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The PP2PP experiment at RHIC: silicon detectors installed in Roman Pots for forward proton detection close to the beam

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Abstract

The PP2PP experiment is one of five experiments at the Relativistic Heavy Ion Collider (RHIC) at the Brookhaven National Laboratory, Long Island, New York. It is designed to measure the elastic scattering of protons at $\sqrt{s}$ = 50–500 GeV. The detector consists of silicon strip detectors mounted in Roman Pots and installed in the RHIC ring 60 m from the interaction region. During the engineering run of 2002 and physics run of 2003 the detectors were inserted as close as 15 mm from the proton beam. An overview of the experiment and details of the detector design and performance will be presented.

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1. Introduction

PP2PP [1] is one of five experiments at the Relativistic Heavy Ion Collider (RHIC) at the Brookhaven National Laboratory (BNL), Long Island, New York. In addition to its heavy ion physics program, RHIC has a dedicated program of colliding polarized protons at $\sqrt{s}$ = 50–500 GeV. PP2PP completed its engineering run in January 2002 and its first physics run in May 2003.

PP2PP is designed to measure the spin dependence of proton elastic scattering in the squared four-momentum transfer range $4 \times 10^{-4} \leqslant |t| \leqslant 1.3$ $(\mathrm{GeV/c})^2$. At such small scattering angles it is necessary to position the detectors far from the interaction region (IR) where the scattered protons are separated from the beams. This necessitates positioning the detectors where the beams and scattered protons have passed through bending and steering magnets. Fig. 1 shows the location of the Roman Pot Stations (to be described below) which house the detectors. They are located after two dipole magnets (D0, DX) and three quadrapoles (not shown). To a good approximation the equations connecting the vertical coordinate y_0 and scattering angle θ_y^* to the vertical coordinate y and track angle θ_y at a Roman Pot station are

$$y = a_{11} \cdot y_0 + L_{\mathrm{eff}}^y \cdot \theta_y^*,$$

$$\theta_y = a_{12} \cdot y_0 + a_{22} \cdot \theta_y^*.$$

The coefficients are a function of z, the distance of the Roman Pot from the IR. The position of the Roman Pots closest to the IR (RP1 and RP3) was chosen such that a_{11} is small and L_{eff}^y is large, so that to a good approximation:

$$y \approx L_{\mathrm{eff}}^y \cdot \theta_y^*.$$

This is referred to as parallel-to-point focusing for which the hit position is a function of only the scattering angle. A large L_{eff}^y results in a greater acceptance at smaller $|t|$. Similar equations govern the horizontal variable x and θ_x, except that it is not possible to have parallel-to-point focusing in both coordinates at the same z. Therefore both x and θ_x must be considered variables of both x_0 and θ_x^*.

2. Roman Pots

In order to detect the scattered protons at the lowest $|t|$, PP2PP developed its own version of Roman Pots, a technology first used at CERN's ISR in the early 1970s and since used in a number of experiments at various colliders. Roman Pots are cylindrical vessels in which detectors can be mounted. Their purpose is to permit the detectors to be moved close to the beam while they remain isolated from the beam vacuum.

Fig. 2 shows a picture of the PP2PP Roman Pot. A thin stainless-steel window made of 300 μm

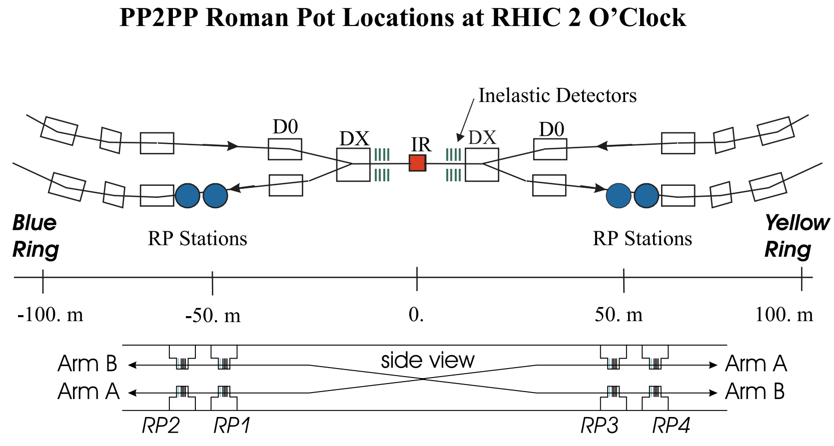

Fig. 1. Locations of the four Roman Pots stations in the RHIC tunnel.

