national accelerator laboratory

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REPORT ON THE JULY MUON BEAM TUNING AND COMPARISON WITH THE CALCULATIONS

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SUMMARY

The observed yield of 100 GeV muons at the Muon Lab target was measured on July 21, 1972 to be:

$$\frac{\mu}{p} = 5.4 \times 10^{-10} \qquad (\lesssim 30\% \text{ error})$$

$$E_p = 200 \text{ GeV}$$

In this note we discuss:

(a) The consistency between this number and the calculations, as well as intermediate observations along the beam.

(b) The rate expected from the present beam - target train configuration after the CEA quads are turned on, with vacuum is installed on the train and along the beam.

(c) Short term ($\leq$ 1 month) changes in the present beam which will produce an acceptable μ/p yield and allow Experiment 26 to begin taking data.

Our conclusions are:

(a) There is excellent agreement with the calculations everywhere along the beam.

(b) After the CEA quads are on and the complete vacuum line is installed in both the train and the beam we would expect (calculation)

$$\frac{\mu}{p} = 4.5 \times 10^{-8} \quad \text{or} \quad 4.5 \times 10^{4}\ \mu/10^{12}\ p$$

(c) It now appears that straightforward changes to the present trainloan can produce a beam of enough intensity to begin phase A of Experiment 26. This might be a temporary configuration pending development by the Neutrino Lab of a more permanent train. In our preliminary calculations we have gained more than one order of magnitude.

I. THE JULY 21 $\frac{\mu}{p}$ MEASUREMENT

$M_7 = 1102$ (2" x 4")

$T = 862$ (8" wide x 9.5" high)

N_p (foil) $= 1.6 \times 10^{12}$

M_7 was located just before the last set of dipoles in the muon beam, while T (actually in coincidence with another, larger counter) was located at the E26 target. Proportional chamber data taken simultaneously showed the beam spot to be 7 cm high x 13 cm wide with little halo, so the T counts will all be assumed to be beam muons.

Then $\frac{\mu}{p} = \frac{862}{1.6.10^{12}} = 5.4 \times 10^{-10}$

Also, <u>transmission of 104 dipoles</u> $= \frac{862}{1102} = 78\%$

The foil monitoring was checked against the secondary emission monitor (see TM-385) on September 5 (pg. 121vi - ν Lab notebook) and found to agree.

observed $\frac{\mu}{p}$	$=$	5.4×10^{-10}	(±~ 30%)
calculated$^{(1)}$ $\frac{\mu}{p}$	$=$	10×10^{-10}	CEA Quads off, air + material
		1.1×10^{-8}	CEA Quads on, air + material
		4.5×10^{-8}	CEA Quads on, vacuum

The CEA quads gain a calculated factor of 11 when properly tuned. The error on the calculation is hard to estimate but is probably a factor of 2.

The present material in the train loses us about a factor of 3 in pion flux between the production target and the enclosure 100 counters, but very little for muons. An additional factor of ~3 muon loss comes from having the rest of the beam filled with air rather than vacuum.

II. MEASURED COUNTER RATES FOR THE TUNED BEAM

To show that our agreement between calculation and observation is not an accident we present a check of the rates observed in the counters M1-M4 against the SEM:

(pg. 126ff, notebook vi)

9/5 run		Observed rates SEM volt	Calculated Rate* SEM volt
M1•M2	2" x 4" counters in E100	12.5K/volt	19K
M1•M2•M3	M3 - 2" x 4" upstream E101 dipoles	2.6K/volt	1.9K

*Assuming a P/π ratio in the secondary beam of 3. 1 volt SEM = 2.5×10^9 protons.[2]

The train conditions at this time were:

Δp slits: 8.5 target: $\frac{1}{16}" \times \frac{3"}{16}$ (T1) quads: at peak

On an earlier run (7/26) tuning curves for the E100 and E101 dipoles were taken and a ratio of singles rates measured for M1-M4. This is a test of the complete beam performance from the production target all the way to E102 - the location of the polyethylene absorber.

