

Transport investigations in pellet-fuelled plasmas of ASDEX Upgrade

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GOALS

- Better understanding of pellet physics in a tokamak via
- Pellet ablation and deposition modelling (SMART¹)
 - Transport simulations (ASTRA² + TGLF-SAT2³)
 - Direct comparison to ASDEX Upgrade (AUG) experimental data, both in H-mode and L-mode
- This is important as
- Pellet injection is currently the most promising way to efficiently fuel reactor-relevant plasmas
 - Introducing cryogenic pellets leads to strong modifications of the plasma profiles, which introduce additional transport effects

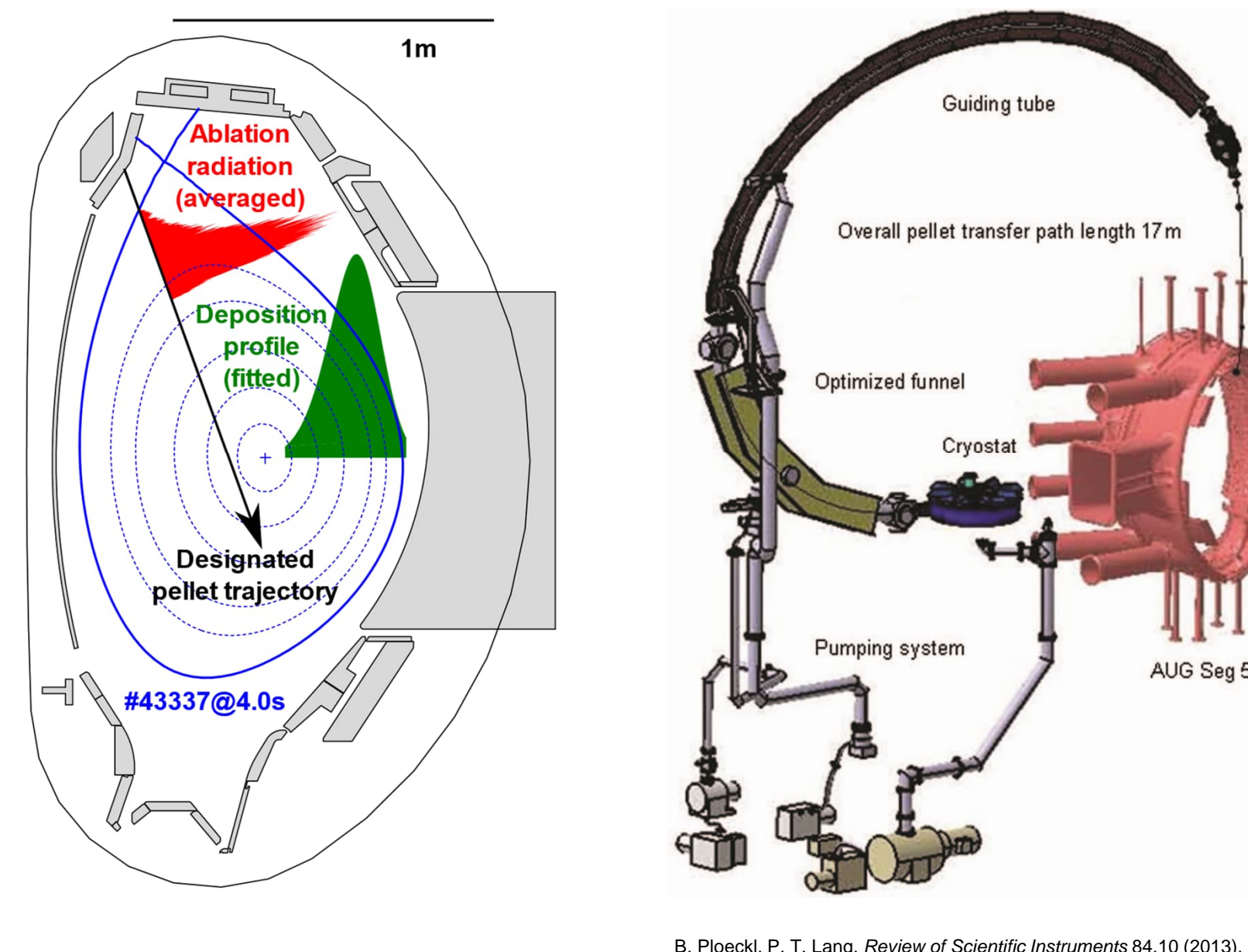
PELLET-PLASMA INTERACTION

- **Pellet ablation ($t < 2\text{ms}$):** Pellet material ablates and forms a gas cloud around the pellet. Excitation and recombination effects lead to light emission.
- **Pellet particle deposition ($t \approx 2\text{ms}$):** The grad-B drift combined with a non-axisymmetric density perturbation induces a drift of the ionized pellet-material towards the low-field side (LFS). High-field side (HFS) injection therefore results in a much deeper particle deposition.
- **Transport ($t \approx 50\text{ms}$):** Large modifications of the plasma profiles (after the pellet material got ionized and distributed along the flux surfaces) lead to additional transport effects.

