L/T Separations in Hall C Status and Opportunities

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Hall C Collaboration Meeting
18/Feb/2022
Outline

- L/T Separation Methodology Overview
  - Unveiling the secrets of R/T separation experts

- Hall C L/T Program Status
  - Pion Form Factor
  - Neutral Pion Spectrometer
  - $u$-Channel $\pi^0$

- Opportunities ? !
The Rosenbluth Separation

Rosenbluth Separation requirements:

- Separate measurements at different $\varepsilon$ (virtual photon polarization)
- All Lorentz invariant physics quantities: $Q^2$, $W$, $t$, $u$, remain constant
- Beam energy, scattered $e$ angle and virtual photon angle will change as the result, thus event rates are dramatically different

Virtual-photon polarization:

$$\varepsilon = \left(1 + 2 \frac{(E_e - E_{\gamma})^2 + Q^2}{Q^2} \tan^2 \frac{\theta_e}{2}\right)^{-1}$$

$$2\pi \frac{d\sigma}{dt d\phi} = \varepsilon \frac{d\sigma_L}{dt} + \frac{d\sigma_T}{dt} + \sqrt{2\varepsilon (\varepsilon + 1)} \frac{d\sigma_{LT}}{dt} \cos \phi + \varepsilon \frac{d\sigma_{TT}}{dt} \cos 2\phi$$
Two Measurement at the Same Kinematics Variable

Low $\epsilon$
$\epsilon = 0.27$
$Q^2 = 2.45 \text{ GeV}^2$
$W = 2.21 \text{ GeV}$

Low $\epsilon$
$\epsilon = 0.554$
$Q^2 = 2.45 \text{ GeV}^2$
$W = 2.21 \text{ GeV}$
Diamond plot

- L/T expert’s secret #1 diamond plot
- Kinematics information
- Overlap between the two diamonds
Iterative Procedure (Recipe) to a LT Separation

Improve $\phi$ coverage by taking data at multiple HMS angles, $-3^\circ < \theta_p < +3^\circ$.

$\theta_{pq} = -3$

$\theta_{pq} = 0$

$\theta_{pq} = +3$

$-u=0.0$

$-u=0.3$

$-u=0.5$

3 $u$-bins

8 phi-bins

Extracting T, L, LT, TT via simultaneous fit

$$2\pi \frac{d^2\sigma}{dt d\phi} = \frac{d\sigma_L}{dt} + \varepsilon \frac{d\sigma_L}{dt} + \sqrt{2}\varepsilon(\varepsilon + 1) \frac{d\sigma_{LT}}{dt} \cos\phi + \varepsilon \frac{d\sigma_T}{dt} \cos 2\phi$$

Empirical Model

Unseparated X-section

Separated X-section

Background subtraction

$$R = \frac{Y_{Exp} - Y_{\omega \text{ sim}} - Y_{Xspace \text{ sim}} - Y_{\eta \text{ sim}}}{Y_{\omega \text{ sim}}}$$

Combine ratios for settings together, propagating errors accordingly.
LT Results from 6 GeV $\omega$ Electroproduction

\[ Q^2 = 2.45 \text{ GeV} \]

\[ \sigma_T \]

\[ \sigma_L \]

\[ \frac{\sigma_L}{\sigma_T} \text{ Ratio} \]
L/T Separation Study and Hall C

Fpi-12 E12-19-006 (2020)
88 days
(T. Horn*, G. Huber*, D. Gaskell)
(running at Hall C right now!)

