Study of runaway electrons at GOLEM

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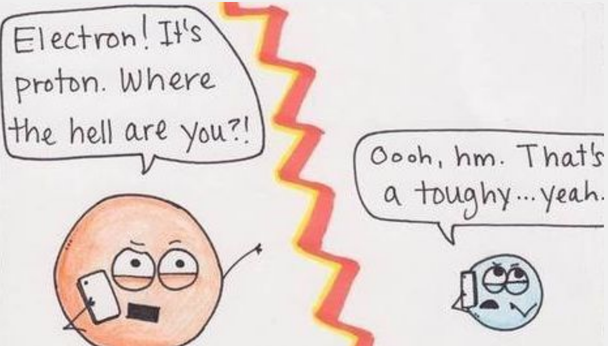

What are we going to talk about?

- Introduction about runaway electrons
- Basic theory of runaway electrons
- The aim of the project
- Experimental methods
- Results with interpretation
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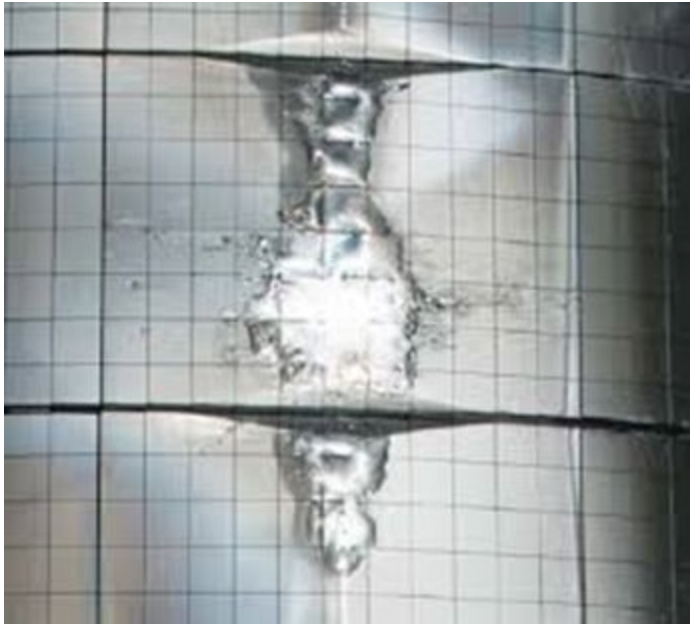
Introduction

- Runaway electrons are energetic particles, accelerating to relativistic speeds due to electric fields
- They appear in tokamaks when the acceleration due to the toroidal electric field exceeds the drag force
- Runaway beams can damage the plasma facing components
- Major concern on ITER



[Matthews, et al-2016]

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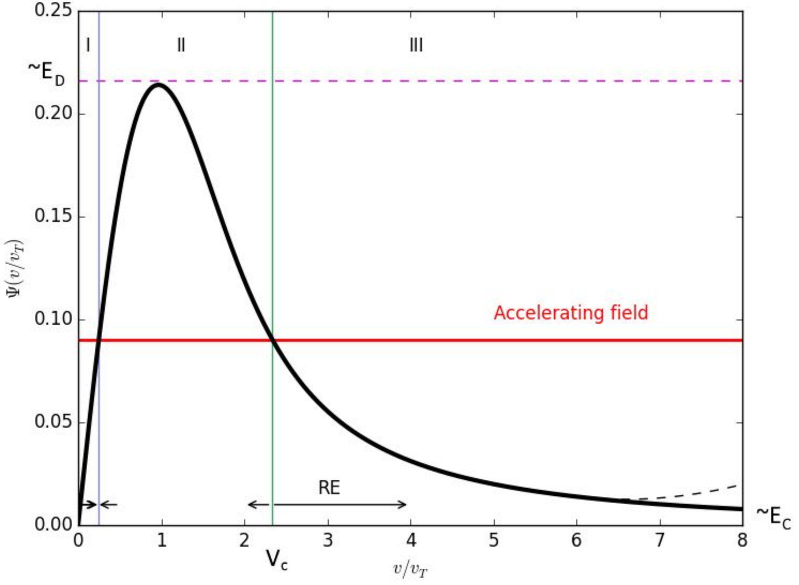
Short theory

Main forces which determine runaway electrons in magnetized plasma:

- Friction force due to collisions - proportional to electron density
- Acceleration due to electric field

