Investigation of Runaway Electron generation and Mitigation on TEXTOR

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Disruption Physics at TEXTOR

- TEXTOR is well suited to study disruption physics (especially REs)
  - Carbon walls / limiter
- Two DMVs
  - 50 ml; 3.5 MPa; 10 mm; 40 mm tube; 1.5 m from LCFS
  - 110 ml; 10 MPa; 30 mm; no tube; 0.1 m from LCFS
- IR camera measuring the synchrotron radiation from REs (W_{RE} ~ 25 MeV)
- Dispersion interferometer
  - CO_2 laser
  - Able to measure extremely high densities after MGI

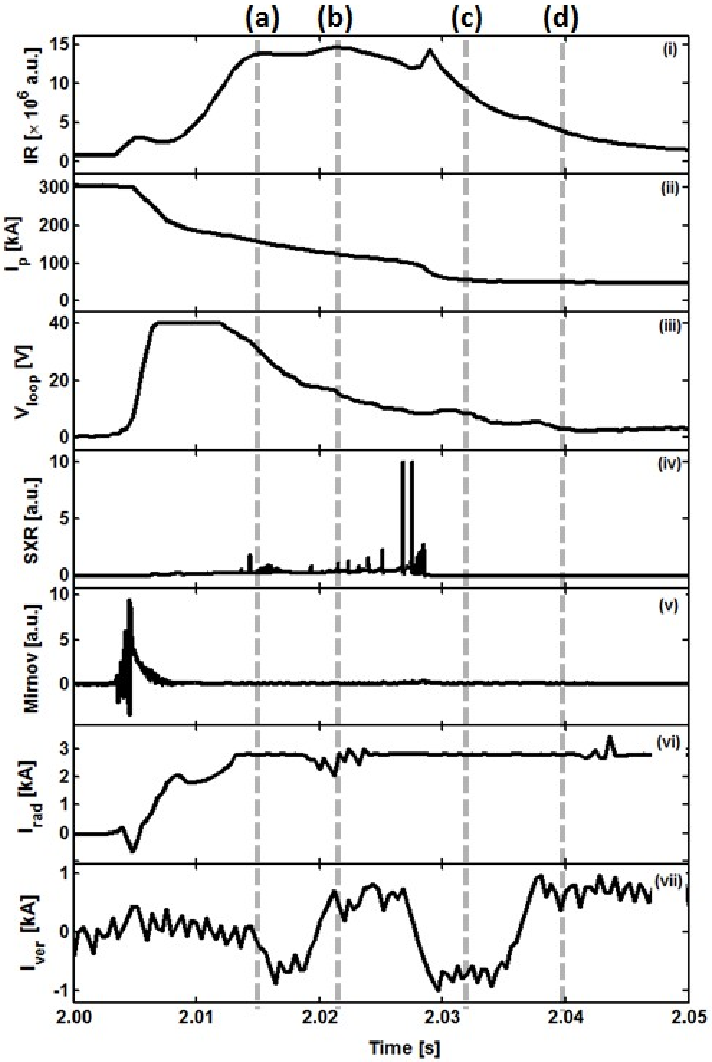
Runaway Electron Suppression

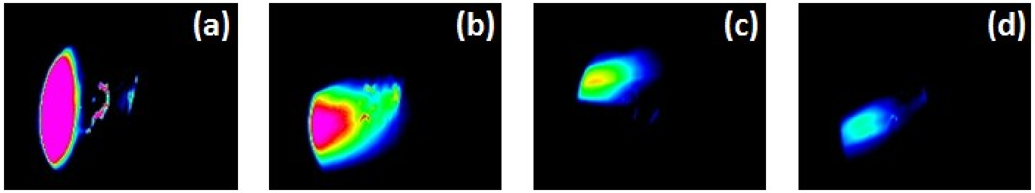
- One possible option for the DMS on ITER is MGI
  - Mitigation of **heat loads** (ok), reduction of **forces** (ok), suppression of **runaway electrons** (?)
- Deliberate RE generation on present machines uses MGI
  - MGI below critical density may make things worse!
  - Little experimental proof of achievement of critical density in present machines up to now
  - Parameter range of present machines may not allow to show that collisional RE generation is suppressed
- Alternative option:
  - Control RE beam for sufficient time to allow actions for controlled (slow) de-confinement of RE

