PHYSIKALISCHES INSTITUT UNIVERSITÄT HEIDELBERG

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W. Beusch¹, J. Engelfried², S.G. Gerassimov³, J. Heintze²,
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HD-PY 92/07

PHILOSOPHENWEG 12 D-6900 HEIDELBERG
GERMANY

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Abstract

The hyperon beam experiment WA89 at the CERN-SPS uses a ring-imaging Cherenkov counter (RICH) for identification of secondaries from $\Sigma^- N$ reactions. Cherenkov photons are generated in a 5 m long radiator volume filled with nitrogen at atmospheric pressure and detected in drift chambers. The drift chambers cover an active surface of $1.6 \times 0.75 \text{ m}^2$, with a maximum drift path of 41 cm. Photo-electrons are counted on 1280 wires with a pitch of 2.54 mm, equipped with multihit-TDC's. The counting gas is ethane saturated with TMAE at 30°C. The counter was operated in two beam periods in 1990 and 1991. The spatial resolution of the chambers is better than 2 mm and under normal running conditions 14 photo-electrons per ring have been detected on average.

Talk given at the Wire Chamber Conference, Vienna 1992
To be published in Nuclear Instruments and Methods

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- 1) CERN European Organization for Nuclear Research, Geneva, Switzerland
 - 2) Physikalisches Institut, Univ. Heidelberg, Germany
 - 3) Max-Planck-Institut für Kernphysik, Heidelberg, Germany
 - 4) Institut für Kernphysik, Univ. Mainz, Germany

†) On leave from Lebedev Inst., Moscow, Russia

*) present address: Cavendish Lab., Cambridge, UK

§) present address: Paul Scherrer Institut, Villigen, Switzerland

1 Introduction

We report on the construction and operation of a ring-imaging Cherenkov counter (RICH) in the hyperon beam experiment WA89, which is currently performed in the Omega facility at the CERN-SPS [1]. The main objectives for this experiment are the study of charmed-strange baryons and the search for exotic states (U(3100) [2], hexaquark H [3]). For this, $\pi/K/p(\bar{p})$ identification of decay particles is necessary for momenta up to and beyond 100 GeV/c, the beam momentum being 340 GeV/c. It was therefore decided to upgrade the existing RICH counter at the Omega facility [4] in particular by introducing new UV-detecting drift chambers. Also the central part of the mirror surface was replaced and a new gas system was built. This report concentrates on the design and performance of the drift chambers and on the particle identification achieved.

The experiment layout is shown in fig. 1. The RICH is placed downstream of the Omega magnet. The radiator volume is 5 m long in the beam direction. To detect the Cherenkov rings from particles with momenta down to 15 GeV/c, a detector surface of $1.6 \times 0.75 \text{ m}^2$ is needed. For the required particle identification, separation of Cherenkov ring radii differing by a few mm only is needed, which implies an accuracy of about 2 mm for photon detection.

In view of these requirements UV-sensitive drift chambers were chosen as photon detectors. They measure the coordinates of the photon conversion points in the direction along the chamber surfaces: the horizontal coordinate by the counting wire address, the vertical coordinate by the drift time. The coordinate normal to the chamber surface is not measured, which may lead to unacceptable parallax errors in case of large photon absorption lengths.

The large surface dictated the use of quartz glass for the chamber windows, which in turn left TMAE¹ as the only possible choice of photo-ionizing agent [5]. TMAE at room temperatures has an absorption length $\lambda_{\text{abs}} = 30 \text{ mm}$ [6]. The resulting parallax errors would be about 3 mm for 30 GeV/c particles and thus too large. It was therefore decided to saturate the counting gas with TMAE at temperatures up to 30°C, where $\lambda_{\text{abs}} = 11 \text{ mm}$. This in turn necessitates heating the RICH and the gas supply system to above 40°C to avoid any danger of TMAE condensation.

The detector consists of five chambers each with an active surface of $325 \times 750 \text{ mm}^2$. The RICH was first operated in April–June 1990 with 3 chambers; during this period the performance was studied and steadily improved. During the second run in April–June 1991 the RICH ran steadily with all chambers.

