HIGH ENERGY PHOTOPRODUCTION OF HIGH $P_T$ PHOTONS

NA14 CERN COLLABORATION

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Talk given at the Seminar on $\gamma\gamma$ Physics
Paris, April 5-6, 1984

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INTRODUCTION

The presence at CERN of a pure and intense tagged photon beam has allowed the measurement of the deep inelastic Compton scattering (DICS) in the 100 GeV energy domain. The NA14 collaboration has registered the photoproduction of prompt photons at high transverse momenta —between 2 and 4 GeV/c— and has compared the result to theoretical predictions.

In the first paragraph we present the DICS on the experimental side whereas in the second one we detail the nice theoretical features of this reaction as a QCD test. The third paragraph is devoted to the rejection and control of the background to DICS. Our results are presented in the fourth paragraph so that the impetuous reader can skip all that is before but at the expense of a large misunderstanding of the nice characteristics of this experiment. These results will be published by the end of this year and the final numbers have to be found into these publications.

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I. - MEASURING THE DICS - A FEW EXPERIMENTAL CONSTRAINTS

This reaction shown schematically on fig. a is expected to take place at high incident energy and high momentum transferred to the emitted photon.

In this domain, as for deep inelastic scattering (DIS), the photon interacts incoherently on the individual constituents inside the nucleon. Bjorken and Paschos⁴ have studied this reaction in the framework of the parton model and related its cross section to that of DIS.

The cross section is proportional to the fourth power of the quark charges and, as we are dealing with 2 massless photons, such a process appears to be a good laboratory to test integer-charged quark models⁵.

The first measurement of DICS was done at SLAC at "medium" energies (below 20 GeV) and $P_T$ below 2 GeV/c⁶. The net result was a photon production in great excess to the parton model prediction, even using integer-charged quarks (fig. 1). The data were interpreted in terms of the constituent interchange model meaning that the applicability domain of the naive parton model was not yet reached.

The expected properties of DICS has imposed a few constraints on our apparatus (fig. 2):

i) we have to detect photons at $P_T$ above 2 GeV/c, spanning an energy range between 10 and 100 GeV; this implies a large solid angle coverage by e.m. calorimeters. Photons emitted at angles up to 300 mrad are measured.
ii) the energy momentum conservation is ensured by the emitted photon and a quark jet. To detect the particles coming from this jet large multiwire proportional chambers have been built which provide an angular coverage within ± 400 mrad.

iii) As the emitted photon does not take part to the hadronization of the final state we expect a small hadronic multiplicity which will depend on the $P_T$ and $P_L$ of the photon. Such a behaviour is observed - for instance - in the DIS of $\nu$, measured in bubble chamber experiments. We have taken care of this expected behaviour by imposing very loose trigger conditions on the emitted hadrons namely:

- at least 1 particle crossing the 2 magnets
- or at least 2 particles crossing the first magnet.

These conditions correspond to very small losses of DICS events: less than 5% at $P_T = 3$ GeV/c and $P_L = 70$ GeV as determined with a Monte Carlo program using an incident energy of 100 GeV.

iv) The expected cross section for DICS is rather small, of the order of 1 nb at the energy of 100 GeV and $P_T$ above 3 GeV/c and to study it in some details, a high luminosity experiment is needed. The registered data correspond to 2.5 events/pb (which is equivalent to about 12 events/nb for a pion induced reaction).

A few details about our beam line and the currently data taking conditions are given in the appendix.
II - DEEP INELASTIC COMPTON SCATTERING AND Q.C.D.

i - A few words on kinematics

The DICS is a two-body interaction between a photon and a parton giving rise to a photon and a quark jet (fig. b-c)

\[ \gamma p \rightarrow \gamma' p^* \rightarrow E_0^\gamma, E_T^\gamma, p_T^\gamma \]

Fig. b - γp center of mass system

Thus, by measuring in the laboratory \( E_0^\gamma, E_T^\gamma \) and \( p_T^\gamma \) we can explore the \( X_T^* \) and \( X_L^* \) dependance of the cross section.

