DOE/ER/40033--29

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TECHNICAL PROGRESS REPORT

Experimental Studies of Elementary-Particle Interactions at High Energies

October 1, 1982

Technical Report No.
DOE/ER/40033-29

The Rockefeller University
New York, N.Y. 10021

DISCLAIMER

I. RESEARCH PROGRAM AT CERN

A. I.S.R. Experiments R-108 and R-110 -

Analysis of the large body of data on p-p collisions accumulated in experiment R-108 continued during 1982. Simultaneously, the revised apparatus of R-110 has been operated to collect data on both p-p and $\bar{p}$-p collisions with the new configuration of detectors. Some preliminary results from analysis of R-110 data have been obtained, reported at the International Conference in Paris, and prepared for formal publication.

Because of the large data base accumulated during R-110, we have been able to make a detailed study of the production of $\pi^0 - \pi^0$ paris with very large effective mass. The cross section as a function of mass m is shown in Figure 1 for $8 < m < 18$ GeV/c^2 at $\sqrt{s}$ values of 62.4 and 44.8 GeV. The data displayed is restricted to events with low transverse momentum ($P_T < 1.0$ GeV/c).

The current best candidate for a theory of strong interactions, QCD, predicts that such events of large effective mass should originate from the collisions of two elementary constituents of nucleons (quarks and gluons). Moreover, QCD predicts the angular distributions to be expected for the outgoing scattered constituents. We have been able to show from the data and from Monte Carlo studies that the mean direction of the $\pi^0 - \pi^0$ pair axis represents quite accurately the outgoing constituent axis when m is large and P_T is small. Thus the angular distribution of the mean $\pi^0 - \pi^0$ axis is an excellent measurement of the angular distribution of the elementary constituent scattering. Our data thus gives for the first time a determination of the energy and angular distribution of hard constituent scattering. The measured distribution is then compared to the

QCD prediction. The result, shown in Figure 2, agrees well with that expected for quark-quark collisions. The results, presented at the Paris Conference[1], were of great experimental and theoretical interest; they have been submitted for publication.

During 1981, antiprotons were injected into the ISR and $\bar{p} - p$ collisions were obtained for the first time at energy of $\sqrt{s} = 52.7$ GeV. At the beginning, luminosities were very small. Fortunately the luminosity has slowly improved during the past year. Although the luminosity is still well below the design value, it has been sufficient to obtain a first look at $\bar{p} - p$ physics and to make some comparisons to $p - p$ collisions at the same values of $\sqrt{s}$. Because of the low luminosity these comparisons for π^0 production have been limited to $P_T < 5$ GeV/c and for total transverse neutral energy to $\Sigma E_T < 10$ GeV. These results, the first on the subject from the ISR, were presented at the Paris Conference and have been submitted to Physics Letters[2]. The results are displayed in Figure 3. These data show that $\bar{p} - p$ and $p - p$ are very similar in this range of the variables. This conclusion is in accord with expectations from the QCD model. Higher luminosity will be needed to explore at higher transverse momentum and energy where differences are predicted, especially for those processes in which quark-antiquark annihilation is expected to play a crucial role.

For $p - p$ collisions, where high luminosity is available, data on total transverse energy (neutral) out to $\Sigma E_T \cong 25$ GeV has been obtained at two values of $\sqrt{s}$. These data exhibit a cross section which falls exponentially over six orders of magnitude, $d\sigma/d\Sigma E_T^0 \cong \exp(-\alpha \Sigma E_T^0)$ with $\alpha = 0.86$ GeV^{-1}. The results[3] are shown in Figure 4.

Results on high P_T production of π^0 mesons from $\alpha\alpha$ and αp collisions which were reported in a preliminary way last year have now been accepted for publication in Physics Letters B[4].

B. S.P.S. Collider Experiment UA-6 -

Apparatus for this new experiment which will study $\bar{p}$-p collisions with a hydrogen jet target has been under design and construction during 1982. The concept and physics of this experiment were described in detail in our Technical Progress Report of last year. Installation of the apparatus is scheduled to begin in January 1983.

Rockefeller University has taken primary responsibility for the design and construction of three items of equipment needed for this work. These items are the following:

1) The solid state counters and special electronics required to study low $|t|$ elastic and inelastic diffractive $\bar{p}p$ and p-p scattering and to provide an accurate ($\sim$1%) monitor for other absolute cross section measurements.

2) Special high speed electronics to provide the on-line trigger for the two-arm spectrometer. The electronics uses $\sim$ 150 channels of fast sample and hold circuits and analogue to digital converters. These data on the energy deposited in an electromagnetic calorimeter are then processed by fast adders and correlation circuits to select desired events which are recorded on magnetic tape for detailed analysis.

3) Two transition radiation counters each of $\sim$ 90 × 130 cm in cross section. These counters which will use lithium foil radiators and xenon proportional wire chambers are needed to identify electrons in a large background of π-mesons. The counters will be built in the

Rockefeller laboratory and taken to CERN where the lithium radiator will be fabricated and installed using special CERN facilities.

All of these projects are now underway in various stages of design and construction. It appears that these components can be ready for installation as required by the CERN SPSC schedule.

REFERENCES

1. "Determination of the Angular and Energy Dependence of Hard Constituent Scattering from π^0 Pair Events at the CERN ISR." DOE Report No. DOE/ER/40033-32 (submitted to the 21st International Conference on High Energy Physics, PARIS), and being submitted to Nuclear Physics B.

2. "A Comparison of the Production of π^0-Mesons in $p\bar{p}$ and pp Interactions." Rockefeller University Report No. RU 81/A-25 (submitted to Phys. Lett. B).

3. "Neutral Transverse Energy Spectra at $\sqrt{s}$ = 52 and 63 GeV." DOE Report No. DOE/ER/40033-26 (submitted to the 21st International Conference on High Energy Physics, PARIS).

4. "High p_T π^0 Production from $\alpha\alpha$ and αp Collisions at the CERN ISR." Rockefeller University Report No. RU 81/A-11 (submitted to Phys. Lett. B).

