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Observations of Plasma Tearing Instabilities and Associated Axial Translation in Field-Reversed Experiments

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OBSERVATIONS OF PLASMA TEARING INSTABILITIES AND ASSOCIATED AXIAL TRANSLATION IN FIELD-REVERSED EXPERIMENTS

by

W. T. Armstrong, J. C. Cochrane, J. Lipson, M. Tuszewski

ABSTRACT

Tearing and reconnection processes during the formation and quiescent periods of a field-reversed configuration are studied with an axial array of compensated diamagnetic loops. Several representative plasma shots are documented.

The formation of a field-reversed configuration (FRC) includes the resistive tearing and reconnection of oppositely directed field lines at the ends of a hot plasma produced in a theta-pinch.[1,2] A single, closed-field-line FRC is obtained, which typically persists in a quiescent, equilibrium state for up to 50 μs before a rotational instability disrupts the configuration. Various past work indicates that further tearing during the quiescent phase may occur and result in multiple FRC cells.[3,4,5] Experiments on the FRX-B field-reversed theta-pinch have typically not shown such tearing phenomena at later times.[1] However, recent experiments on FRX-B at higher fields and higher densities have indicated that tearing effects appear on ~30% of the shots. The characteristics of these tearing modes vary greatly from shot to shot. The tearing rate may be controlled by local resistivity changes due to variation in impurity distributions, pre-ionization conditions or anomalous turbulence levels. The tearing rate may be further affected by plasma flow. Because there are so many contributing factors to the tearing rate, it is extremely difficult to quantify the tearing behavior under the present experimental controls. Hence, this report is intended to simply document representative plasma shots which display the diversity of the observed tearing behavior.

The experimental conditions are as follows:

Coil i.d.	25 cm
Coil length	100 cm
End-mirrors	10% in vacuum

Fill gas	29 to 49 mtorr D_2
B_{bias}	-3.0 kG
B_{max}	+13.0 kG
$B(t = 10\ \mu s)$	~10.0 kG
$\tau_{1/4}$	~2.6 μs
$\tau_{L/R}$	~120 μs.

where $\tau_{1/4}$ is the quarter period rise time of the main field. The principal diagnostic is an axial array of nine compensated diamagnetic loops. This diagnostic provides an axial profile of the effective diamagnetic radius, or excluded flux radius, defined by

$$r_{\Delta\phi} = r_\ell \left(1 - \frac{\int_\ell BdA}{\pi r_\ell^2 B_o}\right)^{1/2} ,$$

where r_ℓ is the radius of the conducting loop measuring the enclosed flux $\int_\ell BdA$ and B_o is the external field measured at r_ℓ. In the present study a single loop measuring the enclosed flux was used. The loop was positioned in the coil midplane just inside the coil. Since the coil surface approximates a flux surface to a high accuracy, a single loop suffices. The nine probes along the axis measuring the local B_o are balanced with the loop on a vacuum shot to calibrate differences in sensitivity and phase. The diagnostic data presented here includes:

$r_{\Delta\phi}$ axial profiles	vs t
$r_{\Delta\phi}$ at each station	vs t
B_o in the midplane	vs t
T_i from CV 2271Å Doppler broadening	vs t
CV 2271Å total intensity (I)	vs t
T_i from gaussian fit of CV 2271Å profile	at t = 10 μs
Intensity of CV 2271Å in channels separated by ~.3Å.	vs t

The $r_{\Delta\phi}$ axial profiles display the gross plasma changes due to tearing and axial translation which are of present interest. The history of T_i is a good indicator of the lifetime of the closed-field-line FRC. Whereas, the individual channel signals of CV 2271Å radiation clearly show the onset of the rotational instability in the appearance of a modulation of the signal amplitude.

Tearing is associated with other plasma behavior found in the following data. In particular, axial translation of the FRC sometimes occurs. Translation may in some instances be due to nonsymmetric field reconnection during FRC formation or due to additional tearing at later times.

There are seven shots presented displaying the following behavior:

1) no translation, or tearing (typical of 70% of the shots taken)
2) early rapid translation
3) later translation
4) tearing into two FRC's with each FRC persisting
5) tearing into two FRC's which coalesce
6) tearing into two FRC's with one possibly translating out of the coil
7) early translation with later tearing and total disruption of the FRC.

Each shot is characterized by the following information:

shot #
fill pressure P_o
time at which main field was initiated
tearing and translation behavior
stable period τ_s (to the onset of the rotational instability)
lifetime (to the disruption of the FRC).

Otherwise, the data is presented without further interpretation.

Case #1

Shot #3016

P_o = 29 mtorr

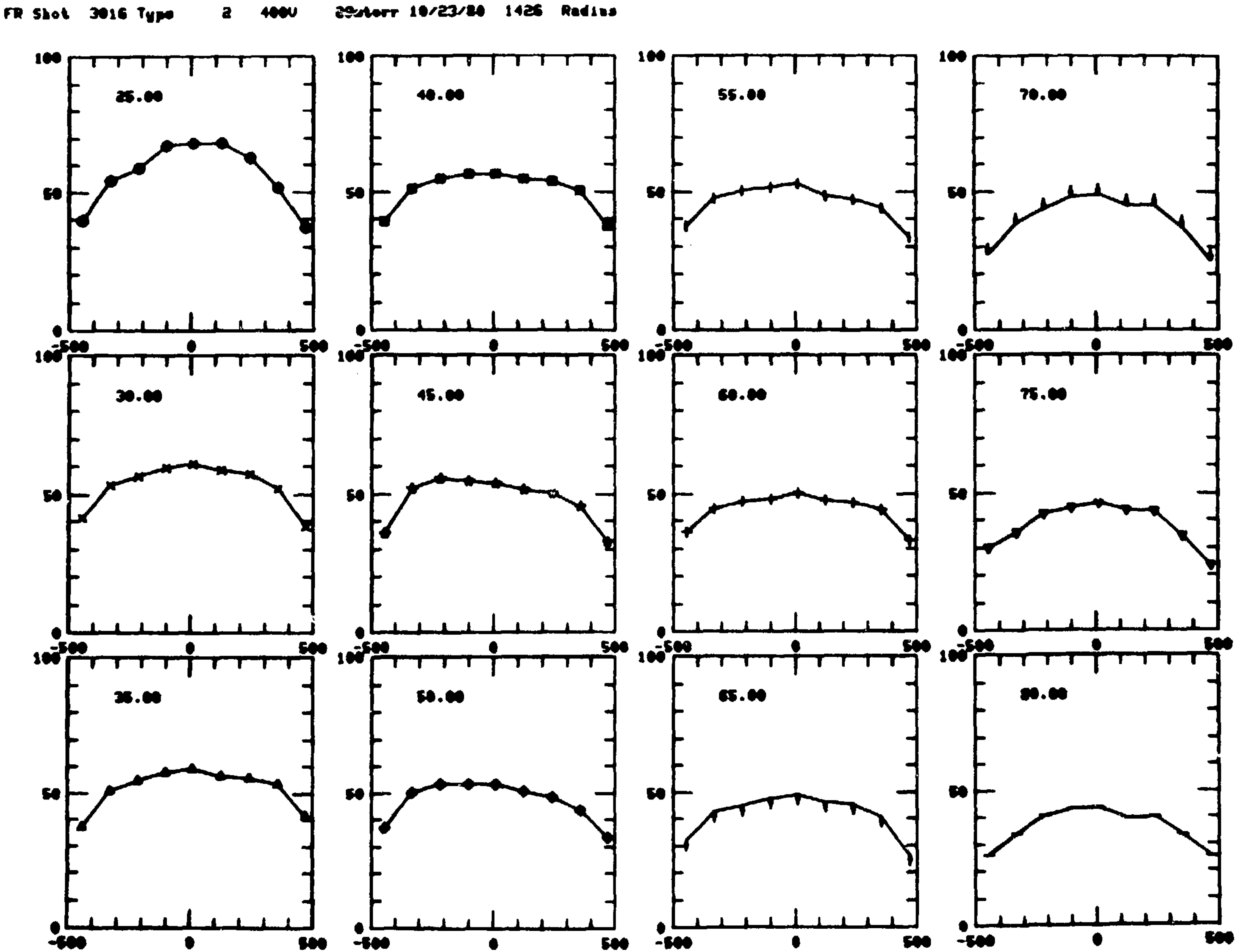
t_o = 20.0 μs

no translation or tearing

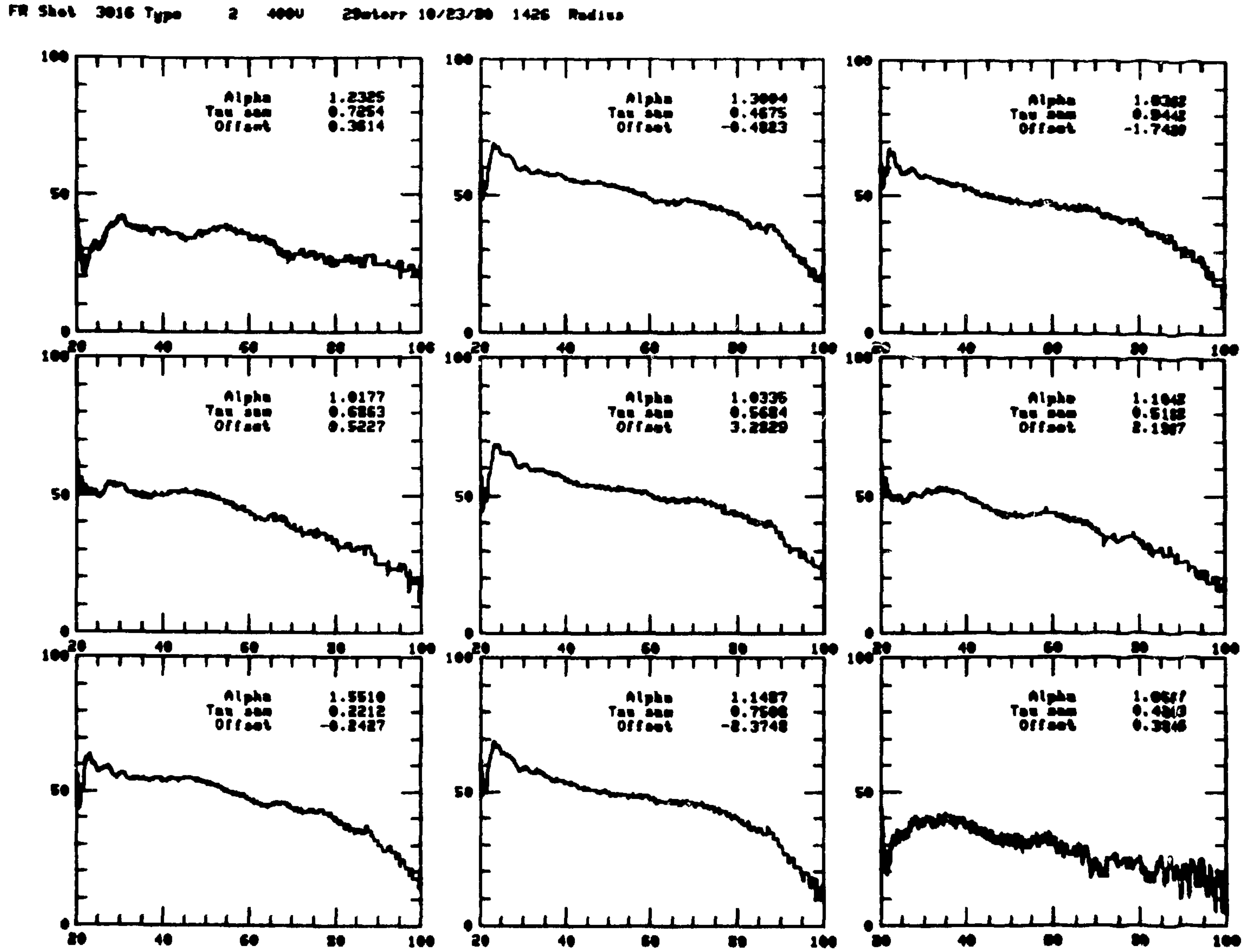
$\tau_s \simeq 42$ μs

$\tau_\ell \simeq 80$ μs

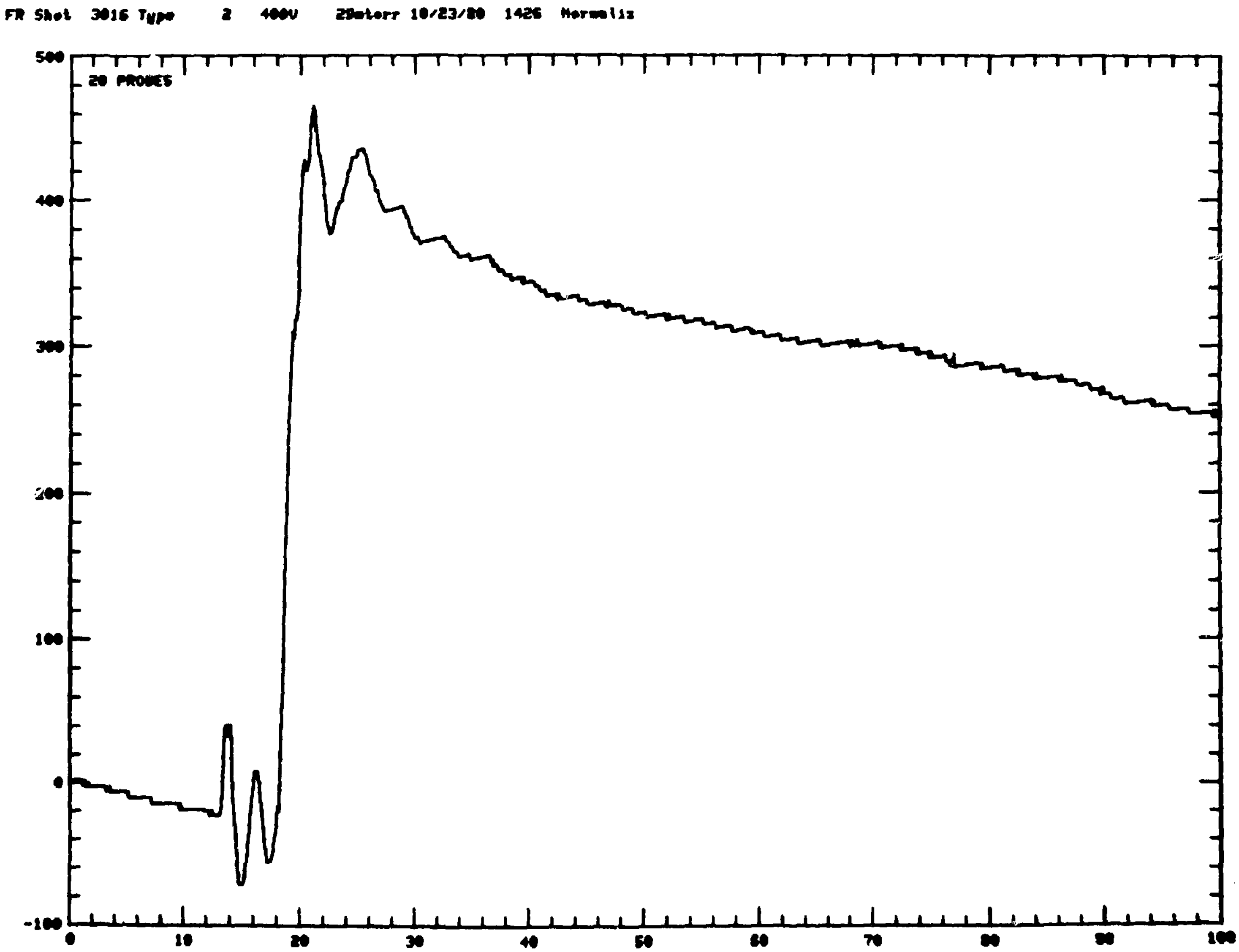
(typical of ~70% of the shots taken)



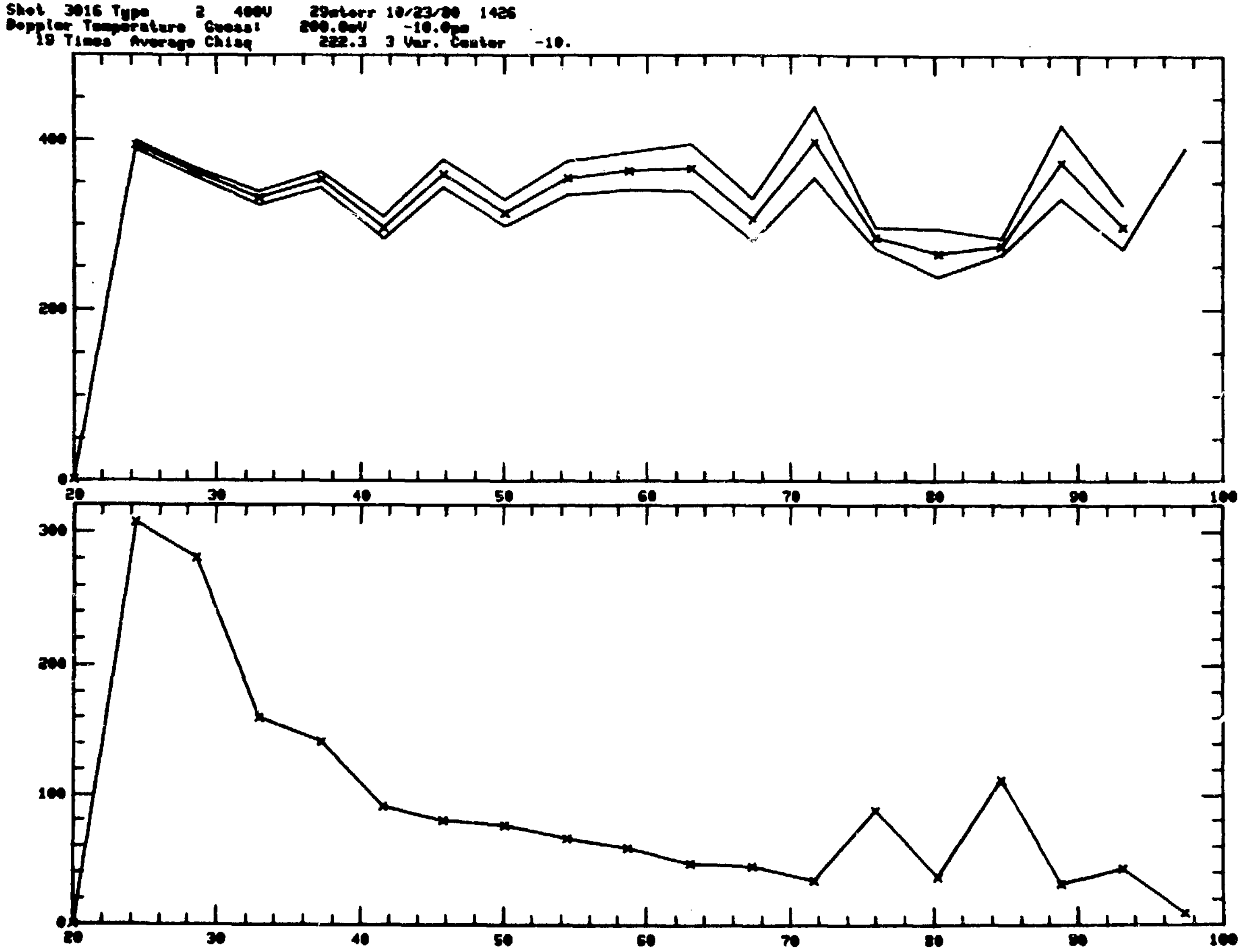
$r_{\Delta\phi}$(mm) vs z(mm) and t(μs)



