$$\frac{dN}{dE} = \frac{0.14}{\text{cm}^2\ \text{sr s GeV}} \cdot \text{A} \cdot \left(\frac{E_\mu}{\text{GeV}}\right)^{-\gamma} \cdot \left(\frac{1}{1+\frac{1.1 E_\mu \cos(\theta)}{115\ \text{GeV}}} + \frac{0.054}{1+\frac{1.1 E_\mu \cos(\theta)}{850\ \text{GeV}}}\right) \tag{1}$$

$$d\Phi_Z/dE = \Phi_Z^0 E^{-\gamma_Z} \left[1+\left(\frac{E}{E_Z}\right)^{\epsilon_c}\right]^{\frac{-\Delta\gamma}{\epsilon_c}}$$

$$\theta > 70^\circ$$

$$E_{cr}^{\pi}(\theta) = 115\ \text{GeV}/\cos(\theta)$$

$$E_{cr}^{K}(\theta) = 850\ \text{GeV}/\cos(\theta)$$

$$X_m = (1 + 0.04 \cdot \log_{10}(E/1\ \text{TeV})) \cdot 85\ \text{g/cm}^2$$

$$X_{int}^{\pi,K} = \int\limits_{x-\delta x_{\pi,K}}^{x} \rho dx \approx \rho(h(x)) \cdot \delta x_{\pi,K}$$

$$l_{\pi,k} = \frac{\tau_{\pi,K} E_{\pi,K}}{m_{\pi,K} c}$$

$$l_{\pi,k} = \delta x_{\pi,K}$$

$$E_{cr}^{\pi,K} = \frac{X_{int}^{\pi,K} m_{\pi,K} c}{\rho(h(x)) \tau_{\pi,K}} \propto \frac{1}{\rho(h(x))}$$

$$\cos(\theta^*) = E_{cr}^{\pi,K}(0)/E_{cr}^{\pi,K}(\theta) = \rho(h(x(\theta)))/\rho(h(x(0)))$$

$$\theta < 70^\circ$$

$$x = h/\cos(\theta)$$

$$\approx 200\ \text{g/cm}^2$$

$$\rho(h) \propto \exp(-h/h_0)$$

$$X = \int\limits_{x}^{\infty} \rho(h(x)) dx = \int\limits_{h}^{\infty} \frac{\rho(h) \cdot dh}{\cos(\theta)} = \frac{1}{\cos(\theta)} \int\limits_{h}^{\infty} \rho(h) \cdot dh = \frac{h_0 \cdot \rho(h)}{\cos(\theta)} \tag{2}$$

$$\rho(h) \propto \cos(\theta)$$

$$\cos(\theta^*) = \cos(\theta)$$

$$X(\theta) = X(0)$$

$$X(\theta) = \int\limits_{h_i(\theta)}^{\infty} \rho(h) \frac{dx}{dh}\, dh = \int\limits_{h_i(\theta)}^{\infty} \frac{\rho(h)\, dh}{\sqrt{1 - \frac{\sin^2(\theta)}{(1+h/R)^2}}}$$

$$\cos(\theta^*) = \rho(h_i(\theta))/\rho(h_i(0))$$

$$l(\theta) = \sqrt{R^2 \cos^2(\theta) + 2Rh_i + h_i^2} - R\cos(\theta)$$

$$h_i(\theta; X)$$

$$\cos(\theta^*; X)$$

$$l(\theta; X)$$

$$\exp(-X/X_0)/X_0$$

$$h_i(\theta) = p_5 \frac{1 + p_3 \sin^{p_4}(\theta)}{\left[1 - \frac{\sin^2(\theta)}{(1+p_1)^2}\right]^{p_2}} \text{ km}$$

$$\cos(\theta^*) = \sqrt{\frac{x^2 + p_1^2 + p_2 x^{p_3} + p_4 x^{p_5}}{1 + p_1^2 + p_2 + p_4}}$$

$$\text{and} \quad l(\theta) = \frac{10^3 \text{ km}}{p_1 + p_2 x^{p_3} + p_4 (1 - x^2)^{p_5}}$$

$$x = \cos(\theta)$$

$$X_{tot}(\theta) = \frac{1 \text{ mwe}}{p_1 + p_2 x^{p_3} + p_4 (1 - x^2)^{p_5}}.$$

