Italian National Agency for New Technologies, Energy and Sustainable Economic Development

Detection of plasma waves emitted by runaway electrons in FTU

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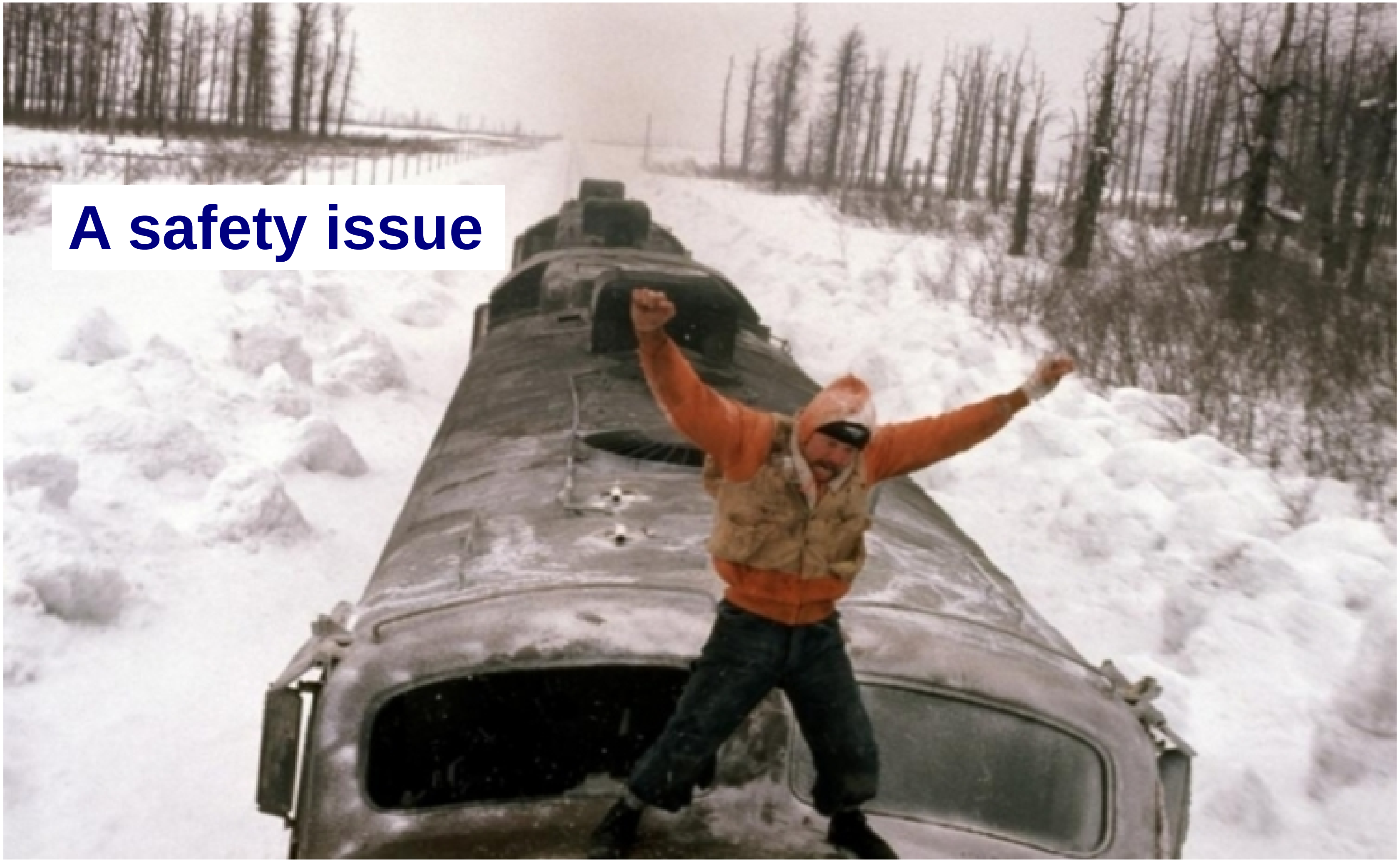
Runaway

- Free-fall acceleration of electrons above a critical velocity (under the action of an applied electric field)



Energy limits for runaway electrons

1. Synchrotron radiation
2. Residence time before drifting away

- Both depend on transverse momentum

- Collisional scattering is weak

- Is there substantial scattering by interaction with plasma waves?

