New Simulation of BNB Neutrino Flux

Raquel Castillo Fernández (on behalf of many people)

ICARUS Collaboration meeting
16th October January 2024

Overview

1. Yesterday you heard from Leo Aliaga the description and status of the current BNB simulation and uncertainties, SBN-doc-38254-v1. Inherited from MiniBooNE, adopted by MicroBooNE. It uses GSimple.

   - Several assumptions due to past limitations, reflected in limited robustness in the current BNB uncertainty estimation.
   - Lack of reproducibility of the current BNB simulation.
   - It uses **GSimple**.

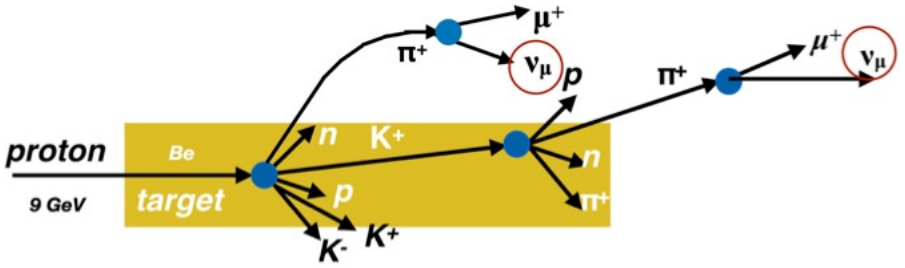
2. We are implementing a new BNB simulation and new framework for the uncertainty assessment of this new simulation. Many people is involved in several ways:

   - **Baseline new BNB simulation and validation**: Josie Paton, Zarko Pavlovic, Marco del Tutto
   - **BNB uncertainties**: Leo Aliaga, Megan Pounds, Diya Ranjit, Manuel Dall'Olio, (RCF)
   - **Incorporation of neutral mesons** (not producing neutrinos) for BSM searches: Ken Lin, Rohan Rajagopalan
   - And more **people contributing to the discussions**: Joseph Zennamo + others.
   - It uses ~~GSimple~~ **dk2nu**, it keeps all neutrino ancestry.

   We try to report in both SBND and ICARUS and use as much as possible joint SBN meetings.

Limitations of current BNB simulation

- Lack of reproducibility. It used Geant 4-08-01-patch-02, FNAL machine has been decommissioned. Current BNB simulation uses the original MiniBooNE ntuples.
- GSimple format:
  - The full ancestry of the neutrino is not stored, only the immediate parent and no information about potential secondary interactions.
  - Non-Be interactions are treated as Be interactions for the uncertainties.
  - HARP data coverage is limited, and in the uncertainty calculations pi+ out of coverage are pushed to be within HARP coverage.



From Leo Aliaga

Every neutrino should have a systematic that considers all the weights of the different processes (blue circles) till the neutrino is created.

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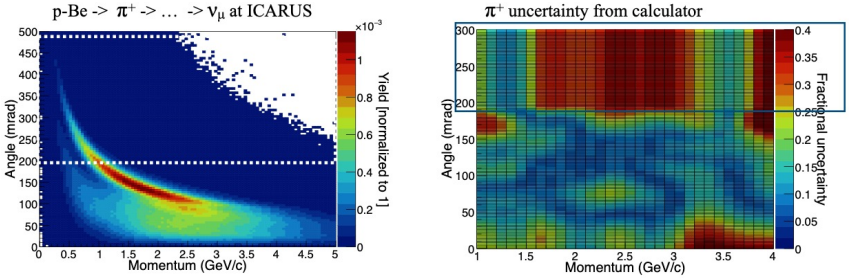
Impact of HARP Extrapolation at Large Angles



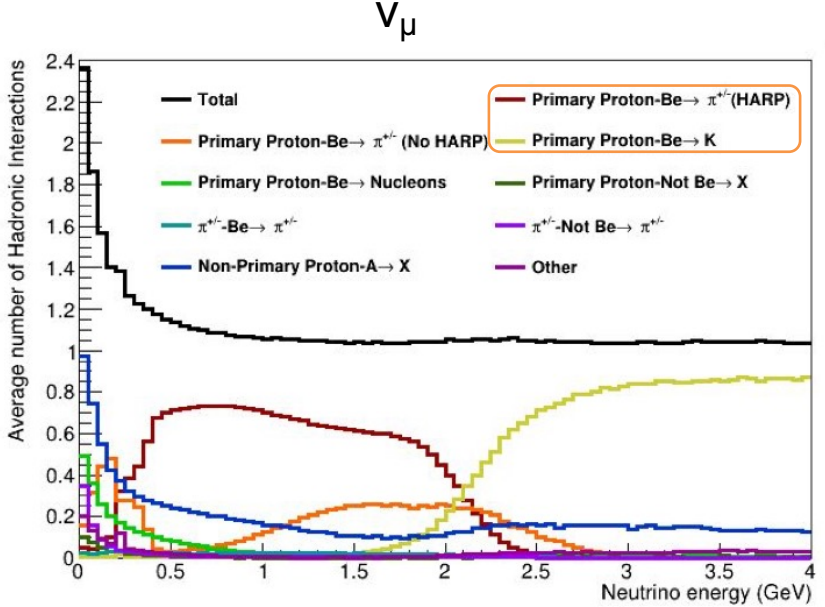
Caveat: the calculator assigns 195 mrad angle for pi+ (out of HARP coverage). The reason is to control the spline variations.

