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PROTON STORAGE RING COMMISSIONING

1985 - 1987

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Eugene Colton
Dan Fitzgerald
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Robert Hardekopf
Jim Hurd
Richard Hutson
Andrew Jason
George Lawrence
Augusto Lombardi
Bob Macek
Fesseha Mariam
John McGill
David Neuffer
Sho Ohnuma
Mike Plum
Rich Ryder
Bob Shafer
George Swain
Arch Thiessen
Tai-sen Wang

presented by E. COLTON

Santa Margherita, Oct. 5, 1987

Results Of Commissioning Of The Proton Storage Ring (PSR) At Los Alamos

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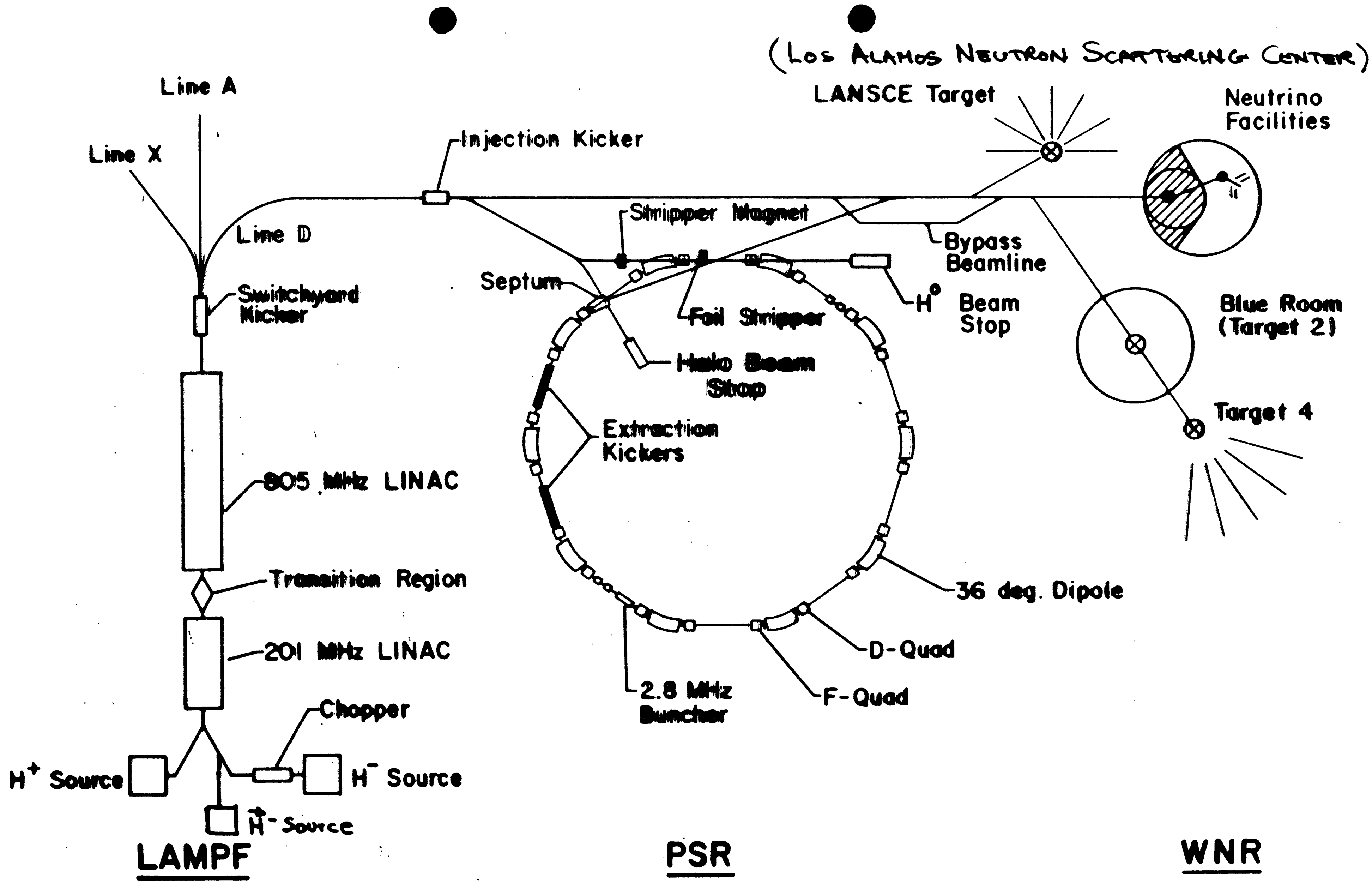
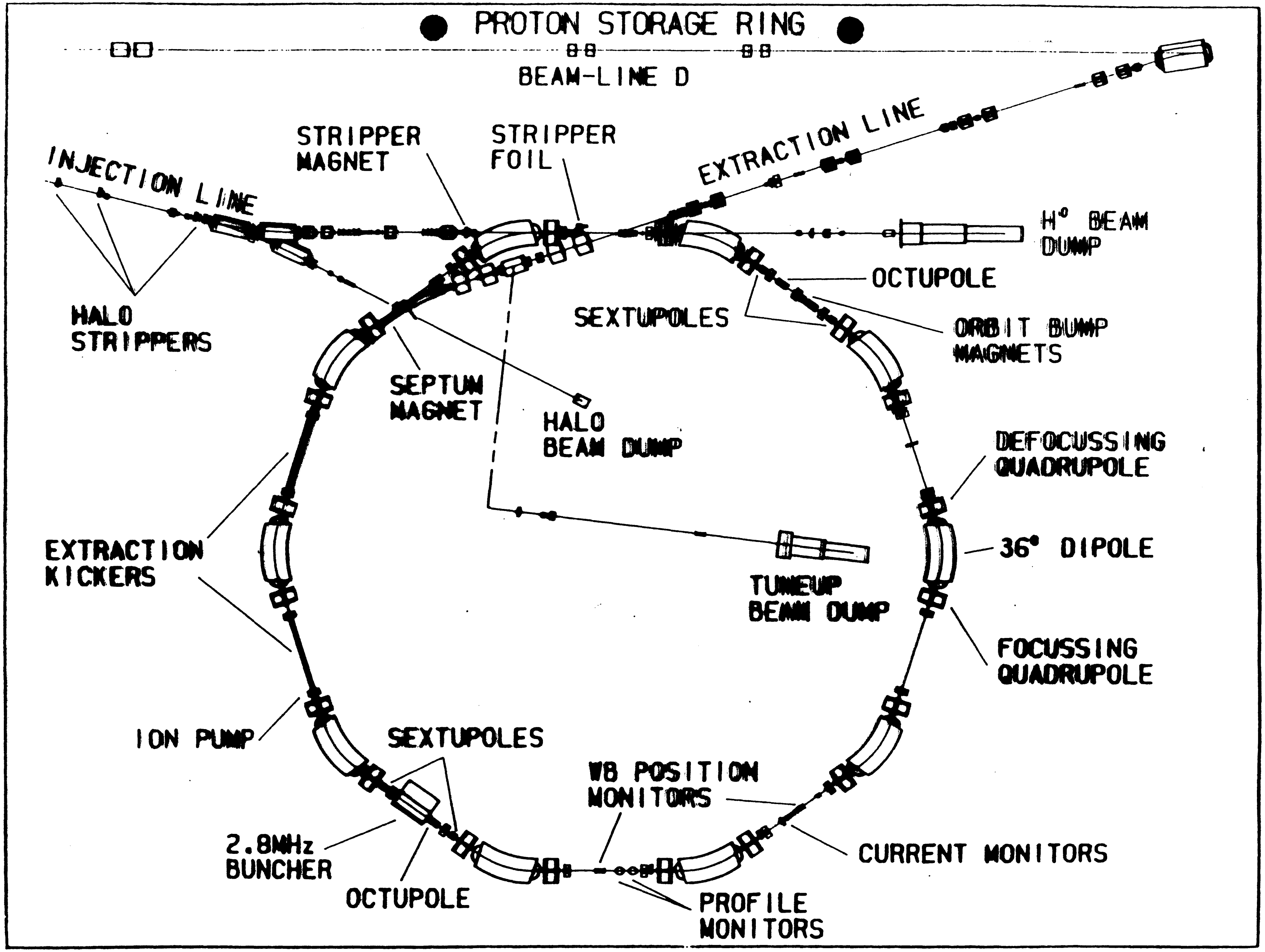
Purpose:

To deliver high intensity (100 μamp ave.) proton beam of 800 MeV kinetic energy to a target in a very short period (250 nanosecond) to produce spallation neutrons. Applications mostly in materials science. Also to produce neutrons.


(Los Alamos Neutron Scattering Center)
LANSCE Target
Neutrino Facilities
Line A
Line X
Line D
Injection Kicker
Stripper Magnet
Bypass Beamline
Septum
Switchyard Kicker
Foil Stripper
H° Beam Stop
Blue Room (Target 2)
Halo Beam Stop
Target 4
Extraction Kickers
805 MHz LINAC
Transition Region
36 deg. Dipole
201 MHz LINAC
D-Quad
2.8 MHz Buncher
F-Quad
Chopper
H+ Source
H- Source
H- Source
LAMPF
PSR
WNR


PROTON STORAGE RING
BEAM-LINE D
INJECTION LINE
STRIPPER MAGNET
STRIPPER FOIL
EXTRACTION LINE
H^0 BEAM DUMP
OCTUPOLE
SEXTUPOLES
ORBIT BUMP MAGNETS
HALO STRIPPERS
SEPTUM MAGNET
HALO BEAM DUMP
DEFOCUSSING QUADRUPOLE
36° DIPOLE
EXTRACTION KICKERS
TUNEUP BEAM DUMP
FOCUSSING QUADRUPOLE
ION PUMP
SEXTUPOLES
WB POSITION MONITORS
2.8MHz BUNCHER
CURRENT MONITORS
OCTUPOLE
PROFILE MONITORS

PSR Parameters

roton Kinetic Energy	T	797 MeV
ircumference	$2 \pi R$	90.2 m
verage Beam Pipe Radius	b	0.05 m
etatron Tunes	ν_x, ν_y	3.2 , 2.2
ransition Gamma	γ_T	3.1
etatron Amplitudes	β_{min}, β_{max}	~~1.5 m, 12.0 m~~ 1.0, 14.0 m
ispersion	η_{min}, η_{max}	1.1 m, 2.[illegible] m
hromaticities (measured)	ξ_x, ξ_y	−1.3, −1.0
uncher Harmonic, Frequency	h, f	1, 2.795 MHz
eak rf Voltage	V	15 kV
laximum Synchrotron Tune	ν_s	0.0006
esign Stored Beam	N_{max}	5.2×10^{13} (3.8×10^{13} achieved)
esign Peak Current	$I_{max} = 2 \bar{I}$	46.3 A

PSR Principles of Operation

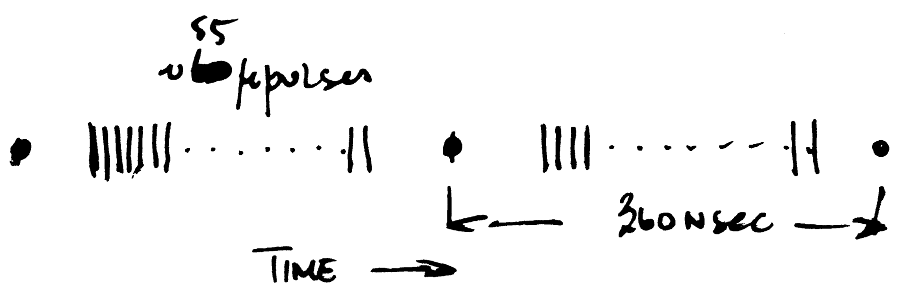
(vi) One Radio Frequency Cavity to Maintain Extraction Gap and Increase Energy Spread of the Beam

