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A Profile-based Gaseous Detector with Capacitive Pad Readout as the Prototype of the Shower Maximum Detector for the Endcap Electromagnetic Calorimeter for the STAR Experiment

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Abstract

The results of testing of the full scale prototype of a profile-based shower maximum detector with external pick-up pads for the endcap EMC for the STAR experiment at RHIC are presented. It is shown the plastic streamer tubes with coverless profile operating in proportional mode with low gain are suitable basic unit for shower maximum detector.

The investigation has been performed at the Laboratory of High Energies, JINR, Dubna.

1 Introduction

In our previous report [1] we presented the results of MC simulations and conceptual design of gaseous Shower Maximum Detector (SMD) with a pad(strip) readout of signal for endcap EMC of STAR experiment at RHIC [2]. Two types of detectors were proposed: MWPC and profile-based chamber. A posibility to use plastic streamer tubes operating in proportional mode with analog readout of external pick-up pads (strips) for precise coordinate measurements is attractive for us. Profile-based particle detector can be as precise as conventional MWPC with pad (strip) readout [3],[4]. Detector mechanical tolerances are significantly relaxed. The space resolution would be determined by the quality of pad (strip) board and readout electronics.

The shower maximum detector will be placed in thin 25mm gap in the endcap EMC. The number of γ's in the SMD acceptance is about 800 for the central Au-Au collision at RHIC energies and the number of charge particles is the same. As showers as charge particles will detect. The size of pads decreases going towards the beam axes to resolve ambiguites due to increasing multiplicity. The time between bunches at RHIC will be about 100ns. So for high time occupancy a readout electronics need to have an integration time about 50ns, wide dynamic range, small signal/noise ratio for various pad's capacitance and as small as possible power dissipation.

Following the above arguments and the resoning our report [1] we have manufactured a full scale profile-based shower maximum detector prototype with pad capacitive readout. In this report we present results of testing of the prototype with a certain suitable readout electronics.

2 Description of prototype

A schematic view of the cross section of the prototype and the layout of measurement is shown in fig.1.

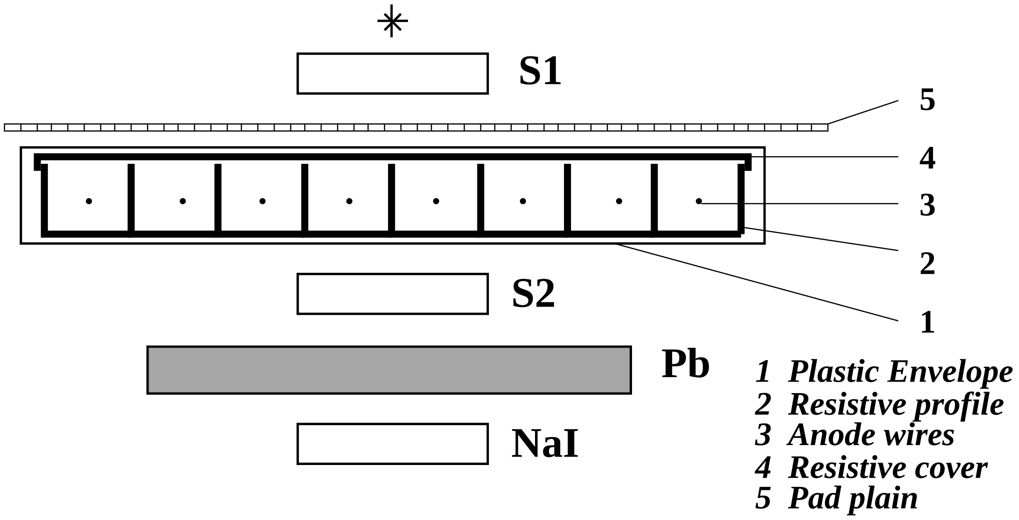

Fig.1. Block diagram of the test setup

The prototype consist of four plastic profile tubes each with 8 cells of $9 \times 9\text{mm}^2$ in size with 1mm thick separating walls inserted in a gas-tight plastic envelope. The profile used for the prototype was one of those made for the DELPHI hadron calorimeter [5]. The inner cathode surface of profile is coated by resistive carbon paint. The cathode resistivity of the profile is about $200K\Omega$ per square. The anode is the gold plated tungsten wire of 20 μm diameter strung in each profile cell with tension of 80g and supported by spacer in the middle point. The gas mixture used is argon + isobutane in the ratio 4:1 at normal pressure.

The size of the prototype is $40 \times 120 cm^2$. Both tubes with resistive cover and coverless have been used in prototype tests.

The G10 outer pad (strip) board with pads (strips) facing detector is placed directly on the tube plastic envelope. The sizes of the pads are 4×40 mm, 12×130 mm and 12×400 mm. Readout electronics is placed on the opposite pad side of the board.

The anode wires in each tube are connected together serving one readout channel. The anode signals are used only for tuning of operational high voltage applied to the tube.

3 Front End Electronics

Following the results of MC simulation the total electronic channel number of the endcap EMC shower maximum detector should be about 25000 with analog readout of anode wires (2000 channels) and cathode pads (23000 channels). The position of EM shower or the entrance point of minimum ionising particle (MIP) will be measured. Front End Electronics (FEE) is needed for a fast two-dimensional coding of the analog data.

