Investigation of fast ion transport induced by ICRF heating and MHD instabilities in JET plasma discharges

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**See the author list of 'Overview of JET results for optimising ITER operation' by J. Mailloux et al to be published in Nuclear Fusion Special issue: Overview and Summary Papers from the 28th Fusion Energy Conference (Nice, France, 10-15 May 2021)*

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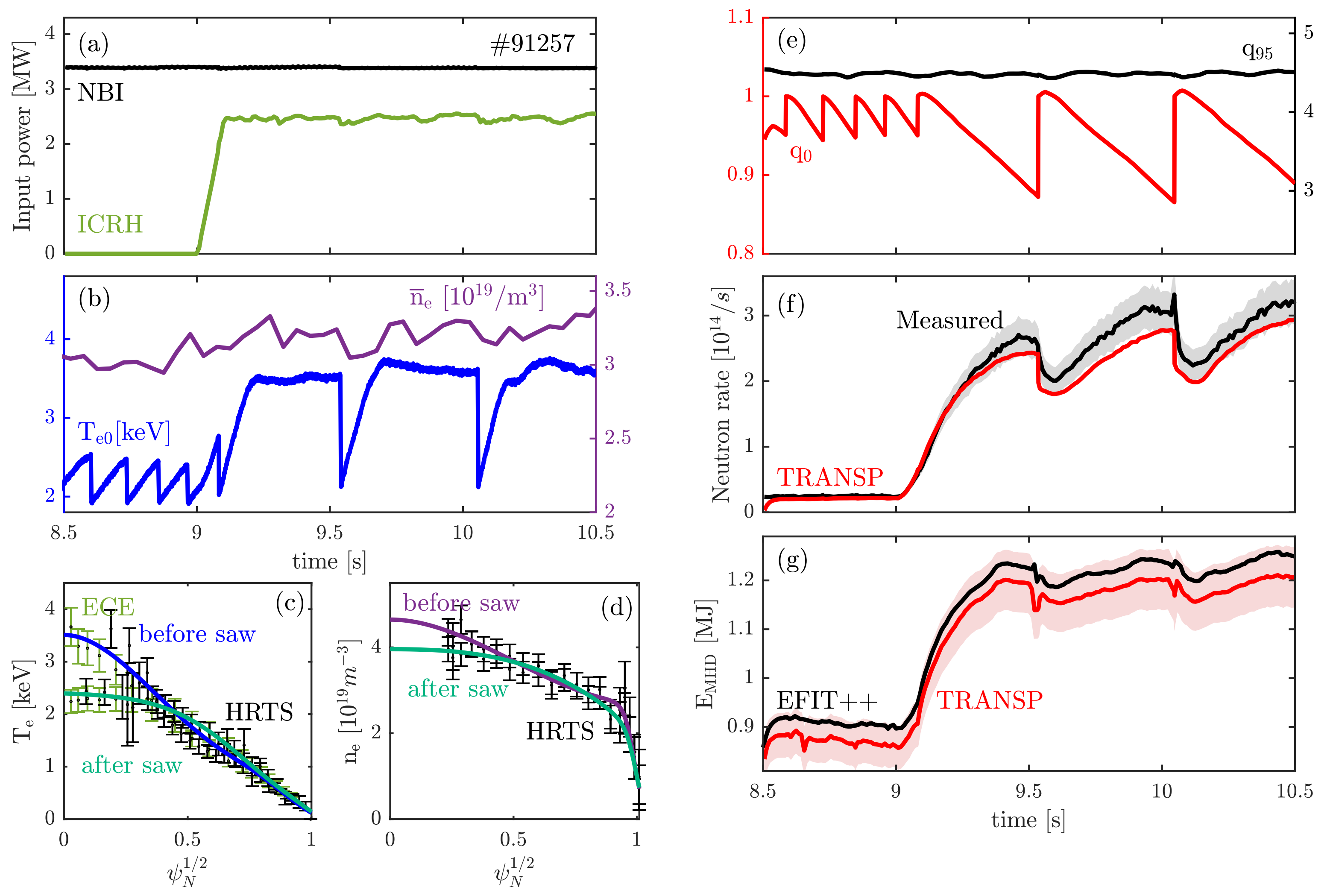
1. Introduction

