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**FAST RICH DETECTOR USING A MWPC AT ATMOSPHERIC PRESSURE
WITH A PAD STRUCTURE READ OUT BY VLSI CIRCUITS**

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ABSTRACT

We report on the study of a Fast RICH Detector with a CaF_2 radiator, able to stand a high rate of events. The photon detector is a MWPC of 2 mm half gap, operated with methane and TEA at n.t.p. The simultaneous localization of charged particles and Cherenkov photo-electrons is performed at the sense wires and by measurement of induced pulses at pads equipped with the VLSI CMOS Amplex (ECN of 1100 electrons) and a fast analog multiplexed read-out. Measurements are presented concerning: (i) detection efficiency and spread of induced signals from charged particles and single electrons and (ii) observation of Cherenkov rings.

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1. INTRODUCTION TO THE FAST RICH PROBLEMATIC

Numerous are the applications where a high interaction rate of events still awaits for suited read-out scheme to capture the complex patterns issued from RICH detectors. Two approaches are now proposed, satisfying the two imperative constraints: minimum resolving time and two-dimensional localization: an optical solution where CCD's record light emitted by the detector [1], or, more conventionally, an electronical read-out of highly segmented "pad" structures [2]. In the case where compactness is also necessary, the second way looks unavoidable, however made attractive by the availability of monolithic circuitry and their capability of processing data *in situ*.

This work studies a pad solution with an effort of keeping the detector assembly as simple as possible, thanks to a very sensitive electronics. In that point of view, the use of a MultiWire Proportional Chamber (MWPC) as the photosensitive detector fulfils both requirements of fast collection time, about 50 ns, and two dimensionality by measuring pulses induced at a segmented cathode. The filtering time constants of the electronics will be the ultimate limitations to the maximum rate of events, assuming that the decision for event taking introduces an equally short dead time.

For obvious technical reasons, we opted for an operation at atmospheric pressure. Problems arising from such choices are well known. The geometry of the chamber will have to be optimized for a simultaneous detection of charged particles and of single electrons with a maximum efficiency. It is expected that the larger primary ionization deposited by the particle causes a spread of induced pulses such that the detection of the tiny single electron signal could be hindered around the particle impact point. This argument pushes to work with as thin a gap as possible. On the other hand, as the pad size is a limitation to the localization accuracy, centroid calculation could improve the situation at the expense of a necessary spread of induced signals, leading to compromise between gap width versus number and size of pads.

The most severe inconvenience of a MWPC without "cloisons" [3] is the photon feedback problem: if TMAE were to be used, photon mean free path, l_{ph} (pulse height), could be made smaller than the wire pitch by a high temperature operation (2). In fact, as our specific development aims to particle identification in a range of low velocities, $0.66 < \beta < 0.99$, a radiator of calcium fluoride was chosen, whose optical transmission allows the use of TEA. In this case, the possibility of a room temperature operation without "cloisons" may be investigated, as l_{ph} is < 1 mm in TEA.

This discussion settles the measurements necessary to optimize the chamber geometry, that are: detection efficiency and spread of induced signals from charged particles and single electrons, the sensitivity of the electronics being the key factor for a safe operation at the expected high rate and high gain in presence of TEA admixture.

2. DESCRIPTION OF THE APPARATUS

2.1 The detector (described from the top of fig. 1)

The Cherenkov radiator is a 10 mm thick plate of calcium fluoride. Its refractive index of 1.52 at 182 nm puts the Cherenkov threshold at $\beta = 0.656$; a transmission of 50% at 126 nm is quoted by the manufacturer (Harshaw). A gap of 20–40 mm, filled with helium, is necessary to adapt the ring radii to the size of the chamber input window of 100 mm diameter, made also of CaF_2 , but 5 mm thick.

The photosensitive detector is a MWPC with anode wires of 20 μm diameter, 4 mm pitch, 400 mm in length without support lines. One cathode is a mesh (500 μm square 50 μm wire) pressed against the window. The pad cathode is made of two thin G10 boards glued on either face of a foam plate. The inner board is etched to provide convenient pad patterns and connections. The pad gap width is adjustable from outside (0 to 5 mm) while the mesh gap is kept fixed at 2 or 5 mm. Mechanical tolerances, flatness etc., are of 50 μm .

2.2 The electronics

Anode wires are equipped with preamps–shaping amplifiers providing signals of base width < 100 ns [4]. Analog and digital signals are recorded.

