# EXPERIMENTAL VALIDATION OF AN INTEGRATED MODELLING APPROACH TO NEUTRON EMISSION STUDIES AT JET

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## MOTIVATION

- Neutrons are carriers of information on the plasma state
- Calculation of realistic plasma neutron sources - effect on neutron diagnostics and fusion power measurements
- Experimental validation of methodology on JET

## METHODOLOGY - Neutron emission modelling

- Plasma transport with TRANSP and NUBEAM/TORIC heating modules
- Neutron spectra calculations with DRESS
- Neutron transport with MCNP
- Two JET discharges analysed - baseline #94968 and three-ion RF #94700 (Fig. 1)

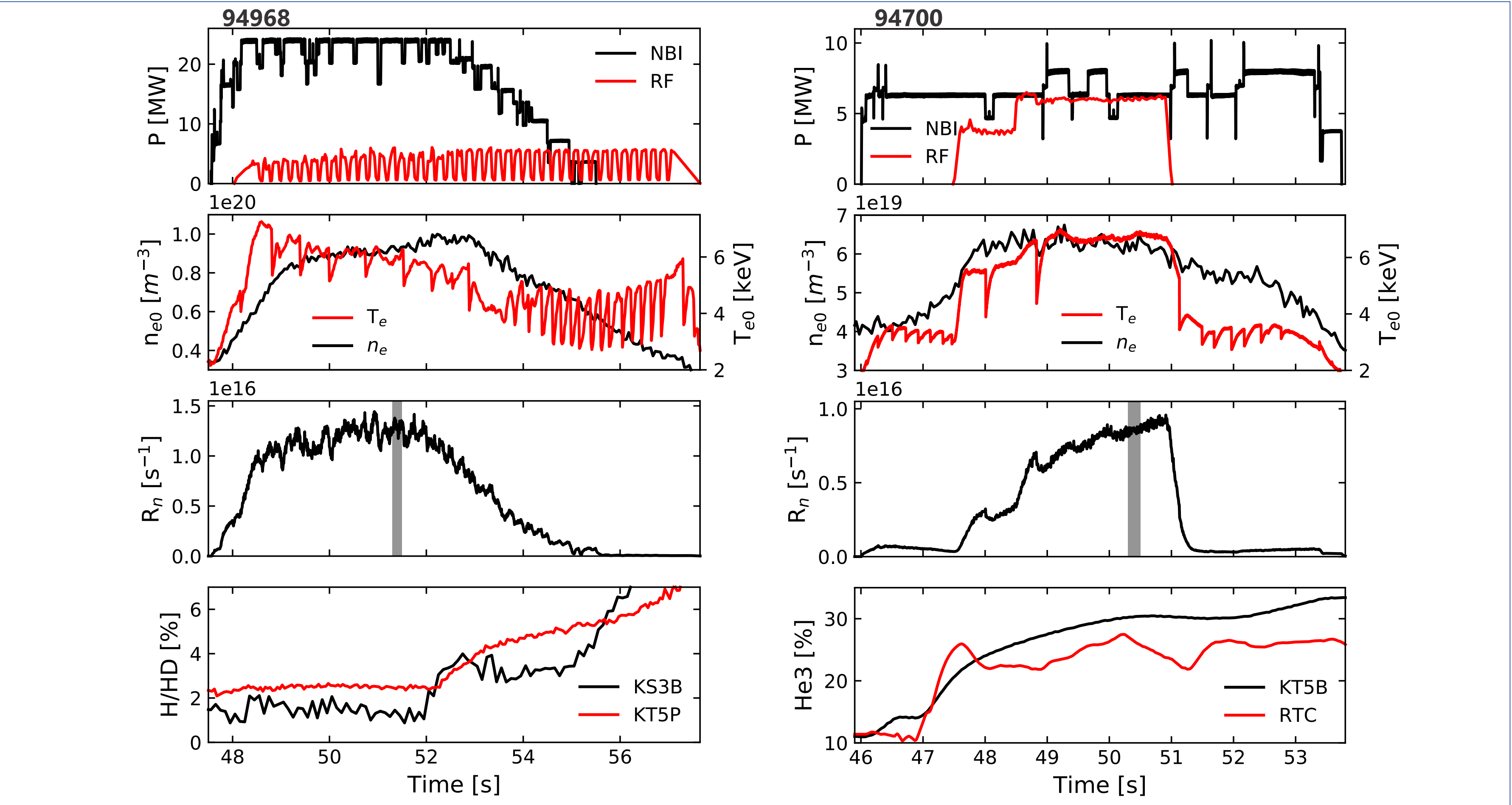

**Fig. 1**: Overview of the baseline #94968 and three-ion #94700 discharge. Displayed: NBI and RF heating power, electron density and temperature, total neutron rate, measured H RF minority concentration, and $^3$He concentration.

