Spectroscopy of ^{120}Sn homologous levels via the ^{123}Sb ($\vec{p}$,α) ^{120}Sn reaction

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Data Taking:

Beschleuniger Laboratorium - Garching

Tandem Accelerator, Polarized Source,

Q3D, Focal Plane Detector

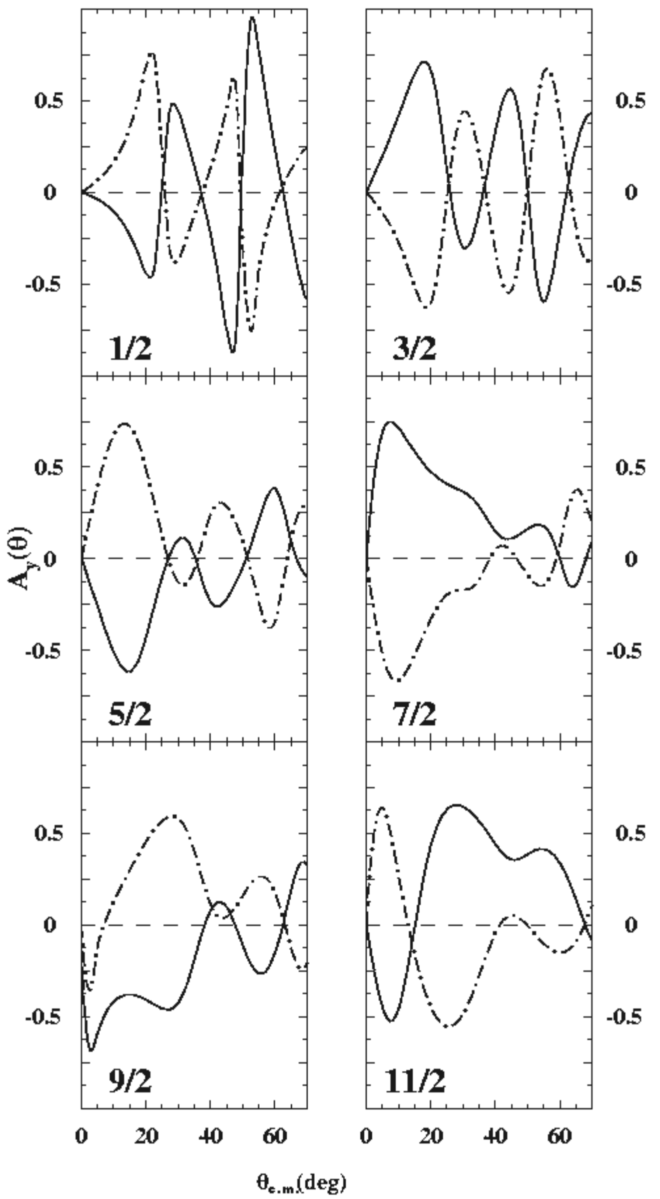
The dependence of $\sigma(\theta)$ and $A_y(\theta)$ of the emitted particles on the transferred total angular momentum *J* is of the greatest importance for identifying the spin and parity of the levels excited in a nuclear reaction.
In particular for $(\vec{p},\alpha)$ reactions, as a general rule, the mean behavior is strictly J^π dependent ----->

^{122}Sn $(\vec{p},\alpha)$ ^{119}In

Hypothetical level at E_x=1500 keV

—— positive parity states

– · – negative parity states



(p,α) and ($\vec{p}$,α) reactions studied for even-even target nuclei

Only one transferred orbital and total angular momentum

(p,α) and ($\vec{p}$,α) reactions on odd mass target nuclei; several *l* and *j* transferred; necessity of incoherent sum of different contributions

Great advantage if only one *l* and *j* dominate a given transition amplitude

Good spectroscopic information from the analysis of the experimental data

When only one l and j dominate a given transition amplitude for (p,α) reactions on odd mass target nuclei?

This behavior can be systematically observed for a number of transitions induced on near magic target nuclei having one unpaired nucleon outside a completely filled magic shell

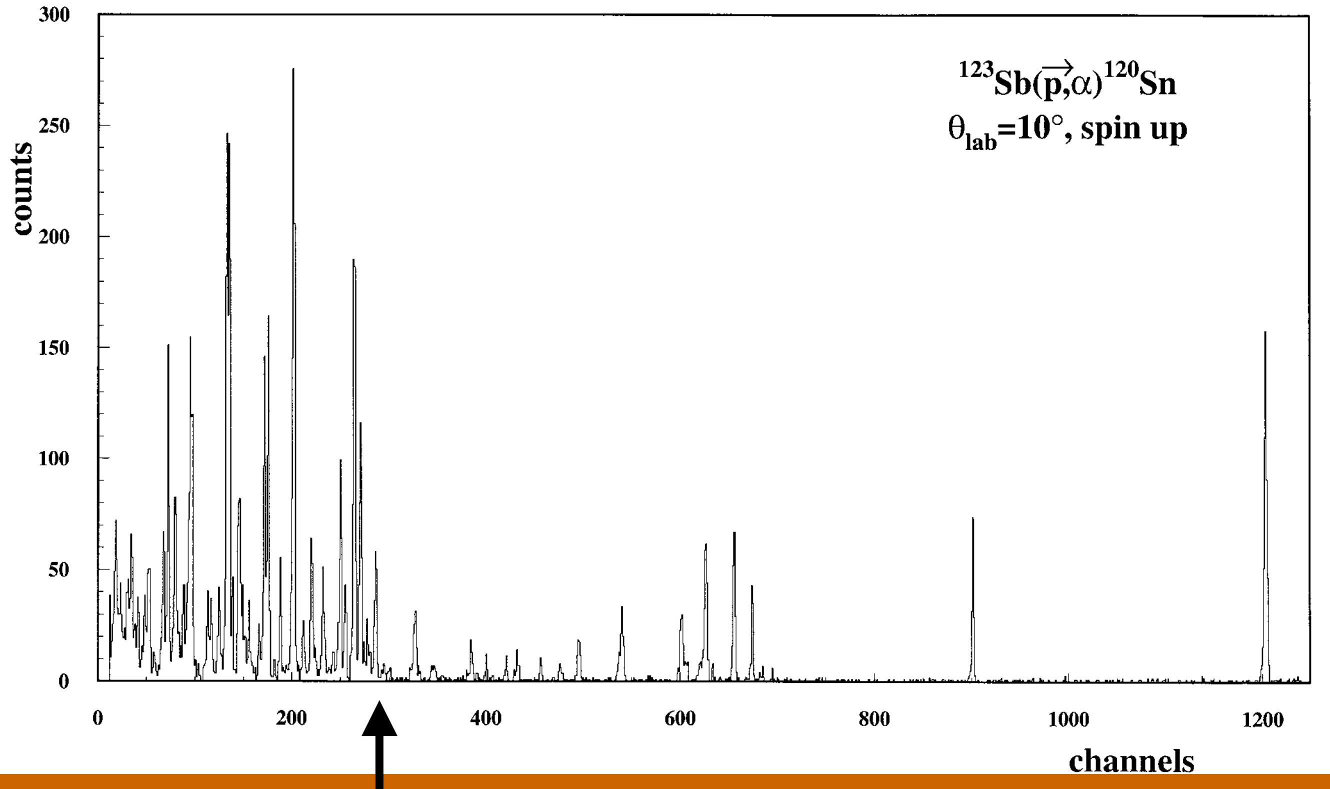
The dominant contribution to the $\alpha-$spectrum results from a process in which the incident proton picks up a proton and a pair of neutrons from the nuclear core, while the valence nucleon outside the core acts as spectator

two parts in the $\alpha-$spectrum :

at higher excitation energies, multiplets of states are found, whose configuration results from a process in which the unpaired nucleon is not involved

at lower excitation energies, weakly excited states are found, populated by a process involving the unpaired nucleon

$^{123}Sb(\vec{p}, \alpha)^{120}Sn$



~ 3.6 MeV

$^{123}Sb\ (p,\alpha)\ ^{120}Sn$	Q_{val} = 6.745 MeV
$^{122}Sn(p,\alpha)\ ^{119}In$	Q_{val} = 2.623 MeV

ΔQ_{val} = 4.122 MeV

HOMOLOGOUS STATES

The one-proton-hole-two-neutron-hole states excited in $(\vec{p},\alpha)$ reactions on magic target nuclei, with a magic neutron and/or proton shell-
we denote as *parent states*.

