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A THRESHOLD IMAGING CHERENKOV DETECTOR WITH CSI PHOTOCATHODES

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Abstract

A Threshold Imaging Cherenkov (TIC) detector, in conjunction with a tracking device and a time-of-flight system, has been developed to allow pion, kaon and proton identification in the 3–8 GeV/c range of momenta. The system allows spatial identification of the photons of particles above the Cherenkov threshold and their correlation to a particular track. The TIC detector uses a MWPC detector with a CsI coated photocathode for photon conversion. The results obtained in ultrarelativistic lead–lead collisions at the CERN SPS accelerator are presented.

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1 Introduction

In order to take advantage of the properties of threshold Cherenkov detectors when there are several particles within the acceptance, we have built a system for imaging the Cherenkov photons produced by particles above threshold, which permits detailed information about the position of the emitted photons to be gathered. With this device it is possible to achieve a very high granularity for a limited cost using pad-segmented MWPCs for UV photon detection, thus allowing complex pattern recognition which is otherwise difficult to achieve with conventional threshold detectors. By combining the Threshold Imaging Cherenkov (TIC) detector with a time-of-flight (TOF) wall, complete identification of pions, kaons and protons in the 3.0–8 GeV/c range is possible. The detector system has been conceived for the heavy-ion experiment NA44, currently running at the CERN SPS.

NA44 [1], the 'Focusing Spectrometer', is a second-generation relativistic heavy-ion experiment at the CERN SPS accelerator. The spectrometer is equipped with trigger devices which permit single particles or pairs of rare particles to be triggered for. NA44 uses superconducting quadrupoles and warm-dipole magnets to produce a magnified image of the target on the tracking detectors—two hodoscopes, pad and strip chambers. The tracking information defines the momentum, whilst the timing information from the scintillation hodoscopes (time resolution = 100 ps) defines the velocity and therefore the mass of the particles.

An earlier version [2, 3] was developed using TMAE gas as the photoconverting agent. The use of TMAE for photoconversion at rather low temperatures ($\sim 30°$) implies the use of large conversion lengths (30 mm). The large conversion volume filled with methane placed in a sizeable neutron background, resulted in unacceptable currents in the chamber during the beam spills at the beam rates used in NA44.

2 TIC operating principle and main components

The TIC's operation is based on the 2-D localization of the Cherenkov photons created in a gas volume, where pions are above the Cherenkov threshold and kaons and protons are below it. The spatial information, correlated with the tracking information, allows unequivocal identification of pions. The identification of kaons and protons is achieved using the TOF information.

The TIC's main components are: the radiator, where the UV photons are created, with two 45° mirrors; the photon detector; and the gas container. In Fig. 1 we show a schematic view of the TIC with two particle tracks, one being above the Cherenkov threshold emitting photons along its path.

The photons created all along the pion path in the radiator are emitted under the characteristic Cherenkov angle. The photons are reflected by two mirrors placed at 45° to the radiator axis, and enter the photon detector through a UV-transparent quartz window. A particle of mass m, traversing a radiator of refractive index n, above the Cherenkov momentum threshold p^t, given by

$$p^t = m \left(\frac{1}{\mathrm{n}\sqrt{1 - 1/\mathrm{n}^2}} \right) ,$$

will result in a number of photons being detected in the TIC within a fiducial disc, created by the projection of the cone of emission of photons in the radiator onto the detector plane. The purpose of the mirrors is as follows. If the photon detector were placed within the acceptance of the spectrometer, both the tracks and the photons would leave a signal in the chamber. The mirrors reflect the Cherenkov photons so that when the momentum is below the threshold no signal is read in the chambers. The two-mirror solution was adopted to minimize the difference in the radiator length within the acceptance, and also to simplify the construction of the photon detectors.

