Towards an optimized EU-DEMO scenario

Integrated Modelling activites at DIFFER

S. Wiesen et al

Dutch Fusion Day, May 3rd 2024

What is EU-DEMO?

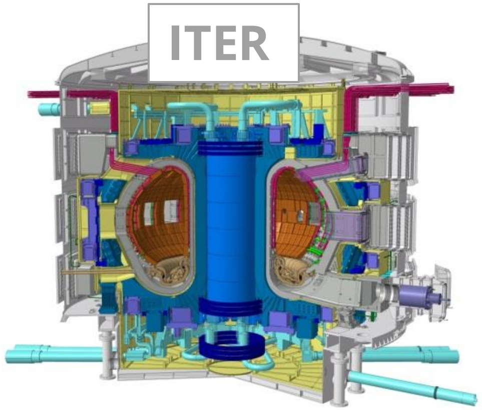
There is no unique definition of DEMO, and different parties have different opinions

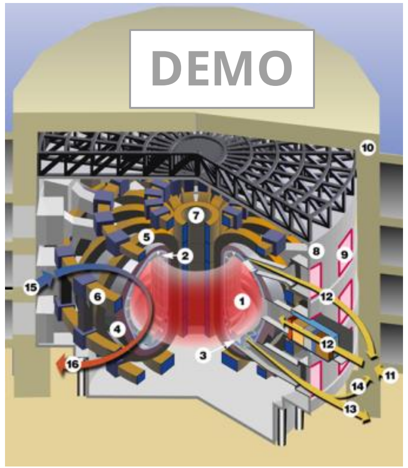
In the current EU Roadmap, DEMO is the single step between ITER and a Fusion Power Plant (FPP)

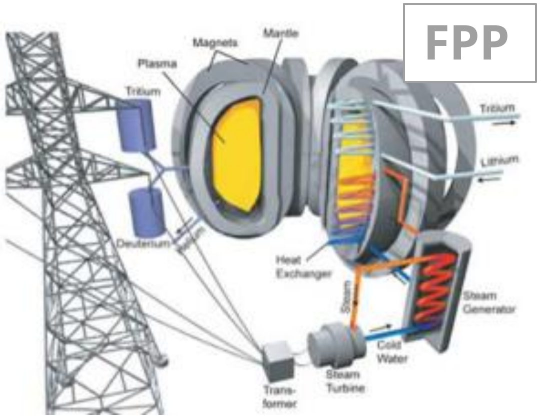
An EU high-level stakeholder group defined the following goals:

- large scale (100s of MW) predictable net electricity production $\Rightarrow$ *300 – 500 MW$_e$*
- self-sufficient fuel cycle $\Rightarrow$ $TBR_{eff} > 1$
- high reliability and availability over a reasonable time span $\Rightarrow$ $\tau_{pulse} \geq 2$ *hrs*

