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DESIGN OF AN EXPERIMENT TO MEASURE σ_{TOT} ($\gamma p \to$ HADRONS) AT VERY HIGH ENERGIES

W. T. Toner
Stanford Linear Accelerator Center

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Introduction

Independently of immediate theoretical ideas it is clear that a good measurement of σ_{TOT} ($\gamma p \to$ hadrons) will be of interest at the highest possible energy, likewise of σ_{TOT} ($\gamma n \to$ hadrons) via H_2-D_2 difference. I take good to mean to the order of 1 or 2 percent. This note sketches a possible way of doing this and goes into just enough detail to uncover the problems which arise in trying to obtain such precision.

Outline of the Method

A possible layout is sketched in Fig. 1. A tagged photon beam interacts in a liquid hydrogen (deuterium) target. The electron beam upstream of the tagging radiator is focused so that the photons converge to a spot several meters downstream of the target. At this point, a lead-sandwich counter hodoscope, backed by a shower counter, is placed to detect forward interaction products and the transmitted photons. The large angle interaction products are detected in an almost 4π arrangement of lead-sandwich counters surrounding the hydrogen target.

The measurement consists of counting the number of hadronic interactions per incident photon. It is quite different from the transmission method usual for measuring hadron total cross sections.

Event Rate and Beam Requirements

The cross section is expected to be ~ 100 μbarns. The number of hadronic events per gm/cm^2 of liquid hydrogen is

$$\text{events} = A \ln \frac{K_2}{K_1} \times 6 \times 10^{-5},$$

where K_2, K_1 are the maximum and minimum energies of the photons of interest. An event rate of 1 per pulse will give 1% statistics in each of 9 energy bins per 100 hours of data time. To get this for $K_2/K_1 = 2.7$ we need $A = 1.66 \times 10^4$ per pulse. If we use a 0.01 radiation length target to keep secondary processes to a minimum, we need 1.66×10^6 electrons or positrons per pulse in the beam. This can be got comfortably in a beam with a 1 μsteradian acceptance and a 1% momentum bite[1] at 100 GeV. The phase space occupied by such a beam, expressed in terms of transverse momentum, is 100 MeV/c-mm. The beam diameter at the hydrogen target will have to be 1 cm if we are to detect processes involving a momentum transfer to a single forward particle of ~ 10 MeV/c, not too elaborate a requirement for a total cross-section measurement. Making the beam come to a focus some meters downstream of the target is the most effective way to ensure spatial separation of such particles from the transmitted beam. The H_2 target thickness should be kept small in order to reduce secondary electromagnetic processes. A thickness of 1 gm/cm^2 seems reasonable. The target thickness should be varied to study this type of background.

e^+e^- Background

The most frequent interaction will be e^+e^- production on the target protons and electrons. Of the incident photons, 2.3% will interact in this way. This is more than 400 times the hadronic interaction rate. In order to do a 1% experiment, we have to eliminate, or measure, this background to the level of one part in forty thousand. This is not so difficult as it might seem. Almost all the energy of the incident photon goes forward in a cone of half angle m_e/E. e^+e^- pairs will to all intents and purposes look like transmitted photons. In a very small fraction of the cases, a low energy electron will come out at a finite angle. This will most frequently be the target electron in the $\gamma + e^- \rightarrow e^+e^-e^-$ process. If we guess this to happen in less than 1% of the cases, (this should be properly estimated some time), then we only need $\times$ 400 rejection, not such a big number. The energy still goes forward into the central counter of the forward hodoscope. To help deal with this class of events, it might be worthwhile to look at the outputs of the "core" region of the shower counter and of the "peripheral" region separately.

The effectiveness with which the e^+e^- rejection is working can be checked by replacing the hydrogen target with a heavy element radiator of the same e^+e^- yield. If necessary, a rejection of only 4×10^3 could be tolerated and a subtraction made by a measurement of this type. This does not help in the case of pair production on electrons.

Note that the H_2-D_2 difference is insensitive to this and all other background processes.

γe Compton Scattering

This process has a much wider angular distribution, with momentum transfers ~ m_π at 100 GeV. It is therefore much more likely to be confused with a hadronic process, e.g., single π^0 production. However, the increase in momentum transfer produces a decrease in cross section. At 1 GeV the total Compton cross section is 1100 μbarns, at 8 GeV it is 170 μbarns and at 100 GeV it is only 17 μbarns. It should present no great problem and might even be calculated and subtracted.

Detection of Hadronic Processes

Multi-pion processes, including $\gamma p \to \rho p$ etc., are straightforward: several counters will be hit, and very little energy will be deposited in the forward shower counter. Single particle channels are likely to go down with energy. For moderate momentum transfers a recoil will be observed in the "4π" system. Even one π^0 in the forward direction should be detectable: the photons receive transverse momenta ~ 0.070 GeV/c and will count in the outer regions of the forward hodoscope and shower counter.

In order to be sure of what is going on, it will probably be necessary to log each event on magnetic tape via a small computer, and study angular and pulse-height distributions.

Accidentals and Related Problems

True accidentals are unlikely to present any problem at the in-
-ities we are considering. If we integrate the bremmstrahlung

spectrum from 100 GeV to 1 MeV we get only 1.9×10^5 photons/second, instantaneous.

