



TSVV11: Validated Frameworks for the Reliable Prediction of Plasma Performance and Operational Limits in Tokamaks
Update, Thrust 5

C. Bourdelle

07/06/2023

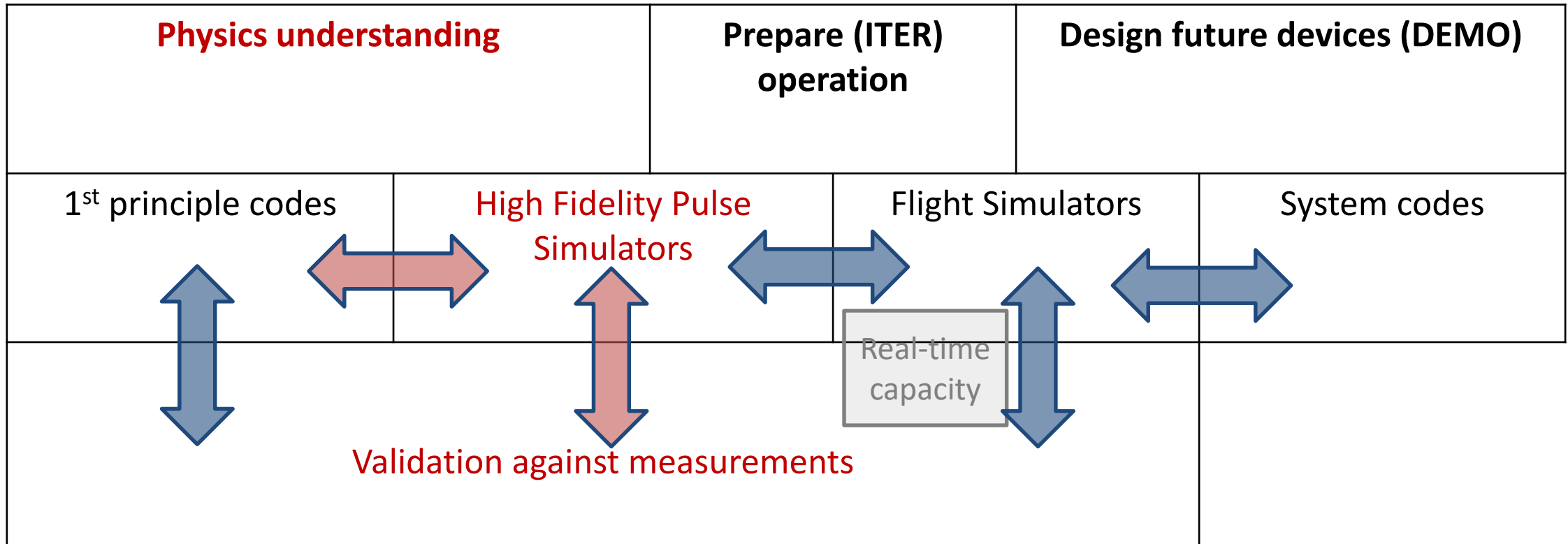


This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European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

Integrated modelling landscape, preparing tokamak operation



Model integration, longer plasma time frames
Requires faster yes accurate physics models

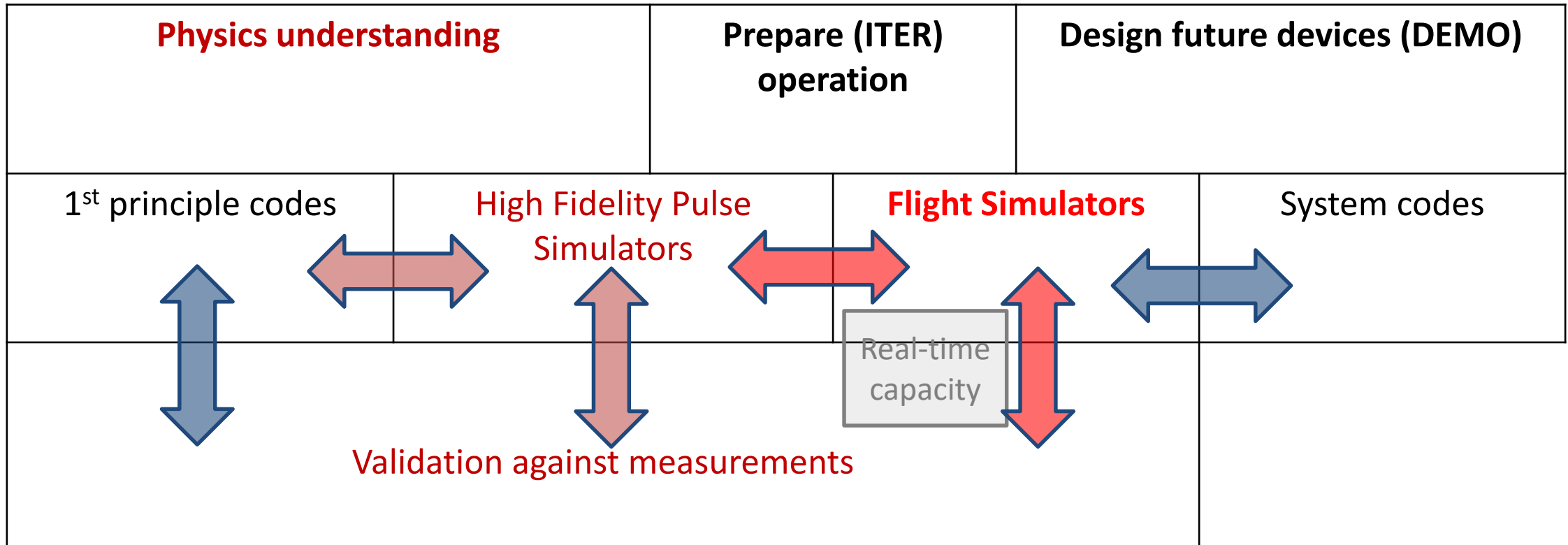


The focus of the TSVV11 activity is on the physics understanding side of the coin.
7 ppy + 3 ppy in ACH

Integrated modelling landscape, preparing tokamak operation



Model integration, longer plasma time frames
Requires faster yes accurate physics models



The focus of the TSVV11 activity is on the physics understanding side of the coin.
7+2 ppy 3 ppy ACH

TSVV11 extended to *Pulse Design Tool*



19/04/2023 and 03/05/2023: overview of Pulse Design Simulators, Flight Simulators activities and plans

Back to: [Meetings with the Fusion Science Division \(PSD-FSD\)](#)

Goal: In view of developing activities on “Pulse Design Simulators / Flight simulators” with EUROfusion, at first:

- obtain a broad (undetailed at this stage) picture of the existing rich landscape across EU and ITER
- collect suggestions/needs/wishes from today’s actors towards EUROfusion FSD & FTD management

https://wiki.euro-fusion.org/wiki/19/04/2023_and_03/05/2023:_overview_of_Pulse_Design_Simulators,_Flight_Simulators_activities_and_plans

April 19 2023:

- Intro including definitions ;) [C. Bourdelle](#)
- CREATE breakdown modelling and more [M Mattei](#)
- METIS based JT60-SA flight simulator [JF Artaud](#)
- FENIX for AUG/DEMO/TCV [E. Fable](#)
- UKAEA / HPFS flight simulator [F. Casson](#)
- Compass Upgrade flight simulator [L. Kripner](#)

May 3rd 2023:

- RAPTOR+MEQ on TCV, AUG, ITER, DEMO [F. Felici](#)
- JINTRAC-RAPDENS [M. van Berkel](#)
- WEST flight simulator [R. Nouailletas](#)
- PDS ITER call in 2020 coordinated EU reply [F. Imbeaux](#)
- ITER plans towards a fast integrated modelling code (PDS/FS) [R. Pitts](#)

May 17th 2023:

- Internal EUROfusion debrief
- 1st version of 'Strategy on development of the Pulse Design Tool' [V. Naulin](#), [D. Kalupin](#)

- General EF Assembly, April 6-7: 2ppy per year (starting 2023) on « Pulse Design Simulator & control developments for ITER & DEMO »
- Strategy on development of the Pulse Design Tool (PDT) by [V Naulin](#), [D Kalupin](#) to be discussed within ETASC SB. 2ppy in 2023

New lead for the IO PDS development. Mireille Schneider, previously within the Plasma Modelling and Analysis Section in the IO Science Division, will move to Experiments and Plasma Operations Section from June 1 2023 as **Coordinating Scientist for Pulse Design**.