TEXTOR Experiments

- Investigate and understand dynamics (stability) of RE beam (and thermal plasma which is surrounds REs)
  - Keep plasma control on after disruption
  - Use all available diagnostics to characterise RE plasma
  - Understand MHD stability issues which may influence generation and loss of RE (fast particle driven modes, ideal stability)
- Investigate RE production and loss processes
  - Dreicer, Avalanche, Hot tail RE generation
  - Magnetic turbulence
  - MGI and RMP

Dynamics of RE Beam





- Control of RE beam difficult because of transients which are clipped in amplifier before integrator
- RT feedback perturbed
- Feed forward approach allows better control of REs
- Synchrotron radiation (emitted by ~25 MeV REs) allows to determine size and position of RE beam

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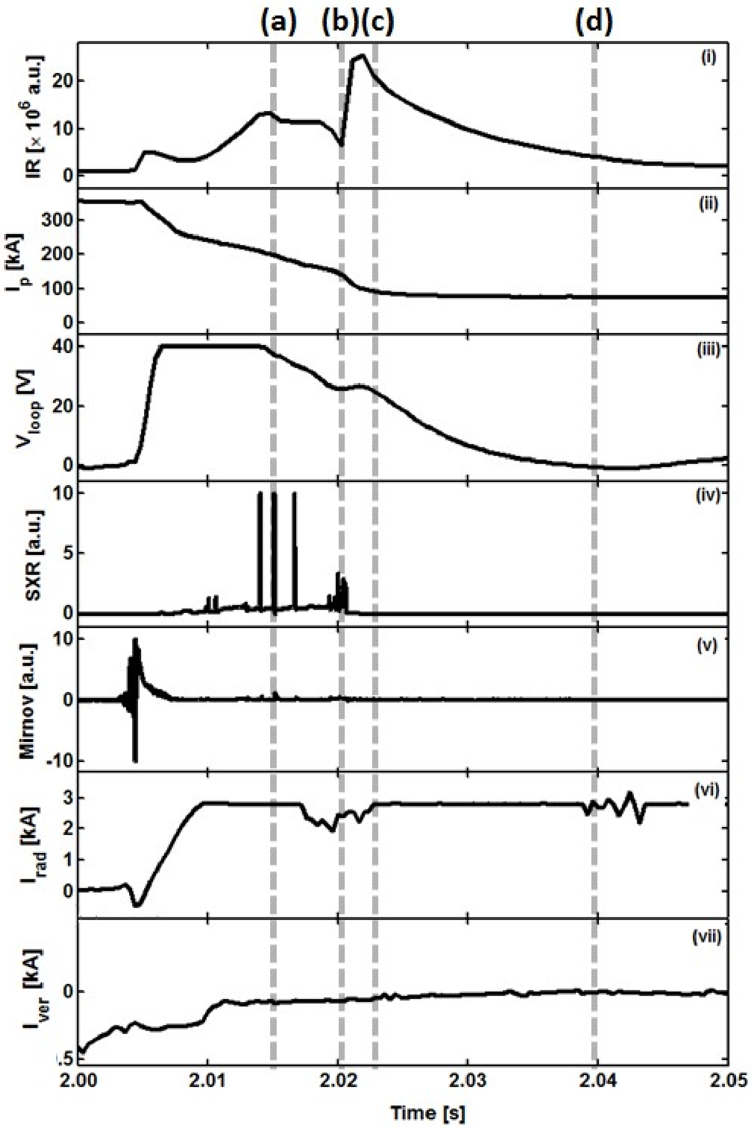
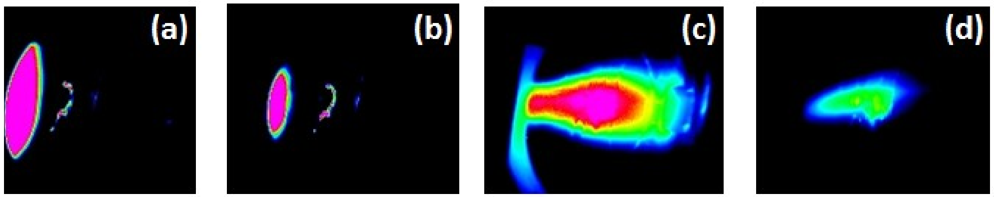
RE Beam Confinement





- During current drop
  - RE beam suddenly moves toward LFS
  - Current drops to (almost) zero
- After end of current plateau
  - High energy REs survive over a few tens of milliseconds
  - Runaways decay smoothly
  - No change in radial position
- Observed in 23 discharges