- ❖ Significant fast ion population can be generated by applying the 3-ion ICRF heating schemes in which large fraction of ICRF energy is absorbed by beam ions [1, 2]. The 3-ion schemes are applied to mixed plasmas discharges with at least two thermal ion species. The TRANSP code [3, 4] allows to model thermal and fast ion transport consistently thanks to build in modules for various heating schemes and multiple options to describe thermal ion transport.
- ❖ We assess influence of the uncertainties in the input parameters and thermal ion transport models on the simulation results and contribute to development of the fast ion transport models.
- ❖ Two main mechanisms are responsible for fast ion redistribution: reconnection of magnetic field lines between the plasma axis and *q = 1* surface that ions are tend to follow and resonance interaction between the internal kink mode and ions.
- ❖ We investigate differences in transport models accounting for resonant and non-resonant interaction between fast ions and sawtooth instability with the ORBIT code [5] and the Kadomtsev model [6] in TRANSP correspondingly.

2. Interpretative analysis of a mixed plasma discharge

JET #91257 95% H, 5% D plasma discharge

- 3.2 MW D-NBI (100 keV), 2.4 MW ICRH (25 MHz); EFIT++ plasma boundary time evolution;
- T_e and n_e fitted profiles are based on HRTS and ECE (for T_e) diagnostic measurements;
- sawtooth crash times are extracted from the ECE T_e central signal;
- NUBEAM [7] for fast ion tracking and TORIC [8] for RF wave propagation and absorption;
- the Kadomtsev sawtooth reconnection model for all plasma species;
- the RF-kick operator [9] is used to compute RF-NBI resonance energy exchange;
- limitations due to a lack of data: Be9 single impurity, Z_{eff} = 1.2, T_i=T_e, no plasma rotation.