PELLET LAUNCHING SYSTEM

The ASDEX Upgrade pellet launching system comprises the following key parts:

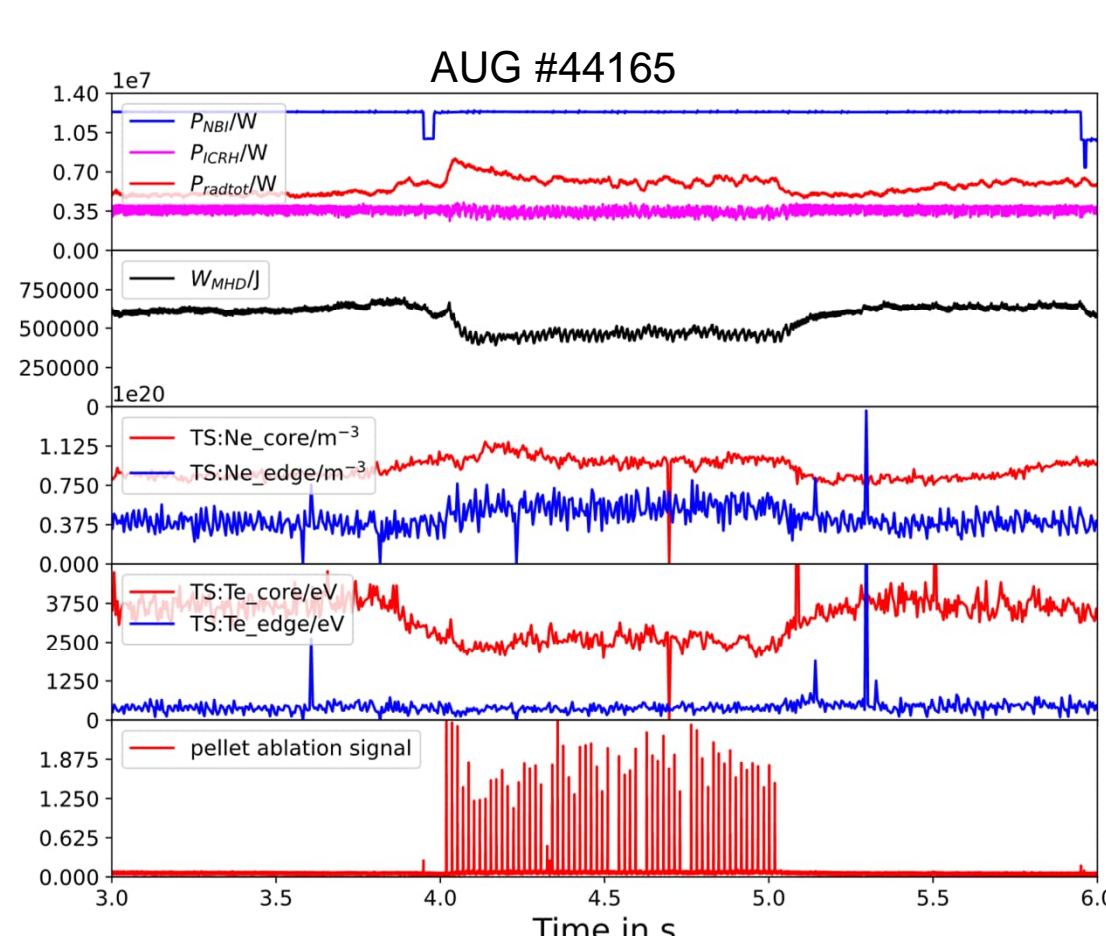
- **Pellet source:** Hydrogen (mostly deuterium) is cooled to around 10K, compressed, and formed into a 19cm long rod.
- **Storage cryostat:** This rod is stored and cooled until pellets are requested in the experiment.
- **Centrifuge:** The rod is cut into individual pellets, which drop into the centrifuge for acceleration.
- **Guiding tube:** The accelerated pellets are guided through a tube („looping“) towards the HFS injection port, where they enter the plasma vessel.