$\Rightarrow$ allow assessment of economic and environmental prospects of FPPs



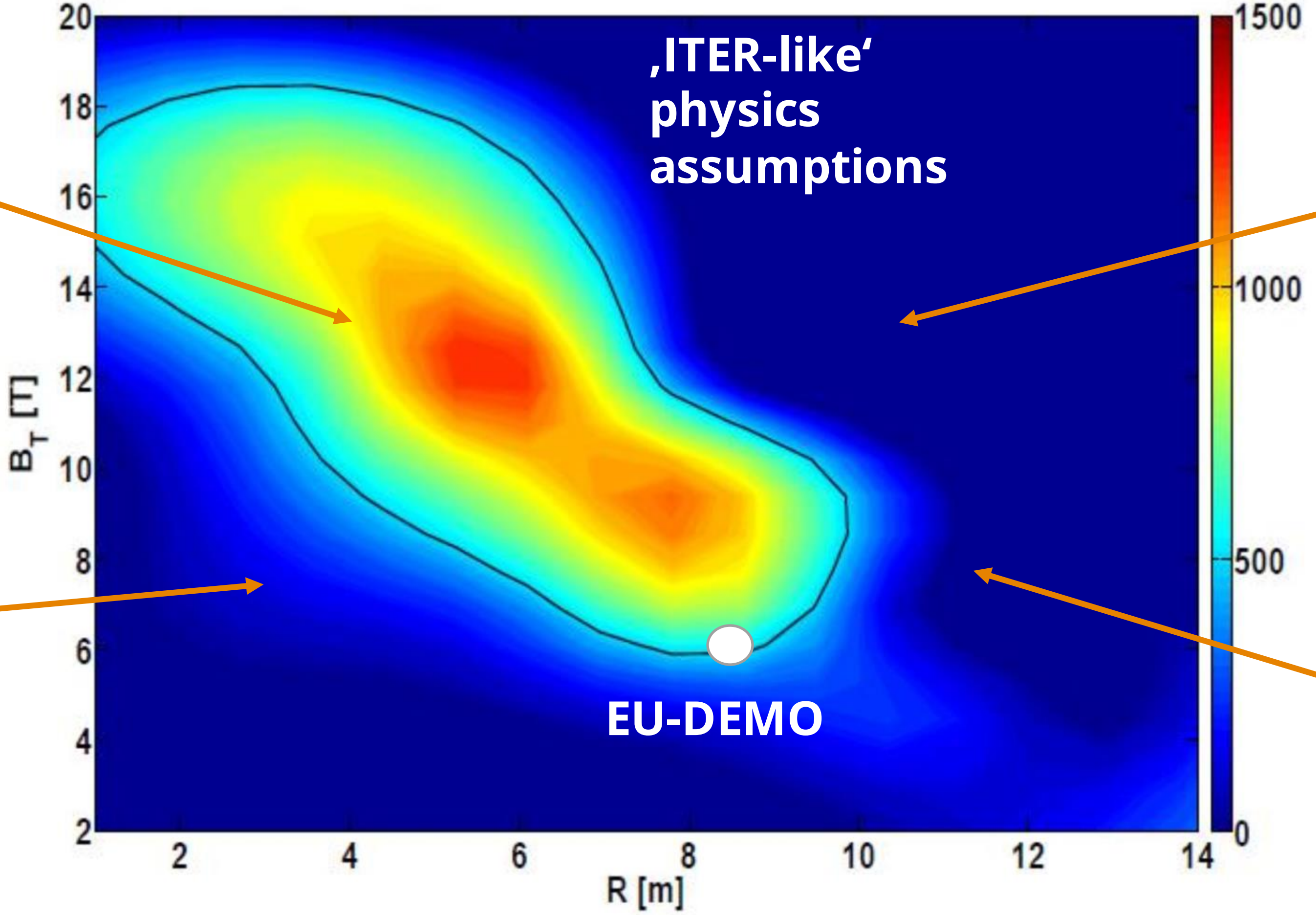




DEMO design space heavily constrained by physics and technology

technology not (yet) mature to reach high B_t

synchrotron radiation losses too high

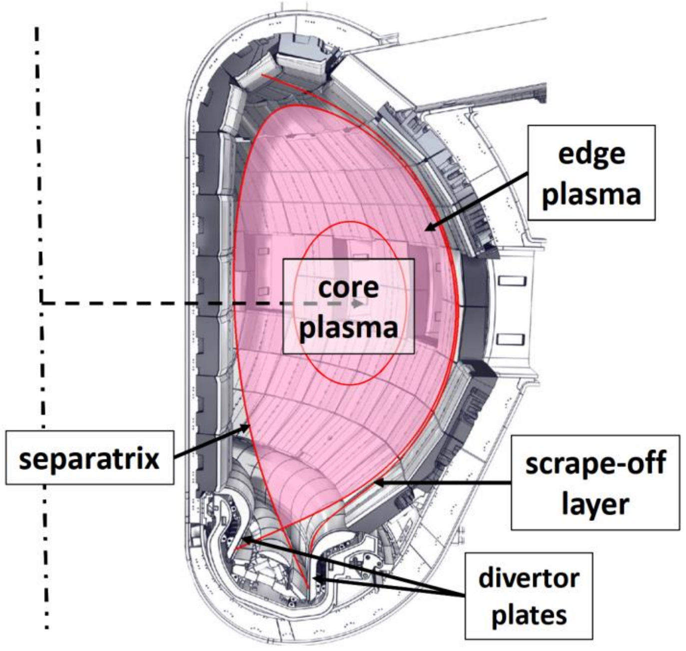


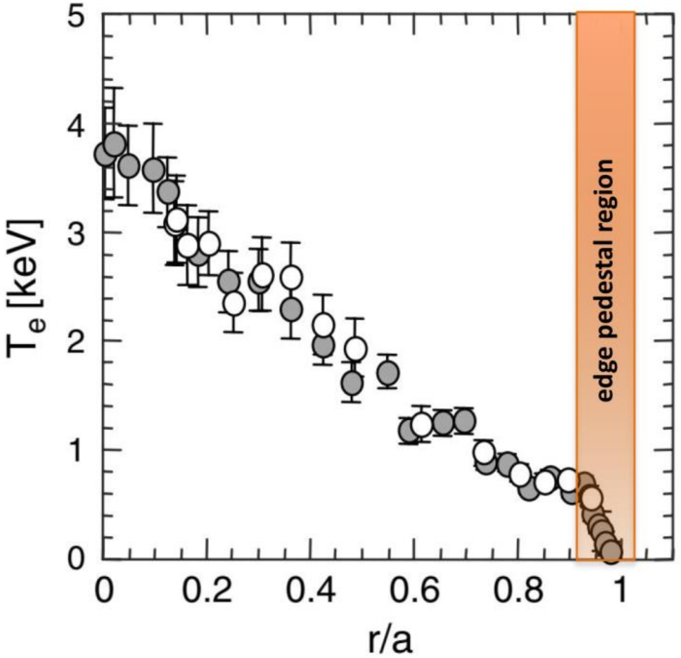
confinement too low to achieve necessary Q