The spatial resolution achievable by using an interpolation method depends on several parameters, in particular the signal to noise ratio S/N. A small noise allows to reach wide dynamic range at lower gas gain and, consequently, to slow down the detector aging.

The major problem of the FEE design is extremely limited space (25mm) given for placing of the shower maximum detector with the associated electronics and the cable communications that imposes the request of as small as possible power consumption [2].

Therefore the main parameters of the FEE are: peaking time (T_p), dynamic range, S/N ratio and power dissipation per channel (P_D).

Peaking time T_p should be match to one half of the crossing time (the time between bunches). At high channel occupancy (up to 100% for Au-Au collisions) the drift time should not exceed value of the crossing time, i.e. 100 ns. For the typical drift velocity of about 20 (ns/mm)$^{-1}$ this means that in the final design the profile cell size must be about 5-6 mm.

Mean number of particles in shower is about 100, so a noticeable total charge will be collected even at such small peaking time. But for MIP we should increase the gas gain.

To meet the high count rate ($T_p \sim 50ns$) and the low noise ($< 2000e^{-}@C_{pad} \sim$ hundreds pF) a bipolar IC technology is more prefered instead of CMOS. A common emitter chain in the first stage of the preamplifire (PA) with resistive feedback, forming a transimpedance amplifier, can provide the high gain at acceptable power. To prevent strong the gain and a pulse shape degradation at a large input capacitance the PA should have a high value of open loop gain [6]:

$$V_{out} \sim \frac{Q_{in}}{C_f^{eff}}; \qquad \tau_{rise} \sim \frac{C_{pad} C_c}{g_m C_f^{eff}}$$

where $C_f^{eff} = C_f + \frac{C_{pad}}{g_m R_c}$ - effective feedback capacitance, R_c, C_c - collector resistor and capacitance, respectively, and g_m - transconductance of a bipolar transistor.

If open loop gain $g_m R_c$ is rather large, the sensitivity of PA to C_{pad} value is reduced. However it demands higher $g_m \sim I_c$, i.e. to increase power consumption. Also serial noise must be small at short T_p.

To keep good double pulse resolution and high value of S/N ratio the PA has to be followed a multipole shaping amplifier (SA). The shaper should include also $1/t$ tail cancellation and transform input pulse into a near gaussian shape. From EMC physics considerations the dynamic range is requested as large as 1000. This value is more than enough for getting needed spatial resolution in interpolation method (~ 0.1 of pad pitch) [7]. Concerning on the FEE design it is desirable to realize this parameters at low as possible noise and, hence, at smaller power dissipation.

After amplifying and shaping the data from SMD have to be delayed and digitized. Since Shower Maximum Detector is a fast detector, the readout electronics delay circuits have to provide write and readout modes simultaneously. The delay of $\sim 1\mu s$, needed for Level 0 trigger decision, can be performed, in principal, by two ways as shown in Fig.2.

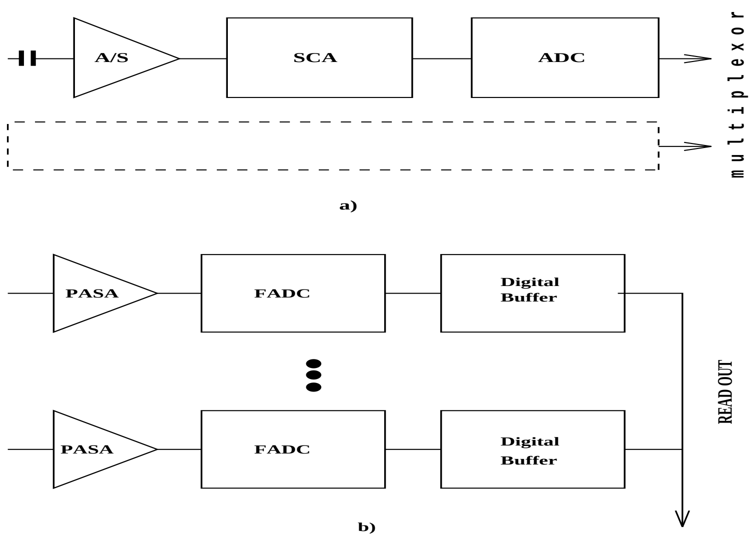

Fig.2. The scheme of diffrent variants of shaped SMD signal delay

The first (Fig.2a), analogue, is based on Sequential Capacitors Array (SCA) and the second (Fig.2b) is used the flash ADC with digital pipeline. The solution based on SCA approach is cheaper and consumer significantly lower power. The suitable number of pipeline cells is $10 \div 20$. Application of higher clock frequency (up to 40 MHz) can give a possibility to know a channel history and make an amplitude correction. The number of the ADC bits must be matched to dynamic range. Therefore FEE should use 10 bits linear or 8-bits non-linear ADC.

Following the arguments described above we have designed the multichannel electronics based on 32-chip (PASA) [8] developed by D.Dorfan (UC, Santa Cruz) for testing of the SMD prototype. This IC has extremely low power consumption $\sim 2mW/ch$. Other parameters such as peaking time $\sim 75ns$, $1/t$ cancellation and low noise (5 nA, r.m.s) are near values needed for the prototype.

