10th workshop on Neutrino-Nucleus Interactions in the few GeV region (NuInt 2015)

Generators for the SIS/DIS region

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2015-11-19

KAVLI IPMU

Introduction

- Generator comparison: run the different generators at different fixed energies for different targets and compare the ouputs

- Focus on **charged current interactions**
Assume SIS/DIS region = **W>1.7 GeV**
All interactions from **muon neutrinos and anti-neutrinos**

- Comparisons will be mainly multiplicities (charged hadrons, pions and neutral pions) and some kinematical variables (W, Q2, leading pion momentum)

- Also have a look at particle content for the “custom models” used by generators to model DIS interactions where PYTHIA cannot be used

- Start by describing how the generators treat the transition and DIS regions

Generators

Generated event for the following 3 generators:

- ➔ **NEUT 5.3.4**
- ➔ **GENIE 2.10 (hA and hN)**
- ➔ **NuWro11q**

CC DIS and RES modes only (+QE charm for GENIE)

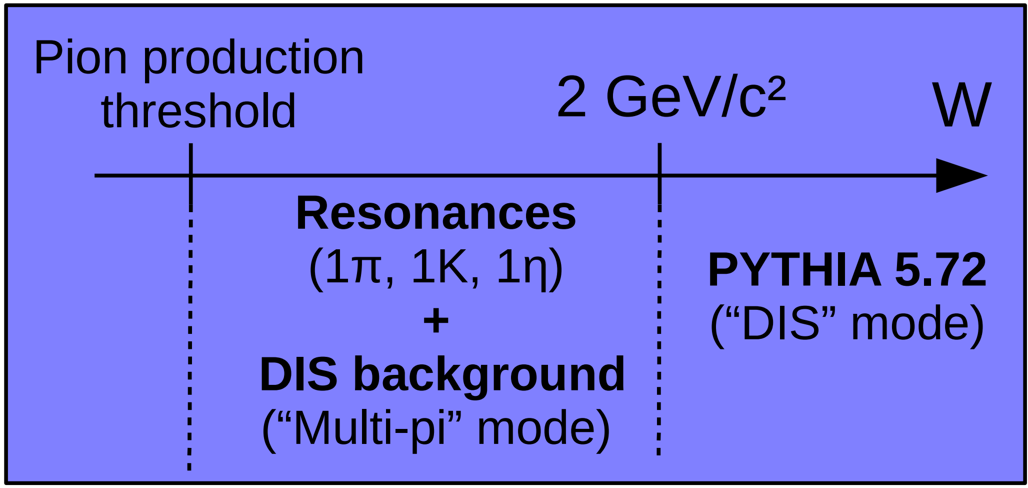
When possible took information for GiBUU from O. Lalakulich and U. Mosel, AIP Conf.Proc. 1663 (2015) 040004 arxiv: 1303.6677v2

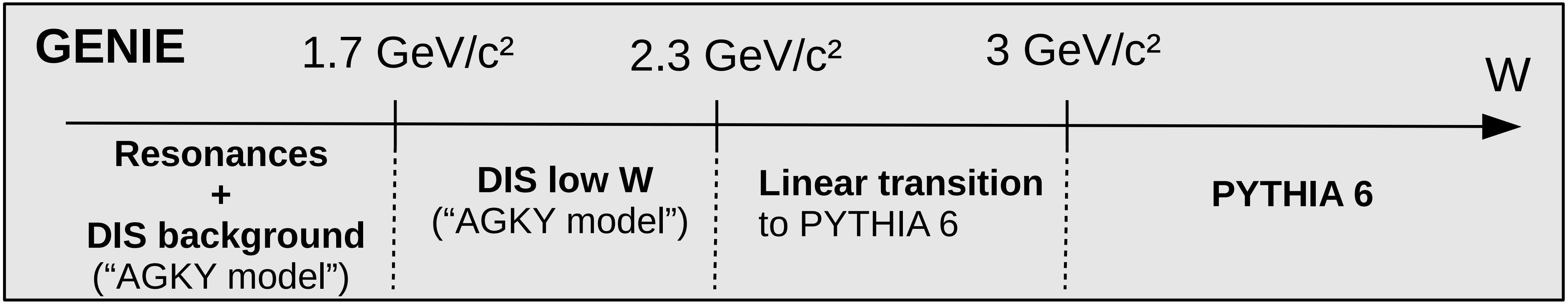
See dedicated talks on Friday
for more details on the generators

SIS-DIS region in the generators

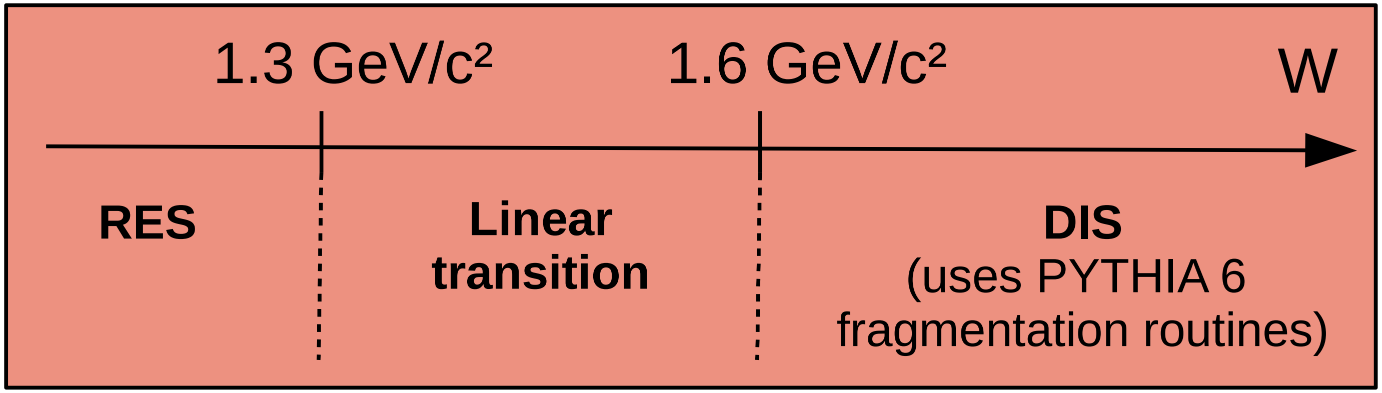
- Different models as a function of W
- Combination of resonances and DIS continuous parametrization
- Use GRV98 + Bodek-Yang corrections for cross-sections of the DIS components

NEUT



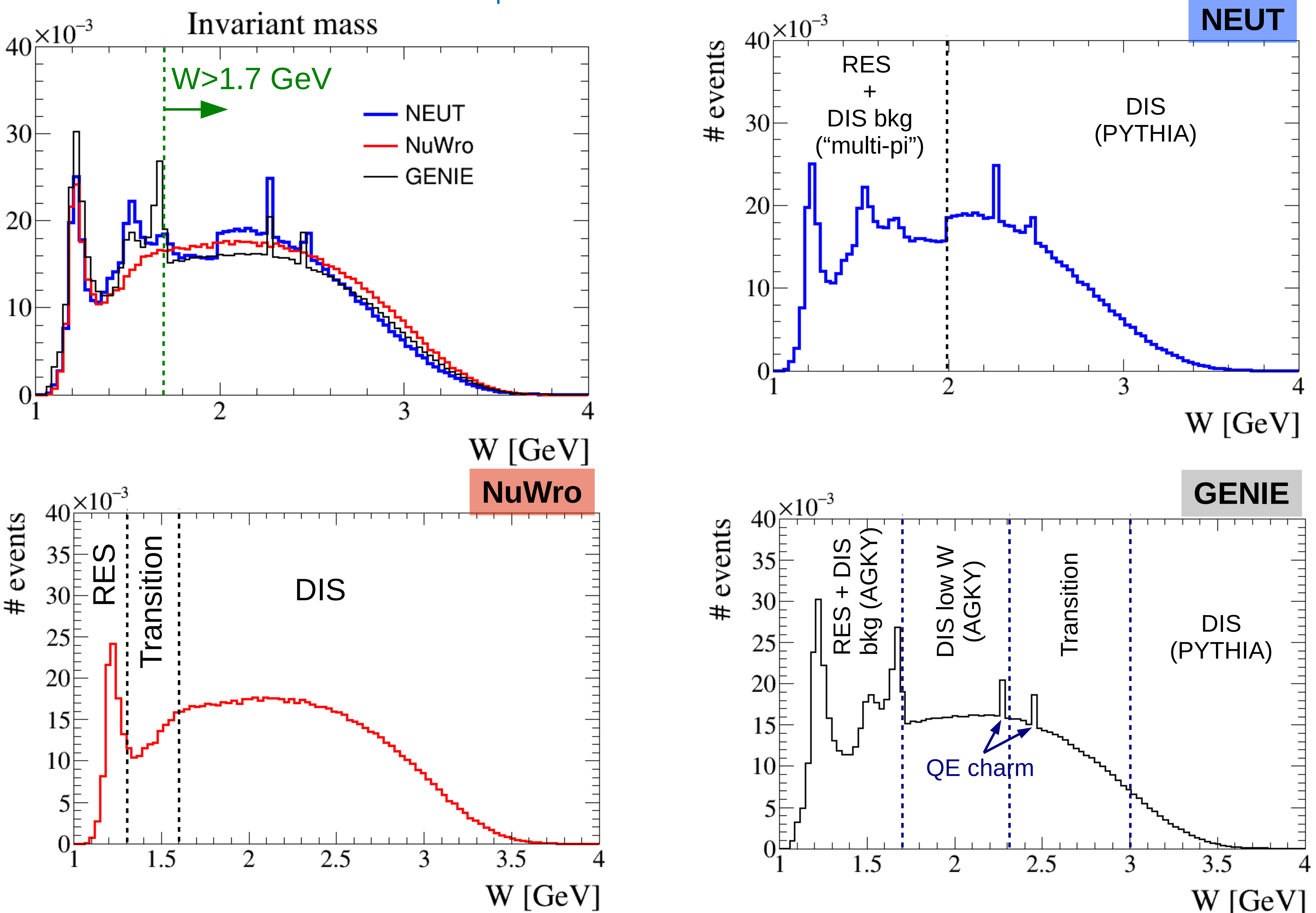


NuWro



Invariant mass distribution

ν_μ on Fe, E_ν=6.0 GeV



Charged hadron multiplicities

- Generators then convert the available W into particles
  First look at how many particles get created

- Multiplicities visible in the detector also depends on FSI.
  Start by checking generator output before FSI by looking at interactions on free nucleons

- Bubble chamber experiments measured charged hadron multiplicities in neutrino/anti-neutrino interactions on deuterium:
  - BEBC from B. JongeJans et al., Nuovo Cim. A **101**, 435 (1989)
  - Fermilab 15' from D. Zieminska et al., Phys. Rev. D **27**, 47 (1983)

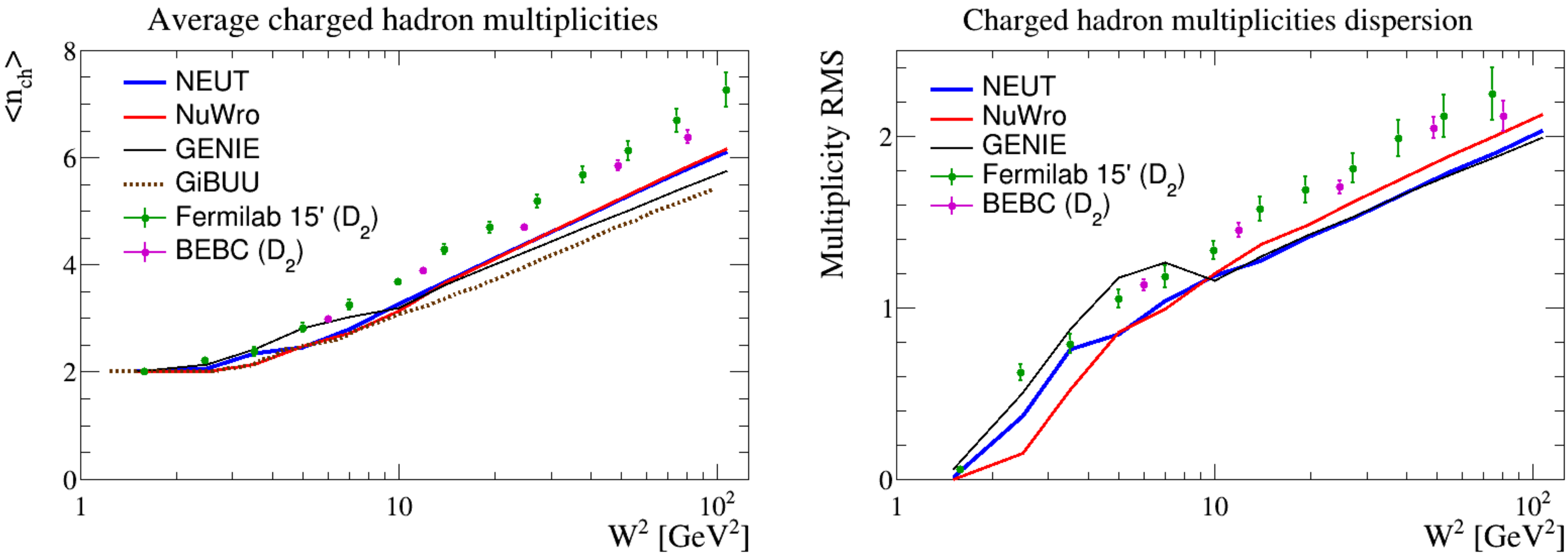
Settings

(similar to GENIE validation tools)

- Free neutron and proton for GENIE and NuWro
  CH without FSI for NEUT
- 0.5 GeV < E_ν < 80 GeV
- Flux proportional to $1/E_\nu$

Charged hadron multiplicities
Neutrinos on proton

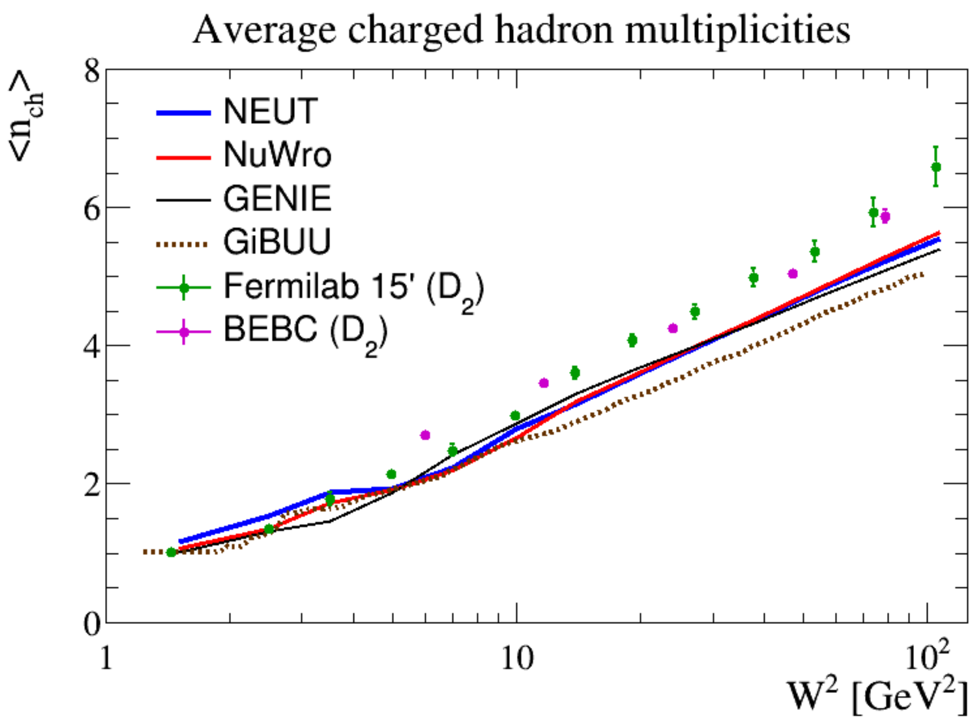
- Average charged hadron multiplicity observed to be a linear fonction of log(W^2) in bubble chamber data
  (K. Kuzmin and V. Naumov argue for a quadratic function at low W in PRC 88, 065501 (2013))

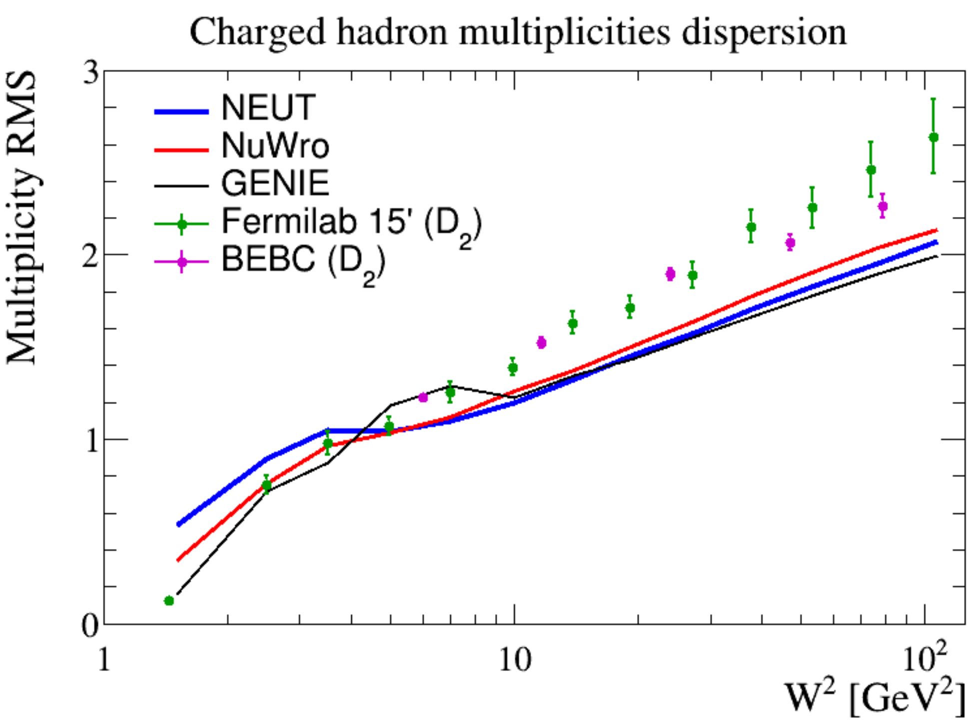


All generators seem to underestimate both average and dispersion of the charged hadron multiplicities

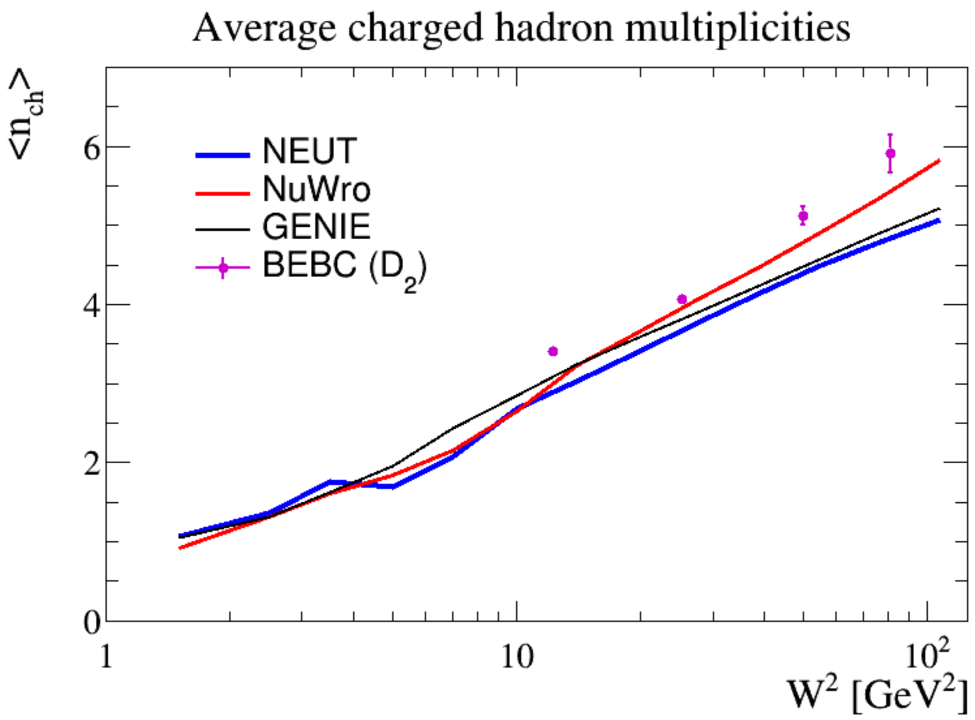
Charged hadron multiplicities
Neutrinos on neutron

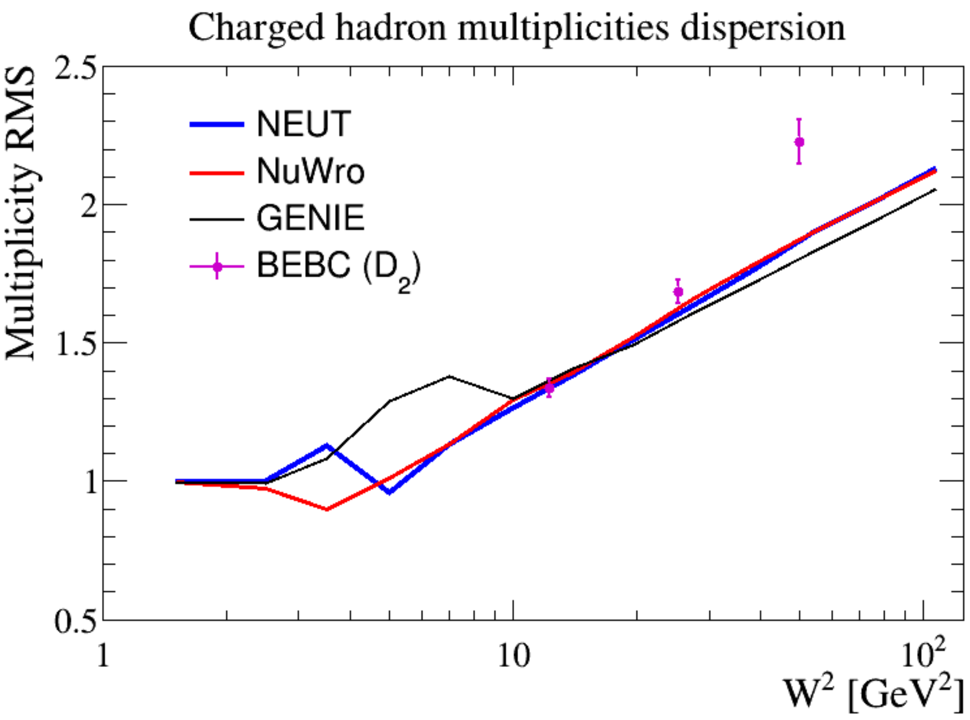
Similar pattern for interaction of neutrinos on neutron:



