Observation of the Giant monopole resonances in the Sn isotopes via (α,α') reactions at 400 MeV at RCNP
- Latest results and implications -

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5) **Summary**

Our Aim

In the supernova explosion processes, the iron core absorbs electrons via the electron capture process, and the core is dominated with neutron excess nuclei.

→ **This process proceeds at? $_0$**

→ **In the region ? $_0$, the core become hard**

→ **Rebounding happens**

→ **Explosion**

http://heasarc.gsfc.nasa.gov/docs/snr.html

Thus, an important factor for supernova explosion is the hardness of the core with neutron excess nuclei.

↓

Incompressibility

Isotope dependence of Incompressiblity → $K_{sym}\left(\frac{N-Z}{A}\right)^2$

Two Major Unsolved Issues in Nuclear Incompressibility

1. Different K_A ($K_{\therefore}$)values from ISGMR and ISGDR

$$E_{ISGMR} \doteq \sqrt{\frac{K_A}{m<r^2>}}$$

$$E_{ISGDR} \doteq \sqrt{\frac{7}{3}\frac{K_A+(27/25)\varepsilon_F}{m<r^2>}}$$

2. From the same GMR data, Non-relativistic and Relativistic calculations gave different $K_{\therefore}$ values;

    220 MeV non-rel.

    270 MeV rel.

The first of these has been resolved. With the background-free spectra, ISGDR strength at higher Ex than before. Now, same calculations give reasonable agreement with E_{GMR} and E_{ISGDR}.

The second issue still remained unsolved.

	E_{GMR}-NR.	E_{GMR}-Rel.
^{112}Sn	17.7 MeV	18.3 MeV
^{124}Sn	16.9 MeV	17.0 MeV
$\Delta[^{124}Sn-^{112}Sn]$	**0.8 MeV**	**1.3 MeV**

We need precise numbers for E_{GMR} for the whole series of Sn isotopes to fully constrain the values of K_{sym}.

E_{GMR} for several Sn isotopes with uncertainties of 0.1 MeV

→ High statistics data required.

⇒ to be well done.

There was the consensus among the theorists that the Primary difference between the non-relativistic and relativistic calculations comes from the "symmetry energy" term.

$$K_A \sim K_{\therefore}(1+cA^{-1/3}) + K_{sym}((N-Z)/A)^2 + K_{Coul}Z^2A^{-4/3}$$

K_{sym} = -400 ~ +466 MeV; not well obtained

B.A. Li, PRL 85, 4221 (2000),
B.A. Li, C.M.Ko, and W. Bauer, Int. J. Mod. Phys. E7, 147 (1998).
B.A.Li, W.Udo, Nova Science Publishers.
R.J. Furnstahl, nucl-th/0112085.

Clearly the (N-Z)/A term is very important

in nuclear structure, heavy ion collision, astronuclearphysics.

The widest range of (N-Z)/A in an isotope series (in medium and heavy mass nuclei) is in Sn:

^{112}Sn	**0.107**
^{124}Sn	**0.194**

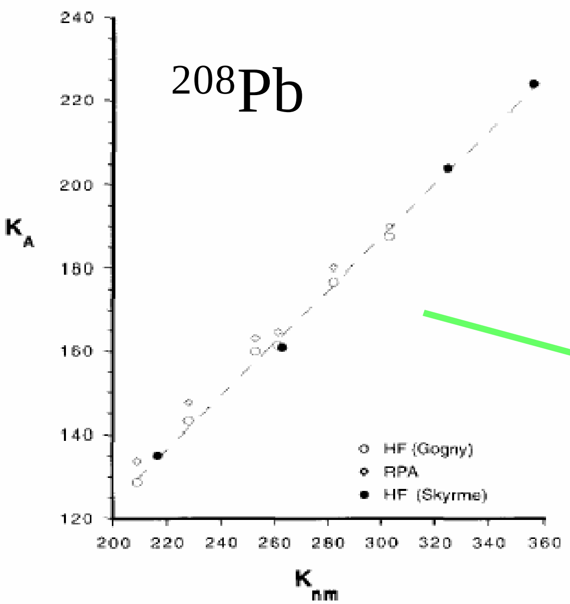
Incompressibility of nuclear matter → Impossible to be determined from the observation. → Need help from theory

$$K_\infty = \left[9 r^2 \frac{d^2 (E/A)}{dr^2} \right]_{r=r_0}$$

E/A : Binding energy /A

? : nuclear density

$?_0$: nuclear density at equiblrilum



1 . Determine K_A for finite nuclei.

2 . Ontain the relation ship between K_A and

K_A is K_8 obtained from the information on the excitation energy of ISGMR , ISGDR) .

$$E_{ISGMR} = \hbar \sqrt{\frac{K_A}{m < r^2 >}}$$

$$E_{ISGDR} = \hbar \sqrt{\frac{3}{7} \frac{K_A + (27/25) e_F}{m < r^2 >}}$$

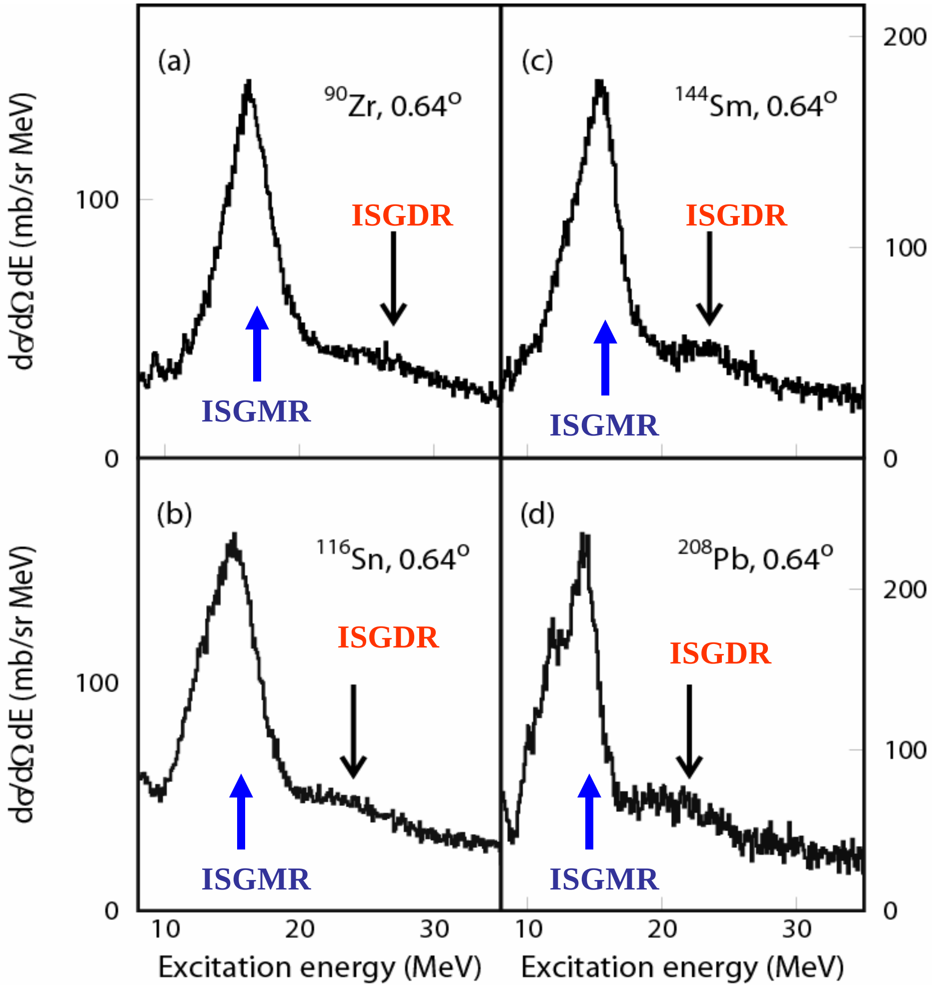
Relation between K_A and K_8 ,

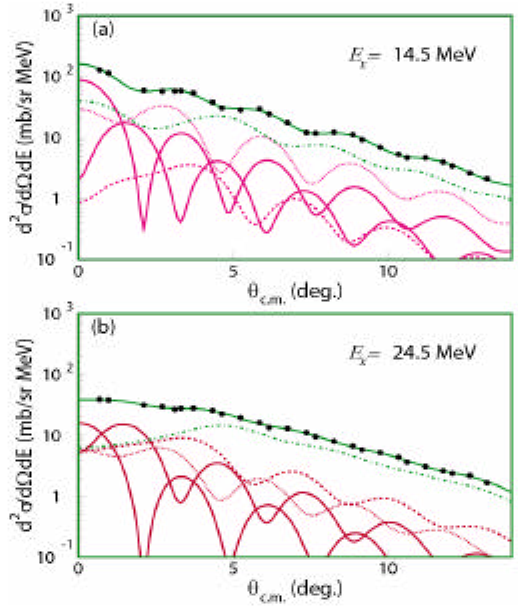
$K_A = 0.64 K_8 - 3.5$

(J.P.Blaizot, NPA591,435,1995)

Uchida et al., PRC

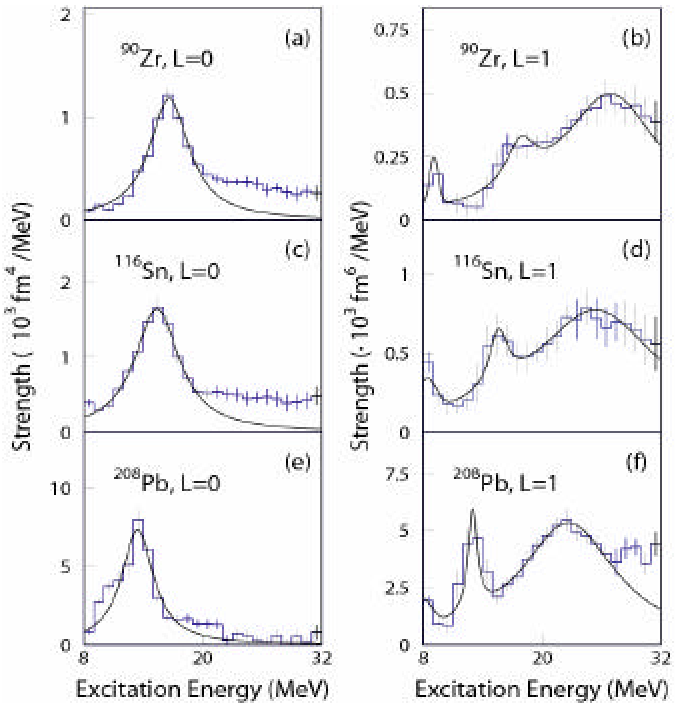
(α,α') spectra at 386 MeV





^{116}Sn

MDA results for L=0 and L=1



Giant Resonances

- (? T=0)

