T-2 light element evaluations for neutron cross section standards

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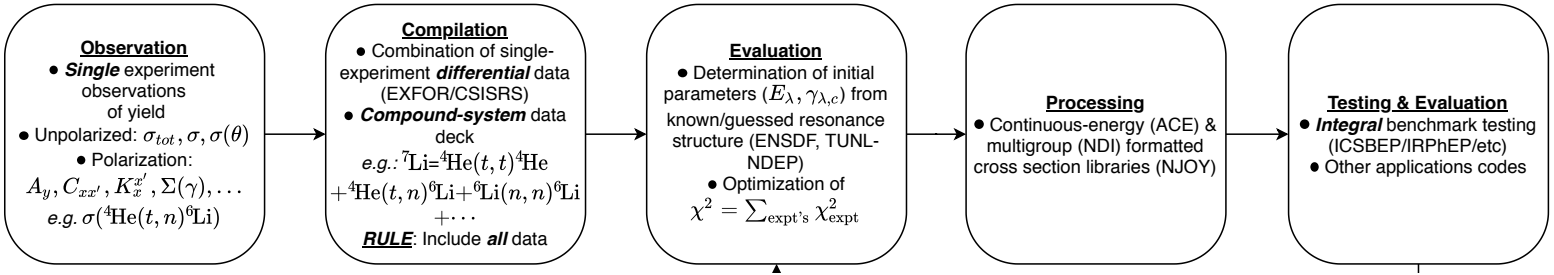
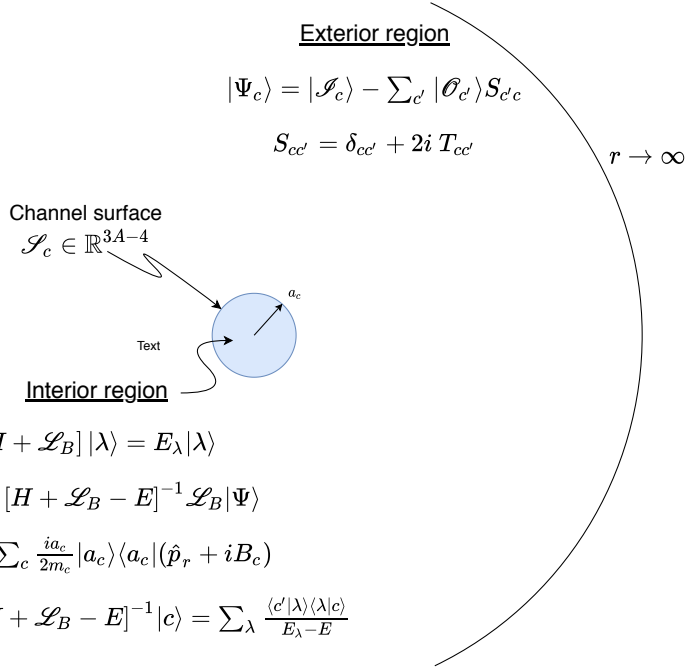
IAEA Standards
2026-01-26--30

LA-UR-26-20441

R-matrix evaluation for light nuclear systems



- Cross section evaluation for light-elements (A≦20)
  - Quantum mechanical R-matrix (Wigner)
  - Correlates ***all*** experimental data simultaneously
    - pol/unpol; neutrons/charged-particles
    - Elastic/inel/transfer/reaction/break-up
    - Upper energy-limit restricted (break-up) < 20 MeV



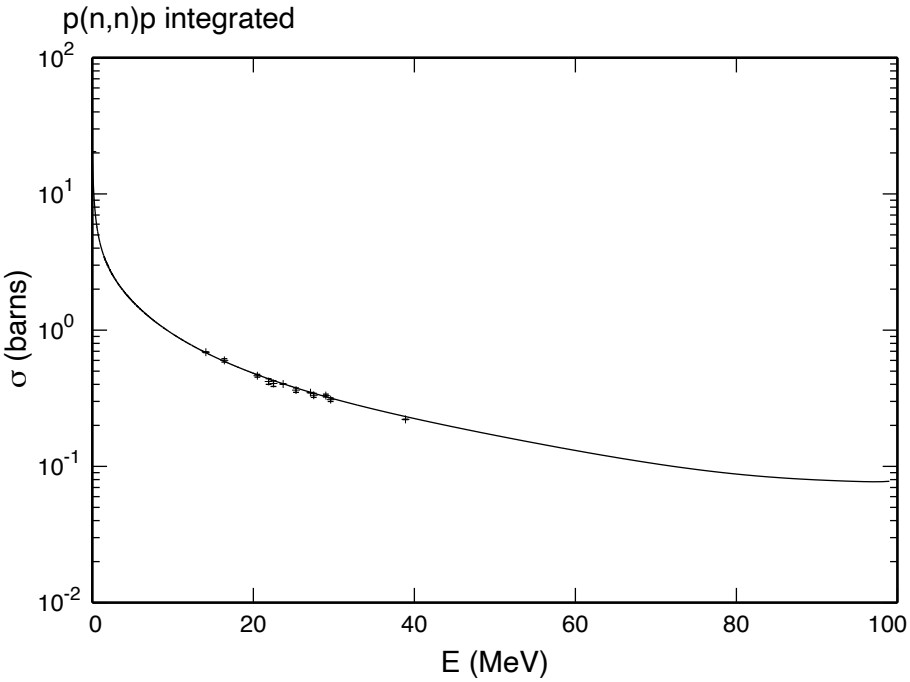
Present Results for n-p Scattering (^{1}H) Evaluation up to 100 MeV

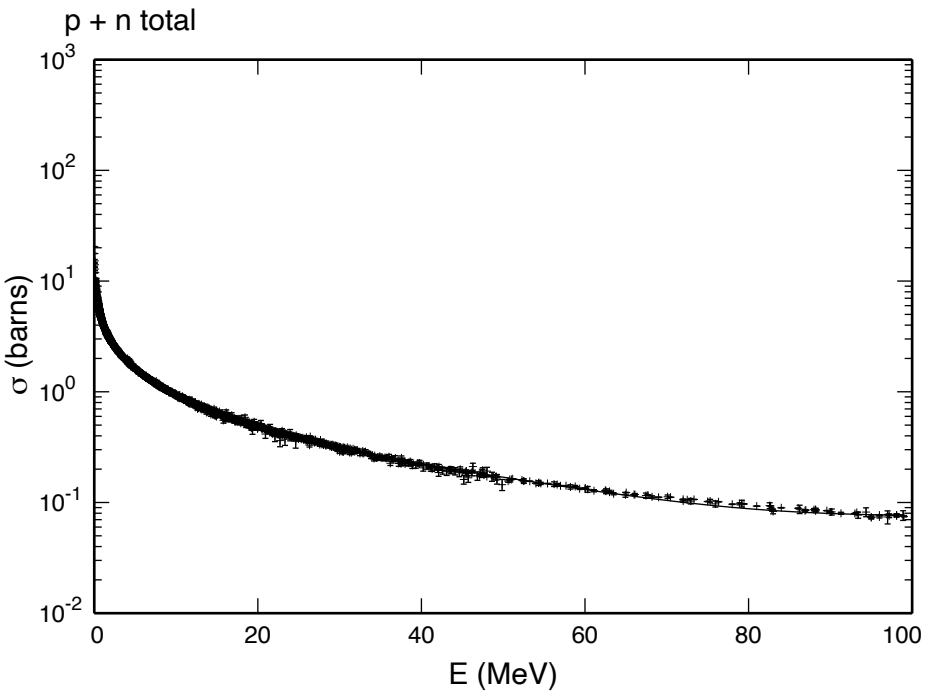
Charge-Independent Analysis of N-N System up to 100 MeV

Channel	a_c (fm)	l_{max}
p+p	3.26	3
n+n	3.26	3
n+p	3.26	3
γ+d	84.6	1

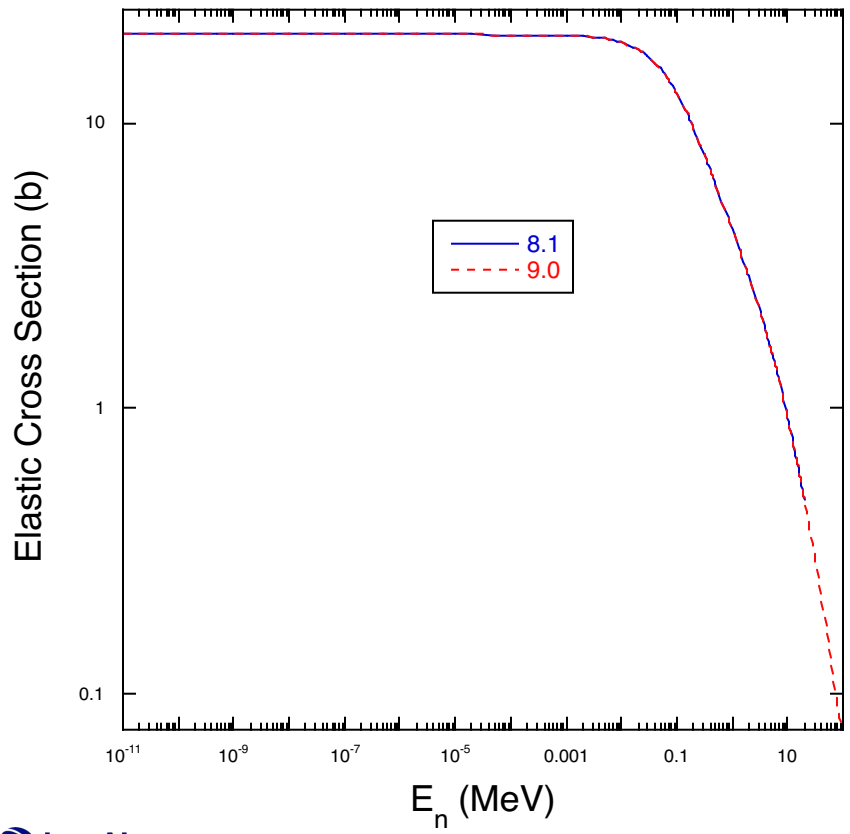
Reaction	# Pts.	χ^2	Observable Types
p(p,p)p	717	1311	$\sigma(\theta)$, $A_y(p)$, $C_{x,x}$, $C_{y,y}$, $K_x^{x'}$, $K_y^{y'}$, $K_z^{x'}$
n(n,n)n	1	0	σ_{int} (a_0)
p(n,n)p	5285	4622	σ_T, $\sigma(\theta)$, $A_y(n)$, $C_{y,y}$, $K_y^{y'}$
p(n,γ)d	85	159	σ_{int}, $\sigma(\theta)$, $A_y(n)$
d(γ,n)p	82	88	σ_{int}, $\sigma(\theta)$, $\Sigma(\gamma)$, $P_y(n)$
Total	6170	6180	19

free parameters = 52 $\Rightarrow$ χ^2/degree of freedom = 1.01

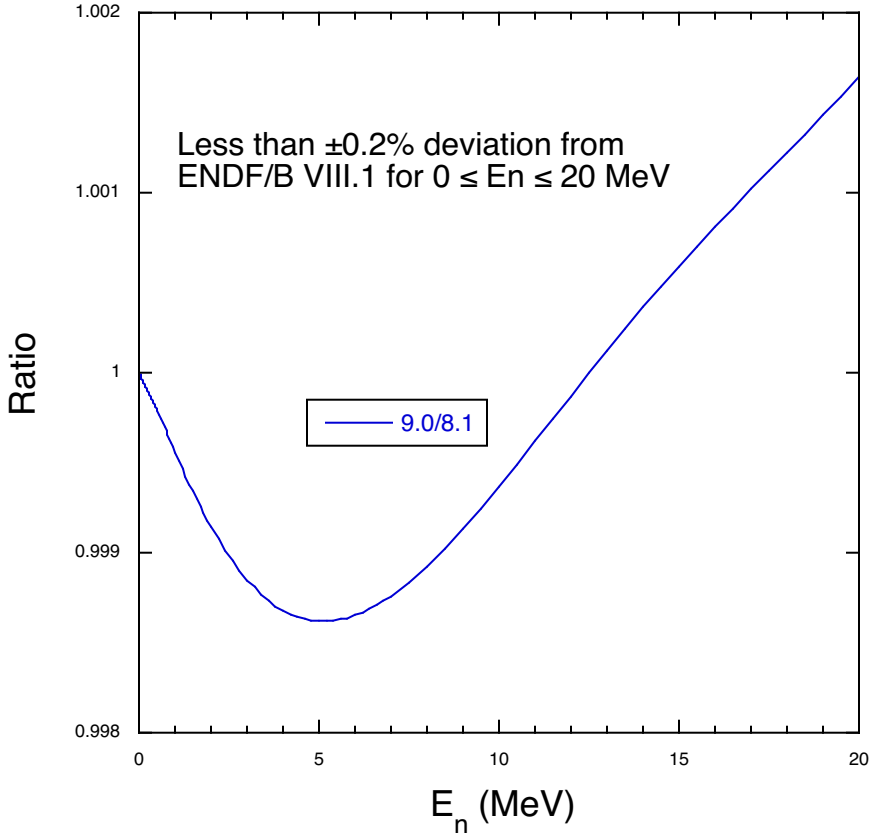

p(n,n)p integrated
σ (barns)
E (MeV)
10^2
10^1
10^0
10^-1
10^-2
0
20
40
60
80
100


