DRAFT: Probing for high momentum protons in \(^{4}\text{He} \) via the \(^{4}\text{He}(e,e'p)X\) reaction


(The Jefferson Lab Hall A Collaboration)

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I. INTRODUCTION

Nucleon momentum distributions in atomic nuclei are known to be governed by an average nuclear potential plus additional nucleon-nucleon multi body interactions. Momentum distributions below the Fermi momentum essentially reflect the size of the "box" in which the nucleons are contained. One way to model this distribution is in the simplest limit of a cluster model where a given nucleon interacts with the average potential of the other nucleons. For momenta greater than the Fermi momentum the cluster models of nuclear structure provide enhanced strength in the momentum distribution by allowing nucleon-nucleon spatial distributions to become shorter than the average nucleon-nucleon spacing. Experimental access to proton momentum distributions is possible through the missing momentum \( p_m \) and the missing energy \( E_m \) in the \( (e,e'p)X \) reaction. Where \( \vec{p}_X = \vec{p}_e - \vec{p}_e' - \vec{p}_p, \ p_m = |\vec{p}_X| \), is the momentum of the residual nucleus. The missing energy, \( E_m \), of the reaction is the excitation energy of the system; it is the difference between the electron transferred energy \( (\omega=E_e - E_e') \) and the kinetic energies of the knocked out proton and the residual system, \( T_p \) and \( T_X \), respectively.

Interpretation of cross sections \( \sigma(p_m) \) to deduce nucleon momentum distributions requires the inclusion of final state interactions in the outgoing \( (e'pX) \) system. Microscopic nuclear structure calculations based on realistic two and three body nucleon-nucleon calculations are available for low mass nuclei. In the case of \( ^4\text{He} \) proton momentum distributions have been calculated for proton-triton (pt) and deuteron-deuteron (dd) clusters. Recent measurements of proton-nucleon coincidences in the \( ^4\text{He}(e,e'pN) \) reaction have shown strong correlations of back to back emission of nucleon pairs for large missing momentum \( p_m > 400 \text{ MeV}/c \). Moreover, the increasing pair ratio \( \frac{\#pp}{\#pn} \) as a function of \( p_m > 400 \text{ MeV}/c \) is interpreted as a sign that the nucleon-nucleon interaction switches from the tensor interaction to the strong repulsive short range interaction. Besides nucleon-nucleon correlations the experiment also obtained data on the proton-triton (pt) final hadronic state.

This paper provides experimental differential cross sections based on the \( ^4\text{He}(e,e'p)3\text{N} \) reaction over a range of momenta, \( 25 < p_m < 632 \text{ MeV}/c \), where \( 3\text{N} = ^3\text{H} \) and \( X \). These experimental results are compared to state-of-the-art relativistic calculations.

These measurements ran in parallel with the triple-coincidence short-range correlation experiment described in Ref. [3].

II. EXPERIMENTAL SETUP

A. Spectrometer settings

Experiments E07006 [8] and E08009 [7] at the Thomas Jefferson National Accelerator Facility in experimental Hall A [8], ran in February, March and April of 2011. Data for kinematic settings of 0.153 and 0.353 \text{ GeV}/c missing momentum were obtained using electron beam currents between 47\( \mu \text{A} \) to 60\( \mu \text{A} \), for E08009. In addition to these kinematic settings the Short Range Correlation(SRC) [3] experiment also obtained data at kinematic settings out to 0.632 \text{ GeV}/c missing momentum including the multi-body break up channel \( p+3\text{N} \). These higher missing momenta data were collected using 4 to 5 \( \mu \text{A} \) electron beam currents but sufficient accumulated charge was measured to be able to extract cross sections beyond the original goal set for E08009. Moreover, the acceptances of the Hall A spectrometers allowed for cross sections to be determined across a larger missing momentum range than the central value kinematic settings would suggest.

The electron spectrometer was fixed in angle and central momentum while the proton spectrometer's angles and central momenta were changed.

