A mathematical study of the PASA response function
STAR Note 355

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Abstract

The dependance of the PASA output signal from the input signal as it is shaped from the PASA is discussed. The dependance of the output signal from the PASA parameters is also discussed.

As known, the Laplace transform of the PASA response function to a Dirac delta-like current in input is, at first order:

$$F_{pasa}(s) \propto \frac{s}{(s+1/\tau_s)^5 \cdot (s+1/\tau_l)}; \tag{1}$$

where τ_l and τ_s are two time constants that depend on the details of the PASA [1]. For this study, when not explicitly stated, the time constants are kept fixed to the canonical values:

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$$\tau_s = 11.5ns, \tau_l = 500ns. \tag{2}$$

The actual response function has the following extended form:

$$f_{pasa}(t) = b{\cdot}e^{-b\cdot t}/c^5 + e^{-a\cdot t}\cdot(-b/c^5 + b{\cdot}t/c^4 - b{\cdot}t^2/(2{\cdot}c^3) + b{\cdot}t^3/(6{\cdot}c^2) - a{\cdot}t^4/(24{\cdot}c)), \tag{3}$$

where $a = 1/\tau_s$, $b = 1/\tau_l$ and $c = b - a$ and it is shown in figure 1.

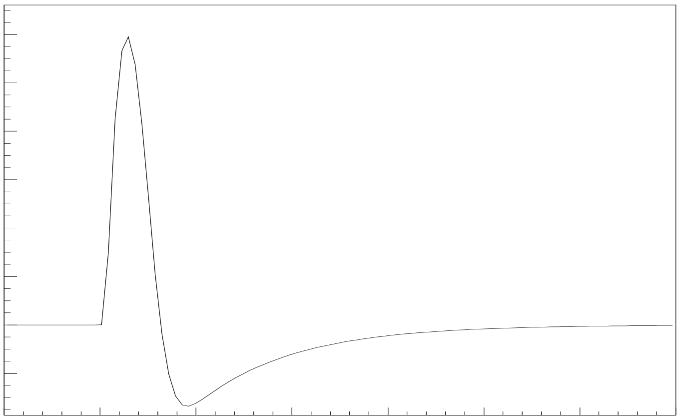

Figure 1: The PASA response function.

The shape of the signal collected after the PASA is a convolution of the PASA response function and the shape of the signal left in the detector by a crossing particle. The hypothesis that the signal before the PASA (or the charge distribution in the detector after a particle left some energy on it) has a gaussian shape will be made, and numerical (not analytical) integration will be performed to obtain the final signal shape. This work investigates whether changes in the characteristics of the input signal of the PASA or changes in the parameters that define the response function are going to affect significantly the output signal.

A subsection will be dedicated to each of the quantities whose effects on the output signal shape are studied. The characteristics of the output signal that are going to be studied are the positive area, the positive peak position, the first and the second moment. First and second moments will be ever referred to the drift direction. The performed analysis is purely mathematical.

Output signal dependance on the input signal width.

The dependance of the positive area and the peak position of the positive signal

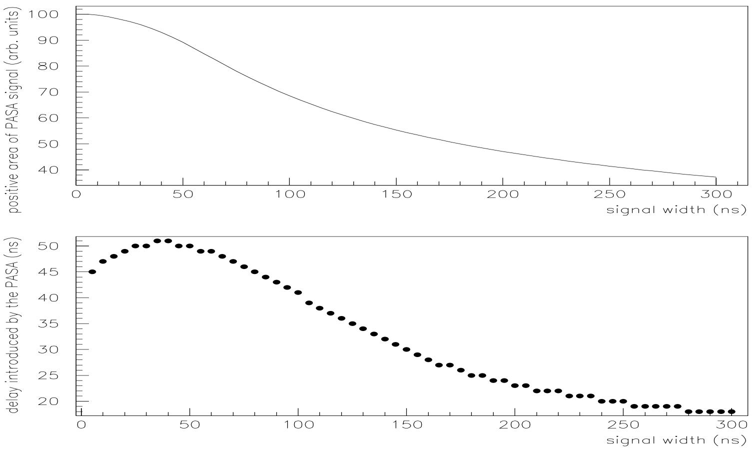

Figure 2: The top panel shows the variation of the positive area of the output signal with the width of the input signal, the bottom panel shows the variation of the peak position of the output signal with the width of the input signal.

