Projected FSI changes in GENIE

Steve Dytman, Grace Chu Univ. of Pittsburgh
Marc Vololoniaina, Antananarivo, Madagascar
Robert Hatcher, FNAL

11 February, 2019

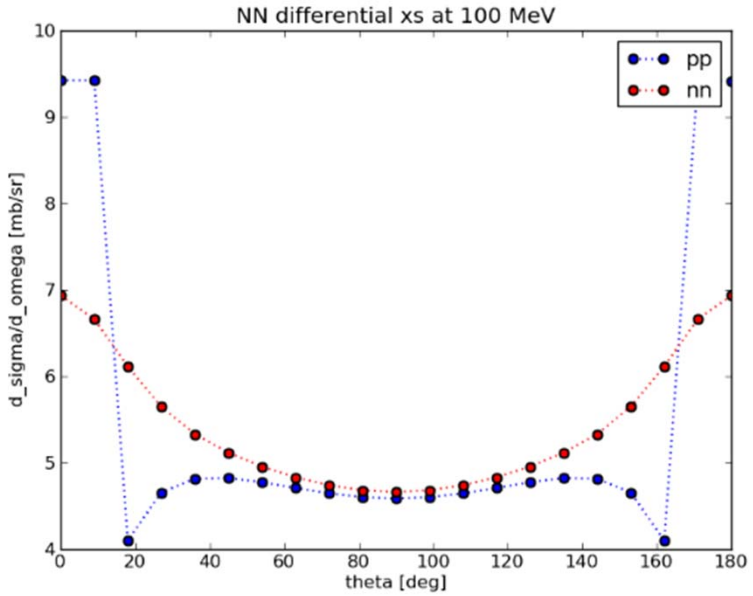
- Review 4 projects – students can't attend
- Various stages of accomplishment, difficulty
- How do we go forward?

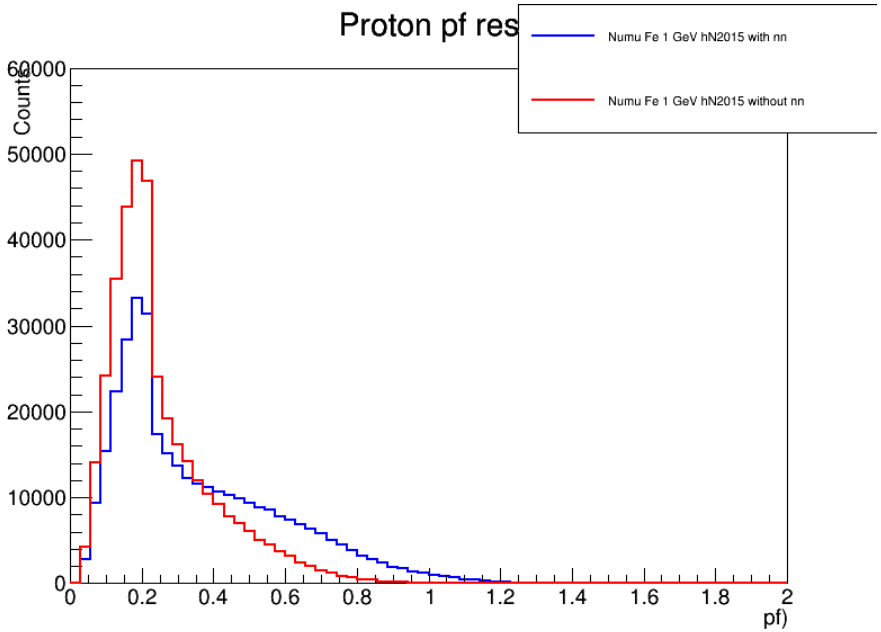
Overview

- π^0N, nn updates – Grace Chu
  - Simple replacement of data files
- **INCL++ - Marc Vololoniaina, Robert Hatcher**
  - **New FSI – very good for low energy process, e.g. γ, 2H**
  - **Focus for today**
- GEANT4 – Dennis Wright, Marc, Robert
  - New FSI – widely used in particle physics
  - Dennis was forced to leave the project, Marc finished code
- New hN processes from Sato-Lee – Grace Chu, Harry Lee
  - See https://www.phy.anl.gov/theory/research/anl-osaka-pwa/
  - Includes $\pi N \rightarrow \pi\Lambda$, $\pi N \rightarrow \pi\Delta$, $NN \rightarrow N\Delta$....
- Binding energies in pion absorption - Steve

