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

Lower Hybrid Current Drive (LHCD) is proposed to drive current non-inductively in future fusion devices. This experiment is designed to obtain high resolution (time and space) measurements of the current profile in high power LHCD discharges with a significant non-inductive current. These experiments continue previous work toward validating LH models using C-Mod plasmas, this time with improved Motional Stark Effect (MSE) and Diagnostic Neutral Beam (DNB) systems and the new LH launcher (LH2). The current density profile will be measured as LH power is increased and as the LHCD phase is changed and as the density is raised to approach the Lower Hybrid density limit.

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

LHCD has been demonstrated on C-Mod to significantly modify the current profile, creating reverse shear and fully non-inductive scenarios [1]. The profile of this driven current depends on various parameters including the spectrum of the launched LH waves. Recent work has demonstrated that the current drive efficiency drops precipitously with increasing density [2]. Work was done in FY08 to measure the driven current profile using the MSE system on C-Mod [3]. The results of this work indicated that current was driven off axis, consistent with LHCD models but consisted of only a small scan in parameters.

We propose to revisit this topic with an improved diagnostic set to document the current profile in strongly driven LHCD discharges. The MSE system has been improved with
an inter-shot calibration system to allow calibration between discharges, a change in views and additional diagnostic verification. The DNB system is capable of more pulses and higher performance. C-Mod has a new Lyman alpha array to diagnose edge recombination and new probes to monitor LH waves. The LHCD launcher has been replaced with an upgraded coupler. Additionally, extensive experiments show a precipitous drop off in current drive with density and a moderate recovery when the discharge is limited, a regime that has not been previously measured with MSE.

Measuring the current profile as the LH power is increased and the launched spectrum is changed can be used to verify LHCD modeling. We plan to determine if the current profile changes as the density is raised and current drive decreases as well as when the plasma is limited. These experiments have not been performed on C-Mod or elsewhere and rely on C-Mod’s unique LH system.

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.

See Experimental Plan.

4. Resources

4.1 Machine and Plasma Parameters

Give values or range for:

Toroidal Field: 5.4T
Plasma Current: 500kA nominal, can vary to avoid MHD
Working Gas Species: D
Density: line averaged 0.5-1.5x10^{20} m^{-3}
LHCD after Boronization Requested: No, can be run prior to boronization, especially if degradation to LHCD after Boronization is likely.
Equilibrium configuration (if possible, refer to database equilibria): 1120601025 unless noted.

4.2 Auxiliary Systems

ICRF Power, pulse length, phasing: No
LHCD Power, pulse length, phasing: Essential, 0.5-0.75s at various phasings, conditioned to provide up to 900kW
Pellet Injection (species): NA
Impurity blow-off injection: none
Diagnostic Neutral Beam: Essential. 48-50keV, 6.5A, high-reliability
Special gas puffing: none
Cryopump: not required
Non-axisymmetric Coils (Connections, Current): no
Other: None

4.3 Diagnostics
List required diagnostics, and any special setup or configuration, e.g. non-standard digitization rate.
MSE – Essential, setup for Pi lines at 5.4T, 50keV w/ ISC system
ECE – desirable setup to look at non-thermals,
Hard X-ray camera – essential, shielding so that we can get the whole range of densities without saturation,
Polarimeter, can piggyback
Lyman Alpha array, desirable
Thomson, essential
HiReX-Sr (will allow Ar puffing and a locked mode shot), desirable
Reflectometer (at C OR H port), desirable
Xtomo arrays, essential
TCI, essential
LH and divertor probes (Seung Gyou Baek piggyback with frequency analyzer)
no gas puffing due to density control issues.

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.
1 run day should be sufficient. The run will be done in 3 parts, a power scan, followed by a LH phase scan and finally a density scan with two limited discharges. We will do a plasma sweep MSE calibration shot at the beginning and end of the day to check the offset in the MSE polarization angle against the results from the Inter-shot calibration system.

