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

C. Bourdelle and the TSVV11 team

11/09/2023

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.

TSVV11 team

- Team members

C. Angioni, J.-F. Artaud, Y. Camenen, F.J. Casson, E. Fable, A. Ho, P. Maget, P. Manas, M. Marin, J. Morales, O. Sauter, G. Tardini, N. Cummings, E. Tholerus, Z. Stancar

- Previous team members

J. Citrin, F. Felici, K. van de Plassche, F. Koechl

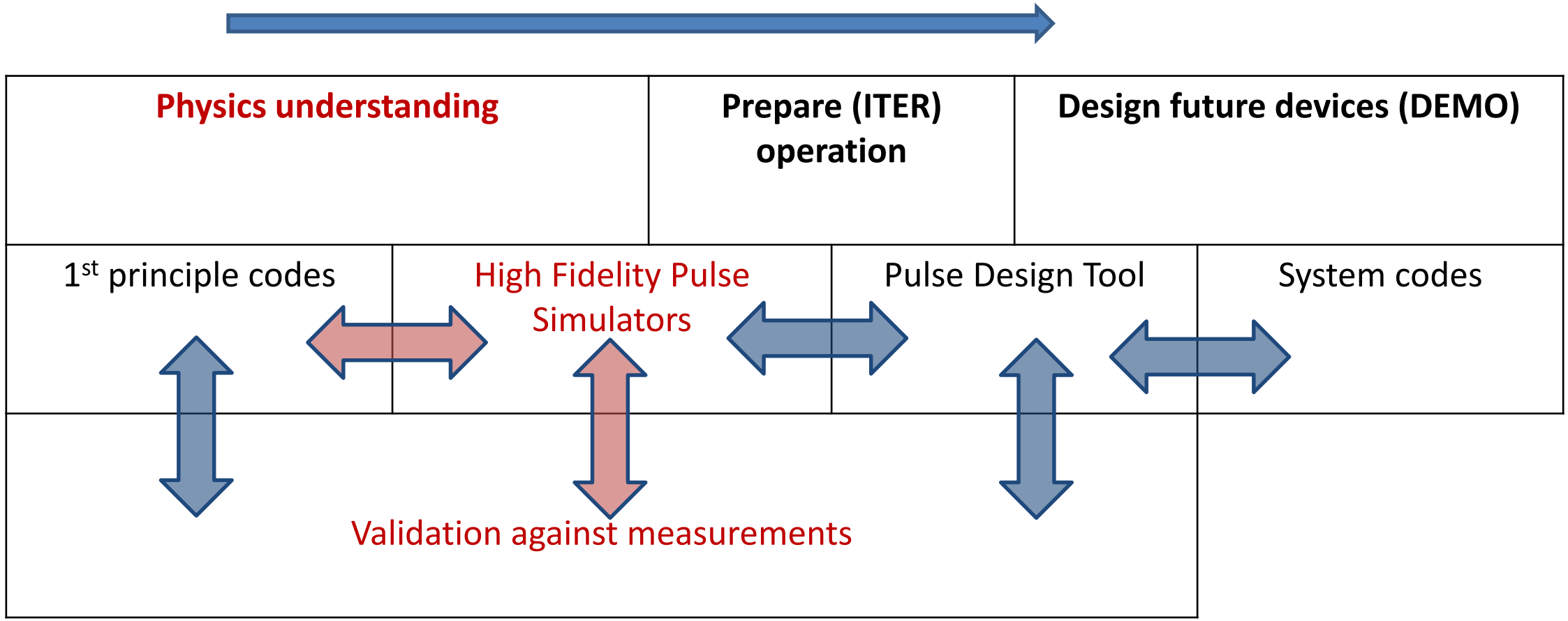
- Regular participants

L. Garzotti, P. Knight, T. Luda, Th. Jonsson, V.K. Zotta, S. Gabriellini, G. Snoep, R. Coelho, P. Strand, D. Yadykin, C. Giroud, L. Chôné, F. Imbeaux, R. Dumont, D. Fajardo, P. Vincenzi, M. Valisa, E. Militello-Asp, P. Mantica, J. Simpson, A. Järvinen, A. Kit, Ph. Huynh, N. Bonanomi, S. Shi, H. Dudding, B. Labit, T. Fonghetti, A. Panera, A. Kirjasuo, J. Lombardo, F. Eriksson

Integrated modelling landscape, preparing tokamak operation

Model integration, longer plasma time frames

Requires faster yes accurate physics models



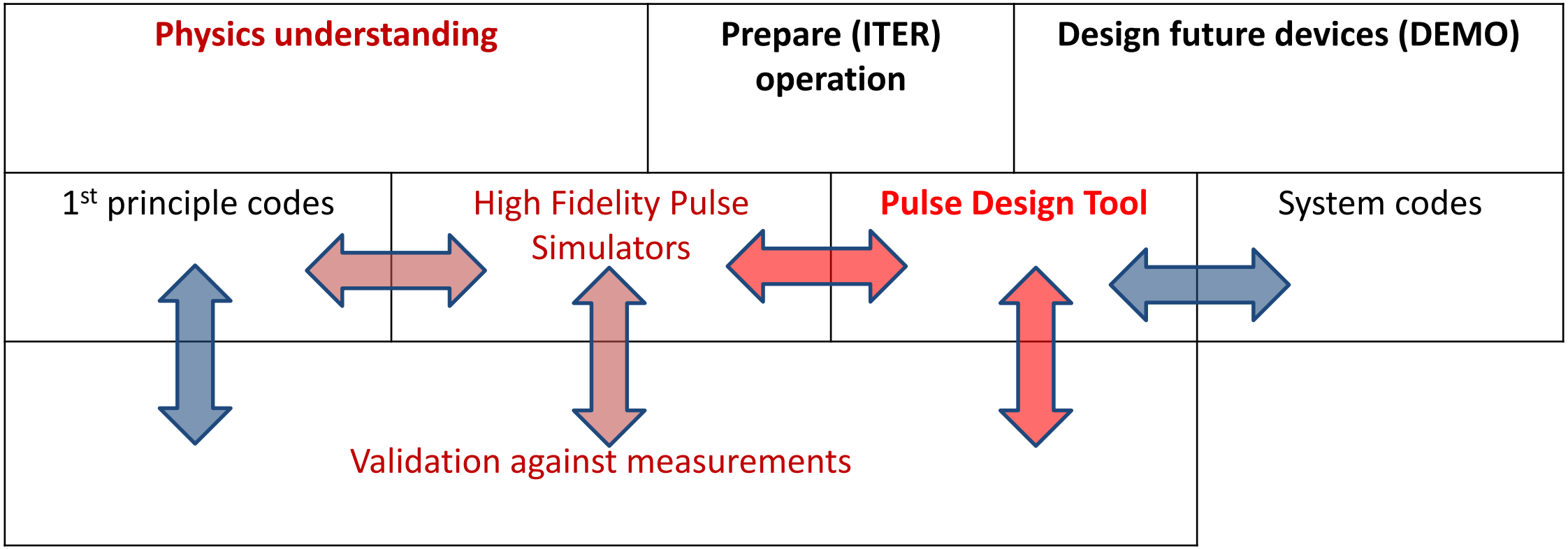
The focus of the TSVV11 activity is on the physics understanding side of the coin.

