Validating Monte Carlo

Experience from Pion Physics

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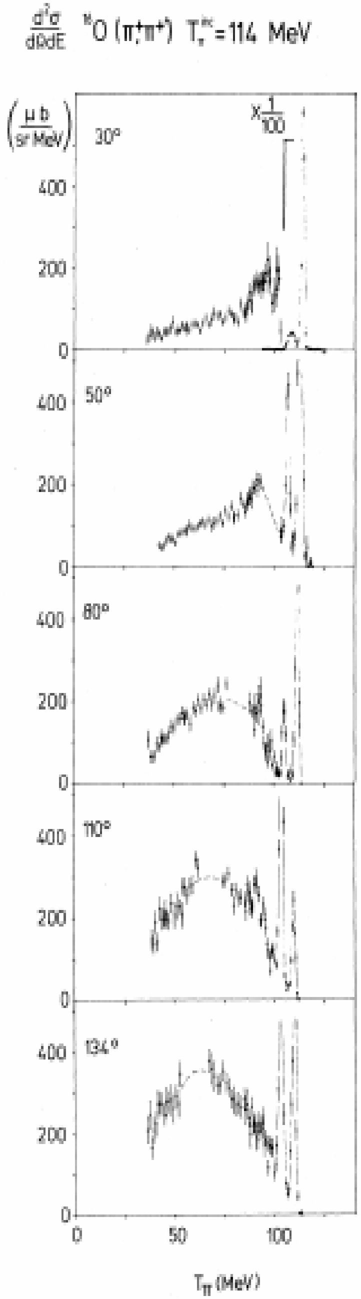
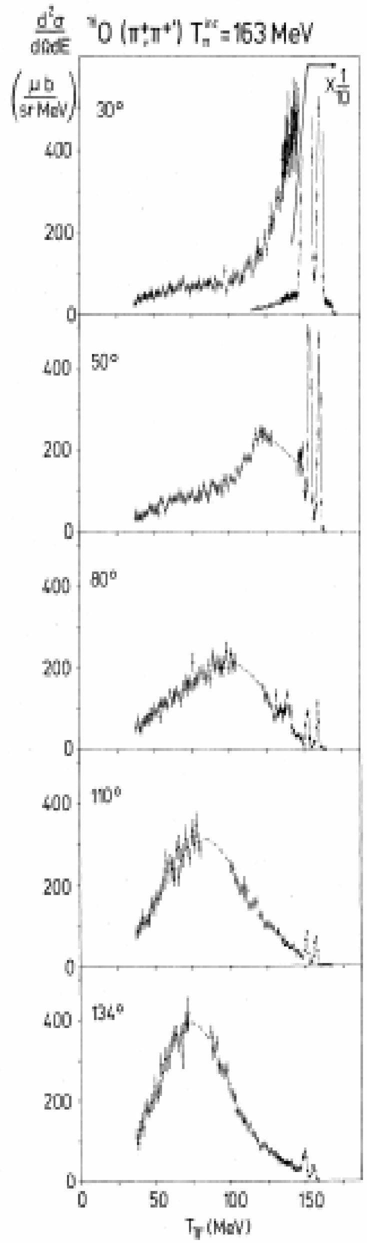
Want to try to use the same basic model employed by Neut and Genie to simulate CCQE and apply it to quasi-elastic pion-nucleus (i.e. (π,π')) scattering.

I am not aware of any publications where this has been done, but there is available data with which to compare:

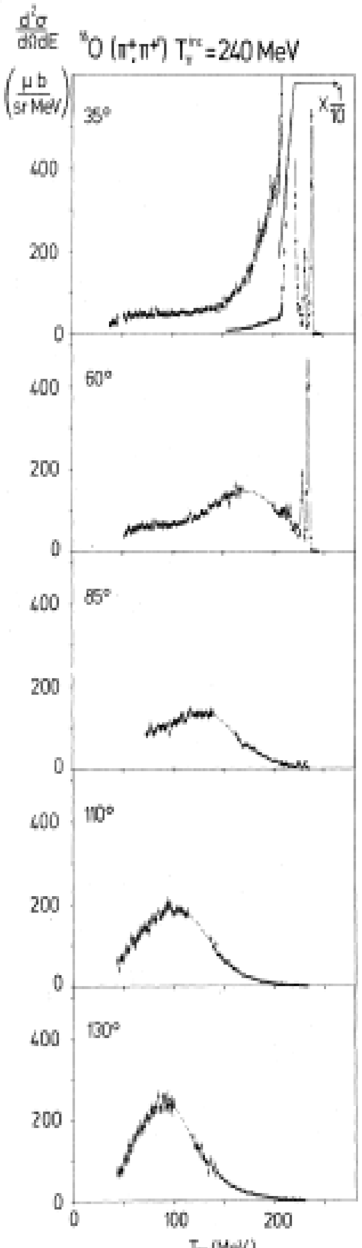
Ingram *et al*, Phys Rev C27 (1983) 1578, report measurements of ^{16}O(π,π') at three incident energies, at several angles.



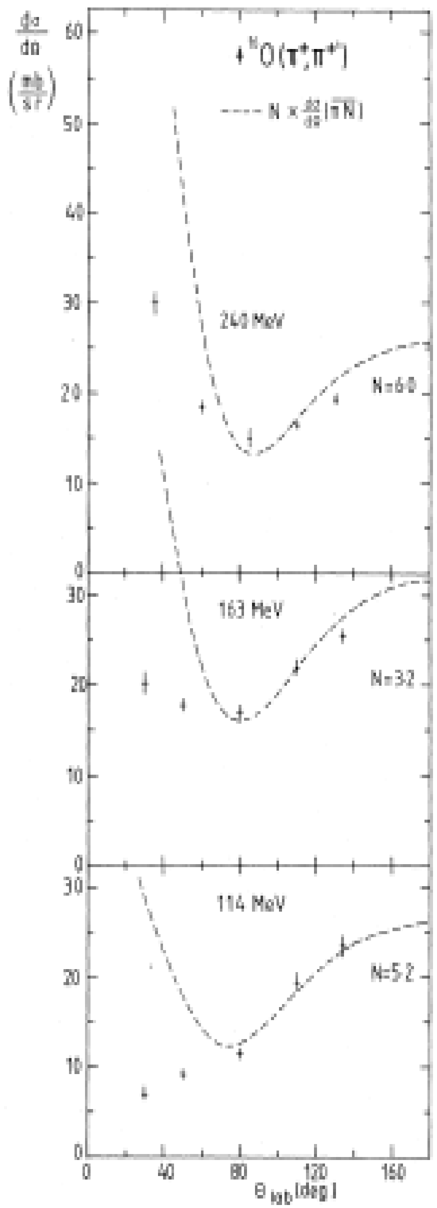
114 MeV



163 MeV



240 MeV



Energy distributions measured at each angle extrapolated to 0, and integrated to yield dσ/dΩ.

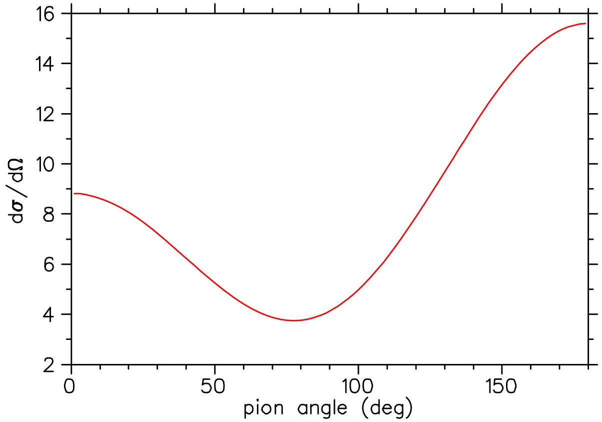
Comparison with scaled free nucleon angular distribution shows evidence of Pauli blocking.