In near magic target nuclei, with one more nucleon outside the magic shell
-the spectator nucleon-
the weak coupling of a parent state with the spectator nucleon originates a multiplet of states, *son states* ,with spin J

$$|J_p - J_c| \leq J \leq (J_p + J_c)$$

J_p= spin of the spectator
J_c = spin of the core.

We denote the son states and the corresponding parent state
as
HOMOLOGOUS STATES
i.e.
states with a close structural relationship

Methodology

In case of *weak coupling* between the *parent state* and the *spectator nucleon*, it is expected for the *excited multiplets* of son states THAT:

1

Angular distributions of $\sigma(\theta)$ and $A_y(\theta)$ *very similar in shape* for all the multiplet and parent states

scaled by $(2J_i+1)/\Sigma_i\,(2J_i+1)$

2

Parent state $\sigma(\theta)$ magnitude same as $\sigma(\theta)$ SUM of all the corresponding son states (cumulative)

3

ratio between son (J) $\sigma(\theta)$ and parent state $\sigma(\theta)$ PROPORTIONAL (2J+1)

1

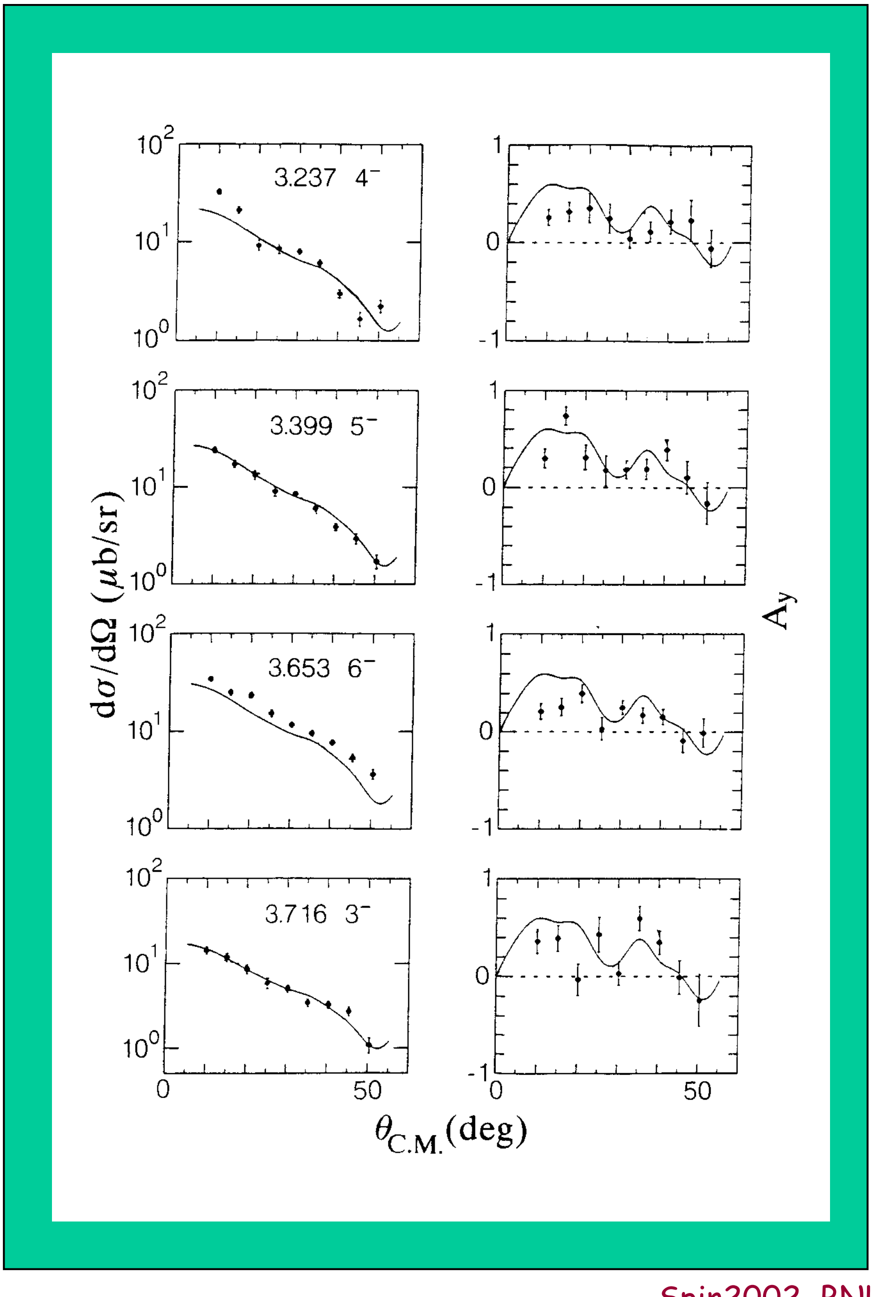
Angular distributions of $\sigma(\theta)$ and $A_y(\theta)$ very similar in shape for all the multiplet states and the parent state

scaled by $(2J_i+1)/\Sigma_i\,(2J_i+1)$

Parent	^{205}Tl 0.204 MeV $3/2^+$
Sons	^{206}Pb Quartet 3^- 4^- 5^- 6^-

$^{208}Pb(\vec{p},\alpha)^{205}Tl$

$^{209}Bi(\vec{p},\alpha)^{206}Pb$



2

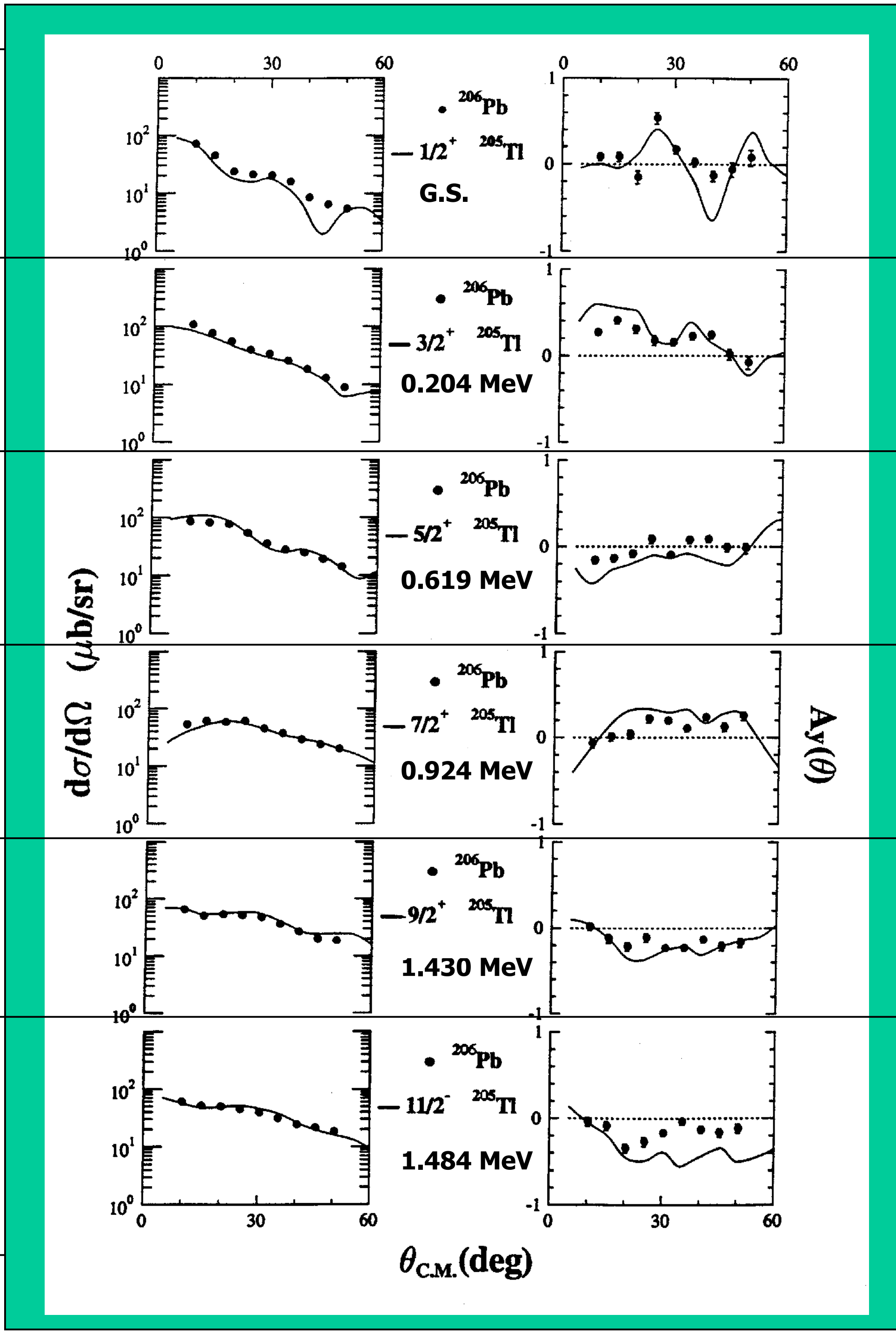
σ(θ) for the parent state is the same as the SUM of the σ(θ)'s of all the corresponding son states of the multiplet

