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ELEMENTARY PARTICLE INTERACTIONS

PROGRESS REPORT TO DEPARTMENT OF ENERGY
DOE DE-AS05-76ER03956

(October 1, 1989 - September 30, 1990)

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E. L. Hart. B. F. L. Ward, F. E. Close,
and L. G. Christophorou

Department of Physics
The University of Tennessee

October 1990

DISCLAIMER

ELEMENTARY PARTICLE INTERACTIONS

PROGRESS REPORT TO DEPARTMENT OF ENERGY
DOE DE-AS05-76ER03956

TASK A

W. M. Bugg, G. T. Condo,
T. Handler, and E. L. Hart

PROGRESS REPORT

TASK A

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* All preprints and reprints have been removed and cycled separately.

I. Data Analysis

A. Fermilab E-745 (with Tohoku, MIT, Brown, Indiana, IHEP Beijing, and Tohoku Gakuin)

Data collection from this series of high energy neutrino exposures in the Tohoku freon bubble chamber at Fermilab has been complete for some time. No new papers have been published this year, probably because the full efforts of the experimenters involved have been required to set up and carry out the follow-on experiment, E-782, to be described later. However, a further study has been made of the effects of the length of the leading μ meson on the distributions of the cross section ratio as a function of Feynman x for events with and without visible spectator protons. This is the distribution that is critical to our detecting the EMC effect in weak interactions in freon. As shown in figure 1, a fiducial volume cut that yields a μ track length > 50 cm results in an enhanced effect due to better beam energy resolution. The figures shown also represent a 50% increase in the statistics simply due to the completion of the data summary tape since the last publication.

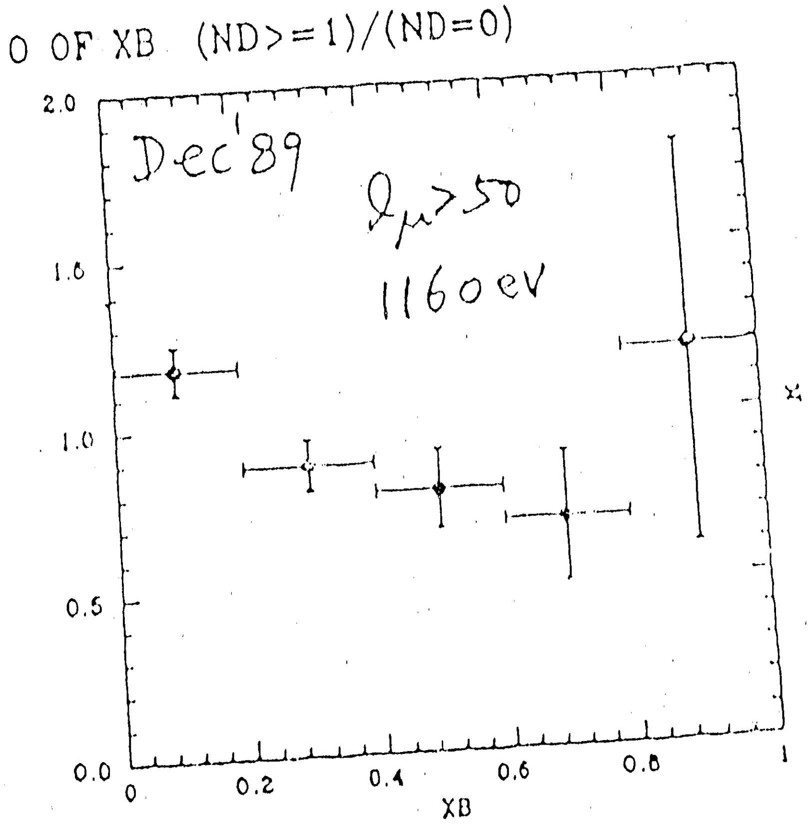
In 1989 Guy et al.[1] disputed our findings using data from a series of exposures at CERN in BEBC. They argue that the same modification in the x distribution that Kitagaki et al.[2] attribute to interactions with deeply bound nucleons in freon can also be observed in interactions in deuterium as long as slow protons are observed to emerge from the interactions. That would deny that what Kitagaki et al. see is due to nuclear effects. This result is disputed by some members of our group, and a repetition of the basic experiment using μ^+ mesons, E-782, is a possible response.

Other projects currently underway in this experiment are:

1. A gluon jet analysis which is the completed Ph.D. thesis of M. Susaki, Tohoku University (figures 2,3);
2. A study of the Bose Einstein Effect, a masters thesis topic for H. Kawamoto, Tohoku University;
3. An intense study of a possible $\nu_\tau \rightarrow \tau$ candidate being carried out at Tohoku (figure 4).

References

1. T. Guy et al., "Neutrino Interactions, Proton Production, and a Nuclear Effect," Phys. Lett. 229B, 421 (1989).
2. T. Kitagaki et al., "A New Method to Investigate the Nuclear Effect in Leptonic Interactions," Phys. Lett. 214B, 281 (1988).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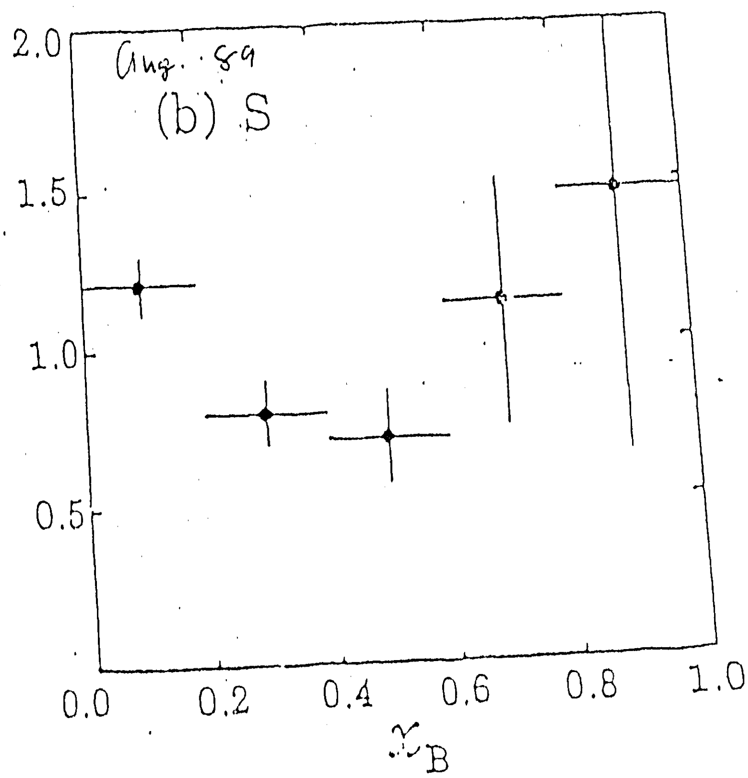
Aug. 89
(b) S
2.0
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FIGURE 1

Gluon Jet Analysis, E745

CERN WA59

15'BC

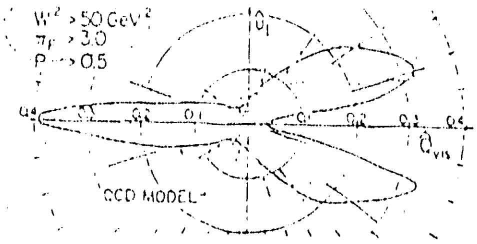


FIG. 4. (a) The angular energy flow, projected onto the $(\hat{Q}_{vis}, \hat{u})$ plane, for all events with $W^2 > 50$ GeV^2. The curve is the QCD model calculation. (b) Same as (a), but for the 47 evetits with $\eta_F > 3.0$ and $P > 0.5$. Kinematic offects and forward-backward-symmetric backgrounds are discussed in the text.

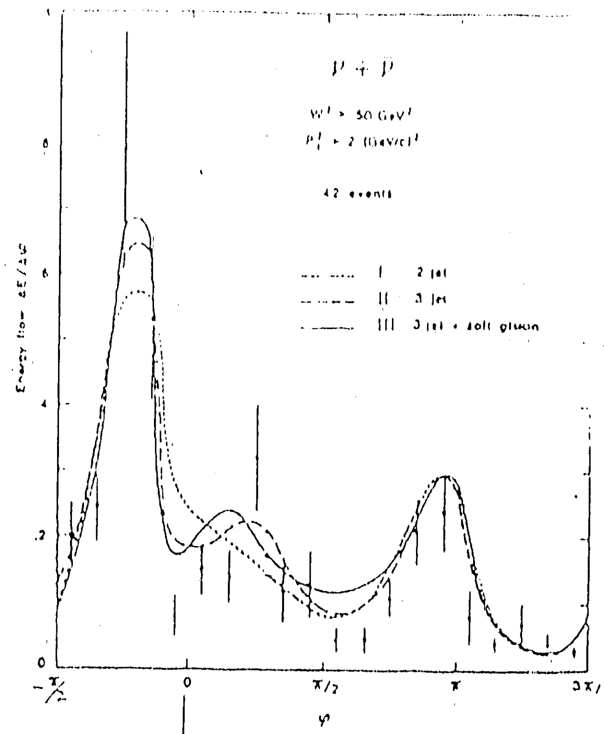
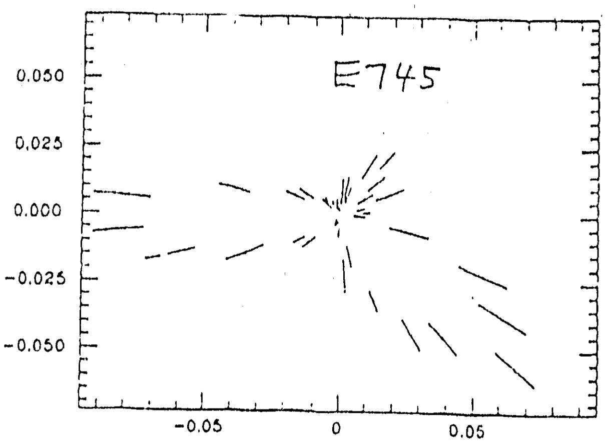
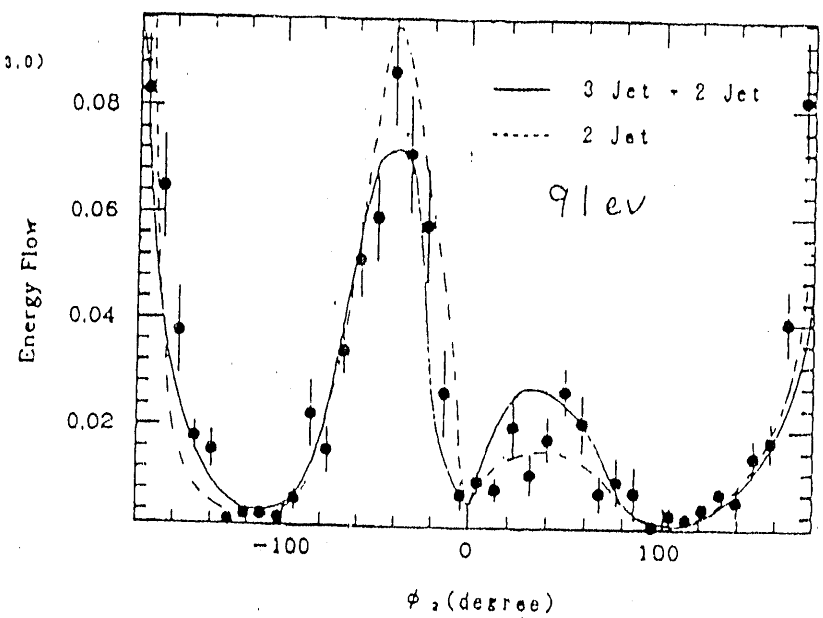


Fig. 14. Energy flow distribution events with $W^2 > 50$ (GeV^2) and a forward track with $p_t^2 > 2$ (GeV/c)^2. The curve I corresponds to the two-jet model. The curve II corresponds to the three-jet model. The curve III corresponds to the three-jet model with soft gluon emission



E745



d) ϕ_2-dependence ($W > 9$(GeV/c^2), $P > 0.5$, $D_F > 3.0$) ← Planarity

$$D_F = \frac{4.0}{\sqrt{N_F}} \Sigma (P_T - \langle P_T \rangle)$$

Angular Energy Flow

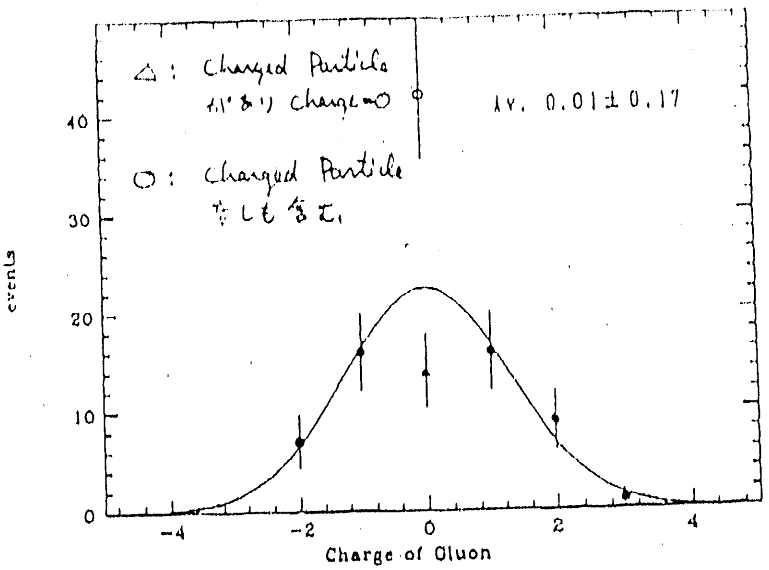
$\langle P_T \rangle = 0.44$

N_F: $X_F > 0$ n

FIGURE 2

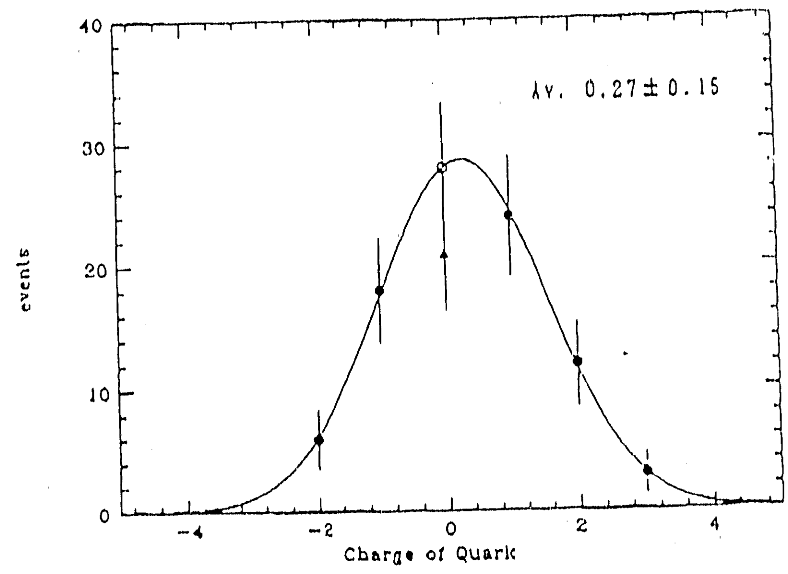
Ref. 12.

