Nuclear Inst. and Methods in Physics Research, A 970 (2020) 163440

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

A rich legacy

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ARTICLE INFO

Keywords:
Thomas Ypsilantis
Cherenkov Ring Imaging
RICH
TEA
Multistep chamber
E605
TMAE
DELPHI RICH

ABSTRACT

This note describes the early developments at CERN of the Cherenkov Ring Imaging technique, inspired by the seminal works of Tom Ypsilantis and Jacques Séguinot, continuing by the construction and operation of the RICH counter for the experiment E605 at Fermilab and soon followed by the large OMEGA and DELPHI barrel RICH systems at CERN.

1. Introduction

The Cherenkov Ring Imaging technique, proposed in 1977 by Thomas Ypsilantis and Jacques Séguinot, appeared as a revolutionary way to achieve particle identification at GeV energies [1]. Nicknamed RICH,[1] the method relied on the use of position-sensitive gaseous detectors, filled with a photosensitive vapor, to detect the UV photons emitted in a radiator by charged particles having a velocity above the Cherenkov threshold. With suitable optical arrangements, the detected photons form a characteristic ring pattern, the radius of which is determined by the particle's velocity. Coupled to a measurement of momentum, deduced from the sagitta of the particle trajectories in magnetic field, the arrangement achieves particle identification.

Employing position-sensitive Multiwire Proportional Chamber detectors, and owing to their multi-particle capabilities and large area coverage, several RICH systems of various design were implemented in particle physics experiments. Using the new generation of Micro-Pattern Gaseous Detectors as sensors, RICH devices with improved performances are in use today.

The present note recollects the writer's early experience in the development and applications of the new technology, initiated in collaboration with Tom and Jacques, and is a modest tribute to their outstanding contribution to the field of particle physics experimentation.

2. The RICH concept

The basic concept of RICH counters relies on the use of gaseous devices for the conversion, multiplication and detection of single photons. The early design of a large acceptance RICH system, suitable for colliding beams physics, is shown in Fig. 1 [1]. UV photons, emitted by the Cherenkov effect in a radiator, are reflected and focussed in a ring pattern on the detector placed on the image plane. Detection is made possible by the addition to the gas of the counter of a vapor with low photoionization threshold and high quantum efficiency; the region of

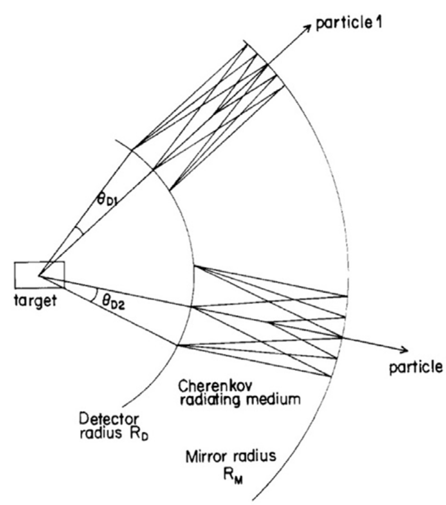

Fig. 1. Conceptual design of a large acceptance RICH counter [1].

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[1] Also called CRID on the other side of the ocean.

https://doi.org/10.1016/j.nima.2020.163440
Received 16 August 2019; Received in revised form 10 December 2019; Accepted 13 January 2020
Available online 17 January 2020

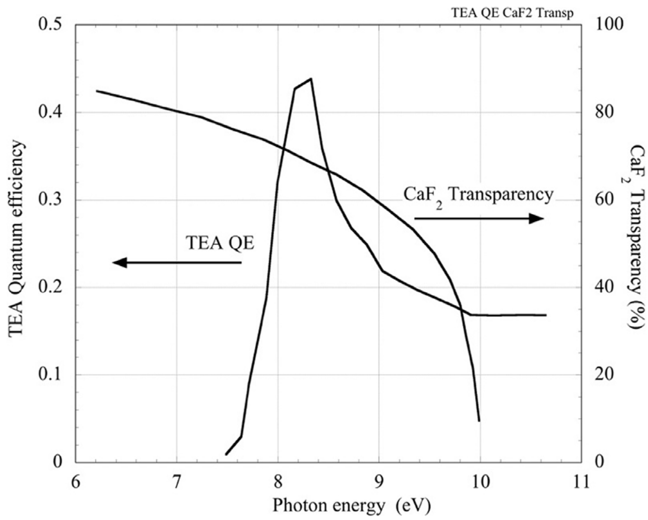

Fig. 2. TEA quantum efficiency and CaF_2 transparency as a function of photon energy (from various sources).

