GEANT Simulations for E08009

Konrad A. Aniol, Nathaniel See, Sophia Iqbal, CSULA

September 26, 2013

Contents

List of Tables

List of Figures

Abstract

GEANT Monte Carlo simulations were performed for the E08009 experiment at Jefferson Lab. The fortran version of GEANT (3.2), packaged as COMGEANT from Eugene Chudakov [1], was used. The simulation provides a missing energy spectrum for the triton ground state from $^4He(e,e'p)^3H$ which is broadened to fit the measured spectrum shape. We also use the simulation to calculate the missing momentum acceptance fraction for 0.05 GeV/c size bins of missing momentum. A calculation of the average cross section from the theoretical cross sections provided by the Madrid group [2] for $^4He(e,e'p)^3H$ using the simulation is shown.

0.1 Using the GEANT3.2/COMGEANT Code

E08009 used a cryogenic target of ^4He of length 20 cm and $20^\circ K, 198$ psia. Aluminum end caps at the beam in and beam out ends of the target are 20 cm apart. A picture of the target shown with the Computational Fluid Dynamics(CFD) calculation is in figure 1. A description of the target's performance is given in reference [3]. In this report we are concerned with the GEANT simulations.

The user portions of the code were written by K. Aniol and employed for the lead/bismuth experiment (E06007) and other experiments requiring a vertex production of a scattered electron and an outgoing particle, h. The type of reaction that can be handled is A(e,e'h)B. The input file contains the massess of A, B, e, and h. The distances, locations and sizes of the apertures to the high resolution spectrometers(LHRS,RHRS) are included. The incident beam energy and central momenta of the HRSs are included. The geometry file includes the target description and all the material between the target and the entrance apertures of the HRSs. Particles are not followed through the spectrometers themselves. Practice has shown that one normally needs to smear the resolutions predicted by Monte Carlo codes even if the the spectrometer fields and detector geometries and resolutions are part of the simulation.

The code output is a hbook file containing a ntuple. This hbook file can be analyzed using the CERN paw program or it is converted to a root file for the CERN root program. For each event where a vertex in the target is created the following variables are in the ntuple or root tree for A(e,e'p)B. Coordinates are the Hall A coordinates, z is toward the beam dump, y is vertically upward and x is to the beam left for a RH coordinate system.

```
variables from geant
px0,py0,pz0 : incident electron momenta at vertex
ee,eex,eey,eev : electron momenta entering LHRS
eev,eexv,eeyv,eezv : scattered electron at the vertex
xe7,ye7,ze7 : coordinates at entrance of electron to LHRS
pproton,ppx,ppy,ppz : proton momenta entering RHRS
ppv,ppxv,ppyv,ppzv : proton momenta at the vertex
xp8,yp8,zp8 : coordinates at entrance of proton to RHRS
xvert,yvert,zvert : coordinates of the vertex
xrast0,yrast0 : raster coordinates
```

The electron momenta at the vertex, px0, py0, pz0, include external bremsstrahlung which is automatically a feature of GEANT. At the vertex the electrons must also undergo significant radiation loss. Internal bremstrahlung is not included in the GEANT code so this is handled by a separate user provided subroutine(see appendix). In the cases discussed here this is done by using the Schwinger prescription. The electrons and protons created at the vertex are followed through all remaining material and air to the spectrometer entrances. Additional radiative losses and mulitple scattering are handled by GEANT. Since the vertex

