Performance of the PHOBOS Silicon Sensors

M.P. Decowski [d 1], B.B. Back [a], M.D. Baker [b], D.S. Barton [b], R.R. Betts [a,f], R. Bindel [g], A. Budzanowski [c], W. Busza [d], A. Carroll [b], E. Garcia [g], N. George [a], K. Gulbrandsen [d], S. Gushue [b], C. Halliwell [f], J. Hamblen [h], G.A. Heintzelman [b], C. Henderson [d], R. Hołyński [c], D.J. Hofman [f], B. Holzman [f], E. Johnson [h], J.L. Kane [d], J. Katzy [d], N. Khan [h], W. Kucewicz [f,i], P. Kulinich [d], W.T. Lin [e], S. Manly [h], D. McLeod [f], J. Michałowski [c], A.C. Mignerey [g], J. Mülmenstädt [d], R. Nouicer [f], A. Olszewski [b,c], R. Pak [b], I.C. Park [h], H. Pernegger [d], C. Reed [d], L.P. Remsberg [b], M. Reuter [f], C. Roland [d], G. Roland [d], L. Rosenberg [d], P. Sarin [d], P. Sawicki [c], W. Skulski [h], S.G. Steadman [d], G.S.F. Stephans [d], P. Steinberg [b], M. Stodulski [c], A. Sukhanov [b], J.-L. Tang [e], R. Teng [h], A. Trzupek [c], C. Vale [d], G.J. van Nieuwenhuizen [d], R. Verdier [d], B. Wadsworth [d], F.L.H. Wolfs [h], B. Wosiek [c], K. Woźniak [c], A.H. Wuosmaa [a], B. Wysłouch [d]

[a] *Physics Division, Argonne National Laboratory, Argonne, IL 60439-4843*

[b] *Chemistry and Collider-Accelerator Departments, Brookhaven National Laboratory, Upton, NY 11973-5000*

[c] *Institute of Nuclear Physics, Kraków, Poland*

[d] *Laboratory for Nuclear Science, Massachusetts Institute of Technology, Cambridge, MA 02139-4307*

[e] *Department of Physics, National Central University, Chung-Li, Taiwan*

[f] *Department of Physics, University of Illinois at Chicago, Chicago, IL 60607-7059*

[g] *Department of Chemistry and Biochemistry, University of Maryland, College Park, MD 20742*

[h] *Department of Physics and Astronomy, University of Rochester, Rochester, NY 14627*

[i] *Electronics Department, University of Mining and Metallurgy, Kraków, Poland*

[1] decowski@mit.edu

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The PHOBOS detector is designed to study the physics of Au+Au collisions at the Relativistic Heavy Ion Collider. The detector is almost entirely made of silicon pad detectors and was fully operational during the first year of operation. The detector is described, and key performance characteristics are summarized.

1 Introduction

The PHOBOS experiment is one of four experiments at the Relativistic Heavy Ion Collider (RHIC). RHIC started operation in the summer of 2000, delivering beams of gold ions at $\sqrt{s_{NN}} = 56$ and 130 GeV nucleon-nucleon center-of-mass energy, creating the highest extended energy densities ever achieved in the laboratory. The aim of PHOBOS is to study QCD under these extreme conditions and to search for manifestations of novel physics, such as the formation of the Quark Gluon Plasma (QGP). Two goals drove the experimental design: large flexibility in the experimental setup in case something unexpected happens, and the assumption that any new processes would be rare and that a large number of events would need to be acquired in order to find them.

2 The PHOBOS detector

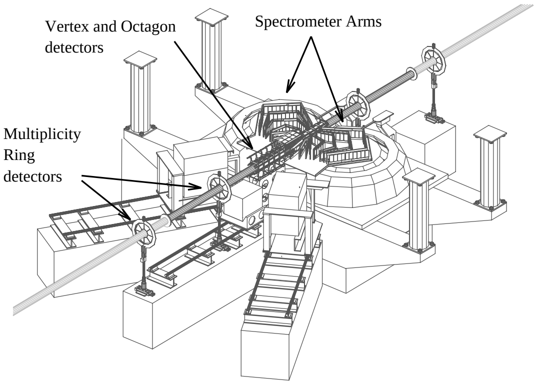

Fig. 1. The PHOBOS Detector. The top of the magnet is shown removed, making the two spectrometer arms visible. All detectors indicated are made of silicon.