L=0 ISGMR

L=1 ISGDR

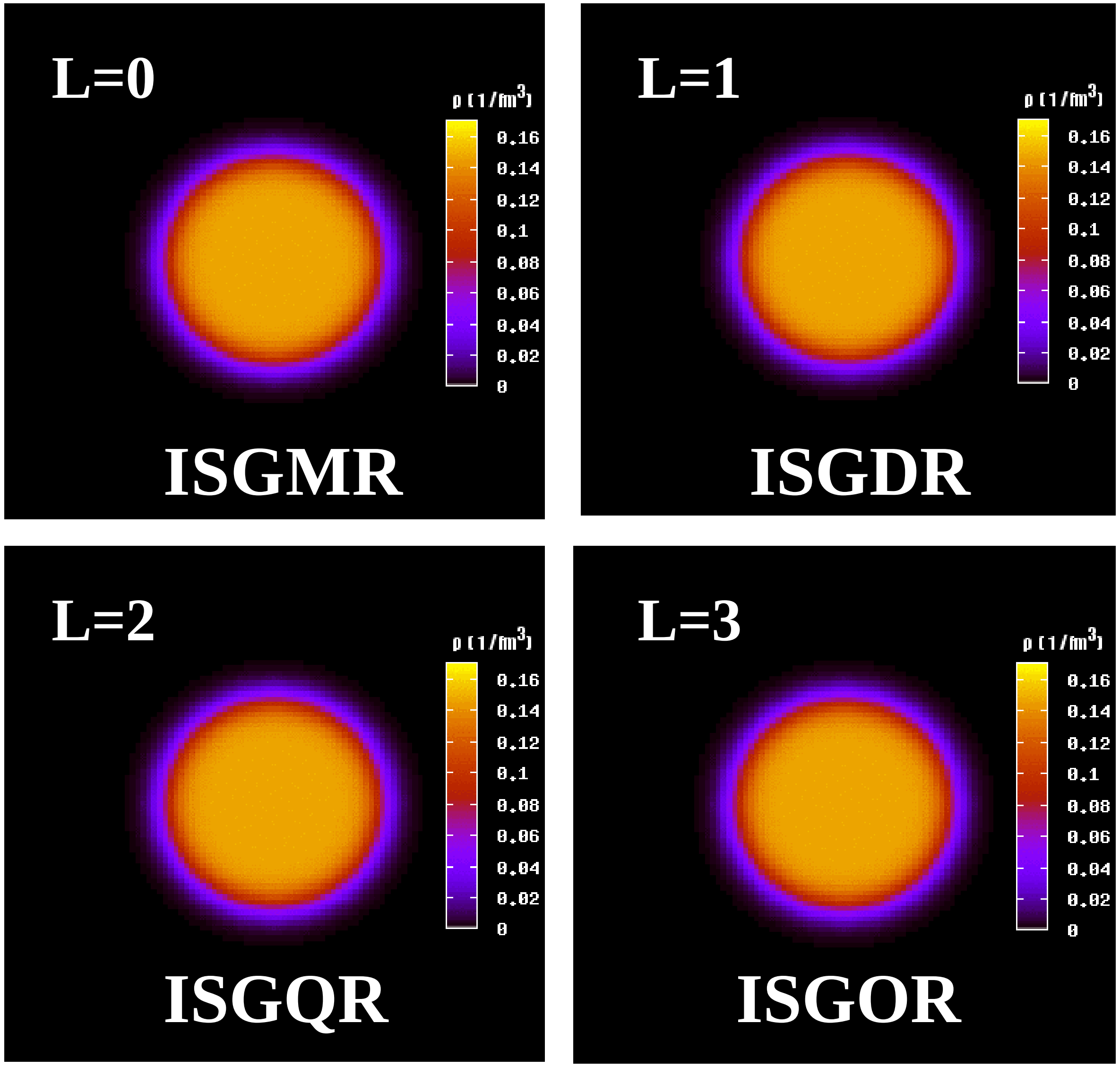
L=2 ISGQR

L=3 ISGOR

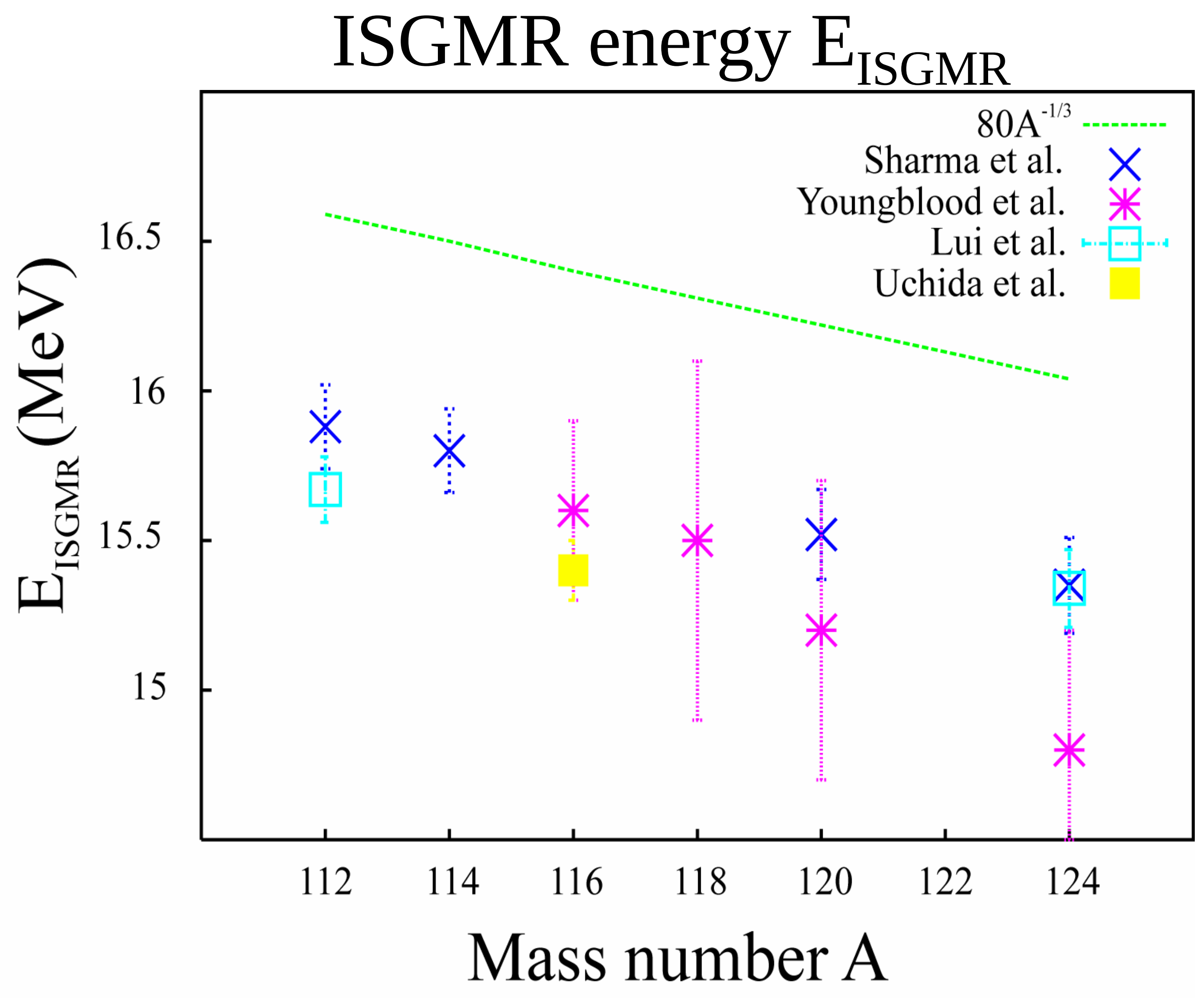
⋮ ⋮

- (? T=1)

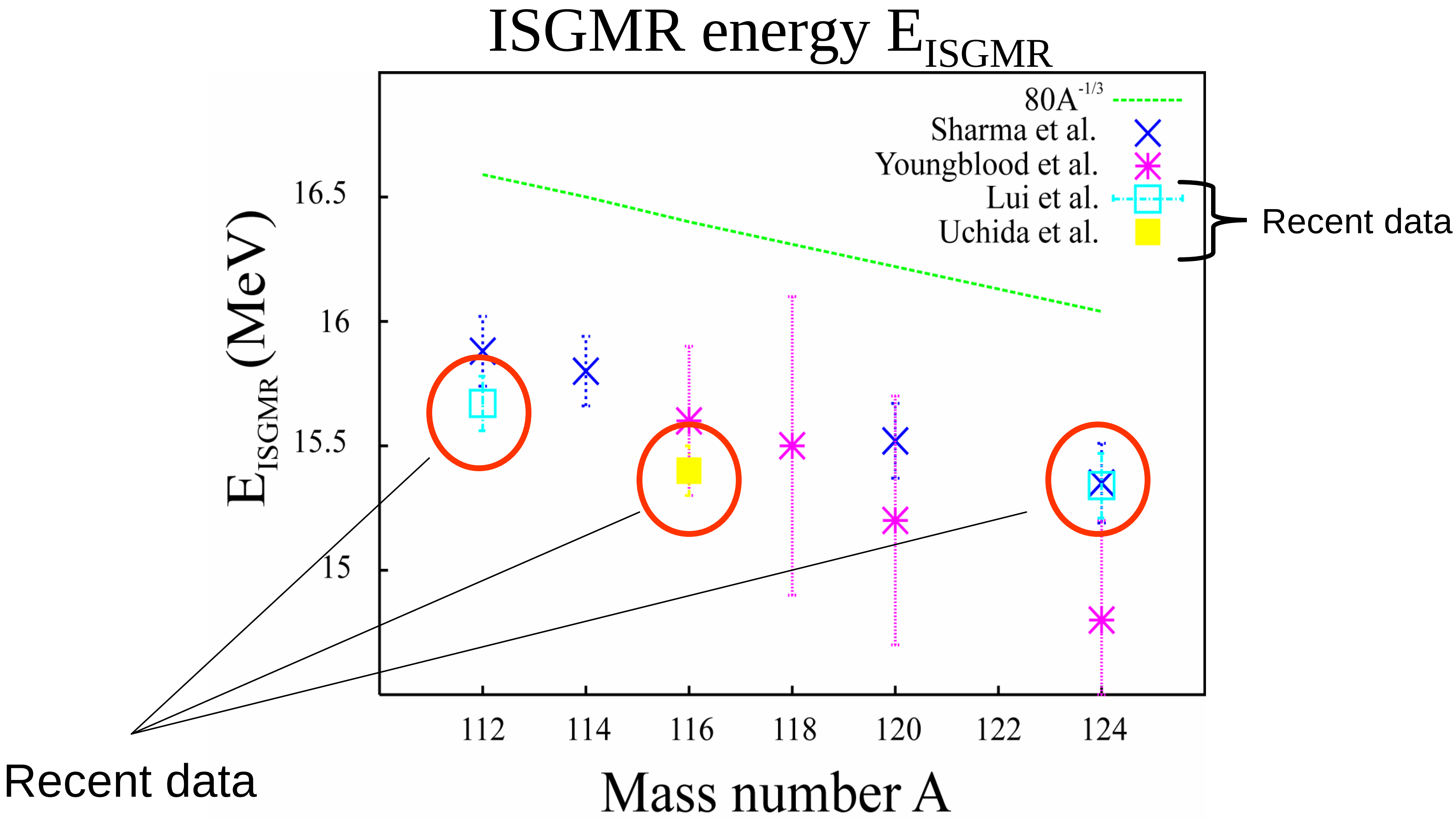
L=1 IVGDR



Experimantal data on ISGMR



Experimental data on ISGMR

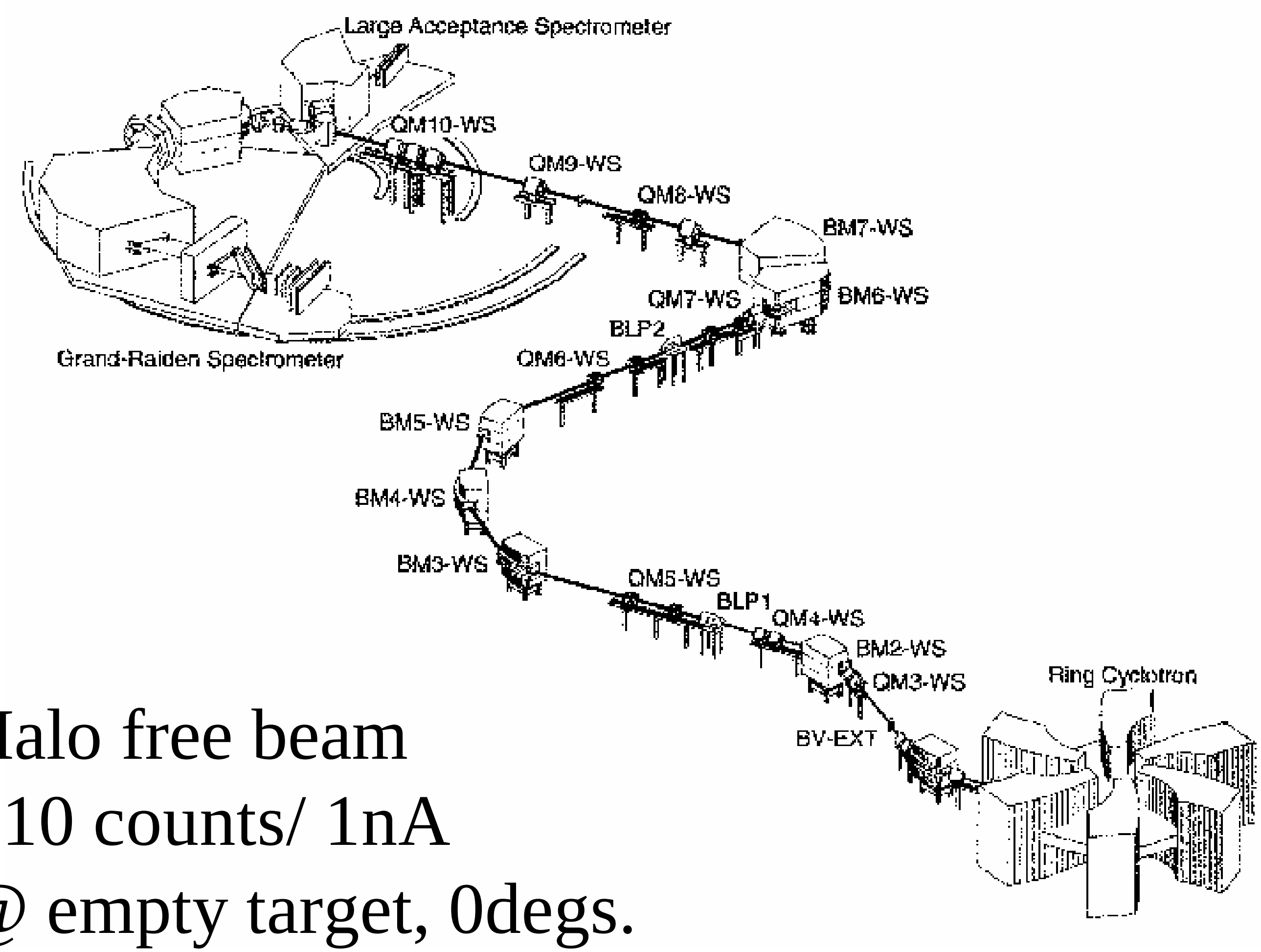


In the present experiment

- Obtain good (α,α') spectra including 0 degrees for ^{112}Sn to ^{124}Sn
- Using MDA analyses, we obtain the L=0 cross section distribution for ISGMR, and determine the peak location in excitation energy.
- Obtain K_{sym}.

