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Low Intensity Emittance Measurements for ISA

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DISCLAIMER

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AGS Studies May 26, 1975 0700 - ≅ 1600

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<u>Objective</u>: Low intensity beam phase space parameters measurement relevant to the objective of using the AGS as the injector for the ISA.

a) Starting with standard full intensity extraction for the υ target, to set up subsequently the AGS for ~ 2.5 10^{12} ppp operation by modifying the injection parameters. Since it is desired to maintain high phase space density, populating only the central part of the AGS acceptance phase space, the low efficiency multi stacking part of the present multiturn injection mode will be used whereby most of the injected beam will be scraped by the injection septum.

b) With this injection mode and resultant beam intensity of ~ 2.5 10^{12} to optimize the rf system capture parameters (mainly V_{rf} vs time) so that minimum longitudinal phase space dilution occurs during the AGS cycle.

c) To measure beam size in the AGS at low and high energy in order to determine transverse phase space magnitude, both vertically and horizontally. (Since the horizontal beam size value is a composite of betatron amplitude and local momentum dispersion the longitudinal parameters need to be measured also, see below.) Beam size will be measured by using presently existing scraping targets (J19 and F20).

d) To measure longitudinal phase space magnitude by measuring bunch shape detail by means of the existing broad ban pick-up electrode unit. (It may only be good enough to establish an upper limit value.)

e) To measure the beam emittance in the fast external beam line by beam size observation with the profile monitors located at (U273), U303, U380 and U667. (Number of operable beam profile monitors may be inadequate.)

f) To verify with this low intensity beam, i.e. low ν spread beam, the absence of horizontal-vertical coupling with the standard mode of measurement and by measuring the ν_x, ν_y values.

g) To check quantitaively the effectiveness of phase space clean-up with a clean-up target as is being done now regularly for the fast beam.

Results and Discussion

1. AGS Performance

At the start of the studies some parameters of the AGS were as follows:

Linac beam: 110 μsec
40 mA (beam pulse had anomalous "hash".)*

Stacked beam: 8 10^{12}ppp

Early monitor (190 msec): 6.6 10^{12}ppp

The accelerated beam intensity reduced to ~ 5 to 5.5 10^{12}ppp when the fast ejection septum magnet was retracted in order to provide access to the fast beam cave. Because it would be costly in time, no effort was made to correct for this by changing the low field correction parameters. Consequently, during the subsequent low intensity studies somewhat more injected turns were required to reach the objective intensity, than otherwise would have been the case.

*Because of imminent turnoff no time was taken during the preceding week to change the ion source.

2. Linac Beam Emittance

The following values were obtained ($A_{90\%}$ = 5.5 π μrad.m):

Horiz.	$A_{80\%}$ 1.7 π μrad.m		Vert.	$A_{80\%}$ 2.8 π μrad.m
	$A_{50\%}$ 0.8 π μrad.m			$A_{50\%}$ 1.1 π μrad.m
	α 3.2			α -0.8
	β 23.5 m.			β 11.8 m.

The vertical emittance values are in agreement with those usually obtained for good linac performance. The horizontal values are anomalously small, by almost a factor of two, compared with normal good linac performance. Since the collimator in the LEBT line has been recently removed, there has been some evidence of horizontal "side lobes"* and it is not excluded that this horizontal measurement may only have taken into account the central domain of the emittance distribution. Regarding also the reported performance of previous running days the linac beam emittance values will be taken here as:

$A_{v,80\%} = 2.8\ \pi\ \mu rad.m$ $\qquad$ $A_{v,90\%} = 5.5\ \pi\ \mu rad.m$

$A_{h,80\%} = \geq 3\ \pi\ \mu rad.m$ $\qquad$ $A_{h,90\%} \sim 6\ \pi$

*K. Batchelor, private communication.

3. Beam Matching

With the existing transport matching quadrupoles the measured emittance translated to the exit of the inflector as follows:

$\alpha_x = 0.2$ $\qquad$ $\alpha_y = 2.9$

$\beta_x = 4.8$ m. $\qquad$ $\beta_y = 34.8$ m.

A proper match to the AGS vertical acceptance requires $\alpha_y = 1.1$ $\beta_y = 13.0$ m. The vertical phase space dilution factor at injection associated with this mismatch would be ≈ 1.5. During subsequent studies a vertical corrected "match" only was implemented (see below), since, with the horizontal stacking mode only a proper overlap of the sequence of horizontal acceptances is required, rather than exact horizontal phase space matching.

Even though it would have been desirable, because of time limiations, no effort was made to check or optimize the vertical steering of the injection trajectory. In case of misdirection significant enlargement of the measured phase space could result at injection because of the induced coherent betatron oscillation. Therefore, a smaller or larger fraction of the vertical beam dilution factor (see below) at injection could be due to this.

This part can be eliminated by further studies in the future.

4. High Intensity Beam Size Measurements

Prior to reducing the AGS intensity in the manner indicated below, a few beam size measurements were taken at full intensity. The results are contained in the attached graphs.

5. Injection Parameter Correction

The calculated optimum value for the ratio of the B7 bump coil current to that of the A13 bump coil current, at the time of injection, is ~ 1.3. The actual running value was 1.5. Correction of this by reducing the B7 bump amplitude somewhat did not change the early stacked beam intensity. With a short linac beam pulse the time (or bump amplitude or local closed orbit displacement) for zero injected charge was determined. Maintaining the start of the linac pulse at approximately minus 5 μsec delay with respect to this (in order to dispose of the linac transient) the linac pulse length was adjusted for the desired AGS beam intensity. During these studies no effort was made to also change the bump collapse rate in order to operate with either smaller or larger instantaneous partial acceptances.

Prior to reducing the beam intensity the transverse stacking efficiency was checked and found to be near optimum (45% for a pulse length of 80 μsec, earlier data indicated η_{net} = 50% for a 80 μsec pulse length with somewhat lower values for (dI/dt)bumps).

6. Beam sizes were measured vertically at J19 ($\beta_v = \hat{\beta} = 23$ m) and horizontally at B1 ($\beta_h = \hat{\beta} = 23$ m). After measuring the horizontal beam size at full intensity, the target mechanism (B1) failed and could not be removed adequately from the beam. This unit had to be completely extracted from the AGS chamber in order to continue the studies and no further horizontal profiles were measured during this period with a flipping target mode.

7. In addition to measuring the beam sizes with the clipping targets, the in ring ionization profile monitor at I5 ($\beta_h = \hat{\beta} = 23$ m; $\beta_v = \check{\beta} = 11.5$ m) was used. Good agreement was obtained between the two modes of beam size measurement. This will be quantitatively indicated below.

Low Intensity Mode

With injection conditions corrected as indicated above, the "zero survival" point was found for the (A13, B7) bump amplitudes (i.e. at the time of the injected pulse the local closed orbit displacement is approximately 5 cm (injection septum offset)). The bump pair trigger was then advanced a further 5 μsec to eliminate the linac transient and the beam pulse length was set at ~ 50 μsec (nominal 11 turns) which resulted in a stacked beam of 4 10^{12} ppp. After optimization of the capture parameters a beam of 2.4 10^{12} ppp was accelerated ($\eta_{rf} \cong 60\%$).

[Note: 50 μsec ~ 11 turns

with I_L = 40 mA → 440 mA turns	
for 100% efficient stacking →	13.2 10^{12} pr.
actual stacked	4.0 10^{12}
net efficiency	30%
number of equiv. 100% turns	3.3 .]

Low Intensity Beam Size Measurements

The results of the low intensity beam size measurements are given in Fig. 1. All data refer to 90% profile measurements and are normalized to $\hat{\beta}$ = 23 m locations.