$^{208}Pb(\vec{p},\alpha)^{205}Tl$

$^{209}Bi(\vec{p},\alpha)^{206}Pb$

SONS

found	missed
4-,5-	==
3-,4-, 5-,6-	==
2-,3-,4-, 5-,6-,7-	==
2-,3-,4- 5-,6-,7-, 8-	1-
2-,3-,5- 6-,7-,8-, 9-	0-,1-, 4-
3+,4+,5+, 1+,2+ 6+,7+,8+, 9+,10+	



cumulative angular distributions

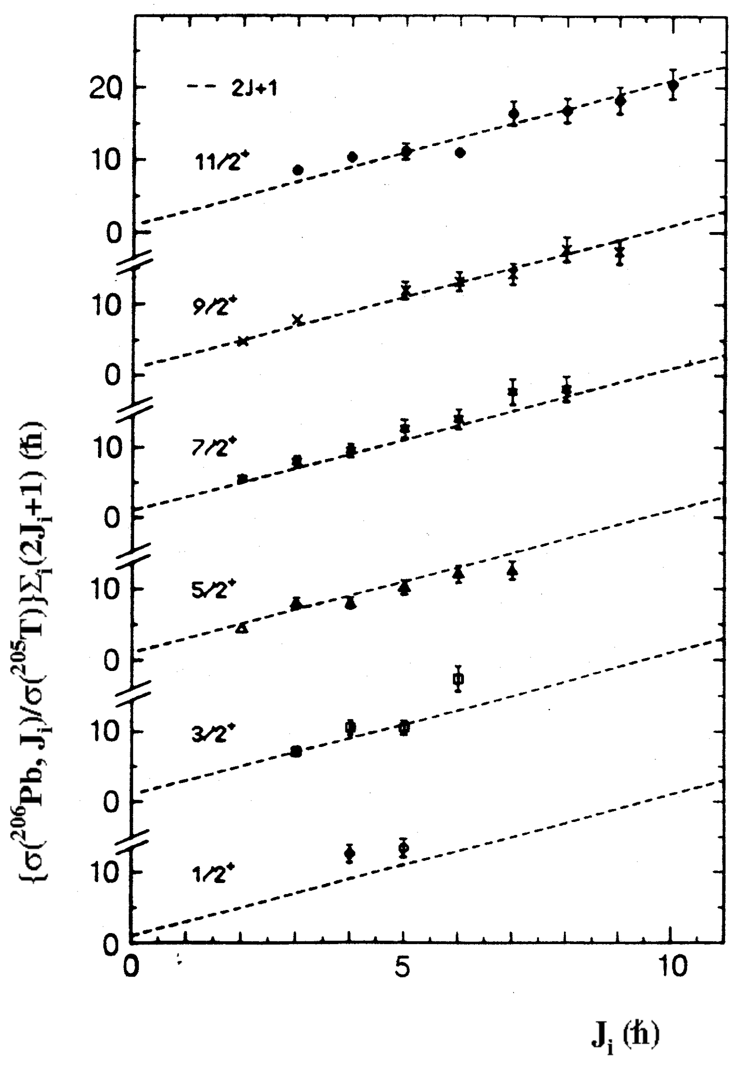
3

The ratio between the son (J_i) $\sigma(\theta)$ and parent state $\sigma(\theta)$ is PROPORTIONAL to $(2J_i+1)$.

$$\sigma_{son}(^{206}Pb, J_i) = \sigma_{parent}(^{205}Tl) * (2J_i+1)/\Sigma(2J_i+1)$$

$^{208}Pb(\vec{p},\alpha)^{205}Tl$

$^{209}Bi(\vec{p},\alpha)^{206}Pb$



Experiments

The concept of

homologous states

has been investigated in

high resolution experiments

Beschleuniger Laboratorium - Garching

Tandem Accelerator, Polarized Source,

Q3D, Focal Plane Detector

Studied nuclei:

the pair ^{209}Bi, ^{208}Pb

----> closed shells Z=82, N=126

$^{209}Bi(\vec{p},\alpha)^{206}Pb$ at E_p=22 MeV

$^{208}Pb(\vec{p},\alpha)^{205}Tl$ at E_p=22 MeV

spectator nucleon: proton $1h_{9/2}$

the pair ^{91,90}Zr

----> closed shell N=50

$^{91}Zr(\vec{p},\alpha)^{88}Y$ at E_p=22 MeV

$^{90}Zr(\vec{p},\alpha)^{87}Y$ at E_p=22 MeV

spectator nucleon: neutron $2d_{5/2}$

Under investigation:

the pair ^{123}Sb, ^{122}Sn ----> closed shell Z=50

$^{122}Sn\,(\vec{p},\alpha)\,^{119}In$ measured at E_p=26 MeV

$^{123}Sb\,(\vec{p},\alpha)\,^{122}Sn$ measured at E_p=24 MeV

spectator nucleon: proton $1g_{7/2}$

Under theoretical study:

$^{89}Y\,(\vec{p},\alpha)\,^{86}Sr$

$^{88}Sr\,(\vec{p},\alpha)\,^{85}Rb$ Z=38 Subshell

spectator nucleon: proton $2p_{1/2}$

Possible more candidates:

$^{93}Nb\,(\vec{p},\alpha)\,^{90}Zr$

$^{92}Zr\,(\vec{p},\alpha)\,^{89}Y$ Z=40 Subshell

spectator nucleon: proton $1g_{9/2}$

----> closed shell N=82

$^{143}Nd\,(\vec{p},\alpha)\,^{140}Pr$

$^{142}Nd\,(\vec{p},\alpha)\,^{139}Pr$

spectator nucleon: neutron $2f_{7/2}$

Recent Results

$^{123}Sb(\vec{p},\alpha)^{120}Sn$ ***sons***

$^{122}Sn(\vec{p},\alpha)^{119}In$ ***parent***

spectator nucleon: proton $1g_{7/2}$

$\sigma(\theta)$ values
for all the son states of a multiplet
scaled by the factor
$(2J_i+1)/\Sigma_i\,(2J_i+1)$
with respect to the parent state