Friction reduces with speed of electrons

$$E_c = \frac{n_e e^3 \ln\Lambda}{4\pi\varepsilon_0^2 m_e c^2} \qquad E_{Dreicer} = 0.43\,\frac{n_e Z e^3 \ln\Lambda}{8\pi\varepsilon_0^2 \kappa T_e}$$



Short theory - Friction

- Friction force due to collisions between particles
- Proportional to density
- It has a minimum value at relativistic speeds
- Maximum at thermal speed

Balance of forces:

$$E = -\frac{n_e q_i e^2 \ln\Lambda}{4\pi\varepsilon_0^2 \mu_e}\left\{\frac{\partial}{\partial v}\left[v^{-1}\mathrm{erf}\left(\sqrt{\frac{m_e}{2\kappa T_e}}v\right)\right]\right\}$$

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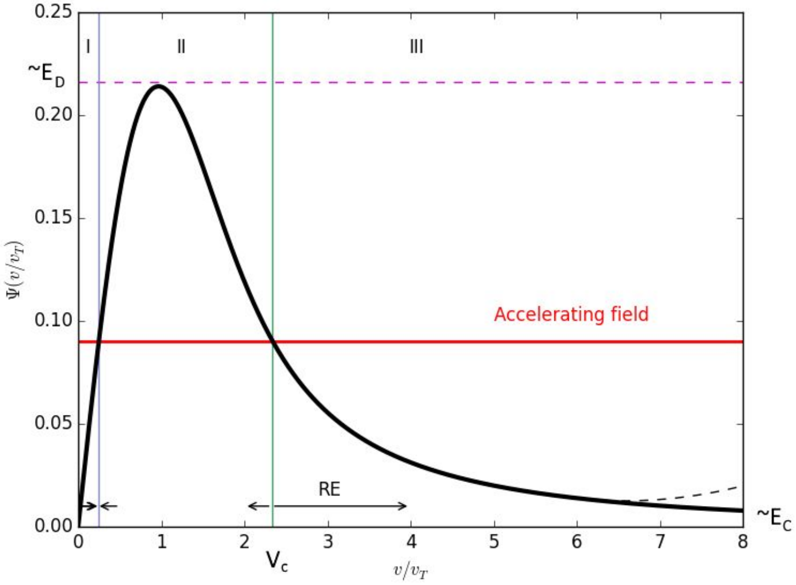
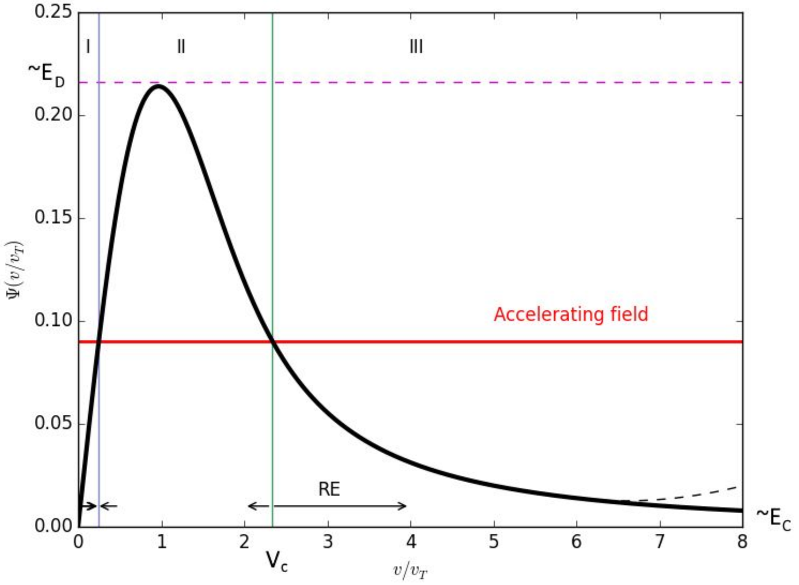


Short theory - Electric field

- May accelerate particles to relativistic speeds
- Critical field is the minimum field required for runaway generation
- Dreicer field is the field at the maximum of friction force

$$E_c = \frac{n_e e^3 \ln\Lambda}{4\pi\varepsilon_0^2 m_e c^2} \qquad E_{Dreicer} = 0.43\,\frac{n_e Z e^3 \ln\Lambda}{8\pi\varepsilon_0^2 \kappa T_e}$$