Model quasi-elastic scattering using the following main steps:

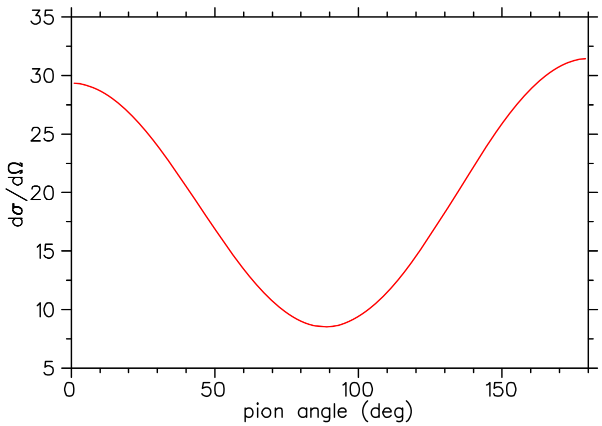
- Choose random momentum for moving nucleon
- Find energy available for scattering
- Choose random scattered pion angle from free $d\sigma/d\Omega$
- Calculate kinematic quantities of interest and histogram

This is same basic procedure followed by Neut and Genie (where free $d\sigma/dQ^2$ is used in third step)

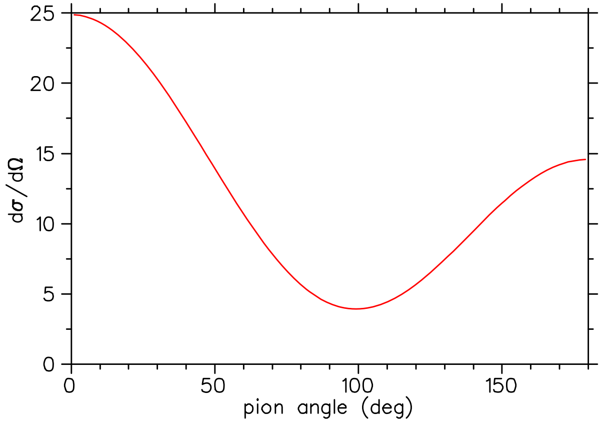
114 MeV



163 MeV



240 MeV



Free dσ/dΩ can easily be calculated from global phase shift analysis

see:

http://gwdac.phys.gwu.edu

Neut and Genie use Fermi Gas distribution for nucleon momentum.

Why not something more realistic?

For example, consider data reported by

Bernheim *et al*, PRL 32 (1974) 898

for ^{12}C(e,e'p) scattering at Saclay

Different distributions for p-shell (upper) and s-shell (lower) knockout

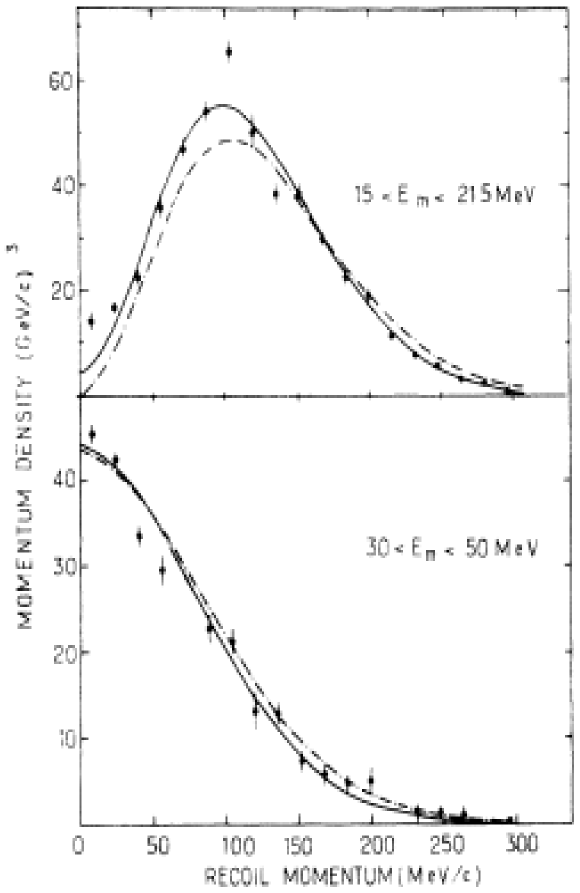


FIG. 2. Recoil momentum distributions in different regions of separation energies. The DWIA (solid line) and PWIA results (dashed line) were normalized by least-squares fits to the data.

This is what one might naively expect:

Consider 3D H.O. wavefunctions from introductory nuclear physics:

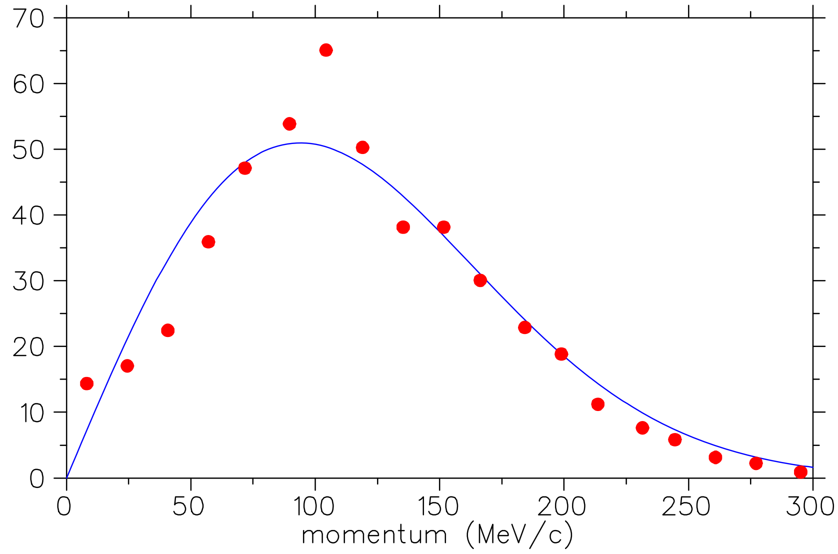
for n=0, l=0 $R_0(r) \approx \exp(-\alpha^2 r^2/2)$

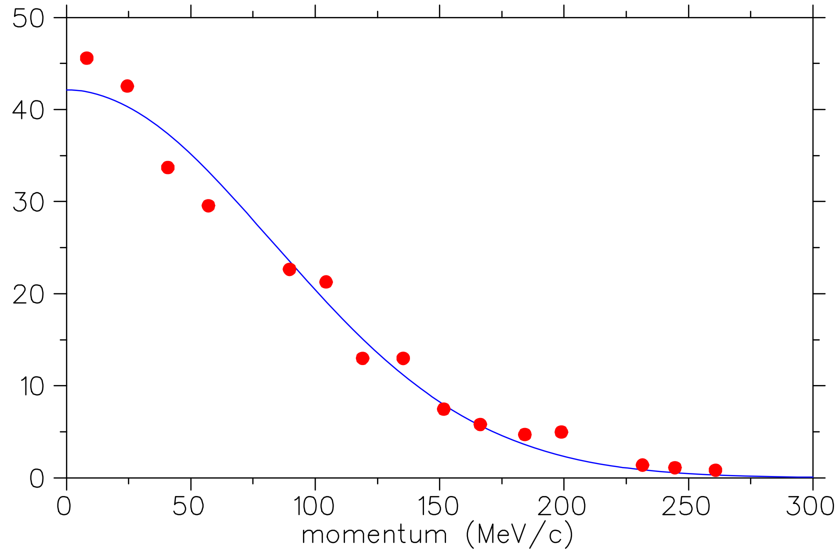
for n=1, l=1 $R_1(r) \approx r \exp(-\alpha^2 r^2/2)$

after a lot of work taking the Fourier transform:

$\phi_0(k) \approx \exp(-k^2/2\alpha^2)$

and $\phi_1(k) \approx k \exp(-k^2/2\alpha^2)$



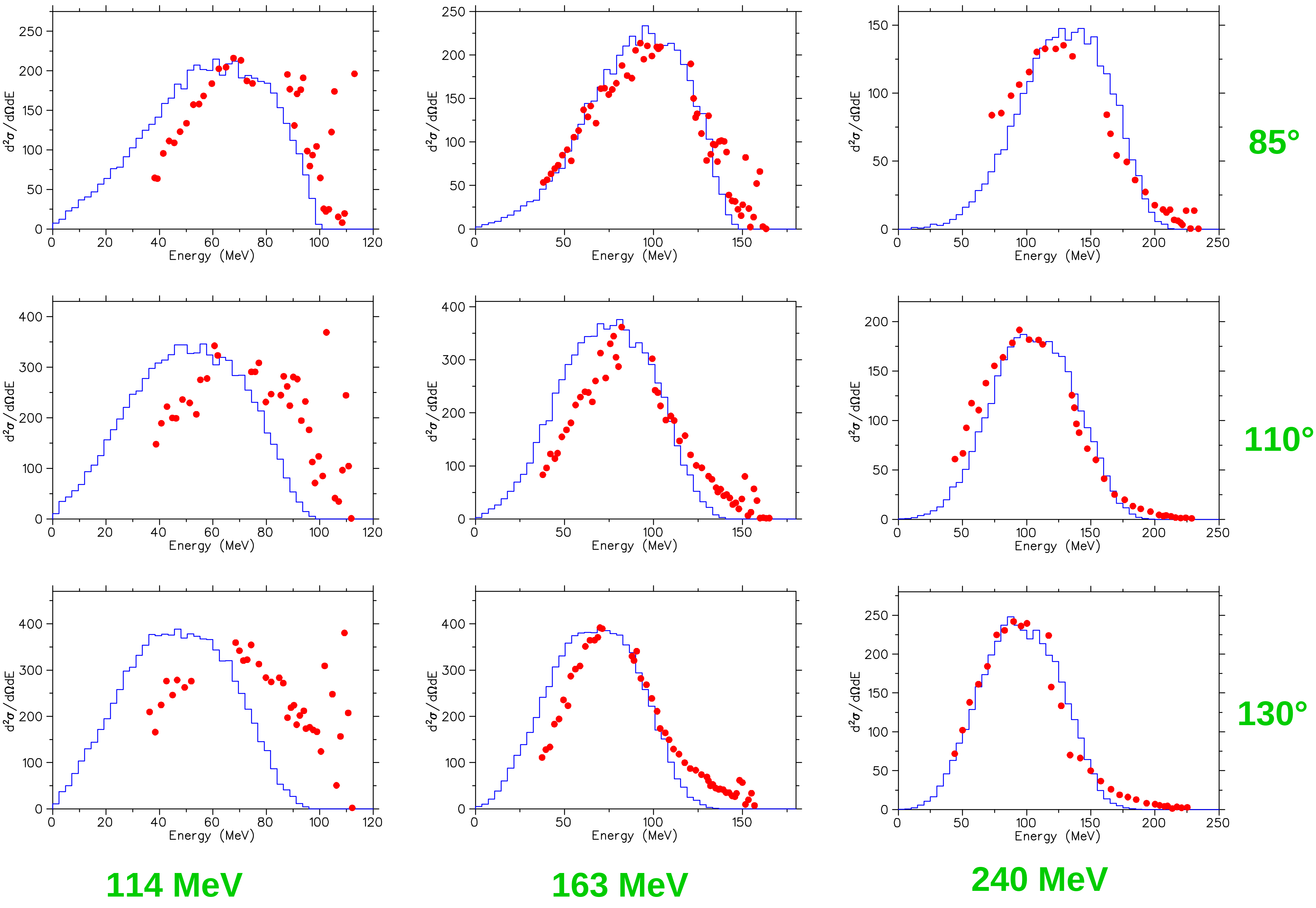


Fit (e,e'p) distributions with H.O. shapes

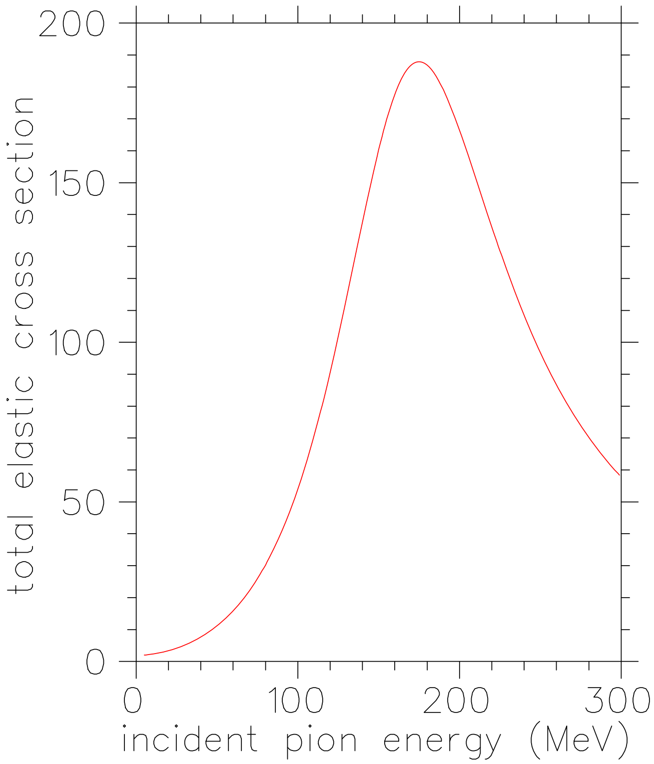
Best-fit value for s-shell gaussian is σ = 83 MeV/c

Run simplest model with p-shell shape with that value of σ

First results using simplest model:

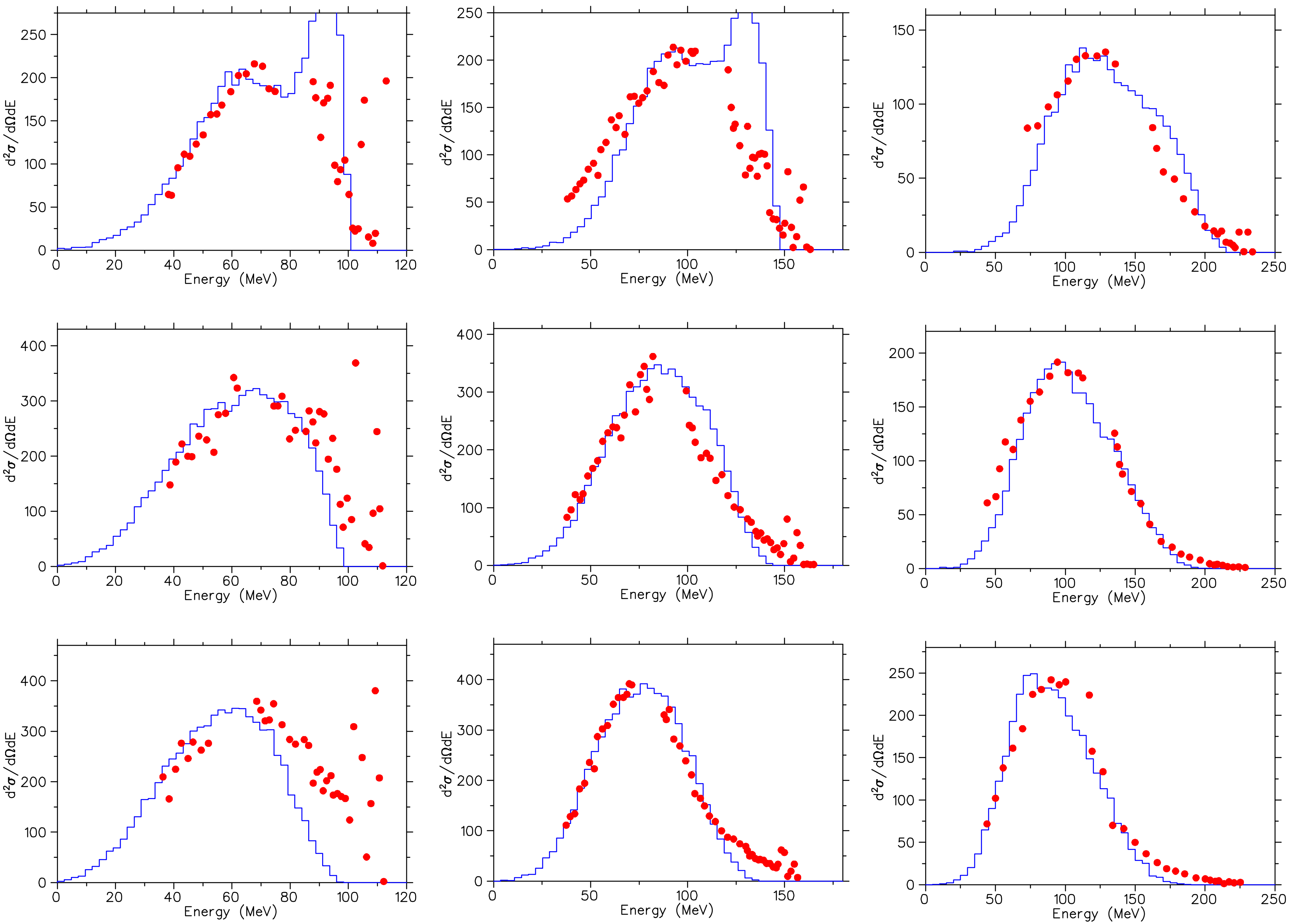


One ingredient missing from simplest model:
strong energy dependence of free π-p interaction



Instead of just choosing magnitude and angles of struck nucleon at random, first choose just angles, then weigh magnitude with total π-p cross section evaluated at the corresponding effective energy. (This is done in Neut.)

