Hyperon Production Background for the Moller Experiment

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1) Why consider hyperon decays?

2) Bremsstrahlung production of kaons - empirical fit

3) Comparison of empirical fit to kaon production data, $\gamma + p \rightarrow K^{+} + X$

4) How to calculate the number of kaons/electron for moller target

5) Model for $\gamma + p \rightarrow K^{+} + H + Q$

6) Examples of space & momentum distribution of hyperons/electron

7) Examples of space and momentum distributions of hyperon decay particles

1) Why consider hyperon decays? Abstract

Using the bremsstrahlung data from Wiser's thesis[1] and the virtual photon approximations from Tiator and Wright[4] we develop the files needed to account for hyperon weak decay backgrounds in the Moller experiment from the following reactions.

$$\gamma + p \rightarrow \Lambda + K^{+} + X, \gamma + p \rightarrow \Sigma^{+} + K^{0} + X, \gamma + p \rightarrow \Sigma^{0} + K^{+} + X$$

The hyperon decays in the rest frame have a distribution of decay product momenta which depends on the angle between the rest frame polarization of the hyperon and the vector momentum of the outgoing particles.

$$\frac{dN}{d\Omega} = \frac{N}{4\pi}(1 + h\alpha \vec{S_R} \cdot \hat{k_R}).$$

Here h is the electron helicity, α is the hyperon weak decay asymmetry parameter, $\vec{S_R}$ is the hyperon rest frame polarization and $\hat{k_R}$ is the momentum direction of the decay particle measured in the hyperon rest frame.

Scripts, spectra, particle distribution files and this report are found in

`https://userweb.jlab.org/~aniol/moller/`

2) Bremsstrahlung production of kaons - empirical fit

Wiser measured an integrated yield of kaons, $\gamma + p \rightarrow K^+ + X$. Although there is not a breakdown of the type of hyperon or what other types of products X are produced, strangeness conservation ensures that there is a hyperon produced for each kaon produced.

$$N_k = N_\Lambda + N_{\Sigma^0} + N_{\Sigma^+}, \quad in\ a\ ratio\ 3/2/1. \tag{11}$$

$$\sigma_{eff}(pLab, P_{trans}, P_L^*, t) = dEQ \int_{kmin}^{k_0} (E\frac{d\sigma^3}{dp^3}) \frac{\alpha(k, k_0)dk}{k} \tag{9}$$

The function $\alpha(k, k_0)$ for the first order photon bremsstrahlung spectrumi [2] from Tsai and Van Whitis is

$$\alpha(k, k_0) = (r^{z1} - exp(-z2))/(\frac{7}{9} + \frac{4ln(r)}{3}) \tag{5}$$

Where $z1 = 4t/3$, $z2 = 7t/9$, $r = 1 - k/k_0$, and t is the fractional radiation length.

3) Comparison of empirical fit to kaon production data, $\gamma + p \rightarrow K^{+} + X$

pLab GeV/c	P_L^* GeV/c	sigma $\mu b/GeV^2$	dsigma $\mu b/GeV^2$	sigfit $\mu b/GeV^2$
3.	-0.72	3.86e-4	0.68e-4	4.77e-4
4.	-0.151	6.67e-4	0.69e-4	8.82e-4
5.	0.255	4.40e-4	0.47e-4	8.89e-4
6.	0.588	3.37e-4	0.34e-4	6.68e-4
7.	0.882	1.75e-4	0.15e-4	4.03e-4
8.	1.152	1.20e-4	0.11e-4	1.61e-4

Table 1: Measured cross sections for kaon production and the parametrized fit(sigfit) from Wiser's data for $P_{trans} = 1.625 GeV/c$ for several lab momenta. Radiation thickness = 0.025, $k_0 = 11$ GeV. P_L^* is the longitudinal momentum in the center of mass as calculated by the method described in the text.

3) Comparison of empirical fit to kaon production data, $\gamma + p \rightarrow K^+ + X$

P_{trans} GeV/c	P_L^* GeV/c	sigma $\mu b/GeV^2$	dsigma $\mu b/GeV^2$	sigfit $\mu b/GeV^2$
0.875	0.488	2.82e-1	0.16e-1	4.00e-1
1.001	0.410	1.17e-1	0.07e-1	1.66e-1
1.125	0.321	3.63e-2	0.12e-1	6.68e-2
1.250	0.221	1.53e-2	0.07e-2	2.52e-2
1.375	0.110	6.77e-3	0.52e-3	9.00e-3
1.500	-0.014	2.04e-3	0.16e-3	2.96e-3
1.625	-0.151	6.67e-4	0.69e-4	8.82e-4
1.750	-0.300	1.43e-4	0.21e-4	2.27e-4
1.875	-0.464	2.24e-5	0.64e-5	4.38e-5

Table 2: Measured cross sections for kaon production and the parametrized fit(sigfit) from Wiser's data for $P_L = 4GeV/c$ for several transverse momenta, P_{trans}. Radiation thickness = 0.025, k_0=11 GeV. P_L^* is the longitudinal momentum in the center of mass as calculated by the method described in the text.

4) How to calculate the number of kaons/electron for moller target

The number of kaons per incident electron is calculated from eq. 26

$$\frac{dN_k}{dN_e} = eff * \sum_t \Delta t \sum_{p_t} \Delta p_t \sum_{p_k} \Delta p_k \cdot (2\pi\rho \frac{p_t}{E_k cos(\theta)} \sigma_{eff}). \qquad (26)$$

0.2 Input files for geant4 use of hyperon data

I suggest we create a file which has as its parameters for each event
(i) x_H,y_H,z_H (decay point in lab of hyperon)
(ii) $p_H(x)$,$p_H(y)$,$p_H(z)$ (lab momenta of hyperon at decay point)
(iii) rest frame polarization of hyperon, S_{xR}, S_{yR}, S_{zR}
(iv) cross section weight for hyperon creation from equation 25.

$$weight(p_t, E_k, t) = (Frac_H)\Delta t \Delta p_k \Delta p_t \cdot (2\pi \frac{p_t}{E_k cos(\theta)} \sigma_{eff}). \qquad (27)$$

Here p_t and E_k are the transverse momentum and lab energy of the kaon.

