q < 1 TOKAMAK DISCHARGES IN THE TOKAPOLE II UPGRADE

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ABSTRACT (modified)

q<1 Tokamak Discharges in the Tokapole II Upgrade*: J.A. Goetz, R.N. Dexter, R.A. Moyer, Z. Ning, S.C. Prager, J.C. Sprott, I.H. Tan, Univ. of Wisconsin - Madison. An upgrade of the Tokapole II poloidal divertor tokamak to obtain q<1 discharges with higher electron temperature and lower resistivity has been completed. Upgrade plasmas with higher plasma current and toroidal field than previous Tokapole II discharges have been obtained. Initial experiments compare the stability and confinement of q<1 magnetically limited disharges at high and low plasma current with results obtained on the pre-upgrade device.

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MOTIVATION

Background:

Previously, $q_a < 1$ tokamak discharges were produced with novel stability features:

- $q_a \approx 0.6$ during soft x-ray sawteeth
- partial reconnection

Goals:

Study $q_a < 1$ plasmas at increased plasma current:

- temperature scaling
- role of separatrix and the scrape-off layer
- sawteeth and partial reconnection

Experiment:

Comparison of post-upgrade to pre-upgrade plasmas
- gross equilibrium properties
- stability and confinement
- scaling of temperature and confinement time

Discharges are limited by extraneous effects
- impurity radiation
- machine conditioning and optimization

TOKAPOLE II UPGRADE

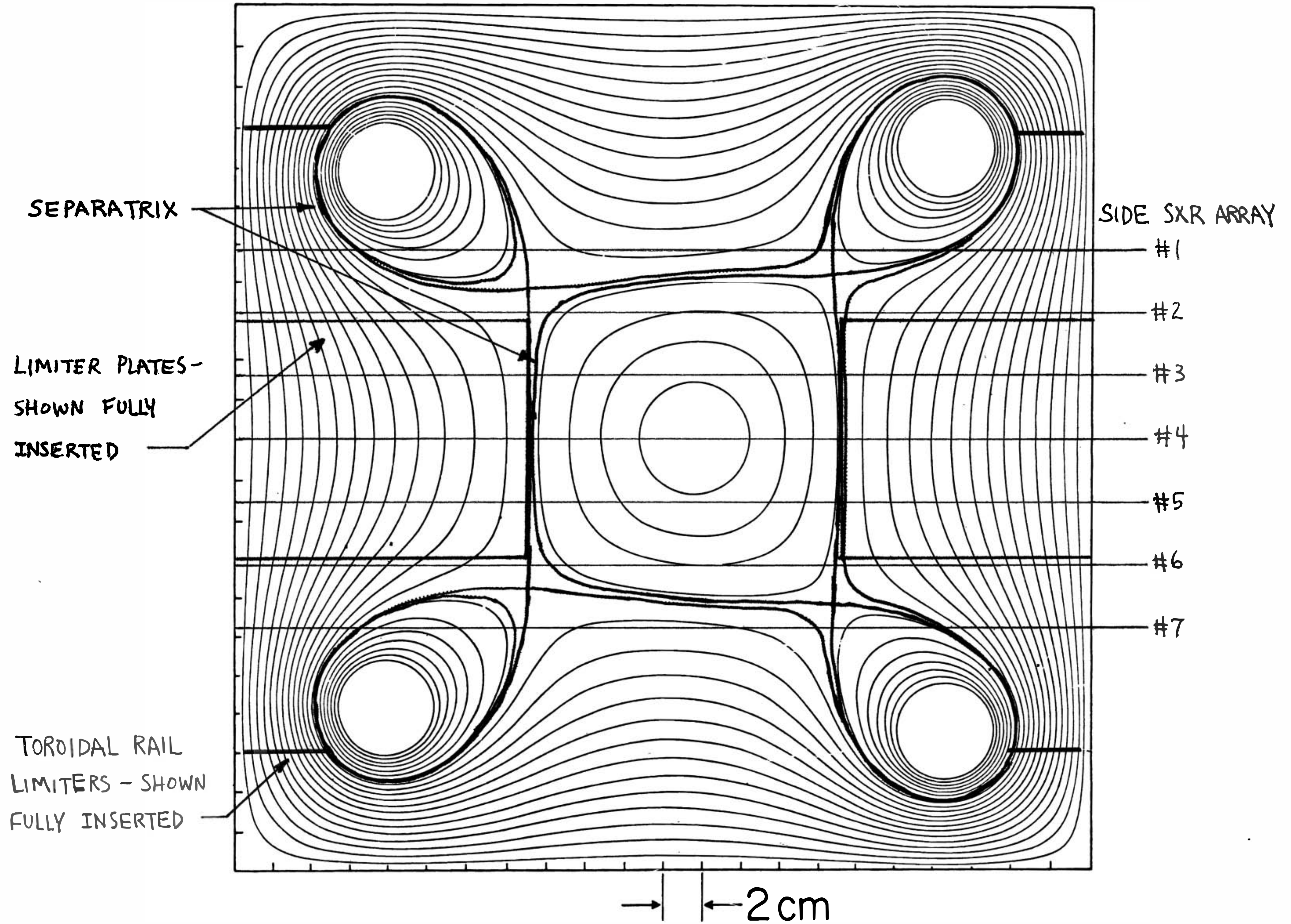
A. New supports for the divertor rings offer improved mechanical strength and thus allow for higher plasma current and longer discharge length.

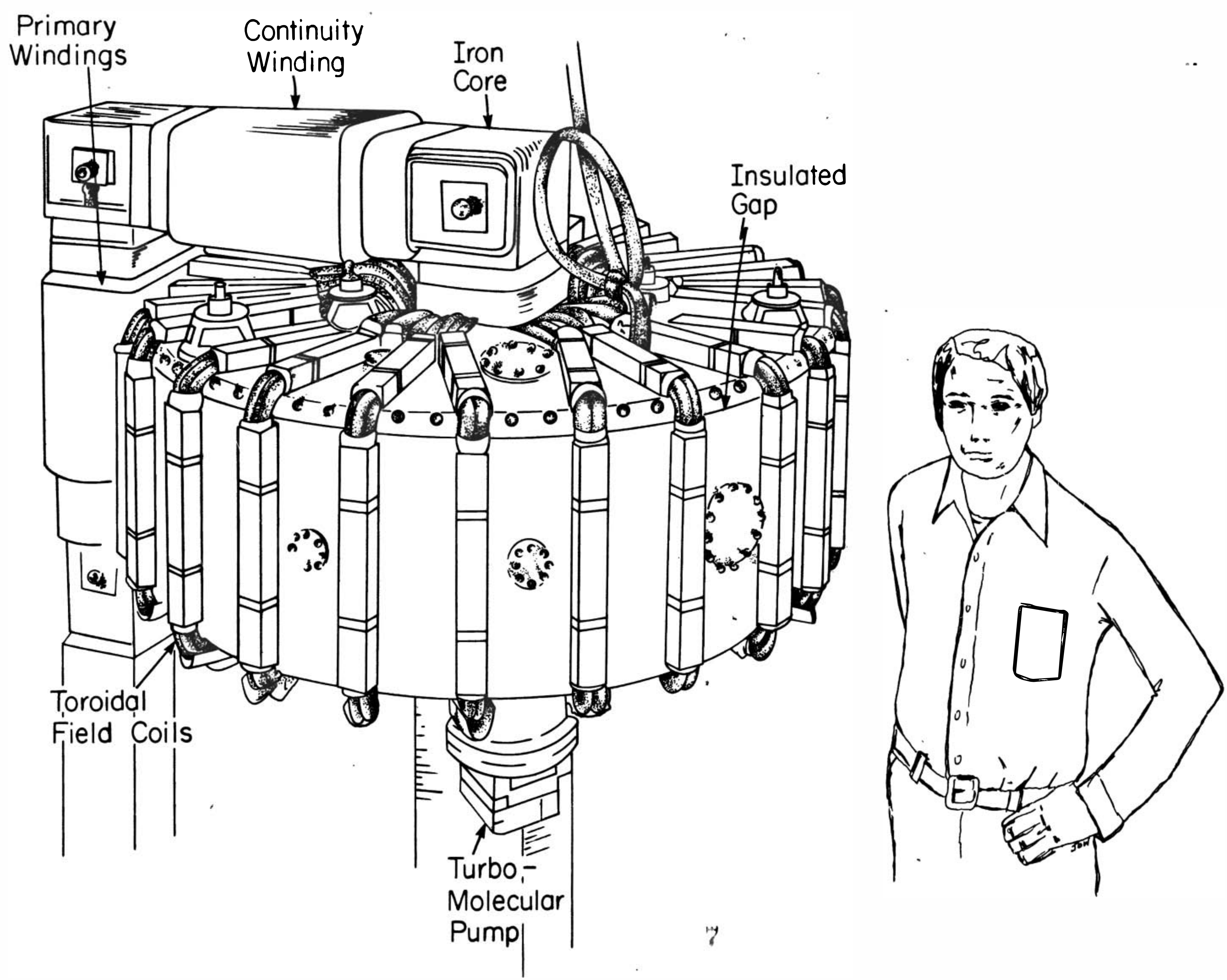
B. Toroidal rail limiters
   1. Fully retractable and insertable to separatrix
   2. One limiter per ring

C. External B-dot array is in the process of being assembled and installed.

TOKAPOLE II PARAMETERS

Four node poloidal divertor	
Major radius	50 cm
Minor radius	8 - 10 cm typical
Toroidal field	2.5 - 5.5 kGauss
Plasma current	15 - 80 kAmps
Line averaged density	2 - 10 x 10^{12} cm^{-3}
Electron temperature	~ 100 ev
Ion temperature	~ 20 ev
Discharge length	3 - 7+ msec
Base vacuum	4 x 10^{-7} torr


SEPARATRIX
LIMITER PLATES - SHOWN FULLY INSERTED
TOROIDAL RAIL LIMITERS - SHOWN FULLY INSERTED
SIDE SXR ARRAY
#1
#2
#3
#4
#5
#6
#7
2 cm



Primary Windings
Continuity Winding
Iron Core
Insulated Gap
Toroidal Field Coils
Turbo-Molecular Pump

Global plasma parameters remain qualitatively the same as plasma current is increased, although the length of the discharge is seen to decrease slightly. →

q_a can be held constant as plasma current is increased. Also q_a can be decreased to nearly 0.5. Conductivity temperature remains the same and confinement time decreases with increasing current. The very low q_a discharges are similar to the high current discharges.