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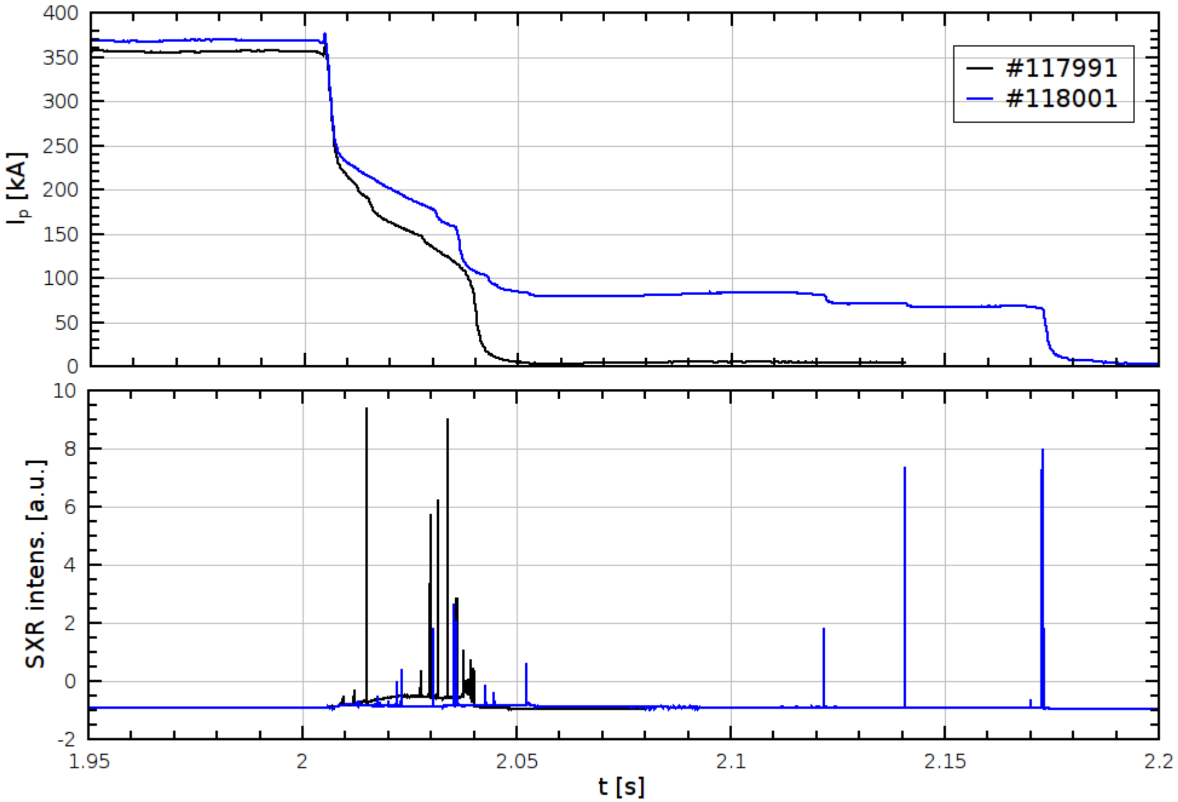
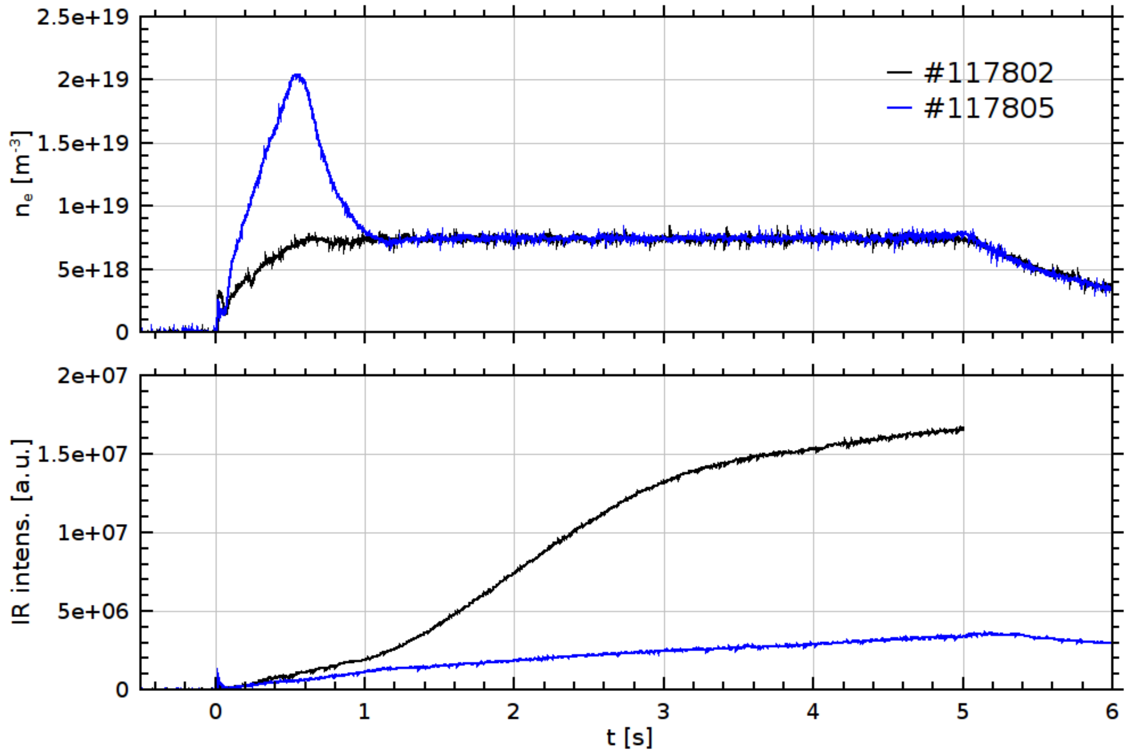
Optimised Control of REs