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

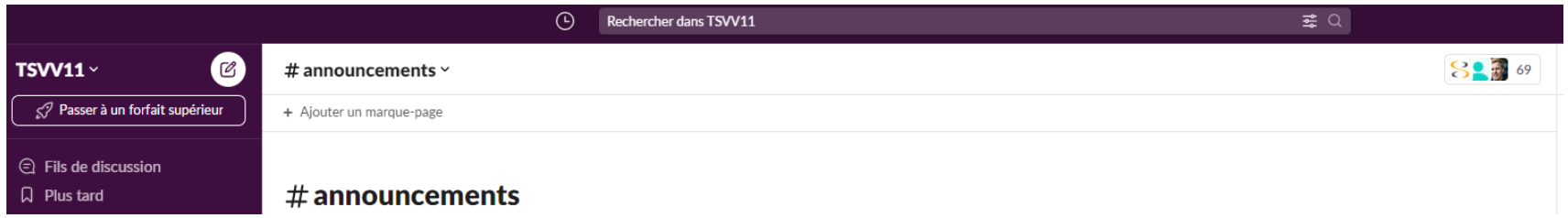
TSVV11 scientific life: wikipages, regular meetings -open to integrated modelers-, slack, yearly in-person meetings

TSVV-11-general-meetings

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

- 30th general meetiing, TTF rehearsals: TCV Ip ramp up (M Marin), impurity transport in AUG (D. Fajardo), Bayesian Optimization in WEST LHCD [T. Fonghetti), N2 seeding modelling WEST (S. Shi)
- 29th general meetiing, EPS poster rehearsals: large scale valdiation on JET database (A. Ho) and TCV Ip ramp up gyrokinetic modelling (Y. Camenen)
- 28th general meeting, June 16th 2023: WEST ICRH impact on core heating with HFPS and JINTRAC ITER Q=10 modelling
- 27th general meeting, June 9th 2023: JINTRAC modelling of JT60-SA and STEP
- 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

1st in person meeting April 2022 Poznan



Ecosystem around the EUROfusion integrated modelling "TSVV11" activity

2nd in person TSVV11 meeting
37 persons meeting on-site, Eindhoven NL
20-24 March 2023

WP2:Validate, improve physics modules (Y. Camenen, C. Bourdelle, C. Angioni, J.-F. Artaud, P. Maget)

Other EUROfusion + labs activities

ACH PSNC

WP1:Workflow orchestration and module coupling framework (F.J. Casson)

WP4: systematic validation (A. Ho)

ACH VTT

WP3: pulse design tool (E. Fable)

In Jan 2024, at ITER Org

Guidelines for the High Fidelity Pulse Simulator and Pulse Design Tool

	High Fidelity Pulse Simulator (since April 2021)	**Pulse Design Tool** (Since Sept 2023)
Infrastructure	**Align with ITER workhorse**: Python-driven workflow based on IMASified JINTRAC	exploit a few available workflows (METIS+NICE, RAPTOR, RAPDENS, ASTRA, etc)
On-going	IMAS data structure for inputs and outputs NB: Open-sourcing at ITER in the pipeline	
	Validate advanced physics modules in flux driven int. modelling	**Speed up** some key modules
	Synergy with other physics activities within EUROfusion and elsewhere	
	Large scale validation against EU operating tokamaks, incl. automated validation tools	For now, test each existing workflow on at least 2 tokamaks
upcoming	Planned devt: Open-sourcing the workflow and most modules, use of Muscle3 lib. in python workflow	Development shall target interoperability, modularity, max synergy with ITER, etc

« The » High Fidelity Pulse Simulator

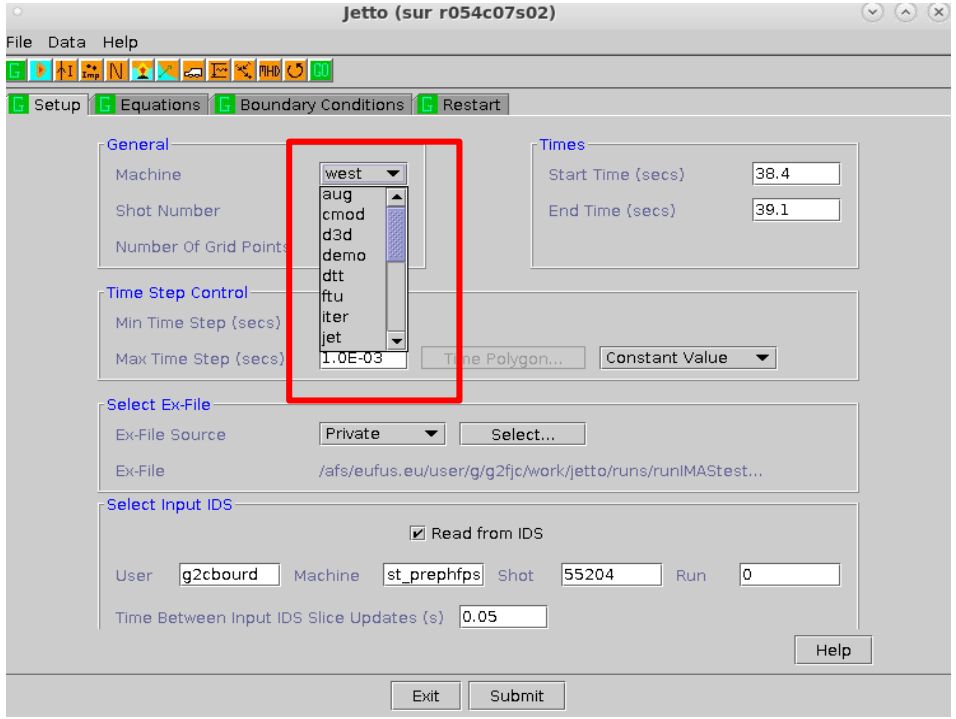
What is the High Fidelity Pulse Simulator?

Python-driven workflow based on **IMASified JINTRAC (i.e. JETTO+EDGE2D, from the core to the SOL)**

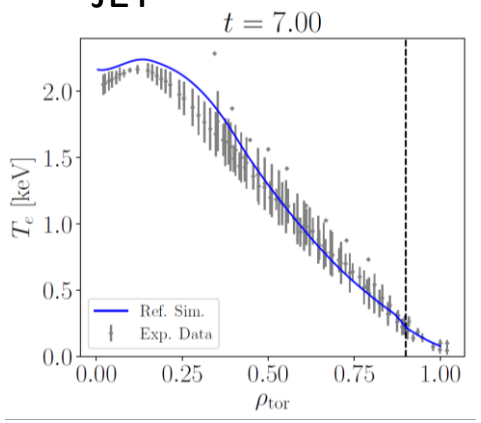
Workhorse for scenario preparation in ITER Physics Dept.

any IMASified physics module can be included

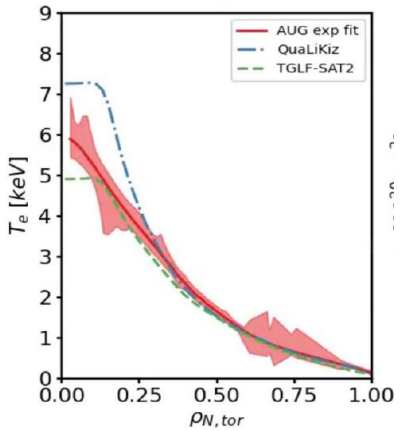
Coupled to experimental IMAS data from AUG, JET, TCV, WEST, **on the EUROfusion Gateway**



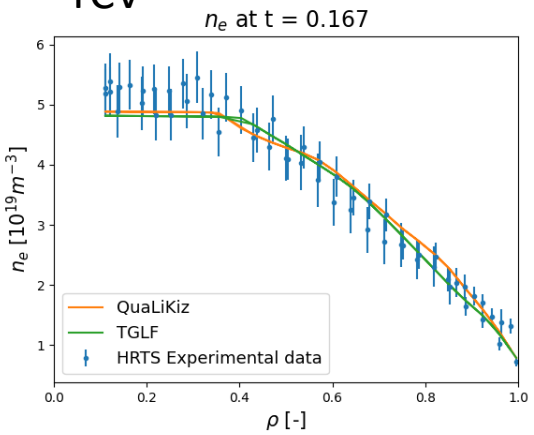
JET



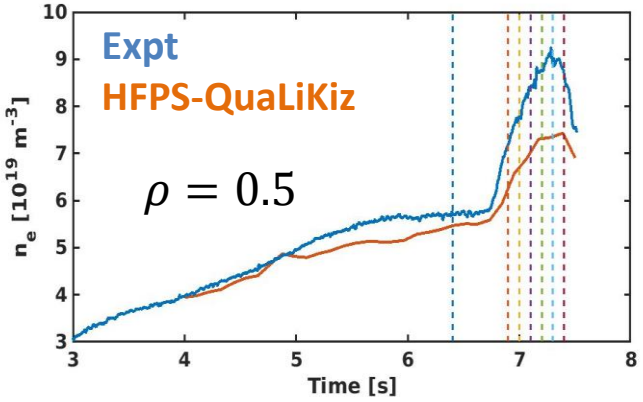
AUG



TCV



WEST



A key tool: IMAS data structure

IMAS : **I**ntegrated **M**odelling and **A**nalysis **S**uite Data Dictionary.