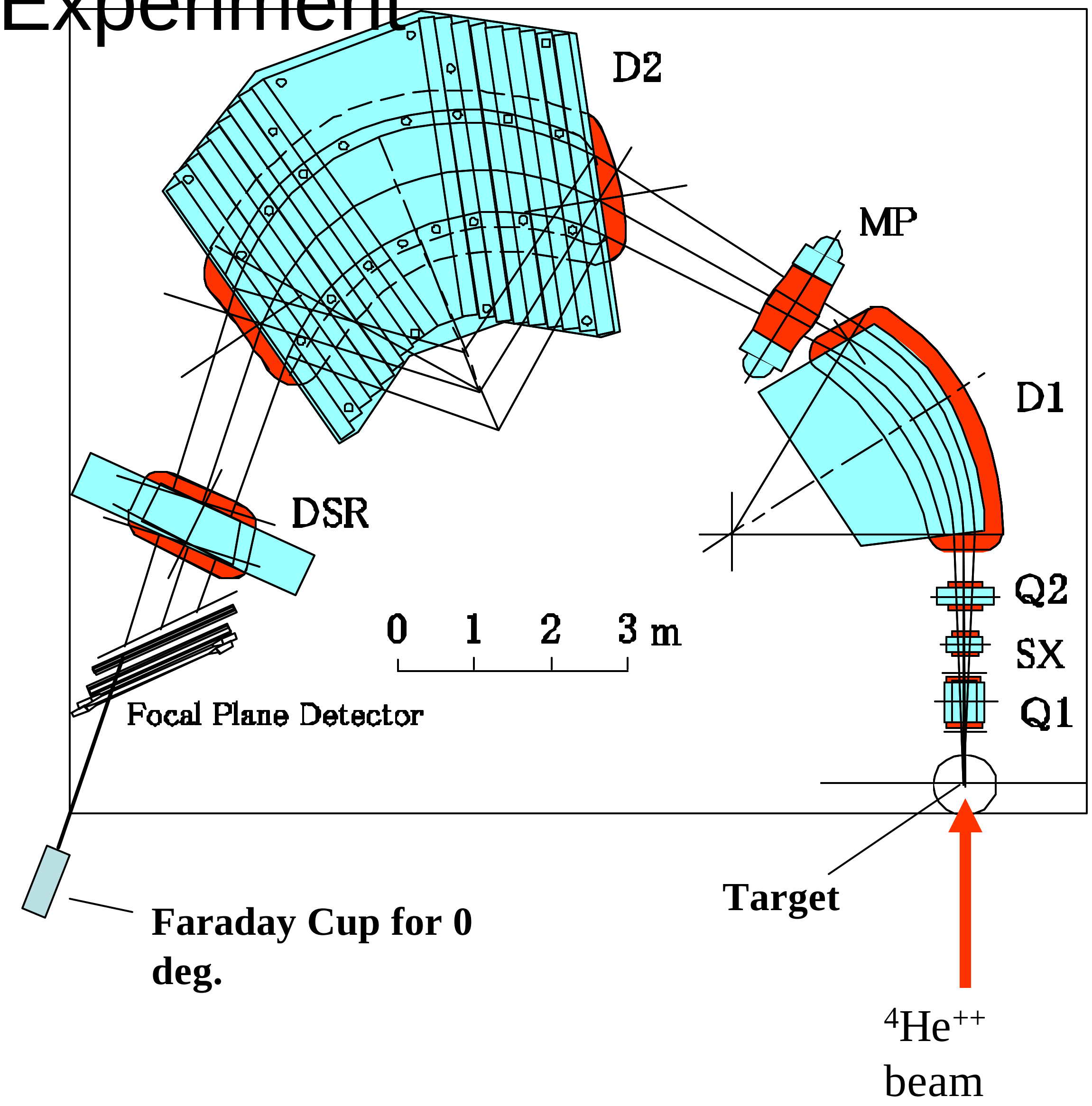
RCNP ring cyclotron facility

E_{α}=386 MeV



Halo free beam
~10 counts/ 1nA
@ empty target, 0degs.

Experiment



Incidence $^4He^{++}$ beam

Energy 386 MeV

Measured angles

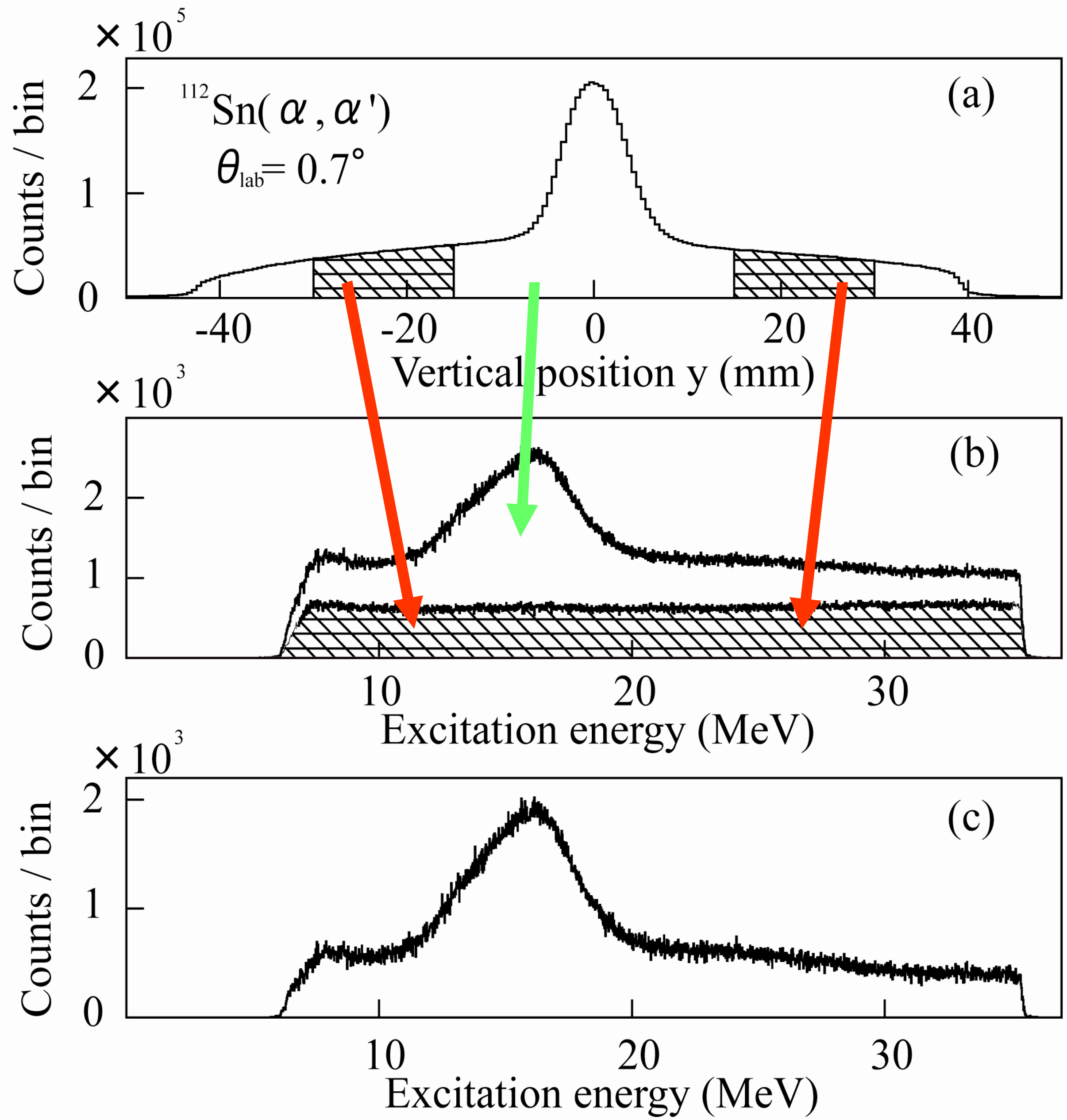
1 1 2 ? 1 1 4 ? 1 1 8 ? 1 2 0 ? 1 2 2 ? 1 2 4 Sn

0 ° ~ 8 °

^{116}Sn Uchida et al.

Targets	Thickness (mg/cm^2)	Enrichment (%)
^{112}Sn	5.5	99.5
^{114}Sn	7.5	87.1
^{116}Sn	10.0	95.6
^{118}Sn	5.7	96.5
^{120}Sn	5.1	98.4
^{122}Sn	9.3	92.2
^{124}Sn	5.0	96.7

Data Analysis



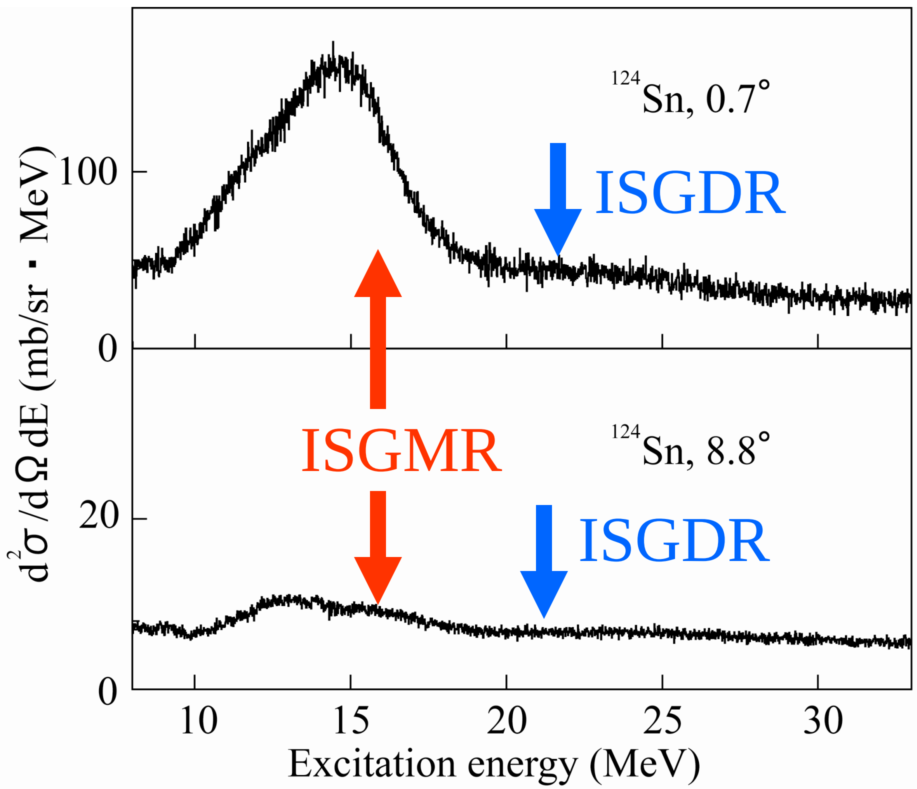
Background rejection with the focal plane detector system of the spectrometer Grand Raiden.

(a) one-dimensional spectrum along the vertical direction. Background events correspond to the hatched area.True and background events are in the central region.