Balance of forces:

$$E = -\frac{n_e q_i e^2 \ln\Lambda}{4\pi\varepsilon_0^2 \mu_e}\left\{\frac{\partial}{\partial v}\left[v^{-1}\mathrm{erf}\left(\sqrt{\frac{m_e}{2\kappa T_e}}\,v\right)\right]\right\}$$

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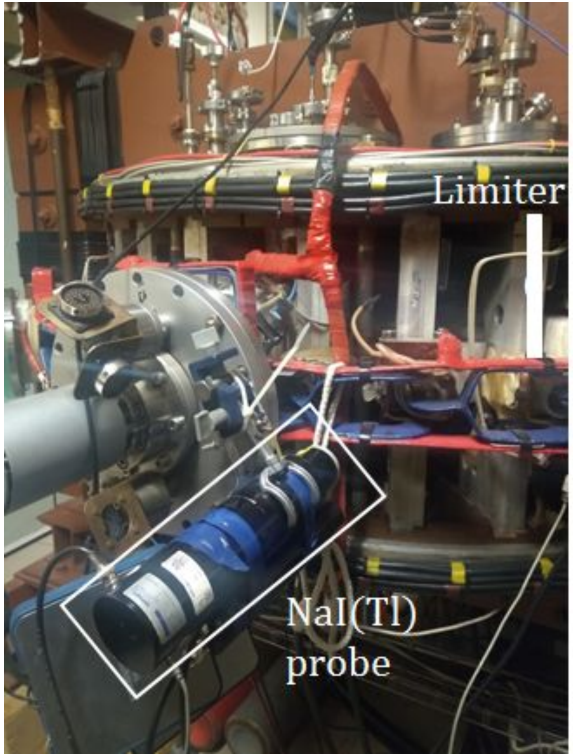
Aim of the project

- To find the signs of the presence of runaway electrons
- To study conditions for runaway generation in GOLEM discharges
- We used a NaI(TI) scintillator for HXR detection with a bias of 560V
- HRX signals are created when runaways hit the molybdenum limiter



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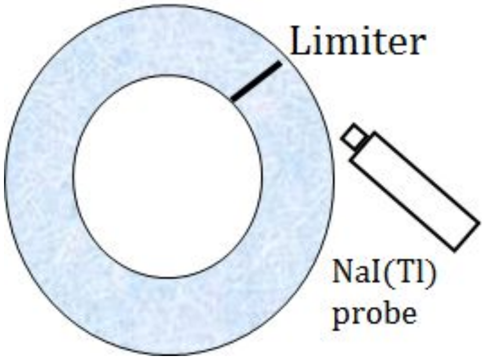
Methods, experimental setup

- Electric and magnetic fields are in clockwise direction as seen from the top
- Twelve shots with varying pressure and toroidal electric field
- Observe the change in the HXR signals

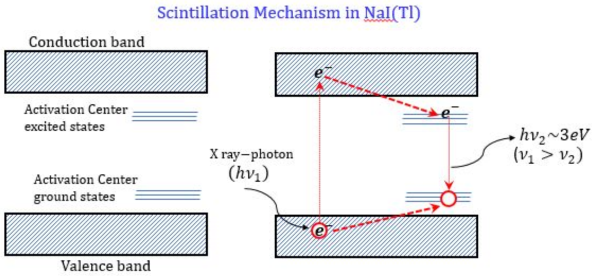
Ubt = 1.1 kV
Working gas: H
Preionization: Electron gun

