GENIE needs from Lariat

10 July, 2014

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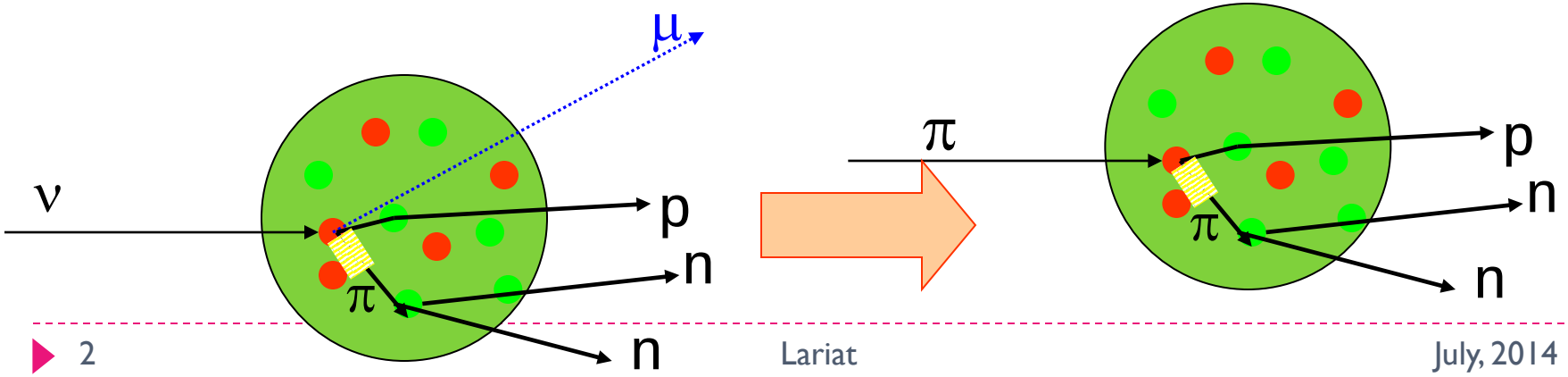
- general overview
- some examples
- short talk, not much detail

General Characteristics of GENIE models
Intranuclear Cascade (INC), real and inspired.

- hN is straightforward INC
  - Uses free 2- and 3-particle **free** cross sections + Fermi motion
  - Success comes from importance of quasielastic reaction mechanism in nuclear physics *and* existence of PWA data.
- hA is simplified INC (data-driven) [default]
  - Construct models of full chain of events
  - Uses simple representations of hN code, data, and intuition.
  - Easily reweighted (exact) because **each particle has at most 1 interaction as it propagates through residual nucleus**.



Capabilities

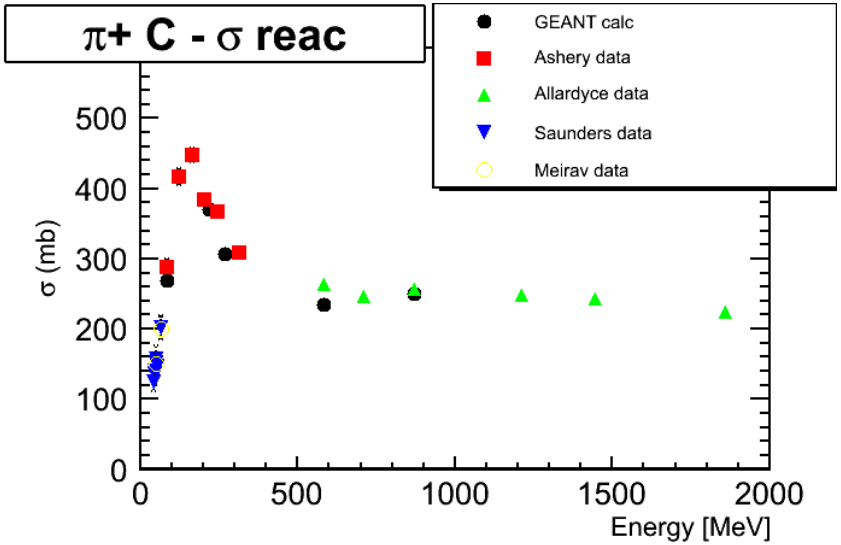
- GENIE (gevgen_hadron) can calculate any cross section for pions, K+, p, and n T<~1.8 GeV. Accuracy is mixed.
- Minerva (work of Leo Aliaga, extended by Juan Pablo Velasquez) has a program to calculate many observables with hadron beams using GEANT models.
- GENIE has extensive data base of measured cross sections in v2.8.0 and following. User-friendly validation tools will come in v2.8.2 (soon).
- Most of the work was done by Pittsburgh group. Tomek Golan has joined the FNAL group and will take responsibility for making grand validation programs.

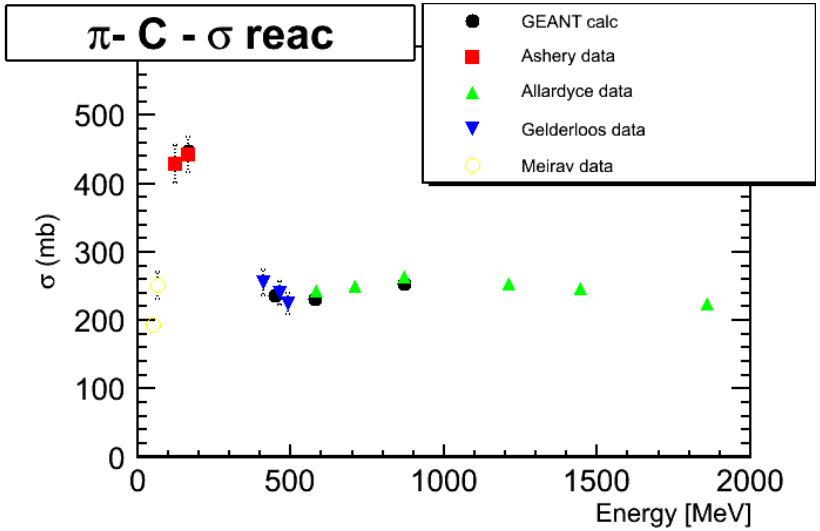
What GENIE has (shading gives needs)

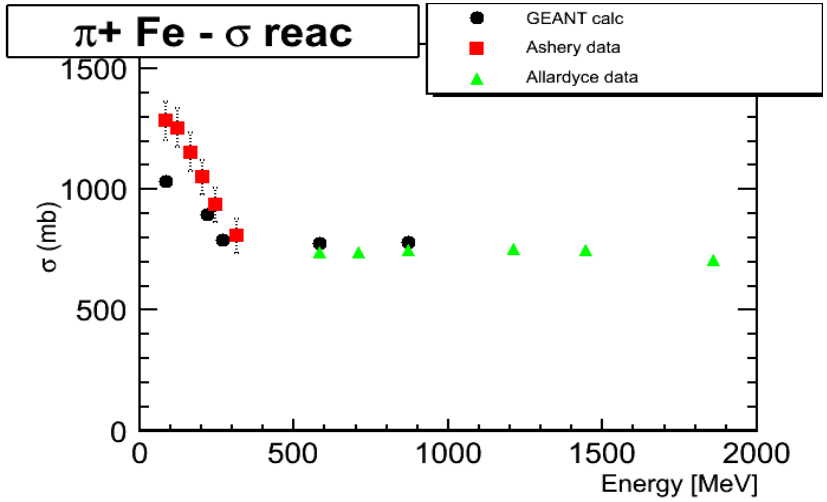
	PIONS	KAONS	PROTONS	NEUTRON
Elastic	Lots	Little	Some	Some
Inelastic	Some	Almost none	Some	Some
Charge exchange	Little	Almost none	Lots (confusing)	Lots (good)
Absorption (p, K) Spallation (n, p)	Little	Almost none	Almost none	Almost none

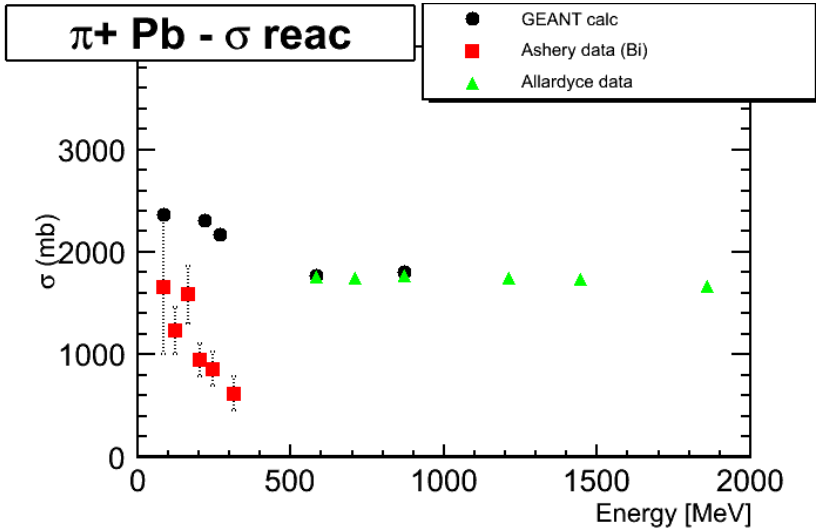
- Many ways for Lariat to contribute! (N.B. no red color)
  - ❑ Should be fully corrected cross section
- Minimum momentum ~400 MeV/c is good for nucleons, kaons – not as good for pions (Minerva experience)
- Hard to be so broad, should be discussed