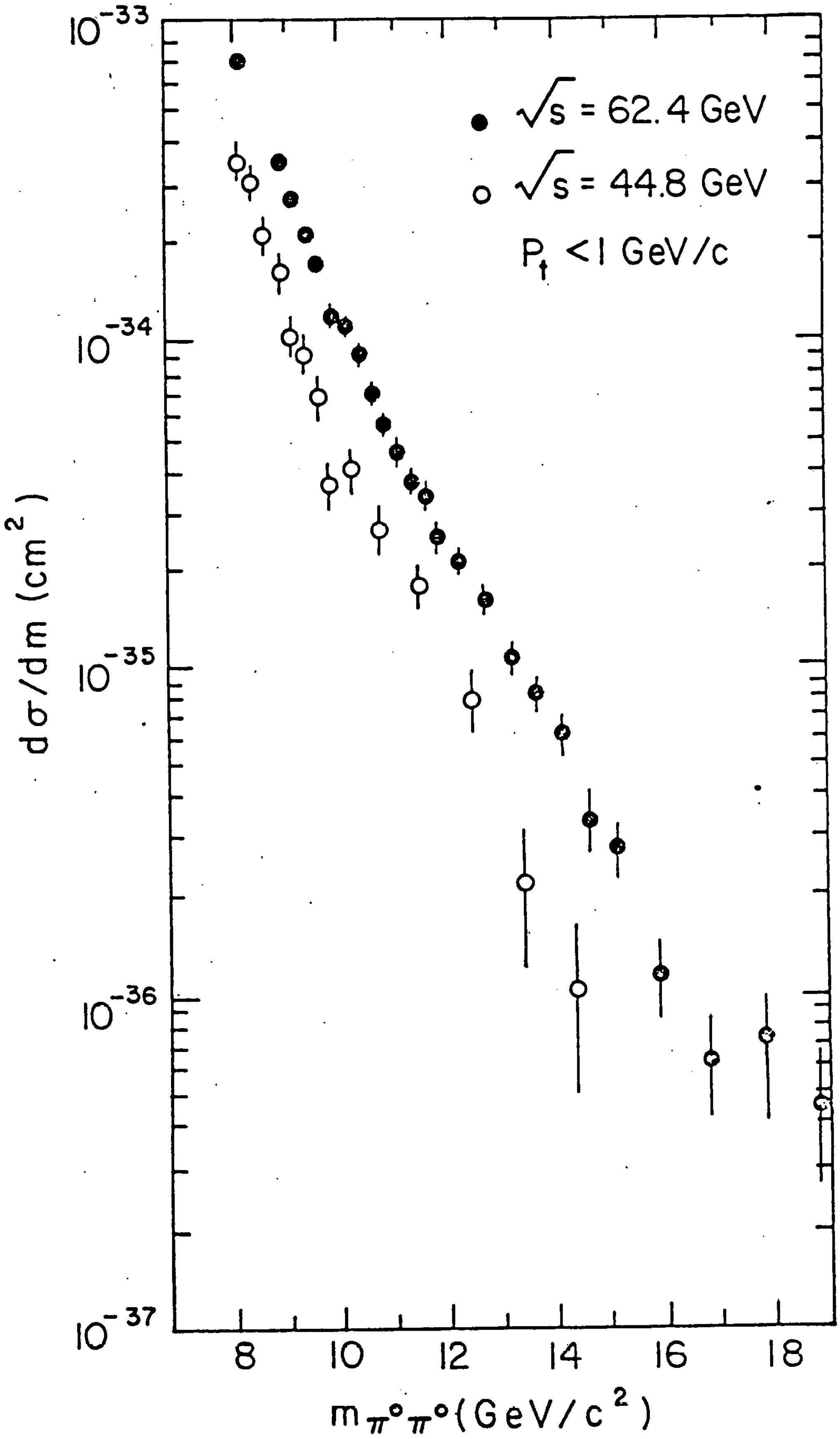

FIG. 1 - dσ/dm versus m for events with $P_T < 1.0$ GeV/c

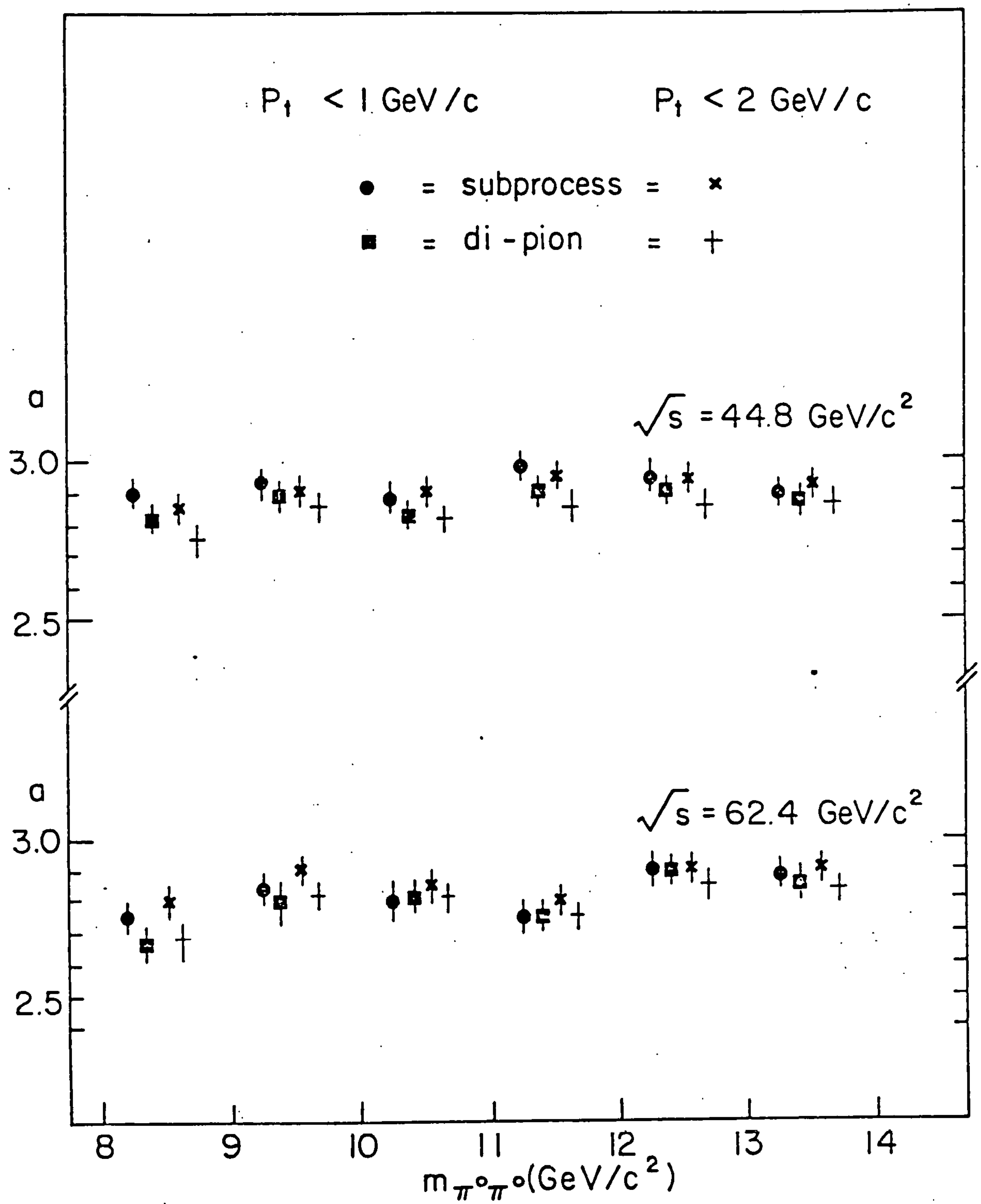

FIG. 2 - A comparison of the parameter a extracted from fits to the hard scattering process to the observed distribution of the axis of the dipion system.

