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February 13, 1975

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415-854-3300, X2805

SUMMARY

SEARCH FOR SHORT LIVED STATES DECAYING WEAKLY VIA LEPTONIC MODES

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We propose to search for short lived states decaying weakly via leptonic (or semileptonic) modes. We will perform the experiment in the new Laboratory E, in the existing hadron beam to the 15' B.C., and use the μ toroidal spectrometer currently under construction for ν studies. The hadron beam will strike a specially constructed fine-grained calorimeter placed upstream of the μ spectrometer. The calorimeter will act simultaneously as a target and will give an accurate ($\Delta E/E \approx 5\%$) energy measurement.

The unique features of the experiment are the detection of missing energy (presumably carried off by neutrinos) and a very wide solid angle acceptance for muons. The contemplated triggering modes include large-energy-loss trigger, high p_T($\gtrsim 1.5$ GeV/c) single muon trigger, and dimuon trigger with a variable p_T cut. Thus the experiment could detect postulated charmed hadrons, color states, heavy leptons, and W bosons (up to W mass of about 20 GeV). Furthermore the experiment would be sensitive to any new phenomena involving single muon production or production of "direct" neutrinos.

We are requesting approval for 1000 hours at the highest beam energy available and at an intensity of 10^6 protons/pulse. A run of this duration would allow us to perform an initial exploratory experiment with all trigger modes and achieve a sensitivity of about 10^{-36}-$10^{-37}cm^2$.

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1. Introduction

We propose an experiment to look for the leptonic weak decays of high mass states which would have lifetimes of less than 10^{-11} sec. A plethora of theoretical speculations can be found to motivate such a search: charm and color quantum numbers, heavy leptons, intermediate vector bosons, etc., etc. However, the search for such objects is interesting independent of any specific theoretical model.

We propose here a generalized search for weak leptonic decays of any such particles produced in collisions of the highest energy hadrons available at Fermilab. The sensitivity of the experiment to prompt decays yielding muons and/or neutrinos will be at the level of $\sim 10^{-36} - 10^{-37} cm^2$. Briefly, our scheme is to run the incident hadron beam into a precise target-calorimeter and study events where a significant amount of energy is carried off by leptons (μ's and/or ν's). The final state hadronic energy will be measured in the target-calorimeter, while identification of the final state muons will be made by penetration and their energy measured in the Lab-E magnetic spectrometer system.

The contemplated system has a very large acceptance for muons and a mass resolution for μ pairs of the order of ± 250 MeV in the region of 3 GeV. Thus simultaneously with the search for weak leptonic decays we will be able to do a detailed study of multi-muon production and the di-muon mass spectrum up to the highest effective mass kinematically possible.

We propose to carry out the experiment in the new Lab-E, currently under construction, and use the existing hadron beam to the 15 ft. bubble chamber that passes through that building. That beam is capable of delivering adequate proton flux, can reach maximum NAL energy, and can provide π's, K's or protons with good Cerenkov tagging.

The experiment proposed here has many unique features:

(1) Identification of ν's in final state by observing "missing energy" in the reaction.

(2) Very large solid angle for the <u>observation</u> of final state muons (entire forward 45° in the laboratory).

(3) Very large solid angle for the <u>measurement</u> of sign and momentum of the final-state muon(s) (forward 15° cone in the laboratory).

(4) Energy measurement of the final-state hadronic system

(5) Flexible triggering arrangement

(6) Provision for various incident particles ($\pi^{\pm}$, $K^{\pm}$, p, $\bar{p}$).

The new Lab-E toroidal magnet system and the existing Caltech wire chambers will be used for muon identification and muon energy measurement. Furthermore, most of the electronics will be the existing Caltech electronics used in the neutrino experiments. Thus the only "new" major piece of experimental equipment necessary would be the target-calorimeter.

2. Theory

Are there relatively heavy ($\gtrsim$ 2 GeV) particles which are forbidden to decay strongly or electromagnetically? We believe this to be an important question, and one that warrants an experimental investigation regarcdless of what one's favorite theory says. The fact that most of the theories currently in vogue postulate the existence of particles of this kind only reinforces the need for an experimental search. More specifically, possible theoretical candidates that would satisfy the above criteria would be: charged charmed particles, low-lying color states, heavy leptons, and last but certainly not least, the weak vector bosons. If the strong or electromagnetic decays are forbidden, the postulated new states must either decay weakly or be absolutely stable. If the former hypothesis holds true, then the leptonic decays, i.e.

$$X^{\pm} \rightarrow \ell^{\pm} + \nu + \text{hadrons}$$

should form an appreciable fraction of the total decay rate.

The last few weeks have seen such a volume of theoretical pollution on the subject of newly discovered ψ (J) particles that it would be impossible to extract the relevant features into a proposal of length commensurate with the style of our groups. Accordingly, we shall limit ourselves to some very rough guesses as to the likely cross section levels that one would like to explore if charmed or color particles did indeed exist.

The apparent production cross section for ψ(3105) by neutrons at NAL energies seems to be in excess of 10^{-31}cm^2.[(1)] We might take that to be a representative scale for a production of a pair of charged charmed mesons, e.g. D^+ and D^-. Furthermore, the conventional wisdom[(2)] predicts a branching ratio of about 10% into the semileptonic mode, even though the exotic quantum numbers of D^+ and D^- might inhibit the purely hadronic mode, thus increasing the importance of the semileptonic decay channels. Thus 10^{-33}cm^2 would appear to be a rough order of magnitude estimate for production of, for example,

$$p\ p \rightarrow D^+ + D^- + \text{anything}$$

$$D^- \rightarrow \mu^-\nu + \text{hadrons}$$

$$D^+ \rightarrow \mu^+\nu + \text{hadrons}$$

A hypothesis that the same kind of sensitivity is relevant for color schemes would probably constitute as good a guess as any.

If heavy leptons exist, presumably one of the mechanisms for their production in an experiment of the type we are proposing is pair photoproduction by γ's from π^o decays. The kind of sensitivity required can be estimated from some of the recent total cross section calculations of Tsai[(3)]:

$$\sigma\ (\gamma + \text{Be} \rightarrow e^+e^-\ \text{Be}) = 1.8 \times 10^{-25}\text{cm}^2$$

$$\sigma\ (\gamma + \text{Be} \rightarrow \ell^+\ell^- + \text{anything}) = 3.3 \times 10^{-34}\text{cm}^2 \quad m_\ell = 2\ \text{GeV},\ p_\gamma = 100\ \text{GeV}$$

$$\sigma\ (\gamma + \text{Be} \rightarrow \ell^+\ell^- + \text{anything}) = 3.7 \times 10^{-36}\text{cm}^2 \quad m_\ell = 4\ \text{GeV},\ p_\gamma = 100\ \text{GeV}$$

$$\sigma\ (\gamma + \text{Be} \quad \ell^+\ell^- + \text{anything}) = 2.7 \times 10^{-35}\text{cm}^2 \quad m_\ell = 4\ \text{GeV},\ p_\gamma = 200\ \text{GeV}$$

The branching ratio for

$$\ell^\pm \rightarrow \mu^\pm\ \nu\ \bar{\nu}$$

can be estimated[(4)] to be of the order of 10% for $m_\ell > 3$ GeV if one takes cognizance of the relatively high value of R observed at Frascati, CEA, and SPEAR.

Another mechanism for heavy lepton production would be presumably via some kind of Drell-Yan mechanism[(5)], i.e.

$$p\ p \rightarrow \ell^+\ell^- + \text{hadrons}.$$

An estimate of the importance of this kind of process can be obtained by noting that the cross section in the MIT-Brookhaven experiment[(6)] for making e^+e^- pairs with a mass around 3 to 4 GeV is about 10^{-35}cm^2/GeV. At NAL energies, this cross section might be 1 or 2 orders of magnitude higher, and thus this process might actually dominate over photoproduction.

In high energy p p collisions one can also make W bosons by a process of the form

$$p\ p \to W^{\pm} + \text{hadrons}.$$

The $W^{\pm}$ are expected to decay into $\mu^{\pm}\nu$ about 20% of the time. The cross section for $W^{\pm}$ production can be related via CVC to production of massive $\mu^{+}\mu^{-}$ pairs; since the present limit on W mass[7] is already $m_W \geq 8$ GeV, the W signature would be a muon of a very large transverse momentum accompanied by missing energy. The searches for directly produced W bosons by neutrinos will probably not be sensitive to masses exceeding ~ 10 GeV/c^2. Indirect searches looking for propagator effects are potentially sensitive to higher masses but are presently inconclusive.

The sensitivity of the proposed experiment covers the range from 10-20 GeV/c^2, with the exact range being somewhat model dependent. The W signature should be very clear since both a peak in the transverse momentum distribution of single muons and missing energy, characteristic of the existence of a neutrino in the final state, will be observed.

An estimate[8] of the cross-sections for W-production from 400 GeV incident protons is given below:

W-Mass	Cross Section
9 GeV/c^2	2×10^{-33} cm^2
15 GeV/c^2	10^{-34} cm^2
20 GeV/c^2	10^{-35} cm^2

3. Apparatus

We propose to perform the experiment in the laboratory E building, currently under construction, in the hadron beam ordinarily destined for the 15' bubble chamber. The main advantages of this siting are the availability of a large fraction of the necessary equipment which is being assembled for neutrino experiments, availability of a beam that can go to highest NAL energy, can deliver adequate flux, and has a facility to provide mass tagging of the incident particle by means of a Cerenkov counter.

In keeping with the exploratory nature of this experiment we would like to keep the experimental arrangement relatively modular and flexible, so that one could respond relatively easily to any new findings. At present we are still investigating the optimum arrangement for the start of the experiment; some of the ideas we are pursuing are outlined in Appendix A. What follows here is a description of a tentative initial setup. All of the efficiency and rate calculations referred to subsequently are based on this setup and thus represent minimum results that can be achieved. It is very likely, however, that some of our present ideas, when developed further, might lead to an improved version of the experiment.

The main components of the proposed apparatus starting at the upstream end are (refer to Fig. 1):

a) a proportional chamber hodoscope, to define the position and momentum of the incident beam particle

b) a calorimeter, functioning simultaneously as a target and a device to measure total hadronic and electromagnetic energy deposited

c) a large acceptance muon spectrometer consisting of the 2 11'

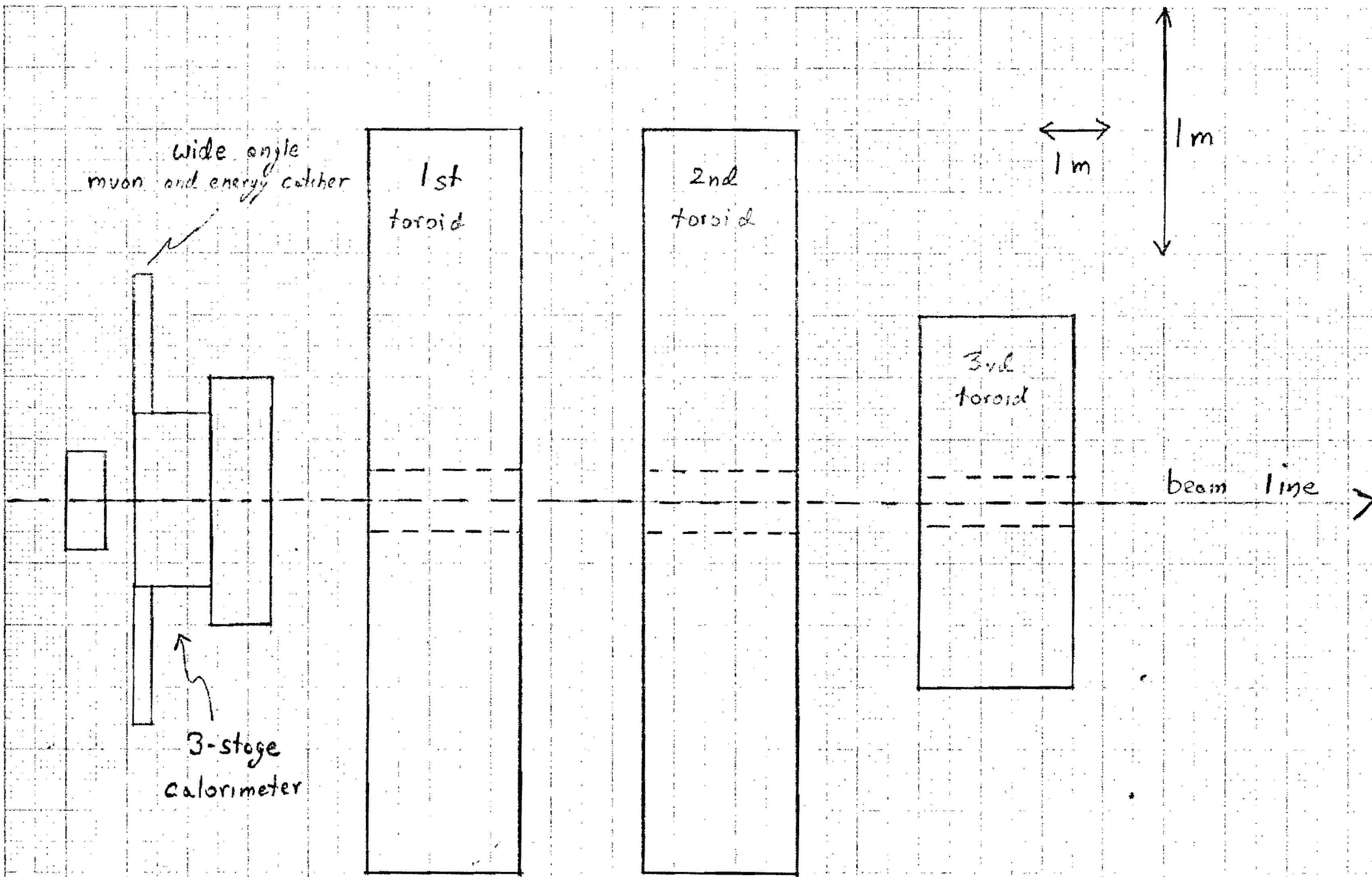


Fig. 1 – Schematic of apparatus.
(detectors between toroids not shown)

diameter toroidal LAB E magnets, the present 5' diameter wonder building magnet, and associated wire chambers.

A more detailed description of the individual elements follows.

The proportional chamber hodoscope will consist of two or more small chambers before the dipole magnet upstream of Laboratory E and two or more chambers after the magnet, the size of the chambers being determined by the size of the beam in that region. The main purpose of this system would allow one to localize the interaction point in the calorimeter. A momentum measurement to a precision of 1 or 2% is sufficient.

The calorimeter we are planning to build should have the following features:

a) large enough transverse and longitudinal dimensions so as to practically eliminate energy leakage

b) sufficient segmentation so that one would know if an anomalously large amount of energy were deposited near the edges

c) high density, so as to minimize number of π and K decays

d) long radiation length so as to minimize Coulomb scattering

e) frequent enough sampling to obtain the best possible energy measurement

f) ability to change the mean density in the front end to calibrate the number of π and K decays.

There is enough literature on the subject of calorimetry today, both experimental(9) and theoretical(10) so that one can readily outline the general design of the calorimeter. The final design will be based on some additional tests that we hope to perform in the near future.

We are thinking about dividing the calorimeter into three parts along the longitudinal direction, the design of each part basically determined by the characteristics of a hadron shower. The first part could be relatively small in transverse dimensions (about 40 cm on each side), would have very fine graininess (2 r.l. between each scintillator plate), and be 4 absorption lengths long. Furthermore, one would have the ability to telescope this part out, so as to change the mean density. This would be accomplished by leaving a gap of 3 absorption lengths before the second part of the calorimeter during normal running. The mean density could be decreased by up to a factor of 2 by spreading out the metal-scintillator sandwiches while keeping the 1 absorption length point into the calorimeter at a fixed position. This would ensure that on the average, the acceptance of the system would be independent of the spacing.

About 70% of the total energy would be deposited in the first section so that precise energy measurement is very important here. Since the interesting events would be produced in this region, one would like to optimize the material in this part of the calorimeter. We assume that a basic module would consist of 2 radiation lengths of metal, followed immediately by an 1/8" plastic scintillator. To decide on the metal to be used we must minimize the absorption length and minimize the absorption length/radiation length ratio. We clearly cannot do both, so a compromise must be reached. Since the probability of two $\pi \rightarrow \mu\nu$ decays goes quadratically with the absorption length, while measurement accuracy goes only as the square root of the a.l./r.l. ratio, we might expect that a good figure of merit for 2 μ events might be a product of the square of the first quantity times the square root of the second one.

As illustrated in the Table below, of the common materials copper is the best, followed by iron.

Table I

Material	Radiation Length	Length of Basic Module	Absorp.Length (Incl.Scint.) (A)	$\frac{\text{Abs.Length}}{\text{Rad.Length}} = R$	$A^2 R$
Al	9.0 cm	18.3 cm	37.82	4.13	2906
Fe	1.77	3.84	18.55	9.66	1069
C_U	1.45	3.2	16.33	10.21	852
W	0.35	1.0	14.71	29.43	1173
Pb	0.56	1.42	23.46	33.0	3163

Since the difference in price between these two is only a factor of two or so[11], and the amount of material is rather small, we plan to use copper slabs in the first part of the calorimeter.

The second part of the calorimeter would be a scaled up version of the first part: about 70 cm square, 1.5 m long, with a width of each metal slab about 3 r.l.. The density of material is no longer so important here; the main merit of a short absorption length is the improved acceptance of the apparatus. Thus even though copper would be a preferred material here, iron plates would also be satisfactory.

Just in front of the second part of the calorimeter we plan to place a sandwich of scintillators and iron (about 30 cm thick), about 1.8 m square with a 70 cm square hole in the center, to identify those events with a large amount of energy carried off by the wide angle component of the shower. In addition, the iron in the middle of the sandwich would identify the wide angle muons, which otherwise would leak out undetected from the calorimeter.

The last part of the calorimeter can be relatively coarse-grained, as it is designed to catch the energy in the anomolously long hadron showers. Conceivably, the events with a large amount of energy deposited here would be rejected in the analysis. Typical dimensions here might be 1 m in all directions and the basic unit would consist of 4" thick steel plates followed by scintillator. The total length of the 3 calorimeters is 20 absorption lengths.

The toroidal magnetic spectrometer has been described in detail previously(12). Very briefly, it consists of wire chamber system 10' by 10' in transverse dimensions on both sides of each toroid and two toroidal magnets, 8' long, 11.5' in diameter, with the B field varying from 21.3 kg at the center to 17.1 kg at the edge and giving a mean field integral of 46.4 kg m. The two big toroids are followed by the presently existing 5' diameter toroid. The central clearance holes for the coils are 10" in diameter. The overall precision of the momentum measurement is determined by Coulomb scattering and is $\sim$9% for any two toroids.

4. Sensitivity and Resolution

We are planning on a maximum flux of 10^6 particles/pulse assuming 1 second long spill. This would give only a 2% loss due to 2 or more particles in the same RF bucket. We intend to modify the wire chamber pulsing system to be able to take up to 30 triggers per pulse. The proton total cross section at these energies is about 42 mb, of which about 7 mb is the elastic cross section. Thus the absorption cross section is about 35 mb. Assuming

10^4 pulses/day, this would give us a sensitivity per day to a cross section of $3.5 \times 10^{-26}/10^{10} \approx 3.5 \times 10^{-36} cm^2$ assuming 100% detection efficiency. We lose a factor of 2 or 3 due to detection efficiency, but will regain a comparable factor due to the existence of high energy secondaries that will also contribute to the production of interesting events.