Electron arm's kinematic settings for the experiment are as follows: incident beam energy 4.4506 \text{ GeV}, electron spectrometer angle 20.3\(^\circ\) electron spectrometer momentum 3.602 \text{ GeV}/c, four momentum transfer \( Q^2 = 2.0 \text{ (GeV}/c)^2 \) and Bjorken \( x_b = 1.24 \), 3 momentum transfer of

\[ x_b = \frac{Q^2}{2 \text{MeV}/c^2} \]

\[ p_m = \text{MeV}/c \]

\[ E_m = \text{MeV} \]
B. Cryogenic target

The cryogenic target was gas $^4$He contained in an aluminum can of length 20 cm. The nominal temperature of the gas was 20\(^\circ\)K at 199 psia. $^4$He enters and exits at the upstream end of the target. There is no outlet for the fluid at the downstream end of the can. A determination of target density along the beam path was done by comparing the normalized yield of scattered electrons at 47\(\mu\)A and 60\(\mu\)A beam currents to the yield at 4\(\mu\)A. Since the electron spectrometer was held at a fixed momentum and angle the electron spectrometer served as a density monitor. For this target at a beam current of 4\(\mu\)A a conventional putational fluid dynamics (CFD) calculation predicts an average density drop of 2.3\% from strictly thermodynamic parameters. A comparison of the measured yield at 4\(\mu\)A to the CFD calculation gives an uncertainty in the target density dependence along the beam of 1.1\%.

More detail for the treatment of the target density used in the data analysis is available in [7]. Across the ± 8 cm effective target length and for the different beam currents, the target densities are summarized in table II.

III. DATA ANALYSIS

For this experiment, event triggers were performed by coincident signals from scintillator arrays. Particle tracks were reconstructed using the high resolution spectrometer’s vertical drift chambers. The small $\pi^-$ background in the electron arm was rejected using a CO\(_2\) gas Cherenkov detector. In the proton spectrometer, coincident $\pi^+$, and other positively charged nuclei like $^2$H and $^3$H were separated from the protons using the time difference between particles detected in the two spectrometers. Most of the accidental coincident events were rejected by cuts on the difference between interaction points in the target along the beam as reconstructed by the two spectrometers. The remaining accidental background was subtracted using the coincidence timing between the spectrometers. Fig. I shows a coincidence time of flight for the 333 MeV/c kinematics. The number of real coincidence events in a 20 ns time window around the peak were obtained by subtracting the accidentals under the peak considering a flat background under the whole spectrum.

For the determination of the cross section the following cuts are applied to the data for both electron and proton spectrometers: horizontal angle ±0.04 radians, vertical angle ±0.03 radians, vertex position ±8 cm and the deviation from central momentum ±4.5\%. The full data set after accidental and background subtraction is presented in figure 2.

The average cross section for the $^4$He(e, e’p)X reaction per missing momentum bin was extracted for the triton region and it is given by:

$$<\sigma(p_m)> = \frac{n(p_m) \times RSC}{\Delta \Omega_c \Delta \Omega_p \Delta E_e N_e N_{tgt} \times EFF},$$

- $n(p_m)$ is the net counts in the triton region between missing energies of 0.017 GeV to 0.022 GeV, after randoms and background subtraction. The three nucleon region, 3N, lies between 0.017 GeV and 0.029 GeV in the missing energy spectrum. Background subtraction in the triton region was done using either a simple constant background or a sloped straight line background below 0.029 GeV.

- RSC is the radiative and straggling correction factor, more details on this correction are given in section IIIB.

- $\Delta \Omega_c$ and $\Delta \Omega_p$ are the geometrical solid angles of the spectrometer apertures.

- $\Delta E_e$ is the size of the electron’s momentum bin in coincidence with protons. There is an uncertainty in $\Delta E_e$ of 10\% which is included in the error bars of the cross sections.

- $N_e = Q/e$, the number of electrons that passed through the target, where e is the charge on an electron and Q is the total charge.

- $N_{tgt} = \rho(I) \times z_{tgt}$ is the number of nuclei per cm\(^2\) in the beam. I is the beam current, $\rho(I)$ is the number of nuclei per cm\(^3\) and $z_{tgt}$ is the effective target length. Target densities along the ± 8 cm effective target length for different beam currents are presented in table II.

- EFF is the efficiency factor and it accounts for: a missing momentum acceptance factor (explained in section IIIA), data acquisition live time, electronics live time, wire chamber and tracking efficiencies. The live time of the trigger acquisition system, LTDAQ, was 0.916 ± 0.01, and 0.95 ± 0.01 for the 153 MeV/c and 353 MeV/c kinematics, respectively. For the higher missing momentum settings, LTDAQ was larger than 0.99. The remaining efficiencies are displayed in table II.
FIG. 1. Coincidence time of flight spectrum for the 353 MeV/c setting.