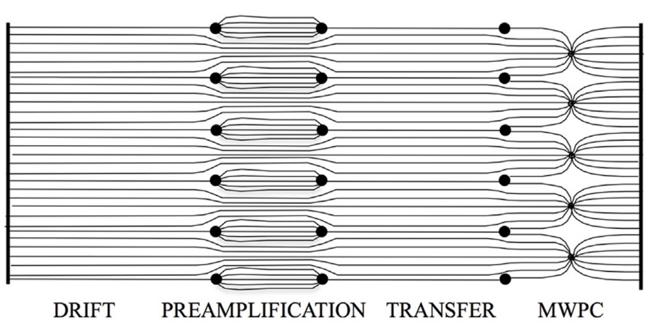

Fig. 3. Schematic structure and field lines in the Multistep Chamber (drawing not to scale).

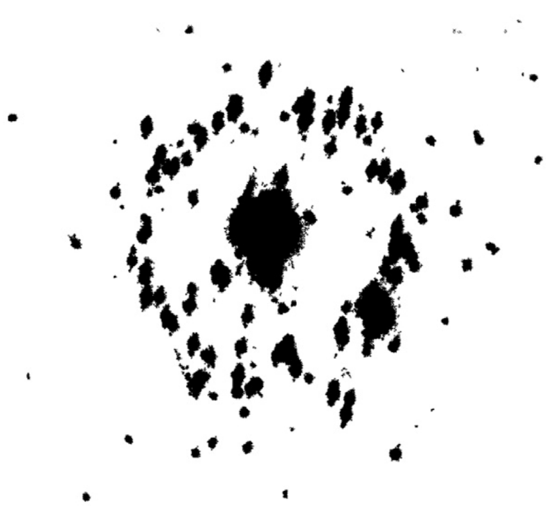

Fig. 4. Integrated image of ~30 events, produced by a 15 GeV electron beam in 1 m long argon radiator. The central spot corresponds to the direct beam ionization [2].

spectral sensitivity, in the far ultraviolet, is the interval between the vapor ionization threshold and the window's transparency cut-off. In their seminal 1977 paper, the authors discuss several combinations of fluoride windows with vapors of benzene, acetone, ethyl bromide and more. In later studies, triethyl amine, TEA ($(C_3H_5)_3N$) was found to be a better choice, owing to its high vapor pressure and low toxicity [9,10].

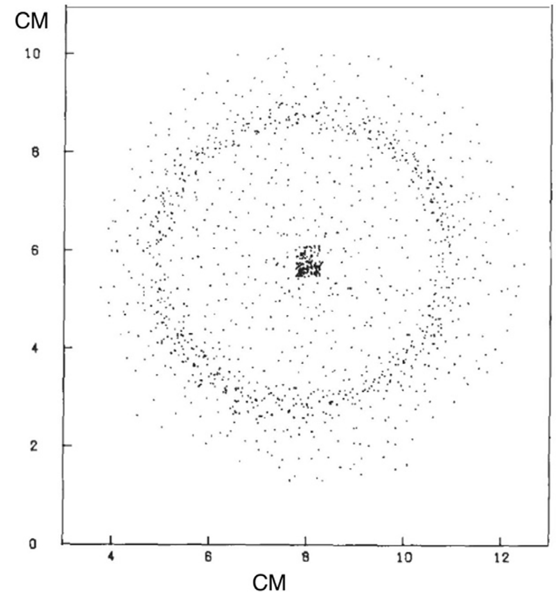

Fig. 5. Overlapping Cherenkov rings recorded in a 10 GEV pion beam using a TV digitizer [3].