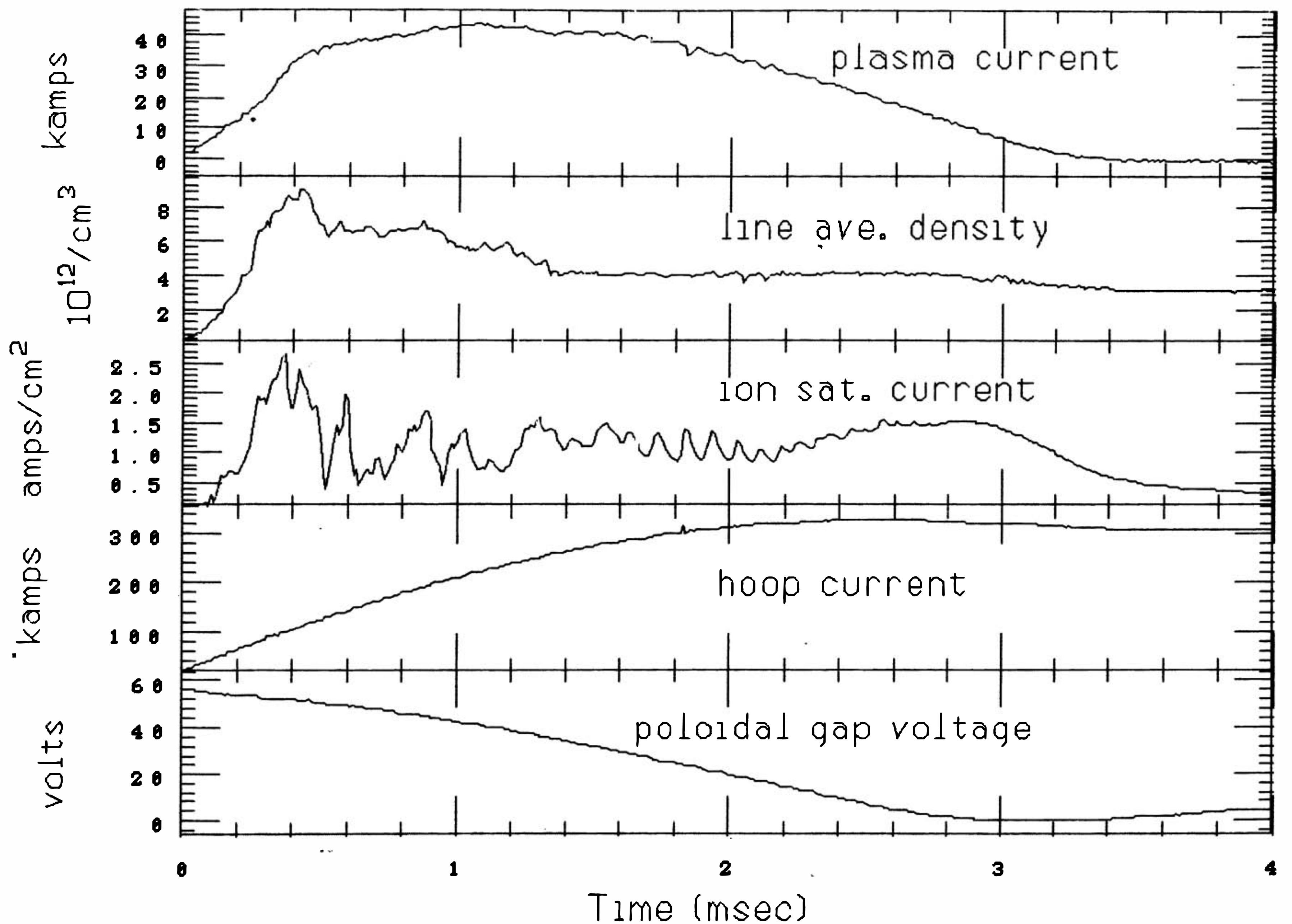
Soft x-ray (sxr) signals from high current discharges are very large, without sawtooth activity and thus indicate high impurity density. At very low q_{a}, the sxr signals begin to show rounded sawteeth.

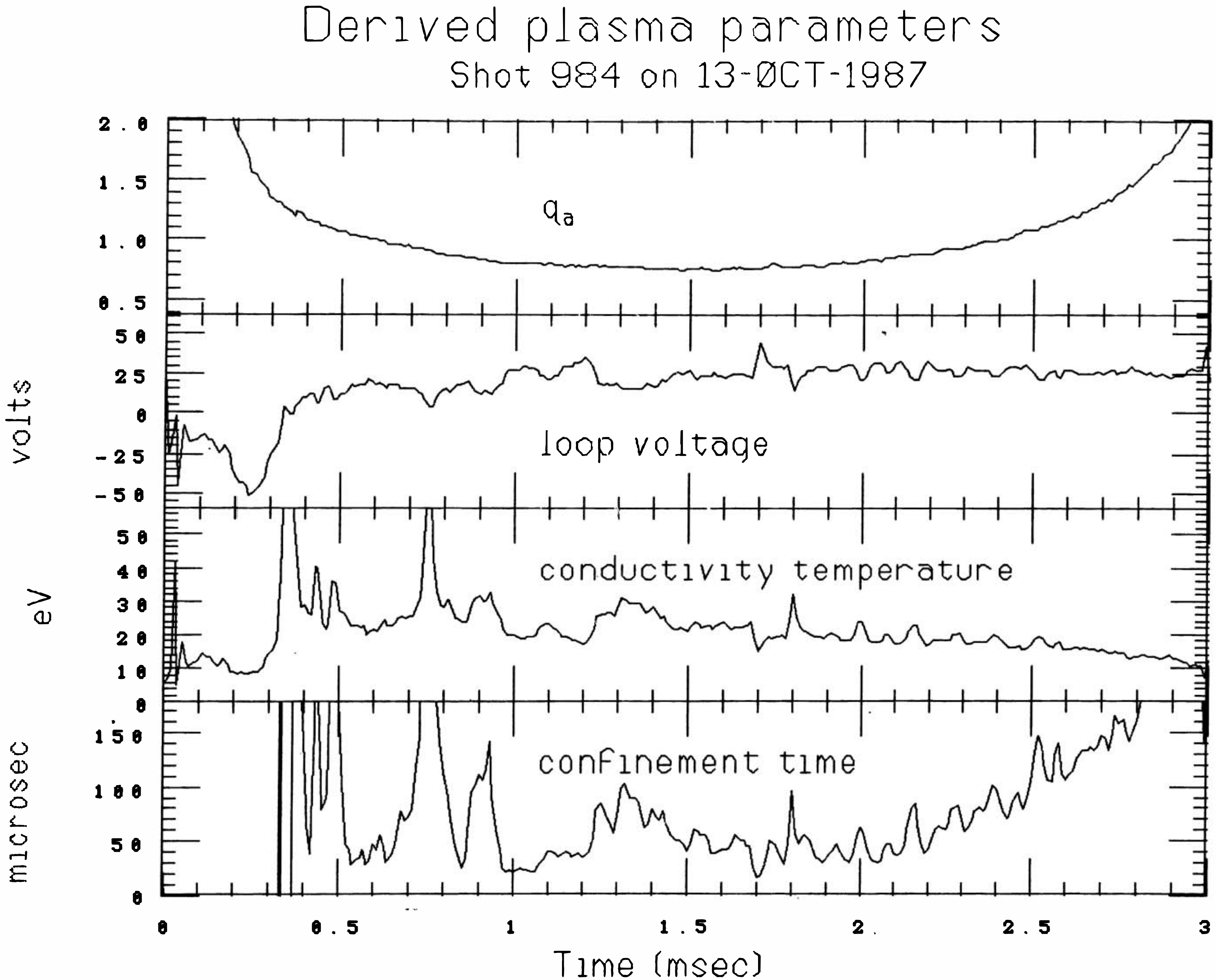
Optical line radiation signals indicate that a significant amount of copper is liberated during the discharge. Carbon and nitrogen impurities are present at high plasma current. The Lyman alpha signal shows that hydrogen is never competely ionized for discharges at low plasma current.

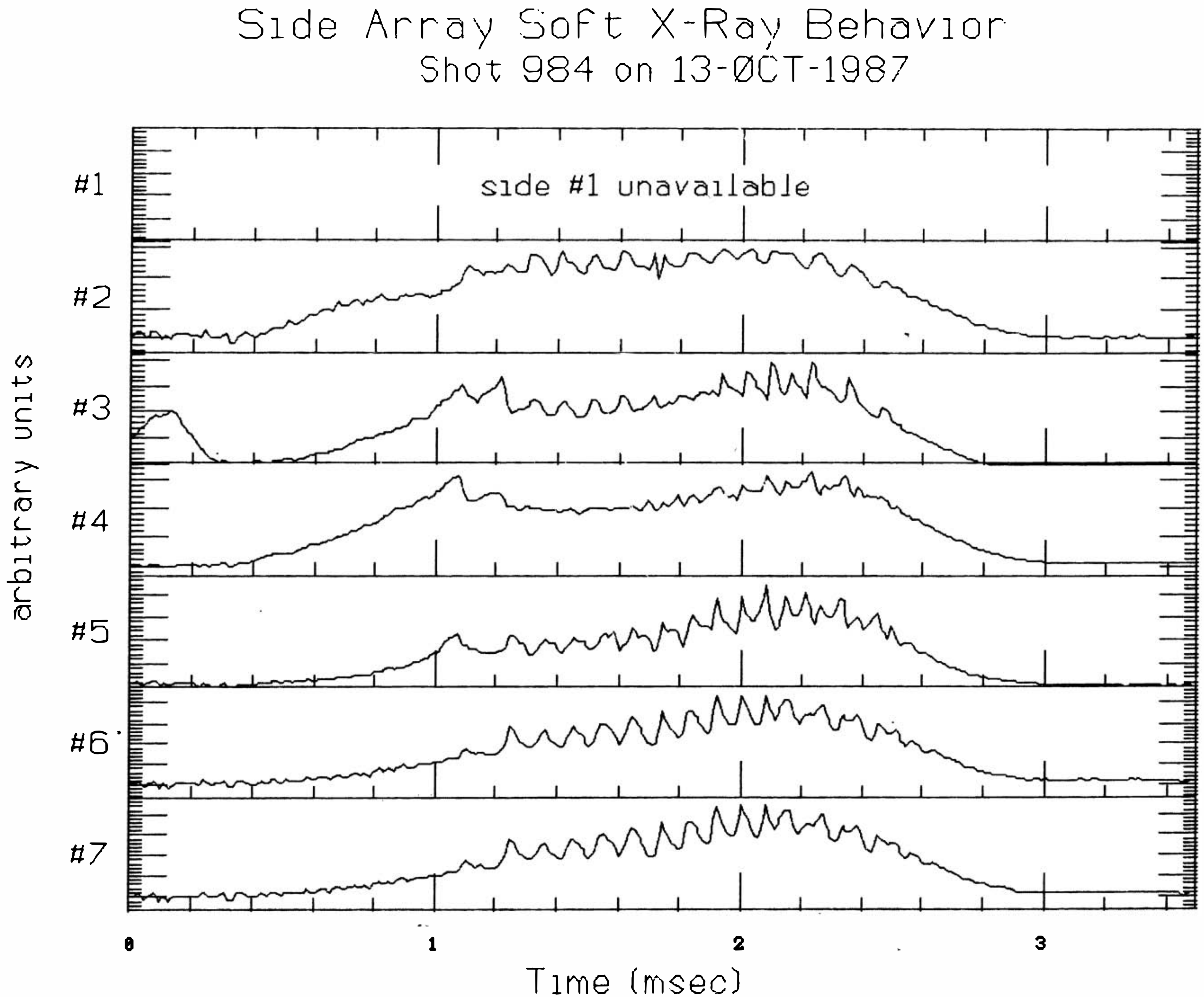
An oxygen line radiation series for low plasma current discharges is similar to pre-upgrade discharges. As plasma current is increased, the radiation from the higher oxidation states of oxygen increases late in the discharge.

