DOE/ER/40627-4

"ELEMENTARY PARTICLE INTERACTIONS"

PROGRESS REPORT TO DEPARTMENT OF ENERGY

DOE DE-FG05-91ER40627

(October 1, 1994 - September 30, 1995)

W. M. Bugg, G. T. Condo, T. Handler, E. L. Hart, K. Read, G. Siopsis, and B. F. L. Ward

October 1995

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October 1995

**PREPARED FOR THE U.S. DEPARTMENT OF ENERGY
UNDER GRANT NUMBER DE-FG05-91ER40627**

"Elementary Particle Interactions"

PROGRESS REPORT TO DEPARTMENT OF ENERGY

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<u>TASK A</u>

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

I. Introduction

This year has been a busy and demanding one with completion of a long SLD run, much progress on light quark states from E-687 resulting in strong evidence for two new states, observation in E-144 of non-linear Compton scattering (multiphoton absorption by electrons) up to N - 4 and initial evidence for e^+e^- pair production in Compton process.

We have also made considerable progress toward preparation for a n - $\bar{n}$ oscillation experiment and have carried out experimental studies of quartz fiber calorimetry for SLD polarimeter and forward calorimeter for CMS and LHC including a thorough set of gamma ray and neutron radiation damage studies on quartz fiber.

Two graduate students received their Ph.D.s this year, Kathy Danyo Blackett on data from Fermilab E-687 and Sharon White on SLD radiative Bhabha scattering.

1 Introduction

The interaction of electrons with intense wave fields was first considered by Schott[1] which led to the introduction of the dimensionless measure of field strength

$$\eta = \frac{eE_{\rm rms}}{m\omega_0 c} = \frac{eE_{\rm rms}\lambda_0/2\pi}{mc^2} = \frac{e\sqrt{\langle A_\mu A^\mu\rangle}}{mc^2},$$

for a plane wave of laboratory frequency ω_0, wavelength λ_0, electric field E and four-vector potential A_μ. A field with $\eta = 1$ has a voltage drop of an electron rest mass per laser wavelength. In the average rest frame of an electron in a wave field the transverse motion has characteristic velocity $\beta^\star = v^\star/c$ related by $\gamma^\star\beta^\star = \eta$, where $\gamma = 1/\sqrt{1-\beta^2}$, so that parameter η is often called $v_{\rm osc}/c$ in weak fields. As η approaches and exceeds unity the classical radiation spectrum includes higher harmonics of the wave frequency ω_0 (multipole radiation). In the quantum view this corresponds to absorption of several wave photons before emission of a single photon of frequency ω:

$$e + n\omega_0 \rightarrow e' + \omega.$$

Only one observation of this effect has been reported: a weak signal of second-harmonic radiation in scattering of 1-keV electrons from a Q-switched Nd:YAG laser.[2] A closely related effect is higher-harmonic generation in a free-electron laser,[3] where η is often called k.

A quantum description of electrons in a strong wave field utilizes the Volkov solutions[4,5] to the Dirac equation, in which an electron is 'dressed' by continual absorption and re-emission of wave photons leading to an effective mass

$$\overline{m} = m\sqrt{1+\eta^2}.$$

The role of the effective mass in Compton scattering of electrons in a strong wave field was discussed by Sengupta[6] and others.[7–10] In nonuniform waves the effective energy $\overline{m}c^2$ is called the ponderomotive potential, which describes the forces on a charged particle as it enters or exits the wave.[11,12] Ponderomotive effects on electrons ejected from atoms in a wave field with $\eta \approx 1$ have recently been observed by Moore *et al.*.[13]

We report on an experiment in which 46.6-GeV electrons are scattered at the focus of an intense laser with wavelength $\lambda_0 = 1054$ (infrared) or 527 nm (green). Under these conditions the photon energy in the rest frame of the electron beam is of order of the electron rest mass so that recoil effects are important. Absorption of a single photon corresponds to ordinary Compton scattering. However, at the laser intensities achieved ($I \approx 10^{18}$ W/cm^2, $\eta \approx 0.6$) the probability for multiphoton absorption is large and this effect was readily observed.

When n photons are absorbed by an electron of initial energy ε_0 from a laser pulse with intensity parameter η and crossing angle θ_0 to the electron beam the minimum energy of the scattered electrons is

$$\varepsilon_{\min} = \varepsilon_0/[1 + 2n\varepsilon_0\omega_0(1 + \cos\theta_0)/\overline{m}^2].$$

The higher effective mass of the electron in the wave field shifts the minimum scattered energy to slightly higher values. For ordinary Compton scattering ($n = 1$) the minimum scattered-electron energy is 25.6 GeV at $\varepsilon_0 = 46.6$ GeV, $\eta = 0$, and $\theta_0 = 17°$. The spectrum of electrons scattered by absorption of more than one laser photon extends below 25.6 GeV permitting an identification of multiphoton (nonlinear) Compton scattering.

Figure 1 shows spectra of scattered electrons calculated according to ref.[10] for conditions representative of the present experiment with $\eta = 0.5$. The calculation includes the space-time profiles of the electron and laser beams and makes the adiabatic approximation that the rate based on infinite plane waves holds for the local value of η. The calculation also includes the effect of multiple Compton scattering in which an electron undergoes successive ordinary Compton scatters at different points as it traverses the laser focus. This process is physically distinct from nonlinear Compton scattering in which several photons are absorbed at a single point and a single high-energy photon is emitted.

Figure 2a represents $n = 2$ nonlinear Compton scattering, while Fig. 2b represents two successive ordinary Compton scatters. Electron e' in Fig. 2b is real. The black circles indicate that the absorption of a wave photon by an electron in a Volkov state is not simply described by a vertex factor of charge e.

The curves in Fig. 1 are labeled by the highest number of photons that are absorbed in a single scattering event. Thus the dashed curve labeled $n = 1$ corresponds to ordinary Compton scattering, but extends below 25.6 GeV because of multiple ordinary Compton scattering. The curve labeled $n = 2$ also extends below the nominal minimum energy for nonlinear Compton scattering because additional ordinary Compton scatters also occur. The upper solid curve is the sum of all possible scatterings. Note that the simulated electron rates for $n = 2$ non-

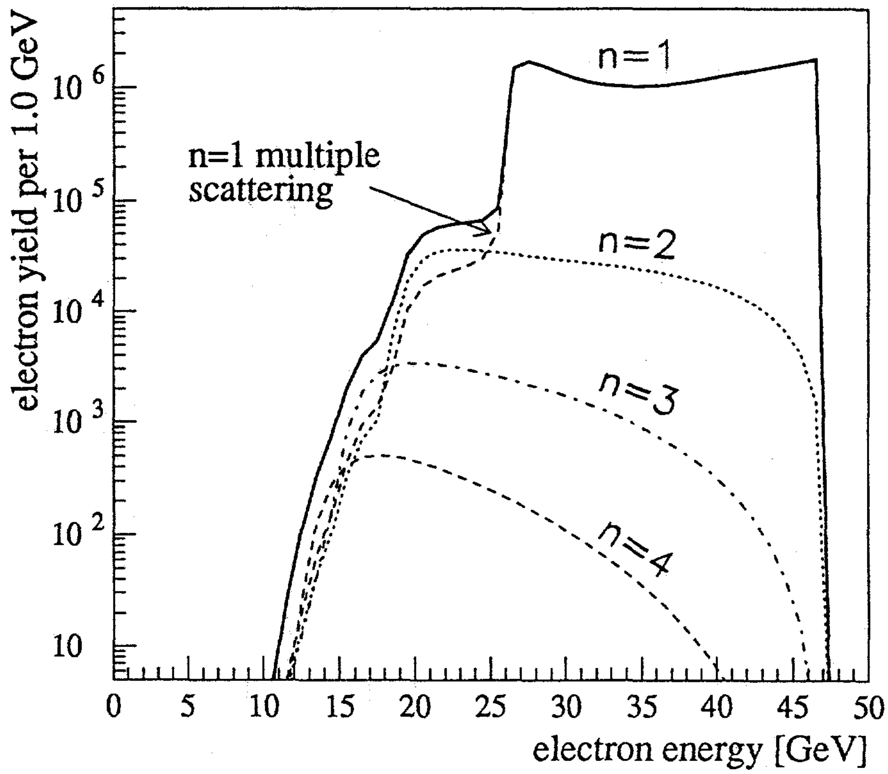


Figure 1: Calculated yield of scattered electrons from the collision of 5×10^9 46.6-GeV electrons with a circularly-polarized 1054-nm laser pulse with intensity parameter $\eta = 0.5$.

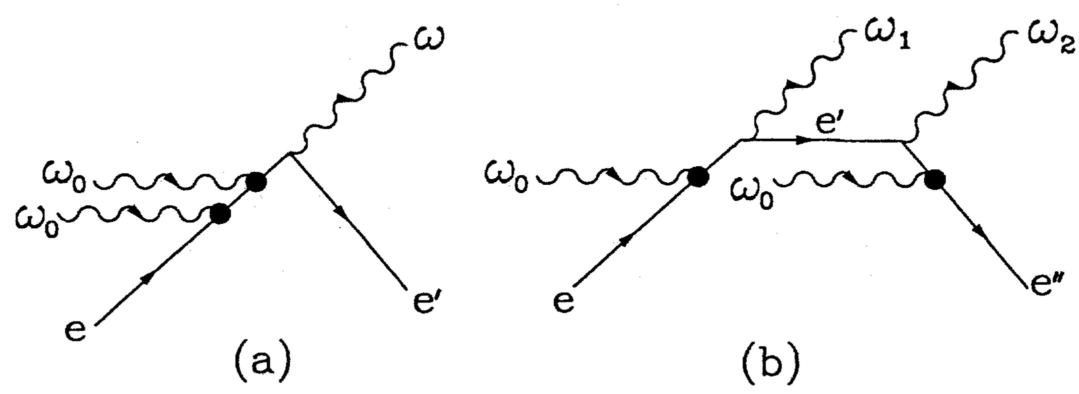


Figure 2: Diagrams representing (a) $n = 2$ nonlinear Compton scattering, and (b) double ordinary Compton scattering.

linear Compton scattering and double ordinary Compton scattering are roughly equal in the energy range 20-25 GeV.

In quantum electrodynamics a natural measure of electromagnetic field strength is the so-called critical field for which the voltage drop across a Compton wavelength is an electron rest mass:

$$E_{\text{crit}} = \frac{m^2c^3}{e\hbar} = 1.3 \times 10^{16}\ \text{V/cm} = 4.4 \times 10^{13}\ \text{gauss}.$$

The critical field was first introduced by Sauter[14] as the characteristic field strength at which Klein's paradox[15] becomes important and was further interpreted by Heisenberg and Euler[16] as the field strength at which electron-positron pair creation becomes copious. For a particle in a strong wave field a useful dimensionless invariant is

$$\Upsilon = \frac{e\hbar}{m^3c^5}\sqrt{(F_{\mu\nu}p^{\nu})^2} = \frac{E^\star}{E_{\text{crit}}} \simeq \frac{2\gamma E}{E_{\text{crit}}},$$

where $F_{\mu\nu}$ is the field tensor and p_ν is the particle's 4-vector; $E^\star$ is the wave field in the particle's rest frame, and the final equality holds only if the particle is moving anticollinear to the wave with Lorentz boost γ. Static fields with values of Υ approaching one are thought to exist at the surface of neutron stars. The field at the surface of a nucleus has Υ less than one, but quasistatic fields with Υ exceeding unity arise in MeV heavy-ion collisions.

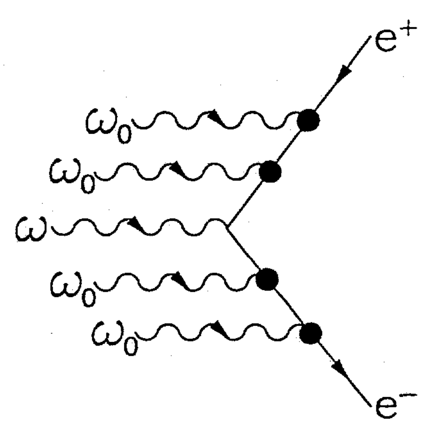


Figure 3: Diagram representing multiphoton pair creation.

Electron-positron creation can arise in the interactions of electrons with a wave in a two-step process in which a Compton-scattered photon collides with wave photons to produce the pair. Weak-field pair creation by photons was first considered by Breit and Wheeler,[17] and Reiss[18] first discussed the strong-field case,

$$\omega + n\omega_0 \rightarrow e^+e^-,$$

in which several wave photons participate; see also refs.[8,10] Figure 3 represents the latter process for a case where an external photon and four wave photons combine to produce a pair.

The present experiment studies the basic interactions of electrons and photons in fields near the QED critical field strength. It is also relevant to the understanding of so-called beamstrahlung processes at future e^+e^-colliders where the fields surrounding the beam bunches approach E_{crit},[19] and where the consequent pair creation will be a limiting background. The experiment provides a demonstration of the technology for e-γ and γ-γ collider options,[20] leading to measurements of the γWW coupling via the reaction $e\gamma \rightarrow W\nu$,[21] *etc.* Copious production of positrons in e-γ collisions can provide a low-emittance positron source due to the absence of final-state Coulomb scattering.[22]

The parameters η and Υ are not independent, and for electrons colliding head-on with a wave their relation is $\Upsilon/\eta = 2\gamma\hbar\omega_0/mc^2$. For GeV electrons interacting with a laser the ratio of Υ to η is near one, so experiments in these conditions probe nonlinear effects due to both multiphoton absorption and vacuum polarization.

2 Experimental Setup

2.1 Phase I

The experiment presented here is carried out in the Final Focus Test Beam at SLAC.[23] The setup for the first phase of the experiment is shown schematically in Fig. 4. The laser is focused at the interaction point, IP1, 10 m downstream of the Final Focus. A set of permanent dump magnets is used to direct the electron beam downwards to the dump and also serves as the analyzing magnet of our experiment.

Compton-scattered electrons are deflected away from the primary electron

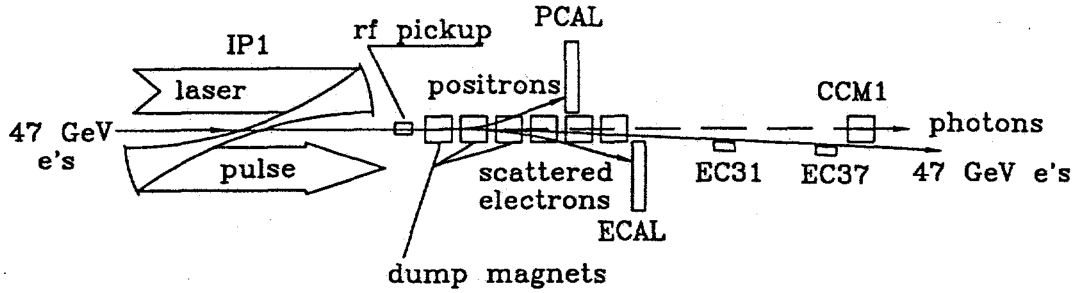


Figure 4: Sketch of experiment E-144 to detect scattered electrons and positrons produced in e-laser collisions at the SLAC Final Focus Test Beam.

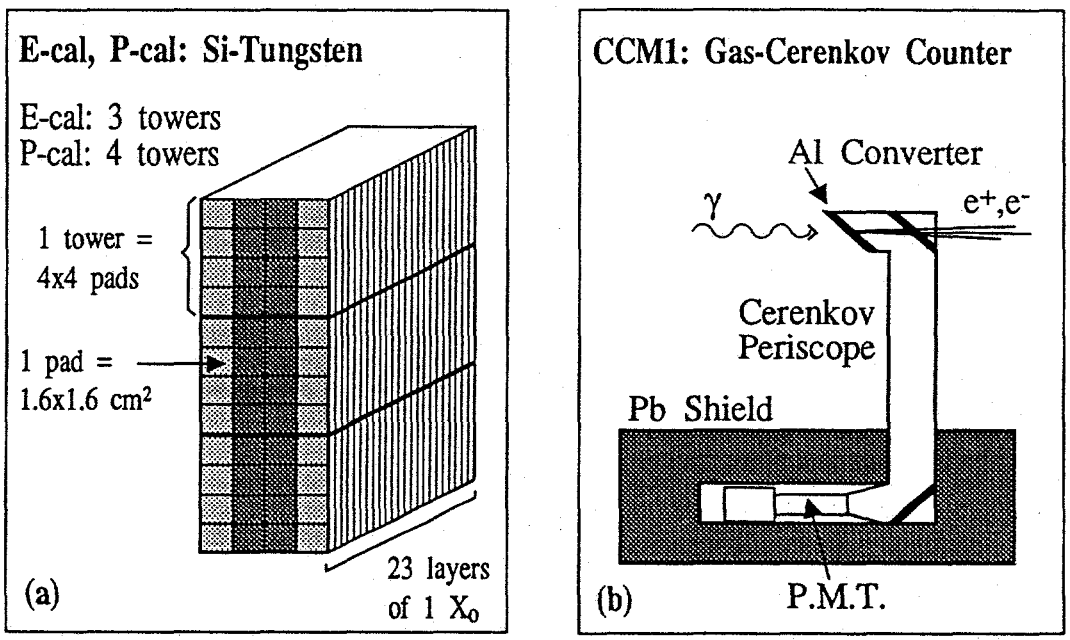


Figure 5: (a) The Silicon-Tungsten calorimeters ECAL and PCAL. (b) The gas Čerenkov monitor CCM1; monitors EC31 and EC37 are of similar construction.

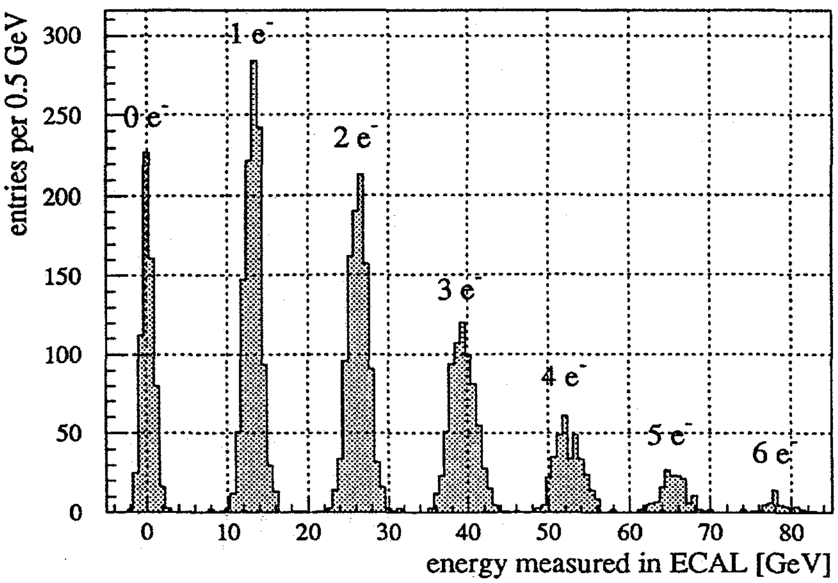


Figure 6: Energy measured by the calorimeter ECAL during a calibration run with 13 GeV electrons.

beam by the dump magnets and are detected in a Silicon-Tungsten calorimeter (ECAL),[29] sketched in Fig. 5a. Positrons were deflected to the opposite side of the electron beam where they could be detected in a similar calorimeter (PCAL). High-energy backscattered photons were detected by monitor CCM1 (Fig 5b) which observed Čerenkov light from the conversion of the photons in 0.2 radiation lengths of aluminum. Scattered electrons in the range 30-40 GeV were detected in Čerenkov monitors EC31 and EC37 of similar construction.

The Silicon-Tungsten calorimeters are segmented vertically and horizontally in 1.6 cm × 1.6 cm pads. The calorimeter energy resolution is $\sigma_E/E \approx 0.25/\sqrt{E(\mathrm{GeV})}$, whereas the size of the pads resulted in a momentum resolution of $\sigma_p/p \approx 0.04$. Both ECAL and PCAL were calibrated in parasitic running of the FFTB to the SLC program in which linac-halo electrons of energies between 5 and 25 GeV were transmitted by the FFTB when tuned to a lower energy. The number of such electrons varied between 1 and 100 per pulse, which provided an excellent calibration of the ECAL and PCAL over a wide dynamic range. Figure 6 shows the ECAL response to a 13 GeV test beam. The peaks corresponding to events with 0 to 6 electrons per beam bunch can easily be distinguished. The calibration runs also allowed a check of the field maps of the FFTB dump magnets that are used in our spectrometer.

2.2 Phase II and III

In the next phase of the experiment (Fig. 7) a thin foil or wire will convert high-energy Compton photons to pairs that will be analyzed in a pair spectrometer based on CCD's. The CCD pair spectrometer, sketched in figure 8, will reconstruct the photon-energy spectrum with resolution sufficient to discern the effective mass $\overline{m}$.

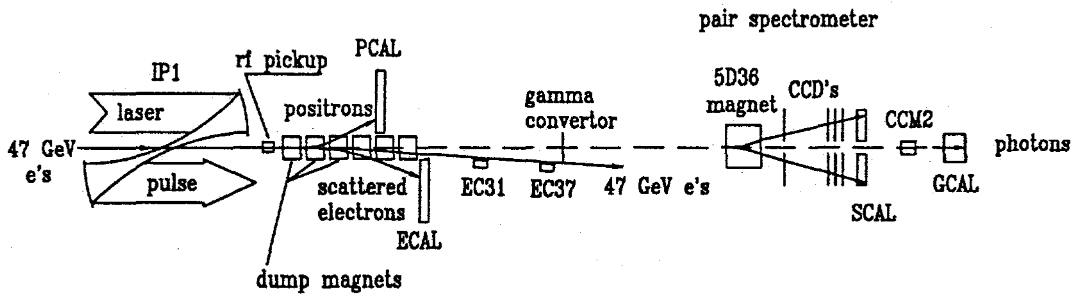


Figure 7: Sketch of the experiment with the addition of a pair spectrometer to analyze converted Compton photons.

In a third phase (Fig. 9), part of the laser beam will collide with the high-energy Compton photons at a new interaction point, IP2, and the invariant mass of resulting pairs will be analyzed in the pair spectrometer free from backgrounds of electrons and positrons produced at IP1.

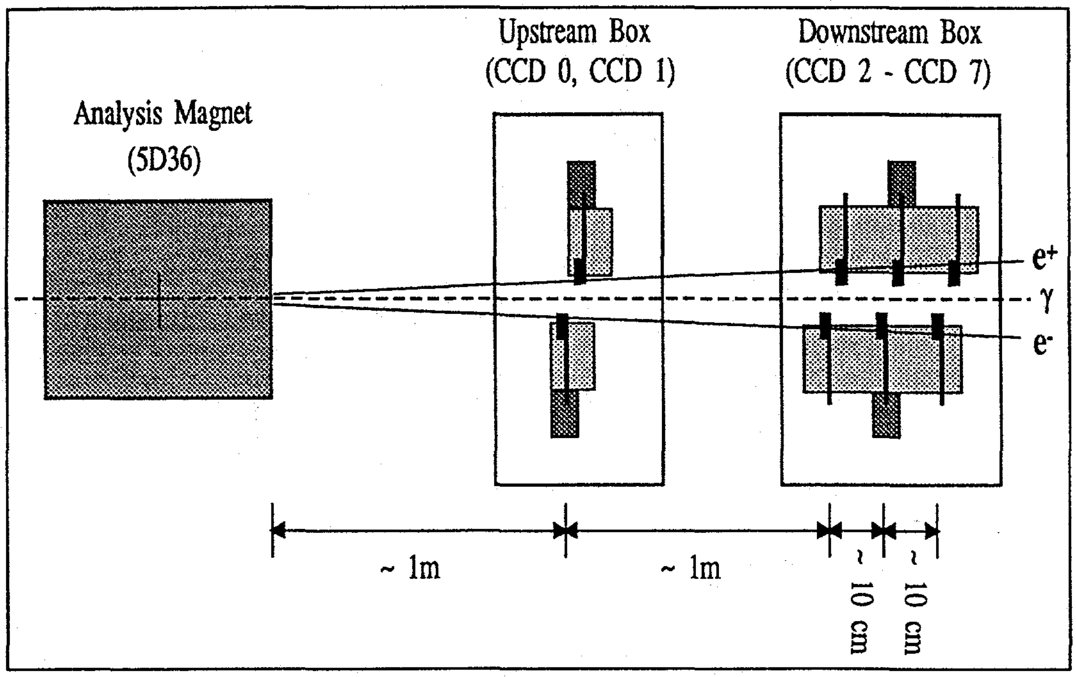


Figure 8: The CCD pair spectrometer.

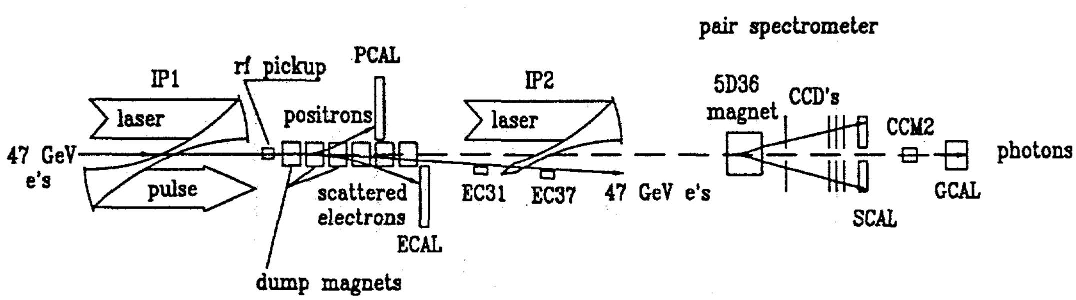


Figure 9: Sketch of the experiment with the addition of a second laser interaction point to study pair creation by light.

3 The Laser System

The beam from a chirped-pulse-amplified terawatt Nd:glass laser system[24,25] is focused by off-axis-parabolic mirrors of 30 cm focal length with a 17° crossing angle onto the electron beam at IP1. The laser system is shown in Fig. 10 and delivered 1.5-ps (fwhm) wide pulses at 0.5 Hz of up to 1.2 J of infrared light, or 1 J of green light after frequency doubling in a KDP crystal. The relatively high repetition rate is achieved in a final laser amplifier with slab geometry.[26]

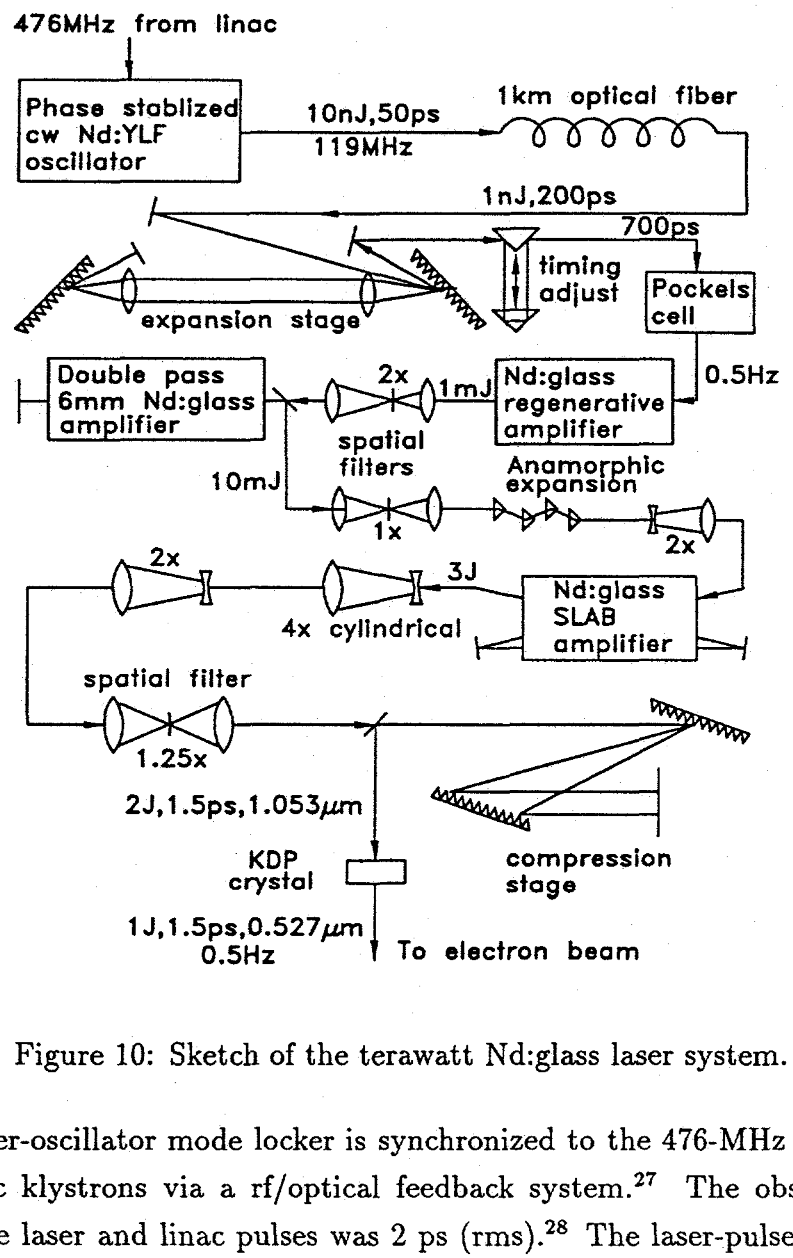


Figure 10: Sketch of the terawatt Nd:glass laser system.

The laser-oscillator mode locker is synchronized to the 476-MHz drive of the SLAC linac klystrons via a rf/optical feedback system.[27] The observed jitter between the laser and linac pulses was 2 ps (rms).[28] The laser-pulse energy and area were measured for each shot. The laser pulse length was available for each shot during infrared running and as averages over short time intervals for green.

The peak focused laser intensity was obtained for infrared pulses of energy $U = 800$ mJ, focal area $A = 60\ \mu m^2$ and pulse width $\Delta t = 1.5$ ps, for which $I = U/A\Delta t \approx 10^{18}$ W/cm^2 at $\lambda = 1054$nm, corresponding to a value of $\eta = 0.6$. Electrons that passed through the focus of the laser at peak intensity had a 25% probability of interacting.

