RESULTS FROM THE SLAC PSC DEVELOPMENT PROGRAM

W. B. Atwood
Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

Planar Spark Counters (PSC's) have unique detection properties for charged particles. These counters have achieved the best time resolutions of any particle detector.[1] This in combination with their other properties makes PSC's attractive for use in high energy particle physics. At SLAC a program to develop this technology has been in progress since 1978.[2] Last year we tested a pair of PSC's at the PEP storage ring and I will report on the results here.[3]

Provided that one can extend the PSC technology to large devices, PSC systems could have time resolutions of 50 psec or better. In Fig. 1 I have plotted the momentum for 50 and 100 psec time-of-flight particle separation over a 1.7 m flight path for various pairs of particle. It is seen from this figure that such a system would make good inroads on the difficult 1-2 GeV momentum region. PSC systems will have a granularity dictated by the cost of electronics channels: at least an order of magnitude over conventional scintillation counter systems is not unreasonable, e.g., a cylindrical array of 1,000 PSC strip lines compared to one hundred or so scintillation counters. This feature will reduce ambiguities arising from more than one particle striking a single detector element.

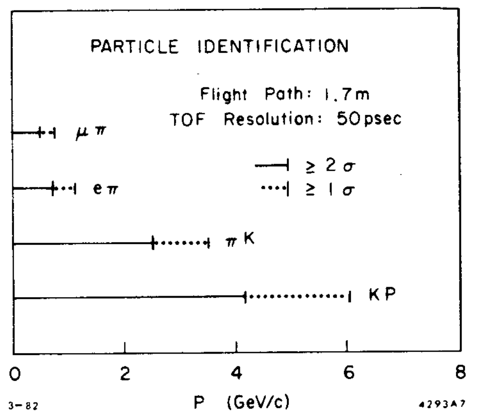

Fig. 1. Time-of-flight separation for various pairs of particle types.

As I will show later in this report, PSC's measure space-time points. The accuracy of the coordinate along the PSC strip-line can be as good as 200 μm,[1] while the resolution of the coordinate transverse to the PSC strip will be set by its width. If the strips are made narrow enough to have appreciable pulse height sharing, excellent transverse coordinate information may be obtained. In addition, the pulse height from the PSC strips provide a good indicator of the number of particles striking that strip.

PSC Counter Details

Some details of the PSC design used at SLAC are shown in Fig. 2. Most of our counters have an area of 9 cm × 9 cm with a gap dimension of 185 μm. Two to three microns of copper deposited over ~100 Å of chromium on a substrate of ordinary window glass is used for the cathode. Four indium plated brass washers determine the gap dimension. The variations in the gap are required to be less than 3 microns. Semiconducting glass with a volume resistance of about $10^{10}\Omega$ cm is used for the anode. Copper strip lines were vacuum deposited on the side opposite the gap to conduct the high frequency signals to coaxial output cables. Coupling to the cathode is accomplished using a parallel plate capacitor with mylar dielectric. The capacitance of the coupler is about 180 pF.

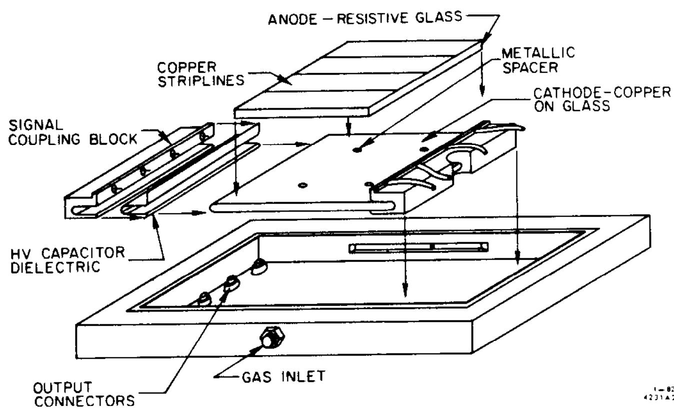

Fig. 2. Exploded view of SLAC PSC construction.

We have run our PSC's at gas pressures in the range of 6-12 atmospheres. The components of the gas we use are 70% argon or neon, 16% isobutane, 3.3% ethylene, 3.3% 1-3 butadiene and 7.4% hydrogen. We have also added up to 1-1/2% ether for some runs.[3] The gas is recirculated through the spark gap with a linear velocity of about 10 cm/sec. The only purifiers in the gas system are a .03 μm dust filters located just in front of the counters' gas inlets.