Quick review of π^0N, nn

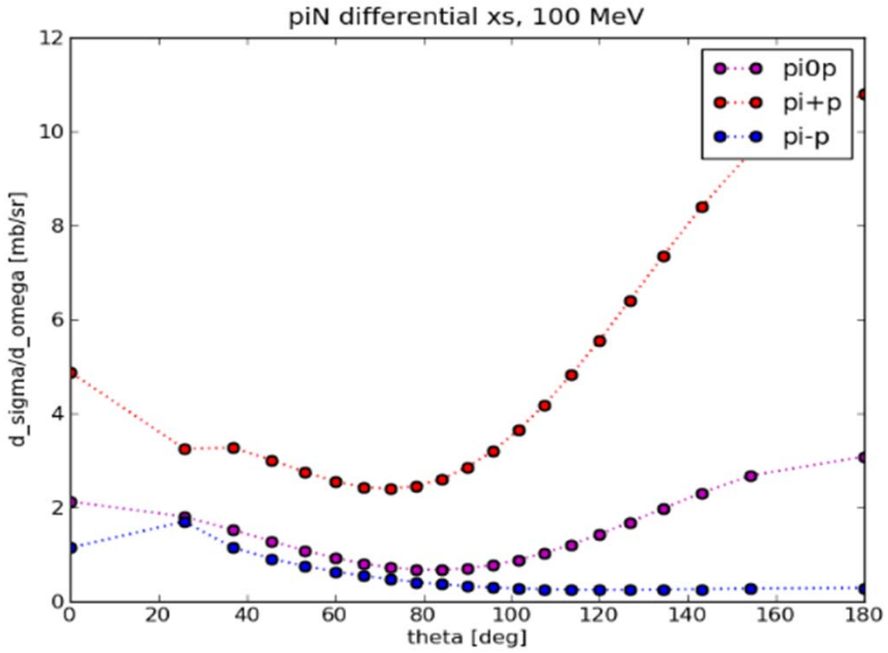
- All hadron-nucleon data comes from SAID (GWU)
  - They post pp and np, not nn, π^+p, π^-p, and π^-p cex, not π^0N
- Get nn from SAID code provided by Igor Strakovsky (GWU)
  - Due to isospin symmetry nn is same as pp with Coulomb turned off





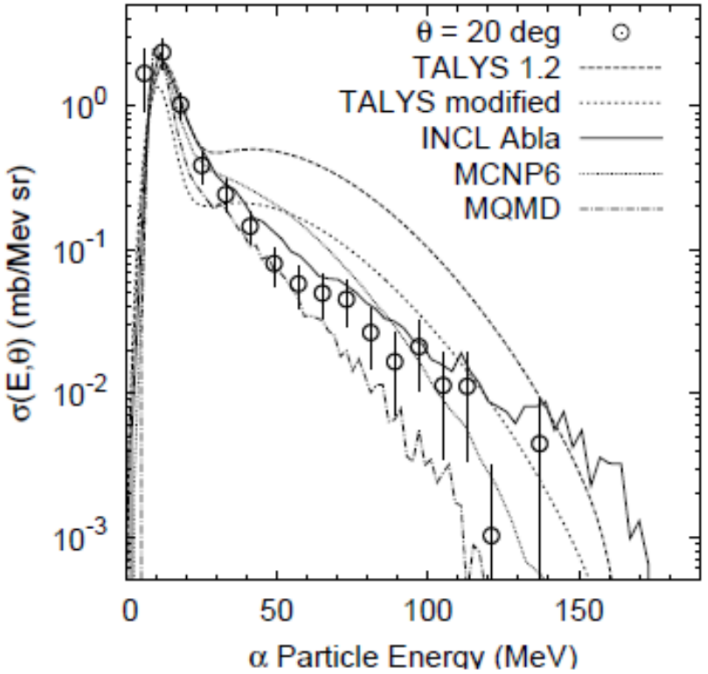
Quick review of π^0N, nn

- Get π^0N from Pitt Phd thesis output
  - No data, use isospin relations (similar to what is now used)
  - Some say $\sigma(\pi^0 p) = 0.5[\sigma(\pi^+ p) + \sigma(\pi^- p)]$, sort of right



INCL++

- Code developed by Liege Univ and others, aimed at low energy hadron beam experiments.
- Public and written in C++, well documented and widely used
- Our contact is Davide Mancusi, has been helpful
- Main GENIE work done by Marc, PhD student in Madgascar. He was at Pitt for 6 months in 2017, learned a lot. He will graduate in June, 2019.



Plot from R. Bevilaqua, et al for 2013 Intl Conf on Nuclear Data for Science and Technology.
175 MeV n Fe → 4He X
What we use is solid line.

method

- Wide variety of hadron+nucleus Monte Carlo, final states include wide variety of particles – γ, π, K, N, light ions
- Evolution in time and distance
- *Potentially* able to do all GENIE FSI
- INC at KE>~100 MeV, switch to ABLA evaporation model as KE decreases [$t=70(A/208)^{0.6}$=26ns for Ar]
- Evaporation is low energy process where entire nucleus is excited and γ, n, p, light ions emitted slowly – primary reaction mechanism for KE<~20 MeV