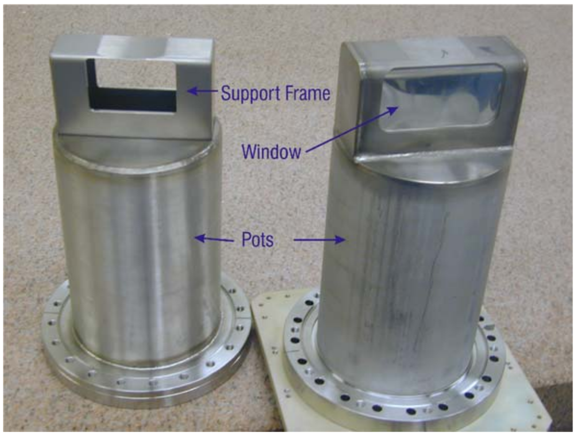

Fig. 2. PP2PP Roman Pots.

thick steel is welded to a window frame. The window frame is then welded to the cylinder. As the interior of the pot is at atmospheric pressure and the exterior is exposed directly to the beam vacuum the window frame serves to prevent the thin window from bulging into the beam. A profile is machined in the window frame to permit the closest approach of the pot to the beam. For safety reasons the window was required to be at least 300 μm thick. This requirement was due to the necessity that the window should retain its strength (and thus preserve the beam pipe vacuum) should the proton beam be accidentally dumped directly into the pot.

3. Silicon strip detectors

Four silicon strip detectors for measuring the position of the scattered proton and one scintillator for triggering are assembled into one package for mounting in each Roman Pot. The detectors exist in two variants, an *x*-view detector with vertical strips and a *y*-view detector with horizontal strips. Both detectors have an active area of approximately, $75 \times 45\,\text{mm}^2$ and are 400 μm thick. The detectors used in the engineering run were designed and manufactured at the BNL Instrumentation Division and differed from those used in the physics run. These were designed and manufactured by Hamamatsu Photonics.

The BNL detectors were manufactured on 4" wafers and featured p^+ implants on n material and were capacitively coupled to aluminum strips on top of the implants. The strip pitch was approximately 100 μm for both views, and the strip width approximately 70 μm. A unique feature of these detectors, first implemented in 1997, is their use of implanted resistors to bias each strip. The p^+ strip and the resistor are implanted simultaneously. High resistance (nominally 2 MΩ) is simply achieved by making the resistor implant narrow (~7 μm) compared to the p^+ strips (~70 μm). A drawback is that the bias resistor is relatively long (~3 mm). Fig. 3 is a picture of the corner of a *y*-view detector. The edge of the detector that was closest to the beam was cut to within 500 μm of the first strip in an attempt to minimize the dead area and increase the low $|t|$ acceptance.

A fan-in of aluminum strips was fabricated on the same wafer as the detector. The purpose of the fan-in was to match the 100 μm detector strip pitch to the 48 μm pitch of the readout chip bonding pads. Although the detector and fan-in were cut from the wafer as an integrated unit, an extra row of bond wires over the guard ring and connecting the fan-in to the detector strips was required.

The Hamamatsu detectors were fabricated on 6" wafers, two detectors (one *x*-view and one *y*-view) per wafer. They were similar to the BNL detectors with a few differences. Polysilicon rather than implanted resistors were used, and this

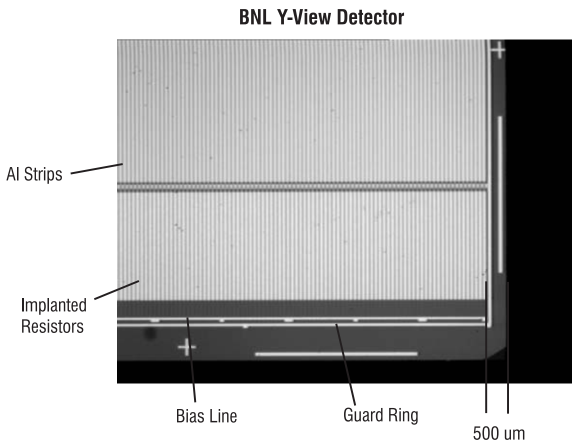

Fig. 3. BNL strip detector design.

shortened the length of the biasing region to 350 μm. Additionally, the resistors connected to a bias ring that simultaneously served as the guard ring. This helped to minimize the inactive area of the detector. Hamamatsu's double metal process permitted direct connection of the strips to an integrated fan-in, thus saving one wire bonding step. It was learned during preparations for the engineering run that the first and last channels of the 128-channel readout chip (described below) had offset pedestals which would make them inefficient in zero-suppression mode. Therefore the Hamamatsu detectors were designed with only 126 strips per readout chip so that the end channels of the chip could be left unbonded.

4. Readout and assembly

The detectors were read out by the SVXIIE [2], a custom-designed chip that is used by the D0 collaboration at Fermilab. It features 128 input channels and zero-suppression capability. Digitized charge information is output for each channel read out.

