Helium-4 Elastic Cross Section Acceptance Scale Factor

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"Empty" runs normalized to experimental cross section, without solid angle acceptance

$$\sigma_{unscaled} = \frac{d\sigma^{raw}}{d\Omega dE'}\Delta\Omega = \frac{ps_1 N}{\frac{Q_{tot}}{e}\rho(LT)\varepsilon_{det}}\frac{1}{\Delta E' \Delta Z}$$

N is the yield, the number of scattered electrons
e is the electron charge
Quantitities from MySQL: ps_1 is the prescale factor, Q_{tot} is the total charge, ρ is the number density of the electron beam, LT is the livetime, ε_{det} is the product of all detector efficiencies.
$\Delta\Omega$ is the solid angle acceptance. Toby cross section cut used:

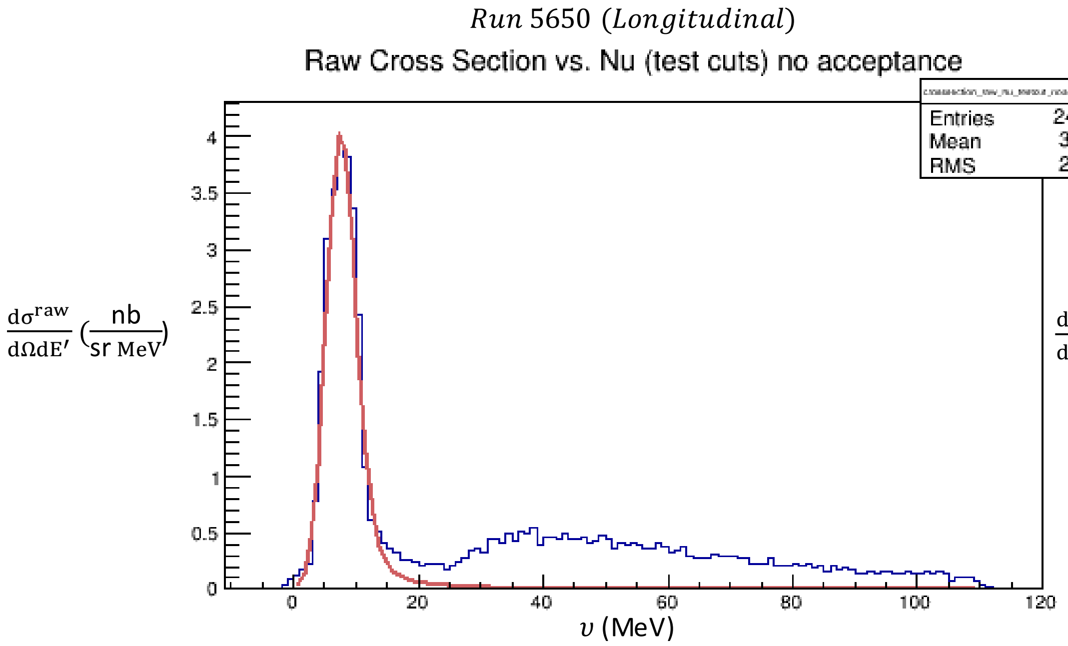
$-0.005 < \phi < 0.005$ | $-0.01 < \theta < 0.01$