Relative singles rates:

M_2	M_3	M_4		
1.0	0.103	.025		(observed)
1.0	.06±.03	.016±.01	(air)	(calculated*)
	.04	.035	(vacuum)	M3, M4 1.5" x 1.5"
	0.15	0.13		M3, M4 2" x 4"

* Conditions: Δp slits 8.45 M3, M4 are $(1.5\ \text{in})^2$ counters

3Q84's off

III. TUNING CURVES ON π/μ BEAM

	Curve	Beam	How Measured	Ref: Page, Book	Observed FWHM	Calculated FWHM
dipoles	100	π	$M_1 \cdot M_3/M_1$	48, E26	~9%	8-10% depends on Δp
	101	π	M_4/M_2	17vii	2-4%	2.5%
	102	μ	M_7/Toroid	15V	3.7% (CEA off)	10% (CEA on)
	104	μ	BVit/M6 or Toroid	18V	messy, CEA quads off.	
vert steering	100a	π	M_3/M_4	48, E26	~60A	~60A
	100b	π			60A	o.k.
	101	π	M_4/Beeper	150iv	60A	o.k.
	102	μ	M_7/Toroid	32v	not sensitive (30% ± 70A) set to 0	not sensitive

Note the setting of 94A at the 100 vert. steering corresponds to 0.48 mrad at 100 GeV (no fringe field correction). The nominal value is 0.50 mrad, which agrees.

	Curve	Beam	How Measured	Ref: Page, Book	Observed FWHM	Calculated FWHM
Quads	101	π	M_4/M_2	47, E26	peak = 1900A off = 50%	peak = 1800A off = 65%(vac
	103	μ	CEA quads are not yet adequately measured (The calculated values are 876A, 830A x 0.9 = 785A,745A			

Note that all 8 curves which have been measured in this part of the beam agree quite well with the calculated values. We have some evidence that the CEA quads will work when properly tuned from the following:

1. An increase of x 2.5 in the yield at M7 (2" x 4" in front of 104 dipoles) was observed at nominal values of (880A, 800A). It is

not yet known whether this agrees with the expected gain when the farthese upstream quad is not functioning since the proper calculation has not been done.

2. The ratio

$\frac{M6}{\overline{BV}.T}$	(1' x 2' counter downstream of 102) (target counters)	~5-8

There is some evidence M6 was losing counts on fast spill. This ratio should be ~10 or 11 if we assume M6 contains the entire muon beam to be focused by the CEA quads. This ratio is not too trustworthy but certainly it says a substantial number of muons are being lost after 102.

Hence we conclude there is no known discrepancy in the pion and muon beam. The CEA quads need to be studied but are probably o.k.

IV. TUNING CURVES FOR THE TRAINLOAD

Although agreement of the above numbers with the calculation implies probably agreements of the more detailed trainload measurements, it is useful to examine them more fully as a prelude to further trainload design work.

Tuning curves for the train use the M1·M2 coincidence normalized to the SEM. The best curves are to be found in ν-lab notebook vi, pg. 126. They are in agreement with earlier curves taken with cruder monitoring techniques. Some data also exists using the Cal Tech counters in the decay channel.

Tuning Curve	How Measured	Ref: page, book	OBS. Setting	Calc. Setting (3)
Quads	$\frac{M1.M2.M3}{SEM}$	126vi	41.5 A 32 A	44 x .97 = 42.5A 34 x .97 = 33.0

See Figure 2 for a graph of the quad tuning with calculated values also shown.

	Measured	Calculated
Horizontal Trim	M1.M2/SEM 18A (FWHM)	26A FWHM
Vertical Trim	M1.M2/SEM peak at 12.2A down 50% at 31A	agreement excellent, see figure

Calculated hadron beam spot size at end of decay channel: ±6.1" high, ±1.7" wide (RMS) for a 60 mil (RMS) proton spot This gives an apparent size of 16" x 8.9" when tuning is over a 2" x 4" aperture.