Results with slightly improved model



85°

110°

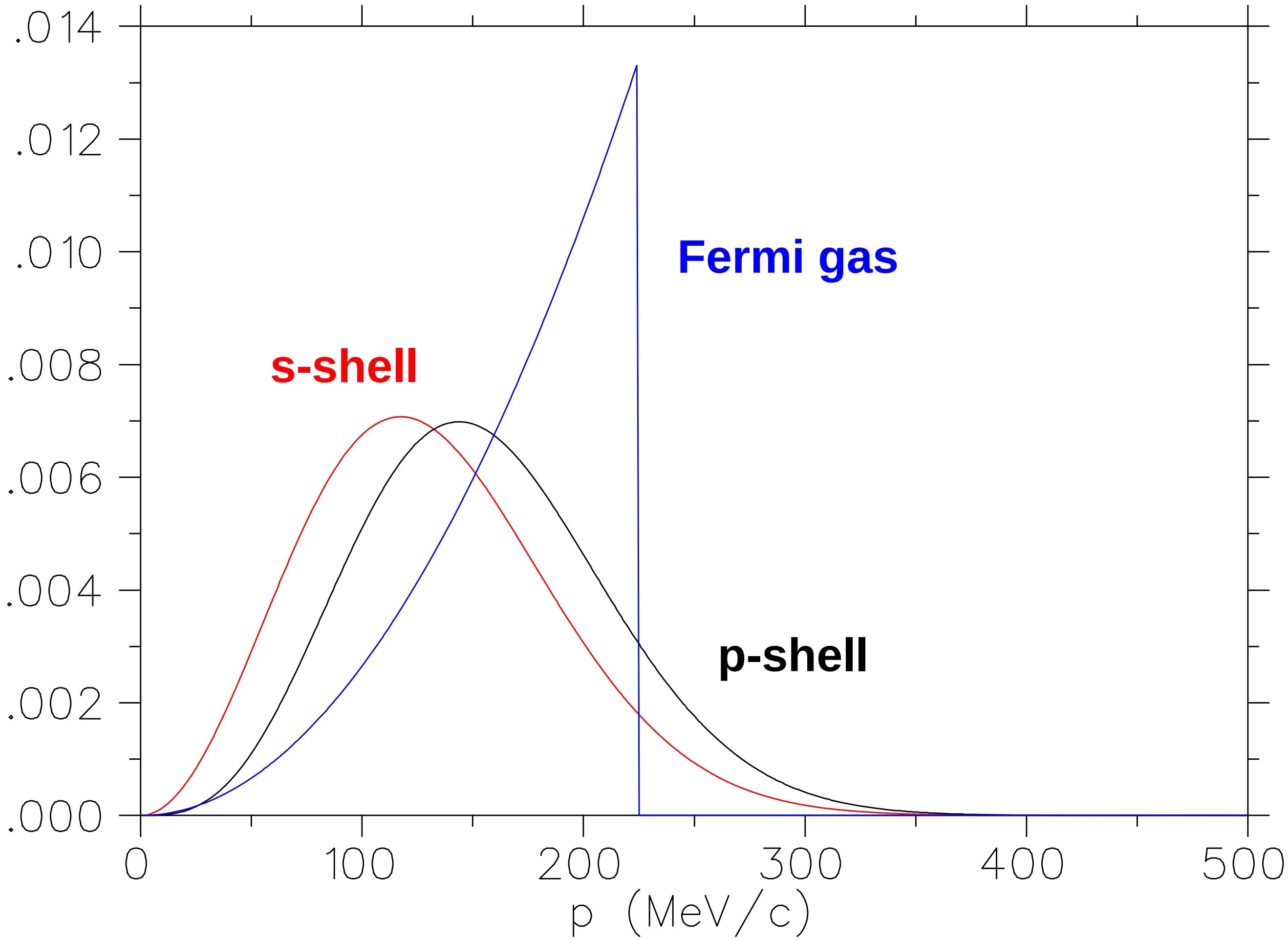
130°

114 MeV

163 MeV

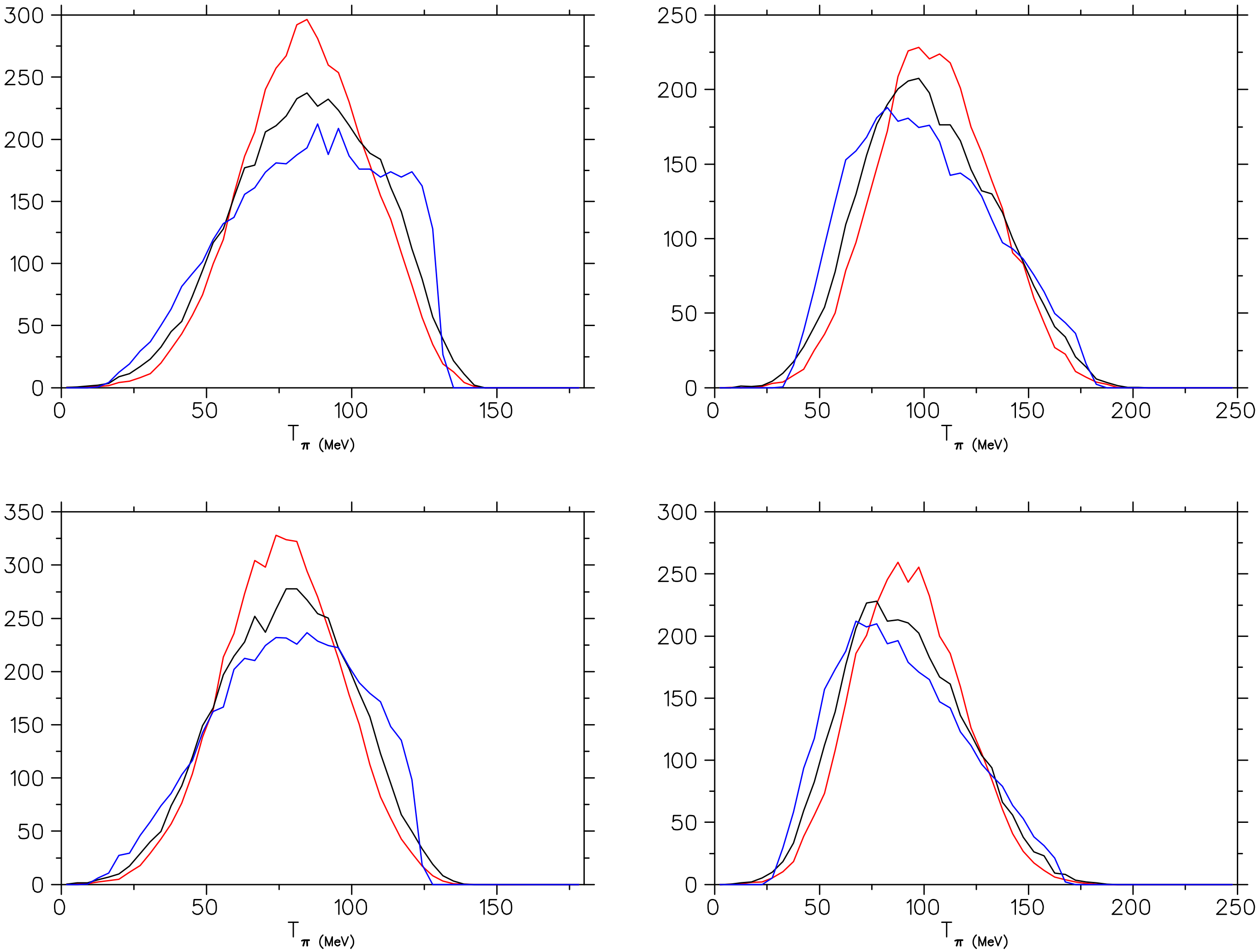
240 MeV

What happens in the slightly improved model if one uses different momentum distributions?



Plotted: $p_F \times d^3p = p_F \times p^2$ to help get a feeling for differences

Predicted pion energy distributions using **s-shell knockout**, **p-shell knockout**, or **Fermi gas** momentum distributions



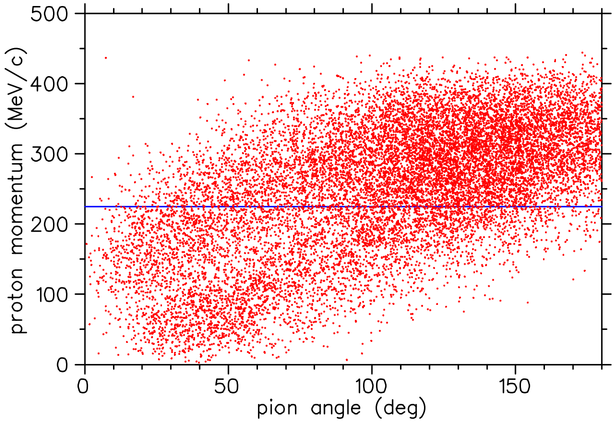
110°

130°

163 MeV

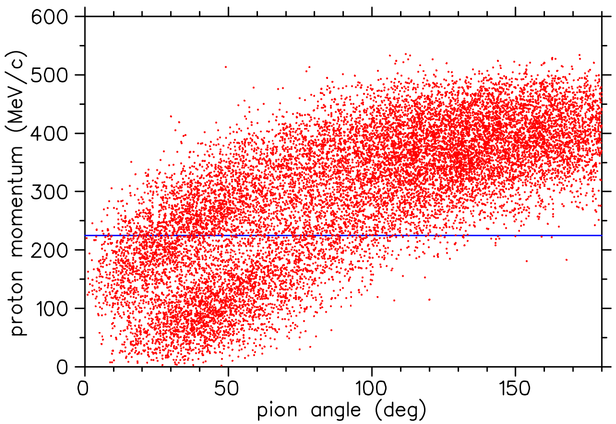
240 MeV

114 MeV



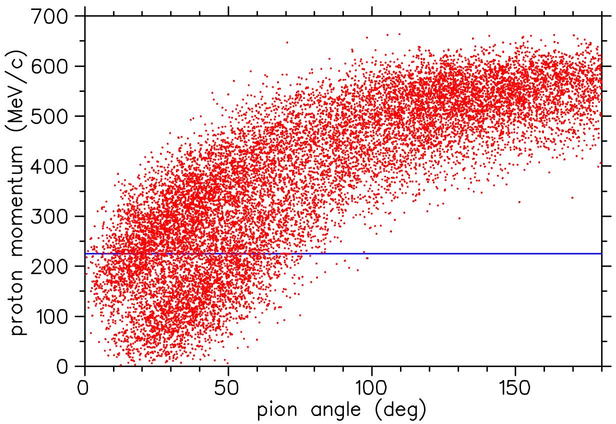
Pauli Blocking?

