Coupled-channel vibrational-model studies of nucleon scattering from oxygen isotopes and the corresponding mirror systems

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and collaborators

Outline for MCAS

The MCAS formulation, brief review
K. Amos, *et al*, Nuclear Physics, **A728** (2003) 65

Mirror nuclei method

Proof of concept:
Calculations and experiments for ^{15}F

Application of MCAS method to ^{16}O
The vibrational model

MCAS:
Multichannel Algebraic Scattering Formalism

1. Discretization of the coupled-channel equations by separable expansion of the channel interactions.
2. Pauli principle inclusion by use of orthogonalizing pseudo-potentials.
3. Fast, effective search procedure for resonances and bound states.
4. Adaptive mesh size for plotting cross sections through the resonances.

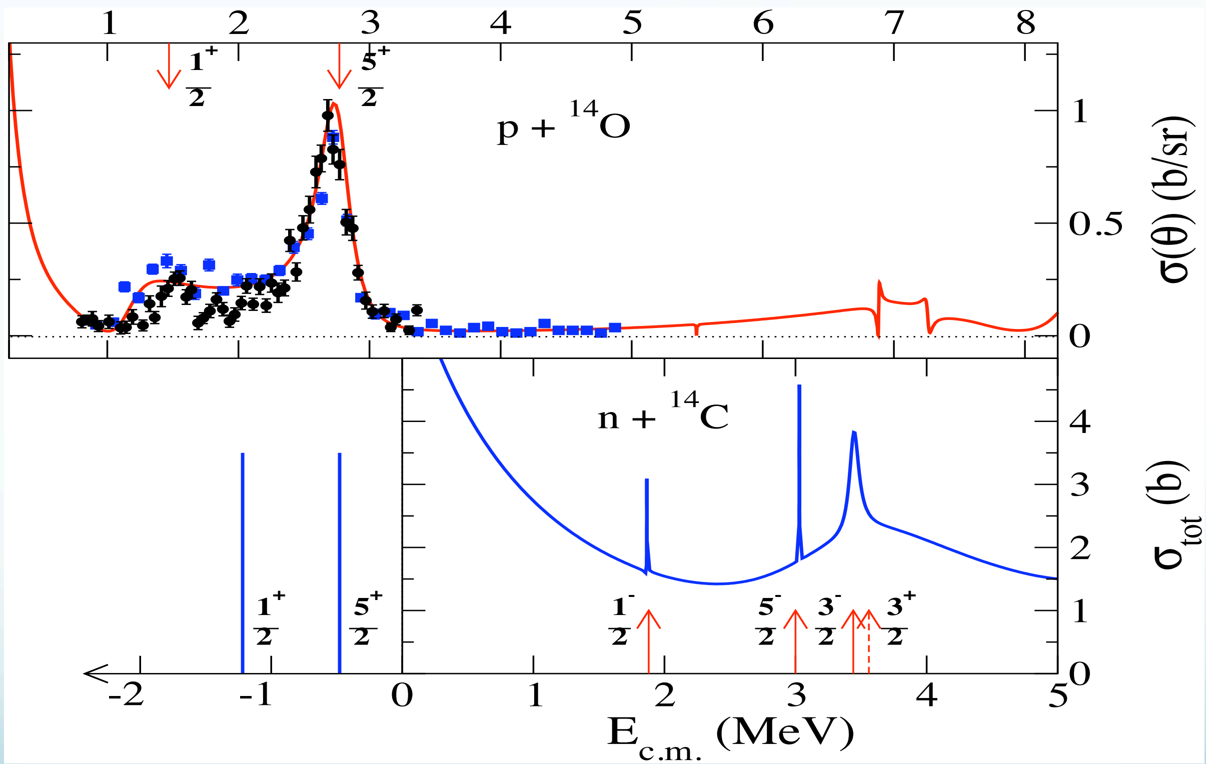
Why mirror nuclei

- Two nuclei are called “mirror nuclei” if one changes into the other by interchanging all protons and neutrons
- Example: ^{14}C, the isotope of carbon used in carbon dating (half-life ≅ 5700 years) has as its mirror ^{14}O, a short-lived isotope of oxygen (half life = 70.6 sec)
- Nuclei with a proton excess tend to be less stable than those with a neutron excess
- Current MCAS role: analyze bound and resonant spectra to support and interpret experimental work

