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Helium Doped Plasmas on FTU

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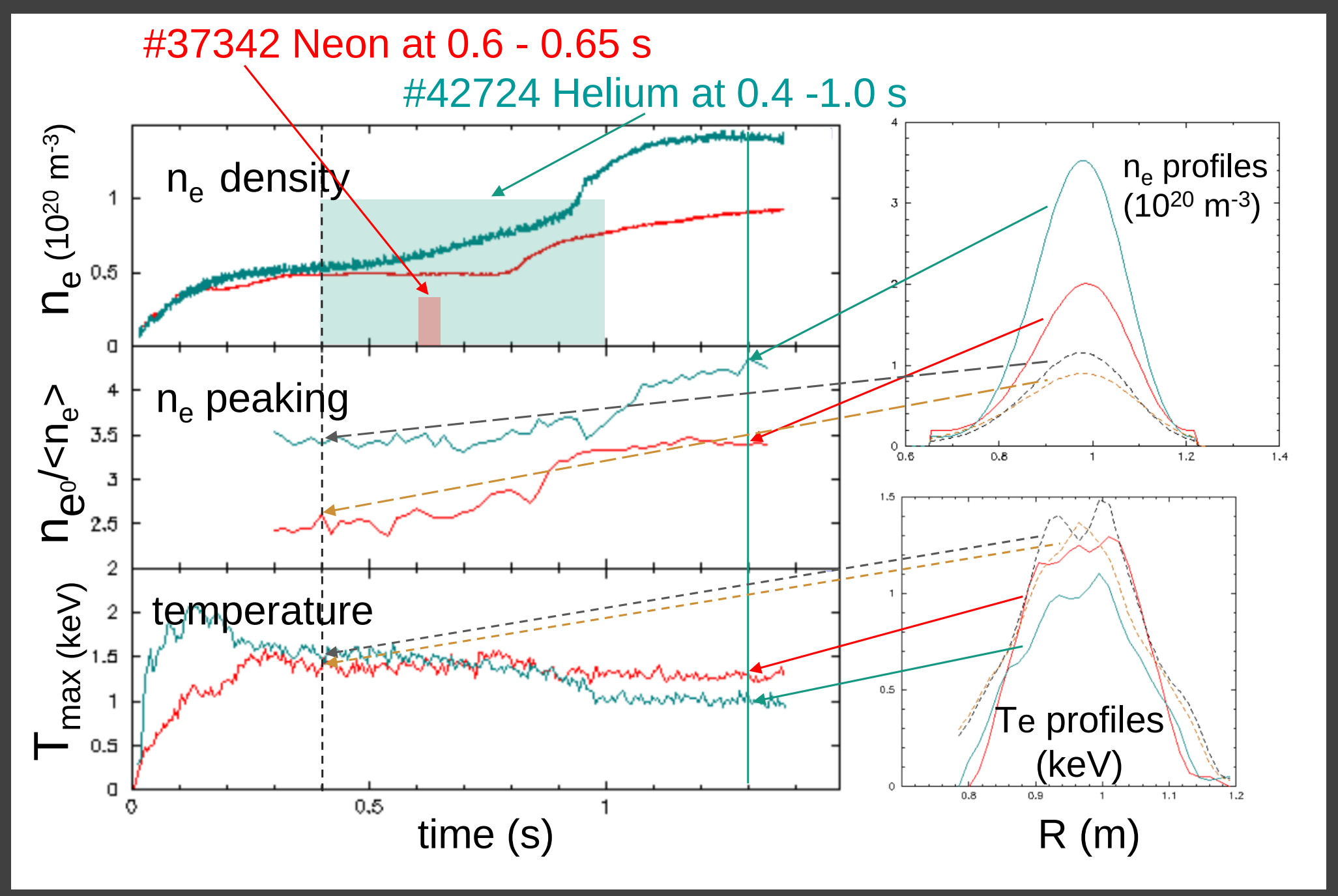
ABSTRACT

- On FTU some sessions have been performed by injecting Helium gas on the L-mode plasmas, in order to extend previous observations about Neon doping already reported.
- Not only the total amount of Helium, but also rate of injection intervenes in triggering particle inflow; It's possible to reach the value of 5 in the electron density peaking.
- VUV spectroscopy measurements help to evaluate the Helium ionization, a model to estimate concentrations of impurities is proposed for the first time.
- The Helium effect on plasma behavior and edge conditioning is exposed.

