The effect of the gas filling the detector volume on the tracking resolution

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Abstract

The effect of the gas filling the detector volume on the tracking resolution is investigated. The comparison is between the low-Z helium, that might have negative effect on the TOF tubes and nitrogen. The use of nitrogen results in a small degradation in tracking resolution.

1 Introduction

The tracking section of the MEG detector [1] consists of a set of drift chambers for momentum measurement followed by a Time Of Flight scintillator hodoscope for trigger and background suppression purpose. The chambers themselves occupy only a fraction of the track path, the rest being in gas filling volume.
Given the very low momentum of the positron ($\approx 52 Mev$) the multiple scattering effect of the gas might be not negligible. That suggest the use of helium with its long radiation length. The problem is that the phototubes of the TOF are located in the same volume and that helium can leak into and spoil them.
A solution consists in wrapping the two half TOF sections in nitrogen filled bags to insulate them from helium. That adds to the mechanical complexity of the detector and would be nice to avoid.
It is therefore important to quantify the loss in momentum resolution, due to the use of nitrogen rather than helium.

2 Momentum resolution of the tracking devices

Approximate formulae for momentum resolution of a magnetic spectrometer are given in [2].
In presence of a constant magnetic field of strength B, a particle with

charge ze and pitch angle λ with respect to the field moves along a helix with radius of curvature R in the transverse plane given by

$$p(GeV/c)\cos\lambda = 0.3zB(T)R(m). \tag{1}$$

The momentum resolution depends on two terms, the first depends on the hit measurement error, the second on the multiple scattering

$$d\left(\frac{1}{R}\right)^2 = d\left(\frac{1}{R}\right)^2_{res} + d\left(\frac{1}{R}\right)^2_{ms}. \tag{2}$$

For enough ($N \geq 10$) measurement points uniformly spaced with measurement error ϵ the resolution is

$$d\left(\frac{1}{R}\right)_{res} = \frac{\epsilon}{L^2\cos^2\lambda}\sqrt{\frac{720}{N+4}}. \tag{3}$$

The resolution due to the multiple scattering is

$$d\left(\frac{1}{R}\right)_{ms} = \frac{0.016(Gev/c)z}{Lp(Gev/c)\beta\cos^2\lambda}\sqrt{\frac{L}{X_0}}. \tag{4}$$

L in both equations is the length of the track used for the measurement.

From the expanded view of the tracking devices in Fig.1, the the track length within the tracking volume is about half the total track length. The diameter of the track is about 25.3 cm, so that $L\cos\lambda = \pi 25/2cm = 0.39m$.
The number of chamber hits is $N = 8, 9$, counting two plane hits in the same chamber as a single hit, that marginally satisfy the requirement for applying Eq.3.
For tracks in the chamber volume ($|\cos\theta| < 0.35$) it is $\cos\lambda \approx 0.985$.
The resolution in the radial direction is $\epsilon = 300\mu m$.
For a positron $z = 1$ and the average field is such that $\frac{B}{\cos\lambda} = 1.39T$.
Putting Eq.1-3 together, the resolution due to the measurement error is

$$\left(\frac{dp}{p}\right)_{res} = \frac{\cos\lambda}{0.3zB}\frac{\epsilon}{L^2\cos^2\lambda}\sqrt{\frac{720}{N+4}}p = 3.7110^{-2}p = 0.194\% \tag{5}$$

3 Mass distribution in the tracking region

Before calculating the resolution due to multiple scattering, the material on the track path has to be described in detail.
From the expanded view of the tracking devices in Fig.1 it is apparent that the material encountered by the track in the momentum measuring section consists only of the chamber material and of the volume filling gas.
We need to calculate the average radiation length encountered by the track on his path. The basic periodic cell consists of a drift cell along the radial direction and of intrachamber gas gap plus a chamber in the