are shown in figure 2. The top panel, where the highest point of the curve is normalized to 100, suggests that the area of the positive output signal diminishes continuously as the width of the input signal increases. For instance, the area goes from 100 to 70 when the width changes from zero to 100 ns. The curve could be fitted to an inverse polynomial:

$$positive\ area = \frac{1}{P1 + x \cdot P2 + x^2 \cdot P3 + x^3 \cdot P4 + x^4 \cdot P5 + x^5 \cdot P6}, \qquad (4)$$

where:

$$x = signal\ width\ (ns), \quad (5)$$

$$P1 = 0.10 \cdot 10^{-1}, \quad (6)$$

$$P2 = -0.35 \cdot 10^{-4}, \quad (7)$$

$$P3 = 0.15 \cdot 10^{-5}, \quad (8)$$

$$P4 = -0.10 \cdot 10^{-7}, \quad (9)$$

$$P5 = 0.33 \cdot 10^{-10}, \quad (10)$$

$$P6 = -0.39 \cdot 10^{-13}. \quad (11)$$

The bottom panel shows that the delay introduced by the PASA, i.e. the difference in time between the peak position of the input and the output signal, changes significantly with the input signal width and is not monotonic.

The output signal RMS (second moment) in the drift direction varies with the input signal width as shown in figure 3. It should be noticed that once the width of

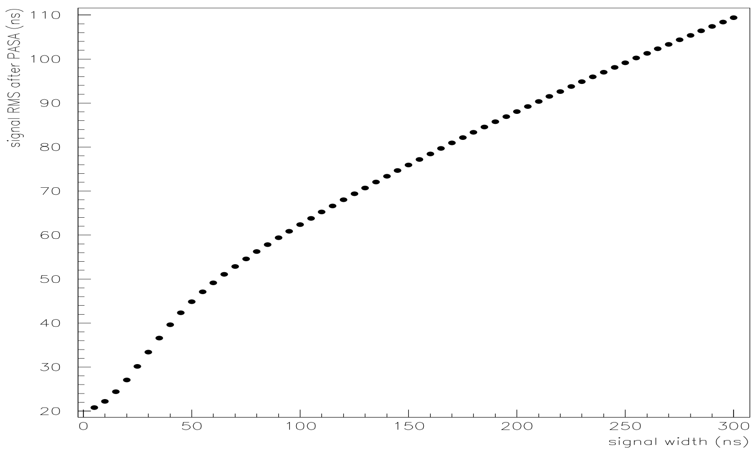

Figure 3: Output signal RMS versus input signal width.

the input signal is greater than 30 ns, the width of the output signal becomes systematically smaller than the width of the input one. According to the plot in figure 3, an RMS of the output signal of 110 ns corresponds to a width of the input signal of 300 ns, RMSs as big as 110 ns are realistic, and they were measured several times, however RMSs between 20 ns and 60 ns are expected for MIPs, depending on their position along the drift direction and the inclination of the track.

The hit position in the drift direction can be calculated either by fitting the output signal shape with the proper function, and using the positive peak as an indicator, or by computing the first moment (centroid) of the positive output signal.

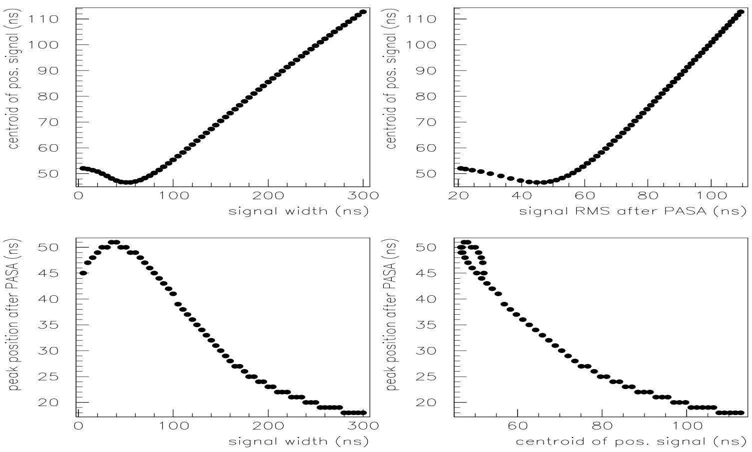

Figure 4: Peak position and centroid position of the positive output signal versus the width of the input signal, whose peak is at 0 ns. In the bottom right panel is shown the correlation between the two indicators of the hit position in the drift direction.

In figure 4, in the top left panel, is shown how the position in time of the centroid of the positive output signal varies as a function of the input signal width (the peak of the input signal is at 0 ns). Notice that the trend is extremely different from what is shown for the peak of the output signal. A possible cause is the fact that the PASA response function is asymmetric around the positive peak. The top right panel shows the centroid position as a function of the output signal RMS (second moment). The bottom left panel is intended for direct comparison of the shape of the centroid and peak position versus the input signal width. Finally the bottom right panel clearly shows the lack of biunivocity between the peak and the centroid position of the output signal.