The pad front end electronics is based on the VLSI CMOS chip, Amplex [5]. Its main features are: (i) 16 charge preamps (Operational Transconductance Amplifiers) and shapers, (ii) serial multiplexer operating up to 1 MHz, (iii) chip carrier in a package of 8 x 8 mm², 2 mW/channel power consumption, (iv) several chips (up to 16) can be daisy chained. Analog pulses are stretched at the maximum of amplitude by an external signal (hold), possibly generated by the event itself. The pre–amplifier peaking time of 600 ns provides the necessary delay to send the hold signal with the proper timing. The present version of Amplex has an occupation time (at the filtering stage) of $\approx 1.5 \mu\text{s}^{(*)}$.

The read–out system is based on a newly developed CAMAC card, referred as DRAMS (Digital Read–out for Analog Multiplexed Signals) [6]. A card comprises two blocks processing 512 channels each, with the following functions: (i) digitization by an 8–bit FADC whose dynamical range can be split into four different slopes, (ii) data comparison to threshold values stored in a memory; data smaller than threshold are suppressed, (iii) pedestal values, resident in another memory are subtracted from data above threshold. The result and the associated address are stored in a RAM read via CAMAC standard, (iv) a fast private bus is also available to scan several cards and get a fast data transfer to any external buffer memory.

(*) A new version of Amplex is under preparation where rise time, occupation time, dynamical range and DC level control will be improved.

2.3 Performance of the pad electronics

Having 16 chips (256 channels) connected to a chamber with pad capacitance of 10 pF, we measured: (i) a sensitivity of 0.30 fC (1900 electrons) per ADC channel, (ii) a mean noise figure of 0.58 ± 0.07 ADC channel (1100 electrons), (iii) a linear dynamic range of 80 fC, (iv) a total multiplexing rate of up to 1 MHz within this dynamic range, (v) a pedestal stability < 0.2 ADC channel/day, (vi) a gain uniformity $< 2\%$. More details are found in ref. [6].

3. DETECTION OF SINGLE ELECTRONS

3.1 Evaluation of the detection efficiency

An UV beam, issued from a deuterium lamp, extracts single electrons from a spot $< 1 \text{ mm}^2$ at the pad electrode by photoelectric effect. The detection efficiency of single electrons is measured at the anode wires as these signals will serve to trigger the pad electronics. Two methods are practised.

With such a small spot, counting rates of the source are found stable and reproducible if accurately positionned. Figure 2 shows the plateau obtained when respectively high voltage or electronic threshold are varied, the other parameter being kept constant. The beginning of a plateau is observed at 2200–2250 V.

The assumption of an efficiency > 0.8 at the voltage of the beginning of plateau can be confirmed by another method. At low gain, the distribution of pulse height A , is exponential for avalanches issued from single electrons [7]. Taking A_0 as the mean and A_{th} as the minimum pulse height detectable by the electronics, the fraction R of the number of events where $A_{th} < A < A_0$ to the total number of events is $R(A_0) = \exp(-A_{th}/A_0) - 1/e$. When A_{th} goes to zero or $A_{th} \ll A_0$, that is that the efficiency approaches 1, then $R(A_0)$ goes to 0.632. In fig. 3, the three pulse height distributions (2, 3 and 4) show an exponential behaviour over 3 orders of magnitude and provide the numbers of table 1, supporting again an efficiency > 0.8 at 2200 V. The fourth distribution, at 2250 V, has a “Polya” shape [7] consistent with a value of $m = 1.20$. The same kind of calculation as above gives a mean of 56 ADC channels (17 fC) and an efficiency of 0.95.

3.2 Spread of the charge induced at the cathode by single electrons

The mean number of pad hit per event, having the UV beam centred on a pad is shown in fig. 4 at various high voltages. Measurements are plotted versus an additional cut applied at the software level to the pad pulse height data (ADC channel unit). This will be found necessary (sect. 4) to reduce the spread of induced signals of charged particles. Triggering with anode signals, such a cut affects the pad efficiency relatively to the wire efficiency. This relative loss fraction, shown in

fig. 4, multiplies the wire efficiency at a given HV (table 1) to give the pad efficiency. This correction is more important for events occurring between two pads as the induction is shared between them.