Harmonic # = 1 = $\frac{f_{RF}}{f_{REV}} = \frac{f_{RF}\, 2\pi R}{\beta c}$

$f_{REV} = 2.795$ MHz

Accumulation Process

Send Chopped Beam H^- from LAMPF for up to 10^{-3} secs (~2700 turns in PSR)



LAMPF output μ pulses at 201.25 MHz

Separation

(i) H^- Stripped to H^0 IN FRINGE FIELD OF STRONG DIPOLE

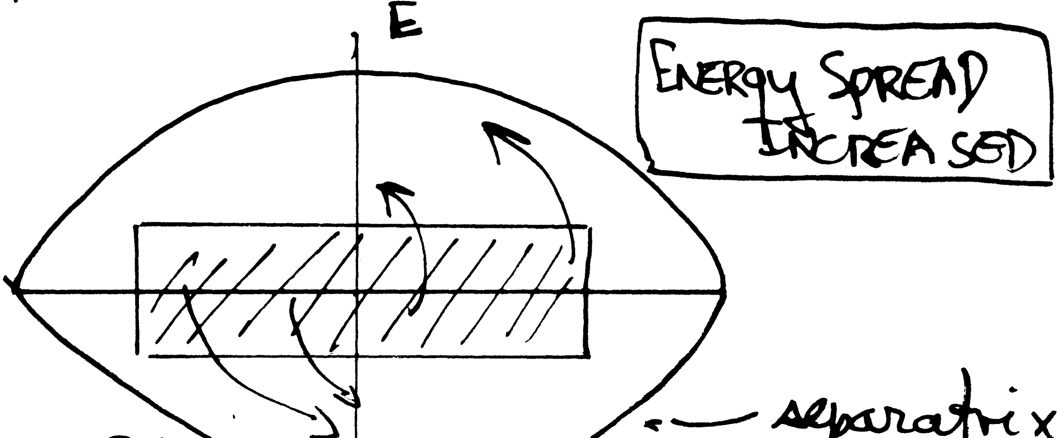
(ii) H^0 SENT THROUGH HOLE IN MAGNET

- STRIPS to H^+ IN CARBON FOIL

(iii) BEAM CIRCULATES UP TO END OF INJECTION

MAX ~ 2700 turns $\left(\frac{10^{-3}\,\text{sec}}{360\,\text{Nsec}} \right)$

- (iv) LONGITUDINAL PHASE SPACE EACH TURN



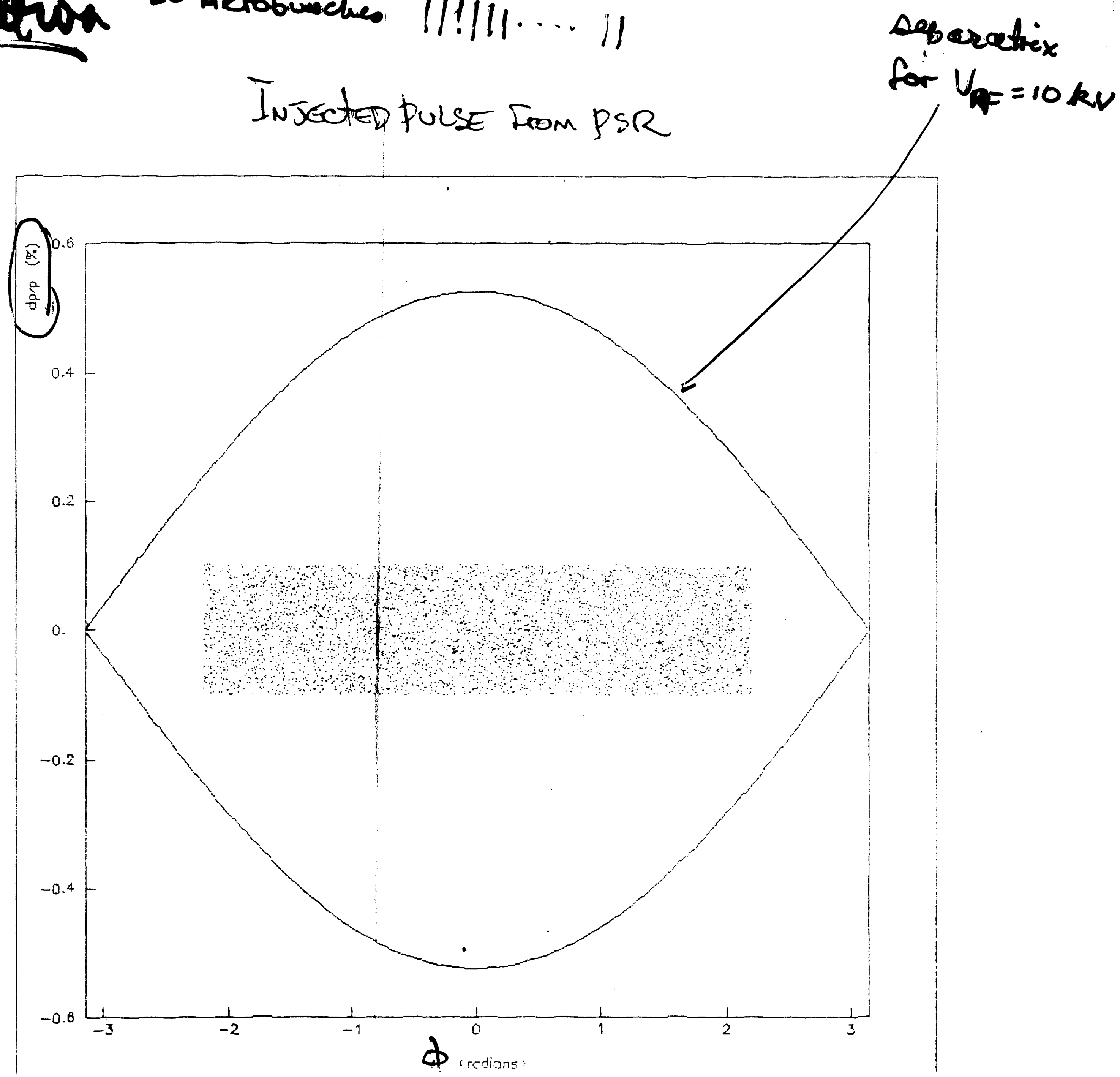
$\sigma \frac{dp}{p} = .05\%$

AT 1% LEVEL FULL width ~ 0.4% AT BASE

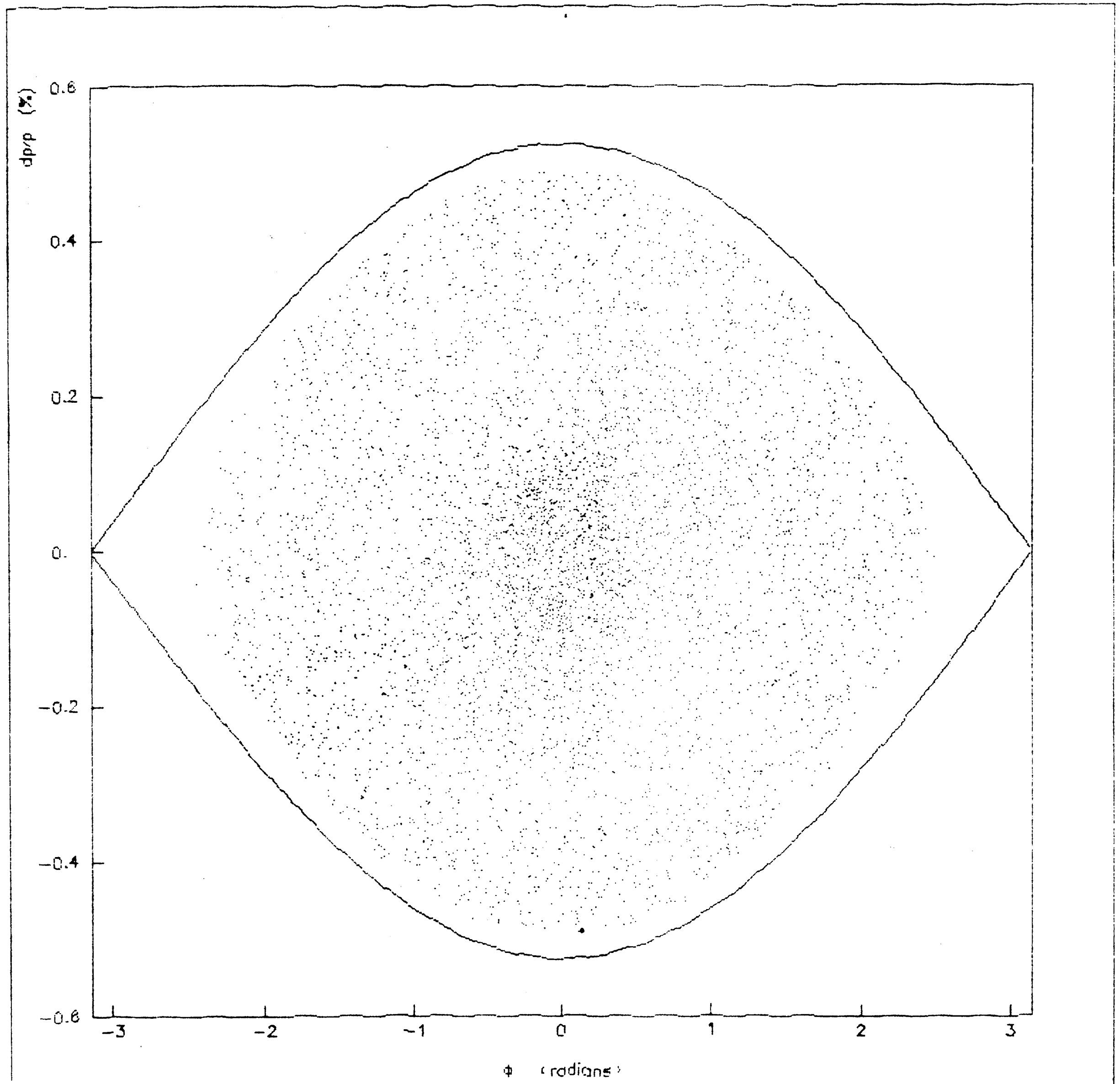
Simulation

- Microbunches ||||||.... ||

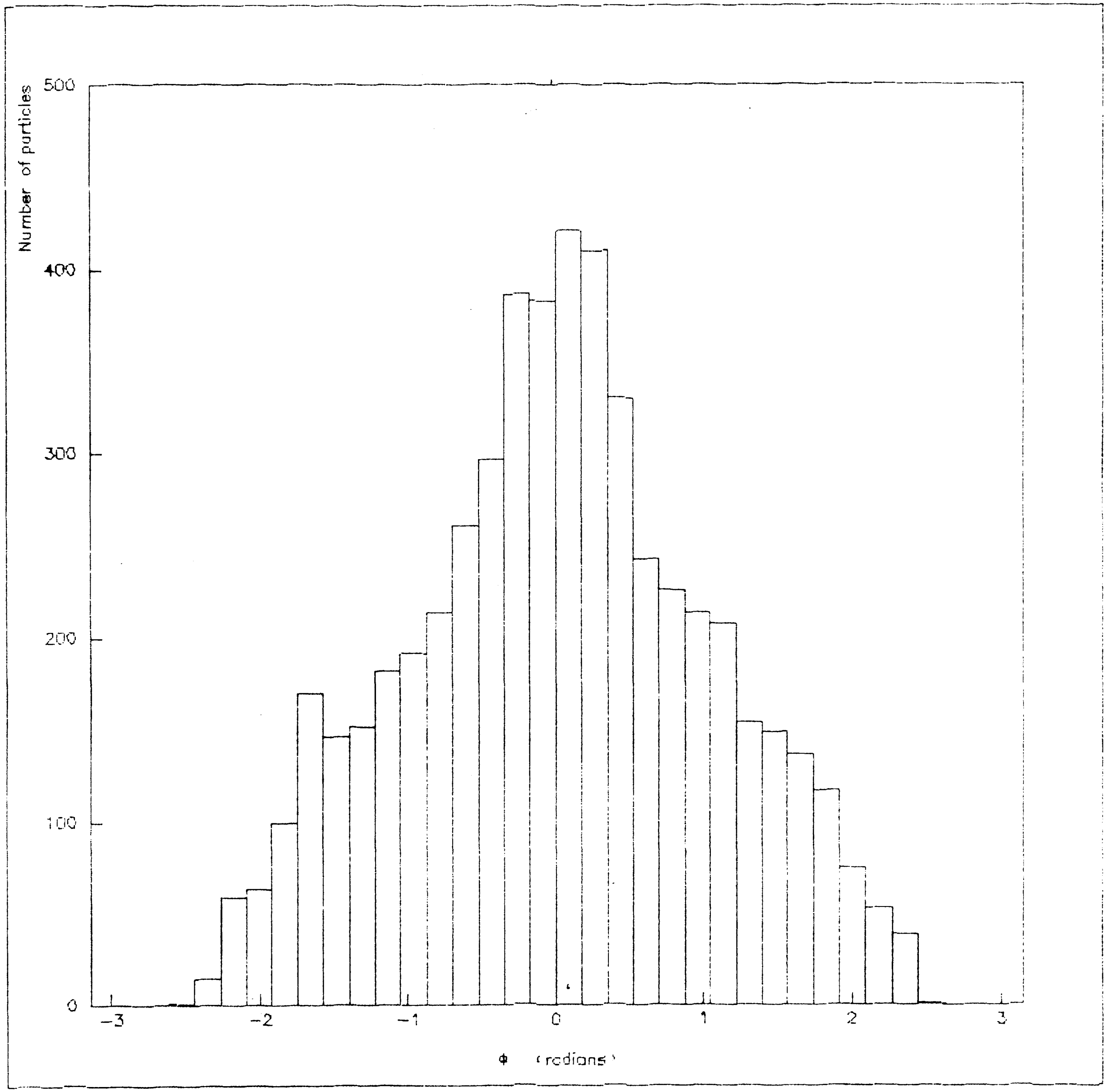
INJECTED PULSE FROM PSR



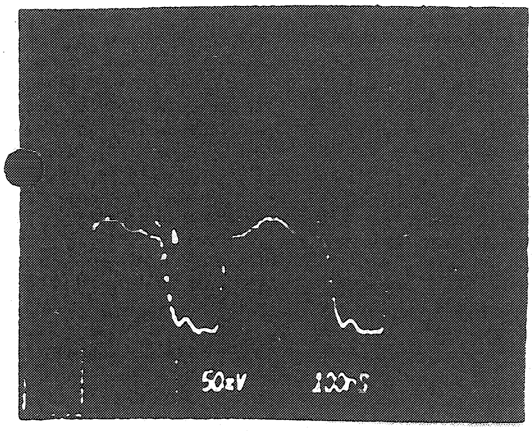
2700 turns INJECTED



