The Evaluation, Correction and Calculation of Some Charged Particle Excitation Functions Measured by Activation Method

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Charged Particle Excitation Functions

- Introduction
- Evaluation and Correction
- Theoretical Calculation
- Conclusion

Introduction

Activation reaction: A(a, b)*B

Residual nucleus is active product

The cross section formula of charged particle excitation function :

$$\sigma = \frac{M}{n\varepsilon paN_0} \cdot \frac{c}{t} \cdot \frac{1}{\chi} \cdot \frac{1.6\times 10^{-19} t_i}{Q} \cdot \frac{e^{\lambda t_d}}{1-e^{-\lambda t_i}} \cdot 10^{24} b$$

Introduction

There, M—Target molecular weight, n—Target nucleus number in a molecule, ε—Detection efficiency of detector at full energy peak, p—γ-ray branch ratio, a—Isotope abundance, N_0—Avogadro constant, c/t—Accounting γ-ray number at full energy peak in a unit time, χ—Target weight in a unit area, t_i—Irradiation time, Q—Total integrated beam current (in Coulomb), t_d—Cooling time (start from stop irradiation), λ—Radioactive decay constant.

Introduction

From the mentioned-above formula:

$\boldsymbol{\sigma} \propto 1/p$

is inversely proportional to *p*—γray branch ratio

Introduction

and if relative measurement,

$\sigma \propto$ standard $\sigma_{standard}$

is directly proportional to standard cross section $\sigma_{standard}$

Introduction

- Relation of σ and λ—Radioactive decay constant ($\lambda = 0.693/T_{1/2}$), T—Irradiation time, t—Cooling time

$$\sigma \propto \frac{1}{(1-e^{-\lambda T})e^{-\lambda t}}$$

Introduction

According to these relations, σ can be corrected by new and standard *p*, *λ* and σ_{standard}.

Introduction

The corrective factors can be obtained in practice:

- branch ratio p : p(old)/ p(new)
- Standard cross section $\sigma_{standard}$:
  $\sigma_{standard}$(new)/ $\sigma_{standard}$(old)
- Radioactive decay constant λ, Irradiation time T and Cooling time t :

$$(1-e^{-\lambda T})e^{-\lambda t}\ \text{(old)}\ /\ (1-e^{-\lambda T})e^{-\lambda t}\ \text{(new)}$$

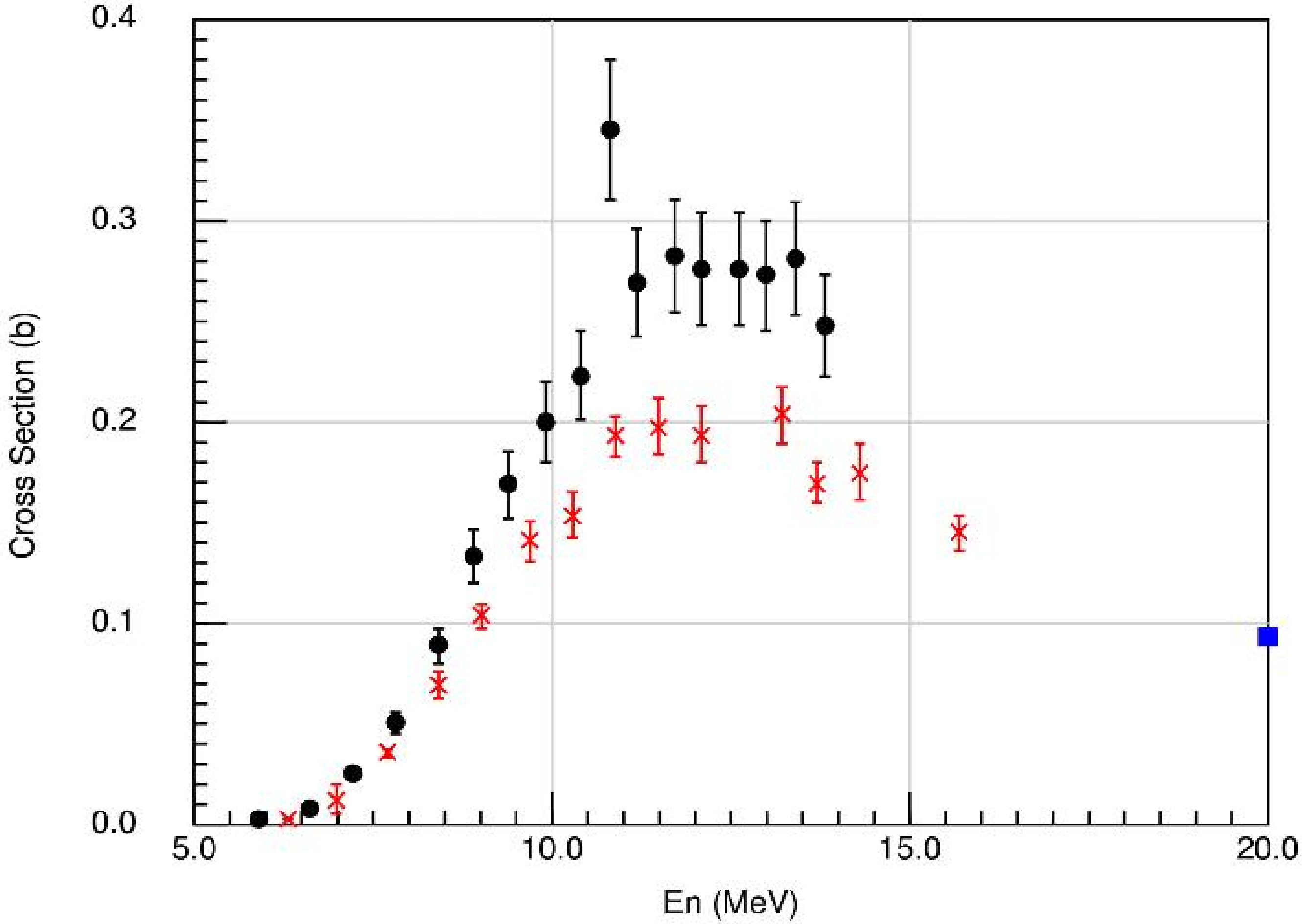
Ⅰ. Evaluation and Correction

There are 3 measurements for $^{186}W(d,p)^{187}W$

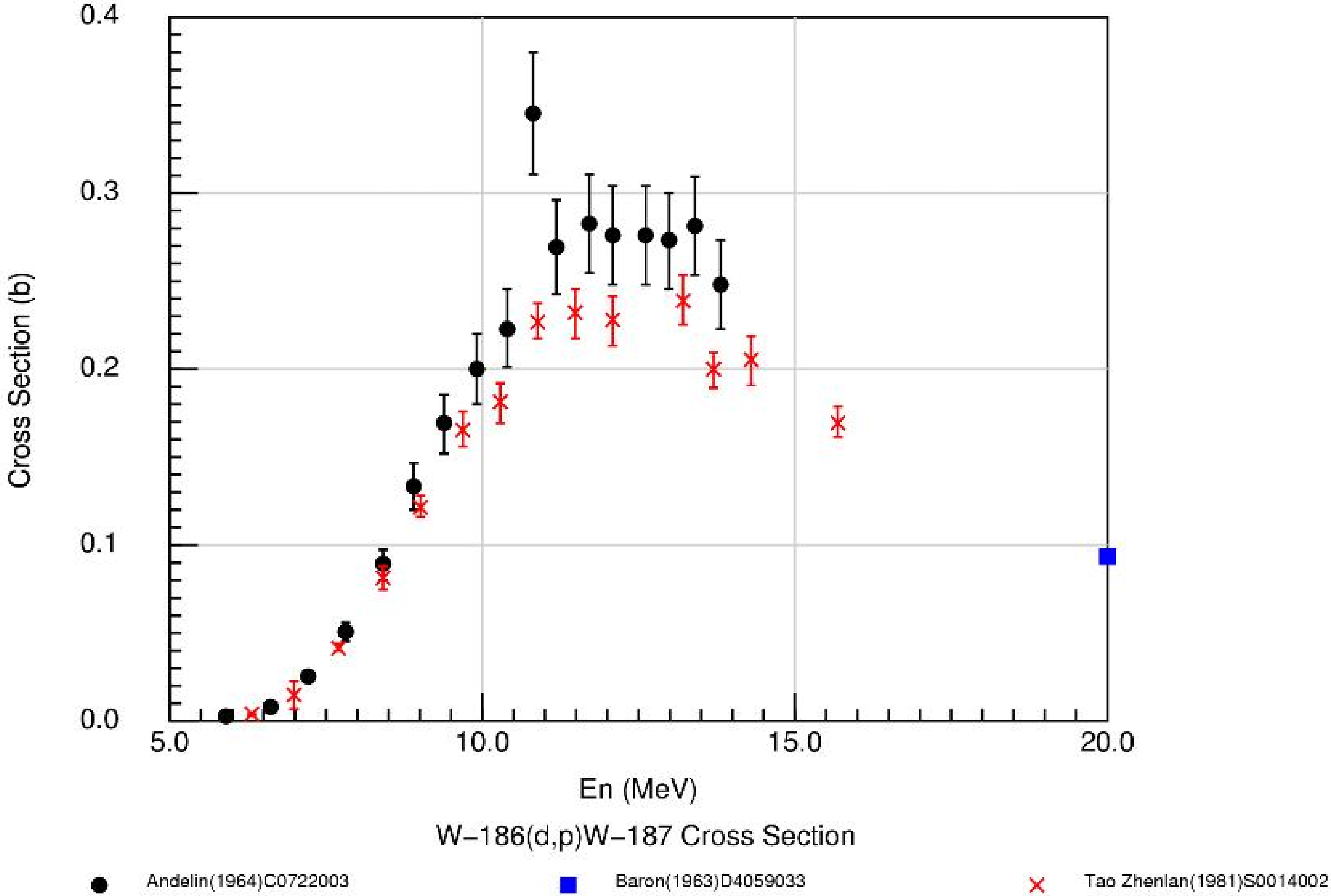
1. R. L. Andelin, C0722.003
   DECAY-DATA(74-W-187,23.7HR,B,630.)
2. N. Baron, D4059.008
   DECAY-DATA(74-W-187,24.3HR,B)
3. Tao Zhenlan, S0014.002
   DECAY-DATA(74-187,23.9HR,DG,479.5,0.256)
   DECAY-DATA(74-187,23.7HR,DG,479.5,0.218)

Branch ratio corrected for S0014.002

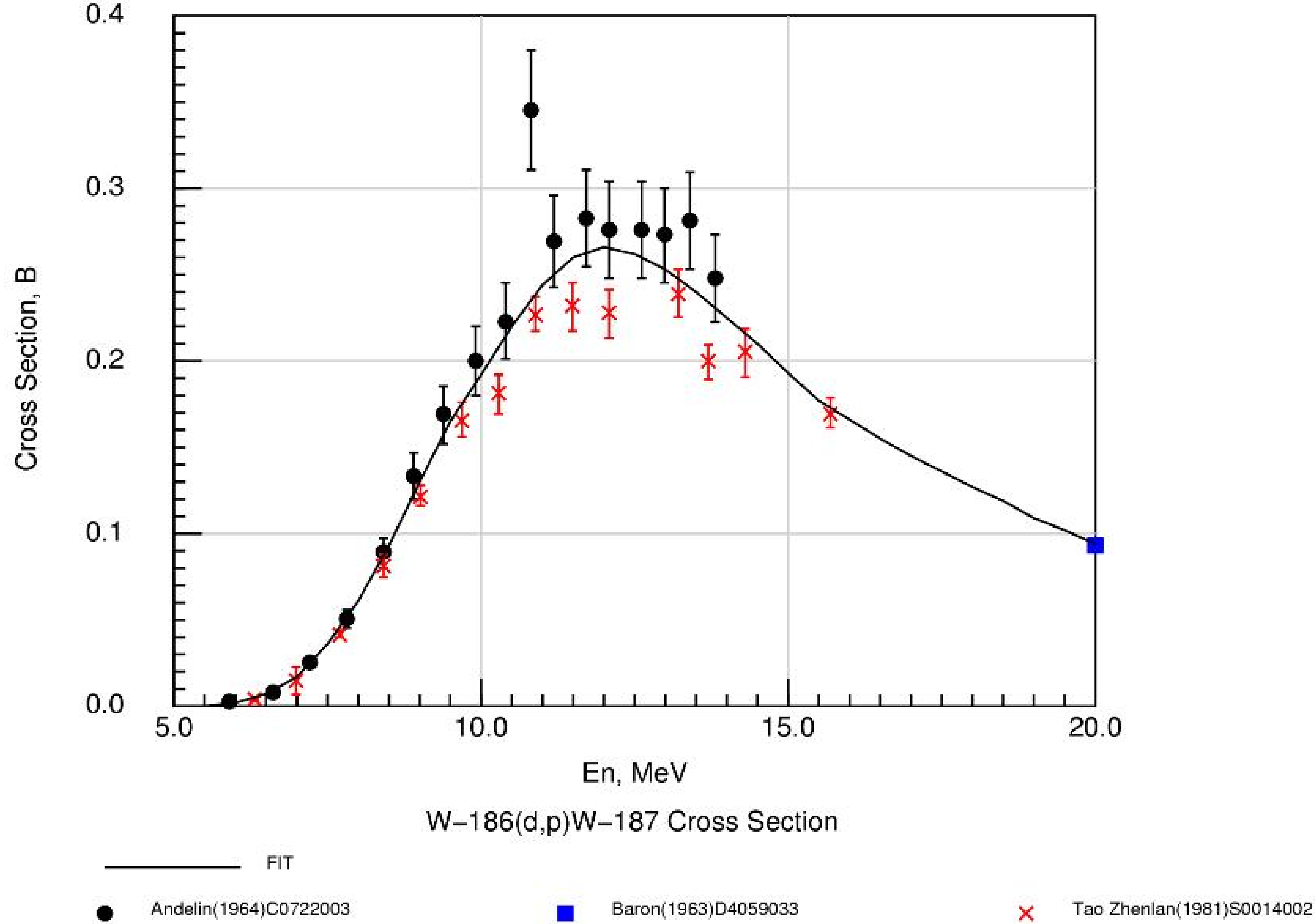
corrective factor: 0.256/0.218=1.174



W−186(d,p)W−187 Cross Section



W–186(d,p)W–187 Cross Section



0.4
0.3
0.2
0.1
0.0
5.0
10.0
15.0
20.0
Cross Section, B
En, MeV
W−186(d,p)W−187 Cross Section
FIT
Andelin(1964)C0722003
Baron(1963)D4059033
Tao Zhenlan(1981)S0014002

