Study of fusion rate drops induced by fishbones on JET

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[±]See the Appendix of F. Romanelli et al., Fusion Energy Conference 2008 (Proc. 22nd Int. FEC Geneva, 2008) IAEA, (2008).

Association Euratom–Tekes

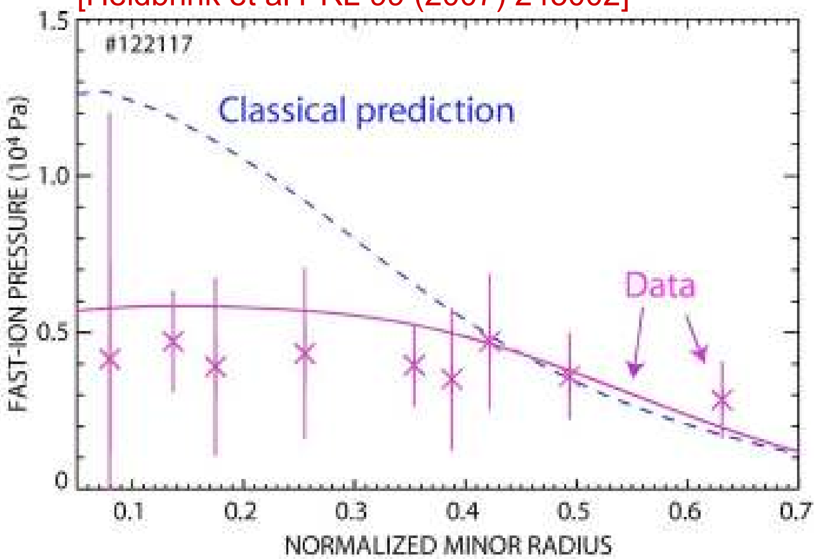
Motivation

Fast ion transport in the presence of MHD instabilities:

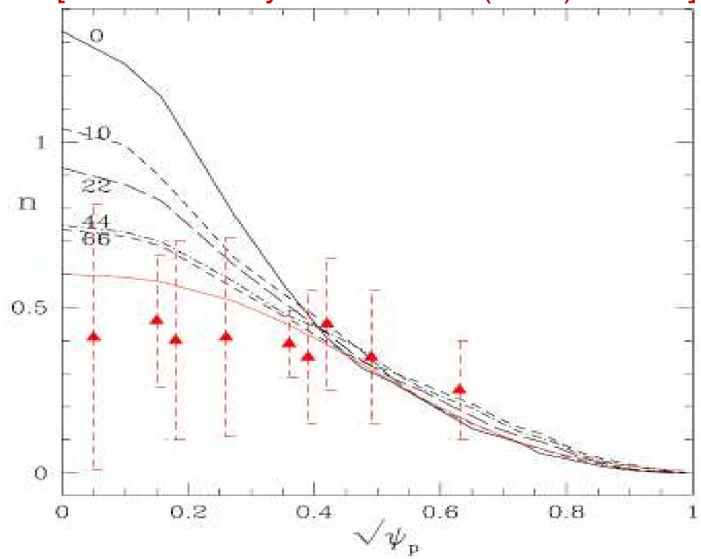
• Solid qualitative understanding of possible transport mechanisms, but so far only a handful of <u>quantitative</u> comparisons with theory.

• Quantitative studies <u>for AEs</u> highlighted importance of electrostatic potential (otherwise FI transport is significantly underestimated)

[Heidbrink et al PRL 99 (2007) 245002]