Which plasma waves?

- Gyroresonances and Doppler effect

$$\omega - k_{\parallel} v_{\parallel} = m \frac{|\Omega_{ce}|}{\gamma} \qquad v_{\parallel} = \mathbf{v} \cdot \mathbf{B}/B$$

- *m* = 1, 2, … cyclotron/synchrotron radiation: photon emission with electron cooling
- *m* = 0 Cherenkov resonance: plasmon emission with electron *slowing*
- *m* = -1, … anomalous Doppler resonance: plasmon emission with electron *scattering*

ENEA

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  photon emission with electron cooling
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  plasmon emission with electron *slowing*
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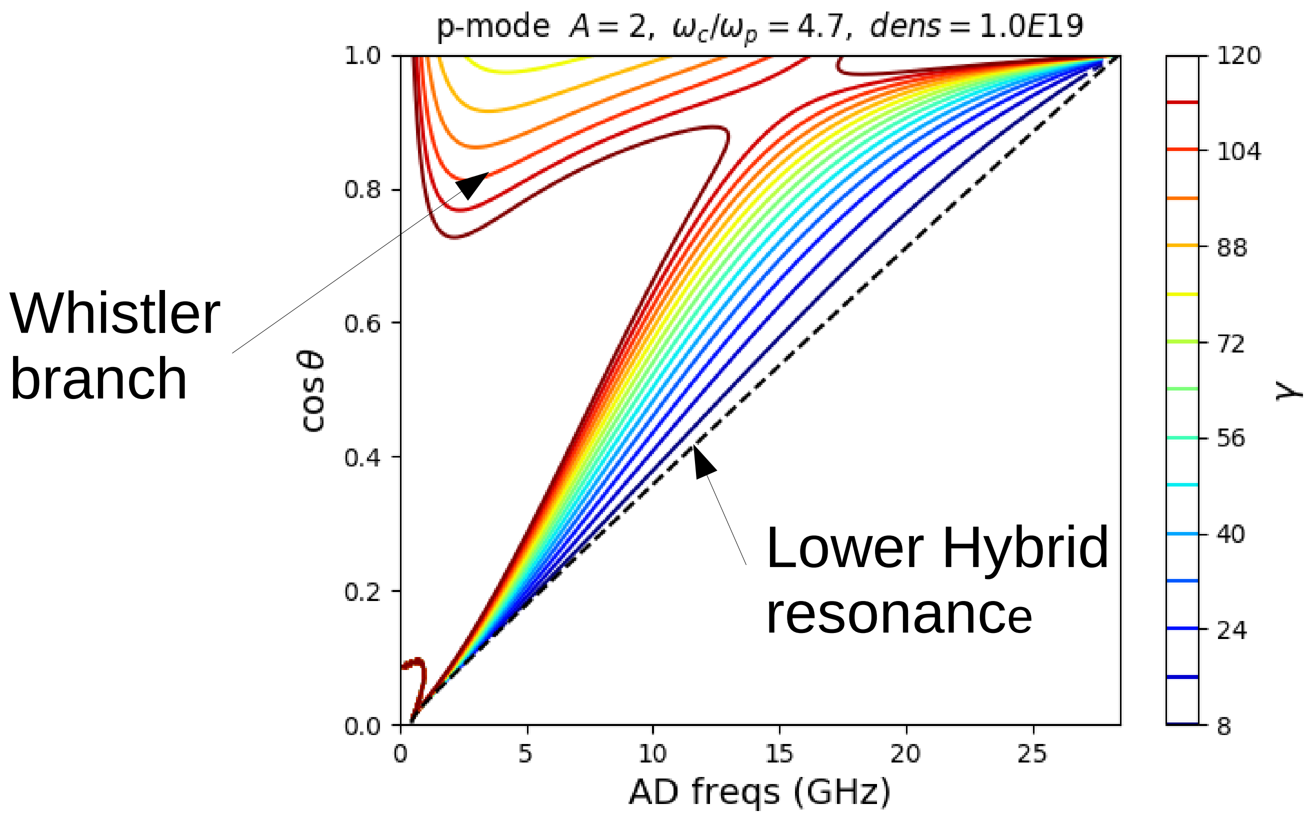
  plasmon emission with electron *scattering*

$$\frac{c\,k_{||}}{\omega} \equiv N_{||} = \frac{1}{\beta_{||}}\left(1 - m\frac{|\Omega_{ce}|}{\gamma\omega}\right)$$

