Layout and tests of silicon pad detectors for the PHOBOS experiment at RHIC

Heinz Pernegger [a]

[a] *Massachusetts Institute of Technology,*
77 Massachusetts Avenue
Cambridge MA 02139
USA
phone: + 1 617 258 0688, fax: + 1 617 253 4360
email: heinz.pernegger@cern.ch

For the PHOBOS collaboration [1]

The PHOBOS experiment at RHIC, which is currently under construction, is designed to measure the particle multiplicity and to reconstruct low momentum tracks in heavy ion Au-Au collisions. Both tasks are accomplished with silicon pad detectors. The silicon pad detectors are single-side devices with up to 1540 pads per detector. A special double-metal readout scheme for pad detectors provides a cost-effective method to connect detectors with different pad geometries to identical standard VLSI electronics. Different pad geometries have been designed and tested to optimise for pulse height and position measurement. Results of tests on the signal response and detector parameters for different pad configurations are be presented.

Key words: silicon, pad detector, double metal, readout scheme

1 Introduction

The aim of the PHOBOS experiment is to search for manifestations of the quark gluon plasma in Au-Au collisions at a center of mass energy of 200GeV per nucleon at RHIC. PHOBOS is designed to measure the particle multiplicity over the full solid angle and to reconstruct tracks in the mid-rapidity range. The main characteristic of central heavy ion collisions is the large number of produced charged particles (>5000 particles/collision). Thus the detector has

[1] Members of the PHOBOS collaboration are listed in the appendix

to cope with high occupancy near the interaction region and has to provide sufficient spatial resolution to allow track reconstruction of low momentum pions ($p_\pi \geq$70MeV/c) and protons ($p_p \geq$300MeV/c). The experiment consists of two separate silicon detectors:

(i) A single-layer silicon multiplicity detector, consisting of a barrel section named "Octagon" and forward ring detectors, measuring the number of produced charged particles over the full solid angle. The overall acceptance of the multiplicity detector ranges in units of pseudo-rapidity from $\eta = -5.4$ to $\eta = 5.4$. The vertex position is measured by additional two layers of silicon detectors, named vertex detectors.
(ii) Two spectrometer arms which reconstruct the tracks of approximately 1% of the produced particles to measure particle correlations and momentum spectra. The spectrometer will also identify particles by multiple dE/dx measurements. Each arm has a total of 14 silicon layers.

The spectrometer is located between the pole faces of a magnet, which provides a field of 2T for momentum measurement. The particle identification is enhanced by a time-of-flight wall behind the spectrometer. A detailed description of the experiment layout can be found in reference [1].

2 Layout of PHOBOS silicon pad detectors

The detector system is based on silicon pad detectors which provide two-dimensional position measurement and pulse height information. Silicon pad detectors are ideal for the experiment as they can measure the number of particles in small azimuthal and polar segments in the multiplicity detector by measuring the energy loss per pad. At the same time they can be used to track low momentum pions and protons in the spectrometer arms with minimal multiple scattering. PHOBOS will use large pads in the multiplicity detectors and smaller pads in the spectrometer. Large pads in the multiplicity detectors are necessary to limit the total number of channels. The spectrometer detectors have smaller pads to improve the spatial resolution and reduce the pad occupancy. Layout parameters of the different detector types are summarised in table 1. The silicon detectors are single-sided, AC coupled devices. Pad implants are biased via individual 5MΩ polysilicon resistors.

One of the biggest challenges in the design of PHOBOS was to find a common readout scheme for different pad configurations, that would allow to use a single type of electronics for all different detector types. We use a double-metal layer to route signals from the pads to the VLSI electronics: Each pad consists of the p^+ implant, a coupling oxide-nitride-oxide (ONO) layer of 300nm thickness and a metal 1 pad, which extends over the whole implant area. Each metal

1 pad is connected to one readout line in the second metal layer. The readout line starts at the pad, runs along the pad column and ends on a bond-pad at the detector edge. The two metal layers are separated by a 1.2μm thick oxide-nitride layer. The above configuration is shown in figure 1 for Spectrometer Type 1 detectors.

This readout scheme provides a cost-effective method for the readout of pad detectors. It allows the use of conventional VLSI strip-detector readout electronics for pad detectors. Several different detector geometries can be read out with identical chips. Another crucial advantage of this readout scheme is that all electronics can be placed outside the active detector area, which minimises multiple scattering.

