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THE STUDY OF PROMPT LEPTON PRODUCTION IN ANTIPROTON-PROTON INTERACTIONS AT 70 GeV/c IN BEBC EQUIPPED WITH A TRACK SENSITIVE TARGET

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Summary

A 300.000 picture exposure of BEBC to a beam of antiprotons of 70 GeV/c is requested. The chamber should be filled with a H_2-Ne mixture and equipped with the neutrino TST, filled with hydrogen, and preferably also with the EMI. The proposed experiment should yield information on exclusive prompt $e^{\pm}$-production, allowing for a detailed analysis of the production reactions. The occurrence of (e-e), (e-μ) and (μ-μ) correlation will be investigated.

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I. MOTIVATION

A series of counter experiments[1 to 10] have established a surprisingly high inclusive direct lepton to pion production ratio $R = \frac{\ell}{\pi}$ (with $\ell \equiv e$ or μ) in proton nucleon collisions. These results are relevant to two distinct kinematical regions :

a) High transverse momenta ($p_T > 1$ GeV/c)[1 to 6] leading to a canonical value of $R \simeq 10^{-4}$. These high transverse momentum data suggest that the value of R is only weakly dependent on the transverse momentum p_T and on the incident proton beam momentum p_{beam} (on a stationary target) extending from 10 GeV/c to 1400 GeV/c. Inclusive $e^{\pm}$ and $\mu^{\pm}$ rates, when compared, are found to be approximately equal and charge symmetric.

b) Two experiments[7,8] performed by Leipuner et al. have studied forward prompt muon production in 28 GeV/c and 400 GeV/c proton-nucleus interactions. The 28 GeV/c experiment explores higher $x = p_L/p_{beam}$ values ($.5 \lesssim x < 1$) than the 400 GeV/c experiment ($.1 \lesssim x \lesssim .5$). Both experiments indicate a decrease of R with increasing x, with $R \simeq 10^{-4}$ at the lowest x-values reached in each experiment. The x-dependence of the results obtained by Buchholz et al[9] shows the same trend.

Prompt $e^{\pm}$ emission in the transverse momentum interval .2 GeV/c < p_T < 1.5 GeV/c has recently been observed at the CERN-I.S.R.[10] for $\theta_{cm} = 30°$ and $s = 2800$ GeV^2. At these low transverse momenta (but high s-value) the e/π ratio appears to rise as p_T^{-1} from a value of $(1.28 \pm .3) \times 10^{-4}$ for 1. GeV/c < p_T < 2. GeV/c to $(5.87 \pm .96)$ 10^{-4} for $.2 \lesssim p_T \lesssim .3$ GeV/c.

An inclusive lepton to pion ratio $R \gtrsim 10^{-4}$ appears to be inexplicable [1 to 11] in terms of known lepton production processes, either direct (Q.E.D.) or through the decay of known vector mesons (ρ, ω, φ, Ψ (3.1), etc), so that the origin of these phenomena remains obscure, essentially due to the inclusive nature of the experiments.

We wish to point out that the use of BEBC could throw an entirely new light on the problem. Although the numbers of events would be limited, BEBC, equipped with the neutrino TST and preferably the EMI, could provide a unique opportunity to examine not only

single lepton production but also possible ee, μμ, eμ[+] correlations together with a virtually complete study of the accompanying hadrons in each event (including π^0's and neutral strange particles). It should also be pointed out that the studies of direct lepton production have so far been confined to proton-nucleon collisions. This work should be extended to other beam particles. In this connection it has been reported[12] that Ψ procution in $\pi^- p$ collisions at 100 GeV/c could be considerably larger ($\sim$ 7 times) than in pp. This could be due to the different quark content of the two systems. In the long term a systematic program with different beam particles at different momenta may prove necessary, however for an initial run we suggest that $\bar{p}p$ interactions with their charge conjugate quark content may well prove to be fruitfull.