- parallel refraction index > 1 for Cherenkov and anomalous Doppler, “superluminal” electrons.

Which plasma waves?

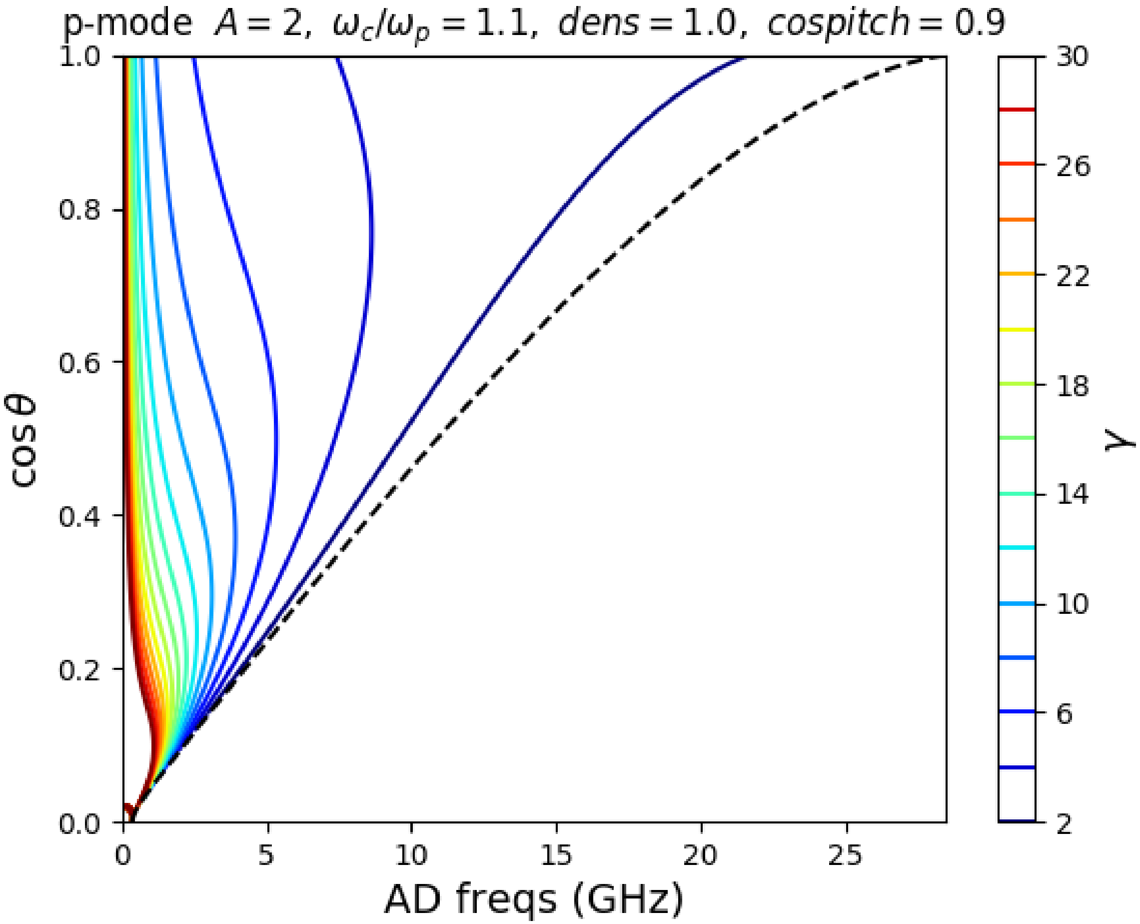
- Cold plasma dispersion relation $\omega_c/\omega_p >> 1$ (FTU)



- Anomalous Doppler resonance in the frequency - angle dispersion diagram ($\cos\theta = 0$ is perpendicular propagation)
- Resonances up to the electron plasma frequency

Which plasma waves?

