1. Title of Project:

   Applications of ANL-Osaka Amplitudes to the analysis of meson production reaction data from JLab, J-PARC, and Fermi Lab.

2. Name and title of the applicant:

   Dr. T.-S. Harry Lee, Physics Division, Argonne National Laboratory, Argonne, IL 60439, United States

3. Name and title of the host:

   Dr. Toru Sato, Research Center for Nuclear Physics, Osaka University, Osaka, Japan.

4. Intended project dates: April 1, 2021- March 31, 2022

5. Expected total budget request: $11560

I. PROPOSED COLLABORATION RESEARCH

Within a Dynamical Coupled-Channel (DCC) model, the Argonne National Laboratory-Osaka University (ANL-Osaka) collaboration, with the support of Excited Baryon Analysis Center (EBAC) at JLab during 2006-2012, had carried out the analysis of the world data of πN and γN reactions up to invariant mass $W = 2$ GeV. The calculations for the analysis involved solving coupled-channel scattering equations with 8 channels: γN, πN, ηN, $K\Lambda$, $K\Sigma$, and πNN which has $\pi\Delta$, ρN, σN resonant components. The parameters of the model were determined by performing χ^2-fits to the world data of $\gamma N, \pi N \to \pi N, \eta N, K\Lambda, K\Sigma$ (about 30,000 data points).

In addition to extracting 22 nucleon resonances (N^*) for investigating the structure of the nucleon, the partial-wave amplitudes (PWA) of $\gamma N, \pi N \to \pi N, \eta N, K\Lambda, K\Sigma, \pi\Delta, \sigma N, \rho N$ have been determined from the ANL-Osaka DCC analysis. The ANL-Osaka model was also extended to include axial currents to investigate the neutrino-induced meson production reactions on the nucleon. Thus the ANL-Osaka amplitudes can also be used to analyze the data from neutrino experiments. With DOE's support during 2017-2019, the ANL-Osaka amplitudes had been presented on "https://www.phy.anl.gov/theory/research/anl-osakapwa" for the nuclear and hadron physics communities to get access.

We propose to apply the ANL-Osaka amplitudes to the analysis of meson production data from JLab, J-PARC, and Fermi Lab. We will carry out the following projects:

1. The available information on N^* with mass M_{N^*} above about 1.6 GeV have large uncertainties; in particular the decay widths of $N^* \to \pi\Delta, \rho N, \sigma N \to \pi\pi N$. This is due to the lack of accurate data of $\pi N \to \pi\pi N$ to constrain the partial-wave analyses. We will apply the ANL-Osaka amplitudes to provide the base-line predictions for an approved $\pi N \to \pi\pi N$ experiment at J-PARC. When the J-PARC data and the $\gamma N \to \pi NN$ data from CLAS-12 become availabe, the ANL-Osaka PWA will be improved to perform more accurate extractions of $N^* \to \pi\Delta, \rho N, \sigma N \to \pi\pi N$ parameters.

2. We will apply the ANL-Osaka amplitudes to assist the interpretations of the N^* extracted from the data of $\gamma N \to \pi\Delta, \rho N, \sigma N \to \pi\pi N$ of CLAS. This will involve a collaboration with V. Mokeev of JLab.

3. We will apply the ANL-Osaka amplitudes to predict the cross sections of $\pi N \leftrightarrow \pi\Delta, \rho N, \sigma N$ and $NN \leftrightarrow N\Delta$. These cross sections are the essential input to the simulation programs (such as GINIE of Fermi Lab) which are needed to analyze the neutrino-induced reaction data from the Deep Underground Neutrino Experiment (DUNE) in US and the experiments in Japan.

4. We will apply the ANL-Osaka amplitudes to calculate the current matrix elements of $J^\mu + NN \to N\Delta \to NN$ to predict the two-body contributions to inclusive $A(e, e')X$ and $A(\nu, \mu)X$ reactions in the "deep" region where the available data are poorly understood.

II. ITEMIZED BUDGET REQUEST

1. Visit Dates:
   (a) 2 weeks in September-October, 2021
   (b) 2 weeks in January-April, 2022
2. Total cost :$11560
   (a) Lodgging :[(200$/day)*14]*2=$ 5600
   (b) Perdim: [($70/day)*14]*2=$1960
   (c) Airfare:($ 2000/trip)*2=$4000