# ANISOTROPY IN PRE-FISSION AND (n,nγ) NEUTRON SPECTRA OF 239-Pu+n

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# SCOPE

**Fissile targets  Prompt Fission Neutron Spectra**

**Asymmetry of first neutron emission in (n,nγ) En=14 MeV**

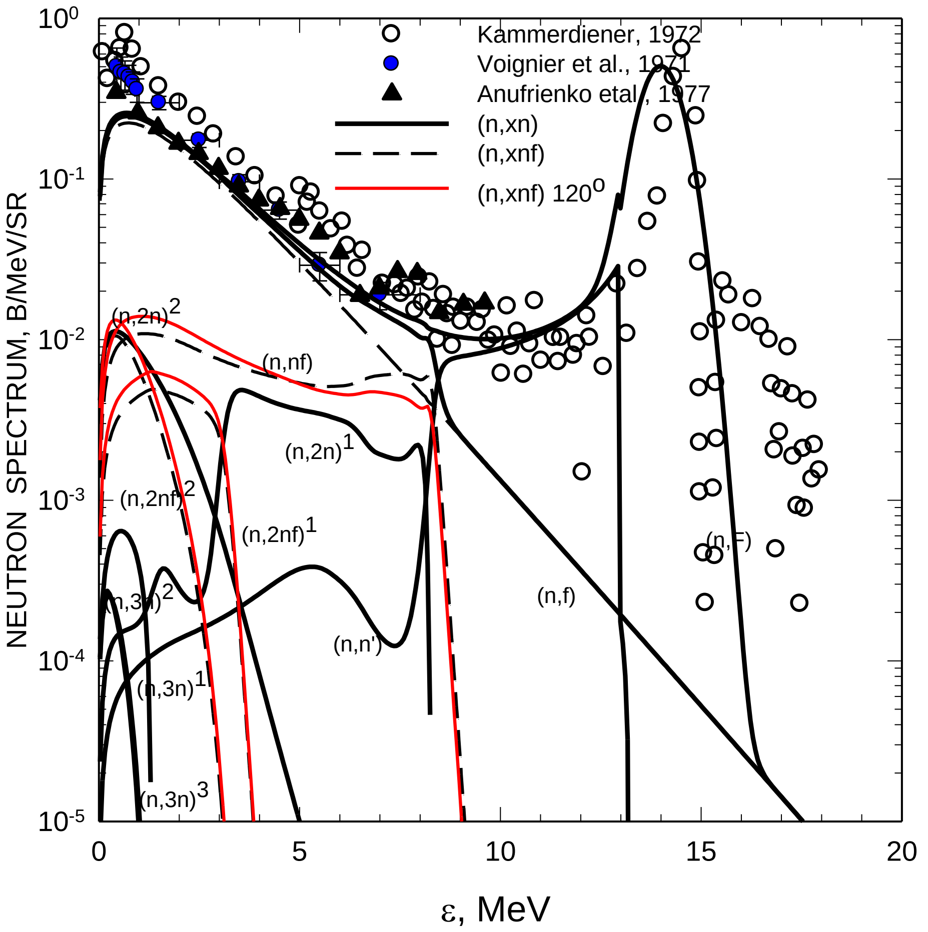
Kammerdiener J.L., UCRL-51232, 1972.

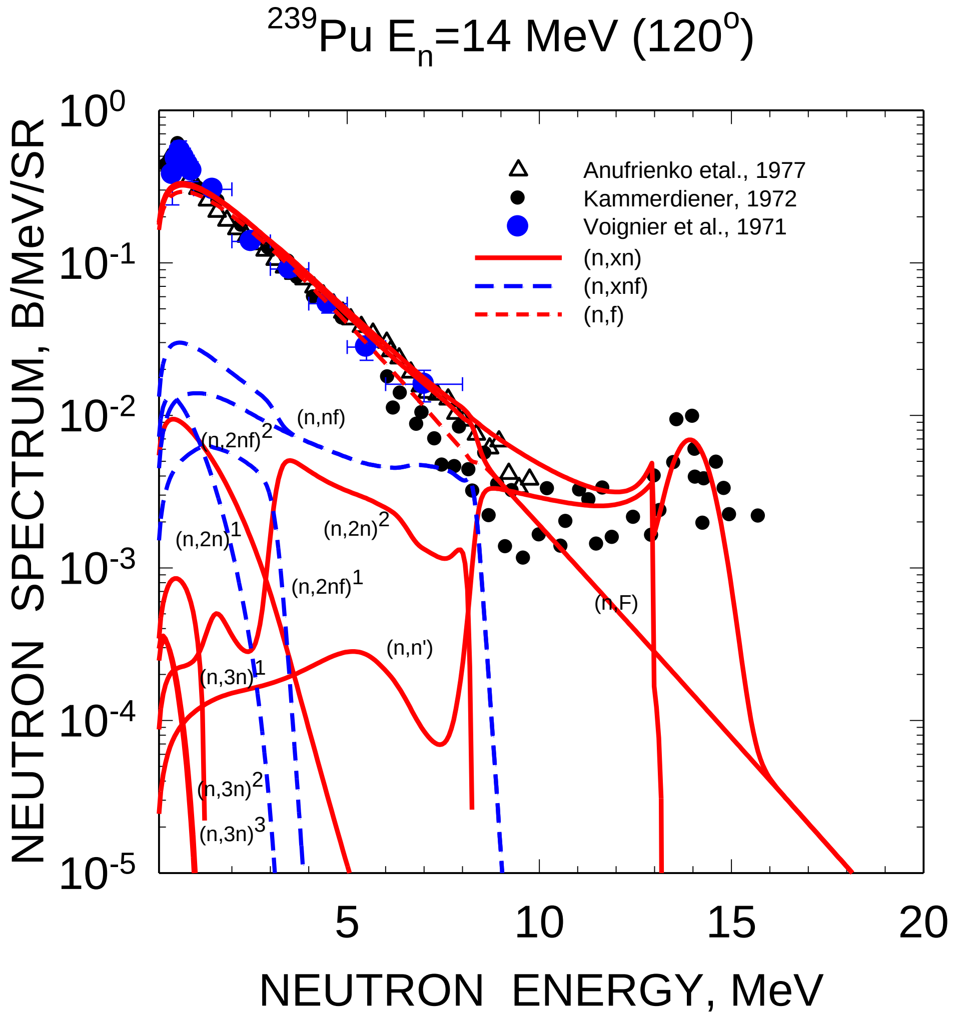
**Asymmetry of pre-fission neutron emission**

Kelly e. a., Phys. Rev. Lett., 2019, v. 122, p. 072503

**Emissive (n,xnf) fission En>12 MeV**

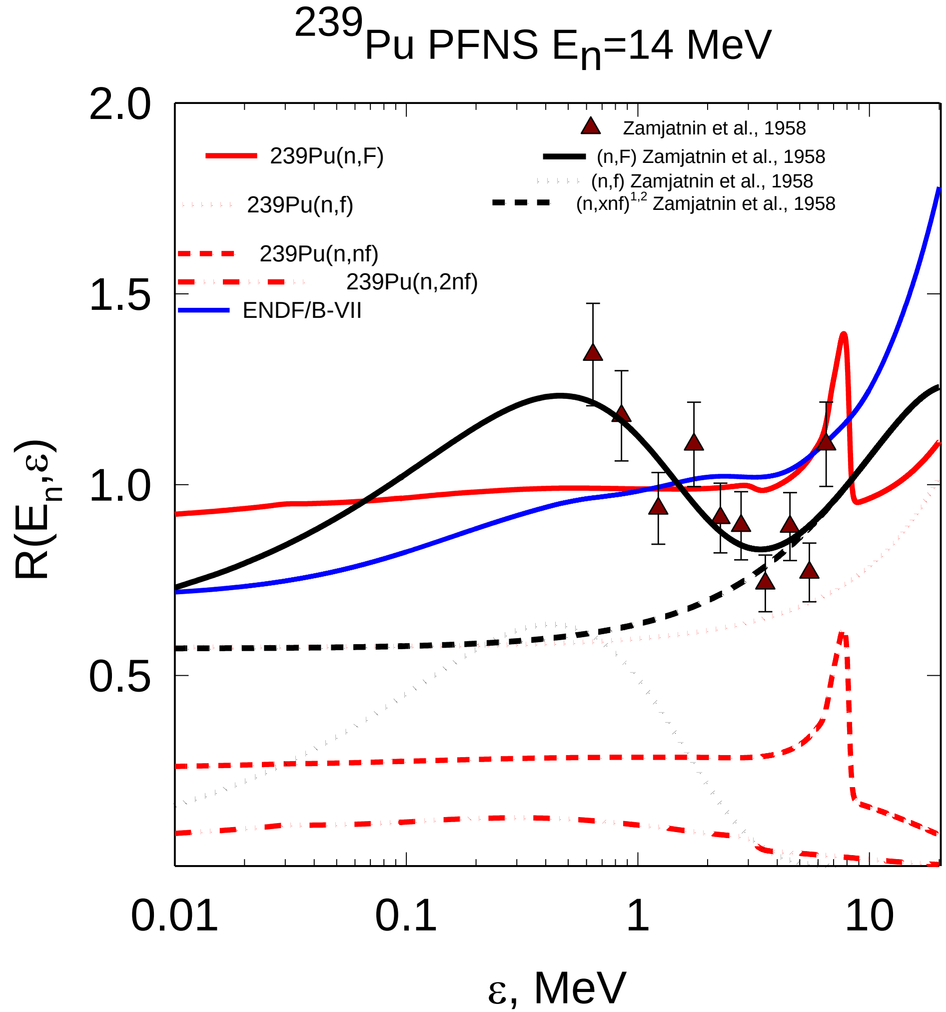
Neutron emission spectrum of $^{239}$Pu at $E_n$=14 MeV ($30^o$)



