Romanian Reports in Physics, Vol. 61, No. 3, P. 513–521, 2009

A COORDINATE SENSITIVE DETECTOR FOR PARTICLES GENERATED IN HIGH ENERGY REACTIONS

MADALINA CRUCERU[1,2], D. BARTOS[1], I. CRUCERU[1], G. CARAGHEORGHIOPOL[1],
O. G. DULIU[2], A. BARBORICA[2], P. CRISTEA[2], C. M. NICULAE[2], R. C. BOBULESCU[2]

[1] *"Horia Hulubei" National Institute for R&D in Physics and Nuclear Engineering,*
407 Atomistilor Str., P.O.Box MG-6, 077125 Magurele (Ilfov), Romania,
Fax: 4021-4574440, e-mail: cruceru@ifin.nipne.ro
[2]*University of Bucharest, Faculty of Physics,*
P.O. Box MG-11. Magurele (Ilfov), RO-077125, Romania; e-mail: duliu@b.astral.ro

(Received September 16, 2008)

Abstract. The investigation of multiple particles production can be possible by using a 4π detection consisting of a position sensitive detector, placed in the immediately vicinity of the target, and thus allowing the determination by coincidence measurements of the initial impact point. The construction, testing as well as installation procedures of such a kind of detector designed and built at the National Institute of Physics and Nuclear Engineering – Bucharest are presented and discussed.

Key words: position detector, cumulative regime, spatial resolution, temporal resolution, detection efficiency.

1. INTRODUCTION

To detect particles generated in cumulative regime it needs the exact registration of both generation moment and initial positions of involved particles, task which can be very well accomplished by using a set of position sensitive detectors coupled by means of fast coincidences circuits.

Although cumulative reactions have been intensively investigated in past decades [1-3], due to the complexity of such measurements a great variety of detection systems were developed and successfully used [4–6].

It is worth mentioning that the development of long scintilator rods detectors opened new opportunities in realization of 3D position sensitive detection systems that allow determining the coordinates of the impact initial point in cumulative reactions.

For this reason, each experiment, by its specific condition, needs a particular tailored system of detection.

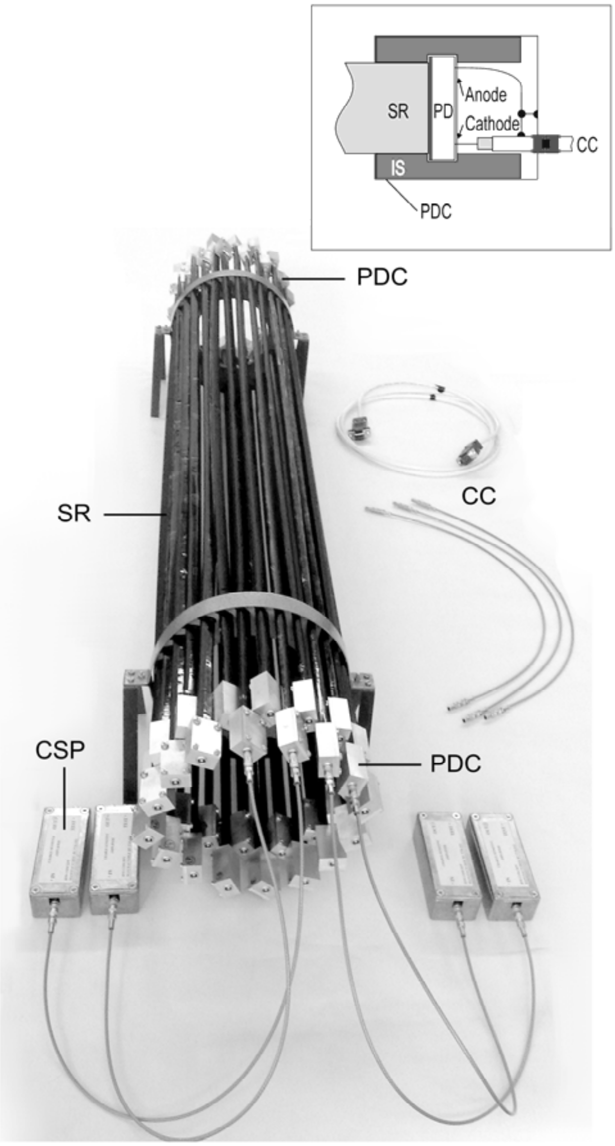

Fig. 1 – A general view of the detection system. The inset illustrates a schematic drawing of the photodiode case (PDC): SR – scintilator road; PD – photodiode; CSP – charge sensitive preamplifier; CC – connection cables.