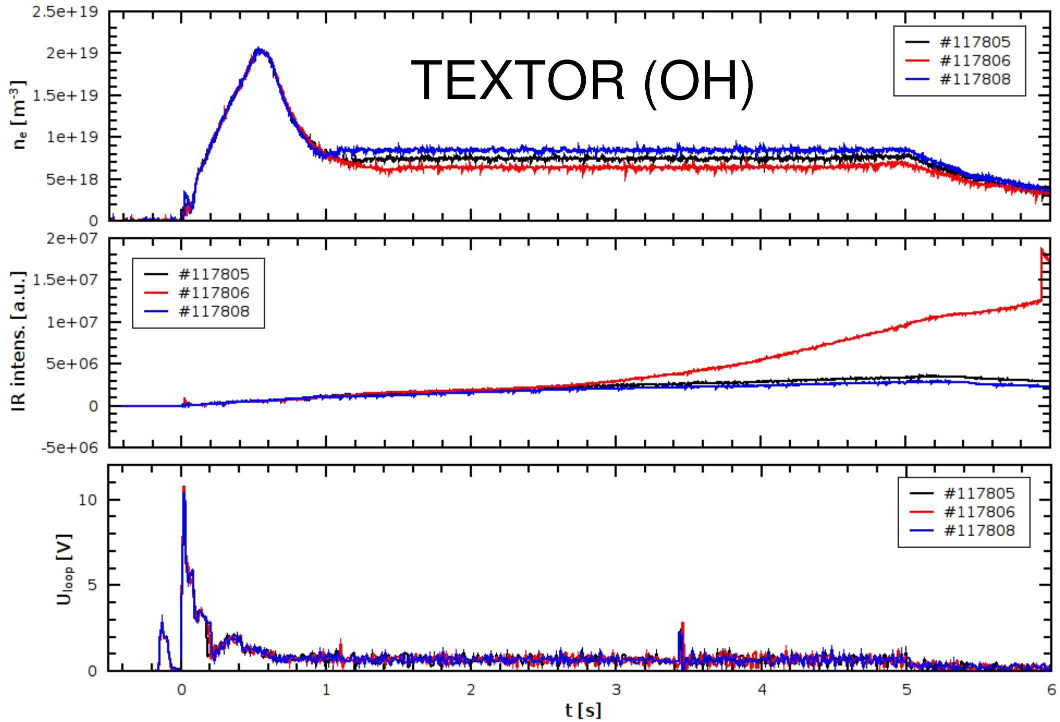
- REs are generated by MGI using Ar
- No RE plateau, but no. of REs decays (probaly because of high gas pressure in vessel)
- SXR spikes indicate rapid loss processes (accompanied by decreases in RE content)
- RE currents below some critical value decay quickly to zero (ideal instability?)

