Really Cool Halo Current Measurements in Alcator C-Mod

R. Granetz, A. Tinguely, A. Berg,
A. Kuang, D. Brunner, B. LaBombard

MIT Plasma Science and Fusion Center

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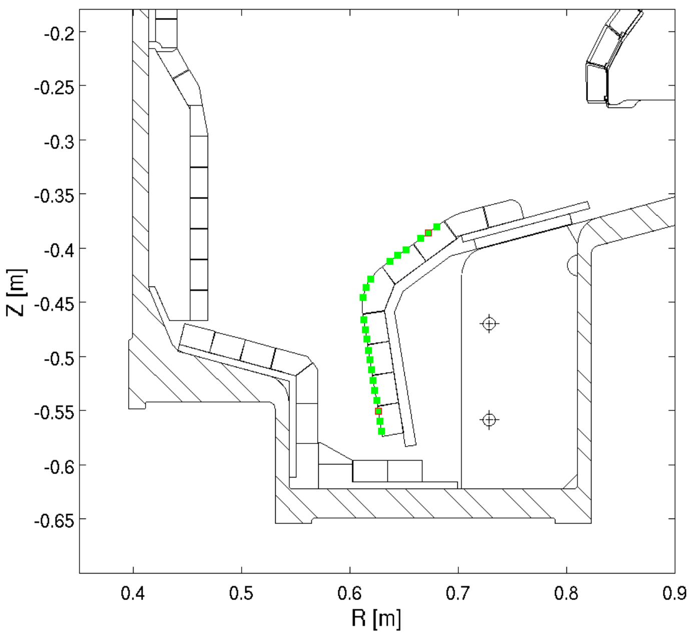
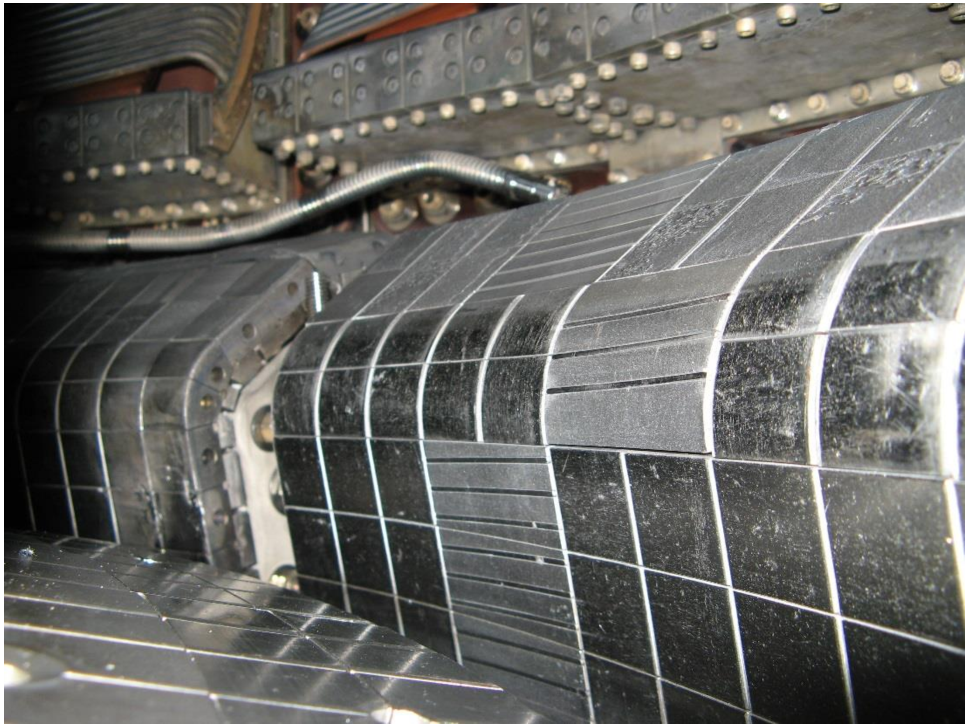
New SOL diagnostic: Langmuir rail probes

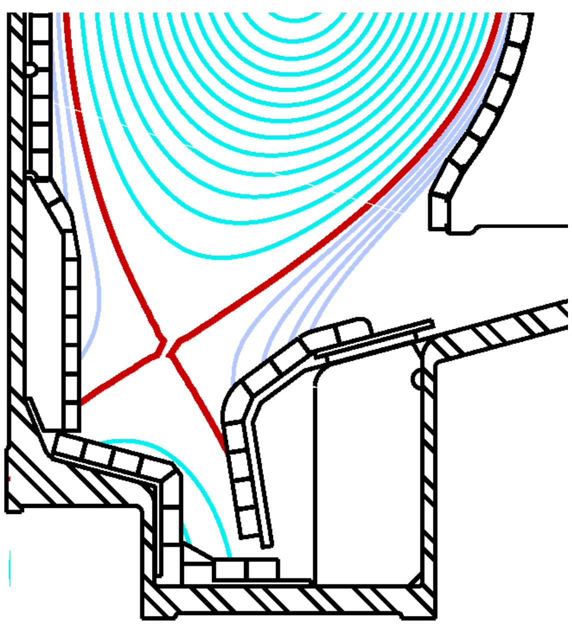
- 21 flush-mounted Langmuir rail probes give SOL profiles from bottom to top of outboard divertor plate with fast time resolution

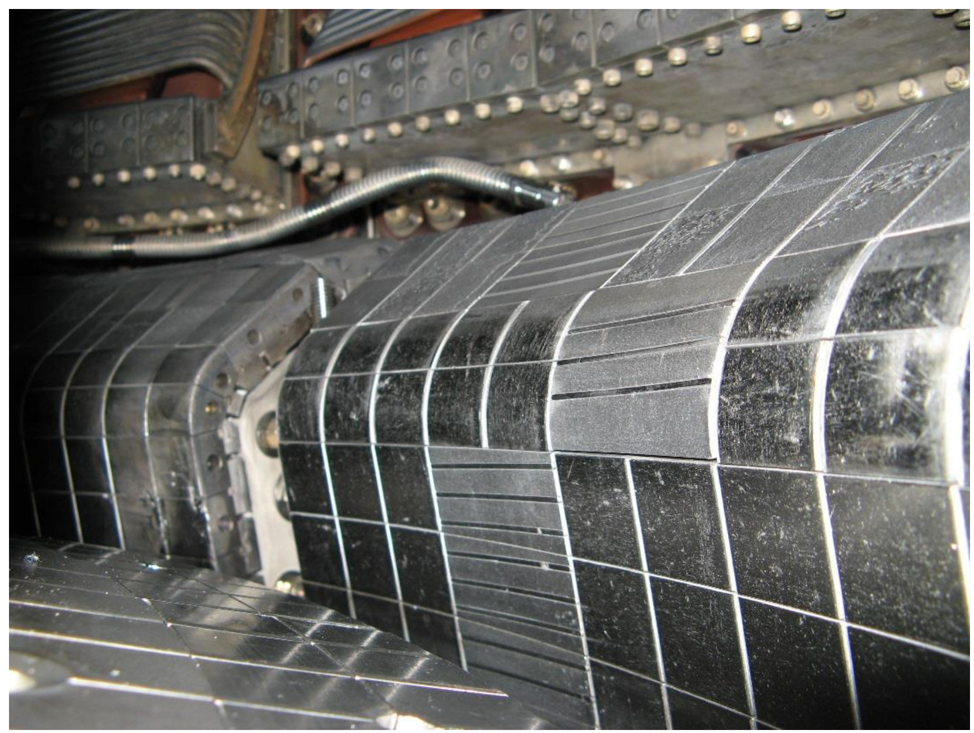




New SOL diagnostic: Langmuir rail probes

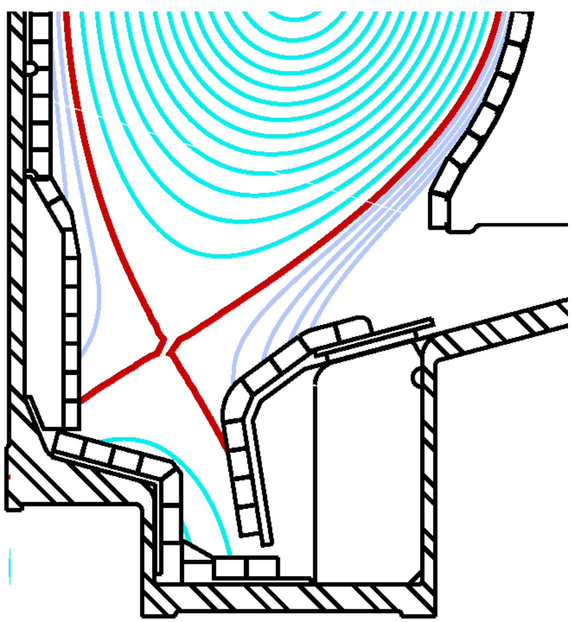
- 21 flush-mounted Langmuir rail probes give SOL profiles from bottom to top of outboard divertor plate with fast time resolution
- Primarily intended to measure I-V characteristics to provide $T_e(\psi)$, $n_e(\psi)$, and $V_f(\psi)$ in the SOL at the outboard divertor plate

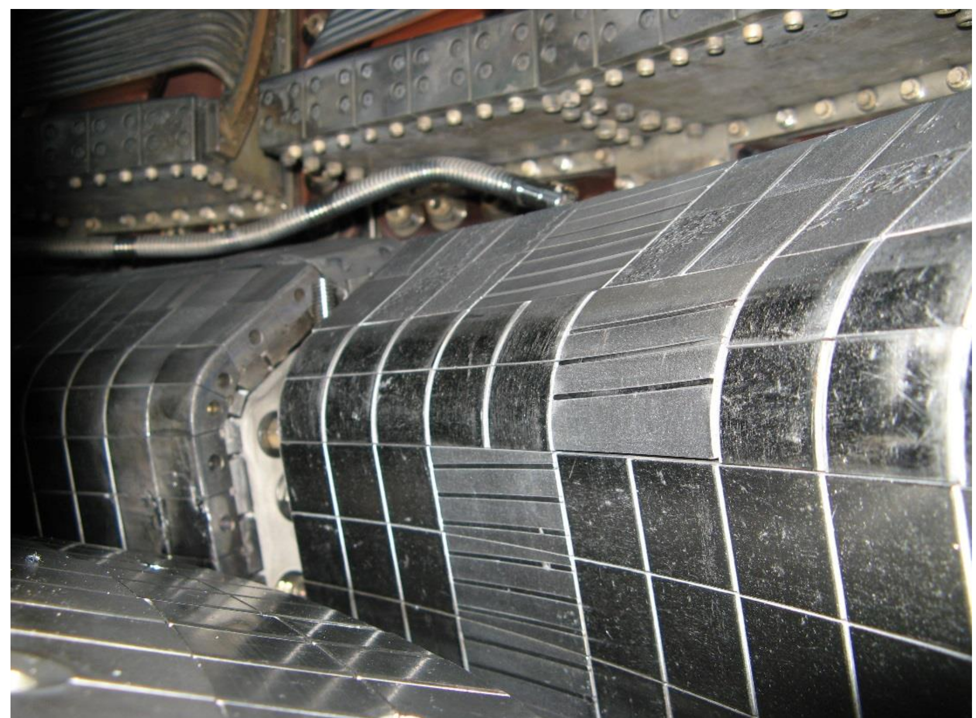




New SOL diagnostic: Langmuir rail probes

- When run in “grounded” mode, the probes appear to the plasma to just be part of the divertor plate surface
- Current flowing in/out of the probes can be measured while in grounded mode.

