ICRF IN THE WISCONSIN TOKAMAK AND TOKAPOLE II

(Presented at the 20th Annual Meeting, Division of Plasma Physics, American Physical Society.)

A.P. Biddle
J.C. Sprott

PLP 779

February 1979

Plasma Studies

University of Wisconsin

ABSTRACT

Heating in the Ion Cyclotron Range of Frequencies in the Wisconsin Tokamak and Tokapole II.* A.P. BIDDLE and J.C. SPROTT. U. of Wisconsin, Madison, Wisconsin. Studies of wave coupling at powers ≃ 250 watts in the Wisconsin Tokamak using insulated, unshielded, inductive antennae showed good coupling to low order eigenmodes, but with excessive parasitic loading. Low power, ≃ 100 watts, studies in Tokapole II, a toroidal octupole with major radius of 50 cm, 4 kG toroidal field and ohmic heating currents of 40 kA at densities ≃ 10^{13}, have shown coupling to eigenmodes with resistances ≃ one ohm. Use of the inductor as the launching device has resulted in frequency shifts ≃ 5% in the vicinity of strongly coupled modes, giving a limited passive tracking capability. A similar source at the 2 MW power level is being install for use at lower power levels with the interim antenna. Low poloidal magnetic flux is expected to result in a large loss cone however.

---

*This work is supported by U.S.D.O.E.

Preliminary fast wave propagation measurements were made in the final days of the Supported Octupole with the hoops removed, running as a tokamak. Advantage was taken of the old hoop support mounts to install 3/8" brass nodes with glass sleeves, spaced toroidally 120° from each other. Fig. 1 gives the basic installation. The basic experiment consisted of matching the antenna to the RF source by means of a wide band matching unit. Multiple shots were taken, with adjustments being made until the VSWR was at a minimum for the plasma at peak density. No attempt was made to match to the eigenmodes because of their short duration, and the small perturbation they presented to the general plasma loading. Rather, the modes were observed as increases in reflected powers, shown in Fig. 2a. Good correlation was found between the peaks in loading, and the increases in the received signal, Fig. 2b. Most loading was found to be the result of electrostatic loading of the plasma on the antennae. Fig. 2b just shows that the overall signal was attenuated over the vacuum case, with the eigenmodes standing out over the background level. The initial tests were done with antennae in the old outer supports. Because the tokamak relied on the thick conducting wall for stabilization, the plasma density was higher toward the outer wall. The eigenmodes were almost completely masked by the other plasma loading. The antennae were then moved to the inner hoop positions, and while the parasitic loading persisted, the slightly decreased density allowed the modes to be more clearly observed.

After Tokapole II was operational, measurements were made with first a small, ~ 200 watt oscillator, and then a larger 2 MW unit. Both were essentially as shown in Fig. 3. These units have the virtue of using the inductor as the launching device, allowing the oscillator to track changes in reactance, but at the loss of ability to match efficiently loads which differ significantly from the tube parameters. The high power unit produces a 1 ms pulse at 10.7 MHz, and has been operated at the 1 MW input level into an interim antenna. This antenna is a copper bar 5" × 1" × 1/8" which is completely external to the machine. As shown in Fig. 4, a part with a Macor inset is centered in the bottom of the machine. While allowing experimentation with different structures, such an antenna inherently links almost no wave flux, and so couples poorly into eigenmodes. This can be seen in Figs. 5a and 5b, where except for a region at 1.5 ms, all of the loading and depression of the resonant frequency can be attributed to parasitic loading. This is also reflected in Fig. 6, in which the parallel plasma loading roughly parallels the density fluctuations.

Sufficient coupling was achieved for both propagation and heating studies. For the former, a probe was constructed consisting of a stainless steel tube with a Macor tip enclosing a 4 turn coil, Fig. 7. This probe was used to map out the b_z (toroidal) magnetic field by slowly moving the probe across the plasma on a shot by shot basis. Fig. 7 shows the relative amplitude mapped out. This shows good agreement with Fig. 8, indicating we are seeing the $\nu = 2$, $n = 5$, where ν is the number of half wavelengths across the machine, and n the number of full wavelengths around the machine. The density profile used was a two-step one, in which all the plasma was assumed to be found within the boundary of the hoops, and none outside. This rather simple model nevertheless gives good agreement.

Ion heating in this machine is severely limited by the low amounts of poloidal flux. While the exact theory of the confinement is still being developed, rough calculations show that energies of no more than about 200 eV can be contained. Since heating at $\omega \approx \omega_{ci}$ is a finite gyro radius effect, we suffer from a shortage of high energy population to heat, while Z_{eff} is low, we still have significant impurities present. When RF is applied to the antenna for the first time after several shots without RF, large increases in some impurity radiation are noticed, which then slowly subside after several shots to a steady value. This possible source of enhanced ohmic heating should be kept in mind when considering Fig. 9. This shows an increase of T_i measured by Doppler broadening of He II 4687 Å lines, which occurs after the RF is applied at 1 msec. Though time resolution is poor, the delay of roughly .5 msec may indicate a process of impurities diffusing inward. The time for the plasma to drop to the ohmic value is in rough agreement with the calculated ion energy confinement time of 350 μsec.

Plans for increasing coupling include a new antenna structure, increasing the toroidal field, and heating minority species.