A much more severe problem is caused by the "duty cycle" of the electrons themselves. The probability that an electron radiates twice in the radiator is[2]

$$\frac{2\alpha}{\pi} \quad \ell n \quad \frac{E}{m_e} \quad + \quad \frac{t}{2}.$$

This is ~ 6% at 100 GeV. (To get a chance rate as high as this, one would have to use several times 10^6 photons per second.) There are three problems. First, that there are more photons capable of making hadronic interactions than one thinks. I don't think that this is a serious problem. Second, a combination of two electromagnetic processes may stimulate a hadronic interaction. Again, this is unlikely to be serious, since the energy of both photons goes forward. Third, some hadronic interactions due to high-energy photons will be accompanied by a very small angle, relatively low energy, photon. Therefore, we cannot reject all events where the central hodoscope counter registers a particle. We must also use the pulse-height information in the forward shower counter. This means that the "hadronic" signal is less clean-cut than one would like, even for multiparticle final states.

Tagging System

The tagging system has not been considered in detail. It is likely to be rather big due to the choice of focus downstream of the hydrogen target. The tagging bank should incorporate a shower counter and hodoscope. Anti's to veto direct pair production or reconversion will be necessary.

Other Points

Vacuum will be necessary through the beam line up to the forward hodoscope in order to minimize electromagnetic interactions in the air. Ten meters of air is 3% of a radiation length.

Conclusions

An experiment aiming at a few percent systematic uncertainty seems possible. The most severe problem is likely to be the self-induced "bad duty cycle" of the electrons due to double processes in the radiator.

An experiment very similar to the one discussed above is presently being carried out at SLAC by a group from U. C. Santa Barbara. Despite the 5×10^{-4} duty cycle of SLAC, preliminary data[3] indicate that it is working very well at 16-GeV photon energy. They find it possible to use a 1 meter hydrogen target. The principal difference between the UCSB experiment and the one described above is a very tight requirement for hadron counts: either a substantial amount of energy must be deposited in their sandwich counters, or the particle must penetrate 4 layers of Pb-scintillator sandwich.

REFERENCES

[1]W. T. Toner, NAL Summer Study Report B. 9-68-31, 1968.

[2]R. Wilson and M. Wong, Lawrence Radiation Laboratory UCRL-16830, Vol. III, p. 149.

[3]F. Murphy (private communication).

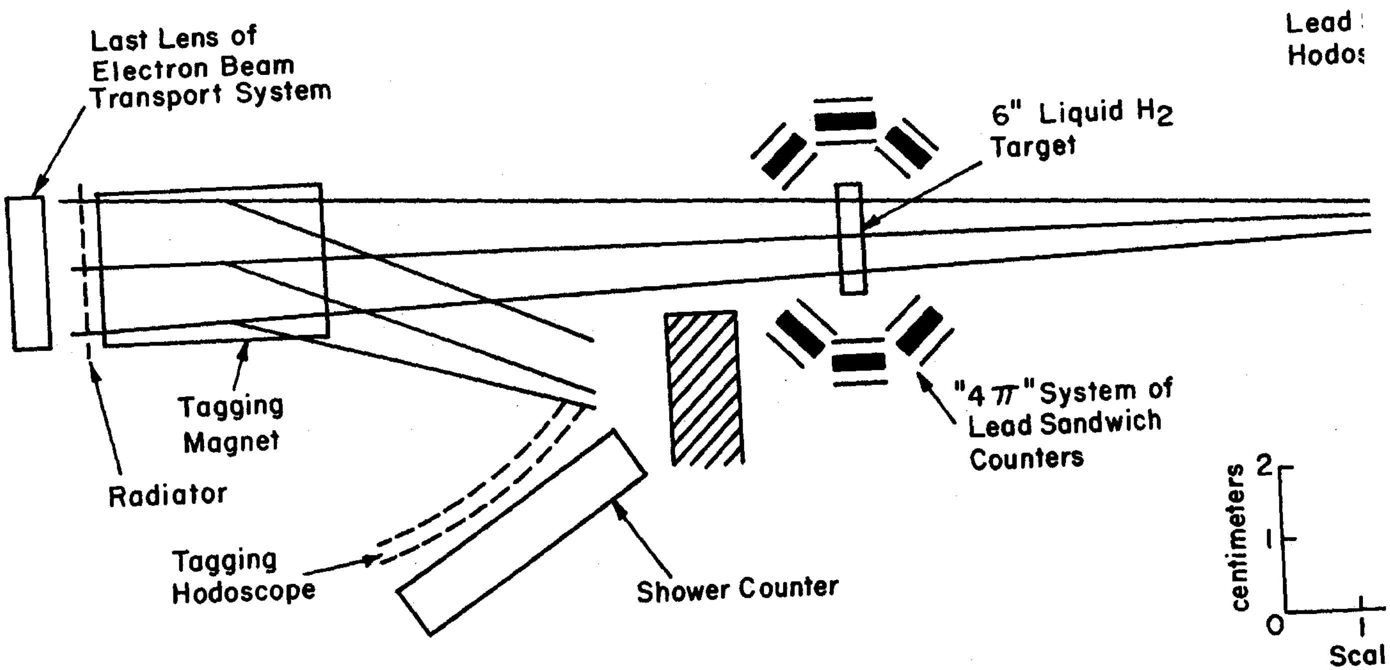

Fig. 1. Layout for hadron photoproduction experiment.