5) Model for $\gamma + p \rightarrow K^+ + H + Q$

Procedure for Hyperon Production, mass m_H, step sizes dz, dp_T, dp_k

Sum over (x_v, y_v, z_v) $\rightarrow$ Sum over p_T $\rightarrow$ Sum over p_k

p_T, p_k $\rightarrow$ kmin for gammas, pick k_γ, kmin< $k_\gamma < k_0$

$k_\gamma + p \rightarrow K^+ + X \rightarrow$ gives s_X for X = H + Q, pick m_Q

$0 < m_Q < \sqrt{s_X} - m_H$, assume uniform m_Q distribution $\rightarrow$ implies pcm_X of H

Assume isotropic decay of H+Q in cm of X $\rightarrow$ transform H momentum in X to Lab

H lab momentum allows displacement of decay point to be selected.

Weight for event is determined by kaon momenta, p_T and p_k

Store $(x_H, y_H, z_H$,Px,Py,Pz, Weight) $\rightarrow$ File

File contains hyperon decay point, momenta and weight

6) Examples of space & momentum distribution of hyperons/electron

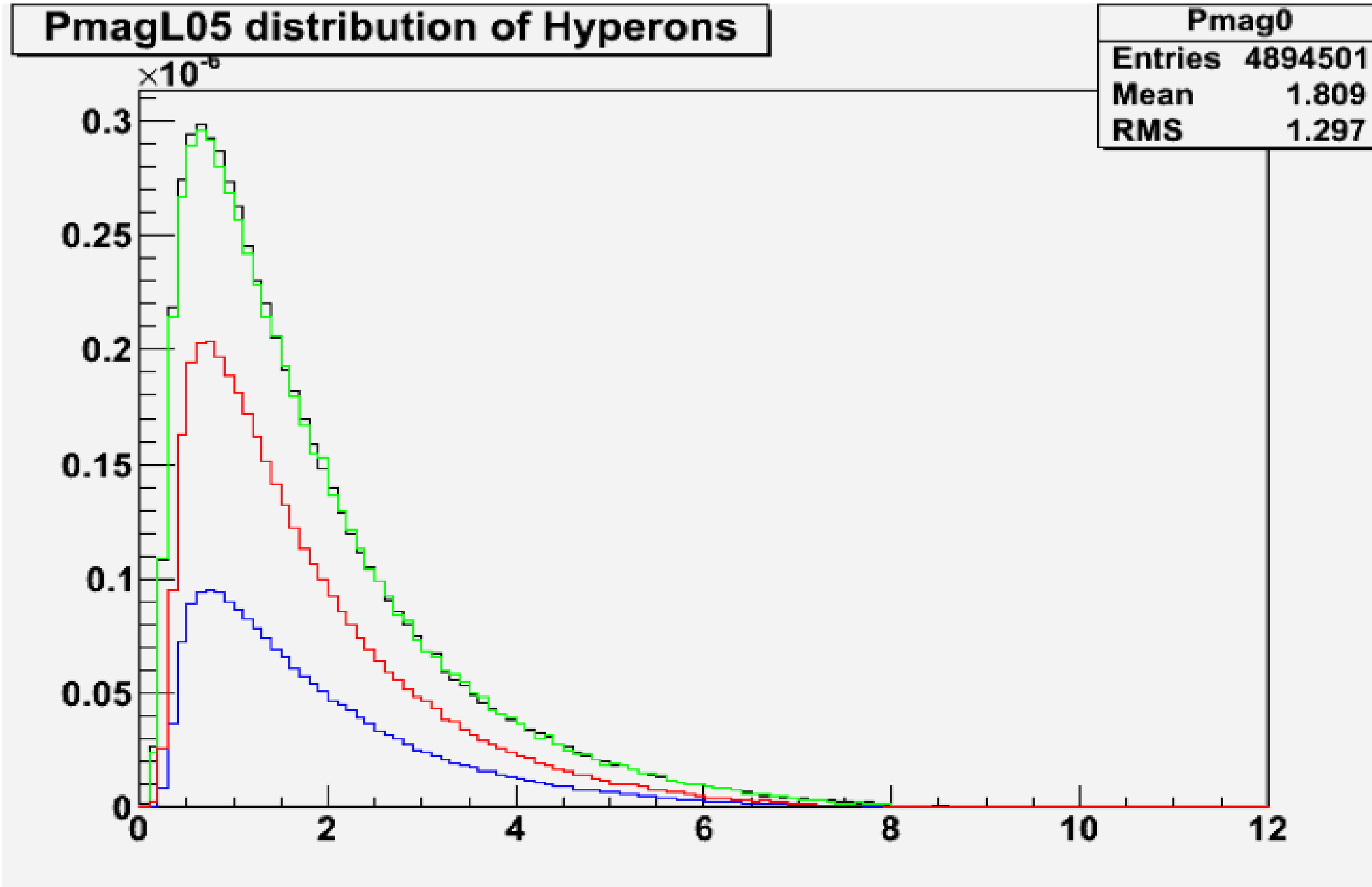

Figure 2: Predicted Hyperon momentum distributions, $\frac{dN_\Lambda}{dN_e}$. Λ for two separate runs using $\Delta p_t = 0.05 GeV/c$(black) compared to $\Delta p_t = 0.1 GeV/c$(light green). Σ^0(red), Σ^+(blue). In all cases $\Delta t = 0.1 cm$, $\Delta p_k = 0.1 GeV/c$. Hyperon cross sections are in the ratio 3/2/1.

