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Section A

RICH detectors operated in the visible light region

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Abstract

A new generation of Ring Imaging Cherenkov (RICH) devices based on visible light photodetectors is expected to emerge in the next years. Following the discussion on benefits and drawbacks of such technique, examples of its application in particle physics experiments will be presented. © 1998 Published by Elsevier Science B.V. All rights reserved.

1. Introduction

The infancy of the RICH detector technique was characterized by vacuum based photodetectors [1,2], but after the successful results achieved by J. Seguinot and T. Ypsilantis in 1977 [3], the design of almost all the existing large area RICH devices has been based on gaseous single ultraviolet photon detectors mainly containing TMAE vapours [4].

During the last years, a considerable effort has been done to prove that a thin film of CsI deposited onto the cathode plane of a gaseous detector is a valid alternative to the use of TMAE in large area RICH detectors [5,6].

From the other side, the recent advances in the technologies associated with the detection of visible light [7] have stimulated fruitful ideas [8,9]. As a result, a renewed interest of operating RICH detectors in the visible light region is taking place.

This new direction in the technique of Cherenkov light imaging is supported by several advantages on both operational aspects and performance.

On the detector operational aspects, the main benefits are as follows:

- no special handling for nasty photosensitive vapours such as TMAE;
- modest service and maintenance needs;
- savings in operating costs since gas circulation systems and expensive UV windows are no more needed;
- high segmentation flexibility and compactness.

The detector performance improves as follows:

- larger detector figure of merit due to the enlarged bandwidth for the relevant photo-electron yield;
- increased identification power due to the reduced radiator chromatic aberrations at the longer wavelengths;
- high rate capability and availability of the detector for triggering;
- a larger choice of materials as radiator, in particular the possibility of using aerogel (see Section 3);
- removal of background due to incoming neutrons (neutrons create spurious hits in the hydrogenous gas mixtures used in RICH photon detectors as a consequence of proton recoils).

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Although, in principle, this technique has no intrinsic disadvantage, the main drawbacks are closely connected to the specific technology adopted in detecting the Cherenkov visible photons as it will be pointed out in Section 2, where a short review of the properties of present vacuum based photodetectors is presented. In Section 3, the attractive properties of the new generation aerogel are discussed and finally, in Sections 4 and 5 the LHC-B and HERMES apparatus are respectively described, as examples of application of this technique in future experiments.

2. Review of vacuum-based photodetectors

Visible light RICH photodetectors must satisfy the following requirements:

- single photon sensitivity;
- good localization accuracy;
- fast response;
- low noise;
- long-term stability;
- low cost.

In the following, a brief comparison among existing technologies is presented.

2.1. *Image intensifiers and CCDs*

Sugitate et al. [8] reported results from successful tests of detection of Cherenkov rings focused onto an image intensifier coupled to a CCD camera. Although this technique seems very promising, CCDs are small and quite slow devices. This last constraint is severe, in fact the acquisition rate of RICH detectors barely relevant a few years ago it has now become a crucial issue. Indeed, also on the side of gaseous photocathodes, the main drawback with TMAE and CsI photocathodes is the count rate limitation [10,11].

2.2. *"Quantacon-type" photomultipliers*

Phototubes (PMT) have the merits of robustness, low-noise, high-gain and high rate capabilities but they are sensitive to magnetic fields. "Quantacon-like" PMTs have a high single-photoelectron efficiency but a high cost/channel (larger than 100$). A powerful application is represented by the experiment SELEX at Fermilab where almost 3000 PMTs have been employed to detect the Cherenkov light from a gaseous RICH device [9,12]. The future experiments PHENIX [13] and BABAR [14] also plan to detect the Cherenkov light with an array of PMTs.

2.3. *Multianode PMTs and fine mesh PMTs*

In large area applications, multianode PMTs are more suitable since they offer the advantage of many channels with a single common power supply and a compact readout. Multianode PMTs, firstly used by Endo et al. [15], are now the baseline photodetectors for the Hera-B [10] and Brahms [16] RICHs. The commercial tubes show a cross-talk much less than 1% and a pad-to-pad variation in gain less than 30% [17]. Use in magnetic field over 1.5 T is possible using fine mesh tubes, although at high cost and with lower single photon sensitivity.