For a fixed incident photon energy \( E_0^\gamma = 100 \text{ GeV} \), fig.3 indicates the acceptance of our apparatus in terms of the \( X_T^* \) and \( X_L^* \) variables. The association of the three calorimeters named: F.C. (forward calorimeter), I.C. (intermediate calorimeter) and B.C. (backward calorimeter) provides a large coverage of the Peyrou plot. Constant x lines, which are essentially also lines of constant cross section (fig. 4) indicate that the backward calorimeter (B.C.) will register less DICS photons than the other two.
Unfortunately, on the theoretical side, the DICS is not the only reaction which can produce high $P_T$ prompt photons; this will be detailed in the following. On the experimental side we have also to be able to distinguish between prompt photons emitted from the target during the interaction and non-prompt candidates coming from decays. The background control will be described in the next paragraph.

\[ \text{QCD corrections to DICS} \]

The reader is invited to get any details in [4] because I shall only quote the main characteristics of the QCD corrections which show that the measurement of high $P_T$ photon photoproduction is a nice test for this theory.

The so-called "Born Term" (fig. 5.a) from the naive parton model still dominates at high $P_T$ above 3.5 GeV/c and, in any case can always be isolated by considering differences of semi-inclusive cross sections: $\sigma(\gamma N - \gamma h') - \sigma(\gamma N - \gamma h X)$ if the interaction occurs on an isoscalar target. We have used a cylindrical of $^6\text{Li}$ as a target; this choice was motivated in fact to study the photoproduction of high $P_T$ pions for which the measurement of such differences is important when we want to isolate the QCD contributions.

The "Leading logarithm" (fig. 5-b) corrections to the Born term are rather large at moderate $P_T$ up to 3 GeV and computable. They are of the same order, $\alpha^2$, as the Born Term.

The $\alpha^2 g_s$ contributions (fig. 6) are also exactly computable, they involve a much smaller number of graphs than in usual hadronic interactions. Furthermore they are small, typically a few tens of percent, and this implies a fast convergence of the QCD expansion.
The relative importance of these different contributions to the inclusive photon photoproduction cross section is displayed in Fig. 7.

iii - Non-perturbative contributions

It is well known that the photon interacts also with matter as a hadron. In the framework of the V.D.M. model the photon behaves as a vector meson. Such a component can give rise to an hadronic production of prompt photons very similar to that measured using pion beams.

This production is expected to be small in our energy and $P_T$ ranges furthermore, the way we measure the background can partly account for it.

An other non-perturbative contribution to prompt photon photoproduction comes from the intrinsic $P_T$ component of the partons inside the nucleon. This effect has been studied carefully in [5] and, for DICS the cross section induced variation is small (less than 30 %). This comes essentially because we are dealing with a parton -the photon- in the initial or in the final state of the elementary processes.

III - BACKGROUND TO PROMPT PHOTON CANDIDATES

1 - Background sources

To be called a photon, an electromagnetic calorimeter cluster -calorimeters are divided into cells- has to satisfy several cuts ensuring essentially that it is induced by a neutral particle and has an electromagnetic "profile". These candidates are thus:
i) genuine photons: apart from the prompt photon source they come mainly from the decays of \( \pi^0 \) and \( \eta^0 \) mesons. The other photon from the decay has a too low energy to be detected or has been converted into an electro-magnetic pair somewhere in the target or in the detectors.

ii) \( \pi^0 \) giving two nearby photons: the two photons are merged into the same calorimeter cluster which has the appearance of a single electromagnetic shower. Such candidates are present at high energy (above 30 GeV) in the F.C. and most of them are eliminated using two crossed hodoscopes made of scintillating fingers 1.5 cm wide placed after 3X0 of active lead glass converter (fig. 2) which allows to distinguish electromagnetic clusters associated to 1 or more impacts (2 for a \( \pi^0 \)). In this way about half of these \( \pi^0 \)'s are eliminated.