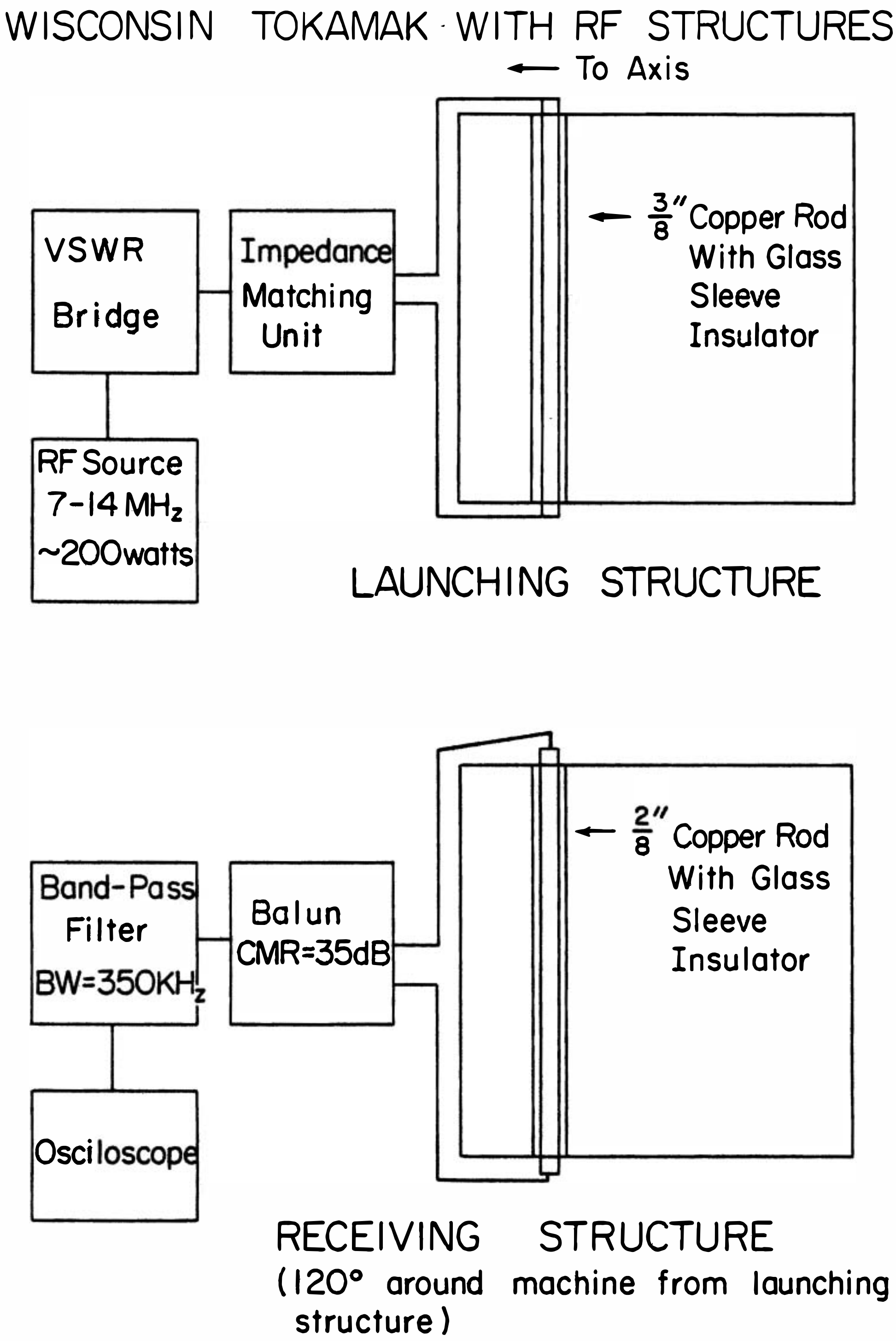
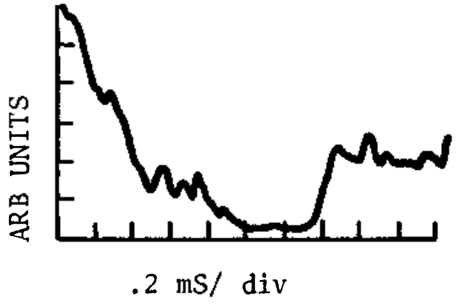

WISCONSIN TOKAMAK WITH RF STRUCTURES
← To Axis
VSWR Bridge
Impedance Matching Unit
RF Source 7-14 MHz ~200watts
← 3/8″ Copper Rod With Glass Sleeve Insulator
LAUNCHING STRUCTURE
Band-Pass Filter BW=350KHz
Balun CMR=35dB
Osciloscope
← 2/8″ Copper Rod With Glass Sleeve Insulator
RECEIVING STRUCTURE
(120° around machine from launching structure)