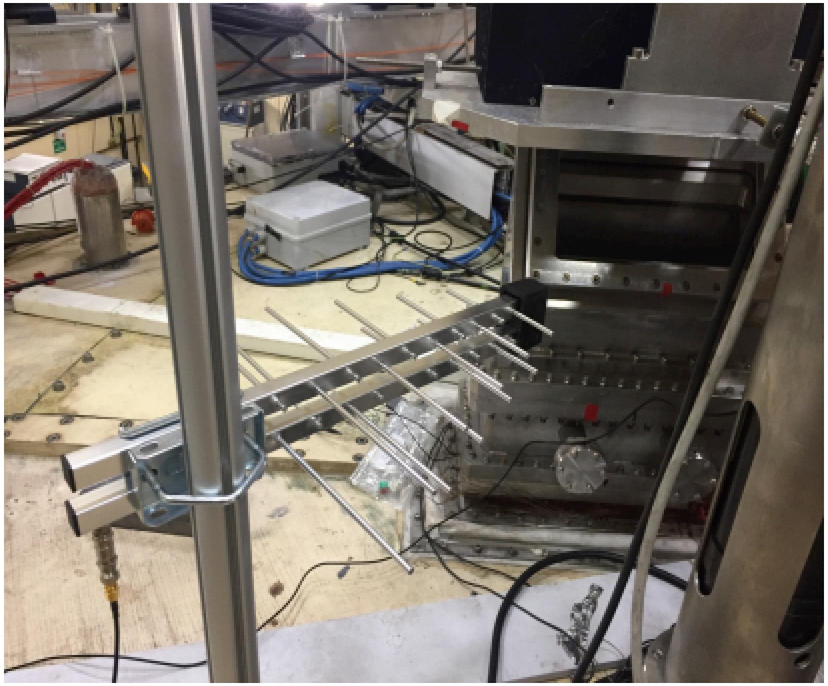
- Cold plasma dispersion relation $\omega_c/\omega_p \approx 1$ (others)



- Whistler branch excited at much lower energies, gamma > 5, it was gamma > 70 in the FTU case.

Wave detection

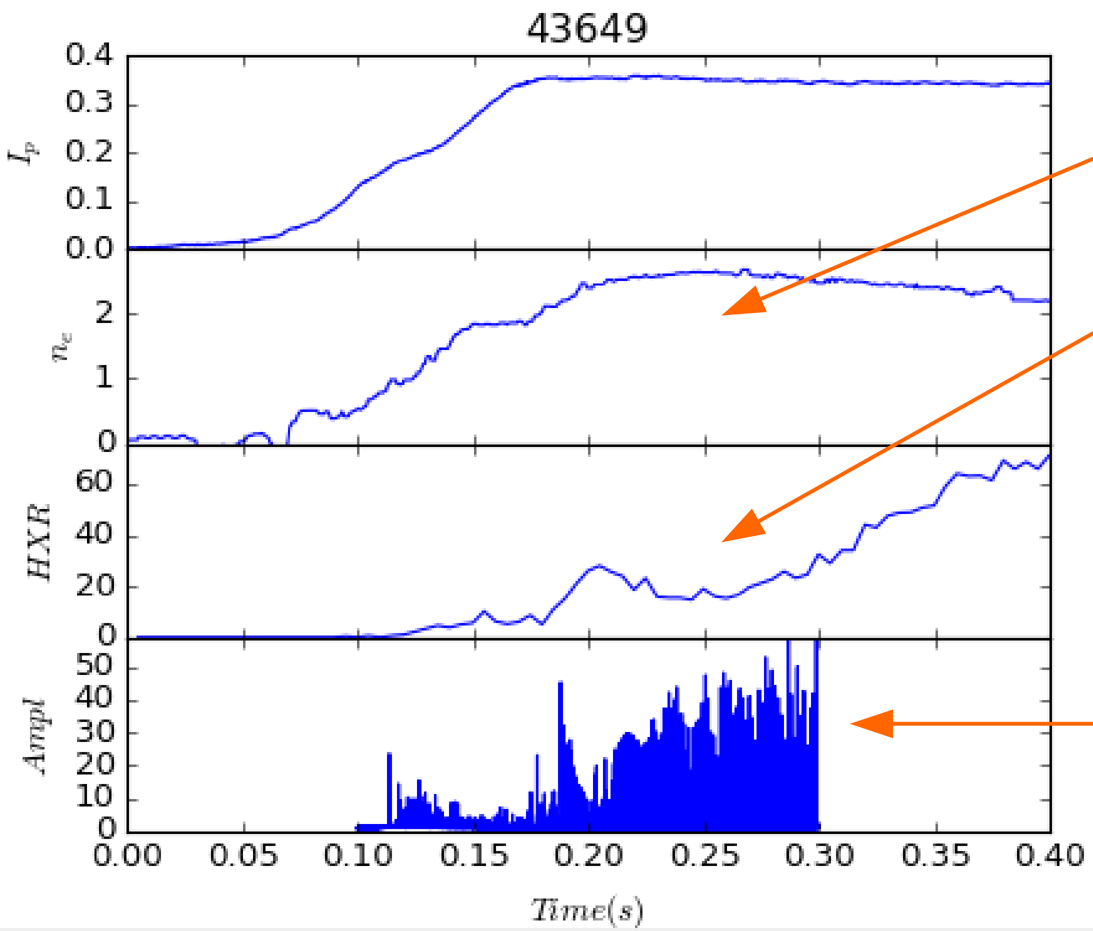
- Collect e.m. waves generated by mode conversion