Pion Total reaction cross sections vs. QGSP_BERT

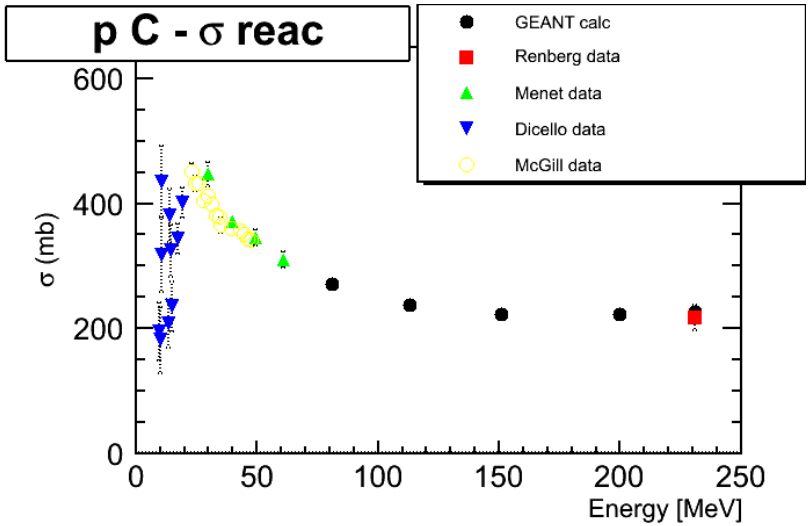


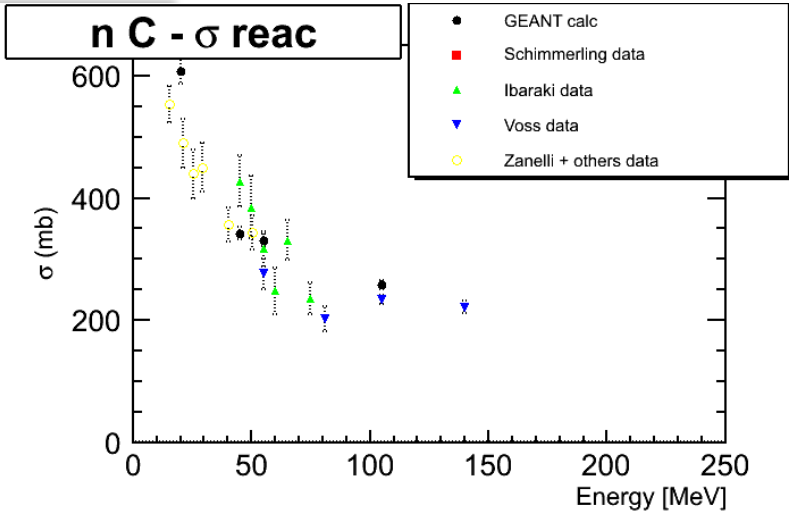


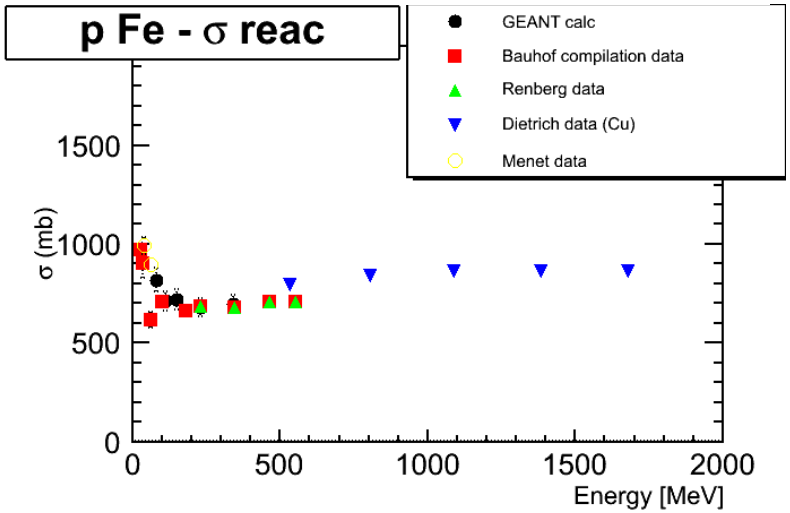


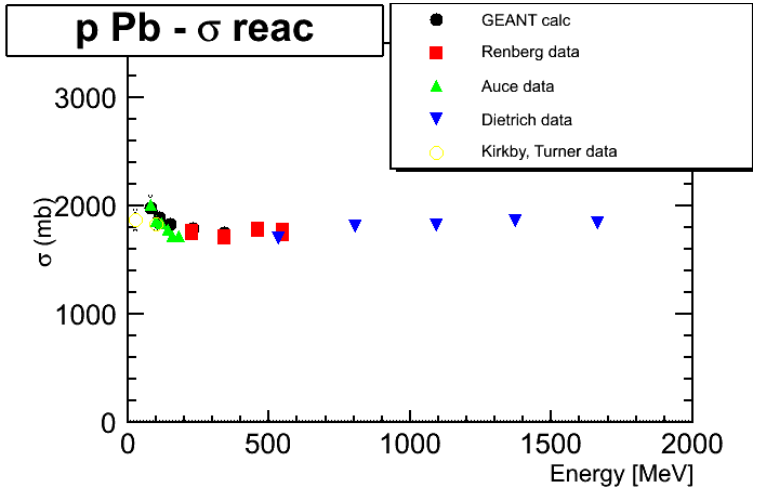


Nucleon Total reaction cross sections vs. QGSP_BERT



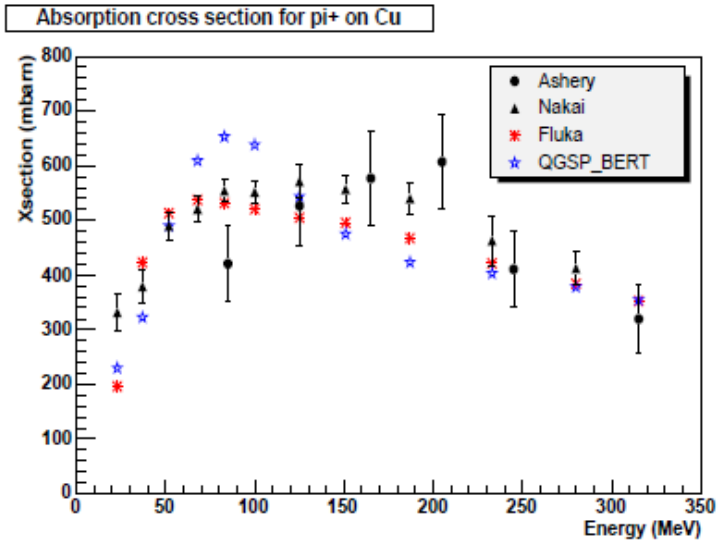




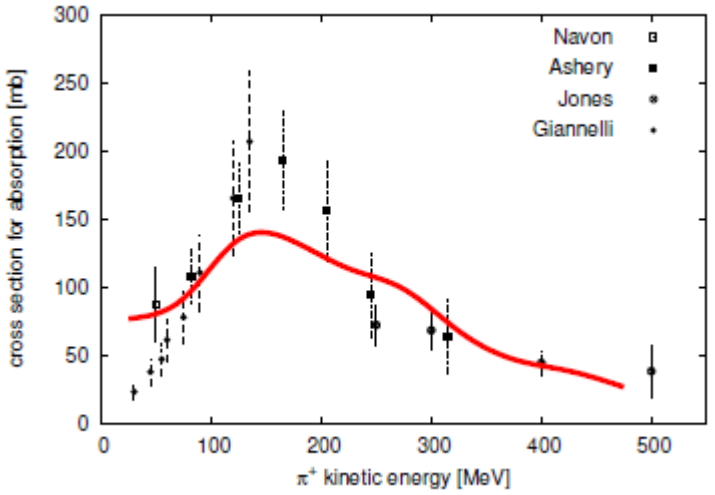


Pion absorption (some good, some bad)

- Ashery data is abs+cex, they subtract calc for cex
- Nakai data is in conflict with Ashery data
- Almost no information for T_π>400 MeV
- Focus on total abs xs is good, but can be misleading



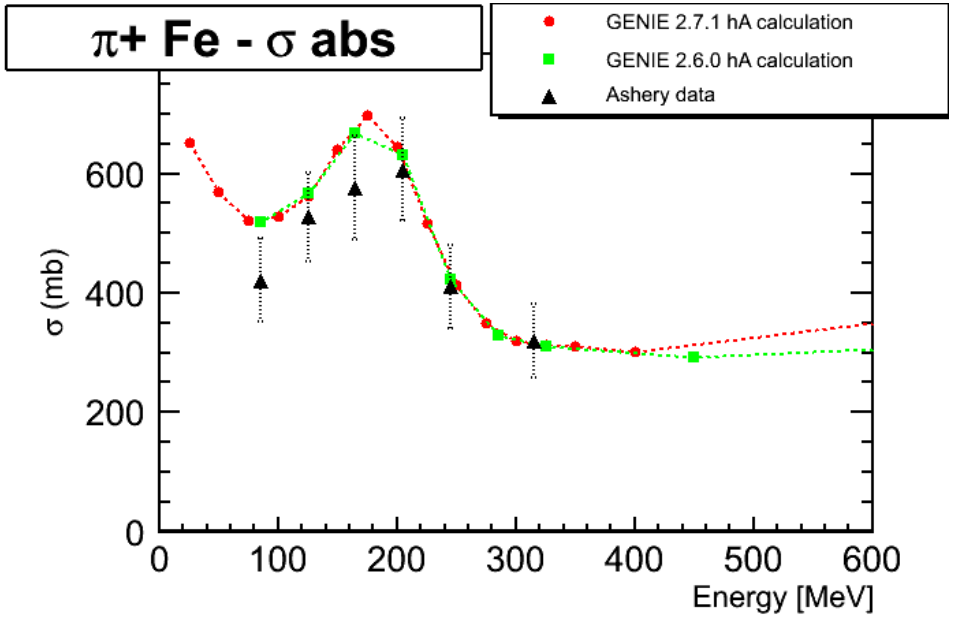
From GEANT study (2004)