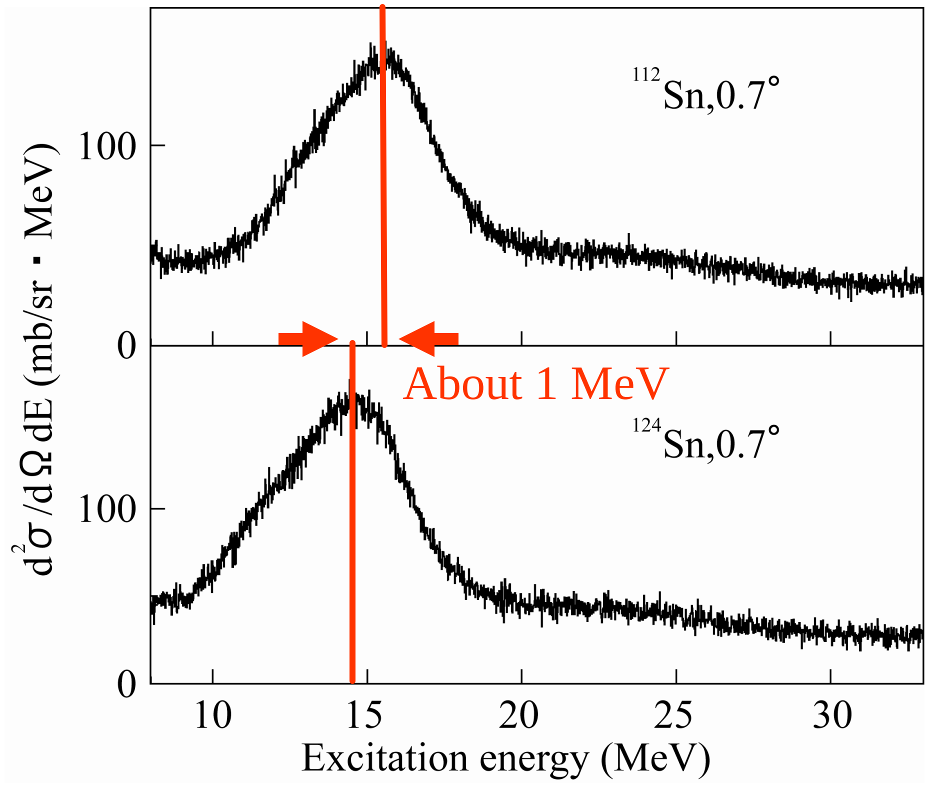
(b) The energy spectra for the true + background events, and for the background Events.

(c) Difference spectrum for true events.

^{124}Sn(a ,a ') spectra

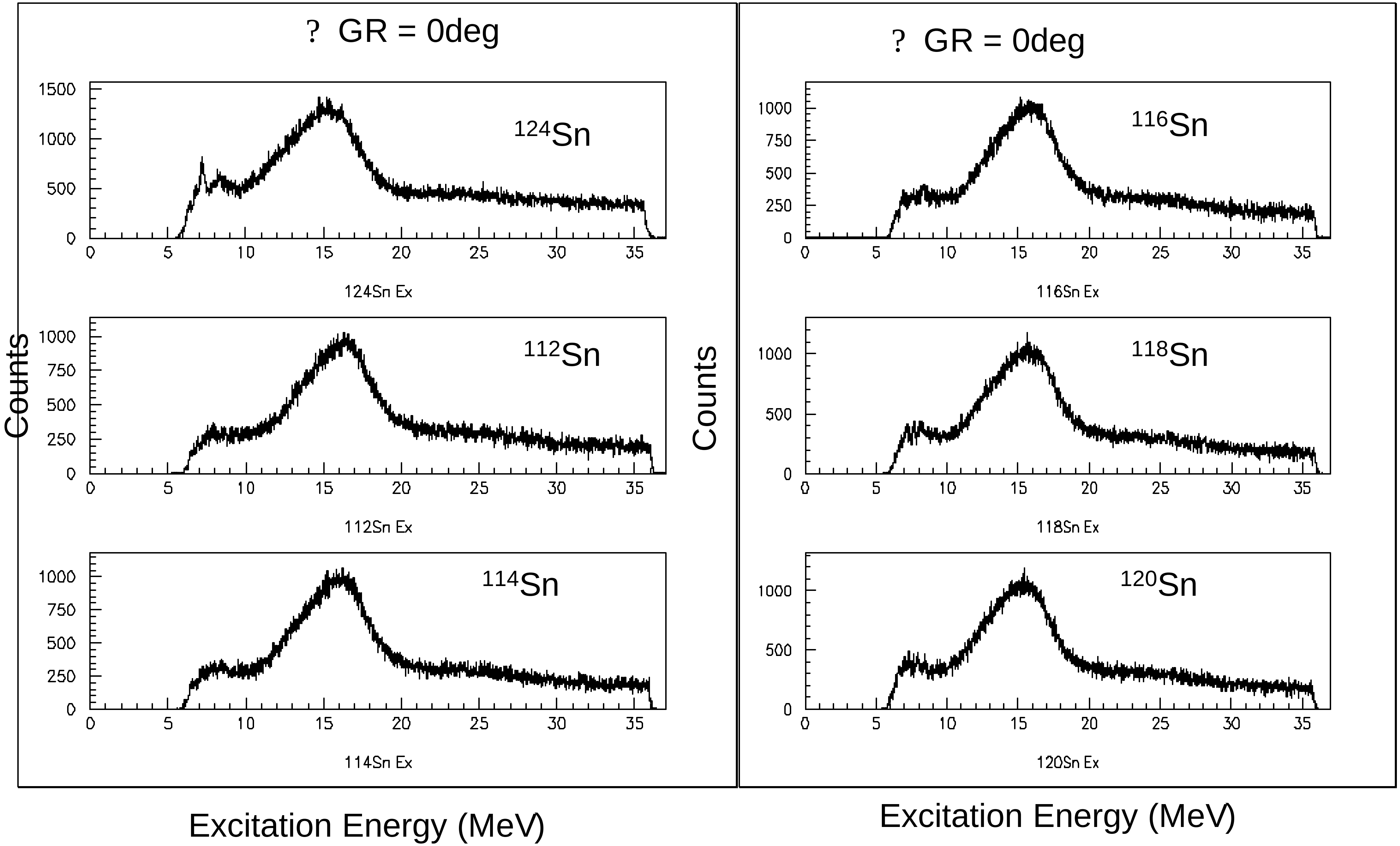


^{112,124}Sn(a ,a ') spectra



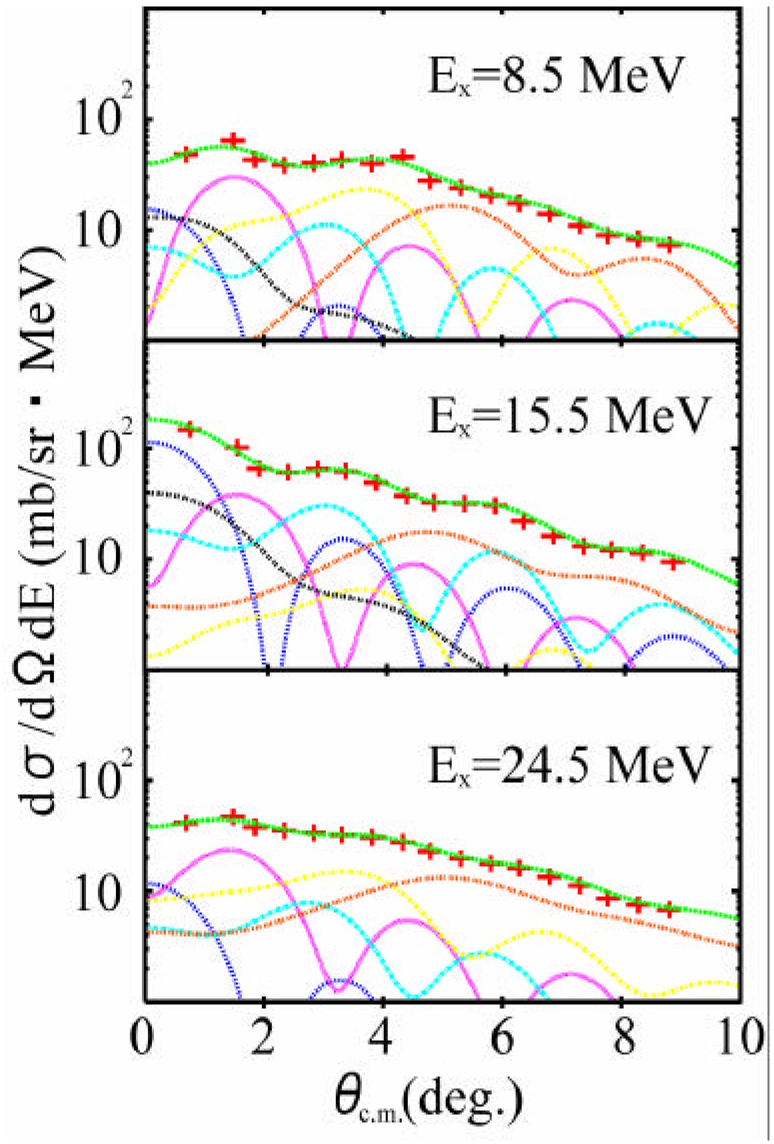
- Superposition of components with various L transfer in the Sn (α,α') spectra.
- In order to extract the ISGMR peak position, it is necessary for us to extract the L=0 component from the excitation energy spectra.

Energy Spectra



Multipole-decomposition analysis

^{124}Sn(a ,a ’)