Using this gas mixture with argon for the noble gas, we observe a threshold for sparks at about 3,500 volts across the spark gap. By 4,000 volts the counter has plateaued with a singles counting rate of about .02 Hz/cm^2 (consistant with the cosmic ray background). At 7,000 volts the counting rate has risen to about .025 Hz/cm^2 and then quickly increases with further high voltage increases. We operate our counters just before this rapid rise in the singles rates. We attribute the excess counting rate to after pulsing in our counters with second sparks following the initial discharge by up to 300 nsec. Experience has shown that extended operation in this region eventually leads to a "run-away" situation from which the counter does not recover.

The output pulse from our PSC's has a rise time of about 200 psec, is 1-2 volts in amplitude, and has a width of 5-10 nsec. Our measurements of the frequency response of the strip lines in the PSC's have shown them to be similar to RG174 coaxial cable and we attribute the 200 psec rise time in our counters to the limitations of the strip lines. We have measured the rise-time through 80 cm of PSC strip line using a 25 psec rise time input pulse. A 600 psec rise time output pulse was observed.

In Figs. 3-5 I show typical results from our 9 cm × 9 cm PSC's obtained using cosmic rays. The time-of-flight shown in Fig. 3 is the time difference between the PSC's. The time for each PSC is the average of the times measured from the two ends of the PSC strip-line with the largest pulse height for that event. The coordinate resolution shown in Fig. 4 is the location of the hit in the PSC inferred from the difference in times from the two ends of the hit strip minus the predicted hit location determined by a drift chamber equipped cosmic ray telescope. Our coordinate resolution is consistent with the least count accuracy of the TDC units used for measuring the times from the PSC strip lines.

Figure 5 shows a PSC pulse height distributions from the cosmic ray running. The PSC was operated at the end of the high voltage plateau curve for this data. The FWHM is approximately equal to 100% of the mean. At lower voltages this distribution becomes narrower.

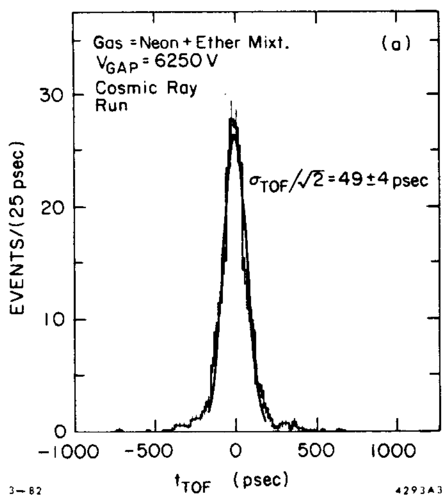

Fig. 3. Time-of-flight distribution from PSC's using cosmic rays.

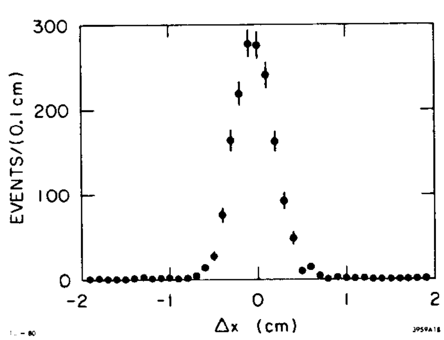

Fig. 4. Spacial coordinate resolution of PSC's along the strip lines from cosmic ray data.

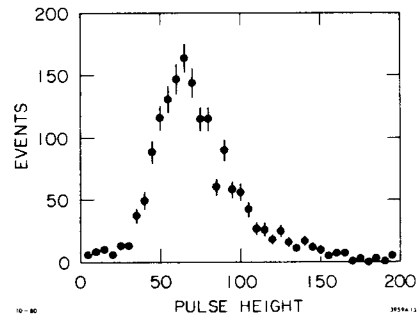

Fig. 5. PSC pulse height distribution from cosmic ray data.

PSC Tests at PEP

In June of 1981 a pair of 9 cm × 9 cm PSC's were installed and operated in IR8 at the PEP Storage Ring.[3] Figure 6 shows details of this installation. The PSC's were mounted on the face of the DELCO luminosity monitors and covered about 30% of one sectant on each side. The luminosity monitor itself had aperture defining, face counters (F1 and F2) backed by wave-bar read-out, sampling shower counters (L1 and L2). The trigger for data taking was F1.L1.F2.L2 and had a large component of small angle Bhabha scattering. The trigger rate was about 1 Hz. Of these triggers about 1/10 had PSC hits. The pulse heights from L1 and L2 are shown in Fig. 7 and the events with large, correlated pulse heights in the two shower counters are from Bhabha scattering.

