Understanding of the Proportional Counter Pulse Shape
Andrew Durocher
RARAF
Abstract

Overall purpose is to create an effective way to extract information from x-ray pulses in a proportional counter created from an x-ray microbeam which has pulses arrive in short bursts of 200 nanoseconds long about 10 x-rays per pulse.
What is a proportional counter?

• A proportional counter is a type of high speed ionization chamber used to amplify signals that contain too few electrons to observe directly.

• Specifically measuring the voltage, from the observation a proportional relation to initial charge inputted into the counter can be obtained
Geometry of a Proportional Counter

• There is an outer cylinder (cathode) with a negative voltage
• Inside there is a helix with a positive voltage
• Inside that is a central wire (anode) with a much higher positive voltage.
• With this system, electrons inside the counter will drift towards the center while positively charged ions will drift outwards toward the outer cylinder.
Multiplication/Avalanche

- When electrons drift close enough to the anode. Approximately the radius of the anode in distance the multiplication will start.
- This avalanche will create a large number of electrons and positive ions that will be somewhere around $10^4$ times the initial charge.
Operating Regions and Gain vs. Voltage

- The chamber geometry, filling gas and applied voltage determines the multiplication.
- There are several operating regions, depending on applied voltage, which are shown in the figure.
Chamber Potential for a Single Ion Pair

- $P(t) = -\frac{e + q_+(t)}{C}$

- $-e$ is the charge of the electron which is collected on the anode at time zero. $q_+(t)$ is the charge induced by the positive ion at its position which is a function of time. $C$ is the capacity of the chamber.
Pulse Shape Equation for a Single Ion Pair

\[ P(t) = -e \ln\left( \frac{2VKt}{a^2 \ln(b/a)} + 1 \right) \frac{1}{2C \ln(b/a)} \]

- \( V \) is the voltage difference between the helix and the anode, \( K \) is the ionic mobility based off the pressure and gas type inside the proportional counter.
Electron signal and Mirror Charge

- Once multiplication has occurred, the electrons have reached the anode, and created a voltage step.
- Though it is not first noticeable due to the mirror charge created by the positive ions.
- The positive ions quickly move away due to the charge of the E field and the pulse is created.
Equation simplification

- \( P(t) = A \ln\left( \frac{t}{\tau} + 1 \right) \)
- \( A = \frac{q - \frac{a^2 \ln(b/a)}{2VK}}{2C \ln(b/a)} \)
- \( \tau = \frac{a^2 \ln(b/a)}{2VK} \)
- \( A \) and \( \tau \) are treated as experimental constants
Raw data of an alpha particle
Smoothing the data

• Using excel we took all the data points, and fit the data to a linear least squares curve also known as a sliding average

• We use this new curve as our pulse
Our equation compared with data

- This is a graph showing how similar data curve of an alpha particle is compared to our theoretical equation.
Guide Line

• In the initial rise approximately 50-60% of the total voltage is obtained, if a pulse looks has multiple humps, by measuring the height and the number of humps it will be possible to measure the input x-ray’s energy, as well as the number of x-ray’s within the pulse.
Pulse shape combination

- Unfortunately, it is not guaranteed that pulses will come at a minimum of intervals of 5 nano seconds, meaning if two pulses arrive too close together, they could be read as one pulse instead of 2. Our goal is to see the initial rise of the first pulse completely before seeing it jump again.
Derivative of equation

- Taking our simplified equation, \( P(t) = A \cdot \ln(1+t/t_o) \), then taking the derivative of this, which will give an expression of \( P(t) \) rise changes in time, so we can see how to make the initial rise move quickest.

- \( \frac{dP(t)}{dt} = \frac{A}{t_o} / \left(1 + \frac{t}{t_o}\right) \)

- As seen to the right when you plot this new equation and play with \( A \) and \( t_o \) you see that changing \( A \) changes how quickly the pulse shape rises. So we want a small \( A \), meaning a large \( b/a \) ratio.
Conclusion

• Though I was never able to actually test my work on the actual x-ray microbeam

• I was able to fully understand how the proportional counter works and advise the best settings for the proportional counter to be under.

• Create a system guide line for extracting results from the data that will be collected
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