CONCLUSIONS

- Dedicated experiments with tailored pellet injection performed
- Experimental data can be improved by taking a statistical approach using the average over multiple similar pellet perturbations
- Pellet particle confinement times in the L-mode (deeper penetration) are longer than in H-mode
- SMART code calculates pellets deposition in H-mode well, but could not be used for the L-mode
- ASTRA + TGLF-SAT2 transport simulations result in reasonable agreement with the experiment
- For both H- and L-mode, simulations reproduce temperature recovery after a pellet well (although with a overshoot in H-mode), but underestimate particle transport (both inwards and outwards)

OUTLOOK



Recent experiment:
➤ Phase of high-frequency pellet leads to a significant decrease of W_{MHD} (black).
➤ Reproducing and understanding this behavior is a future goal of this work.

COMPARISON OF ASTRA + TGLF-SAT2 SIMULATIONS WITH THE EXPERIMENT – WORK IN PROGRESS

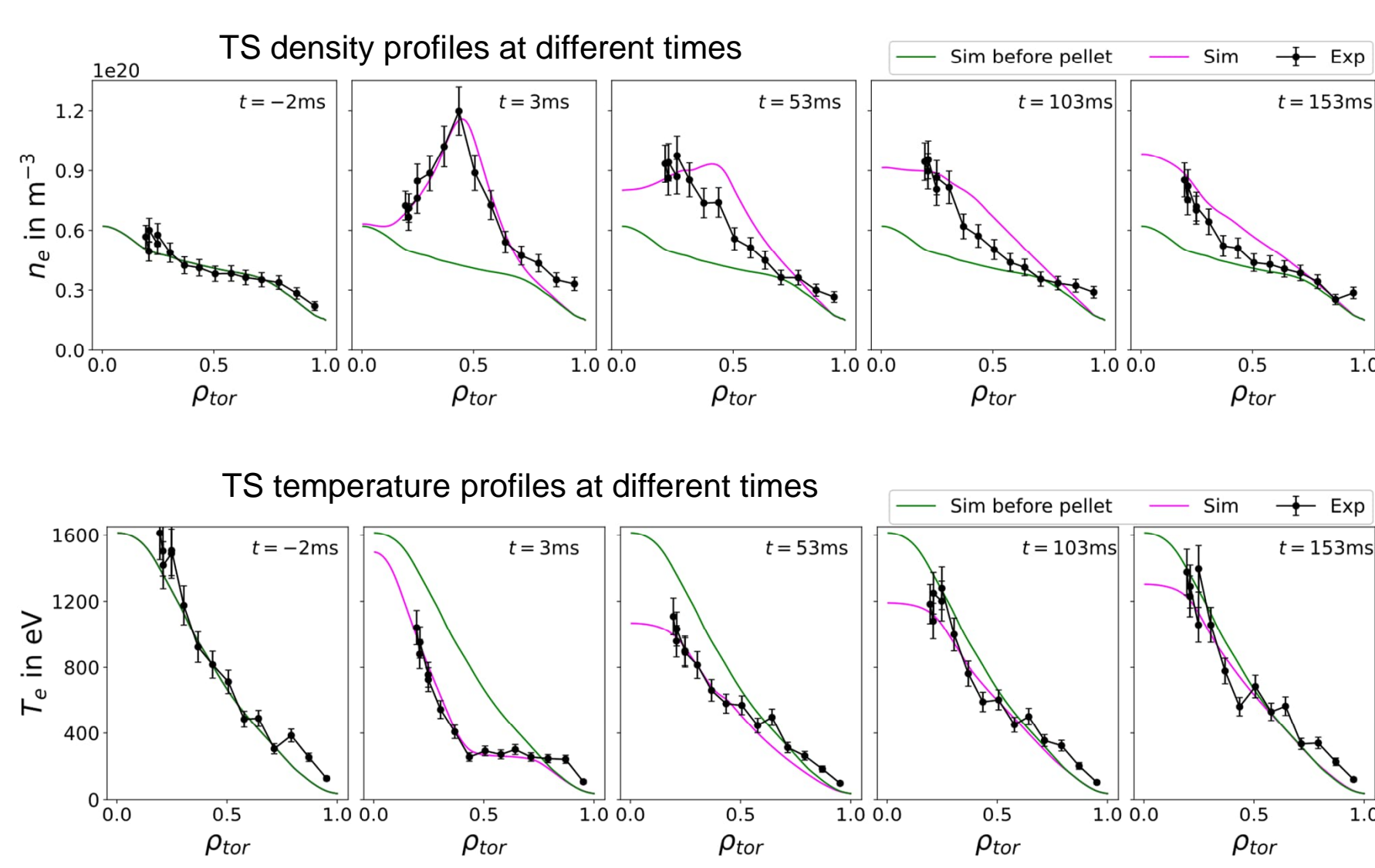
L-MODE (AUG #43895)

