A PROPOSAL FOR A PROGRAMME OF PHOTON AND ELECTRON PHYSICS

THE Ω SPECTROMETER AND THE CERN SPS

by a collaboration including the following:

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ABSTRACT

Tagged photons are produced by a high energy (up to 80 GeV) electron beam which is derived from 200 GeV proton interactions. Photoproduction processes are observed using the Omega as a multiparticle spectrometer. Exclusive final states such as production of known vector and pseudo-scalar mesons and, possibly, new vector mesons can be studied in detail in a new energy range. The study will include production with polarized photons. Use of a deuterium target allows separation of isospin 0 and 1 contributions. The experiment can be extended by the use of a polarized proton target to enable a more complete amplitude analysis to be made. At a later stage the measurement of inelastic electron scattering with analysis of hadronic final states seems possible and would extend photoproduction ($q^2=0$) to values of the invariant photon mass of $q^2 = 9\text{(GeV/c)}^2$.  

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SUMMARY

We propose to study the photoproduction and electroproduction of hadrons for incident particle energies from 10 to 60 GeV. At present no data exists above 20 GeV and only very limited data in the range 10 to 20 GeV. The photoproduction is carried out using photons of known energy identified by a tagging system. These photons will be polarized when produced from a suitable crystal radiator. The aim is to use the $\Omega$ spectrometer with additional $\pi^0$ detectors and a suitable trigger system designed to suppress electromagnetic background without selecting particular types of hadronic event. We envisage a continuing development of the $\Omega$ detector system towards a higher momentum resolution and event rate capability.

Using the above system we can study a large range of exclusive channels with up to 5 charged prongs. In order to study particular reactions clearly we will identify not only the projectile fragments but also the target recoil (or target fragments). Reactions we will study include:

a) Vector meson photoproduction

The extent of the study of these diffractive processes to higher energies should enable deviations from simple vector meson dominance model to be investigated. This model gives general agreement with experiment at lower energy.

This can be carried out for $\rho$, $\omega$ and $\phi$ photoproduction with both polarized and unpolarized photons and should yield considerable information about the relevant amplitudes. New vector meson states, if they exist, should be produced cleanly in the system. For example the $\rho'$ is not clearly understood and should be produced in adequate number for a detailed study.

Vector mesons are produced not only by $\gamma p \rightarrow Vp$ but by processes such as $\gamma p \rightarrow V\Delta$ and the geometry 2 $\Omega$ detectors are invaluable for studying the recoil particles. Factorization makes predictions on the ratios of various diffraction dissociation processes.
induced by photons as well as other particles. These can be investigated. With an incident proton beam of $3 \times 10^{12}$ per pulse at 200 GeV we expect to obtain $2 \times 10^5$ tagged photons in the energy range 10 to 60 GeV. With a 30 cm long liquid hydrogen target, acceptance of 50% and a running efficiency of 70% we expect to obtain $1.5 \times 10^4$ events/µB in a period of 500 hours with 1 SPS pulse every 9 seconds. This corresponds to $\sim 10^5 \rho$-photoproduction events.

b) **Elastic Compton scattering**

Extention of the study of this process to higher values of $E_\gamma$ and varying values of $t$ is of interest in terms of reaction mechanisms.

c) **Pseudoscalar meson production.**

The cross-section for this process decreases with energy apparently $\propto 1/E_\gamma^2$ up to $\sim 10$ GeV and appears to be due to more than one mechanism. It may well be that the energy and $t$ dependence found at lower energies will not continue into the 20 GeV range. This whole area has not been well studied and it will be an important part of our work for photon energies in the lower part of the photon energy range.

d) **Polarized target measurements particularly of vector meson photoproduction**

Measurements with a polarized beam and polarized target allow one to measure, in principle, 5 polarization parameters. These will allow a very complete amplitude analysis of the major processes such as $\rho$ photoproduction.

e) **Electroproduction**

Almost all the processes described above are of great interest not only for real (mass = 0) photons but for virtual (mass > 0) photons seen in electroproduction. We believe that the system, when fully developed, will be a powerful tool to make such measurements.
The general field outlined here represents a developing area of interesting physics which could take several years to carry out in the Ω-system. Current developments in the understanding of electron-photon physics indicate that there may be exciting results to be obtained in this new and very wide energy range.
SECTION 1  INTRODUCTION