iii) neutral hadrons: \( n \) and \( K^0_L \) can interact in the calorimeters and satisfy the cuts.

iv) muon induced background: the photon beam requires a high proton intensity —cf appendix— on the primary target which induces a high muon flux through the experiment. Usually these muons are not passing through the experimental target and radiate a shower before or inside calorimeters. They thus simulate a high \( P_T \) candidate when we assume that it comes from the interaction vertex. (fig. d).
2 - Background control

These various background components can be estimated by appropriate Monte Carlo simulations. We have used this approach to evaluate the first two sources which are the most important and the easiest to compute.

We have rejected the muon induced background to a negligible level using several vetoes:
  - a scintillator wall is placed upstream from the target
  - calorimeter trigger cells are read by TDC and the corresponding time has to be compatible with the time of the charged particles emitted during the interaction
  - in 90% of the cases, particles accompanying the triggering muon are of electromagnetic nature
  - at last all high $P_T$ events -above 3 GeV/c- have been scanned to detect a muon track visible in MWPC's.

To check our Monte Carlo estimates and to be confident with our background control we have used, in addition, an experimental measurement. We have sent a pion beam through our apparatus and have taken data with the same triggering conditions in calorimeters. By measuring the high $P_T$ production of candidate photons and $\pi^0$ with these conditions we can easily obtain the amount of non prompt and VDM type prompt photons which are present in any of our photon induced photon distributions. If we call $R_{\pi} = N_\pi^\gamma / N_\pi^\pi$ the ratio of the numbers of $\gamma$ candidates over the number of $\pi^0$ observed in a given bin of some variable -$P_T, P_L$...- measured with incident pions, the number of photons coming from "background" in the same bin of the same photon induced photon distribution will be:
\[ N_{\gamma \text{BKG}}^\gamma = N_{\pi^0}^\gamma \times R_{\pi} \]

Were \( N_{\pi^0}^\gamma \) is the number of photoproduced \( \pi^0 \) in the same bin of this distribution.

This approach rests on the hypothesis that the abundances of the other main background sources are in the same ratios to those for \( \pi^0 \) in photo and pion production. If we take, as an example, the analysis done with the I.C. we get

\[ R_{\pi} = 27 \% \]

which, from Monte Carlo evaluation can be dispatched among the various contributing sources as:

\[ \pi^0 : 20 \% \quad \eta : 5 \% \quad \omega : 1 \% \quad \eta' : 5 \% \]

using \( \eta/\pi^0 = .5 \) at high \( P_T \) and \( \omega/\pi^0 = 1. \)

We have measured a ratio \( \eta/\pi^0 = 52 \pm 15 \% \) using the F.C. and we observe that we can vary \( \omega/\pi^0 \) and \( \eta'/\pi^0 \) within a very large domain before getting any sensitivity in our results.

To illustrate the quality of the data some typical \( \gamma-\gamma \) mass distributions are given in fig. 8 and 9. \( \pi^0 \)'s are reconstructed up to 100 GeV and a nice \( \eta \) peak is observed.

With our Monte Carlo we can compare the reconstructed \( \pi^0 \) \( P_T \) (or \( P_L \)) distributions using \( \pi^- \) beams with those measured at Fermilab [6]. The agreement is very good (fig. 10). The Monte Carlo can also be used to estimate the candidate photon distributions using a pion beam. The agreement with the data is also nice (fig. 11) implying that the neutral hadron induced background and the prompt photon pion production at these energies are small.
By taking π beam data with a muon induced background similar to the conditions observed in photon beam we have also experimentally verified that this last background source was effectively negligible.

IV - PHOTOPRODUCTION OF PROMPT PHOTONS

The observed $P_T$ distribution of photoproduced prompt photons is given in fig. 12 and 13 for the three calorimeters. The corresponding data have been analysed independently by the three groups having in charge each calorimeter.