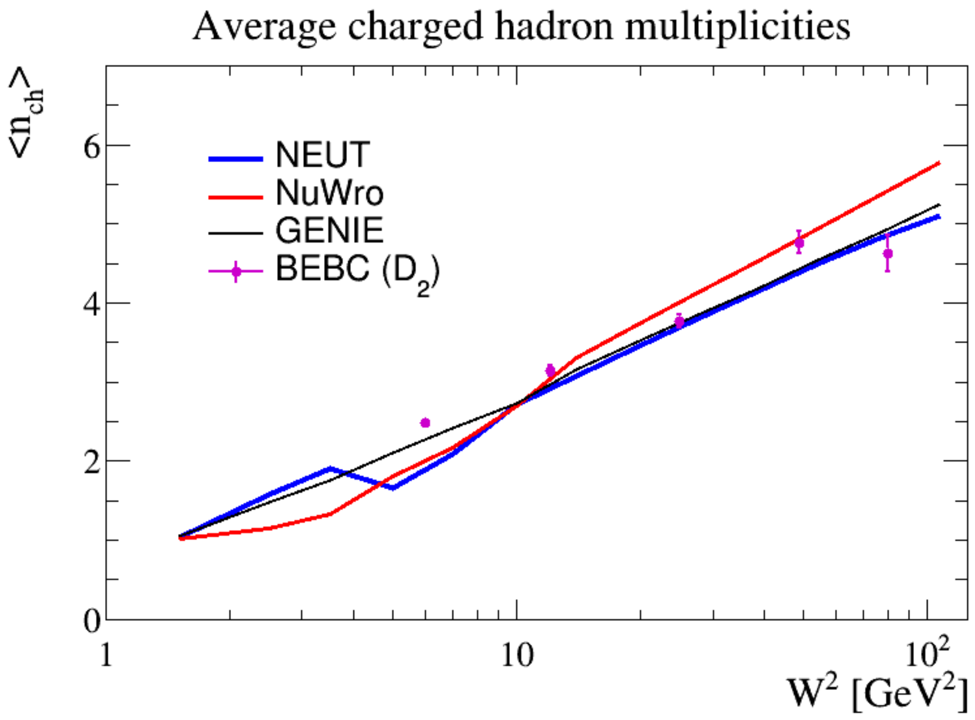


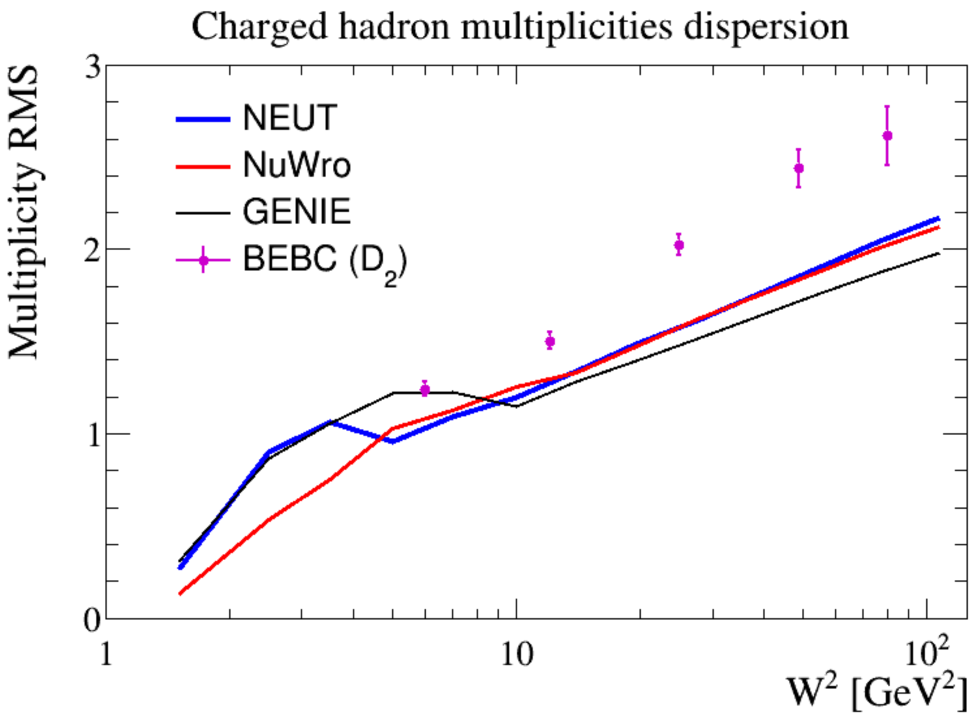
Charged hadron multiplicities
Anti-neutrinos on proton





Charged hadron multiplicities
Anti-neutrinos on neutron

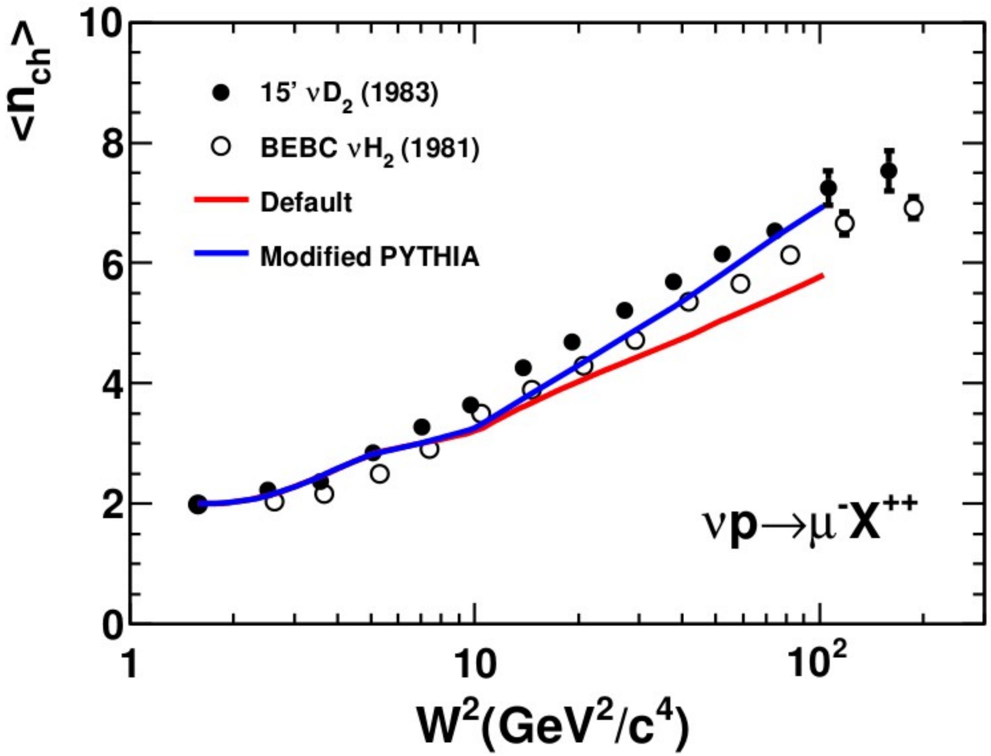


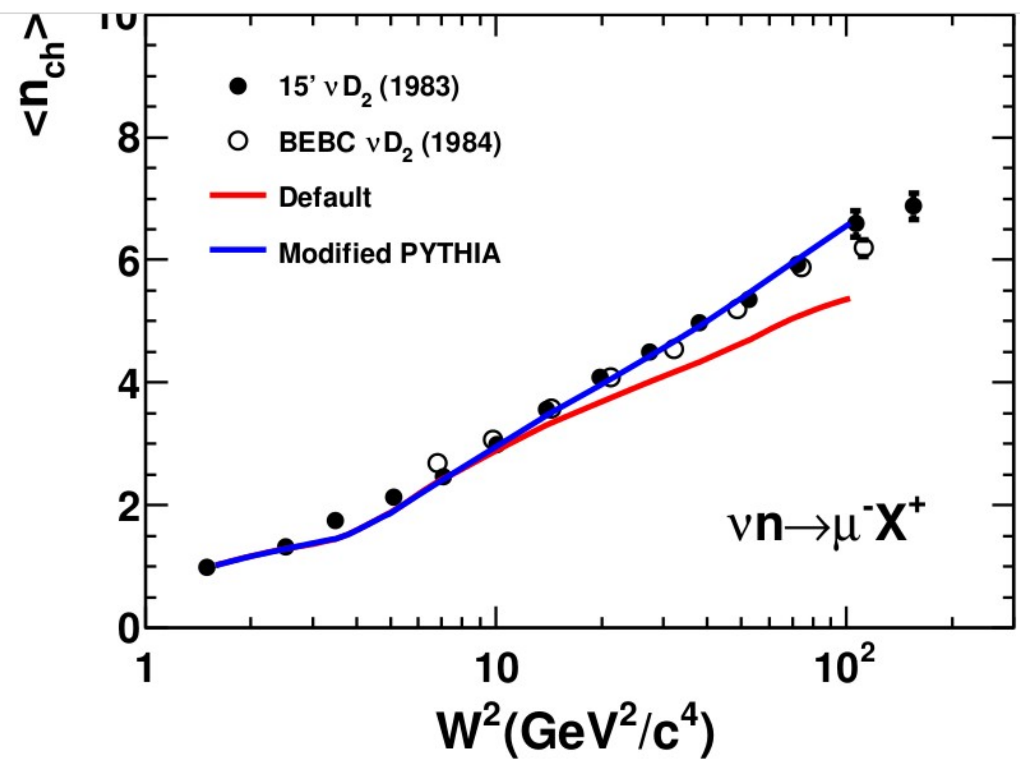


Tuning charged hadron multiplicities
Tuning PYTHIA

Tuned PYTHIA parameters using expertise from members of the HERMES collaboration

Allows to properly reproduce average charged hadron multiplicities when tested in GENIE:





<u>Also found some difficulties:</u>

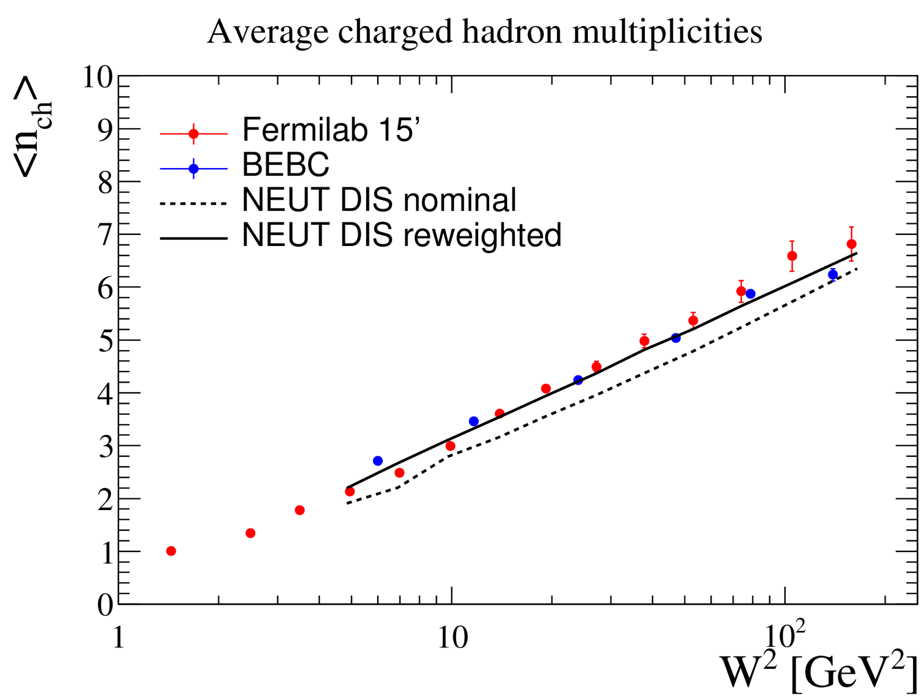
- dispersion of the charged hadron multiplicities
- neutral hadron multiplicities

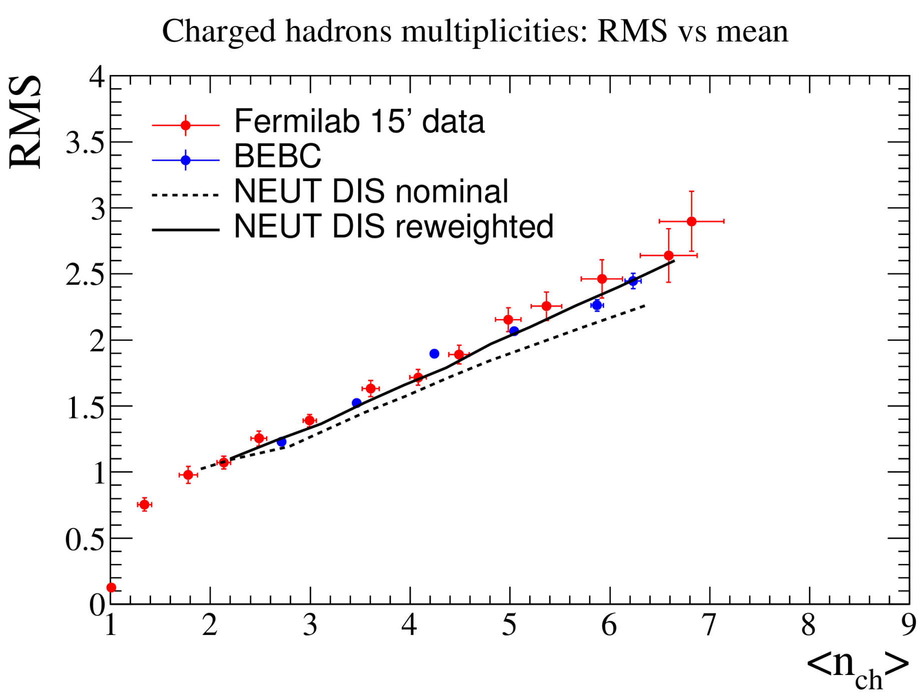
"Further tuning is ongoing"

T. Katori, S. Mandalia
arxiv: 1412.4301v3

Tuning charged hadron multiplicities
Reweighting approach

- Apply weights to event generated by NEUT to make them reproduce 2D distribution (W^2, n_{ch}) measured by bubble chamber experiments.
- By construction gives good agreement for both average multiplicities and the dispersion (but need to check effect on neutral hadrons)





Plan to use this reweighting approach to propagate uncertainties on charged hadron multiplicities to physics analyses

C.B, poster G-1 at NuInt 2015

Comparisons for different targets and energies

Now moving to the comparisons on different targets at fixed energies:

- **CH at 2 GeV** (6 bound protons, 6 bound neutrons, 1 free proton)
- **Ar at 2.5 GeV** (18 bound protons, 22 bound neutrons, 0 free protons)
- **H_2O at 4 GeV** (8 bound protons, 8 bound neutrons, 2 free protons)
- **Fe at 6 GeV** (26 bound protons, 30 bound neutrons, 0 free protons)

5 different comparisons for each:

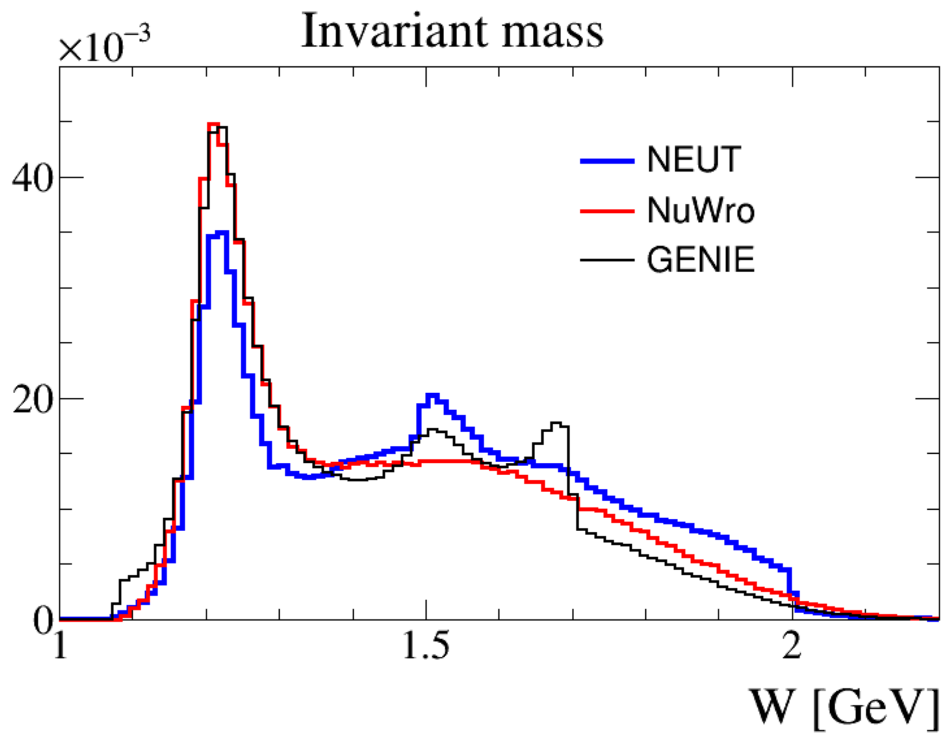
- **W** distribution - computed as $W^2=(P_\nu+P_{nuc}-P_\mu)^2$
- **Q^2** distribution - computed as $Q^2=(P_\nu-P_\mu)^2$
- **n_{ch}**: charged hadron multiplicities
- **n_π**: pion (charged + neutral) multiplicities
- **$n_{\pi 0}$**: neutral pion multiplicities

Except for the W distributions, a cut W>1.7 GeV is applied

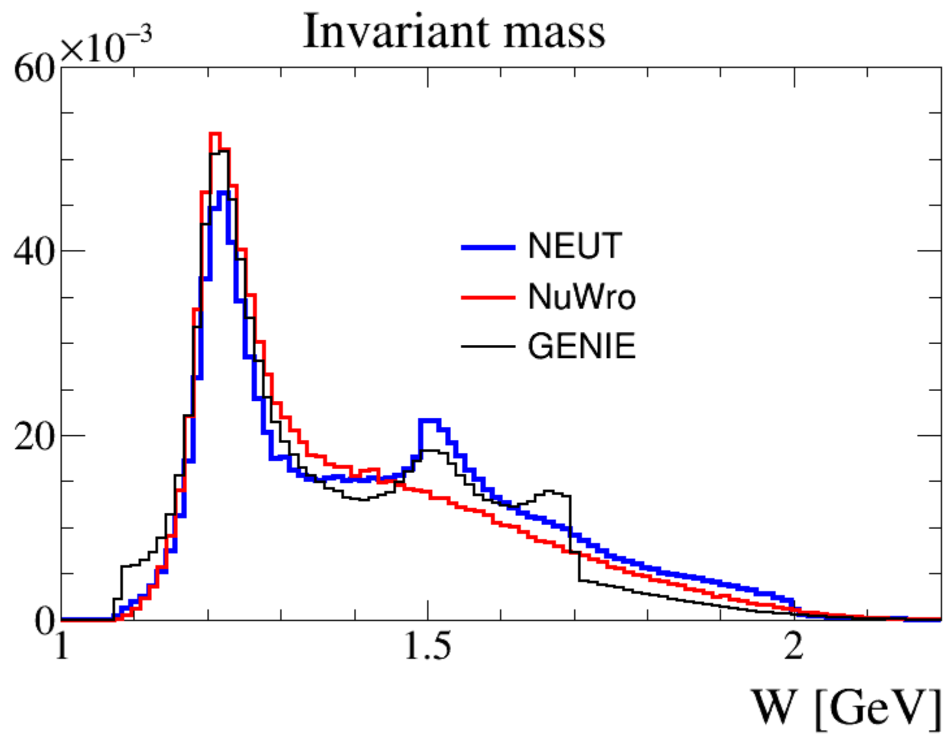
All plots are normalized by area

W distributions
CH, E_ν=2.0 GeV

Neutrino



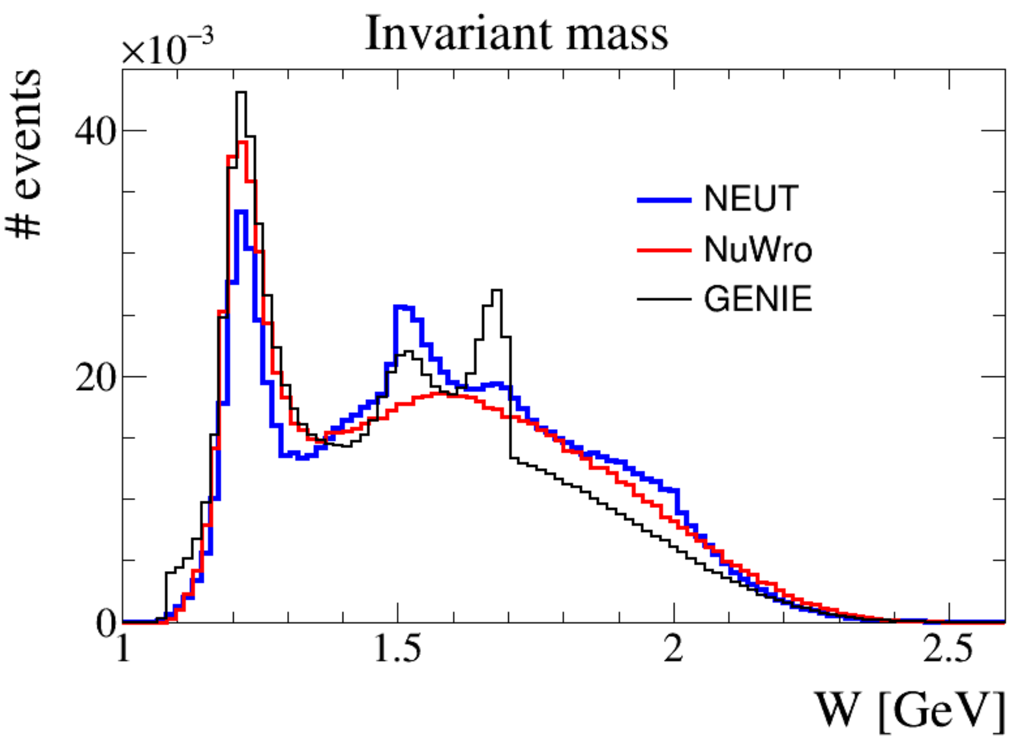
Anti-neutrino



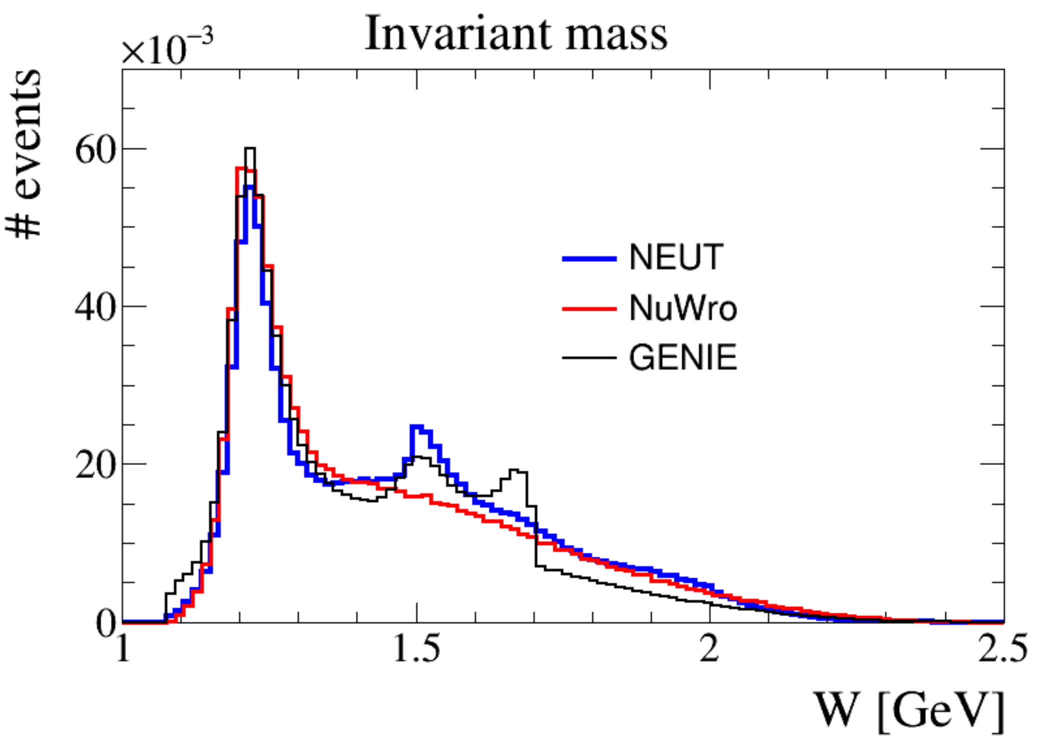
Main differences are presence or absence of certain resonances
Won't affect comparisons at W>1.7 GeV