II. PROMPT LEPTON DETECTION IN BEBC EQUIPPED WITH A TST AND AN EMI

A large bubble chamber such as BEBC filled with a H_2-Ne mixture and equipped with a neutrino type[++] H_2- TST whose typical dimensions are specified by fig. 1, should be an almost ideal instrument to study prompt $e^{\pm}$-production in hadron-hadron interactions allowing for the identification and analysis of the production events. A choice of a 25/75 mole % H_2-Ne mixture corresponds to a radiation length of 40 cm (85 % γ-detection probability) and a hadron interaction length of

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(+) In this proposal we shall use the symbols e, μ to signify either particle or antiparticle.

(++) The question arises whether a shallow (30 cm) hadron TST, continuing through the entire diameter of BEBC, or a wider and shorter neutrino TST extending over approximately 60 % of its length, should be selected for the study of prompt lepton production. A hadron TST offers the advantage that the beam and the fast forward secondary particles do not enter the H_2-Ne mixture. This type of TST presents however the disadvantage that, unless BEBC is equipped with a forward γ-detector, good $e^{\pm}$ and γ-detection will not be ensured in the most forward direction.

150 cm for σ = 30 mb. The detection efficiency for $e^{\pm}$-particles produced in pure H_2, but penetrating several radiation lengths of this H_2-Ne mixture, is almost 100 %. Moreover, this set-up ensures a high π° (γ) and a useful neutron detection efficiency, thus providing a nearly 4π detection of neutral as well as charged particles produced in the primary reaction. A H_2 filled TST is essential as background rejection (see section III) will partly rely upon charge balance checks made at the interaction vertex. It should be realized that although the presence of a 1 m long H_2-Ne blanket beyond the TST will ensure almost 4π - $e^{\pm}$ and γ-detection an essential feature for the suggested experiment, this can only be obtained at the expense of a loss in hadron identification efficiency in the external particle identifier (EPI). Forward emitted hadrons will indeed often interact in the H_2-Ne mixture before they reach the EPI.

Prompt muon detection could be made possible by the presence of the external muon identifier (EMI), presently designed to detect muons of energy > 4 GeV emitted in the forward hemisphere. Decays at rest of slow (E_μ < 1 GeV) negative muons trapped in the high (B = 3.5 T) magnetic field of BEBC will also be detected. Both muon signals will however be largely due to the roughly 1 % of $\pi^{\pm}$ (and $K^{\pm}$) decaying in flight, for which the decay point remains undetected. The identification of singly produced muons appears hence to be very inefficient in the type of experiment proposed in view of the very unfavourable signal to background ratio ($\sim 10^{-2}$). The study of muon pair production appears nevertheless to be possible (see section III).

In contrast to the expectations for direct single muon or even di-muon production, a relatively clean (see section III) experimental sample of events exhibiting prompt (e-e) and (e-μ) production could be collected by a detailed analysis of events with at least one identified $e^{\pm}$-track.

III. SIGNAL TO BACKGROUND RATIO

Prompt $e^{\pm}$-production could be simulated by the following processes :

i) $\pi^\circ \rightarrow \gamma\gamma$ decays leading to e^+e^- pair or Compton production at small

ii) $\pi^\circ \to e^+e^-\gamma$ Dalitz decays.

iii) K_{e3} decays in flight.

iv) High energy δ-rays created close to the primary vertex.

The first process will only occur with a rate $\sim 10^{-3}$ as compared to the π°-decay rate, and will hence be dominated by the experimentally similar Dalitz decay mode.