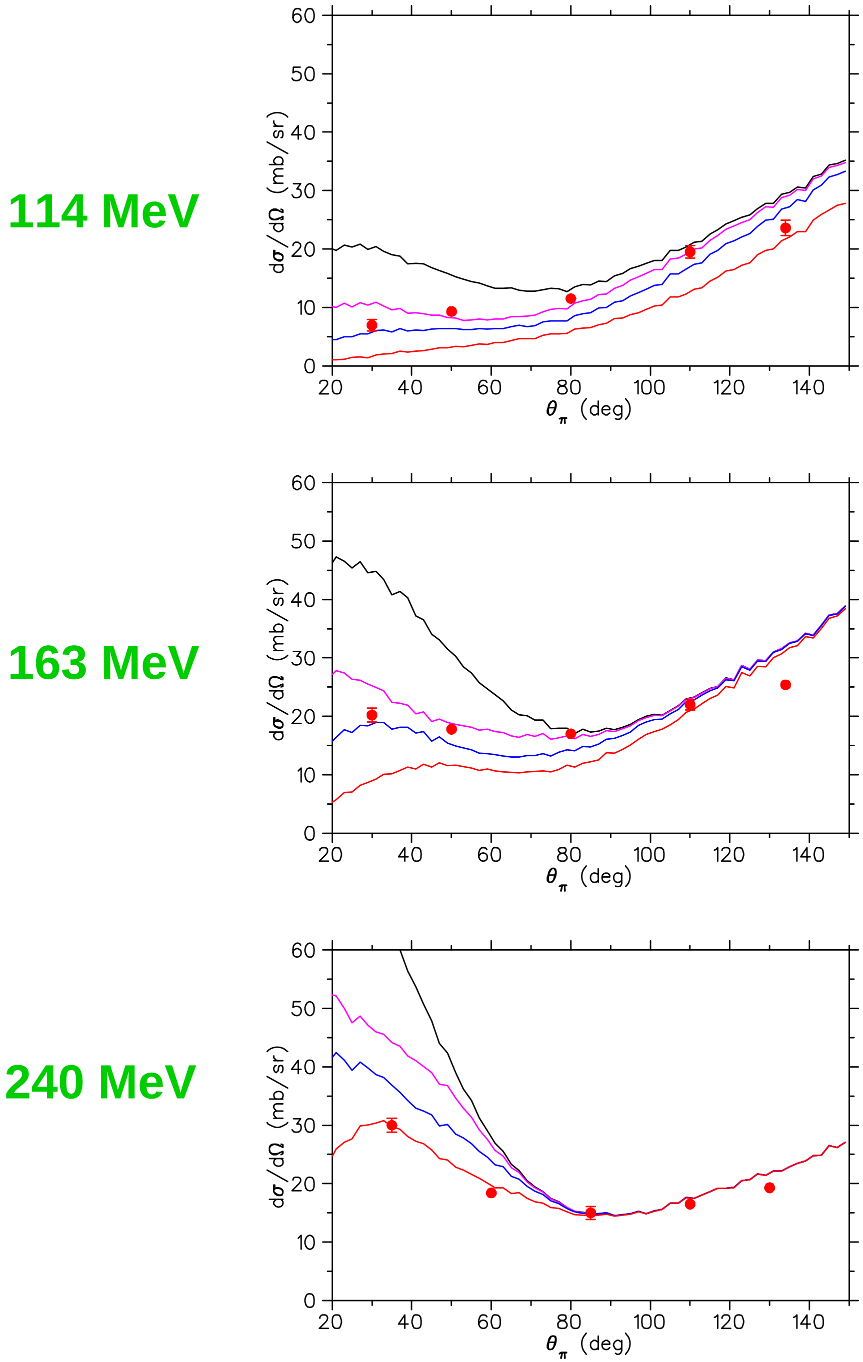
163 MeV



In Neut and Genie modelled by imposing straight cut on outgoing proton momentum

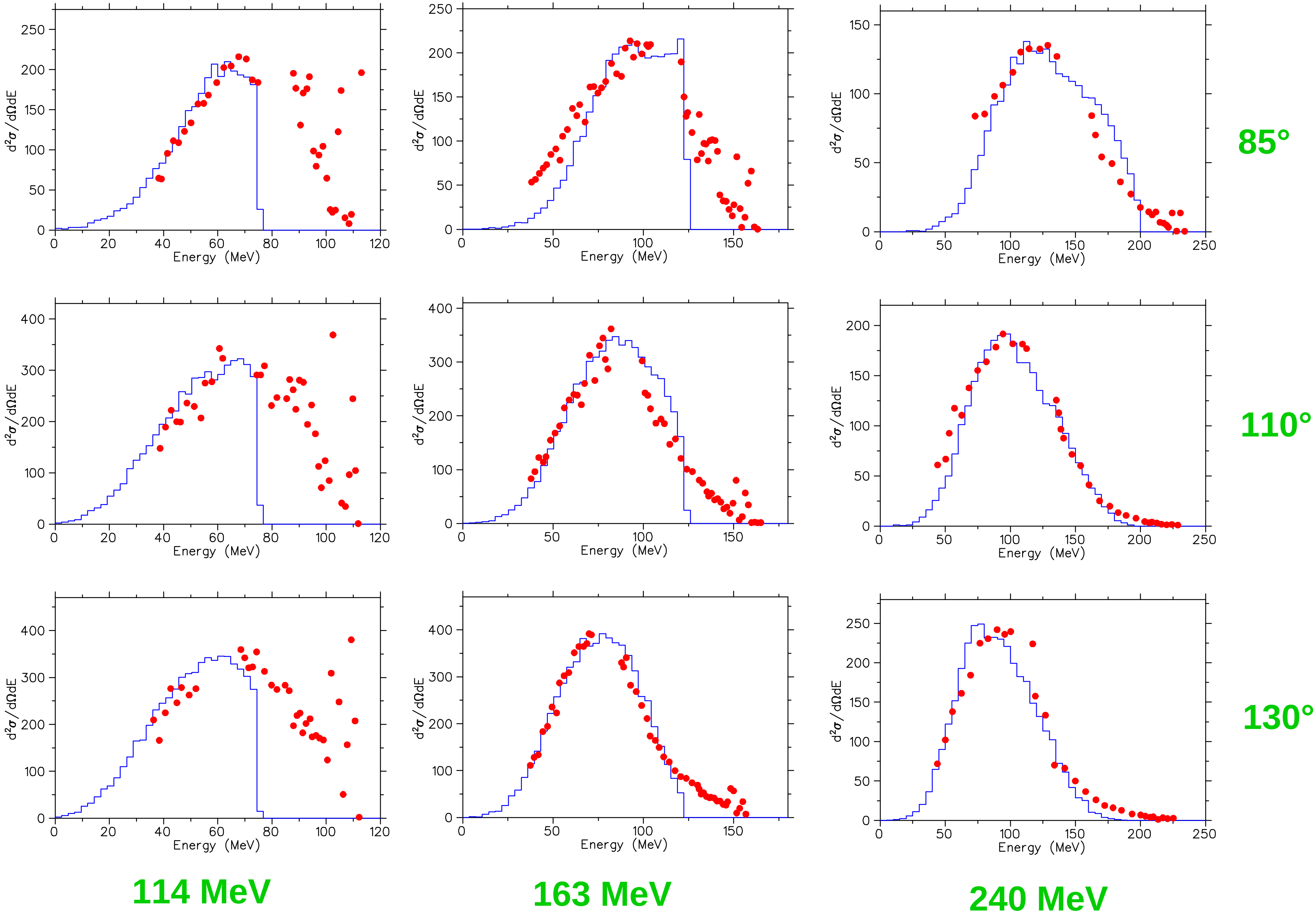
240 MeV





Shown is the effect of imposing straight cut at different values of p_p

Results after Pauli Blocking cut on pp > 225 MeV/c



One assumption of the model: that the residual nucleus is left in its ground state, is clearly wrong

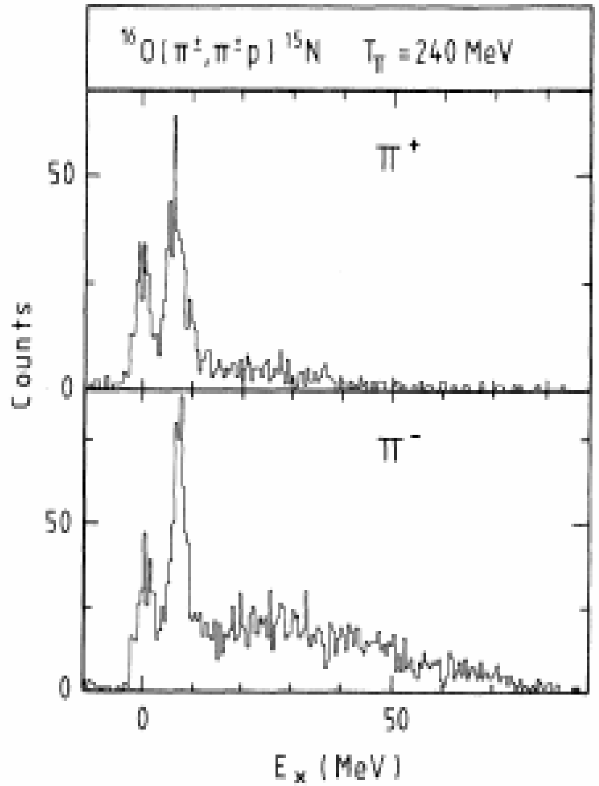
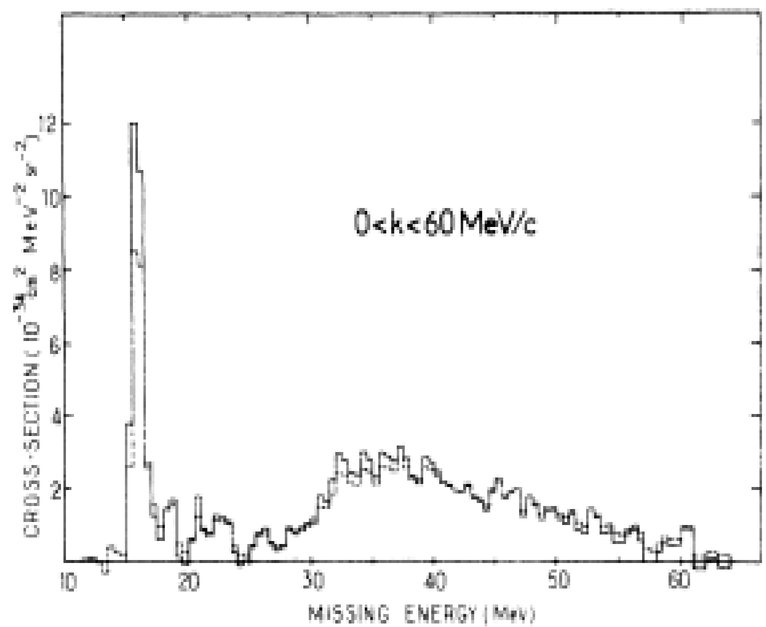