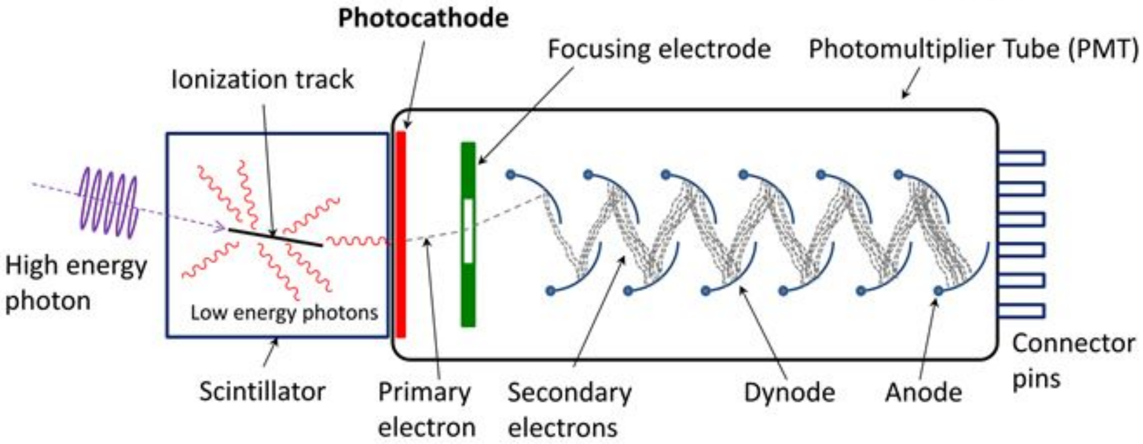


Comment	Shot No.	Request No.	U_{Bt} [V]	U_{cd} [V]	gas [mPa]
GOMTRAIC Runaway shot 1	29712	12843	1100	550	8 (H)
GOMTRAIC Runaway shot 2	29713	12844	1100	600	8 (H)
GOMTRAIC Runaway Shot 3	29714	12845	1100	650	8 (H)
GOMTRAIC Runaway Shot 4	29717	12848	1100	700	8 (H)
GOMTRAIC Runaway Shot 5	29718	12849	1100	500	8 (H)
GOMTRAIC Runaway Shot 6	29721	12854	1100	450	8 (H)
GOMTRAIC Runaway shot 7	29722	12855	1100	550	10 (H)
GOMTRAIC Runaway Shot 8	29724	12857	1100	550	12 (H)
GOMTRAIC Runaway Shot 9	29725	12858	1100	550	14 (H)
GOMTRAIC Runaway Shot 10	29726	12859	1100	550	16 (H)
GOMTRAIC Runaway Shot 11	29727	12860	1100	550	18 (H)
GOMTRAIC Runaway Shot 12	29728	12861	1100	550	20 (H)

Methods, experimental setup

- The scintillator converts high energy photons to low energy photons
- Produce electrons via photoelectric effect
- Multiply their numbers in the PMT





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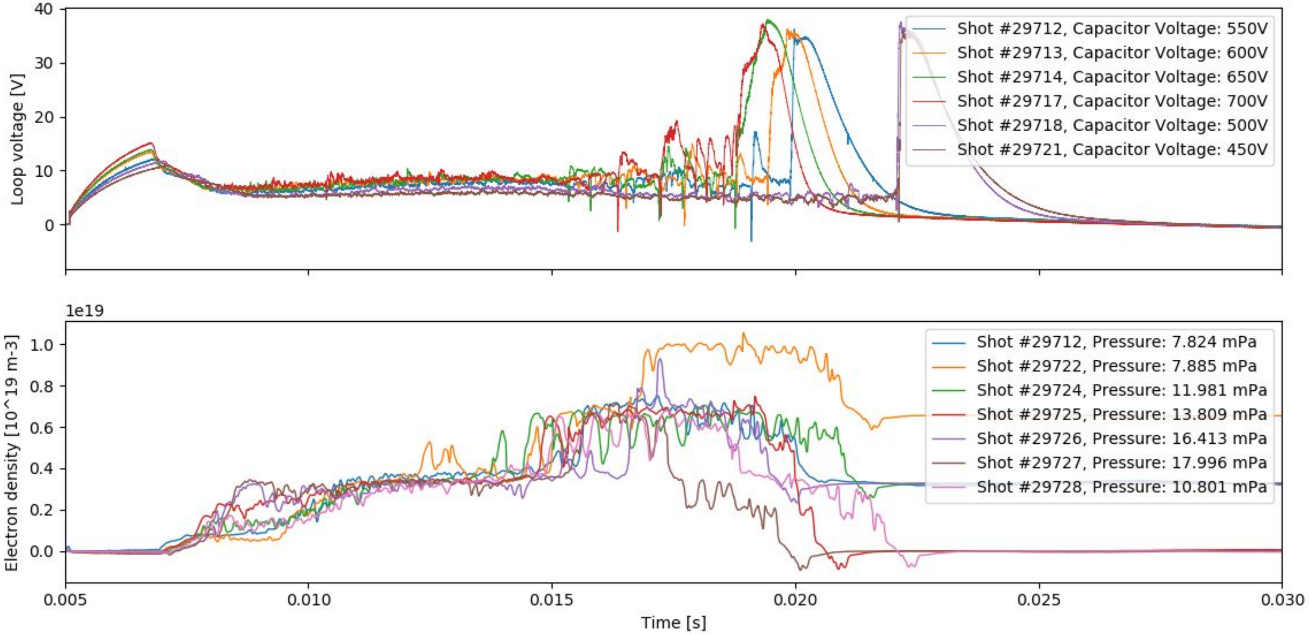
Results with interpretation