4. RESULTS WITH CHARGED PARTICLES WITHOUT CHERENKOV EFFECT

4.1 Set-up, efficiency and rates

The detector was installed at a test beam (T11/PS/CERN) of positive particles, pion and proton, tuneable between 0.5 and 3 GeV/c. A Time-Of-Flight (TOF) allows particles to be tagged at the software level. A set of scintillators defines an event trigger in an active beam area of $10 \times 10 \text{ mm}^2$ in the chamber. The chamber has a 2 mm half-gap width, 256 pads of $8 \times 8 \text{ mm}^2$ size and 32 wires equipped. Working at a beam momentum $> 2 \text{ GeV/c}$ and orthogonal track incidence ensure that no Cherenkov photons can, in principle, escape the CaF_2 windows because of trapping by total reflection ($\beta_{\text{tr}} = 0.746$ at $n = 1.52$). That allows the study of charged particles in gas mixtures with or without TEA in absence of contribution of Cherenkov light.

Figure 5 shows an earlier beginning of plateau when TEA is added to pure methane. Also presented are particle rates, normalized to a fixed number of triggers and the mean number of wires hit per event; both increase continuously up to the operating voltage for full detection of single electrons. In absence of TEA, better detection of adjacent sharing of ionization is responsible for a modest rise while an additional contribution appears with TEA: photon feedback is not the only cause as it cannot explain many events where photo-electrons were even observed centimetres away from the particle impact (pion beam profile in sect. 5). It is probable that imperfections of the surface of the window let escape some Cherenkov photons. The chamber was operated safely at 2100 V with methane and TEA at a wire rate up to 10 kHz.

4.2 Spread of the charge induced at the cathode by charged particles

Figure 6 shows distributions of the number of pad hit per event for different values of a cut applied at the software level to the pad data. At the lowest value of the cut, the distribution is broadened by a second peak attributed to a setting of the whole chip (16 channels) due to a shift of the DC base line at too large input signals ($>> 80 \text{ fC}$). As shown in fig. 7, this defect is cured, for the moment [6], by increasing the cut level by an amount such that the single electron detection efficiency is still kept high (fig. 4). Again, the presence of TEA increases those numbers by 30% compared to pure methane.

Let us summarize the influence of the spread of induced signals on the measurement of rings. At 2100 V, with a cut of 8 ADC channels, an area of 7 ± 4 pads is obscured around the particle

impact, leaving the single electron detection efficiency at a 80% level on the rest of the cathode area. Figure 8 represents the geometry of Cherenkov rings expected with a distance of 35 mm between radiator and window and track incidence angle of 25° . The grid corresponds to pads of $8 \times 8 \text{ mm}^2$. The smaller ring has a β of 0.66, further incremented by steps of 0.02. The shadowed area around the impact of the particle is the particle induction spread, showing that rings of $\beta \geq 0.68$ must be detectable.

5. MEASUREMENT OF CHERENKOV RINGS

Results are obtained at a beam momentum of 1.10 GeV/c, with respective values of β for pions and protons of 0.992 and 0.761. As said before, the total reflexion condition should only let the CaF_2 windows be transparent to the Cherenkov light emitted by the protons. Therefore, by selecting pions from protons in the same run, we can obtain distributions of number of detecting elements hit per event with and without emission of Cherenkov light. That is shown in fig. 9 for pads, wires and beam profile. The contributions of particles and of photons emitted by the radiator and the window are summed up in the distributions obtained with protons. An estimate of the mean number of photo-electrons per ring can be made, e.g. for a pad cut of 8 ADC channel at 2100 V. With the measured mean numbers of pads hit per event of 24 ± 7 , 7 ± 4 and 2 ± 0.5 , respectively for total distribution, particle without Cherenkov, single electrons, one gets 8–9 photo-electrons per ring. A coarse evaluation of the ring diameter (60 mm at 1.10 GeV/c) is compatible with the expected value of the refractive index of 1.53. The separation of the peaks in the distributions of number of wires hit/event could be exploited as a Cherenkov threshold decision from a fast measurement of the wire multiplicity (≈ 200 ns). The relative frequencies of getting a pad hit are represented in fig. 10. The whole plot is broadened by the size of the beam ($10 \times 10 \text{ mm}^2$) as no corrections are made for the beam impact position.

Table 2 summarizes some other results taken at different values of HV, momenta and cuts. A merit factor number of 31 cm^{-1} is obtained at 1.10 GeV/c, 10 mm radiator thickness. An analysis of the analog pad pattern (in progress) solving the problem of pulse overlap of nearby photons is clearly needed to evaluate correctly the detector performances. Let us remark that too many photons per ring may not be welcomed for this task.

