EmC 62/15
3.4. 1962

A PROPOSAL TO DETECT IN PHOTOGRAPHIC EMULSION DELAYED γ-RAYS FROM NUCLEAR COLLISIONS AT 27 BEV.

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INTRODUCTION

γ-rays are not produced directly in nuclear collisions; they result from the decay of other particles produced in strong interactions: namely pions (neutral), kaons, and hyperons. In all these cases, but for the Σ^0, the γ-rays result only from the π^0-chain of the decay. Because of the short lifetime of the π^0($\simeq 1.6 \times 10^{-16}$ sec) the γ-rays originating from directly produced π^0 and also from mesonic and baryonic resonance states that decay into π^0 are considered as prompt γ-rays. This category includes as well the γ-rays from the $\Sigma^0 \rightarrow \gamma + \Lambda^0$ decay with a lifetime of $< 10^{-11}$ sec. All other γ-ray sources have lifetimes of $\sim 10^{-10}$ sec or longer, and yield delayed γ-rays. The main purpose in this experiment is to detect γ-rays from hyperon decays connected with the processes:
$\Sigma^+ \rightarrow P + \pi^0 \rightarrow p + 2\gamma$ ($T_{\Sigma^+} = .8 \times 10^{-10}$ sec) and $\Lambda^0 \rightarrow n + \pi^0 \rightarrow n + 2\gamma$ ($T_{\Lambda^0} \approx 3 \times 10^{-10}$ sec). These γ-rays are of particular interest because they are connected with the baryonic component produced in nuclear collisions. There is some evidence from cosmic-ray work at higher energies (≥ 1000 BeV) that in the c.m.s. of the collision little energy and momentum is transformed to the directly produced π mesons, while most of the energy and momentum is retained by a single forward nucleon (the primary). This "forward" nucleon is very likely to be ejected as a hyperon(1) if strange particle production is copious. In this case the delayed γ-rays will be associated with the forward nucleonic component. K^+-particle production at 27 BeV(2) is estimated at $\sim 25\%$ of all neutral pions and $K^-/K^+ = 1/2$. This corresponds to $\sim 12\%$ of hyperons

per π^o under the assumption that strangeness —1 anti-hyperon pair production is negligible. Now the average number of neutral pions produced at 27 BeV is ~2.5 per interaction in emulsion, so that on the average 1/3 of a hyperon is produced per interaction. We expect that some of these hyperons, but not more than 1/2, will be "forward Baryons". Thus at best there are 0.16 forward hyperons per interaction. One of the objects of this experiment is to detect these hyperons and to estimate their rate of production and to find out what proportion of them (if any) belong to the forward baryonic component in the sense that they carry most of the primary energy and momentum.

Another delayed γ-ray component of the same lifetime arises from the decay $K_1^o \rightarrow \pi^o + \pi^o \rightarrow 4\gamma$ with a lifetime of $\tau = 10^{-10}$ sec. The intensity of this γ-ray component is of the same order of the delayed hyperonic component. The delayed kaonic γ-rays are of mesonic origin and we hope to distinguish between them and the hyperonic γ-rays on the general assumption that forward baryons are emitted with higher energies and with a more collimated angular distribution than mesons. According to this assumption the Lorentz factors of forward hyperons and kaons are estimated to be $\gamma_H \geq 15$ and $\gamma_{K^o} \simeq 4$ respectively. This factor of about 4 in the Lorentz factors has a double effect in favour of detecting forward hyperonic γ-rays: (1) it will shorten the decay m.f.p. of the K^o by a factor of four and (2) increase its angular spread in space by a factor of sixteen.

EXPERIMENTAL ARRANGEMENT

It is proposed to use the 27 BeV scattered proton beam of the PS to detect delayed γ-rays of hyperonic origin. A useful experimental arrangement is one that: (1) selects **delayed** γ-rays against the background of the prompt ones, and (2) prefers γ-rays resulting from the decay of the hyperonic component. Our experimental arrangement is shown in Fig. 1.

The scattered proton beam produces nuclear interactions in a production layer. In order to produce as many forward baryons as possible the production layer has to be made of light material. In the present experimental arrangement we use a rectangular production layer made out of carbon with dimensions a = 1 or 2 cm wide, h = 10 cm high and X = 60 cm long. The interaction m.f.p. in carbon with density $\rho = 1.5\ gm/cm^3$ is $\lambda_{int} = 39$ cm. In order to estimate the expected numbers of the various components which emerge from the production layer the following assumptions were made: (1) All particles travel parallel to the primary direction. (One dimensional cascade). Corrections for angular spread are made in a later stage. (2) "Forward" hyperons are produced with a Lorentz factor $\gamma_y = 15$; the various different hyperonic states Σ^+; Σ^0; Σ^- and Λ^0 are equally produced, and they have the same interaction m.f.p. as nucleons. Thus the attenuation m.f.p's including decay in flight of Σ^+ and Λ^0 (with $\gamma = 15$) in carbon are: $\lambda_{\Sigma^+} = 17.6$ cm, $\lambda_{\Lambda^0} = 29.8$ cm respectively. (3) The average Lorentz factor of the K-mesons is $\gamma_K = 4$, so that the attenuation m.f.p. including decay in flight of the K^0 in carbon is $\lambda_{K^0} = 9.2$ cm. (4) The attenuation m.f.p. of 27 BeV protons in carbon is 50 cm.

