Update on Pion-LT Experiment

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OHIO UNIVERSITY (NSF AWARD #1913170)
HALL C COLLABORATION MEETING
Spokespersons:
Dave Gaskell (Jlab), Tanja Horn (CUA), Garth Huber (Regina)

Graduate Students
Nathan Heinrich (Regina), Muhammad Junaid (Regina), Jacob Murphy (Ohio U)

Key Members:
Vladimir Berdnikov (CUA), Stephen Kay (Regina), Vijay Kumar (Regina), Julie Roche (Ohio U), Petr Stepanov (CUA), Richard Trotta (CUA), Ali Usman (Regina), Carlos Yero (Jlab)
Experiment Goals: Reliable $F_\pi$ Extraction

- Reliable Charged Pion Form Factor ($F_\pi$) extraction to highest possible $Q^2$
  - Using the proton’s “pion cloud” and pion electroproduction $p(e, e'\pi^+)n$
  - At small $-t$, pion pole process dominates in $\sigma_L$

- Precise $F_\pi$ extraction up to $Q^2 = 6\, GeV^2$
  - Highest possible $F_\pi$ extraction at 8.5 $GeV^2$

- Low $Q^2$ data (taken in 2019) allows for testing if $\pi^+$ electroproduction measures on-shell form factor
  - Compare $p(e, e'\pi^+)n$ $F_\pi$ extraction with elastic $e\pi^+$ at same $Q^2$
Experiment Goals: Validation of $F_{\pi}$ Extraction

- Validation of $F_{\pi}$ extractions at highest possible $Q^2$
- Extract $F_{\pi}$ at fixed $Q^2$, scanning $t$
  - $F_{\pi}$ should be independent of $-t$
- Check dominance of $t$-channel process
  - Examine ratio of $\sigma_L$ for $d(e,e'\pi^-)pp_{sp}$ and $d(e,e'\pi^+)nn_{sp}$
  - Tests to be repeated at $Q^2 = 1.60, 3.85, 6.0$ GeV$^2$

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G. Huber et al, PRL112 (2014)182501
Experiment Goals: L/T Separated Pion Cross Sections

- Scaling Study at fixed $x = 0.31, 0.39, 0.55$ as a function of $Q^2$
- QCD counting rules predict $1/Q^n$ dependence of $p(e, e'\pi^+)n$ cross sections in Hard Scattering Regime:
  - $\sigma_L$, to leading order, scales as $1/Q^6$
  - $\sigma_T$ scales as $1/Q^8$
  - At large $Q^2$, $\sigma_L >\!> \sigma_T$
- Study hard-soft factorization for GPD extraction
  - If $\sigma_L$ becomes large, would allow for leading twist GPD study
  - If $\sigma_T$ becomes large, could allow for transversity GPD study
Optimized W vs $Q^2$ Settings for $F_\pi$

Extraction and Pion Scaling Study

- Vertical dashed lines scan $t$ at fixed $Q^2$
  - Allows for $F_{\pi}$ extraction at varying distance from pion pole
  - Check that model accurately accounts for:
    - $\pi^+$ production mechanism
    - Spectator nucleon
    - Off-shell ($t$-dependent) effects

- Points marked with an ‘x’ are instrumental in higher $Q^2$ $F_{\pi}$ extraction
  - $Q^2 = 8.5 \text{ GeV}^2$ is highest achievable extraction at JLab

- Red lines allow for $1/Q^n$ scaling study at fixed $x = 0.31, 0.39, 0.55$
L/T Separation via Rosenbluth Technique

- Measure cross section at two beam energies with $Q^2$, $W$, and $t$ fixed
  - Scan $\theta_{\pi q}$ across left and right of $\theta_{\pi}$

- Carry out simultaneous fit at two different $\epsilon$ using the azimuthal angle $\phi_{\pi}$
  - Allows for separation of $\sigma_L$, $\sigma_T$, $\sigma_{LT}$, and $\sigma_{TT}$

- See Richard Trotta’s Kaon LT talk for more details

\[
\frac{d^2\sigma}{dt d\phi_{\pi}} = \frac{1}{2\pi} \left( \frac{d\sigma_T}{dt} + \epsilon \frac{d\sigma_L}{dt} + \sqrt{2\epsilon(1+\epsilon)} \frac{d\sigma_{LT}}{dt} \cos\phi_{\pi} + \epsilon \frac{d\sigma_{TT}}{dt} \cos2\phi_{\pi} \right)
\]
Fall 2021 Completed Kinematics

- Kinematic settings for data collection from September 2021 to February 2022
  - $\theta_{\pi q}$ settings are limited
    - Right-angle setting not always possible with hard limit of 5.5° for SHMS
    - $Q^2 = 8.50$ limited to central angle due to event rate (388 hrs in PAC 47 proposal)
  - Each setting is one part of the data needed for an L/T separation
    - Need AT LEAST two beam energies
    - Some settings have 3 $\epsilon$ points
  - $Q^2 = 1.60$ setting requires low-$\epsilon$ data and rest require high-$\epsilon$