$$s^{\exp}(q,E_x)=\sum_L a_L(E_x)s_L^{calc}(q,E_x)$$

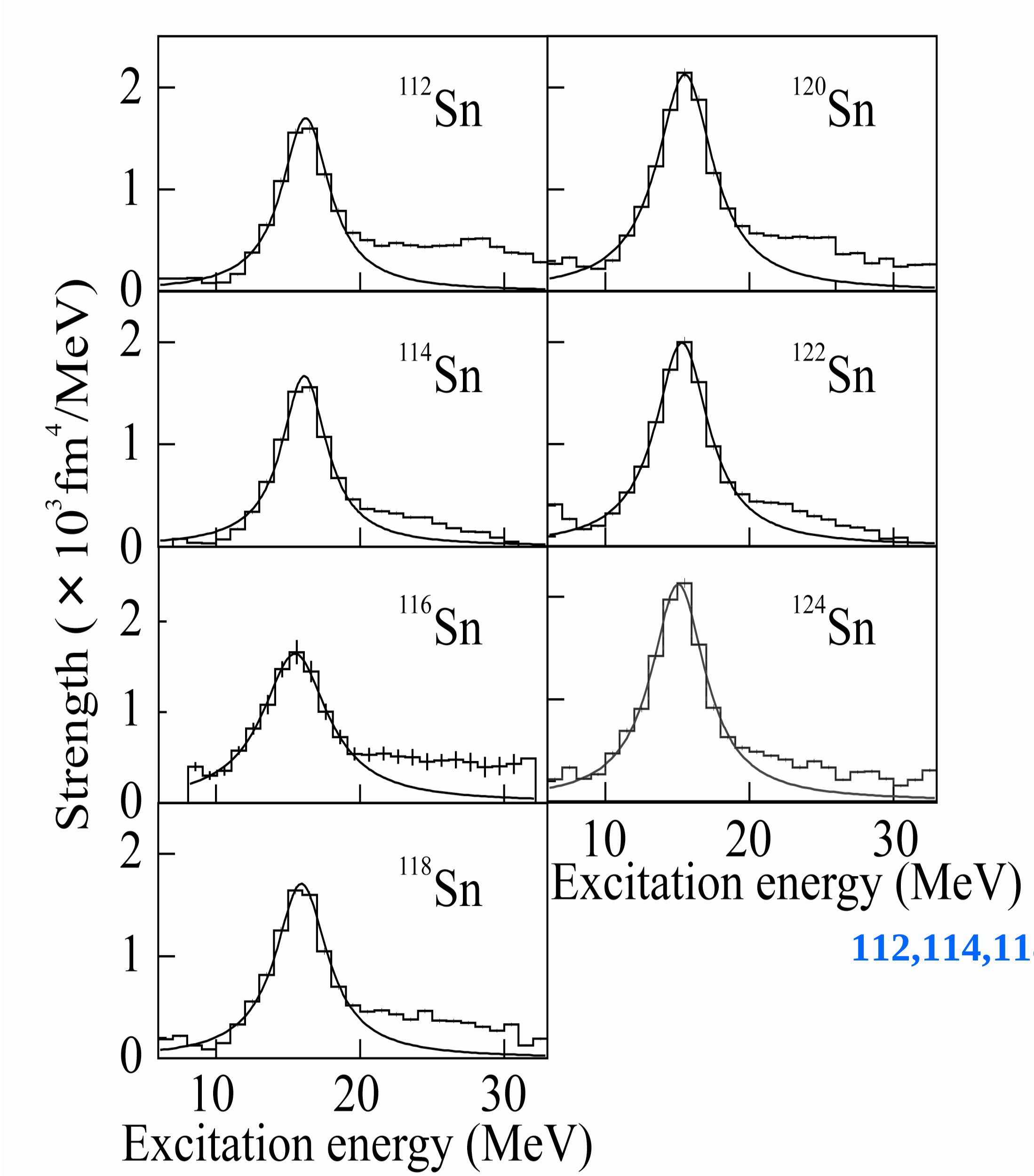
Cross sections

DWBA calculations

(L=0~ 15) and IVGDR cross section

- ? L = 0
- ? L = 1
- ? L = 2
- ? L = 3
- ? L > 3
- ? L = 1 , ? T = 1

L=0



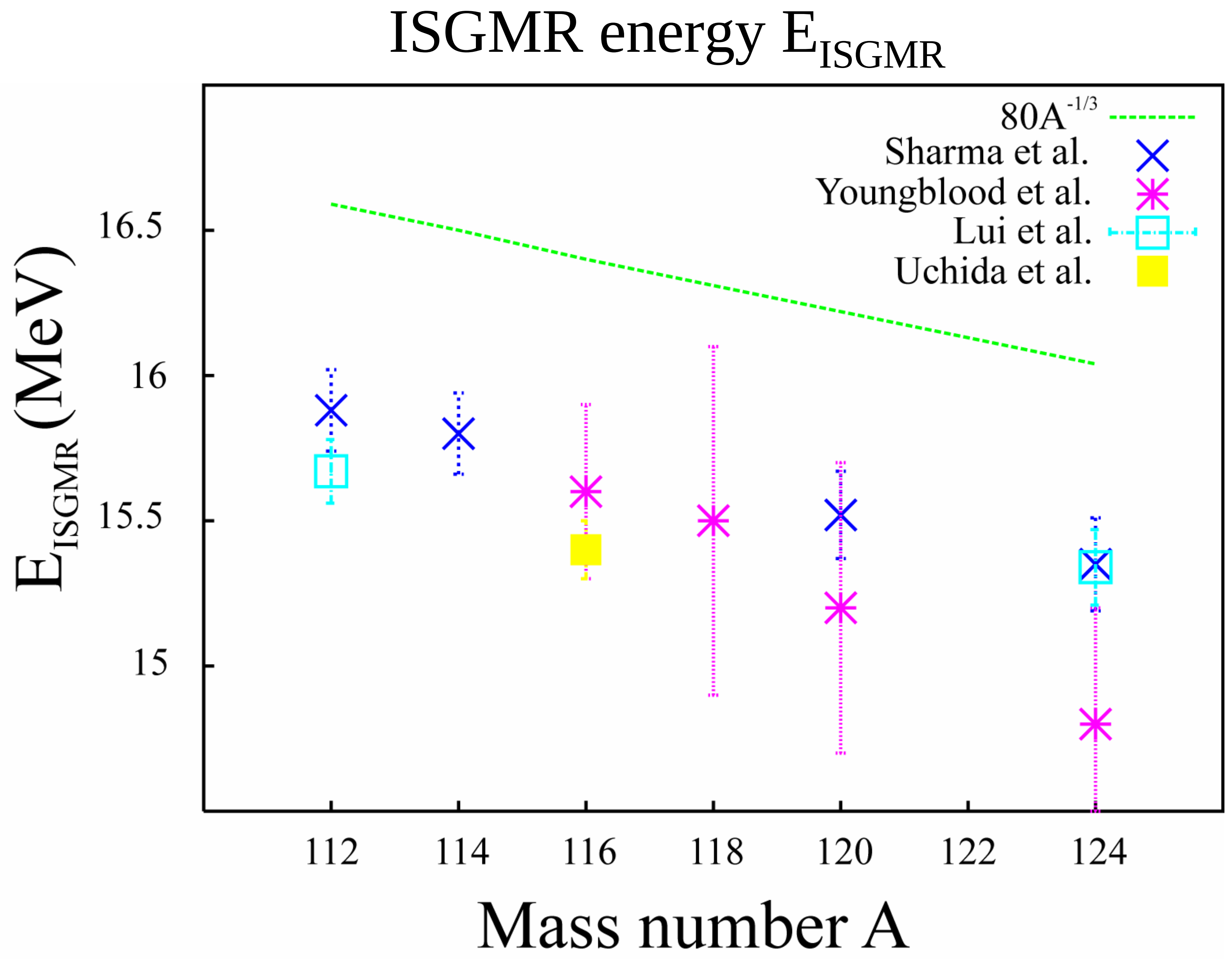
Breit-Wigner function

$$s(E) = \frac{s_m}{(E - E_m)^2 + \Gamma_m}$$

	E_m (MeV)	G $_m$ (MeV)
^{112}Sn	16.1 ± 0.1	4.4 ± 0.2
^{114}Sn	16.0 ± 0.1	4.0 ± 0.1
^{116}Sn	15.4 ± 0.1	5.7 ± 0.3
^{118}Sn	15.7 ± 0.1	4.6 ± 0.2
^{120}Sn	15.3 ± 0.1	4.8 ± 0.2
^{122}Sn	15.1 ± 0.1	4.5 ± 0.2
^{124}Sn	14.9 ± 0.1	4.5 ± 0.3

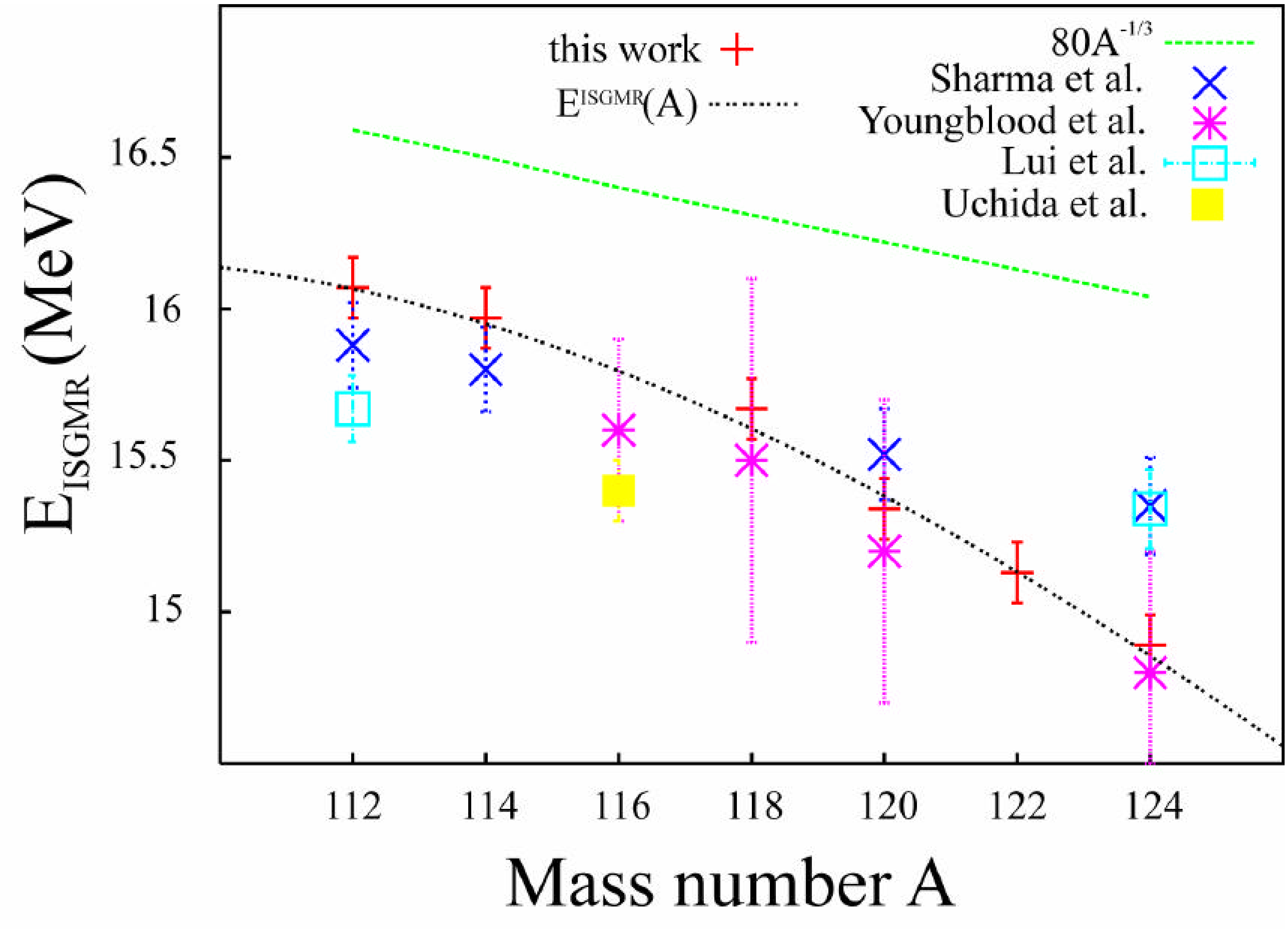
^{112,114,118,120,122,124}Sn : this work

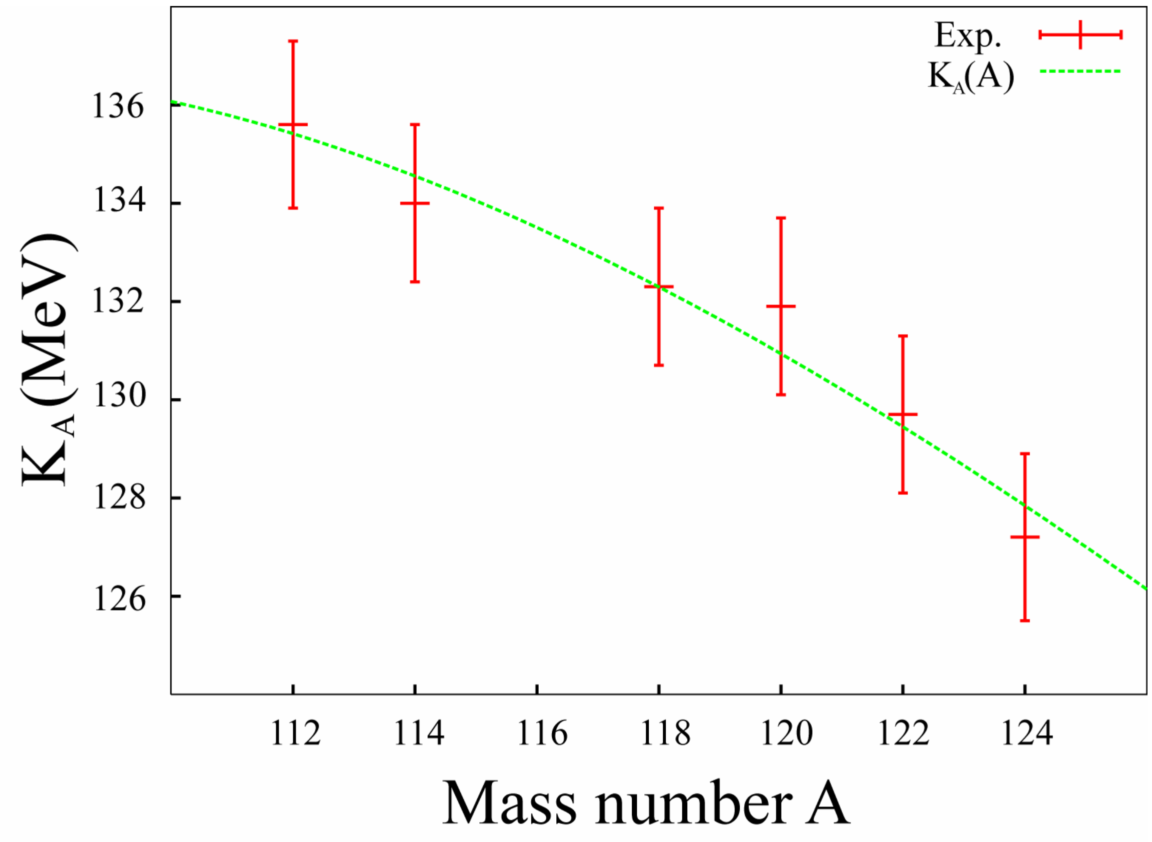
^{116}Sn : Uchida et al.