One drawback of the double metal structure however is the increase in total detector capacitance due to the metal 1 - metal 2 capacitance, which may lead to higher noise. The readout lines increase the capacitance between pads in the column, which may lead to increasing crosstalk. In the next section measurements are presented which address these concerns.

3 Test results of pad detectors with small and large pads

We tested the detector capacitances, signal response and cross talk for detector type 1 and detector type 5. We chose these two types because of their different pad configuration.

3.1 Test detectors and setup

Detector Type 1 has small pads with an area of $1\times1\text{mm}^2$ and short readout lines, 7mm long lines for pads in row 0 and 18mm in row 10. Type 5 has large rectangular pads with an area of $0.67\times19\text{mm}^2$. The readout line length ranges from about 2mm in row 0 to 62 mm in row 3. The readout line is 10μm wide and the gap between pads is 50μm for both detectors. The detectors were manufactured by Miracle Technology Inc.,Taiwan.

The detectors have been tested in a source-test setup with a ^{90}Sr source and a testbeam at the CERN SPS with 100GeV/c pions. In the testbeam a system of reference detectors was used to reconstruct tracks [2]. The test detectors were read out with Viking VAHDR-1 VLSI readout chips, manufactured by IDE AS [3], which incorporate a preamplifier, RC-CR shaper and multiplexer for 128 channels per chip. The chip has a dynamic range of greater than $\pm$300fC input charge. The peaking time of the shaper output was set to 1.0μs during source tests and to 1.2μs during the testbeam. The multiplexed analog output of the chip is digitized by a 12-bit ADC at 1MHz frequency. The same chips will be used for the readout of all PHOBOS silicon pad detectors.

3.2 Measurement of detector capacitances

We measured the capacitance between metal 1 pads and metal 2 readout lines (C_{M1M2}) on a Type 5 detector. The capacitance was measured between the bond-pad of a row-3 pad and the bond-pads of all other pads in the same column (row-0 to row-2). Pad row-0 to row-2 were interconnected for this test. The overlap of the row-3 readout line with metal 1 pads in row-0 to-2 is 57mm$\times$10μm. All pads in neighbouring columns were grounded to reduce the influence of stray capacitances. The detector was operated at full depletion voltage of V_{fd}=105V during the test. The capacitance measurement was done with a Boonton 7200 LCR meter at 1MHz frequency. We measured a capacitance per unit length of C_{M1M2}=5.1pF/cm between readout line and metal 1 pads. In a second measurement we determined the backplane capacitance of a Type 5 pad. The low terminal of the LCR was connected to the bond pad of a row-3 pad and the high terminal to the backplane. All neighbouring pads and pads of the same column were grounded via their bond-pads. We measured a backplane capacitance at full depletion of 5.3pF for the pad area of 12.7mm^2. Figure 2 shows the capacitance between readout line and metal 1 pads and the backplane capacitances versus backplane voltage.

3.3 Measurement of the signal response

The signal response of a Type 1 and Type 5 detector was tested in a testbeam and a ^{90}Sr source test. Figure 3 shows the pad signal-to-noise distribution measured on the Type 1 detector in the testbeam and the Type 5 detector in the source test. The lower signal-to-noise on the Type 5 detector is mainly due to the longer readout lines and larger pads, which result in higher load capacitance and pad leakage current than in the Type 1 detector.

Signal cross-talk specific to our detector layout may occur due to the overlap of readout lines and metal 1 pads. This overlap effectively increases the pad-to-pad capacitance of pads in the same column. The increase in pad-to-pad capacitance is proportional to C_{M1M2} times pad height, thus the additional coupling is larger for the Type 5 detector than for the Type 1 detector.

To measure signal cross-talk we recorded signal distributions for the pad where the hit occurred and pads in the same column as the hit pad. The cross-talk is defined as the mean signal of a pad divided by the most probable signal of the hit pad. Figure 4 shows the signal distributions measured on the Type 1 and Type 5 detector for the hit pad and pads in the same column ("top" and "bottom"). For all pads next to the hit pad the signal cross-talk is less than 1% for both detector types.

We also tested the uniformity of the signal response for pads in the same column. The Type 1 detector exhibits a small trend of smaller signal amplitudes for longer readout lines. No similar trend could be observed on the Type 5 detector due to higher noise. The variation of mean signal on all pads is less than $\pm 2.5\%$ for both detector types.