Background to single electron production

Single electron production could be simulated by Compton electrons (i) or δ-rays (iv) apparantly attached to the primary vertex, or by very asymmetric Dalitz or nearby e^+e^- -pairs with an $e^\pm$ track sufficiently short ($E_{e^\pm} \lesssim 5$ MeV) to remain undetected. Such events will however not balance electric charge and can be rejected. The charge conservation requirement will nevertheless be met by Dalitz - or nearby e^+e^- pairs for which one $e^\pm$-track should remain unidentified instead of undetected. Although the misidentification of $e^\pm$-tracks should be extremely unlikely within a potential path of 2.5 radiation lengths (see figure 1), the necessity of recording prompt $e^\pm$-candidates with an associated ambiguous $e^\pm$-track, has to be considered. Such ambiguous electrons are expected to be of moderate energy (a few GeV), as electrons of lower momentum will be trapped inside the magnetic field of the chamber and identified whereas those of higher momentum will deposite enough visible energy inside the H_2-Ne to be recognized with high efficiency. Ambiguous electrons will however be identified after the measurements (using mass dependent geometry) of all possible prompt $e^\pm$-candidates retained at the time of scanning. In fact, from our experience gained from the analysis of BEBC films, we have learned that low energy pions can occasionally simulate $e^\pm$-tracks in H_2 in the strong magnetic field of BEBC. Those events will also be rejected after measurement.

$K^\pm_{e3}$-decay in flight, with an unobserved $K \to e$ transition could constitute the most serious background problem affecting single "prompt" $e^\pm$-production. A detailed Monte-Carlo estimate of this effect has been made (see appendix). The results of these calculations indicate that this background source will be lower than the expected prompt lepton signal, as long as the beam particle is not a K-meson. In the

where e_K stands for the $e^{\pm}$-background signal arising from K_{e3}-decay, appears to be a reasonable estimate. Internal experimental checks based on the observed data such as τ^- and identified K_{e3}-decays (from visible K_{e3}-decay points and/or observed correlated γ's), will allow a precise evaluation of the actual importance of this contamination which will decrease inversely as the distance from the primary vertex to the downstream wall of the TST.

Background to lepton pair production

The frequency of (ee) and (eμ) pair production will be investigated on the following basis :

i) A prompt e^+e^- pair will have a negligible probability to be confused with a Dalitz decay above a given opening angle[13]. The remaining background arising from Dalitz pairs can be recognized by measuring the invariant e^+e^- mass.

ii) If all muons detected in the EMI associated to "prompt" electrons arise from undetected π (or K) decays in flight, the recorded e-μ correlation should only be of the order of 10^{-2} and leptons of equal or opposite charge should be found with the same probability. Hence, if (e-μ) events are found to occur at a substantially higher rate and the leptons are preferentially of opposite charge, this would be evidence for the existence of prompt (e-μ) production processes.

If prompt leptons are dominantly produced in pairs, muon pair production could be detected by the EMI with a signal to background ratio of the order of 1. The probability for two pions to decay before they reach the EMI will indeed be $\sim 10^{-4}$. Again this background will not favor the occurrence of opposite muon charges.

IV. BEAM SELECTION

On the basis of the existing results, any hadron beam of momentum well above 10 GeV/c could be suited to study prompt lepton production. The selection of incident K-mesons should however be avoided as K_{e3}-decay in flight is suspected to be the severest source of background in the case of bubble chamber experiments. In view of the general physics interest of the groups making this proposal, who have also sub-

mitted a proposal to study $\bar{p}p$-interactions in BEBC without a TST(*), we request that BEBC equipped with a neutrino TST should be exposed to antiprotons of 70 GeV/c. The choice of antiprotons as beam particles offers not only the advantage of allowing a study of initial states with conjugate quark content, but $\bar{p}p$-interactions also lead to final states with the broadest p_T spectrum at a given beam momentum. One further advantage of studying $\bar{p}p$-interactions is that the overall final data should be charge symmetric, allowing internal checks on the selection criteria to be made. For example, one requires equal numbers of prompt e^+ and e^- within statistics.

Our request depends upon the simulatneous availability of BEBC equipped with a H_2-TST and the RF seperated antiproton beam. If the RF beam is not available at the appropriate time, we would still suggest to do the experiment, but with incident π^--mesons instead of antiprotons.