In our case we had to take into account a set of local limitations related to target location, beam current density, presence of intense magnetic field as well as detector efficiency which should be of minimum 90% in Minim Ionization Particles (MIP) mode.

Table 1

The main characteristics of Hamamatsu S7510 PIN photodiodes at 25° C

Parameter	Values
Active area	6 × 11 mm
Photo sensitivity	45% at $\lambda = 660$ nm
Spectral response domain	320 nm to 1100 nm with a maximum at 960 nm
Dark current	1.0 nA typical and 10 nA at V_R=10V
Terminal capacitance	80 pF at 1MHz and V_R=10V
Cut-off frequency	15 MHz at R_L=50Ω and V_R= 10V.

R_L = bias detector, V_R= bias voltage

Further in this paper will present the constructive plan as well as the preliminary performances of a 3D position sensitive detecting system provided with a cylindric array of rod-like long scintilator detectors designed and built at the National Institute for Physics and Nuclear Engineering, Bucharest. This detector is a part of a more complex system: SFERA designed to work with the Nuclotron Particle Accelerator now under commissioning at the Joint Institute of Nuclear Research (JINR), Dubna, Russian Federation.

2. MATERIALS AND METHODS

2.1. DETECTOR

The system consists of an array of 36 detecting elements to form a cylindrical structure, with the inner diameter of 100 mm and the outer one of 140 mm. Each individual detecting element is represented by a BC 430, (Bycron Corporation-Saint Gobain) 1 m long plastic scintillation rod with S5710 Hamamatsu PIN photodiodes at both ends (Fig. 1, Table 1).

The BC 430 plastic scintilator was chosen owing to its 580 nm maximum spectral emission [7] *i.e.* at 48% of the PIN photodiode spectral sensitivity. As the detection system was designed to work in the presence of intense magnetic fields up to 1.5 T, PIN photodiodes were preferred to photomultiplier tubes, because their electric characteristics are not affected by magnetic field.

Each individual detector consists of a 1000 × 10 × 5 mm plastic rod wrapped with a Tyvek type reflection paper and optically connected at both ends by means of some special designed shielded case to PIN photodiodes (Fig. 1).

The dimensions of scintillation rods were chosen to obtain a spatial resolution better than 5 mm at the level of each individual detector as well as a good detection efficiency.

A typical connection for PIN diodes [6] to coaxial cable and external shielded case is presented in Fig. 1. The anode grounded connection was recommended by diode manufacturer.

2.2. CHARGE SENSITIVE PREAMPLIFIER

The detection ensemble consisting of a scintillation rod optically connected to a PIN photodiode is working linked to a charge sensitive preamplifier built in a SMD compact structure with discrete FET/BJT components at input and a fast operational amplifier at the output (Fig. 2).

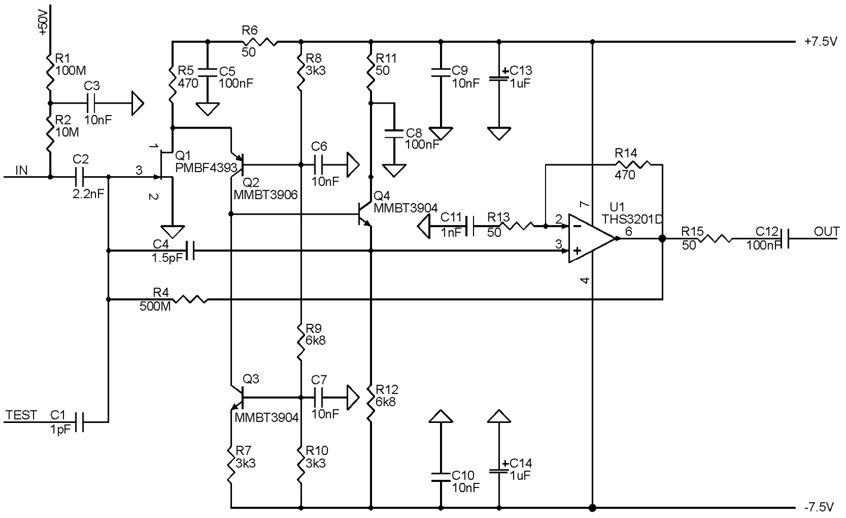

Fig. 2 – The schematic diagram of the charge sensitive preamplifier.