p + n total
σ (barns)
E (MeV)
10^3
10^2
10^1
10^0
10^-1
10^-2
0
20
40
60
80
100

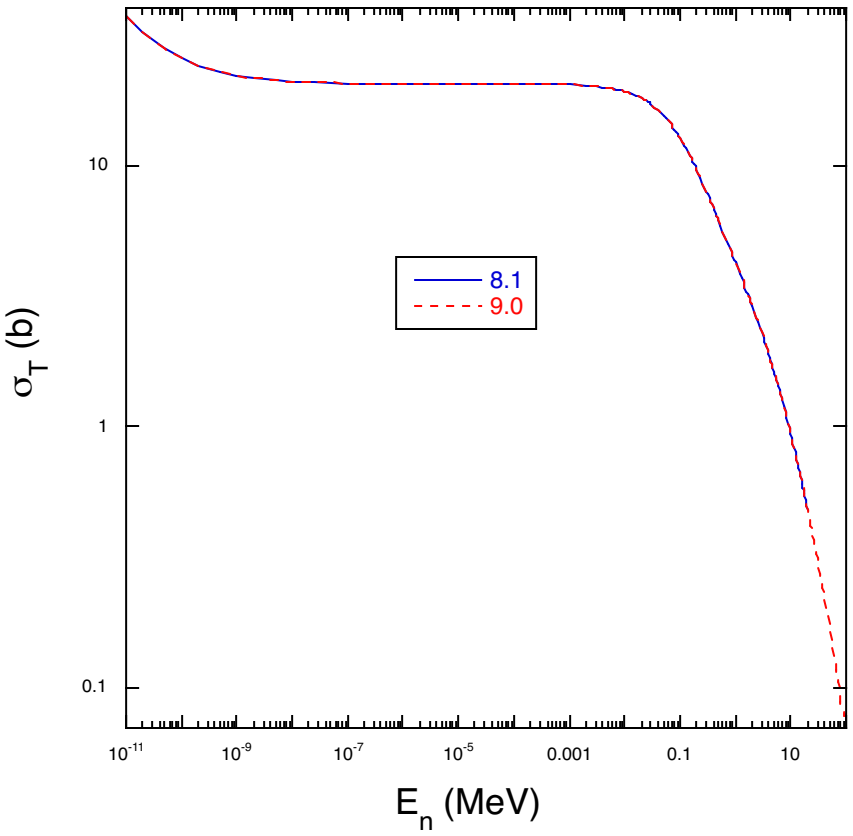
Elastic Cross Section



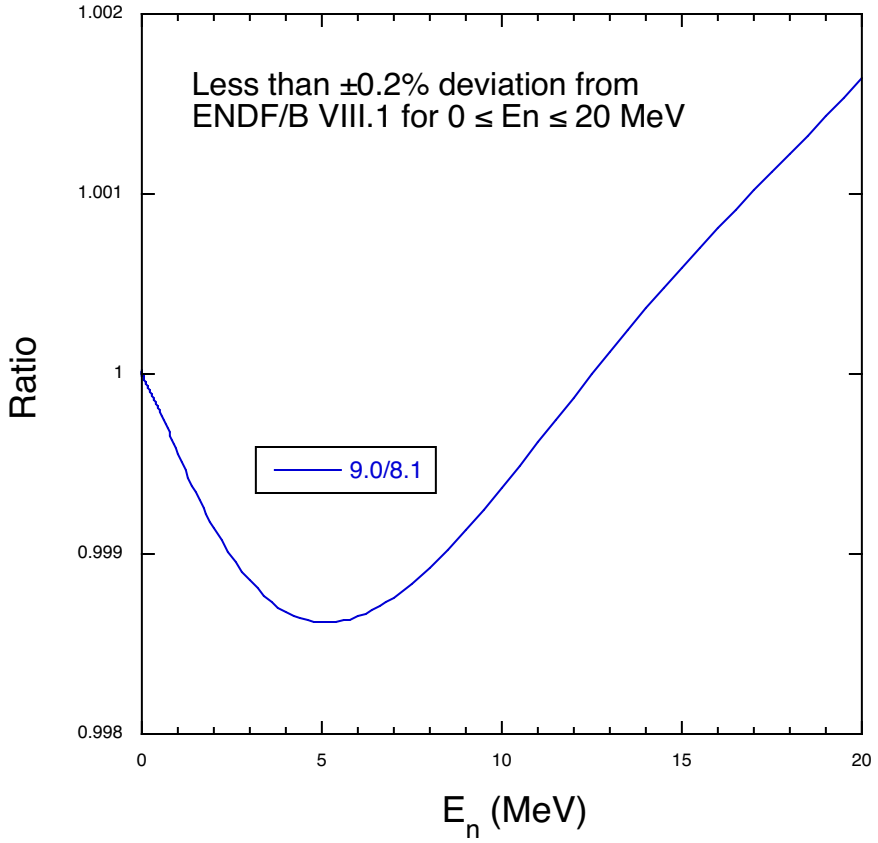
Ratio of Elastic Cross Sections



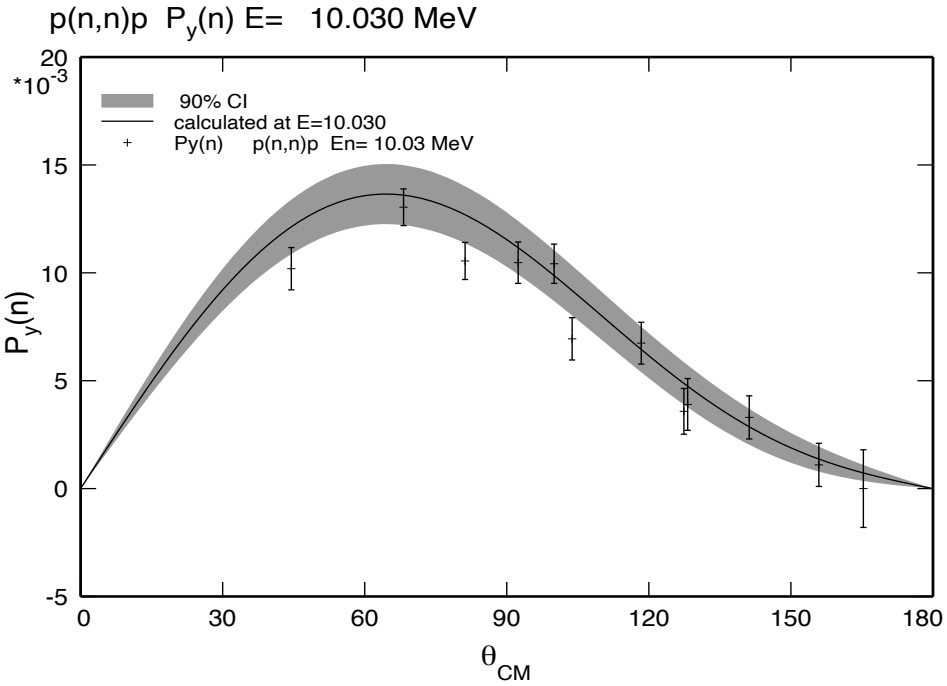
Total Cross Section

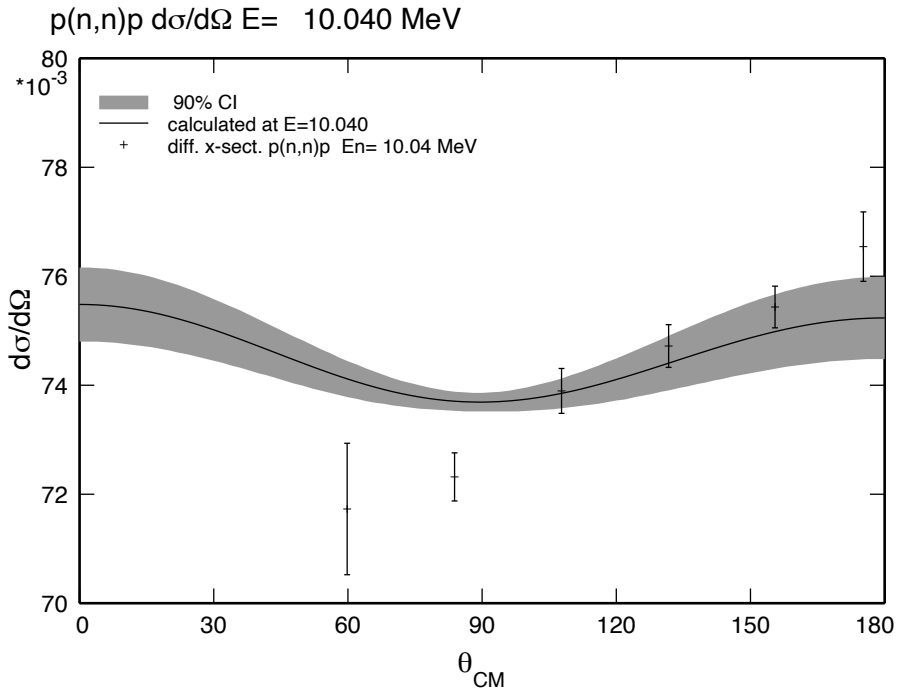


Ratio of Total Cross Sections

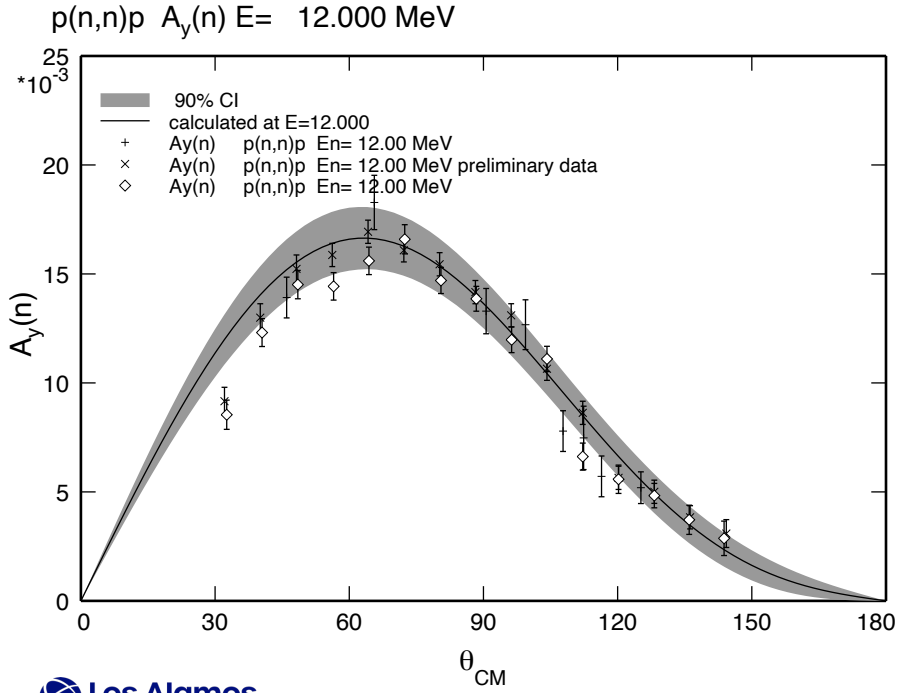


