Interactions of low energy pions with nuclei (Part II)

Below 600 MeV laboratory kinetic energy of pion

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Conclusions from previous talk

- At pion energies below 600 MeV pion absorption is frequent.
- Pion absorption occurs on 2 or more nucleons.

Absorption on one nucleon is improbable due to energy-momentum conservation.
The energy liberated in the absorption > Mpi = 140 MeV. The corresponding momentum of the single nucleon should be 500 MeV/c, much larger than the typical Fermi momentum. Two nucleons share the liberated energy and leave with opposite momentum. Quite frequently more than two nucleons appear in final state. Is it direct absorption on more than 2 nucleons, or Initial and Final State Interaction?

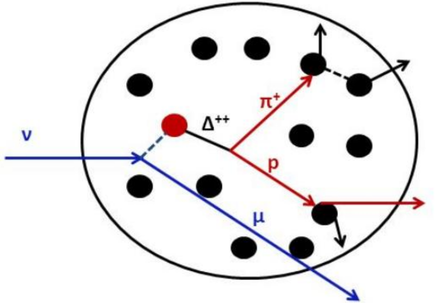
Conclusions

- The cross section energy and angular dependence similar to that in $\pi^+ d -> pp$, $np -> \pi^0 d$, $pp -> \pi^+ d$. Delta J=3/2,T=3/2 resonance production dominates.
- Quite frequently more than two nucleons appear in final state. Is it direct absorption on more than 2 nucleons, or Initial and Final State Interaction?

TABLE I. The total *observed* cross sections for 2NP, >2NP, and MNKO processes at T_π = 200, 240, and 280 MeV.

T_π (MeV)	σ_{obs}^{2NP} (mb)	$\sigma_{obs}^{>2NP}$ (mb)	σ_{obs}^{MNKO} (mb)	$\frac{2NP}{2NP+>2NP}$
200	0.463	0.814	0.103	0.36
240	0.305	0.704	0.158	0.30
280	0.260	0.770	0.246	0.25

Final State Interactions of Pions for neutrino interaction



Methods developed for pion-nucleus reactions transported to propagation of pions from neutrino-nucleus reactions through the nucleus.

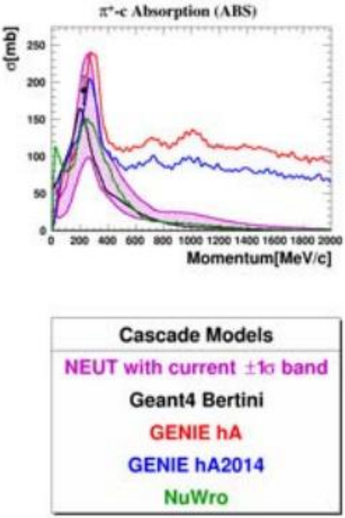
Generators:

NEUT, GENIE, GEANT4, NuWro, FLUKA Recently for energies < 1GeV PEANUT may be incorporated in FLUKA and GEANT4 Mainly microscopic, intranucleonic cascades. Tuning using experimental informations on the cross section. ,proton multiplicity,

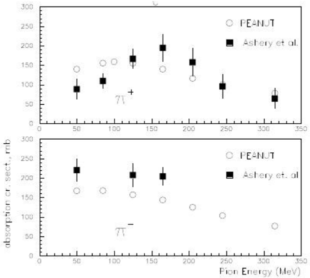
Neutrino Event Generators

- GENIE:
  - In use by NOvA, MicroBooNE, MINERvA, SBND and ICARUS, and DUNE
  - Also being tested in MINERvA, and used by T2K's near detector analyses
- NEUT
  - In use by Super-K (atmospheric neutrino analyses), T2K's far and near detectors
  - Cascade model tuned by external DUET data
- NuWro
  - PYTHIA used for hadronization in DIS
  - Follows NEUT and GENIE in many respects
- FLUKA (NUNDIS)
  - Adapting FLUKA framework to accommodate neutrino interactions
- GIBUU
  - Full cascade model for propagation through nucleus, "first principles" generator for all processes, but still has to add in coherent scattering off entire nucleus

Final State Interactions of Pions for neutrino interaction



← *W.Y.Ma, J.Phys.Conf. 888 (2017) 012171*



A.Fasso et al., SATIF-1 Conf.(2020) FLUKA/PEANUT

FLUKA generator

A.Fasso et al.Contribution to SATIF-1 (2020) FLUKA: performances and applications in the intermediate energy region. (especially 20 MeV-1 GeV)
G.Battistoni et al., Annals Nucl.Energy 82(2015)10 Overview of the FLUKA code.
NA61/SHINE got satisfactory agreement with the experiment for pC at 31 GeV/c using FLUKA. However the cross check for small pion momenta not performed below about 250 MeV/c (kinetic energy 120 MeV) . We have not seen the source of any fragment of the code. They used the method of cascade calculation of Valenzia group (Oset and collaborators).