divertor protection requires excessive impurity seeding

M. Siccinio et al., Nucl. Fusion 2017

Elements of the DEMO plasma scenario modelling

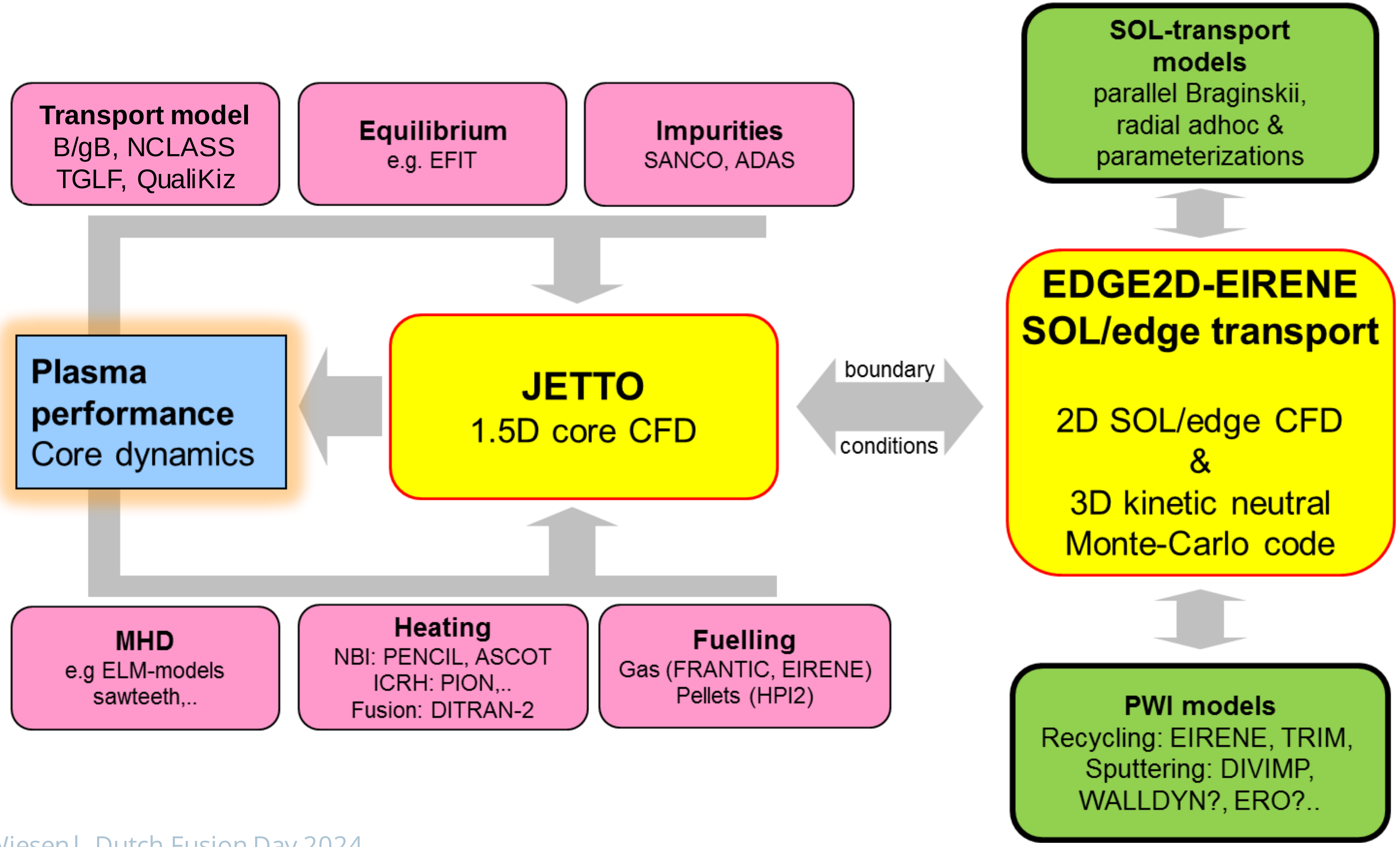




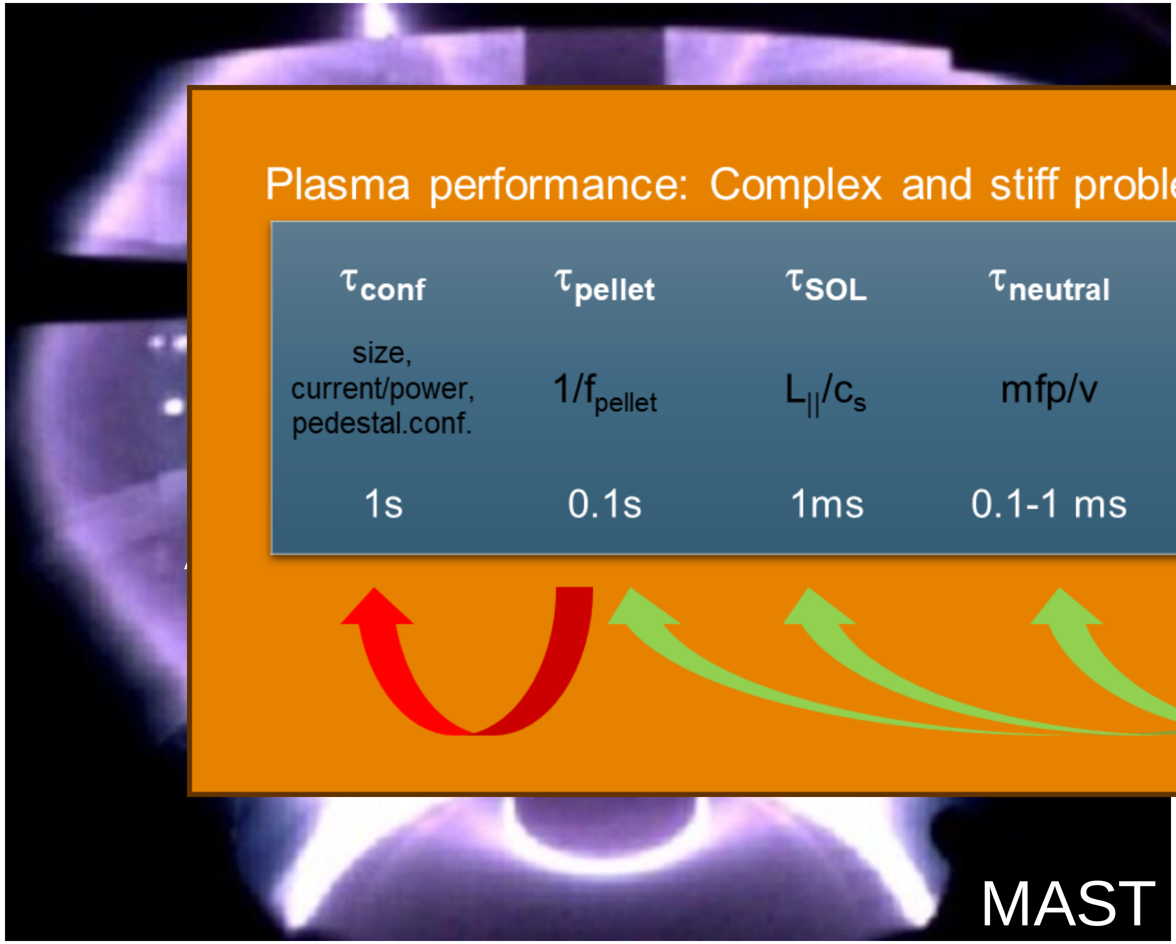
Assumption: plasma volume broken down into 3 regions (non-linearly coupled)

- core: closed flux surfaces - burning plasma ($T_i \approx T_e \approx 30$ keV, $2 \times n_D \approx 2 \times n_T \approx n_e \approx 10^{20}\ m^{-3}$)
- scrape-off-layer / divertor: plasma flows along ‚open' field lines to divertor ($T_e = 5$ eV)
- edge: connects core and scrape-off-layer (closed flux surfaces, but different physics)