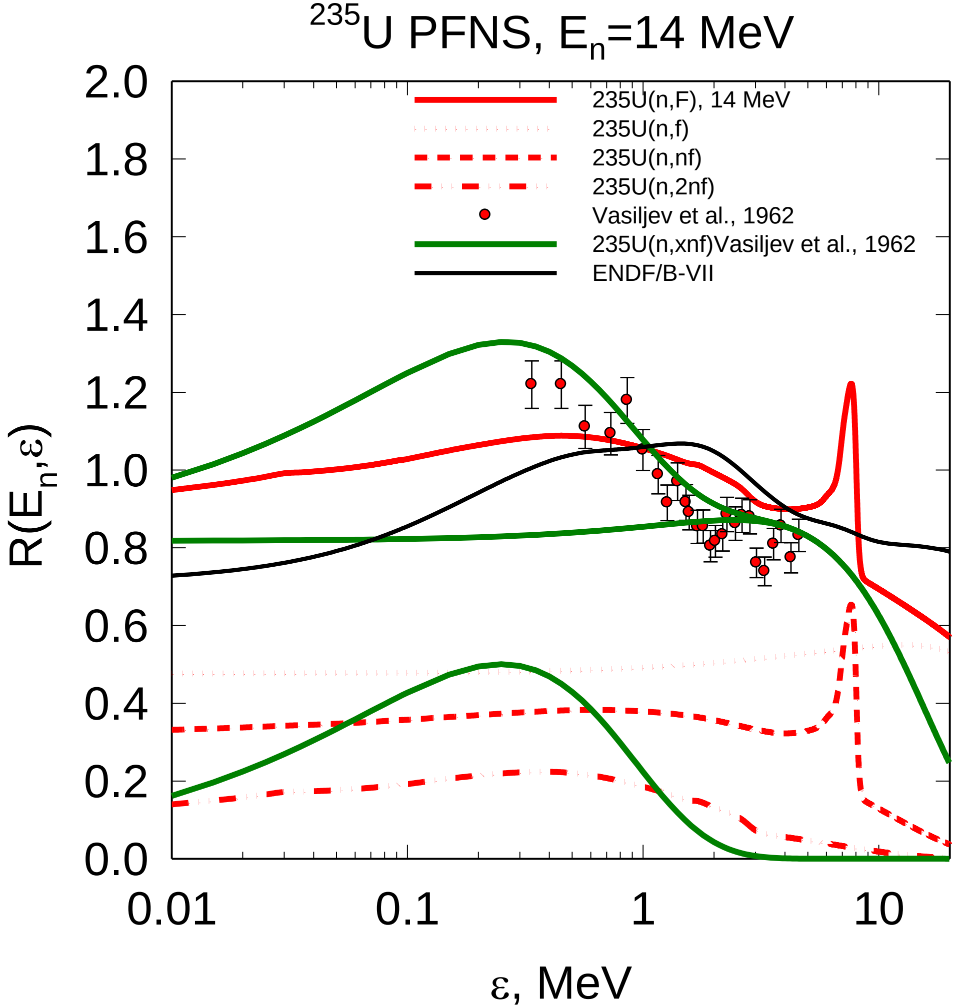


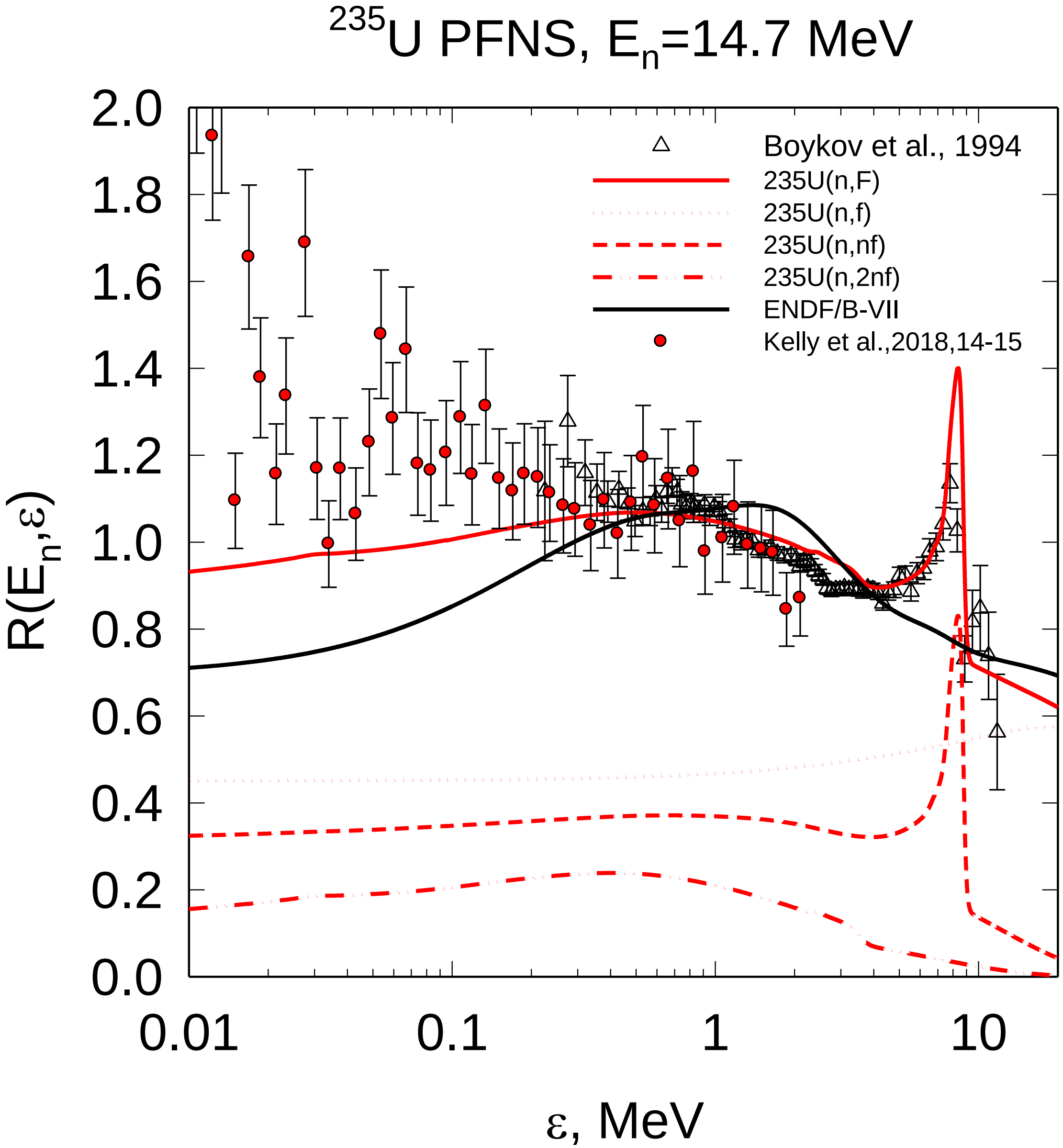
239Pu En=14 MeV (120o)
NEUTRON SPECTRUM, B/MeV/SR
NEUTRON ENERGY, MeV
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
5
10
15
20
Anufrienko etal., 1977
Kammerdiener, 1972
Voignier et al., 1971
(n,xn)
(n,xnf)
(n,f)
(n,nf)
(n,2nf)2
(n,2n)1
(n,2n)2
(n,2nf)1
(n,n')
(n,3n)1
(n,3n)2
(n,3n)3
(n,F)