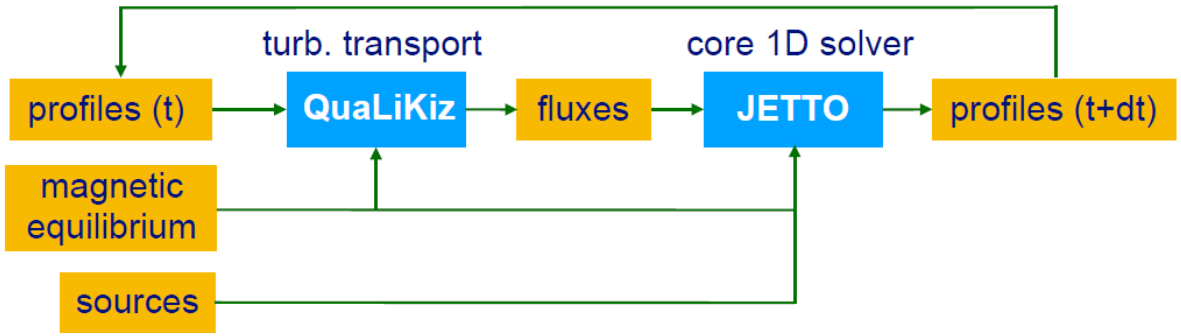
Chosen by IO **for ITER future experimental data** and present modelling in/output.

Machine and code generic. Capable of covering all experiment subsystems and plasma physics, **extensible**

Promoted as the **standard to** access all experimental results within EUROfusion in a unique data format in the FAIR and open science requirements

IMAS infrastructure includes:

- **Data Dictionary** : machine generic
  - What data exist ?
  - What are they called ?
  - How are they structured ?
- **Data Access** : functions to read/write objects
- **Workflow component generator** : encapsulate physics codes to turn them into components that can be coupled in a workflow



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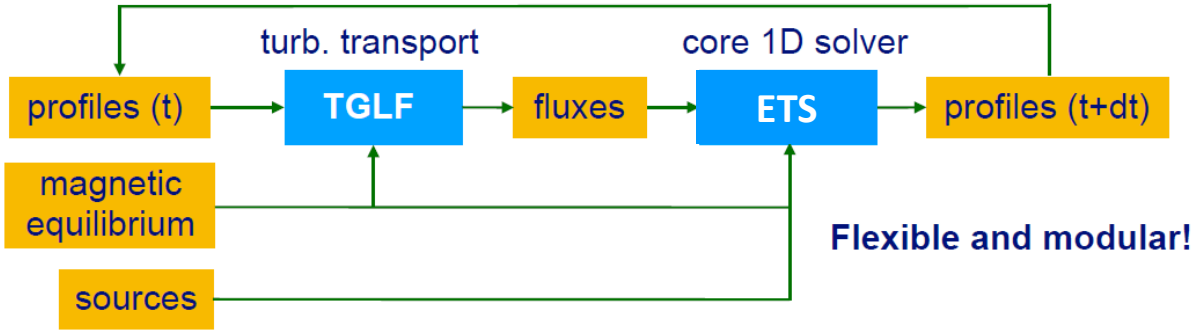


outline

- **WP1: HFPS Workflow orchestration and module coupling framework** (coordinator: F.J. Casson, 3 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

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

- Combines ETS components (HCD) and all JINTRAC components
- Coupling *framework* prototypical but functional: we hope it will grow further

All actors take physics input / output from IMAS Data Structure via argument

- Actors wrapped via FC2K -> **migrating to Persistent Actor Framework MUSCLE3**
- Each actor handles code specific params in it's own way
- GUI collects *all* input files in one folder, launches workflow.
- Non JINTRAC actors provide their own GUI
- MDS+ and HDF5 backends supported
- Most JINTRAC components containerized, deployed to cloud resources

netherlands eScience center

IGNITIONCOMPUTING

ACH PSNC

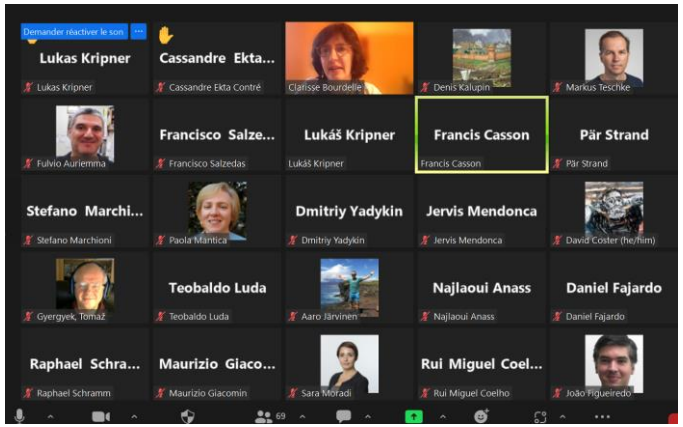
How it could evolve

- Agree standards for IMAS python workflows, converge on common methodology / tools with ETS, ASTRA and ITER-Pulse Design Simulator
- Add new actors as they are adapted to python
- A common GUI

- Twice / year: ASTRA, ETS, HFPS meeting on workflow/module coupling framework, next is Sept 29
- Monthly update with ITER Org : S. Pinches et al, NB: new responsibles for HFPS and Pulse Design Simulator at IO

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)**: · Recent achievements of integrated modelling · What 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.

Btw yearly training, TSVV11 meetings to support new users, focused on physics module: past FRANTIC neutral source, coming turbulent transport codes QuaLiKiz/TGLF and impurity SANCO

Training repeated yearly, next Jan 2024

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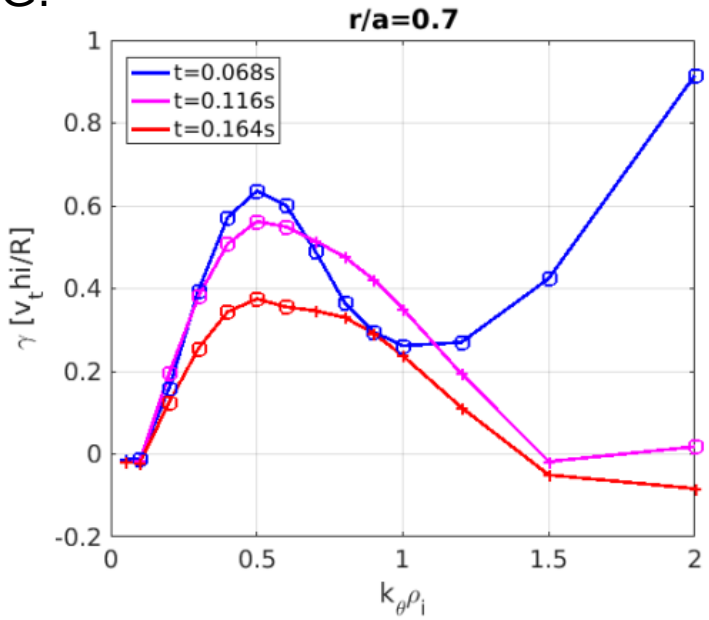
WP2-D1: Turbulent transport reduced models targeted validation, Y. Camenen

Focus on current ramp-up

- Critical: need to minimize magnetic flux consumption while avoiding MHD instabilities
- Target: TCV plasma with electron (Thomson Scattering) and ion (CXRS) measurements
- Specific conditions: high Te/Ti, high q, high collisionality
- Validate quasi-linear against non-linear gyrokinetic simulations