1. Until very recently the study of electromagnetic processes by means of intense beams of electrons and photons has been confined exclusively to electron accelerators. This is now no longer the case. The copious production of pions (neutral pions in particular) from proton-nuclear collisions in the $\gtrsim 100$ GeV region and the natural confinement of these pions (and their decay products) to angles close to the forward direction has made possible the formation of electron and photon beams at high-energy proton accelerators. Measurements of photon total cross sections have already been made at the 70 GeV proton accelerator at Serpukhov USSR\(^{1.1}\). Similar work is planned at the NAL accelerator, Batavia, USA\(^{1.2}\). It is the purpose of this document to propose a programme of photon and electron physics using the 200 GeV proton beam which will be available in the West Hall of the SPS.

2. We consider that the conjunction of a good tagged photon beam, such as can be generated in the SPS West Area, with the $\Omega$ spectrometer system offers a unique opportunity to study real photon physics up to the highest photon energies available. Emphasis would be put on the study of the various exclusive channels which build up photoproduction. Data would be taken mainly with an interaction trigger. The yield of tagged photons one can expect is quite sufficient to study the very rich class of diffractive processes in great detail. Non-diffractive processes will also be cleanly studied in the lower part of the energy spectrum. The cross sections anticipated for these processes may exclude detailed measurements at the higher energies. The development, with energy, of the exclusive channels which combine to give an almost constant total cross section will be investigated. The use of a polarized photon beam, which is possible with good intensity, and eventually of a polarized target, will permit amplitude analysis and spin-parity determinations.
3. For the initial operation of \( \Omega \) with the SPS we assume a detection system incorporating optical chambers and we present figures for the data collection rate which are compatible with the characteristics of these devices. At a later stage a complete wire chamber system will enable the data collection rate to be increased with, possibly, a selective trigger. Thus the study of lower cross section channels will become possible.

4. We also show that electron scattering - that is physics with virtual photons - is possible when the \( \Omega \) is equipped with a complete wire chamber system. This line of physics would provide detailed information (in a moderate kinematic range) on the exclusive channels of virtual photon interactions. The fine optical properties of the electron beam and the quality of the \( \Omega \) spectrometer would allow us to do clean physics in this domain which will be complementary to that suggested for the muon beam in the SPS North Area.

5. We outline here the plan of this proposal. In Section 2 we present certain theoretical considerations which form the basis for the physics which we wish to do. Section 3 summarizes the properties of the electron and the tagged photon beam. Expected reaction rates for real photon processes are described in Section 4, which also contain a discussion of the trigger system and of accidental rate problems. The physics problems of selected real photon processes are discussed in Section 5, where we relate these processes to their study in the \( \Omega \) spectrometer. The required properties of that spectrometer are summarized in Section 6. In Section 7 we outline a method of approach to the study of virtual photon processes. Section 8 summarized the strategy which would be followed in the use of \( \Omega \) for photon and electron physics. Appendices 1 and 2 give details of the beam and tagging system and the \( \pi^0 \) detector, respectively.
SECTION 2 THEORETICAL CONSIDERATIONS

1. There are many similarities between the behaviour of real photons and the behaviour of hadrons. For example, there is the near constancy of the total $\gamma p$ cross section, the behaviour of inclusive spectra induced by both types of particles and the strong parallel between vector meson photo production and elastic hadron scattering. These results may be summarized in terms of the Vector Meson Dominance (VMD) hypothesis which identifies the photon with a coherent superposition of the $\rho$, $\omega$ and $\phi$ vector mesons. However it can be argued that the hadron-like properties of the photon may not give a complete account of its behaviour. An experimental consequence is the possibility of a common detector for hadron and photon physics. This conclusion is not altered by experimental problems associated with the electromagnetic background generated by the photon beam which we discuss in some detail in Section 4.

