FIRST-GENERATION ELECTROMAGNETIC EXPERIMENTS AT NAL

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ABSTRACT

Several possible first-generation electron and photon experiments are listed and two are studied in some detail in this paper. These are Compton scattering and photoproduction of vector mesons.

I. INTRODUCTION

As a part of the 1969 Summer Study a group of us* have explored once again the ground covered very well last summer, especially by Wilson,[1] Toner,[2] and by others including Heusch[3] and Clegg et al.[4] We addressed ourselves to those experiments which appeared to be most likely candidates for first-generation electromagnetic experiments at NAL. We also had somewhat more realistic estimates of the electron and tagged photon beam to be expected with the current beam disposition in target-area 2. These properties, based upon the general beam design concepts of Heusch[5] and Toner,[6] are documented in a 1969 Summer Study report by Diebold and Hand.[7]

With this information in hand we chose to scrutinize several experiments in enough detail so as to ascertain the feasibility of their success. In this note two classes of experiments are discussed, including:

1. Compton scattering
2. Vector meson photoproduction

In separate papers the following experiments are discussed:

3. Total photoproduction cross sections (Diebold and Hand)[8]
4. Elastic ep scattering (Hofstadter)[9]
5. Inelastic ep scattering (Hand)[10]

Other experiments discussed earlier[1-4] either were less interesting (to us) at this point in time or on the surface appeared to be too difficult to serve as first-generation experiments.

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II. COMPTON SCATTERING

The cross section for Compton scattering, assuming vector dominace, has a form:

$$\frac{d\sigma}{dt} = A\, e^{10\,t}.$$

Vector dominance and recent measurements at SLAC at 18 GeV/c are consistent with

$$A \approx 1.0\ \mu b/(GeV/c)^2,$$

neglecting the real part of the amplitude, and vector dominance predicts constancy with energy.

Integrating the cross section over all t gives:

$$\sigma_{total}^{Compton} = \frac{1}{10}\ \mu b.$$

Table I gives the angle of the scattered photon and the range of the recoil proton in liquid hydrogen as a function of t and for 50 and 100 GeV/c incident photons. It is clear from the table there is a reasonable breakpoint in performing the experiment at about $t = -0.1\ (GeV/c)^2$. Above that value it is possible to do a coincidence experiment and measure both the scattered photon and the recoil proton. Much below $t = -0.1$ it is difficult to measure the recoil proton and one must rely on a precision measurement of the scattered photon and of course the known (tagged) incident photon energy. We will look at these two regions separately.

A. Coincidence Experiment

For the coincidence experiment consider the experimental arrangement shown in Fig. 1. The momentum-analyzed, approximately parallel electron beam (energy E_e) strikes a high-Z radiator ($\sim 0.02\ X_0$) and is tagged to a precision $\Delta k/k = \pm 2\%$, in the photon range $0.45 \le k/E_e \le 0.9$. The tagged photons, with characteristics

$$\Delta X = 2.0\ \text{cm} \qquad \Delta\theta_x = 0.2\ \text{mrad}$$

$$\Delta Y = 2.5\ \text{cm} \qquad \Delta\theta_y = 0.3\ \text{mrad},$$

are incident on a 2-meter long liquid hydrogen target about 7 cm in diameter. Surrounding the target is a wire spark-chamber system S_1 and S_2 subtending approximately a 2π azimuthal angle, followed by the counters C_2.

The scattered photon is measured in the total absorption counters C_5 which should have an energy resolution better than 1%. C_5 also has as an integral part of it a coarse (~ 1 cm) resolution hodoscope (C_{p_i}) counter. This counter system covers a large part of 2π in azimuthal angle. C_6 is another total absorption counter used in anticoincidence. Thus the trigger consists of $C_{b_i}\,C_{t_i}\,\overline{C}_a\,\overline{C}_1\,C_2\,\overline{C}_3\,\overline{C}_4\,C_5\,\overline{C}_6$, where the first three logic elements constitute the signature of a tagged photon. In addition, pulse-height information is obtained from C_2 and C_5. This setup measures t, with $\Delta t/t \approx \pm 8\%$ at $t = 0.1$.