Fig. 4 Net Charge



Gluon jet

a) Gluon ($0^\circ \leqq \Phi_2 \leqq 110^\circ$)

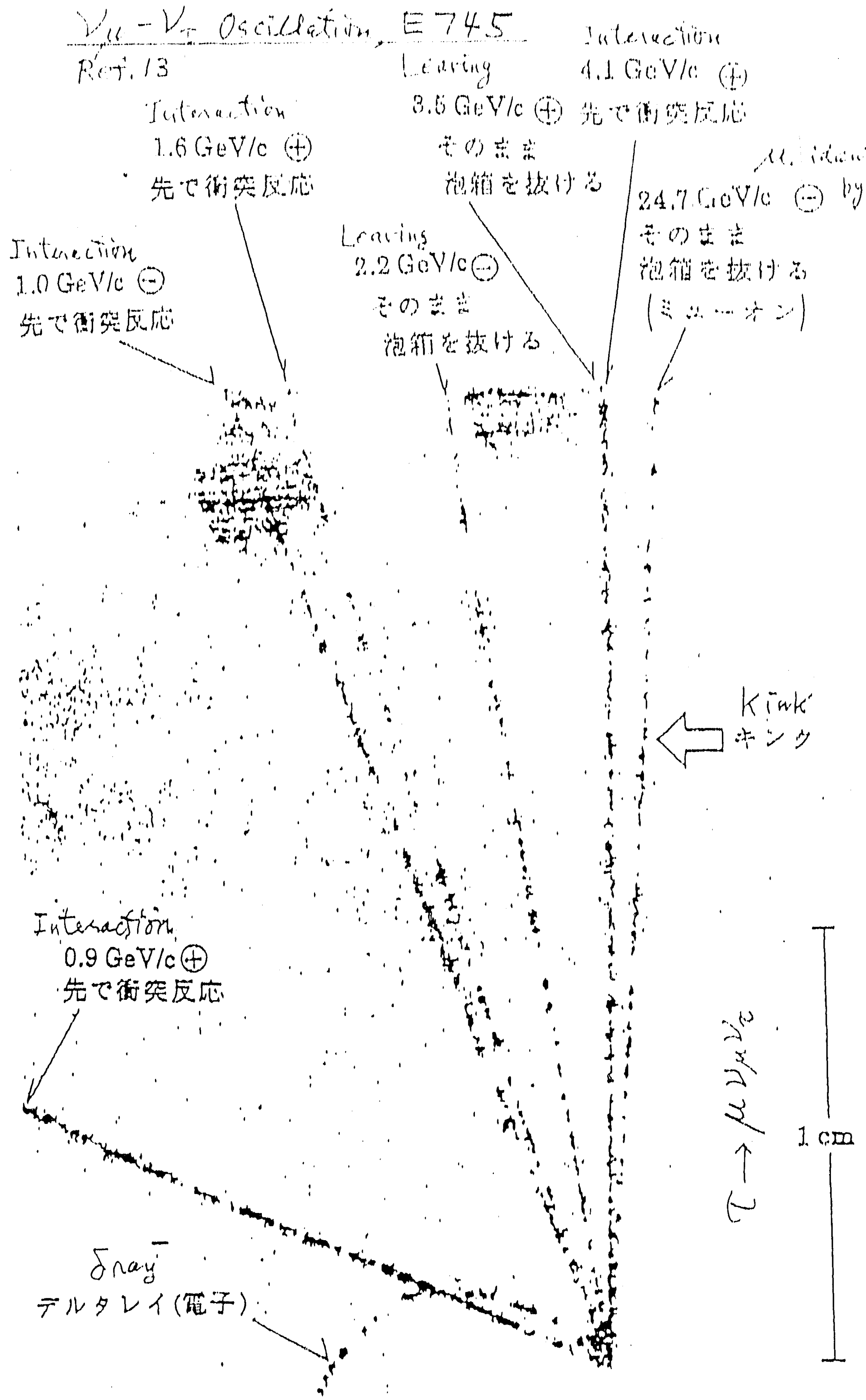


Quark jet
u

b) Quark ($-110^\circ \leqq \Phi_2 \leqq 0^\circ$)

Net Charge Distribution ($W > 9(GeV/c^2)$, $P > 0.6$, $D_1 > 3.0$)

FIGURE 3



Holographic pix. of ν_τ candidate

図 6 － 1. タウ候補のホログラフィー

B. Fermilab E-782 (with Tohoku University, MIT, Brown, IHEP Beijing, and Tohoku Gakuin)

Starting in the Fall of 1989, the Fermilab experiment E-782, a 300,000 picture exposure of 200 GeV/c μ^+ mesons, was set up and run in the Tohoku one meter freon bubble chamber. Tennessee's association with this experiment started as an agreement to give support in those areas in which we had been active in the previous E-745 such as building and installing drift chambers and associated electronics, and supplying expertise in FAST-BUSS and data acquisition programs. It was not intended that Tennessee would actually take part in the run and subsequent data analysis, since we had a commitment to SLD which forbid joining new experiments, which this technically was.

E-782 was set up and run over the period November 1989 - July 1990, and our actual efforts in manpower and resources in its behalf over that period were as large as they would have been if we had actually been officially part of the experiment. We constructed, serviced, and brought into operation ten single-plane and three new multi-plane drift chambers; supplied much of the expertise for the spectrometer electronics and FAST-BUSS; carried out various surveys; and had at Lab F, for extensive periods before and during the run, 3 faculty and 3 research associates. At least one member of our group was on the operating crew over most of the run. In the meantime, at SLD, it became clear that the rule about participants not joining other experiments would have to be waived, so at the end of the run we made formal, what was already a fait-acomplis, and joined the experiment.

The four-month run in the Spring of 1990 was a success with 300,000 good pictures taken. The 200 beam tracks/frame average intensity produced pictures which are surprisingly easy to scan, mainly because the events, one in every ten frames, are quite prominent. The cross section is ~12 μb, mostly low-momentum-transfer coulomb scattering.

$$\mu^+ + Fr(p,n) \rightarrow \mu^+ + X.$$

The drift chamber efficiency averaged 80-90%, and the processes of following the beam μ through the upstream and downstream spectrometer is quite simple (figure 1). A hadron trigger was used because the outgoing μ from in interaction has too small a deflection to be distinguishable from a beam μ. Every ping was photographed by the two high resolution 70 mm cameras and the three 35 mm sterio cameras, irrespective of the presence of a trigger signal.

The produced film has been divided between Tohoku and Tennessee, there being no other scanning and measuring facilities left in the collaboration. The Tennessee share, 60,000 frames, should yield about 6,000 events. Tennessee has reconstituted a scanning/measuring shop using equipment from E-745, and scanning and measuring are currently underway. This is discussed further in our renewal proposal.

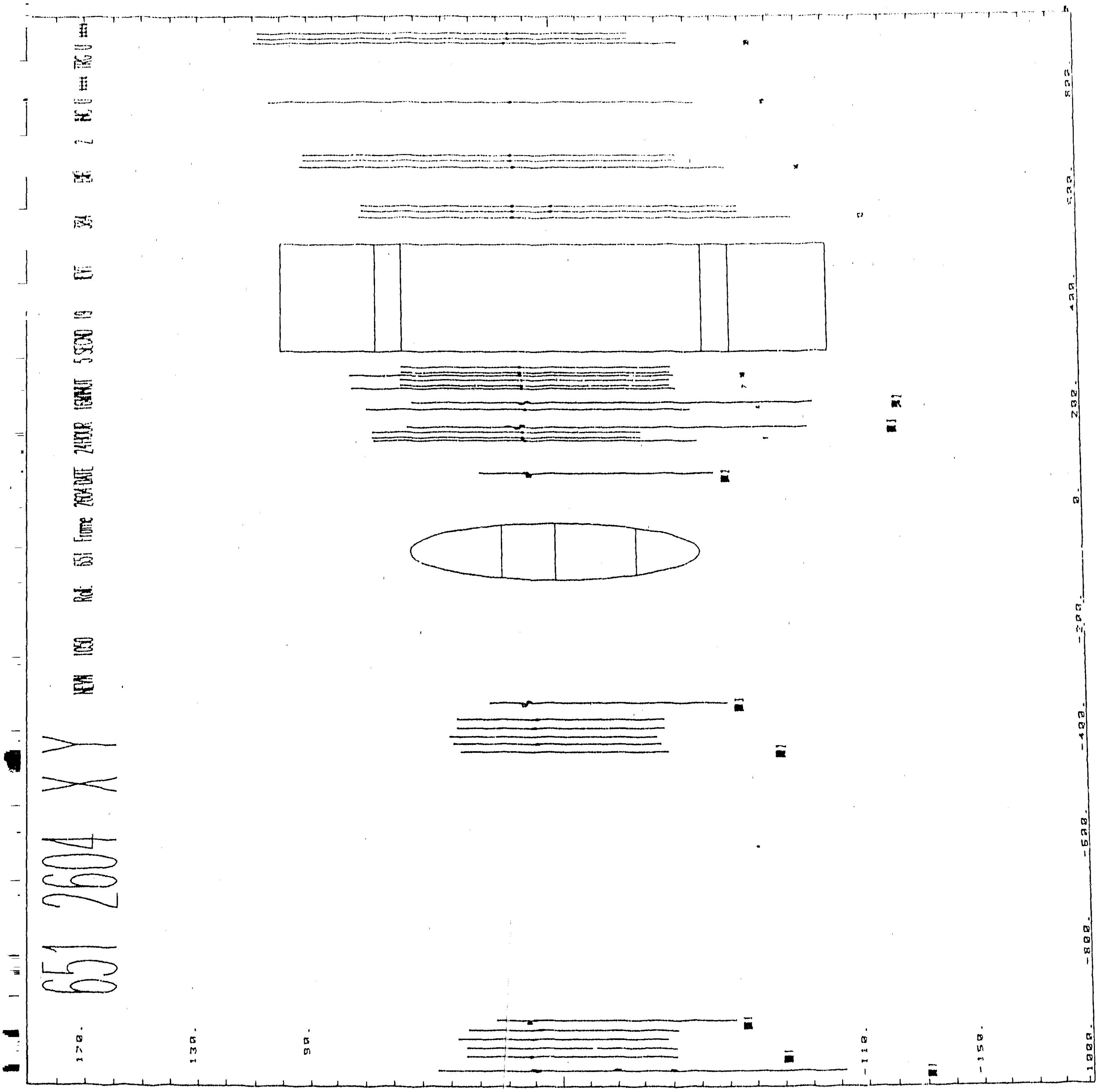


FIGURE 5

C. Moderate Energy Photoproduction

During the past year, one paper has been published[1] and another has been submitted to Phys. Rev. D. The published work presents our results on the charge exchange photoproduction of the negatively charged a_2 meson in association with a Δ^{++} baryon via the reaction: $\gamma p \rightarrow \Delta^{++} a_2^-$. This is the only published example of any meson photoproduction, opposite a Δ^{++}, except for the ρ^-. Of some interest is the fact that, in the a_2 mass region, nearly the entire cross section is due to a_2^- production with, at most, an ~20% admixture of a_1^- photoproduction. This is difficult to understand if the mass of the a_1^- approximates that of the a_2^- and if the radiative width $(\Gamma(a_{1,2}^- \rightarrow \pi^- \gamma))$ of the a_1 exceeds that of the a_2 as indicated by a previous experiment.[2] Work is continuing on this problem.

The paper, now under consideration at Physical Review, concerns a state which appears at a 3π mass of ~1780 MeV in both of the charge exchange photoproduction reactions:

$$\gamma p \rightarrow \Delta^{++}\pi^+\pi^-\pi^- \qquad\qquad \gamma p \rightarrow n\pi^+\pi^+\pi^-$$

A similar state has been seen in at least one previous photoproduction experiment.[3] Its mass is rather too large to be identifiable as the $\pi_2(1670)$ and its decay branching ratios favor $\rho\pi$ rather than $f_2\pi$ as is the case in $\pi_2(1670)$ decay. If we invoke the argument of Chanowitz and Sharpe[4] that this state is too near the $\pi_2(1670)$ to be a radial excitation thereof, its quantum numbers, J^P, must then be other than 2^-.

If we assume t-channel helicity conservation (one pion exchange), the polar angular distributions of the decay plane normal and the associated azimuth as well as the helicity frame angular distribution of the ρ strongly suggest that $J^P = 1^-$. An isovector $\rho\pi$ state with $J^P = 1^-$ must have even charge conjugation (C = +1) so that $J^{PC} = 1^{-+}$. This thus forms the observation of an exotic meson in the sense that it cannot be formed from a $q\bar{q}$ combination.

References

1. G. T. Condo *et al.*, Phys. Rev. D41, 3317 (1990).
2. S. Cihangir *et al.*, Phys. Lett. 117B, 119 (1982); M. Zielinski, Phys. Rev. Lett. 52, 1195 (1984).
3. D. Aston *et al.*, Nucl. Phys. B189, 15 (1981).
4. M. Chanowitz and S. Sharpe, Nucl. Phys. B222, 211 (1983).

D. Simulation Efforts

Abstract

During the past year Tennesse has expended considerable effort in calorimetry simulation using the CALOR89 code system. The CALOR89 code system has been used to generate data for radiation damage studies, signal collection time and compensation characteristics of various calorimeter designs.

Introduction

Calorimeter development for the Superconducting Super Collider will involve a large simulation effort because of the large expense in building and testing of reasonable size prototypes. Therefore only a few such devices will be built and tested. The remaining studies concerning calorimetry will be through simulation. This approach is being followed by several of the proposed experiments and subsystem proposals.

CALOR89

The CALOR89 code system consists of several codes and analysis programs. The transport codes are: HETC88, which generates all high energy particles and transports the hadronic portion; EGS4, the electron, positron, and gamma ray transport code; and MORSE and MICAP, which are the low energy (< 20 MeV) neutron transport code. In addition to these transport codes there is the analysis program SPECT, which analyzes the hadron energy deposition. With these transport codes are various ancillary programs which generate needed constants, (LIGHT) and cross sections (PEGS4). The program LIGHT generates correction factors for saturation/recombination effects in the active media. An outline of the CALOR89 code system is presented in Figure 1.

Effects of Saturation and Signal Collection Time on Compensation

Two simple lead-scintillator slab calorimeters were setup and studied. The lead sheets were of 4mm and 3mm thickness, while the scintillator was kept fixed at a thickness of 1 mm. Incident pions, protons, and electrons of 10 GeV kinetic energy were used. The generated pulse height distributions of these incident particles were found to be gaussian in nature and all subsequent results are based on gaussian fits to the calculated data.

Saturation effects can be very strong in a scintillator based calorimeter. Presented in Figure 2 is the compensa-tion characteristics for the 4 mm Pb/ 1 mm Scint slab calorimeter as a function of signal collection time and for two levels of saturation corrections. As can be seen the calorimeter would be overly compensating if the saturation effects had not been taken into account. This is a fact that is often neglected when various types of scintillator are examined. As this study also implies, careful control of the production of the scintillator will be important to assure uniform saturation effects throughout the volume of the calorimeter.

As can also be seen in the figure, it requires approximately 50-75 nsec to collect most of the signal and to obtain compensation. This is strictly due to the low energy neutrons that are produced in the calorimeter. Time effects in the calorimeter also play an important role in the amount of background noise that is perceived to be in the calorimeter.

Results of these calculations were presented at the Workshop on Major SSC Detectors held at Tucson in February 1990.

Radiation Damage Effects

It has been previously suggested at past conferences that a calorimeter should have equal response to both electromagnetic and hadronic particles--compensation. To achieve compensation various combinations of passive and active media are used. It has been shown that plastic scintillator in combination with lead or uranium can achieve this desired result.

The SSC environment for detectors will be a harsh radiation environment that has been previoulsy not been seen at other accelerators. Thus long-term radiation effects are unknown. It has been suggested and shown by others that plastic scintillator is in fact damaged when exposed to radiation. The signal output is degraded and the scintillator does not fully recover to output levels that existed prior to radiation exposure. The data that was generated for the 4 mm Pb/1 mm Scint calorimeter was used to study the effects of radiation damage on the compensation chracteristics of the calorimeter. The results of this investigation were presented at the Radiation Damage Conference held at Florida State in the spring of 1990. A copy of the paper is enclosed as Appendix A.

The reults can be summarized as follows: Depending upon the exact dose rates that the scintillator is exposed to, the compensation characteristics of the detector can decrease by as much as 17% within two years of operation. As the results in the paper suggest, there may be regions within a calorimeter that would have to be replaced because of the radiation damage.

L*

Design calculations were carried out in the Spring of 1990 for the L* EOI. These calculations simulated a Lead-Iron-Silicon system that was segemented into an electromagnetic section and a hadronic section. Results from these calculations showed that the compensation characteristics of such a calorimeter were undesirable (see Figures 3-5).

Because of these disappointing results, another design was tried using BaF_2 crystals. Three crystal sections were followed again by a lead-iron-silicon system. Good electron resolution was obtained with such a system. See Figure 6. However compenstion was not acheived.

