The tokamak GOLEM CAAS report #3

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on behalf of the tokamak GOLEM team

3rd February 2020

Overview

1. Runaway electrons at GOLEM
   - Basic physics of RE
   - Prediction for Golem
2. Characterization of HXR radiation
   - Experimental setup
   - GOLEM and COMPASS experimental data
3. Future work
   - Inspiration from different tokamaks
4. Conclusion

Introduction to RE physics in tokamaks

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  $\rightarrow$ favourable conditions for RE generation
- various mechanisms of generation assumed
  $\rightarrow$ Dreicer mechanism
  $\rightarrow$ hot-tail mechanism
  $\rightarrow$ avalanche mechanism
  $\rightarrow$ tritium decay and Compton scattering

Introduction to RE physics in tokamaks

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  $\rightarrow$ Dreicer mechanism
  $\rightarrow$ hot-tail mechanism
  $\rightarrow$ avalanche mechanism
  $\rightarrow$ tritium decay and Compton scattering
- usually unwanted phenomena in tokamaks (thread for ITER)
  $\rightarrow$ mitigation strategies: MGI, SPI, RMP

GOLEM vs. RE

- mechanism of generation:

$$\frac{\mathrm{d}n_r}{\mathrm{d}t} = \left(\frac{\mathrm{d}n_r}{\mathrm{d}t}\right)_{Dreicer} + \left(\frac{\mathrm{d}n_r}{\mathrm{d}t}\right)_{Avalanche} \quad (1)$$

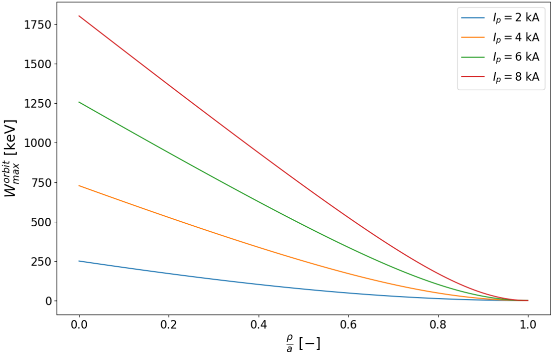
- avalanche time: $t_{Av} \approx 22.5\ \mathrm{ms} \rightarrow t_{discharge} \leq t_{Av}$
  $\rightarrow$ only Dreicer mechanism is important for Golem

$$\frac{\mathrm{d}n_r}{\mathrm{d}t} = C n_e \nu_{th} \varepsilon^{-3(1+Z_{eff}/16)} \exp(-\frac{1}{4\epsilon} - \sqrt{\frac{1+Z_{eff}}{\varepsilon}}) \quad (2)$$

- critical energy: $W_c = 1.76\ \mathrm{keV}$

Energy limits of RE:

- high energy of RE $\rightarrow$ shift of trajectory to LFS



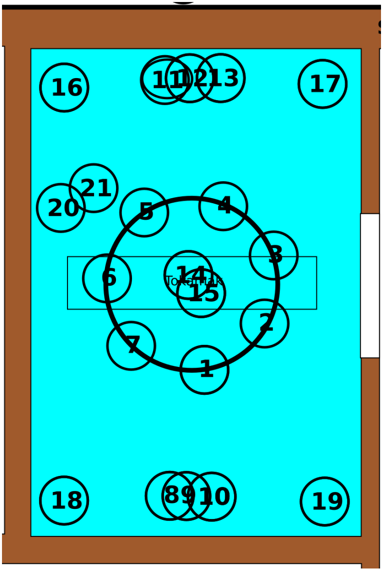
- time limit: $W_{max}^{time} \approx 2-4\ \mathrm{MeV}$

Characterization of HXR radiation

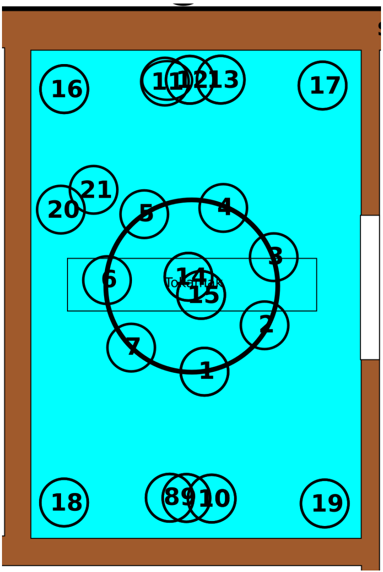
- HXR radiation caused by RE characterized by two different approaches

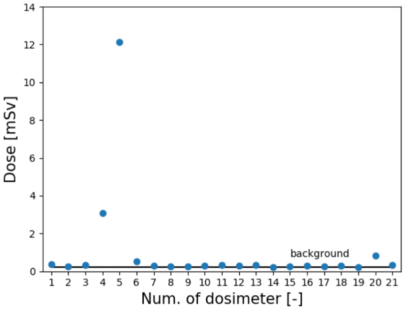
→ monitoring by set of dosimeters
→ usage of scintillation detectors