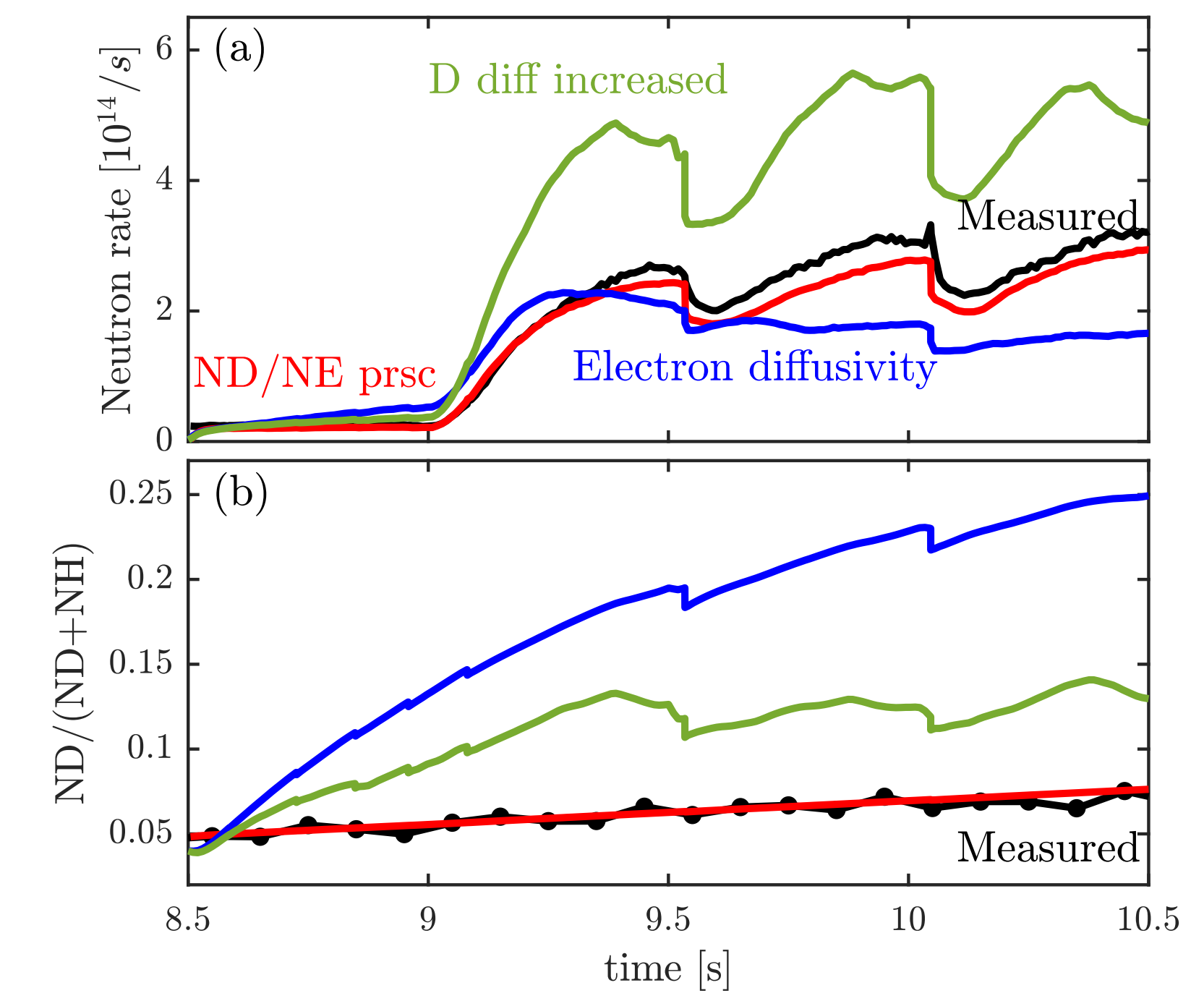
⇒ Predicted *q*-profiles reproduce sawtooth crashes, the mixing radius ρ_{torn}=0.3 (~250 cm).

⇒ TRANSP neutron rate reproduces main trends in the measured neutron rate.

⇒ TRANSP and EFIT++ computed energy has less than 5% difference. 5% uncertainty in input T_e or n_e results in 5% variation in the plasma energy (shaded).

2.1 Thermal ion transport model

- Similar transport for electrons and ions results in thermal D ion density n_D is increased up to 25%.
- With increased diffusivity n_D is reduced, though it still increases during the simulation up to 13%.
- To reproduce increase from 5% to 7% observed in the diagnostic signal of the relative thermal D ion density n_D/n_e.
- Uncertainties in the input parameters and model settings affect simulation results in terms of n_D and the neutron rate.



⇒ Prescribed n_D/n_e is used in the TRANSP interpretative simulation to reduce uncertainties in fast ion transport analysis.

