Charged Particle Mirroring

What is the approximation/assumption used in Magnetic Mirroring Theory ?

i) Fields are changing slowly with respect to gyro-period (i.e.) Scale Lengths are long with respect to gyro radius (*Ref. Pg 58, Ch 3, Intro. To Sp. Sci. by C.T. Russell*)

In the scaled down version of the system, as compared to Earth or other industrial setup itself, the input parameters are chosen such that the above assumption is not violated.

ii) Averaging over one Gyro Orbit, $\vec{v}_\perp = v_\theta \hat{\theta}$ and gyro radius $\approx R_L$.

Example - 1

Mirroring outside the ring system

Analogous to electron mirroring by Earth’s dynamo.

Input Conditions

density = 2e3; % Density in [kg m^-3]

radius = 1e-6; % Radius in [m]

q = 1e-12; % Charge in [C]

m = density * (4/3)*pi*(radius^3); % Mass in [Kg]

Input initial position and velocity (User Input)

x(1) = -0.2; % in [m]

y(1) = -0.15; % in [m]

z(1) = -0.25; % in [m]

vx(1) = 57.735; % in [m s^-1]

vy(1) = 57.735; % in [m s^-1]

vz(1) = 57.735; % in [m s^-1]

% Coil Parameters;

R1 = 0.05; % Radius of Coil 1 in [m]

R2 = 0.25; % Radius of Coil 2 in [m]

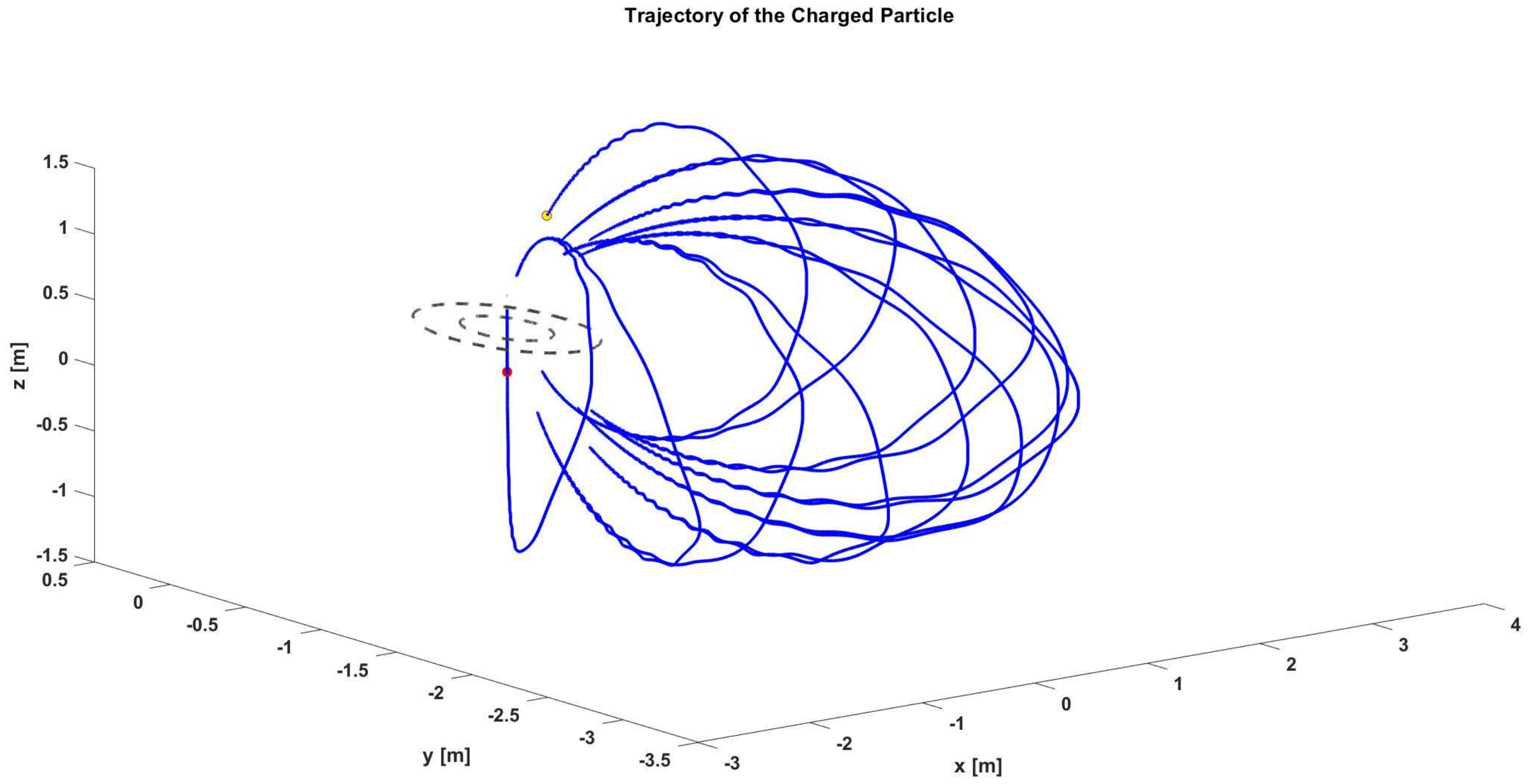
R3 = 0.50; % Radius of Coil 3 in [m]

d12 = 0.25; % Distance between Coil 1 and Coil 2 in [m]