W distributions
Ar, E_ν=2.5 GeV

<u>Neutrino</u>



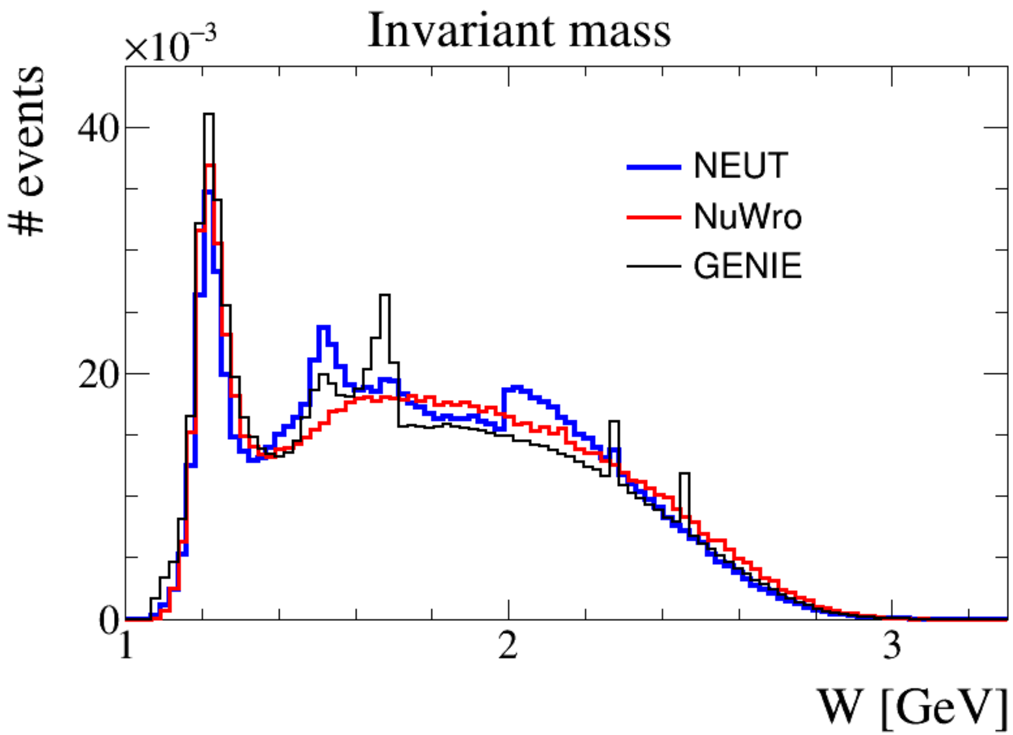
<u>Anti-neutrino</u>



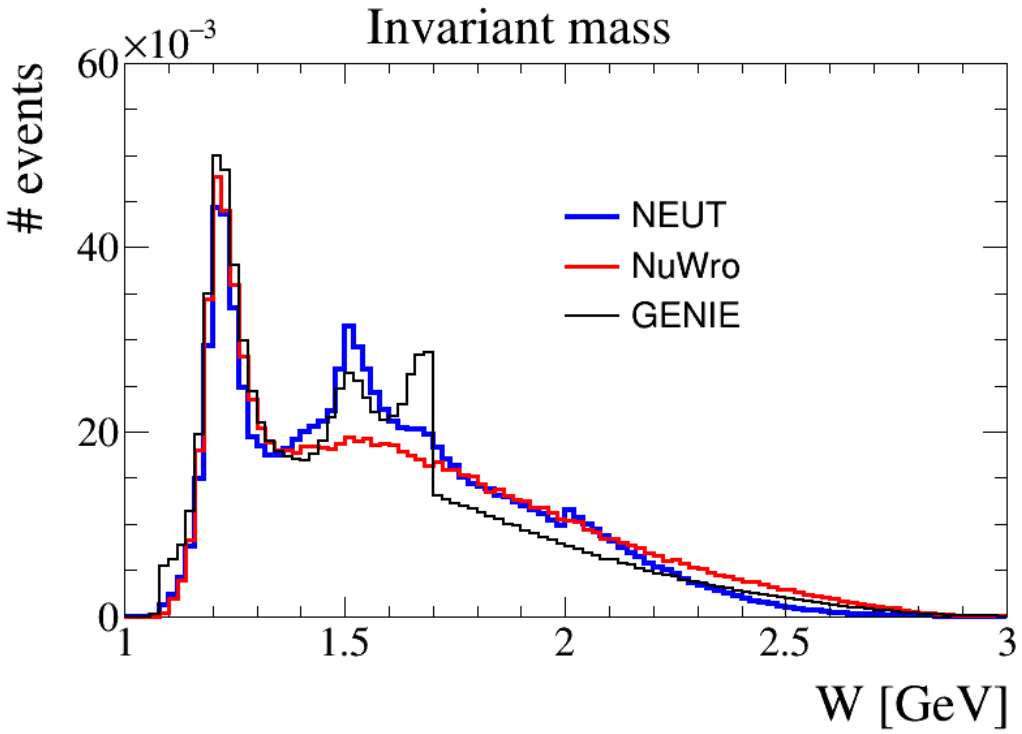
Same patter as CH at 2.0 GeV

W distributions
H_2O, E_ν=4.0 GeV

Neutrino



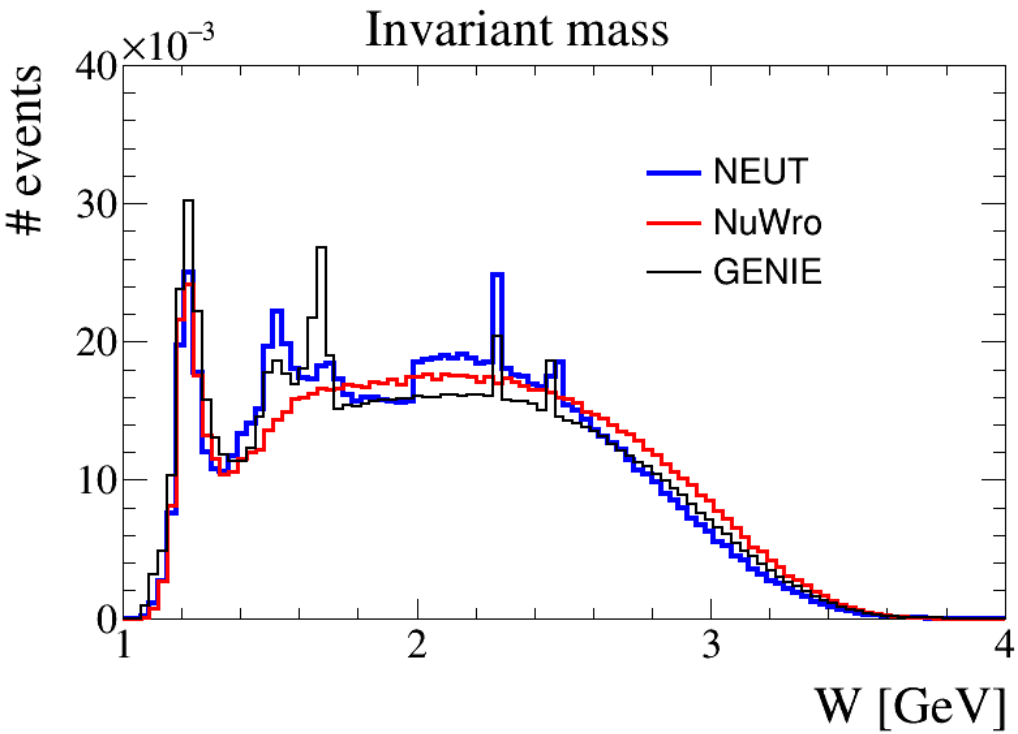
Anti-neutrino



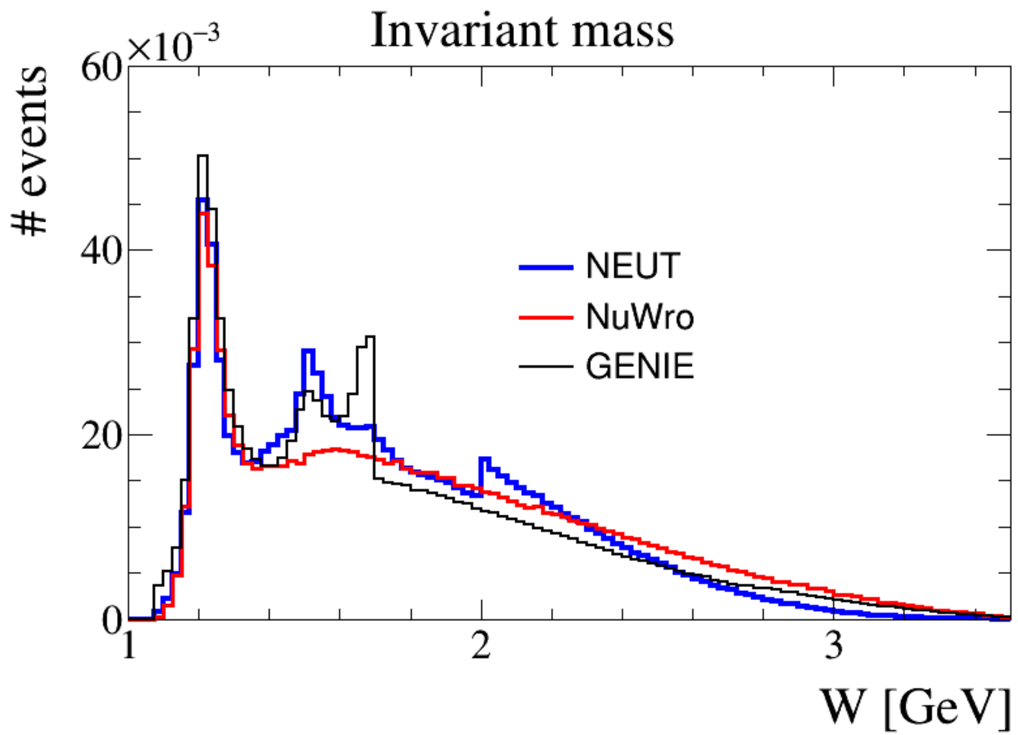
Additional difference is the discontinuity at W=2.0 GeV for NEUT

W distributions
Fe, E_ν=6.0 GeV

Neutrino



Anti-neutrino

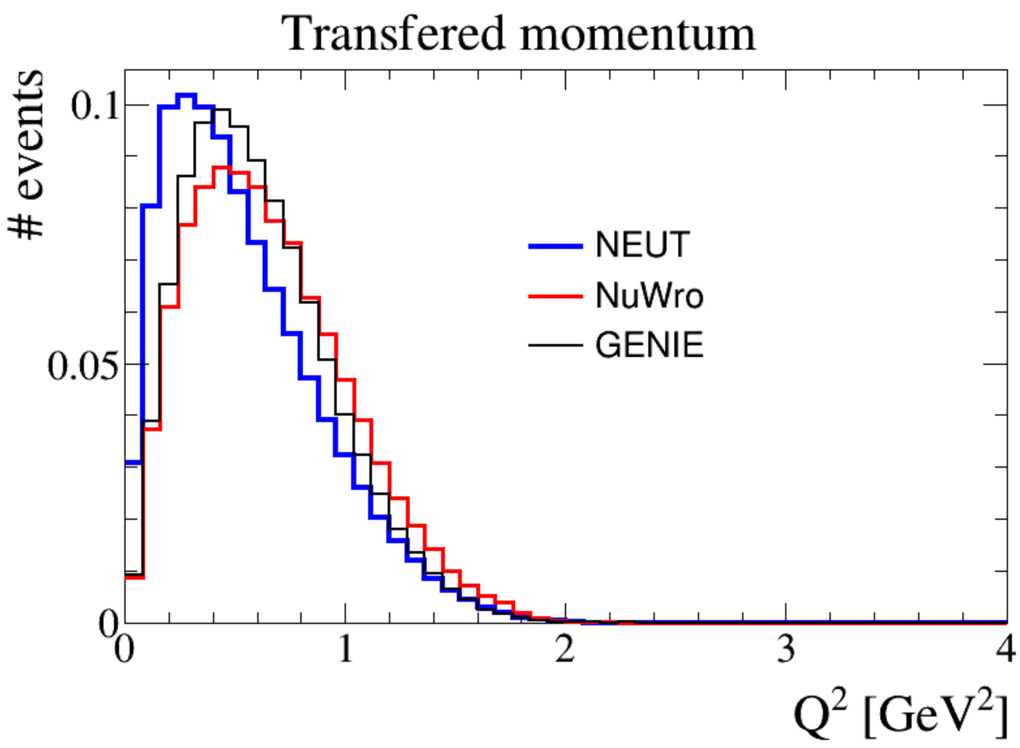


Peak for QE charm events scales differently with energy for GENIE and NEUT.
Not seen in NuWro

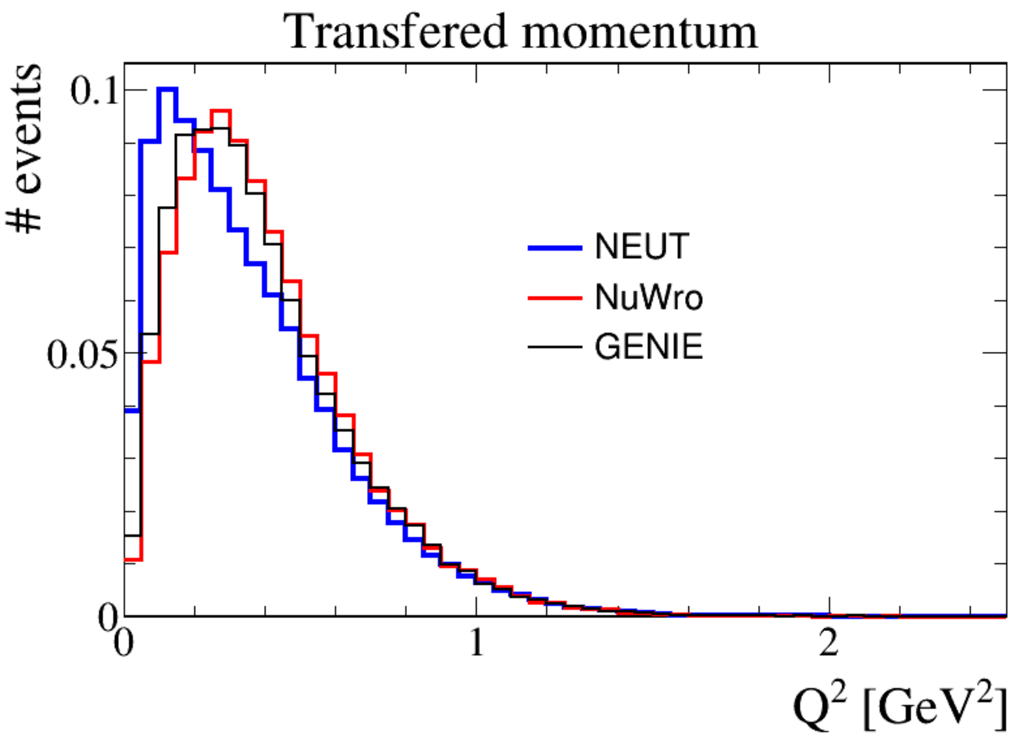
Q^2 distributions
CH, E_ν=2.0 GeV

W>1.7 GeV

Neutrino



Anti-neutrino

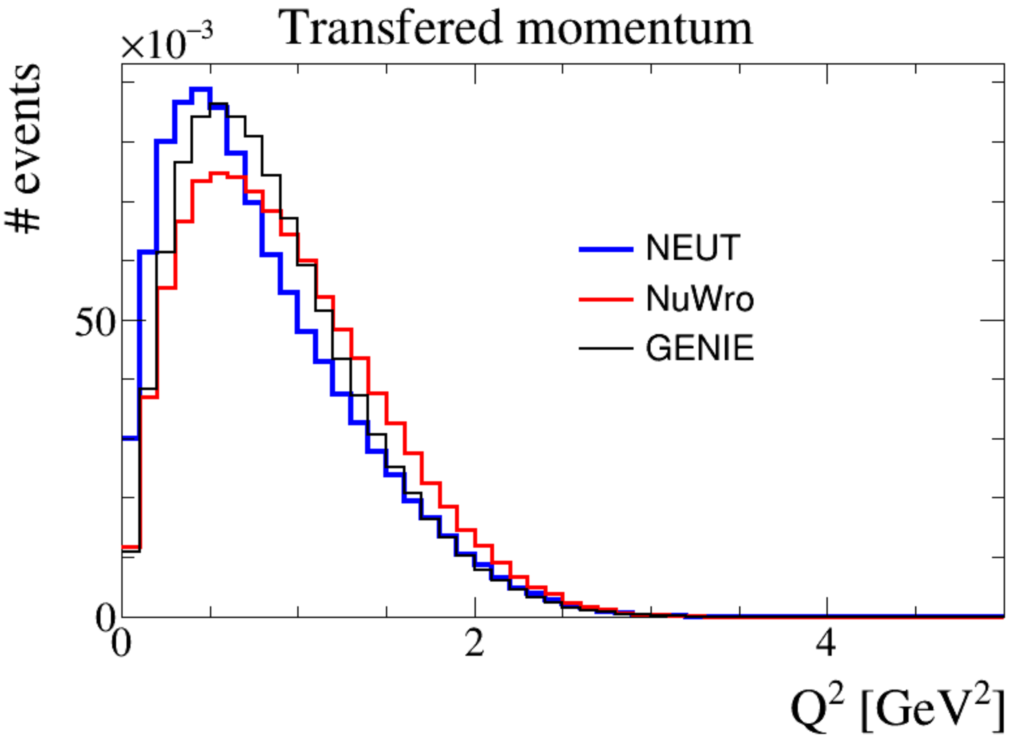


NEUT distributions peaked at lower Q^2

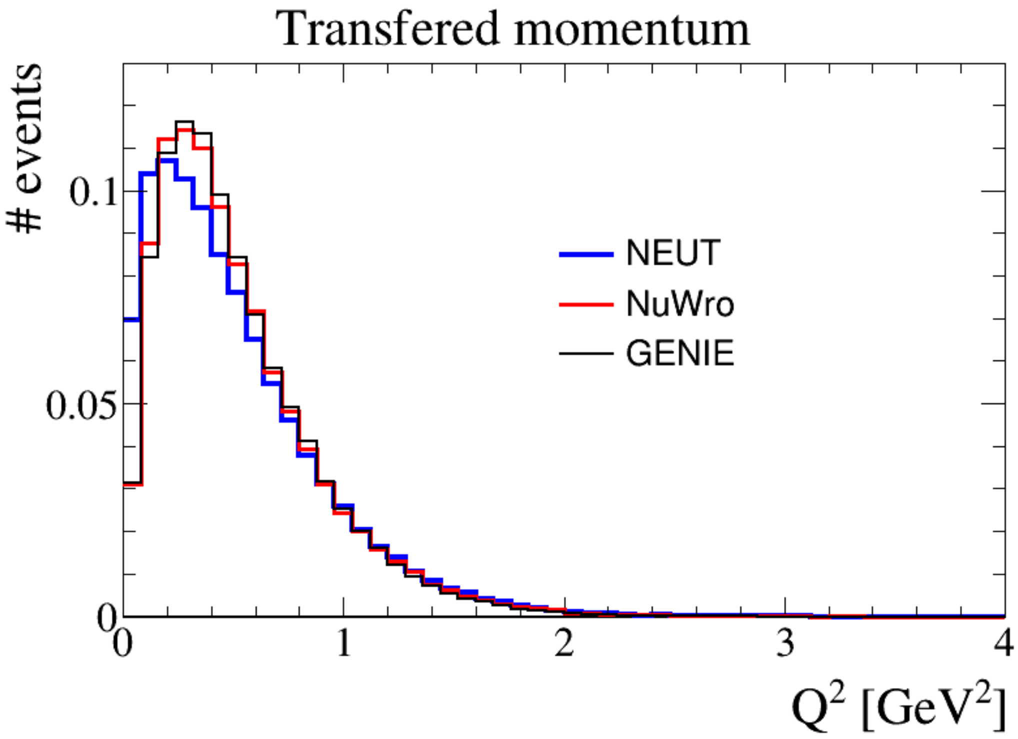
Q^2 distributions
Ar, E_ν=2.5 GeV

W>1.7 GeV

Neutrino



Anti-neutrino

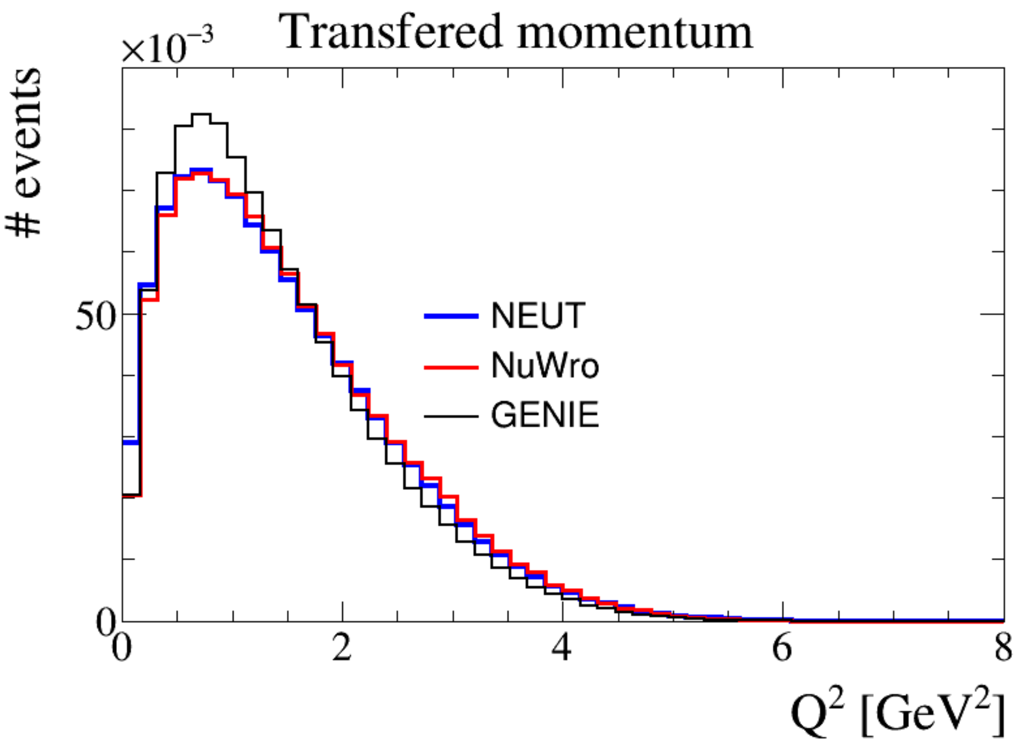


NEUT distributions still peaked at lower $Q^{2,}$ but get closer to the other generators.