These results are used to arrive at beam dilution factors (or enlargement of the momentum normalized phase space area) vs time or vs $\beta\gamma$, all with reference to the measured linac beam emittance. This is given in Figs. 2 and 3. In addition, bunch measurements were made and longitudinal parameters were arrived at. All results are summarized in Table I and compared with present assumptions for the beam parameters for the AGS as an ISA injector.

Orbit Details

Injection	(mean orbit)	(p)	ν_h = 8.69	ν_v = 8.93
106 msec	- 0.87 cm	1.25 BeV/c	8.76	8.87
550 msec	- 1.61 -	24.8 -	8.76	8.72

These data are also indicated in Fig. 4.

Skew Quad Excitation

The effect of crossing the $\nu_x = \nu_y$ coupling line after beam transition has been explored by using the skew quadrupoles with pulsed current excitation, starting at t = 300 msec. On the basis of previous studies (E. Raka) an excitation current of 300 A was used to reduce the horizontal-vertical coupling to a negligible magnitude. Observing horizontal and vertical beam profiles at t = 550 msec, the effect of the skew quad excitation was perceptible but negligible in magnitude. Actually, since the horizontal and vertical phase space magnitudes are nearly equal (ratio 1 to 1.4) between transition and high energy no significant beam size effect should be expected by use of the skew quadrupoles after transition. In addition, it is not clear from the limited observations (Fig. 4) that traversal through the coupling line $\nu_x = \nu_y$ occurred after 300 msec when the skew quads were turned on during this preliminary exploration of their effect on the presumed H-V phase space interchange. The results are shown in Fig. 5.

Anomalous Vertical Dilution

As indicated in the footnote in Table I, some skepticism exist with regard to the validity of the vertical phase space data. In addition, to errors in basic beam size determination with the ionization scanner, the possibility that the above transition data were masked by a (limited amplitude) transverse vertical beam instability is not excluded, even though an effort was made to suppress this. Two high energy vertical beam size observations with and without this instability are shown in Fig. 6.

Comparison With Earlier Data

The vertical emittance data only as obtained during this study period and on earlier occasions are collected and shown in Fig. 7. On the basis of this and ignoring to a certain extent the latest vertical emittance data, the best AGS emittance data at 28.5 GeV/c, as presently known, are summarized as follows:

Int.	$6\ 10^{12}$ ppp ,	$V_{90} \times H_{90}$; 28.5 BeV/c	:	$2.5\pi \times 2.7\pi$ $(\mu\text{rad-m})^2$
	$2\ 10^{12}$ ppp ,	same	:	$1.2\pi \times (<2.7\pi)$ -
[1975 data,	$2.6\ 10^{12}$ ppp,	same	:	$3.1\pi \times 2.2\pi$ -] .

Miscellaneous Observations

Using the ionization profile monitor some interesting observations were made indicating--

a) a vertical orbit medium plane shift as a result of a horizontal orbit (t = 300 msec radius shift) change. (See Fig. 8),

b) an apparent beam size dependence (horizontal) associated with the value of the radius or tune of the AGS (Fig. 9).

Time did not permit to pursue these observations during this study period.

Conclusions

It is obvious that further studies are essential to develop the AGS as a suitable injector for the ISA. The best phase space values, as measured, and stated above, are longitudinally a factor of two larger and transversely (in each phase plane) approximately a factor of 5 larger than the values assumed for the AGS as the injector for ISA.

TABLE I

AGS Data - May 26, 1975	AGS Injector For ISA present assumptions
Linac: 200 MeV, $I_L = 40$ mA $A_{v,90\%} = 5.5\ \pi\ \mu$rad-m $A_{v,80\%} = 2.8\ \pi\ \mu$rad-m $A_{v,50\%} = 1.1\ \pi\ \mu$rad-m $A_{h,90\%} \gtrsim 6\ \pi\ \mu$rad-m $(\Delta p/p)_{fw} \lesssim \pm 1.5\ 10^{-3}$.	Linac: 200 MeV, $I_L = 50$ mA $A_{t,80\%} = 3\ \pi\ 10^{-6}$ rad-m $(\Delta p/p)_{fw} = \pm 1.1\ 10^{-3}$
AGS injection: limited multiturn ($\simeq$ 11 turns) $N_{stacked}$ 4.0 10^{12} ppp (eff. 3.3 turns) phase space, 200 MeV, $A_{v,90} \times A_{h,90}$ (no dilution: $5.5\ \pi \times 19.8\ \pi\ (\mu\text{rad-m})^2$) (see graph 2). $14.3\ \pi \times 35.6\ \pi\ (\mu\text{rad-m})^2$. Observed dilution factors at 200 MeV injection (see graph) $d_v = 3$; $d_h = 1.8$.	AGS injection: limited multiturn (low efficiency, max. transverse density). $N_{stacked}$ 3.6 10^{12} ppp (eff. 3 turns) phase space, 200 MeV, $A_{v,80} \times A_{h,80}$ $4.5\ \pi \times 13.5\ \pi\ (\mu\text{rad-m})^2$. (A dilution factor of 1.5 has been assumed for both the horizontal and vertical phase space beam density.)
$N_{captured}$ (12 bunches) $\simeq 2.6\ 10^{12}$ ppp.	$N_{captured}$ (12 bunched) 2.5 10^{12} ppp.
Bunch data at injection poor, however, longitudinal phase space < 0.6 eV-sec/bunch.	$A_{2,\ell}$, single bunch, 200 MeV = 0.32 eV-sec.
Transition dilution?	Transition longitudinal dilution $\simeq$ 1.1.
Transverse phase space dilution, during cycle -- $d_v \simeq 8$; $d_h \simeq 1$.	Transverse phase space dilution, $d_v \simeq 2$. $d_h \simeq 1$

(Note: The observed dilution factors, during the AGS cycle, are anomously large, for reasons not yet understood. Some reservations exist about the validity of the ionization monitor high energy beam size data, notwithstanding that agreement exist with the limited number of observations done with a scanning target at injection energy, and, for a single beam size observation at high energy, see graph 1.)

Data, obtained with a scanning target, by J. Herrera, 3/9/74, for a full intensity AGS beam ($\sim 6\ 10^{12}$ ppp), indicated a vertical dilution factor of $\simeq 2.4$, during the AGS cycle. However, in that case the vertical emittance at 200 MeV in the AGS was $\sim 34\ \pi\ \mu$rad-m compared with a presumed linac emittance of ($A_{v,90\%} \simeq$ 5.5 μrad-m, i.e. a d_v (at injection) of ~ 6. The overall dilution vertical, in that case was $\simeq 14$. The corresponding factor, obtained during these measurements was 24).

TABLE I, cont'd.

AGS Data - May 26, 1975	AGS Injector For ISA present assumptions
Beam parameters at 28.5 BeV: Phase space, transverse, $V_{90} \times H_{90}$ $3.1\ \pi \times 2.2\ \pi\ (\mu\text{rad-m})^2$. Phase space, longitudinal 0.57 eV-sec./bunch (actually at E = 25.2 BeV) . (V_{rf} = 242 kV; $\dot{B}$ = 2.05 T/sec) = ± 15° at 4.45 MHz $(\Delta p/p)_{fw} = \pm\ 0.76\ 10^{-3}$	Beam parameters at 28.5 BeV: Phase space, transverse, $V_{80} \times H_{80}$ $0.2\ \pi \times 0.3\ \pi\ (\mu\text{rad-m})^2$. Phase space longitudinal 0.36 eV-sec./bunch $\delta E = \pm\ 18.2$ MeV $\delta\varphi = \pm\ 0.176$ (± 10° at 4.45 MHz) $(\Delta p/p)_{fw} = \pm\ 0.59\ 10^{-3}$. Parameters, after adiabatic debunching (V_{rf} 384 kV → 36 kV) and ejection: longitudinal: $(\Delta p/p)_{f\omega} = \pm\ 0.33\ 10^{-3}$; $\delta\varphi = \pm\ 0.32$ transverse (V × H): $0.25\pi \times 0.4\pi\ (\mu\text{rad-m})^2$ [Parameters, transverse, after injection into ISA: $0.4\pi \times 0.4\pi\ (\mu\text{rad-m})^2$.]