Current Work

Currently calculations are being carried out for the Scintillating Plate Calorimeter Subsystem. These calculations are being carried out on a matrix of absorber materials, thicknesses of absorbers, and thicknesses of active materials. The primary absorbers are Depleted Uranium, Lead, and Iron. The compensation and resolution characteristics are being examined as a function of the various thicknesses of absorber (0.5, 1.0, 2.0, 4.0 radiation lengths), thicknesses of active material (1, 2.5, 5, 10 mm),incident particle energies (2, 5, and 10 GeV), and gate lengths for signal integration (16, 32, 48, 96, 192, 288 500 nsec).

Preliminary results point to Depleted Uranium as having potential problems because of capture gammas being released over a long period of time, up to 500 nsec.

Future Plans

Work will continue on the design calculations for the Scintillating Plate Calorimeter Subsytem. This will involve completeing the matrix of calcluations as far as thicknesses of both the absorber and the scintillator. It will also entail running the calculations at different energies and with different incident particles. Besides the one type of absorber, it is expected that calculations will be done with mixtures of absorbers, such as lead and iron. This will further increase the complexity of the design studies.

It is also expected that design calculations will start for the Liquid Argon Subsystem, for the Silicon Subsystem, and for the Liquid Scintillator Subsystem.

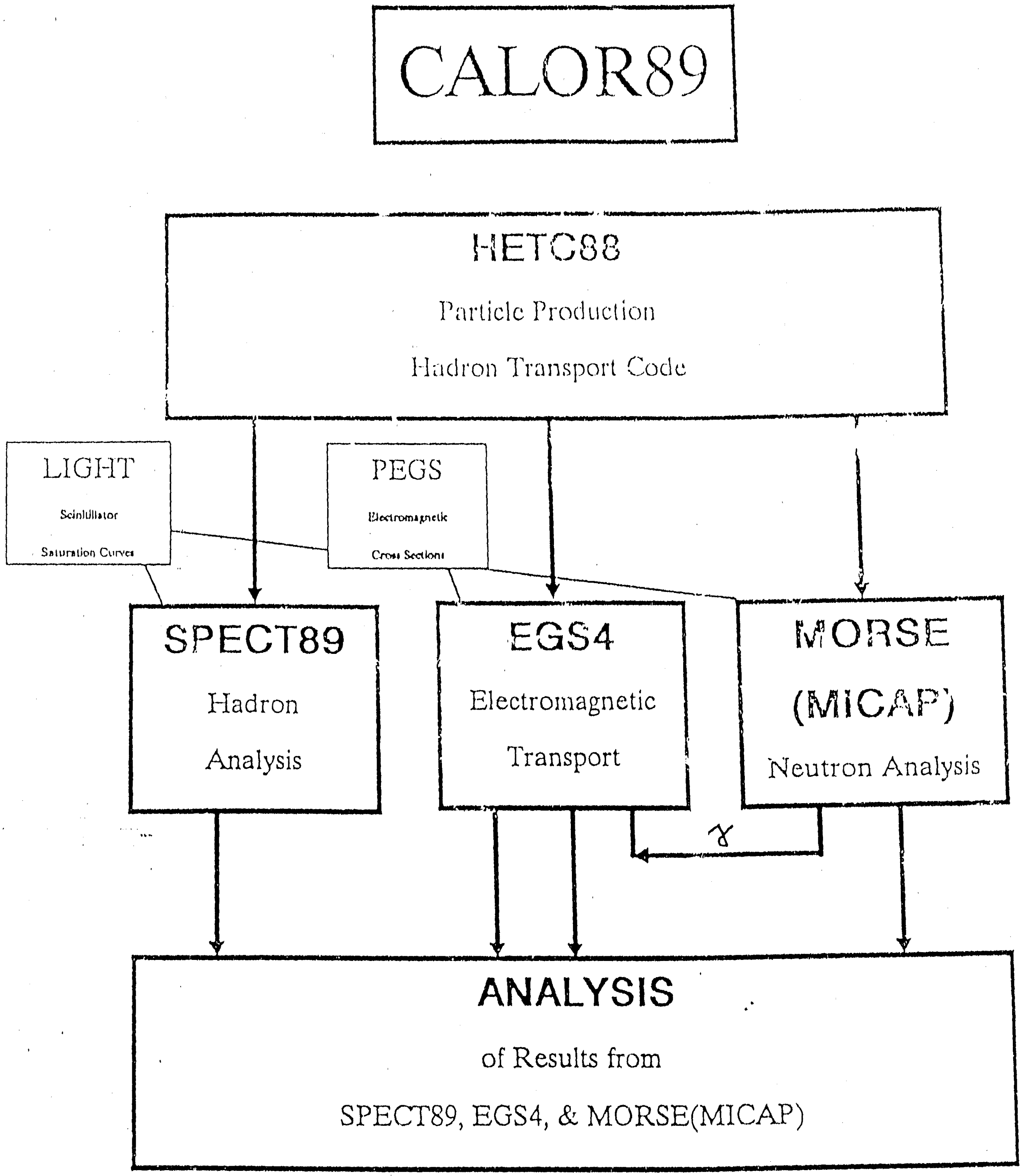

CALOR89
HETC88
Particle Production
Hadron Transport Code
LIGHT
Scintillator
Saturation Curves
PEGS
Electromagnetic
Cross Sections
SPECT89
Hadron
Analysis
EGS4
Electromagnetic
Transport
MORSE
(MICAP)
Neutron Analysis
γ
ANALYSIS
of Results from
SPECT89, EGS4, & MORSE(MICAP)

FIGURE 1

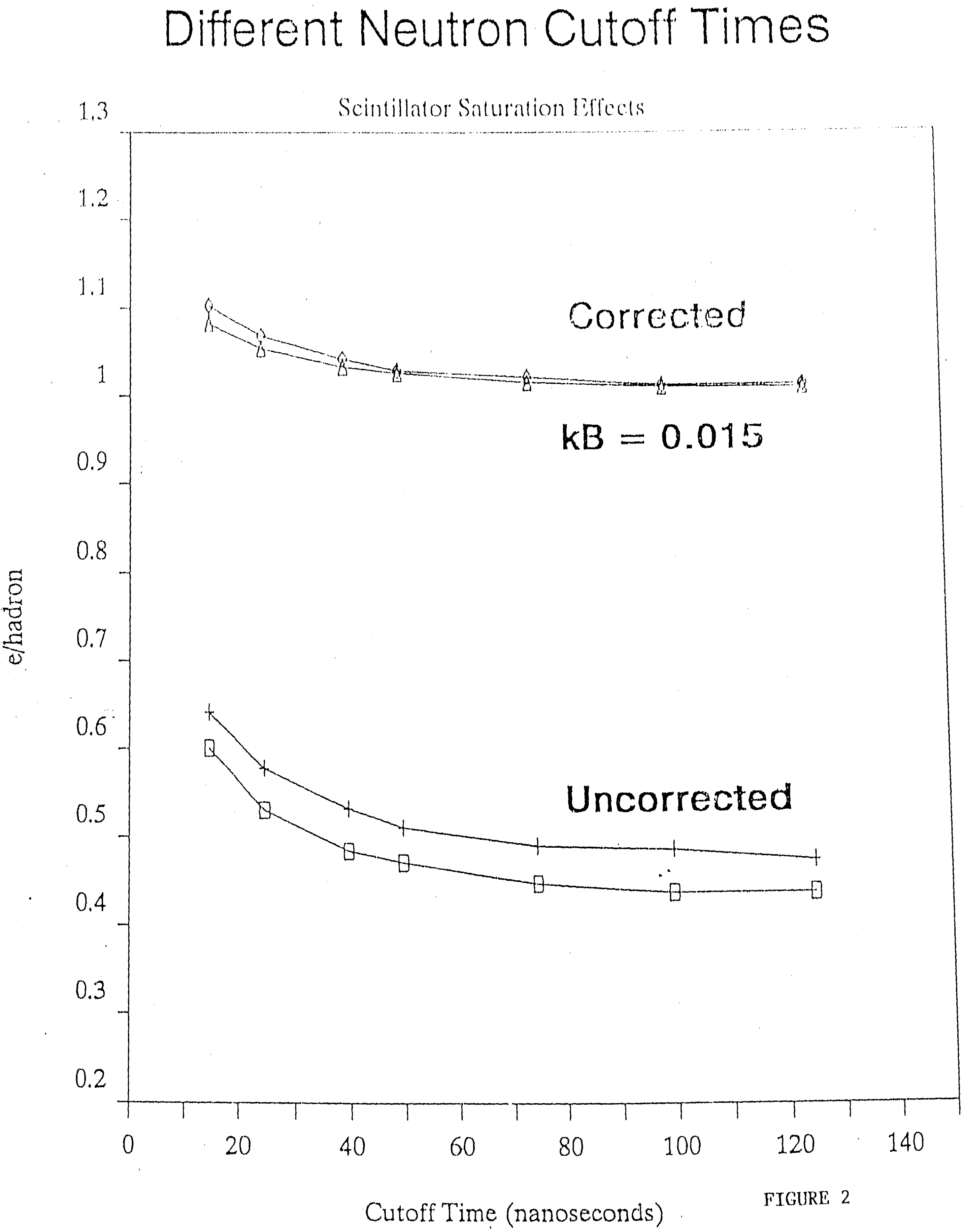

Different Neutron Cutoff Times
Scintillator Saturation Effects
Corrected
kB = 0.015
Uncorrected
e/hadron
Cutoff Time (nanoseconds)
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
20
40
60
80
100
120
140

FIGURE 2

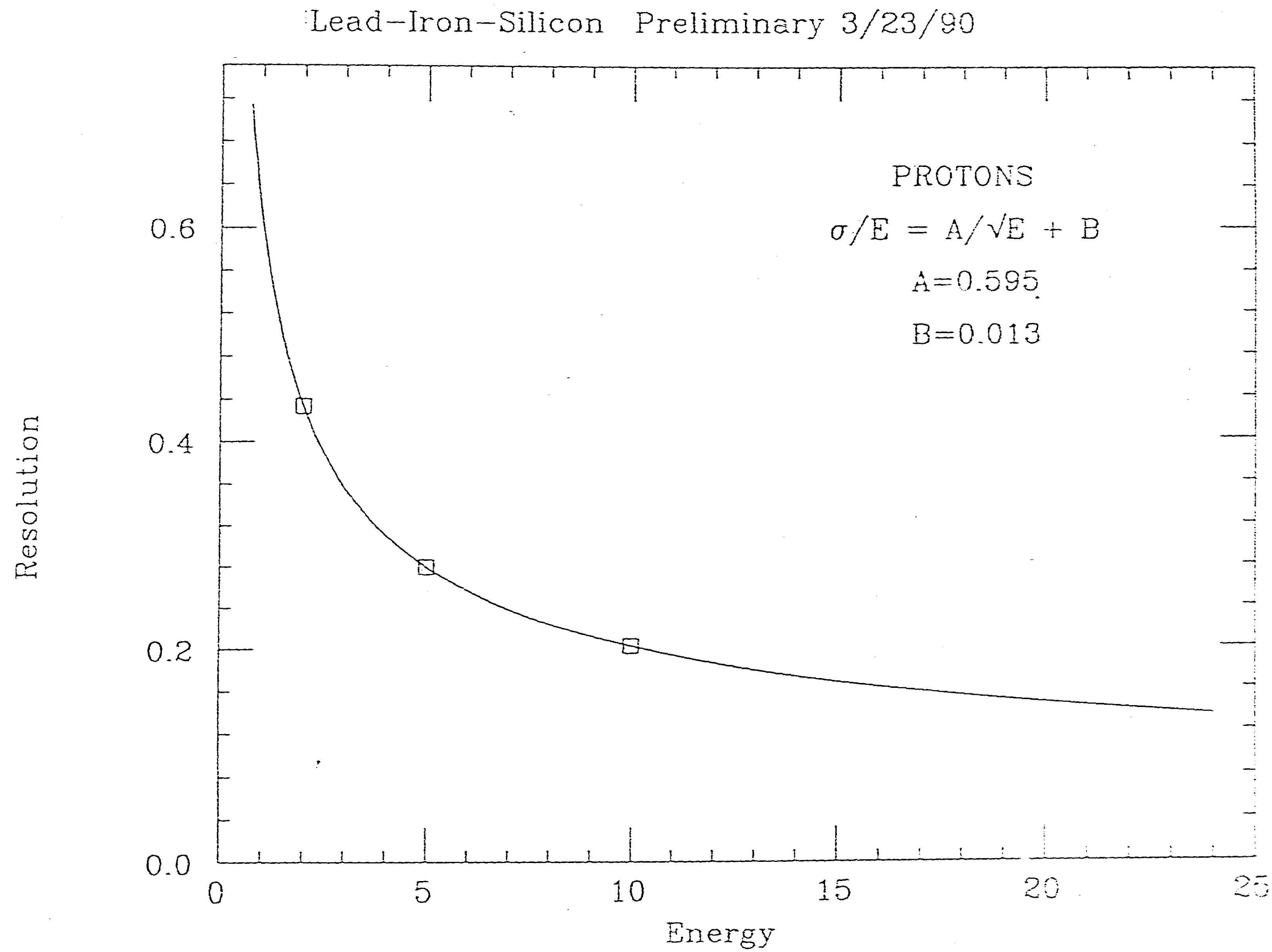
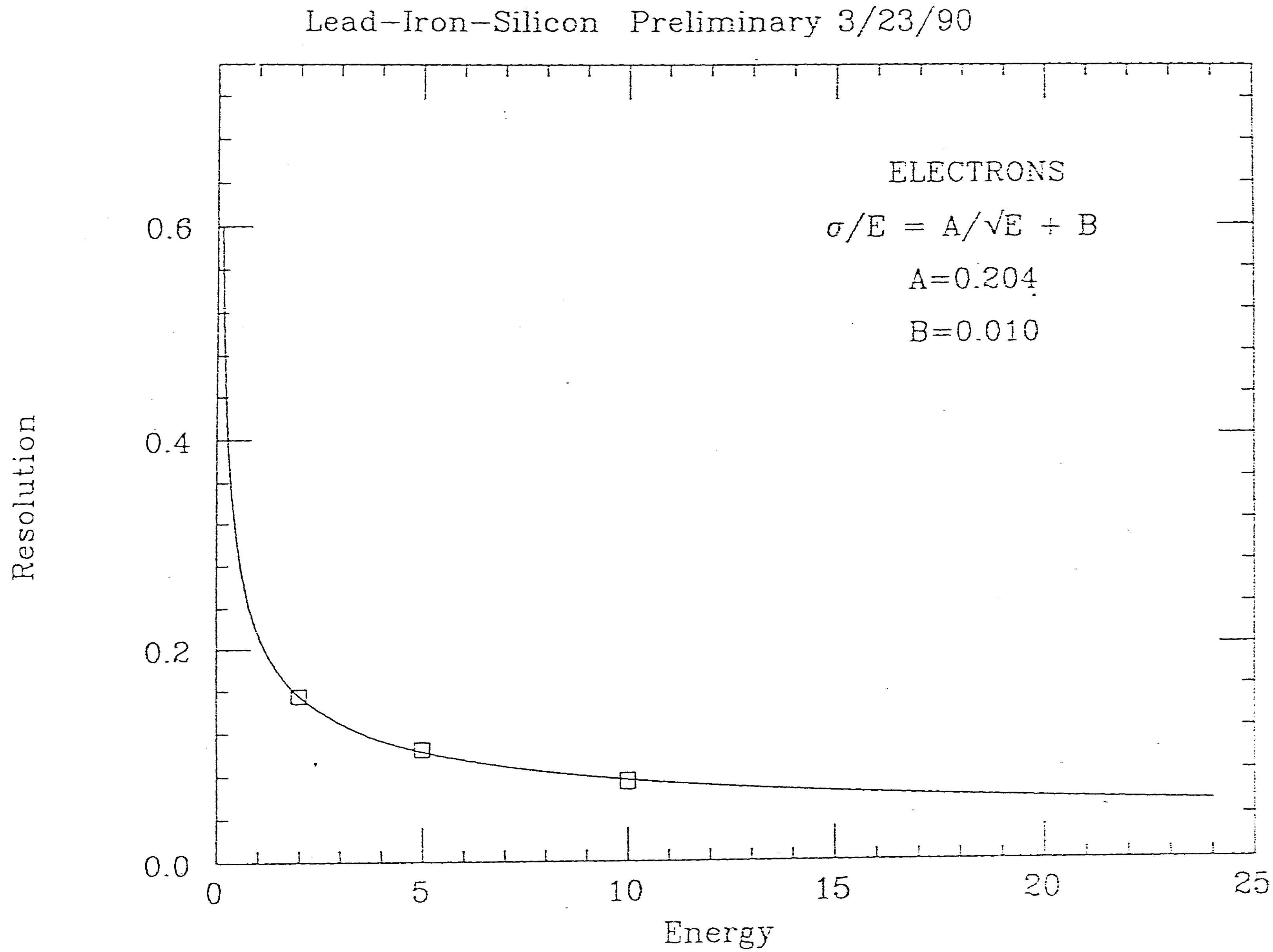