All the physics that we master now has to be available from ITER control room

Guiding principles:

- **Align with ITER technical choices** in terms of integrated modelling workflow and database management
- **Improve and validate advanced physics modules** focusing on high priority modelling extensions that will be needed for multi-physics full predictive modelling, with the help of other TSVV activities and in coherence with WPTE priorities
- Demonstrate validation of full pulse predictive modelling **from breakdown to termination**, including a realistic assessment of operational limits *extension to Flight Simulators*
- **Support extended validation against EU operating tokamaks** by providing to users outside this TSVV **yearly training** on the integrated modelling workflow, a detailed and clear **documentation** on the workflow and the embedded physics modules, **a user friendly interface** and **automated validation tools**

TSVV11 7 ppy 2023, update



name	2023 pm	2023 changes
Yann Camenen (01-CNRS)	64.8	
Clarisse Bourdelle (CEA)	6	
Jean Francois Artaud (CEA)	4,8	
Patrick Maget (CEA)	4,8 6	
Pierre Manas (CEA)	6	
Jorge Morales (CEA)	6	
Francis Casson (UKAEA)	6	
Žiga Štancar (UKAEA)		6
Emmi Thorus (UKAEA)		6
Florian Köchl Nathan Cummings (UKAEA)	6	
Jonathan Citrin (DIFFER)	6	2.8
PhD (Alex Pañera from 11/23) (DIFFER)	10.8	2
Aaron Ho (DIFFER)	6	
Michele Marin (SPC)	6	
Clemente Angioni (MPG)	4,8	
Emiliano Fable (MPG)	4,8	
Giovanni Tardini (MPG)	6	
Karel van de Plassche (DIFFER)	4,8	
Pulse Design Tool		+2 ppy
total	7ppy	9 ppy

2024 and 2025 will continue with 7 ppy TSVV11 + 2ppy "Pulse Design Tool"

TSVV11 team building!



Regular meetings open to TSVV11 members and “friends”

<https://wiki.euro-fusion.org/wiki/TSVV-11>

TSVV-11-general-meetings

- 26th general meeting, June 2nd, 2023: TSVV11 updates on deliverables for 2023, and ITER integrated modelling
- 25th general meeting, May 12, 2023: Validation of D-T fusion power prediction capability against 2021 JET D-T experiments [↗](#)
- 24th general meeting, April 14, 2023: summary of Eindhoven and general TSVV11 goals revision
- 2nd in person meeting March 20-24 2023, Eindhoven
- Training took place Jan 25-26 and a TSVV11 meeting was dedicated to a follow up support to new users March 8
- 23rd general meeting, January 20th 2023: preparing ref cases for the HFPS training Jan25-26
- 22nd general meeting, January 13th 2023: improving reduced turbulent transport models
- 21st general meeting, November 18th 2022: L mode full radius predictive modelling
- 20th general meeting, November 4th 2022: demonstration of simDB on the Gateway + the fusion-duqtools
- 19th general meeting, September 30th 2022, L to H mode modeling
- 18th general meeting, September 19th 2022, energetic particle transport IMAS workflow + general update on 2022 milestones and 2023 perspectives
- 17th general meeting, June 24th 2022, equipartition and turbulence in electron heated plasmas
- 16th general meeting, June 17th 2022, open and fair data, automated validation poster rehearsal
- 15th general meeting, June 10th 2022, HFPS users feedback on numerical issues (JET DT, WEST Boron dopper)

1st in person meeting April 2022 Poznan



Rechercher dans TSVV11

TSVV11 

Passer à un forfait supérieur

Fils de discussion

Plus tard

annonces

+ Ajouter un marque-page

annonces

2nd in person meeting March 20-24, Eindhoven, DIFFER

Joined with NL eScience center synergistic project on tools for large scale validation



This flexible format allowed having **37 persons meeting on-site** from

- TSVV11 (EUROfusion financed)

And more participants financed thanks to the NL eScience center grant from:

- new HFPS users
- NL eScience center
- Ignition Computing company
- Advanced Computing Hub of Poland
- Advanced Computing Hub of Finland
- ITER Organization

This 2 year project with the NL eScience center is managed by J. Citrin, A. Ho at DIFFER and S. Smeets, V. Aziz at the NL eScience center.

Within Feb 2024, another meeting taking advantage of this synergy will be organized, maybe hosted at ITER (tbc).



Thanks to Jonathan Citrin!





- **WP1: HFPS Workflow orchestration and module coupling framework** (coordinator: F.J. Casson, 2.5 ppy incl. 1.5 ACH)
- **WP2: HFPS key physics modules validation** (3.5 ppy incl. 1 from ACH)
- **WP3-HFPS full pulse modelling capability demonstration** (coordinator: E. Fable, 2 ppy)
- **WP4-HFPS systematic validation** (coordinator: A. Ho, 1ppy incl. 0.5 from ACH)
- **WP5- HFPS initial ITER phase modelling** (coordinator: J. Citrin, total effort 0.5 ppy)

WP1: HFPS Workflow orchestration and module coupling framework, F. Casson

Persistent Actor Framework

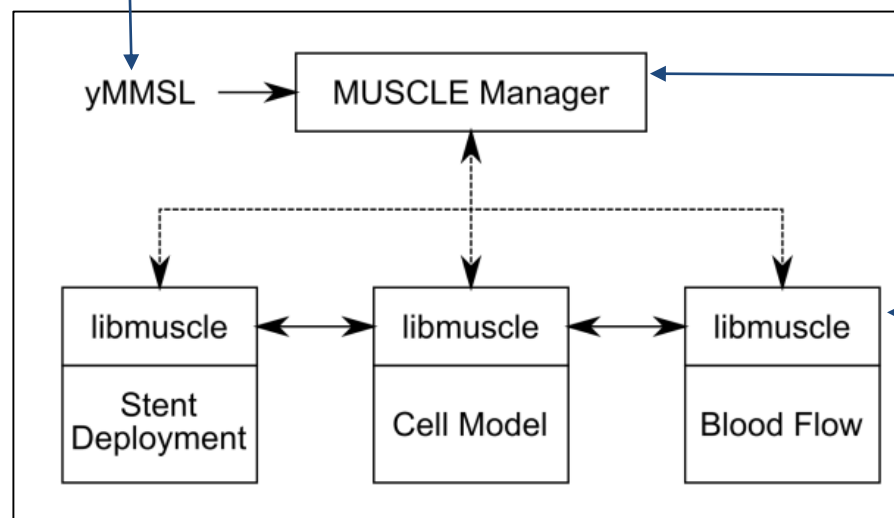


- Context: Persistent Actor Framework contract (1.5 year started ~Feb 2022- end in August 2023) between ITER and DIFFER, NL eScience center, Ignition Computing, PSNC (coord. J. Citrin, Daan Van Vugt).
- MUSCLE3: a Multiscale Modelling and Simulation Framework dealing with separate persistent processes. It has a long devt history, not fusion specific. IMAS updated for sending IDss with MUSCLE3

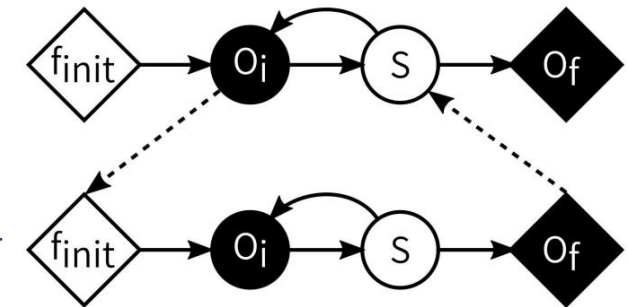
- University of Amsterdam, University of Geneva (~2007, Alfons Hoekstra and Bastien Chopard)
 - COAST EU project
 - Coupling Cellular Automata
 - MUSCLE
- MAPPER project (~2013, Joris Borgdorff, Hoekstra, Chopard)
 - MMSF
 - MUSCLE2
 - MPI-PP tokamak simulations
- e-MUSC, with NLeSC (2016-2022, Lourens Veen, Alfons Hoekstra)
 - Uncertainty Quantification
 - MUSCLE3
- ComPat, VECMA, SEAVEA
- ITER Persistent Actors Framework

Lourens Veen (NL eScience center)

Simple config file



Example:



Library (not a framework)
Compatible with: Fortran,
Python, Matlab/Simulink,
C++

WP1: HFPS Workflow orchestration and module coupling framework, F. Casson

status of the HFPS and synergies with ETS/ASTRA and ITER



HFPS: F. Casson

The HFPS is a collection of IMAS actors used together in a python workflow

- Already combines ETS components (HCD) and all JINTRAC components
- Planned: DINA coupling, reduced SOL models, reduced pedestal models, surrogate transport models, new TSVV models, FBE
- Coupling *framework* prototypical but functional: we hope it will grow further

Status

- All actors take physics input / output from IDS via argument
- Actors wrapped via FC2K -> **Plan to migrate to MUSCLE3** (Skip IWrap for JINTRAC actors)
- Each actor handles code specific params in it's own way
- JAMS GUI collects *all* input files in one folder, launches workflow.
- Non JINTRAC actors provide their own GUI (JAMS can launch) to configure parameters
- MDS+ and HDF5 backends supported, but trouble with HDF5 inputs (getslice interp?)
- Some performance (AL) and memory (FC2K) issues compared to non-IMAS JINTRAC usage
- Most JINTRAC components containerized, deployed to cloud resources

How it could evolve

- Agree standards for IMAS python workflows, converge on common methodology / tools
- Evolve the generic python driver loop to match these standards and to be truly generic
- Add new actors as they are adapted to python
- A common GUI
- Couple to a control framework

ITER: M. Schneider

Muscle3 for flexibility with Iwrap for modularity

Tested on IDA, tested IMAS-PCSSP proto (fueling, DINA), in HCD

ETS: D. Coster

Strategy:

- build only on established and tested approaches....
- move Kepler actors to iWrap python actors...Evaluate WORKFLOW IDS as transfer me
- Start with rebuilding subworkflows as straight python WFs maintain granularity
- Define the convergence loop driver in a suitable frame(work).
 - Parallelism
 - Consider moving to MUSCLE3 when understanding impact - discussions/testing with NLeSC??? Still "extensions needed" for comfort...
 - Consider other toolsets?? No idea what though....DASK....
- Restrict external dependencies to a minimum
- Reusability and Maintainability - a real challenge with the current ETS implmentation

ASTRA:

G. Tardini



ASTRA ↔ IMAS: workflows



As for py-wroflows:

- ASTRA build needs linking to many scattered libs and modules. Does MUSCLE3 facilitate this? With fc2k it was very difficult
- ASTRA main strength: fast calculation with theory-based (TGLF, QLK), via IPC parallelisation and Pereverzev-Corrihan stiffness algorithm. That will probably be lost, or requires some thoughts to be preserved

This seems to rule out an actor-ification of ASTRA as a whole. What

Starting now, great opportunity to share strategies

IMAS input/output : all on the same page

Code modularity level : Iwrap or not Iwrap

Persistent actor workflow choice: Muscle3 or not

GUI: autoGUI based workflow or not

Proposing: 2 meetings/year HFPS/ASTRA/ETS (and ITER)

WP1 deliverables for 2023

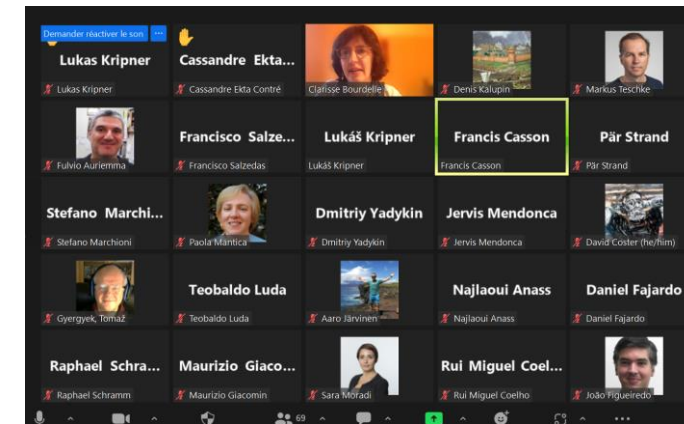


WP1 Planned milestones for 2023	status
Milestone 1.2 M3 Adapted existing HFPS components (for SOL, MHD, pedestal and breakdown/burn-through) to follow new Python workflow specifications - Dec 2023	Planned for 2023 HFPS workflow to Muscle3 with support of PAF contract and ACH in Poznan.
Milestone 1.3.M1 Adapted existing HFPS components to workflow settings management specifications Dec 2023	Need to interact with ITER on flexibility vs modularity and make sure HFPS muscle3 EF/ITER is aligned.
Milestone 1.4.M4 All existing HFPS components configurable from common GUI and integrated with common simulation cataloging system Dec 2023	Cataloguing OK, post-pone to Dec 2024
	Demonstrate JINTRAC with IMAS input in HDF5 format from at least two EF tokamaks Demonstrate containerised JINTRAC-IMAS running in the cloud Demonstrate multi-container workflow with JINTRAC + HCD
With WP2	MISHKA and CASTOR: output in IDS (Florian, test: Patrick) Δ' calculation (Florian, test on Ip ramp Patrick) Er boundary condition free to be user chosen (Florian, test: Clarisse) FACIT coupling and test (Francis, tests Patrick, Pierre) QLKNN-edge in TCI/HFPS (Jonathan, tests: Clarisse, Pierre) HFPS-HCD with LHCD/ICRH demonstration (Nathan, tests: Théo, Patrick) HPI2 in HFPS on GW (Florian, test: Clarisse) Verify TGLF impurity transport decomposition in SANCO against ASTRA and fix if needed.

1st HFPS training open to all EUROfusion



Wed. Jan. 25th 10.30-12.30 CET	General introduction and overview (open to all, no registration needed): <ul style="list-style-type: none">Recent achievements of integrated modellingWhat is the High Fidelity Pulse Simulator?
Wed. Jan. 25th 14.30-17.30 CET	2.30 CET: all, Intro/demo interpretative case: F. Casson Breakout rooms as needed (ref. supervisor see table below) 5 pm CET: all, update on progresses/issues
Thur. Jan. 26th 9.30-12.30 CET	9.30 CET: all, intro/demo predictive case with QLKNN Breakout rooms as needed (ref. supervisor see table below) 12.00 CET: all, update on progresses/issues



Registered participants
13 persons

JET, AUG and TCV

Using zoom and breakout rooms.

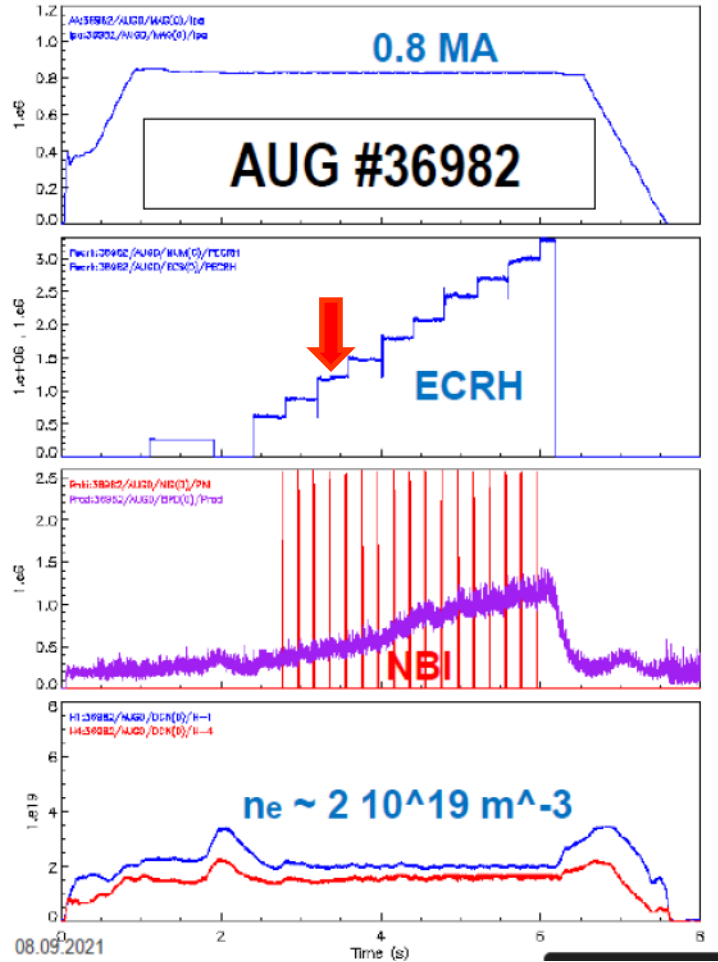
In the mean time every 3 months we will have TSVV11 meetings dedicated to debugging/analysis support to older and newer HFPS users.

Will be repeated yearly

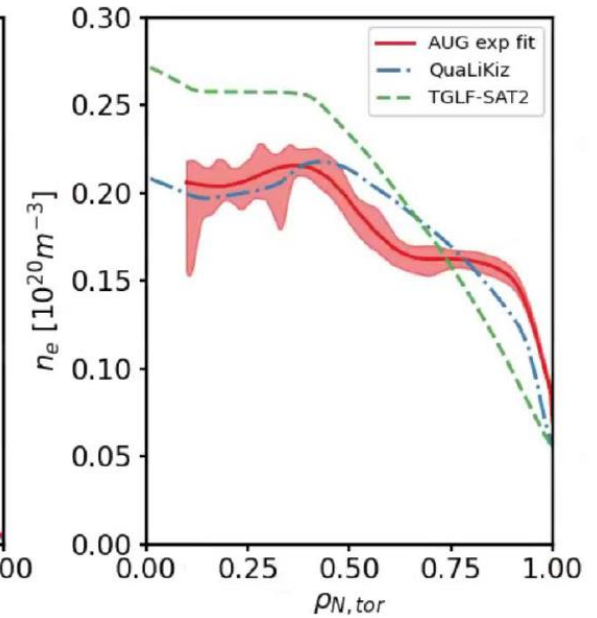
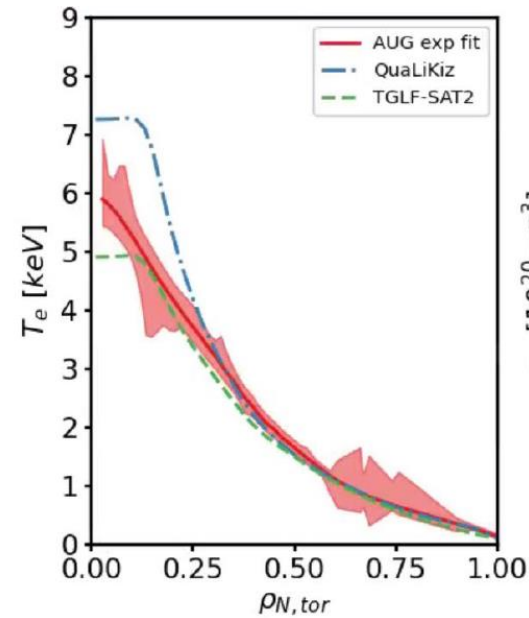
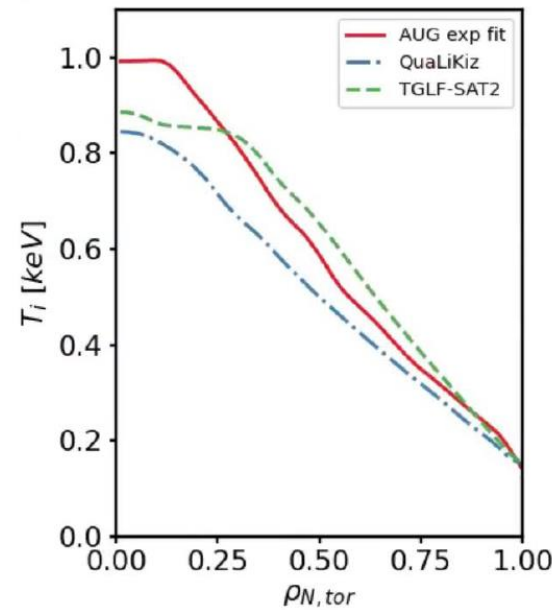
IMAS AUG data modelled by the HFPSL mode up to the LCFS