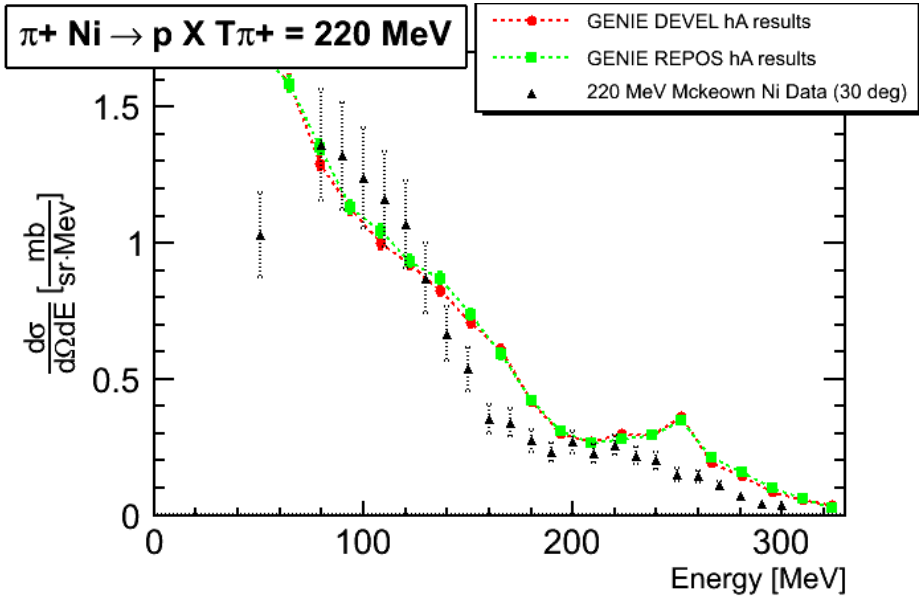


From Golan, et. al (NuWro)

Pion absorption in GENIE

- Previously focused on Fe
- Recent improvements to get light nuclei better
  - Get A dependence from data as much as possible (Ashery)
  - Has direct effect (few %) on CC pi prod mis-IDed as QE

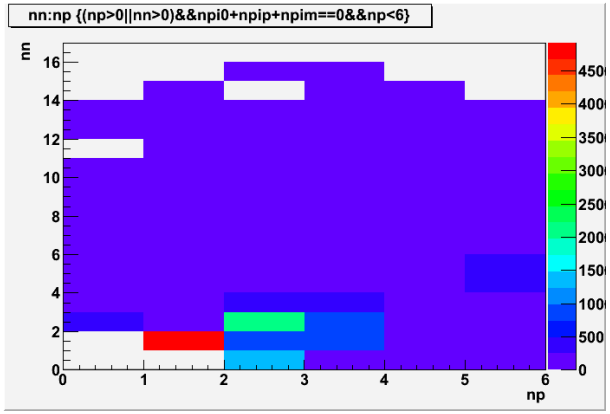


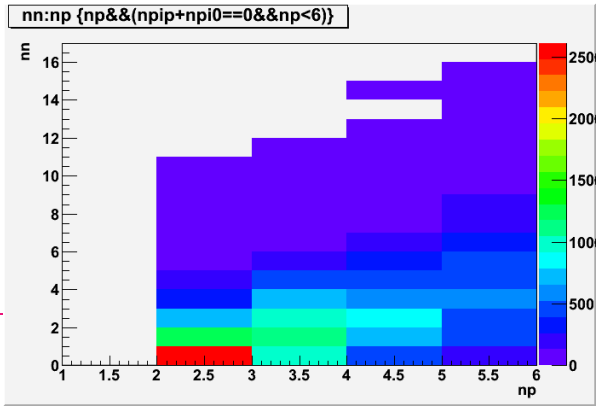


LADS pion abs data for Argon

- Lots of data for 239 MeV, some for other energies, tgts
- Variation among these final states is complicated.
- Note significant corrections for data below threshold.
- Do we need to get agreement with all of these?
- IMHO, no!

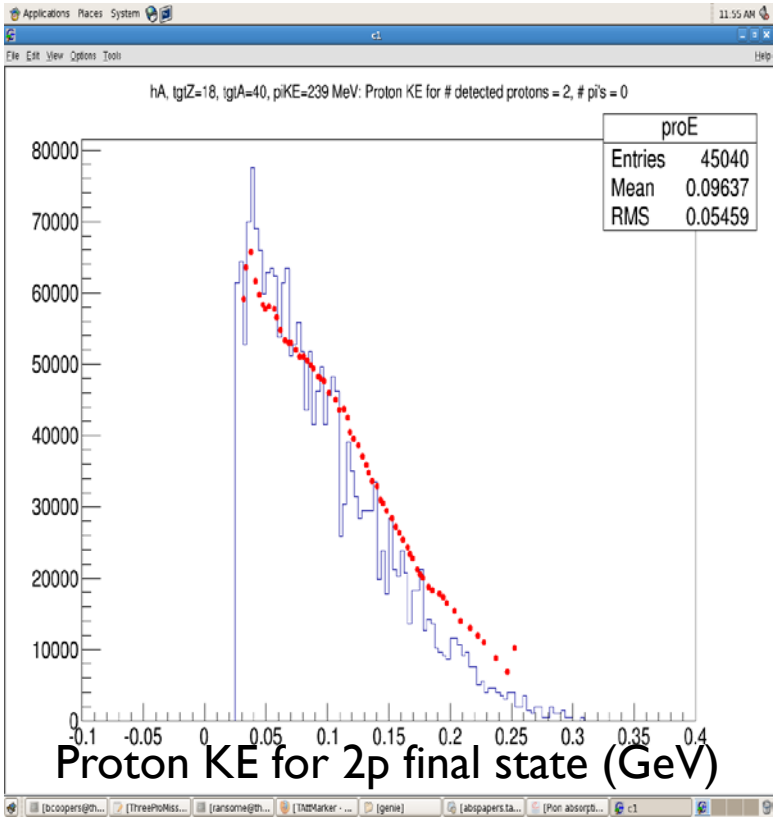
	Raw Data	30 MeV Threshold	Extrapolated to 0 MeV
5p	0.013 ± 0.001	0.04 ± 0.01	0.64 ± 0.13
4p	1.11 ± 0.10	2.0 ± 0.2	5.1 ± 1.0
3p	19.9 ± 1.2	26.8 ± 2.5	28.4 ± 4.0
3pn	2.0 ± 0.2	11.9 ± 1.3	33.2 ± 7.5
2p	69.8 ± 4.2	72.9 ± 5.8	43.6 ± 5.2
2p1n	11.9 ± 0.9	62.9 ± 6.6	$75. \pm 10.$
2p2n	0.67 ± 0.05	5.6 ± 1.0	$21. \pm 8.$
2pd	9.2 ± 1.0	10.3 ± 1.2	7.9 ± 1.4
pd	14.6 ± 2.3	9.8 ± 1.7	4.2 ± 1.0
pdn	3.0 ± 0.4	13.8 ± 2.4	10.6 ± 2.5

