The Addition of an Air Gap in the Meson Test Secondary Beamline

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1 Introduction

The purpose of this document is to describe the proposed addition of a 1 meter air gap in the Meson Test secondary beamline to accomodate additional beam instrumenation to be used as the first trigger in a time of flight measurement. The air gap will be in between the quadrupole MT4Q6 and the vertical corrector MT5VT1. The accelerator division will facilitate the: removal of a 1.17 Meter section of 6 Inch beam pipe, the addition of 2 Titanium windows, and the reinstatement of a vacuum bypass that was historically used for this very purpose. The Minerva collaboration is building and installing the instrumentation using four scintillators to improve timing resolution. This will be documented separately before installation. This document only describes the air gap and vacuum windows.

2 Radiation Length

To determine the impact of the addition of two vacuum windows and 1.1684 M of air on the wide range of particle beam delivered in the Meson Test secondary beamline, we must first know the Radiation Length of both the foil for the vacuum windows and the additional air. The foil is documented in mechanical drawing number F10007215 which is shown in figure 1. According the this drawing the foil is constructed of Titanium TI-6AL-4V. Information on this type of Titanium can be found in table 1.

Table 1: Composite Information for TI-6AL-4V [1] [2]

Component	Percentage of Weight	Radiation Length (cm)	Radiation Length $\frac{g}{cm^2}$
Al	6%	8.897	24.01
Fe	Max .25%	1.757	13.84
O	Max .2%	25710	34.24
Ti	90%	3.560	16.16
V	4%	2.593	15.84

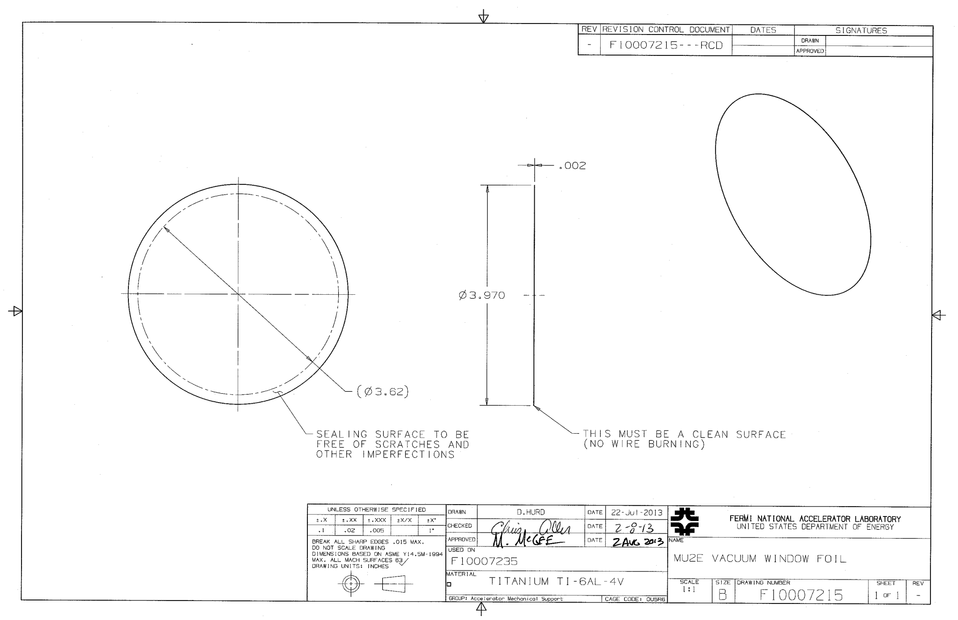

Figure 1: Mechanical Support Drawing of Window Foil

The general formula shown in equation 1 is used to estimate the radiation length of the composite material TI-6AL-4V. The variable W_0 is the total mass of the sample in g. X_0 is the combined radiation length of the sample in $\frac{g}{cm^2}$. W_i is the mass of the individual component in g and X_i is the radiation length of the individual component in $\frac{g}{cm^2}$ [3]. Using numbers from table 1 we get equation 2.