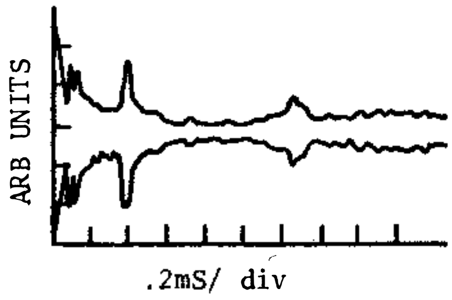
Figure 1

WAVE LOADING AND TRANSMISSION



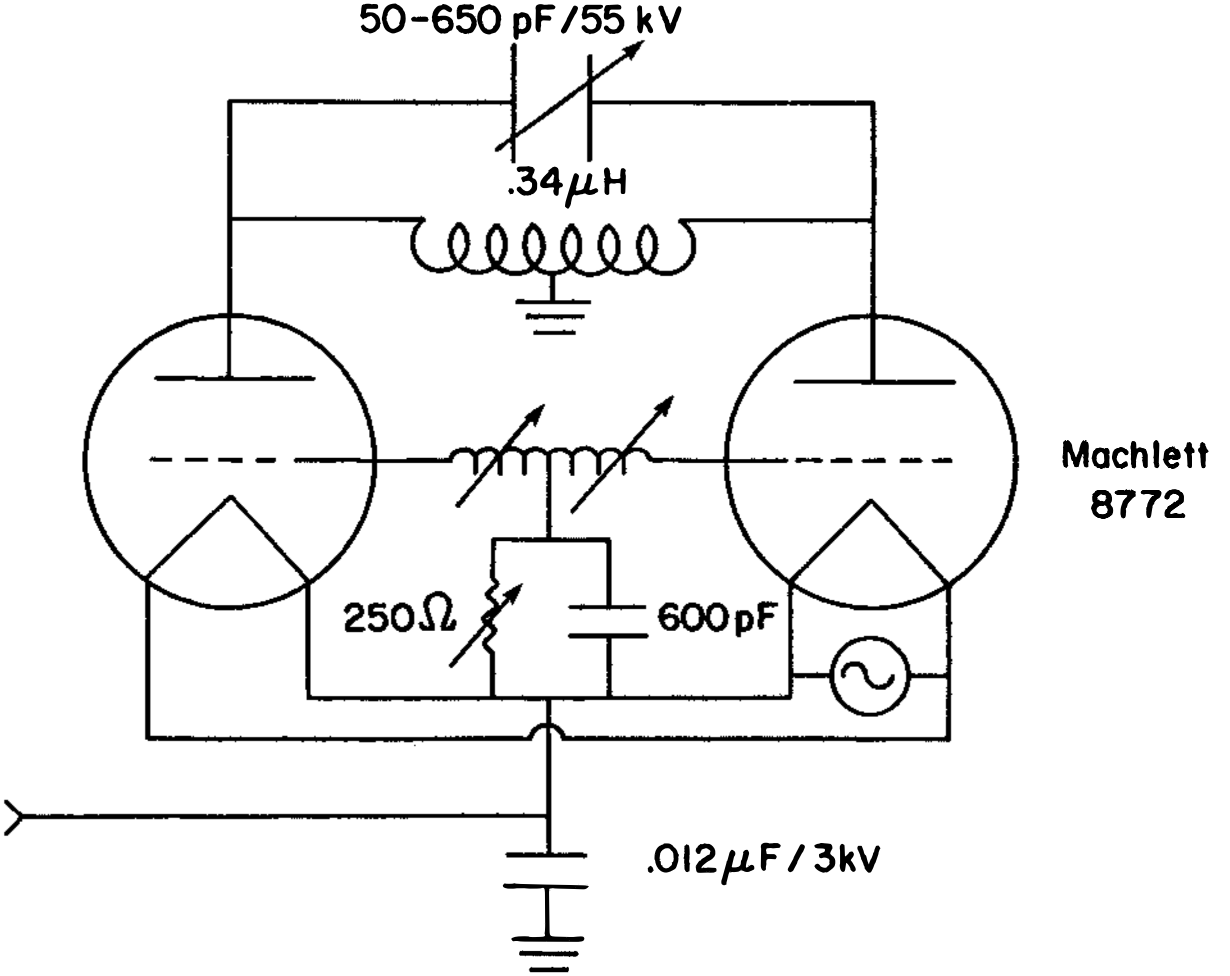
Reflected Power

Figure 2a



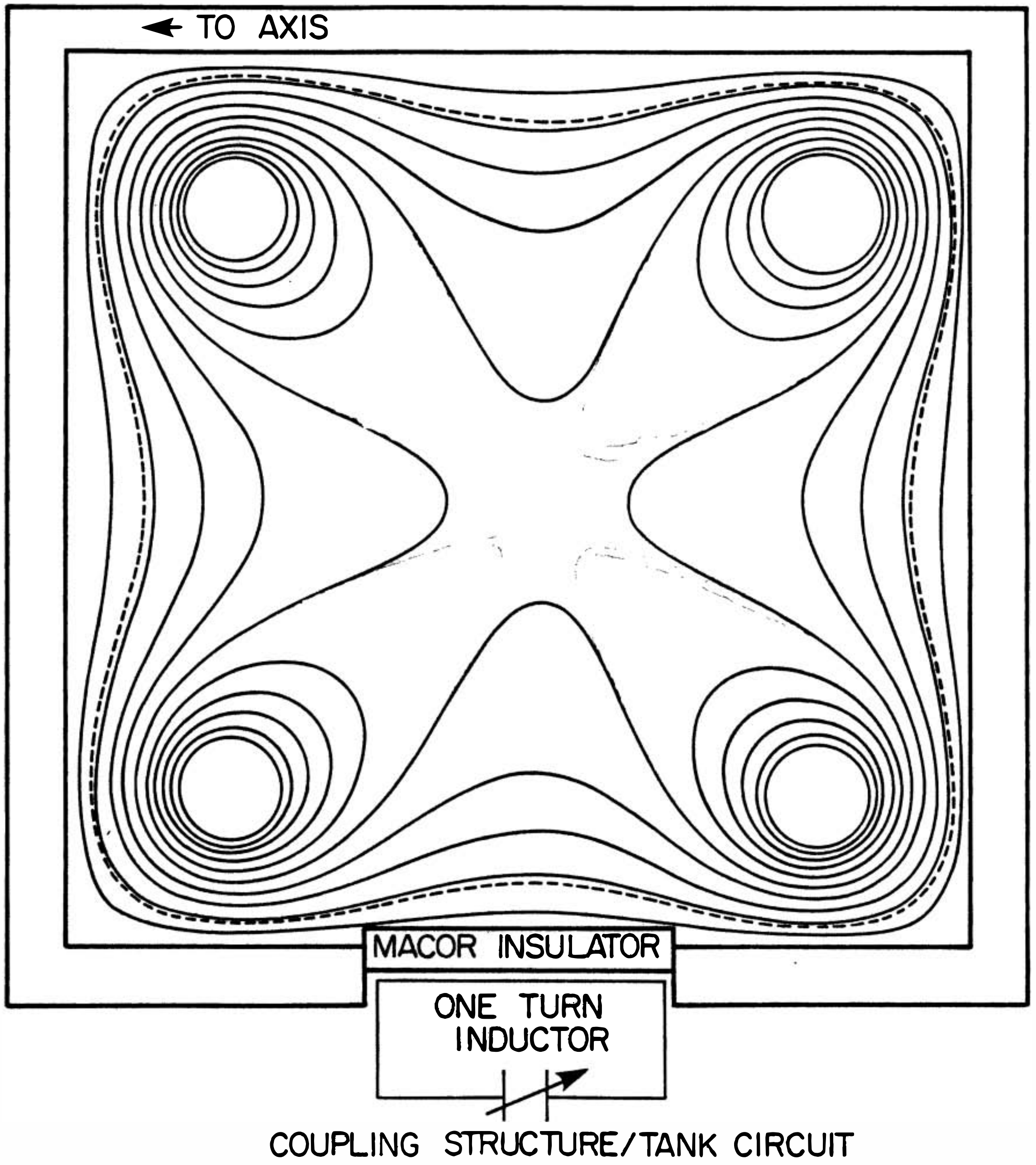
Received Signal