6. CONCLUSION

Preliminary results have shown that a thin symmetric MWPC without “cloisons”, filled with methane plus TEA at atmospheric pressure and room temperature, can be operated as a

photosensitive detector associated with a CaF_2 radiator for particle velocity measurement in the range $\beta = 0.68$ to 1.0. The two-dimensional localization of the photo-electrons and incident particle is achieved by a segmented cathode whose pads are read out by a VLSI chip, Amplex (1100 electrons ECN) followed by a fast multiplexed read-out. 8–9 photo-electrons are detected per ring at 1.10 GeV/c. Work is under progress to reduce the filtering time constant of the pad electronics for operation in the megahertz range of interaction rate.

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TABLE 1

Evaluation of the efficiency of detection of single electrons in pure methane.
The total number of events was 80 000 in a run.

V(kV)	A ₀ [adc bin]	A ₀ [fC]	Number of events Ath < A < A ₀	R(A ₀)	Efficiency
2100	11	3.3	22245	0.278	0.44
2150	19	5.7	32450	0.406	0.64
2200	34	10	41460	0.518	0.82

TABLE 2

Measurements of Cherenkov rings obtained from protons with a distance radiator window of 20 mm (300–500 events per run). The too small value of number of pads hit/ev. found at 1.15 GeV/c is attributed to a lack of acceptance at the pad cathode and an increasing number of overlaps.

HV [V]	p [GeV/c]	Pulse hight pad cut	Mean number pad hit	Mean number wire hit	Ring diameter
2100	1.00	8	21 ± 7	7.8 ± 3	45 ± 5
2100	1.10	8	24 ± 7	9.5 ± 3	60 ± 5
2100	1.10	6	29 ± 9	9.5 ± 3	60 ± 5
2100	1.10	12	18.6 ± 6	9.5 ± 3	60 ± 5
2100	1.10	15	16.3 ± 5	9.5 ± 3	60 ± 5
2100	1.15	8	20 ± 7.4	8.1 ± 3	68 ± 5
2050	1.15	8	15.4 ± 5	7 ± 2.7	68 ± 5
2000	1.15	8	11.4 ± 3	5.7 ± 2	68 ± 5

FIGURE CAPTIONS

- Fig. 1 Cross section through the detector elements. Relative position between pads ($8 \times 8 \text{ mm}^2$) and anode wires (4 mm pitch).
- Fig. 2 Single electrons in methane. Open points: pulse height measurements at anode wires and cathode pads for 2-pad gap widths. The mesh gap is of 2 mm, pad size $8 \times 8 \text{ mm}^2$. Filled points: UV source rate measurement, $2 + 2 \text{ mm}$ gaps.
- Fig. 3 Single electrons in methane: 2 mm half gap. Curves 1, 2, 3 and 4: pad pulse height distributions at 2250, 2200, 2150 and 2100 V. One ordinate value is indicated per curve (N's), respectively 1, 1, 10, 10×10^3 . To be associated with table 1 and fig. 2 for efficiency evaluation. Least square fit done over 2 orders of magnitude at 2250 V, 3 orders of magnitude for the others.
- Fig. 4 Single electrons in methane: mean number of pads hit per event and fraction lost in pad efficiency relative to wire versus a cut to pad pulse height data: 2 mm half gap, $8 \times 8 \text{ mm}^2$ pad size.
- Fig. 5 Charged particles: efficiency plateau, rate and number of hit/event at anode wires in methane (cross) and methane plus TEA (circle); (2 mm half gap).
- Fig. 6 Charged particles: distributions of mean number of pads hit/event in methane plus TEA at 2100 V for 3 values of the pad pulse height cut: 3, 6 and 12 ADC channel.
- Fig. 7 Charged particles: mean number of pads hit per event versus a cut to the pad pulse height data. Left: methane plus TEA, top curve at 2100 V; in next curves, the HV is decremented by step of 50 V. Right: methane, respectively 2250 V and 50 V step. The same anode gain is achieved in the presence of TEA with 100 V less than in pure methane (2 mm half gap, $8 \times 8 \text{ mm}^2$ pad size).
- Fig. 8 Calculated geometry of Cherenkov rings at a track angle of incidence of 25° : $n(\text{CaF}_2) = 1.53$, photons emitted at 5 mm from the radiator surface. Cross: particle impact point. Hatched circle: spread of particle induction.
- Fig. 9 Anode wires maps and distributions of number of wires and pads hit per event, without and with emission of Cherenkov photons from pions and protons at 1.10 GeV/c. Methane plus TEA, 2100 V, 2 mm half gap, $8 \times 8 \text{ mm}^2$ pad size.
- Fig. 10 Plot of relative frequencies of getting a pad hit. Same conditions as in fig. 9.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9

Fig. 10