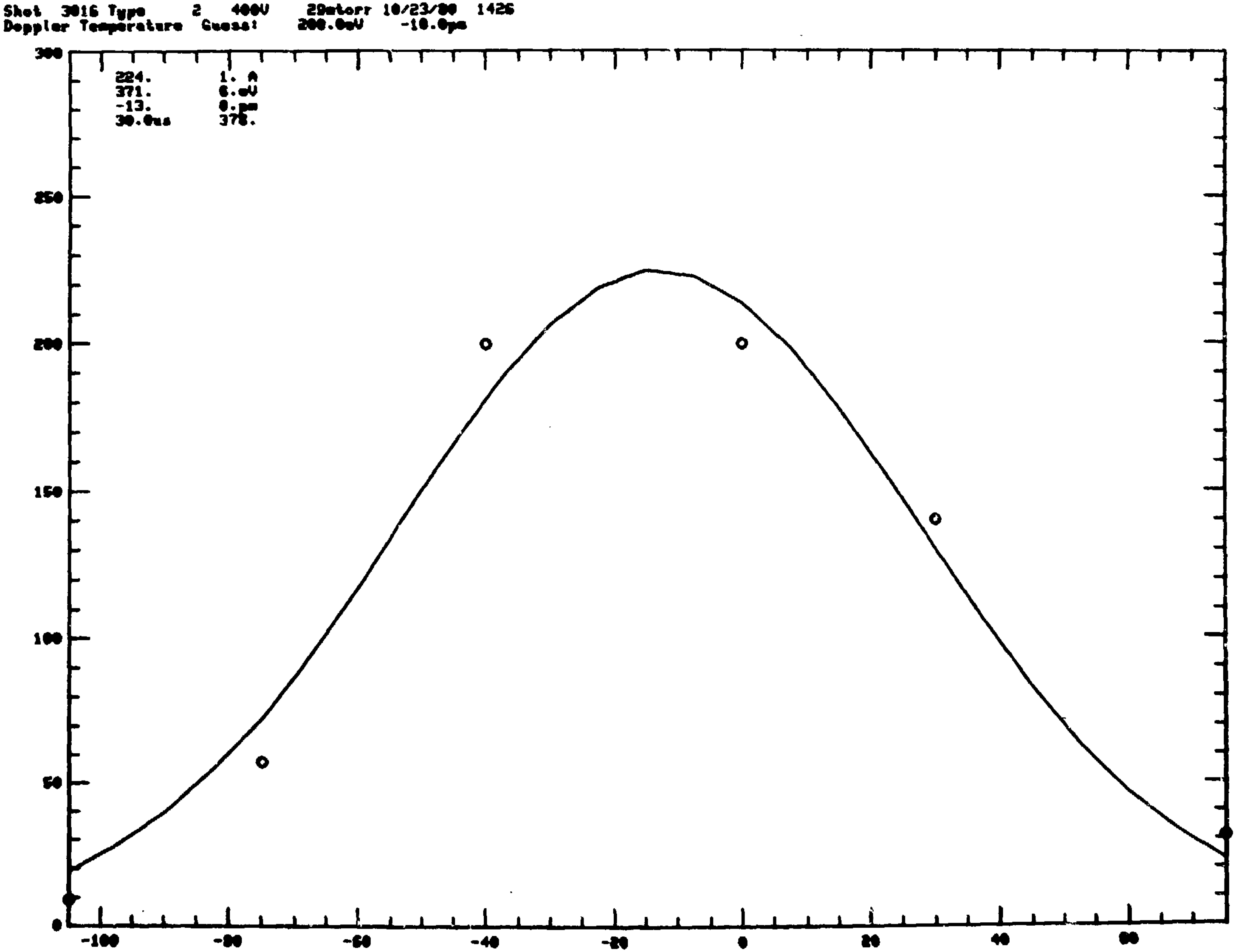
r_{AA} (μm) vs t(μs) and z(mm)



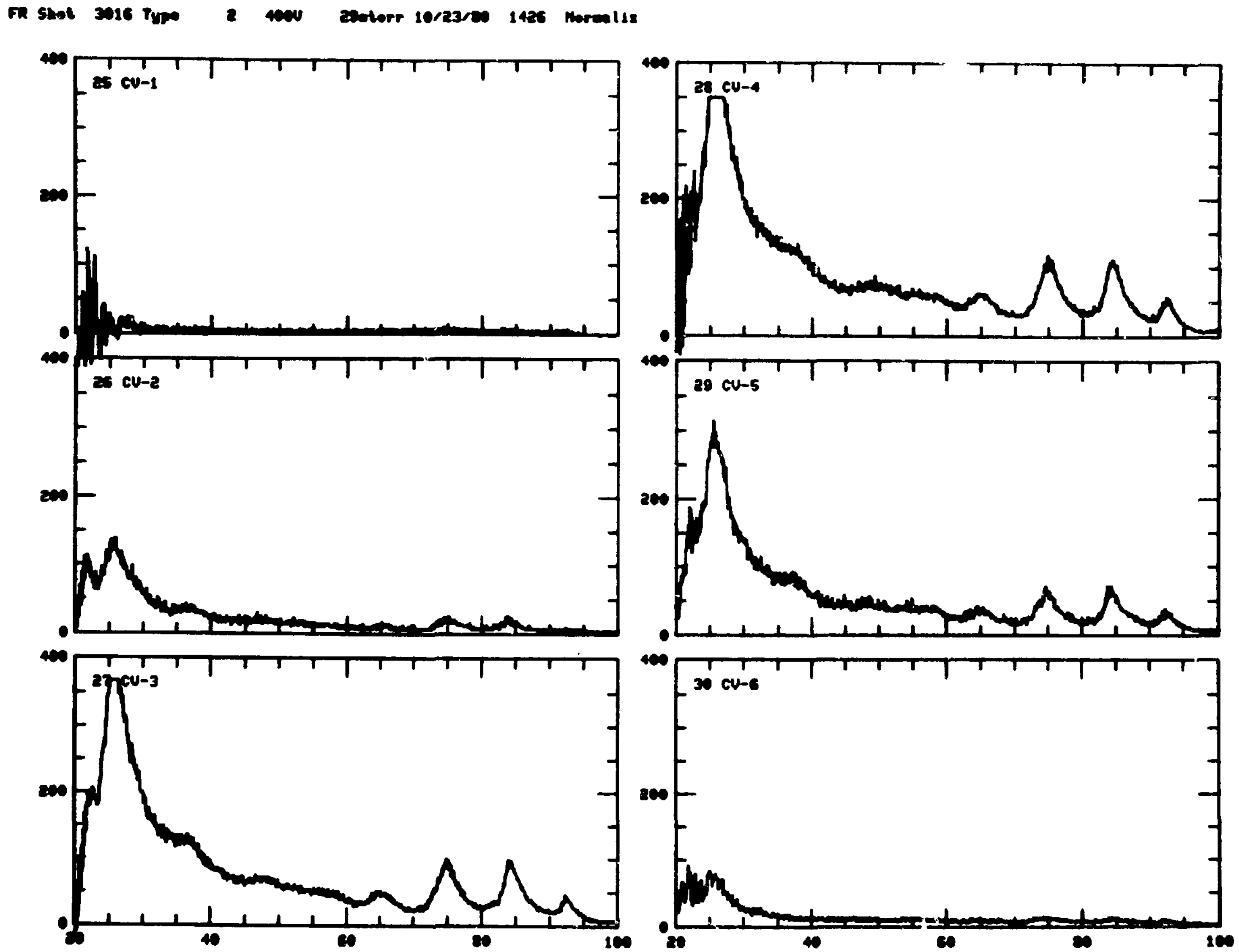
B_o (arbitrary units) vs t(μs) at z = o



T_i(eV) vs t(μs) and I(arbitrary units) vs t(μs)



I(Δλ)(arbitrary units) vs Δλ(pm) at t = 10 μs



I in each CV channel vs t(μs)

Case #2

Shot #3013

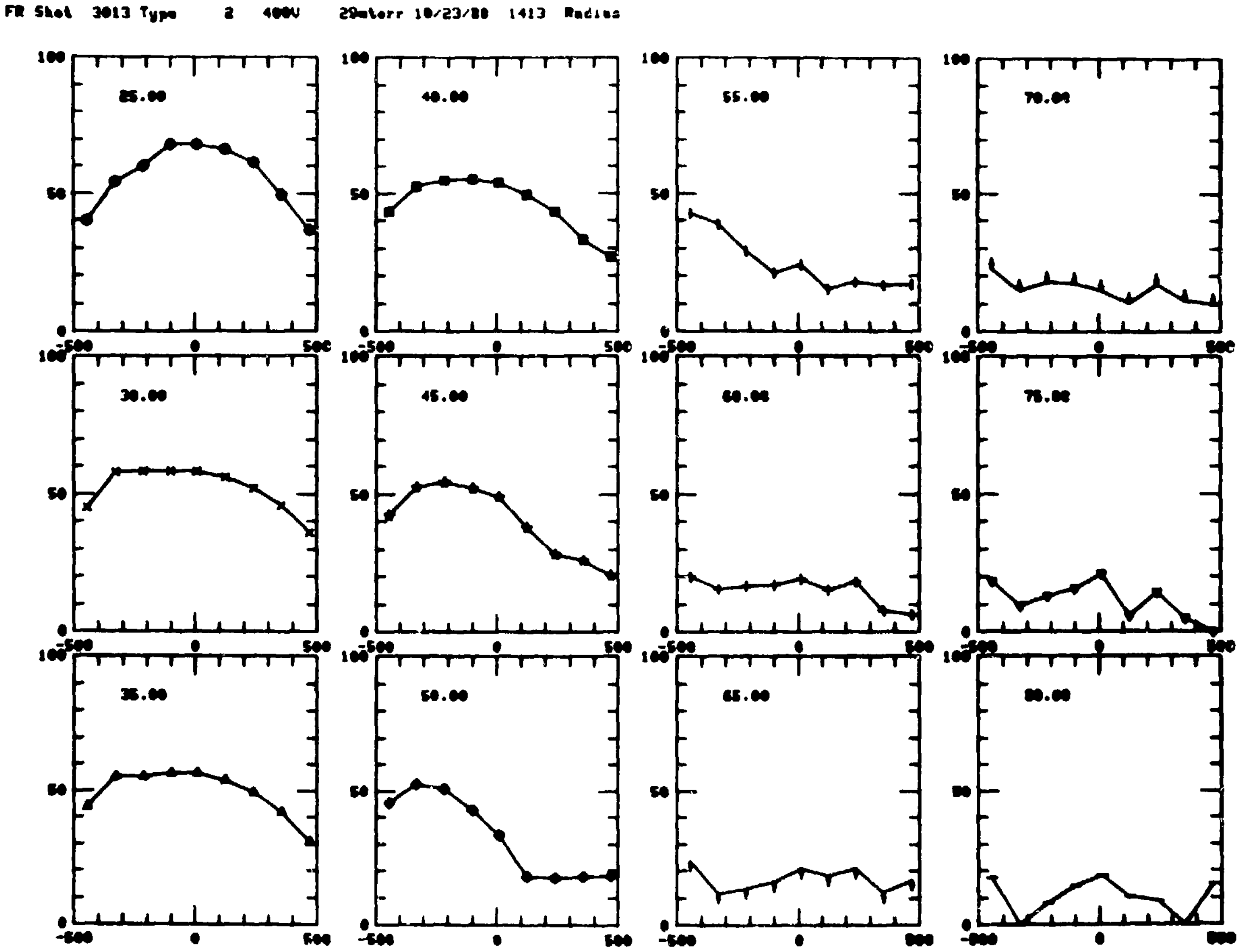
P_o = 29 mtorr

t_o = 20.0 μs

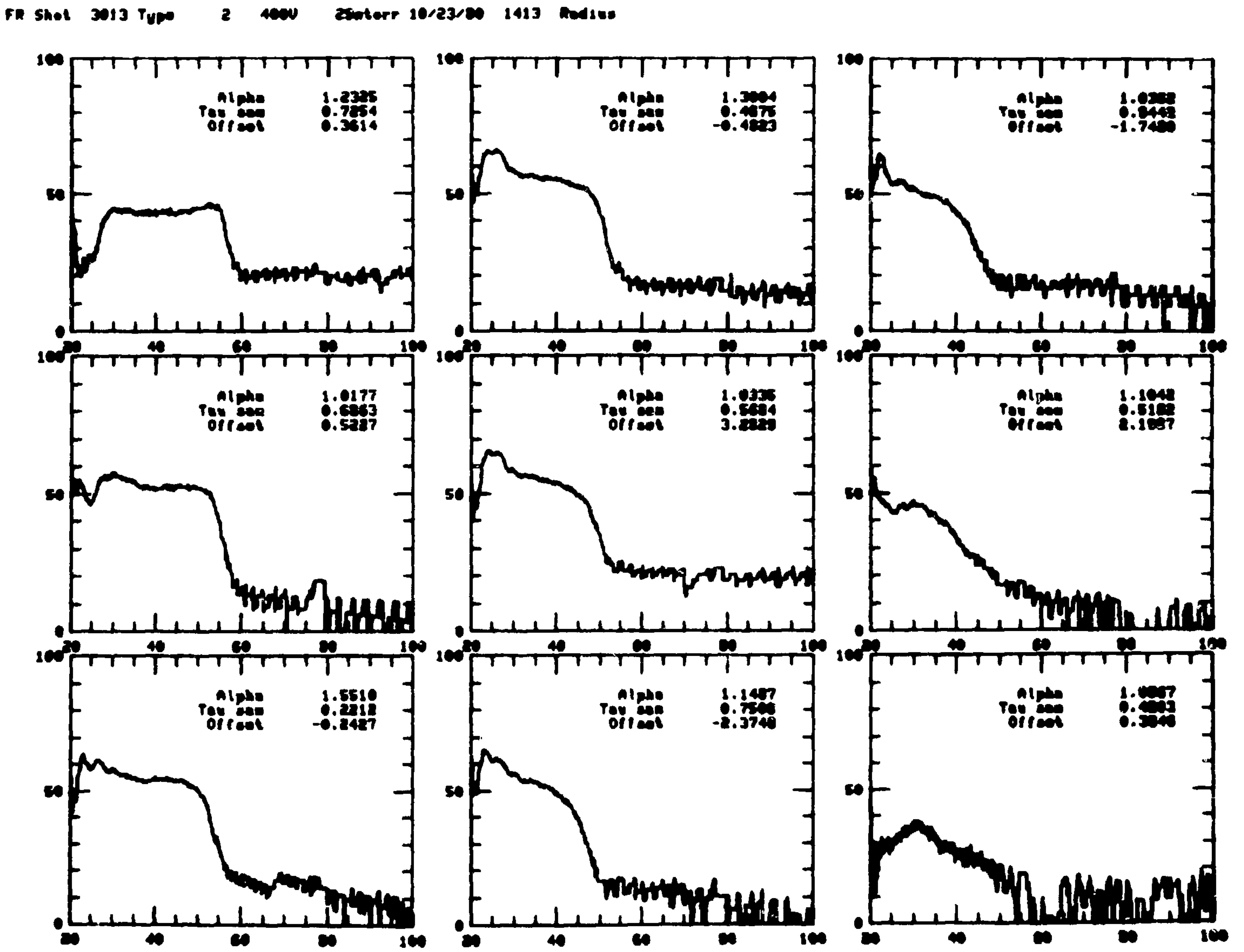
rapid translation left at t_o + 20 μs destroying FRC

τ_s = ? (rotational instability not observed)

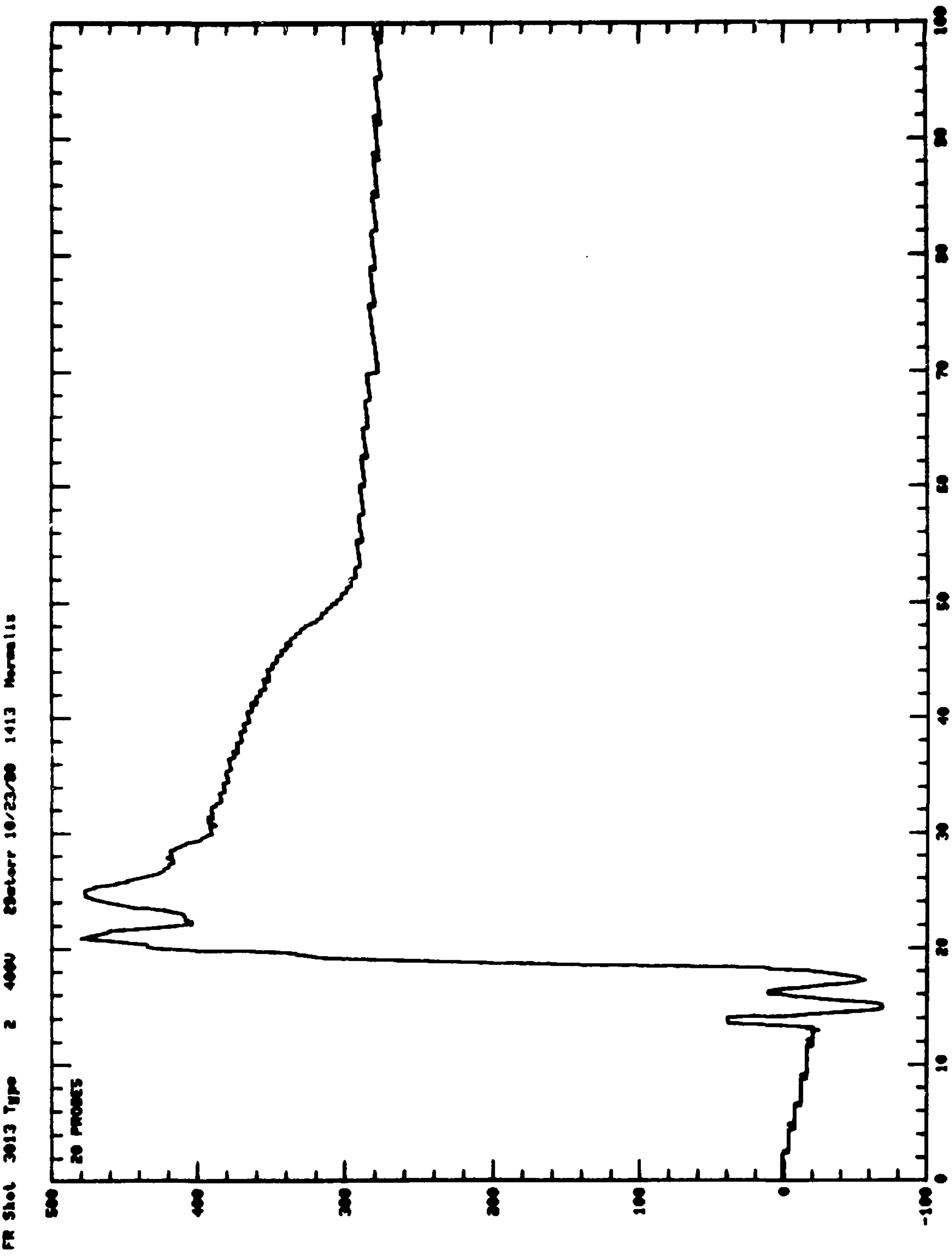
$\tau_\ell \simeq$ 27 μs



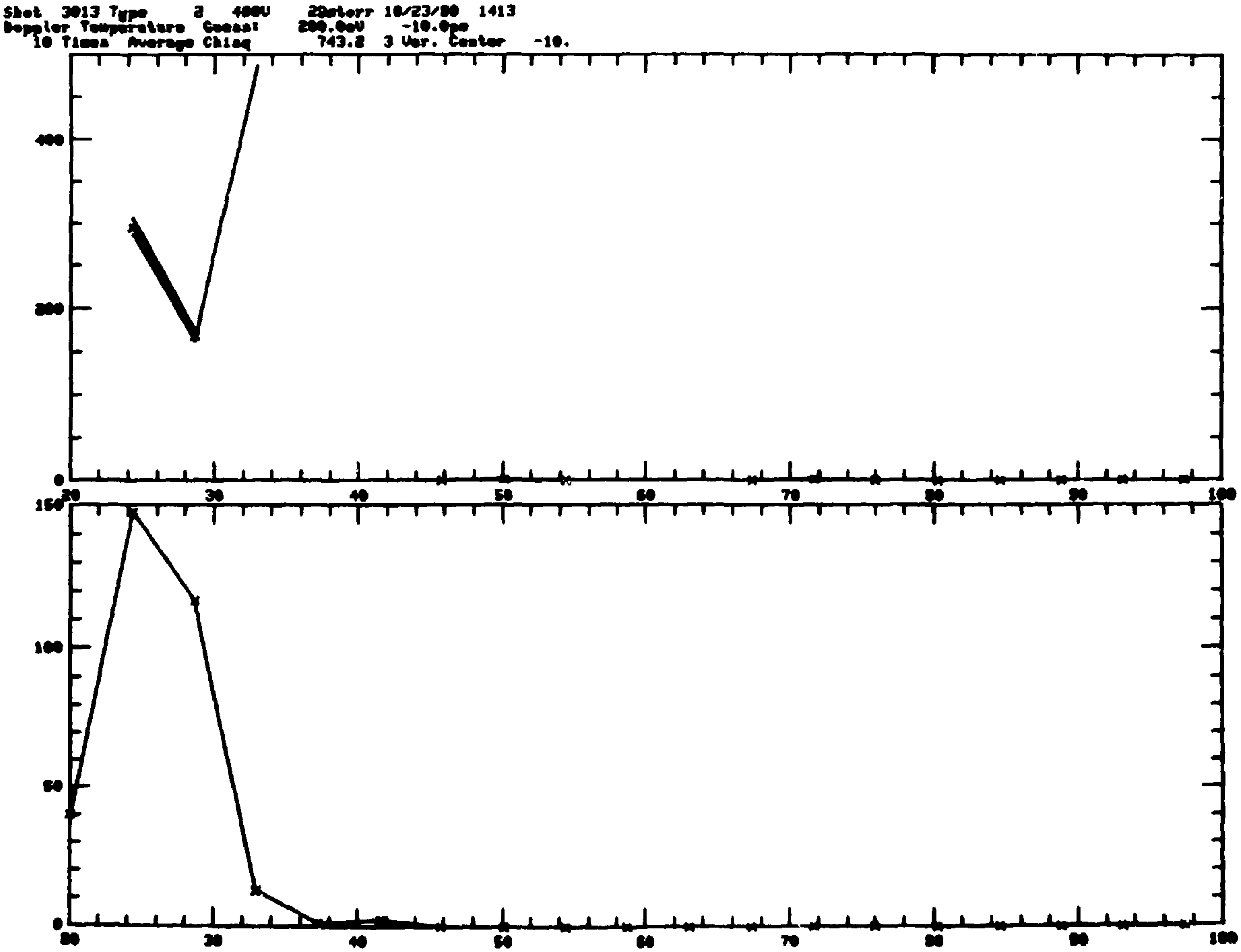
$r_{\Delta\phi}$ (mm) vs z(mm) and t(μs)