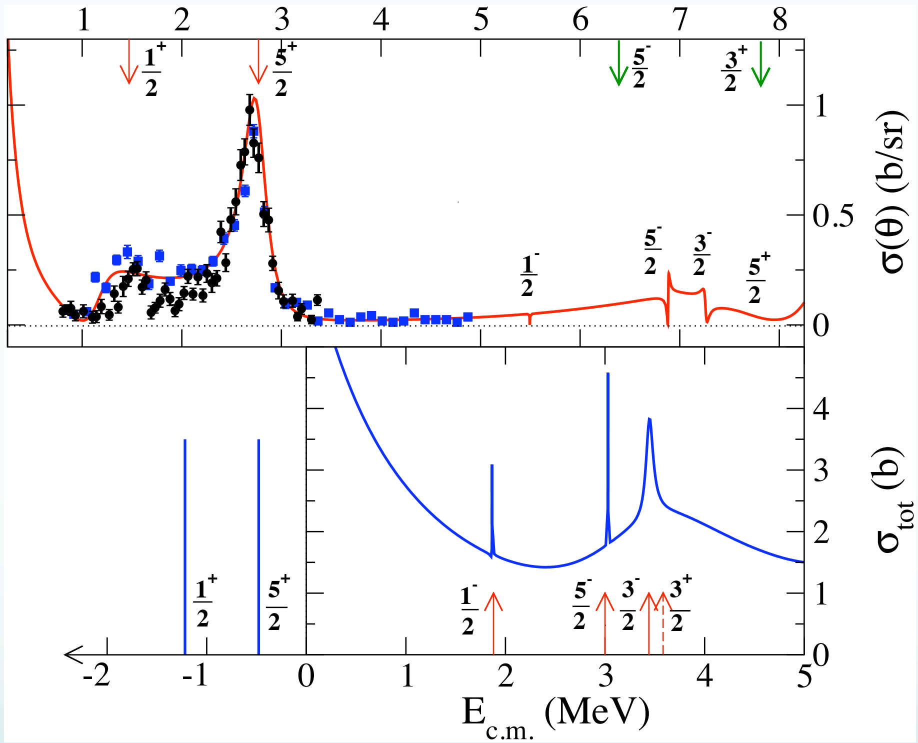
The proton-unstable nucleus: ^{15}F

- The neutron-^{12}C: a success story for bound and resonant states from MCAS.
- MCAS has been demonstrated to have predictive power.
- We extend to this to n+^{14}C and p+^{14}O, a mirror pair, to get the structure of ^{15}F.
- See Canton, *et* al, PRL **96**, 072502 (2006); Mukha, *et al*, PRC **79**, 061301 (2009).

^{15}F: a success story



^{15}F: experimental verification



Nucleon – ^{16}O scattering

The mirror concept cannot be used to get information on ^{16}O, since it is its own mirror.

However, energy levels of ^{16}O, as well as those of ^{17}O, the compound system of n+^{16}O, are well known.

So, we carry out MCAS calculations on n+^{16}O scattering, to get accurate fits to the spectrum, including resonant states, of ^{17}O. From these we extract neutron scattering "data".

Using the same parameters, but adding a Coulomb force, we obtain a spectrum for ^{17}F, as well as proton scattering cross sections. ^{17}F is the mirror system to ^{17}O.

The next slides show a sample of results obtained to date.

