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Change in Energy Loss and Flux for Cavities in Khufu (Version Two)

Tabitha Welch

We are interested in how much energy a muon traveling through the pyramid does *not* lose when it encounters a void, such as any of the known chambers, and we would like to use this information to find the change in muon flux that we expect to see for voids of various sizes. To that end, Tables 1 and 2 contain each of the following, for the case that some interesting feature is present and the case that it is not:

1. **Path Length (GeV):** the approximate amount of energy a muon would lose by traveling from one side of the pyramid to the other, along a trajectory that would take it through the center coordinates of the feature in question and subsequently to the center of the nearest detector. I assume that there is one detector on each side of the pyramid, centered on that side. For the King's Chamber and Phantom Chamber, the nearest detector is to the south; for the Queen's Chamber, it is to the east; for the Grand Gallery, it is to the north. I also assume a solid concrete pyramid, which has density 2.300 g/cm^3 and $\langle \frac{-dE}{dx} \rangle$ of 1.711 MeV cm^2/g; the particle will therefore lose about 3.935 MeV per cm.

2. **Number of μ:** the total number of muons that we expect to see with a detector of area 125 m^2 after an exposure time of 1 year, "binned" by the length of the feature. To calculate this, I use the Gaisser formula to find the muon flux at the appropriate energy E_μ, assuming $\theta = 45°$ (which may not be strictly appropriate for all features):

$$\frac{dN_\mu}{dE_\mu} = \frac{0.14 \cdot E_\mu^{-2.7}}{cm^2 \cdot sec \cdot sr \cdot GeV} \left[\frac{1}{1 + \frac{1.11 \cdot E_\mu \cdot cos(\theta)}{115GeV}} + \frac{0.054}{1 + \frac{1.11 \cdot E_\mu \cdot cos(\theta)}{850GeV}} \right] \tag{1}$$

   I then multiply this result by the detector size, exposure time, bin size (i.e., the feature length in GeV, given in column 2), and solid angle of the feature.

3. **Integral to 350 GeV:** the integral of the flux, evaluated from E_μ to 350 GeV:

$$\int_{E_\mu}^{350} \frac{0.14 \cdot (E'_\mu)^{-2.7}}{cm^2 \cdot sec \cdot sr \cdot GeV} \left[\frac{1}{1 + \frac{1.11 \cdot E'_\mu \cdot cos(\theta)}{115GeV}} + \frac{0.054}{1 + \frac{1.11 \cdot E'_\mu \cdot cos(\theta)}{850GeV}} \right] \mathrm{d}E'_\mu \tag{2}$$

   and multiplied by the relevant scaling factors (detector size, exposure time, and solid angle) as above.

4. $\sqrt{Integral}$ **(1 σ):** the square root of the previous column, representing 1 σ.

Finally, the tables contain a column labelled **Number of σ**; this is the number of muons expected if there is a void, divided by the expected σ if there is no void. This represents the number of σ that the integral would have to fluctuate in order for us to see this many muons when no void is actually present.

Feature	**Feature Length (GeV)**	**Void Present?**	**Path Length (GeV)**	**Number of μ**	**Integral to 350 GeV**	$\sqrt{Integral}$ **(1 σ)**	**Number of σ**
King's Chamber	2.06	No	66.5	$3.44 \cdot 10^5$	$5.19 \cdot 10^6$	2280	166
		Yes	64.4	$3.79 \cdot 10^5$	$5.55 \cdot 10^6$	2360	
Queen's Chamber	2.26	No	75.9	$1.27 \cdot 10^5$	$1.95 \cdot 10^6$	1396	99.7
		Yes	73.6	$1.39 \cdot 10^5$	$2.08 \cdot 10^6$	1440	
Grand Gallery	18.4	No	69.6	$4.11 \cdot 10^5$	$7.20 \cdot 10^5$	849	*1200*
		Yes	51.2	$1.02 \cdot 10^6$	$1.38 \cdot 10^6$	1170	
Phantom Chamber	2.06	No	30.0	$1.89 \cdot 10^6$	$1.41 \cdot 10^7$	3750	621
		Yes	27.9	$2.33 \cdot 10^6$	$1.62 \cdot 10^7$	4030	

Table 1: For the north-south direction, the feature name, its length in GeV, and several other relevant calculations are given (see list, above). I have assumed the same dimensions for the Phantom Chamber and the King's Chamber. For the Grand Gallery, I assume that the particle passes through the full length of the corridor; for a particle traveling horizontally north-south, this is obviously untrue.

Feature	**Feature Length (GeV)**	**Void Present?**	**Path Length (GeV)**	**Number of μ**	**Integral to 350 GeV**	$\sqrt{Integral}$ **(1 σ)**	**Number of σ**
King's Chamber	4.13	No	66.5	$3.44 \cdot 10^5$	$2.58 \cdot 10^6$	1610	258
		Yes	62.4	$4.16 \cdot 10^5$	$2.96 \cdot 10^6$	1720	
Queen's Chamber	2.06	No	75.9	$1.27 \cdot 10^5$	$2.14 \cdot 10^6$	1460	94.5
		Yes	73.8	$1.38 \cdot 10^5$	$2.28 \cdot 10^6$	1510	
Grand Gallery	0.590	No	69.6	$5.97 \cdot 10^5$	$3.27 \cdot 10^7$	5710	107
		Yes	69.0	$6.13 \cdot 10^5$	$3.33 \cdot 10^7$	5770	
Phantom Chamber	4.13	No	30.0	$1.89 \cdot 10^6$	$7.02 \cdot 10^6$	2650	1080
		Yes	25.9	$2.87 \cdot 10^6$	$9.34 \cdot 10^6$	3060	

Table 2: Here, the calculations from Table 1 are repeated for the east-west direction. As before, I assume the same dimensions for the Phantom and King's Chambers.