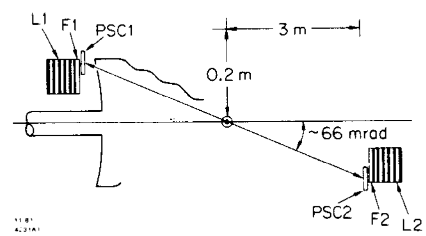

Fig. 6. Schematic of PSC installation in IR8 at PEP.

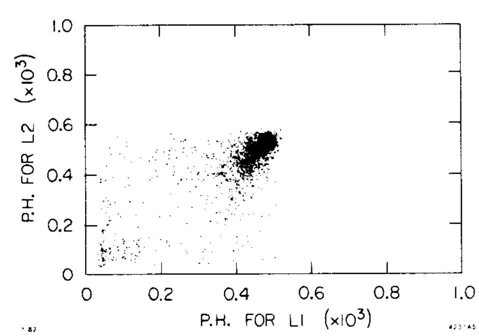

Fig. 7. Scatter plot of luminosity shower counter pulse heights, L1 and L2.

The counting rates into our PSC's in these locations varied between 1 and 5 kHz/81 cm^2. This rate was a factor of 10 higher than the rates which the counters had been previously subjected to using a Co^{60} source. The RC recovery time for a PSC is approximately equal to the product of the dielectric constant and the volume resistivity (ρ) of the semiconducting glass. For our counters $\rho = 3$ and $6 \times 10^{10}\Omega$ cm which results in time constants of ~25 and ~50 msec. At a 2 kHz rate into our PSC's the mean time between sparks in the same local area (~.25 cm)[5] is about 150 msec. Thus we expect to see some rate effects arising from partially recovered regions of the spark gap. These effects may be lowered by about an order of magnitude by using more conductive glass (the lower limit is $\rho \sim 10^9\Omega$ cm).[1,5] The rate effect should worsen the time resolution and lower the pulse height. We observed both.

Figure 8 shows the pulse height distributions from the two PSC's for Bhabha events in which both PSC's recorded a hit (pulse height ≥ 20 channels above pedestal). In both counters we observe a long tail extending to large pulse heights. We interpret these events as ones in which more than one particle struck the PSC. In Fig. 9 scatter plots for L1 vs L2 are shown for the cases (a) when both PSC's are hit and (b) when both PSC's are hit by one particle. The events which are eliminated are likely to be "spray" events caused by electrons (positions) showering off the edges of small angle lead masks in front of the luminosity counters.

The single counter time resolutions are shown in Fig. 10 for Bhabha events. The start for the TDC was the discriminated, beam button, pick-up signal and the TDC stops were the discriminated pulses from the PSC strip lines. The time that the PSC was hit is gotten by averaging the times from the two ends of the hit strip. We see in the comparison of PSC1 and PSC2 that the counter with the higher resistive semiconducting glass has a worse resolution as expected from the high counting rate conditions.

We also observed "albedo events" in our PSC's. These are events in which the pulse heights from L1 and L2 are consistant with the Bhabha signal but only one of the PSC's registered a hit. This may arise from shower particles (mostly gamma rays) coming back out of the shower counter and converting the the PSC. The time distribution for these events is shown in Fig. 10 by the shade area. It is seen to be on the average later and broader than the distribution for the events in which both PSC's were hit, consistent with the longer and varied flight paths albedo events would have to follow to register in the PSC's.

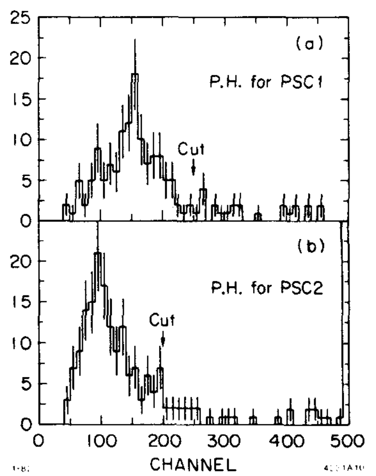

Fig. 8. Pulse height distributions from PSC1 and PSC2 from small angle Bhabha scattering.