Lead-Iron-Silicon Preliminary 3/23/90
PROTONS
σ/E = A/√E + B
A=0.595
B=0.013
Resolution
0.0
0.2
0.4
0.6
0
5
10
15
20
25
Energy

FIGURE 3



Lead-Iron-Silicon Preliminary 3/23/90
ELECTRONS
σ/E = A/√E + B
A=0.204
B=0.010
0.6
0.4
0.2
0.0
Resolution
0
5
10
15
20
25
Energy

FIGURE 4

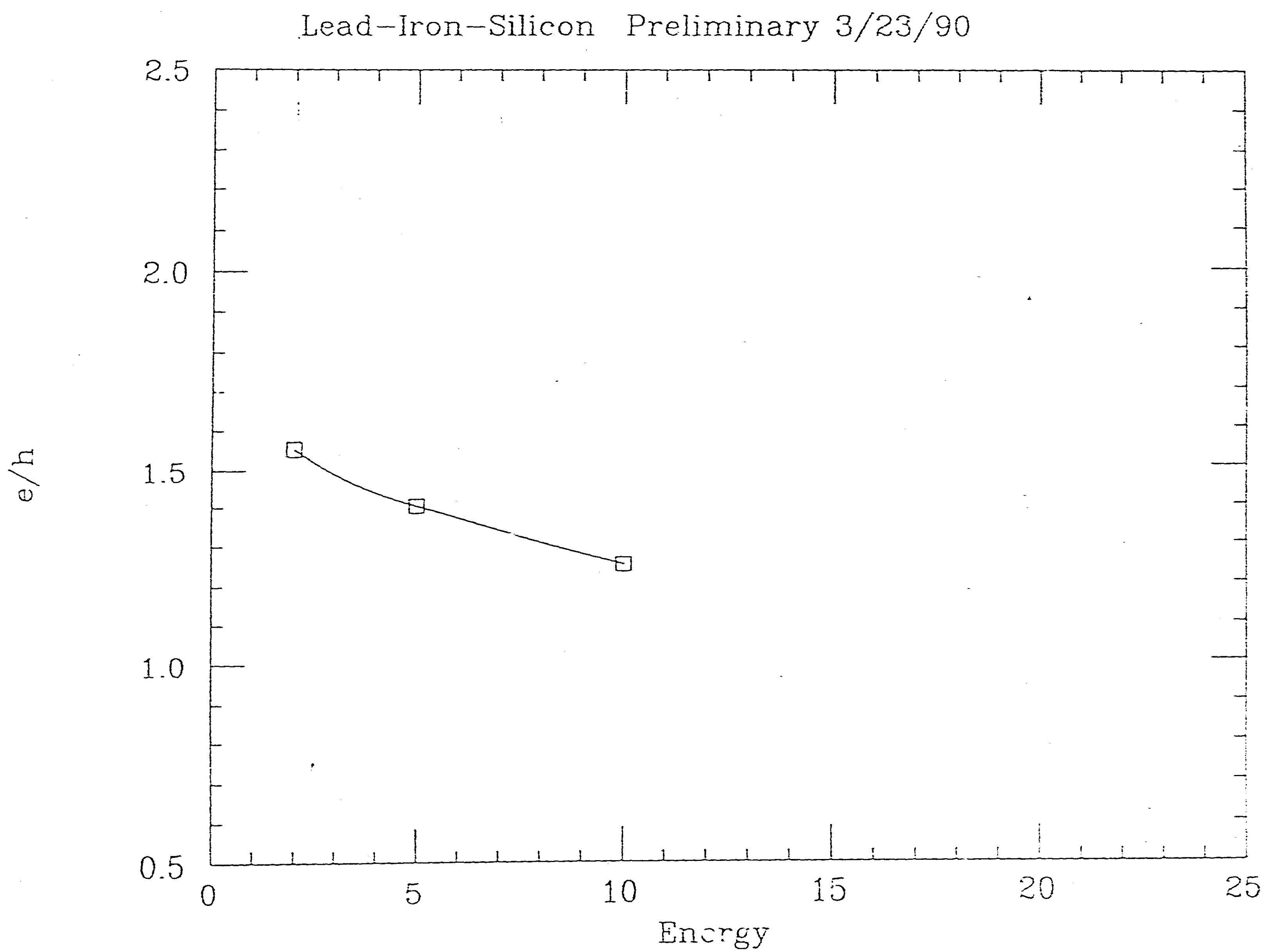

Lead-Iron-Silicon Preliminary 3/23/90
e/h
2.5
2.0
1.5
1.0
0.5
0
5
10
15
20
25
Energy

FIGURE 5

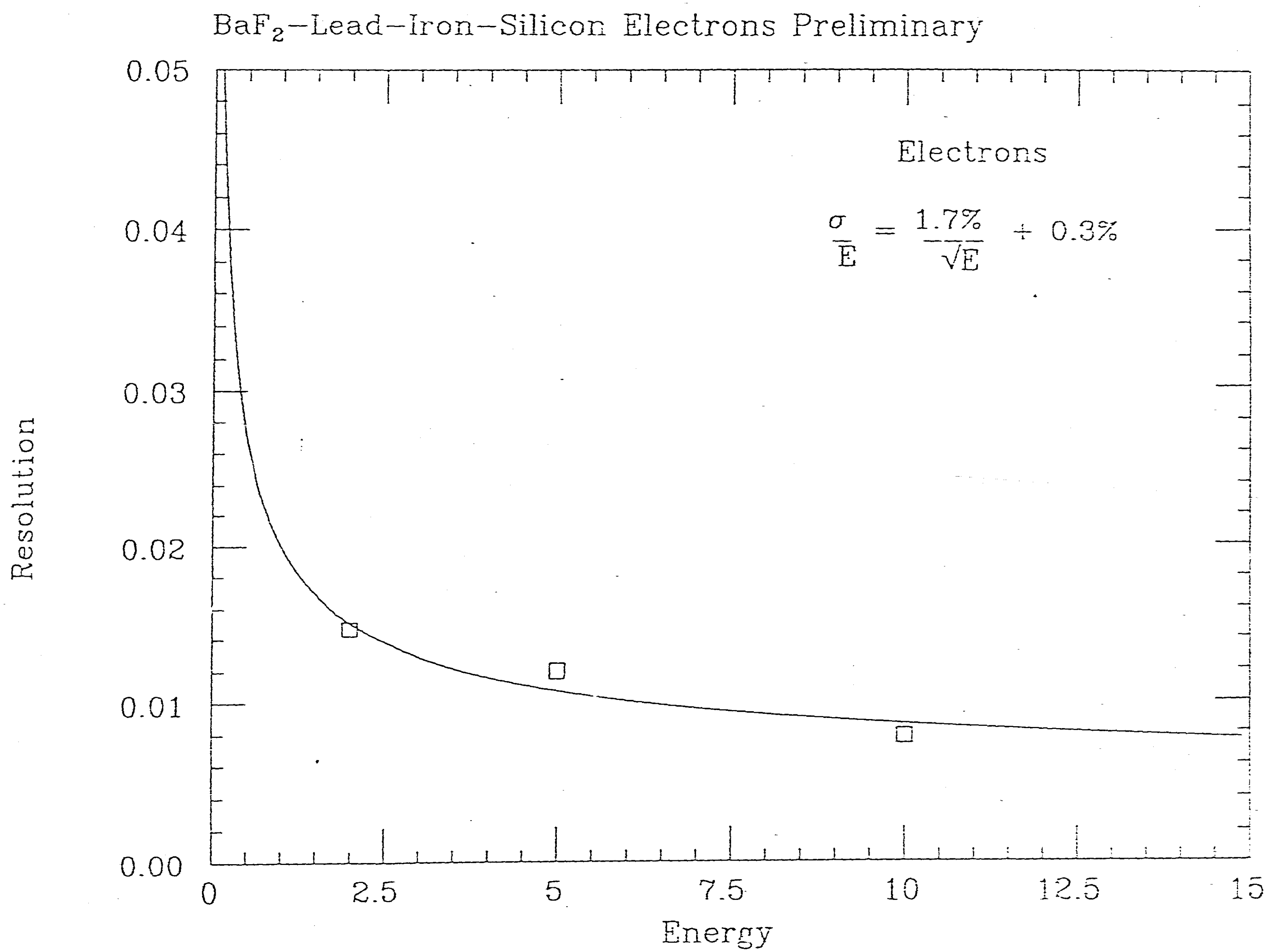

BaF2–Lead–Iron–Silicon Electrons Preliminary
Electrons
σ/E = 1.7%/√E + 0.3%
Resolution
Energy
0.05
0.04
0.03
0.02
0.01
0.00
0
2.5
5
7.5
10
12.5
15

FIGURE 6

II. SLD at SLC

SLD work has proceeded on schedule.

Cosmic Ray Test

Four silicon tungsten electromagnetic calorimeters, two luminosity monitors (23-65 milliradian) and two medium angle calorimeters (65-190 mr) have been delivered to SLAC and equipped with SLD electronics and are currently undergoing channel tests with SLD computer and on-line software. The medium angle calorimeters are installed on a specially constructed test rig designed to hold both these calorimeters and the installation version of the QCD vertex detector. Glitches in the vertex detector schedule have delayed installation of this module into the detector for cosmic ray tests now underway. Insertion of this specially designed R-20 module with VXD-1 and MASIC is now scheduled for November 10, 1990. At the same time the luminosity monitor designed and constructed in Tennessee will be mounted on final focus cryostat and tested with the full detector. The detector will move onto beam line in late 1990 and is scheduled for operation at SLC in Spring or Summer 1991.

On-Line Software

On-line software for control of data taking has been developed which is similar in principle to the Liquid Argon Calorimeter control system. Control programs have been thoroughly tested with Monte Carlo data and will be used in the upcoming cosmic ray test. R. Kroeger is in charge of this project.

Off-Line Software

Tennessee has taken responsibility for the insertion of numerous Monte Carlo generators into the SLD code, most particularly those associated with the generation of Z_0 events and Bhabba's which of course are associated to the study of luminosity efficiency of the detector. Jet finding codes and many other analyses codes for the main calorimeter and for the LMSAT and medium angle calorimeter has been modified to conform to the SLD code requirements and are now fully incorporated in the SLD off-line software system. A. Weidemann has carried out this work for the SLD collaboration as a whole and our system in particular.

Luminosity Studies

Of crucial import to the measurement of cross sections near the Z_0 is the measurement of a known cross section. The best determined theoretical cross section is for the Bhabba process $e^+ + e^- \rightarrow e^+ + e^- + n\gamma$. This has been treated most completely by Ward and Jadach and the cross sections with radiative corrections are known (at small angles) to about 0.2%. To fully test many of the predictions of electroweak theory and the standard model, one needs to measure Z_0 cross sections to comparable accuracy. This places a great burden on the elimination of systematic errors in the measurement of the Bhabba cross section. S. L. White, who has carried a complete Monte Carlo study of this measurement, has devised algorithms for the elimination of system errors (which are primarily due to uncertainties of location of the monitor with respect to the interaction point). Corrections for even relatively large displacements are possible which reduce the systematic errors from this source to values well below the systematic errors seen for samples of several times 10^5 Z_0's. Appendix B describes this work.

III. SSC Detector R and D

In the past year, we have worked on the design of EM calorimeters for the Silicon Electromagnetic Calorimeter Collaboration whose spokesman is W. M. Bugg of Tennessee. The key institutions in this collaboration are Tennessee, ORNL, University of Oregon, and to a lesser extent Carnegie Mellon University. In the absence of SSC funding until very late in the year, much of Tennessee's effort has been to organize a collection of radiation damage experts in this country and abroad with expertise ranging from solid state theory and experiment to fast electronics along with pioneer detector experts to develop techniques for improvement of radiation damage of silicon detectors. This is an extremely important question to SSC detector development not only in calorimetry but perhaps more importantly in tracking detectors. Overtures through L* have been made to physicists in the Soviet Union to work on this problem and the allied question of silicon detector procurement in the USSR which promises to be a major source of detectors for SSC calorimeters. We have set up a working relationship with the Institute of Theoretical and Experimental Physics in Moscow and the Joint Institute of Nuclear Research, Dubna to involve Russian industry and manufacturers along with University groups to establish criteria for detector performance and technique for economical production.

During the year much effort was spent on the preparation of the L* Expression of Interest to the SSC laboratory. Tennessee, ORNL and ITEP have full responsibility for construction of the central barrel calorimeter for the L* collaboration.

TASK A

IV. APPENDICES

removed and cycled separately

TASK A

V. LIST OF PUBLICATIONS AND RELEVANT REPRINTS

PROGRESS REPORT TO DEPARTMENT OF ENERGY
DOE DE-AS05-76ER03956

TASK A

V. List of Publications

1. "Charge-exchange Photoproduction of the $A_2^-(1320)$ in Association with Δ^{++} at 19.3 GeV/c," (with G.T. Condo, et al.), Phys. Rev. D41, 3317 (1990).

2. "Neutrino Counting with the SLD at the Stanford Linear Collider," (with H. Band, et al.), Annals of the New York Academy of Sciences V578, 445 (1989).

3. "Beam Test of the SLD Silicon-Tungsten Luminosity Monitor," (with S. Berridge, et al.), IEEE Trans. Nucl. Sci. 37, 1191 (1990).

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ELEMENTARY PARTICLE INTERACTIONS

PROGRESS REPORT TO DEPARTMENT OF ENERGY
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TASK B

B. F. L. Ward

TASK B

B. F. L. Ward

The research in Task B during 1989-1990 focussed on the further development and application of our new YFS (Yennie-Frautschi-Suura) Monte Carlo approach[1] to $SU_2 \times U_1$ radiative corrections in the Z° physics scenarios at the SLC and LEP. In addition, progress was made on the application of perturbative QCD methods to heavy quark decay physics, beam polarization phenomena in high energy e^+e^- collider physics, and manifestly gauge invariant covariant (closed) string field theory.

Specifically, during 1989-1990, we completed the application of our YFS[1] Monte Carlo procedure to the processes $e^+e^- \rightarrow f\ \bar{f} + n\gamma$, $f = \mu, \tau$, neutrino, quark, to the level of .1% accuracy. Thus, the LEP and SLC collaborations all have the respective YFS2 Fortran program which allows them to simulate ,in the presence of detector cuts, the effects of multiple photon radiation on an event-by-event basis; the respective multiple photon 4-vectors are included in the list of final particle 4-vectors with no restriction on their number for the first time ever in $SU_2 \times U_1$ radiative correction simulations. Additionally, we succeeded in integrating this YFS2 calculation into the pure electroweak corrections program KORALZ in version KORALZ3 [2], so that for the first time one may study the interplay of pure electroweak effects on the one hand with multiple photon effects on the other hand,on an event-by-event basis. This program KORALZ3 is now in use by all LEP and SLC collaborations and has been useful in the respective

$f\bar{f} + n(\gamma)$ final states physics analyses, $f \neq e$. It has been demonstrated that the two pure weak libraries in KORALZ3 (one by W. Hollik and one by R. Stuart) agree within .3% on the absolute normalization of the cross section near the Z^0 resonance in e^+e^- annihilation so that, for the present at SLC and LEP, we have an adequate knowledge of the respective pure weak effects. We must improve on this agreement in the not-too-distant future, in view of the current Z° production rate at LEP and the expected long term rate at the SLC.