Multiplet corresponding to ^{119}In G.S. $9/2^+$

σ_{int}**=85.341 μb**

$|J_p-J_c| \leq J \leq (J_p+J_c) \rightarrow J^\pi=(1,2,3,4,5,6,7,8)^+$

$\sigma(\theta)$ **values for all the son states**

$J^\pi=1^+$ $\sigma(\theta)$ *parent* scaled by 0.0375

$J^\pi=2^+$ $\sigma(\theta)$ *parent* scaled by 0.0625

$J^\pi=3^+$ $\sigma(\theta)$ *parent* scaled by 0.0875

$J^\pi=4^+$ $\sigma(\theta)$ *parent* scaled by 0.1125

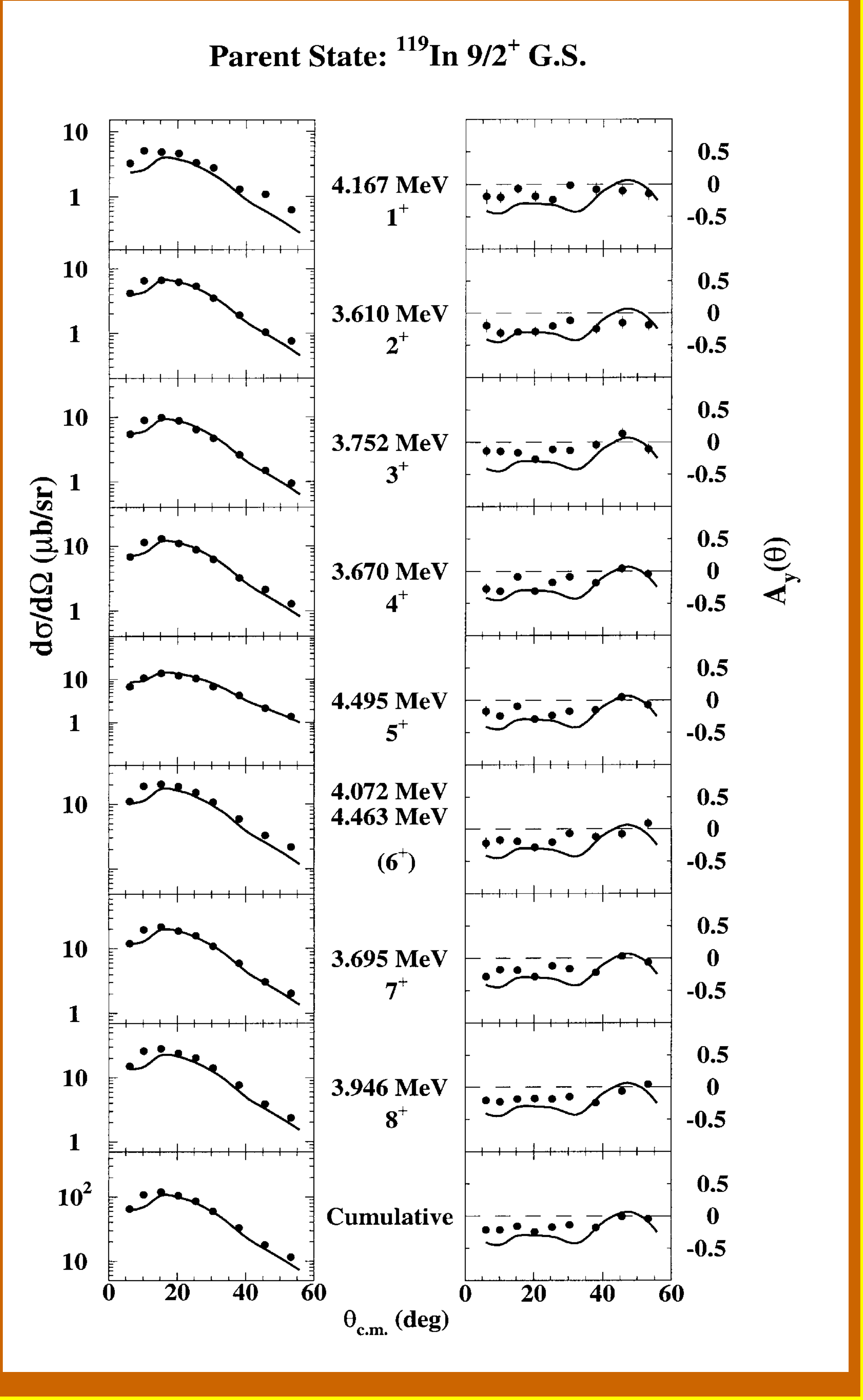
$J^\pi=5^+$ $\sigma(\theta)$ *parent* scaled by 0.1375

$J^\pi=6^+$ $\sigma(\theta)$ *parent* scaled by 0.1625

$J^\pi=7^+$ $\sigma(\theta)$ *parent* scaled by 0.1875

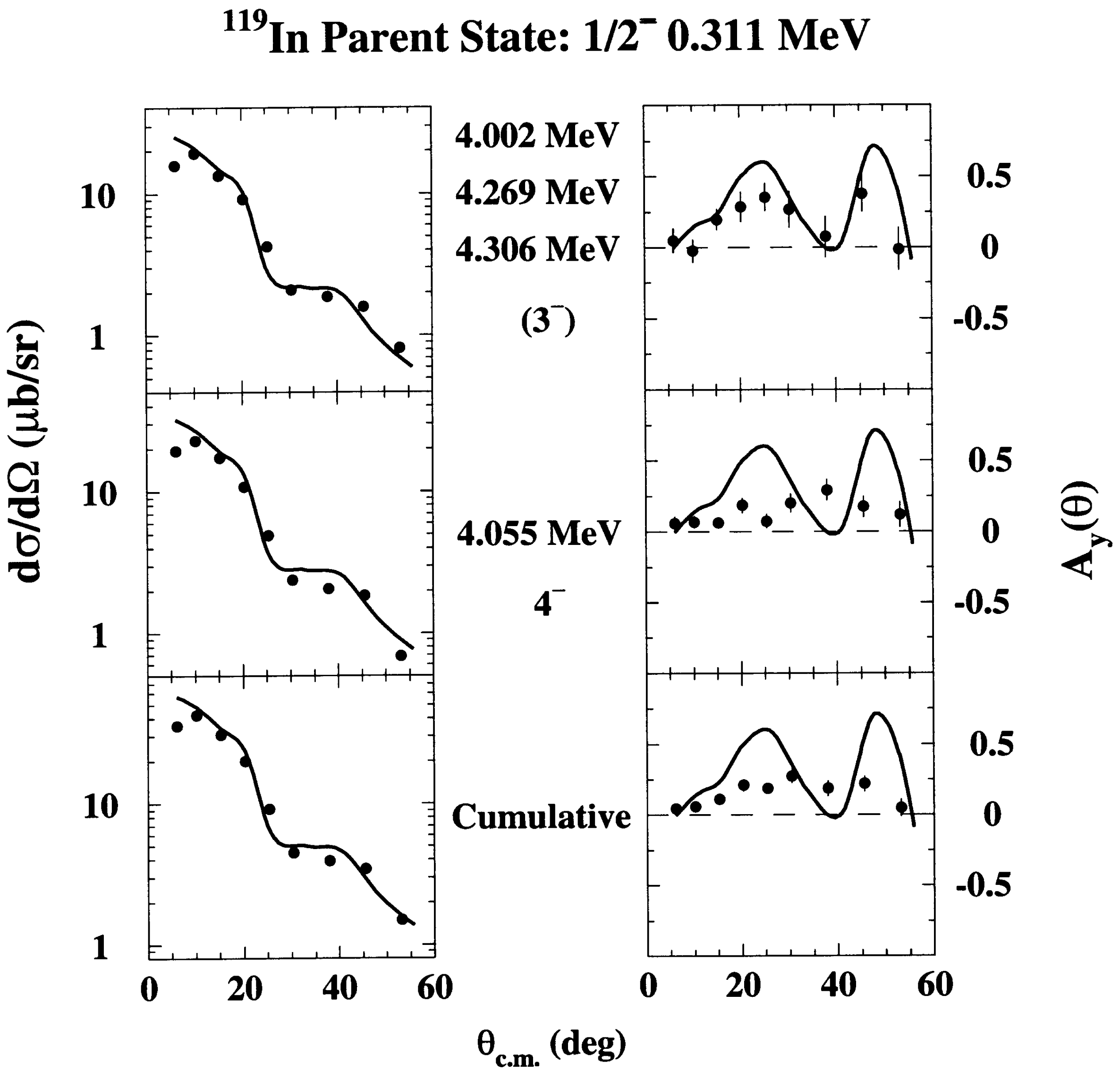
$J^\pi=8^+$ $\sigma(\theta)$ *parent* scaled by 0.2125