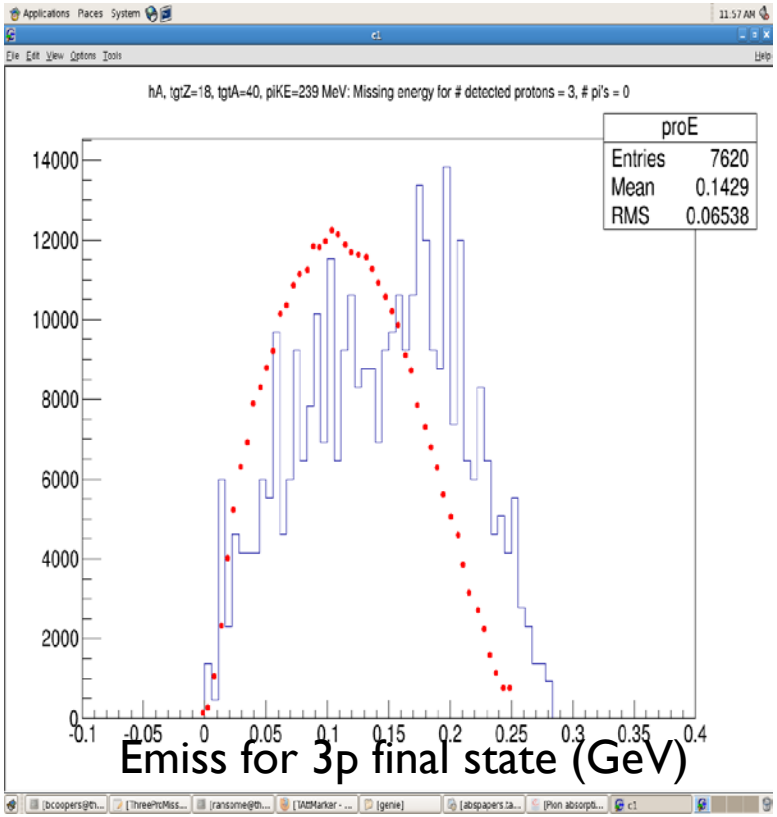




More detailed data

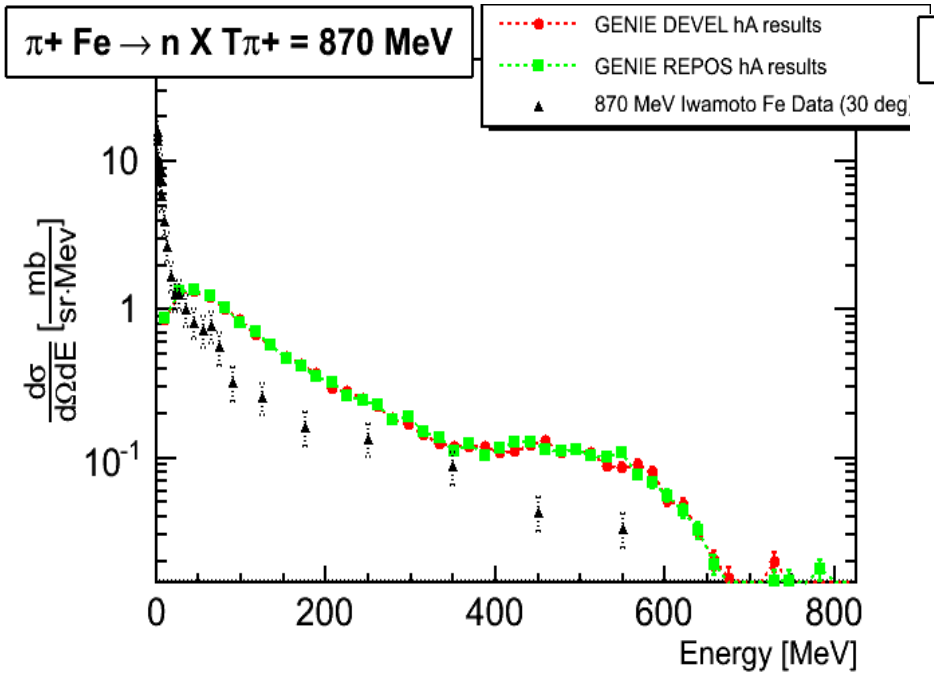
- Work by Rutgers (Coopersmith, Ransome) still unfinished
- N.B. data (unnormalized) is red, GENIE is blue

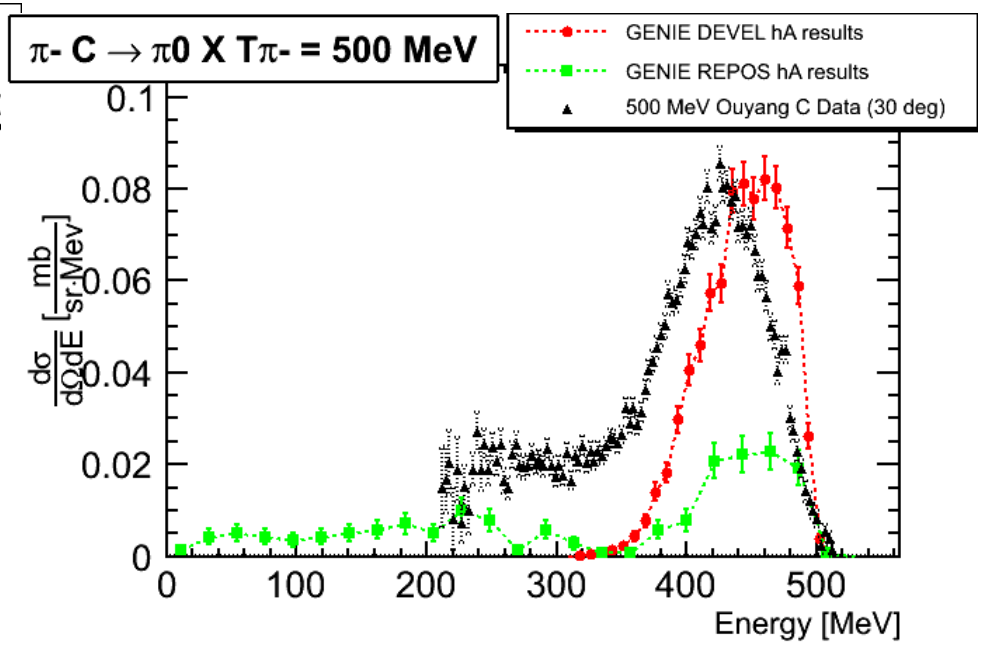




Pions Tπ>~500 MeV (not much)

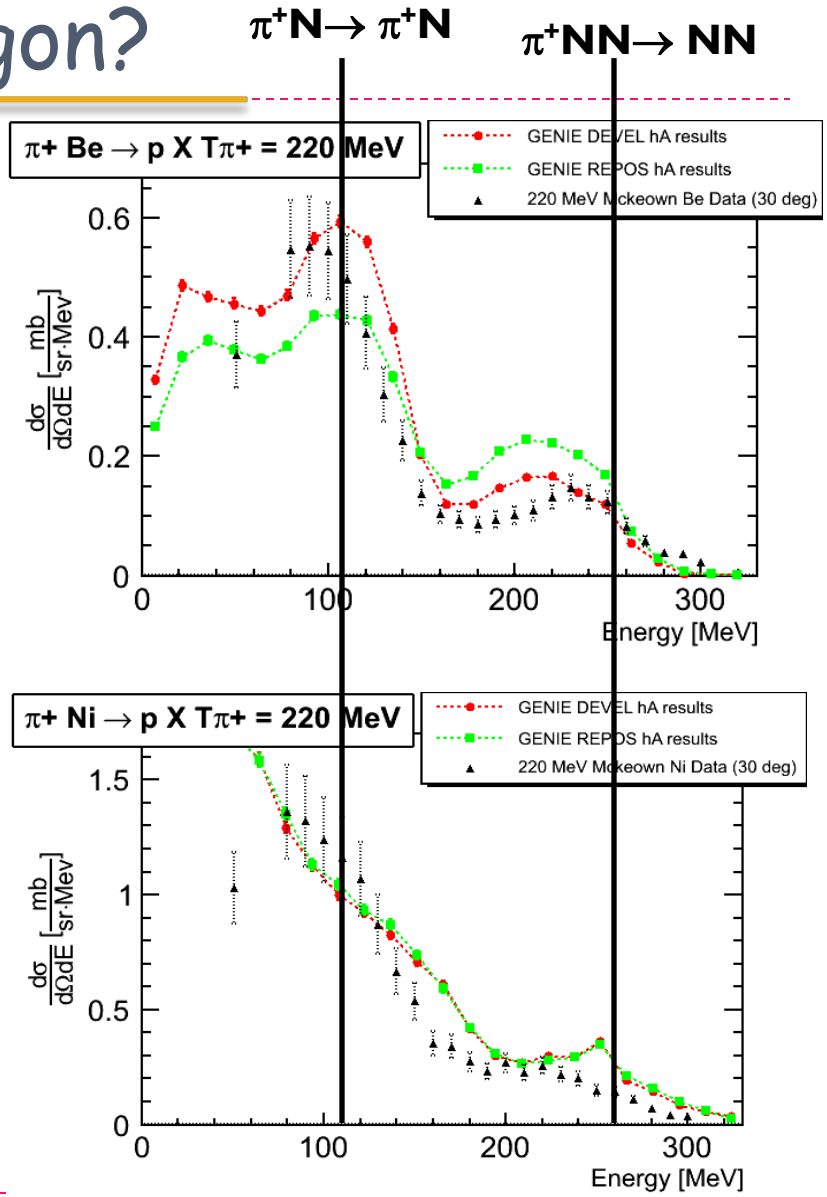
- Not much? Important?
- Simple models should work well, but ~0 data
- $\sigma_{reac} = \sigma_{abs} + \sigma_{cex} + \sigma_{inel}$





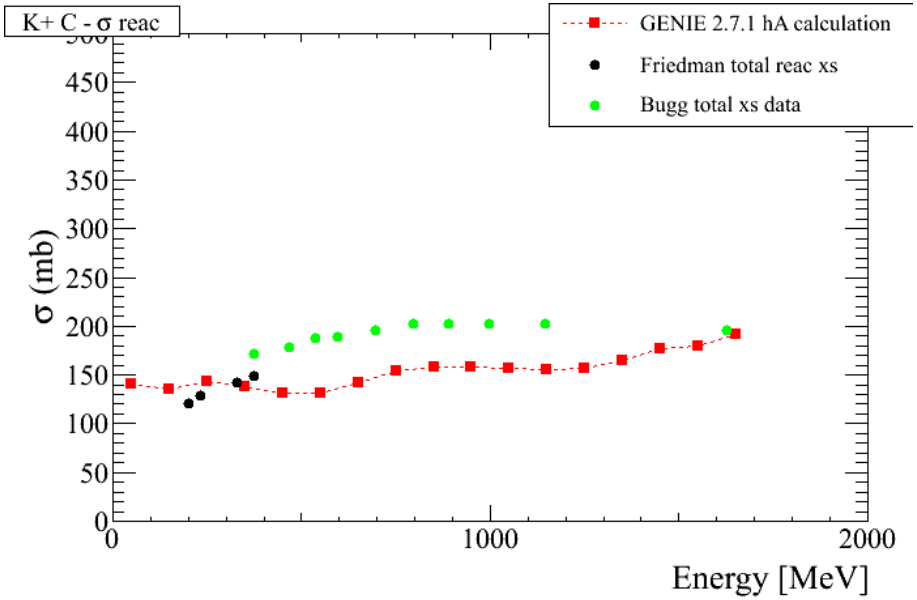
Can GENIE predict Argon?

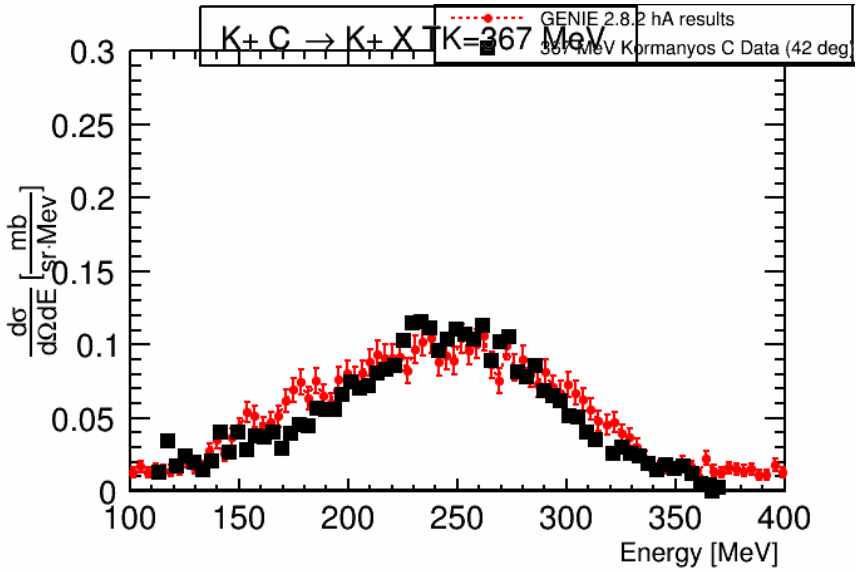
- Why do we do well despite lack of tuning?
- Hadron total cross sections all scale by powers of A
  - Power~2/3 for absorption, 0.8 for total
- In light nuclei, predominance of single nucleon processes obvious. Signs still there in heavier nuclei.



