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Gamma ray measurements of the runaway electron distribution function in disruption mitigation experiments at the ASDEX Upgrade tokamak

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Introduction

The generation of **runaway electrons (RE)** during disruption events in large tokamaks can endanger the integrity of plasma facing components and hinder the machine operation. Great effort is currently being made by the MCF community to understand this phenomenon and to find strategies to avoid or to mitigate these events.

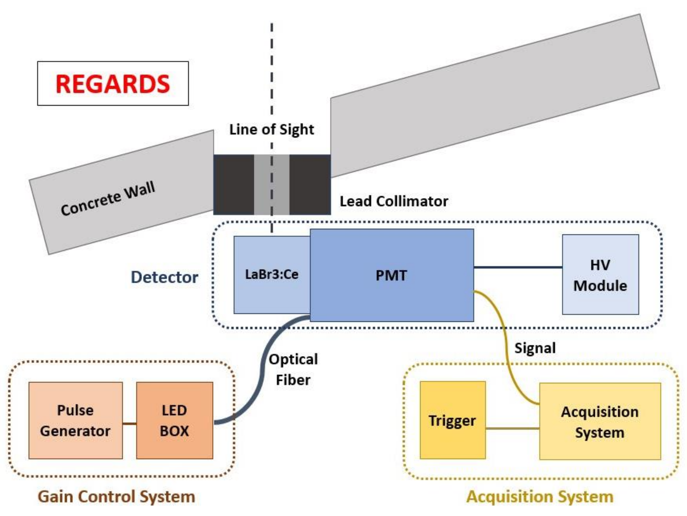
In principle it is possible to reconstruct the **runaway electron (RE) energy distribution** in the post-disruption phase by measuring the hard x-ray (HXR) bremsstrahlung emission spectrum in the MeV range of the RE beam interacting with the plasma.

In this work we present **recent advancements** in the determination of the RE distribution function in disruption mitigation experiments at the **ASDEX Upgrade (AUG) tokamak**.

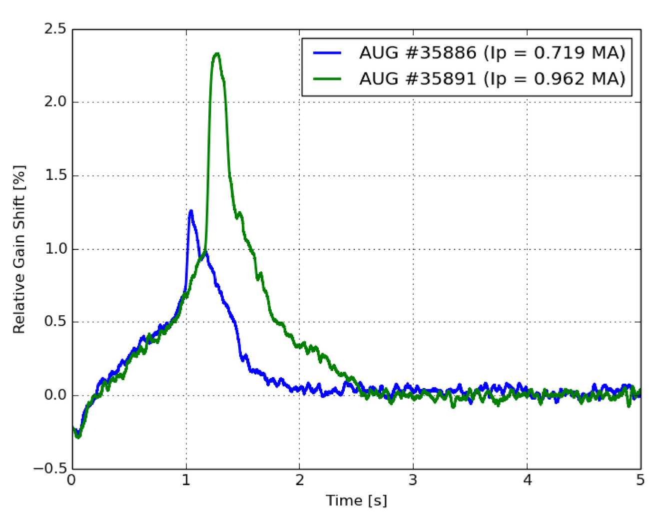
A new HXR spectrometer for RE measurements at ASDEX Upgrade

The REGARDS (Runaway Electron GAmma-Ray Detection System) detector [1] has been developed to measure the HXR spectrum in the MeV range from REs and complements an existing detector [2]. It is made of different components:

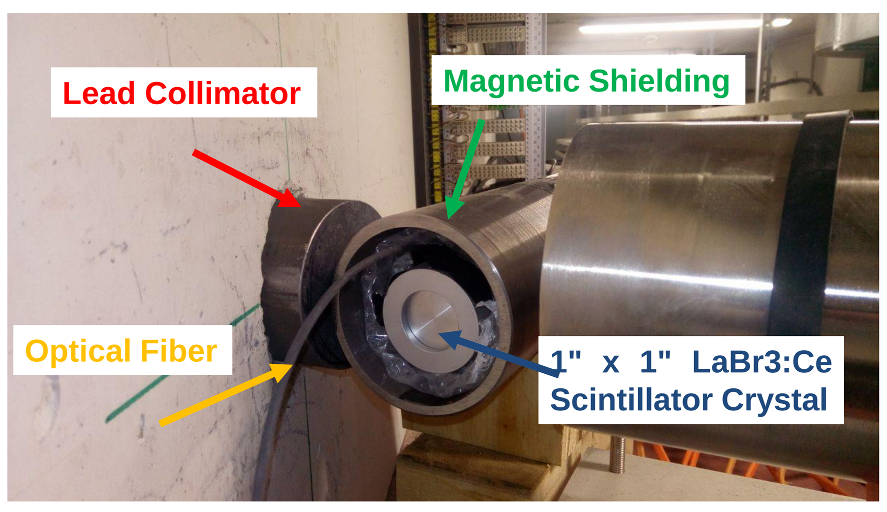
- The **crystal:** 1"x1" cerium doped lanthanum bromide ($LaBr_3$:Ce) scintillator crystal coupled with a PMT with magnetic shielding
- The **gain control system** uses LED pulses to monitor the PMT stability. He gain is stable at the some % level.
- The **acquisition system** collects data in continuous mode at a 400 MHz sampling rate for 10 seconds. Pile up events are resolved and recovered.
- **Well shielded radial line of sight** shared with the AUG neutron detector



A schematic representation of the REGARDS system.



Stability of the gain in RE discharges



Picture of the REGARDS detector. The lead collimator positioned inside the view line is visible on the left. In this picture are also visible the soft iron magnetic shielding covering the detector, the optical fibre carrying the light emitted by the reference LED to the detector and the scintillator crystal in its aluminum case.

HXR data and the RE distribution function

The measured **signal S** depends on the **RE distribution function F** through a **transfer matrix W**, in addition to the noise n, i.e.

$$S = W * F + n$$

As most of the times F is hard to calculate, we must **infer F from data**.

Transfer matrix

The **transfer matrix W** contains information on the **bremsstrahlung emission** (**W_b**) and on the **detector response** to the gamma-ray radiation (**W_d**, including photon transport from the plasma to the detector), i.e.

$$W = W_d * W_b$$

W_d and **W_b** are computed by Monte Carlo codes with good accuracy [3].