We believe on the basis of the available experimental evidence that one can attain a resolution in the calorimeter of the order of 4 to 5% (HWHM) at 400 GeV. The outgoing muons will be measured in the magnetic spectrometer to ±9%. Thus, on the average we hope to measure the total energy to ±20 GeV. More important then resolution is the elimination of the low energy tails. We plan to investigate its sources in more detail during the coming tests, but one can briefly discuss some of the possible mechanisms and ways to combat them:

a) off momentum beam particles. These will be eliminated by the beam particle momentum measurement.

b) catastrophic muon collisions in the magnets. The majority of these can be eliminated by a consistency requirement between the two magnets.

c) transverse or longitudinal energy leakage. This can be eliminated by using the information on the shape of the shower as well as information from the "wide energy catchers".

The error on p_T and $m_{\mu\mu}$ will be dominated by the Coulomb scattering in the low energy limit and by the momentum measurement error in the high energy limit. Assuming that we know the transverse position of the interaction point from the proportional chamber information,the error in p_T due to Coulomb scattering will be

$$\delta\, p_T^{Coul} = 15 \times \sqrt{200}/\sqrt{3}\ \text{MeV/c} \approx 120\ \text{MeV/c}$$

and due to momentum measurement

$$\delta\, p_T^{mom} = 0.09 \times p_T$$

Thus for $p_T \approx 1$ GeV/c, the error $\delta\, p_T \approx 150$ MeV/c.

For an almost symmetric decay, the effective mass squared is given by

$$M^2 \approx p_1 p_2\, (\theta_1 + \theta_2)^2$$

and thus the error will be

$$\frac{\delta M}{M} = \sqrt{\tfrac{1}{4}\left(\frac{\delta p_1}{p_1}\right)^2 + \tfrac{1}{4}\left(\frac{\delta p_2}{p_2}\right)^2 + \left(\frac{\delta\theta}{\theta}\right)^2} \quad 8.5\%\ \text{for}\ M \approx 3\ \text{GeV}$$

5. Trigger Rates and Acceptance

Here we would like to estimate the potential trigger rates, their sources, and the extent to which they contribute to our background.

A. Energy Loss Trigger

The simplest trigger that might be used in this experiment is a requirement on the total energy as measured in the calorimeter. A deposited energy substantially less than the incident (300 GeV) energy could signal, in the most unbiased way, the production of muons or neutrinos. The spark chambers and downstream counters might then provide information on the existence and number of final state muons.

The major limitation on sensitivity in this trigger mode is the intrinsic resolution of the calorimeter, and in particular any low energy tails that may exist. For this reason, the beam must be well-instrumented to provide information on the momentum of each incident particle. (Low energy tails in calorimetry tests done thus far have generally been attributed to low energy components of the beam).

We believe on the basis of past experiences that a calorimeter giving an on-line gaussian resolution of σ = 7% at 300 GeV is technically rather easy. We shall aim to do somewhat better than this. For illustration, the table below gives the cross-section sensitivity as a function of maximum energy deposition used in triggering, assuming a 7% gaussian error on calorimetry and a total absorption cross-section of 35 mb.

Standard Deviations	E_{trig}	Prob($E<E_{trig}$)	Cross-Section Sensitivity
2	258 GeV	.023	3.9×10^{-28}
3	237	1.3×10^{-3}	2.2×10^{-29}
4	216	3.1×10^{-5}	5.3×10^{-31}
5	195	2.9×10^{-7}	5.0×10^{-33}

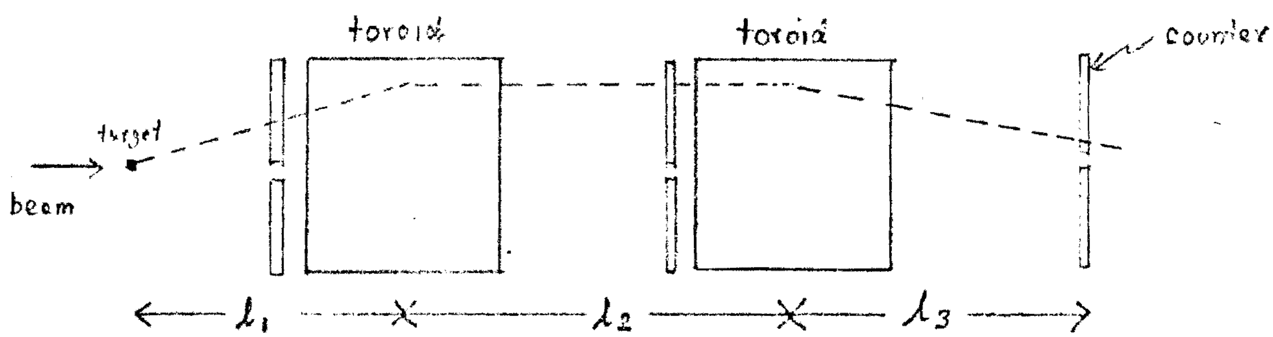
To set the scale, we expect single muon production at a level of 10^{-30} to $10^{-32} cm^2$ for $p_T \gtrsim 1$ GeV/c.

B. Single Muon Trigger

The next least restrictive element to add to the energy requirement is a trigger on at least one muon with a minimum transverse momentum.

Since the rate for single muon production falls approximately as $e^{-3.5\ p_T}$, this seems the most advantageous method of controlling trigger rate. For example, with 10^6 protons incident per pulse, we expect approximately .01 to .1 triggers/pulse with at least one muon having p_T >2 GeV/c, based on the observed rate of muon production. At very low transverse momenta ($p_T \leq 1$ GeV/c), backgrounds from pion and kaon decay, vector meson decay, and pair production will likely become dominant.

To accomplish this triggering we plan to use pie-shaped trigger counters centered on the toroids (see sketch below).



Each toroid imparts a transverse momentum of p_o = 1.4 GeV/c. The radial displacement of a particle at a distance ℓ_3 downstream of the center of the last toroid is $r = \frac{1}{p}\ (\ell_1 + \ell_2 + \ell_3)\ p_T - (\ell_2 + 2\ell_3)\ p_o$ where p = particle momentum and p_T = particle transverse momentum. So the particle crosses-over to the other half plane if

$$p_T < \frac{\ell_2 + 2\ell_3}{\ell_1 + \ell_2 + \ell_3}\ p_o, \text{ independent of p.}$$

By adjusting the location of this last trigger counter (ℓ_3), the transverse momentum lower limit on a muon of the appropriate sign can be continuously varied up to over 2 GeV/c.

The finite size of the toroids and trigger counters creates a region of acceptance in the p_T - p_{lab} plane for the triggering muon. This is shown schematically in Figure 2 for 10' diameter trigger elements and toroids, and p_T^{min} cut at 1.4 GeV/c. To set the scale, we note that muons made in the forward cone in the center-of-mass must have

$$p_{lab} \geq \gamma \, p_T.$$

At 300 GeV, γ = 12.6. The line p_{lab} = 12.6 p_T is shown for comparison. Clearly, a very large fraction of muons will trigger the system. We might add that a pair of oppositely charged muons cannot fake a high p_T muon by a cross-over mechanism since the toroidal system focuses muons of one sign and defocuses those of the opposite sign. The wrong sign (i.e. defocused) muons will give some small number of undesired triggers (see Fig. 2b); the number of such triggers can, however, be drastically reduced and/or eliminated with only a small loss of acceptance at high p_T by decreasing the diameter of the trigger counter at ℓ_3.

C. Di-Muon Trigger

In order to search at lower p_T, and to study multi-muon states in their own right a trigger optimized for $\geq$ 2 's will be employed. The Chicago group[13] has measured the rate of 2μ triggers produced by a beam of incident 150 GeV π's with the requirement that each p_μ > 12 GeV. Their experimental number is 33 triggers/10^6 interacting π's. One might attempt to extrapolate from that measurement to our situation of 2μ's with p_μ > 9 GeV, 400 GeV protons. Certainly our lower

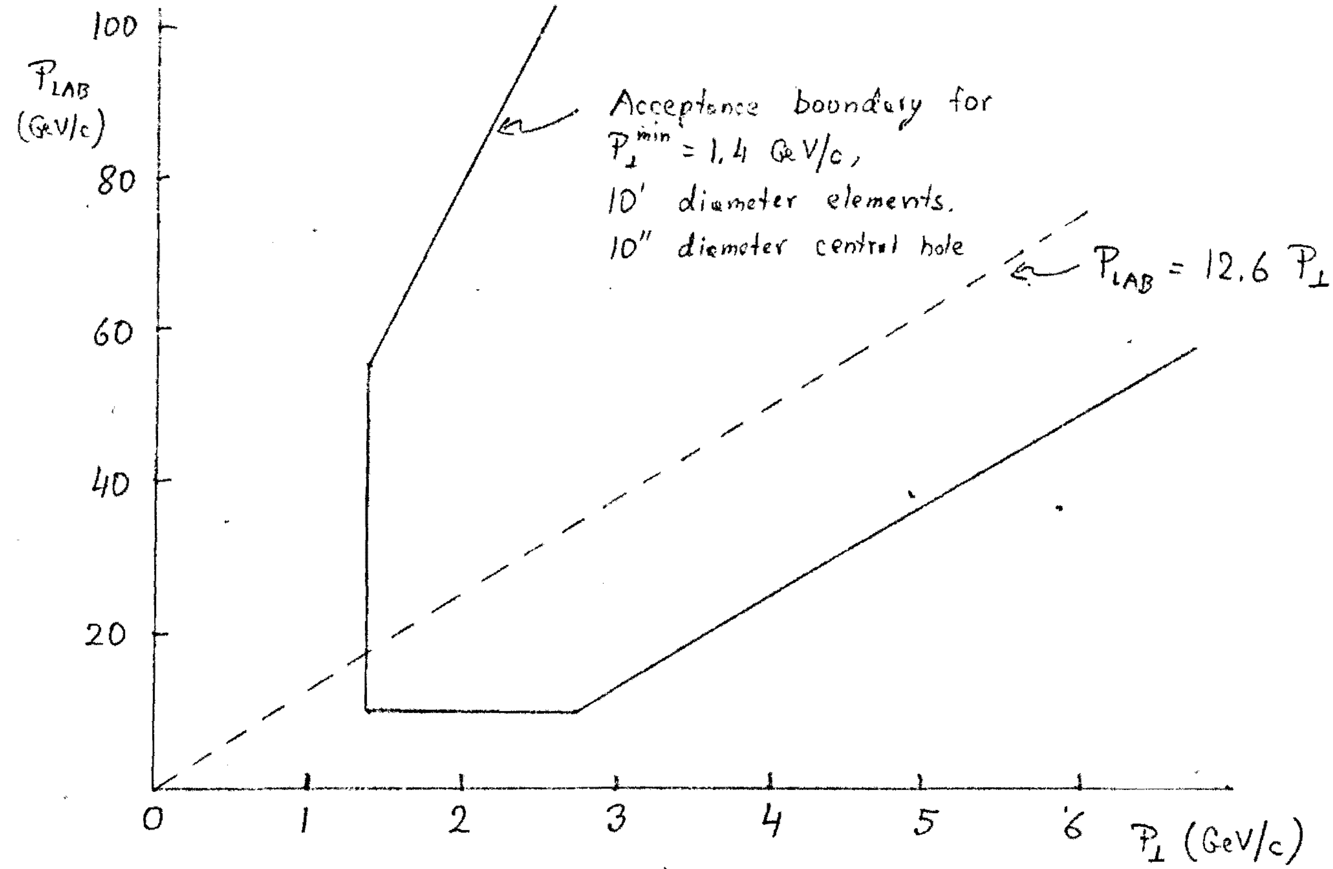


Fig. 2a. Acceptance region for focused muons

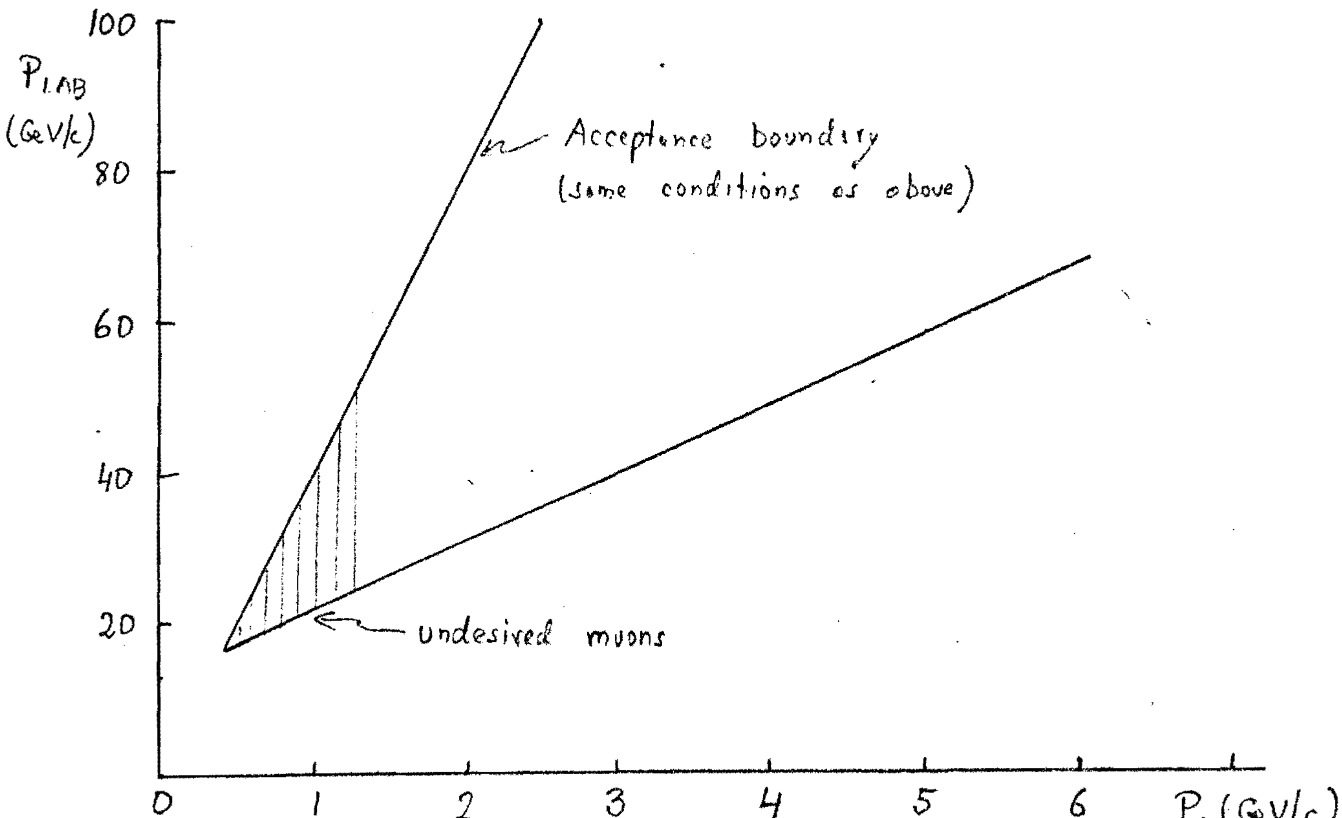


Fig 2b. Acceptance region for defocused muons

energy cutoff and higher incident energy would tend to increase that rate; the nature of the projectile (proton vs. π^-) would probably decrease it.

To try to make a better estimate, we consider the various potential mechanisms that might contribute here. For a moment we ignore the fact that the experimental arrangement discussed above discriminates against low p_T μ's.

a) $\gamma Z \rightarrow \mu^+\mu^- Z$. The probability of a conversion to a muon pair vs. an electron pair[3] is about 10^{-5} for high energy γ's. Furthermore, a 40 GeV γ-ray will have about a 50% probability of giving both μ's with $P_\mu > 9$ GeV. One might guess that on the average a 400 GeV proton will give about 1 γ with energy greater than 40 GeV. Thus, the trigger rate here is probably about $5\text{-}10/10^6$ protons. It is certainly easier for π's to give high energy photons than for the protons. Thus the contribution from this source could be comparable.

b) $pp \rightarrow V^o$ + anything, $V^o \rightarrow \mu^+\mu^-$. Here V^o is a vector meson, ρ, ω, or ϕ. These cross sections are not known at NAL energies. The most relevant numbers are:

σ ($pp \rightarrow \rho^o$+ anything) = 3.49 ± 0.42 mb at 24 GeV/c[14]

σ ($\pi^+p \rightarrow \rho^o$ + anything) = 6.03 ± 0.71 mb at 22 GeV/c[15]

and σ ($\pi^-p \rightarrow \rho^o$ + anything) = 13.5 ± 3.4 mb at 205 GeV/c[16].

Thus at medium energies, <u>per interaction</u> π's are about 4 times more efficient than protons in making ρ's. There is no meaningful data on inclusvie ω production in π nucleon interactions, and some indication[14] that ω production is comparable to ρ^o production in pp collisions at 24 GeV/c. Since the inclusive production tends to increase with energy, one might guess that on the average about 0.25 ρ and 0.5 vector meson is produced per interaction in p-p collisions at 400 GeV. Probably only about 50% of these are above 30 GeV, and even those have only about 50% probability of giving both μ's with $p_\mu > 9$ GeV. Thus for a branching ratio of 6.7×10^{-5}, vector meson production should contribute about 8 triggers/pulse. This estimate, however, could easily be wrong by a factor of 2 or 3 . The contribution from this source in our situation will probably be comparable to 150 GeV π^-.

c) $\pi^\pm$, $K^\pm$, or $Y^\pm$ decay. Consider first the probability of 2 $\pi \to \mu\nu$ decays. A pessimistic assumption would be that we create 10 25 GeV charged π mesons in the primary collision. The mean decay path length for each π is then

$$\lambda_\pi = 7.8 \times 25/0.14 = 1393 \text{ m}$$

The mean absorption length is 16.3 cm giving a decay probability for each pion of 1.17×10^{-4}. Thus the probability of getting a μ^+ and μ^- from π decays is

$$(1.17 \times 10^{-4})^2 \times 5 \times 5 = 3.4 \times 10^{-7}$$

i.e. less than 1 trigger per pulse.

The K mean decay path length at this energy into $\mu\nu$ is 296 m. At 750 MeV/c transverse momentum the K^+/π^+ ratio is about 3, while the K^-/π^- ratio is about 5[17]. This ratio tends to increase as we go to lower p_T's. Thus the assumption of 1 K^+ and 1 K^-/interaction is pessimistic and K decays also contribute a negligible amount to the trigger.

