<u>Proposal for a *Cross Collaboration Working Group* on *Cross Section Measurement Communication*</u>

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<u>Executive Summary</u>

In general, the consumers for cross-section measurements are external groups, who use them to test and tune their cross-section model(s). The publicly disseminated cross-section measurements often depend, in subtle ways, on the details of the cross-section models used by the analyses. Adequately communicating these model dependencies and providing the full set of information required to interpret the measurements can be difficult. In addition, each group of cross-section measurement producers and consumers use subtly different definitions for common terms, and make different assumptions about how analyses were performed.

This document proposes the creation of a Cross Collaboration Working Group (WG) on Cross Section Measurement Communication. The goal is to build consensus, aid communication, and provide a service to the neutrino-nucleus interaction community. It will be comprised of representatives from the various Collaborations, Organizations, and Groups, (COGs) that produce and consume cross-section data. The WG will meet bi-monthly (at least to start) to discuss issues, develop documentation for guidelines and best practices, and build consensus on how to produce and communicate the cross-section measurements required by the next generation of neutrino oscillation parameter measurements. COG representatives will also be tasked with communicating the needs of their COG to the WG and communicating the consensus of the WG to their COG. The COGs whose representatives comprise the WG are in no way committed to contribute any resources to the WG. Neither are they committed to adopt any of the guidelines suggested or software tools developed under the guidance of the WG. They are however, encouraged to do so.

This document introduces the issues faced when making and communicating cross section measurements, lays out a charge to the WG, establishes policies and procedures, and lists all (possible) participating COGs. Once the WG is established it will need to create and ratify it's bylaws, and develop a detailed list of projects with priorities and time lines. In its current state (v062119) this document is a draft, and feedback is welcome.

<u>Introduction</u>

Several experimental collaborations produce cross section measurements, as either their main purpose, or as measurements complimentary to their primary physics goals. In general, cross section measurements are used to motivate development of neutrino-nucleus interaction models and to tune neutrino interaction models in Monte Carlo (MC) generators. These tunes are based on external (published) data along with data collected by the experiment. While the external data is usually provided in the form of cross section measurements, the internal data is used more directly e.g. MC fits to selected event rate data. Thus, any cross-section data published by an experiment is, in general, intended to be consumed by other collaborations. (Of course, collaborations do not ignore their own cross section measurements, and have used them as cross checks or in selecting the set of models to use, etc.)

There are several challenges involved in packaging and communicating cross section data, as well as in interpreting and utilizing data published by other experiments. These challenges are all related to the difficulty in extracting model independent cross section measurements. These difficulties fall into a few distinct categories: flux, background subtraction, nuclear effects, efficiency/acceptance corrections, cross section extraction, and detector effects. (See Appendix 1 for a detailed description of each topic.)

All together it is clear that both reporting and making use of published cross section data is a minefield of model dependence, and hidden information. Clear and detailed reporting of the models, assumptions and procedures used in each cross-section measurements is crucial to producing a useful global data set. Just as important as reporting all the related information developing tools that can take advantage of this information to produce a coherent neutrino-nucleus interactions model that accurately reflects the sum of all knowledge and the related uncertainties.

The nature of these problems and the cross section analyses they apply to make universal solutions difficult. Techniques that may improve one analysis may not apply to others, and new issues are expected to arise as statistics increase and new, higher-resolution detectors come into use. Experimental collaborations will continue to develop new analysis methods, and new theories will be developed and coded into generators. Communicating these advancements regularly, and with adequate details will ensure that community and our experiments are using consistent, and well-motivated neutrino-nucleus interaction simulations. Building sustainable solutions will require continued efforts and regular communication suggesting the need for regular meetings involving representation from the entire cross section community.

In order to make the best use of the wealth of neutrino interaction data that will be collected in the future, the community will need to work together to address these issues. If it does not, there is a great risk of producing measurements that disagree, not because of disparate data, but because of inconsistent approaches and incomplete reporting of results. These differences will in turn limit the ultimate precision of neutrino oscillation and astro-particle physics, reducing the impact of neutrinos as a tool to understand the universe.

Charge to the Working Group

The goal of this document is to lay out a structure and broad goal for the WG. Once formed the members of the WG will be responsible for determining the more specific goals and strategies for accomplishing those goals. The first goal of the WG will be to prepare a detailed list of projects with timescales and priorities. This will discussed in the first meeting, and small group will be asked to produce a proposal. This proposal will be edited over email, and voted on at the next meeting.