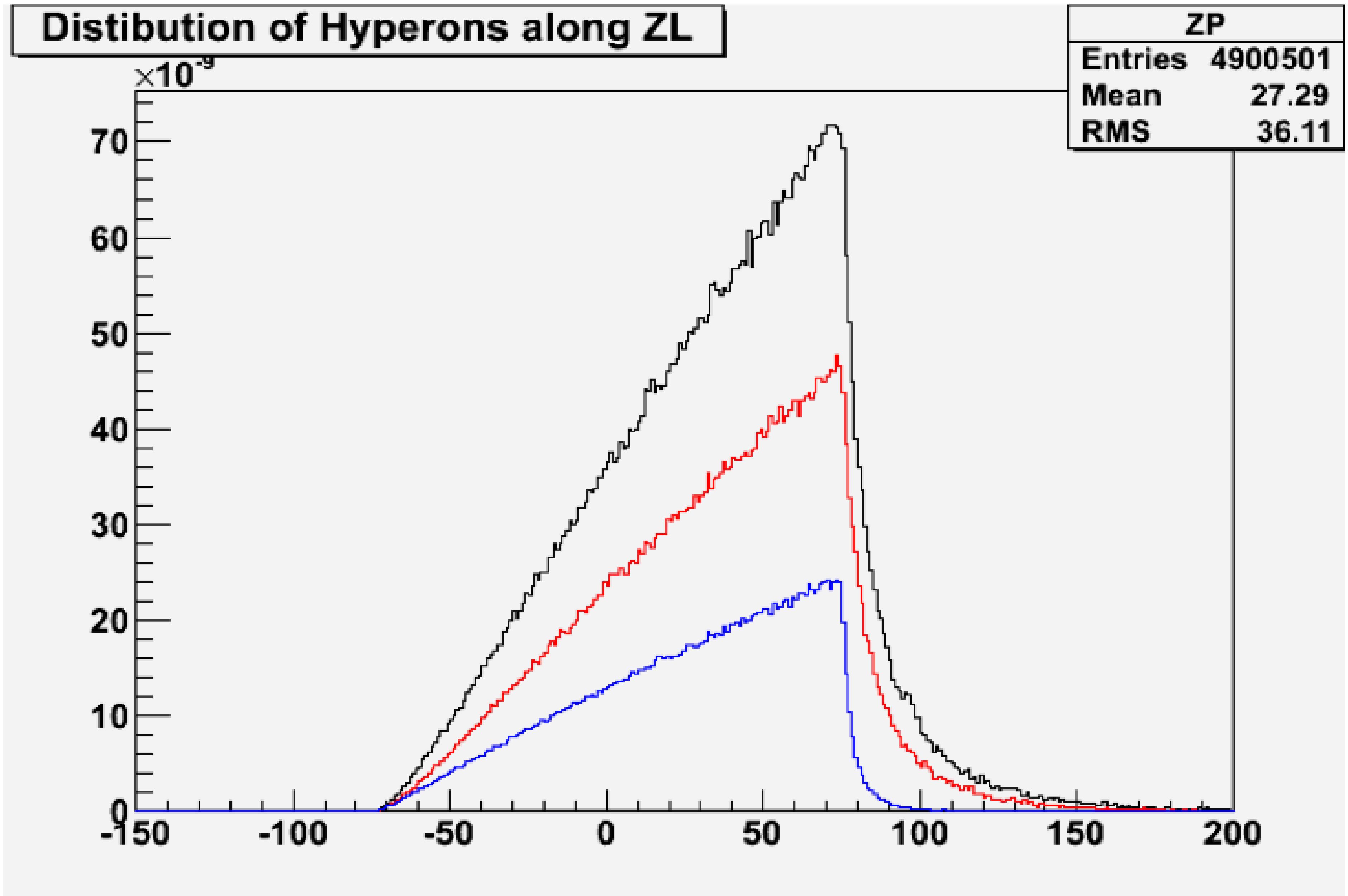

Figure 3: Predicted Hyperon Z distribution $\frac{dN_\Lambda}{dN_e}$ for $\Delta t = 0.1cm$, $\Delta p_k = 0.1GeV/c$, $\Delta p_t = 0.05GeV/c$. The three distributions are for Λ (black), Σ^0 (red), Σ^+ (blue) with cross sections in the relation 3/2/1.