Finally, among the hyperons $\Sigma^- \to n\mu^-\nu$ decay is probably the most serious, having a branching ratio of 4.5×10^{-4}. But the minimum momentum necessary for a Σ^- to give a μ of 9 GeV/c is about 25 GeV/c, giving a λ_T of 95 cm. Thus the decay probability into $n\mu\nu$ is

$$P_\Sigma = \frac{16.3}{95} \times 4.5 \times 10^{-4} = 7.7 \times 10^{-5}$$

i.e. completely negligible.

d) ψ decays. Assuming 10^{-32}cm^2 cross section for ψ production followed by $\mu^+\mu^-$ decay,[1] we obtain about 1/3 $\psi \to \mu\mu$ event/pulse assuming 100% detection efficiency.

e) η decays. The branching ratio for $\eta \to \mu^+\mu^-$ is quoted to be 2.2×10^{-5}. There is no good data on inclusive η production although at high p_T at ISR, η's appear to be produced at a rate comparable to π^o's. Another estimate might be able to compare exclusive channels[18] at 24 GeV/c:

$$\sigma\ (pp \to pp\ \rho^o) = 125 \pm 19\ \mu b$$

$$\sigma\ (pp \to pp\ \eta) = 32 \pm \mu b.$$

Thus a very crude guess might be 1/4 η/proton interaction, giving us about 5 triggers/pulse.

f) $K^o \rightarrow \pi\mu\nu$ decays. This rate is about 1/10 of $K^+ \rightarrow \mu\nu$ rate, and thus completely negligible.

g) di-muon continuum. This is very difficult to estimate, but some crude guesses can be made. The number of events in the MIT-Brookhaven experiment[6] of the type

$$pp \rightarrow e^+e^- \text{ anything} \qquad 3\text{ GeV} < m_{ee} < 4\text{ GeV}$$

corresponds to a cross section of the order of 10^{-35} cm^2/GeV. Furthermore, per mass interval, that cross section appears to go down[19] as $1/m^6$. Thus for $m_{ee} > 1$ GeV, we might have a cross section of about $10^{-32} cm^2$. At NAL energies, this might go up by 1 or 2 orders of magnitude, giving about 3-30 triggers/pulse with $m_{\mu\mu} > 1$ GeV. (There are some arguments[20] that the continuum contribution for dilepton pairs should go smoothly into dilepton contribution from vector meson decays). This estimate is probably on the pessimistic side (very roughly, the rate of μ pairs above 1 GeV observed by W. Y. Lee, T. O'Halloran, et al., appears to agree with a rate of about 3 triggers/pulse for our experimental setup), if one looks at the results of the Chicago group, but probably does indicate that this will be the largest source of dimuon pairs.

In summary, one would expect a raw trigger rate of 30-50 μ's/pulse if there were no low p_T cutoff. From the arguments above, however, we see that most of these muons have a relatively low p_T and thus our geometrical arrangement should easily suppress those by at least an order of magnitude. If one wanted to investigate the low p_T dimuon pairs, a special run could be made at about 10^5 protons/pulse with the calorimeter moved upstream to improve the low p_T acceptance.

The acceptance of the entire system is illustrated in Fig. 3. For the purpose of this calculation it is assumed that the field direction alternates in each successive toroid. This is the optimum polarity arrangement if one wants to maximize 2μ acceptance. A μ is considered accepted if it passes through at least 2 whole toroids. The cutoff at low p_T is due to the muon passing through at least a part of the central hole in two or more toroids, and can be made less severe if desired by moving the whole calorimeter further upstream of the toroids. Coulomb scattering in both the calorimeter and the toroids has been included in the calculations.

As can be seen, the acceptance for this configuration as a function of angle is close to 100% out to about 120 mr. It is essentially independent of muon momentum, once the muon exceeds the range cutoff of ∿9 GeV, corresponding to the thickness of the calorimeter and the two toroids. This acceptance should be compared with γ^{-1} (82 mr for 300 GeV incident particle, 71 mr for 400 GeV incident particle) which corresponds to the laboratory angle for a particle imitted at 90^{o} in the center of mass. Thus we accept all of the

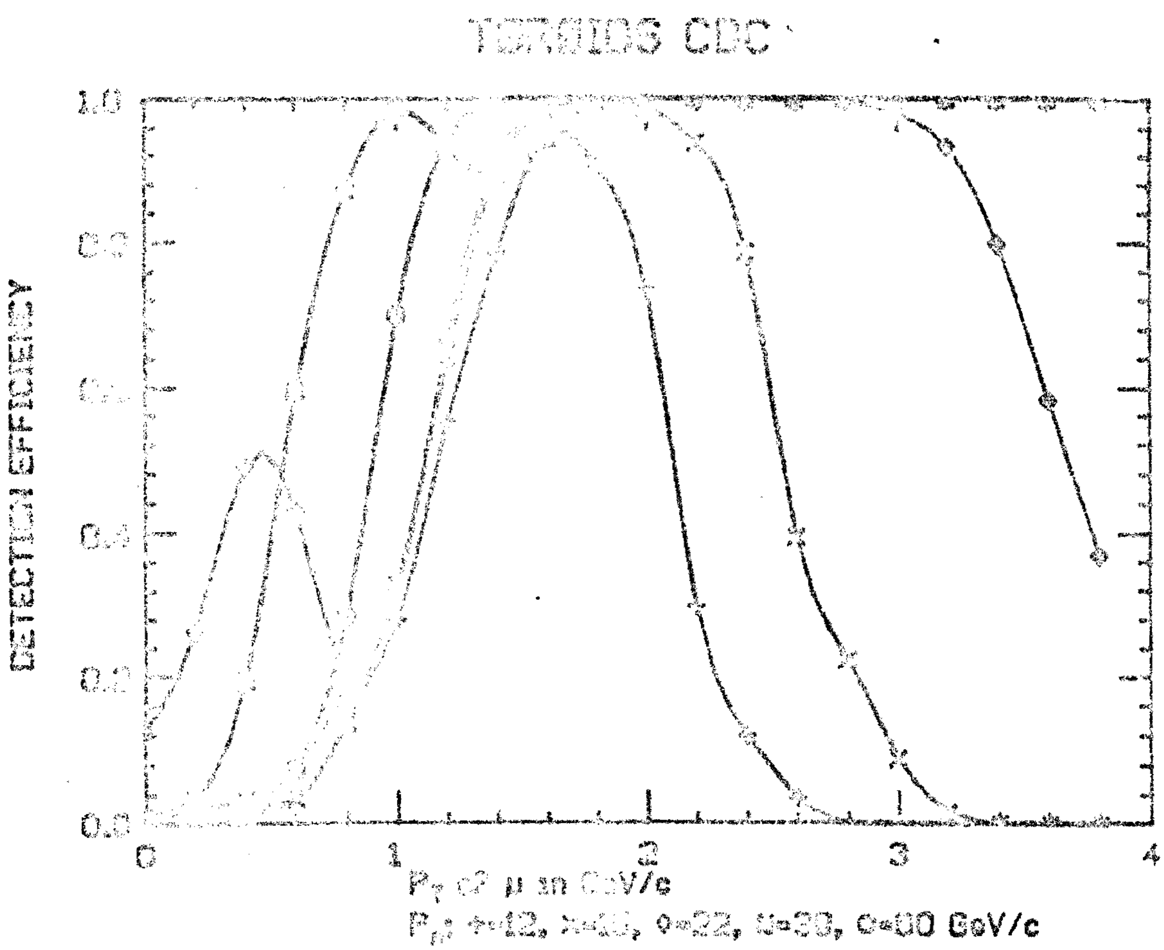


Fig. 3c – μ acceptance for converging-diverging-converging situation

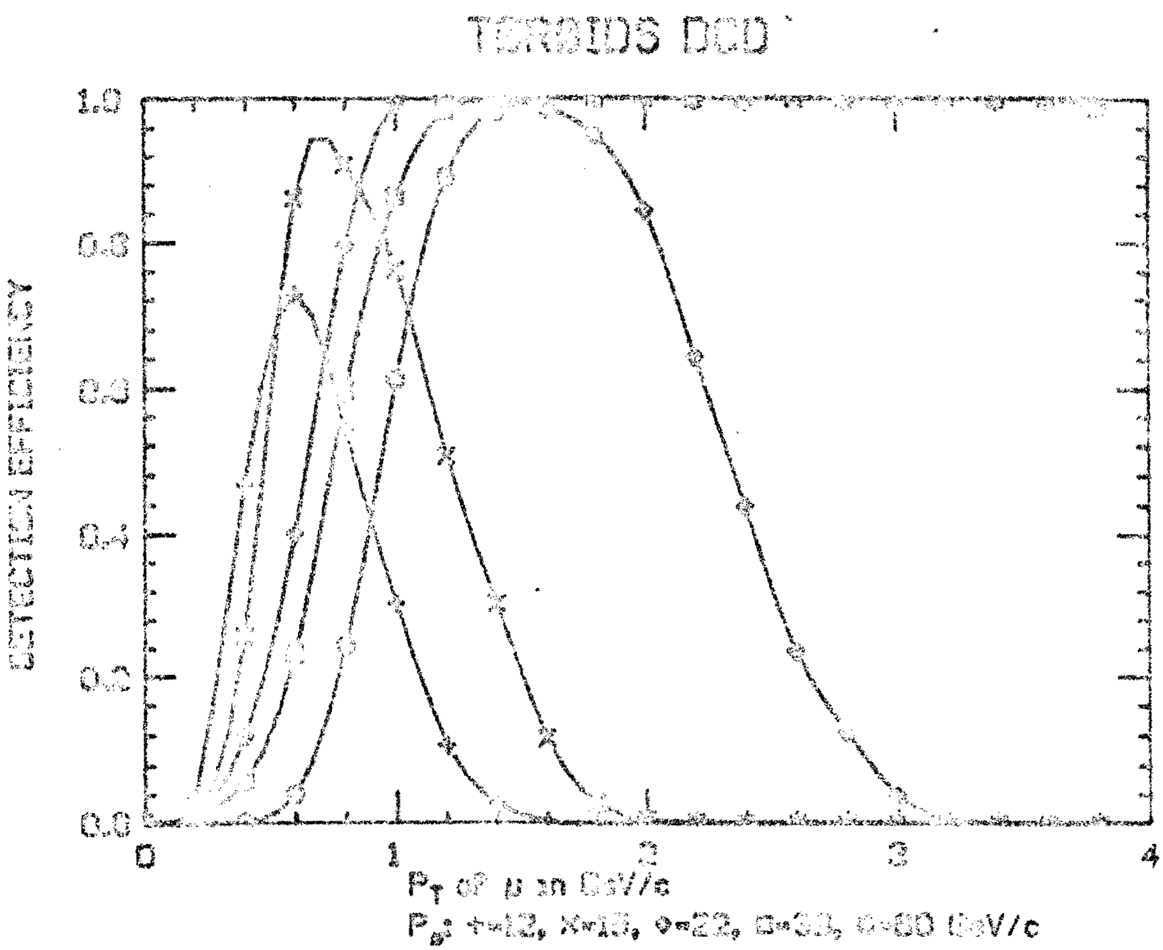


Fig 36 - μ acceptance for diverging - converging - diverging situation forward hemisphere, and a large fraction of the backward hemisphere. Another meaningful scale to keep in mind is that a 750 MeV/c μ in the center of mass emitted at 90°, would have 0.75 γ GeV in the Lab (9.2 GeV for 300 GeV projectile, 10.6 GeV for 400 GeV). Thus our low energy cutoff is well matched to our angular acceptance,since we are interested in looking for muons with p_T in excess of 750 MeV/c

6. Backgrounds

We address ourselves now to the question to what extent the dimuon events discussed above as well as single high p_T μ's could also be deficient in energy. There are two physical mechanisms that could bring this about: or K decays and catastrophic collisions in an iron toroid. We first discuss these phenomena from the point of view of background to the dimuon events.

a) π and K decays. Let us first calculate the probability of obtaining from this source a dimuon pair, each with $p_T \geq 750$ MeV/c. To do this calculation we assume e^{-6p_T} for hadrons, integrate the fraction of hadrons above a certain p_T, and then integrate over all cm decay angles (we assume here that the transverse momentum generated in $\pi\to\mu\nu$ on $K\to\mu\nu$ is negligible and compared to 0.75 GeV/c). We find that a muon with $p_T >$ 0.75 GeV/c will be produced by 2.2% of π decays and 1.6% of K decays. Combining this with the trigger probability of 3.4×10^{-7} calculated in section 5, we obtain

$$3.4 \times 10^{-7} \times (2.2 \times 10^{-2}) \times 10^{10} = 1.6 \text{ event/day due to } 2\pi \text{ decays.}$$

and

$$(1.17 \times 10^{-4} \times 1393/296)^2 \times \frac{5}{3} \times (1.6 \times 10^{-2})^2 = 1.2 \text{ event/day due to 2 K decays.}$$

Furthermore, the p_T requirement strongly favor those decays with a very small fraction of energy given to the neutrinos. This background can also be easily calibrated, since a variation of density by a factor of 2 should change this background by a factor of 4. The correlations between high p_T particles might conceivably increase this process by some factor.

b) energy loss by muons in the toroids. In general, these processes will be detected because of the incompatibility of the measurement in each magnet. However, one can think of 3 kinds of events where this incompatibility would not exist i.e.:

1 - high ν, low q^2 muon scattering at the beginning of 1st magnet.

2 - high ν, high q^2 muon scattering near the center of the first toroid, the combination of energy loss and direction of scattering combining to give the appearance that nothing unusual has happened.

3 - relatively high q^2 μ-e scattering, i.e. energetic δ rays, at the beginning of the 1st magnet.

The order of magnitude of these processes can be estimated quite reliably. Even though the first process corresponds to values of q^2 and ν that are not in the scaling domain, the 0^o inelastic scattering can be estimated from QED and real photon-nucleon cross section.[21] The magnitude of the second process can be extracted by using scaling to extrapolate from the measured ep and μp inelastic scattering. Finally, the third process corresponds to elastic scattering of two point particles and can be calculated from QED.

For what might be considered a "typical relevant" case, i.e. a 50% energy loss of a 40 GeV μ, we obtain a combined probability/muon of the order of 3×10^{-4}. Assuming one $\mu^+\mu^-$ pair/pulse with each p_T 750 MeV/c, this would give us few background events/day.

Finally, we would like to make several additional remarks on this point:

1) Because of the steeply falling muon spectrum with p_T and the fact that these processes can only generate energy loss, the actual background is even less severe than estimated, since the original muon must have had an even higher p_T.

2) All of these processes can be measured experimentally during the actual data taking: the first and the third by observing the number of such events in the second magnet, the second by observing the number of events with the right ν and polar scattering angle, but different azimuthal angle.

3) Empirical measurements of these mechanisms are being performed at this time using the neutrino data from E-21.

4) These mechanisms could be eliminated almost entirely by splitting and instrumenting the toroids (see discussion in Appendix A).

Finally, we consider the missing energy background for single, high p_T muons. The dominant source here will be $K \rightarrow \mu\nu$ decays. We have estimated about $1\ \mu$ (p_T>1.5 GeV/c) from this source per pulse. We now want to impose the additional requirement that the neutrino carry off a sizable fraction of the energy. Requiring that the neutrino have at least as much energy as the muon, would raise the p_T of the K meson to 3 GeV/c. From the measured[(17)] p_T dependence of hadrons, one would estimate another suppression by a factor of about 10^{-3}. Thus the background level would correspond to about 10 events/day.

Since the catastrophic energy loss in a toroid has a probability of about 10^{-4}, that background would be comparable on the basis of these conside ra= considerations alone. However, we have an additional suppression factor due to the fact that the initial μ must have a considerably higher p_T initially. This background source can thus be neglected.

7. Time Scale

It appears that Lab-E and its toroidal spectrometer system could be operational by next fall. On the other hand, the neutrino calorimeter will have to be modified and remounted and are not expected to be ready until several months later. We believe that given approval in March, we could have the special target-calorimeter for this experiment ready in the fall. It should be noted that at least roughly the main responsibility for the calorimeter will lie with the Stanford group and the μ-spectrometer with the Caltech group. In that way, the main Caltech effort will be on apparatus needed for the neutrino experiment anyway. The best arrangement for building the iron toroid system has not been settled (see Appendix A). However, the problems are mutual for the ν effort and this experiment, and no compromises to the neutrino apparatus are envisioned.

Our specific request is for 1,000 hours of running time in a proton beam at the highest available energy. Further, we expect to need some test time at low intensity to understand our calorimeter and calibrate it. Tests of trigger rates at an early stage would also be useful. It would be advantageous for us to do as many of these tests in the final location as possible.

8. NAL Contributions

We are requesting Fermilab to provide:

(1) PREP electronics for the trigger system for this experiment. Existing ν electronics will be used for pulse height analysis and spark chamber readout.

(2) Proportional chambers for instrumenting the beam to determine the momentum of individual beam particles.

(3) Mounts for the target-calorimeter. A flexible mounting system (that will be non-interfering with the ν-calorimeter) and have the ability of changing the longitudinal position (rails?) relative to the toroidal system will be needed.

(4) Toroidal magnet system for detection of muons (see Appendix A)

(5) Metal plates for the calorimeter.

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1) W. Y. Lee and T. O'Halloran, private communication.

2) M. K. Gaillard, B. W. Lee, and J. L. Rosner, Fermilab-PUB-74/86.

3) Y. S. Tsai, Rev. Mod. Phys., Vol. 46, No. 4.

4) Y. S. Tsai, Phys. Rev. D4, 2821 (1971).

5) S. Drell and T. M. Yan, PRL 25, 316 (1970).

6) J. J. Aubert et al., PRL 33, 1404 (1974) and PRL 33, 1624 (1974).

7) B. C. Barish et al., PRL 31, 180 (1973); subsequent runs improved the quoted limit to about 8 GeV/c^2.

8) S. Berman, J. Bjorken, and J. Kogut, Phys. Rev. D4, 3388 (1971).

9) B. C. Barish et al., NIM 116 (1974), 413; L. W. Jones, et al., NIM 118, (1974) 431. This list is by no means meant to be complete.

10) A. Baroncelli, NIM, 118 (1974), 445.

11) For a more detailed discussion of this point see Appendix B.

12) B. C. Barish et al., Projected Lab-E Dichromatic electronic Detector Facility, CALT-68-469.

13) K. Anderson et al., Addendum to Fermilab proposal #331.

14) V. Blobel et al., PL 48B, 73 (1974).

15) H. A. Gordon et al., PRL 34, 284 (1975).

16) F. C. Winkelman et al., LBL-3390, November 14, 1974.

17) J. W. Cronin et al., PRL 31, 1426 (1973).

18) V. Blobel et al, NP B69, 237 (1974).

19) J. H. Christenson et al., PRL 25, 1523 (1970).

20) J. J. Sakurai and H. B. Thacker, 1973 Erioe lectures.

21) See for example - B. D. Dieterle et al., PRL 23, 1187 (1969); L. N. Hand, PR 129, 1834 (1963).

Appendix A

The purpose of this appendix is to note several alternative possibilities for the apparatus from those discussed in the main body of the proposal. None of these developments, however, are necessary to conduct the proposed initial experiment, but rather they represent improvements which we are prepared to make if this line of research proves interesting.

I. Instrumented Toroids

The present proposal uses standard "blind" toroids. There are a variety of mechanisms where a muon might lose energy in traversing such a system. This problem is addressed in section 6 b) and calculations of the expected background levels from various energy loss mechanisms are discussed.

Also, empirical measurements of energy loss of muons traversing steel are being performed using the neutrino data from E-21. Although the calculated level appears to be too low to be a problem in an initial experiment, it appears that these loss mechanisms might well be the ultimate limitation of our proposed technique. It might be pointed out that extraneous energy loss mechanisms in Fe will also provide limitations for ν-experiments for large data samples. (They tend artifically to create high y-events!)