$^{123}Sb(\vec{p},\alpha)^{120}Sn$



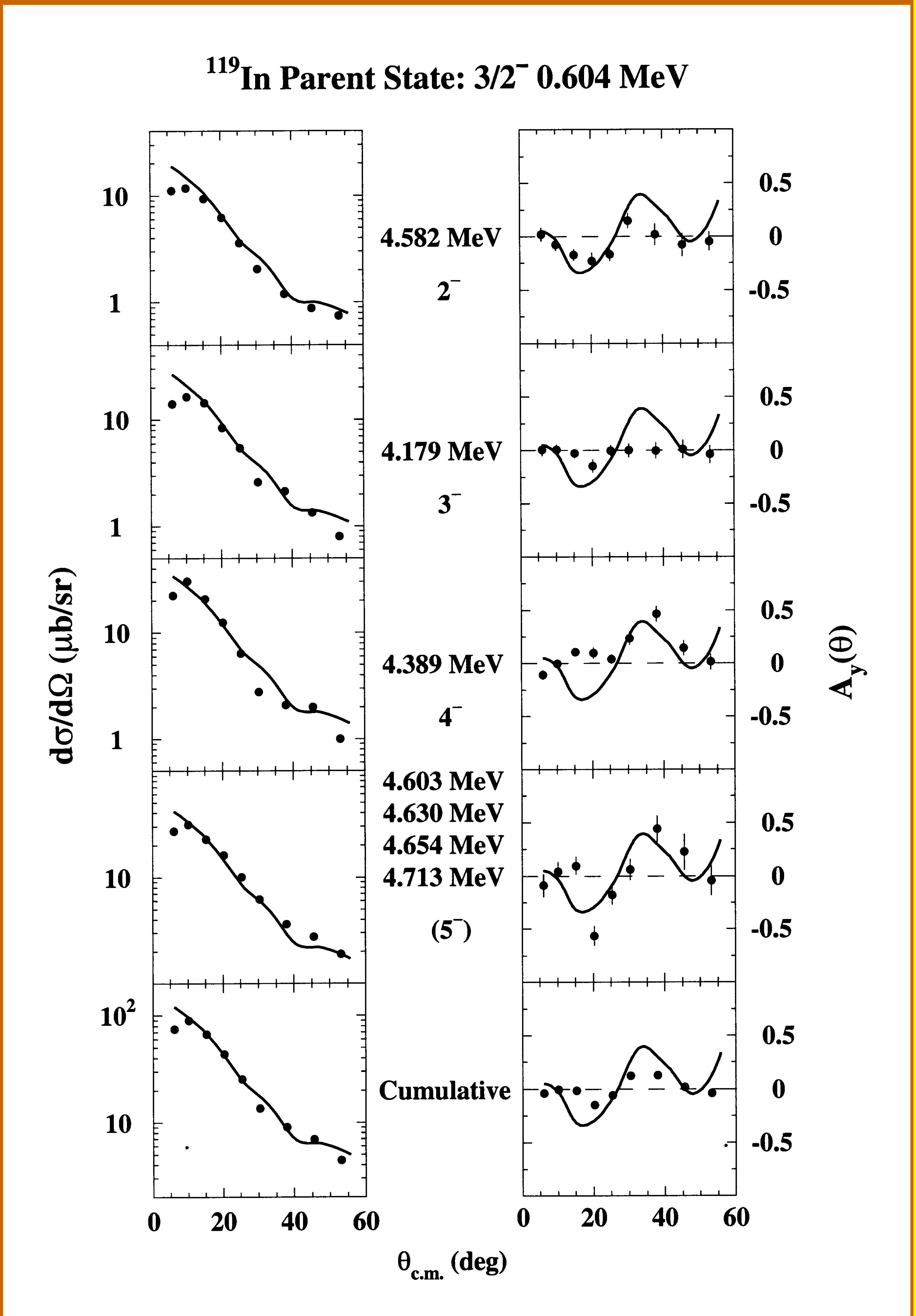
Spin2002. BNL, September 9-14,2002

$^{123}Sb(\vec{p},\alpha)^{120}Sn$



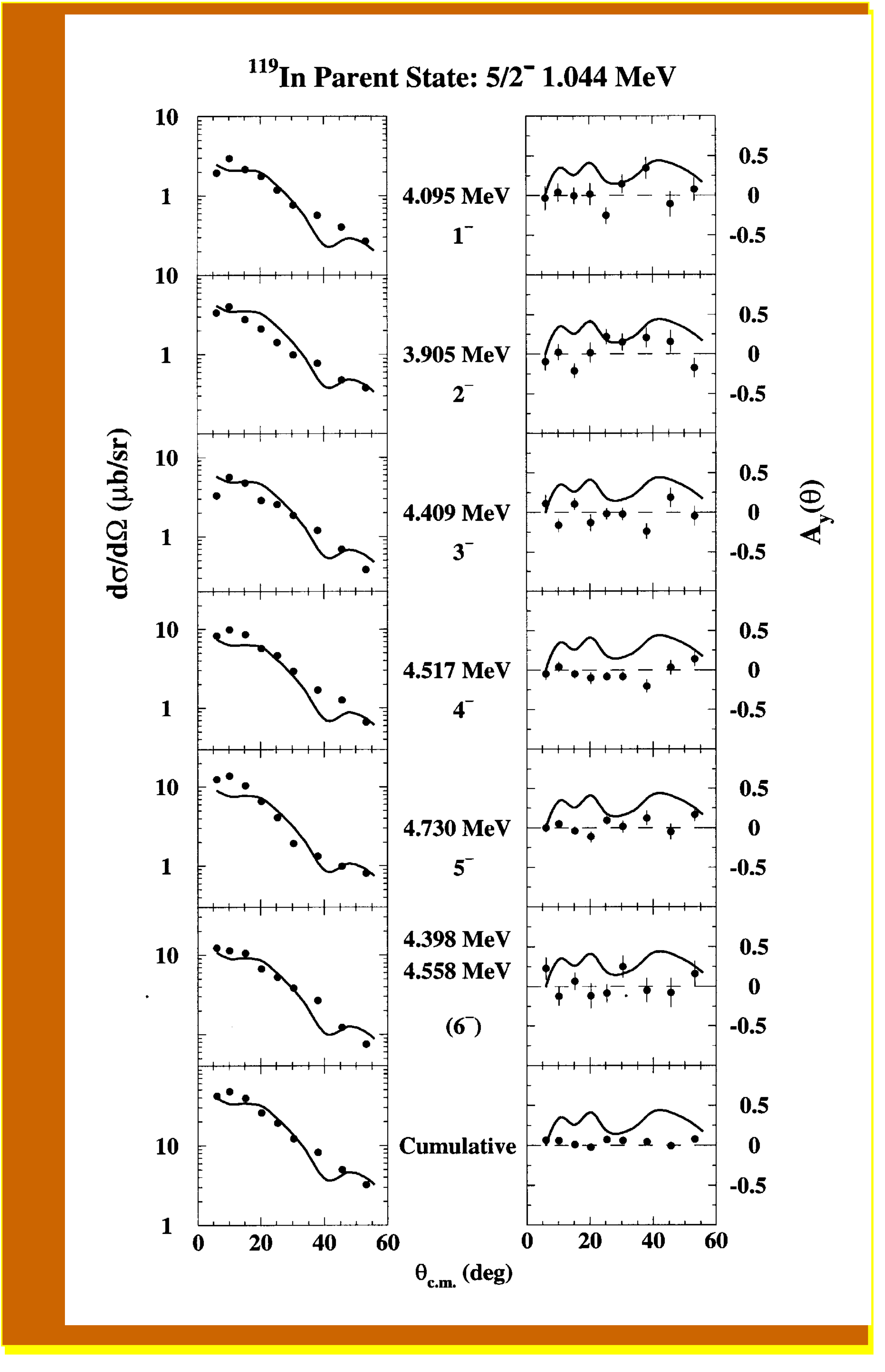
Spin2002. BNL, September 9-14,2002

$^{123}Sb(\vec{p},\alpha)^{120}Sn$



Spin2002. BNL, September 9-14,2002

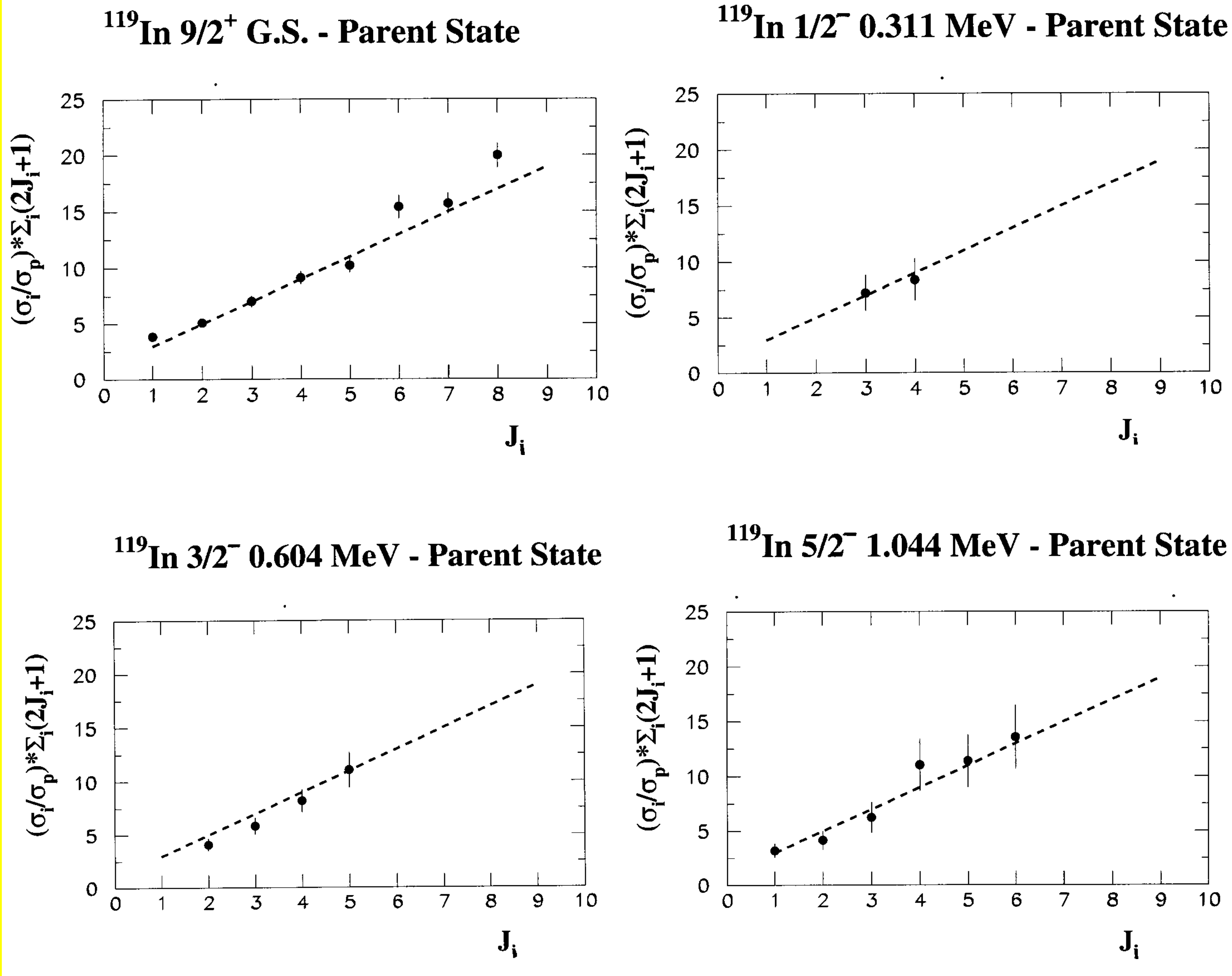
$^{123}Sb(\vec{p},\alpha)^{120}Sn$



$^{123}Sb(\vec{p},\alpha)^{120}Sn$

The ratio between the son (J_i) $\sigma(\theta)$ and parent state $\sigma(\theta)$ is PROPORTIONAL to ($2 J_i +1$).

$$\sigma_{son}(^{120}Sn, J_i) = \sigma_{parent}(^{119}In) * (2J_i+1)/\Sigma(2J_i+1)$$



$^{123}Sb(\vec{p},\alpha)^{120}Sn$

Present Work Eexc	Present Work Homology Parent	J^π	Int. Xsec. μb	NDS Eexc	NDS J^π
0.0			12.4	0.0	0^+
1.171			4.9	1171.265	2^+
1.875			---	1875.107	0^+
2.098			---	2097.201	2^+
2.160			---	2159.930	0^+
2.195			3.8	2194.292	4^+
2.284			7.3	2284.26	5^-
2.356			---	2355.382	2^+
2.402			8.1	2400.29	3^-
2.462			1.6	2465.633	(4+)
2.482			4.1	2481.61	$(7)^-$
2.686			4.3	2685.15	$(6)^+$
2.836			3.1	2836.51	(8^-)
2.900			2.0	2902.21	(10^-)
2.976			1.1	2975.68	(4^-)
3.060			1.3	3057.943	4^+
3.104			0.8	3120 (+/—20)	—
3.179			1.5	3179.08	4^+
3.236			1.6	3231.95/3237.32	1,2,3/
3.380			1.2	3386.32	1,2
3.456			3.6	3446.47	$(7^-,8^-)$
3.610	GS	2^+	7.5	3600	
3.642			4.1	3644.32	(7^-)
3.670	GS	4^+	13.4		
3.695	GS	7^+	23.0		
3.733			4.1		
3.752	GS	3^+	10.3		
3.778			2.1	3777.21	4^+
3.824			5.5		
3.858			3.0	3857.56	(4)
3.873			6.2	3874.95	2^+
3.905	1.044	2^-	2.9	3906.6	—
3.946	GS	8^+	29.3	3955	
4.002	0.311 [3^-]	—	3.6	4000/4006.5	+/

Spin2002. BNL, September 9-14,2002

$^{123}Sb(\vec{p},\alpha)^{120}Sn$

Present Work Eexc	Present Work Homology Parent	J$^\pi$	Int. Xsec. μb	NDS Eexc	NDS J$^\pi$
4.055	0.311	4^-	12.2		
4.072	GS [6^+]	+	11.6	4079.0	$1^+,2^+,3^+$
4.095	1.044	1^-	2.3	4096.5	
4.135			3.3		
4.167	GS	1^+	5.7		
4.179	0.604	3^-	10.5	4180	−
4.225			28.5	4230	+
4.235			11.6	4230	+
4.269	0.311 [3^-]	−	3.3	4280 +/−20	
4.306	0.311 [3^-]	−	3.5		
4.319			2.5	4318.2	$0^-,1^-,2^-$
4.389	0.604	4^-	14.7	4360+/−20	−
4.398	1.044 [6^-]	−	7.7		