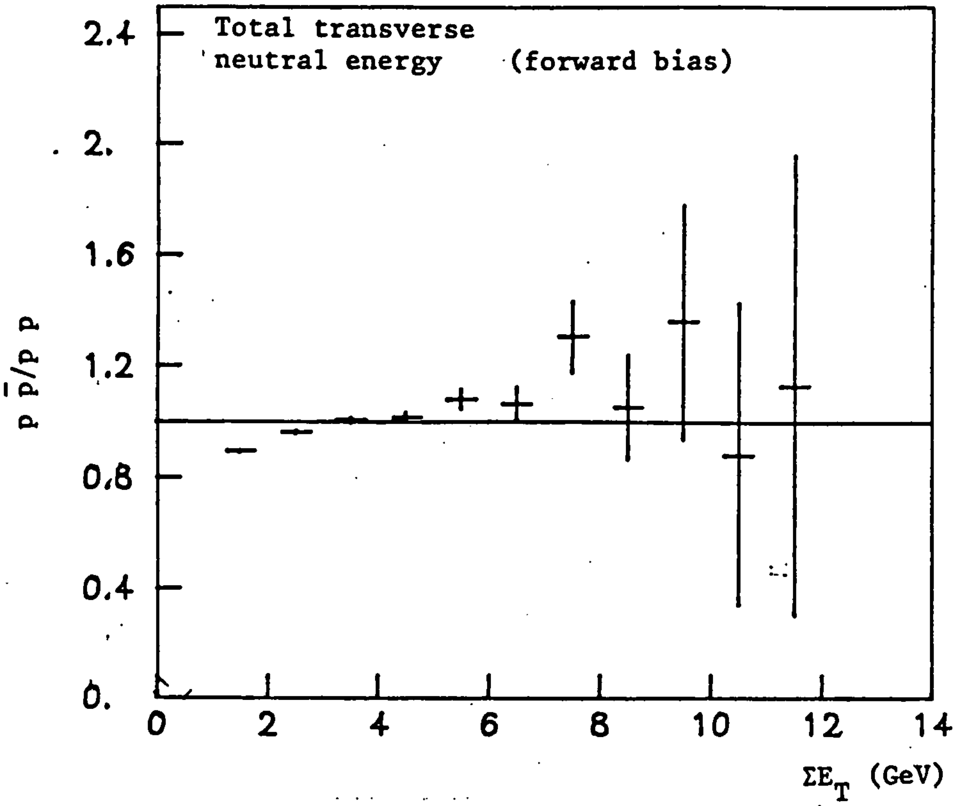

FIG. 3a - The ratio of the ΣE_T spectrum obtained in $\bar{p}$-p collisions to that from p-p collisions.

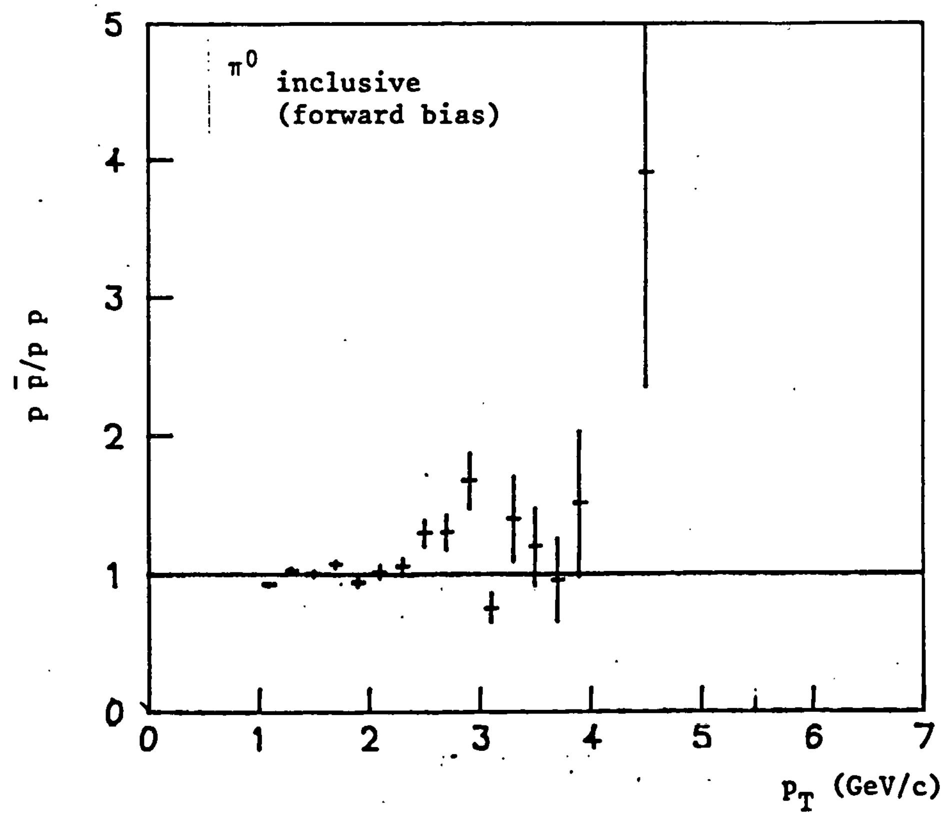

FIG. 3b - The ratio of the π^0 inclusive cross-section obtained in $\bar{p}$-p collisions to that for p-p collisions.