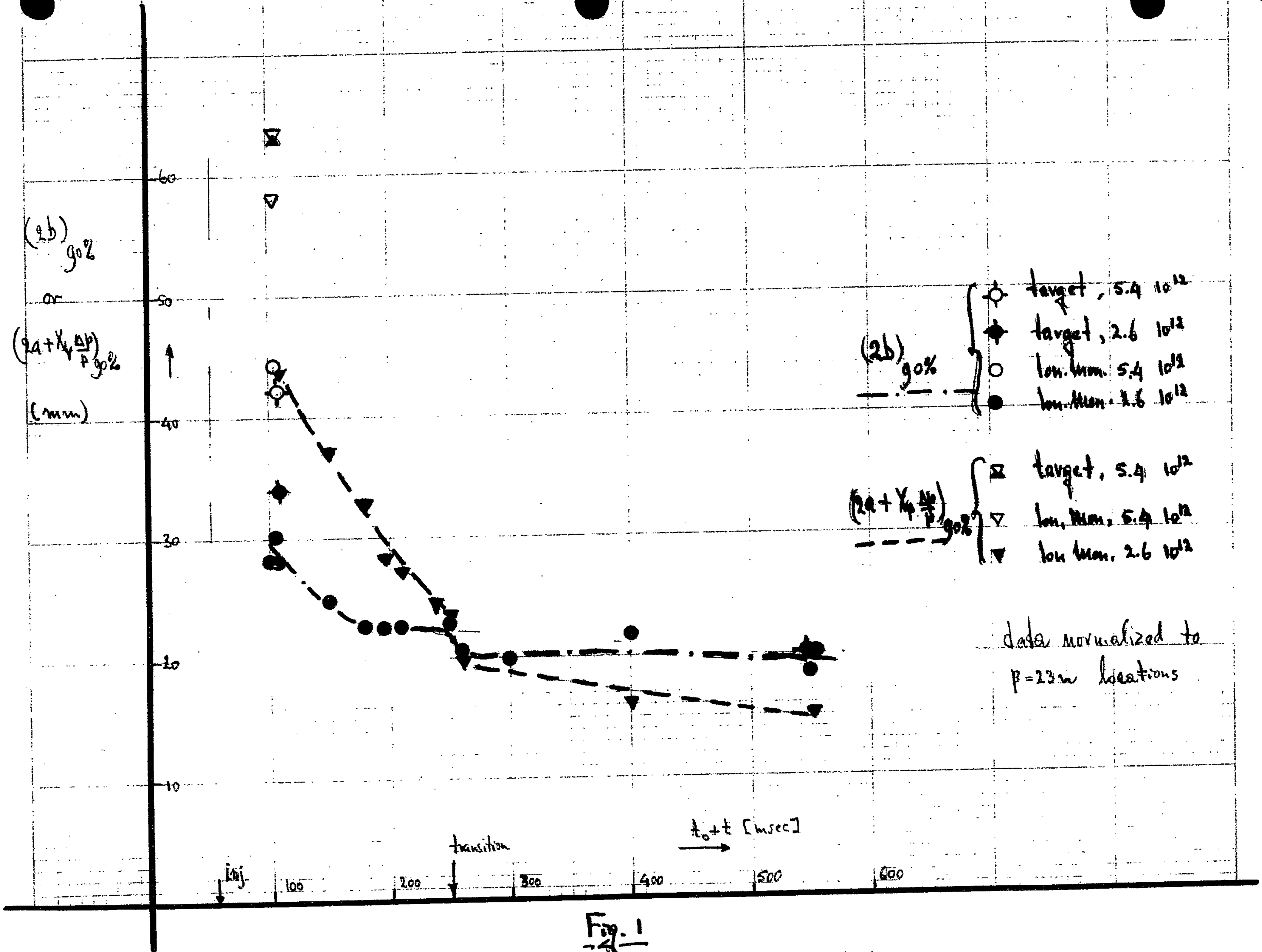
(2b) 90% or (2a + X4 Δp/p) 90% (mm)
60
50
40
30
20
10
inj.
100
200
transition
300
400
500
600
t0+t [msec]
(2b) 90%
target, 5.4 10^12
target, 2.6 10^12
low. mom. 5.4 10^12
low. mom. 2.6 10^12
(2a + X4 Δp/p) 90%
target, 5.4 10^12
low. mom. 5.4 10^12
low mom. 2.6 10^12
data normalized to
β=23m locations