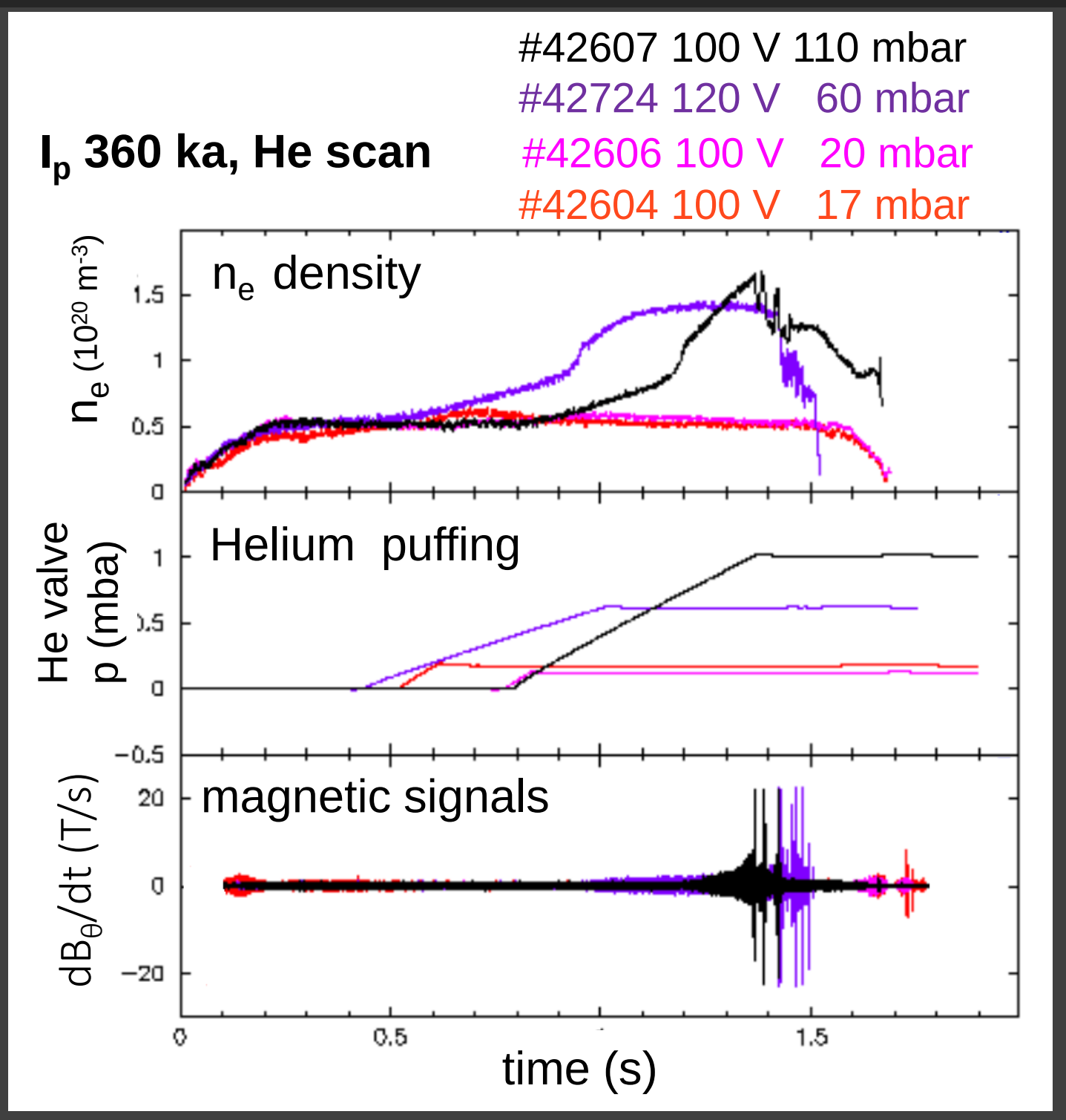
HELIUM VS NEON COMPARISON

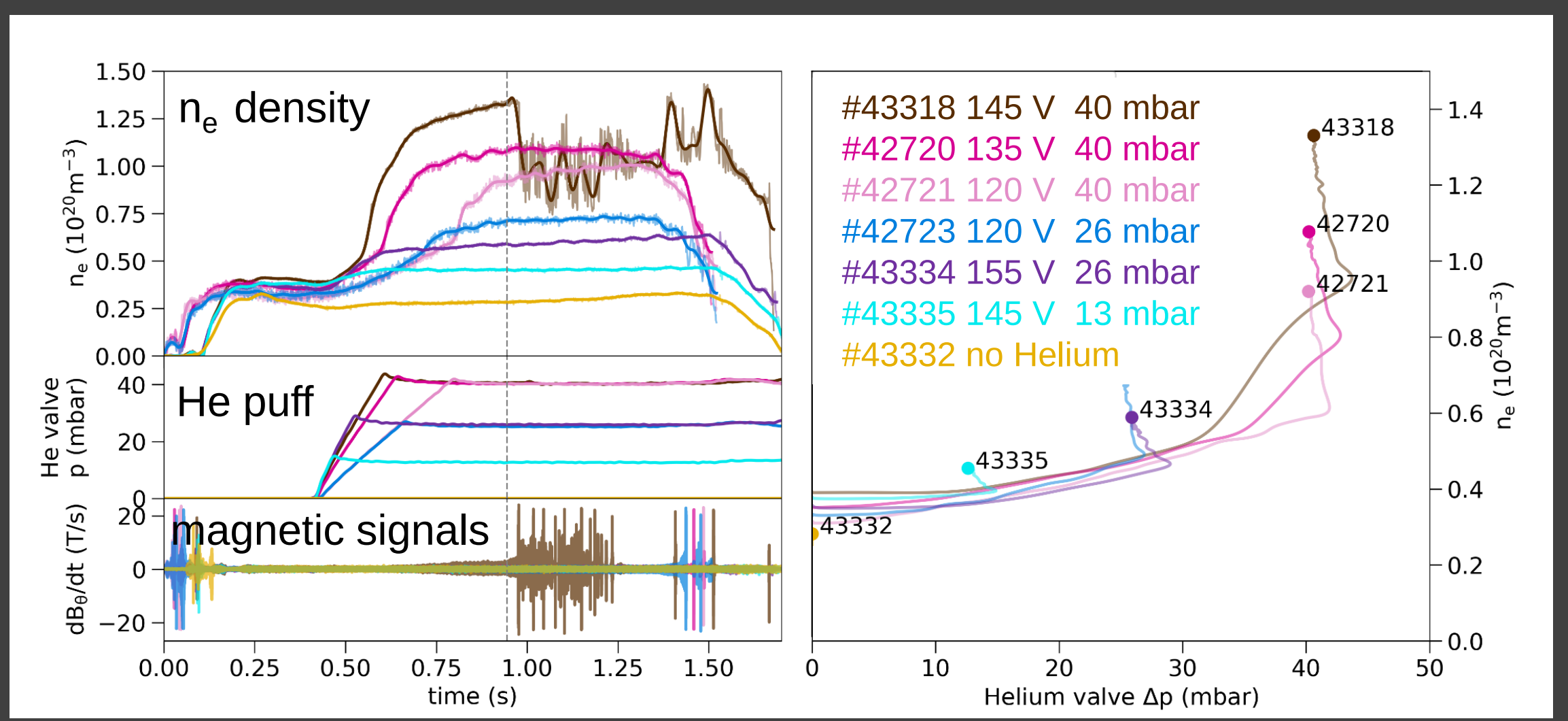


The #37342 has a Neon injection (0.6 - 0.65 s) and reaches a n_e peaking of 3.5, the #42724 recent pulse, with Helium puff (0.4 s for 600 ms) has the same trend in the peaking and arrives to 4. These plasmas with same initial parameters (L-mode, I_p = 360 kA, B_T = 5.2 T, n_{e0} = 0.5 10^{20} m^{-3} T_{e0} = 1.5 keV) have both the D fueling off during density rise and identical T_e profiles before the seeding. The #42724 has undergone a greater cooling.