FIG. 2. Missing Energy spectra for all the kinematical settings. Data are in blue and the simulated two body breakup channel is in red. From top to Bottom: (a) $p_m = 153$ MeV/c, (b) $p_m = 353$ MeV/c, (c) $p_m = 466$ MeV/c and (d) $p_m = 632$ MeV/c.

<table>
<thead>
<tr>
<th>Beam current ($\mu$A)</th>
<th>Target density (nuclei/cm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.014</td>
<td>$7.84 \pm 0.087 \times 10^{22}$</td>
</tr>
<tr>
<td>45.46</td>
<td>$6.732 \pm 0.077 \times 10^{22}$</td>
</tr>
<tr>
<td>60.71</td>
<td>$5.662 \pm 0.065 \times 10^{22}$</td>
</tr>
</tbody>
</table>

TABLE II. Target density dependence on beam heating as a function of beam current.

<table>
<thead>
<tr>
<th>Efficiency</th>
<th>value</th>
<th>Uncertainty (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electronic live time</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Trigger efficiency</td>
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<td>1</td>
</tr>
<tr>
<td>Wire chamber efficiency</td>
<td>0.995</td>
<td>0.1</td>
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<tr>
<td>Tracking efficiency</td>
<td>0.9895</td>
<td>0.75</td>
</tr>
</tbody>
</table>

TABLE III. General uncertainties

Data analysis is aided by the Monte Carlo simulation (GEANT 3.2 [10]) of the transport of the incident electron, scattered electron and proton through the target cell into the spectrometer apertures assuming a p + triton final hadronic state. The identification of the p + triton final state is possible by calculating the missing energy in the scattered electron + p state. A peak in the missing energy spectrum corresponding to the triton ground state mass identifies the $^4H(e, e'p)^3H$ reaction, where $m_X = \text{triton mass}$, as seen in figure 2.

A. Missing momentum acceptance efficiency

The wide momentum acceptance of the spectrometers allows for a broad missing momentum acceptance. In the simulation a vertex point in the gas target is chosen which gives the incoming electron’s momentum at interaction point. Then hit points within the apertures of the spectrometers for the outgoing electron and proton are randomly selected. Each point within the spectrometers’ apertures has an equal probability of being selected. This allows for the vertex angles of the electron and proton to be determined. An energy for the outgoing electron is chosen within the momentum acceptance of the electron spectrometer. From the incident electron’s momentum, the scattered electron’s momentum and the angles for the ejected proton three body kinematics for the $^4H(e, e'p)^3H$ reaction allows for the proton’s vertex momentum to be determined. The electron and proton are followed from the vertex to the final hit points in the spectrometers’ apertures. Thus complete information about the location and momenta at the vertex and the spectrometers’ apertures is known.

The three body kinematical and geometrical limitations for particles arriving at the hit points within the apertures are calculated by GEANT and thus allows the
missing momentum, \( \vec{p}_m = \vec{p}_1 - \vec{p}_2 - \vec{p}_p \) to be calculated. In the analysis we bin \( |\vec{p}_m| \) into 50 MeV/c bins. We define the missing momentum acceptance factor, \( f(p_m) \), for a bin of missing momentum centered around \( p_m \) as

\[
f(p_m) = \frac{n(p_m)}{\sum n(p_m)},
\]

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 proton kinematic setting. The same Gaussian broadening used for the simulation fit in figure 2(b) is used to generate the values of \( p_m \) needed to calculate \( f(p_m) \).

Experimental cross sections are given in table IV.

### B. Peak broadening effects

Straggling and external bremsstrahlung obtained from the GEANT simulation produce a broadening and a characteristic tail on the missing energy spectrum. In practice the long target introduces additional broadening beyond the intrinsic point source resolution of the spectrometers. The additional broadening is included in the simulation by a Gaussian broadening of the momenta at the apertures. This additional broadening typically is a factor of three to four bigger than the resolution for the point source peak. The amount of Gaussian smearing needed is determined by the best fit of a strong missing energy data peak such as at the lowest missing momentum. An example of the fit is seen in figure 2(b).

 Corrections to the cross section due to the tail on the missing energy spectrum are determined by comparing the number of events in a 5 MeV window centered on the triton peak to the total number of events in the simulation.