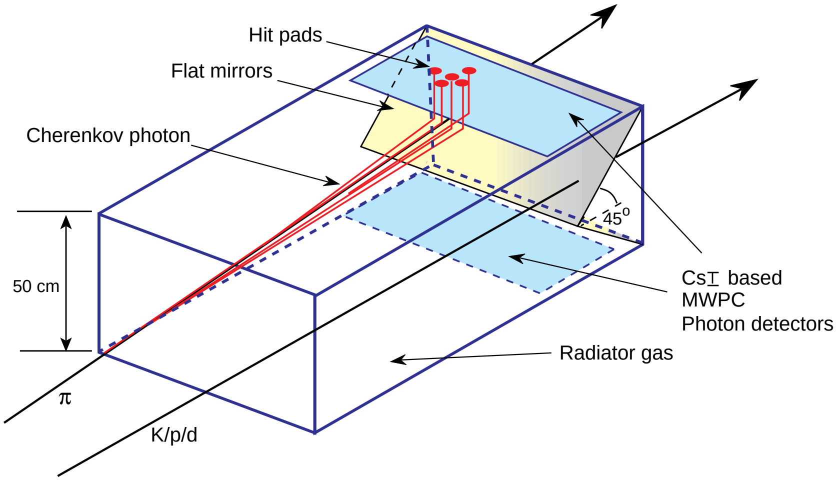

Figure 1: Schematic view of the Threshold Imaging Cherenkov detector.

2.1 Radiator and mirrors

The radiator consists of a $130 \times 90 \times 40$ cm^3 tank filled with isobutane at atmospheric pressure. The tank is continuously flushed with gas through a large Oxysorb purifier cartridge. The transparency of the gas is controlled by a UV monochromator. Isobutane was chosen as a convenient radiator because of its refractive index ($n = 1.0017$ for photons of 7 eV), resulting in a threshold momentum of 2.2 GeV/c and 7.9 GeV/c for pions and kaons, respectively, which allows spanning of the whole range of interest. Another gas with a similar refractive index is C_4F_{10}, but its high price and the need for a closed circulation system made isobutane a simpler, more cost-effective solution.

The radiator and detector assembly are placed in a gas-tight container flushed with nitrogen, as isobutane and air would produce an explosive mixture if there were a leak in the radiator.

The radiator length was fixed at 1 m, as an appropriate compromise between the number of photons finally detected and the spread of the photon fiducial disc in the detector. (If the radiator length is too great, then attributing a specific photon disc to a specific track may be difficult in the case of tracks which are close together.) In our case the radius of the photon fiducial disc in the chamber is 8 cm.

The mirrors were made from 2 mm of glass with a UV-reflective aluminium coating, itself covered with a thin layer of MgF_2. To prevent the mirrors sagging, a supporting frame was constructed, and the mirrors' edges were reinforced with a thin aluminium L-profile mounted to bind them at the central edge.

2.2 Photon detector and front-end electronics

The photon detector is a classical multiwire proportional chamber (MWPC) with a pad cathode covered with an evaporated CsI layer which serves as a photocathode for the conversion of the Cherenkov photons.

The technical specifications of the TIC photon detectors are given in Table 1.

Table 1: Technical specifications for the TIC photon detection chambers

Active area	78×19 cm^2
Number of pads	96×24
Pad size	8×8 mm^2
Pad-plane composition	35 μm Cu + 15 μm Ni + 0.05 μm Au on 1 mm G10
Chamber gas	CH_4
Quartz-window thickness	5 mm
Half-gap	2 mm
Anode-wire pitch	4 mm
Anode-wire diameter	20 μm
Cathode-wire pitch	2 mm
Cathode-wire diameter	100 μm

The photocathodes have been prepared using the procedure developed by the RD26 collaboration at CERN [5]: a circuit board consisting of a copper layer on a G10 foil was used to produce the pad pattern employing standard etching techniques; the pad-printed board was then polished using alumina paste and chemical polishing, and a thick homogeneous layer of nickel (15 μm) was chemically deposited, followed by a gold layer on top of this. Onto these substrates, CsI was evaporated under high vacuum to form a 500 nm layer. After evaporation, the photocathode was heat-treated for five hours at a temperature of 50°C. Such photocathodes have been found to have a surface structure and quantum efficiency equivalent to those observed in small polished metallic surfaces.

2.3 Signal read-out

The signal, induced by the charge amplification, is processed analogically by a 16-channel GASSIPLEX [6] front-end chip, The chip consists of a charge amplifier, shaping amplifier, track and hold, and multiplexing stage. The chip is equipped with a dedicated filter to deconvolute the detector signal. The important feature of the front-end electronics is its long integration time—500 ns. This allows a large induced signal, keeping the amplification in the MWPC to the relatively low level of 10^5 even for single electrons (with a detection efficiency of $\sim 90\%$), as is the case in the detection of Cherenkov radiation [4]. The integration time is still sufficiently small to allow applicability in all cases where the detection rate is below 10^5 Hz. The read-out of the GASSIPLEX chips is performed by C-RAMS (CAEN-Read-out for Analog Multiplexed Signals) where the signal is sampled by the ADC (10 bit) and compared with a pedestal/threshold memory. Only those values exceeding the threshold are recorded.