Fpi-2 E-01-004 (2001)
14 days
(H. Blok*, G. Huber, D. Mack)

Fpi-1 E-93-021 (1993)
9 days
(D. Mack*, R. Whitney)

Shift sign-up Page:
https://misportal.jlab.org/mis/apps/physics/shiftSchedule/index.cfm?experimentRunId=HALLC-PIONLT

Fpi @ EIC (data by 2032)
10fb⁻¹ a year of running
(G. Huber and others)

Figure by G. Huber and S. Kay
Hall C 12 GeV LT Separation Experiment Summary

Experiments

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Description</th>
<th>PAC</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>E12-19-006</td>
<td>Study of the L–T Separated Pion Electroproduction to High Q2</td>
<td>88</td>
<td>A</td>
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<tr>
<td>E12-09-011</td>
<td>Studies of the L-T Separated Kaon Electroproduction Cross Section from 5-11 GeV</td>
<td>40</td>
<td>B+</td>
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<tr>
<td>E12-13-010</td>
<td>Exclusive Deeply Virtual Compton and Neutral Pion Cross-Section Measurements in Hall C</td>
<td>53</td>
<td>A</td>
</tr>
<tr>
<td>E12-20-007</td>
<td>Backward-angle Exclusive piz0 Production above the Resonance Region</td>
<td>29</td>
<td>B</td>
</tr>
</tbody>
</table>

SHMS + HMS, (ongoing), partially completed, see status in following slides.

NPS + HMS, received ERR, being scheduled, running in 2024-2025?

Simple experiment, ERR not required, beam time request is being submitted

We completed ~15% of the Hall C L/T program so far.
The \( p(e, e'K\Lambda,\Sigma) \) experiment ran in Hall C at Jefferson Lab over the fall 2018 and spring 2019. Spokesperson: T. Horn*, G. Huber

30-40% completed?

Data Collected

Information taken from Richard’s talk:
E12-19-006: Charged Pion Form Factor

- T. Horn*, G. Huber*, D. Gaskell
- Very important and long experiment
  - Took data in 2019, 2021 and 2022
- <30% completed?

We are here!

Highest $Q^2$=8.5 GeV$^2$ also completed

![Graph showing $Q^2 F_n(Q^2)$ vs $Q^2$]

Full detail see Jacob’s talk: [https://indico.jlab.org/event/517/contributions/9319/attachments/7544/10497/HallC_winter_meeting_PionLT2022.pdf](https://indico.jlab.org/event/517/contributions/9319/attachments/7544/10497/HallC_winter_meeting_PionLT2022.pdf)
E12-13-010 DVCS and $\pi^0$ at Hall C (PAC 40)

- E12-13-010 performs measurement of DVCS at Hall C
- Spokesperson: C. Munoz Camacho*, T. Horn, C. Hyde, R. Paremuzyan, J. Roche (NPS collaboration)
- Scaling of the Compton Form Factor
- L/T Separation of the $\pi^0$

Full detail see Carlos’ recent talk:
David’s talk
https://indico.jlab.org/event/517/contributions/9328/attachments/7552/10508/NPSPhys_HallC_DJH_Feb22.pdf
E12-20-007: Backward-angle $\pi^0$ (PAC 48)

First dedicated $u$-channel electroproduction study above the resonance region: $^1\text{H}(e,e'p)\pi^0$
- $Q^2$ coverage: $2.0 < Q^2 < 6.25 \text{ GeV}^2$.
- $x=0.36$
- $u$ coverage: $0 < -u' < 0.5 \text{ GeV}^2$

Objective:
- Study soft-hard transition
- Validating TDA

My Previous talk: https://indico.jlab.org/event/422/contributions/7649/attachments/6435/8535/2021_Jan_JLab_Hall_C_Collaboration_Meeting.pdf
Synergy between E12-13-010 and E12-20-007

E12-13-010 NPS experiment provide low -t L/T separated cross section

E12-13-010 NPS Experiment

E12-13-010 NPS Experiment provide L/T separated cross section

Demonstrating the existence of the u-channel peaks for H(e,e’p)π^0 and provide L/T separated cross section

E12-20-007

Demo plot for ω electroproduction

x=0.36
# t-Channel and u-Channel Opportunities

<table>
<thead>
<tr>
<th></th>
<th>$t$-Channel L/T Separation</th>
<th>$u$-Channel L/T Separation</th>
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</thead>
<tbody>
<tr>
<td>$\pi^0$</td>
<td>✓</td>
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<tr>
<td>$\pi^+$</td>
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<td>$\pi^-$</td>
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<tr>
<td>$K^0$</td>
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<tr>
<td>$K^+$</td>
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<td>$\eta'$</td>
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<tr>
<td>$\phi$</td>
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<tr>
<td>DVCS</td>
<td>✓</td>
<td>✓</td>
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Clean channels are measured and pushed to the 12 GeV limit

Wide open for new proposal!