$$S_{240}(\varepsilon, E_n) = (1-\beta)\varepsilon \exp\left(-\frac{\varepsilon}{T}\right) + \beta \exp\left(-\frac{\varepsilon}{T_f}\right)\frac{sh(2\sqrt{\omega\varepsilon})}{T_f}$$



$$S_{240}(\varepsilon, E_n) = (1-\beta)\varepsilon \exp\left(-\frac{\varepsilon}{T}\right) + \beta \exp\left(-\frac{\varepsilon}{T_f}\right)\frac{sh(2\sqrt{\omega\varepsilon})}{T_f}$$

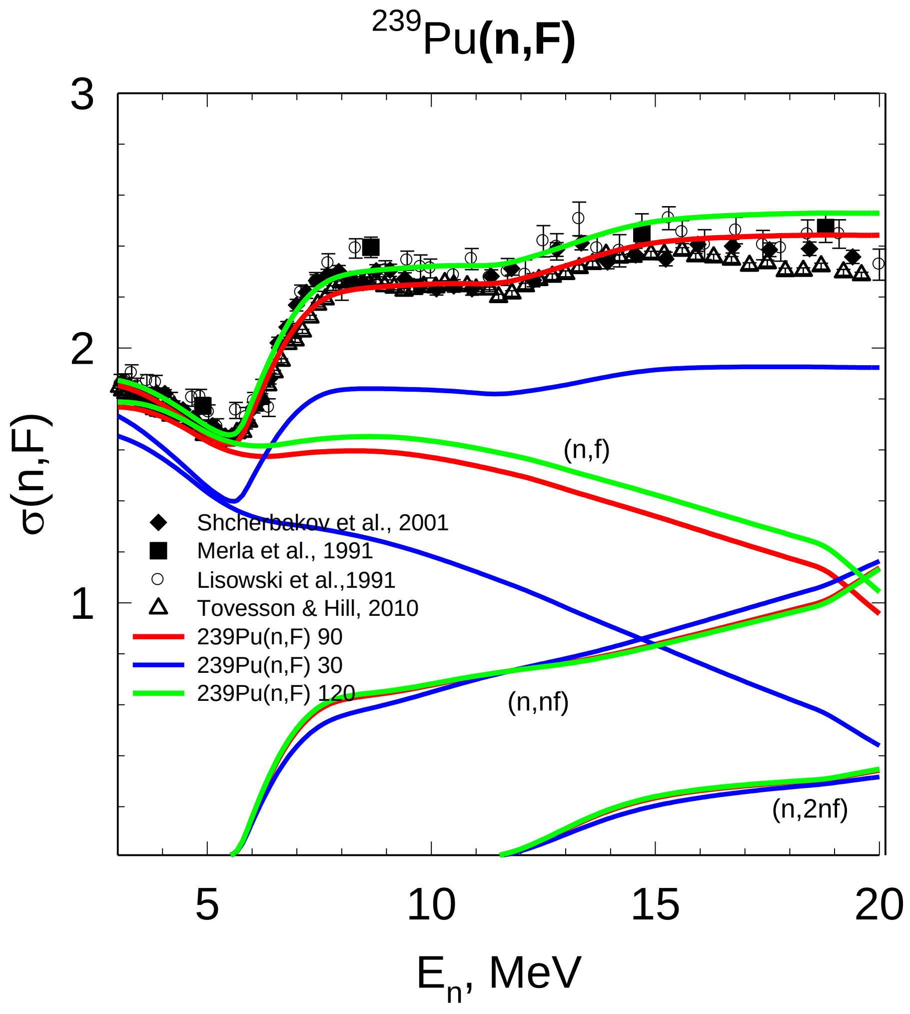


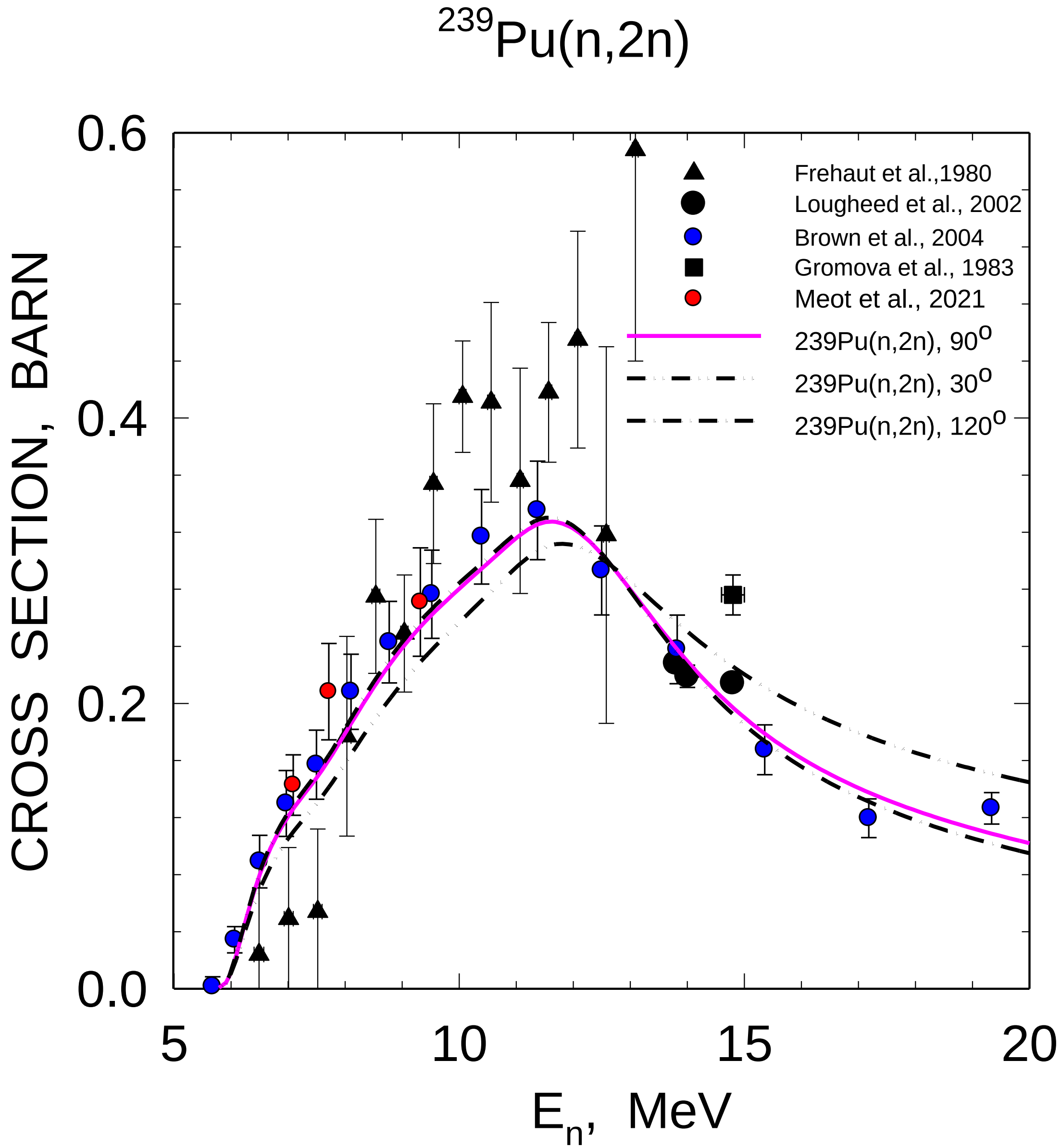


235U PFNS, En=14.7 MeV
R(En,ε)
ε, MeV
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.01
0.1
1
10
Boykov et al., 1994
235U(n,F)
235U(n,f)
235U(n,nf)
235U(n,2nf)
ENDF/B-VII
Kelly et al.,2018,14-15

$$\sigma_{\mathrm{nF}}\left(E_n\right)=\sigma_{\mathrm{nf}}\left(E_n\right)+\sum_{x=1}^{X}\sigma_{\mathrm{n,xnf}}\left(E_n\right)$$

$$\sigma_{\mathrm{n,xnf}}\left(E_n\right)=\sum_{J\pi}^{J}\int_{0}^{U_{\mathrm{max}}}W_{x+1}^{J\pi}(U)P_{f\,(x+1)}^{J\pi}(U)dU$$