Output signal dependance on the input charge.

In this study the width of the input signal is kept constant. It is clear that, in general, a hit with more deposited charge, will have a wider input signal to the PASA, however here the different effects are studied separately.

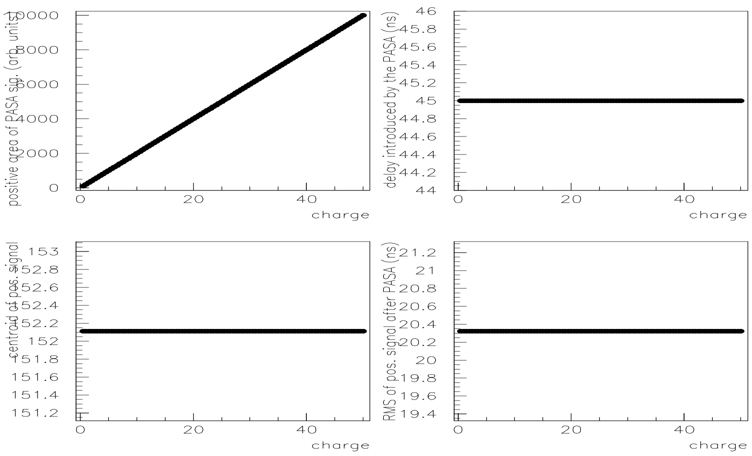

Figure 5: Positive area, peak position (delay introduced by PASA), centroid position and RMS of the output signal as a function of the amplitude (charge) of the input signal.

In figure 5 is shown how the positive area, peak position, centroid position and RMS of the output signal vary with the input charge. By input charge is meant the area of the input signal (gaussian with fixed width); this quantity, in fact, is proportional to the charge made available in the detector by the incoming particle.

As expected the positive area increases linearly with the input charge and the peak position, centroid position and RMS of the output signal are constant.

Output signal dependance on τ_s.

As it is well known, the parameter τ_s in the PASA response function is associated with the positive part of the output signal, while the parameter τ_l is mainly responsible for the negative one (undershoot). Therefore we expect a significative variation of the behavior of the positive part of the output signal while varying τ_s.

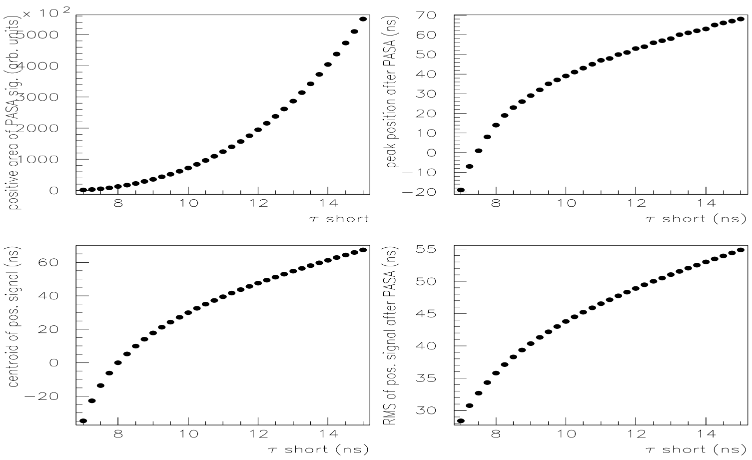

Figure 6: Positive area, peak position (delay introduced by PASA), centroid position and RMS of the output signal as a function of τ_s.

In figure 6 is shown how the positive area, peak position, centroid position and RMS of the output signal vary with τ_s. In particular, from the top right panel and from the bottom left one is possible to see that a variation of τ_s of 10% with respect to the 'canonical' value (11.5 ns) is responsible for a shift of about 10 ns in the peak position or in the centroid position. Depending on the drift velocity, this indetermination in time will reflect on an indetermination in space of about $60\mu m$.

Output signal dependance on τ_l.