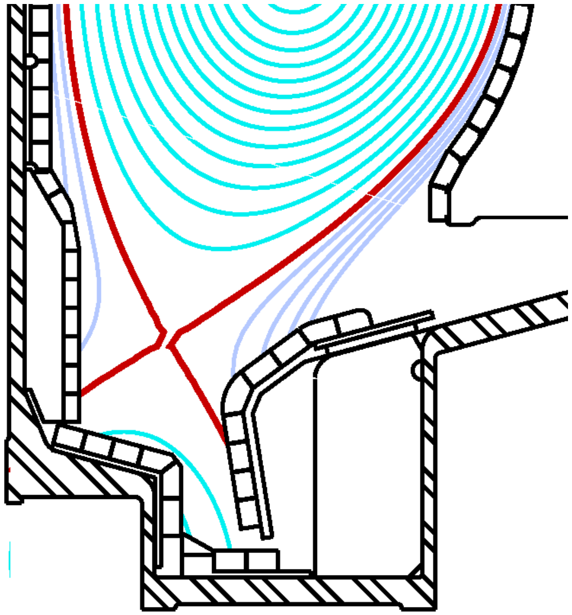


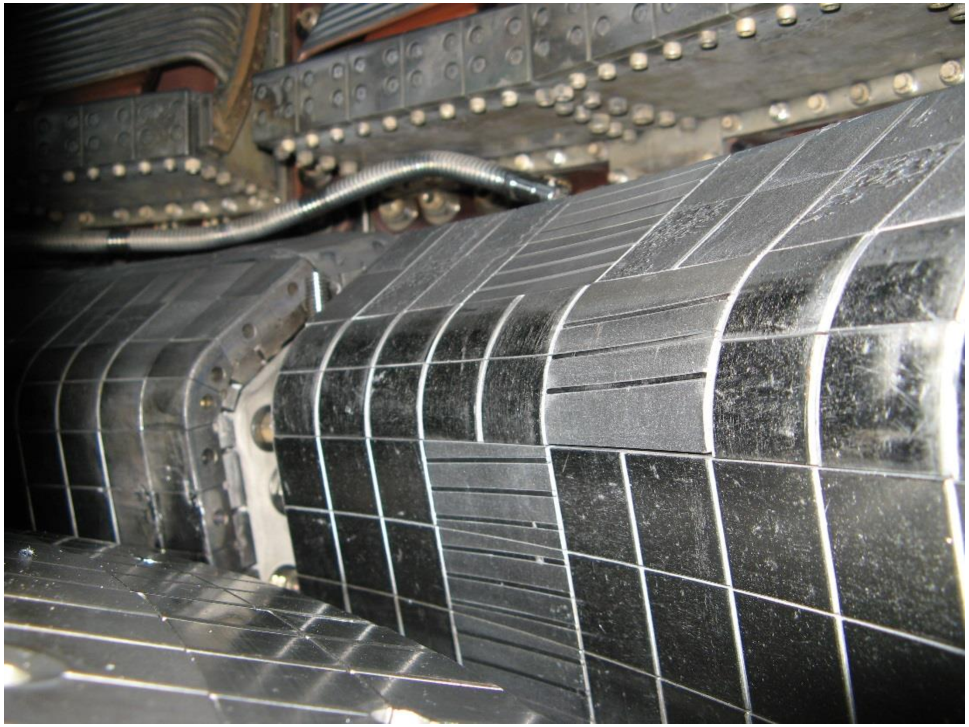


New SOL diagnostic: Langmuir rail probes

Alcator C-Mod

- When run in “grounded” mode, the probes appear to the plasma to just be part of the divertor plate surface (almost)
- Current flowing in/out of the probes can be measured while in grounded mode.





New SOL diagnostic: Langmuir rail probes

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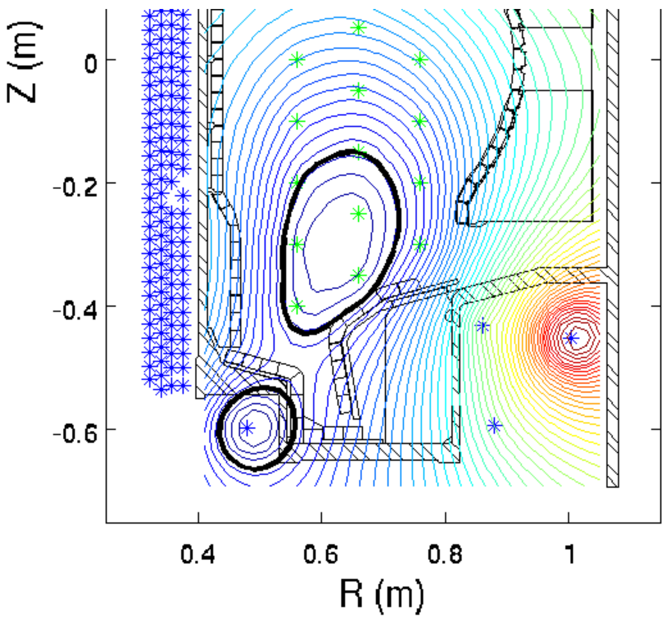
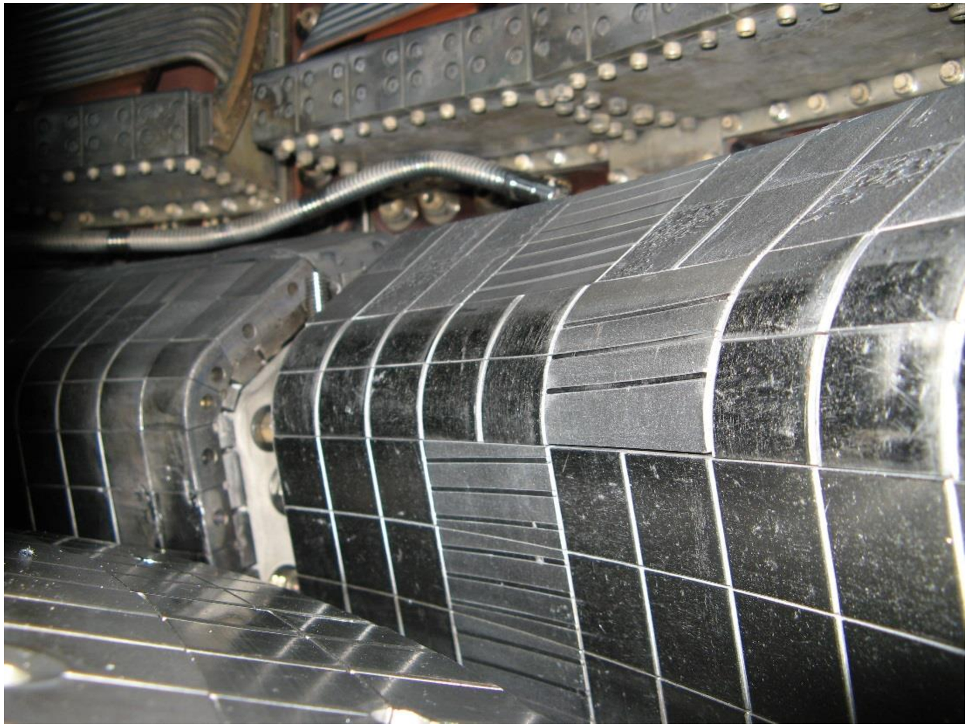
- Current flowing in/out of the probes can be measured while in grounded mode. ***During disruptions, halo currents can be measured.***