4.409	1.044	3^-	4.4	4410	−
4.463	GS [6^+]	+	10.9	4460	−
4.495	GS	5^+	15.0		
4.517	1.044	4^-	7.8		
4.558	1.044 [6^-]	−	1.9		
4.582	0.604	2^-	7.3	4580	
4.603	0.604 [5^-]	−	4.3		
4.630	0.604 [5^-]	−	6.0		
4.654	0.604 [5^-]	−	3.2	4650	−
4.662			8.8		
4.684			6.4	4690	−
4.713	0.604 [5^-]	−	6.2	4720 (?)	
4.730	1.044	5^-	8.1	4720 (?)	
4.739			4.5		

Multiplet of ^{119}In G.S.

Multiplet of ^{119}In 0.604

Multiplet of ^{119}In 0.311

Multiplet of ^{119}In 1.044

Centroid Computation

^{209}Bi (p,α) ^{206}Pb Q_{val} = 10.392 MeV
^{208}Pb (p,α) ^{205}Tl Q_{val} = 6.935 MeV

^{205}Tl (parent)	**^{206}Pb** (son)	
Level Q_{val}	Level J^π	Multiplet Q_{ave}
(G.S. $1/2^+$) **6.935 MeV**	$4^-,5^-$	**6.926 MeV**
(0.204 $3/2^+$) **6.735 MeV**	$3^-,4^-,5^-,6^-$	**6.884 MeV**
(0.619 $5/2^+$) **6.320 MeV**	$2^-,3^-,4^-,$ $5^-,6^-,7^-$	**6.370 MeV**
(0.924 $7/2^+$) **6.015 MeV**	$2^-,3^-,4^-,5^-,$ $6^-,7^-,8^-$	**6.017 MeV**
(1.430 $9/2^+$) **5.509 MeV**	$2^-,3^-,4^-,5^-,$ $6^-,7^-,8^-,9^-$	**5.652 MeV**
(1.484 $11/2^+$) **5.455 MeV**	$2^+,3^+,4^+,$ $5^+,6^+,7^+,$ $8^+,9^+,10^+$	**5.408 MeV**

^{91}Zr (p,α) ^{88}Y Q_{val} = 1.27 MeV
^{90}Zr (p,α) ^{87}Y Q_{val} = - 0.887 MeV

^{87}Y (parent)	**^{88}Y** (son)	
Level Q_{val}	Level J^π	Multiplet Q_{ave}
(G.S. $1/2^-$) **-0.887 MeV**	$2^-,3^-$	**-1.110 MeV**
(0.794 $5/2^-$) **-1.691 MeV**	$0^-,1^-,2^-,3^-$ $4^-,5^-,^-,^-$	**-1.629 MeV**
(0.982 $3/2^-$) **-1.879 MeV**	$1^-,2^-,3^-,$ $^-,^-,^-$	**-1.771 MeV**

^{123}Sb (p,α) ^{120}Sn **Q_{val} = 6.745 MeV**
^{122}Sn(p,α) ^{119}In **Q_{val} = 2.623 MeV**

^{119}In(parent)	**^{120}Sn** (son)	
Level Q_{val}	Level J^π	Multiplet Q_{ave}
(G.S. $9/2^+$) **2.623 MeV**	$1^+,2^+,3^+,4^+,$ $5^+,6^+,7^+,8^+$	**2.778 MeV**
(0.311 $1/2^-$) **2.312 MeV**	$3^-,4^-$	**2.628 MeV**
(0.604 $3/2^-$) **2.019 MeV**	$2^-,3^-,4^-,5^-$	**2.270 MeV**
(1.044 $5/2^-$) **1.579 MeV**	$1^-,2^-,3^-,$ $4^-,5^-,6^-,$	**2.295 MeV**

CLUSTER DWBA CALCULATIONS

A generally accepted rule for (p,α) reactions is that α's feeding states with the same J^{π} have nearly the same shape for angular distributions of cross sections and asymmetries.