ISGMR energy E_{ISGMR}
E_{ISGMR} (MeV)
Mass number A
$80A^{-1/3}$
Sharma et al.
Youngblood et al.
Lui et al.
Uchida et al.
16.5
16
15.5
15
112
114
116
118
120
122
124

ISGMR energy E_{ISGMR}





$$E_{ISGMR} = \hbar\sqrt{\frac{K_A}{m < r^2 >}}$$

$$K_A \sim \; K_{\therefore}(1+cA^{-1/3}) + K_{sym}((N-Z)/A)^2 + K_{Coul}Z^2A^{-4/3}$$

c =-1 K_{Coul} = -5

G. Colo et al. PRC **70** 024307 (2004)

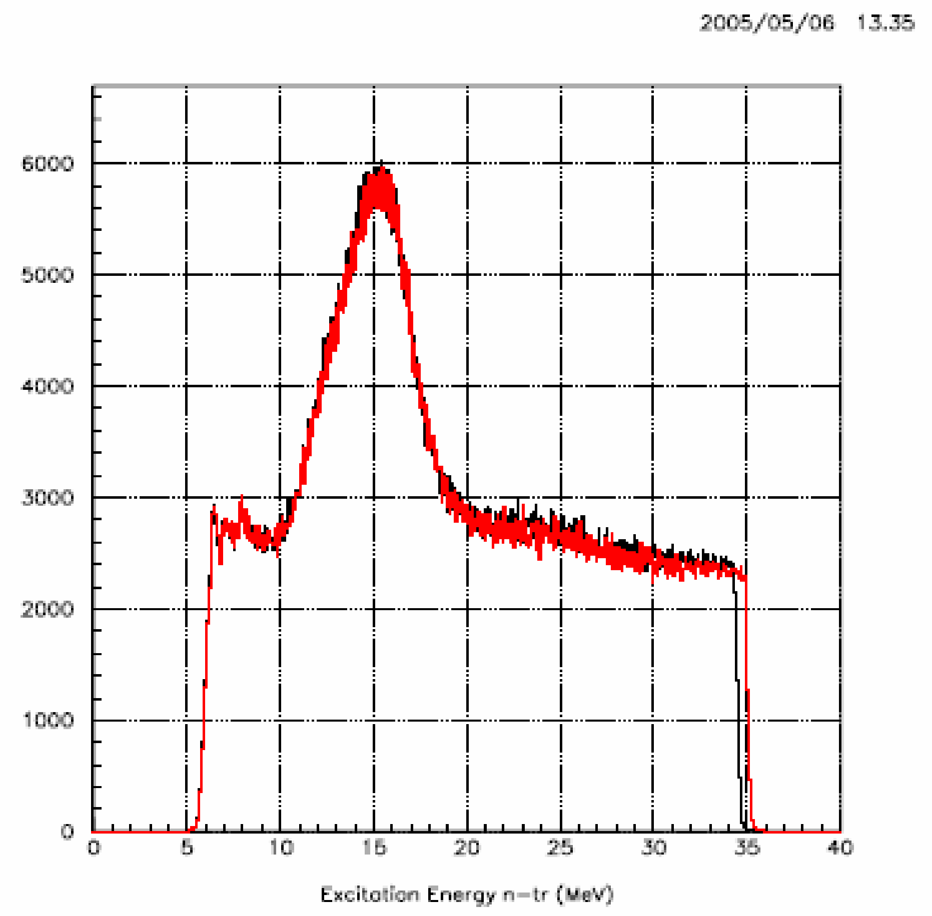
-580 < K_{sym} < -380

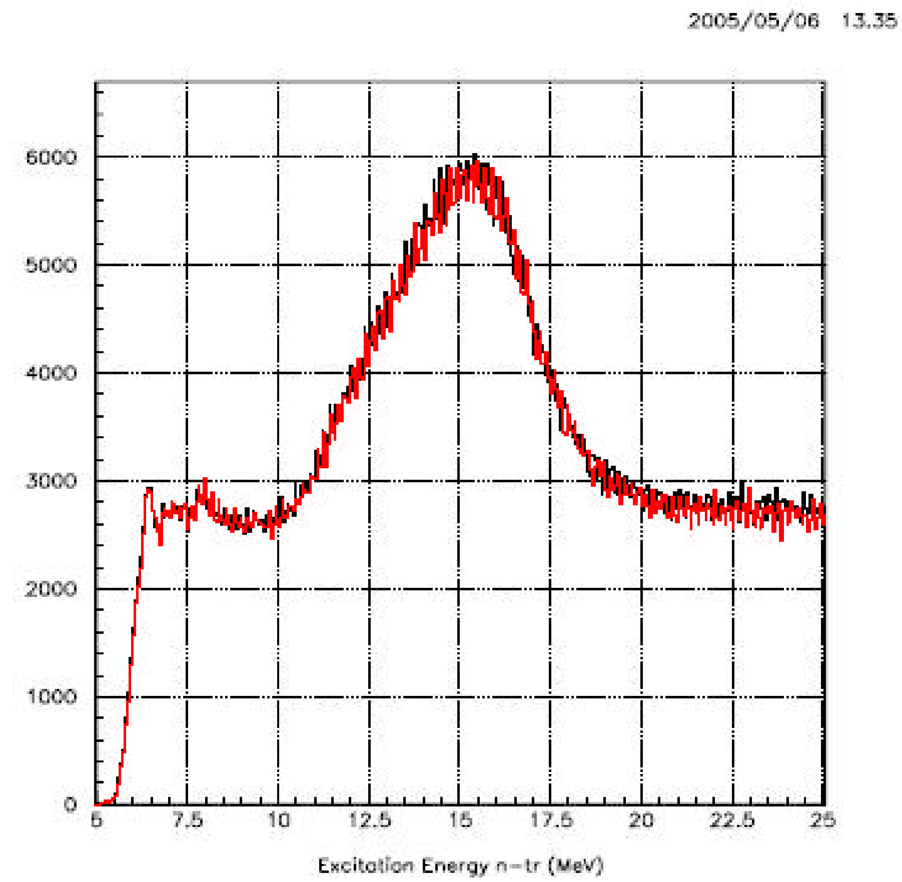
Summary

1) ISGMR in $^{112,114,118,120,122,124}Sn$ via (α,α')
2) We obtained the ISGMR cross section distribution and peak positions.
3) $K_{sym.}$ is most likely $-580 < K_{sym} < -380$ MeV.

	E_{GMR}-NR.	E_{GMR}-Rel.	Exp.
^{112}Sn	17.7 MeV	18.3 MeV	16.1 MeV
^{124}Sn	16.9 MeV	17.0 MeV	14.9 MeV
$\Delta[^{124}Sn-^{112}Sn]$	**0.8 MeV**	**1.3 MeV**	1.2 MeV

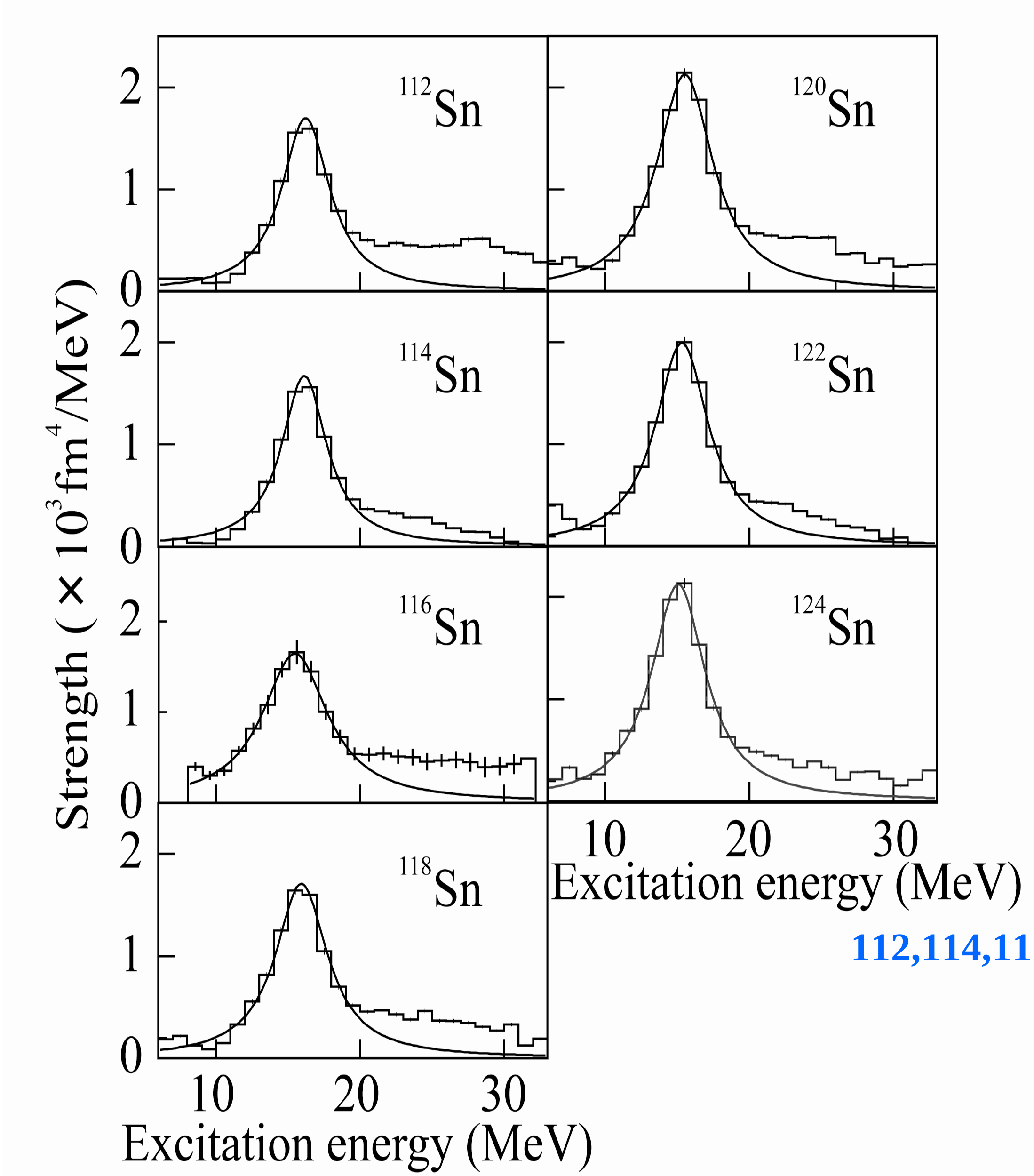
Comparison between two spectra calibrated by Ex and p.





Red: Ex
Black: momentum (correct method)

L=0



Breit-Wigner function

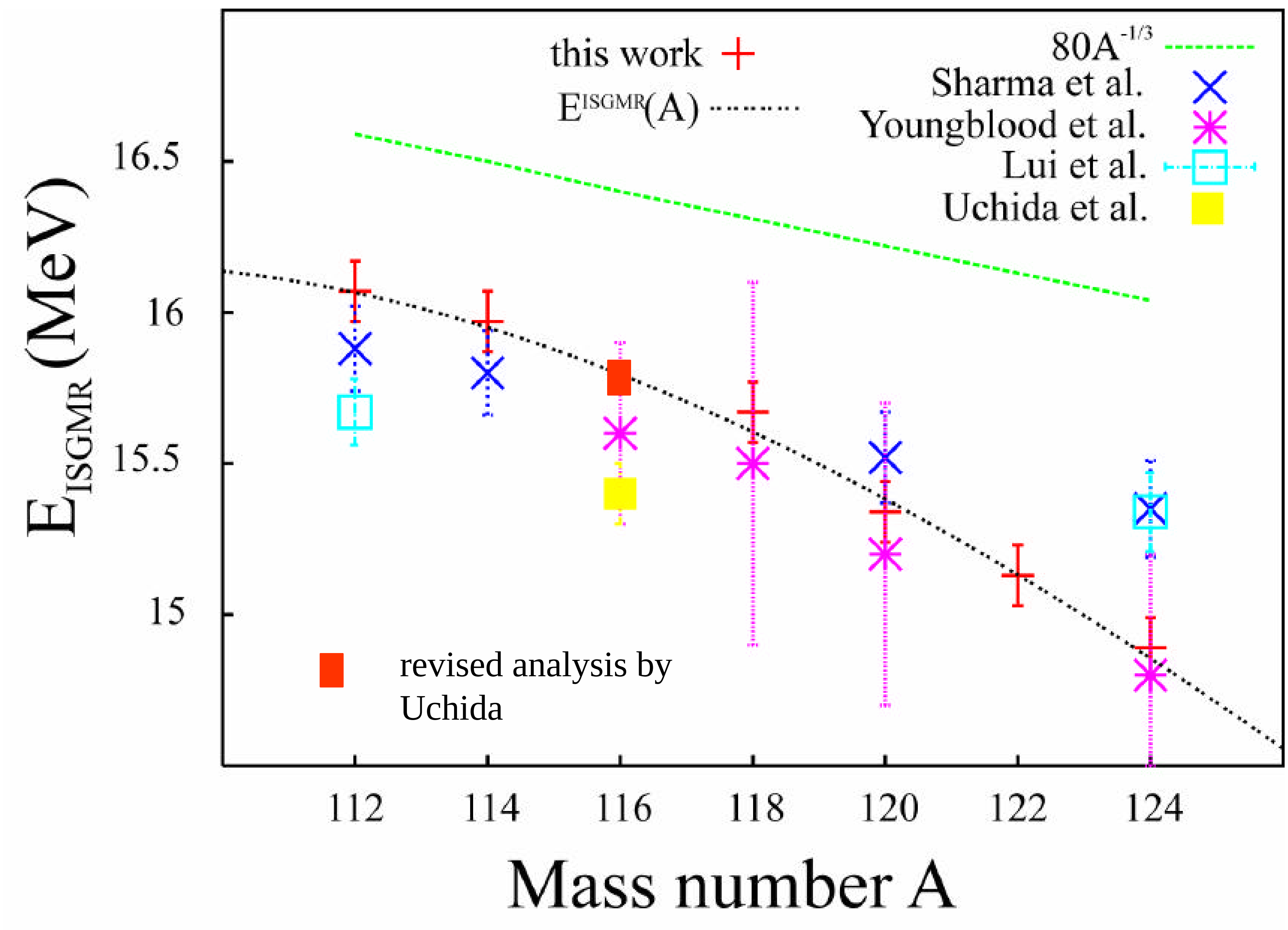
$$s(E) = \frac{s_m}{(E - E_m)^2 + \Gamma_m}$$

	E_m (MeV)	G_m (MeV)
^{112}Sn	16.1 ± 0.1	4.4 ± 0.2
^{114}Sn	16.0 ± 0.1	4.0 ± 0.1
^{116}Sn	15.8 ± 0.1	4.9 ± 0.3
^{118}Sn	15.7 ± 0.1	4.6 ± 0.2
^{120}Sn	15.3 ± 0.1	4.8 ± 0.2
^{122}Sn	15.1 ± 0.1	4.5 ± 0.2
^{124}Sn	14.9 ± 0.1	4.5 ± 0.3

^{112,114,118,120,122,124}Sn : this work

^{116}Sn : Uchida et al.