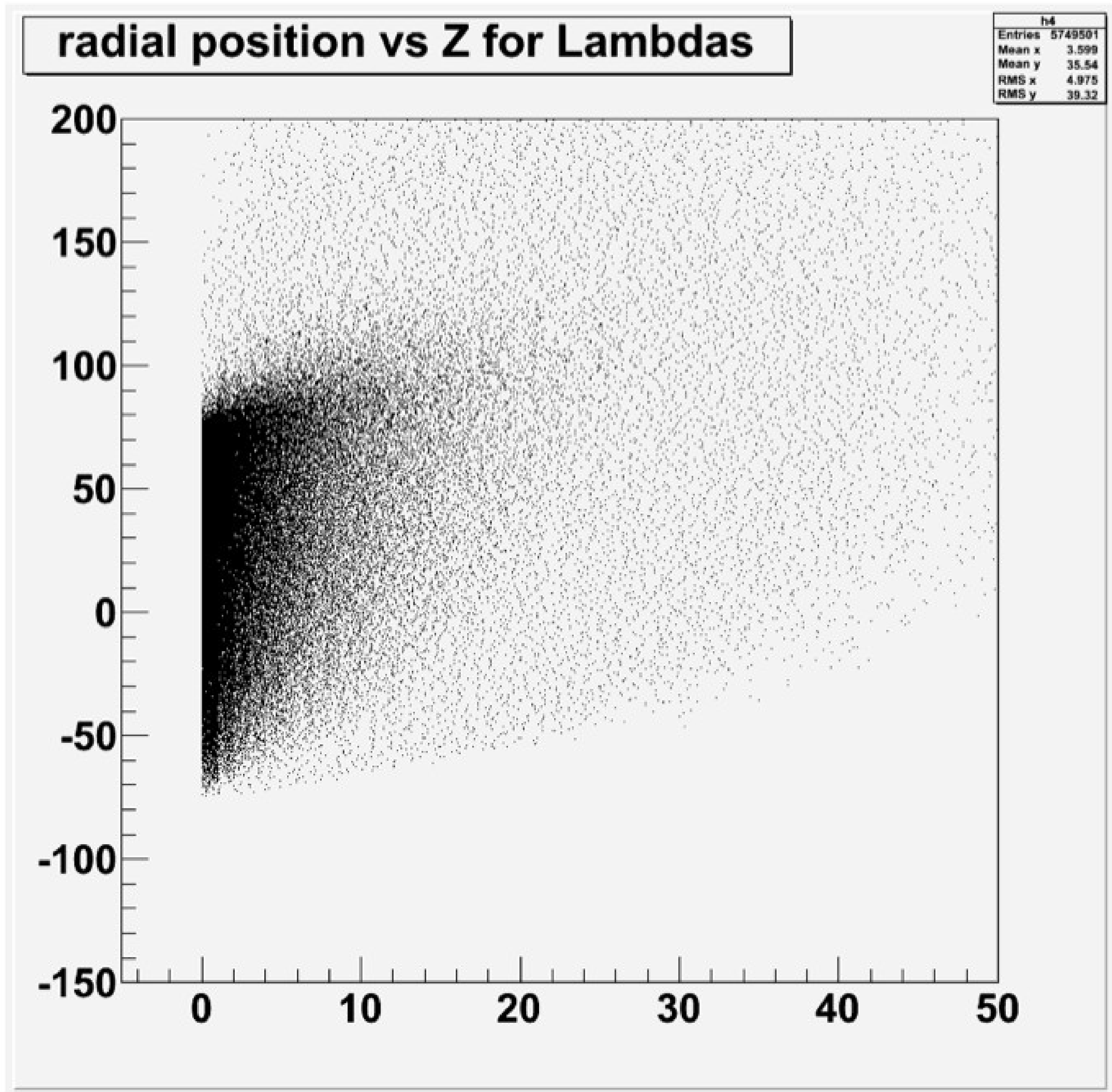

Figure 4: Predicted Lambda radial vs Z distribution $\frac{dN_\Lambda}{dN_e}$ for $\Delta t = 0.1cm$, $\Delta p_k = 0.1GeV/c$, $\Delta p_t = 0.05GeV/c$. The axes are in cm.

7) Examples of space and momentum distributions of hyperon decay particles

Example - Lambda decay spectra

$$\Lambda \rightarrow p + \pi^{-} \quad (64\%) \qquad \Lambda \rightarrow n + \pi^{0} \quad (36\%)$$

Lambda transferred polarizations are typically 75%. This is seen in the CLASS data and is cited by Jianglai Liu in his PhD thesis for G0.

The transferred polarization is along the direction of the virtual or real photon. In the case of Bremsstrahlung this is the Lab z direction.

The Lambda distribution was analyzed in a separate script to extract the sample momentum distributions for the decay products. The vertical axis is in pions or photons per electron for the 150cm LH2 target.