Setup:

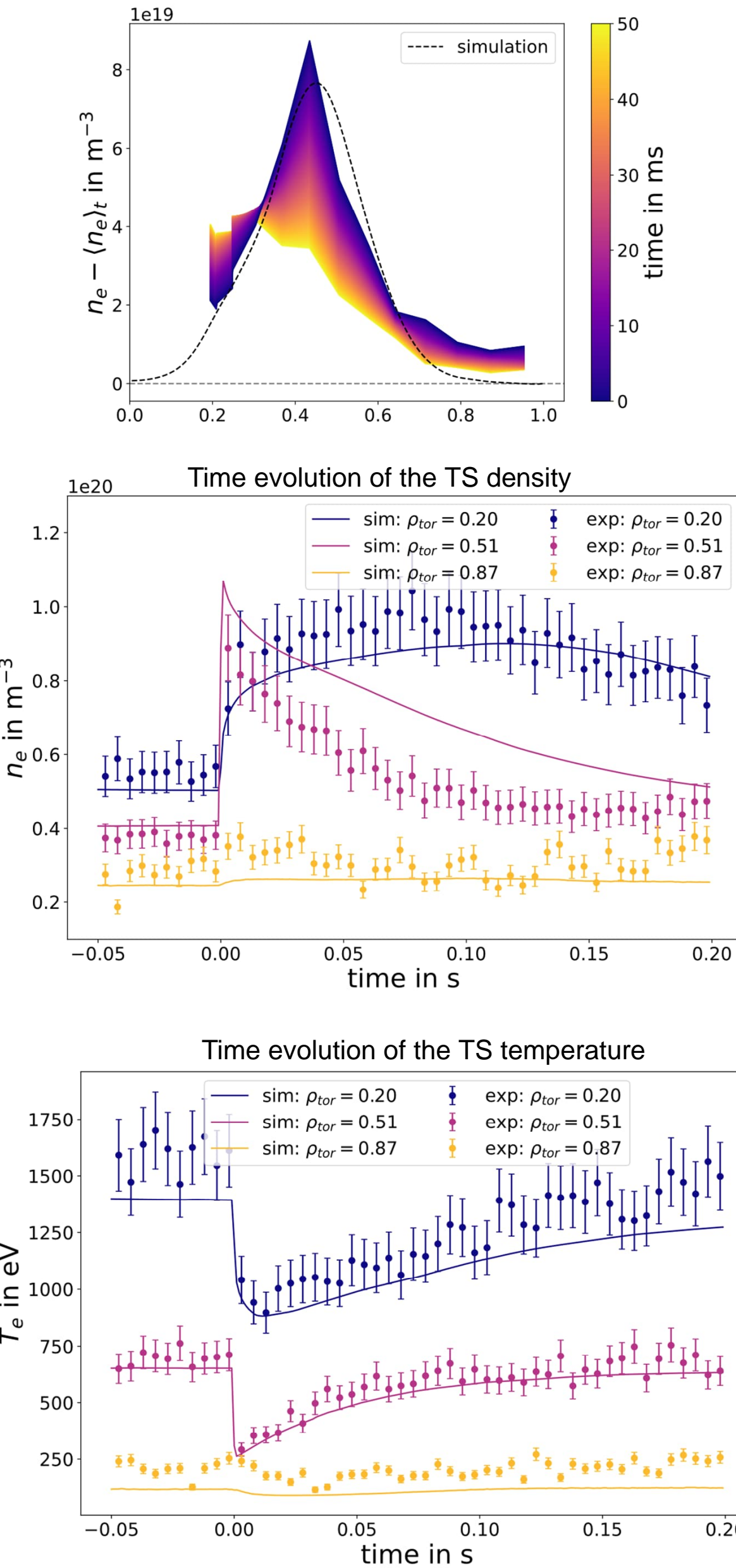
- ASTRA + TGLF-SAT2 full-radius without SMART
- Pellet deposition has been approximated via a Gaussian particle source