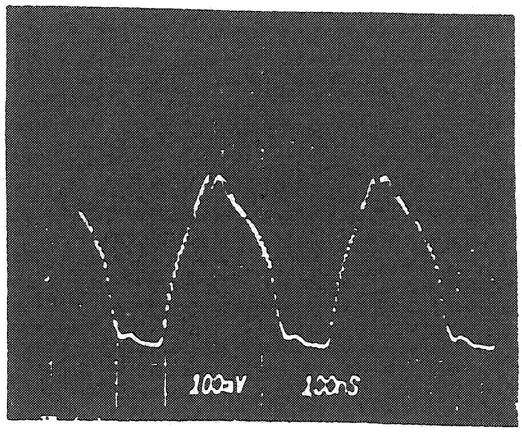
ϕ PROJECTION



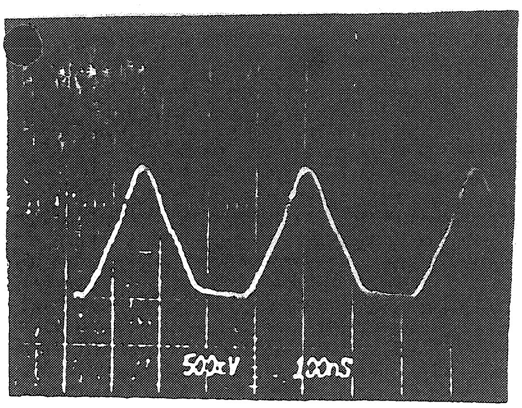
LONGITUDINAL BUNCH SHAPE DURING ACCUMULATION



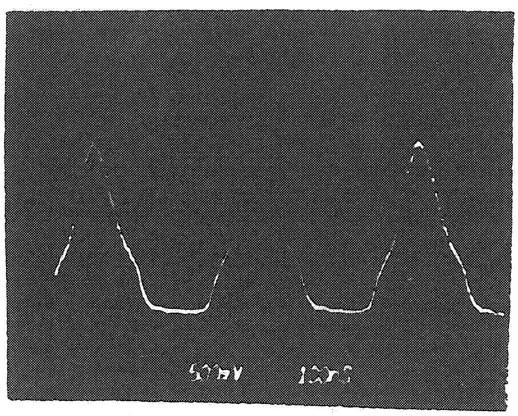
2.2×10^{12} ppp



4.6×10^{12} ppp



1.2×10^{13} ppp



2.0×10^{13} ppp

v) TRANSVERSE PHASE SPACE

H° BEAM DRIFTS FROM STRIPPER MAGNET TO 200-300 μg/cm² Carbon Foil.

• H° phase space not generally matched to ring acceptance

1. No Dispersion Matching

3. No Painting (Time Dependent)

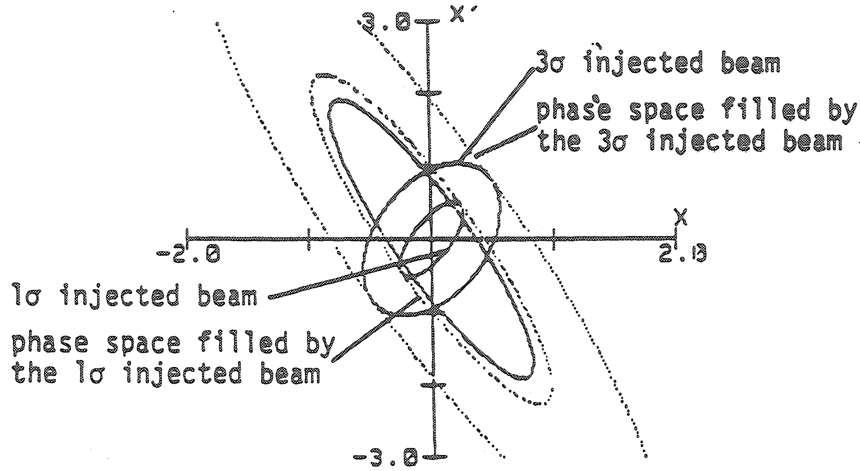
4. • Horizontal and vertical steering are used to move H° beam on foil, however.

Estimates of RMS geometric emit.

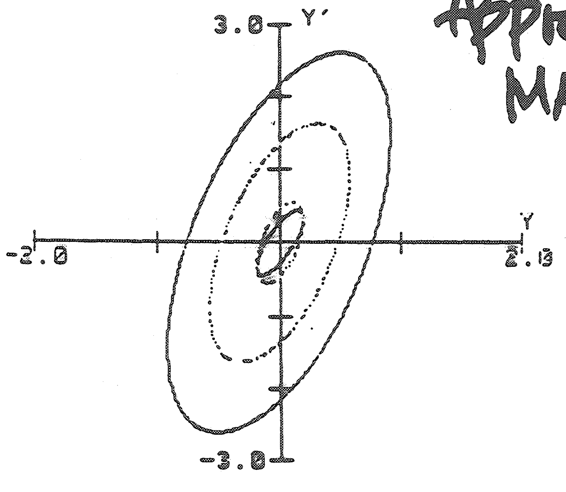
From linac H^- $\varepsilon \approx 0.3\pi$ mm-mr

H^0 at foil $\varepsilon \approx 1.0-1.5\pi$ mm-mr

SM gap horizontal – Ring Matching



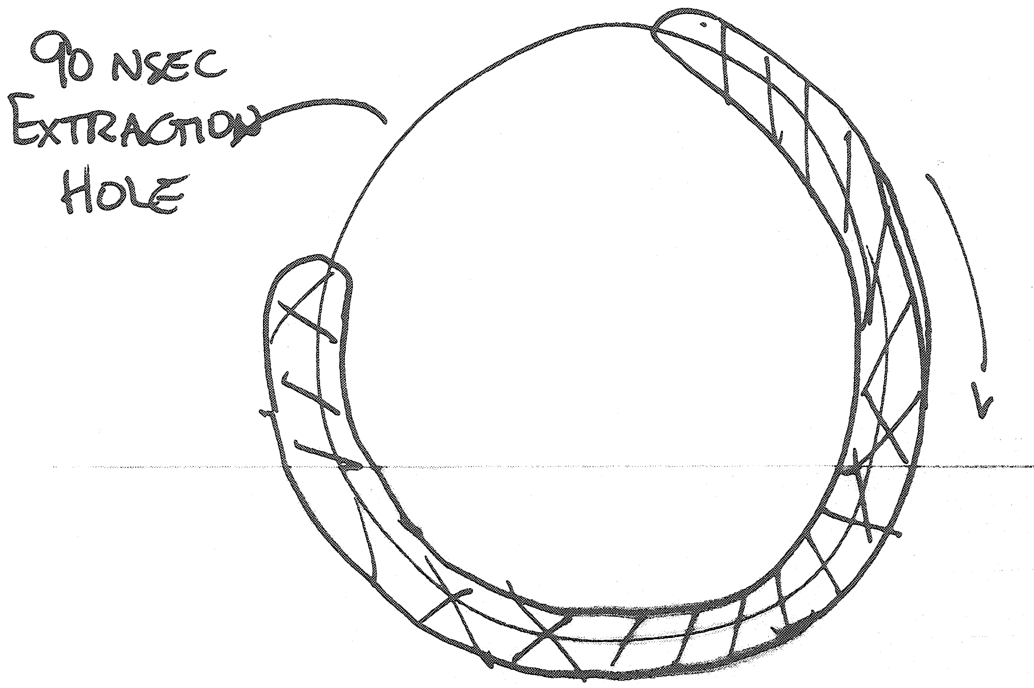
INJECTED BEAM APPROX MATCHED TO MACHINE ACCEP.