L mode on AUG, 1.2 MW of ECRH



HFPS-QuaLiKiz or TGLFsat2-FRANTIC (neutrals at 5eV)
 Predictive modeling up to separatrix, heat and particle



IMAS WEST data modelled by the HFPS Boron dropper enhancing L mode confinement



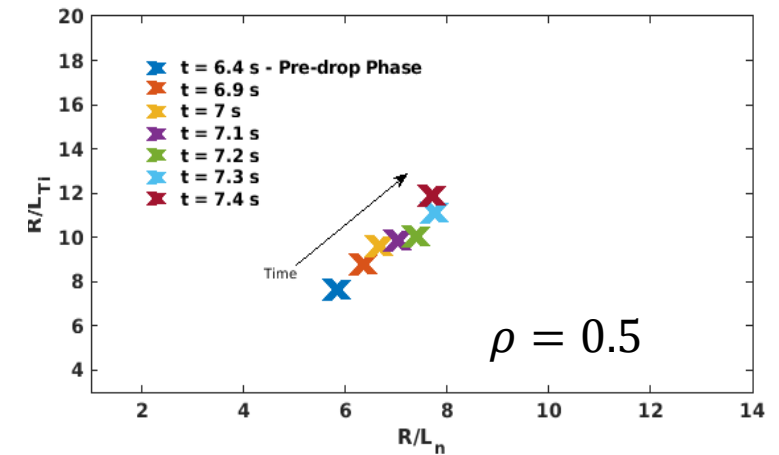
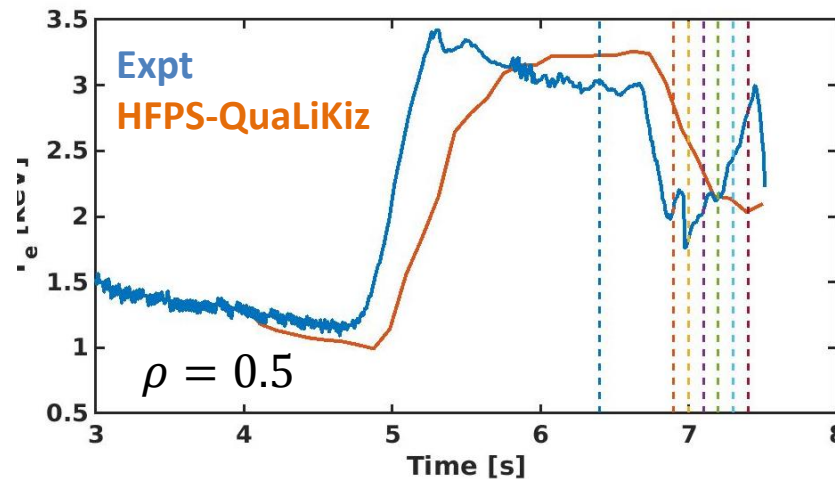
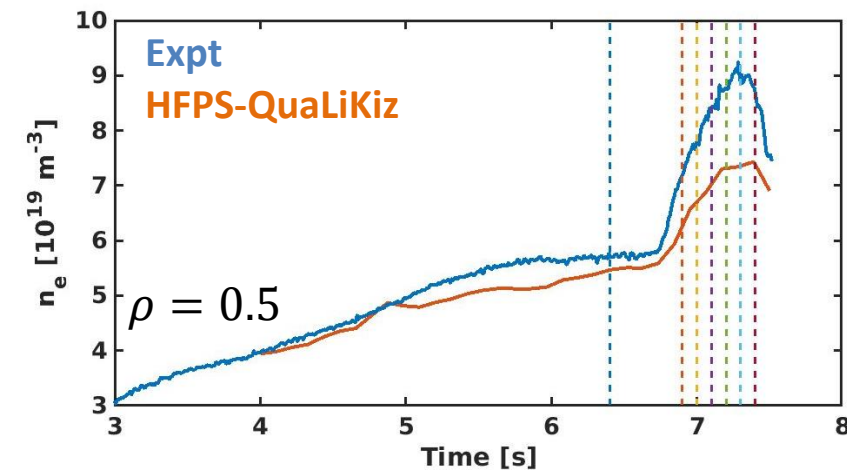
HFPS-QuaLiKiz

Predictive modeling up to $\rho=0.9$, heat and particle over 3.5 s of plasma evolution

Largest Boron powder injection in WEST LHCD heated L mode, leads to increased energy content [[Bodner NF2022](#)]

Key role of enhanced Z_{eff} and collisionality on turbulence stabilization

#56920



[G. Bodner, P. Manas et al]

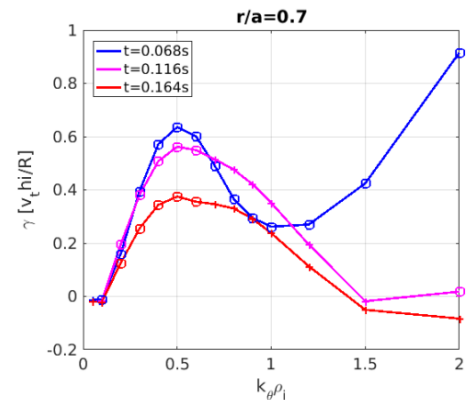


- **WP1: HFPS Workflow orchestration and module coupling framework** (coordinator: F.J. Casson, 2.5 ppy incl. 1.5 ACH)
- **WP2: HFPS key physics modules validation** (3.5 ppy incl. 1 from ACH)
- WP3-HFPS full pulse modelling capability demonstration (coordinator: E. Fable, 2 ppy)
- **WP4-HFPS systematic validation** (coordinator: A. Ho, 1ppy incl. 0.5 from ACH)
- WP5- HFPS initial ITER phase modelling (coordinator: J. Citrin, total effort 0.5 ppy)



Ip ramp up

Ramp up, TCV, GKW modelling Y. Camenen
 TEM stabilized as rIp ramps up confirming previous E. Fable's work



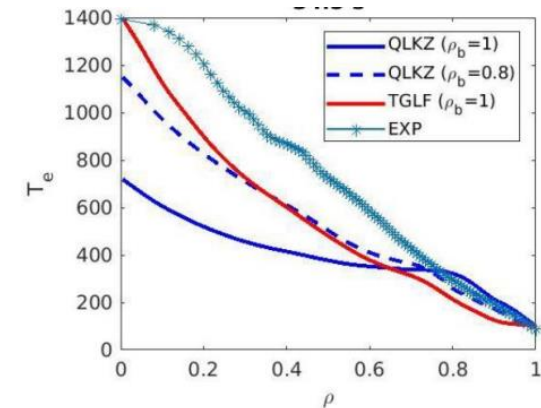
► Validate QL models vs NL simulations in early ramp-up phase

- Channels: heat, particles, impurities
- Models: GKW-QL (for particles and impurities), QLK, TGLF

M. Marin's HFPS on TCV, using QuaLiKiz, good agreement
 But still some tests (energy of neutrals, etc) before using dUQtools

- Fully predictive: j, n_e, n_C, T_e, T_i
- Feedback control for the density is needed
- Boundaries at $\rho = 0.99$. Impurities are predicted till $\rho = 1$ to avoid very large unphysical fluxes. Can create numerical problems (I have not found a very robust recipe yet)

P. Manas,
 HFPS on WEST
 Not as good, need to understand why



Milestones planned 2023	status
Milestone 2.1.M1: Validated L mode edge capability for TGLF and QLKNN in Ip ramp up extended QLKNN for edge. T1 2023	OK for ramp up : EPS, TTF and M. Marin publication QLKNN edge (L. Chôné, J. Citrin et al) now available for testing in HFPS Ramp down postponed to 2024
Milestone 2.1.M2 in Ip ramp down Dec 2023	