4 Laser Pulse and Electron Bunch Overlap

The electron beam was operated at 10-30 Hz with an energy of 46.6 GeV and emittances $\varepsilon_x = 3 \times 10^{-10}$ m-rad and $\varepsilon_y = 3 \times 10^{-11}$ m-rad. The beam was tuned to a focus with $\sigma_x = 60\ \mu$m and $\sigma_y = 70\ \mu$m at the laser-electron interaction point. The electron bunch length was expanded to 3.6 ps (rms) to minimize the effect of the time jitter between the laser and electron pulses. Typical bunches contained 5×10^9 electrons. However, since the electron beam was significantly larger than the laser focal area only a small fraction of the electrons crossed through the peak field region.

The spatial and temporal overlap of the electron and laser beams was monitored by observing the Compton scattering rate in the ECAL and CCM1 detectors during horizontal (x), vertical (y) and time (t) scans of one beam across the other. Figure 11 shows results of a combined x-t scan. Figure 11a is derived from scattered photons and is dominated by ordinary Compton scattering. The slope of the data agrees with the 17° beam-crossing angle. Figure 11b is derived from electrons of energy less than 25.6 GeV where single Compton scattering does not contribute. The peak in Fig. 11b has a smaller space-time extent than that in Fig. 11a because the nonlinear process is more probable in the higher intensity regions of the laser beam.

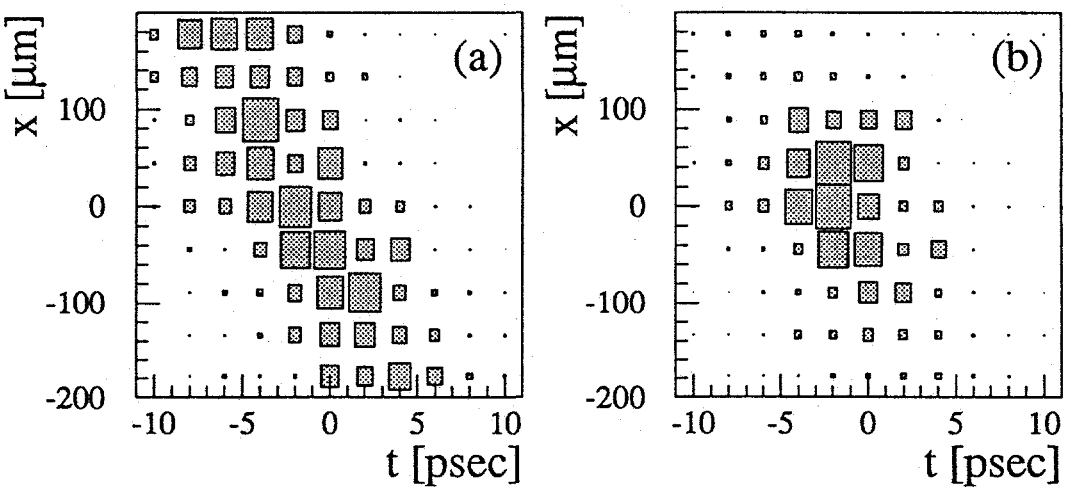


Figure 11: Observed rates of (a) ordinary and (b) nonlinear and multiple Compton scattering as a function of x and t offsets between the electron and laser beams. The area of each box is proportional to the signal size.

5 First Results

5.1 Electron Beam Polarization Measurement

In the commissioning of the present experiment in April 1994 a measurement was made of the longitudinal polarization of the electron beam. The result was $P_e = 0.81^{+0.04}_{-0.01}$,[30] in good agreement with measurements of the SLD collaboration. The upper error of 0.04 on the polarization is due to the uncertainty in the degree of circular polarization of the laser, and could readily be reduced to 0.01 in any future measurements.

5.2 Nonlinear Compton Scattering

Nonlinear effects in Compton scattering were investigated by detecting the scattered electrons. The ECAL sampled the scattered electrons in energy intervals about 1.5 GeV wide. The highest energy sampled was 30 GeV, but the maximum sampled energy could be reduced by lowering the entire calorimeter away from the beam. When positioned with maximum energy below 25.6 GeV, only electrons from nonlinear scattering were detected.

An ECAL channel saturated at 12 TeV, while at peak laser intensity some 10^7 Compton scatters occur per pulse. Hence the ECAL could not be used to study ordinary Compton scattering for laser intensities higher than about 0.001 of peak. Shower cross-talk between calorimeter pads and backsplash from ordinary Compton-scattered electrons that hit components of the beamline limited the dynamic range of ECAL to about 100:1. Because of this and the rapidly decreasing detector yield at lower energies only data from the top 4 calorimeter rows were used in the analysis. Thus the complete mapping of the nonlinear Compton spectrum required data collection at several laser intensities and positions of the ECAL. Figure 12 summarizes the data collection strategy for runs with the infrared laser beam. The accessible range of the scattered electron energy versus the laser intensity is shown as the white area. In the dark shaded area some of the ECAL channels would saturate, while the light shaded area corresponds to signals in ECAL pads dominated by cross-talk and background.

Data were collected with circularly polarized beams at laser pulse energies between 14 and 800 mJ at $\lambda_0 = 1054$ nm, and between 7 and 320 mJ at 527 nm. The energy measured in the calorimeter pads, each of which accepted a limited mo-

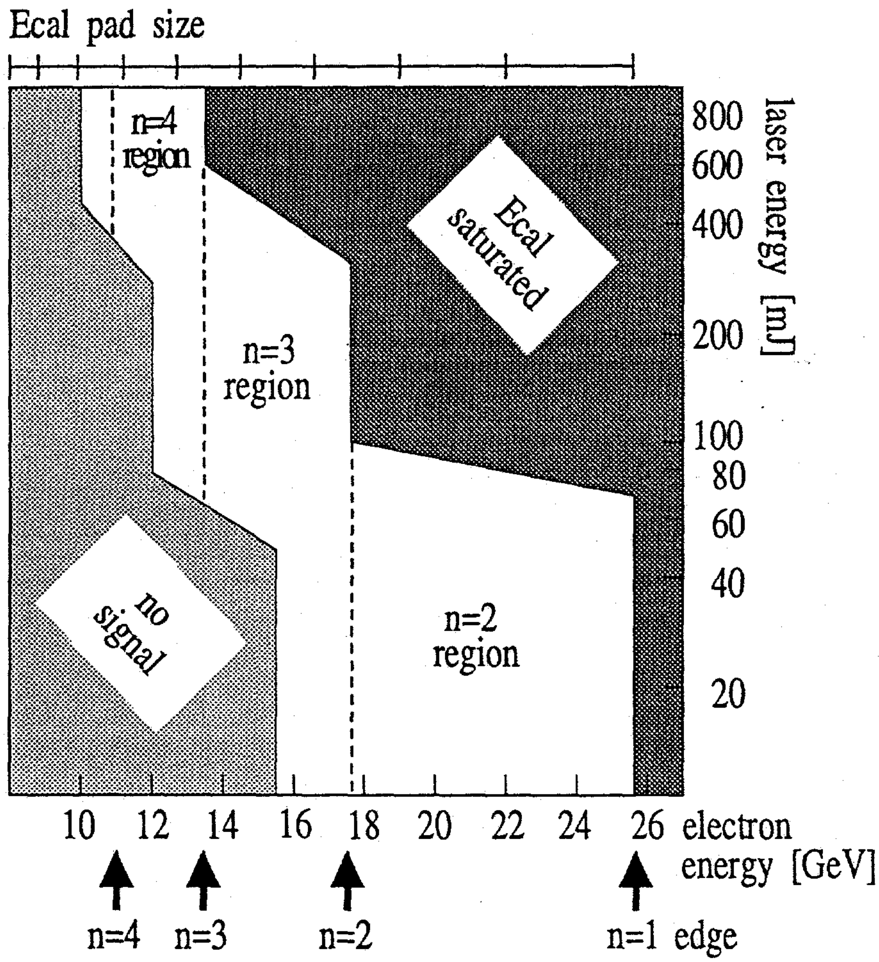


Figure 12: Data collection strategy for the infrared laser beam. The size of an ECAL pad is shown at the top of the figure. The minimum energy of an electron scattered off n laser photons is indicated at the bottom.

mentum bite, gave the spectrum of electrons scattered in that pulse. Corrections were applied for shower cross-talk between calorimeter pads, and for backgrounds from high energy Compton scattered electrons that hit beamline components. Two methods were used to estimate the corrections, based on shower spread information from calibration runs and on signal in calorimeter channels outside the acceptance for Compton scattering. The average of the two methods is used, and the difference is taken as a contribution to the systematic uncertainty.

Because of the time jitter between the electron and laser pulses the interaction flux was not readily determined from beam measurements alone. Instead, we use the rate of Compton-scattered photons, N_γ, measured by CCM1 as a normalization. To first order the normalized rate equals the normalized cross section:

$$\frac{1}{N_\gamma}\frac{dN}{dE} \approx \frac{1}{\sigma}\frac{d\sigma}{dE},$$

where σ is the total cross section which is close to the ordinary Compton cross section, $\sigma_C = 1.9 \times 10^{-25}$ cm^2 for infrared and 3.0×10^{-25} cm^2 for green.

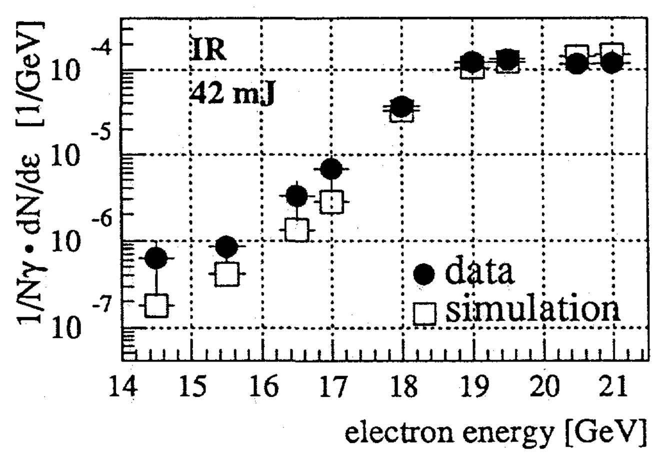


Figure 13: Energy spectra of scattered electrons as observed in the ECAL calorimeter for infrared laser pulses of 42 mJ energy.

In Figure 13, the rate of scattered electrons normalized to the Compton γ-ray rate is plotted against the electron energy, for infrared laser pulses with a nominal energy of 42 mJ. The open squares represent a simulation of each pulse using the corresponding laser and electron beam parameters at the collision point. The simulation includes both nonlinear and multiple ordinary Compton scatterings. Only energies below the minimum for single Compton scattering are shown. The plateau at 19-21 GeV corresponds to two-photon scatters, and the fall-off at 17-18 GeV is evidence for the two-photon kinematic limit at 17.6 GeV as smeared by the spatial resolution of the calorimeter.

To compensate for small variations in the beam parameters during the run, the data in Figs. 14-16 have been scaled by the ratio of the simulated rates at observed and standard values of electron and laser beam-spot dimensions. Figure 14 shows results from infrared data at 6 laser energies differing by more than an order of magnitude. The full simulation is shown as the solid curve. The rate calculated for multiple ordinary Compton scattering is shown as the dashed curve which clearly cannot account for the observations. The kinematic limit for $n = 3$ scattering at 13.5 GeV cannot be resolved in the data, but the expected effect is only a very small shoulder in the rate. Figure 15 shows similar results for green laser light. The $n = 2$ kinematic limit at 10.9 GeV can be discerned in the data.

In figure 16 we illustrate the rise in the normalized nonlinear rate with laser intensity. As the rates are normalized to the total Compton-scattering photon signal which is primarily ordinary Compton scattering, data at electron energies dominated by order n should vary with laser pulse intensity as I^{n-1}. The four data sets in Fig. 16a and the two sets in Fig. 16b agree reasonably well with expectations for these slopes. The magnitudes of the rates also agree within the uncertainty in the laser intensity of $\Delta I/I = 0.3$ for infrared and $\Delta I/I =^{+0.5}_{-0.3}$ for green laser pulses, which are shown as a band for each electron energy.

The error bars shown in Fig. 13 represent statistical uncertainty in the number of scattered electrons, the systematic uncertainty in the correction for backgrounds in the calorimeter, and a systematic error of $\pm 10\%$ in the photon rate as measured by CCM1. In Figs. 14-16 the error bars also include uncertainties in the scaling to standard beam conditions.

In conclusion we have observed nonlinear Compton scattering with the absorption of up to 4 laser photons in a single scattering event. The spectra of scattered electrons agree within experimental uncertainty with theory[10] at two different laser wavelengths and over a wide range of laser pulse energies.

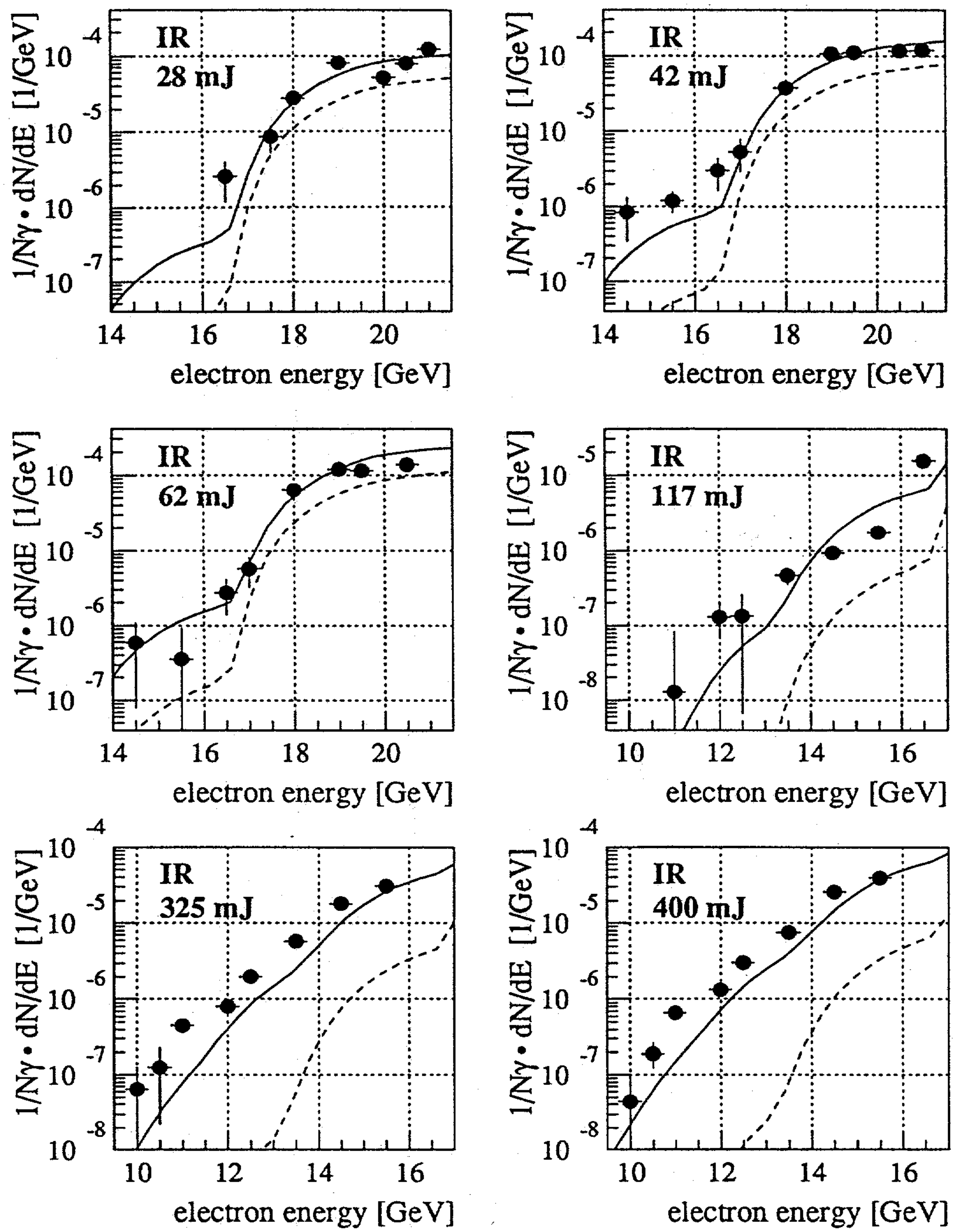
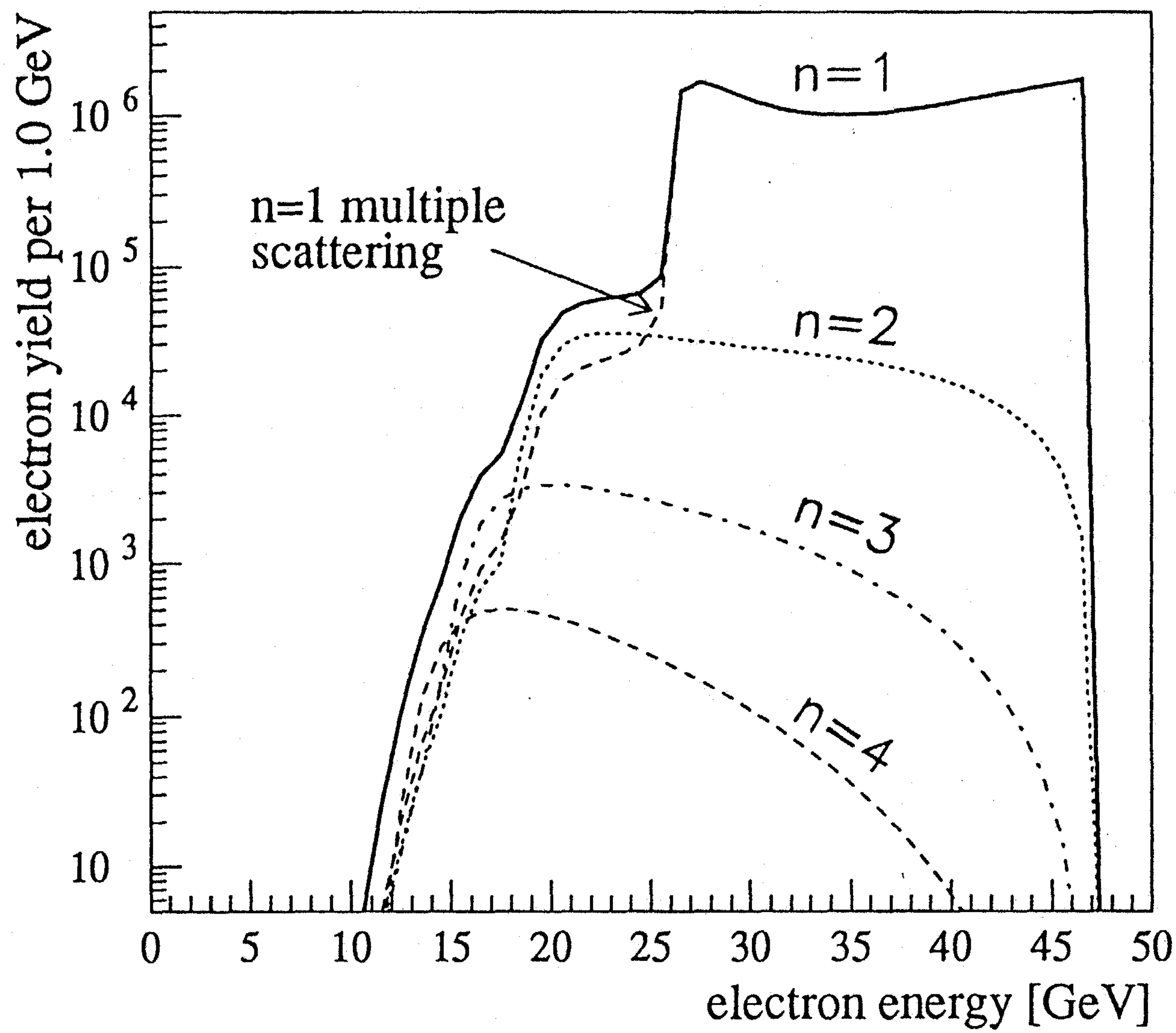


Figure 14: Energy spectra of scattered electrons for infrared laser pulses with circular polarization and nominal energies between 28 mJ and 400 mJ. The data (filled-in circles) has been scaled to standard values of the interaction geometry. The solid line represents the simulation and the dashed line shows the simulated contribution for multiple ordinary Compton scattering only.



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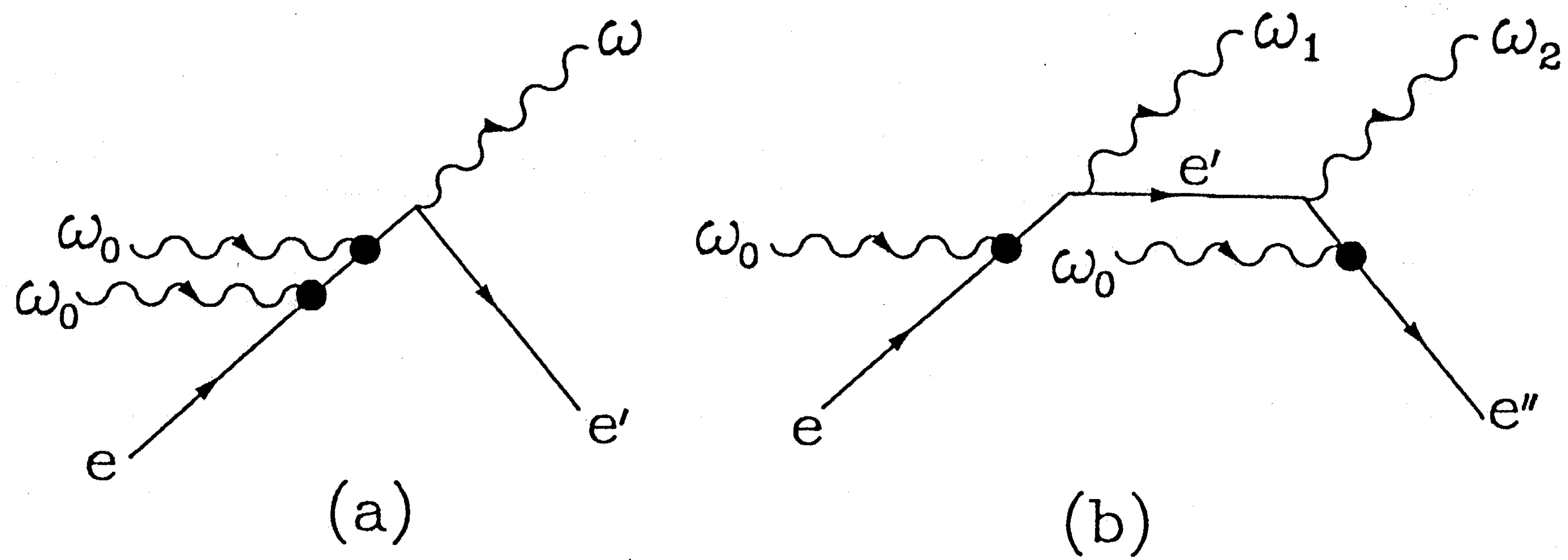

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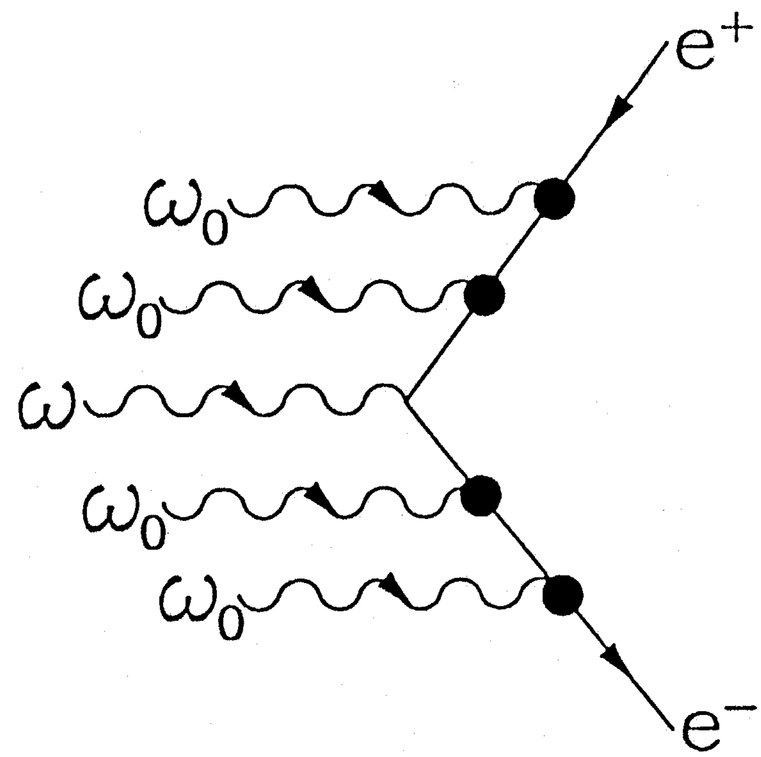
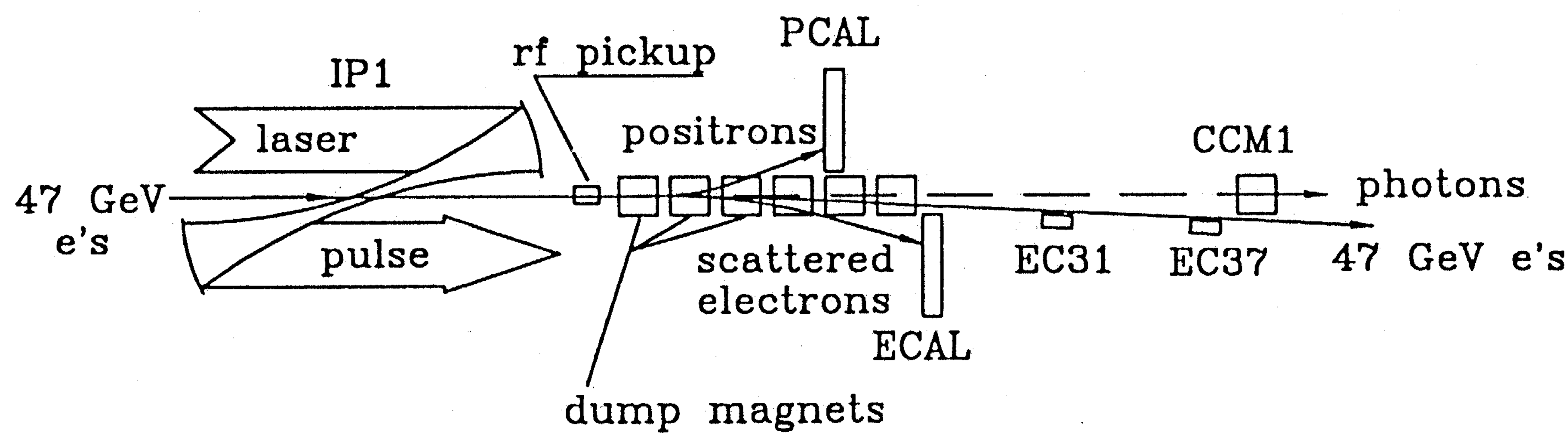


Figure 3: Diagram representing multiphoton pair creation.