True Not Homologous States

False Homologous States

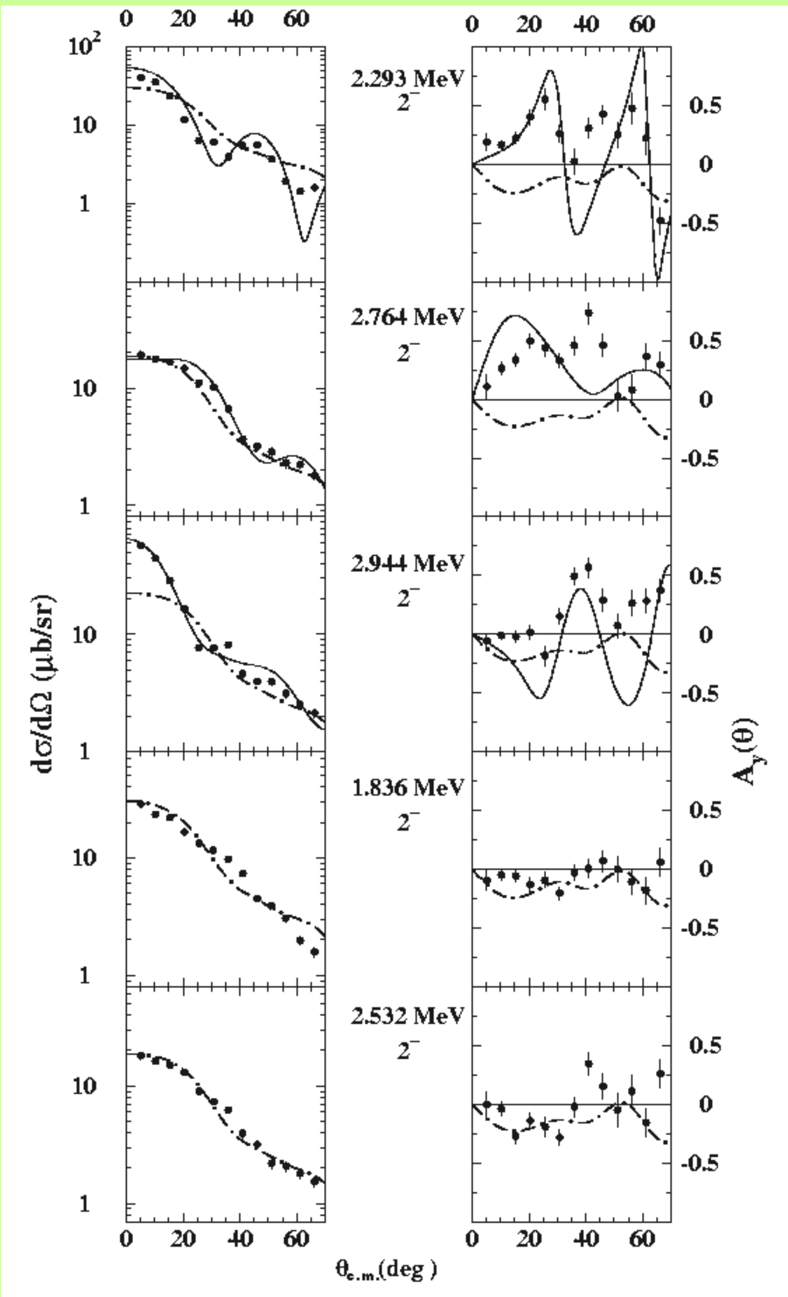
$^{91}Zr(\vec{p},\alpha)^{88}Y$ *sons*

$^{90}Zr(\vec{p},\alpha)^{87}Y$ *parent*

DWBA - configuration of the parent state

DWBA - incoh. sum of different l,j ang. distr.

^{88}Y - experimental values



Homologous

^{87}Y G.S. 1/2$^-$

Homologous

^{87}Y 0.794 5/2$^-$

Homologous

^{87}Y 0.982 3/2$^-$

Not Homologous

Not Homologous

SHELL MODEL CALCULATIONS

FOR THE HOMOLOGOUS STATES

$A \approx 208$

$A \approx 90$

Done

$A \approx 120$

Investigating a truncation scheme for ^{120}Sn, leading to realistic wave functions

The achieved results

clearly indicate:

COMMON CONFIGURATIONS

for

HOMOLOGOUS STATES

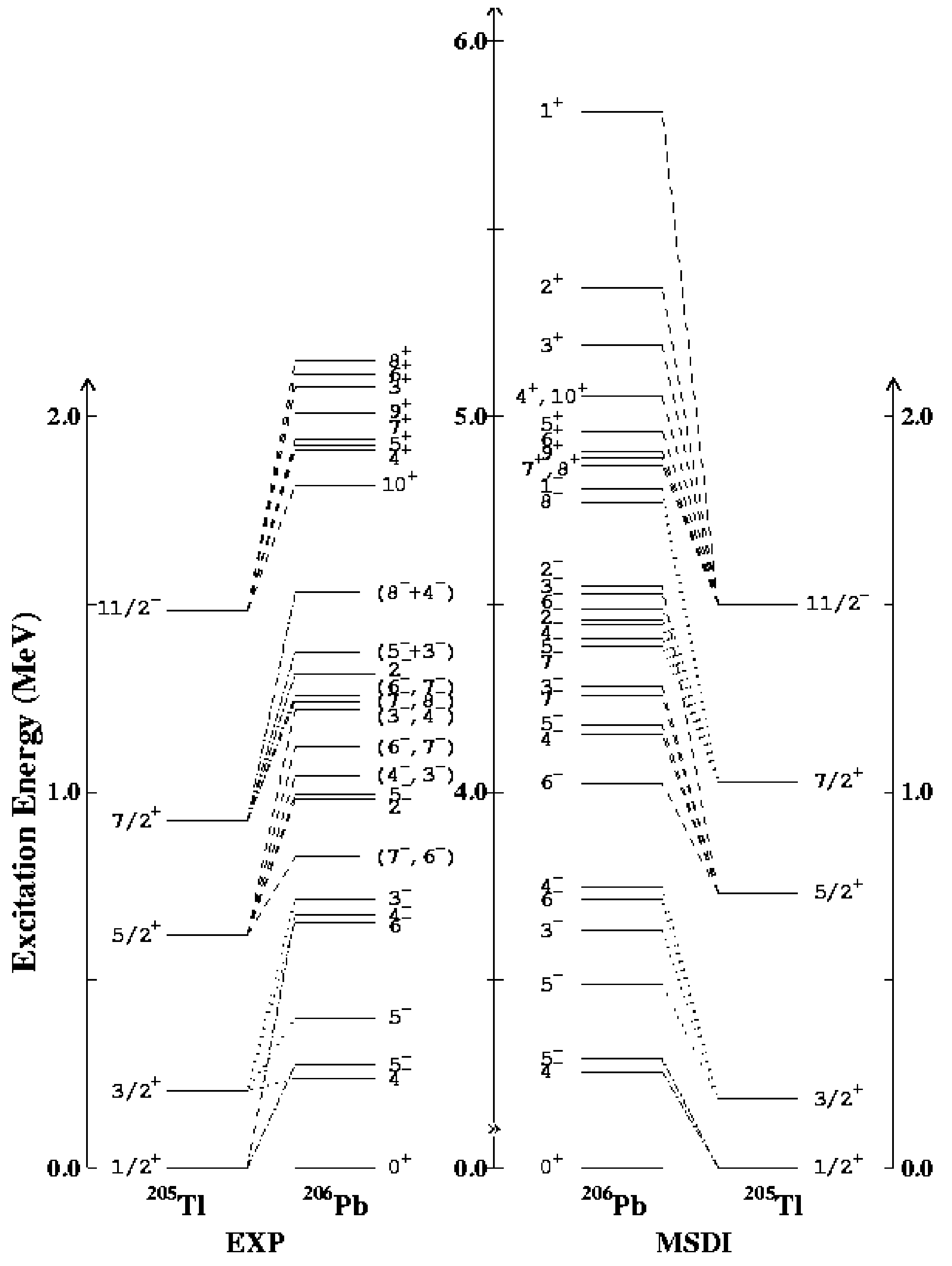
This similarity is more evident in case of purest states as, for example, the ^{206}Pb multiplet of son states, homologous to the 1.484 MeV, $11/2^-$, ^{205}Tl parent state.