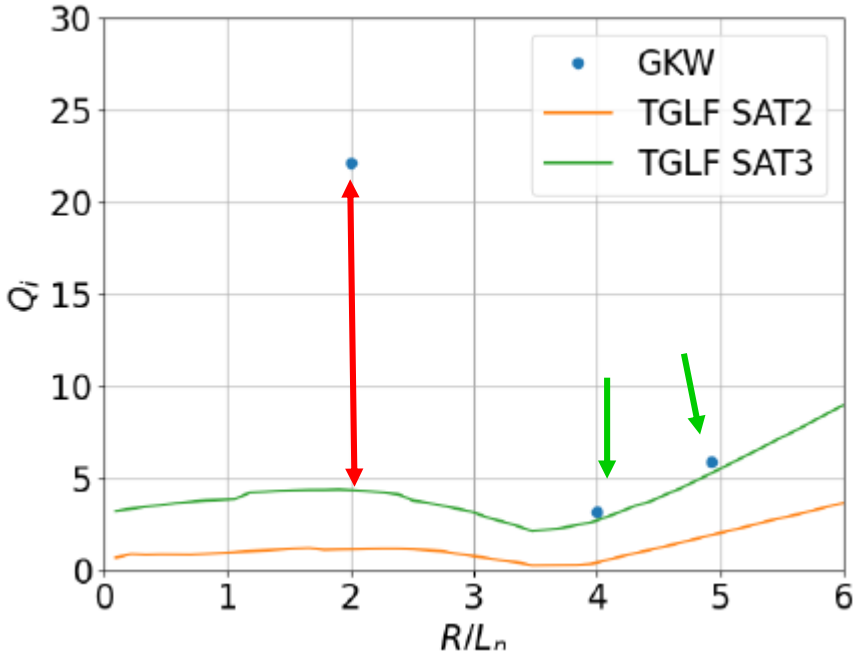
TEM dominated (R/L_n driven), especially in the early phase and at long wavelength, then hybrid TEM-ITG.



[Y. Camenen EPS 2023, TTF 2023]

TGLF/GKW comparison for a R/Ln scan at r/a=0.5, t=0.068s

- TEM threshold and stiffness versus R/Ln OK
- Saturation level in the ITG branch largely underestimated



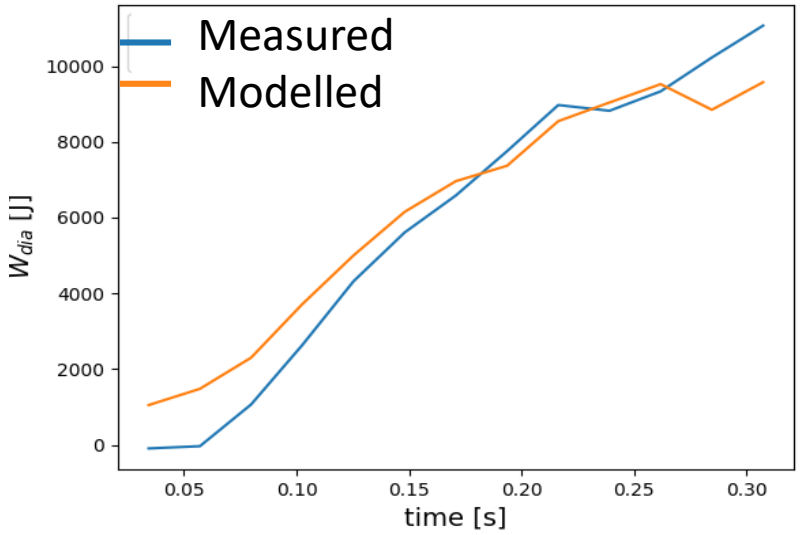
WP2-D1: Turbulent transport reduced models targeted validation, Y. Camenen

Focus on current ramp-up

- Integrated modelling of 4 TCV ramps
- **Predicting j, ne, nC, Te and Ti up to ρ=0.99**

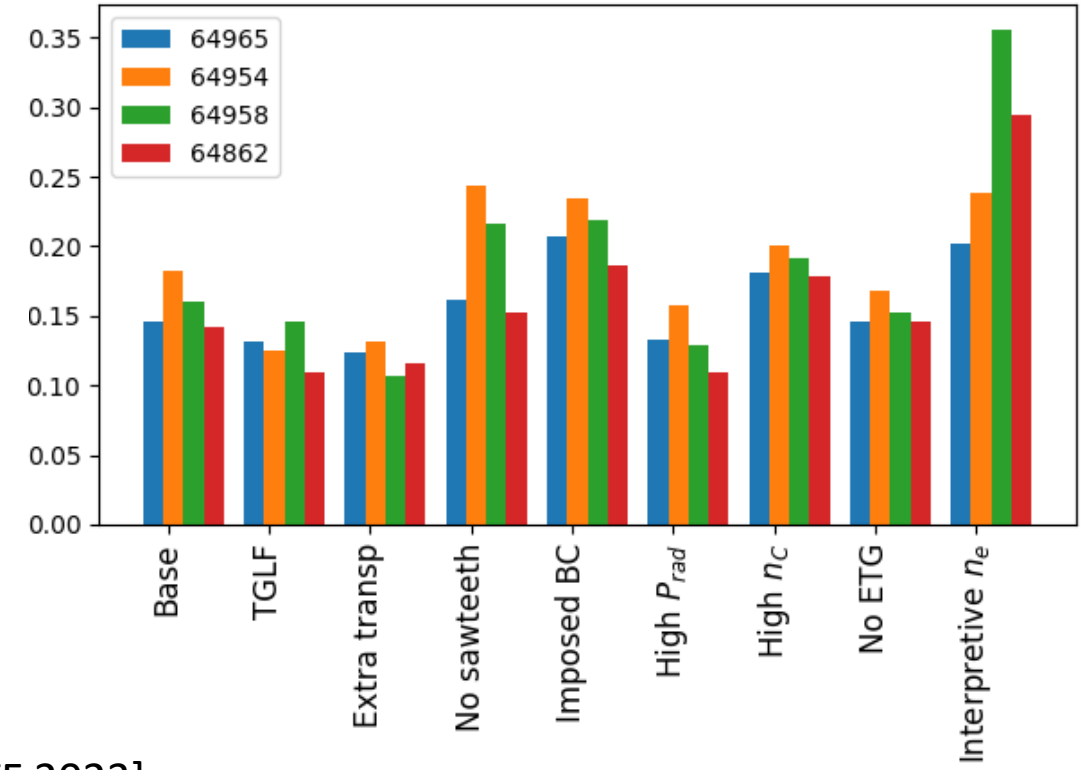
The same settings on 4 TCV ramps
Extensive sensitivities to explore robustness
- TGLF vs QuaLiKiz similar perf
- Worse T_e prediction with n_e <u>not</u> predicted!

W_{dia}



difference meas./model averaged in t, r

T_e



WEST I_P ramp cases on-going

[M. Marin, TTF 2023]

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

Neural Network surrogate of QuaLiKiz extended to L mode edge parameters, incl. Ip ramps

- Some overlap with QLKNN original hypercube [VanDerPlassche NF2020]
- Far into the extreme range of parameters
- Extension to more values of Ti/Te considered in the future

	R/L_{T_e}	R/L_{T_i}	R/L_{T_n}	q	$\hat{s}$	r/R	T_i/T_e	ν^*	Z_{eff}
# Points	16	16	13	10	12	1	1	8	5
Min.	5	5	2	2	1	0.95	1	1×10^{-1}	1
Max.	150	150	120	30	40	-	-	3	2.5

