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XTR-DETECTOR FOR HADRON IDENTIFICATION IN THE (30-300) GeV/c MOMENTUM RANGE

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Abstract

A new type of XTR-detector is proposed which allows pions to be separated from kaons and protons at relatively low $\gamma = E/mc^2$ values, viz in the (30-300) GeV/c momentum range. Particles are identified in this momentum region by making maximum use of the low-energy part ($\hbar\omega \lesssim$ 5 keV) of the XTR spectrum.

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It is not feasible to use Cherenkov counters to identify π/K or π/p in the momentum region $P \gtrsim 50$ GeV/c /1/. Moreover, the known types of XTR detector can be used only at $P \gtrsim 300$ GeV/c ($\gamma = \frac{E}{mc^2} \gtrsim 2.10^3$). Therefore, in the momentum range $50 \lesssim P \lesssim$ 300 GeV/c, corresponding to the energy level of proton accelerators now in operation or under construction, the problem of hadron identification is still not solved.

The best instrument at present is the XTR detector based on the energy release method. This type of detector consists of a large number (up to 30) of stages, each of which includes an XTR radiator (50-200 plates of light material $a \simeq 5 - 20\ \mu$ thick and $b \simeq 0.1 - 5\ \mu\mu$ apart) and a multiwire proportional chamber. When a particle passes through this system, an electric pulse is formed in each of the proportional chambers which is proportional to the total amount of energy released as a result of ionization losses Wu and the absorption of the particle's transition radiation quanta Wn in the chamber gas. If $W_\Sigma = W_u + W_n > Wu$, the charged particle can be identified. In order to reduce fluctuations in the amount of energy released, i.e. to increase identification efficiency, the readings from all the proportional chambers are usually averaged arithmetically or geometrically.

It follows from reports /2/ that, if $W_\Sigma / W_u \gtrsim 1.3 - 1.4$, then it is possible to separate two particles when using a 30-stage XTR detector.

It is virtually impossible to obtain $W_\Sigma \gtrsim W_u$ in the region $\gamma \lesssim 2.10^3$ for the following two reasons.

1. Some of the transition radiation quanta will obviously be absorbed in the radiator itself. The frequency range $\hbar\omega \lesssim$ 5 - 10 keV is thus pointlessly lost. However, the transition radiation intensity of particles with $\gamma \lesssim 2.10^3$ is mainly concentrated in precisely that frequency range. On the other hand, the quantum recording efficiency in proportional chambers is close to 1 in the soft part of the spectrum and drops off sharply as the spectrum

hardens. As a result of these processes, of the total number m of boundaries in the radiator, it is as if only m_{ef} (ω) boundaries are used for a quantum of frequency (ω), and, at all $\hbar\omega$ energies except $\hbar\omega \sim 5 - 15$ keV, m_{ef} (ω) $\ll$ m. By way of an illustration fig. 1 shows m_{ef} as a function of $\hbar\omega$ in the case where the radiator consists of $\frac{m}{2}$ = 100 layers of polyethylene a = 6 μ thick, and the proportional chamber provides a 1 cm path length of xenon at a pressure of 1 atm. (plot 1). The effective number of boundaries m_{ef} (ω) is calculated by means of the formula

$$m_{ef}(\omega) = \left(1 + e^{-\mu_n(\omega)\rho_n a}\right)\left(1 - e^{-\mu_{xe}(\omega)\rho_{xe} \cdot b}\right)\left[\frac{1 - e^{-m\mu_n(\omega)\rho_n a}}{1 - e^{-\mu_n(\omega)\rho_n a}}\right],$$

where a, ρ_n, μ_n and $b, \rho_{xe}, \mu_n(\omega)$ are the depth and density of the polyethylene and xenon and μ_n (ω) and μ_{xe} (ω) are the quantum absorption coefficients in polyethylene and xenon respectively. The same figure shows the spectral distribution of the transition radiation caused at one boundary by a 100 GeV π meson (plot 2). All the radiation is clearly concentrated in the region $\hbar\omega \lesssim 5$ keV where m_{ef} $\ll$ m.

In order to achieve $m_{ef} \sim$ m in a broader quantum energy region, it is obviously essential to reduce radiation absorption in the radiator. This may be done by reducing the thickness of each of the plates. However, reports /3, 4/ show that the radiation itself is considerably suppressed as a result. Another possible method is to select a radiator material with the lowest possible values of ρ and Z. There are, therefore, proposals to use Li /5/ or even a foam of liquid deuterium /6/. However, apart from the purely technical complexity of these devices, radiators with low ρ do not provide much of an extension to the low γ region because the radiation intensity depends on the plasma frequency $\omega_0 \simeq 30\sqrt{\rho\frac{Z}{A}}$; moreover, even in these radiators the absorption is considerable at $\hbar\omega \lesssim 2 - 3$ keV.