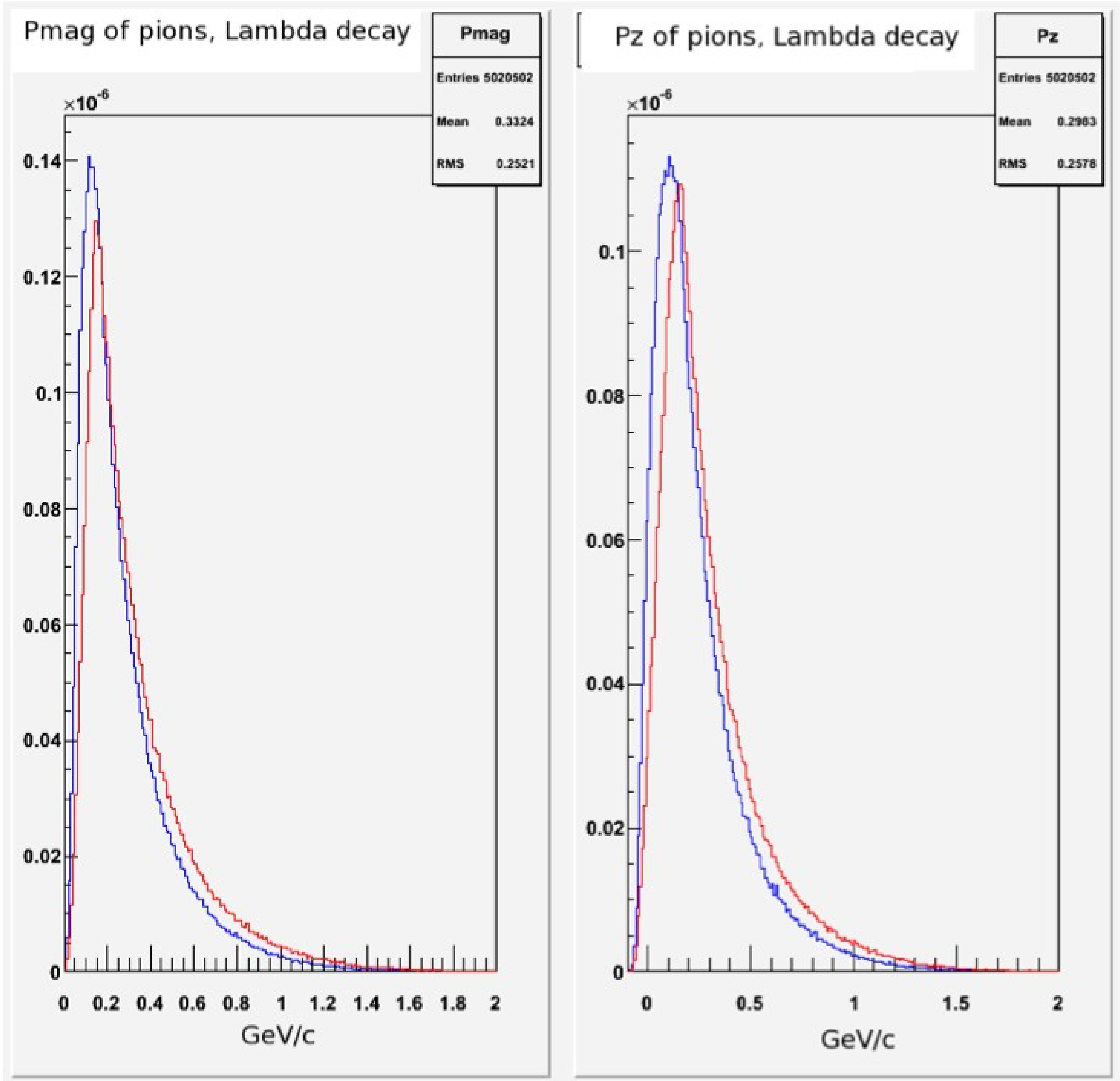

Figure 5: Pion total momentum and Pz distribution for $\Lambda \to p + \pi^-$ for the two helicity states; h = -1, blue and h = +1, red. The vertical axes is $\frac{N_\pi}{N_e}$ for the Moller target.

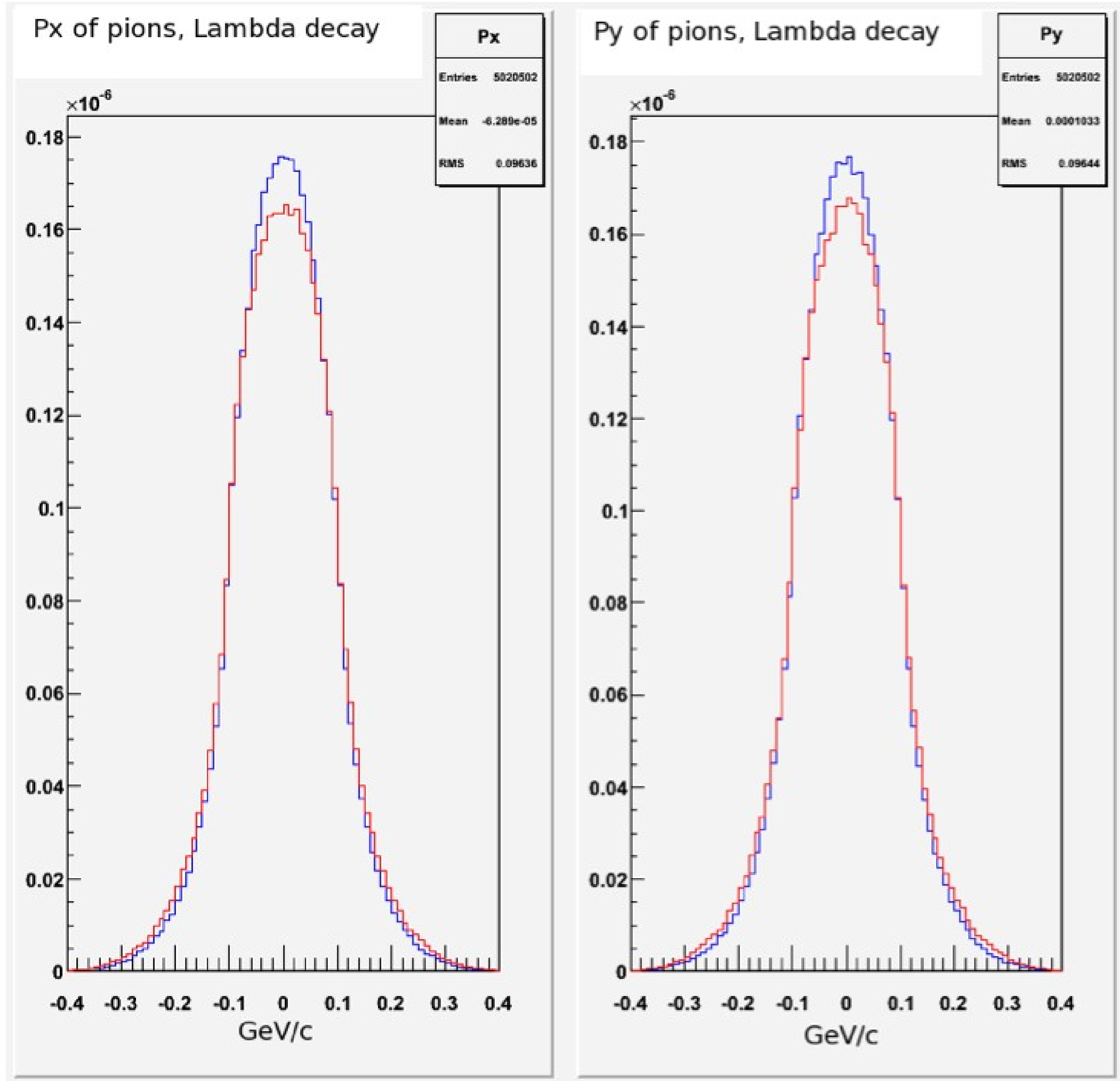

Figure 6: Pion Px and Py distribution for $\Lambda \rightarrow p + \pi^-$ for the two helicity states; h = -1, blue and h = +1, red. The vertical axes is $\frac{N_\pi}{N_e}$ for the Moller target.