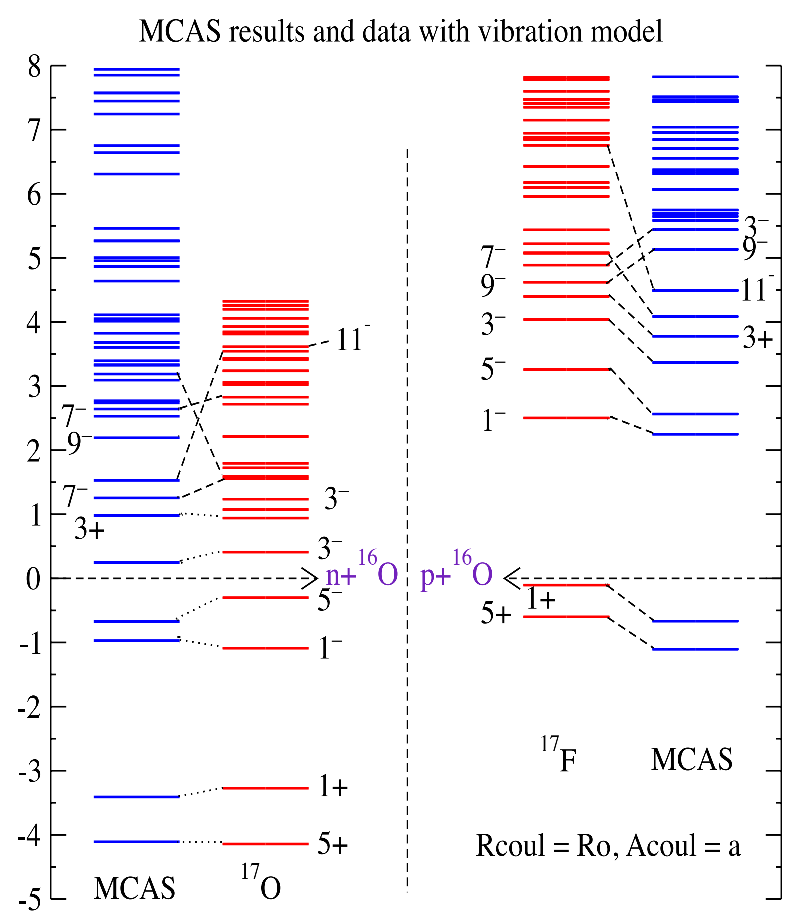
Difficulties with MCAS for ^{16}O

- ^{16}O is a doubly-magic nucleus: 8 protons in the $0s_{1/2}$, $0p_{3/2}$ and $0p_{1/2}$ states: filled s and p shells.
- That means ^{16}O is spherical in its ground state, which causes difficulties for us, since we need the assumption of a deformed target nucleus to which the incoming neutron or proton is coupled. The rotational model does not work well with a spherical ground state.
- So, instead, we use the vibrational model, for the first time with MCAS. Now the deformation is dynamic, and coupling to the projectile works better.
- Most results shown here are obtained with the vibrational model. This is a more complicated model, and obtaining good results has required much work.

The parameters

MeV	parity -	parity +	geometry	value	
V_0	– 47.5	– 50.5	R_0	3.15 fm	
V_{LL}	2.55	0.0	a	0.65 fm	
V_{Ls}	6.9	7.2	β_2	0.21	
V_{ss}	2.5	– 2.0	β_3	0.42	
I^{π}_n	E_n (MeV)	$0s_{1/2}$	$0p_{3/2}$	$0p_{1/2}$	$0d_{5/2}$
0^+_1	0.0	10^6	10^6	10^6	0.0
0^+_2	6.049	10^6	10^6	0.0	0.0
3^-_1	6.13	10^6	10^6	5.0	0.0
2^+_1	6.92	10^6	10^6	0.0	0.0
1^-_1	7.12	10^6	10^6	5.0	1.0

Spectra of ^{17}O and ^{17}F



The 10 lowest-E states

J^π	$^{17}O_{exp}$	Γ_{exp}	E_{mcas}	$\Gamma/2$	$^{17}F_{exp}$	Γ_{exp}	E_{mcas}	$\Gamma/2$
(5/2)+	–4.1436	—	–4.1436	—	–0.6005	—	–1.1047	—
(1/2)+	–3.2729	—	–3.4099	—	–0.1052	—	–0.6678	—
(1/2)–	–1.0882	—	–0.9713	—	2.5035	19	2.2485	$2.8(10)^{-5}$
(5/2)–	–0.3008	—	–0.6719	—	3.2565	1.5	2.5644	$4.9(10)^{-6}$
(3/2)–	0.4102	40	0.2474	0.0003	4.0395	225	3.3688	0.0028
(3/2)+	0.9412	96	0.9814	0.060	4.3995	1530	3.7763	0.4530
(9/2)–	1.0722	< 0.1	2.1920	$5.8(10)^{-11}$	4.6195	–	5.1331	0.0151
(3/2)–	1.2356	28	2.7706	0.0004	4.8875	68	5.5840	$1.2(10)^{-4}$
(7/2)–	1.5537	3.4	1.2546	$9.1(10)^{-5}$	5.0715	40	4.0854	$6.3(10)^{-5}$
(5/2)–	1.5892	<1	3.1885	0.0001	5.0815	< 0.6	6.0667	0.00195