Figure 2b



TWO MW PUSH-PULL OSCILLATOR

Figure 3



TOKAPOLE II FLUX PLOT
AND LAUNCHING STRUCTURE

Figure 4

FREQUENCY SHIFT AND LOADING

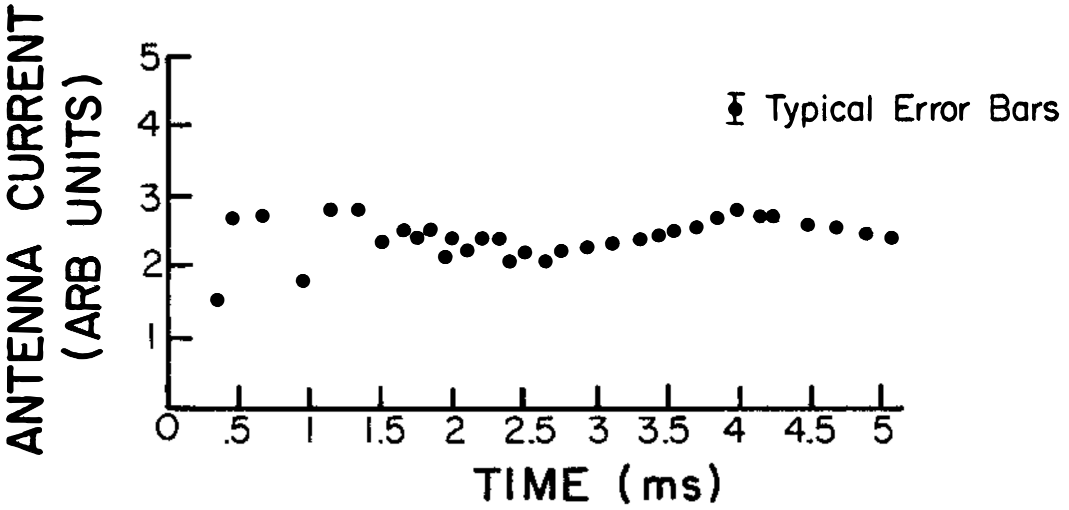


Figure 5a

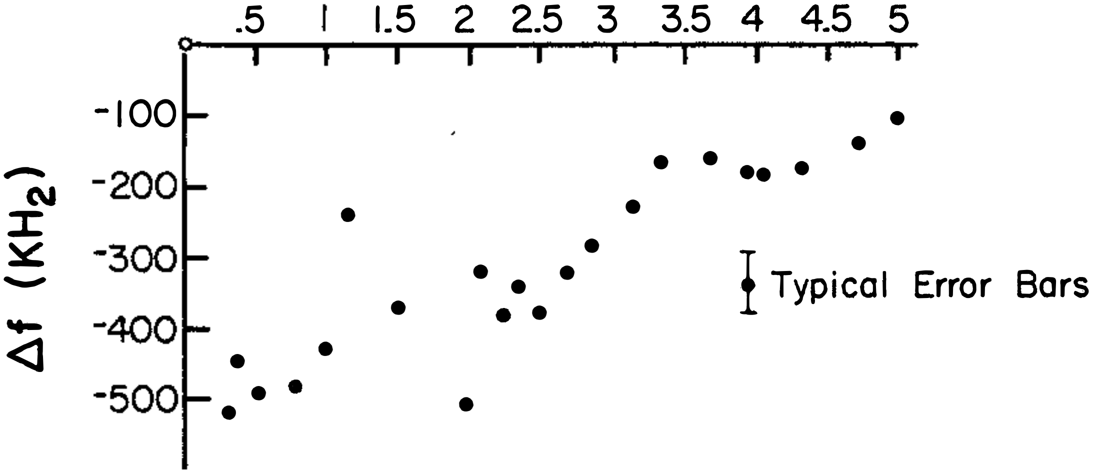


