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ABSTRACT. -

Results are presented of a measurement of wide angle electron proton cross section. The agreement with the quantum electrodynamics prediction is good at the probed masses of 70 and 100 MeV of the virtual electron.

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1. - The differential cross section for wide angle electron-proton bremsstrahlung (WAB)

$$e + p \rightarrow e + p + \gamma$$

has been measured using the external electron beam of the Frascati 1 GeV Synchrotron.

The relevant features of this process from QED (Quantum Electro Dynamics) point of view are characterized by the two invariants

$$q_s^2 = (p - k)^2 \qquad \text{(space - like)}$$
$$q_t^2 = (p' + k)^2 \qquad \text{(time - like)}$$

(x) - Istituto di Fisica Superiore dell'Università di Napoli, and INFN Sezione di Napoli.
(o) - Istituto di Fisica dell'Università di Roma, and INFN Sezione di Roma.

where p, p' and k are the 4-momenta of the ingoing, outgoing electrons and photon respectively. In the two lowest order diagrams (Fig. 1) q_s and q_t correspond to the 4-momenta of the virtual lepton.

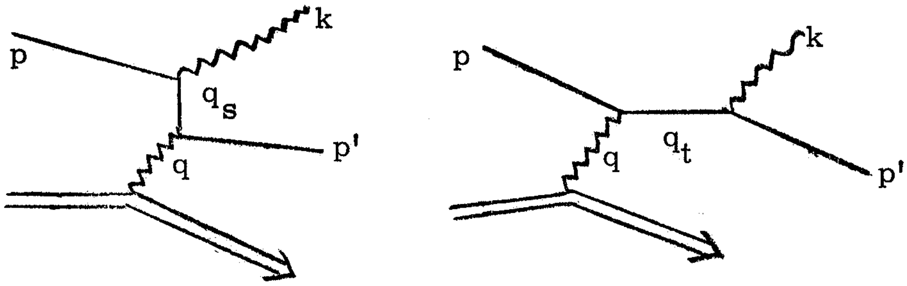

FIG. 1

The principal virtue of this experiment is that it explores QED in the time-like lepton propagator region where data are still lacking[1].

Space-like lepton propagators have already been investigated in wide angle electron and muon pair photoproduction: no significant deviation from predictions of QED has been discovered till now, for q_s^2 up to $\approx -(500\ \mathrm{MeV})^2$ [2].

The cross section for WAB has been calculated by time-honored QED to lowest order in e^2 including proton form factors[3]. Also, attempts have been done at the evaluation of virtual Compton diagrams using more or less refined models for the proton Compton contribution[4].

In this experiment we have done an absolute measurement of the wholly differential cross section for WAB and compared the results to theoretical predictions including the virtual-Compton contribution; radiative corrections have not yet been evaluated in detail. No significant deviation of the measured from the expected cross section has been found, to within 5% accuracy, at the two measured points ($q_s^2 = -(260)^2\,(\mathrm{MeV})^2$, $q_t^2 = (70)^2\,(\mathrm{MeV})^2$ and $q_s^2 = -(265)^2\,(\mathrm{MeV})^2$, $q_t^2 = (100)^2\,(\mathrm{MeV})^2$).

Kinematics is chosen in such a way as to make a good definition of q_t^2, keeping at the same time $-q_s^2 \gg q_t^2$. The invariant mass q_t^2 of the outgoing e, γ system, could be completely fixed by the proton energy and angle; however it also strongly depends on the angles of the outgoing particles. In particular it is sharply defined by the angle between the outgoing electron and the γ ray (for a fixed total 3-momentum direction of these particles), at least near the symmetric situation, here chosen, in which the electron and photon energies are equal. The measurement of the proton kinetic energy can thus be used as a check "a posteriori", it's spectrum being sharply determined by requirements on the angles.

Having fixed q_t^2 in this way, q_s^2 is mainly determined by the rotation angle of the outgoing electron and photon plane around the total 3-momentum of these two particles. This allows fixing q_s^2 quite independently of q_t^2 : in this experiment the e, γ plane has been chosen at right angle to the plane defined by the ingoing electron and the recoil proton (fig. 2).

The proton energy was kept the same at the two measured points, q_t^2 being varied by changing the angles: as a consequence, the same proton form factors occur in the two calculated cross sections, apart from slightly different averages because of a different behaviour of the WAB cross section over the aperture of the apparatus.

2. - A sketch of the experimental apparatus is given in Fig. 2. A 20 cm long cylindrical H_2 target was used. The three outgoing particles (proton, electron and γ ray) were detected by counters. Time of flight and pulse amplitude were recorded in the proton range telescope. The electron and the photon were detected by two lead glass Cerenkov counter, whose pulse height was recorded; the nature of the particle (either γ or electron) was determined by looking at signals from two plastic scintillators placed in front of each Cerenkov counter.