Fig. 1

Fig. 2

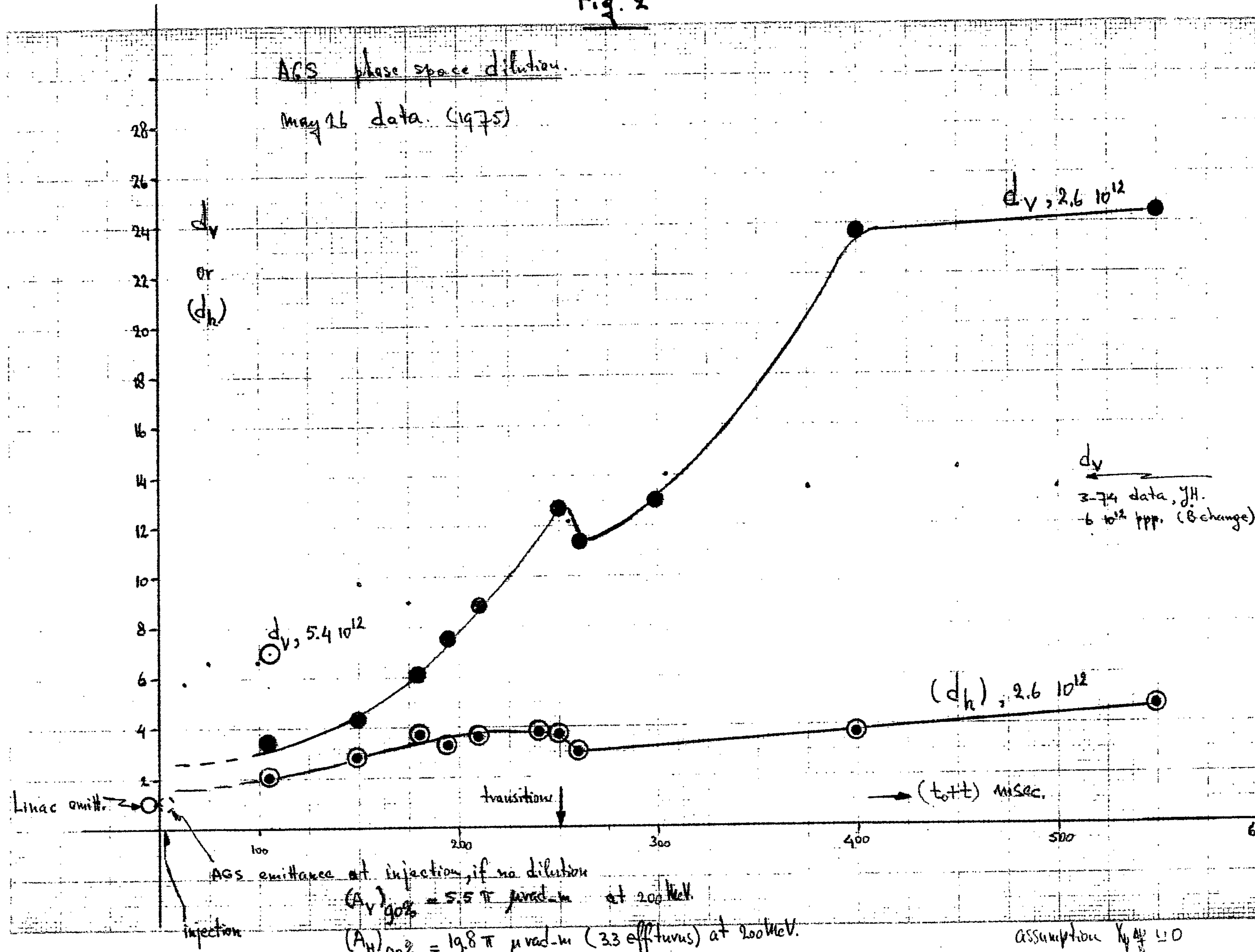

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Fig 3

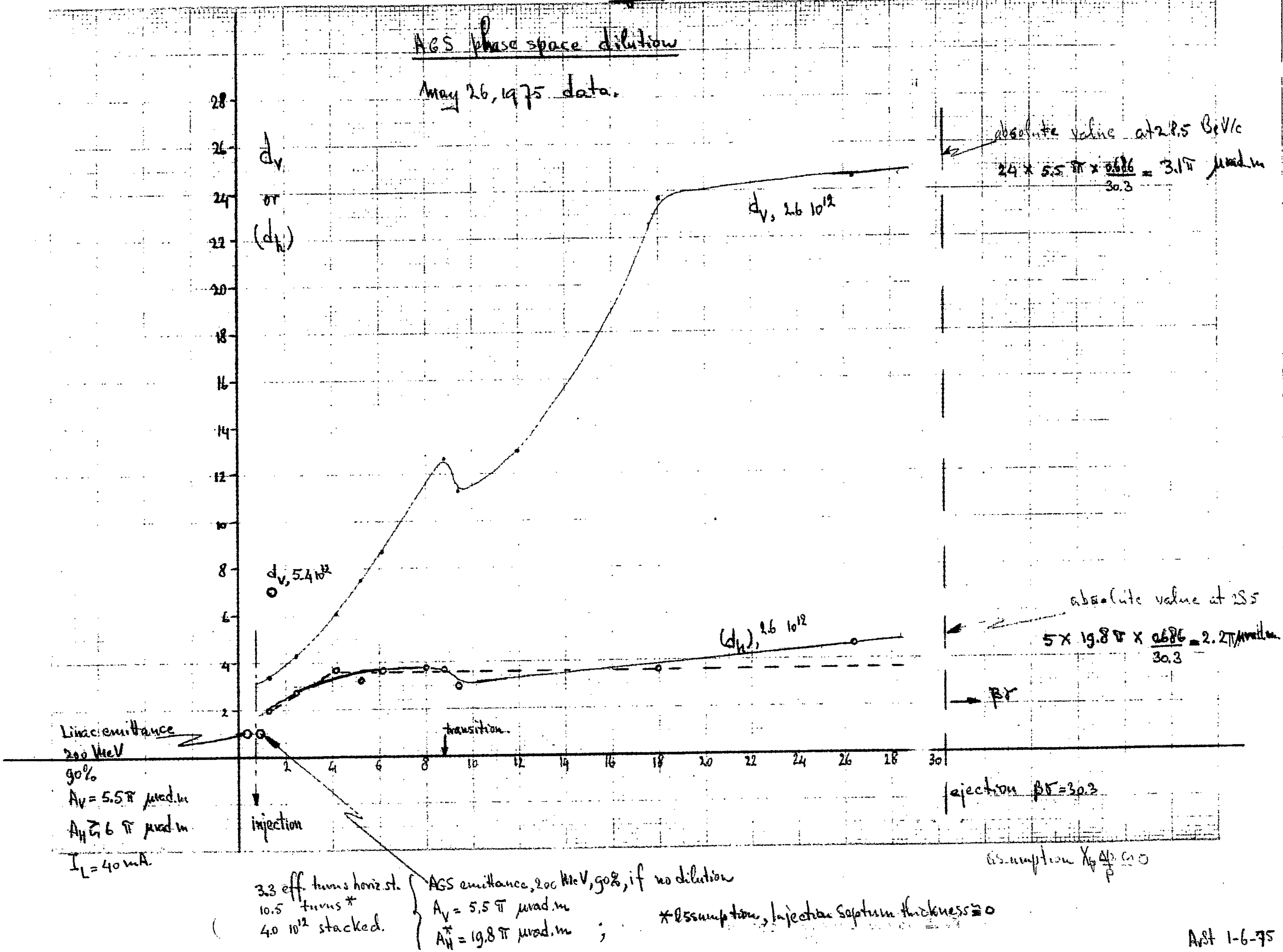

AGS phase space dilution
May 26, 1975 data.
d_V or (d_h)
28
26
24
22
20
18
16
14
12
10
8
6
4
2
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
d_V, 5.4 10^{12}
d_V, 2.6 10^{12}
(d_H), 2.6 10^{12}
transition
injection
Linac emittance
200 MeV
90%
$A_V = 5.5\pi$ μrad.m
$A_H \gtrsim 6\pi$ μrad.m
$I_L = 40$ mA.
absolute value at 28.5 BeV/c
$24 \times 5.5\pi \times \frac{0.686}{30.3} = 3.1\pi$ μrad.m
absolute value at 28.5
$5 \times 19.8\pi \times \frac{0.686}{30.3} = 2.2\pi$ μrad.m
βγ
injection βγ = 30.3
3.3 eff. turns horiz. st.
10.5 turns *
4.0 10^{12} stacked.
AGS emittance, 200 MeV, 90%, if no dilution
$A_V = 5.5\pi$ μrad.m
$A_H^* = 19.8\pi$ μrad.m
* assumption, injection septum thickness ≅ 0
AvSt 1-6-75