2. As was stated above, owing to the absorption of transition radiation in the radiator, its spectrum hardens, as a result of which the probability of quantum absorption in the proportional chamber's

gas is reduced. In order to improve the radiation quantum recording efficiency, i.e. W_n, the path length of the gas in the chamber must be increased. However, this leads to a proportional increase in the amount of energy released owing to particle ionization losses W_H, which again makes it difficult to fulfil the condition $W_\Sigma \gtrsim W_H$.

We shall now consider a new type of XTR detector which will allow pions to be separated from kaons or protons in the (30 - 300) GeV/c momentum region ($200 \lesssim \gamma \lesssim 2000$). The design of the detector is basically the following. A radiator (laminar medium) is placed in xenon. If two flat metal electrodes are placed along the laminar medium (fig. 2a) or if the plates of the laminar medium are used as negative electrodes and metal wires are drawn between them to form positive electrodes (fig. 2b), then such a device can be used either as a system of proportional scintillation counters /7, 8/ or as a system of multiwire proportional chambers in which transition radiation is produced and absorbed in xenon, and the amount of energy released is recorded.

If the density ρ_n in the detector, the plate thickness a, their spacing b and the xenon pressure, i.e. its density ρ_{xe}, are such that the condition $\mu_{xe}\,\rho_{xe}\,b > \mu_n\,\rho_n\,a$, then the radiation produced at each boundary of the laminar medium is more likely to be absorbed in the xenon than in the plates. This allows the low-energy part of the transition radiation spectrum to be recorded very efficiently and the $m_{ef}(\omega)$ value to be increased considerably. Figure 1 shows m_{ef} as a function of ω in the case of laminar media consisting of m = 200, 400 and 800 boundaries (100, 200 and 400 sheets od polyethylene with a thickness a = 6 μ) and 6.10 g/cm^2 of xenon between the layers. The effective number of boundaries $m_{ef}(\omega)$ is calculated using the formula

$$m_{ef}(\omega) = \frac{(1+e^{-\mu_n \rho_n a})(1-e^{-\mu_{xe}(\omega)\rho_{xe} b})}{} \times$$

$$\times \left[m - \frac{(1-e^{-m(\mu_n \rho_n a + \mu_{xe}\rho_{xe} b)})\, e^{-(\mu_n \rho_n a + \mu_{xe}\rho_{xe} b)}}{1-e^{-(\mu_n \rho_n a + \mu_{xe}\rho_{xe} b)}} \right]$$

Given the same values for the total path length of the xenon (1 cm) and the same number of boundaries (200) in the region $\hbar\omega \lesssim 5$ keV, there is a considerable difference in efficiency of the known (plot 1) and proposed (plot 2) methods. We would point out that even in the ultra-violet part of the spectrum ($\hbar\omega < 1$ keV) $m_{ef} \simeq \frac{m}{2}$ and yet none of the known types of XTR detector allows this part of the spectrum to be used.

Clearly, if two particles are to be efficiently identified, not only must the difference between their probable total energy release values be maintained but also the fluctuation of these values must be reduced wherever possible. When transition radiation is recorded, the number of quanta fluctuates, as does the energy release values W_n. The larger the number of quanta recorded, the smaller the fluctuations. Fig. 3 shows the number of quanta recorded at energies $\hbar\omega \geqslant 0.1$ keV as a function of the momentum of the π and k mesons (plots 1 and 2). Even at P = 30 GeV/c almost every π meson will be accompanied by the detection of transition radiation. When the existing method is used (plot 3), the recording efficiency is not 100% even at P $\simeq$ 500 GeV/c.(The calculations for fig. 3 were made for the above laminar media).

It should be pointed out that, unlike all types of XTR detector, the use of light radiators (lithium- or deuterium-type) leads to a reduction both in the number of quanta and in W_n. This is due to the fact that in our case there is little radiation absorption in the plates themselves, and the reduction in ρ leads only to a reduction in the plasma frequency ω_0 , i.e. W_n.

Fig. 4 shows the total pion and kaon energy release as a function of particle momentum. Throughout the momentum range this dependence is extremely logarithmic and $W_n > W_k$.