4 Layout and Test of the PHOBOS spectrometer module

The silicon detectors are arranged in the form of modules in the multiplicity detector and spectrometer. Figure 5 shows a spectrometer module consisting of four Type 5 detectors and the electronic hybrid. Each silicon detector is read out via four VAHDR-1 chips. All chips, up to 16 per hybrid, are controlled and read out on a common bus on the ceramic hybrid. The analog information is transfered to Front-End Controller modules near the detector, where the analog signals are digitized. The digitized data are then transmitted via optical links to a processor farm in the counting room which provides online signal correction and zero-suppression.

We tested the first fully assembled spectrometer module using the ^{90}Sr source setup. Figure 6 shows the hit profile measured on the four Type 5 detectors on the module. The figure shows the relative number of hits per pad versus detector row and column. Column 0 to 63 belong to the first detector, column 64 to 127 to the second, column 128 to 191 to the third and column 192 to 256 to the forth detector. The source was positioned on four different spots of the module. The source position was approximately centered in between row 0 and 1 of each detector. The four locations of the source are excellently reproduced in the hit profile. Middle and bottom plots in figure 6 show the signal distributions obtained during this source test for the individual detectors. We found the signal response to be very uniform across the full module. We measured the most probable signal-to-noise ratio of 16:1 on the full module.

5 Conclusion

We tested silicon pad detectors with large and small pads for their signal response properties and the influence of the double metal readout scheme on cross-talk and signal uniformity. During these tests we achieved the most probable signal-to-noise ratio of 16:1 for large pads and 25:1 for small pads. The signal cross-talk was found to be less than 1%, the variation of the mean signal amplitude across the detector is less than ±2.5%. A PHOBOS spectrometer module, fully assembled with four silicon pad detectors, was tested and found to be completely operational.

6 Acknowledgements

I would like to thank G. Van Nieuwenhuizen, B. Wadsworth, M. Neal, P. Haridas and J. Michalowski for their help in preparing the test module and C. M. Vale and P. Sarin for their help during the tests. I also thank Peter Weilhammer at CERN for the possibility to participate in the RD42 testbeam and Ogmundur Runolfsson for his support during the assembly preparation. This research has been supported by the US Department of Energy under the cooperative agreement DE-FC02-94ER40818 and by the Maria Sklodowska-Curie Fund II, grant PAA/NSF-95-229.

Appendix: Members of the PHOBOS collaboration

B. Back[a], M. Baker[g], D. Barton[b], R. Betts[i], A. Bialas[f], A. Budzanowski[e], W. Busza[g], A. Carroll[b], Y. Chang[h], A. Chen[h], W. Czyz[f], P. Decowski[g], K. Galuszka[e], E. Garcia-Solis[b], K. Gulbrandsen[g], S. Gushue[b], C. Halliwell[i], P. Haridas[g], A. Hayes[k], R. Holynski[e], B. Holzman[i], E. Johnson[k], J. Katzy[i], J. Kotula[e], P. Kulinich[g], M. Lemler[e], W. Lin[h], S. Manly[l], D. McLeod[i], J. Michalowski[e], A. Mignerey[j], G. Nieuwenhuizen[g], A. Olszewski[e], R. Pak[k], H. Pernegger[g], M. Plesko[g], L. Remsberg[b], M. Reuter[i], G. Roland[d], L. Rosenberg[g], A. Sanzgiri[l], P. Sarin[g], S. Steadman[g], G. Stephans[g], M. Stodulski[e], C. Taylor[c], A. Trzupek[e], C. Vale[g], R. Verdier[g], B. Wadsworth[g], F. Wolfs[k], B. Wosiek[e], K. Wozniak[e], A. Wuosmaa[a], B. Wyslouch[g], K. Zalewski[f]
[a]*Argonne National Laboratory, USA*
[b]*Brookhaven National Laboratory, USA*
[c]*Case-Western Reserve University, USA*
[d]*Goethe Universität, Frankfurt, Germany*
[e]*Institute of Nuclear Physics, Krakow, Poland*
[f]*Jagellonian University, Krakow, Poland*
[g]*Massachusetts Institute of Technology, USA*
[h]*National Central University, Taiwan*
[i]*University of Illinois at Chicago, USA*
[j]*University of Maryland, USA*

