition studies implemented with available reduced physics models:**
  - Work-in-progress:
    currently, high-dimensional micro-instability scan with GENE for QuaLiKiz tuning/assessment repeated to take into account revised profiles

- **Reduced models for selected edge/pedestal modes**
  - Work-in-progress:
    Focus is on Micro-tearing Modes – currently refinement of simulation data base and tuning of reduced model

Project members

Family name	First name	Beneficiary	2021 ppy	2022 ppy	2023+ ppy
Bergmann	Andreas	MPG	**0.36**	0.5	0.5
Brzozowski	Robert	MPG	**0.36**	**0.5**	**0.5**
Chowdhury	Jugal	CCFE	**0.36**	**0.5**	**0.5**
Donnel	Peter	EPFL-SPC	**0.0 (*)**	**0.3 (*)**	**0.5**
Falchetto	Gloria	CEA	**0.36**	0.5	0.5 (2023)
Garbet	Xavier	CEA	**0.18**	0.25	0.25
Giacomin	Maurizio	EPFL-SPC	**0.36**	**0.5**	**0.5**
Görler	Tobias	MPG	**0.36**	0.5	0.5
Hamed	Myriam	DIFFER	**0.36**	0.5	0.5
Leppin	Leonhard	MPG	**0.36**	0.5	0.5
Luda di Cortemiglia	Teobaldo	MPG	**0.36**	0.5	0.5
Snoep	Garud	DIFFER	**0.36**	0.5	0.5
Stimmel	Karl	MPG	**0.0 (*)**	**0.0 (*)**	**0.0**
Varennes	Robin	CEA	**0.0 (*)**	0.0 (*)	0.5
Vermare	Laure	CEA	**0.36**	0.5	0.5
Volcokas	Arnas	EPFL-SPC	**0.54**	0.75	0.75

linear reduction in 2021 following postponed project start

project members to be substituted

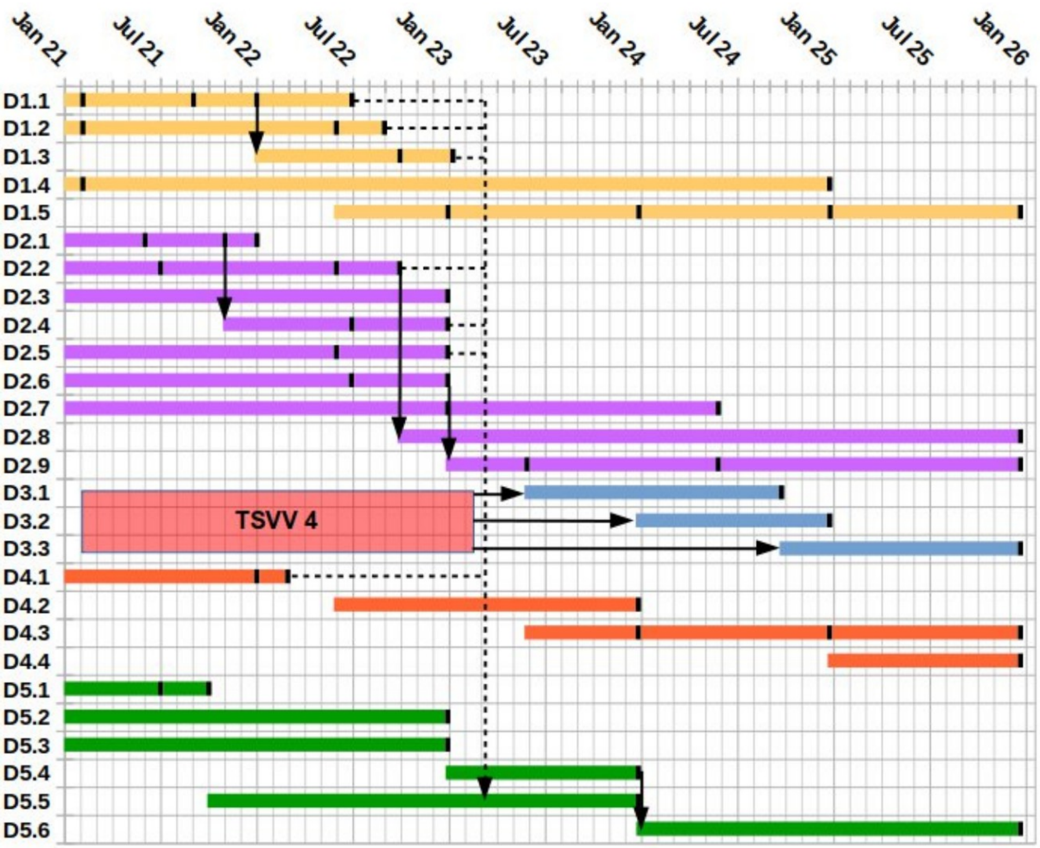
Infrastructure & organizational aspects

- **Official wiki:** https://wiki.euro-fusion.org/wiki/TSVV-01
- **Official INDICO:** https://indico.euro-fusion.org/category/274/
- **Mailing list:** tsvv1@lists.euro-fusion.org

- **Kick-Off-Meeting held: Apr 20, 2021**
- **Monthly team meetings implemented for exchanges, organizational aspects and progress monitoring**
- **2-3 day workshop anticipated for Oct/Nov this year**

- **Joint Marconi-Fusion compute time proposal accepted & active**
- **ACH-requests largely granted**

Summary



- **All tasks relevant to this year launched successfully**
- **Delay compared to original work plan according to late project start**
- **Some staff chances anticipated (~usual fluctuations)**
- **Regular meetings implemented + workshop planned**