Y.Hayato, Act.Phys. Pol. B40 2477 (2009) Black area - pion escaping from the nucleus.

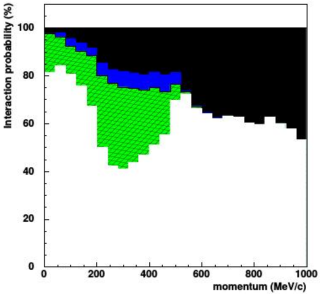


Fig. 6. Interaction probabilities of π^+ in ^{16}O. The filled area corresponds to the inelastic scattering including particle production, the shaded area corresponds to the charge exchange interaction, the hatched area corresponds to the absorption, and blank area corresponds to the escaped pions without interaction, respectively.

NuWro : $\pi^+ C$ interaction

T.Golan, C.Juszczak, T.Sobczyk, Phys.ReV. 444 C86 015505 (2012)

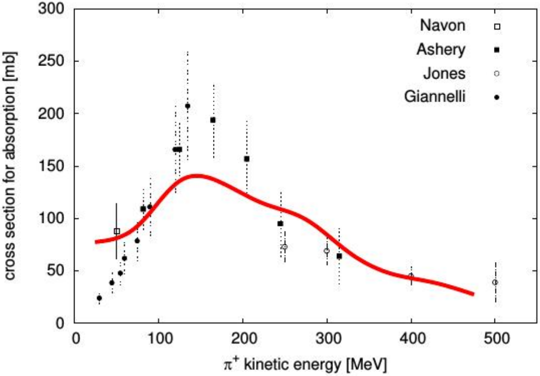


FIG. 4. π^+ ^{12}C absorption cross section. The data points are taken from: Ashery [35], Navon [36], Jones [37] and Giannelli [38]. The solid line shows NuWro predictions.

Pion Absorption Experiment $\pi^+ + ^{12}C$ CHAOS at TRIUMF

R.Tacik et al.,Phys.Rev. C57, 1295(1998) T_{π^+} 200, 240, 280 MeV, 10% of 4pi, Min. proton energy > 20 MeV (200 MeV/c) Protons with energy >20 MeV (200 MeV/c) were measured. How many such protons in final state?

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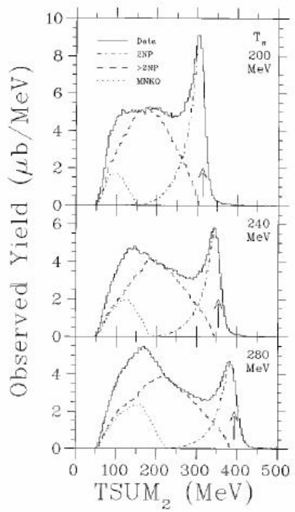


$$T_{max} = T_\pi + m_\pi + M_C - 2m_p - M_B$$

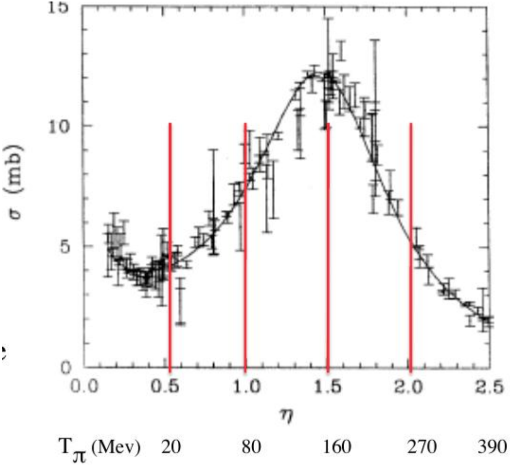
Conclusions

The errors in absorption cross sections of MC simulations are of the order of 25percent in the pion energy region considered. Large discrepancies between results of MC generators seems strange. Tuning to the existing and not exploited data could be done in my opinion.

Backup

The simplest case: absorption on deuteron

Clearly dominated at the pion energy below about 600 MeV by the $\Delta(1232)$ resonance with spin and isospin 3/2.



At small energies the cross sections are frequently presented vs $\eta = P_{\pi}^{CMS}/m_{\pi}$.