JINTRAC High-Fidelity Plasma Simulator (HFPS) EUROFusion / ITER



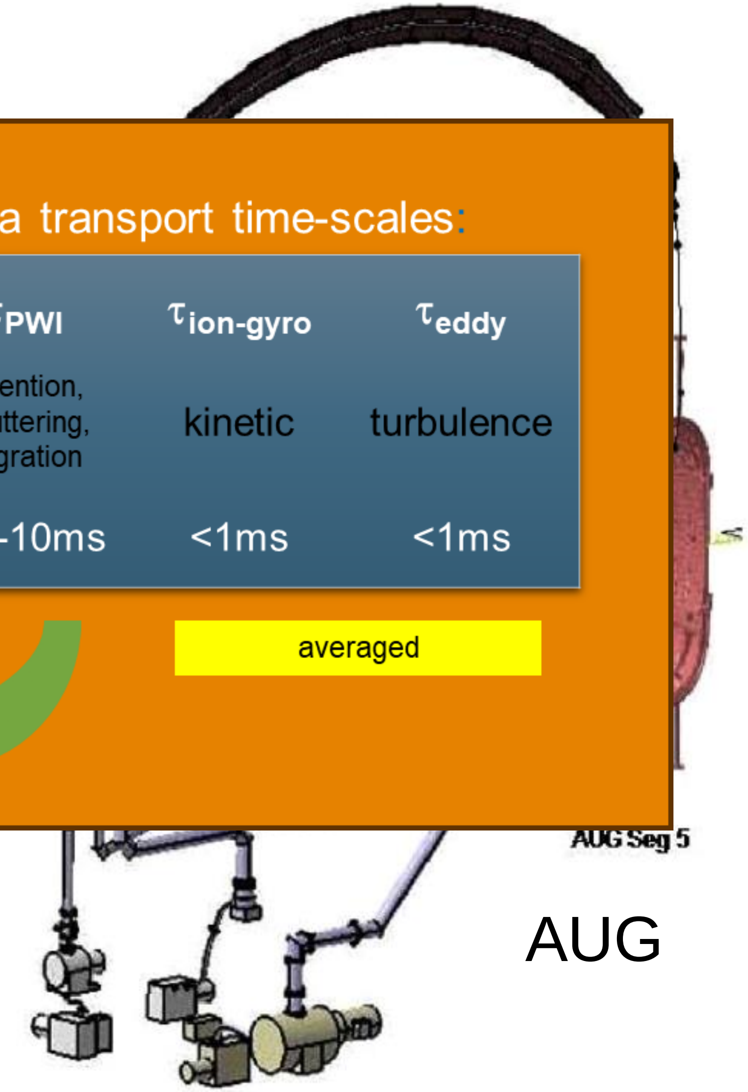
Example for transients in a fusion reactor: Pellet fuelling



Plasma performance: Complex and stiff problem, e.g. plasma transport time-scales:

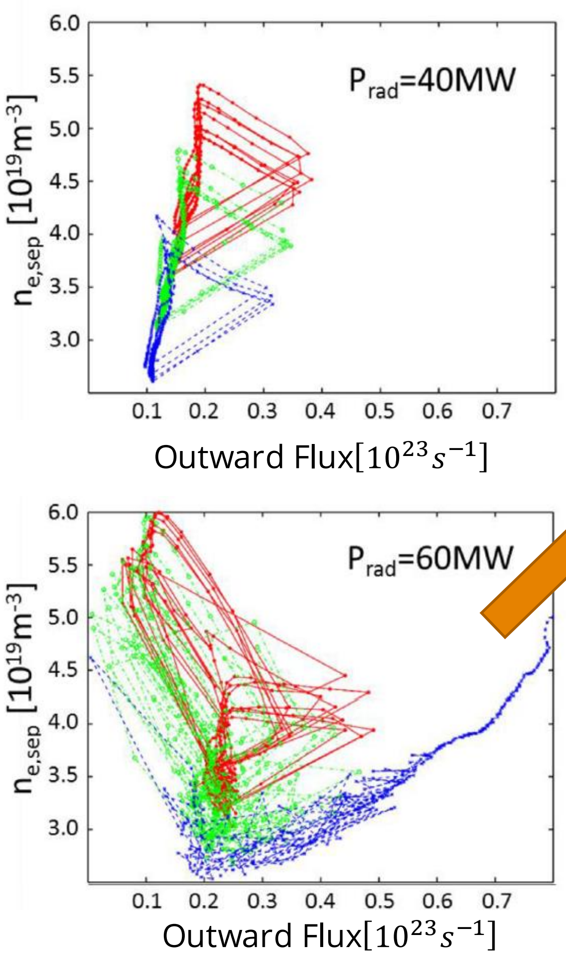
τ_{conf}	τ_{pellet}	τ_{SOL}	$\tau_{neutral}$	τ_{ELM}	τ_{PWI}	$\tau_{ion\text{-}gyro}$	τ_{eddy}
size, current/power, pedestal.conf.	$1/f_{pellet}$	$L_{\|\|}/c_s$	mfp/v	MHD	retention, sputtering, migration	kinetic	turbulence
1s	0.1s	1ms	0.1-1 ms	0.1ms	0.1-10ms	<1ms	<1ms