[k] *University of Rochester, USA*
[l] *Yale University, USA*

References

[1] PHOBOS Conceptual design report, BNL, 1994

[2] C. Colleani et al., Nucl. Inst. and Meth. A372(1996)415-420

[3] Integrated Detector & Electronics, Veritasveien 9, N-1322 Hovik, Norway

Sensor type	Pad size (width $\times$height mm^2)	Pad rows$\times$ columns
Spectrometer		
Type 1	1$\times$1	22$\times$70
Type 2	0.43$\times$6	8$\times$64
Type 3	0.67$\times$7.5	8$\times$64
Type 4	0.67$\times$15	4$\times$64
Type 5	0.67$\times$19	4$\times$64
Multiplicity		
Octagon	2.6$\times$9.5	30$\times$4
Ring	$\approx$ 50	64 $r\phi$ pads
Vertex 1	0.32$\times$23.3	2$\times$256
Vertex 2	0.32$\times$46.6	1$\times$256

Table 1
Pad size and number of pads per detector for the different layouts required for the PHOBOS experiment

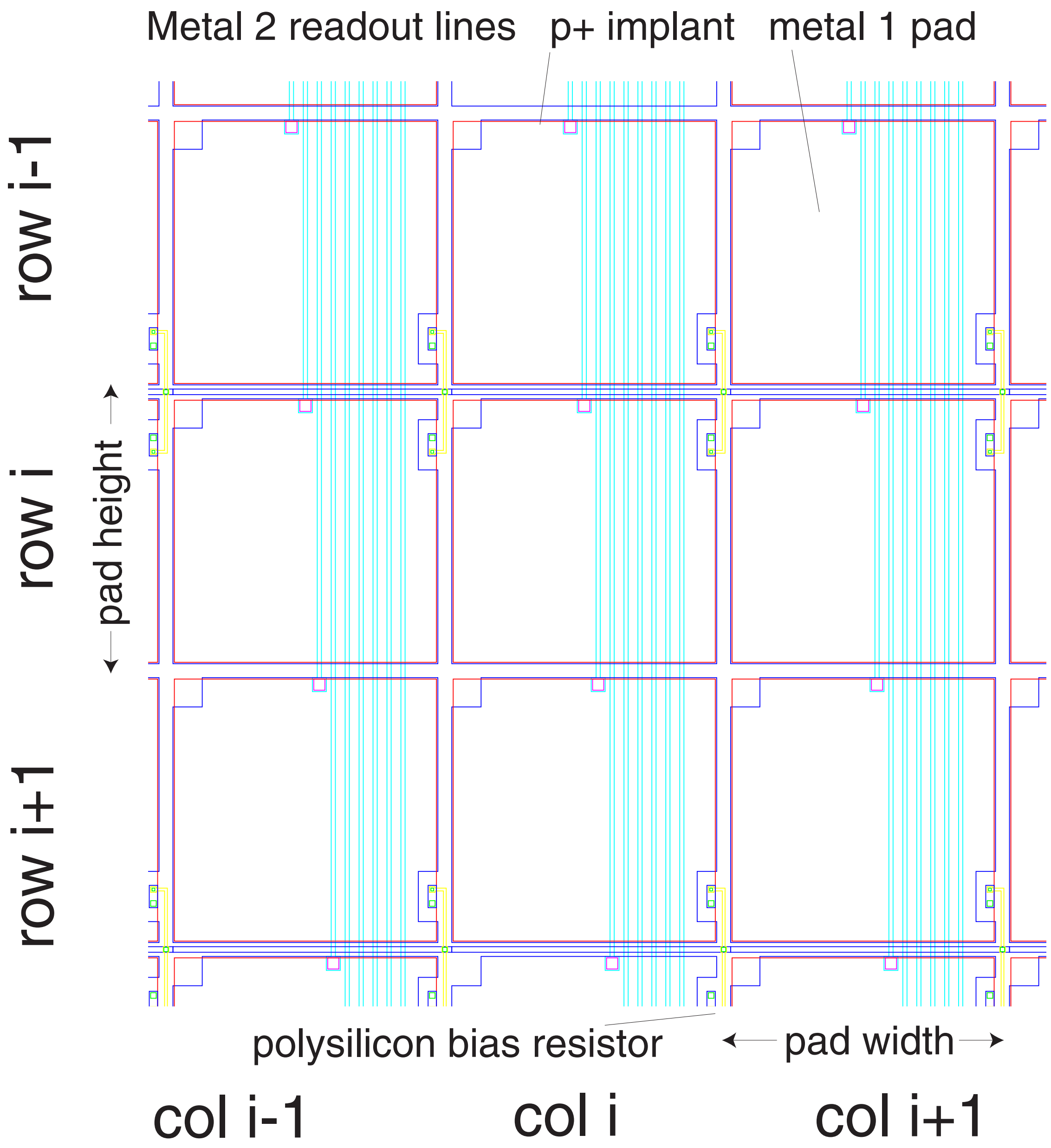

Fig. 1. Layout of the Type 1 spectrometer detector

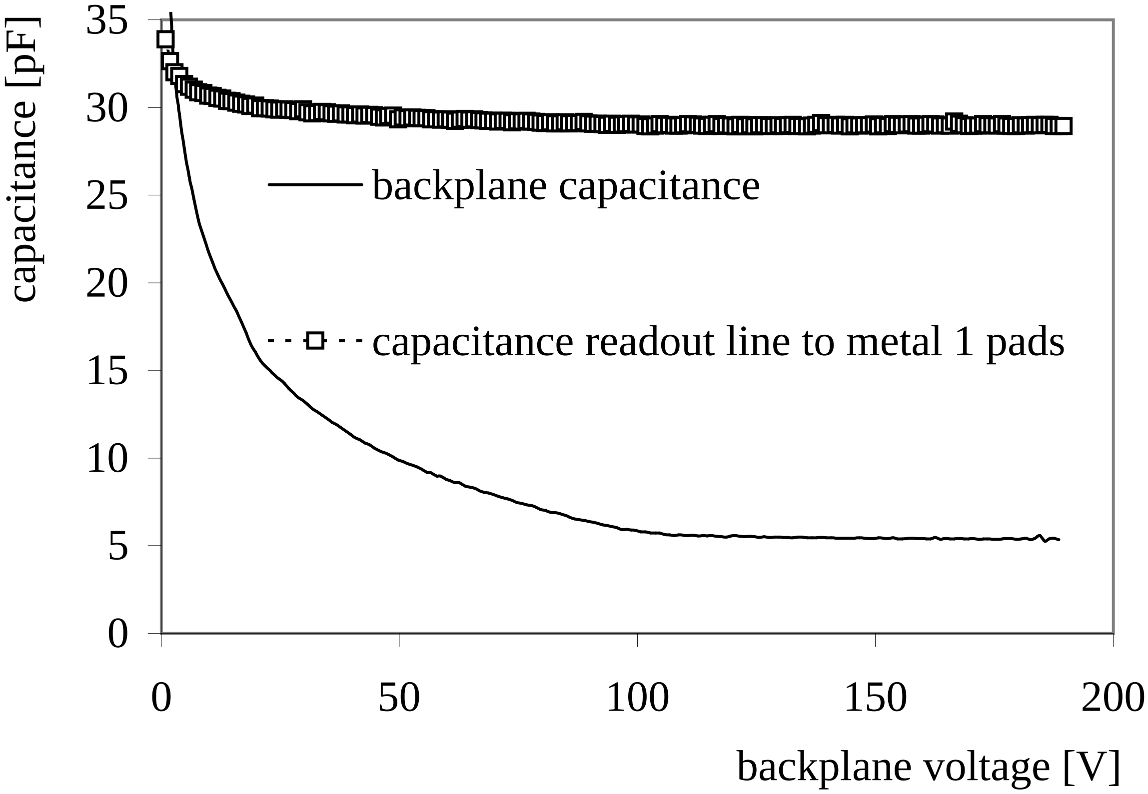

Fig. 2. Readout line to metal-1 pad capacitance and backplane capacitance versus bias voltage on the Type 5 detector