2. However, real photons have quantum numbers which differ from those of the usual hadronic beam particles, and so lead to different physics. Because they have spin-parity $J^P = 1^-$ they are coupled to vector meson states so that, for instance, they are the right particle with which to search for new vector mesons. Furthermore, the different $J^{PG}$ of photons should result in diffractive production of states with different probabilities compared with their production by pions or kaons.

3. Real photon beams can be transversely polarized which gives the possibility of separating natural and un-natural parity exchange in the photo production process. The important role of polarization in the elucidation of the spin-parity of final states is well illustrated by the study of the $\rho'$ vector meson (2.1).

4. A further property of the photon is that, as the exchanged particle in electron scattering, its mass can be varied. This virtual photon is polarized both transversely and longitudinally. It follows that electron-proton scattering provides an additional dimension to the investigation of photon interactions which is
not available to hadronic projectiles except in a strongly model-dependent way. It is therefore important to carry out an integrated programme of physics in which, as far as possible, the same exclusive channels are studied with both real and virtual photons.

5. In spite of the success of the VMD hypothesis, fundamental questions about the nature of the photon still remain. In particular, the hypothesis, as stated above does not reproduce the facts exactly. For example, the VMD sum-rule is unsaturated by $\sim 20\%$ \textsuperscript{(2.2)}, shadowing of real photons in nuclei is less than the VMD prediction, and for virtual photons shadowing appears to be non-existent \textsuperscript{(2.3)}. Several explanations of these facts are possible. For example, the apparently hadronic nature of the photon could perhaps be retained if one considered additional new vector mesons and added these to the list of states to which the photon couples. An alternative point of view is to consider the photon as the superposition of a bare point-like object and a hadron-like one \textsuperscript{(2.4)}. These are fundamental questions about the nature of the photon. It is the aim of this collaboration to provide information which will bear upon these problems. The programme of work presented in this proposal is directed to that end.
SECTION 3.  THE ELECTRON AND TAGGED PHOTON BEAMS

1. The electron beam proposed for this experimental programme is described in Section 2 of Appendix 1. Electrons are produced by converting γ rays from π⁰ decay. The π⁰'s are produced in target T3 (Fig. 1 of Appendix 1) and the conversion of the γ's takes place in a Pb radiator a few metres downstream. The rate has been calculated by assuming:

(i) the validity of scaling for charged pion production, which has been checked from PS to ISR energies over a restricted range of longitudinal and transverse momentum,

(ii) the π⁰ production cross section is the average of those for π⁺ and π⁻,

(iii) an incident proton flux of 3 × 10¹² protons/burst.

The properties of this beam are summarized in Table 3.1 where it is indicated that the expected yield is 10⁷ electrons/pulse.

2. The electron flux is expected to depend strongly on the energy of the electron beam. For example it is believed that a reduction in the beam energy from 80 to 60 GeV would provide for a ×3 increase in the electron yield. It follows that reduction of the electron energy could be used to provide some compensation for any lack of incident beam during the first experience of SPS operation. However, it should be noted that all calculations of fluxes and expected rates are made using the conditions detailed in Table 1.

3. The tagging system which it is proposed to use in conjunction with the electron beam is also described in detail in Appendix 1. It can be used to provide tagged photons between 10 and 60 GeV for an incident beam of 80 GeV energy. With a radiator of thickness 1% radiation length (RL), a total photon intensity of 1.8 × 10⁵ photons/pulse would be obtained. This is detailed in Table 3.1. The radiator thickness could be increased to ≈5% RL in order to increase the photon intensity. However, this would be at the expense of increased double bremsstrahlung effect.
The angular uncertainty in the incident electron direction will be \( \pm 0.1 \) mr and the momentum uncertainty will be \( \pm 170 \) MeV/c at 80 GeV. Thus for the incident photon, \( \Delta P_T \leq 10 \text{ MeV/c} \) which is within the Aspen criterion for 4C fit separation. The photon momentum resolution is expected to be \( \sim m_\pi \) over most of the momentum range.

