Development of JET Hybrid Plasmas in Deuterium and Deuterium-Tritium for Impurity Screening

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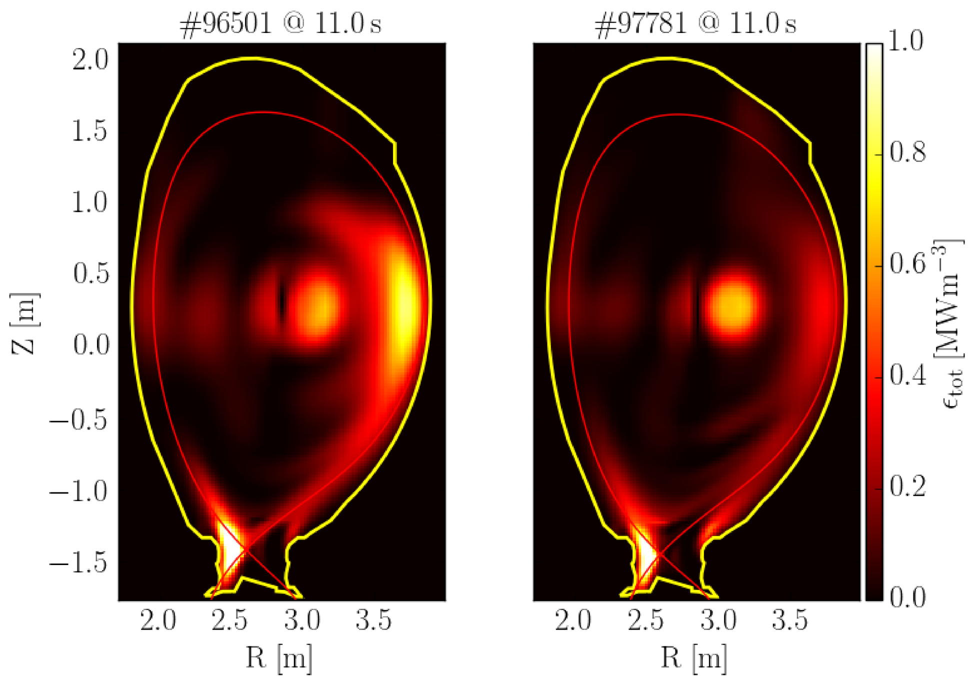
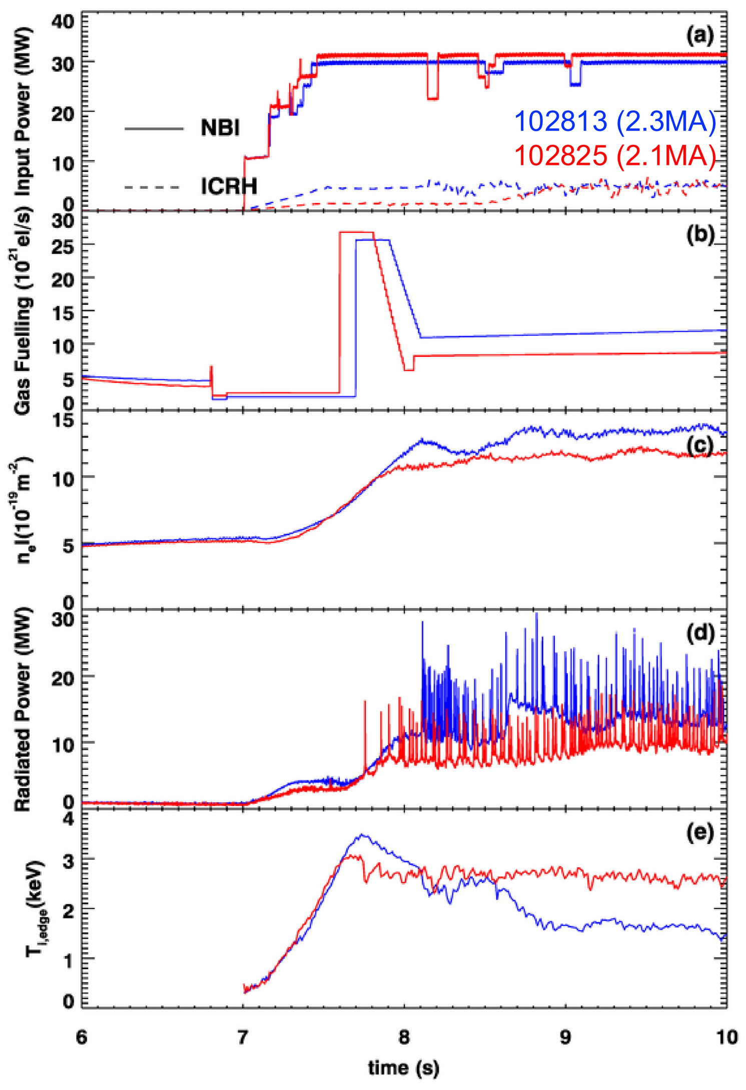
Background