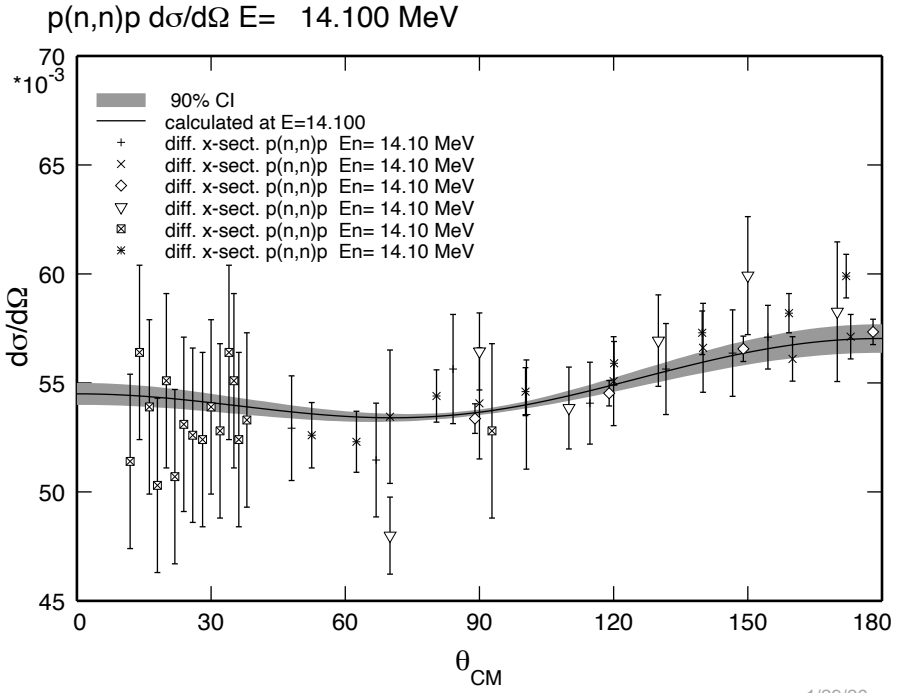
Differential Data



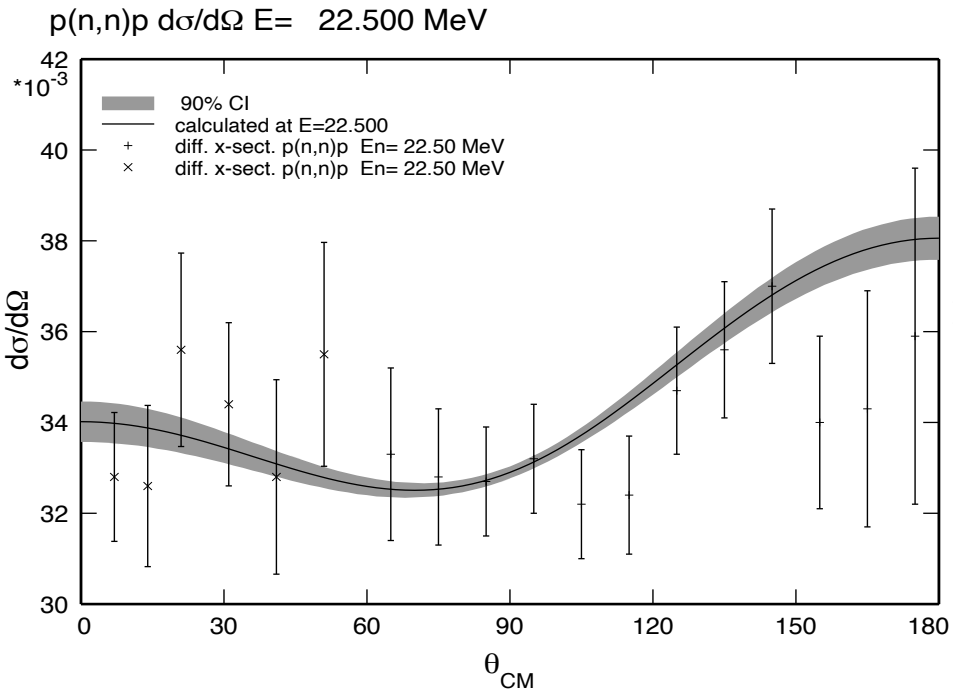


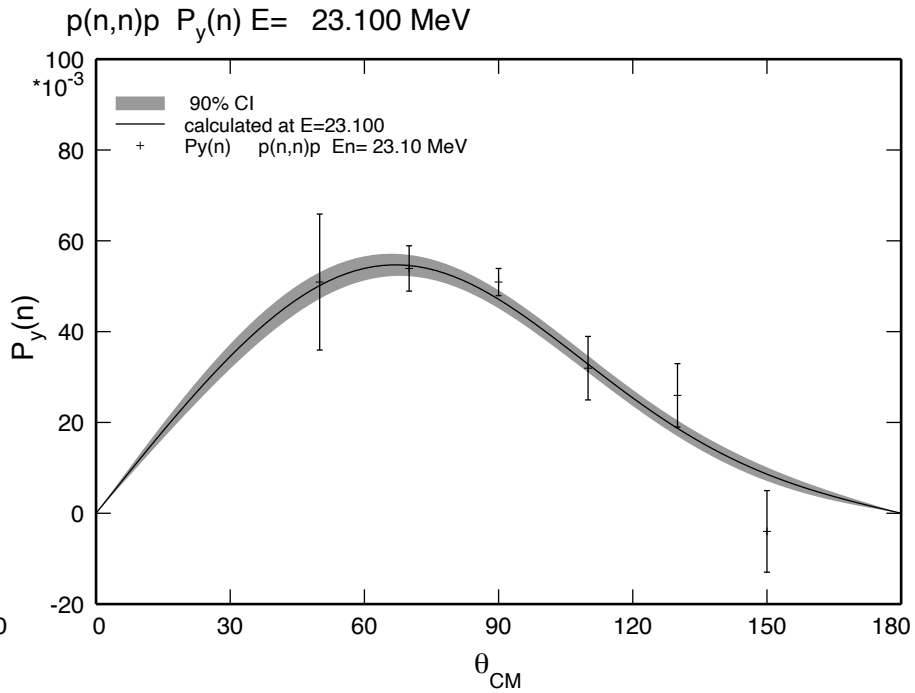
Differential Data, cont.



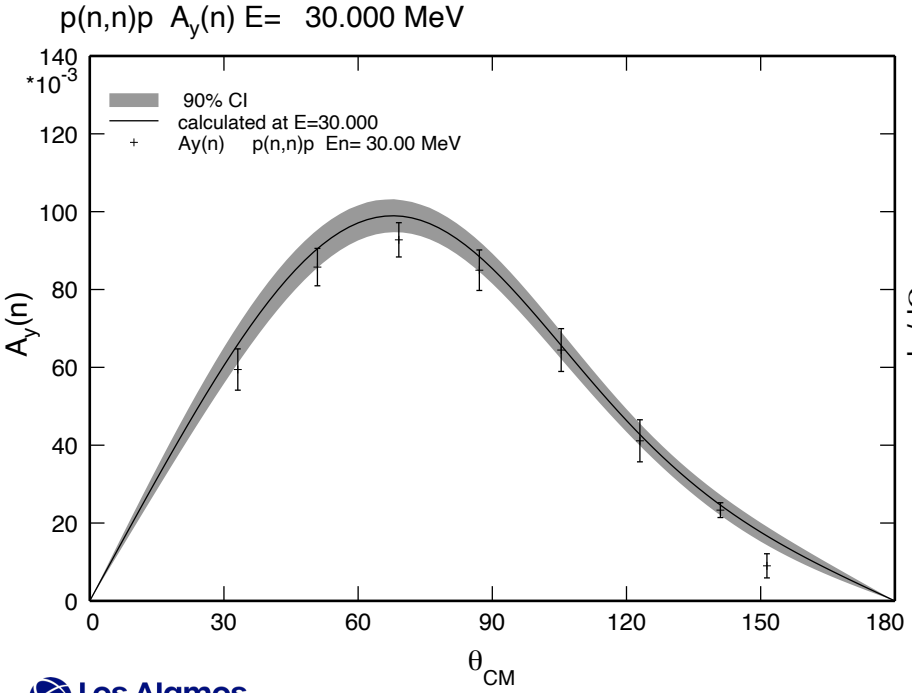


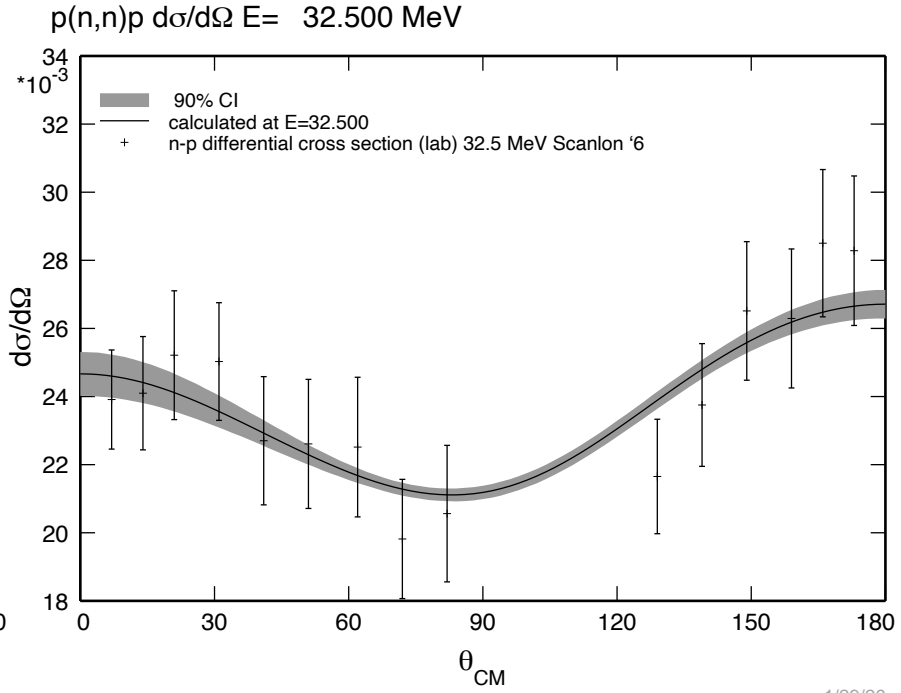
Differential Data, cont.



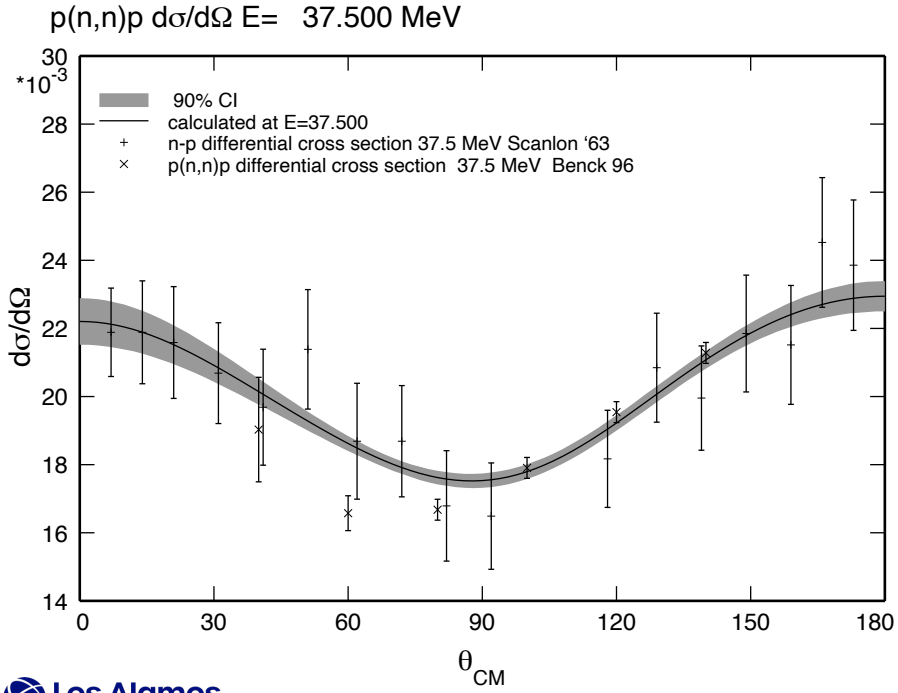


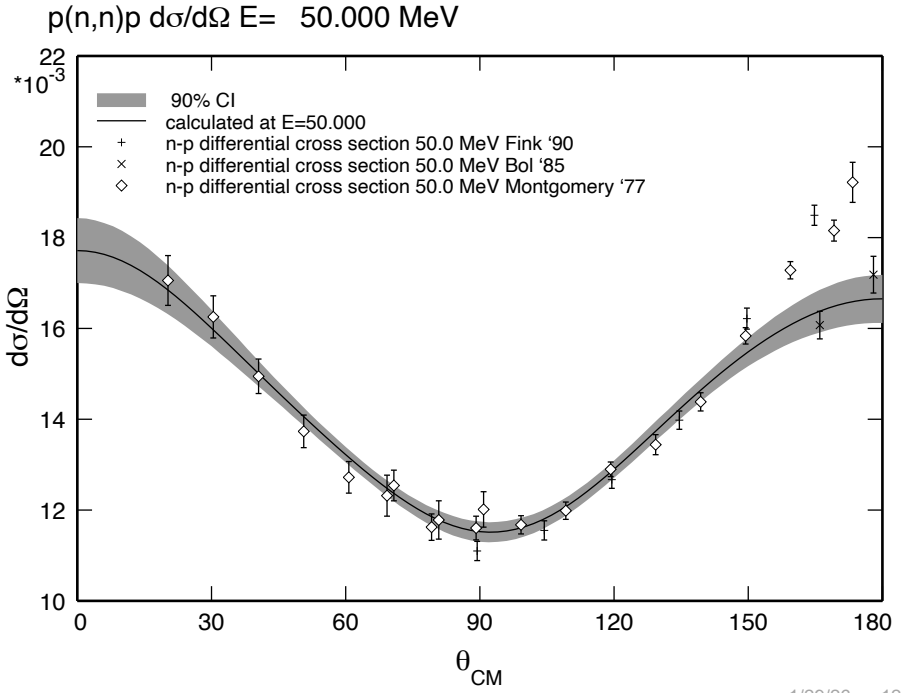
Differential Data, cont.