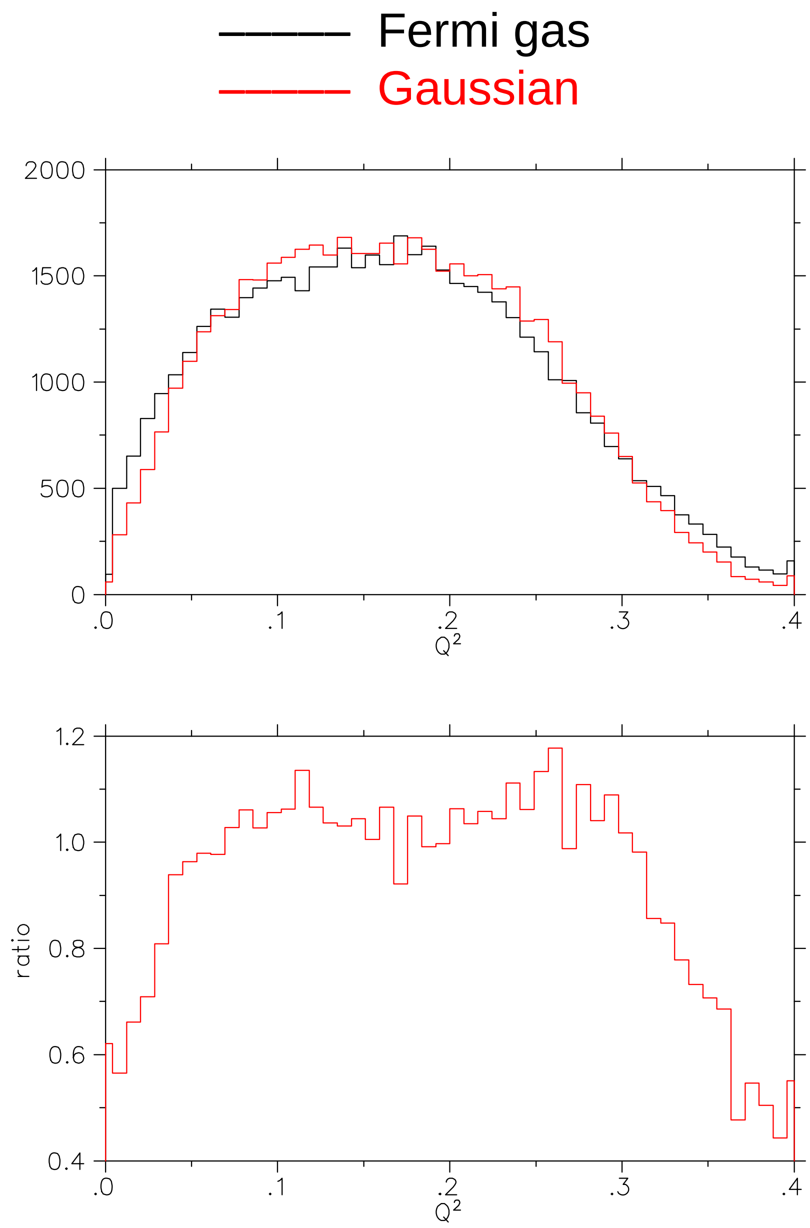
FIG. 1. Excitation-energy spectra of the residual $^{15}N_{g.s.}$ nucleus for π^+- and π^--induced reactions, for $\theta_\pi = 60°$, $\theta_p = -35°$, and $T_{\pi'} = 110–170$ MeV.

Kyle *et al*, PRL 52 (84) 974

^{12}C(e,e'p)



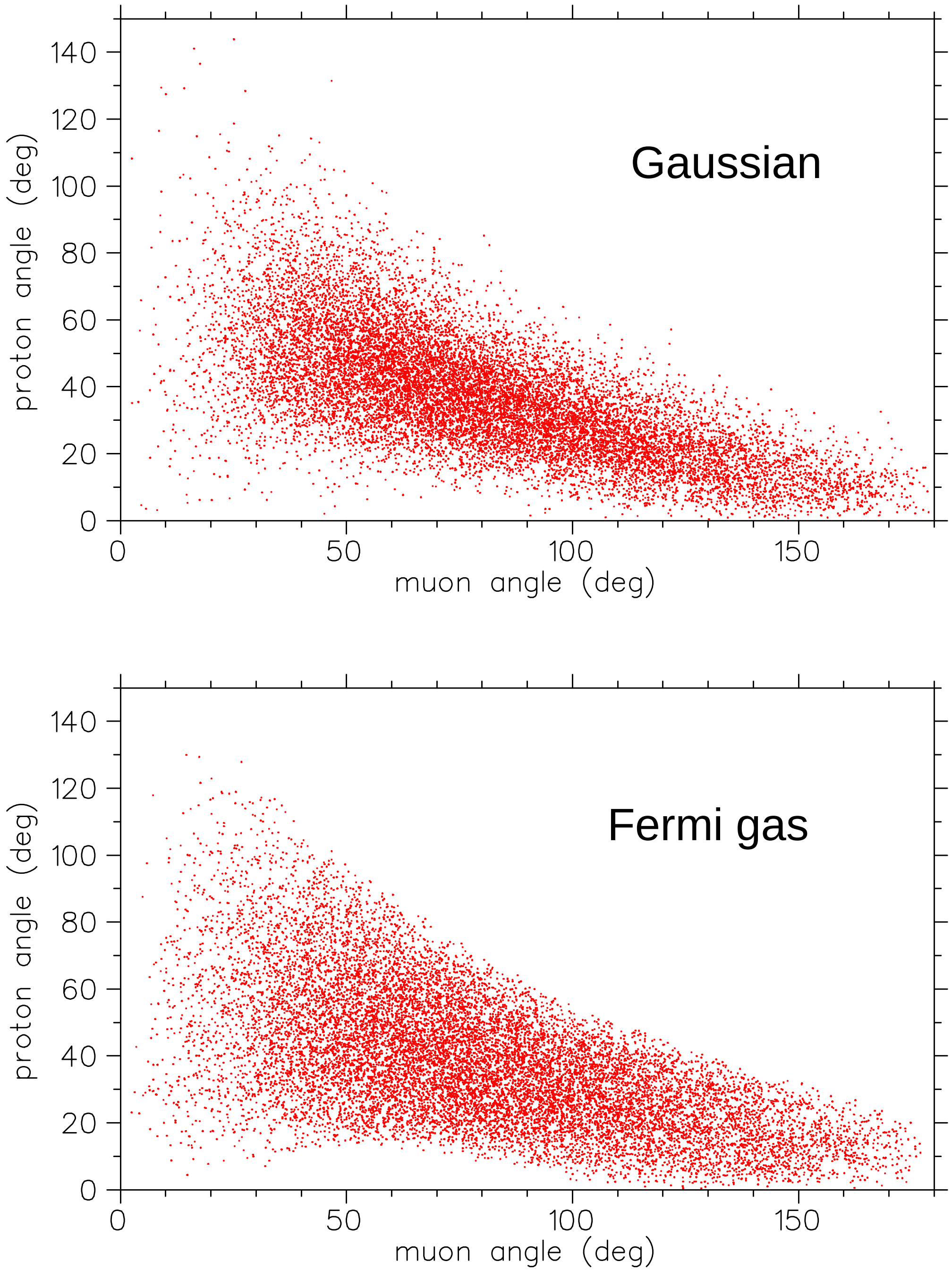
Bernheim *et al*, PRL 32 (1974) 898



ν_μ energy 400 MeV

Choice of momentum distributions affects Q^2 distributions for ν_μ CCQE

Calculation performed with code extracted from Neut, and modified to allow different forms for nucleon momentum