ISGMR energy E_{ISGMR}

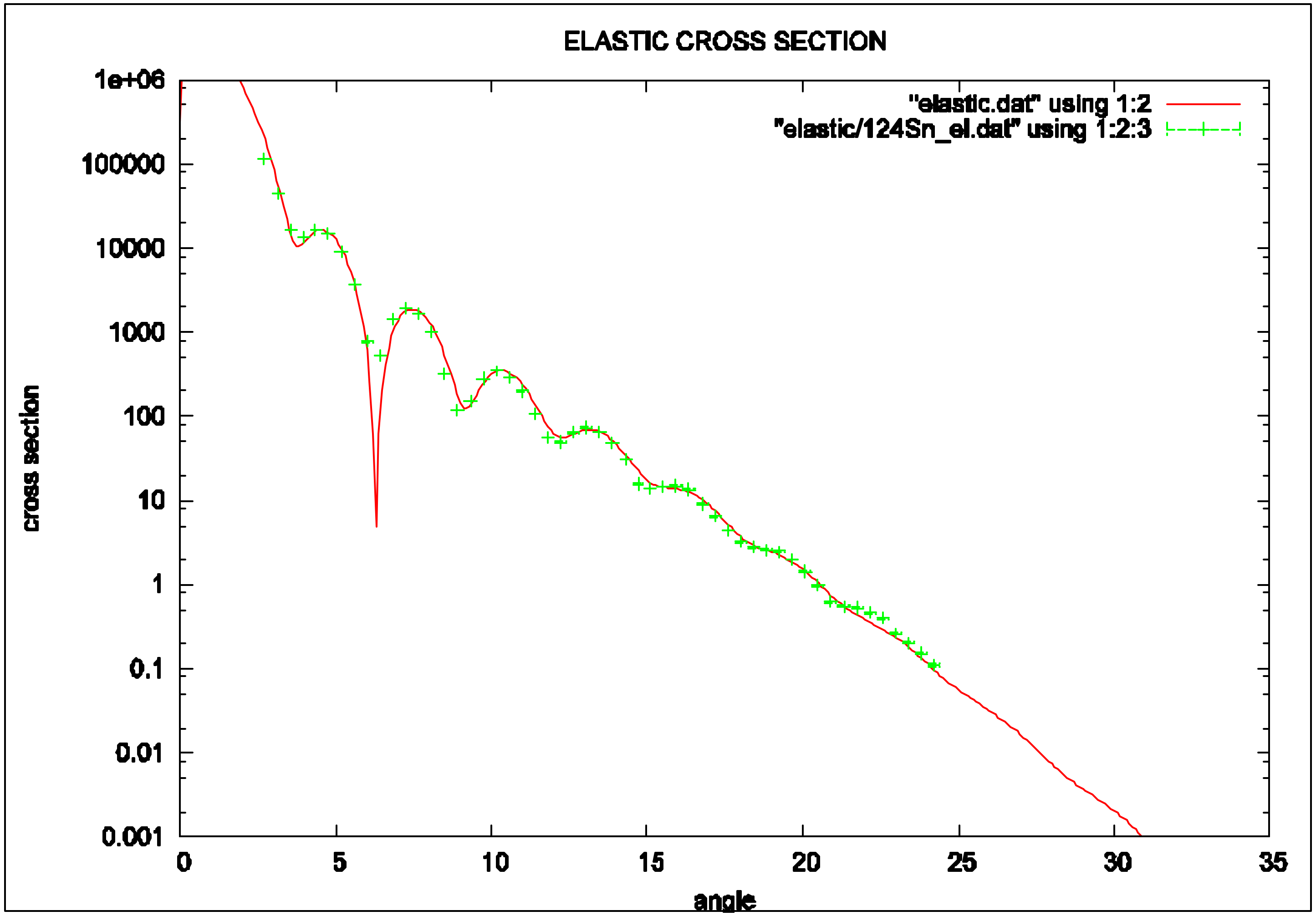


Density-dependent N-a interaction

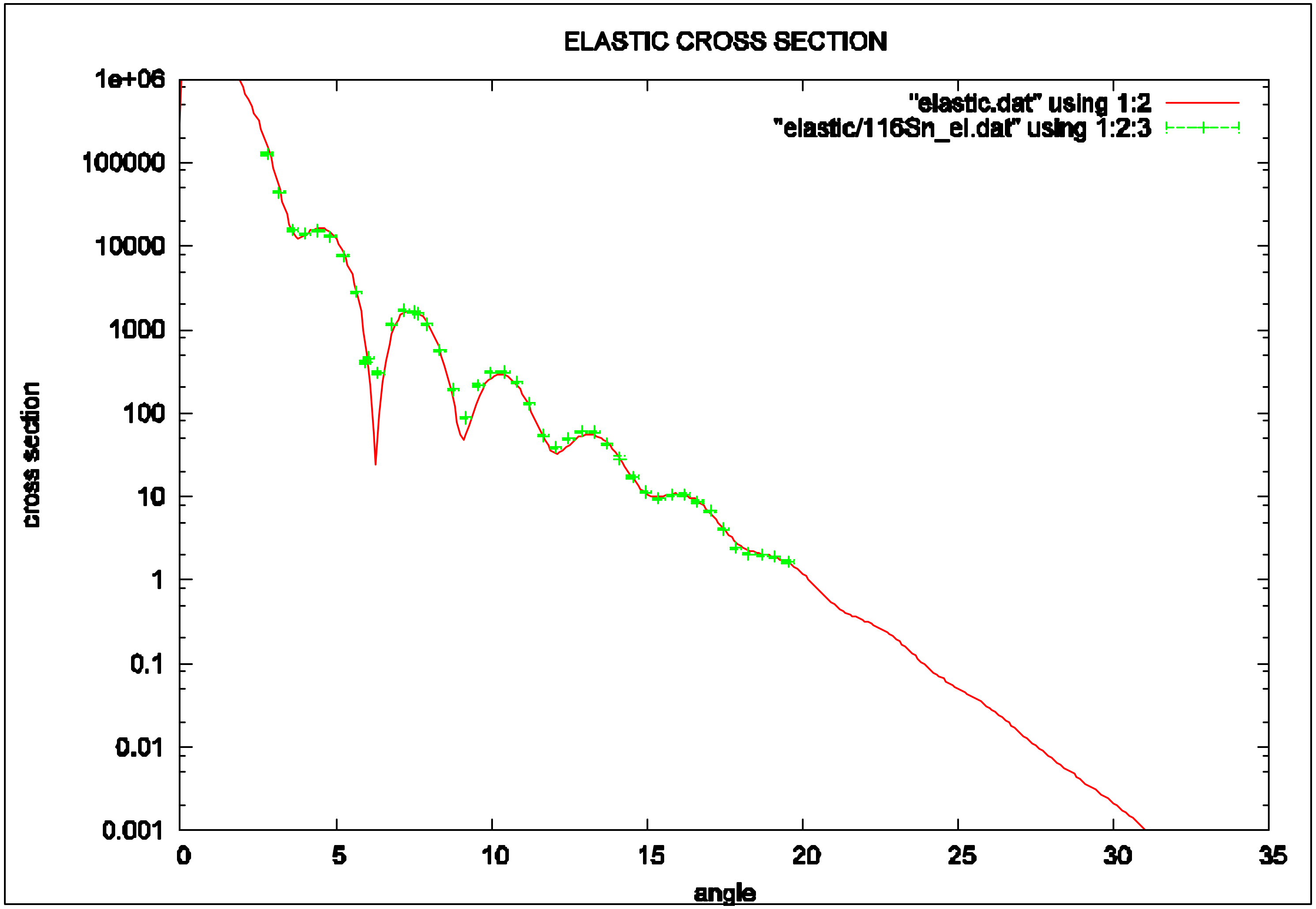
$$V(|\vec{r}-\vec{r}'|, r_0(r')) = -V(1+b_V\, r_0(r')^{2/3})\exp(-|r-r'|^2/a_V) - iW(1+b_W\, r_0(r')^{2/3})\exp(-|r-r'|^2/a_W)$$

Interaction parameters were obtained for ^{124}Sn by fitting the elastic scattering.

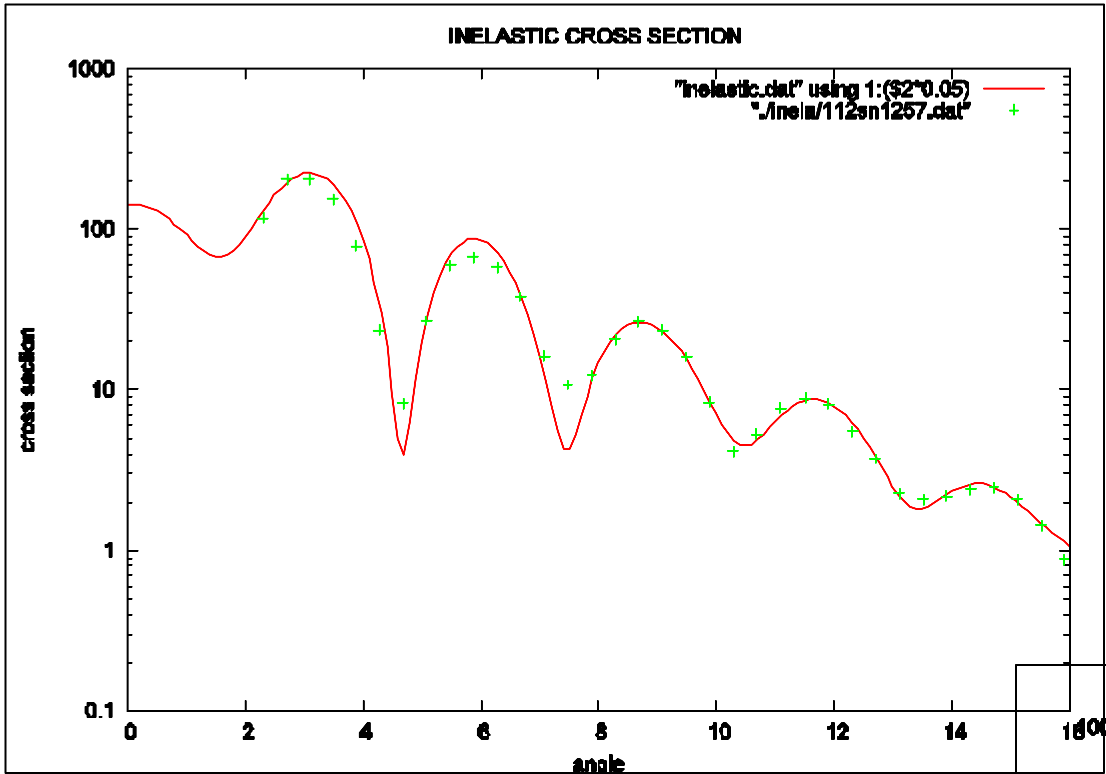
The angler distributions were calculated with the DWBA code "ECIS95"