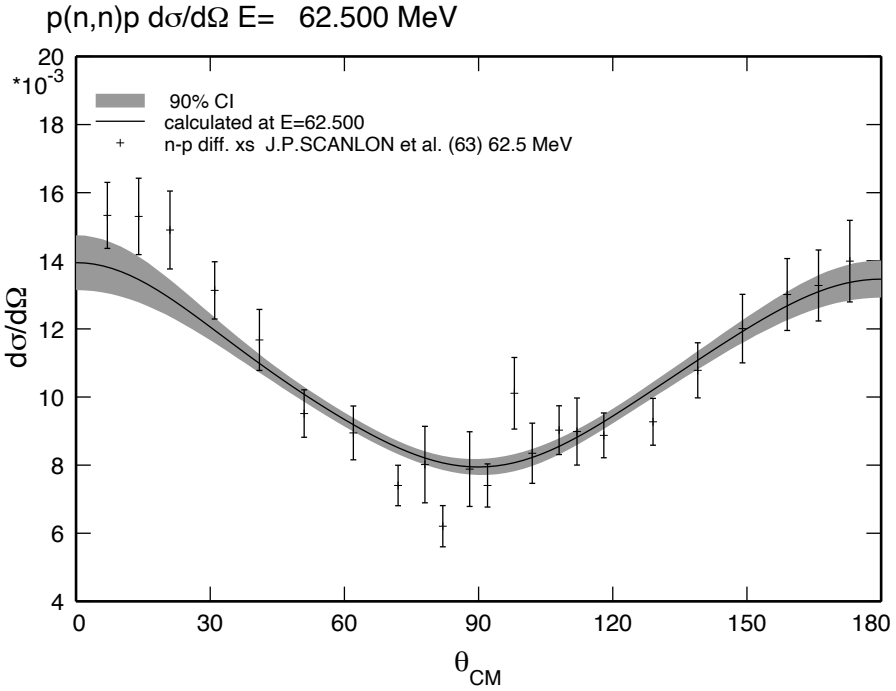


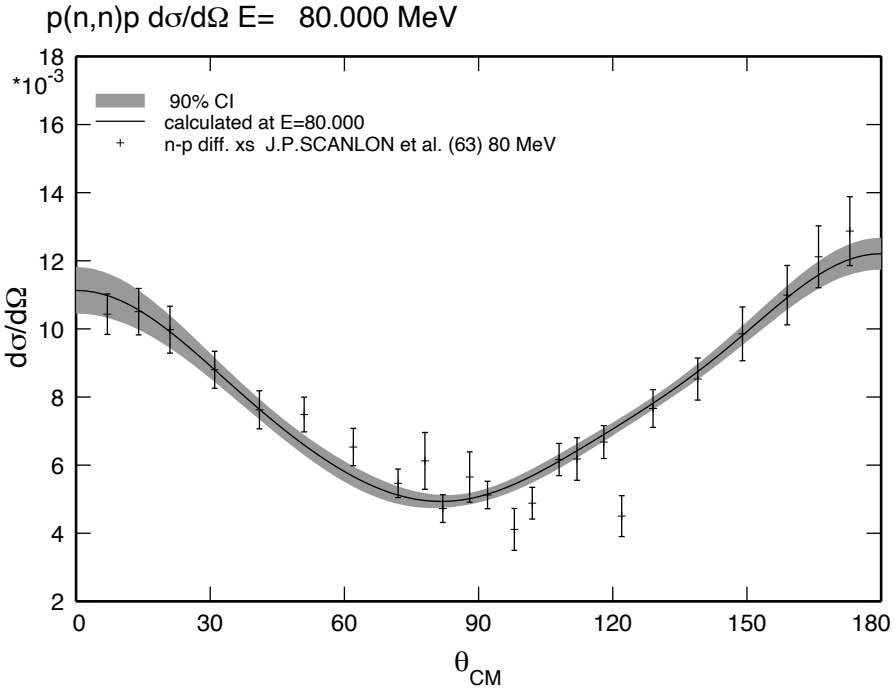


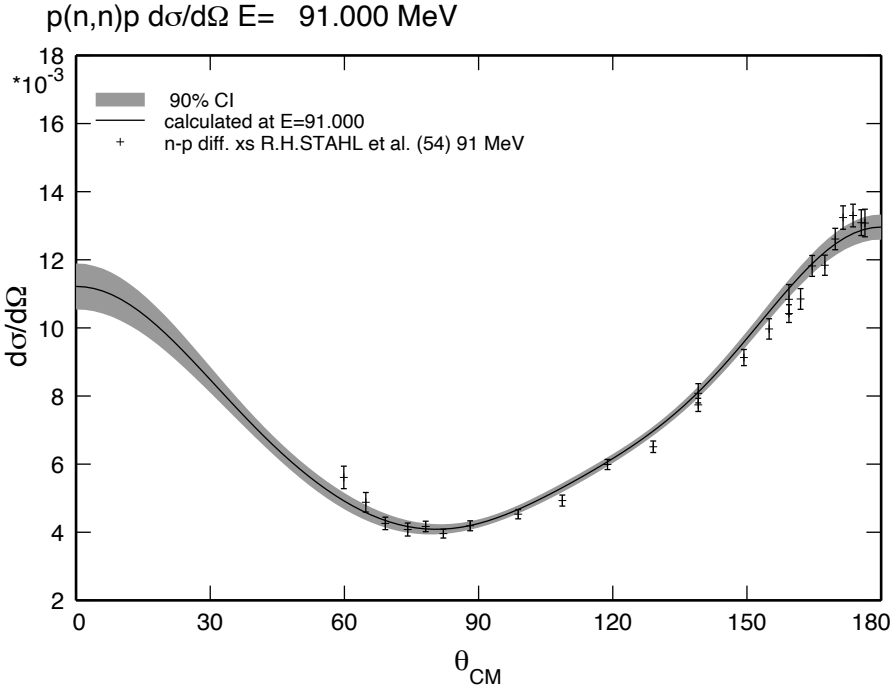
Differential Data, cont.

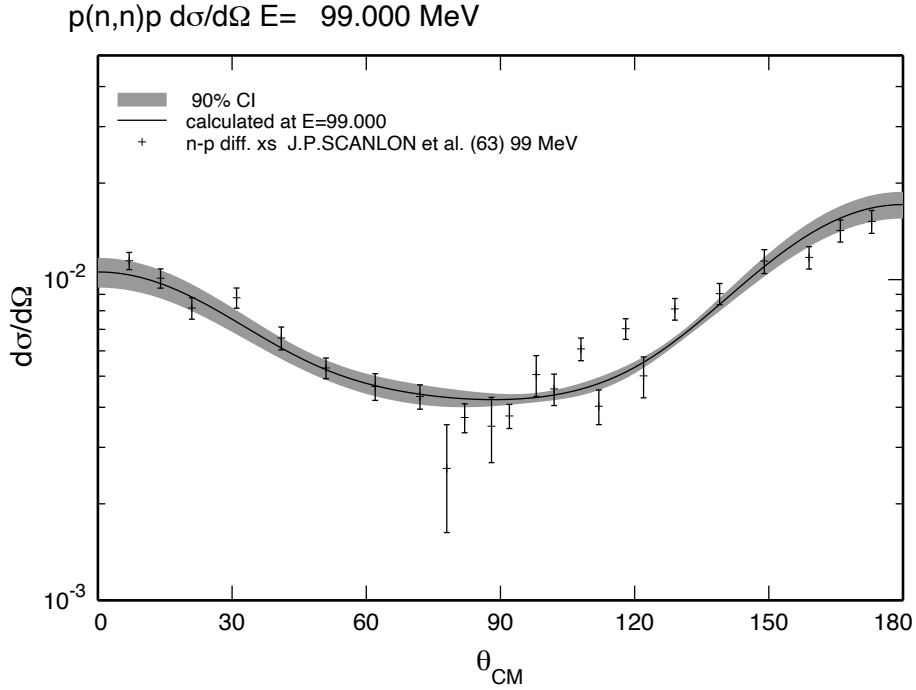




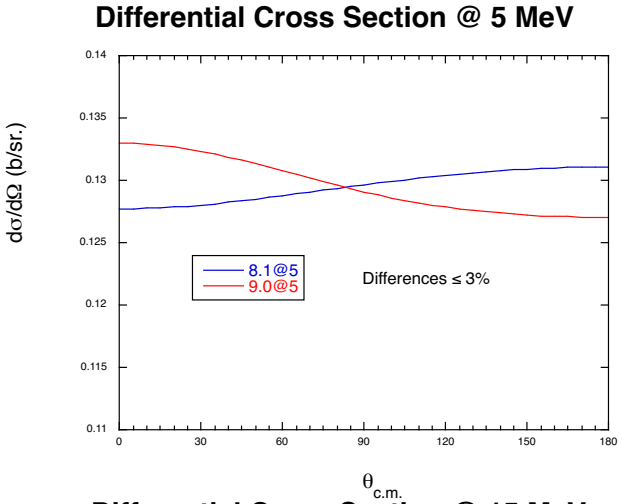

p(n,n)p dσ/dΩ E= 62.500 MeV
*10-3
90% CI
calculated at E=62.500
n-p diff. xs J.P.SCANLON et al. (63) 62.5 MeV
dσ/dΩ
θCM

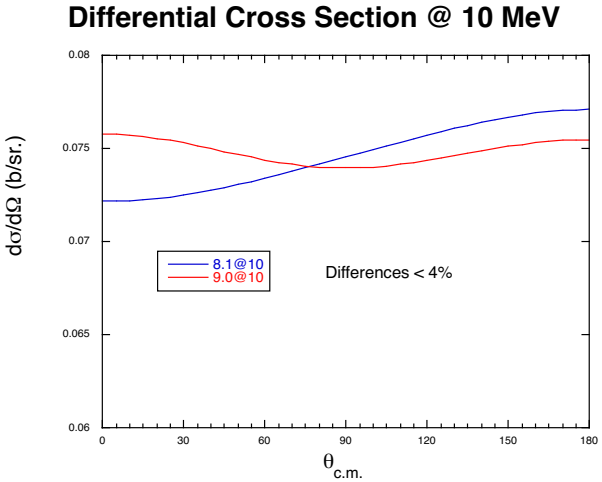

p(n,n)p dσ/dΩ E= 80.000 MeV
*10-3
90% CI
calculated at E=80.000
n-p diff. xs J.P.SCANLON et al. (63) 80 MeV
dσ/dΩ
θCM

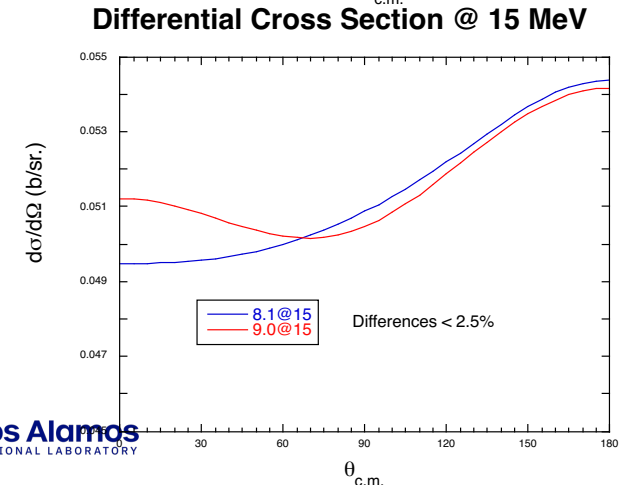

p(n,n)p dσ/dΩ E= 91.000 MeV
*10-3
18
16
14
12
10
8
6
4
2
dσ/dΩ
90% CI
calculated at E=91.000
n-p diff. xs R.H.STAHL et al. (54) 91 MeV
0
30
60
90
120
150
180
θCM

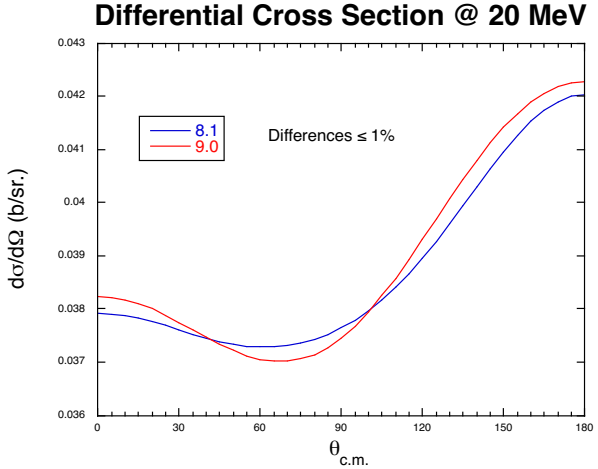

p(n,n)p dσ/dΩ E= 99.000 MeV
10-2
10-3
dσ/dΩ
90% CI
calculated at E=99.000
n-p diff. xs J.P.SCANLON et al. (63) 99 MeV
0
30
60
90
120
150
180
θCM

Differences with ENDF 8.1 Angular Distributions









Conclusions

- NN analysis up to 100 MeV gives a good description of most of the data included for all the reactions considered.
- Integrated n-p cross sections do not change from the previous analysis by more than 0.2% up to 20 MeV.
- Much larger deviations occur for the angular distributions, becoming as large as ~4% at 10 MeV. This should be investigated further, as this is the energy of one of the better measurements of the angular distribution (Boukharouba et al.)