	He	N	Ethane	Mylar	Fe	W
$X_0(cm)$	528000	30400	34035	28.7	1.76	0.35

Table 1: Some radiation length, for gas at STP (from [2])

azimuthal direction.
The chambers are located between $R_1 = 17.95cm$ and $R_2 = 27.90cm$ displaced of $10°$ in azimuth.
Each chamber consists of two planes of wires strechted along the z coordinate, staggered of half a cell period in the radial direction. Each plane consists of 9 drift cells with period $p = 0.9cm$. The innermost cell starts at $R_i = 19.3cm$ and the outermost ends at $R_o = 27.9cm$. Each cell has a potential wire made of tungsten with diameter $d_W = 50\mu m$ and a readout wire made of steel with diameter $d_{Fe} = 25\mu m$. The chamber gas is a mixture 50%-50% He-Ethane. The total gas gap of a chamber is $1.70cm$. The mechanical structure consists of 4 Mylar foils each $12\mu m$ thick.
The average gas gap between the chambers can be calculated at mid radius $R_{ave} = (R_i + R_o)/2 = 23.6cm$. The length of the arc between the centers of the rightmost and leftmost chambers is $R_{ave}\, 2\pi\, 160/360 = 66.0cm$ and includes 16 chambers and 16 gas gaps. Hence $d_{gas} = 66.0/16 - 1.70 = 2.42cm$.
In each chamber the thickness stems from the previously mentioned mylar foils and gas plus the wires. The equivalent thickness t of a wire with diameter d is calculated assuming that its material is spread uniformly on the pitch p, that is $tp = \pi(d/2)^2$. Therefore $t_W = 2.18\, 10^{-5}\, cm$ and $t_{Fe} = 0.55\, 10^{-5}\, cm$. For each cell there are two tungsten and two steel wires.
The X_0 from Eq.4 is the average radiation length expressed in unit of length. From [2] the radiation length of a mixture expressed in massive units is

$$\frac{1}{X_0} = \Sigma_i \frac{w_i}{X_{i0}}$$

where w_i is the weight fraction, that, using length units, becomes

$$\frac{1}{X_0} = \Sigma_i \frac{t_i}{X_{i0}}$$

where t_i is the thickness fraction.
The radiation lengths of the relevant materials expressed in units of length are in Tab.1.

Putting together all the previous information the average radiation length over $L_{tot} = 4.12cm$ is (fthe helium option or the outer gas gap is in parenthesis)

$$\frac{1}{X_0} = \frac{1}{L_{tot}} \left(\overset{Mylar}{\frac{48.\,10^{-4}}{28.7}} + \overset{He}{\frac{0.85}{528000}} + \overset{Ethane}{\frac{0.85}{34035}} + \overset{W}{\frac{4.36\,10^{-5}}{0.35}} + \overset{Fe}{\frac{1.10\,10^{-5}}{1.76}} + \overset{N}{\frac{2.42}{30400}} \left(\overset{He}{\frac{2.42}{528000}} \right) \right)$$

$$
\begin{aligned}
&= \frac{1}{L_{tot}}\left(\overset{Mylar}{1.67} + \overset{He}{0.016} + \overset{Ethane}{0.25} + \overset{W}{1.25} + \overset{Fe}{0.062} + \overset{N}{0.80}\left(\overset{He}{0.045}\right)\right)10^{-4} \\
&= \frac{1}{4.1210^{-2}}\,\overset{N}{4.05}\,(\overset{He}{3.30})10^{-4}m^{-1} = \overset{N}{0.98}\,(\overset{He}{0.80})\,10^{-2}m^{-1} \qquad (6)
\end{aligned}
$$

Putting Eq.1-4-6 together, the resolution due to the measurement error is

$$
\left(\frac{dp}{p}\right)_{ms} = \frac{\cos\lambda}{0.3B}\frac{0.016(GeV/c)}{\sqrt{L\cos\lambda}\sqrt{X_0}} = \frac{0.61(0.55)\%}{\sqrt{\cos\lambda}} \qquad (7)
$$

Another way of formulating this result is that the use of nitrogen as filling gas rather than helium adds quadratically to the resolution a contribution of $\frac{dp}{p} = 0.26\%$. This result is more reliable than the absolute values of the resolution quoted before that depends on the details of the mass distribution within the detector and the validity of the approximate formulae employed to calculate the resolution.

