Simulating Timing Resolution Effects of Scintillation Geometry for the M9 Prototype Muon Spectrometer

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Objective

- Simulate attainable resolution of a prototype spectrometer.

Introduction

Muon Spectrometers are designed to probe the fine magnetic structures of materials being studied. At the Canadian National Subatomic Physics Laboratory TRIUMF, muons are generated using the institutions large cyclotron.

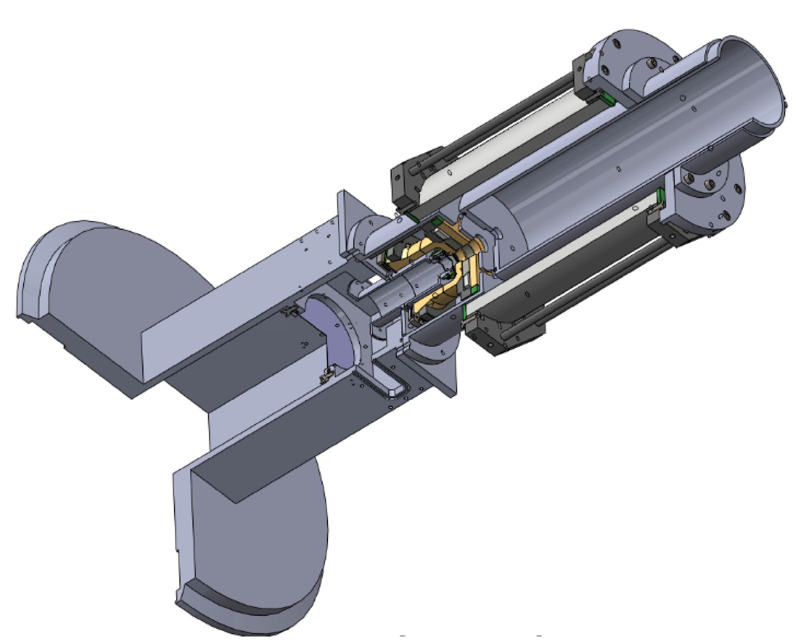

Figure 1: CAD model of M9 Muon Spectrometer

The muons are embedded into materials at low energies (5-50MeV) [2]. While embedded in the sample the muon spin precesses about the local internal magnetic field [1]. The Muons then decay releasing positrons which pass through the scintillator generating a burst of light.

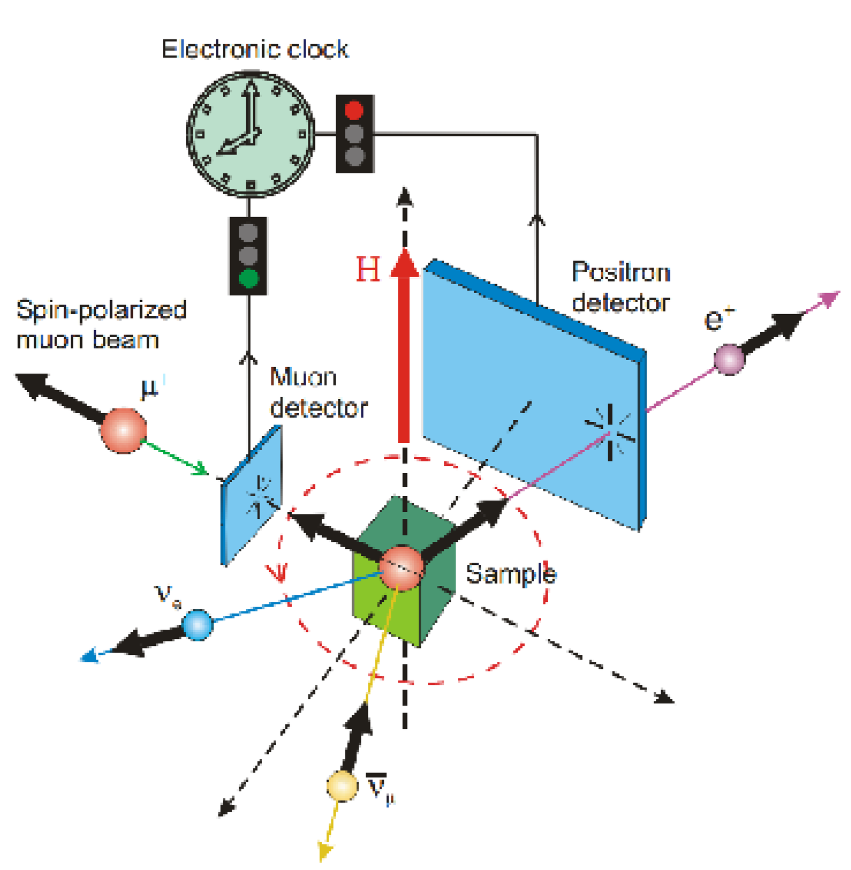

Figure 2: Displays Simplified Diagram of a transverse field muon spectrometer [1]

The time difference between light detection points allows for the positron trajectory to be reconstructed which gives information about the shape of the internal magnetic structure of the sample.

Simulation

A simulation was written in C++ and analyzed using ROOT. The architecture enables simulation of scintillation pieces generated using 3D CAD programs. The simulation generates random photons along a positron trajectory through the scintillator which propagate until they reach a Silicon Photomultiplier (SiPM).

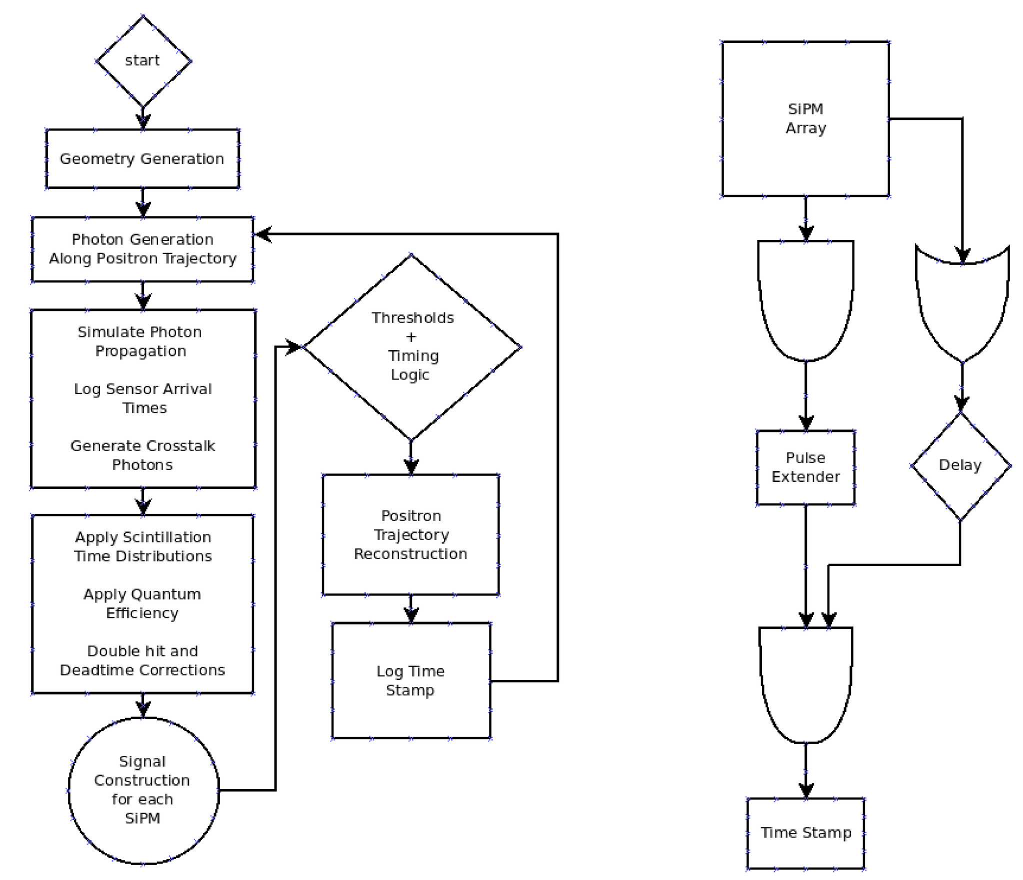

Figure 3: Simulation flow chart with logic discrimination

Each photon is time stamped and checked for double hits. Cross talk and scintillation probabilities are used to adjust each stamp which is then used to generate a pulse. The sum of the pulses from each photon hit forms the final signal. A threshold is applied which gives a time of the incoming pulse. The time of this pulse is stored and the simulation reiterates a new positron event.

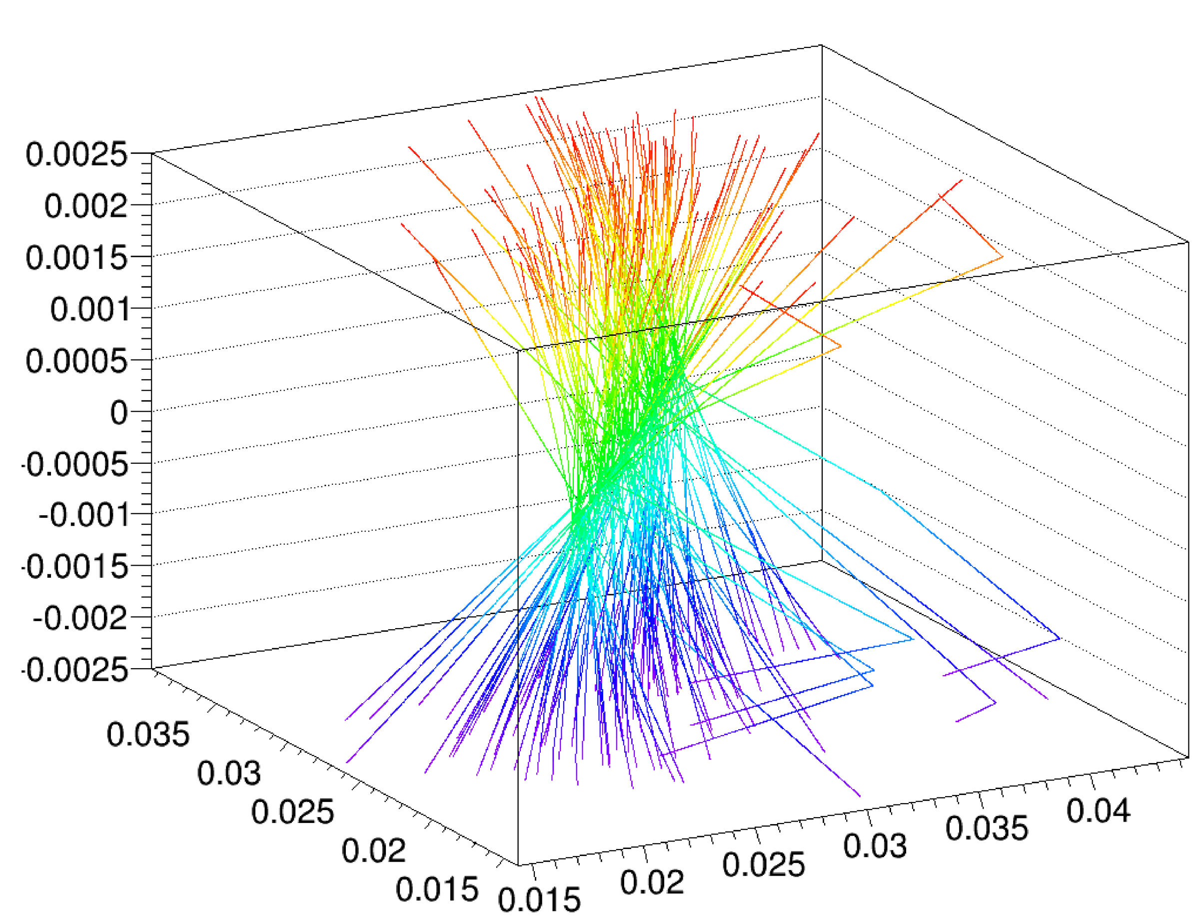

Figure 4: Photons being randomly generated along a positron trajectory

Results

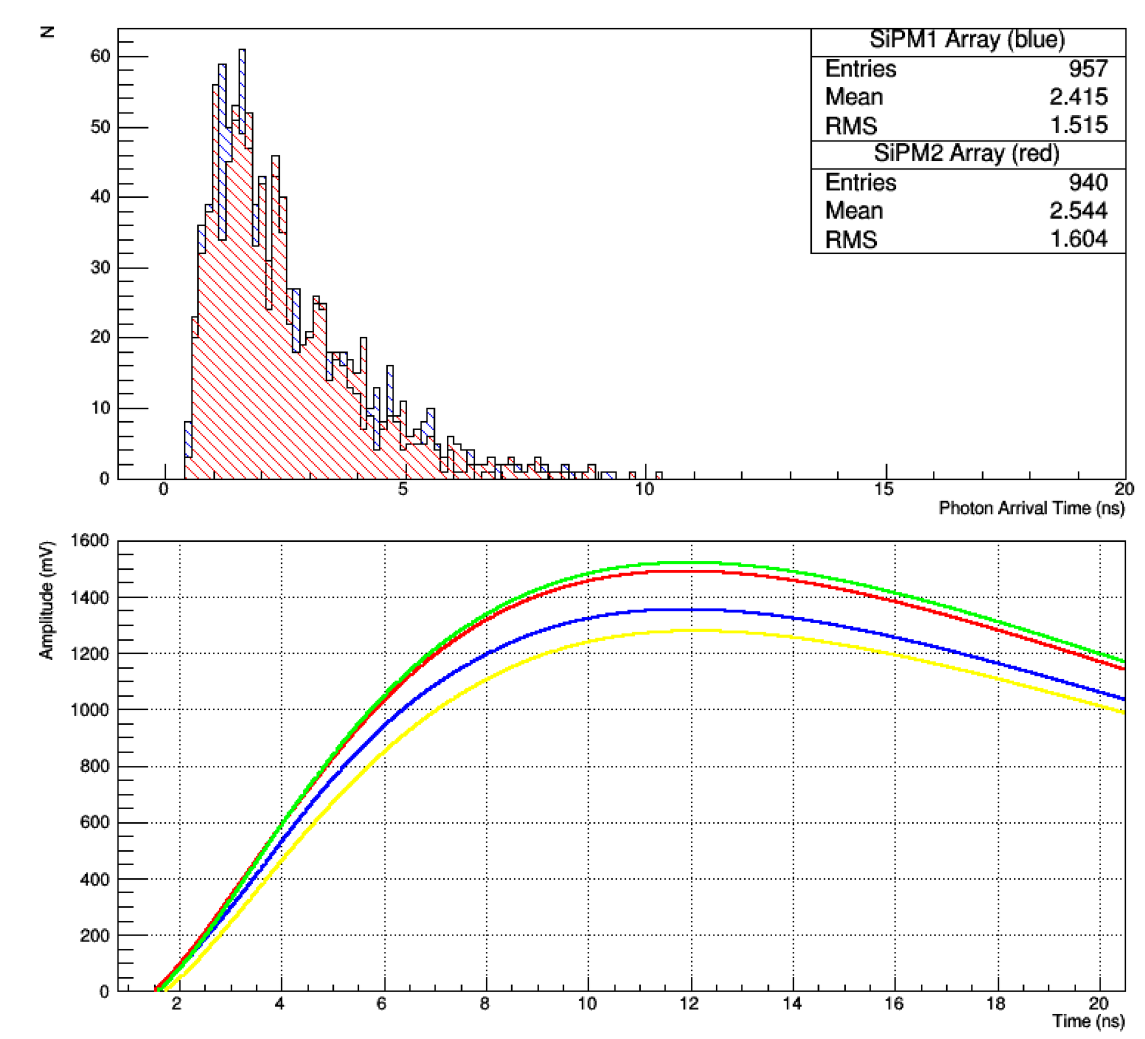

Figure 5: Output of a single positron event. a) Displays all photon arrival times with adjustments. b) SiPM output signals.

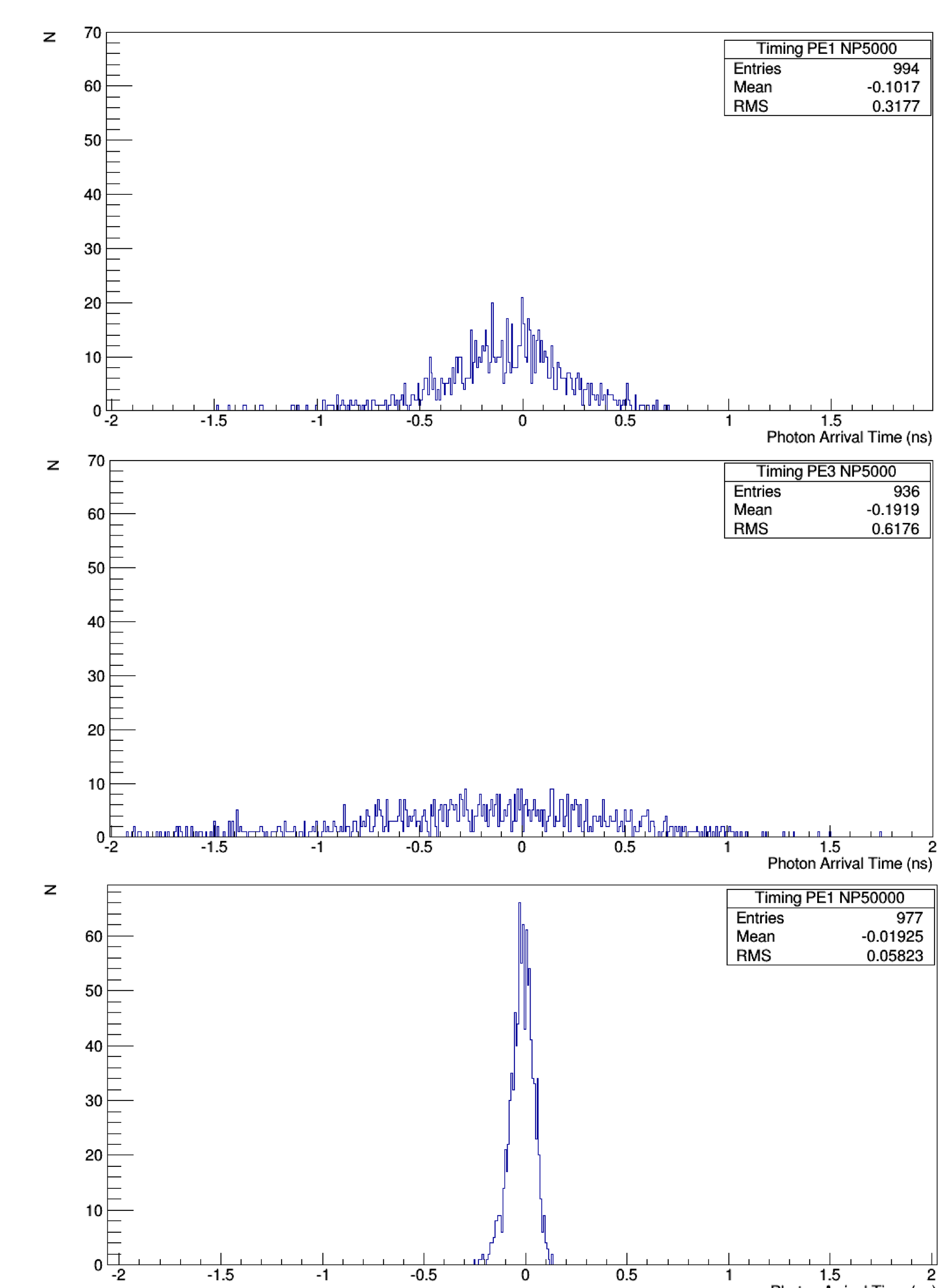

Figure 6: The timing results of multiple positron events for specific energies (5MeV to 50MeV) and thresholds (1PE to 3PE)

Conclusion

The results of the simulation conclude that a 60 picosecond resolution can be attained for the Sensl B-series SiPM given the energy of the positron is sufficiently high and given optimal thresholds are used. It was shown cylindrical scintillation pieces had small contributions to timing as the geometry is isotropic, therefore timing largely dependent on the single photon response of SiPM and methods of discrimination. The Sensl C-series SiPM's (unavailable at the time) due to their low noise capabilities could provide lower positron energy window while still attaining a 60ps resolution.

Important Result

The simulation suggests a 60 ps resolution is attainable using the low noise Silicon photomultipliers with digital logic discrimination.

References

[1] Jeff E. Sonier (2014)
Muon Spin Rotation, Relaxation, Resonance
http://musr.ca/intro/musr/muSRBrochure.pdf

[2] muSR general homepage (2012)
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[3] Joelle Barral (2008)
Study of Silicon Photomultipliers
http://www.stanford.edu/

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TRIUMF

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ROOT Data Analysis Framework

CMMS