3 Results

The TIC using CsI photocathodes has been in use in the NA44 experiment during the 1995 and 1996 physics runs with lead–lead collisions.

The TIC chambers are outside the acceptance of the spectrometer, but are irradiated by neutrons from the lead beam dump. Indeed, we have observed a considerable increase in the detector current during the beam spill (5×10^6 particles on target): 300–400 nA compared with just a few nanoamperes in the absence of the beam. Other sources of background have been identified as well, namely cases where a secondary particle produced in the spectrometer, but not identified as a valid track by the tracking algorithm, creates a photon disc in the TIC. In Fig. 2 we show several events observed in the lead–lead runs. The circles define the fiducial area around the track impact point mirror reflected on the TIC plane. Both photon detection chambers are combined in a single plane in the figures. The circle represents the fiducial disc corresponding to photons if the track is above the emission threshold; adjacent to the ring is the mass-squared value corresponding to the track measured in the TOF wall. We see that the events are very clean—no treatment has been applied to the data. The only choice was to select events with more than one particle in the acceptance.

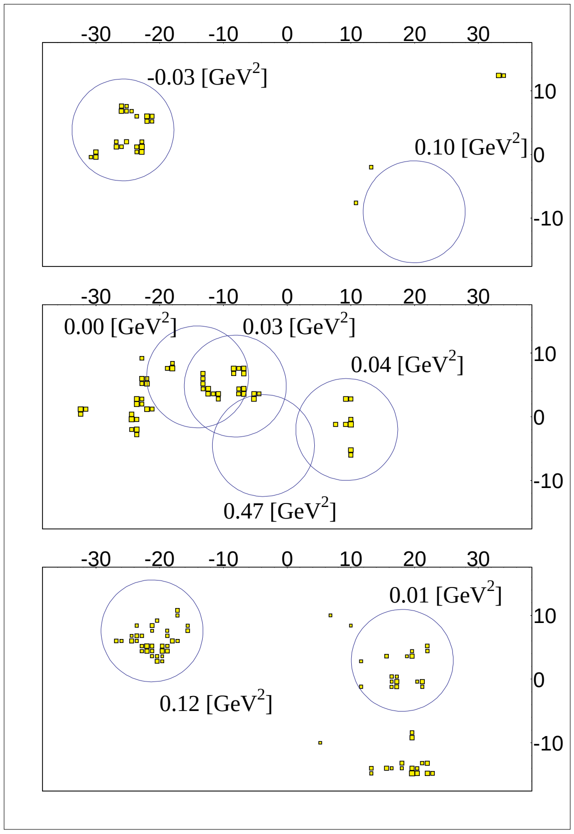

Figure 2: Typical events recorded in lead–lead collisions. The circles show the fiducial area possible for Cherenkov photons emitted by a track impacting the circle in its centre. The mass-squared value for each track is indicated. The dimension of the squares showing the number of pads hit corresponds to the pulse height recorded.

In Fig. 3. we show a 3-D plot of the TIC analysed in conjunction with the TOF wall. For each track the mass-squared value

$$m^2 = p^2(T^2/L^2 - 1) ,$$

where p, T and L are the momentum, the time of flight and the path length, respectively, are displayed in a LEGO plot versus the number of pads hit in the fiducial area in the TIC corresponding to the same track. From the plot one can see that the purpose of the system has been achieved—positive identification of pions by hits in the TIC, and identification of the kaons and protons by the absence of hits in the TIC and the making of the appropriate cuts on the mass-squared axis. From Fig. 3 it is clear that for a small fraction of events the kaons and protons have some pad hits in their fiducials. We attribute these to overlap of fiducial discs (see Fig. 2) or to the background sources. The part attributable to overlap will be studied in a more sophisticated analysis than the present one. A mean number of 12 pads (corresponding to ~ 6 photons) were hit in each fiducial area. The good separation achieved between pions and kaons using the TIC is further illustrated in Fig. 4 where we show the effect of including the TIC criterion in the identification of particles emitted in the spectrometer at the 4 GeV/c setting. The preliminary results of the analysis indicate a rejection of the pions by almost two orders of magnitude, making a track-by-track identification possible.