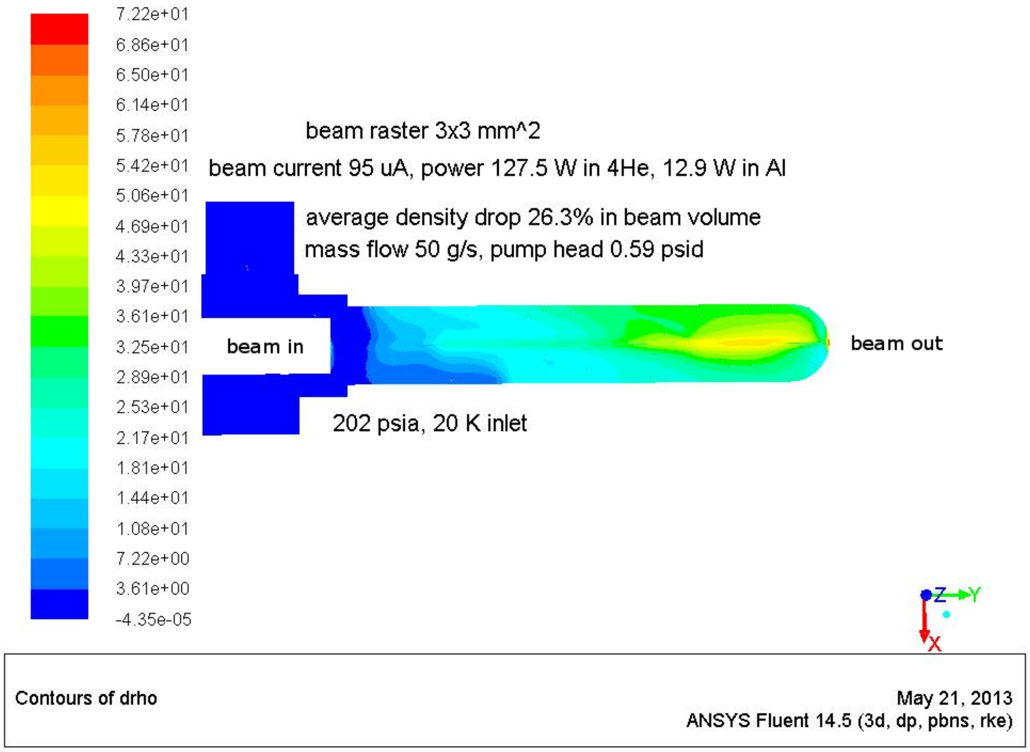

Figure 1: The SRC target showing the change in density of the cryogenic ^4He from S. Covrig [4].

kinematical variables are known it is possible to use the GEANT output to weight each vertex with a theoretical cross section. A flow diagram of the GEANT simulation is shown in figure 2.

0.2 Simulation results for E08009

The simulation uses the kinematical settings for E08009 listed in table 1.

The hbook files created by GEANT3.2 are converted to root trees. A separate c++ script called by root generates histograms from the GEANT variables in the root tree.

0.2.1 Radiative losses and multiple scattering

Examples of losses from the vertex to the aperture are shown in figures 3 and 4 for the electron momentum spectra and the missing energy spectra for the nominal HRS resolution and the broadening and emiss offset needed to fit the