2.4. *Hybrid photodevices (HPD)*

Hybrid photodevices consist of an array of silicon pin diodes placed into a vacuum tube with a standard transmission photocathode kept at a negative voltage of several kV with respect to the silicon. Photoelectrons are accelerated by the electric field and penetrate the solid state diodes where thousands of electron–hole pairs are developed. Two electric field configurations are possible: proximity focussing and electrostatic focussing. The latter allows small detector dead area but it is very sensitive to magnetic fields. HPDs potentially offer outstanding features like high spatial resolution, stable gain, wide dynamic range and an excellent single photoelectron response [18]. Nevertheless, for large area RICH device applications, more R&D for implementing the FE electronics in vacuum is needed in order to avoid the large number of feedthrough lines. In addition, the commercially available devices, although of suitable performances, suffer of large inactive area and high cost. The developments of cheap hybrid devices with large active area is underway at CERN in collaboration with INFN-Bari and ISS-Rome [19]. Large arrays of HPDs are envisaged in the LHC-B [20] and LBL-ν [21,22] experiments.

2.5. Visible light photon counters (VLPCs)

Visible light photon counters (VLPCs) are based on doped SiAs crystals cooled at 7 K, biased at low voltage. Visible photons are guided through glass fibers into the intrinsic region of the detector where create electron–hole pairs [23]. The following impact of one electron on a neutral crystal impurity starts an electron avalanche. VLPCs main advantage is the very high QE (85% for green light). They run with a speed up to 30 MHz, but they are very expensive.

3. Aerogel as a new RICH radiator

Silica aerogel is the only existing material with optical properties suitable to fill the gap in refractive index between liquids and heavy gases.

Recently, hydrophobic, crack-free, very transparent aerogel samples became routinely available [24]. Loss of photons due to absorption and scattering processes in the bulk material has been minimized as observed in test beam studies [25].

Although, silica aerogel has been widely used as radiator in threshold Cherenkov counters, the major merit of its rapid progress in RICH devices must be attributed to J. Seguinot and T. Ypsilantis, who adapted, for application in the LHC-B experiment, the H. van Hecke detector scheme [26] in the light of currently available photodetector technology. Their design also inspired the forthcoming upgrade of HERMES at DESY [27].

3.1. Aerogel optical properties

The granular structure of aerogel with a typical length scale of few nm determines its optical properties. Indeed, the behaviour of visible light in aerogel is dominated by Rayleigh scattering which increases as the fourth power of the frequency. When the Rayleigh scattering occurs, the directionality of the Cherenkov radiation is completely lost. Therefore, the major concern associated with the design and construction of a RICH detector with an aerogel radiator is whether the Cherenkov photons that traverse the aerogel without any scattering are in sufficient number to allow the measurement of their emission angle with the expected accuracy.

Simple calculations show that the useful production of Cherenkov light is limited to the visible. Although this places high demands on photon detection, two experiments are planning to use aerogel as RICH radiator as it will be described in following sections.

4. The LHC-B experiment at CERN

LHC-B is an experiment designed to measure CP violation parameters in B decays at the Large Hadron Collider (LHC) at CERN. The proposed layout (Fig. 1) features an accurate momentum reconstruction and particle identification since precision determination of the CKM unitarity triangle angles requires an excellent pion/kaon separation over the momentum range from 1 to 150 GeV/c.

Since the desired momentum range for pion/kaon separation cannot be spanned by a single refractive index setting, two focused RICH detectors with three radiators have been proposed. The first RICH is placed upstream of the dipole magnet to allow the identification of particles in the low momentum region from 1 to 60 GeV/c. It is based on the innovative idea to implement aerogel and C_4F_{10} radiators in the same focusing system by positioning the aerogel radiator close to the gas vessel entrance window and tilting the 2 m focal length mirror to bring the image out of the beam aperture in order to reduce secondary interactions. Photons are detected via an array of HPD located on each side of the RICH detector (Fig. 2). The second RICH has a 2 m long CF_4 gas radiator to identify high momentum particles between 16 and 150 GeV/c. A plane mirror, inclined to 45°, transfers the ring images to the HPD array located in such a way that it is not traversed by particles.