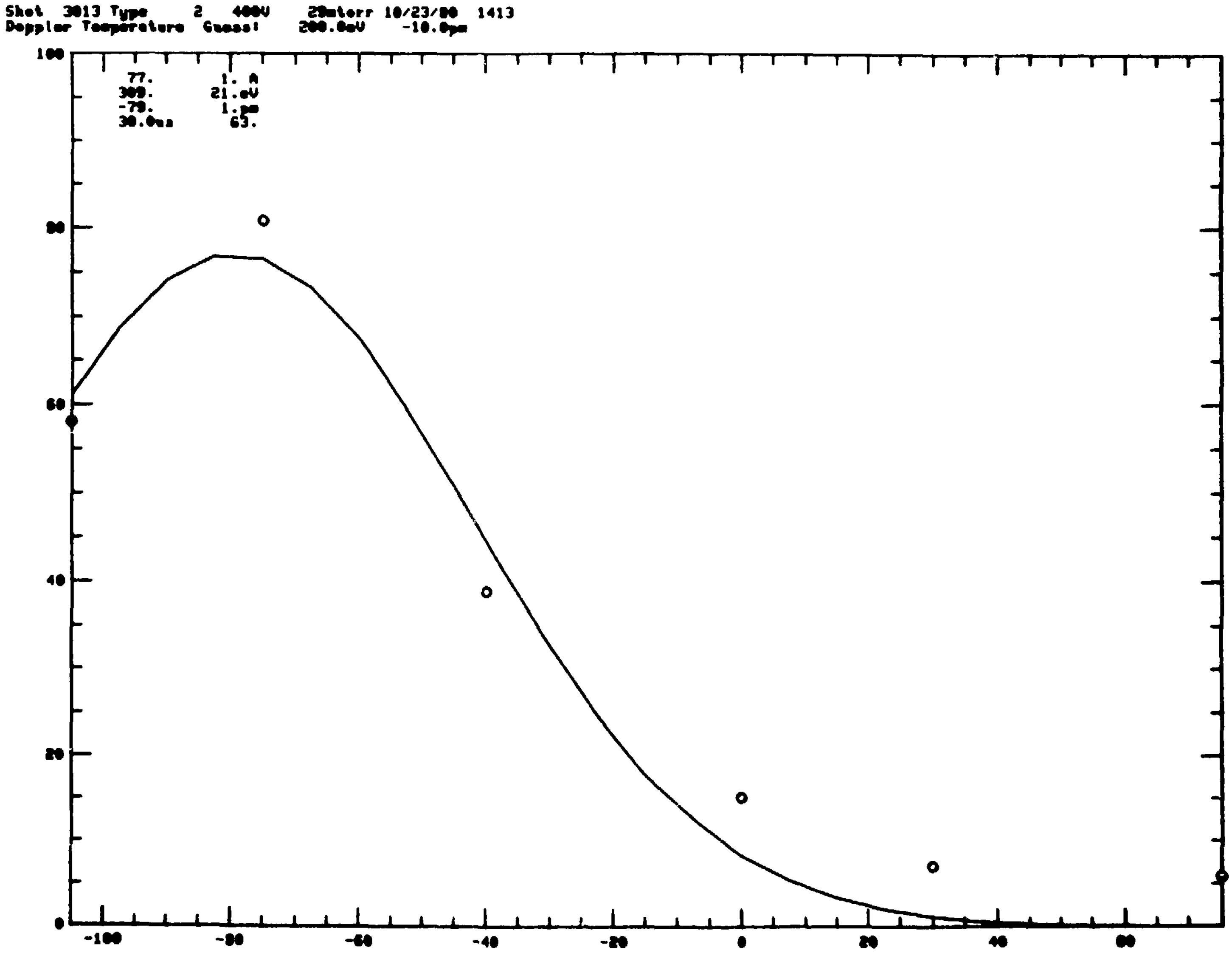
r (mm) vs t(μs) and z(mm)



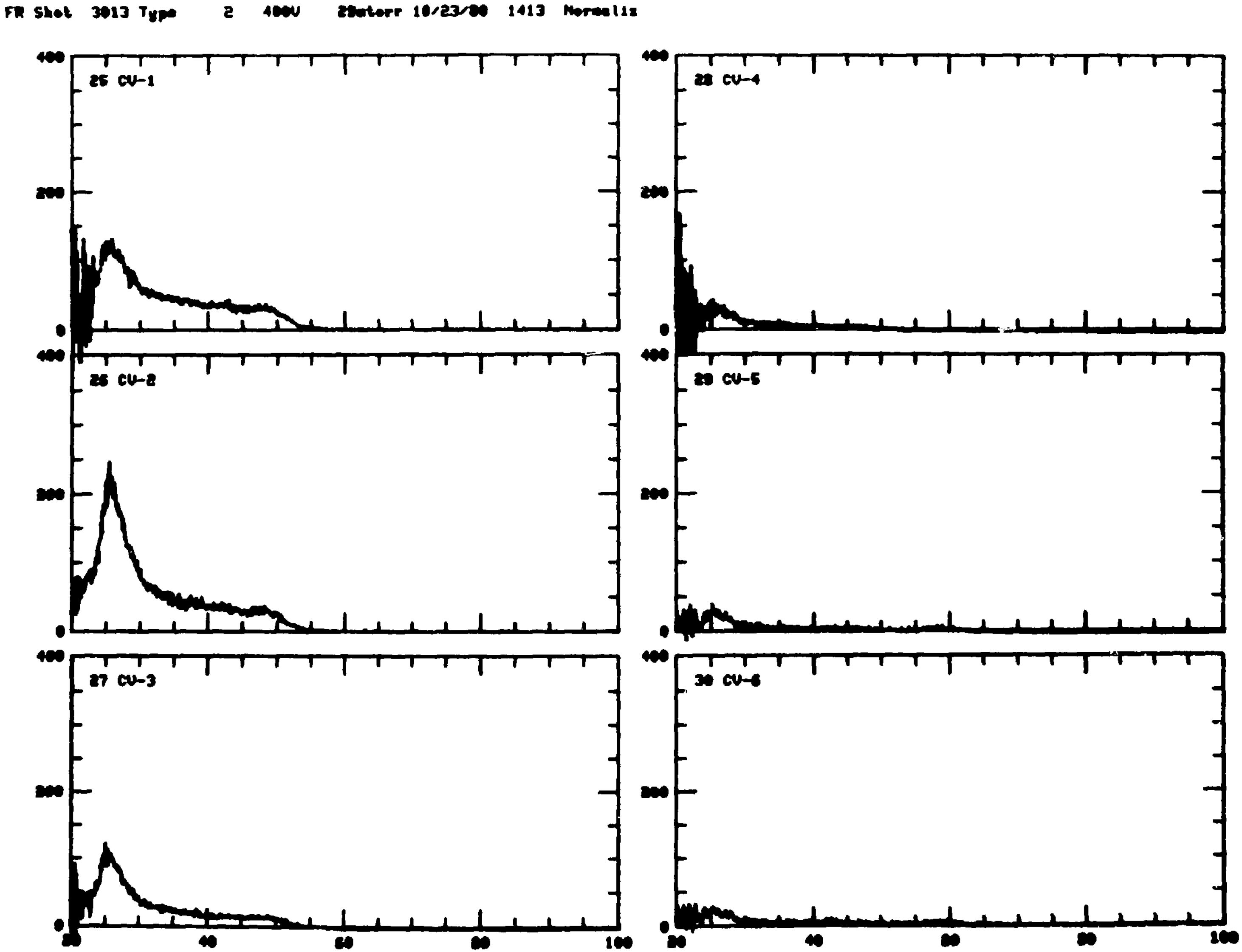
B_o (arbitrary units) vs t(μs) at z = 0



T_i(eV) vs t(μs) and I(arbitrary units) vs t(μs)



I($\Delta\lambda$)(arbitrary units) vs $\Delta\lambda$(pm) at t = 10 μs



I in each CV channel vs t(μs)

Case #3

Shot #3007

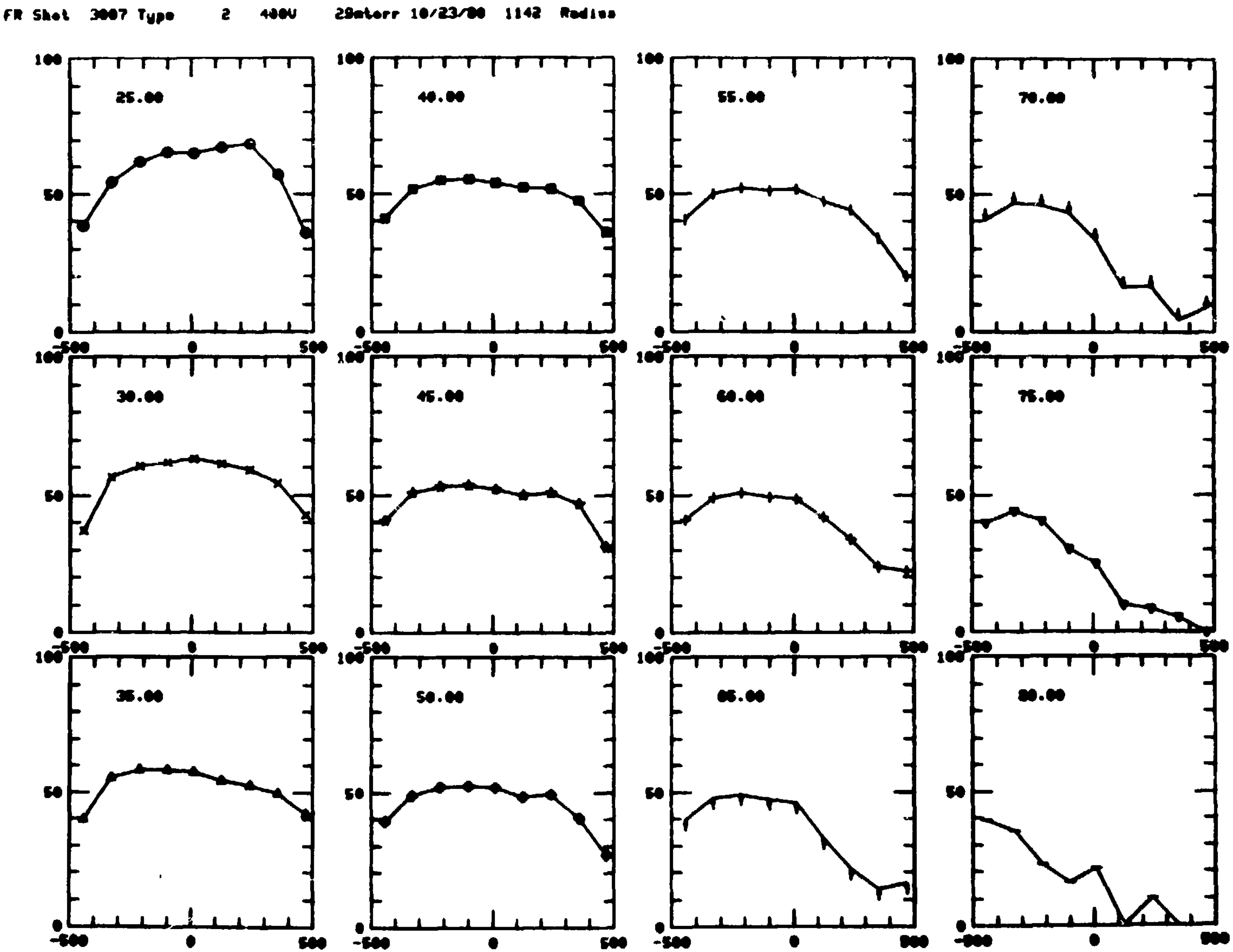
P_o = 29 mtorr

t_o = 20.0 μs

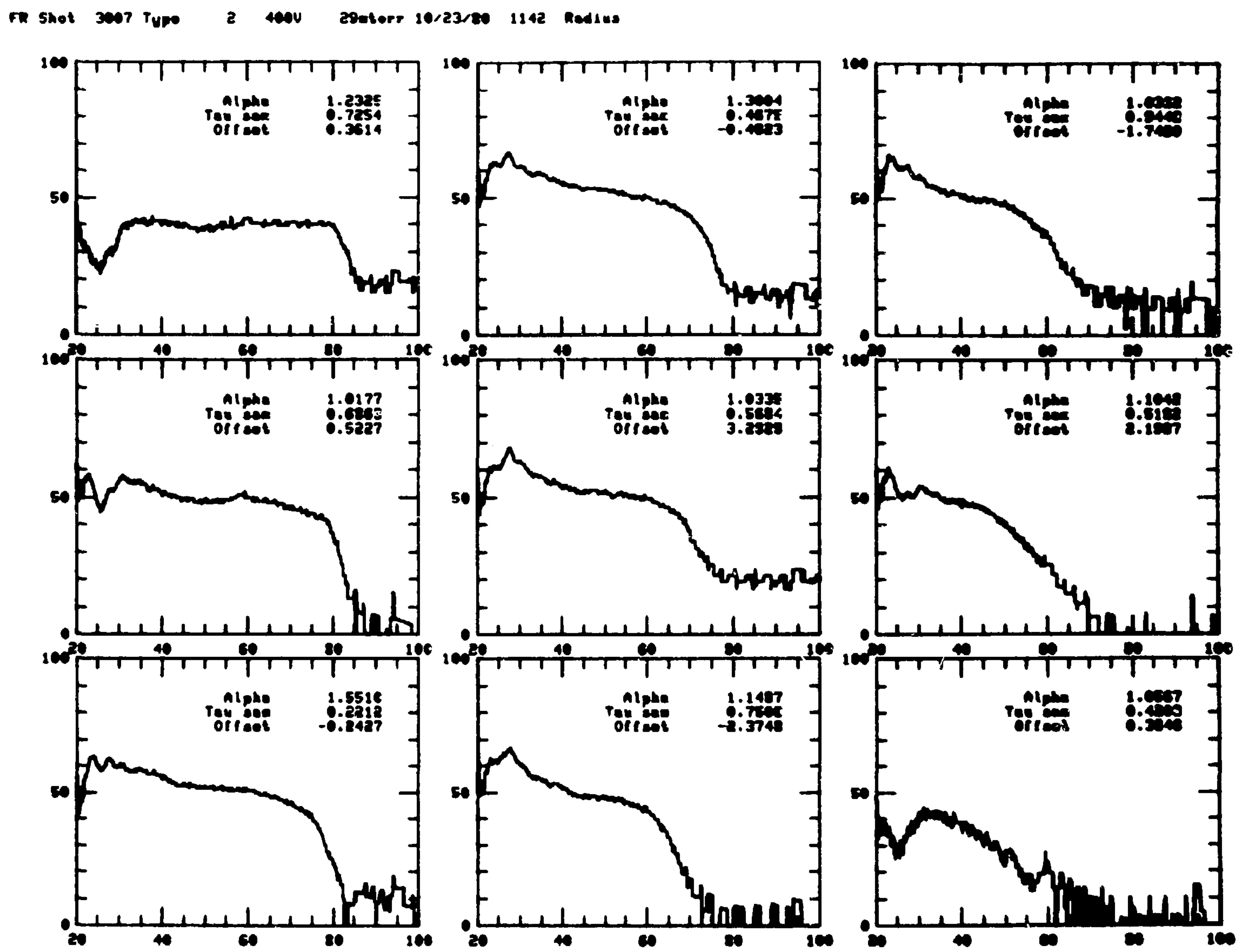
delayed translation left at t_o + 35 μs destroying FRC

τ_s = ? (rotational instability not observed)