239Pu(n,F)
3
2
1
σ(n,F)
5
10
15
20
En, MeV
(n,f)
(n,nf)
(n,2nf)
Shcherbakov et al., 2001
Merla et al., 1991
Lisowski et al.,1991
Tovesson & Hill, 2010
239Pu(n,F) 90
239Pu(n,F) 30
239Pu(n,F) 120



239Pu(n,2n)
0.6
0.4
0.2
0.0
CROSS SECTION, BARN
5
10
15
20
En, MeV
Frehaut et al.,1980
Lougheed et al., 2002
Brown et al., 2004
Gromova et al., 1983
Meot et al., 2021
239Pu(n,2n), 90o
239Pu(n,2n), 30o
239Pu(n,2n), 120o

$$\nu_{\mathrm{p}}(E_n) = \nu_{post} + \nu_{pre} =$$

$$\sum_{x=1}^{X} \nu_{px}(E_{nx}) + \sum_{x=1}^{X} (x-1)\cdot \beta_x(E_n)$$

# Prompt-fission neutron spectra

**superposition of exclusive pre-fission (n,xnf) spectra and post-fission spectra $S_{A+2-x}(\varepsilon,E_n)$**

$$
\begin{aligned}
\mathrm{S}(\varepsilon,\mathrm{E_n}) = {} & \nu^{-1}(E_n)(\nu_1(E_n)\beta_1(E_n)\mathrm{S}_{\mathrm{A+1}}(\varepsilon,\mathrm{E_n}) + \\
& \nu_2(E_n)\beta_2(E_n)\mathrm{S}_A(\varepsilon,\mathrm{E_n}) + \beta_2(E_n)\frac{d\sigma^1_{\mathrm{nnnf}}(E_n)}{d\varepsilon} + \\
& \nu_3(E_n)\beta_3(E_n)\mathrm{S}_{A-1}(\varepsilon,\mathrm{E_n}) + \beta_3(E_n)\left(\frac{d\sigma^1_{\mathrm{n2nnf}}(E_n)}{d\varepsilon} + \frac{d\sigma^2_{\mathrm{n2nnf}}(E_n)}{d\varepsilon}\right) + \\
& \nu_4(E_n)\beta_4(E_n)\mathrm{S}_{A-2}(\varepsilon,\mathrm{E_n}) + \beta_4(E_n)\left(\frac{d\sigma^1_{\mathrm{n3nnf}}(E_n)}{d\varepsilon} + \frac{d\sigma^2_{\mathrm{n3nnf}}(E_n)}{d\varepsilon} + \frac{d\sigma^3_{\mathrm{n3nnf}}(E_n)}{d\varepsilon}\right))
\end{aligned}
$$

$$d\sigma^{1}_{nnx}/d\varepsilon \approx d\tilde{\sigma}^{1}_{nnx}/d\varepsilon + \sqrt{\frac{\varepsilon}{E_n}}\,\frac{\omega(\theta)}{E_n-\varepsilon}$$

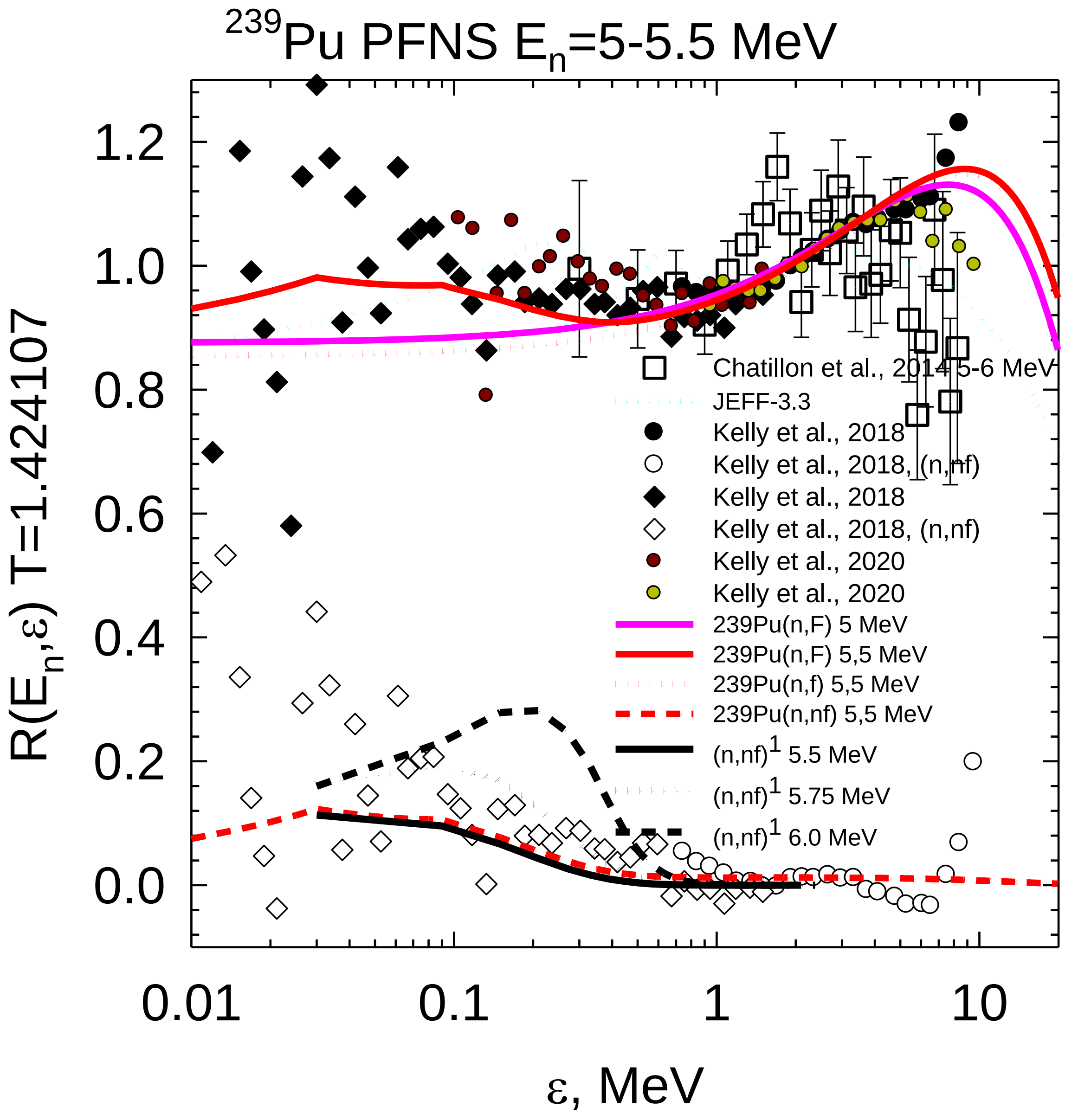
$$\frac{d\sigma^{1}_{n2nx}}{d\varepsilon} = \frac{d\sigma^{1}_{nnx}(\varepsilon)}{d\varepsilon}\,\frac{\Gamma^{A}_{n}(E_n-\varepsilon)}{\Gamma^{A}(E_n-\varepsilon)}$$

$$\frac{d\sigma^{1}_{n2nx}}{d\varepsilon} = \frac{d\sigma^{1}_{nnx}(\varepsilon)}{d\varepsilon}\,\frac{\Gamma^{A}_{n}(E_n-\varepsilon)}{\Gamma^{A}(E_n-\varepsilon)}$$