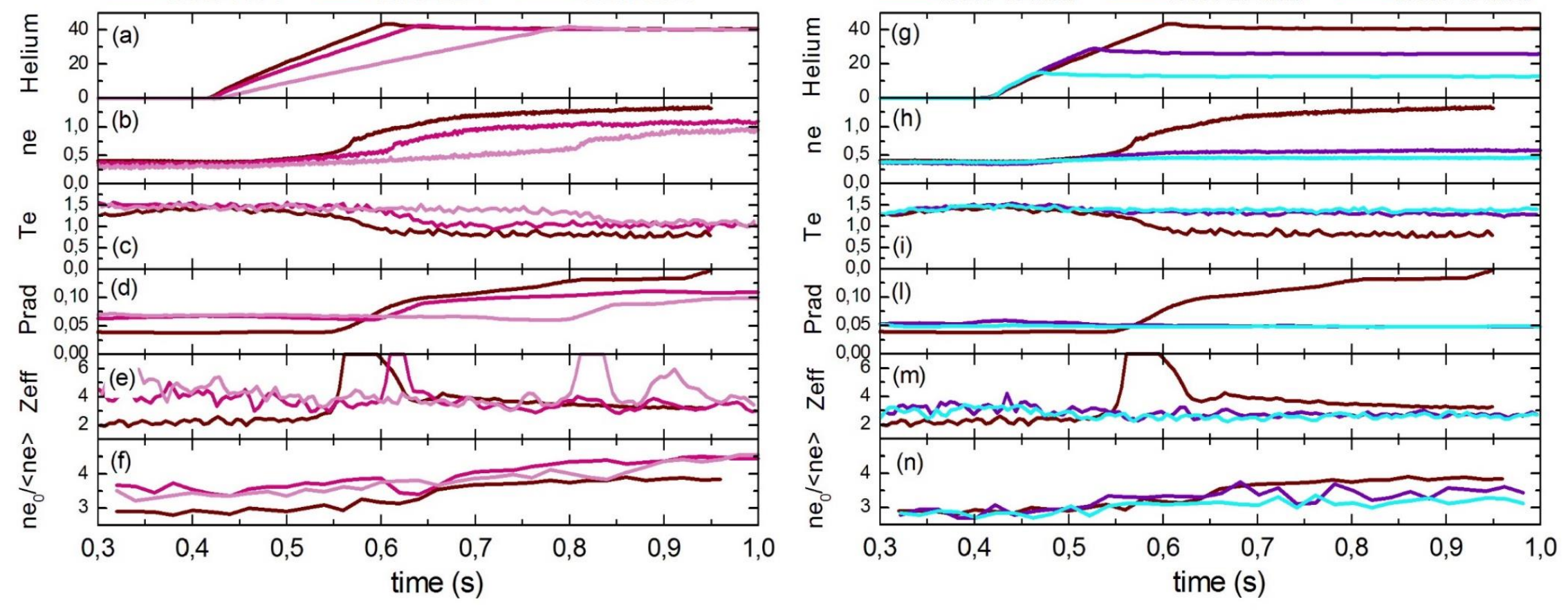
PLASMA RESPONSE TO THE HELIUM INJECTION

At right: pulses at Ip = 360 kA, in the upper panel the ne increase due to He injection. The valve pressure drop Δp scales with He amount (ordinate in the central panel), the rate of injection with the valve voltage (lines slope). The impurity is absorbed as long as triggering a relevant MHD activity (bottom). The #42607 and #42604 establish the min threshold, below no effect can be noticed. An abrupt puff leads to a disruption (#42607), if a soft jab is realized by slowing gas and its rate (#42724), the pulse survives. A He puff working region has been found: 20 – 60 mbar. At 250 kA, 10 mbar is the min threshold, 40 mbar the max (bottom, left fig.). The #43318 (40 mbar) at higher injection rate (145 V) shows an intense MHD activity up disruption.