V. EVENT RATES AND SCANNING AND MEASUREMENT EFFORT

Assuming $R = e^+/\pi^+ = e^-/\pi^- = 10^{-4}$ and taking $< n_{\pi^\pm} > \simeq 5$ for $\bar{p}p$-interactions at 70 GeV/c (σ_{tot} = 43 mb), 300.000 pictures with 3 $\bar{p}$/picture would lead to about 100 genuine prompt electrons within a 1.5 m long fiducial TST-volume. We wish to underline that the recent ISR results suggest that at low p_T-values the assumption of $R \sim 10^{-4}$ could be a lower limit.

The experiment should mainly require scanning with a comparatively low measurement effort. All collaborating laboratories hav experience with $\bar{p}p$ work. Some of us have also experience with big bubble chambers (BEBC, Argonne 12', Mirabelle, Gargamelle) as well as with TST-work in the Rutherford chamber.

(*) We anticipate that, quite apart from the problem of direct lepton production , part of the film will be scanned for γ-rays to provide

APPENDIX

MONTE CARLO STUDY OF THE K_{e3}-BACKGROUND

The production of $K^{\pm}$-mesons in $\bar{p}p$-interactions and their subsequent K_{e3}-decay has been completely simulated in BEBC equipped with a TST of dimensions specified in fig. 1[14].

The K-meson production was simulated at incident $\bar{p}$-momenta of 40, 70 and 100 GeV/c, assuming an x-distribution (defined in the C.M. system) identical to the one obtained for 69 GeV/c pp-interactions[15]. The transverse momentum distribution of the kaons was taken to be proportional to $e^{-3p_T^2}$.

It was assumed that the fiducial volume for $\bar{p}p$-interactions extends up to the center of BEBC, such as to ensure sufficient track length for the momentum measurement of promptly produced $e^{\pm}$-particles. Background K_{e3}-decay was supposed to be confined within a volume extending 20 cm (half a H_2-Ne radiation length) beyond the TST-walls. Pair production from $K_{\ell 3}$ - π^0 -decays was simulated within the H_2-Ne mixture, but e^+e^--pairs produced within 5° from the K_{e3}-decay electron, were assumed to be indistinguisable from the γ-shower produced by the latter. Such γ's, as well as those pointing to the primary vertex within errors, were taken to be uncorrelated to the K-decay vertex.

The results are summarized in table I. It is seen that at 70 GeV/c the fraction of K_{e3}-decays with electron decay angle $\theta_{Ke} < 10°$ and with no π^0-decay gamma emitted at angle $\theta_{K\gamma} > 20°$ amount to 6.7×10^{-4} of all K-decays occurring within the selected decay volume.

Assuming such decays to be unobservable and taking the ratio $(\frac{K}{\pi})^{\pm} = .05$ at production, the corresponding value of $\frac{e_K}{\pi} = 3.3 \times 10^{-5}$ where e_K stands for the electron signal arising from K_{e3}-decay. A compilation of published inclusive $K^{\pm}$ and K^0-production data in $\bar{p}p$ -interactions indicates that a value of $\frac{e_K}{\pi} \simeq 3 \times 10^{-5}$ also holds at incident $\bar{p}$-momenta of 40 and 100 GeV/c.

TABLE I

p_{beam} (GeV/c)	K-decay rate (%)	% of K_{e3}-events with correlated γ's			K_{e3}-decay rates x 10^4 with			
		0 γ's	1 γ	2 γ	$\theta_{Ke} < 10°$	$\theta_{Ke} < 10°$ and no γ with $\theta_{K\gamma} > 20°$	$\theta_{Ke} < 15°$	$\theta_{Ke} < 15°$ and no γ with $\theta_{K\gamma} > 30°$
40	8.1	28.0	38.6	33.4	23.7	7.7	28.	11.8
70	7.0	40	33.5	26.5	22.7	6.7	25.6	10.1
100	6.5	47	29.3	23.7	21.9	5.9	24.4	9.0

