Characterization of ParTI Phoswiches Using Charged Pion Beams

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Motivation and Background

The Partial Truncated Icosahedron (ParTI) detector array consists of 15 phoswiches and was designed to measure charged pions (π) emitted in pionic fusion reactions. Particle Identification (PID) can be achieved for light charged particles using fast vs. slow shape discrimination. In an effort to characterize their PID capabilities and demonstrate their consistency, 4 phoswiches were taken to the Paul Scherrer Institute (PSI) in Switzerland where π^+, π^-, and proton beams were scattered onto them. Using digitizers to record the detector response waveforms, π can also be identified by the characteristic decay pulse of their muon (μ) daughters. To analyze the pion decay, a muon decay trigger was implemented in place of a singles trigger. This would allow for a trigger to happen on possible pion-candidate events by only triggering if the CFD is triggered a second time.

Phoswiches

- ParTI array consists of 15 phoswiches (Figure 1)
  - Approximately 9" diameter
  - Each phoswich has own frame with angled tabs

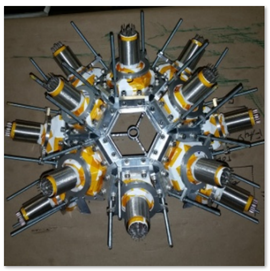

Figure 1

- Phoswich made of 2 scintillating components coupled to a photomultiplier tube (PMT) (Figure 2)
  - EJ-212 scintillating plastic
    - 0.118" thickness
    - Fast scintillation response
    - First scintillator encountered
  - Thallium-doped cesium iodide (CsI(Tl)) crystal
    - 0.59" thickness
    - Slow scintillation response
    - Second scintillator
  - Sensitive to charged and neutral particles
    - Type and amount of energy deposited determines shape of scintillation pulse

Figure 2

Waveforms

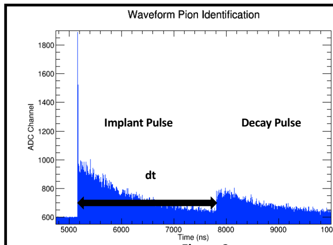

Figure 3

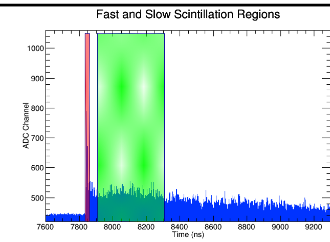

Figure 4

- π decay is not easily detectable
  - Short lifetime (26 ns) and small energy deposit (4.12MeV) when decays
  - Photon pulse hidden under a larger implant pulse of pions.
- $\pi^+ \rightarrow \mu^+ + \nu_\mu \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$
- $\pi^- \rightarrow \mu^- + \bar{\nu}_\mu \rightarrow e^- + \bar{\nu}_e + \nu_\mu$
  - Longer μ lifetime (2200 ns) and larger energy deposit (up to 50 MeV) when e deposits energy
  - Easier π ID due to distortion in waveform (2nd pulse)
    - Difference between pulses (**dt**) shown by arrow (Figure 3)

- Fast and Slow regions (Figure 4)
  - Fast
    - Highlighted in **red**
    - Response from fast plastic scintillation
  - Slow
    - Highlighted in **green**
    - Response from slow CsI(Tl) scintillation

Fast vs Slow Particle Identification

- Particles deposit energy into scintillators
  - Photons produced
  - PMT converts photons to a cascade of electrons
  - Voltage generated on PMT due the electrons
    - Converted to counts of photons/time
- 2 pulses in the waveform designate implantation and decay in detector
  - Area under fast and slow regions is integrated

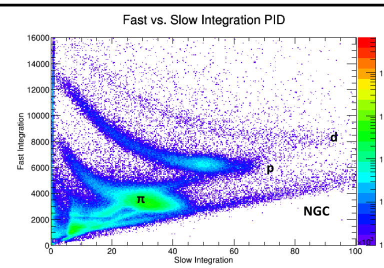

Figure 5

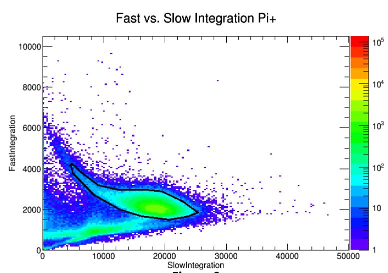

Figure 6

- Fast vs. Slow Integration plot
  - Yields PID lines (Figure 5)
    - Based on relative energy lost in both scintillators
    - Amount of photons produced ≈ energy deposit

- Cuts made gating π^+ section (Figure 6)
- Cuts made gating π^- section (Figure 7)
- Analyze decay behavior inside these pion cuts

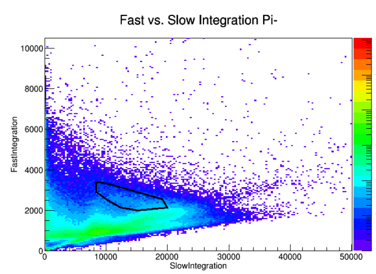

Figure 7

dt and Decay Curves

- dt is the time of survival of the muons
- Plotting dt (Figure 8)
  - Produce exponential curve
  - Decay constant can be generated
    - λ_μ = 4.55 E-4 ns^{-1}
    - $\lambda_{\pi^+} = 4.56\ \mathrm{E}{-4}\ ns^{-1}$
    - $\lambda_{\pi^-} = 5.11\ \mathrm{E}{-4}\ ns^{-1}$

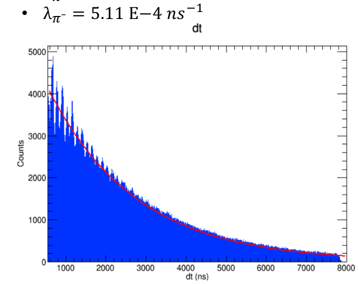

Figure 8

- Mean lifetime of particle (Figure 9)
  - Inverse of decay constant
  - μ = 2197 ns
    - Designated by the red line
  - π^+ events – blue circles
  - π^- events – magenta squares

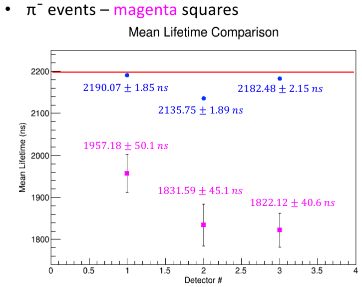

Figure 9

Conclusions

Using Fast vs. Slow PID methods with the phoswiches, pion identification and separation from other light charged particles is possible. By using the decay trigger, the selectivity for pions was increased by an order of magnitude. By focusing in the pion implant region, decay curves for its muon daughter can be reproduced, further identifying the original presence of a pion in its PID region.

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References

[1] A. Zarrella, et. al, *Science Direct,* awaiting publication