The input stage is designed in a rather traditional folded-cascade configuration based on Q1 and Q2 FETs aimed to minimize the Miller effect on the gate-drain capacitance of input Q1 FET. In order to maximize the voltage gain of the input stage, the transistor Q2 has a high-impedance active load built around transistor Q4 and drives the Q5 repeater. The main feedback loop is closed through the capacitor C_1 that makes the circuit of charge amplifier. The input stage sensitivity A_{in} is inversely proportional to the feedback capacitance:

$$A_{in} = 1/C_1 . \tag{1}$$

Therefore a smaller C_1 value is desired. However, the rise time is also inversely proportional to the C_1 value:

$$\tau_t = C_T \left(\frac{C}{C_1 g_m} \right), \tag{2}$$

where C_T is the sum of the detector, preamplifier input, stray, and feedback capacitances; C_1 is the feedback capacitance; C is the internal capacitance of the amplifying mode of the preamplifier, and g_m is the transconductance of the preamplifier input transistor.

Hence, a compromise must be made between sensitivity and rise time when choosing the value of the C_1 capacitance. Also, an increase in the detector capacitance C_T requires a matching increase in the feedback capacitance C_1 in order to preserve the pulse timing.

The fall time $\tau_d = R_1 C_1$ of the pulses, resulting from C_1 discharge through a resistor in parallel with it is also important. Instead of placing a discharge resistor in parallel with C_1, we have pursued the solution suggested by eq. (1) and (2), that results in a faster discharge and/or improves the noise performance of the preamplifier [8].

Accordingly, the discharge resistor R_1 is connected in a feedback loop that includes the output stage, having an additional voltage gain. In this configuration, the additional voltage amplification A of the output stage decreases through the Miller effect the equivalent R_1 resistance by a factor of A. As a result, larger resistors should be used in the loop, resulting in the same capacitor discharge time constant τ_d:

$$\tau_d = \left(\frac{R_1}{A}\right) C_1 . \tag{3}$$

One important advantage of using a larger discharge resistor is the smaller current noise it adds to the input. This configuration is equivalent to using a "cold resistor" $R_c = \frac{R_1}{A}$, that has a spectral noise density $\overline{i_n} = \sqrt{\frac{4kT}{R_1}}$ smaller by a factor of $\sqrt{A}$ compared to the noise of a physical resistor having the equivalent resistance R_c.

The output stage is implemented using a fast operational amplifier U1, THS3201D in a non-inverting configuration that has an amplification factor of A=10.4. This brings the charge sensitivity of the preamplifier up by the same factor, to an upper limit of 6.9 V/pC, if actual shunt, stray and feedback capacitances are neglected. The DC feedback loop is closed by the same discharge resistor $R1$, which results in a DC offset at the U1 output that is typically close to the gate-source cut-off voltage of the Q1 transistor, given the characteristics of the 4393 transistor family characteristics. This requires the insertion of an AC-coupling capacitor $C12$ in series with the output [9].

The main characteristics of the charge sensitive preamplifier constructed in this way and experimentally determined are reproduced in Table 2.

2.3. TIME AND POSITION RESOLUTION

Time resolution is defined by means of rise time δt_1 and δt_2 of amplitude signal generated by PIN1 and PIN2 photodiodes respectively:

$$\delta\tau = \tfrac{1}{2}\sqrt{\delta t_1^2 + \delta t_2^2}\ . \tag{4}$$

For each scintilator rod the impact position P_x was calculated by dividing the difference of signal arrival time t_1 and t_2 for each PIN to the total transit time t equal to the ratio between rod length l and the light speed c_s in the scintilator:

$$P_x = O_f + k\frac{t_1 - t_2}{l / c_s}\ . \tag{5}$$

where O_f represents the offset while k is the slope of the calibration curve.

Table 2

Experimentally characteristics of the charge sensitive preamplifier designed to work in connection with Bycron 430 scintilator rods

Parameter	**Source**	
	^{135}Cs	^{90}Sr/^{90}Y
Detection efficiency (%)	0.6–2.4	0.1–28.0
Spatial resolution (cm)	12–14	8–13
Temporal resolution (ns)	6–10	5–6

By keeping the beta ray source in the same position, we have determined experimentally the impact position spectrum consisting of a single symmetric line whose FWHM represents the detector spatial resolution.

In these conditions, the spatial resolution varied between 8 and 13 cm.

3. RESULTS AND DISCUSSION

3.1. PRELIMINARY EXPERIMENTAL RESULTS

In order to check the system performances, *i.e.* time resolution and position as well as the detection efficiency we have performed a set of measurements by using both beta and gamma isotopic sources. In the case of beta ray we have used a ^{90}Sr/^{90}Y isotopic source with an activity of 3.1 MBq. In order to obtain different energies, we have used Lucite absorbers whose thicknesses varied between 2 and 13 mm. In the case of gamma rays, we have used more isotopic sources such as ^{113}Sn, ^{51}Cr, ^{95}Nb, ^{137}Cs, ^{22}Na and ^{60}Co whose activities varied between 3 and 100 kBq. In both experiments, the sources were placed within detection system, on its longitudinal axes and translated to extremities to simulate the real experimental setup.