From Leo's slides yesterday.

Limitations from current BNB simulation

- There is only one hadronic interaction in the neutrino history. Secondary hadron interactions are not considered
- The primary proton projectile is longitudinal (0,0,8.9GeV)
- Any pion and kaon neutrino parent come from the primary proton interacting in Be
- Only the circled labels (pBe->pions and kaons) have direct data coverage (by the SW fitting)

Only orange circled labels were correctly accounted for.



Leo Aliaga & Megan Pounds

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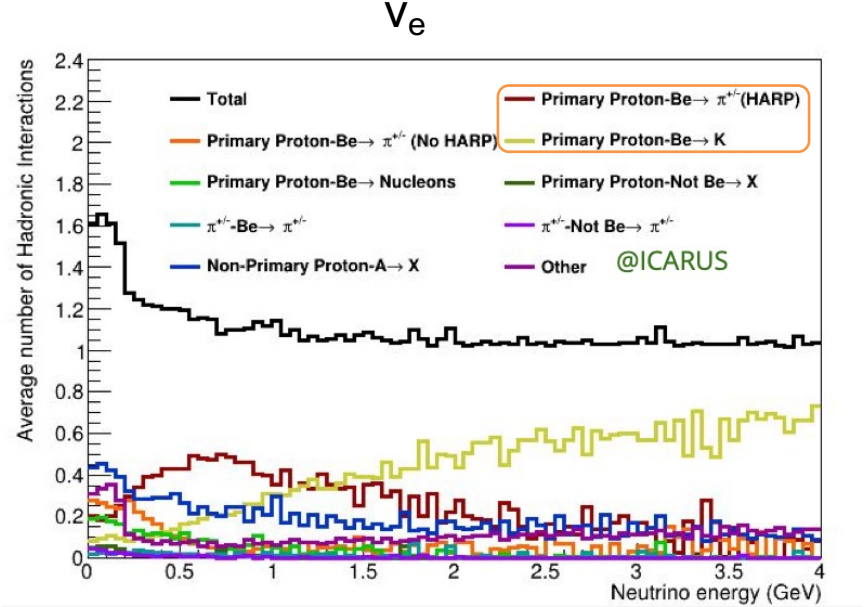

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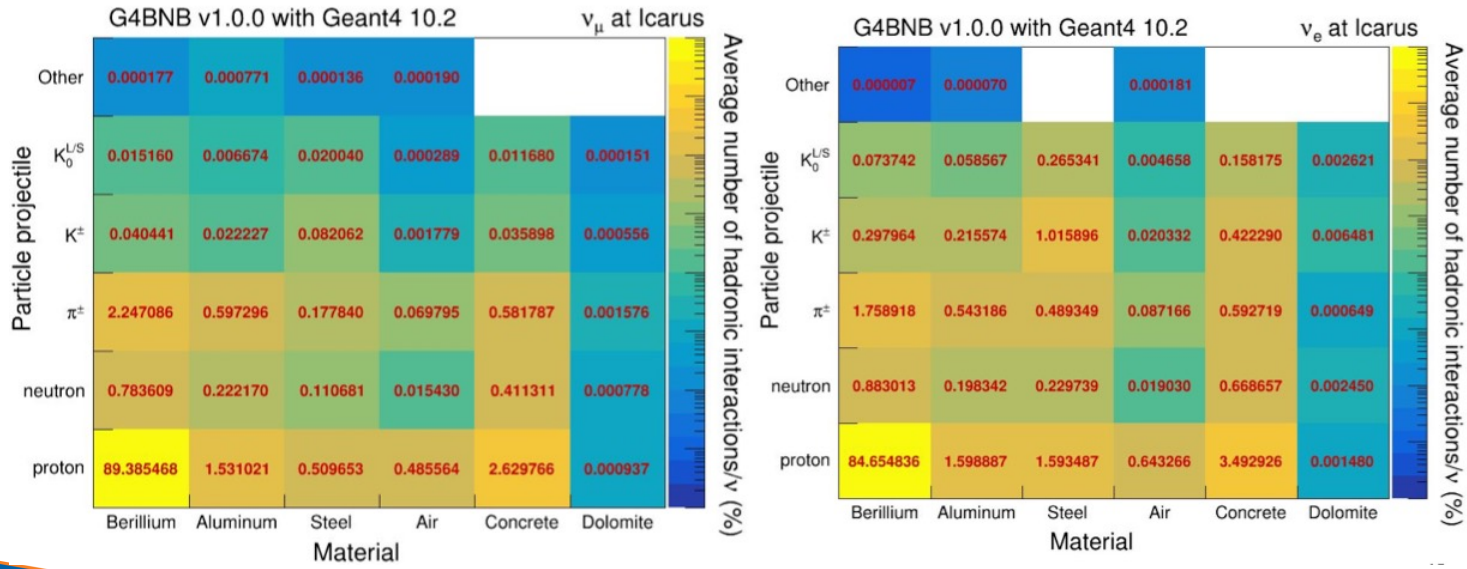
Limitations from current BNB simulation