Indeed, we have begun an independent check of the pure weak libraries by Hollik and Stuart as they are implemented in KORALZ3. This we are doing in collaboration with Prof. Zralek in Silesia, Poland and Prof. Jadach in Krakow, Poland. We have made substantial progress in our check and we hope to report on this progress soon.

In addition, we have made progress in resolving the question left by the LEP100 Line Shape Group in CERN-89-08, Vol. 1: "What is the best way of exponentiating QED corrections?." For, in their final report, the authors of the Line Shape section of the LEP100 Workshop Report were only able to show that five different methods agreed to .2-.3%. In Ref. 3, we show that the YFS-based method is the best one by looking into an exact model calculation and comparing the various ansatz's in the Line Shape Report with the exact result. Thus, our work substantiates the preference of the method based on our YFS procedure over the other naive exponentiation procedures considered in that report.

In view of the need to study in detail the cross section asymmetries in $e^+e^- \to f\,\bar{f} + n(\gamma)$ in order to complete the high precision Z° physics programs at the SLC and LEP, using YFS2 [1], we have analyzed [4], in the presence of detector cuts, the multiple photon effects in asymmetries for the cases $f = \mu$, b. We find that the multiple photon effects are significant and that $A_{FB}(b)$ at LEP is competitive with A_{LR} at SLC for its assessibility in the presence of multiple photon radiation and its sensitivity to $\sin^2\theta_W$ when the high luminosity at LEP is taken into account. Thus, it affords another path to $\sin^2\theta_W$ in the high precision Z° physics tests of the Standard Model.

Concerning the basic luminosity process $e^+e^- \to e^+e^- + n\gamma$ at low angles, we completed the implementation of our BHLUMI Monte Carlo YFS program[5] at SLC and at LEP, so that indeed the higher order corrections to the luminosity are known to 1%. This result has already played a significant role in controlling the systematic error on the measurement of the luminosity at SLC and LEP and, hence, it has made a significant contribution to the recent MkII discovery that the number of massless neutrino generations is 3 (this MkII finding was immediately corroborated by ALEPH on using our BHLUMI program to calculate the higher order corrections to their luminosity). Thus, we feel that our YFS methods have been brought to the level of implementation which was sufficient for the 1989-early 1990 scenario in bhabha scattering at low angles. However, for the current and long term SLC-LEP objectives, we must carry this level of accuracy on the bhabha luminosity process to the .2% and below .1% regimes, respectively.

Accordingly, Prof. Jadach and the PI, working with Drs. Z. and E. Was, have recently established [6] an $O(\alpha)$ baseline description of the luminosity cross section so that it is understood in absolute normalization from both an analytic and Monte Carlo standpoint at the .1% level. This will then allow us to check our Monte Carlo methods for BHLUMI for their absolute normalization to the .2% level by 11/1/90 and to below .1% ultimately with the corresponding improvement in the baseline description to the below .1% regime; we explain this in detail in our 1991-1992 renewal proposal.

What we should emphasize as one our most important successes is our work between SLAC and CERN during the period April, 1989 - September, 1989, as we described in detail in our renewal proposal for 1990-1991. For, the consistent KORALZ3 libraries and the 1% luminosity monitor higher order calculations were all put into practice at SLC and LEP as a direct result of our trips between SLAC and CERN during this period, wherein we worked directly with the CERN LEP100 EW Monte Carlo Working Group(EWMC)[2] chaired by Prof. R. Kleiss and the MkII-SLD SLC EW Working Groups chaired by Prof. P. Rankin and Prof. T. Kozanecka. Indeed, when we arrived at CERN in April, we found that the EWMC physicists were having ~ 5% discrepancies between O(alpha) luminosity monitor calculations and as much as 7% discrepancies between our YFS BHLUMI program and $O(\alpha)$ work. Working with the EWMC Group, we were able to find all the sources of these discrepancies (bad copies of codes, etc.) and achieve the 1% knowledge of the luminosity which has already played an important role in the MKII discovery and its confirmation by ALEPH. This achievement was only possible because I was able to work directly with the members of the CERN EWMC Working Group, Drs. Locci and Burkhardt of ALEPH, Dr. Dam of DELPHI, and Dr. Karlen of OPAL, for example, as we explain in our proposal for 1990-1991 and as we review in our 1991-1992 proposal.

We have recently[7] made progress in understanding the possible meanings of the value $N_\nu = 3$, where N_ν is the number of massless neutrino generations. We interpret this as evidence for an $SU(3)^f$ family symmetry which breaks at a scale ~ 100 TeV. The attendant association of the C-K-M matrix with $SU(3)^f$ mixing interactions then gives the prediction for m_t in terms of $\alpha = V_{cb}/V_{ub}$ and the light quark masses m_q, q = u,d,s,c,b (the respective formula is given in Ref. [7] and in our 1991-1992 renewal proposal). The recent CLEO-ARGUS results for α then allow us to conclude with 95% confidence that

$$67.8 \text{ GeV} \lesssim m_t \lesssim 127.9 \text{ GeV}.$$

This result is then extremely interesting from the standpoint of the CDF Standard Model limit $m_t > 89$ GeV. Perhaps, top will be discovered soon!

We should note that with Dr. Zhang, our former post-doc, and with our collaborators in Cracow, Poland, Prof. Jadach's Group, we have succeeded[8] in obtaining an analytic result for the total differential distribution in $e^+e^- \to \mu \bar{\mu} + 2\gamma$. This result and its generalizations have been used to carry our YFS2 FORTRAN simulations beyond the .1% precision regime in Z° physics. We are now beginning a similar analysis for the process $e^+e^- \rightarrow e^+e^- + 2\gamma$ with our new post-doc, Dr. S. Lomatch.

We should like to note our beam polarization analysis in Ref. 9. Here, we present and illustrate the general expectations of beam polarization in the production of possible new scalars and new fermions in $e^+e^- \rightarrow X$ near the Z° resonance. We find that, for example, the right-left positron polarization asymmetry in the single transverse electron beam polarization asymmetry allows one to study the SUSY chiral mixing angle in the scalar electron pair production, for example. Thus, it is indeed exciting that the SLC has already started the implementation of beam polarization and we await the exploration of such phenomenological possibilities by the SLD.

In the area of QCD methods in heavy quark decay physics, we most recently[10] analyzed the decay $B \rightarrow \psi/JK^*_+$ from the standpoint of the luminosity requirement for CP violation studies at a SLAC-type B-Factory. We find that, in three relativistically invariant models, the CP even decay final state is dominant so that, indeed, this decay can be used for CP violation studies at a SLAC-type B-Factory. The attendant reduction in luminosity required is ~ 2.5. In fact, our result for the Lepage-Brodsky theory prediction for this decay is in agreement in detail with recent measurements by ARGUS[11].

Finally, we had a small amount of time to devote to our quantum gravitation research. The recent result[12] is a solution for the ground state of string theory in the open string case. We used the methods of the operator field to show that the tachyon is really absent in the true spectrum of the theory. We may now hope to incorporate this result into our earlier results[12] for the manifestly gauge invariant closed string field theory to arrive at a sound physical framework from which to study the true spectrum of the heterotic string theory of Gross et. al. eventually. We must emphasize that our pre-occupation with SLC-LEP physics research will not allow us to devote very much time to string theory, however. And, this is as it should be.

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Task B

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6. Kleiss, R. et al., "Electroweak Generators," in Proc. LEP100 Workshop, CERN-89-08, Vol. 1, ed. G. Altarelli (CERN, Geneva, 1989).

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8. Jadach, S., Ward, B. F. L., Was, E. and Zhang, H., "Exact Results on $e^+e^- \to \mu^+\mu^- + 2\gamma$ in the Z° Resonance Region," Phys. Rev. D42, 1990, in press.

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10. Ward, B. F. L., "On the Ground State of String Theory," University of Tennessee preprint UTHEP-90-0101, 1990.

11. Jadach, S. and Ward, B. F. L., "Multiple Photon Effects in Asymmetries: $\mu\bar{\mu}$ vs $b\bar{b}$", Phys. Rev. D42, Sept. 1, 1990, in press.

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ELEMENTARY PARTICLE INTERACTIONS

PROGRESS REPORT TO DEPARTMENT OF ENERGY
DOE DE-AS05-76ER03956

TASK C

F. E. Close

a) Nuclear physics/particle physics interface

There has been much interest in the quark structure of nuclei as revealed by the EMC effect. The original global effect is averaged over quarks throughout the nucleus, but ways have now been devised to locate where in the nucleus the scattering centre is. Various models, devised to explain the global EMC effect, have been analyzed to determine their predictions for local effects. It is found that both the QCD rescaling model and the conservative nuclear binding model predict a larger EMC effect for scattering from a central or deeply-bound constituent than for scattering from a surface or weakly-bound constituent. (RAL-Tennessee collaboration)

b) Spin structure of hadrons

The EMC data on the polarized structure function $g_1(x)$ for the proton have been claimed to conflict with QCD theory. It has been shown that this claim is unfounded and relies in part on the use of an incorrect or outdated value for the F/D ratio for hyperon decays. It turns out that conclusions from the EMC experiment as to the amount of strange-sea polarization are rather sensitive to this value, and that the magnitude of the strange polarization is probably somewhat smaller than has been supposed.

A new investigation has been made into the ways that spin structure may be probed in lower-energy photo- and electro-production of nucleon resonances. A new opportunity for such investigations is about to open up at CEBAF (Continuous Electron Beam Accelerator Facility) in the USA. The calculations are performed in the quark model with QCD mixing effects treated consistently through order v^2/c^2 for the quarks. It is found that the successes of the non- relativistic quark model are preserved, that some problems are removed, and that QCD mixing effects may become important with increasing momentum transfer in electroproduction. For the first time it has been possible to describe both hadron spectroscopy and transitions in a unified treatment. (RAL- Tennessee collaboration)

Jaffe has proposed a new spin-dependent structure function $b_1(x)$ that can arise for nuclei with spin ≥ 1 such as the deuteron. It has been discovered that this structure function satisfies a sum rule $\int dx b_1(x) = 0$ in the quark model, if the sea of quarks and antiquarks in the nucleus is unpolarized, or if the nuclear forces are dominated by single pion exchange.

c) Nature of 0^{++} hadrons

It is generally agreed that the lightest glueballs have quantum numbers $J^{PC} =$

0^{++}. In order to aid their identification it is important to understand in detail the nature of the presently known scalar mesons, in particular the $a_0(980)$ and $f_0(975)$. To complement the dynamical studies of these states (Weinstein et al $K\bar{K}$ molecule studies) we have re-evaluated the theory of $\gamma\gamma$ couplings of light quark systems in the belief that such electromagnetic interactions provide rather sharp probes of the flavour content of hadrons. We find that the existing literature, which compare the 0^{++} and 2^{++} meson couplings, is incomplete or even wrong in that ideas applicable for heavy quark systems (b or c) have been applied uncritically out of their range of validity. We intend to complete a self-consistent theoretical formalism and then identify what are the cleanest experiments that can probe the scalar mesons.

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Co-author of HEPAP Subpanel on US HEP Research Program for the 1990s (Sciulli Committee) US DOE/ER-0453P

Rapporteur on "Deep Inelastic Scattering", 25th Rochester Conference on HEP, Singapore August 1990

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The role of coloured quarks and gluons in hadrons and nuclei, Proc of Taiwan Spring School on Physics, May 1990

ELEMENTARY PARTICLE INTERACTIONS

PROGRESS REPORT TO DEPARTMENT OF ENERGY
DOE DE-AS05-76ER03956

TASK D

L. G. Christophorou,
H. Faidas, and D. L. McCorkle

TASK D

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TASK D

"BASIC RESEARCH ON MATERIALS FOR HIGH ENERGY PHYSICS DETECTORS"

Progress Report
(October 1, 1989 - September 30, 1990)

L. G. Christophorou, H. Faidas, D. L. McCorkle

Summary

The specific tasks performed over the past year can be summarized as follows:

A. Warm-liquid detectors (calorimeters)

1. Development of a laser photoinjection technique to measure electron drift velocities, w, and mobilities, μ, in liquids. The combination of fast lasers and fast electronics makes our technique the most accurate to date for the measurement of w in ultrafast liquids.

2. Use of our technique to measure w and μ as a function of the applied electric field, E, in fast neat liquids (tetramethylsilane (TMS), tetramethyltin (TMT), tetramethylgermanium (TMG), 2,2 dimethylbutane (TMC), 2,2,4,4-tetramethylpentane (TMP) and tetraethylsilane (TES)], and their mixtures.

3. Purchase and incorporation into our experimental system of a new ultrashort pulse N_2 laser (with dye laser and frequency doubler) with pulse duration of ~600 ps. Measurements with this laser will permit us to analyze

the electron drift current waveforms and deduce the electron transport properties and parameters.

4. Studies of the effects of electrical breakdown on liquid decomposition and on the subsequent performance of liquid containing cells.

5. Preliminary assessment of the electrical and other properties of the above fast warm liquids for use in radiation detectors.

6. Preliminary measurements (calibration) of the warm liquid free electron yield, G_{fe}, measurement apparatus.

B. Cryogenic liquids

Calculations of solubilities of various additives in cryogenic liquids, in order to improve their w and G_{fe}.

C. Gases for muon detectors

Electron drift velocity measurements and mean electron energy, $\langle \epsilon \rangle$, and lateral diffusion coefficient calculations for multicomponent-gas mixtures suitable for muon detectors. These studies are part of a collaborative effort between UT, ORNL and MIT to develop and characterize multicomponent gases for muon detectors.

I. Experimental Technique

Figure 1 shows schematically the experimental setup. A laser pulse (308 nm ~ 15 ns or 337 nm ~ 600 ps) struck a metal cathode (stainless steel or aluminum) and injected electrons that drifted across the cathode-anode distance, d, under the influence of an applied uniform electric field $E = V/d$ where V is the applied voltage. The signal was measured as a voltage (Fig. 2a) or current (Fig. 2b) waveform. From these waveforms the drift time, τ, $w = d/\tau$ and $\nu = w/e = d^2/\tau V$ were determined. Numerical differentiation of the current waveforms gave the rate of charge injection at the cathode and charge collection at the anode (Fig. 2c,d). Analysis of the current and charge injection waveforms can give information on the electron transport parameters and the electron states in the liquid (see Appendices B through D).

It should be noted that our laser photoinjection technique has yielded μ and w values for fast warm liquids that are consistently 10-20% higher than similar values measured with conventional bulk ionization techniques. Other researchers using a similar photoinjection technique also measured μ values in liquid methane that were 20% higher than previously measured values. We recently attended the 10th International Conference on Conduction and Breakdown in Dielectric Liquids in Grenoble, France, where we presented our technique and data. It was generally acknowledged that our photoinjection technique is the most accurate to date for measuring w in fast liquids.

II. Purification of the Liquids

The liquids, although fairly pure as purchased (TMS, 99.9%; TMP, 99.99%, TMT, 99%; TMG, 99%; TMC, 99.9%; TES, 95%) require further purification to remove electronegative and/or polar impurities that might capture the electrons produced in them. Drawing on our previous experience in working with nonpolar liquids we developed the following purification protocol:

1. Stirring with H_2SO_4 to remove olefinic impurities (molecules with double bonds);
2. Stirring with $BaCO_3$ to neutralize the H_2SO_4;
3. Preliminary freeze-pump-thaw to remove dissolved air
4. Passage through traps of NaOH, silica gel and activated charcoal to remove CO_2 and H_2O;
5. Passage through liquid nitrogen traps while pumping to remove O_2 and N_2;
6. Storing and stirring over liquid NaK to remove any remaining traces of O_2, H_2O and halogen containing compounds;
7. Transfer into the cell through a 0.5-μ filter.

The above method was followed for TMS, TMP, TMC, TMG, TES and n-pentane. Because TMT reacts with H_2SO_4 and NaK the corresponding purification steps were omitted. For TES, because of its very low vapor pressure, to speed up the liquid transfer the traps had to be heated; this made the purification ineffective (see below).

