1. Purpose of Experiments

Include immediate goal of the experiments, scientific importance and/or programmatic relevance. Refer to any relevant program milestones.

1) To study the use of $B_{tor}$ sweeps to measure the electron temperature gradient scale length. Preliminary work has shown that we now need repeated ‘identical’ shots to determine how reliable this technique is. A single sweep appears capable of providing a very well defined temperature gradient scale length, but shot to shot variation - or variation among multiple sweeps in a single shot - has not yet been quantified.

2) To determine whether the temperature gradient scale length is affected by varying $q$ or collisionality. The experimental results will guide theoretical simulations with GS2 and GYRO, which will lead to a focused experimental proposal designed to test specific theoretical predictions.

2. Background

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

The temperature gradient scale length in C-Mod plasmas is expected to be near the effective critical temperature gradient scale length for microturbulence, so it is of great interest to compare accurate measurements of the temperature gradient scale length to microturbulence simulations to test the underlying theory. The ion temperature gradient is thought to be more important than the electron temperature gradient, so we want to run with sufficiently high density to closely couple the two temperatures (but not so high that we risk encountering radiative collapse or disruption).

Although microturbulence simulations for ohmically heated C-Mod plasmas have not yet been carried out, simulations of a number of tokamaks suggest that several plasma parameters play an important role in determining the effective critical temperature gradient scale length for microturbulence. Varying $q(r)$, and varying the density (which will vary
collisionality, and possibly Ti/Te) can be expected to change the effective critical temperature gradient scale length. The range of variation in $R/L_T$ is likely to be 1 to 2 (away from a typical value of 6-7), so the fractional change in $L_T$ is modest and an accurate measurement of the temperature gradient scale length is essential.

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.

Sweeping $B_{tor}$ moves the location of the radiating layer seen by each ECE channel, and this allows a measurement of the temperature gradient scale length which is not affected by uncertainties in either the absolute calibration or the channel to channel relative calibration. Preliminary analysis of a few shots indicates that, for $r>a/2$, it is possible to obtain a very well defined slope of $T_e$ vs. R in spite of heat pulse noise caused by sawteeth. This is particularly true if the sawtooth period is significantly longer than the duration of a heat pulse; in this case it is possible to select and ignore the heat pulses. The largest question about the usability of this approach concerns the shot to shot variability.

An example of the current status of this analysis is in Fig. 1. The first plot shows the BTOR signal, and the same signal after smoothing to remove the digitization bit noise. The next figure shows the location in major radius of four GPC channels. The second page shows $T_e$ vs. R; the red is the first sweep, and the green is the return sweep. The least squares best fit straight lines are quite similar, (except for the innemost channel, which has been affected by the near absence of heat pulses at the beginning of the first sweep).

For an eventual theoretical comparison it will be desirable to have CHERS/CXRS measurements of $T_i$ and MSE measurements of $q$. It is highly desirable to have these diagnostics take data during these initial exploratory experiments, but if this is not possible the experiment is worthwhile without them.

4. Resources

4.1 Machine and Plasma Parameters

Give values or range for:

- Toroidal Field: 5.4 – 5.6 T
- Plasma Current: 0.5 – 1.5 MA
- Working gas species: D
- Density: $n_e = 1 - 2 \times 10^{20}$
- Equilibrium configuration (if possible, refer to database equilibria): Diverted, single null.
- Pulse length, typical current & density waveforms, etc. Refer to database or sketch desired waveforms.
Figure 1
See attached ‘cartoons’ of $I_p$ and $B_{tor}$ waveforms. Standard ohmic waveforms should be modified to achieve 1.8 second flat top on $I_p$, and $B_{tor}$ should be approximately flat until Ip ramp-down commences. Density should be held steady through the $I_p$ flat-top phase.

The first shot at each $I_p$ will have completely steady $B_{tor}$ (no sweeps) to establish that the discharge can achieve achieve a more or less steady state by the time the sweeps begin in subsequent shots.

Subsequent shots include repeated sweeps of $B_{tor}$ from 5.4 T to 5.6 T and back. The issue of whether the equilibrium temperatures have sufficient $B_{tor}$ dependence to taint the measurement of $L_T$ will be addressed by including a pause at the higher field and by varying the $B_{tor}$ ramp rate to change the degree to which the temperatures are in quasi equilibrium with the instantaneous value of $B_{tor}$. The ramp-up times should vary from 50 to 100 msec. It is desirable to have the ramp-down times be not much longer than the ramp-up time, but it may not be possible to ramp down by 0.2 T in 50 msec. This issue will be explored by Jim Irby in the near future.

4.2 Auxiliary Systems

- **RF Power, pulse length, phasing**: None
- **Pellet Injection (species)**: None
- **Impurity blow-off injection**: None
- **Diagnostic Neutral Beam**: Yes
- **Special gas puffing**: None
- **Other**:

4.3 Diagnostics

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

Required diagnostics are GPC, FRC ECE, TCI, the VB array, and magnetics; it is highly desirable to also have GPC2, core TS, MSE, CHERS/CXRS, BES.

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.

One run day is needed to obtain as much of the sequence as possible. Analysis of the results should be completed before more run days are scheduled.
### 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.

1 shot at $I_p=1$ MA, with $\bar{n}_e = 2 \times 10^{20}$, and steady $B_{tor} = 5.4$ T. If necessary, adjust the control waveforms and repeat to achieve a steady phase by $\sim 0.5$ seconds into the flat top. Then take 3 shots with the $B_{tor}$ sweeps and the pause added (see attached waveforms).

Lower $I_p$ to 0.5 MA, and repeat the above cycle of four shots.

Raise $I_p$ to 1.5 MA (or approach 1.5 MA), and repeat the cycle of four shots.

Back to $I_p=1$ MA, and lower $\bar{n}_e = 1 \times 10^{20}$ (all throughout the flat top phase). Repeat the cycle of four shots.

Lower $I_p$ to 0.5 MA, $\bar{n}_e = 6 \times 10^{19}$, and repeat the above cycle of four shots.

Raise $I_p$ to 1.5 MA, $\bar{n}_e = 6 \times 10^{19}$, and repeat the cycle of four 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, or an external database.

This work should establish whether the $B_{tor}$ sweep technique leads to a reliable measurement of $L_T$ and, if not, what problems need to be overcome. If successful, it will also provide some information on the $q$ and collisionality dependence of $L_T$. It is expected that this would motivate further experiments, and the results would guide GS2 and GYRO simulations that, in turn, can motivate a targeted experimental proposal that would be optimized for testing the theory. It will take several months to do the simulations that would guide the experimental plan, so they should be based on real discharges.

### 7. References

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