Fig. 4

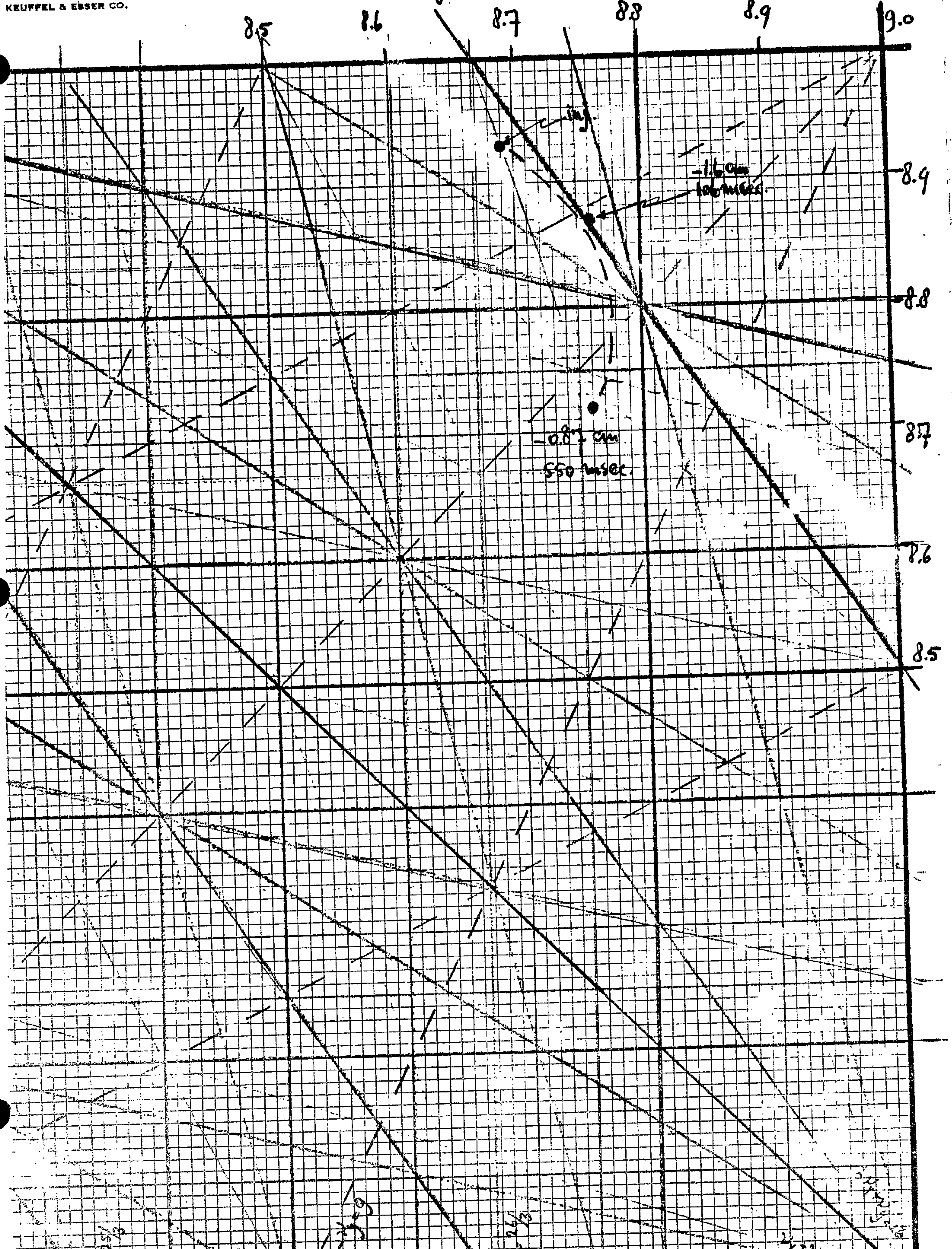
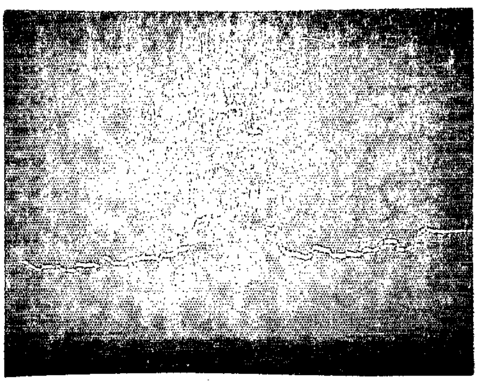


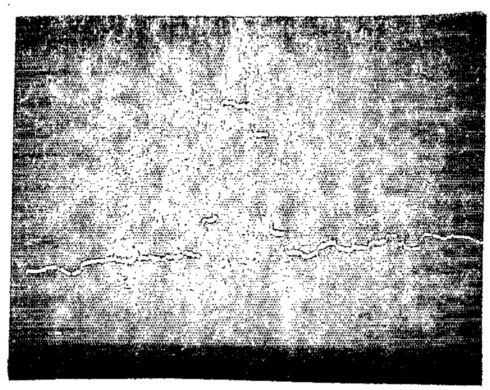
fig.5

Beam profiles at 550 msec
Effect of skew quad excitation. (See notes).

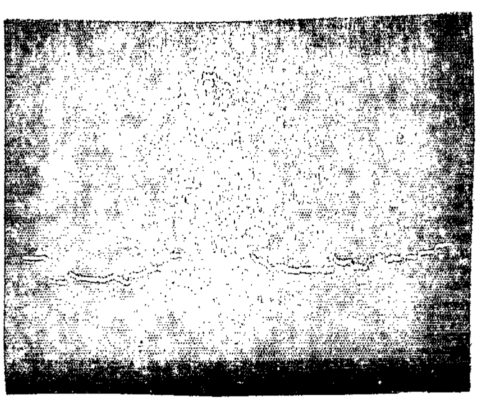
trigger 300 msec.
$\hat{I}_{exc.}$ 300 A.
full excitation 350 msec – >550 msec.



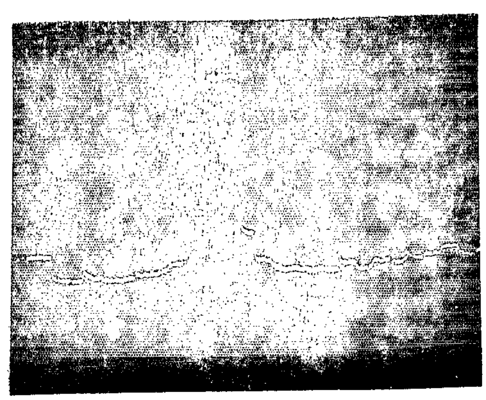
Vert. prof. 550 msec.
Skew. quad excit off



Vert. prof. 550 msec
Skew. quad excit. on

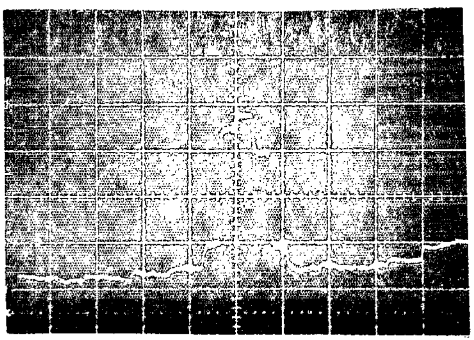


Horiz. prof. 550 msec
Skew quad excit. off.

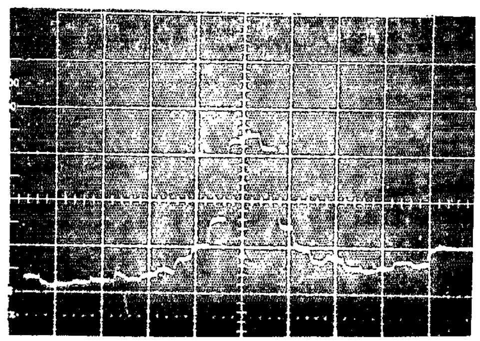


Horiz. prof. 550 msec
Skew quad. excit. on.

Fig. 6.



Vert. profile after transition with instability "suppressed"



Vert. profile after transition with beam instability present.