Our goals were:

1) to design electronics for prototype test with a radioactive source and a beam

2) to investigate possibilities of a low power consuming chain implementation for readout of signals from large pads.

The arranged scheme of protection diodes at inputs and drivers at outputs to route data on cable is shown in Fig.3. The output pulses are transfered via 5m long TWP flat cable to 9-bit ADCs.

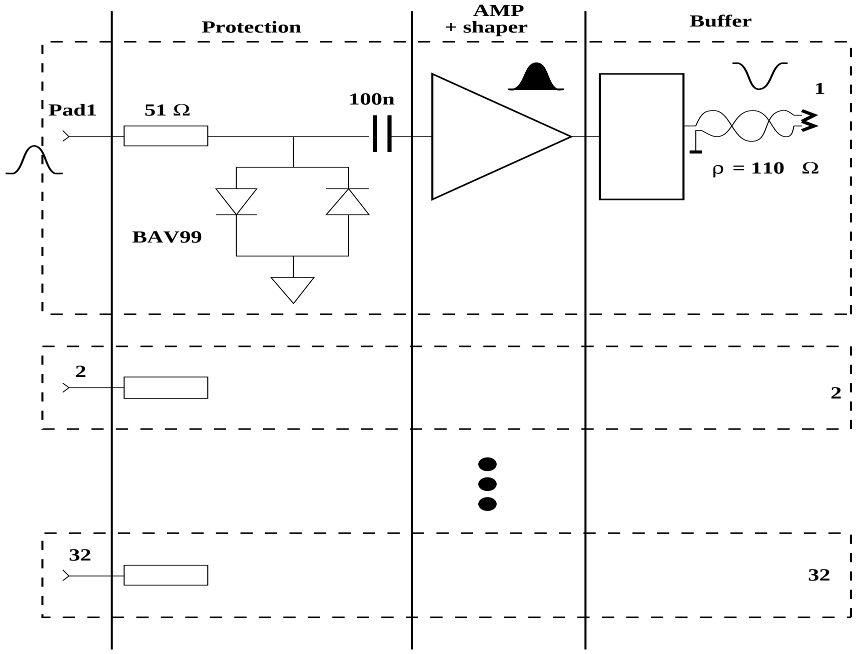

Fig.3. The scheme of readout electronics based on 32-channel chip for the SMD prototype test

Fig 4. shows a general view of the Shower Maximum Detector prototype on the side of the pad board. The 32-channel PASA chip has been mounted on individual board. The connection with pads was realized via input protection circuits by means of 32-pins connectors. A various type pads can connect by turns to the chip inputs.