Figure 5b

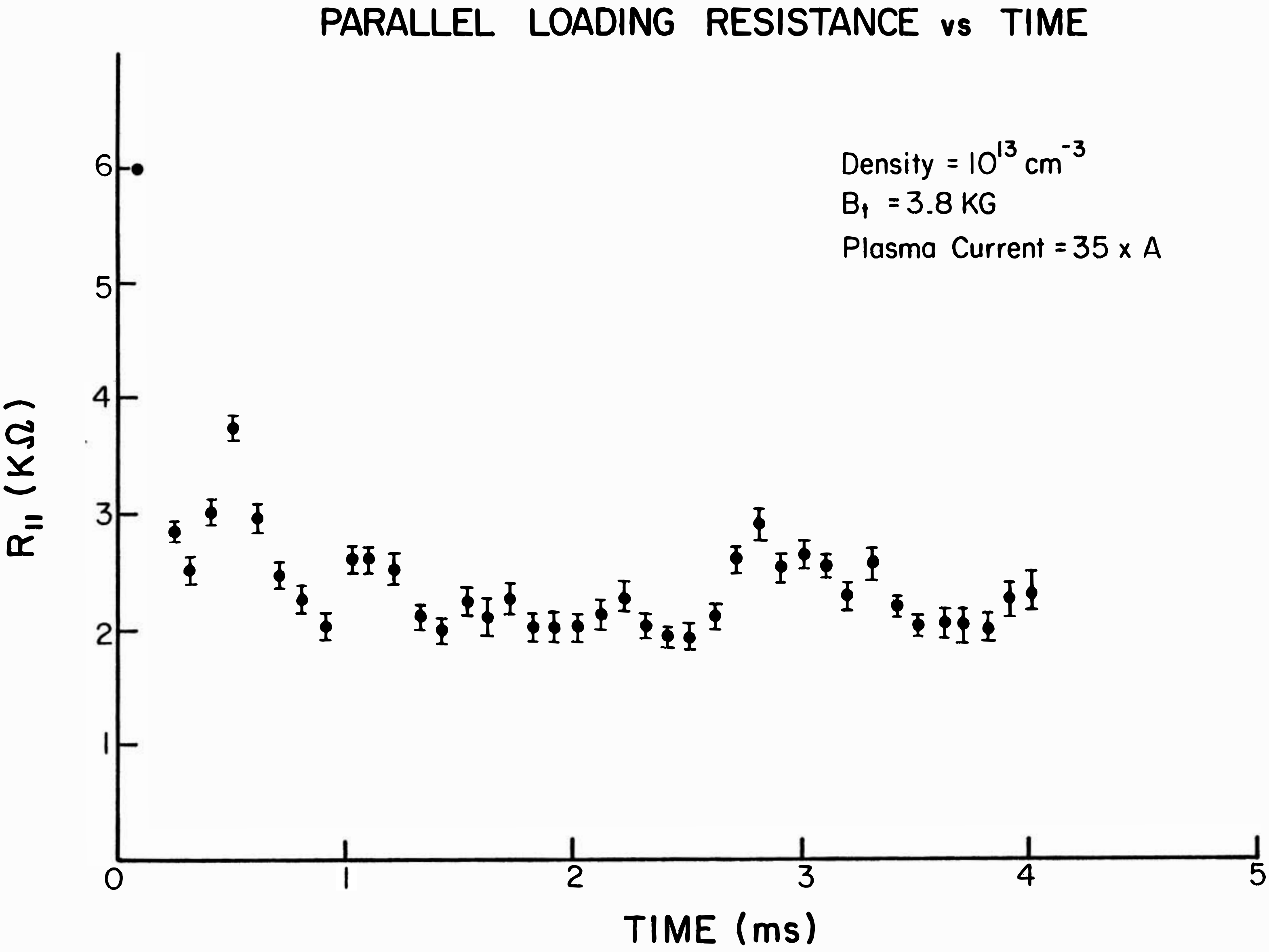

PARALLEL LOADING RESISTANCE vs TIME
Density = 10^{13} cm^{-3}
B_t = 3.8 KG
Plasma Current = 35 x A
$R_{\parallel}$ (KΩ)
6
5
4
3
2
1
0
1
2
3
4
5
TIME (ms)