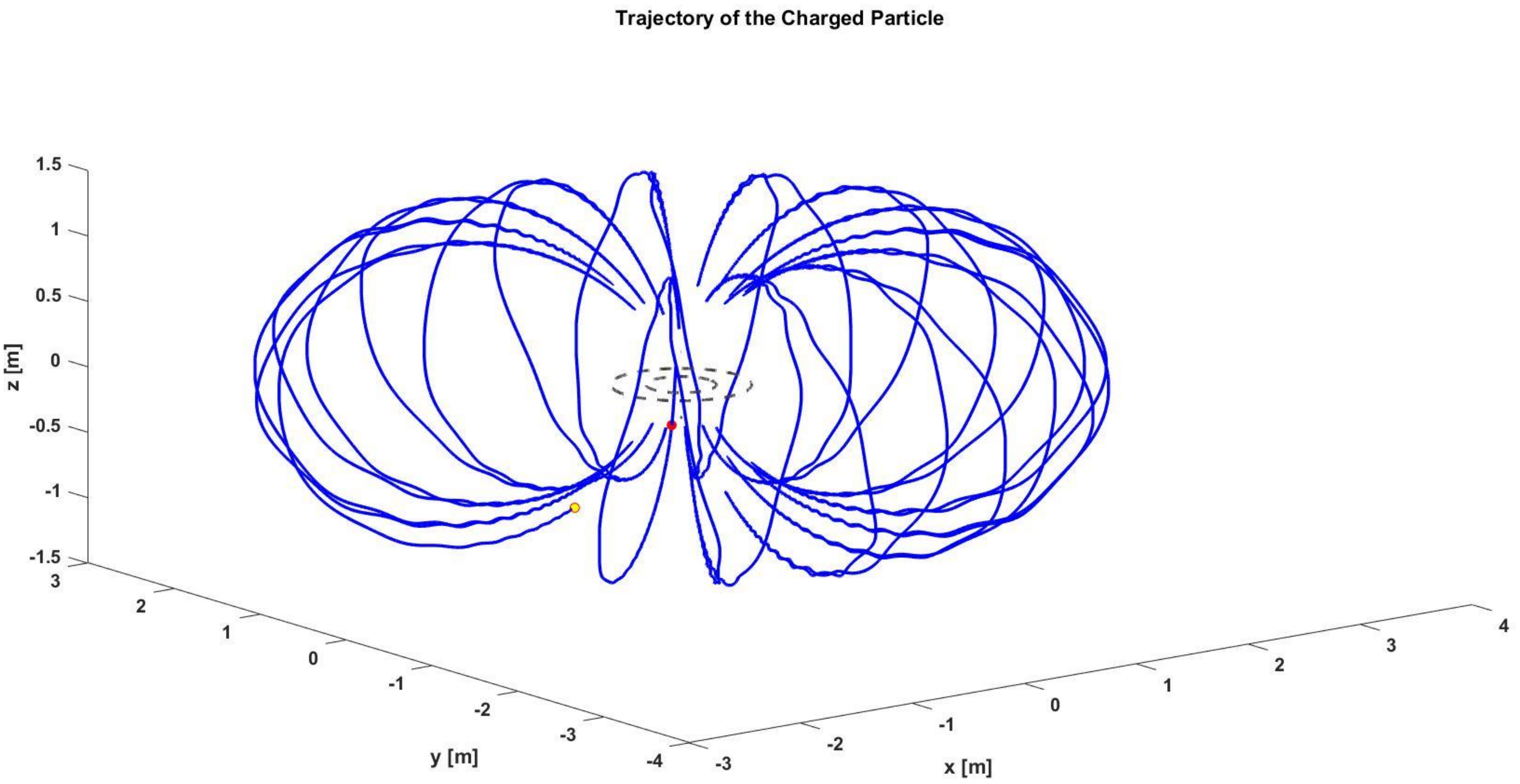
d23 = 0.25; % Distance between Coil 2 and Coil 3 in [m]

Current in all rings is 1e9 A (I know, too high! This is the required levels of field to ensure gyro radius of above described particle is at least comparable than the scale length of the rings)

