Systematically Evaluation of ^{7}Be System using Reduced R-Matrix Theory

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A. 'RAC-CERNGEPLIS' evaluation Method

The classical reduced R-matrix theory[1], covariance statistics[2] and the corresponding program RAC[3] are used to complete this work，which has been introduced in detail in INDC(NDS)-0791.pdf and not be repeated here.

[1] A.M. Lane, R.G. Thomas, Rev. Mod. Phys. 30, 257 (1958)

[2] D.L. Smith, Probability, Statistics, and Data Uncertainties in Nuclear Science and Technology (ANS, Chicago, 1991)

[3] Z.P. Chen, R. Zhang, Y.Y. Sun, T.J. Liu, Science in China (Series G) 46, 225

Firstly, we introduce the **'RAC-CERNGEPLIS' evaluation Method** used in this work. The capital letters in the name RAC-CERNGEPLIS are explained as follow:

1、**RAC**—R-matrix Analysis Code with multi-levels and multi-channels theory in Lane1958;
2、**C**—'Covariance statistics' and 'Generalized Least–squares' in Smith1991 are used;
3、**E**—'Law of Error propagation' is used to get accurate Covariance Matrix;
4、**R**—Relativistic calculation for energy;
5、**N**—Normalization of experimental data relative to the evaluated data in the fitting process;
6、**G**—'Global fitting' is adopted for a nuclear system;
7、**E**—Elimination of channel is used to expend analysis energy range;
8、**P**—Smith's method is used to avoid 'Peelle Pertinent Puzzle' (PPP);
9、**L**—Lett's criteria is used to minimize the effect from occasional 'outliers';
10、**I**—Iterative fitting procedure is used to get the best evaluated values；
11、**S**—Systematic error of the experimental data is updated according to the errors of fitted values.

B. Gauss Markov Theorem

At first, the formula of 'Conventional Least Square' (CLS) is used in this work is as follow,

$$\chi^2 = (\eta - y)^{+} V^{-1} (\eta - y) \Rightarrow minimum \ .$$

Here, η refers to the vector of experimental data, y refers to the vector of calculated values. V^{-1} is the inverse matrix of the covariance matrix of experimental data.

After that, the 'Generalized-Least Square' (GLS) formula of Gauss Markov Theorem is used as follow,

$$\chi^2 = \ （\theta - \theta_a)^+ V_a^{-1} (\theta - \theta_a) + (\eta - y)^+ V^{-1} (\eta - y)) \Rightarrow \text{ minimum}$$

The first item refers to the contribution of the parameter set; θ is the fitting parameter vector, θ_a is the temporary vector of θ obtained in fitting process, V_a is the covariance matrix of θ_a, V_a^{-1} is the inverse matrix of V_a.

In the fitting process, the fitted values of the last fit are used as the original values of the next fit. The experimental data is normalized, and the error of experimental data is also normalized, which is completely in line with the 'Maximum probable theory'. By the minimum of χ^2, the unbiased estimated covariance matrix will be obtained.

C. RAC fitting parameters

In the calculation of the 7Be, six reaction channels of 6Li induced by proton are considered, including 6Li(P,P)6Li, 6Li(P,3He)4He, 6Li(P,P1)6Li, 6Li(P,P2)6Li*, 6Li(P,G0)7Be, 6Li(P,G1)7Be* reactions. And six reaction channels of 4He induced by 3He are considered, including 4He(3He,3He)4He, 4He(3He,P1)6Li*, 4He(3He,P2)6Li*, 4He(3He,G0)7Be, 4He(3He,G1)7Be*, 4He(3He,P)6Li. 250 experimental data set are used in this calculations with 6789 experimental points totally.

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   '6Li(P,P)6Li       '    '6Li(P,3He)4He     '    '6Li(P,P1)6Li*     '
  '6Li(P,P2)6Li*     '    '6Li(P,G0)7Be      '    '6Li(P,G1)7Be*     '
  '4He(3He,3He)4He '     '4He(3He,P1)6Li* '     '4He(3He,P2)6Li* '
  '4He(3He,G0)7Be   '     '4He(3He,G1)7Be* '     '4He(3He,P)6Li     '
  'E(P)LAB              '     'E(3He)               '     'E(P1)LAB            '
  'E(P2)LAB             '     'E(G0)LAB            '     'E(G1)                '
 'ID.CHANN'
     ' P, 6Li '     0.39439688299650E+01 'R'    1.00        4    0.000000
     '3He,4HE '     0.42415108711860E+01 'R'    1.00        5    4.019800
     'P1,6Li* '     0.39439688299650E+01 'R'    1.00        5 -2.186000
     'P2,6Li* '     0.39439688299650E+01 'R'    1.00        5 -3.563000
     'G0,7Be   '     0.39439688299650E+01 'R'    1.00        2    5.610000
     'G1,7Be* '     0.39439688299650E+01 'R'    1.00        2    5.180000
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The information of the experimental data

	Mark	Norm.	factor	Weight	CLSχ^2	GLSχ^2	\	\	Point Numbers
1	'PPDAa035'	0.9323	1.0000	1.0000	1.1645	1.2884	-0.0667	-0.0666	27
2	'PPDAa041'	0.9356	1.0000	1.0000	1.3030	1.3220	-0.0634	-0.0634	27
3	'PPDAa046'	0.8958	1.0000	1.0000	1.1441	1.1912	-0.1032	-0.1032	31
4	'PPDAa052'	0.9588	1.0000	1.0000	0.7326	0.7577	-0.0402	-0.0401	28
5	'PPDAa057'	0.9296	1.0000	1.0000	0.9494	0.9814	-0.0694	-0.0695	31
6	'PPDAa063'	0.9160	1.0000	1.0000	1.4573	1.4995	-0.0830	-0.0830	29
7	'PPDAa068'	0.8582	1.0000	1.0000	0.8002	0.8663	-0.1408	-0.1408	9
8	'PPDAa074'	0.9596	1.0000	1.0000	1.8932	2.0207	-0.0394	-0.0393	9
9	'PPDAa079'	0.8892	1.0000	1.0000	0.7715	0.7590	-0.1098	-0.1099	35
10	'PPDAa084'	1.0119	1.0000	1.0000	1.8392	1.8778	0.0129	0.0129	32
11	'PPDAa090'	0.9191	1.0000	1.0000	1.6418	1.5848	-0.0799	-0.0799	30
12	'PPDAa095'	0.9108	1.0000	1.0000	0.6453	0.6563	-0.0882	-0.0883	34
13	'PPDAa100'	0.9344	1.0000	1.0000	0.8803	0.8875	-0.0646	-0.0646	34