Figure 6

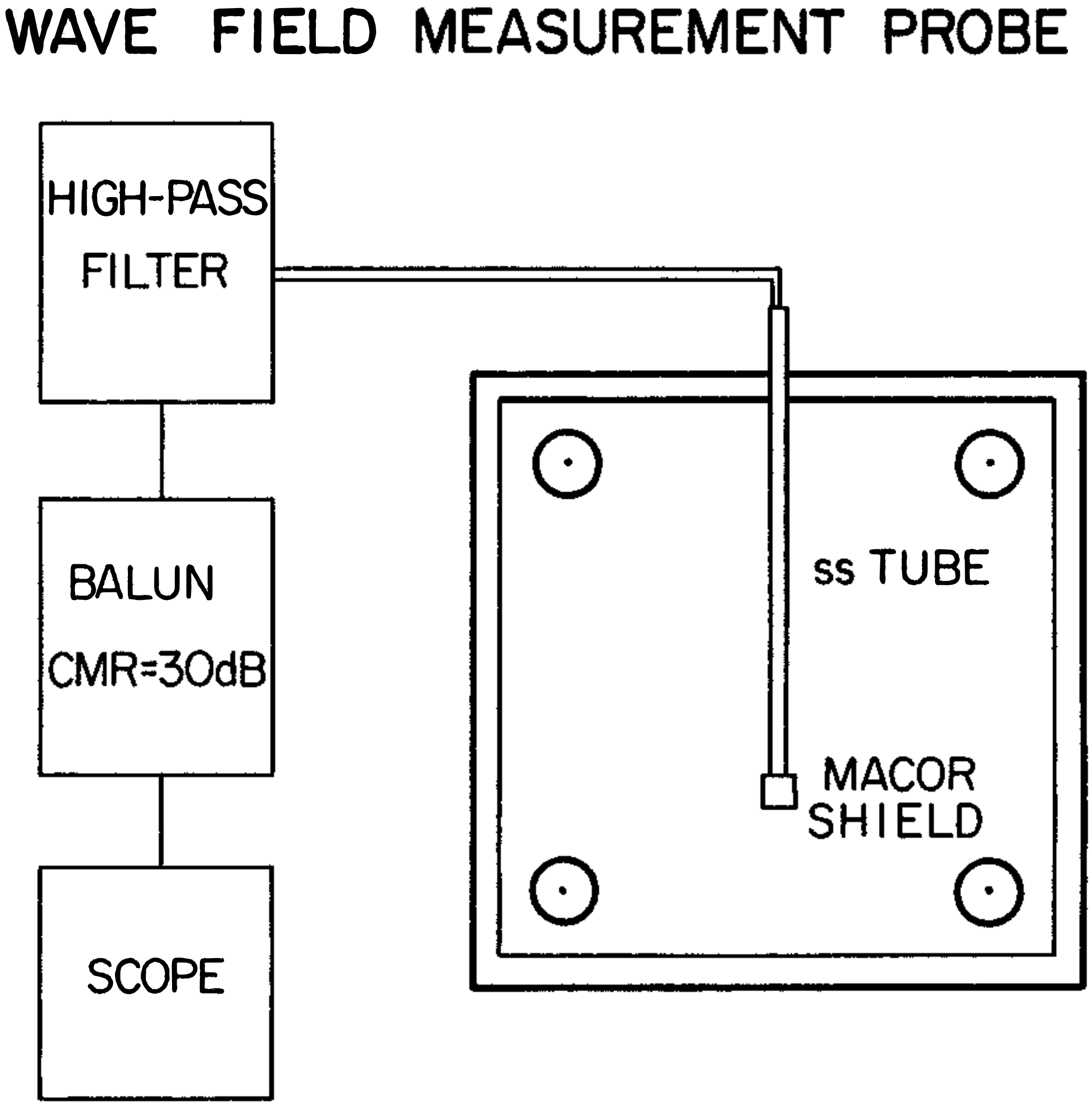

WAVE FIELD MEASUREMENT PROBE
HIGH-PASS FILTER
BALUN
CMR=30dB
SCOPE
ss TUBE
MACOR SHIELD

Figure 7

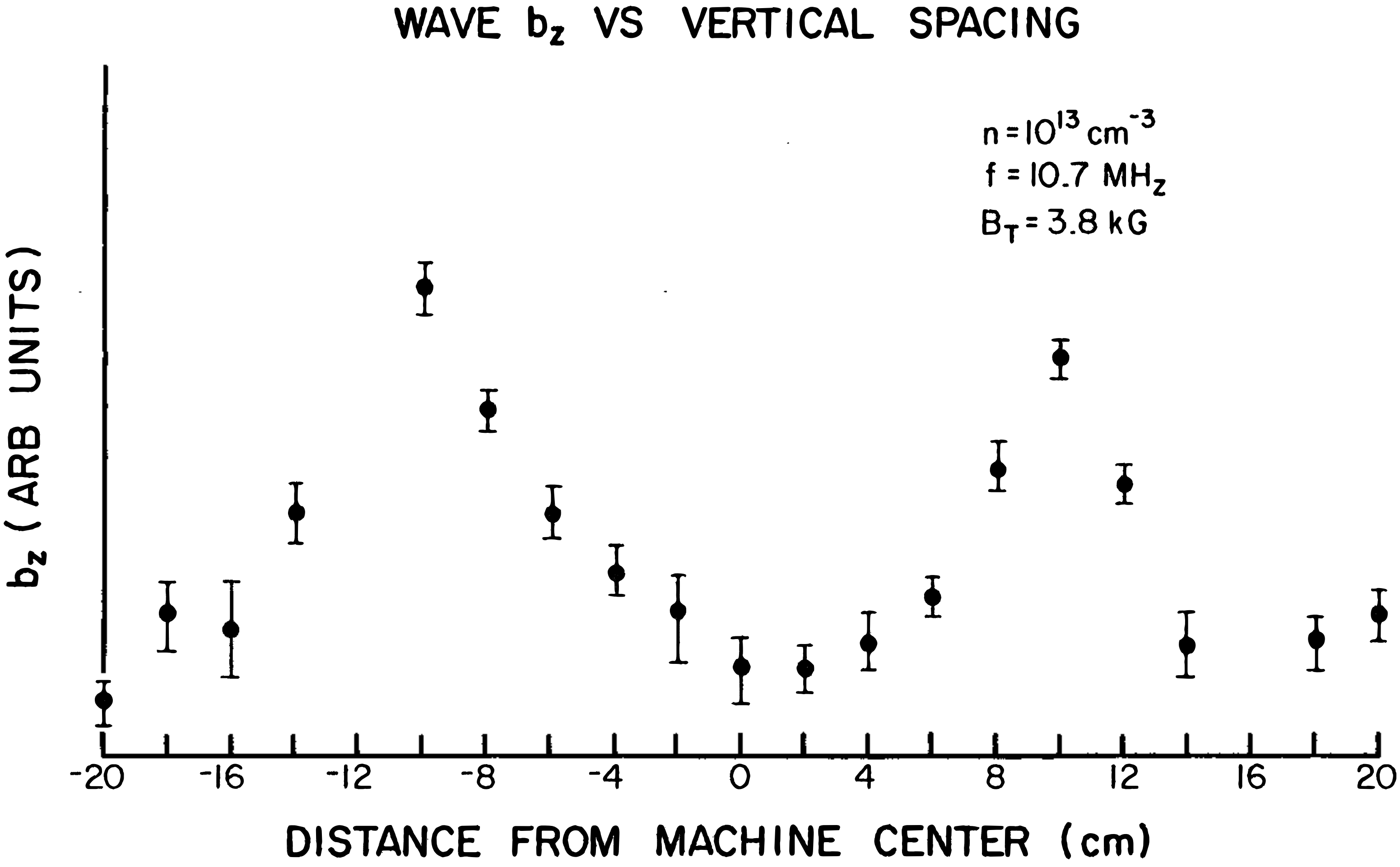

WAVE b_z VS VERTICAL SPACING
$n = 10^{13}$ cm^{-3}
f = 10.7 MH$_z$
B_T = 3.8 kG
b_z (ARB UNITS)
-20
-16
-12
-8
-4
0
4
8
12
16
20
DISTANCE FROM MACHINE CENTER (cm)