## NEUTRON EMISSION IN TOKAMAKS (Fig. 2)

- Total neutron rate - discharge performance and proportional to fusion power
- Neutron emissivity - spatial distribution of neutron source
- Neutron spectrum - reflects thermal and fast ion distribution characteristics

▶ **Baseline**: dominating DNBI-$D_{th}$ fusion, RF H minority heating with low energy 2nd harmonic D RF tail

▶ **Three-ion**: RF scheme D-(DNBI)-$^3$He, energetic NBI+RF synergy tail dominating fusion performance

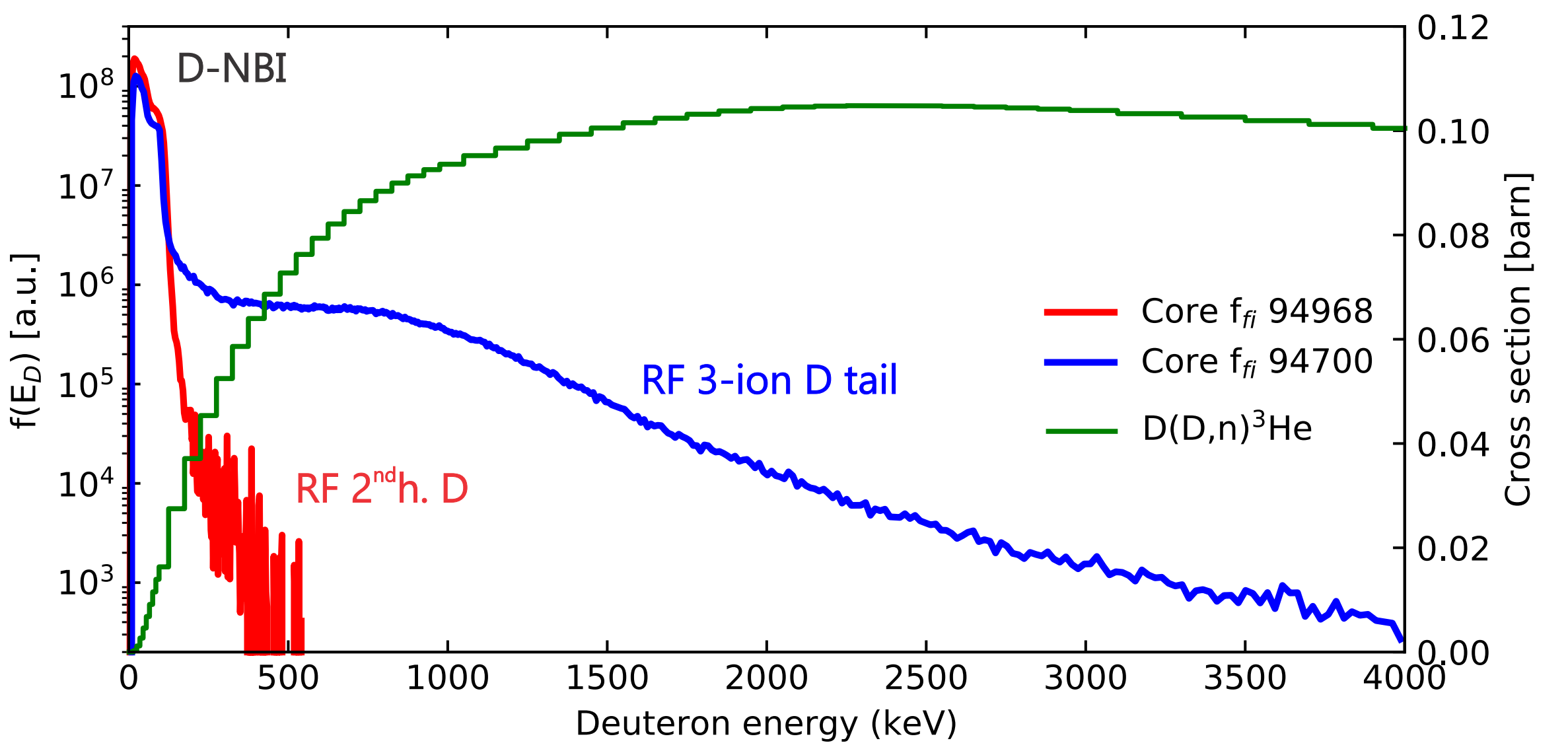