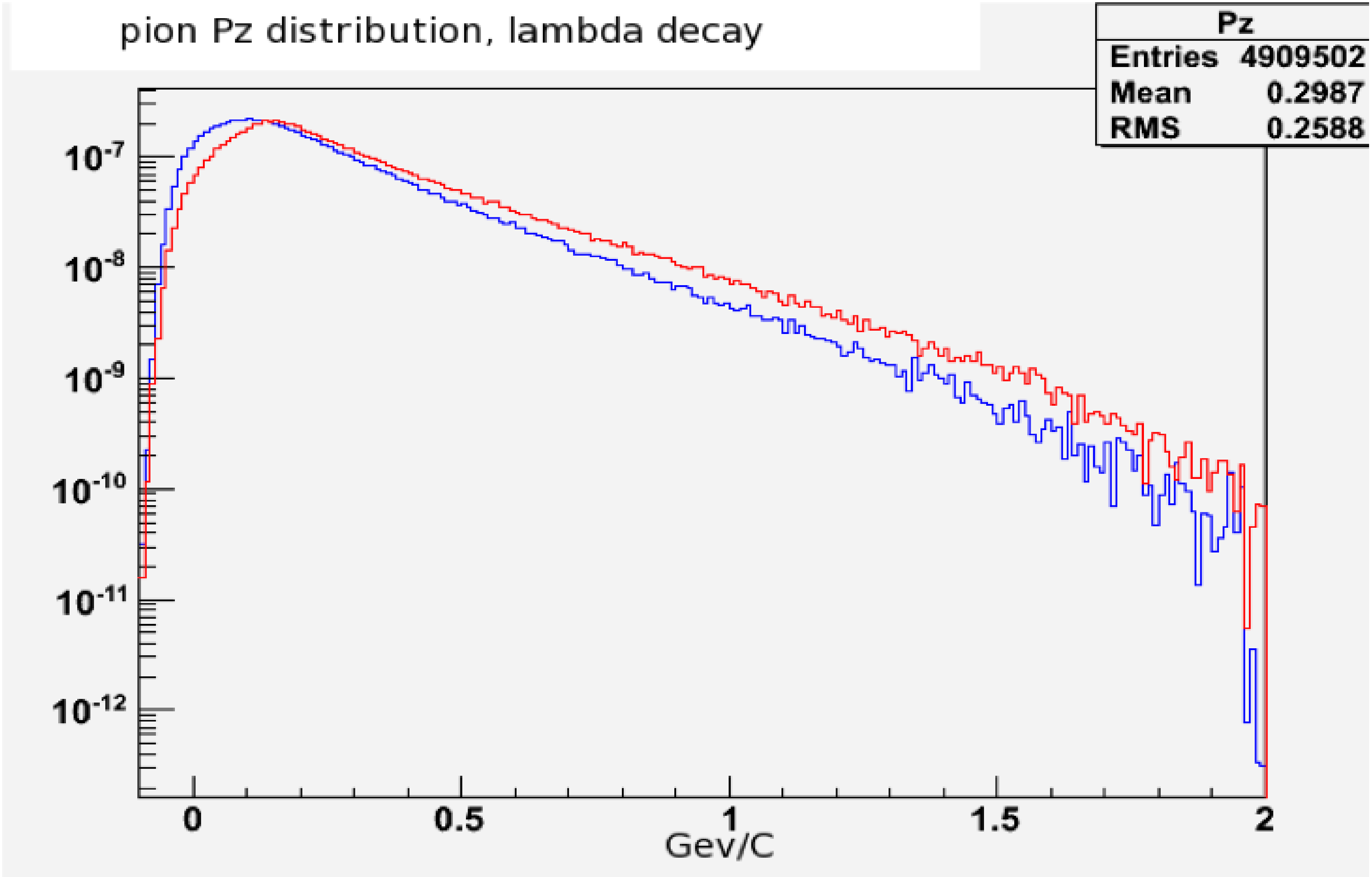

Figure 10: Pion Pz distributions for $\Lambda \rightarrow p + \pi^-$ for the two helicity states; h = -1, blue and h = +1, red. The vertical axes is $\frac{N_\pi}{N_e}$ for the Moller target.