Kaon interactions – just starting, much to do

- Important for recent interest in p decay
- Most data for nucleons
  - Recently discovered source for K+ p,n,&d results of Hyslop et al.
  - Still figuring it out with Flor de Blasczyk
- Very little for nuclei
  - K+ Carbon total reac xs, some inclusive scattering for C, Pb.



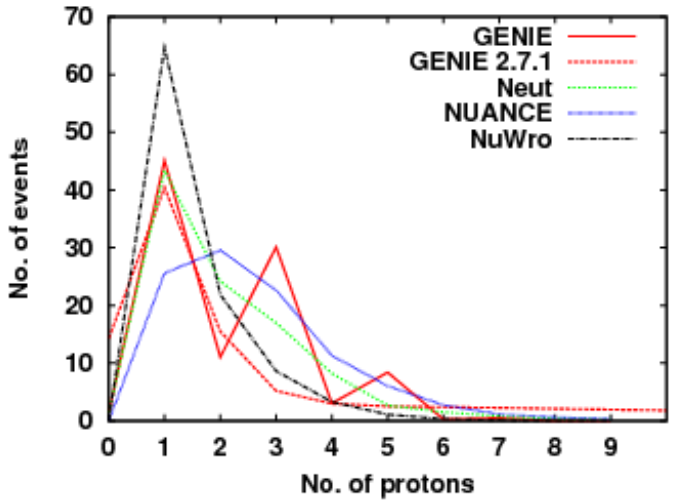


Global variables

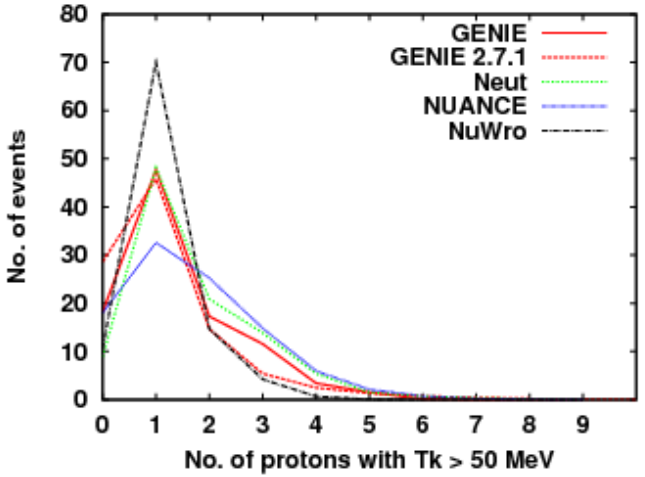
- Argon detectors do it well
  - Argoneut nucleon multiplicity data very interesting, but unmatched for hadron beams
  - Total energy in charged particles

ν_μ Ar – 3 GeV

All Protons (many sources!)



Protons with KE>50 MeV



GENIE is changing

- New structure
  - More horizontal decision-making
  - Hugh Gallagher and I lead Physics Working groups
  - US collaborators working to get DOE funding
- New manpower
  - FNAL hired Gabe Perdue, shifted 3 others toward GENIE
  - Users' Forum trying to form FNAL GENIE-users projects
    - Opportunity for Lariat
  - Developers' workshop in March, 2014 at FNAL had ~15 participants
    - Flor de B working on K FSI, Minerba B on proton FSI
    - Room for someone from Lariat

Conclusions

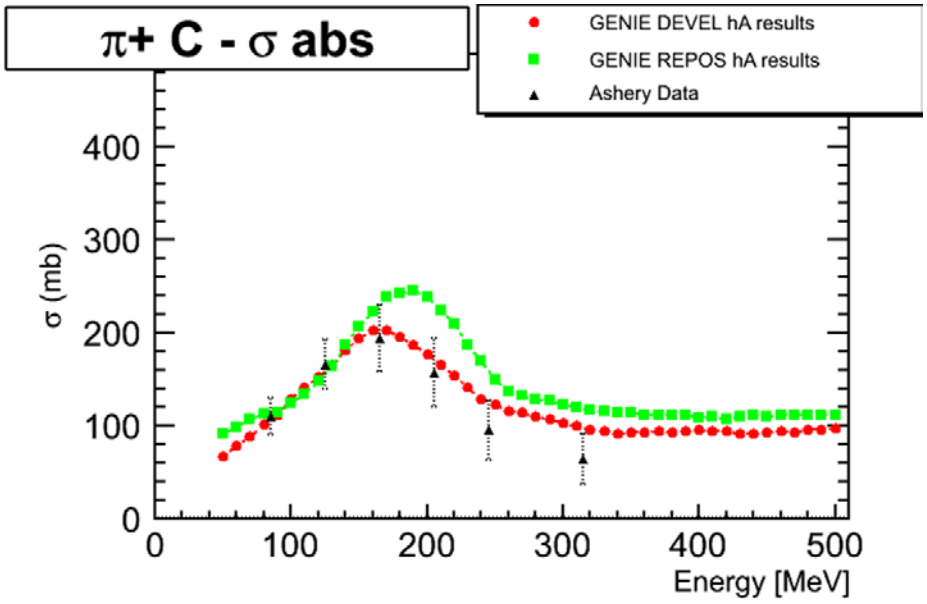
- Many tools available
  - GENIE data sets, validation codes public
  - GEANT code exists, can run against low energy data
- Definitely room for more hadron-nucleus data
  - Almost any Kaon interaction
  - Detailed pion interactions for charge exch, absorption

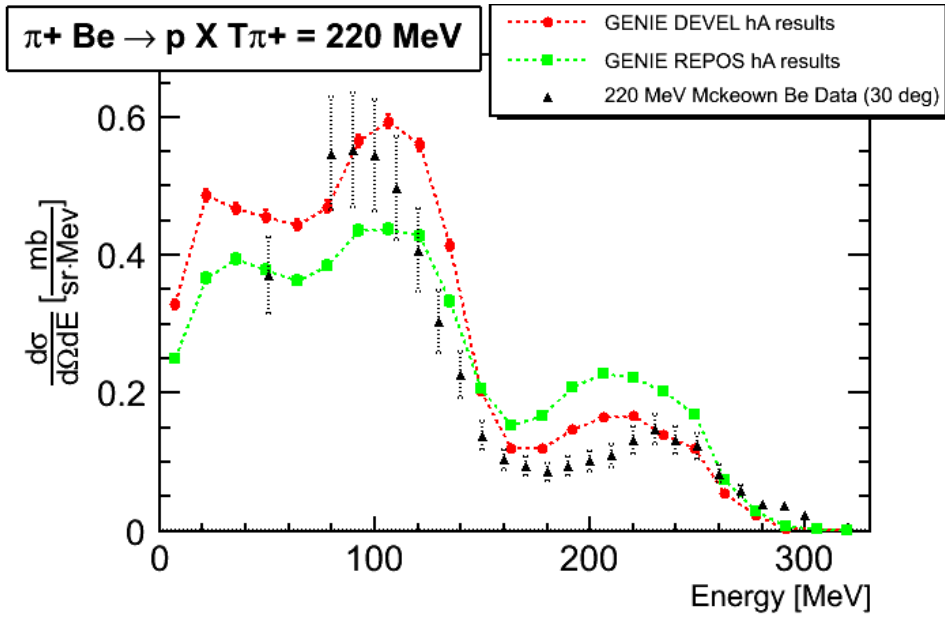
What does FSI do to ν expts?

- ν expts want to make clean identification of physics by topology of events and **FSI masks topologies**.
- Calculate E_ν from QE events.
  - Ideally, ν interacts with single neutron and we see products. $\nu_\mu\ n \rightarrow \mu^-\ p$. In reality, n isn't free and p must get out of nucleus.
  - μ + p ID is much better, but ~35% of protons have significant FSI.
  - μ doesn't give clean ID because pion prod kinematics overlap QE.
  - Not all pion prod events have pion in final state (~25% absorption).
- Need xs π, p at KE <~1 GeV (T2K, MicroBooNe)
  - Overall interaction rates
  - Topology changing interaction rates, e.g. $p \rightarrow n$, $\pi \rightarrow p$ or n.