Fig. 5 shows the W_n / W_k energy dependences for different methods of particle identification. When the relativistic rise of ionization losses (plot 1) is used to identify particles at P $\sim$

30 GeV/c $W_\pi / W_k \simeq 1.2$ and as P increases this ratio drops sharply, i.e. we shall use this method in the $P \lesssim 50$ GeV/c region where repeated measurements are necessary to reduce the W_π and W_k fluctuations. When the existing method is used at $P \simeq 100$ GeV/c $W_\pi / W_k \simeq 1.2$ i.e. in order to identify pions and kaons in this momentum region XTR detectors consisting of an extremely large number of sections ($\gtrsim 30$) /2/ must be used. In the proposed version $W_\pi / W_k \simeq 1.40$ at P = 30 GeV/c and $W_\pi / W_k \sim 1.5 - 2.0$ at $P \simeq 100 - 200$ GeV/c. It is interesting to note that if several stages each consisting of 100 plates are used, the W_π / W_k ratio improves with each stage added. Consequently, when five stages are used at P = 100 GeV/c the W_π / W_k ratio is already ~ 1.73 in the second stage.

Not only transition radiation but also ionization loss fluctuations will be reduced in the proposed detector. Let us present the detector as a series of individual gas gaps separated by plates. In the extreme case, if the plates are thick enough, the total signal will appear as a result of arithmetically averaging $m/2$ independent measurements. Consequently the fluctuations are reduced $\sim \sqrt{m/2}$ times at $m \gg 1$. In the real case the plates have a thickness of ~ 5-10 mg/cm^2 i.e. for δ electrons of $\lesssim$ 30-400 keV they are thick enough /9/ to reduce fluctuations. Moreover, since there is very little gas in each gap and only a slight probability ($\sim$ 0.5) that a primary particle will produce a pair of ions, the probable amount of ionization losses must also decrease, thus improving the W_π / W_k ratio.

A detailed analysis of the proposed detector is now being carried out by the Monte-Carlo method. There are already grounds for hoping that this new type of XTR detector will allow π/k and π/p separation in the range $30 \lesssim P \lesssim 300$ GeV/c.

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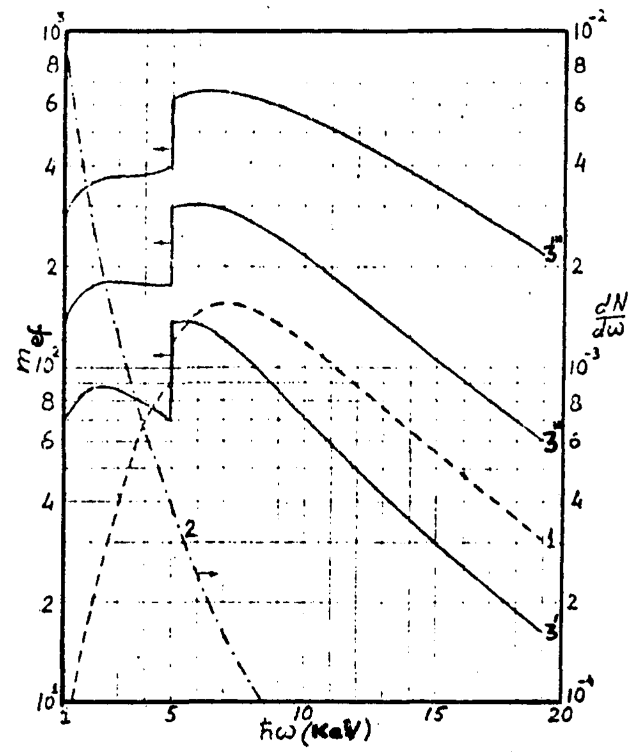


<u>Fig. 1</u> The number of effective boundaries as a function of the quantum energy $\hbar\omega$ using the old method (plot 1) and the proposed method (plots 3', 3'' and 3''' with 100, 200 and 400 radiator plates respectively) and the radiation spectrum at one boundary (plot 2).

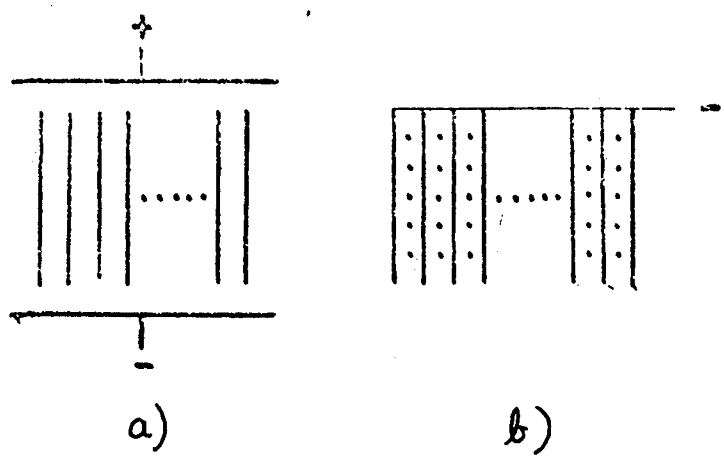


Fig. 2 Basic design of XTR detectors
a) gas scintillation counter type:
b) proportional chamber type.