GENIE installation

GitHub branch inside sg fork - sjgardiner/develop/inclpp

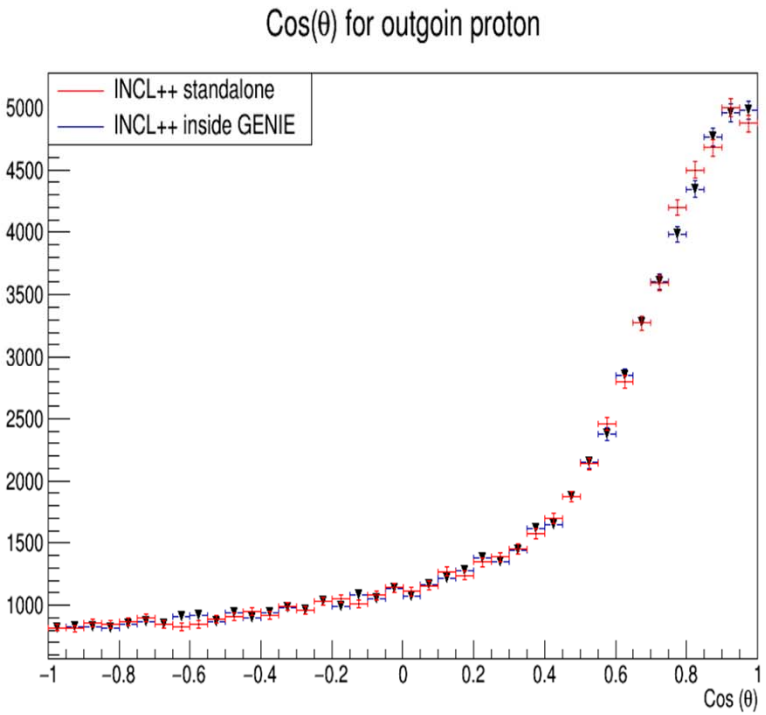
- Conditionally link INCL/ABLA into GENIE
- Set up alternate FSI model
- Write interface to INCL passing appropriate kinematics
- Start propagation in INCL where initial state particle starts – if e.g. π,p order remains an issue
- Transfer final state particles back into GENIE event record
- Modes:
  - INCL inside gevgen_hadron to test hadron-nucleus
  - INCL inside gevgen to include as FSI for ν, e interactions

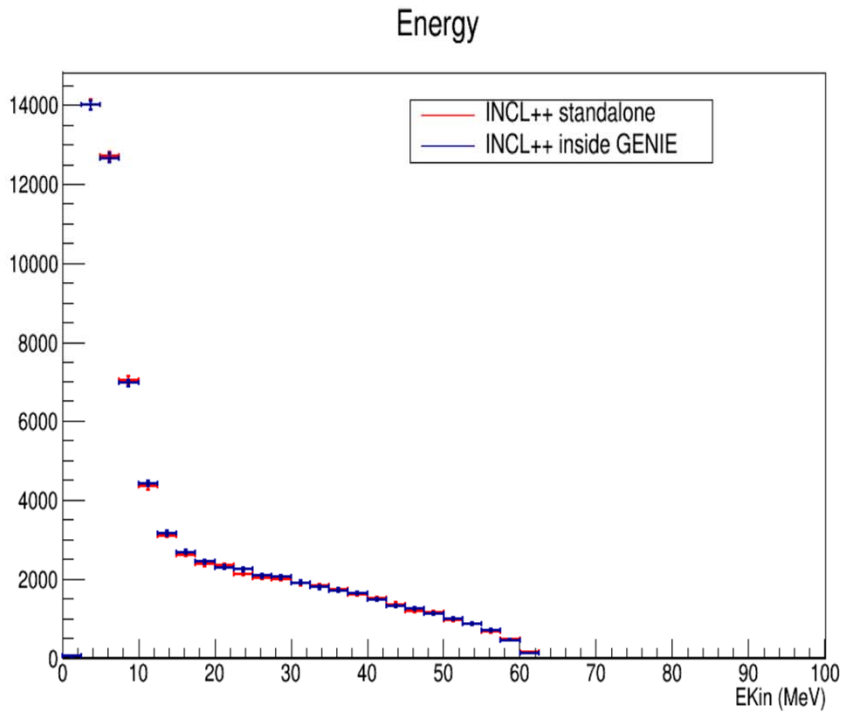
Details

- INCL libraries - libABLA07.a, libDeExcitation.a, libGEMINIXX.a, libSMM.a, libABLAXX.a
- INCL libraries – libINCL_Physics.a, libFERMI_BREAKUP.a, libINCL_IO.a, libINCL Utils.a
- New interface classes in src/Physics/HadronTransport
  - INCLCascade.cxx , .h and HINCLCascade.cxx, .h
  - Direct replacements for HAIntranuke and HNIntranuke
- New config files - INCLcascade.xml, HINCLcascade.xml
- E.g. *gevgen_hadron -p 2212 -t 1000260560 -n 200000 -k 0.062 -m HINCL*
- For ν, e – everything comes from config files

Validation in gevgen_hadron
n, p, π nucleus interactions

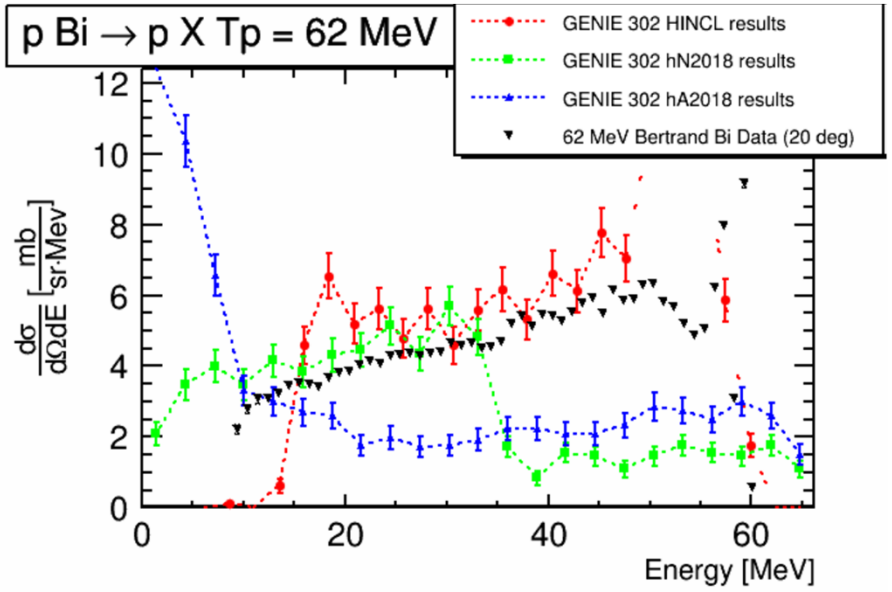
- Verify GENIE INCL agrees with standalone INCL
- 62 MeV p Fe → p X is standard