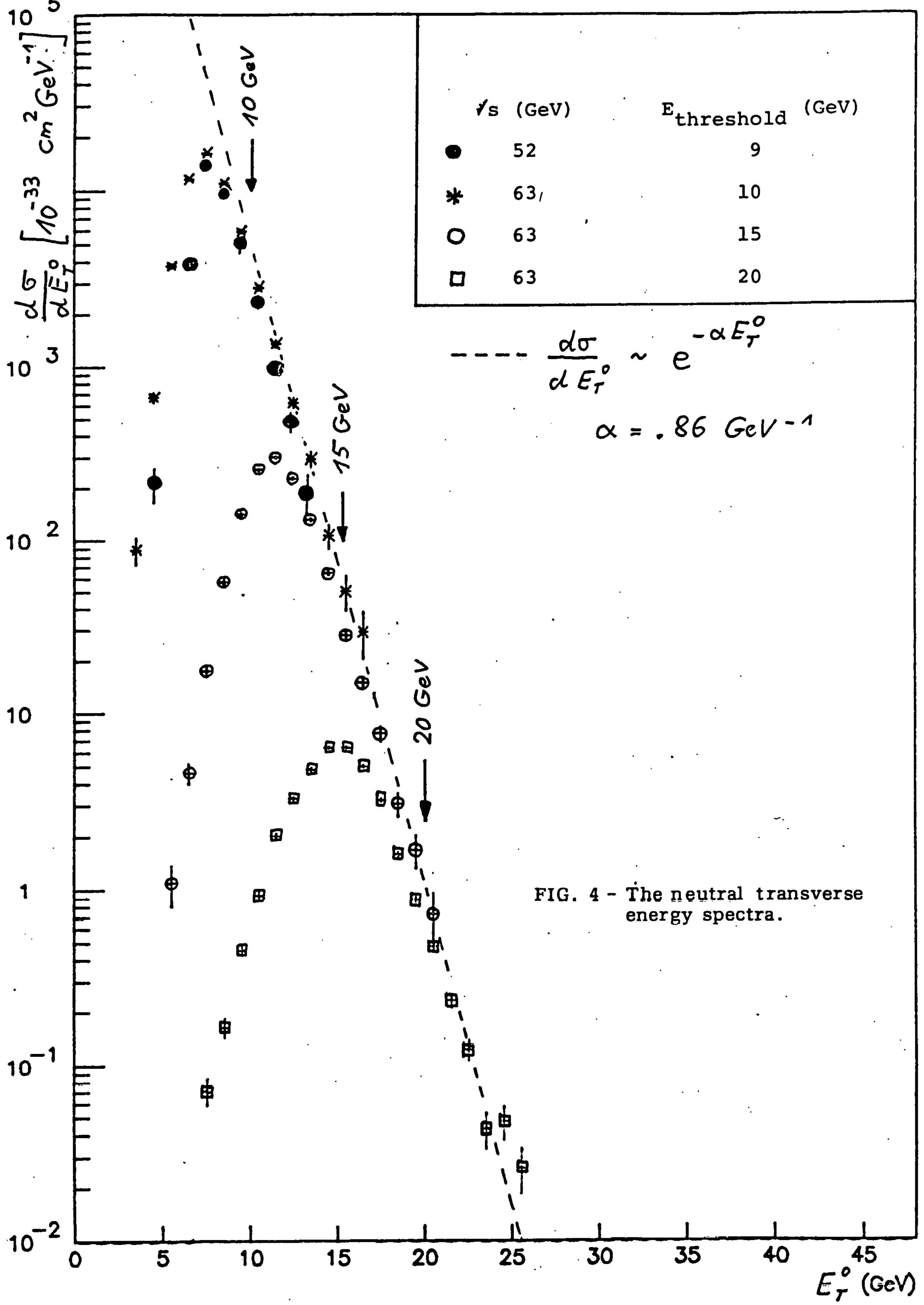

FIG. 4 - The neutral transverse energy spectra.

II. RESEARCH PROGRAM AT FNAL

A. Hadron Dissociation -

Experiment E-396, which measured the differential cross sections for elastic scattering and diffraction dissociation of $\pi^{\pm}$, $K^{\pm}$ and $p^{\pm}$ on p reported last year, has also yielded results on the charge multiplicity distributions of the high-mass diffractive $\pi^{\pm}$, $K^{\pm}$ and $p^{\pm}$ final states. We found that[1] the distributions are described well by a Gaussian function that depends only on the available mass M, has a maximum at $n_o \cong 2M^{\frac{1}{2}}$, and a peak-to-width ratio $n_o/D \cong 2$. Considering that we are dealing only with a few charged particles in the final state, it is somewhat surprising that the distributions are Gaussian rather than Poisson. No theoretical explanation of this finding is yet available.

The uncovering of this simplicity and universality of diffractive charged multiplicities prompted an analysis of all hadronic charged multiplicities. We have shown that[2,3] the charged multiplicity distributions of the non-diffractive components of hadronic interactions, as well as those of hadronic states produced in a variety of other reactions, such as $e^+e^- \rightarrow$ hadrons, follow the same Gaussian function as the diffractive multiplicities. This function is therefore universal, describing all known hadronic multiplicity distributions in terms of only one parameter -- the hadronic mass.

The success of this simple phenomenological description is illustrated by the figures reproduced from Refs. 1 and 2 and presented here as Figure 1.

As a by-product of the work at Fermilab on hadron dissociation, an article is being prepared for publication in Physics Reports[4].

B. Photon Dissociation -

The run for experiment E-612, designed to study the inclusive photon dissociation process $\gamma + p \rightarrow X + p$, started on January 1st and was completed in April 1982. Approximately 400 magnetic tapes of data were collected containing about 40,000 events.

Results from a preliminary analysis of the data were reported at the 21st International Conference in Paris (July 26-31, 1982). We find that, as in hadron dissociation, the differential cross section $d^2\sigma/dtdM_x^2$ is exponential in t and, for $M_x^2 \geq 4$ GeV^2, falls with M_x^2 as $1/M_x^2$ (Figure 2). Comparing the photon data with pion dissociation data collected with the same apparatus during special runs with a pion instead of a photon beam, we find that the high mass diffractive cross sections scale to the corresponding total cross sections, as required by factorization and the Regge theory. This is illustrated in Figure 3 where the pion and photon data have been normalized to the same luminosity $\times$ σ_T.

We estimate that the analysis of the data will be completed by the end of 1982. We then intend to submit a proposal for continuation of the experiment at the higher energies provided by the Tevatron.

References

1. R.L. Cool et al., Phys. Rev. Lett. 48, 1451 (1982).

2. K. Goulianos et al., Phys. Rev. Lett. 48, 1454 (1982).

3. K. Goulianos, AIP Conference Proceedings No. 85, Proton-Antiproton Collider Physics, 469 (1981).

4. K. Goulianos, RU Report No. DOE/ER/40033-24, "Diffractive Interactions of Hadrons at High Energies," submitted to the 21st Interantional Conference, Paris (July 1982).

12.

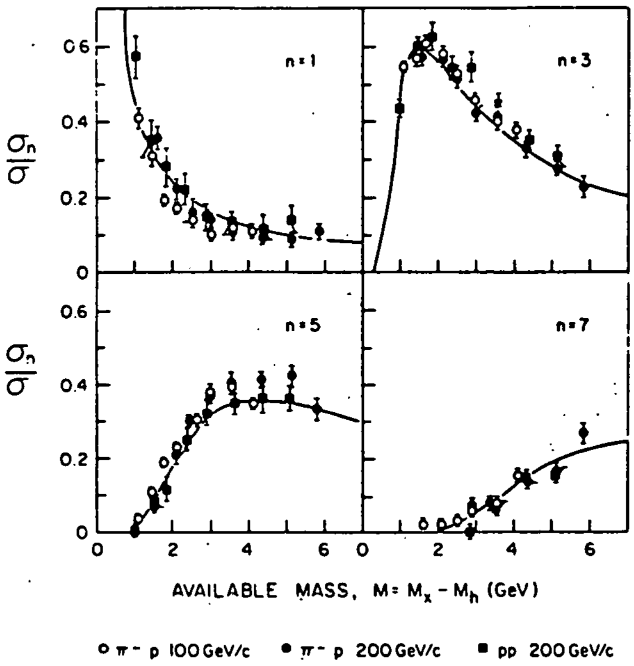

FIG. 4. Topological cross sections σ_n/σ vs available mass for $h+p \rightarrow X+p$ $(h=\pi^-, p)$.

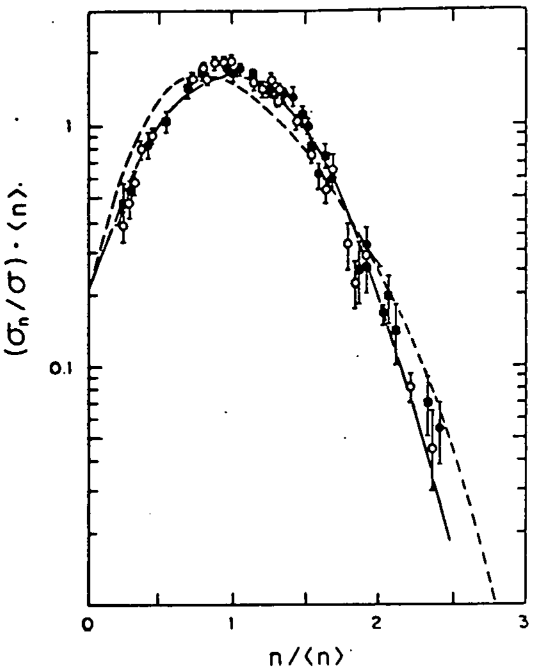

FIG. 5. The product $(\sigma_n/\sigma)\langle n\rangle$ vs $n/\langle n\rangle$ for the data presented in Fig. 4. The solid line represents the Gaussian function discussed in the text [Eq. (4)]. The broken line is from a fit to the inclusive data $h+p \rightarrow$ anything (Ref. 6).