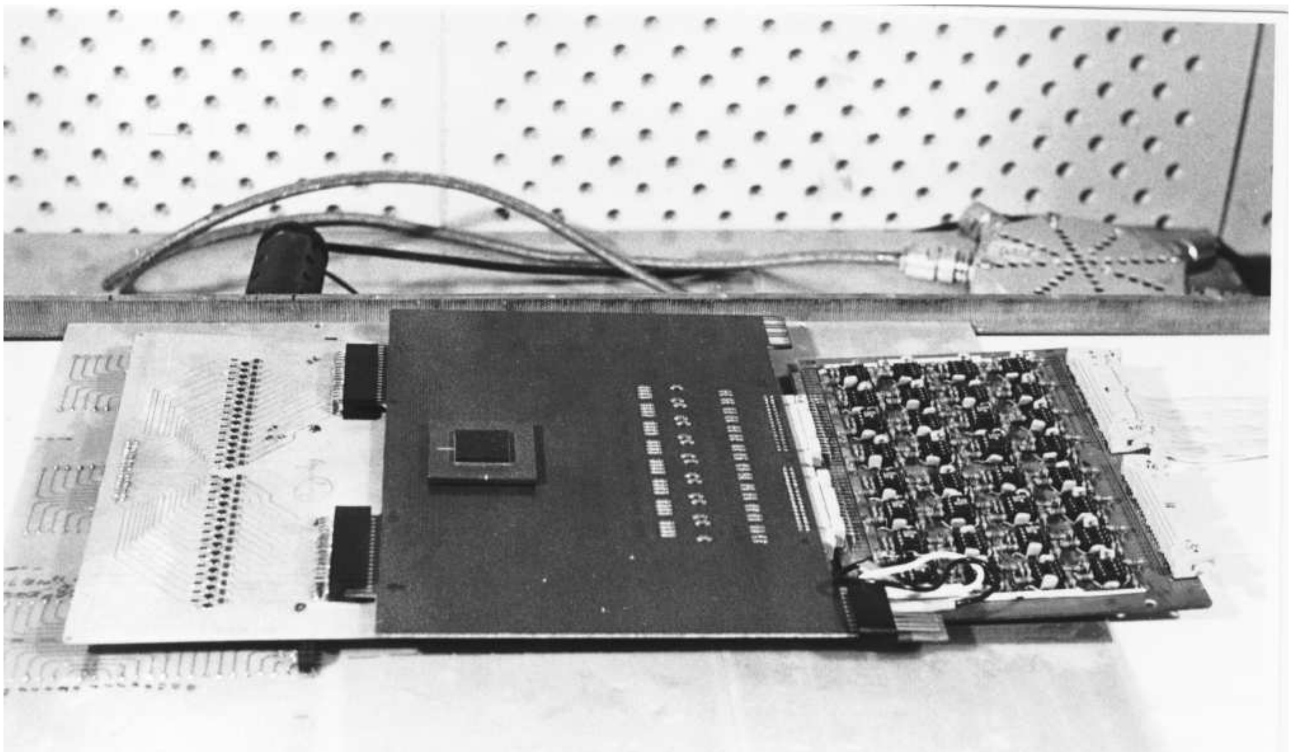

Fig.4. View of the shower maximum detector prototype

4 Test studies of prototype performances

Two types of plastic tubes were used in test studies: with profile closed by resistive cover and with coverless profile. The measurements were carried out using electrons (the energy up to 3 MeV) from Ce^{144} radioactive source. The unnecessary substance from upper and lower prototype screening boards were removed. The narrow upper collimator (2mm diameter slit) were used to define a narrow beam over pad.

The electrons with the energy more than 2 MeV are passed through scintillation counters S1 – S2 (energy loss $\sim$ 1MeV) and plastic tube (energy loss $\sim$ 1MeV). Signals from scintillation counters (S1 and S2 in Fig.1) formed the trigger for the ADC gate.

In experiments with cosmic muons additional large NaI counter was used for the ADC gate trigger too.

Fig. 5a shows the amplitude spectra of an individual pad (4×40 mm) at various operating voltage. The pedestal peak is well separated from the minimum ionising particle signal.

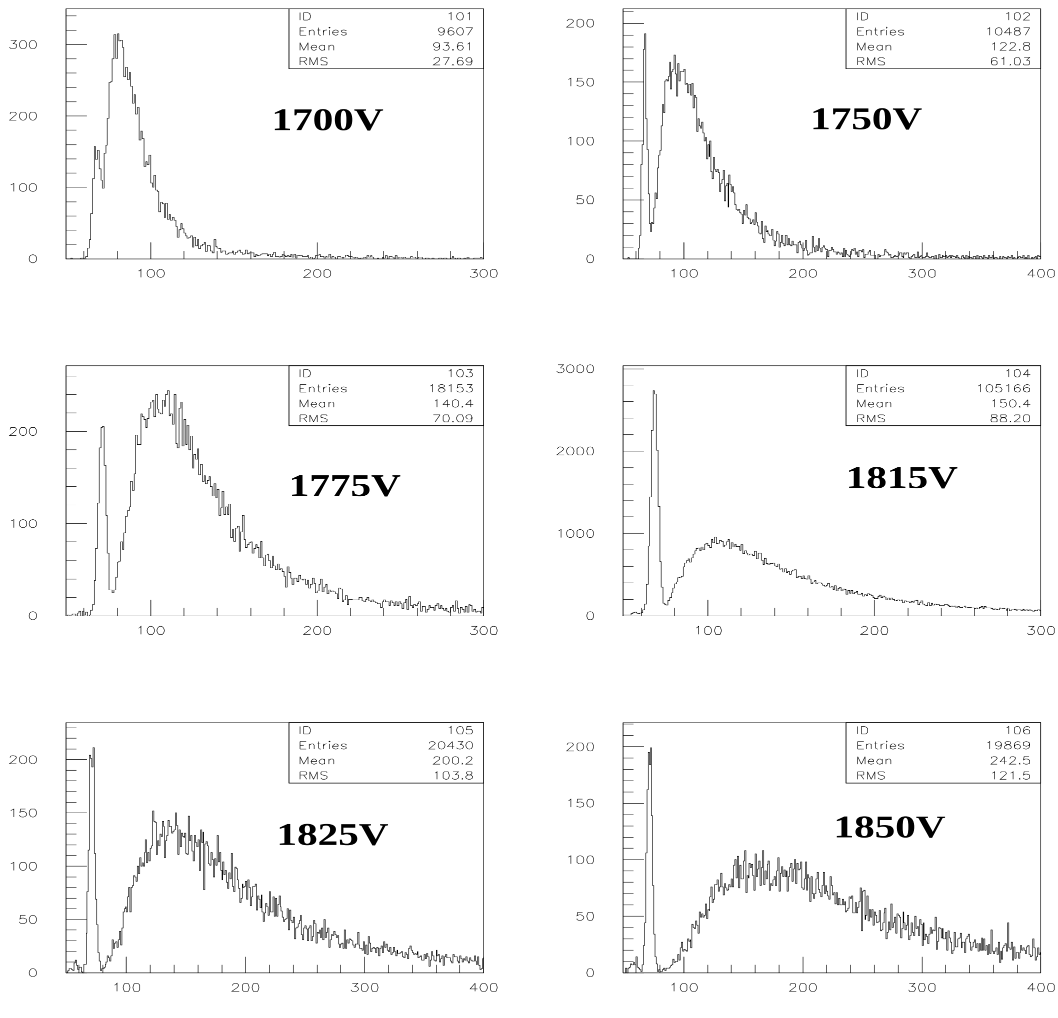

Fig.5a. The amplitude spectra of individual 4x40 mm pad
at various operation voltage
Measurements with radioactive source Ce^{44}

Measurements data with cosmic muons for six nearby pads at 1725V operational voltage in fig.5b shows the same (the ADC's pedestals were subtracted).