For 10^{13} interacting protons at 200 GeV/c, for an electron beam with $\Delta p/p = \pm 1\%$, the yields, from Diebold and Hand,[7] are given in Table II for several electron energies. The actual rates may be somewhat lower due to some solid angle losses. The major background for Compton scattering at lower energies is π^o photoproduction. However, at these energies, the π^o contamination, which goes as $1/s$, is down at the 1% level.

From the rates given in Table II it is clear that in 100 hours of running at $E_e = 60$ GeV/c, with $27 < k_{tagged} < 54$ GeV/c, there will be 7000 events. Dividing these into 7 energy bins and 10 t bins gives ~10% statistics. This rate, although not overwhelming, is certainly acceptable and if one goes to $E_e \approx 40$ GeV/c there is a 50% increase in rate. Also it may be possible to increase the thickness of the radiator and increase the rate, with only minor additional uncertainties due to the additional radiative effects. Thus the experiment appears to be a feasible one.

B. Non-Coincidence Experiment

The experiment to measure $d\sigma/dt|_{\text{Compton}}$ for $t_{min} < t < 0.1\ (\text{GeV/c})^2$, without measuring the recoil proton, has some complications. The major complication has to do with the error in θ, the angle of the scattered photon. The intrinsic error in θ is that of the incident photon angle, which has a $\Delta\theta = \pm 0.3$ mrad. In addition, with a two-meter target, even if the counter distance were 100 meters from the target, the total error in one's knowledge of θ appears to be $\Delta\theta \approx 0.5$ mrad. This gives rise to errors in t, at $t = 0.01$, of $\Delta t/t = 50\%$ at 50 GeV/c. At $t = 0.1$, $\Delta t/t \approx 20\%$, and at $t = 0.0025$, $\Delta t/t = 100\%$.

Although the counting rate appears to be acceptable (~90/hour at $E_e = 60$ GeV/c), the rather large uncertainty in t and the general difficulty suggest that this particular experiment may not be best suited for a first generation experiment to be performed at NAL.

We are thus in agreement with the conclusion of Toner[2] that this may not be a worthwhile experiment to perform. However we find totally unconvincing his general reasons for not measuring $d\sigma/dt\ (t = 0)$ for Compton scattering, but to infer it from $\sigma_{tot}\ (\gamma p \to \text{hadrons})$. In particular the suggestion of Drell[11] that a term λk^2 may be added to the dispersion relation for the forward scattering amplitude makes it particularly interesting to study forward Compton scattering at high energies, as has been suggested by Walker.[12]

III. VECTOR MESON PHOTOPRODUCTION

Vector meson photoproduction is certainly one of the most interesting photoproduction experiments one can do at NAL. It serves as a good check of vector dominance, and if performed with complex nuclei targets allows for a measure of the vector-meson-nucleon cross sections. The three reactions of particular interest are:

$$\gamma p \to \rho^o p \qquad (\rho^o \to \pi^+ + \pi^-)$$

$$\gamma p \to \omega p \qquad (\omega^o \to \pi^+ + \pi^- + \pi^o)$$

$$\gamma p \to \phi p \qquad (\phi^o \to K^+ K^-)$$

We assume for calculation constant cross sections as follows:

$$\left(\frac{d\sigma}{dt}\right)_\rho = 130\, e^{10t}\ \mu b/(\mathrm{GeV}/c)^2$$

$$\left(\frac{d\sigma}{dt}\right)_\omega = 20\, e^{10t}\ \mu b/(\mathrm{GeV}/c)^2$$

$$\left(\frac{d\sigma}{dt}\right)_\phi = 4\, e^{10t}\ \mu b/(\mathrm{GeV}/c)^2 .$$