Results:

- Simulation shows a slightly lower (inward and outward) particle transport
- Temperature evolution could be reproduced with good agreement
- Overall much slower dynamics than in H-mode



Thomson scattering (TS) deposition profile and its evolution



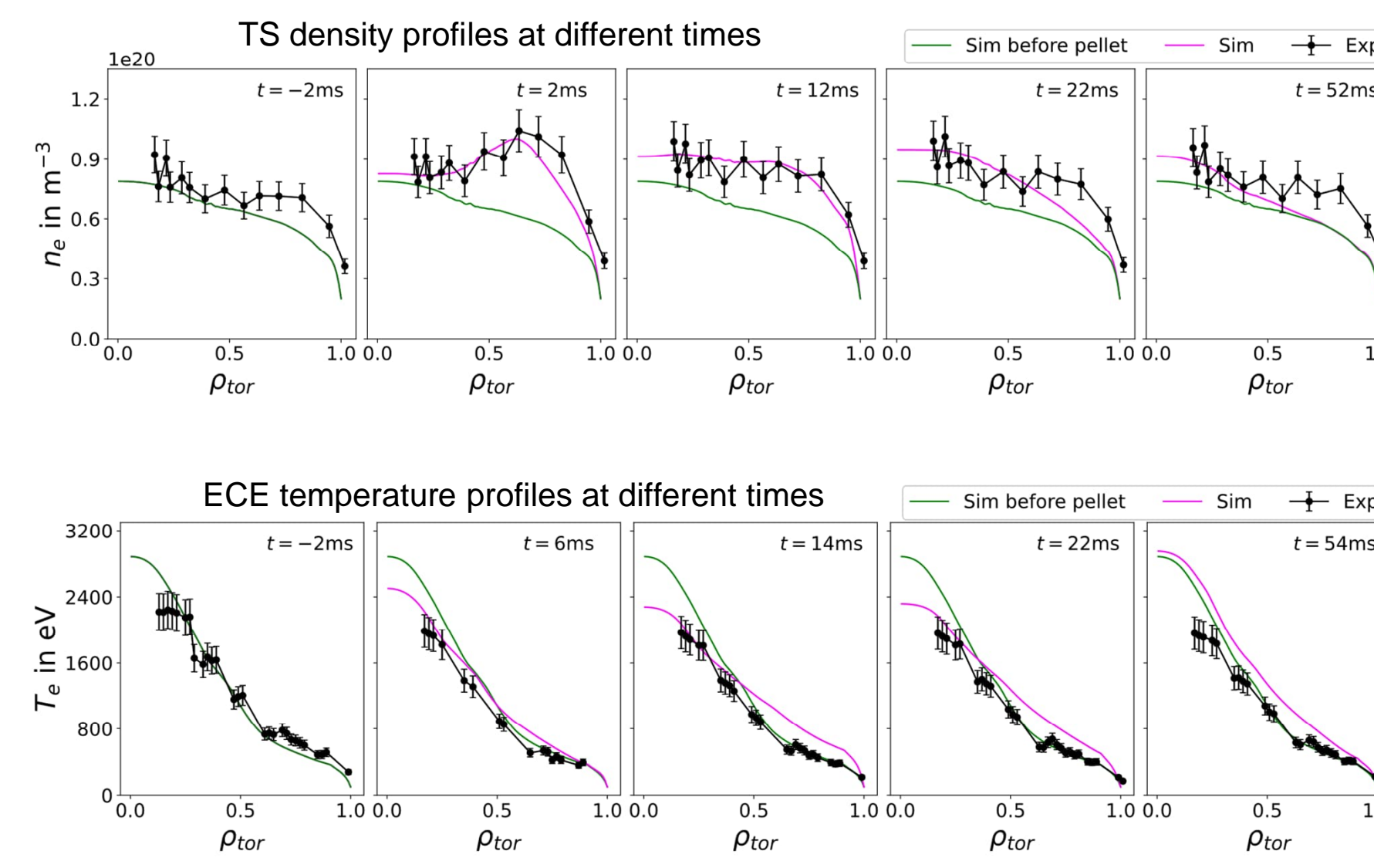
H-MODE (AUG #43337)

Setup:

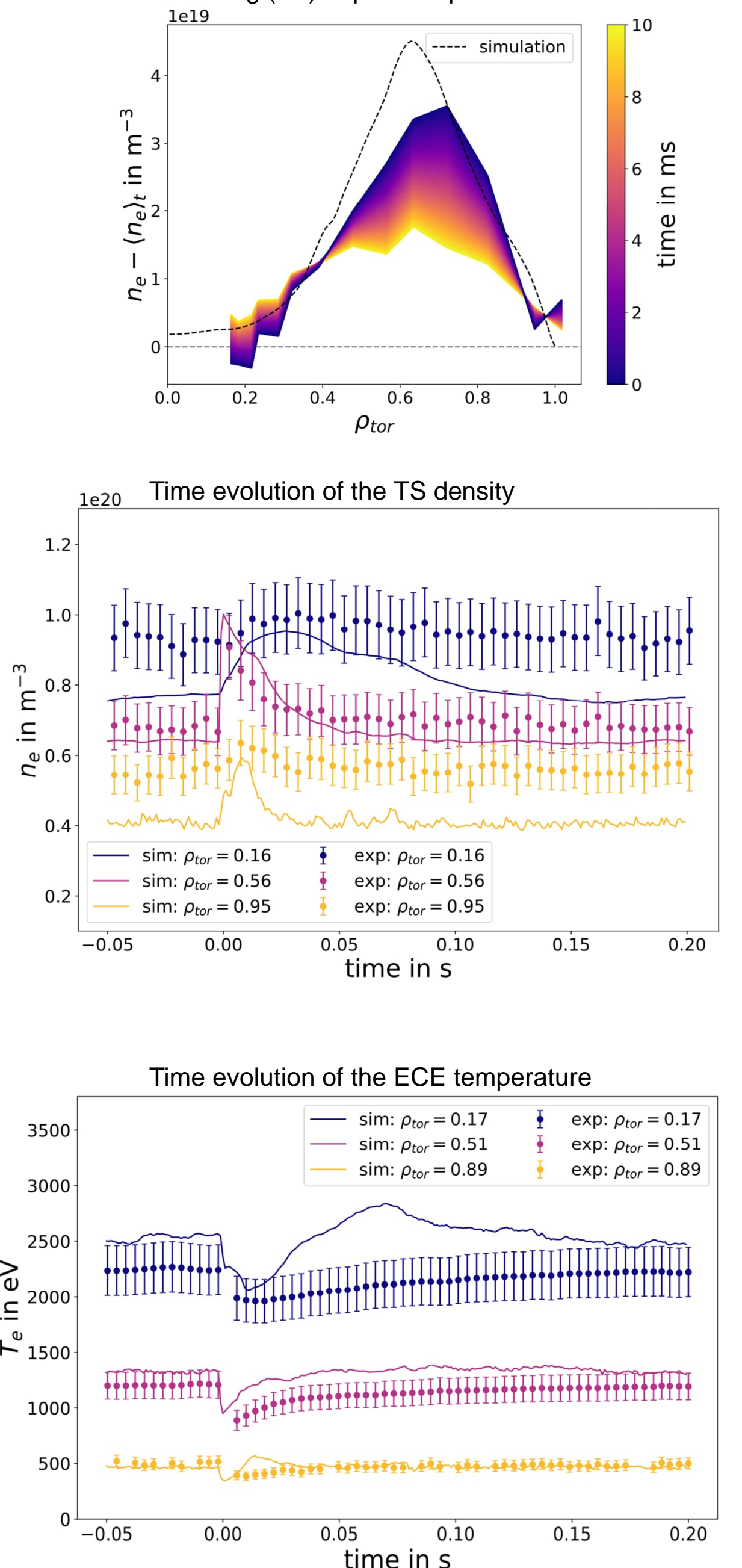
- ASTRA + TGLF-SAT2 full-radius (pedestal pressure in feedback)
- The modelled pellet deposition with SMART is very reasonable.