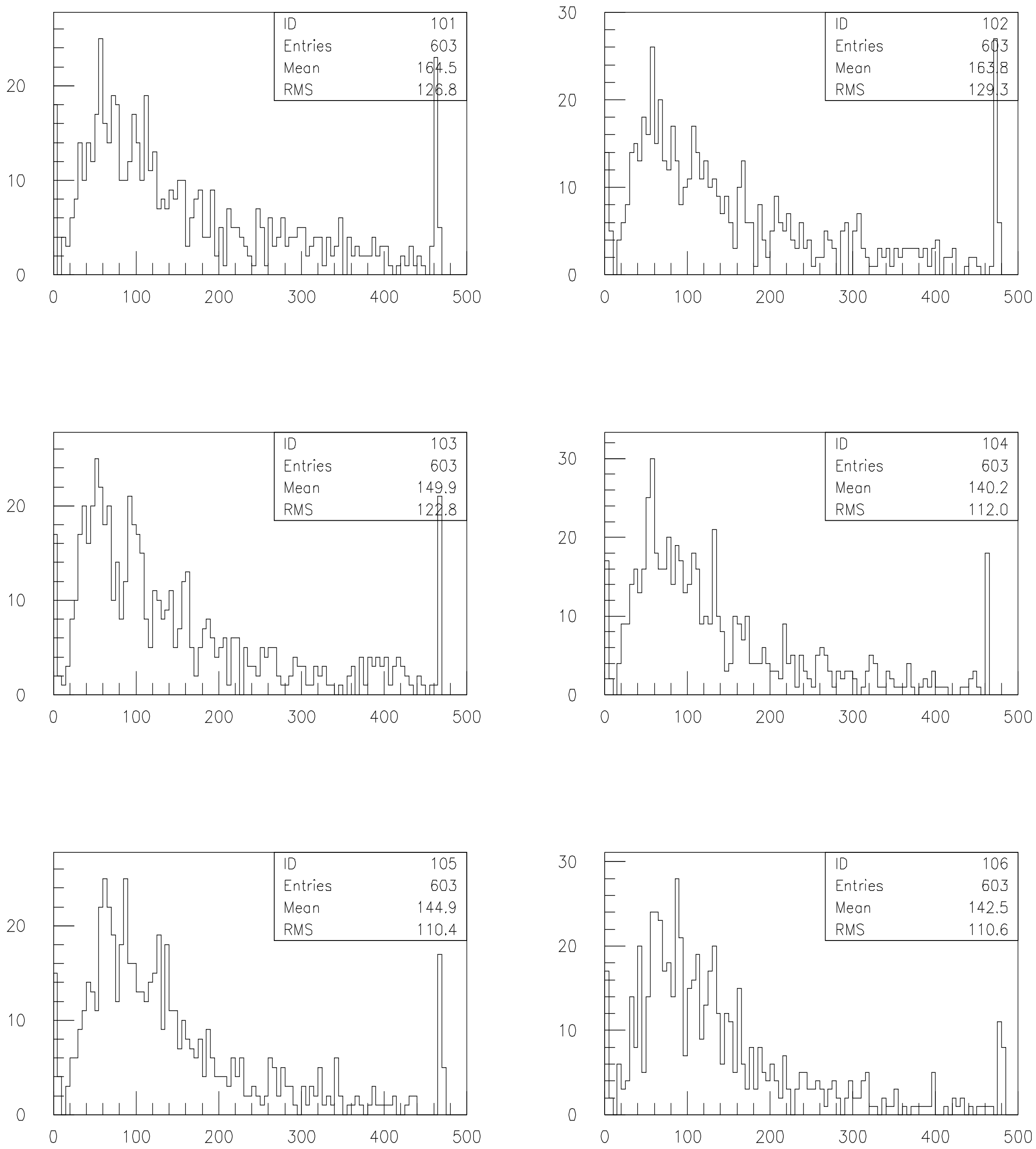

Fig.5b. The same as Fig.5a. at 1725V operation voltage
Measurements with cosmic muons for six nearby pads

The data for middle 12×130 mm and large 12×400 mm pads are shown in fig.6.