Figure 8a

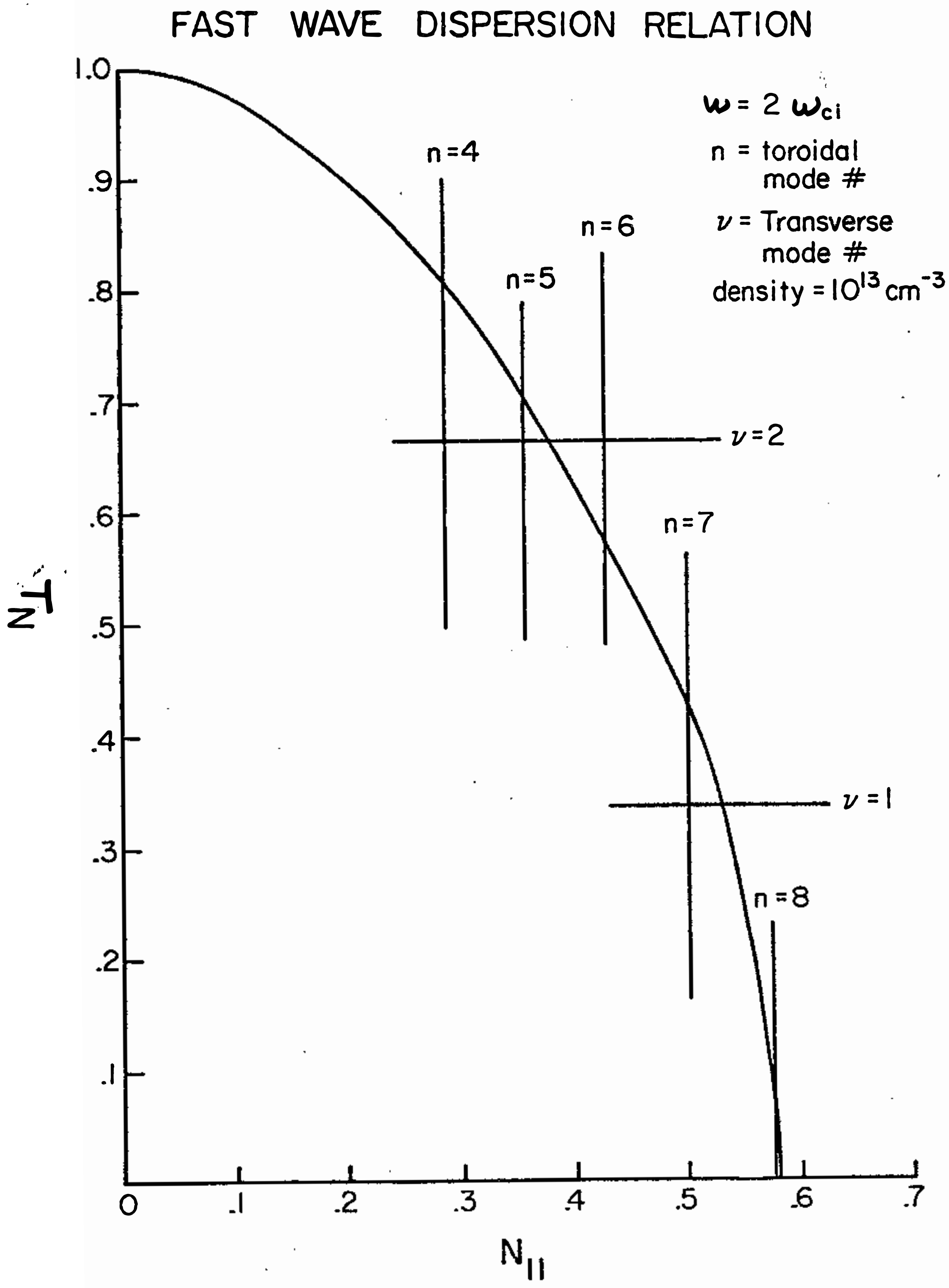

FAST WAVE DISPERSION RELATION
$\omega = 2\,\omega_{ci}$
n = toroidal mode #
ν = Transverse mode #
density = 10^{13} cm^{-3}
n=4
n=5
n=6
n=7
n=8
ν=2
ν=1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
.1