**Fig. 2**: Pitch angle averaged energy distribution functions of TRANSP/NUBEAM/TORIC evolved fast ion population. Distributions display the NBI source fast ions with energies <100 keV, and the distribution tails induced by RF - #94968 2nd harmonic D extending up until ~ 0.5 MeV, and #94700 3-ion accelerated D-NBI ions extending to 4 MeV.

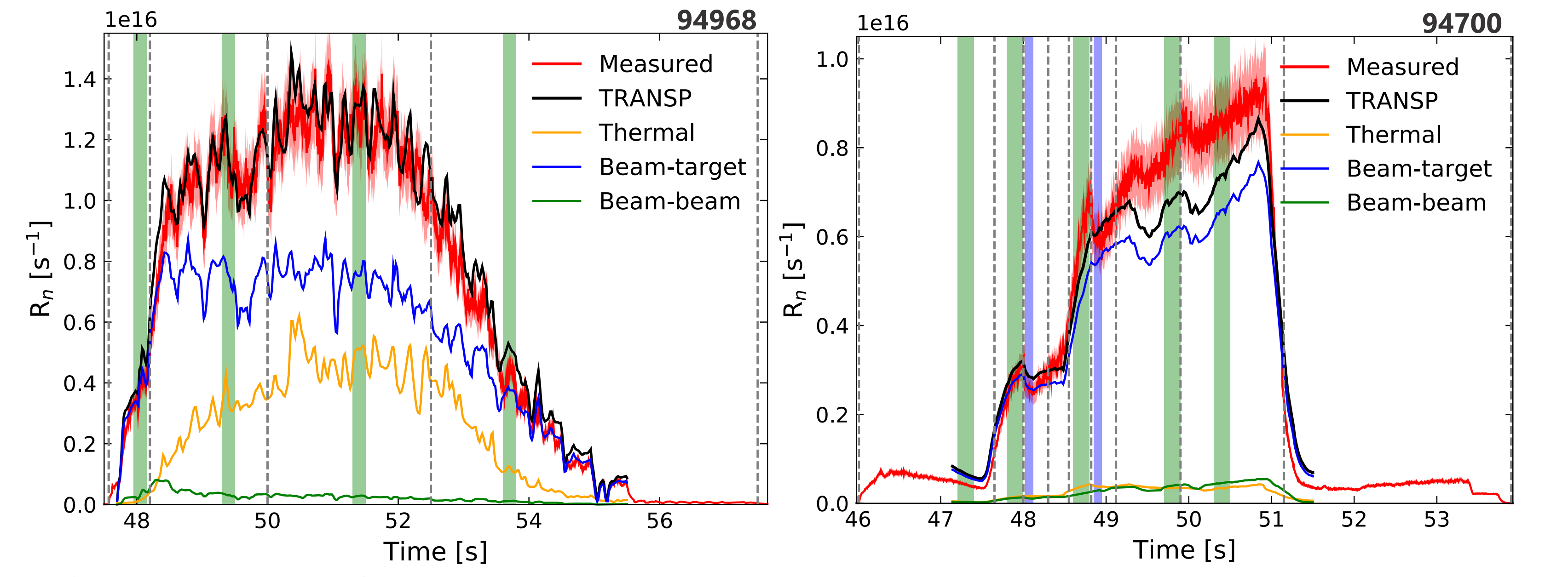

**Fig. 3**: Comparison of measured and TRANSP calculated neutron rates, with thermal, beam-target and beam-beam fusion contributions. Shaded areas denote time slices for fast ion distribution calculation.

