DETECTING COPLANAR CHARGED TRACKS IN MUON DECAY – A MONTE CARLO STUDY

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ABSTRACT

In particle detector, muon decay $u^{+} \rightarrow e^{+}\ e^{+}\ e^{-}$ simulation was use to study of muon particles bombardment to solid surface . In this paper the muon decay was simulated by using Monte Carlo method. The result shows tree tracks charge must be in coplanar position with the surface.

ABSTRAK

Dalam pengesan zarah, Muon pereputan u + → e + e + e-simulasi adalah digunakan untuk mengkaji zarah Muon pengeboman ke permukaan pepejal. Dalam kertas ini pereputan Muon telah disimulasikan dengan menggunakan kaedah Monte Carlo. Hasilnya menunjukkan pokok menjejaki caj mesti berada dalam kedudukan sesatah dengan permukaan.

Keywords: muon, Monte Carlo, detector

INTRODUCTION

The existence of muon was first identified in cosmic ray experiments in 1936.The muon is an elementary particle similar to the electron, with a unitary negative electric charge and a spin of ½. It is classified as a lepton, together with the electron, the tau, and the three neutrinos. It is an unstable subatomic particle with a mean lifetime of 2.2 µs. Like all elementary particles, the muon has a corresponding antiparticle of opposite charge but equal mass and spin: the antimuon (also called a positive muon). Muons are denoted by μ^{-} and antimuons by μ^{+}.Muons have a mass of 105.7 MeV/c2, which is about 200 times the mass of an electron.

CHARGED LEPTON FLAVOUR VIOLATION

Charged-lepton flavour violation (CLFV) is defined by all charged-lepton processes that violate lepton-flavour number. In the minimal standard model neutrinos are massless and lepton flavour is conserved separately for each generation. The muon system is one of the best places to search for lepton-flavour-violating (LFV). In Table 1, the upper limits of various lepton-flavour-violating decays are listed. In this research we select $\mu^{+} \rightarrow e^{+}\ e^{+}\ e^{-}$ as candidate.

The event signature of the decay $\mu^{+} \rightarrow e^{+}\ e^{-}\ e^{+}$ is kinematically well constrained, since all particles in the final state are detectable. The decay width of $\mu^{+} \rightarrow e^{+}\ e^{+}\ e^{-}$ is determined from the *Effective Lagrangian.* In experimental for search $\mu^+ \rightarrow e^+e^+e^-$ have been carried out after the pioneering measurement in 1976 using a cylindrical spectrometer. Table 2 will show the historical progress and summary of searches for $\mu^+ \rightarrow e^+e^+e^-$ decay.

Table 1. Experimental limits for the lepton-flavour-violating decays of muon, tau, pion, kaon, and Z boson.

Reaction	**Present limit**	**Reference**
$\mu^+ \rightarrow e^+ \gamma$	<1.2 x 10^{-11}	Brooks *et al.* (1999)
$\mu^+ \rightarrow e^+ e^+ e^-$	<1.0 x 10^{-12}	Bellgardt *et al.* (1988)
μ^- Ti $\rightarrow e^-$ Ti	<6.1 x 10^{-13}	Wintz (1998)
$\mu^+ e^- \rightarrow \mu^- e^+$	<8.3 x 10^{-11}	Willmann *et al.* (1999)
$\tau \rightarrow e \gamma$	<2.7 x 10^{-6}	Edwards et al. (1997)
$\tau \rightarrow \mu \gamma$	<3.0 x 10^{-6}	Edwards *et al.* (1997)
$\tau \rightarrow \mu \mu \mu$	<1.9 x 10^{-6}	Bliss *et al.* (1998)
$\tau \rightarrow e e e$	<2.9 x 10^{-6}	Bliss *et al.* (1998)
$\pi^0 \rightarrow \mu e$	<8.6 x 10^{-9}	Krolak *et al.* (1994)
$K_L^0 \rightarrow \mu e$	<4.7 x 10^{-12}	Ambrose *et al.* (1998)
$K^+ \rightarrow \pi^+ \mu^+ e^-$	<2.1 x 10^{-10}	Lee *et al.* (1990)
$K_L^0 \rightarrow \pi^0 \mu^+ e^-$	<3.1 x 10^{-9}	Arisaka *et al* (1998)
$Z^0 \rightarrow \mu e$	<1.7 x 10^{-6}	Akers *et al.* (1995)
$Z^0 \rightarrow \tau e$	<9.8 x 10^{-6}	Akers *et al.* (1995)
$Z^0 \rightarrow \tau \mu$	<1.2 x 10^{-5}	Akers *et al.* (1997)

Candidate: $\mu^+ \rightarrow e^+ e^- e^+$

Table2. The historical progress and summary of searches for $\mu^+ \rightarrow e^+e^+e^-$ decay.

Place	Year	90%-C.L. upper limit	**Reference**
JINR	1976	< 1.9 x 10^{-9}	Korenchenko *et al.* (1976)
LANL	1984	< 1.3 x 10^{-10}	Bolton *et al.* (1984)
SIN	1984	< 1.6 x 10^{-10}	Bertl *et al.* (1984)
SIN	1985	< 2.4 x 10^{-12}	Bertl *et al.* (1985)
LANL	1988	< 3.5 x 10^{-11}	Bolton *et al.* (1988)
SIN	1988	< 1.0 x 10^{-12}	Bellgardt *et al.* (1988)
JINR	1991	< 3.6 x 10^{-11}	Baranov *et al.* (1991)

During the muon decay, tree charged particle will produce. Figure1 gives configuration of muon decay in xyz plane, where theta (θ) is a colatitude the angle between the z-axis and the position vector of p_1, p_2 and p_3 .The Phi (ϕ) is measured from the x-axis the same azimuthal angle.

Muon decays at rest has been used in all past experiments. In this case, the conservation of momentum ($|\sum_i p_i|=0$) and ($\sum_i E_i$=mass of muon) could be effectively used together with the timing coincidence between two e+'s and one e-, where pi and Ei(i=1-3),respectively, the momentum and energy of each of the e's. Kinematics of the $\mu^+ \rightarrow e^+ e^+ e^-$ decay in the muon center of mass system, in which P_1, P_2 and P_3 are the momentum vector respectively to the 2 positron and 1 electron.

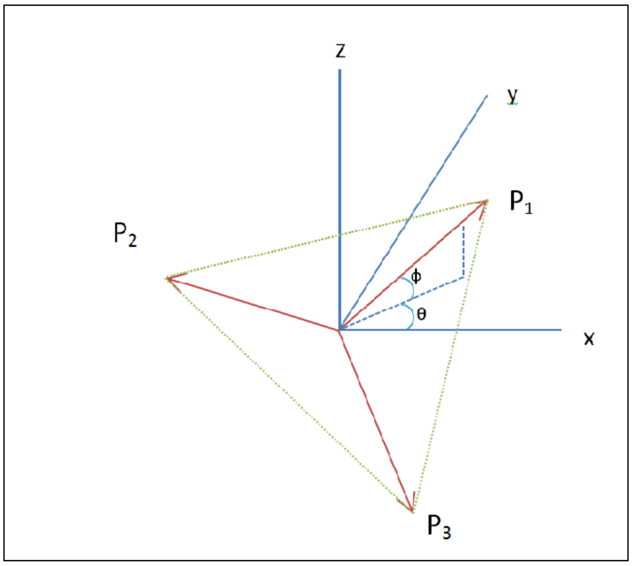


Figure 1. Kinematic variables of $\mu^+ \rightarrow e^+ e^+ e^-$.

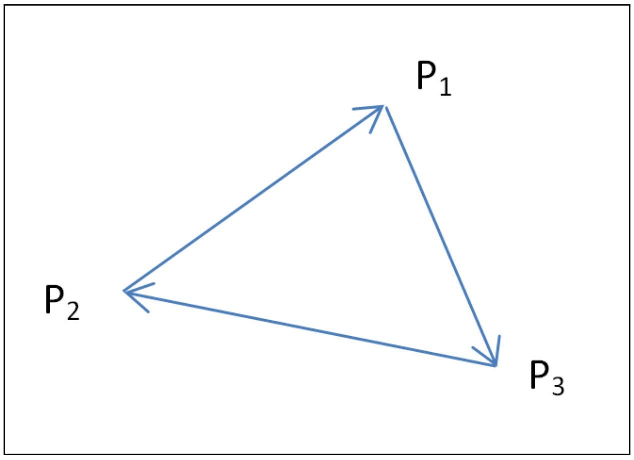


Figure 2. The conservation of momentum = ($|\sum_i p_i|=0$)

SIGNATURE: 3 CHARGED TRACKS IN MUON DECAY – COPLANAR

In particle physics there two ways used to reveal the inner structure of atom. First method we look at smashing beams of particle into target in the lab. Second way we look up at collision of beam with fixed solid target. To observe muon particle, we assume that the muon will decay tree particle charge. This tree charge particle will be detected in coplanar. For simulation we use scalar triple product to make sure that tree charged tracks decay in coplanar position. In simulation the value of $[(v_1 x\ v_2) \bullet v_3]$ must be zero. Zero means its perpendicular and we can say that the tree sub particle charge was in coplanar.

MONTE CARLO STUDY

A Monte Carlo uses random numbers to model some sort of a process.In particle physics we used Monte Carlo method to find the pprobability of particle interacting with matter and surviving the nuclear. In this research a Monte Carlo simulation was to generate the random of data to use in muon decay. From the random data we will generate the simulation of tree charged tracks in coplanar position.

SIMULATION

Firsly, we need generate random data for the muon decay ($\mu^+ \rightarrow e^+e^+e^-$). We need to decide the range value of the component in muon decay.So that data was selected in this range. The range value of the component for each particle charged tracks show in **Table 3.**

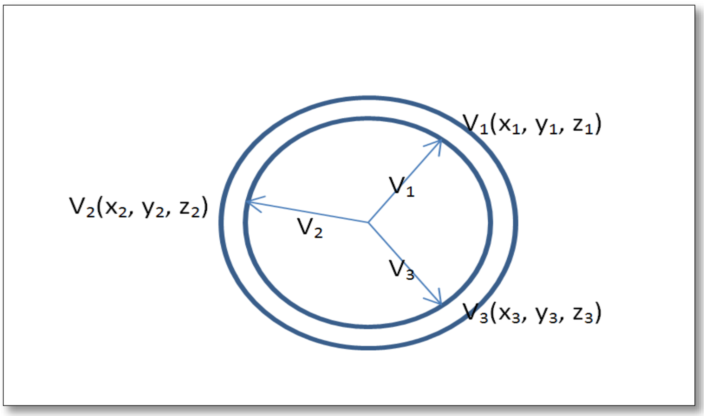


Figure **3.** Figuration of tree charged tracks in mu decay in coplanar.

Table3. Range value of kinematic variable of $\mu^+ \rightarrow e^+e^+e^-$

Variable	**Range value**
Theta(θ)	$0 \rightarrow 2\pi$
Phi(ϕ)	$0 \rightarrow 2\pi$
Psi(ψ)	$-\pi/2 \rightarrow \pi/2$
P_1	$0 \rightarrow$ mass of μ^+(105.7 MeV/c^2)
P_2	$0 \rightarrow$ mass of μ^+ - p_1
P_3	Mass of μ^+ - $(P_1 + P_2)$

After we generate the random data from range value of above variable we can construct momentum of each P_1, P_2 and P_3. The reconstructed momentum of these tree charged tracks as

$$(P_1, P_{1x}, P_{1y}, P_{1z}) = (P_1,\ p_1 \cos\theta \sin\phi,\ p_1\cos\theta \cos\phi,\ p_1\sin\theta)$$

$$(P_2, P_{2x}, P_{2y}, P_{2z})=$$

$$P_{2x} = -P_2 \cos\sigma_3 \cos\theta \cos\phi + P_2 \sin\sigma_3 \sin\psi \sin\theta \cos\phi - P_2 \sin\sigma_3 \cos\psi \sin\phi$$

$$P_{2y} = -P_2 \cos\sigma_3 \cos\theta \sin\phi + P_2 \sin\sigma_3 \sin\psi \sin\theta \sin\phi + P_2 \sin\sigma_3 \cos\psi \cos\phi$$

$$P_{2z} = P_2 \cos\sigma_3 \sin\theta + P_2 \sin\sigma_3 \sin\psi \cos\theta$$

$(P_3, P_{3x}, P_{3y}, P_{3z})=$

$P_{3x} = 0 - P_{1x} - P_{2x}$

$P_{3y} = 0 - P_{1y} - P_{2y}$

$P_{3z} = 0$

For component P_1 we used normal trigonometry and for component P_2 we used transformation translation on origin. After we get the value of P_1 and P_2 we can get the value of P_3. For component P_2 we start when p_1 on the x-axis.

Refer to the Figure 4, A show the origin of kinematic variable of muon decay. B show when theta is zero and C shows the p_1 on the x-axis that means the phi is zero. When p_1 is on the x-axis, to find the P_2 we can look up at xy plane, we can start looking for the P_2 at this point. For P_2 component we need another variable, σ_3 this is an angle between x-axis and y-axis. For σ_3, we can generate this from the cosine law. So start at this point we do tree times transformation on the component p_2 we use the last transformation as a component p_2

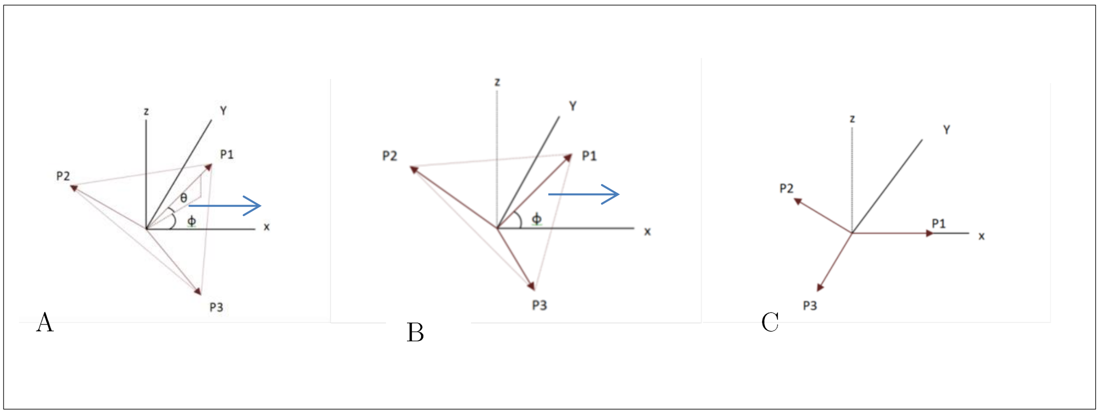


Figure 4. A: Origin of the kinematic of muon decay,B:theta,θ=0, C:phi,ϕ=0.

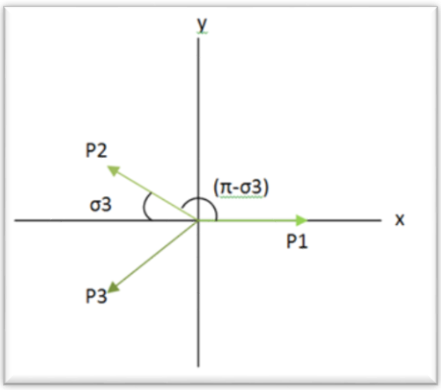


Figure 5. Tree charged tracks on xy plan

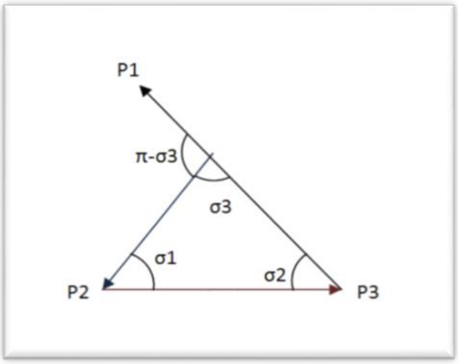


Figure 6. Cosine law to find the angle between P_1 and P_2

RESULTS

Figure 7, show us the distribution of each kinematics variable in the $\mu^+ \rightarrow e^+ e^+ e^-$. This data was generating random number by Monte Carlo simulation. From this data we can compute the value of data for tree charged tracks. In Figure 8.A, the value of coplanarity is zero show us the tree charged track was in coplanar. The rest of the graph shows the efficiency vs angular resolution. This efficiency show when we put some error in calculation. **Figure8.B** show the efficiency when it has 0.005 error**, Figure8.C** show the efficiency when it has 0.010 error and lastly Figure 8.D show the efficiency when it has 0.015 error.

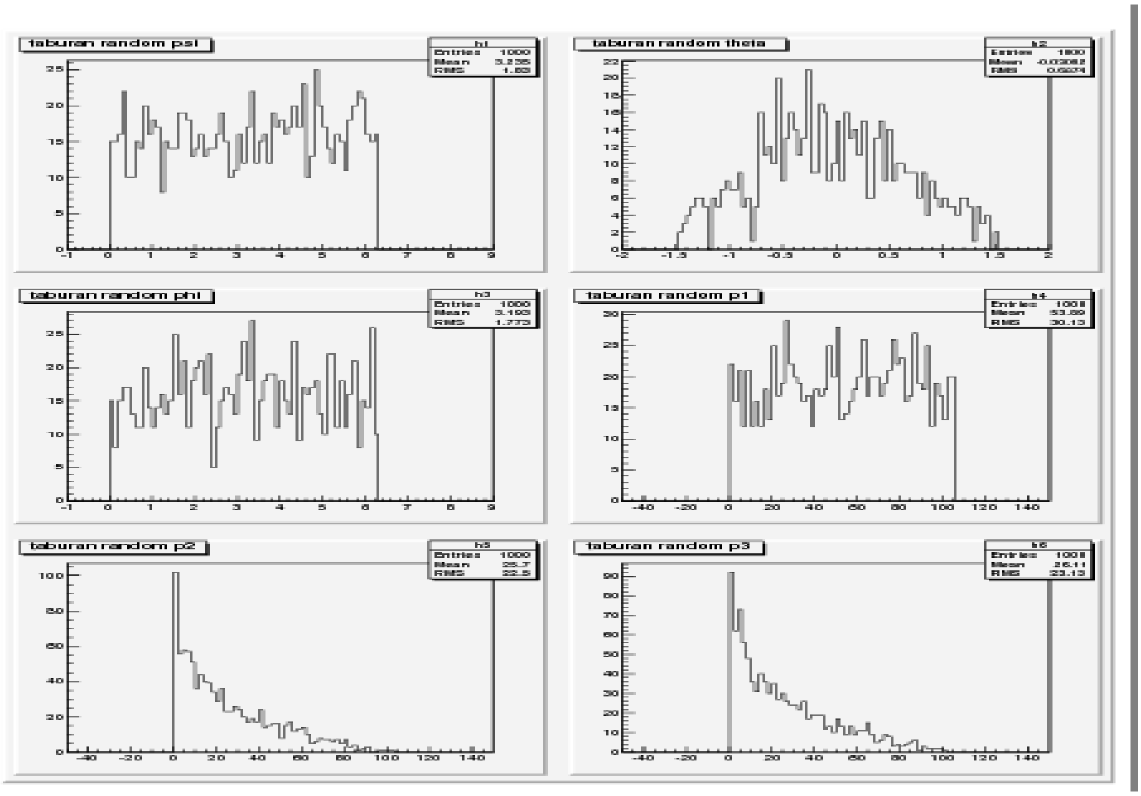
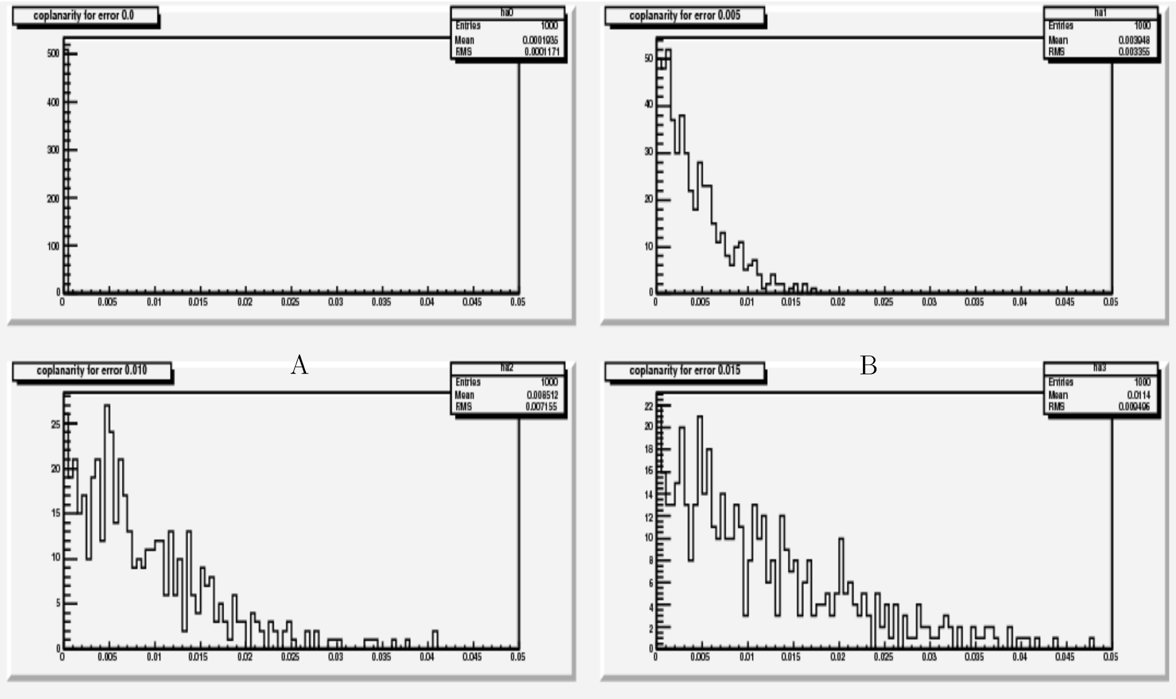


Figure 7. Distribution of random number of kinematic variable in $\mu^+ \rightarrow e^+ e^+ e^-$



C D

Figure8. Efficiency vs angular resolution

CONCLUSION

The simulation of the muon decay needs to be in coplanar. The purpose of this simulation we can expand to the detector in muon detector for the future research.

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