COMPASS
INSTITUTE OF PLASMA PHYSICS ASCR

# Runaway electrons energy measurements by calorimetry probe

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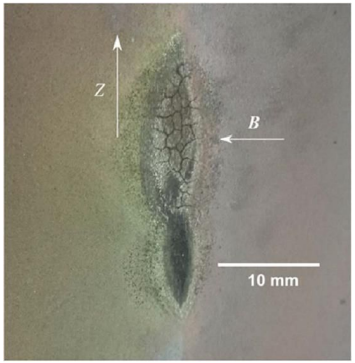
# Introduction and motivation

## Runaway Electrons (RE)

- Electrons accelerated to relativistic velocities by electric field
- Kinetic energy up to tens of MeV (> 90% c)
- Low collisionality
- Produced during low density discharges, breakdown or disruptions
- Possible damage to plasma facing components (PFC)
- Important development of mitigation strategies

Damage to the PFC by REs at COMPASS

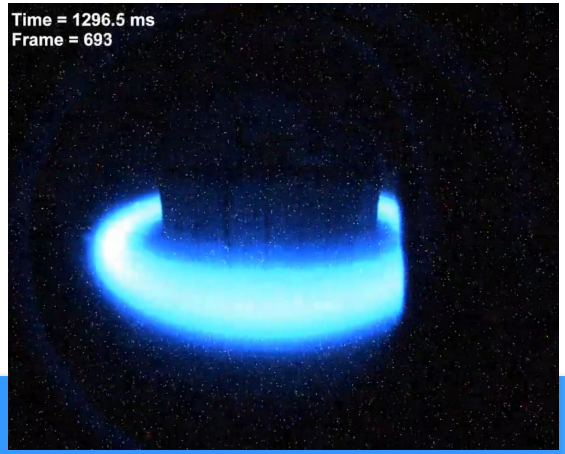



MLYNAR, J., et al. Runaway electron experiments at COMPASS in support of the EUROfusion ITER physics research. Plasma Physics and Controlled Fusion, 2018, 61.1: 014010.


RE damage at T-10

GRASHIN, S. A., et al. ITER-grade tungsten limiters damage under high turbulent heat flux in the T-10 tokamak. *Fusion Engineering and Design*, 2019, 146: 2100-2104.

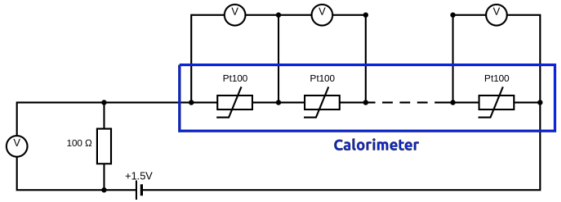
RE beam in COMPASS tokamak



# Calorimetry probe

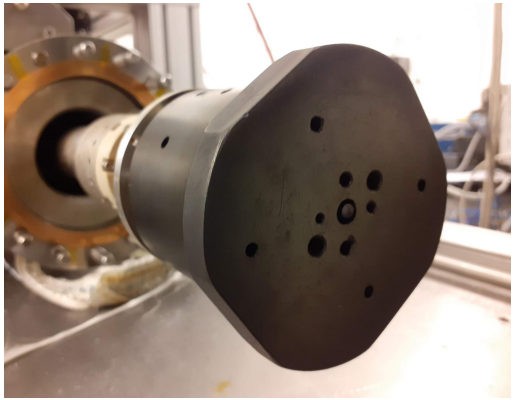
## Calorimetry probe

- Used to measure heat loads on PFC
- Energy estimated from the temperature increase after the discharge
- Acting as a outer wall protection limiter
- Made of graphite - withstand high temperatures without melting
- Temperature change measured by up to 10 resistance temperature detectors (RTD)