The discharges will have a large current drive fraction to create large changes in the current profile. The density and current are chosen to be low to maximize the current drive fraction.

Each discharge will have an Ohmic flattop of 200+ms before LH turn on to allow Intra-shot calibration of MSE in addition to the Inter-shot technique. LH will start at 0.7s and extend to 1.4s. We will extend the flattop to 1.7s on a few of the discharges to monitor the relaxation of the current profile to the Ohmic profile.

DNB timing with 75ms on, 25ms off starting at 0.3s, giving 4 pulses prior to LH turn on allowing the beam current to come up and MSE to obtain an Ohmic reference, no beam overlap with LH turn on. 12 pulses requested (14 for the flattop extension discharges). Beam should be conditioned up for the first shot of the day.

Prior to moving onto the next condition we will check the MSE signal integrity for pitch angle profiles and background issues. It is unlikely we will have between shot MSE-EFIT reconstructions until late in the campaign to guide work during the runday.

During the LH power scan we will watch for MHD activity detrimental to LHCD and change parameters (in order of relevance, Ip, density, LH phasing) if necessary to avoid
onset. If this is unavoidable it may be necessary to transition to another MP until a better understanding of the MHD onset is gained.

**Part a) LH Power scan at fixed LH phase and density (6 shots):**
The goal is to document the current profile modification due as the LH power is increased, hopefully until the discharge is non-inductive. This scan is done first as part of bringing LH power up for the day. Target line-averaged density is 0.5-0.6x10^{20}m^{-3}, LH phase at 75deg, 500kA. We will do new power steps from Ohmic to 1MW (if possible) by steps of 200kW with one shot at 900kW. We will extend the pulse length to 0.7-1.4s LH, with a 0-1.7s flat top.

**Part b) LH phase scan at fixed LH power and density (4 shots):**
Using maximum reliable LH power as determined in part (a) at the part (a) density and current. Vary LH phasing for 60deg, 90deg, 105deg. (not necessary to repeat the phasing done in part (a)). Do one quasi-continuous phase scan from 60deg to 105deg within a single LH pulse with pulse length extension (0.7-1.4s LH, 0-1.7s flat top). This is exploratory work towards demonstrating the effect of using LH phasing for plasma control.

**Part c) Shot to shot density scan at fixed LH power and phase (8 shots):**
Using maximum reliable LH power and LH phase from part (a) we will raise the density shot to shot. Target line-average densities of 0.5, 0.6, 0.7, 0.8, 1.0, 1.25, 1.5 x10^{20}m^{-3}. We may eliminate the highest density shot if there is no signs of current drive in the loop voltage or MSE pitch angles. Once at the high density we will take a limited discharge with an extended pulse length.

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.

1x MSE calibration plasma sweep. Ref shot 1120516020

a: LH power scan at fixed density and LH phase:
   1x 200kW
   1x 400kW
   1x 600kW
   1x 800kW w/ extended LH pulse length/flattop
   1x 900kW
   1x 1000kW (if LH group thinks success likely)

1x Locked mode HiReXSr. Ref shot: use recent successful LM

b: LH phase scan at fixed density and LH power:
   1x 60deg
   1x 75deg (or 90deg which ever not done in part a)
   1x 105deg

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1x semi-continuous phase scan w/ extended LH pulse length/flattop

c1: Shot to shot density scan at fixed LH power and LH phase
1x 0.6 x10^{20} m^{-3} line average
1x 0.7 x10^{20} m^{-3}
1x 0.8 x10^{20} m^{-3}
1x 1.0 x10^{20} m^{-3}
1x 1.25 x10^{20} m^{-3}
1x 1.5 x10^{20} m^{-3}

c2: 1x Limited discharge. Ref shot 1100820003
1x MSE calibration plasma sweep
1x Ohmic if there hasn’t been one during the day
1x Locked mode if there is time

21 discharges total

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.

This experiment will be part of Bob Mumgaard’s thesis work. Some of the discharges will be used to compare to modeling. The results will be incorporated into a paper for publication.

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