Changes in current drive capacitor voltage and pressure for the different shots

p= 8mPa

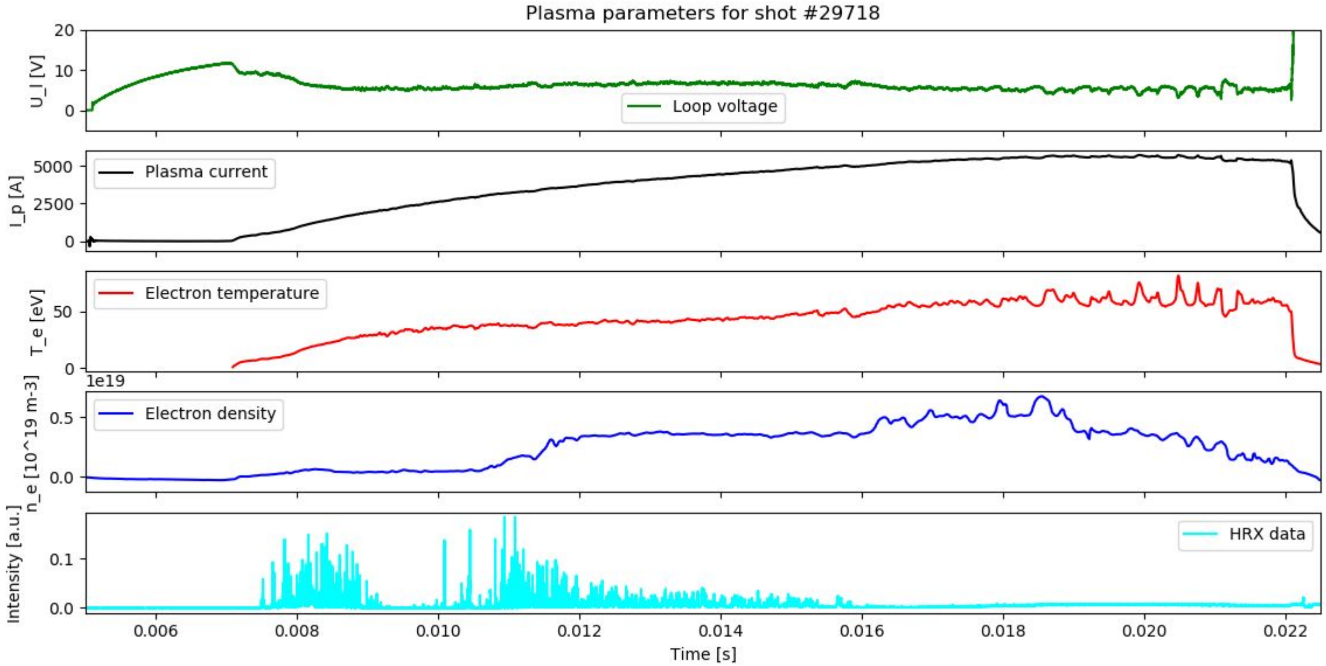
U_cd = 500V



Results with interpretation

Parameters of one of the shots (#29718) with HXR signal

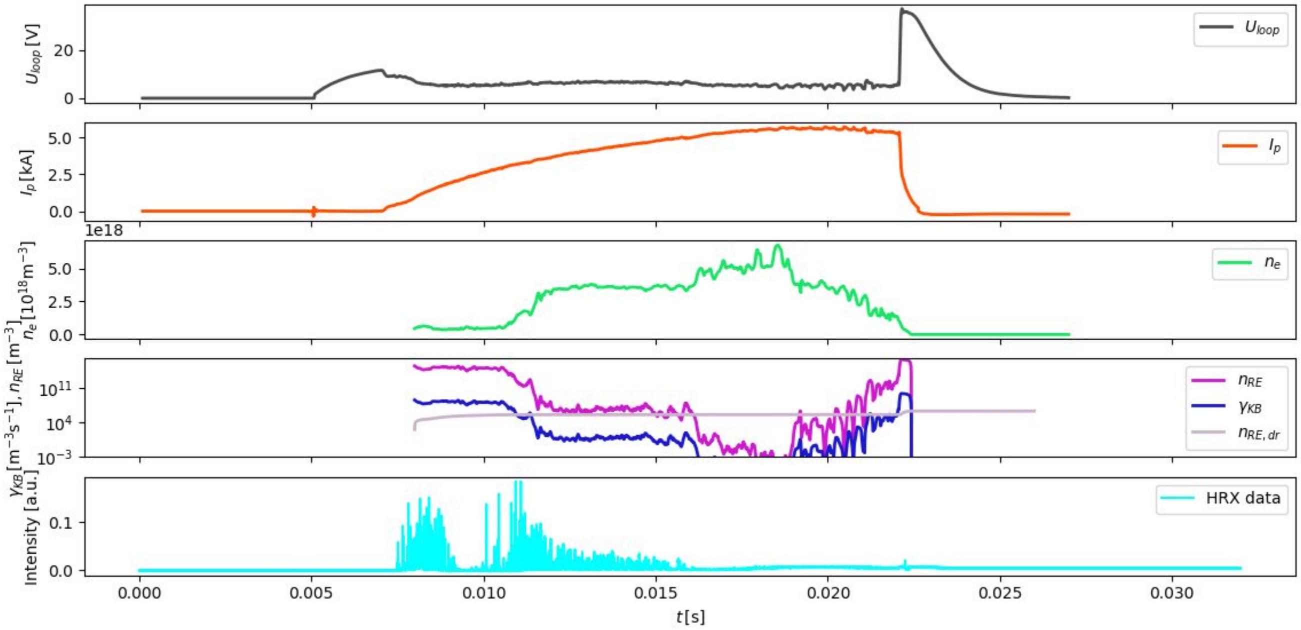
Ubt = 1.1 kV
Uet = 500V
P = 8 mPa



Results with interpretation

Estimation of the RE density and Growth rate (shot #29718)

Ubt = 1.1 kV
Uet = 500V
P = 8 mPa



Results with interpretation