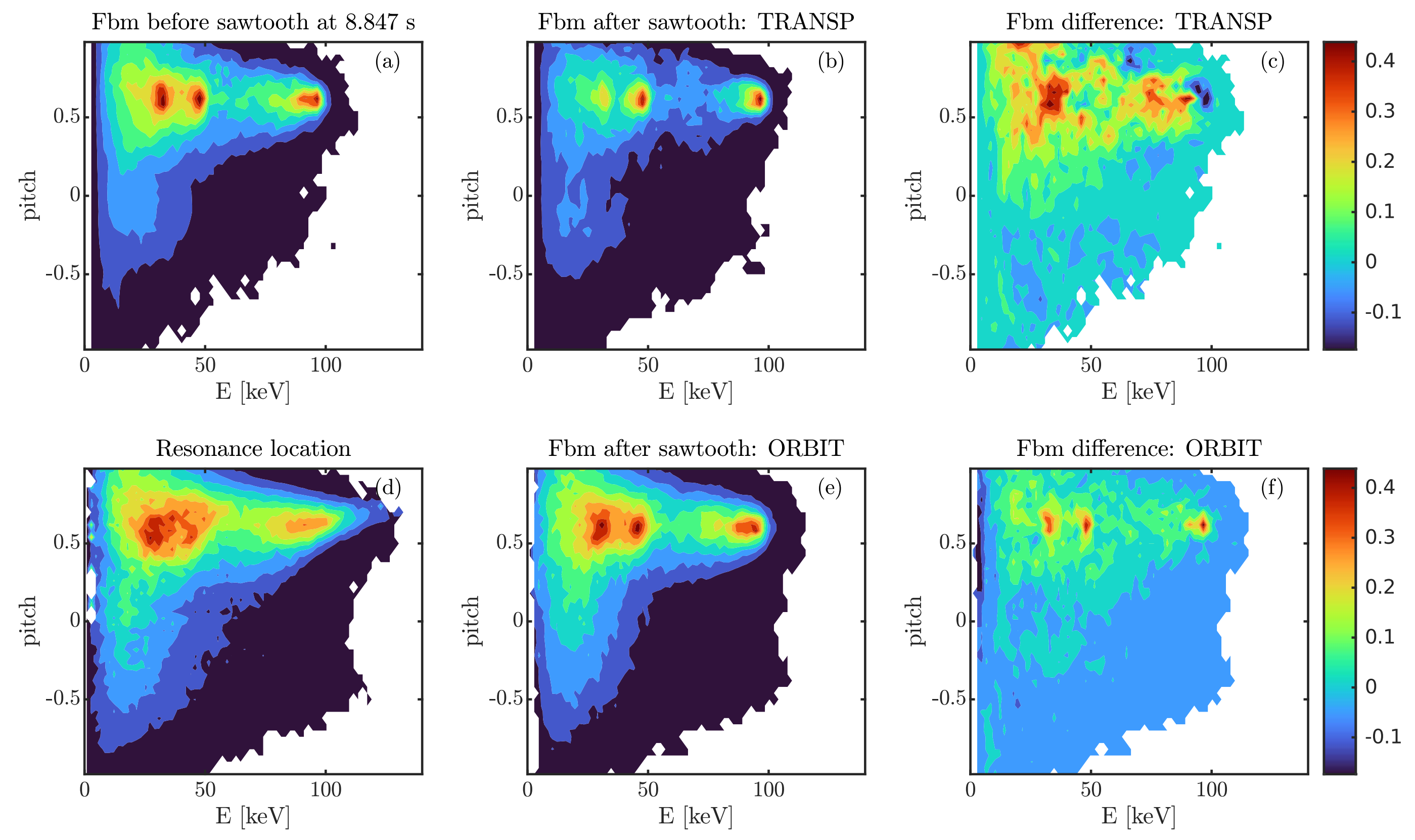
⇒ Most of neutrons are produced by the D (beam) + D (thermal) fusion reaction. Overestimated transport of beam ions might result in the lower neutron rate.

3. Transport of fast ions

Non-resonant fast ion transport: the Kadomtsev sawtooth reconnection model; according to theory in [10] there is a critical energy below which fast ions are strongly redistributed.

Resonant fast ion transport: the ORBIT code is the Hamiltonian guiding center particle motion code that analyses fast ion transport in terms of their energy, toroidal canonical momentum and magnetic moment; ORBIT computes response of unperturbed particle distribution provided by TRANSP to a magnetic perturbation caused by an instability.

Redistribution of D-NBI ions at 8.847 s (NBI-only heating)