Pion abs at low *A*

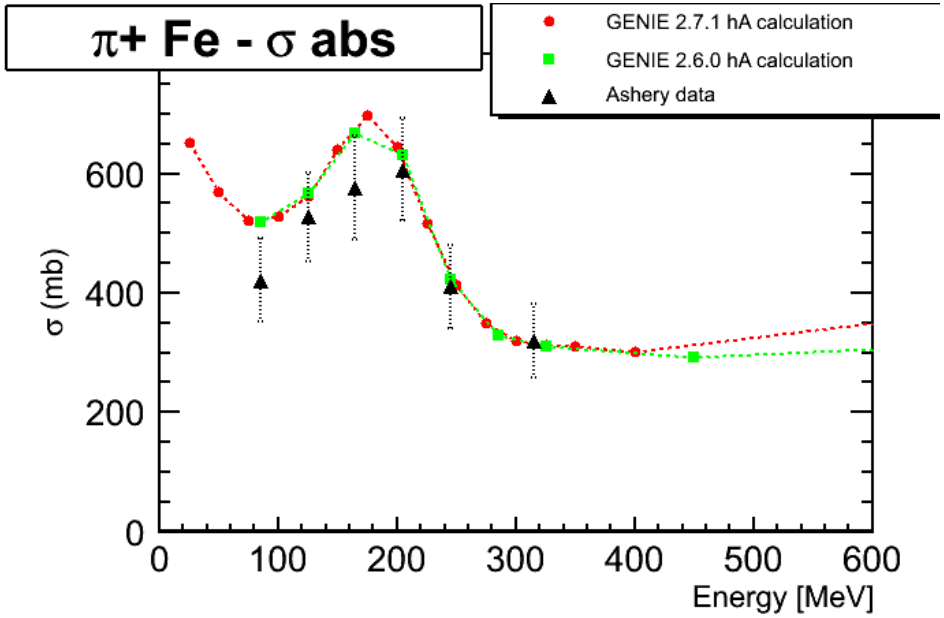
- New tune does much better

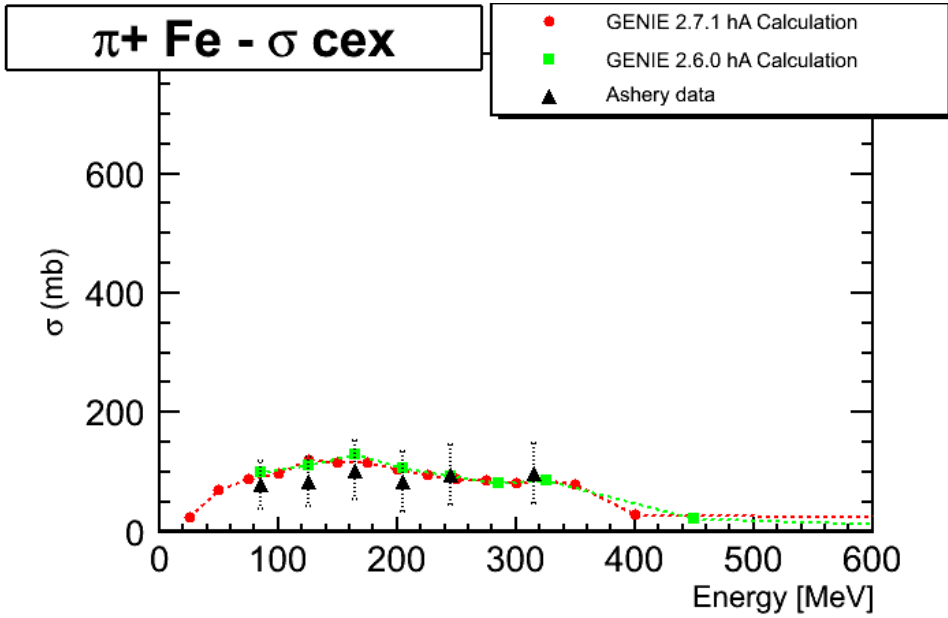




More on total cross sections

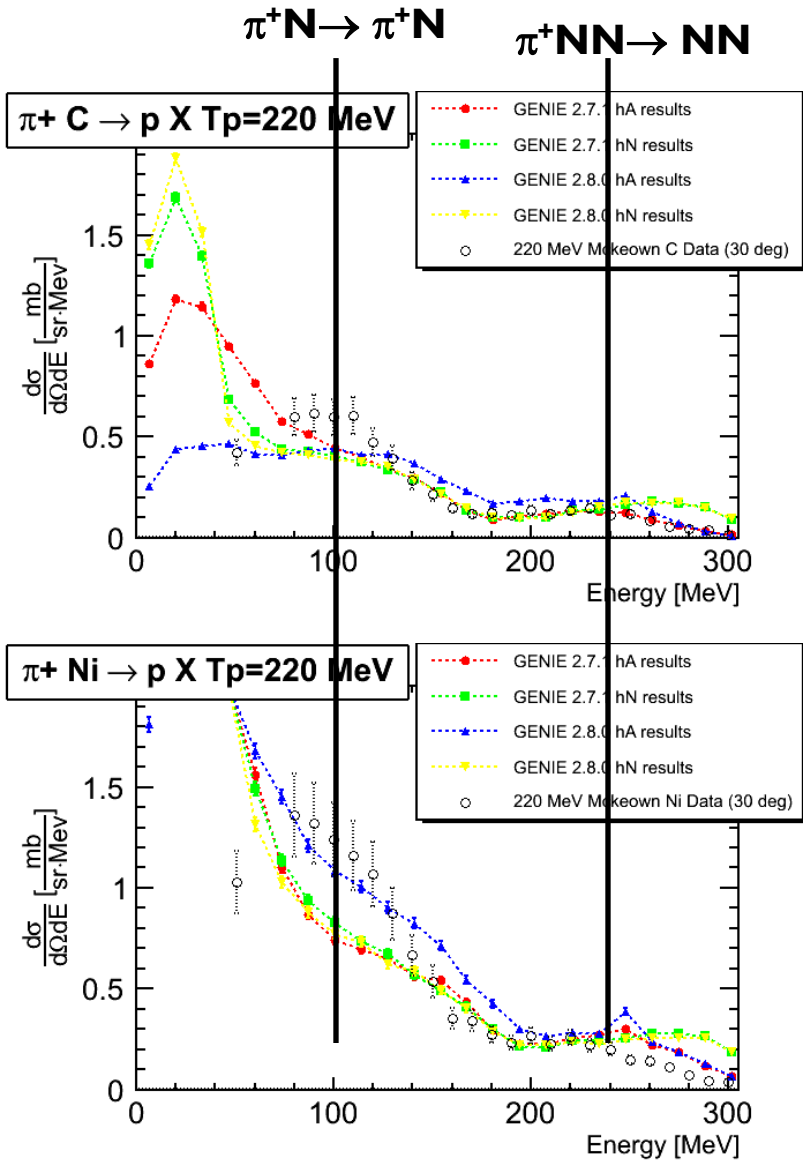
- For pions, we have some data for total xs for specific processes. Note, absorption and scattering more important than charge exchange.
- For nucleons, must use more detailed data and extrapolate.





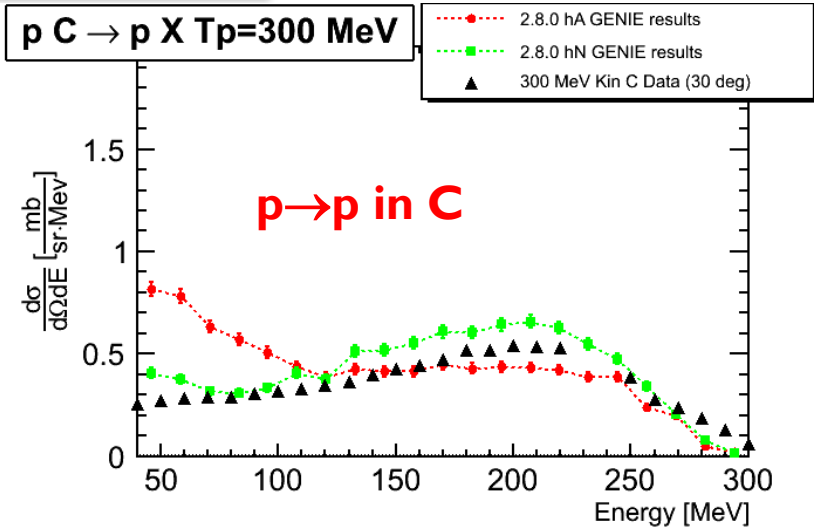
QE processes seen here can check

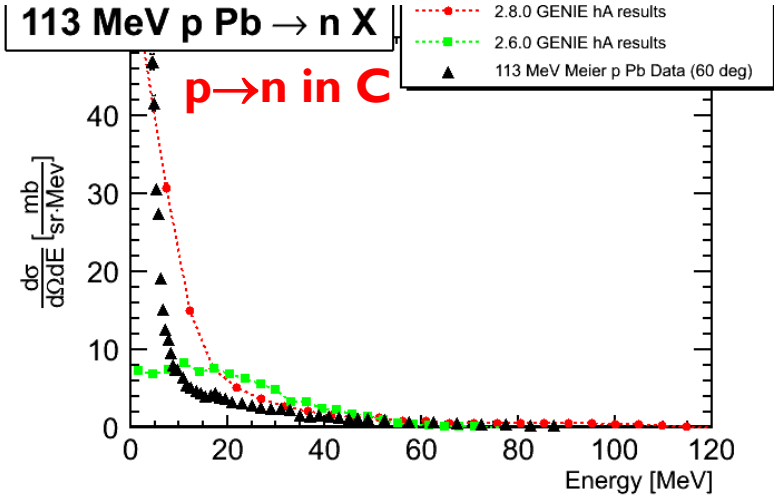
- **$\pi^+N \rightarrow \pi^+N$** QE scattering in medium (don't see falloff on low energy side)
- **$\pi^+NN \rightarrow NN$:** QE absorption in medium
- Peaks shifted and broader because of binding, Fermi motion



Proton scattering is interesting to ArgoNeut

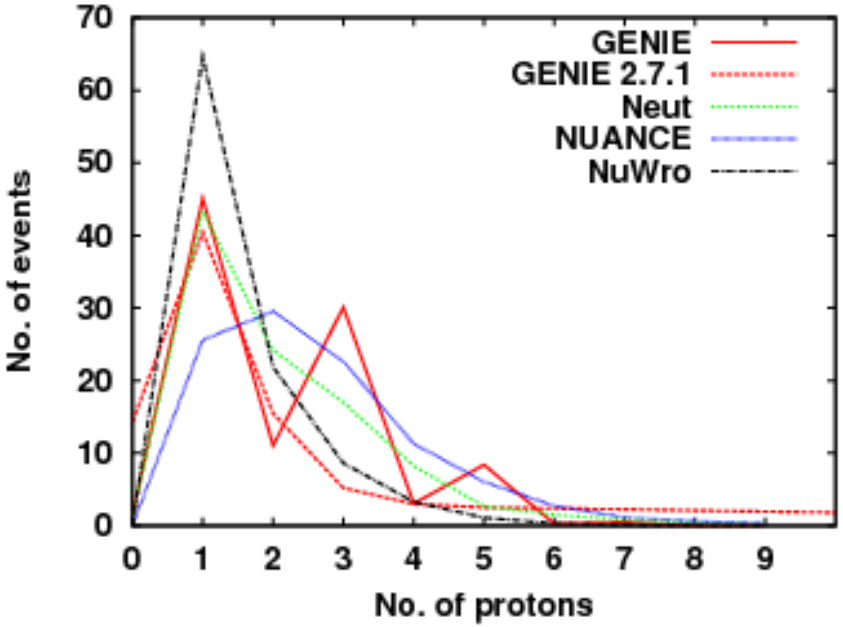
- See effects of protons propagating, energy degrades through multiple interactions.
- Rapid rise in neutron spectra at very low energies due to pre-equilibrium/compound nuclear processes, must be included.