4. The production of polarized photons by the coherent bremsstrahlung of electrons on a crystal lattice is well known. The application of this to the present proposal is discussed in Section 4 of Appendix 1. In spite of the angular divergence of the electron beam, useful average polarization is still obtained. Furthermore, the measurement of the incident electron direction to \( \pm 1 \) mr means that the quality of the polarized beam can be improved a posteriori by rejecting those photons in a given energy bin which are calculated to have small polarization and using them only for unpolarized measurements. Fig. 6 of Appendix 1 shows the variation of maximum polarization with photon energy and demonstrates that useful polarizations can be obtained over a wide energy range.
Table 3.1  BEAM AND TOTAL INTERACTION RATES

<table>
<thead>
<tr>
<th>Incident protons</th>
<th>3 x 10^{12}/pulse. 200 GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target</td>
<td>Beryllium I Radiation Length</td>
</tr>
<tr>
<td>Beam energy</td>
<td>80 GeV</td>
</tr>
<tr>
<td>Beam Acceptance</td>
<td>15 \mu ster. \Delta p/p = \pm 2%</td>
</tr>
<tr>
<td>Intensity</td>
<td>10^{7} electrons/pulse</td>
</tr>
<tr>
<td>Purity</td>
<td>Ratio \tau/e = 10^{-3}</td>
</tr>
<tr>
<td>Spot size</td>
<td>See Appendix I. Section 2</td>
</tr>
<tr>
<td>Divergence</td>
<td></td>
</tr>
</tbody>
</table>

Tagging radiator: 1% Radiation Length (RL)

Photon spectrum: 10^5 dE/E photons/pulse

Tagging range: 10 GeV < E_y < 60 GeV

Photon intensity: 1.8 \times 10^5 photons/pulse integrated over tagging range.

Liquid H_2 target: 30 cm (3.4% RL)

\gamma p cross section: 120 \mu b

Pulse rep. rate: 9 secs (400 pulses/hour)

Running efficiency: 70%

Detection: 50% overall

Running time: 500 hours

<table>
<thead>
<tr>
<th>Energy bin GeV</th>
<th>10-20</th>
<th>20-30</th>
<th>30-40</th>
<th>40-50</th>
<th>50-60</th>
<th>Total</th>
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<tbody>
<tr>
<td>Photons/pulse</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>18</td>
</tr>
<tr>
<td>(\times 10^4)</td>
<td>6.9</td>
<td>4.1</td>
<td>2.9</td>
<td>2.2</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>Events/burst</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>10.4</td>
<td>6.2</td>
<td>4.4</td>
<td>3.3</td>
<td>2.7</td>
<td></td>
</tr>
<tr>
<td>Total events/500 hrs (\times 10^5)</td>
<td>7.1</td>
<td>4.1</td>
<td>2.9</td>
<td>2.2</td>
<td>1.8</td>
<td>18</td>
</tr>
<tr>
<td>Events/\mu b (\times 10^3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>5.8</td>
<td>3.5</td>
<td>2.5</td>
<td>1.9</td>
<td>1.5</td>
<td></td>
</tr>
</tbody>
</table>

Note: Events/burst calculated assuming 100% efficiency.
Total events and events/\mu b assuming (70\times 50)=35% efficiency.
SECTION 4. TRIGGER AND ACCIDENTAL RATES

1. The trigger

In the first stage of photon physics studies with the \( \Omega \) spectrometer (see Fig. 4.1) we propose to trigger on all photon-induced processes which are not electromagnetic in nature. This trigger must reduce the rate for electromagnetic processes to a level where it is less than the rate for hadronic events. The photon rates for various sections of the photon spectrum are shown in Fig. 4.1. The proposed trigger uses:

(i) A signal from the photon tagging system.
(ii) A signal indicating that an interaction in the target has taken place.
(iii) A veto against non-interacting photons.
(iv) A veto against e.m. pairs.

Item (i) has been discussed in the previous section. We will now describe how items (ii) \( \rightarrow \) (iv) could be realised.