Estimation of the RE density and Growth rate (shot #29718)

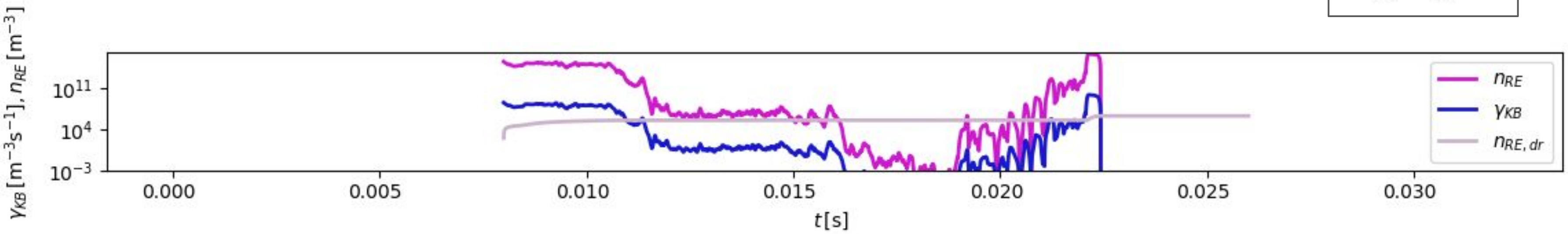
From Kruskal - Bernstein formula:
(Growth rate of the runaway electrons)

$$S_{KB/NR} = C v_{ee} \left(\frac{m_e c^2}{2T_e}\right)^{3/2} \left(\frac{E_D}{E_{\|}}\right)^{\frac{3}{16}(Z_{eff}+1)} e^{-\frac{E_D}{4E_{\|}} - \sqrt{\frac{(Z_{eff}+1)E_D}{E_{\|}}}}$$

From vc(E) and Maxwell distribution:

$$n_{RE} = \int_{v_c}^{c} n_e \left(\frac{m_e}{2\pi k_B T_e}\right) e^{-\frac{m_e v^2}{2k_B T_e}} dv$$