Incident Particles vs Target Materials

Leo Aliaga & Megan Pounds



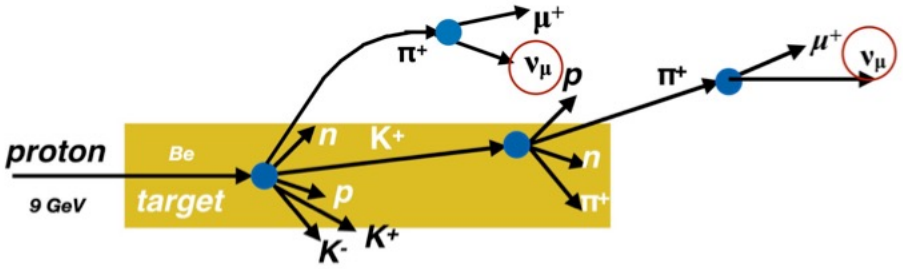
From docdb [34913-v1]

New BNB simulation: G4BNB

- Marco del Tutto and Zarko Pavlovic implemented a new BNB simulation: G4BNB v1.00
- Currently uses Geant 4.10.4 (same as G4NuMI). We are discussing to move instead to 4.10.6 due to better agreement with external data showed by the Geant4 collaboration (Julia Yarba). Last steps of the validation are ongoing (Josie is working on this).
- One of the features is that the neutrino information including the ancestry is stored in Dk2Nu/DkMeta flux record.
- Dk2Nu is a proposed unified flux ntuple format proposed by Robert Hatcher (*MINOS-doc 9070-v4*) for neutrino experiments .
- A Geant4 feature has yet to be resolved (done previously by other experiments such as MINERvA, DUNE, NOvA) where the final momentum of the particles interacting inelastically are stored as 0. We made a quick fix, now we are waiting for Josie to implement it in the G4BNB.

New Flux Uncertainty Framework: BNBFluxCalc

- Highly inspired by PPFX (which was also led by **Leo Aliaga**).
- BNBFluxCalc reads dk2nu as input, parse the neutrino interaction chain and we incorporate the uncertainty calculators.
- First calculators are now in place. Expected to have them all by the end of 2024!
- More details: docdb 36605-v3