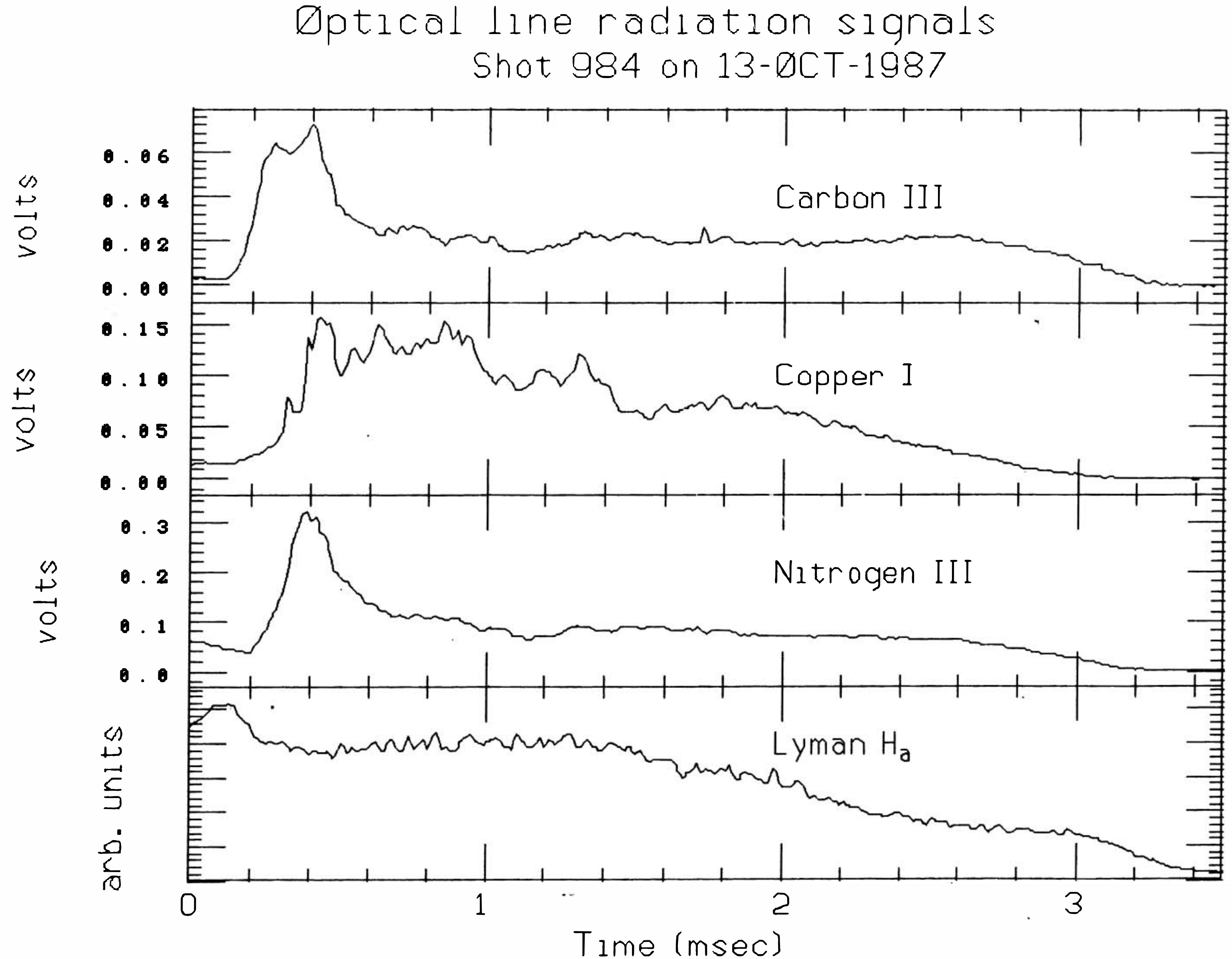
$q_a \approx 0.7$ discharges with $I_p \approx 40$ kAmps

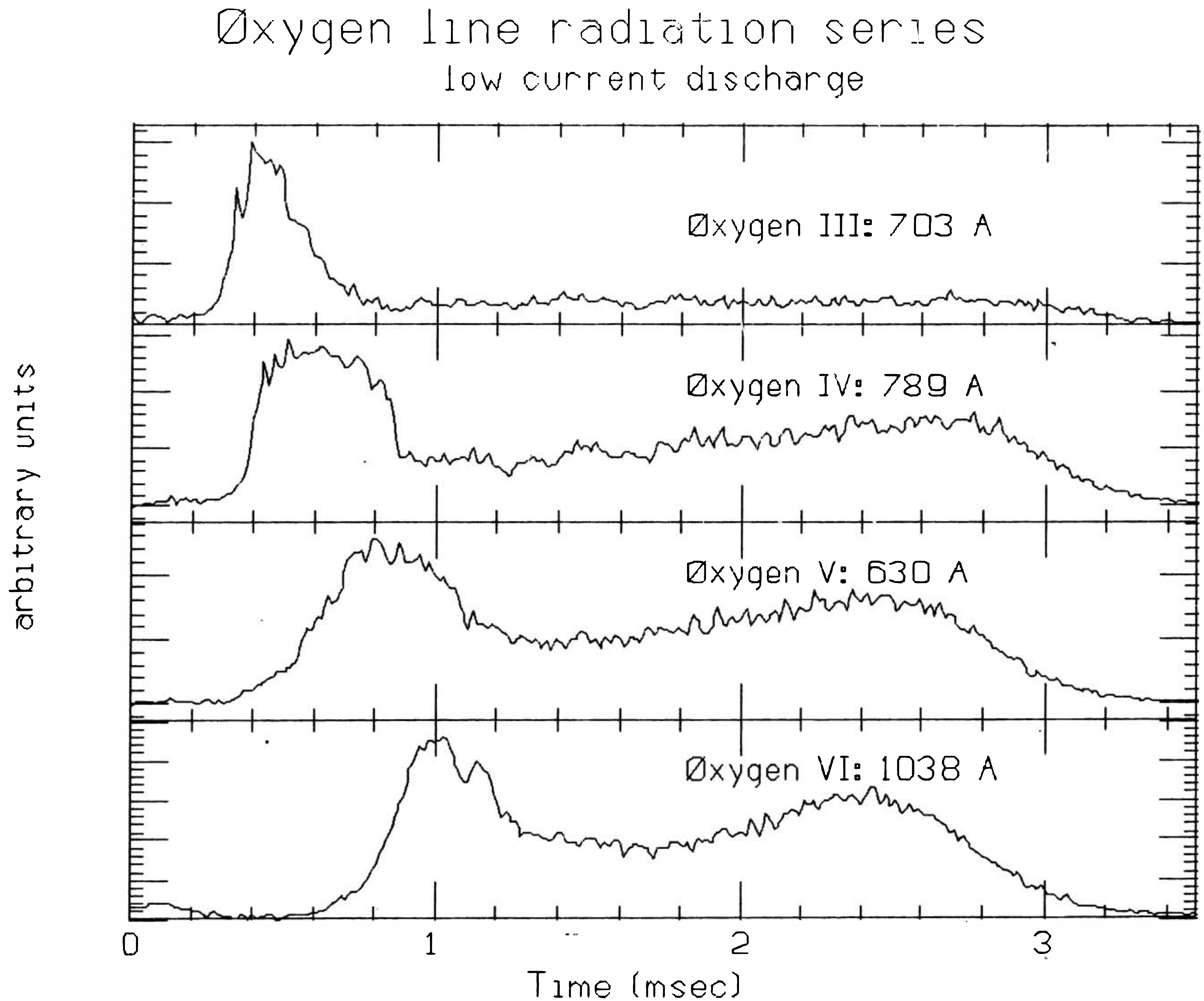
Global plasma parameters
Shot 984 on 13-oct-1987




Derived plasma parameters
Shot 984 on 13-ØCT-1987
q_a
loop voltage
conductivity temperature
confinement time
volts
eV
microsec
Time (msec)
2.0
1.5
1.0
0.5
50
25
0
-25
-50
50
40
30
20
10
0
150
100
50
0
0
0.5
1
1.5
2
2.5
3


Side Array Soft X-Ray Behavior
Shot 984 on 13-OCT-1987
#1
side #1 unavailable
#2
#3
#4
#5
#6
#7
arbitrary units
0
1
2
3
Time (msec)

