MHD instabilities during benign termination of runaway electrons in ASDEX Upgrade

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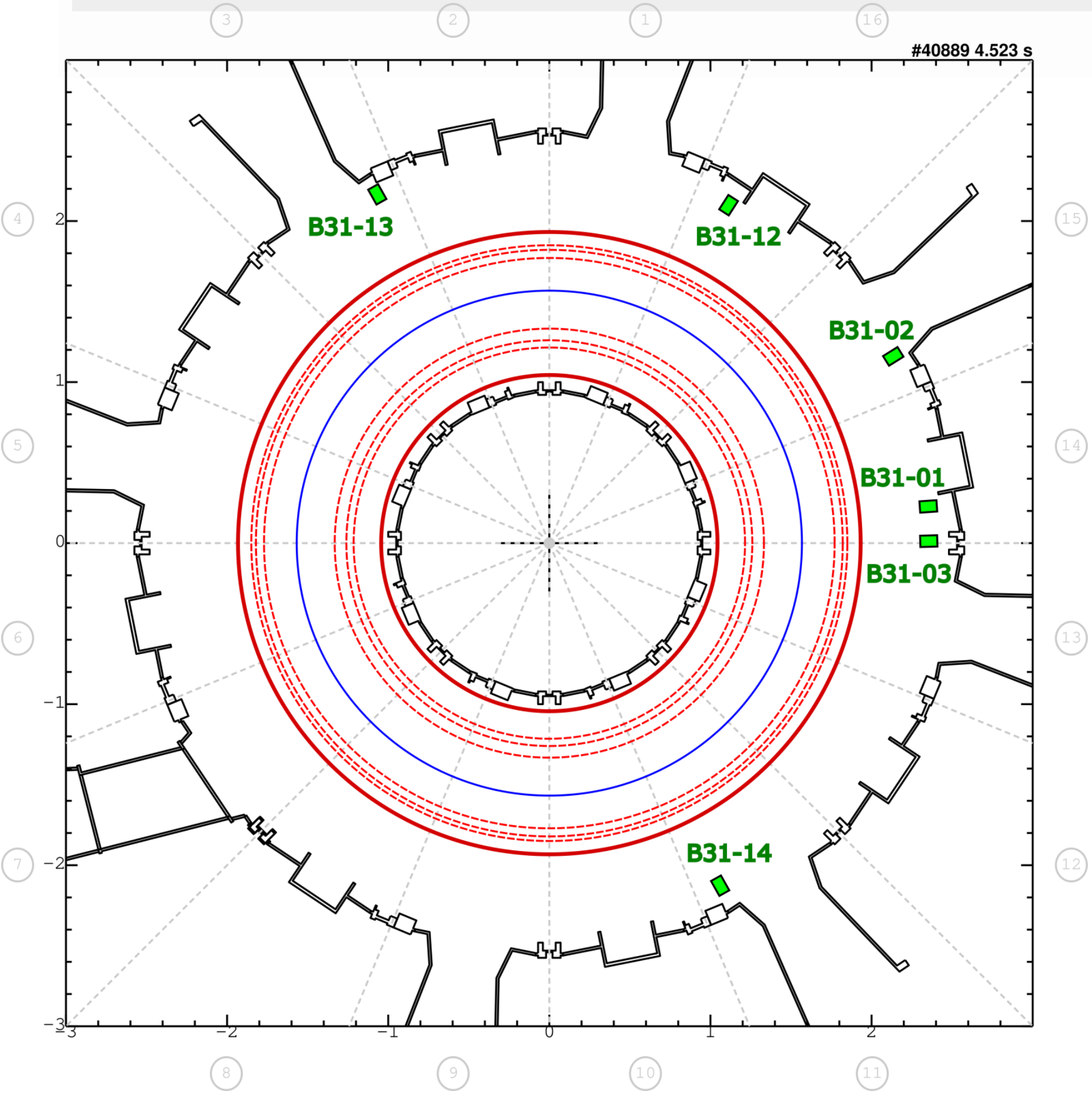
ABSTRACT