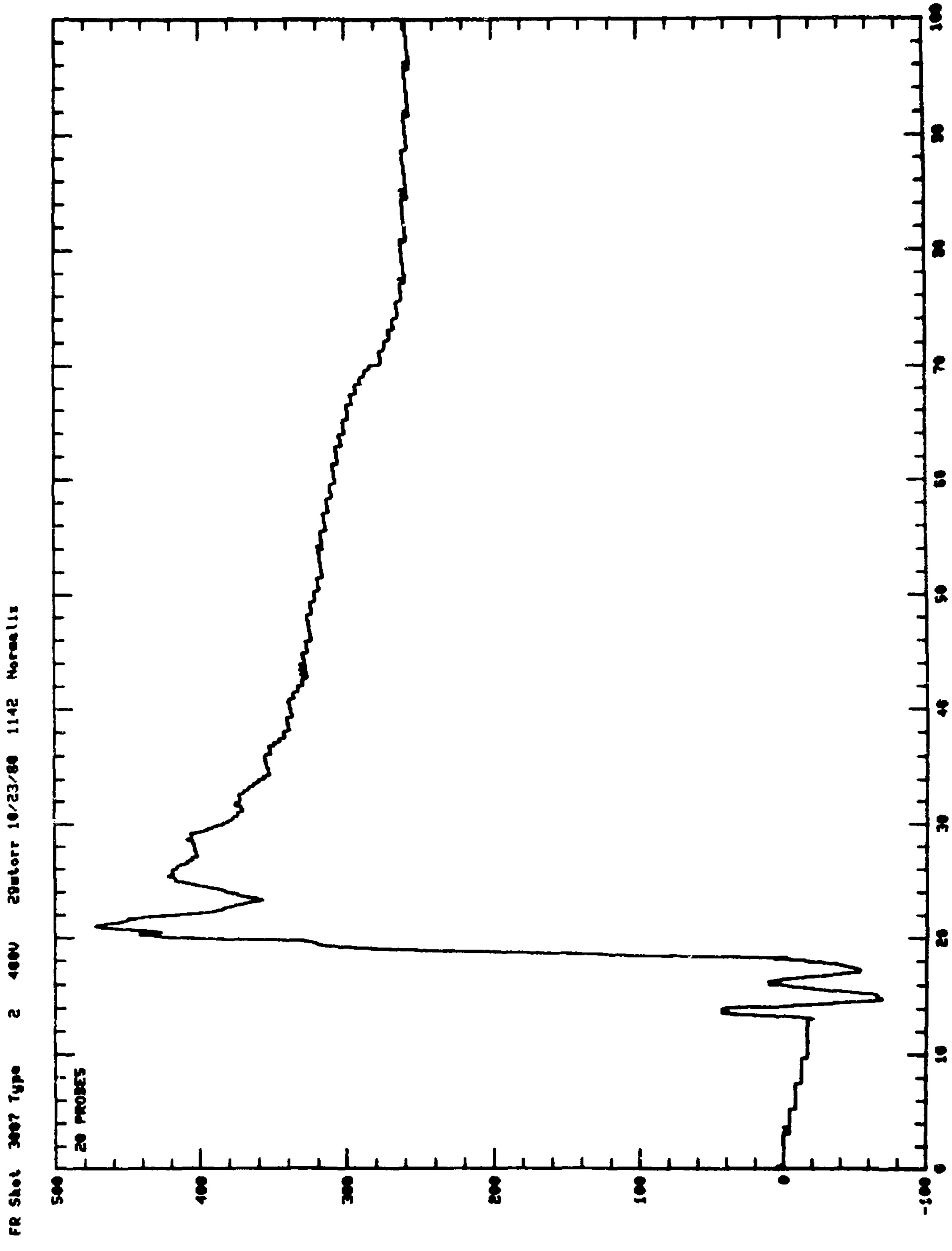
$\tau_\ell \simeq 50$ μs



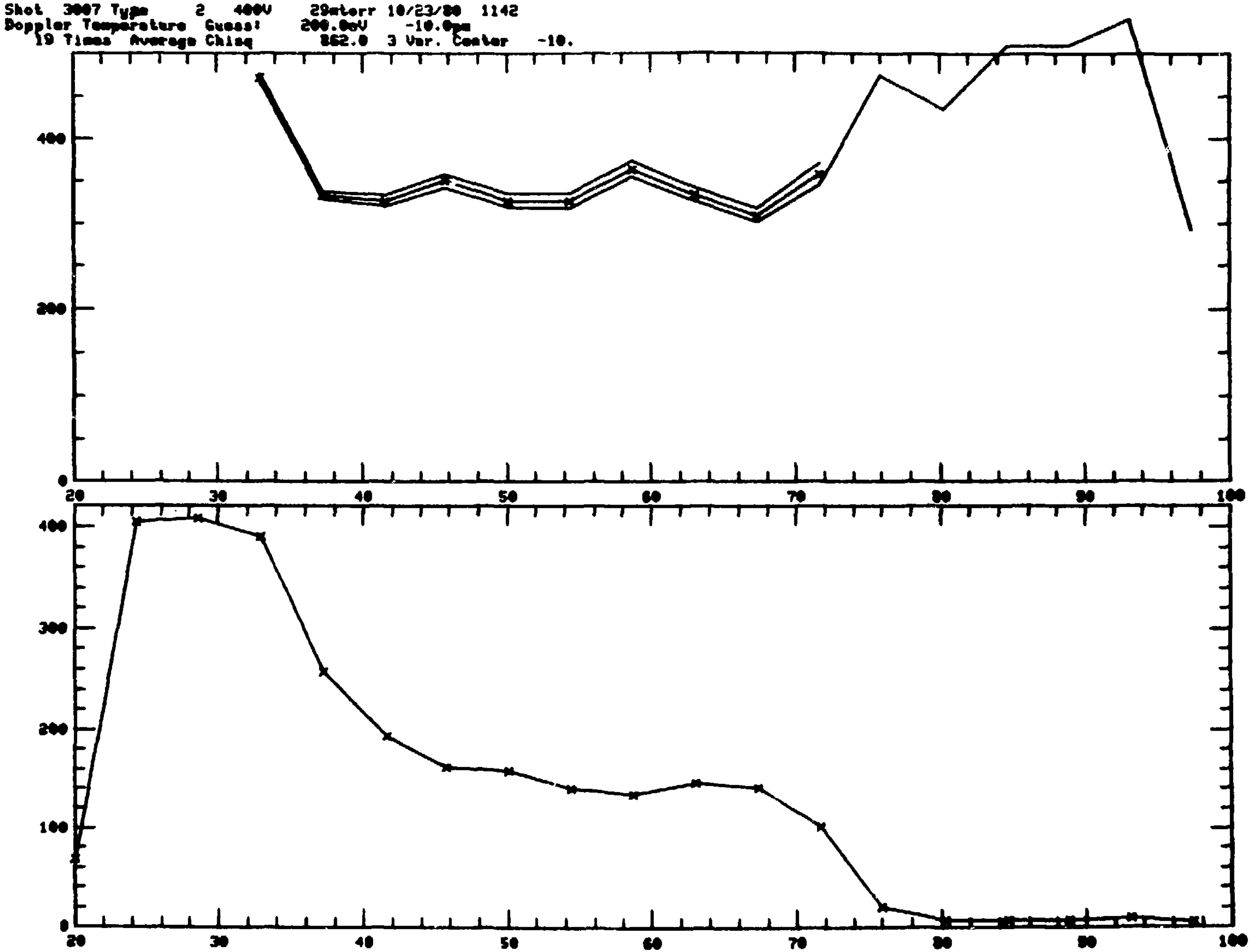
$r_{\Delta\phi}$(mm) vs z(mm) and t(μs)



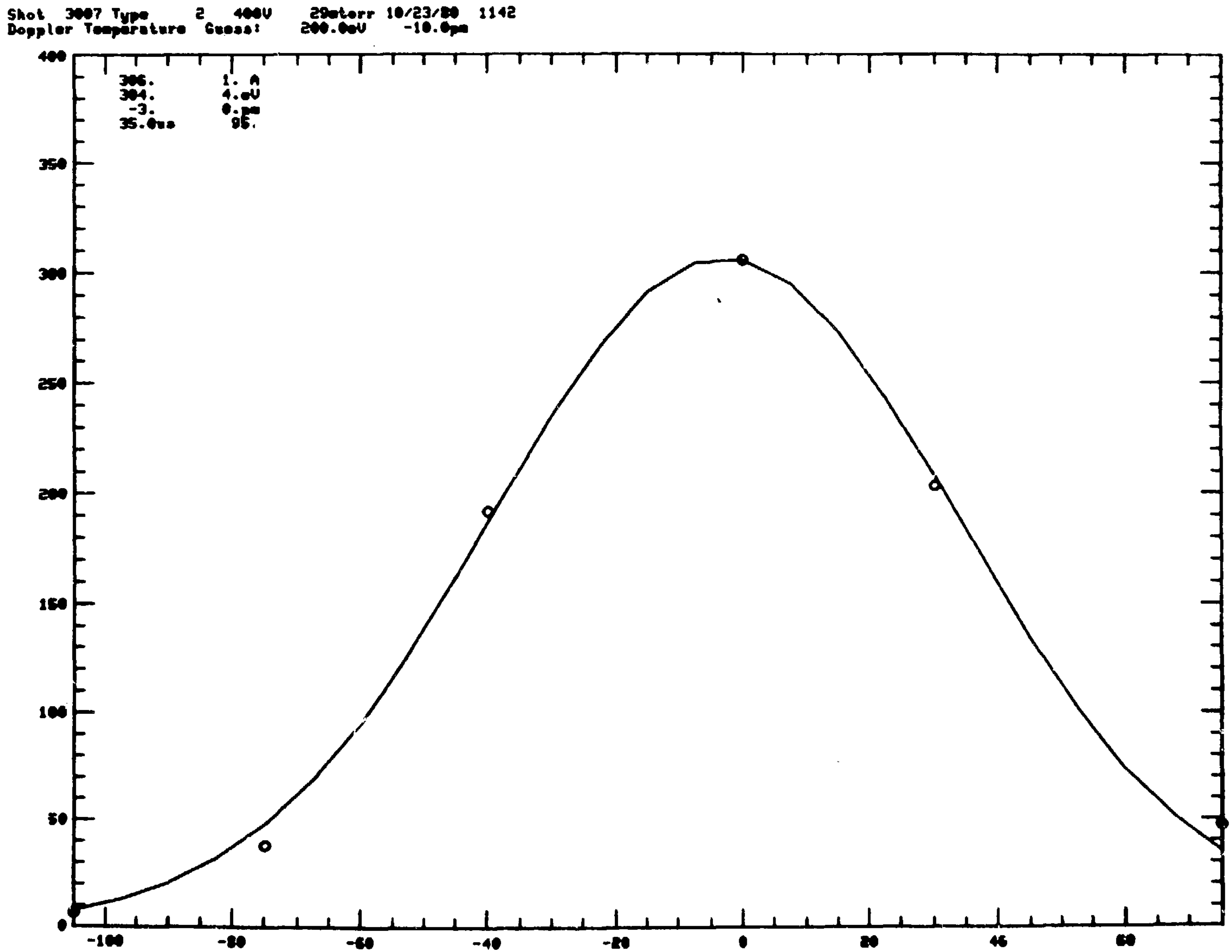
$r_{1/2}$ (mm) vs t(μs) and z(mm)



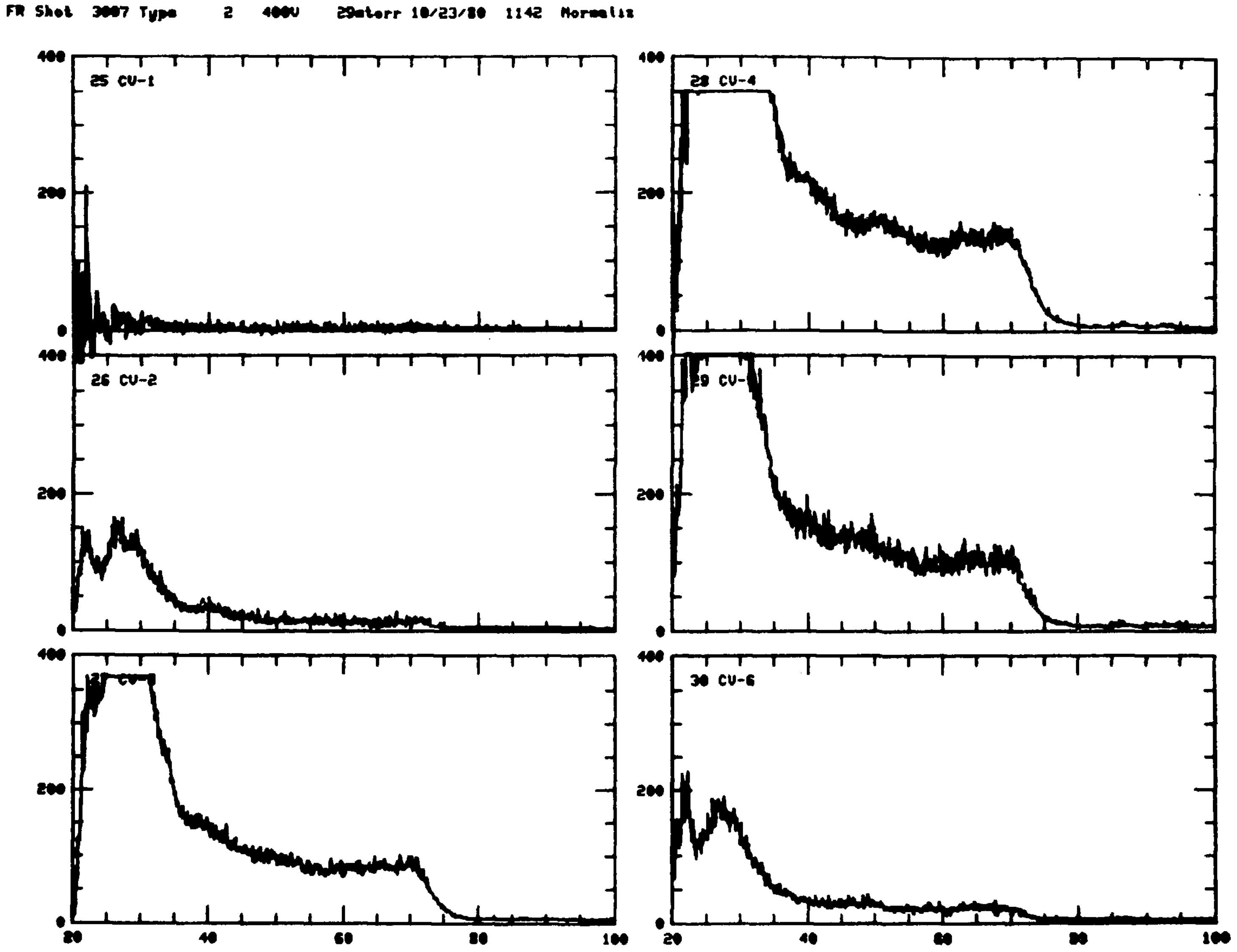
B_o (arbitrary units) vs $t(\mu s)$ at $z = 0$



T_i(eV) vs t(μs) and I(arbitrary units) vs t(μs)



I(Δλ)(arbitrary units) vs Δλ(pm) at t = 10 μs



I in each CV channel vs t(μs)

Case #4

Shot #2998

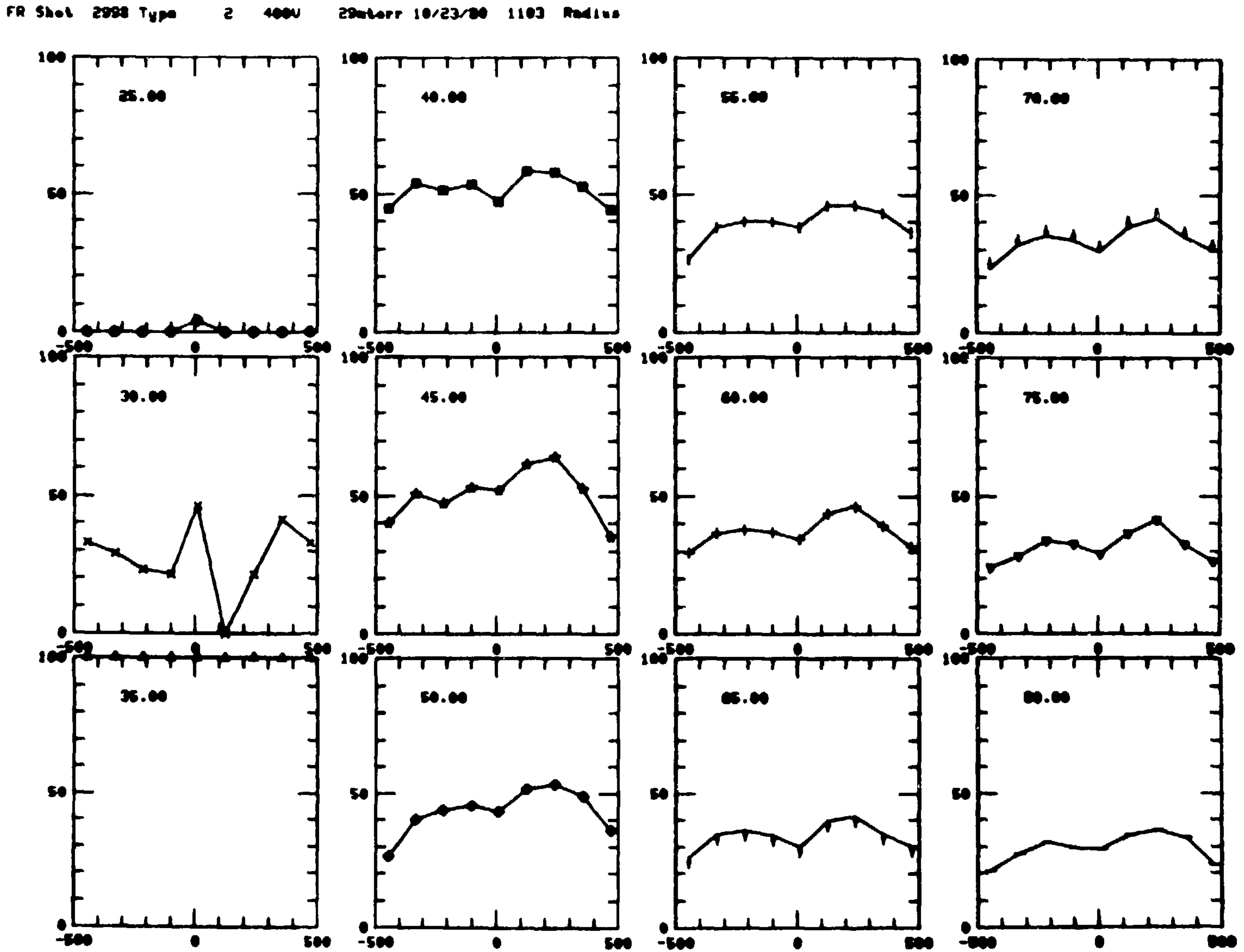
P_o = 29 mtorr

t_o = 40.0 μs

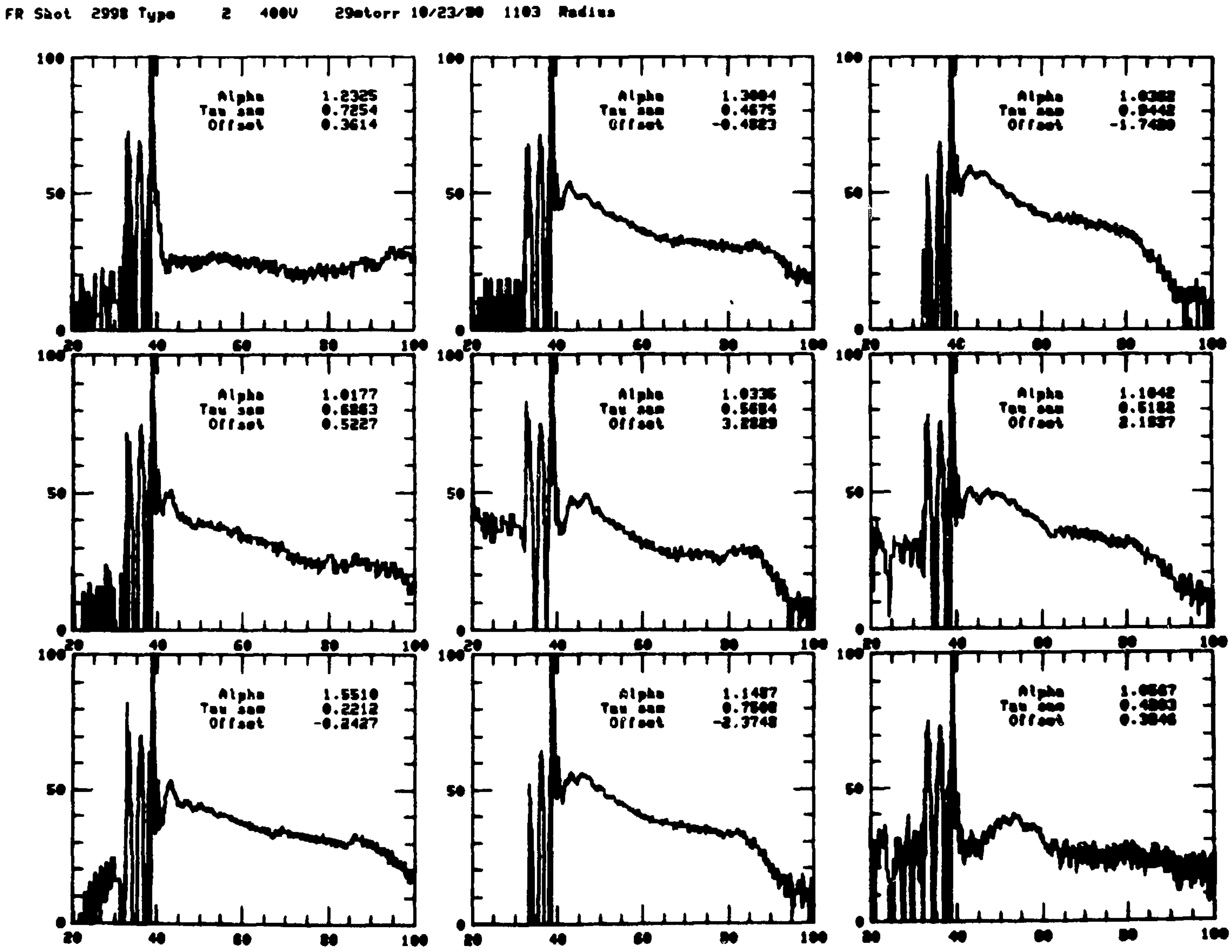
tearing into two FRC's apparent at t_o + 10 μs
without any obvious destructive effects