14	'PPDAa105'	0.9466	1.0000	1.0000	1.0005	1.0278	-0.0524	-0.0524	35
15	'PPDAa110'	1.0074	1.0000	1.0000	0.8664	0.8974	0.0084	0.0084	35
16	'PPDAa114'	0.9775	1.0000	1.0000	1.1408	1.1500	-0.0215	-0.0215	37
17	'PPDAa119'	0.9858	1.0000	1.0000	1.3942	1.3821	-0.0132	-0.0133	36
18	'PPDAa124'	0.9261	1.0000	1.0000	1.0237	1.0649	-0.0729	-0.0729	36
19	'PPDAa128'	0.9452	1.0000	1.0000	0.6655	0.6777	-0.0538	-0.0538	37
20	'PPDAa133'	0.9452	1.0000	1.0000	1.1273	1.1263	-0.0538	-0.0538	35
21	'PPDAa137'	0.8918	1.0000	1.0000	1.0306	1.0507	-0.1072	-0.1072	34
22	'PPDAa142'	0.9081	1.0000	1.0000	2.1644	2.1743	-0.0909	-0.0908	32
23	'PPDAa146'	0.9650	1.0000	1.0000	1.1114	1.0366	-0.0340	-0.0340	37
24	'PPDAa151'	0.9645	1.0000	1.0000	1.1360	1.1521	-0.0345	-0.0345	34
25	'PPDAa155'	0.9839	1.0000	1.0000	0.8090	0.8141	-0.0151	-0.0151	37
26	'PPDAa159'	0.9700	1.0000	1.0000	0.9207	0.8949	-0.0290	-0.0290	35
27	'PPDAa163'	0.9697	1.0000	1.0000	1.2480	1.2073	-0.0293	-0.0293	32
28	'PPDAa168'	0.9801	1.0000	1.0000	1.3033	1.1597	-0.0189	-0.0189	33
29	'PPDAmc70'	1.0181	1.0000	1.0000	2.3620	2.3282	0.0191	0.0191	21
30	'PPDAmc90'	0.9980	1.0000	1.0000	0.1302	0.1307	-0.0010	-0.0009	21
31	'PPDAm110'	0.9457	1.0000	1.0000	1.2010	1.2191	-0.0533	-0.0533	21
32	'PPDAm125'	0.9277	1.0000	1.0000	0.6562	0.6574	-0.0713	-0.0713	21
33	'PPDAm140'	0.9194	1.0000	1.0000	1.3270	1.3421	-0.0796	-0.0796	21
34	'PPDAm160'	0.9301	1.0000	1.0000	0.9631	0.9937	-0.0689	-0.0689	22
35	'PPDAfa54'	1.0019	1.0000	1.0000	1.2034	1.2456	0.0029	0.0030	11
36	'PPDAfa69'	0.9145	1.0000	1.0000	0.2631	0.2735	-0.0845	-0.0845	11
37	'PPDAfa89'	0.8925	1.0000	1.0000	0.9588	1.0202	-0.1065	-0.1065	11
38	'PPDAf109'	0.9157	1.0000	1.0000	1.0325	1.0665	-0.0833	-0.0833	11
39	'PPDAf124'	0.9066	1.0000	1.0000	1.0150	1.0506	-0.0924	-0.0924	11
40	'PPDAf140'	0.9180	1.0000	1.0000	0.4890	0.5121	-0.0810	-0.0810	11
41	'PPDAf149'	0.9197	1.0000	1.0000	0.3275	0.3384	-0.0793	-0.0793	11
42	'PPDAf165'	0.9399	1.0000	1.0000	1.0055	1.0604	-0.0591	-0.0591	11
43	'PPDAmcc0'	1.0000	1.0000	1.0000	5.7437	2.7580	0.0010	0.0010	68
44	'PPDAmcc1'	0.9433	1.0000	1.0000	1.4448	1.4549	-0.0557	-0.0557	68
45	'PPDAmcc2'	0.9125	1.0000	1.0000	2.3805	2.4721	-0.0865	-0.0865	73
46	'PPDAmcc3'	0.9354	1.0000	1.0000	2.1420	2.0214	-0.0636	-0.0636	73
47	'PPDAha39'	0.9304	1.0000	1.0000	2.1714	2.3463	-0.0686	-0.0687	9
48	'PPDAha54'	0.9012	1.0000	1.0000	1.9008	2.0414	-0.0978	-0.0978	17
49	'PPDAha63'	0.8857	1.0000	1.0000	1.3066	1.3081	-0.1133	-0.1133	24
50	'PPDAha73'	0.8739	1.0000	1.0000	1.3304	1.2982	-0.1251	-0.1251	12
51	'PPDAha80'	0.8946	1.0000	1.0000	1.0957	1.2380	-0.1044	-0.1044	25
52	'PPDAha90'	0.9229	1.0000	1.0000	1.2518	1.3476	-0.0761	-0.0761	32
53	'PPDAha99'	0.9375	1.0000	1.0000	1.3426	1.4499	-0.0615	-0.0615	25
54	'PPDAh109'	0.9485	1.0000	1.0000	1.1891	1.2781	-0.0505	-0.0505	14
55	'PPDAh116'	0.9474	1.0000	1.0000	0.8981	0.9471	-0.0516	-0.0516	25
56	'PPDAh125'	0.9585	1.0000	1.0000	0.5987	0.6234	-0.0405	-0.0405	32
57	'PPDAh132'	0.9462	1.0000	1.0000	1.1056	1.2971	-0.0528	-0.0528	10

58	'PPDAh140'	0.9414	1.0000	1.0000	0.6222	0.6992	-0.0576	-0.0575	25
59	'PPDAh150'	0.9303	1.0000	1.0000	0.8548	0.8923	-0.0687	-0.0687	15
60	'PPDAh163'	0.9538	1.0000	1.0000	0.8150	0.8537	-0.0452	-0.0452	25
61	'PPDAfas1'	0.8728	1.0000	1.0000	2.9991	3.1910	-0.1262	-0.1262	30
62	'PPDAfas2'	0.7910	1.0000	1.0000	1.1242	1.2125	-0.2080	-0.2080	32
63	'PPDAfas3'	0.6985	1.0000	1.0000	0.2778	0.2719	-0.3005	-0.3005	53
64	'PPDAfas4'	0.8150	1.0000	1.0000	0.7689	0.7470	-0.1840	-0.1841	58
65	'PPDAfas5'	0.8137	1.0000	1.0000	1.4194	1.4872	-0.1853	-0.1918	57
66	'PPDAfas6'	0.8382	1.0000	1.0000	2.8583	2.9757	-0.1608	-0.1608	58
67	'PPDAfas7'	0.8146	1.0000	1.0000	1.4146	1.4462	-0.1844	-0.1843	60
68	'PPDAfas8'	0.8467	1.0000	1.0000	1.4960	1.5483	-0.1523	-0.1523	58
69	'PPDAscaf'	1.1358	1.1350	1.0000	0.8496	0.7337	0.1368	-0.1523	80
70	'PPDAskl1'	0.9482	1.0000	1.0000	2.0406	2.0435	-0.0508	-0.0508	20
71	'PPDAskl2'	1.0380	1.0000	1.0000	2.8889	2.8941	0.0390	0.0389	20
72	'PPDAskl3'	0.9229	1.0000	1.0000	0.8376	0.8376	-0.0761	-0.0760	20
73	'PPDAskl4'	1.3618	1.0000	1.0000	0.3357	0.3381	0.3628	0.3629	20
74	'PPDAskl5'	1.2167	1.0000	1.0000	0.7461	0.7504	0.2177	0.2177	20
75	'PPDAskl6'	1.1165	1.0000	1.0000	2.8177	2.8207	0.1175	0.1175	20
76	'PPDAskl7'	0.9999	1.0000	1.0000	1.0207	1.0365	0.0009	0.0009	10
77	'PPDAskl8'	1.2567	1.0000	1.0000	0.4176	0.4199	0.2577	0.2577	10
78	'PPDAskl9'	1.3486	1.0000	1.0000	0.3163	0.3168	0.3496	0.3496	10
79	'PPDAsk10'	1.0659	1.0000	1.0000	0.9444	0.9485	0.0669	0.0669	10
80	'PPDAsk11'	1.2085	1.0000	1.0000	0.7562	0.7590	0.2095	0.2095	30
81	'PPDAmere'	1.0514	1.0000	1.0000	1.0902	1.3272	0.0524	0.0525	26
82	'PHCSfied'	1.1011	1.0000	1.0000	0.2246	0.2261	0.1021	0.1021	6
83	'PHCSgeme'	0.7298	1.0000	1.0000	0.6852	0.7100	-0.2692	-0.2692	15
84	'PHCSelwy'	0.7693	1.0000	1.0000	0.5221	0.5255	-0.2297	-0.2297	30
85	'PHCStumi'	0.7761	1.0000	1.0000	0.5075	0.5089	-0.2229	-0.2228	29
86	'PHDAspig'	0.6955	1.0000	1.0000	1.3356	1.2380	-0.3035	-0.3035	32
87	'PHDAkhan'	0.5407	1.0000	1.0000	0.2329	0.2350	-0.4583	-0.4666	12
88	'PHDAkha1'	0.8237	1.0000	1.0000	0.2218	0.2229	-0.1753	-0.1753	14
89	'PHDAbouc'	0.5764	1.0000	1.0000	0.2356	0.2380	-0.4226	-0.4237	15
90	'PHDAbou1'	0.7995	1.0000	1.0000	0.3048	0.3099	-0.1995	-0.1995	14
91	'PHDAel20'	0.6779	1.0000	1.0000	1.0740	1.2074	-0.3211	-0.3211	18
92	'PHDAel30'	0.7478	1.0000	1.0000	1.0360	1.0292	-0.2512	-0.2511	28
93	'PHDAel38'	0.7540	1.0000	1.0000	1.2749	1.2785	-0.2450	-0.2450	29
94	'PHDAel48'	0.8053	1.0000	1.0000	1.1626	1.2197	-0.1937	-0.1938	25
95	'PHDAel59'	0.8320	1.0000	1.0000	1.8165	1.8893	-0.1670	-0.1670	26
96	'PHDAel70'	0.8419	1.0000	1.0000	1.2881	1.3895	-0.1571	-0.1571	32
97	'PHDAel76'	0.8248	1.0000	1.0000	2.1092	2.1759	-0.1742	-0.1742	25
98	'PHDAel86'	0.8471	1.0000	1.0000	2.6928	2.8188	-0.1519	-0.1520	23
99	'PHDAel93'	0.8578	1.0000	1.0000	2.0971	2.4209	-0.1412	-0.1413	15
100	'PHDAe102'	0.8651	1.0000	1.0000	2.1862	2.2975	-0.1339	-0.1339	26
101	'PHDAe106'	0.8200	1.0000	1.0000	1.3316	1.4136	-0.1790	-0.1789	28