It has been apparent for some time that lumped "blind" toroids are not the ideal instruments for the ν experiment. Instead, there are many advantages to constructing a distributed and "instrumented" toroid system. It is inappropriate in this proposal to describe in detail the advantages ofr the ν-experiment. However, briefly there are two motivations.

1) To detect spurious energy loss mechanisms for μ's traversing the iron spectrometer (same motivation as this proposal).

2) An instrumented toroid system would provide a magnetized 400 ton neutrino target and detector with the best possible acceptance for

muons in the final state. An integrated target-magnetic detector gives the best possible solid angle for muon detection.

Anyway, for the purpose of this proposal (and for completeness) Figures B1-B3 are included to illustrate how the instrumented toroids system mgiht look. The actual physical arrangement is still being discussed but the principle is to separate each 8" ring with à 2" gap to insert scintillators. Position detectors (spark chambers) will be placed after every 4th ring.

A large pulse height in a given scintillator would indicate anomolous energy loss of a muon and the event would be discarded in the proposed experiment. Also, the scintillators would be used to develop the most flexible possible trigger for this experiment. Momentum resolution remains the same as for "blind" toroids.

II. Air-Gap Magnet

An air core magnet after the calorimeter would allow one to measure precisely the momentum of very forward muons. Since we are contemplating a very large solid angle system, one could not think about catching all the muons in an air-core magnet. The philosophy would be to use the air-core magnet to measure the energy of forward, and hence most likely energetic, muons, and the toroid magnets to measure the momentum of less energetic, wider angle muons. One can think of several pro and con arguments regarding the inclusion of such a magnet in this sytem. To state the arguments for inclusion:

a) precise measurement of energy of high energy, forward muons.

b) freedom from worry about large energy losses by muons in an inelastic collision in a "blind" toroid magnet.

c) no dead spot corresponding to central 10" hole in the toroids.

And the arguments against inclusion:

(1 cm = 20")

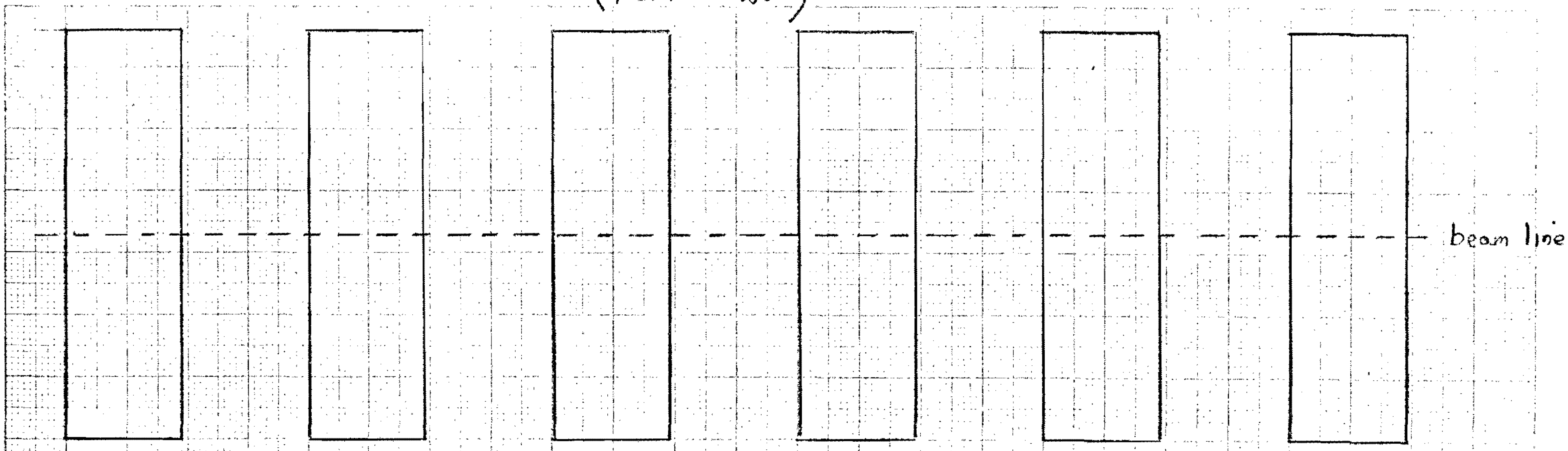


Fig. B1 - Schematic arrangement of the "distributed" μ spectrometer

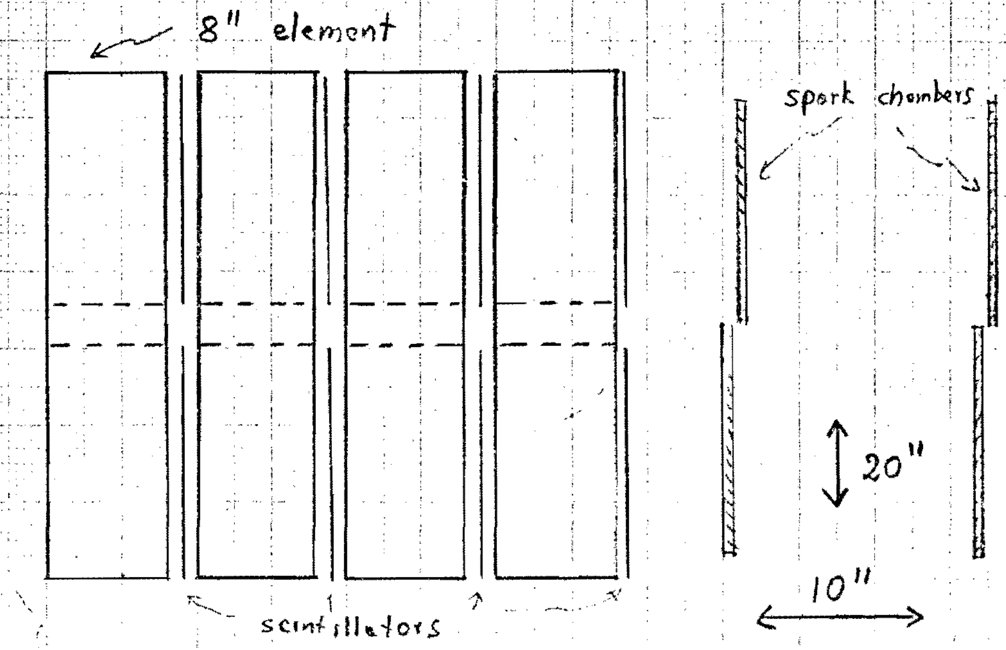


Fig. B2 - Detail of one spectrometer module

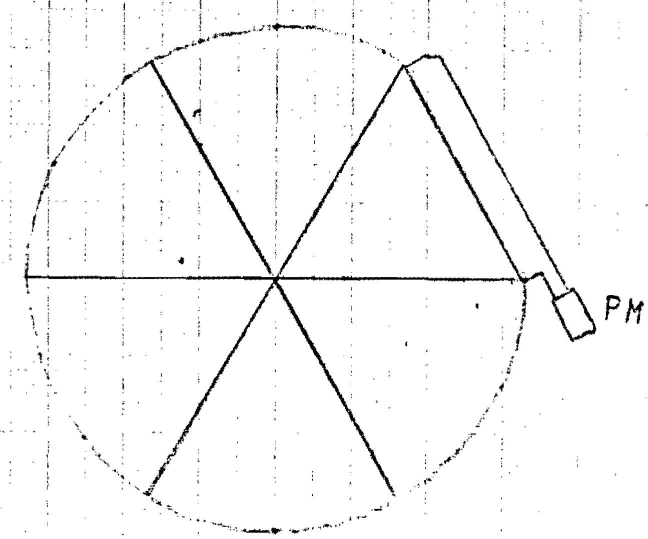


Fig. B3 - Possible Counter Arrangement in Gaps (6 counters/gap)

a) Poorer overall acceptance since such a magnet system with associated chambers would probably add about 5 m to the overall length of the system.

b) postponment of the experiment due to additional complications.

We feel that the last argument is probably most relevant in light of the contemplated time scale. Accordingly, we are planning to start the experiment without such a magnet but are leaving the setup flexible enough to be able to insert it into the system later on.

III. Position Detectors in the Target-Calorimeter

The main unique feature of this experiment compared to other hadron experiments detecting muons in the final state is the measurement of the E_{had} for each event. If the physics turns out to be interesting it would be logical to pursue this philosophy one step further.

In particular, one could measure some of the features of the final state hadrons in events giving final state muons. We would propose to measure θ_h(the directions of the hadrons), and ϕ_h^2 (the spread in the hadrons which is proportional to the invariant mass in the hadron system). These ideas are discussed in the documents on the Proposed Lab-E Neutrino Detector.

The problem is a lot easier here than for the neutrino experiments because of the localization of the incident hadron beam. We intend to build the target-calorimeter with enough flexibility so that position detectors could be inserted near the front of the apparatus to determine θ_h and ϕ_h^2. This equipment would be added in a future run if we decided that this was a viable option.

E379

MUON PRODUCTION BY HADRONS

or SEARCH FOR NEW PHENOMENA

with emphasis on

1) MEASUREMENT OF TOTAL HADRONIC ENERGY
2) LARGE SOLID ANGLE

CAL TECH - STANFORD COLLABORATION

OUTLINE

A) EXPERIMENTAL
   1) DISCUSSION OF APPARATUS
   2) ACCEPTANCE FOR MUONS
   3) PRESENT STATUS OF CALORIMETRY
   4) TRIGGERS AND RATES,

B) DISCUSSION OF SPECIFIC PHYSICS EXPT - CHARM
   1) PRESENT LIMITS ON CHARM PRODUCTION
   2) MODEL
   3) MISSING ENERGY DISCUSSION
   4) DETECTION OF 2ND MUON

C) TRIGGERS AND ASSOCIATED PHYSICS

D) PRESENT REQUEST AND LONG RANGE GOALS.

CHAIRMAN MAO ON THE LIMITATIONS OF SMALL APERTURE EXPERIMENTS:

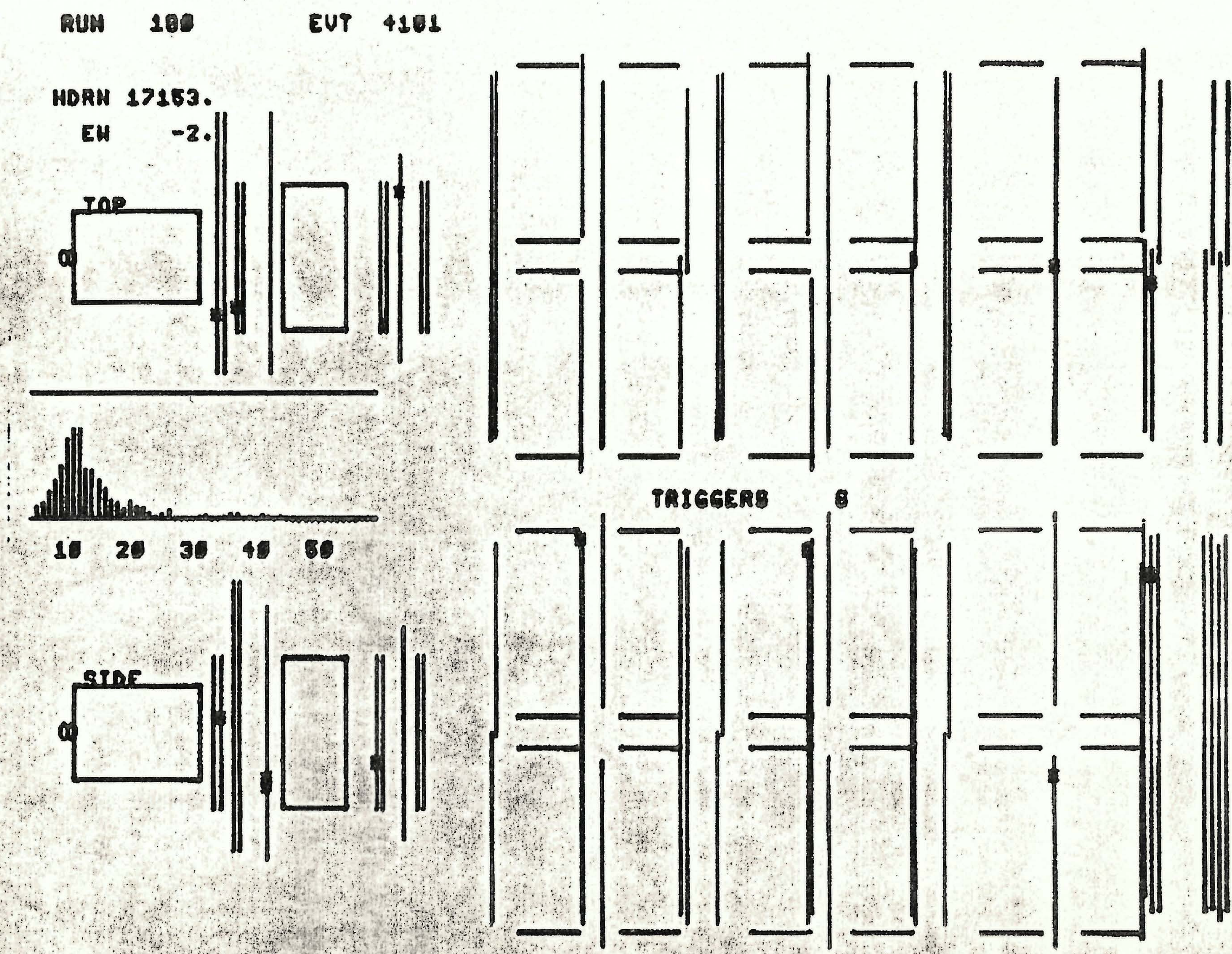
"... SHOULD SEE THE WHOLE AS WELL AS THE PARTS. A FROG IN THE WELL SAYS, "THE SKY IS NO BIGGER THAN THE MOUTH OF THE WELL." THAT IS NOT TRUE, FOR THE SKY IS NOT JUST THE SIZE OF THE MOUTH OF THE WELL."

MAO TSETUNG
SELECTED WORKS, VOL. I

AND ON THE ADVANTAGES OF TRYING DIFFERENT EXPERIMENTAL METHODS:

"IN THIS WORLD, THINGS ARE COMPLICATED AND ARE DECIDED BY MANY FACTORS. WE SHOULD LOOK AT PROBLEMS FROM DIFFERENT ASPECTS, NOT FROM JUST ONE"

MAO TSETUNG
SELECTED WORKS, VOL. IV.



RUN 100
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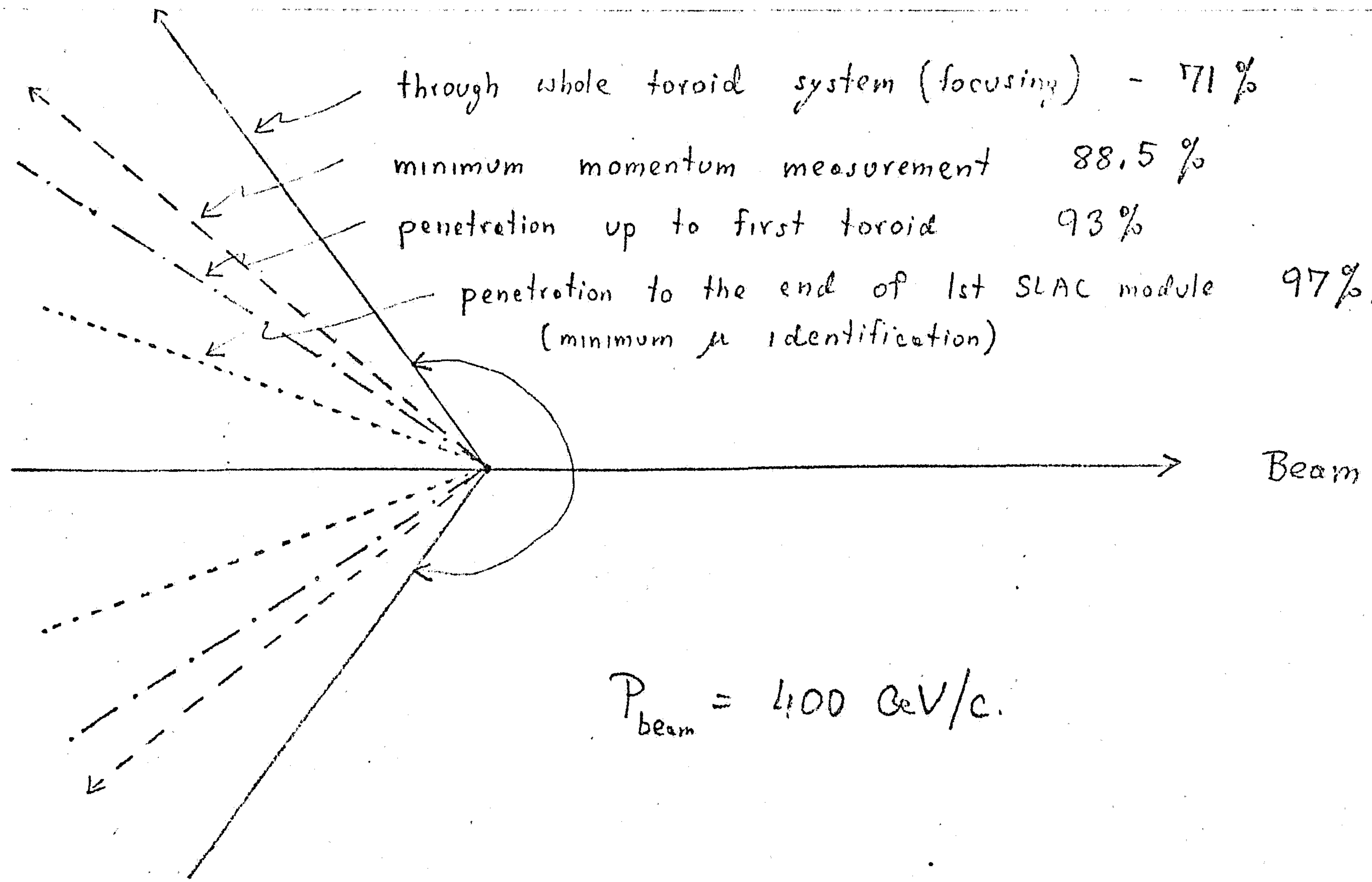
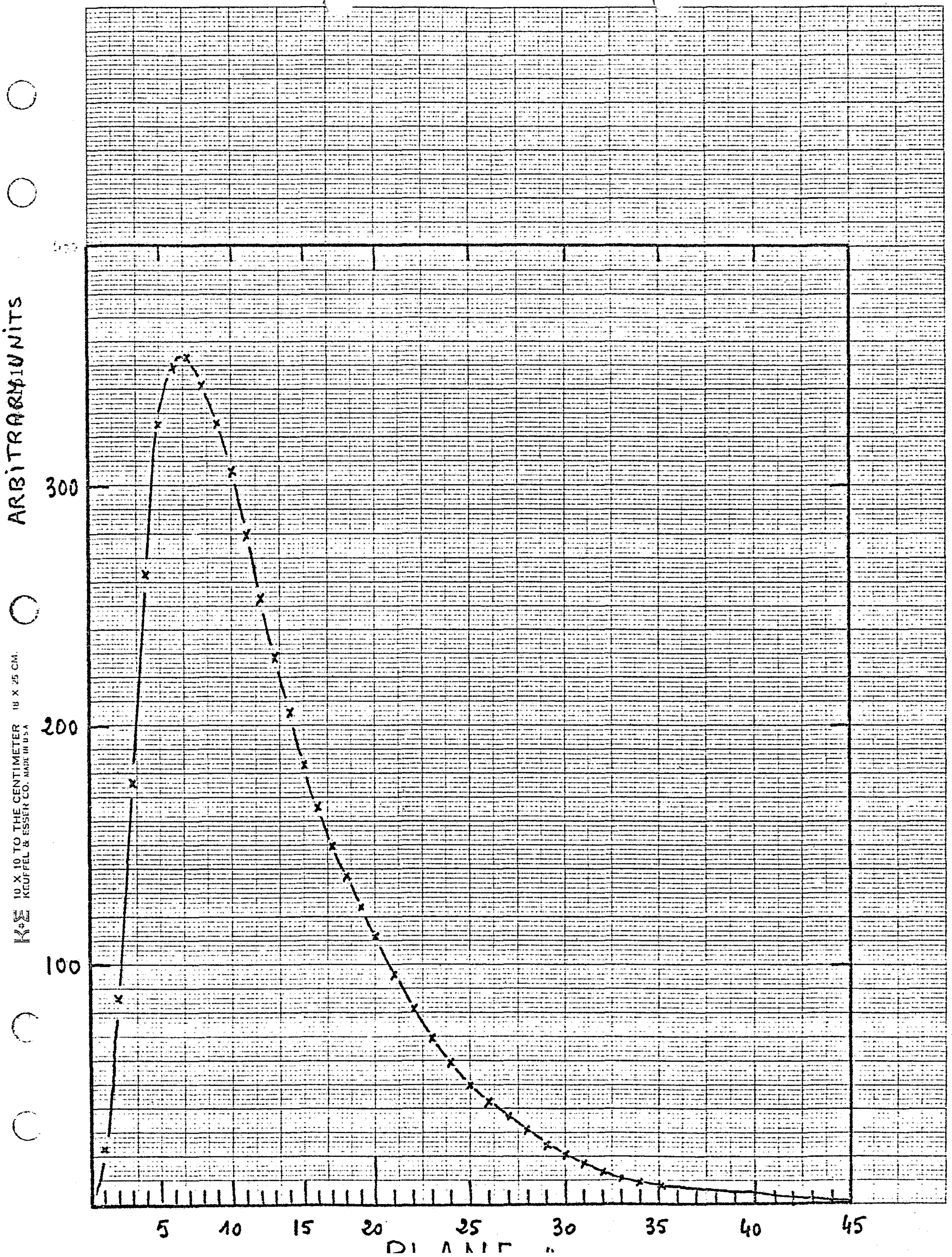
10 20 30 40 50
TRIGGERS 8



