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** See annex of J. Pamela et al, "Overview of JET Results ",*
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In next-step fusion devices like ITER, the confinement of energetic particles (fast ions from auxilliary heating and especially fusion born alpha particles) is of critical importance [1]. In order to study particle losses more in detail, new diagnostics have been installed at ASDEX Upgrade and JET, both of which are experiments with high relevance for ITER. Here we report on first results of the JET scintillator probe and compare the capabilities and applications of both devices.

The collimator of the JET scintillator probe has been optimised using the orbit-tracing Monte-Carlo code 'e pdesign' [2]. It was shaped to select particles with larmor radii from 4 to 13cm and pitch angles δ ($\cos\delta = \vec{v} \cdot \vec{B}/(vB)$ between 34 and 86 degrees, which hit the scintillating plate in a well defined region. A gold foil (1μm) behind the entrance aperture is used to block the low energy (200keV) hydrogen isotopes from prompt losses of NBI. The scintillator material P56 ($Y_2O_3 : Eu^{3+}$) has been chosen for its high photon rate per incident ion (compared to P46 and P43) and high life-expectancy and has a decay time of about 2ms. Thus, the time resolution is intrinsically restricted to events on timescales above a few milliseconds. An image of the plate is relayed by a set of lenses onto a coherent fibre optics bundle, which is viewed at the cold end with an arrangement of a frame-transfer (no dead time) CCD camera (RoperScientific Cascade 512B) and a 4×4 photomultiplier tube array (Hamamatsu) both observing the same image by means of a cube beam splitter. The achievable time-resolution with the full spatial resolution that the fibre bundle provides (95×36) is 20Hz using the CCD camera, but can be increased on demand by trading for spatial resolution or phase-space coverage. The photomultiplier array distinguishes light from 9 different sections of the scintillator plate and is sampled at 1.6kHz by default.

The ASDEX Upgrade Fast Ion Loss Detector (FILD) [3] is based on the same principle and similar in design to the JET device. The novelty of this diagnostic is its fast response scintillator material (TG-Green, Sarnoff, $SrGa_2S_4 : Eu^{2+}$) that has a decay time of just 500ns. This makes it ideal for the investigation of fast MHD events (ELMs, NTMs, etc.) with respect to their induced particle losses, e.g. by correlation analysis. FILD also uses a beam splitter to obtain identical images with a CCD camera at 25Hz (20ms exposure) time resolution and a 5×4 photomultiplier array (Hamamatsu) at up to 2MHz sampling rate. The pitch angle range covers losses from passing particles ($\delta = 20^o$) to deeply trapped ($\delta = 87^o$) and has a resolution of ≈10%. The detector head aperture allows particles with larmor radii between 2 and 12 cm to pass through the aperture (no blocking foil). The need to detect particles with such small radii compromises the phase-space resolution for particles with larger energies. Due to the high particle fluxes a significant fraction of the ionoluminescence is generated by hydrogen ion isotopes instead of helium and fast protons as is the normal case at JET, where NBI injection prompt losses are absorbed by the gold foil.

An important tool for the interpretation of data is the correct mapping of phase-space into scintillator plate coordinates. For that purpose, 'e pdesign' is used both for the JET and the ASDEX Upgrade diagnostic. In figure 1 (left), several clusters of particle trajectories are shown. All particles of an individual group have identical start conditions in pitch and energy, but hit the plate distributed due to the finite size of the aperture. The size and shape of this aperture determines the attainable resolution. The centroids of each group of particle trajectories define the grid points which are used in the data interpretation as seen in the image besides.

At ASDEX Upgrade, it is sufficient to run any of the neutral beam injectors to recognize a signal caused by prompt losses. At JET only pulses with high enough NBI power for a given plasma density (typically 8MW) or significant amounts of ICRH heating generate high enough particle losses at detectable energies to pass the detection threshold. High neutron fluxes do generate luminescence from the scintillation material which is not caused by charged particle impact. This background light needs to be subtracted even for semi-quantitative analysis.