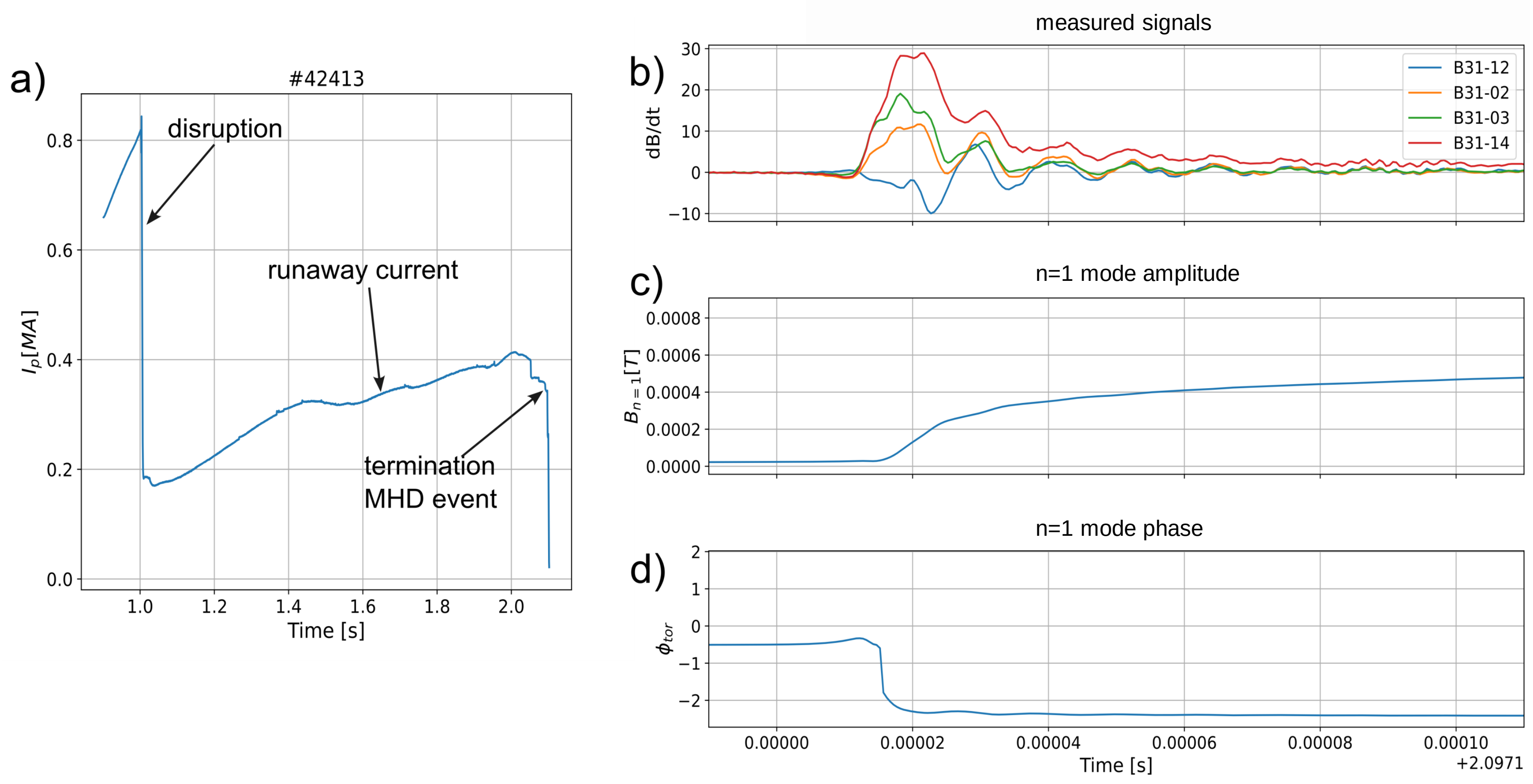
Tokamak plasmas are subject to disruptive events. While such events have to be rare in future large devices, they are problematic since, in addition to other off-normal loads, part of the electron population can be accelerated to relativistic velocities and can damage the device [1]. Currently, one of the promising approaches for runaway (RE) mitigation is 'benign termination' via low-Z injection and excitation of an MHD instability to expel the electrons without their regeneration [2,3]. The key to success lies in converting magnetic energy into thermal energy and spreading it over a larger area. **MHD instabilities are a crucial component of this process.** Current results suggests that broad stochasticity initiated by large MHD perturbations can distribute the heat load evenly across the device.