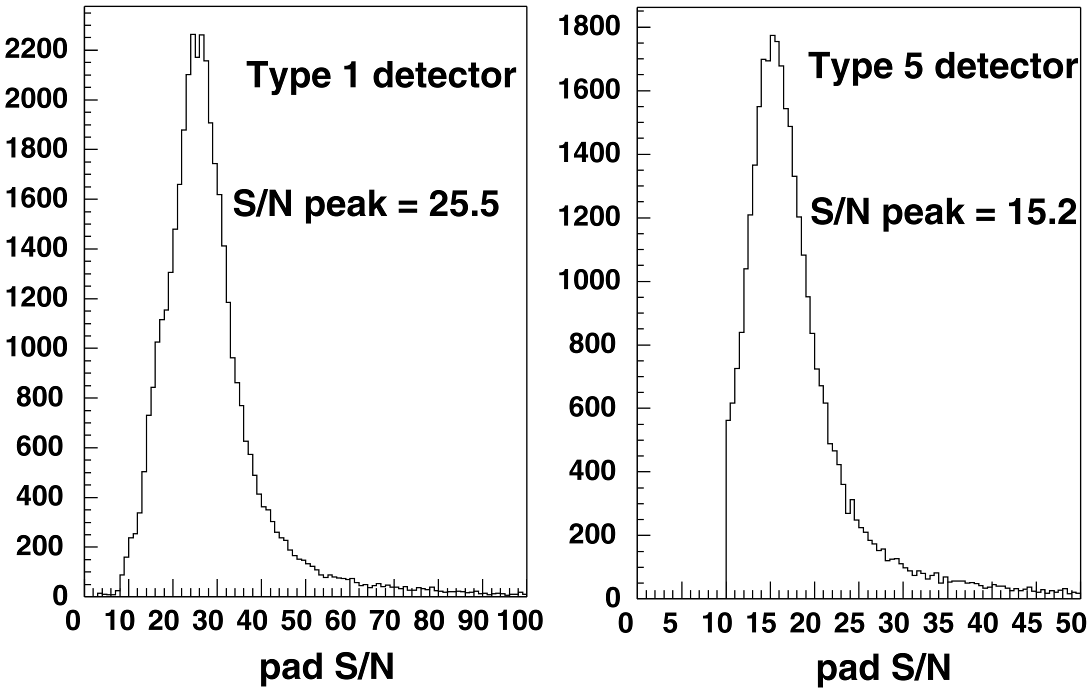

Fig. 3. Signal-to-noise distribution obtained in testbeam and source test for Type 1 and Type 5 detector