	V (MeV)	a_v(fm^2)	ß $_v$(fm^2)	W (MeV)	a_w(fm^2)	ß $_w$(fm^2)
^{124}Sn	29.39	4.09	1.9	14.99	4.31	1.9

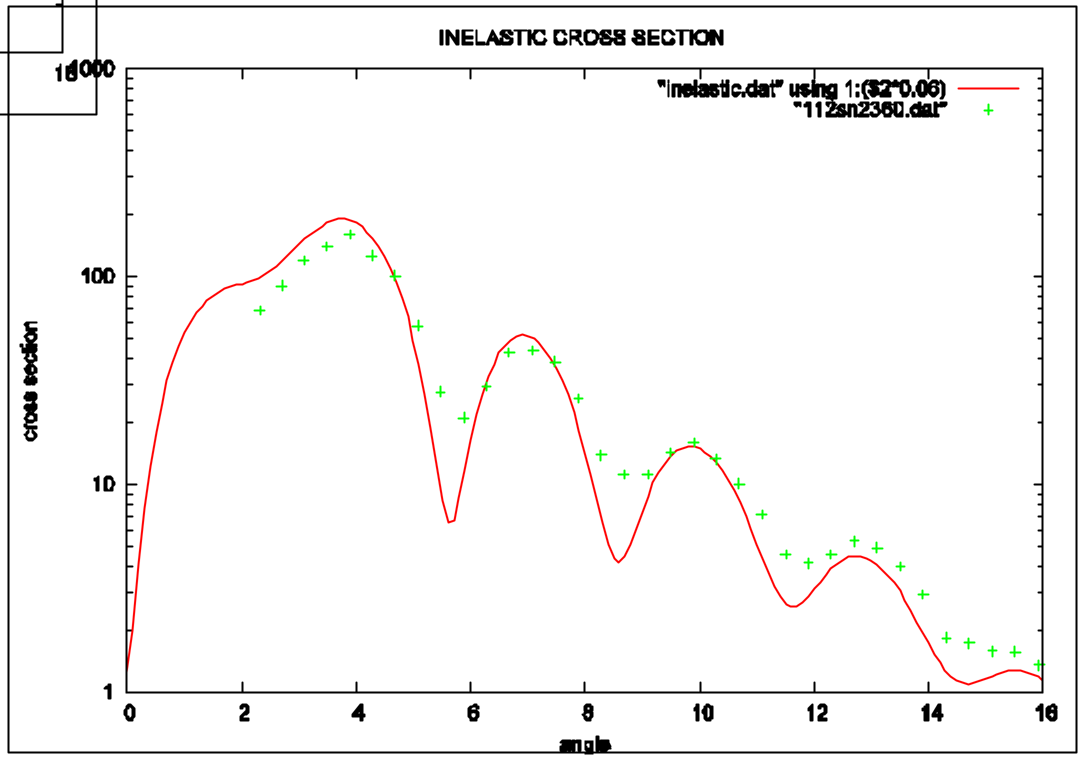


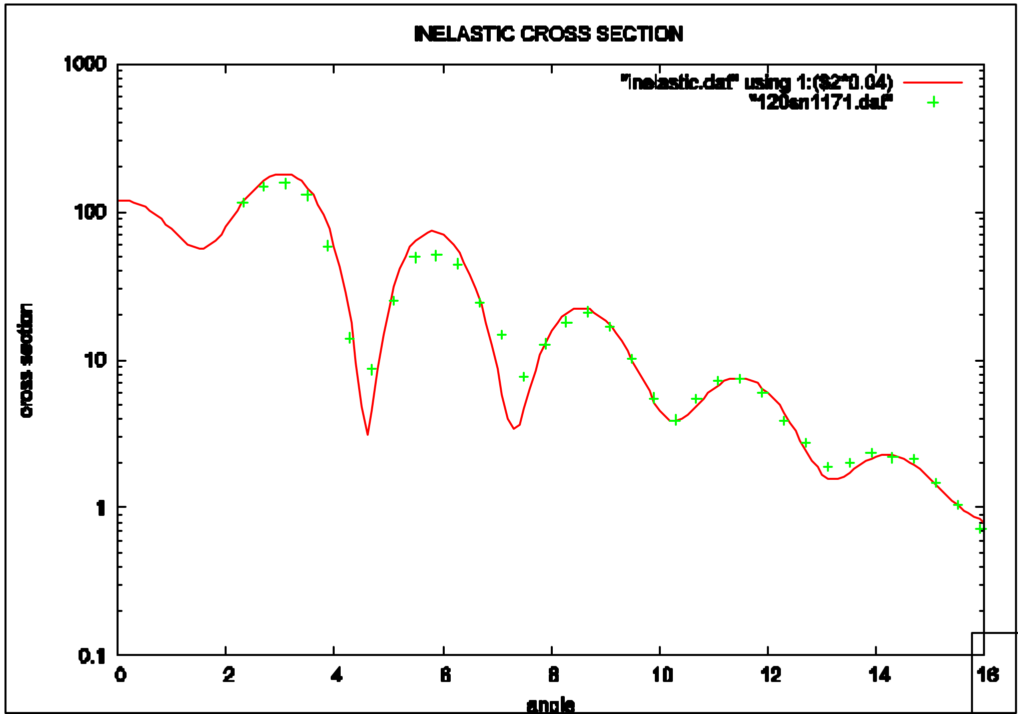
	V (MeV)	a v(fm²)	ß v(fm²)	W (MeV)	a w(fm²)	ß w(fm²)
^{116}Sn	31.19	3.82	1.9	16.47	4.15	1.9
	29.70	3.82	1.9	14.82	4.15	1.9



$^{112}Sn\ 3^{-}$ (2.360MeV)

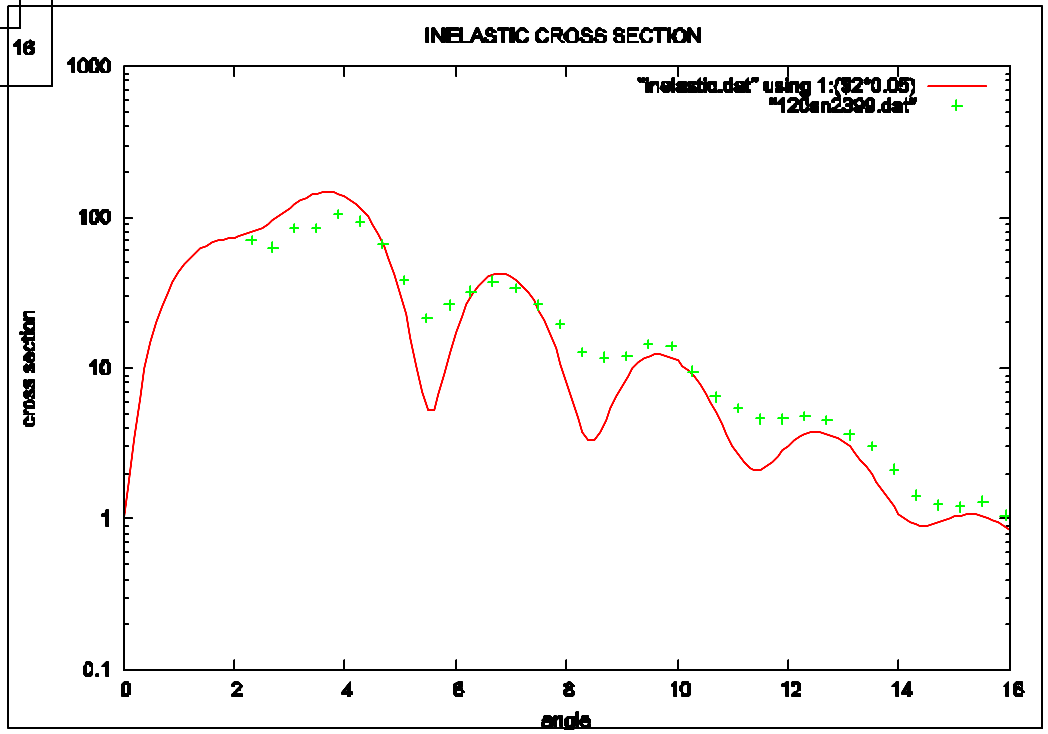
$^{112}Sn\ 2^{+}$ (1.257MeV)



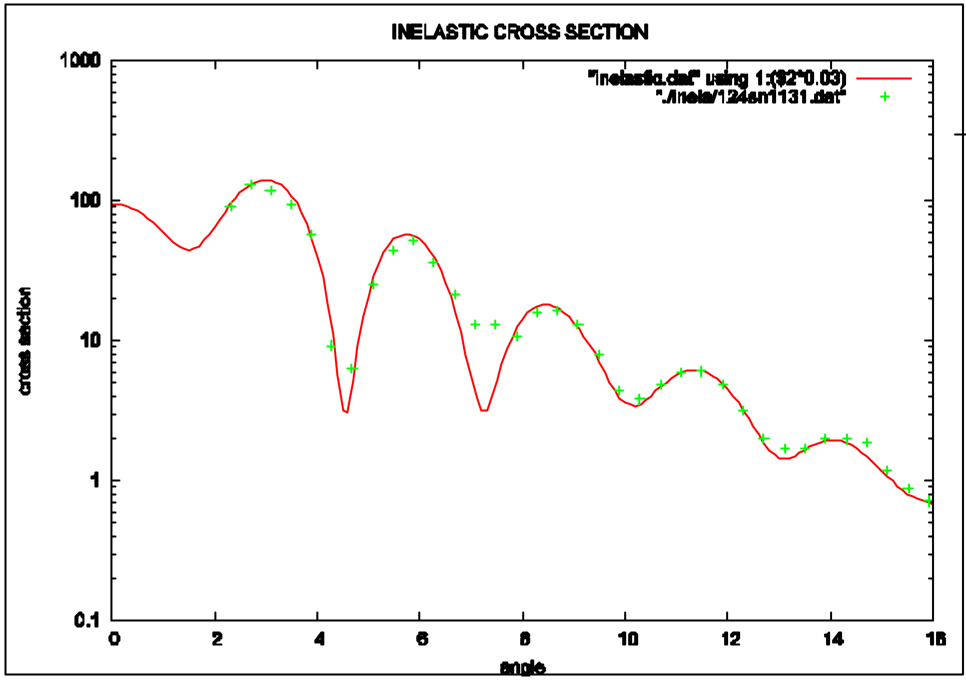


$^{120}Sn\ 2^{+}$ (1.171MeV)

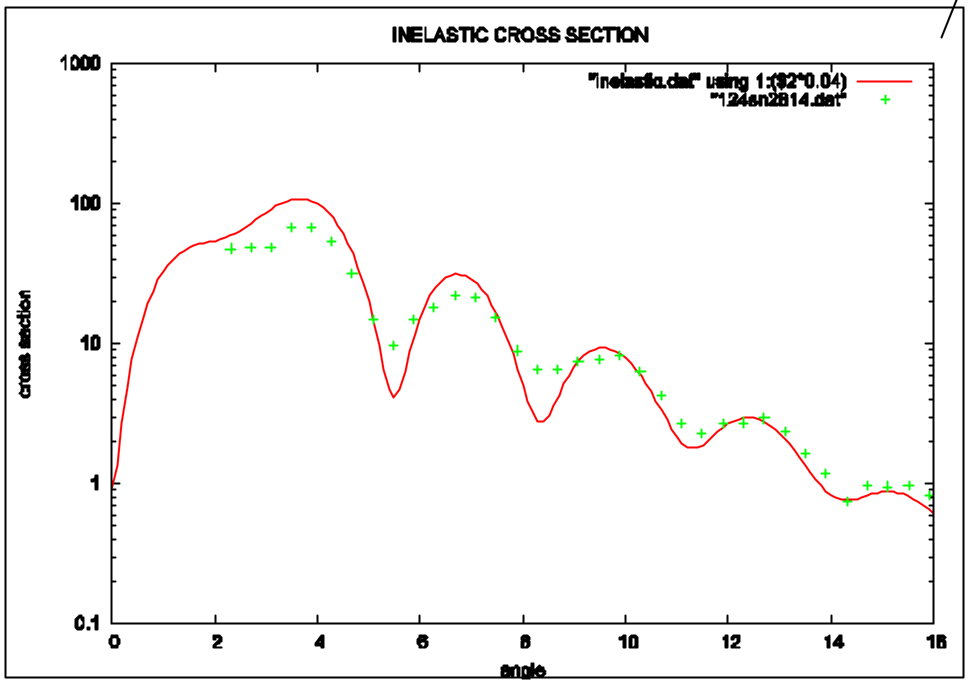
$^{120}Sn\ 3^{-}$ (2.399MeV)



$^{124}Sn\ 2^{+}$ (1.131MeV)



$^{124}Sn\ 3^{-}$ (2.614MeV)



$^{124}Sn\ 4^{+}$ (3.158MeV)