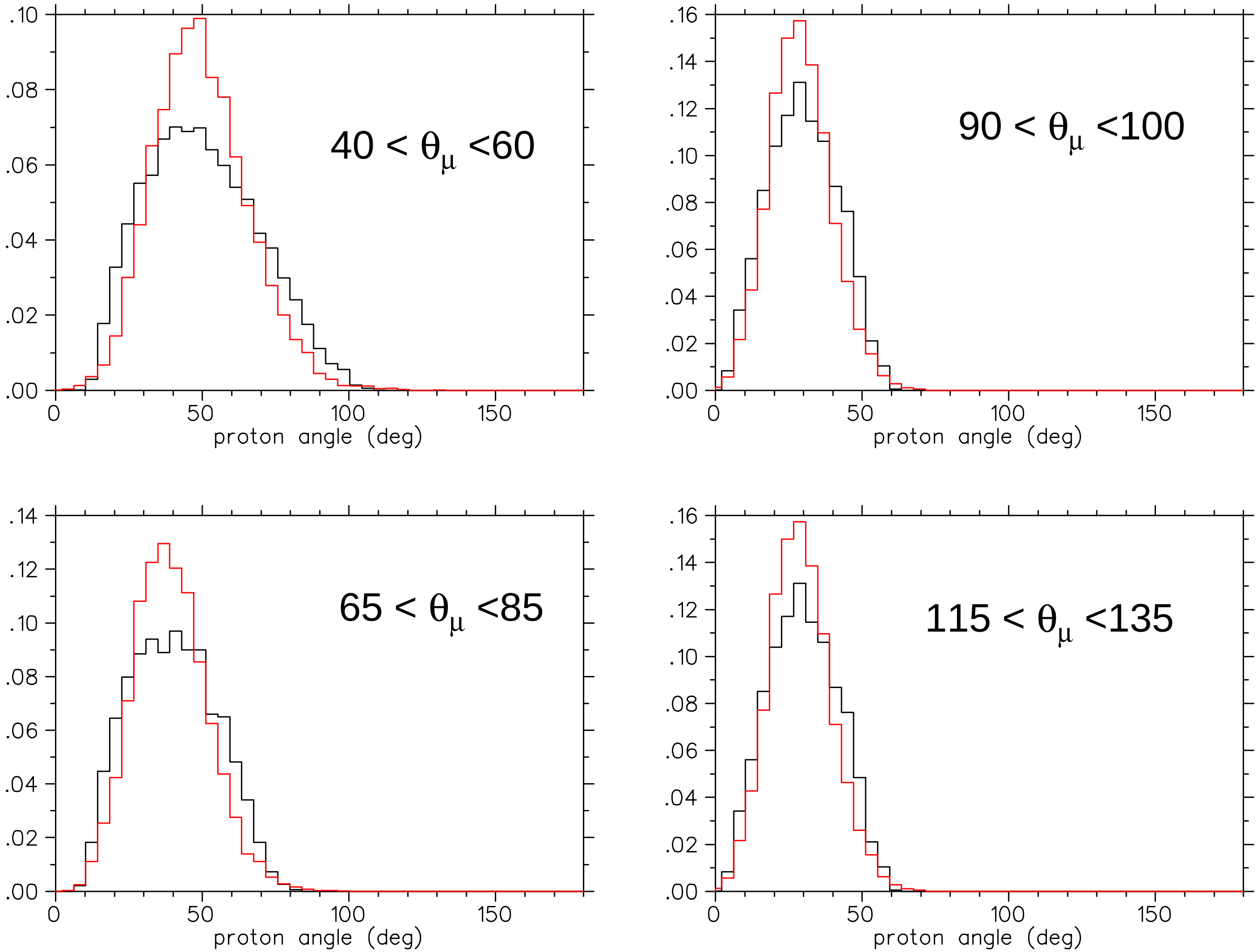


Is there a way to tell the difference using data?

Obviously, can't use width of T_μ for fixed θ_μ, but consider the θ_μ θ_p correlation

Plot for T_ν = 400 MeV

proton angular distributions at a fixed muon angles

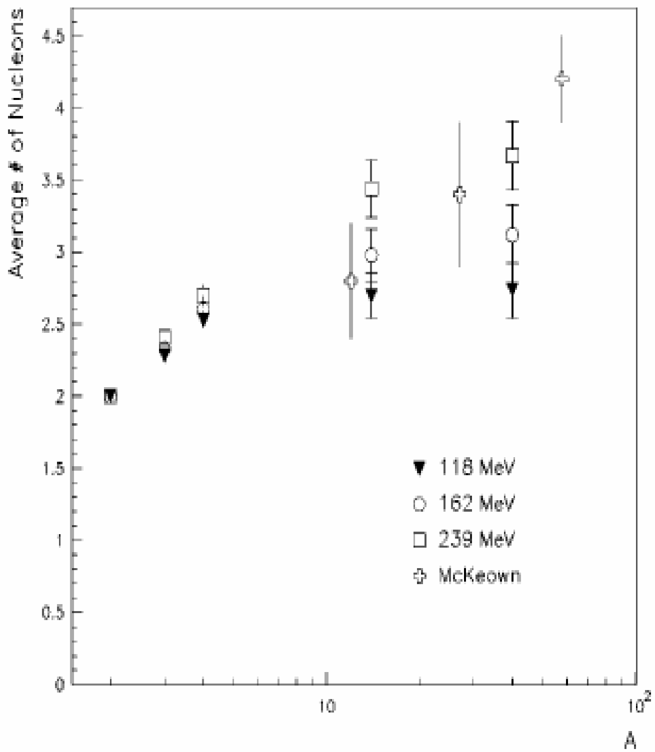


Fermi Gas (black) distributions are broader than Gaussian (red)

A few words about pion absorption:

Simple models able to describe distributions measured with small counters, but no consensus on underlying mechanisms. (In my opinion due to varying assumptions used in the models.)

Last set of experiments performed with Large Acceptance LADS detector at PSI. Unable to describe data with simple models. Missing dynamics?



Rowntree *et al*, Phys Rev C**60** (99) 054610 provide tables of outgoing energetic particle multiplicities following pion absorption

Surprisingly large number of final state deuterons

$T_\pi = 162$ MeV

Charge multiplicity	(mb)	Deuterons	$0n$	$1n$	$2n$	$\geqslant 3n$
$1C$	27.2 ± 4.4	0	8.6 ± 4.2	14.4 ± 1.6	2.8 ± 0.4	0.9 ± 0.3
		1	0.8 ± 0.3	<0.2	<0.1	0.1 ± 0.1
$2C$	98.7 ± 5.4	0	56.1 ± 4.7	28.3 ± 2.7	4.7 ± 1.0	0.4 ± 0.2
		1	5.4 ± 1.2	3.2 ± 0.7	0.5 ± 0.2	–
$3C$	33.8 ± 2.4	0	15.6 ± 1.6	7.4 ± 0.9	1.0 ± 0.2	0.1 ± 0.1
		1	7.1 ± 0.9	2.5 ± 0.4	0.2 ± 0.1	–
$\geqslant 4C$	3.6 ± 0.3	0	1.1 ± 0.2	0.5 ± 0.1	0.1 ± 0.1	–
		1	1.5 ± 0.2	0.5 ± 0.1	–	–