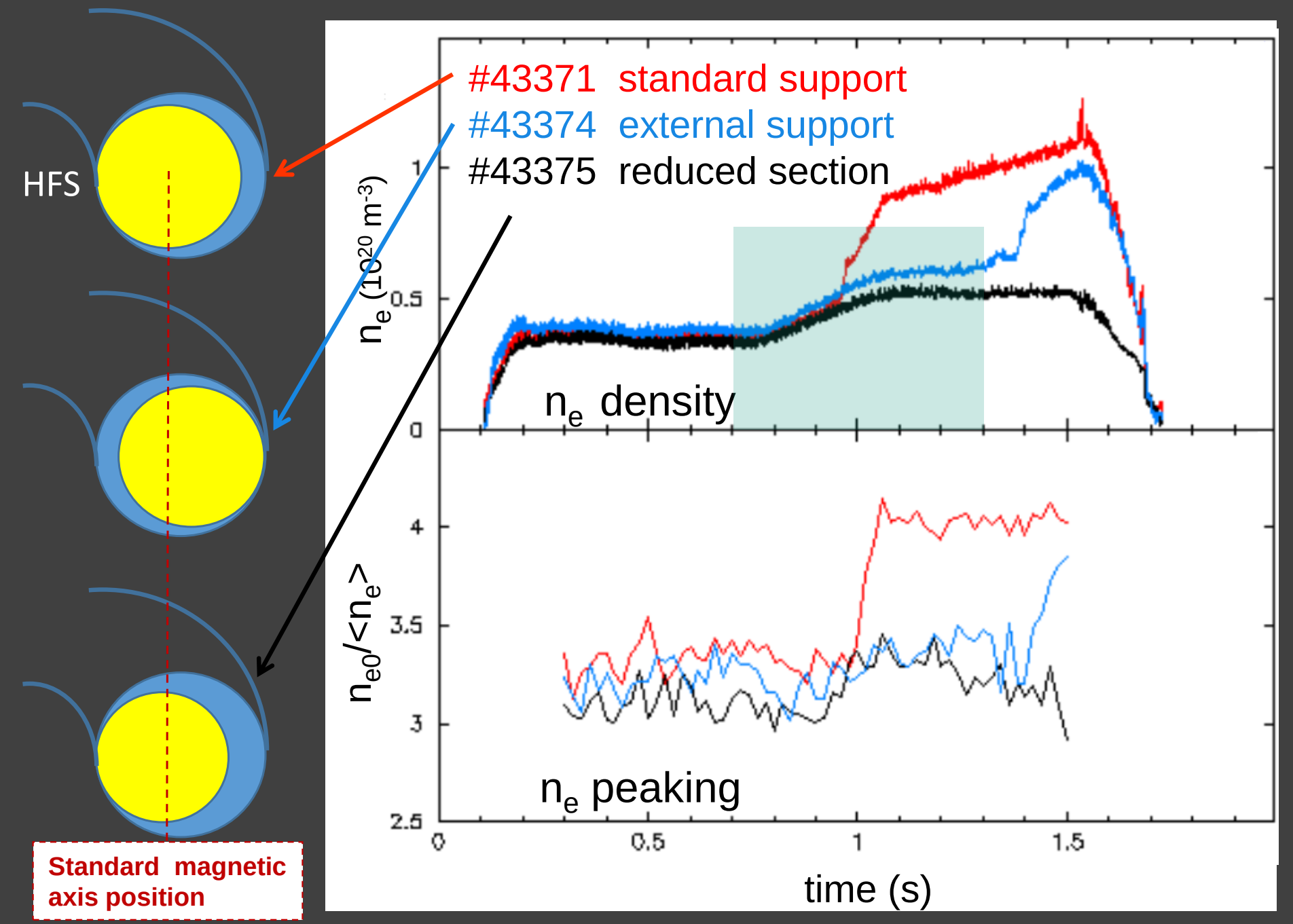


The #42720 same 40 mbar, survives because the injection is slower (135 V). The right box shows a scanner plot of the He amount vs line density response. The particle inflow, visible in the density rise and proportional to the He, is confirmed also when the He ends (vertical ascents).



At left the same released He amount: the n_e rise of the #43318 is immediately visible for the higher injection rate, anyway this pulse is more "dirty". So, by comparing #42720 and #42721: T_{max} and P_{rad} follow the same trend, both signals show a predictable quicker cooling for the #42720 pulse with respect to the #42721; the density peaking rise and grow until 5. On the right, the He amount at two low levels with same rate of injection to find the min threshold.

EDGE EFFECT



Different plasma shapes have been performed with He inj. at 0.7 s. The #43371 has its standard formation on HFS, after seeding the n_e grows. The #43374 is realized forcing support on the LFS. At the end of the pulse, it comes back into its natural configuration leaning at the HFS, only at that moment, the density rise is observed. This behavior is quite unexpected, because the He is spread all over the SOL. The third shape is a smaller section (-2 cm) with usual HFS support, in this case the presence of the Helium almost seems to disappear.