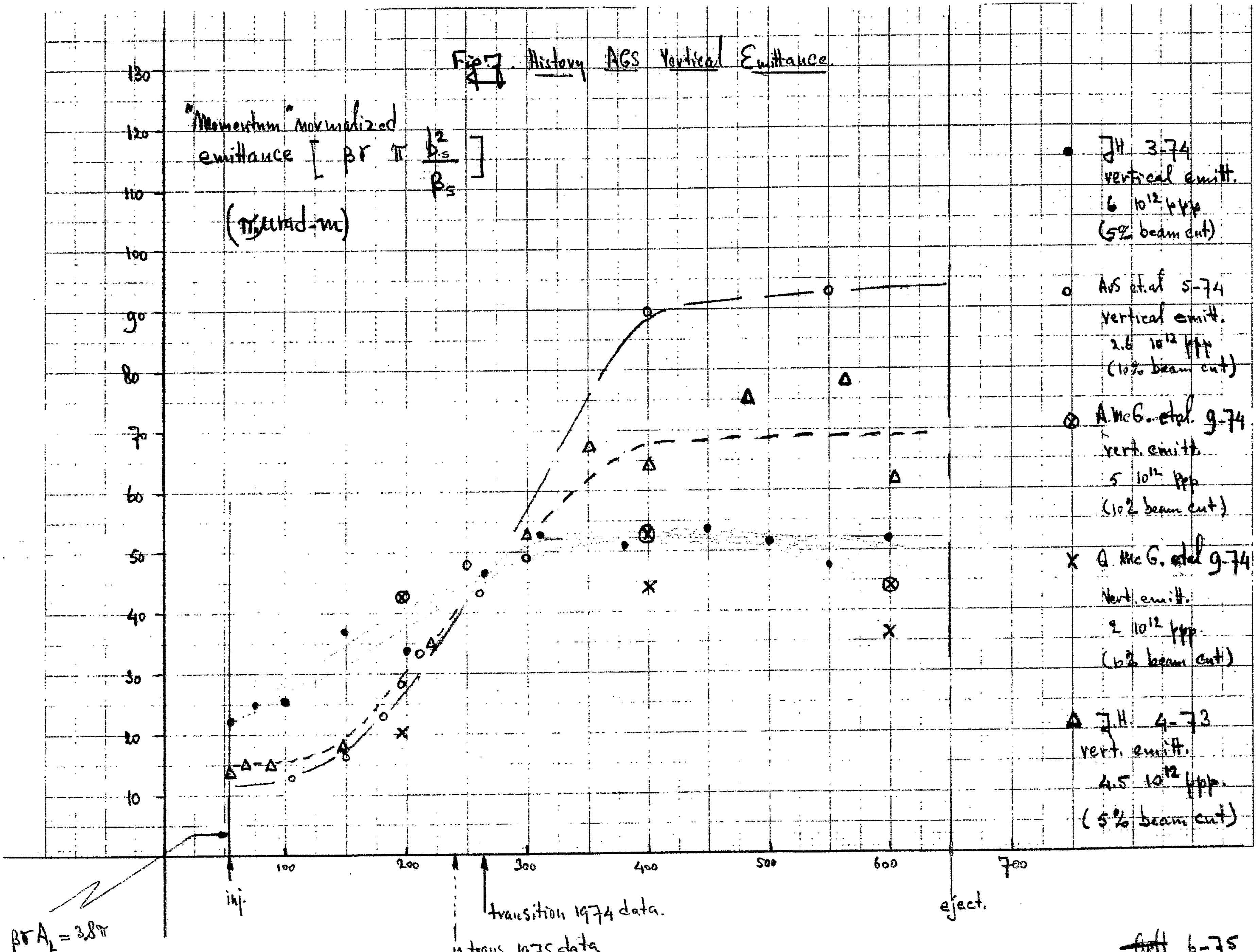
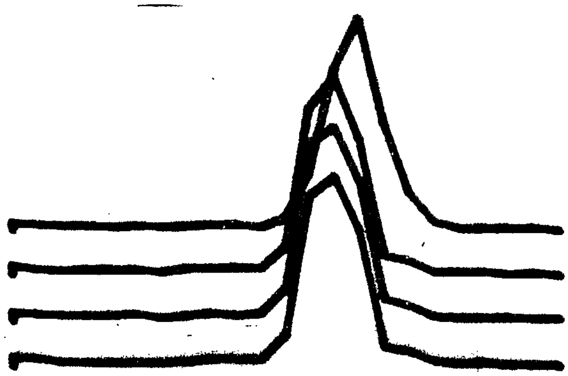


Fig 7. History AGS Vertical Emittance.
"Momentum" normalized emittance [βγ π b_s^2 / $β_s$]
(π μrad-m)
130
120
110
100
90
80
70
60
50
40
30
20
10
100
200
300
400
500
600
700
inj.
transition 1974 data.
tr trans. 1975 data
eject.
βγA_L = 3.8π
● JH 3-74
vertical emitt.
6 10^{12} ppp
(5% beam cut)
○ AvS et.al 5-74
vertical emitt.
2.6 10^{12} ppp
(10% beam cut)
⊗ A. McG. et al. 9-74
vert. emitt.
5 10^{12} ppp
(10% beam cut)
X A. McG. et al 9-74
Vert. emitt.
2 10^{12} ppp.
(10% beam cut)
Δ J.H. 4-73
vert. emitt.
4.5 10^{12} ppp.
(5% beam cut)
6-75

Fig. 8.

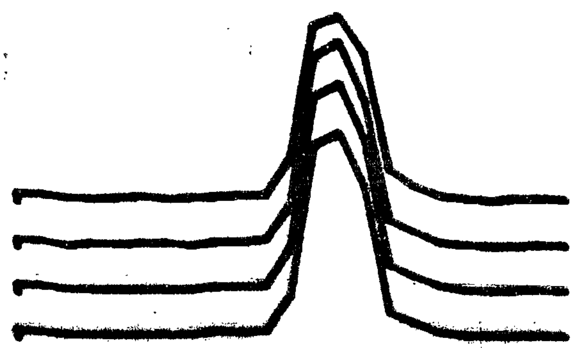
Vertical orbit medium plane shift as a result of a horizontal radius shift.

NO	P#	T
1	2219	300
2	2219	400
3	2219	500
4	2219	550



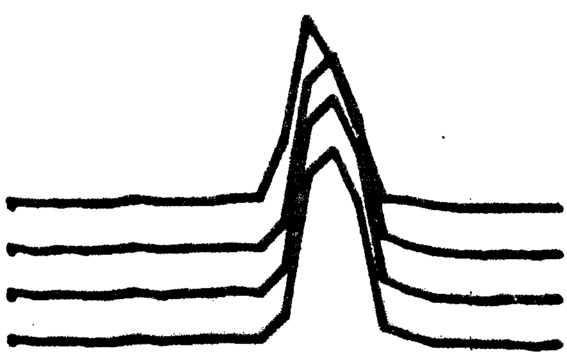
MEAN	RMS
2.121	3.050
1.219	3.136
1.270	3.134
1.260	3.179

NO	P#	T
1	2200	300
2	2200	400
3	2200	500
4	2200	550



MEAN	RMS
1.447	2.790
1.470	2.644
1.468	2.680
1.444	2.814

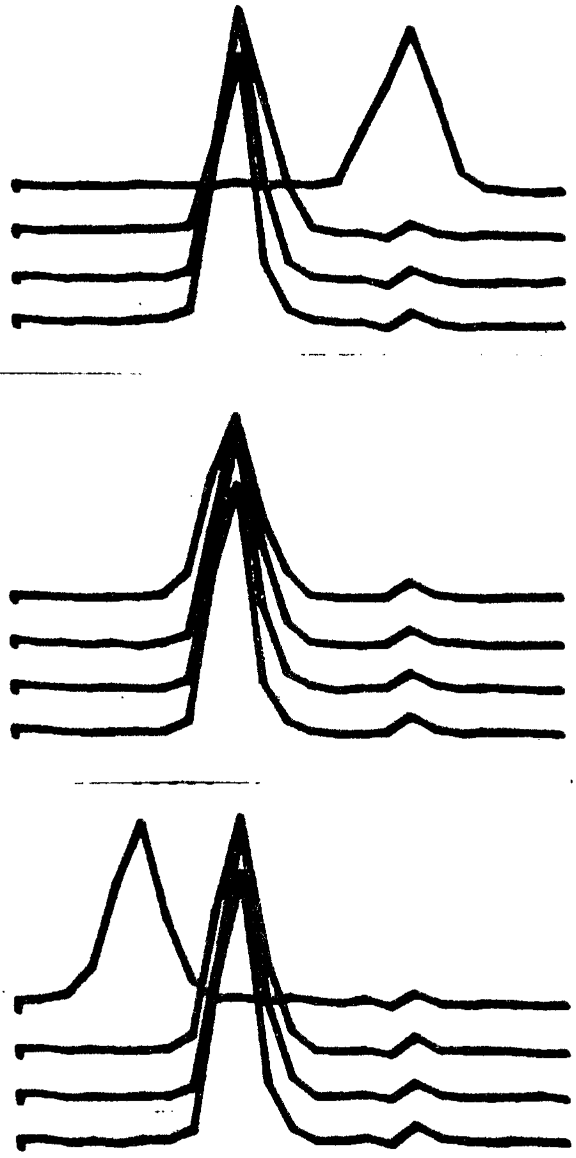
NO	P#	T
1	2257	300
2	2257	400
3	2257	500
4	2257	550



MEAN	RMS
0.898	2.745
1.412	2.604
1.345	2.661
1.568	2.450

Fig. 9.