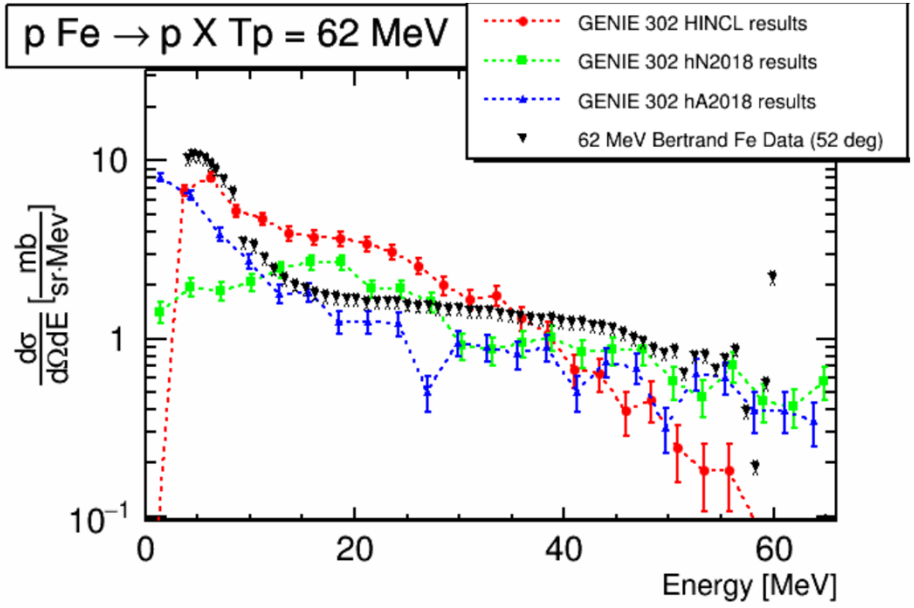




Validation in gevgen_hadron
n, p, π nucleus interactions

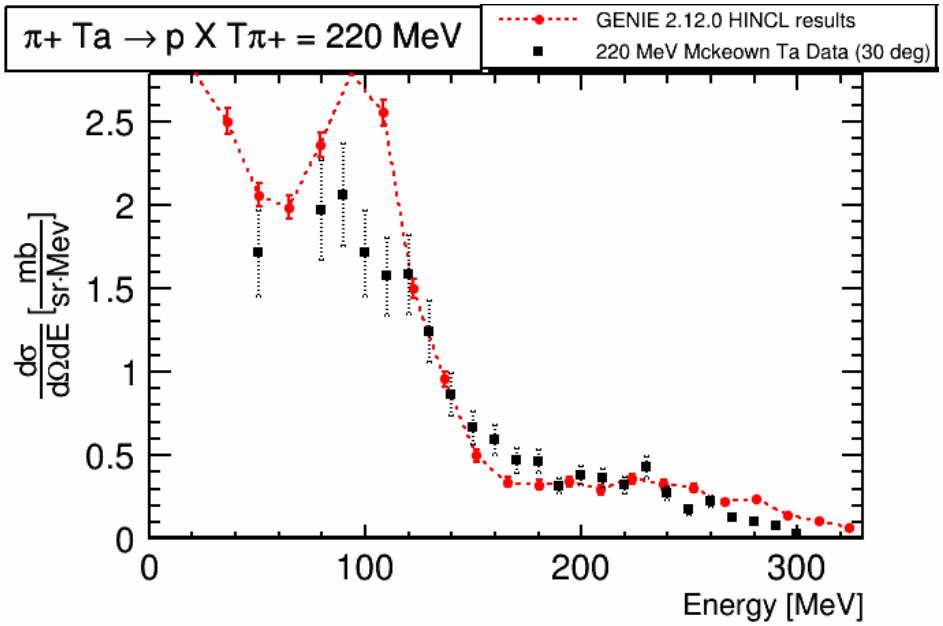
- Compare INCL with hA2018 and hN2018
- INCL has better agreement with pFe and pBi at 62 MeV
  - Solid, but not dramatic improvement