III. Cleaning of the Cell

The cell components (cell body, windows, feedthroughs, flanges, valves and electrodes) were cleaned in the following way:

1. Rubbing with ethanol or acetone wetted cotton applicators to remove any deposits from previous experiments.
2. Cleaning with acetone in an ultrasonic bath for 1 to 2 hours.
3. Drying in an evacuated oven at 150°C.
4. Following assembly, heating to 200°C and pumping down to 1 x 10^{-7} Torr for several days before the liquid is introduced into the cell.

IV. Results on Warm Liquids

Figures 3a,b show w(E) and $\mu(E)$ for neat TMC, TMS, TMG, TMT and TMP, while Figs. 2c,d show the same data for the mixtures. Table 1 lists the neat liquids/mixtures studied, the mole fraction of the mixtures, the critical field E_c, above which the mobility decreases (the electrons become hot), the thermal electron mobility, μ_{th}, the maximum E-field reached without having an electrical breakdown (EB) and the corresponding maximum drift velocity measured w_{max}. In TES we were unable to measure its low field mobility and the w-values because the electrons were attached by impurities before they were collected. At any rate this liquid appears to be so slow that it is of no interest for detector applications.

V. Findings on Warm Liquids Relevant to High Energy Physics Detectors

Table 2 shows the comparative properties of TMC, TMS, TMG, TMT and TMP. In all liquids except TMT EB occurred at E > 10^5 V cm^{-1}. The TMS/n-pentane mixtures appear to have relatively higher dialectric strenghts. All liquids underwent various degrees of decomposition after an EB. In TMS it was minimal and did not noticeably effect the subsequent performance of the system or the measurements. In TMG and more so in TMT extensive liquid decomposition occurred, the cell surfaces were covered with heavy layers of Ge and Sn[1] (see Fig. 4) respectively and the dielectric strength of the liquids was lowered to ~20 to 30 kV cm^{-1}. In TMP and TMG electronegative impurities were formed that reduced the free electron lifetime to less than ~100 ns and ~10 ns respectively. Gas chromatographic analyses of the samples detected electronegative impurities but were otherwise inconclusive. The compatibility of TMS and stainless steel appears to be good. Figure 5 shows mobility data in TMS taken with a fresh sample (open circles) and the same sample after 2 months in the stainless steel cell under voltage (X's).

[1]Analyses by the ESCA technique of the cell surfaces after an EB with TMT and TMG showed the existence of layers of tin and germanium and their oxides, respectively. The oxides comprising the outer layers were probably formed after the cell surfaces were exposed to air.

VI. Additives for Cryogenic Mixtures

Our earlier studies have indicated that the performance of cryogenic liquid-filled detectors may be enhanced by two types of additives to the basic liquid (Ar or Xe) in a binary or ternary system. These include (1) molecular additives in concentrations of 0.5 to 5% that increase the electron drift velocity, especially at high fields and (2) low ionization threshold additives in ppm concentrations to improve G_{fe} and thus the detector sensitivity.

Using the Scatchard-Hildebrand theory, we calculated the solubilities for a number of molecular additives with a spherical shape. For liquid Xe in the 165-178 K range the solubilities are: 75-100% for TMS, 40-50% for TMC, 25-40% for TMP, 45-75% for TMG, and 25-35% for TMT. For Ar in the 87-100 k range they are: 0.2-0.3% for TMS, 3-4% for TMC, 0.02-0.06% for TMP, 0.03-0.1% for TMG, and 0.03-0.07% for TMT. From these calculations it appears that in LXe all of the above additives can be dissolved in concentrations sufficient to increase both w and G_{fe}, while in LAr only TMC can do so.

Besides solubility a generic program on cryogenic additives must consider the following questions: (1) how to match the absorption spectrum of the ionizable additive to the emission of the liquid; (2) how to avoid absorption of the radiation by non-ionizing additives; and (3) the effects of radiation damage and decomposition of the additives. These questions are important if the usefullness of the cryogenic additives is to be assessed.

VII. Gases for Muon Detectors

We have measured w and have performed mean electron energy, $\langle\epsilon\rangle$ calculations as a function of E/N for a number of gaseous mixtures, namely CO_2/CH_4, $Ar/CF_4/NH_3$ and Ar/TMS (see Figs. 6-10). These preliminary results show that it is possible to develop multicomponent gases that are both fast ($w > 10^7$ cm s^{-1}) and cool ($\langle\epsilon\rangle < 1$ eV). While these mixtures appear promising based on their w and $\langle\epsilon\rangle$ values, a number of other properties need to be investigated before an assessment can be made of their usability for muon detectors. These include their free electron yield, their electron attachment rate constant as a function of E/N or $\langle\epsilon\rangle$ and their electrical properties such as breakdown and corona inception voltage and decomposition.

VIII. Publications/Presentations

1. L. G. Christophorou, H. Faidas, and D. L. McCorkle, "Ultrafast and Ultrasensitive Dielectric Liquids/Mixtures: Basic Measurements and Applications." Paper presented at the 6th International Swarm Seminar, Glen Cove, New York, August 2-5, 1989. To be published in Non-Equilibrium Effects in Ion and Electron Transport, E. E. Kunhardt, R. Van Brunt, J. Gallagher, and D. Hudson (Eds.), Plenum Press, New York. (Appendix A)

2. H. Faidas, L. G. Christophorou, and D. L. McCorkle, "Drift Velocities of Excess Electrons in 2,2,4,4-Tetramethylpentane and Tetramethylsilane: A Fast Drift Technique," Chem. Phys. Lett. 163, 495 (1989). (Appendix B)

3. H. Faidas, L. G. Christophorou, and D. L. McCorkle, "Novel Liquids for the SSC Calorimeter," 1990 International Industrial Symposium on the SSC, Miami Beach, Florida, March 14-16, 1990.

4. H. Faidas, L. G. Christophorou, D. L. McCorkle, and J. G. Carter, "Electron Drift Velocities and Electron Mobilities in Fast Room-Temperature Dielectric Liquids and Their Corresponding Vapors," Nucl. Instr. and Meth. (in press). (Appendix C)

5. H. Faidas, L. G. Christophorou, and D. L. McCorkle, "Electron Transport in Fast Dielectric Liquids at High Applied Electric Fields." Paper presented at the 10th International Conference on Conduction and Breakdown in Dielectric Liquids, Grenoble, France, September 10-14, 1990. Published in the Conference Record 10th ICDL, P. Atten and R. Tobazeon (Eds.), pp. 34-38. (Appendix D)

6. H. Faidas, L. G. Christophorou, D. L. McCorkle, and J. G. Carter, "Electron Drift Velocities in Fast Dielectric Liquids and Their Vapors." Paper presented at the 6th International Symposium on Gaseous Dielectrics, Knoxville, Tennessee, September 24-27, 1990.

7. H. Faidas, D. L. McCorkle, and L. G. Christophorou, "Warm Liquids for SSC Calorimetry: Electron Transport and Electrical Properties," and L. G. Christophorou, P. G. Datskos, and J. G. Carter, "Gases for an SSC Muon Detector." Papers to be presented at the Symposium on Detector Research and Development for the Superconducting Super Collider, Fort Worth, Texas, October 15-18, 1990.

IX. Conclusions

Based on our results to date the following conclusions can be drawn:

(1) TMS and its mixtures with n-pentane appear the most promising in terms of drift velocity (and therefore speed), dielectric strength, and decomposition by-products.

(2) TMT has excellent drift velocity properties, but is poor in terms of dielectric strength and decomposition by-products.

(3) TMP while being a fast liquid is significantly slower than either TMS or TMT. It has relatively good dielectric strength, but the electronegative impurity produced in it following breakdown is a potential problem.

(4) TMG has high dielectric strength and high speed (higher than TMS for $E > 2 \times 10^4$ V cm^{-1}) but suffers from severe decomposition following an electrical breakdown.

(5) More work is needed on identifying ways to:

-- increase the dielectric strength

-- reduce the severity of breakdown

-- avoid the formation of harmful by-products.

TABLE 1

Mole Ratio M, Critical Electric Field E_c, Thermal Electron Mobility μ_{th}, Maximum Electric Field E_{max}, and Maximum Electron Drift Velocity w_{max}, for the Fast Neat Liquids and Mixtures Studied.

Liquid/Mixture	M	E_c (kV cm^{-1})	μ_{th} (cm^2 s^{-1} V^{-1})	E_{max} (kV cm^{-1})	w_{max} (10^6 cm s^{-1})
TMC	Neat	3.5	71.5	116[a]	3.3
TMS	Neat	7	119.3	125	7.2
TMG	Neat	15	114.7	109[b]	7.4
TMT	Neat	30	85.7	75	6.0
TMP	Neat	15	31.8	115	2.6
TMS/TMP	1.31/1	18	39.1	105	3.2
TMS/n-pentane	102/1	7	118	105[a]	6.8
TMS/n-pentane	17/1	8	85	145[a]	6.8
TMS/n-pentane	5.6/1	15	47.6	145	4.9

[a]E_{max} was not limited by electrical breakdown.

[b]Electrical breakdown occurred at 120 kV cm^{-1}.

TABLE 2

Comparative "Practical" Properties of TMC, TMS, TMG, TMT, and TMP

Liquid	Purification	Drift Velocity	Dielectric Strength	Effects of Electical Breakdown
TMC	Easy/Quick	Intermediate	High	
TMS	Easy/Quick	Fast	High	No apparent liquid deterioration. Damage to electronics/ pitting of electrodes.
TMG	Easy/Quick	Fast	High	Extensive liquid decomposition rendered system unusable. Electronegative impurity(ies) formed. Damage to electronics/pitting of electrodes.
TMT	Difficult (reacts with H_2SO_4 and NaK)	Fast	Low	Same as TMG
TMP	Slow	Slow	High	Electronegative impurity(ies) formed.

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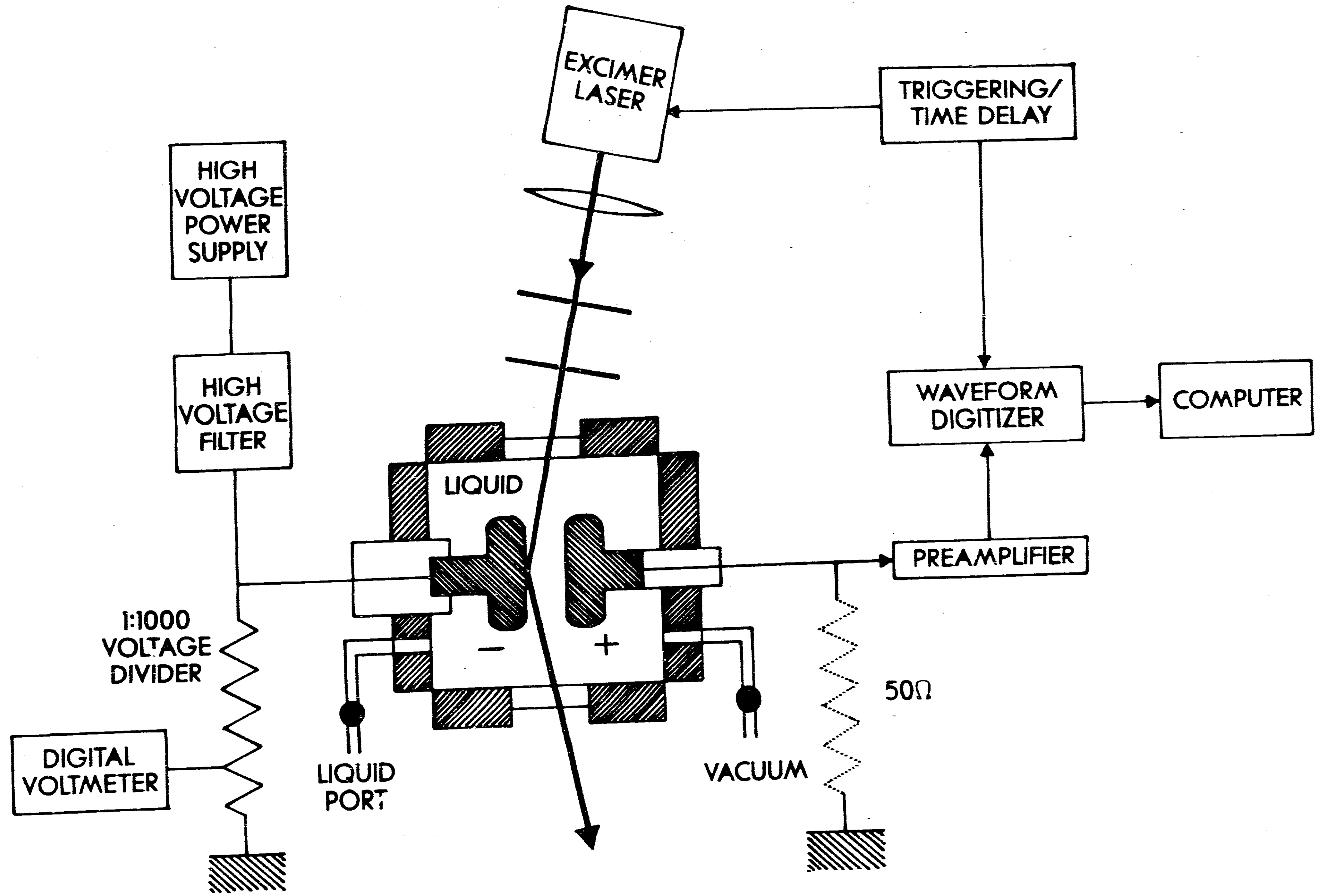

FIG. 1. Experimental set-up

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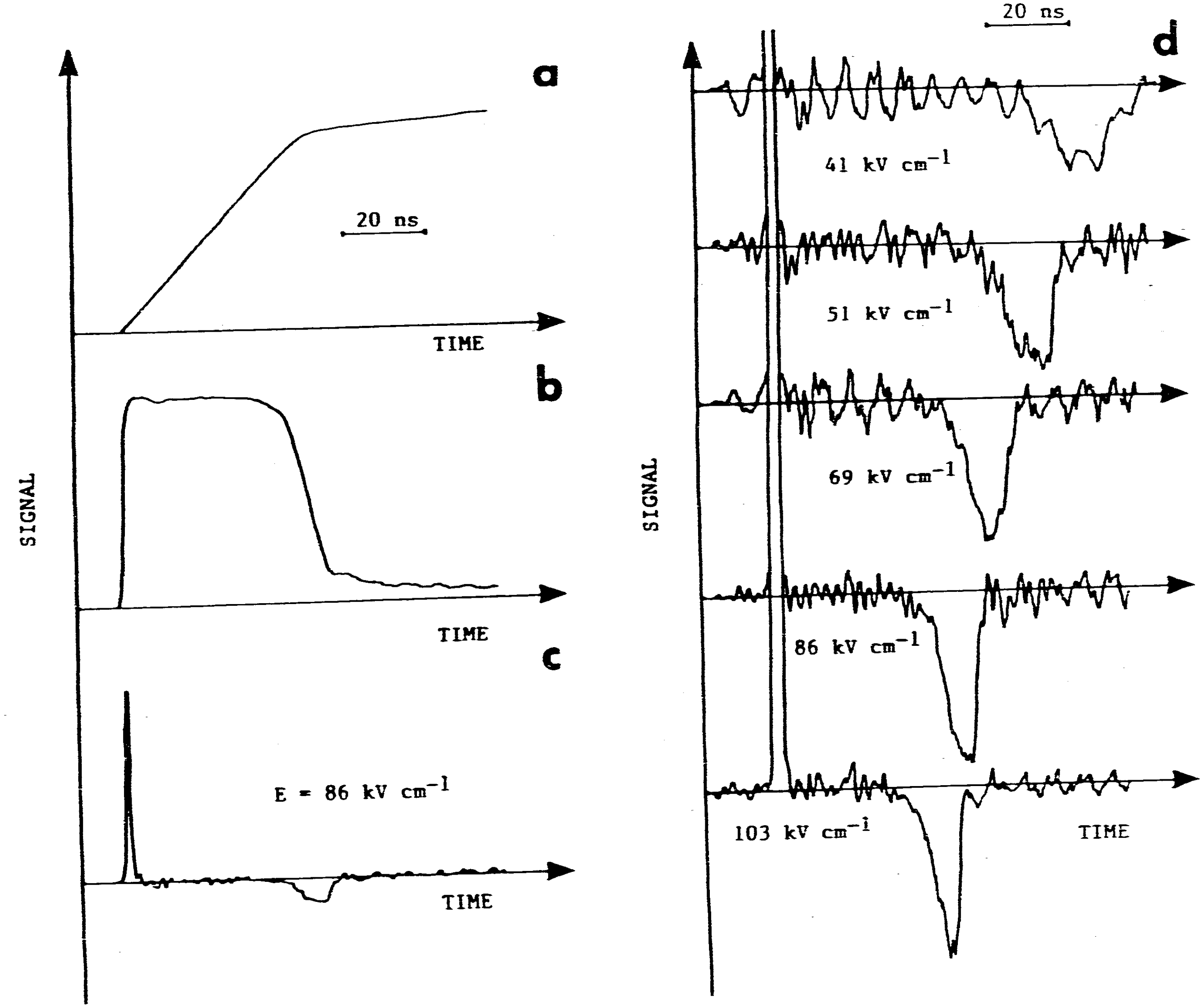