$\tau_s \simeq 35$ μs

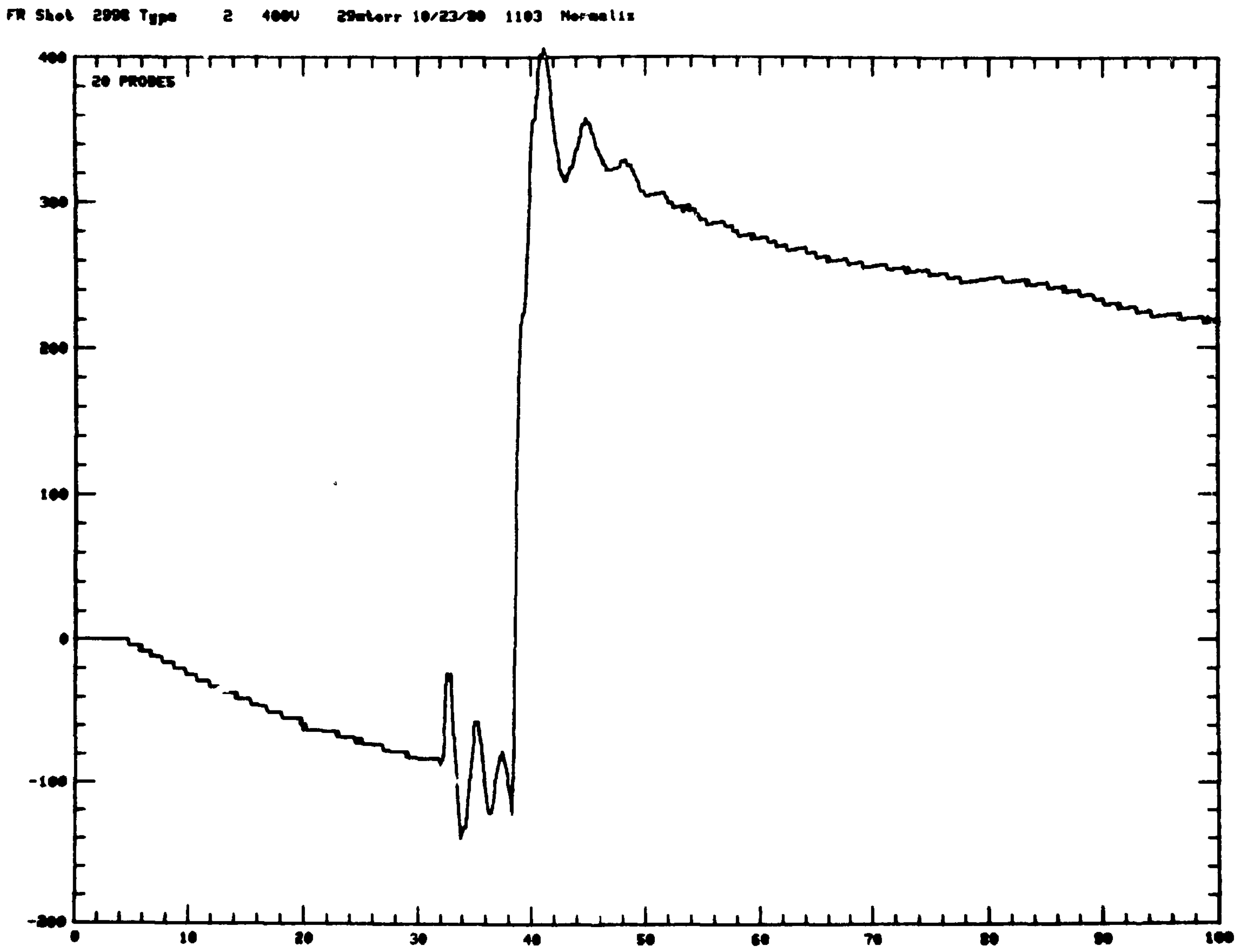
$\tau_\ell \simeq 50$ μs



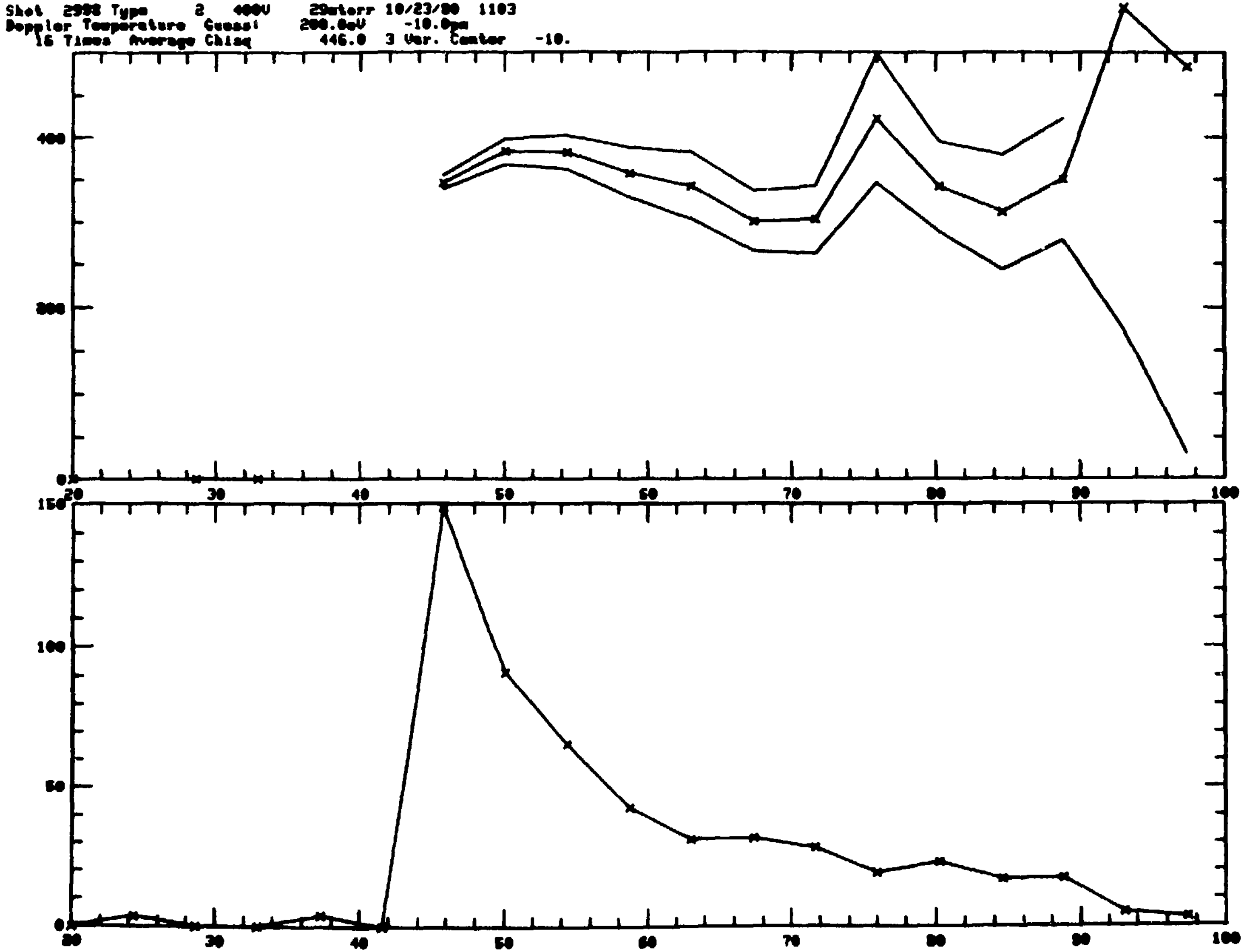
$r_{\Lambda\phi}$(mm) vs z(mm) and t(μs)



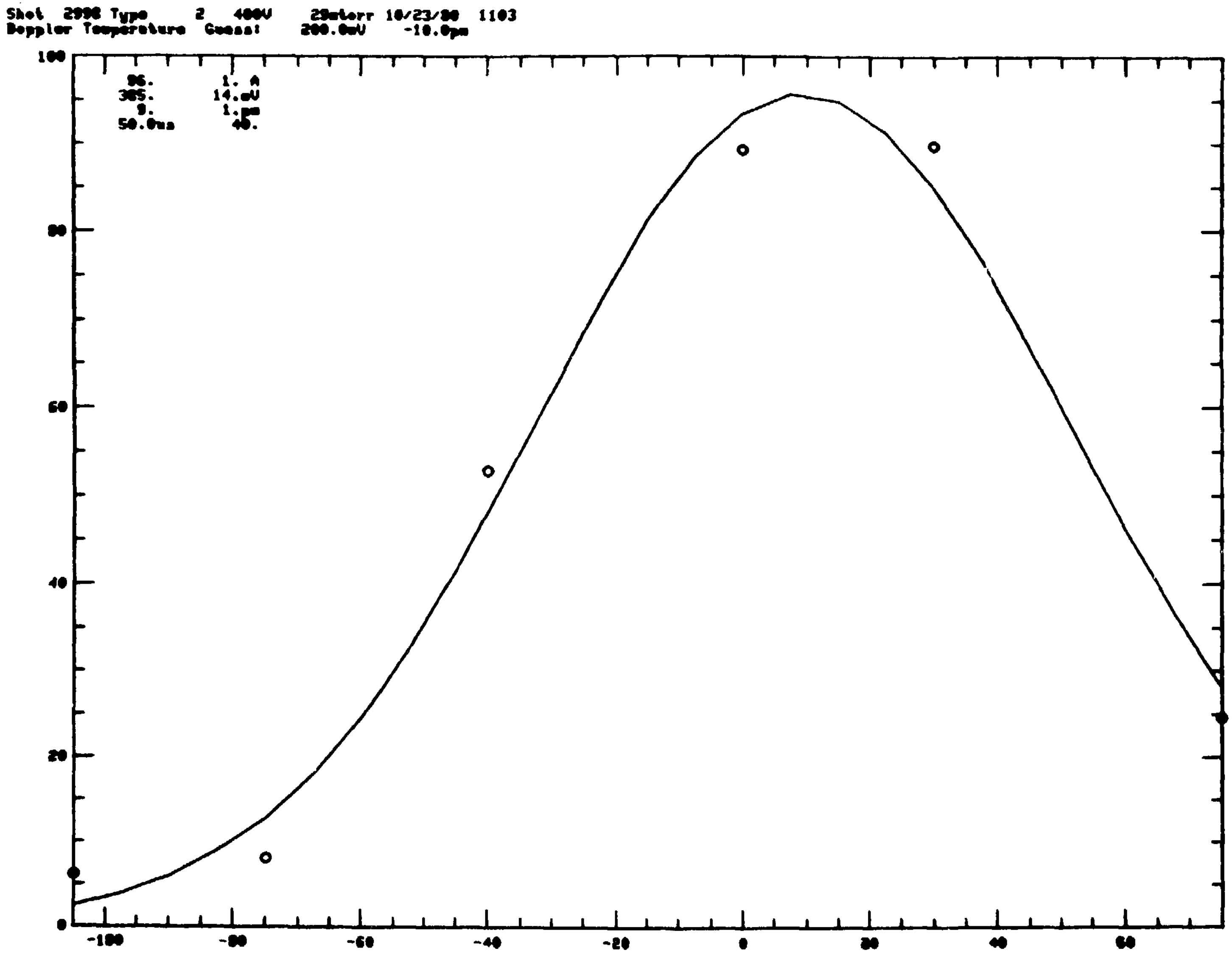
$r_{[illegible]}$ (mm) vs t(μs) and z(mm)



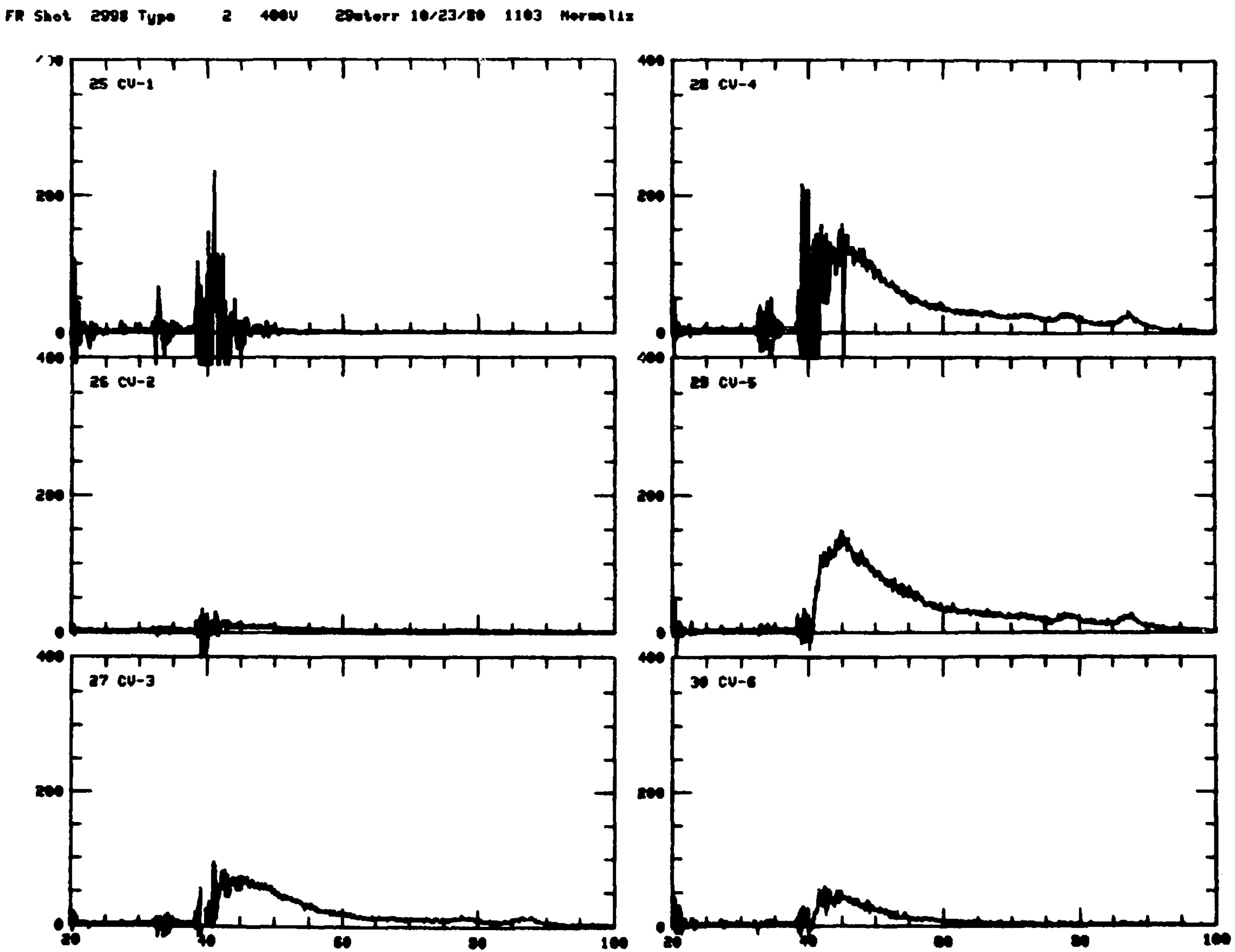
B_o (arbitrary units) vs t(μs) at z = o



T_i (eV) vs t(μs) and I(arbitrary units) vs t(μs)



I(Δλ)(arbitrary units) vs Δλ(pm) at t = 17 μs



I in each CV channel vs t(μs)