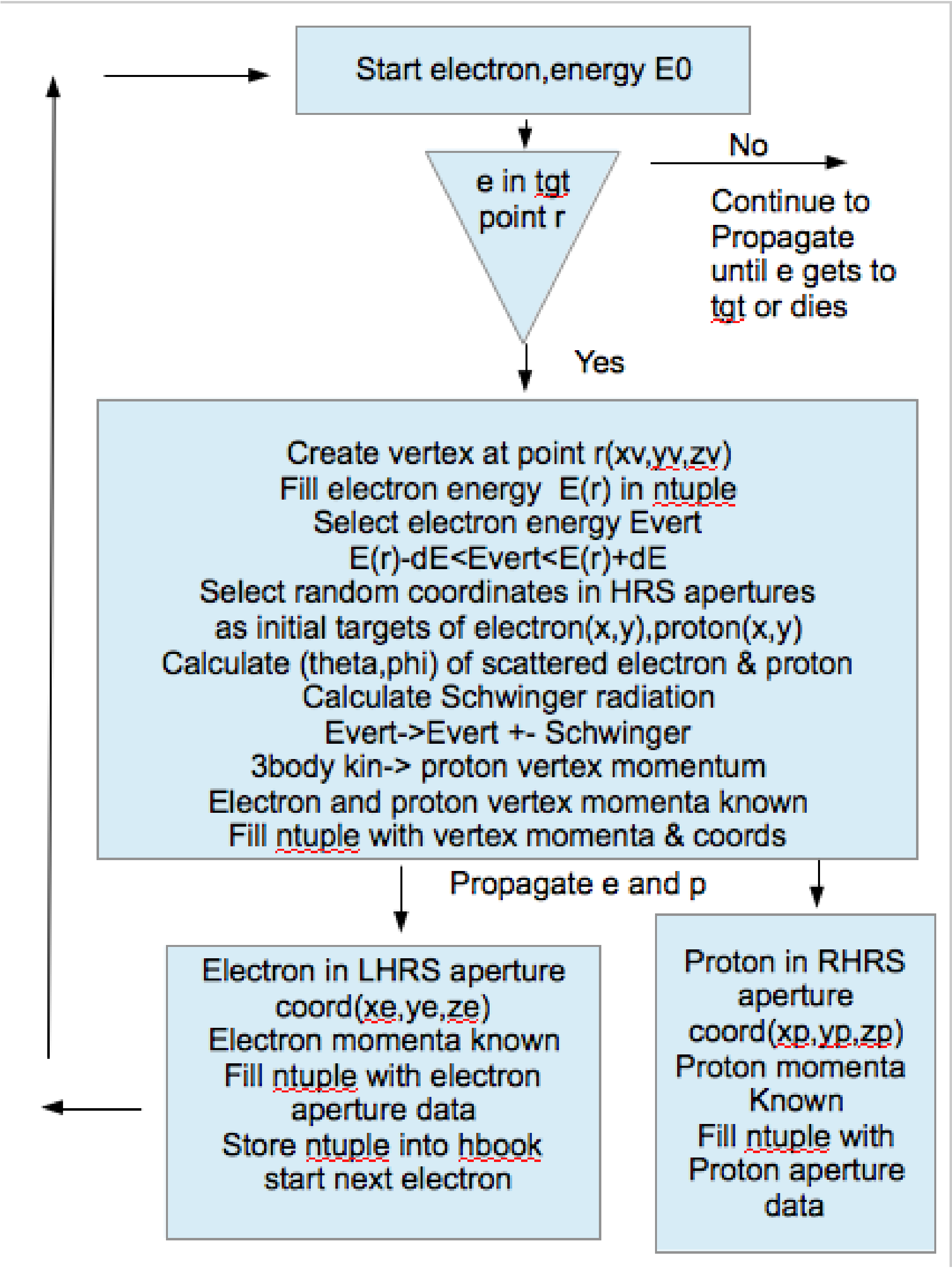

Figure 2: The tracking and storage of electrons and protons in the GEANT simulation. The quantity dE = dp*E(r), where dp is typically 0.045 corresponding to the momentum acceptances of the HRSs. Here $E(r) = \sqrt{px0^2 + py0^2 + pz0^2 + m_e^2} - \omega$ is the LHRS central momentum setting.

P_{miss} GeV/c	θ_p degrees	RHRS momentum GeV/c
0.153	47.0	1.500
0.353	38.5	1.449
0.500	33.5	1.383
0.625	29.0	1.308
0.755	24.5	1.196

Table 1: Kinematic settings for E08009. The incident electron energy was 4.4506 GeV, the LHRS was set at 20.3° and 3.601 GeV/c.

data. A comparison of the data for 0.153 GeV/c data and simulation is shown in figure 5. This comparison enables us to determine the fraction of the triton missing energy spectrum we can use to calculate the cross section. For the 12 MeV interval around the data peak used in the analysis we see we account for a fraction of 0.629 of the total triton yield. During the root analysis the Gaussian broadening is accomplished on the momenta determined at the apertures via equation 1, for example, eex. Here gRandom = new TRandom3(); , mean = 1., and sig1 is varied to fit the width of the data.