The PHOBOS detector is almost exclusively made of silicon pads used in two separate detector subsystems. The layout is illustrated in figure 1. A single layer, almost 4π hermetic coverage, silicon multiplicity detector measures the number of charged particles produced in the collision over a large pseudo-rapidity interval. The second subsystem has two spectrometer arms at mid-rapidity, each consisting of 14 layers of silicon. The spectrometer arms track a fraction of the total produced charged particles in a 2 T magnetic field. The spectrometer identifies particles by a dE/dx measurement, with a TOF further

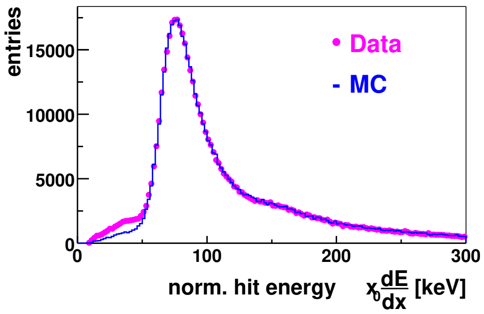

Fig. 2. Distribution of hit energy for data and simulation. Both signals have been angle corrected and normalized to 300 μm detector thickness.

extending the particle identification capabilities to higher momenta. A silicon vertex and scintillator paddle detector provide global event characterization. Details of the experimental setup can be found in [1].

All silicon sensors in PHOBOS are AC-coupled single-sided, double metal pad detectors with pads varying from 1 to 30 mm^2. The p+ implants are rectangular pads providing two-dimensional position information. The implants are biased by 2 $M\Omega$ polysilicon resistors which are connected to a common bias line. The output signals are AC coupled through a coupling capacitor consisting of the implant, a 200 nm oxide-nitride-oxide (ONO) layer and the first metal layer. There is an additional 1200 nm ONO layer on top of the first metal to carry the second metal signal traces out to the readout system. Using this technology [2], all signals appear on bonding pads at one edge of the sensor, where hybrids with the read out electronics are glued and bonded to the sensor. This setup minimizes the amount of material in the active detector area. All the silicon sensors are read out with VA-HDR-1 front-end chips [3], providing an analog measurement with large dynamic range (up to 100 MIP) of the ionization charge deposited in each pad. The analog signals are multiplexed out and sent over kapton cables to be digitized by 12-bit ADCs in the read out system. Integrated into the read out chain is a gain calibration system, which can be used to calibrate each individual channel.

Crucial to extracting meaningful physics results is the detailed simulation of the detector system. Figure 2 shows the simulated and measured signal. Both were angle corrected and normalized to 300 μm detector thickness. The simulation was done using the GEANT package, with additional contributions such as the electronic noise and the Shulek correction describing the variation in ionization potential for electrons in different Si-shells. With these corrections, the sensor response is described very well by the simulation and was further studied in a test-beam.

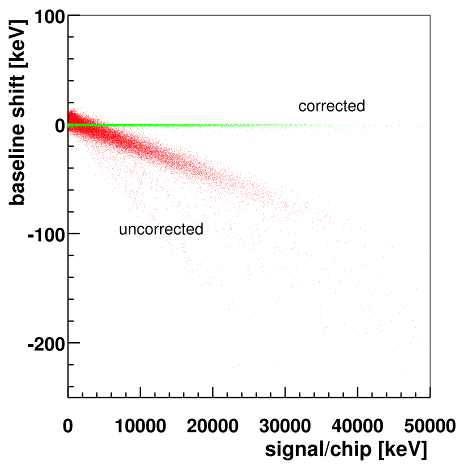

Fig. 3. Baseline shift in the multiplicity array. The baseline can be fully corrected in the offline analysis.