The ρ photoproduction is by far the most straightforward to perform. A typical experimental setup is shown in Fig. 2. At 50 GeV/c incident photons for small momentum transfer, ~0.1 GeV/c, the ρ production angle is ~ 2 mrad. The maximum opening angle between the decay pions is 24 mrad. The magnet M_1, of strength ~ 10 kG-meter, serves to spread the decay pions. The magnet M_2 of the same strength and opposite polarity brings the pions approximately back to their original direction. The trajectories are measured in wire spark chambers S_1, S_2, S_3, and S_4. The trigger is $\overline{C}_1 C_2 C_3 C_4 C_5 \overline{C}_6$, where C_1, C_2, C_3, C_4, and C_5 are thin scintillation counters and C_6 is a total absorption counter. The latter guards against a π^o in the forward direction. With a reasonable size magnet M_2 (a gap ~ 0.5 meter) one subtends essentially the full useful solid angle, and obtains, with 1% measurements on the momentum and opening angle of each pion, a mass resolution of $\Delta M_\rho / M_\rho$ = 30 MeV at 750 MeV.

Assuming the Diebold and Hand[7] tagged photon beam parameters for 10^{13} interacting protons, with the same phase space used for the Compton experiment calculation, we get the rates given in Table III. It is clear that even for 100 GeV/c electrons the rates are very good indeed, allowing an exploration of ρ photoproduction by up to 90 GeV/c photons.

The photoproduction of ϕ mesons in principle uses the same apparatus. Here, because of the lower Q of the decay, the maximum opening angle is only 5 mrad. With a mass resolution of better than 5%, it should be possible to perform the experiment without any K-π discrimination, by just looking for the ϕ peak above the ρ tail. On the other hand, it may be possible to insert a wide-angle Cerenkov counter or similar β-measuring instrument behind C_4 and C_5 to make the K-π discrimination. The expected rates for ϕ photoproduction are also given in Table III. The rates are adequate to do a reasonable experiment with photon energies exceeding 50 GeV/c.

The ω experiment is the hardest one of the three vector meson photoproduction experiments because of the existence of the neutral pion. If one does not measure the recoil proton (and we do not propose doing that here) then it is necessary to at least measure the directions of the pizero decay photons. That can be accomplished by introducing a high-Z spark chamber behind counters C_4 and C_5. The geometric acceptance function to see both charged pions and both photon showers for such a setup must be studied in detail, but the reduction factor should not be very large. An estimate of the expected rates is also given in Table III.

It should be noted that these experiments can also be done very effectively as a function of atomic mass.

IV. CONCLUSIONS

In this note it has been shown that with the proposed tagged photon beam facility in target-area 2, experiments on vector meson photoproduction, which is of current interest, can very effectively be performed. In addition it has been shown that for momentum transfer greater than about $t = -0.1\ (\mathrm{GeV/c})^2$ Compton scattering can be done at a rate which is just about acceptable. A factor of two or more one way or the other in actual photon flux will have a major effect on the desirability of performing the Compton experiment.

In a separate paper by Diebold and Hand[8] it is shown that the total γp cross-section experiment can be performed very well indeed at NAL. Thus it appears that there are at least two major experimental programs and possibly a third experiment, which are appropriate for the NAL first generation round of experiments. Furthermore, experience at CEA has shown the general utility and wide demand for such an electron and tagged photon facility, especially for testing and calibrating of total absorption counters and other detectors. For these reasons we strongly recommend that the proposed electron-tagged photon beam be implemented early in the NAL facilities development program.

REFERENCES

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Table I. Scattered Photon Angle and Range of Recoil Proton in Liquid Hydrogen for Compton Scattering Experiment.

$-t\ (\mathrm{GeV}/c)^2$	50 GeV/c θ (mrad)	100 GeV/c θ (mrad)	Proton Range (cm of LH_2)
0.2	9.0	4.5	
0.1	6.3	3.2	13
0.04	4.0	2.0	3
0.01	2.0	1.0	0.2

Table II. Yields for Coincidence Compton Scattering Experiment.

E_e, GeV	N_γ Tagged Photons	Events/hour
40	3×10^5	110
60	1.9×10^5	70
80	7.4×10^4	28
100	2.1×10^4	7

Table III. Yields for Vector Meson Photoproduction (Events/hour).