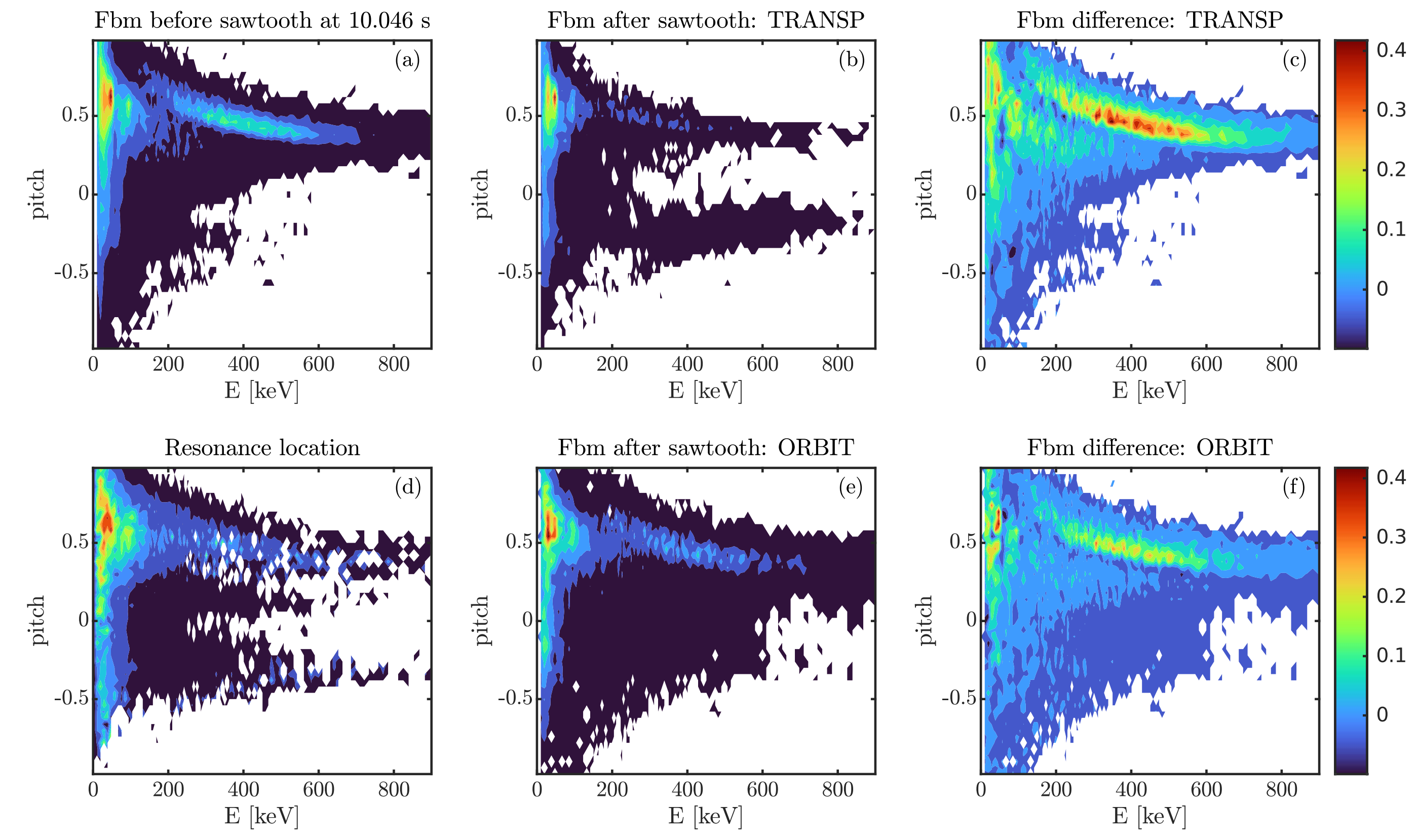


$E_{crit}^{trp} = 140\ keV$

D-NBI energy 100 keV

- Trapped and passing beam ions are redistributed.
- Stronger transport of co-passing particles in TRANSP
- More particles become trapped according to ORBIT simulation.