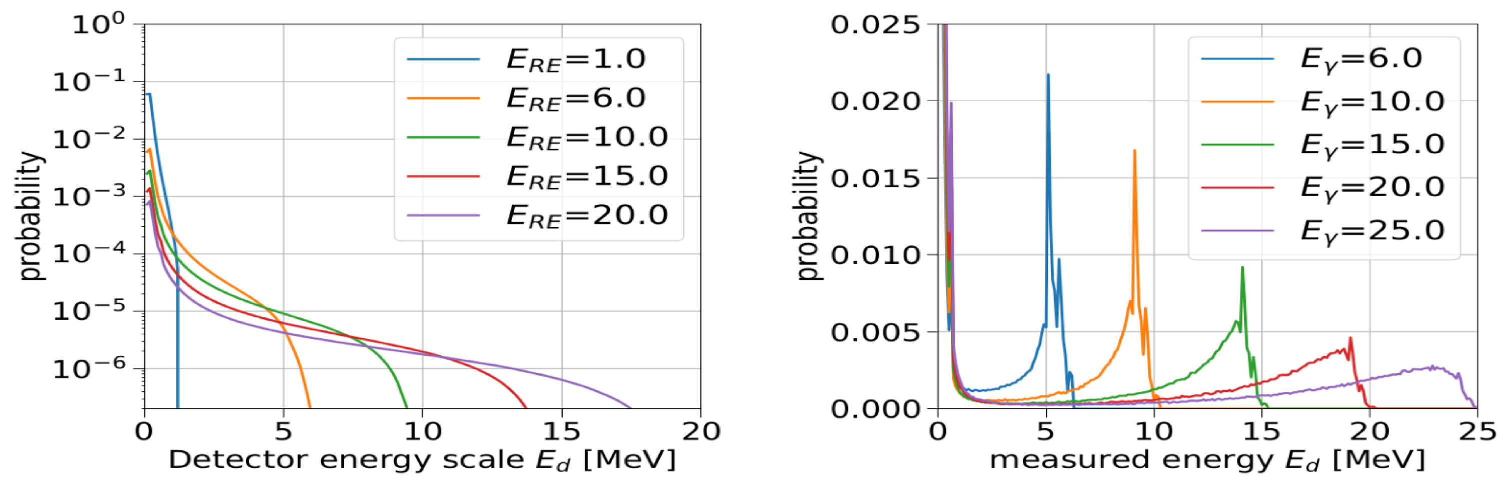
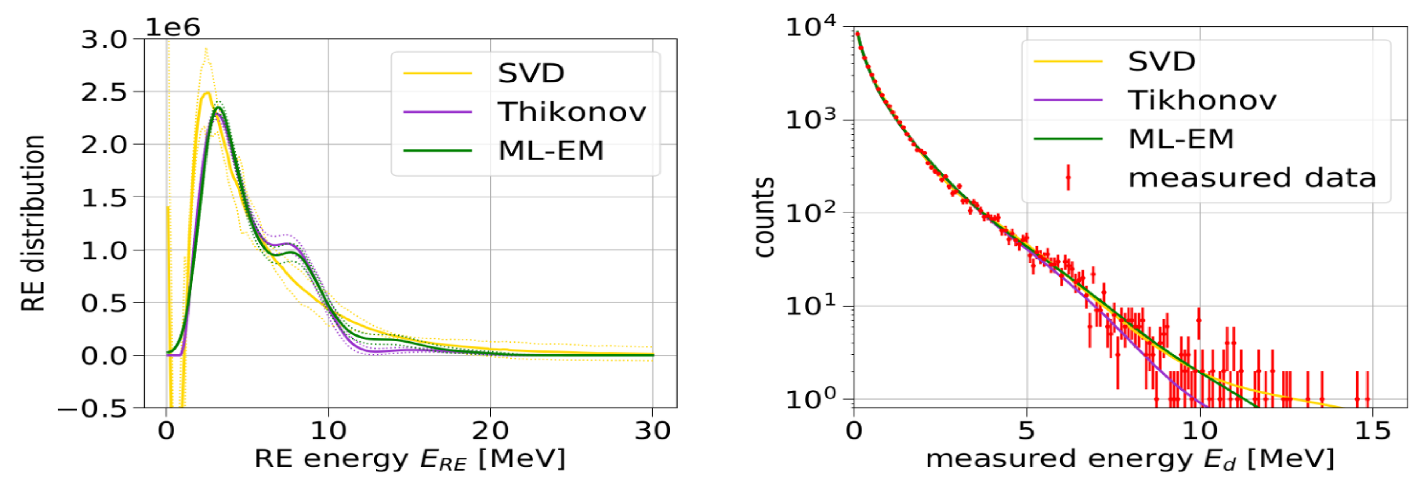


Illustration of the W_b (left) and W_d (right) parts of the transfer matrix W for REs and gamma-rays, respectively, and at the energies specified in the caption.

Inversion of HXR data

Different inversion algorithms (ML-EM, Tikhonov, SVD) have been tested to obtain F from S [4].