L. Chôné, VTT Advanced Computing Hub and TSVV11 members (K. VanDePlassche, J. Citrin)

ACH VTT

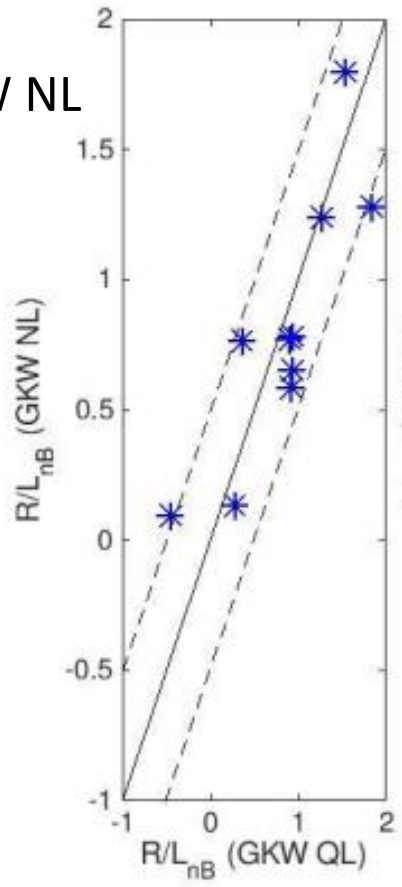
Now available in the HFPS for testing

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

Reduced model validation for turbulent transport of impurities

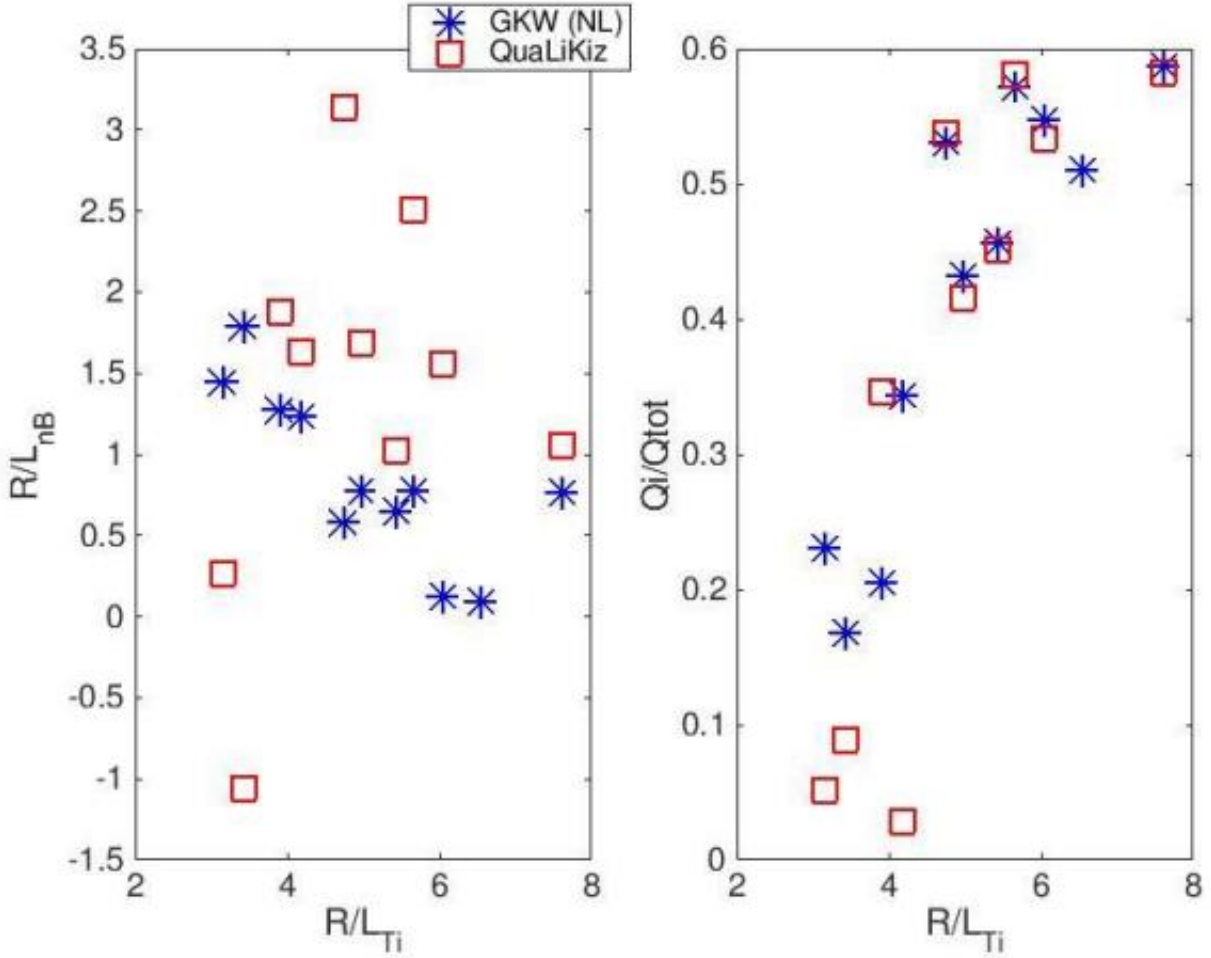
Boron, AUG database

GKW QL~GKW NL



[P. Manas TTF2023]

QuaLiKiz Boron peaking at ρ=0.5 more scattered than GKW-NL



[D. Fajardo TTF2023]

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

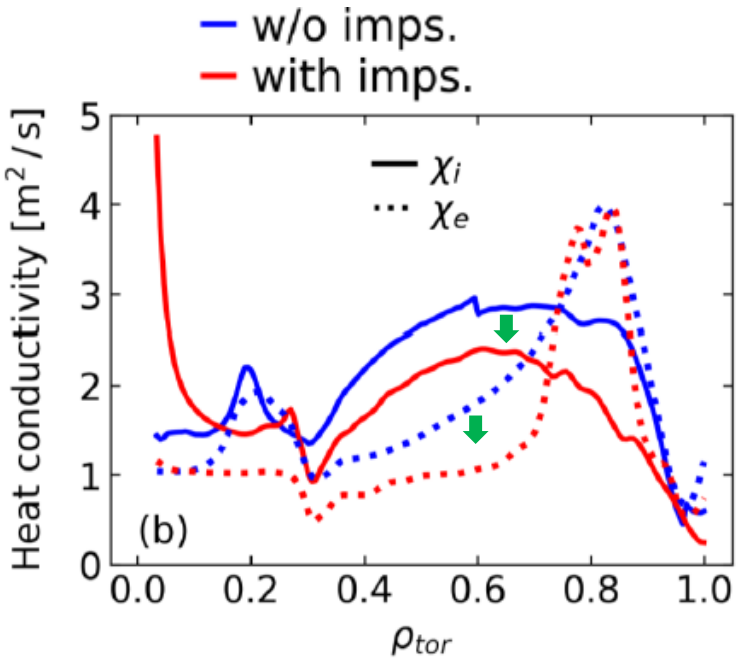
Integrated modelling of radiative experiments

- AUG: Radiative L-mode with X-point radiation, Ar seeding

ASTRA-TGLFsat2 up to ρ=1: Te, Ti, nD, nW, nAr predicted self-consistently

Improved ion and electron heat transport

[D. Fajardo TTF2023]

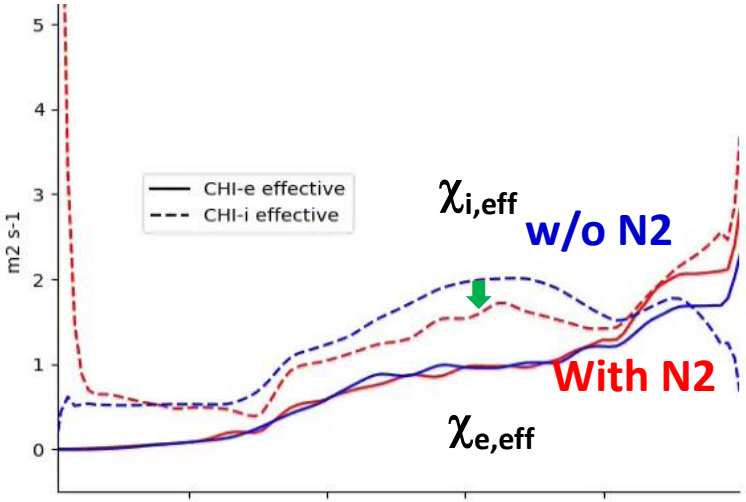


- WEST: X point radiative L mode, with N2 seeding

HFPS-TGLFsat 1 up to ρ=1: j, Te, Ti, nD, nW, nN predicted self-consistently

Improved ion heat transport, reduced W core peaking

[S. Shi TTF2023]