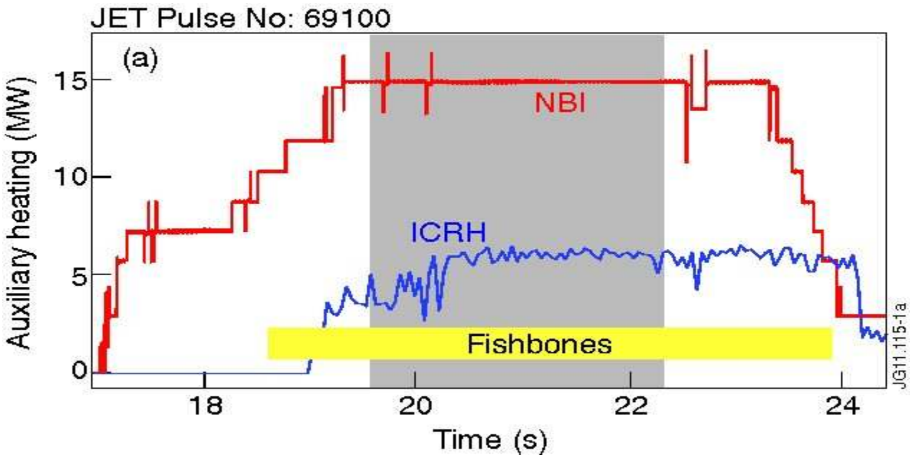


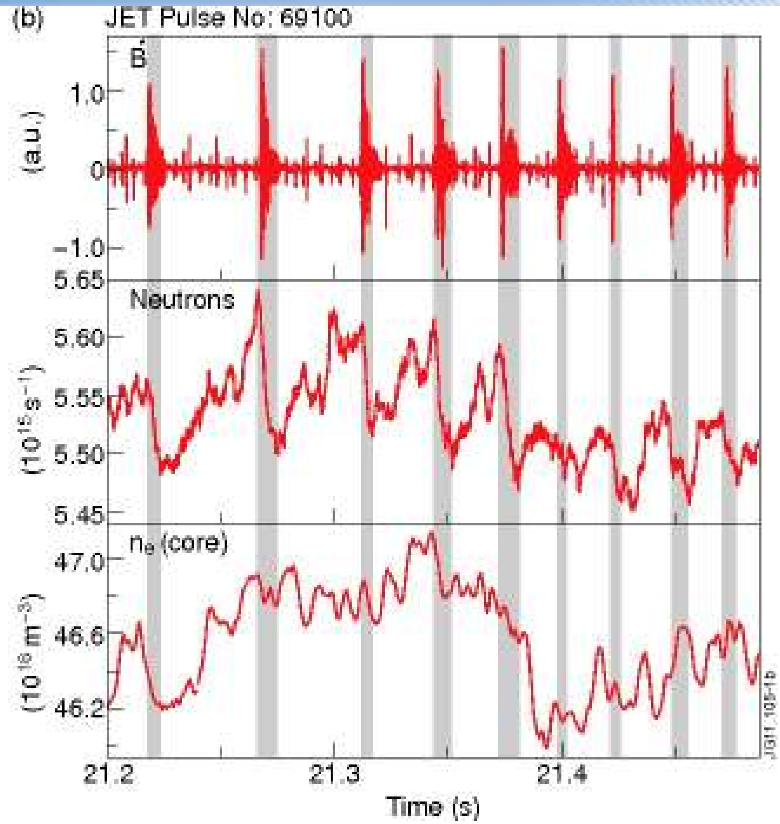
[White et al Phys Plasmas 17 (2010) 056107]



Here try to make similar assessment for case of <u>fishbones</u>, using measured transient drops in neutron emission as benchmark.