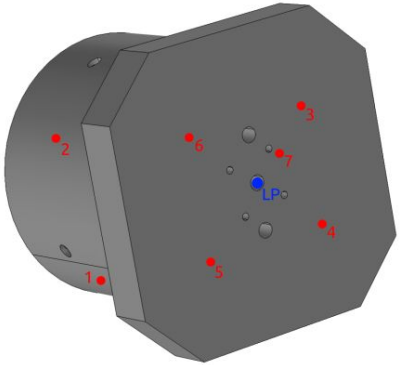



Scheme of the temperature measuring circuit

Calorimetry probe before experiment

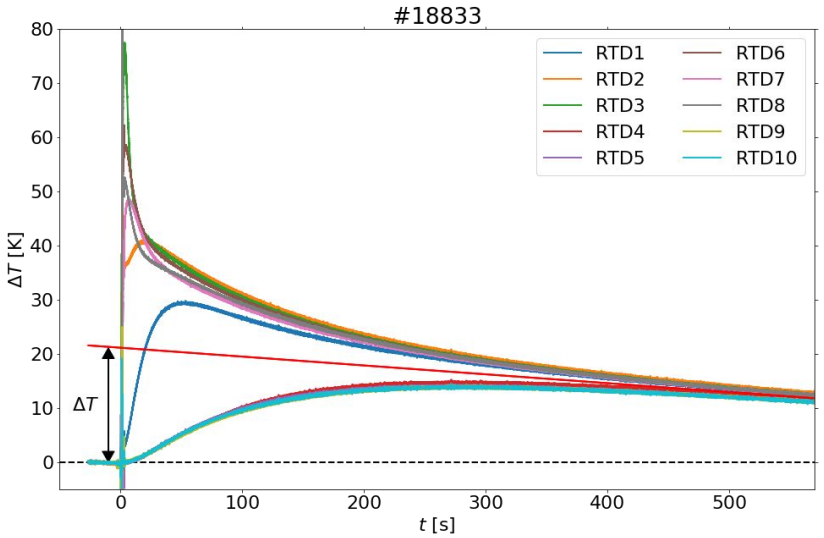


CAD model of calorimeter with RTD locations

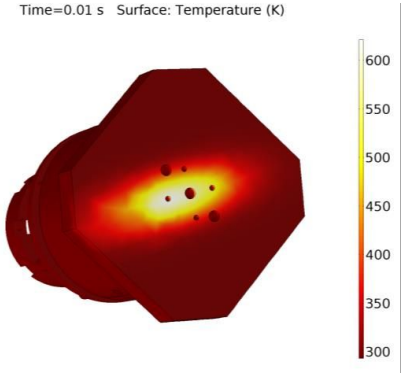


# Temperature measurements

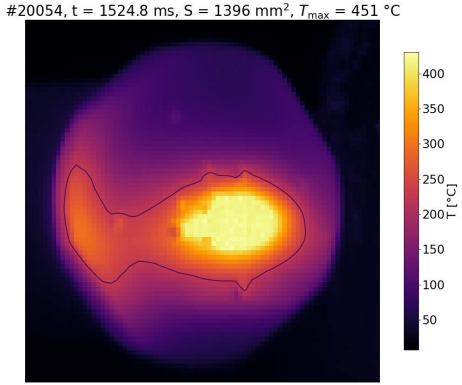
- During discharge - temperature measured by RTDs and IR camera
- Temperature balance requires long duration of measurements
- Total energy estimated from the linear fit of temperature