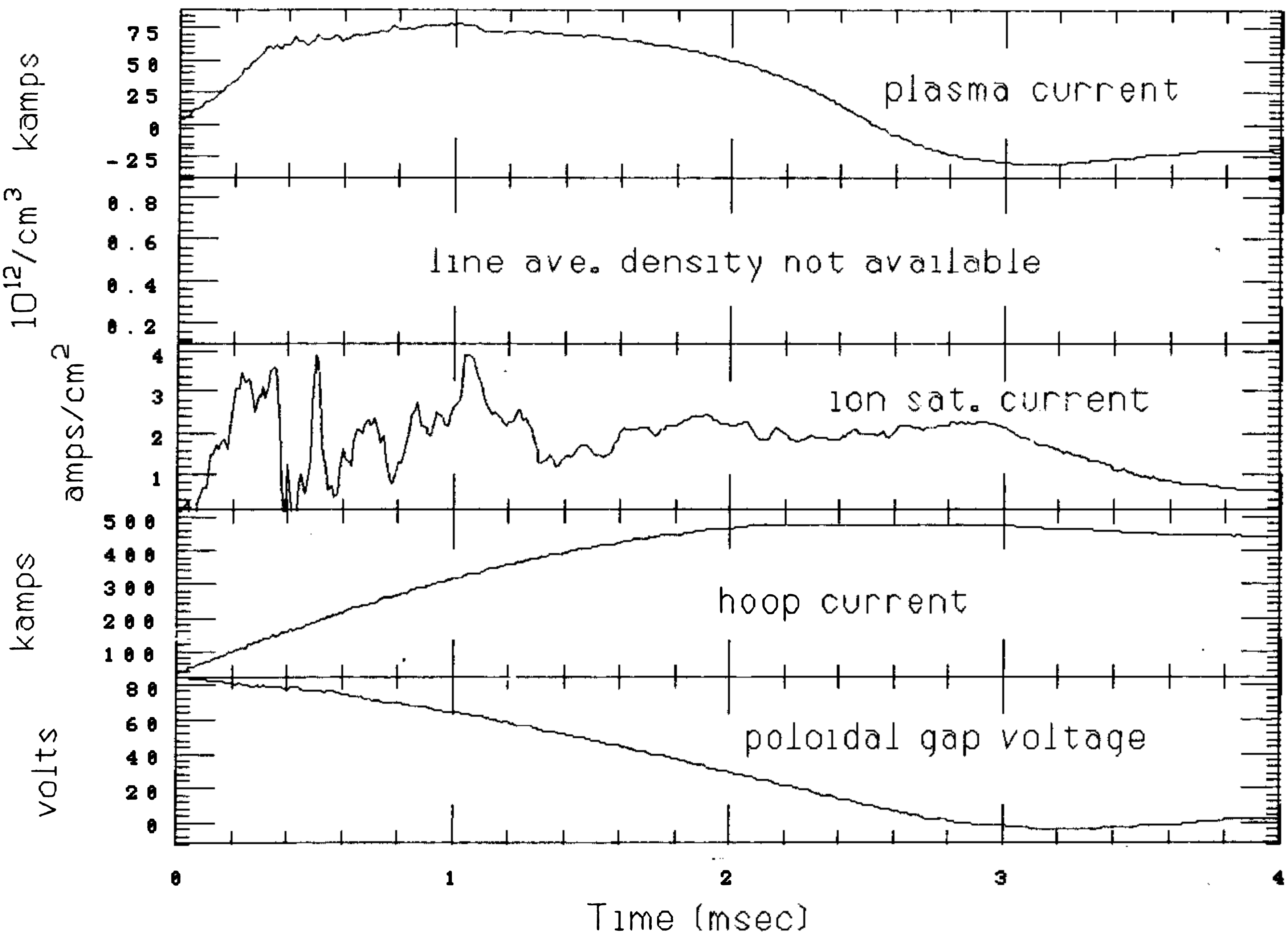

Øptical line radiation signals
Shot 984 on 13-ØCT-1987
volts
0.06
0.04
0.02
0.00
Carbon III
volts
0.15
0.10
0.05
0.00
Copper I
volts
0.3
0.2
0.1
0.0
Nitrogen III
arb. units
Lyman Ha
0
1
2
3
Time (msec)

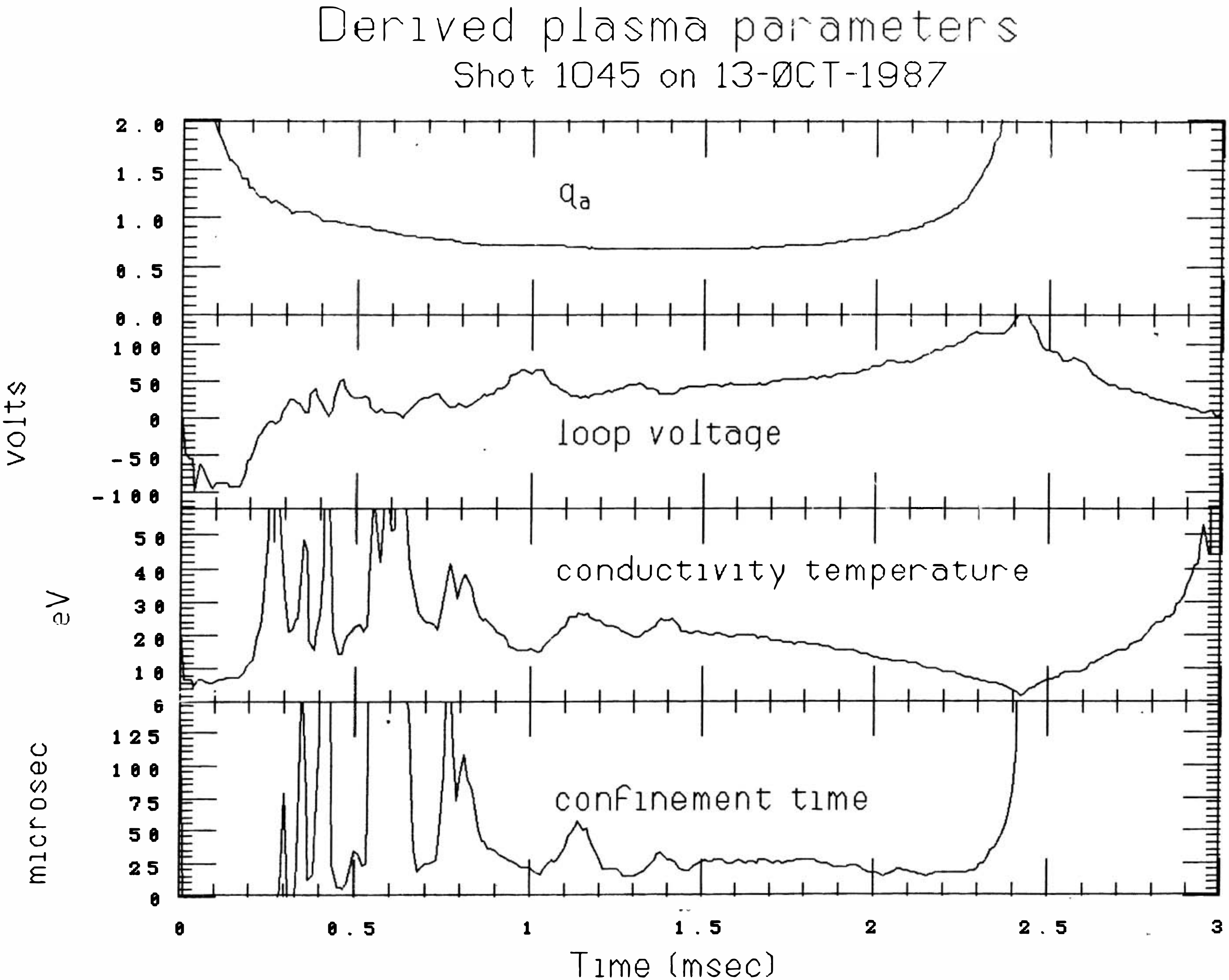

Øxygen line radiation series
low current discharge
Øxygen III: 703 A
Øxygen IV: 789 A
Øxygen V: 630 A
Øxygen VI: 1038 A
arbitrary units
0
1
2
3
Time (msec)

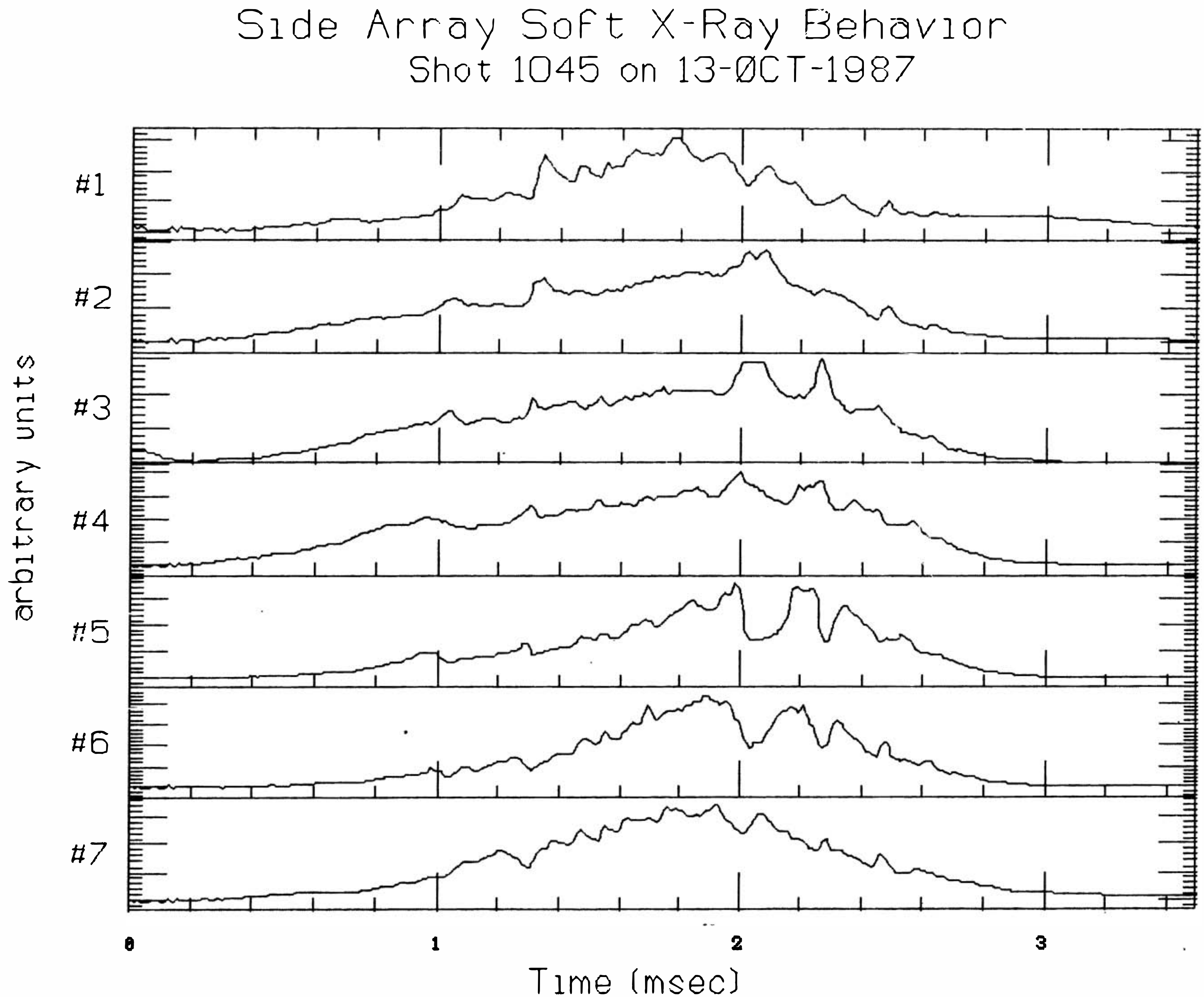
$q_a \approx 0.7$ discharges with $I_p \approx 80$ kAmps