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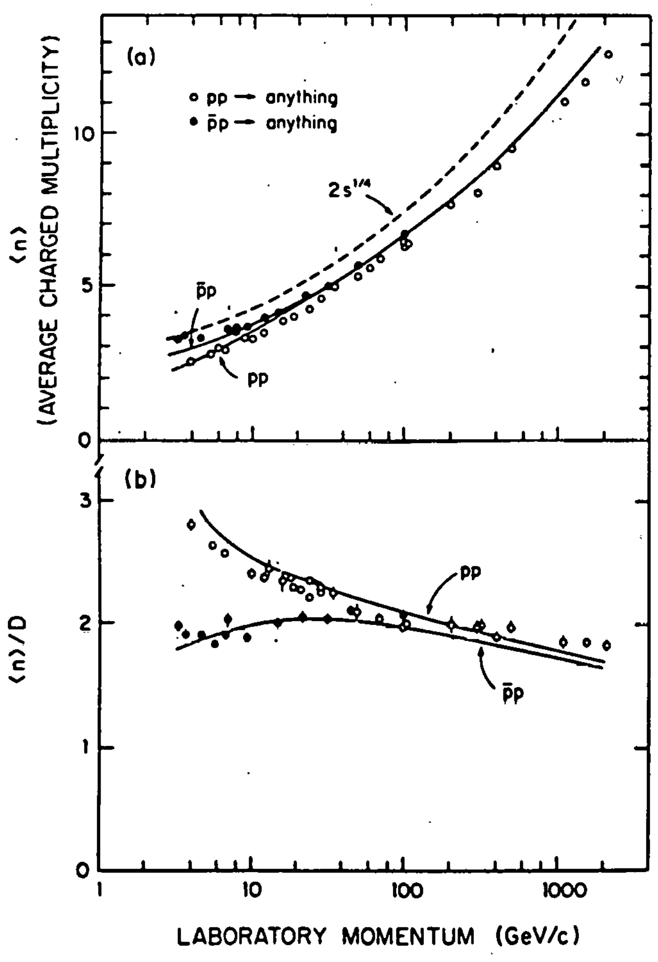

FIG. 1. The average charged multiplicity and the ratio of the average to the width as a function of laboratory momentum for $pp \rightarrow$ anything and $\bar{p}p \rightarrow$ anything. The solid curves were calculated using Eqs. (5) and (6) in the text.

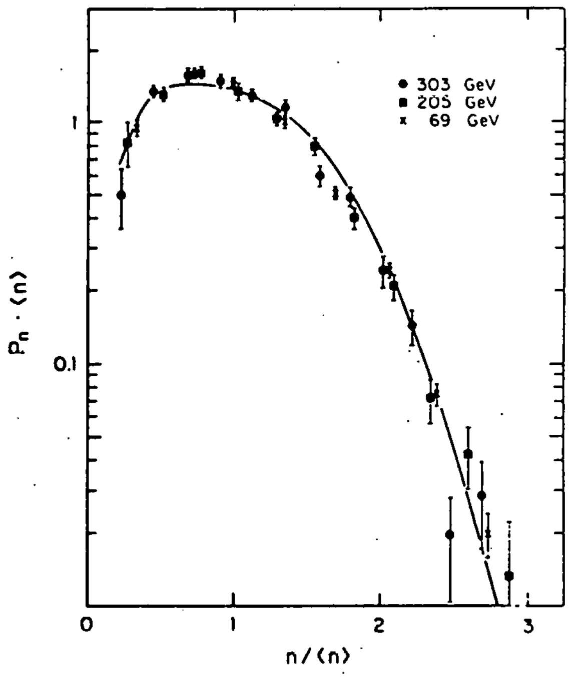

FIG. 2. The product $P_n\langle n\rangle$ vs $n/\langle n\rangle$ for charged particles in $pp \rightarrow$ anything. The curve was calculated using Eq. (5) in the text. The data are from Ref. 6: 69 GeV, V. V. Ammosov *et al.*; 205 GeV, S. Barish *et al.*; 303 GeV, A. Firestone *et al.*

FIG. 1

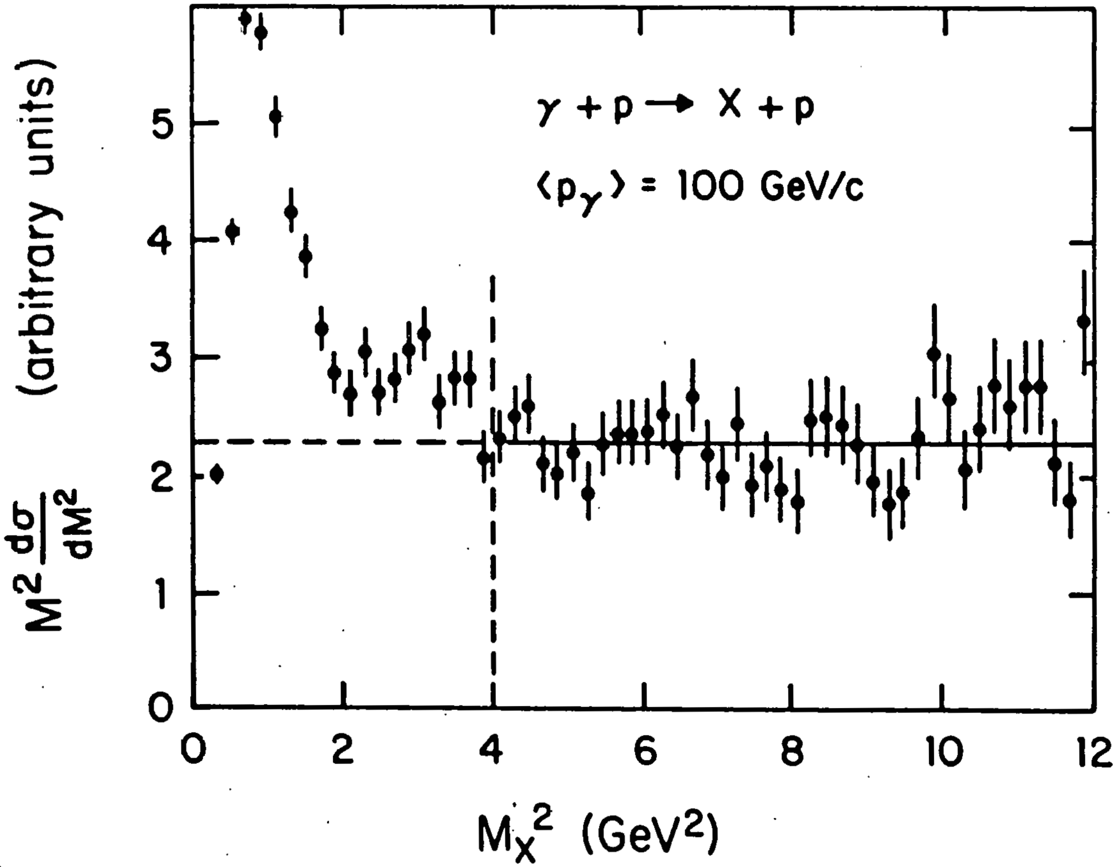

FIG. 2 - The inclusive photon dissociation cross section, $d\sigma/dM_x^2$, multiplied by M_x^2 for $0.02 < |t| < 0.1$ $(GeV/c)^2$. The $1/M_x^2$ behavior for $M_x^2 \gtrsim 4$ GeV^2 is clearly established.