(vi) Extraction

Use two FAST STRIPLINE Kickers + Septum

RISE TIME < 50 Nsec



(vii) Betatron Resonances

$N_x \nu_x + N_y \nu_y = p$ an integer

$|N_x| + |N_y| =$ ORDER

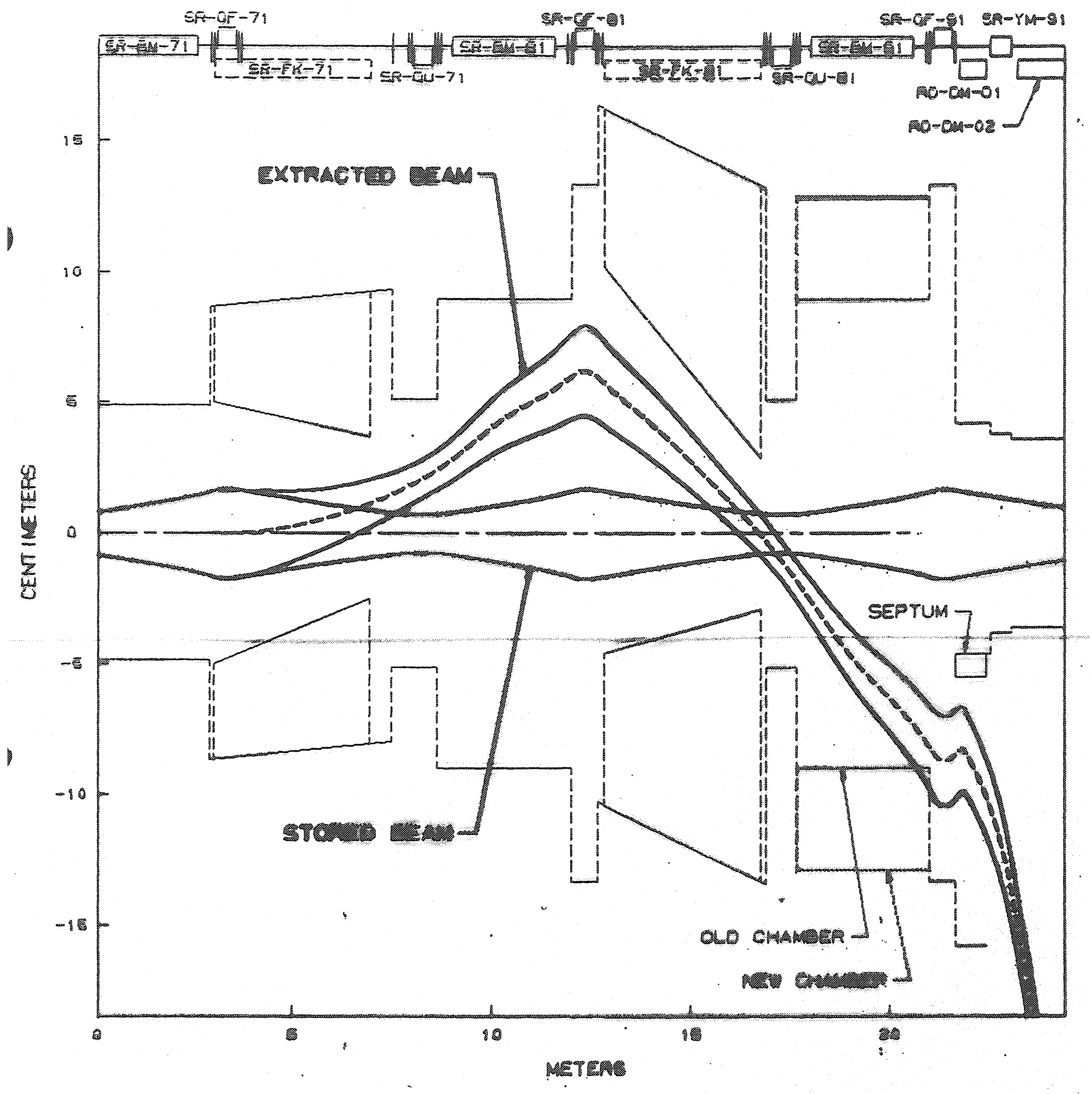
If a p^{th} harmonic is strong due to error K

$$\int_0^{2\pi} K/\beta \, e^{ip\theta} \, d\theta$$

CAN HAVE REINFORCEMENT OF PERTURBING KICKS

→ BEAM LOSS.

BEAM AND VACUUM ENVELOPES FOR DESIGN KICK



Basic Measurements

Closed orbit (correction)

Horizontal: dipole shunts
Vertical: quadrupole translation
Tolerance: +/− 1 mm

Betatron tunes

Stripline BPM with Fourier analysis
Capacitive BPM with spectrum analyzer
Agreement within 0.5% (3.23,2.21)
Agreement with quad currents to 1%

Resonance map

Survey 1/2 integer square near operating pt
Identify 1/2, 1/3, 1/4 integer lines
No strong resonances near operating pt

Chromaticities

Measure by varying B and p independently
Measurements: (x) −1.25; (y) −0.96
Calculations: (x) −0.82; (y) −1.30

Transition gamma

Measure revolution frequency vs B field
Measurement: 3.22; calculation: 3.08

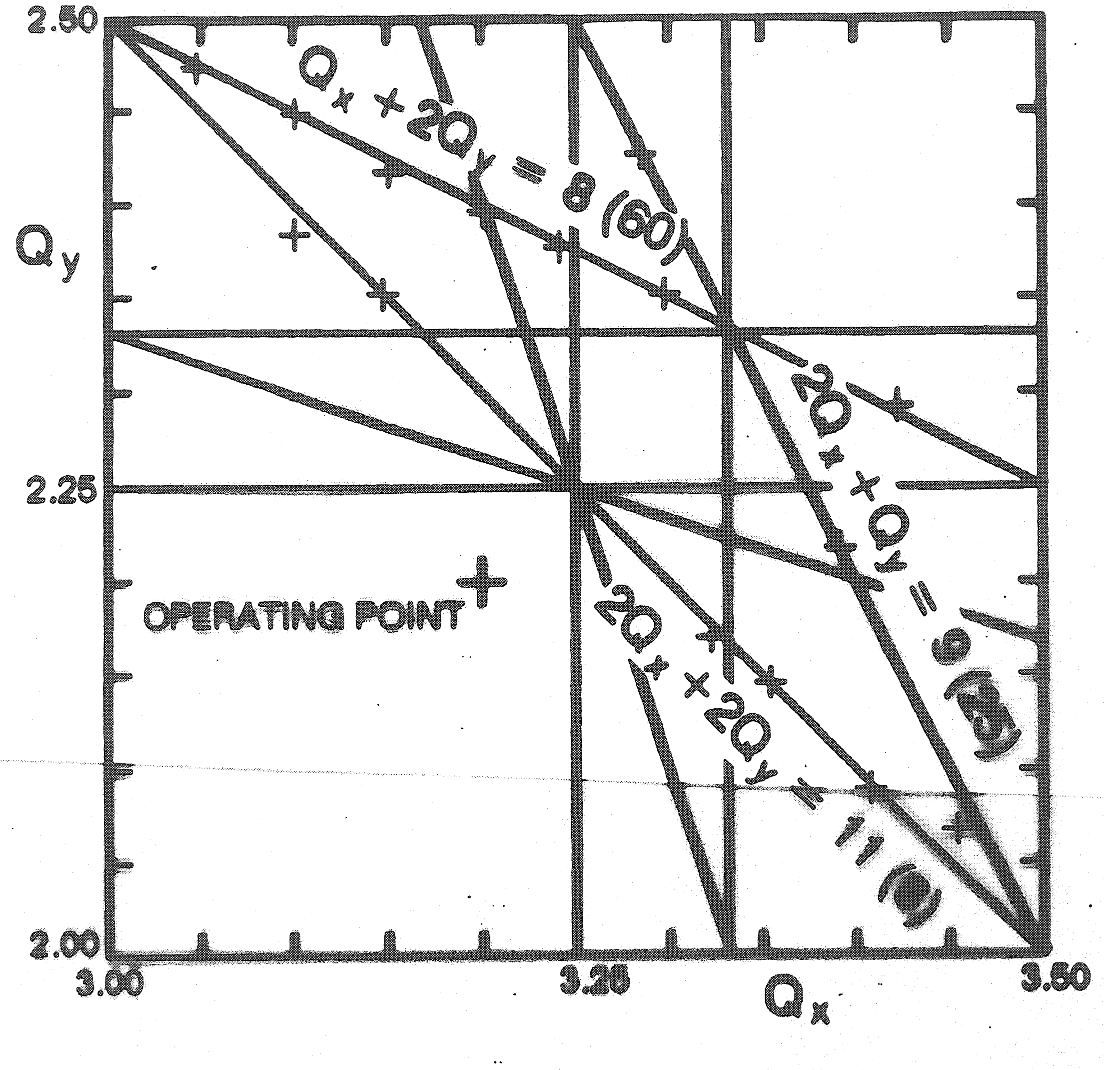
Beta functions

To be measured in 1987

LOS ALAMOS

ACCELERATOR TECHNOLOGY DIVISION

PSR TUNE SPACE MAP



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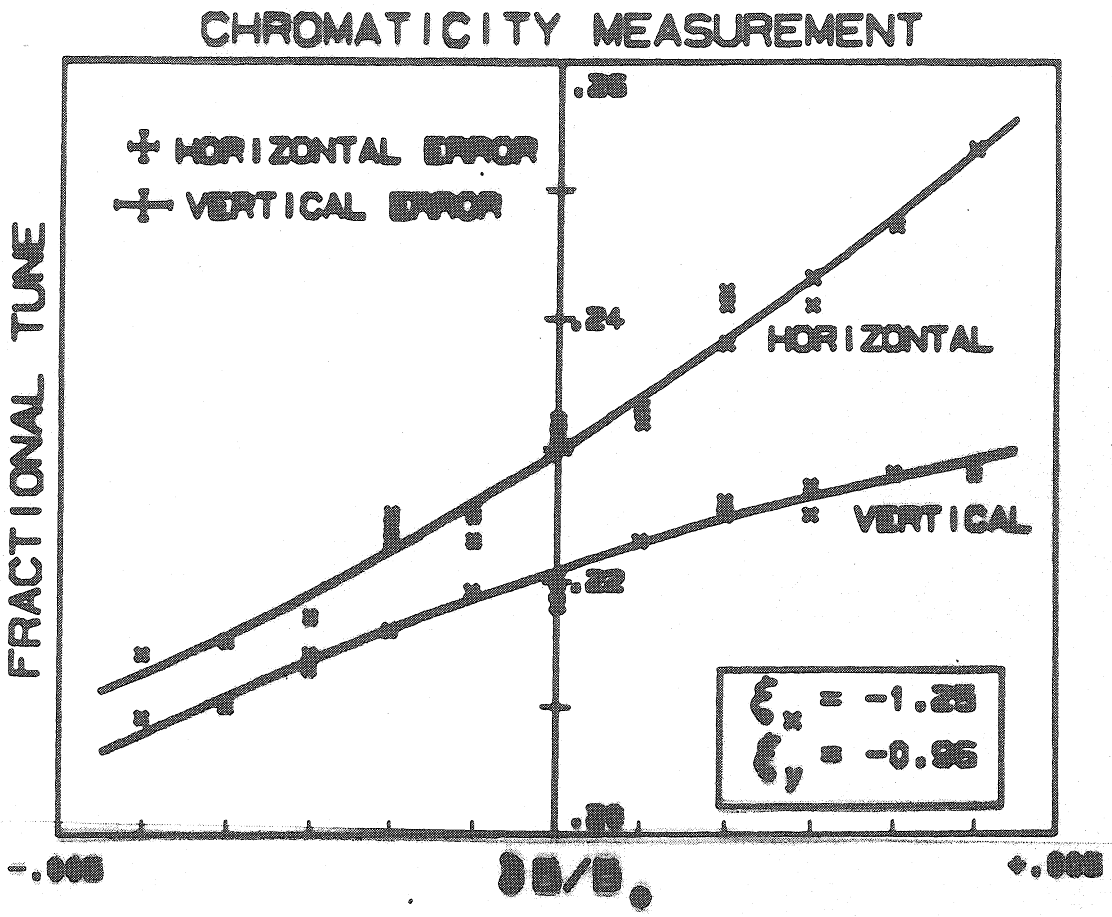


THEORY

x-chromaticity -0.82
y-chromaticity -1.30

LOS ALAMOS

ACCELERATOR TECHNOLOGY DIVISION

<u>Current Status of PSR</u>

(i) We deliver 30 μA to experiments at e.g., 15 Hz and 1.25×10^{13} ppp.