I. Evaluation and Correction

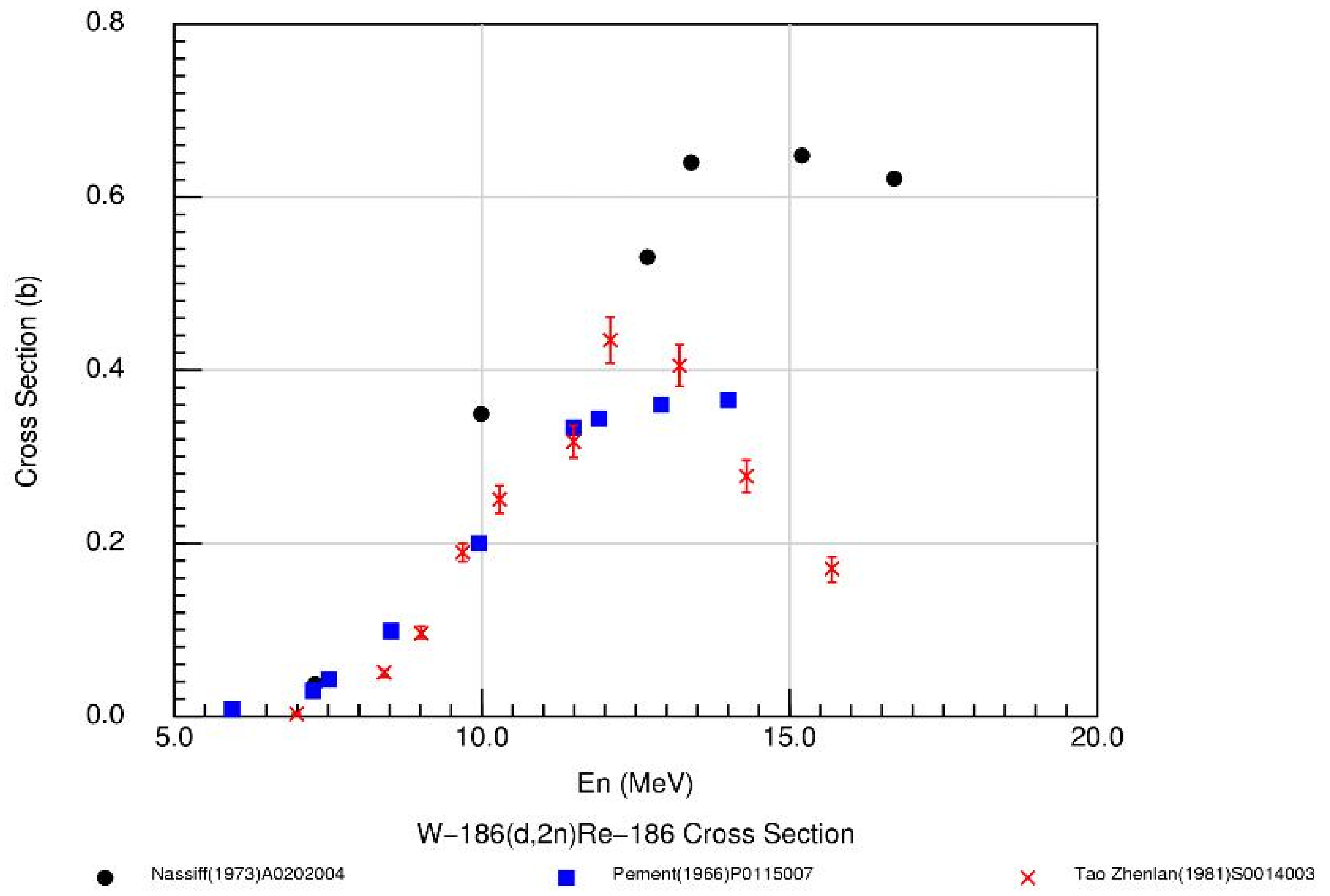
There are 3 measurements for $^{186}W(d,2n)^{186}Re$

1. S. J. Nassiff, A0202.003, RCA, 19(3), 97, 1973
   DECAY-DATA(74-W-186,,DG,137.2,0.048)
2. F. W. Pement, P0115.007, NP, 86, 429, 1966
   DECAY-DATA(74-W-186,,B) enriched target, ^{186}W: 97.2%
3. Tao Zhenlan, S0014.003, CNP, 3, 242, 1981
   DECAY-DATA(74-W-186,37.77D,DG,137.16,0.092)

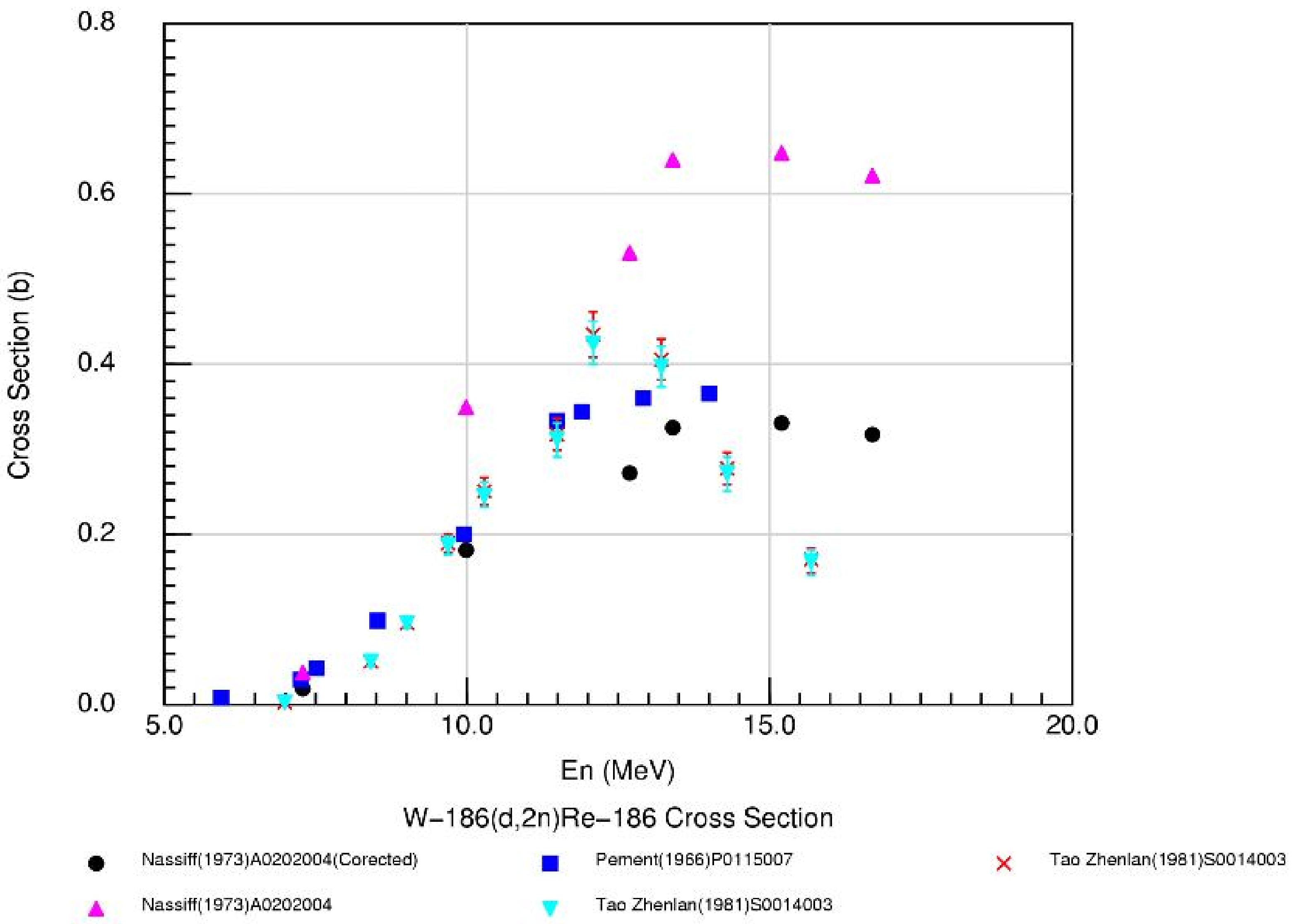
Corrected:

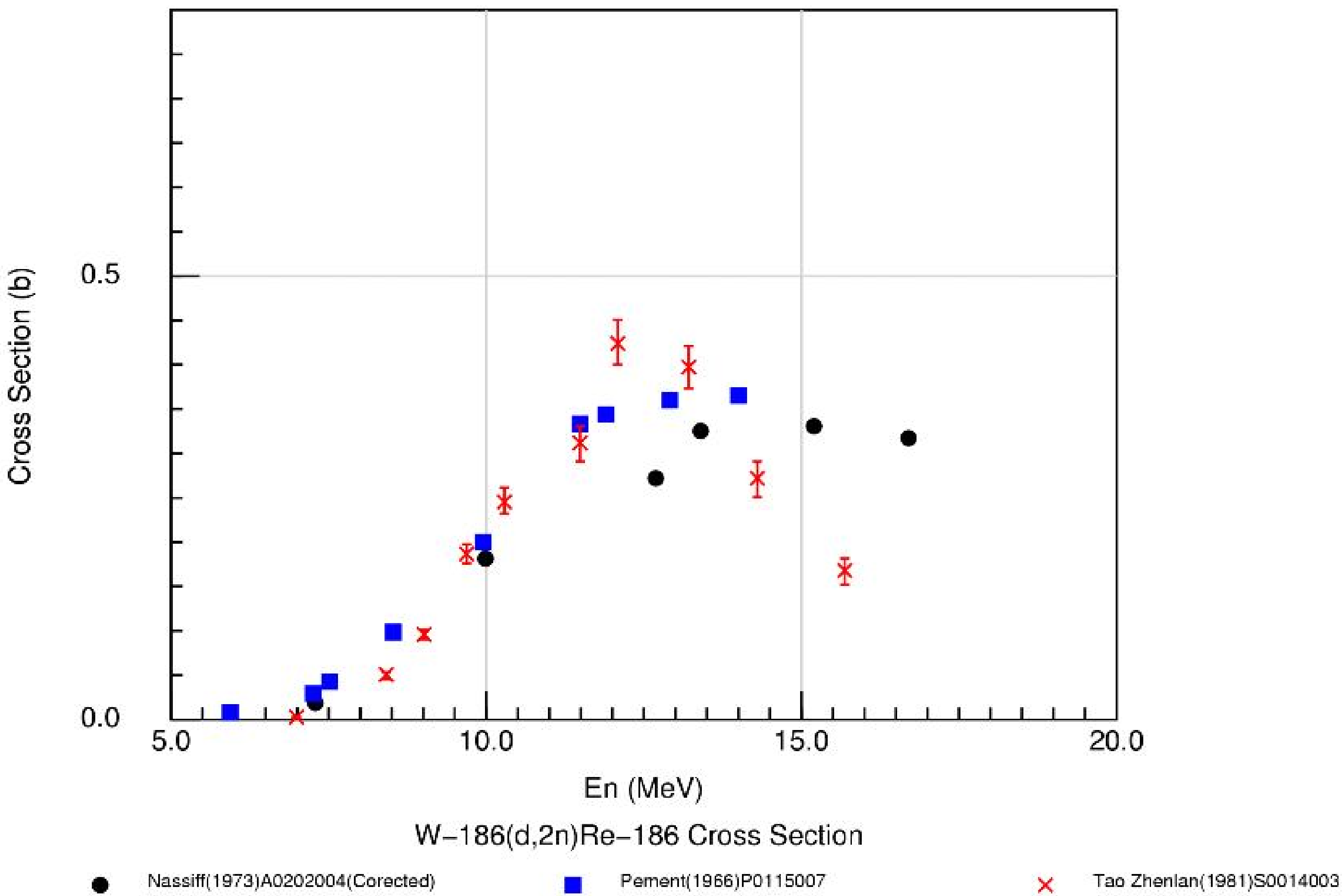
1. p=0.048 ⇒ 0.0942 0.048/0.0942=0.51

3. p=0.092 ⇒ 0.0942 0.092/0.0942=0.98



0.8
0.6
0.4
0.2
0.0
5.0
10.0
15.0
20.0
Cross Section (b)
En (MeV)
W−186(d,2n)Re−186 Cross Section
Nassiff(1973)A0202004
Pement(1966)P0115007
Tao Zhenlan(1981)S0014003