Anticipated performances of the RICH systems are listed in Table 1. In order to show the feasibility to use a HPD array for detecting Cherenkov

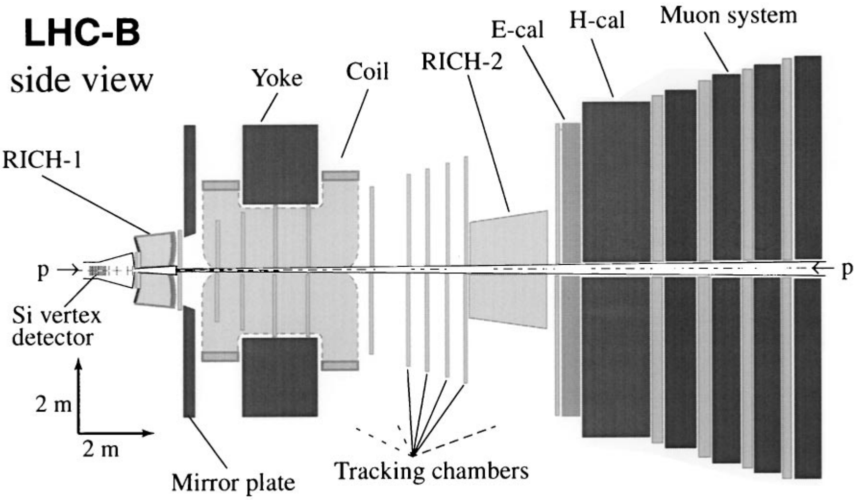

Fig. 1. Layout of the LHC-B experiment.

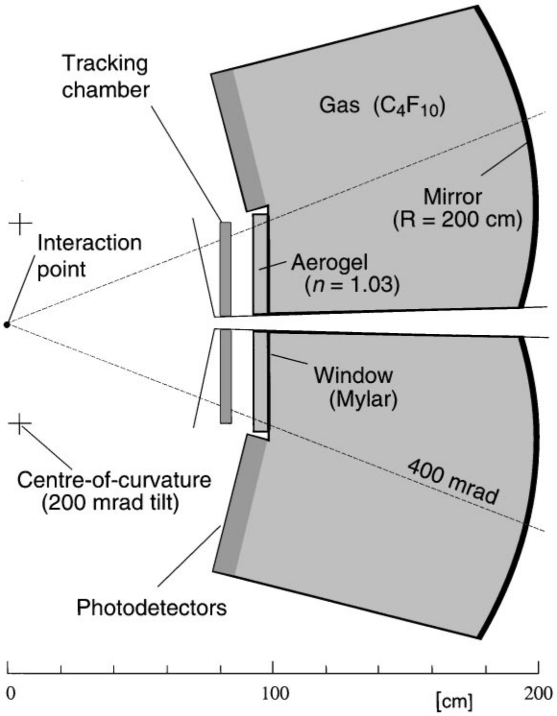

Fig. 2. Schematic view of the combined aerogel and gas RICH detector envisaged in LHC-B.

Table 1
Expected performances of LHC-B RICH detectors with $n = 1.03$ aerogel radiator and CF_4,C_4F_{10} gas radiators. The following factors are listed: momentum thresholds for pions and kaons, maximum Cherenkov emission angle, contributions to the angle resolution from the uncertainty of the photon emission-point, from the radiator chromatic dispersion and from photon detector spatial resolution (assuming $2\times2\,\mathrm{mm}^2$ pixel size), total angle resolution per photoelectron and the momentum upper limit of $3\sigma_{\pi/K}$ separation

n	1.03 (aerogel)	1.0005 (CF_4)	1.0014 (C_4F_{10})
$p_{\mathrm{tresh},\pi}$ (GeV/c)	0.6	4.6	2.7
$p_{\mathrm{tresh,K}}$ (GeV/c)	2.0	16.3	9.4
θ_C (mrad)	240	30	53
$\sigma_\theta^{\mathrm{emission}}$ (mrad)	0.3	0.1	0.6
$\sigma_\theta^{\mathrm{chromatic}}$ (mrad)	1.2	0.3	0.6
$\sigma_\theta^{\mathrm{pixel}}$ (mrad)	0.5	0.2	0.5
$\sigma_\theta^{\mathrm{total}}$ (mrad)	1.4	0.4	1.0
$p_{\max}$ (GeV/c)	20	146	73

light from aerogel, tests carried on by the UK group in the LHC-B collaboration are in progress at CERN. Fig. 3 shows a HPD array hit map obtained superimposing several events taken with a dual radiator RICH prototype [28].