3 Multiplicity Array

The multiplicity array consists of 22000 channels of large ($\sim 30\ mm^2$) pads, with a central silicon barrel covering $|\eta| < 3.5$ and six ring detectors extending the coverage up to $|\eta| = 5.4$. The charged particle multiplicity is measured using the particle ionization in a single layer of silicon. In order to extract the final multiplicity as a function of both pseudo-rapidity and azimuthal angle, a precise knowledge of the detector response and careful detector calibration is essential.

The high particle density of $\sim$ 4000 charged particles produced in a central Au-Au collision at $\sqrt{s_{NN}} = 130\ GeV$ gives channel occupancies exceeding 80%. Careful study revealed that the baseline of the VA-HDR-1 chip shifted by an amount depending on the total input charge to the chip. The baseline is determined from the channels without hits; Figure 3 shows the chip baseline versus the total integrated signal deposited in the chip. The offline analysis could fully correct baseline shifts up to and beyond 100 keV using the information from channels without hits. After the baseline correction, the overall pad-to-pad uniformity was found to be better than 2%, while the signal-to-noise ratio was found to be $\sim$ 13, significantly higher than the design specification of 10.

Background from secondary particles can be suppressed by an η dependent cut on the energy deposition. Particles originating at the vertex will traverse the silicon with a shallow angle and thus a long track-length in the high η region. Therefore, they will deposit a large amount of energy. Secondary particles, produced away from the vertex, in the beam pipe for example, will traverse the silicon with much smaller angles and deposit less energy. We found that a large portion of the secondary contamination at $|\eta| > 1.2$ in our barrel detector

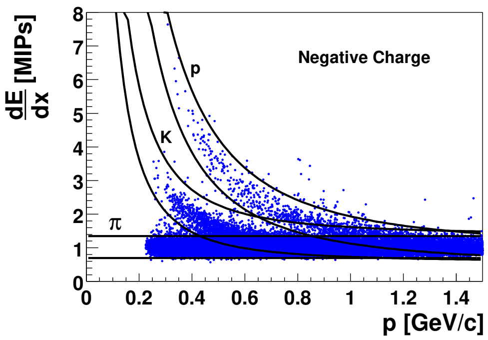

Fig. 4. Particle identification in the spectrometer.

could be suppressed by an energy cut that varied as $\cosh \eta$.

4 Spectrometer

The 14 silicon layers of the spectrometer are in a 2 T magnetic field. The double dipole magnet has been optimized to provide a large and uniform magnetic field in the momentum measuring region and a low field near the beam pipe. Straight tracks in the low field region provide seeds for the pattern recognition necessary in the high field region. The silicon detectors of the spectrometer have finer granularity than the multiplicity array detectors and consist of 120000 channels in 280 sensors for two arms. There are sensors with five different pad sizes in the spectrometer, optimizing the tradeoff between physics requirement and channel count. The thin beryllium beam-pipe and the use of silicon makes it possible to extend the low-p_T coverage to less than 50 MeV for pions and 100 MeV for protons.

The typical pad-to-pad signal uniformity in the spectrometer wafers was found to be better than 1%, while the signal-to-noise ratio was ~ 18.

Particle identification of pions, kaons and protons is possible through multiple dE/dx measurements in several silicon planes traversed by the particle. To achieve good separation of the particle species, it is crucial that the detector response after gain, track angle and detector thickness correction be uniform throughout the spectrometer and only depend on the particle species and momentum. Figure 4 illustrates the dE/dx capabilities of the PHOBOS silicon, the K/p bands are clearly separated up to 1 GeV/c momentum. In the future we will extend the PID capabilities by a TOF wall for high momentum particles.

5 Conclusion

The PHOBOS experiment uses silicon detectors for charged particle multiplicity measurements, particle identification and tracking. In all these measurements, exact knowledge of the signal response is important. PHOBOS successfully ran during the first year of physics running at RHIC. The silicon performed very well, yielding the first RHIC physics results. The PHOBOS silicon is ready for the summer 2001 physics run at $\sqrt{s_{NN}} = 200\ GeV$.

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