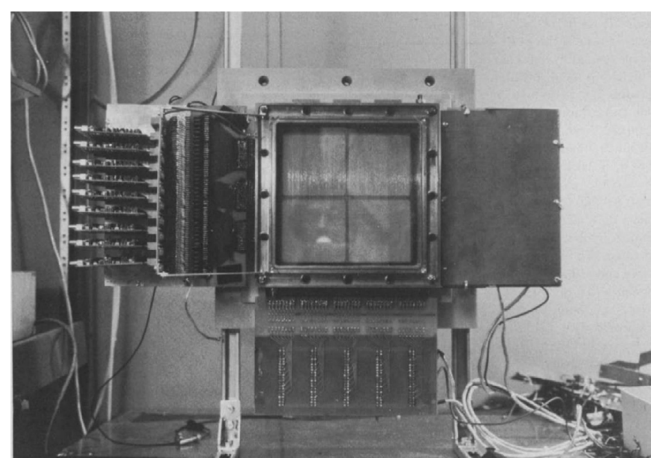

Fig. 6. A 20 × 20 cm^2 multistep chamber prototype with a composite CaF_2 window and full electronics charge recording on cathode and anode wires [4].

A liquid with a vapor pressure of 55 torr at room temperature and a photoionization threshold of 7.45 eV, TEA can be used with calcium fluoride windows to cover a spectral region between 7.5 and 9.5 eV, Fig. 2. Added to a gas mixture transparent in the region of spectral sensitivity, saturated TEA vapors have an absorption length at room temperature around one mm, permitting the use of thin conversion gaps and therefore the realization of fast UV photon detectors.

The original paper was followed by numerous detailed studies on the performance and particle resolution power of the technology [11–14]; an historical survey of the major experimental results in the mid-nineties can be found in Séguinot and Ypsilantis [15].

3. Photosensitive gaseous detectors

To perform detection and localization of single photoelectrons required the development of devices capable of amplifying the signal by a large factor; with the electronics available in the early eighties, a gain above 10^5 was deemed necessary to achieve good efficiency and localization properties. While Multiwire Proportional Chambers (MWPC) were appropriate to cover the large sensitive areas required by

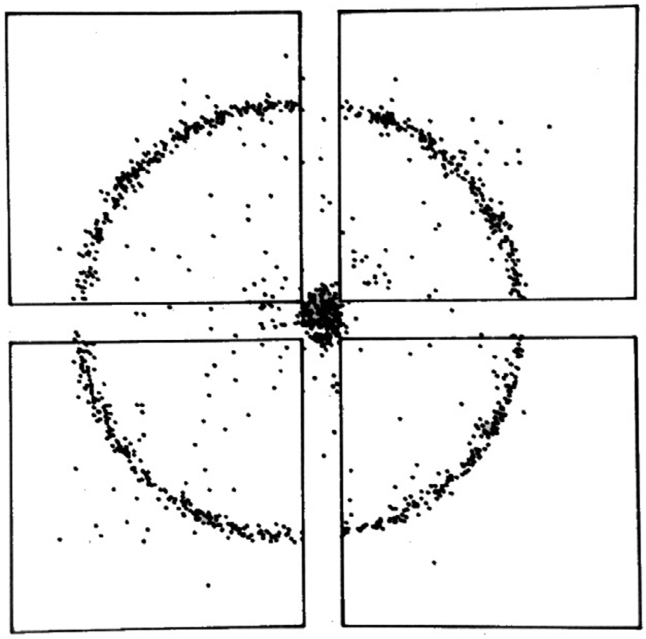

Fig. 7. Overlapping Cherenkov photon rings recorded with the prototype detector [5].