The arrangement is symmetric above and below the plane defined by the ingoing electron and the outgoing proton. Thus kinematically equivalent WAB events are marked (using the notations in Fig. 2) by

$$(P_1 P_2 P_3 \overline{P}_A) \cdot (E_1 E'_1 C_1) \cdot (\overline{E}_2 \overline{E}'_2 C_2) \qquad \text{or}$$

$$(P_1 P_2 P_3 \overline{P}_A) \cdot (\overline{E}_1 \overline{E}'_1 C_1) \cdot (E_2 E'_2 C_2) \, .$$

Monte Carlo calculations using the WAB cross section give the spectra of some relevant quantities (shown in Fig. 3a-3e for the point $q_t^2 = (70 \text{ MeV})^2$ and Fig. 3f-3j for the point $q_t^2 = (100 \text{ MeV})^2$) as measured by the apparatus.

3. - Results are summarized in Table I. The incoming flux of electrons has been determined by a Wilson quantameter, whose constant is taken to be $Q = 4.62 \times 10^{18}$ MeV/Coulomb, in agreement with the intercalibrations performed in various laboratories: the measurements of $d\sigma_{exp}$ are thus absolute determinations. No attempt has been made to attach an error to Q. As a check, the cross section for e-p scattering

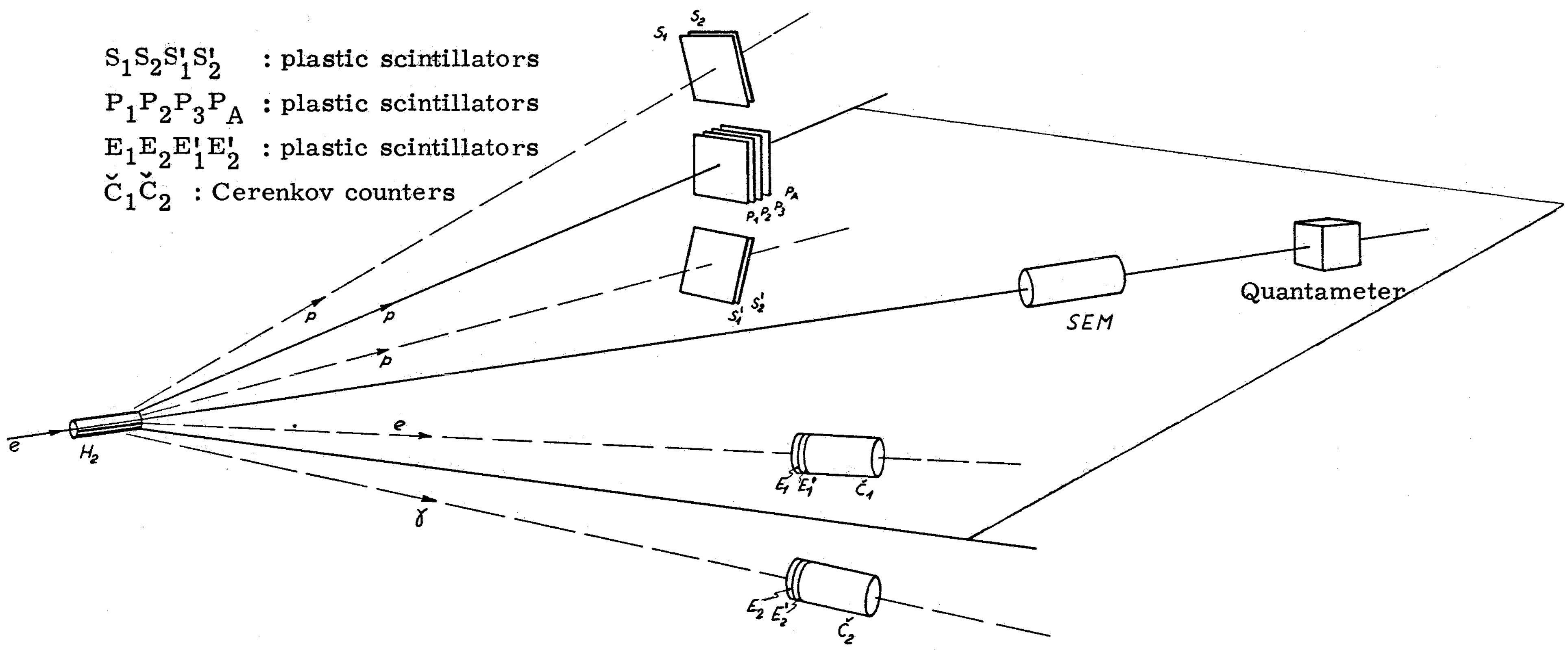

FIG. 2 - Experimental apparatus. - $P_1P_2P_3P_A$ is the proton range telescope; $E_1E'_1\check{C}_1$, $E_2E'_2\check{C}_2$ (symmetrical with respect to the orizontal plane) are the electron and photon detectors); S_1S_2, $S'_1S'_2$ are the proton scattering telescopes; an e-p scattering event is defined by $(S_1S_2)\cdot(E_1E'_1\check{C}_1)$ or $(S'_1S'_2)\cdot(E_2E'_2\check{C}_2)$.