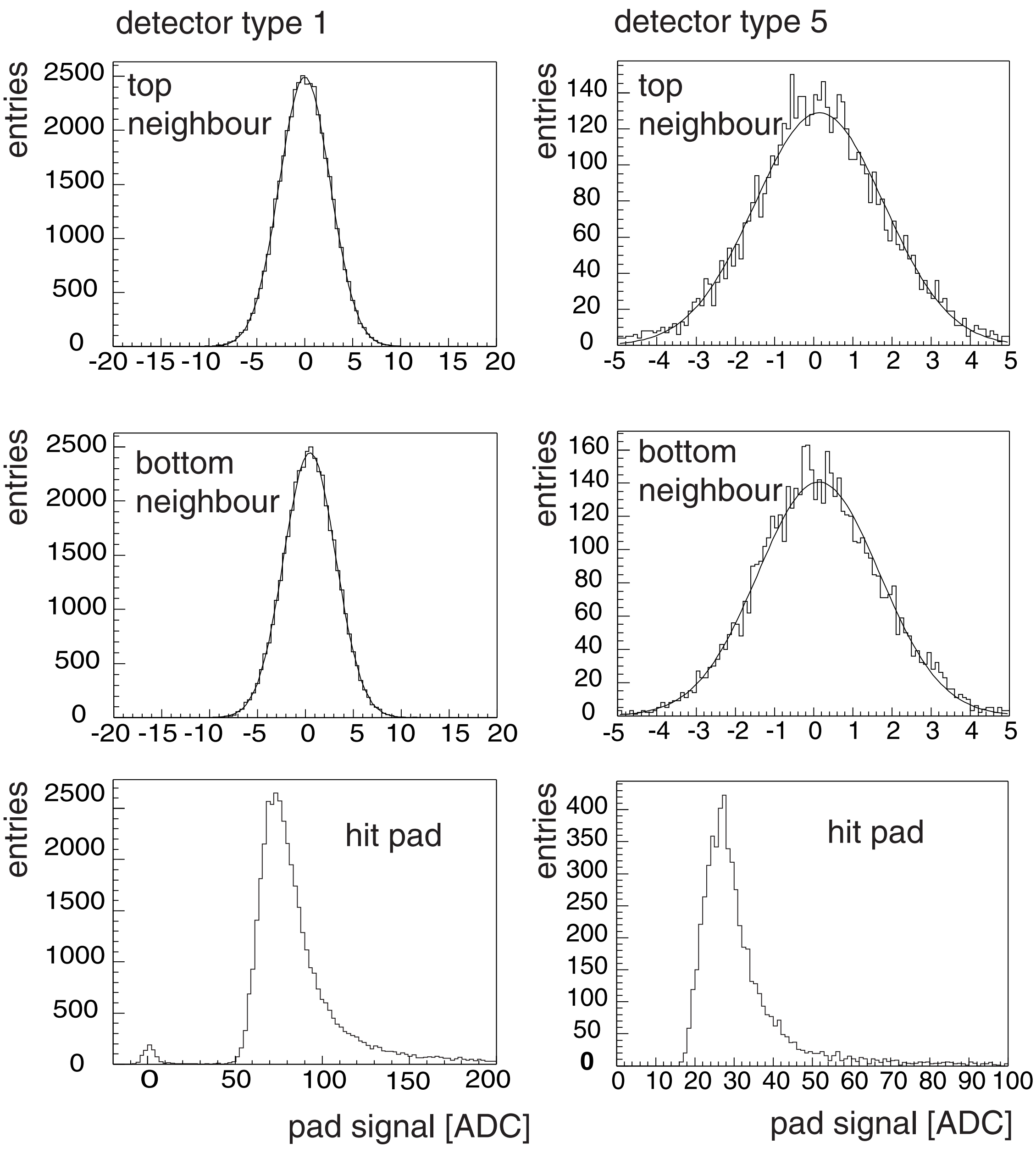

Fig. 4. Signal distributions on pads next to the hit pad and the hit pad (see text)