	Measured	Calculated
Proton Spot Size	Vert: .065" Hor: .090"	
Horizontal Sweep (NOTGT)	FWHM: ±.2"	Agrees
Vertical Sweep (DX1 Current)	+16% (intensity down 50%) spot raised ~.12"	Hadron spot down 8" at Enc. 100 if target spot is raised .12"

From this we conclude:

(1) The optical properties of the present trainload are <u>well</u> understood.

(2) The transmission of particles through the trainload is in agreement with the calculations to sufficient accuracy for most purposes.

(3) This is good circumstantial evidence that nothing peculiar happens to the particle yields - i.e. a theory which predicts both the AGS and the ISR yields also predicts them for NAL to ~50% accuracy.

Further studies of the trainload could be conducted to provide accurate yield measurements but will not improve the understanding of the muon beam a great deal.

IV. SHORT TERM SOLUTION TO THE MUON INTENSITY QUESTION FOR E26

The solution proposed below uses existing elements, power supplies etc. plus one additional 3Q120 quadrupole. Existing bedplates on the train also can be used with different shims. A new low intensity beam dump must be built.

The first five elements in the present beam are two quads, two dipoles and a quad. The present beam would simply replace a dipole with a quad. Other elements on the present train except for the vernier steering magents would be removed. The quadrupoles would be run as a symmetric triplet. A gain of x10 in the muon/ flux could be achieved, particularly if the other improvements suggested in the Strovink-Hand report are also adopted. These are:

1. An additional set of 3Q84's in enclosure 100.
2. New 104 dipoles with a 3" aperture.

Footnotes and References

(1) A report written by M. Strovink and L. Hand dated November 21, 1971 predicted

$$\frac{\mu}{p} = 2.8 \times 10^{-8} \qquad \text{i.e.} \quad 28{,}000\mu/10^{12}p$$

The assumptions of that report were:

$\Delta p/p = \pm 5\%$

2 quads on train (now there are 3)

CEA quads on

Perfect vacuum throughout the beam

24" Be target

1.4 mm r.m.s. spot size

The new calculation reflects all of the changes in the actual realization of the beam.

(2) See CERN Report, May 1972 by G. Giacomelli for a review of $E \frac{d^2\sigma}{dp_{\shortparallel} d^2 p_{\perp}}$ and p/π, k/π etc. from the ISR as well as a comparison with lower energy results. Our yields have not been checked against the recent data, but agreed with the early ISR data quite well.

(3) 0.97 is a fringe field correction to the magnetic length of the quadrupole, adding 1/2 gap at either end.

TABLE I

CALCULATED RESULTS FOR IMPROVED[a] VERSION OF THE PRESENT BEAM

Position Along Beam	$10^{-6} N_{\mu}/10^{12} p$	Transmission From Previous	Cumulative Transmission	<P>	$\frac{\Delta p}{p}$ (RMS)
End of Decay pipe	23[b]	1	1	76.6	±18%
Upstream of Dipoles, Enclosure 100 (2"x4")	2.0	.087	8.7%	75.9	±16%
Upstream of Quads, Enclosure 101 (2"x4")	0.53	.26	2.3%	90.8	±9.5%
Upstream of Dipoles Enclosure 102 (2"x4")	0.13	.24	0.6%	95	
Upstream of Dipoles Enclosure 104 (2"x4")	0.058	.45	0.25%	96±1.2	
Muon Lab (9.5"x8")	0.043	.75	0.19%		

Conditions: Vacuum .065 (vert.) x .09 (hor.) spot size at target
$\Delta p = \pm 1"$

a. Uses existing trainload and beam configuration with CEA quads on.

b. Subject to corrections for yields and finite granularity of program.