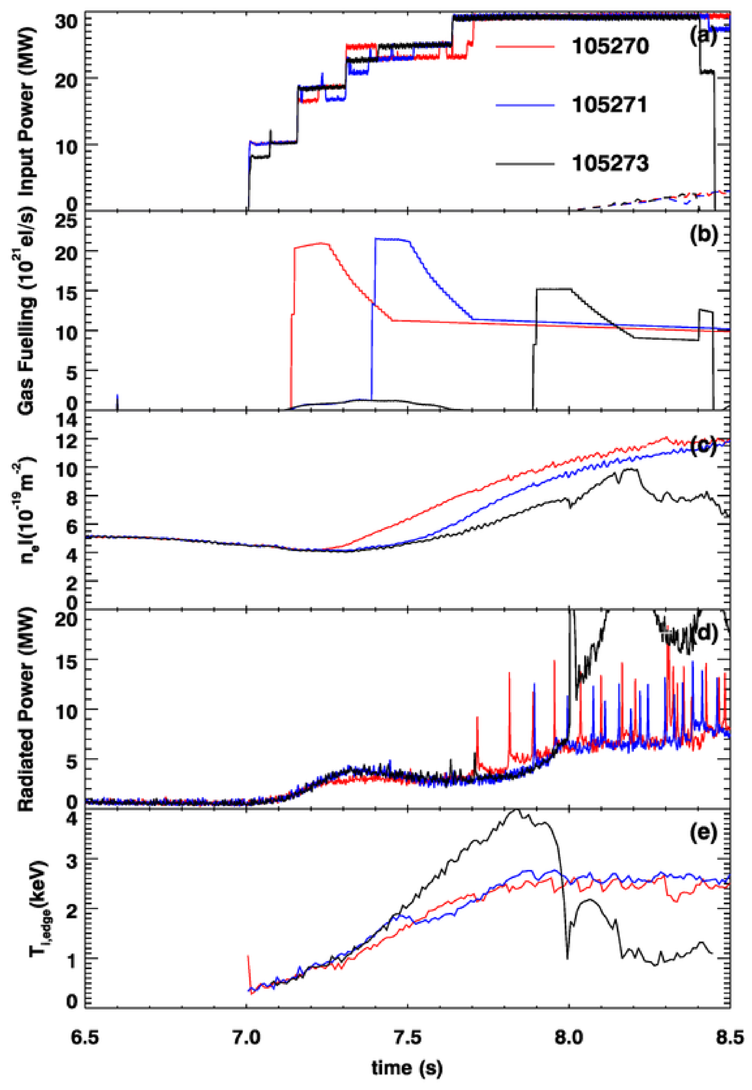
- Tungsten accumulation in the core of tokamak plasmas can limit the overall performance of a device.
- Temperature gradient screening, where neoclassical transport of tungsten is favourable can mitigate this [1,2].
- Hybrid plasmas on JET have exhibited temperature screening related to low. collisionality and strong rotation in the edge [3,4].
- Radiation profiles of two JET pulses are shown to demonstrate the effect. the left pulse is not optimised for screening and shows high edge radiation while the right pulse is strongly optimised and showed impurity screening.
- Bolometer data is used to determine if a plasma is screening impurities inter-ELM or flushing them during an ELM as shown in [4].
- The goal of this work was to further optimise the pulse and vary parameters to study impurity screening.