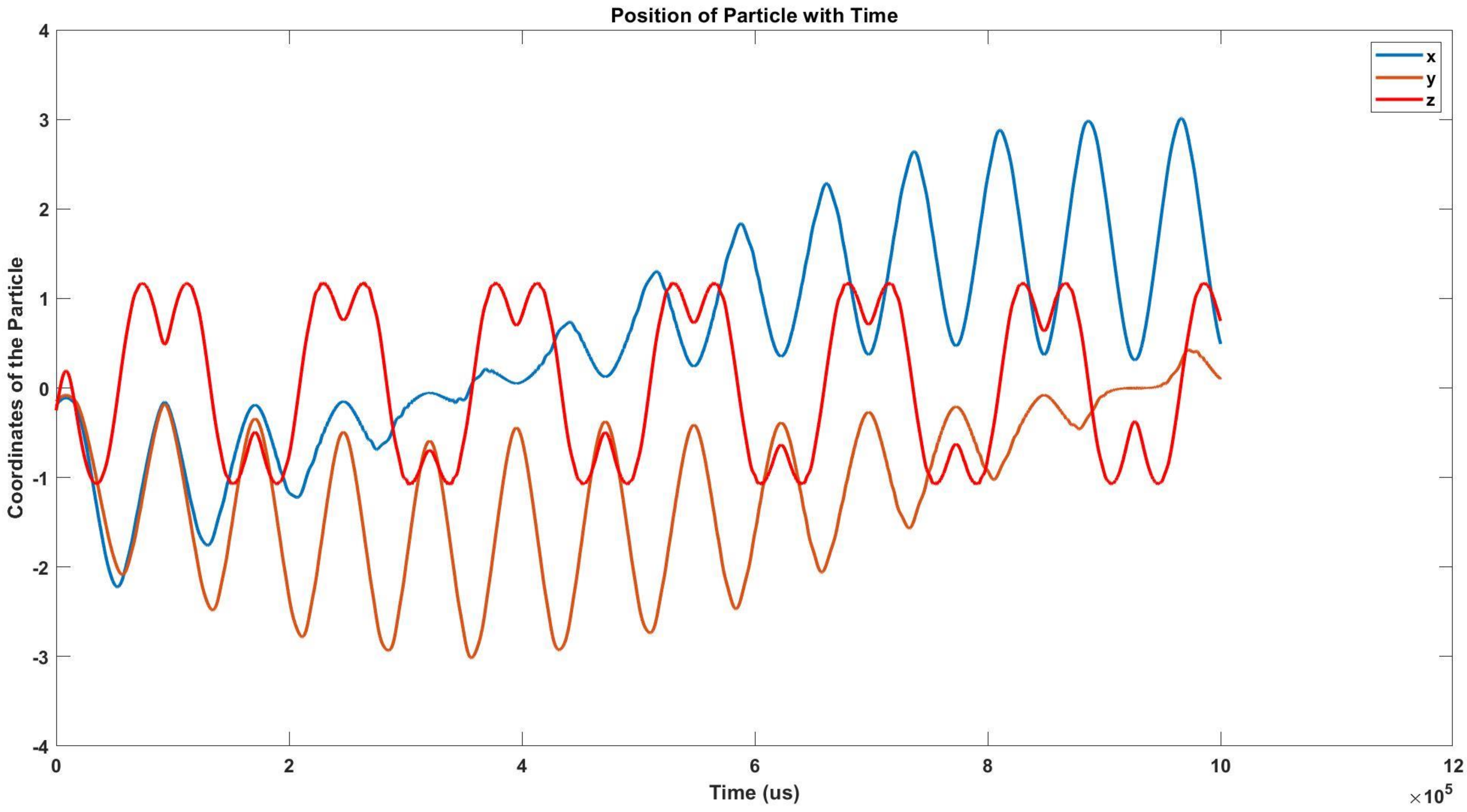
Red Dot is start point and Yellow Dot is the end point



Same Result as earlier, just longer simulation time



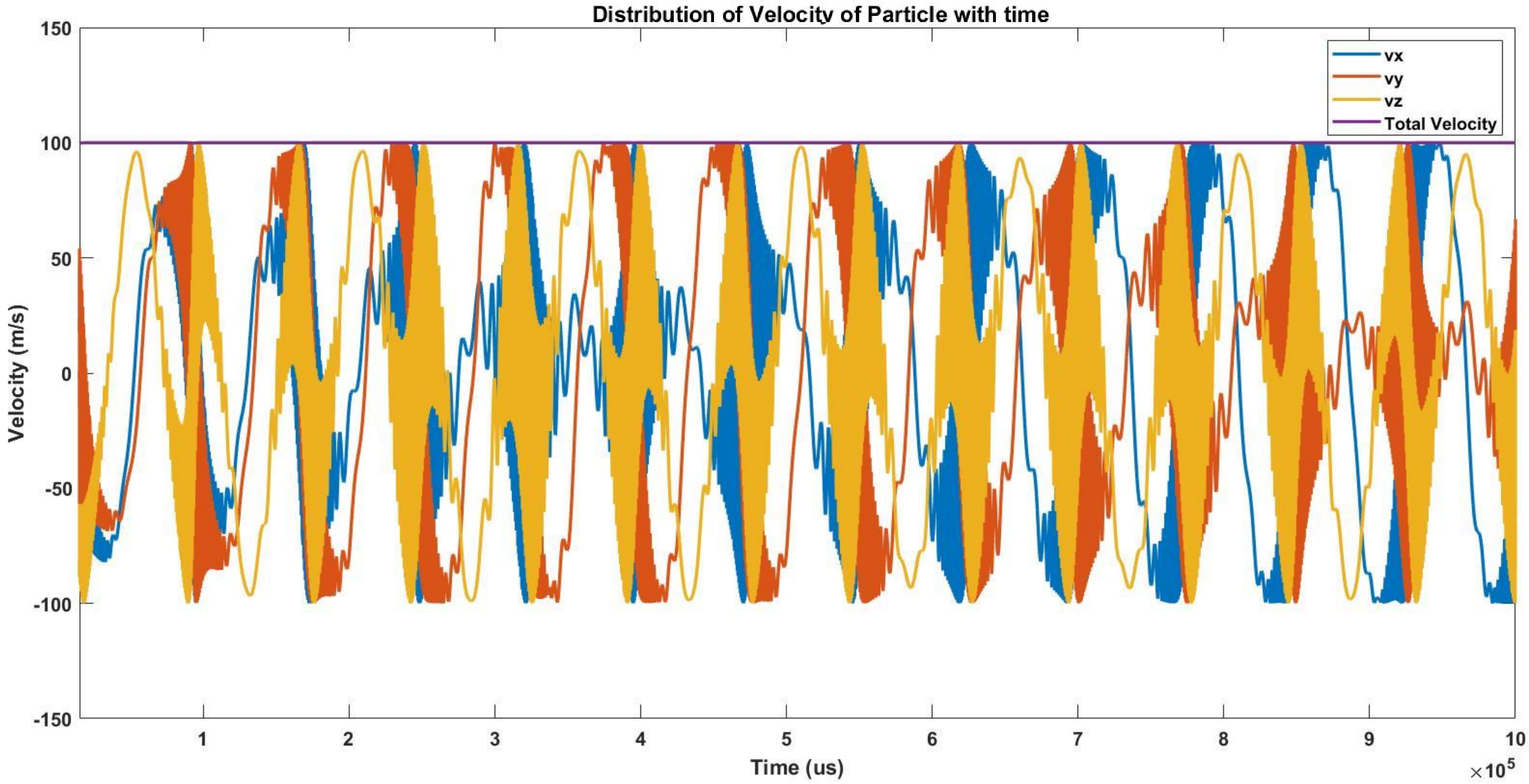
In case last result didn't make sense, try to use this to understand how position of particle varies with time