Results:

- Simulation shows a slower particle transport than found in the experiment
- Higher core density increase probably due to slight difference in deposition profile
- Temperature evolution overall in good agreement (although with an overshoot in the core)



Thomson scattering (TS) deposition profile and its evolution



IMPROVEMENT OF THE SIGNAL-TO-NOISE RATIO

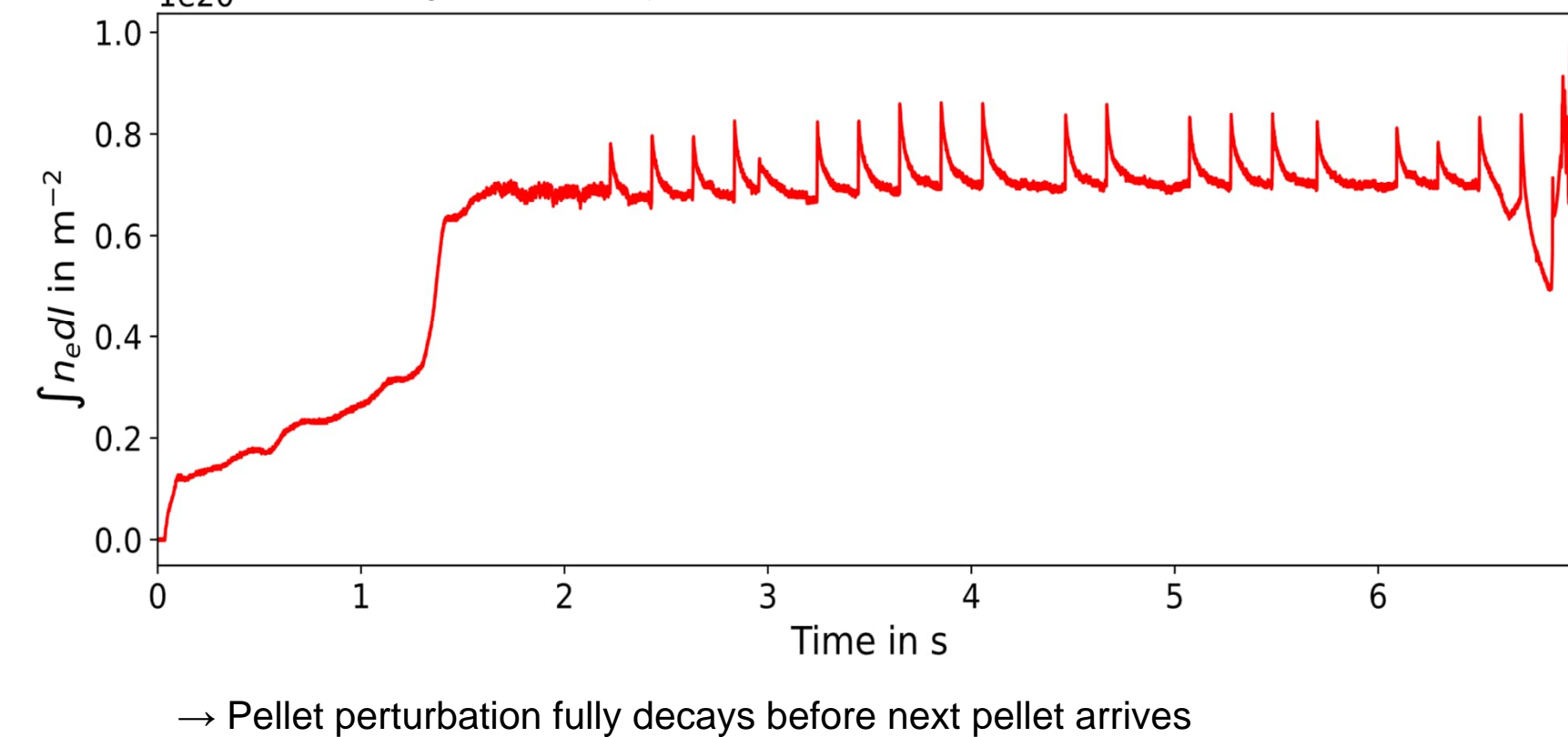
Pellet perturbation occurs on a millisecond time scale

- Difficult to find diagnostics with high time resolution and good SNR
- Therefore a dedicated shot has been set up with a statistical approach, namely averaging over multiple similar pellets, to improve SNR

H-mode shot with many similar pellets ($f = 5\text{ Hz}$)