(a) Target interaction trigger

This trigger signal can be obtained from wire chamber planes and scintillation counters suitable located in the \( \Omega \) spectrometer. It is important to keep multiple Coulomb scattering to a minimum. As far as possible therefore the interaction signal should be taken from the wire planes. A possible arrangement is shown in Fig. 4.1. A charged particle with \( p \geq 1.5 \text{ GeV/c} \) is detected in two wire planes or scintillators downstream of the target. Both hadrons and electrons can satisfy this trigger. The trigger could in principle be made more selective by requiring a signal from a cylindrical chamber around the hydrogen target, however this trigger would not detect processes such as \( \gamma p \rightarrow \pi^+ n \) and would also be very sensitive to low energy electrons. Hence we prefer to use just the downstream interaction trigger. For processes, such as Compton scattering, with no forward charged particle, we require an alternative trigger generated by the photon detector with a charged particle anticoincidence in front of it.
(b) **Beam veto trigger**

Electromagnetic interactions of untagged γ's in the target and thereabouts lead to large numbers of accidental coincidences between the tagging pulse and the positive interaction trigger. A beam veto trigger provided by a lead glass counter in the photon beam downstream of the whole Ω set-up is therefore valuable. Such a device is straightforward to make and install. This will also veto tagged photons which have not interacted in the target. It is not necessary to worry about two tagged photons within the chamber resolving time because these can be flagged in the tagging system.

(c) **Rejection of e+e− pairs in the trigger**

In principle the e+e− pairs are confined to the horizontal plane but in practice this plane is spread into a band of width ≈ 10 cm at 18 m downstream of the target (behind C3) by beam divergence and multiple scattering effects. This band will also be illuminated by the products of vector meson decays and it is important that the e+e− veto does not generate a bias against these events.

For pairs generated by tagged photons, at least one of the members of the pair must have an energy greater than 5 GeV, and will therefore exit from the rear of the Ω magnet. Electrons of higher energy will enter the photon detector. They will do so near to its horizontal median plane. This part of the photon detector, particularly if it is a row of lead glass blocks, can provide a signal. Electrons going to somewhat larger angles can be detected by counters downstream of C2 and the outer parts of C1. Information from a fast chamber close to the target could be incorporated in this trigger in order to keep secondary photons, converting in the Cherenkov counter walls or elsewhere, from generating a veto signal.
Another source of unwanted triggers is a random coincidence between an electromagnetic interaction of an untagged photon ($E_\gamma < 10$ GeV) and a tagging system signal. In the majority of cases the tagged $\gamma$ will not interact in the target and will therefore fire the beam veto trigger, thus vetoing the event.

A further possible method of vetoing pairs is the use of a fast hardware coplanarity requirement on a horizontal wire MWPC located within $\Omega$. Such an MWPC need have very few wires.

Table 3.1 shows the event rate expected for a total $\gamma p$ cross section of 120 $\mu$b and a 30 cm liquid hydrogen target. This rate, which is 27 hadronic events/pulse is within the capabilities of the present $\Omega$ system with a dead time of 10 ms provided that the number of false triggers can be kept to a low value. The electromagnetic events, from hydrogen, are $\sim 200 \times$ more numerous than hadronic events.

We believe that a suitable combination of the electromagnetic vetoes discussed above will provide a completely adequate rejection of electromagnetic events in the trigger.

2. Chamber backgrounds

Although only those photons within the tagging range can contribute to the true trigger rate, the hydrogen target sees the entire bremsstrahlung spectrum from the tagging radiator and synchrotron radiation from the tagging system. The synchrotron radiation dominates in the Compton region. Photons below $\sim 100$ keV must be absorbed by a lead foil of $\sim 0.03$ RL. If the background in the Compton region is still too large, photons in this region can be scattered out of the beam by a target of $\sim 0.1$ RL of light material. This must be done just inside the last tagging magnet after the electron beam has been swept sufficiently away from the photon beam.
The untagged photons can interact in the target and detectors, thus making tracks in the chambers if they occur within the chamber sensitive time. We now consider these photons in two energy ranges.