Very Difficult to make sense of this! But make note of two things :

i) Total Velocity is constant with time! Only Lorentz force is involved, and since it’s a conservative force, no energy is lost.

ii) Velocity is redistributed across its components with time.



Example 2

Deflection within a ring system

Input Conditions

```
% Particle Parameters
density = 2e3;  % Density in [kg m^-3]
radius  = 1e-8; % Radius of [m]
V = 1e1;        % Potential in [V]
m = density *(4/3)*pi*(radius^3); % Mass in [Kg]
q = 4*pi*epsilon_o*radius*V;       % Charge in [C]

% Input Initial Position and Velocity

x(1) = R1/3;          y(1) = R1/3;      z(1)  = 1*(d12);

vx(1) =vy(1) = vz(1) = -20/sqrt(3)
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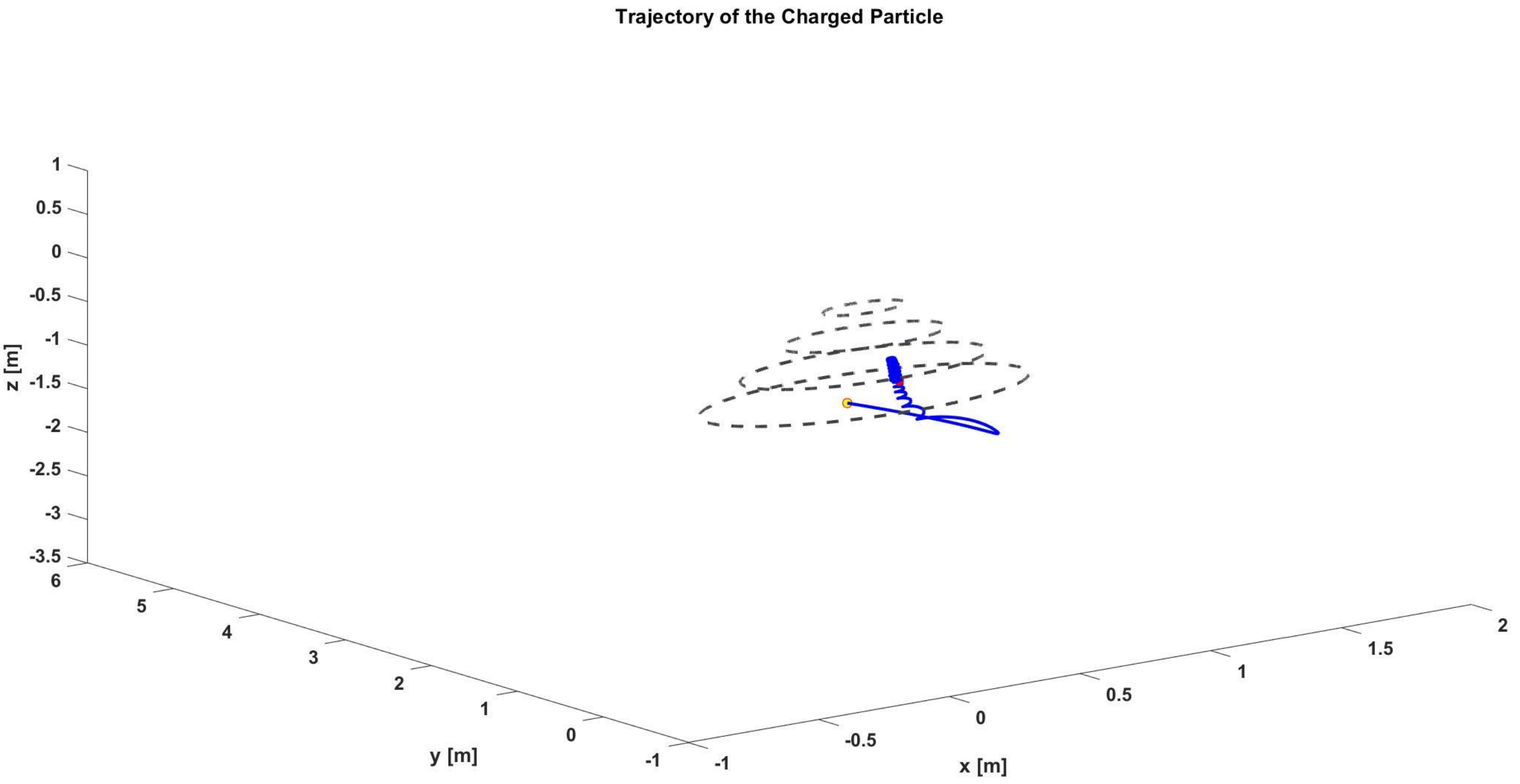
```
% Coil Parameters;