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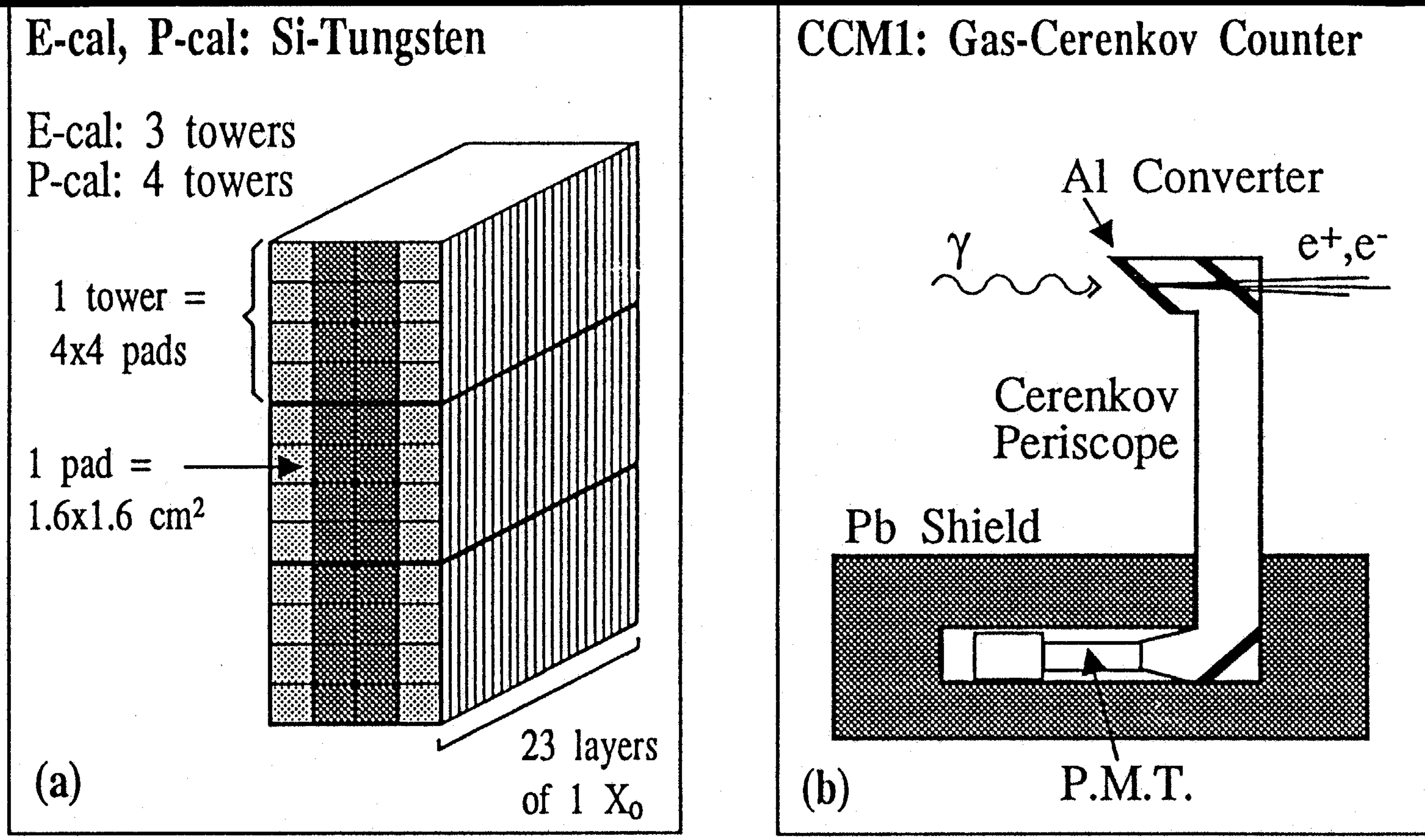

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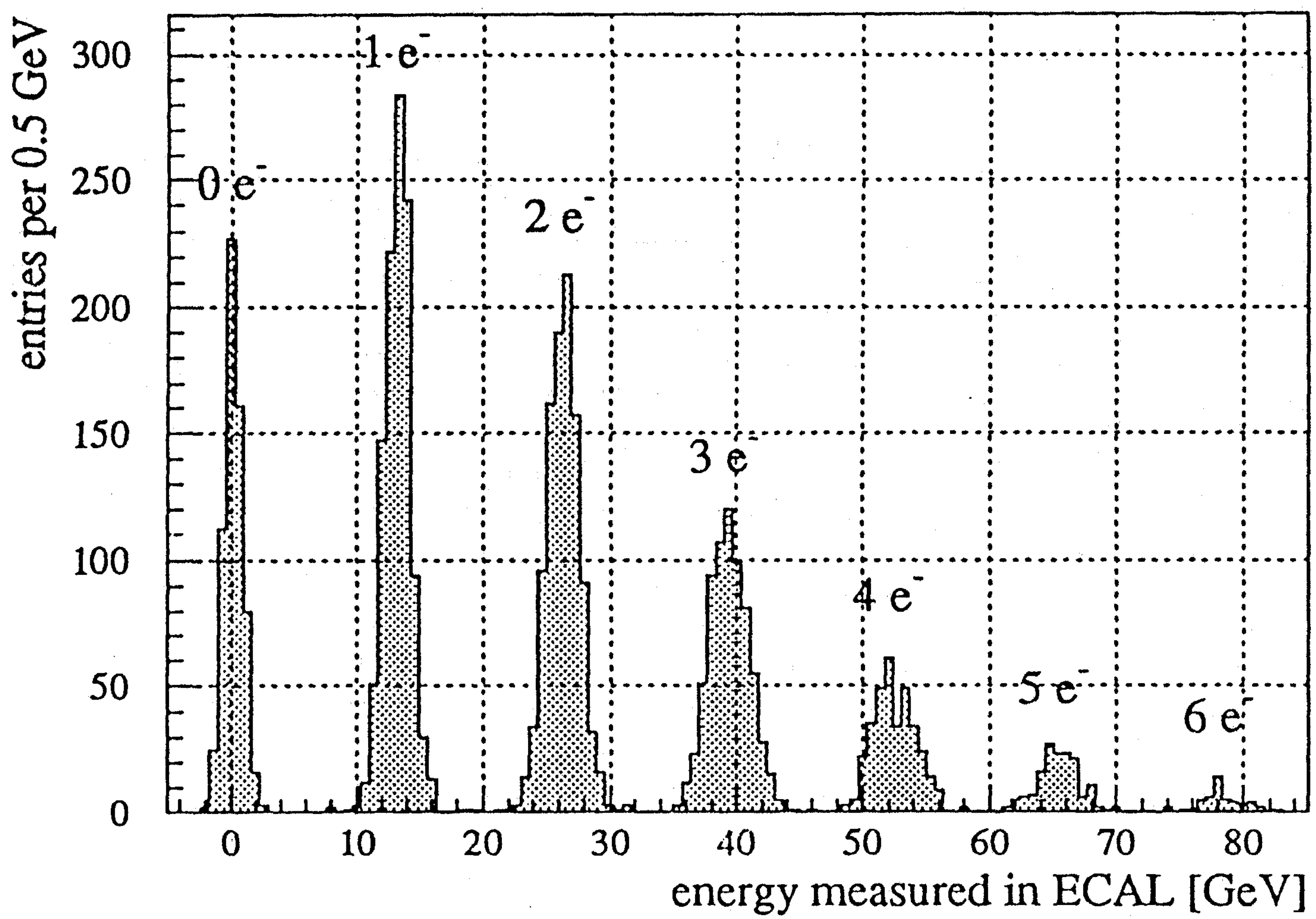
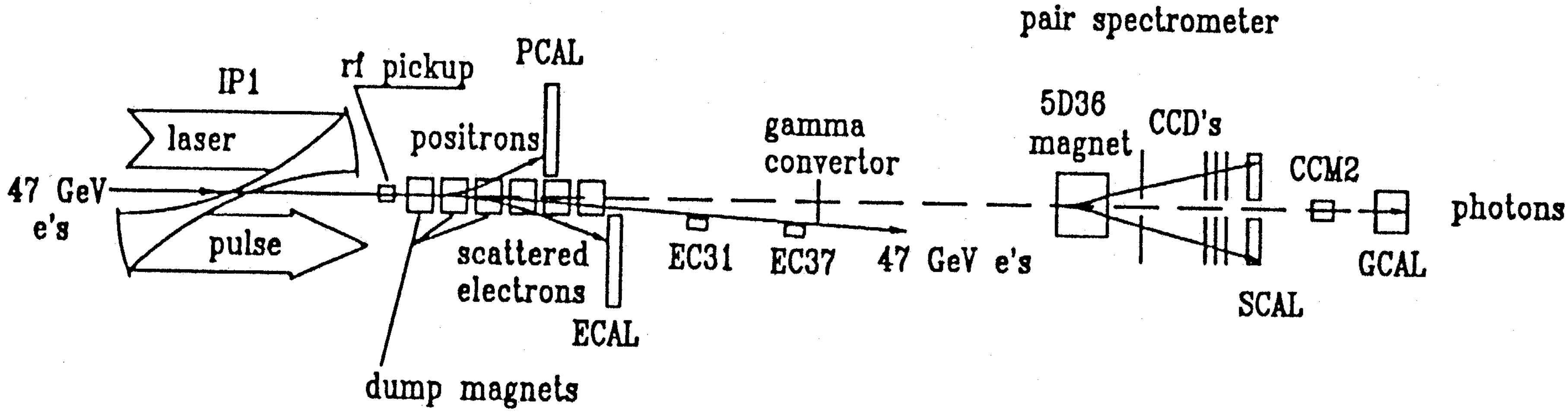


Figure 6: Energy measured by the calorimeter ECAL during a calibration run with 13 GeV electrons



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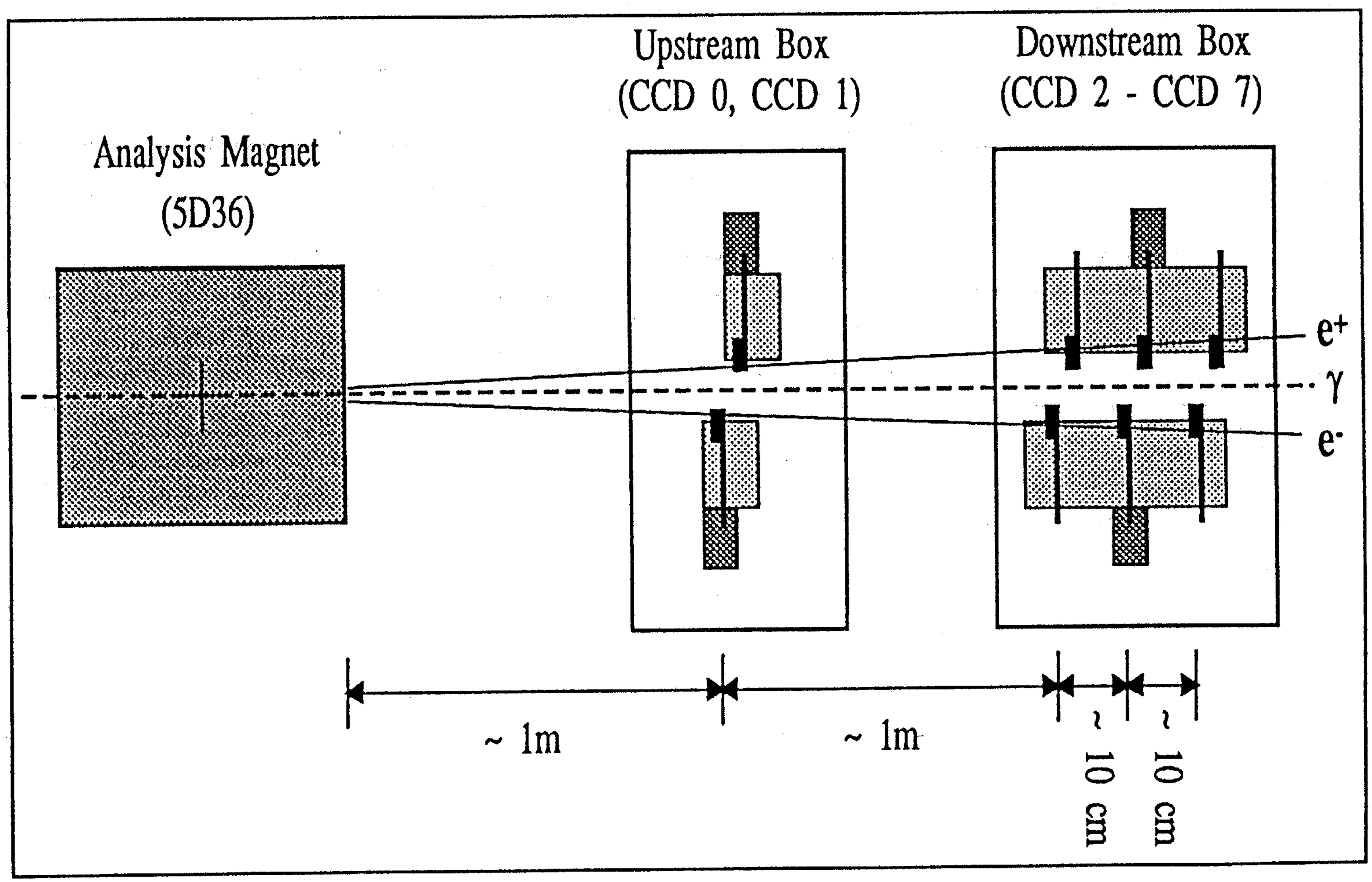


Figure 8: The CCD pair spectrometer.

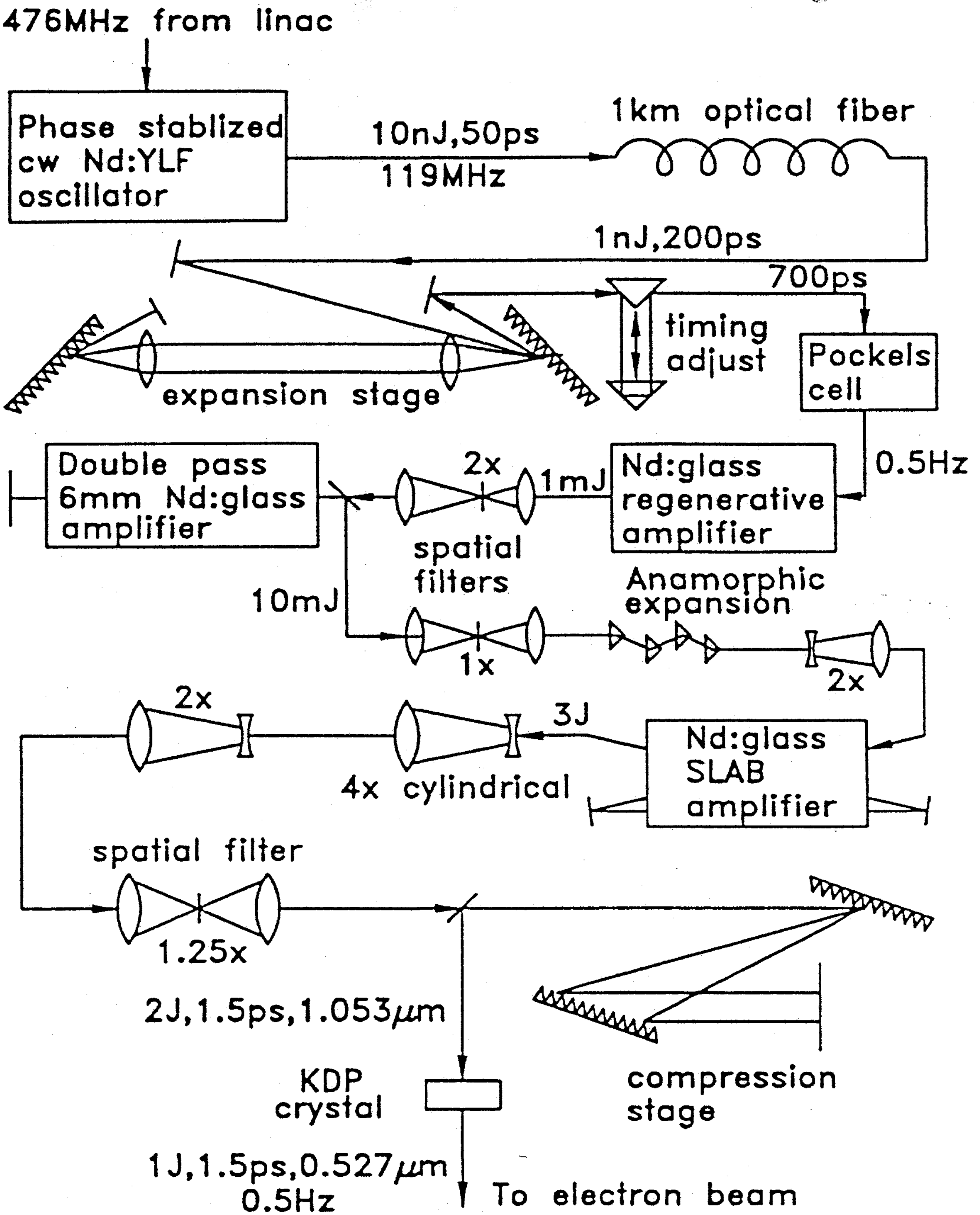


Figure 10: Sketch of the terawatt Nd:glass laser system.

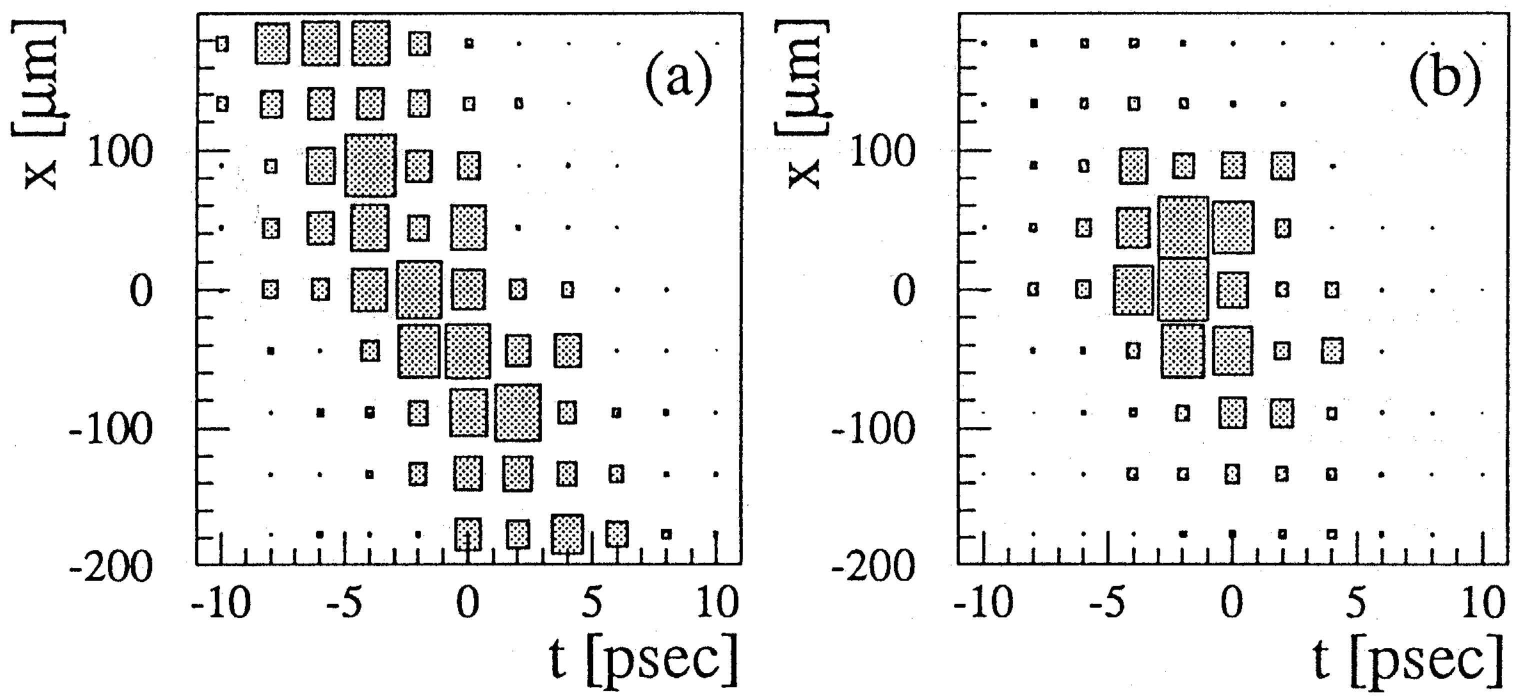


Figure 11: Observed rates of (a) ordinary and (b) nonlinear and multiple Compton scattering as a function of x and t offsets between the electron and laser beams. The area of each box is proportional to the signal size.

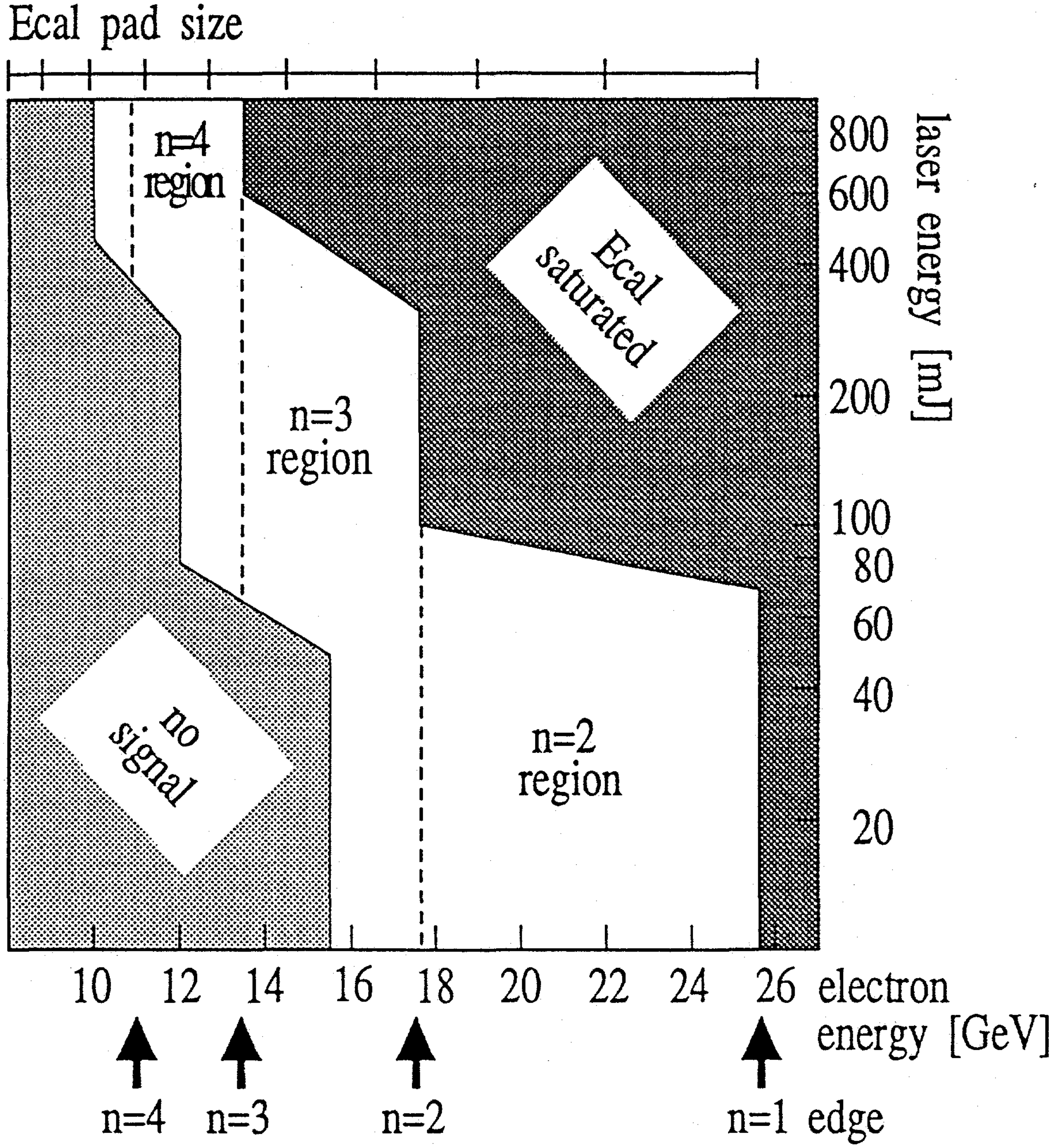


Figure 12: Data collection strategy for the infrared laser beam. The size of an ECAL pad is shown at the top of the figure. The minimum energy of an electron scattered off n laser photons is indicated at the bottom.

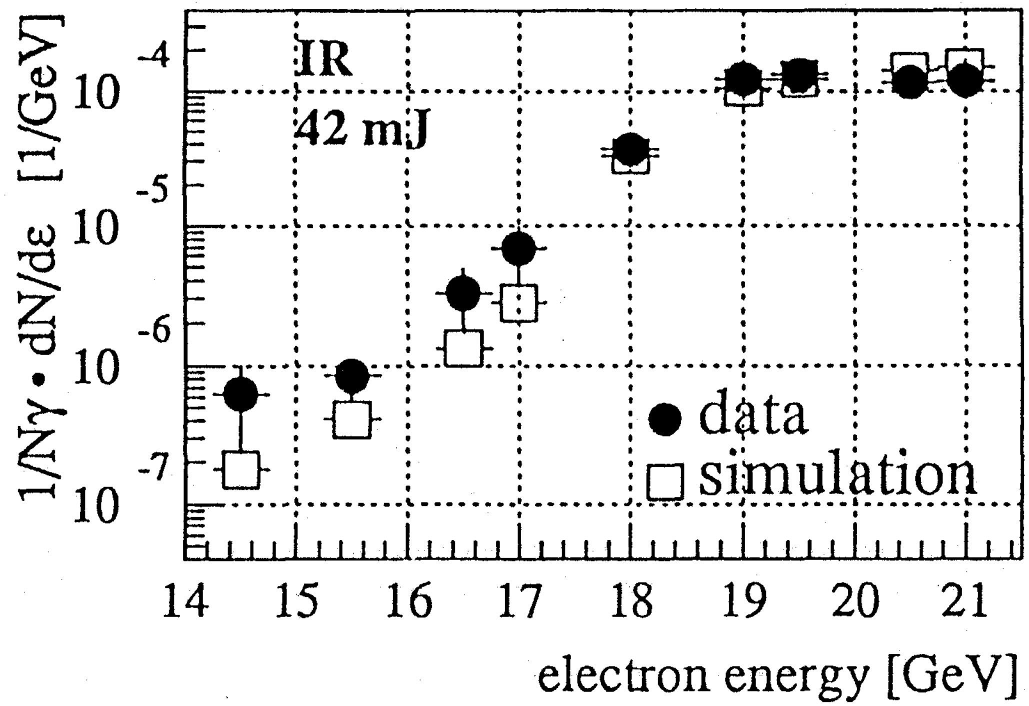


Figure 13: Energy spectra of scattered electrons as observed in the ECAL calorimeter for infrared laser pulses of 42 mJ energy.

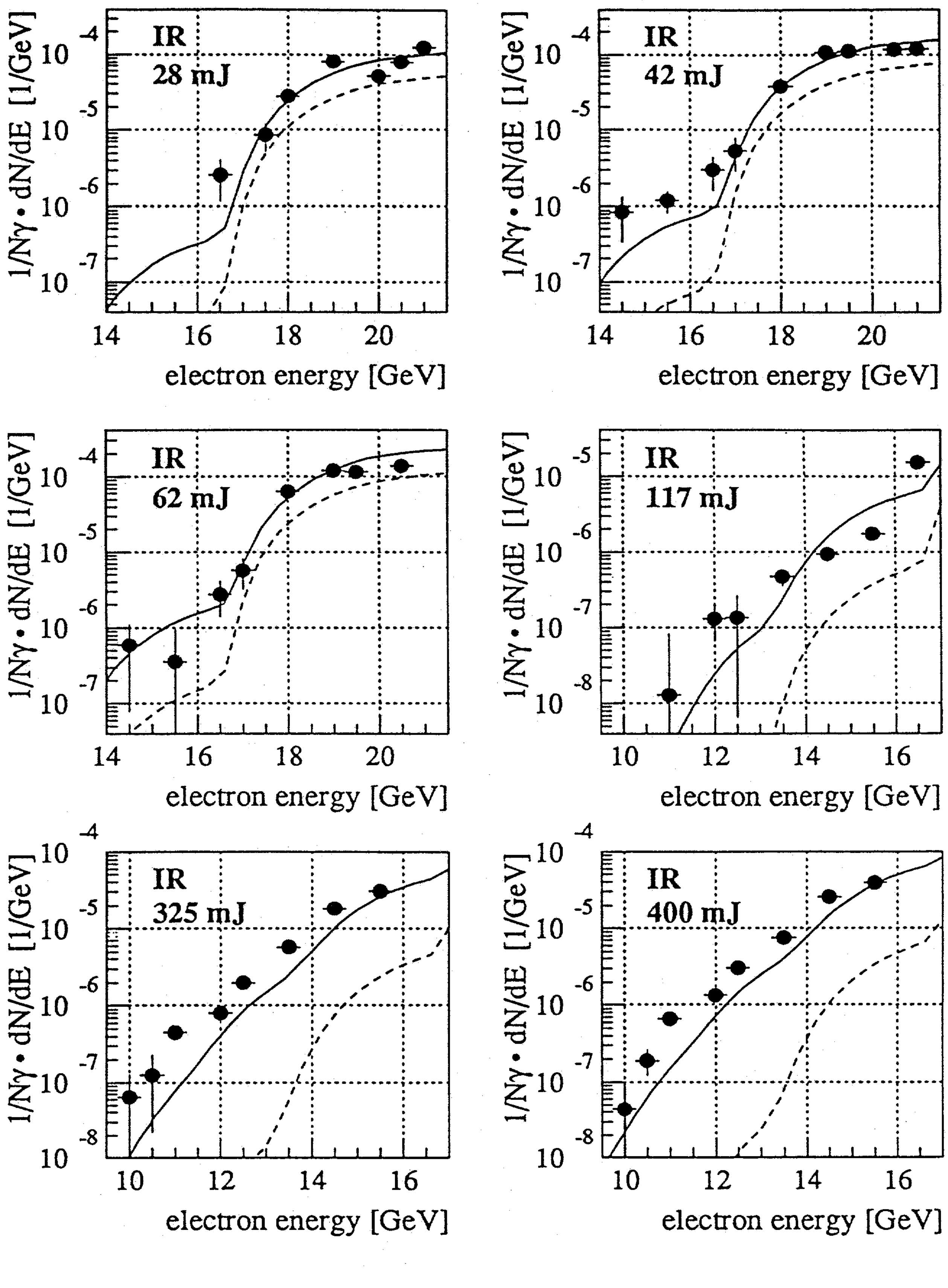


Figure 14: Energy spectra of scattered electrons for infrared laser pulses with circular polarization and nominal energies between 28 mJ and 400 mJ. The data (filled-in circles) has been scaled to standard values of the interaction geometry. The solid line represents the simulation and the dashed line shows the simulated contribution for multiple ordinary Compton scattering only.

III. E687: Progress Report.

In the past year, substantial progress was made in the analysis of light quark meson (LQM) photoproduction. This progress occurred primarily through the dissertation research of Kathy Danyo Blackett. Two papers have been prepared and submitted for the internal review process established by the FNAL E687 collaboration. While the dissertation is too long for inclusion in this report a brief summary of their findings precedes the inclusion of these 'preprints' in this document.

A. The photoproduction of a $\pi f_1(1285)$ State.

A resonance of mass 1748 – 12 MeV, width 136 – 30 MeV has been observed in the photoproduction of the $\pi f_1(1285)$ system. The decay angular distribution strongly suggests that the $J^{PC}=1^{-+}$. The existence of a $J^{PC}=1^{-+}$ amplitude in the $\pi f_1(1285)$ system extending from 1.6 to 2.2 GeV has been presented by lee et al (Phys. Letts. B323, 227 (1994)). These authors employed πp collisions and found that ρ or $f_2(1270)$ exchange dominated the πf_1 final state.

In our experiment, the photoproduction of the πf_1 system required a charge exchange process, which if we assume one pion exchange and vector dominance of the photon, yields exactly the same production vertex as does the experiment of Lee et al. This is furthermore the same vertex that was involved in a previous paper (Condo et al, Phys. Rev. D43, 2787 (1991)) where the existence of a meson of approximately the same mass and width was observed through its $\rho\pi$ and $f_2(1270)\pi$ decay modes. Thus the evidence for the existence of a meson with $J^{PC}=1^{-+}$ is intensifying.