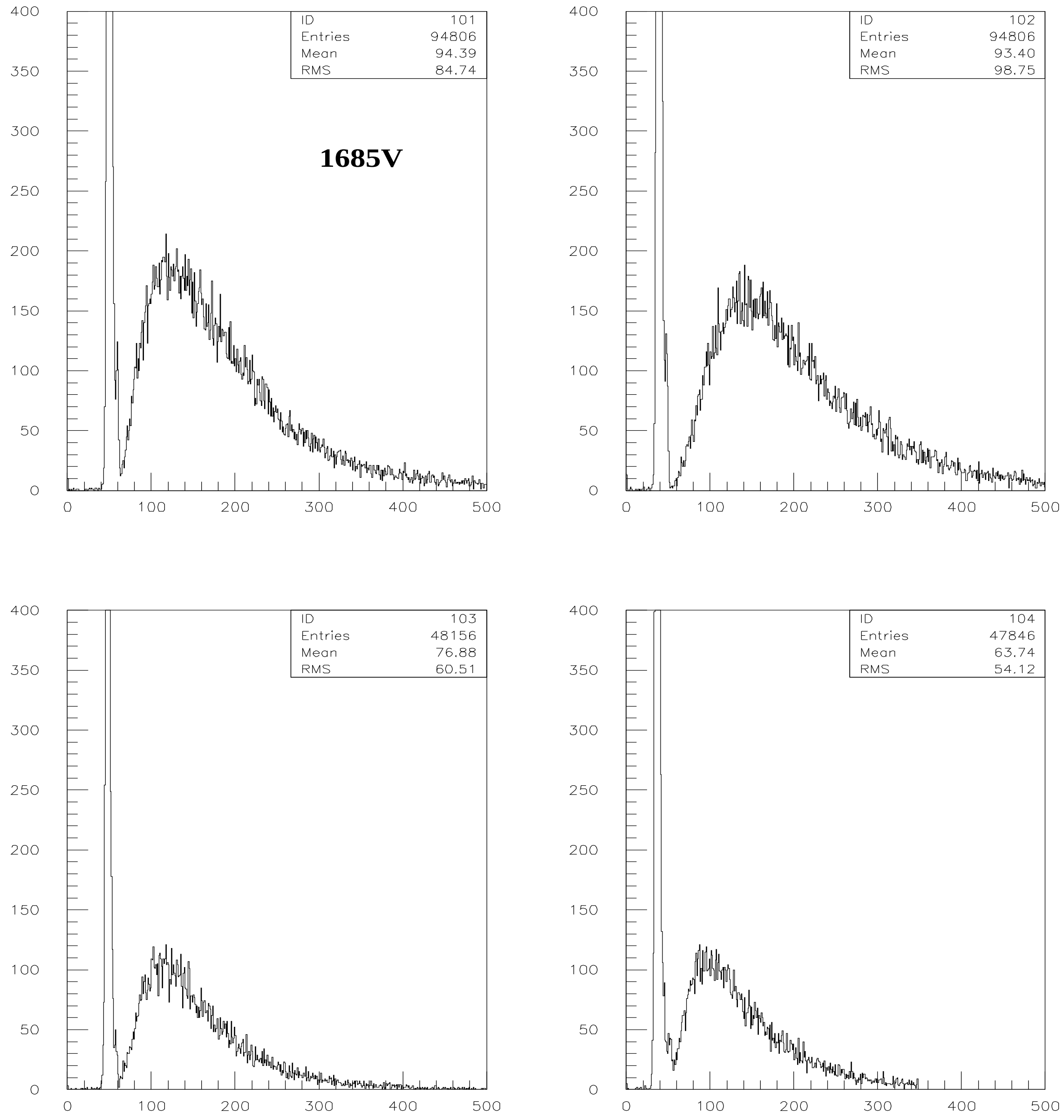

Fig.6. The amplitude spectra for two nearby 12x130 mm (top) and 12x400 mm (bottom) pads.
Attenuation is 5 (top) and 10 (bottom).

It is seen that at operating voltage value of about $1700 \div 1750$V we have well defined signal from minimum ionising particle. The tube operates in the proportional regime with the gain at the level of $10^4 - 10^5$. The pulse duration was not exceed about 150 ns at 1/10th of maximum height for different input pad capacitances of readout electronics. The output signal amplitude is nearly proportional to the value of pad capacitance that means the preamplifire gain doesn't change noticeable.

The amplitude spectra for tube with coverless profile for four nearby 4×40 mm pads are shown in fig.7.