0.8
0.6
0.4
0.2
0.0
5.0
10.0
15.0
20.0
Cross Section (b)
En (MeV)
W-186(d,2n)Re-186 Cross Section
Nassiff(1973)A0202004(Corected)
Pement(1966)P0115007
Tao Zhenlan(1981)S0014003
Nassiff(1973)A0202004
Tao Zhenlan(1981)S0014003



Cross Section (b)
0.5
0.0
5.0
10.0
15.0
20.0
En (MeV)
W−186(d,2n)Re−186 Cross Section
Nassiff(1973)A0202004(Corected)
Pement(1966)P0115007
Tao Zhenlan(1981)S0014003

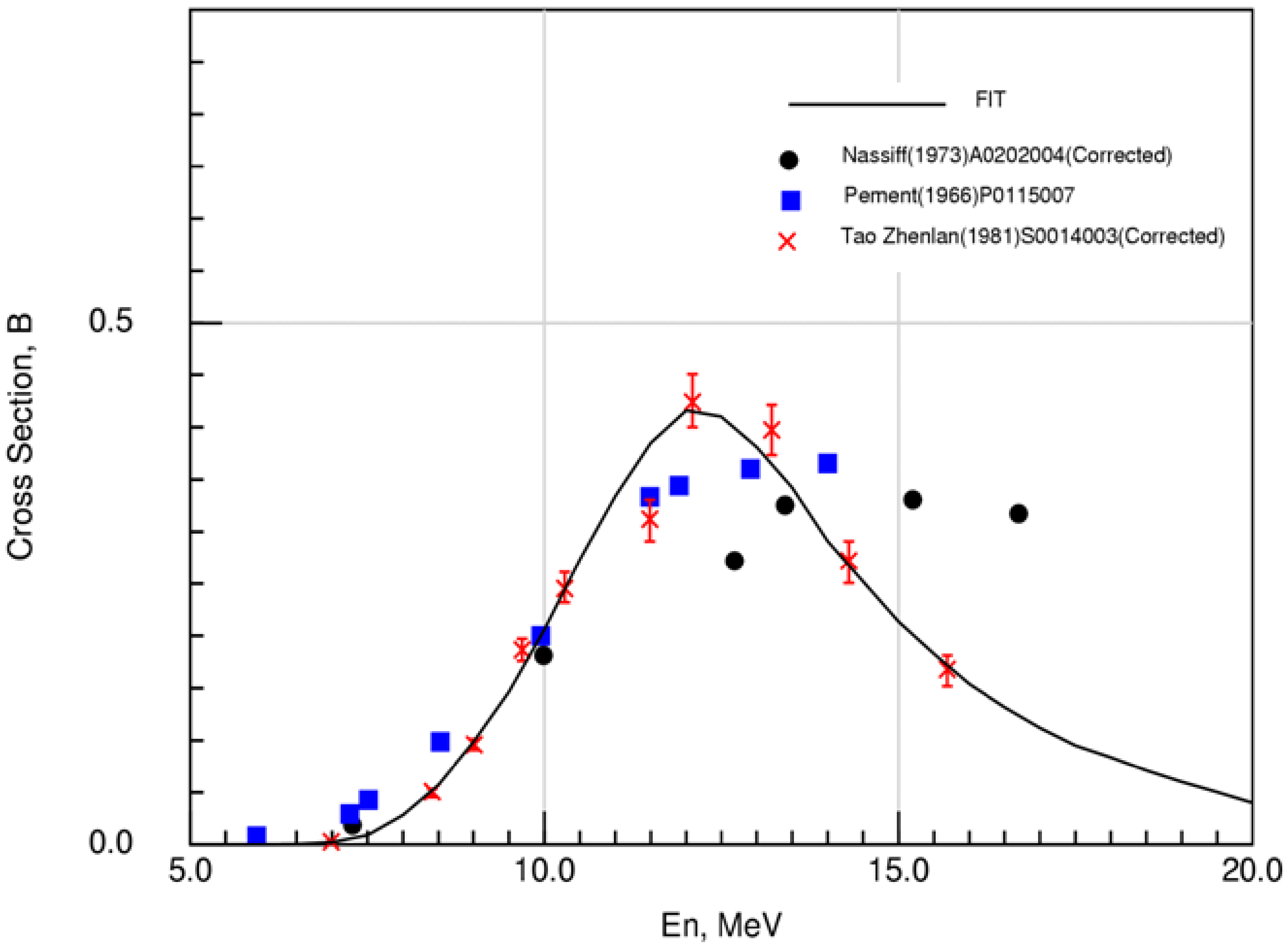


Fig.4 $^{186}W(d,2n)^{186}Re$ corrected experimental data

I. Evaluation and Correction

There are 12 measurements for

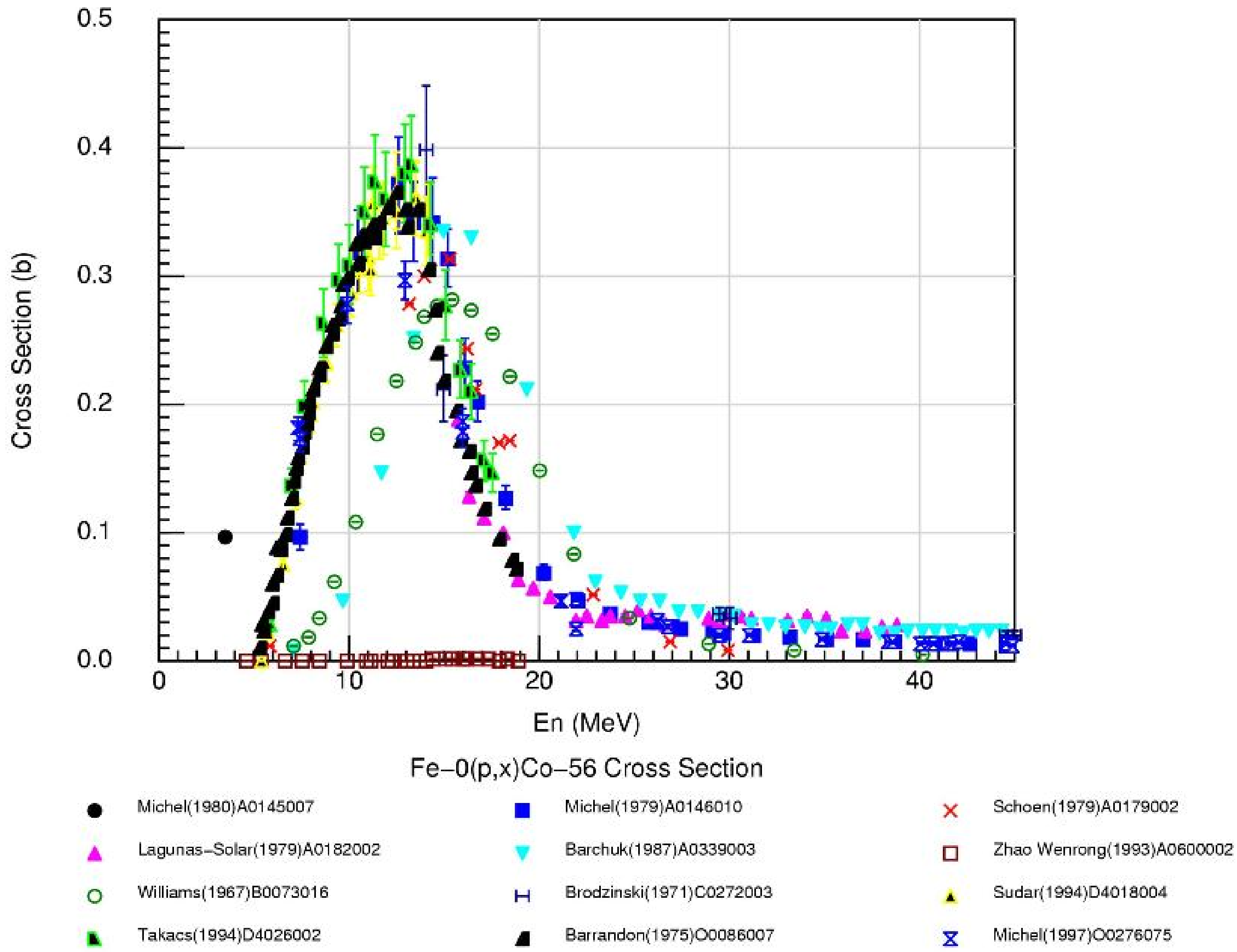
$^{Nat}Fe(p,x)^{56}Co$

- There is something wrong in EXFOR:

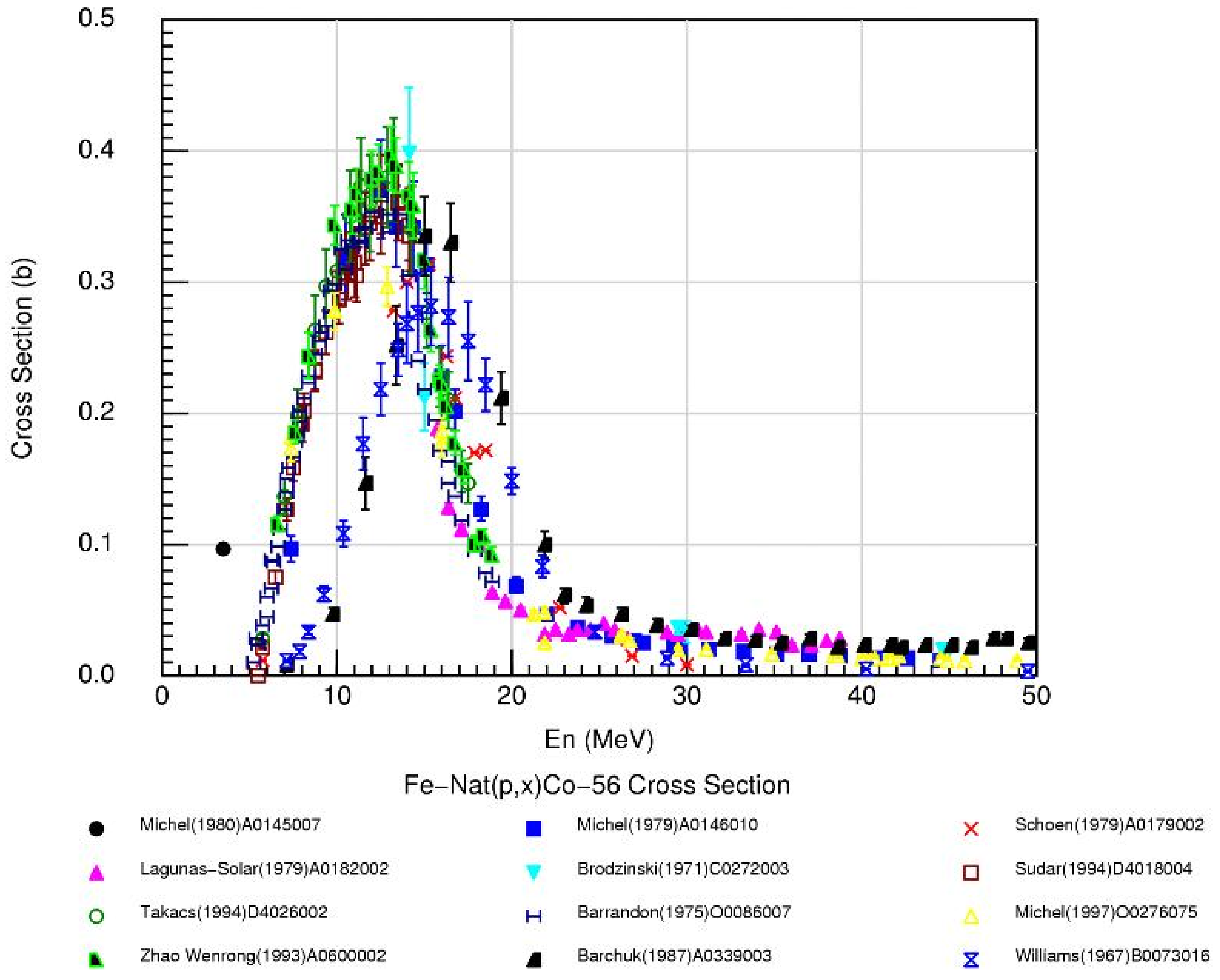
  $^{Nat}Fe(p,x)^{55}Co$ and $^{Nat}Fe(p,x)^{56}Co$ data are reversed in A0600