WP2-D1: Turbulent transport reduced models targeted validation, Y. Camenen

QuaLiKiz, QLKNN for edge etc



- Status of NN turbulent transport models available in HFPS
 - QuaLiKiz with collisionality operator improved [Stephens PhD and paper to be sub. soon]
 - QLKNN-10D 300 millions datapoints hypercube trained on previous collisionality operator [VandePlassche PoP2020]. Recommendation is to apply 0.25 to collisionality when using it... [Ho NF2022 Ip ramp in JET as ref].
 - **Database 11D 2.8 billion QuaLiKiz new collisionality operator points exists, but no NN training... open source it to zenodo, find someone to do NN (on-going)**
 - QLKNN-15D 21 million datapoints, JET specific [Ho PoP2021]
 - **QLKNN-edge by L. Chôné soon available in TCI-HFPS**, very valuable for Ip ramps, L mode etc. (TSVV11 meeting Jan 13, 23) last checks + strategy QLK-QLKNN-edge switches J. Citrin
 - Plans: project FASTER to train NN on higher fidelity GK codes . (see TSVV11 meeting Jan 13, 2023)
- **QuaLiKiz itself in L mode does not capture the Ip scaling unlike TGLF** [C. Angioni], issue in the q scaling of the TEM mode width identified [C. Stephens]. Work discussion May 4th. To impact strategy for NN regression. **Hypercubes are heavy to make, unsmart, but great production tools... cf QLKNN-10D.**

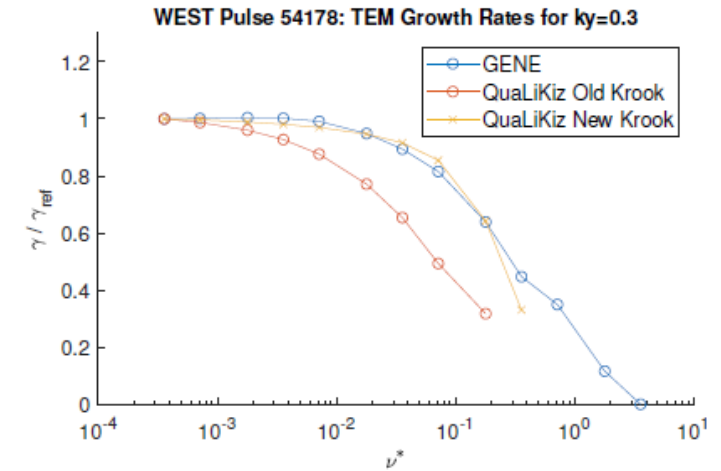
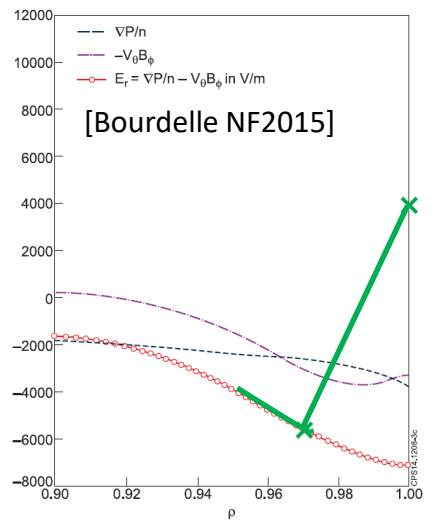


Figure 10. Collisional TEM growth rates calculated by GENE and QuaLiKiz (relative to their reference growth rates). Here, we use WEST pulse 54178 parameters where $k_{\theta}\rho_s = 0.3$ and plot against ν^* for $\epsilon = 0.10$. Note the significantly improved agreement between GENE and New Krook implemented in QuaLiKiz.

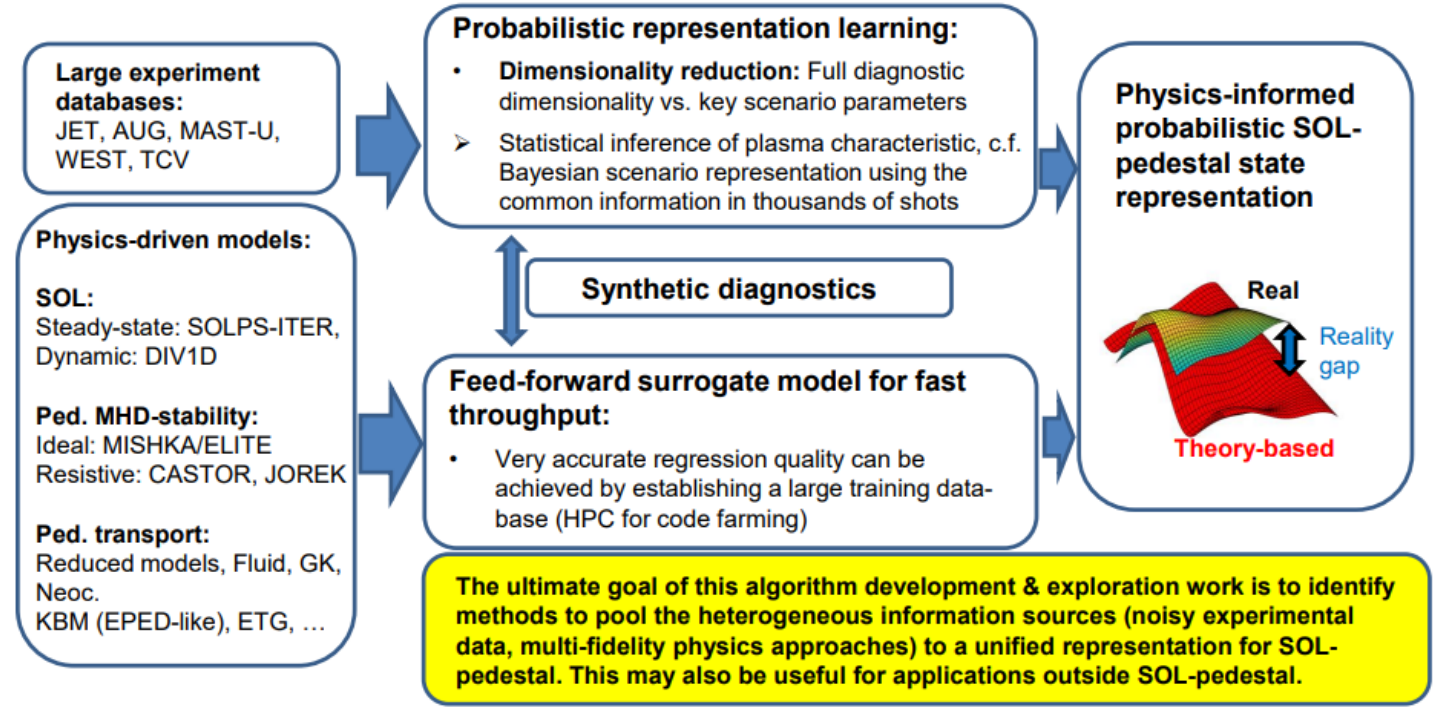
WP2-D2: Core-edge-SOL coupling targeted validation, C. Bourdelle



Er boundary condition to be chosen freely as also the width over which Er from force balance to SOL BC
 See Bonanomi's ASTRA talk TSVV11 meeting Sept 30 2022
 ASTRA routine shared by Clemente to Florian, will be soon available in HFPS



Longer term, synergy with ENR project A. Järvinen, S. Wiesen, A. Kit, et al
Plans for future: Use AI methods to establish a fast, high-fidelity coupled SOL-pedestal module for EUROfusion tokamaks



Milestones planned 2023

Milestone 2.2.M1 validated reduced SOL model in the HFPS.
 Milestone 2.2.M4 validated reduced pedestal models in the HFPS

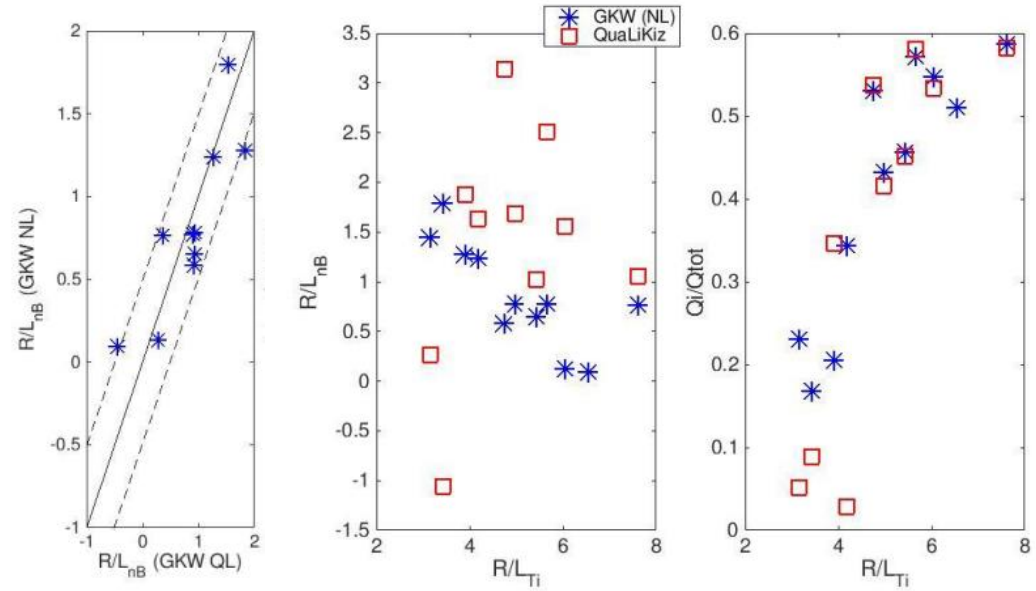
status

ENR synergy so milestones rather for 2024
 IMEP in ASTRA for now not in HFPS, maybe 2024
 EUROPED NN to be implemented? Tested? Need physics driven topic, synergy MHD stab
For 2023: tests of Er separatrix to fixed value on WEST/JET L modes
 ITER-DEMO sep scaling avail. HFPS tests on WEST L mode. Some EDGE2D coupling validation should be done (see ETS warning by D. Coster) but lack of experts in TSVV11