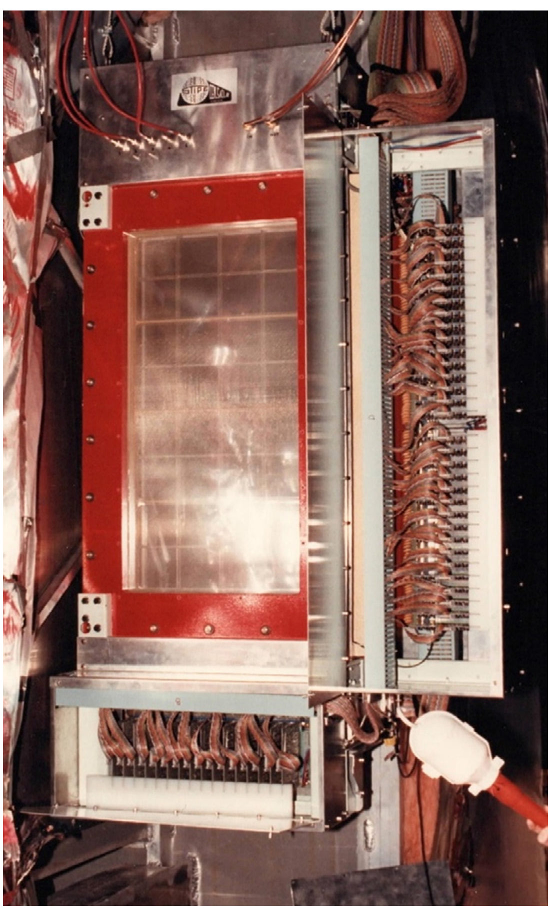

Fig. 8. One of the large multistep chambers for E605, fully equipped with readout electronics. The frame of the composite CaF_2 window is visible (picture by the author).

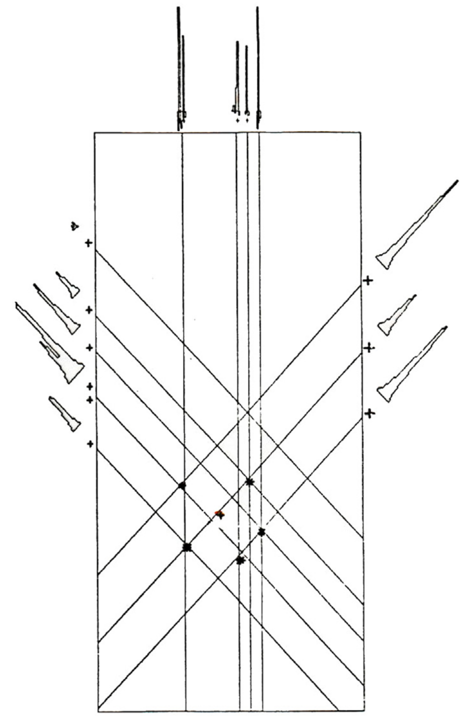

Fig. 9. A five-photons event recorded with the E605 RICH [6].

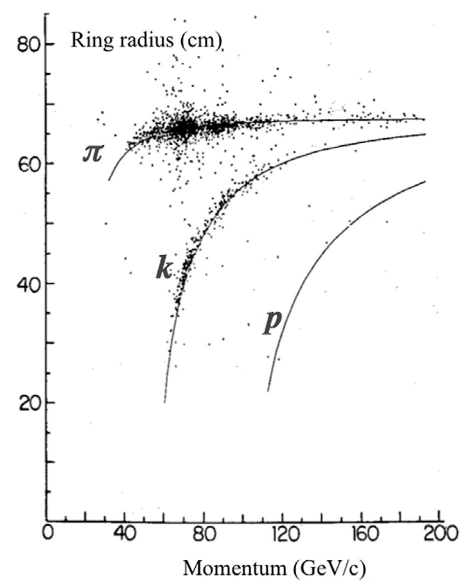

Fig. 10. Particle identification power of the E605 RICH detector [7].

RICH systems, it appeared that the addition of a photosensitive vapor to the gas mixture was prone to induce charge spread and discharges due to reconversion in the sensitive volume of UV photons generated in the multiplication process. The newly introduced Multistep Chamber (MSC) solved the problem [16]. The device adds to a standard MWPC a preamplification structure, with a high field region between two wire meshes placed between the sensitive volume and the MWPC, Fig. 3. Ionization electrons released in the drift gap enter the high field region and multiply in avalanche; a fraction of the electron charge then proceeds into the transfer gap and is further amplified by the MWPC. Originally developed to permit a gated operation, exploiting the delay between ionization and detection of the amplified charge, the MSC operates particularly well in a gas mixture including a photosensitive vapor as TEA, suggesting a photon-mediated charge transmission between the preamplification and transfer gaps. While this explanation was