I. Evaluation and Correction

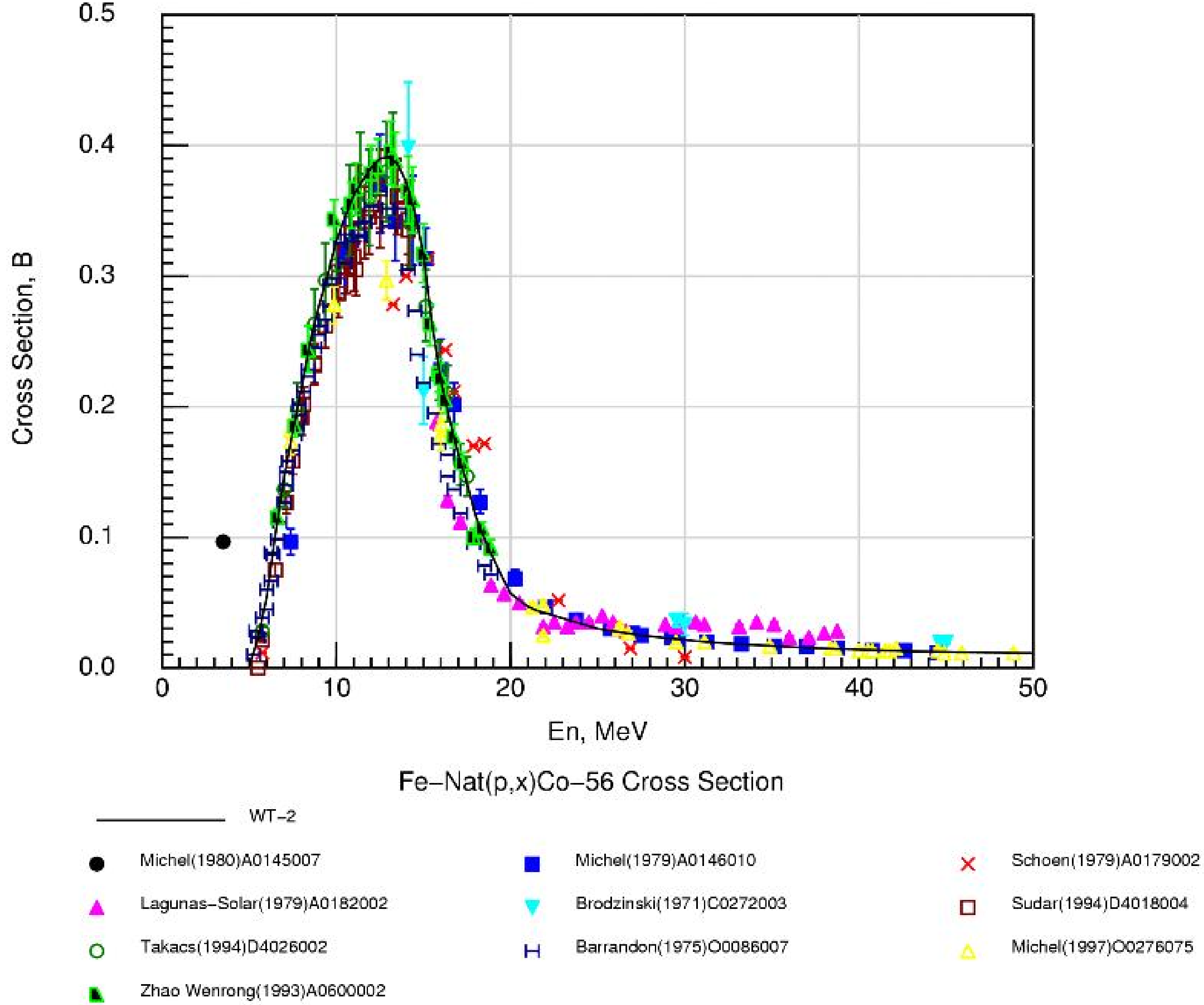
- B0073.016 and A0339.003 were excluded due to incident energy shift.
- After the reversion and exclusion, all of them tend towards the consistency



Cross Section (b)
0.0
0.1
0.2
0.3
0.4
0.5
0
10
20
30
40
En (MeV)
Fe−0(p,x)Co−56 Cross Section
Michel(1980)A0145007
Michel(1979)A0146010
Schoen(1979)A0179002
Lagunas-Solar(1979)A0182002
Barchuk(1987)A0339003
Zhao Wenrong(1993)A0600002
Williams(1967)B0073016
Brodzinski(1971)C0272003
Sudar(1994)D4018004
Takacs(1994)D4026002
Barrandon(1975)O0086007
Michel(1997)O0276075



0.5
0.4
0.3
0.2
0.1
0.0
Cross Section (b)
0
10
20
30
40
50
En (MeV)
Fe−Nat(p,x)Co−56 Cross Section
Michel(1980)A0145007
Michel(1979)A0146010
Schoen(1979)A0179002
Lagunas−Solar(1979)A0182002
Brodzinski(1971)C0272003
Sudar(1994)D4018004
Takacs(1994)D4026002
Barrandon(1975)O0086007
Michel(1997)O0276075
Zhao Wenrong(1993)A0600002
Barchuk(1987)A0339003
Williams(1967)B0073016


0.5
0.4
0.3
0.2
0.1
0.0
Cross Section, B
0
10
20
30
40
50
En, MeV
Fe–Nat(p,x)Co–56 Cross Section
WT–2
Michel(1980)A0145007
Michel(1979)A0146010
Schoen(1979)A0179002
Lagunas–Solar(1979)A0182002
Brodzinski(1971)C0272003
Sudar(1994)D4018004
Takacs(1994)D4026002
Barrandon(1975)O0086007
Michel(1997)O0276075
Zhao Wenrong(1993)A0600002

I. Evaluation and Correction

There are 5 measurements for $^{Nat}Ti(\alpha,x)^{51}Cr$

- D4089002, beter: complete data, good quality
- There are 3 measurements to be corrected:

A0148.002:

MORNIT-REF(A0153.002,MICHEL+,...) higher 0.70

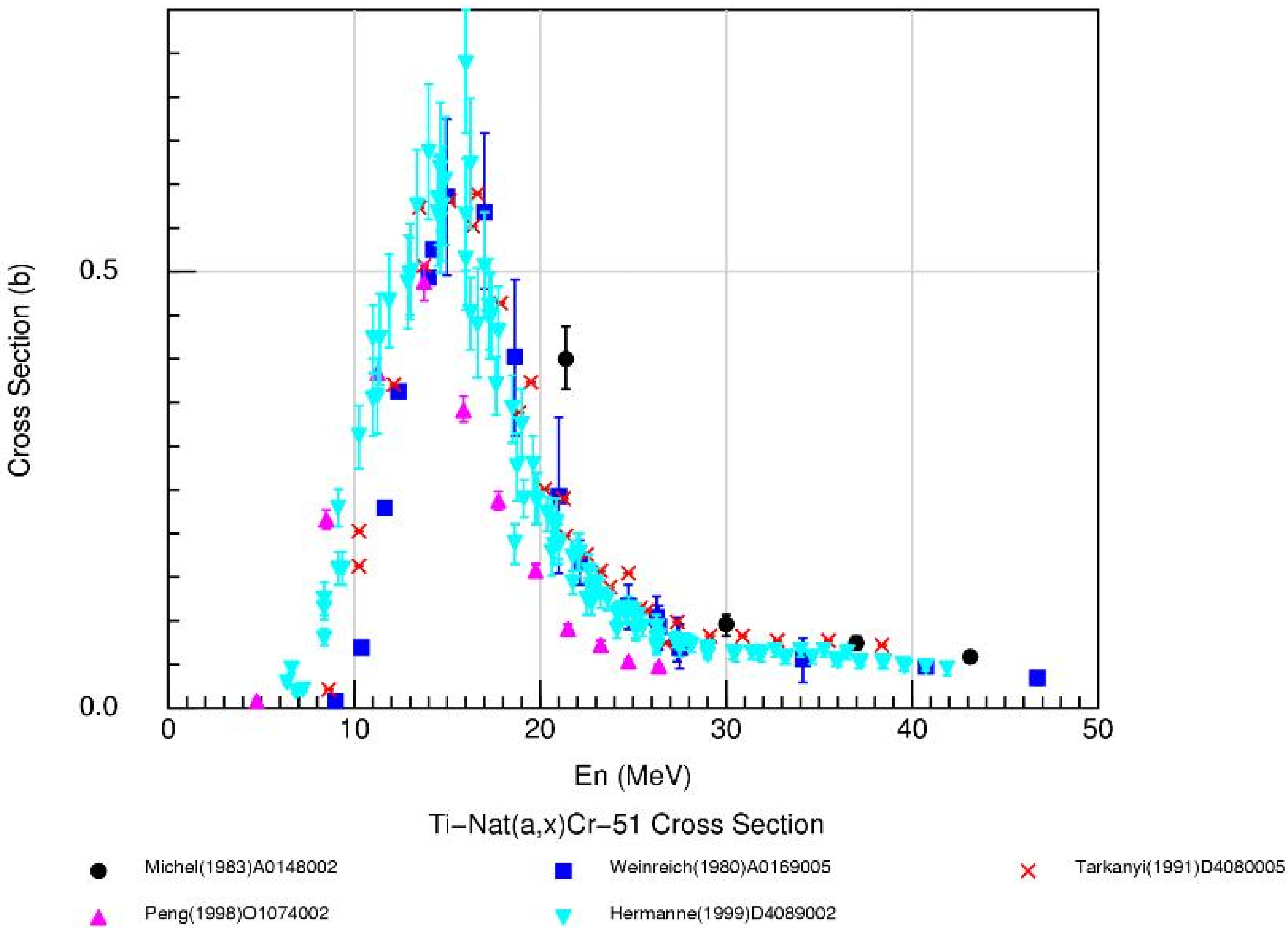
A0160.005: energy error ±0.62 MeV, 0.102/0.0987=1.033

DECAY-DATA(234-Cr-51,27.72D,DG,320,0.102)

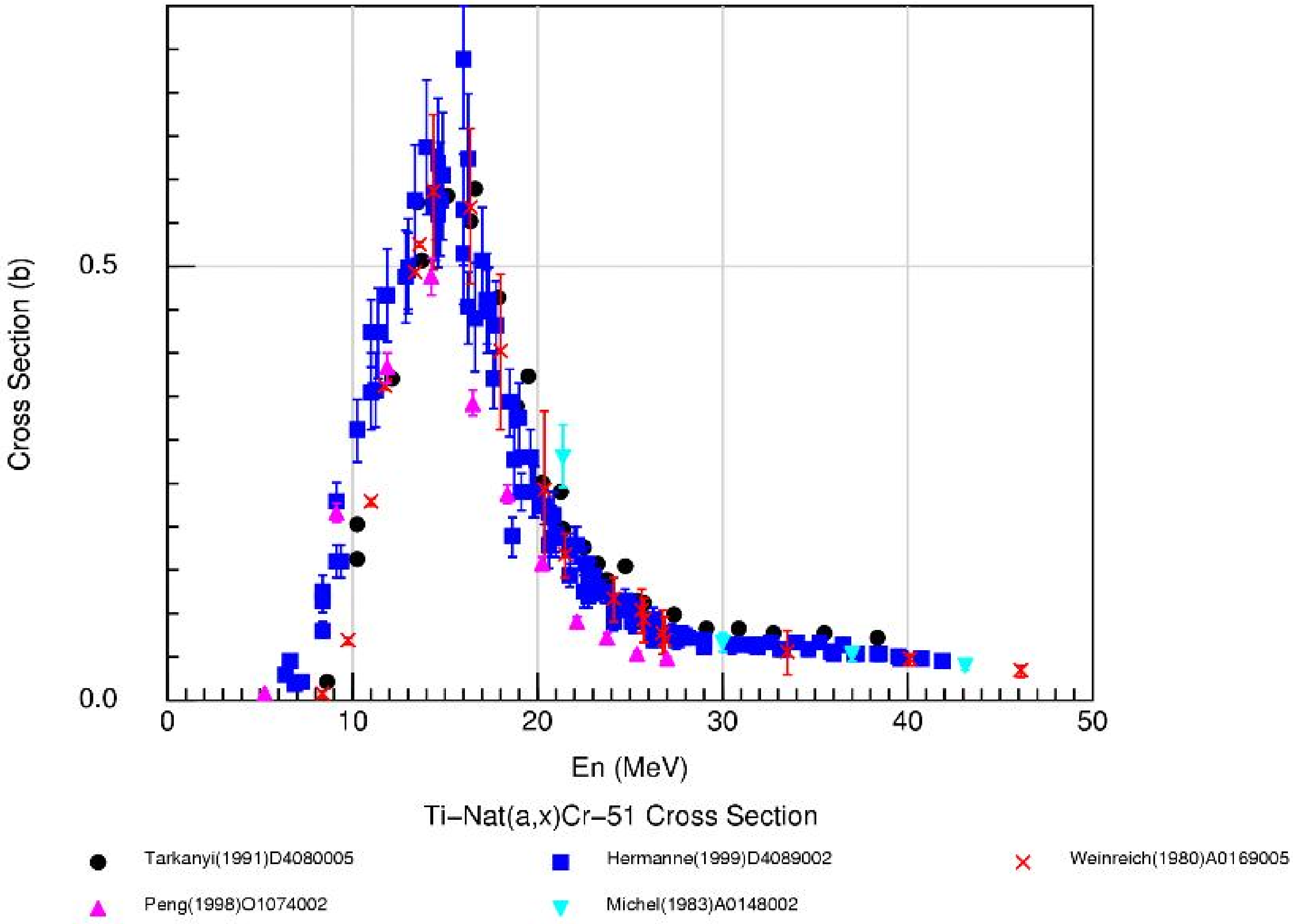
O1074.002: energy error ±0.60 MeV, 0.1008/0.0987=1.021