## EXPERIMENTAL VALIDATION

- Total neutron rate: good match with fission chamber measurements (Fig. 3)
- Neutron emissivity profiles: qualitative match with neutron camera measurements (Fig. 4)

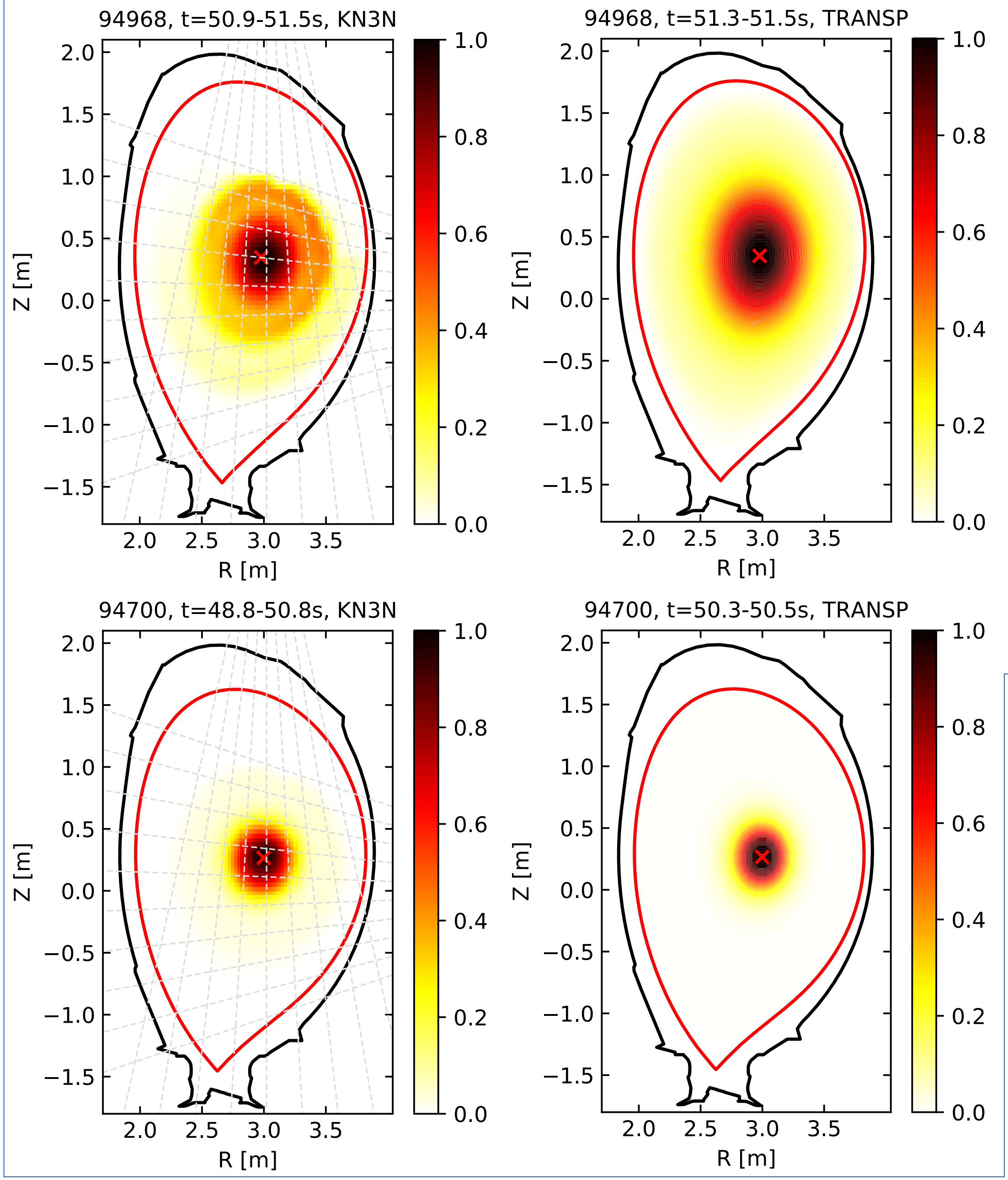

**Fig. 4**: Comparison of normalized neutron emissivity profiles for discharge #94968 and #94700. Left: profile camera measurements (KN3N) with 19 lines of sight denoted with dashed grey. Right: TRANSP simulations. Plasma boundary (red), JET limiter (black) and plasma magnetic axis (red ×). Emissivity in #94968 is broad due a radially wide distribution of beam ions and ion temperature profile, and contribution of trapped particles. Emissivity in #94700 is highly peaked because of its dependency on the distribution of RF fast ions, which is peaked on-axis where the resonant layer is positioned.