Ex-vessel log-periodic antenna

- Acquire wave field with high sampling rate
- Displaly short-time rms amplitude and spectrogram

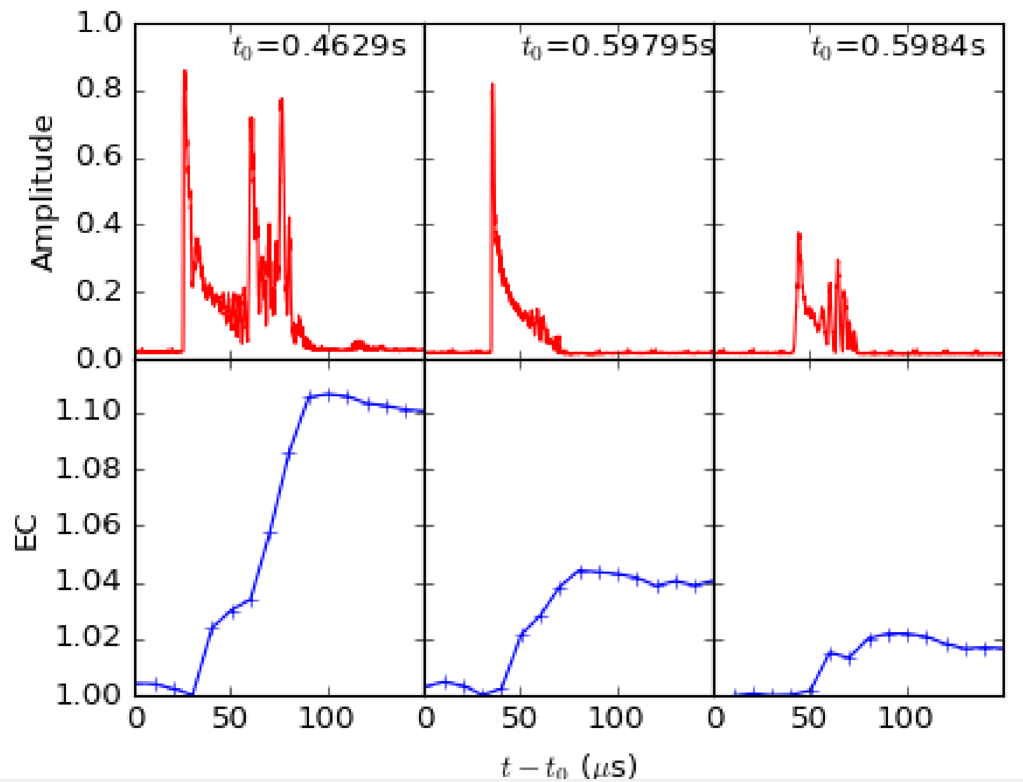
Results 1



- Detection in low-density plasmas <3E19
- with high hard x-ray count rates (the RE signature).
- Bursty character of the amplitude envelope