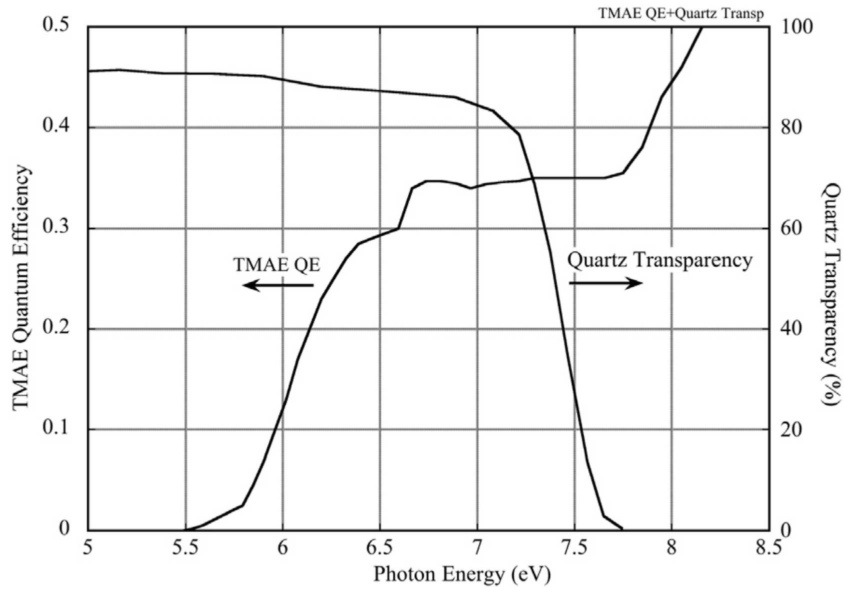

Fig. 11. TMAE quantum efficiency and quartz window transparency as a function of photon energy (compilation from various sources).

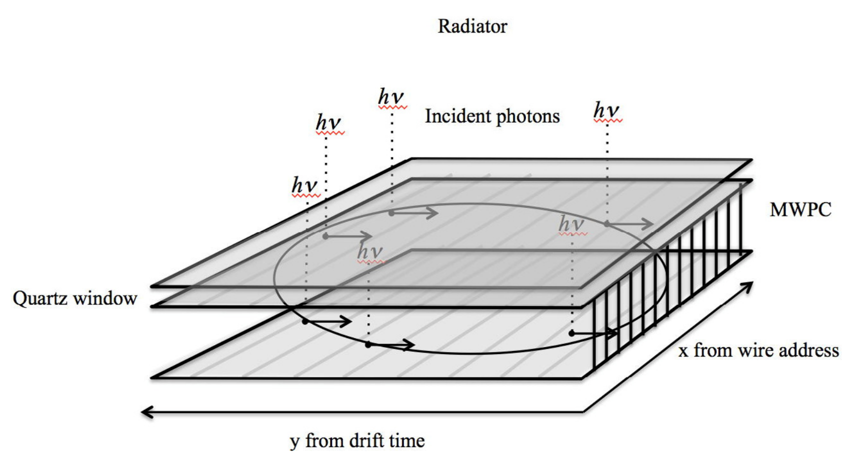

Fig. 12. A drift chamber configured as photon detector. Cherenkov UV photons generated in the radiator cross the window and ionize the gas. The photoelectrons drift to an end-cap MWPC where they are detected and localized [8].

questioned later by simpler considerations on the ratio of fields between the two gaps, it resulted in the development of a detector capable of achieving gains in excess of 10^6 in a photosensitive gas mixture, suitable for the RICH applications. Examples of simulated photon ring were reported in the original MSC paper.

Aside from permitting higher gains, the double structure strongly suppresses secondary photon-mediated processes, as the photons emitted by the avalanches in the MWPC are absorbed in the gas before reaching the drift gap and received full amplification. The Gas Electron Multiplier (GEM) introduced by the author in the late nineties exploits a similar concept to achieve high gains in photosensitive gases [17,18].

In their collaborative work, Ypsilantis and CERN's Gas Detectors Development group (GDD) demonstrated the photon imaging performances of the MSC, replacing the MWPC, suitable for high rate applications but requiring complex electronics for signals readout, with a simpler spark chamber, triggered by an external beam signal; the image was recorded by photography, Fig. 4 [2]. The average radius of the ring, about 24 mm, corresponds well to the expectations for the radiator used (one meter of argon at STP). In the same work, images obtained with thin lithium and calcium fluoride crystals as radiators were shown, prefiguring the system later named "proximity focussing" RICH.