Table 3

Experimentally characteristics of detection system as determined by means of ^{137}Cs gamma-ray and ^{90}Sr/^{90}Y beta-ray radiation sources

Parameter	**Source**	
	^{135}Cs	^{90}Sr/^{90}Y
Detection efficiency (%)	0.6 – 2.4	0.1 – 28.0
Spatial resolution (cm)	12 – 14	8 - 13
Temporal resolution (ns)	6 – 10	5 -6

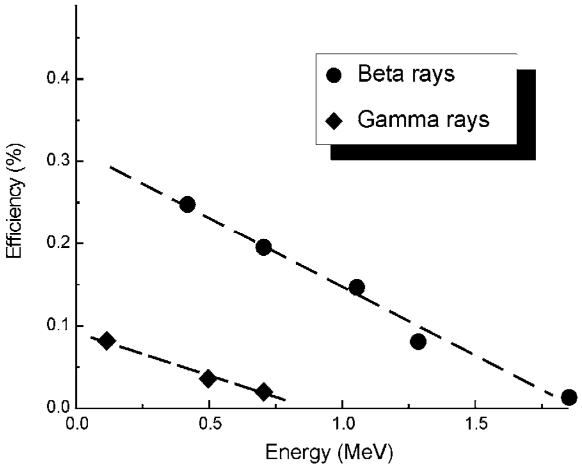

Fig. 3 – Experimental energy dependence of the intrinsic detection efficiency in the case of beta as well as gamma-ray.

In this way it was possible to analyze the amplitude of the light pulses generated in scintillator rod and arrived at PIN photodiodes.

In these conditions, the average time resolution of individual detectors as experimentally determined was of 2 ± 0.1 while for the entire detection system we have obtained values varying between 5 and 6 ns for ^{90}Sr/^{90}Y source and between 6 and 10 ns in the case of ^{137}Cs (Table 3).

By keeping the beta ray source in the same position, we have determined experimentally the impact position spectrum consisting of a single symmetric line whose FWHM represents the detector spatial resolution. In our measurements the spatial resolution varied between 8 and 13 cm for beta-ray source and between 6 and 10 cm for gamma-ray source (Table 3).

Further, by means of eq. (5) we calculated the speed of light inside of scintillator rods. By repeating such measurements for different positions of beta source along detector axis, we have obtained for the light speed in plastic scintilator a value of 12.6 ± 1.0 cm/ns.

BICRON CORPORATION, the supplier of plastic scintillator BC430, gives for refractive index the value 1.58 [7] and in this situation the calculated speed is 19.2 cm/ns. The difference between calculated and experimentally determined speed of light and is due, in our opinion, to the multiple reflections which increases the optical path beyond the geometrical distance between the impact scintillator point and PIN photodiode.

To determine the detector intrinsic efficiency we have registered the count rate given by each pair of PIN corresponding to each individual scintilator rod when a beta ray source of ^{90}Sr/^{90}Y was placed within detection system and translated along its longitudinal axis.

In Fig. 3 we have plotted the intrinsic efficiency for single detector element as a function of electrons as well as photons energy. By analyzing this graph it follows that in both cases, the detection efficiency is inversely correlated with radiation energy, and, for the same energies the efficiency corresponding to beta-ray is significantly higher than the corresponding to gamma-ray one (Table 3).

4. CONCLUDING REMARKS

A position sensitive detection system consisting of an arrangement of 36 individual plastic scintilator rods planned to investigate cumulative reactions was designed, assembled and preliminary commissioned at the National Institute for Physics and Nuclear Engineering-Bucharest. Finally, this detector will be included in the SFERA detection system planed to be installed at the JINR- Dubna Nuclotron accelerator. The originality of our solution consists of using instead of photomultipliers, PIN diodes which are significantly less sensitive to magnetic fields. In this way, our detection system maintains their performances regardless of the presence of external magnetic fields.

Preliminary measurements, performed by means of beta as well as gamma ray isotopic sources, allowed to obtained a spatial resolution varying by respect to source position between 8 and 13 cm while the temporal resolution was of 2 ± 0.1 ns while the global detection efficiency was significantly higher for beta-ray than for gamma-rays.

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