JET discharge 69100





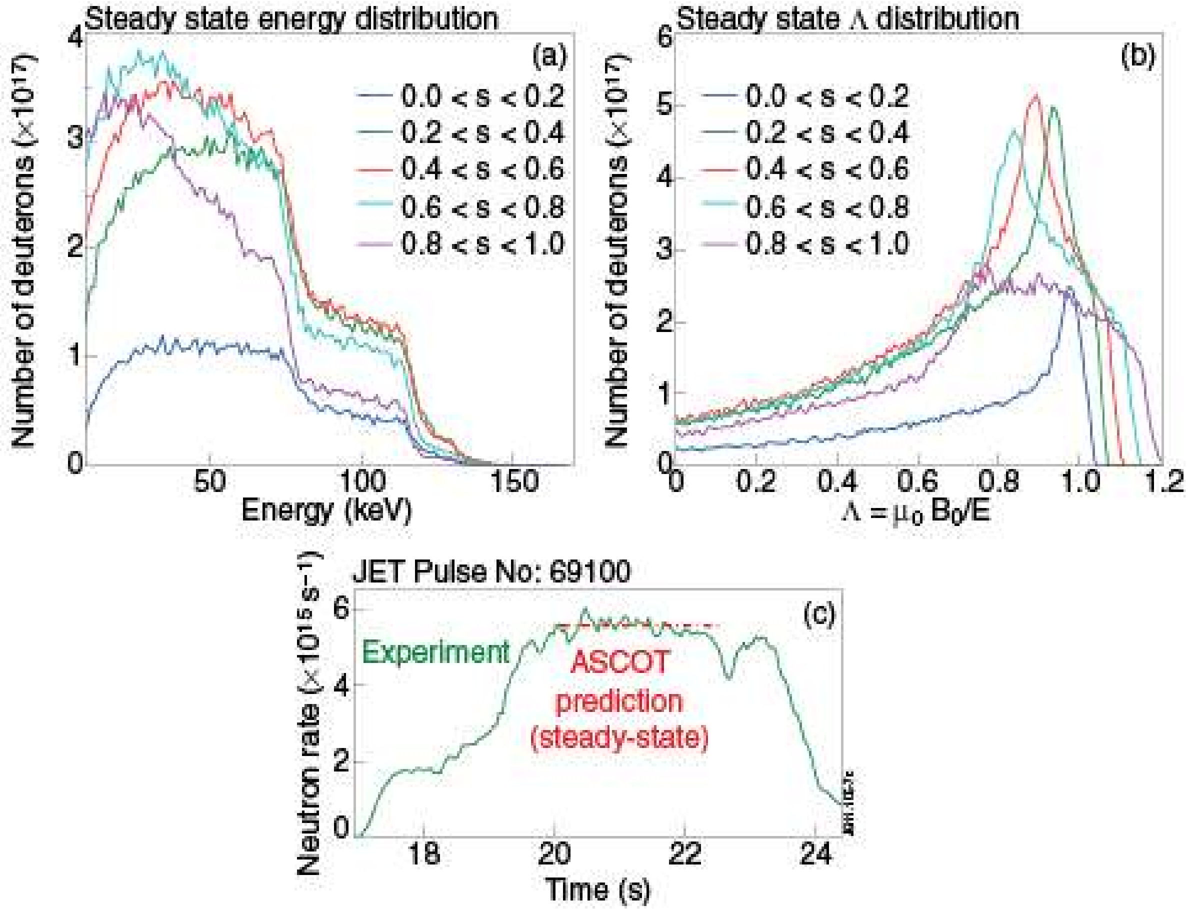
- Previously documented and well diagnosed
- B=2.7T, I=1.2MA, q95=6.5, β_N=2.6,β_{pol}=1.8, δ ~ 0.4, n_e/n_{GW}=0.77, 15 MW NBI, 6 MW RF (H-minority)
- NPAs and gamma ray spectrometers show negligible second harmonic D acceleration (in agreement with PION and SELFO)
- 95% of neutrons originate from beam-target or beam-beam (TRANSP)
- Timing of FB occurrence and RF-free reference discharge show that FBs destabilised by NBI
- One of the ^{235}U fission chambers connected to fast DAQ, measures fast drops in neutron rate correlated with the FBs

Simulation strategy (I)

STEP 1:

NBI distribution from guiding center Monte Carlo solver ASCOT with neoclassical fast ion transport (~635.000 markers representing 1.04 x 10^{20} fast ions).

Assume that after a fishbone burst the fast ion distribution is able to fully recover before the next fishbone.