Case #5

Shot #3145

P_o = 49 mtorr

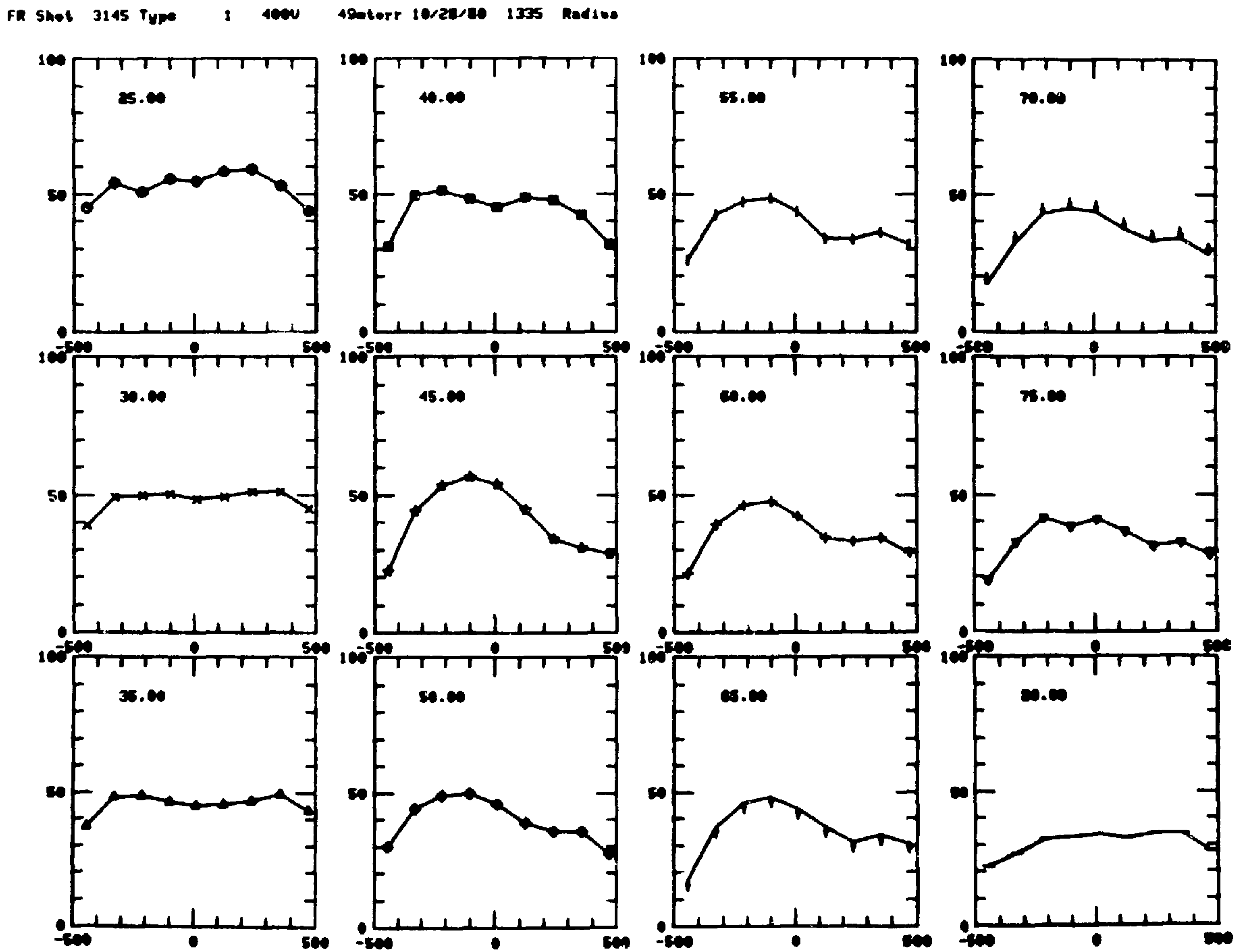
t_o = 20.0 μs

tearing into two FRC's apparent at t_o + 40 μs

but FRC's coalesce by t_o + 45 μs

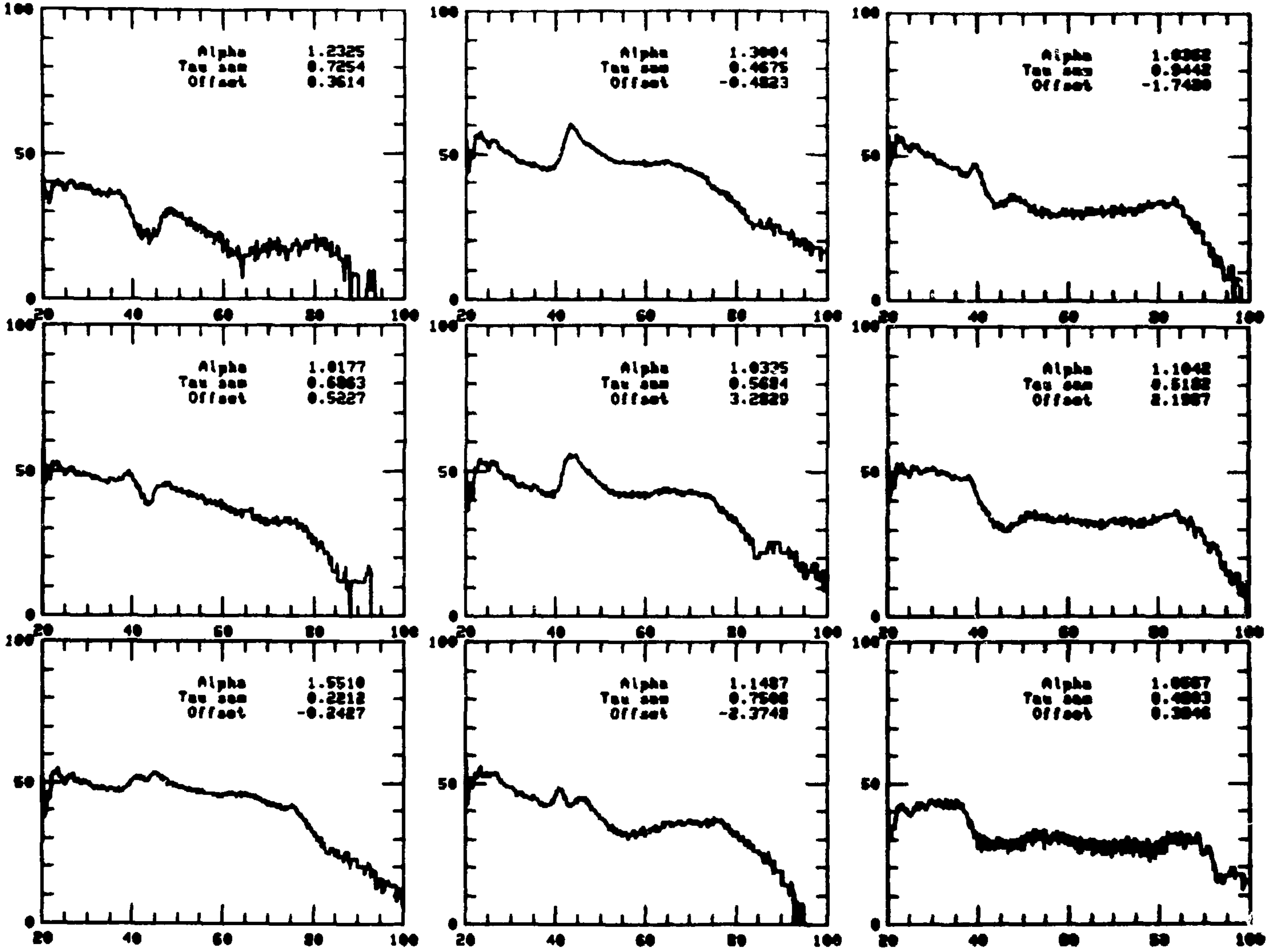
$\tau_s \simeq 50$ μs

$\tau_\ell \simeq 65$ μs

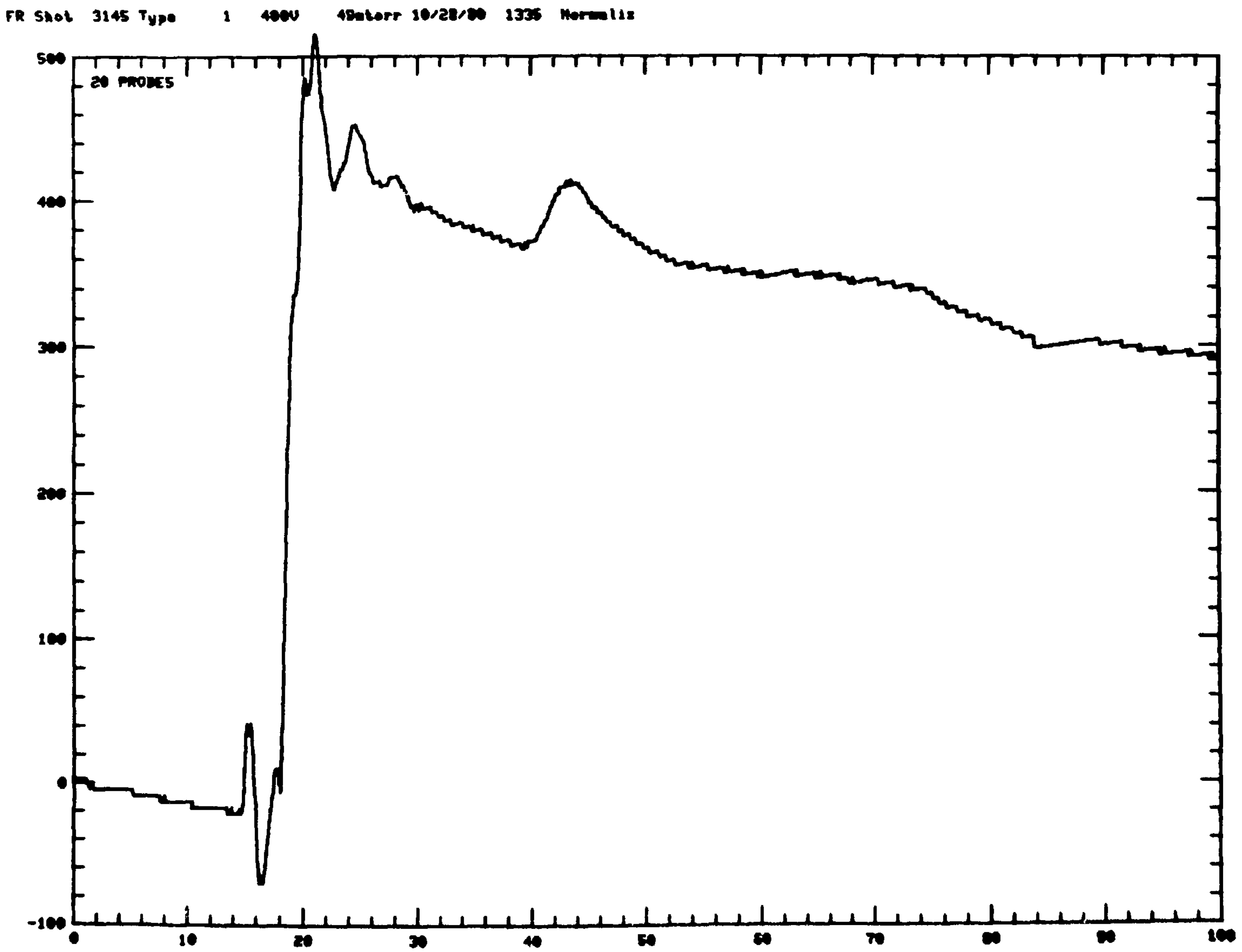


$r_{\Delta\phi}$(mm) vs z(mm) and t(μs)

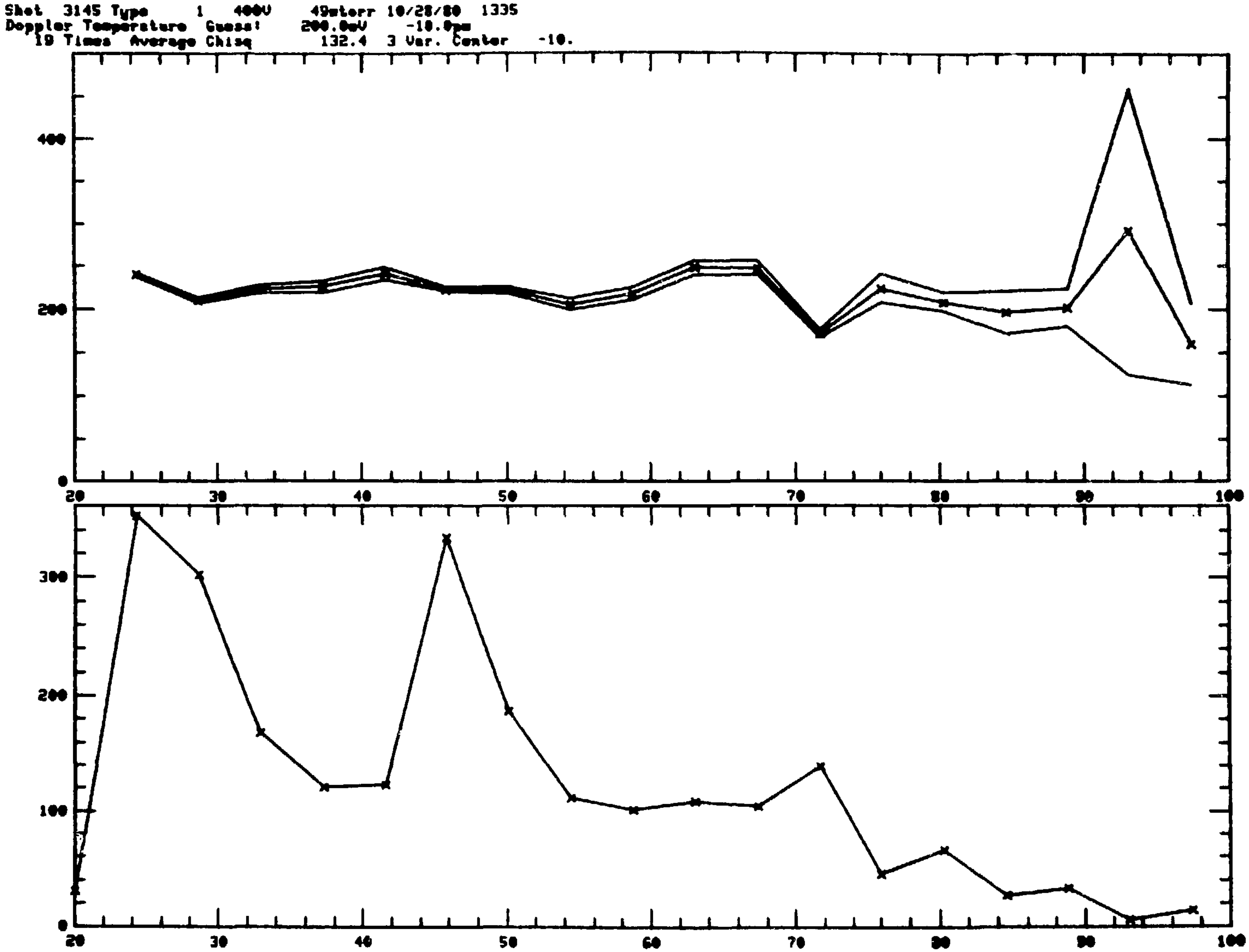
FR Shot 3145 Type 1 400U 49mtorr 10/28/80 1335 Radius



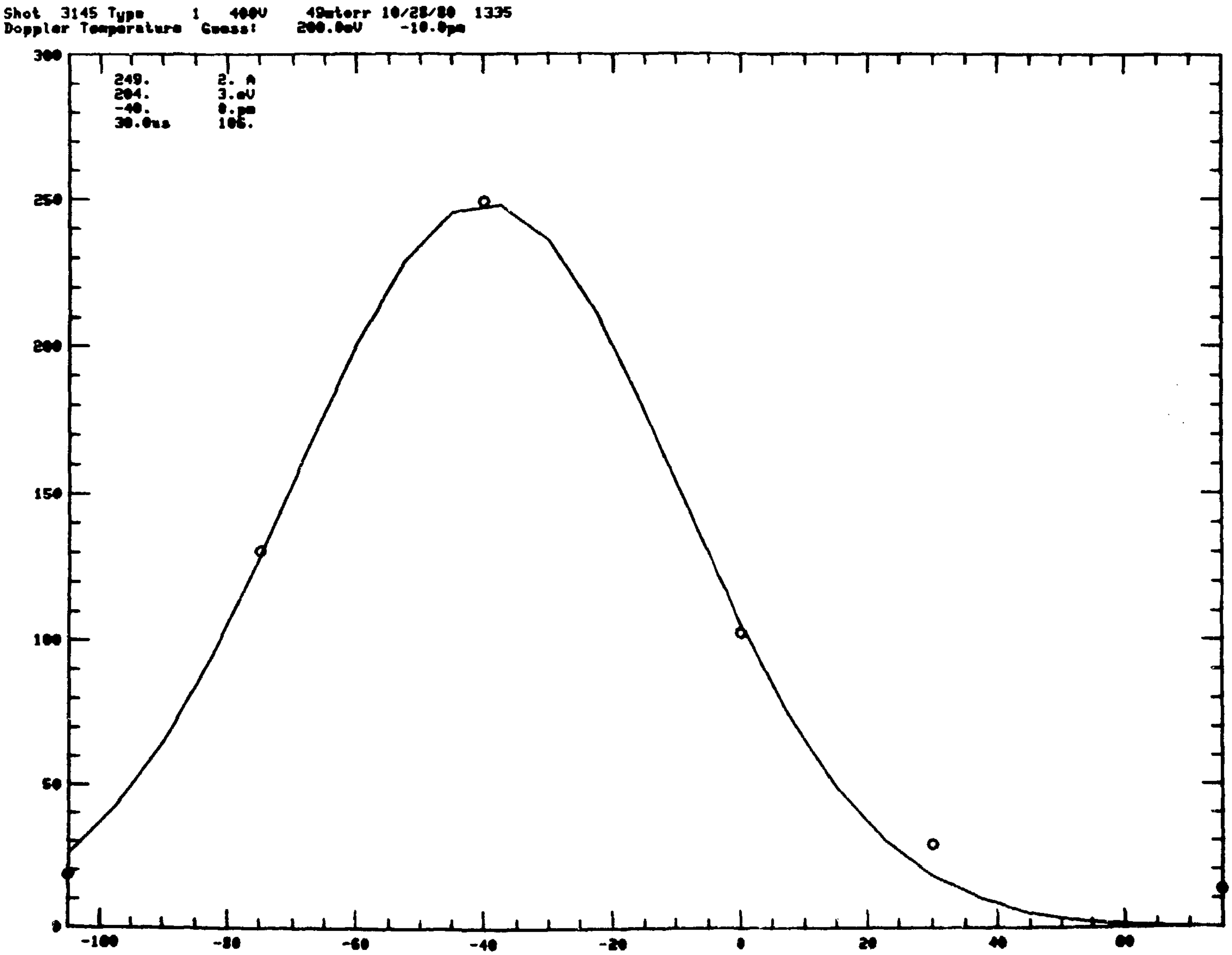
$r_{\Delta\phi}$ (mm) vs t(μs) and z(mm)



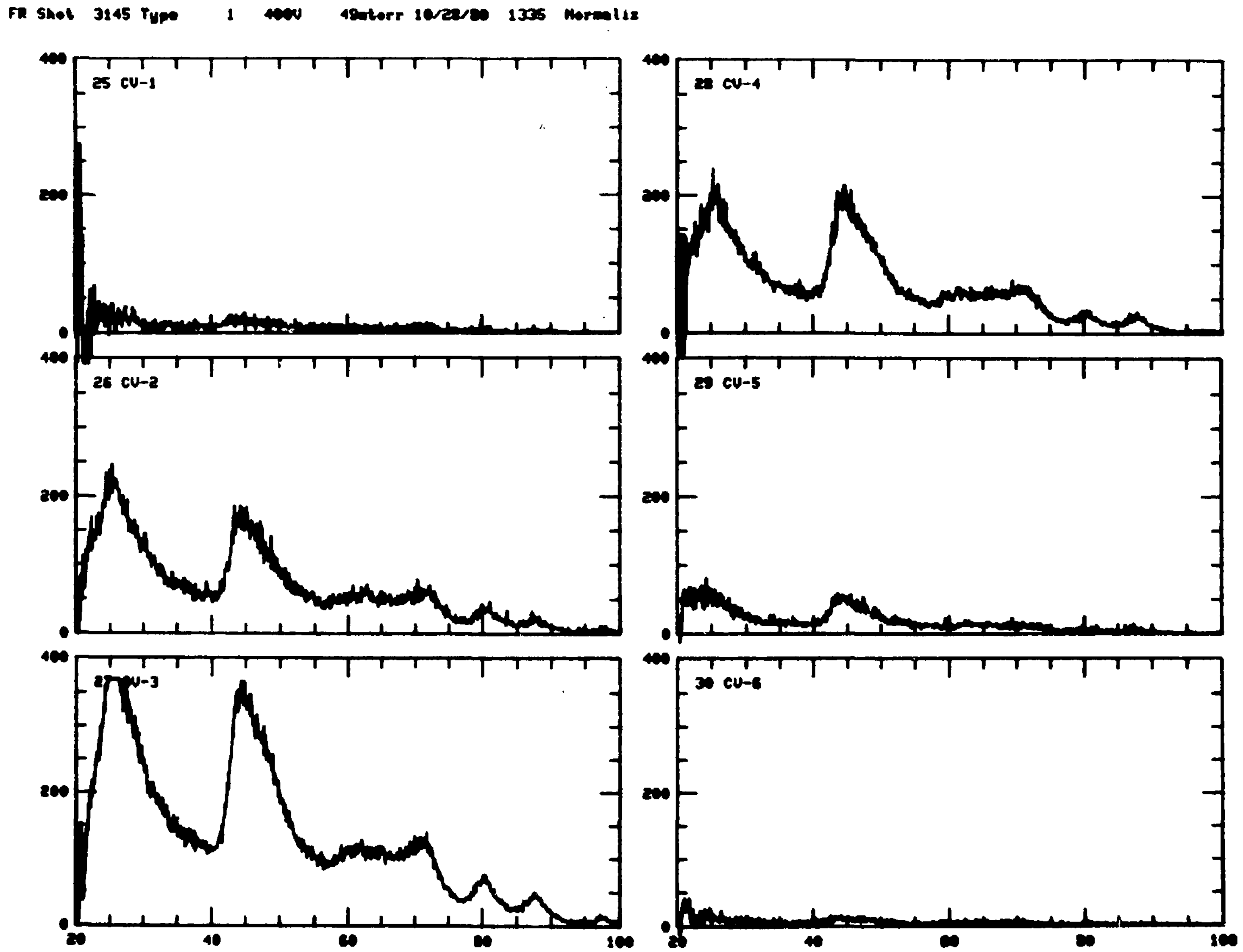
B_θ (arbitrary units) vs t(μs) at [illegible]



T_i (eV) vs t(μs) and I(arbitrary units) vs t(μs)



I(Δλ)(arbitrary units) vs Δλ(pm) at t = 10 μs



I in each CV channel vs t(μs)

Case #6

Shot #3148

P_o = 49 mtorr

t_o = 20.0 μs

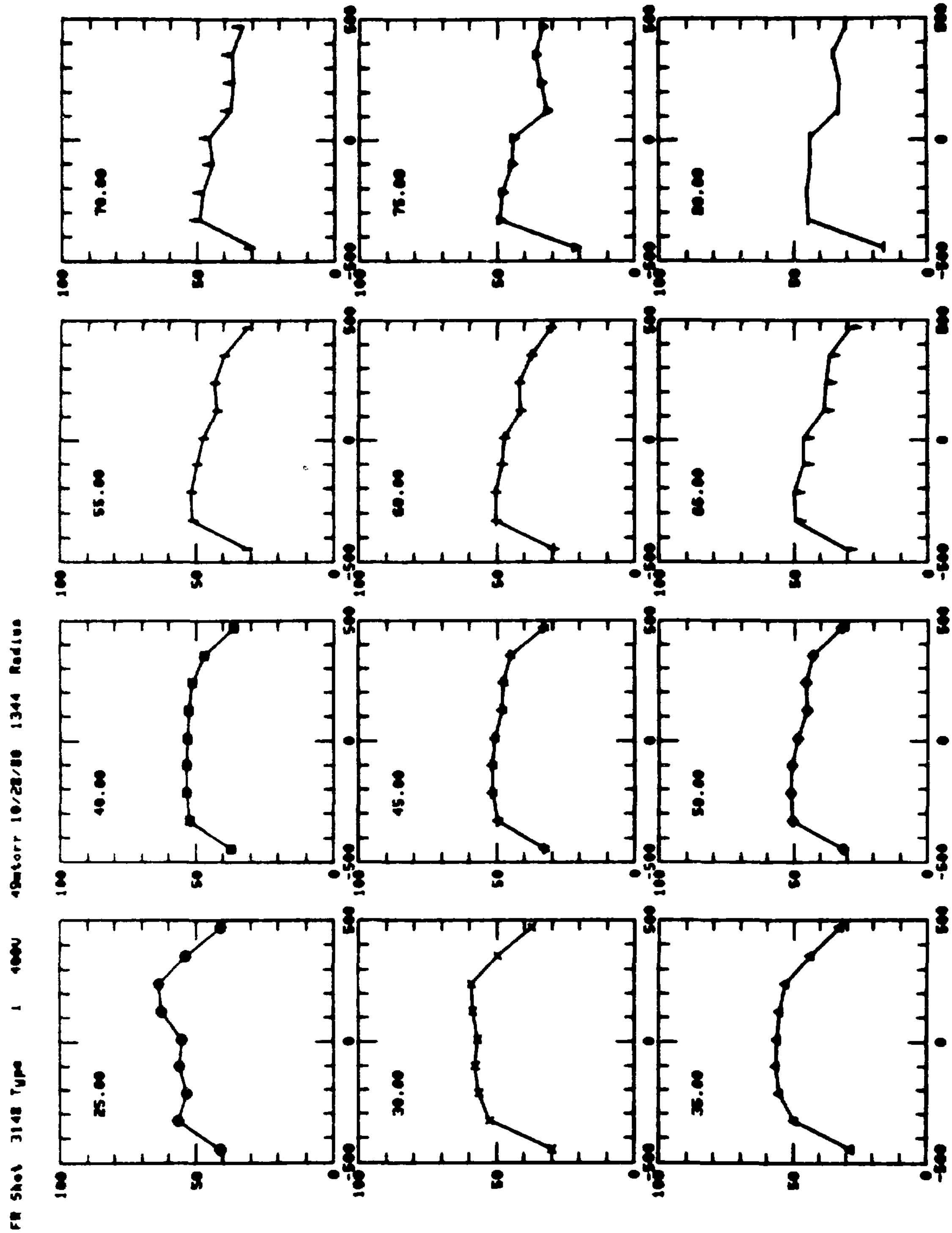
tearing into two FRC's apparent at t_o + 40 μs,