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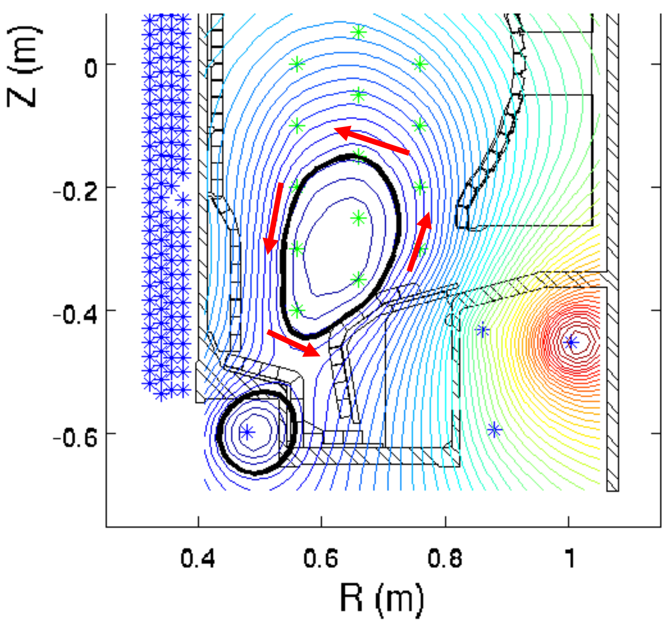
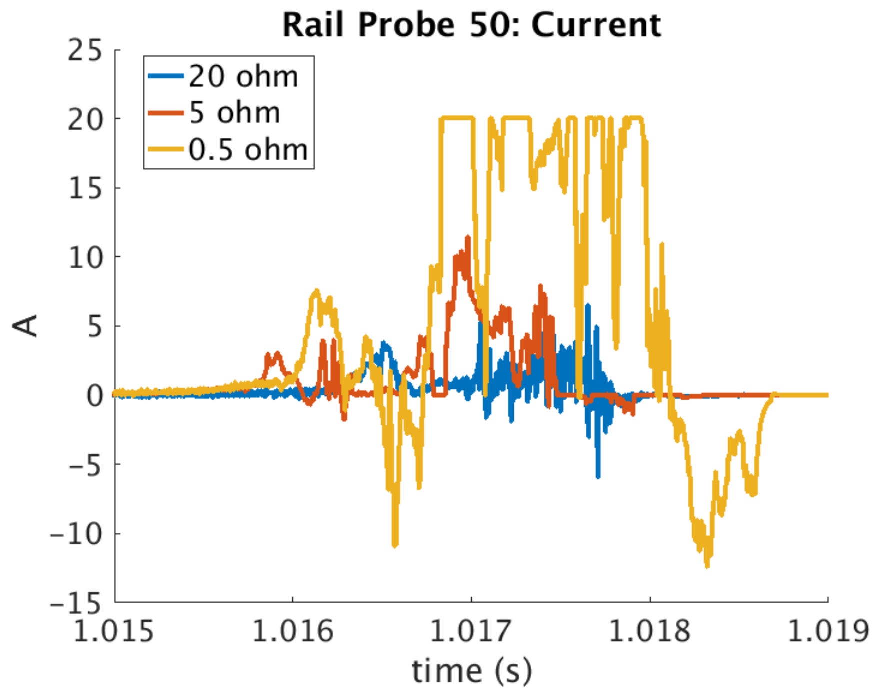
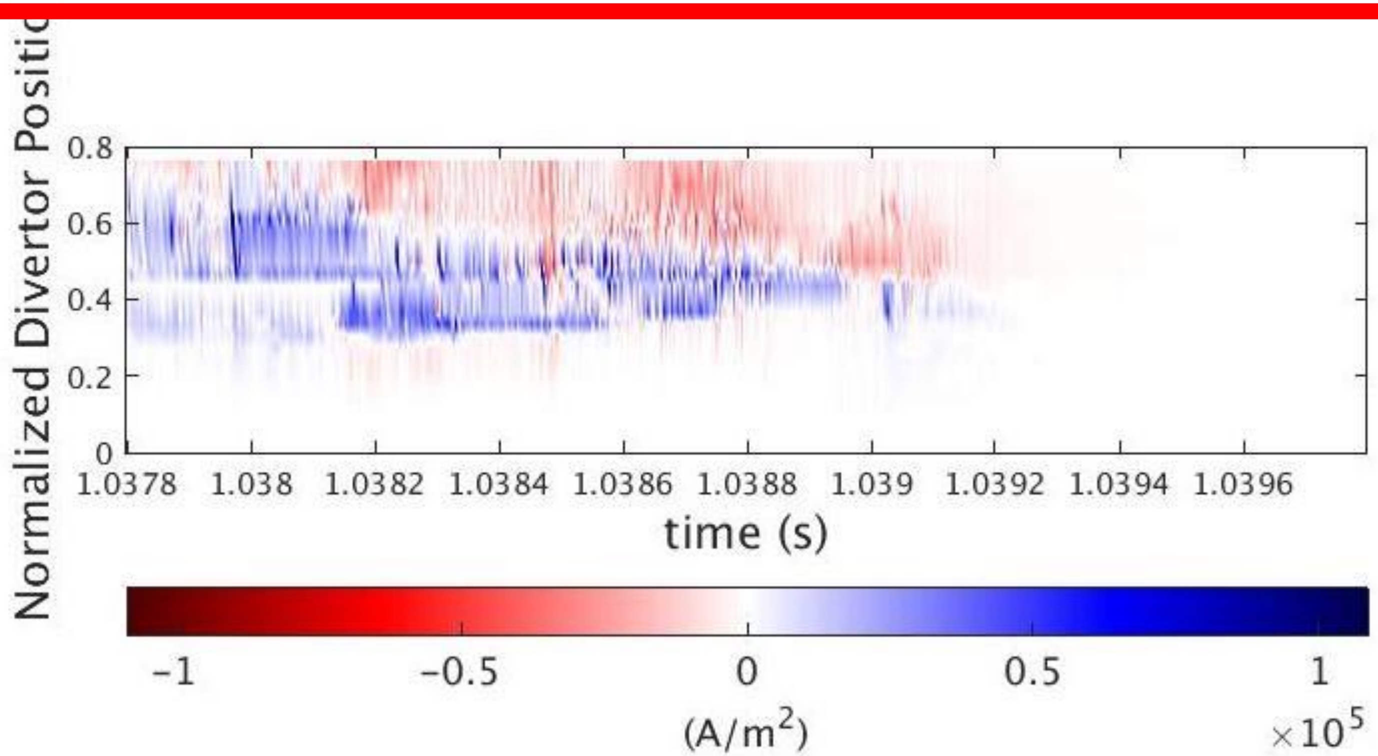


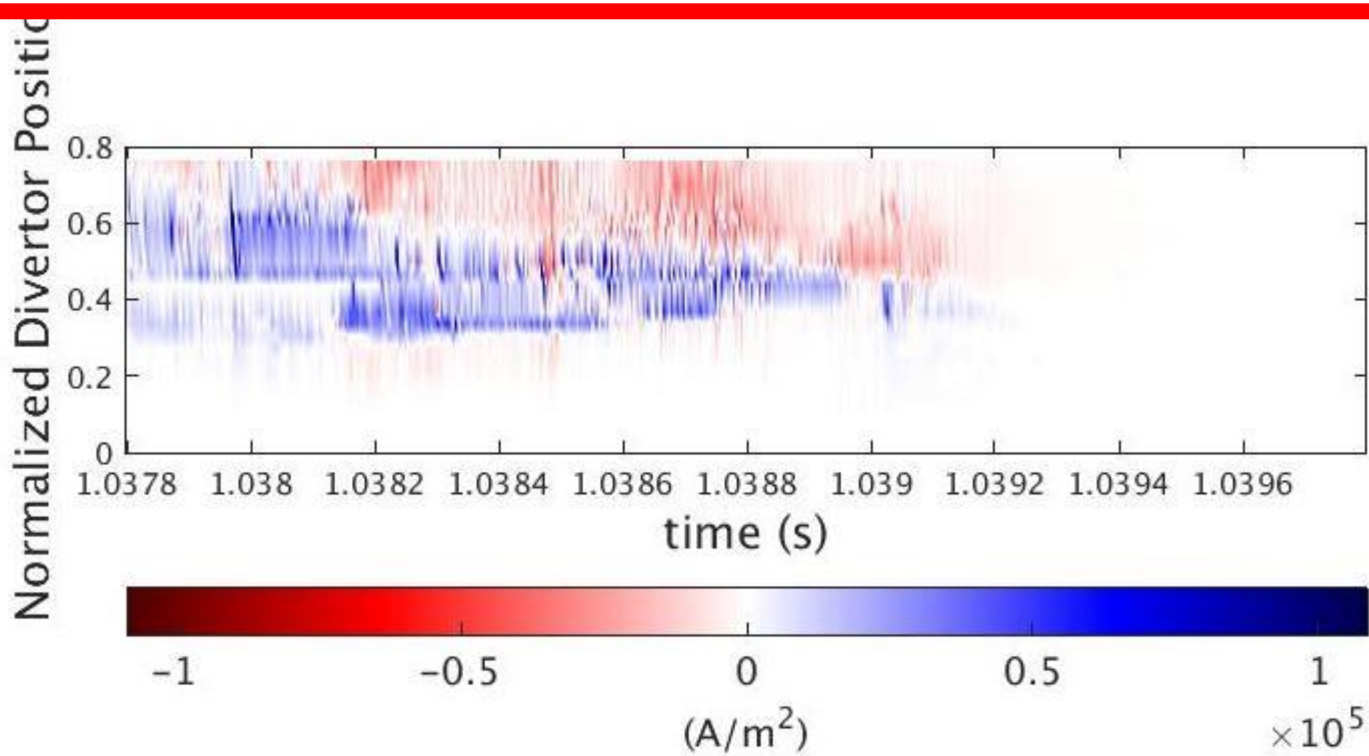


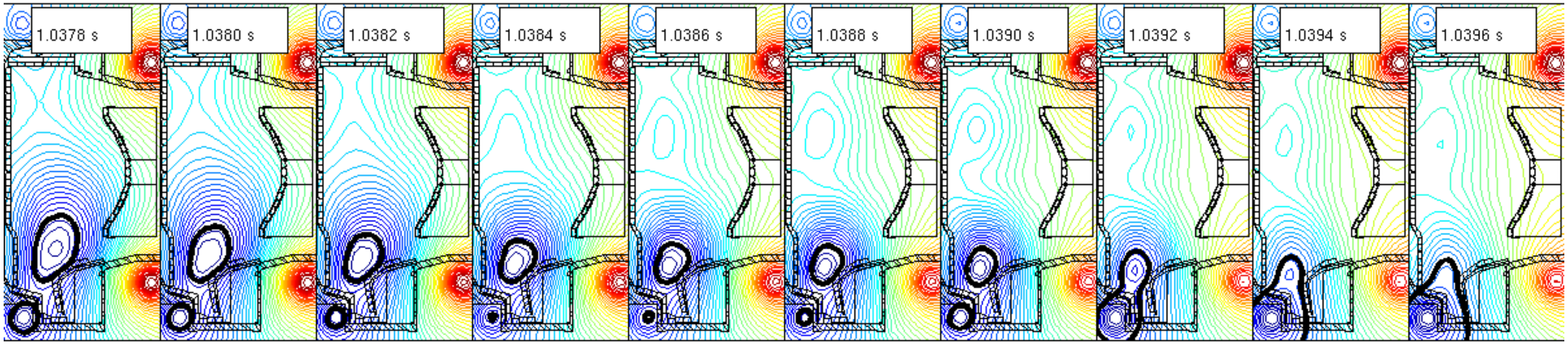
Spatially-resolved halo currents are measured during disruptions