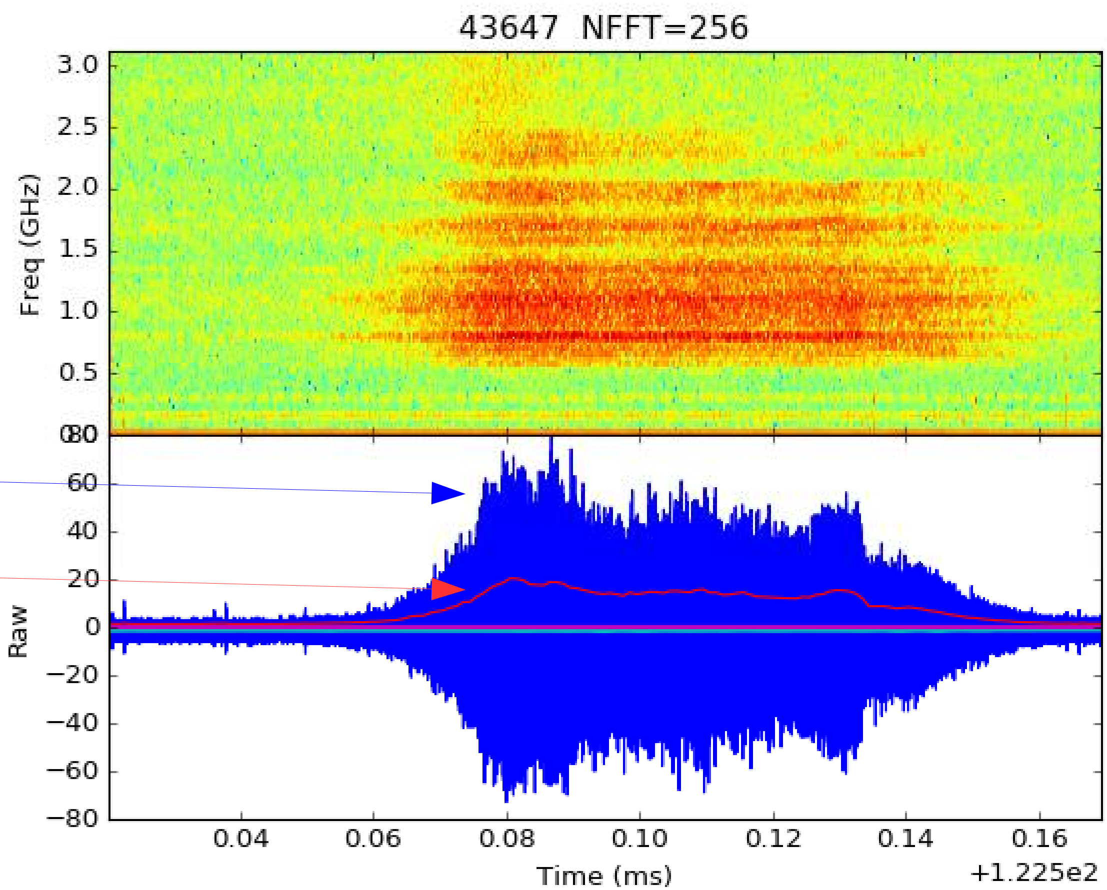
- Wave emission associated with instabilities, with prevalent stimulated emission

Results 2



- Wave emission bursts are correlated with jumps of cyclotron emission
- a sign of pitch angle scattering, i.e. these waves can reduce the energy limit of runaway electrons