102	'PHDAe118'	0.8484	1.0000	1.0000	1.2773	1.3581	-0.1506	-0.1506	26
103	'PHDAe130'	0.8803	1.0000	1.0000	1.6590	1.5325	-0.1187	-0.1188	30
104	'PHDAe141'	0.8866	1.0000	1.0000	2.3803	1.2597	-0.1124	-0.1317	30
105	'PHDAe149'	0.9516	1.0000	1.0000	1.7619	1.9183	-0.0474	-0.0473	21
106	'PHDAe156'	0.8316	1.0000	1.0000	3.4759	2.5935	-0.1674	-0.1983	14
107	'PHDAli23'	0.7963	1.0000	1.0000	0.9241	0.9502	-0.2027	-0.2027	11
108	'PHDAli28'	0.7981	1.0000	1.0000	1.0531	1.1188	-0.2009	-0.2009	7
109	'PHDAli38'	0.8383	1.0000	1.0000	1.2770	1.3558	-0.1607	-0.1607	16
110	'PHDAli52'	0.8762	1.0000	1.0000	1.5866	1.6768	-0.1228	-0.1228	17
111	'PHDAli62'	0.8983	1.0000	1.0000	2.0011	2.1337	-0.1007	-0.1007	18
112	'PHDAli74'	0.9487	1.0000	1.0000	1.7562	1.8467	-0.0503	-0.0502	26
113	'PHDAli80'	0.9341	1.0000	1.0000	1.7982	1.8849	-0.0649	-0.0649	16
114	'PHDAli86'	0.9388	1.0000	1.0000	1.0377	1.1036	-0.0602	-0.0602	12
115	'PHDAli89'	0.9176	1.0000	1.0000	1.2908	1.3676	-0.0814	-0.0814	13
116	'PHDAli94'	0.9062	1.0000	1.0000	1.4797	1.5233	-0.0928	-0.0928	13
117	'PHDAli99'	0.8992	1.0000	1.0000	0.7826	0.8520	-0.0998	-0.0998	16
118	'PHDAl105'	0.8956	1.0000	1.0000	1.8958	1.9675	-0.1034	-0.1034	16
119	'PHDAl110'	0.8915	1.0000	1.0000	1.9001	2.0378	-0.1075	-0.1076	12
120	'PHDAl121'	0.9573	1.0000	1.0000	0.7834	0.8499	-0.0417	-0.0417	16
121	'PHDAl132'	0.9626	1.0000	1.0000	2.1464	2.3087	-0.0364	-0.0364	17
122	'PHDAl145'	0.9782	1.0000	1.0000	1.6768	1.9635	-0.0208	-0.0208	17
123	'PHDAl156'	0.9607	1.0000	1.0000	1.2745	1.4924	-0.0383	-0.0383	17
124	'PHAYbr29'	0.7025	1.0000	1.0000	0.7531	0.7619	-0.2965	-0.2965	4
125	'PHAYbr39'	0.6024	1.0000	1.0000	1.8391	1.9173	-0.3966	-0.3966	7
126	'PHAYbr47'	0.6016	1.0000	1.0000	1.3328	1.6051	-0.3974	-0.3974	3
127	'PHAYbr57'	0.6257	1.0000	1.0000	1.6844	1.7384	-0.3733	-0.3733	10
128	'PHAYbr67'	0.5511	1.0000	1.0000	4.2534	4.3811	-0.4479	-0.4480	9
129	'PHAYbr81'	0.6447	1.0000	1.0000	2.2668	2.7437	-0.3543	-0.3543	14
130	'PHAYbr96'	0.6733	1.0000	1.0000	4.2486	4.4137	-0.3257	-0.3257	12
131	'PHAYb115'	0.7425	1.0000	1.0000	4.2403	4.6015	-0.2565	-0.2565	23
132	'PHAYb121'	0.8033	1.0000	1.0000	0.9416	1.0214	-0.1957	-0.1957	12
133	'PHAYb131'	0.8190	1.0000	1.0000	2.0309	2.0754	-0.1800	-0.1800	10
134	'PHAYb140'	0.7834	1.0000	1.0000	2.1209	2.1420	-0.2156	-0.2156	11
135	'PHAYb149'	0.8415	1.0000	1.0000	0.4492	0.4552	-0.1575	-0.1575	6
136	'PHDAb167'	1.4687	1.0000	1.0000	0.3549	0.3626	0.4697	0.4698	30
137	'PHDAgou1'	0.7606	1.0000	1.0000	2.7700	2.7857	-0.2384	-0.2384	14
138	'PHDAgou2'	0.5960	1.0000	1.0000	0.5070	0.6033	-0.4030	-0.4031	14
139	'PHDAgou3'	0.7579	1.0000	1.0000	0.3321	0.3438	-0.2411	-0.2412	14
140	'PHDAsch1'	0.5955	1.0000	1.0000	2.7648	2.1112	-0.4035	-0.4035	19
141	'PHDAsch2'	0.5717	1.0000	1.0000	0.4950	0.5332	-0.4273	-0.4274	22
142	'PHDAsch3'	0.6670	1.0000	1.0000	0.7100	0.8060	-0.3320	-0.3320	25
143	'PHDAsch4'	0.7868	1.0000	1.0000	0.5352	0.5999	-0.2122	-0.2122	24
144	'PHDAsch5'	0.8638	1.0000	1.0000	0.4131	0.4656	-0.1352	-0.1352	25
145	'PHDAsch6'	0.9183	1.0000	1.0000	0.3902	0.3373	-0.0807	-0.0807	25

146	'PHDAsch7'	2.7539	1.0000	1.0000	0.2698	0.2868	1.7549	1.7549	17
147	'PHDAgu08'	0.6917	1.0000	1.0000	0.5130	0.5382	-0.3073	-0.3073	17
148	'PHDAgu10'	0.8767	1.0000	1.0000	0.7234	0.7479	-0.1223	-0.1223	18
149	'PP1CShar'	1.0000	1.0000	1.0000	3.3879	2.0278	0.0010	0.0010	12
150	'PP1Dgoul'	0.9376	1.0000	1.0000	1.6256	1.4336	-0.0614	-0.0614	53
151	'PP1DAhar'	0.9393	1.0000	1.0000	1.4297	2.1285	-0.0597	-0.0598	41
152	'PP1Dmere'	1.0000	1.0000	1.0000	0.6106	0.7148	0.0010	0.0010	28
153	'PP1Dgou1'	1.2184	1.0000	1.0000	0.2483	0.2745	0.2194	0.2195	28
154	'PP1Dgou2'	0.7103	1.0000	1.0000	1.0083	1.1094	-0.2887	-0.2887	24
155	'PP1Dgou3'	0.5916	1.0000	1.0000	0.9656	1.0034	-0.4074	-0.4074	25
156	'PP2Charr'	1.0000	1.0000	1.0000	0.9006	1.1382	0.0010	0.0010	50
157	'PP2DAhar'	0.3748	1.0000	1.0000	0.3929	0.3990	-0.6242	-0.6242	22
158	'PP2DAha1'	1.2219	1.0000	1.0000	1.2042	1.2348	0.2229	0.2230	10
159	'PP2Dmere'	1.0000	1.0000	1.0000	0.5123	0.5418	0.0010	0.0010	20
160	'PG0Cswit'	0.9997	1.0000	1.0000	0.9908	1.0403	0.0007	0.0010	9
161	'PG0Dosto'	0.8341	1.0000	1.0000	0.8058	0.8333	-0.1649	-0.1649	8
162	'PG1Cbrus'	1.0004	1.0000	1.0000	0.4854	0.4901	0.0014	0.0010	14
163	'PG1Cswit'	1.0002	1.0000	1.0000	1.2559	1.3982	0.0012	0.0010	19
164	'PG1Dosto'	0.7028	1.0000	1.0000	1.0026	1.0488	-0.2962	-0.2962	8
165	'HHDAmo34'	0.9343	1.0000	1.0000	0.4832	0.5108	-0.0647	-0.0647	4
166	'HHDAmo40'	1.0131	1.0000	1.0000	2.1511	2.2839	0.0141	0.0141	10
167	'HHDAmo43'	0.9097	1.0000	1.0000	1.9342	2.0454	-0.0893	-0.0893	10
168	'HHDAmo60'	0.9463	1.0000	1.0000	3.4052	3.5184	-0.0527	-0.0527	17
169	'HHDAmo68'	0.8850	1.0000	1.0000	1.1449	1.1665	-0.1140	-0.1140	10
170	'HHDAmo80'	0.9676	1.0000	1.0000	3.3840	3.5818	-0.0314	-0.0314	7
171	'HHDAmo85'	0.9826	1.0000	1.0000	2.8863	2.7504	-0.0164	-0.0163	7
172	'HHDAm100'	0.9838	1.0000	1.0000	4.1636	4.6741	-0.0152	-0.0152	19
173	'HHDAm110'	0.9821	1.0000	1.0000	2.1316	2.2382	-0.0169	-0.0169	9
174	'HHDAm114'	0.9934	1.0000	1.0000	1.9559	2.2934	-0.0056	-0.0057	10
175	'HHDAm127'	1.0836	1.0000	1.0000	0.5001	0.5204	0.0846	0.0846	3
176	'HHDAm130'	0.8617	1.0000	1.0000	1.9639	2.0507	-0.1373	-0.1372	8
177	'HHDAm140'	0.9789	1.0000	1.0000	1.9879	1.9960	-0.0201	-0.0201	10
178	'HHDAm147'	0.9606	1.0000	1.0000	2.1937	2.3402	-0.0384	-0.0384	4
179	'HHDAba54'	0.9055	1.0000	1.0000	2.4436	2.4617	-0.0935	-0.0935	75
180	'HHDAba63'	0.9239	1.0000	1.0000	0.5464	0.5521	-0.0751	-0.0751	85
181	'HHDAba73'	0.9353	1.0000	1.0000	0.2491	0.2470	-0.0637	-0.0637	124
182	'HHDAba90'	0.9539	1.0000	1.0000	0.2187	0.2206	-0.0451	-0.0451	125
183	'HHDAb104'	0.9715	1.0000	1.0000	0.6738	0.6861	-0.0275	-0.0275	162
184	'HHDAb116'	0.9705	1.0000	1.0000	1.0264	1.0491	-0.0285	-0.0285	104
185	'HHDAb125'	0.9672	1.0000	1.0000	0.6678	0.6819	-0.0318	-0.0319	81
186	'HHDAb140'	0.9617	1.0000	1.0000	0.5545	0.5698	-0.0373	-0.0373	54
187	'HHDAsp39'	0.8287	1.0000	1.0000	0.6020	0.6040	-0.1703	-0.1703	35
188	'HHDAsp47'	0.8709	1.0000	1.0000	0.6510	0.5986	-0.1281	-0.1281	35
189	'HHDAsp54'	0.8578	1.0000	1.0000	1.1606	1.1119	-0.1412	-0.1413	35