B. The Photoproduction of a $J^{PC}=1^{-}$ Resonance in the $\phi\eta$ Channel.

No light quark state listed in the Particle Data Tables has even a mention of the existence of a $\phi\eta$ decay mode. With the large sample of photoproduced events available in E687, Kathy Danyo, in her dissertation was able to identify ~50 such events. Nearly all of these events had an effective $\phi\eta$ mass between 1.7 and 2.1 GeV. A Breit-Wigner fit gave a mass of 1915 ± 15 MeV and a width of 396 ± 115 MeV. The vector nature of this state was determined from the decay angular distribution ($J^{PC}=1^{-}$). The assignment ($J^{PC}=2^{+-}$) also fits the data reasonably well, but since this J^{PC} combination cannot correspond to a $q\bar{q}$ state, our inclination is to ignore this possibility. We also think it unlikely this is the alternate decay mode found by Close & Page for a cryptoexotic vector meson hypothesized in the flux tube model. More likely, we judge, is assignment of this state as the second radial excitation of the $\phi(1020)$ which is also expected in this mass region.

IV. SLD

SLD effort since the end of last run in March 1995 has concentrated on two areas: radiative Bhabha scattering and development of neutral (photon) beam calorimetry for precision polarization measurement. Since quartz fiber calorimeters are the instrument of choice for these polarimetry measurements, these are briefly discussed in section on quartz fiber calorimeter. The calorimeter is near completion at present time, will be installed prior to next SLD run and commissioned during the run from Jan-July 1996. We include in this section only the conclusion pages from Sharon White's dissertation as the entire document is too long.

Chapter 7

Conclusions

Small angle Bhabha scattering has been used to measure the luminosity at SLD for the 1993 run. A silicon tungsten luminosity monitor was used to detect the Bhabha scattering events, and a description of this device and its performance characteristics were presented. The luminosity was measured using two different methods to correct for small displacements of the luminosity monitor, and the results were:

$$\mathcal{L} = 1726.5 \pm 5.1_{stat} \pm 3.9_{sys} \pm 4.6_{MC} \text{ nbarn}^{-1}$$

$$\mathcal{L} = 1718.5 \pm 5.0_{stat} \pm 2.2_{sys} \pm 5.5_{MC} \text{ nbarn}^{-1}$$

The BHLUMI 2.01 Monte Carlo program was used to determine the theoretical cross section for Bhabha scattering.

A study of radiative Bhabha events at small angles, (28-68 mrad) was also undertaken. Two types of radiative events were studied, those with a visible photon in the luminosity monitor and events with an undetected photon radiated down the beampipe. The cross section for these types of events in the luminosity monitor acceptance region was measured by counting the number of events of this type and dividing by the measured luminosity. The measured cross section for the events with a visible photon in the luminosity monitor was:

$$\sigma_{sep\ photon} = 0.644 \pm 0.019_{stat} \pm 0.013_{sys} \pm 0.003_{lum} \text{ nbarn}$$

and the prediction from BHLUMI was:

$$\sigma_{BHLUMI} = 0.665 \pm 0.025 \text{ nbarn.}$$

For events with a photon down the beampipe, the measured cross section was:

$$\sigma_{\text{beampipe}} = 7.45 \pm 0.22_{sys} \pm 0.07_{stat} \pm 0.03_{lum} \text{ nbarn}$$

and the BHLUMI prediction for the cross section was:

$$\sigma_{\text{BHLUMI}} = 7.26 \pm .12 \text{ nbarn.}$$

In both cases the measured value and Monte Carlo predictions agreed within errors. Characteristics of the radiative events, the photon energy distribution and acollinearity distributions, were also compared to BHLUMI distributions and it was shown that BHLUMI reproduced the characteristics of the data, confirming that radiative corrections are well described by BHLUMI.

V. Quartz Fiber Calorimetry

Tennessee has been engaged in a long term study of quartz fiber calorimetry, beginning in GEM detector days at SSC. We have developed specialized quantitative computer codes to deal with questions of Cherenkov light production and transmission thru fibers and are now able to predict absolute light intensity to within 20%. We have built prototype calorimeters with fibers approximately parallel to beam for CMS at LHC, an additional prototype with fibers at 90° to beam for SLD at SLAC and finally a production 90° calorimeter for transverse and longitudinal election polarization measurements at SLD.

We have conducted rather complete radiation damage studies (up to 23 Giga rad) for photon damage and 10^{15} neutrons/cm^2 for neutron damage . These results are summarized in the enclosed presentation by Yuri Efremenko at BNL workshop on zero degree calorimetry for RHIC.

Quartz Fiber Calorimeter Development at ORNL/UTK

Yu.Efremenko

Zero Degree Workshop
Oct. 6 1995, BNL

We start it as a part of SSC program (forward calorimeter for GEM detector)

So far our major activity relates to SLAC only

Calorimeters with Quartz Fiber has the following advantages:

- **Radiation hard.**
- **Fast (Cherenkov light)**
- **No saturation**
- **High cut-off energy (Cherenkov)**
- **Possibilities to build calorimeter with very fine segmentation**
- **Compact and Flexible**

Quartz Fiber calorimeter disadvantages are:

- **Low light yield**
  - **To achieve good energy resolution high energy flux is required**
- **Relatively Expensive**
  - **Compact**

Quartz Fiber Calorimetry Applications

- **Detect the big energy flow**

- **Work at the high radiation environment**

- **Work with the high repetition rate**

- **Work at the presence of intense, low energy background.**
For example, synchrotron radiation.

Our activities at present are:

1. Prototype and beam test of Cu/QF 0^{o} Spaghetti Calorimeter.

Status: prototype has been built and tested at SLAC. Data is available.

2. Prototype and beam test of W/QF 90^{o} Compton Photon Calorimeter.

Status: prototype has been built and will be tested at SLAC at the end of the year.

3. Study of radiation damage of the Quartz Fibers.

Status: the samples has been irradiated at the HFIR reactor at ORNL. Final data will be available in a month.

Spaghetti type Quartz Fiber Calorimeter

ORNL
UTK
MISSISSIPPI
IOWA
SLAC

The calorimeter was made from the 50 layers of machined 2.0 mm brass plates with the 50 grooves in each.

Calorimeter length is 40 cm or 25 X_0

The total of 6600 Quartz Fibers polished from one end had been used.

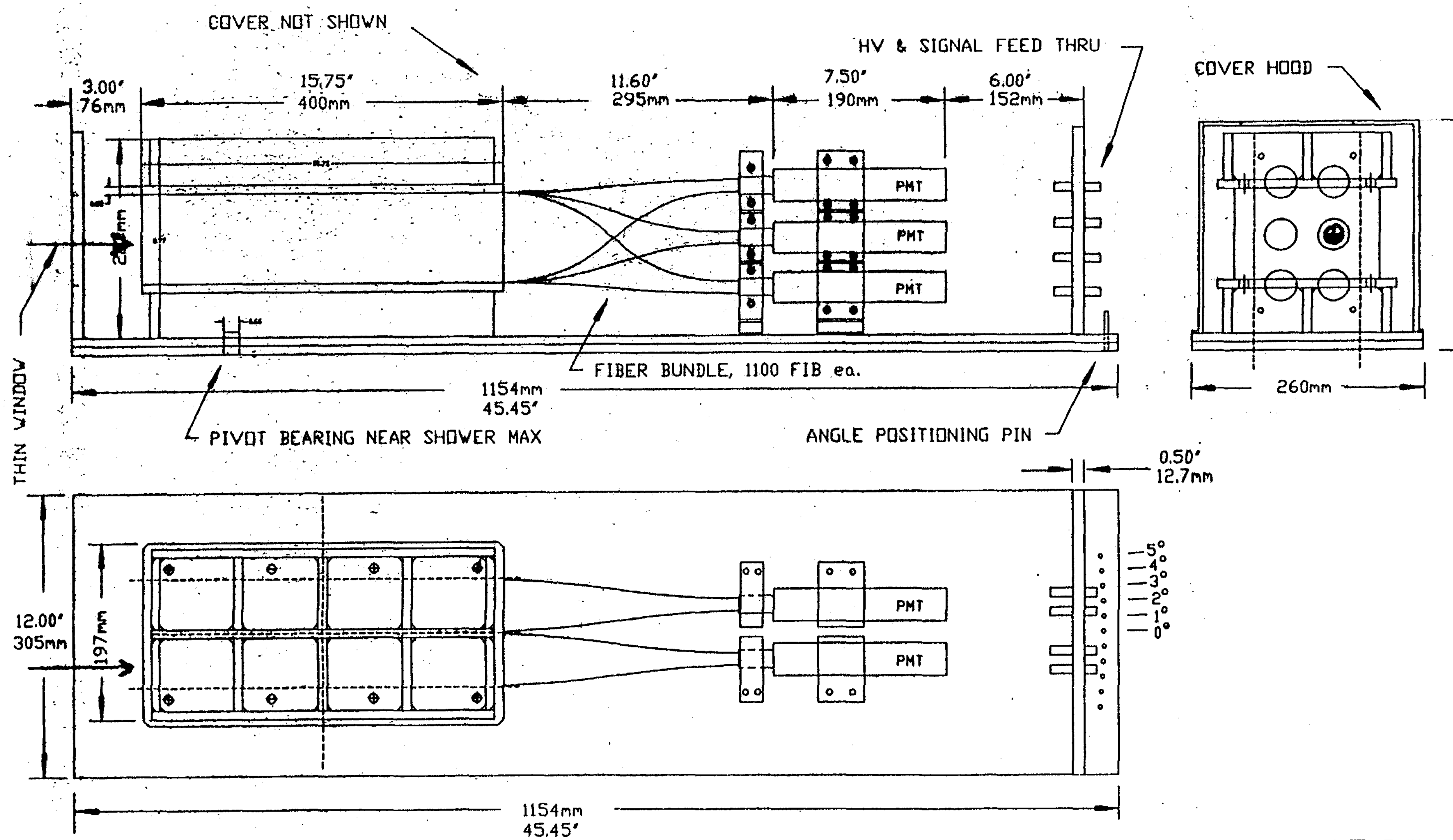
Three fibers are inserted in each groove.

Fibers from the same groove are coupled to the different PMT. In addition calorimeter has a transverse segmentation.

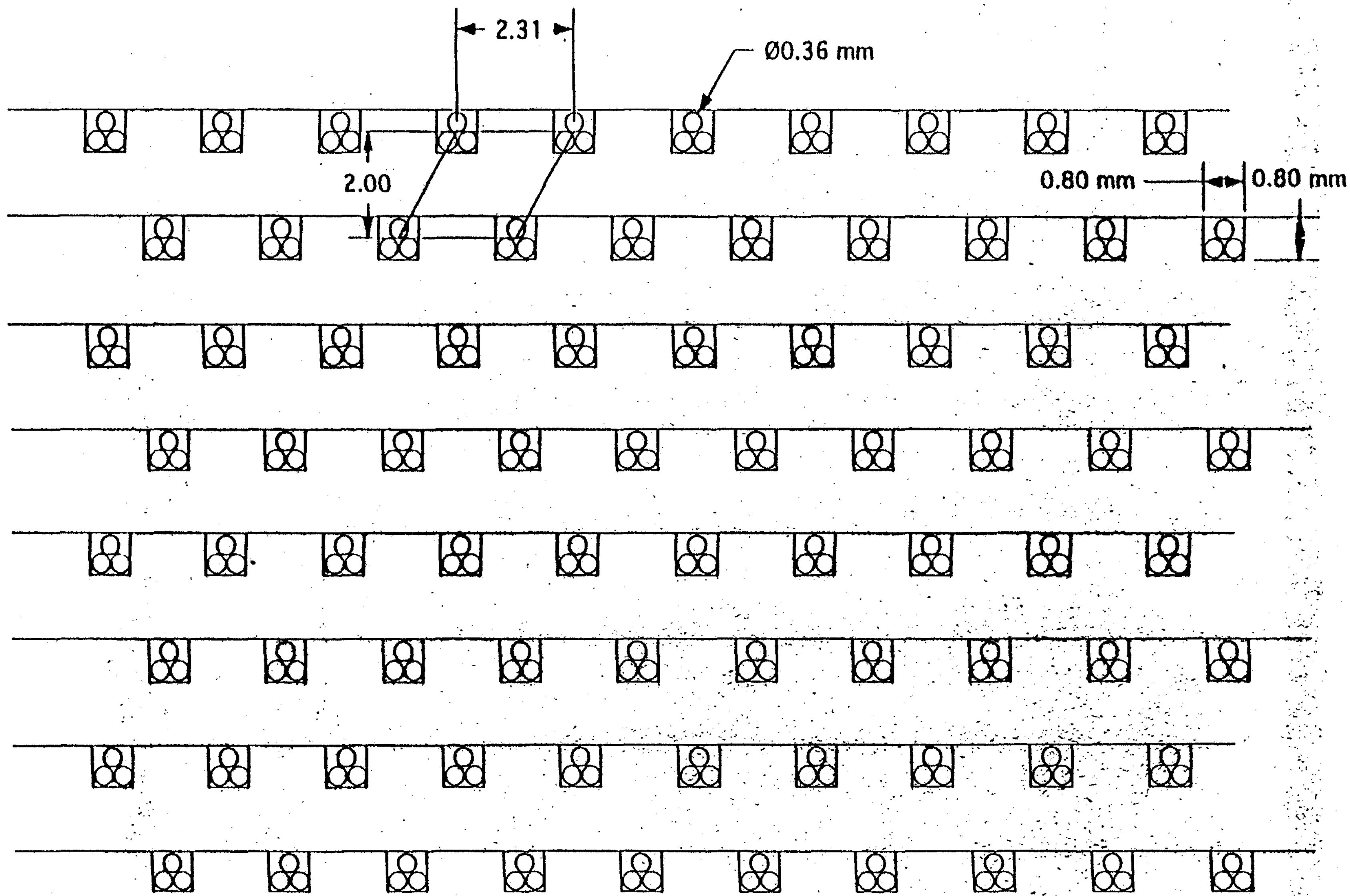
Totally, calorimeter has six readout channels.

Sampling Fraction $\approx$ 4%

BRASS ABSORBER CALORIMETER LAYOUT



H.O.COHN
10-14-1994



QUARTZ FIBER OPTION ARRANGEMENT - Cu Absorber

SM C

Test Beam at SLAC

H.Cohn, Yu.Efremenko, Yu.Kamyshkov, F.Plasil
Oak Ridge National Laboratory

S.Berridge, W.Bugg, K.Shmakov,
A.Weidemann
University of Tennessee.

N.Akchurin, Y.Onel
University of Iowa

M.Booke, L.Cremaldi, J.Reidy
University of Mississippi

W.Wisniewski
SLAC

Test beam parameters.

The calorimeter has been tested at the SLAC FFTB area from Jan. 30 till Feb. 3 1995, experiment T-408.

1. Beam size: 1 mm.

2. Repetition rate 120 Hz

3. Intensity 0 - 20 electrons/bunch

4. Bunch length ~ 10 psec

5. Two bunch separated on 59 nsec

6. Available energy range 5 -29 GeV.

Calorimeter has been installed on the movable table.

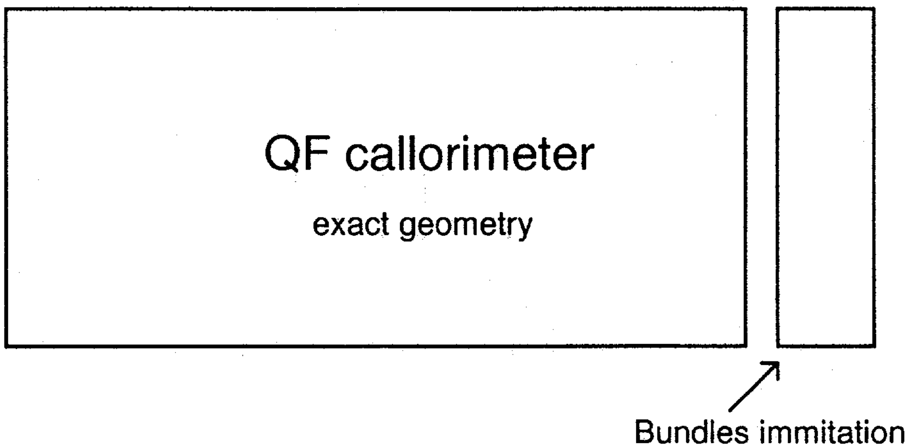
We were able:

1. Rotate calorimeter with accuracy 5'

2. Shift calorimeter across the beam with accuracy 5 μm.

Monte Carlo Simulations

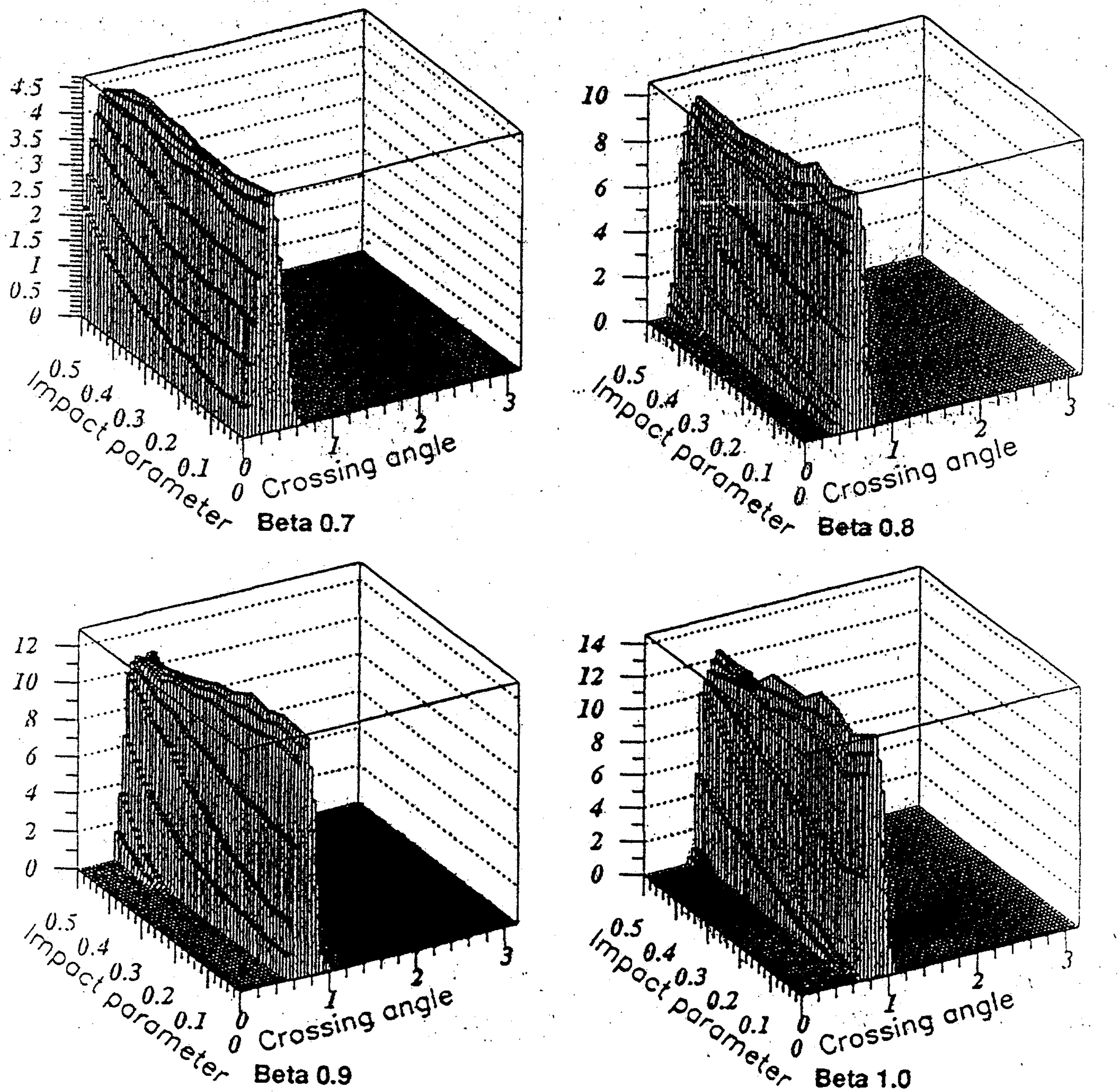
LTRANS + GEANT



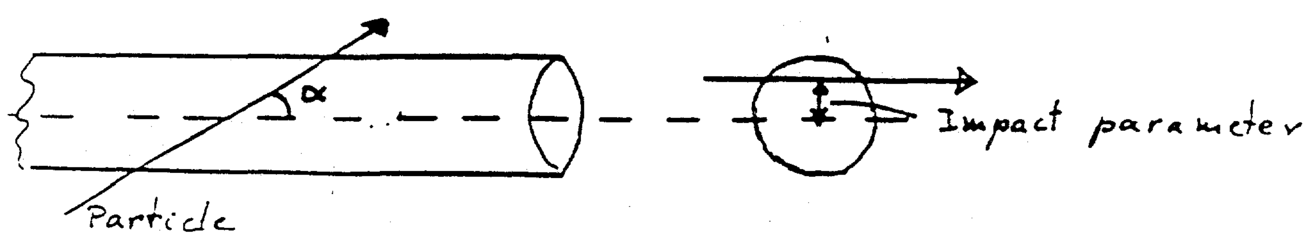
$$A_{tot} = A_{cal} + k \bullet A_{bund}$$

k - is the only free parameter.

Number of photoelectrons per 1 cm.



E.Tarkovsky



Test beam results:

• **Presents of the non Gaussian tail at the big amplitudes. Later developed showers hit fibers bundles and cause this tail. Channeling effect.**

• **Channeling might be eliminated by:**
rotating calorimeter;
adding extra absorber plate in the front of the calorimeter;
software corrected.

• **Energy resolution $\delta E/E = a/\sqrt{E} \oplus b$**
$a = 82.6 \pm 0.4$ % $b \leq 3.7$ %

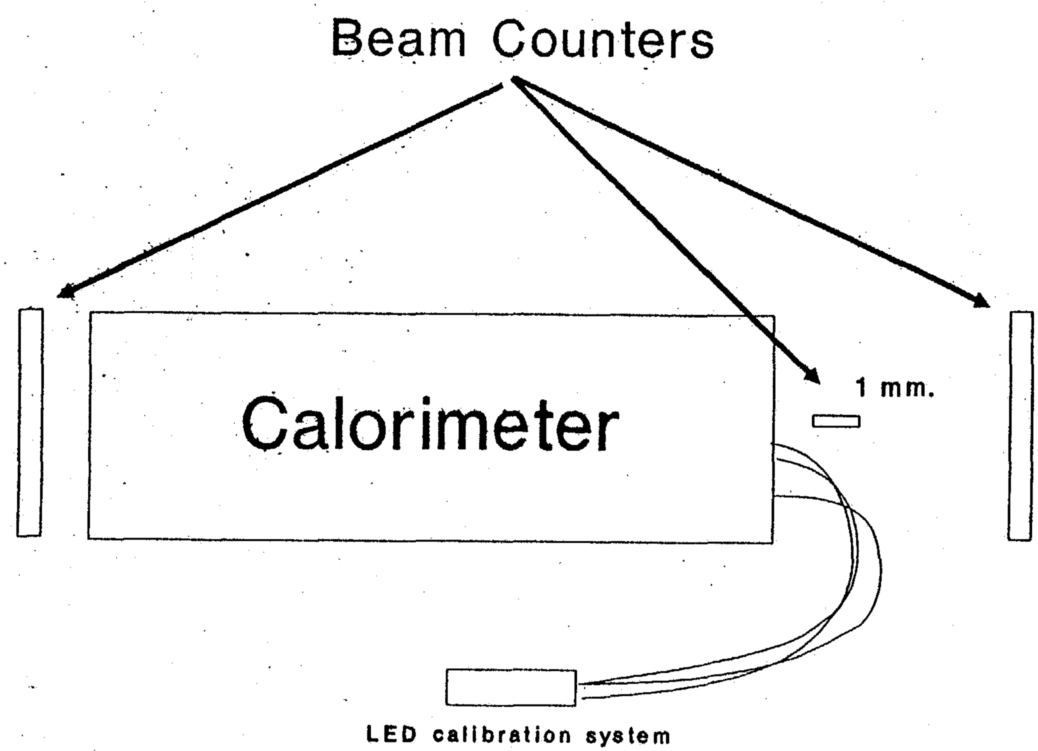
• **Linear from 5 to 29 GeV.**

• **Light output is 2.2 Ph.e. per 1 GeV**

• **RMS of transverse shower size $\approx$ 4 mm.**

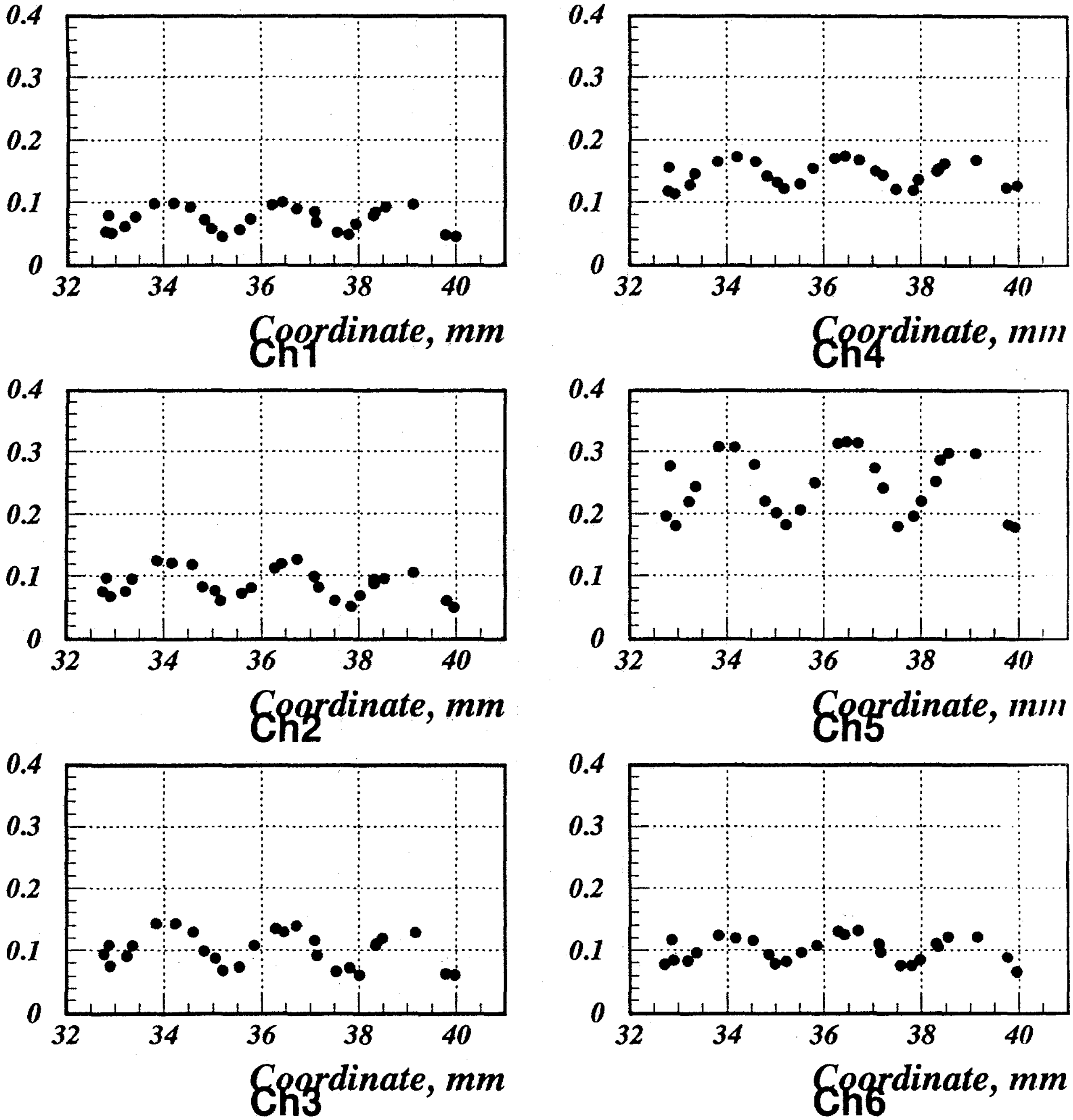
• **Attenuation of the detected light in the quartz fibers is 4.9 m**