averaged



JINTRAC flight-simulator example: Pellets in ITER

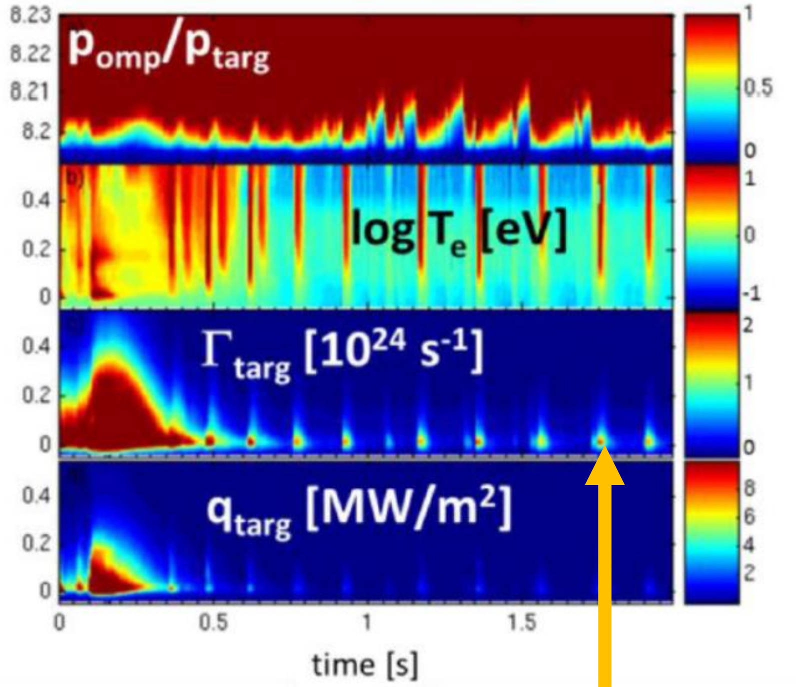
Density at core plasma



Impurity radiation control required

Add more impurities to radiate extra power

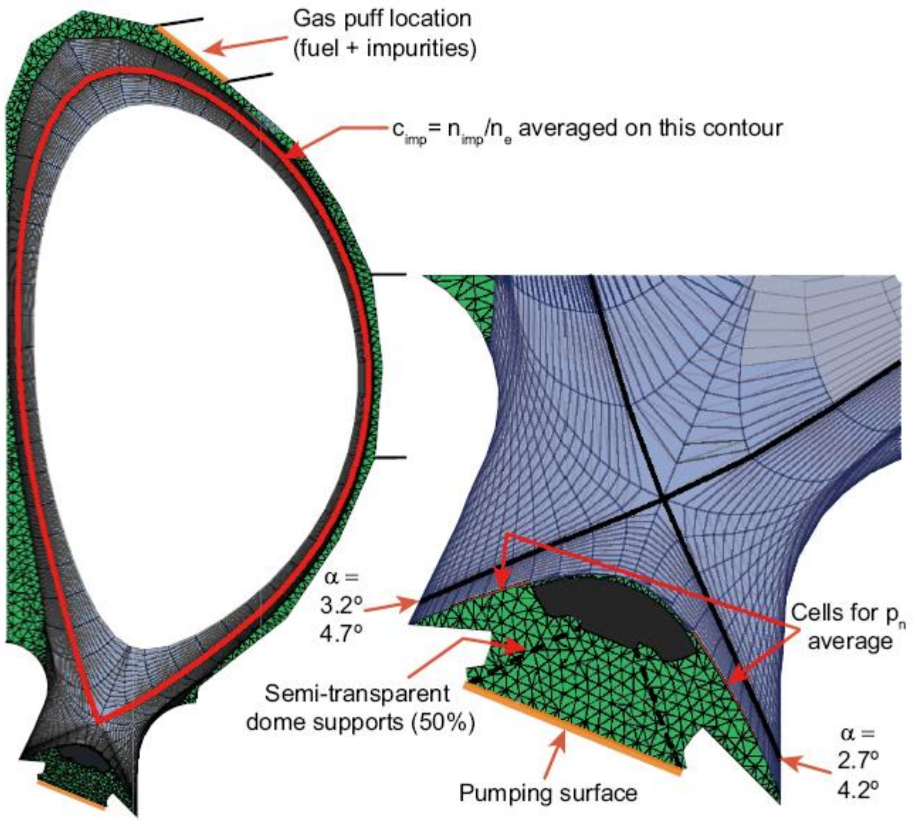
Divertor Conditions ("cold")