### IV. RESULTS

#### A. Comparison of data to theoretical predictions

Experimental differential cross sections are compared to relativistic distorted wave impulse approximation calculations of the Madrid theory group \[11\-14\]. The \(^4\text{He}_{238}\) ground state is described by a relativistic solution of the Dirac equation phenomenologically adjusted to fit the observed served radius and binding energy of \(^4\text{He}\). These calculations were first introduced in \[14\].

Vertex values of the incident electron’s momentum at various positions within the target and the momenta of the scattered electron and ejected proton were provided to the Madrid theory group for calculation of the cross section at each event vertex in the GEANT simulation. The GEANT simulation also contains the detected electron and proton momenta at the spectrometers’ apertures. In this way the vertex cross section can be associated with the missing momentum at the apertures.

Theoretical cross sections integrated over the experimental acceptances for the full Madrid treatment and using the effective momentum approximation, EMA, treatment are presented in tables \[V\] and \[VI\]. Plots of the data for the two theoretical treatments are shown in figures \[3\] and \[4\].

Data and calculations show the same missing momenta dependence for the measured or calculated cross section as a function of kinematic setting. Even though the same
magnitude of \( p_m \) is reached for different proton angles the 
cross section does not simply factor as a function of \( p_m \). 
Good agreements between the Madrid calculation and 
and the data extend to about 420 MeV/c in missing momen-
tum. It can be also noticed that both data and theory 
show an inflection in the slope of the cross section be-
tween 300 and 400 MeV/c. In recent calculations on light 
uclei \([2]\), an inflection in the proton momentum distri-
butions was predicted in the momentum range between 1 
and 3 fm\(^{-1}\). For \(^3\)He, this inflection appears to be due to 
the triton+proton cluster distribution exhibiting a deep 
minimum in the proton momentum distribution. When 
added to the deuteron deuteron cluster distribution, the 
inflexion appears below and close to 2 fm\(^{-1}\) in the total 
proton density distribution, which is in agreement with 
the one we see in these data.

V. DISCUSSION

For this experiment, the three momenta of the out-
going proton and scattered electron in the \(^4\)He(e,e\(^'\)p)\(X\) 
reaction are measured. Using the known momentum of 
the initial state we deduce the missing momentum of the 
residual hadronic state \( X \). The theoretical analysis of 
the data here is limited to a specific exit channel, \( X = 3\)H. However, considering the theoretical cluster contri-
butions to the proton momenta \([2]\) in \(^4\)He, the contribu-
tion of the \( pt \) cluster to the proton momentum dis-
tribution is expected to be negligible above about \( p_m \) 
\( \approx 250 \text{ MeV}/c \).

The ratio of experimental cross section to the Madrid \([40]\) 
full predictions; in logarithmic scale, is shown in figure \([41]\) 
for the four proton spectrometer central momentum \([42]\) 
settings. The blue squares; at the lowest missing mo-
tum setting, hover around a ratio of 1, showing good\([44]\) 
agreement between data and predictions. The green dots\([46]\) 
are for the 0.353 GeV/c setting and we see a distinctive\([46,47]\) 
pattern for these data. The ratio at 0.225 GeV/c is 0.34,\([47]\) 
substantially different from the model prediction. This\([48]\) 
behavior cannot be traced to a statistical fluctuation be-
cause as we see in figure \(2\) (b), there is a substantial\([49]\) 
peak at the triton missing energy location. The cross\([51]\) 
section decreases by a factor of 12 between 0.225 and \(0.325 \text{ GeV}/c\) and over the full range in missing momen-
tum for this proton angle setting the cross section falls\([52]\) 
by a factor of 30. This fluctuation of the data to theory\([53]\) 
suggests that some significant physics is not ade-
quately included in the theoretical model for this range\([55]\) 
of missing momentum with these spectrometer settings\([56]\) 
For the data at the 0.466 and 0.632 GeV/c settings the\([57]\) 
ratio again shows a smooth missing momentum depen-
dence.

However, the overall dependence of the cross section\([58]\) 
by the Madrid full model in figure \(3\) is qualitatively de-
scribed.

From \([2]\), the high proton momentum is attributed to 
the repulsive nucleon-nucleon core. Fig. \(2\) shows a 
broad peak in the missing energy spectrum which shifts 
in position kinematically with the photon being absorbed 
on a correlated pair of nucleons. This feature has been 
previously seen in \(^3\)He(e,e\(^'\)p)\(X\) measurements in Ref. 
\([16]\) and \([17]\) and in \(^4\)He(e,e\(^'\)p)\(X\) continuum channel in Ref. \([18]\).