• **Remarkable agreement between data and MC.**

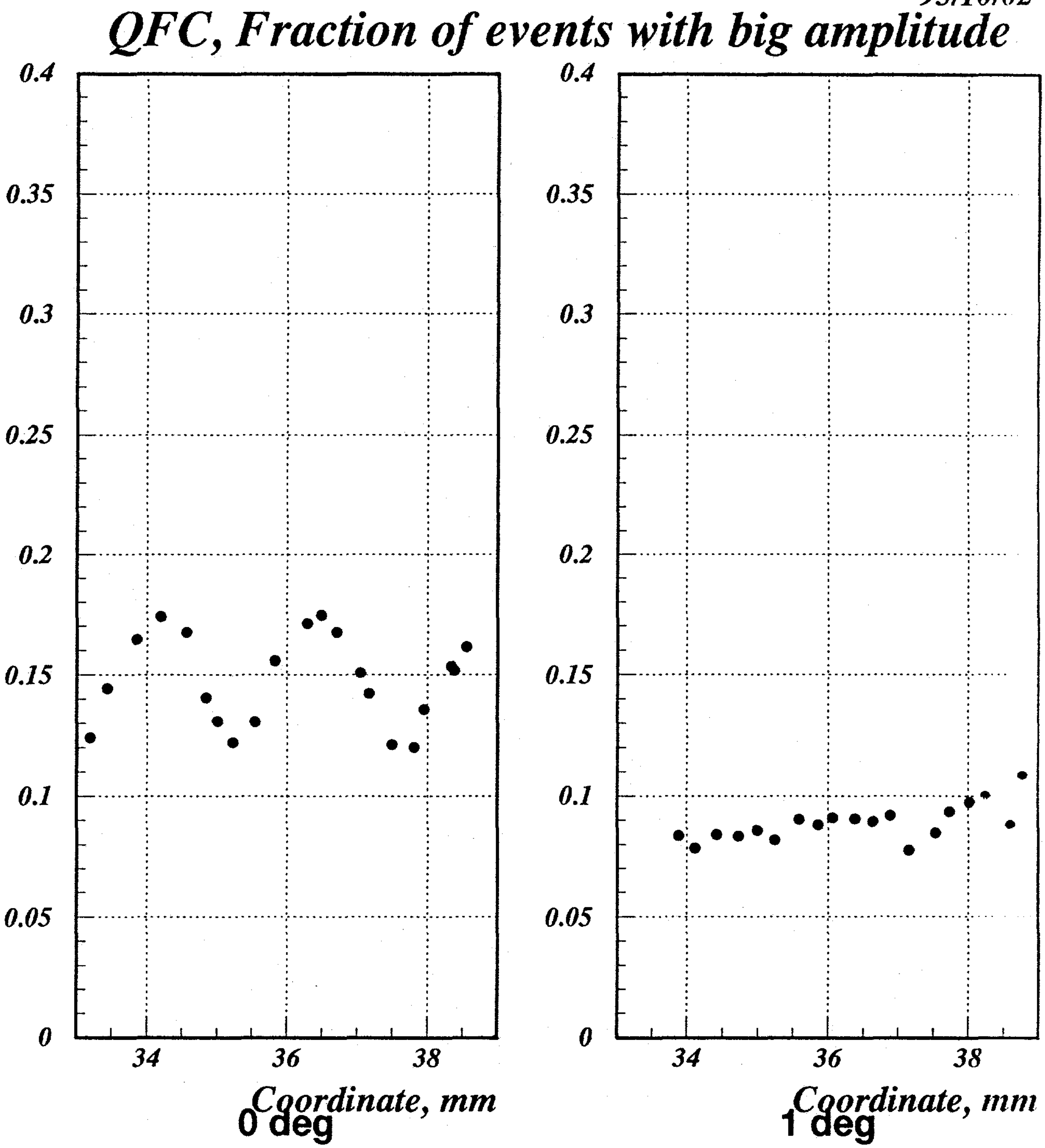

Beam Counters
Calorimeter
1 mm.
LED calibration system

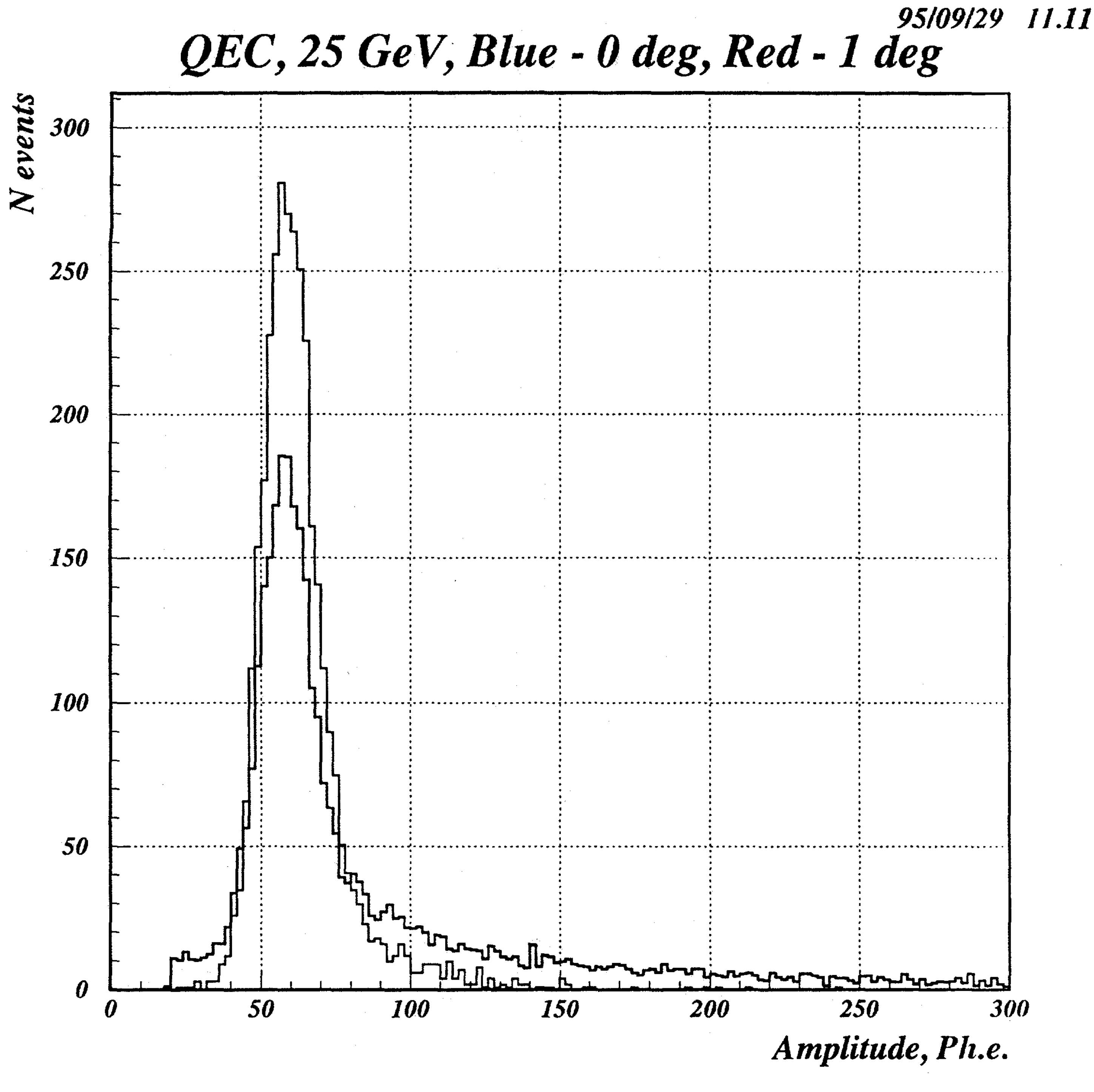
95/10/02 16.50

QFC, Fraction of events with big amplitude

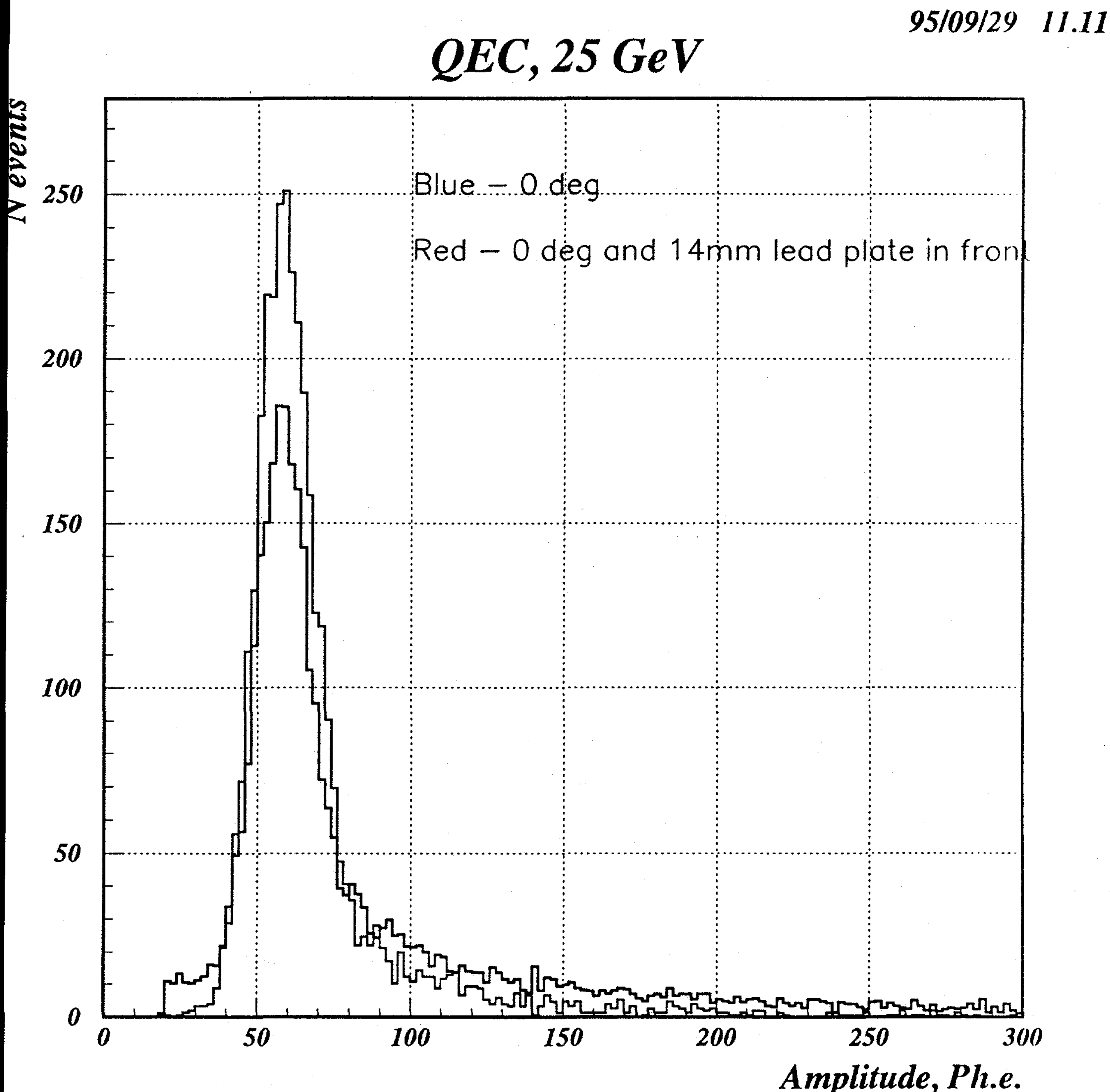


95/10/02 17.11


QFC, Fraction of events with big amplitude
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
34
36
38
Coordinate, mm
0 deg
1 deg



95/09/29 11.11
QEC, 25 GeV, Blue - 0 deg, Red - 1 deg
N events
0
50
100
150
200
250
300
Amplitude, Ph.e.


95/09/29 11.11
QEC, 25 GeV
N events
Blue – 0 deg
Red – 0 deg and 14mm lead plate in front
250
200
150
100
50
0
0
50
100
150
200
250
300
Amplitude, Ph.e.

Amplitude correction.

For each half of the calorimeter the following procedure has been applied:

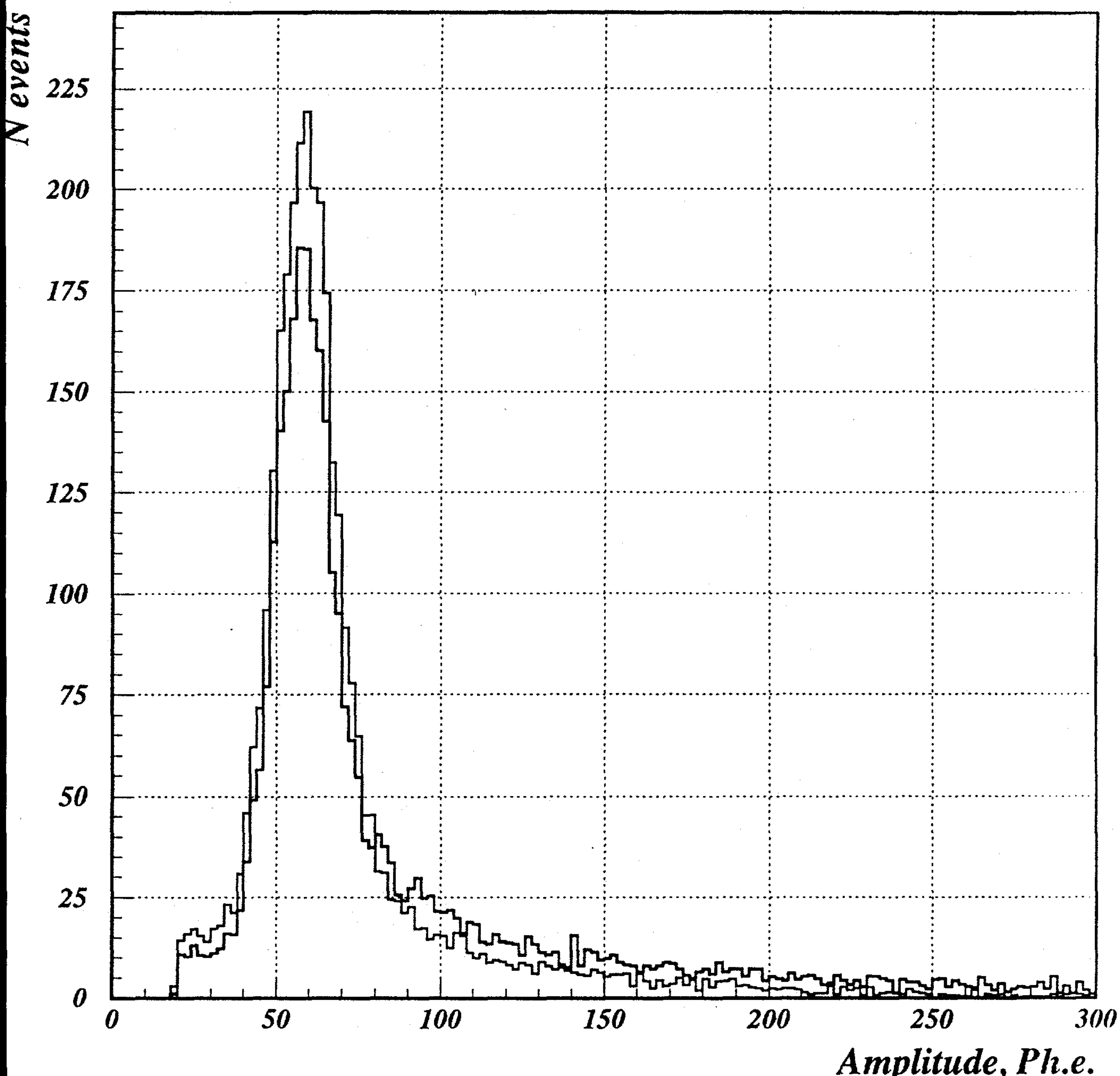
found MAX$\{A_i\}$

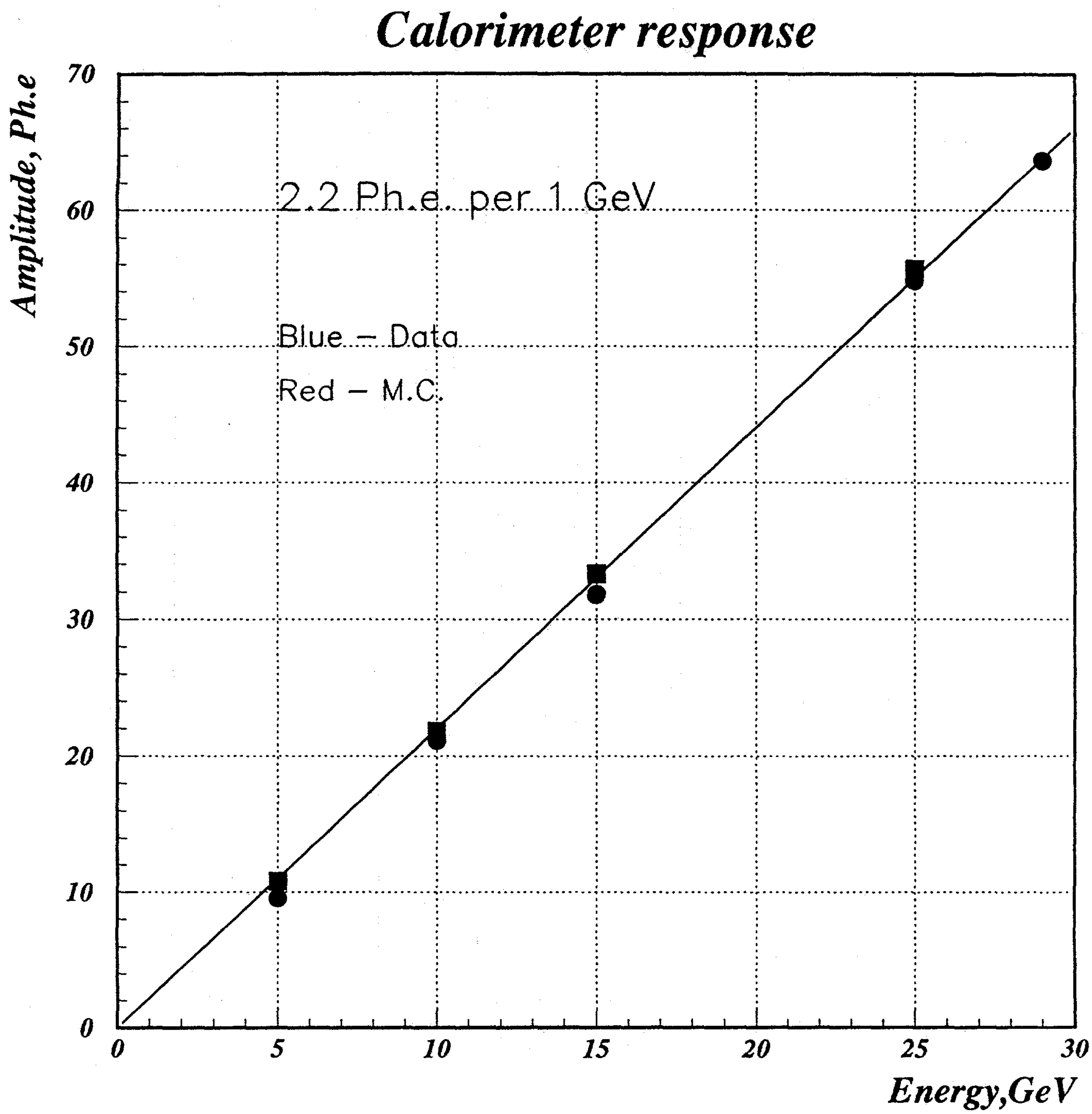
$$\text{if } A_i > A_i + 2 \bullet \delta_i \quad \text{then}$$

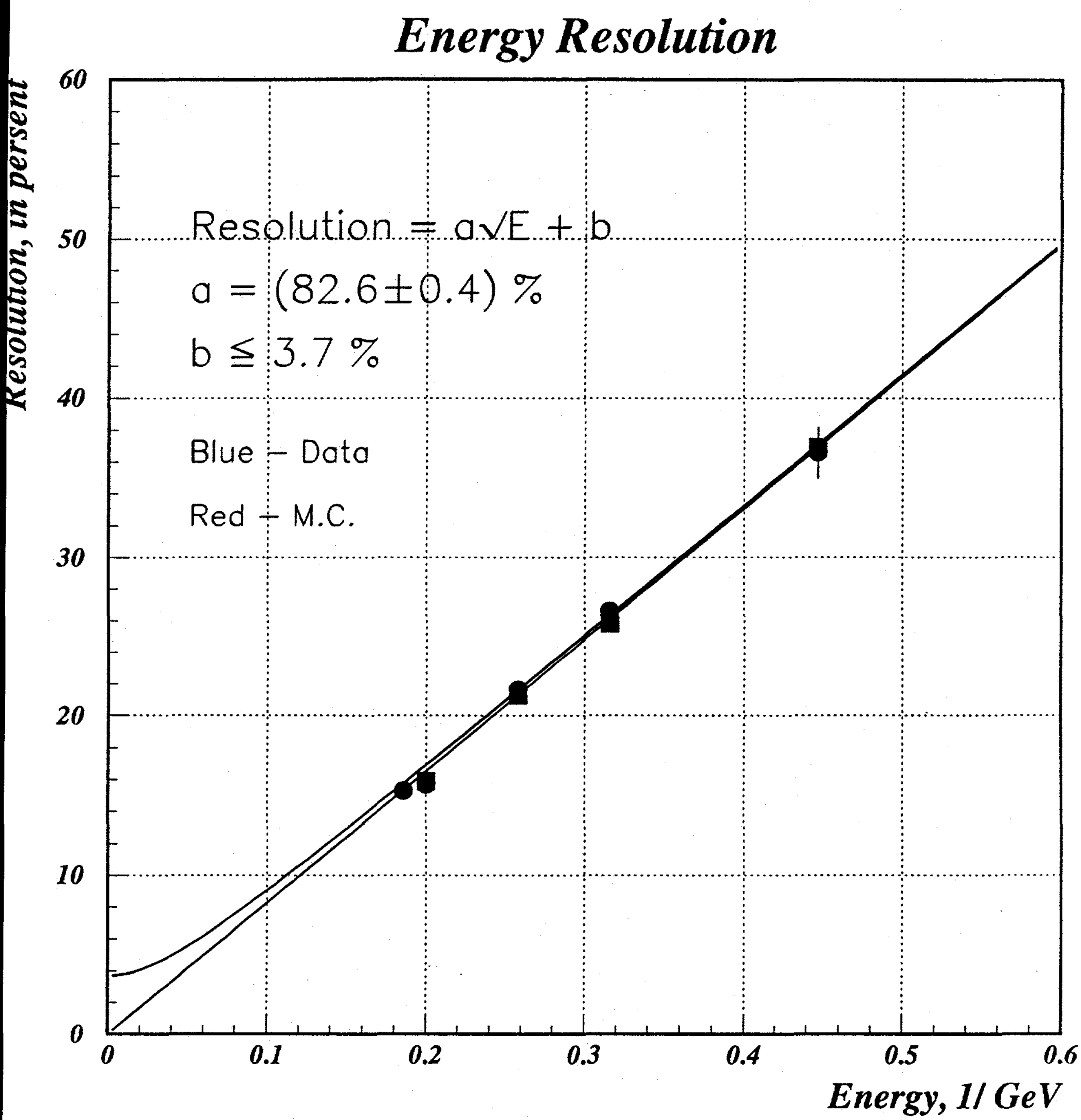
$$A_i = 0.5 \bullet \sum_{k}^{k \neq i} A_k$$

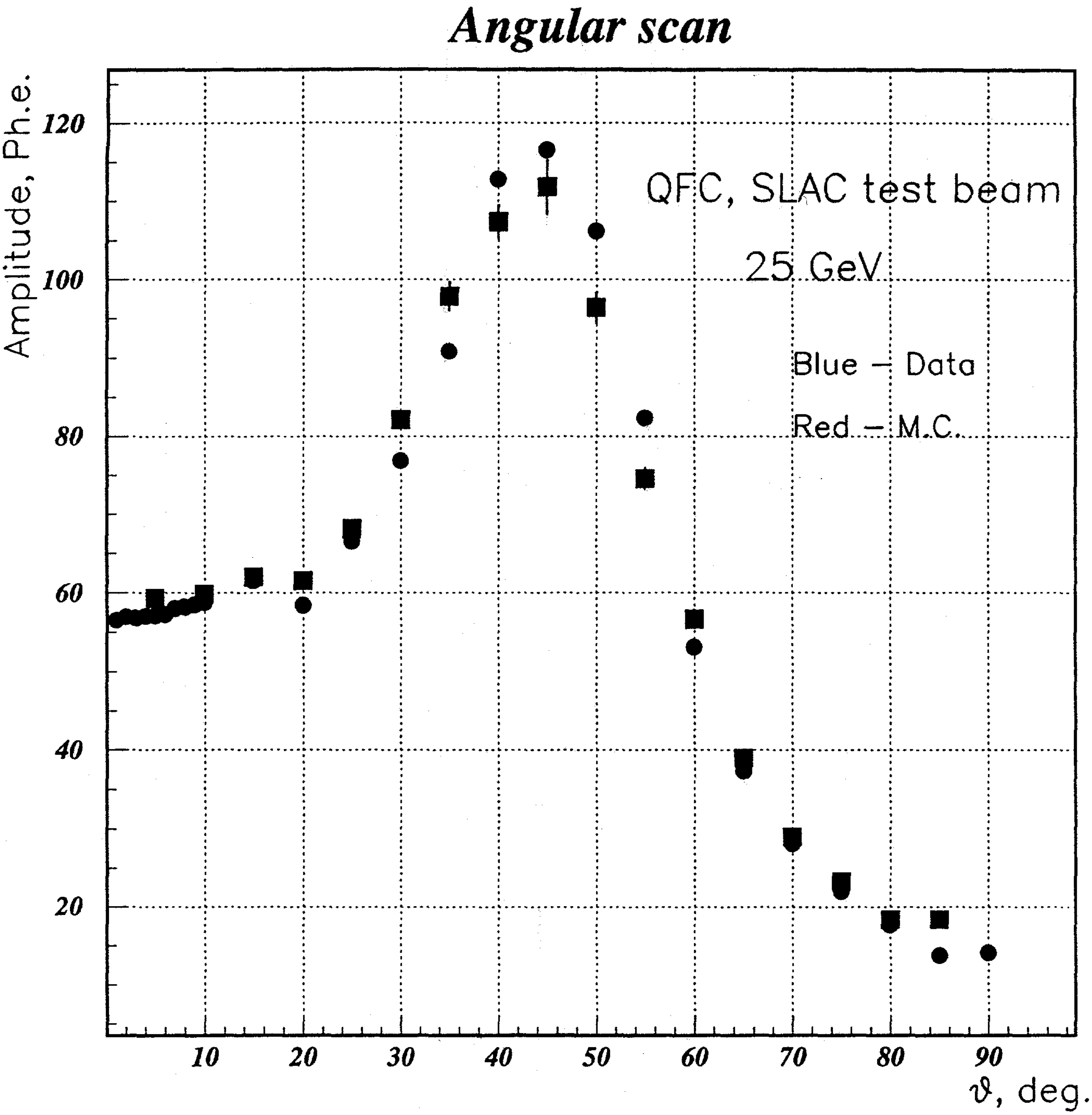
95/09/29 11.11

QEC, 25 GeV, Blue - before correction, Red - after

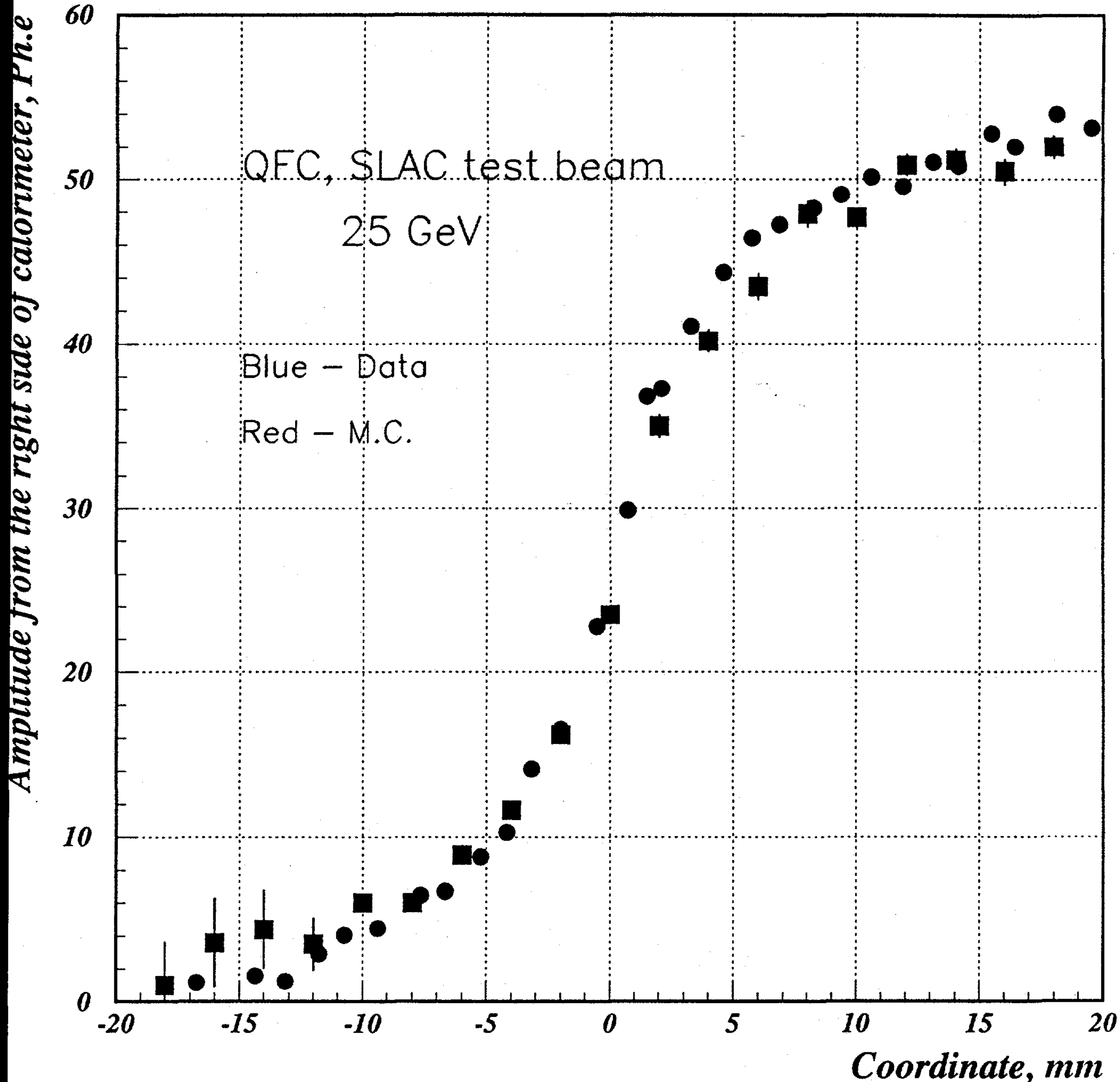



Calorimeter response
Amplitude, Ph.e
Energy,GeV
2.2 Ph.e. per 1 GeV
Blue – Data
Red – M.C.
0
10
20
30
40
50
60
70
0
5
10
15
20
25
30


Energy Resolution
Resolution, in persent
Energy, 1/ GeV
Resolution = a√E + b
a = (82.6±0.4) %
b ≦ 3.7 %
Blue – Data
Red – M.C.
0
10
20
30
40
50
60
0
0.1
0.2
0.3
0.4
0.5
0.6

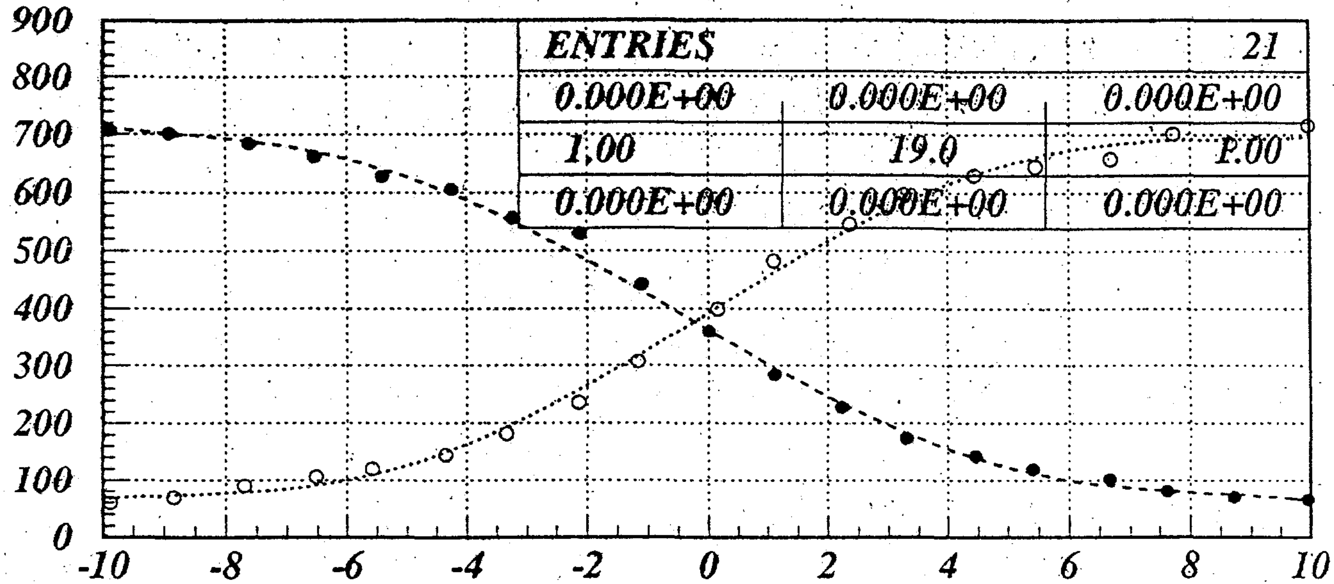

Angular scan
Amplitude, Ph.e.
120
100
80
60
40
20
10
20
30
40
50
60
70
80
90
ϑ, deg.
QFC, SLAC test beam
25 GeV
Blue – Data
Red – M.C.