$$eex = eex * gRandom.Gaus(mean, sig1); \tag{1}$$

0.2.2 Missing Momentum Acceptance

The wide momentum acceptance of the the HRSs' allows for a broad missing momentum acceptance. In the simulation each point within the spectrometers' apertures has an equal probability of being a target for a vertex electron and proton. The 3 body kinematical and geometrical limitations for particles arriving at the target points in the apertures are correctly calculated by GEANT. We thus have defined the missing momentum acceptance factor, $f(p_m)$, for a bin of missing momentum centered around p_m as

$$f(p_m) = \frac{n(p_m)}{\sum n(p_m)}. \tag{2}$$

Where $n(p_m)$ is the number of triton events in the missing momentum bin centered on p_m and $\sum n(p_m)$ is the total number of triton events over all missing momenta for the particular kinematic setting. An example of GEANT missing momentum spectra binned into 50 MeV/c size bins for the 0.153 GeV/c and 0.353 GeV/c kinematic settings is shown in figure 6. The same Gaussian broadening used in figure 4 was applied in generating figure 6. Table 2 lists the simulated fractional acceptance from equation 2 for the 0.153 GeV/c and 0.353 GeV/c kinematic settings.

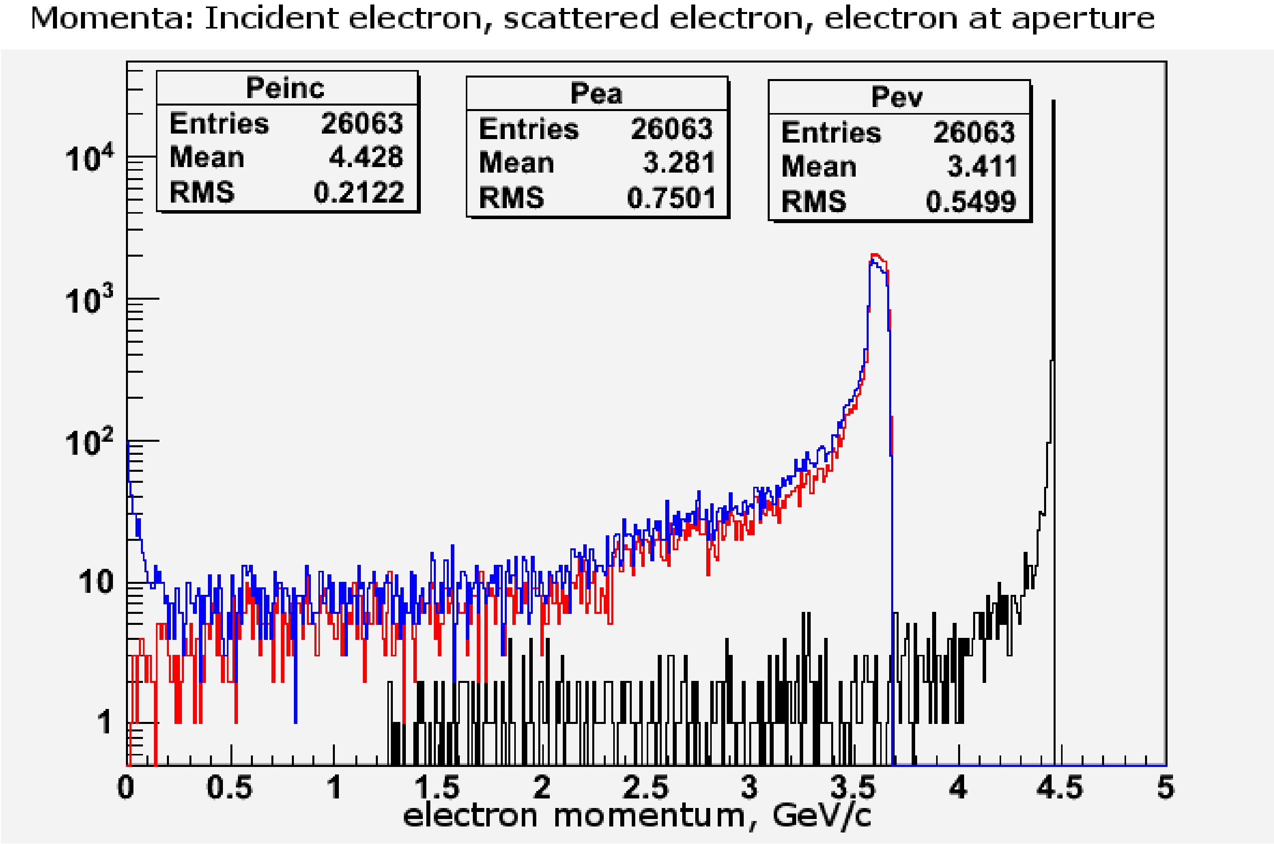

Figure 3: Predicted electron momentum spectra for the incident electron at the vertex(black), for the scattered electron at the vertex(red) and for the electron at the aperture(blue). A proton within 4.5% of the RHRS central proton momentum of 1.449 GeV/c is required. The fraction of electrons accepted at the aperture to the electrons leaving the vertex is 0.746.