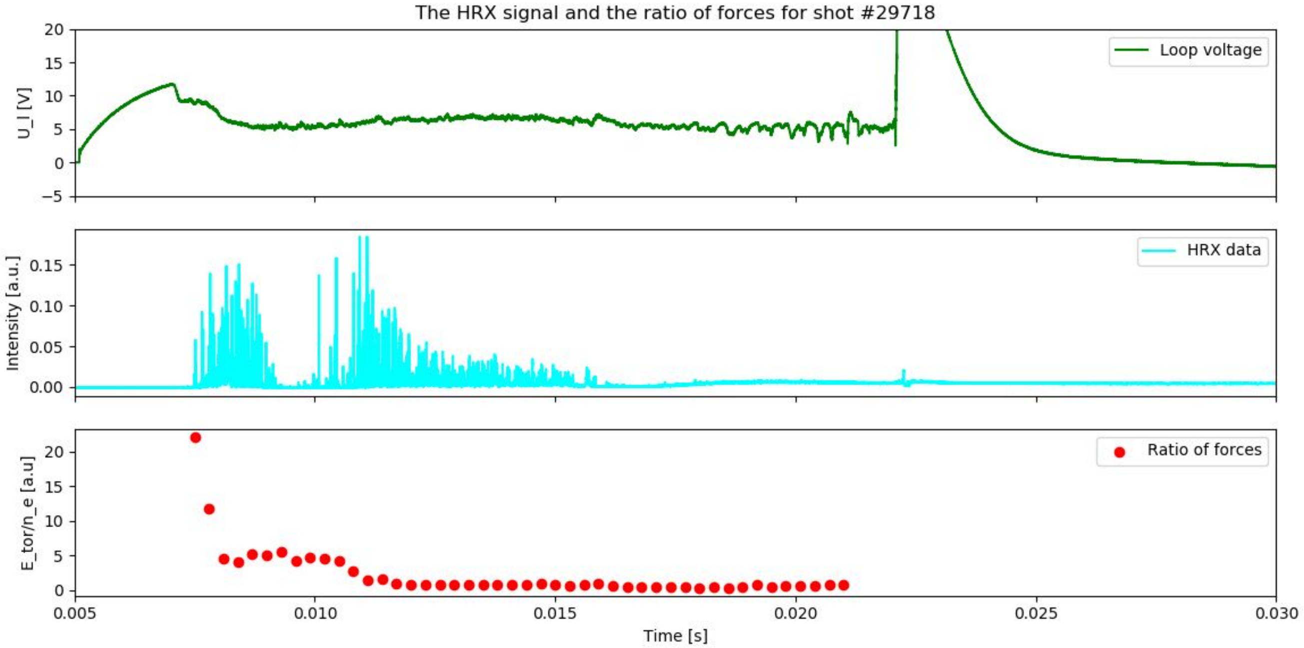
$$\boxed{E_\varphi \propto T_e^{-3/2}}$$



Results with interpretation

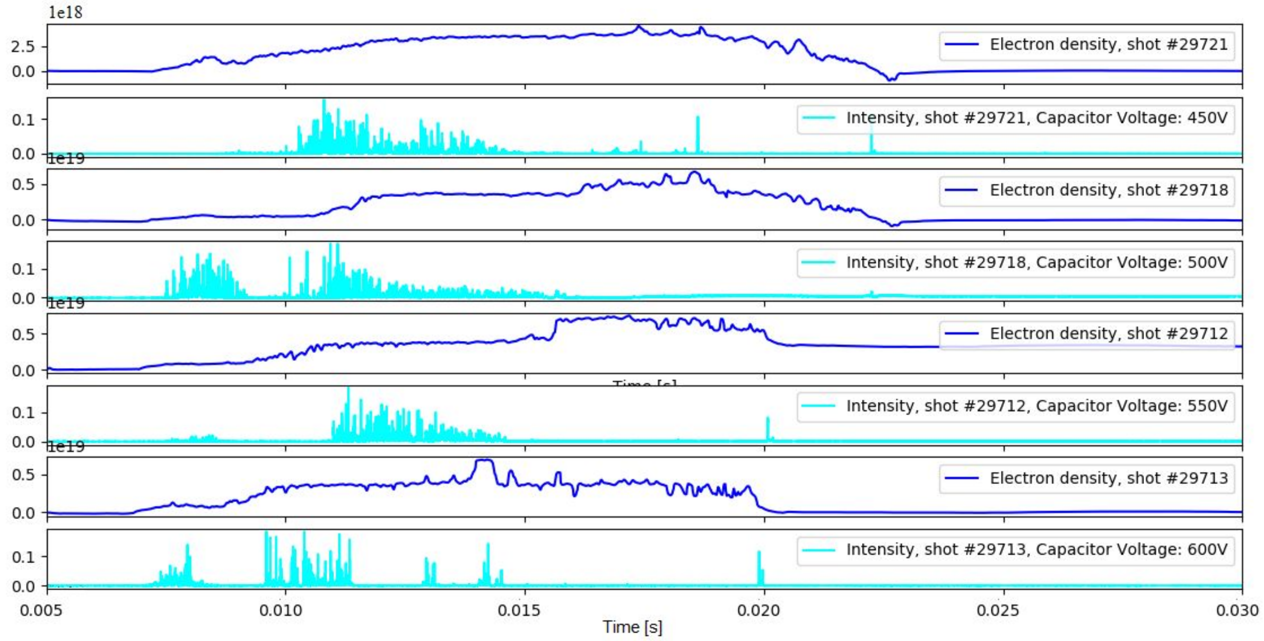
The plot of the ratio of the electric field and the density of the electrons