Transverse scan

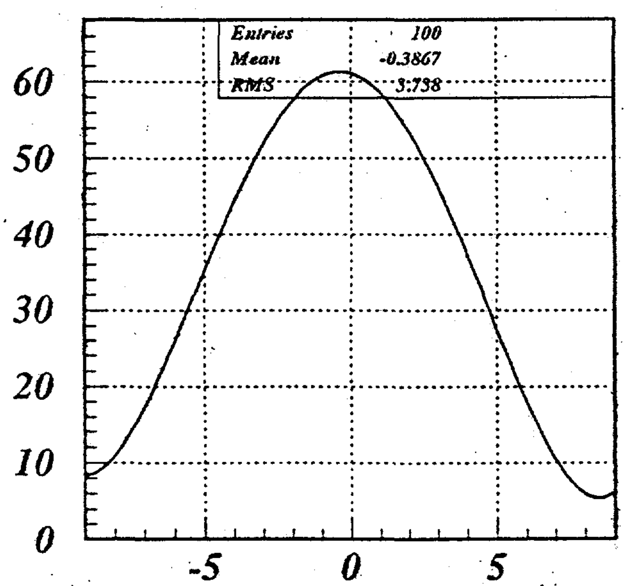


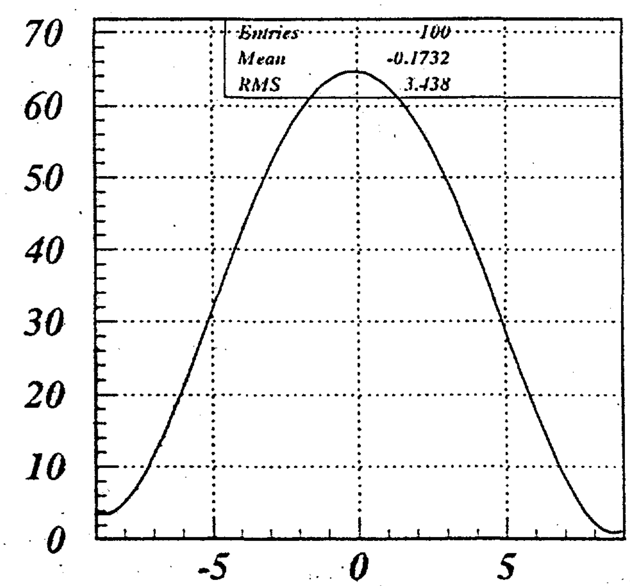
95/05/22 17.20

20 GeV

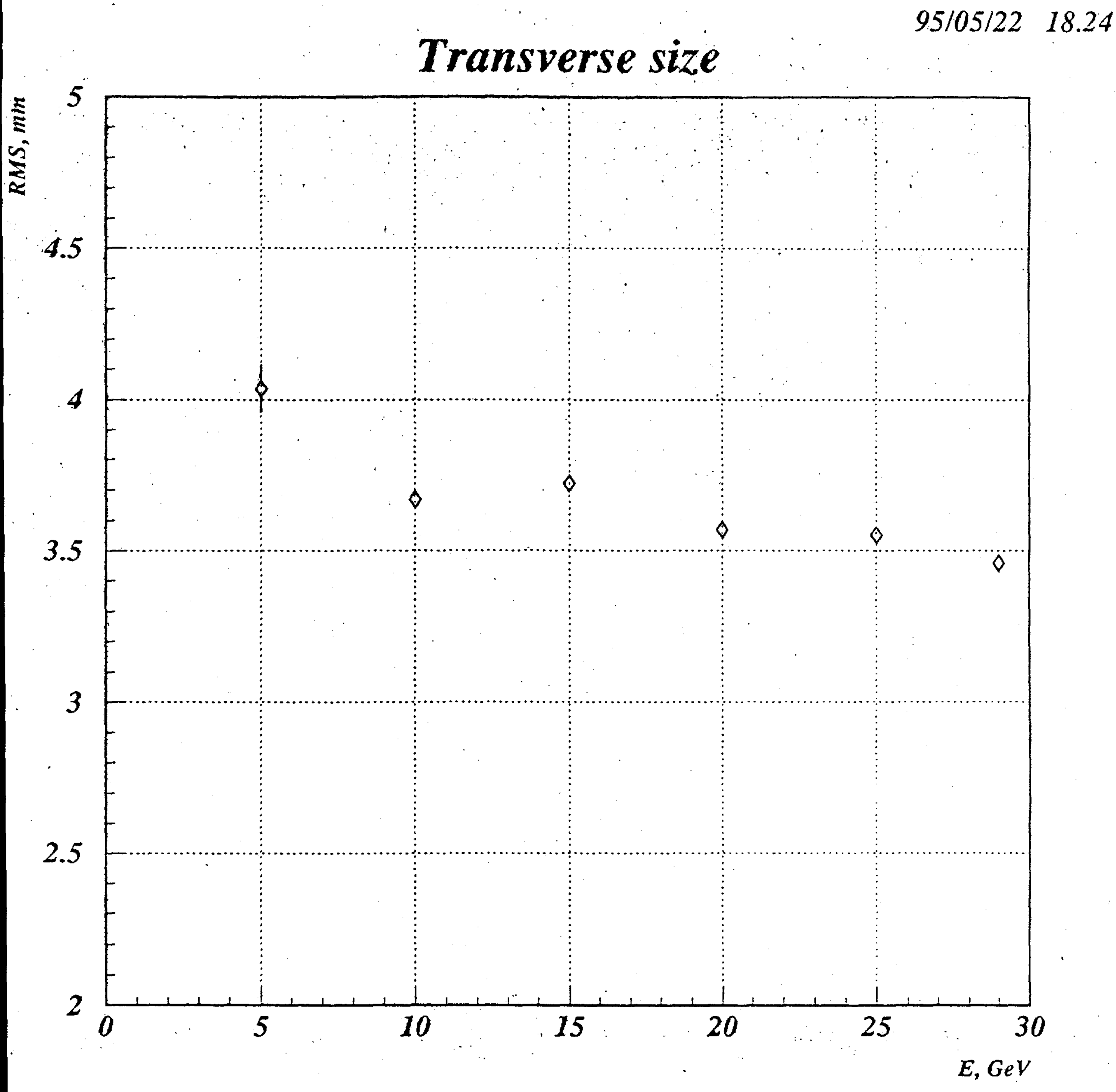


A1 and A2

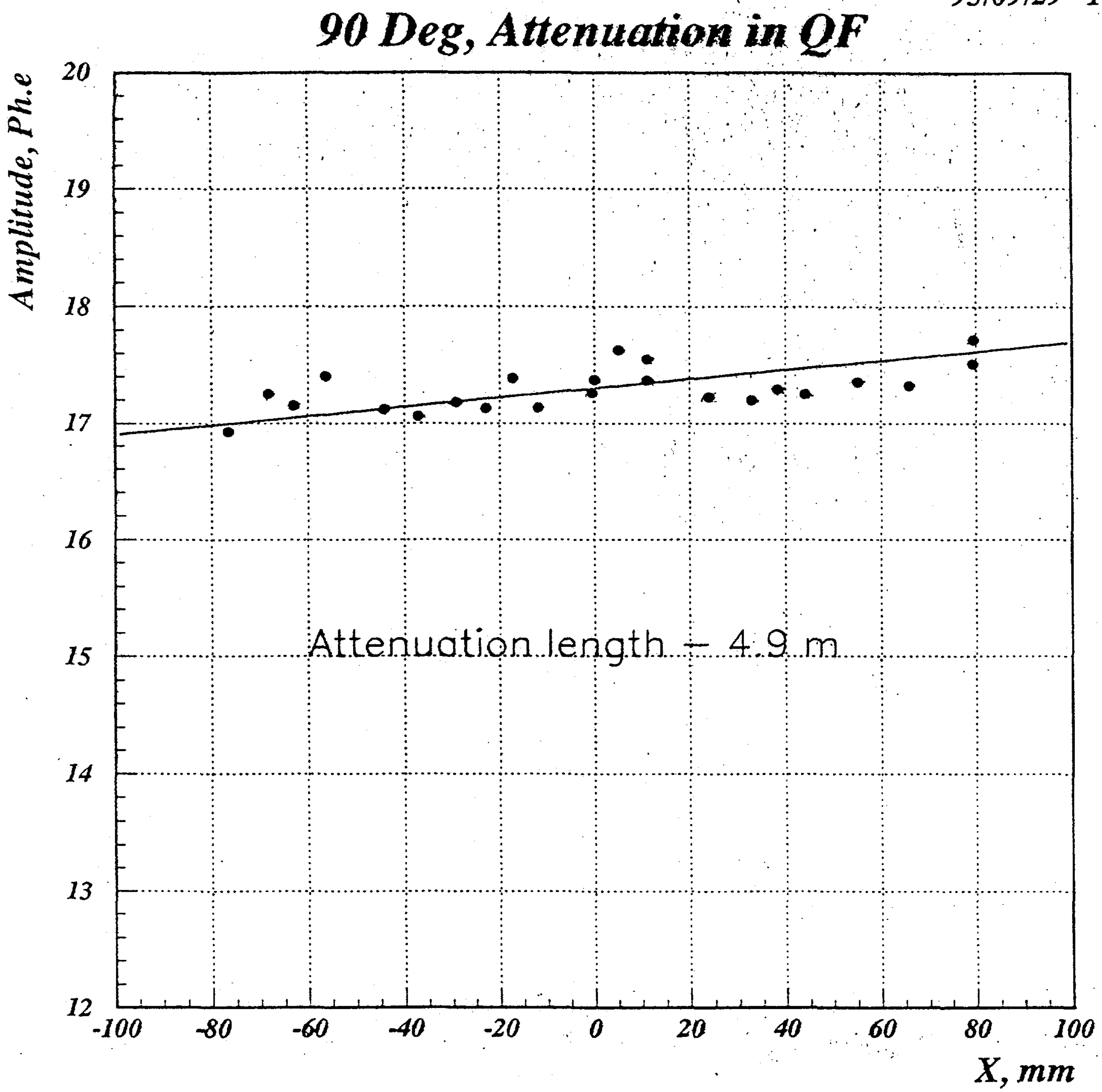




-1.*-61.1356-2.*0.54497*X-3.*0.47593*X**2-4*-0.00303019*X**3-5*-0.00[illegible]*X**4 [illegible]0.175709*X+3.*-0.550344*X**2+4*0.000672324*X**3+5*0.00218225*X**4


95/05/22 18.24
Transverse size
RMS, mm
E, GeV
5
4.5
4
3.5
3
2.5
2
0
5
10
15
20
25
30

95/09/29 13.11


90 Deg, Attenuation in QF
Amplitude, Ph.e
20
19
18
17
16
15
14
13
12
-100
-80
-60
-40
-20
0
20
40
60
80
100
X, mm
Attenuation length = 4.9 m

Quartz-Tungsten Calorimeter for SLD Compton Polarimeter

ORNL
UTK
MISSISSIPPI

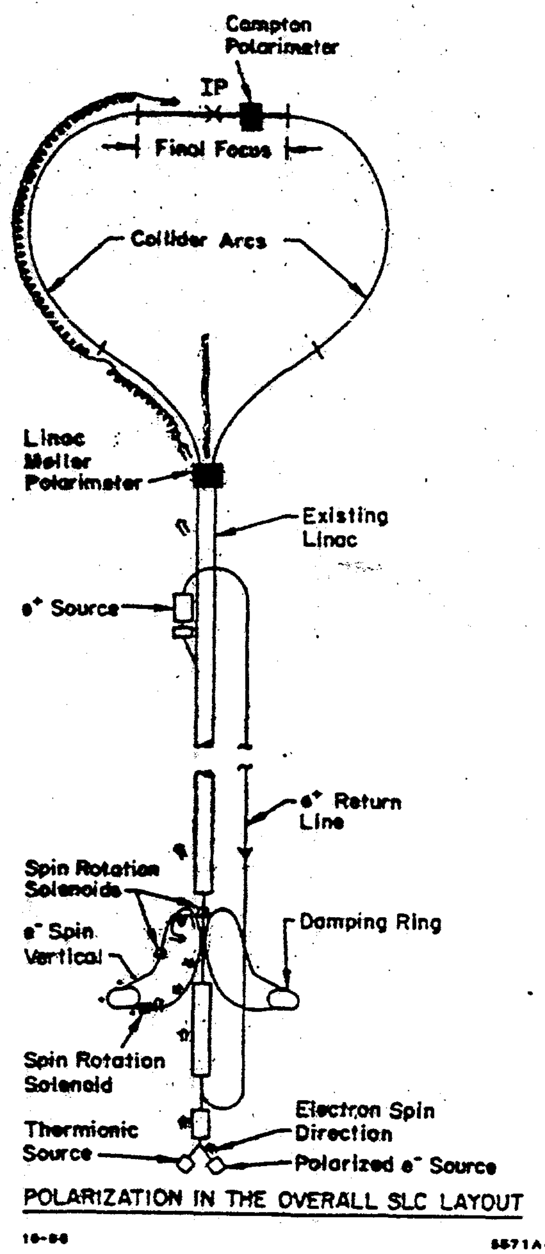
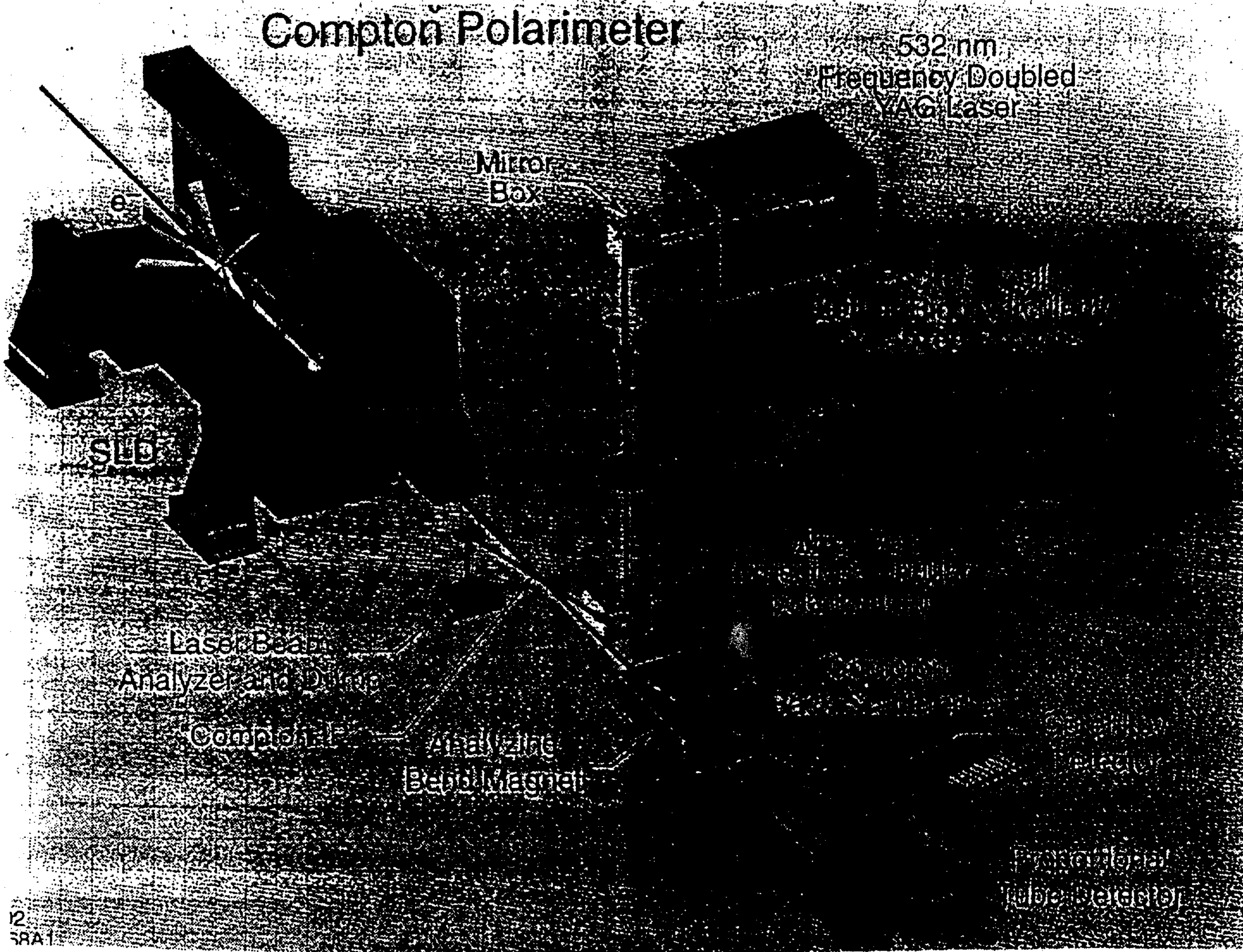


Figure 8. A simplified schematic of the SLC indicating those components that feature in the generation, transport, and measurement of polarized electrons.

50K Z with polarization 62% at 1993

35K Z with polarization 80% at 1994

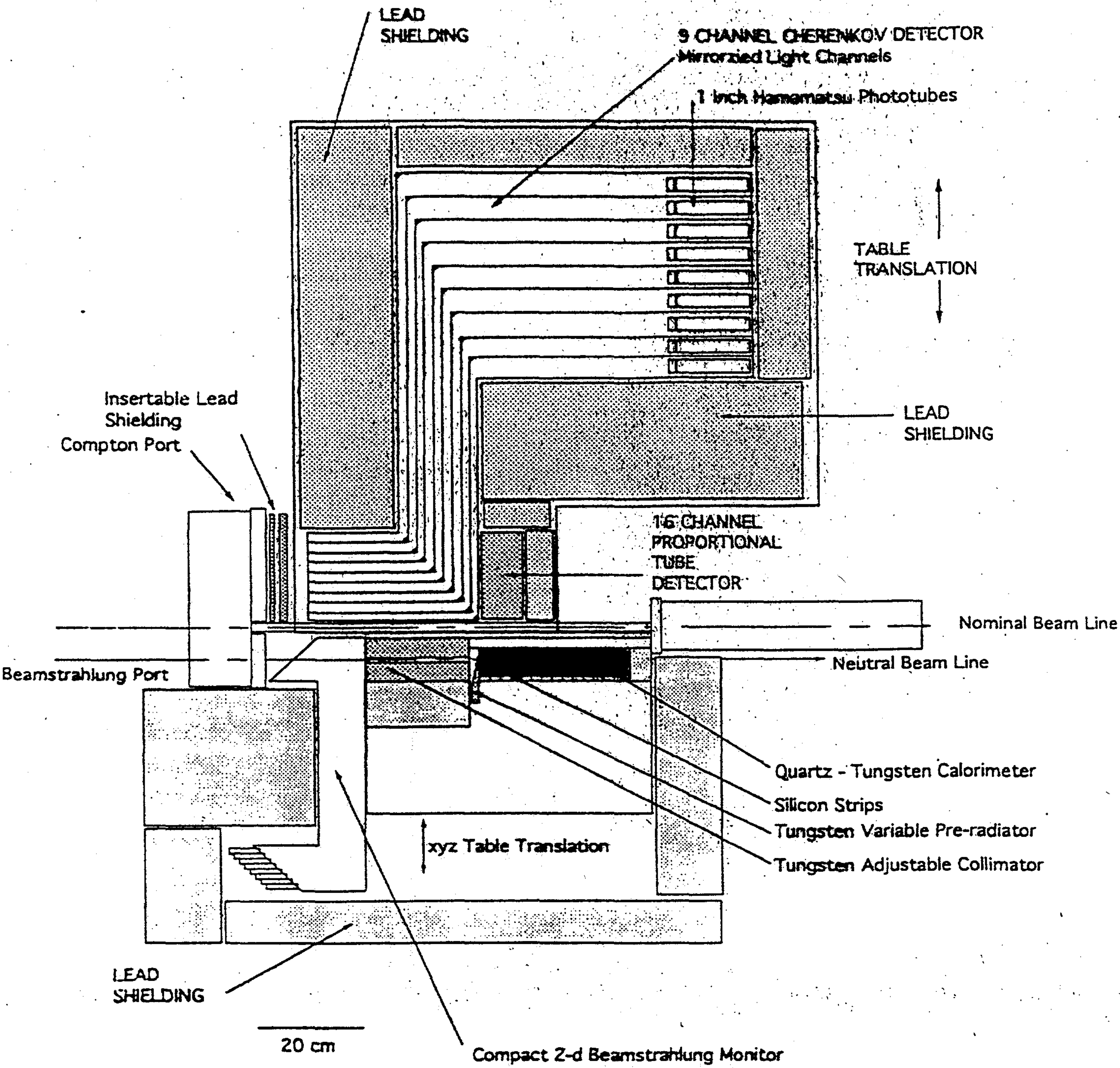
Quartz-Tungsten Calorimeter for SLD Compton Polarimeter



- Handle big energy flow (E_{tot}=30 TeV)
- Radiation Hard
- Not sensitivie to synchrotron radiation

compact.

COMPTON DETECTOR LAYOUT - TOP VIEW



M. Fero
Last Modified 11/29/93

What are the requirements for the photon detector?

- To handle the big energy flow.

$<E_\gamma> \approx 15$ GeV, 2000 γ per pulse $\Rightarrow$ $\mathbf{E_{tot} = 30}$ **TeV.**

- Energy resolution.

$$\delta E / E = \frac{250\%}{\sqrt{E(\text{GeV})}}$$

- Precision position measurements.

better than 0.2 μm.

- Linearity should be better then 1%

- Radiation Hardness.

- Reliability.

- Compactness.

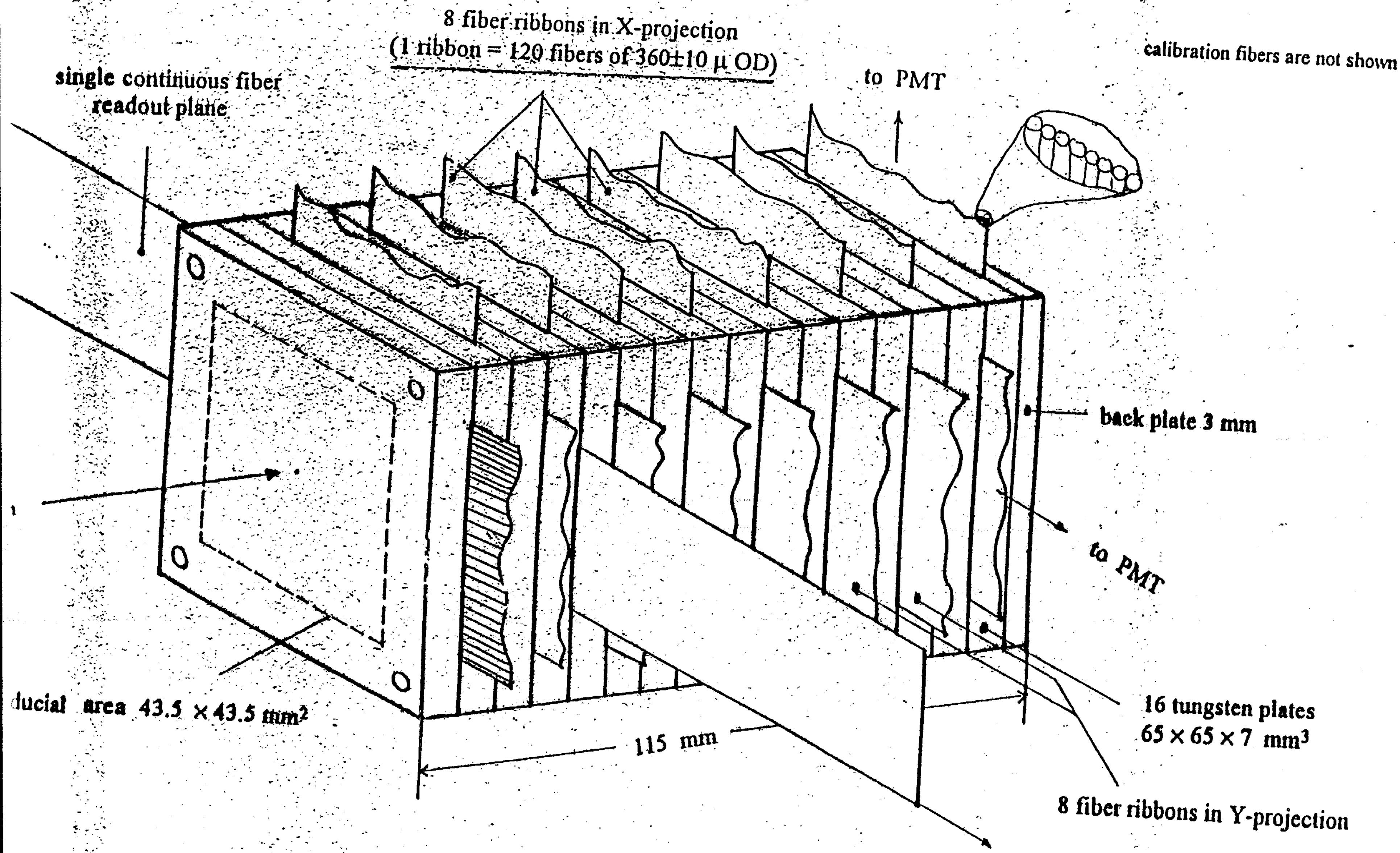
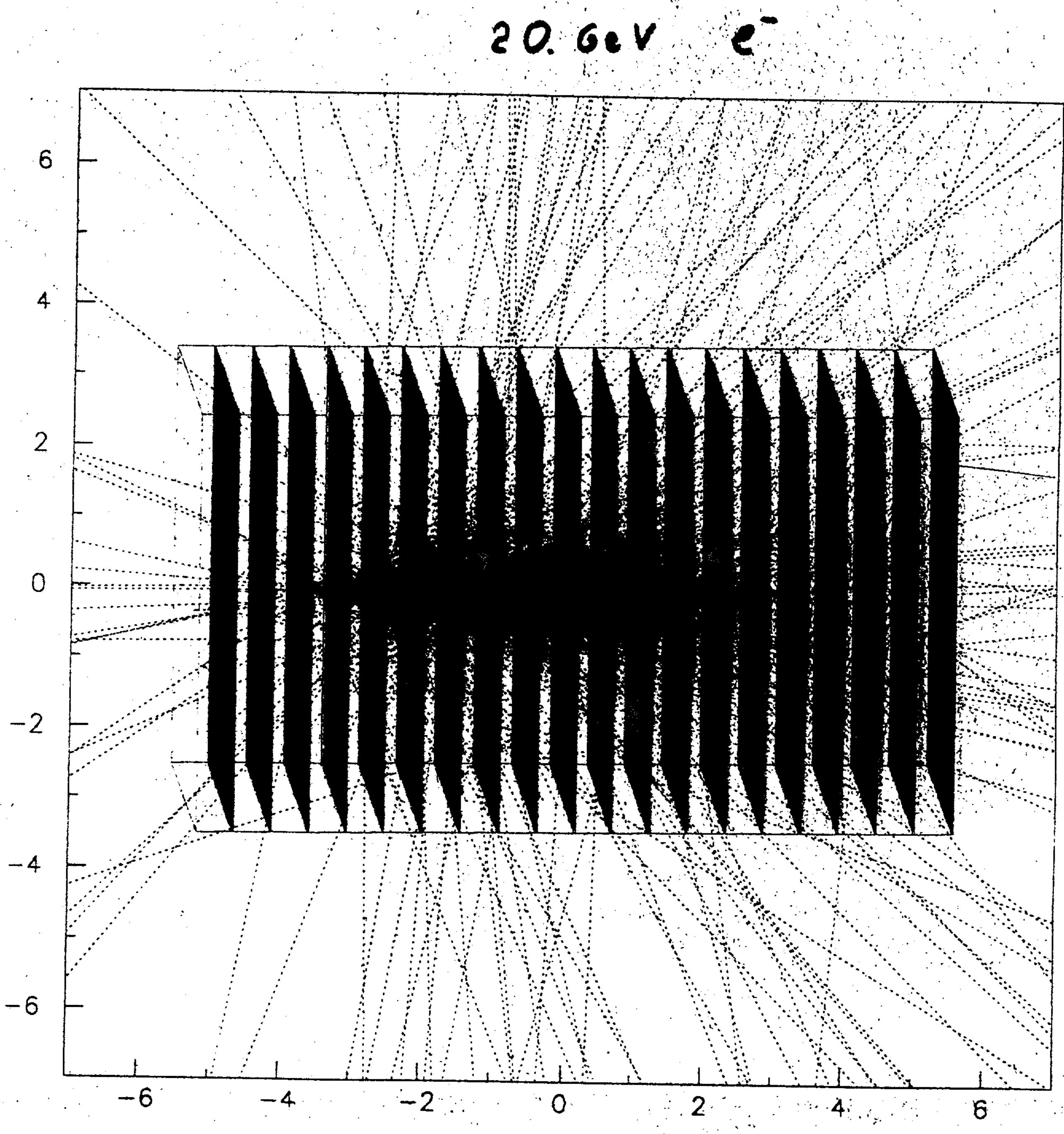


Figure 29.