The expected intensities of particles that emerge from the production layer, as a result of the bombardment of 10^7 protons/cm^2 are given in Table I. For comparison, intensities resulting from production layers of lead and carbon of different length, x, are also included.

TABLE I

Particles Produced in Different Production Layers per 10^7 protons/cm^2

PRODUCTION LAYERS

Component	60 cm C	60 cm Pb	27.5C + + 5 Pb	82.5C + + 5 Pb
Prompt γ-rays	1.5×10^7	6×10^4	8.6×10^5	2.8×10^5
27 BeV Protons	3×10^6	3×10^5	4.3×10^6	1.4×10^6
Sec.Charged Part.	1.9×10^7	4.25×10^6	2.0×10^7	1.4×10^7
K_1^o	5.4×10^5	1.4×10^5	12.5×10^5	4.2×10^5
Σ^+	1.4×10^5	2.7×10^4	2.3×10^5	1.0×10^5
Λ^o	4.75×10^5	1.0×10^5	6.0×10^5	3.5×10^5

Next we take advantage of the highly collimated nature of the forward hyperonic beam and its long lifetime to detect delayed γ-rays of hyperonic origin. To this end a narrow (a = 1 or 2 cm wide) and long (ℓ = 55 or 96 cm long) tunnel is put immediately after the production layer. The walls of the tunnel are made of lead. Nuclear emulsion detectors (to detect electron pairs) are placed 192 cm.from the face of the production layer in a plane perpendicular to the beam direction, and at b = 1 cm away from the centre of the beam to avoid the primary protons that penetrate through the production layer, and go along the tunnel. In this arrangement the emulsion detectors for b > 3 cm are shielded by the tunnel shielding against any component that emerges directly from the face of the production layer. Thus, practically no secondary charged particles or prompt γ-rays produced in the production layer will reach the emulsion detectors directly. The only components that can reach the emulsion detectors are : (1) Decay products of strange particlesi.e., (a) delayed γ-rays from the decay of K^o, Λ^o and Σ^+, and (b) nucleons and pions from the same and similar decays.

(2) General background of particles including particles from secondary and higher order interactions in the various absorbers shielding the arrangement.

The expected intensities of delayed γ-rays from the decay of K^o, Λ^o, and Σ^+ for a primary beam of 10^7 protons/cm^2 were calculated on the assumption that these three components travel parallel to the primary direction. In this case the angular distribution of the γ-rays is

$$\frac{dN}{d(\cos\theta)} = \frac{1}{\gamma^2(1 - \beta\cos\theta)^2}$$

where γ is the Lorentz factor of the parent particle. Some results for different tunnel lengths and dimensions at positions b = 3 cm and b = 6 cm to the centre of the beam and at y = 192 cm away from the perpendicular face of the production layer are summarized in Table II.

TABLE II

Number of γ/cm^2 for 60 cm C Production Layer for 10^7 Protons/cm^2 at y = 192 cm from Carbon Face

Component	ℓ = 55 a = 1 b = 3	55 1 6	96 2 3	96 2 6
Prompt γ-rays	0	0	0	0
K^o_1	27	6	32	1.2
Σ^+	210	70	302	51
Λ^o	855	285	1500	356
$\frac{\Sigma + \Lambda}{K}$	39	59	56	340