190	'HHDAsp63'	0.8848	1.0000	1.0000	0.9407	0.9581	-0.1142	-0.1142	35
191	'HHDAsp70'	0.9046	1.0000	1.0000	0.3111	0.3161	-0.0944	-0.0944	35
192	'HHDAsp77'	0.9115	1.0000	1.0000	0.3402	0.3448	-0.0875	-0.0874	35
193	'HHDAsp80'	0.9037	1.0000	1.0000	0.3759	0.3759	-0.0953	-0.0953	35
194	'HHDAsp85'	0.9038	1.0000	1.0000	0.2998	0.3026	-0.0952	-0.0952	35
195	'HHDAsp90'	0.8812	1.0000	1.0000	0.4833	0.4940	-0.1178	-0.1178	35
196	'HHDAsp98'	0.8802	1.0000	1.0000	0.6376	0.6527	-0.1188	-0.1188	35
197	'HHDAs106'	0.8819	1.0000	1.0000	0.5309	0.5433	-0.1171	-0.1171	35
198	'HHDAs116'	0.9112	1.0000	1.0000	0.7467	0.7462	-0.0878	-0.0879	35
199	'HHDAs125'	0.9027	1.0000	1.0000	0.4807	0.4792	-0.0963	-0.0963	35
200	'HHDAs135'	0.8843	1.0000	1.0000	1.0742	1.1610	-0.1147	-0.1147	35
201	'HHDAsp55'	0.8427	1.0000	1.0000	2.5463	2.4911	-0.1563	-0.1412	51
202	'HHDAsp91'	0.8857	1.0000	1.0000	2.6877	2.9523	-0.1133	-0.0983	55
203	'HHDAs126'	0.9958	1.0000	1.0000	2.6633	2.4245	-0.0032	-0.0070	48
204	'HHDAtom1'	0.9985	1.0000	1.0000	1.0039	1.1176	-0.0005	-0.0006	49
205	'HHDAtom2'	1.0065	1.0000	1.0000	1.5594	1.6756	0.0075	0.0075	66
206	'HHDAtom3'	1.0695	1.0000	1.0000	0.9445	0.9877	0.0705	0.0704	45
207	'HHDAtom4'	1.0713	1.0000	1.0000	1.0643	1.0836	0.0723	0.0722	56
208	'HHDAtom5'	1.0400	1.0000	1.0000	1.5547	1.5968	0.0410	0.0411	60
209	'HHDAtom6'	1.0342	1.0000	1.0000	1.9926	1.4135	0.0352	0.0352	46
210	'HHDAtom7'	0.9980	1.0000	1.0000	1.8296	1.5484	-0.0010	-0.0010	60
211	'HHDAtom8'	0.9886	1.0000	1.0000	2.6211	2.3362	-0.0104	-0.0104	69
212	'HHDAgorp'	1.3959	1.0000	1.0000	2.0414	2.0377	0.3969	0.3968	33
213	'HHDAteb6'	0.9315	1.0000	1.0000	4.0320	3.9750	-0.0675	-0.0675	34
214	'HHDAteb8'	0.9422	1.0000	1.0000	5.0109	5.1469	-0.0568	-0.0568	36
215	'HHDAteb9'	0.9826	1.0000	1.0000	5.5196	4.5586	-0.0164	-0.0164	19
216	'HHDAte11'	0.9971	1.0000	1.0000	3.6082	4.2110	-0.0019	-0.0019	23
217	'HHDAja18'	1.1479	1.0000	1.0000	2.6842	2.4308	0.1489	0.1490	52
218	'HHDAja20'	1.1642	1.0000	1.0000	1.5072	1.4424	0.1652	0.1652	38
219	'HHDAja22'	1.0409	1.0000	1.0000	1.3054	1.2499	0.0419	0.0420	38
220	'HHDAja24'	1.0631	1.0000	1.0000	1.1487	1.1494	0.0641	0.0642	37
221	'HHDAja26'	1.0174	1.0000	1.0000	1.0215	0.9489	0.0184	0.0184	38
222	'HHDAja28'	0.9768	1.0000	1.0000	0.9898	0.9283	-0.0222	-0.0223	38
223	'HHDAja30'	1.1129	1.0000	1.0000	0.7397	0.7356	0.1139	0.1138	38
224	'HHAYbo72'	0.8021	1.0000	1.0000	2.6057	2.4799	-0.1969	-0.1969	13
225	'HHAYbo87'	0.9111	1.0000	1.0000	0.5801	0.5588	-0.0879	-0.0879	14
226	'HHAYb120'	0.5463	1.0000	1.0000	0.6568	0.6526	-0.4527	-0.4527	14
227	'HHAYha40'	1.1511	1.0000	1.0000	0.0553	0.0566	0.1521	0.1521	3
228	'HHAYha79'	0.9605	1.0000	1.0000	0.7581	0.8297	-0.0386	-0.0386	12
229	'HHAYh114'	1.0703	1.0000	1.0000	1.5747	1.5640	0.0713	0.0713	12
230	'HP1Dspig'	0.3185	1.0000	1.0000	0.8439	0.8564	-0.6805	-0.6805	18
231	'HP1Dspi1'	0.3491	1.0000	1.0000	0.7031	0.6841	-0.6499	-0.6499	18
232	'HG0Cosbo'	0.9996	1.0000	1.0000	0.1836	0.1841	0.0006	0.0010	16
233	'HG0Csing'	1.0003	1.0000	1.0000	0.6740	0.7694	0.0013	0.0010	24

234 'HG1Cosbo'	1.0001	1.0000	1.0000	0.3065	0.3173	0.0011	0.0010	16
235 'HG1Csing'	0.9998	1.0000	1.0000	0.6557	0.7619	0.0008	0.0010	24
236 'HPDAsp25'	0.7299	1.0000	1.0000	0.6482	0.6903	-0.2691	-0.2691	23
237 'HPDAsp35'	0.7186	1.0000	1.0000	0.4687	0.4916	-0.2804	-0.2804	8
238 'HPDAsp41'	0.7621	1.0000	1.0000	0.6836	0.7207	-0.2369	-0.2369	21
239 'HPDAsp49'	0.7495	1.0000	1.0000	0.7856	0.8240	-0.2495	-0.2495	9
240 'HPDAsp57'	0.7804	1.0000	1.0000	0.3262	0.3468	-0.2186	-0.2186	9
241 'HPDAsp65'	0.8028	1.0000	1.0000	0.7068	0.7461	-0.1962	-0.1962	8
242 'HPDAsp73'	0.7641	1.0000	1.0000	0.7280	0.7670	-0.2349	-0.2349	14
243 'HPDAsp78'	0.7950	1.0000	1.0000	0.1611	0.1703	-0.2040	-0.2040	9
244 'HPDAsp88'	0.7393	1.0000	1.0000	0.5227	0.5646	-0.2597	-0.2597	3
245 'HPDAsp95'	0.7374	1.0000	1.0000	0.3190	0.3508	-0.2616	-0.2616	3
246 'HPDAs101'	0.7436	1.0000	1.0000	1.0554	1.1315	-0.2554	-0.2554	7
247 'HPDAs113'	0.7063	1.0000	1.0000	0.3562	0.3876	-0.2927	-0.2927	2
248 'HPDAs121'	0.7654	1.0000	1.0000	1.6456	1.8157	-0.2336	-0.2336	4
249 'HPDAsp28'	0.7722	1.0000	1.0000	2.1820	2.5472	-0.2268	-0.2269	26
250 'HPDAsp56'	0.8774	1.0000	1.0000	1.7589	1.1875	-0.1216	-0.1215	53