5. The HERMES experiment at DESY

Hermes is an internal gas-target experiment designed to investigate the nucleon spin structure functions at HERA [29]. An open spectrometer has been

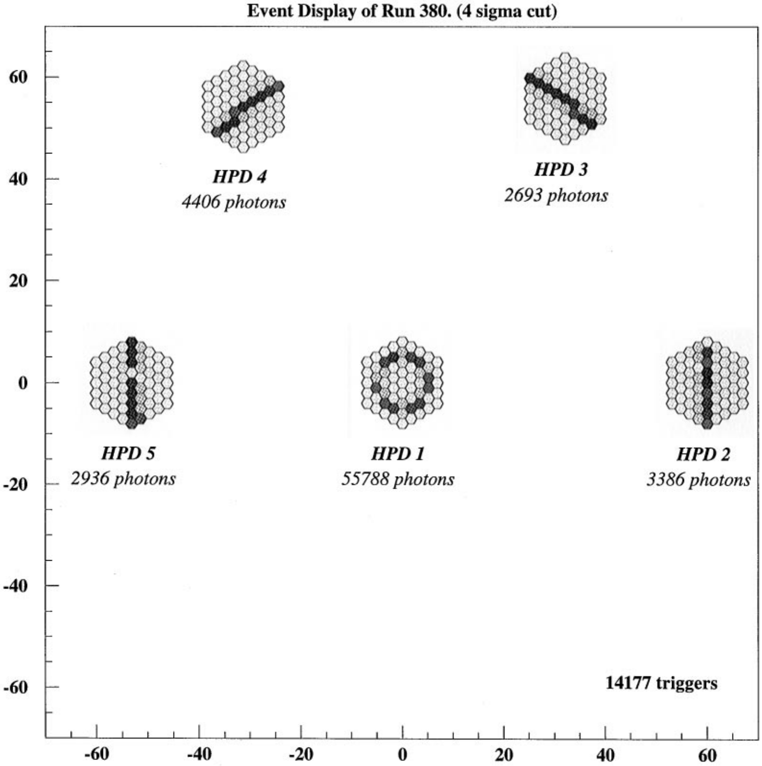

Fig. 3. Integrated hit map in a 14177 event run showing Cherenkov patterns detected with commercial 61 channel HPDs provided by DEP-Holland. The inner HPD shows the focussed Cherenkov light emitted in air by 10 GeV/c pions while the four outer HPDs sample the wider ring obtained focussing the Cherenkov light produced in 2 cm thick aerogel with 1.03 refractive index.

built with the aim to measure the scattered electron and the leading hadrons coming from the target fragmentation with a momentum and angle resolution of 1% and 1 mrad (at 4 GeV/c), respectively.

The spectrometer consists of a conventional dipole magnet of 1.3 Tm and tracking chambers for the event reconstruction (Fig. 4). The scattered primary electron is identified with an efficiency greater than 97% (with less than 1% of hadron contamination) by the combination of a lead glass calorimeter, a preshower and a transition radiation detector. Moreover, a threshold Cherenkov detector allows the identification of pions above a threshold of 3 GeV/c using C_4F_{10}.

To fully exploit the unique opportunity to provide valuable information on the flavor dependence of the spin structure functions and estimates of the strange sea polarization, an unambigous identification of pions, kaons and protons is required on the momentum range from 3 to 20 GeV/c. Therefore, the conversion of the present gas threshold Cherenkov detector into a Ring Imaging Cherenkov detector (RICH) has been proposed [30]. A conventional focused RICH with the highest refractive index gas radiator available (C_5F_{12}) would not allow to positively identify kaons below 8 GeV/c. This poses an unacceptable limitation to physics measurements. On the other hand, identification in the full momentum range can be accomplished using a LHCB-like dual radiator RICH. Detailed studies are underway in preparation for the HERMES upgrade conceptual design.

6. Conclusions

The improvements in the technology and performance of visible light photodetectors open up the