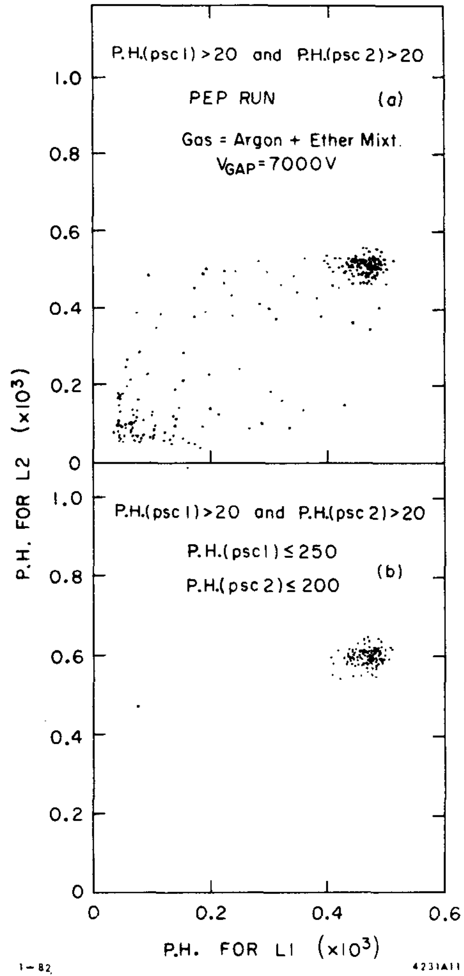

Fig. 9. Correlated shower counter distributions L1 and L2 before (a) and after (b) requiring PSC's to be hit by one particle.

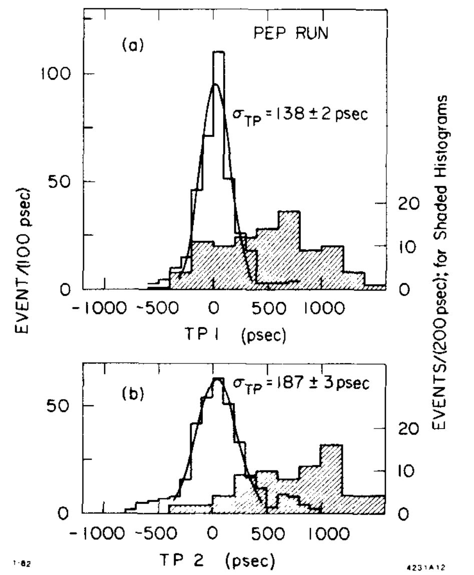

Fig. 10. Single PSC time distributions using the beam crossing signal for the TDC start. Data cut on Bhabha events from L1 and L2 pulse heights.

In Fig. 11 the time difference (t_{TOF}) of the single counter times is plotted. Any jitter in the TDC start signal will be correlated for t_{TOF} and drop out. Using the single counter times (TP1 and TP2) together with t_{TOF} we can estimate the contributions to the measured time resolutions from various sources:

$$\sigma^2(\mathrm{TP1,2}) = \sigma^2(\mathrm{PSC1,2}) + \sigma^2(\mathrm{X}) + \sigma^2(\mathrm{BUNCH})$$

$$\sigma^2(t_{TOF}) = \sigma^2(\mathrm{PSC1}) + \sigma^2(\mathrm{PSC2}) + 2\sigma^2(\mathrm{BUNCH}) .$$

The σ's labeled PSC1 and PSC2 are the counter resolutions, σ(X) is the contribution arising from jitter in the start pulse for the TDC's and σ(BUNCH) is the contribution from the finite bunch length of the stored beams (σ(BUNCH) = 2 cm). As such

$$\left.\begin{array}{ll} \sigma(\mathrm{TP1}) & = 138\ \mathrm{psec} \\ \sigma(\mathrm{TP2}) & = 187\ \mathrm{psec} \\ \sigma(t_{TOF}) & = 192\ \mathrm{psec} \\ \sigma(\mathrm{BUNCH}) & = 68\ \mathrm{psec} \end{array}\right\} = \left\{\begin{array}{ll} \sigma(\mathrm{PSC1}) & = 76\ \mathrm{psec} \\ \sigma(\mathrm{PSC2}) & = 148\ \mathrm{psec} \\ \sigma(\mathrm{X}) & = 93\ \mathrm{psec} \end{array}\right.$$