COMSOL simulation

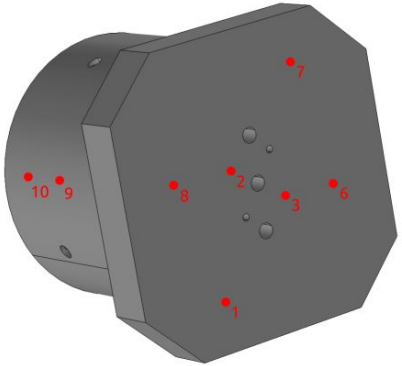


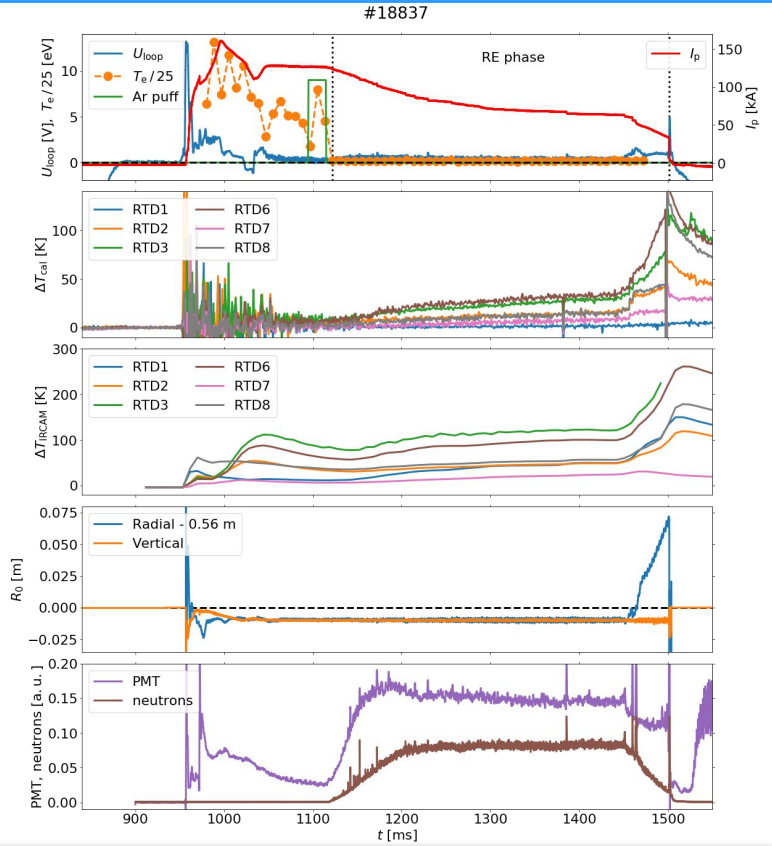

IR camera image



# Experimental scenario

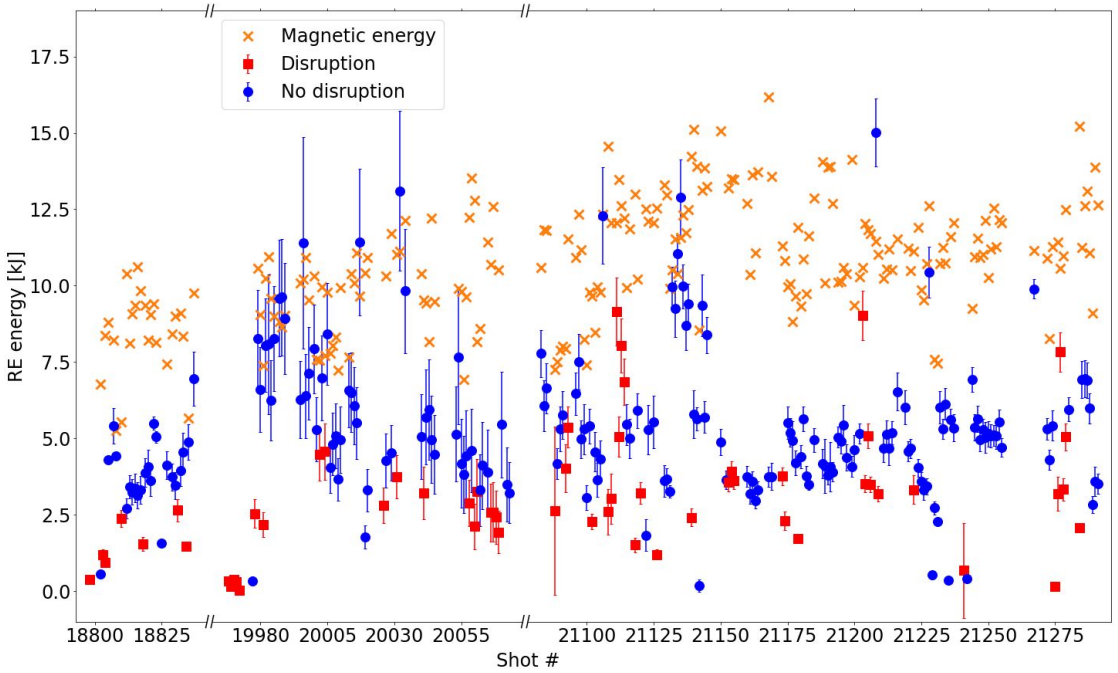
- Special experimental scenario for generation of RE beam in low density discharge
- Studies of various effects on RE decay and PFC heat loads
- Studied effects:
  - Mitigation strategies
    - Gas injection
    - Solid pellet injection
    - Resonant magnetic perturbations
  - RE control techniques
    - Radial position control
    - Additional RE drive