The measurements of \([3]\) are consistent with the NN 
short range force becoming repulsive. However, it is 
counter intuitive and in disagreement with theoretical ex-
pectations \([2]\) that tritons should be ejected from \(^4\)He 
along with protons emerging from short range encoun-
ters.

The fact that we observe events in the triton region 
up to 632 MeV/c involves processes beyond the impulse 
approximation. Final state interactions of the outgoing 
proton may take a proton knocked out of a \( pt \) cluster ini-
tially at a low value of \( p_T \) to appear as if its momentum 
at the vertex was \( p_m \). This is accounted for to some ex-
tent by the optical model potential treatment of the final 
\( pt \) unbound state. We see good agreement between the 
theory and data in figure \(3\) up to about \( p_m = 420 \text{ MeV}/c \).

Beyond about 450 MeV/c in \( p_m \) substantially more 
triton region events are measured than what the Madrid 
full theory predicts. In this case three nucleons emitted 
at high \( p_m \) may be a signature of other reactions allowing 
the three nucleon cluster to emerge as a bound or quasi 
bound state. Since the kinematics for the electron were 
chosen for \( x_p = 1.24 \), protons in more intimate interac-
tions with neighbors than quasi-elastic conditions \( (x_p \approx 1) \) 
may favor other reactions leading to three nucleon 
clusters exiting in the missing energy region near the tri-
ton.

Portions of the missing energy spectrum in the triton 
energy range are shown in figures \(6\). We see a change in
the distribution of events as a function of missing momentum going from 153 MeV/c to 575 MeV/c. At low missing momenta the triton peak is centered at the expected value of 19.8 MeV. At higher missing momenta, the event are higher in missing energy by few MeVs. From left to right, the three arrows in each figure point to the expected locations of the thresholds of the hadronic states $X=(t)$, $X=(n,d)$ and $X=(p,n,n)$, respectively.

An interesting question is the impact of three-nucleon forces, $V_{ijk}$, at high $p_{m}$. $V_{ijk}$ are known to increase the binding energy of nuclei [19] so they would be natural actors in the formation of bound tritons or closely bound three nucleon groups among the outgoing hadronic channels, $X$, at high missing momentum. The principal sources of data to help refine models of possible three-nucleon interactions are binding energies of ground and excited states of $A<8$ nuclei and point proton charge distributions [19]. However, these data are not extensive enough to select unambiguously a particular set of parameters or models for $V_{ijk}$ and other observables are needed as discussed in [19] [20].

More extensive and detailed data in the three nucleon triton mass region and the existence of microscopic calculations for these nuclei opens the possibility of exploiting the shapes of the missing energy spectra in $A(e,e'p)X$ reactions as additional observables for developing models of three-nucleon interactions.

ACKNOWLEDGMENTS

Special thanks to Silviu Covrig for providing the CFD calculations as a possibility to understanding the target vertex spectra for the SRC Target. The research presented in this paper is partially supported by the U.S. National Science Foundation grants PHY 09-69380 and PHY 12-08056. This work was supported by the U.S. Department of Energy contract DE-AC05-06OR23177 under which Jefferson Science Associates operates the Thomas Jefferson National Accelerator Facility.

VI. APPENDIX

Experimental differential cross sections for $^4He(e,e'p)X$; in nb/sr/MeV, are summarized in table [IV] for the four different spectrometer settings. The analysis was done on 50 MeV/c wide bins on missing momentum, $p_{m}$. Errors are both statistics and systematics added in quadrature. The systematic uncertainty of 10% was included in the cross sections due to defining the size of the energy window, $dE_{e}$, on the electron spectrum.

Tables [VI] and [V] summarize the Madrid EMA and full calculations respectively in the momentum range from 12.5 to 637.5 MeV/c.