$P_{beam} = 400$ GeV/c.



ARBITRARY UNITS
300
200
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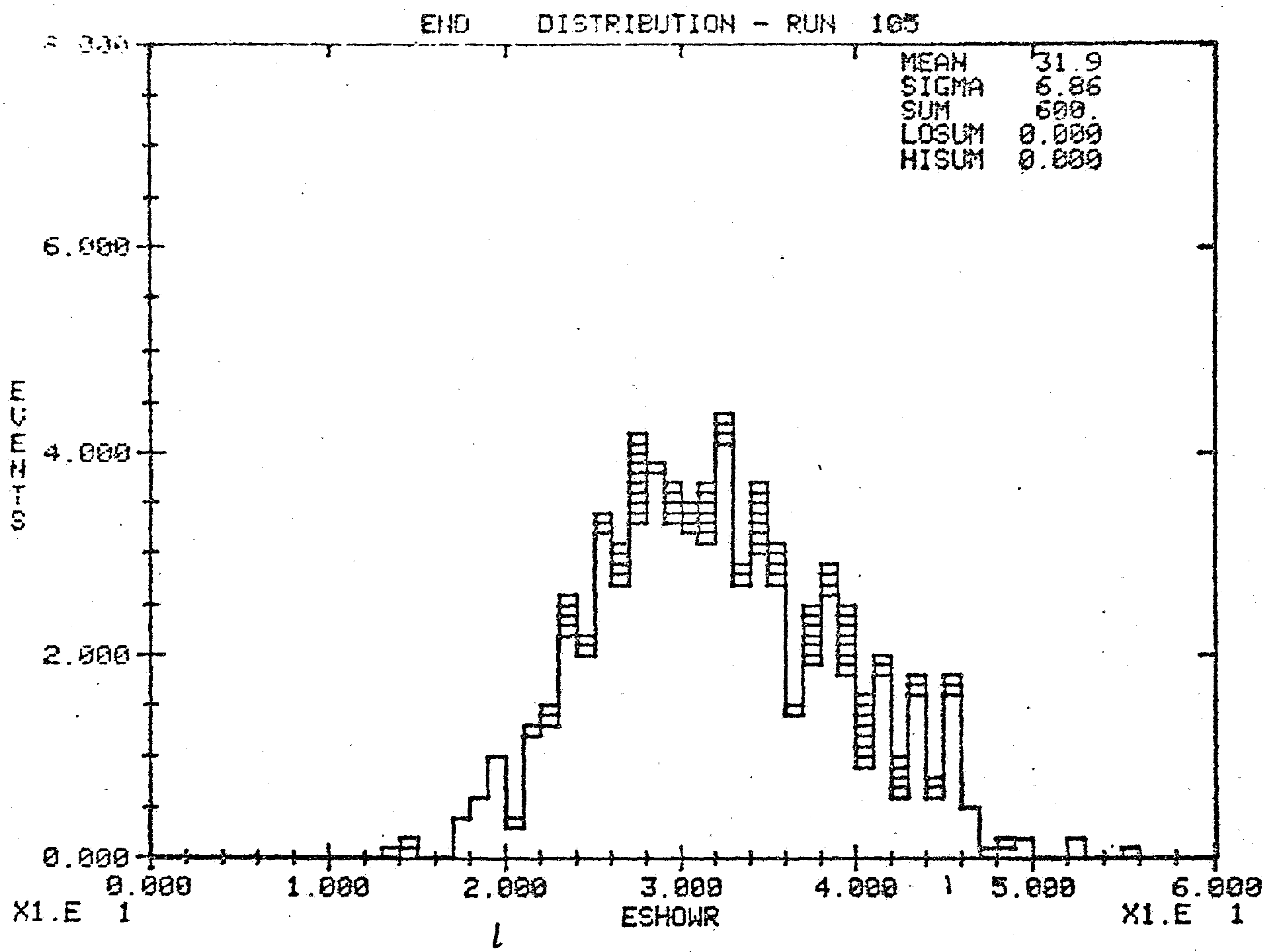
PLANE
10 X 10 TO THE CENTIMETER 18 X 25 CM.
KEUFFEL & ESSER CO. MADE IN U.S.A.



END DISTRIBUTION - RUN 105
MEAN 31.9
SIGMA 6.86
SUM 600.
LOSUM 0.000
HISUM 0.000
EVENTS
6.000
4.000
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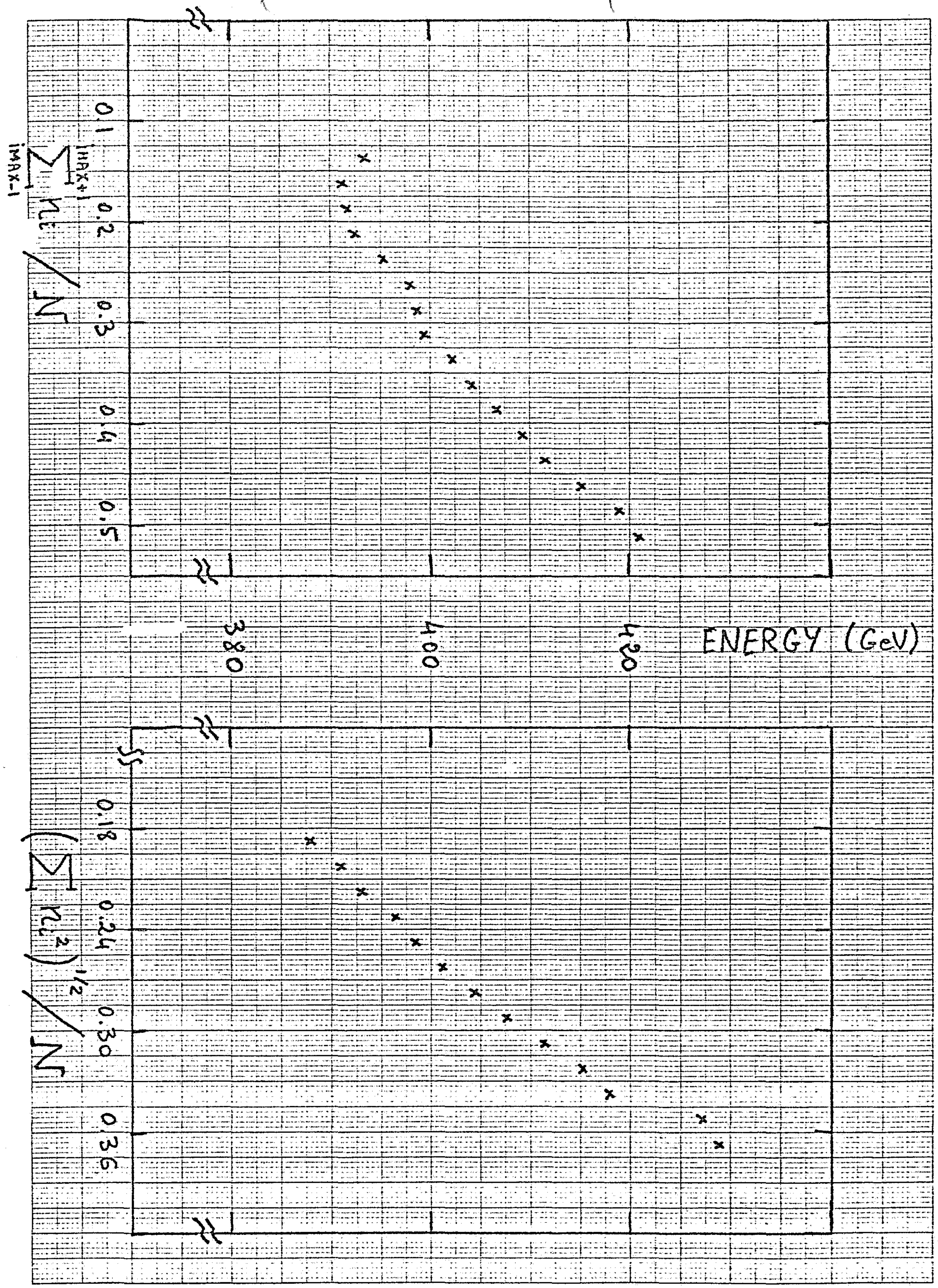
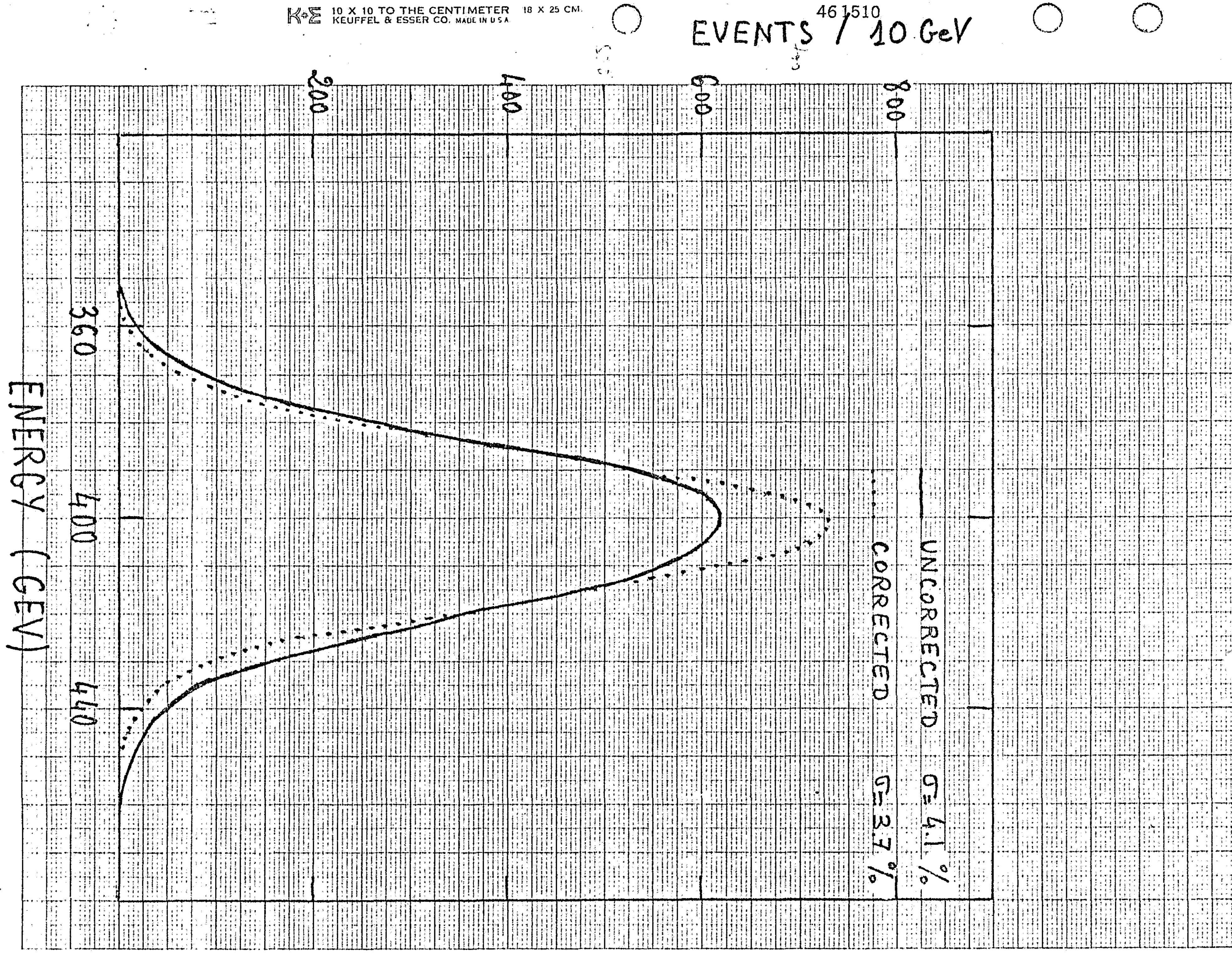


0.1
0.2
0.3
0.4
0.5
$\sum_{IMAX-1}^{IMAX+1} n_i / N$
380
400
420
ENERGY (GeV)
0.18
0.24
0.30
0.36
$\left(\sum n_i^2\right)^{1/2} / N$


EVENTS / 10 GeV
200
400
600
800
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440
ENERGY (GEV)
UNCORRECTED σ = 4.1 %
CORRECTED σ = 3.7 %

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STOGRAMME    9  ARG( 10)
I2=VRAI,START OF SHOWER 1-9  // 13=VRAI,CHIEF LT 1.5          //
.CULATED ENERGY                                                PAS DE    8

 1      3100.        0
 2      3200.        0
 3      3300.        0
 4      3400.        0
 5      3500.        6   X
 6      3600.       46   XXXXXX
 7      3700.      159   XXXXXXXXXXXXXXXXXXXX
 8      3800.      398   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 9      3900.      603   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 0      4000.      606   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 1      4100.      478   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 2      4200.      249   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
13      4300.       77   XXXXXXXXXX
 4      4400.       27   XXX
 5      4500.        5   X
 6      4600.        1
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RECTED ENERGY                                                  PAS DE    9

 1      3100.        0
 2      3200.        0
 3      3300.        0
 4      3400.        0
 5      3500.        4
 6      3600.       29   XXX
 7      3700.      133   XXXXXXXXXXXXXXX
 8      3800.      381   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 9      3900.      666   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 0      4000.      708   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 1      4100.      490   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 2      4200.      188   XXXXXXXXXXXXXXXXXXXXX
 3      4300.       45   XXXXX
 4      4400.       11   X
 5      4500.        0
 6      4600.        0
 7      4700.        0
 8      4800.        0

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    MOYENNE   4015.        DEVIATION STANDART   147.6       PRECISION   .3676E-01
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TRIGGERS
(AND OPTIMUM EXPERIMENTAL ARRANGEMENT)