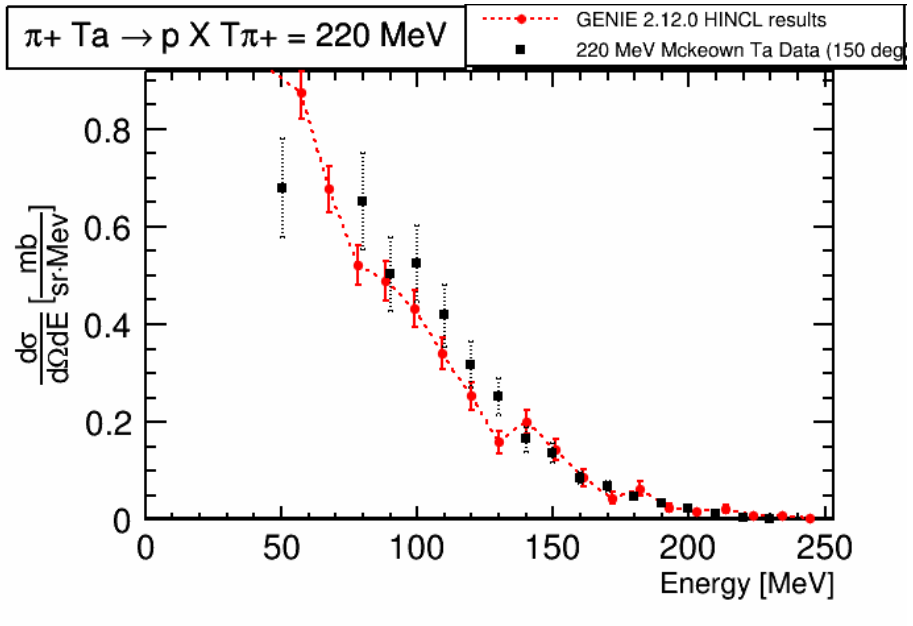




Validation in gevgen_hadron
n, p, π nucleus interactions

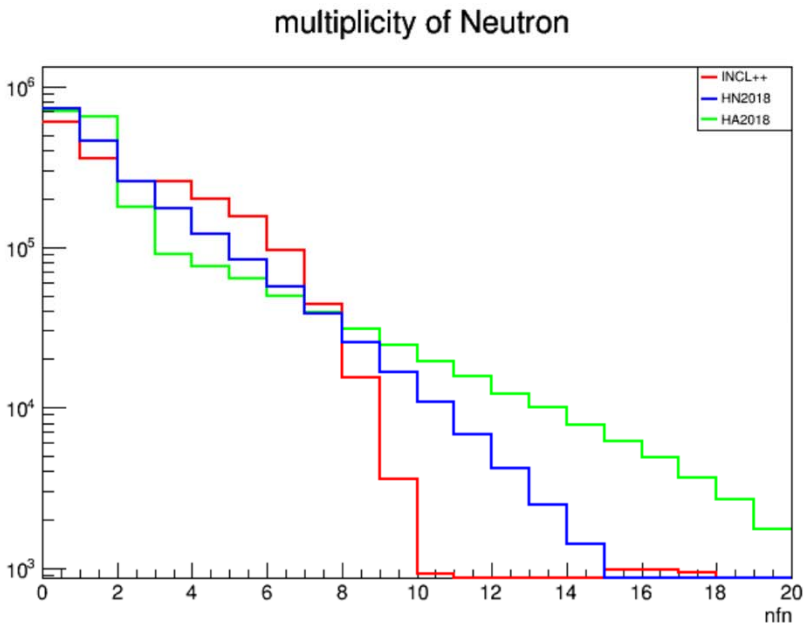
- 220 MeV π^+ A $\rightarrow$ p X tests pion, proton interactions
- Surprisingly good agreement (equal to hA or hN)