the right FRC translated out of coil at t_o + 45 μs,

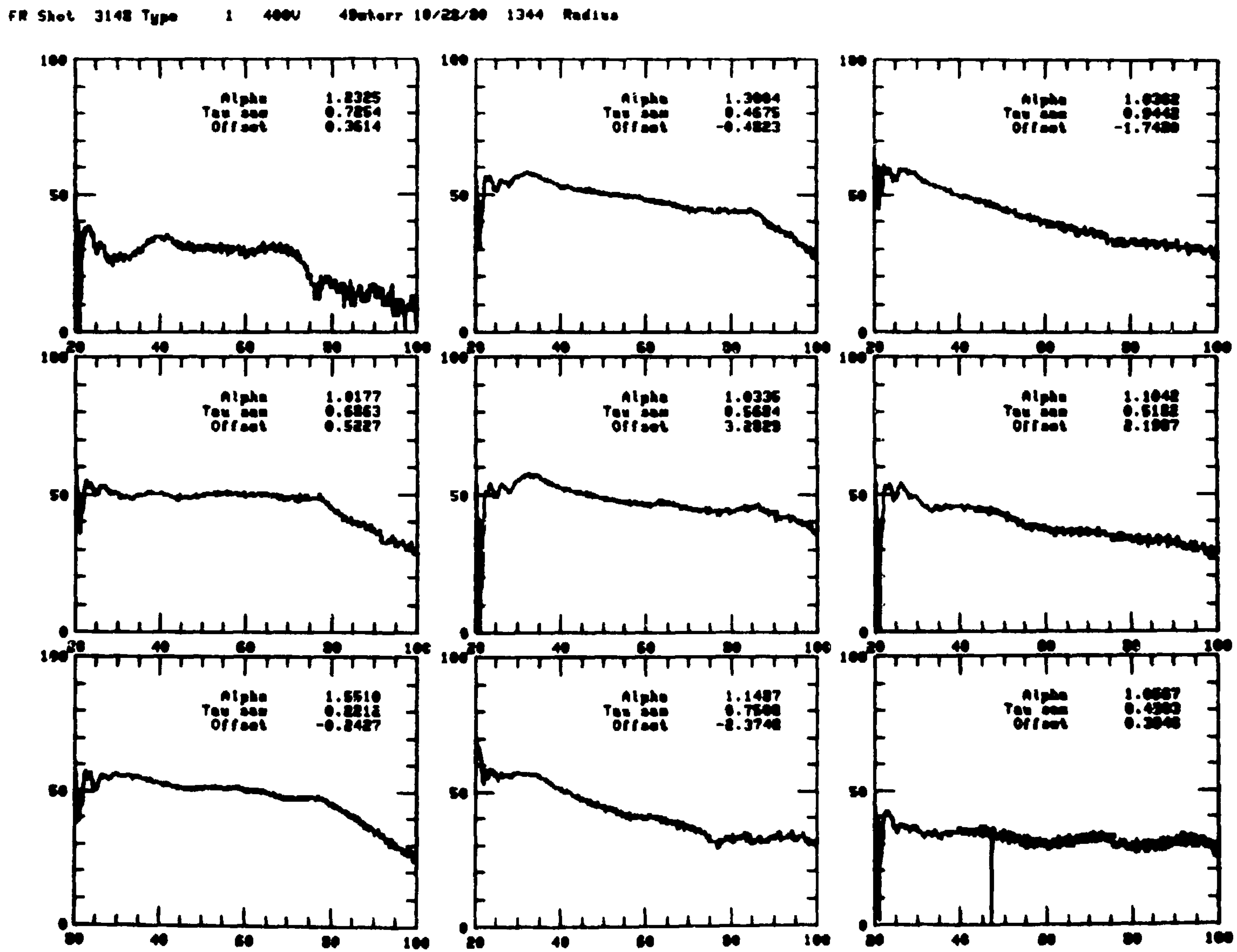
the left FRC remains intact

$\tau_s \simeq 43$ μs

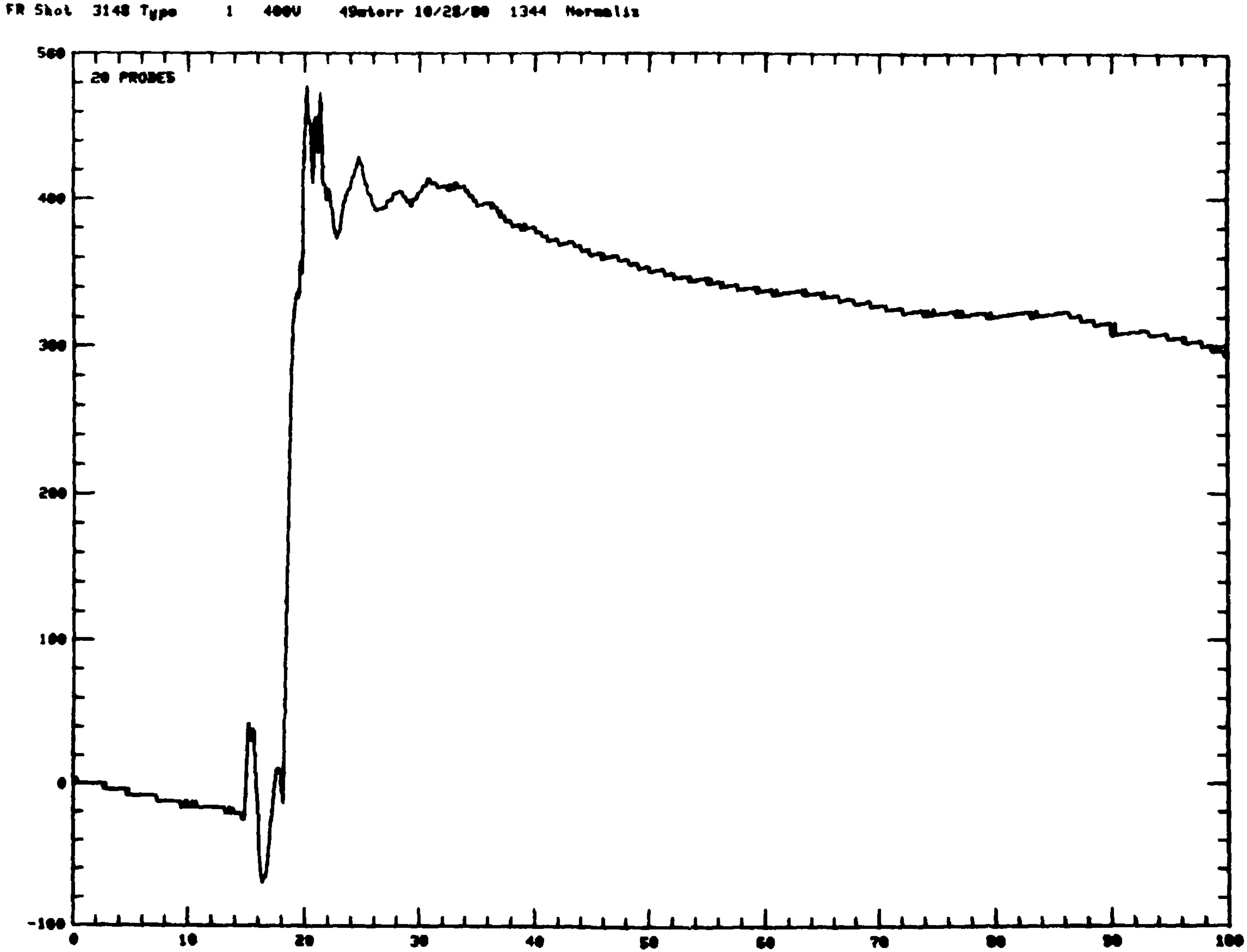
$\tau_\ell \simeq 80$ μs



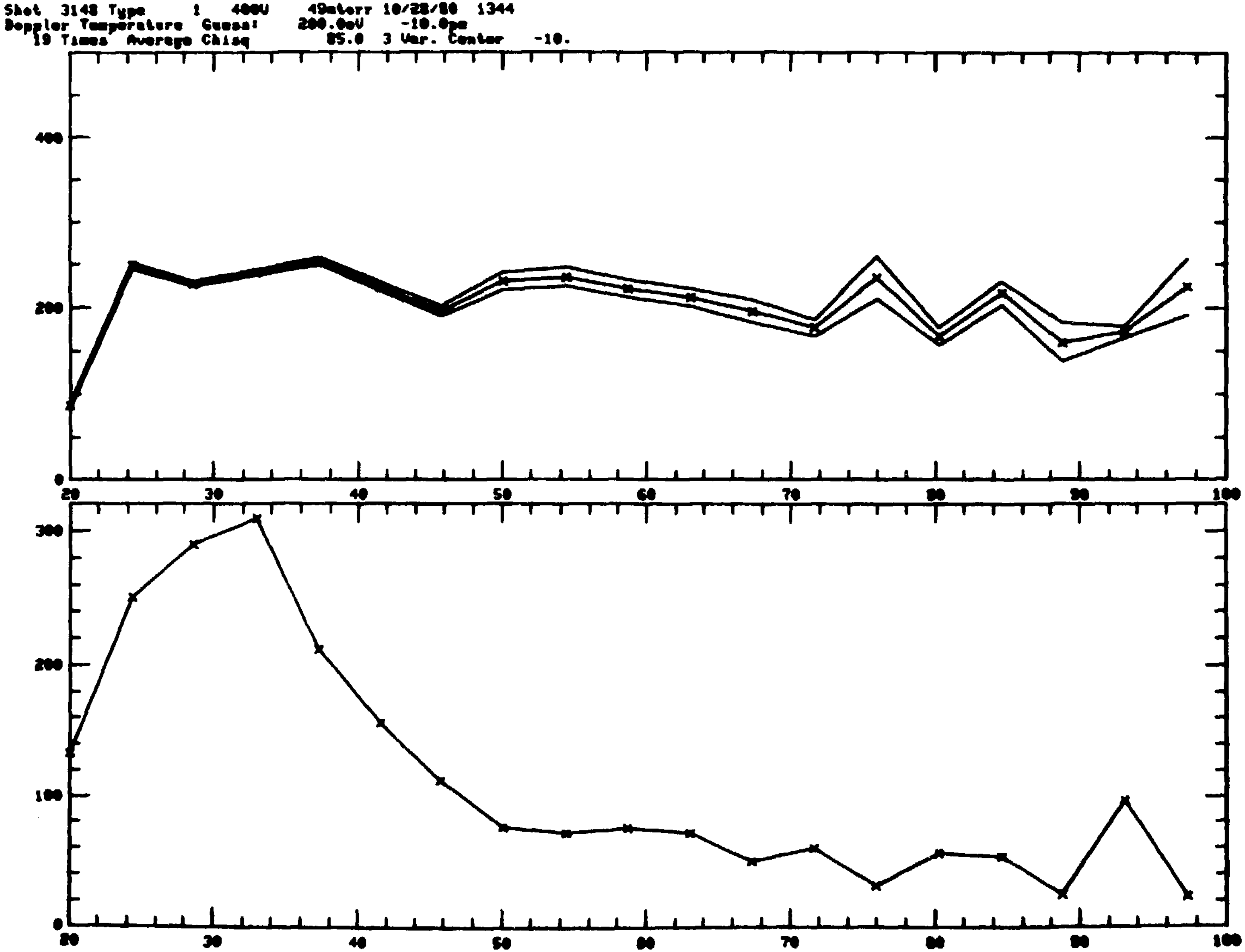
$r_{\Delta\phi}$(mm) vs z(mm) and t(μs)



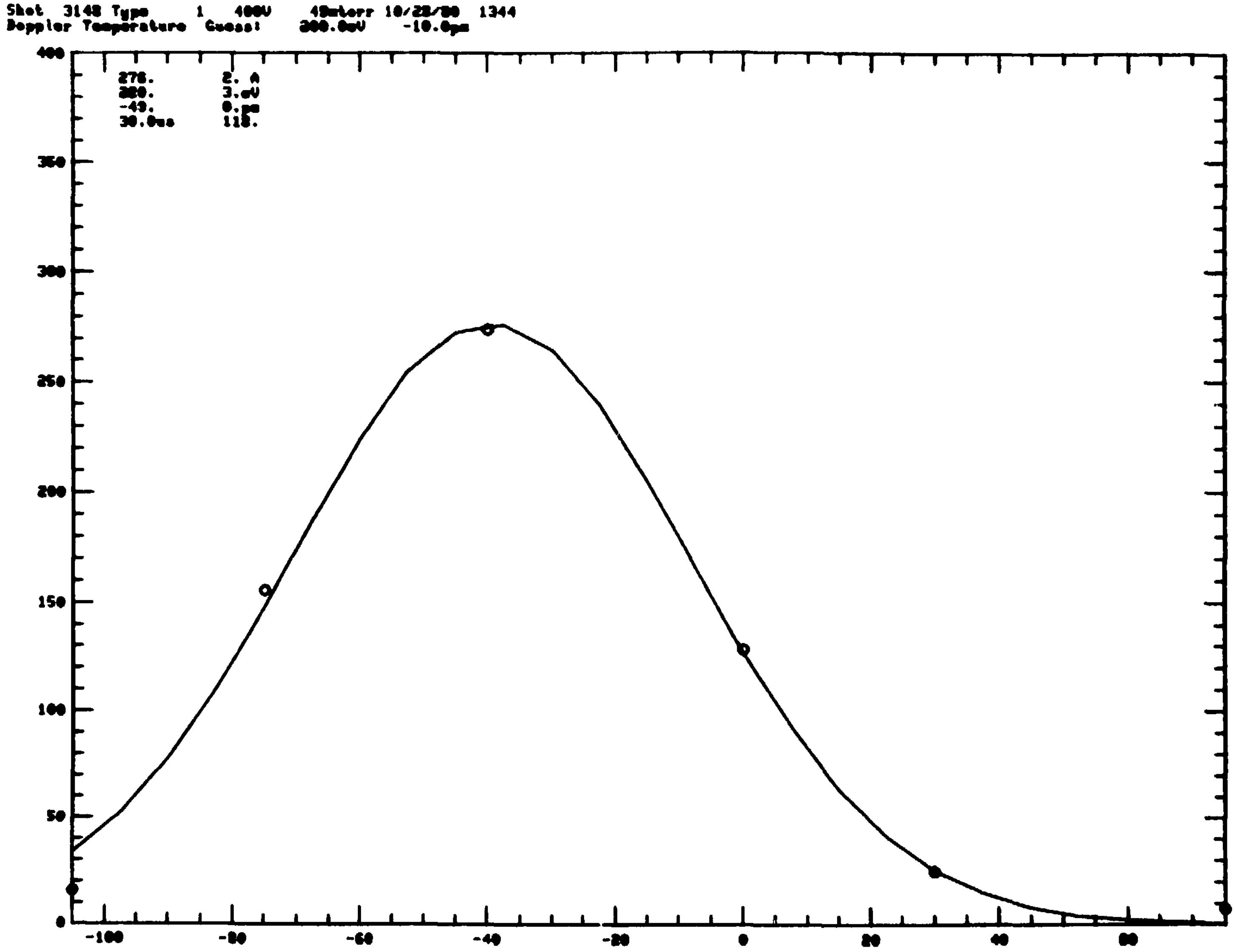
$r_{1/2}$ (mm) vs t(μs) and z(mm)



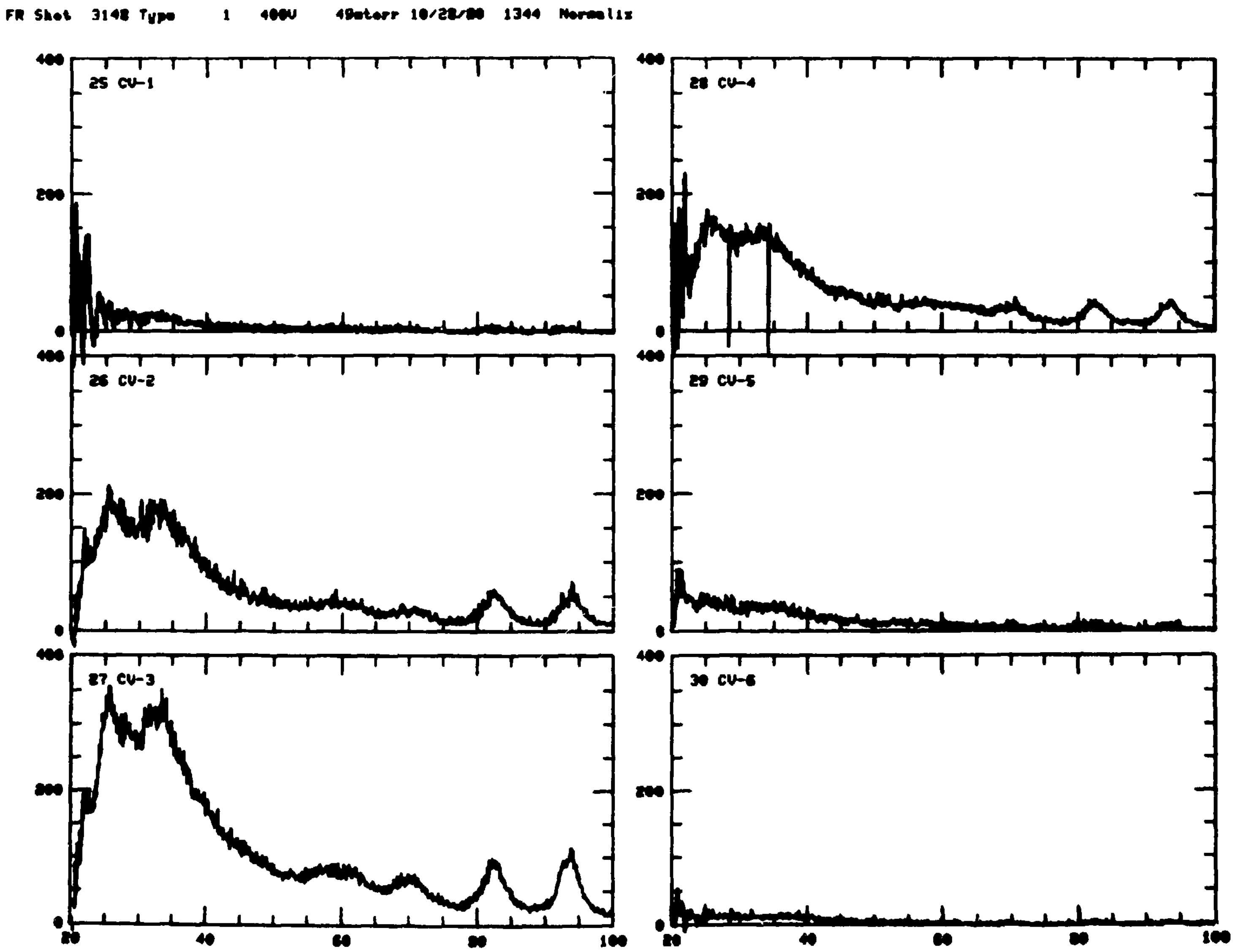
B_o (arbitrary units) vs t(μs) at z = 0



T_i(eV) vs t(μs) and I(arbitrary units) vs t(μs)



$I(\Delta\lambda)$ (arbitrary units) vs $\Delta\lambda$ (pm) at $t = 10$ μs



I in each CV channel vs t (μs)