1) HIGH PT ($P_\perp \gtrsim 1$ GeV/c)

   a) ALL TOROIDS SAME POLARITY

   b) ALL TOROIDS ON AXIS

2) SINGLE μ TRIGGER

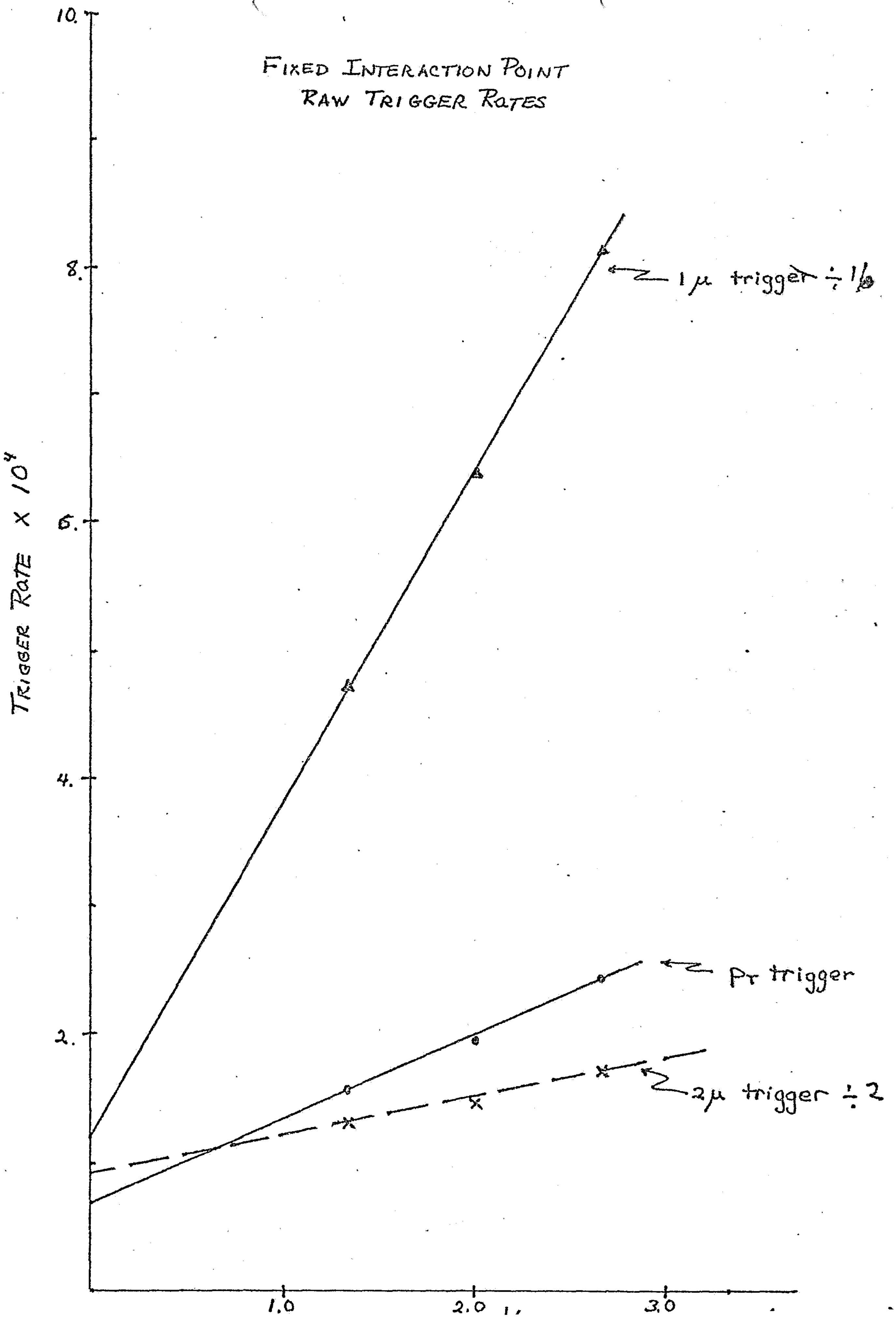
   a) TOROIDS DISPLACED OFF AXIS

3) 2 μ TRIGGER

   a) TOROIDS ALTERNATING IN POLARITY

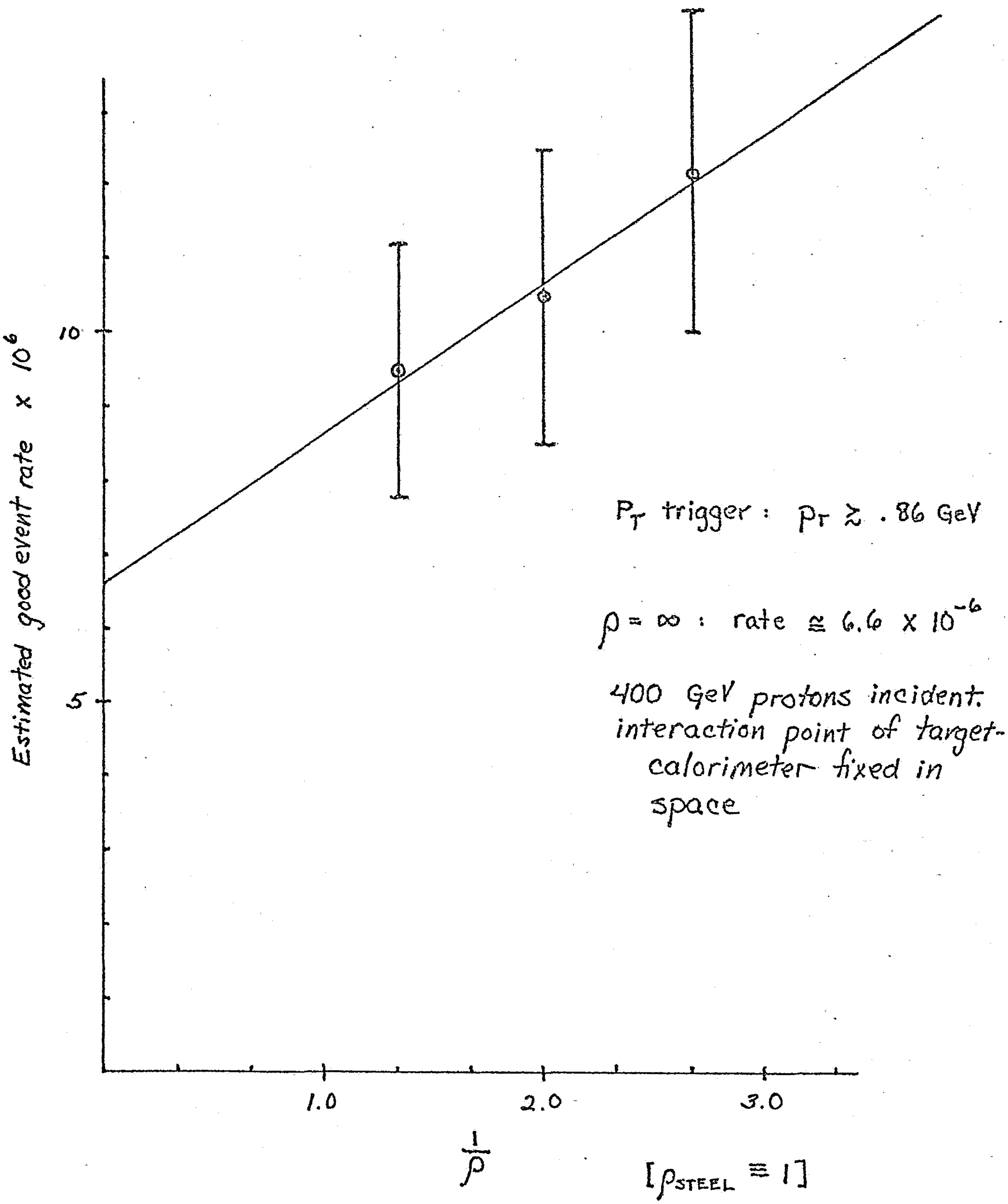
   b) ALL TOROIDS ON AXIS

4) INTERACTING BEAM
   (FOR CALIBRATION)



FIXED INTERACTION POINT
RAW TRIGGER RATES
TRIGGER RATE × 10^4
10.
8.
6.
4.
2.
1.0
2.0
3.0
1μ trigger ÷ 1/6
Pr trigger
2μ trigger ÷ 2

8 - Nov - 76



Estimated good event rate × 10^6
10
5
1.0
2.0
3.0
1/ρ
[ρ STEEL ≡ 1]
P_T trigger : $p_T \gtrsim .86$ GeV
ρ = ∞ : rate ≅ 6.6 × 10^-6
400 GeV protons incident.
interaction point of target-
calorimeter fixed in
space

SEARCH FOR CHARM IN HADRONIC INTERACTIONS

1) LOOK FOR $K\pi$ BUMP

EXPRESS RESULT AS A VALUE OF S_c

$$S_c \equiv \sigma_c B_{hh} / \sigma_\psi B_{\psi \to \mu\mu}$$

PUBLISHED VALUE $S_c \leq 400$

2) LOOK FOR SEMILEPTONIC DECAY

EXPRESS RESULT AS A VALUE OF S_μ

$$S_\mu \equiv \sigma_c B_{\mu x} / \sigma_\psi B_{\mu\mu}$$

BECAUSE $B_{\mu x} \approx 5 \times B_{K\pi}$

$$S_\mu \longleftrightarrow 5 \cdot S_c$$

$1\mu - 2\mu$ COMPARISON EXPERIMENTS CAN SET A LIMIT ON S_μ. VERY MODEL DEPENDENT.

PROBABLY $S_\mu \leq 100$ $\quad S_\mu \approx 1 \Leftrightarrow \sigma B \approx 10\,\text{nb}$

3) EMULSIONS (?)

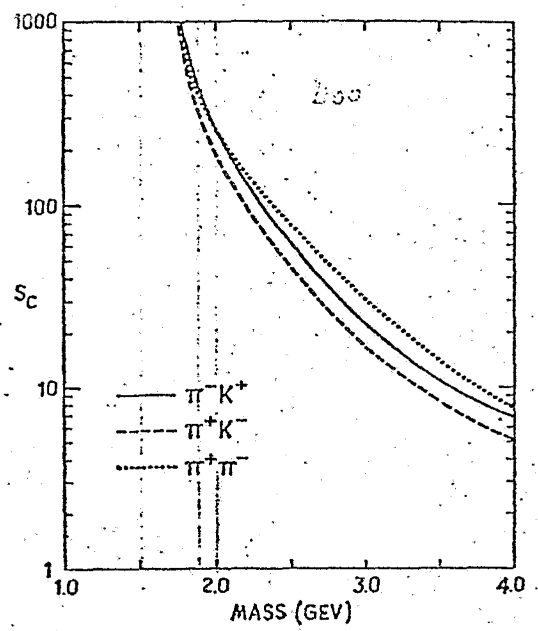


FIG. 4. Cross sections required for observing a 4-standard-deviation peak in π^-K^+, π^+K^-, and $\pi^+\pi^-$ mass spectra as a function of the hadron pair effective mass. Cross sections are expressed in units of $\sigma_{J/\psi}B_{\mu\mu}$ ($\simeq$10 nb) so that $S_C \equiv \sigma_C B_{hh}/\sigma_{J/\psi}B_{\mu\mu}$.

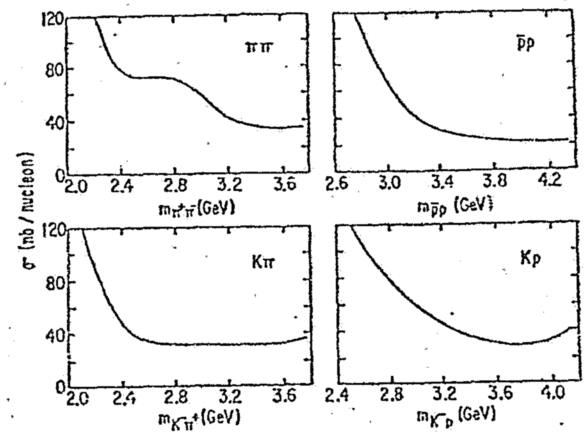
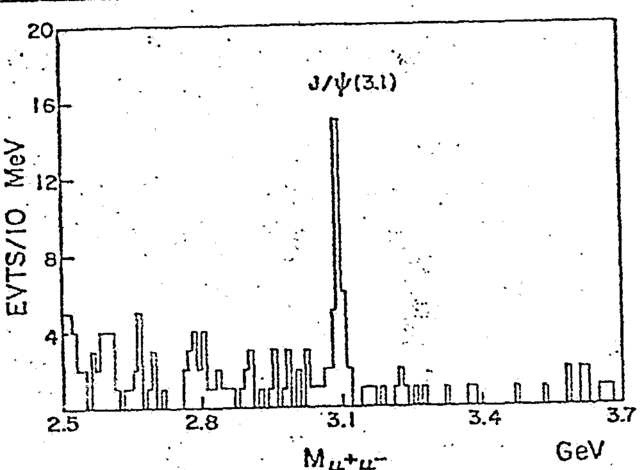


FIG. 4. "4σ" upper limits for the inclusive production of narrow resonances in the channels $\pi^-\pi^+$, $K^-\pi^+$, $\bar{p}p$, and K^-p.

[1]B. J. Bjorken and S. L. Glashow, Phys. Lett. 11, 255 (1964); S. L. Glashow, J. Iliopoulos, and L. Maiani, Phys. Rev. D 2, 1285 (1970); M. K. Gaillard, B. W. Lee, and J. L. Rosner, Rev. Mod. Phys. 47, 277 (1975).
[2]J. J. Aubert *et al.*, Phys. Rev. Lett. 33, 1404 (1974).



cm². If charmed particles with masses near 2 GeV/c^2 are produced with cross sections similar to that of J/ψ, they will not be observable in a hadron experiment of this kind unless a more

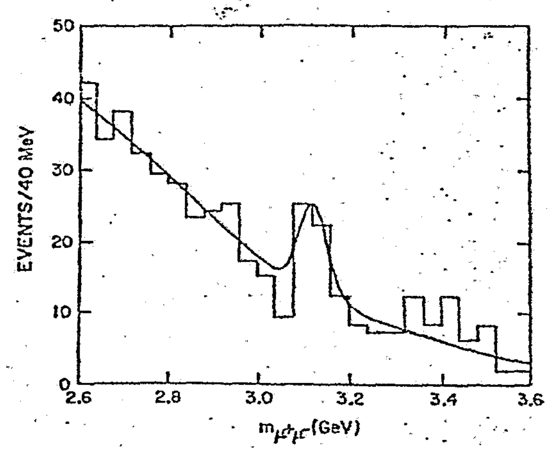


FIG. 2. $\mu^+\mu^-$ mass distribution near the ψ. The smooth curve is a polynomial fit to the data plus a Gaussian for the ψ.

provides a measure of sensitivity which is relatively free of systematic errors.

(Gaillard + Bourquin model

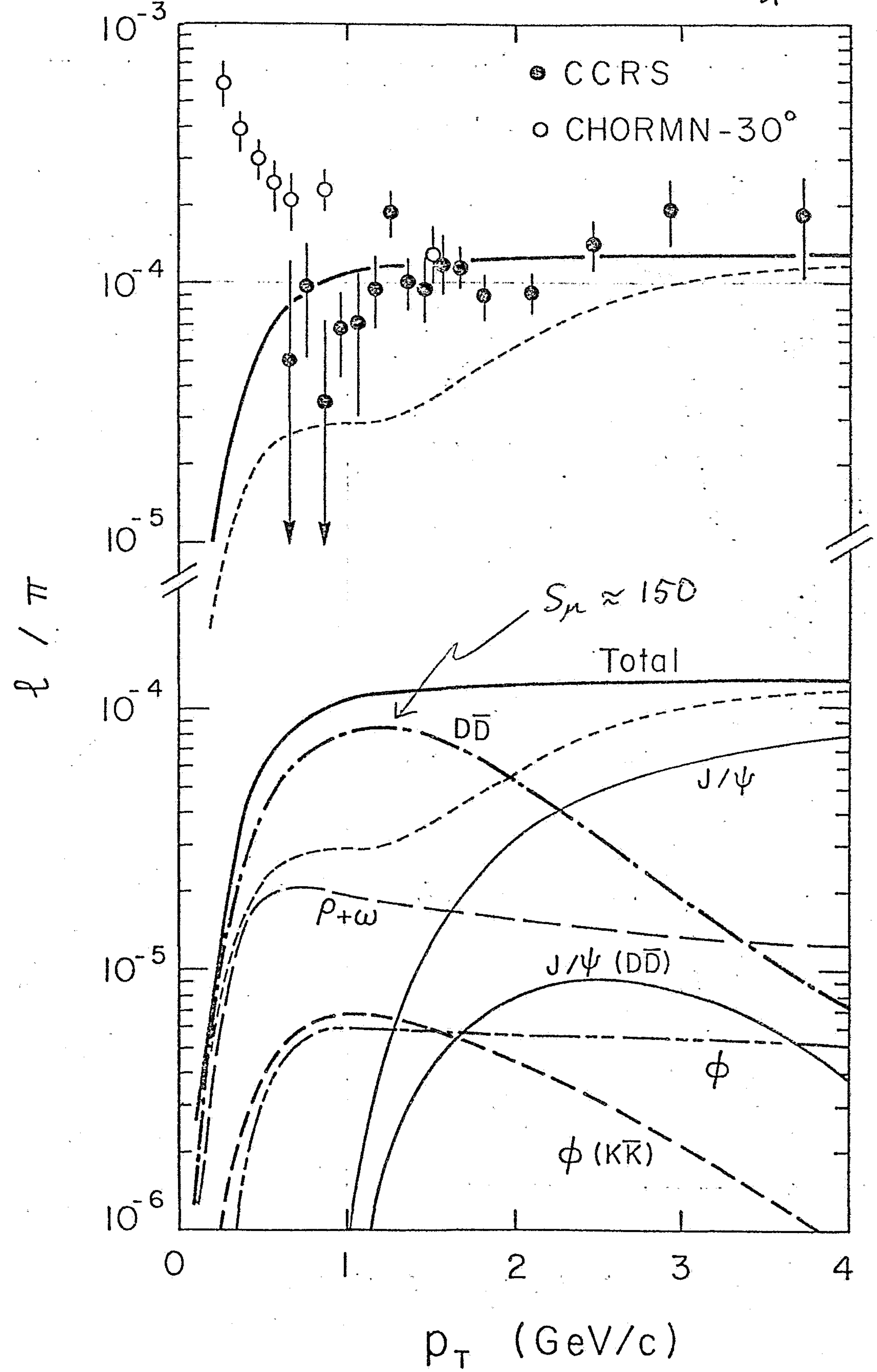
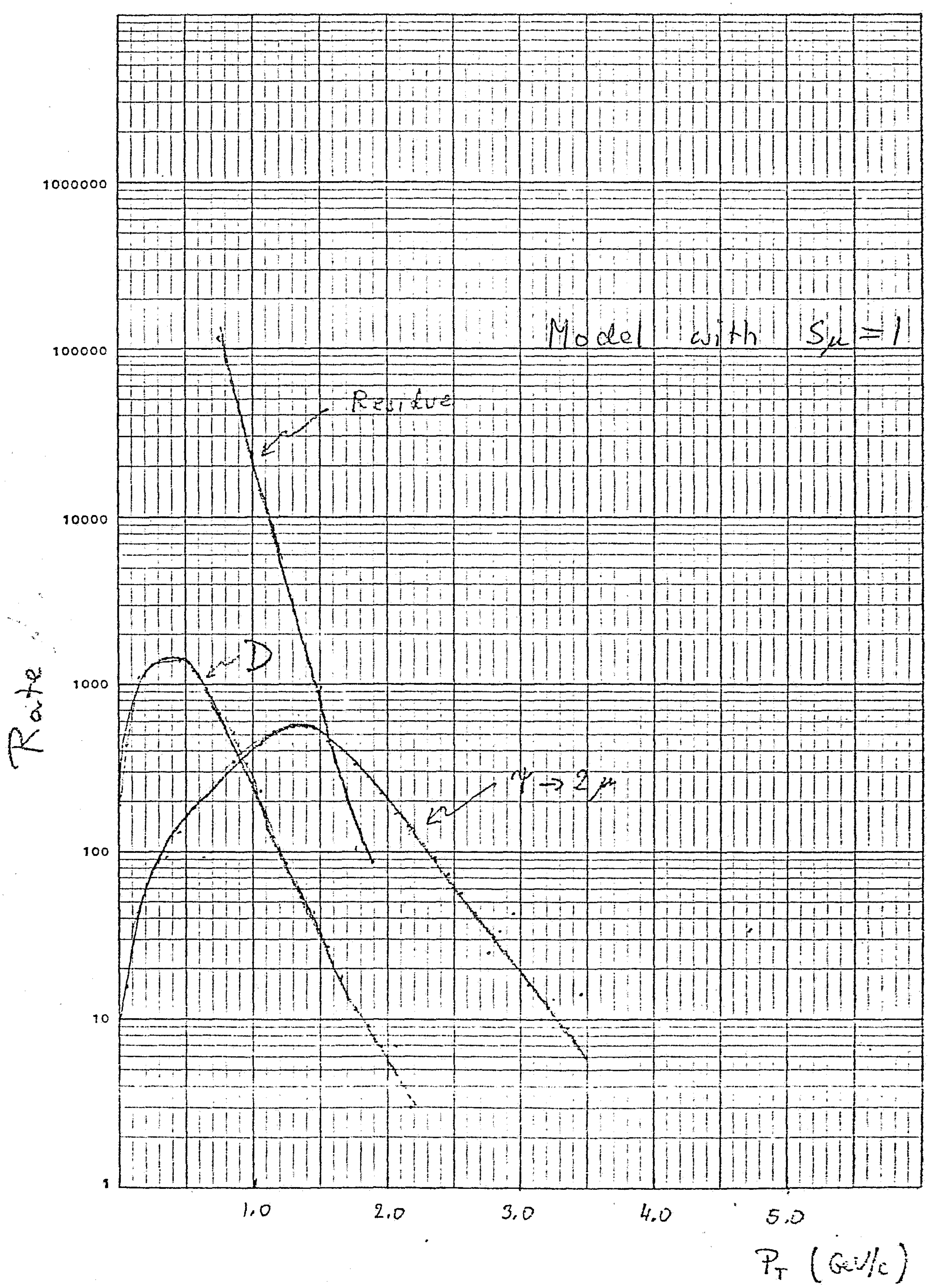
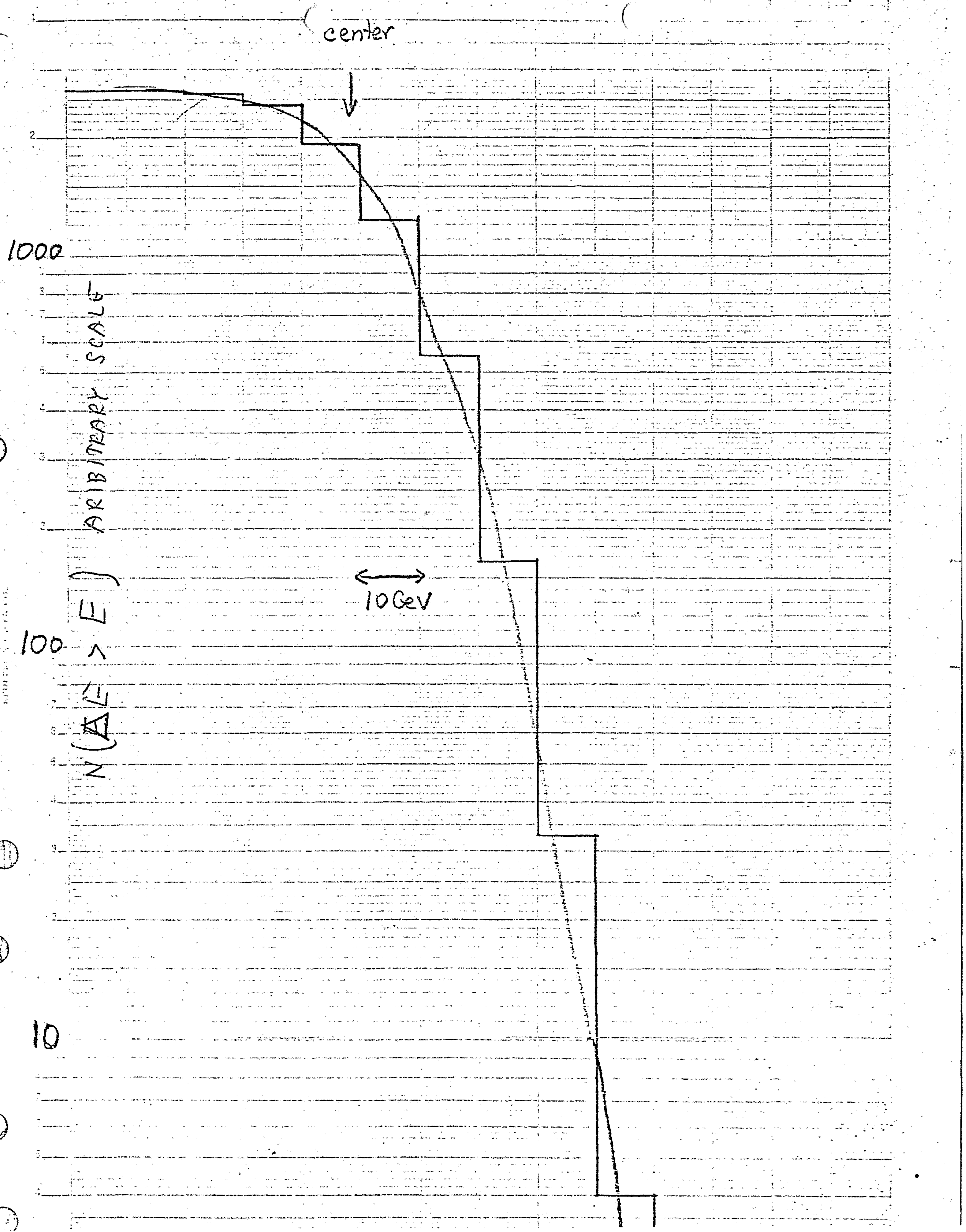