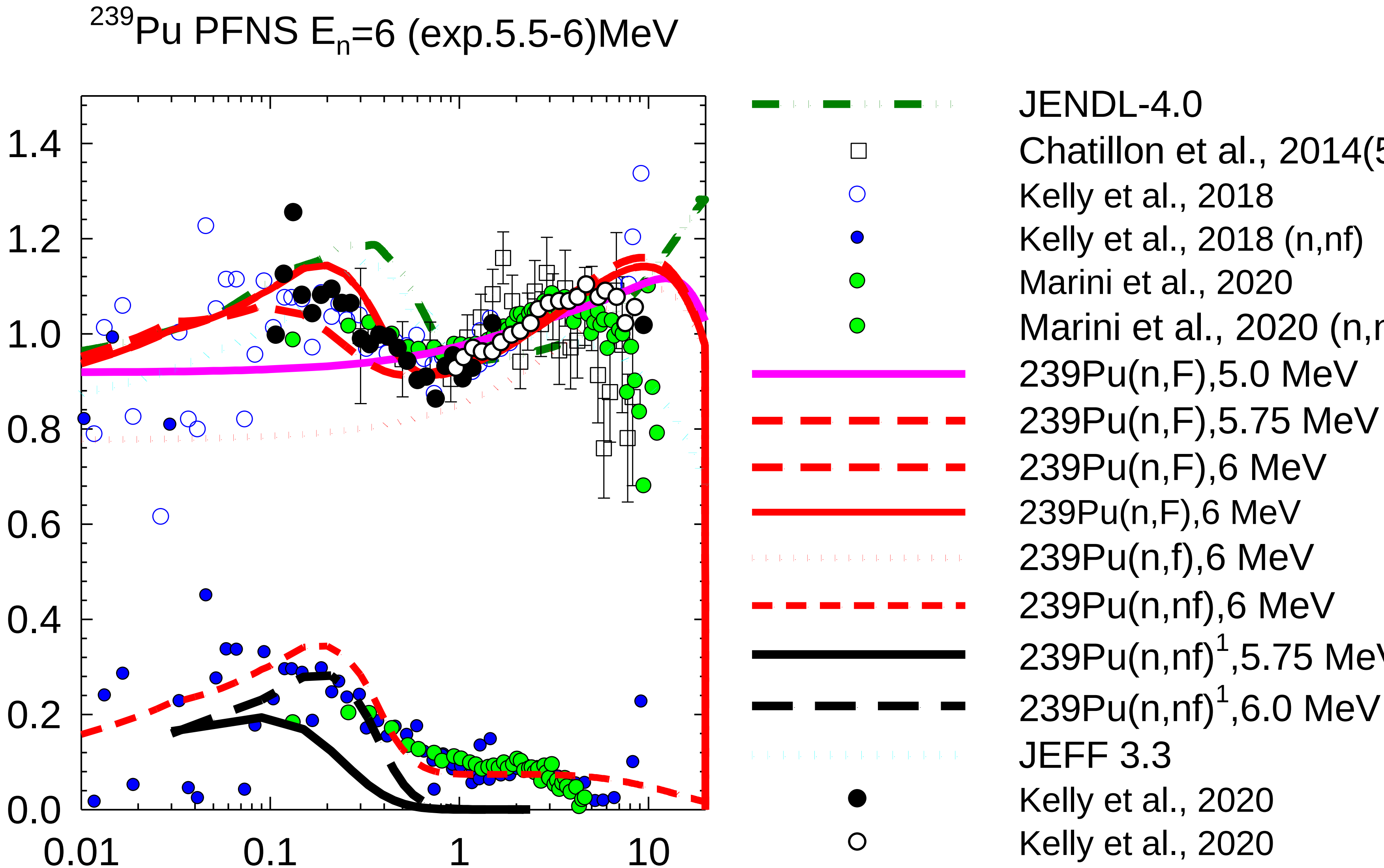
$$\frac{d\sigma^{1}_{n2nf}}{d\varepsilon} = \int_{0}^{E\ -B_n-\varepsilon} \frac{d\sigma^{1}_{n2nx}(\varepsilon)}{d\varepsilon}\,\frac{\Gamma^{A-1}_{f}(E_n-B^{A}_{n}-\varepsilon-\varepsilon_1)}{\Gamma^{A-1}(E_n-B^{A}_{n}-\varepsilon-\varepsilon_1)}\,d\varepsilon_1$$

$$\frac{d\sigma^{2}_{n2nx}}{d\varepsilon} = \int_{0}^{E\ -B_n^A-\varepsilon} \frac{d\sigma^{1}_{n2nx}(\varepsilon)}{d\varepsilon} \frac{\Gamma_n^A(E_n - B_n^A - \varepsilon - \varepsilon_1)}{\Gamma^A(E_n - B_n^A - \varepsilon - \varepsilon_1)} d\varepsilon_1$$

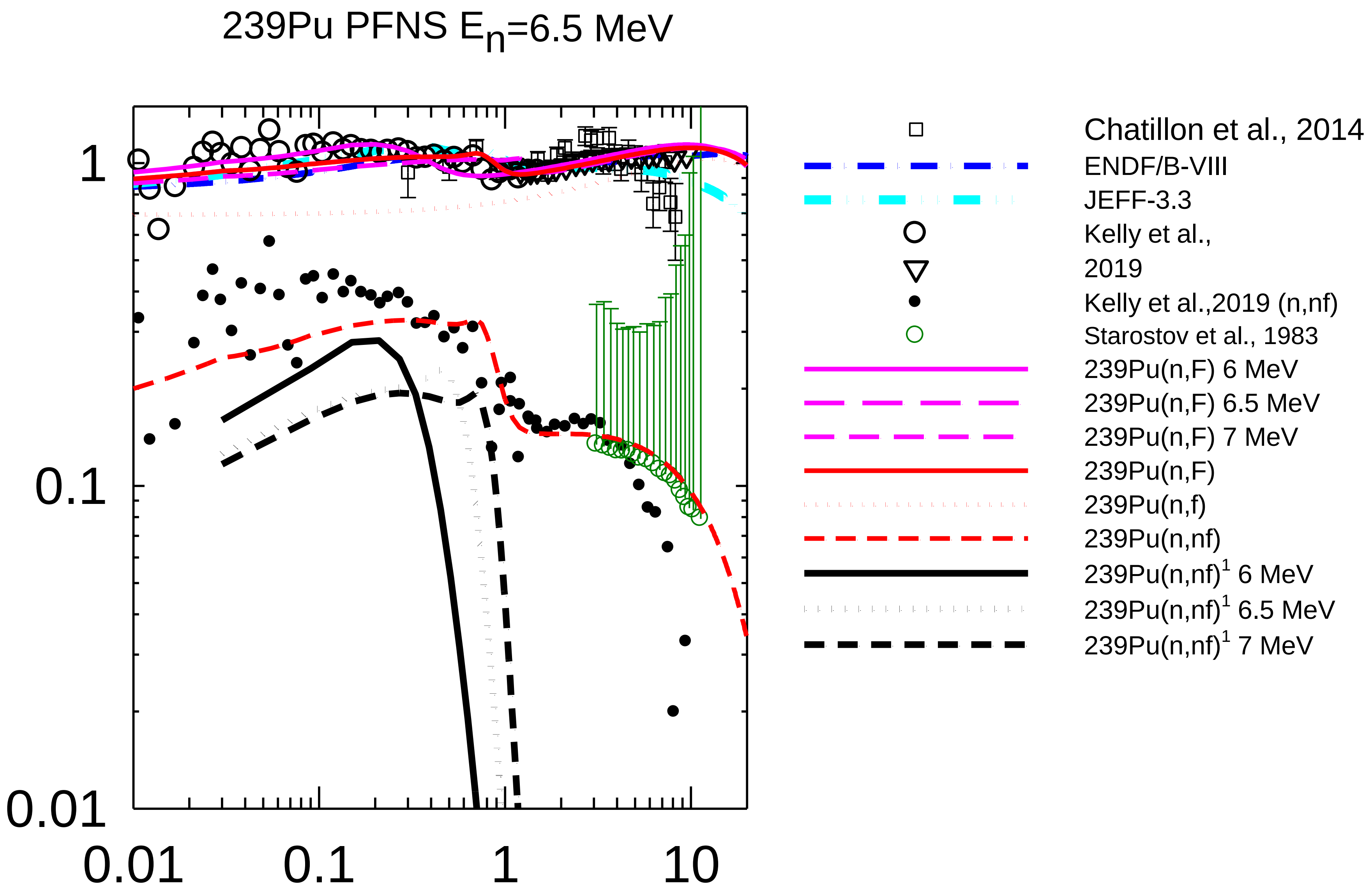
$$\frac{d\sigma^{2}_{n2nf}}{d\varepsilon} = \int_{0}^{E\ -B_n} \frac{d\sigma^{2}_{n2nx}(\varepsilon)}{d\varepsilon} \frac{\Gamma_f^{A-1}(E_n - B_n^A - \varepsilon_1 - \varepsilon_2)}{\Gamma^{A-1}(E_n - B_n^A - \varepsilon_1 - \varepsilon_2)} d\varepsilon_1$$