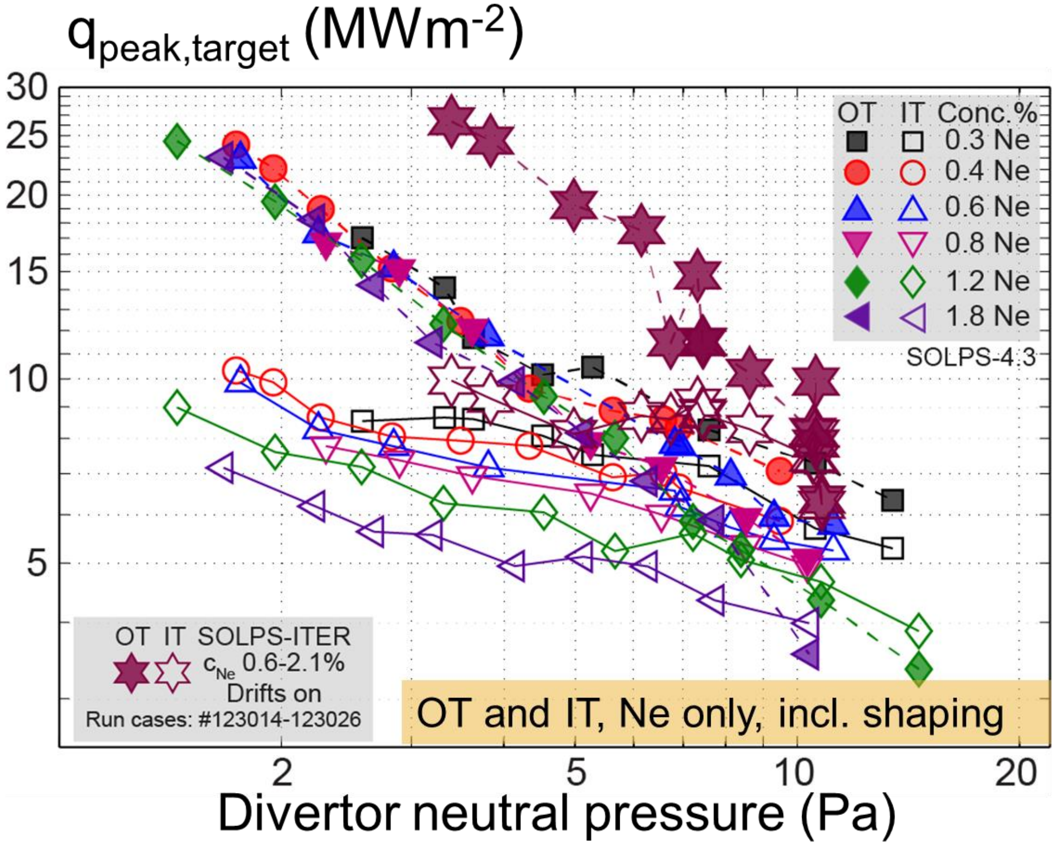


Bursts of transient fusion power increase during pellet ablation → causes re-attachment of plasma at divertor plates

[Wiesen, Köchl, NF 2017]

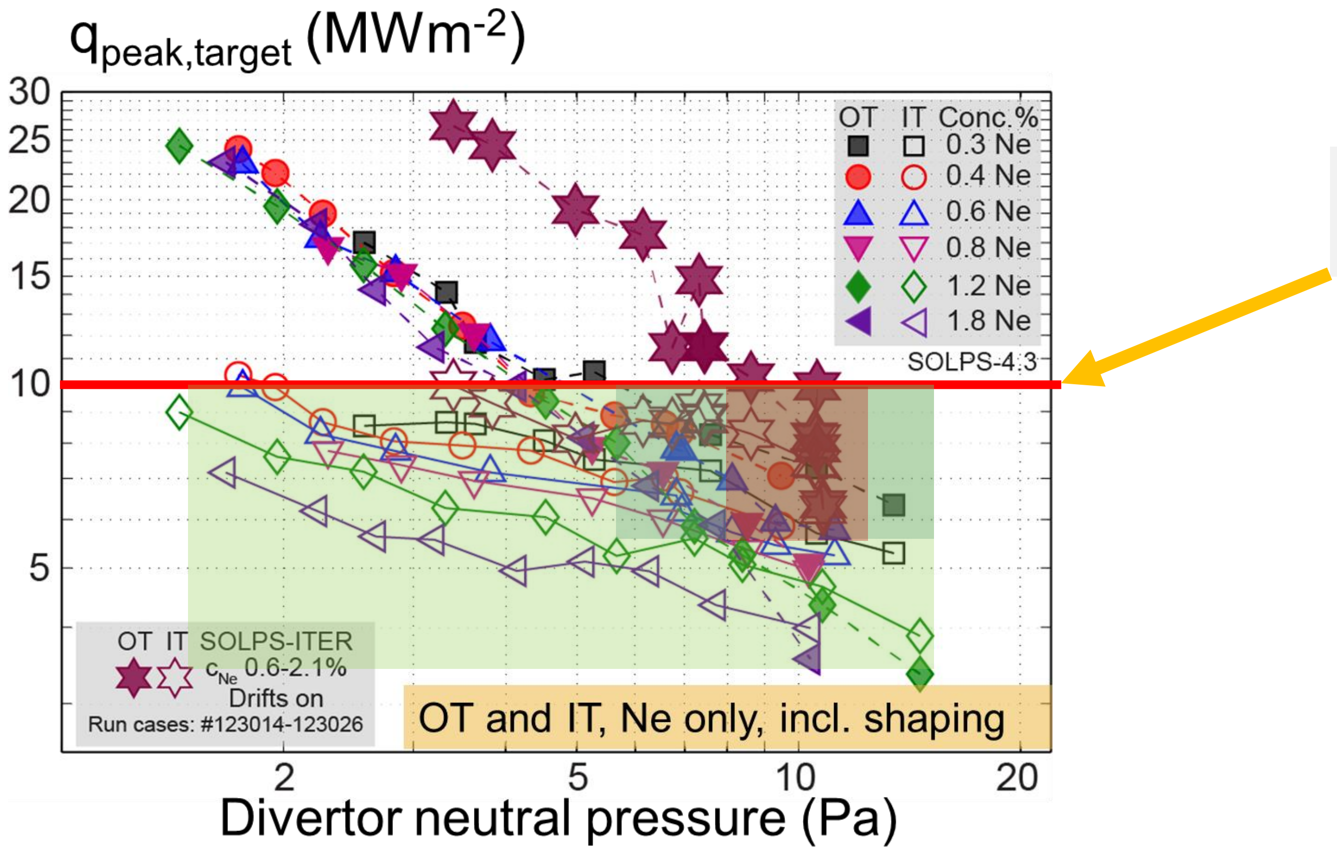
Physics Excursion: ITER Divertor Design - SOLPS-ITER





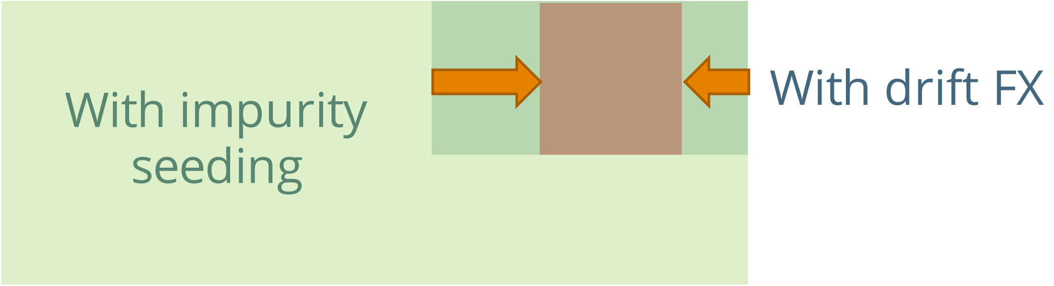
R.A. Pitts, E. Kaveeva, V. Rozhanski, S. Wiesen, X. Bonnin et al, NME 2019