FIG. 6. From top to bottom: Missing energy region up to 50 MeV of excitation in $^4He(e,e'p)X$ for $p_{m}=153$, 352, 475 and 575 MeV/c, respectively. The three arrows point to the expected locations of the thresholds of the hadronic states $X=(t)$, $X=(n,d)$ and $X=(p,n,n)$. 
\[
\begin{array}{|c|c|c|c|c|}
\hline
p_m & \theta_p = 47^\circ & \theta_p = 38.5^\circ & \theta_p = 33.5^\circ & \theta_p = 29^\circ \\
\text{(MeV/c)} & & & & \\
25 & (3.38 \pm 0.52) & (4.40 \pm 0.14) \times 10^{-3} & (6.59 \pm 2.7) \times 10^{-4} & (3.7 \pm 2.3) \times 10^{-5} \\
75 & (1.13 \pm 0.17) & (1.27 \pm 0.03) \times 10^{-3} & (3.22 \pm 0.89) \times 10^{-4} & \\
125 & (3.13 \pm 0.48) \times 10^{-1} & (6.11 \pm 0.14) \times 10^{-4} & (1.68 \pm 0.45) \times 10^{-4} & \\
175 & (7.18 \pm 1.1) \times 10^{-2} & (3.57 \pm 0.88) \times 10^{-4} & (0.91 \pm 0.43) \times 10^{-4} & \\
225 & (1.44 \pm 0.22) \times 10^{-2} & & & \\
275 & (3.06 \pm 0.57) \times 10^{-3} & & & \\
325 & & & & \\
375 & & & & \\
425 & & & & \\
475 & & & & \\
525 & & & & \\
575 & & & & \\
632 & & & & \\
\hline
\end{array}
\]

TABLE IV. Experimental differential cross sections, \( \frac{d\sigma}{d\eta d\Omega_c dE} \), for \( ^4He(e,e'p)X \); where \( X = ^3H \) or \( ^3N \), from E08009, for different kinematical settings given by the proton spectrometer central angle. Units are \( nb/sr^2/\text{MeV} \).

---

\begin{table}
\begin{center}
\begin{tabular}{|c|c|c|c|c|}
\hline
$\theta_p$ & 153 & 353 & 466 & 632 \\
$\theta_p = 47^\circ$ & $\theta_p = 38.5^\circ$ & $\theta_p = 33.5^\circ$ & $\theta_p = 29^\circ$ \\
\hline
12.5 & 2.2059 & & & \\
37.5 & 1.8287 & & & \\
62.5 & 1.3139 & & & \\
87.5 & 8.516e-01 & & & \\
112.5 & 5.070e-01 & & & \\
137.5 & 2.699e-01 & & & \\
162.5 & 1.311e-01 & & & \\
187.5 & 5.987e-02 & & & \\
212.5 & 2.583e-02 & 1.918e-02 & & \\
237.5 & 1.044e-02 & 6.724e-03 & & \\
262.5 & 3.951e-03 & 2.209e-03 & & \\
287.5 & 1.370e-03 & 6.686e-04 & & \\
312.5 & 4.901e-04 & 3.578e-04 & & \\
337.5 & 1.858e-04 & 3.095e-04 & & \\
362.5 & 9.309e-05 & 2.687e-04 & & \\
387.5 & 5.639e-05 & 2.077e-04 & & \\
412.5 & 1.419e-04 & 5.283e-04 & & \\
437.5 & 8.366e-05 & 3.402e-04 & & \\
462.5 & 4.808e-05 & 2.225e-04 & & \\
487.5 & 2.739e-05 & 1.262e-04 & 2.206e-04 & \\
512.5 & 1.542e-05 & 6.542e-05 & 1.491e-04 & \\
537.5 & 9.478e-06 & 2.980e-05 & 8.585e-05 & \\
562.5 & 1.289e-05 & 4.400e-05 & & \\
587.5 & 5.077e-06 & 1.977e-05 & & \\
612.5 & 2.008e-06 & 7.741e-06 & & \\
637.5 & 8.357e-07 & 2.834e-06 & & \\
\hline
\end{tabular}
\end{center}
\caption{Madrid full theoretical cross sections integrated over the experimental acceptances for $^4\text{He}(e,e'p)^3\text{H}$ for E08009, for different kinematical settings given by the proton spectrometer central angle. Units are $\text{nb/}sr^2/\text{MeV}$.}
\end{table}
<table>
<thead>
<tr>
<th>$p_m$ (MeV/c)</th>
<th>$\theta_p = 47^\circ$</th>
<th>$\theta_p = 38.5^\circ$</th>
<th>$\theta_p = 33.5^\circ$</th>
<th>$\theta_p = 29^\circ$</th>
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TABLE VI. Madrid EMA theoretical cross sections integrated over the experimental acceptances for $^4H(e,e'p)^3H$ for E08009, for different kinematical settings given by the proton spectrometer central angle. Units are $nb/sr^2/MeV$. 