IDENTIFICATION OF MHD MODES



Investigating these modes poses a real challenge:

- MHD modes are not always locked. The same analysis is required for both rotating and non-rotating cases.
- The modes grow fast, and most magnetic signals are not optimised for these ranges and are in cut-off. Only part of the probes do not have this problem and can be used for the analysis.



The integrated signal will grow constantly over time*, so a practical cut-off criterion is required.* The saturated mode amplitude corresponds to the first plateau after the first mode growth, where the amplitude of the magnetic signals (dB/dt) reduces at least 5 times from its peak value. The growth rate is calculated based on the integrated signal.

RELATIVE ENERGY ANALYSIS

$$W_{tot} = W_{kin} + W_m \qquad W_{kin} = \frac{\gamma m_e n_e c^2}{2} \qquad W_m = \frac{L_p I_{re}^2}{2}$$

$$W_{pert} = \int \frac{\langle\tilde{B}\rangle^2}{2\mu_0} dV \approx \frac{\langle\tilde{B}\rangle^2}{2\mu_0} V = \frac{\langle\tilde{B}\rangle^2}{2\mu_0}\left(2\pi^2 a^2 R\right) = \frac{\langle\tilde{B}\rangle^2 \pi^2 a^2 R}{\mu_0}$$

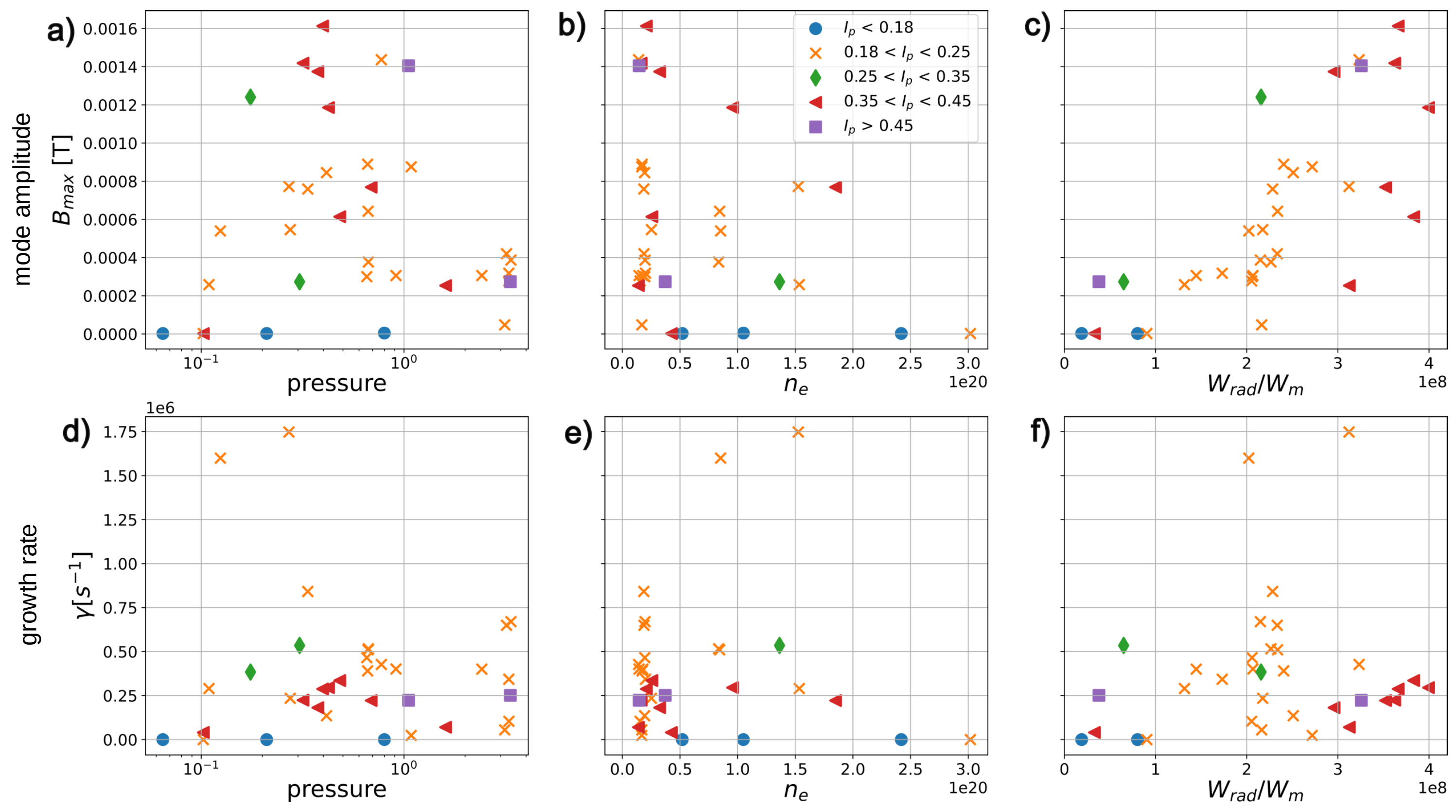
$$\frac{W_{pert}}{W_m} = \frac{\langle\tilde{B}\rangle^2 V}{\mu_0 L_p I_{re}^2} \qquad L_p = \mu_0 R\left(ln\frac{8R}{a} + \frac{l_i}{2} - 2\right) \text{ from [5]}$$