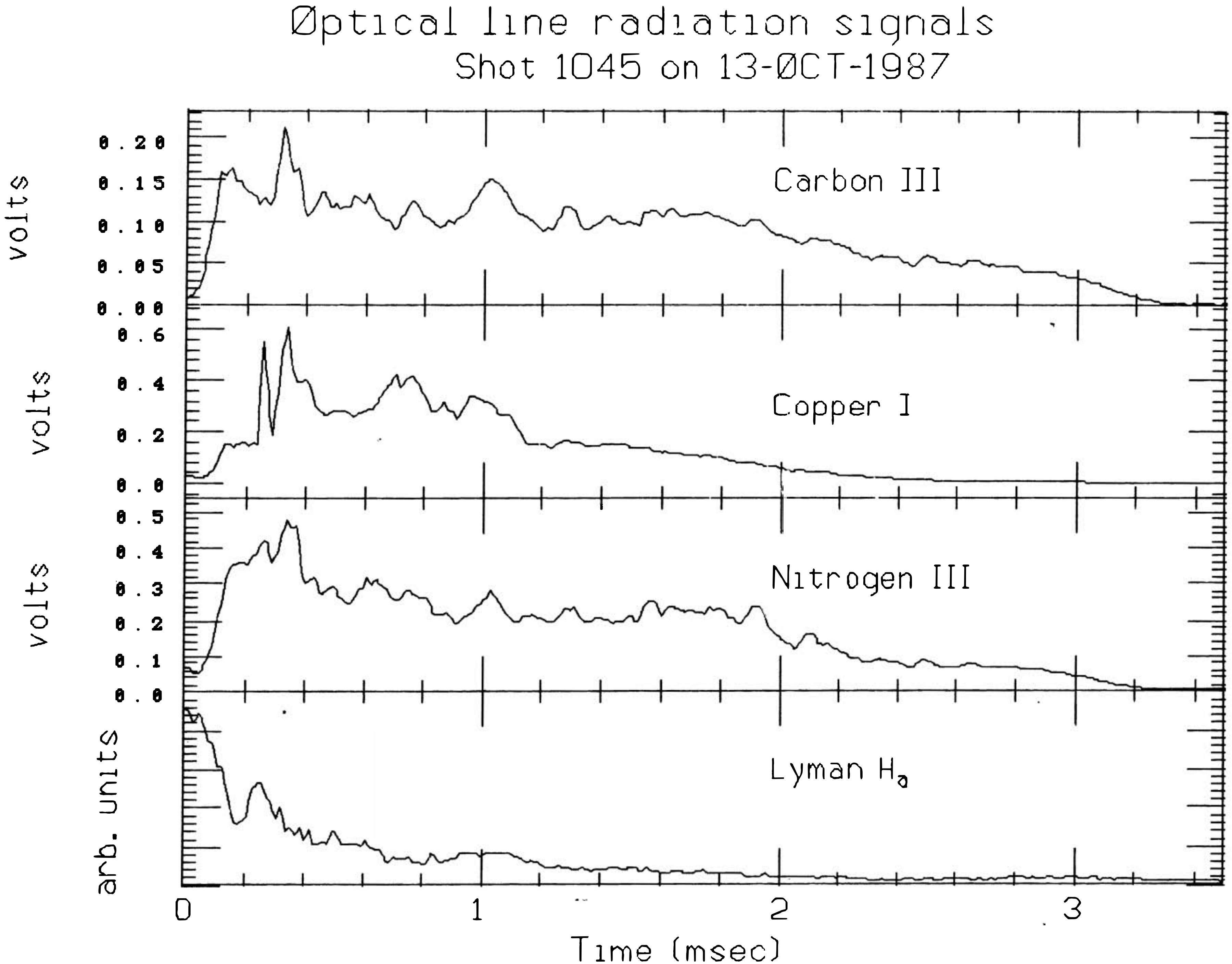
Global plasma parameters

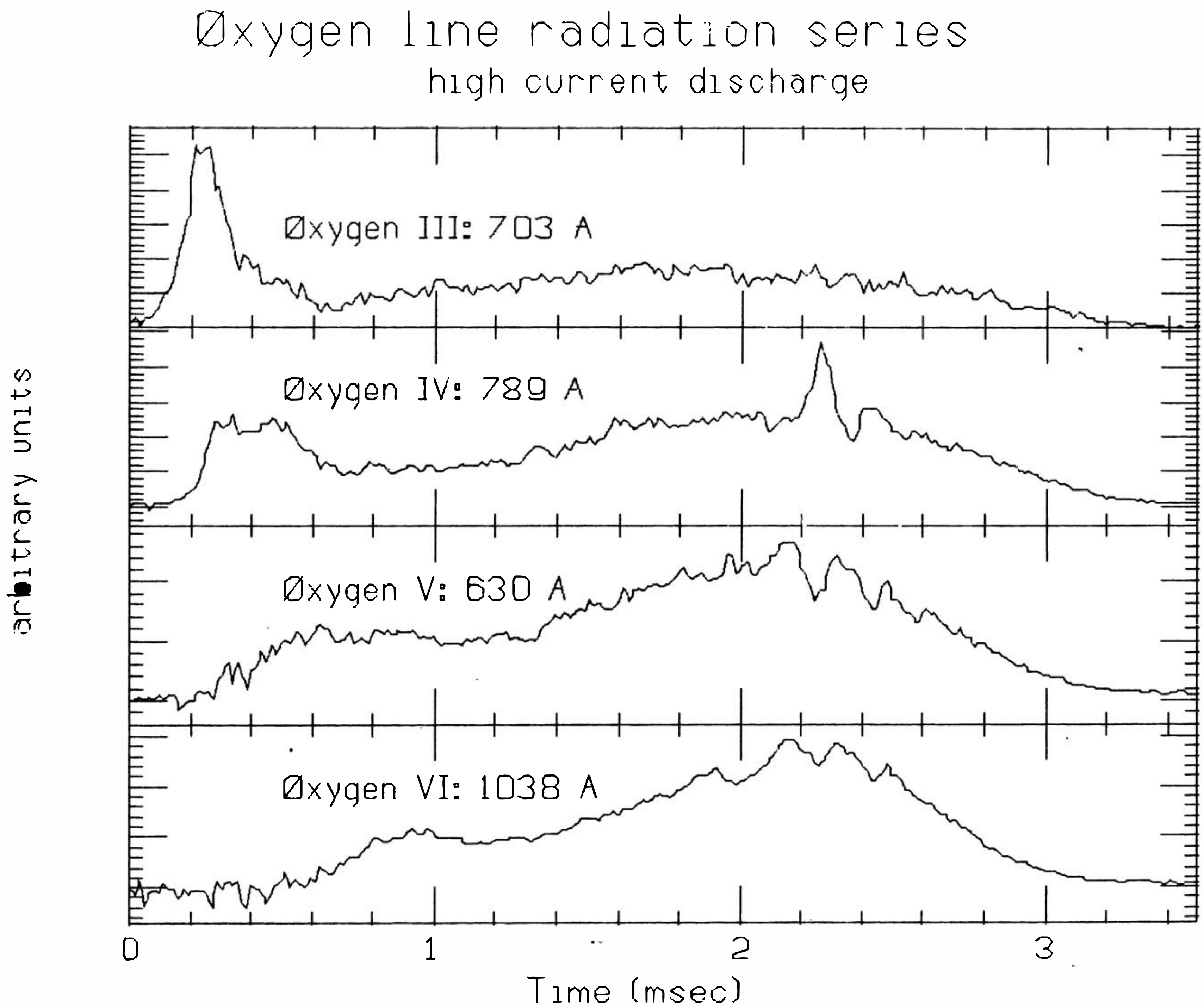
Shot 1045 on 13-oct-1987



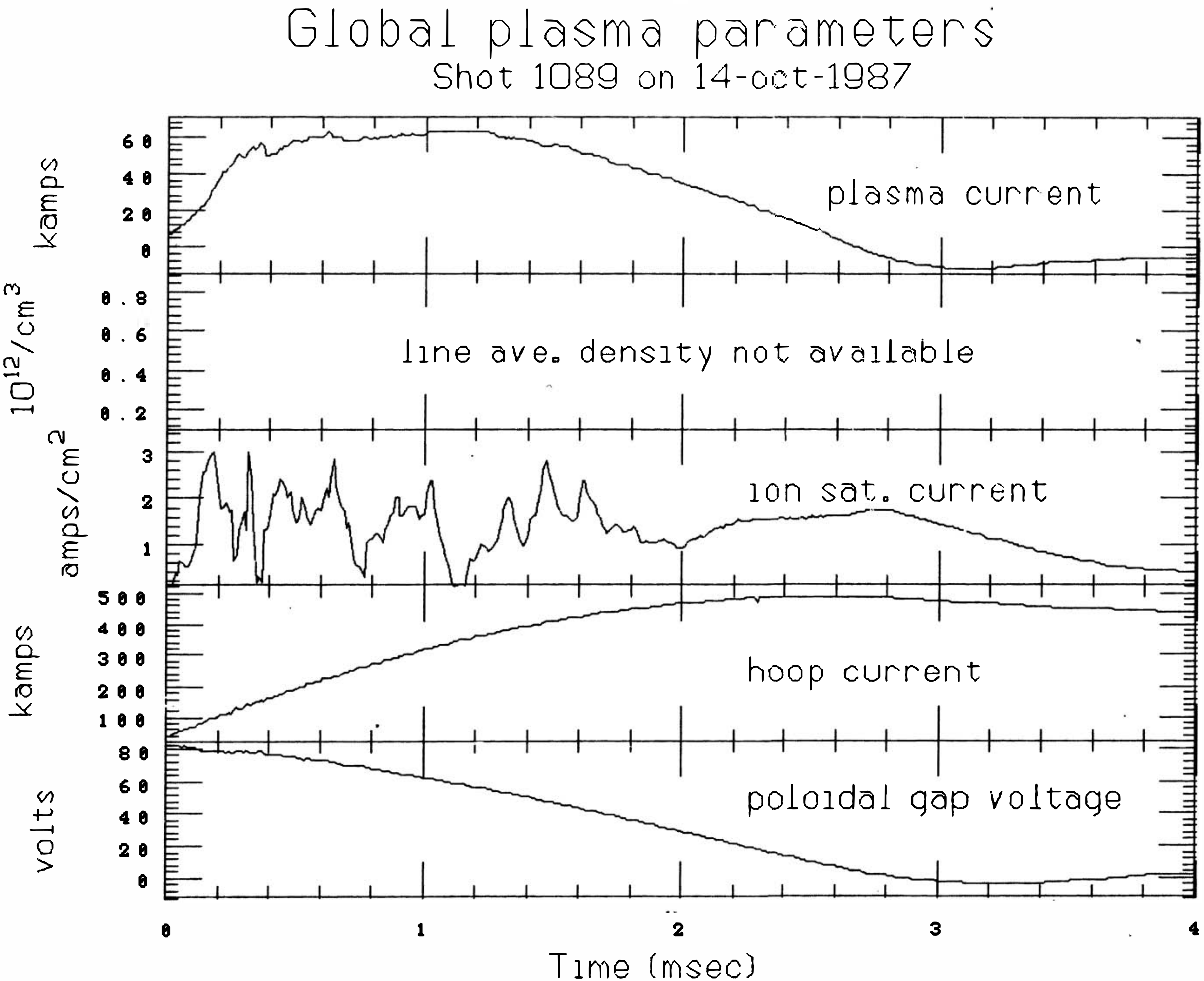

Derived plasma parameters
Shot 1045 on 13-OCT-1987
q_a
loop voltage
conductivity temperature
confinement time
volts
eV
microsec
Time (msec)
2.0
1.5
1.0
0.5
0.0
100
50
0
-50
-100
50
40
30
20
10
0
125
100
75
50
25
0
0
0.5
1
1.5
2
2.5
3