$$\frac{R}{L_{T_i}} > C_{TS} \times \frac{R}{L_{n_i}}$$

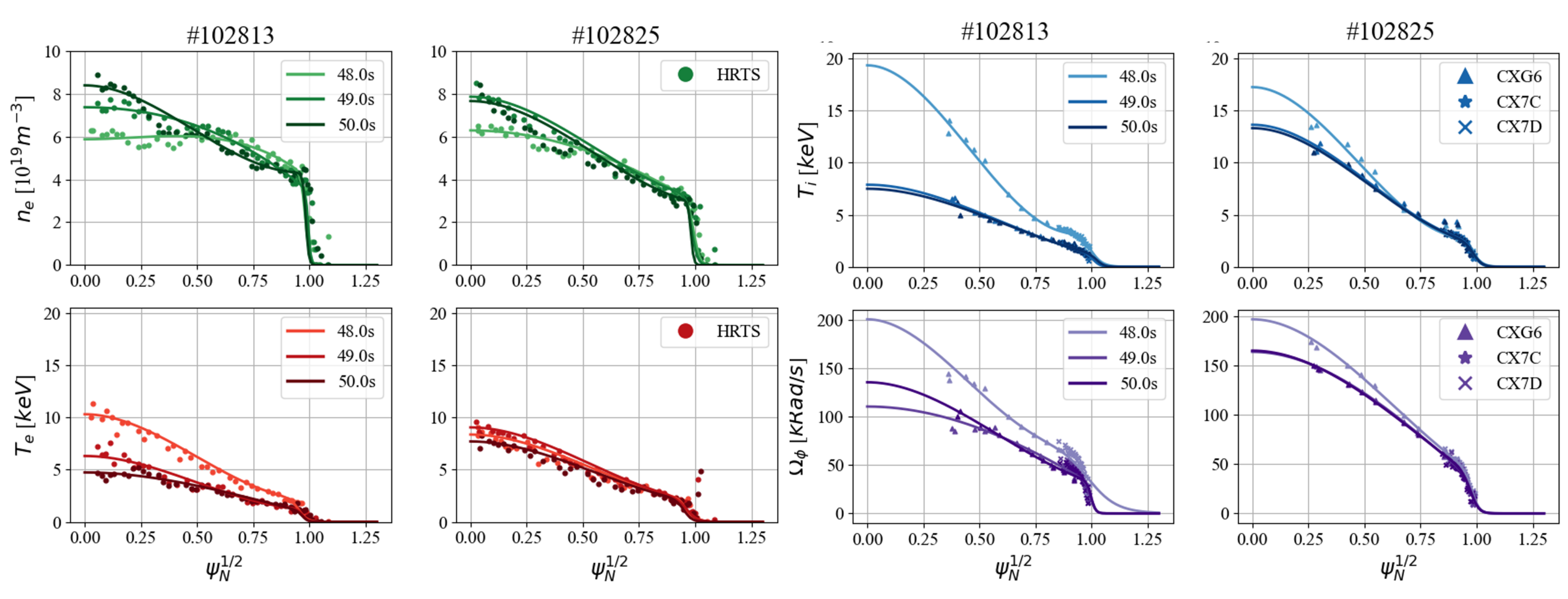
Conditions required for impurity screening. C_{TS} ~0.5 for mantle