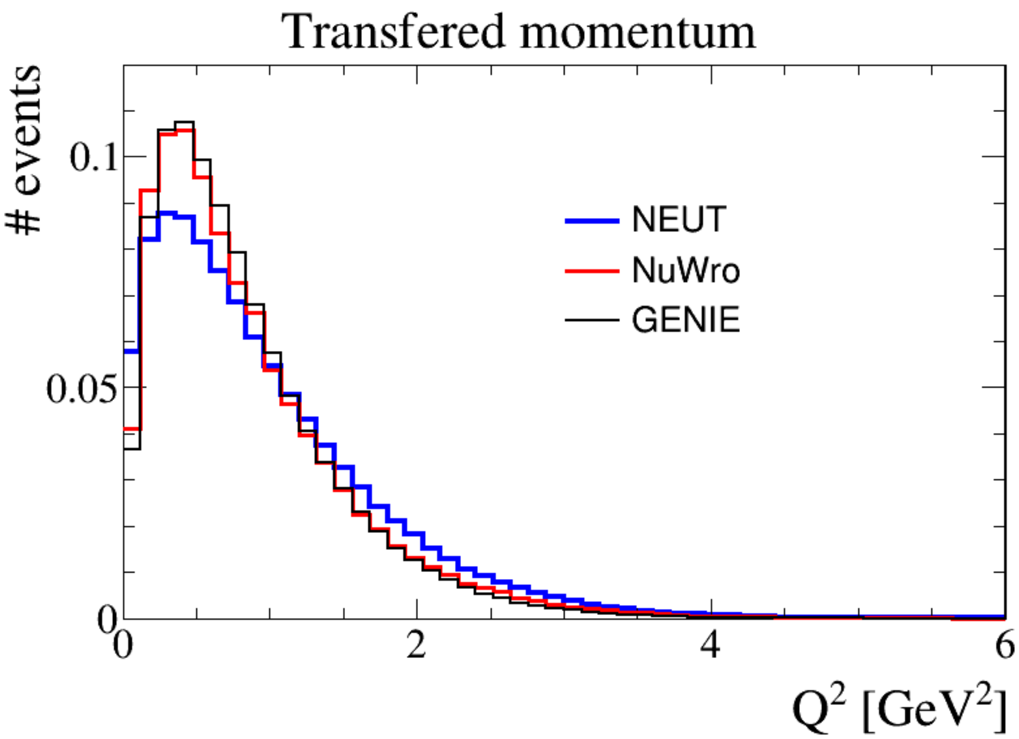
Q^2 distributions
H_2O, E_ν=4.0 GeV

W>1.7 GeV

Neutrino



Anti-neutrino

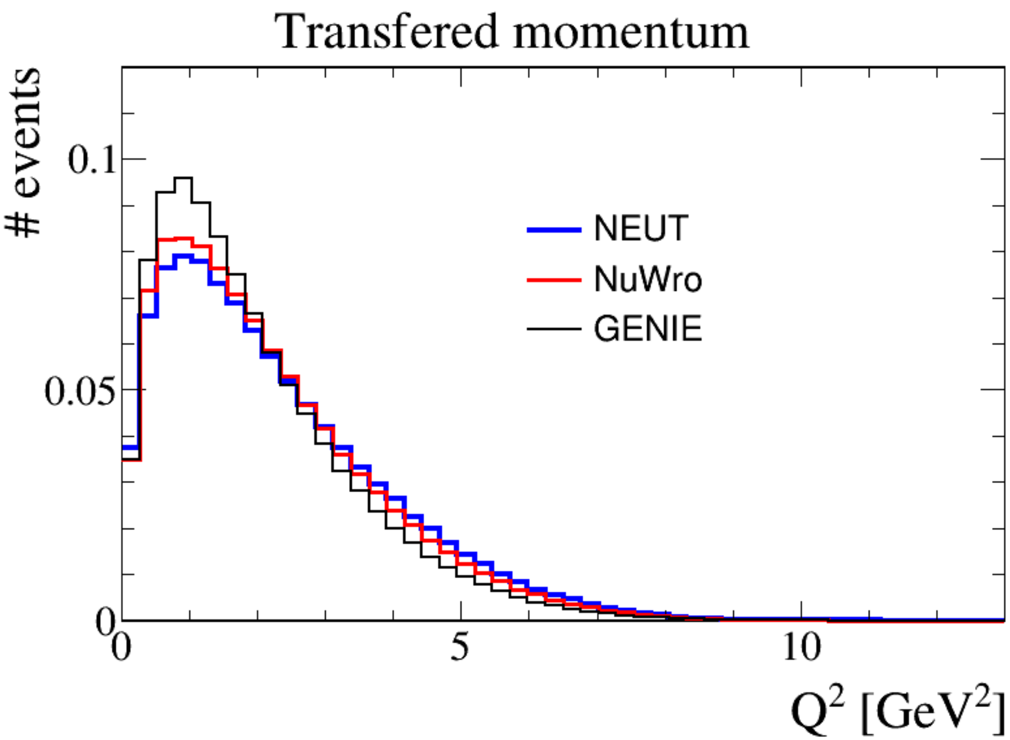


All 3 generators peaked around the same Q^2 value, but difference in spread

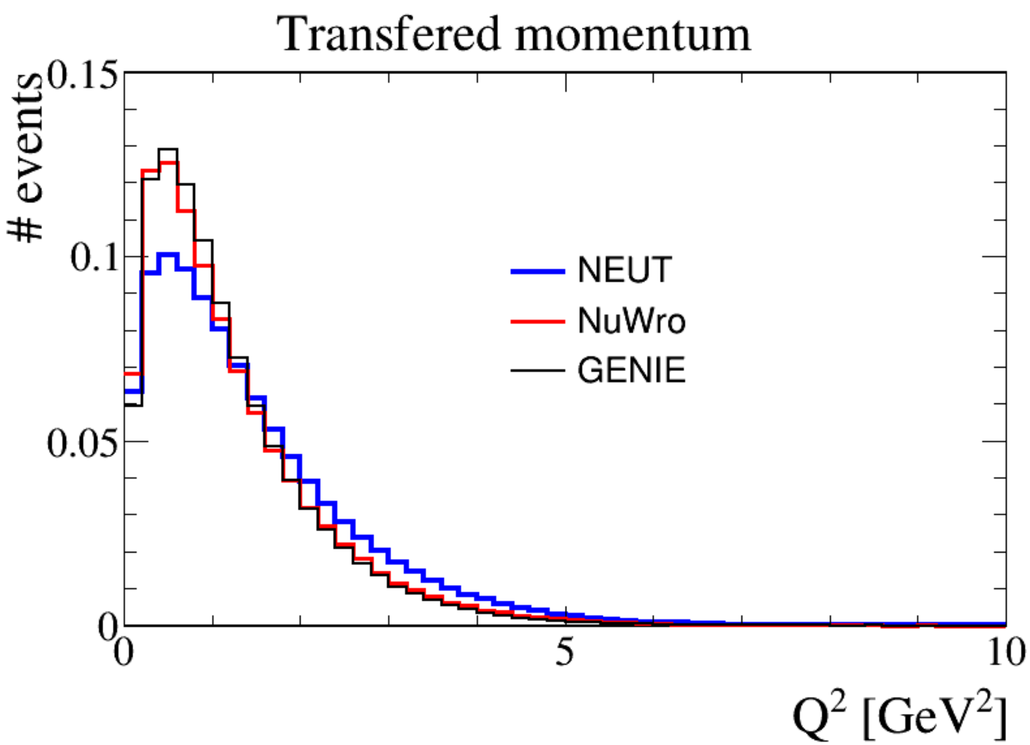
Q^2 distributions
Fe, E_ν=6.0 GeV

W>1.7 GeV

Neutrino



Anti-neutrino

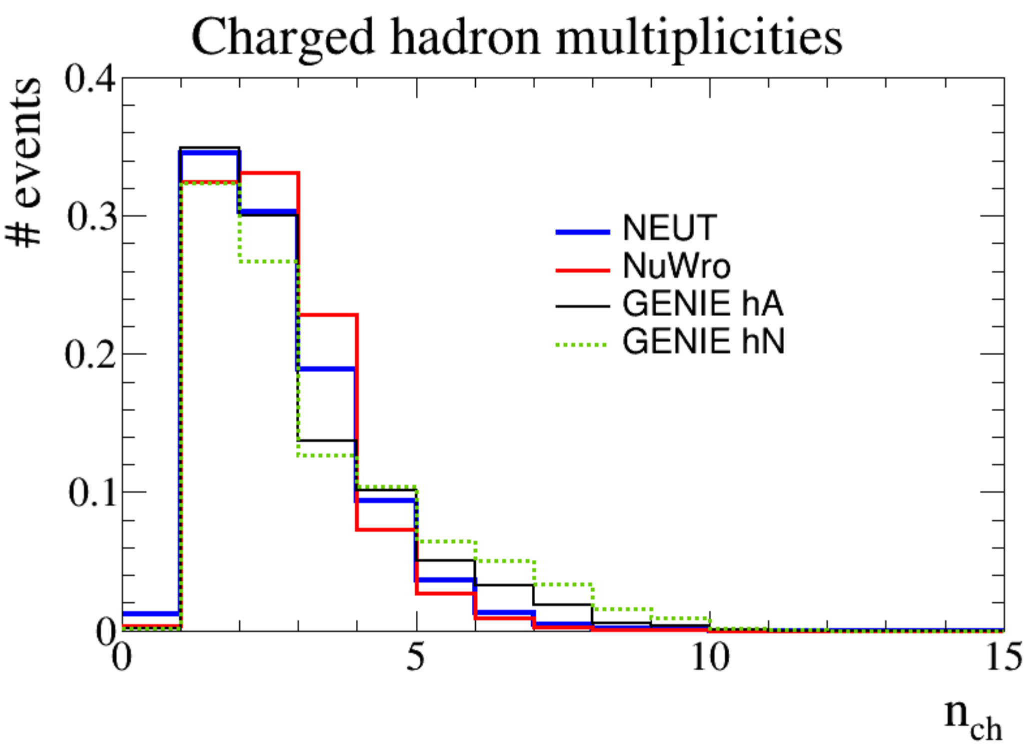


Similar to previous slide

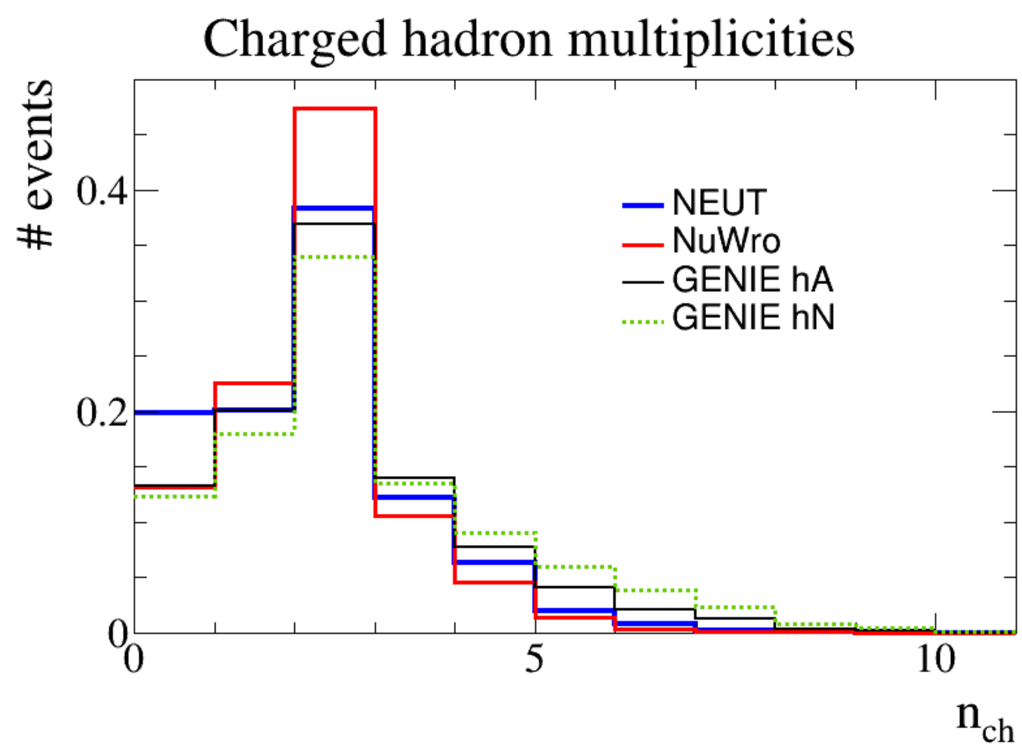
Charged hadron multiplicities
CH, E_ν=2.0 GeV

W>1.7 GeV

Neutrino



Anti-neutrino

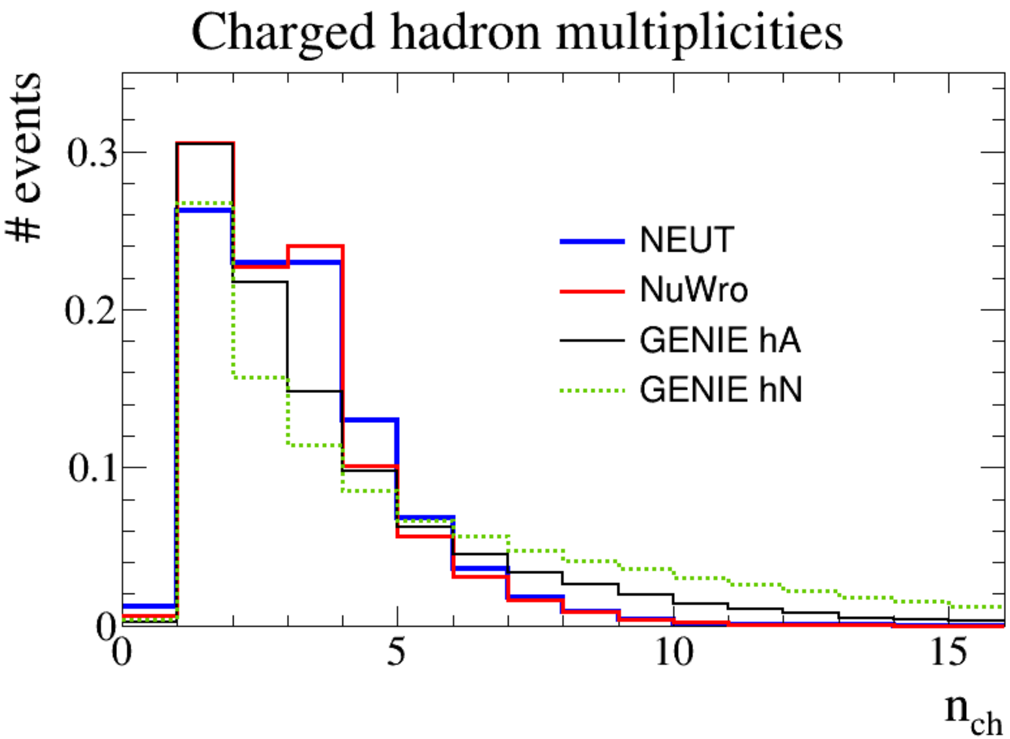


GENIE predicts larger number of charged hadrons than other generators
NuWro more strongly peaked at intermediate values

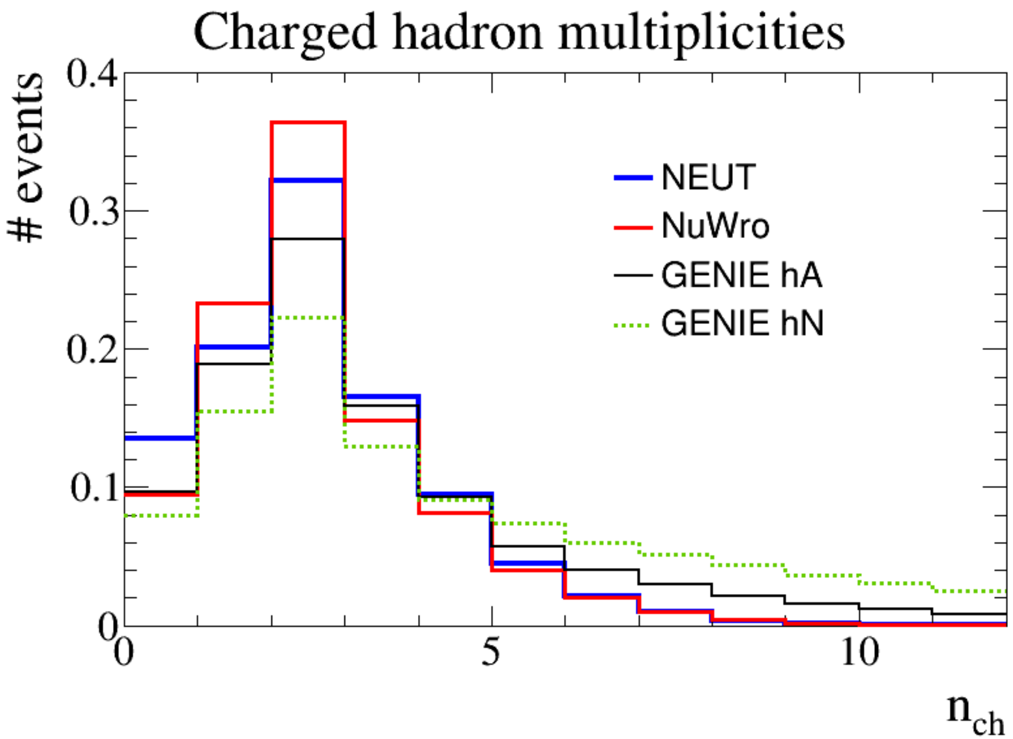
Charged hadron multiplicities
Ar, E_ν=2.5 GeV

W>1.7 GeV

Neutrino



Anti-neutrino

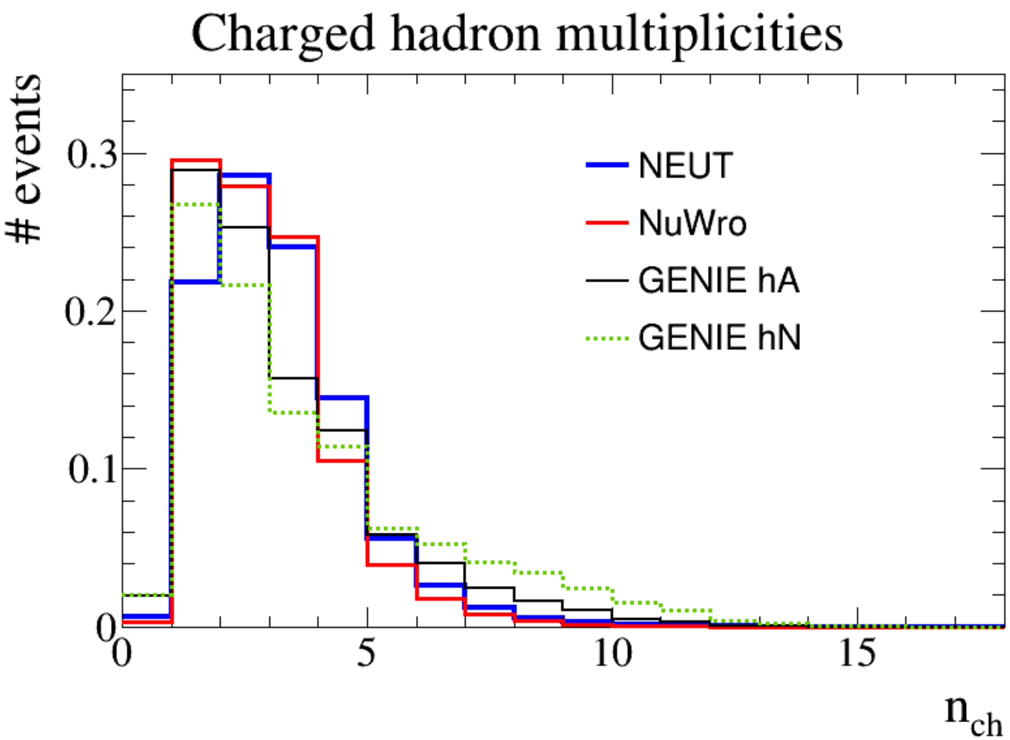


Relative agreement between NEUT and NuWro
GENIE predicts more charged hadrons than others