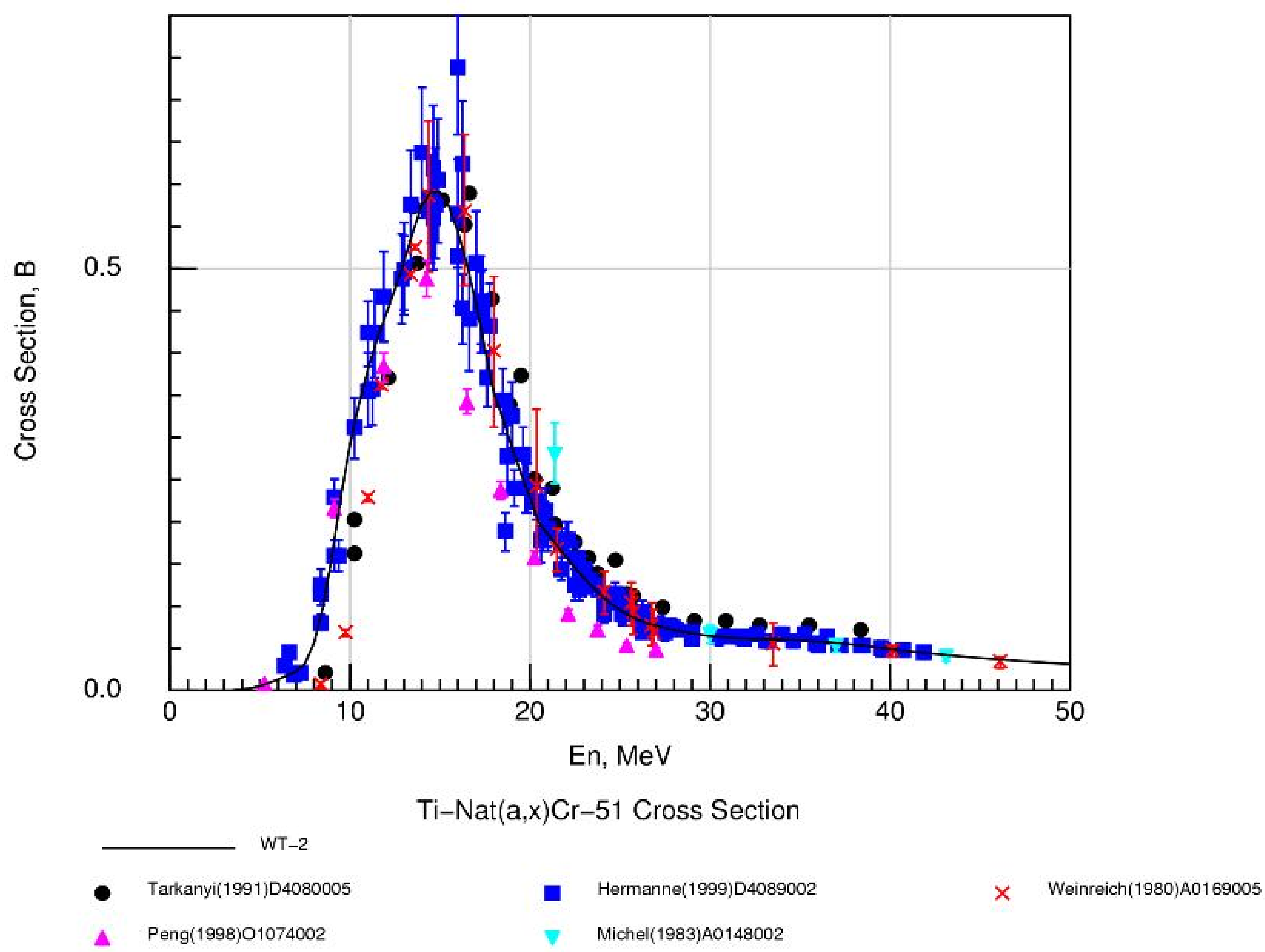
DECAY-DATA(234-Cr-51,27.704D,DG,320.084,0.1008)

DECAY-DATA(234-Cr-51,27.703D,DG,320.1,0.0987)



Cross Section (b)
0.5
0.0
0
10
20
30
40
50
En (MeV)
Ti−Nat(a,x)Cr−51 Cross Section
Michel(1983)A0148002
Weinreich(1980)A0169005
Tarkanyi(1991)D4080005
Peng(1998)O1074002
Hermanne(1999)D4089002


Cross Section (b)
0.5
0.0
0
10
20
30
40
50
En (MeV)
Ti–Nat(a,x)Cr–51 Cross Section
Tarkanyi(1991)D4080005
Hermanne(1999)D4089002
Weinreich(1980)A0169005
Peng(1998)O1074002
Michel(1983)A0148002



Cross Section, B
0.5
0.0
0
10
20
30
40
50
En, MeV
Ti−Nat(a,x)Cr−51 Cross Section
WT−2
Tarkanyi(1991)D4080005
Hermanne(1999)D4089002
Weinreich(1980)A0169005
Peng(1998)O1074002
Michel(1983)A0148002

Ⅰ. Evaluation and Correction

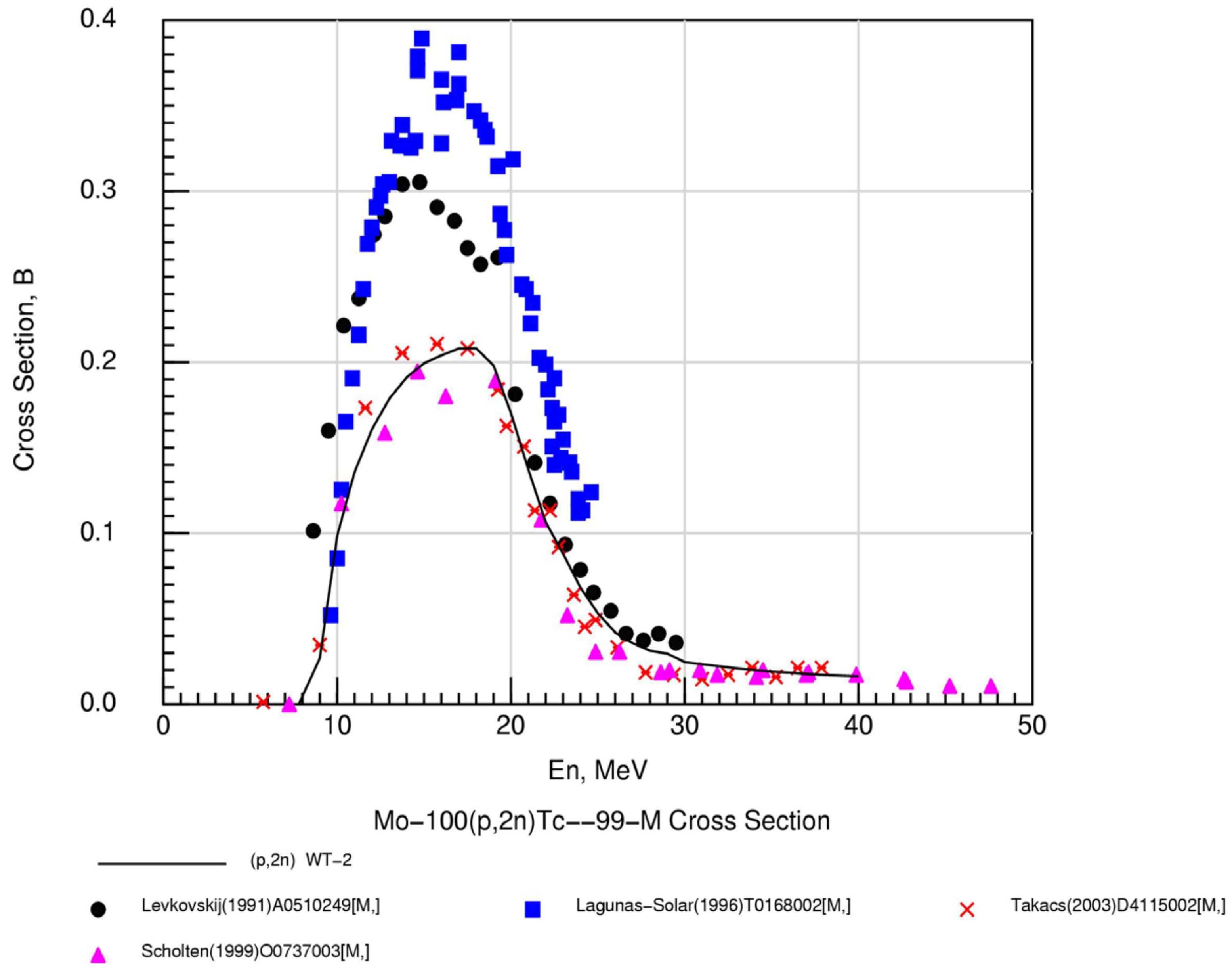
There are 4 measurements for $^{100}Mo(p,2n)^{99m}Tc$, data are complete

Author / Year	Lab. / EXFOR	Reference/Method	Energy range / Point
Levkovskij (1991)	4KASKAZ A0510.249	B, LEVKOVSKIJ, 91 Activation, GeLi	8.6∽29.5 MeV (24)
Lagunas-Solar (1996)	1USADAV C0963.002	J, ANS 74(1996)137 Activation, HPGe	9.5∽24.6 MeV (75)
Scholten (1999)	2GERJUL O0737.003	J, ARI, 51(1999)69 Activation, HPGe	7.2∽64.8 MeV (27)
Takacs (2003)	3HUNDEB D4115.002	J, JRN 257(2003)195 Activation, HPGe	5.7∽37.9 MeV

Ⅰ. Evaluation and Correction

There are big differences between these measurements, divided roughly into two groups:

- Higher : Levkovskij and Lagunas-Solar, natural Molybdenum, the abundance of ^{100}Mo: 9.63％;
- Lower : Scholten and Takacs, high enriched ^{100}Mo, the abundances: 97.4％ and 99.9％ respectively; The two measurements are recommended due to more accurate and reliable.


0.4
0.3
0.2
0.1
0.0
Cross Section, B
0
10
20
30
40
50
En, MeV
Mo−100(p,2n)Tc−−99−M Cross Section
(p,2n) WT−2
Levkovskij(1991)A0510249[M,]
Lagunas−Solar(1996)T0168002[M,]
Takacs(2003)D4115002[M,]
Scholten(1999)O0737003[M,]

Ⅱ.Theoretical Calculation

Theoretical codes for CPND

- **Middle and heavy nuclides:**

  CUNF, SPEC, EMPIRE …;

- **Fission nuclides:**

  CFUP1, EMPIRE etc.