Common features between FILD and the JET probe involve the verification of expected particle losses caused by ICRH heating (see figure 1 and figure 2). The illustrated low-density JET discharge shows ICR heating losses appearing with a broad distribution in phase space. The spread in larmor radius direction is clearly larger than what would be expected from the instrument response to a sharply defined high energy particle source. Losses from a high power NBI phase show different features (compare figure 3). The pitch angle spread here is quite broad, but the distribution across larmor radius is of the order of what is expected from the instrument resolution. This indicates that a clearly defined momentum characterises the source of those particle losses. Using the field at the entry slit (B = 2.11T) and the reasonable assumption that an abundant species (hydrogen isotopes or helium) is generating the signal, the grid calculated with e pdesign (Figure 3) shows that these losses appear with a larmor radius matching that of DD fusion products ^{3}T (1.008MeV) and ^{1}p (3.024MeV). A preliminary assessment of the expected prompt losses by beam target DD fusion using the JET NBI geometry indicate a qualitative agreement of the data's intensity dependence on pitch angle with theory [4].

Results have been obtained regarding losses induced by MHD activity. Figure 2 shows the two directly following frames (exposure time: 50ms) of the example from figure 1. The discharge is an L-mode plasma with low density and ≈5.2MW of ICRH power, which developes monster sawteeth with a period of more than 1s. The sawtooth crash at 16.823s as determined from the soft X-ray diagnostic triggers clearly visible losses with a peak at pitch angle $\delta \approx 50^{o}$ and larmor radii between 4 and 6 cm, which are much less before and after.

Slow events like monster sawteeth and slow composite ELMs (not shown here) are well diagnosed with the JET probe due to its good phase space resolution. For the analysis of losses induced by fast MHD events, like Neoclassical Tearing Modes (NTM), the ASDEX Upgrade probe is better equipped due to its fast scintillator material and the absence of a blocking foil which enables the detection of hydrogen and deuterium. As an example from the wealth of results published in [3], figure 4 shows the correlation between MHD modes and particle losses. The JET scintillator probe takes an in depth look on fusion born particle losses and slow MHD, while ASDEX Upgrade investigates fast MHD and the direct correlation with particle losses. Both diagnostics are providing a rich and complementing variety of results.

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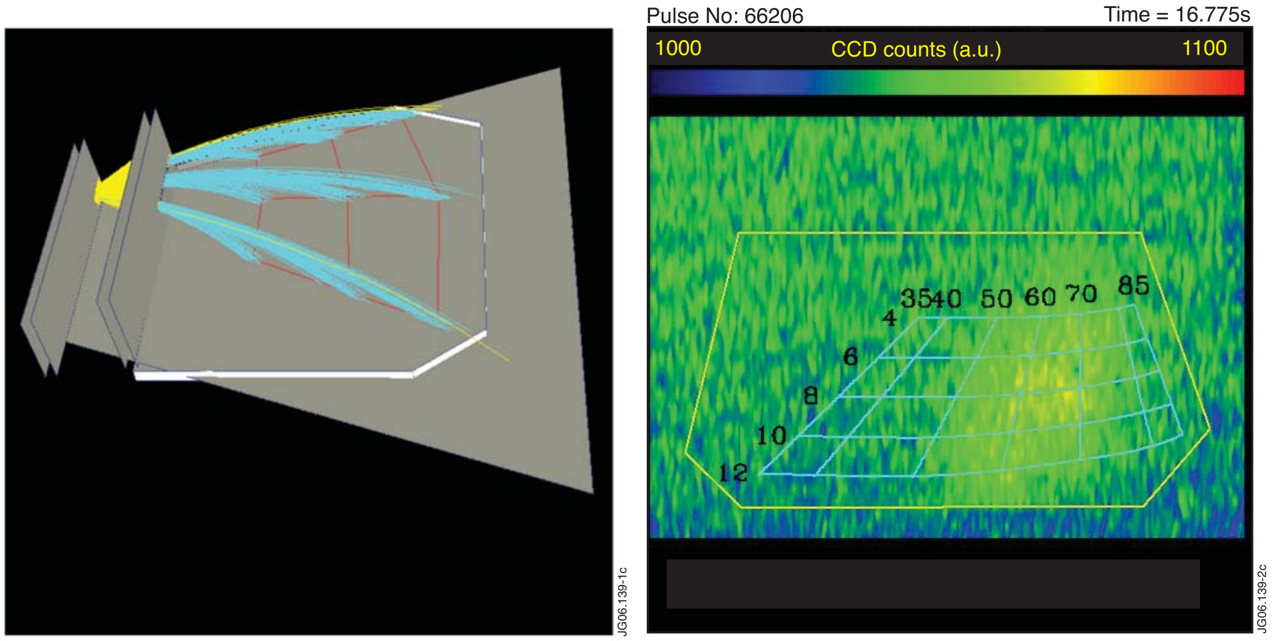

Figure 1: Left: 3D visualisation of particle orbits with JET probe geometry resulting in a sample 3x3 grid (red). Yellow particle orbits are discarded. Right: Emission pattern overlayed with 5x6 grid covering the accessible phase-space.