DISCUSSION

It appears from Table II that our experimental arrangement is capable of sorting out the delayed γ-rays of hyperonic origin from the prompt γ-rays and the delayed kaonic γ-rays. The preferred arrangement is with a = 2 cm and a 96 cm long tunnel. The expected intensity of γ-rays of hyperonic origin at b = 3 cm for a primary flux of 10^7 protons/cm^2 is 1800 γ/cm^2. The number of γ-rays that will materialize as electron pairs in scanning 1 cm of emulsion normal to the γ-ray beam direction is $\frac{\Delta X \times 1800 \times .06}{3}$, where ΔX is the distance scanned in the beam direction. To reduce cascade effects $\Delta X << 3$ (the radiation length in emulsion) and a reasonable value is $\Delta X = \frac{1}{2}$ cm., so that the number of electron pairs is 18 per linear cm. per $\frac{1}{2}$ cm in the beam direction. Now this estimate is only from interactions occurring in 1 x 2 cm^2 of the cross-section of the production layer. However the production layer cross-section is 10 times larger (2 x 10 cm^2) and so is the number of expected γ-rays. However because of the geometry of our experimental arrangement, an emulsion pellicle detector will not record with the same efficiency all pairs originating from unstable secondaries at different parts of the production layer cross-section. We estimate a geometrical overall detection efficiency of 0.5 so that the expected number of pairs from the whole cross-section of the production layer at b = 3 is 90 pairs per linear cm per 1/2 cm in the beam direction and at a position b = 6 cm the corresponding number is 20. A fair intensity for an emulsion experiment is 10 pairs in these units so that our experiment is certainly feasible. Moreover, even if the number of forward hyperons is smaller by an order of magnitude than our expected number we shall be able to detect them. Thus, with our experimental arrangement we should be able to demonstrate the existence of the forward hyperonic component if it is of the order of 0.01 per nuclear interaction.

Moreover if this component, does exist we may, by using different tunnel arrangements, and by measuring the intensities of γ-rays at various positions, b, deduce the energy spectrum of the forward hyperonic component.

An additional check on our assumptions can be realized by measuring the energy of the electron pairs. This is in fact necessary to obtain the forward hyperonic energy spectrum. These measurements can be made by well known techniques in nuclear emulsion.

The γ-ray background will come mainly from K^o decays and it is quite small: 2% at position b = 3 cm and 0.3% at b = 6 cm. In reality this background is even smaller; because in estimating the γ-rays of kaonic origin it was assumed that all K-particles are emitted in the forward direction parallel to the primary direction like the forward hyperons. However, this is not the case and in reality the kaons are emitted with a much wider angular distribution than the forward hyperons so that the relative number of kaonic delayed γ-rays will be even smaller.

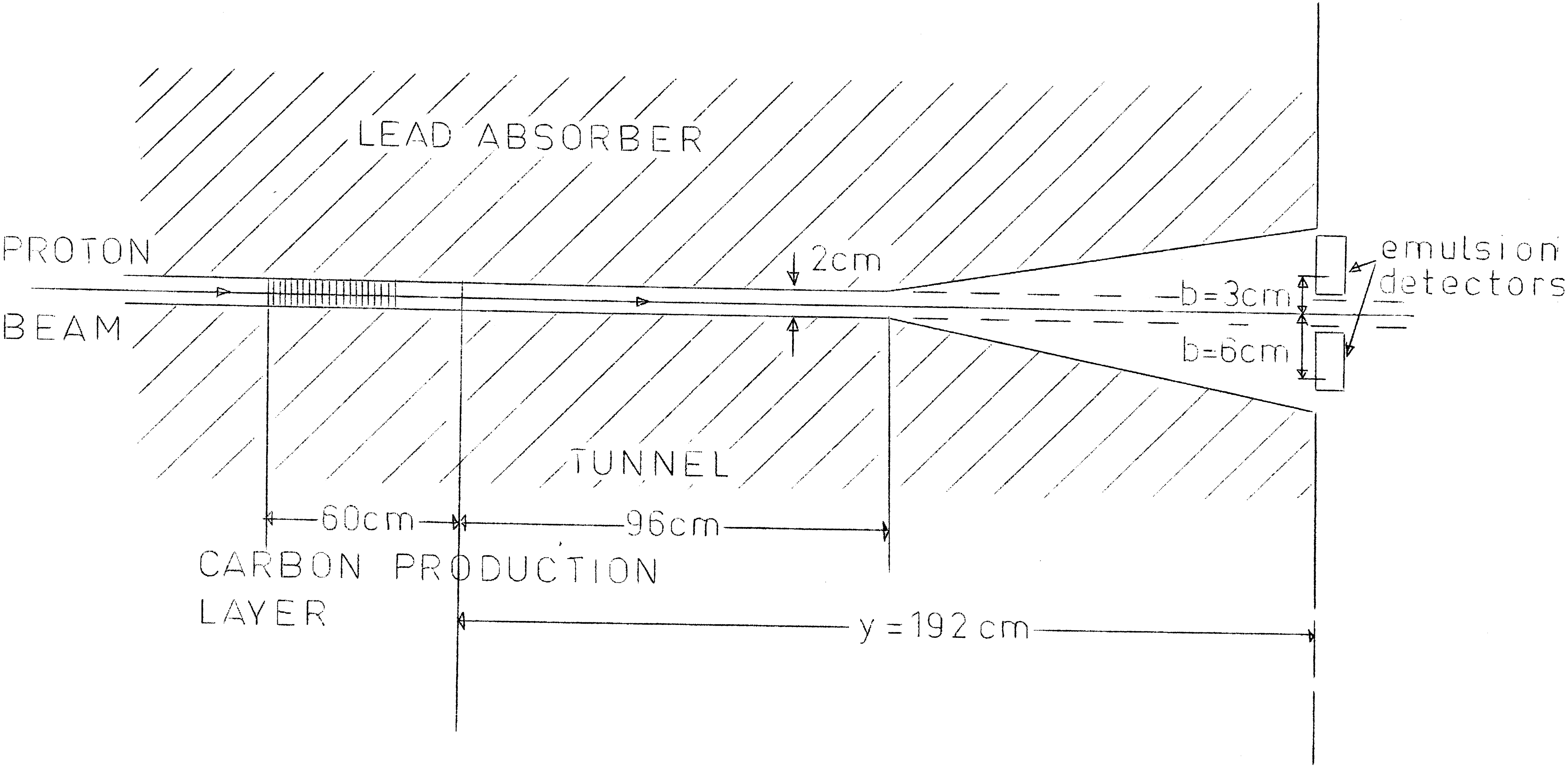
No estimate was made on the general background of charged particles in the emulsion detector. However from observations of nuclear emulsion plates directly exposed to the primary beam one finds that electron pairs can be detected fairly well in a flux as high as 10^5 primary protons/cm^2. The detection of electron pairs in a dense beam is limited because of the highly collimated nature (tracks look like pairs) of the primary beam; an uncollimated intensity can be even higher than 10^5/cm^2. Now in our experimental arrangement, the collimated proton flux in the centre of the tunnel (at b = 0) is 3×10^6/cm^2. The secondary flux at b >3 is much lower and uncollimated, because it can reach this position only by cascading through the lead shield, and thus it will not (to our best judgement) deteriorate strongly the conditions for electron pair detection in nuclear emulsion.