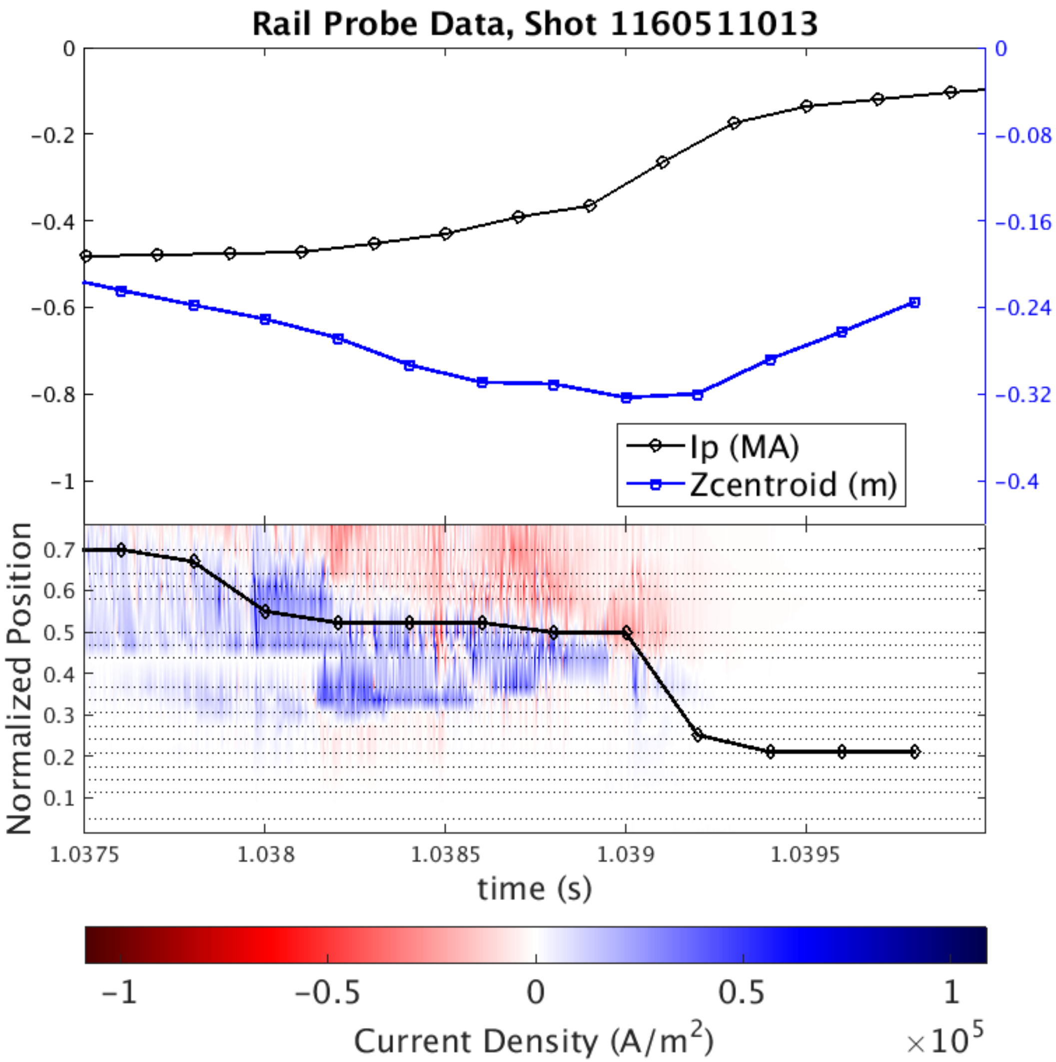
Division between + and – currents slides down the divertor face during the current quench

Spatially-resolved halo currents are measured during disruptions





Plasma contact point vs time compared to +/- halo boundary



On many disruptions there is good correspondence between contact point and +/- halo boundary vs time

$I_p(t)$ and $Z_c(t)$ are also shown

Contact point is obtained from flux reconstructions using fixed filament model

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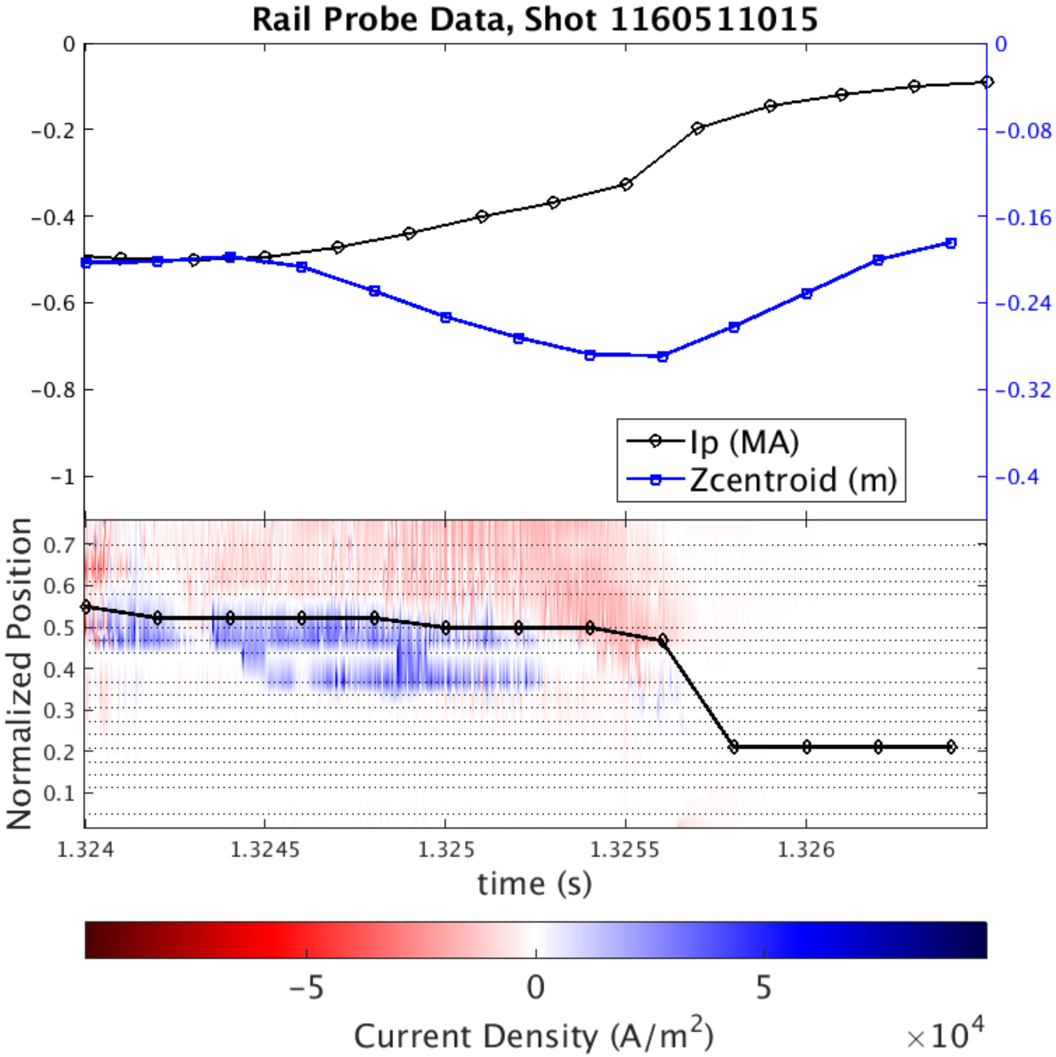

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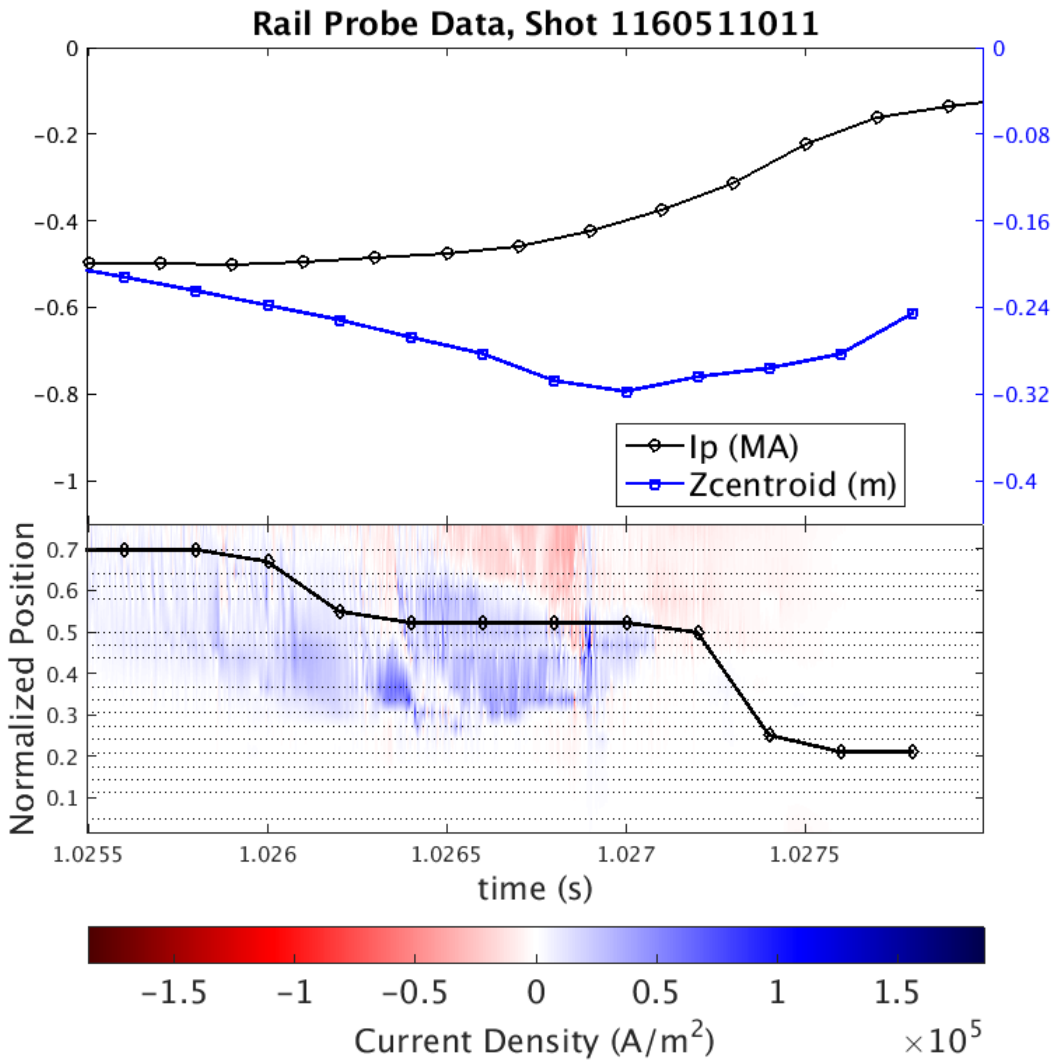
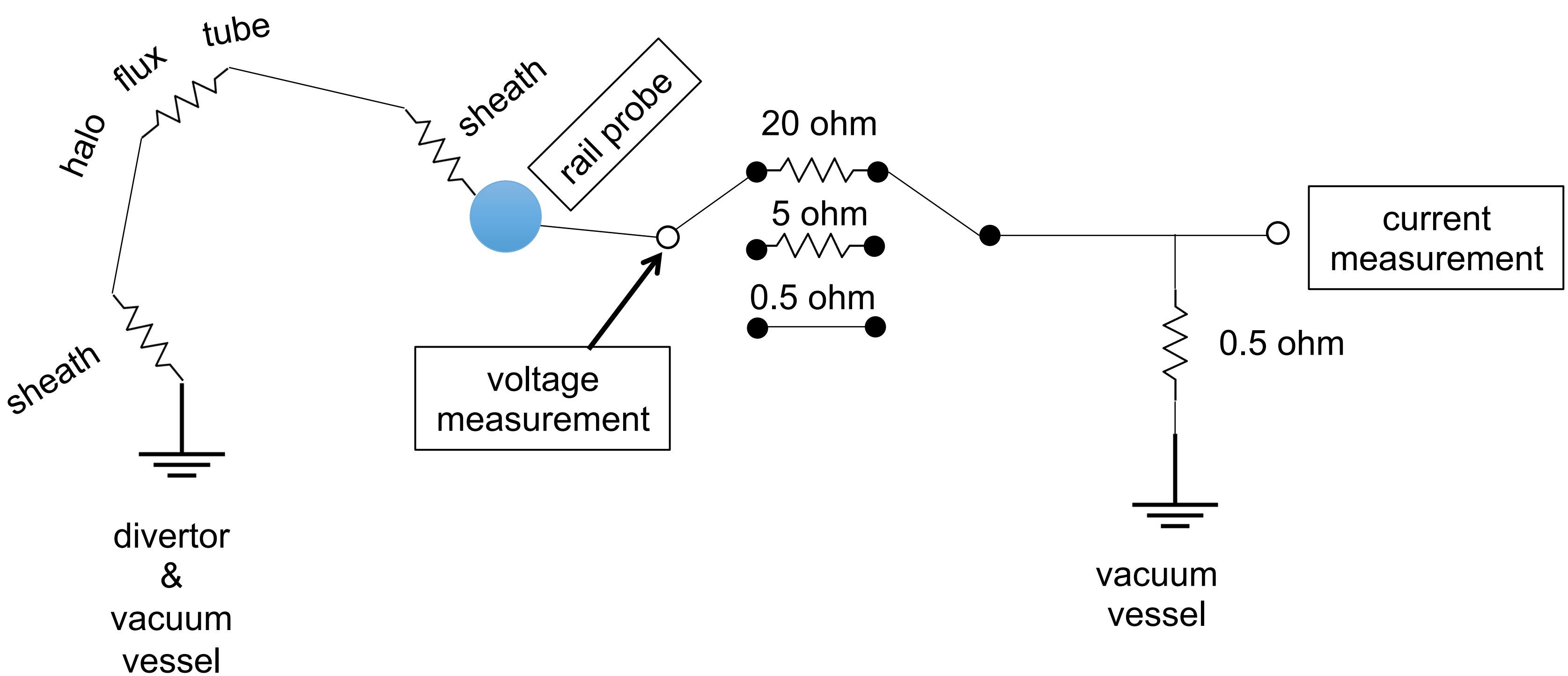