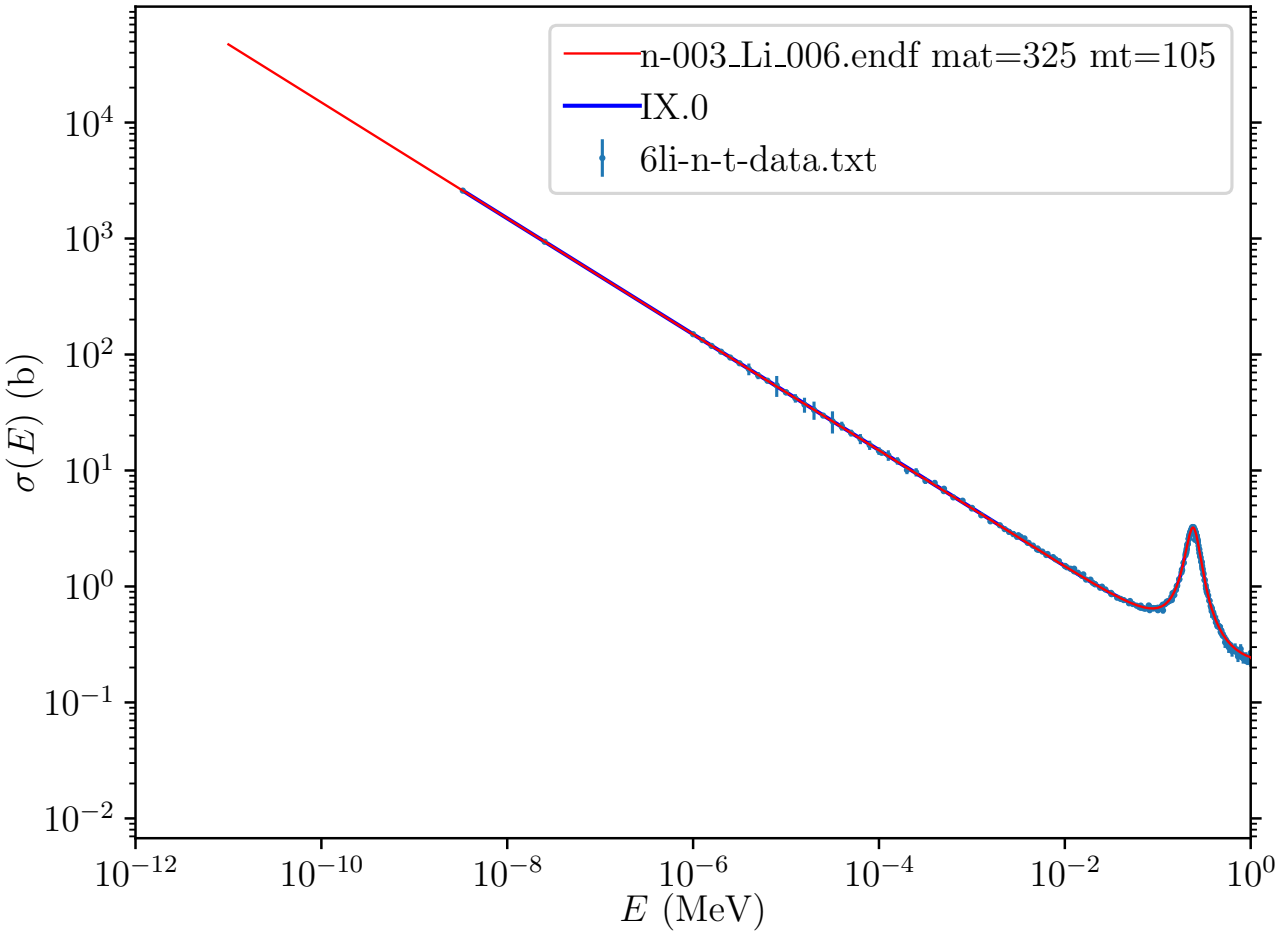
Summary of ^{7}Li R-matrix Analysis

Channel	l_{max}	a_c (fm)
t+^{4}He	5	4.0
n+^{6}Li	3	5.0
d+^{5}He	1	7.5
n+^{6}Li*	1	5.0
p+^{6}He	1	5.0
n+^{6}Li**	1	5.5

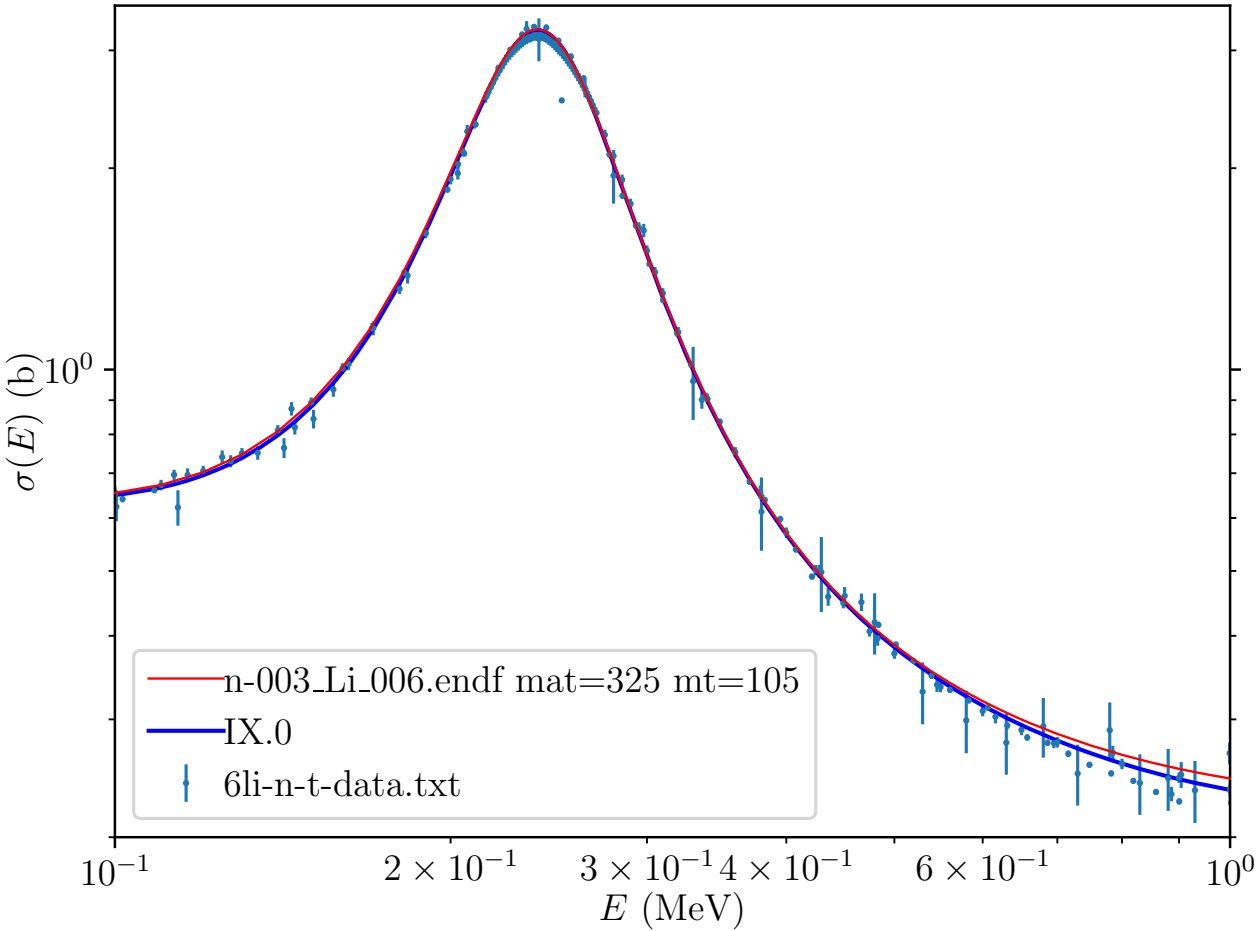
Reaction	Energy range	Observables	# data points	χ^2/point
^{4}He(t,t)^{4}He	E_t = 3-17 MeV	$\sigma(\theta)$, $A_y(\theta)$	1689	1.03
^{4}He(t,n)^{6}Li	E_t = 8.75-14.4 MeV	$\sigma(\theta)$	39	1.14
^{4}He(t,n)^{6}Li*	E_t = 8.75-14.4 MeV	$\sigma(\theta)$	3	0.42
^{6}Li(n,t)^{4}He	E_n = 0-8 MeV	σ_{int} , $\sigma(\theta)$	2840	1.44
^{6}Li(n,n_0) ^{6}Li	E_n = 0-8 MeV	σ_{int} , σ_T, $\sigma(\theta)$, $P_y(\theta)$	1451	1.36
^{6}Li(n,d) ^{6}Li	E_n = 0-8 MeV	σ_{int} , $\sigma(\theta)$	28	11.9
^{6}Li(n,n_1) ^{6}Li*	E_n = 0-8 MeV	σ_{int} , $\sigma(\theta)$	175	2.11
^{6}Li(n,p) ^{6}He	E_n = 0-8 MeV	σ_{int} , $\sigma(\theta)$	92	1.58
^{6}Li(n,n_2) ^{6}Li**	E_n = 0-8 MeV	σ_{int}	41	0.30
Totals		17	6358	1.39*

*For 170 free parameters, χ^2/ν = 1.43

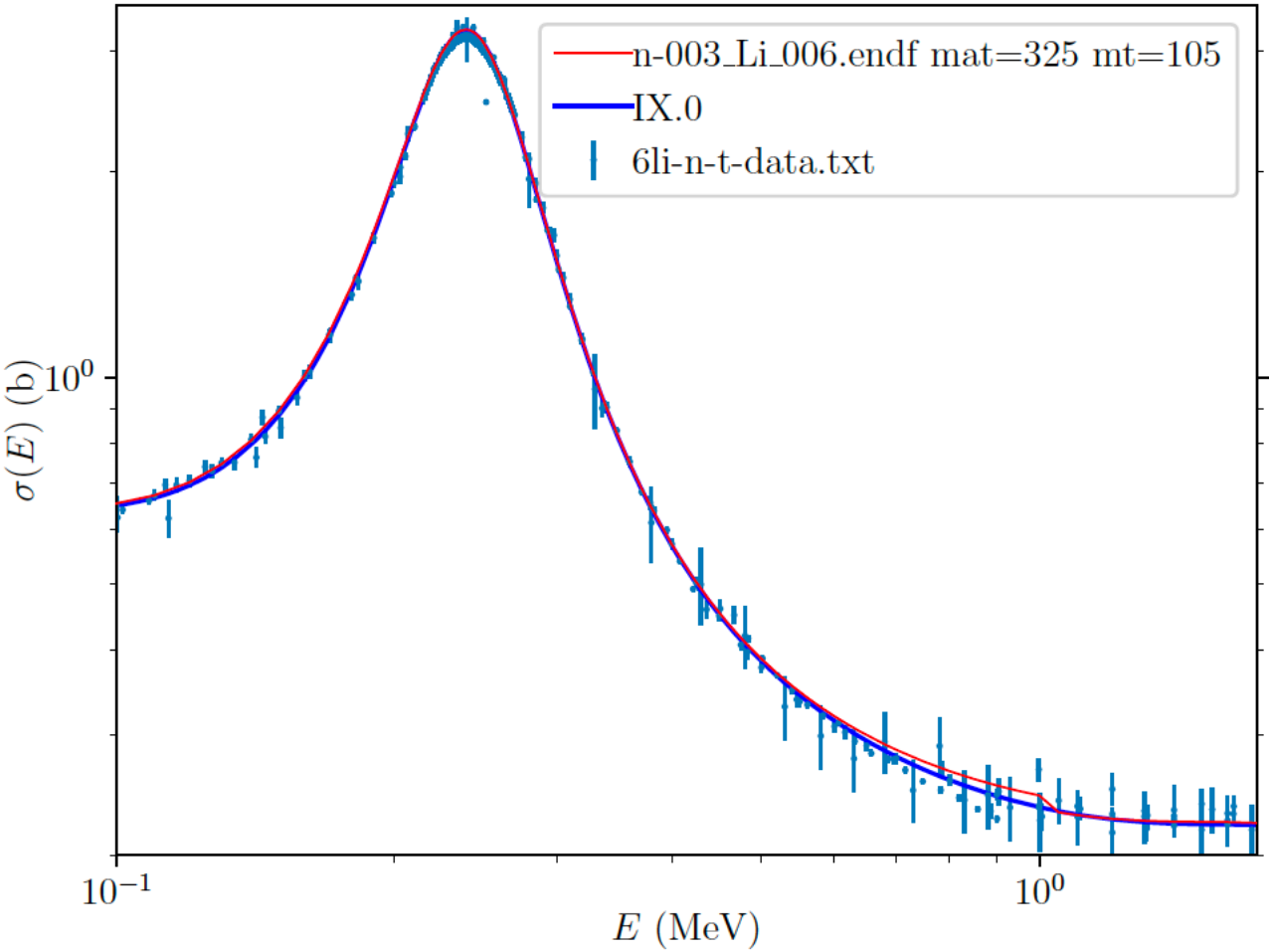
^{7}Li


n-003_Li_006.endf mat=325 mt=105
IX.0
6li-n-t-data.txt
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
$\sigma(E)$ (b)
10^{-12}
10^{-10}
10^{-8}
10^{-6}
10^{-4}
10^{-2}
10^{0}
E (MeV)