Fig. 17

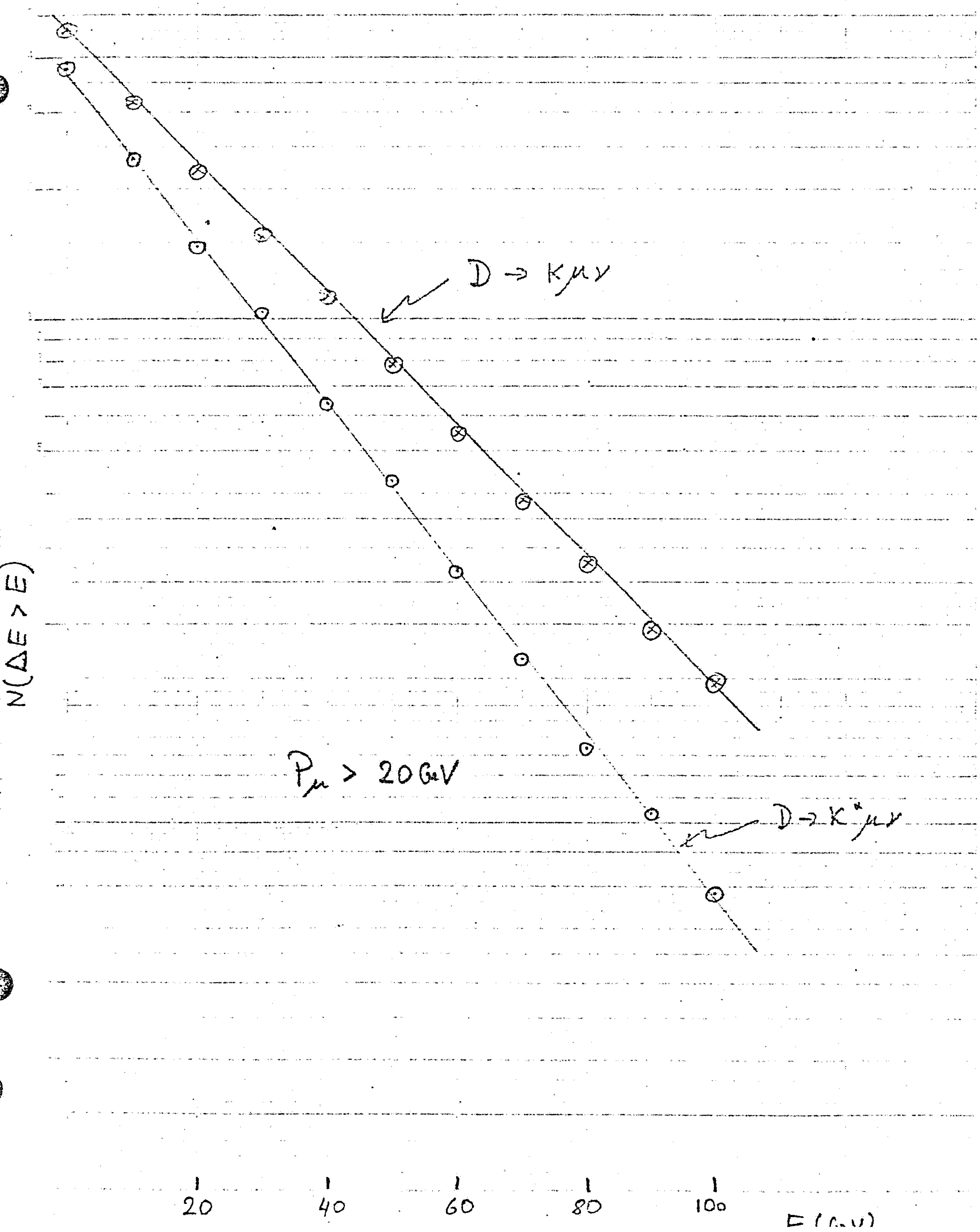
MODEL DATE



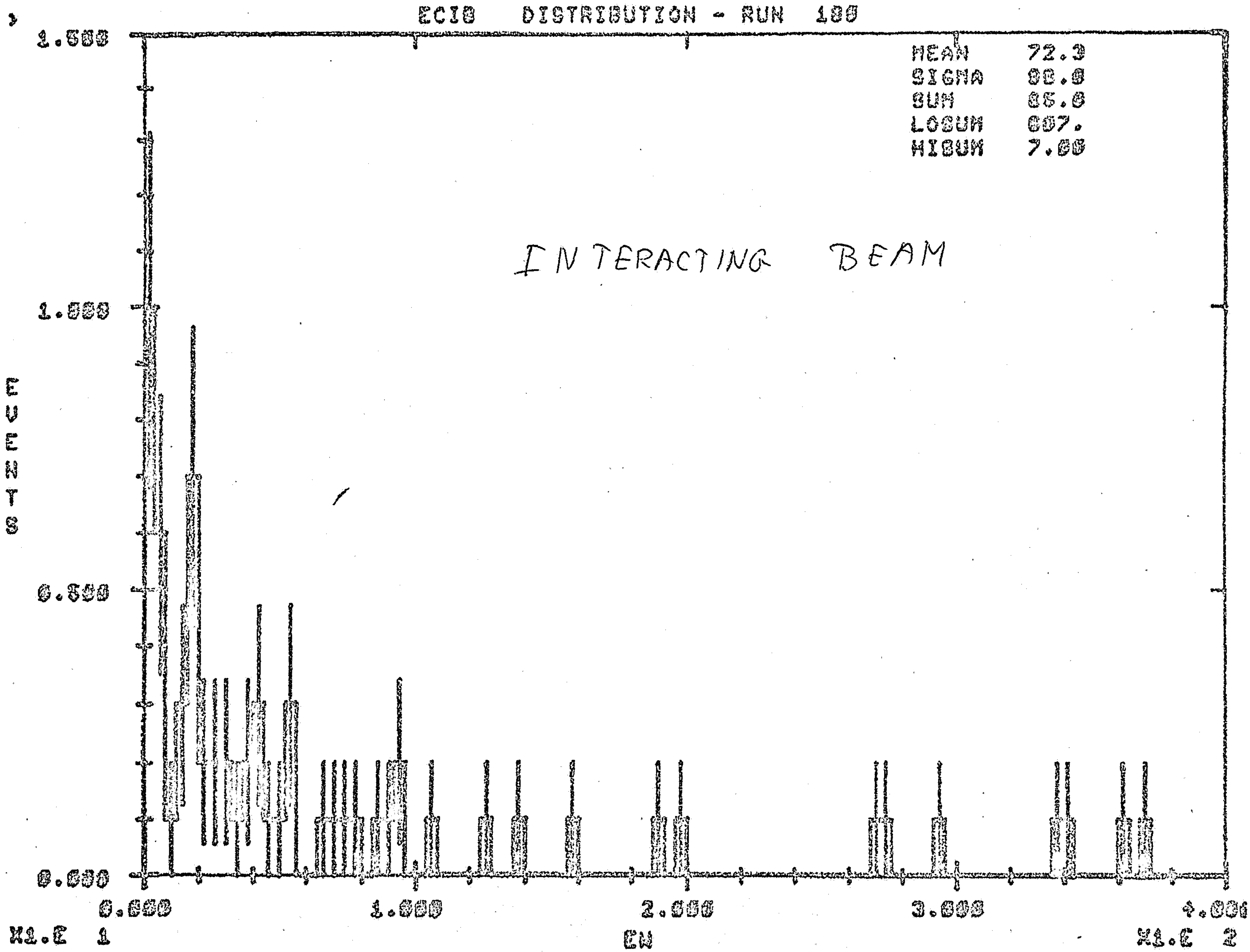
Model with $S_\mu = 1$
Residue
D
$\psi \to 2\mu$
Rate
1000000
100000
10000
1000
100
10
1
1.0
2.0
3.0
4.0
5.0
P_T (GeV/c)