Each silicon detector is glued to a detector board and aligned relative to a tooling hole and precision slot drilled into the printed circuit board. The gluing takes place on a Nikon Video Measuring machine so that alignment to within 10 μm is achieved. The detector boards contain SVXIIE chips and differential drivers/receivers for communication with a sequencer module (described below). A photo of the assembled board is shown in Fig. 4.

Four detectors, two x-view and two y-view were assembled into a compact package as shown in Fig. 5. Alignment pins through the detector boards align the boards relative to one another. The alignment pins are then measured to reference spheres on a coordinate measuring machine to within 25 μm. The reference spheres are later used to survey the detector packages in the RHIC tunnel after installation in the Roman Pots. A programmable power board connects to each detector board. The power board contains a microcontroller that enables voltage regulators in the proper sequence to generate the various voltages required by the detector board.

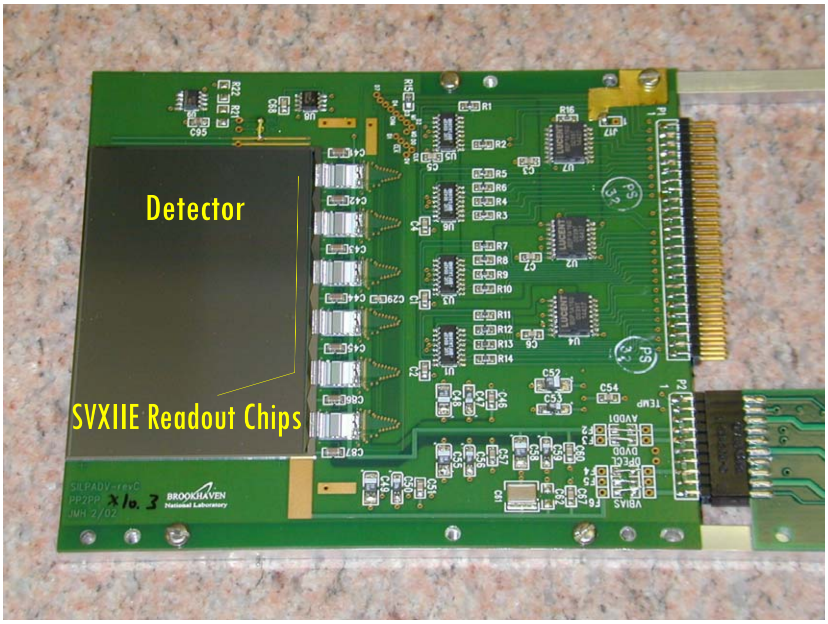

Fig. 4. An X-view detector board.

Fig. 5. A detector package being surveyed.

A trigger scintillator (not shown in Fig. 5) is mounted on each detector package. Each scintillator was 8 mm thick had an area of $80 \times 50\,\mathrm{mm}^2$ that was approximately matched to the active area of the silicon detectors. Each is read out by two photomultiplier tubes for redundancy.

For the engineering run, the SVXIIE chips were clocked, controlled and read out by the Stand-Alone SVX Sequencer (SAS) [3] VME module obtained from the D0 experiment. The maximum readout rate from the SASs was about 100 events/s. For the physics run, a new VME module called the ppSEQ was designed. The new sequencer is based on the Xilinx Virtex II FPGA and is designed to achieve a higher readout event rate. It also has the capability to perform zero suppression with individually settable thresholds for each channel. The maximum readout rate (without zero suppression) was about 500 events/s in the 2003 run.

5. Performance

In the engineering run of January 2002 PP2PP collected $3 \cdot 10^5$ elastic events in 14 h of running. In the physics run of May 2003, PP2PP was able to collect $3 \cdot 10^6$ elastic events in 10 h due to increased readout rate capability and higher machine luminosity. In each run the trigger consisted of a coincidence of the scintillators in RP1 and RP3, either arm A or arm B (see Fig. 1). In both runs the Roman Pots were inserted to about $15\,\mathrm{mm} = 15\sigma$ from the beam. Further scraping was not attempted due to the short time allotted to PP2PP running.

The average signal-to-noise in the engineering run is 11. The average detector efficiency (probability a hit is reconstructed given that a proton track is projected to hit the detector) was 93%. Average Roman Pot reconstruction efficiency (i.e. probability both an x and y coordinate is reconstructed from that detector package) was 99%.

The attempt to cut the side of the y-view detector closest to the beam to within 500 μm of the first strip was only partially successful. The first strip in general saw no hits while the second strip was typically 99% efficient.

Early analysis of the 2003 data indicates the average detector efficiency is 98.7% in arm A (similar efficiencies are expected for arm B). This excellent percentage is attributed to the extremely high quality detectors produced by Hamamatsu, as well as to very careful wire bonding and assembly. The average Roman Pot (arm A) reconstruction efficiency is 99.98%. The average signal-to-noise is 20.

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