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WP4-HFPS systematic validation, A. Ho
large scale simulation launching

Duqtools is a tool for Dynamic Undertainty Quantification 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	zeff
0.8	0.8
1.0	1.0
1.2	1.2

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

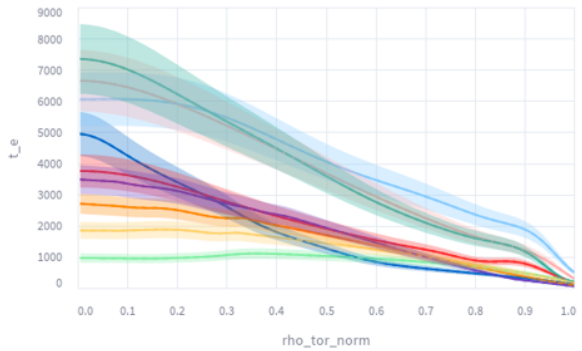
List of IMAS data

```
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
...
```

Canonical UQ template

```yaml
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
```

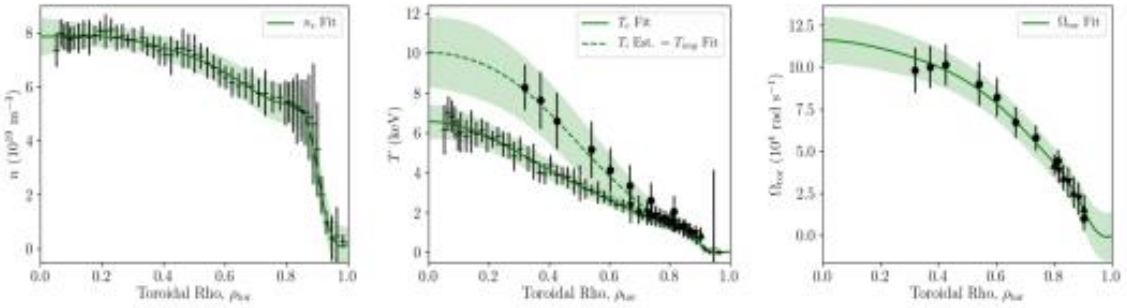
duqduq



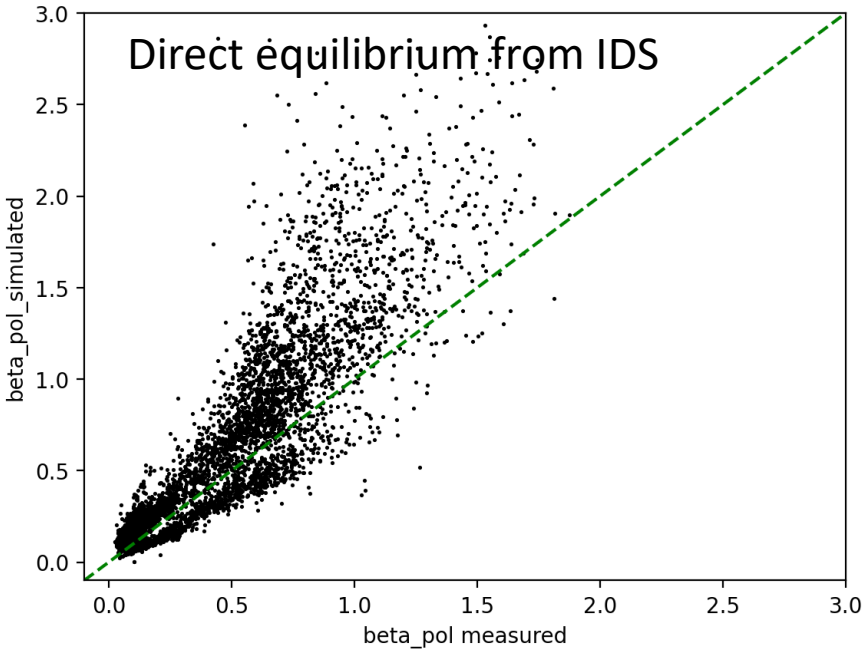
https://github.com/duqtools/duqtools (open-source)]

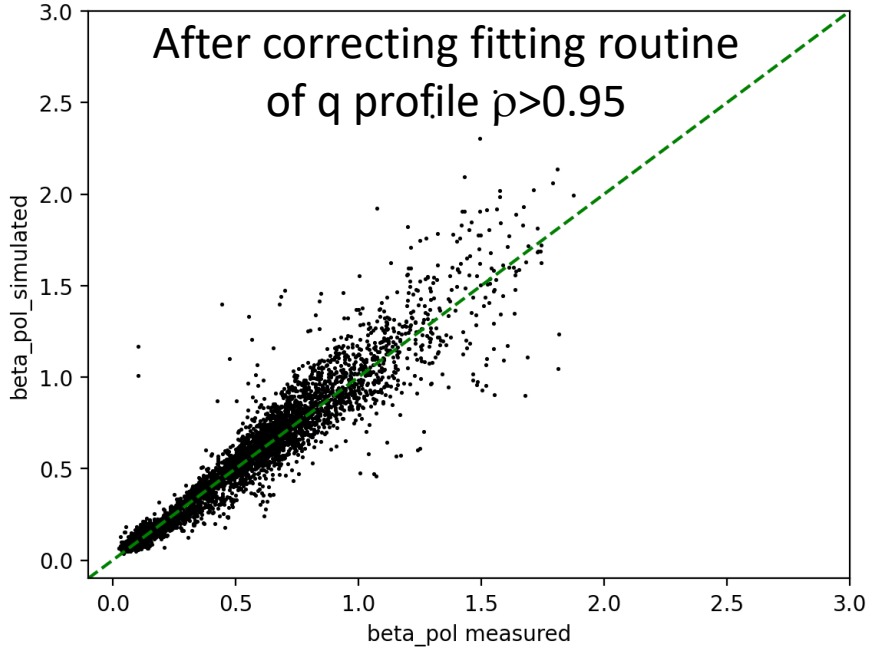
WP4-HFPS systematic validation, A. Ho
1st results

- **JET extraction routine**, EX2GK [A. Ho NF2019], generates IMAS data structure for HFPS initial/boundary conditions **w/o manual adjustments**
- 5721 plateaus (500 ms width) prepared
- **Automatically launched 5721 HFPS runs** nothing predicted here 'just' sanity check



Power of insights from large-scale execution

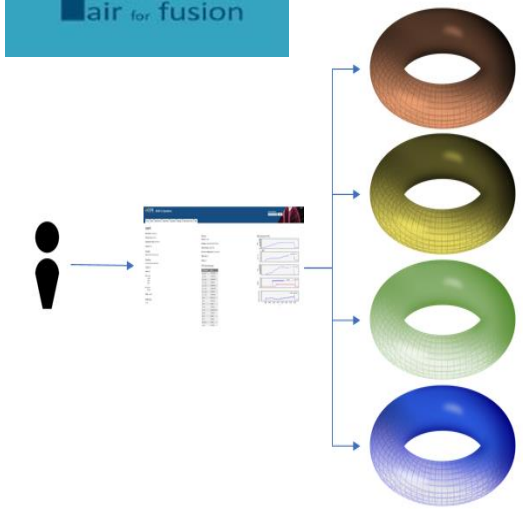




On-going:
Automate flagging of inconsistencies
Develop accuracy metrics
Extend to heat/particle predictive simulations
Extend to WEST L mode database of 36850 plateaus

JINTRAC version: JINTRAC-IMAS, g2fjc / v230123, IMAS 3.37.0 (run on Gateway)

Large scale validation requires:
access to experimental data and simulation database



Experimental data access:
4 scenarios proposed
A : Share physics metadata within the community (central catalogue)
B : Central access point for full data of all EU experiments
C : Add PIDs, links to publications + provenance
D : Opening data to the general public

Simulation database on Gateway available: simDB (also used by ITER)
Requires **software and hardware support**: Long Term Storage Facility see Gateway expert group 07/21 recommendation #6