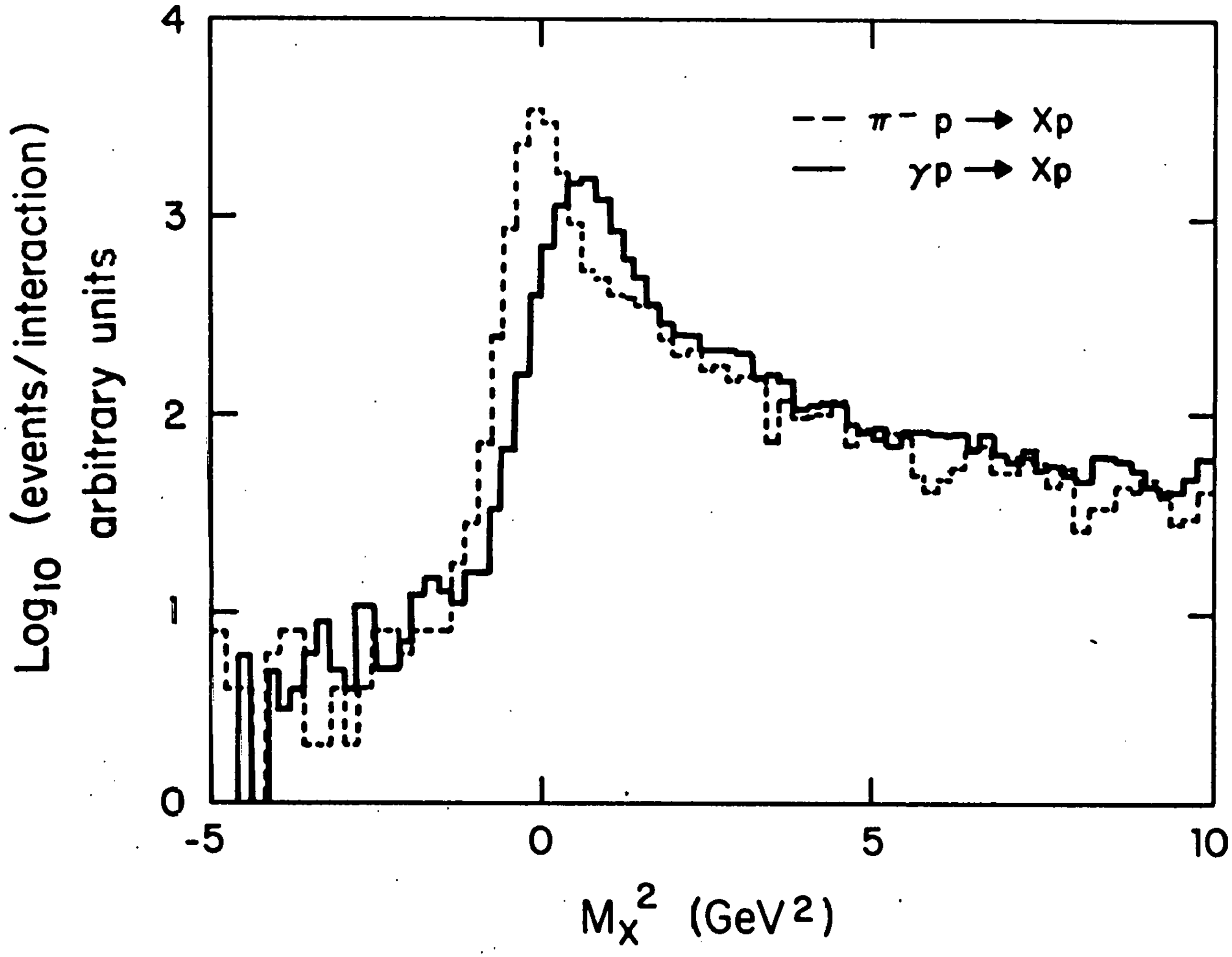

FIG. 3 – Inclusive M_X^2 spectra for $\gamma p \rightarrow Xp$ and $\pi^- p \rightarrow Xp$, normalized respectively to the γp and $\pi^- p$ total cross sections.

III. LIVERMORE LABORATORY PROGRAM:

Electron Neutrino Mass Experiment -

Considerable progress has been made in the neutrino mass experiment during the past year. The physics design has been completed. Some changes in our original concepts were necessary because of engineering considerations but we believe the basic design goal of determining the neutrino mass to ±2 eV, if its mass is greater than 4 eV, has been preserved.

I. Status of Equipment Design and Construction:

Fermilab has been supplying drafting and engineering support during this past year. A full-time draftsman has been making the necessary drawings. Fabrication of the apparatus is progressing rapidly with the construction of each new subassembly beginning as the drawings are completed.

The sections of the vacuum vessel housing the collimator, spectrometer, focusing elements, and optical detector are presently being constructed with shipment to Livermore scheduled during the month of November. The original expectation was that the vessel would be constructed at Fermilab. Unfortunately, the Fermilab shop was unable to construct it which necessitated construction by industry. Consequently, the vacuum vessel is costing about $20,000 more than we had anticipated.

The cryostat design proved to be very subtle. The physics of liquid Helium at its Lambda point greatly influenced the final cryostat design. As a consequence, the cryostats are fairly complex. They are presently being constructed in our shop here at Rockefeller. Most of the individual parts for the cryostats have been machined and the welding and vacuum testing is progressing rapidly.

The collimator design is complete. The intricate foil planes have been fabricated, and the machine work for the collimator support structure is being handled by Fermilab.

The spectrometer grid planes have been designed and samples of grid wires have been examined under a secondary emission microscope to choose the best wire fabrication method for minimizing field emission. A new and possibly unique technique using semiconducting glass for the electrostatic field shaping has been devised. The mechanical viability of this technique has been evaluated and appears to be very good.

A sample lithium drift solid-state detector has been fabricated and has been tested with photons. The photon resolution is ~ 1.2 KeV full width at half height which is extremely good for such a large-area detector. Consequently the expected electron resolution is more than adequate to meet our needs.

It appears that the time scale for completion of the various components is commensurate with the expected delivery and testing time of the vacuum vessel.