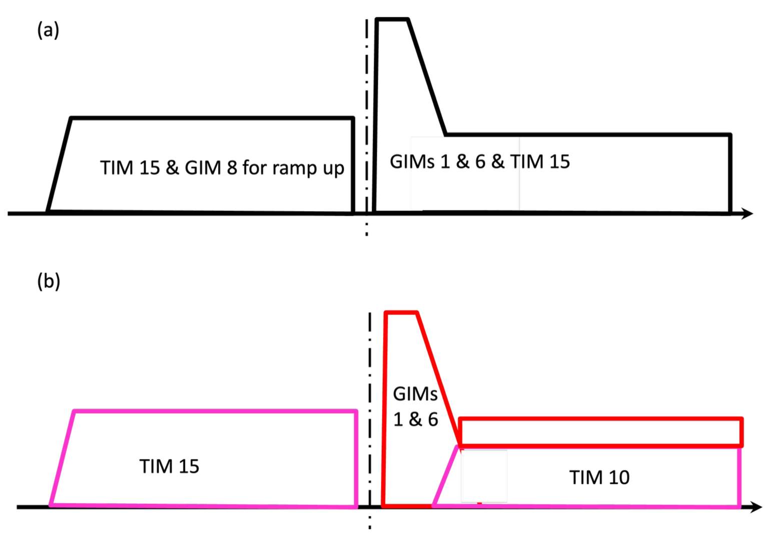
Deuterium Experiments

- The key optimisation of the pulse is the H-mode entry, heating is applied with low gas level until a high temperature pedestal is achieved then gas is puffed after a delay. If this delay is too small, then the high temperature is not achieved but if it is too late then the first ELM is too large. This optimisation took place in the 2020 JET experimental campaign within 2.3MA/3.45T plasmas.
- Variations in the pedestal were pursued to attempt to change the collisionality and/or rotation and explore the screening effect. This was done by varying plasma current, density at the point of NBI injection and timing of gas-puff for first ELM triggering.
- The above left plot shows the pulses achieved at 2.1MA and 2.3MA. It can be seen that a lower density was achieved in the 2.1MA plasma and hence this pulse should be more favourable for impurity screening.
- The above right plot shows the variation with gas puff timing. It can be seen here that the earlier gas puff (red) leads to higher density and earlier ELMs while the latest gas puff (black) leads to higher Ti but on the first ELM the radiation is too high and the plasma is stopped. The blue pulse could be considered optimal.
- The plasma profiles for the pulses with different plasma current are shown below. Here the reduction in $n_{e,ped}$ at lower current and the commensurate increase in Ti,ped and rotation can be seen.
- Previously there was evidence for impurity screening in D-T plasmas, however due to some issues with the tritium gas injection interfering with the key bolometer data the result was not clear. Hence to achieve clear results in D-T a strategy to avoid this was required.