Dosimeters monitoring



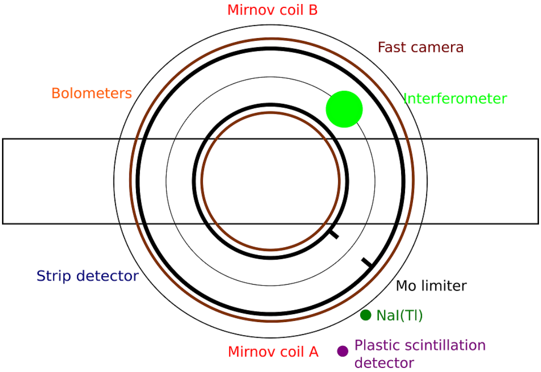
Dosimeters monitoring

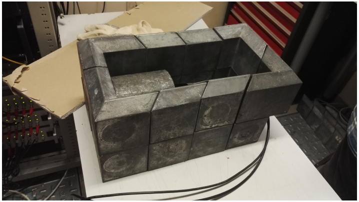




- dose measured only on dosimeters near Mo limiter
- asymmetry in radiation pattern observed

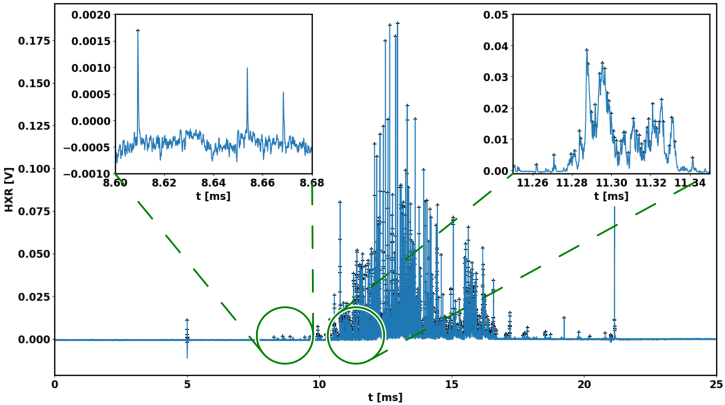
Experimental setup - GOLEM





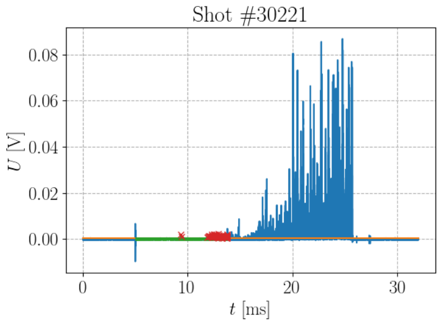
- 2x NaI(Tl) scintillation detectors
- different shielding variants tested

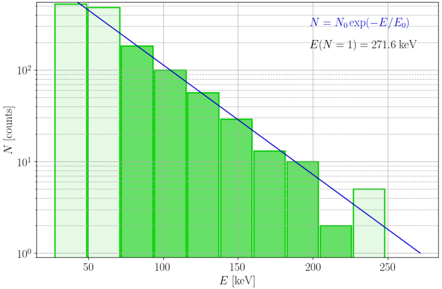
Measured data

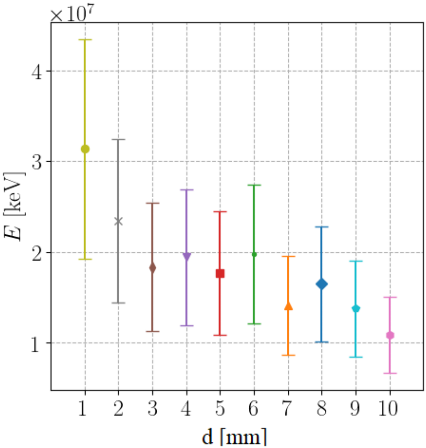


- fast data acquisition system used (PXI NI)
  $\rightarrow$ up to 200 MHz, input impedance: 50 Ohm
- number of pile-up events observed $\rightarrow$ usage of colimator and shielding