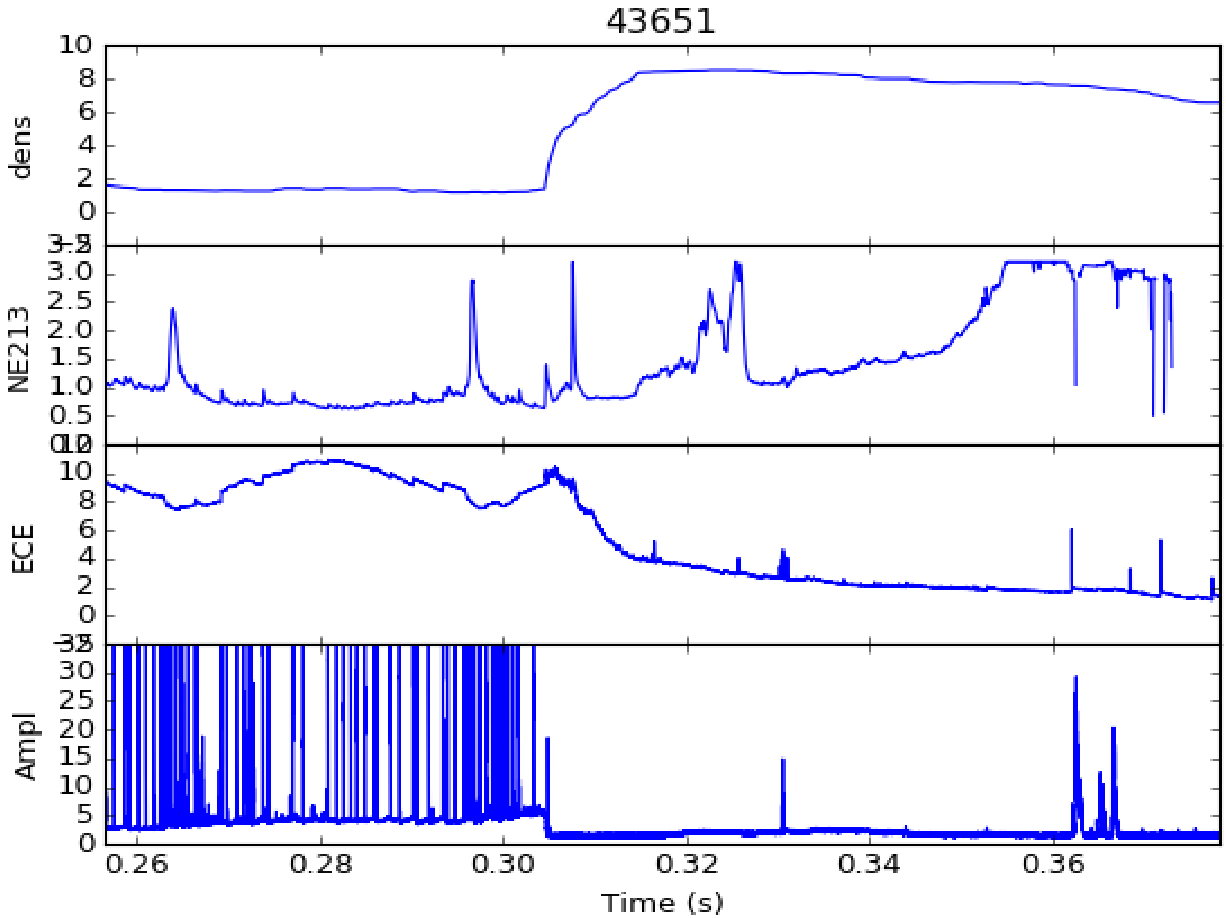
Results 3



- Spectrogram
- Signal amplitude
- Short-time rms

- waves begin at around 1 GHZ
- broadband (detailed structure not reliable)
- low-freq suppression partly due to propagation across the FTU port
- coherent waves observed in some cases

Results 4



- Wave emission suddenly disappears when a solid deuterium pellet is injected
- Likely due to higher density and lower temperature of the background plasma, which give higher wave collisional daming

Summary and perspectives

- Plasma wave emission associated with intermittent instabilities of runaway electron populations has been detected.
- Port to other tokamaks, TCV, COMPASS, others
- Complete analysis of FTU data
- Model instability conditions and dynamics
- Can the instability be controlled to alleviate the risk of damage by runaway electrons?