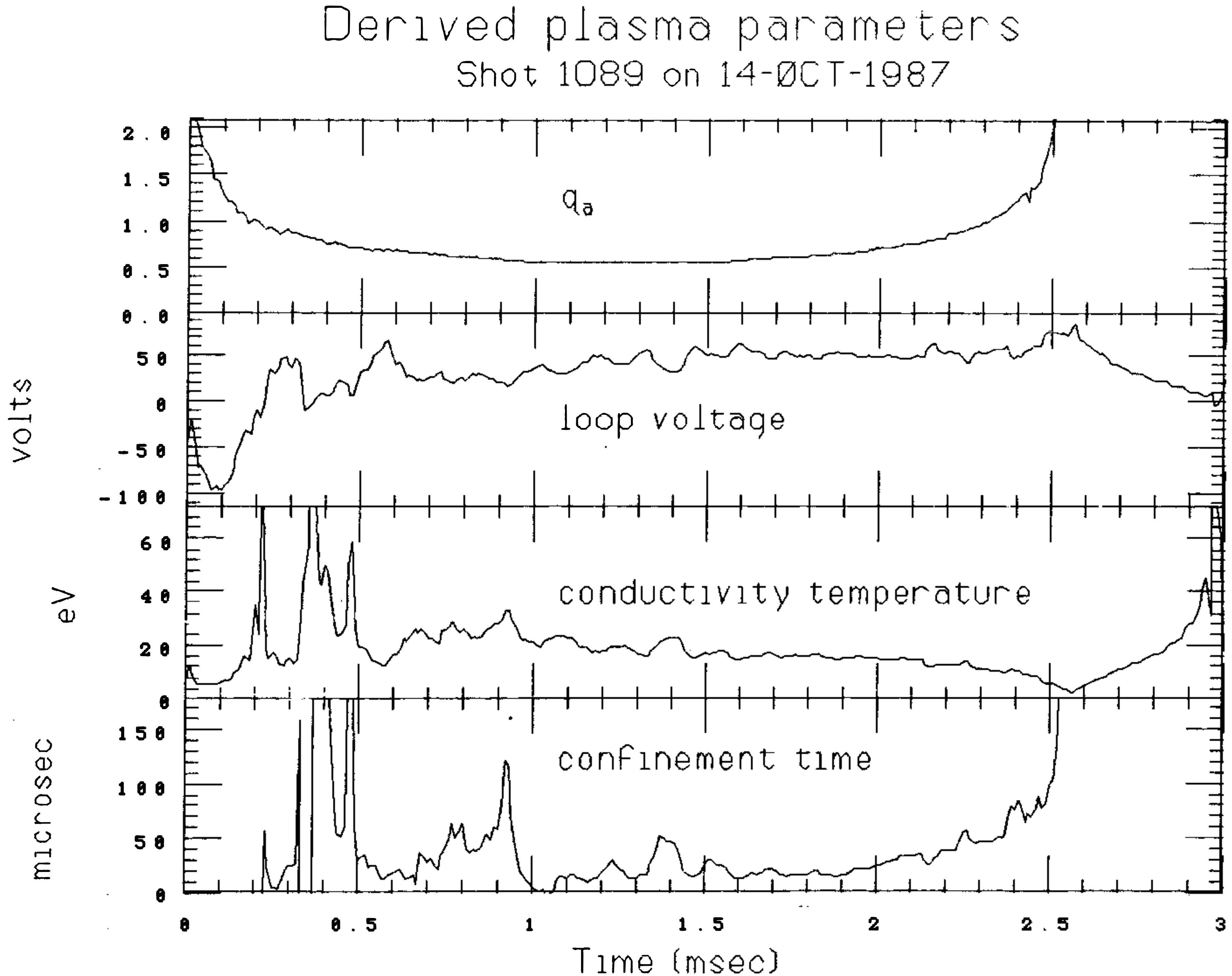

Side Array Soft X-Ray Behavior
Shot 1045 on 13-ØCT-1987
arbitrary units
#1
#2
#3
#4
#5
#6
#7
0
1
2
3
Time (msec)

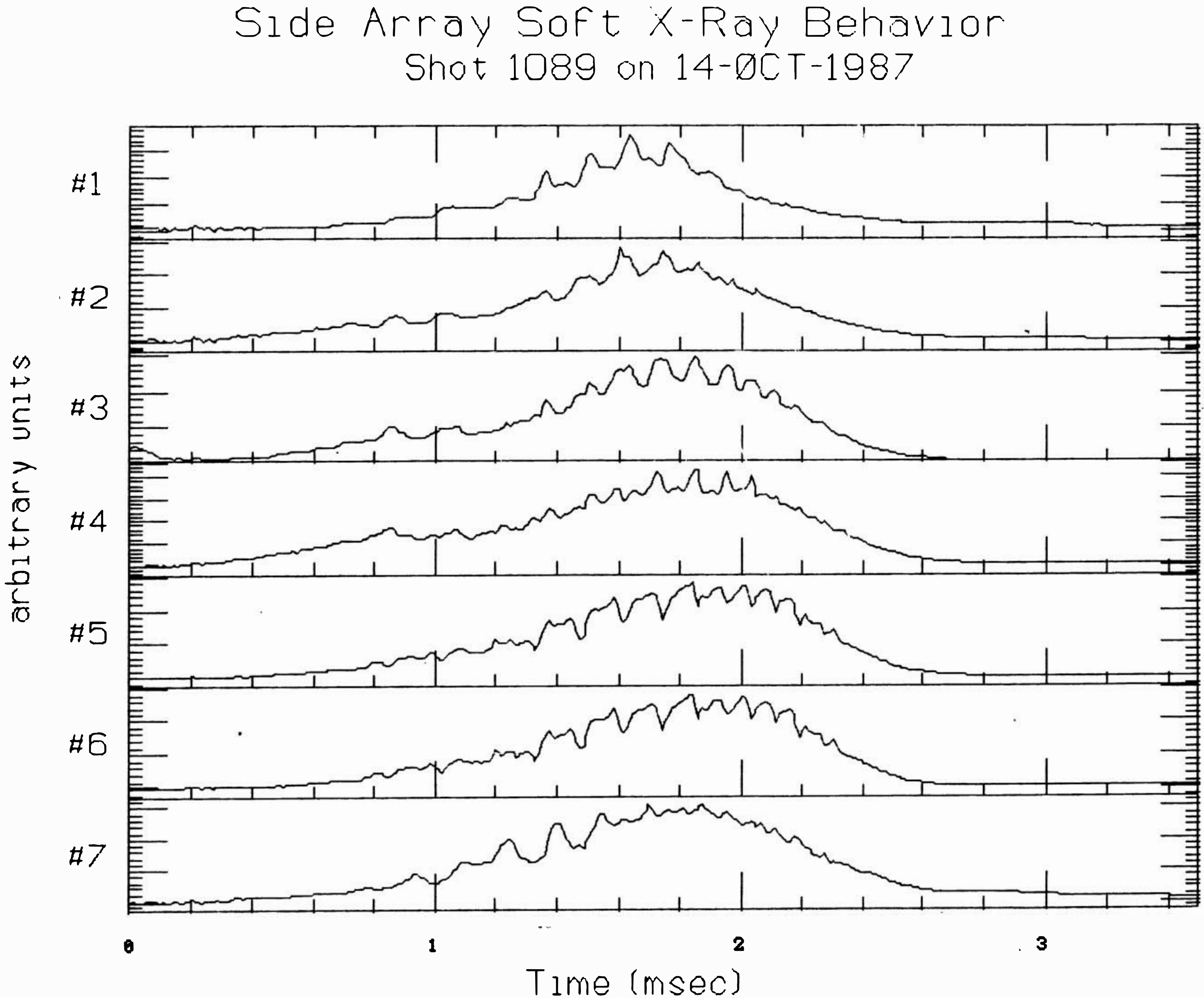

Øptical line radiation signals
Shot 1045 on 13-ØCT-1987
volts
0.20
0.15
0.10
0.05
0.00
Carbon III
volts
0.6
0.4
0.2
0.0
Copper I
volts
0.5
0.4
0.3
0.2
0.1
0.0
Nitrogen III
arb. units
Lyman H_a
0
1
2
3
Time (msec)