Redistribution of D-NBI ions accelerated by RF-waves at 10.046 s (ICRF-NBI heating)



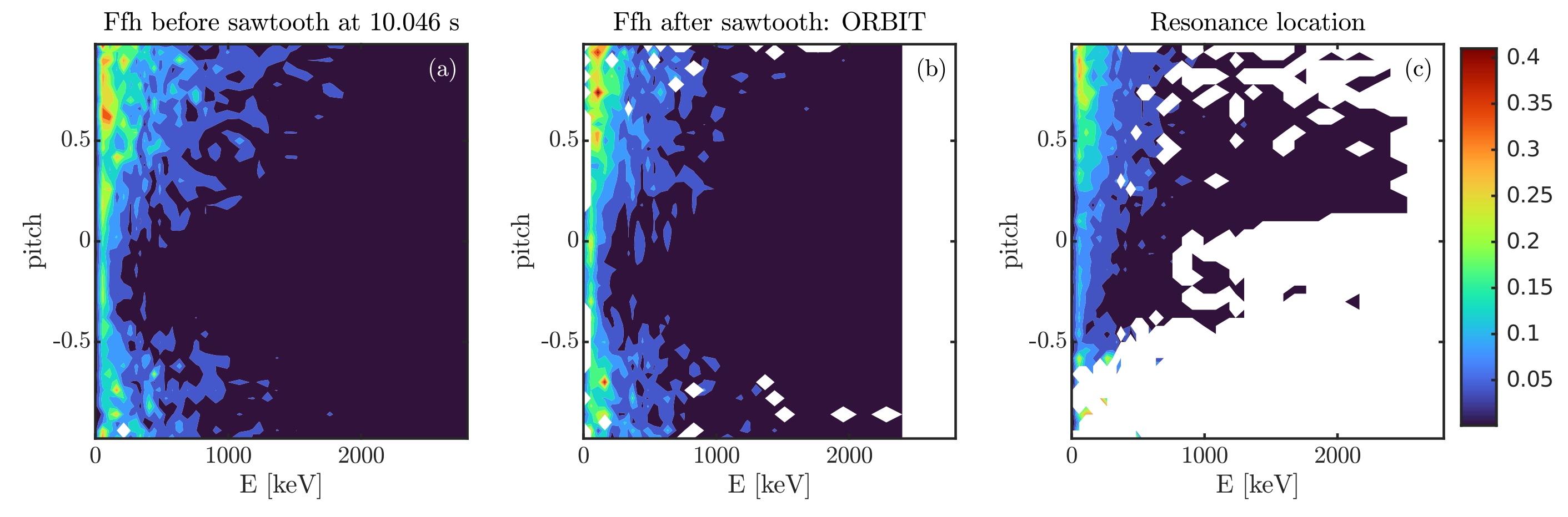
$E_{crit}^{trp} = 200\ keV$

- Resonance transport of deuterons takes place up to 600 keV for trapped particles and up to 800 keV for passing particles, i.e. higher than theoretical E_{crit}^{trp}.
- Overall effect on energetic D ion distribution is smaller in ORBIT than in TRANSP.

⇒ Resonant transport can significantly perturb distribution of high-energy fast ions.

3.1 Transport of fusion products

- ❖ Fusion products such as high-energy H ions have very peaked profiles which can be significantly affected by the sawtooth crashes.