STORAGE LIMITATION

RESPONSIBILITY FOR ONGOING MAINTENANCE

Conferences in 2023

- EPS in Bordeaux:
  - **Aaron Ho's poster on large scale validation, JET data**
  - **Y. Camenen TCV GKW ramp up modelling**
- TTF in Nancy this week:
  - **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 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

Publications foreseen in 2023

- **using HFPS on Gateway and incl. uncertainty quantification, optimization**

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:

P. Maget et al Radiative collapse modelling of WEST ICRH discharge

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

Summary of the achievements

- **Integrated modelling EUROfusion community has a well organized framework** (wiki, meetings, slack) to share results, exchange good practice, train new users
- **HFPS available on the Gateway** to all, is running from **AUG, JET, TCV and WEST IMAS data** input, with a simulation database in place
- **Physics module validation** (turb. in ramp up, impurity) through int. modelling on-going on physics driven integrated modelling works
- **Large scale validation tools in production**
- **Gained momentum to agree on standards for IMAS python workflows/tools** btw existing transport codes, with ITER Org., and hope for converging also with for e.g. MOSAIC at CFS

Challenges ahead and proposals

- **Challenges**
  - HFPS: IMAS actors in python workflow based on HCD+JINTRAC dev. UKAEA with ITER Org contract. Not possible anymore.
  - HFPS/PDS team at ITER is changing. Need to actively share devt strategy. E.g. Persistent Actor Framework contract (Muscle3) just ended btw ITER and PSNC/DIFFER/Ignition computing
  - Large scale validation tools (dUQtools) developed through DIFFER-NL eScience center contract outside TSVV11. J. Citrin entry point left EUROfusion.
  - IMAS data access existing but not ideal, e.g. A. Ho (post-doc at DIFFER) produces JET IMAS data!
- **Proposals, TSVV11 specific**
  - **Reinforcing the ACH** technical support **for stable in-house EUROfusion software/workflow** support (e.g. incl. NL eScience center)
  - Need **more hands on support on physics module coupling/update in the HFPS workflow**
- **Proposals, likely not TSVV11 only specific, more towards 'team of teams'**
  - **Reinforcing the ACH long-term support for ML** surrogates (extend ACH VTT)
  - **Manned support for FAIR access to all EU tokamak** databases in IMAS format
  - **Long term storage facility at Gateway** with soft and hardware support
  - Transparent yearly mission budget, at least enough for 5 days meeting of all TSVVs members

- Backups

TSVV11 7 ppy 2023, update

name	2023 pm	2023 changes
Yann Camenen (01-CNRS)	~~6~~4.8	
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”

workpackages	deliverables	Status / perspective
1-HFPS Workflow orchestration and module coupling framework	A set of advanced codes/models (developed in this or other TSVV Tasks, or in the wider community) fully incorporated into an integrated modelling framework focusing on the self-consistent treatment of core, pedestal, and SOL physics.	**A** integrated modeling framework in place New physics module coupling not as fast as wished, would need more hands-on support tightly coupled with physicists
2- HFPS key physics modules validation	Relevant validated physics modules in IMAS format; contributions to the requirements and the development of IMAS if and when needed.	Some on-going within TSVV11 (neoclassical impurity, Er BC, edge QLKNN) next challenge is interfacing int. modelling with other TSVV inputs
3-HFPS full pulse modelling capability demonstration	Demonstrated capability to simulate plasma flat-top, formation, and dynamics for existing tokamaks and ITER, respecting operational limits and accounting for isotope effects	On-going and reinforced by the new Pulse Design Tool activity
4- HFPS systematic validation	Procedure for systematic validation using synthetic diagnostics and experimental databases. Specific plan for dissemination to the wider community, involving the ACHs	Started, results with heat and particle prediction to come very soon! Relied on tools produced by NL e-science center, need to be consolidated on long term, incl. NL e-science center in ACH?
5- HFPS initial ITER phase modelling	Integrated scenario simulations in support of the initial phase of ITER operation	Focused on ECRH heated L mode, now on hold (J. Citrin left). Possibly could restart on joined TSVV10-TSVV11 on burning plasma

WP1 deliverables for 2023

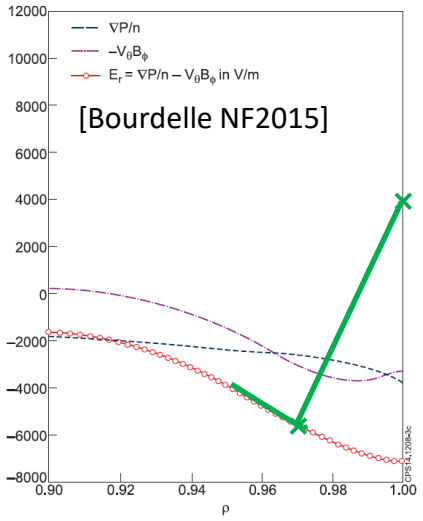
WP1 Planned milestones for 2023	status
Milestone 1.2 M3 Adapted existing HFPS components (for SOL, MHD, pedestal and breakdown/burn-through) to **follow new Python workflow specifications-** Dec 2023	Planned for 2023 HFPS workflow to **Muscle3** with support of PAF contract and ACH in Poznan. Need to **interact with ITER on flexibility vs modularity** and make sure HFPS muscle3 EF/ITER is aligned.
Milestone 1.3.M1 Adapted existing HFPS components to workflow settings management specifications Dec 2023	
Milestone 1.4.M4 All existing HFPS components configurable from **common GUI** and integrated with common simulation cataloging system Dec 2023	Cataloguing OK, post-poned 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.

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

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 Milestone 2.1.M2 in Ip ramp down Dec 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

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

Large experiment databases:
JET, AUG, MAST-U, WEST, TCV

Physics-driven models:

SOL:
Steady-state: SOLPS-ITER,
Dynamic: DIV1D

Ped. MHD-stability:
Ideal: MISHKA/ELITE
Resistive: CASTOR, JOREK

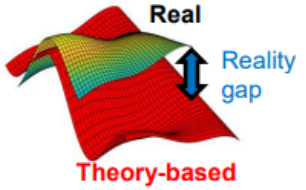
Ped. transport:
Reduced models, Fluid, GK, Neoc.
KBM (EPED-like), ETG, …

Probabilistic representation learning:
- **Dimensionality reduction:** Full diagnostic dimensionality vs. key scenario parameters
- ➢ Statistical inference of plasma characteristic, c.f. Bayesian scenario representation using the common information in thousands of shots

Synthetic diagnostics

Feed-forward surrogate model for fast throughput:
- Very accurate regression quality can be achieved by establishing a large training data-base (HPC for code farming)

Physics-informed probabilistic SOL-pedestal state representation

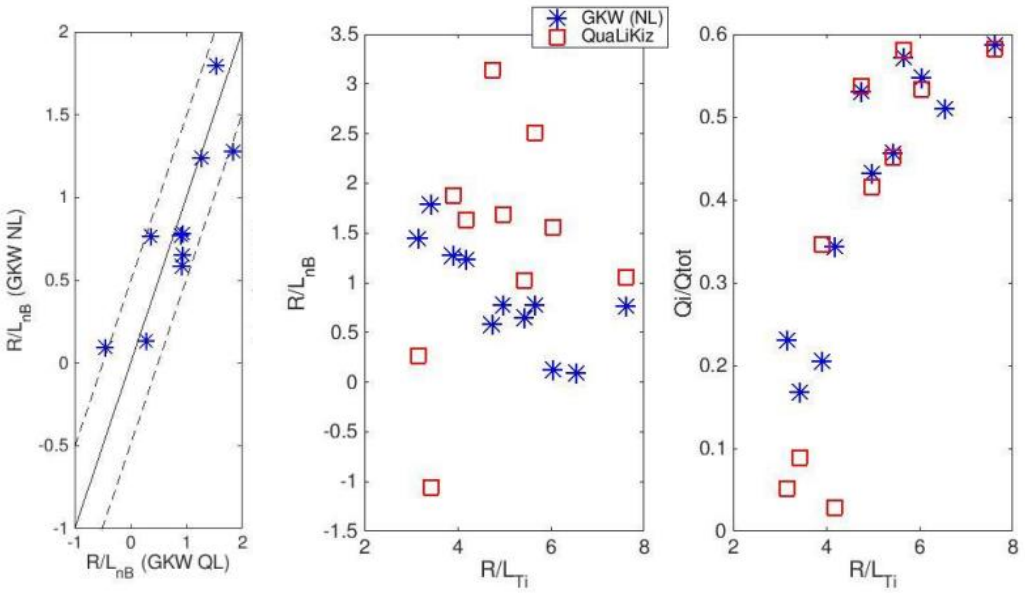


The ultimate goal of this algorithm development & exploration work is to identify methods to pool the heterogeneous information sources (noisy experimental data, multi-fidelity physics approaches) to a unified representation for SOL-pedestal. This may also be useful for applications outside SOL-pedestal.