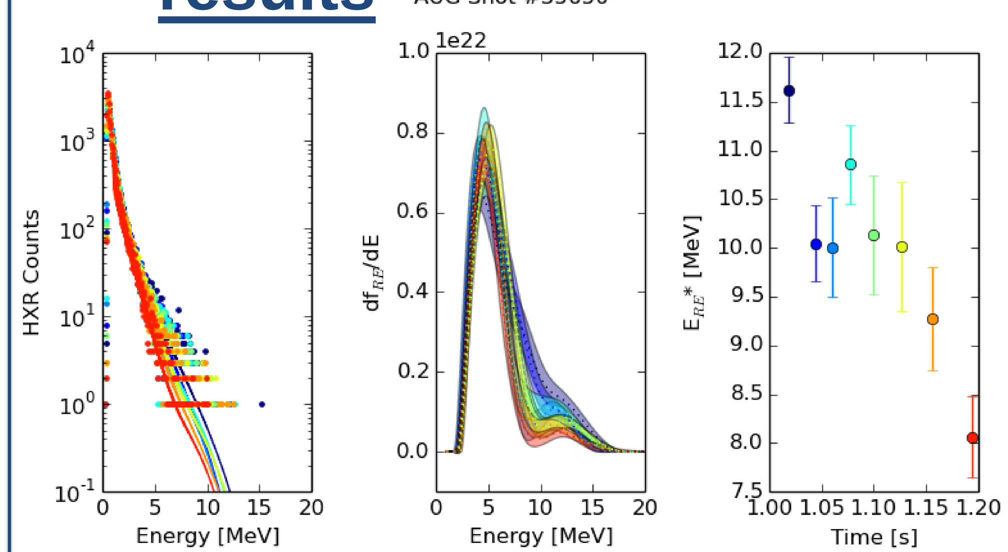
- **Oscillations** are commonly observed in the solution F.
- From F we define the **ending energy E_{max}** as the one which comprises 90% of the REs.
- E_{max} is **independent from the algorithm** and the regularization level applied.



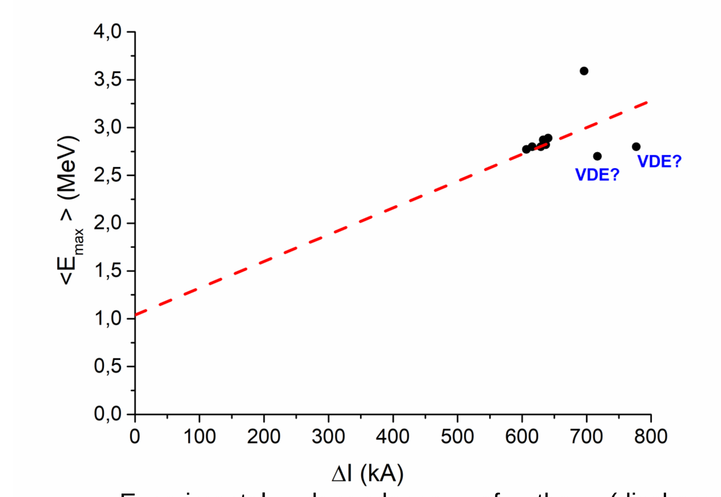
(Left) Inverted RE distribution functions (F) using different algorithms and (right) comparison of the corresponding, synthetic HXR spectra with measured data (S)

Preliminary results

- Observation of **time changes of E_{max}** within a discharge
- **Correlation** between **<E_{max}>** and the current drop **ΔI**



Evolution of the HXR spectrum in a typical AUG discharge with massive gas injection (left). The middle and right figures show the corresponding time dependence of the RE distribution function and of E_{max} (E_{RE} in the figure), respectively, as obtained from the inversion of the data.



Experimental dependence of the (discharge averaged) E_{max} on the post-disruption current drop ΔI. Outliers likely due to loss of the RE beam (probably from Vertical Displacemment Events) are also found.

Conclusions

- A **new HXR detector** (REGARDS) has been developed for **RE experiments at ASDEX Upgrade**
- The **RE distribution function** is obtained from HXR data through inversion algorithms. In particular, we evaluate the **maximum RE energy E_{max}**
- Preliminary results show that **E_{max}** can be evaluated with **some ms time resolution** and **increases with the current drop**

References

[1] A. Dal Molin et al., 46th EPS Conference on Plasma Physics, P1.1015 [2] M. Nocente et al. RSI 89 10I124 (2018)
[3] M. Nocente et al. Nucl. Fusion 57 076016 (2017) [4] E. Panontin et al. ., 46th EPS Conference on Plasma Physics, P4.1002

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