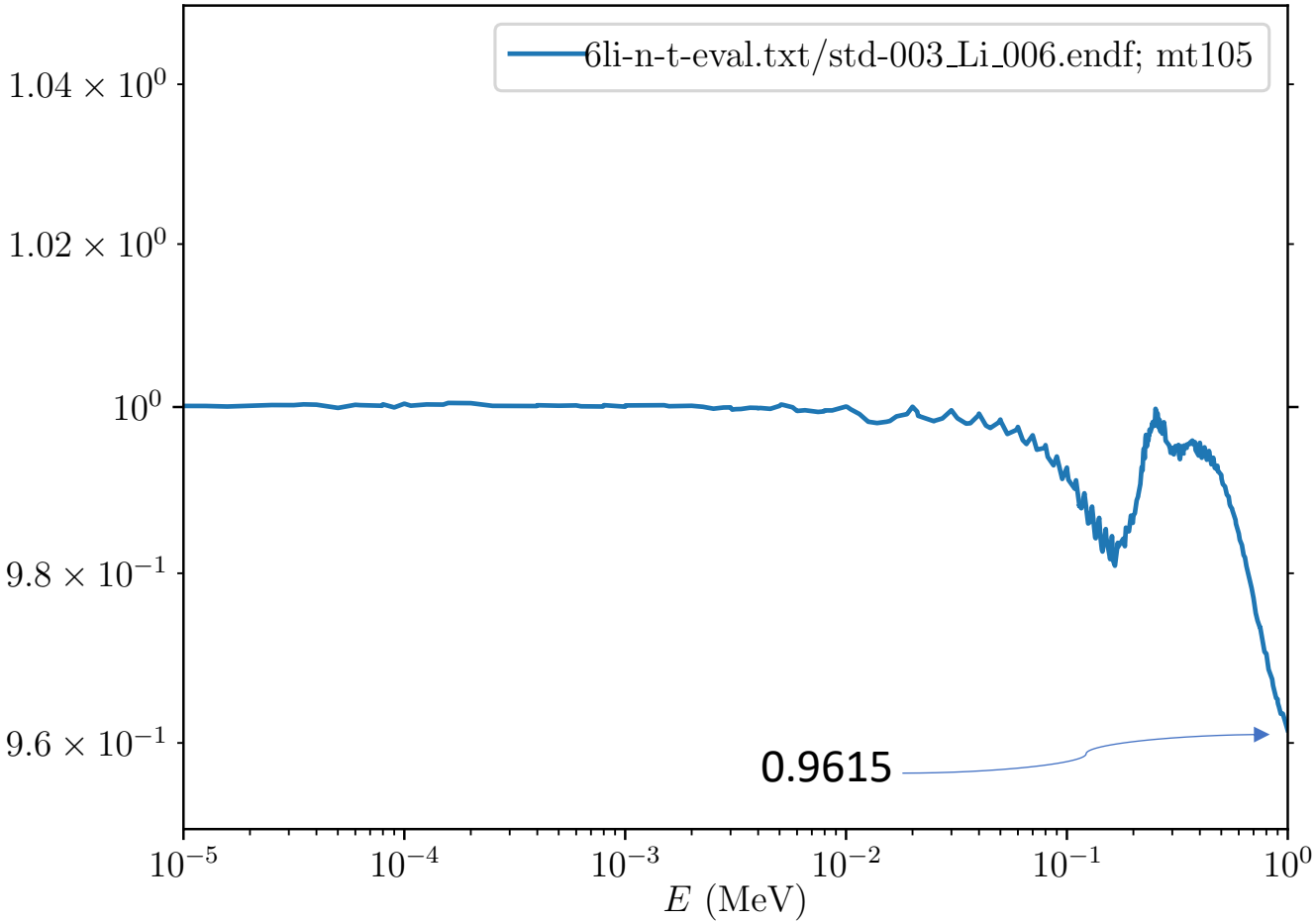
^{7}Li


10^0
$\sigma(E)$ (b)
n-003_Li_006.endf mat=325 mt=105
IX.0
6li-n-t-data.txt
10^{-1}
2×10^{-1}
3×10^{-1}
4×10^{-1}
6×10^{-1}
10^0
E (MeV)

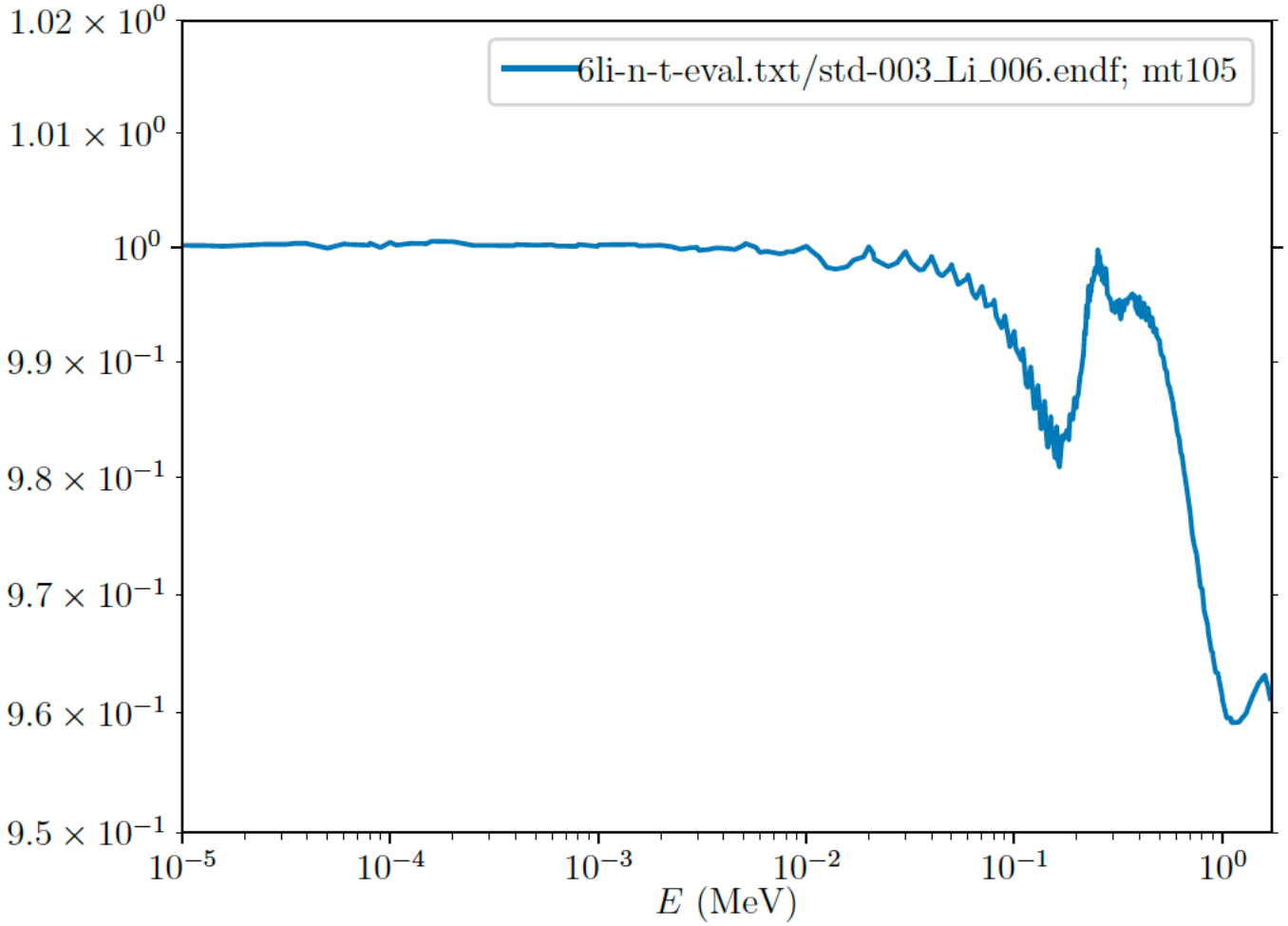
^{7}Li update


n-003_Li_006.endf mat=325 mt=105
IX.0
6li-n-t-data.txt
$\sigma(E)$ (b)
10^{0}
10^{-1}
10^{0}
E (MeV)

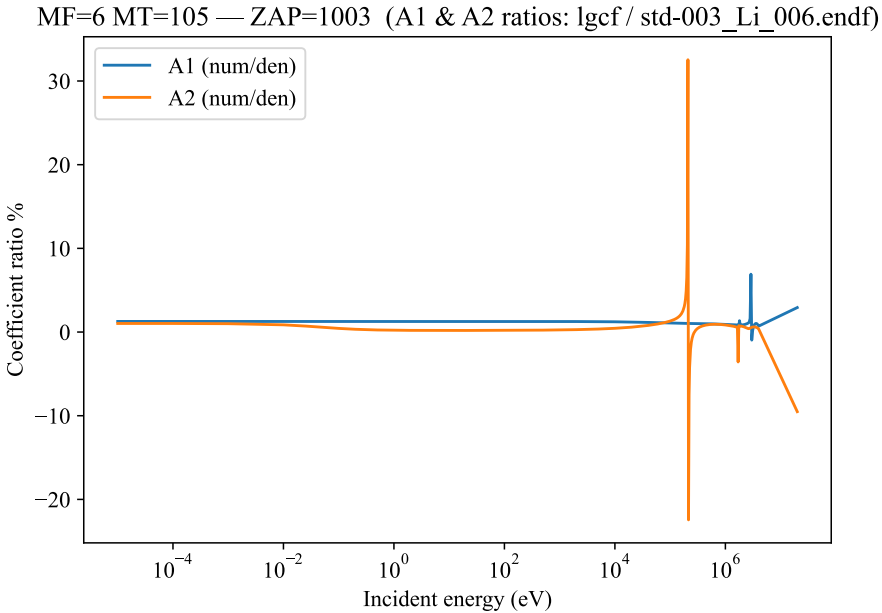
^{7}Li

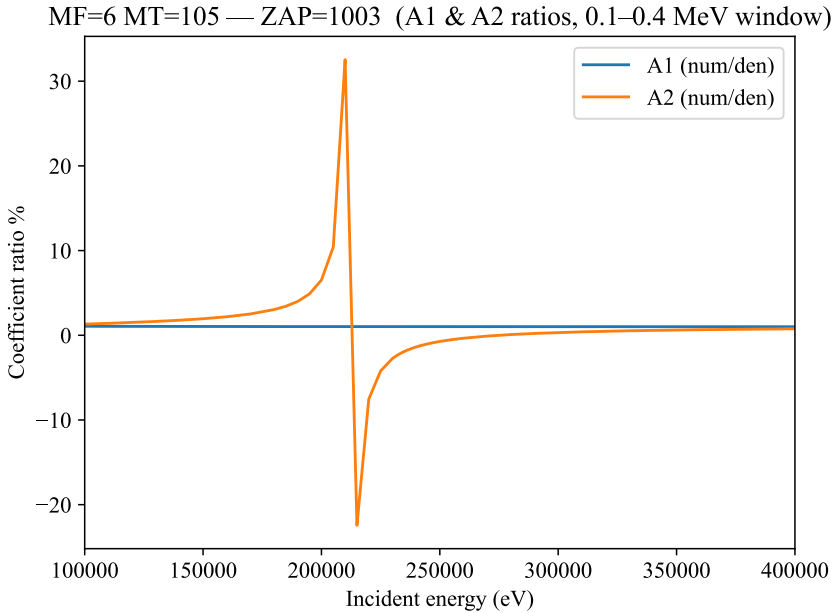

6li-n-t-eval.txt/std-003_Li_006.endf; mt105
1.04 × 10^0
1.02 × 10^0
10^0
9.8 × 10^−1
9.6 × 10^−1
0.9615
10^−5
10^−4
10^−3
10^−2
10^−1
10^0
E (MeV)

^{7}Li update


6li-n-t-eval.txt/std-003_Li_006.endf; mt105
1.02×10^{0}
1.01×10^{0}
10^{0}
9.9×10^{-1}
9.8×10^{-1}
9.7×10^{-1}
9.6×10^{-1}
9.5×10^{-1}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
E (MeV)

^{7}Li


MF=6 MT=105 — ZAP=1003 (A1 & A2 ratios: lgcf / std-003_Li_006.endf)
A1 (num/den)
A2 (num/den)
Coefficient ratio %
Incident energy (eV)


MF=6 MT=105 — ZAP=1003 (A1 & A2 ratios, 0.1–0.4 MeV window)
A1 (num/den)
A2 (num/den)
Coefficient ratio %
Incident energy (eV)

^{13}C

ENDF/B-VIII.0

Reaction-by-reaction summary

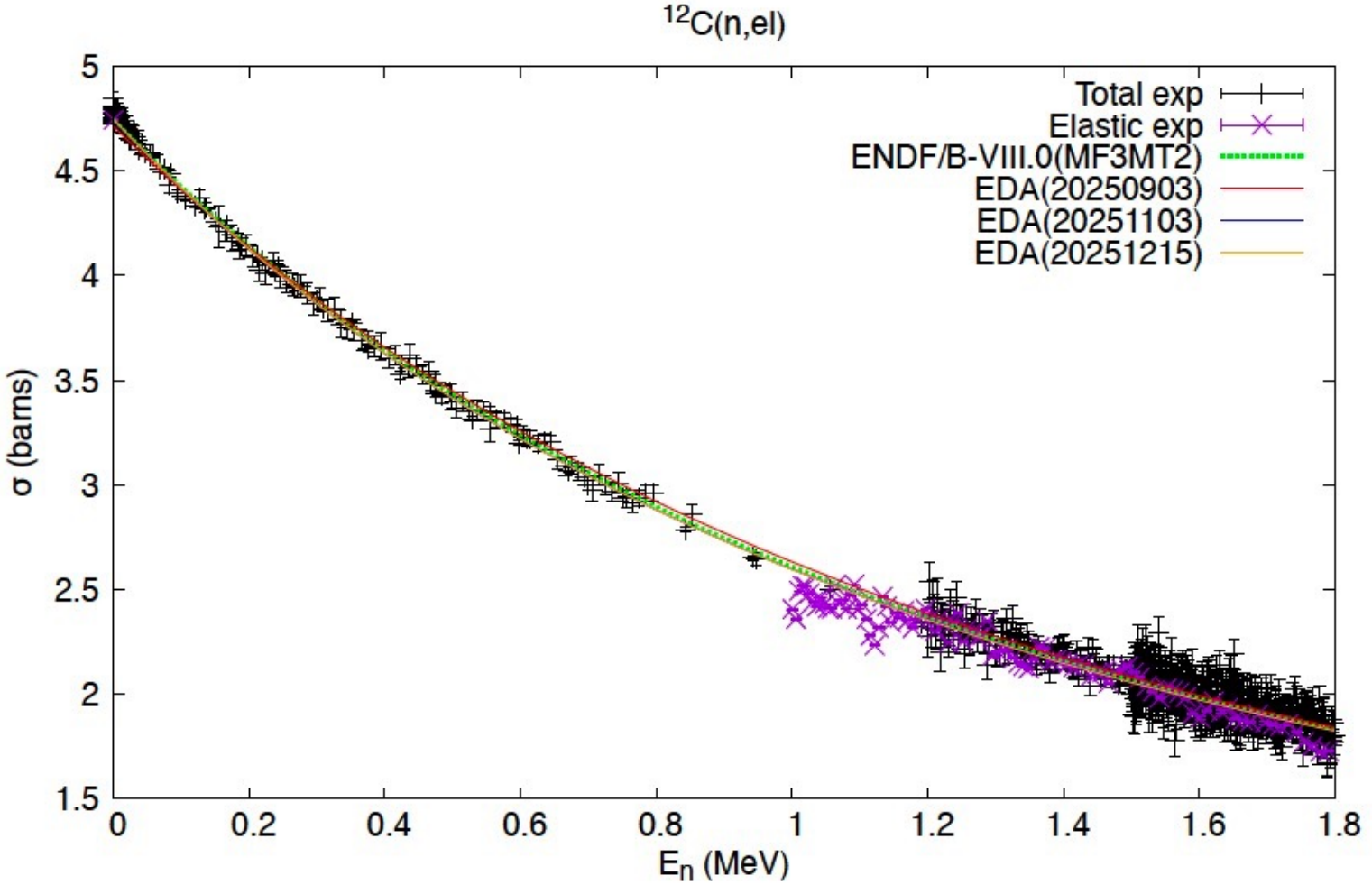
Reaction	E#	Emin(MeV)	Emax(MeV)	Obs#	Pts	Sca
12c(n,n)12c	4839	6e-10	6.4489	4839	2437	4595
12c(n,n)12c*	149	4.8197	6.58	149	322	127