1 - Prompt photon signal

On each measured photon candidate distribution —fig.12, 13— we have plotted the photon "background" determined with the technique described in the previous paragraph. In addition to the excess of photons candidates present above the "background" there is a definite difference between the slopes of the two curves. Prompt photon candidates have a flatter distribution.

These considerations are independent of any normalisation of the experiment, the uncertainties are those of the technique used to fix the background which are presently estimated to be $\pm 20\%$.

2 - Comparison with the standard theory

We have chosen to add, on top of the background, the expected number of prompt photons as given by the theory. The Orsay theoretical group$^{[7]}$ has provided us with a computer program giving the cross section for prompt photon photoproduction. Knowing our experimental sensitivity and having a
Monte Carlo program which gives the probability that a prompt photon will be detected we have determined the number of expected prompt photons which must appear in our distributions. The uncertainties in this procedure are estimated to be $\pm 20\%$.

We consider, as an example, the data coming from the F.C. and, taking into account our uncertainties, normalise the curves giving the expected number of photons such that they reproduce the data at low $P_T$.

On fig. 14 the addition of the Born Term to the background account for the data at low $P_T$ (initial condition) and at large $P_T$ (above 3.5 GeV/c), it presents some discrepancy around 3 GeV/c.

On fig. 15 the complete QCD calculation has been introduced and the curve agrees with the data in essentially all the $P_T$ range.

3 - Comparison with integer charge parton models

We have not found, up to now, a QCD type computation based on integer-charged partons which includes the same orders in the serie expansion as the one we used.

If we consider the Born Terms for fractionnal and integer-charged partons, they are in the ratio of 2.5. We have assumed that this ratio is maintained when we add higher orders. fig. 16 shows the comparison with our data -adding calorimeters- to the predictions got from fractionnal and integer charged parton. Within our last hypothesis, integer charged partons are excluded.
CONCLUSION

We have measured the photoproduction of a high rate of prompt photon if we compare it to hadron induced photon production in the same $P_T$ and energy ranges.

At high $P_T$—above 3.5 GeV/c—where the QCD corrections are expected to be small (20-30%) we observe a good agreement with the Born Term predictions using fractionnally charged partons.

At lower $P_T$, where the QCD corrections are important—about a factor 2 at 2 GeV/c—we get a good agreement with these predictions.
FIGURE CAPTIONS

Fig. 1 : Measurement of photon production at SLAC with a photon beam produced by bremsstrahlung of a 21 GeV e⁻ beam

Fig. 2 : NA14 experiment (horizontal cut)

Fig. 3 : Acceptance to DICS in NA14 for a 100 GeV incident photon and considering that the emitted photon is produced in the horizontal plane of the experiment.

Fig. 4 : Expected cross section for DICS.

Fig. 5 : Dominant diagrams for DICS.

Fig. 6 : Terms of \( \alpha_s^2 \) order contributing to DICS.

Fig. 7 : Comparison between QCD contribution and Born Term to DICS.

Fig. 8 : Measurement of \( \pi^0 \)'s in NA14 Forward calorimeter

Fig. 9 : Measurement of \( \eta^0 \) in NA14 Forward calorimeter

Fig. 10 : Incident \( \pi^- \) data.
The \( \pi^0 \) \( P_T \) distribution observed in the I.C. is compared to the expectation from a M.C. which uses similar data registred at Fermilab as an input

Fig. 11 : Comparison between the observed and the expected "prompt photons" candidates with incident \( \pi^- \)

Fig. 12 : \( P_T \) distribution of prompt photons observed in the I.C. and in the P.C.

Fig. 13 : \( P_T \) distribution of prompt photons measured in the B.C.

Fig. 14 : Comparison between the observed photon spectrum and the expectations from a Monte Carlo which computes the contributions from photons coming from \( \pi^0, \eta^0 \) decays and from the DICS Born Term in the P.C.