I0 = 300;   % Current in Coils in [A]
L  = 5e3;   % Length of Coil in [m]
R1 = 0.600; R2 = 0.450 R3 = 0.300;         R4 = 0.150
d12 = 1/3;  d23 = 1/3;   d34 = 1/3;

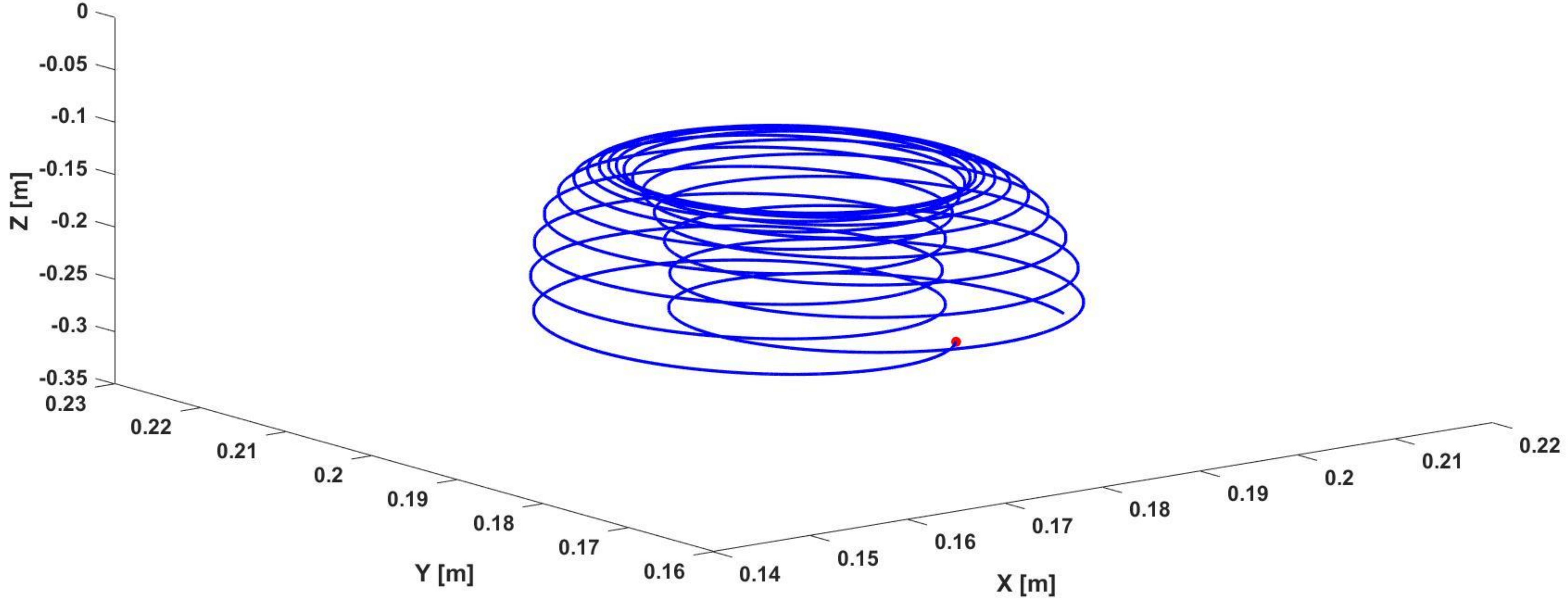
n1 = L/(2*pi*R1);    n2 = L/(2*pi*R2);
n3 = L/(2*pi*R3);    n4 = L/(2*pi*R4);