MODEL FOR THE ESTIMATION OF IMPURITIES

Due to the difficulties to assess the absorbed amount of Helium, an approximate method to evaluate the impurities is outlined, by taking into account the effective charge variation and the radiated power as summation of its respective species. A system with several unknowns can be written, and resolved by using VUV spectroscopy and respective normalized brightness.

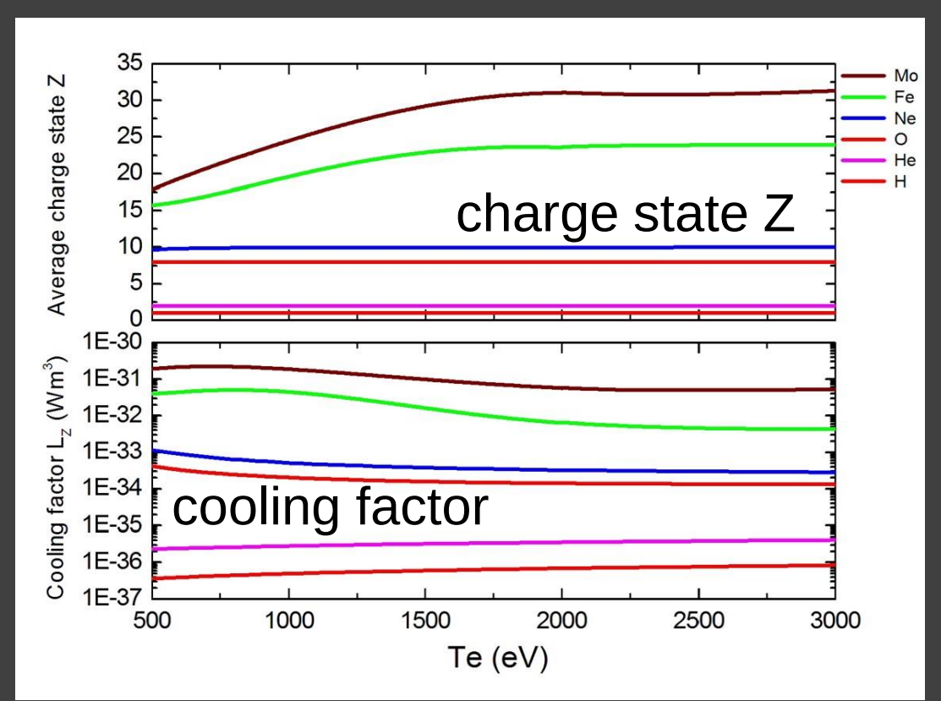
$$n_e(\rho) = \sum_j n_j(\rho)\,\bar{Z}_j(\rho) = n_D(\rho) + \sum_{j\neq D} n_j(\rho)\,\bar{Z}_j(\rho) \Rightarrow \frac{n_D(\rho)}{n_e(\rho)} = 1 - \sum_{j\neq D} C_j(\rho)\,\bar{Z}_j(\rho)$$

where D stands for Deuterium species, j is the ion, n_e the electron density, n_j the density of the j species, the dilution n_D/n_e . Defining $C_j(\rho) \equiv \frac{n_j(\rho)}{n_e(\rho)}$ the impurity concentration and $\bar{Z}(\rho)$ the averaged charge state (both function of radial coordinates ρ); the effective charge results:

$$Z_{eff}(\rho) = \frac{\sum_j n_j(\rho)\,\overline{Z_j^2}(\rho)}{\sum_j n_j(\rho)\,\bar{Z}_j(\rho)} = \sum_{j\neq D} \frac{n_j(\rho)}{n_e(\rho)}_j \bar{Z}_j^2(\rho) = \frac{n_D(\rho)}{n_e(\rho)} + \sum_{j\neq D} \frac{n_j(\rho)}{n_e(\rho)}_j \bar{Z}_j^2(\rho) = 1 + \sum_{j\neq D} C_j(\rho)\left[\bar{Z}_j^2(\rho) - \bar{Z}_j(\rho)\right]$$