Fig. 15 : Same comparison, the QCD contributions have been added to the Born Term

Fig. 16 : Photons from I.C. and P.C. have been added into this distribution.
REFERENCES


  - P. Aureneche et al. LPTHE - Orsay 83/36


[7] : M. Fontannaz - D. Schiff
NA14 photon beam
\[ 1.5 \times 10^{12} \text{ pp} \]
\[ \rightarrow \text{Be target} \]
\[ \text{charged particles are swept.} \]
\[ \rightarrow \text{neutrals} \]
\[ \rightarrow \text{Lead converter} \]
\[ n, K_L^0 \rightarrow e^- \quad \langle E_e \rangle = 140 \text{ GeV} \]
\[ \sim 10^8 \text{ pp} \]
\[ \rightarrow \text{neutron dump} \]
\[ \rightarrow \text{position measurements} \]
\[ \rightarrow \text{initial momentum} \]
\[ \text{radiator} \]
\[ 10\% \text{ Xo lead} \]
\[ \rightarrow \text{position measurements} \]
\[ \rightarrow \text{final momentum} \]
\[ \gamma \]
\[ 10^7 \text{ pp} \]
\[ E_\gamma > 50 \text{ GeV} \]

Typical rates per pulse:
- pairs (untagged) \( \sim 4 \times 10^6 \) mostly in medium plane
- hadronic interactions (untagged) \( \sim 8000 \)
- muons background \( \sim 5 \times 10^5 \) spread over the whole detector
- pretriggers \( \sim 25000 \)
- events on tape \( \sim 60 \)

Total experiment:
- 15 M events (\( \pi^0 - \gamma - e \))
- the use of filters to select high \( P_T \) candidates \( \rightarrow \) a few \( 10^4 \)
  completely analysed events.
FIG. 3. Excess-photon (inelastic Compton) cross sections for four values of $p_T$: (a) 1.1 GeV/c, (b) 1.3 GeV/c, (c) 1.5 GeV/c, and (d) 1.7 GeV/c. The solid curves (with systematic error bars) show cross sections after subtraction of $\pi^0$ and $\eta$ contributions. The long-dashed curves assume that all low-$p_T$ photons are hadronic (see text). The short-dashed curves are parton-model predictions (Ref. 1) for integer-charged partons.

FIG. 4. CIM diagrams for inelastic Compton scattering. (See text and Ref. 7.)
\[ \frac{d^2\sigma}{dx_T \, dx_L} \quad \text{QED Compton} \quad \text{in unit of nb} \]

Fig. 4
(a) Born Term

(b) "Leading log."

(c) Box diagram

Fig. 5
Next to leading log. contributions

Fig. 6
after integration on $y$ from 0 to $y_{\max}$

Fig. 7
\[ E_{T_1} + E_{T_2} \in [20-40] \text{GeV} \]

\[ E_{T_1} + E_{T_2} \in [40-60] \text{GeV} \]

\[ m_{\gamma\gamma} \left( p_{T_1} + p_{T_2} > 2 \text{GeV} \right) \]

\[ E_{T_1} + E_{T_2} \in [60-80] \text{GeV} \]

\[ E_{T_1} + E_{T_2} \in [80-120] \text{GeV} \]

Fig. 8
$E_{Y_{1,2}} > 4$ GeV

Fig. 9
\[ \pi^{-}N \rightarrow \pi^{0}X \]

- \( p_{T}^{\text{Trigger}} > 0.9 \text{ GeV}/c \)
- \( p_{T}^{\text{Trigger}} > 1.7 \text{ GeV}/c \)

- Data From Fermilab
- \( \times \) Acceptance
$\gamma p \rightarrow \gamma^* x$  F.C.

$P > 40 \text{ GeV}$

--- non prompt photon background

Fig. 12
Fig. 13

\[ \gamma + N \rightarrow \gamma + X \quad \text{(B.C.)} \]

non prompt \( \gamma \)

\[ \text{EVTS / 200 MeV} \]

\[ P_{T}^{\gamma} \text{(GeV)} \]
\[ \gamma N \rightarrow \gamma X \]  
(F.C. + I.C.)

Fig. 16