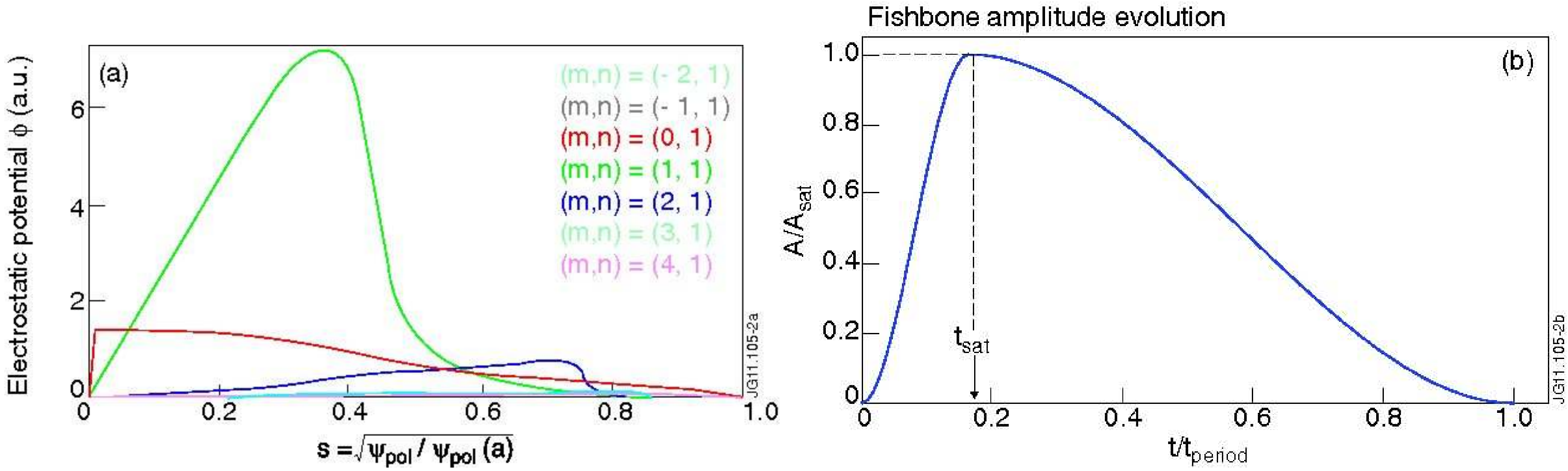
Steady state fusion rate predicted by ASCOT has right order of magnitude (here even better despite ASCOT not knowing about MHD, which supports above assumption).

Main focus on <u>relative</u> changes to the neutron rate (pre- and post-FB).

Simulation strategy (II)

STEP 2:

Follow the ion trajectories in the presence of FB perturbation (with HAGIS):



- Use internally constrained EFIT magnetic equilibrium (incl. MSE etc)
- Use internal kink perturbation field structure (from MISHKA)
- Prescribe frequency and amplitude evolution analytically to resemble typical fishbone (piecewise 3rd order polynomial)
- Scale amplitude to match ECE measurements (assuming plasma incompressibility)