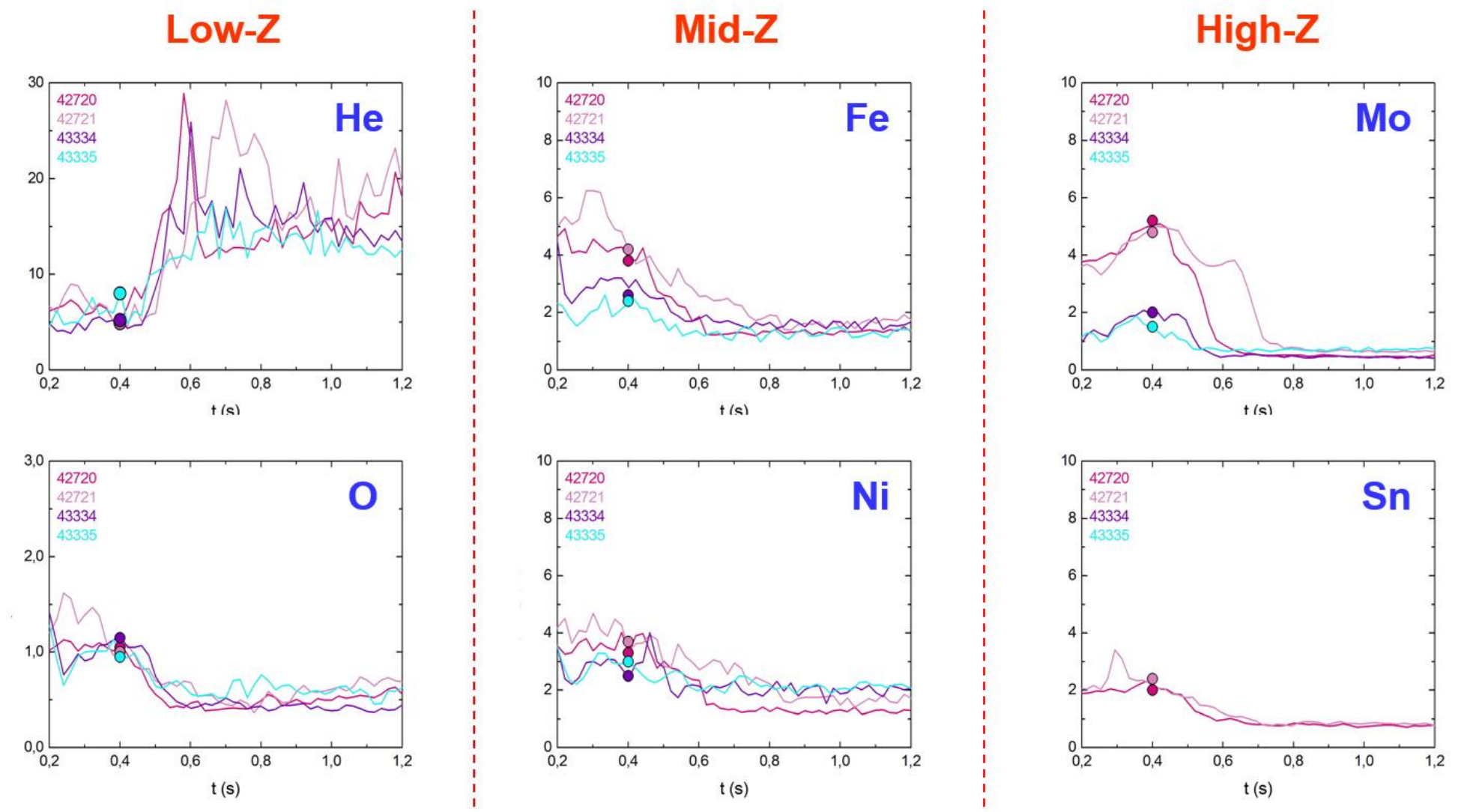
and the P_{rad} is $P_{rad} = \sum_j \int_V n_e(\rho) n_j(\rho) L_j[T_e(\rho)]dV$

where, L_j is the cooling factor as a function of electron temperature T_e.