D. New Experimental data added in this evaluation

Compared with our old evaluations at 2018, only one set of experimental data was found in EXFOR, which has been added in our new fitting. The new experimental data is the excitation function of the ^{6}Li(p, p)^{6}Li reaction at 165 degrees, which is the first experimental data at 165 degrees. The experimental data at 163 degrees is also plot in the figure for comparison, which is close to each other. As shown in the figure, the new calculations are consistent with the experimental data, which indicates the new experimental data is reasonable. The new experimental data makes a contribution to our new evaluation.

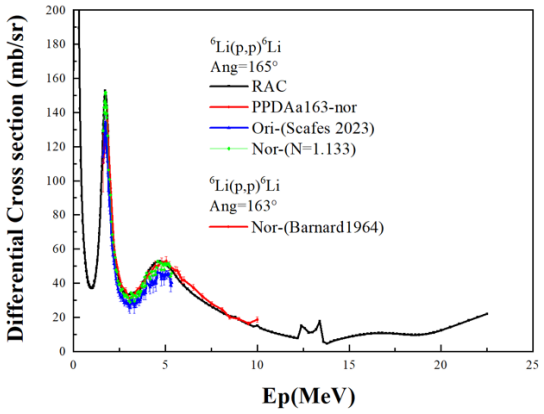


FIG 1. The ^{6}Li (p, p) ^{6}Li excitation function at 165 degrees,

E. Typical results of the evaluation of ^{7}Be system

The criteria for judging whether the final evaluation result is reliable and reasonable include: first, the average χ^2 should be less than 2; in this work, the average χ^2 is 1.41. Second, the original data, the normalized experimental data and the evaluation values should be consistent within the error range of the original experimental data. Therefore, in the iteration process, a detailed comparison of the diagram should be drawn for each type of the integral cross section, the angular distribution of each energy point, and the excitation function of each angle. The fitting should be kept on until you

are satisfied. In this report, only one graph is displayed for each reaction channel, please see a future article for details.

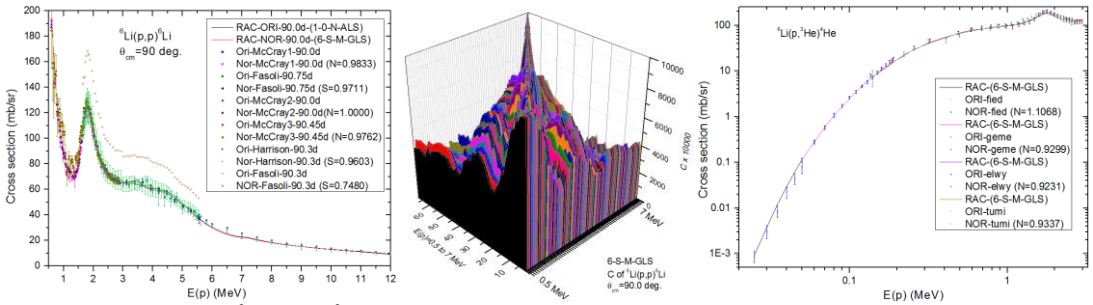


FIG 2. (left). The ^{6}Li(p, p)^{6}Li excitation function at 90 degrees, the fits are excellent. (middle). The correlation factor (C) for the excitation function of ^{6}Li(p, p) ^{6}Li at 90 degrees, and E_p = 0.5 to 7 MeV. In the C matrix the diagonal elements $C_{ii} \equiv 1$. (right). The integrated cross section of the ^{6}Li(p, ^{3}He)^{4}He reaction, the fit is very good.

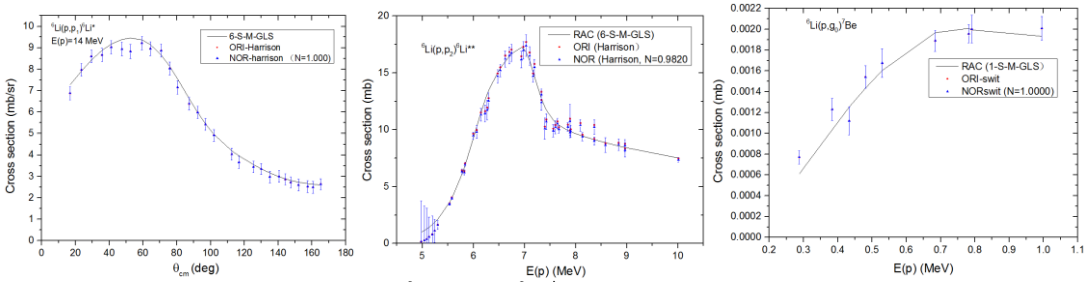


FIG 3. (left).The fit of the DA of ^{6}Li (p,p$_1$) ^{6}Li* at E_p = 14 MeV, which is the largest energy used in database located in the non-resolved resonance region. (middle). The fit of the integrated cross sections of ^{6}Li(p,p$_2$)^{6}Li** , N=1 means that the data are not normalized. The fit looks good. (right). The fit for the integrated cross section of ^{6}Li(p,γ_0)^{7}Be. N=1 means data are not normalized. The fit looks good.

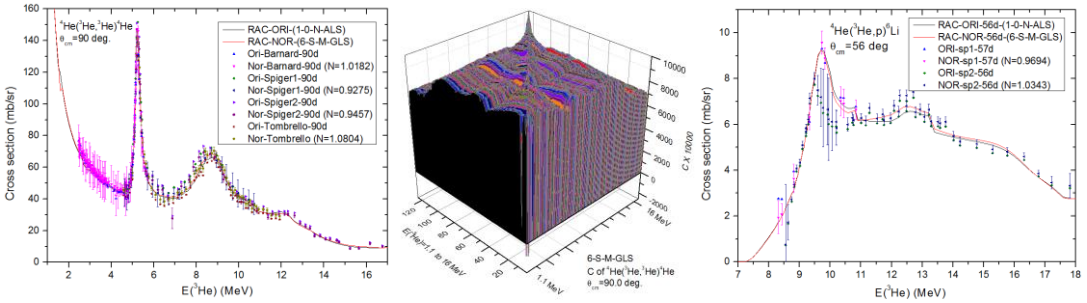


FIG 4. (left). Fit for the excitation function of ^{4}He(^{3}He,^{3}He)^{4}He at 90 degrees. The data from 14 to 18 MeV are in the non-resolved resonance region. (middle). Correlation factor (C) for the excitation function of ^{4}He(^{3}He,^{3}He)^{4}He at 90 degrees for E_{3He} = 1.1 MeV to 16 MeV. (right). Fit for the excitation function of ^{4}He(^{3}He, p)^{6}Li at 56 degrees. N = 0.9694, 1.0343 are the NCs.

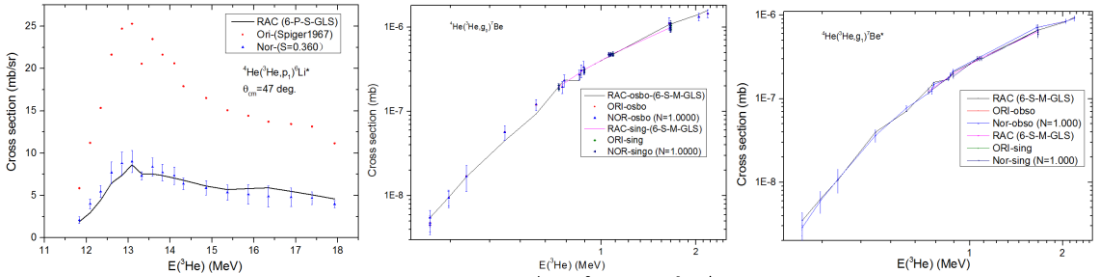


FIG 5. (left) Fit for the excitation function of ^{4}He(^{3}He, p$_1$)^{6}Li* at 47 degrees, these are shape data. (middle). Fit for integrated cross sections of ^{4}He(^{3}He, γ_0)^{7}Be. (right). Fit for integrated cross sections of ^{4}He(^{3}He, γ_1)^{7}Be*.