ENDF/B-IX.0

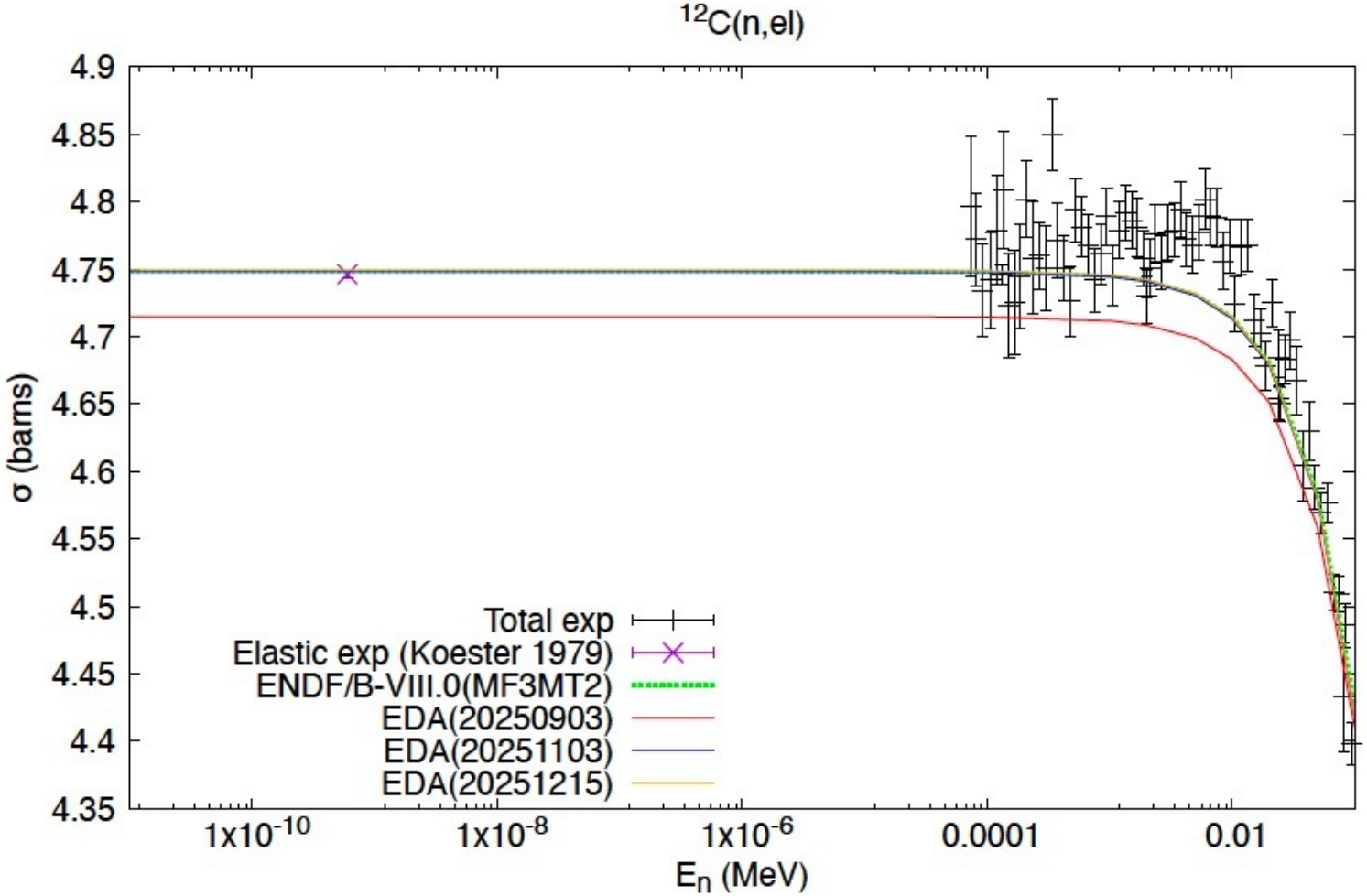
Reaction-by-reaction summary

Reaction	E#	Emin(MeV)	Emax(MeV)	Obs#	Pts	Sca
12c(n,n)12c	6627	6e-10	15.97	6883	7102	6235
12c(n,n)12c*	1219	4.8106	16.41	1219	2037	108
12c(n,gamma)13c	7	0.021	0.199	7	0	7
12c(n,4he)9be	177	7.24	21.56	177	0	177
9be(4he,4he)9be	551	0.366328	3.552	551	0	620

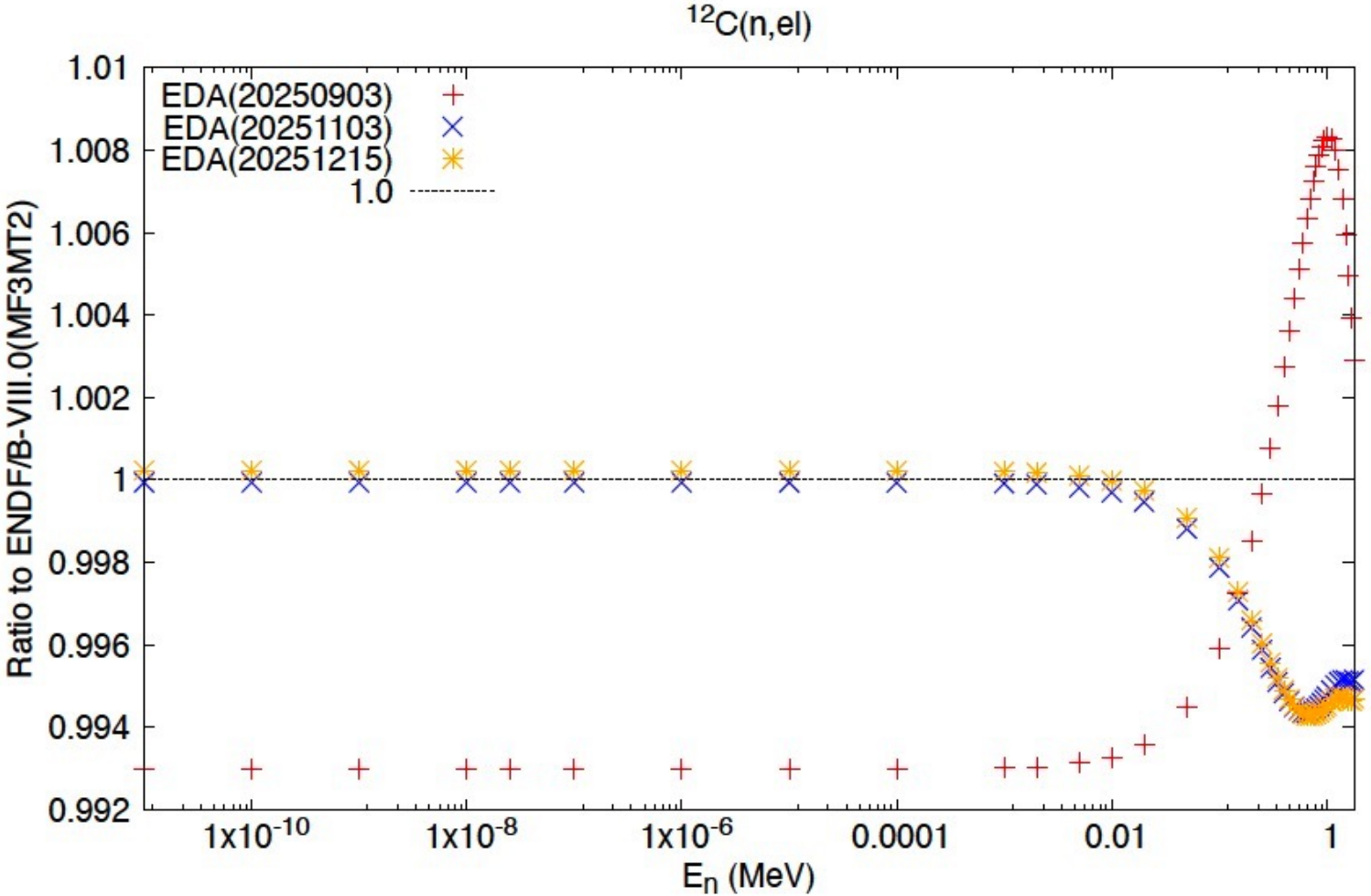
^{13}C

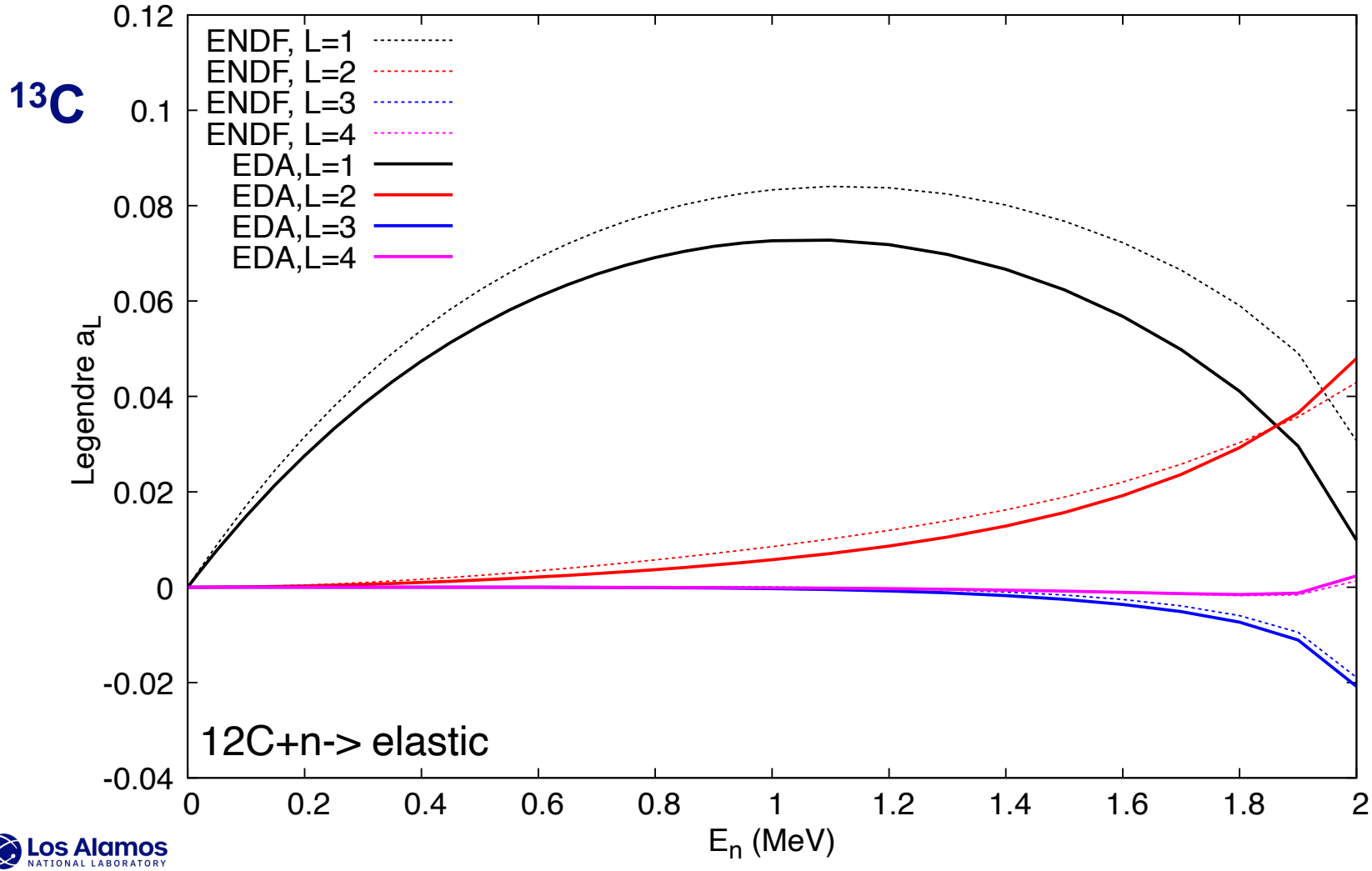

^{12}C(n,el)
Total exp
Elastic exp
ENDF/B-VIII.0(MF3MT2)
EDA(20250903)
EDA(20251103)
EDA(20251215)
σ (bams)
E_n (MeV)
5
4.5
4
3.5
3
2.5
2
1.5
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8