Limitation: <u>Accumulation Losses</u>.

The losses increase <u>quadratically</u> with injection ~~take~~ time so production running uses 375 μsec injection period. Losses occurs in horizontal plane. Consistent with "tails" of beam striking limiting apertures.

PSR Development meeting Sept 3, 1987

STATUS OF ACCUMULATION LOSS PROBLEM

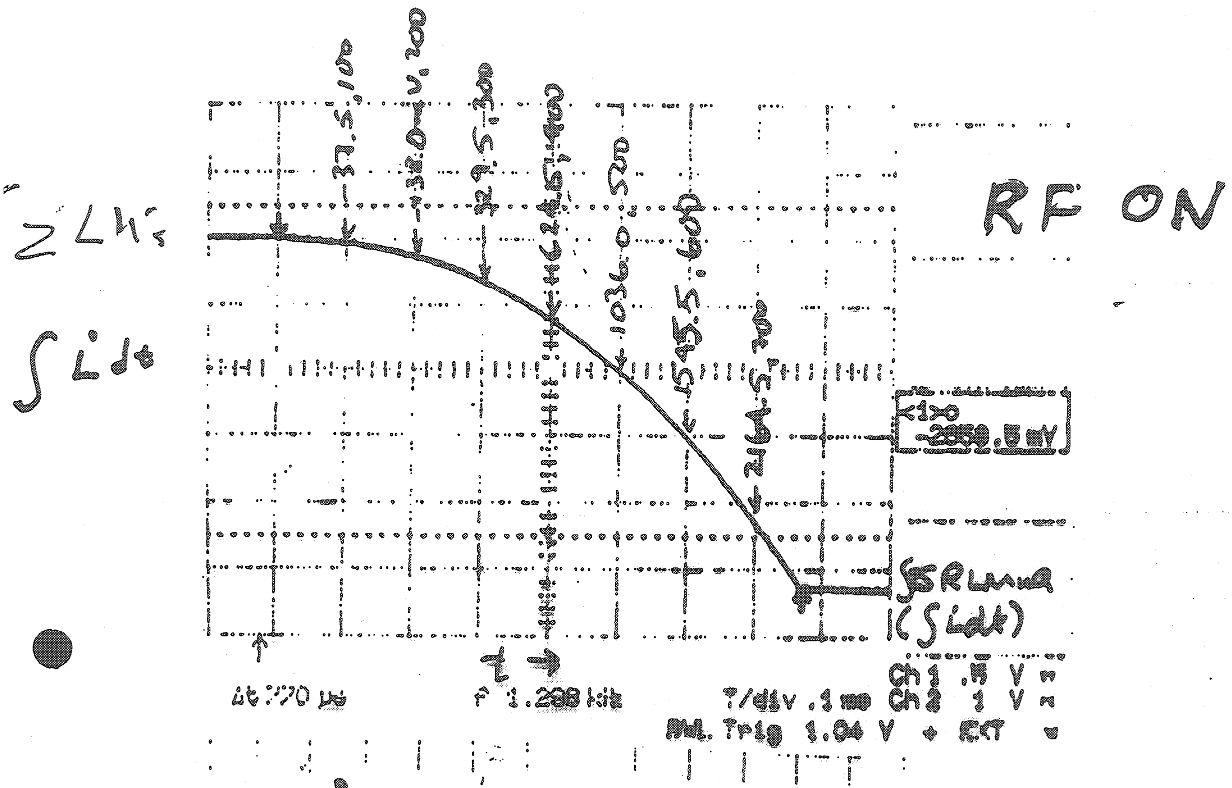
- OBSERVED MECHANISMS FOR 1.6% LOSSES @ 375μs accumulation (SR ST01 injection)
  - FIRST TURN ~7% (.1%)
  - NUC SCATTERING IN FOIL ~10% (.15%)
  - FROM ACTION OF BUNCHER ~30% (.5%)
  - EMITTANCE GROWTH FROM FOIL SCATTERING 53%
    - THE BALANCE? (.8%)

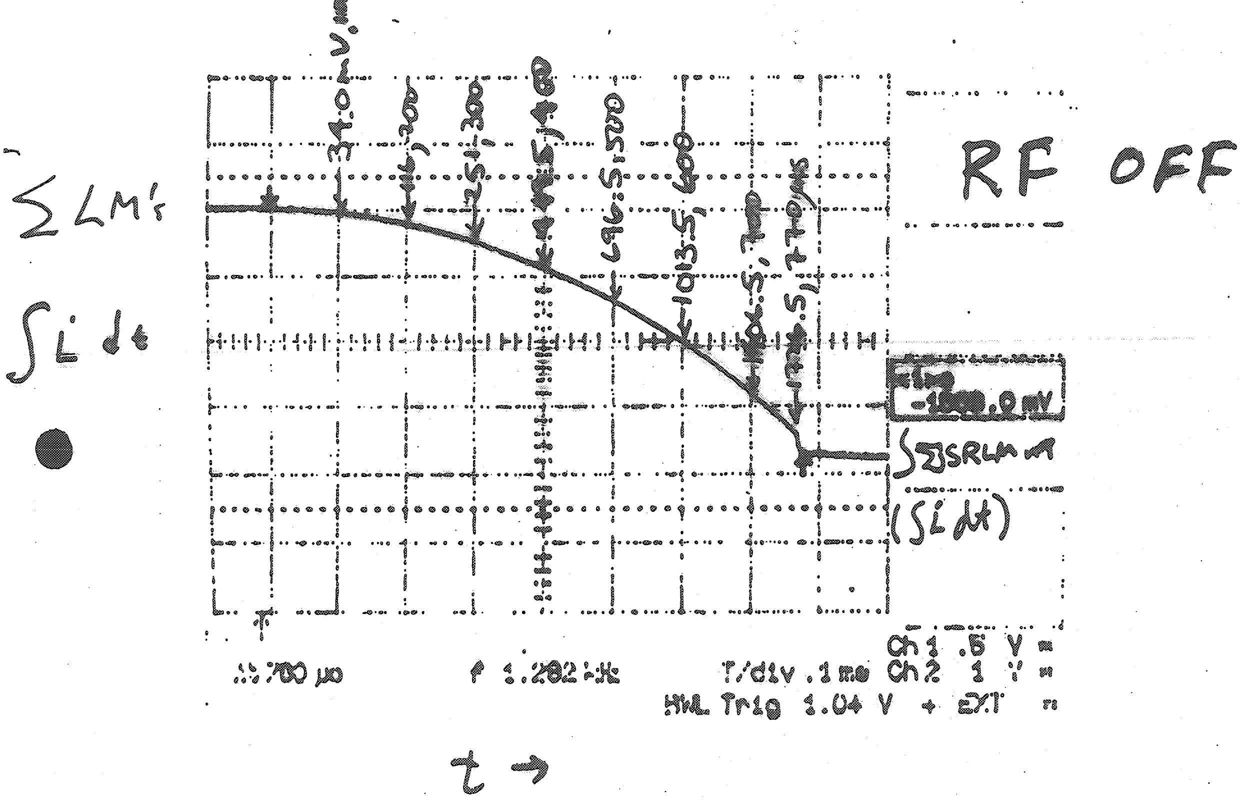
- KNOWN APERTURE LIMITATIONS
  - 40 MM AT EXTRACTION SEPTUM
  - ~33 MM AT 3" PIPE DOWNSTREAM OF RODM01
  - ~36 MM AT SRST01 FOIL HOLDER

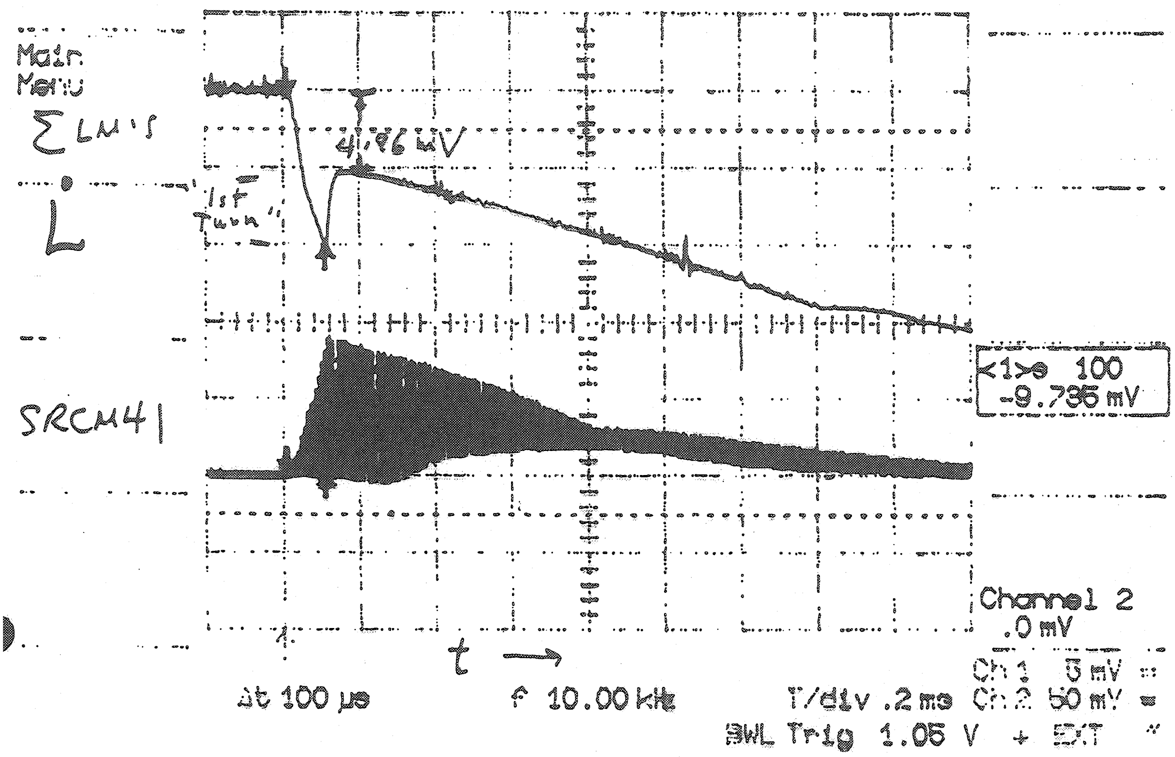
- SPILL PATTERNS CONSISTENT WITH SPILL AT THESE APERTURES.