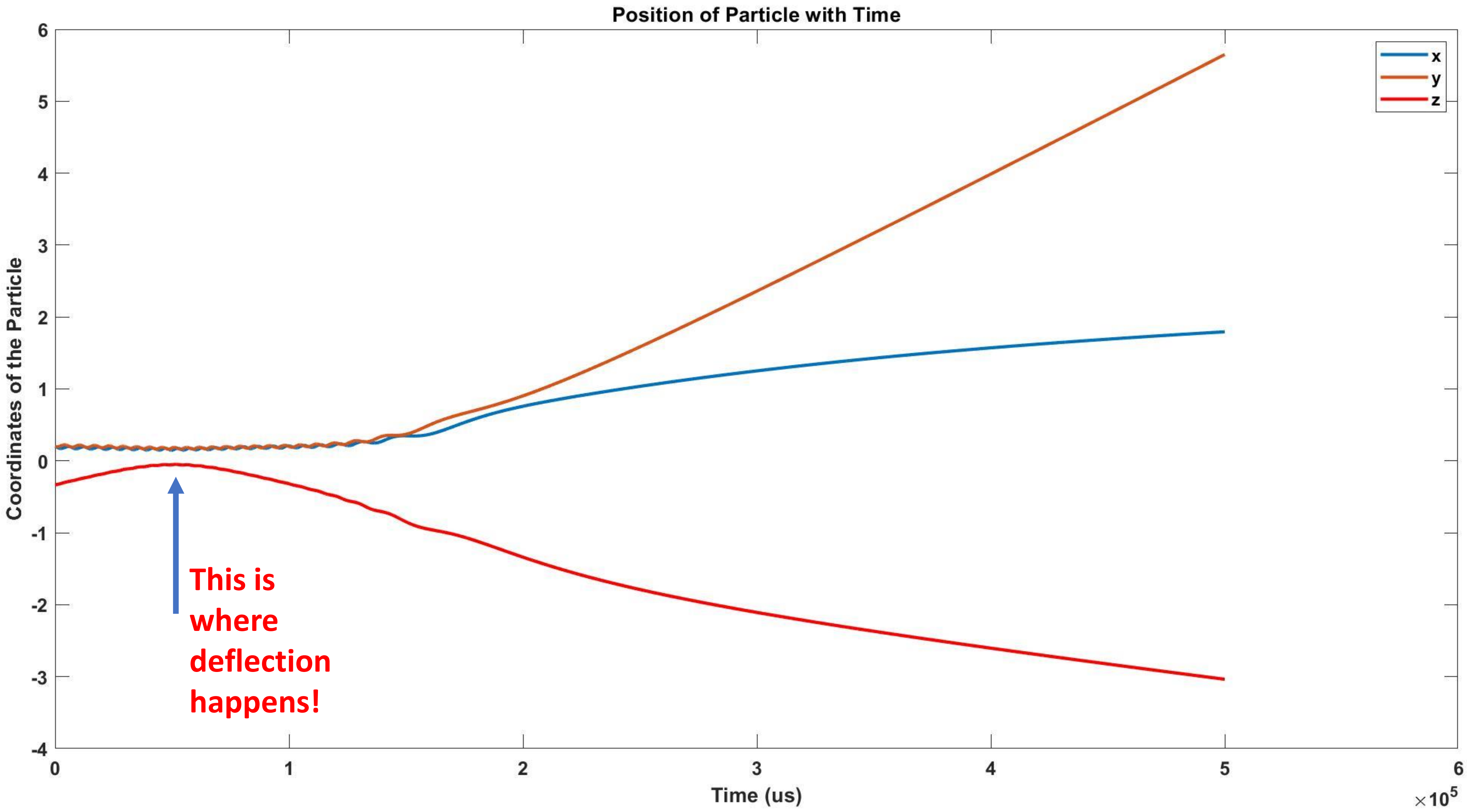
I1 = n1*I0;  I2 = n2*I0;  I3 = n3*I0; I4 = n4*I0;
% Centre of Coil 1 is (0,0,-d12), Coil 2 is (0,0,0),
% Coil 3 is (0,0,+d23), Coil 4 is (0,0,d23+d34)
```

Red Dot is start point and Yellow Dot is the end point

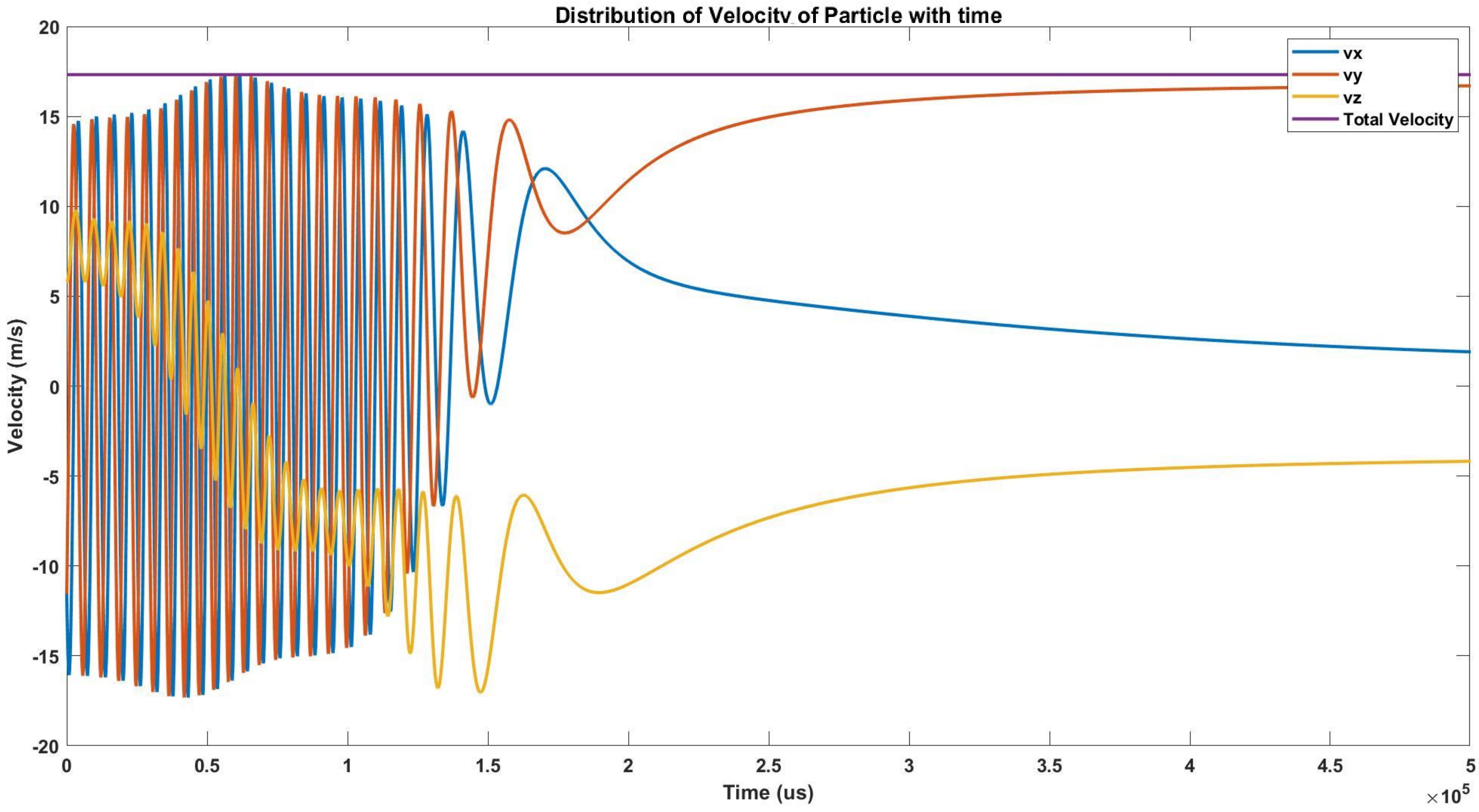


Closer Look at Trajectory (Red is start point)





Position of Particle with Time