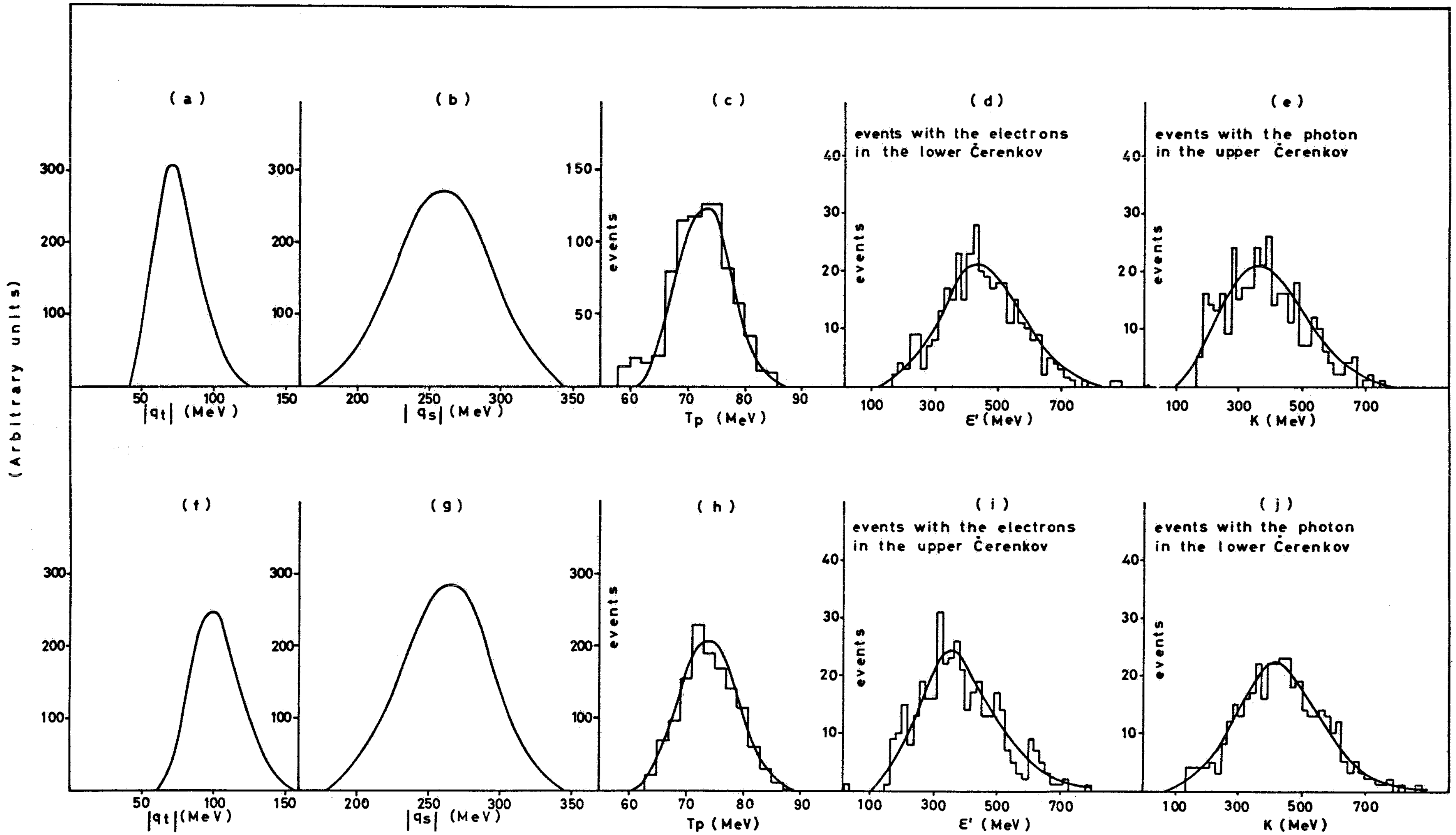

FIG. 3 - Spectra of the relevant kinematical parameters, as obtained from Monte Carlo calculations, including experimental acceptance and resolution (full line). For comparison with the theoretical prediction, we show in (c) (d) (e) (h) (i) (j) the measured spectra relative to a sample of the events. T_p, $\mathcal{E}'$, k are the kinetic energy of the emitted proton, the energy of the emitted electron and photon respectively.