Ⅱ.Theoretical Calculation

Calculated power

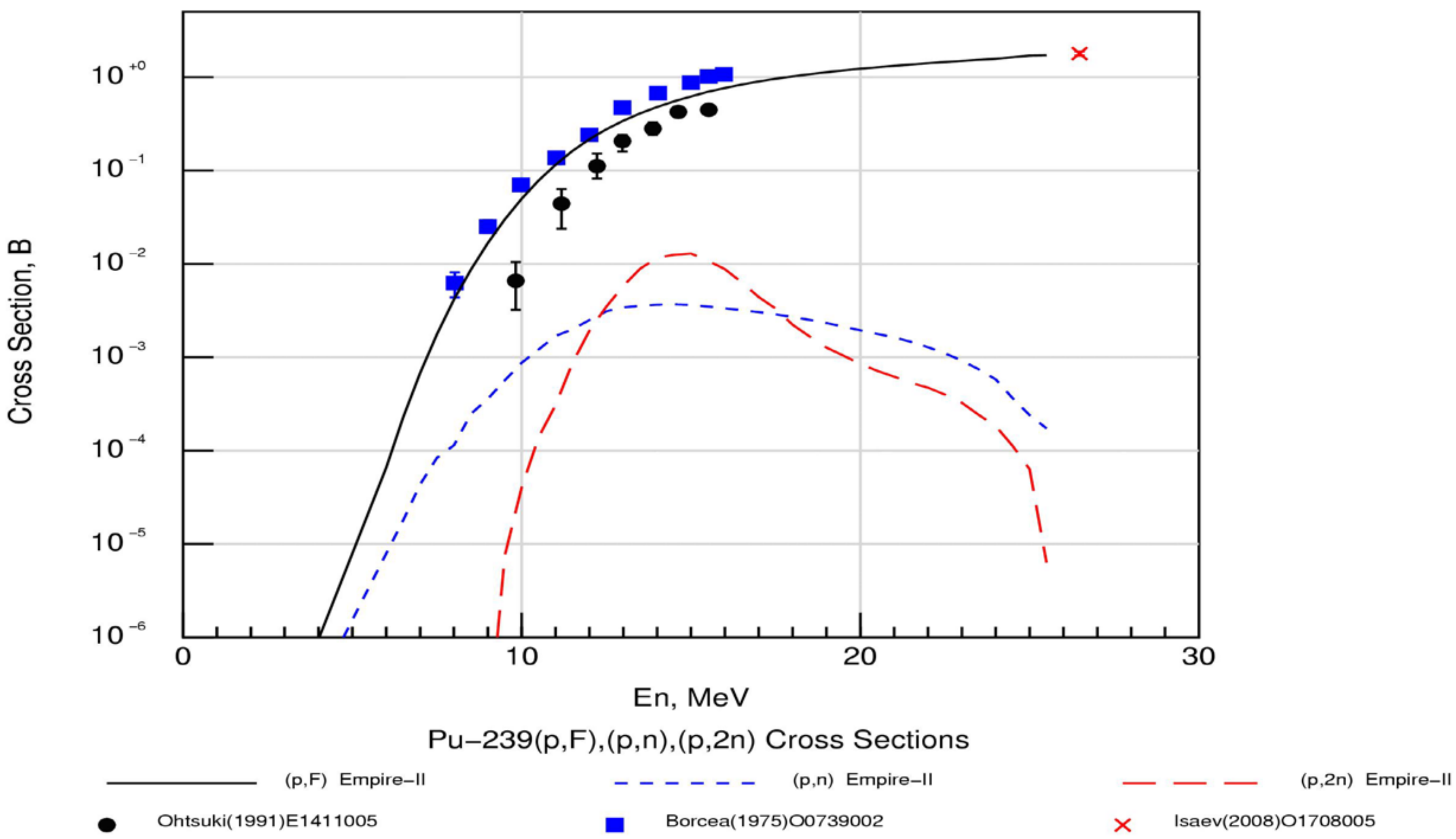
- **Incident proton：**
  (p,n),(p,2n) … better
- **Incident deuteron and heavier：**
  It can not met the needs of the user, (d,n),(d,2n),(d,3n) …
  Some complicated reaction mechanisms are not included in the codes. SPEC little better

Ⅱ.Theoretical Calculation

Incident proton：

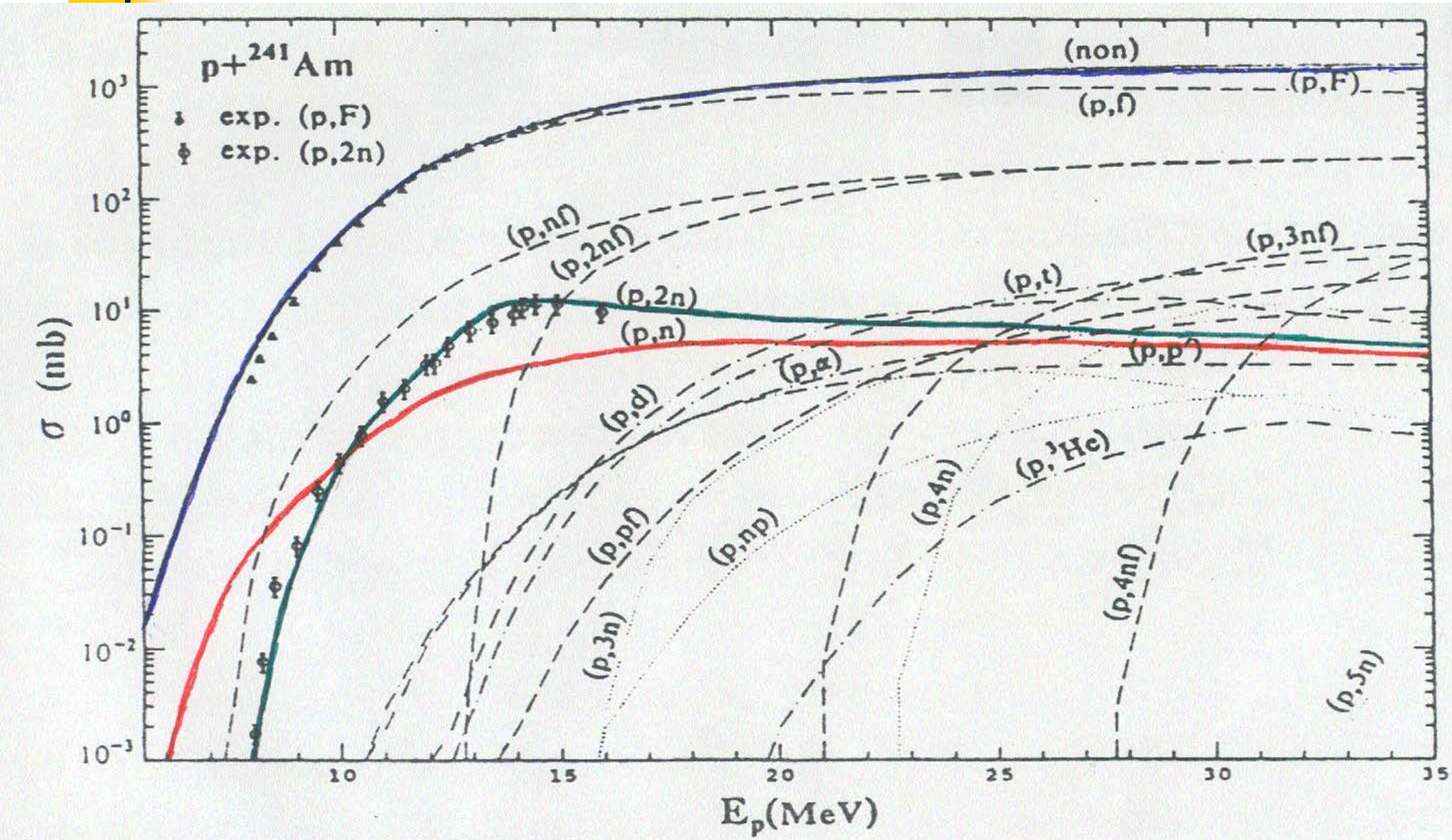
^{239}Pu， ^{241}Am(p, n), (p, 2n)

$^{239}Pu(p,n),(p,2n)$



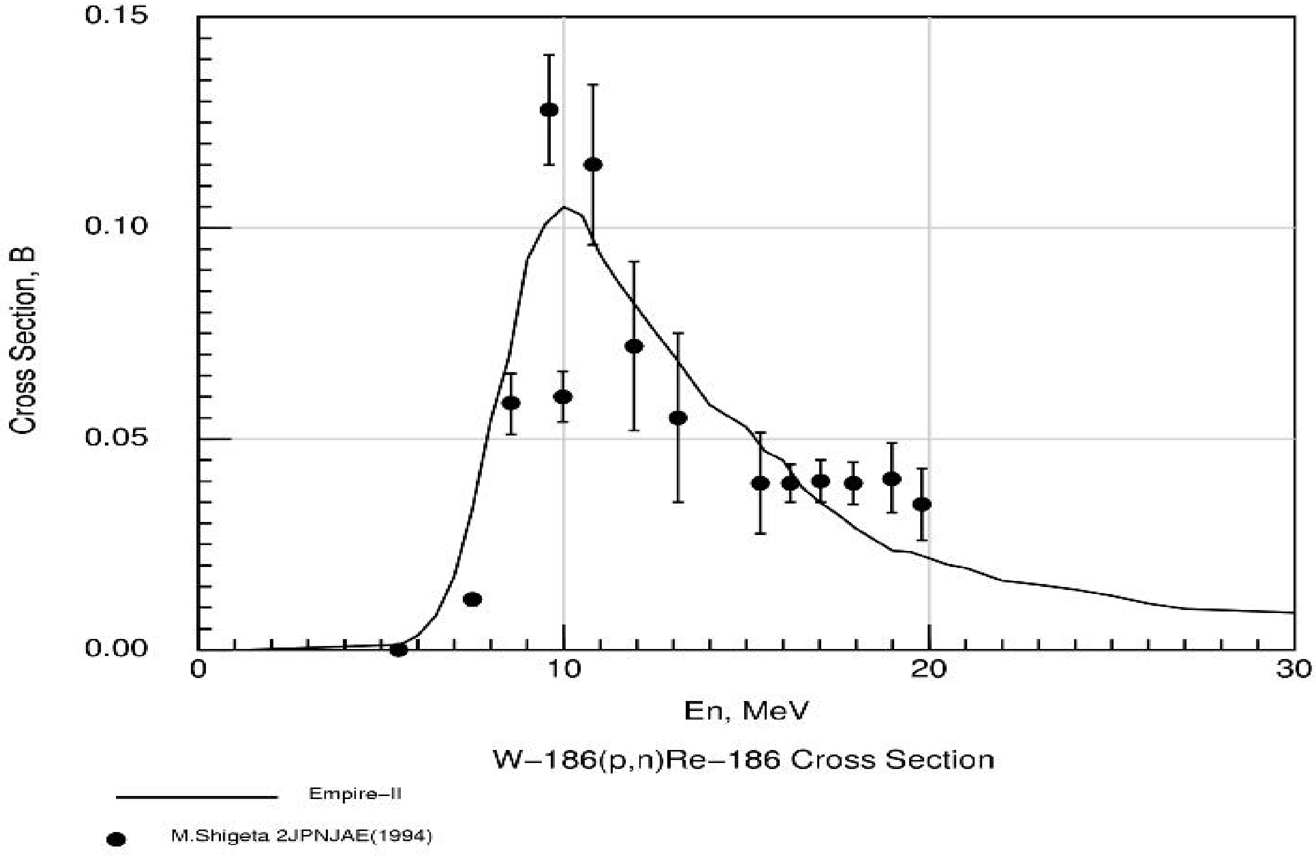
Cross Section, B
10^+0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
0
10
20
30
En, MeV
Pu−239(p,F),(p,n),(p,2n) Cross Sections
(p,F) Empire−II
(p,n) Empire−II
(p,2n) Empire−II
Ohtsuki(1991)E1411005
Borcea(1975)O0739002
Isaev(2008)O1708005