2 Construction

2.1 General properties

In the overview diagram fig. 1, the size of the RICH and the positions of the mirrors and the UV-detecting chambers are indicated. Particles traversing the RICH generate Cherenkov light in the 5 m long radiator volume. The Cherenkov light is focused by an array of hexagonal mirrors with curvatures of 10 m onto a focal sphere with 5 m radius. The chambers are positioned such that the focal sphere is at 10 mm inside of the chamber windows, on average. The particles have to traverse the drift chambers, producing about 500 electrons per charged particle track. The design of the chamber has to take care of this problem. The radiator, which has a total volume of 120 m^3 , and the chambers are kept at atmospheric

¹Tetrakis(dimethylamino)ethylene, RSA Corp., Ardsley, N.Y., USA

pressure. Until now nitrogen was used as radiator gas. It has a convenient threshold at $\gamma_{\text{thr}} = 40$, but it also has a fairly large dispersion in the wavelength range 160 – 220 nm, where the chamber is sensitive. This dispersion leads to a variation of Cherenkov angles corresponding to a spatial error of about 1.7 mm. During operation of the RICH, the oxygen and water content of the radiator gas are monitored and the UV transmission is measured frequently to ensure that Cherenkov photon absorption in the radiator is small.

The chambers are fitted into a support frame and can be mounted and dismounted independently. They are tightened against the frame with soft O-rings. The radiator volume can be sealed towards the frame by a sliding door, to allow installation of the chambers without contamination of the radiator by air.

The TMAE must be specially cleaned² and the counting gas must be kept free of all impurities, in particular of oxygen, because TMAE oxidation products are chemically aggressive, will absorb UV photons without being ionized [7], and show electron attachment [8]. To minimize the possibility of air seeping into the chambers, a protective volume on the backside of the chambers is flushed with pure nitrogen. Under these circumstances, the oxygen contamination of the chamber gas was measured to be 1 ppm or less at the chamber exhaust, in the absence of TMAE.

Ethane was chosen as the counting gas because of its low diffusion coefficients [9, 10] and good counting properties for single photo-electrons. At the chosen drift field of 1 kV/cm, the drift velocity is 5.3 cm/ μ s. The absorption of light by ethane is negligible in the wavelength interval considered [11].

Two hydrogen-filled flashlamps were mounted below the mirrors for the purpose of testing the response to UV light. They were tuned to produce about 100 photo-electrons in each half-chamber per flash, with a fairly uniform distribution.

2.2 Chamber construction

Figure 2 shows one chamber. It has two symmetrical parts separated by a common central high voltage electrode. UV photons traversing the quartz window create photo-electrons in the sensitive chamber volume, which are guided by a homogeneous drift field of 1 kV/cm towards the counting modules at the upper and lower end of the chamber, respectively. Homogeneity of the drift field is ensured by potential strips on the window and the side and back walls of the drift volume. All materials exposed to the TMAE-loaded gas were carefully tested for TMAE resistance.

The 345 × 810 mm² large quartz windows were produced using two different kinds of synthetic silica: Suprasil II³ and Fused Silica Code 7940⁴. The plates were ground to a thickness of ≈ 3 mm and polished by an optical company⁵. They carry conductive strips on each side, with a spacing of 1.27 mm and a width of 40 ± 5 μ m, thus minimizing field distortions and shadowing effects. The strips consist of a 0.02 μ m thick chromium layer and were applied by the Lift-Off-Process⁶. On both ends there are soldering pads (4×0.6 mm²) which are reinforced by a 0.25 μ m nickel layer.

The transmission of all quartz sheets was measured in a vacuum test station, large enough to allow a UV beam to scan the whole surface of a chamber window. The transmis-

²Bayer AG, 5090 Leverkusen, Germany

³Heraeus Quarzschmelze GmbH, 6450 Hanau 1, Germany

⁴Corning Glass Works, Canton, NY 12617, USA

⁵Plan-Optik GmbH, 5439 Elsoff, Germany

⁶DIADUR procedure, Dr. Johannes Heidenhain GmbH, 8225 Traunreut, Germany

sion showed a cut-off at 160 nm and reached 80 % at 180 nm for windows with strips.