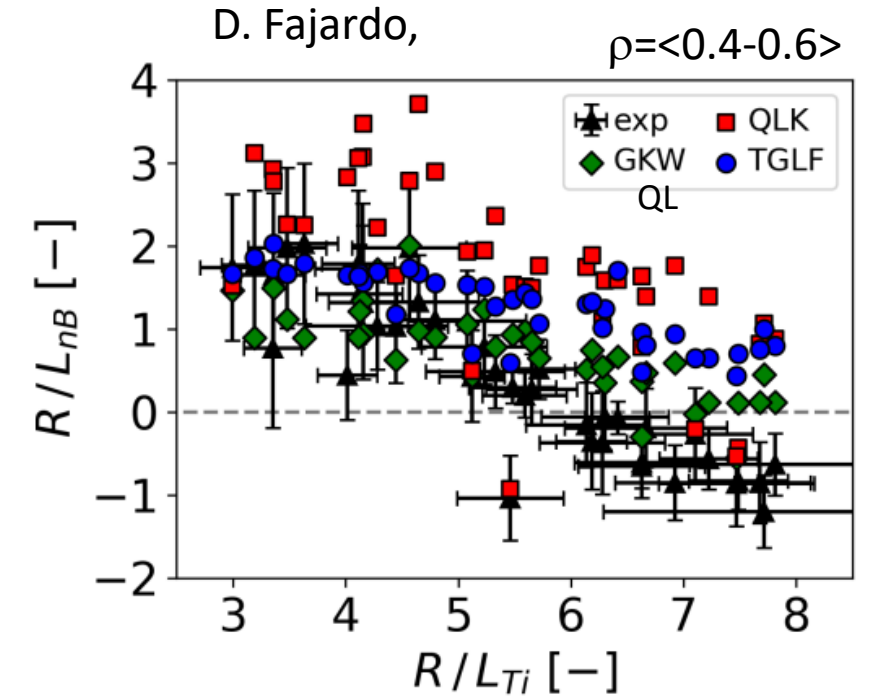
WP2-D3: Impurity transport, development of reduced models, verification and targeted validation. C. Angioni



Reduced model validation for turbulent transport of impurities



Boron, AUG database, QuaLiKiz Boron peaking at $\rho=0.5$ more scattered than GKW-NL, GKW QL~GKW NL
P. Manas
TTF+publi



Impurity transport in ASTRA for AUG [D. Fajardo et al, @TTF] FYI S. Gabriellini JINTRAC Ne seeding JET (Sept21 talk) [sub to NF](#)

Milestones planned (2022) 2024	status
Milestone 2.3.M2: Validated impurity collisional and turbulent transport capability for the new neoclassical code and the QLK-NN incl. impurities in Ip ramp conditions. - Dec 2022	FACIT coupling available soon, for tests in Ip ramp up and other cases, Francis.
Milestone 2.3.M3: Validated impurity collisional and turbulent transport capability for the new neoclassical code and the QLK-NN incl. impurities in presence of poloidal asymmetries. - Dec 2024	On-going verification QuaLiKiz, TGLF vs GKW for impurity turbulent transport. Would need QLKNN-11D to extend to NN. AUG NBI+ECRH cases, WEST ICRH cases, ramp ups...



Linear MHD - ideal & resistive implemented

Targeted simulations

- Plasma current ramp-up : identify Double Tearing Mode configuration
 - WEST -> old example available.
 - JET -> example from Pucella
- Non-inductive plasma discharges / Advanced Tokamak configuration (high-beta, hollow current profile)
 - WEST examples available at beta poloidal ~ 1 / scenario development for future campaigns

Workflow action for Double Tearing Mode

- Trigger full reconnection : consistent with first principle MHD code simulation
 - Above some criteria in linear growth rate (as for pedestal stability)

Work to be done

- Run an experimental case: preferably WEST
- Triggering of full reconnection process : is the model for sawtooth adapted to Double-Tearing Mode ?

Linear MHD outputs to IDS –IMAS work -> Rui's input

1. Stand alone test

Benchmark between MISHKA/CASTOR HFPS & Rui's workflow

Writing IDSs in mhd_linear either post-processing or from Rui's workflow

ILSA version in replacement of MISHKA/CASTOR ?

Milestones planned (2022) 2024

Milestone 2.4.M1: validated ideal MHD limit calculation in the HFPS- Dec 2021

Milestone 2.4.M3: validated Double-Tearing Mode model available in the HFPS- Dec 2023

Milestone 2.4.M4: validated impurity transport model in presence of magnetic island available in the HFPS-Dec 2024

status

Ideal MHD stand alone done

Within TSVV11 not yet MHD limit tests using HFPS

-Planned for Ip ramp up modelling (TCV-WEST), in particular Double tearing modes (Delta prime routine in HFPS, Florian's support)

-computing linear MHD from MISHKA/CASTOR in IDS

WP2-D5: Plasma initiation (Breakdown and burn-through and MHD equilibrium) integration and validation. J-F Artaud



Milestones planned 2022-2023	status
<p>Milestone 2.5.M1: IMAS database of plasma initiation phases having data from more 5 plasma descriptions from at least 2 tokamaks- Dec 2022</p> <p>Milestone 2.5.M2: Validated coupling between the breakdown and burn-through models and the self-consistent equilibrium and plasma evolution - Dec 2023</p>	<p>WEST database OK, adding MAST using DYON IMAS coupling (on-going under WPPriO), soon OK</p> <p>WPPriO meeting May 24. interfaces WPSA, WPTE...</p> <p>Coupling FBE after breakdown, loose coupling might be enough, w/o FBE, will be tried with METIS on WEST, post poned to Dec 2024</p>

WP2 HFPS key physics modules validation 2023 deliverables, additional revisions?



might appear in the Pulse Design part?

Other topics discussed at Eindhoven	Potential changes within TSVVV11 for 2023-2025
Pellets: HPI2 available from HFPS on gateway, on-going a workaround possible with Florian's help for now	V. Konrad at JET, T. Luda at AUG, Alex Panera on WEST/AUG, key for ITER/DEMO incl. for flight simulator, controller training. On-going HPI2 refactoring



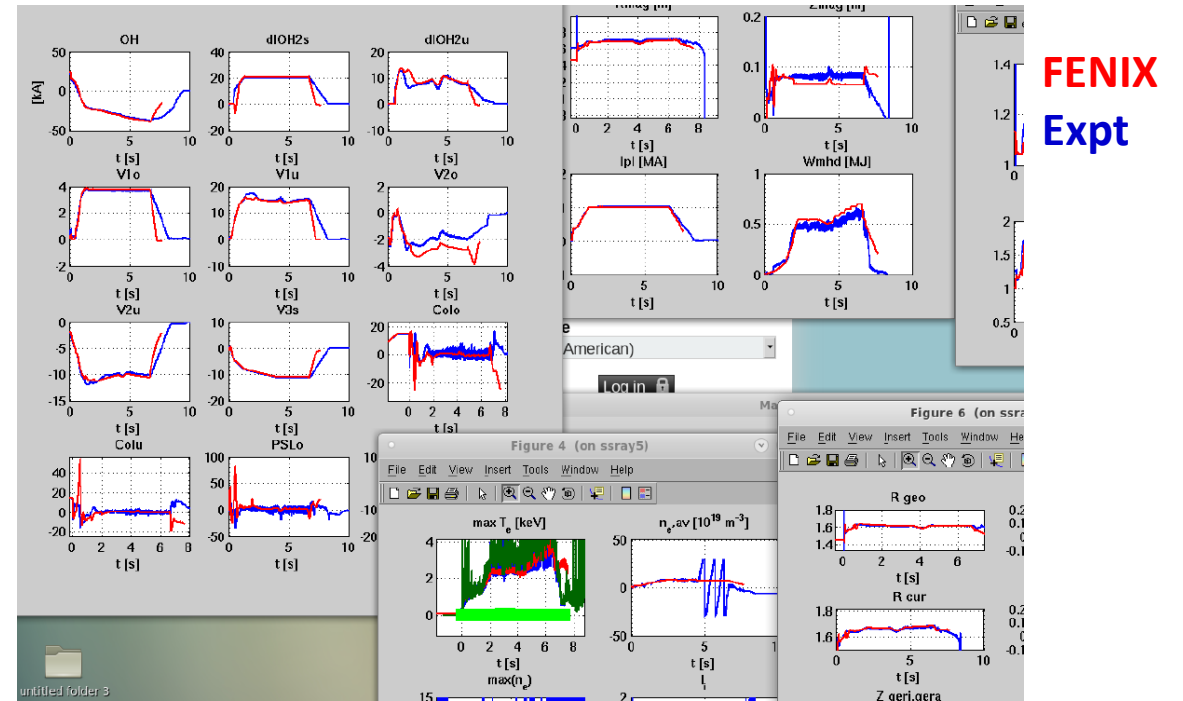
- **WP1: HFPS Workflow orchestration and module coupling framework** (coordinator: F.J. Casson, 2.5 ppy incl. 1.5 ACH)
- **WP2: HFPS key physics modules validation** (3.5 ppy incl. 1 from ACH)
- **WP3-HFPS full pulse modelling capability demonstration** (coordinator: E. Fable, 2 ppy)
- **WP4-HFPS systematic validation** (coordinator: A. Ho, 1ppy incl. 0.5 from ACH)
- **WP5- HFPS initial ITER phase modelling** (coordinator: J. Citrin, total effort 0.5 ppy)