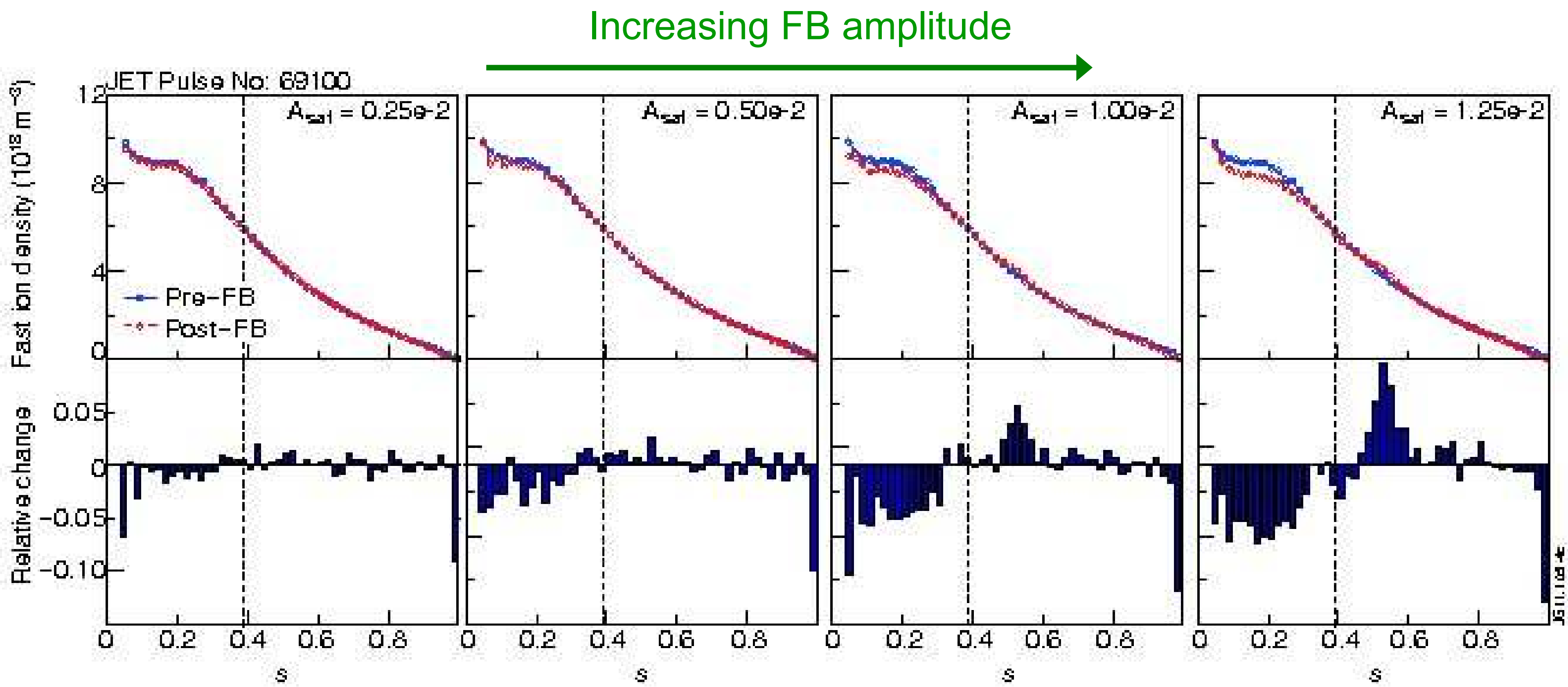
Simulation strategy (III)

STEP 3:

Re-compute D-D fusion rate with ASCOT:

- Cannot use continuous additional heating source in these runs, hence cannot directly compare with the steady-state yield shown earlier
- Instead, slowing of ions is followed for a time interval of 5 ms during which the DD yield is collected. This is done for the pre-fishbone and each of the post-fishbone distributions.
- This approach results in a slightly reduced yield compared to the steady-state yield, but still allows the two cases (pre- and post-fishbone yields) to be compared
- Choice of 5 ms is compromise of getting low statistics noise and but still maintaining nearly the same steady-state distribution
- Plasma background profiles kept fixed

F.I. Redistribution (I)