E. Evaluation results at 90 energy points and 180 degrees

The covariance matrix of the parameters obtained by our R matrix fitting of the database can be used to produce all kind of cross sections and the corresponding covariance matrix which you need.

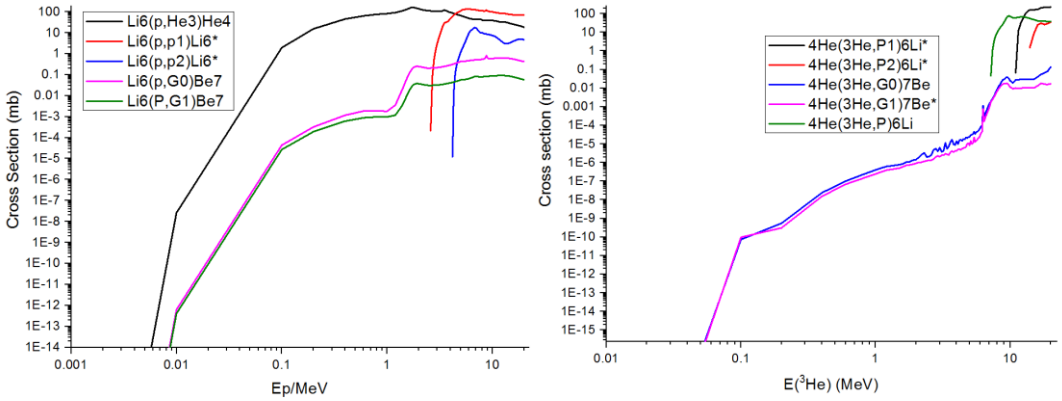


FIG.6 (left) the integrated cross section of the 6Li induced by proton at 90 energy points and (right) the integrated cross section of the 4He induced by 3He at 90 energy points.

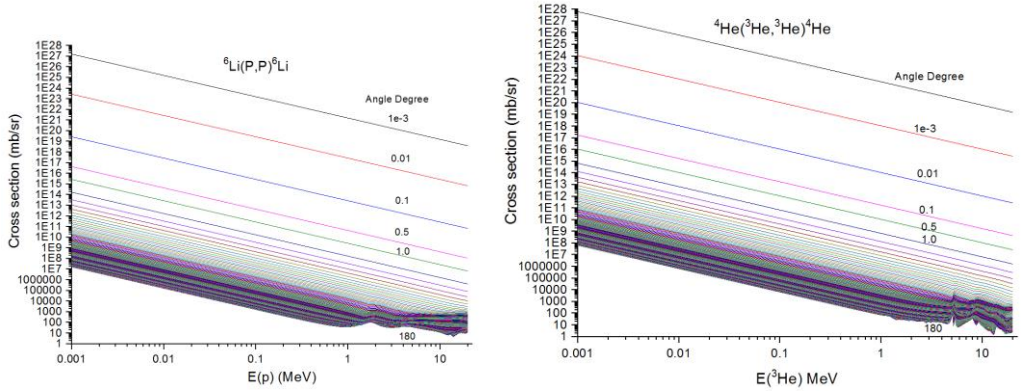


FIG.7 (left) the excitation function of the 6Li(p, p) reaction at 180 degrees and (right) the excitation function of the 4He(3He, 3He) reaction at 180 degrees.

Two ideas to give the covriance of charge paritials differential cross section

1. List of Table

We have already given the covariance data for a certain angular under different energy points by the calculation of the RAC, and the simplest way to do this is to give this data in the form of a list.

Angle = θ_1, θ_2,...,θ_k

	E_1	**E_2**	**...**	**E_n**
E_1	cov_data_11	cov_data_12	...	cov_data_1n
E_2	cov_data_21	cov_data_22	...	cov_data_2n
...		...	...	**...**
E_n	cov_data_n1	cov_data_n2	...	cov_data_nn

In data file, given in the following format. There are 6 data in a row

E_1	E_2	E_3	E_4	E_5	E_6
E_7	...	E_n	cov_data_11	cov_data_12	...
cov_data_1n	cov_data_21	cov_data_22	...	cov_data_2n	...
cov_data_n1	cov_data_n2	...	cov_data_nn		

Advantage: simple, easy read and not need interpolation

Disadvantage: extremely large amounts of data and excessive file lengths

2. The covariance between the fit parameters

A multi-parameter function is used to fit the angular distribution and excitation function. The covariance between the parameters can be given according to the theory of error propagation. The covariance between different angles or different energy points is reproduced by the covariance between the parameters.

1. Construct a function to depict the angular distribution and excitation function.

- A function describing the angular distribution can give the correlation between different angles at the same energy
- A function describing the excitation function can give the correlation between different energies at the same angle

	Angular distribution	**Excitation function**
Invariant parameter	E	θ
Independent variable	θ	E
Description of the covariance	θ_i to θ_j	E_i to E_j

2. The covariance between the fit parameters

2. Functions describing the angular distribution of elastic scattering of charged particles (from File 6).

The net elastic scattering cross section for distinguishable particles may be written as:

$$\sigma_{ed}(\mu, E) = \sigma_{cd}(\mu, E) - \frac{2\eta}{1-\mu}\mathrm{Re}\left\{\exp\left(i\eta \ln\frac{1-\mu}{2}\right)\sum_{l=0}^{\mathrm{NL}}\frac{2l+1}{2}a_l(E)P_l(\mu)\right\} + \sum_{l=0}^{2\mathrm{NL}}\frac{2l+1}{2}b_l(E)P_l(\mu) \qquad (6.13)$$

The process of constructing the parameter covariance is shown below

1. Construct the covariance matrix ($\boldsymbol{V_y}$) and weight matrix ($\boldsymbol{W}$) of the original data based on the original data errors.

2. Construct the sensitivity matrix ($\boldsymbol{S}$) of the parameters based on the fitted completed parameters (For complex nonlinear functions, the elements of the sensitivity matrix are difficult to obtain directly, so numerical methods are generally used to calculate the partial derivatives of each parameter. This can be done by **the finite difference method**).

3. Construct the covariance matrix between the parameters ($\boldsymbol{V_p}$).

2. The covariance between the fit parameters

2. Functions describing the angular distribution of elastic scattering of charged particles (from File 6).

The net elastic scattering cross section for distinguishable particles may be written as:

$$\sigma_{ed}(\mu, E) = \sigma_{cd}(\mu, E) - \frac{2\eta}{1-\mu}\mathrm{Re}\left\{\exp\left(i\eta \ln\frac{1-\mu}{2}\right)\sum_{l=0}^{\mathrm{NL}}\frac{2l+1}{2}a_l(E)P_l(\mu)\right\} + \sum_{l=0}^{2\mathrm{NL}}\frac{2l+1}{2}b_l(E)P_l(\mu) \qquad (6.13)$$

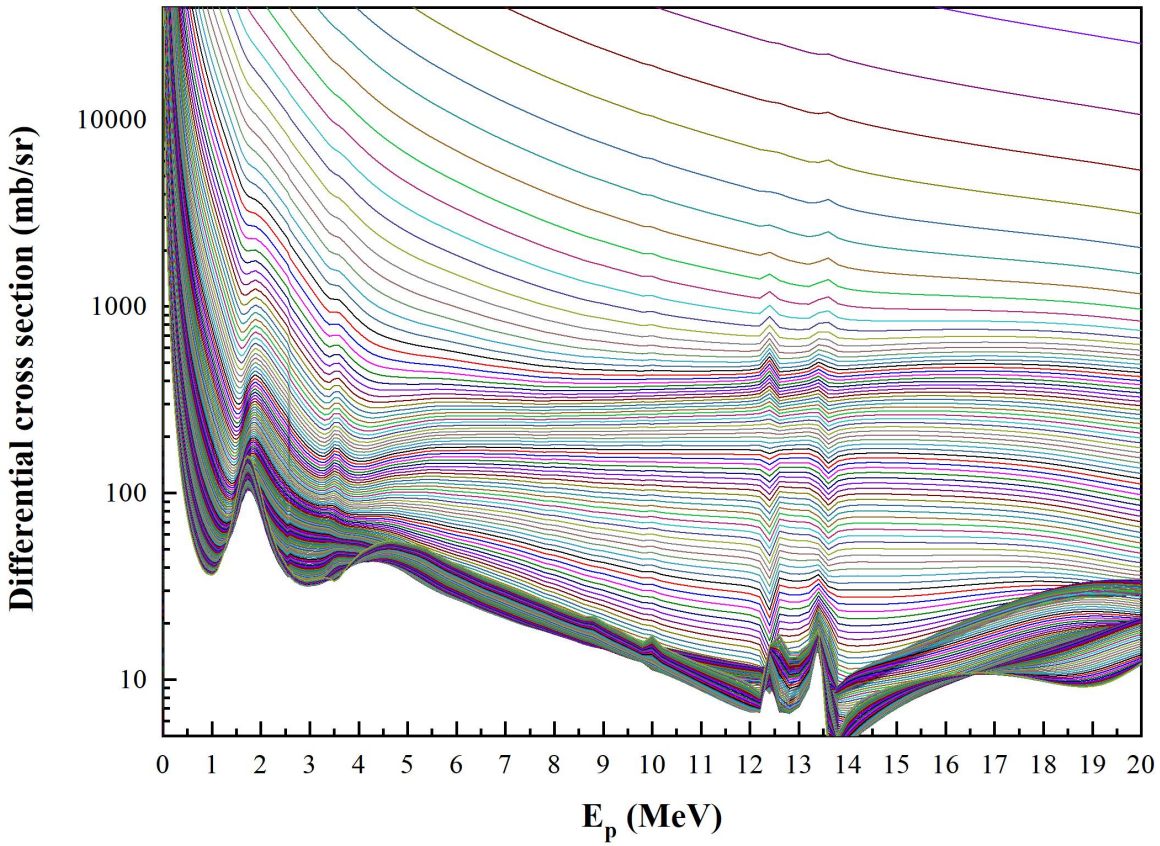
The covariance between the parameters (a_l , b_l) of this function can be obtained according to the method described above