At left: charge state and cooling factor (Wm^3) of the impurities as a function of T_e. The light species are completely ionized yet at 500 eV, the ionizations of the medium and heavy ones is never complete; > 2000 eV all cooling factors remain constant. For this, a zero order approximation is taken with flat concentration profiles, n_e profiles as parabolic, averaged charge state as constant; defining T_{e0} the temperature on axis, the system results:

$$\begin{cases} C_j(\rho) \equiv C_j \\ n_e(\rho) \approx \frac{3}{2}\bar{n}_e(1-\rho^2) \\ L_j(\rho) \approx L_j(0) \\ Z(\rho) \approx Z(0) \end{cases} \Rightarrow \begin{cases} P_{rad} = \sum_j C_j \frac{9}{4}\bar{n}_e^2 L_j(T_{e0})\, 2\pi R_0 \frac{\pi a^2}{3} \approx \frac{3}{4} V_{pl}\,\bar{n}_e^2 \sum_j C_j L_j(T_{e0}) \\ \Delta Z_{eff,\,j} = C_j \cdot \left[\bar{Z}_j^2 - \bar{Z}_j\right] \end{cases}$$



The variation in the VUV spectroscopic measurements before the injection (Phase I = 0.3-0.4 s) and after (Phase II = 1 - 1.1 s) can be exploited. In the figure at left (pulse #42720) the circles identify the input data of the model. As first example, a rough estimation of the He can be found, by considering one heavy and one medium species. The volume radiated power associated with Mo concentration has to be in agreement with measured P_{rad} [13] for the Phase 1:

$$\begin{cases} \bar{n}_e = 0.35 \cdot 10^{20} m^{-3} \\ T_{e0} = 1.50\ keV \\ P_{rad} = 0.13\ MW \end{cases} \Rightarrow C_{Mo} \approx \frac{P_{rad}}{\frac{3}{4} V_{pl}\,\bar{n}_e^2 L_{Mo}(T_{e0})} = 11 \cdot 10^{-4} \Rightarrow \Delta Z_{eff}^{(Mo)} = 0.9$$

The contribution to the Z_{eff} from the Oxygen concentration has to be in agreement with the measured Z_{eff}.

$$\begin{cases} Z_{eff} = 4.0 \\ \Delta Z_{eff}^{(Mo)} = 0.9 \end{cases} \Rightarrow \Delta Z_{eff}^{(o)} = 2.1 \Rightarrow C_o = \frac{\Delta Z_{eff}^{(0)}}{\bar{Z}_o^2 - \bar{Z}_o} = 3.8 \cdot 10^{-2}$$

Repeating the order zero calculation for the Phase II, the concentration of Mo results to be 1. 10^{-4} and the ΔZ_{eff} of the Mo = 0.1. By assuming constant the concentration of the Oxygen at 3.8 10^{-2}, the He one must be in agreement with measured Z_{eff}. So, the C_{He} results 5.0 10^{-2}. By way of example, one could estimate that, if the O concentration were halved, then the C_{He} will be 55 %. A more refine result can be obtained if, to the flat profiles, a charge state and a power loss, are taken in the radial position where the maximum emission occurs for each species. Summarizing: Br is the spectral brightness, C_j the concentration, β_j the sensitivity threshold of the measures (a sort of offset to be subtracted), the constraints are the P_{rad} and Z_{eff}: $C_j \equiv \alpha_j \cdot \left[\left(\frac{Br}{n_e^2}\right)_j - \beta_j\right]$

By using the radial profiles values for $\bar{Z}_j$ and L_j, the ΔP_{rad} and Δz_{eff} between Phase 1 and 2 the model can be extended:

$$\begin{cases} P_{rad,j} = C_j \cdot \int_V n_e^2(\rho)\, L_j(\rho) dV \\ \Delta Z_{eff,j} = C_j \cdot \frac{1}{L}\int_L \left[\bar{Z}_j^2(\rho) - \bar{Z}_j(\rho)\right] dL \end{cases}$$

by solving the system, the concentrations of the impurities can be estimated.

The model is promising and a consistency check is ongoing.

CONCLUSIONS

- In FTU the Helium seeded pulses show a spontaneous rise of the ne as for the Neon doping, leading to a remarkable increase of the peaking. The injection effects can be enhanced by acting both on the total amount of impurity, and on the injection rate; a very high density peaking is reached with the impressive value of 5.
- To establish the quantity of the impurities, an approximated model has been developed. An esteem of the species concentrations, included Helium, can be found with a multi unknowns system that uses measurements of Zeff, radiation losses and VUV spectroscopy.
- The phenomenology related to the combination of Helium seeding, plasma shapes and edge conditioning, suggests mutual effects to investigate.