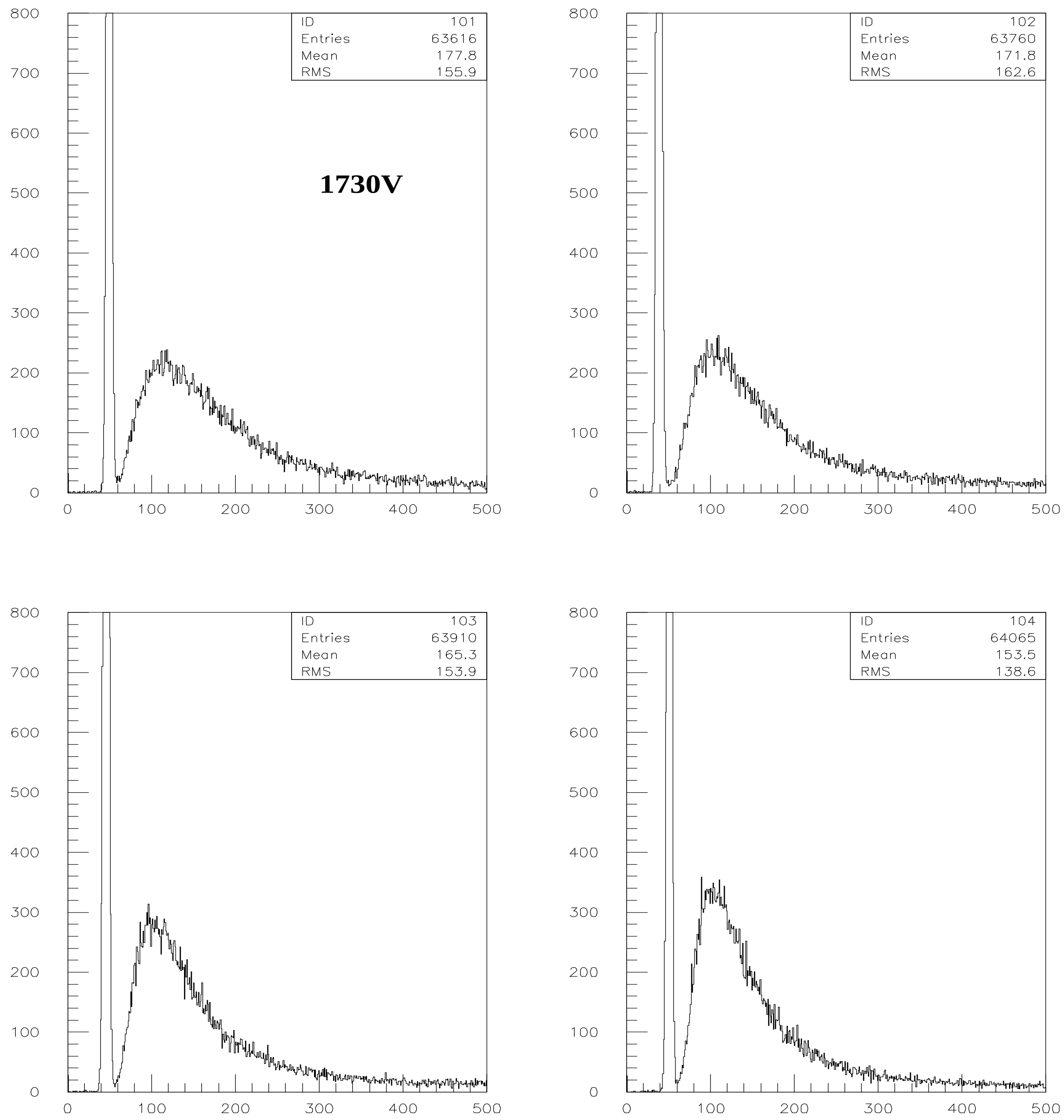

Fig.7. The amplitude spectra for 4x40 mm four nearby pads for tube with open profile

To investigate the position resolution we have measured a distribution of charge induced on the six nearby pads. The measurements with the tubes with profile closed by resistive cover have been made using cosmic muons. In experiments with the tubes with coverless profile the collimated radioactive source was used. The events with maximum charge on the middle (third) pad were selected.

In fig.8 the distributions of charge over six 4x40mm nearby pads for the tube with coverless profile and for the tube with profile closed by the resistive cover are shown.

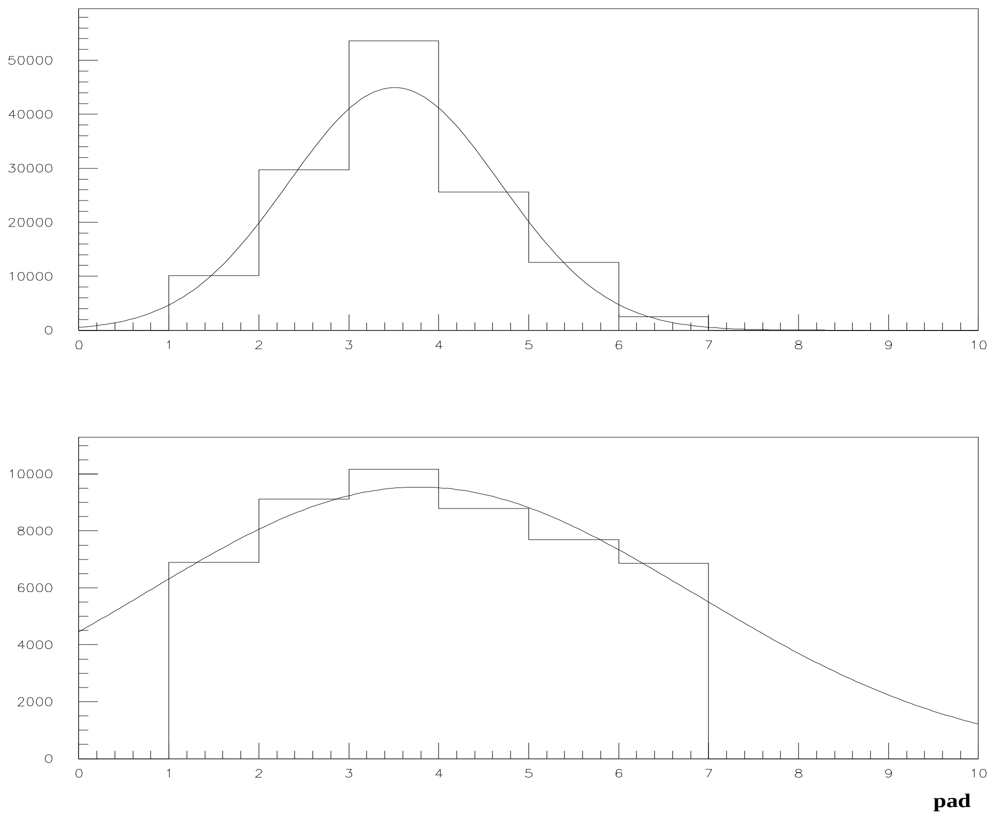

Fig.8. Charge distribution over six nearby 40x40 mm pads for the tube with opened (top) and closed (bottom) profile.