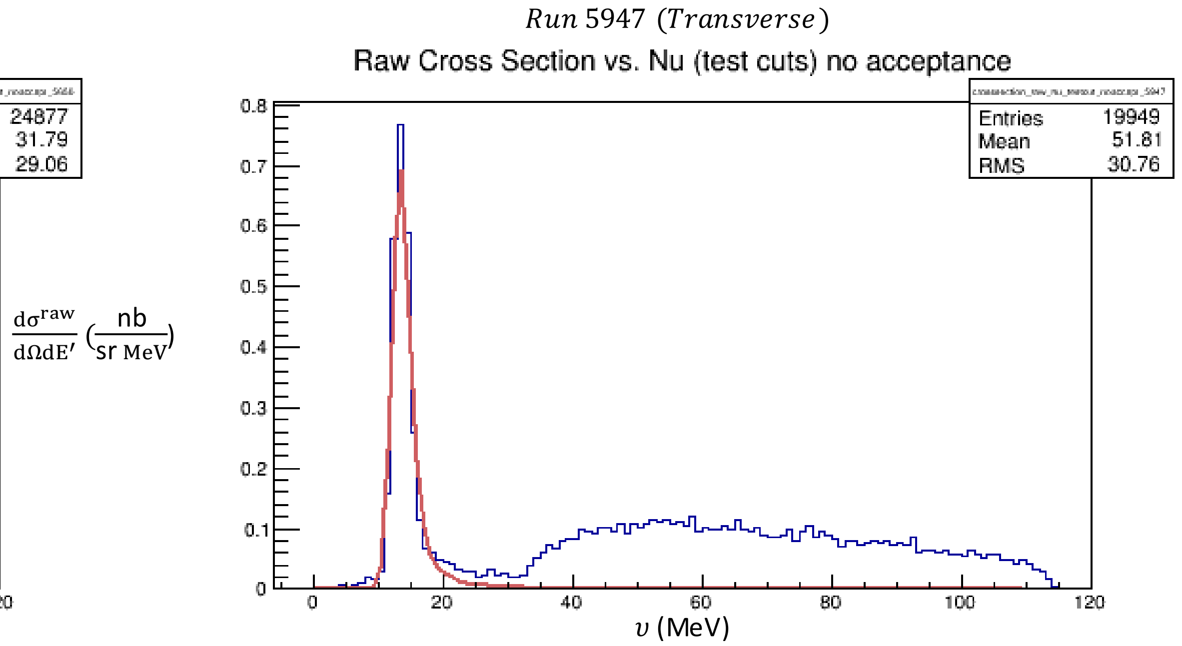
$\Delta E'$ is the energy acceptance: 1 MeV bins
ΔZ is the target length from Ryan's Tech Note #19

All runs are 2.2 GeV incident energy, 5 T magnetic field, Helium-4 / 'Empty' target

1. "The Spin Structure of 3He and the Neutron at Low Q^2, A Measurement of the Generalized GDH Integrand", 116, V. Sulkosky, 2007
2. "Radiation Thickness, Collisional Thickness, and Most Probable Collisional Energy Loss for E08-027", 17, R. Zielinski, 2016

Elastic and quasielastic peaks fit, with fake bins to force QE fit to go to zero by 15 MeV





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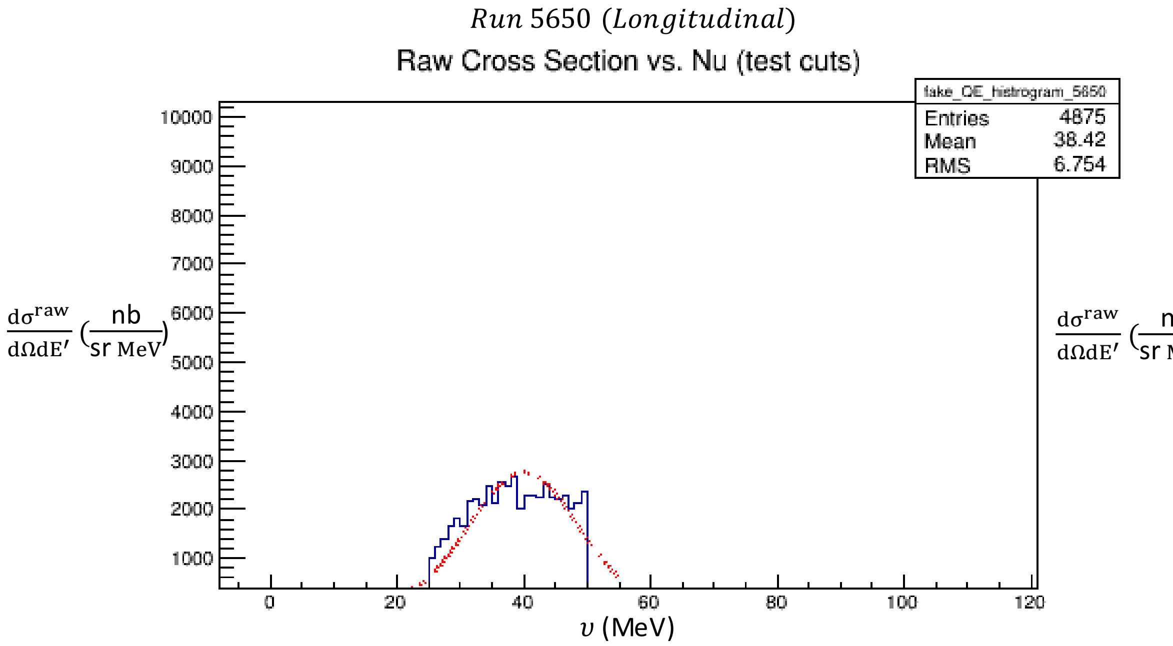