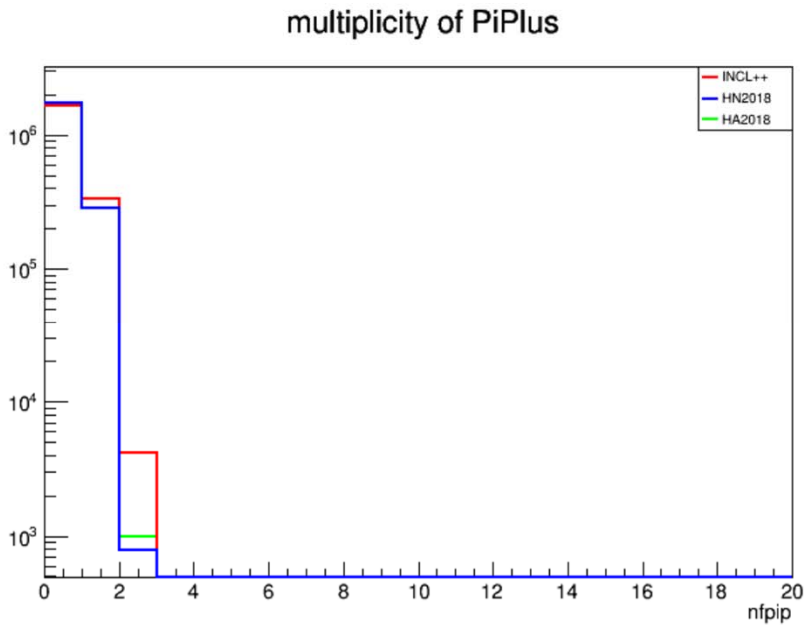




Validation in gevgen
2 GeV ν Ar multiplicity

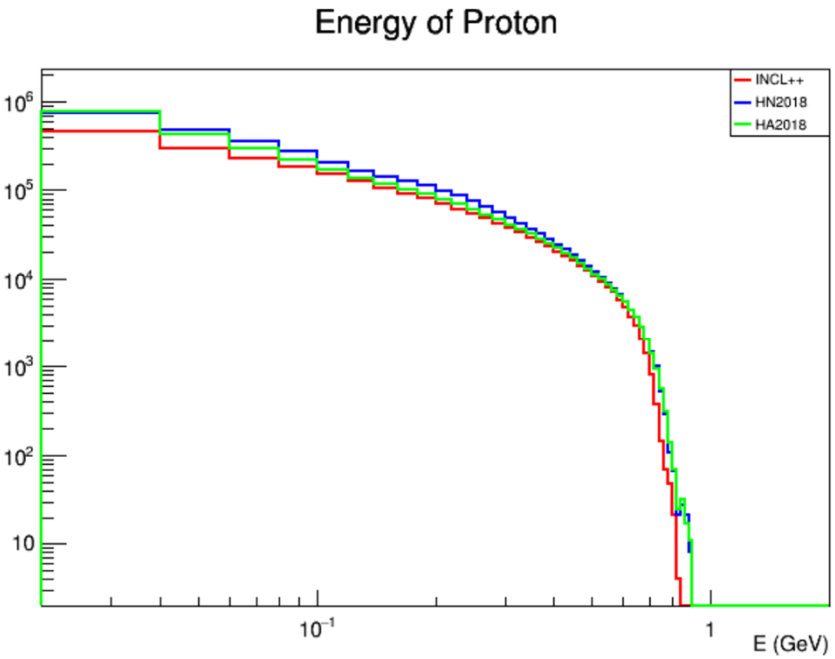
- This is a test for important nucleus where many kinds of primary processes can be examined
- Neutrons somewhat different, pions very similar

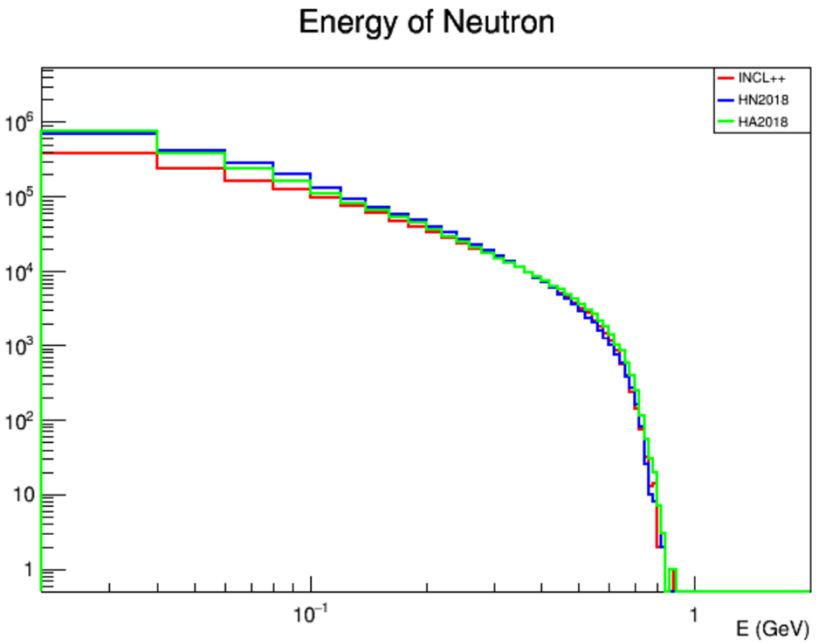




Validation in gevgen
2 GeV ν Ar energy distributions

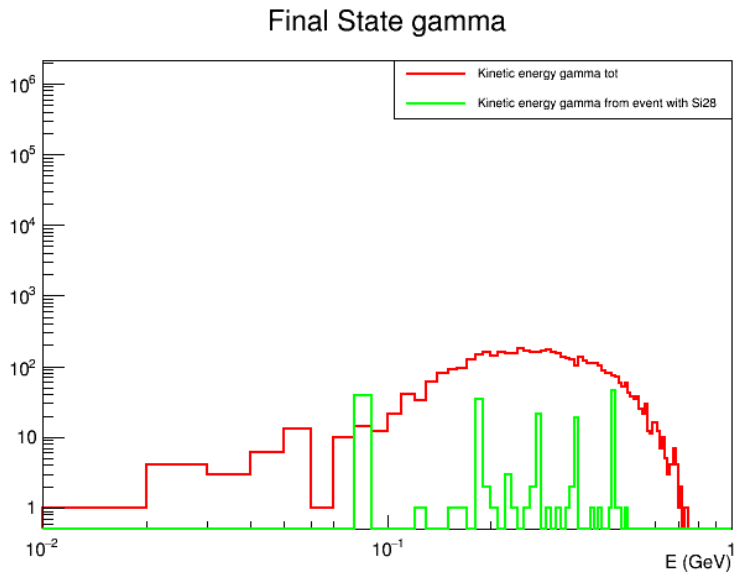
- hA and hN known to be bad for p vs. n
  - p and n equal but should be more n due to Coulomb
- Differences not large on log-log plot