The remainder of the drift box is made of epoxy-fibreglass material⁷ ("FR4"). The potential strips on the FR4 walls are 0.5 mm wide with a pitch of 1.27 mm and are made of nickel-coated copper. These strips are provided on both sides of the rear plate and the two side plates. The FR4 parts and the quartz window are glued together with epoxy resin⁸.

The polymerization of the glue at 55°C guaranties a safe operation up to 40°C, where the different thermal expansions of quartz (0.5 ppm/K) and FR4 (10 ppm/K) cause contractile forces only. Tensile forces may crack the brittle windows. Moreover there are several elastic compensators to limit the tensions. The quartz plate withstands a pressure difference of 7 mbar between radiator gas and counting gas, with a safety factor 7. To the upper and lower end of the driftbox, solid metal frames (nickel-coated brass) were fixed by glueing. They serve for housing the counting modules.

Electrically the window electrodes are connected by soldering 0.35 mm wide and 0.05 mm thick nickel ribbons between the pads and the corresponding strips of the side plates. This connection is done outside of the gas volume. The potential strips on the windows and side walls are arranged to provide a constant drift field pointing away from the quartz window at an angle of 50 mrad. This was done to avoid losing photo-electrons by diffusion onto the window. Because of the inclined drift field geometry, the sensitive depth of the chamber varies from 40 mm at the central electrode to 60 mm near the counting wires.

2.3 Counting modules

Each chamber has two detachable wire modules, at the upper and lower end respectively, fixed to the brass frame, as shown in fig. 2. One wire module contains 128 counting wires with 2.54 mm pitch and a sensitive length of 60 mm. The wire material is gold-coated tungsten with a diameter of 15 μ m. This was chosen as a result of extensive systematic studies. In an ethane-TMAE mixture, a photo-electron detection efficiency close to 100% and very stable counting operation were obtained.

For the definition of the individual counting cells and for suppression of photon crosstalk, separator plates with dimension $60 \times 18 \text{ mm}^2$ and a thickness of 0.25 mm are inserted between the counting wires, forming a venetian blind structure (fig. 3). The material is Al_2O_3 ceramics⁹. The plates carry conductive strips of nickel-plated sintered tungsten, serving for field shaping as discussed in the next section. The wire and blind supports are mounted on a detachable FR4 base plate, which is sealed against the brass frame by an O-ring.

2.4 High voltage system and gating

The drift field is generated by supplying a potential of -40 kV to the central electrode of the chamber. The potential strips on the window and on the side and back walls are connected to the central electrode by a resistor chain. In this way a homogeneous drift field of 1 kV/cm is produced between the central electrode and the front edge of the venetian blinds.

The electric field between the plates of the venetian blind must be stronger by a factor of about 2 than the field outside, to focus the photo-electrons onto the counting wires. The counting voltage and the focusing field can be adjusted independently.

⁷Epoxid-GHW, Glasotext-EP, quality FR4, AEG Isolier- und Kunststoff GmbH, 3500 Kassel, Germany

⁸Araldite AW 116 with hardener HV 953 U, Ciba Geigy, 7867 Wehr, Germany

⁹Rubalit 708, Hoechst Ceram Tec AG, 8590 Marktredwitz, Germany

Under typical experimental conditions, the chambers are traversed by about 10^6 charged particles in one SPS spill of 2 s. Although an area of $12 \times 6 \text{ cm}^2$ around the beam spot is made insensitive, the counting action of the chambers has to be gated in order to suppress field distortions and photo-electron losses from space charges in the drift region. This is achieved without the need for an additional grid, in the following way [12]: In the “gate closed” mode, the static potentials on the uppermost strips of the venetian blinds are held at potentials which essentially inhibit transfer of photo-electrons to the counting wires. This is achieved by adding to the potentials of optimum electron transfer +200 V on even-numbered blinds and -200 V on odd-numbered blinds. With these values, there are no field lines leading from the drift region to the counting region (see fig. 3b). After a trigger, a symmetric pulse of $\mp 200 \text{ V}$ is supplied to the even-numbered and odd-numbered blinds, respectively, which “opens” the chamber for a time of $8 \mu\text{s}$, corresponding to the maximum drift time. The opening time is so short that no ions can drift back to the drift region before the chamber is “closed” again.