But not all disruptions have a good correspondence between contact point and +/- halo boundary vs time

$I_p(t)$ and $Z_c(t)$ are also shown

Contact point is obtained from flux reconstructions using fixed filament model

Resistance of measuring circuit makes a difference



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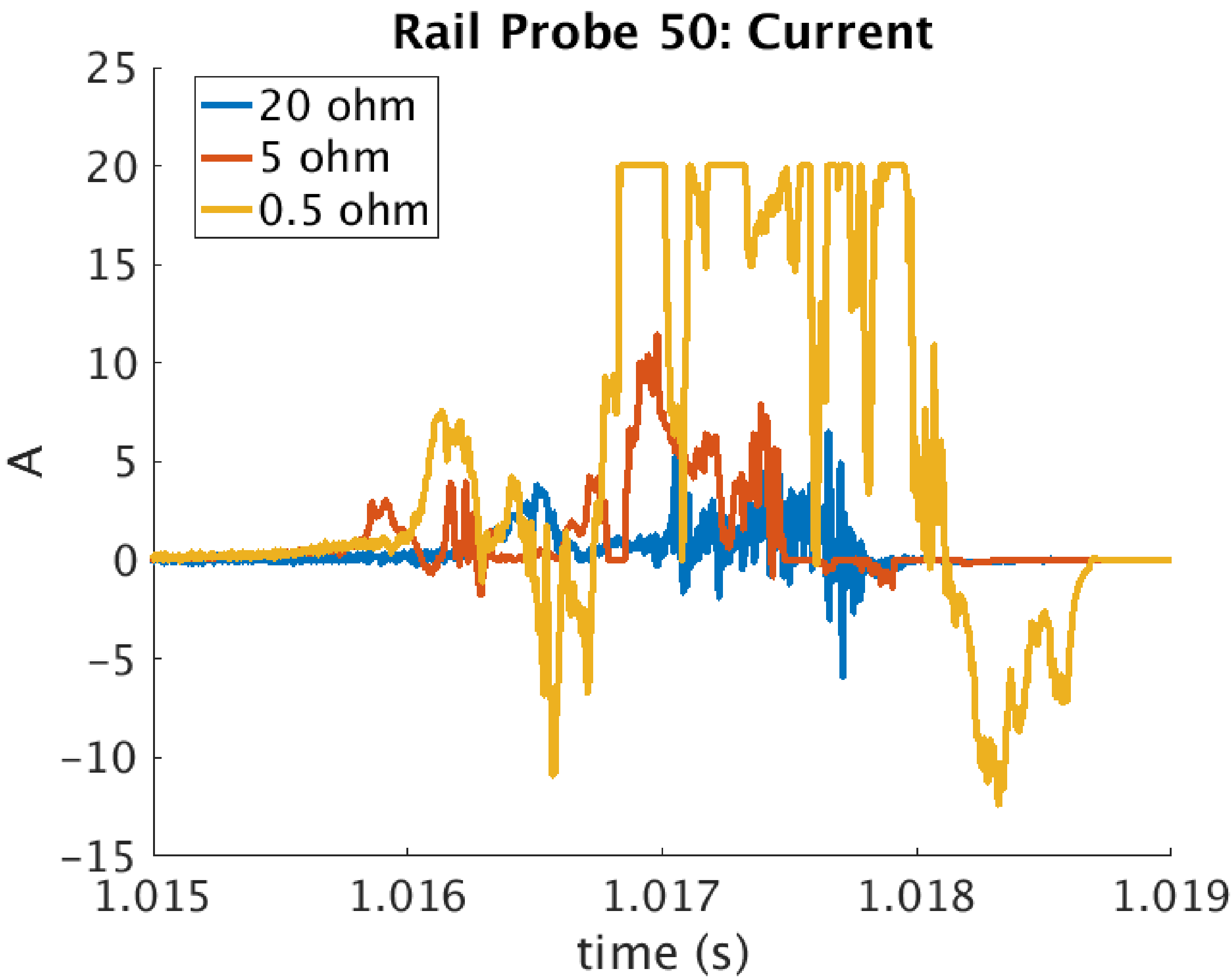

Resistance of measuring circuit makes a difference

- Halo current measurements with 3 different circuit resistors have been obtained at most of the spatial positions
  - At the lowest resistance, we measure total halo current that matches our results from 20 years ago (measured with Rogowski sensors)
  - This dependence on the circuit resistor may allow us to deduce the actual SOL resistivity magnitude *and* SOL resistivity profile
  - Could be ***very*** useful for input to halo current modeling efforts
  - Might even be able to separate sheath potential from plasma flux tube resistance, which is exciting to SOL/divertor enthusiasts

Summary

- Divertor Langmuir rail probes provide unprecedented spatially-resolved measurements of disruption halo currents in the SOL
  - Allows detailed comparison of quenching plasma geometry with halo current structure
  - We're also trying to correlate halo currents with edge *q* of quenching plasma
- Dependence on measurement resistors may yield information on SOL resistivity and structure
  - Should be useful for modeling
  - Studies of sheath potentials and other edge physics?

Does synchrotron emission really limit the runaway energy in Alcator C-Mod?

Alcator C-Mod

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Motivation

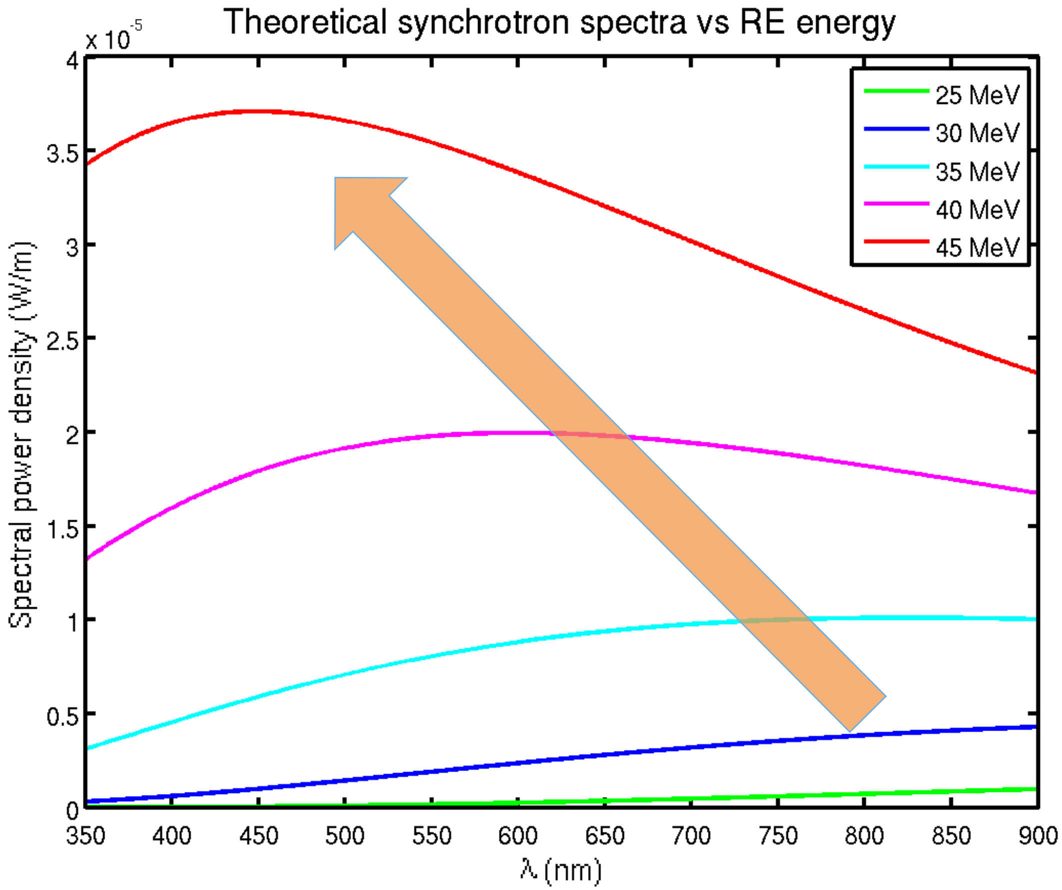
- In principle, RE synchrotron emission (SE) can reveal information about the RE energy distribution, pitch angle distribution, population density, spatial distribution, etcetera.
- By analyzing the shape of individual SE spectra from Alcator C-Mod, we have been trying to distinguish the synchrotron emission of a <u>mono-energetic</u> (and mono-pitch) beam of runaway electrons from that of a <u>continuum energy distribution</u> (monotonically decreasing)
  - So far, we find it difficult to distinguish between the two types of distributions, based solely on individual spectra (see Alex Tinguely's presentation)
- But we may be able to get additional clues by studying the temporal evolution of the spectra during a discharge, and/or by comparing spectra from different discharges