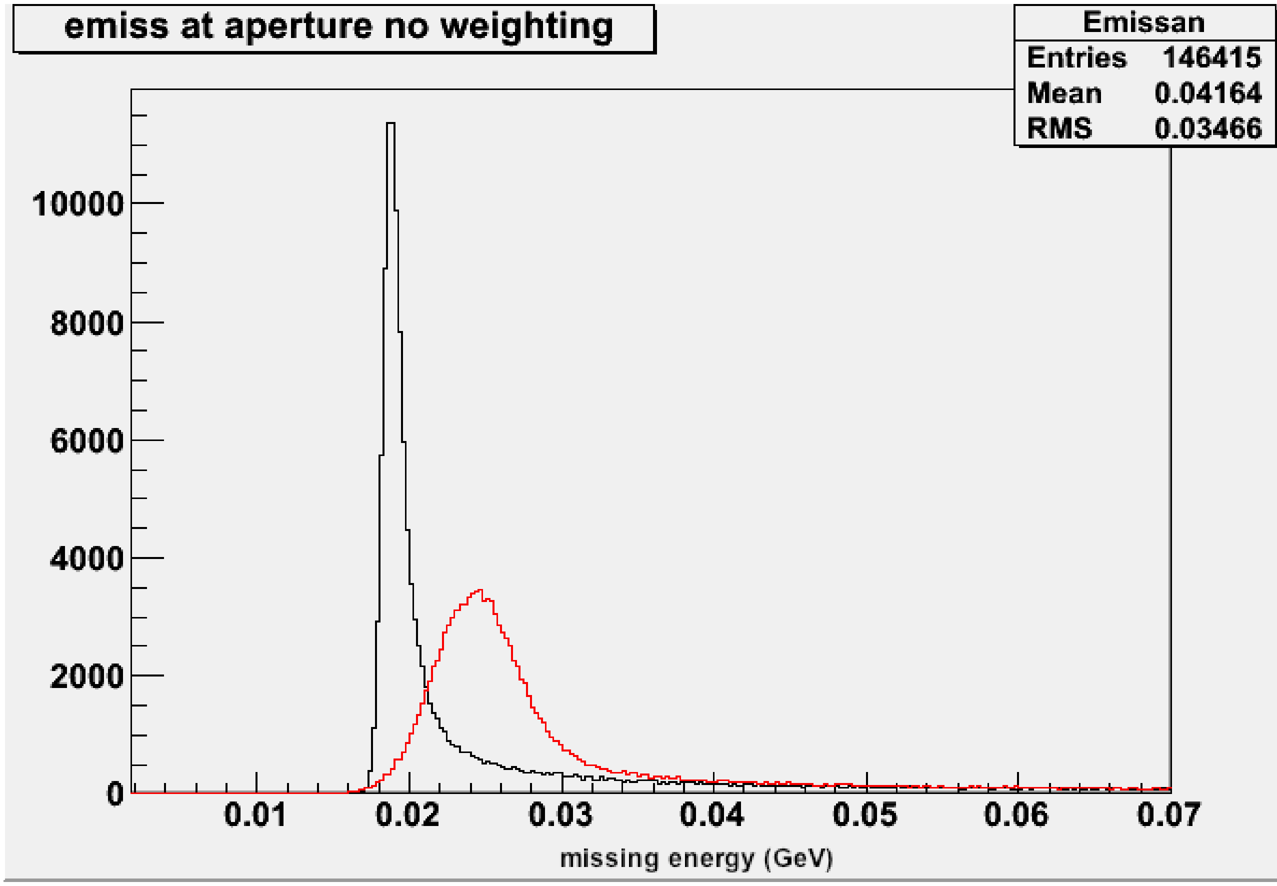

Figure 4: A comparison of GEANT's prediction for the nominal momentum uncertainty, $\sigma = 1. \times 10^{-4}$ (black) to the Gaussian broadening required to match the data, $\sigma = 6.53 \times 10^{-4}$ (red). The broad specrum has an offset of 4.95 MeV to match the data peak location.