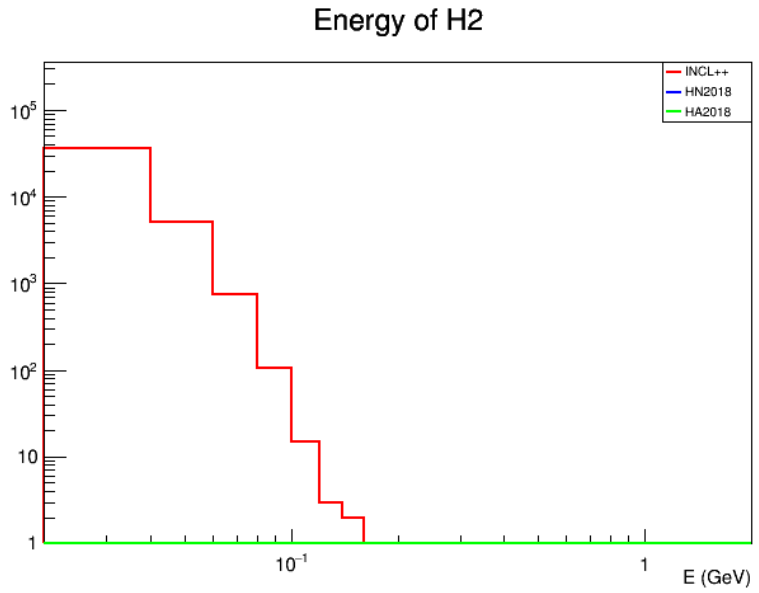




Validation in gevgen
2 GeV ν Ar energy distributions

- Final state particles not now available in GENIE



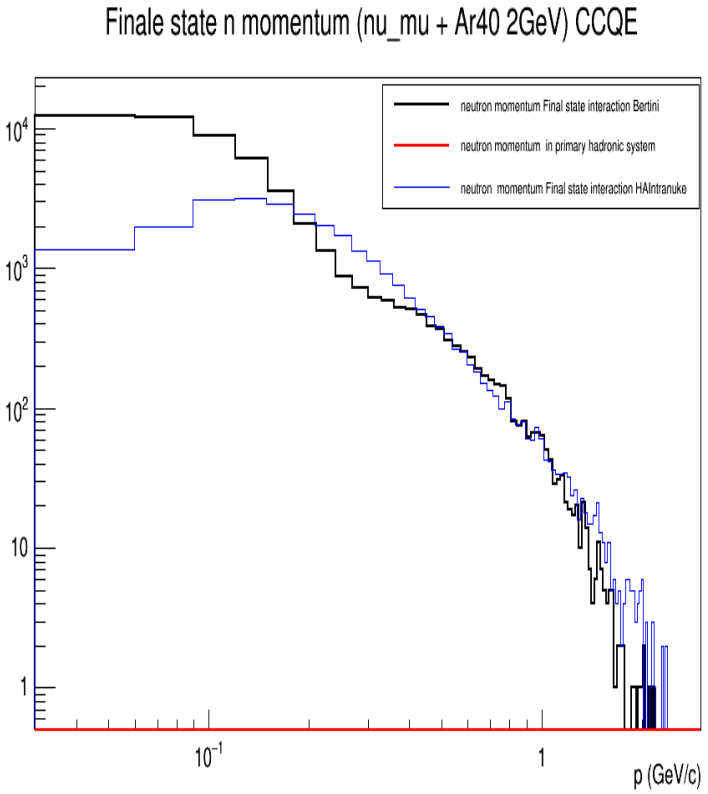


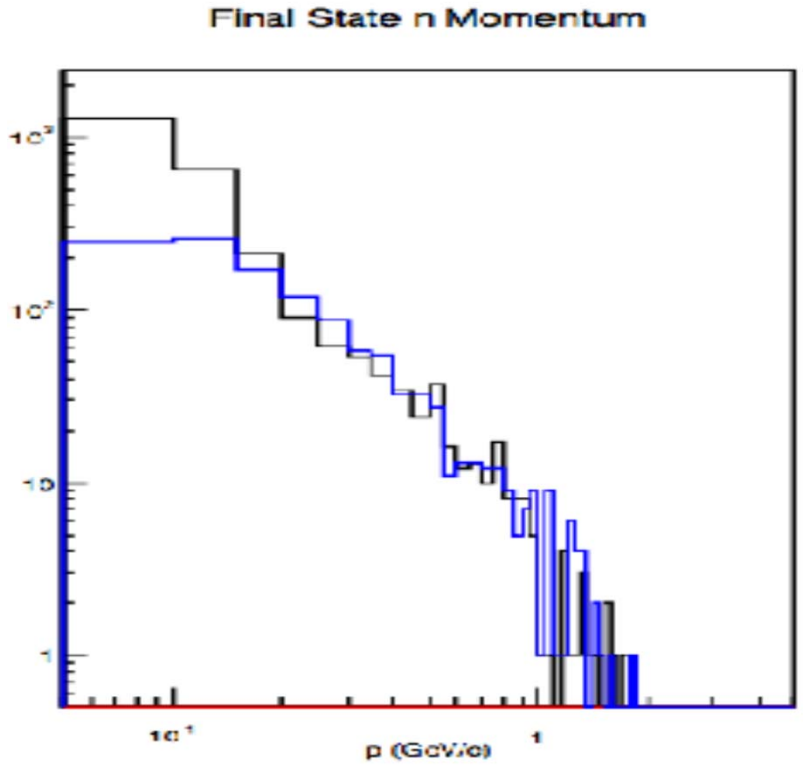
GEANT4 progress

- Initial work by Dennis Wright 2015-6 in consultation with Gabe, Robert, and me
- DOE project makes it more important
- DOE forced Dennis off the project as it was completing
  - Marc did work to verify code in Hepforge was correct
- Marc added the gevgen_hadron interface, no results at the moment