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- Neutron spectrum: good match with time-of-flight spectrometer DD-peak measurements (Fig. 5)

▶ Three-ion: temperature of high energy RF tail neutrons well matched, but relative intensities of thermal (<60 ns) vs. fast (>60 ns) not well described due to TOFOR line-of-sight and finite Larmor radius effects

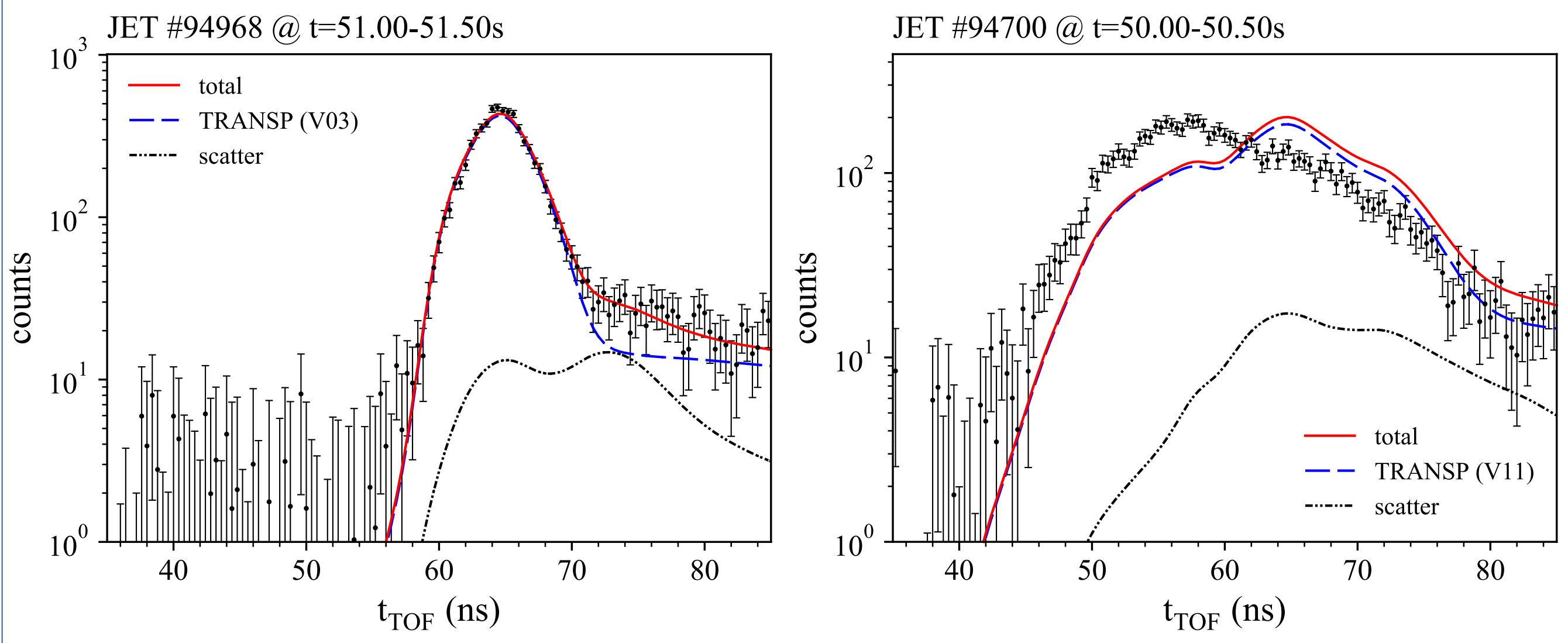

**Fig. 5**: Comparison of TOFOR measured (black points with uncertainties) and computed (red) neutron spectra for #94968 and #94700. Calculations are based on TRANSP distribution functions and neutron transport to assess the detector response and scattering contribution.

- Computational analysis of realistic spectra and response of neutron foil activation system (Fig. 6)

▶ Neutron foil activation spectra modelling, including T burnup and D-9Be, showed that the Al/In reaction rate ratio changes by approximately a factor of 2 between the two discharges, detecting the presence of RF ions accelerated with the three-ion scheme.