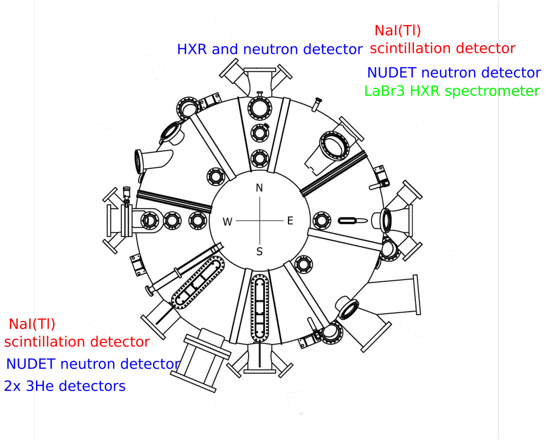
Measured data - analysis example

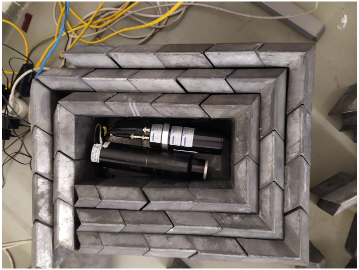






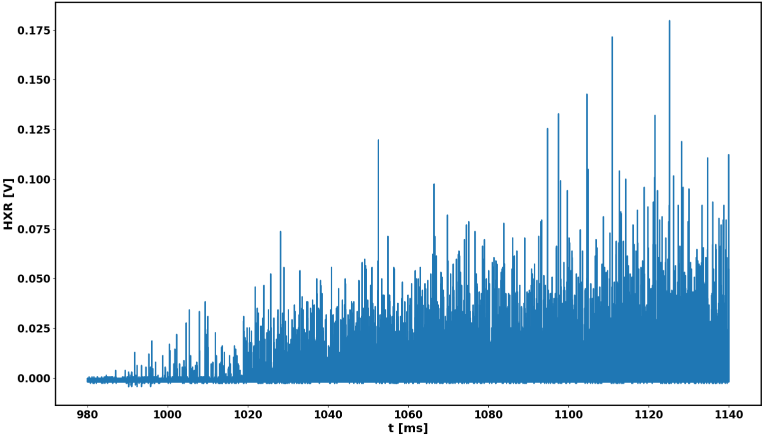
Experimental setup - COMPASS



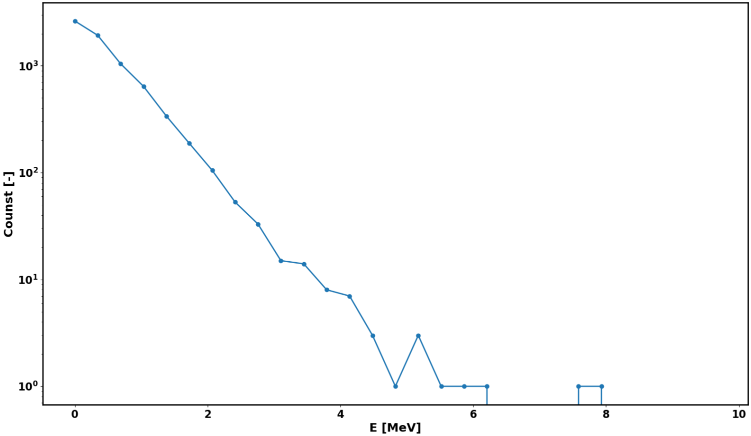


- 2x NaI(Tl) installed at the COMPASS
- placed inside led bunker or behind wall

Measured data - example

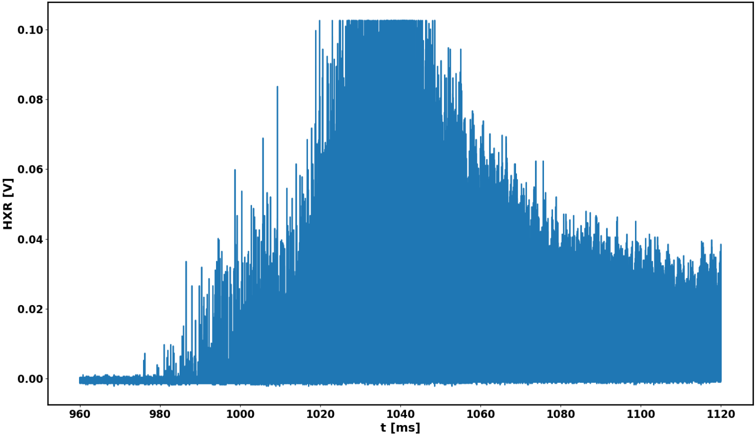


Measured data - spectrum example



- usually energy of HXR measured up to 8 MeV

Measured data



- "proper" RE discharge → early saturation

HXR spectroscopy at COMPASS

- useful for determination of seed of runaway electrons in discharge
- estimation of RE energies
  $\rightarrow$ roughly 8 MeV after 100 ms of discharge
- possible comparison with spectrometer made in Milan (campaign January 2020)

Inspiration from "GOLEM-like" devices

IR-TM1

- HXR spectroscopy and comparison with simplified modeling of RE
- usage of biasing probe/limiter for controlling of RE

ISSTOK

- measurements with Cherenkov detector (unsuccessful negotiation in past)

CASTOR

- HXR spectroscopy and comparison of different regimes of tokamak discharge

Future work

- continuation with HXR spectroscopy
  $\rightarrow$ better understanding of HXR generation and shielding against HXR radiation (modelling with FLUKA?)
  $\rightarrow$ building stand for scintillation detector and proper shielding with possibility of collimation of HXR radiation
- broader involvement of different experimental techniques
  $\rightarrow$ Timepix detectors, scintillation detectors with different crystals
- installation of detectors from GOLEM at COMPASS and measurements during last RE campaign
- development of automatic routines for calibration and pile up detection

Conclusion

- characterization of HXR radiation at two different tokamaks with similar diagnostics setting
- current diagnostic setting useful only in low runaway populated discharges and in the beginning of discharge at COMPASS
- interpretation of GOLEM data is challenging $\rightarrow$ improvements in diagnostic setup e.g. shielding, ...