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

The goal of this mini-proposal is to demonstrate that the lower hybrid current drive (LHCD) is possible in the single pass absorption regime at densities exceeding the experimentally observed density limit on Alcator C-Mod. LHCD in a single pass absorption regime is expected in high temperature (6-10keV) plasmas and this is what was planned for Alcator C-Mod AT scenarios [1]. This regime is also what is expected for ITER LHCD. Demonstrating current drive in such a regime is of crucial importance for the C-Mod program and for the future of ITER LHCD. In addition, this mini-proposal will help clarify if at high density, LH waves penetrate beyond the separatrix or they are completely trapped in the SOL region.

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

The role of LHCD on Alcator C-Mod is to provide the current profile modification necessary to access so-called Advanced Tokamak (AT) regime [1]. In this regime, more than a half of the plasma current is expected to be driven by bootstrap current. The remaining portion is driven by LHCD, which is also used to maintain shear reversal in the q-profile. Figure 1, cited from Ref [1], shows ray trajectories in such a moderately high density (\( <n> = 1 \times 10^{20} \text{ m}^{-3} \)) high temperature (\( T_{e0} = 6\text{keV} \)) plasma. Under these conditions the waves are expected to be absorbed through the first pass from the launcher to the core (i.e., single pass absorption).
Recently, difficulties in achieving this goal were encountered because of the density limit threshold, which on C-Mod was observed to be lower than expected. However, it is important to keep in mind that the density scan experiments in MP 551 used Ohmic target plasmas and the electron temperature was from 1 to 3 keV and the wave absorption is in the multipass regime.

In a single pass absorption regime, once the LH wave passes through the SOL in front of the launcher, it propagates to the core region, where it can be absorbed via ELD. On the other hand, in multipass regime, the wave passes through the low temperature SOL region several times before acquiring an up-shifting in parallel wave number which is enough to allow the waves to be absorbed via ELD. The experimental observations of efficient core LHCD and strong hard x-ray emission in the multi-pass damping regime below $n_e(\text{bar}) \approx 1 \times 10^{20} \text{ m}^{-3}$ raises the possibility that as the density is raised, wave propagation in the SOL is altered in such a way that multiple reflections from edge cutoffs cannot be relied upon to achieve eventual core wave absorption. PTB added this statement but it could be removed.

Figure 1: Ray trajectories and current and safety factor profiles of an Alcator C-Mod AT scenario.
MP612 was intended to address this issue by using a hot I-mode plasma as a target. However, due to low $N_{//}$ used in this experiment, the wave absorption was still in the multipass regime, although an improvement of LHCD was suggested by GENRAY/CQL3D simulations (Fig 2). Experimentally, the high background signal due to the neutron radiation makes the HXR diagnostic analysis very difficult, and despite the fact that we observed a significant increase in the HXR count rate and the non-thermal emission, it is difficult to derive a clear conclusion to the question whether the density limit was solved or not.

A key question is whether the LH waves can penetrate beyond the separatrix or whether they are completely trapped in the SOL region as the density limit is approached. Both ray-tracing with a SOL (see Fig. 13 in Ref.2) and full wave simulations suggest that most of rays (or wave power) pass through the core plasma instead of being completely trapped in the SOL region. Recent observation of enhanced HXR emission in limited discharges seem to support this is the case. However there has been thus far no direct experimental confirmation that the LH waves passed through the separatrix even once. Based on these considerations, we propose a LHCD experiment whereby high electron temperature was achieved. 8T mode conversion (MC) heated plasmas, demonstrated in 1100210 run, was such an example. According to an exercise using raytracing+FP code, the wave absorption became to enter a single pass absorption regime when $N_{//} \sim 3.1$, $T_e \sim 6\text{keV}$, and $n_e(\text{bar}) = 1 \times 10^{20} \text{ m}^{-3}$.

![Fig 2: GENRAY/CQL3D prediction of HXR emission count rate dependence on the density and temperature. GENRAY/CQL3D with SOL was used in the simulation and $T_{\text{edge}}$ was fixed to be $70\text{eV}$](image)

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.

We proposed to study LHCD in high density regime using high temperature He4 plasmas. In particular, we explore the possibility of LHCD improvement using a high $N_e$. Several previous plasmas can be chosen as a target: 1) 1100210012 (8T, 80MHz MC ICRF heated), 2) 1100910021: I-mode (900kA, 5.6T, USN, $T_{e0}$=6keV, and $n_{e0}$=0.8e19), and 3) 1091124035 and 1110317021 (50 MHz MH plasmas). These reference plasmas are all D2 plasmas, part of uncertainty is how plasma changes by using He4 as a main gas. Also, we are probably not able to use D antenna during LHCD phase. Once we established a target plasma, we apply LHCD using $N_i$/=1.9, 2.8, and 3.1.

4. Resources

4.1 Machine and Plasma Parameters

Give values or range for:

- Toroidal Field: 8 T (5.6T)
- Plasma Current: 1 MA (0.9MA)
- Working Gas Species: D2
- Density: $n_{e0}$ 0.7-0.8 e19/m2
- Boronization Requested (if yes, specify whether overnight or between-shot, how recently needed, and any special conditions.): Equilibrium configuration (if possible, refer to database equilibria): 1100201012 (1100910021)

4.2 Auxiliary Systems

- ICRF Power, pulse length, phasing: D/E/J-port (50/80 MHZ)
- LHCD Power, pulse length, phasing: 0.5-1MW, 90/120/150 deg.
- Pellet Injection (species): Impurity blow-off injection: No
- Diagnostic Neutral Beam: yes
- Special gas puffing: He4 ECDC (minimum 30min?) and working gas is He4
- Cryopump: yes
- Non-axisymmetric Coils (Connections, Current):
- Other:

4.3 Diagnostics

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

- HXR camera, ECE diagnostics

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.
We request minimum a half day run.

#1-#3 Establish target plasma

#4-#5 Apply LHCD using 90 deg phasing for a reference.

#6-#16 Increase the N// to 2.8, 3.1 and 3.3.

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.

The main goal is to clarify if the LH wave can pass through the SOL at lease once and enter the core plasma region. Confirming this experimentally is very important for further planning AT scenarios for Alcator C-Mod. The results of this MP will also have an impact on the ITER LHCD program. At the same time, this run will provide important information towards the understanding of the low density limit threshold so far observed in the multi-pass regime.

7. **References**

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