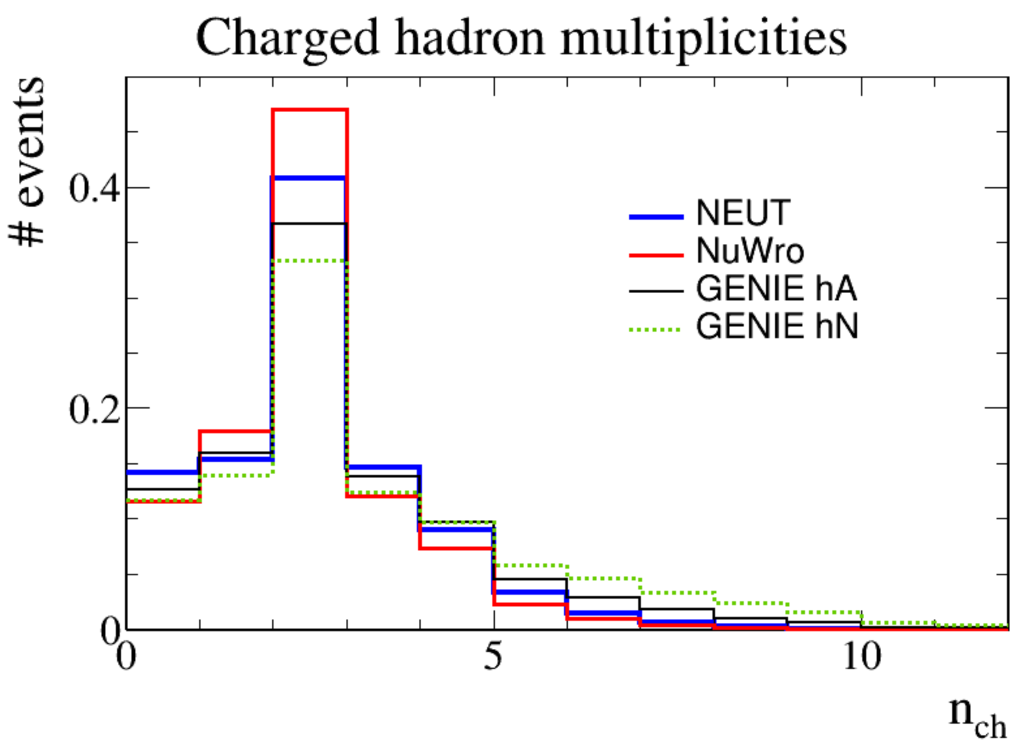
Charged hadron multiplicities
H_2O, E_ν=4.0 GeV

W>1.7 GeV

Neutrino



Anti-neutrino

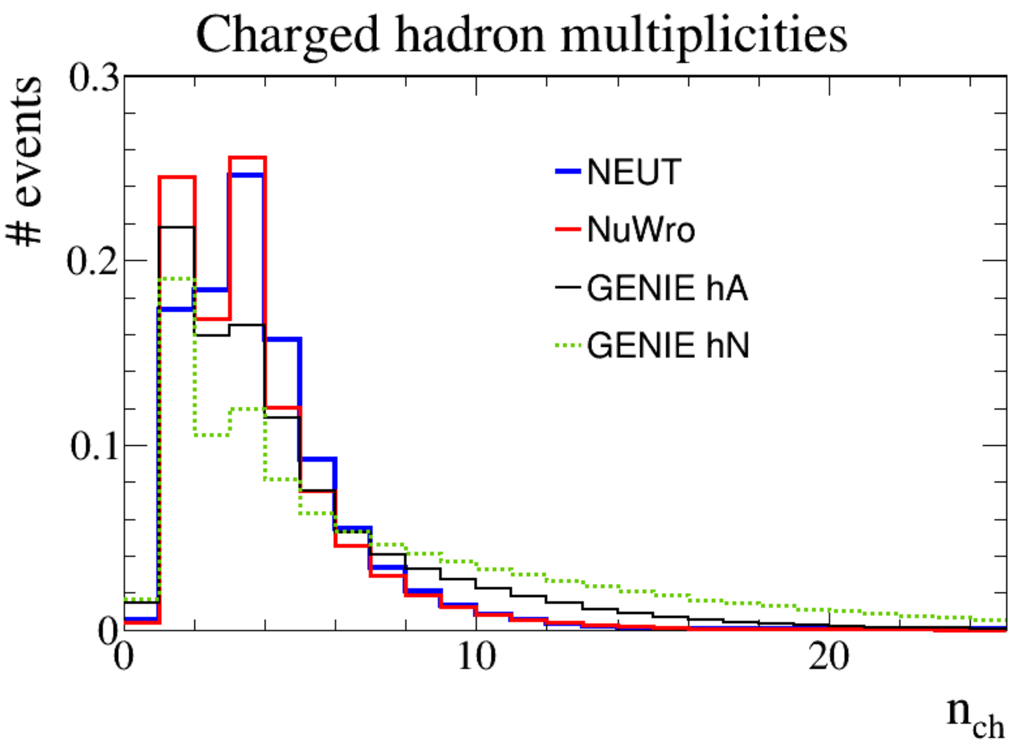


Essentially the same pattern, with a bit more differences between NEUT and NuWro

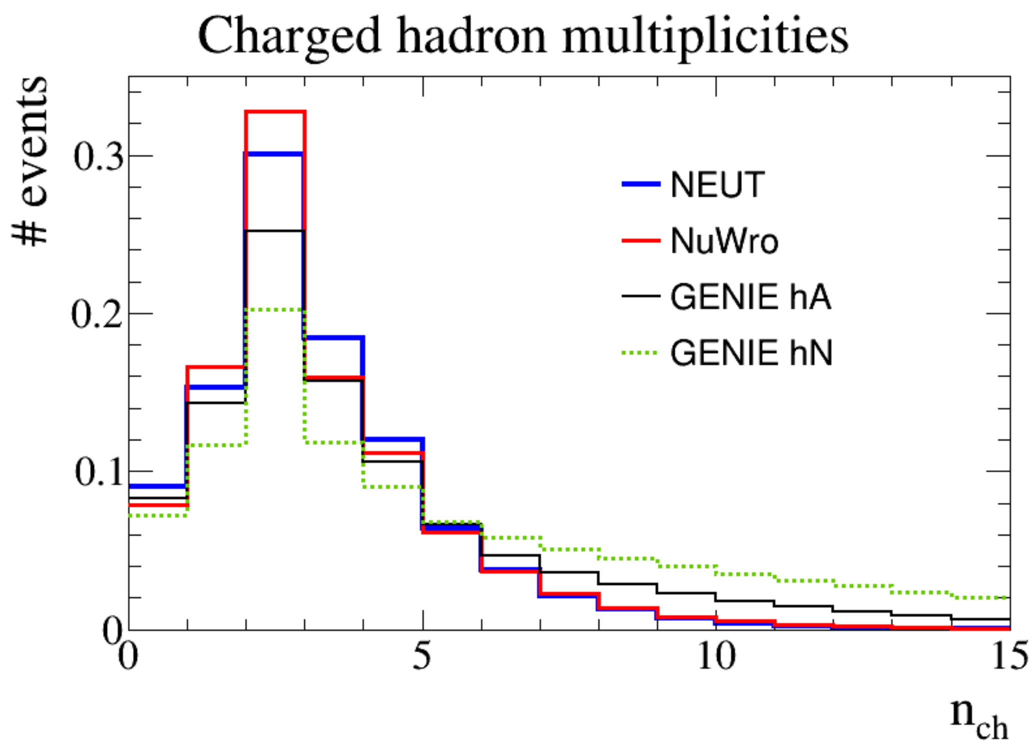
Charged hadron multiplicities
Fe, E_ν=6.0 GeV

W>1.7 GeV

Neutrino



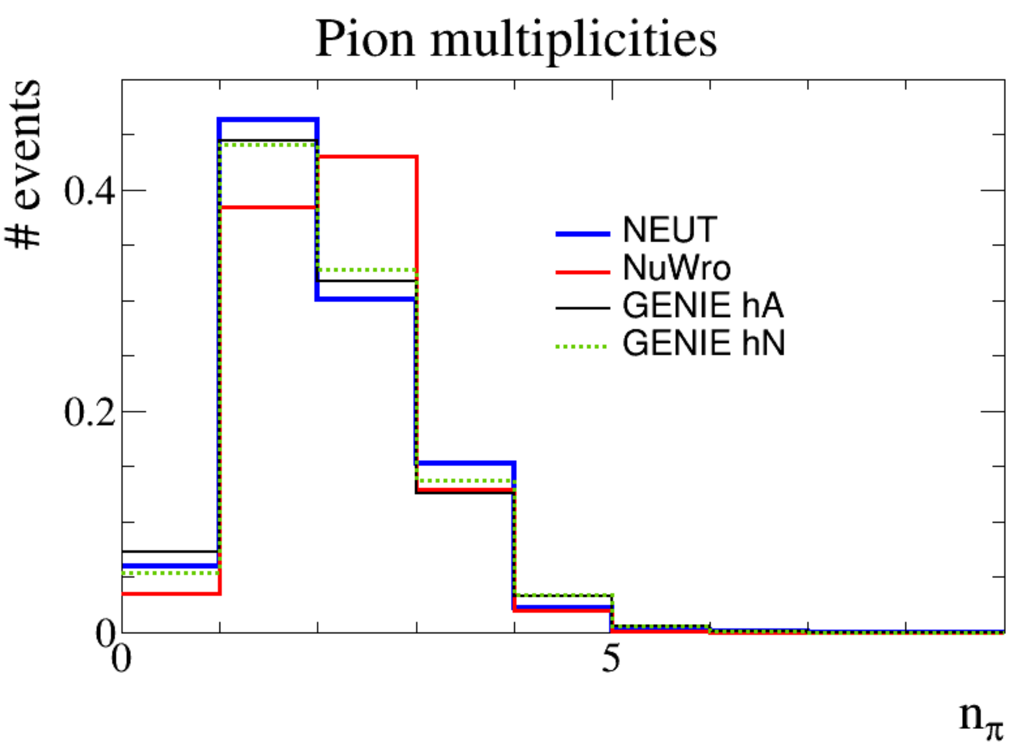
Anti-neutrino



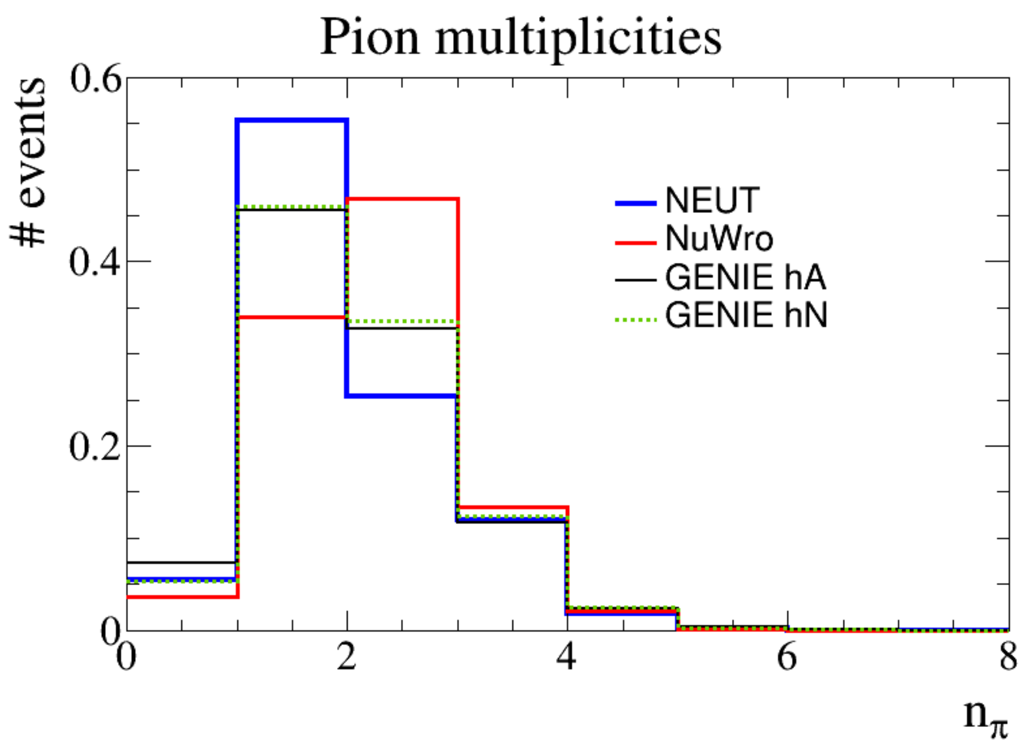
Pion multiplicities
CH, E_{ν}=2.0 GeV

W>1.7 GeV

Neutrino



Anti-neutrino

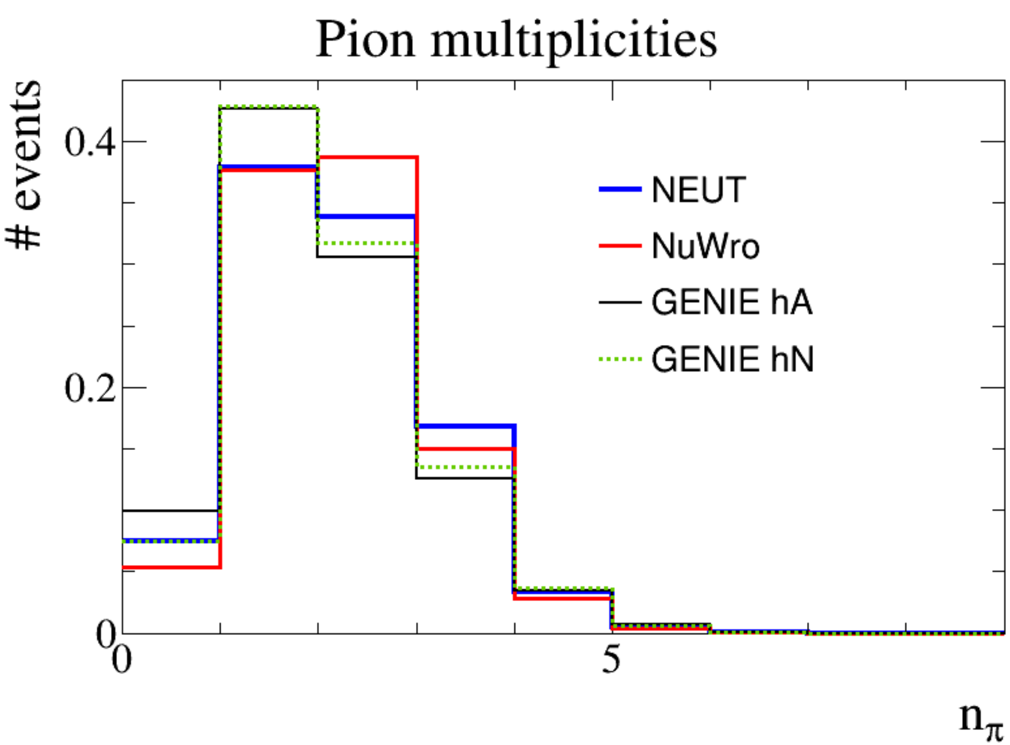


No big differences between the 2 GENIE FSI models
NuWro predicts more pions than the other generators