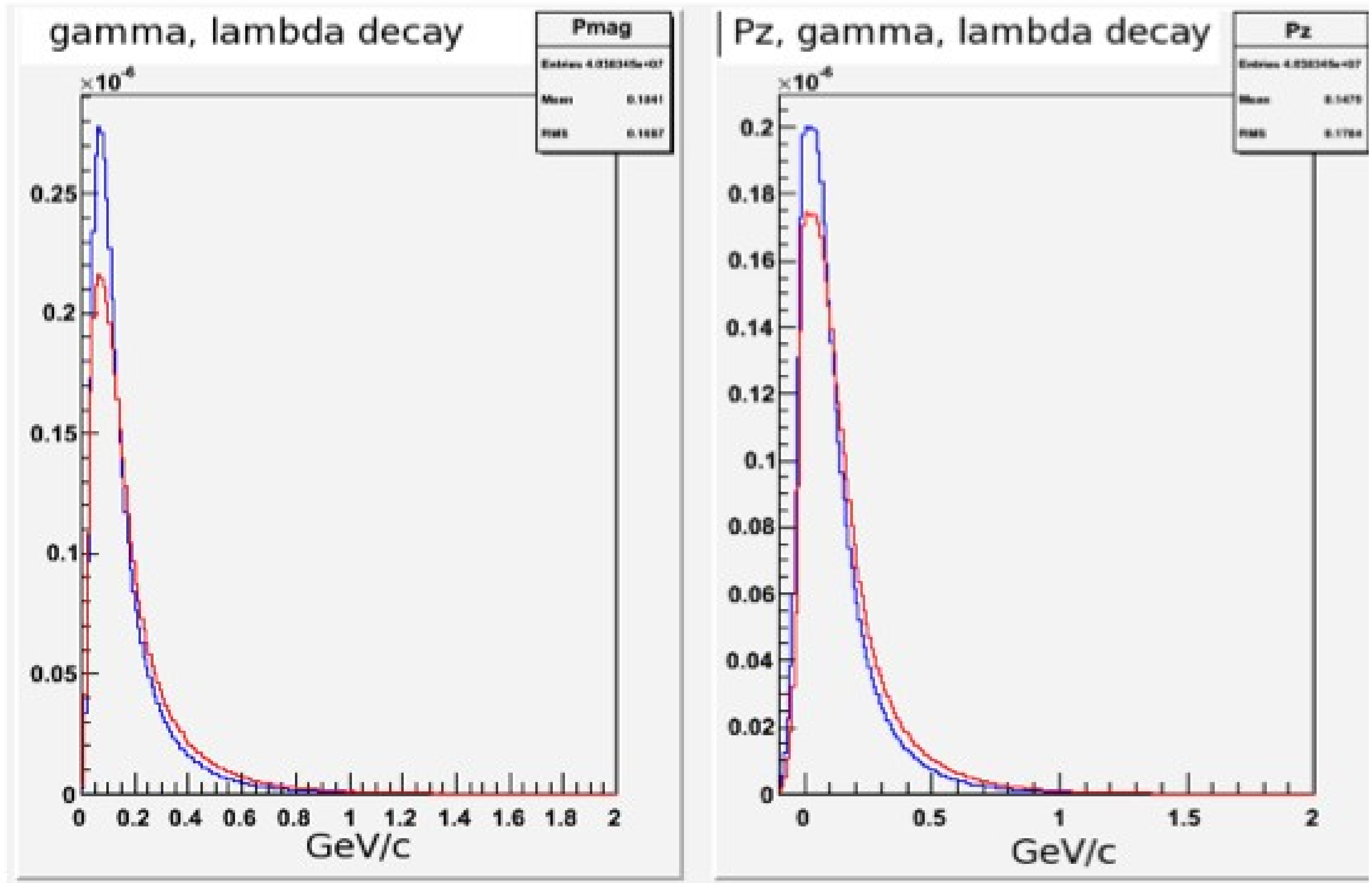

Figure 7: Gamma total momentum and Pz distribution for $\Lambda \rightarrow n + \pi^0$ for the two helicity states; h = -1, blue and h = +1, red. The vertical axes is $\frac{N_\gamma}{N_e}$ for the Moller target.

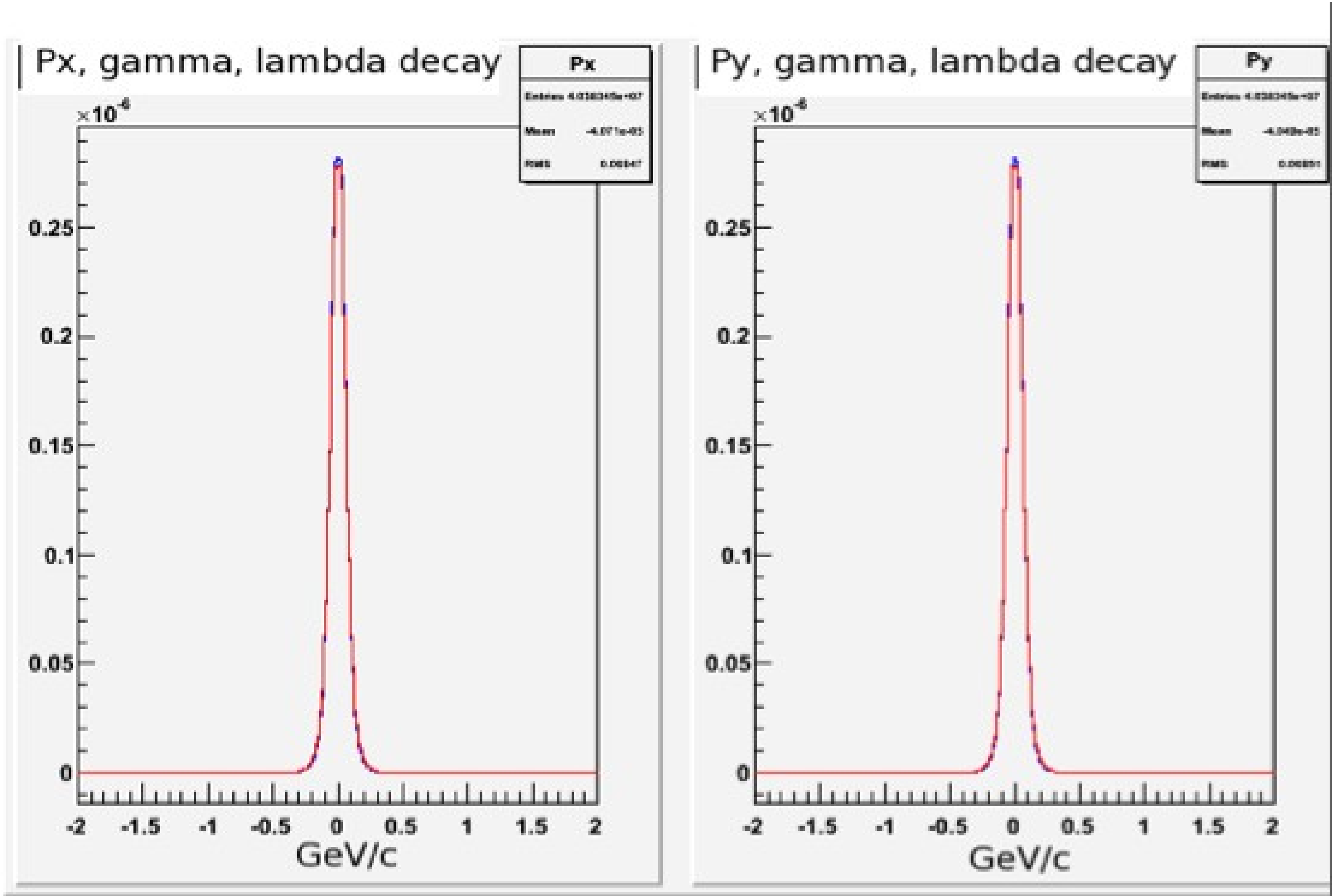

Figure 8: Gamma Px and Py distribution for $\Lambda \rightarrow n + \pi^0$ for the two helicity states; h = -1, blue and h = +1, red. The vertical axes is $\frac{N_\gamma}{N_e}$ for the Moller target.