Milestones planned 2023	status
Milestone 2.2.M1 validated reduced SOL model in the HFPS. Milestone 2.2.M4 validated reduced pedestal models in the HFPS	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

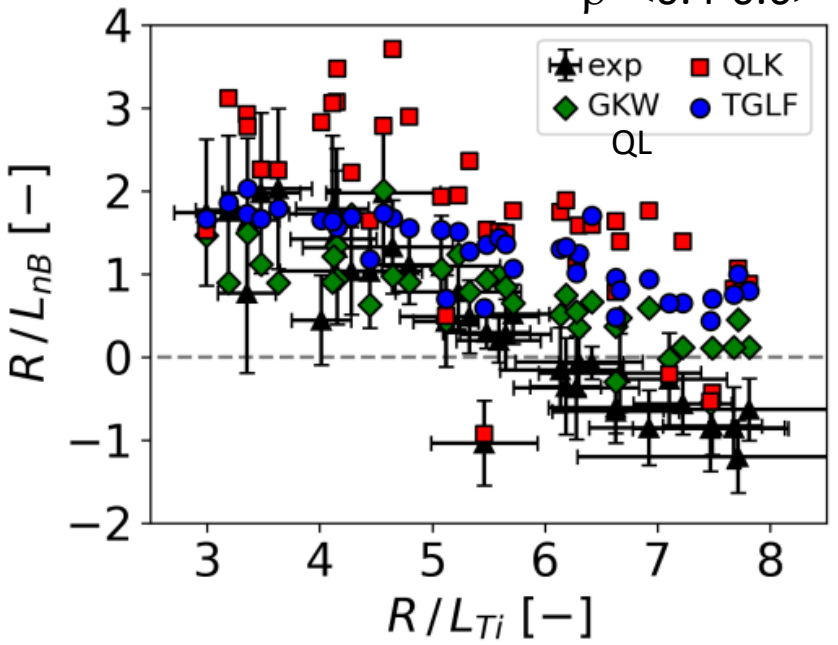
Reduced model validation for turbulent transport of impurities



Boron, AUG database, QuaLiKiz Boron peaking at ρ=0.5 more scattered than GKW-NL, GKW QL~GKW NL

P. Manas TTF+publi

D. Fajardo, ρ=<0.4-0.6>



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 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	FACIT coupling available soon, for tests in Ip ramp up and other cases, Francis. 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…

WP2-D4: MHD modules targeted validation, P. Maget

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

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

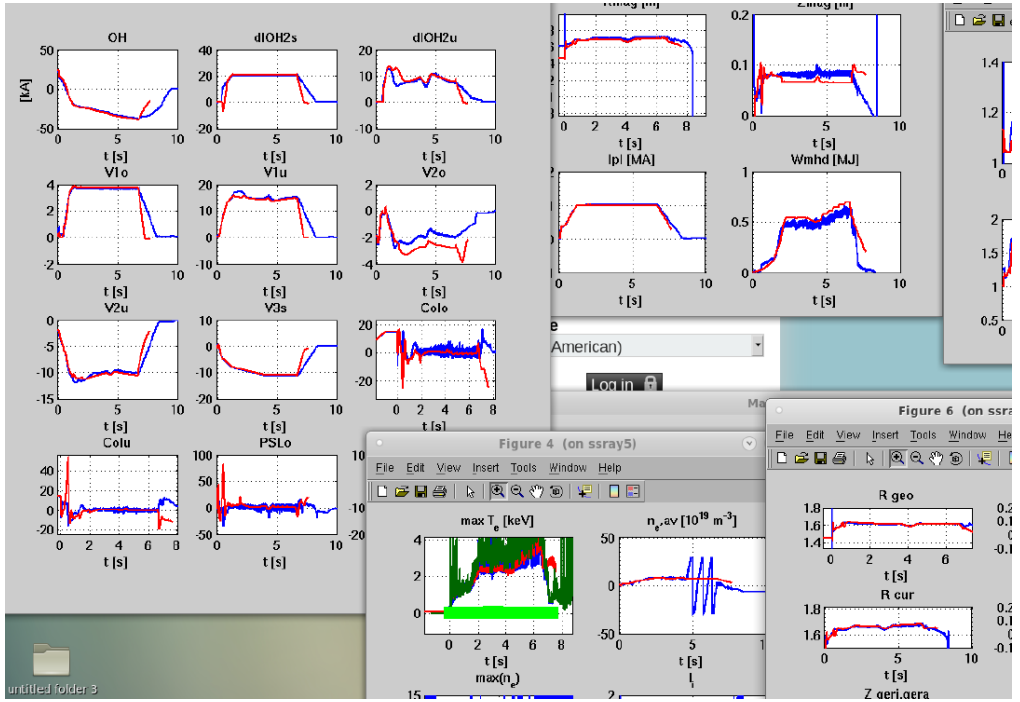
will appear in the Pulse Design

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

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

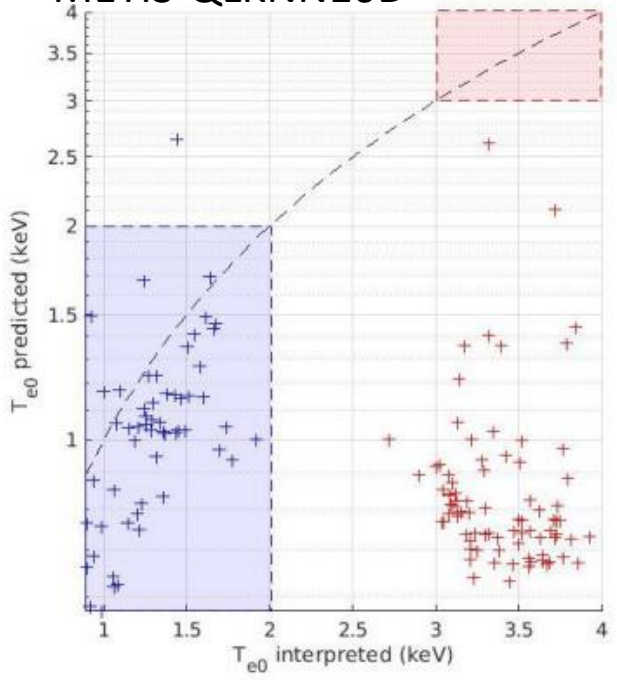
WP4-HFPS systematic validation: 1st project on Bayesian Optimisation

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

METIS-QLKNN10D



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

WP4-HFPS systematic validation, A. Ho: 2023 milestones revision

Milestones foreseen for 2023	Suggested modifications
Milestone 4.2.M1: demonstrated 0D data consistency, e.g. Wth<WMHD, li, neutron flux, Prad-div, Prad_bulk, <Zeff>, <n> on more than 10 plasmas Dec 2022 Milestone 4.2.M2 demonstrated 1D data consistency, e.g. core profiles Te, Ne, Ti, Vtor, Zeff, Er on more than 10 plasmas from more than 2 tokamaks Dec 2022 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	By Dec 2022 we demonstrated on a reduced dataset a 0D check on AUG, JET, TCV and WEST 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** Dec 2024: addition of other tokamaks and of synthetic diagnostics for bolometry, SXR
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	OK, based on EPS TTF A. Ho contributions