$^{241}Am(p,n),(p,2n)$



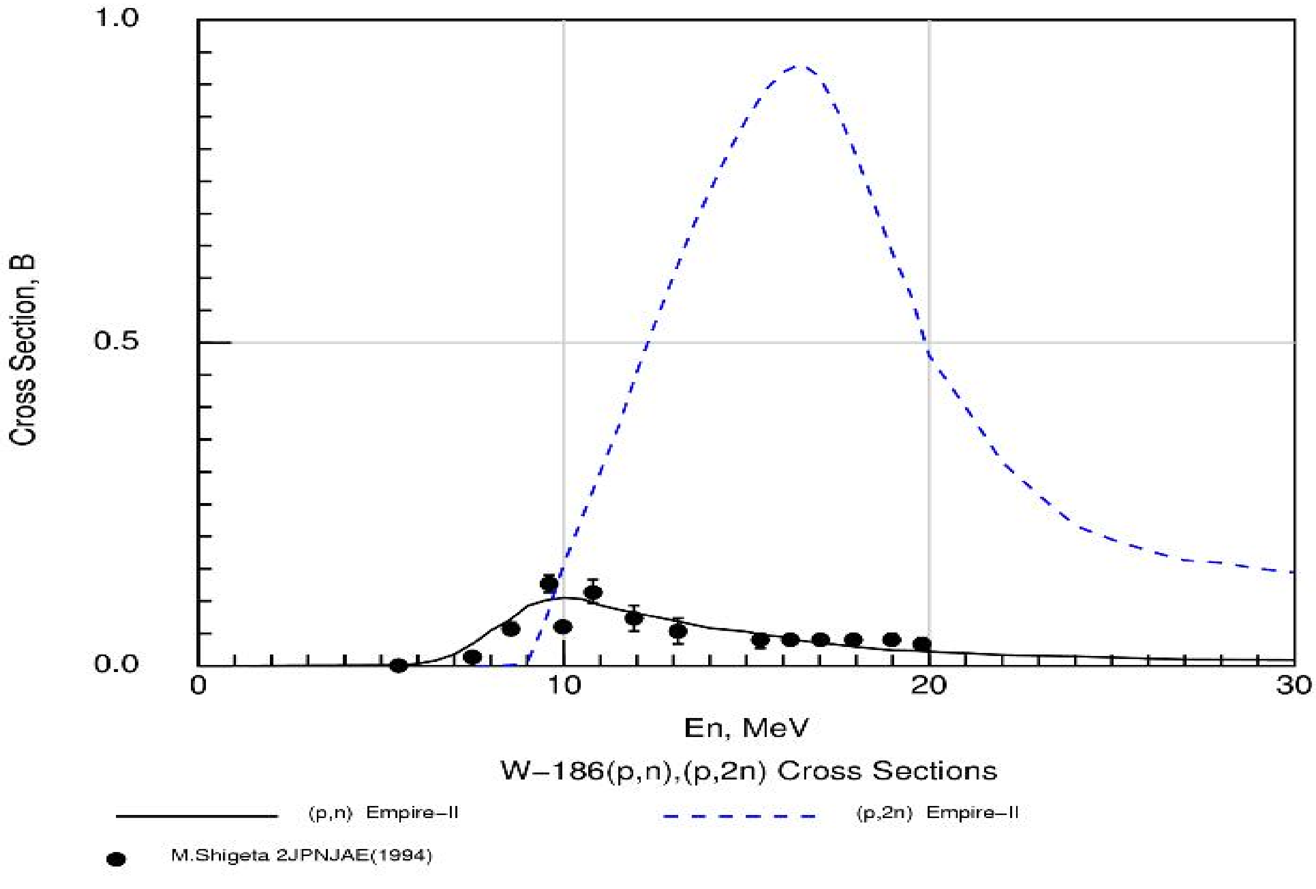
p + ^{241}Am 反应截面 —CFUP1 计算

$^{186}W(p,n)$



0.15
0.10
0.05
0.00
Cross Section, B
0
10
20
30
En, MeV
W−186(p,n)Re−186 Cross Section
Empire−II
M.Shigeta 2JPNJAE(1994)

$^{186}W(p,n),(p,2n)$



1.0
0.5
0.0
Cross Section, B
0
10
20
30
En, MeV
W–186(p,n),(p,2n) Cross Sections
(p,n) Empire–II
(p,2n) Empire–II
M.Shigeta 2JPNJAE(1994)

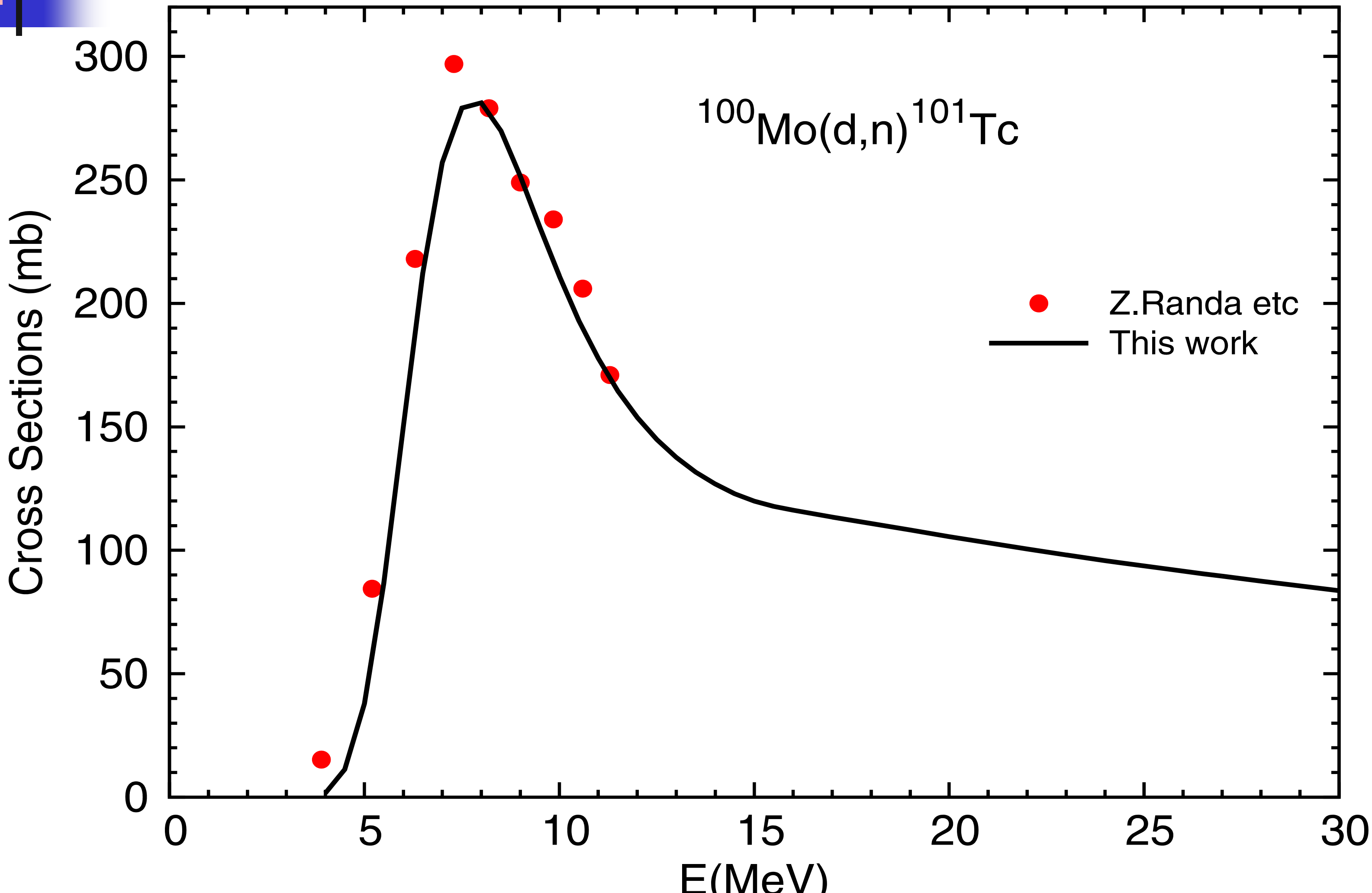
Ⅱ.Theoretical Calculation

Incident deuteron:

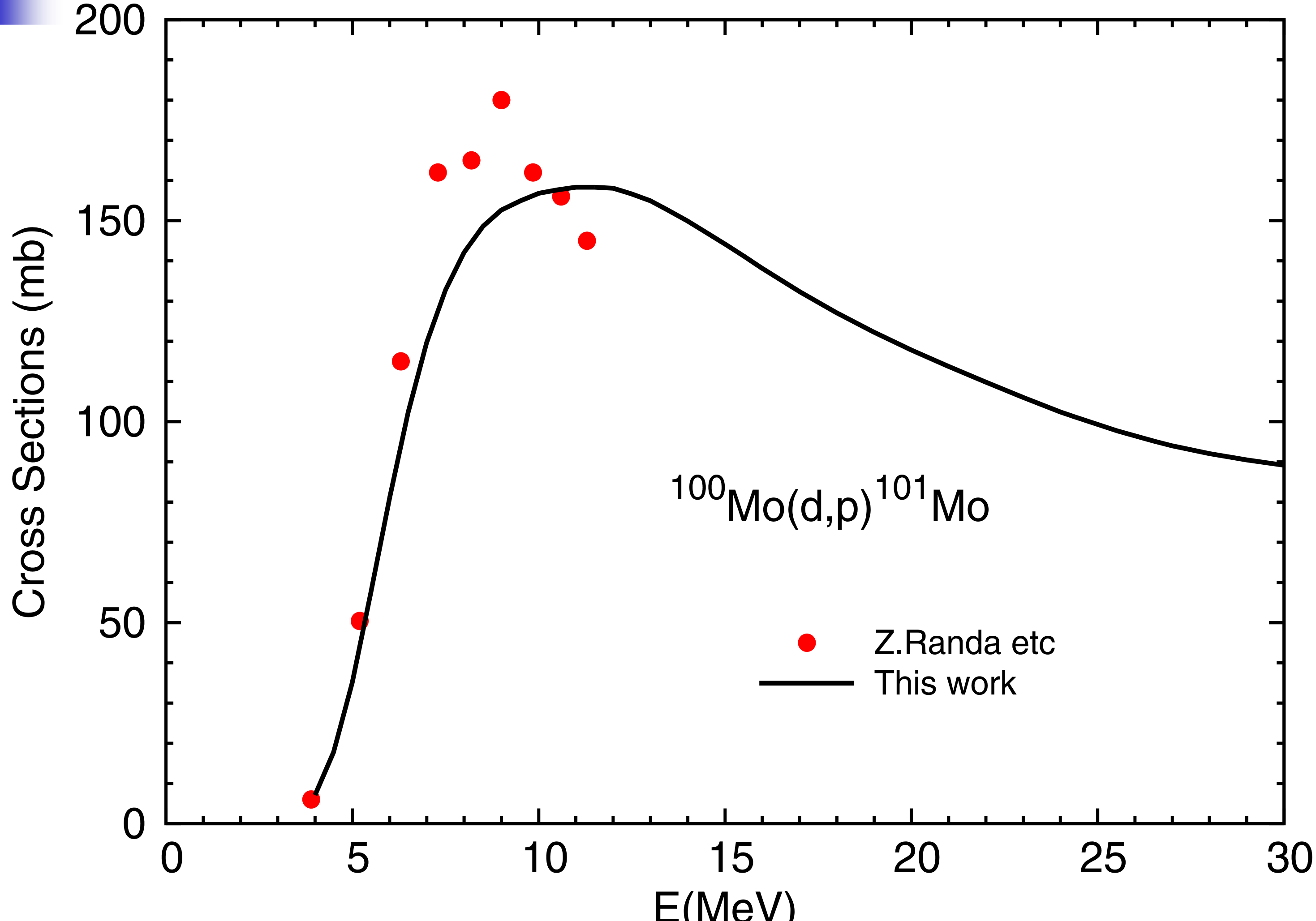
^{100}Mo(d, n), (d, 2n), (d, 3n)