$$\frac{W_0}{X_0} = \sum \frac{W_i}{X_i} \tag{1}$$

$$\frac{W_0}{X_0} = \frac{.06 \times W_0}{24.01} + \frac{.0025 \times W_0}{13.84} + \frac{.002 \times W_0}{34.24} + \frac{.9 \times W_0}{16.16} + \frac{.04 \times W_0}{15.84} \tag{2}$$

The initial mass of the sample, W_0, cancels out allowing one to solve for the combined radiation length, X_0. X_0 for the Titanium composite used in the windows to be installed is 16.4 $\frac{g}{cm^2}$. The Titanium composite material has a density of 4.43 $\frac{g}{cm^3}$, thus dividing the radiation length in $\frac{g}{cm^2}$ by the density gives us a radiation length of 3.7032 cm.

With regards to air, the radiation length of 30050 cm will be used for this analysis. This was taken from reference [4]

3 Scattering Angle

To determine the expected scattering angle caused by the addition of two Titanium windows and a 1.1684 m air gap we use equation 3 [5]. The variable θ_x is the scattering angle in the x direction, though y will be the same. PC is the momenum times the speed of light. L is the length of the scattering medium and L_r is the radiation length in cm. β is the velocity divided by the speed of light which for a 2000 $\frac{MeV}{c}$ Pion beam is .9975. We will consider it to be 1 for the remainder of this analysis. The window foil is .002 Inches or 0.00508 Centimeter as shown in figure 1. Using these values for a 2000 $\frac{MeV}{c}$ beam leads to a scattering angle of .220 MilliRadians for each window. For 1.1684 Meter of air the scattering angle is .379 MilliRadians. To determine the combined scattering angle from both windows and the air, one should add each scattering angle in quadrature as in Equation 4 [6]. Thus the total scattering angle for a 2000 $\frac{MeV}{c}$ beam is .49 MilliRadians.

As the energy increases, the scattering angle is reduced. For a 32000 $\frac{MeV}{c}$ beam the combined scattering angle for both windows and 1 meter of air is .031 MilliRadians. Table 2 shows angles for common secondary beam momentums between 2 GeV and 32 GeV.

$$\theta_x = \frac{13.6}{PC * \beta} \sqrt{\frac{L}{L_r}} \left(1 + .038 * \log \sqrt{\frac{L}{L_r}} \right) \tag{3}$$

$$\theta_{total} = \sqrt{\theta_1^2 + \theta_2^2 + \theta_3^2} \tag{4}$$

Table 2: Scattering Angle vs Secondary Momentum

Momentum (GeV)	Horizontal Angle (mR)	Vertical Angle (mR)
2	.49	.49
8	.12	.12
16	.06	.06
24	.04	.04
30	.033	.033
32	.031	.031

4 Effects of Scattering Angle Simulated With Transport

The final step of this analysis is to simulate the effects of this new scattering mechanism on the current beamline. The transport model Standard Energy File will be used for this purpose. An initial beam size of 4 mm in both transverse planes was used based on Operational log book entry number 32606. Initial divergence of 0 was used for the simulation. Simulations were performed for the beamline with no additional scattering media, for a scattering angle using a 2 GeV beam and using the scattering angle of a 32 GeV beam. The scattering occurs at a longitudinal distance of 67.85 meters in the simulation. Figures 2 and 3 show the result of these simulations. There is no noteable difference between the 32 GeV scattering simulation and the simulation with no additional scattering material. The differences at 2 GeV are apparent, though not alarming.