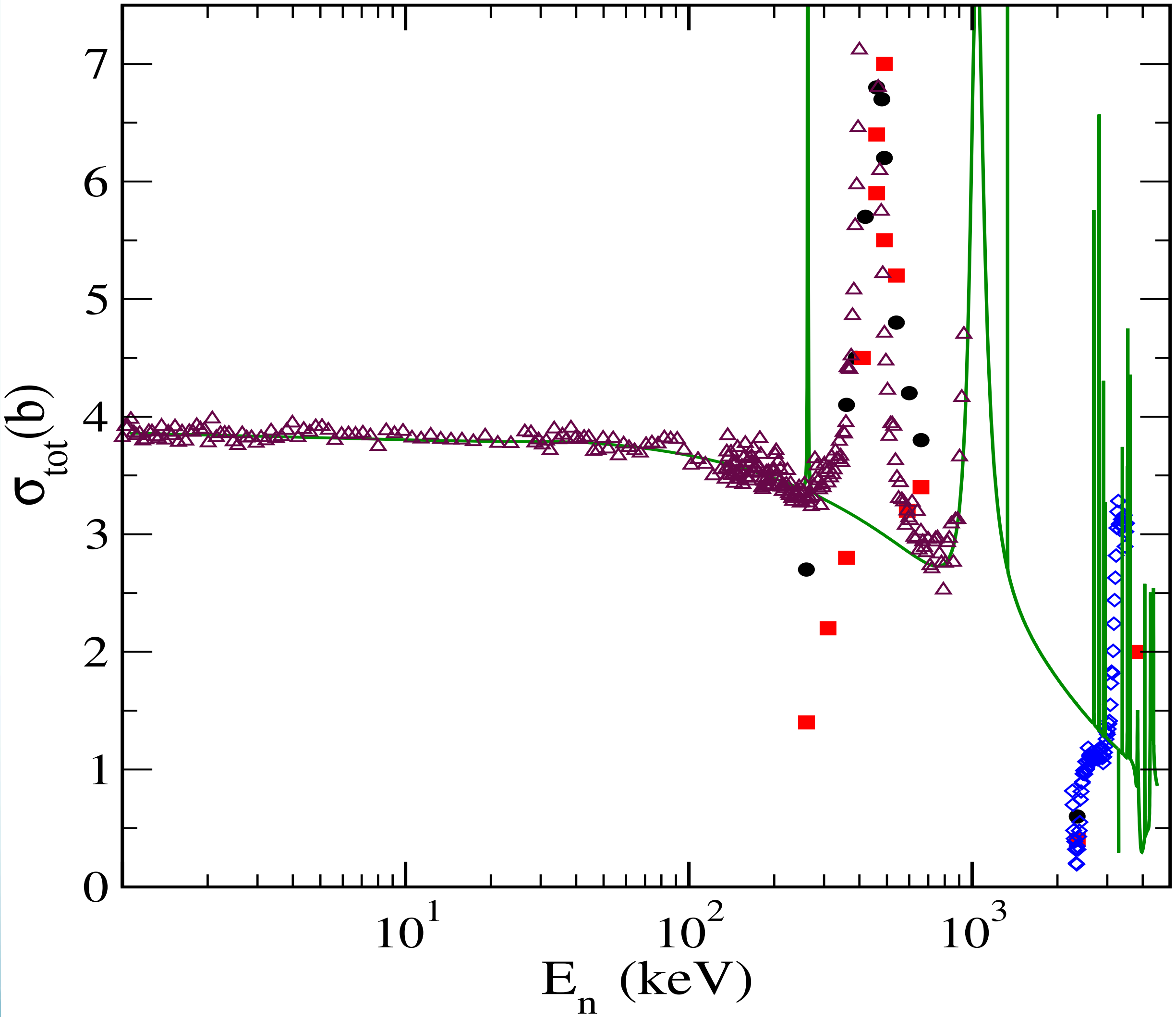
A figure of merit

A figure of merit is the root-mean-square deviation between experimental and MCAS calculated energy levels:

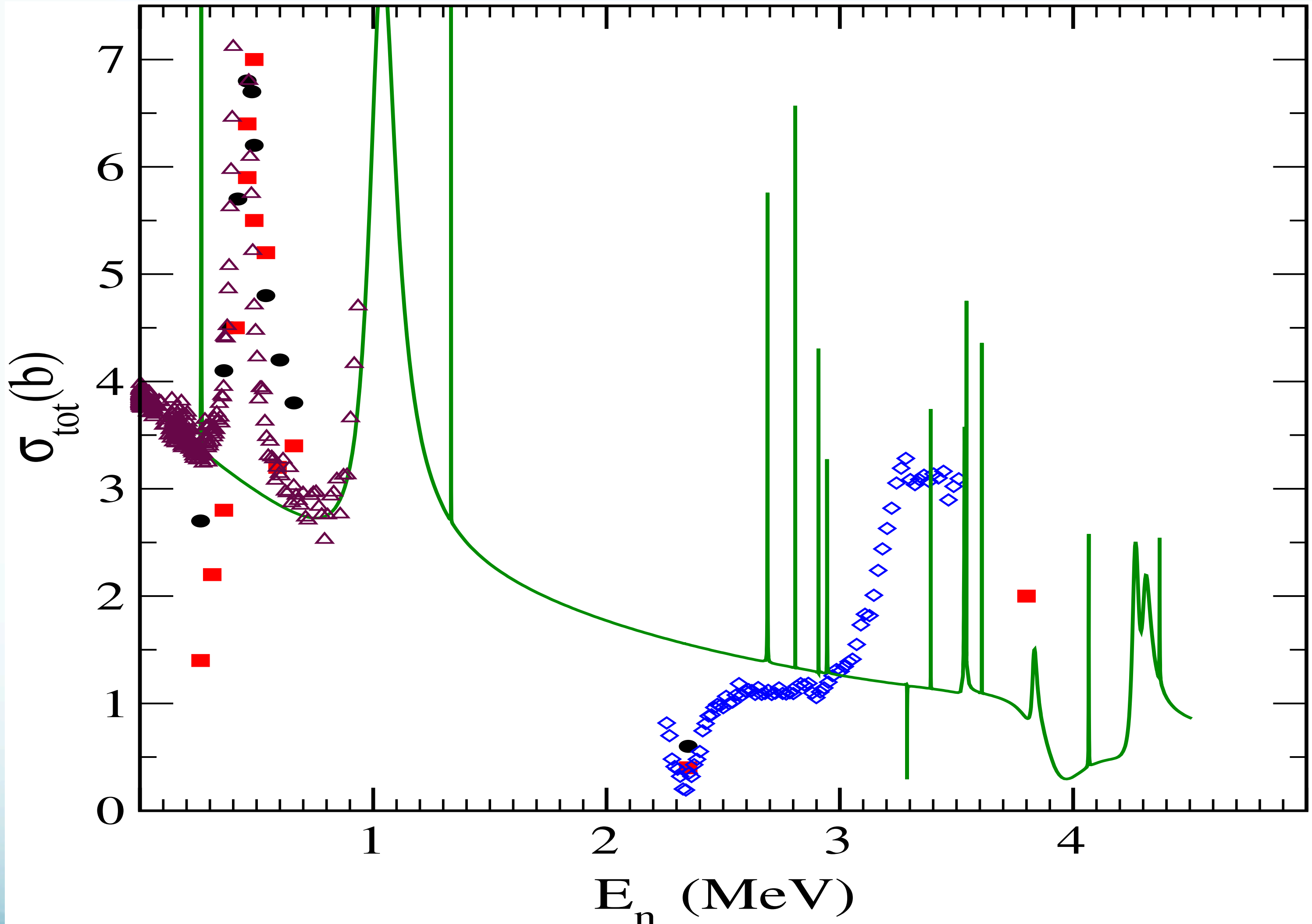
$$\mu_N^i = \sqrt{\frac{\sum_{n=1}^{N}[E_{\exp}(n) - E_i(n)]^2}{N}}$$

For the results shown in slide 11, for ^{17}O and 30 levels, $\mu = 1.2058$, for 20 levels, $\mu = 1.1265$.
For ^{17}F these numbers are 0.9198 and 0.9296, respectively.