- This describes the covariance between different angles at the same energy

The angular distribution has a standard function to describe it, the question is how to describe the excitation function ?

2. The covariance between the fit parameters

3. Functions describing the excitation function of elastic scattering of charged particles.



- Taking ^{6}Li(p, p)^{6}Li as an example, the excitation function results are shown on the left, from 0.001 degree to 180 degree. The resonance width and location is change regularly with angles.

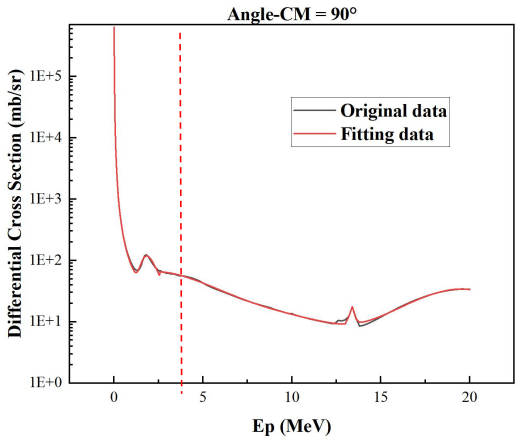
- After testing, it is difficult to use function (6.13) from File 6 to describe the excitation function for the entire energy region

- We found that we can depict the excitation function in separate energy regions and then splice it together

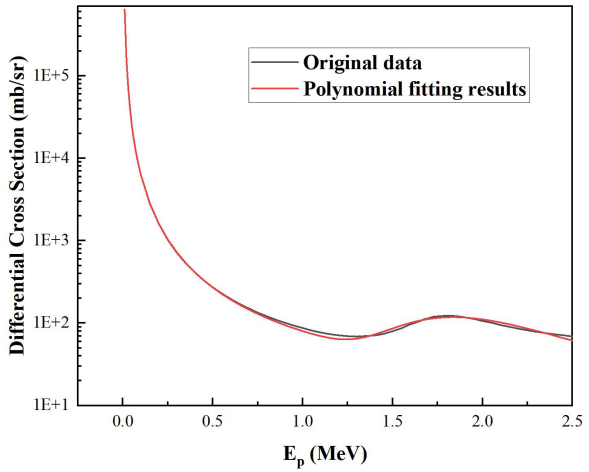
2. The covariance between the fit parameters

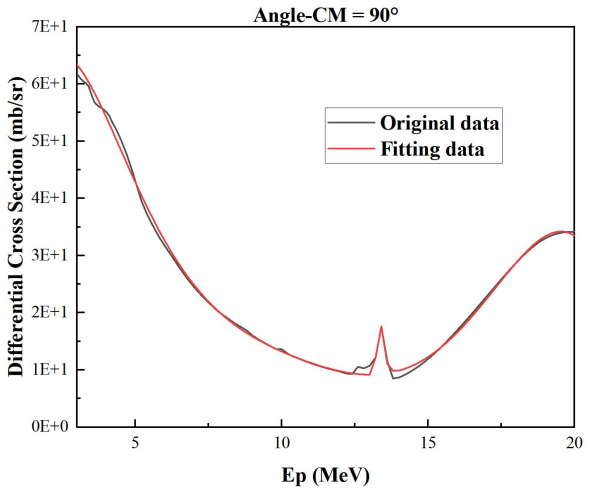
3. Functions describing the excitation function of elastic scattering of charged particles (90°).

Rapid descent energy region



Slowly changing energy region





- Construct a function to describe the region of rapid descent: $y_{10} = a_0 E^{a_1}$
- Construct a function to describe the resonance peaks:

$$y_{11} = a_2 + a_3 e^{(-e^{(-z)})-z+1}; z = (E - a_4)/a_5$$

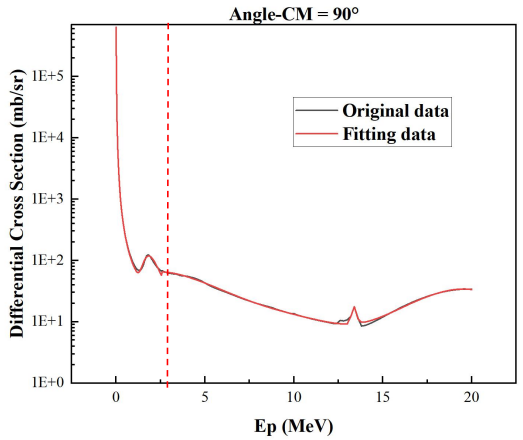
- First function:

$$y_1 = y_{10} + y_{11} = a_0 E^{a_1} + a_2 + a_3 e^{(-e^{(-z)})-z+1}$$

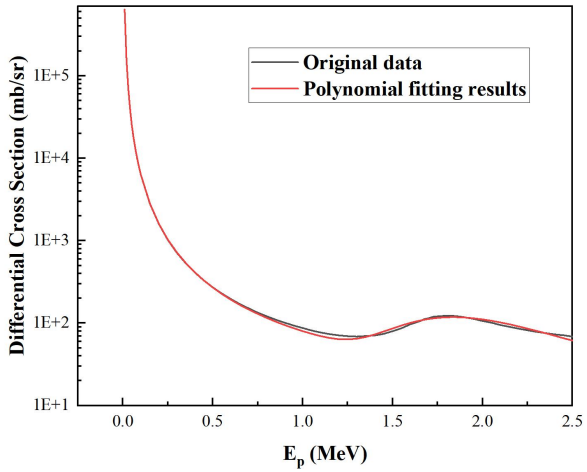
2. The covariance between the fit parameters

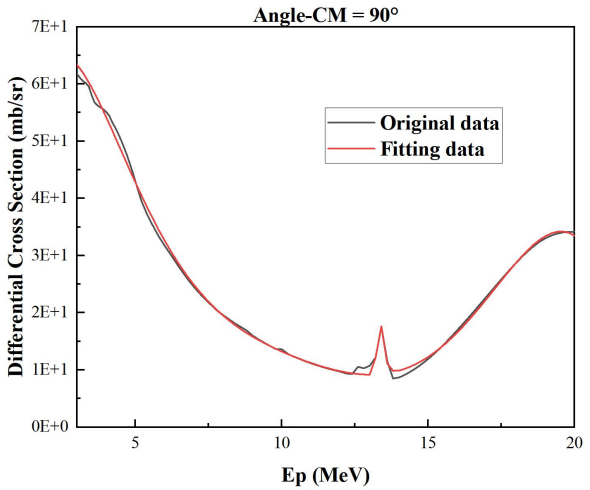
3. Functions describing the excitation function of elastic scattering of charged particles (90°).

Rapid descent energy region



Slowly changing energy region





- Second function:
  - $y_{20} = a_6 e^{(-e^{(-z)})-z+1)}; z = (E - a_7)/a_8;$
  - $y_{21} = a_9 + a_{10} * E + \ldots + a_{15} * E^6$
  - $y_2 = y_{20} + y_{21} = a_6 e^{(-e^{(-z)})-z+1)} + a_9 + a_{10} * E + \ldots + a_{15} * E^6$
- Final function:

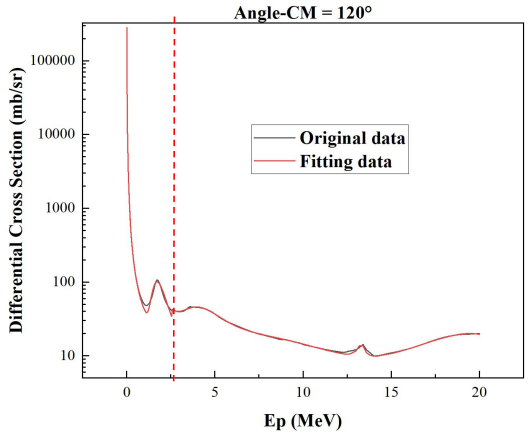
$$f(E) = \begin{cases} a_0 E^{a_1} + a_2 + a_3 e^{(-e^{(-z)})-z+1)} \\ a_6 e^{(-e^{(-z)})-z+1)} + a_9 + a_{10} * E + \ldots + a_{15} * E^6 \end{cases}$$

After fitting, we can obtain the 16 parameters from a_0 to a_{15} for the total function.