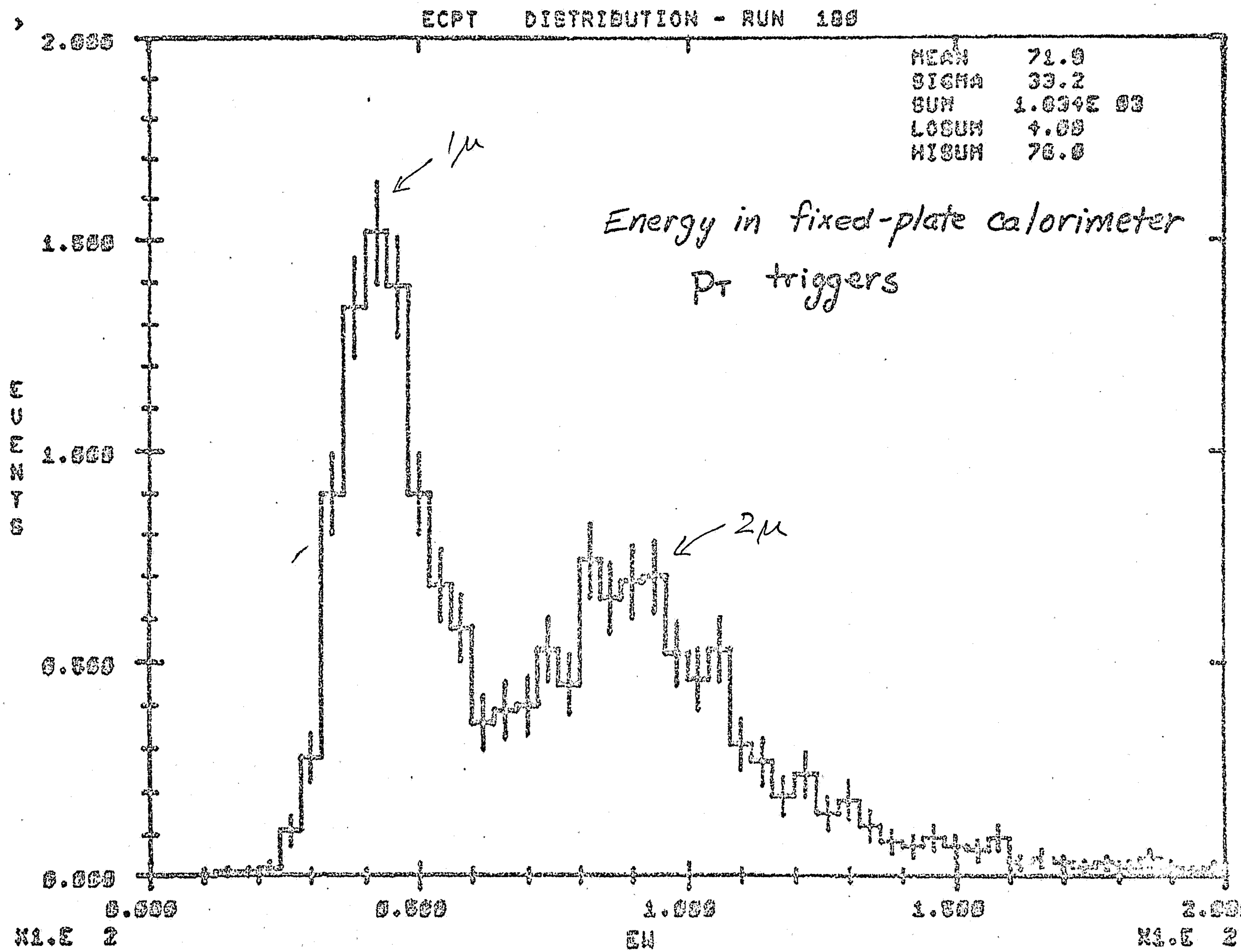


center
1000
100
10
N(ΔE > E) ARIBITRARY SCALE
10GeV

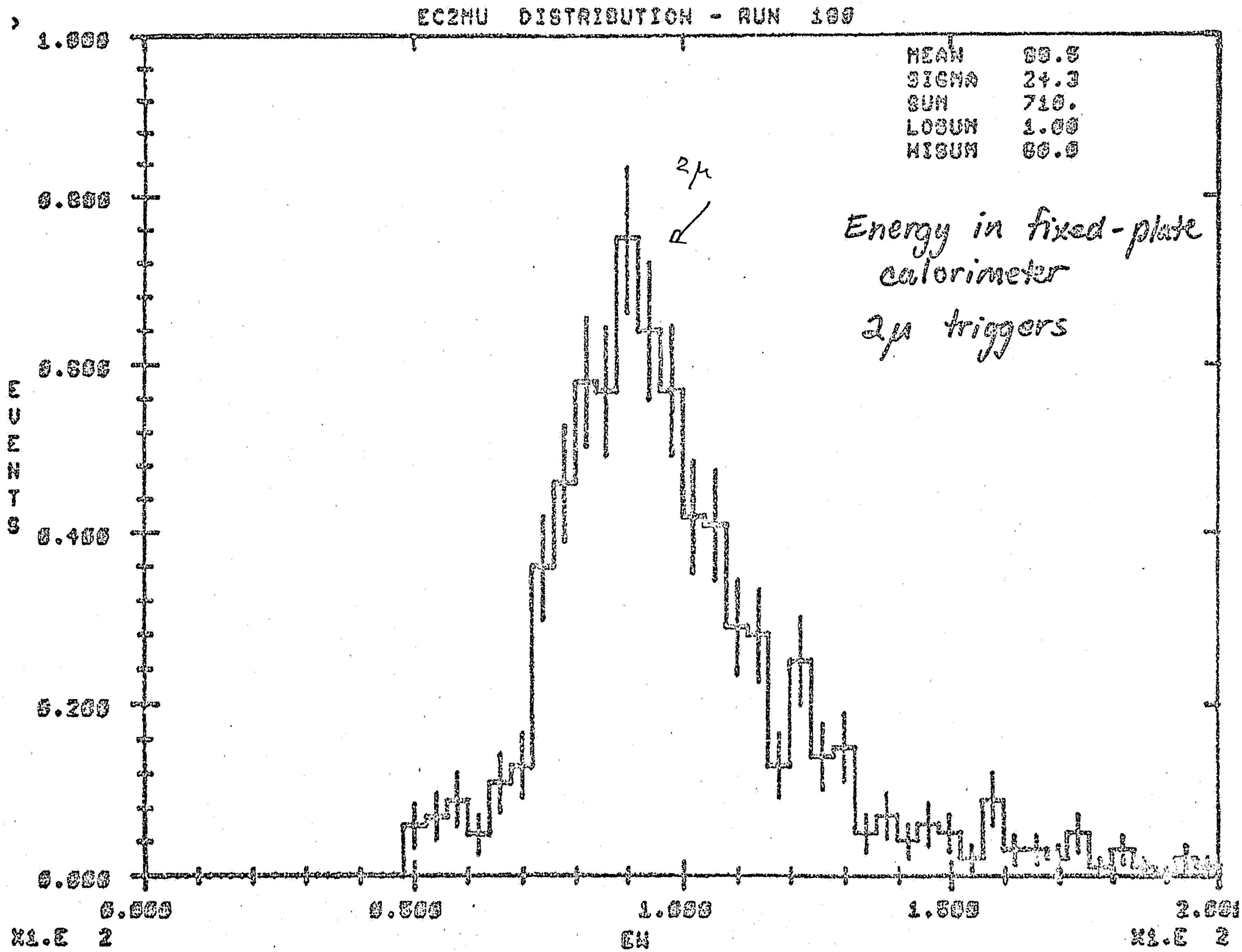


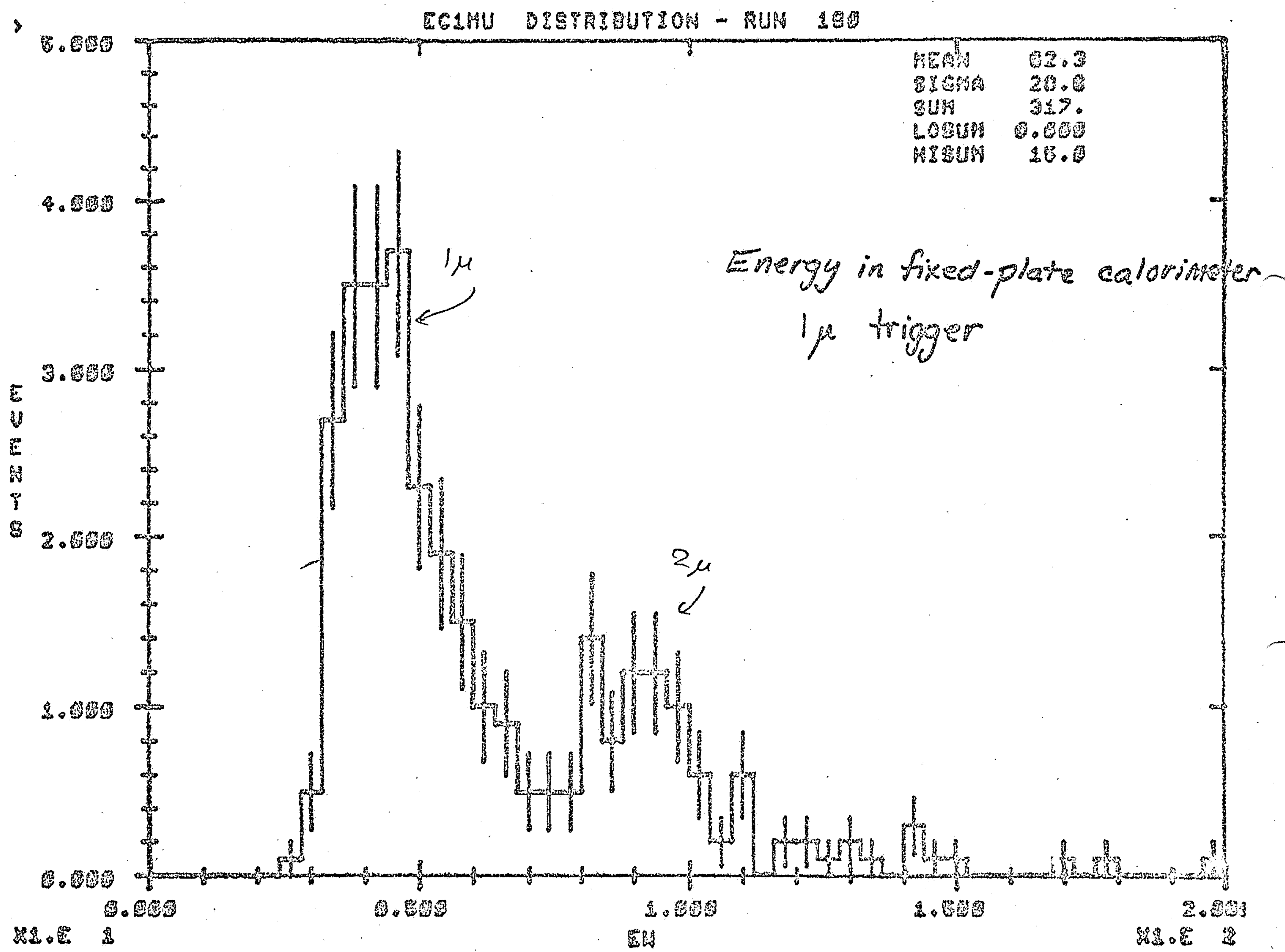
D → Kμν
D → K*μν
Pμ > 20 GeV
N(ΔE > E)
20
40
60
80
100


ECI0 DISTRIBUTION - RUN 100
MEAN 72.3
SIGMA 80.0
SUM 65.0
LOSUM 607.
HISUM 7.00
INTERACTING BEAM
1.500
1.000
0.500
0.000
EVENTS
0.000
1.000
2.000
3.000
4.000
X1.E 1
EN
X1.E 2

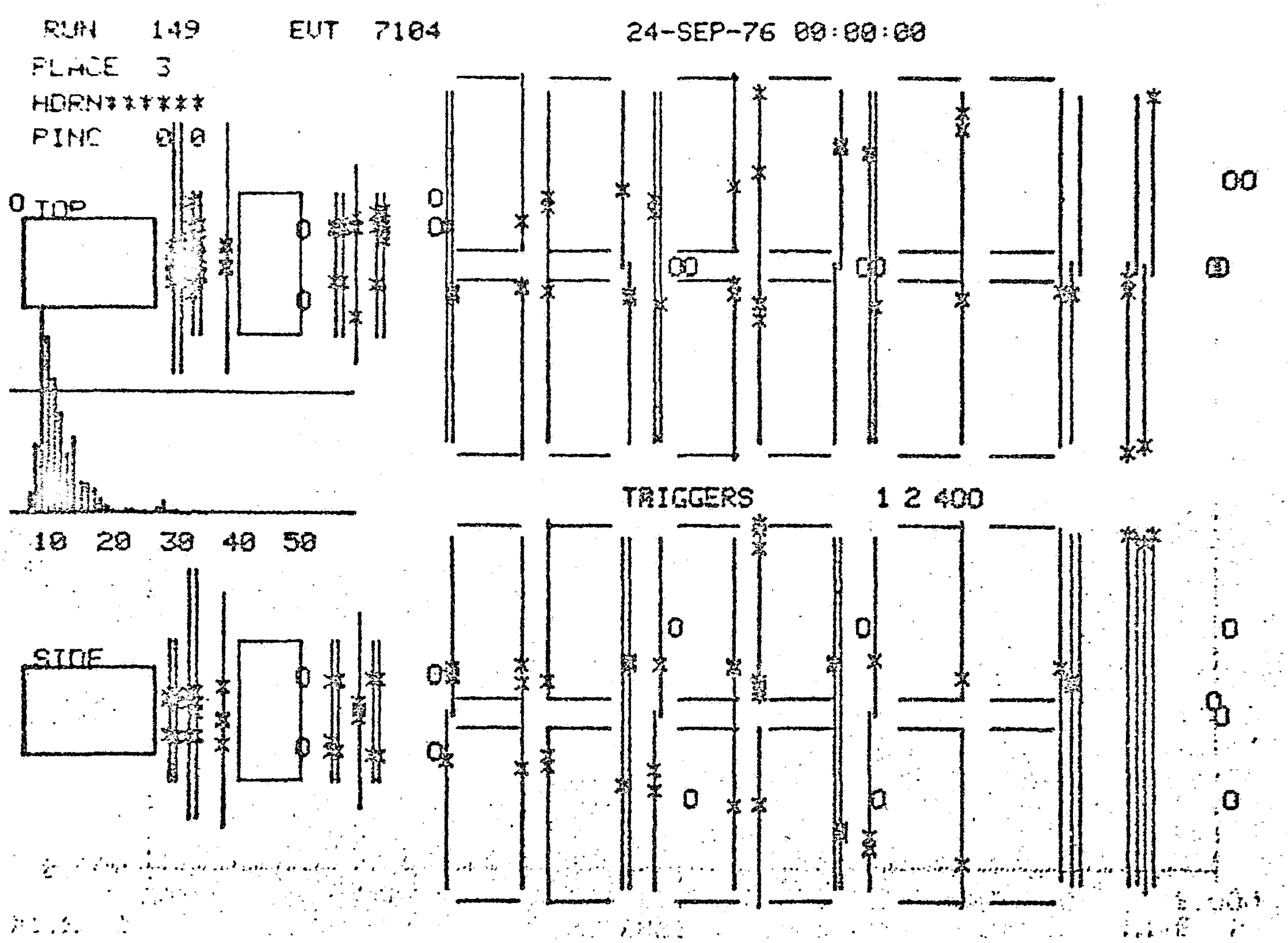


ECPT DISTRIBUTION - RUN 180
MEAN 71.9
SIGMA 33.2
SUM 1.034E 03
LOSUM 4.00
HISUM 76.0
1μ
2μ
Energy in fixed-plate calorimeter
P_T triggers
EVENTS
2.000
1.500
1.000
0.500
0.000
0.000
0.500
1.000
1.500
2.000
X1.E 2
EW
X1.E 2

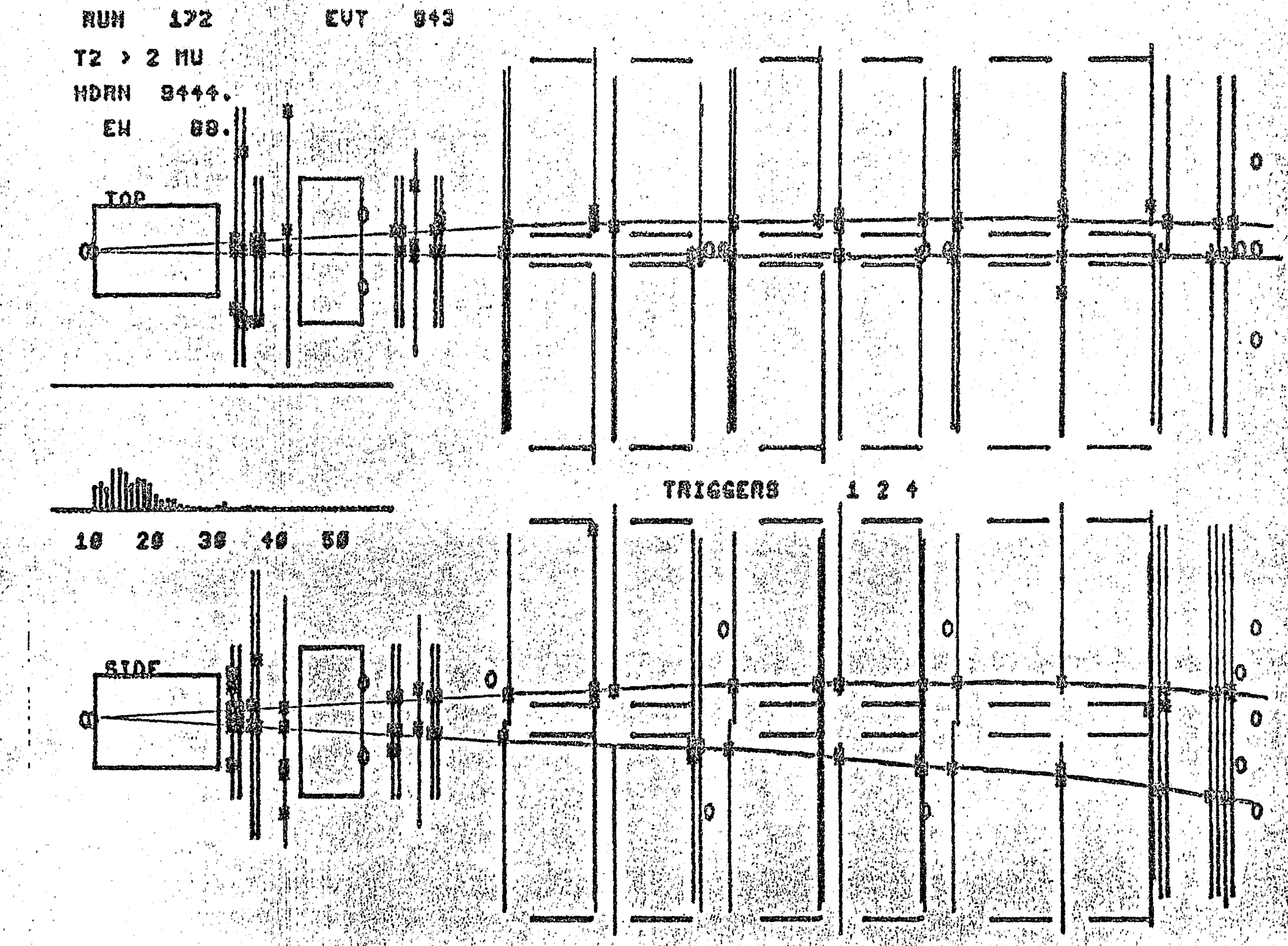

EC2MU DISTRIBUTION - RUN 100
MEAN 88.5
SIGMA 24.3
SUM 710.
LOSUM 1.00
HISUM 66.0
2μ
Energy in fixed-plate calorimeter
2μ triggers
EVENTS
1.000
0.800
0.600
0.400
0.200
0.000
0.000
0.500
1.000
1.500
2.000
X1.E 2
EN
X1.E 2

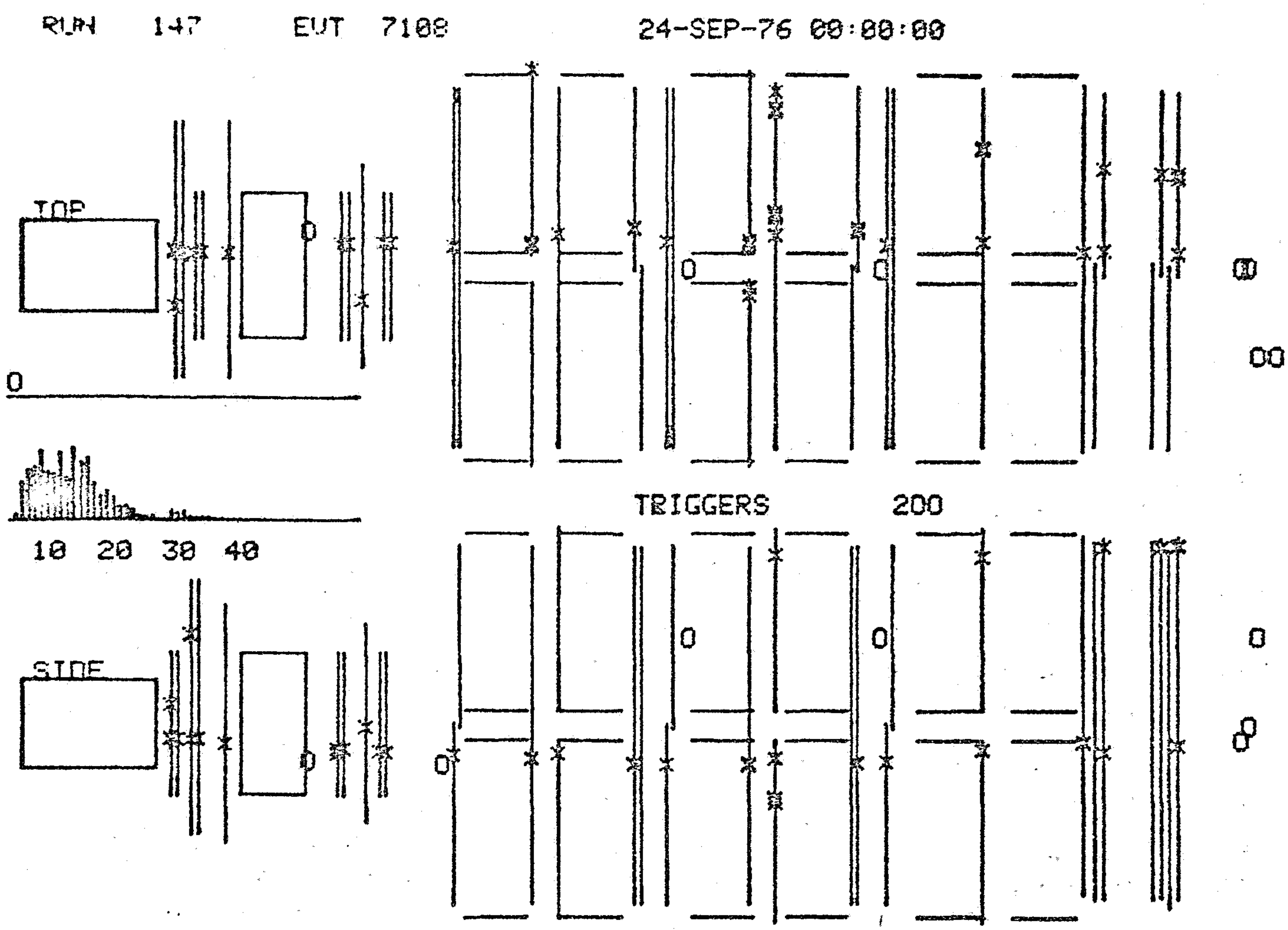


EC1MU DISTRIBUTION - RUN 190
MEAN 62.3
SIGMA 28.8
SUM 317.
LOSUM 0.000
HISUM 16.0
EVENTS
EN
X1.E 1
X1.E 2
1μ
2μ
Energy in fixed-plate calorimeter
1μ trigger



RUN 149 EVT 7104 24-SEP-76 00:00:00
PLACE 3
HORN******
PINC 0 0
TOP
10 20 30 40 50
TRIGGERS 1 2 400
SIDE


RUN 172
EVT 943
T2 > 2 MU
HDRN 9444.
EW 88.
TOP
10 20 30 40 50
SIDE
TRIGGERS 1 2 4


RUN 147
EVT 7108
24-SEP-76 00:00:00
TOP
SIDE
0
10 20 30 40
TRIGGERS 200

TRIGGER - PHYSICS CORRELATION

1) HIGH P_T $P_\perp \gtrsim 1.0$ GeV/c

   a) Υ PRODUCTION DYNAMICS

   b) TRI-MUON PHYSICS e.g. $\Upsilon D\bar{D}$, $\Upsilon\Upsilon$, etc.

   c) SEARCH FOR "NEW" PARTICLES

2) SINGLE MUON TRIGGER

   a) CHARM PRODUCTION

   b) INCLUSIVE MUON PRODUCTION WITH LARGE Ω AND LIVE TARGET.

3) DI-MUON TRIGGER

   a) CHARM PRODUCTION ($D\bar{D}$ STRONGLY CORRELATED

   b) DIMUON PRODUCTION DYNAMICS

PRESENT REQUEST
AND LONG RANGE GOALS

1) 400 HRS OF 400 GeV PROTONS FOR HIGH P_T TRIGGER.
2) 400 HRS OF 400 GeV PROTONS FOR SINGLE MUON TRIGGER

(SOME 2μ TRIGGERS WILL BE TAKEN CONCURRENTL

3) REASONABLE LENGTH RUNNING PERIODS
NO MAJOR DISRUPTIONS

IN THE FUTURE .... (NEW #)

1) HIGH ENERGY π^-
REQUEST ENCOURAGEMENT NOW FOR HIGHER INTENSITY MODIFICATION
2) μ POLARIZATION (???)
3) MORE DETAILS ON HADRONIC SHOWER (PWC'S IN CALORIMETER)