- INJECTION MATCH DIFFICULT
  INITIAL x EMITTANCE MAY BE TOO LARGE

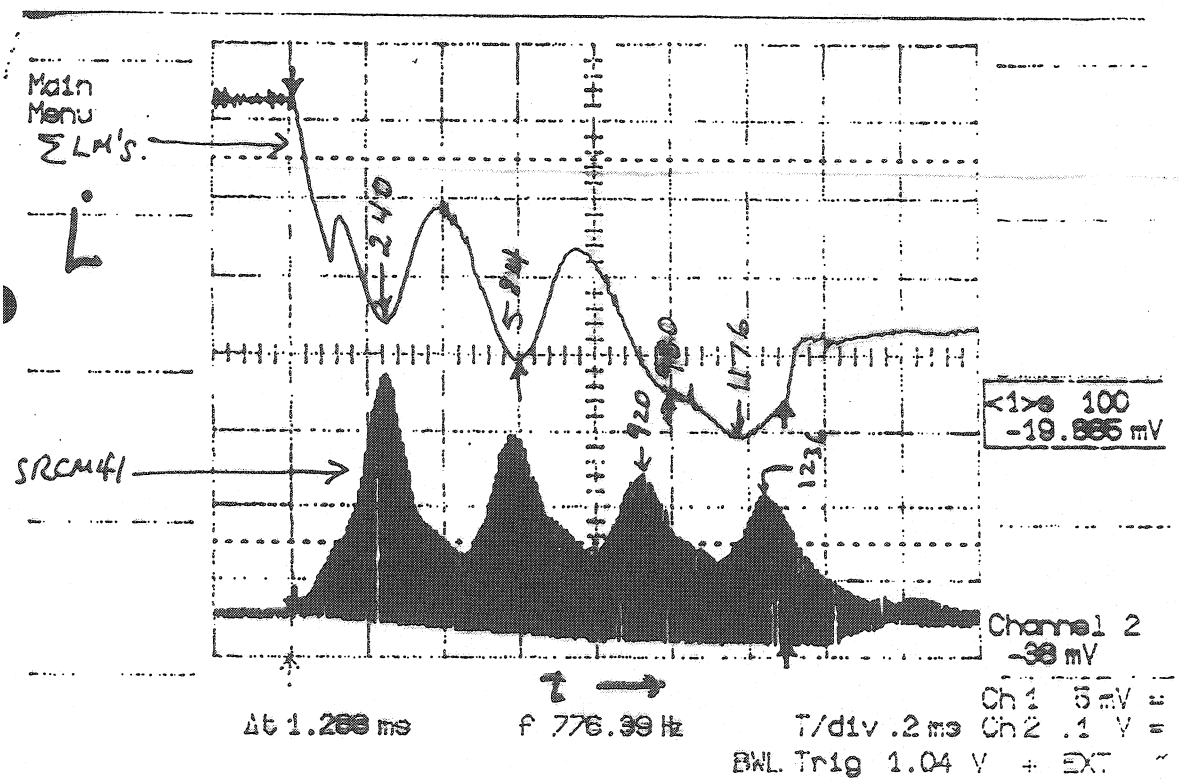
QUADRATIC ACCUM. LOSS



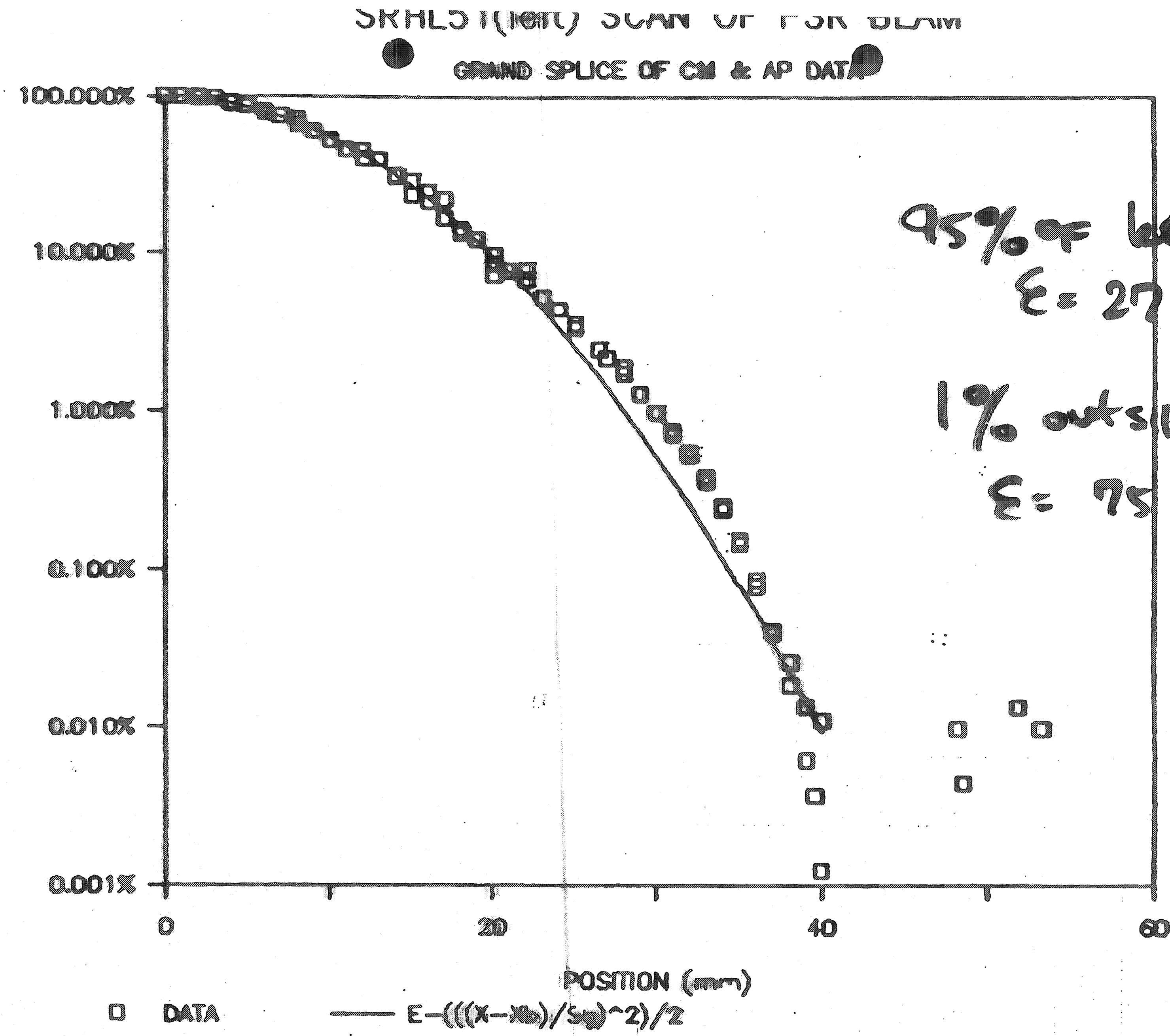




RF OFF



RF ON – 12.55 KV



95% of beam
ε = 27 mm-mr

1% outside
ε = 75 mm-mr

$\bar{X} = -0.16$ mm

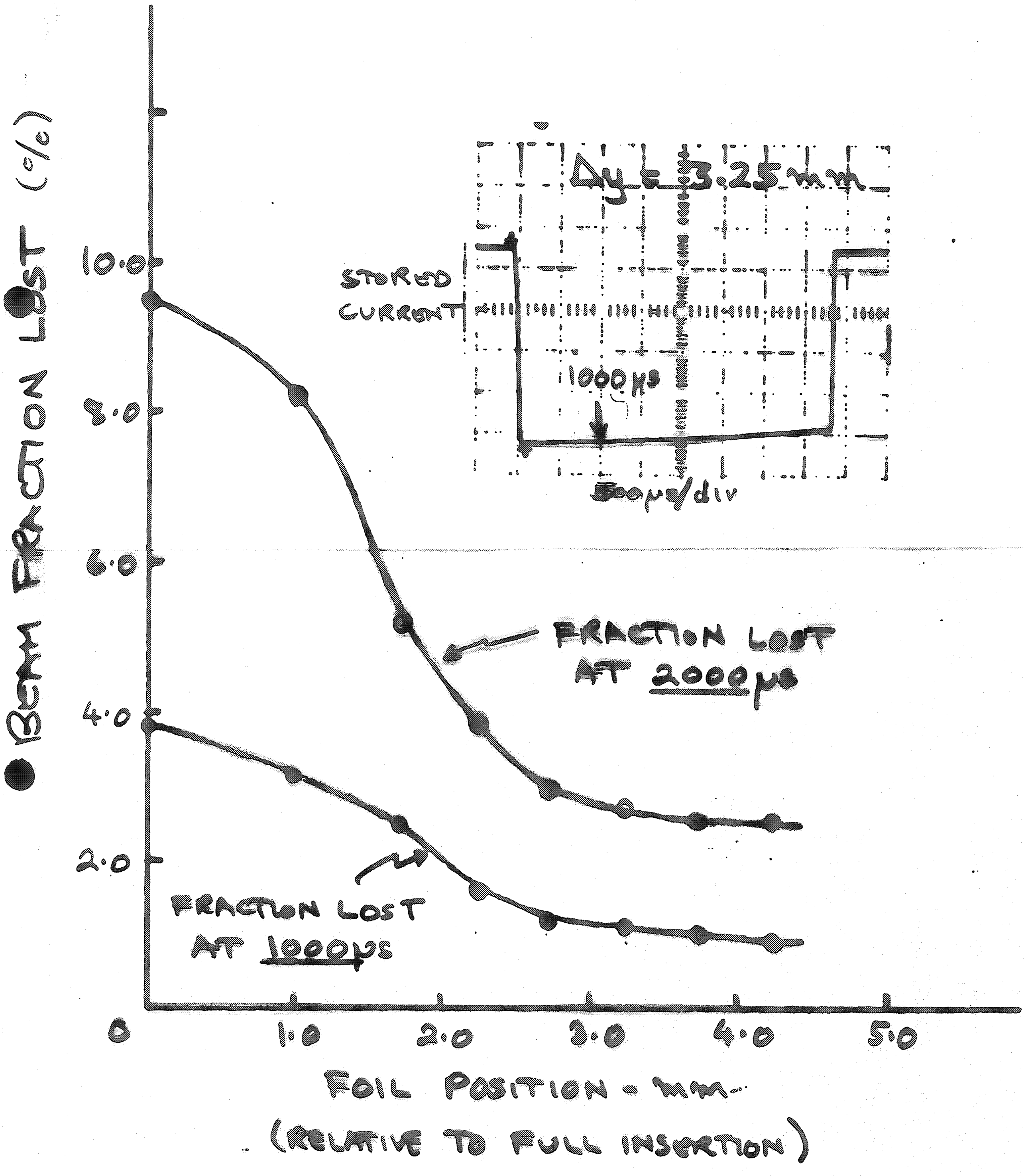
$\sigma = 9.33$ mm

THE FOIL IS THE MAJOR PROBLEM!