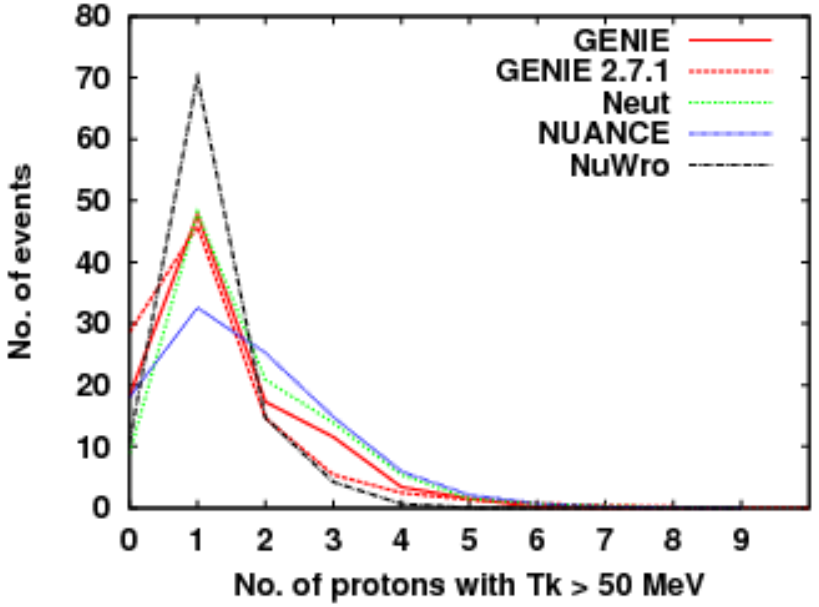


Example – proton multiplicity
ν_μ Ar – 3 GeV (ArgoNeut for NUINT12)

All Protons (many sources!)

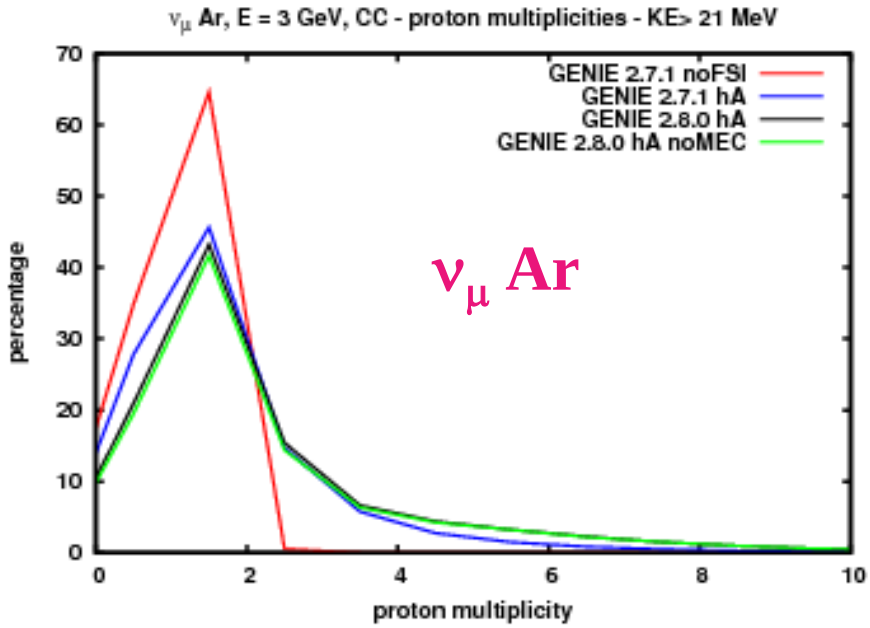


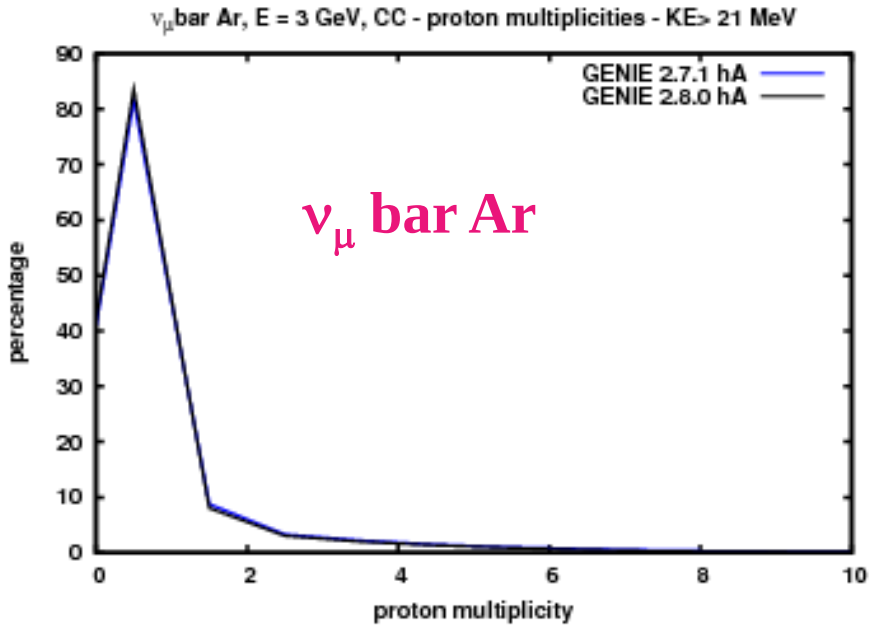
Protons with KE>50 MeV



proton multiplicity
ν_μ Ar – 3 GeV (ArgoNeut for NUINT12)

- Compare v2.7.1 (Dec) with v2.8.0
- For ν_μ, also show results from taking out FSI and MEC

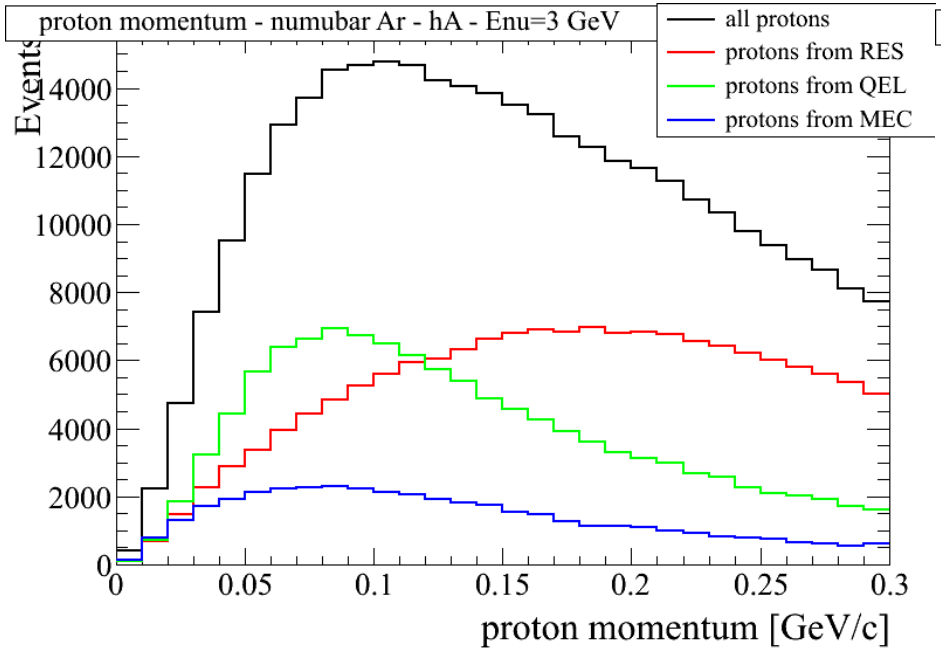




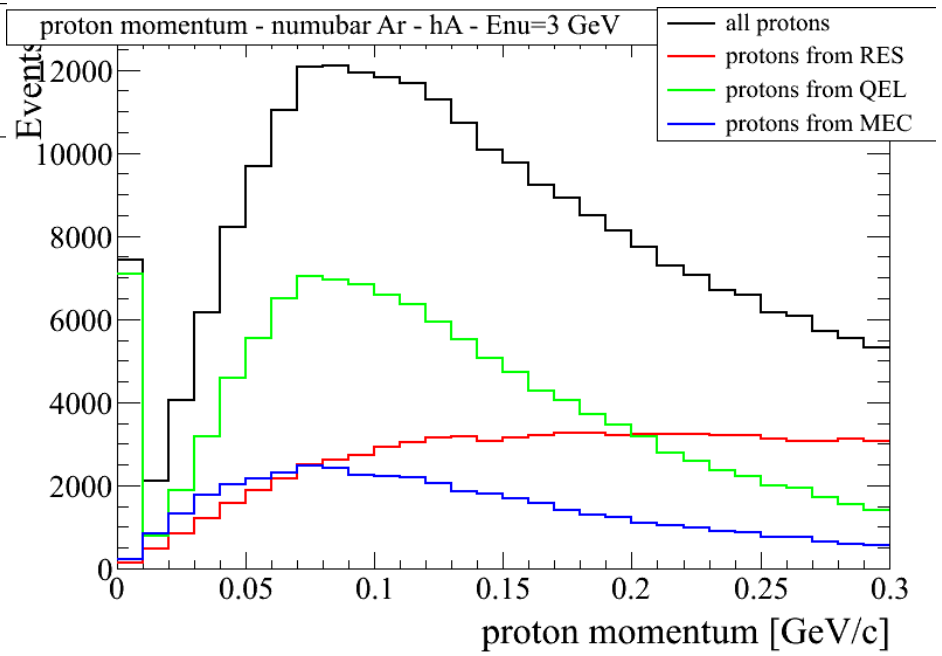
Proton energy distributions - $\bar{\nu}_\mu$ Ar – 3 GeV