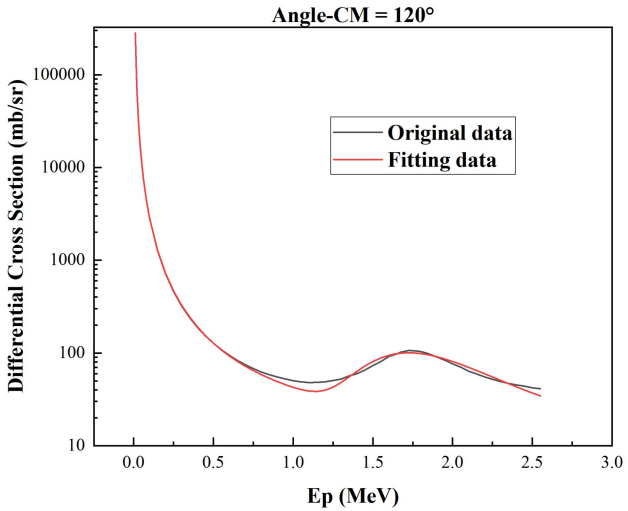
2. The covariance between the fit parameters

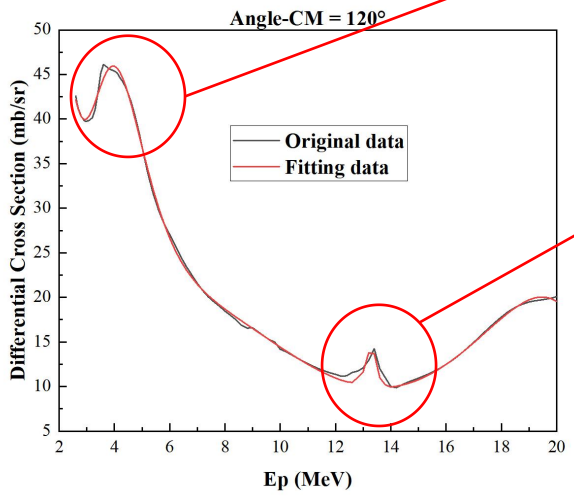
3. Functions describing the excitation function of elastic scattering of charged particles (120°).

Rapid descent energy region



Slowly changing energy region





- Final function:

$$f(E) = \begin{cases} a_0 E^{a_1} + a_2 + a_3 e^{(-e^{(-z)})-z+1)} \\ a_6 e^{(-e^{(-z)})-z+1)} + a_9 e^{(-e^{(-z)})-z+1)} + a_{12} + a_{13} * E + \ldots + a_{18} * E^6 \end{cases}$$

- For higher energy regions, more resonance peaks can be added to describe more resonance functions
- It is always possible to find a multi-parameter function to describe the excitation function

2. The covariance between the fit parameters

4. Construct the covariance matrix of the fitted parameters and reconstruct.

$$V_y \approx V_{y'}$$

$$S\ ;\ S_{ij} = \frac{\partial y_{(x_i)}}{\partial a_j}$$

$$V_{y'} = S V_p S^T$$

$$V_p = (S^T (V_y)^{-1} S)^{-1}$$

V_y: The original covariance matrix of the excitation function calculated by RAC

$V_{y'}$: Reconstruct covariance matrix of excitation function

S: Sensitivity matrix of the fitted parameters

S_{ij}: Matrix elements of the sensitivity matrix

$y(x)$: Fit function

a: Fitted parameter

V_p is the final result given in the file, giving the covariance between the parameters

2. The covariance between the fit parameters

4. Construct the covariance matrix of the fitted parameters and reconstruct (90°).

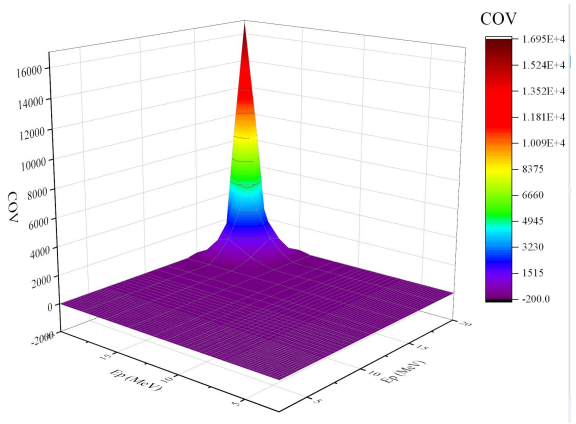
V_y ≈ $V_{y'}$

$$S\ ;\ S_{ij} = \frac{\partial y_{(x_i)}}{\partial a_j}$$

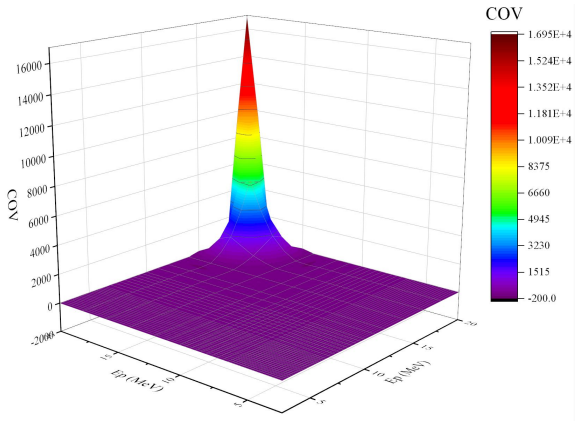
$$V_p = (S^T (V_y)^{-1} S)^{-1}$$

$$V_{y'} = S V_p S^T$$

V_y:



$V_{y'}$:



- The average error of the reconstructed covariance matrix elements (**90°**) is around 0.361‰.

$$Error = \frac{1}{i * j} \sum_i \sum_j \frac{ABS(V_{y_{ij}} - V_{y'_{ij}})}{V_{y_{ij}}}$$

2. The covariance between the fit parameters

5. The final file (the covariance between the coefficients), take the excitation function as an example .

```
0.00000+00 0.00000+00          0          1          1          1923734 2     6
0.00000+00 0.00000+00          0          5       1981          45923734 2     7
1.000000-5 2.000000+4 2.253600+4 2.837100+4 3.571700+4 4.496500+4923734 2     8
5.660800+4 7.126400+4 8.971600+4 1.129400+5 1.421900+5 1.790100+5923734 2     9
2.253600+5 2.837100+5 3.571700+5 4.496500+5 5.660800+5 7.126400+5923734 2     10
8.971600+5 1.129400+6 1.335700+6 1.498700+6 1.790100+6 2.253600+6923734 2     11
2.837100+6 3.571700+6 4.496500+6 5.317600+6 5.966500+6 6.694600+6923734 2     12
7.511400+6 8.178600+6 8.663200+6 9.456200+6 1.061000+7 1.155200+7923734 2     13
1.223700+7 1.335700+7 1.454400+7 1.540600+7 1.631800+7 1.728600+7923734 2     14
1.886800+7 2.253600+7 3.000000+7 0.00000+00 0.00000+00 0.00000+00923734 2     15
```

θ_1	E_1	E_2	E_3	...	E_i
cov_a_{00}	...	cov_a_{0i}	cov_a_{11}	...	cov_a_{ii}
θ_n	E_1	E_2	E_3	...	E_i
cov_a_{00}	...	cov_a_{0i}	cov_a_{11}	...	cov_a_{ii}

Advantage: very low data volume , easy to reconstruct V_y and higher accuracy

Disadvantage: 0.4 ‰ difference between V_y and $V_{y'}$

Conclusion

Conclusion

- The new evaluation of ^{7}Be system in this work is reliable. The new experiment data of ^{6}Li(p, p)^{6}Li reaction at 2023 has been considered in the new RAC calculation and there is a good agreement between the experiment data and calculations.

- New evaluation data can be use to construct evaluation database as ENDF-6 format.

- Two ideas have been proposed to give the covariance of the excitation function of elastic scattering of charged particles in a standard file.

  1. List of Table
  2. Fit the excitation function and then give the covariance between the fit parameters

  Maybe the second method is better to be accepted.

Thanks for your attention