- o BEAM LIFETIME OFF FOIL = 1000 ms (500 x LONGER THAN ON FOIL)
- o ON-FOIL LIFETIME IS INDEPENDENT OF BEAM INTENSITY OVER SEVERAL ORDERS OF MAGNITUDE
- o LIFETIME IS INDEPENDENT OF TUNE OVER LARGE AREA OF TUNE SPACE NEAR OPERATING POINT
- o LIFETIME UNAFFECTED BY STORAGE RING VACUUM

× WE TRY TO REDUCE SCATTERING EFFECTS BY ELEVATING FOIL EDGE AND VERTICAL INJ. STEERING

LOSS REDUCTION FROM ELEVATING FOIL EDGE + VERTICAL INJECTION STEERING



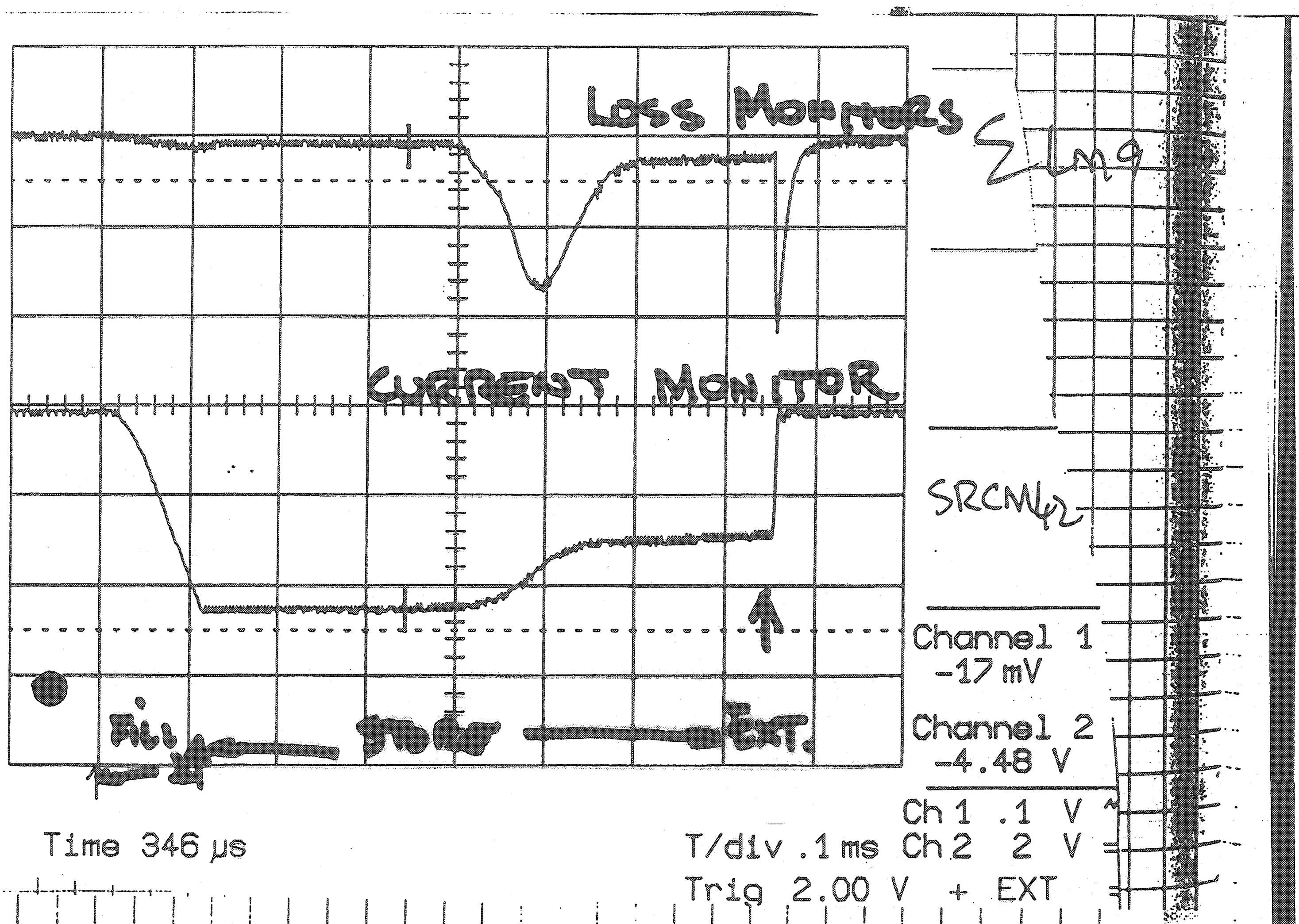
(ii) We observe a coherent transverse instability in both a coasting and "bunched" mode.

Coasting Threshold:

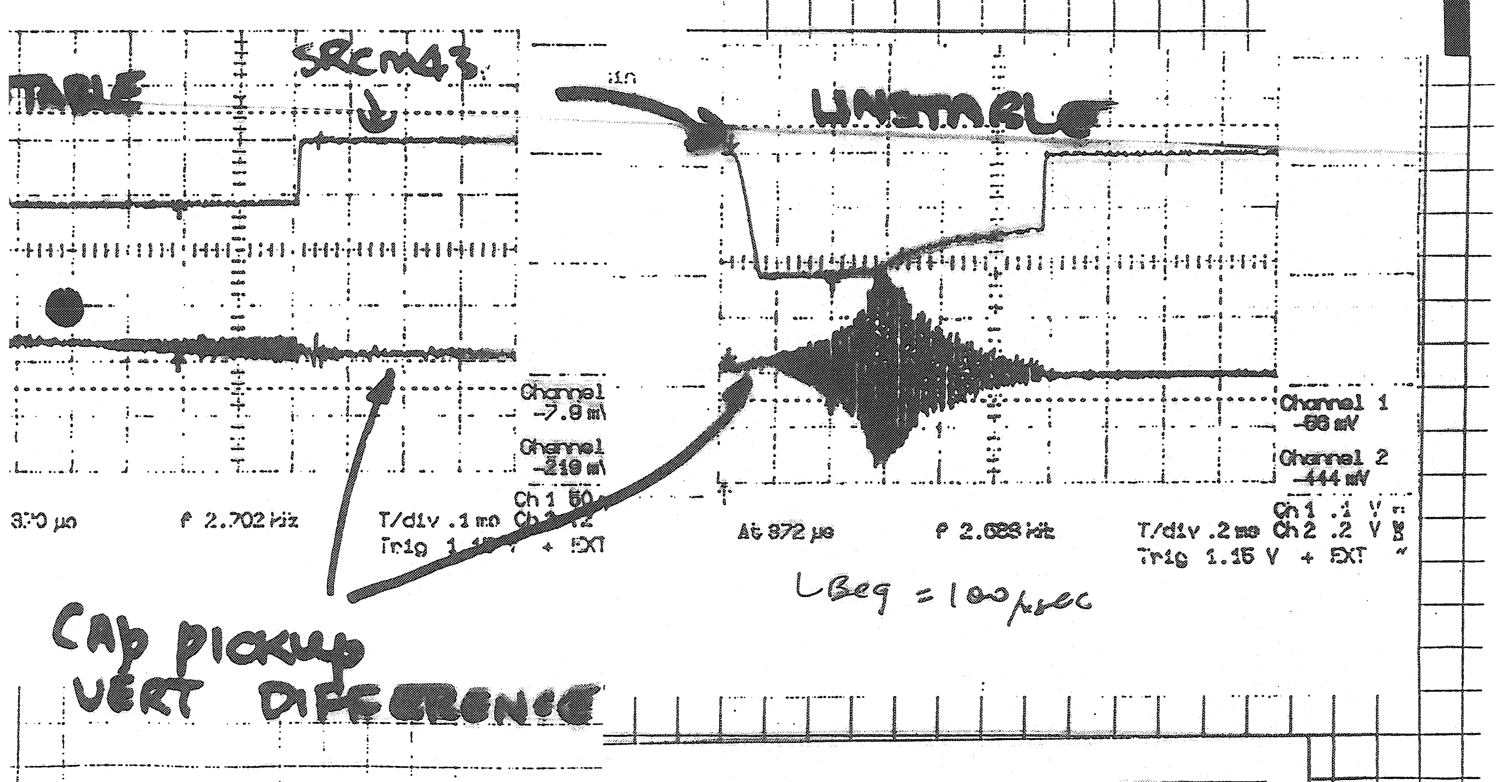
0.4 - 1.1 X 10^{13} depending upon injected vertical beam size.

Signature:

Rapid coherent transverse beam growth (usually vertical) followed by beam loss and ensuing stability.



LOSS MONITORS
Σ Ln9
CURRENT MONITOR
FILL
STORE
EXT.
SRCM42
Channel 1
-17 mV
Channel 2
-4.48 V
Ch 1 .1 V
Time 346 µs
T/div .1 ms Ch 2 2 V
Trig 2.00 V + EXT



STABLE
SRCM43
UNSTABLE
Channel
-7.9 mV
Channel
-219 mV
Ch 1 50
f 2.702 kHz
T/div .1 ms
Channel 1
-66 mV
Channel 2
-444 mV
Ch 1 .1 V
Ch 2 .2 V
At 872 µs
f 2.628 kHz
T/div .2 ms
Trig 1.15 V + EXT
LBeq = 100 µsec
CAP PICKUP
VERT DIFFERENCE