Quartz-Tungsten Compton Photon Calorimeter Prototype


20. GeV e⁻
6
4
2
0
−2
−4
−6
−6
−4
−2
0
2
4
6

Longitudinal beam polarization

100% polarization - 17.4% in energy asymmetry
For 1% polarization accuracy one has
to measure **energy** flow better than **0.1 %**

Transverse Beam polarization

100% polarization - shift of gamma beam center of gravity on 24μ
For 1% polarization accuracy one has
to measure central gravity **position** better than **0.2μ.**

These accuracy's can be achieved by multiple repetitive measurements.

According to central limiting theorem, accuracy can be improved as $\propto 1 / \sqrt{N}$.

The limit is determined by **systematic** errors.

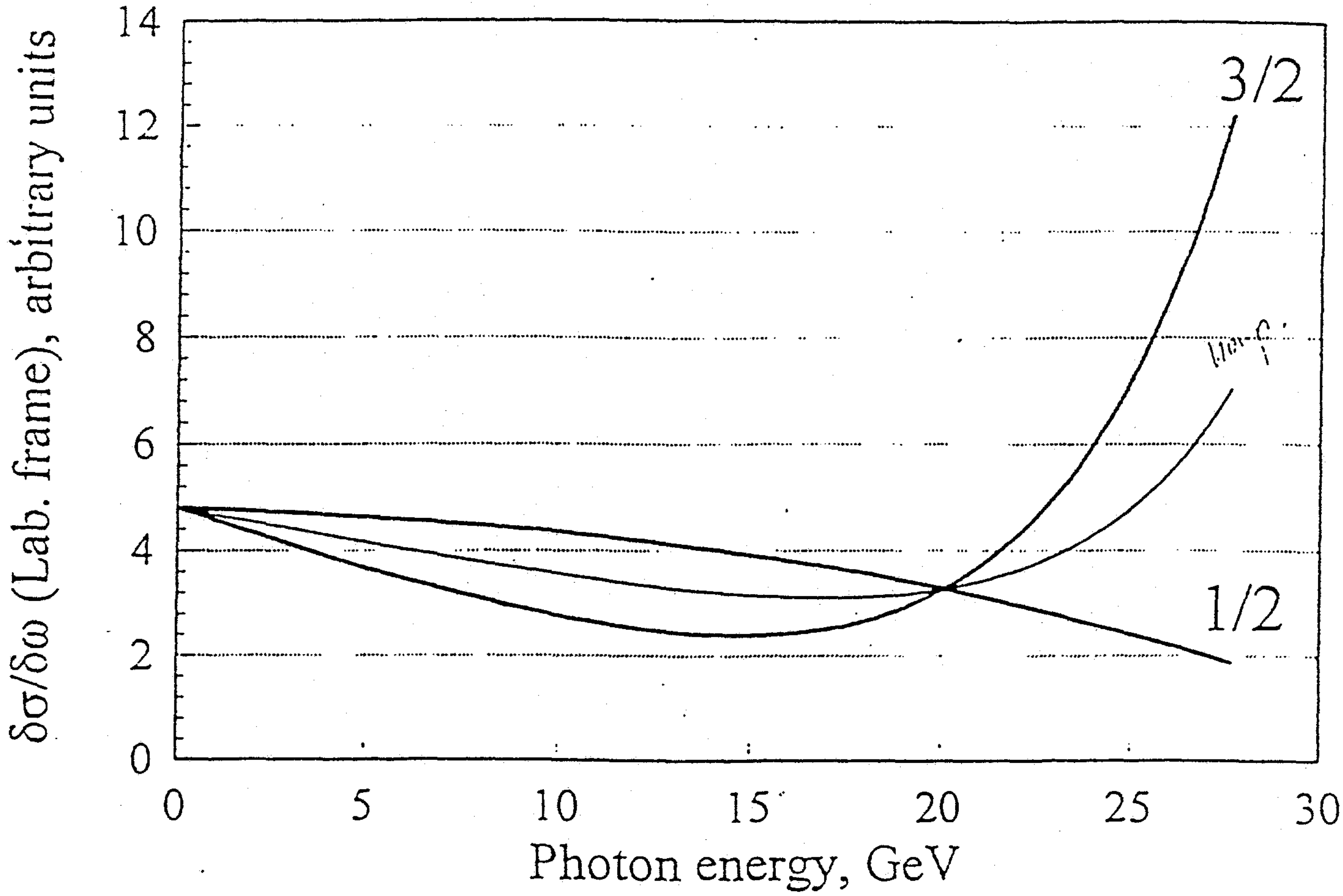
In Compton Photon Polarimeter 2000 photons per pulse are expected 11 times per second.

Longitudinal Polarization effects

$\delta\sigma/\delta\omega$ in the Lab frame

Electron beam: E=45.1 GeV

Laser beam: ω=2.33 eV



Energy assymmetry 17.4%

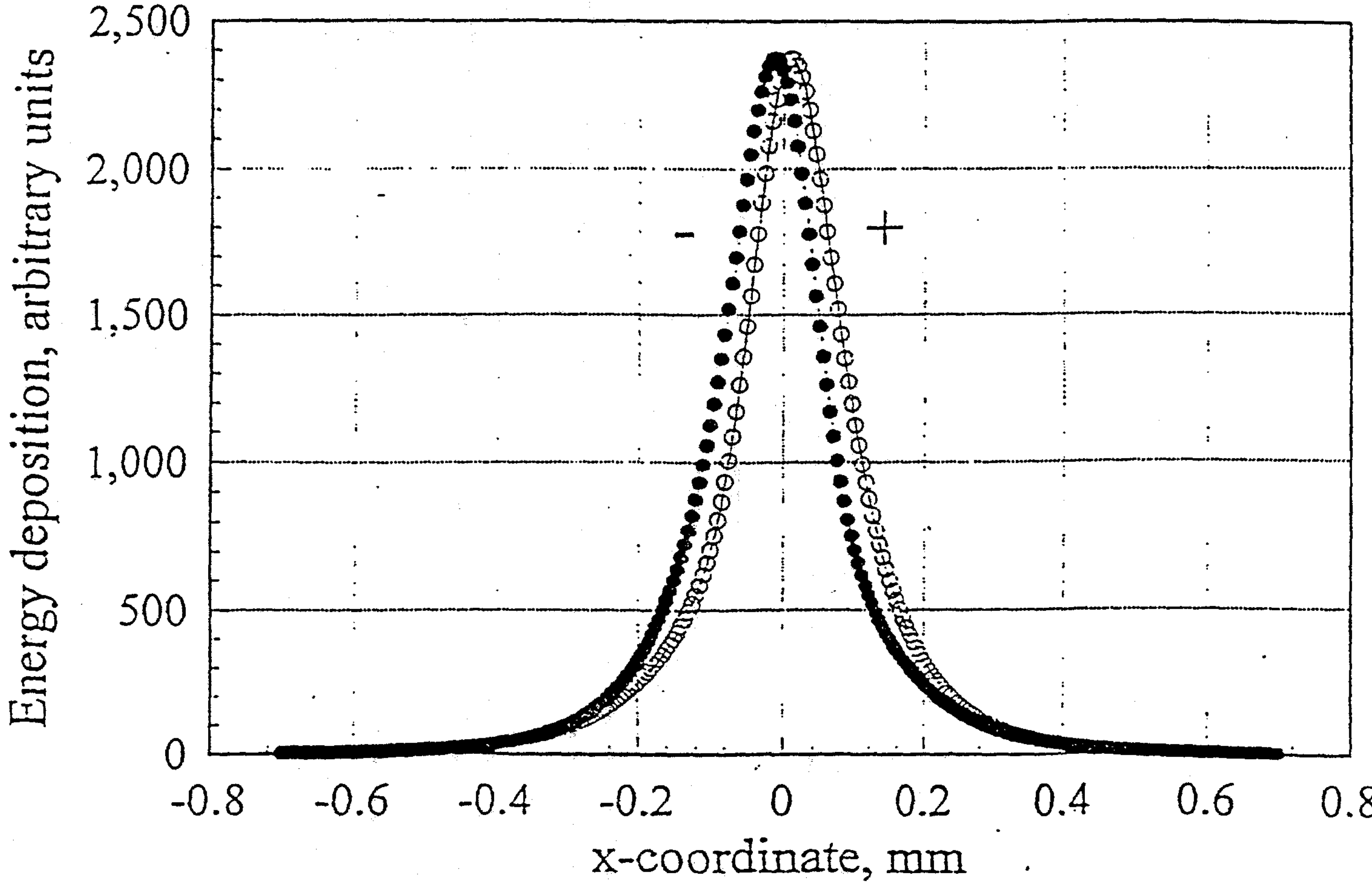
K.D. Shmakov

Transverse Polarization effects

X(Y)-direction Profile of the enery deposition
at 11m from the interaction point.

$\delta\sigma/\delta x$

No beam divergence. No beam jitter.



<25.4 μm>

for 100% transverse polarization

K.D. Shmakov

Detector has to fit inside 10x10x25 cm^3 volume.

Quartz Fiber Radiation Damage Study

- **Use HFIR reactor spent fuel elements as γ-source**
  rate: 70 - 10 MRad/hour

- **Irradiate from 100 MRad to 23 GRad**

- **Use Silica Core - Silica Cladding fibers**
12 different types with different OH content and buffer material

- **Fibers:**
length 50 cm

fiber diameter	**300**	**330**	**360**	**μ**
	core	**cladding**	**buffer**	

- **All fibers have been irradiated.**
Final results will be available in a month.

- **Now some samples are irradiated by neutrons at ORELA, ORNL.**
Flux - up to 10^{16} n/cm^2

Fig. 1. Stainless steel tube facility for irradiation in spent HFIR fuel assemblies.

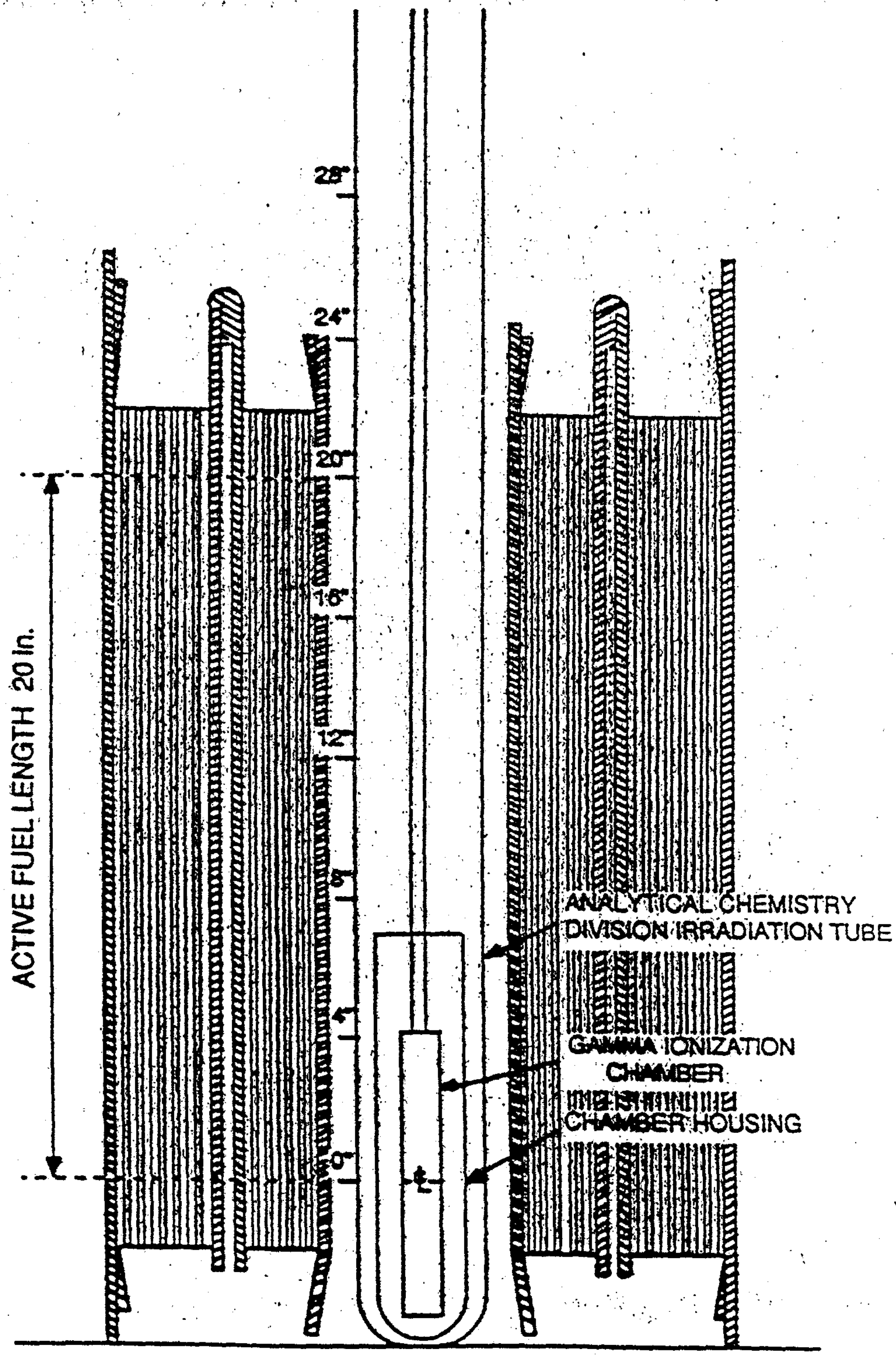


Fig. 3. Cross-sectional view of HFIR fuel assembly with Analytical Chemistry irradiation tube.

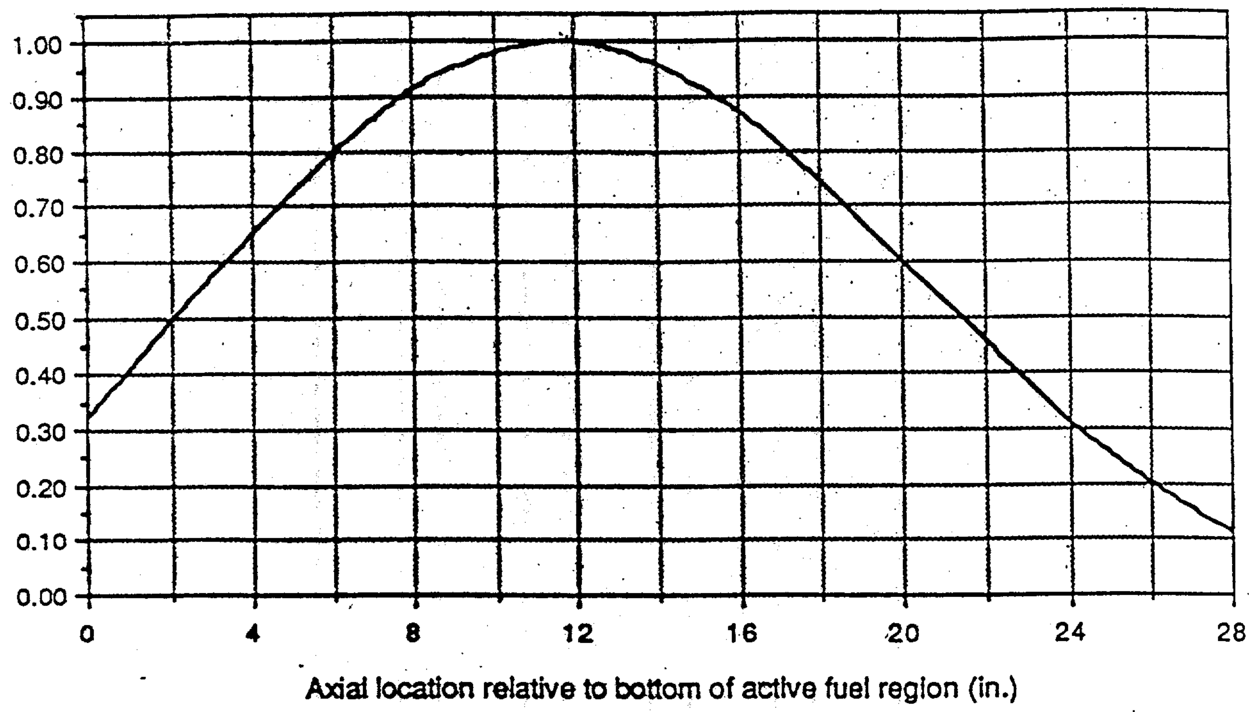


Fig. 4. Axial dose rate relative to peak dose rate.

VI. $n\bar{n}$ Oscillations

We completed in previous contract year a rather complete study of an $n\bar{n}$ oscillation experiment at proposed Advanced Neutron Source at ORNL. Since demise of ANS we have looked at feasibility of doing the experiment and proposed upgraded HFIR reactor at ORNL and find the potential to be excellent, ultimately comparable to ANS. We currently studying the adaptation of the previous work to HFIR. Much is unchanged, the major modifications having to do with the reactor experiment interface which is work in progress. We include in this section a brief report of our preliminary findings and an announcement of an International Workshop on Baryon Stability. It is our very strong belief that it would be a serious oversight if a major upgrade of neutron sources in US would occur without making provision for a sensitive $n\bar{n}$ experiment.

Design of an Experiment to Search for Baryon Nonconservation in Neutron-Antineutron Transitions

Originally proposed for the Advanced Neutron Source (ANS) reactor, the experiment would search for neutron-antineutron oscillations (transitions). Matter-antimatter oscillations is a well-established phenomenon in $K^0 \to \overline{K}^0$ and $B^0 \to \overline{B}^0$ transitions. Transitions of neutrons to antineutrons are forbidden by baryon number conservation (M. Gell-Mann and A. Pais, 1955). The reasons to question baryon number conservation are: (a) the observed "baryon asymmetry" of the Universe (A. Sakharov, 1967; V. Kuzmin, 1970) and (b) Grand Unification Theory (GUT) models (S. Glashow, 1979; R. Marshak and R. Mohapatra, 1980). In some GUT models the $n \to \overline{n}$ transition with characteristic time of $\tau_{n\overline{n}} \sim 10^8 - 10^{10}$ sec might exist as a complementary, or as an alternative, possibility to the proton decay. If found with characteristic time in this range, the $n \to \overline{n}$ transition would correspond to new physics emerging on the scale of $\sim 10^5 - 10^6$ GeV, which is inaccessible by modern high-energy colliders.

The best most recent limit of $\tau_{n\overline{n}} > 8.6 \cdot 10^7$ sec for $n \to \overline{n}$ transitions with free-flying neutrons was set in a reactor experiment at Grenoble (M. Baldo-Ceolin et al., 1994). With neutron-focusing improvements proposed for the ANS experiment, it would have been possible for one year of ANS operation to increase the $n \to \overline{n}$ discovery potential by a factor of ~10,000 as compared to Grenoble experiment, or to obtain a limit of $\tau_{n\overline{n}} > 10^{10}$sec. After the demise of the ANS, the effort of designing the $n \to \overline{n}$ oscillation experiment was refocused on the possibility to achieve a significant experimental result with alternative neutron sources that might become available at ORNL: either at the existing or upgraded High Flux Isotope Reactor (HFIR) or at the proposed Spallation Neutron Source (SNS). The discovery potential of a HFIR-based experiment, after three years of operation, using a cold neutron moderator of the ANS type and a similar focusing reflector, would be close to that which was expected for the ANS-based experiment. The lower integral neutron flux of the proposed SNS (relative to HFIR) would require the development of a "super-cold" neutron moderator (SCNM) thermalizing neutrons down to the temperatures of few Kelvin (solud methane or deuterium pellets immersed in superfluid helium). The latter development is a subject of independent R&D study which might result in the construction at HFIR and/or at SNS of a new generation of cold neutron source facilities required for various applications. With the SCNM, the discovery potential for $n \to \overline{n}$ search at SNS can be maximized if a vertical layout of the experiment will be used to compensate for effects of gravity. Various experimental options related to the possible HFIR and SNS $n \to \overline{n}$ searches are shown in the following table.

Table 1.

Experimental Options for Neutron-Antineutron Transitions Search

(The discovery potential of ILL-Grenoble experiment is taken as 1.)

Neutron source	Neutron moderator	Discovery potential gain for one year of operation
ILL'94 *finished experiment*	Liq D_2 @ 25 K	× 1
~~ANS~~ *discontinued*	Large Liq D_2 @ 25 K	× 13,000
HFIR *present*	Be @ 342 K	× 50
HFIR *present*	Small CH_4 @ 20 K	× 300
HFIR modified *with new Be reflector*	Large CH_4 @ 20 K	× 1000
HFIR upgraded *with D_2O reflector*	Large Liq D_2 @ 25 K	× 5,000
HFIR upgraded *with D_2O reflector*	SCNM @ 1 K	× 23,000
Spallation source *horizontal layout*	SCNM @ 1 K	× 1,000
Spallation source *vertical layout*	SCNM @ 1 K	× 8,000

The concept of an experiment to search for $n \rightarrow \bar{n}$ transitions with a large neutron focusing reflector was presented at a meeting of the American Physical Society (Washington, DC, April 1995); at the International Conference Nucleon-Antinucleon' 95 (Moscow, Russia, September 1995); at the International Conference on Theoretical Aspects of Underground Physics' 95 (Toledo, Spain, September 1995); and at the 13th Meeting of the International Collaboration on Advanced Neutron Sources (PSI, Switzerland, October 1995). An international workshop on the future prospects of baryon instability search in p-decay and in $n \rightarrow \bar{n}$ oscillation experiments is being organized at ORNL and will be held in March 1996. The design of the $n \rightarrow \bar{n}$ search experiment is being pursued by the ORNL group in collaboration with the University of Tennessee, Harvard University, University of Washington, and the Institute of Theoretical and Experimental Physics (Moscow, Russia).

International Workshop on
Future Prospects of Baryon Instability Search in p-Decay and n-$\bar{n}$ Oscillation Experiments

Oak Ridge, Tennessee, March 28–30, 1996

October 25, 1995

FIRST ANNOUNCEMENT

Scope

Future prospects of baryon instability search rely upon a new generation of experiments. Super Kamiokande will come into operation in the spring of 1996 and ICARUS within the next few years. There is also an idea of a large "1 km^3" detector which might result in a detecting mass that is an order of magnitude higher than that of Super Kamiokande. Recently a proposal has been developed at ORNL to perform a new search for neutron-antineutron transitions with a discovery potential that is a few orders of magnitude higher than those of earlier experiments. The purpose of the Workshop is to review the present theoretical and experimental aspects of baryon instability search, to understand what can be learned from the next generations of experiments, and to focus on the directions of future studies. Related theoretical and experimental topics such as baryogenesis in the early Universe, search for antimatter and dark matter, and other cosmological and particle physics problems will also be addressed.

The Workshop is sponsored by the Oak Ridge National Laboratory and the University of Tennessee.

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Workshop Secretary
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Phone: (423) 574-4681; FAX: (423) 576-2822; e-mail: SBALL@orph01.phy.ornl.gov

Format, Contributions, and Proceedings

The following plenary sessions are planned :

A. Theoretical aspects of baryon number nonconservation
B. Cosmological aspects of baryon number nonconservation
C. Nuclear physics effects
D. Present and future experiments

The preliminary scientific program will be given in the second announcement scheduled for early January 1996.

No parallel sessions are envisaged. There will be invited talks of either 30 minutes or 45 minutes and contributed presentations of 15-20 minutes. Abstracts of the contributions with time requested should be submitted to the Organizing Committee in free format by mail, fax, or e-mail before March 1, 1996.

The Proceedings of the Workshop will be published at ORNL, with a copy distributed to all Workshop participants. The deadline for the submission of manuscripts is May 1, 1996. Format for the written submissions will be given in the second announcement.

Copies of transparencies will be made available during the Workshop for a nominal fee. To speed up this service, speakers are kindly requested to bring a Xerox copy of their talk and turn it in to the secretary after their presentation.

Participation and Registration

The Workshop will be held in the auditorium of the American Museum of Science and Energy in Oak Ridge, Tennessee, from 9:00 a.m., Thursday, March 28, to 1:00 p.m., Saturday, March 30, 1996. Planning to depart Oak Ridge on Sunday, March 31, will result in lower air fares in most cases. Registration of participants will be from 8:00 to 9:00 a.m. on Thursday, March 28, in the American Museum of Science and Energy.

Workshop participation will be by invitation only, and attendance will be limited to ~100 participants. Those interested in attending the Workshop who have not received a personal invitation may request one by sending an e-mail, a letter, or a fax to any member of the Organizing Committee.

Workshop **registration deadline** will be **March 1, 1996**. The registration form and the request for registration fee will be distributed with the second announcement by early January 1996.

All recipients of this letter are asked to complete the **preregistration form** at the end of this announcement and mail, fax, or e-mail it to the Organizing Committee (see address below) **before December 15, 1995**. The Organizing Committee will appreciate an early response. Please respond even if you do not plan to attend the Workshop. Since the participation quota is limited, it will allow the Organizing Committee to take extra requests into consideration and will help us to provide better service to participants.

Please send preregistration form before December 15, 1995, to the following address:

Workshop Secretary, Ms. Shirley Ball
Bldg. 6003, MS-6372, ORNL, P.O. Box 2008, Oak Ridge, TN 37831-6372, USA
Phone: (423) 574-4681, FAX: (423) 576-2822, e-mail: SBall@orph01.phy.ornl.gov

There will be a registration fee of $100 which will cover organizational expenses, proceedings, coffee breaks, and the conference dinner. (Additional conference dinner tickets for accompanying persons can be purchased from the secretary for $25.) The registration fee has to be sent with the registration form (which will be distributed to participants by early January) before March 1, 1996. Payment can be made via personal check or money order payable to "ORNL Baryon Workshop." After March 1, the registration fee will be $125. If paid on arrival, the $125 registration fee may be paid with U.S.$ in cash, traveler checks, money orders, or personal checks written on U.S. banks. No credit cards will be accepted.

Accommodations

The meeting will take place in downtown Oak Ridge at the American Museum of Science and Energy (300 S. Tulane Avenue). Participants can be conveniently accommodated in two nearby hotels located within 5 minutes walking distance from the Museum.

Both hotels are holding blocks of rooms for Workshop participants under the title "Baryon Instability Workshop."

Fifty rooms are blocked at the Garden Plaza Hotel (215 S. Illinois Avenue) for check-in on Wednesday, March 27, and check-out on Sunday, March 31. Cut-off date for making reservations is March 6. Twenty of the rooms are being held at the government rate of $54/inclusive on a first-come–first-served basis. The other 30 will be at $59 + tax (13.25%). Phone number for reservations is (423) 481-2468.

Forty rooms are blocked at the Comfort Inn (433 S. Rutgers Avenue) for check-in on Wednesday, March 27, and check-out on Sunday, March 31. Phone number for reservations is (423) 481-8200. Cut-off date for making reservations is March 10. The rate is $54/inclusive.

All participants are kindly requested to make their own arrangements with the hotels. Special accommodation requests may be addressed to the Organizing Committee.

Travel

Unless you are driving to Tennessee from another state, plan to travel by air to Knoxville. From the Knoxville airport proceed to Oak Ridge by rental car, limousine, or taxi. No special transportation arrangements from / to the airport are planned. The distance from the airport to downtown Oak Ridge is about 30 miles. Driving instructions and local maps will be provided in the second announcement. The name of airport limousine service is the "Airport Express Shuttle." Fare to Oak Ridge is $20/person if the van/limo is not full and $15/person if the van/limo is full. They are located at the baggage claim area and have a stand/counter there. Usually passengers do not have to wait for a long period to leave the airport, typically only a few minutes if there is another flight due in within 15 minutes. Taxi fare from the airport to Oak Ridge is about $30.

Delta Air Lines — the major airline company servicing the Knoxville area — is offering the following special discounted fares for domestic (not international) flights for this Workshop: 10% discount off regular coach fares; 5% discount off any published domestic fare (except group, inclusive tour, military, government, senior citizen, zone, and visit U.S.A. fares). Some restrictions will apply and seats are limited. To obtain these special fares, take the following steps:

1. Call, or have your travel agent call 1-800-241-6760 any day between 8 a.m. and 11 p.m. eastern time
2. Refer to file number I-5355. Reference to the meeting title is not necessary.

International Workshop on
Future Prospects of Baryon Instability Search in p-Decay and n-$\bar{n}$ Oscillation Experiments
Oak Ridge, Tennessee, March 28–30, 1996

PREREGISTRATION FORM

Please mail, fax or e-mail this form to the address below **before December 15, 1995**

First/Middle/Last Name: ....

Home Institution: ....

Current Institution: ....

Current Mailing Address: ....

....

Telephone: ....

Fax: ....

E-mail: ....

[ ] I will attend [ ] I may attend [ ] I will not attend

Optional information:

Time requested for my contribution: .... minutes at the session (A,B,C,D): ....

Title of my presentation: ....

....

....

....