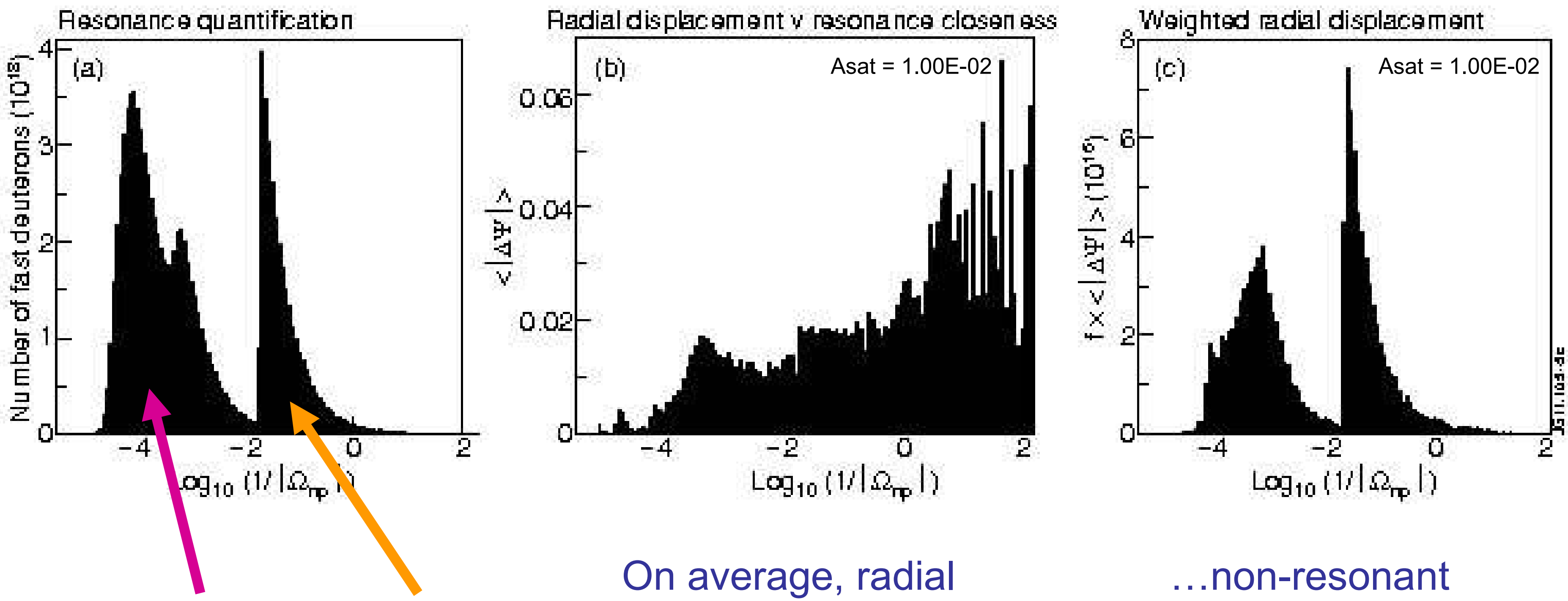
- Main pattern: Fast ions expelled from inside q=1 to outside q=1 (still confined)
- Radial neutron emission profile broadens accordingly. Due to finite peaking of target plasma density, reduction in volume integrated neutron rate can be expected.
- Near plasma boundary: losses from marginally confined ions (large relative change but absolute contribution of losses is actually small)

F.I. Redistribution (II)

Evaluate radial redistribution in terms of proximity to wave-particle resonance:

Resonance parameter: $\Omega_{np} \equiv n\ \omega_{tor} - p\ \omega_{pol} - \omega_{fb}$

(minimise Ω_{np} for each marker by varying $p \in Z$ and ω_{fb} within experimentally observed values)