Case #7

Shot #3038

P_o = 41 mtorr

t_o = 20.0 μs

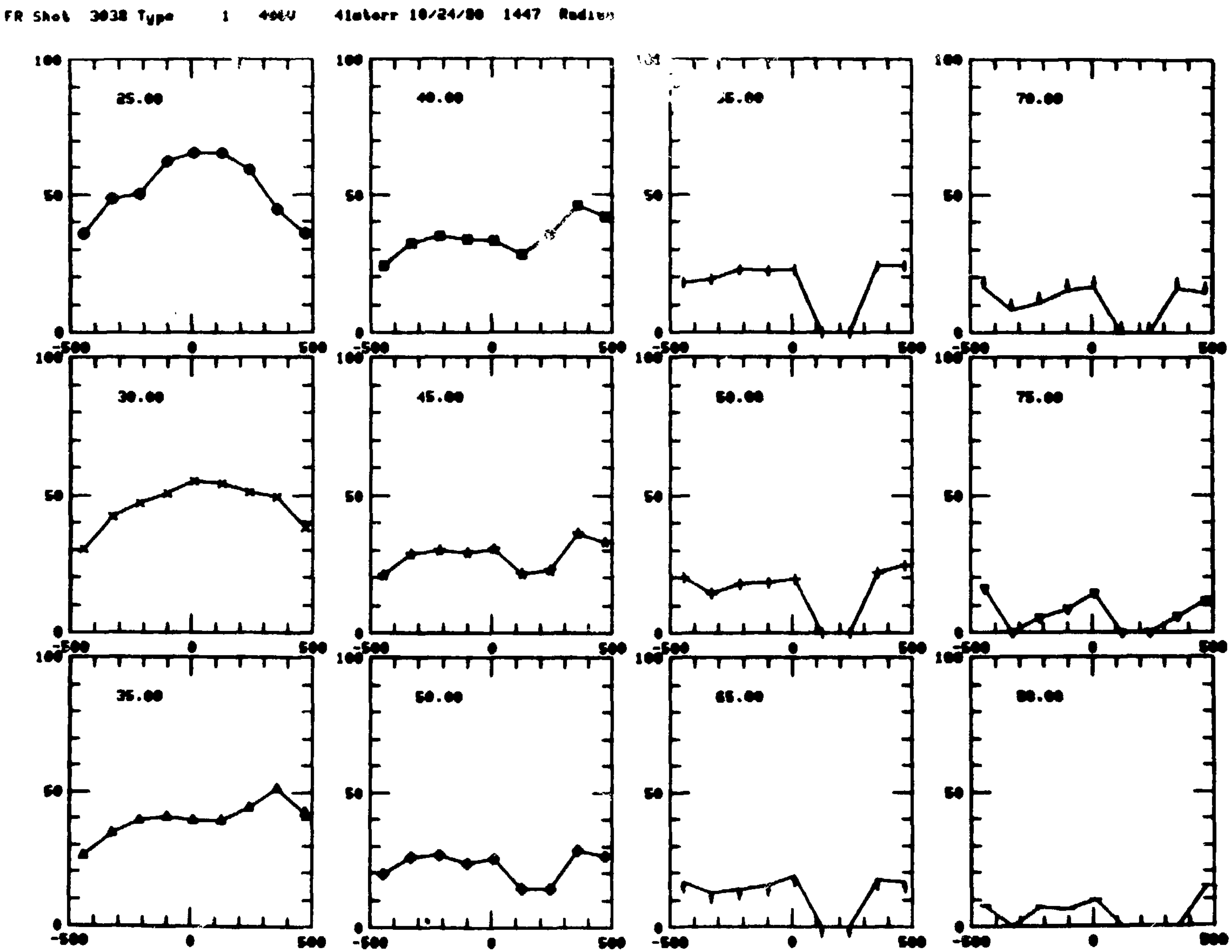
translation of FRC right at t_o + 15 μs,

tearing at t_o + 20 μs,

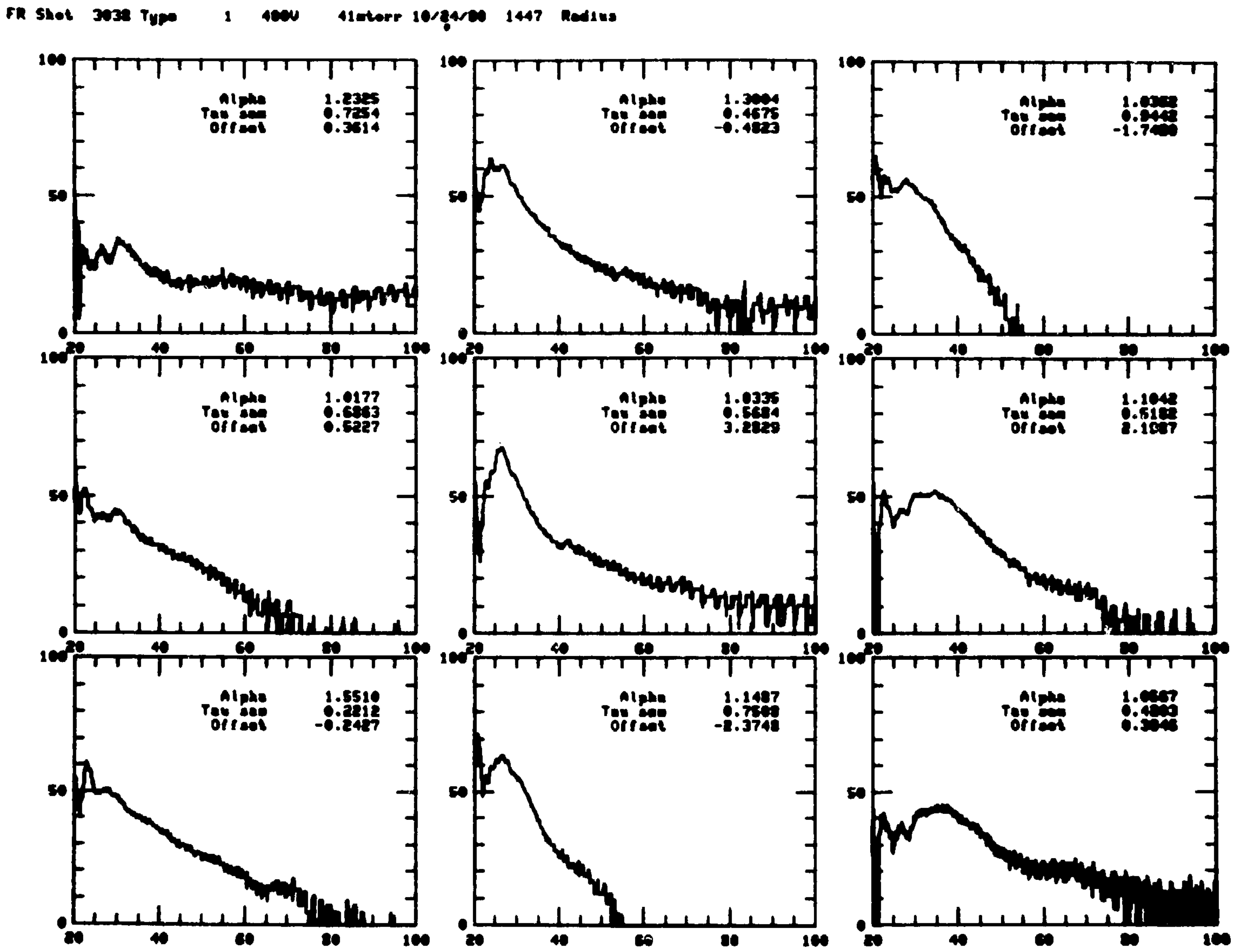
with rapid destruction of FRC

$\tau_s \simeq 28$ μs

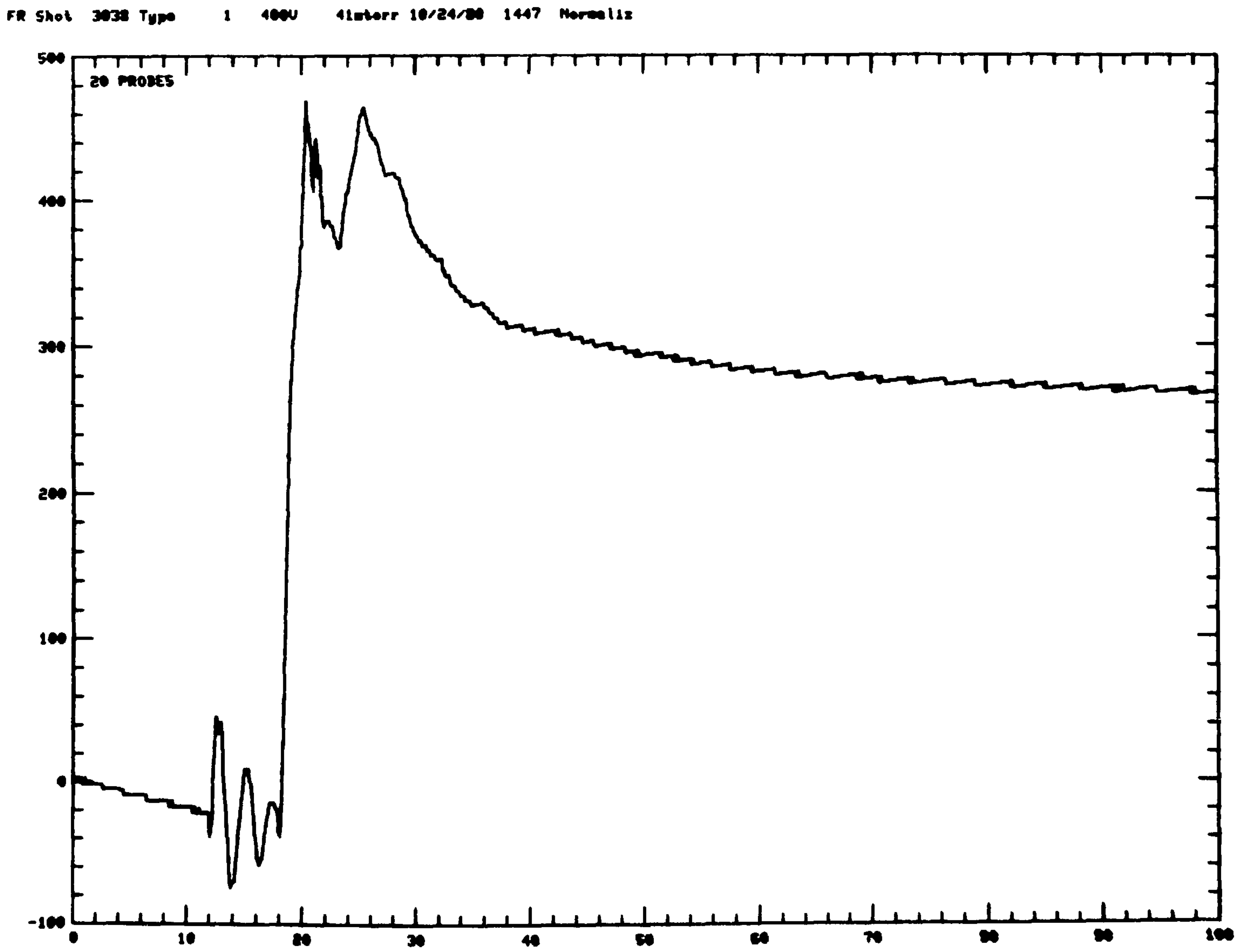
$\tau_\ell \simeq 30$ μs



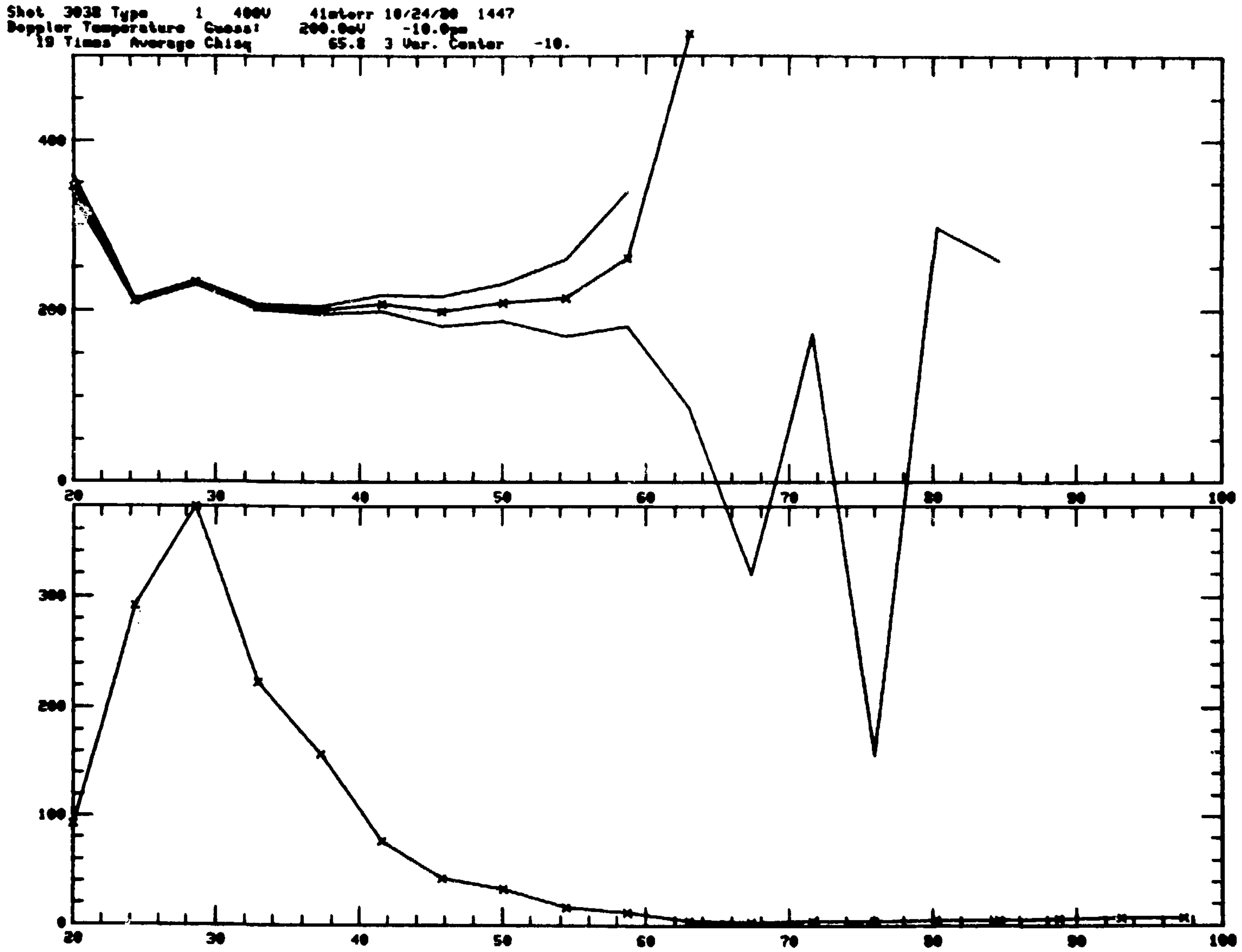
$r_{\Delta\phi}$ (mm) vs z(mm) and t(μs)



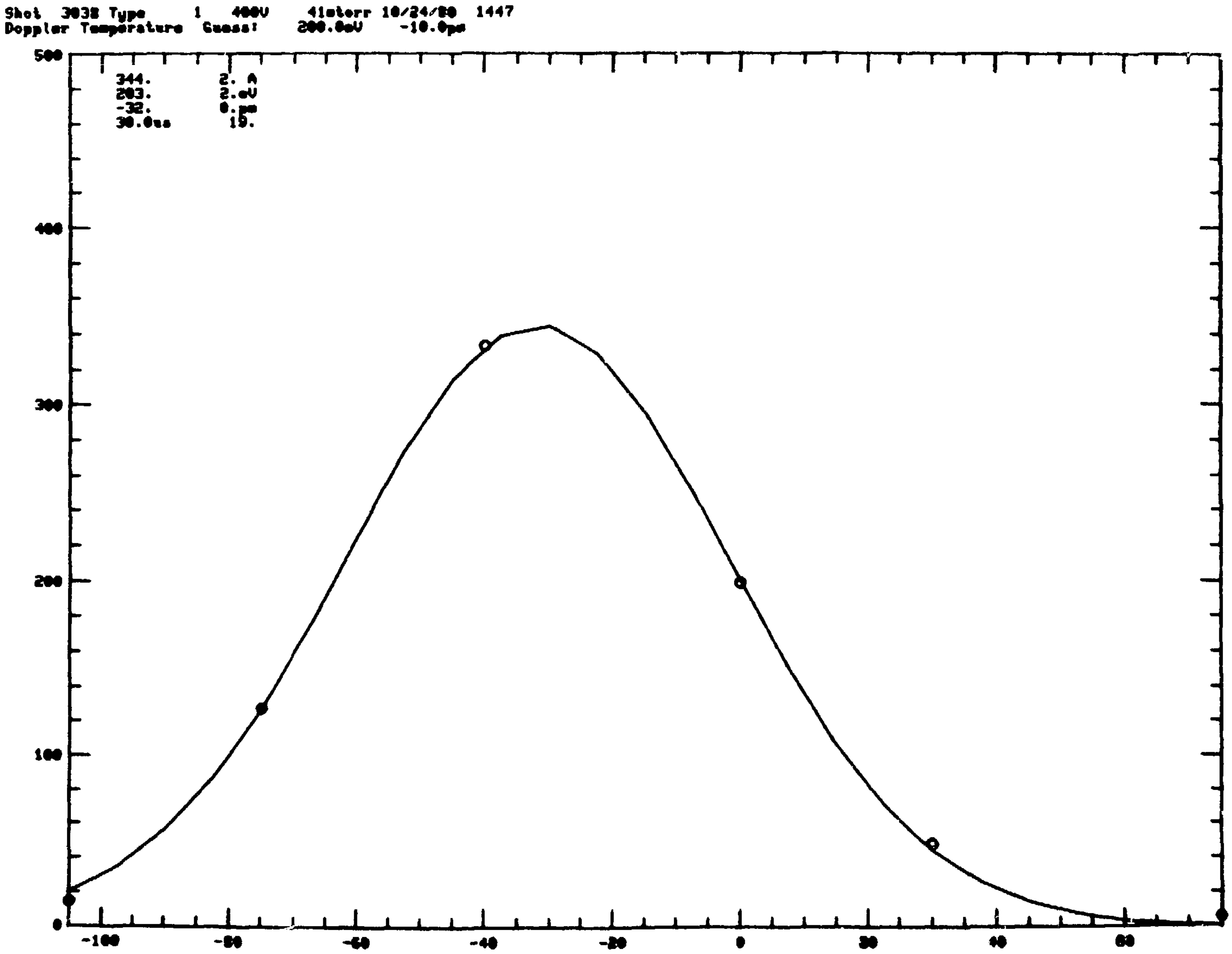
r_s (mm) vs t (μs) and z (mm)



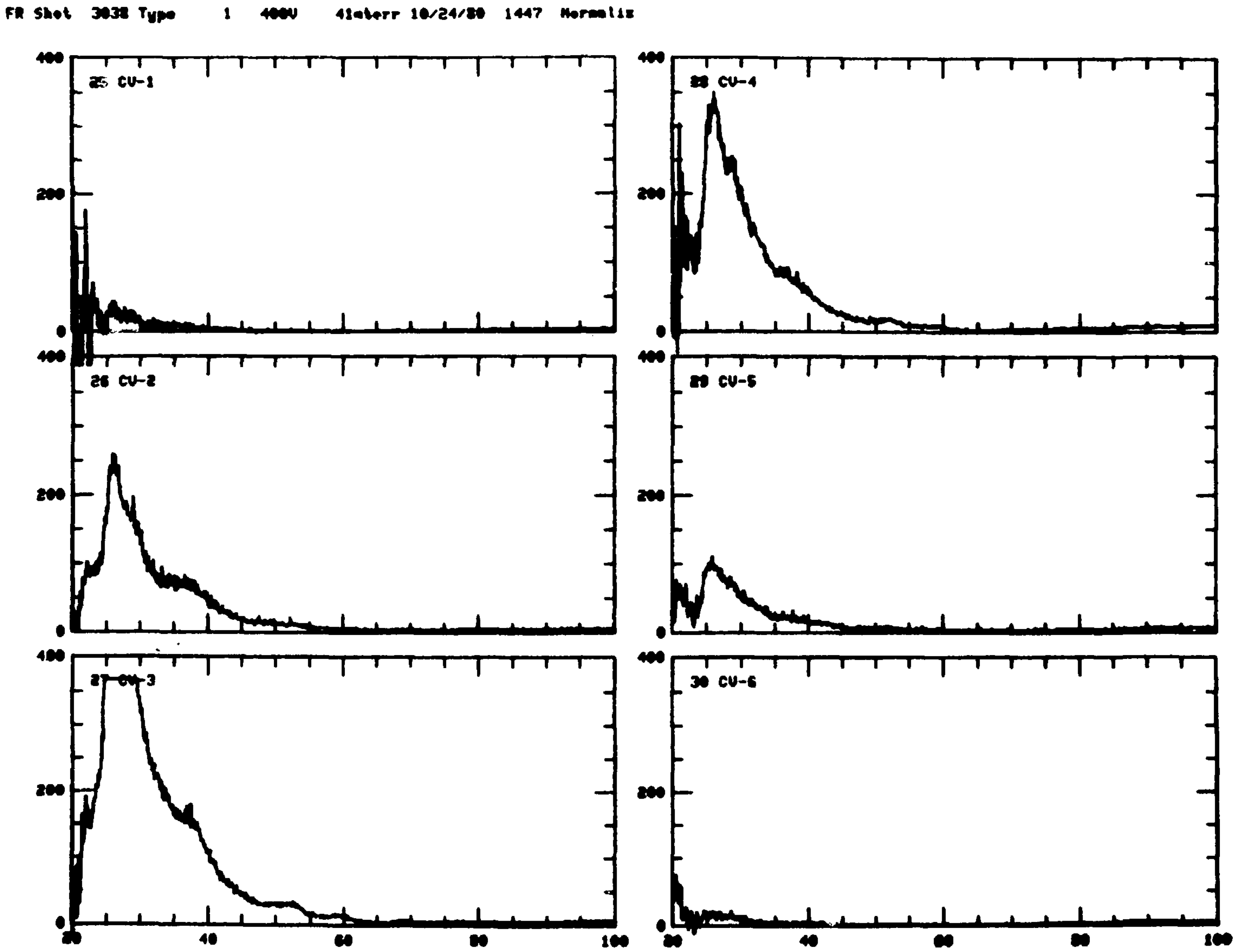
B_o (arbitrary units) vs t(μs) at z = 0



T_i(eV) vs t(μs) and I(arbitrary units) vs t(μs)



I(Δλ)(arbitrary units) vs Δλ(pm) at t = 10 μs



I in each CV channel vs t(μs)

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