Physics Excursion: ITER Divertor Design - SOLPS-ITER



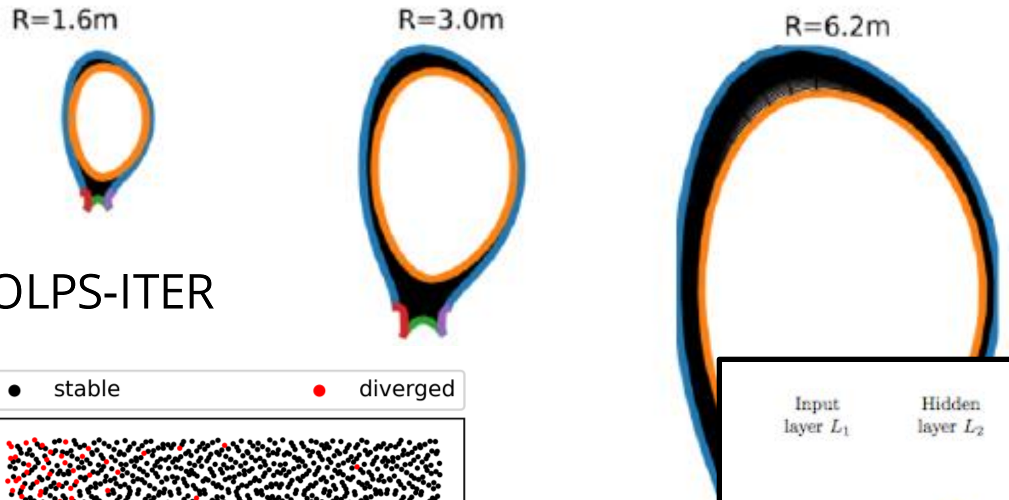
Material limit
10 MW/m²

More physics also requires longer simulation times

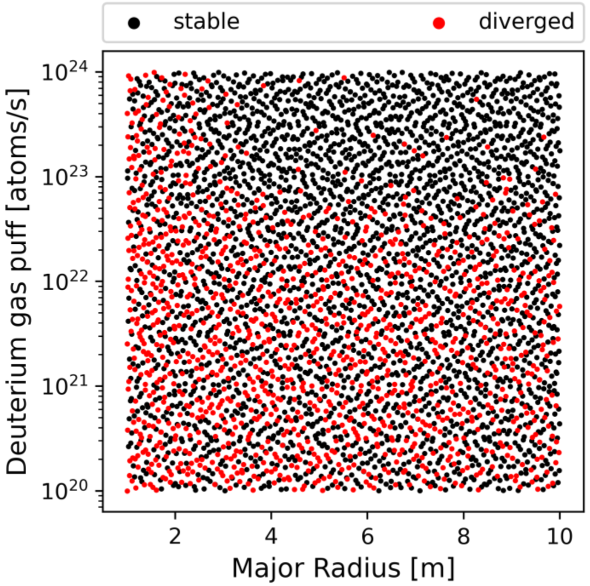


Size of divertor operational window

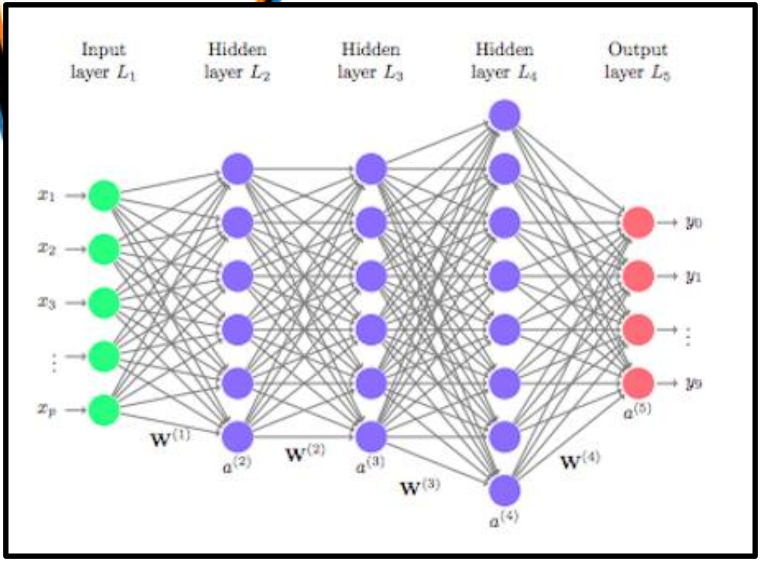
Speeding up the SOL: fast, model based deep learning surrogates



SOLPS-ITER



S. Dasbach, S. Wiesen
PSI2022, ENR-AI project

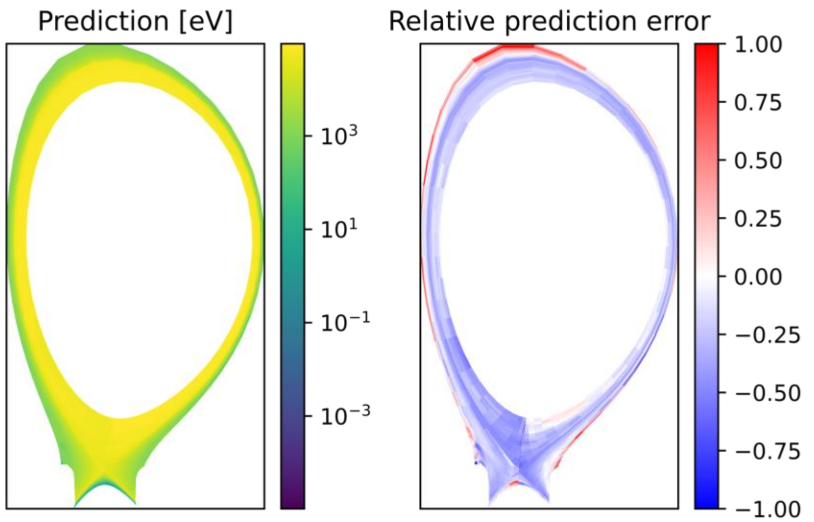


SOLPS-NN trained by using data from SOLPS-ITER baseline simulations with fluid neutrals