4 Conclusion

The momentum resolution for positron from $\mu \to e\gamma$ is dominated by multiple scattering as long as the measurement error is $300\mu m$ (or also a factor of two larger). The dominant contributors to the multiple scattering induced resolution are in similar parts the mylar planes, the wires and, if present, the nitrogen between chambers.
The choise of Helium rather than Nitrogen decreases quadratically the measurement error of 0.26%.
For the resolution calculated according to the prevuous approximate formulae, it amount to a 10% improvement. In realistic condition it can be somehow less.
This improvement has to be balanced against the additional construction complexity demanded by the need to insulate the photomultiplier of the TOF from the helium atmosphere with nitrogen filled bags.

References

[1] A. Baldini et al. The meg experiment: search for the decay $\mu^+ \to e^+\gamma$ at psi, 1989.

[2] Particle data group. Review of particle physics. *European Physical Journal C*, 3(1-4):1–794, 1998.

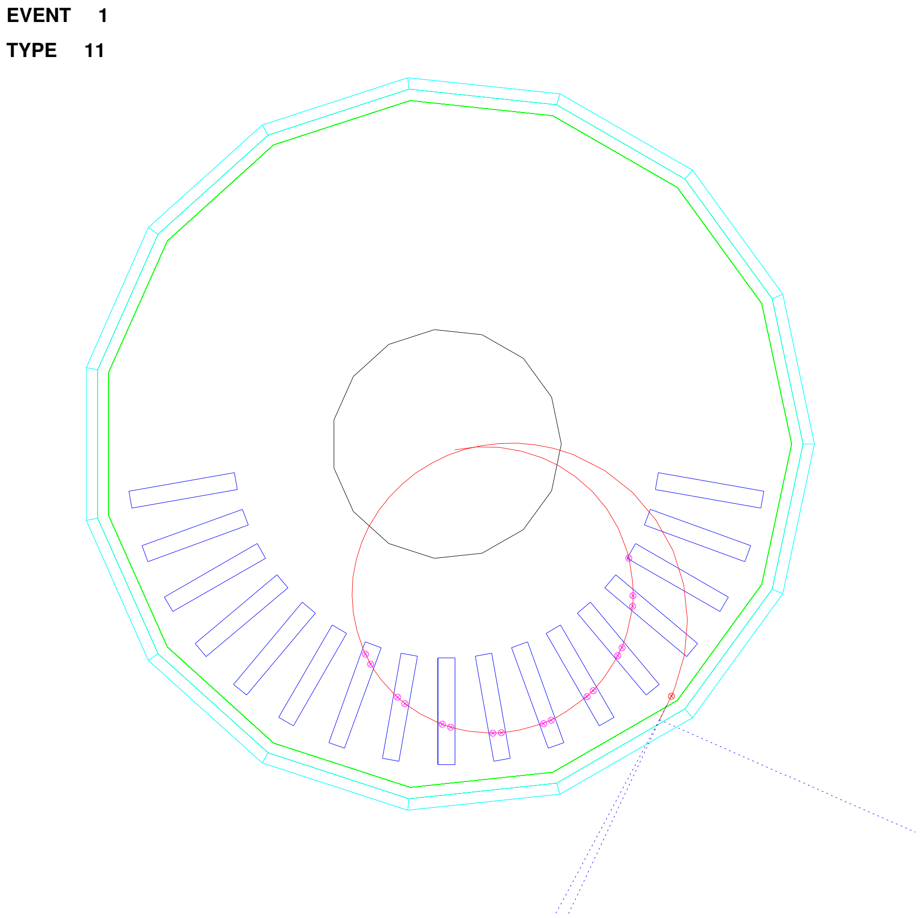

Figure 1: Expanded view of the tracking devices