II. Final Molecular State Calculations:

A major limitation of all previous electron neutrino mass experiments has been the lack of knowledge of excited molecular final states after the tritium decay. One major advantage of this experiment is that by using a pure frozen T_2 source the effect of these states is well calculable. Nick

Winter from Lawrence Livermore Laboratory has been working with us on these calculations with preliminary indications that 79% of the time, the resulting HeT^+ ion is in its ground electronic state after the beta decay. This probability is very close to the atomic case where 75% of the time, it is in its ground state after the decay. Unlike the atomic case, it is also possible for the resulting HeT^+ ion to be left in an excited vibrational and/or rotational state. Figure 1 shows a preliminary calculation of the probability of the HeT^+ ion to be in each of its vibrational and rotational states plotted versus the energy of that state. The full energy range of these states is 2.3 eV with the full width at half height of the distribution being $\sim$ 1 eV. It is clear from these calculations that the frozen T_2 source is ideal for minimizing the uncertainty in the neutrino mass resulting from final excited state effects.

III. Funding from Livermore and Fermilab:

Attached is a letter written by Bob Woerner, our Livermore collaborator, in which he requested financial support from Livermore Laboratory. This money is to cover tritium building changes, the cost of a technician, liquid helium, and other operating costs as well as vacuum equipment. Thus far, we have not received a reply to this request. A copy of a letter to John Anderson, Head of the Livermore Physics Department, requesting engineering support at Livermore is also attached. This request was approved.

Marshall Mugge has obtained a $45,000 equipment budget from Fermilab. These funds reflect the additional cost of the vacuum vessel fabrication. The funds from Fermilab together with the already budgeted DOE funds supplied to Rockefeller University are sufficient to get a non-cryogenic version of the experiment working.

IV. Projected Time Scale:

We plan to begin assembling the vacuum vessel at Livermore and begin vacuum checking before the end of November. Data-taking with a non-cryogenic source is expected by February 1983. Once the experiment is debugged with the non-cryogenic source, the cryogenic T_2 source should be ready.

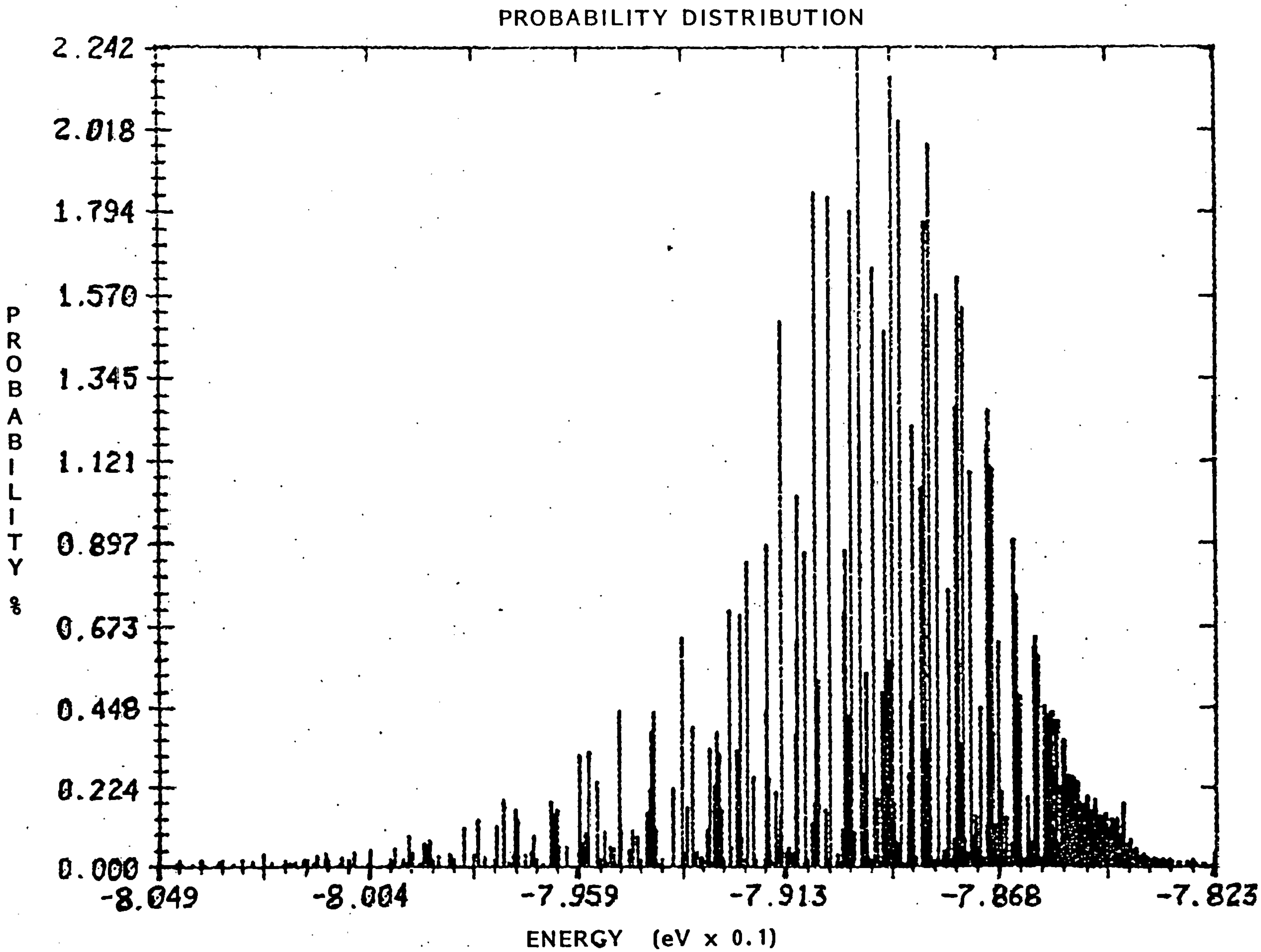

FIG. 1 - Probability of the HeT^+ ion to be in each of its vibrational and rotational states plotted versus the energy of that state. The abscissa covers a range of 2.3 eV.

Interdepartmental letterhead

Mail Station L-

Ext:

June 3, 1982
PPA 82-36

TO: J.L. Emmett

FROM: R.L. Woerner

SUBJ: Neutrino Mass Experiment

Summary:

We can do an experiment in the next year and a half with sufficient accuracy to be definitive on whether the neutrino is massive enough to close the universe. Exclusive of manpower the experiment will require 538K to cover operating expenses and equipment. I am requesting that you allocate $175 K, spread over FY 82 and 83, to cover staging costs in the tritium building plus some of the costs associated with constructing and operating the cryogenic T_2 source. We have enough support through Rockefeller University and Fermi Lab to cover the rest of the operating and manpower expenses.

The purpose of the neutrino experiment is to determine the electron neutrino mass by measuring the tritium beta decay spectrum near its endpoint. This experiment is extremely important to understanding the underlying structure of matter and whether the universe in which we live is closed -- A neutrino mass of 20 - 30 eV is sufficient to close the universe. A recent and controversial Russian experiment suggests that the electron neutrino mass is between 14 and 46 eV.

Our experiment is designed to overcome the limitation of the Russian and other electron neutrino mass experiments and consequently is unique in two major respects. First, the pure frozen T_2 source allows calculation of the molecular final state effects to the required high accuracy.