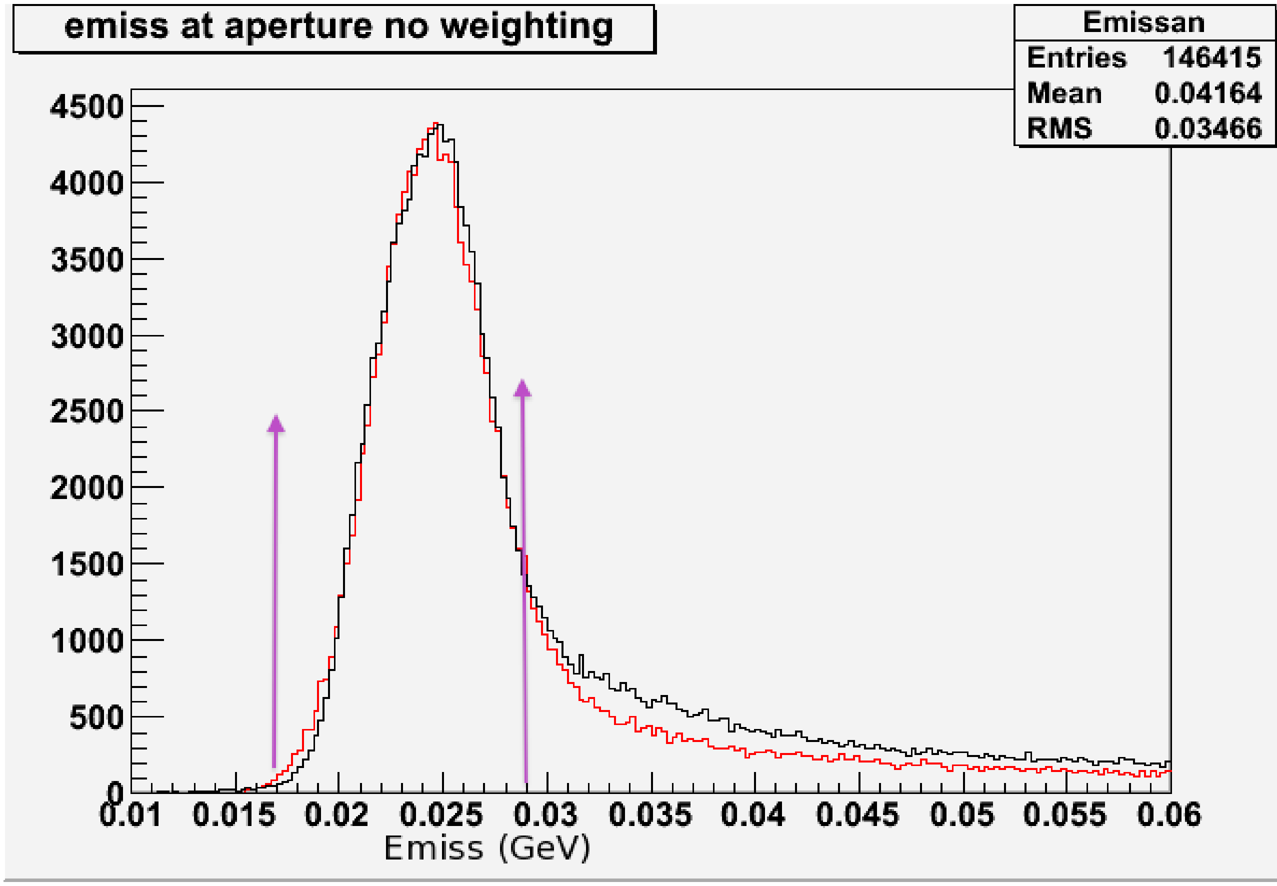

Figure 5: A comparison of the data(black) for 0.153 GeV/c to the geant prediction(red) for the same kinematics for $^4He(e,e'p)^3H$ with Gaussian broadening to match the FWHM of the data. The arrows at 17 and 29 MeV show the region of emiss attributal to the triton ground state. The fraction of the triton state within this emiss interval is 0.629 compared to the total triton spectrum. The predicted emiss spectrum extends to emiss = 250 MeV.

p_m bin GeV/c	$f(p_m)$ for 0.153	$\delta f(p_m)$ for 0.153	$f(p_m)$ for 0.353	$\delta f(p_m)$ for 0.353
0.0-0.05	0.0021	0.00012		
0.05-0.10	0.0421	0.00054		
0.10-0.15	0.1423	0.00099		
0.15-0.20	0.2558	0.00132	0.00065	0.00007
0.20-0.25	0.2808	0.00138	0.01128	0.0003
0.25-0.30	0.1927	0.00115	0.08666	0.0008