Apparent Horizontal beam size dependence as a function of radius (tune).

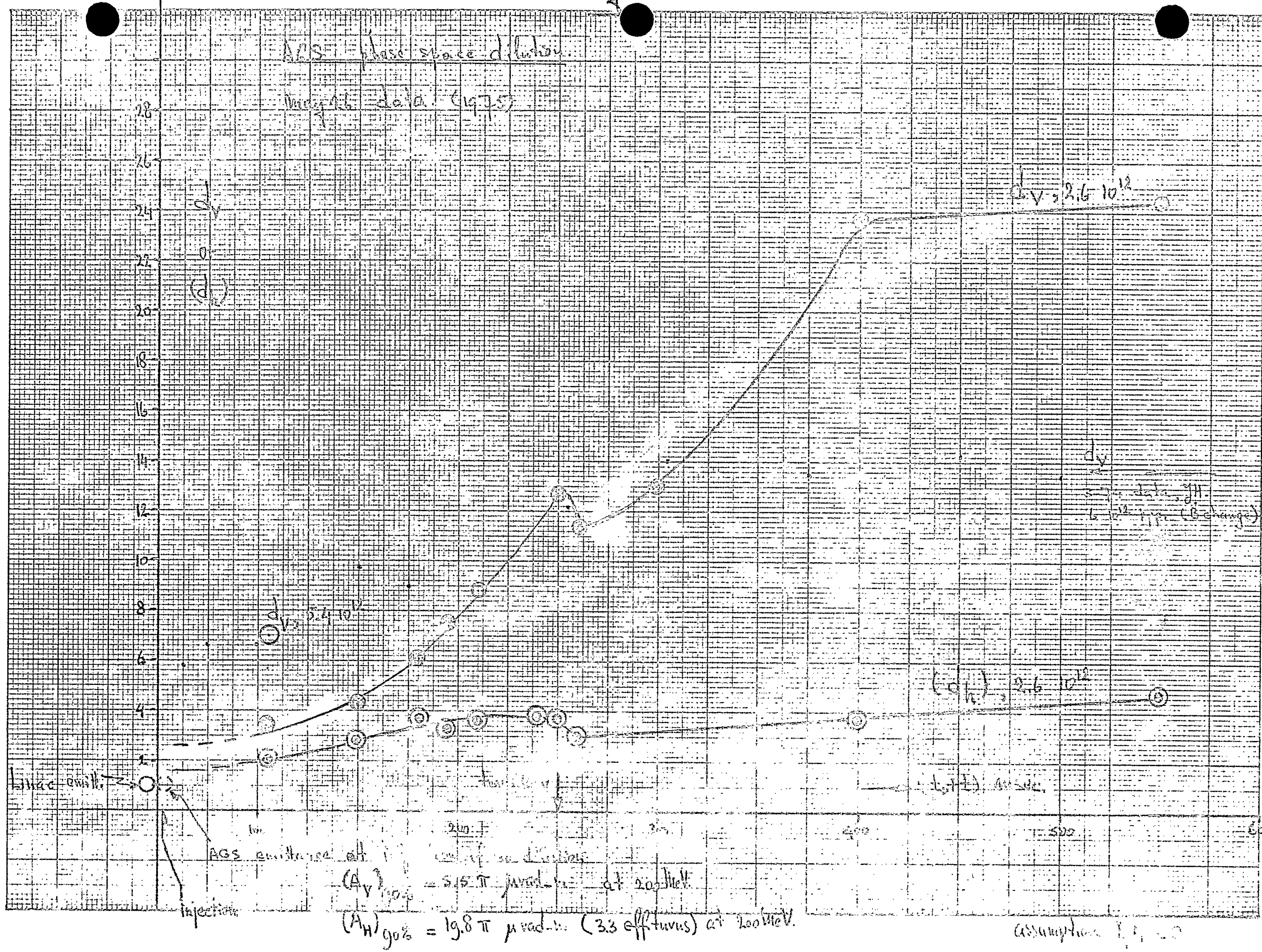


NO	P#	T	MEAN	RMS
1	1892	300	3.506	3.609
2	1892	400	-1.796	2.713
3	1892	500	-1.998	2.371
4	1892	550	-2.190	2.633

NO	P#	T	MEAN	RMS
1	1971	300	-1.832	2.878
2	1971	400	-1.924	2.377
3	1971	500	-1.885	2.774
4	1971	550	-1.920	3.048

NO	P#	T	MEAN	RMS
1	1950	300	-4.937	3.856
2	1950	400	-2.053	2.874
3	1950	500	-1.900	2.717
4	1950	550	-1.902	2.981

Fig. 2



AGS phase space dilution
Magnet data (1975)
d_v
or
(d_h)
$d_v = 2.6 \cdot 10^{12}$
$d_v = 5.4 \cdot 10^{12}$
$(d_h) = 2.6 \cdot 10^{12}$
Linac emitt.
injection
AGS emittance at
$(A_v)_{90\%} = 5.5\pi$ μrad-m at 200 MeV
$(A_H)_{90\%} = 19.8\pi$ μrad-m (3.3 eff turns) at 200 MeV.