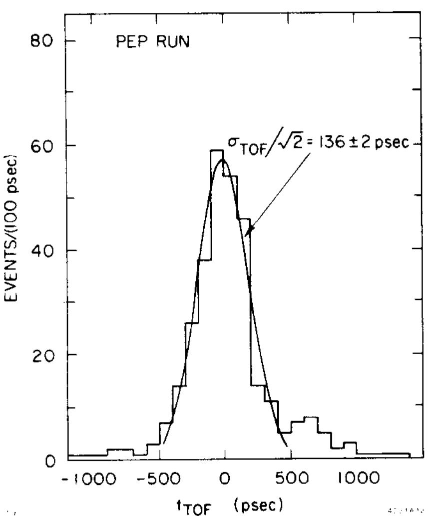

Fig. 11. Time difference of PSC1 and PSC2 measured on Bhabha events.

Due to the highly collinear nature of Bhabha scattering the locations of the hits in our PSC's should be anticorrelated. The PSC strip lines were oriented to be vertical and perpendicular to the beam direction. We call this the Y coordinate. In Fig. 12(a) the Y coordinate is plotted for each PSC derived from the time difference of the two measured times on the hit strip. (The signal velocity on the PSC strip lines is about 15 cm/nsec.) Figure 12(b) shows the sum of Y(PSC1) and Y(PSC2). The width of this distribution has contributions from the least count accuracy of the TDC's (σ(TDC)), radiative correction to Bhabha scattering (σ(RAD)), and variations in the vertical position of the beam (σ(BEAM) < 1 mm). We calculated σ(RAD) using a Monte Carlo program and estimate it to be ~2 mm. Using these we estimate σ(TDC) ~ 18 psec (2.6 mm) which is not inconsistant with the TDC accuracy due to its 50 psec bins ($50\ \mathrm{psec}/\sqrt{12}$ = 14 psec).

A major concern was the liftime of PSC's under storage ring conditions. Both PSC1 and PSC2 were powered up for about 150 hours with circulating beams present. At the start of the PEP running PSC1 was about 1 year old and PSC2 was 2 months old. We observed

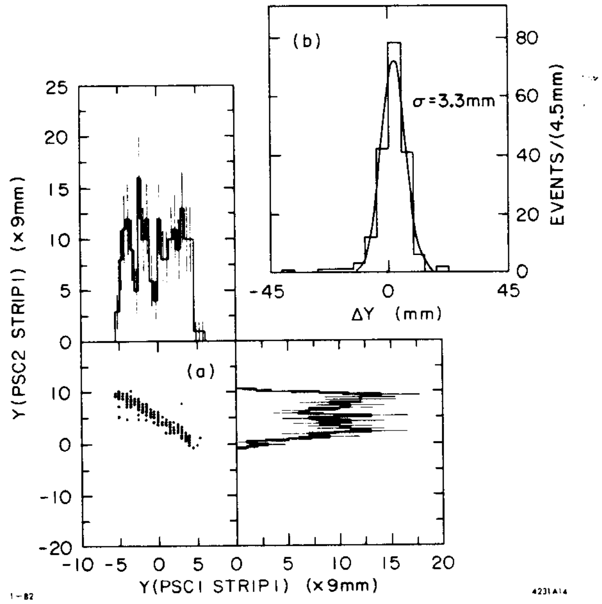

Fig. 12. (a) PSC1 and PSC2 Y coordinate correlation for Bhabha events, and (b) sum of Y(PSC1) + Y(PSC2) for Bhabha events.

no deterioration in these PSC's operating characteristics during or after the PEP running. In fact the time resolution measured on cosmic rays shown in Fig. 3 was taken with these PSC's after PEP had shut down for the summer.

Our conclusions from this test are:

(1) There were no surprises. PSC's perform as other HEP particle detectors even under high rate conditions near the beam.

(2) High rates degraded pulse height and time resolution by a factor of 2-4. The rate dependence was due to the unnecessarily high resistance of the semiconducting glass anodes. The rate dependence can be improved by a factor of 10 by using more conductive glass.

(3) The correlated information of two times and one pulse height from each strip gives a space-time point of good accuracy and the strip multiplicity for each event. This provides a powerful tool for understanding various event types.

(4) PSC's can withstand harsh experimental environments.

The SLAC PSC development project is presently building two 10 cm × 120 cm counter. We are also making a 20 layer, atmospheric pressure, electromagnetic shower counter using PSC's as the sampling detectors. And finally, we are investigating the use of various semiconducting plastics from which to make the electrodes.

References

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