(i) Photons in the energy range $100\text{keV} < E_\gamma < 5\text{ MeV}$ may Compton scatter to produce recoil electrons. Those produced in the detector system will be recognized as tight spirals of $<1\text{ cm}$ radius. The rate of production of Compton scatters in hydrogen is $5 \times 10^6$/burst. Almost all the recoil electrons will be confined within the target because of their short range combined with the spiralling effect. However the photons themselves will be scattered out of the target and will be distributed approximately isotropically over the detector system. These will have opportunity to interact in the detectors as of course will those photons which have passed through the target. We expect a total of $6 \times 10^5$ Compton interactions per burst in the planes of the optical spark chambers. About half of these interactions will be in the beam region and the remainder spread over the volume of the chamber system. These numbers could be reduced by an order of magnitude by using a harder in the beam, increasing the length of the hydrogen and tagging targets and reducing the electron beam intensity.

(ii) For photons above 5 MeV pair production dominates. When $5 \text{ MeV} < E_\gamma < 100\text{ MeV}$ the mean $e^\pm$ momentum will be $<50\text{ MeV/c}$. These electrons have a spiralling radius of $<8\text{ cm}$ so that most of them will not reach the detectors even though they can escape from the target. It follows that the range $5 \text{ MeV} < E_\gamma < 100\text{ MeV}$ will produce visible pairs only by interaction in the chamber planes whereas those photons with $E_\gamma > 100\text{ MeV}$ can produce visible pairs in either the target or the detectors. The total number of visible pairs produced in the hydrogen target (3.5% RL) is calculated to be $2 \times 10^6$/burst and in the detector planes (3% RL, assuming optical chambers) $3 \times 10^6$/burst.
The use of some wire chambers in conjunction with the optical system is important as it will enable rapid elimination of some of the accidental tracks at the pattern recognition stage. Thus information from the wire planes would be used off-line to improve the effective time resolution of the whole system.
SECTION 5 - TYPICAL REACTION CHANNELS

1. In this section we discuss in detail some of the physics which could be investigated with real photons using the Omega equipment. We observe at the outset that present experience with the detector system has shown that pattern recognition problems inhibit the study of high multiplicity events - at least at the present level of understanding of the equipment. Considerable progress in the direction of improved pattern recognition has been made but in this proposal we confine our detailed discussion to events with at most five charged prongs. There is of course a large class of events with >5 prongs - the average charged multiplicity is expected to be $6^{5.1}$ (if photons show the same overall interaction characteristics as hadrons at these energies) so there is a large amount of information in the high multiplicity channels. In particular one could imagine studies of rapidity and correlation distributions for $\gamma p$ collisions similar to those carried out for pp studies at NAL and at the ISR. At 60-70 GeV/c for photons the rapidity range is close to that for 100 GeV/c pp collisions so that a comparison between the two cases would have considerable merit. There is therefore a strong incentive to work towards better pattern recognition possibilities. This does not form part of the justification of the present proposal.

We have calculated expected rates for many of the processes whose physics interest we discuss here. The results of these calculations are shown in Table 5.1

2. Vector Meson Photoproduction $\rho,\omega,\phi$.

The photoproduction of neutral vector mesons is interpreted in the framework of VMD as the scattering of the vector mesons on the target nucleon. The additional assumption of the
5.2

quark model then relates the vector meson scattering to pseudoscalar meson scattering. Differential cross-sections for $\rho$-meson production have been measured. With some assumptions about the $\rho$-meson alignment, these cross sections are in good agreement with this picture, and the more scarce measurements of $\omega$-meson and $\phi$-meson production lend some further support.

The recent bubble chamber measurements\(^5\) of $\rho$-meson photoproduction by polarized protons of 4.7 and 9.3 GeV/c have studied the complete $\rho$-meson decay angular distribution and so measured the $\rho$-meson alignment. Using this information an attempt at an amplitude analysis has been made, which gives indications of contributions from both Pomeron and $f$-meson exchange. The data demonstrate the importance of $S$-channel helicity conservation (SCHC) but are not able to say whether its small but significant failure is due to Pomeron or to $f$-meson exchange. We should be able to extend such amplitude analysis to higher energies. The variation of the amplitudes with energy will help in working out the effects of different exchange mechanisms, and so make tests of VMD more certain.

Further advantages in going to higher energies are:

a) the minimum momentum transfer $|t|$ for the production of a vector meson of mass $m$ decreases as $(m^2/2 E_\gamma)^2$, and

b) the problem of background subtraction is much reduced.

These lead to less uncertainty in the value of the production cross-section.