239Pu PFNS En=5-5.5 MeV
R(En,ε) T=1.424107
ε, MeV
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.01
0.1
1
10
Chatillon et al., 2014 5-6 MeV
JEFF-3.3
Kelly et al., 2018
Kelly et al., 2018, (n,nf)
Kelly et al., 2018
Kelly et al., 2018, (n,nf)
Kelly et al., 2020
Kelly et al., 2020
239Pu(n,F) 5 MeV
239Pu(n,F) 5,5 MeV
239Pu(n,f) 5,5 MeV
239Pu(n,nf) 5,5 MeV
(n,nf)1 5.5 MeV
(n,nf)1 5.75 MeV
(n,nf)1 6.0 MeV

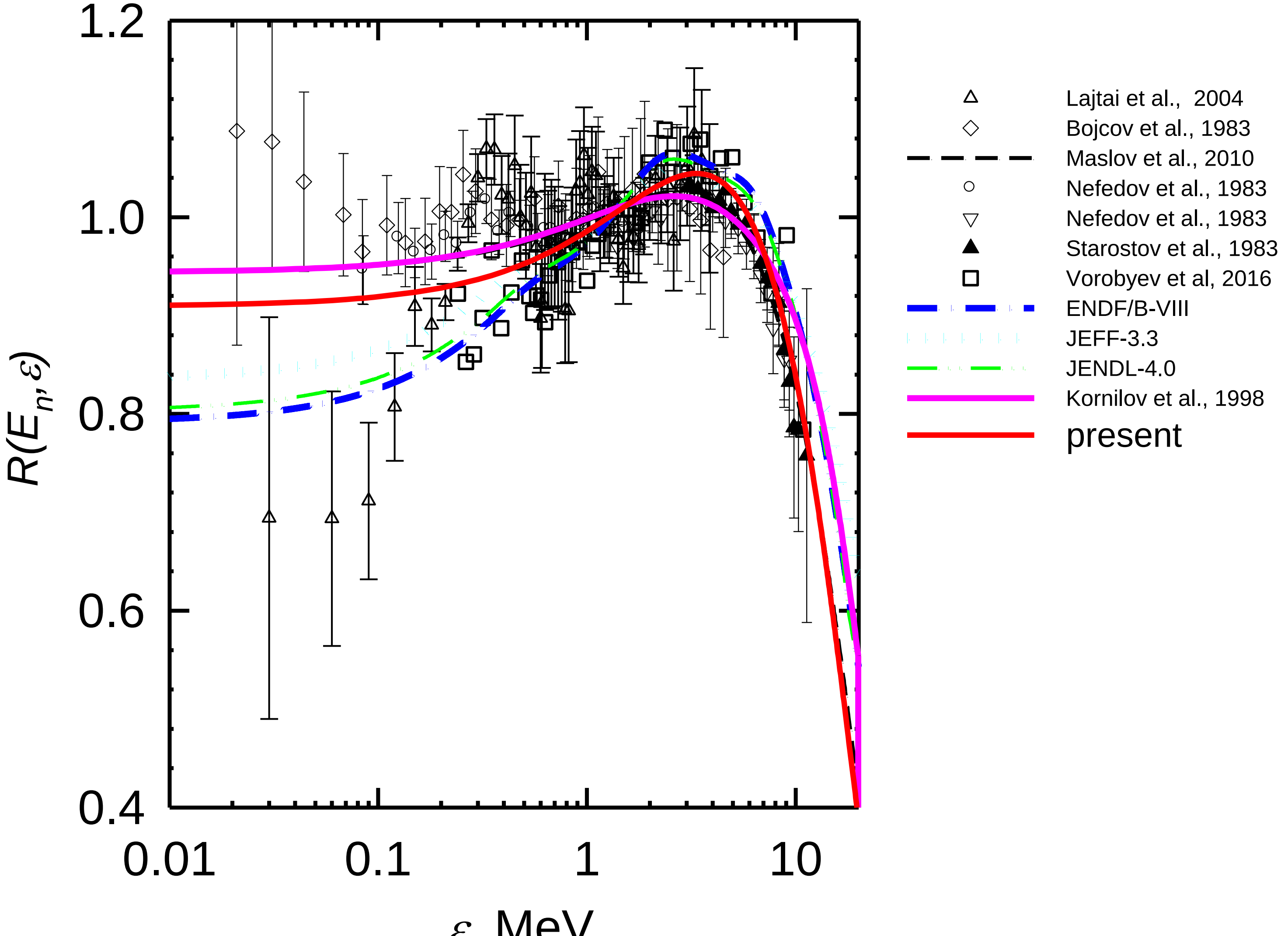


239Pu PFNS En=6 (exp.5.5-6)MeV
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.01
0.1
1
10
JENDL-4.0
Chatillon et al., 2014(5
Kelly et al., 2018
Kelly et al., 2018 (n,nf)
Marini et al., 2020
Marini et al., 2020 (n,n
239Pu(n,F),5.0 MeV
239Pu(n,F),5.75 MeV
239Pu(n,F),6 MeV
239Pu(n,F),6 MeV
239Pu(n,f),6 MeV
239Pu(n,nf),6 MeV
239Pu(n,nf)1,5.75 MeV
239Pu(n,nf)1,6.0 MeV
JEFF 3.3
Kelly et al., 2020
Kelly et al., 2020