<u>References:</u>

1. B. Peters, Report at 1961 International Conference on Cosmic Rays, Kyoto, Japan.

2. V.T. Cocconi: Phys. Rev. Letters, 5, 19 (1960)

FIG. 1



note: do not scale

Additional comments on background

The number of background pairs originating from nuclear interactions in the emulsion detector in the first ΔX cm of the emulsion block is $\frac{\pi_o N_o (\Delta X)^2}{\lambda_n \lambda_p}$ where: N_o is the flux of strongly interacting particle at the emulsion edge, π_o is the average number of neutral pions produced per nuclear interaction by these particles, λ_p and λ_n are the pair production and nuclear interaction m.f.p's in emulsion respectively. The number of pairs originating from delayed γ-rays are given by $\frac{N_\gamma \Delta X}{\lambda p}$ where N_γ is the flux of delayed γ-rays at the emulsion. The ratio background to signal is $\frac{\pi_o N_o \Delta X}{N_\gamma \lambda_n}$. Now there are two sources for nucleons and pions at the emulsions. (a) Secondaries entering the tunnel from the face of the carbon layer and (b) secondaries from hyperon decay in the tunnel. The number of secondary charged particles at the face of the production layer is 1.9×10^7 particles (for 10^7 primary protons, see Table I). Most of these secondaries are pions, however, we may add some 20% to account for possible neutrons, this will make it 2.3×10^7 particles. Now using the angular distribution of Jain et al., Nuovo Cimento 21, 859 for 28 GeV/c protons we find that 10% of the secondaries are emitted within 5^o to the primary direction. Hence only $N_o = 2.3 \times 10^3$ cm^{-2} pions and nucleons will reach the emulsion surface. A 28 GeV proton produces on the average 2.5 neutral pions per interaction, secondaries of this proton will produce less neutral pions, say 1.5 per interaction. Using $\lambda_n = 37$ cm for the interaction m.f.p. in emulsion one finds a background of 2.6% at position b = 3 cm, and a background of 12% at position b = 6 cm. This is the ratio of pairs produced in the emulsion by secondaries from the carbon layer to pairs produced by the delayed γ-rays. One has to keep in mind, however, that this ratio is an upper limit to the background, because these secondaries have to cascade through the lead shield in order to reach the emulsion.

Next we consider the background from the decay of hyperon. Now for every γ-ray from Σ (or Λ) decay there are 3.5 (or 2.5) nucleons and pions, so that the ratio N_o/N_γ = (Nucleons + pions/γ ray) in the emulsion is 2.7. (This ratio is practically independent of the position at the emulsion)

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Assuming that on the average these pions and nucleons will produce only two neutral pions per interaction, the relative expected background is 7%. There is a basic difference between this background (b) and the one connected with the charged secondaries (a). The first one (b) is directly proportional to the intensity of the delay γ-rays, and so it will always contribute 7% to the background, whereas the other type (a) is less favourable; it is independent on the hyperon flux, and therefore puts a limit to the detection of delayed γ-rays.