Low momentum hadrons

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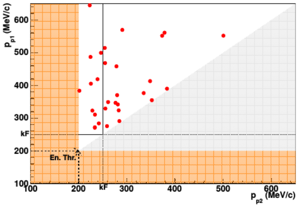
Nucleons

In the Fermi gas model there are no knocked out nucleons with $p \geq k_F$ (k_F is Fermi momentum)

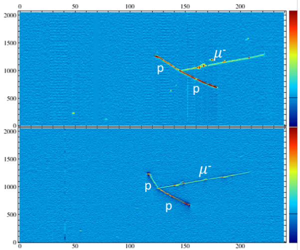
- detection of nucleons with $p \leq k_F$ points directly to physics beyond FG model

There is a lot of discussion about a size of MEC contribution to CC inclusive cross section

- a lot of excitement about Argoneut events back-to-back protons (in LAr a threshold for proton detection is ~ 200 MeV/c i.e. less than k_F for Argon).



Sample of events with 2 protons.



A search for MEC events

The goal is to seperate three contributions to CC0π (defined by a primary interaction in the impulse approximation picture):

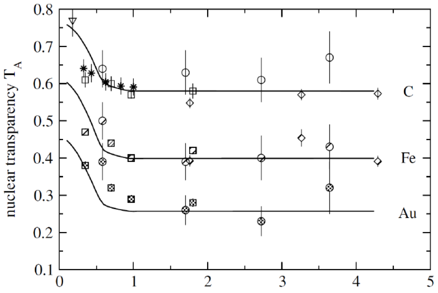
- CCQE
- π production and absorption
- MEC (two body current)

Muon information is not sufficient.

Clearly, the more information we have on final state nucleons more likely it is that a seperation can be done.

Transparency

An interesting observable is proton nuclear transparency, a probability that a proton will reinteract.



On the horizontal axis: proton kinetic energy.

Low momentum protons are less likely to interact (Pauli blocking!) and carry more information about the process in which were produced.

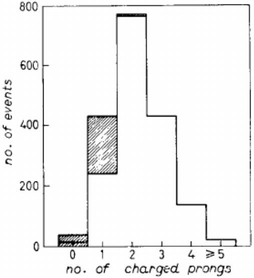
Pion absorption

Low momentum nucleons can be used in pion absorption studies

- a dominant mechanism is two body absorption:

$$\pi N \to \Delta, \qquad \Delta N \to NN.$$

- but more complicated mechanisms are likely to contribute as well
- in the past several interesting proton/deuteron multiplicity studies



Bellotti, Cavalli, Matteuzzi, Nuovo Cim. 18A (1973) 75

Proton detection threshold is $T_p = 12$ MeV i.e. $p = 150$ MeV/c.

Validation of MC simulation tools

Information about low energy hadrons can be used in upgrades of MC events generators

TABLE 1. Data comparison with GENIE for proton multiplicity of μ+Np events for neutrinos in neutrino mode with statistical and preliminary systematic uncertainties.

Multiplicity	Genie Expectation	Genie % of Total	DATA	DATA % of Total
0p+μ	28±4	16%	15±3	14%
1p+μ	80±7	47%	51±10	48%
2p+μ	23±4	13.4%	28±6	26%
3p+μ	14±3	8.3%	13±3	12%
4p+μ	8±2	4.5%	0	0%
Total(including>4p)	172±10	-%	107±12	-%

TABLE 2. Same as Table 1 for antineutrinos in anti-neutrino mode.

Multiplicity	Genie Expectation	Genie % of Total	DATA	DATA % of Total
0p+μ	553±11	60%	422±42	58%
1p+μ	160±6	17%	266±53	37%
2p+μ	68±4	7%	30±6	4%
3p+μ	50±3	5%	3±1	0.4%
4p+μ	32±3	4%	3±1	0.4%
Total(including>4p)	925±15	-%	727±68	-%

TABLE 3. Same as Table 1 for neutrinos in anti-neutrino mode.

Multiplicity	Genie Expectation	Genie % of Total	DATA	DATA % of Total
0p+μ	46±3	14%	60±12	23%
1p+μ	163±6	48%	154±31	59%
2p+μ	46±3	13.6%	33±7	13%
3p+μ	23±2	7%	9±2	3.5%
4p+μ	16±2	5%	4±1	1.5%
Total(including>4p)	337±9	-%	260±34	-%

Argoneut/GENIE proton multiplicities comparison

Partyka, proceedings of NuInt12.

Problems with large multiplicities i.e. at low kinetic energies are clearly seen.