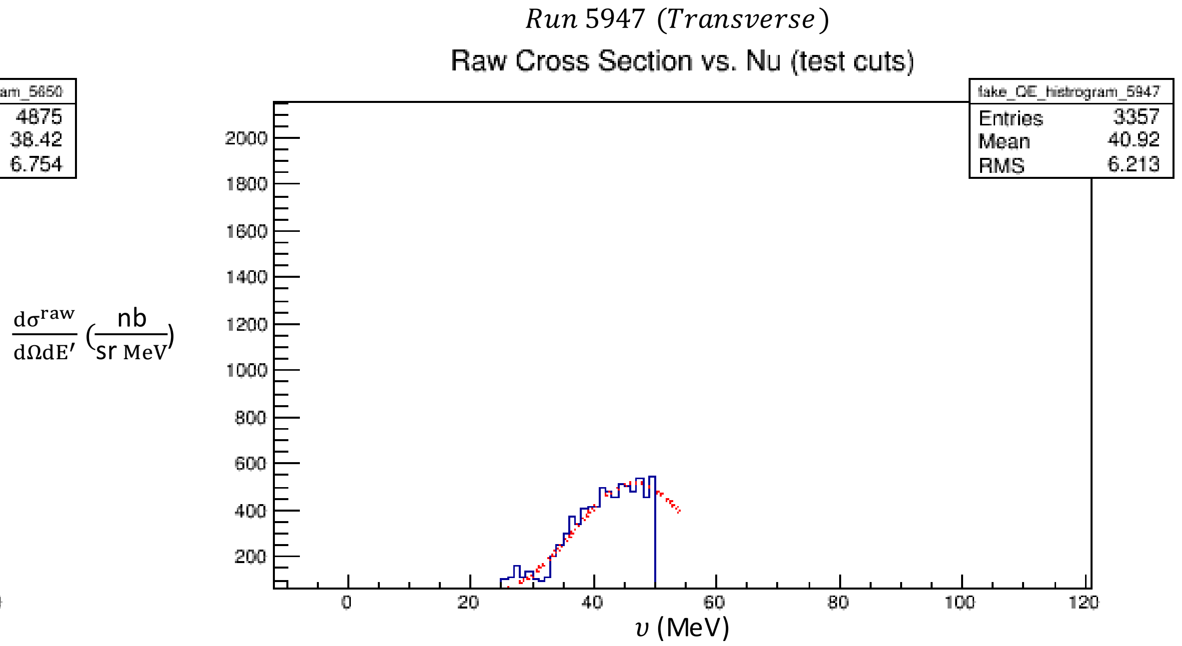

Elastic peak integrated and radiative corrections applied, compared to Rosenbluth cross section for elastic scattering.

Mo and Tsai method used. Formula is lengthy, see image.
All quantities defined well in paper with the exception of "ΔE"

ΔE defined in separate Tsai paper as length of Landau tail on elastic peak, but there is some guesswork in the cut-off.

$$\sigma_{Rosenbluth} = \frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{Mott} \times \left\{\frac{G_E^2(Q^2) + \tau G_M^2(Q^2)}{1+\tau} + 2\tau G_M^2(Q^2)\tan^2\frac{\theta}{2}\right\}$$

Helium form factors taken from McCarthy, Sick, and Whitney, where $G_E = 2F_{ch}$

Our scale factor will be:

$$S = \frac{\sigma_{Rosenbluth}}{\sigma_{unscaled}}$$

$$\begin{aligned}
\delta = \frac{-\alpha}{\pi}\Bigg(& \tfrac{28}{9} - \tfrac{13}{6}\ln\left(\frac{-q^2}{m^2}\right) + \left(\ln\frac{-q^2}{m^2} - 1 + 2Z\ln\eta\right)\left(2\ln\frac{E_1}{\Delta E} - 3\ln\eta\right) - \Phi\left(\frac{E_3-E_1}{E_3}\right) - Z^2\ln\frac{E_4}{M} \\
& + Z^2\ln\frac{M}{\eta\Delta E}\left(\frac{1}{\beta_4}\ln\frac{1+\beta_4}{1-\beta_4} - 2\right) + \frac{Z^2}{\beta_4}\left\{\tfrac{1}{2}\ln\frac{1+\beta_4}{1-\beta_4}\ln\frac{E_4+M}{2M} - \Phi\left[-\left(\frac{E_4-M}{E_4+M}\right)^{1/2}\left(\frac{1+\beta_4}{1-\beta_4}\right)^{1/2}\right]\right\} \\
& + Z\left[\Phi\left(-\frac{M-E_3}{E_1}\right) - \Phi\left(\frac{M(M-E_3)}{2E_3E_4-ME_1}\right) + \Phi\left(\frac{2E_3(M-E_3)}{2E_3E_4-ME_1}\right) + \ln\left|\frac{2E_3E_4-ME_1}{E_1(M-2E_3)}\right|\ln\left(\frac{M}{2E_3}\right)\right] \\
& - Z\left[\Phi\left(-\frac{E_4-E_3}{E_3}\right) - \Phi\left(\frac{M(E_4-E_3)}{2E_1E_4-ME_3}\right) + \Phi\left(\frac{2E_1(E_4-E_3)}{2E_1E_4-ME_3}\right) + \ln\left|\frac{2E_1E_4-ME_3}{E_3(M-2E_1)}\right|\ln\left(\frac{M}{2E_1}\right)\right] \\
& - Z\left[\Phi\left(-\frac{M-E_1}{E_1}\right) - \Phi\left(\frac{M-E_1}{E_1}\right) + \Phi\left(\frac{2(M-E_1)}{M}\right) + \ln\left|\frac{M}{2E_1-M}\right|\ln\left(\frac{M}{2E_1}\right)\right] \\
& + Z\left[\Phi\left(-\frac{M-E_3}{E_3}\right) - \Phi\left(\frac{M-E_3}{E_3}\right) + \Phi\left(\frac{2(M-E_3)}{M}\right) + \ln\left|\frac{M}{2E_3-M}\right|\ln\left(\frac{M}{2E_3}\right)\right]\Bigg) \\
- \frac{\alpha}{\pi}\Bigg(& -\Phi\left(\frac{E_1-E_3}{E_1}\right) + \frac{Z^2}{\beta_4}\left\{\Phi\left[\left(\frac{E_4-M}{E_4+M}\right)^{1/2}\left(\frac{1-\beta_4}{1+\beta_4}\right)^{1/2}\right] - \Phi\left[\left(\frac{E_4-M}{E_4+M}\right)^{1/2}\right] + \Phi\left[-\left(\frac{E_4-M}{E_4+M}\right)^{1/2}\right]\right\}\Bigg). \qquad \text{(II.6)}
\end{aligned}$$

$$\begin{aligned}
\delta_t = -\{ & [b_w t_{iw} + \tfrac{1}{2}bT]\ln(E_1/\eta^2\Delta E) \\
& + [b_w t_{fw} + \tfrac{1}{2}bT]\ln(E_3/\Delta E)\}; \qquad \text{(II.9)}
\end{aligned}$$

$$d\sigma/d\Omega\,|_{\text{meas}} = d\sigma/d\Omega\,|_{\text{Rosenbluth}}\exp(\delta+\delta_t),$$

1. "Radiative Corrections to Elastic and Inelastic ep and up Scattering", L. Mo and Y. Tsai, *Reviews of Modern Physics 41:1*, 1969
2. "Radiative Corrections to Electron-Proton Scattering", Y. Tsai, *Physical Review 122:6*, 1961
3. "Spin Structure of 3He and the Neutron at Low Q^2; A Measurement of the Extended GDH Integral and the Burkhardt-Cottingham Sum Rule", K. Slifer, 2004
4. "Electromagnetic Structure of the Helium Isotopes", J. McCarthy, I. Sick, R. Whitney, *Phys. Rev. C 1396:15*, 1977

Results

Quantity	Systematic Error in S	
Scattering Angle	13.8% (Longitudinal)	17.9% (Transverse)
Mo & Tsai ΔE	4%	
Fit Upper Bound	3.6%	
MSW Form Factors	4.5%	
Incident Charge	1%	
Detector Efficiencies	1%	
Total in Quadrature	15.5% (Longitudinal)	19.3% (Transverse)

Scattering Angle, Mo & Tsai ΔE, Fit Upper Bound: Obtained by varying quantity over an appropriate range

MSW Form Factors: By taking average of data uncertainties that yield MSW fit

Incident Charge, Detector Efficiencies: From MySQL / Ryan

Longitudinal
$S = 4759.26\ Sr^{-1} \pm 15.5\%$

Transverse
$S = 6173.17\ Sr^{-1} \pm 19.3\%$

Scale factor can hopefully be used in place of acceptance for cross sections

$$\sigma_{unscaled} \cdot S = \sigma_{accept}$$

This will hopefully give a smaller systematic error to the other cross sections

Cross section still sensitive to ΔE even with QE Fit forced to zero at a higher Q^2

Error dominated by 2% uncertainty in scattering angle

χ^2 for MSW fit is 0.7, error in fit not known or accounted for.