$$f_i(E_i) = \int\limits_{E_i}^{\infty} \frac{dN_i}{dE}\, dE$$

$$f_f(E_f) = \int\limits_{E_f}^{\infty} df_f(E) = \int\limits_{E_f}^{\infty} \langle df_i(E_i^{\xi}(E)) \rangle = \langle f_i(E_i^{\xi}(E_f)) \rangle$$

$$\langle E_i^{\xi} \rangle = E_f + \Delta E$$

$$dE/dX = a + bE$$

$$\langle E_i^\xi \rangle = ((a + bE_f)\exp(bX) - a)/b \tag{3}$$

$$\langle (E_i^\xi - \langle E_i^\xi \rangle)^2 \rangle = (a^* + b^* E)^2 dX$$

$$\langle (E_i^\xi - \langle E_i^\xi \rangle)^2 \rangle \approx \int_{X_f}^{X_i} (a^* + b^* E)^2 dX = \int_{E_f}^{E_i} \frac{(a^* + b^* E)^2}{a + bE} dE \tag{4}$$

$$f_f(E_f) = \langle f_i(E_i^\xi(E_f)) \rangle = \langle f_i(\langle E_i^\xi \rangle + (E_i^\xi - \langle E_i^\xi \rangle)) \rangle$$

$$\approx f_i(\langle E_i^\xi \rangle) + \frac{1}{2}\frac{d^2 f}{dE^2}(\langle E_i^\xi \rangle)\langle (E_i^\xi - \langle E_i^\xi \rangle)^2 \rangle$$

$$\approx f_i\left(\langle E_i^\xi \rangle + \frac{1}{2}\frac{d^2 f/dE^2}{df/dE}(\langle E_i^\xi \rangle)\langle (E_i^\xi - \langle E_i^\xi \rangle)^2 \rangle\right) = f_i(E_I(E_f))$$

$$\exp(-l\mu c/\tau E_I)$$

$$\frac{dN}{dE} = \frac{2.85 \cdot 10^{-2}}{\text{cm}^2 \text{ sr s GeV}} \cdot \text{A} \cdot \left(\frac{E_{\nu_\mu}}{\text{GeV}}\right)^{-\gamma} \cdot \left(\frac{1}{1 + \frac{6E_{\nu_\mu}\cos(\theta^*)}{121 \text{ GeV}}} + \frac{0.213}{1 + \frac{1.44E_{\nu_\mu}\cos(\theta^*)}{897 \text{ GeV}}}\right)$$

$$\frac{dN}{dE} = \frac{2.4 \cdot 10^{-3}}{\text{cm}^2 \text{ sr s GeV}} \cdot \text{A} \cdot \left(\frac{E_{\nu_e}}{\text{GeV}}\right)^{-\gamma} \cdot \left(\frac{0.05}{1 + \frac{1.5E_{\nu_e}\cos(\theta^*)}{897 \text{ GeV}}} + \frac{0.185}{1 + \frac{1.5E_{\nu_e}\cos(\theta^*)}{194 \text{ GeV}}} + \frac{11.4E_{\nu_e}^{\zeta(\theta)}}{1 + \frac{1.21E_{\nu_e}\cos(\theta^*)}{121 \text{ GeV}}}\right)$$

$$\zeta = a + b\log_{10} E, \quad a = \begin{cases} 0.11 - 2.4\cos(\theta) \\ -0.46 - 0.54\cos(\theta) \end{cases}, \; b = \begin{cases} -0.22 + 0.69\cos(\theta) & \cos(\theta) < 0.3 \\ -0.01 + 0.01\cos(\theta) & \cos(\theta) \geqslant 0.3 \end{cases}$$

	μ	ν_μ	ν_e	μ^-/μ^+	$\nu_\mu/\bar{\nu}_\mu$	$\nu_e/\bar{\nu}_e$
A	0.701 ± 0.006	0.646 ± 0.003	0.828 ± 0.155	0.340/0.367	0.352/0.310	0.465/0.472
γ	2.715 ± 0.001	2.684 ± 0.001	2.710 ± 0.023	2.720/2.712	2.680/2.696	2.719/2.741
A		with γ as given above		0.330/0.374	0.362/0.285	0.437/0.382