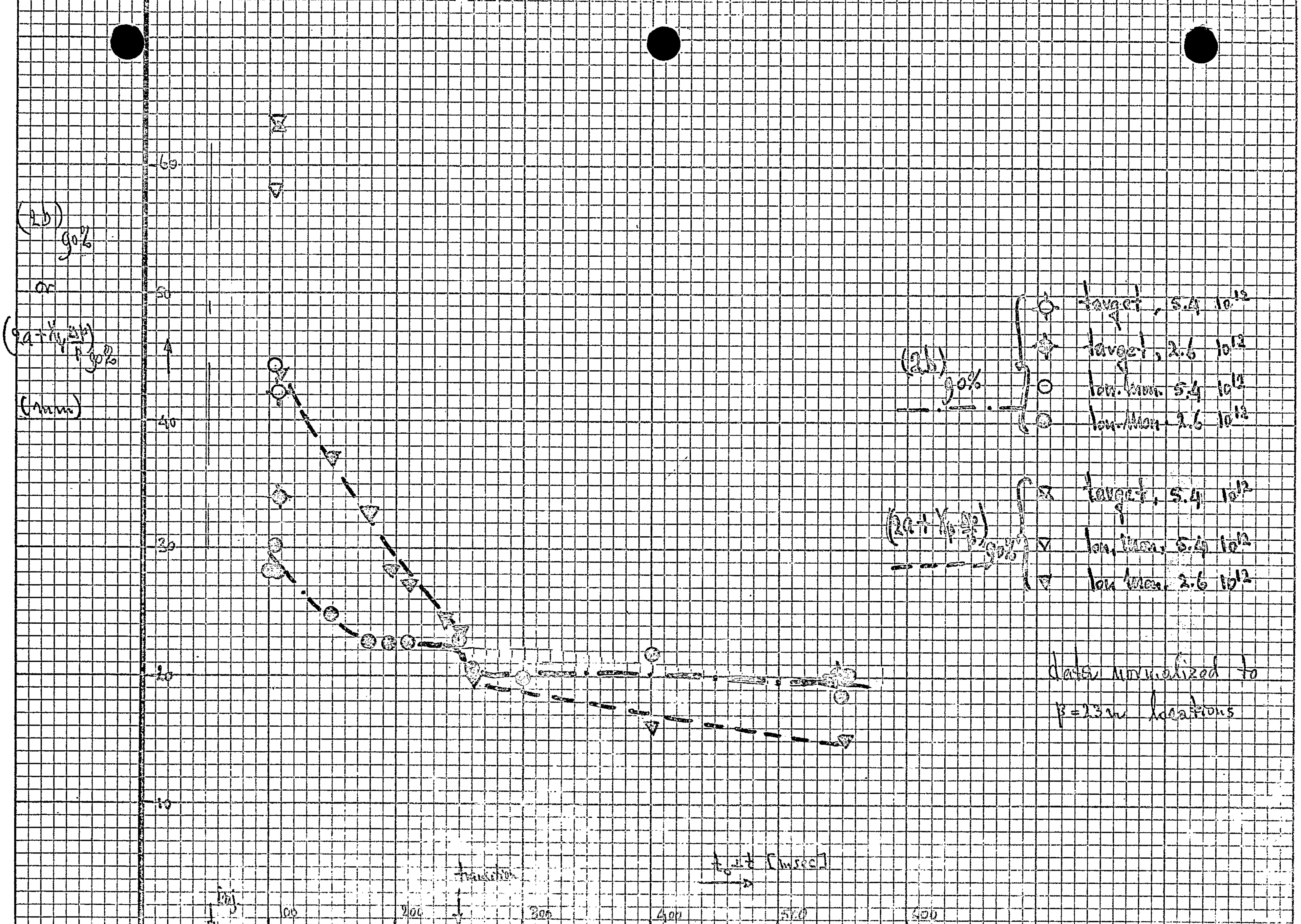
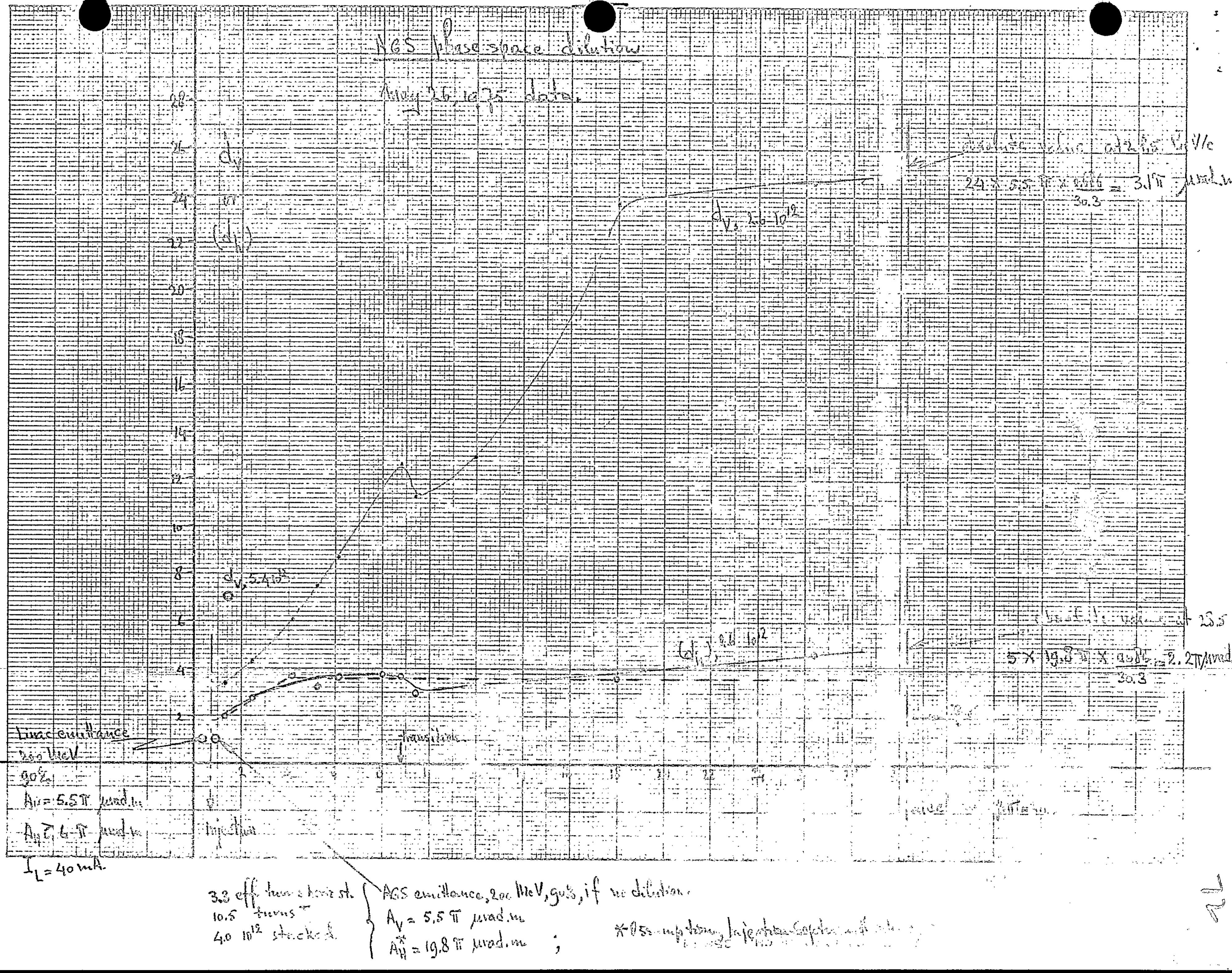

$(2b)_{90\%}$
or
$(2a + \frac{1}{4}\frac{\Delta p}{p})_{90\%}$
(mm)
$(2b)_{90\%}$
target, 5.4 10^{12}
target, 2.6 10^{12}
lon. Mom. 5.4 10^{12}
lon. Mom. 2.6 10^{12}
target, 5.4 10^{12}
lon. Mom. 5.4 10^{12}
lon. Mom. 2.6 10^{12}
data normalized to
β = 23 m locations
transition
$t_0 + t$ [msec]
10
20
30
40
50
60
100
200
300
400
500
600

Fig. 1

Fig 3


AGS phase space dilution
May 26, 1975 data.
d_V or (d_H)
d_V, 5.4 10^{12}
d_V, 26 10^{12}
(d_H), 2.6 10^{12}
$24 \times 5.5\pi \times \frac{0.86}{30.3} = 3.7\pi$ μrad.m
$5 \times 19.8\pi \times \frac{0.86}{30.3} = 2.2\pi$ μrad.m
transition
injection
Linac emittance
200 MeV
90%
$A_V = 5.5\pi$ μrad.m
$A_H \geq 6\pi$ μrad.m
$I_L = 40$ mA
3.3 eff. turns stored
10.5 turns*
4.0 10^{12} stacked
AGS emittance, 200 MeV, 90%, if no dilution.
$A_V = 5.5\pi$ μrad.m
$A_H^* = 19.8\pi$ μrad.m