Code SPEC

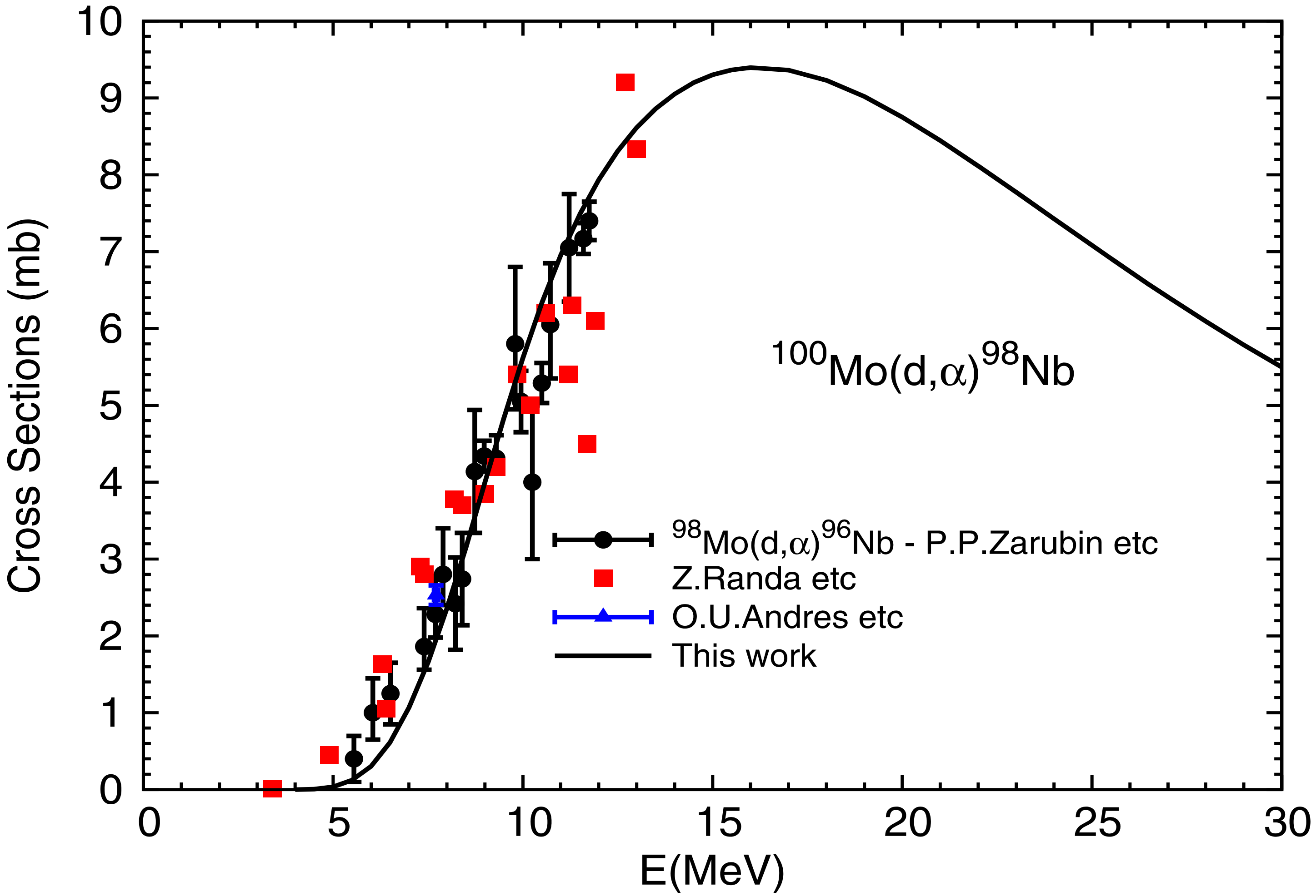
II .Theoretical Calculation



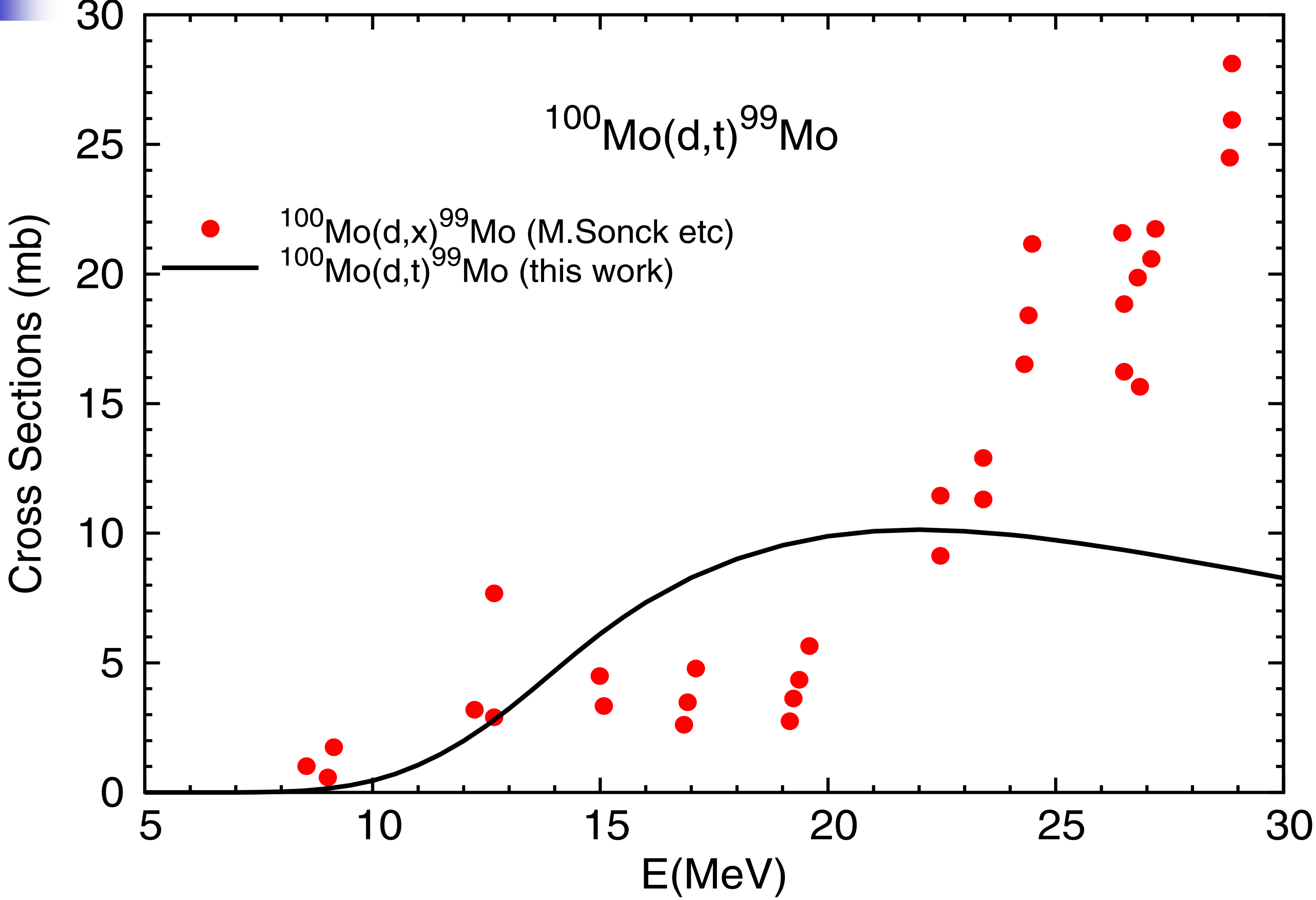
Ⅱ .Theoretical Calculation



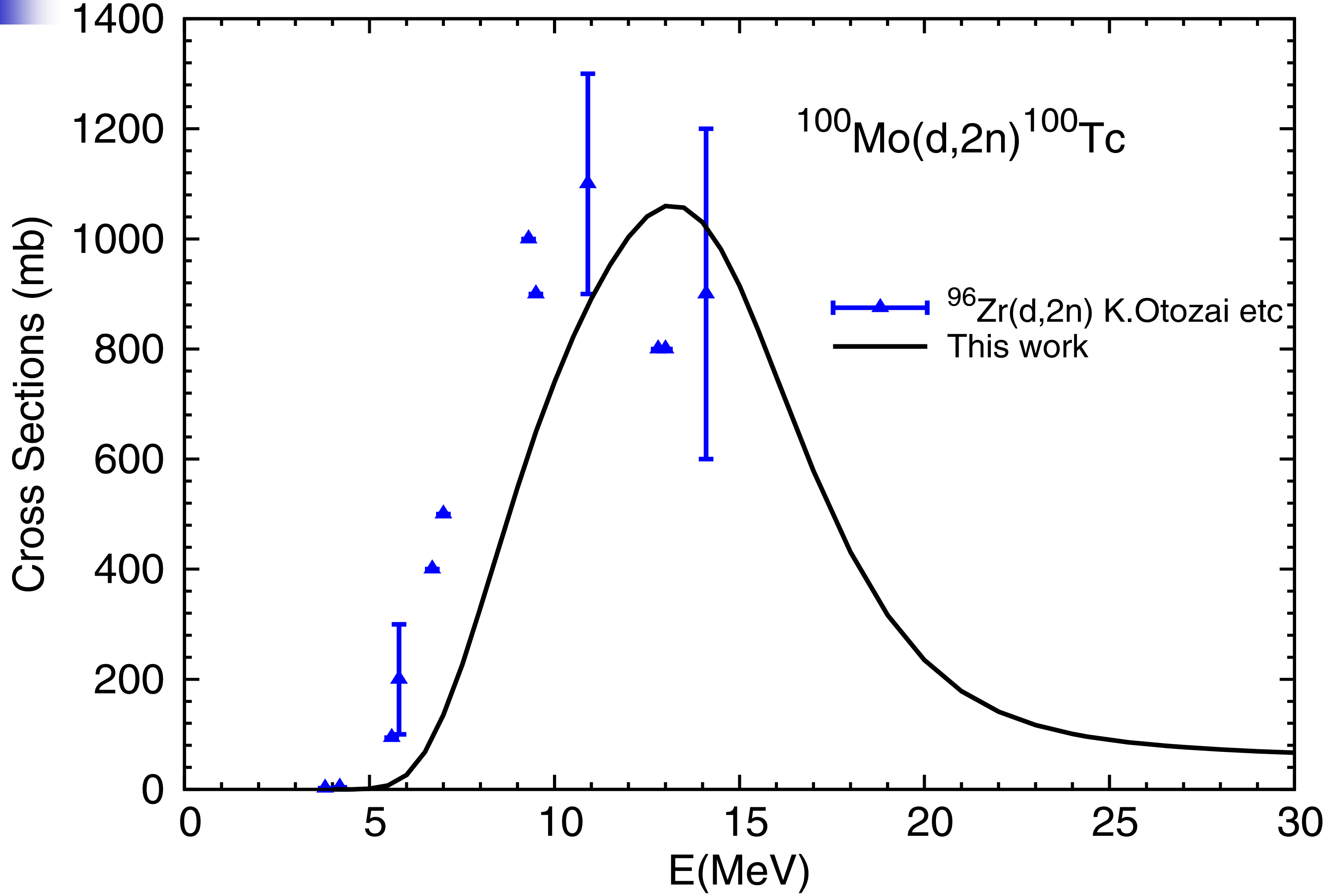
II .Theoretical Calculation



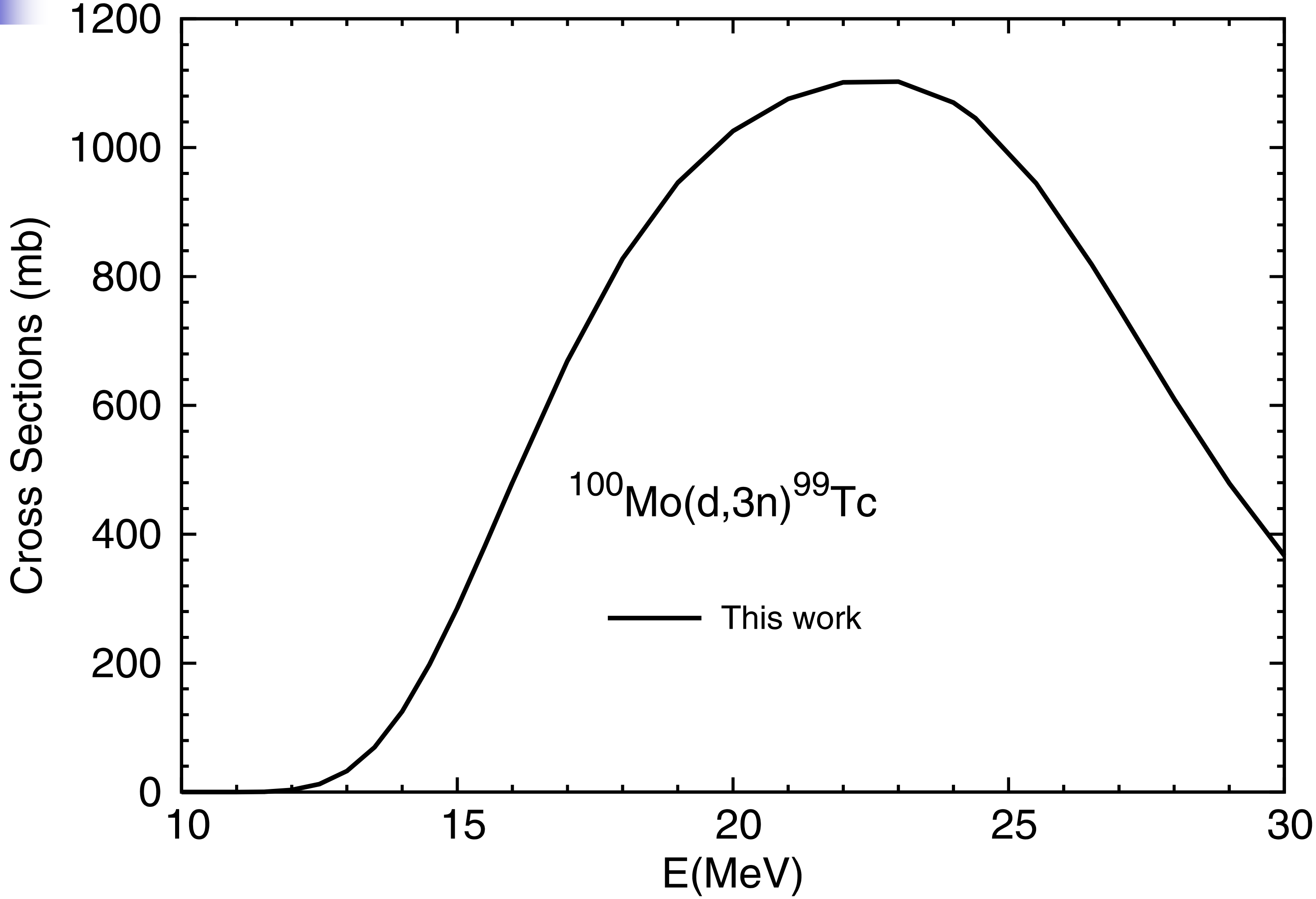
II .Theoretical Calculation



II .Theoretical Calculation



II .Theoretical Calculation



Ⅲ .Conclusion

Evaluation and recommendation of charged particle excitation functions

- **First, do our best to make evaluation and correction**

  Reliable evaluation is based on full and accurate experimental data

- **Second, combine theoretical calculation with experimental evaluation, in order to get a complete set of recommended data**

Thank you

For your support and cooperation