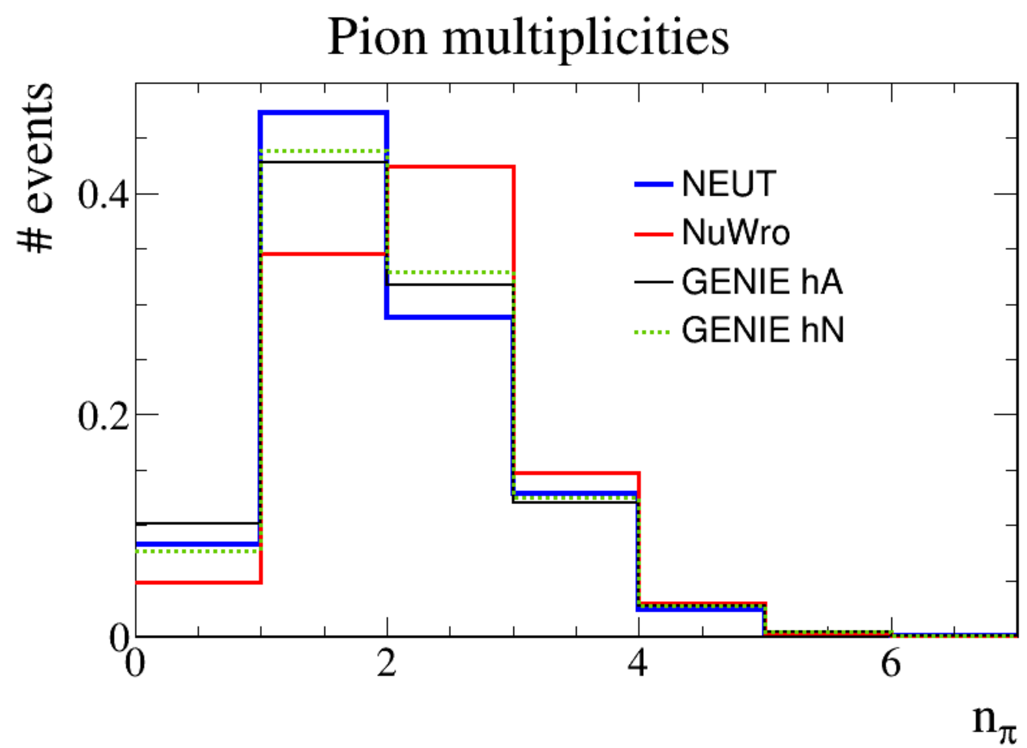
Pion multiplicities
Ar, E_ν=2.5 GeV

W>1.7 GeV

Neutrino



Anti-neutrino

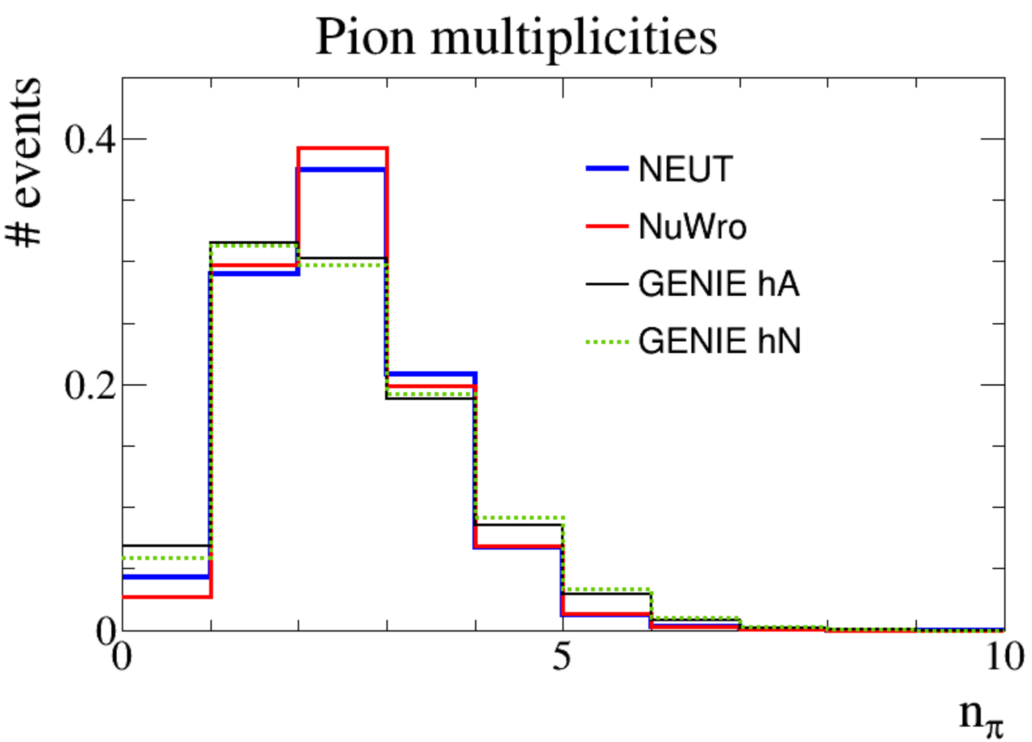


Similar pattern, difference between NEUT and NuWro slightly smaller

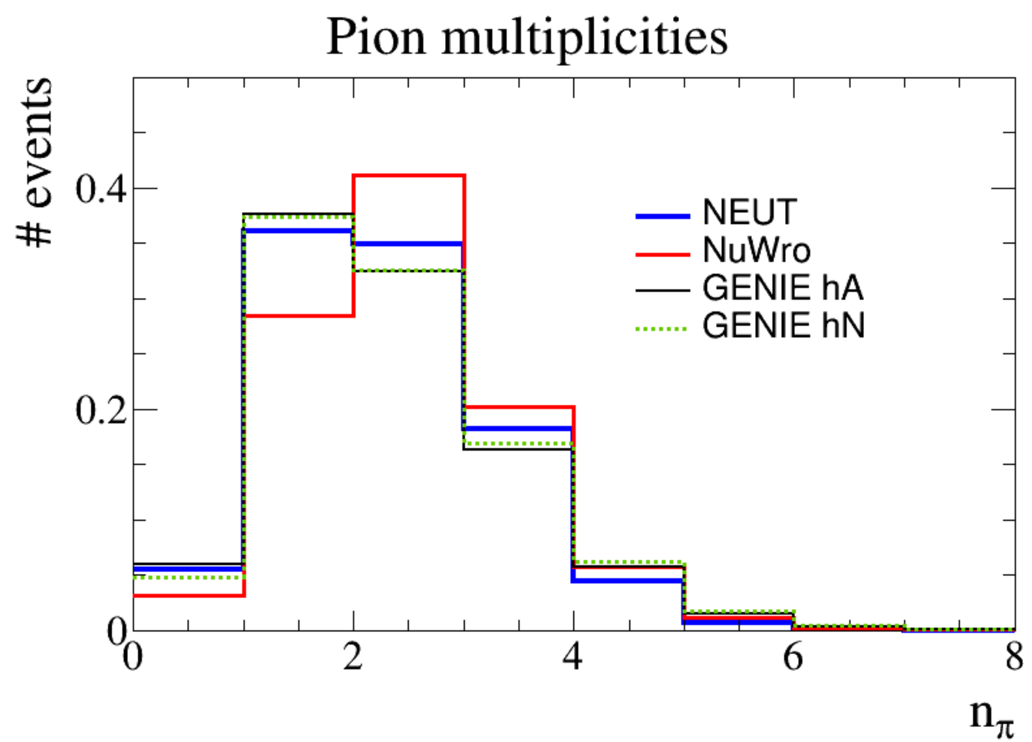
Pion multiplicities
H_2O, E_ν=4.0 GeV

W>1.7 GeV

Neutrino



Anti-neutrino

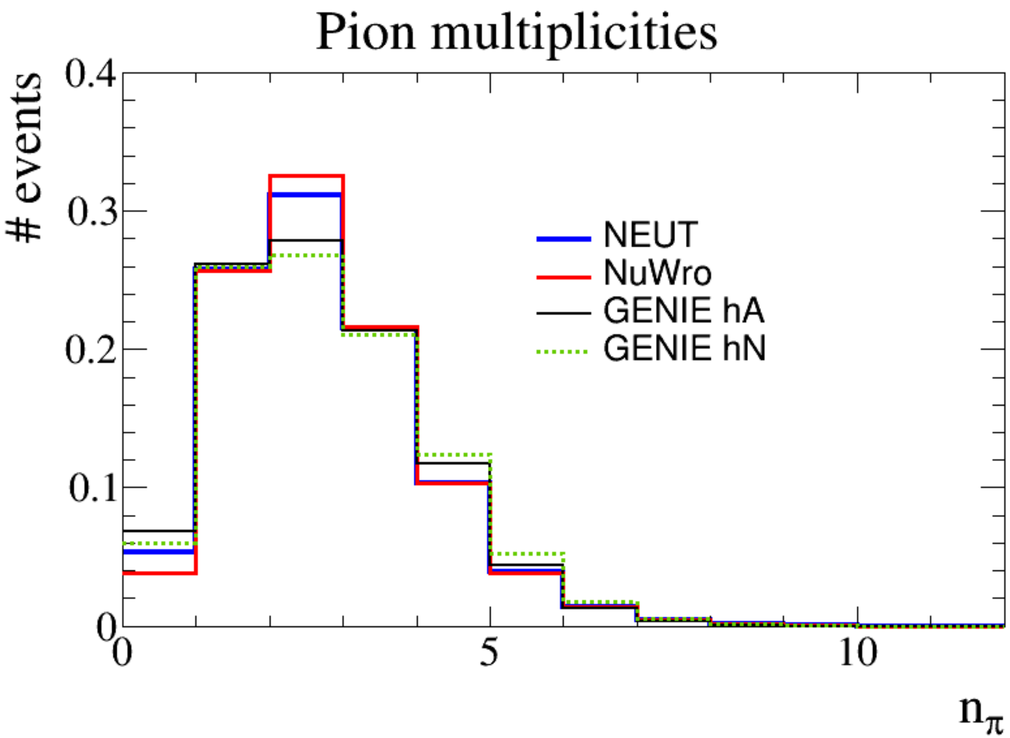


NEUT and NuWro get closer for neutrinos, GENIE and NEUT for anti-neutrinos

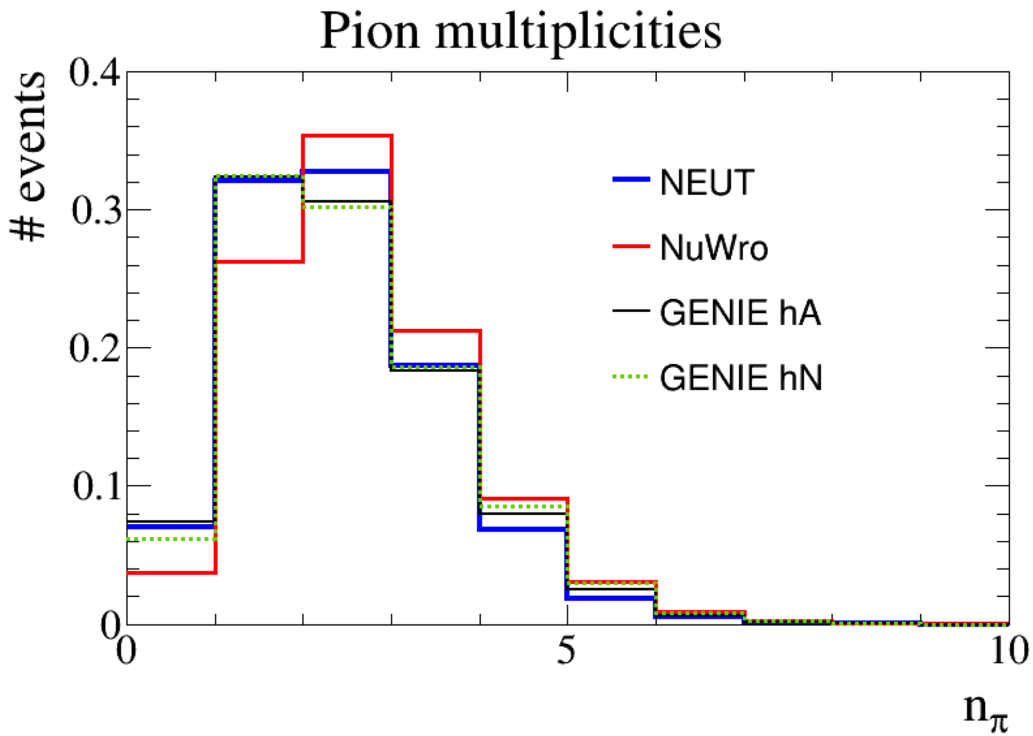
Pion multiplicities
Fe, E_ν=6.0 GeV

W>1.7 GeV

Neutrino



Anti-neutrino

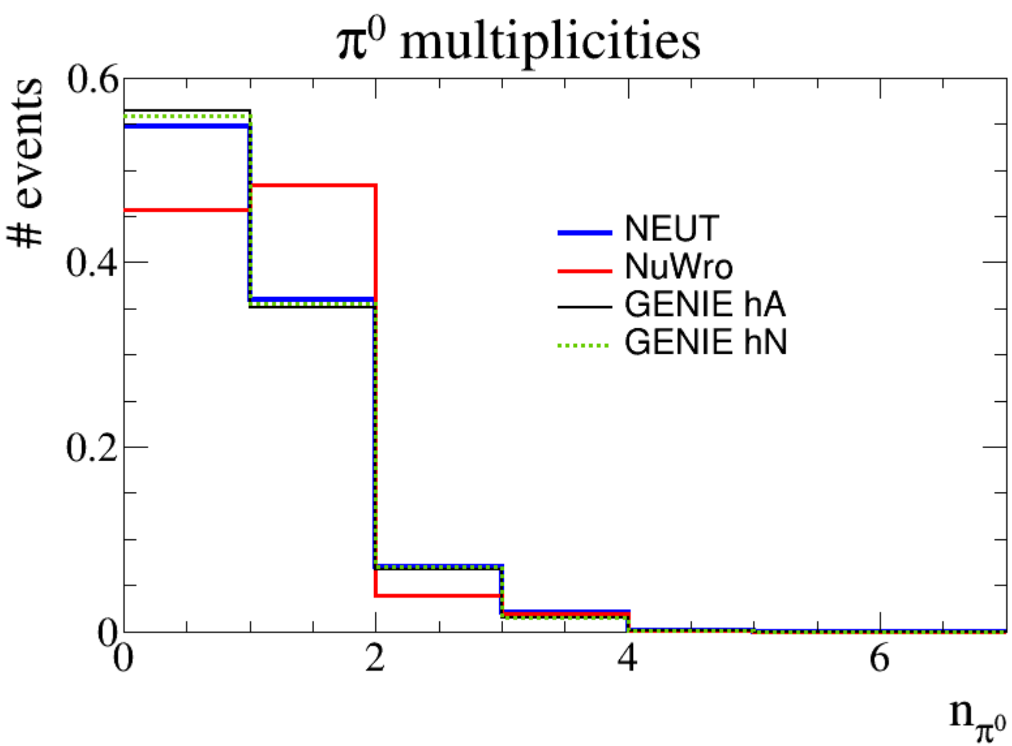


The different distributions get closer for neutrino interactions
Slightly larger multiplicities for NuWro for anti-neutrinos

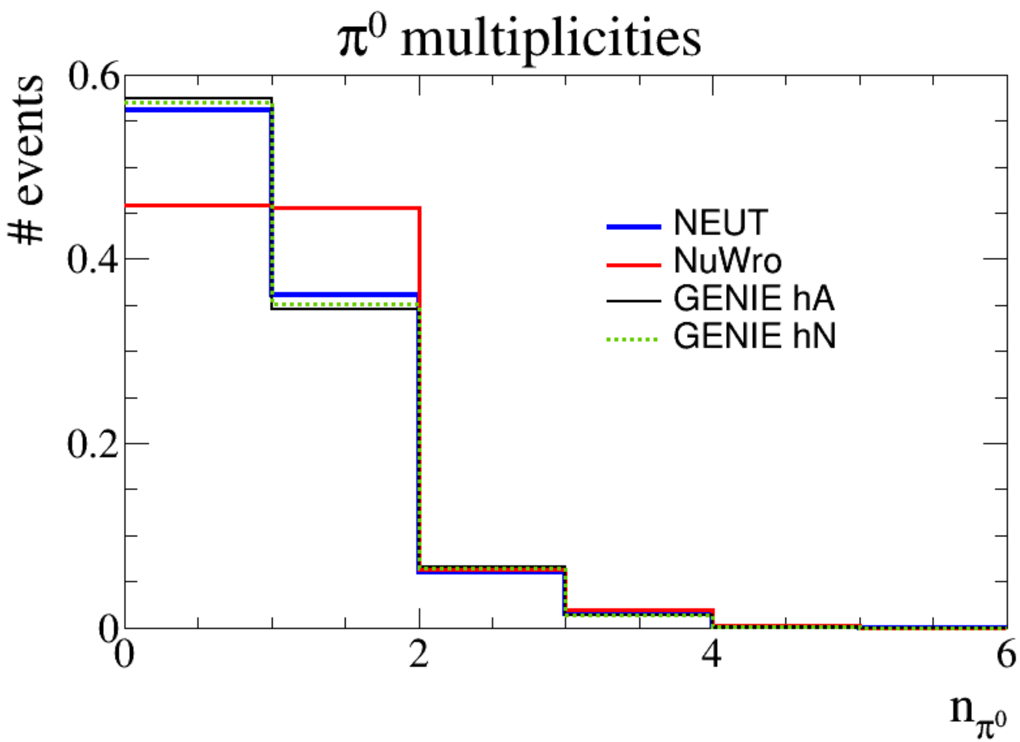
Neutral pion multiplicities
CH, E_ν=2.0 GeV

W>1.7 GeV

Neutrino



Anti-neutrino

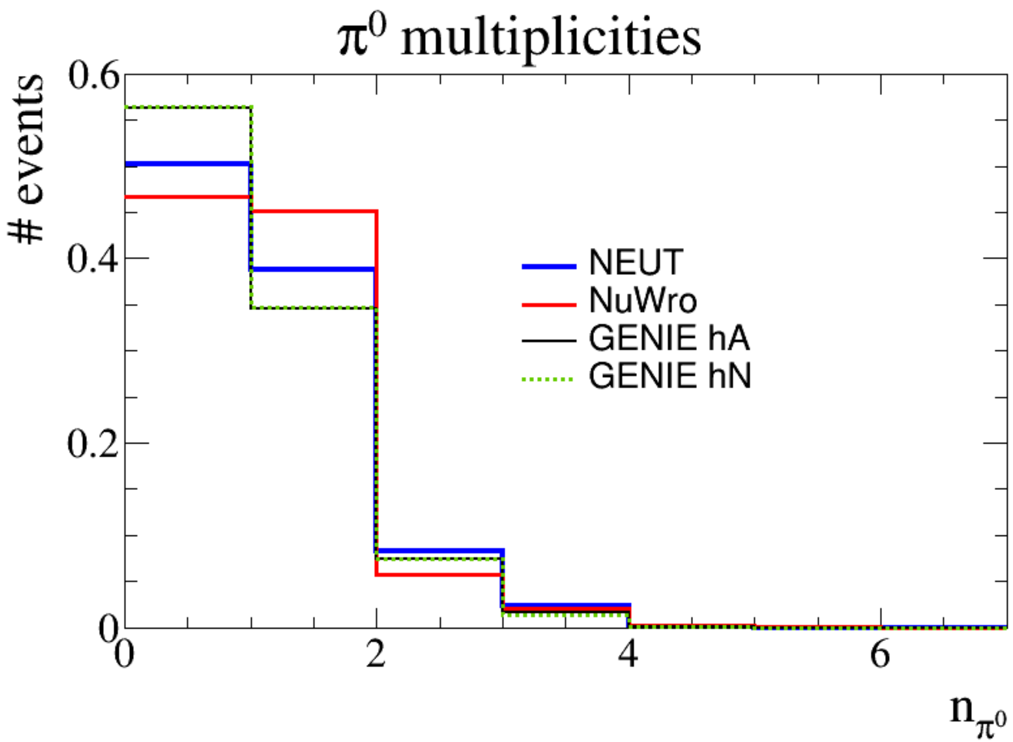


Good agreement between NEUT and GENIE.
NuWro predicts more π^0

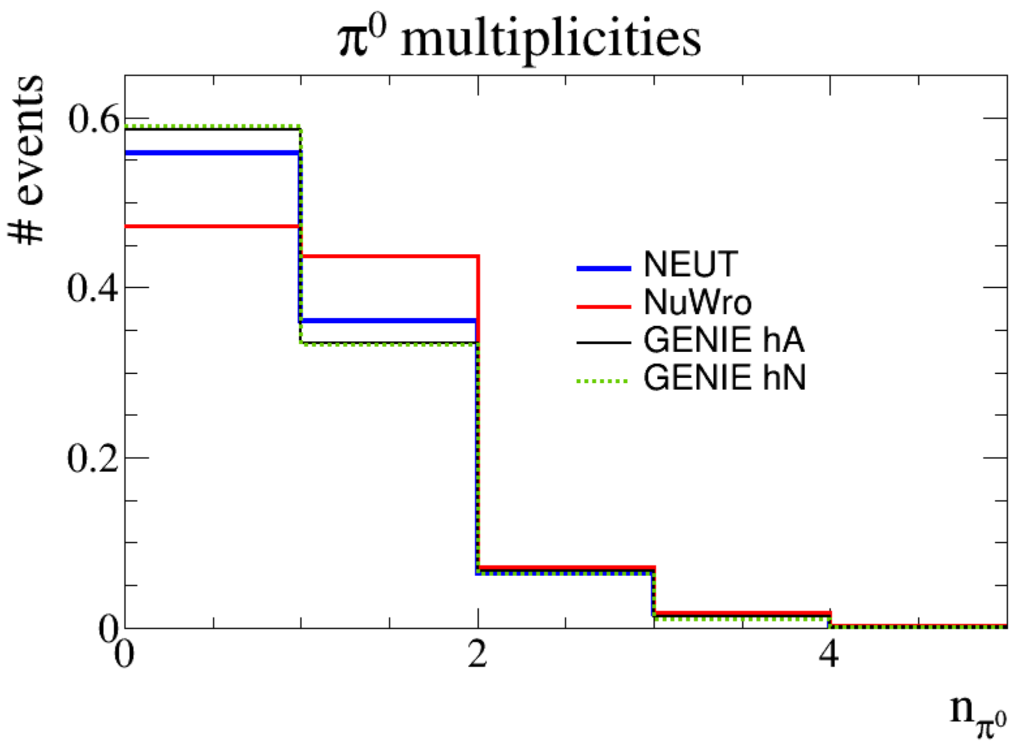
Neutral pion multiplicities
Ar, E_ν=2.5 GeV

W>1.7 GeV

Neutrino



Anti-neutrino

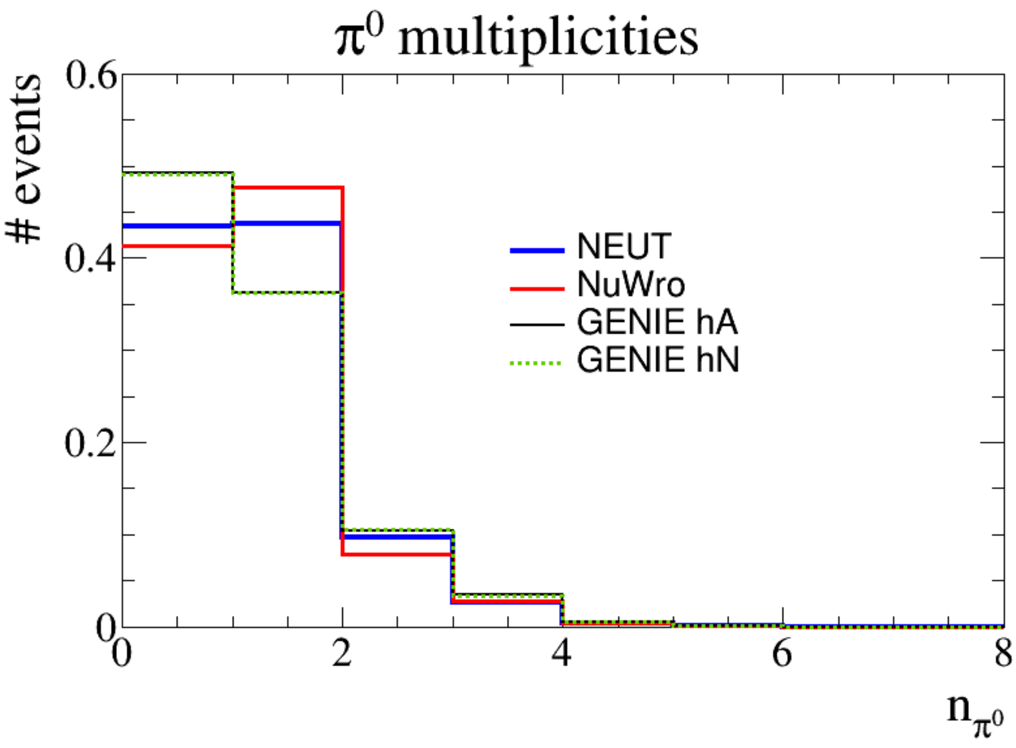


A bit more differences between NEUT and GENIE, especially for neutrinos
NuWro still predicts more π^0 than the others

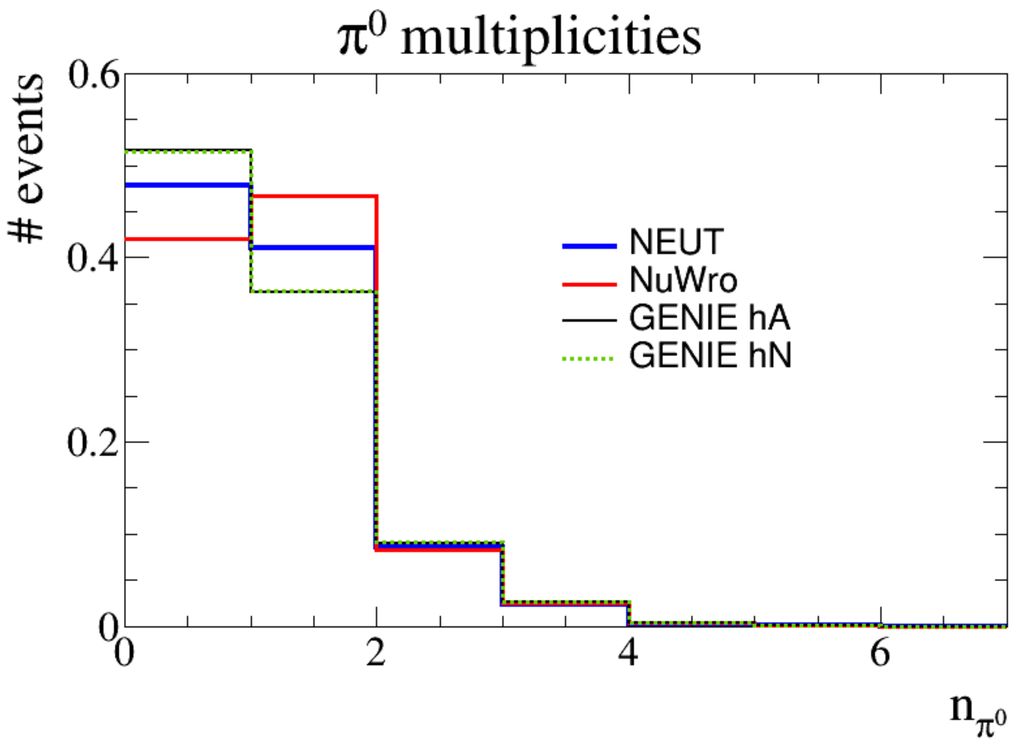
Neutral pion multiplicities
H_2O, E_ν=4.0 GeV

W>1.7 GeV

Neutrino



Anti-neutrino

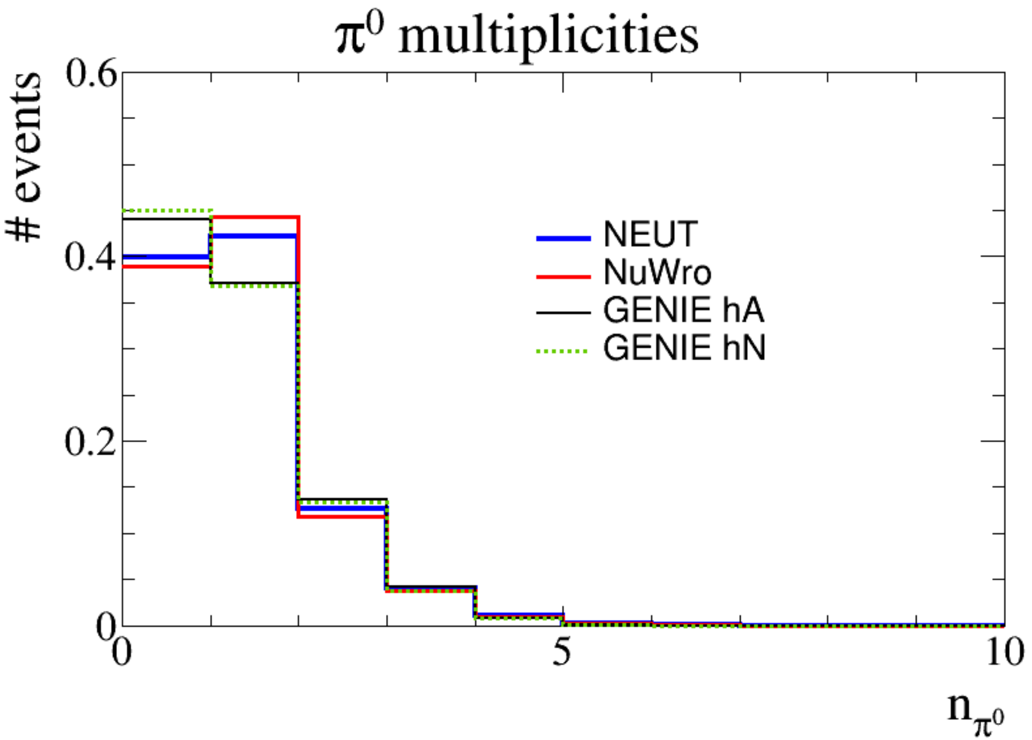


NEUT becomes intermediate between GENIE and NuWro

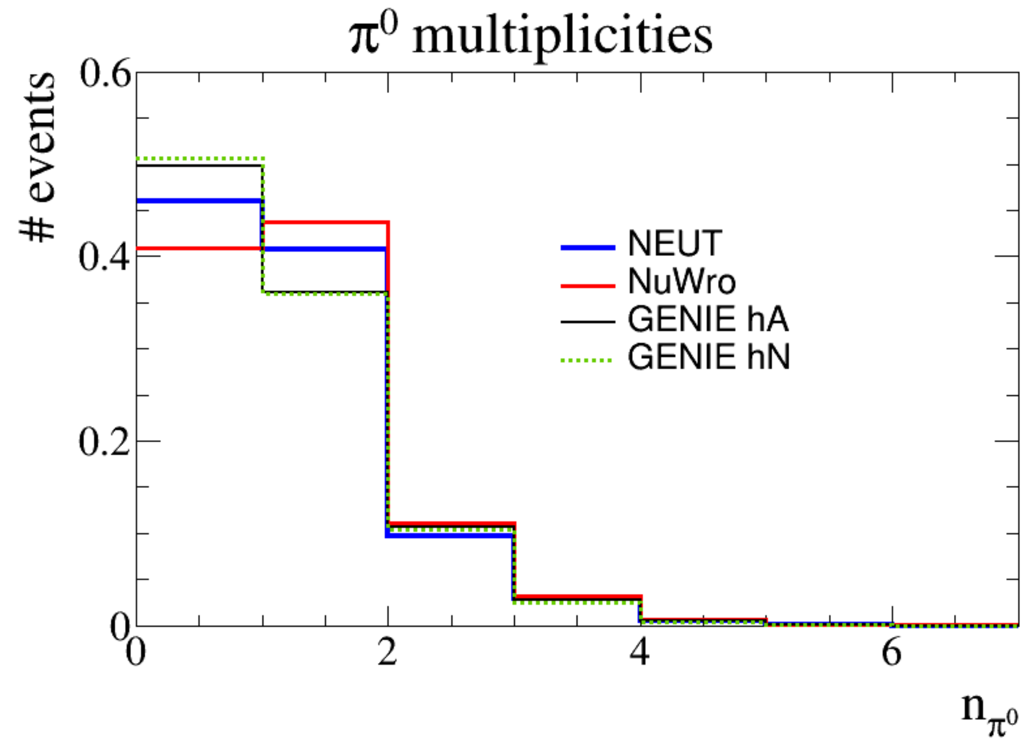
Neutral pion multiplicities
Fe, E_ν=6.0 GeV