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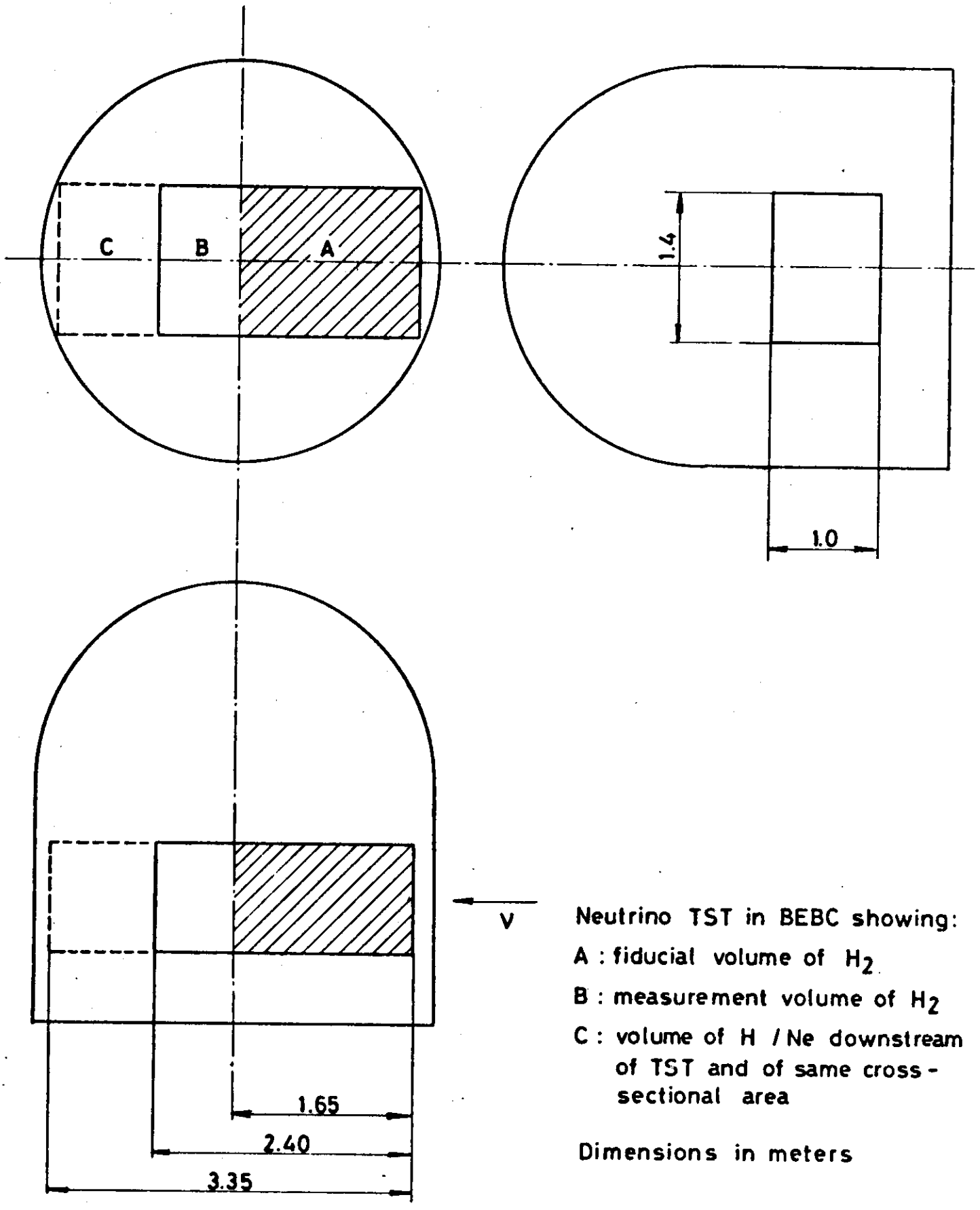
Fig. 1



Neutrino TST in BEBC showing:

A : fiducial volume of H_2

B : measurement volume of H_2

C : volume of H / Ne downstream of TST and of same cross-sectional area

Dimensions in meters