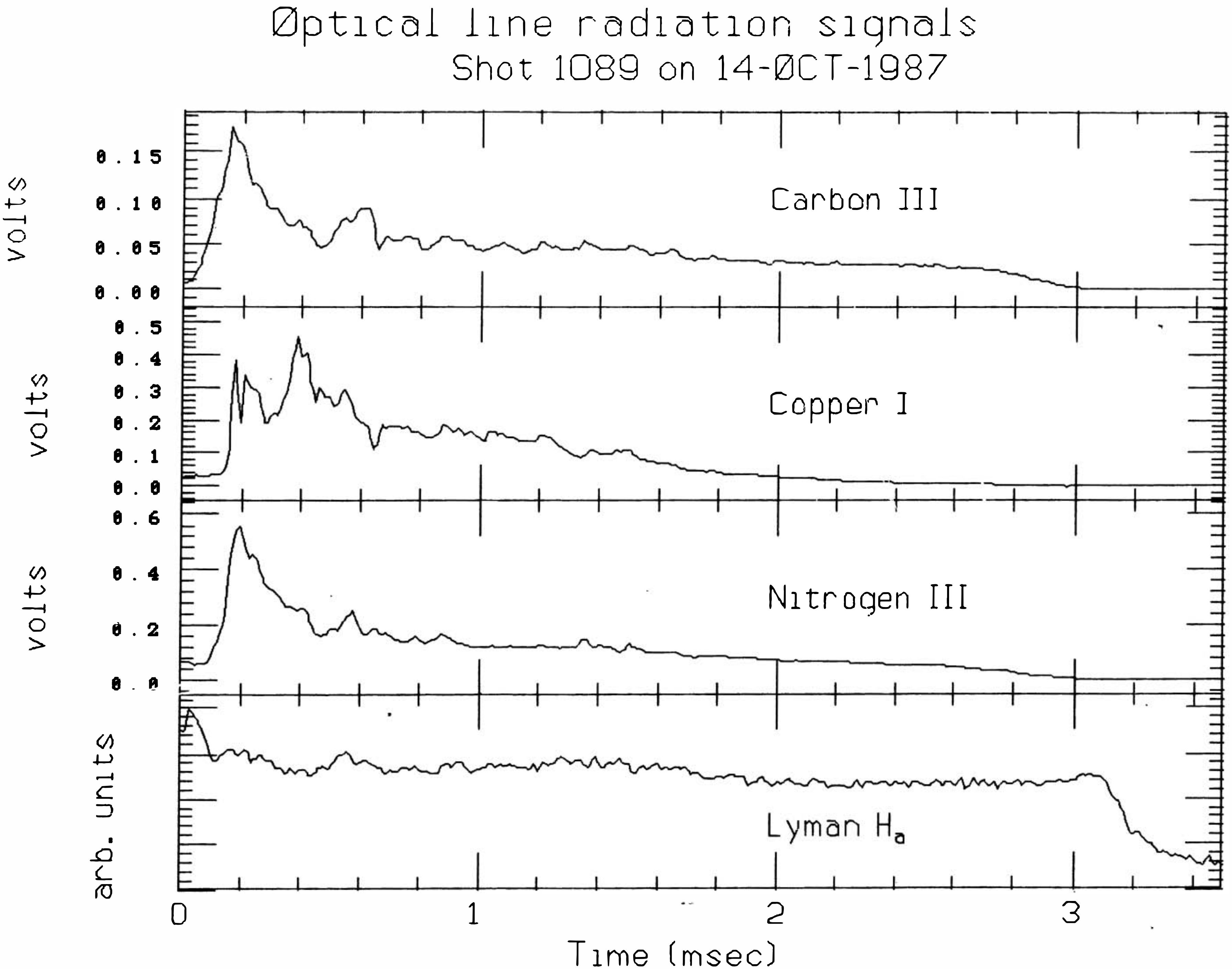

Øxygen line radiation series
high current discharge
Øxygen III: 703 A
Øxygen IV: 789 A
Øxygen V: 630 A
Øxygen VI: 1038 A
arbitrary units
0
1
2
3
Time (msec)

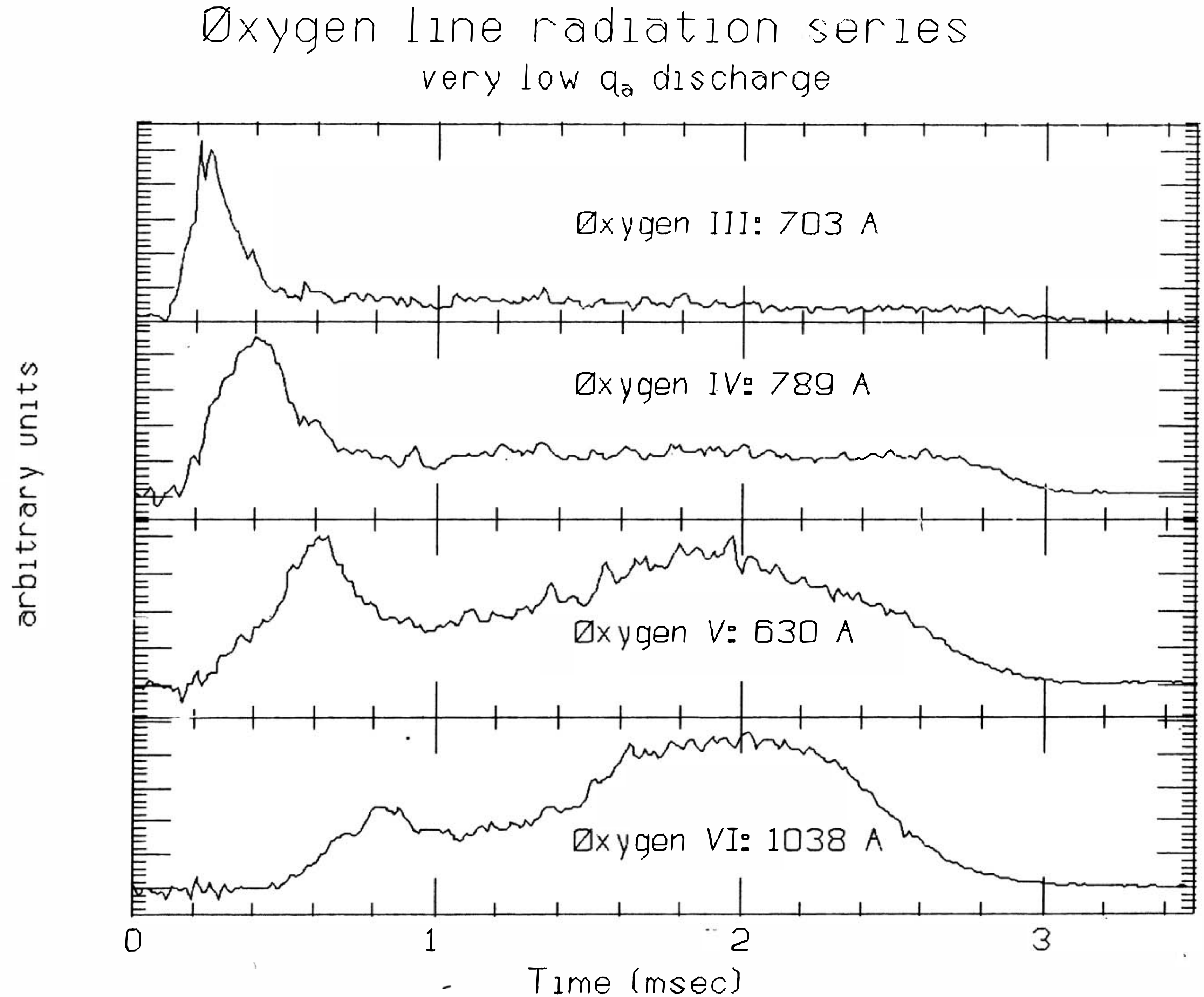
$q_a \approx 0.55$ discharges with $I_p \approx 60$ kAmps


Global plasma parameters
Shot 1089 on 14-oct-1987
kamps
60
40
20
0
plasma current
$10^{12}/cm^3$
0.8
0.6
0.4
0.2
line ave. density not available
$amps/cm^2$
3
2
1
ion sat. current
kamps
500
400
300
200
100
hoop current
volts
80
60
40
20
0
poloidal gap voltage
0
1
2
3
4
Time (msec)

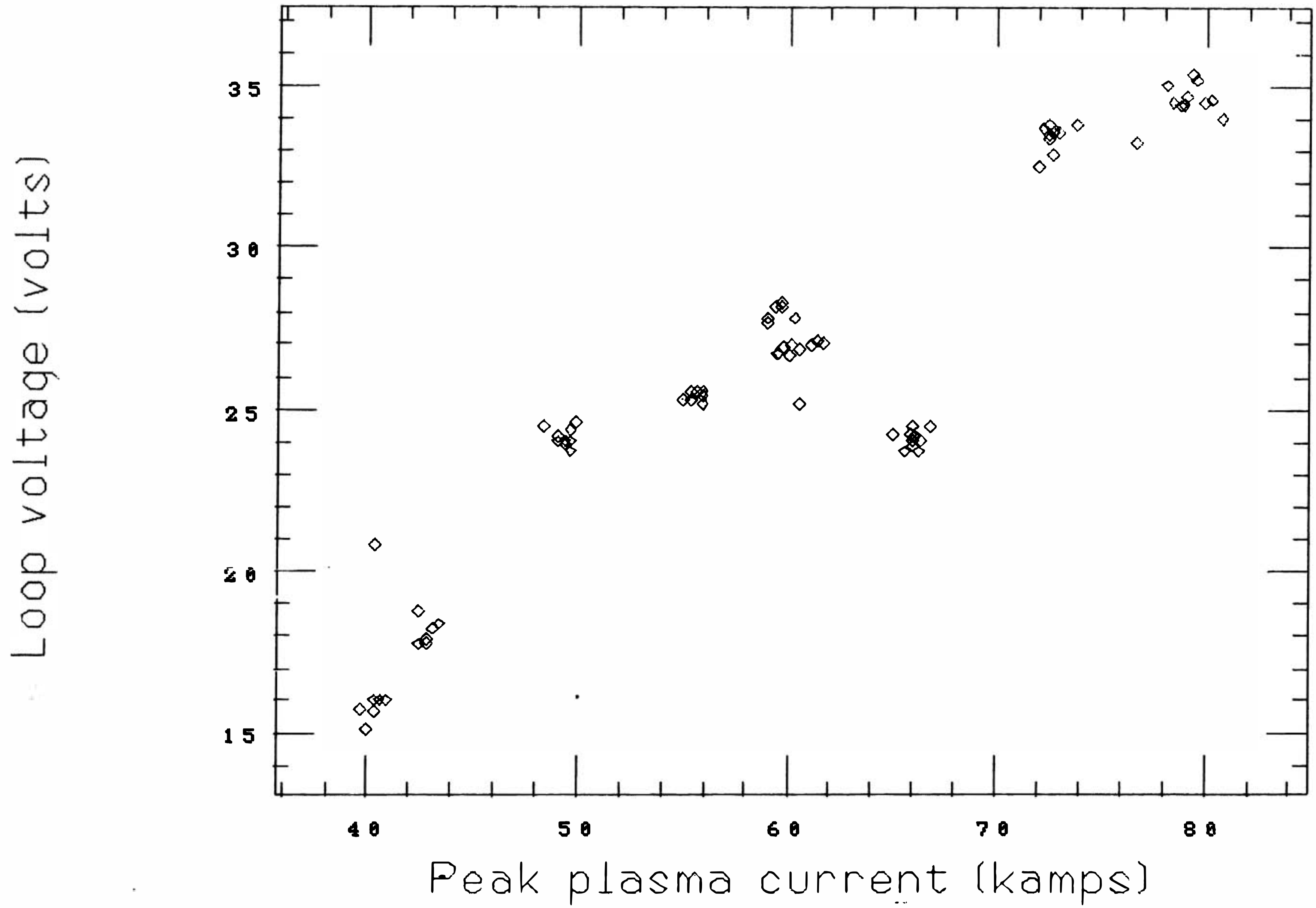

Derived plasma parameters
Shot 1089 on 14-ØCT-1987
q_a
loop voltage
conductivity temperature
confinement time
volts
eV
microsec
2.0
1.5
1.0
0.5
0.0
50
0
-50
-100
60
40
20
0
150
100
50
0
0.5
1
1.5
2
2.5
3
Time (msec)