n+^{16}O total scattering cross section



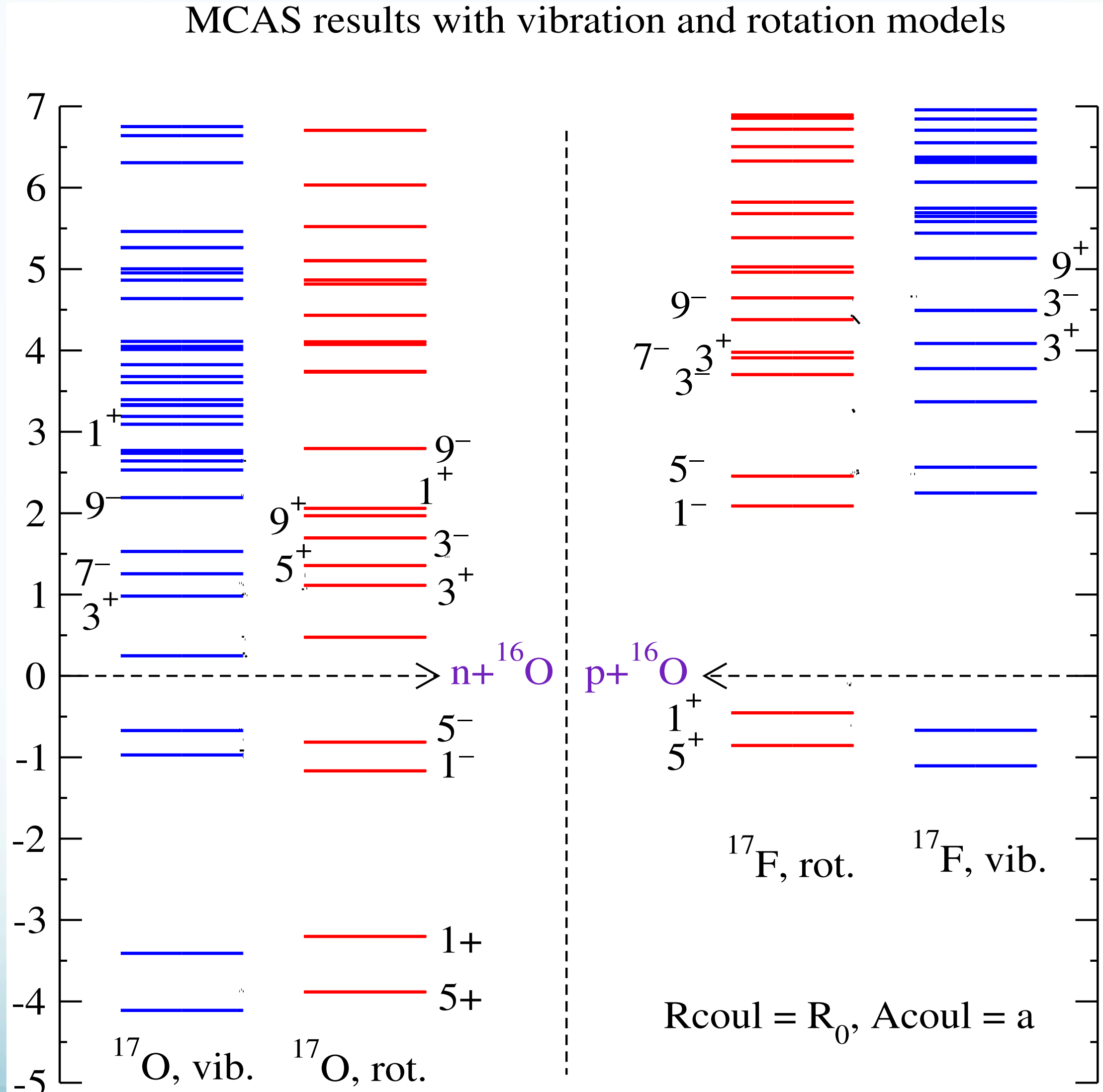
n+^{16}O scattering, linear scale



Rotational model results

- Despite the closed-shell nature of ^{16}O, we have also calculated MCAS results using the same parameters, but with the rotational model, after having obtained the “best” results from the vibrational model already shown.
- The rotational-model results resemble the vibrational ones somewhat, but the levels appear to be more sparse, and the comparison to data is less favourable than that obtained from the vibrational model.

