1. Purpose of Experiments

The primary goal is to monitor the evolution of relativistic runaway electrons (REs) at various magnetic field strengths. The RE forward-peaking synchrotron spectrum, intensity, and polarization, as well as the RE density and current will be measured. The effects of different magnetic fields and ramping up/down these fields will be investigated. A secondary goal is to compare the synchrotron emission data to current theoretical models, which predict the maximum energy of the RE distribution. Finally, the HXR camera will be used to measure the RE current, which has not yet been done for runaway beams in C-Mod.
2. **Background**

Discuss Physics Basis of the proposed research. Prior results at Alcator or elsewhere, and any related work being carried out separately.

In a plasma, if the electric force on a particle overcomes its collisional friction (which decreases as velocity increases), that particle will “runaway” to relativistic speeds. Typically these are runaway electrons, which can have energies up to tens of MeV and carry up to 60% of the plasma current [1]. REs emit forward-peaking synchrotron radiation, which acts as a power loss mechanism and can limit the maximum RE energy. As seen in Figures 1 and 2, higher magnetic fields lead to more synchrotron radiation and power lost by the particle. Thus, if synchrotron emission were the dominant power loss mechanism limiting the maximum RE energy, we would expect that increasing the magnetic field would decrease the RE density. However, recent experiments on DIII-D [2] have shown that decreasing the magnetic field leads to a greater decrease in HXR signal, a sign of decrease in the RE population. So far, C-Mod has only synchrotron data at 5.4T, but has the ability to run a similar experiment.

![Figure 1](image.png)

*Figure 1. The synchrotron spectral power density [W/m] of an electron with an energy of 40MeV and pitch (v_perpendicular/v_parallel) of 0.1 is plotted over the wavelength range of our visible spectrometers for three different magnetic fields (2.7, 5.4, and 8.0 T). The spectral power density increases and peak wavelength decreases with increasing field strength.*
Recent theoretical studies [3-5] have predicted that REs will accelerate to a maximum energy at which the synchrotron radiation reaction and collisional friction will balance the electric force, forming a “bump” on the tail of the energy distribution function. The synchrotron spectrum would then be dominated by the high-energy bump. Other studies [6-7] have suggested that a broader distribution contributes to the spectra. Previous synchrotron data gathered on C-Mod [8] has not been able to distinguish the two cases. However, higher magnetic fields shift the spectral power density peak toward shorter wavelengths (as seen in Fig. 1) and could allow the visible spectrometers to more easily identify the correct energy distribution.

In addition, this recent RE work on C-Mod [8] fit the synchrotron brightness to theoretical models and calculated the RE current to be as low as ~100A of the 1MA plasma current. The HXR camera can allow us to confirm or reject this measurement.

3. **Approach**
Describe the methodology to be employed; explain the rationale for the choice of parameters, etc. Describe the analysis techniques to be employed in interpreting the data, if applicable. If the approach is standard or otherwise self-evident, this section may be absorbed into the Experimental Plan.

The approach first consists of attaining runaway electrons during the quiescent flattop current in forward-field (LSN), where there are fewer issues with the error field coils and locked modes. The density will be reduced at the start of the flattop to $\langle n_e \rangle = 0.25 - 0.5 \times 10^{20} \text{ m}^{-3}$, where REs were seen in the 2015 campaign. Several shots will be taken at different magnetic field strengths (2.7T, 5.4T, 8.0T), which last for the entire flattop. In addition, other shots will involve ramping up/down to different magnetic fields during the shot.

For this run, two visible spectrometers will be used to measure the synchrotron emission. Multiple views are available to us, including those on INV_PLTFRM. The HXR camera, MSE, and Thomson scattering diagnostics will be used to measure the runaway current and z profile, synchrotron polarization, and temperature, respectively, to help diagnose RE evolution.

4. **Resources**

4.1 Machine and Plasma Parameters

Give values or range for:

- **Toroidal Field:** 2.7T, 5.4T, 8.0T
- **Plasma Current:** 1.0MA (forward-field preferred)
- **Working Gas Species:** Deuterium
- **Density:** $\langle n_e \rangle = 0.25 - 0.5 \times 10^{20} \text{ m}^{-3}$
- **Boronization Requested (if yes, specify whether overnight or between-shot, how recently needed, and any special conditions.):** No
- **Equilibrium configuration (if possible, refer to database equilibria):** LSN, 1160421016

4.2 Auxiliary Systems
ICRF Power, pulse length, phasing: none
LHCD Power, pulse length, phasing: none
Pellet Injection (species): none
Impurity blow-off injection: none
Diagnostic Neutral Beam: no
Special gas puffing: no
Cryopump: yes, available if needed for low densities
Non-axisymmetric Coils (Connections, Current): standard m=2/n=1 feedback mode to prevent locked modes at low densities
Other:

4.3 Diagnostics
List required diagnostics, and any special setup or configuration, e.g. non-standard digitization rate.

Ocean Optics spectrometers for visible synchrotron emission
Thomson scattering for Te
MSE for synchrotron polarization
HXR camera
Z-meter

5. Experimental Plan
Both sections must be filled in.

5.1 Run sequence Plan
Specify total number of runs required, and any special requirements, such as consecutive days, no Monday runs, extended run period – 10 hours maximum – etc.
5.2 Shot sequence plan

For each run day, give detailed specification for proposed shot sequence: number of shots at each condition, specific parameters and auxiliary systems requirements, etc. Include contingency plans, if appropriate.

10 shots for discharge setup – i.e. Reproducible initiation of REs between t=0.5-0.6s by slow decay of density (at 5.4T, 1.0MA)

3-4 different magnetic field strengths constant for entire flattop (2.7T, 5.4T, 8.0T)
2 shots at each level= 6-8 shots

2-3 different ways to ramp up/down magnetic fields (e.g. 5.4T → 2.7T, 5.4T → 8.0T)
2 shots for each case = 4-6 shots

6. Anticipated Results

Discuss possible experimental outcomes and implications. Indicate if the program may be expected to lead to publications, milestone completions, improved operating techniques, etc. Indicate if the experiments are intended to contribute to a joint research effort, an ITER request, or an external database.

At higher magnetic fields, we expect higher intensities of synchrotron radiation as well as a shift in the peak of the spectrum toward shorter wavelengths. From the DIII-D results, we also expect that decreasing the magnetic field during the flattop REs will lead to a decrease in the HXR signal and runaway density. It is unclear what RE current will be measured, but ~100A would match previous measurements as calculated from fits of our spectral data.

7. References

Include references both to external and internal literature or communications which bear on this proposal. See Section 2.