The parent state $11/2^-$ of ^{205}Tl at 1.501 MeV (Calc.) (1.484 MeV - Exp.)

[NO]	p(%)	D5	D3	S1	H11	F5	P3	P1	I13
[1]	7.97	6	4	2	11	6	4	2	12
[3]	1.48	6	3	2	12	5	4	2	13
[3]	1.00	6	4	2	11	5	3	2	14
[3]	1.13	6	3	2	12	6	3	2	13
[1]	17.28	6	4	2	11	4	4	2	14
[3]	0.66	5	4	2	12	6	4	1	13
[3]	8.61	6	4	2	11	5	4	1	14
[3]	1.28	6	4	1	12	6	3	2	13
[3]	9.52	6	3	2	12	6	4	1	13
[3]	3.68	6	4	2	11	6	3	1	14
[1]	5.60	6	4	2	11	6	2	2	14
[1]	40.90	6	4	2	11	6	4	0	14

Homologous states: ^{206}Pb, ^{205}TI

Parent	Son States									
$11/2^-$	10+	9+	8+	7+	6+	5+	4+	3+	2+	1+
1.501	5.068	4.909	4.886	4.887	4.923	4.977	5.068	5.202	5.356	5.833
1.484	4.818	5.011	5.149	4.941	5.112	4.925	4.912	5.078		
7.97	6.79	6.86	6.47	6.54	6.49	6.75	7.03	7.44	8.14	5.76
1.48	3.32	2.36	2.13	1.97	2.04	2.00	1.90	1.69	1.30	2.77
1.00	1.87	1.80	1.69	1.53	1.67	1.89	1.98	1.76	1.20	1.36
1.13		1.25	1.10	1.23	1.23	1.33	1.32	1.23	1.01	
17.28	17.75	16.33	16.40	15.88	16.33	16.76	17.68	18.24	19.34	16.01
0.66										
8.61	12.53	13.17	14.41	14.52	14.70	14.31	13.12	11.47	7.61	17.54
1.28	1.11	1.43	1.12	1.26	1.12	1.20	1.09	1.13		
9.52	6.54	9.61	8.02	8.82	8.12	8.37	7.89	8.18	7.88	10.84
3.68	4.80	5.31	5.71	5.76	5.86	5.74	5.19	4.38	2.68	4.23
5.60	5.27	5.17	5.12	5.02	5.10	5.25	5.47	5.61	5.88	4.42
40.90	35.66	34.60	35.37	35.28	35.07	34.41	35.46	37.23	42.43	32.41


Excitation Energy (MeV)
205Tl
206Pb
EXP
206Pb
205Tl
MSDI
1/2+
3/2+
5/2+
7/2+
11/2-
0+
10+
(8-+4-)
(5-+3-)
(7-,6-)
(6-,7-)
(4-,3-)
(3-,4-)
1+
2+
3+
4+,10+
7+,8+

MICROSCOPIC DWBA CALCULATIONS

Fully microscopic calculations: the proton and two neutrons are picked up from individual shell-model states, and then their overlap with respect to the transferred three-particle cluster is calculated

^{123}Sb G.S. is taken to be a $1g_{7/2}$ proton outside filled proton shells.
22 valence neutrons move in the
$1g_{7/2} - 2d_{5/2} - 2d_{3/2} - 3s_{1/2} - 1h_{11/2}$ shells
interacting via a neutron-neutron pairing force which spreads the neutrons over the valence cells with a total neutron angular momentum of zero

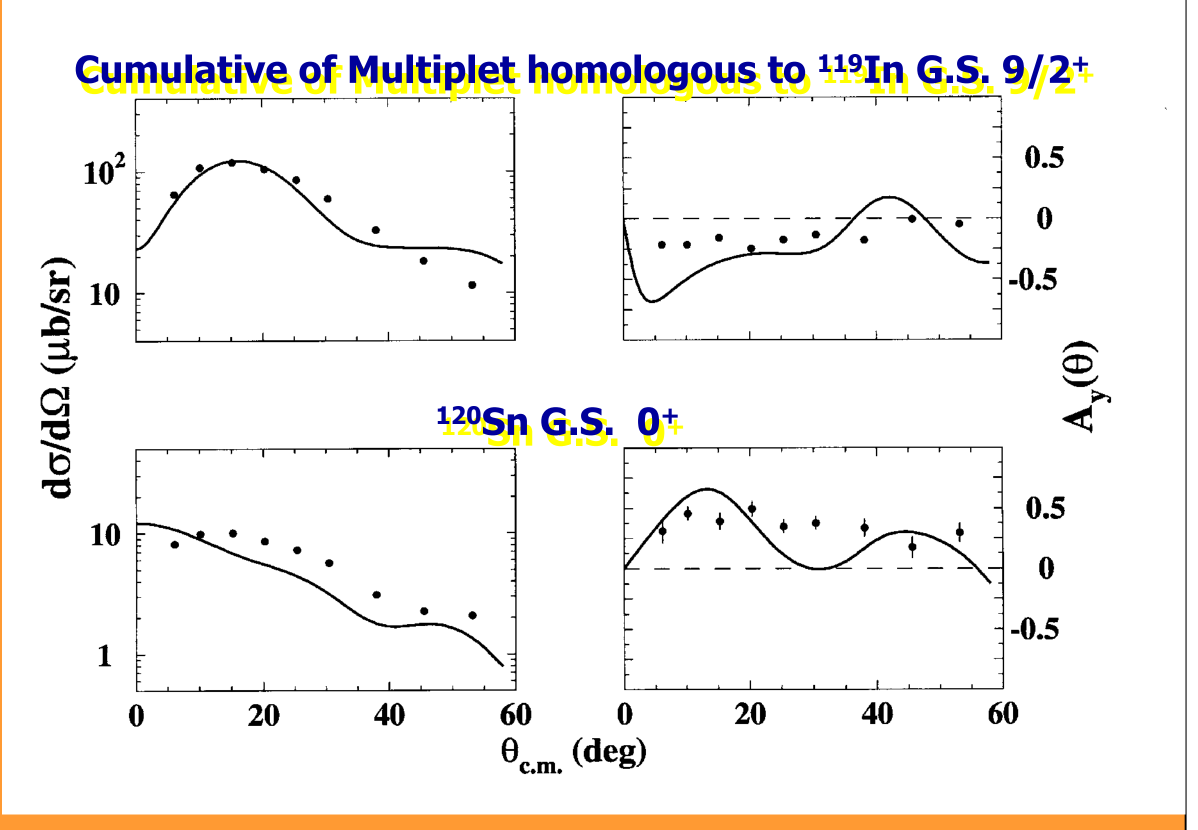
The pickup reaction to ^{120}Sn G.S. involves the transfer of a $1g_{7/2}$ proton and a neutron pair coupled to zero angular-momentum

The pickup reaction to ^{120}Sn multiplet homologous to ^{119}In G.S. removes a $1g_{9/2}$ proton and a neutron pair coupled to zero angular-momentum,
while the $1g_{7/2}$ proton remains spectator

$^{123}Sb(\vec{p},\alpha)^{120}Sn$

MICROSCOPIC DWBA CALCULATIONS

Preliminary Results



Dots : experimental values

Solid : Microscopic DWBA calculations

CONCLUSIONS

- Shell Model calculations strongly support the Homologous state experimental results
- Shell Model calculations seem to indicate the correctness of the approach also for closed subshells, to be verified experimentally
- Applicability limits for the theory are the shell model limitations

CONCLUSIONS

- **DWBA microscopic calculations also support the validity of the spectator role of the unpaired proton weakly coupled to the parent core-state.**

- **Homology concept useful spectroscopic tool for regions nearby closed shells**

- **The use of the concept of the spectator nucleon allows a *unambiguous* attribution of spin and parity to several states at relatively high excitation energies.**