- Compare GENIE versions from fall and new frozen v2.8.0
- (will be a little harder to use development versions)
- Cuts same as ArgoNeut (no pions)

2.7.1 Dec, 2012



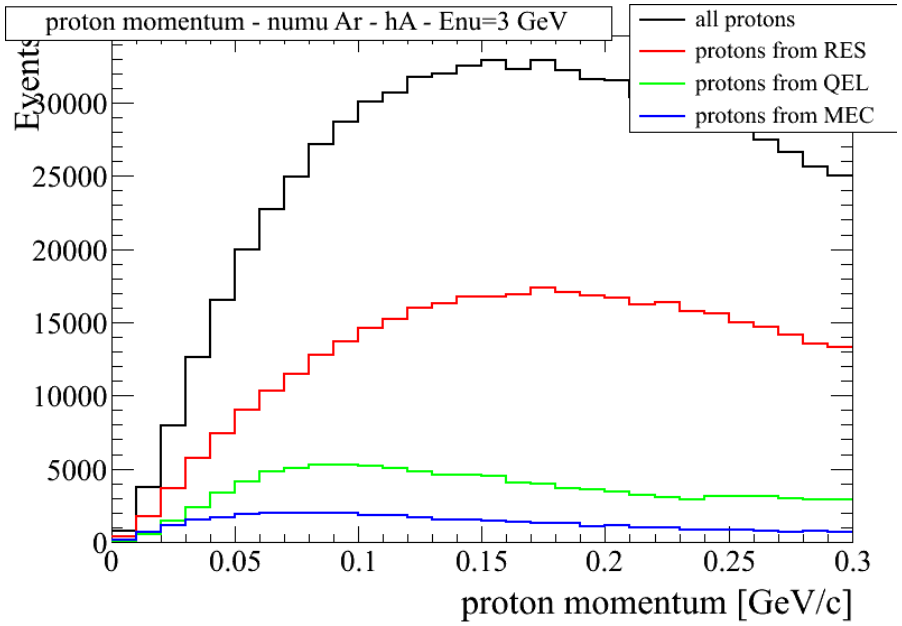
2.8.0 Mar, 2013



Proton energy distributions - ν_μ Ar – 3 GeV

- Differences stronger here, still not severe.
- Note difference in vertical scale (should investigate)
- Where did protons at momentum~0 come from?

2.7.1 Dec, 2012



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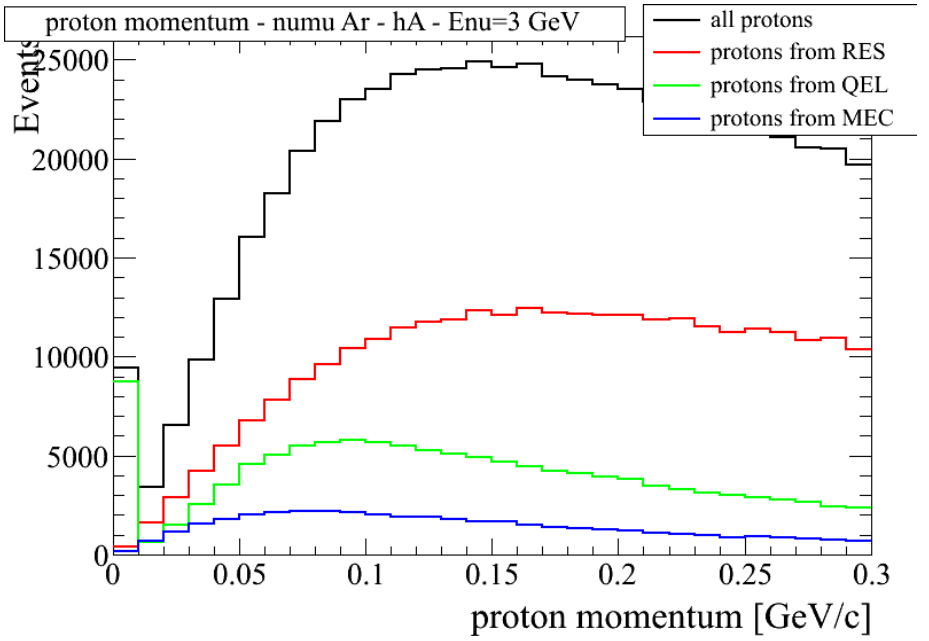
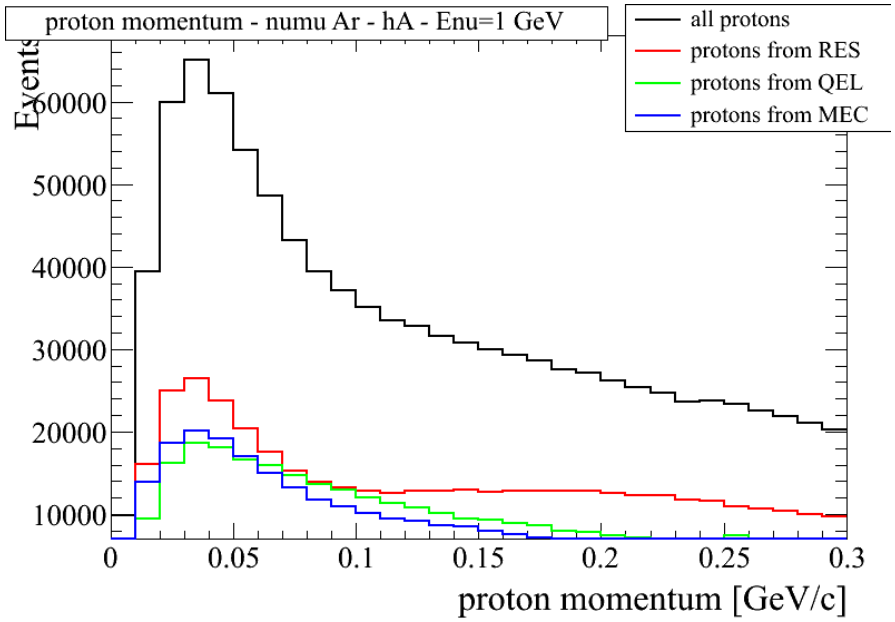
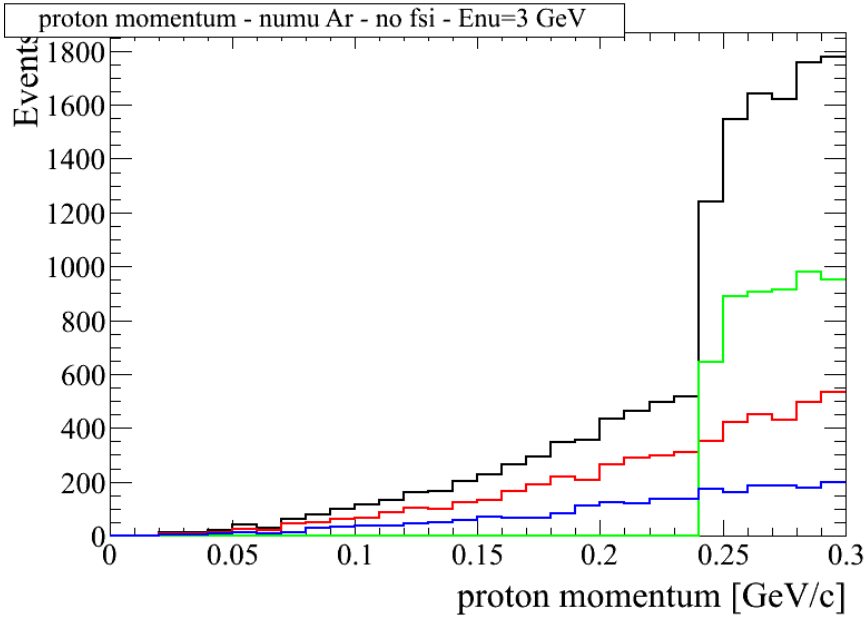


FSI is strong effect

- Here are what spectra look like for ν_μ Ar at 1 GeV (left) and 3 GeV (right).





conclusions

- ν oscillation expts depend on MC, cross section results
- GENIE is most modern, highest quality νA event generator
- Small, but dedicated group but manpower *always* an issue
- Excellent agreement with existing ν xs data (meagre).
- Extensive validation features vs. νA, hA, and eA.
- Need more ν cross section data for nuclei
  - MiniBoone now, Minerva (FNAL) and T2K in near future
- New 2.8.0 has improved FSI, first MEC
- Validation against all (e,e') data underway (fix vector int)
- Experiments in progress have a lot to help model building.