### Kinematic Settings

<table>
<thead>
<tr>
<th>$Q^2$</th>
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<th>$x$</th>
<th>Run Type</th>
<th>$\theta_q$</th>
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<td>+0.06°</td>
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- LH+: $p(e, e'\pi^+)n$
- LD+: $d(e, e'\pi^+)nn_{sp}$
- LD-: $d(e, e'\pi^-)pp_{sp}$
\[ Q^2 = 3.85, \ W = 3.07, \ x = 0.31 \text{ for } p(e, e'\pi^+)n \]
\( Q^2 = 3.85, W = 3.07, x = 0.31 \) for \( d(e, e'\pi^+)nn_{sp} \)

\( \theta_{SHMS} = 8.39^\circ \)

\( \theta_{SHMS} = 6.39^\circ \)

\( \theta_{SHMS} = 5.5^\circ \)
Hall C Extremes in this Experiment

- Several kinematic settings used the SHMS at its minimum angle of 5.5 deg
  - Ran continuously at this angle from October 3rd through November 5th, 2021
- Minimum opening angle between SHMS and HMS was reached for this experiment
  - HMS moved to 11.01 deg and SHMS moved 18 deg away at 6.99 deg
- Thank you to Hall C staff for making this possible!
Spectrometer Issues While Running

- Radiation damage affected hall equipment and electronics
  - SHMS UPS dying caused ALL magnets to interlock

- SHMS Q1 interlocked at increased frequency near end-of-run
  - Burns are visible from experiment running

Thanks to the efforts of the hall staff, our run coordinators, and shift workers, these challenges did not hamper our data collection in this very successful run.
New EDTM GUI and EDTM Studies for TLT

- Brad Sawatzky’s GUI sets EDTM clock by desired EDTM rate:
  - \( EDTM_{acc} = \frac{EDTM_{sent}}{PSF_{min}} \)

- \( EDTM_{acc} \) measured by event count in EDMT tdc Time Raw

- Examining prescaled non-coin data, determined that equation is closer to:
  - \( EDTM_{acc} = \frac{EDTM_{sent}}{PSF_1} + \frac{EDTM_{sent}}{PSF_2} - \frac{EDTM_{sent}}{PSF_1 \times PSF_2} \)

- Prescale correction improves TLT calculation, but still have runs with TLT>1
  - Richard Trotta and Jacob Murphy looking into this
Pion LT 2021 Running Complete!

- Completion of a very successful data run
- COVID restrictions limited international collaboration
- With pandemic border restrictions improving, we are optimistic that international collaborators will have more opportunities to be involved this fall!

Ranking of most weighted shifts, combining institutions and individuals:

Note Owl was weighted as 1.5 shifts

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<th>Rank</th>
<th>Institution/ Individual Name</th>
<th>Number of Shifts</th>
<th>Number of Shifts with Weight</th>
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π-Chart of Participating Institutions

- University of Regina, Regina, SK, Canada
- Jefferson Lab
- Catholic University of America, Washington, DC
- Ohio University, Athens, OH
- Artem Alikhanian National Laboratory (AANL)
- University of Connecticut, Storrs, CT

π-Chart of Participating Institutions’ Countries

- United States Institutions
- University of Regina, Regina, SK, Canada
- Artem Alikhanian National Laboratory (AANL)
- A.I. Alikhanian National Science Laboratory
## Fall 2022 Planned Kinematics

<table>
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<tr>
<th>$Q^2$</th>
<th>$W$</th>
<th>$x$</th>
<th>Run Type</th>
<th>$\epsilon$</th>
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<td>2.79</td>
<td>0.55</td>
<td>LH+</td>
<td>high</td>
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- Complementary of data taken in 2019 and 2021
  - Kinematics are fixed by data already taken
- High-$\epsilon$ data is necessary for L/T separation and for experiment goals to be met
  - Further data taken at same beam energies will not allow for an LT separation
- Higher beam energy allows for larger $\Delta \epsilon$
  - Experiment results are very sensitive to this gradient
  - Large impact on data quality

LH+: $p(e, e'\pi^+)n$
LD+: $d(e, e'\pi^+)nn_{sp}$
LD-: $d(e, e'\pi^-)pp_{sp}$
Call for Collaborators

- Data collection for fall 2021 was very successful
  - Thank you to the Hall C staff/users and our collaborators!
  - We need your continued support to complete this experiment!!

- The high-ε kinematics are an absolute necessity for L/T separation and our experimental goals

- E12-19-006 is currently scheduled to run October 1\textsuperscript{st} 2022 through December 4\textsuperscript{th} 2022

WE REALLY NEED YOUR CONTINUED ASSISTANCE TO MAKE THIS EXPERIMENT A SUCCESS!!!
Extra Slides
• Kinematics for the pion form factor study (left) and pion scaling study (right)
• Blue settings are used in both studies
• Red kinematics taken in 2019
• Angles and beam energies NOT final for black and blue settings
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