Ticks: data taken
circle: upcoming experiment
Backward-angle structure of Atom

- **Forward scattered alpha particle**: extracting the interaction radius of the nucleus and mapping out the transverse structure of the atom (mostly empty).

- **Recoiling alpha particle**: stiffness of the “point-like” structure.

- **Full structure** must incorporate both forward angle and backward angle observables.
Rutherford backscattering spectrometry

From Wikipedia, the free encyclopedia

**Rutherford backscattering spectrometry (RBS)** is an analytical technique used in materials science. Sometimes referred to as high-energy ion scattering (HEIS) spectrometry, RBS is used to determine the structure and composition of materials by measuring the backscattering of a beam of high energy ions (typically protons or alpha particles) impinging on a sample.

### Contents [hide]

1. Geiger-Marsden experiment
2. Basic principles
3. Instrumentation
4. Composition and depth measurement
5. Structural measurements: blocking and channeling  
   5.1 Profiling of displaced atoms
6. Surface sensitivity
7. See also

\[
\frac{d\omega}{d\Omega} = \left( \frac{Z_1 Z_2 e^2}{4E_0} \right)^2 \frac{1}{(\sin \theta/2)^4} \]

[2]

Resemble?

*Left: Expected results: alpha particles passing through the plum pudding model of the atom undisturbed.*

*Right: Observed results: a small portion of the particles were deflected, indicating a small, concentrated positive charge.*

Figure from Wikipedia
Very low hanging fruit. Data mining is enough for the L/T separation study.

Data mining is enough to extract cross section, not enough for L/T separation.
$u$-Channel $\pi^+, K^+$ Electroproduction L/T Study

\[ H(\pi^+, e', n) + N \rightarrow e^+ + \eta + K^0 \]

\[ H(\pi^+, e', \Lambda) + N \rightarrow e^+ + K^+ + K^- \]

<table>
<thead>
<tr>
<th>Backward-angle Peak Seen?</th>
<th>L/T Separation</th>
</tr>
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<tbody>
<tr>
<td>$\pi^0$</td>
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<tr>
<td>$\pi^+$</td>
<td>√√</td>
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<td>$\pi^-$</td>
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<td>$\phi$</td>
<td>√</td>
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<tr>
<td>DVCS</td>
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### $u$-Channel $\pi^-$ Electroproduction L/T Study

#### Ideally: $n(e,e'p)\pi^-$

#### Realistically: $D(e,e'p)X$

**Looked similar to Mark’s e+D Tagg Study?**

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<td>$\pi^0$</td>
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Tagging of proton and neutron in $e+D\rightarrow e+\text{backward }N+X$ as a probe of the origin of the EMC effect (FS 85)

Interesting to measure tagged structure functions where modification is expected to increase quadratically with tagged nucleon momentum. It is applicable for searches of the form factor modification in $(e,e'N)$.

[https://indico.jlab.org/event/517/contributions/9323/attachments/7539/10491/hallc22.pdf](https://indico.jlab.org/event/517/contributions/9323/attachments/7539/10491/hallc22.pdf)
$u$-Channel DVCS L/T Study

$^1H(e,e'p)\gamma$

Photon Tag

<table>
<thead>
<tr>
<th>Particle</th>
<th>Backward-angle Peak Seen?</th>
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DVCS
In 10 Years (my wishful thinking)

- Dedicated L/T studies will be completed!
- Data mining L/T studies will be completed!
- In the process of being completed?

Q: when do we start with the *u*-Channel polarized target program? :D
Summary and Thank You!

- Hall C LT summary
- Vast opportunities in $u$-Channel L/T studies.