Granetz's simplistic view of the universe

Synchrotron emission that is increasing in time can be explained in two ways (or some combination of the two):

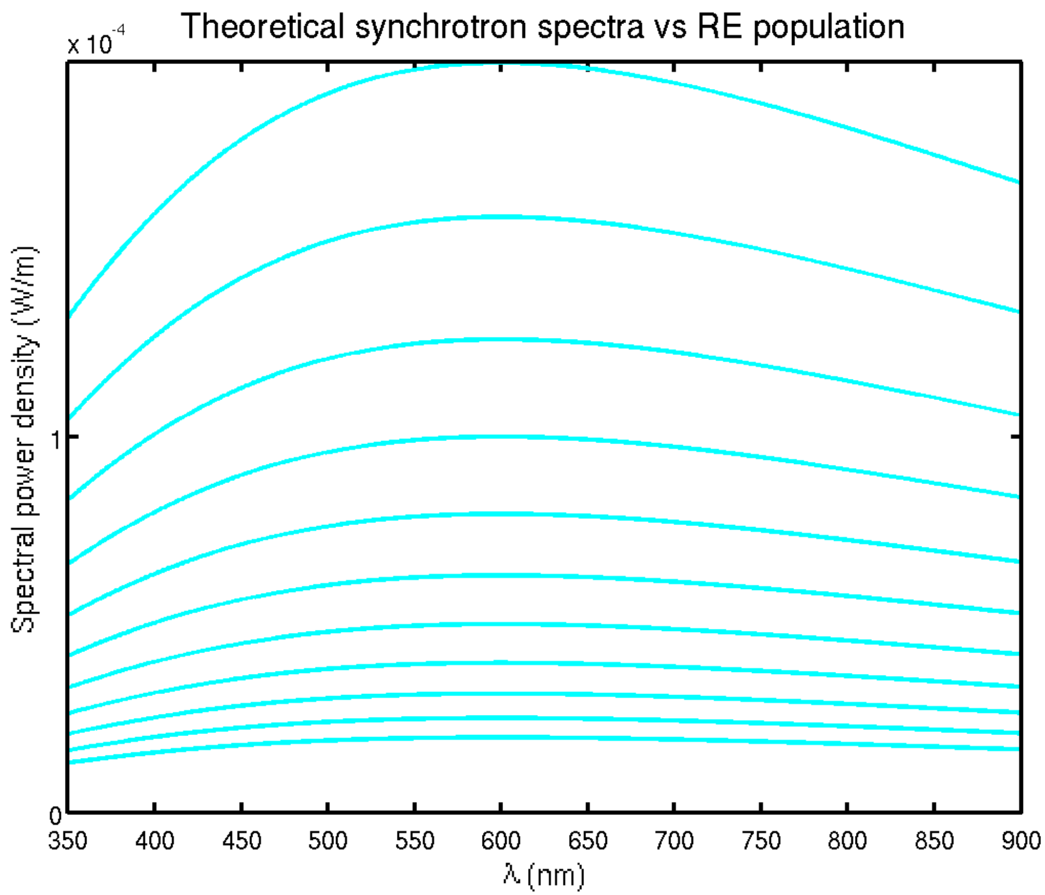
1) Increase in each runaway electron's energy, with the runaway population remaining constant
2) Increase in the runaway electron population, with the energy of each runaway electron remaining constant. In this case, we also need an energy loss mechanism to keep the RE energy constant in the presence of finite loop voltage

Way #1: Increase in each electron's energy, while keeping population fixed



Synchrotron emitted power increases as RE energy increases, ***and*** the spectrum also shifts towards shorter wavelengths

Way #2: Increase in RE population, while keeping each RE's energy fixed



Synchrotron emitted power increases, but spectral shape remains self-similar

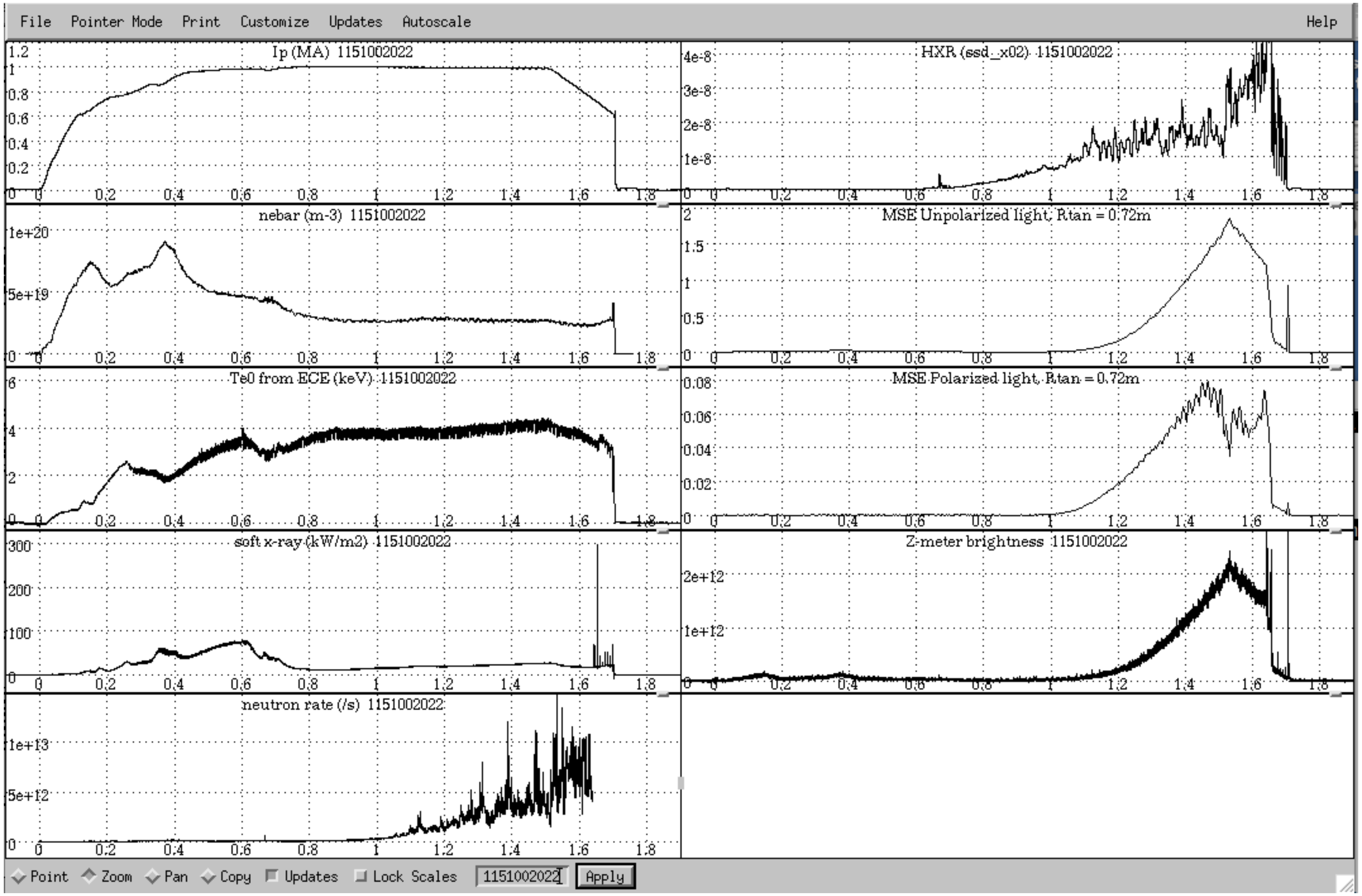
So what do we see in Alcator C-Mod?

Steady-state RE discharge

Ip (MA)

n_e (m^{-3})

T_e (keV)