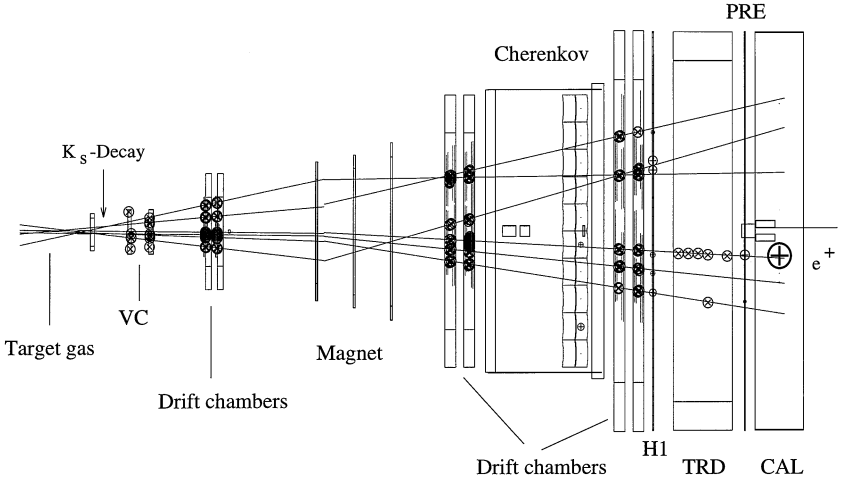

Fig. 4. Layout of the HERMES experiment.

possibility of exploiting the RICH technique in application unexpected still few years ago. The interest of the community of particle physicists has grown and ambitious devices are being designed on the basis of reasonable extrapolations of present technologies. Additionally, such a technique shows an attractive conceptual simplicity due to the modest service and maintenance needs.

The major drawback of this technique is the high detector cost per unit of surface, therefore a parallel activity to operate gaseous photodevices in the visible light range is being pursued by A. Breskin and his team [31] by protecting sensitive photocathodes with a thin solid dielectric film. These studies may mark future directions in large area RICH detectors.

References

[1] A. Roberts, Nucl. Instr. and Meth. 9 (1960) 55.
[2] S.K. Poultney et al., Rev. Sci. Instr. 33 (1962) 574.
[3] J. Seguinot, T. Ypsilantis, Nucl. Instr. and Meth. 142 (1977) 377.
[4] First Workshop on RICH detectors, Bari, Italy, Nucl. Instr. and Meth. A 343 (1994).
[5] E. Nappi et al., Status report of the CsI-RICH collaboration, CERN/LHCC 96-20.
[6] F. Piuz, Nucl. Instr. and Meth. A 371 (1996) 96.
[7] Proc. 1st Conf. New Developments in Photo-detection, Beaune, France, Nucl. Instr. and Meth. A 387 (1997).
[8] T. Sugitate et al., Nucl. Instr. and Meth. A 307 (1991) 265.
[9] M. Maia et al., Nucl. Instr. and Meth. A 326 (1993).
[10] P. Krizan et al., Nucl. Instr. and Meth. A 387 (1997) 146.
[11] J. Va'vra, Nucl. Instr. and Meth. A 371 (1996) 33.
[12] L. Stutte et al., talk at this Conference.
[13] PHENIX Conceptual Design Report, January 1993.
[14] B.N. Ratcliff, Nucl. Instr. and Meth. A 371 (1996) 309.
[15] S. Endo et al., A test of an improved RICH prototype, Annual Report, Institute for Nuclear Study, Tokyo, 1990.
[16] R. Debbe et al., Nucl. Instr. and Meth. A 371 (1996) 327.
[17] Y. Yoshizawa, J. Takenchi, Nucl. Instr. and Meth. A 387 (1997) 33.
[18] R. DeSalvo, Nucl. Instr. and Meth. A 387 (1997) 92.
[19] LHC-B status report, CERN/LHCC 96-38.
[20] LoI for LHC-B, CERN/LHCC 95-5, 1995.
[21] LoI for Long Baseline RICH, CERN-LAA/96-01, 1/1/96.
[22] T. Ypsilantis et al., CERN-LAA/96-13.
[23] M.D. Petroff, M. Atac, IEEE Trans. Nucl. Sci. NS-36 (1989) 163.
[24] I. Adachi et al., Nucl. Instr. and Meth. A 355 (1995) 390.
[25] R. De Leo et al., Nucl. Instr. and Meth. A 401 (1997) 187.
[26] D.E. Fields et al., Nucl. Instr. and Meth. A 34 (1994) 431.
[27] E. Nappi, Nucl. Phys. B (Proc. Suppl.) 61B (1998) 270.
[28] D. Websdale, private communications.
[29] HERMES Technical Design Report, DESY-PRC 93/06, 1993.
[30] E. Cisbani et al., Proposal for a dual radiator RICH for Hermes, Hermes-internal note 97-005.
[31] A. Buzulutskov et al., Nucl. Instr. and Meth. A 387 (1997) 176.