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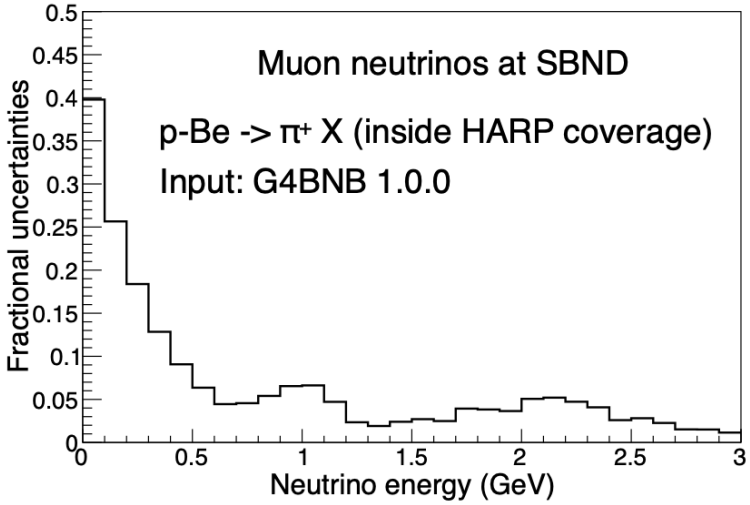
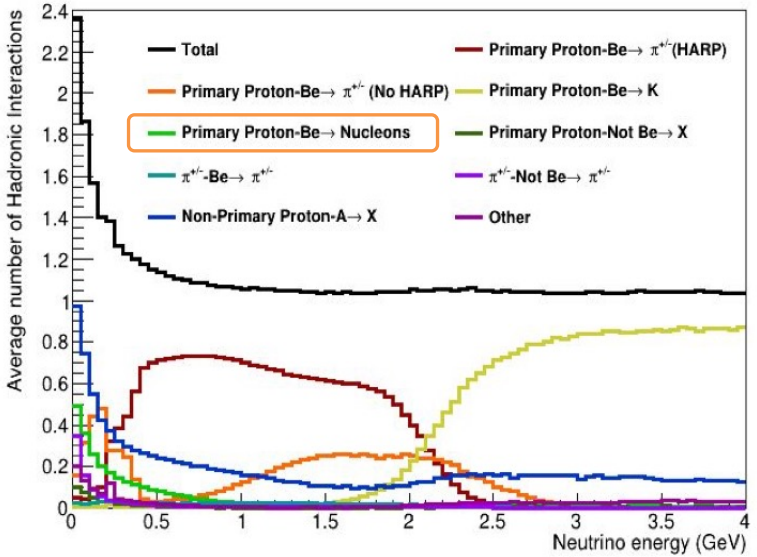


Example of performance of one of the calculators.

New Flux Uncertainty Framework: BNBFluxCalc

- Implementing p-Be-> protons uncertainty using HARP data at 8.9 GeV (David Schmitz's thesis, he shared the data and covariances ☺)
- Investigating Feynman-scaling and material scaling (Manuel Dall'Olio) to use more data to constraint our non-Beryllium interactions and/or uncovered phase space by HARP.
- More details: docdb 36605-v3



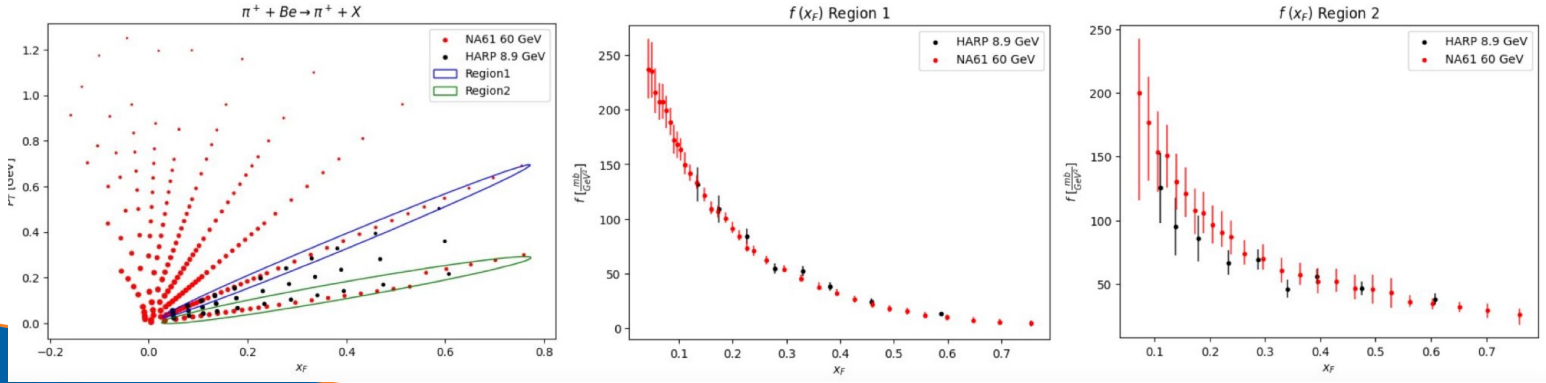
New Flux Uncertainty Framework: BNBFluxCalc

HP from pion-Be interactions

Studies on secondaries

- We select 2 regions with good data bin overlap between both experiments
- The (xF, pT) values are taken as the center of the bins
- We calculate the invariant cross sections from both results
- There is a good agreement between both datasets