Superthermal Electrons Produced During Plasma Startup



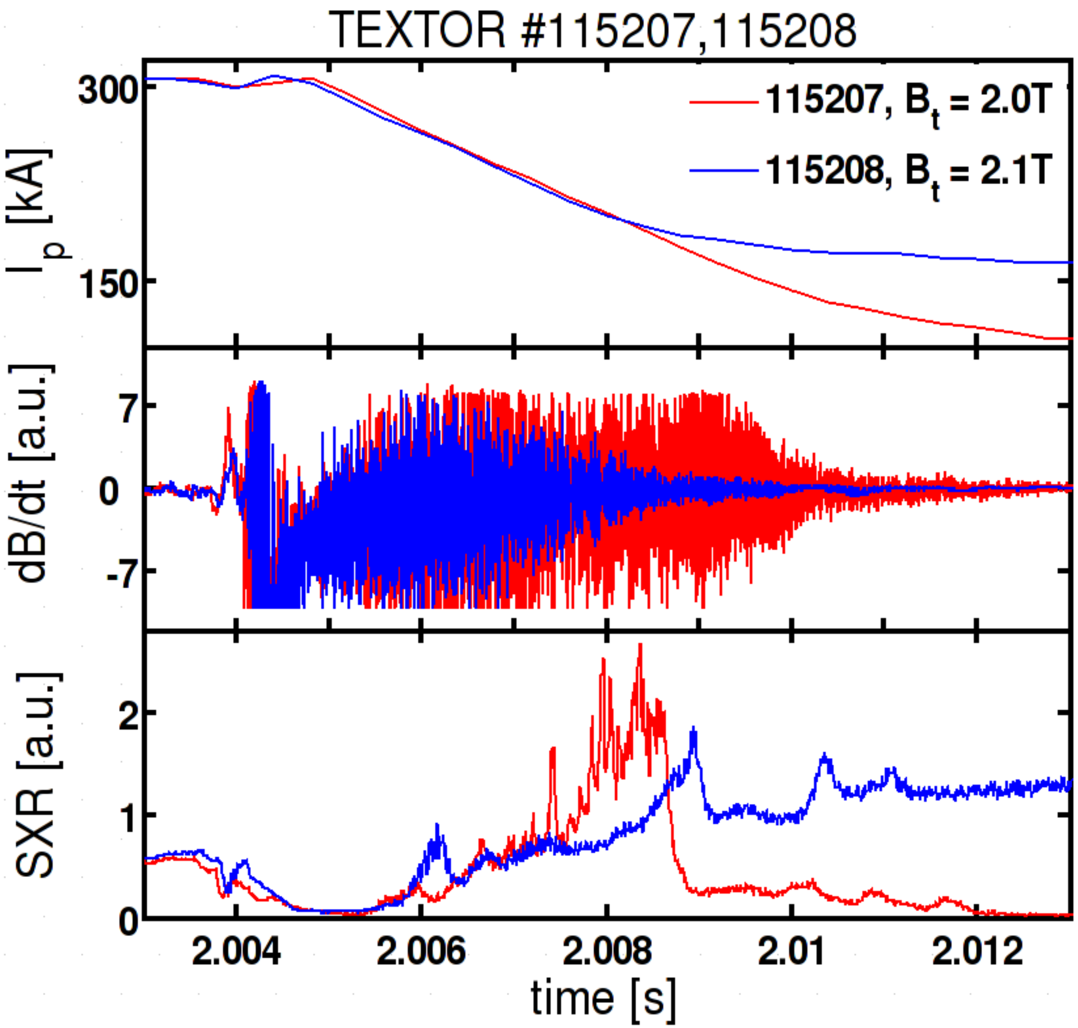
- IR camera detects synchrotron radiation from electrons with 25 MeV
- Plasma startup at high U_{loop} produces high energetic tail of electron energy distribution
- Density pulse strongly suppresses superthermals during startup

Measure E_{crit} under well-controlled conditions (MDC-16)



- Threshold for (high energetic) REs : n_e ~ 0.7* 10^{19} m^{-3}
- Temperature (measurement difficult!) : T_e ~ 2 keV
- **E_R ~ 0.0056 V/m ⇔ $U_{loop}/(2\pi R)$ ~ 0.066 V/m <<< E_D ~ 1.4 V/m**
- Result suggests that additional loss mechanisms are at work

Magnetic Fluctuations during current quench



- #115207
  - without RE
  - B_t=2.0 T
  - sudden decrease in SXR signal
  - amplitude of magnetic fluctuations is large
- #115208
  - with RE
  - B_t=2.1 T
  - SXR signal increases gradually
  - magnetic fluctuations disapear