TABLE I - SUMMARY OF RESULTS

1	2	3	4	5	6	7	8	9
$q_t^2 (MeV)^2$	$q_s^2 (MeV)^2$	T_p (MeV)	ε (MeV)	uncorrected events	corrected events	$\frac{d\sigma_{exp}}{d\sigma_{BH}}$	$\frac{d\sigma_{exp}}{d\sigma_{BH+C}}$	$\left(\frac{d\sigma_{exp}}{d\sigma_{th}}\right)_{scatt}$
$(70)^2$	$(260)^2$	74	900	1872	2083	$.995 \pm .04$	$.955 \pm .04$	$.935 \pm .04$
$(100)^2$	$(265)^2$	74	900	1282	1130	$1.065 \pm .05$	$.993 \pm .05$	$.995 \pm .03$

col. 1, 2 : mass squared of electron propagators (see Figg. 1, 3, 4).
col. 3 : central value of the proton kinetic energy spectrum (see Figg. 3, 4).
col. 4 : incident electron beam energy.
col. 5, 6 : number of WAB events (see text, § 3).
col. 7 : ratio between experimental WAB cross section and theoretical Bethe-Heitler cross section, including proton form factor. The errors are only statistical.
col. 8 : idem as in col. 7, but with theoretical cross section including virtual Compton contribution. The error are only statistical.
col. 9 : Ratio between the experimental scattering cross section and the theoretical one (see text, § 3). The error are only statistical.

has been measured in two independent channels in parallel to the WAB measurements, using the same Cerenkov counters for the electron, and in addition two auxiliary telescopes to detect the recoil proton. The results of this measurements are shown in the last column of Table I (radiative corrections are negligible in this case). The agreement is considered to be satisfactory since the counting rate is much more sensitive to geometry (in particular to the primary beam alignement and angular spread) for scattering than for WAB. The difference between "uncorrected" and corrected" number of WAB events occurs because of two types of background. Besides the (e, γ, p) events we also recorded events in which the proton is accompanied by two charged particles (called (e, e)) or by two neutrals (called (γ, γ)). In both cases the nature of the signals from the scintillation counters in front of the Cerenkov counters gave the only difference from the expected (e, γ) events, all the other requirements (proton, pulse amplitudes) being well met.

We did not find any allowed genuine physical process giving a significant number of events of the (e, e) type, and attributed these to accidentals of soft electrons from the target and (e, γ) events. A weak magnetic field on the H_2 target helped to sweep out most of the soft electrons, providing thus a partial check of this assumption. Direct determination of the accidental rates allows correction for the (e, e) effect; the result of the correction checks pretty well with the assumption that no genuine (e, e) events are produced. Also, (γ, γ) events can occur because of π^o production in the target, although events of the (e, γ) type are strictly forbidden when $q_t^2 < m_\pi^2 = (135\ \text{MeV})^2$. Conversion of a (γ, γ) event into an (e, γ) is again due to accidentals with soft alectrons so that a subtraction has to be applied.

The overall correction, both for (e, e) and (γ, γ), is quite insensitive to the accidental rates for the two measured points. The situation is slightly better at $q_t^2 = (70\ \text{MeV})^2$ than at $q_t^2 = (100\ \text{MeV})^2$ but we are confident that both points do not suffer of significant uncertainties because of backgrounds.

An attempt to measure the cross section at $q_t^2 = (140\ \text{MeV})^2$ was however unsuccesfull because of a too large π^o electroproduction contribution coming in.

4. - To evaluate the WAB cross section $d\sigma_{BH}$, including the proton recoil, the scaling law $G_E = G_M/\mu$ was used for the proton form factors.

Also, the dipole fit $G_E(q^2) = (1 - \frac{q^2}{0.71\ \text{GeV}^2})^{-2}$ has been adopted in the Monte Carlo calculation after checking that the experimental values of G_E and G_M were well reproduced in the range of interest.

The virtual proton Compton contribution was evaluated by using the formulas by M. Greco, A. Tenore and A. Verganelakis[4]; their model includes both the proton and the first isobar. As can be seen from the ratio $d\sigma_{BH+C}/d\sigma_{BH}$ from Table I the correction for the virtual Compton contribution amounts to $\sim 4\%$ at $q_t^2 = (70\ \mathrm{MeV})^2$, and $\sim 7\%$ at $q_t^2 = (100\ \mathrm{MeV})^2$. This correction becomes larger when q_t^2 increases, at least for primary electron energies of 900 MeV like in our case.

Radiative corrections have not yet been applied; calculations are in progress, in particular for the loop part which is quite laborious.

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