E_e	$(\rho \to \pi^+ \pi^-)$	$(\phi \to K^+ K^-)$	$(\omega \to \pi^- \pi^+ \pi^0)^a$
40	14,000	210	1950
60	8,800	130	1200
80	3,500	51	480
100	950	14	130

[a]Note: these rates must be reduced by the geometric acceptance factor for the three pions.

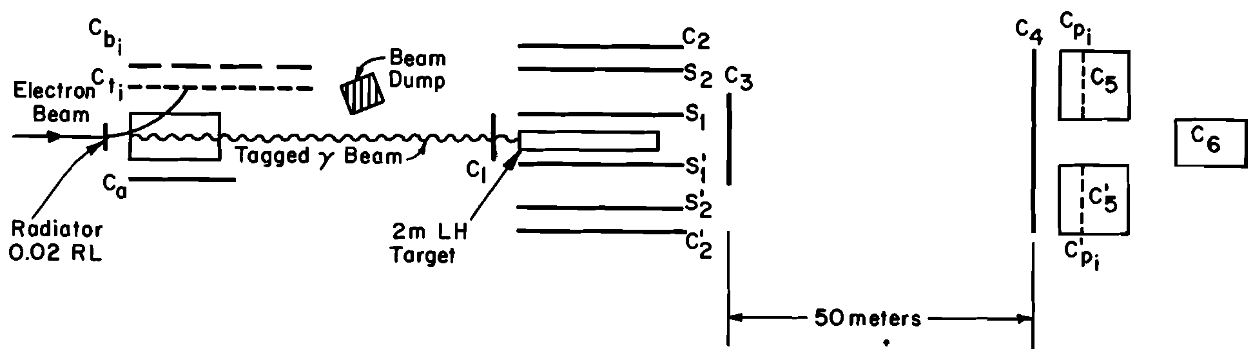

Fig. 1. Coincidence Compton scattering experiment. Ct_i and Cb_i are the tagging system counters and C_a is a guard anti-counter. The trigger is $Cb_i\ Ct_i\ \overline{C}_a\ \overline{C}_1\ C_2\ \overline{C}_3\ \overline{C}_4\ C_5\ \overline{C}_6$. S_1 and S_2 are spark chambers and Cp_i is a picket fence hodoscope in the total absorption counters C_5.

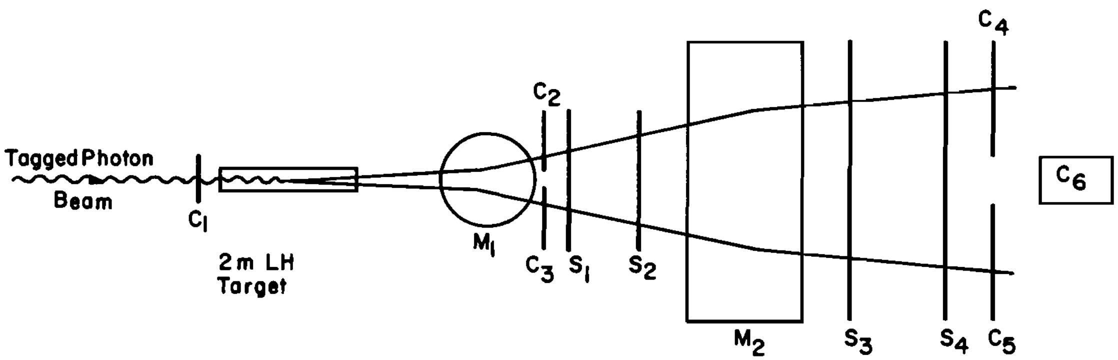

Fig. 2. Basic experimental setup for vector meson photoproduction. The trigger for ρ's and ϕ's is $\overline{C}_1\ C_2\ C_3\ C_4\ C_5\ \overline{C}_6$ plus a tagged photon signal. S_1, S_2, S_3, and S_4 are wire spark chambers and C_6 is a total absorption counter. M_1 and M_2 are magnets with $B \cdot \ell \approx 10$ kG-meters.