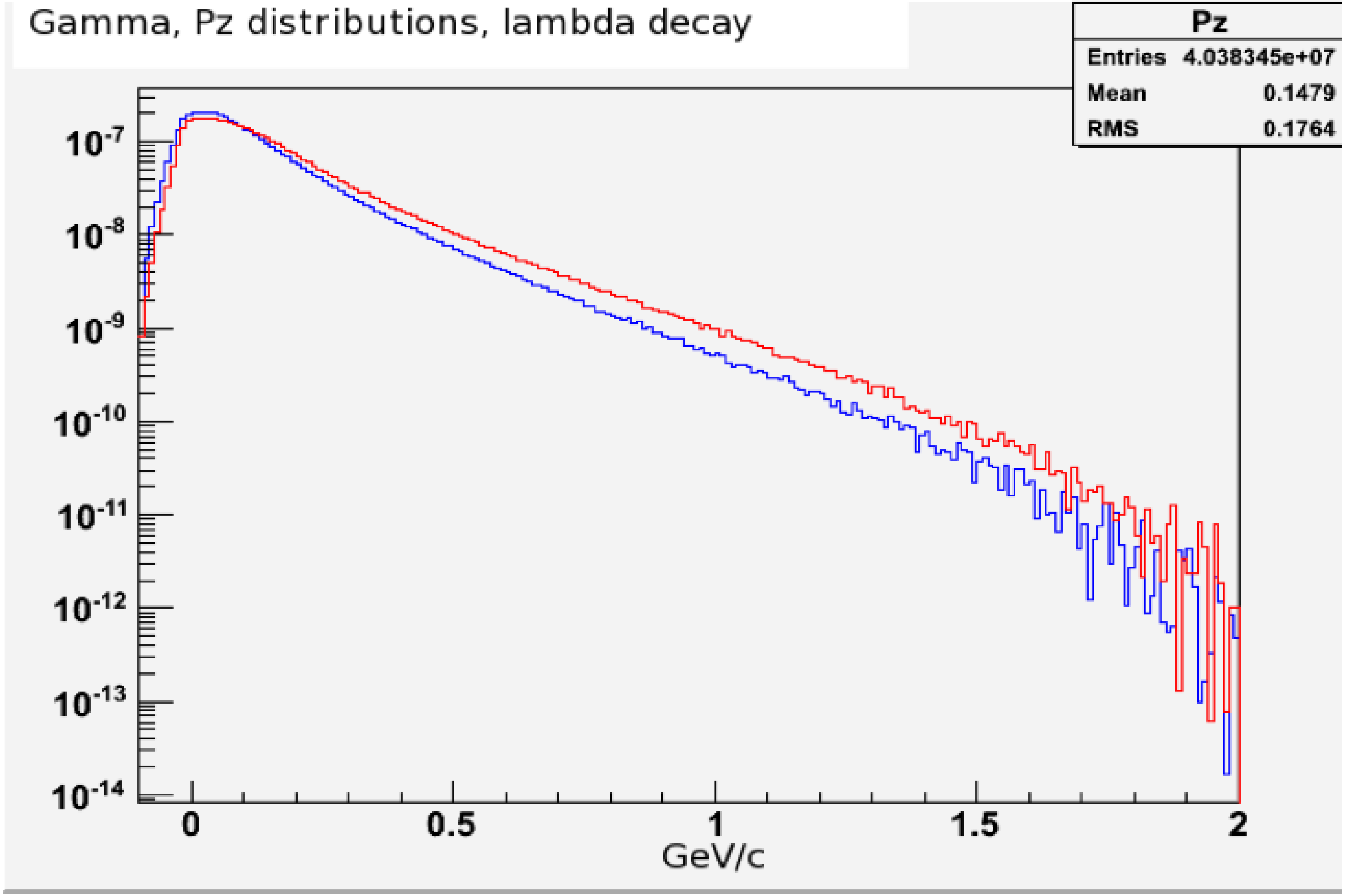

Figure 9: Gamma momentum Pz distribution for $\Lambda \to n + \pi^0$ for the two helicity states; h = -1, blue and h = +1, red. The vertical axes is $\frac{N_\gamma}{N_e}$ for the Moller target.

Next step is to use the decay product files as event generators for the Moller experiment configuration.

The decay product files contain about 20-40 x 10^6 events. The weights are in absolute numbers of particles/electron. Running the same file many times through the experimental configuration using geant should give an estimate, for the asymmetry background from hyperons.

[1] *Inclusive Photoproduction of protons, Kaons, and Pions at SLAC Energies*, David Earl Wiser, 1977, University of Wisconsin, PhD Thesis

[2] *Thick target Bremsstrahlung and Target Consideration for Secondary Particle Production by Electrons*, Y. S. Tsai and Van Whitis, March 1966, Stanford Linear Accelerator Center, SLAC-PUB-184

[3] *A measurement of the Strange Quark Contributions to the Electromagnetic Form Factors of the Nucleon*, Jianglai Liu, 2006, University of Maryland, College Park, PhD Thesis

[4] *Virtual Photons in Pion Electroproduction*, L. Tiator and L.E. Wright, NPA379(1982) 407-414

[5] *Beam-recoil polarization transfer in the nucleon resonance region in the exclusive* $ep \rightarrow e'K^+\Lambda$ *and* $ep \rightarrow e'K^+\Sigma^0$ *reactions at the CLAS spectrometer*, D.S.Carman, *et al.*, PhysRev **C79**, 065205(2009)
First Measurement of Transferred Polarization in the Exclusive $ep \rightarrow e'K + \Lambda$ *Reaction*, D.S. Carman, *et al.*, PhysRevLett **90** 131804(2003)

[6] *Relativistic Kinematics, A guide to the kinematic problems of highenergy physics*, R.Hagedorn and J.D.Jackson, W.A.Benjamin, Inc, 1963
Classical Electrodynamics, 2nd Edition, J.D.Jackson, John Wiley & Sons, 1975