In an ensuing work, using the same experimental setup, the photographic recording was replaced by an electronic television digitizer, permitting faster data elaboration; Fig. 5 is an example of computer rendering of approximately 100 overlapping Cherenkov rings, recorded in a 10 GeV pions beam. The pattern has a radius of 30 mm, with a 3% resolution [3]. The paper reports also early results obtained replacing TEA with TMAE, to be used later in the large DELFI RICH system.

Useful for the initial performance investigation, the spark chamber readout is not suitable for high rate experiments, and was replaced in later works with a fully electronics recording of the charge detected on a MWPC anodes and cathodes.

4. The RICH detector for E605

In view of applications of the technology in high-rate experiments, a small RICH detector, instrumented with fast electronics readout, was developed in the early eighties by a CERN-Saclay-Stony Brook collaboration [4]. Fig. 6 shows the medium-size TEA-filled MSC prototype,

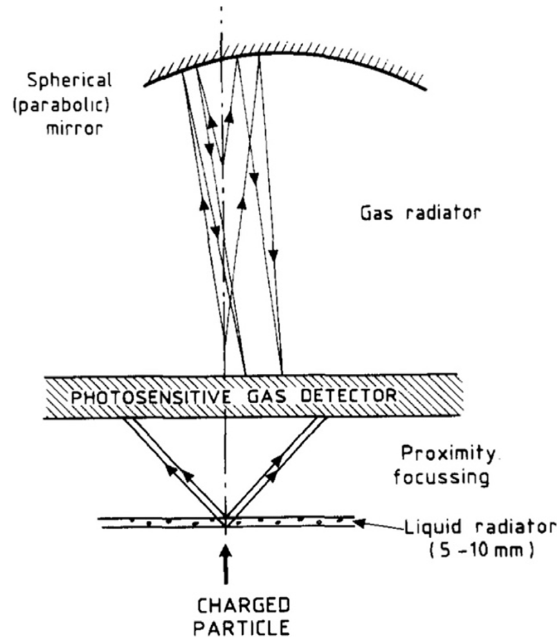

Fig. 13. The dual radiator scheme of the DELFI barrel RICH. The central drift chamber detects photons emitted by charged particles in the gas radiator and reflected on the image plane, as well as those generated in the liquid radiator following the proximity focussing scheme [19].

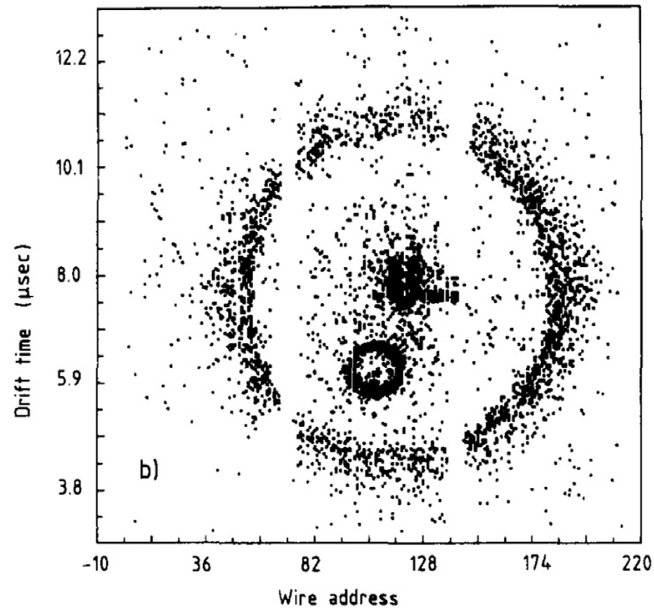

Fig. 14. Photon rings recorded with the double-radiator RICH prototype [20].