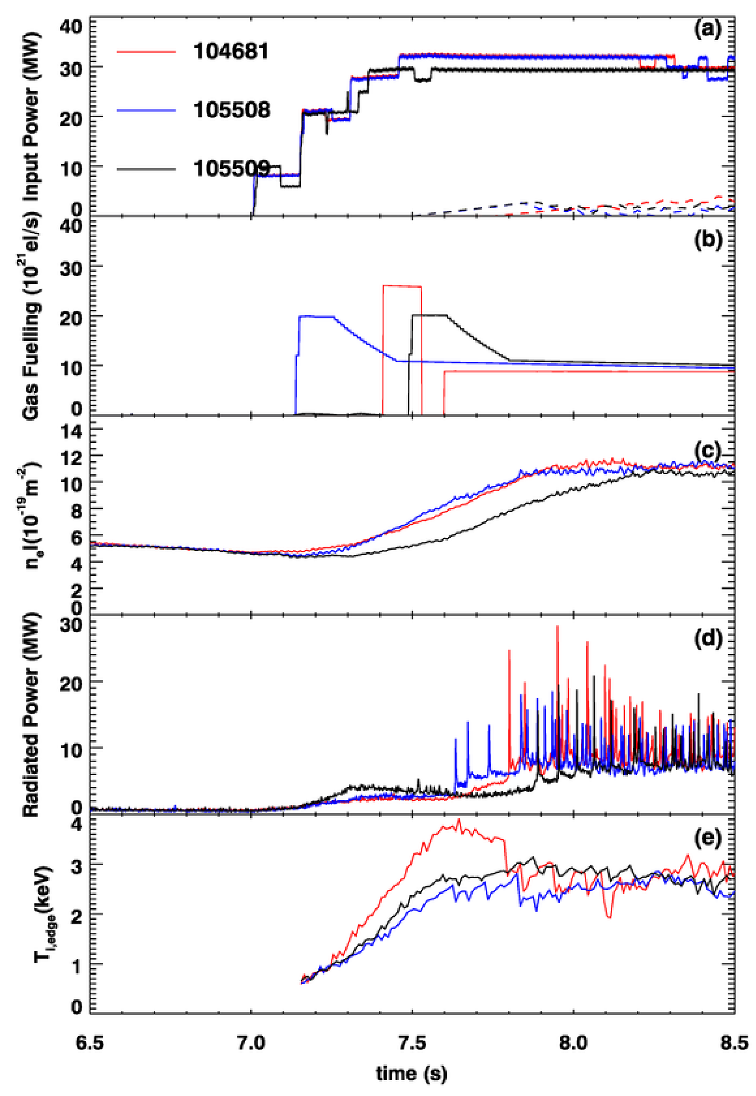
Preparation for D-T

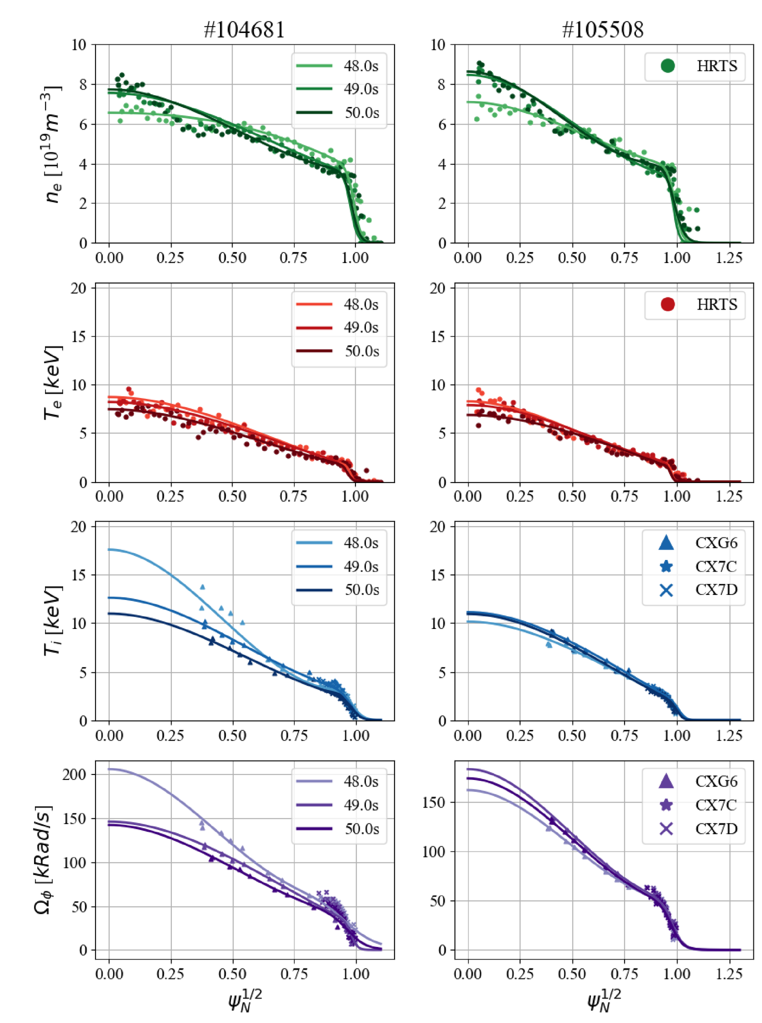
- The impurity screening is accessed on JET with precise timing of main chamber gas
- On JET the Gas Injection Modules (GIMs) and Tritium Injection Modules (TIMs) have different behaviours and are in different locations on the torus. TIM15 is a main chamber TIM near the bolometer.
- The DTE2 strategy is shown in (a) while the DTE3 strategy is shown in (b)
- In DTE3 the main chamber GIMs (1 & 6 as in D) were used for the precise gas timing, the divertor TIM (10) in main phase for tritium fuelling
- Combined with D NBI this could lead to D-rich plasma
- Begin with T-rich plasma to compensate for D-T ratio