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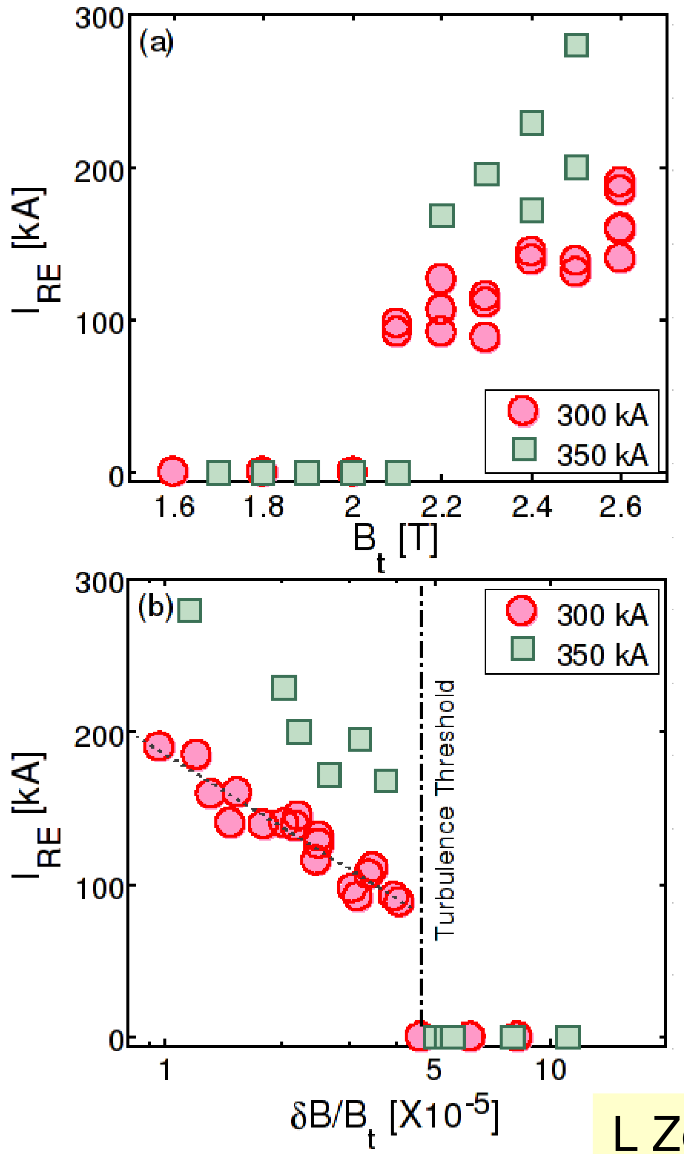
TF Threshold for RE Generation

- Runaway electrons in most situations are only observed with Bt >2 T
- This observation does not depend on machine size (JET, JT-60, Tore Supra, TEXTOR, etc.)
- TEXTOR experiments shown a threshold in magnetic turbulence
- The magnetic turbulence during the current quench decreases with increasing B_t
- Magnetic fluctuations originate mainly from background plasma



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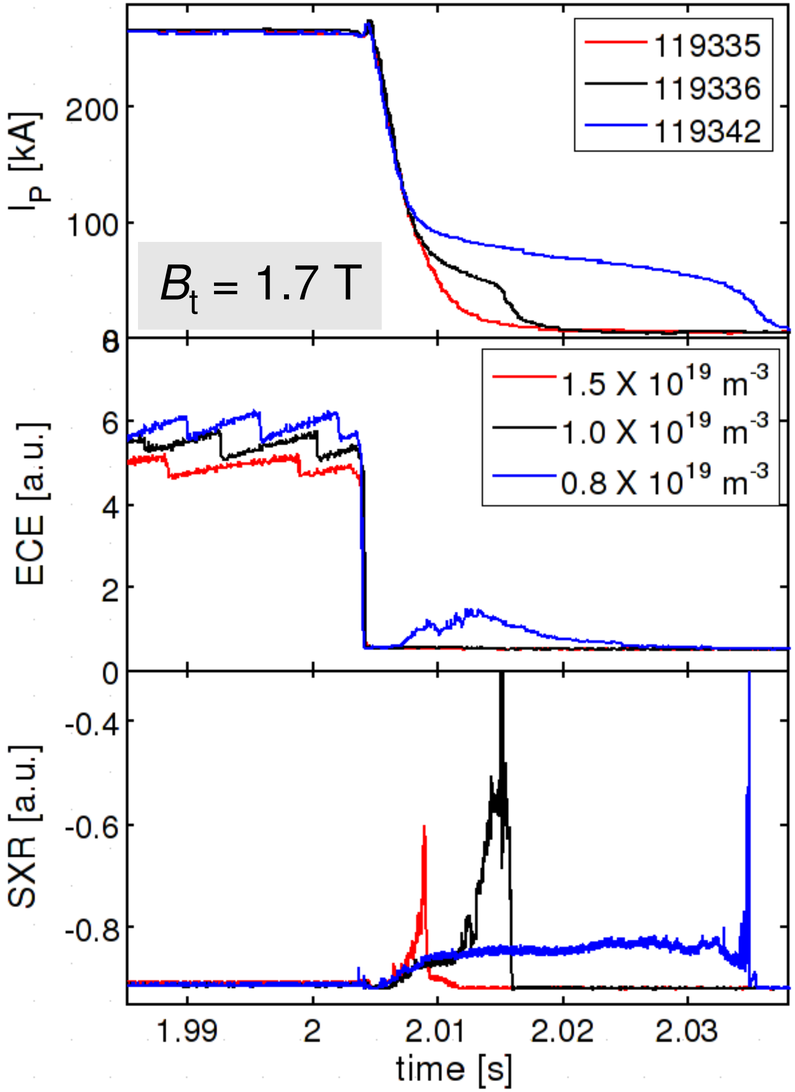
Hot Tail RE Generation