That being said, the broad charge to to the Working Group is:

1) Establish lines of communication between experiments on a timescale much less than the international conference schedule (e.g. NuInt),
2) Agree on definitions for commonly used terminology, correct implementations of commonly used techniques, and proper applications of statistical methods,
3) Provide a platform to discuss new and interesting techniques in cross section analyses,
4) Agree upon the structure and contents of a universal data release format for cross sections, and recruit members of the community to develop tools for producing, housing, accessing and interpreting data produced in this format,
5) Work with generator (and related tool) developers to create common tools for model/generator tuning based on cross section data, and
6) Work with the cross section community as a whole to establish solutions to major challenges in producing cross section measurements as highlighted in, but not limited to, Appendix 1.

There are many existing tools that address several of these problems. The suggested list of member COGs is intended to include the developers and users of the existing tools, so that they can be discussed, promoted, and developed into universal tools for use by the entire community.

Working Group Organization and Procedures

The WG will consist of representative from the constituent COGs. These representatives are to be determined by the constituent COGs but should people with experience in cross section measurements and/or model development. The WG will meet bi-monthly in a regular time slot determined by an initial doodle poll, which can be redone as necessary. Meetings will initially be chaired by DDC, but once procedures have been established, and spokespeople have been elected, the chairing responsibilities will rotate amongst constituent COGs. Meeting attendance will be limited to representatives and invited guests. All representatives may invite guests as they see fit without the need for approval from other representatives. COGs may change their representatives at any time or alternate them as need be.

A mailing list of representatives will be maintained. All concurrent representatives from each COG should be on the mailing list. Representatives are expected to disseminate information to their respective COGs, and to inform the WG of relevant ongoing work within their COG. Representatives should also propose reading materials, discussion topics, and talks from colleagues to be given at meetings. A slack channel will also be formed for ongoing discussions.

New COGs can be added at any time. Any representative can propose adding a new COG. The proposal must be approved by a simple majority of the current set of representatives, and the COG must agree to join and appoint at least one representative. Rules for changes to the WG organization, WG procedures or this document require a written proposal which must presented at a meeting, then be seconded to induce a vote. Approval is determined by simple majority of the representatives in attendance.

The group can also propose workshops or cohost workshops with other established groups (e.g. NuSTEC) or workshop series (e.g. TENSIONS).

The COGs whose representatives comprise the WG are in no way committed to contribute any resources to the WG. Neither are they committed to adopt any of the guidelines suggested or software tools developed under the guidance of the WG. The goal is to build consensus, aid communication, and provide a service to the neutrino-nucleus interaction community.

Spokespeople for the WG will be elected once the WG has formed, and its bylaws and election procedures written have been approved. The role of the spokespeople will be to 1) represent the WG to outside entities, 2) organize mailing lists, chairing schedules, etc., and 3) organize the recruiting of teams to complete projects agreed upon by the WG.

Appendix 1: Detailed breakdown of issues facing cross section analyses

1) Flux
    a. Neutrino fluxes are only known, at best, to the ~10% level. New hadron production measurements are helping to reduce these uncertainties to the ~5% level, and in situ measurements of well-known cross sections (nu+e scattering) will help future experiments. However, all recent, in-progress, and near-future measurements will be limited by the propagated flux uncertainty.
    b. Neutrino energy is a difficult observable to accurately reconstruct. Thus, measurements are limited to integrated cross sections, or flux-integrated cross sections in other differential variables. Therefor all measurements must be interpreted through the flux of the experiment that produced them.

2) Background subtraction
    a. All cross-section analyses suffer from some level of background contamination. Estimating the background levels is an inherently model dependent procedure. Either the background is extracted directly from MC or extrapolated from sideband measurements. While the latter is preferred, the extrapolation procedure still introduces model dependence. In both cases the uncertainties stemming from the model dependence are difficult to estimate, and often introduce significant bias to the result.
    b. Changing the underlying background model can significantly change the interpretation of the results. This makes comparison with alternate models complicated, and often functionally impossible to do correctly. This leads to incorrect interpretation of data, and improperly tuned modes and generators. Reporting the background estimate and the total (non-background-subtracted) data can alleviate some of these issues, but problems with understanding the details of the reported background model may persist.