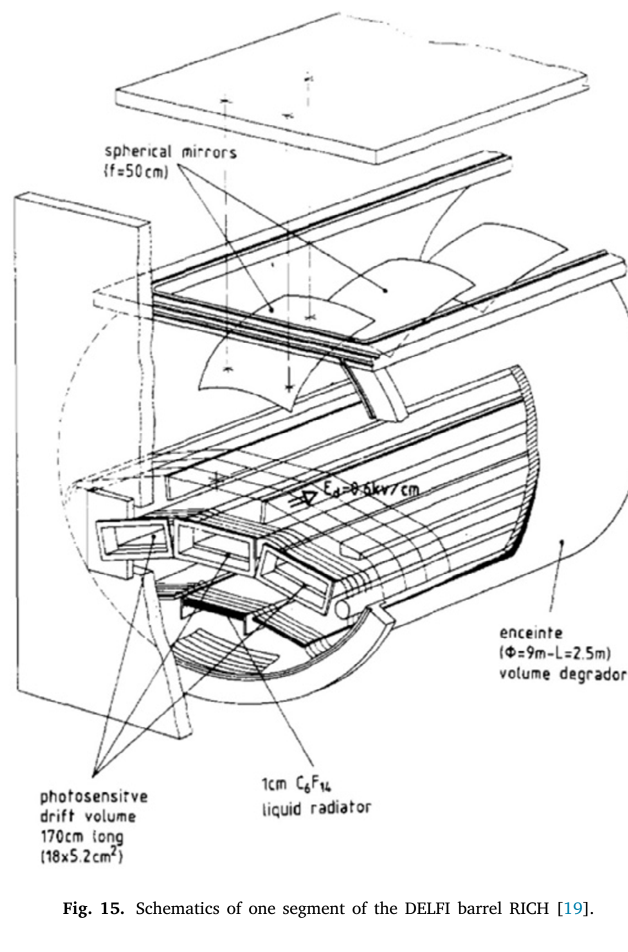

Fig. 15. Schematics of one segment of the DELFI barrel RICH [19].

with 20 × 20 cm^2 active area and a composite CaF_2 window. The MWPC electrodes were instrumented with fast multi-channel charge recording electronics, connected to groups of cathode wires along two perpendicular directions, and on the anode wires at 45° to the cathodes, providing a full 2-D image, capable of ambiguity-free reconstruction of multi-photon events. Efficiency, localization accuracy and resolution were studied by exposing a prototype detector to collimated UV photons generated by gas scintillation in argon; a center-of-gravity calculation of the detected charge profiles provided a single-photon position accuracy better than 500 μm rms, appropriate to the requirements of a RICH imager. Mounted on an eight meters long helium-filled radiator, the detector was exposed to a 200 GeV test beam at FERMILAB. An example of 200 overlapping events is shown in Fig. 7 [5]; the outlines correspond to the position of the four segments of a composite CaF_2 window.

Encouraged by the promising results achieved with the prototype, the group initiated the development of a large RICH system aimed at particle identification for the E605 experiment at FERMILAB. The dual-arm system included a large, helium-filled radiator vessel, 15 m long, a 4 × 4 array of mirrors at the far end, and two composite CaF_2 windows on the image planes upstream on each sides of the radiator. Two identical multistep detectors, with an active area of 40 × 80 cm^2 each, were mounted on both ports of the radiator, and operated with a helium-TEA gas filling, Fig. 8. Fig. 9 is an example of an event recorded with one detector; thanks to the three-coordinates projections, the five photons are reconstructed without ambiguities [6].

The system operated reliably for many years, providing particle identification between 50 and 150 GeV, Fig. 10 [7].

5. Second generation RICH detectors

Despite the great success of the early systems, the spectral response of TEA in the far UV demanded the use of expensive and fragile fluoride windows. The MWPC cathode readout, requiring a dense charge recording electronics, limits also the applications to relatively small detection surfaces. The discovery of a vapor with the exceptionally low photoionization threshold of 5.5 eV, TMAE (tetrakis dimethyl amino ethylene, $C_2[(CH_3)_2N]_4$) [21], permitting the use of quartz windows, represented a considerable advantage, Fig. 11.