^{13}C

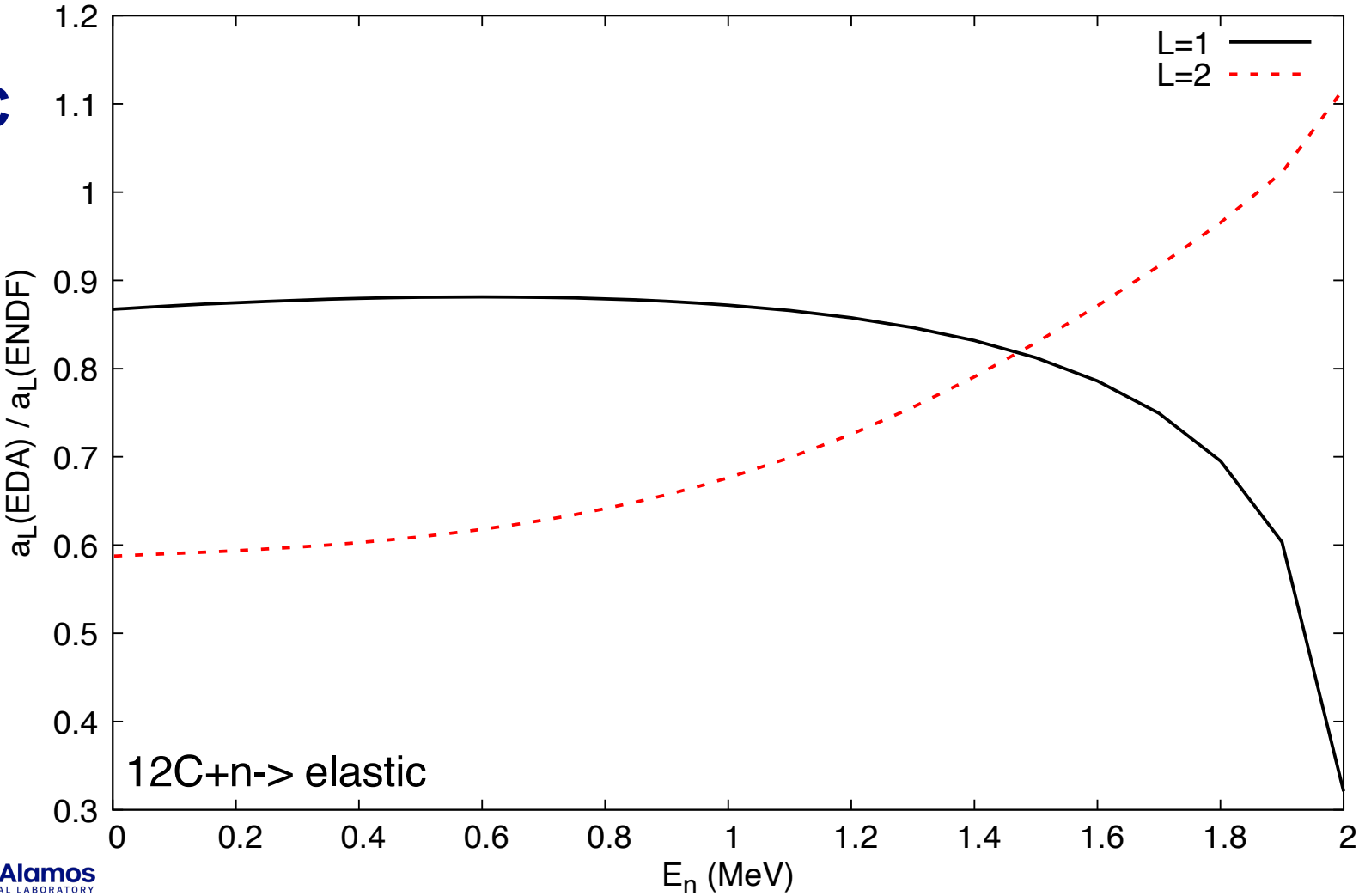

^{12}C(n,el)
σ (bams)
4.9
4.85
4.8
4.75
4.7
4.65
4.6
4.55
4.5
4.45
4.4
4.35
1x10^{-10}
1x10^{-8}
1x10^{-6}
0.0001
0.01
E_n (MeV)
Total exp
Elastic exp (Koester 1979)
ENDF/B-VIII.0(MF3MT2)
EDA(20250903)
EDA(20251103)
EDA(20251215)

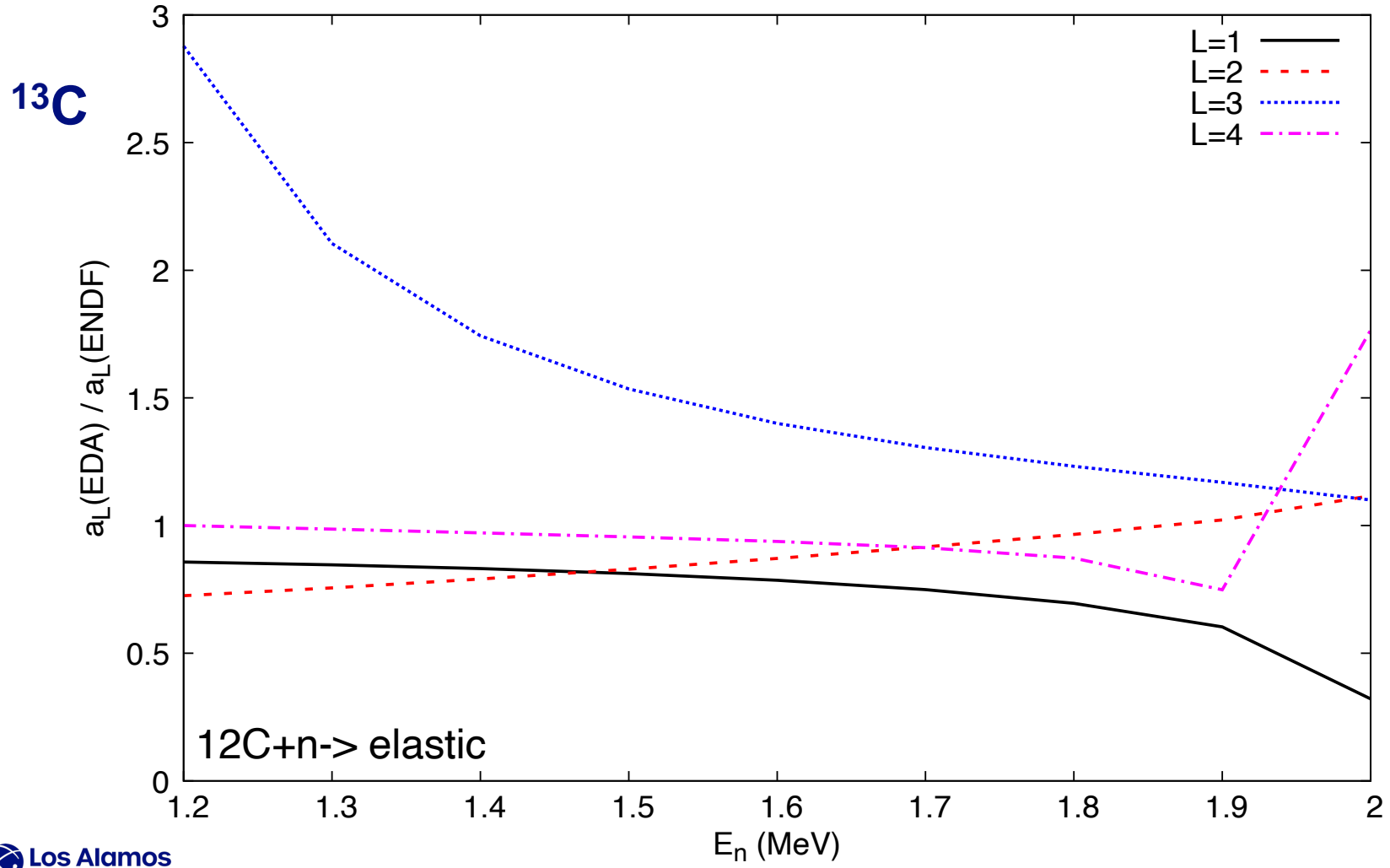
^{13}C


$^{12}C(n,el)$
EDA(20250903)
EDA(20251103)
EDA(20251215)
1.0
Ratio to ENDF/B-VIII.0(MF3MT2)
1.01
1.008
1.006
1.004
1.002
1
0.998
0.996
0.994
0.992
1x10^{-10}
1x10^{-8}
1x10^{-6}
0.0001
0.01
1
E_n (MeV)

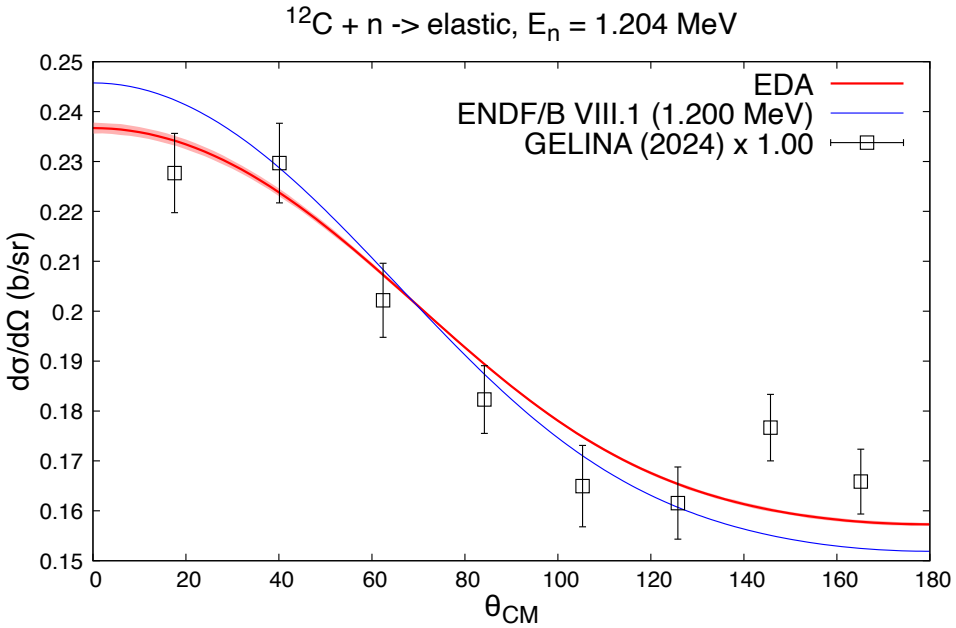

^{13}C
ENDF, L=1
ENDF, L=2
ENDF, L=3
ENDF, L=4
EDA,L=1
EDA,L=2
EDA,L=3
EDA,L=4
Legendre a_L
E_n (MeV)
12C+n-> elastic
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2

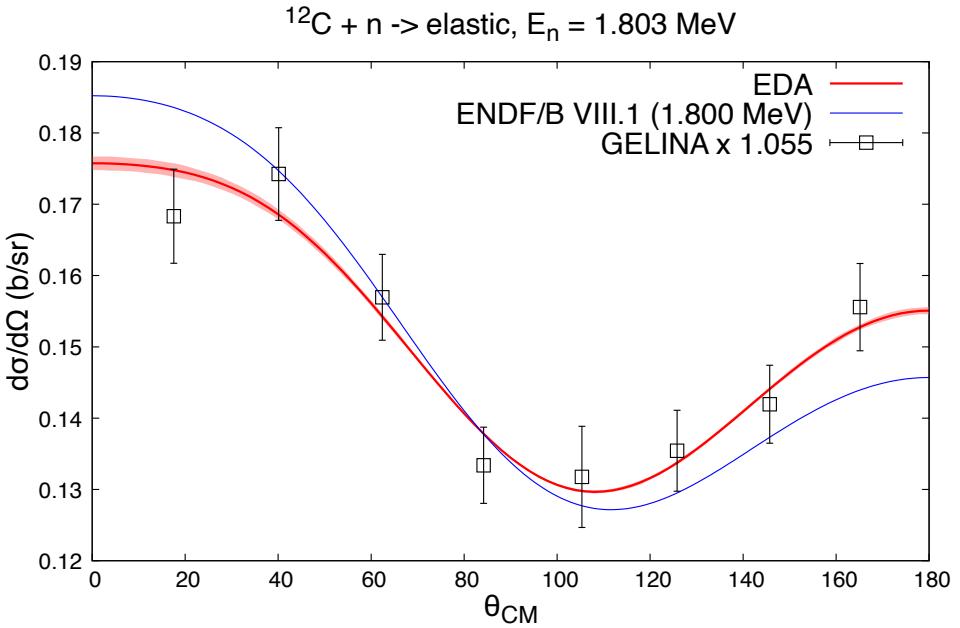
^{13}C


L=1
L=2
12C+n-> elastic
a_L(EDA) / a_L(ENDF)
E_n (MeV)
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2


^{13}C
L=1
L=2
L=3
L=4
a_L(EDA) / a_L(ENDF)
12C+n-> elastic
E_n (MeV)
0
0.5
1
1.5
2
2.5
3
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2

^{13}C


^{12}C + n -> elastic, E_n = 1.204 MeV
EDA
ENDF/B VIII.1 (1.200 MeV)
GELINA (2024) x 1.00
dσ/dΩ (b/sr)
θCM


^{12}C + n -> elastic, E_n = 1.803 MeV
EDA
ENDF/B VIII.1 (1.800 MeV)
GELINA x 1.055
dσ/dΩ (b/sr)
θCM