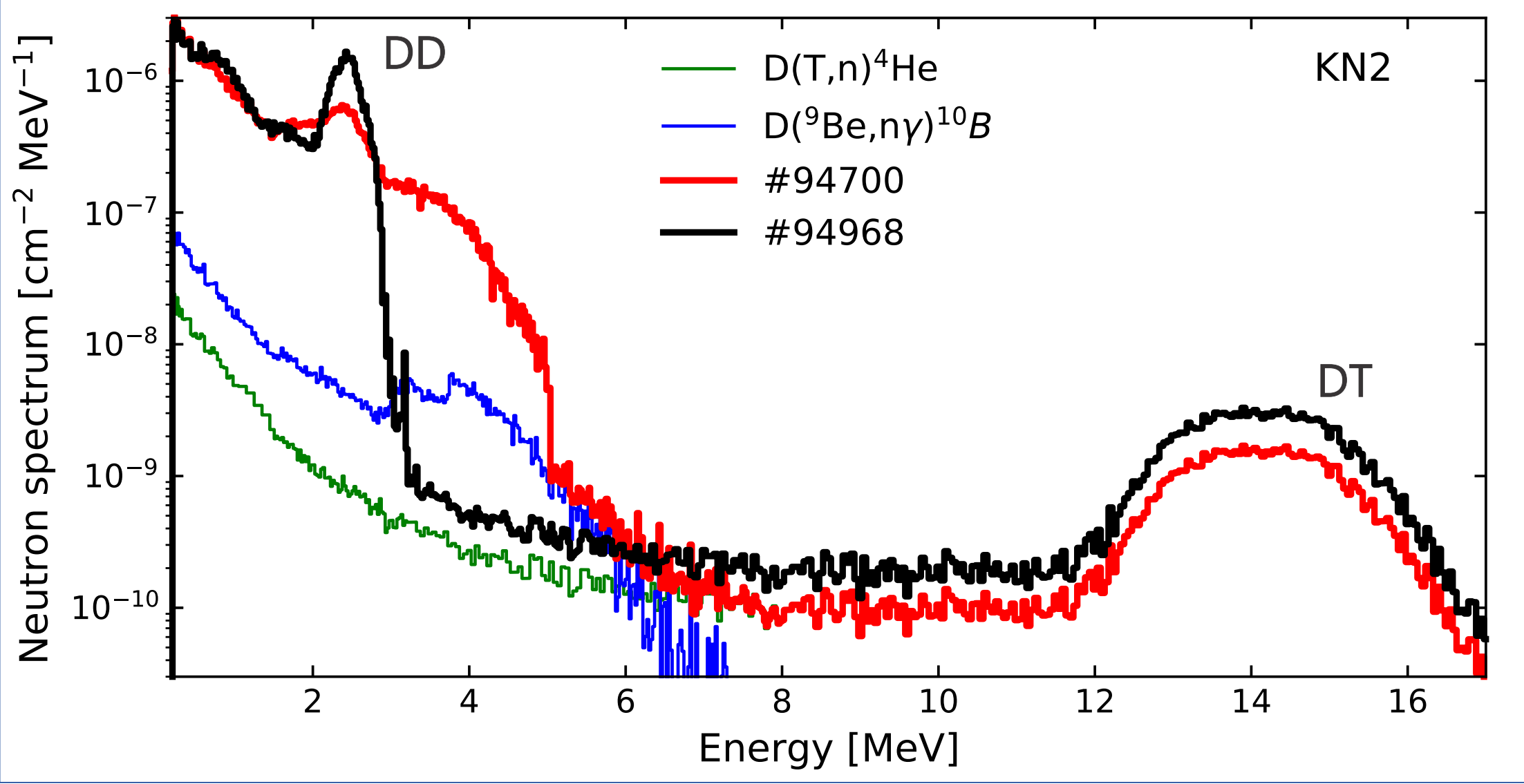

**Fig. 6**: Comparison of total neutron spectra calculated at the position of the neutron foil activation system at JET (KN2) for #94968 and #94700. In the latter the DD peak centered at 2.45 MeV displays high levels of anisotropy due to the effects of the energetic RF ion tail, while the baseline spectrum is dominated by thermal and NBI fusion emission. The contribution of T-burnup DT (green) and D($^9$Be,nγ)$^{10}$B (blue) neutrons to #94700 spectrum are added.

## CONCLUSIONS

- Neutron emission modelling validated against measurements for a baseline and 3-ion RF JET scenario
- Supporting in-vessel absolute fusion power calibration procedure at JET
- Methodology verified and ready for applications to DT plasmas. ITER studies

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