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TABLE II

BEAM AT MUON LAB

	Calculated		Observed*	
	Hor.	Vert.	Hor.	Vert.
Size (inches)	4.6"	2.3"	5.1"	2.8"
Angular Divergence (mrad)	1.8	0.75	1.7	0.8

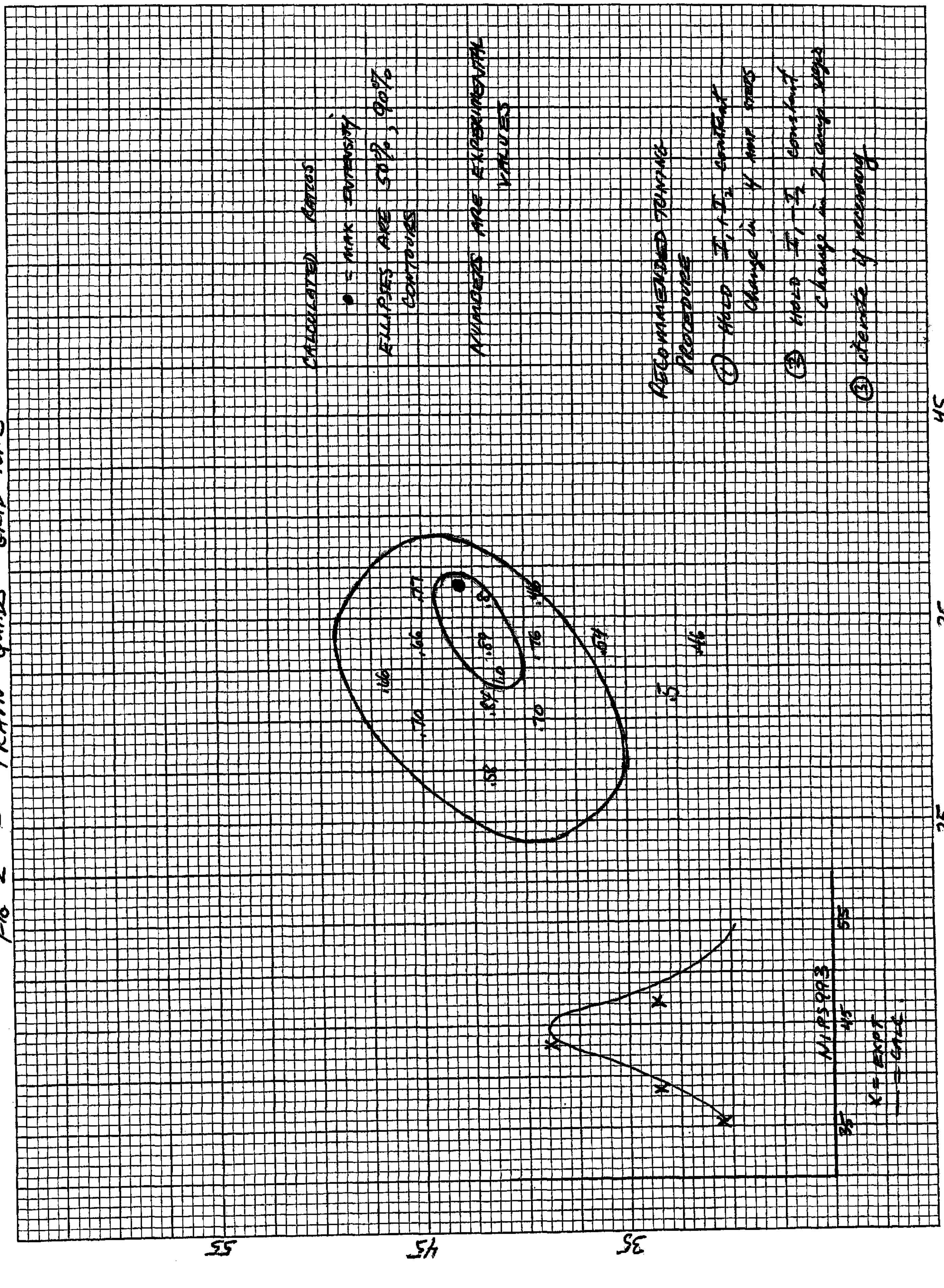
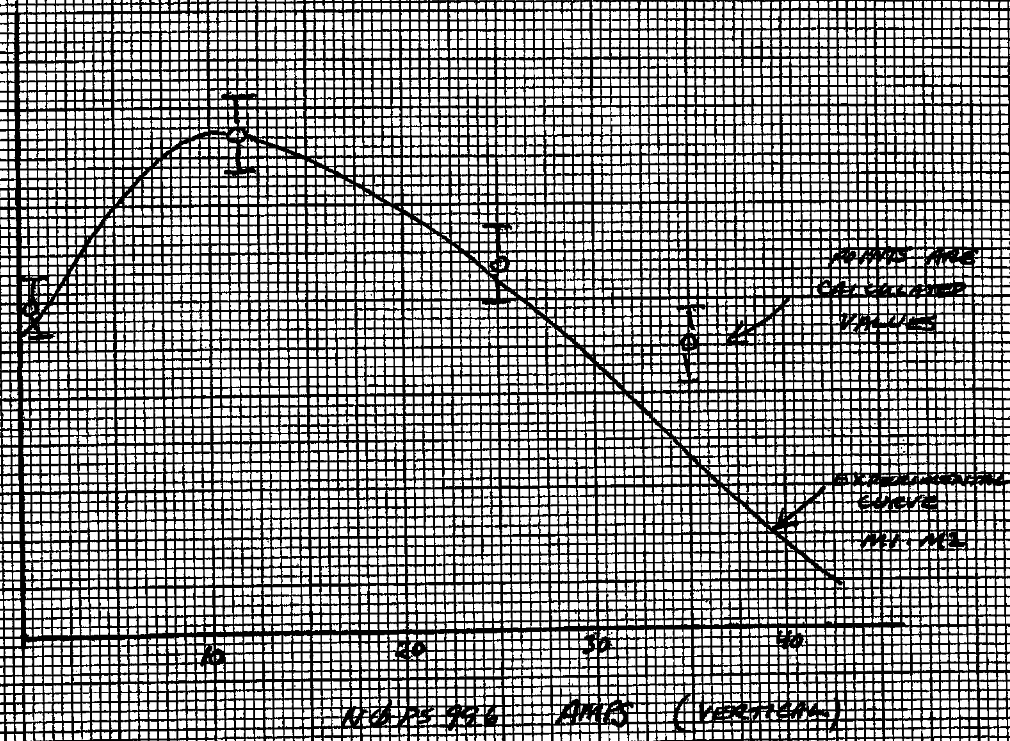
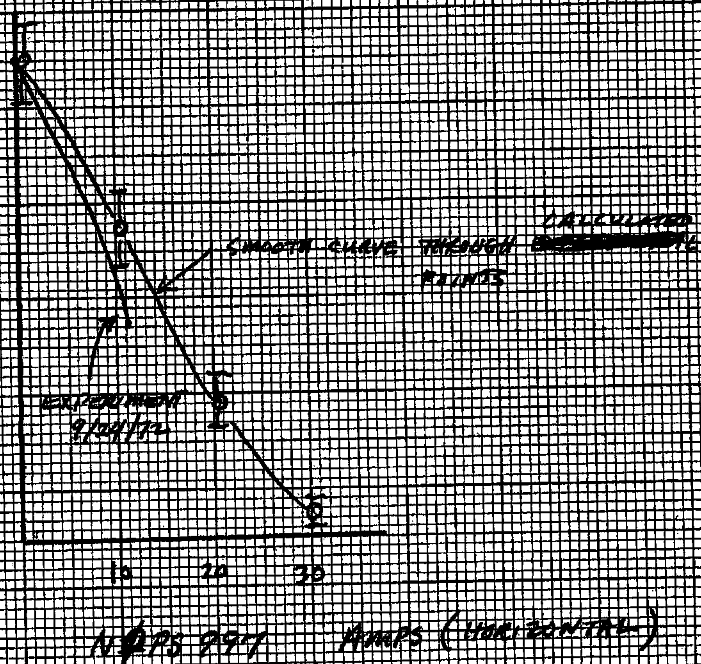
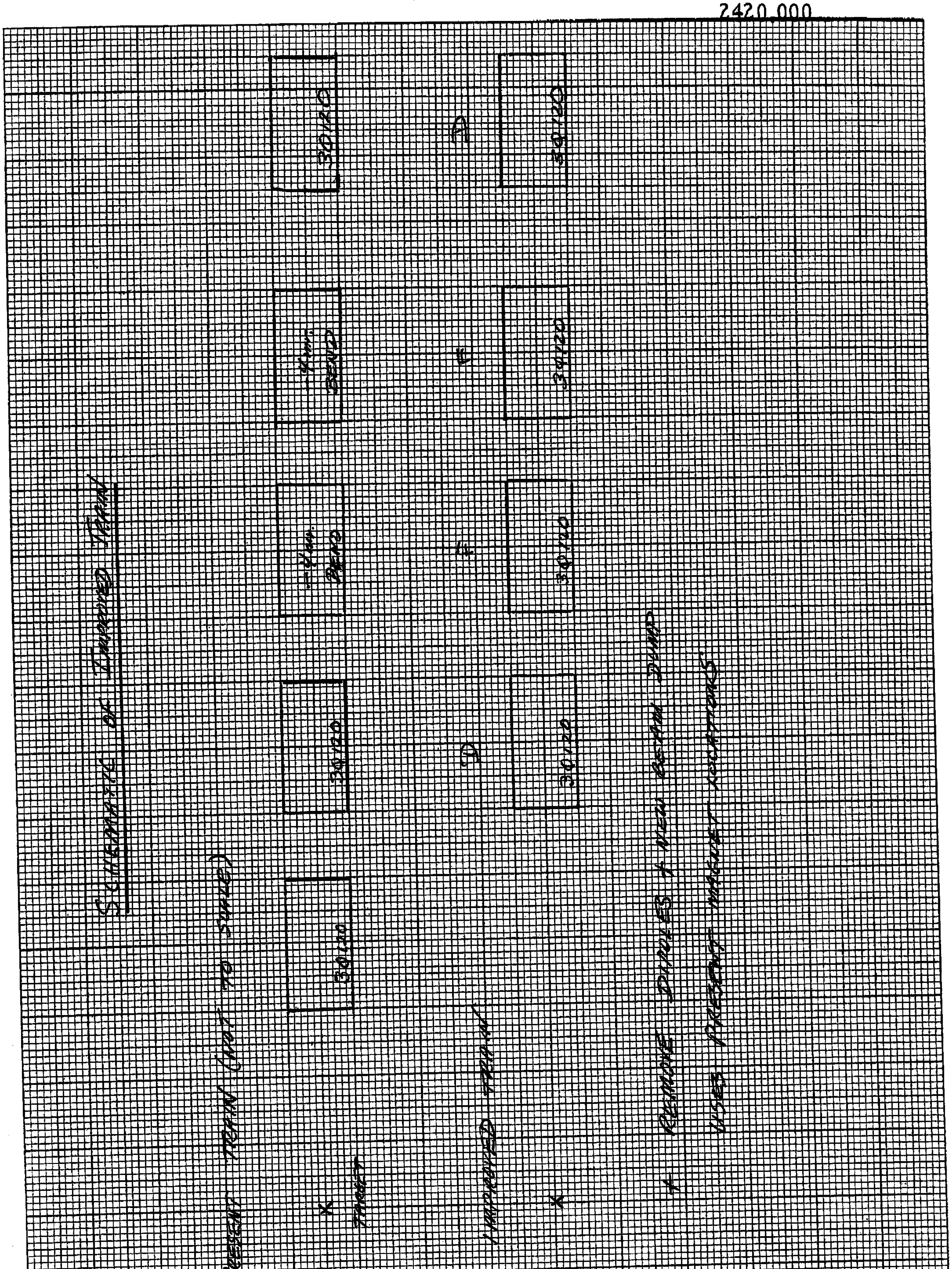


FIG 2 - TRAIN QUADS - GRID TUNE

VERTICAL AND HORIZONTAL TRIM ON TRAIN






SCHEMATIC OF IMPROVED TRAIN
PRESENT TRAIN (NOT TO SCALE)
TARGET
30120
30120
-4mr. BEND
-4mr. BEND
30120
IMPROVED TRAIN
D
E
F
A
30120
30120
30120
30120
+ REMOVE DIPOLES + NEW BEAM DUMP
USES PRESENT MAGNET LOCATIONS