HXR

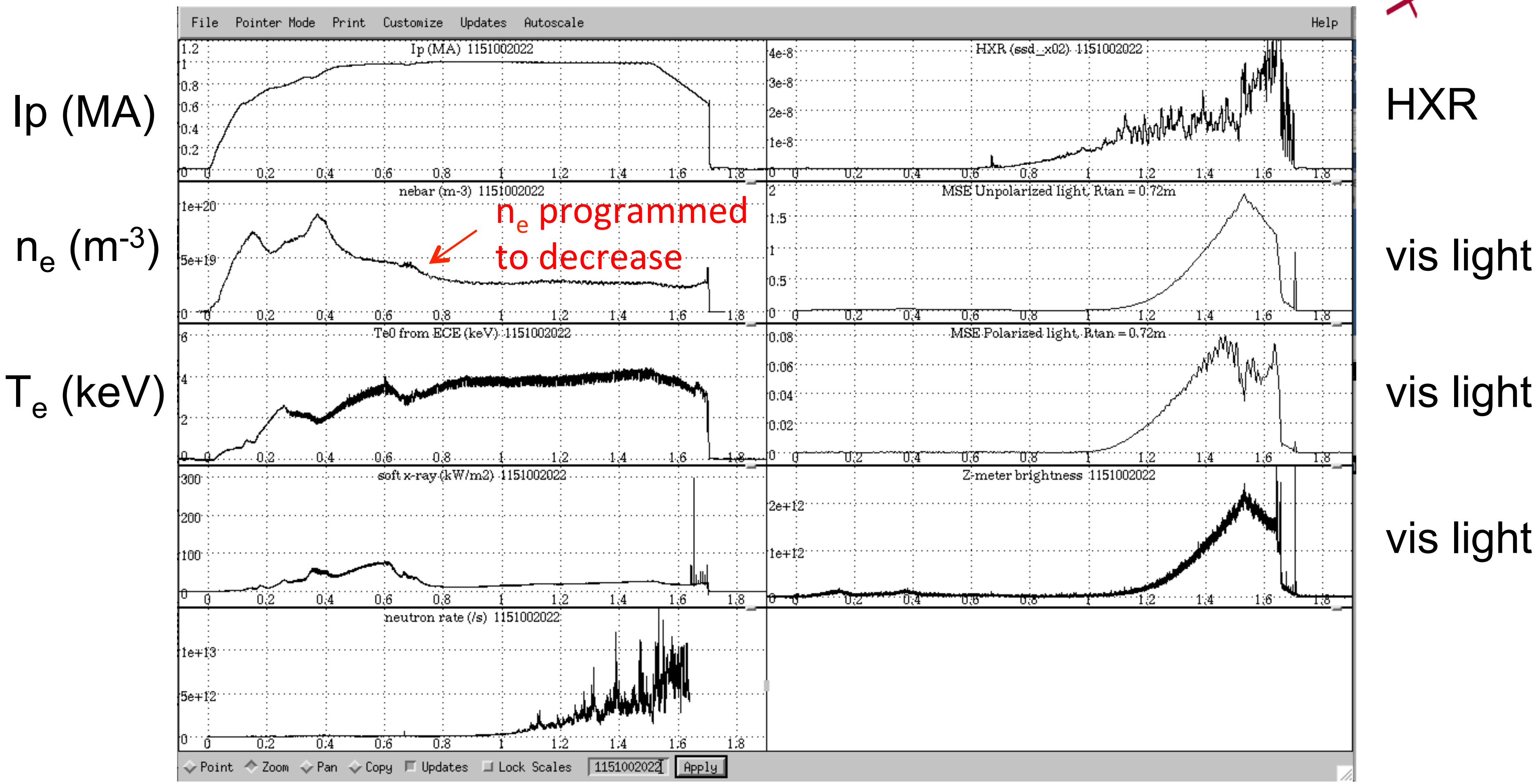
vis light

vis light

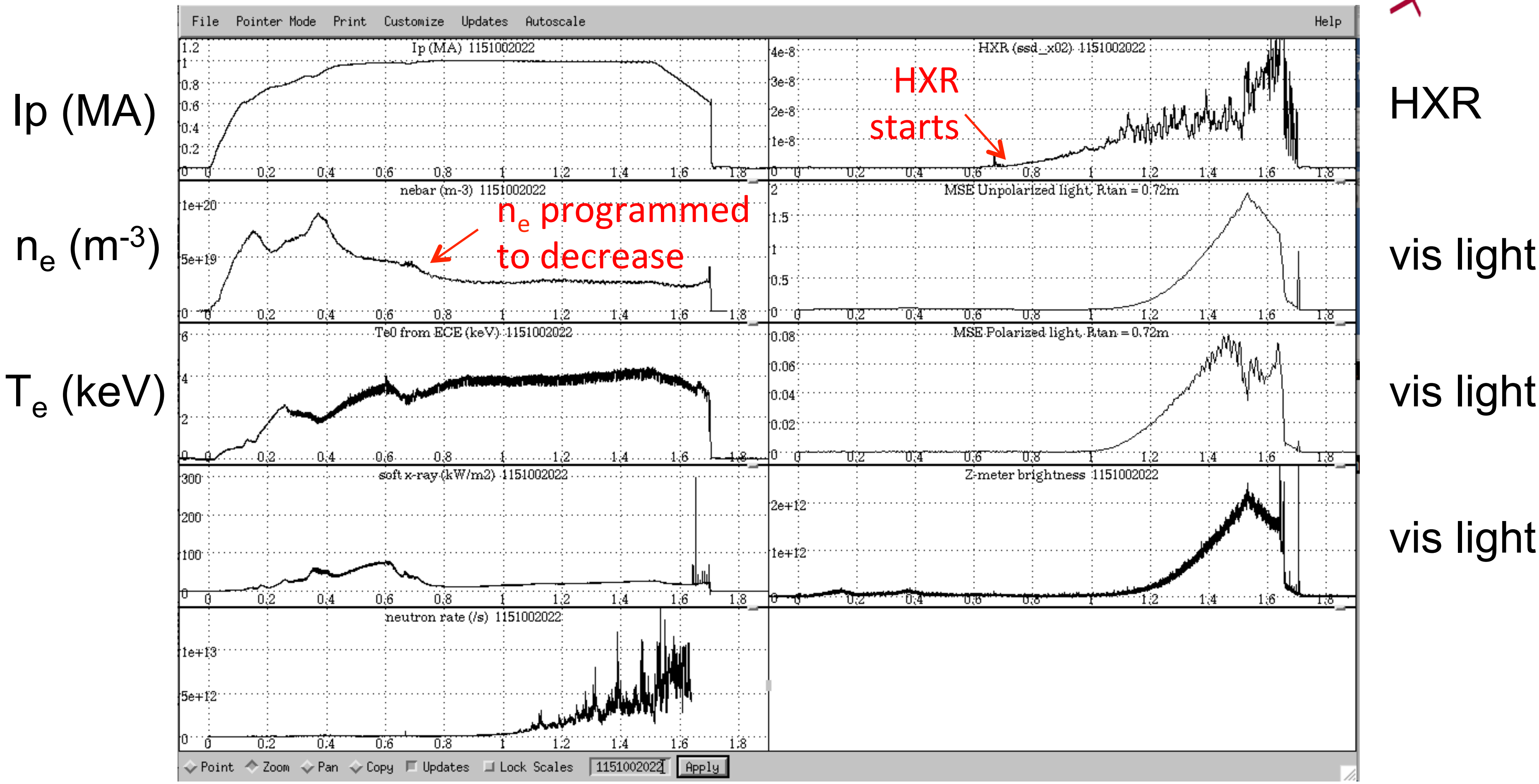
vis light

Steady-state RE discharge

Alcator C-Mod

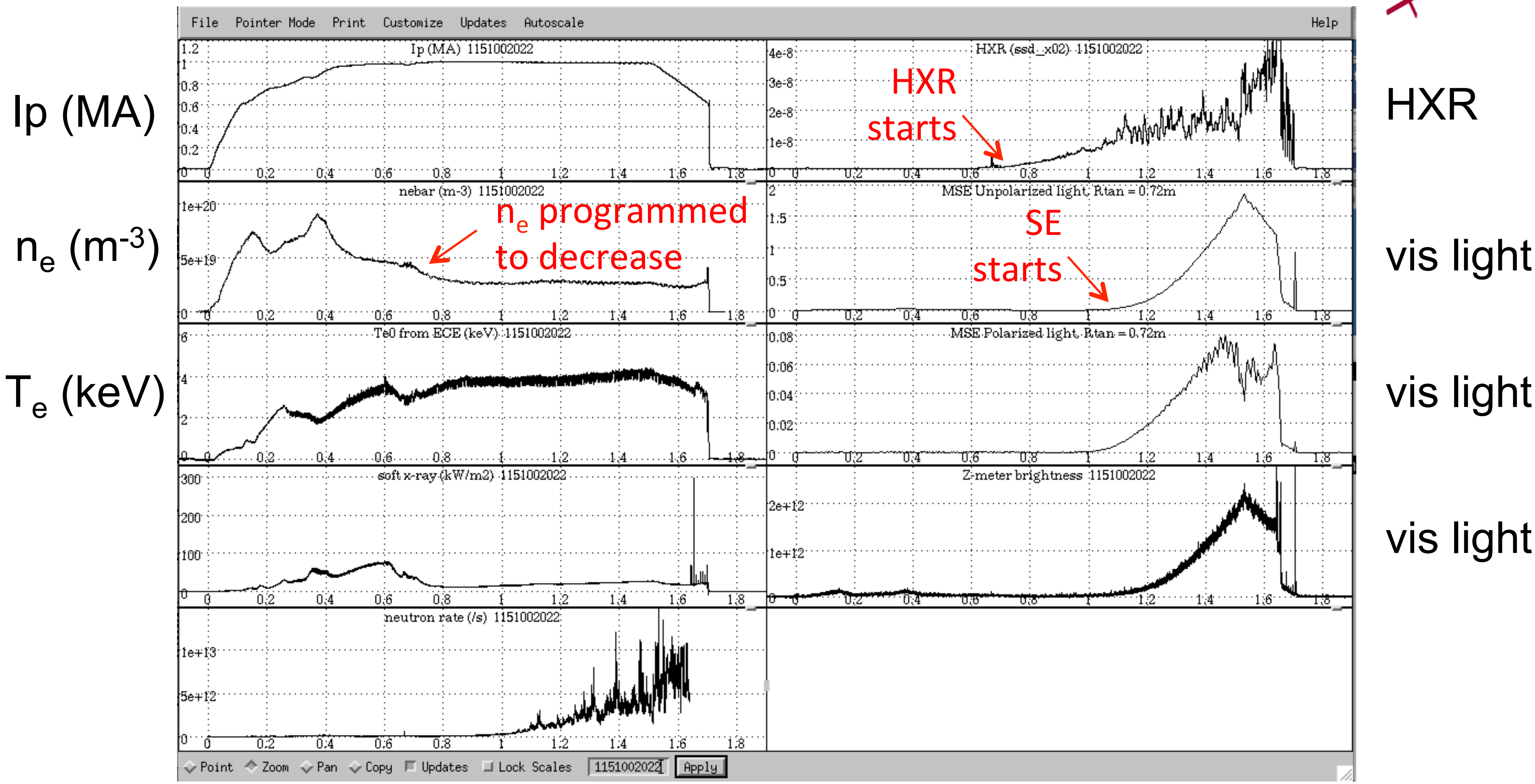


Steady-state RE discharge



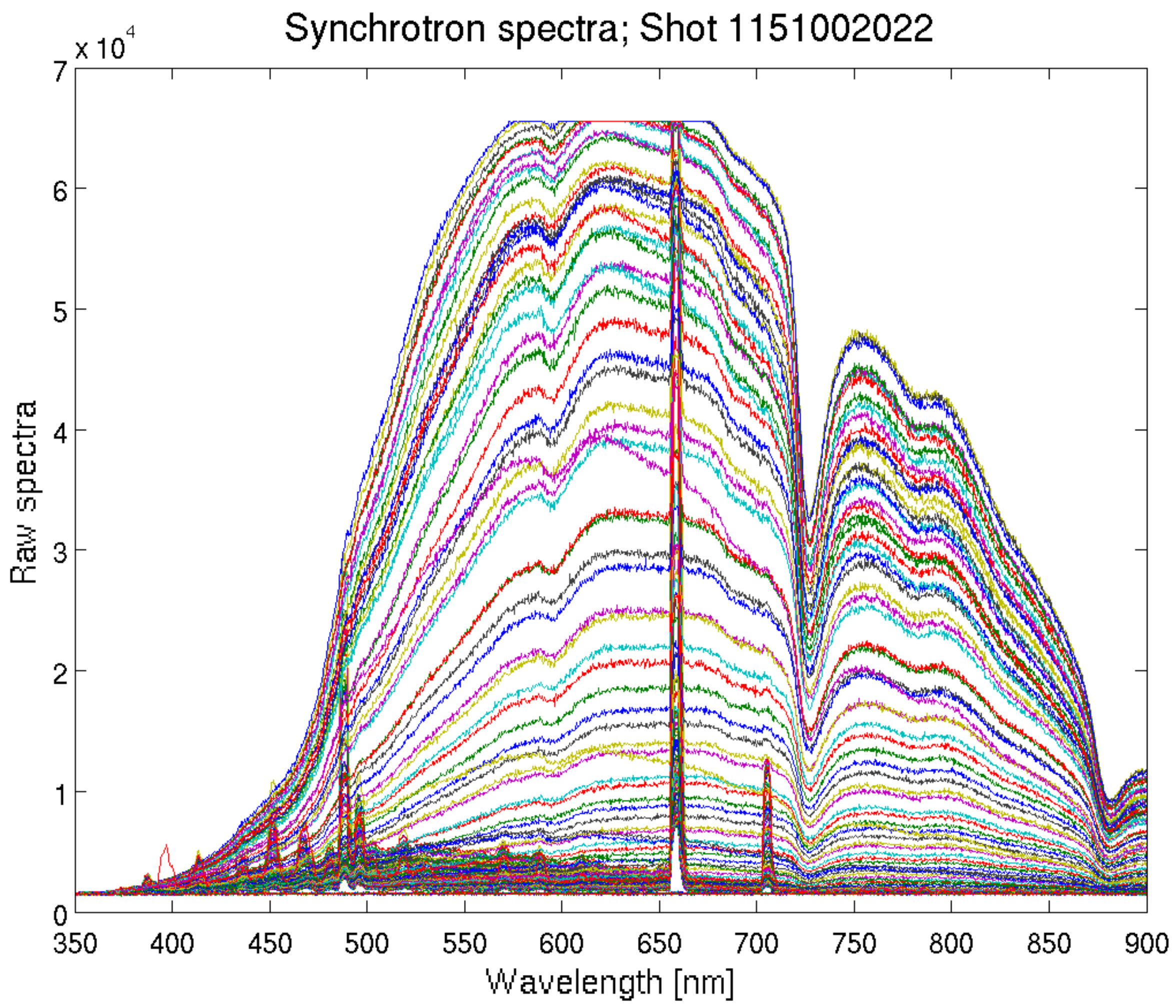
Steady-state RE discharge

Alcator C-Mod



HXR (100's of keV) starts before SE (10's of MeV): implies max electron energy is increasing in time, at least until SE emission starts

SE spectra grow a lot in amplitude, but remain approximately self-similar



NOTE: uncalibrated spectra are shown (not corrected for detector sensitivity or fibreoptic absorption bands)

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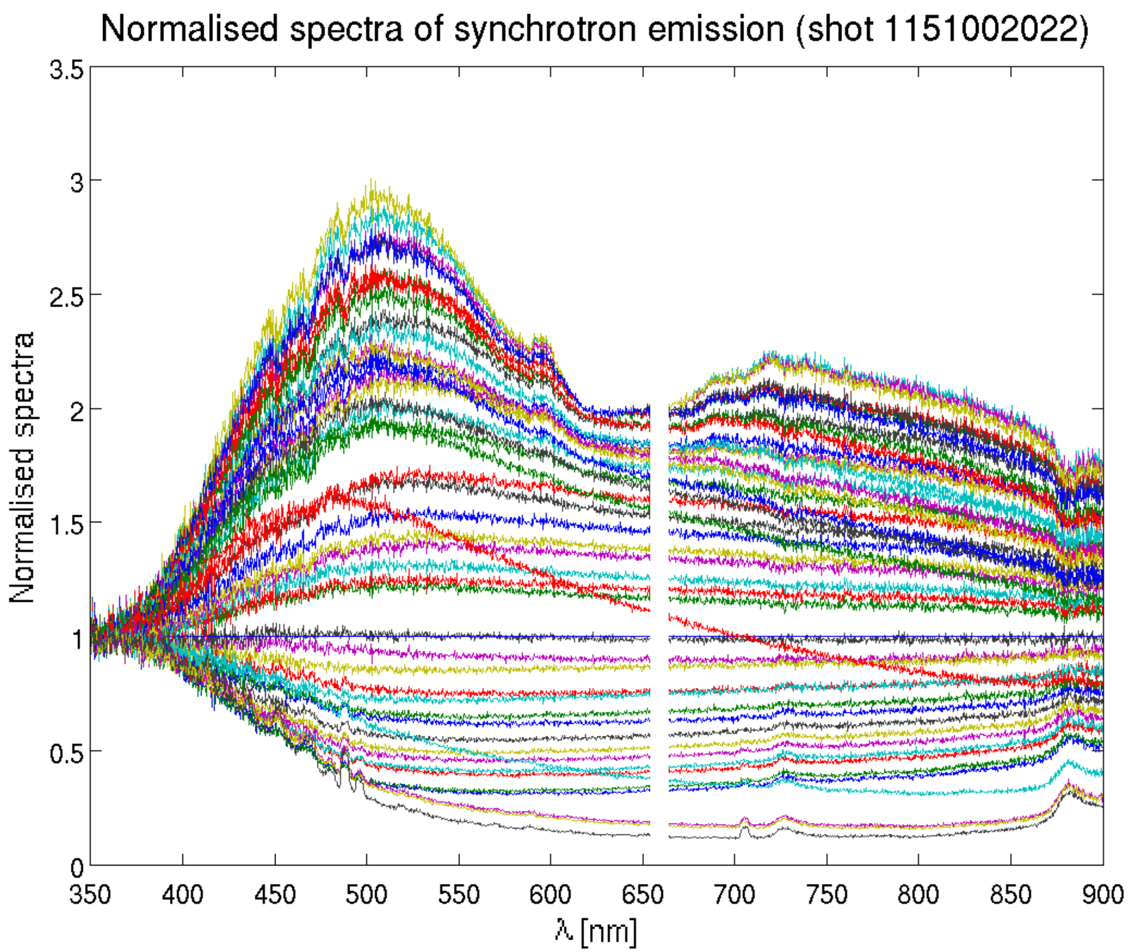
Alcator C-Mod