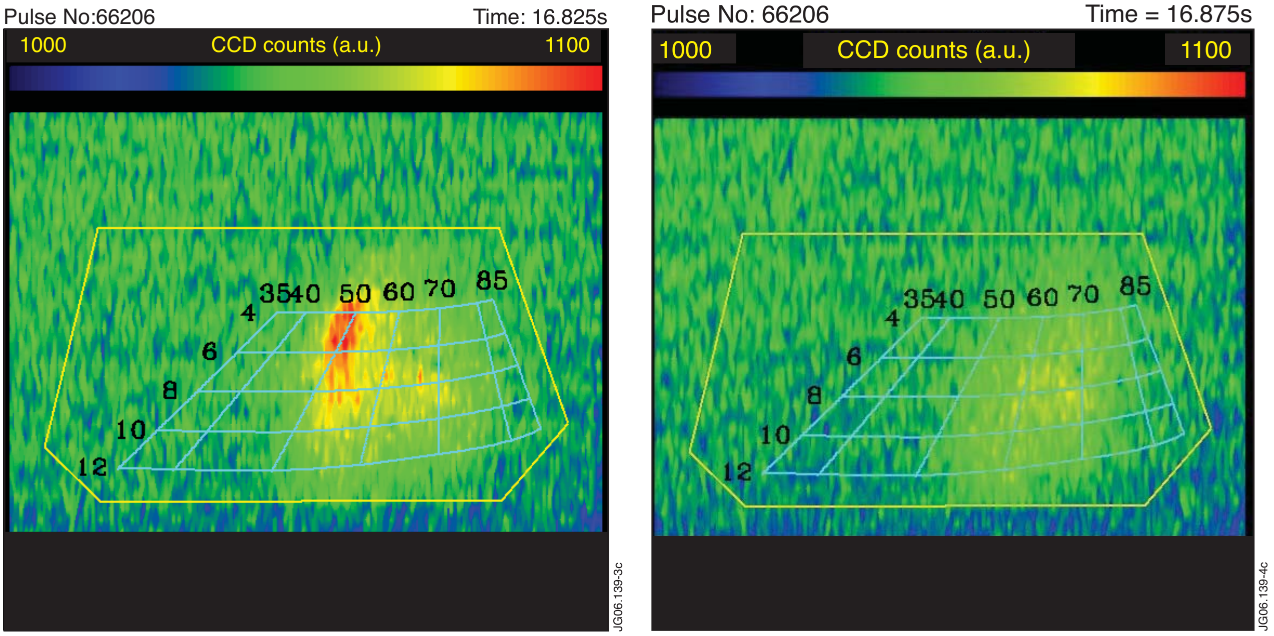

Figure 2: CCD camera images (Units: counts) with phase-space mapping of consecutive times of JET No: 66206 illustrating the additional losses due to sawtooth activity (during the exposure time lasting from 16.80s - 16.85s). The image sequence is representative of all monster sawtooth induced particle losses observed so far.