Deuterium-Tritium Results

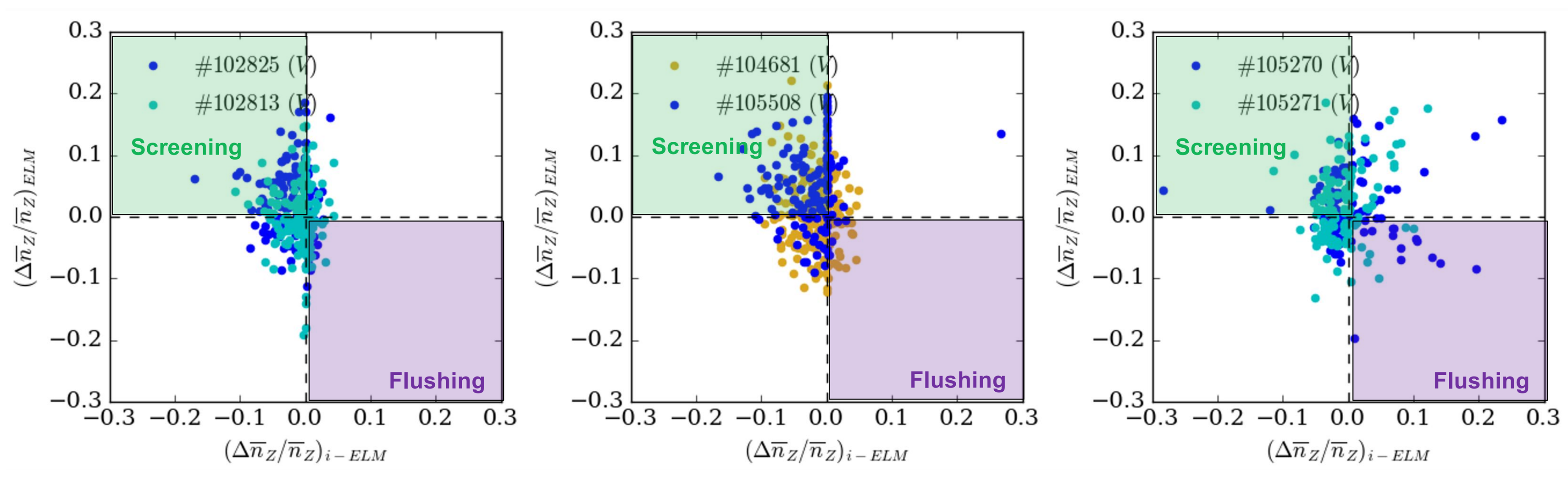
- Begin with ohmic plasma for q-profile check then carry out pulses as prepared from rehearsed D pulses.
- Initial high power led to too-high density in T due to LH power change with isotope.
- Resolved by reducing power ramp.
- Results showed good performance however MHD modes (3/2) were observed in many pulses.
- Increased TF from 3.45T to 3.85T to increase P_{LH} and use full power in initial phase of plasma.
- Further change to gas fuelling made with only divertor TIM in plasma ramp up to further aid bolometer data.
- Following D-T campaign deuterium references were performed (no 3.85T D pulse existed) with different gas timings used to find best match to D-T pulse.
- Comparison of best D-T plasma (104681) with the 2 D plasmas (105508, 105509) shown here. In all cases a high edge Ti was achieved with higher initial Ti achieved in the D-T plasma.
- The profiles of a D vs D-T pulses are shown below, it can be seen that the densities are very similar while the D-T pulse has slightly higher temperature initially.





Screening Results

- By analysing the bolometer data as in [4] it is possible to show if time points within the pulse are showing inter-ELM screening or ELM flushing.
- Shown below are the relative changes in the W content of the plasma due to ELM flushing $(\Delta\overline{nW}/\overline{nW})_{ELM}$ vs the change due to the inter-ELM influx $(\Delta\overline{nW}/\overline{nW})$i–ELM. The I_P variation is shown in panel (a), the D vs D-T variation is shown in panel (b) and the gas puff timing variation is shown in panel (c).
- The plots show that all pulses are demonstrating inter-ELM screening however some pulses show a small variation in screening seen by the points in the upper left corner of the plot.



Summary

- The work required to develop a scenario on JET where impurity screening can be studied has been shown, including the precise gas fuelling strategy, conversion of D to D-T and the adaptation required with the isotope change. A full description of this work is shown in an upcoming paper.
- A deeper analysis of the screening figures shown and simulations of the neo-classical transport of these pulses are shown in a separate work [5].

Key References

[1] Angioni C et al. 2018 Physics of Plasmas 25 082517 [2] Fajardo D et al. 2023 Plasma Phys. and Contr. Fusion 65, 035021 [3] Hobirk J et al. Nucl. Fusion 63, 112001 [4] Field A et al. 2022 Nucl. Fusion 63, 016028 [5] Field A et al. 2025 submitted to Nucl. Fusion

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