It will also be important to make such amplitude analysis for $\phi$-meson and $\omega$-meson production using studies of their decay angular distributions, preferably with a polarized photon beam. In particular it will be important, from comparison of such analysis, to test the hypothesis that $\phi$-meson production is more strongly dominated by Pomeron exchange than are the other two.
5.3

It will also be interesting to see if SCHC is equally important for \( \phi \)-meson and for \( \omega \)-meson production. At present energies the picture is somewhat confused, particularly for \( \omega \)-meson production, due to large contributions from what may be pion exchange.

The rates calculated in Table 5.1 are based on the assumption that the expression \( \frac{d\sigma}{dt} = A e^{bt} \) applies with \( A, b \) constant at the same values found at lower energies \(^5.\). With this assumption these rates suggest that the study of \( \rho, \omega \) and \( \phi \) production can be pushed to quite large values of \(|t|\) and the \(|t|\) distribution studied with good statistics as a function of energy.

In order to study the production of these vector mesons the requirements on Omega are not severe at lower photon energies and for these the present Omega system would probably suffice. However, in order to make detailed measurements and to push the energy above 30 GeV the hybrid system of optical chambers with the addition of a wire chamber lever-arm and two sets of wire planes downstream of the hydrogen target (see fig. 4.1) is needed. These wire planes are essential at higher energies both to provide high momentum resolution for forward particles and for good spatial resolution close to the hydrogen target.

For every \( \gamma p \to Vp \) process, factorization indicates that the process \( \gamma p \to VN \), where \( N \) denotes diffraction dissociation of the target nucleon to masses \(< 2 \text{ GeV/c}^2 \), will also occur with relative probability of at least 20%. Beside the intrinsic interest of these processes (which we discuss in 5.4) one sees that it is also necessary to separate them in order to obtain a pure sample of \( \gamma p \to Vp \). Hence it will be essential to detect the recoiling particle and measure its momentum. For \( \gamma p \to Vp \) the recoil proton always appears at \( \theta > 60^\circ \) and with momentum \( 0.1 < P < 1 \text{ GeV/c} \) for \( 0.1 > |t| > 0.01 (\text{GeV/c})^2 \). It follows that detectors such as the Geometry II
optical chambers represent an adequate but minimum system and additional wire chambers around the target would lead to a considerable enhancement of detection efficiency.

To identify $\rho$, $\omega$ and $\phi$ decay it will be important to distinguish $\pi$ and $K$ using the downstream Cerenkov counters. Identification of $\pi$ and $K$ mesons up to 40 GeV/c, using the existing C1 counter and the proposed C2 counter, will allow coverage of most of the decay angular distributions for $\rho$ and $\phi$ mesons up to 50 GeV/c. The additional identification of a $\pi^0$ will be necessary in the case of $\omega$ decay (and for the elimination of events with additional $\pi^0$'s in the other cases). This will be done using the downstream photon detector whose properties are described in Appendix 2.


The failure of the simple VMD hypothesis to explain photo-production by coupling the photon solely to $\rho$, $\omega$ and $\phi$ is well known. The relation between the $\gamma p$ Compton scattering cross section, the $\gamma-V$ coupling constant and the production cross section for transversely polarized vector mesons can be written in the form:

$$\left[\frac{d\sigma}{dt} (\gamma p \rightarrow \gamma p)\right]^{\frac{1}{2}} = \frac{\alpha}{4} \sum_{\rho, \omega, \phi} \left[\frac{4\pi}{\sqrt{2}}\right] \frac{d\sigma}{dt} (\gamma p \rightarrow V_{T} p)\right]^{\frac{1}{2}}$$

The l.h.s. of this sum is $(0.87 \pm 0.02)$ and the r.h.s. is $(0.63 \pm 0.05)$, the units being $(\mu b/GeV)\frac{1}{2}$. In terms of measured cross sections the r.h.s. is low by a factor of $\sqrt{2}$\(^5\). This large disagreement stimulates the search for new vector meson states which could in principle provide the required saturation of this sum. The present situation in this search is somewhat confused. It has been surveyed by Moffeit\(^5\), and can be summarized as follows: