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Addendum to:

THE STUDY OF INTERACTIONS IN WHICH γ RAYS AND ELECTRONS WITH LARGE TRANSVERSE MOMENTUM ARE EMITTED

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INTRODUCTION

The main objective of our preliminary proposal was to search for reactions in which a single electron (or a pair) would be emitted with large transverse momentum. We also listed some of the other processes which we could measure with the same apparatus [1, 2].

In this addendum we will first define more precisely the method we propose to use in order to identify single large transverse momentum electrons (or pairs) in a large background of low momentum π, K.. etc.

In the second part, we will precise the spectra, and the momentum range in which they could effectively be measured at the starting period of ISR operation.

(I) IDENTIFICATION OF SINGLE LARGE TRANSVERSE MOMENTUM ELECTRONS (OR PAIRS) :

The maximum number of events which will be observed with the nominal ISR luminosity $L = 4\ 10^{30}\ \mathrm{cm}^{-2}\ \mathrm{sec}^{-1}$ in a reasonably long run : $\tau \simeq 10^3$ hours, for some rare process such that the product : $\sigma \times B \times \varepsilon = 10^{-35} \mathrm{cm}^2$ [σ = production cross section, B = decay branching ratio to the observed mode, ε = geometric detection efficiency]
is equal to :

$$N = \sigma \times B \times \varepsilon \times L \times \tau \simeq 150 \text{ events}$$

A realistic limit for small cross section processes to be observed is thus equal to :

$$\sigma \times B \times \varepsilon \simeq 10^{-36}\ \mathrm{cm}^2.$$

In comparison, the $\pi^\pm$ background is given by an estimate of the production cross section for pions with a transverse momentum larger than 1.5 GeV/c, which is approximately $\simeq 5\ 10^{-29}\ \mathrm{cm}^2$; so that the ratio between the cross sections for a rare process such as : $\sigma \leqslant 10^{-35}\ \mathrm{cm}^2$ and the $\pi^\pm$ background is larger than $\geqslant 5\ 10^6$.

In particular in the proposed experiment the total expected number of $\pi^\pm$ going through the large solid angle detector $\Delta\Omega \simeq \pi$ (at 90° with respect to the ISR proton beams), in a corresponding long run of

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10^3 hours, has been calculated using the $\pi^\pm$ production rates [1]; and is given in the following table as a function of momentum :

MOMENTUM INTERVAL GEV/C	TOTAL NUMBER OF $\pi^\pm$ IN 10^3 HOURS
0 - 0.75	2.7 10^{11}
0.75 - 1.5	5 10^{10}
1.5 - 2.5	5 10^9
$P\pi \geqslant 2.5$	3 10^7

TABLE I

It is clearly seen that the identification of large transverse momentum electron events will depend criticaly on the rejection efficiency of the detector for low momentum $\pi^\pm$ and $K^\pm$.

In our preliminary proposal [1] we proposed to use a Cerenkov counter to identify electrons and discriminate $\pi^\pm$ with a rejection ratio of the order $\simeq 10^{-4}$, plus an assembly of counters in the shower detector in order to measure the electron shower energy. Such shower detectors have been built with large scintillation counters assembly and operated succesfully with a rejection ratio $\simeq$ 5 10^{-4} against pions [3].

We will now consider more in detail the total rejection efficeincy of such a system ($\sim 10^{-4} \times 5\ 10^{-4}$) against low momentum pions when the threshold of the shower energy is set at : $E \geqslant 2.5$ GeV; in order to eliminate the most abundant source of pion contamination (TABLE I).

1) Efficiency of the Cerenkov counter discrimination against $\pi^\pm$, $K^\pm$:

The major contribution to the contamination from low momentum $\pi^\pm$ comes from knock-on electrons. With a Cerenkov counter 60 cm long filled with N_2 at pressure $p = 1$ atmosph. the threshold for detecting electrons is = 20 MeV/c. This threshold corresponds to the maximum momentum of δ-rays emitted by pions having a momentum $P\pi \simeq 750$ MeV/c.

The number of δ-rays emitted by $\pi^{\pm}$ with $P\pi \geqslant 750$ MeV/c in this Cerenkov counter has been calculated using the $\pi^{\pm}$ production rate spectra [1] (TABLE I), together with the well known production cross section of δ-rays having a momentum above 20 MeV/c. These numbers calculated for a $\tau = 10^3$ hours period are presented in TABLE II.

MOMENTUM INTERVAL GeV/c	TOTAL NUMBER $\pi^{\pm}$ IN $= 10^3$ HOURS	TOTAL δ - CONTAMINATION
0.75 - 1.5	5.10^{10}	$1,2\ 10^6$
1.5 - 2.5	$5\ 10^9$	10^5
$P\pi \geqslant 2.5$	$3\ 10^7$	$1.5\ 10^3$

TABLE II

these numbers should be increased by a factor ~ 2 in order to take care of $K^{\pm}$ contamination.

This contamination of the trigger of the Cerenkov counter for $\pi^{\pm}$ momentum larger than 2.5 GeV/c corresponds to a few counts per hour. It would be dangerous only if no other discrimination against $\pi^{\pm}$ followed, however one should note that it will be decreased in the following way :

a) scanning of the spark chamber pictures where one will ask for a single high transverse momentum electron originating from the interaction region and producing in the shower detector a well defined shower with an energy greater than 2.5 GeV.

The probability of $\pi^{\pm}$ charge exchange process in 10 radiation length lead plates in the very forward direction followed by a Dalitz pair conversion is smaller than a factor 10^{-5}. Furthermore the electron pair should have an energy greater than $\simeq 2.5$ GeV.

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b) The knock-on electrons having a momentum larger than 20 MeV/c which will be produced by $\pi^{\pm}$ having typicaly a momentum $P\pi \simeq 2.5$ GeV/c will be emitted at an angle smaller than 10° with respect to the pion. These δ - rays will come through the thin end wall of the Cerenkov counter and will be detected in the first ten very thin plates of the shower detector located behind the Cerenkov counter. These events with a low momentum electron issued from the Cerenkov counter will be easily recognizable and rejected when scanning the spark chamber pictures.

c) A large amount of this $\pi^{\pm}$ contamination in the electron Cerenkov counter will be further decreased by the shower detector energy threshold.

2) $\pi^{\pm}$ rejection ratio of the electron shower detector :

The $\pi^{\pm}$ rejection ratio of a large electron shower detector with an assembly of scintillation counters has been measured and is equal to $\sim 5\ 10^{-4}$ [3].

The discrimination against low momentum $\pi^{\pm}$ should be highly increased when the shower energy cut-off is raised above 2.5 GeV.

An assembly of scintillation counters plus spark chamber plates will be tested in an electron and pion beam in order to measure more accurately the $\pi^{\pm}$ rejection as a function of the energy cut off. The design of such a shower detector will be studied carefully in order to get the optimum $(\pi^{\pm}/e)$ rejection ratio.

3) Further improvements of the trigger system :

One of the possible improvements of the trigger system we are actually studying is to ask that only one electron (or pair) be emitted in a large solid angle $\Delta\Omega = 2\pi$ around the interaction region.

As the average multiplicity will be of the order ~ 12 charged particles per collision and as the mean polar angle of these secondaries is about $\sim 40°$, more then $\geqslant 6$ charged particles on the average will go through a large solid angle detector $\Delta\Omega = 2\pi$ around interaction region. The condition that only one electron (or pair) has been emitted would be highly restrictive and would help to eliminate drastically the multi-

$(\pi^{\pm}\ \pi^{\circ})$ events.

This condition in the trigger system would help to reduce on one hand the $\pi^{\pm}$ background contamination events and on the other hand it would also help to discriminate against π° background events.

4) Discrimination against electron background from Dalitz pairs and γ ray materialisation :

The number of π° going through the Cerenkov and shower detector in a long run : $\tau = 10^3$ hours will be roughly half the $\pi^{\pm}$ number listed in Table I. As the electron shower energy threshold will be set above $\geqslant$ 2.5 GeV we will calculate how many of the $\sim 2\ 10^7\ \pi^{\circ}$ will simulate a single high transverse momentum electron (or pair).

a) The γ ray materialisation in the vacuum chamber wall or the Dalitz pair process have approximately the same probability $\sim 10^{-2}$, so that electron pairs will be created by either process with a probability α :

$$\alpha \simeq 2\ 10^{-2}$$

b) In the $\pi^{\circ} \rightarrow \gamma\gamma$ decay the γ ray momentum distribution extends from zero to $P\pi^{\circ}$, so that the electron pair distribution (from γ ray materialisation) is reduced by a factor $\beta \simeq 2\ 10^{-1}$ for momenta above $\geqslant$ 2.5 GeV/c, and a 20% energy resolution.

c) The possibility to identify one or two electrons from a $e^+ e^-$ pair will reduce by a factor γ the unidentified "one electron" events.

The technical feasibility of such a discrimination between one or two electrons will be discussed below. For momenta above 2.5 GeV/c and a minimum electron energy about 15 MeV/c, only a fraction γ of the electron pairs will be mis-identified for single electrons :

$$\gamma \simeq 5.10^{-3}$$

With these three first criteria : $\alpha \times \beta \times \gamma = 2\ 10^{-5}$ only a small fraction N of the incoming π°'s will simulate the trigger from a single high transverse momentum electron :

$$N = 2\ 10^7 \times 2\ 10^{-5} = 400$$

The scanning of the shower spark chamber pictures should provide further rejection of π° ; specially by looking at the second γ ray materialisation in the 15 radiation lengths large solid angle shower detector. However the opening angle distribution shows that less than 3 10^{-2} π° decays with an opening angle larger than 30° for momenta $\simeq$ 2 GeV/c. This escape probability sets an average limit for the detection of the 2nd γ ray from the π° decay.

The total rejection of π° with the detector trigger system plus the scanning of the spark chamber pictures would be approximately $\sim 2\ 10^{-5} \times 3\ 10^{-2} = 6\ 10^{-7}$.

Even if this rejection ratio would appear optimistic one should remember that the largest rejection of multi ($\pi^\pm$ π°) events will be obtained by the rejection either in the trigger logic or in the scanning of the spark chamber pictures of all the events where more than one single high transverse momentum "electron" is emitted in the large solid angle detector around the interaction region.

5) Conclusion :

As a first approximation, these calculations have shown that the total number of background events from $\pi^\pm$ or π° contamination in the electron detector will be limited to a few events per hour. The scanning of the spark chamber pictures will provide a powerful method to eliminate still further these multi ($\pi^\pm$ π°) events. Other possible sources of contamination are being carefully evaluated and will be discussed in a following addendum.

-II- PROPOSED EXPERIMENTAL PROGRAMME FOR THE MEASUREMENT OF THE γ RAY AND ELECTRON SPECTRA .

In order to be more specific, we propose to subdivide the experimental programme into the 3 following and successive parts :

1) Measurement of the γ ray spectrum in the lower momentum range between 1.5 and 3.0 GeV/c

These preliminary measurements should be carried out at the starting period of ISR operation when the circulating proton beam intensity is expected to be low ($\leqslant 10^{13}$ protons):

a) The data taking time will be short : specially for the lower momentum part of the spectrum where the expected rates vary between a few events per second to a few events per minute.

b) The objective is to obtain approximately 5000 events mainly from multi ($\pi^{\pm}$ π°) events.

c) The optical spark chamber pictures and films will be scanne and measured with the automatic measuring device ARIANE in operation at SACLAY in order to reduce the data analysis time .

d) As we will not be looking for some rare type of events in the first part of this experiment, we will reduce the detector solid angle to $\Delta\Omega = 0.1\,\pi$ in order to simplify the setting up of the apparatus, and extend more easily the measurements to more forward angles (i.e. in the region 30° - 60°).

e) The expected signal/background ratio due to $\pi^{\pm}$ contamination is a small correction amounting to a few percent of the total number of events in the lower momentum region (between 1.5 and 3 GeV/c) of the spectrum (Appendix I).

Further discrimination against $\pi^{\pm}$ will be obtained by careful scanning of the shower spark chamber pictures.

f) The expected production rates of secondaries, at the starting period of ISR operation, will be reduced by a factor $\geqslant 10^{2}$ for a stacked proton beam $\leqslant 10^{13}$ protons. This period will certainly be the most favorable time to set-up and optimize the experimental conditions without having large counting rates troubles.

g) These preliminary measurements will provide information on the γ ray spectrum and also on the π° spectrum from the $\gamma\gamma$ events. In particular, the slope of the exponential decrease as a function of momentum, of these spectra, will be particularly useful in planning later stages of this experiment.

h) These measurements will also give some information of multi ($\pi^\pm\pi^\circ$) events, with the very thin plates spark chambers surrounding the interaction region over nearly 4π solid angle. This feature will also be used in later parts of the proposed experiment.

These thin plate spark chambers will have to be compatible with the apparatus of possible other users around the same interaction region.

2) Measurement of the γ ray spectrum at large transverse momenta from 2.5 to 5 GeV/c

We will repeat the previous measurements of the γ ray spectrum for momenta larger than 2.5 GeV/c when the ISR circulating proton beam will have reached an intensity nearer to its nominal value $\sim 10^{14}$ protons.

The solid angle of the shower detector will also be increased to $\Delta\,\Omega \simeq \pi/2$ by adding more detector elements similar to the one used in the first part of the experiment.

With these 2 factors, the data taking time will remain short for the momentum region between 2.5 and 5 GeV/c where the expected trigger rate will vary between a few events per minute to a few events per hour.

The objective will be to obtain $\sim$ 5000 events for that momentum range.

It should be emphasized that the contamination from δ rays in the Cerenkov counter from low energy $\pi^\pm$ will be highly suppressed by triggering the shower scintillation counters for shower energy above 2.5 GeV

During these measurements the identification of multi ($\pi^\pm\pi^\circ$) events will be further studied with the thin plate spark chambers surrounding the interaction region.

We also intend to extend the measurement of the γ ray spectrum with the same apparatus to more forward angles in the 30° to 60° region.

3) Measurement of single high transverse momentum electrons (or pairs)

These measurements, where one will be looking for some rare decay process, will need as we have seen in the first part some 10^3 hours of data taking time, and the maximum proton beam intensity.

The preliminary measurements of the γ ray spectra described in the preceding paragraphs will permit us to calculate more exactly the electron background and the expected rejection ratio of multi ($\pi^{\pm}\pi^{0}$) events. Further discussion of this later part of the experiment will be given in a forthcoming addendum to our proposal.

APPENDIX I

We will consider here only the $\pi^{\pm}$ rejection efficiency of the Cerenkov counter when measuring the γ ray and electron spectra in the momentum range between 1.5 and 3 GeV/c.

The knock-on electrons contamination from $\pi^{\pm}$ and $K^{\pm}$ has been calculated under the following conditions:

1) the nominal proton beam intensity $\sim 1.6\ 10^5$ interacting protons per second and the $\pi^{\pm}$ production rates given in [1].

2) the detector solid angle $\Delta\Omega \simeq 0.1\ \pi$

3) the Cerenkov counter is 60 cm long, filled with N_2 at a pressure $\sim$ 1 atm., with a threshold for detecting electrons above 20 MeV ; so that only pions having a momentum above 700 MeV/c need to be considered as a possible source of δ ray contamination :

$$N_{\delta} \simeq 4.\ 10^{-2}\ /\ \text{sec.}$$

The counting rate for γ ray events in the same momentum range (1.5 - 3 GeV/c) will be more than $\sim 10^2$ times larger. This contamination will give rise at most to a $\sim$ 2% background on the total number of events. The Cerenkov counter alone will provide enough discrimination against low momentum $\pi^{\pm}$ and $K^{\pm}$, when measuring the spectra between 1.5 and 3 GeV/c.

REFERENCES

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