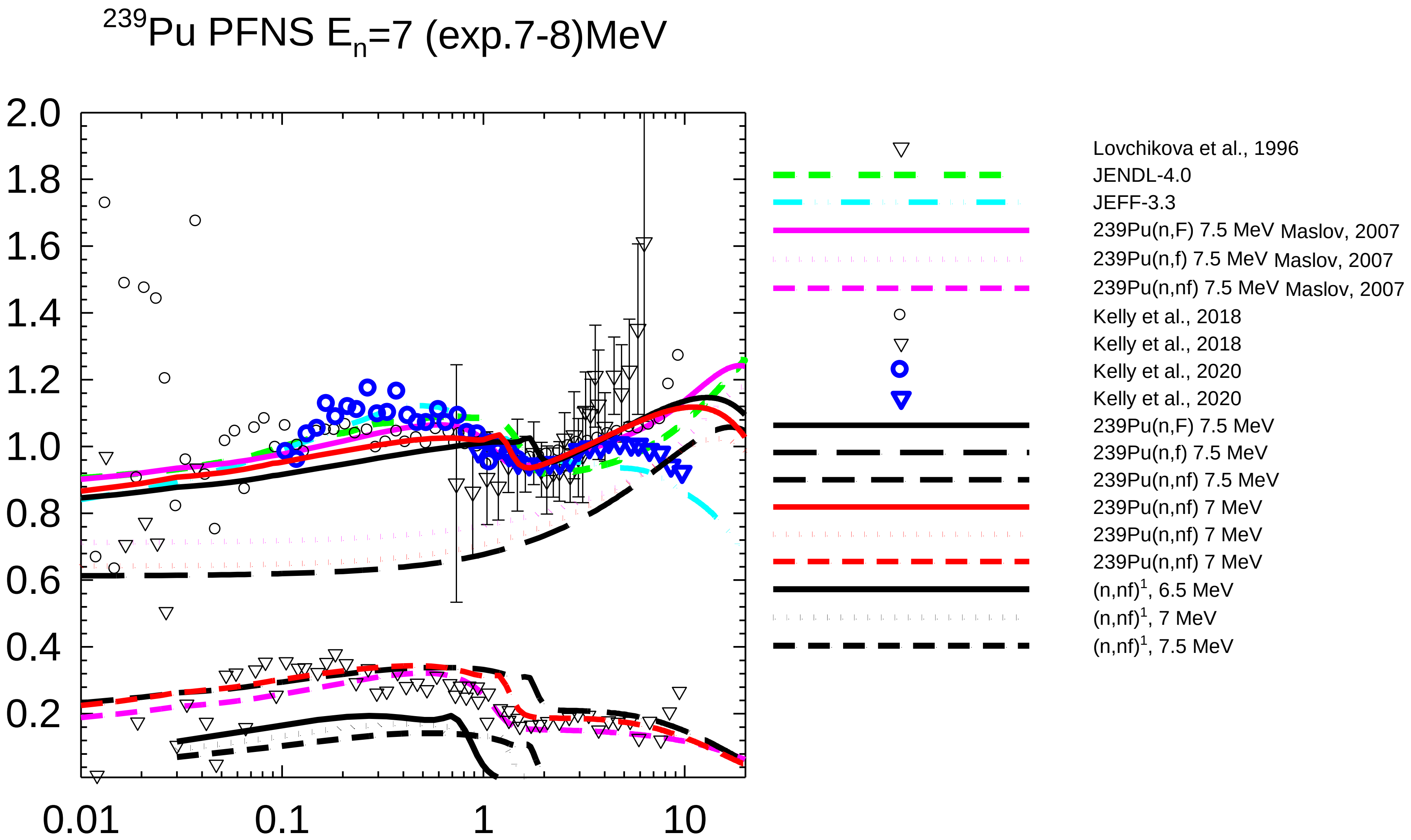


239Pu PFNS En=6.5 MeV
1
0.1
0.01
0.01
0.1
1
10
Chatillon et al., 2014
ENDF/B-VIII
JEFF-3.3
Kelly et al.,
2019
Kelly et al.,2019 (n,nf)
Starostov et al., 1983
239Pu(n,F) 6 MeV
239Pu(n,F) 6.5 MeV
239Pu(n,F) 7 MeV
239Pu(n,F)
239Pu(n,f)
239Pu(n,nf)
239Pu(n,nf)1 6 MeV
239Pu(n,nf)1 6.5 MeV
239Pu(n,nf)1 7 MeV

# E_th



1.2
1.0
0.8
0.6
0.4
0.01
0.1
1
10
$R(E_n,\varepsilon)$
$\varepsilon$, MeV
Lajtai et al., 2004
Bojcov et al., 1983
Maslov et al., 2010
Nefedov et al., 1983
Nefedov et al., 1983
Starostov et al., 1983
Vorobyev et al, 2016
ENDF/B-VIII
JEFF-3.3
JENDL-4.0
Kornilov et al., 1998
present