0.30-0.35	0.0713	0.00070	0.24192	0.0013
0.35-0.40	0.0108	0.00027	0.33097	0.0015
0.40-0.45	0.0011	0.00009	0.23523	0.0013
0.45-0.50	0.0004	0.00006	0.08335	0.0007
0.50-0.55			0.00889	0.00024
0.55-0.60			0.00044	0.00005
0.60-0.65			0.00022	0.00004
0.65-0.70			0.00015	0.00003

Table 2: Missing momentum fractional acceptance at the apertures from the simulation. The fraction, $f(p_m)$, is calculated from equation 2 using data from the 0.153 GeV/c and 0.353 GeV/c kinematic settings shown in figure 6.

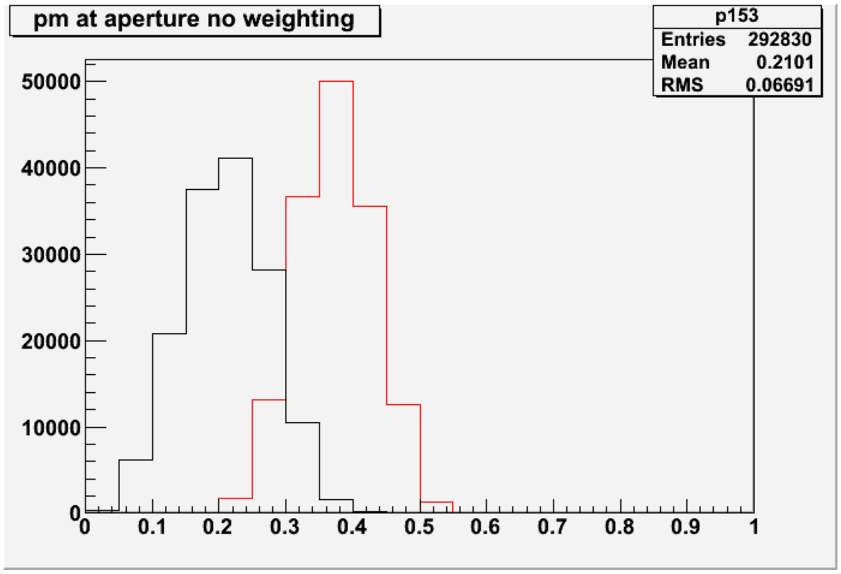

Figure 6: GEANT missing momentum spectrum for the 0.153 GeV/c(black) and 0.353 GeV/c(red) kinematic settings based on aperture values. The electron and proton momenta are broadened by the same parameters as described in figure 4.