2.5 Read-out

The signals from the counting wires are amplified by current-sensitive preamplifiers which provide a gain factor of $25 \text{ mV}/\mu\text{A}$. The amplifier outputs are connected by 3 m twisted-pair ribbon cables to discriminator modules, placed outside of the RICH box, above and below the chambers. For each counting wire, an independent low threshold is provided for detection of single electrons. Furthermore, a second higher threshold is provided for groups of 8 neighbouring wires, in order to identify signals from charged particle tracks. The thresholds can be set by microcomputers. The discriminator signals are sent to multihit TDC’s which digitize the timings in 11 ns steps. The TDC’s are read out by microcomputers [13].

2.6 Monitoring system

Safe operation of the RICH requires monitoring of several parameters, such as temperatures, pressure inside the chambers and inside the radiator volume, gas flows, oxygen content of the ethane, high voltages and currents. Also some of these values are needed in the off-line analysis for calibration, e.g. to calculate the refractive index of the radiator gas one needs radiator temperature and pressure.

A total of about 60 channels is input to two ADC modules¹⁰ and read out via CAMAC. This information is included in the main data stream and written to tape. An on-line monitor task reads the data and can check the different values against safety limits. In case of an exceeded limit, an alarm and an error message are provided to the shift crew.

In addition to the software monitor, the temperatures of TMAE bubbler, gas system, RICH chambers, and the oxygen content of the carrier gas have hardware limits. If one of these is exceeded, or in case of a power failure, the TMAE bubbler will be switched off by a system of pneumatic valves, allowing the carrier gas to bypass the bubbler.

The pressure control and the safety system for the radiator are described in [11].

¹⁰KS 3527, Kinetic Systems, Lockport, Illinois, USA

3 Results

3.1 Calibrations and tests

The chamber positions were determined by geometric measurements and by using particle tracks extrapolated from the spectrometer. Drift velocity and timing offset for each run and each TDC were also calibrated using particle tracks. At present, a uniform drift velocity inside the drift volume is assumed.

The high voltage and discriminator threshold settings were chosen by optimizing the rates of flashlamp-induced signals. Flashlamp signals were also used to look for possible electron losses during the drift process, for instance by attachment to impurities. Such losses were below the 5 % level for the maximum drift length.

3.2 Resolution and photo-electron statistics

In tab. 1 we list contributions to the space resolution for single photo-electrons, as expected from various sources. The values for chromatic dispersion are for a N_2 radiator, whereas the corresponding values in parentheses are for a helium-freon mixture. The parallax errors are calculated for an absorption length of 10 mm. The transverse and longitudinal diffusion constants of ethane were taken from [9, 10].

The resolution achieved under experimental conditions was determined by measuring the distance of every hit to the ring centres predicted from tracks observed in the drift chambers in front of the RICH. Figure 4 shows such a distribution for particles in the momentum range 50 – 55 GeV/c. From the position of the peak centre the refractive index of the radiator gas can be determined.

The pion peak in fig. 4 has a width of $\sigma = 2.8$ mm. This number contains a contribution from the dispersion in the radiator gas, as given above, and a contribution from the errors on the ring centre position, which are $\sigma = 0.5$ mm in the horizontal and $\sigma = 2$ mm in the vertical direction. If these contributions are subtracted, an intrinsic chamber resolution of $\sigma < 2$ mm is obtained.

The number of detected photo-electrons per ring, N_{det} , can also be determined from plots like the one in fig. 4. Under normal running conditions, $N_{\text{det}} = 14$ photo-electrons were found for a full ring, on average. If one uses the well-known formula $N = N_0 \cdot L \cdot \Theta^2$, one obtains the value $N_0 = 49 \text{ cm}^{-1}$ for the *effective quality factor*.