Normalised SE spectra from t=1.2 to 1.7 s. The spectral shape does not vary much as the amplitude grows significantly

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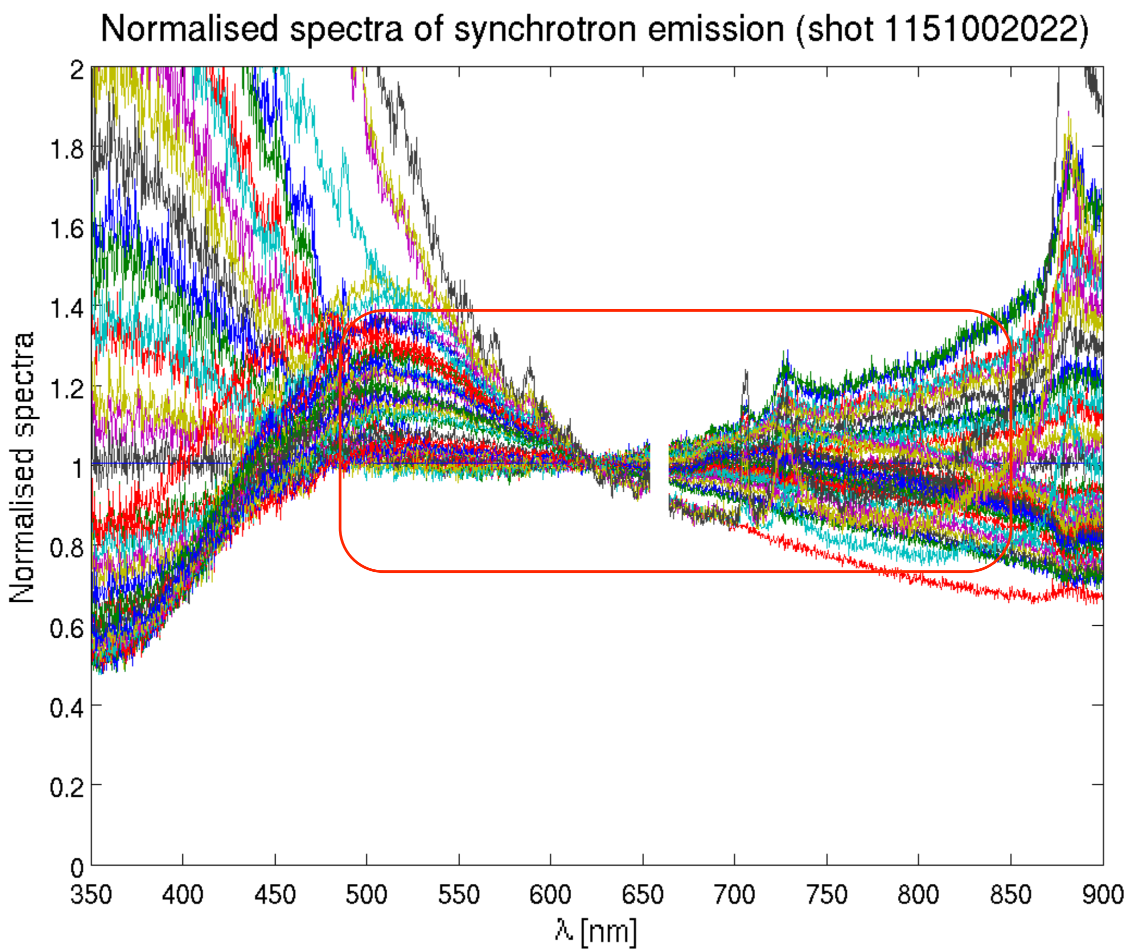

Normalised SE spectra from t=1.2 to 1.7 s. The spectral shape does not vary much as the amplitude grows significantly

Summary

- The HXR clearly starts increasing first, followed by the SE
  - This implies that the maximum electron energy is increasing, at least until the synchrotron emission starts
- But once the SE becomes significant, the SE spectra remain approximately self-similar, even though the SE amplitude increases dramatically.
  - Does this mean that the RE population is growing, but the maximum RE energy is not increasing much?
  - If true, is the SE power loss responsible for limiting the maximum RE energy?