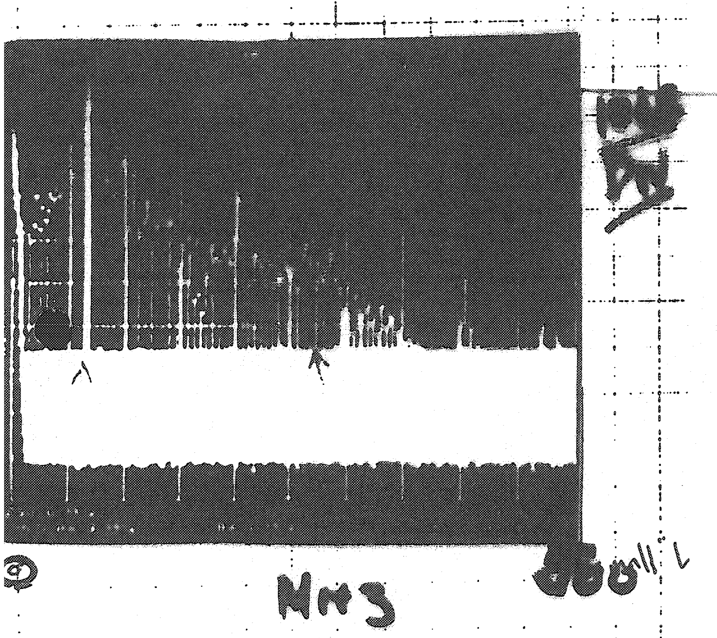
WE STUDIED TRANSVERSE DIFF SIGNALS OF 2 MONITORS

STRIPLINE MONITOR
CAP. PICKUP

USE FAST SCOPE + SPECT. ANALYZ

- STRIPLINE PICKUP: VERT DIFF

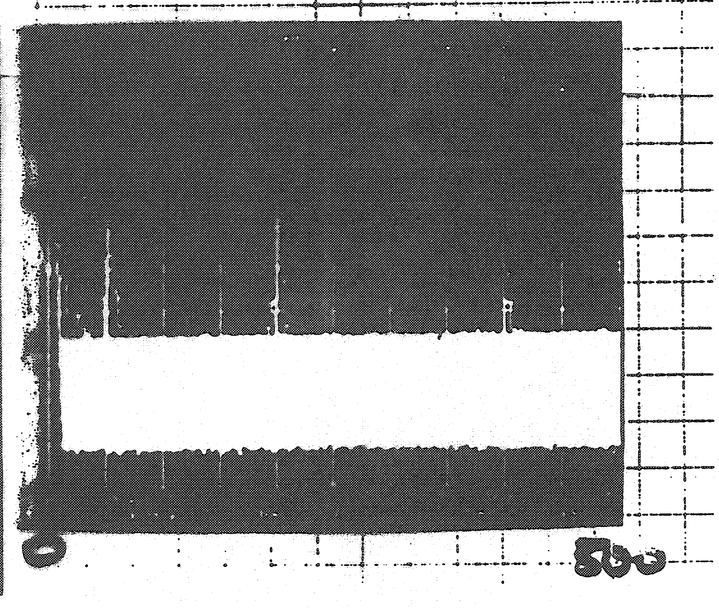
UNSTABLE



8 x 10^{12}

52 MHz	-17.5 dBm
67 MHz	-3.8 dBm
281 MHz	-29.6 dBm
403	-45.8 dBm

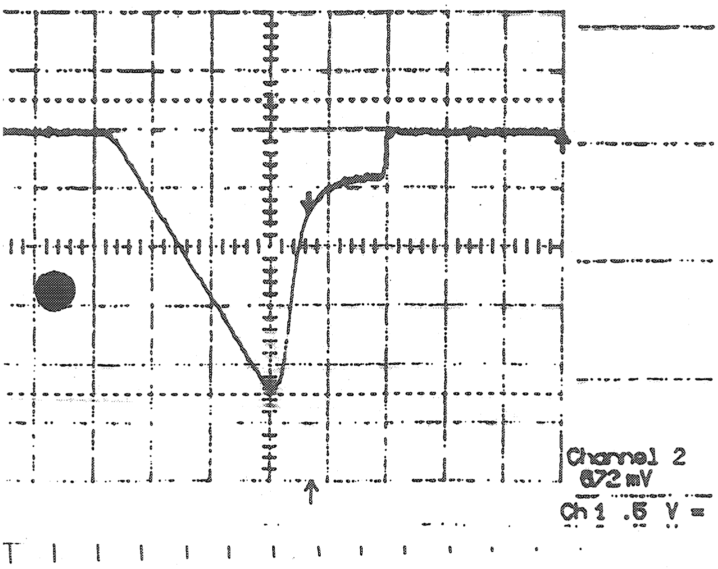
STABLE



4 x 10^{12}

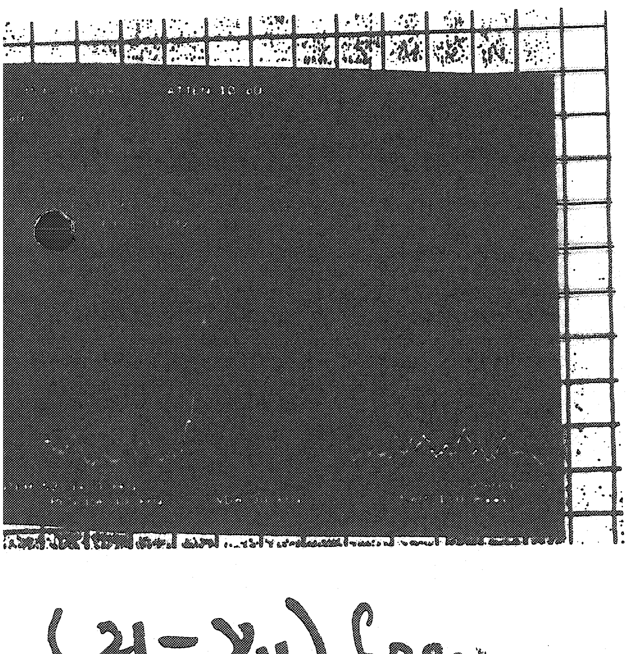
53 MHz	-38.4 dBm
202 MHz	-32.5 dBm
404 MHz	-51.6 dBm

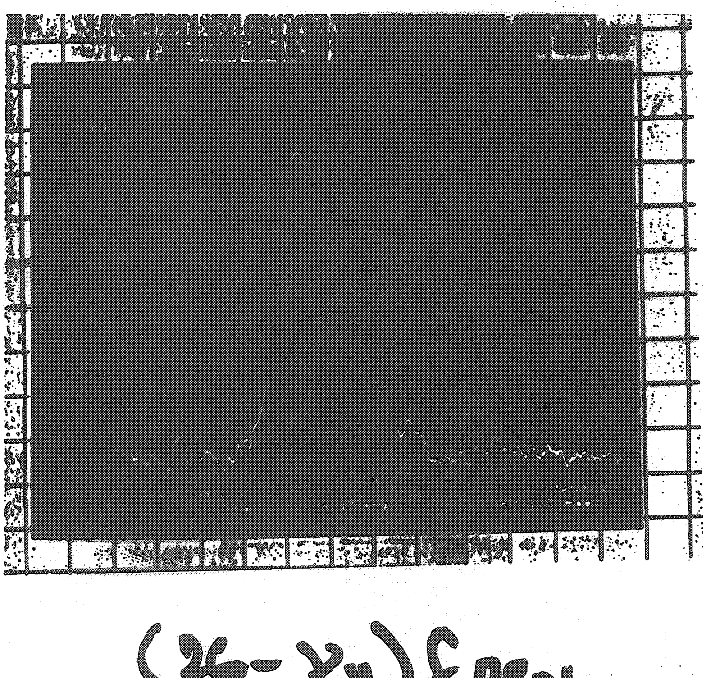
DO TIME DOMAIN STUDIES USING SPECT. ANALYZER OF
$(n - \nu_y) f_{rev}$ lines



BEAM LOSS
300 μsec
AFTER SOI

STRIPLINE PICKUP
VERT DIFF





$(21 - \nu_y) f_{rev}$ $(26 - \nu_y) f_{rev}$

Rise time ~ 50 μsec
LINES arise 300 μsec AFTER SOI

"Bunched" Beam Threshold

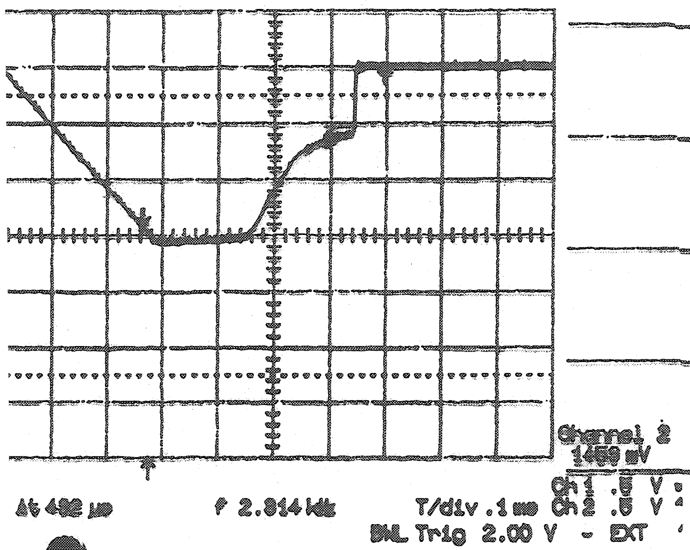
- Can push up to 2.7×10^{13} by using rf cavity to ~ 12 kV.

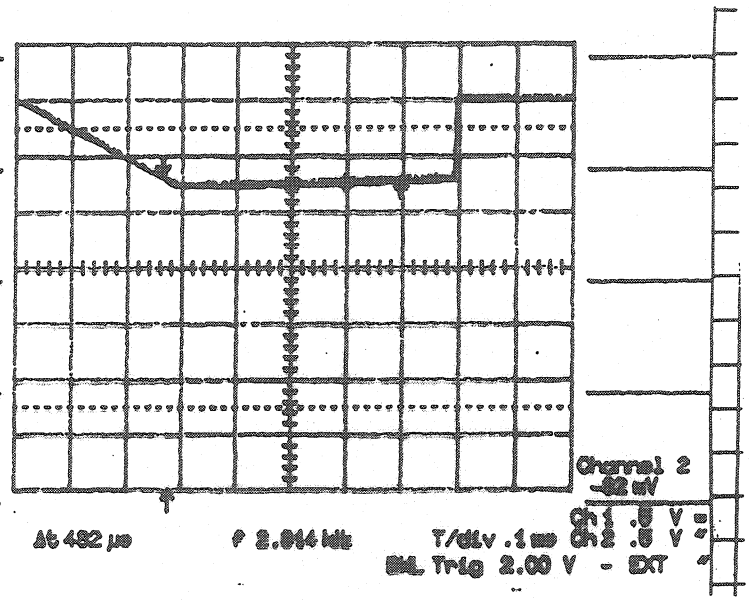
- Additional use of sextupoles, octupoles, second-harmonic rf permit extraction of 3.75×10^{13} protons (source limited).

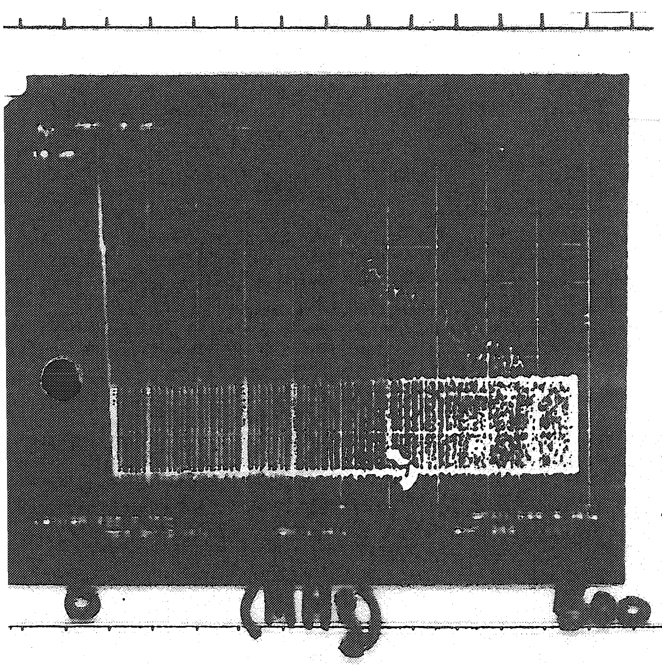
- Frequency and risetime appear to be similar to that of coasting beam.

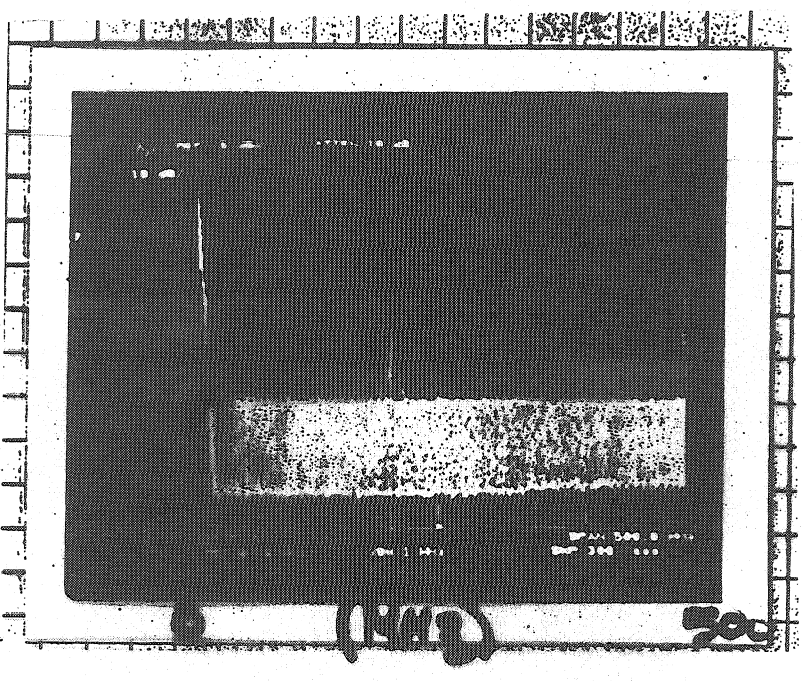
UNSTABLE

STABLE









VERT DIFF STRIP LINE

Coherent Instability Presently Not Inhibiting PSR Performance

- It looks like transverse.

- Stabilized by larger vertical beam size and tune spread.

- Driving impedance seems to be 50 - 150 MHz with fairly low Q.

- Need Re $Z_{\perp} \sim 10^6$ ohm/m to account for rapid growth time.

- Not due to:

  RF cavity, orbit bumpers, stripline kickers, stripping foil cavity.

We are still searching for source.

May need damper (tough).