FIG. 2. (a) Voltage, (b) Current and (c,d) Charge injection wave-forms in TMG with a N_2 laser (600 ps pulse duration d=3.65 mm)

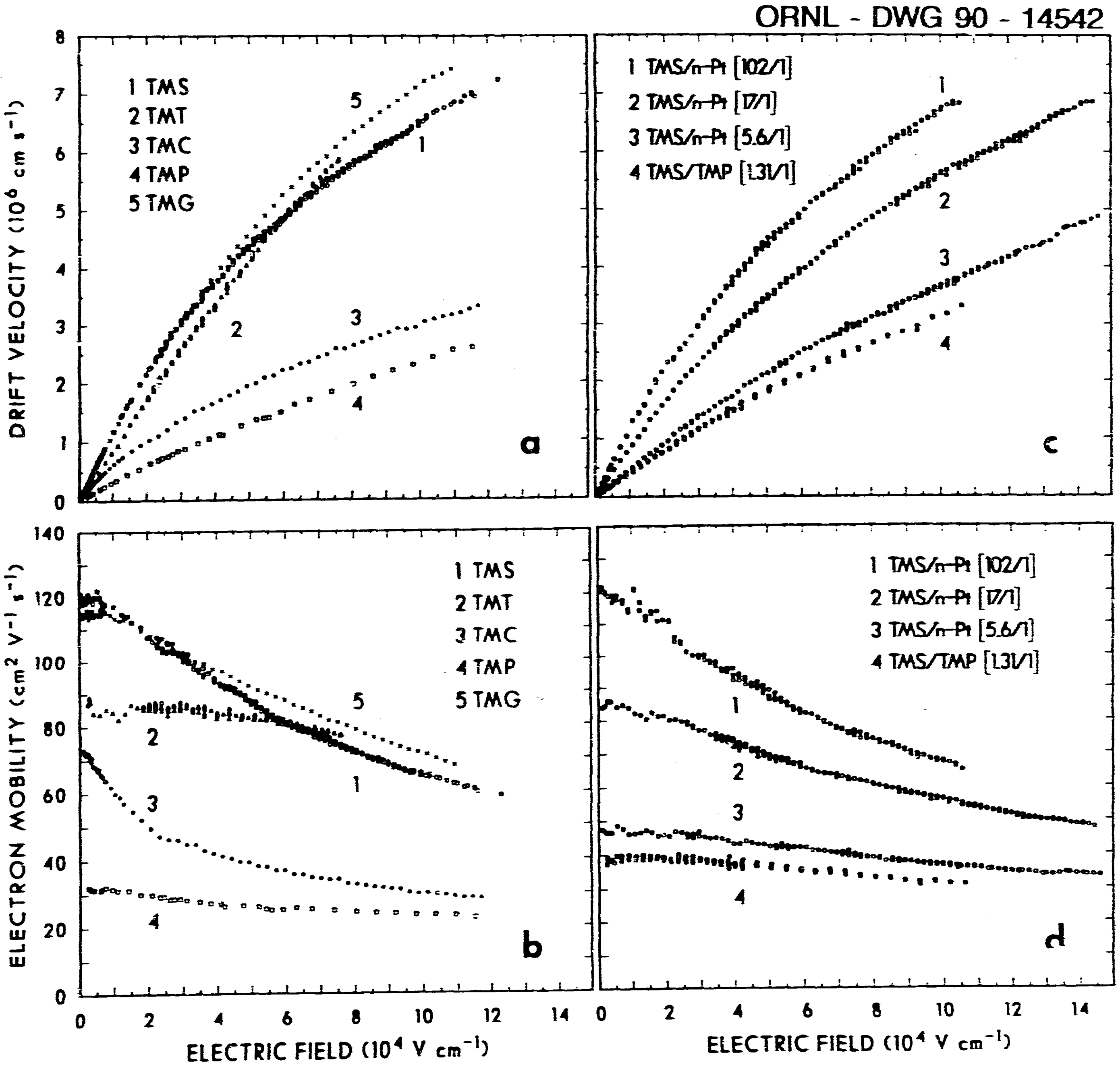


FIG. 3. Electron drift velocity and mobility measurements in fast neat liquids and mixtures

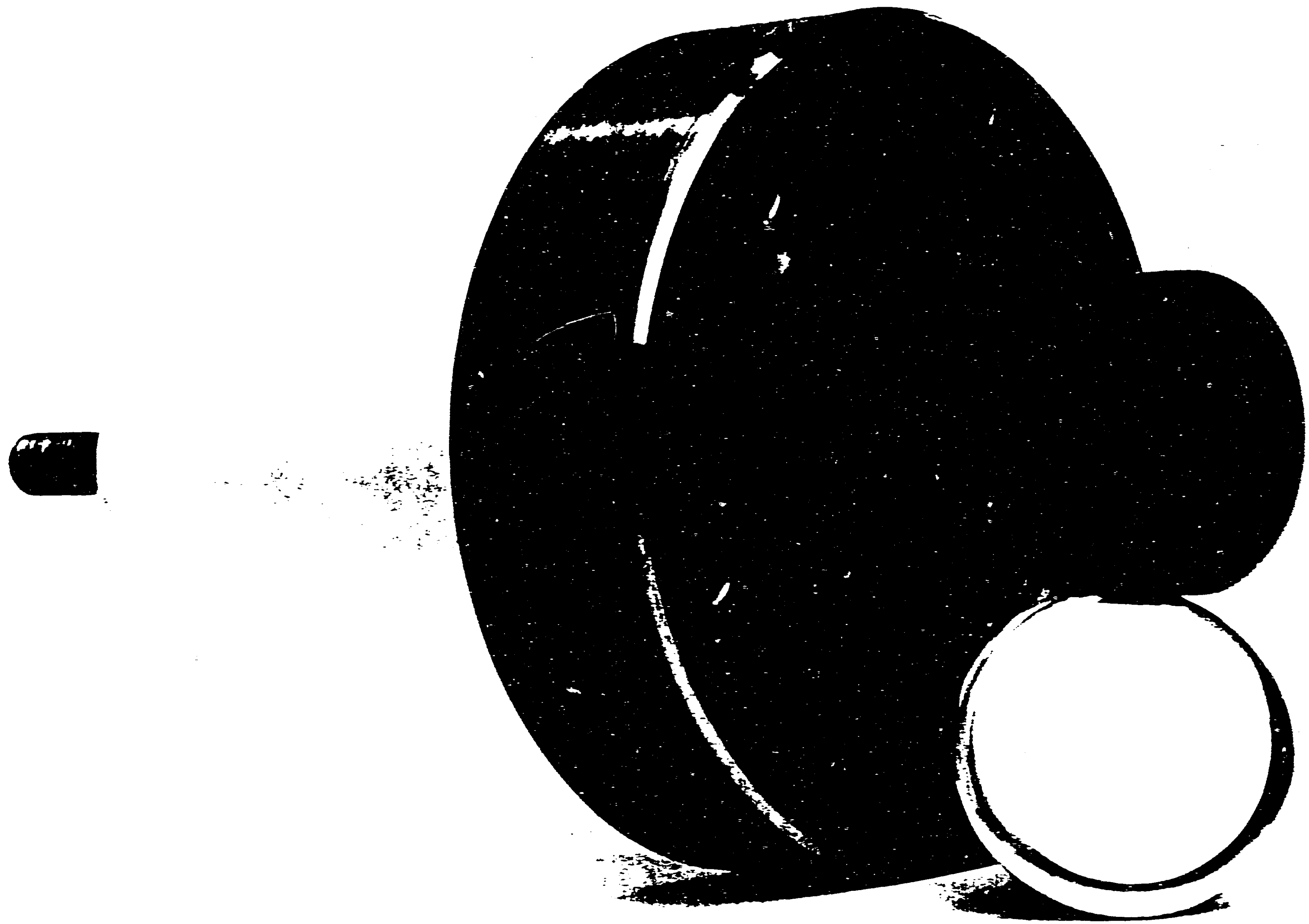
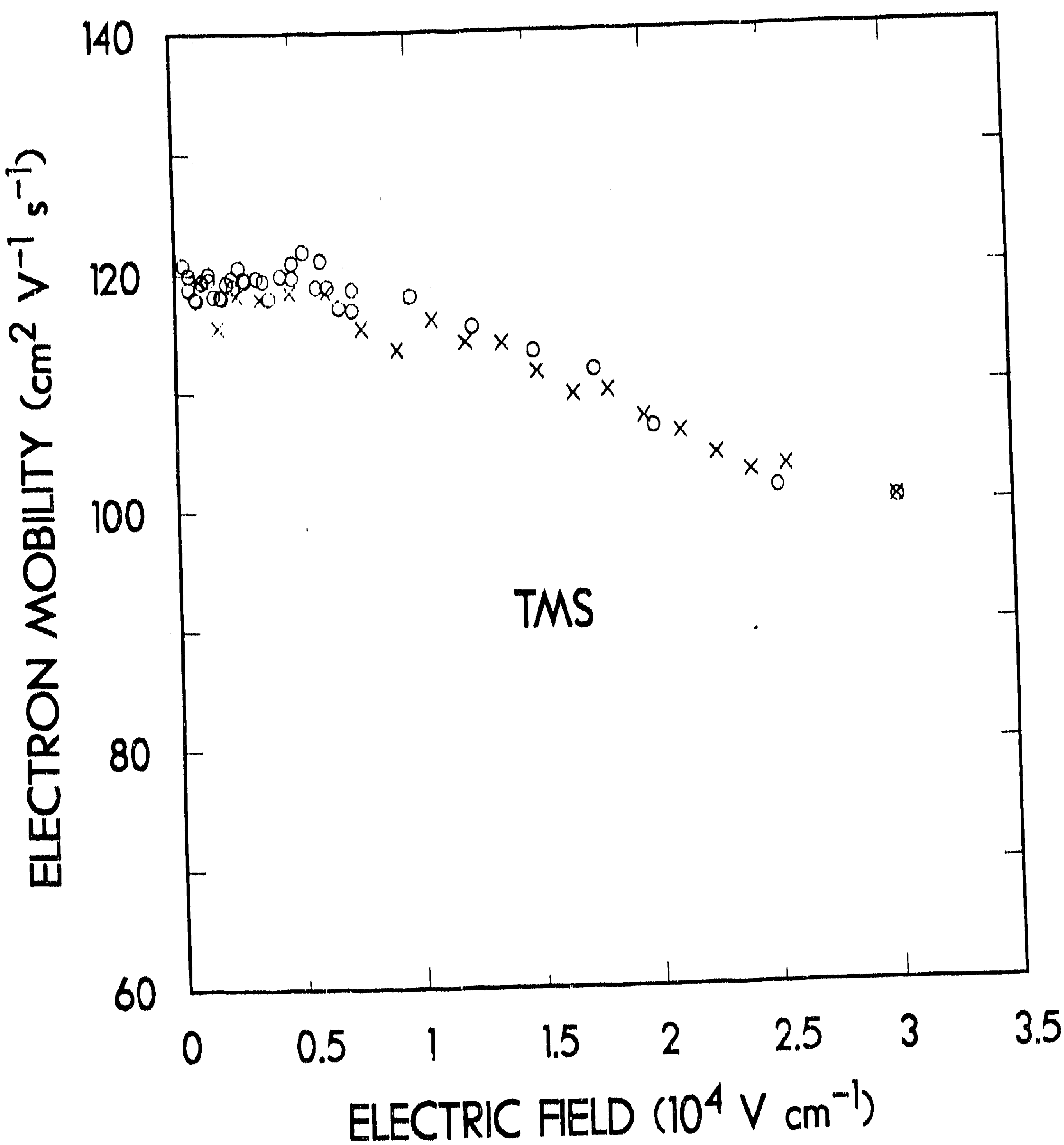


FIG. 4. Stainless steel electrode in TMT before (B) and after (A) an electrical breakdown

FIG. 5. Mobility measurements in fresh TMS (O) and in TMS in contact with the cell surfaces for two months (X)