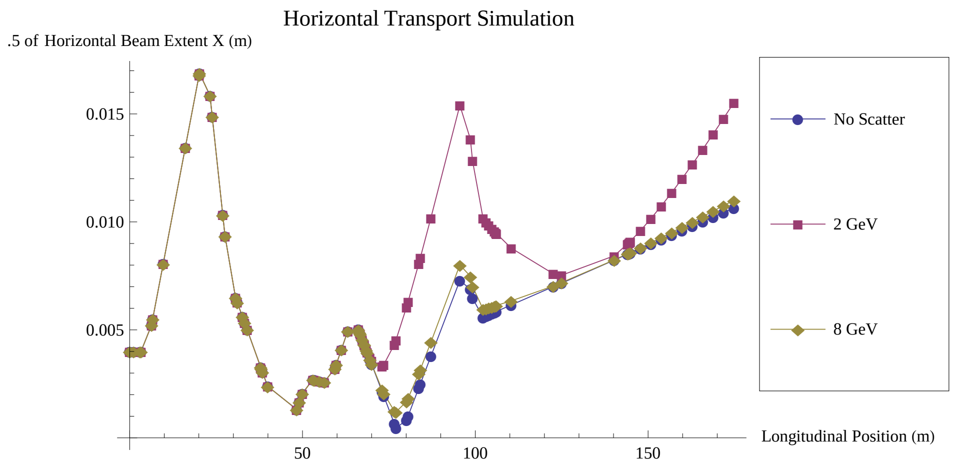

Figure 2: This is a plot of half the horizontal extent of the Mtest secondary beamline simulated in Transport. Above 8 GeV the scattering angle has little effect on the orbit.

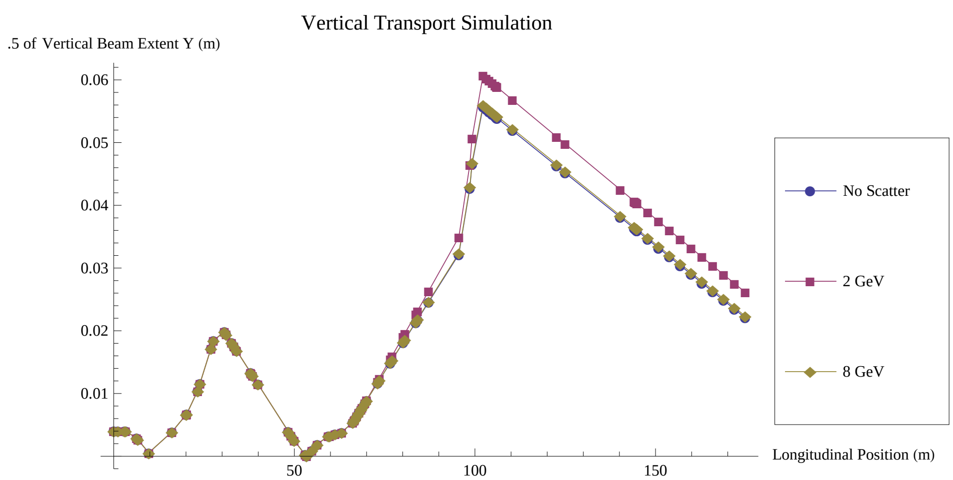

Figure 3: This is a plot of half the vertical extent of the Mtest secondary beamline simulated in Transport. Above 8 GeV the scattering angle has little effect on the orbit.

5 Conclusion

The net effect of the two added windows and 1.1684 meter of air on the beam will be more noticeable at lower energies than high. The scattering angle for the worst case scenario of 2000 $\frac{MeV}{c}$ was still found to be less than 1 MilliRadian. The simulated net effect on the beam at higher energies is small. The simulated net effect at lower energies is acceptable. Tuning can be performed to compensate for the effect at low energies. Prior to the year 2007 the Meson Test Secondary beamline used the air gap configuration that is being proposed for positioning the device F:MT5SC1. In order to accomodate the time of flight needs of the Minerva Test beam we would like to restore this configuration.

References

[1] "http://pdg.lbl.gov/2014/AtomicNuclearProperties/", October 2014.

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[3] M. Gupta, "Calculation of Radiation Length in Materials", Tech Note, Cern, Geneva Switzerland, PH=EP=Tech=Note-2010-013, 2010.

[4] D. Carey, "The Optics of Charged Particle Beams", Harwood Academic Publishers, Fermi National Accelerator Laboratory, Batavia, Illinois, 1987 pp. 269.

[5] N. Nakamura et al. (Particle Data Group), J. Phys. G 37, 075021 (2010) and 2011 partial update for the 2012 edition.

[6] "gray.mgh.harvard.edu/attachments/article/213/06$_Scattering.ppt''$, $October$2014.