[ ] Abstract of my contribution will be sent later

If you have any questions, please write / fax / call / e-mail to the following address:

Ms. Shirley Ball, Workshop Secretary
Bldg. 6003, MS-6372, ORNL, P.O. Box 2008, Oak Ridge, TN 37831-6372, USA
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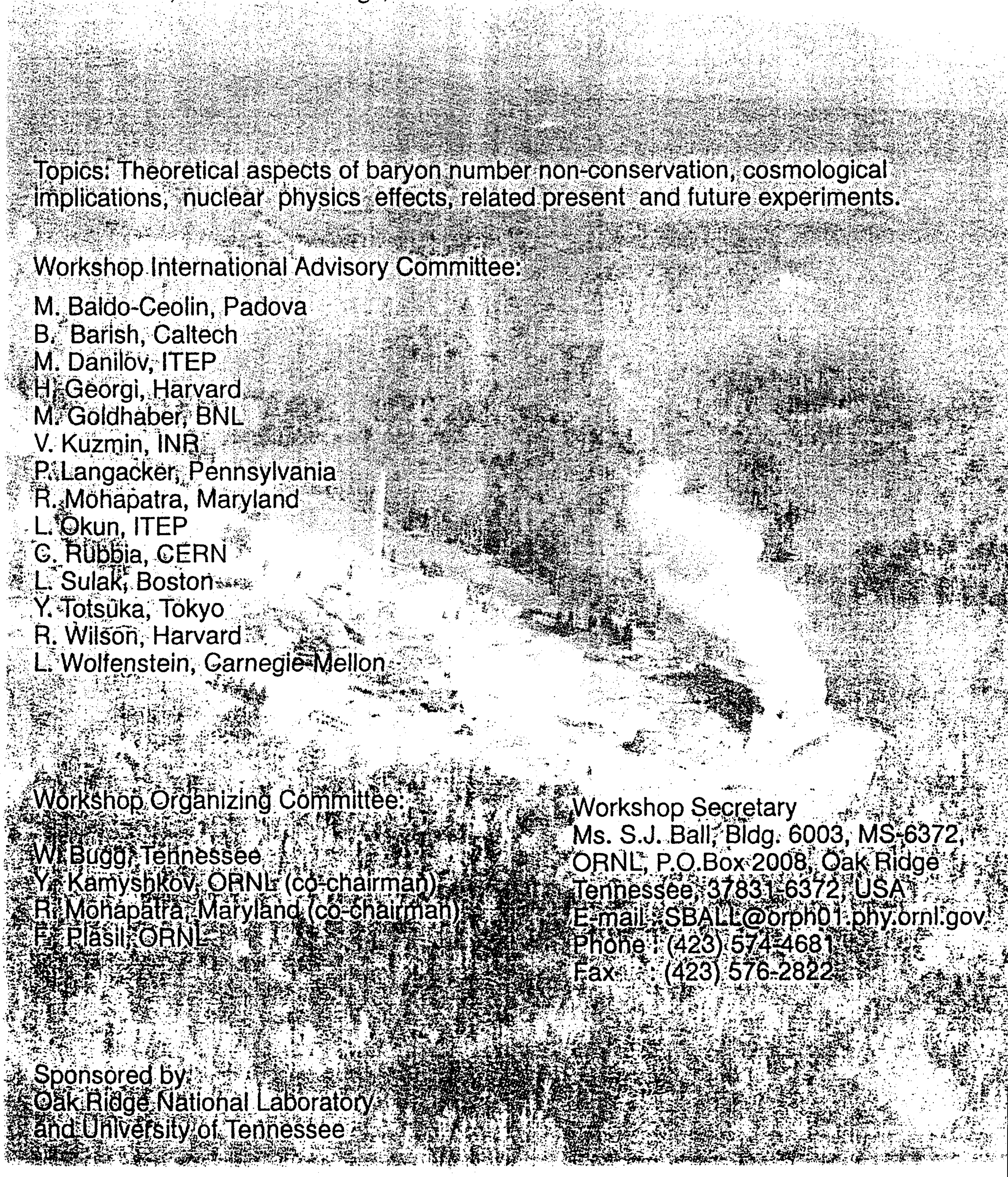
International Workshop on

Future Prospects of Baryon Instability Search in p-decay and $n \Rightarrow \bar{n}$ oscillation experiments

March 28-30, 1996 at Oak Ridge, Tennessee



Topics: Theoretical aspects of baryon number non-conservation, cosmological implications, nuclear physics effects, related present and future experiments.

Workshop International Advisory Committee:

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TASK A

LIST OF PUBLICATIONS

1. K. Abe et al. (SLD Collaboration). "Measurement of the τLifetime at SLD," SLAC-PUB-95-6767, April 95 submitted to Phys. Rev. D.

2. K. Abe et. (SLD Collaboration). "Measurement of the Average B Hadron Lifetime in Z Decays Using Reconstructed Vertices, to be published in Phys. Rev. Lett. (1995).

3. K. Abe et al. (SLD Collaboration). "Comparison of a New Calculation of Energy-Energy Correlations with $e^+e^- \rightarrow$ Hadrons data at the Z^0 Resonance, submitted to Phys. Rev. D.

4. K. Abe et al. (SLD Collaboration). "A Test of the Flavor Independence of Strong Interactions, SLAC-PUB-6687, submitted to Phys. Rev. Letter, (1995).

5. K. Abe et al. (SLD Collaboration). "Measurement of the Parity-Violating Parameter A_b from the Left-Right Forward-Backward Asymmetry of b Quark Production in Z^0 Decays Using a Momentum-Weighted Track Charge Technique," Phys. Rev. Lett. , 2890, (1995).

6. K. Abe et al. (SLD Collaboration) Search for Jet Handedness in Hadronic Z^0 Decays," Phys. Rev. Lett., 1512, (1995).

7. K. Abe et al. (SLD Collaboration). "Measurement of $\alpha_s M_z^2$ from Hadronic Event Observables at the Z^0 Resonance, Phys. Rev. D, 962, (1995).

8. K. Abe et al. (SLD Collaboration). "Polarized Bhabha Scattering and a Precision Measurement of the Electron Neutral Current Couplings, Phys. Rev. Lett. (1995).

1. (E687 Collaboration). "A Measurement of the Cabibbo Suppressed Decays $D^0 \rightarrow \pi^- \pi^+$ and $D^0 \rightarrow K^- K^+$," Phys. Lett. B321 (1994).

2. (E687 Collaboration). "Measurement of the Form-Factors for the Decay $D^+ \rightarrow \phi \mu^+$ Neutrino," Phys. Lett. B328, (1994).

3. (E687 Collaboration). "First Observation of the $\Sigma^- \pi^+ \pi^+$ Decay Mode of the Λ_c Baryon and its Branching Ratio Relative to the $\Sigma^+ \pi^+ \pi^-$ Mode," Phys. Lett B328, (1994).

4. (E687 Collaboration). "Precise Measurements of the D^0 and D^+ Meson Lifetimes, Phys. Lett. B323, (1994).

5. (E687 Collaboration). "Analysis of Three $D \rightarrow K \pi \pi$ Dalitz Plots," Phys. Lett. B331, (1994).

6. (E687 Collaboration). "Observation and Mass Measurement of $\Omega \rightarrow \Sigma^+ K^- K^- \pi^+$," Phys. Lett. B338, (1994).

7. (E687 Collaboration). "Measurement of the Masses and Widths of L = 1 Charm Mesons," Phys. Rev. Lett. 72, (1994).

8. (E687 Collaboration). "An Observation of an Excited State of the Λ_c^+ Baryon," Phys. Rev. Letter 72, (1994).

9. (E687 Collaboration). "Search for CP Violation in Charm Meson Decay," Phys. Rev. D50, (1994).

10. (E687 Collaboration). "Branching Ratios for the Decays $D^0 \rightarrow K^{0-} K^0$ and $D^0 \rightarrow K_s^0 K_s^0 K_s^0$," Phys. Lett 340, (1994).

11. (E687 Collaboration). "Charm Meson Decay into the Final States $K^0 K^+$ and $K^0 K^+$, Phys. Lett. B346, (1995).

12. (E687 Collaboration). "Analysis of the D^+, $D^+ \rightarrow K^+ K^- \pi^+$ Dalitz Plots," Phys. Letter B351, (1995).

13. (E687 Collaboration). "Study of Charged Hadronic Four-body Decays of the D^0 Meson," Phys. Lett. B354, (1995).

14. (E687 Collaboration). "Measurement of the Ω_c^0 Lifetime," Phys. Lett. B357, (1995).

15. (E687 Collaboration). "Doubly and Singly Cabibbo Suppressed Charm Decays into the $K^+ \pi^- \pi^+$ Final State," Phys. Lett. B359, (1995).

"Research in Theoretical High Energy Physics"

PROGRESS REPORT TO DEPARTMENT OF ENERGY

DOE DE-FG05-91ER40627

<u>TASK B</u>

Bennie F. L. Ward and George Siopsis

Progress Report

TASK B

B. F. L. Ward
and
G. Siopsis

The research in Task B during 1993-1994 focussed on the further development and application of our new YFS (Yennie-Frautschi-Suura) Monte Carlo approach[1] to SU_2 x U_1 radiative corrections in the Z° physics scenarios at the SLC and LEP and, recently, to similar SU_{2L} x U_1 x SU_3^c corrections in hadron collider physics. In addition, more progress was made on the application of perturbative QCD methods to heavy quark decay physics in the context of B-Factory high energy e^+e^- collider physics.

Specifically, during 1990-1991, we completed the implementation 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 implemented 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 x 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 has now been in use several years by all LEP and SLC collaborations (for SLC, this is the SLD Collaboration) and has been useful in the respective $f\overline{f} + n(\gamma)$ final states physics analyses, $f \neq e$. It has been demonstrated that the various pure weak libraries in KORALZ3 (one by W. Hollik, one by D. Bardine et al. and one unsupported library by R. Stuart) agree within .3% on the absolute normalization of the cross section near the Z° 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 are in the process of making an independent check of the pure weak libraries by Hollik, Stuart and Bardine et al. as they are implemented in KORALZ3 and of the corresponding libraries of these same three author groups as they are implemented in KORALZ4, our recent upgrade of KORALZ3 (described below). This we are doing in collaboration with Prof. Jadach in Krakow, Poland, with possible further collaboration from Prof. Zralek in Silesia, Poland. We have made substantial progress in our check and we hope to report more on this progress soon. Here, we may note that recently, using our results on the interplay of pure weak corrections and QED, we resolved the issue operationally of the gauge invariance of the renormalized Z° rest mass [3]. This shows that the mass measured at LEP/SLC for the Z° is in fact gauge invariant. We note that in the recent CERN95-03 Yellow Book report of D. Bardin et al., "Reports of the Working Group on "Precision Calculations for the Z° Resonance," it is shown that the theoretical uncertainty on the Hollik and Bardine et al. libraries for $\sin^2\Theta^{\ell}_{eff}$ is ~ .00015 to be compared with the expected ~ .0002 experimental precision of the final LEP/SLC results (20×10^6 Z°'s at LEP/5×10^5 80% beams polarization Z°'s at SLC by its end). Thus, our pure weak corrections check is still important to pursue.

Recently, we have introduced [4] the new YFS Monte Carlo event generator YFS3, which treats for the first time $n(\gamma)$ final state multiphoton radiation in $e^+e^- \rightarrow f\bar{f} + n(\gamma)$, with $f \neq e$. We are currently implementing it into the SLC/LEP experimental activities and refining its precision tag as dictated by the LEP(/SLC) data. Such final state radiation data afford new roads for Standard Model tests.

Indeed, the L3 Collaboration recently observed[5] an accumulation of high $\gamma\gamma$ mass events in $e^-e^+ \rightarrow \ell\bar{\ell} + 2\gamma$ where the photons are at wide angles with respect to the charged particles near the $\gamma\gamma$ mass 60 GeV. Working with us, they used our YFS3 calculation to conclude that the probability that their observation was a fluctuation of the expectations from QED was ~.1%. The current situation[6] is that all LEP collaborations have collectively seen 15 such L3-type events and YFS3 predicts 9. The probability of a fluctuation is now a few % and more data are needed to clarify the situation. Our YFS3 calculation is thus an important part of this exciting analysis of a possible new phenomenon at LEP in Z° physics. And, recently, we have analyzed the LEP data ourselves[7] using YFS3 and our comparison exact $0(\alpha^2)$ double bremsstrahlung result[8], wherein we isolate that part of YFS3 which corresponds to the result in [8] directly. We find that the YFS results are reliable in this NNLL region of phase space so that the estimates given in [6] are reliable.

Concerning the basic luminosity process $e^+e^- \rightarrow e^+e^- + n\gamma$ at low angles, we recall that we had implemented, during 1989-1990, our BHLUMI Monte Carlo YFS program[9] at SLC and at LEP, so that indeed the higher order corrections to the luminosity were known to 1%. This result already played a significant role in controlling the systematic error on the measurement of the luminosity at SLC and LEP and, hence, it made a significant contribution to the 1989 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 were 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 needed to 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 established [10] an $0(\alpha)$ 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, we expected, would 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 explained this in detail in our 1991-1992 renewal proposal.

And, indeed, during 1990-1991, we developed[11] two independent $0(\alpha^2)$ LL YFS exponentiated Monte Carlo's for the higher order corrections to the SLC/LEP luminosity so that, in a CERN Theory Division Seminar by Jadach in 12/90, we already presented a procedure[11] for correcting $O(\alpha)$ Monte Carlo luminosity simulations for higher order effects which was accurate to .2% on the pure bremmstrahlung and to .3% for the total luminosity. In addition, we developed, for the first time, analytic improved naive exponentiated formulae[12] for the luminosity process accurate to a technical precision of .02% so that we could check the normalization of BHLUMI 1.13 to .15%. Finally, to obviate the need of using two different MC simulations in the complicated software management environment of a LEP/SLC collaboration, we developed[11] BHLUMI 2.00 as a single, YFS MC solution to the luminosity problem at SLC/LEP with a total precision of .25%, including an allowance for pairs, vacuum polarization uncertainty, etc. For reference, the 1992 best experimental error from LEP on the luminosity measurement was ALEPH's .5%. Thus, we were providing, during 1992, a sufficiently accurate simulation; we emphasized in our 1992 Progress Report that we would need to improve this in the near future, when ALEPH installs and calibrates its new luminosity monitor. (This improvement is now complete.)

In fact, BHLUMI 2.01, published in Ref. 12, was used widely at LEP [13] for the analyses of the 1991-1992 LEP data (BHLUMI has always been used at MkII and SLD for data analysis). This means that during 1991-1992, we have succeeded with the implementation and acceptance of BHLUMI 2.01 as the basic luminosity data analysis radiative corrections simulator at LEP as a replacement of the Berends-Kleiss-Hollik generator BABAMC [14], which had been the standard data analysis luminosity generator at LEP since 1989-(BHLUMI was previously only used for the higher-order corrections to BABAMC at LEP, as we have explained; now, it is the program which generates the events which are passed through the long LEP detector simulations. This has greatly improved the understanding of these detectors' responses so that it has facilitated the precision tag of ~.5% which ALEPH reached with its original luminosity monitor. Thus, this represents a major achievement for the DOE's investment in Task B.) Recently,[15] using BHLUM2.01 and its new luminosity monitor, ALEPH has reached .32% precision on its luminosity. Thus, BHLUMI continued in 1993 to open the way to higher precision Z° physics.

Indeed, during 1994, OPAL, ALEPH, L3 and DELPHI, all with new luminometers, reported (see D. Schaile, Proc. 1994 Roch. Conf., eds. P.J. Bussey and I. G. Knowles (IOP Publ. Ltd, London, 1995) p. 27) .07%, .09%, .16% and .28% respectively for their experimental errors on the luminosity. Accordingly we, together with Prof. Jadach and Drs. E. R.-Was and Z. Was, have developed BHLUMI4.00, which is the exact order α^2 LL YFS exponentiated Monte Carlo realization of the luminosity process at LEP/SLC. The PI reported the theoretical precision .089% for the NW SICAL acceptance of ALEPH, in the Roch. Conf., 1994, (See B. F. L. Ward, et al., Proc. 1994 Roch. Conf., eds. P. J. Bussey and I. G. Knowles, (IOP Publ. Ltd., London, 1995) p. 407). Version 4.00 was recently published in Phys. Lett. B353, 362 (1995) and is still under final implementation at LEP/SLC and we expect to reach the desired .05% precision limit in the near future.

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. During this period, we and our collaborators resolved discrepancies in KORALZ3 libraries and in the luminosity calculations so that these calculations were in a usable state for the SLC and LEP turn-on's (our higher order bhabha work made the $N_\nu = 3$ discovery possible). We continued this commuting approach between SLAC and CERN during 1990 and 1991 - in the former case, working directly with physicists in both places, we were able to formulate and develope the benchmark $O(\alpha)$ process simulation[11] for the crucial luminosity problem and in the latter case, we were able to arrive at the desired .25% accuracy for our BHLUMI (YFS) calculation using this benchmark. In addition, our interactions with Drs. Locci (ALEPH) and Komamiya (OPAL) allowed us to start the implementation of our wide-angle YFS bhabha MC event generator BHLUMI 3.0, which we had made available to the SLD Collaboration at SLAC (it has already been used in analyzing the initial SLD engineering data (1991) and is now being used, in a new polarization version 3.01, on the 10^4 20% beam polarization $Z°$ data sample (1992) and on the recent 5×10^4 60% beam polarization and on the most recent ~80% beam pol. $Z°$ data sample (1993, 1994, 1995)). During 1991-1992, we continued our commuting approach between SLAC and CERN and thereby made the important acceptance and implementation of BHLUMI 2.01 at LEP possible. Further, we made BHLUMI 3.0 available to OPAL and continued to interact with that Collaboration in its implementation and use at LEP. Similarly, during 1992-1993 and 1993-1995, our

SLAC-CERN commuting arrangement allowed us to assist L3 with the use of YFS3, to prepare for our .05% version of BHLUMI and to interface properly BHLUMI3.01 to SLD/LEP, and to participate effectively in the SLAC B-Factory activities. These achievements at CERN were only possible because I was able to work directly with the members of the CERN EWMC Working Groups, and my collaborators Drs. Jadach, Richter-Was, and Was, as we explain in our proposal for 1990-1991 and as we review in our 1991-1997 proposals.

We have recently[16] made progress in understanding the possible meaning 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 $\alpha \equiv V_{cb}/V_{ub}$ and the light quark masses m_q, q = u,d,s,c,b (the respective formula is given in Ref. [16] and in our 1992-1993 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 extremely interesting from the standpoint of the CDF and Dϕ observations that $m_t = 176 \pm 8 \pm 10$, $199^{+19}_{-20} \pm 20$ GeV. Now that top has been discovered, if m_t remains ~188 GeV with high precision, in the Standard Model, there would be a required change in the details of our model in [16] but not in its general idea.

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[17] in obtaining an analytic result for the important Z° physics total differential distribution in $e^+e^- \to \bar{\mu}\,\mu + 2\gamma$. This result and its generalizations have been used to carry our YFS2 FORTRAN simulations beyond the .1% precision regime in Z° physics. We began a similar analysis for the process $e^+e^- \to e^+e^- + 2\gamma$ with our former post-doc, Dr. S. Lomatch. We had a preliminary[18] formula for the real bremsstrahlung process $e^+e^- \to e^+e^- + 2\gamma$ at SLC/LEP energies and, with Dr. S. Yost, our replacement for Dr. Lomatch, we have recently completed[8] the calculation of 2γ emission part of $\overline{\beta}_2$ for the bhabha process and moved the theoretical uncertainty on the bremsstrahlung process in BHLUMI to the below .1% regime as desired. Working with Prof. Jadach, Dr. Yost and I have recently[7] checked that normalization of YFS3 in the L3 high mass $\gamma\gamma$-event acceptance region to be better than 20%, as needed, as we noted above. Further, the three of us, working with a student M. Melles, have recently used the methods in [8] to check on the subleading α^2 bremsstrahlung effects in BHLUMI4.00. More precisely, have completed (UTHEP-95-0101, to appear) an exact calculation of the $O(\alpha^2)$ virtual correction to the single bremsstrahlung process $e^+e^- \to e^+e^-\,\gamma$ at low angles. This result means that there is now no uncalculated aspect to the total bremsstrahlung error at the .01% level. Only technical precision issues remain to be resolved.

Continuing with our effort to reach the below .1% regime of precision for BHLUMI 2.01, we recently finished with our post-doc M. Skrzypek the calculation[19] of new formulae for the pairs production effect in the Bhabha scattering luminosity process at SLC/LEP. We are now finished with the process of implementing this calculation in BHLUMI[20], resulting in version 2.03 of BHLUMI, so that the soft pairs four-vectors are now available to the experimentalists in the final particle list. This soft pairs effect represents an important step on the way to below .1% precision luminosity simulations and has corroborated our earlier estimates of the size of the soft pairs effects in such simulations.

With the advent of ~60% beam polarization at SLD and an attendant Z° physics sample of 5 x 10^4 produced therewith, Prof. Jadach and I recently looked[21] into the role of A_{LR} in high precision Z° physics to see what effect SLD could have in that physics. We find that A_{LR} does provide a view on the O(α) electroweak corrections, as given in our KORALZ3.8 program from Hollik and from Bardine et al. as described above, which yields new information beyond what is available at LEP. Thus, we encourage the SLD to collect as many high polarized beam Z°'s as possible and we hope the DOE will support both the SLD and us as we help them analyze these Z°s.

Indeed, recently, in order to aid the SLD in an their effort to understand their beam polarization measurements in their Möller polarimeter as those in their production Compton polarimeter in analyzing their recent 80% beam polarization data for A_{LR}, which has recently been measured as .1551 ± .0040 yielding the single most precise determination of $\sin^2\Theta_w^{eff}$ in the world, we (the PI and S. Jadach) developed (UTHEP-94-0702, to appear) the YFS exponentiated O(α) MC for $e^-e^- \rightarrow e^-e^- + n(\gamma)$, BMOLLR1.01 to assess the size of the radiative corrections to the respective Möller process. BMOLLR was used by SLD to help cross check the two sets of polarization measurements and thereby was useful in expanding confidence in the higher precision Compton results which were actually used in the A_{LR} measurements. BMOLLR is alo in use now at CERN for LEPII objectives.

With the regime of $\sim 10^7$ Z°'s at hand, it is important to simulate the basic processes $e^+e^- \rightarrow f\bar{f} + n(\gamma)$, f = e, μ, τ, u, d, s, c, b, υ_ℓ, $\ell=\ell$, μ, τ, as accurately as possible. To this end, during 1993-1994, we completed, with Prof. Jadach and Dr. Z. Was, version 4.00 of KORALZ[22], which now includes the YFS3[4] final state n(γ) radiation in addition to the YFS2 n(γ) initial state multiple photon radiation. This new MC is now implemented at LEP and will soon be implemented at SLC and will play an important role in the next and current rounds of high precision of Z° physics.

In the area of QCD methods in heavy quark decay physics, we[23] analyzed the decay $B \rightarrow \psi/JK^*_+$ from the standpoint of the luminosity requirement for CP violation studies at a SLAC-LBL-LNL-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-LBL-LNL-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 measurements by ARGUS[24].

And, more recently, following further preliminary work by ARGUS[25], we analyzed[26] the decays $B\rightarrow\chi_c K_s$ as possible further new modes for CP violation exploration at the SLAC-LBL-LLNL Asymmetric B-Factory device. We find agreement with the ARGUS results $B(B\rightarrow\chi_c X)=(1.05\pm.35\pm.25)\%$ and $B(B\rightarrow\chi_c K^+)=(.19\pm.13\pm.06)\%$ and that the ratio of CP odd to CP even final states is ~.38, so that, indeed, such modes as $B\rightarrow\chi_c K_s$ can be used to further reduce the required luminosity in the SLAC B-

Factory project. (Just how much it is reduced requires more analysis.)

Continuing our study of new modes for exploration of CP violation in a B-Factory of the SLAC-LBL-LNL asymmetric variety, we have recently developed[27] a benchmark analysis of the decays $D \to \pi\pi$, KK for testing how well one might hope to predict a mode like $B \to \pi\pi$, where isospin considerations have recently been advanced for removing the unwanted penguin-type contributions in the measurement of the unitarity triangle angle α. What we find is that our methods, based on Lepage-Brodsky theory, allow us to predict $\Gamma(D \to K^+K^-)/\Gamma(D \to \pi^+\pi^-) \simeq 2.00$, $\Gamma(D \to K^+K^-) \simeq .561\%$, $\Gamma(D \to \pi^+\pi^-) \simeq .280\%$, to be compared with the ARGUS-CLEO results 2.42 ± .42, .46 ± .06%, .210 ± .031% respectively. Hence, it seems that 25% knowledge of $B \to \pi\pi$ rates and ratios of rates might be possible with our methods and we are currently effecting this.

Indeed, with our success in the development of the relevant quantitative methods in $D \to \pi\pi$, K K, we turned more recently to the analysis of the interplay between penguins and the CKM CP violating phase with an eye toward measuring the unitarity triangle angle α in $B \to \pi\pi$ in the proposed SLAC-LBL-LNL Asymmetric B-Factory device. Our results[28] show that $B \to \pi^+\pi^-$ is resilient to penguins and that α is generally measurable at the ~25% level in this mode; we find that $B \to \pi^\circ\pi^\circ$ is strongly affected by penguins and only Gronau-London type penguin trapping methods could make it useful most probably in a study of α. Our rates for $B \to \pi^+\pi^-$ and $B \to \pi^\circ\pi^\circ$ depend on the allowed variation of the CKM parameters as reported by the 1992 PDG Data Listings for example but are consistent with recent CLEO limits (See P. Drell, in

1992 Rochester Conf., Proc., ed. J. Sanford (AIP, N.Y., 1993), for example) and with a recent penguin-less analysis by A. Sczepaniak et al. (Phys. Lett. B243, 287 (1990)).

We note that, during 1993-1995, we had at best a small amount of time to devote to our quantum gravitation research. The recent result[29] 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. After discussion with Prof. M. E. Peskin of SLAC, we have extended[30] the first paper in Refs. 29 to address several questions which are not discussed therein. We may now hope to incorporate this result into our earlier results[29] 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, while we made a small amount progress toward this end, our pre-occupation with SLAC B-Factory, SLC-LEP and hadron colliders physics research will not allow us to devote very much time to string theory, however. And, this is as it should be.

Indeed, finally, it is appropriate to report that, on March 20, 1991, we were awarded Texas National Research Laboratory Commission grant number RCFY9101 for applying our YFS methods developed in TASK B to higher order radiative corrections to SSC physics processes. On January 15, 1992, this award was renewed for a second year; in February, 1993, it was extended for a third year. These awards were major achievements for the research in TASK B and we feel that this successful application of the work developed in Task B shows that the DOE's investment therein was and is well-placed. (For reference, we list recent preprints from our SSC physics activity in [31].) We had hoped it would encourage the DOE to continue to expand its support for Task B so that even larger applications will be possible, such as the support of Dr. G. Siopsis' bid to join our Task B as an assistant professor. And indeed, in 1994, after SSC cancellation, DOE approved supplemental funds for continuation of our post-doc position and attendant research on hadron colliders radiative corrections via YFS Monte Carlo methods and in 1995, DOE approved Dr. G. Siopsis' bid to join our Task B effort. As a result, we recently completed the analysis[32] of n(γ) radiative effects in the LHC type scenario $q+\overset{(-)}{q}{}' \to X + H \to X + \gamma\gamma$, for the intermediate Higgs mass regime $m_Z \lesssim m_H \lesssim 2m_Z$. The resulting Monte Carlo, SSCYFSH, analyzes these effects on an event-by-event basis so that experimentalists may now have a true picture of such events in the CMS-ATLAS type acceptances. We find that the n(γ) background does not obscure the H signal so that the main issue will be the precise normalization of the respective cross section which gets a several % change due to n(γ) radiation.

In addition, we recently applied our QCD YFS exponentiation results in Phys. Lett. B342, 239 (1995) and Phys. Rev. D52, 108 (1995) to the $O(\alpha_s)$ $\bar{\beta}_1$-level corrections to the processes $q + \overset{(-)}{q}{}' \to q'' + \overset{(-)}{q}{}''' + n(G)$ in the paper UTHEP-95-0201 (version 1.1 of our LHCBHLG Monte Carlo) and to the FNAL top production process $q + \bar{q} \to t + \bar{t} + n\,(G)$, where we presented both semi-analytical (UTHEP-95-0501) and MC event generator (UTHEP-95-0102, to appear) analyses. In UTHEP-95-0201, we find that the $0(\alpha_s)$ $\bar{\beta}_1$ corrections do affect the $\langle P_\perp^2 \rangle$ of the n(G) system for example, so that they must be taken into account for precision data analysis. In UTHEP-95-0501, we show that the ratio of our exponentiated cross section, σ_{exp}, to the unexponentiated one, σ_o, is 1.65 (1.48) for $u\bar{u}$ annihilation for m_t = .176 (.199) TeV respectively for example. These results tend to improve the agreement between theory and experiment for the value of $\sigma(t\bar{t})$. In UTHEP-95-0102, we present the YFS exponentiated MC TOPYFS, which realizes $q + \bar{q} \rightarrow t\bar{t} + n(G)$ on an event-by-event basis in which infrared singularities are canceled to all orders in α_s. The MC results agree with our semi-analytical results on the normalization of σ_{exp} and, further, show that the n(G) radiation carries away a substantial amount of the incoming energy for example, so that it must be taken into account for detailed precision data analysis and comparison with SM expectations. We stress that our YFS exponentiated top results do not suffer from the appearance of a third ad hoc soft separation scale parameter such as the μ_o of Laenen et al. (Phys. Lett. B321, 254 (1994)). Our results are therefore of theoretical interest in their own right. We look forward to further LHC/Tevatron applications of the methods we developed for the SSC with excitement if DOE funding continues.

A further evidence of the success of Task B was our selection to host the 1994 International Symposium on Radiative Corrections, which we held at Gatlinburg, Tenn. during June 27-July 1, 1994. The proceedings for the symposium, Tennessee International Symposium on Radiative Corrections: Status and Outlook, ed. B. F. L. Ward (World Sci. Publ. Co., Singapore, 1995) are now available and represent a state of the art view of radiative corrections to SM processes, both EW and QCD, as of fall, 1994. This volume will be useful to many researchers in the field for years to come and its production by Task B represents a major success of the DOE's investment therein. (We have mailed a copy of the Proceedings to Dr. Williams for reference several months ago.)

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2. Ward, B. F. L., "How Big Are Penguins?," UTHEP-91-0901, submitted to Phys. Rev. D; Phys. Rev. Lett. 70, 2533 (1993).

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