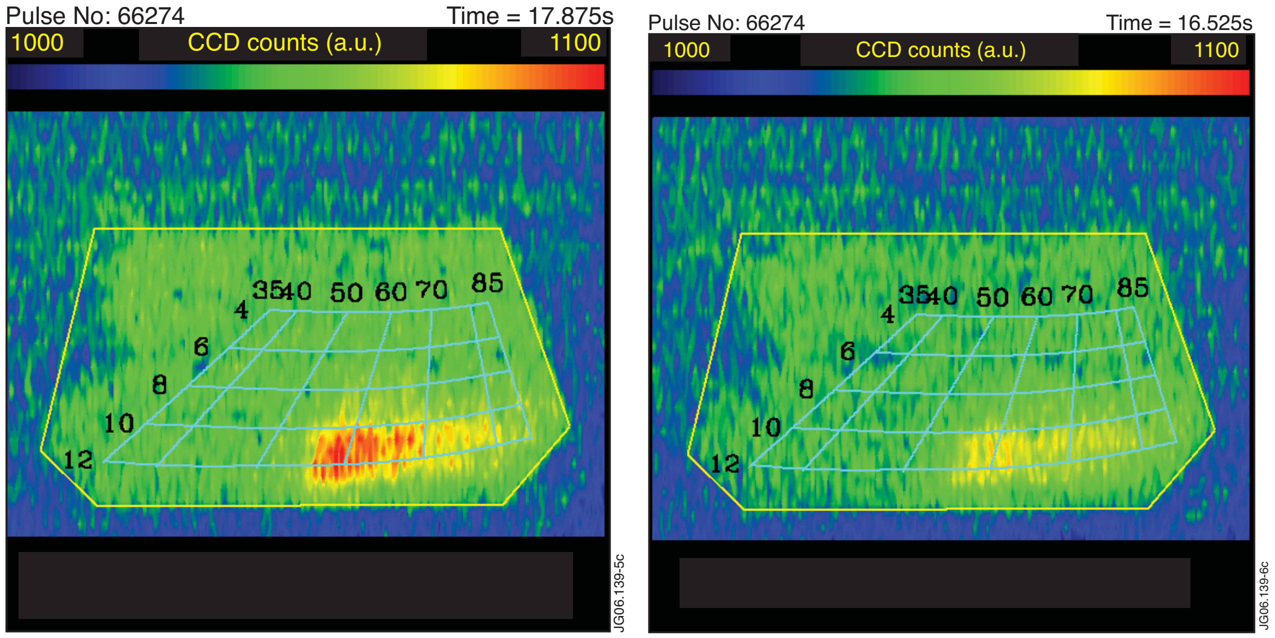

Figure 3: Pulse No: 66274 which was heated with 16MW of NBI power. After 17.0s, 3.3MW of ICR heating have been added. The left image shows the loss products widespread in pitch angle but narrow in energy. With added ICRH some more particles are lost, but seem to be somewhat more localised in pitch angle (50).

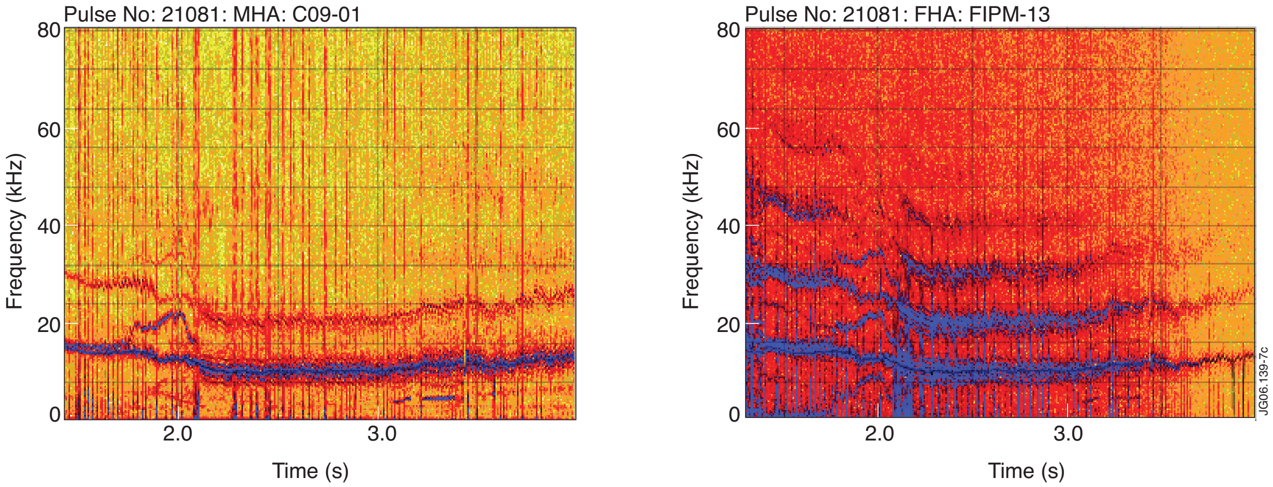

Figure 4: Time evolution analysis of the frequency of a (3,2) NTM magnetic perturbation, $\dot{B}_\theta$, on the left and a FILD channel on the right