- Different plasma temperature before the disruption yields different amount of REs
- Primary generation due to the Dreicer field and the loss due to the magnetic turbulence are almost similar
- Hot tail runaway electron generation is caused by incomplete thermalization of the electron velocity distribution during rapid plasma cooling
  - Important RE production mechanism in tokamak disruptions if the thermal quench phase is sufficiently fast
- MHD modes during the thermal quench cause high energetic electron losses

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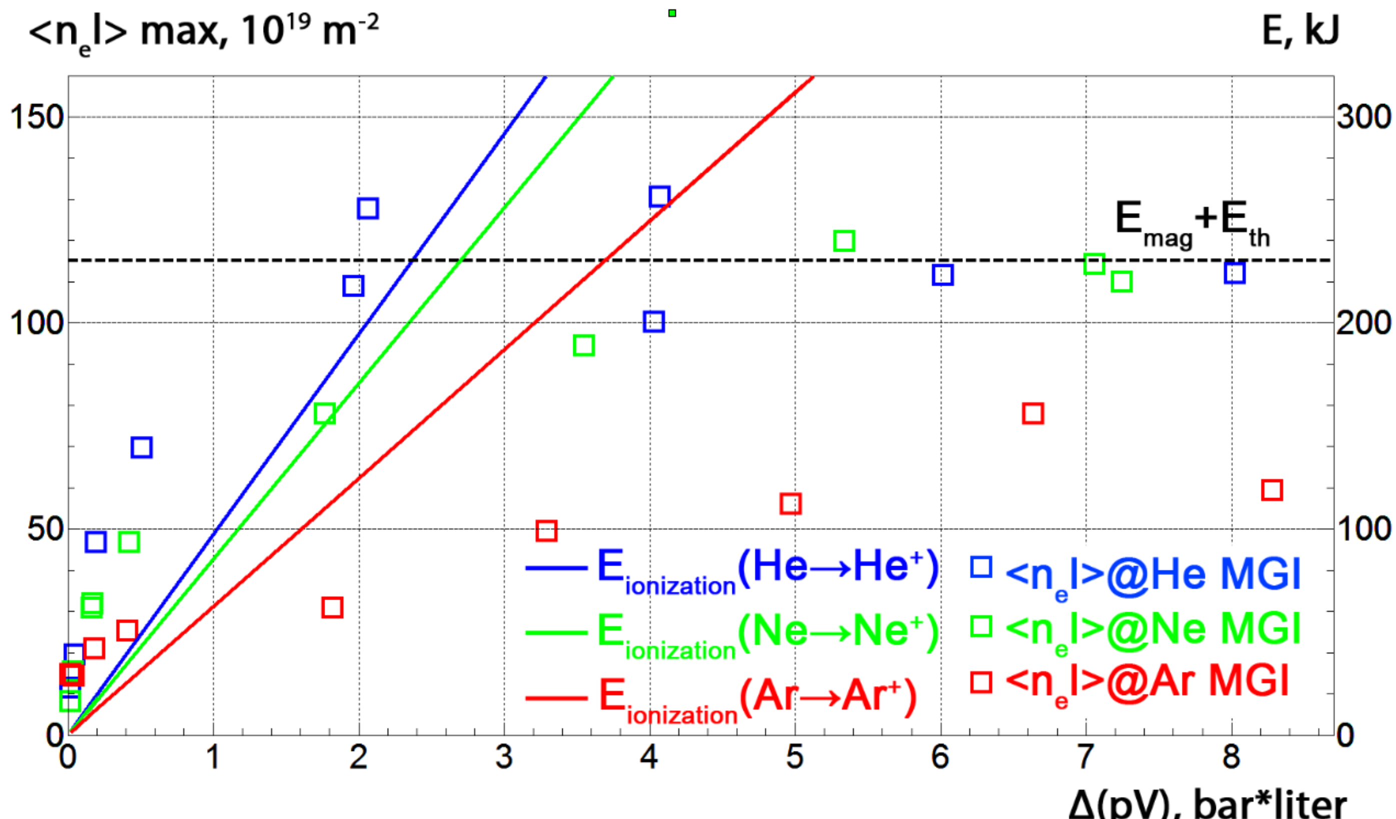
Measured Free Electron Density after MGI