Side Array Soft X-Ray Behavior
Shot 1089 on 14-OCT-1987
#1
#2
#3
#4
#5
#6
#7
arbitrary units
0
1
2
3
Time (msec)

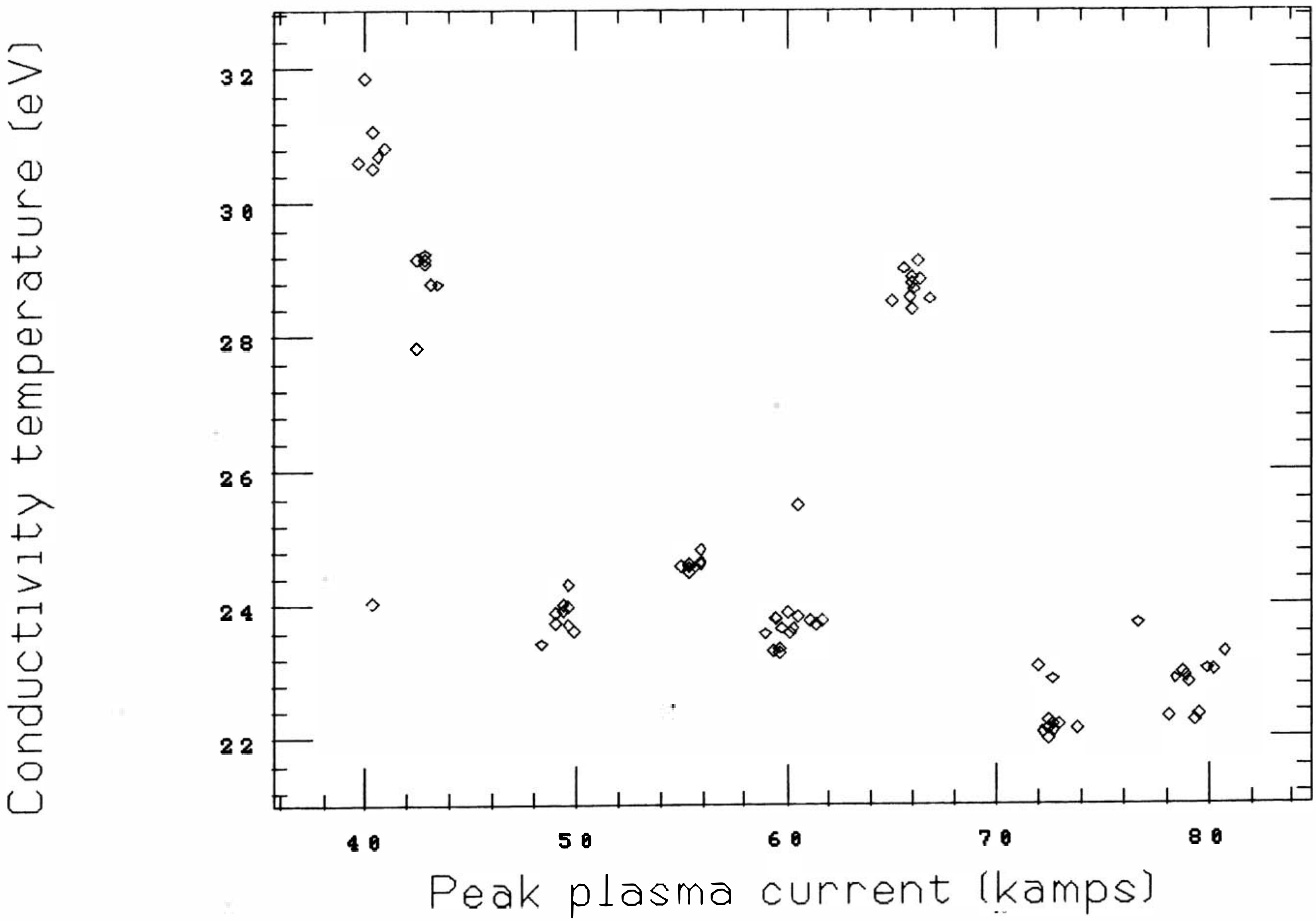

Øptical line radiation signals
Shot 1089 on 14-ØCT-1987
volts
0.15
0.10
0.05
0.00
Carbon III
volts
0.5
0.4
0.3
0.2
0.1
0.0
Copper I
volts
0.6
0.4
0.2
0.0
Nitrogen III
arb. units
Lyman H_a
0
1
2
3
Time (msec)

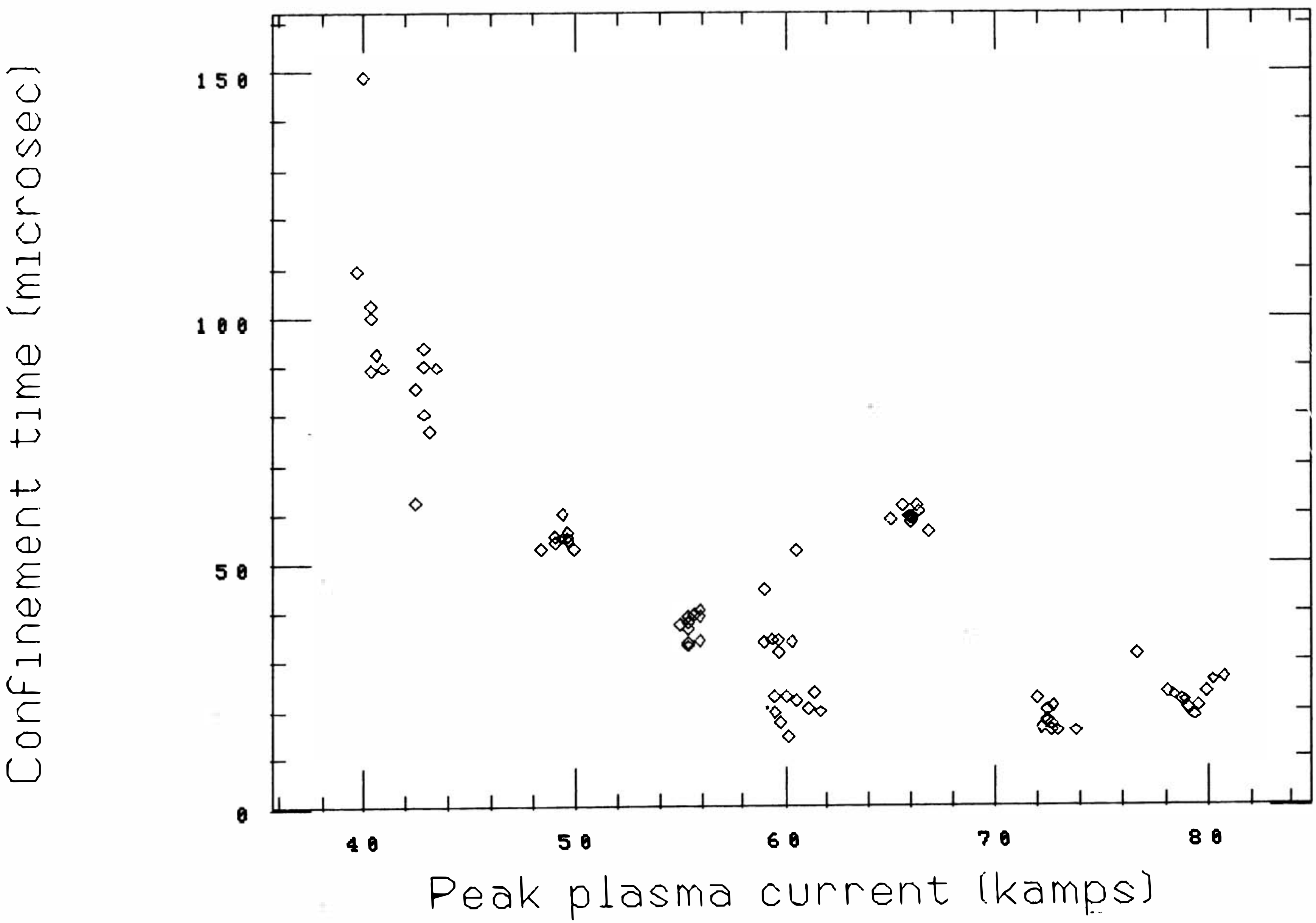

Øxygen line radiation series
very low q_a discharge
Øxygen III: 703 A
Øxygen IV: 789 A
Øxygen V: 630 A
Øxygen VI: 1038 A
arbitrary units
0
1
2
3
Time (msec)

Scaling of plasma parameters at peak plasma current in discharges (unoptimized) at $q_a \approx 0.7$



35
30
25
20
15
40
50
60
70
80
Loop voltage (volts)
Peak plasma current (kamps)


Conductivity temperature (eV)
32
30
28
26
24
22
40
50
60
70
80
Peak plasma current (kamps)



Confinement time (microsec)
150
100
50
0
40
50
60
70
80
Peak plasma current (kamps)

FUTURE WORK

I. Improve the quality of the discharges

II. Investigate the effect of the toroidal rail limiters

III. Finish designing and installing the external b-dot array

IV. Use the soft x-ray arrays on the top and side of Tokapole II to reconstruct profiles

SUMMARY

I. $q<1$ discharges with high plasma current have been achieved

II. Discharges seem to be limited by extraneous effects

- A. Impurity radiation
- B. Machine conditioning and optimization
- C. Objects in the scrape-off region

III. Conductivity temperature appears to remain constant with increasing plasma current

IV. Oxygen line radiation series indicates that the temperature does not increase with an increase in plasma current