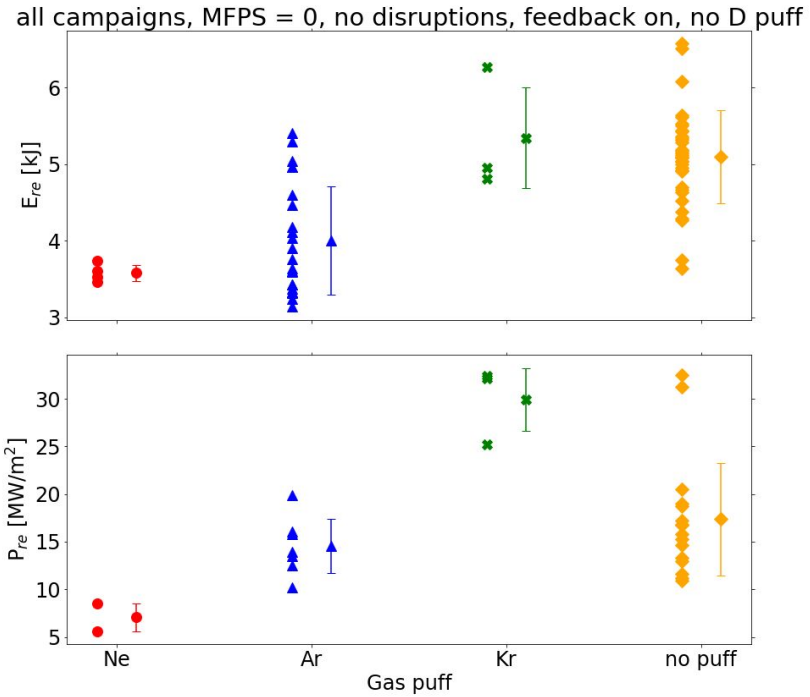
# Results

- Over 250 discharges measured during 3 experimental campaigns
- Energy ranged from a few hundred Joules up to 15 kJ
- From IR camera measurements it is possible to estimate the incident power - max. 30 MW/m$^2$



# Gas injection effects

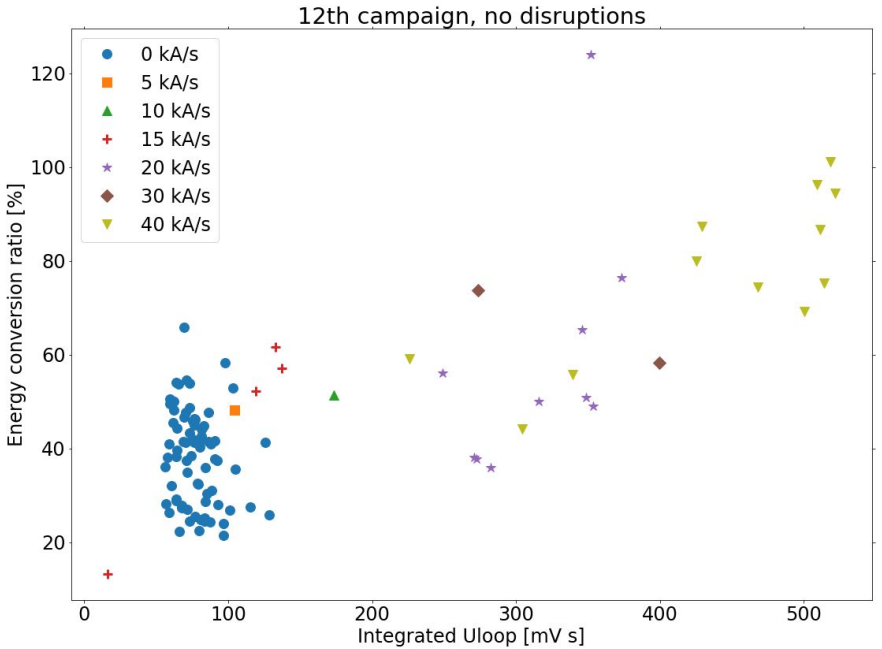
- Thermal quench induced by noble gas injection
- Gas particles then act as impurities on RE beam
- 3 noble gases used - Ne, Ar and Kr
- Energy and power seem to scale with atomic number Z - lowest in the Ne case
- Possibly caused by lowest ionisation energy and mass of Neon



# Additional RE drive effect

- Energy of beam grows with additional acceleration by non-zero loop voltage
- No acceleration - up to 50 % of magnetic energy converted into REs
- With acceleration - RE beam up to 100 % of pre-quench magnetic energy

$$E = \frac{1}{2} L_\mathrm{p} I_\mathrm{p}^2$$



# Summary

**Summary**

- New diagnostic tool - calorimetry probe - was developed to estimate the heat loads on PFC
- More than 250 discharges were measured
- Various mitigation strategies were studied
- Effects of gas injection and position control were observed

**Future plans**

- Calorimetry probe on tokamak GOLEM in development
- Similar system using Fiber Bragg Gratings proposed for new tokamak COMPASS-Upgrade

Thank you for your attention