Validation plots for GEANT4
2 GeV ν Ar – n from CCQE (all from FSI)

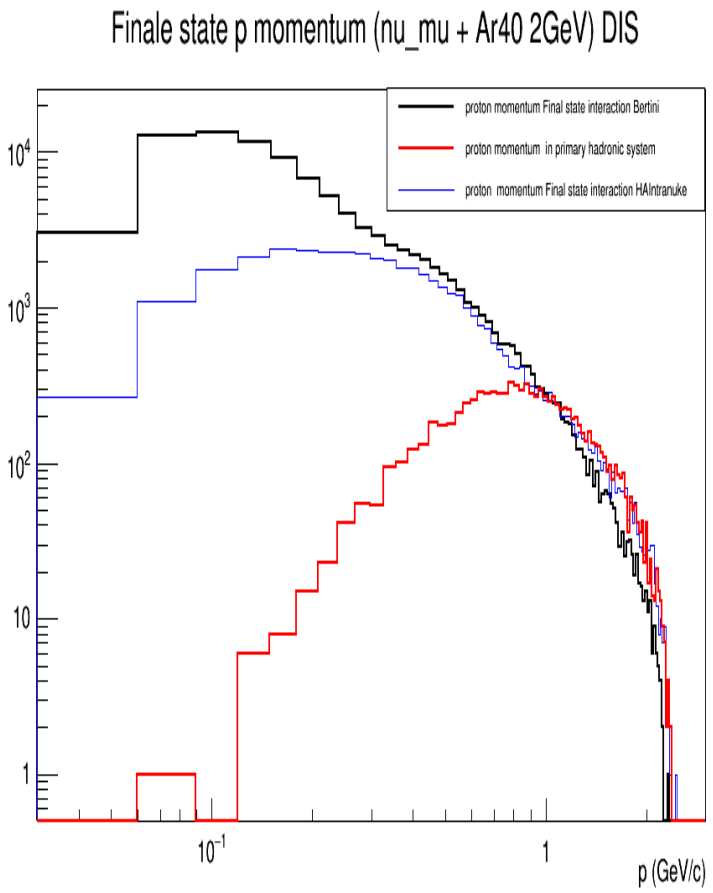
- Produced by Dennis, verified by Marc
- Not in GitHub yet, Robert signed up for final validation

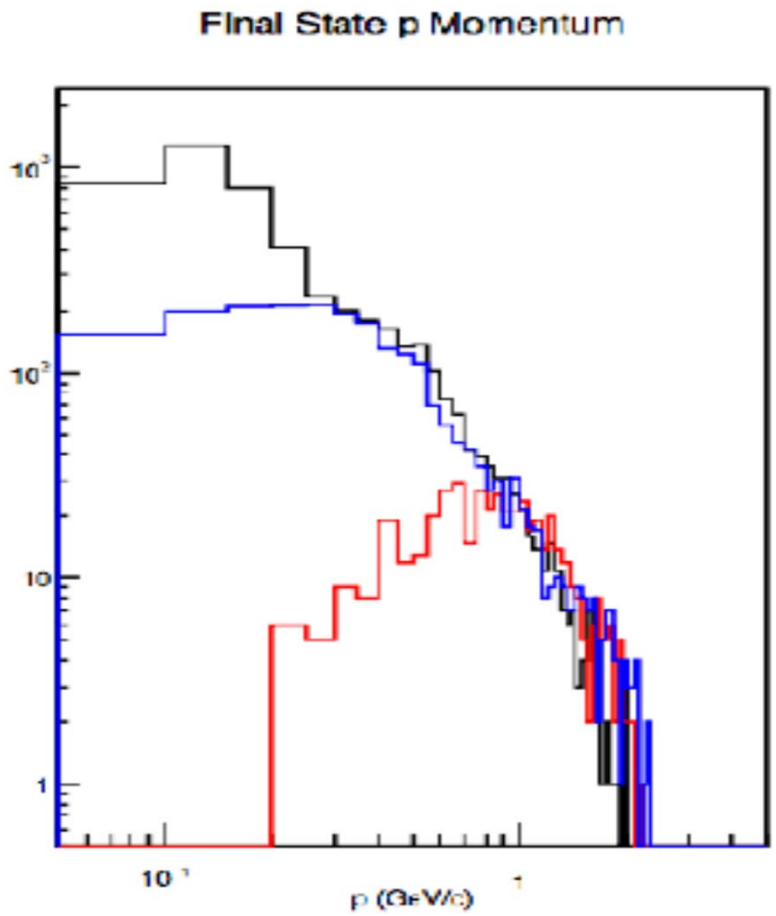




Validation plots for GEANT4
2 GeV ν Ar – p from DIS (almost all from FSI)

- Produced by Dennis, verified by Marc





Summary

- π^0N, nn updates – Grace Chu
  - Should be straightforward, not in GitHub yet
- **INCL++ - Marc Vololoniaina, Robert Hatcher**
  - **Marc needs access to GENIE Comparison software**
  - **Ready for final review?**
- GEANT4 – Dennis Wright, Marc, Robert
  - Ready for final review?
- New hN processes from Sato-Lee – Grace Chu, Harry Lee
  - Project just starting, but simplicity indicates finish in summer, 2019
- Binding energies in pion absorption – Steve
  - Needs manpower and ideas – finish in summer?