W>1.7 GeV

Neutrino



Anti-neutrino



NEUT continues to get closer to NuWro

Custom models for low W

- PYTHIA cannot be used at low W, so generators use their own model for this region

- Particle contents and kinematics are assigned differently, compare a few distributions:
  - Leading pion momentum
  - Fraction of ejected nucleons that are protons
  - Relative fractions of the different kind of pions

- To be in a region where all 3 generators use their custom model, select **1.7 GeV< W < 2.0 GeV**

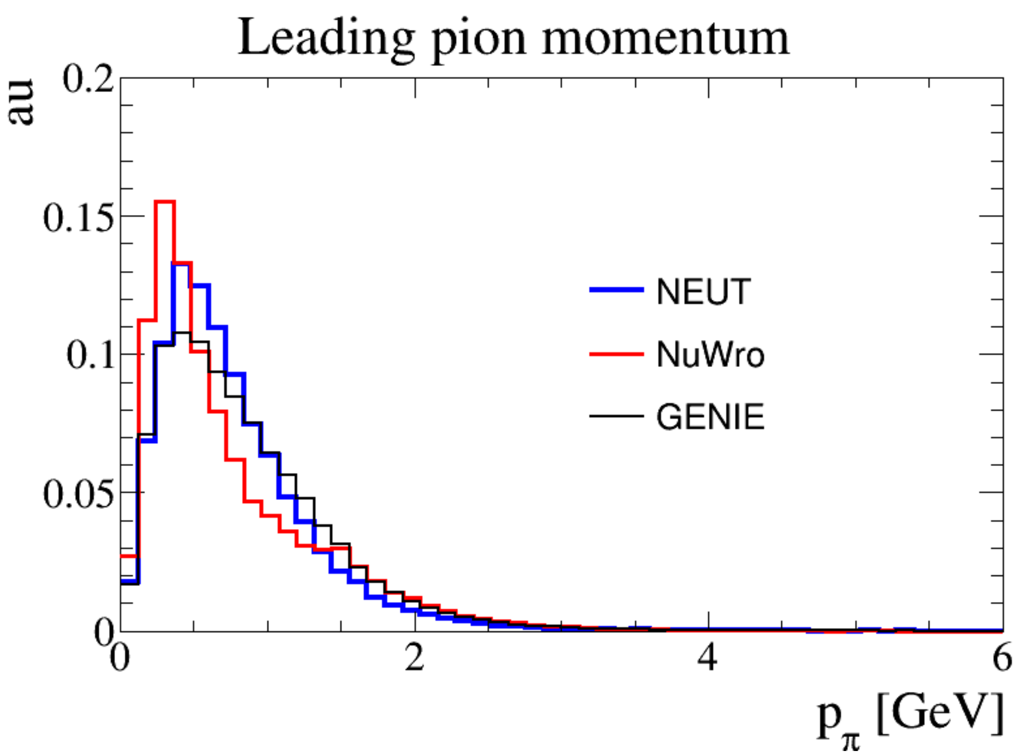
- Similar settings as for hadronization comparisons:

> - Free neutron and proton for GENIE and NuWro CH without FSI for NEUT
> - 0.5 GeV < E_ν < 80 GeV
> - Flux proportional to $1/E_\nu$

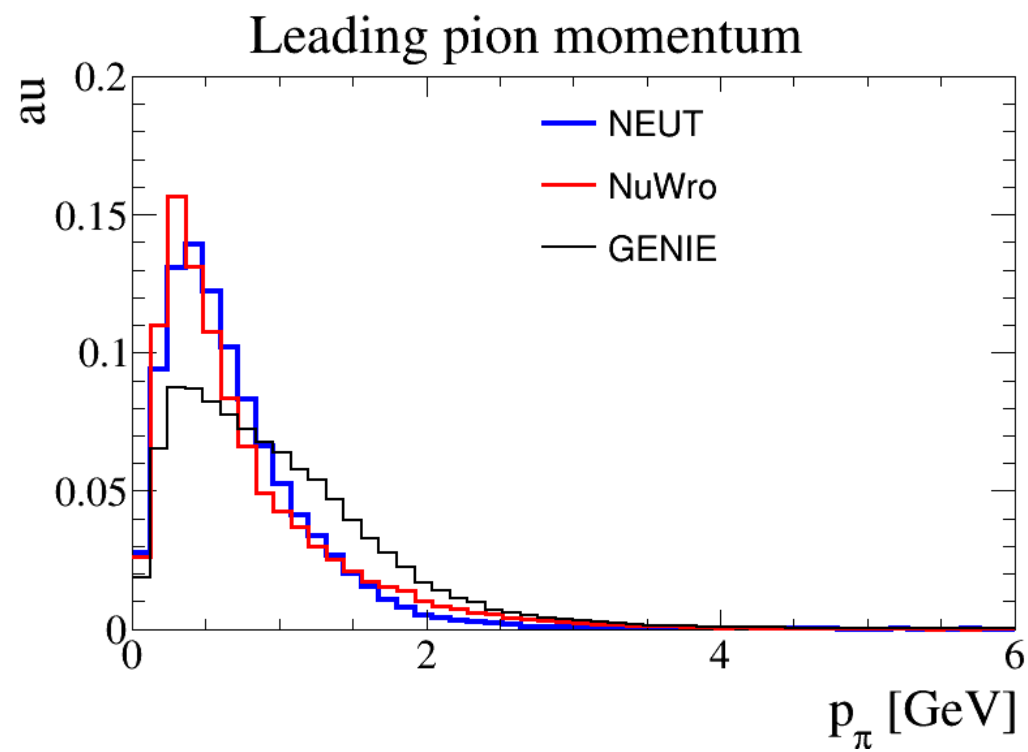
Leading pion momemtum: neutrinos

For neutrino, leading pion is π^+ with highest momentum.

Neutrinos on proton



Neutrinos on neutron



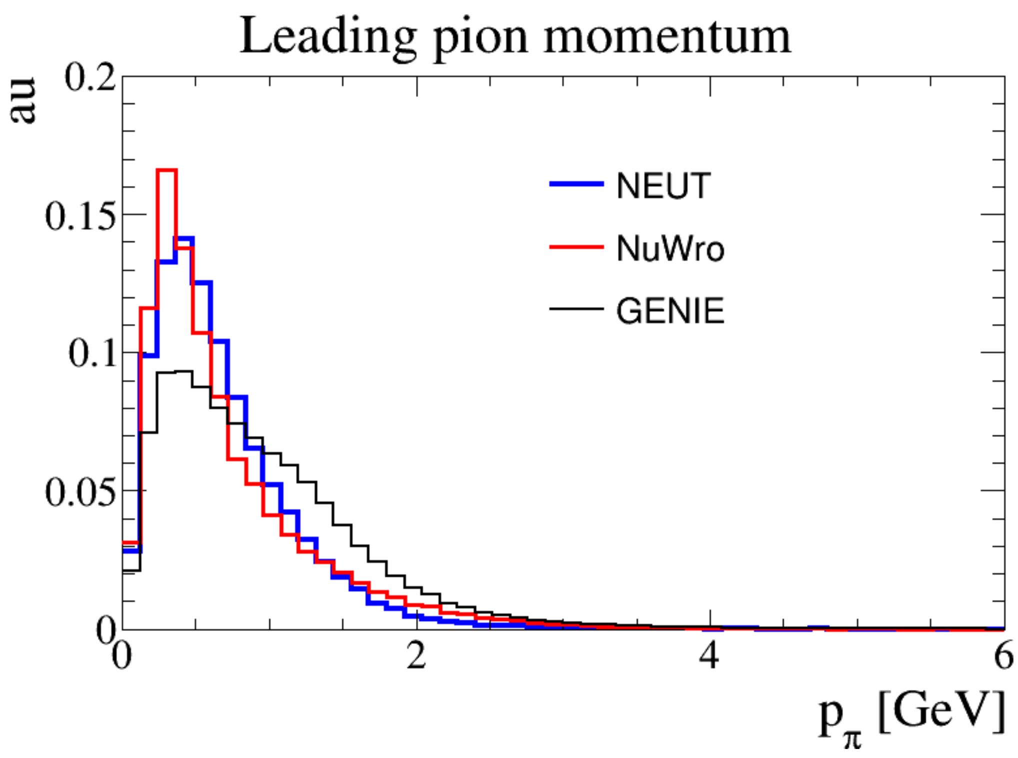
Proton target: NuWro predicts lower momemtum, relative agreement between GENIE and NEUT.

Neutron target: good agreement between NuWro and NEUT, larger momentum spread for GENIE

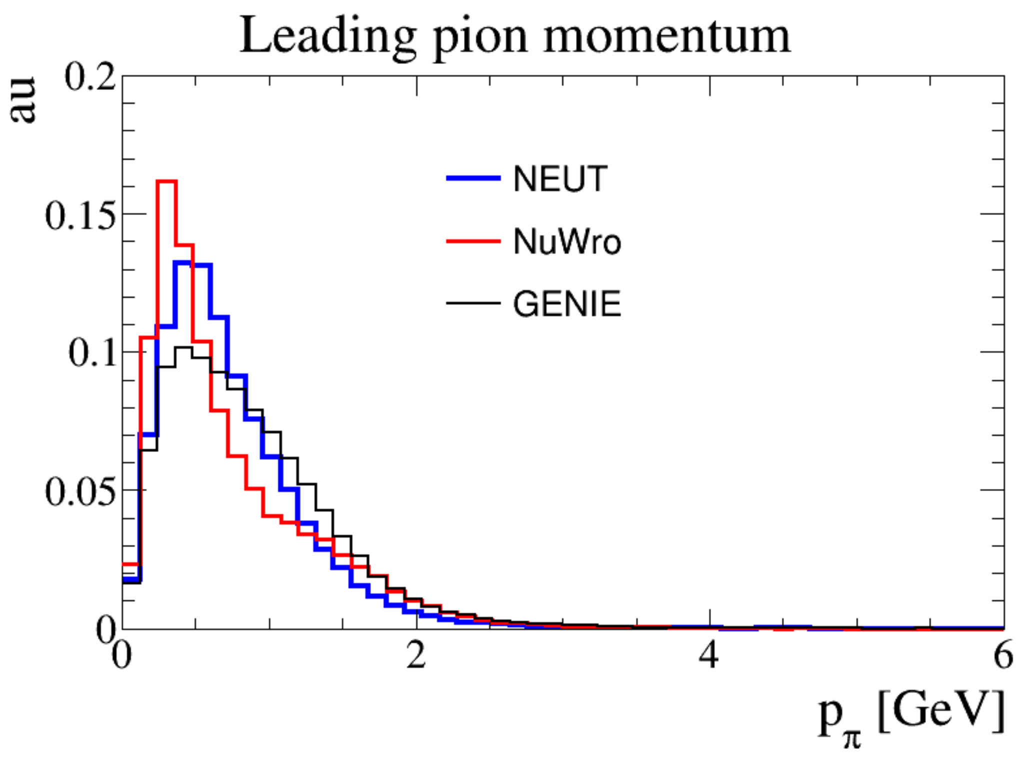
Leading pion momemtum: anti-neutrinos

For neutrino, leading pion is π^- with highest momentum.

<u>Anti-neutrinos on proton</u>



<u>Anti-neutrinos on neutron</u>

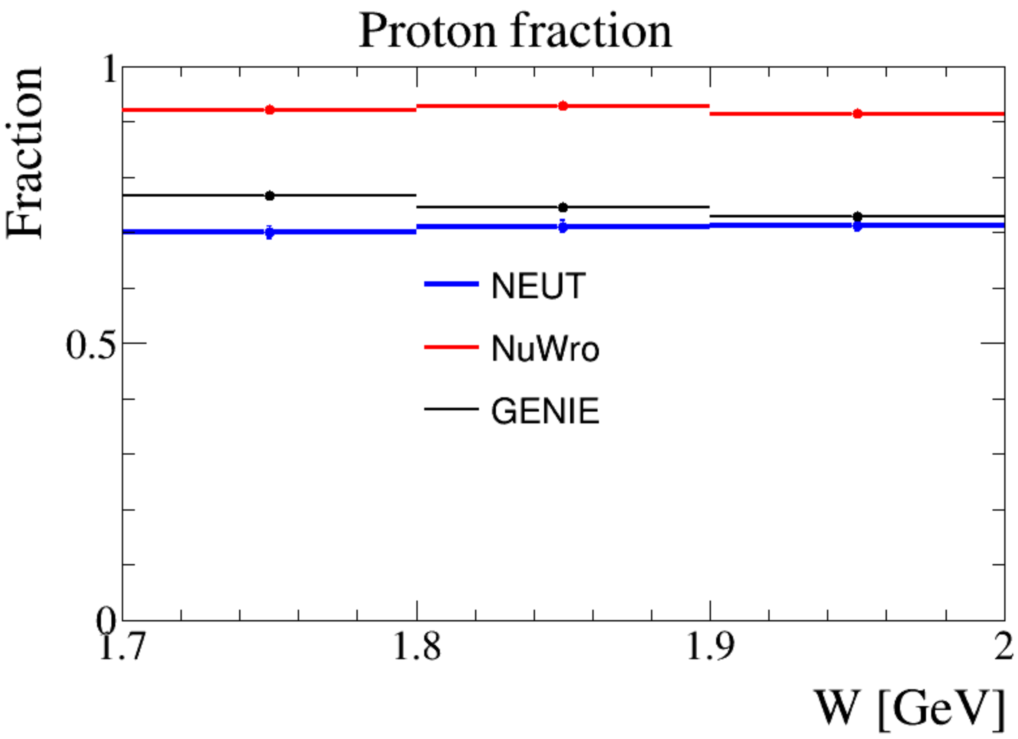


Similar patterns than for neutrino interactions, but inverted between proton and neutron targets