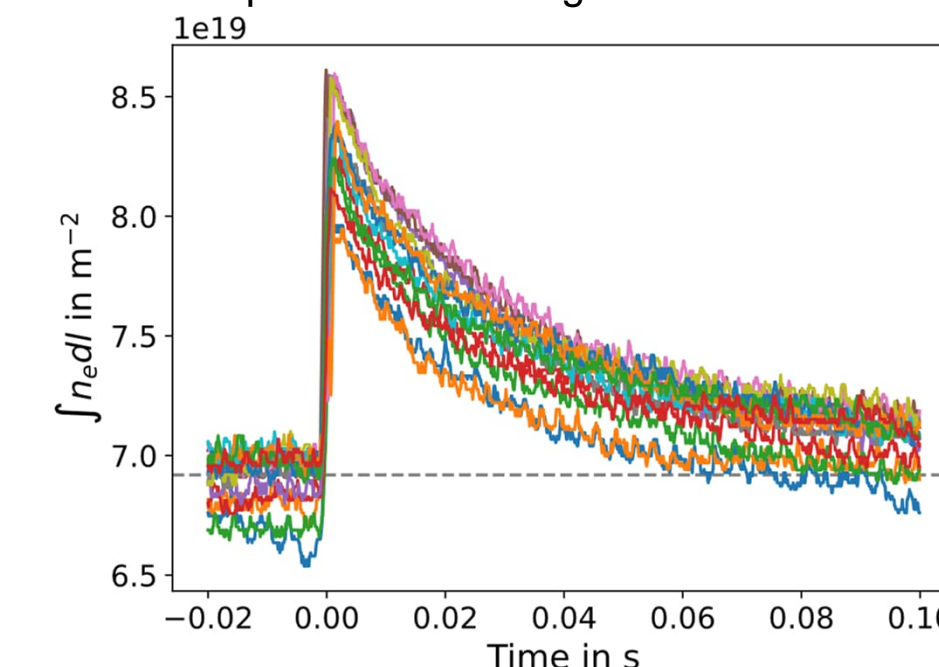
- $I_p = 800\text{ kA}$
- $B_t = 2.6\text{ T}$
- $q_{95} = 5.4$
- $P_{NBI} = 9.8\text{ MW}$
- $P_{ICRH} = 1.62\text{ MW}$

Line-integrated density (DCK:H-1) of the H-mode shot AUG #43337:

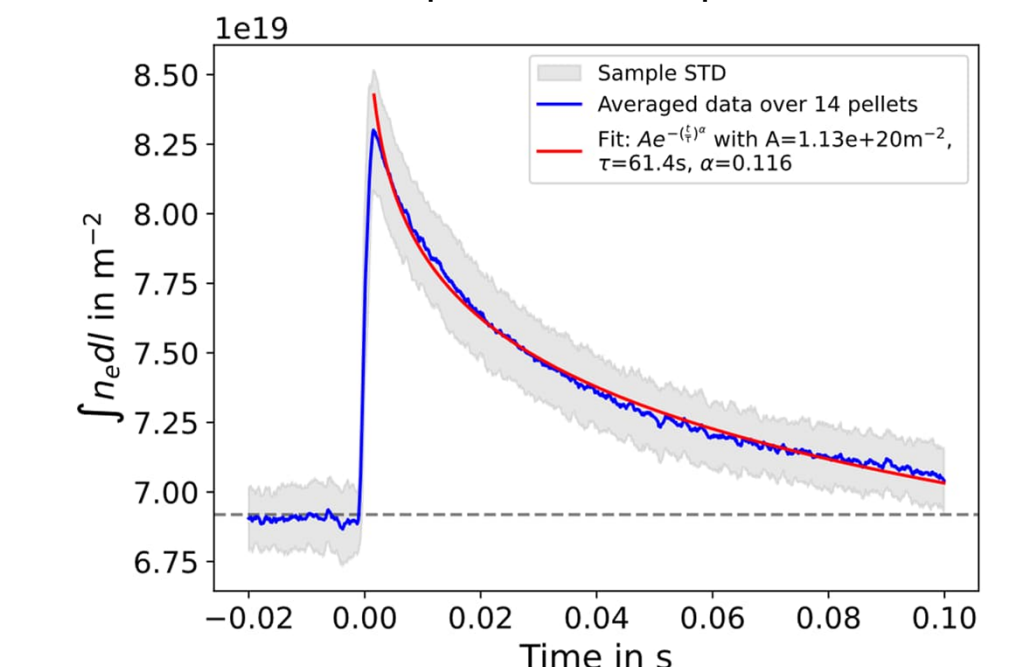


→ Pellet perturbation fully decays before next pellet arrives

Similar pellets are averaged over for better SNR



Stretched-exponential fit explains data well



- (1) A. R. Polevoi et al., *Plasma physics and controlled fusion* 43.11 (2001): 1525.
- (2) G. Tardini et al., *Plasma Phys. Control. Fusion* 68 (2026) 065024.
- (3) G. M. Staebler et al., *Nucl. Fusion* 61 116007 (2021).