Coordinates of the Particle
Time (us)
$\times 10^5$
x
y
z
This is where deflection happens!
6
5
4
3
2
1
0
-1
-2
-3
-4
0
1
2
3
4
5
6

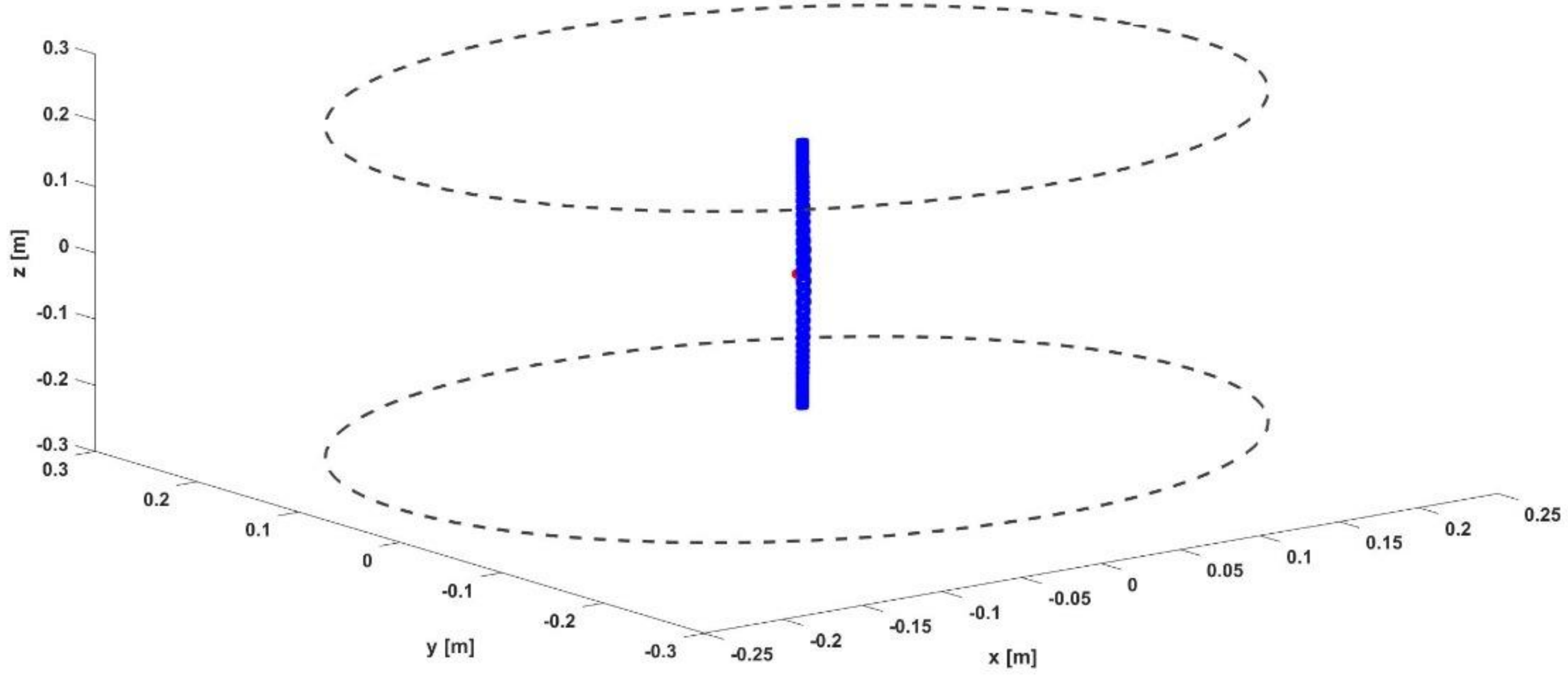

Distribution of Velocity of Particle with time
vx
vy
vz
Total Velocity
Velocity (m/s)
Time (us)
×10^5
20
15
10
5
0
-5
-10
-15
-20
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