Spectra from the rotational model



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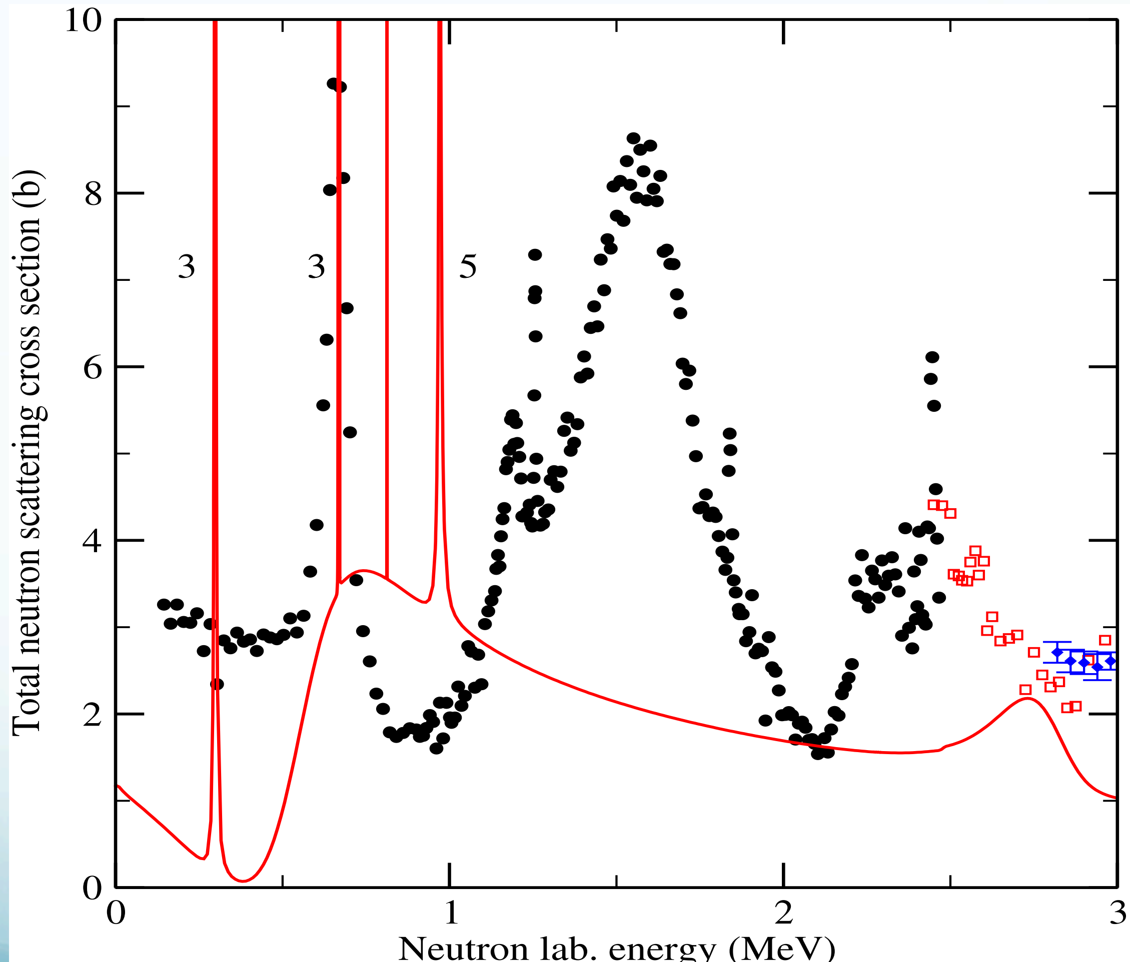
Total elastic cross section of n +^{18}O



Concluding remarks

Our past work on ^{15}F has shown that the MCAS method has predictive power.

Work on neutron-^{16}Oxygen scattering is in progress. Preliminary n+^{16}O results look promising.

Proton-^{16}Oxygen scattering calculations are also under way, and preliminary results have been reported.

We also have work in progress on n + ^{18}O scattering.

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