Manuel Dall'Olio

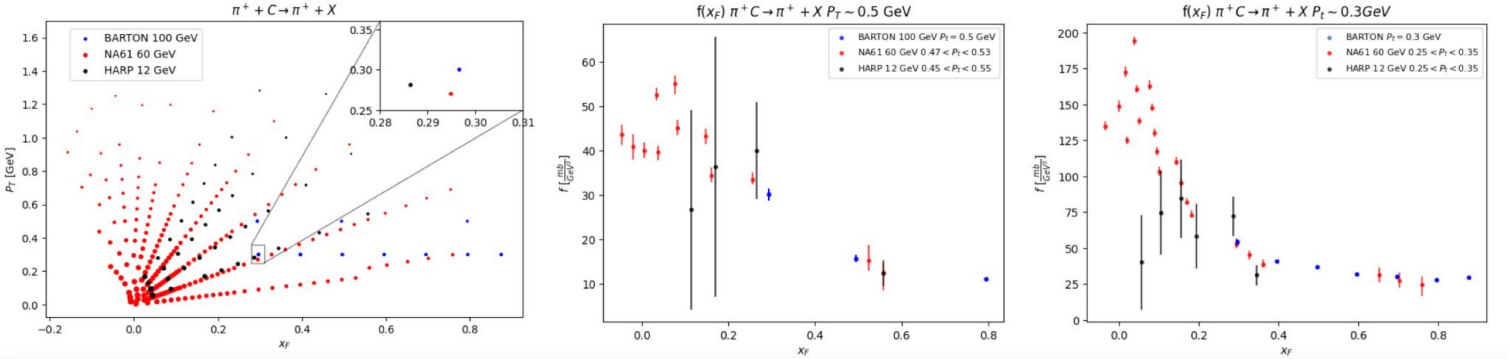


New Flux Uncertainty Framework: BNBFluxCalc

HP from pion-C interactions

- We select 2 regions along the same pT distributions. We also include Barton data
- The (xF, pT) values are taken as the center of the bins
- We calculate the invariant cross sections from both results
- There is not a good agreement between both datasets. **New data is needed!**

Manuel Dall'Olio

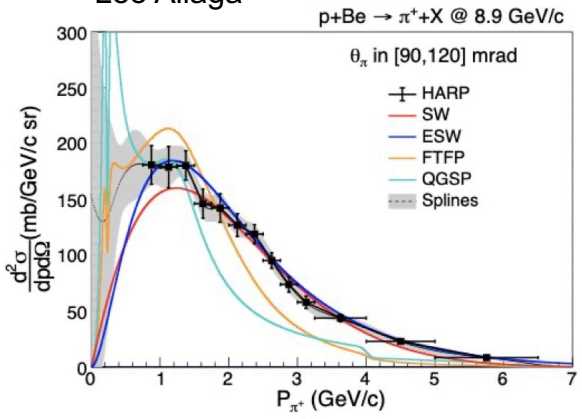


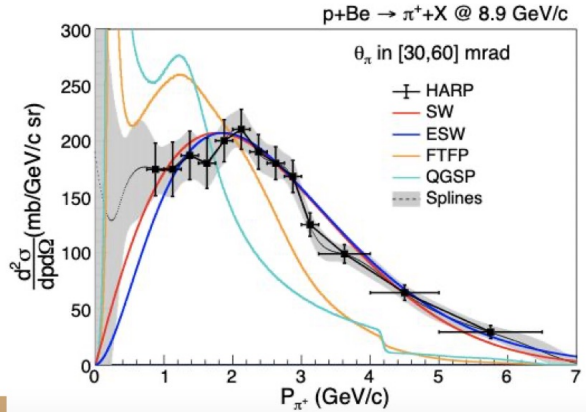
New Flux Uncertainty Framework: BNBFluxCalc

Leo Aliaga

In addition, we are revisiting the previous treatment for low energy that in the old flux used two 1-D splines method.

- Previously, splines (interpolation method) was used to extrapolate HARP data to uncovered regions without boundary conditions.
- This approach made uncertainty too large for low energy neutrinos. We will present a different approach, physically driven and following previous studies from Zarko, in next meeting that will help to reduce those uncertainties.





This work is being done by Leo Aliaga and Manuel Dall'Olio.

Summary

Updating the BNB simulation is the most sensible approach. This will allow us:

- **reproducibility**
- **get rid/add/combine external data for flux constraint**
- **include ALL uncertainties**
- **Revisit methods for the uncertainty calculators**

Dk2nu offers clear advantages with respect to the gsimple ntuples and if we don't move now to this format it is unlikely to happen later within the timeline of SBN.

The new framework for flux uncertainties is coming, expected in December 2024. It is reasonable to publish first results with the new flux and uncertainties and not wonder what to say about what is the impact of all the uncertainties not included or mis-characterized in the past.

We expect to keep implementing further improvements, including new HP data, to further improve uncertainties as new resources from data became available.


Thanks