Ubt = 1.1 kV
Uet = 500V
P = 8 mPa



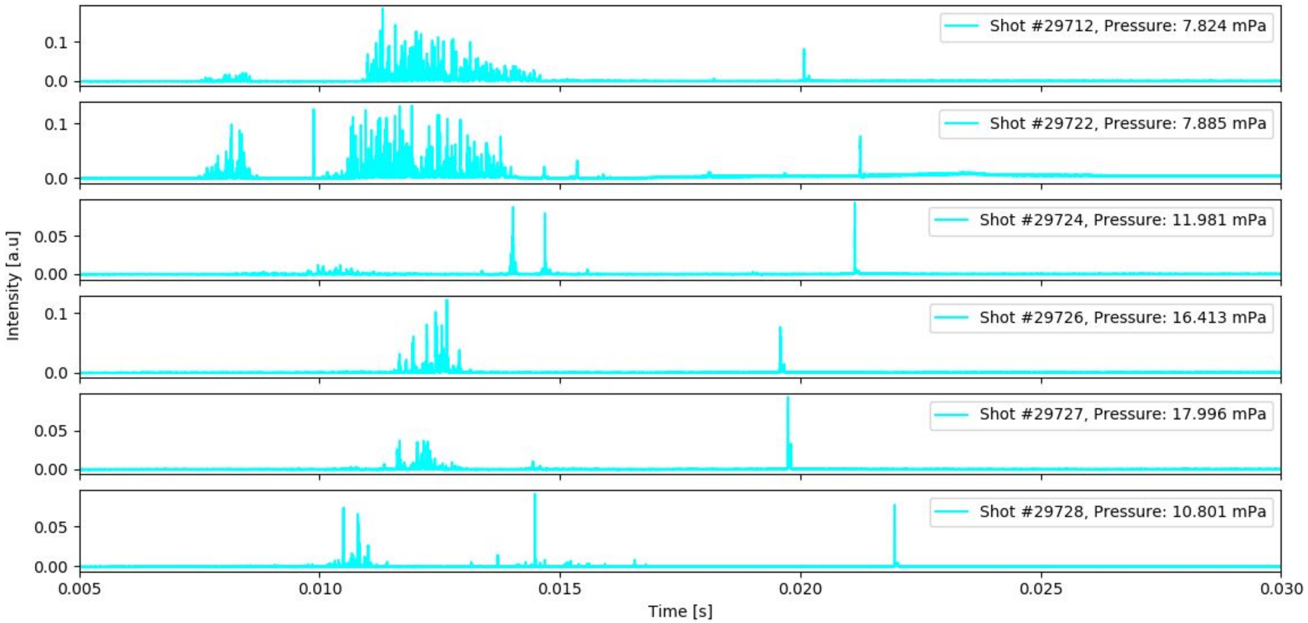
Results with interpretation

The change of HXR signal with changing electric field



Results with interpretation

The change of HRX signal with changing pressure



Summary

- We aimed to measure HXR due to the runaways in GOLEM shots
- Varied either electric field or pressure, while keeping the rest of the shot parameters fixed
- Analysed data to find signs of runaways
- Density seems to play a significant role in HXR generation in GOLEM

Thank you!


That's all Folks!