.2
.3
.4
.5
.6
.7
$N_\perp$
$N_{\parallel}$

Figure 8b

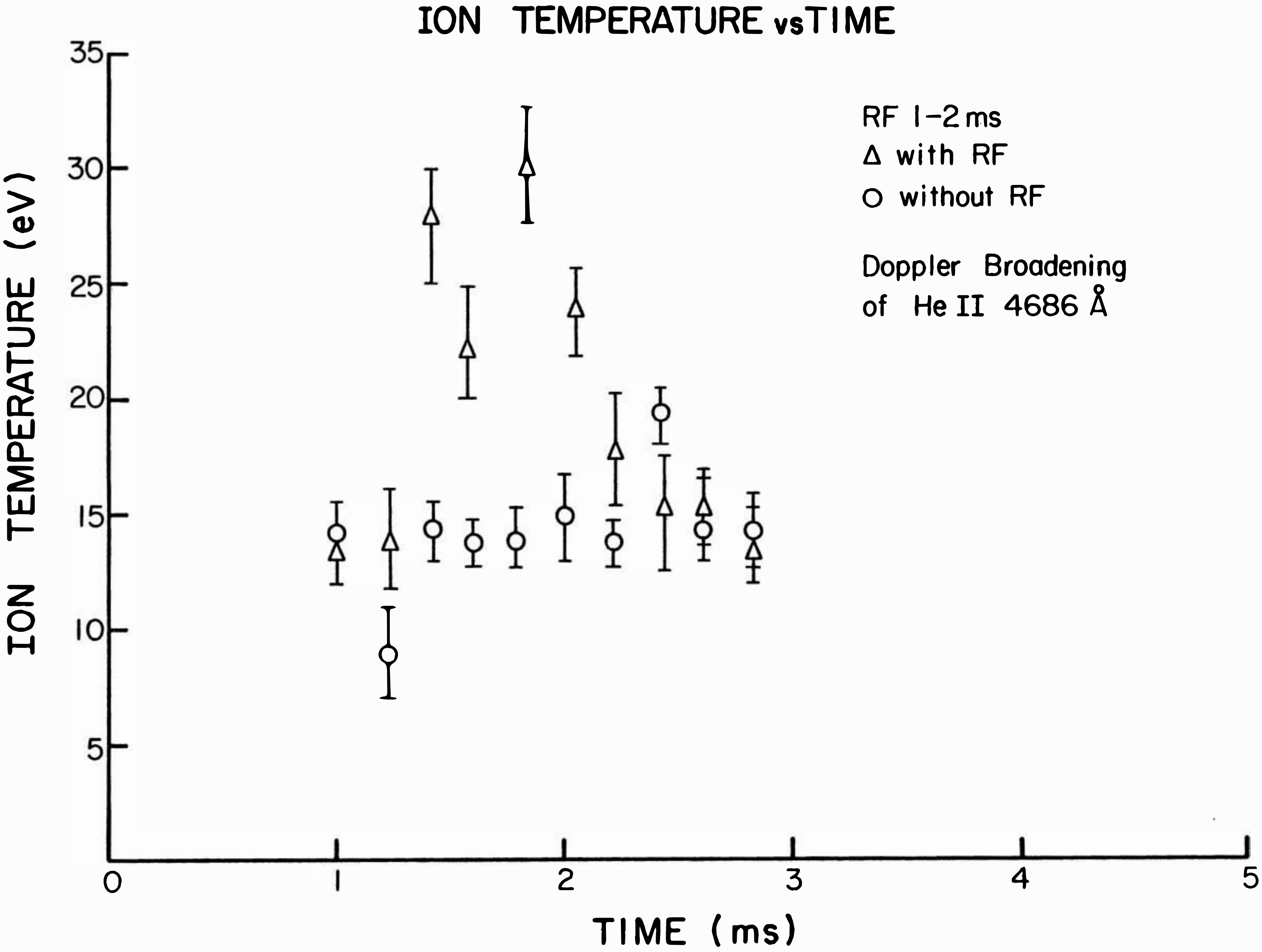

ION TEMPERATURE vs TIME
ION TEMPERATURE (eV)
35
30
25
20
15
10
5
0
1
2
3
4
5
TIME (ms)
RF 1-2 ms
Δ with RF
○ without RF
Doppler Broadening
of He II 4686 Å

Figure 9