3.3 Particle identification

The acceptance of the RICH extends down to momenta of $\approx 15 \text{ GeV}/c$. Since μ and π are very close in mass, we consider only the mass hypotheses e , π , K , and p . For a known momentum (measured by the spectrometer), the position and radius of the ring for the different mass hypotheses can be predicted from track parameters and mirror geometry.

Figure 5 shows an on-line display of one event in the RICH. This display contains the signals observed in the chambers, the particle impacts extrapolated from the spectrometer, and the predicted rings for the mass hypotheses π , K , and p . Also the momenta and charges of the tracks are given. Cherenkov photon signals along the predicted rings are clearly seen. We also note two half-rings in the centre from an out-of-time beam particle or e^+e^- pair.

In the first step of the identification algorithm, background is subtracted by excluding clusters of closely neighbouring hits, and the area around the impact points of tracks extrapolated from the spectrometer.

We use a maximum likelihood approach for particle identification. For each mass hypothesis, we calculate a probability density function of the two space coordinates to observe a signal or background hit. This function is computed at the position of each observed hit. We use a Gaussian distribution for the distance of the photon from the nominal radius, and assume a constant (over space) background density in each chamber.

A likelihood function is calculated for each hypothesis, by multiplying the function values of all hits, and an additional Poissonian distribution for the probability to observe the total number of hits.

To discriminate different particles, a cut on the ratio of the likelihoods is applied. As an example for the particle identification obtained, fig. 6 shows invariant mass spectra for pairs of particles of opposite charge under the mass hypotheses K^+K^- or pK^- , respectively. Clear signals from ϕ and $\Lambda(1520)$ decays are produced by requiring RICH particle identification.

Acknowledgement

Thanks are due to H.-J. Besch, M. Davenport, G. Lenzen, H. Ries, E. Rosso, J. Séguinot and T. Ypsilantis for helpful discussions and advice. We also thank the workshops of the Physikalisches Institut, Universität Heidelberg, for their excellent work in the construction of the chambers, the gas system and the electronics. We are grateful for the support from A. Beer, G. Bosteels, G. Chil, A. Dallüge, F. Faller, R. Monnin and J. Zimmer during set-up and operation at CERN. Finally, we thank all members of the WA89 collaboration for friendly encouragement and support.

This work was supported by the Bundesministerium für Forschung und Technologie.

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error	σ_{vertical} [mm]	$\sigma_{\text{horizontal}}$ [mm]
chrom. dispersion	1.7 (1.0)	1.7 (1.0)
mirrors	0.5	0.5
parallax	0.5	$30/p [\text{GeV}/c]$
diffusion	0.7	1.1
wire spacing	–	0.73
time measurement	0.3	–
total error σ	2.0 (1.4)	2.3 (1.8) for $p = 100 \text{ GeV}/c$

Table 1: Contributions to the spatial resolution of single photo-electrons.

Figure 1: Overview of the hyperon beam experiment WA89. The inside of the Omega spectrometer is equipped with MWPCs; in front of it and behind are drift chambers.

Figure 2: Design of one chamber, seen from the rear.
 The lower counting region is shown in an exploded view.

Figure 3: Counting wires and the venetian blind structure.

a) Mounting of counting wires and separator plates. The non-dotted parts of the plate surfaces are conductive.

b) Continuation of the field lines from the drift region to the counting region, for "gate open" and "gate closed".

Figure 4: Measured distances of individual photon hits to predicted ring centres for particles in the momentum range 50 – 55 GeV/c. The fitted curves show from left to right the contributions of p , K and π .

R4231 B 15720 Event 6611338 in-B 4 Time 06 81509 Trigger 1,3,4

Figure 5: On-line display in the RICH.
Solid circles: rings predicted for the π and p mass hypotheses. Dashed circle: K hypothesis.
Crosses: Predicted track impacts. Momenta and charges of the tracks are displayed on the right-hand side.

Figure 6: Identification of $\phi(1020) \rightarrow K^+K^-$ and $\Lambda(1520) \rightarrow pK^-$ decays.

Left: K^+K^- invariant mass distributions; right: pK^- invariant mass distributions. Top: no particle identification; bottom: particles identified by RICH.