P_{miss} GeV/c	θ_p degrees	proton central momentum GeV/c	$<\sigma>$ $nb/MeV/sr^2$
0.164*	47.0	1.500	6.19×10^{-2}
0.193*	45.0	1.500	5.19×10^{-2}
0.243	42.5	1.475	1.84×10^{-2}
0.302	40.0	1.449	2.91×10^{-3}
0.338	38.5	1.449	1.15×10^{-3}
0.364	37.5	1.449	5.57×10^{-4}
0.427	35.0	1.417	7.45×10^{-5}
0.492	32.5	1.383	3.33×10^{-5}
0.556	30.0	1.353	2.46×10^{-5}
0.621	27.5	1.308	1.72×10^{-5}
0.684	25.0	1.268	1.07×10^{-5}
0.697	24.5	1.200	6.09×10^{-6}

Table 3: $^4He(e,e'p)^3H$ average cross sections from equation 3 from the Madrid theory [2]. The incident electron energy was 4.4506 GeV, the electron was set at 20.3° and 3.601 GeV/c central momentum. * indicates assuming cross sections for $p_m < 0.153$ GeV/c are equal to the 0.153 GeV/c value.

0.3 Theoretical Cross Sections from Madrid

Theoretical cross sections [2] were made available in tabular form in terms of the missing momenta and the angle ϕ between the electron scattering plane and the plane formed from the three momentum transfer, $\vec{q}$ and the proton momentum $\vec{p}$. The cross sections, $x_B = 1.24$, for $^4He(e,e'p)^3H$ were averaged over the missing momentum and angular acceptances at the HRS apertures. The Madrid cross sections for $x_B = 1.24$ were only given above 0.153 GeV/c. In table 3 the * indicates that a significant fraction of the missing momentum, p_m, accepted by the spectrometers is below 0.153 GeV/c. The average cross sections for these p_m are only approximate.

$$< \sigma(p_m) >= \frac{\int \frac{d\sigma}{dEd\Omega_e d\Omega_p} d\Omega_e d\Omega_p}{\int d\Omega_e d\Omega_p} \tag{3}$$

0.4 Appendix

Schwinger calculation for scattering

```
c  from R. Florizone thesis, appendix B
c  Schwinger distribution for real photon emission
c***************************************************************
subroutine schwinger(ei,w,th0,atar,ee)
real ei,ef,w,th,me,mtar,atar,b,eta,eta2,Q2
real alpha,radian,pi,snth,snth2,x1,x2,th0
real gamma,beta,r,fact,ee
data pi/3.141592/,radian/57.29578/,alpha/7.2974e-03/
data amu/0.931494/,me/0.511e-03/
ef = ei - w
mtar = atar*amu
c* note it is assumed that the angles are given in radians
th = th0/2.
snth = sin(th)
snth2 = snth*snth
Q2 = 4.*ei*ef*snth2
b = 1. + 2.*w/mtar*snth2
eta = 1. + 2.*ei/mtar*snth2
eta2 = eta*eta
x1 = ei*ef*b/eta2
beta = log(x1)
x2 = Q2/me/me
gamma = alpha/pi*(log(x2) - 1.)
x1 = beta*gamma
fact = exp(x1)
x1 = 1./2./gamma
r = fact*rand()
ee = ef - r**x1   ! r**x1 is the DeltaE bite in the radiated spectrum

return
end
```

Bibliography

[1] Eugene Chudakov, private communication

[2] Jose Vignote, private communication
Udias J.M. and Vignote J.R.,2000 *Phys. Rev. C* **62** 034302
Malace S.P. et. al. 2011 *Phys. Rev. Lett* **106** 052501

[3] *Analysis of the SRC target Performance*, K.A.Aniol, N.Y.See, S.Iqbal

`https://userweb.jlab.org/~aniol/e08009/iscan_corrections/SRCtgt.pdf`

[4] Silviu Covrig, private communication