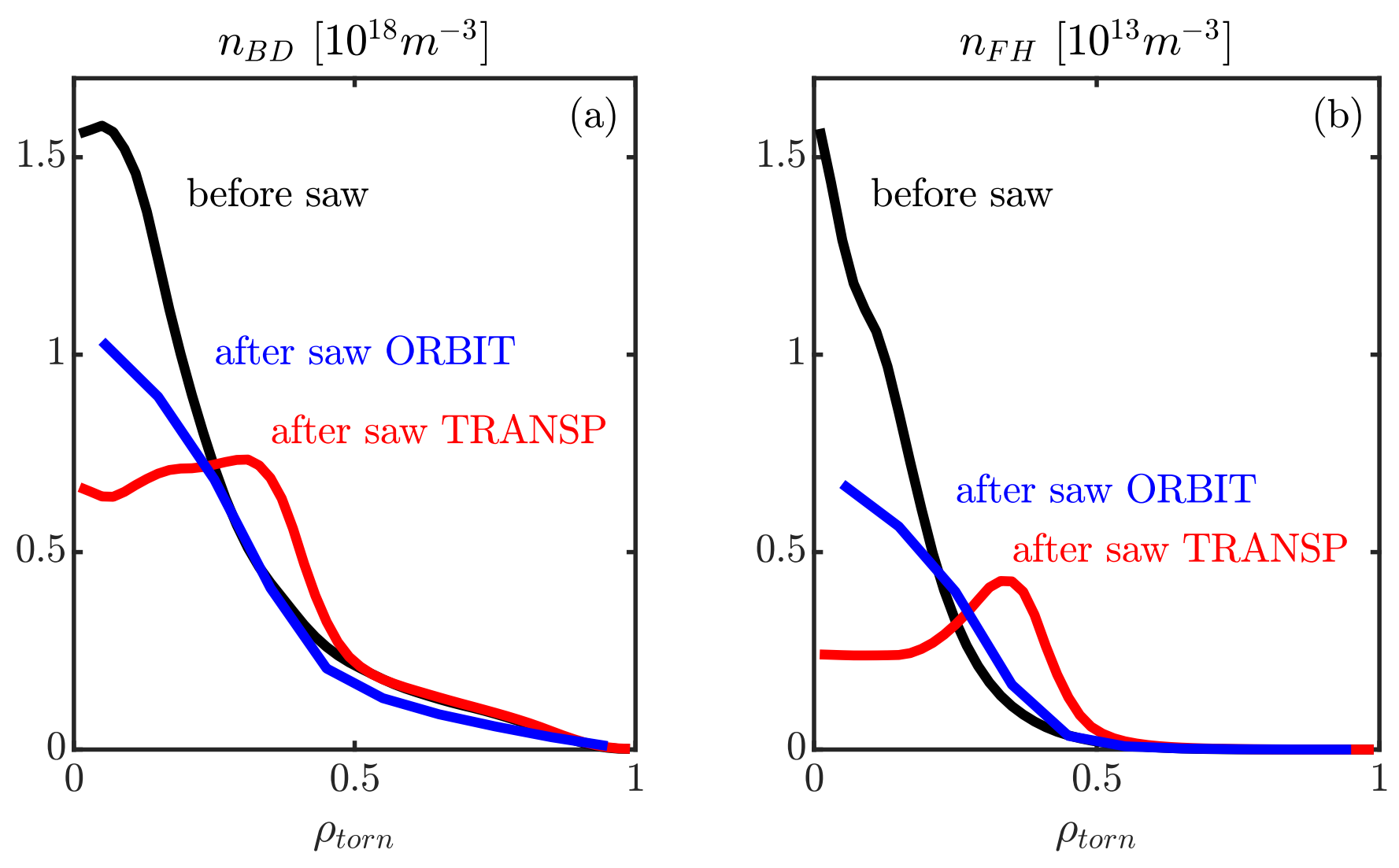


- Resonance transport for H fusion ions is observed mostly for co-passing particles.

⇒ Resonance interaction between trapped particles and the sawtooth instability is observed up to 1 MeV, i.e. up to energies much higher than $E_{crit}^{trp} = 200\ keV$

4. Conclusion

- ❖ Accounting for different orbit types and energies ORBIT can reproduce incomplete redistribution of fast ions by a sawtooth crash.



- ❖ The assumption on similar transport properties of electrons and thermal ions leads to overestimated D thermal ion density, thus the neutron rate.
- ❖ Increased D thermal ion transport is expected referring to TRANSP simulation results and the edge measurements of the hydrogen isotope ratio.
- ❖ For fast ions of high energy, like D beam ions accelerated by RF-waves and H fusion ions, the dominant mechanism of their redistribution by a sawtooth crash is resonant interaction between the sawtooth instability and fast ions.
- ❖ For the considered case, the sawtooth model that tends to flat fast ion profiles within the mixing radius is overestimating transport of fast ions.

ACKNOWLEDGMENTS / REFERENCES

The authors thank P. Bonofiglo, M. Nocente, J. Ongena, Ž. Štancar and G. Szepesi for their contributions.

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This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Fusion Energy Sciences, under contract number DE-AC02-09CH11466.

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.