Summary

From January to July 2018, I was on sabbatical leave from Florida International University and JSA provided additional support for my stay at Jefferson Lab during these time period. During this period, CLAS12 conducted the first period of data taking for Run Group A experiments. I am the contact person and co-spokesperson for one of the RGA experiment, E12-08-005a, the Very Strange experiment, searching for excited baryons with multiple strange quarks, including the Omega and Cascade states. My main focus was the preparation and the data taking for this experiment. Crucial for the very strange group as well as the other spectroscopy experiment MeonX searching for the hybrid mesons is the Forward Tagger (FT) system. I assumed duties as the on-call FT expert including training the next expert. I also acted as the Run Coordinator during the last two weeks of this running period until early May 2018. I mentored two PhD students during this time period, with one of them defended his PhD dissertation in November 2018, and the other one working for his thesis using the new CLAS12 data searching for excited cascades and was onsite at Jefferson lab with me. Together, we also took the most number of shifts (about 20 for each of us) for the whole collaboration, helping out many collaborators due to the unexpected schedule changes. I also gave two invited talk at Meson2018 in Krakow, Poland, for the CLAS collaboration in June, as well as the 10th hadron physics workshop in China in July. In addition, I also met with Japanese Physics Association representatives at the APS headquarter in Maryland for possible future collaboration. Related to the very strange experiment, the CLAS results of the first measurement of cascade polarization in photoproduction was also accepted for publication during my sabbatical.

Very Strange Experiment (E12-08-005a)

In the search for missing nucleon resonances a major difficulty arises due to the fact that there are many overlapping broad states. The identification of a resonances thus requires a coupled-channel analysis and a partial wave analysis to extract their quantum numbers. By comparison, cascade resonances are typically much narrower and could be comparatively easier to identify. According to constituent quark models, there should be a cascade state for each corresponding \(N^*\) and \(\Delta^*\) resonance. In fact, Isgur and Capstick predicted a total of 44 cascade states below 2.5 GeV, using a relativistic quark model with chromodynamics. However, only 6 cascade states (Table 1) are considered to have been established, while only three of them have their quantum numbers \(J^P\) determined. The main problem in the search for missing cascade states has always been the small production cross sections. Recent CLAS data established that the lowest excited cascades can be investigated using photoproduction. The ground state cross sections as well as the polarization have now both been measured and published recently. Limited by beam energies and cross sections, the excited cascades were not found in those data. Such limitation can be addressed by E12-08-005a at CLAS12, with orders of magnitude higher statistics expected, and higher energies of quasi-real photon beams tagged by the Forward Tagger system. The main focus of this
experiment is the photoproduction of the Omega baryons, as well as cascade spectroscopy. In particular, it is possible to search for excited cascades using decay channels such as $\Xi^{-*} \rightarrow K^- \Sigma/\Lambda$ or $\Xi^{-*} \rightarrow \pi^- \Xi^0$. Cascade production is also intimately related to excited hyperons. The $S=-1$ hyperon states above 2GeV can be studied in unique channels such as $Y^* \rightarrow K^+ \Xi^-$. The production mechanisms of both cascade and hyperon states can also be investigated via their decay angular distributions, differential cross sections, and polarization observables. Publication [1] already showed promise of such polarization measurement, and CLAS12 data can prove much more fruitful with the expected statistics to be a couple of order of magnitude higher for the ground state cascades.

<table>
<thead>
<tr>
<th>State</th>
<th>PDG rating</th>
<th>Width (MeV)</th>
<th>$J^P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Xi(1320)$</td>
<td>****</td>
<td></td>
<td>1/2$^+$</td>
</tr>
<tr>
<td>$\Xi(1530)$</td>
<td>****</td>
<td>9.5</td>
<td>3/2$^+$</td>
</tr>
<tr>
<td>$\Xi(1690)$</td>
<td>***</td>
<td>&lt;30</td>
<td>1/2$^{-?}$</td>
</tr>
<tr>
<td>$\Xi(1820)$</td>
<td>***</td>
<td>24</td>
<td>3/2$^-$</td>
</tr>
<tr>
<td>$\Xi(1920)$</td>
<td>***</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>$\Xi(2030)$</td>
<td>***</td>
<td>20</td>
<td>5/2$^?$</td>
</tr>
</tbody>
</table>

Table 1: Well Established Cascade Resonances

In order to search for these states with multiple strangeness, it is important to have excellent particle identification for kaons in reactions such as $ep \rightarrow eK^+K^0\Xi^{-*}$. Fig. 1 shows an excellent kaon signal using the forward time of flight system. Although CLAS12 reconstruction software is still in the process of being finalized, the invariant mass spectrum of $\pi^+\pi^-$ (Fig. 2) also already shows a prominent $\rho$ signal.

![Fig 1. TOF mass measured by the Forward TOF system in CLAS12 showing a promising kaon signal, important for the very strange experiment. The green curve using vertex corrected RF time as the event start time.](image)
Fig 2. Invariant mass spectrum of the $\pi^+\pi^-$ system from Run 4013.

**Student Mentoring**

During my sabbatical stay at Jefferson lab until July 2018, I worked with three graduate students for whom I am co-major advisors. Shankar Adhikari graduated in the fall of 2018, finishing his thesis on the first measurement of Lambda polarization (polarization transfer $C_x$, $C_z$, and induced polarization $P$) at the non-resonance region with circularly polarized photon beam energies up to 5.4GeV using the CLAS data from the g12 experiment. He is currently a postdoc at ODU. The CLAS12 polarization measurement for $\Xi^-$ is the dissertation topic for graduate student Jose Carvajal. I am a co-major advisor for him. Another graduate student, Achyut Khanal will investigate the $\Xi^-(1820)$ via its decay of $K^-\Lambda$.

In addition, I also mentored two other undergraduate students. Brandon Tumeo, who is currently a graduate student at University of South Carolina, worked on the antibaryon photoproduction using CLAS data. Elvis Hernandez, worked on the constituent countings rules in S=-1 hyperon photoproduction using worldwide published data.

**Publications and Presentations**

**Selected 2018 Publications (I am either a lead/contact author, co-spokesperson of the corresponding experiment or collaboration reviewer)**


**Invited talks by me:**
The CLAS12 experiment: status and plans (Meson 2018, Krakow, Poland, June 2018)
Program in Hall B/CLAS12 (10th Workshop on Hadron Physics in China and Opportunities Worldwide, Weihai, China, July 2018)

**Presentation by my student (Shankar Adhikari)**
Measurement of Polarization Observables in the Reaction γp → K⁺Λ, CIPANP 2018, Indian Wells, May 2018

**What is next**

Although the CLAS12 data taken during my sabbatical leave is not yet ready for large scale physics analysis, two of my current graduate students are actively working on the calibration of the data (Center TOF and Forward TOF system, to be specific). I expect CLAS12 will be a goldmine of hadron spectroscopy as well as other aspects of nuclear physics. It is indeed an exciting time.

**Acknowledgement**

It was an honor to receive the JSA sabbatical support, which enabled me to relocate to JLAB and have a very productive research period. It was an exciting time, being in the middle of the first official data taking period at CLAS12. As the last run coordinator of the spring run, I was happy to ensure a successful data taking period despite some challenges. That I also happen to win the “gold” medal of the most shifts taken, was also an unexpected icing on the cake. All these would not have happened without the JSA support, and I particularly want to thank both Elizabeth Lawson and Hall B leader Volker Burkert, who helped me on numerous occasions. I am grateful for this experience.