Input parameters R, B, …
Dimensions: 8

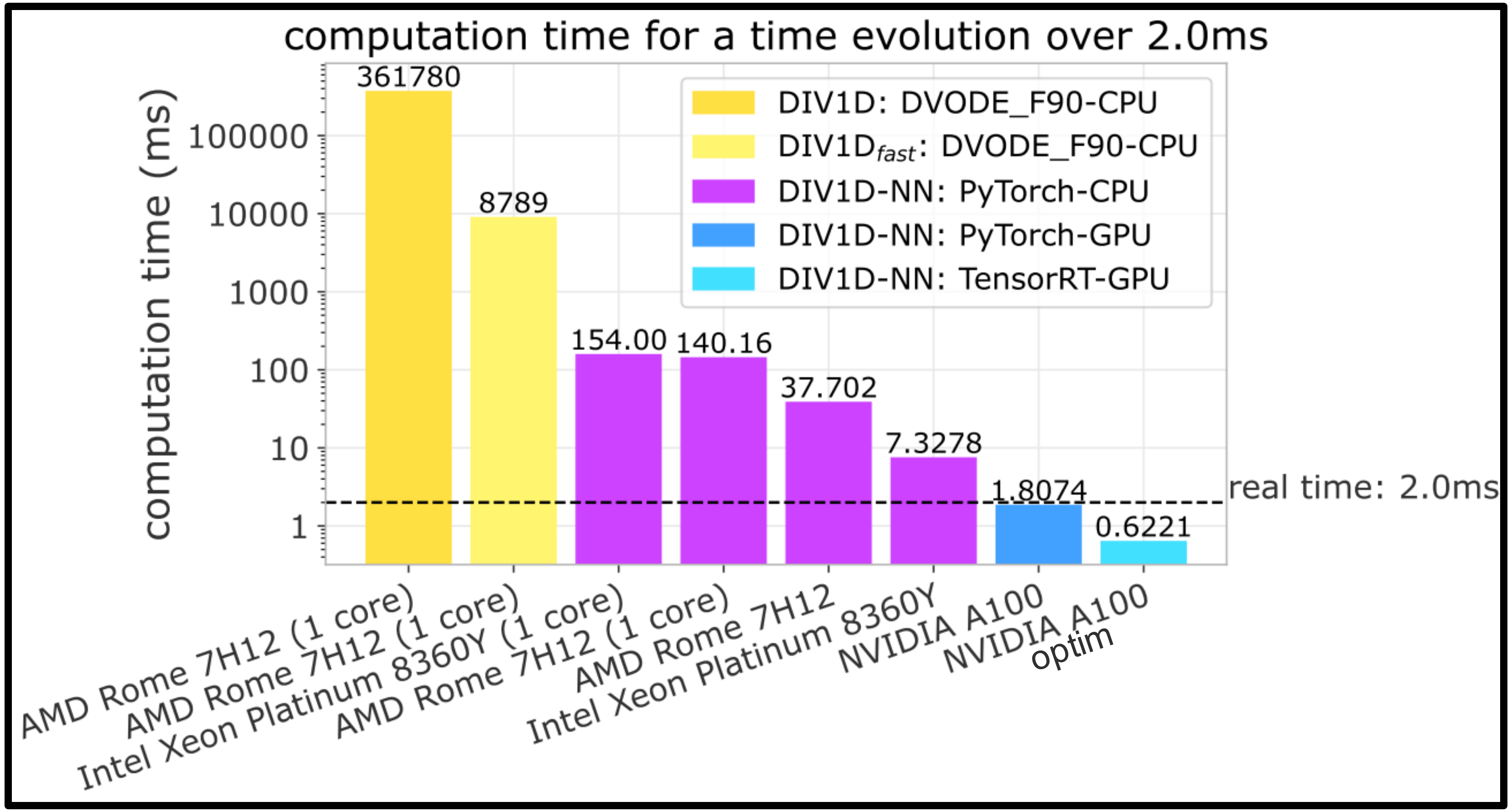
Convolutional Neural Network

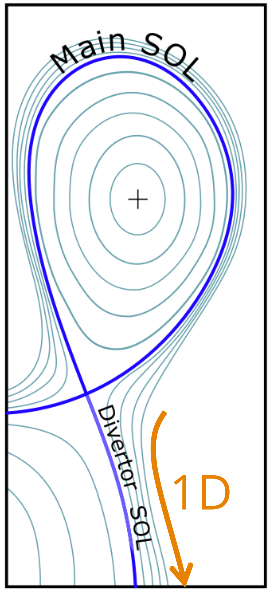
full 2D profiles



Towards time-dependent surrogate models for exhaust

Learn "neural PDE surrogates" from datasets of dynamic DIV1D SOL simulations:





ENR AI project
Y. Poels et al
Nucl. Fusion 63 (2023) 126012

Conclusions

An integrated multi-physics approach advantageous to explore an optimized EU-DEMO operational window for plasma exhaust consistent with fusion core-plasma performance.

Hierarchical system of fidelity required, ranging from/to:

- Systems-codes need heavily reduced models (0D)
- Design studies need (validated) high-fidelity models including lots of physics (2D/3D)
- Control schemes need understanding of dynamics & transients, e.g. re-attachment, f(t)

Recent activities on development of fast AI-based surrogate exhaust models

- Promising: relevant for fast & adequate flight-simulators, plasma-control & pulse-design

Contact

Dr. Sven Wiesen
Groupleader Integrated Modelling
+31 40 3334 838
s.wiesen@differ.nl

DIFFER
Eindhoven, The Netherlands
info@differ.nl | www.differ.nl