Tearing mode equation

$$\underbrace{\frac{1}{r}\frac{d}{dr}\left[r\frac{d\psi}{dr}\right] - \frac{m^2}{r^2}\psi}_{\substack{vacuum,\\ Laplacian\ operator}} = \underbrace{\frac{\frac{dJ_\phi}{dr}}{\frac{B_\theta}{\mu_0}\left(1-\frac{nq}{m}\right)}\psi}_{plasma}$$

- Decay of the measured perturbation was estimated with the tearing mode equation
- The sensitivity of our results was assessed using several different combinations of m = 2, 3 and 4
- **The difference between extreme cases is less than a factor of two.**

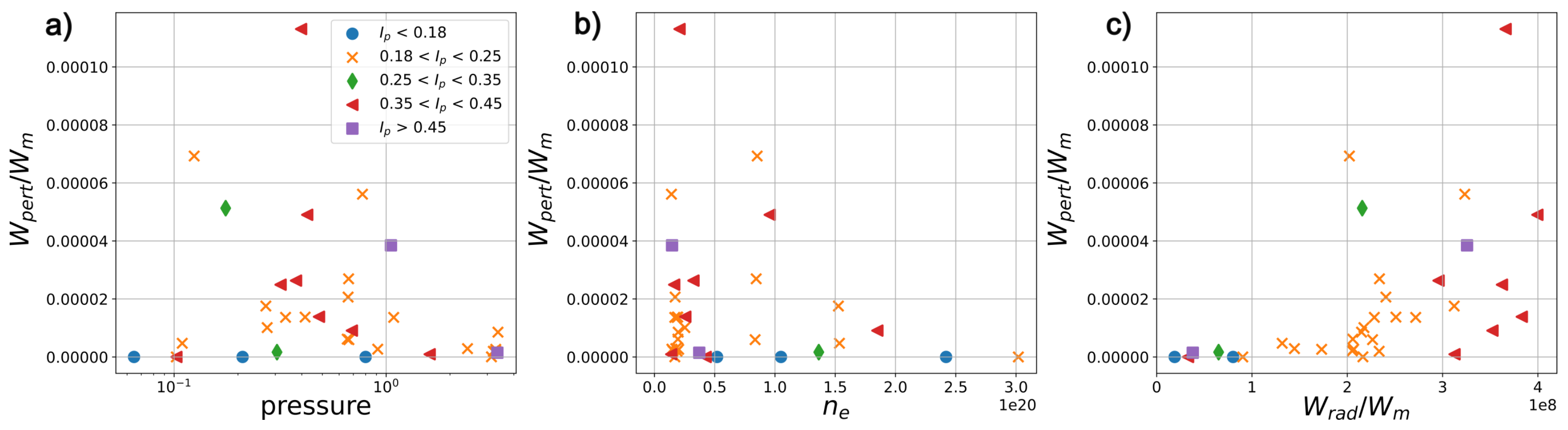
MODE AMPLITUDE OR GROWTH RATE?