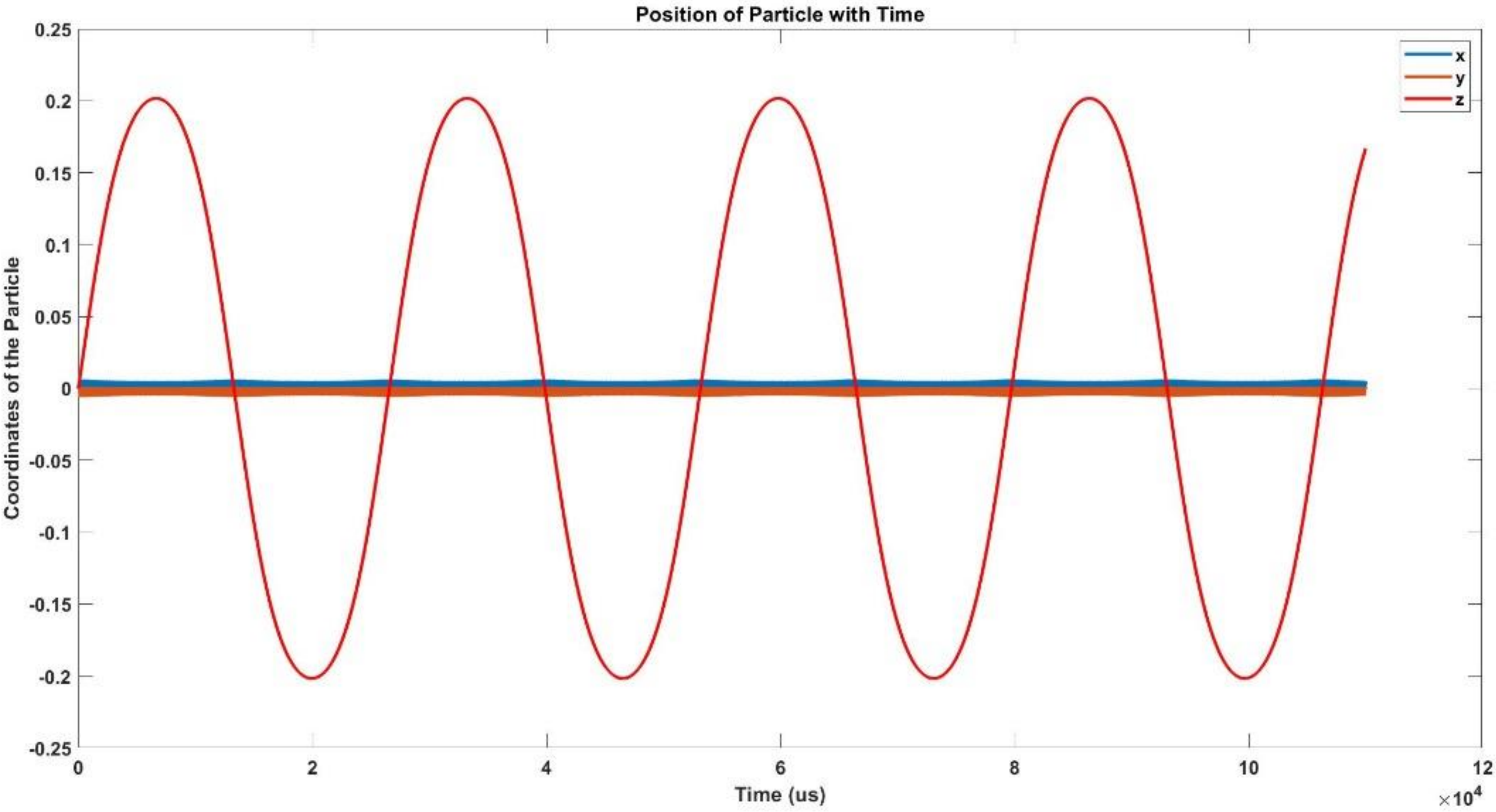
Example -3

Perfect Confinement of a proton within a Helmholtz coil

Typically used in plasma confinement.

Confinement of a proton within Helmholtz coil





Position of Particle with Time
Coordinates of the Particle
Time (us)
$\times 10^4$
x
y
z
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
0
2
4
6
8
10
12