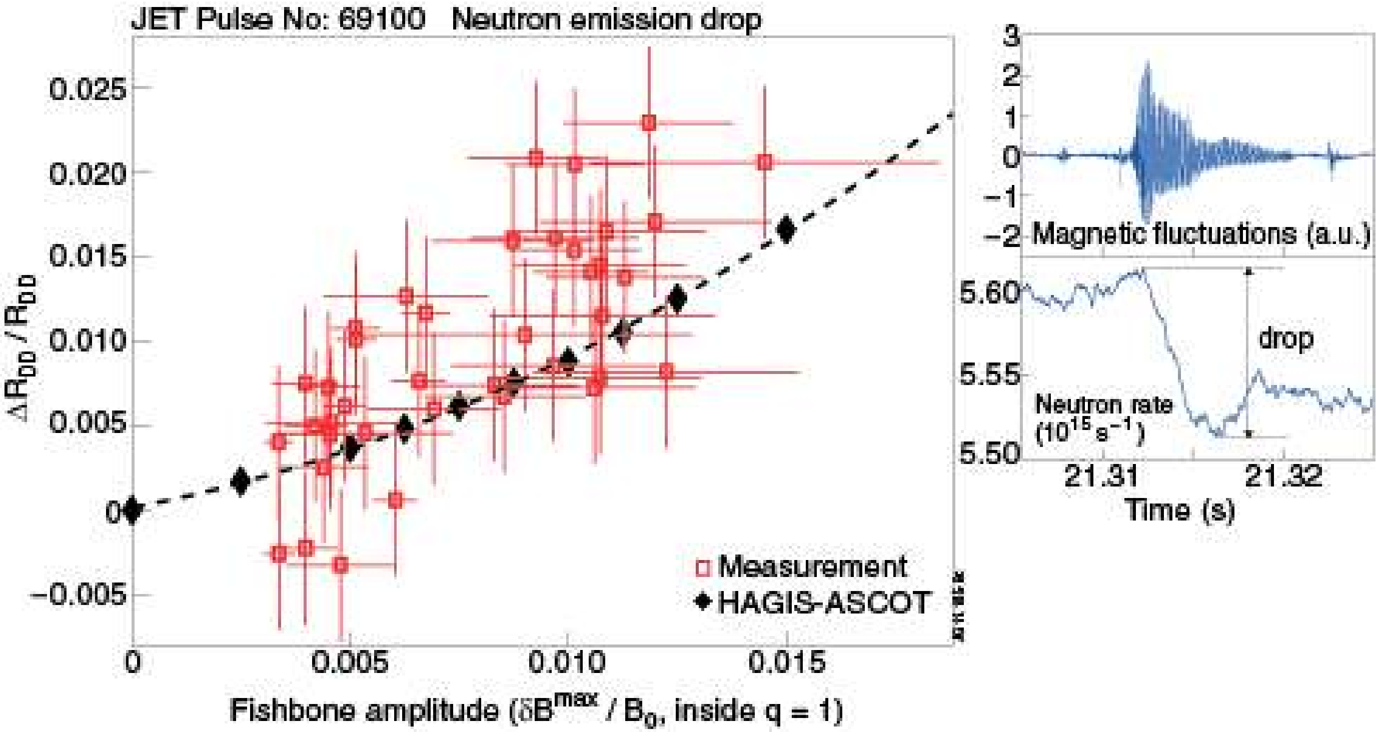
Two groups of NBI particles: One with poor and one good resonance match

On average, radial displacement increases as resonance is approached, but …

…non-resonant interaction processes still very significant (roughly equal contribution).

Drops in neutron emission

- Neutron drops simulated for a set of runs with varying fishbone amplitude (A_{sat})
- Experimental measurements evaluated for an ensemble of 40 fishbones (t=19.6-22.3 s)



- Error bars on fishbone amplitude dominated by measurement uncertainty of local Te gradient
- Error bars on drop due to finite noise on neutron signal

Drop quantification

- For this range of amplitudes simulations predict drops of order 0.5-1.5%. Quadratic dependence on FB amplitude (diffusive-type transport)
- To within a factor 2 measured drops are consistent with simulations.
- Flattening of thermal ion density profile could lead to slight underestimation of simulated drop by not more than a fraction of a percent, which would not affect level of agreement

Conclusions

- Methodology developed to compare fast ion transport in code and experiment in the presence of fishbones.

- Complements nicely code validation through fast ion losses measurements (e.g. fast ion loss detector not absolutely calibrated)

- By coupling HAGIS and ASCOT now able to predict FI redistribution due to FBs quantitatively. Magnitude of drops in D-D fusion reactivity predicted correctly to within factor 2.

THANK YOU!