- Saturation in free electron density due to limited energy content of plasma
- Ar yields lower density than expected
  - Caused by with radiation losses (?)

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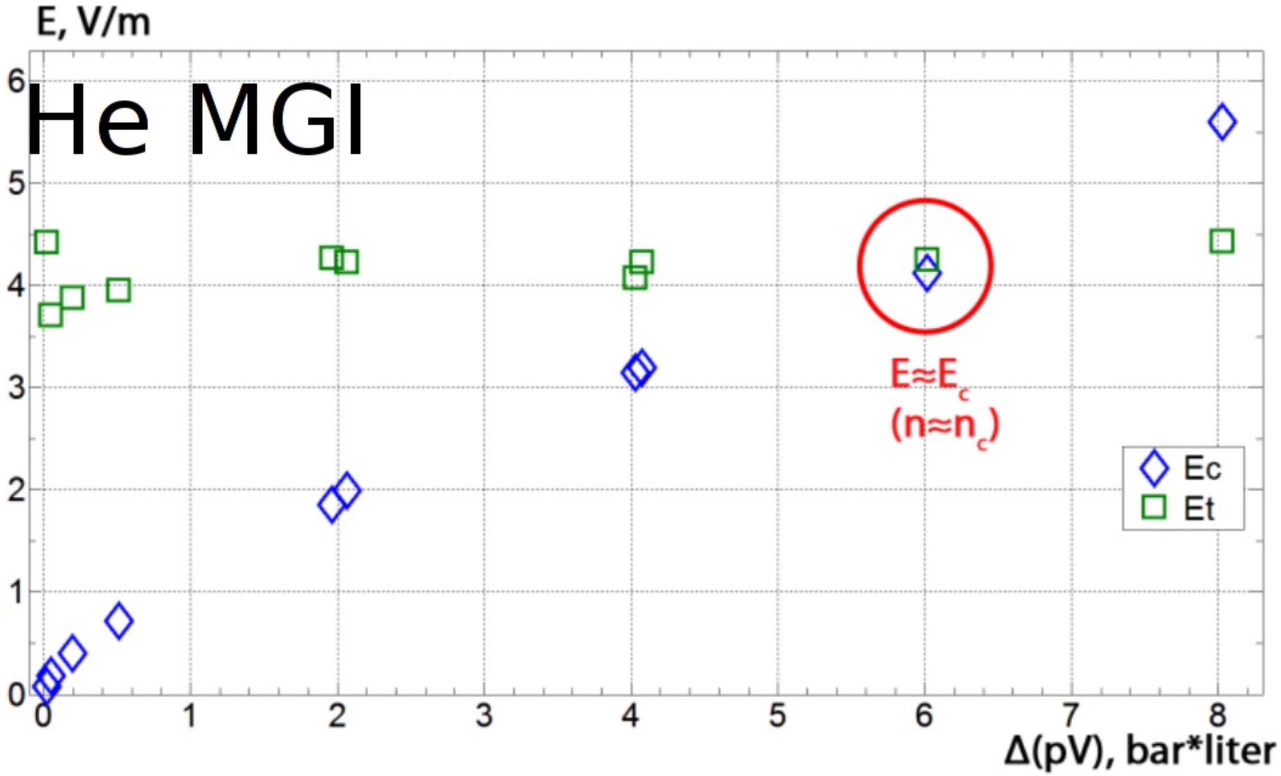
Critical Density for RE Suppression



- (Preliminary) data suggest that the Connor-Hastie-Rosenbluth density could be achieved if
  - It is assumed that “missing” particles after injection are neutral and fill the vacuum vessel
  - Bound electrons are taken into account

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Summary

- Runaway electron beams show rather complex dynamic behaviour
- Control of runaway beam possible but still rapid loss events
- Measured critical electric field for high energy runaway electron generation about 10 times larger than given by relativistic collisional theory
- Connor-Hastie-Rosenbluth density can possibly be reached by massive gas injection