It is seen that the distribution for the tube with coverless profile is narrow enough so it will be possible to separate particles in high multiplicity collisions.

In [9] the detector of electromagnetic shower on the basis of plastic streamer tubes have been investigated but there the tubes were operate in high saturated mode with worse spatial resolution and lower rate capability.

The spatial resolution of detectors on the base of plastic streamer tubes with capacitive readout have been investigate in [3], [4], [10]. It was find that nonuniformity of cathode resistivity significantly impairs the spatial resolution and to use the tube with very high cathode resistivity ($> 10M\Omega$) or with low resistivity and coverless profile is preferable.

Following the results obtained we have designed the 30^o module of shower maximum detector. The assembling drawing is shown in Fig.9. The full technical documentation is prepared.

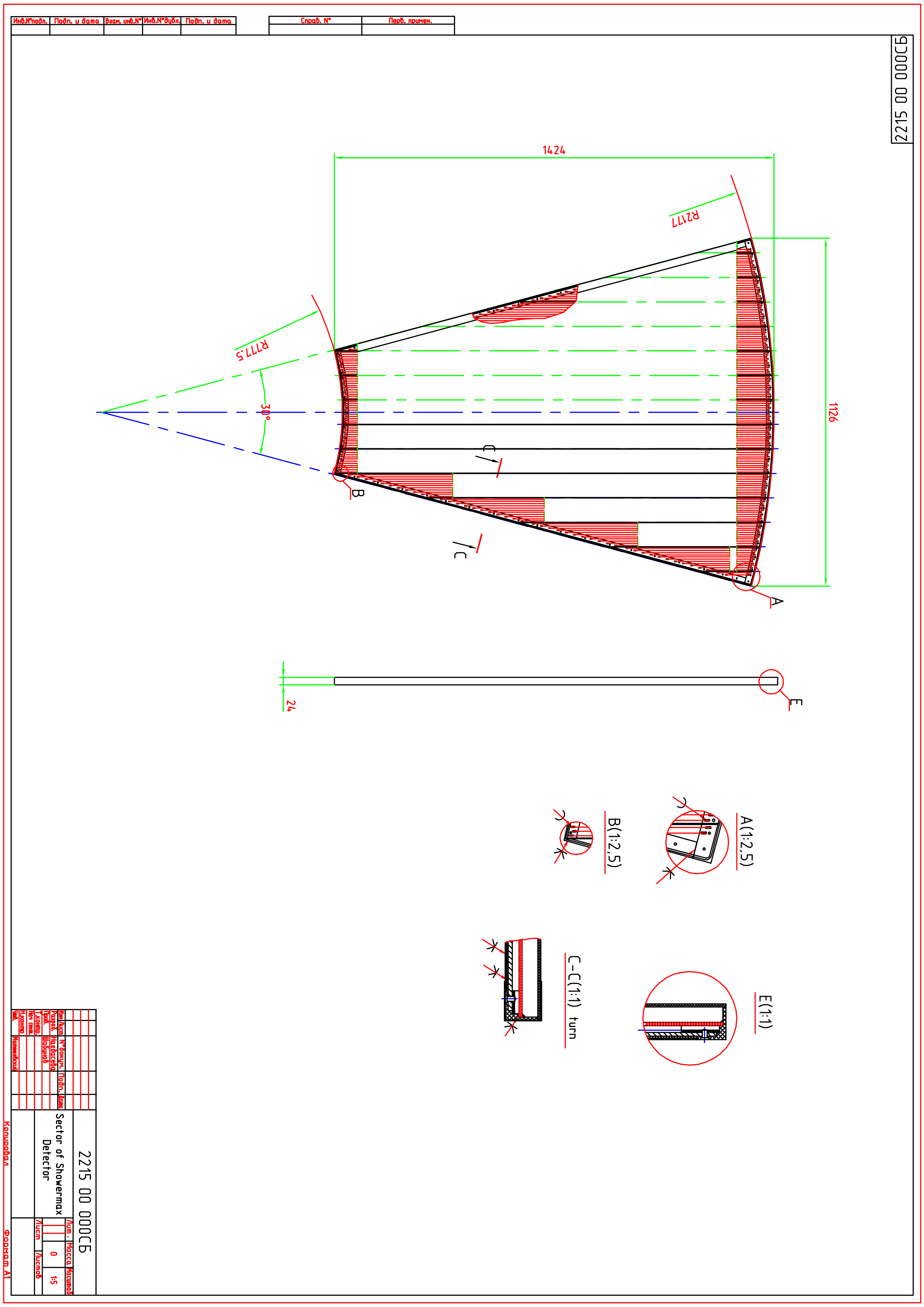

Fig.9. The assembling drawing of the 30^o module of shower maximum detector.

5 Conclusion

The test investigations of the prototype based on the plastic streamer tubes show that the coverless tubes with capacitive readout operating in proportional mode with low gain are suitable basic unit for the Endcap EMC Shower Maximum Detector. The uniformity of the cathode resistivity has a major influence for spatial resolution. The tubes with coverless profile and low resistivity are more preferable.

The readout electronics based on the 32-channel chip PASA [8] can be used for the detector with the $9 \times 9\mathrm{mm}^2$ cell plastic tubes.

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