In figure 7 is shown how the positive area, peak position, centroid position and RMS of the output signal vary with τ_l. No significant changes in the quantities of interest are found by varying τ_l from 500 ns to 800 ns (the 'canonical' value for τ_l is 500 ns)

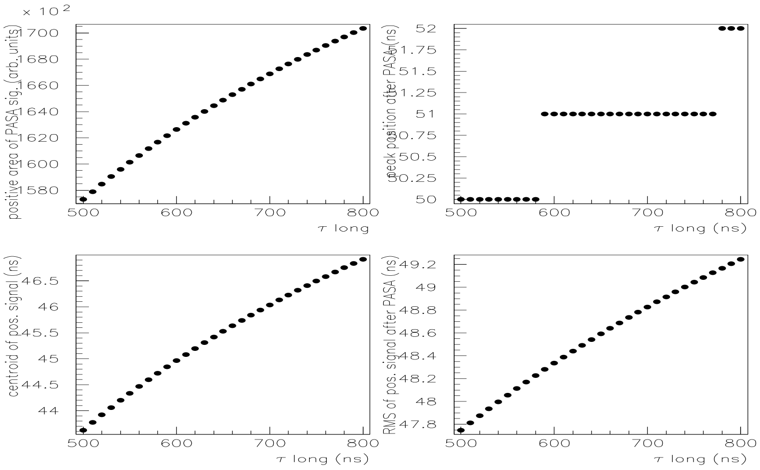

Figure 7: Positive area, peak position (delay introduced by PASA), centroid position and RMS of the output signal as a function of τ_l.

Brief discussion

As the width of the electron cloud (input signal to the PASA) increases with the distance of the hit from the anodes, the top panel of figure 2 shows that an "apparent charge loss" at high drift distances could be detected. From figure 3 it is possible to extract a range of the input signal width corresponding to a range of the output signal RMS. The expected RMS range of the PASA output signal for a hit from a minimum ionizing particle (MIP) is: $20ns \leq RMS \leq 60ns$, depending on its position in the drift direction and its angle of incidence. This corresponds to an input signal width ranging from about 10 ns to about 100 ns, In the interval $10ns \leq signal\ width \leq 100ns$ the positive area of the output signal changes from .99 to .70 (an area equal to 1 corresponding to zero width).

In figure 8 the filled circles show how the ratio pulse-height/noise of the output signal changes as a function of the input signal width ($\tau_{short} = 11.5ns,\ \tau_{long} = 500ns$). The dashed curve represents the ratio as it would be with the amplifier but without the shaper effect. In this calculation it is assumed a two dimensional gaussian charge distribution across the detector. The width in the anode direction is supposed to be equal to the width in the drift direction, and a drift velocity of $6.4\mu m/ns$ is assumed.

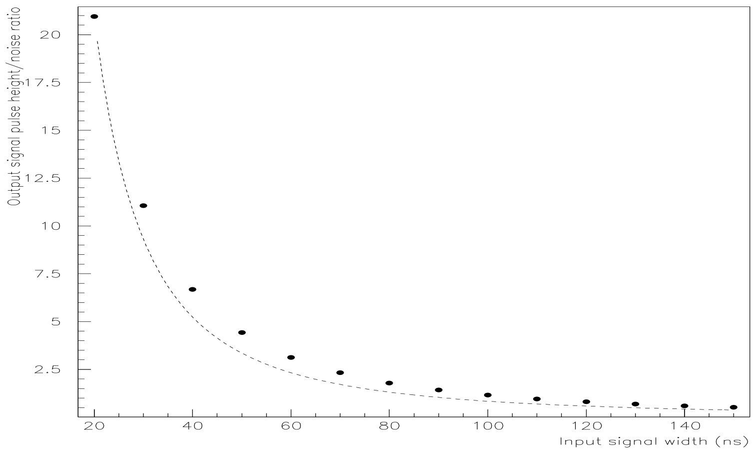

Figure 8: Variation of the pulse height of the output signal divided by the noise, as a function of the input signal width. The noise is fixed to 2.5 ADC counts.

Moreover a constant noise level of 2.5 ADC counts is assumed too. The output signal is normalized in such a way to reproduce observed signals from mips at short drifts. Notice that for an input signal width of 80ns the signal to noise ratio is reduced to 2.

The shift of the peak position or the centroid position is of primary importance, since it may affect the resolution of the detector and the tracking and reconstruction efficiencies. The correct hit position could be obtained by calibrating for the effects of the signal width and τ_s. The latter could be estimated by fitting the hits from high ionization particles, that more clearly show the signal shape. This calibration should be performed anode by anode, or at least, PASA by PASA.

The effects shown are due by the PASA only, once it is described by the response function (1). These effects will make the data analysis more complex and caution has to be used to avoid systematic errors.

References

[1] V. L. Rykov, *STAR note 223.*

[2] D. Lynn, *Private communication.*

[3] I. Kotov, *Private communication.*

[4] V. L. Rykov, *Private communication.*