Having in mind the realization of large systems, in a study co-authored by Ypsilantis, it was proposed to use a drift chamber as photon detector, as illustrated in Fig. 12 [8]. The sensitive volume is structured with field shaping electrodes as a drift chamber, moving photoelectrons

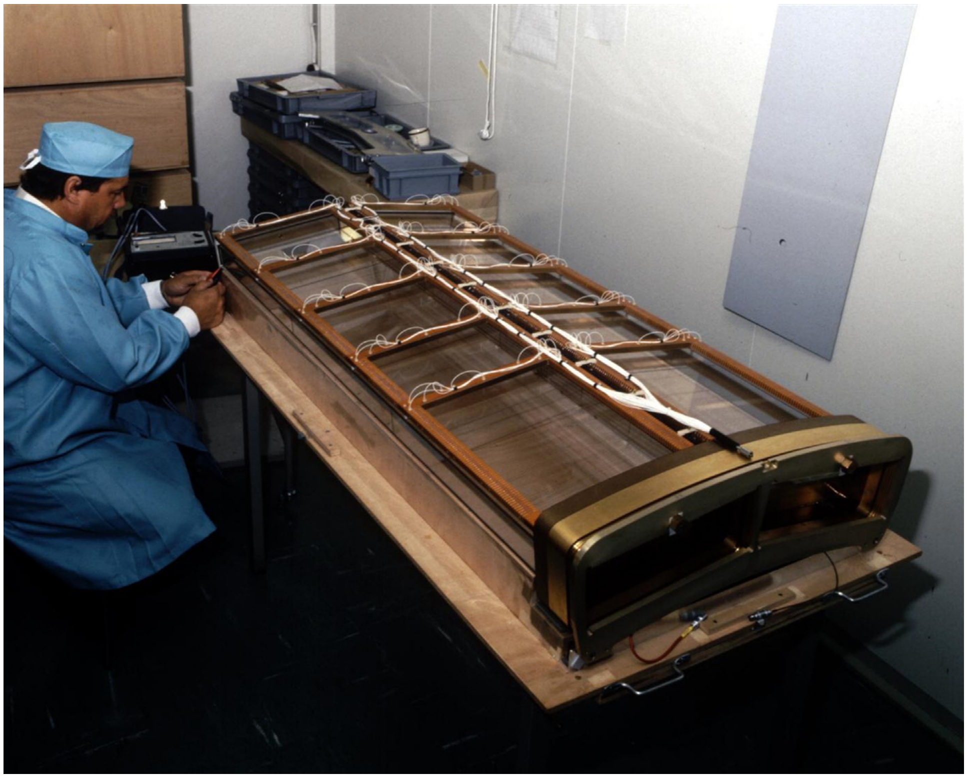

Fig. 16. Two drift chamber modules of the DELPHI barrel RICH prototype during assembly [19].

released in the gas to a thin elongated MWPC at one end. The measurement of the drift time and the wire count provide the longitudinal and transverse coordinates. While limited in rate capability by the long drift time (typically 20 μs for one meter of drift), the design was well suited for the experiments planned at CERN's LEP storage rings.

A dual scheme, with the drift detector mounted between a gaseous and a liquid radiator with a different index of refraction, Fig. 13 permits to extend the range of particle identification; an example of rings detected with the double radiator is given in Fig. 14 [20].

Based on the developments of the technology mentioned above, a large barrel RICH was built as main tool for particle identification of the DELPHI experiment at the LEP storage rings at CERN The modular structure adopted is shown in Fig. 15: drift boxes, 170 cm long and with a quartz window on both sides, are filled with the photosensitive gas mixture (CH_4–C_2H_6-TMAE); the drift field is provided by a set of wires with graded potential along the z direction. To prevent secondary effects due to reconversion of photons, the wires of the end-cap MWPC are surrounded by an enclosure with a narrow opening facing the drift volume. Fig. 16 is a view of the drift chamber prototype during assembly [19].

With a gaseous C_5F_{12} or C_4F_{10} and a liquid C_6F_{14} radiators, the detector it covered most of the solid angle and ensured charged particle identification between ∼2 GeV/c and ∼40 GeV/c [22]. The detector operated successfully from 1991 to the decommissioning of the LEP rings in 2001.

6. Summary and conclusions

This note describes the early developments of the Ring Imaging Cherenkov counter, a powerful particle identification method devised by Thomas Ypsilantis and collaborators. and successfully implemented in experimental setups worldwide. Tom's many related works represent a substantial advance in our understanding of the photons emission in radiators and detection with gaseous counters employing photosensitive vapors.

Further work led to the development of condensed and solid-state photosensitive layers, compatible with the use in gaseous devices [23, 24]; these developments are described in other contributions to this special volume.

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