Second, a spectrometer and detector system has been designed that is capable of better than a 1 eV beta ray energy resolution. As a consequence, our experiment should be able to determine the neutrino mass to about $\pm$ 1 eV if the neutrino mass is greater than 4 eV. This is almost an order of magnitude better than competing experiments.

LLNL can make a unique contribution to this experiment by providing the tritium handling expertise and equipment, laboratory space in the tritium building which is one of the few places in the country where the experiment could be done, and help with the operating and equipment costs associated with the tritium source.

When I first spoke with you last fall about obtaining some support for the nuetrino experiment, you indicated that there might be a possibility. But before making a commitment you wanted the following:

1. An appraisal by John Anderson of the technical merits of the experiment and the abilities of the chief investigators.

2. An accurate estimate for the total cost to complete the experiment.

I now have the information to respond to both requests.

Our experiment to measure the neutrino mass was described in detail by Prof. Orrin Fackler of Rockefeller Univerisity in a seminar attended by, among others, John Anderson and the physicists he asked to help him evaluate the experiment. We were able to respond to all the technical concerns raised during the seminar as well as those brought up in the subsequent discussions with the evaluating committee headed by Carl Poppe. The consensus is that the proposed experiment has been thought through very thoroughly and is worth attempting. It is also felt that the research team assembled by Orrin Fackler of Rockefeller University, Marshall Mugge of Fermi Lab and myself have the expertise to do the experiment.

We are planning to do the experiment in two stages. We expect to set up first a much simpler room temperature version of the experiment in the tritium building this fall. With a room temperature source such as titanium tritide, we can work on reducing backgrounds and demonstrate that the spectrometer works as designed. Upon completion of this first stage of the experiment, we will incorporate the cryogenic T_2 source which will allow us to achieve the projected neutrino mass sensitivity.

For the past year we have been iterating the experimental design, building equipment, and refining the cost estimates. Exclusive of manpower we expect the full experiment to cost about $538 K, for S & E and capital equipment, as shown in the accompanying table. We have a contract through Rockefeller University which will pay $238 K of the operating costs, Fermi Lab will cover an additional $65 K of these costs and we can borrow $48 K worth of equipment. To complete the experiment we need $175 K of operating funds from LLNL to cover staging costs in the tritium building plus the costs associated with the cryogenic T_2 source. (A discussion of the tritium Recharge Policy as it applies to the neutrino experiment is attached.)

In addition to the equipment costs described above, the manpower requirements summed over the life cycle of the experiment is equivalent to 10 FTE's. Most of the manpower costs are being picked up through Rockefeller University and Fermi Lab. The fraction of time that I spend on the experiment will have to be covered by LLNL. The tritium building charges listed above include the costs of technician support for interfacing the experiment with the building.

Robert L. Woerner

hg

cc: J. Davis
J. Holzrichter
W. Krupke

OPERATING AND EQUIPMENT COST SUMMARY EXCLUSIVE OF MANPOWER

ITEM	BORROW	RU/DOE CONT.	FERMI LAB	LLNL	TOTAL (K$)
T_2 Source Substrate	5	22			27
Liquid Helium				40	40
Collimators		12			12
Analyzing Region		15	16		31
Focusing Region		13			13
Detector	2	20			22
Cryopump	3	6			9
Cosmic Ray Veto		3			3
Electronics	20	6			26
Computer		50			50
Vacuum Vessel		15	34		49
Mech. Supports		10			10
Vacuum Equipment	18			27	45
Liq-Nitrogen System		8			8
Other		25			25
T-Bldg. Costs*				60	60
Shipping		20			20
Travel		15	15	3	33
Contingency				45	50
TOTAL	48	238	65	175	538

*The T-Building costs include some technician support for interfacing the experiment with the building.

Tritium Facility - Recharge Policy

The costs of operating the Tritium Facility are distributed yearly among the facilities long term users. In general, the division of costs is proportional to the expected usage, and is revised as required throughout the year. A percentage of these costs are covered by Chemistry Research to encourage small research projects and new efforts just getting underway. This represents Charlie's contribution to new research.

This being the case, new projects are allowed (in fact encouraged) to use the facility without incurring charges for the basic facility maintenance. In most cases, however, projects require some specific effort. This could involve fabrication effort to stage an experiment, or help from technical personnel regarding set-up or operation. These efforts are charged directly to the particular project. For a project the size of the neutrino experiment, the cost of these efforts is estimated at about $30 K/yr. The actual costs will be a function of how much assistance is required to perform the experiment.

This policy has been in effect for about three years, and was agreed to by the major users at that time.

Mail Station L- 405

Ext: 2-4527

July 7, 1982

TO: J. D. Anderson

FROM: C. H. Poppe

SUBJECT: Neutrino Mass Measurement Experiment

In November of 1981, we reviewed the proposal "New Experiments to Measure the ν_e Mass" of Robert Woerner of Y-Program and collaborators from Rockefeller University (see attached memo). The experiment has far-reaching implications for the foundations of our discipline and although it does not have any direct connection to our programs, it is important enough to warrant Physics Department support. In addition to giving us contact with some of the more exciting concepts of present-day physics (baryon stability, neutrino oscillations, cosmology, strong-weak unification, etc.) our association with this experiment would help to strengthen the Laboratory's image in the academic and other communities where there is more emphasis on basic research.

So far, the Physics Department has provided consultation and moral support to this proposed experiment and has acted as a sounding board to review their proposal. At this time, however, they are in need of more substantial support. What is required, however, is not very much--1/2 head for approx. 1/2 year.

Since last November, significant progress has been made in fielding the experiment:

- The vacuum vessels to house the collimator assembly, spectrometer, focussing elements and detector have been designed and are ready to be bid.
- The collimators and focussing elements have been designed. Design of the spectrometer is almost completed, awaiting final calculations of the electrostatic field shaping.
- The cryogenic systems for the tritium source and the pumping reservoir have been designed.
- Specifications for a state-of-the-art high stability power supply to produce the required voltages for the electrostatic spectrometer have been determined. The supply is under construction by an outside contractor.

A sample detector has been acquired from LBL.

A number of tests and supporting calculations have been done. Photon backgrounds have been measured and the photon response of the detector determined. Tests to determine electron backgrounds will begin this week. Outgassing rates have been determined and accounted for appropriately in the design of the cryopumping system.

All in all, preparation for the experiment is proceeding in a timely manner and the collaborators are making careful preliminary investigations of all the different technical details. They expect the vacuum vessel to arrive at Livermore sometime after August 1982. What is needed now, however, is someone to design the high-vacuum gate valve connecting the tritium source region to the rest of the assembly. A person capable to do this job, andseveral other smaller design jobs of a similar nature is undoubtedly available at LLNL. They estimate 1/2 head for approx. 1/2 year would be needed, however, they have no allocation for this, nor an account number to which this effort could be charged. It would be most fitting if such support could come from the Physics Department--a relatively small price to pay to help assure timely completion of this project.

Carl

C. H. Poppe

Attachment

bv/0946a

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RU 81/A-17 -- R.L. Cool, K. Goulianos, S.L. Segler, H. Sticker and S.N. White. *Charged Multiplicities of High Mass Diffractive* $\pi^{\pm}$, $K^{\pm}$ *and* $p^{\pm}$ *States.* Phys. Rev. Lett. 48, 1451 (1982).

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