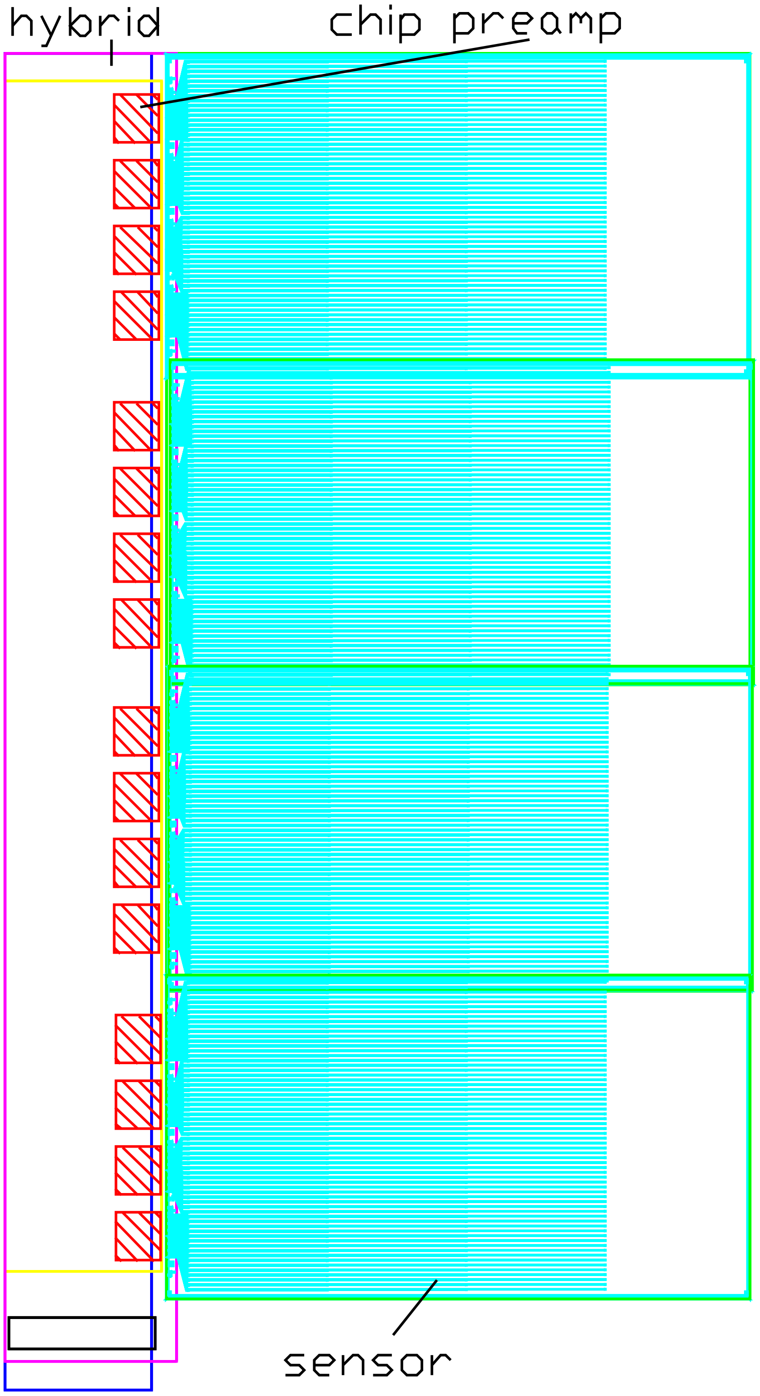

Fig. 5. Schematic illustration of one PHOBOS module in the spectrometer arm

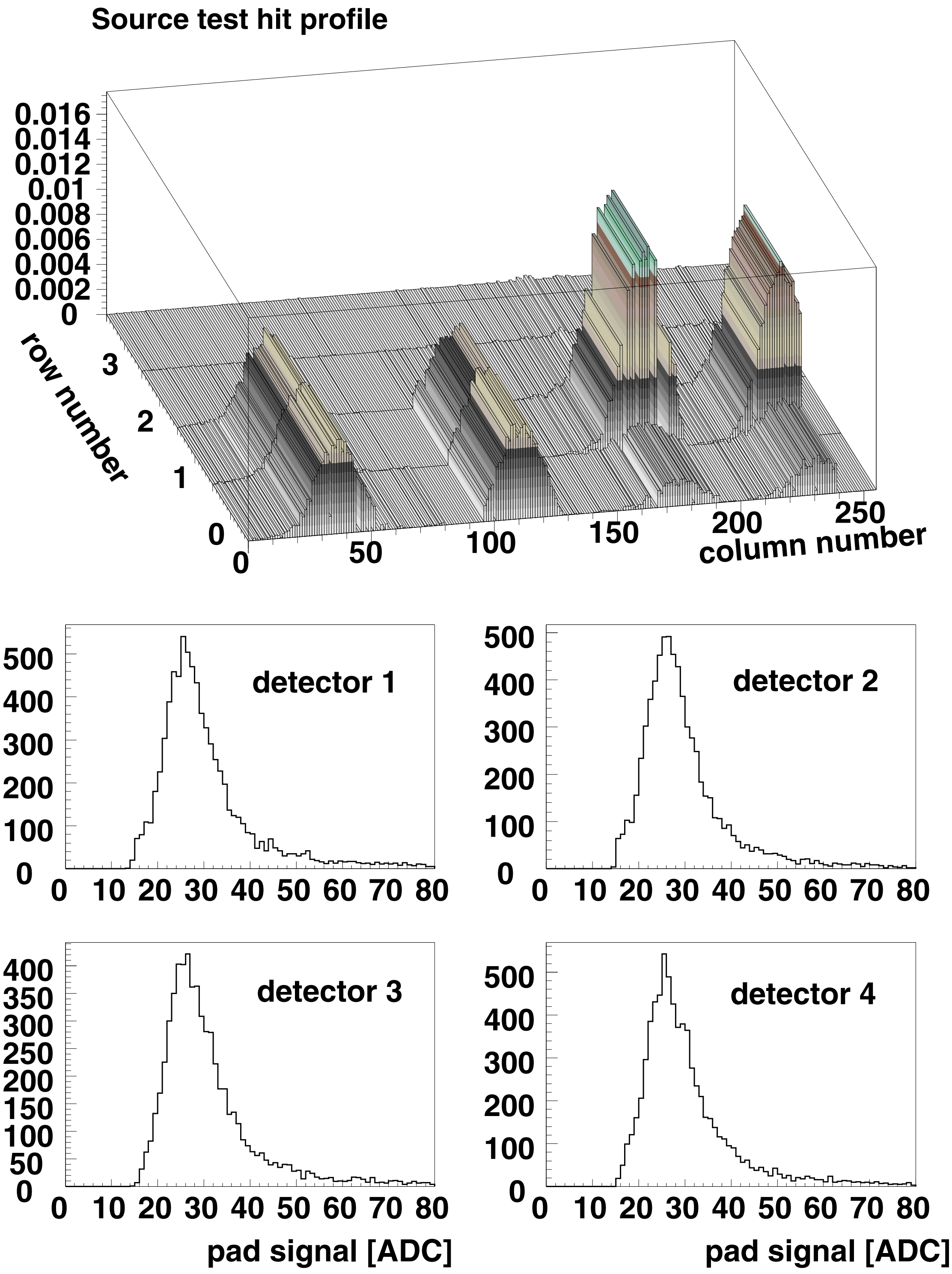

Fig. 6. Source hit profile on a fully assembled PHOBOS spectrometer module (top plot) and signal distributions obtained on the four detectors (middle and bottom plots)