WP3-HFPS full pulse modelling capability demonstration, E. Fable



Reminder, last year in Poznan, current diffusion only was compared btw FENIX and HFPS on AUG case
AUG H-mode discharge #40446, 0.8 MA, and has both NBI and ECRF heating applied (ICRF is also present in the later part of the pulse, but it is ignored for the modeling).

Here, natural extension towards “Pulse Design Tools”, test of control schemes, optimization etc

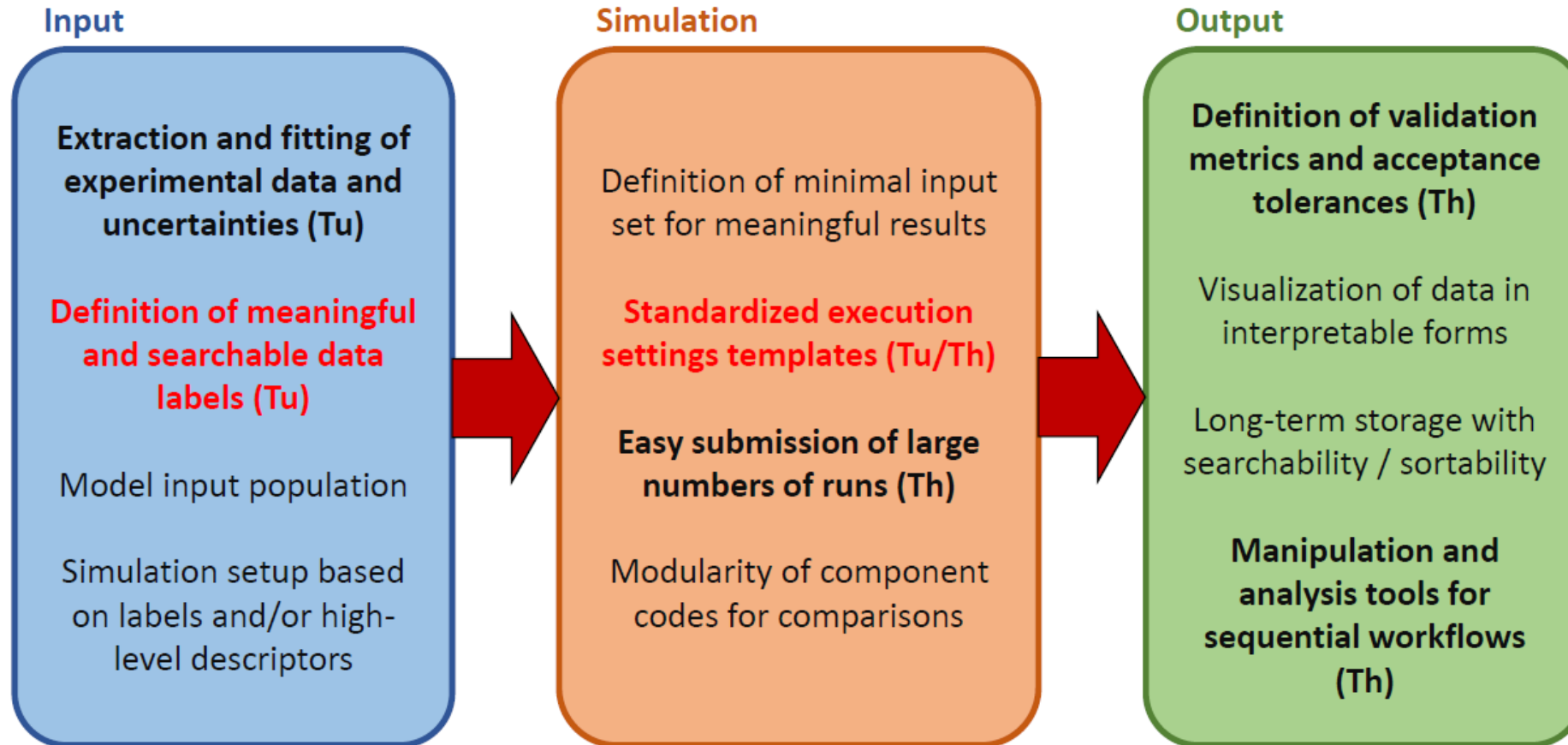


FENIX
Expt

Milestones planned 2023	status
Milestone 3.1.M2: demonstrated full pulse capability for current, heat and main ion particle predictive mode including a SOL model - Dec 2023	OK, strategy: Ohmic pulse of AUG used with Fenix full pulse modelling will be modelled with the HFPS including current, heat and particle (TGLF and QLK). E. Fable and G. Tardini
Milestone 3.1.M3: demonstrate the automated validation of 0D and 1D quantities of a full pulse simulated by the HFPS- Dec 2022	For the automated validation should be a goal for 2024, once steady state large scale validation has taken place



- **WP1: HFPS Workflow orchestration and module coupling framework** (coordinator: F.J. Casson, 2.5 ppy incl. 1.5 ACH)
- **WP2: HFPS key physics modules validation** (3.5 ppy incl. 1 from ACH)
- **WP3-HFPS full pulse modelling capability demonstration** (coordinator: E. Fable, 2 ppy)
- **WP4-HFPS systematic validation** (coordinator: A. Ho, 1ppy incl. 0.5 from ACH)
- **WP5- HFPS initial ITER phase modelling** (coordinator: J. Citrin, total effort 0.5 ppy)



Input:
JET database IMAS format
5500 time average datasets
Aaron Ho,
WEST could easily provide 3800 time average points

dUQ tools see next slide

ACH VTT Emil Amnell, Aaro Järvinen

1st project defined on Bayesian optimization of LHCD



Stef Smeets, Victor Azizi
NL eScience center

Duqtools is a tool for **D**ynamic **U**ndertainty **Q**uantification for Tokamak reactor simulations modelling

- Set up 100s of simulation runs from a single template
- Launch canonical UQ with minimal programming
- Batch job submission and status tracking
- Supports the Standardized Interface Data Structures (IDSs) data directory
- Compare and visualize 100s of simulations in one overview
- Display and merge simulation results as confidence ranges and distributions

Automated run creation

- Template-based run creation
- Set up variable dimensions
 - Generate new IMAS data
 - Smart hypercube sampling
 - Support for coupled variables

t_e	z_eff
0.8	0.8
1.0	1.0
1.2	1.2

```
create:
  dimensions:
    - variable: t_e
      operator: multiply
      values: [0.8, 1.0, 1.2]
    - variable: z_eff
      operator: multiply
      values: [0.8, 1.0, 1.2]
  sampler:
    method: latin-hypercube
    n_samples: 4
```

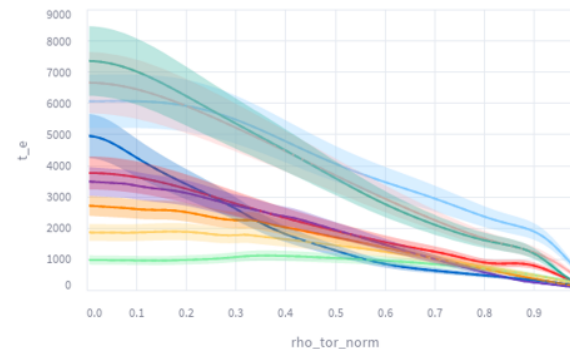
List of IMAS data

Canonical UQ
template

```
g2aho/aug/36982/2
g2aho/jet/75225/2
g2aho/jet/90350/2
g2aho/jet/92432/2
g2aho/jet/94875/1
g2aho/tcv/64958/2
g2aho/west/54568/1
g2aho/west/54728/1
g2aho/west/55181/1
g2aho/west/55525/1
...
```

```
create:
  runs_dir: ./duqduq/{{ run.name }}
  template: ./path/to/template/
  template_data:
    user: {{ handle.user }}
    db: {{ handle.db }}
    shot: {{ handle.shot }}
    run: {{ handle.run }}
  sampler:
    ...
  dimensions:
    ...
  system: jetto-v220922
```

duqduq





After discussions/training in Eindhoven, quite a few project related to duqtools emerged:

- Wider adoption of duqtools for UQ automation (**Stef, Victor**)
 - Demonstration of tools to setup and launch 97 interpretive simulations (all different discharges) within an hour
 - ~10 new feature requests to duqtools (open for more!)
 - Investigate possibility to allow IDS modification
 - Started work to connect with ETS model
- Determined target UQ /duqtools study for EPS (**Aaron**)
 - Investigate impact of q profile on kinetic profile prediction via large-scale UQ
 - Introduced to statistical tools for explaining variance across table of OD parameters (**Emil**)

WP4-HFPS systematic validation: 1st project on Bayesian Optimisation

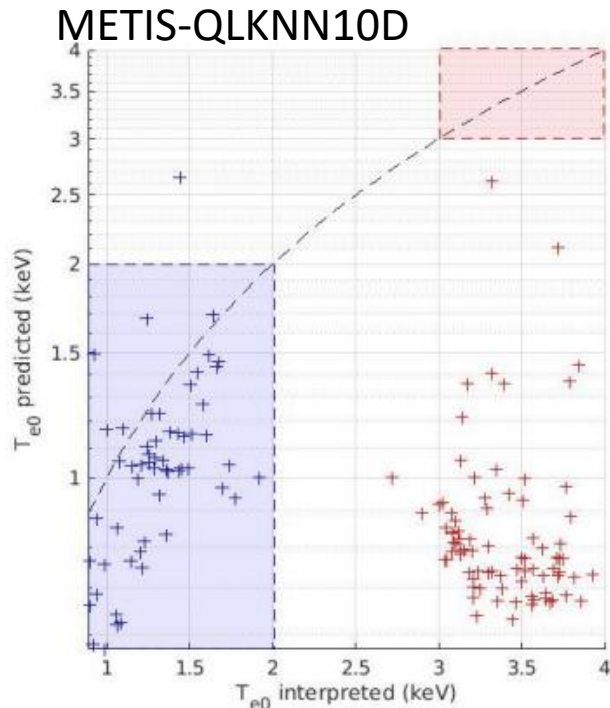


Reminder:

Milestone 4.4.M1 implemented additional validation metrics via Bayesian inferential techniques Dec 2024

Project starting: WEST L mode LHCD heated modelled database (Théo Fonghetti, PhD CEA)

Self-consistent LHCD simulations with reduced model



Mostly underpredicted central electron temperature

Gets even worse with hot branch because of some strong P_{LH} , I_{LH} , q dependencies that gets higher with P_{LH}

What is the **sensitivity to LH model inputs on final electron temperature**? $n_{//0}$, directivity, upshifting, landau resonance position, ...

Understand how to **improve predictions optimizing inputs**?

With ACH-VTT

Emil Amnell and Aaro Järvinen

Gaussian process regression, with Bayesian optimisation to optimize the required number of simulations needed to **find the LHCD power on-axis needed to match the measured temperature.**

Project 'kicked off'

Poster planned at TTF by Théo

Publication ~end of year



Milestones foreseen for 2023	Suggested modifications
<p>Milestone 4.2.M1: demonstrated 0D data consistency, e.g. $W_{th} < W_{MHD}$, I_i, neutron flux, $Prad_{div}$, $Prad_{bulk}$, $\langle Z_{eff} \rangle$, $\langle n \rangle$ on more than 10 plasmas Dec 2022</p> <p>Milestone 4.2.M2 demonstrated 1D data consistency, e.g. core profiles T_e, N_e, T_i, V_{tor}, Z_{eff}, E_r on more than 10 plasmas from more than 2 tokamaks Dec 2022</p> <p>Milestone 4.2.M3 demonstrated 2D line-of-sight synthetic diagnostics (e.g. SXR, bolometer, UV, Langmuir Probes, IR) on more than 10 plasmas from more than 2 tokamaks Dec 2023</p>	<p>By Dec 2022 we demonstrated on a reduced dataset a 0D check on AUG, JET, TCV and WEST</p> <p>Dec 2023: more than 1000 steady state plasma phases on 2 tokamaks demonstrated data consistency checks for current diffusion, heat and particle transport predictions on 0D and 1D data</p> <p>Dec 2024: addition of other tokamaks and of synthetic diagnostics for bolometry, SXR</p>
<p>Higher level deliverable towards EU commission through WPPrIO: “Report on the procedure for an automated and systematic validation of predictive integrated modelling including uncertainty quantification (TSVV11 responsibility)”, Sept 2023</p>	<p>OK, based on EPS TTF A. Ho contributions</p>



- **WP1: HFPS Workflow orchestration and module coupling framework** (coordinator: F.J. Casson, 2.5 ppy incl. 1.5 ACH)
- **WP2: HFPS key physics modules validation** (3.5 ppy incl. 1 from ACH)
- **WP3-HFPS full pulse modelling capability demonstration** (coordinator: E. Fable, 2 ppy)
- **WP4-HFPS systematic validation** (coordinator: A. Ho, 1ppy incl. 0.5 from ACH)
- **WP5- HFPS initial ITER phase modelling** (coordinator: J. Citrin, total effort 0.5 ppy)

WP5: HFPS initial ITER phase modelling, J. Citrin



Milestones foreseen for 2023	status
<p>Milestone 5.2.M1: modelled Ip ramp-up (Dec 2022) and ramp down L-mode plasmas. Estimate the requirements on ECRH for controlling W in ramp-up, avoiding operational constraints, and avoiding (2,1) mode onset, for various W boundary condition assumptions (Dec 2023)</p>	<p>ECRH in L mode modelling of AUG plasmas [C. Angioni with ASTRA and J. Citrin with HFPS] Extrapolation towards ITER L mode C. Angioni</p>
Milestones foreseen for 2024 2025	Proposed revision
<p>Milestone 5.2.M2: modelled full pulse H and He PFPO-1 simulations, up to the LCFS, focusing on operational limits, H-mode accessibility, ramp up and ramp down phases with respect to the timing of LH and HL transitions, transport characteristics in the low $\langle n_e \rangle$ ECH heated H-mode itself. Analyze scenario for predicted pedestal heights, as well as reduced pedestals assuming degradation due to ELM control (Jul 2024)</p> <p>Milestone 5.2.M3 modelled full pulse H and He PFPO-1 as above including both reduced SOL model as well as more advanced EDGE2D-EIRENE model including heat and particle exhaust related operational limits Dec 2024</p>	<p>ITER Research Plan being revised Florian now at ITER, Jonathan not in TSVV11 anymore</p> <p>In 2023/2024: Possible work in synergy with DEMO Central Team (C. Bourdelle, Transport RO) with ITER as a logical 1st step before DEMO ;)</p> <ul style="list-style-type: none">- 'towards reduced transport models for burning plasmas'- 'in burning plasmas, explore the non-linear interplay between fast ion stabilized turbulence and fast ion enhanced diffusion due to fast ion triggered modes' with Ph. Lauber TSVV10



- Coming conferences:
 - EPS in Bordeaux:
 - **Aaron Ho's poster on large scale validation, JET data**
 - **Y. Camenen TCV GKW ramp up modelling**
 - TTF in Nancy:
 - overview talk by myself on "*Understanding of near-edge physics in L-mode, H-mode and ELM-free regimes*" in the context of TTF such talks are more there to share existing works, likely shown in the session following the talk and trigger discussions
 - **M. Marin: TCV ramp up modelling using HFPS and incl. WEST**
 - **Y. Camenen TCV GKW ramp up modelling**
 - D. Fajardo AUG integrated modelling with impurities + **QLK-TGLF-GKW validation**
 - **Aaron Ho on large scale validation likely extended to JET+WEST**
 - G. Tardini: ASTRA modularity and IMASification for integrated modelling workflows
 - Shengyu Shi HFPS used on WEST long pulses
 - J-F Artaud on METIS+QLKNN on Ti saturation modelling in electron heated WEST plasmas
 - P. Manas on Boron transport in AUG
 - **Théo Fonghetti on WEST LHCD heated pulses using Bayesian optimisation of HFPS runs needed**
 - ...
 - IAEA: Bayesian Optimization overview, Aaro Järvinen



- **Journal publications foreseen to be submitted within end of 2023, using HFPS on Gateway and incl. uncertainty quantification, optimization (duqtools)**

A. Ho et al JET based large scale uncertainty exploration for HFPS validation

M. Marin et al TCV ramp up modelling incl. GKW vs reduced models and WEST ramp up sensitivity

T. Fonghetti et al WEST central LHCD deposition optimization thanks to BO on large database

- TSVV11 related publications:

D. Fajardo et al AUG integrated modelling L and H mode with impurities

P. Manas et al Ion temperature saturation in electron heated WEST plasmas using METIS-QLKNN