- There are trends for mode amplitude in dependence from pressure and electron density.
- There is no clear trend for the growth rates of the modes.

Conclusion: Stochastization is important for the destruction of runaway beam (similar to JET and DIII-D results [4]).

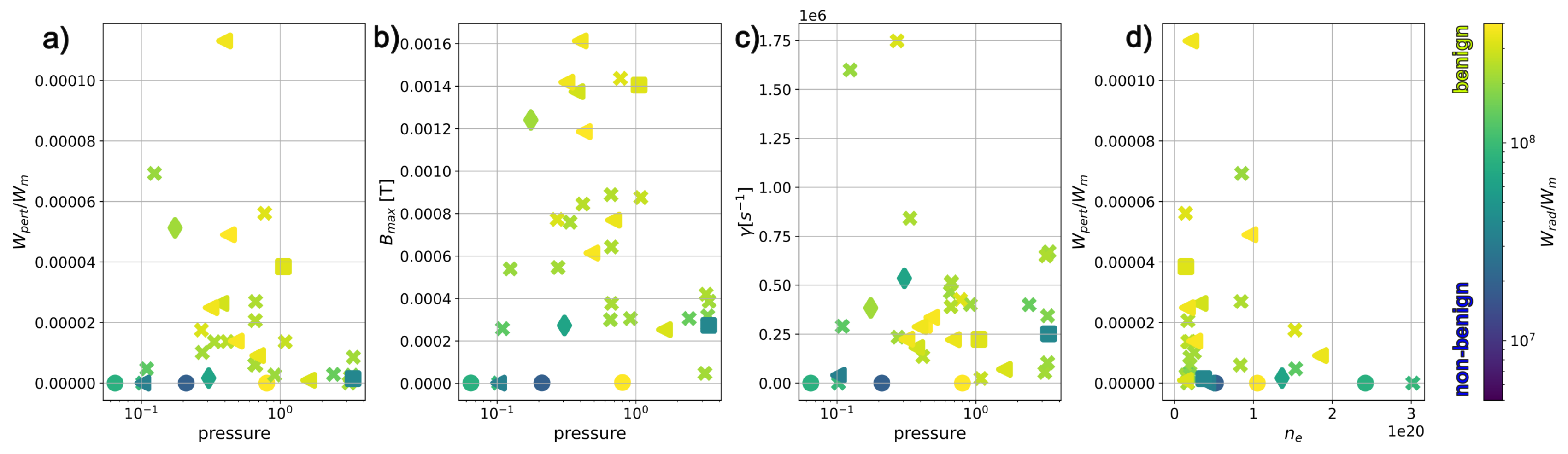
MHD IMPACT ON MAGNETIC FIELD CONFINEMENT



- The relative energy analysis is an integrated analysis that effectively smooths out variations and give quantitative results.
- The energy ratio brings cases with different runaways current closer together.

CHARACTERIZATION OF BENIGN/NON-BENIGN

In the following, we have adopted relation between radiated energy (W_{rad} from bolometry) and magnetic energy (W_m)as a measure for the benign character of the termination.



CONCLUSIONS

MHD modes play an important role in termination of runaway beam. It was found that:

- final mode amplitude is important (not the growth rate) → stochastisty plays an important role
- relation between magnetic energy of the beam and the perturbation is a good value for analysis of different current cases
- relation between radiated and magnetic energy looks promising as a measure of benign/non-benign character

References

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