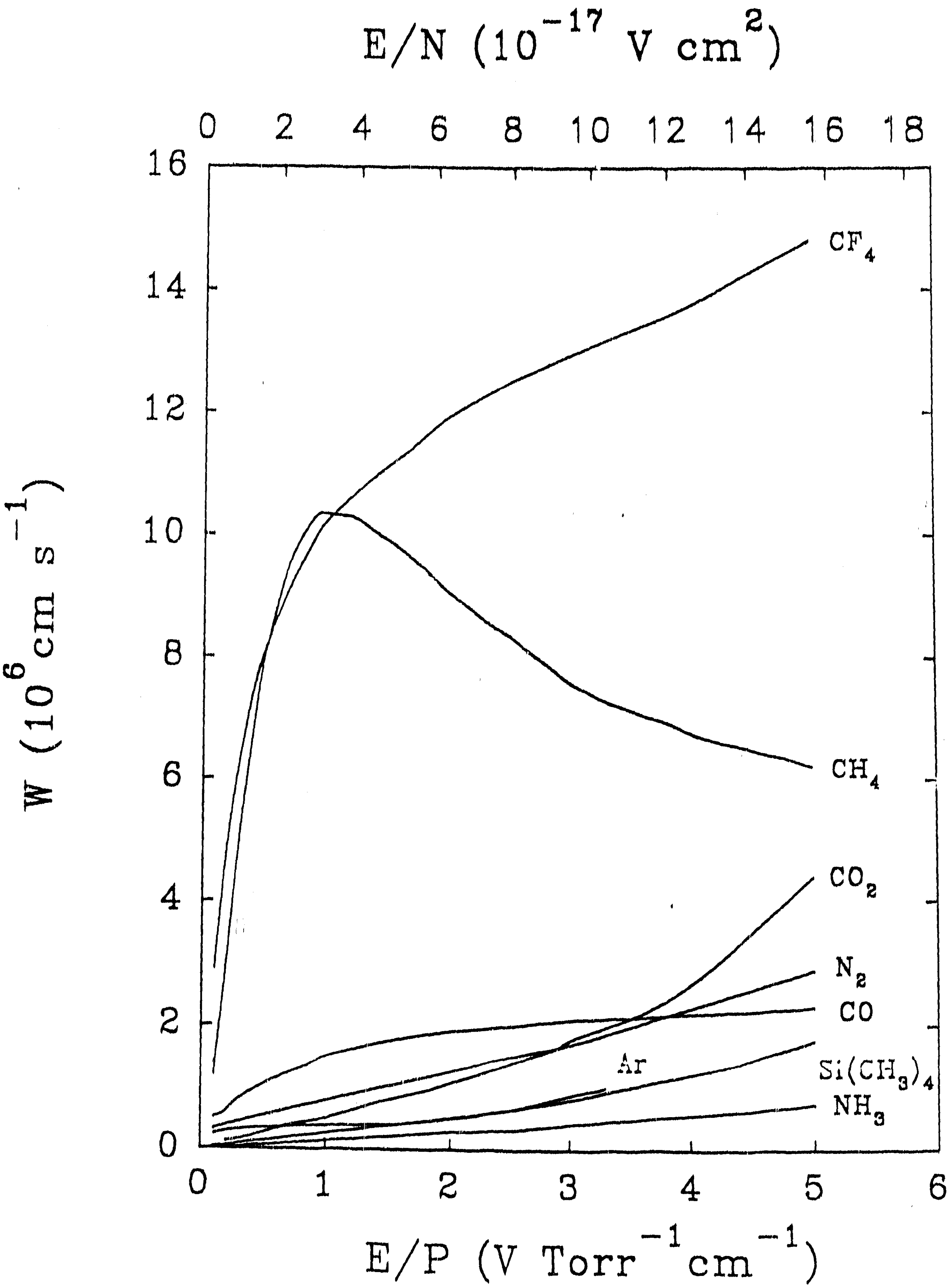


FIG. 6. Electron drift velocity in various gases

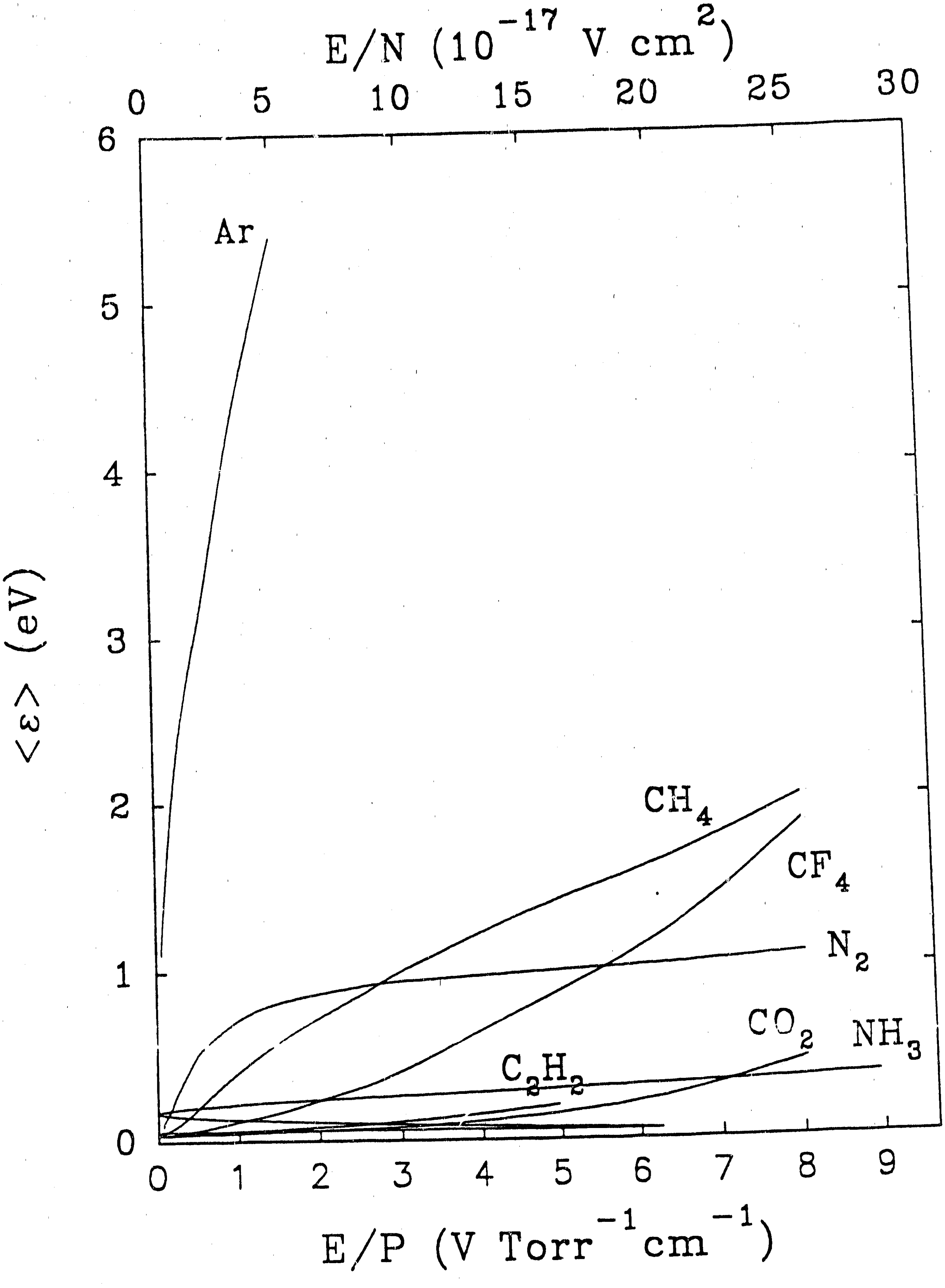


FIG. 7. Electron mean energy in various gases

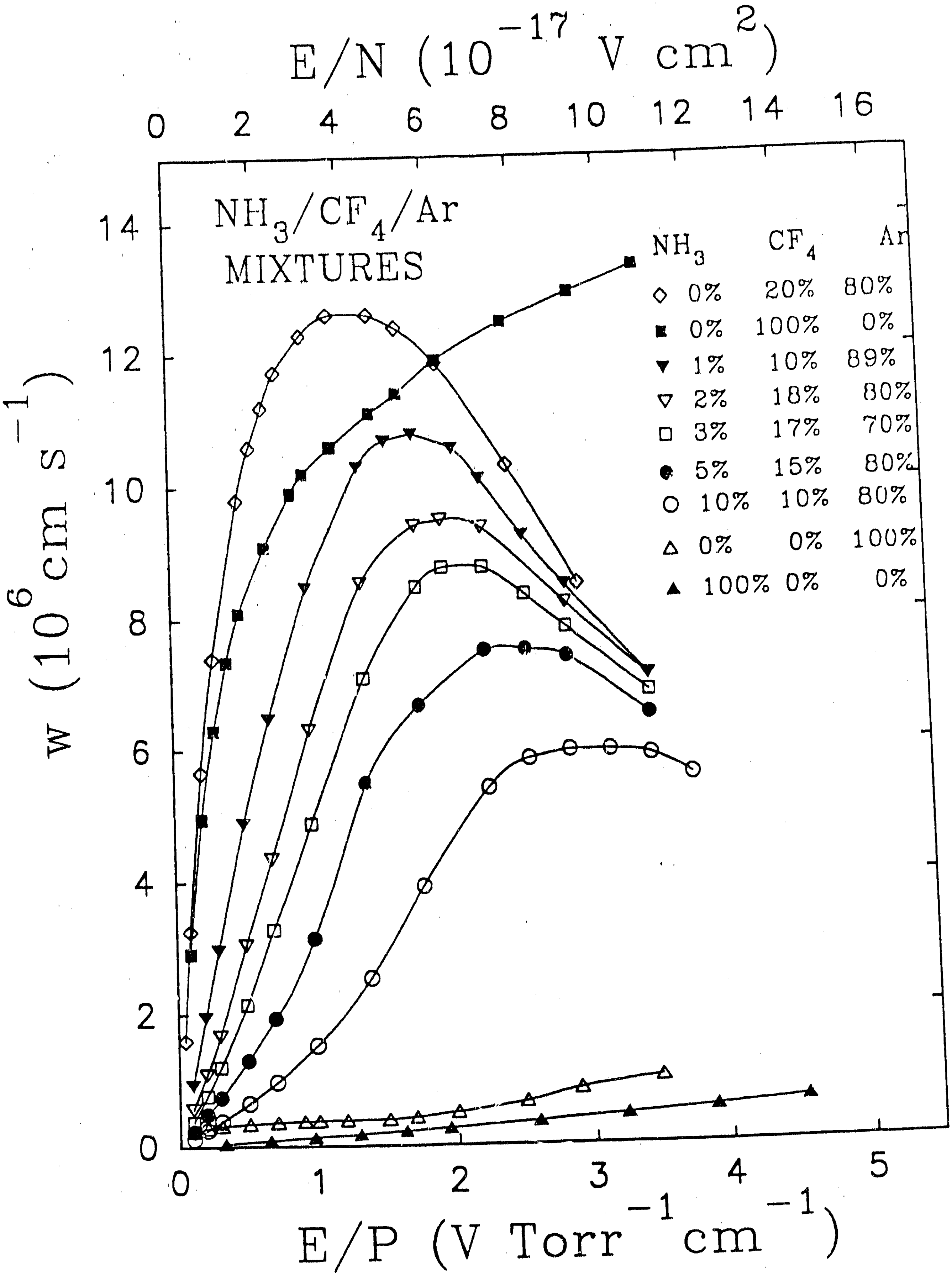


FIG. 8. Electron drift velocity in $Ar/CF_4/NH_3$ mixtures

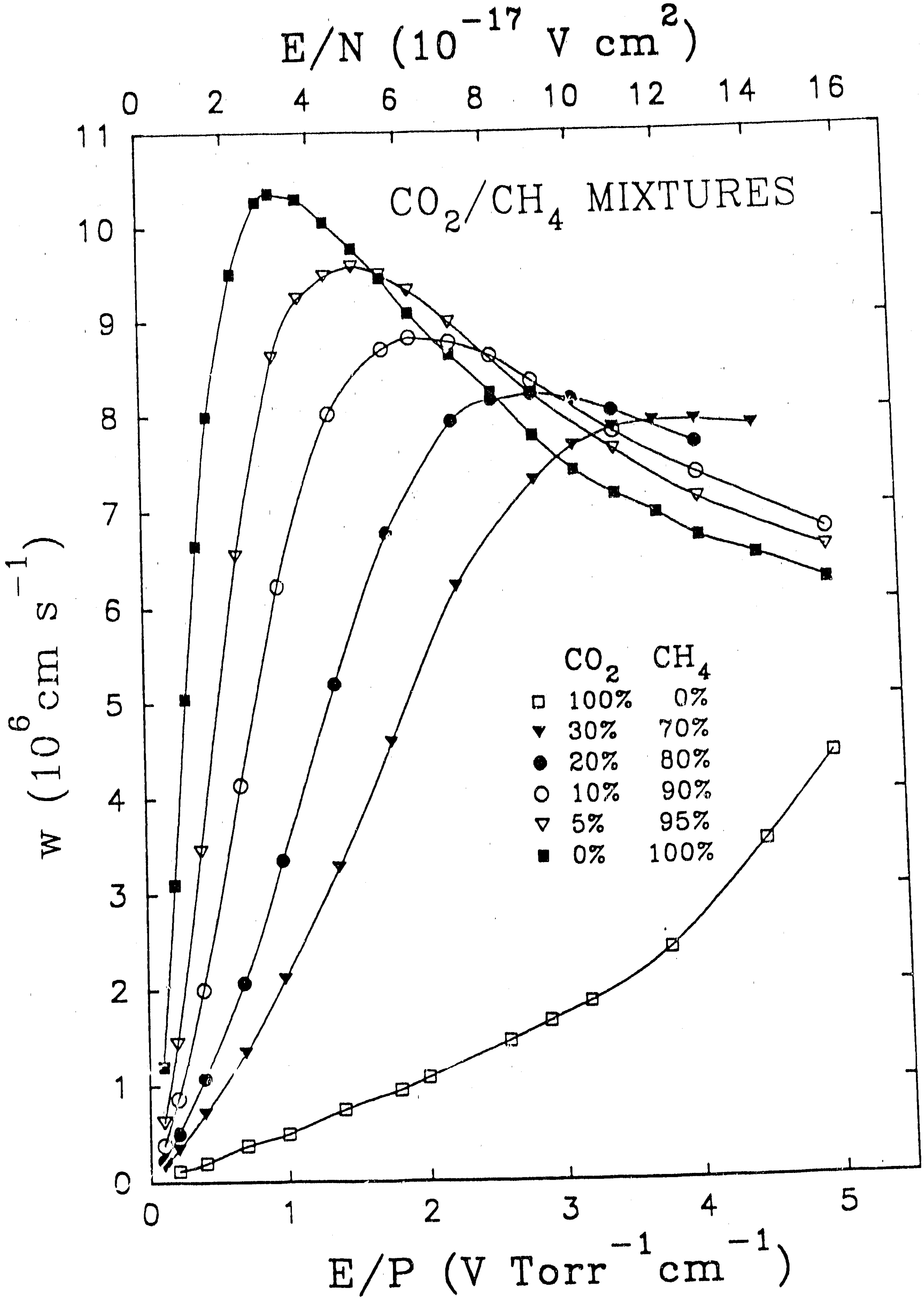


FIG. 9. Electron drift velocity in CH_4/CO_2 mixtures

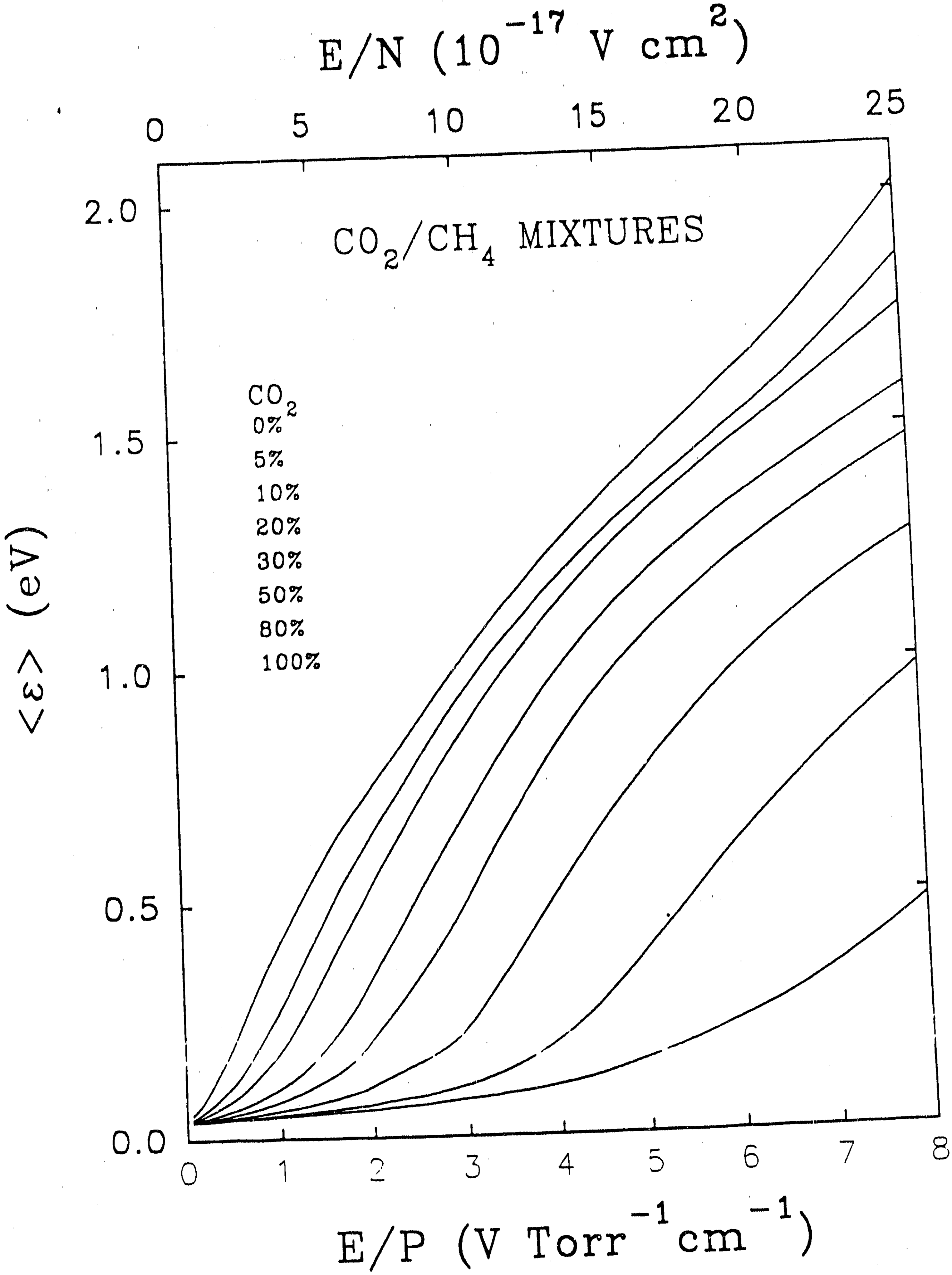


FIG. 10. **Electron mean energy in CH_4/CO_2 mixtures**

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