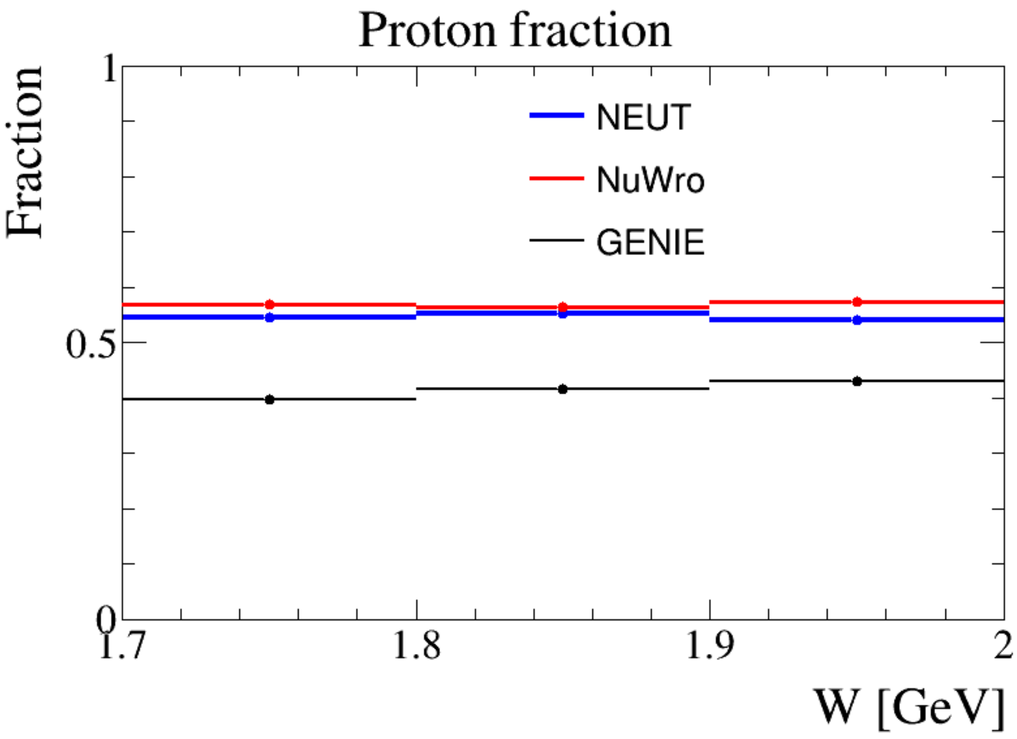
Proton fraction: neutrinos

When the outgoing baryon is a nucleon, fraction that are protons

<u>Neutrinos on proton</u>



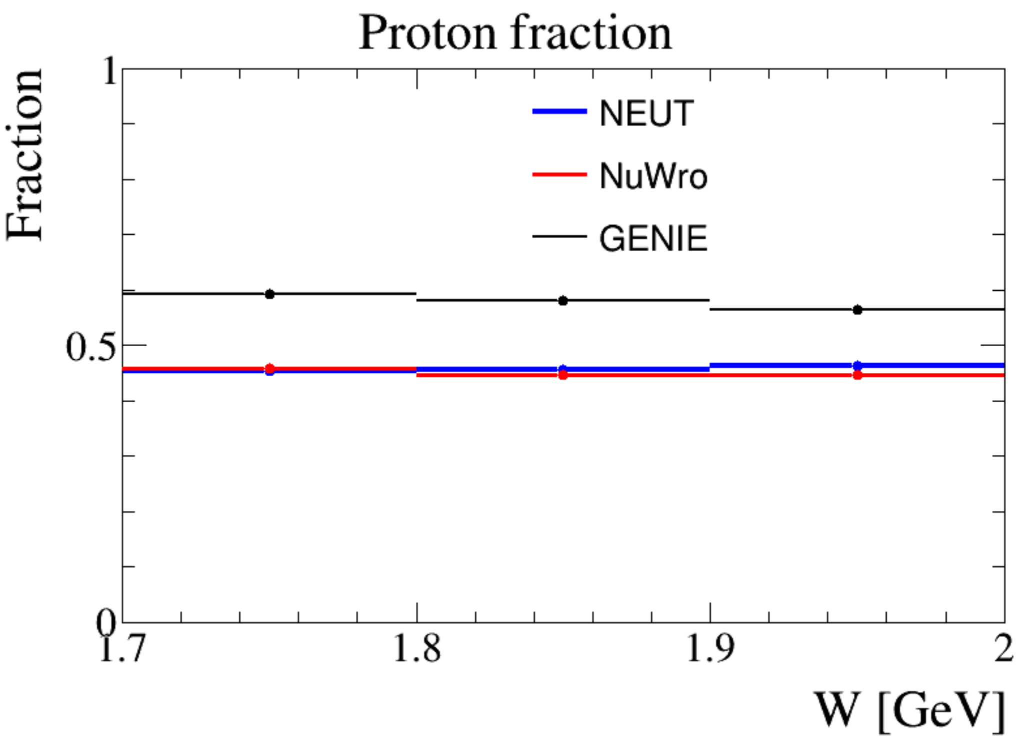
<u>Neutrinos on neutron</u>



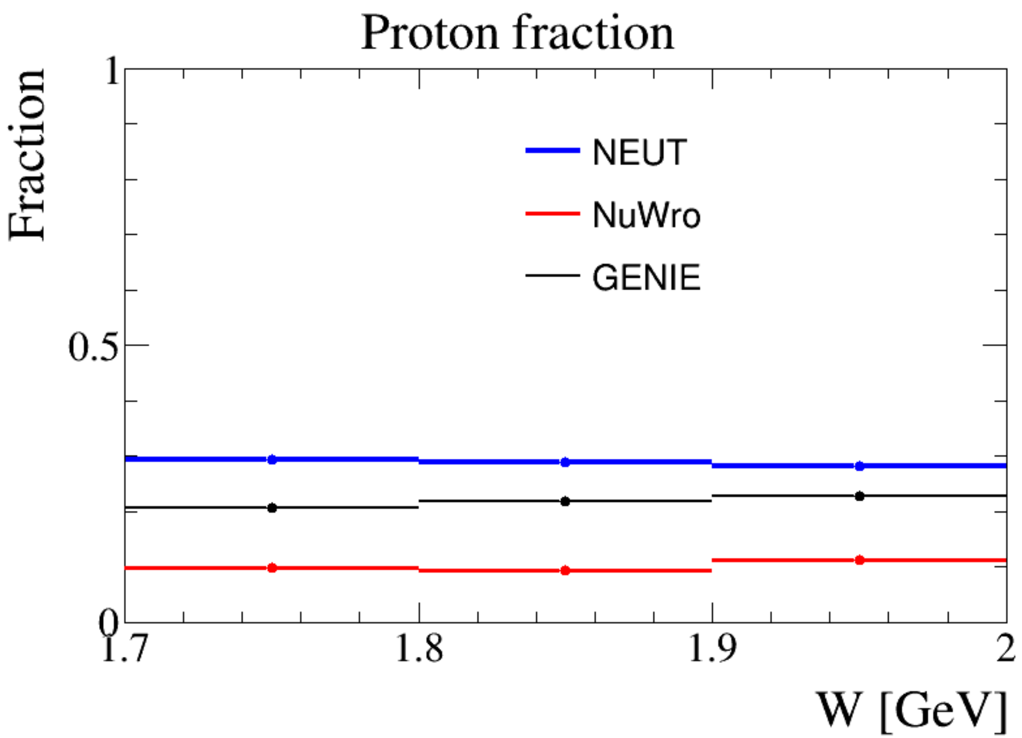
Proton fraction: anti-neutrinos

When the outgoing baryon is a nucleon, fraction that are protons

<u>Anti-neutrinos on proton</u>

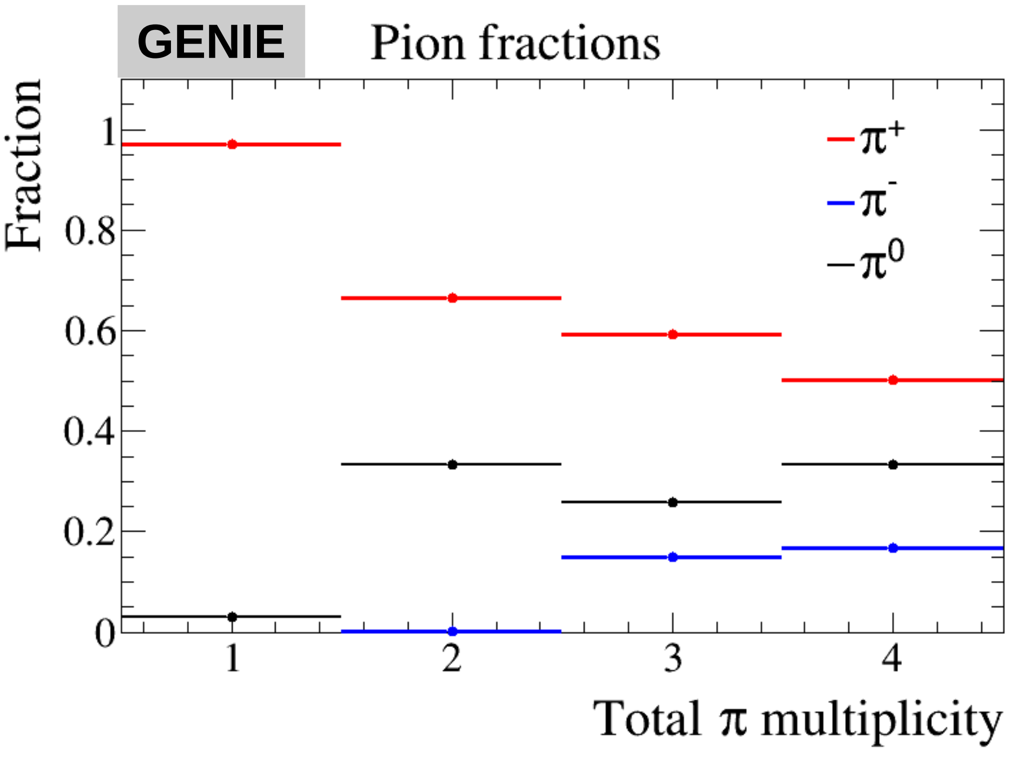


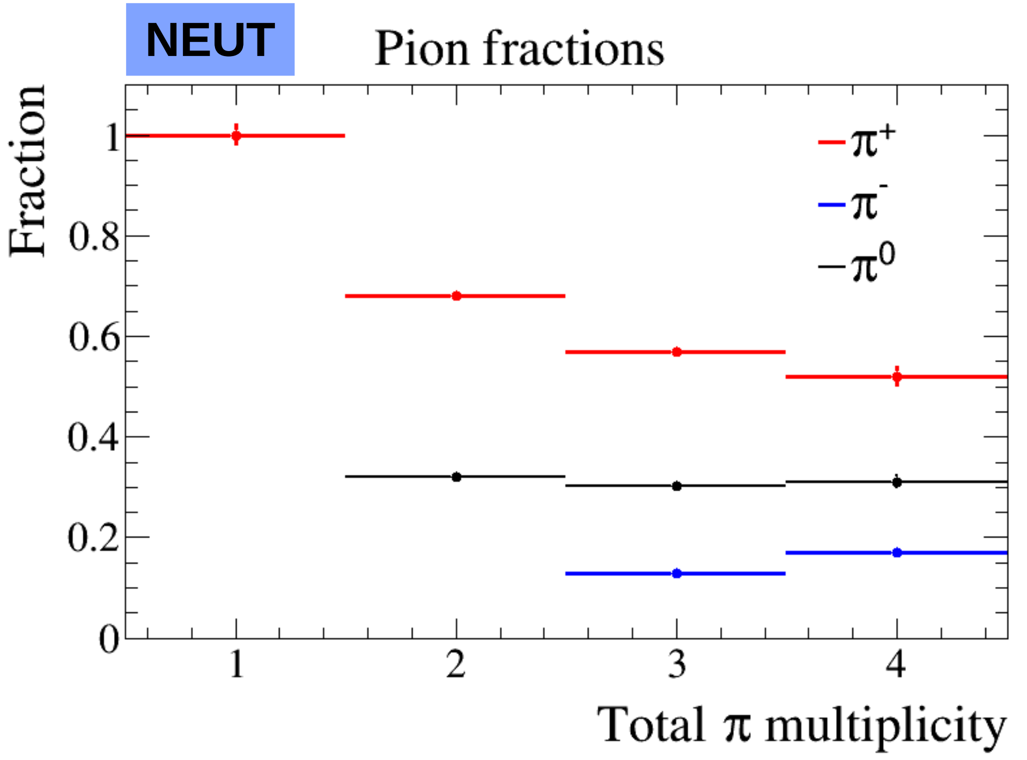
<u>Anti-neutrinos on neutron</u>

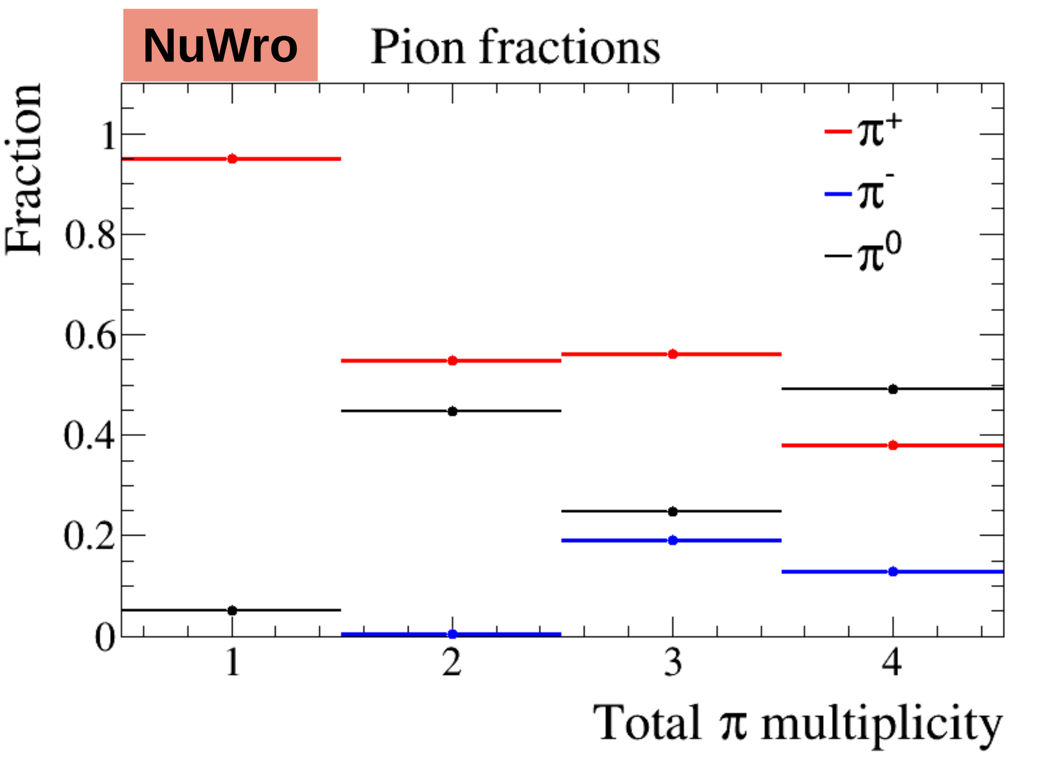


Pion fractions
Neutrino on proton

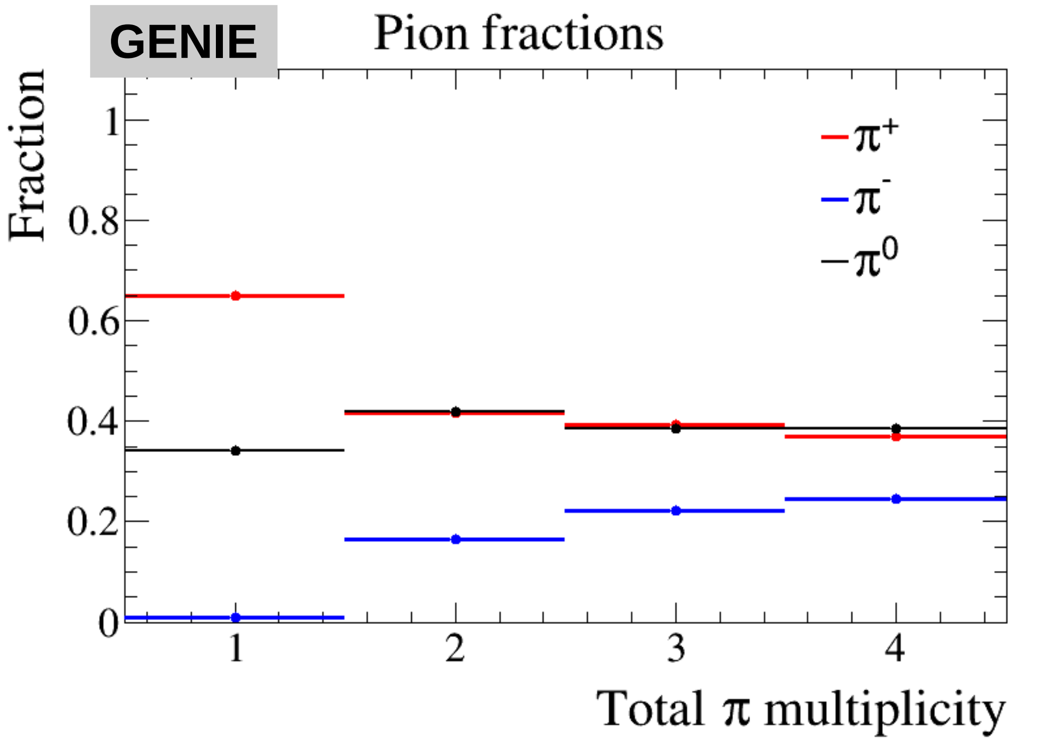
Very similar for GENIE and NEUT
More π^0 for larger multiplicities in NuWro

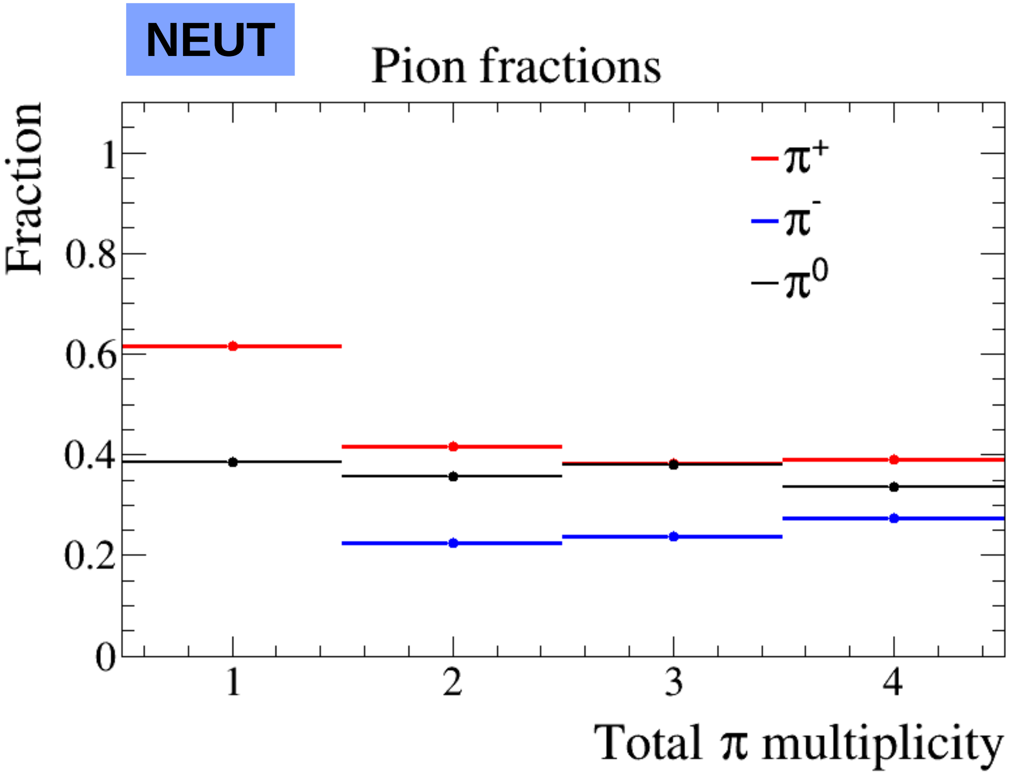


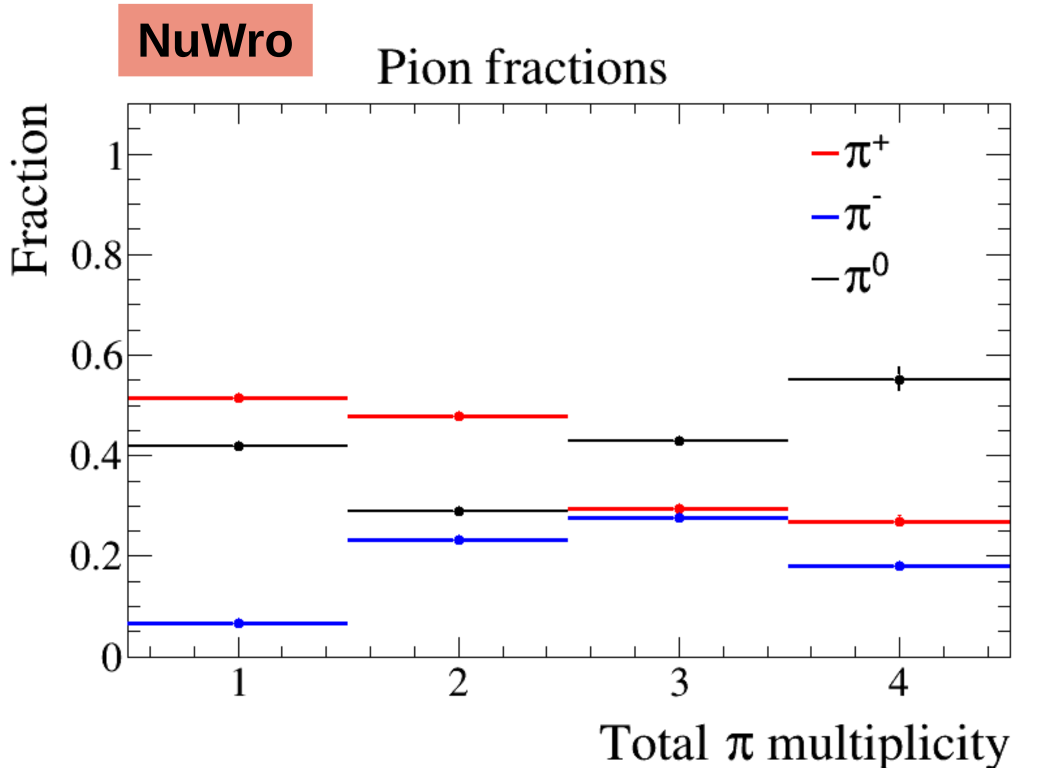




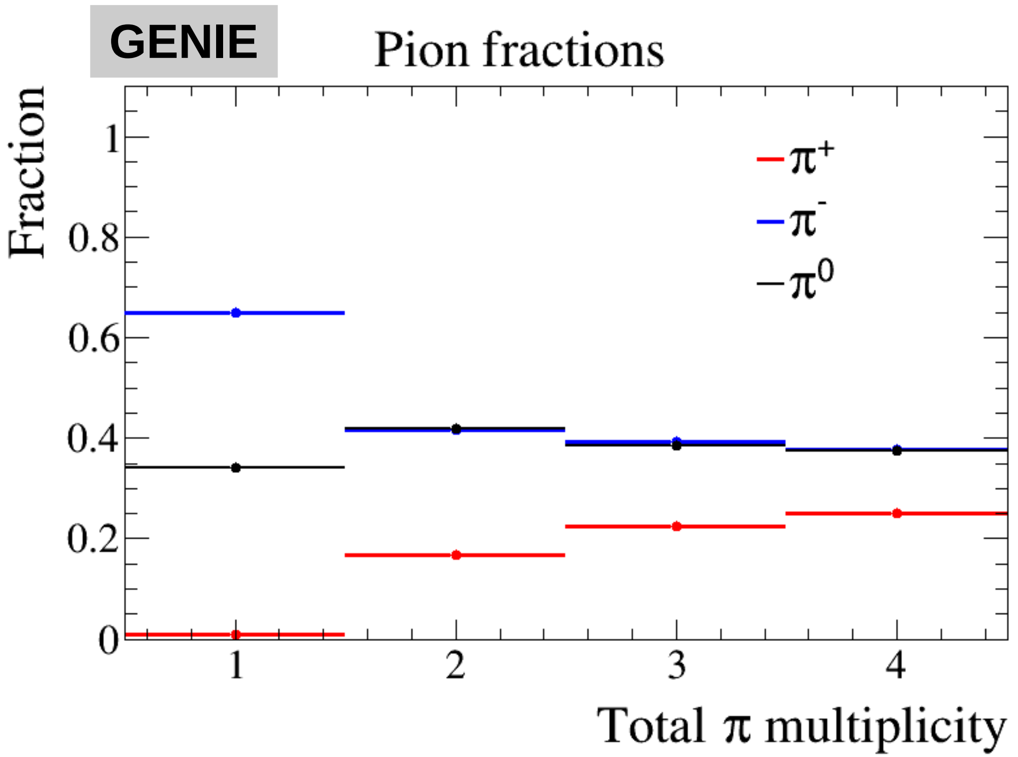
Pion fractions
Neutrino on neutrons

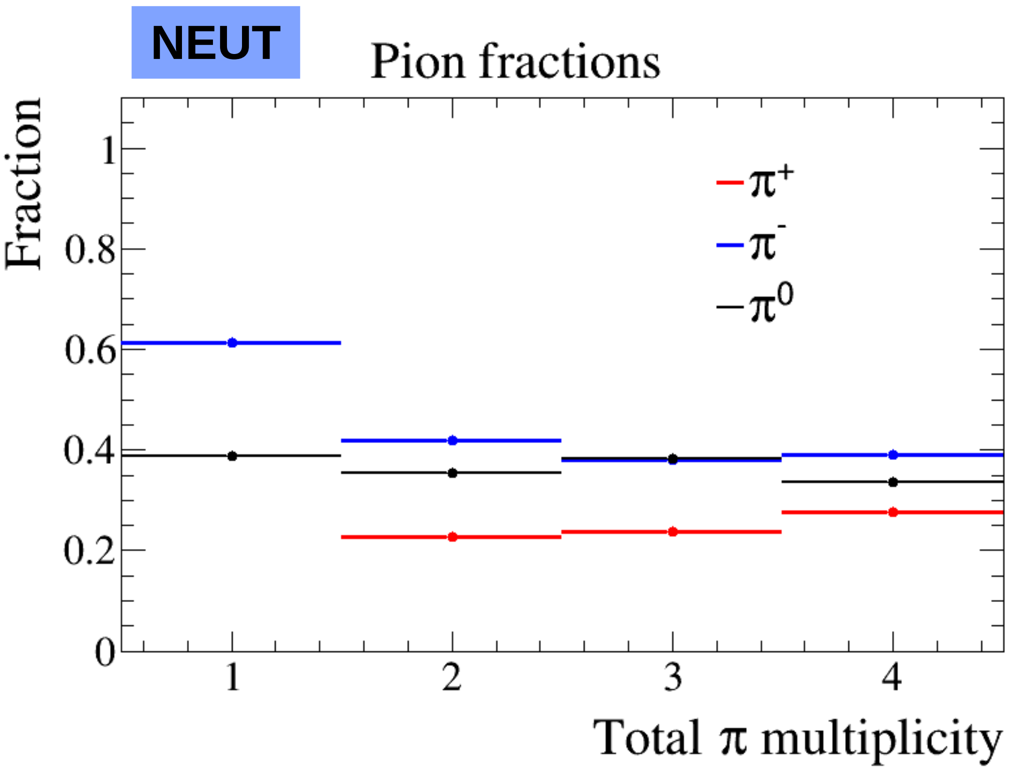


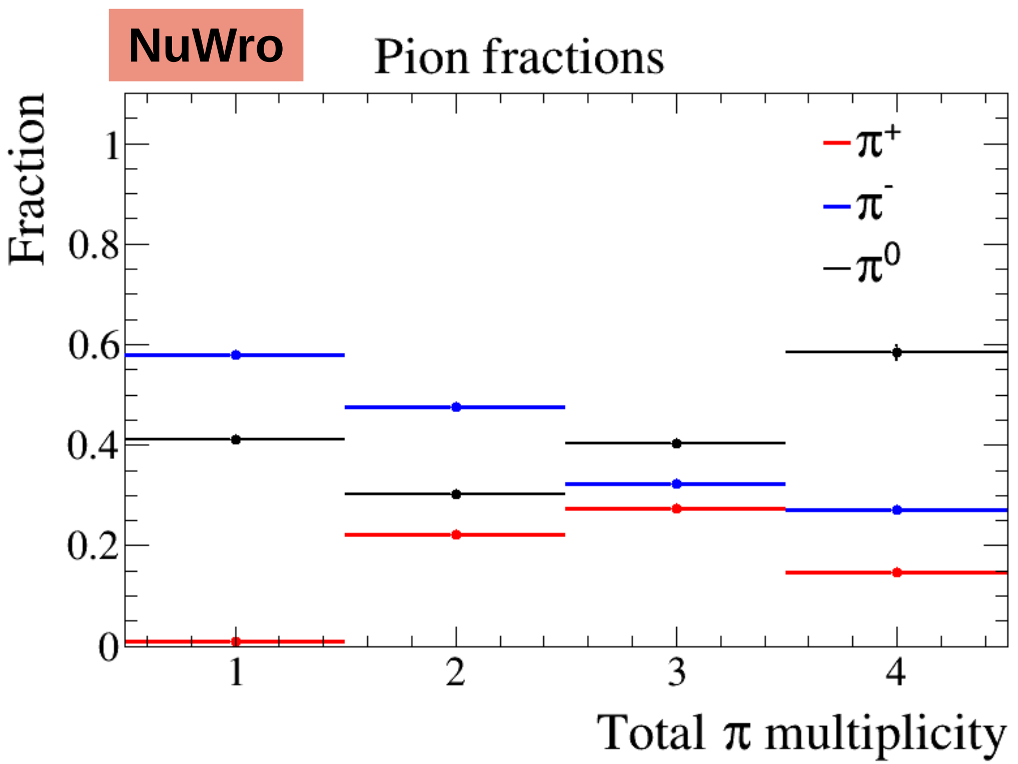




Pion fractions
Anti-neutrino on proton







Pion fractions
Anti-neutrino on neutron