3) Nuclear effects
    a. Neutrino-nucleus scattering models, in general, factorize the interaction between the neutrino and a nucleon, and the interaction between the nucleon and the nuclear medium. This method assumes that the nucleon is essentially a free particle, which can have non-negligible effects on the model prediction. Therefore, using cross section data to constrain neutrino-nucleon scattering models implemented in generators with this factorized approach can produce misleading results.
    b. The nuclear initial-state is the momentum distribution of the nucleons in the nucleus and the energy required to remove them from the nucleus, including correlations (interactions). When the Q^2 of the interaction is on the same scale as (or smaller than) the struck nucleon momentum, the kinematics of the interaction final state can be significantly altered. Also, interaction with correlated nucleon pairs can cause the ejection of multiple nuclei. Currently implemented models of the nuclear initial state produce disparate nucleon momentum distributions, and thus different final-state particle kinematic distributions. In addition, each model factorizes the problem differently, making it difficult to compare various models, or even different implementations of the same model. Clear communication of exactly what sets of models were used and their implementation details is required to accurately interpret results.
    c. Particles created in the nucleus must escape the nuclear medium before they can be detected. These final-state interactions (FSI) can greatly alter the observable final state, acting as a confound for several fundemental observables, like neutrino energy and interaction channel. Similar to initial-state models, the choice of the model used, and the implementation details can greatly alter results, and these choices must be clearly communicated to properly interpret results. Furthermore, since FSI changes the set of

particles that are observable within a detector, they add a layer of confusion between measurements and theory. There has already been a shift in exclusive cross section measurement signal definitions from interaction types to observed final state particle lists. However, this added complication introduces model dependence to the reporting and the interpretation of the cross-section measurements, and the details of the models used must be clearly reported and accessible for future re-analysis.

4) Efficiency/acceptance corrections
   a. The efficiency is the fraction of signal events selected in an analysis. To calculate the total cross section, the number of measured events must be corrected by dividing by the efficiency. The determination the efficiency and the application of the efficiency correction are complex and highly model dependent procedures. Worse, they are dependent on the model of the process being measured. Providing the details of the efficiency function, and explaining the details of the efficiency correction procedure, are important for properly making use of cross section measurements for model comparisons and model tuning.
   b. One way to mitigate the model dependence of efficiency corrections is to apply *phase space restrictions*. Regions where the efficiency is zero, small, or quickly changing are removed from the analysis by changing the definition of the signal. The result is to limit the measurement to regions of kinematic space where the detector can effectively measure particles in a well understood way. This reduces the amount of model extrapolation required to develop the efficiency function. Restricting the measured phase space to kinematic regions accessed by the detector should be part of every analysis. However, removing regions where the efficiency is changing rapidly limit the scope of the measurement. Providing the efficiency function at high resolution over these variables is preferred but not always feasible, either due to low statistics or poor resolution. Either way, complete exposition of the phase space restrictions is required to properly interpret the results.

5) Cross Section Extraction and Detector Effects
   a. Measured quantities used in analyses can have non-negligible resolutions and biases. This means differential measurements need to be unfolded to account for bin migrations caused by differences in true and reconstructed quantities. Unfortunately unfolding is a statistically ill-posed problem with many functionally equivalent degenerate solutions. The exact best fit (maximum likelihood) point may have misleading features. Proper interpretation of that data requires use of the output covariance matrix, which must be provided.
   b. One solution to the unfolding degeneracy is to use regularization in the unfolding procedure in order to limit the range of solutions to those with “physical” features. While this step can be useful in eliminating large subsets of the degenerate solution space, it can also be a potential source of bias, depending on how the analyzer chooses what is deemed to be physical and unphysical. Also, regularization has been demonstrated to reduce confidence interval coverage resulting in the assignment of artificially small uncertainties to the results. Several unfolding methods include some inherent level of regularization, and analyzers must be extremely careful to mitigate the effects of the induced bias and undercoverage in reporting their results.
   c. One way to avoid the entire subject of unfolding and regularization is to present results in the reconstructed space. While this method works quite well for comparing data with models that have been propagated through a full detector MC, it is difficult to compare the data with other models. The solution to this problem is to supply the full smearing and efficiency function extracted from the MC for the signal and background events of

the analysis. Unfortunately providing this function is not necessarily trivial, since the efficiency may be a complex function in many dimensions (kinematic variables). Software machinery to properly make use of this function is also required for practical reasons.