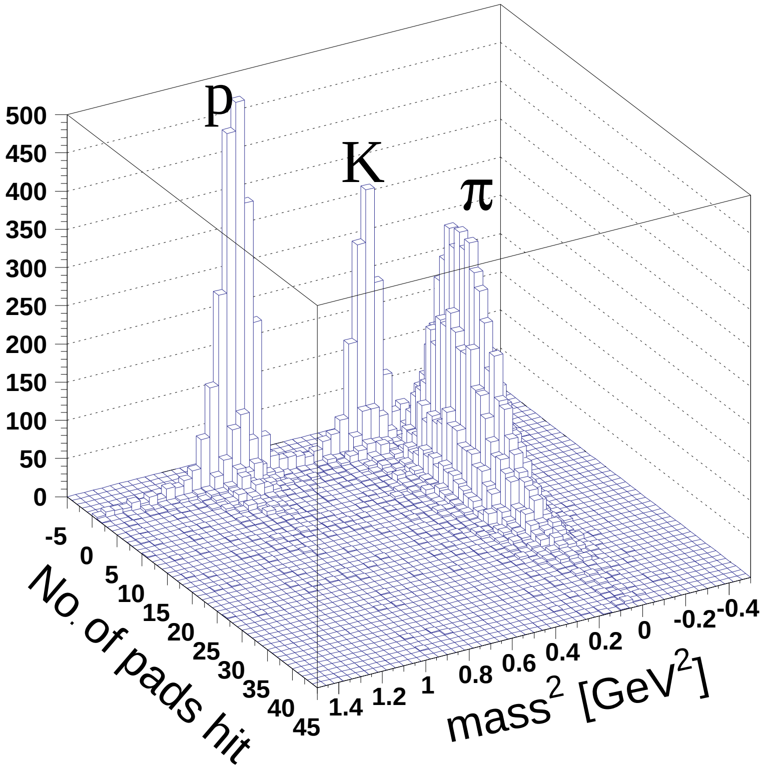

Figure 3: A 3-D view of the TIC results. The number of pads hit per track fiducial is shown on one axis, whilst on the other axis is the mass-squared value obtained from time-of-flight measurements.

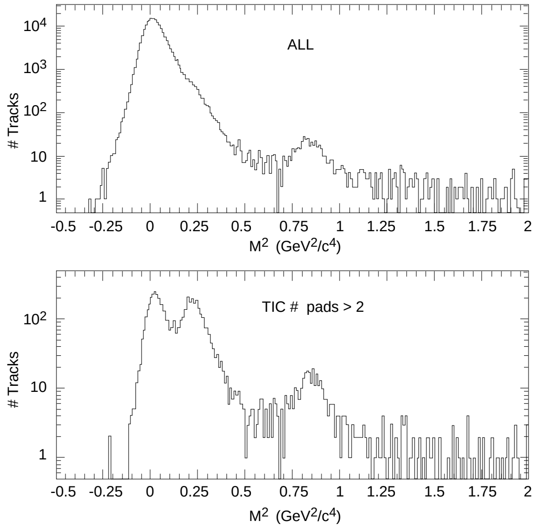

Figure 4: Mass-squared spectra obtained without the TIC (upper part) and with the requirement that there be less than two fired pads in the fiducial.

4 Conclusion

A device combining the easy particle identification of a threshold Cherenkov counter and the possibility of identifying the Cherenkov signal track-by-track has been achieved using an isobutane radiator and a MWPC equipped with a CsI photocathode. It is the first time to our knowledge that a Cherenkov light detector using a CsI photocathode has been integrated into a physics experiment and has successfully been run under high background and high counting rates (up to 10^3 Hz). Furthermore, no deterioration of the photocathodes has been observed during the running of the experiments in spite of the fact that, estimating from the currents of the chamber during the spills, they have sustained bombardments of about 100 μC/cm^2 during the 1995 and 1996 runs. Taking into account that such loads on the photocathodes correspond to about 10 years running of ALICE, the present results confirm the good prospects for the High Momentum PID detector described in this volume [7] for the ALICE detector in heavy-ion collisions at the LHC.

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