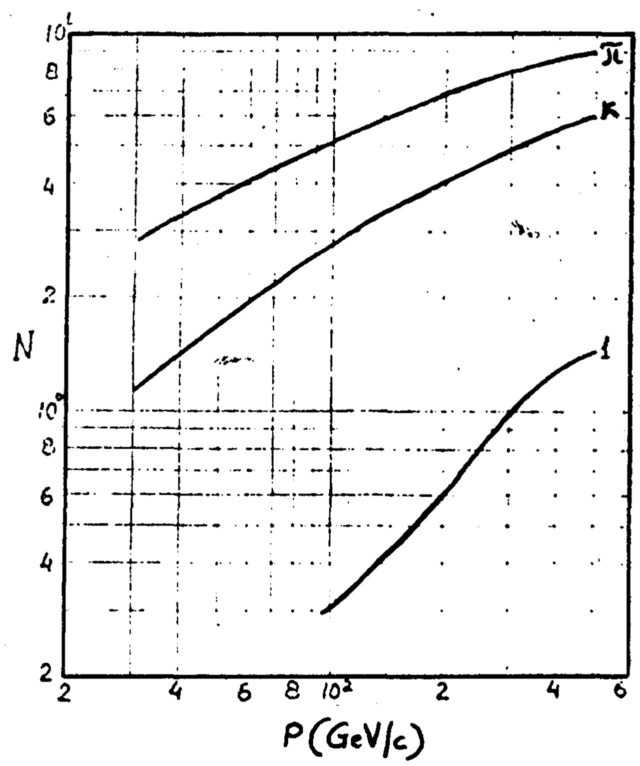


Fig. 3 The number of quanta recorded $\underline{N}$ as a function of particle momentum for pions and kaons in the proposed detector (π ,k plots) and using the old method (plot 1 for pions).

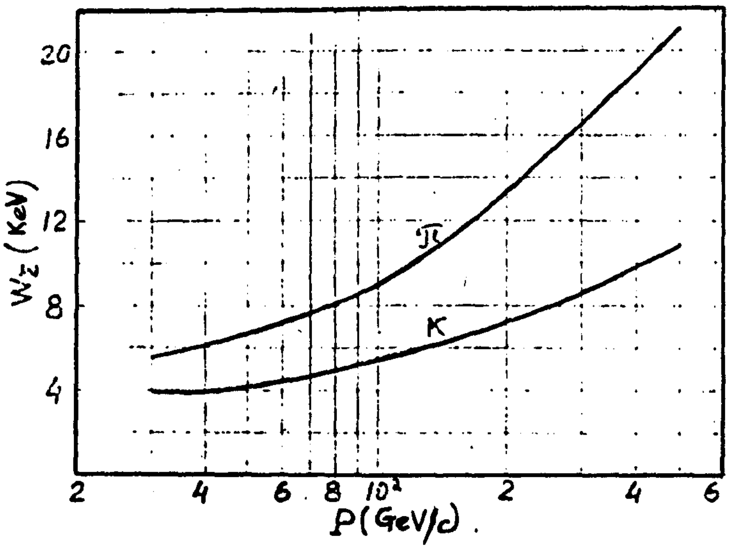
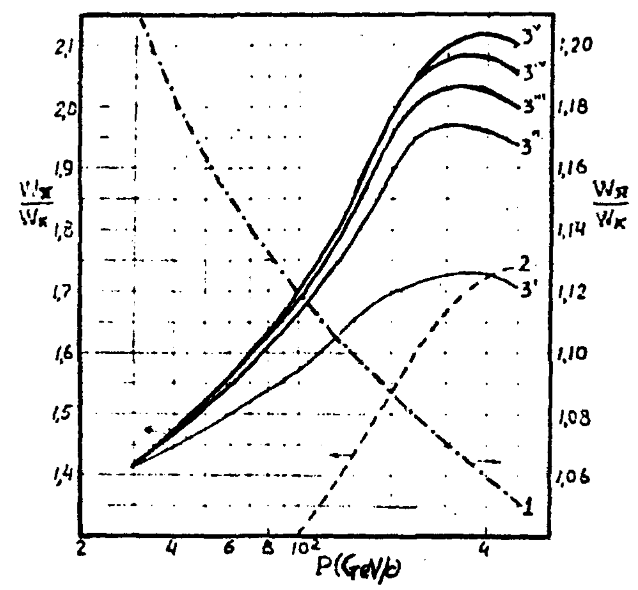


Fig. 4 The total amount of energy released W_Σ by pions and kaons as a function of particle momentum.



<u>Fig. 5</u> The ratio W_π / W_K as a function of particle momentum measured according to the relativistic rise of ionization losses (plot 1), the old method (plot 2) and the proposed method (plots 3), where I-V correspond to the number of 100-plate stages placed in series.