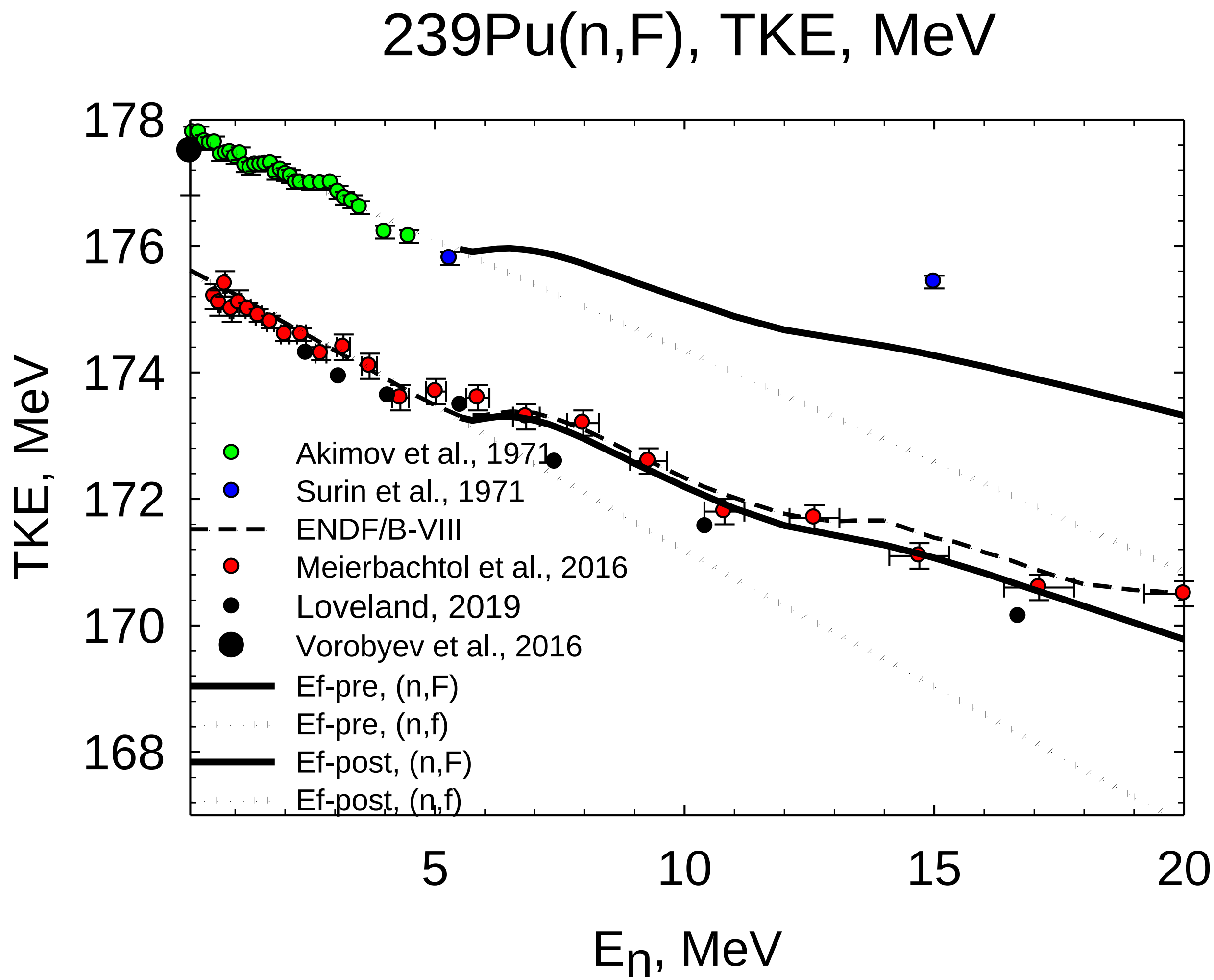


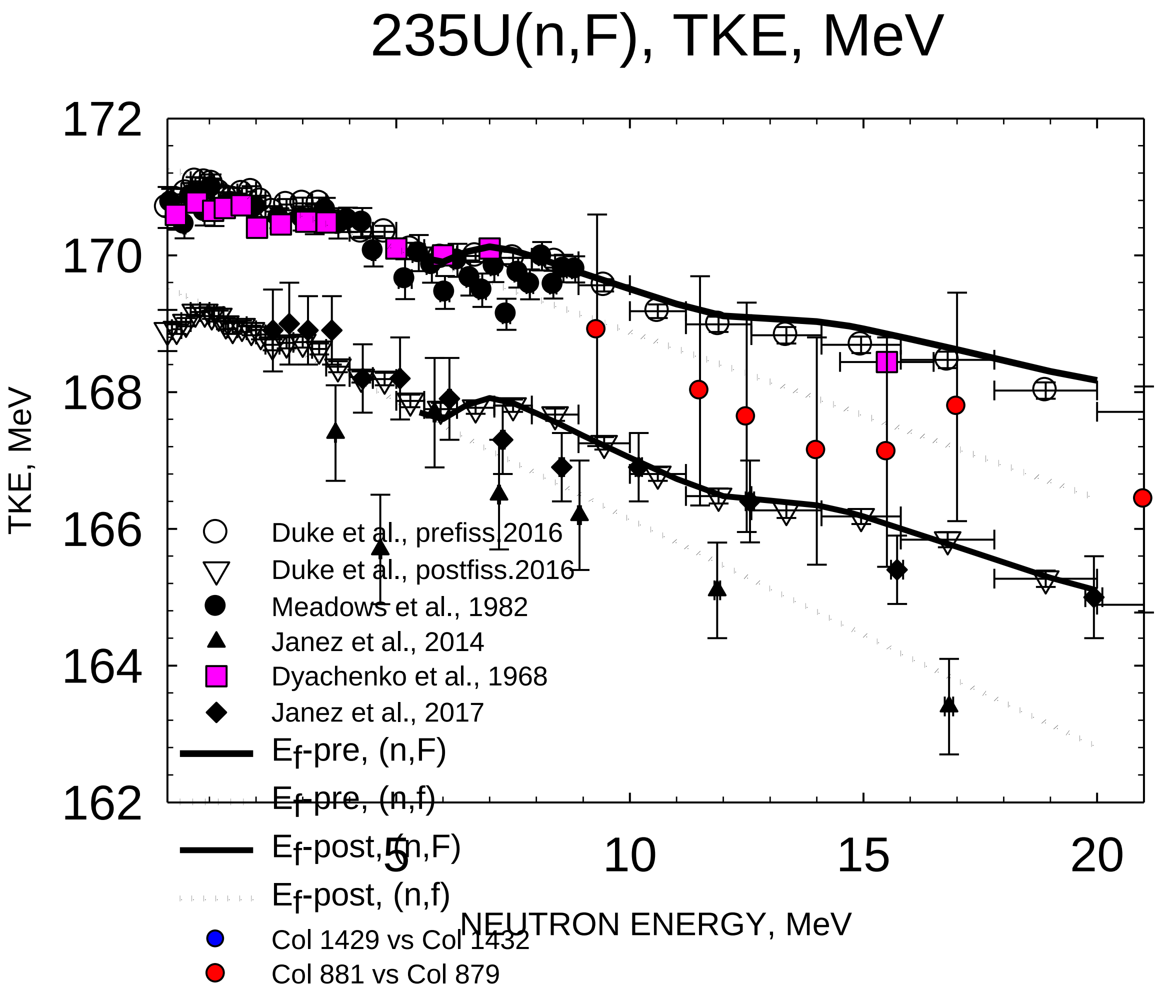
239Pu PFNS En=7 (exp.7-8)MeV
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.01
0.1
1
10
Lovchikova et al., 1996
JENDL-4.0
JEFF-3.3
239Pu(n,F) 7.5 MeV Maslov, 2007
239Pu(n,f) 7.5 MeV Maslov, 2007
239Pu(n,nf) 7.5 MeV Maslov, 2007
Kelly et al., 2018
Kelly et al., 2018
Kelly et al., 2020
Kelly et al., 2020
239Pu(n,F) 7.5 MeV
239Pu(n,f) 7.5 MeV
239Pu(n,nf) 7.5 MeV
239Pu(n,nf) 7 MeV
239Pu(n,nf) 7 MeV
239Pu(n,nf) 7 MeV
(n,nf)1, 6.5 MeV
(n,nf)1, 7 MeV
(n,nf)1, 7.5 MeV

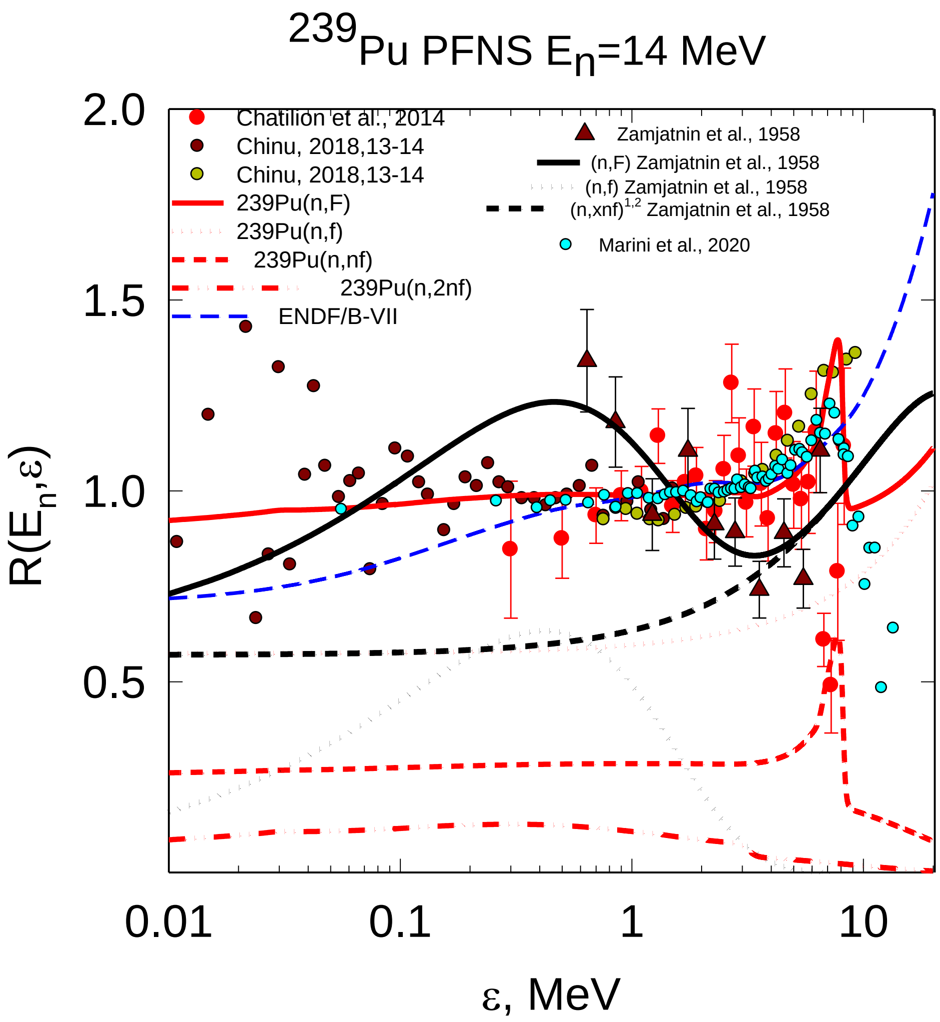
$$E_f^{post} \approx E_f^{pre}\left(1-\nu_{post}/\left(A-\nu_{pre}\right)\right)$$

$$E_f^{pre}(E_n) = \sum_{x=0}^{X} E_{fx}^{pre}(E_{nx}) \cdot \sigma_{n,xnf} / \sigma_{n,F} ,$$

$$E_{nx} = E_n + B_n - \sum_{x=0,1\leq j\leq x}^{X} \left(\left\langle E_{n,xnf}^{j} \right\rangle + B_x\right)$$


239Pu(n,F), TKE, MeV
TKE, MeV
178
176
174
172
170
168
5
10
15
20
En, MeV
Akimov et al., 1971
Surin et al., 1971
ENDF/B-VIII
Meierbachtol et al., 2016
Loveland, 2019
Vorobyev et al., 2016
Ef-pre, (n,F)
Ef-pre, (n,f)
Ef-post, (n,F)
Ef-post, (n,f)


235U(n,F), TKE, MeV
172
170
168
166
164
162
TKE, MeV
5
10
15
20
NEUTRON ENERGY, MeV
Duke et al., prefiss.2016
Duke et al., postfiss.2016
Meadows et al., 1982
Janez et al., 2014
Dyachenko et al., 1968
Janez et al., 2017
Ef-pre, (n,F)
Ef-pre, (n,f)
Ef-post, (n,F)
Ef-post, (n,f)
Col 1429 vs Col 1432
Col 881 vs Col 879



$^{239}$Pu PFNS $E_n$=14 MeV
Chatillon et al., 2014
Chinu, 2018,13-14
Chinu, 2018,13-14
239Pu(n,F)
239Pu(n,f)
239Pu(n,nf)
239Pu(n,2nf)
ENDF/B-VII
Zamjatnin et al., 1958
(n,F) Zamjatnin et al., 1958
(n,f) Zamjatnin et al., 1958
(n,xnf)$^{1,2}$ Zamjatnin et al., 1958
Marini et al., 2020
2.0
1.5
1.0
0.5
0.01
0.1
1
10
$R(E_n,\varepsilon)$
$\varepsilon$, MeV

PREDICTED IN 2005-2010

V.M. Maslov et al., Nucl. Phys. A 760, 274 (2005).

V.M. Maslov et al., Journal of Korean Phys. Soc., 59, 2, 1337 (2011).

V.M. Maslov, Atomic Energy, 103, No. 2, 633 (2007)

V.M. Maslov et al., Atomic Energy, Vol. 108, 432 (2010).

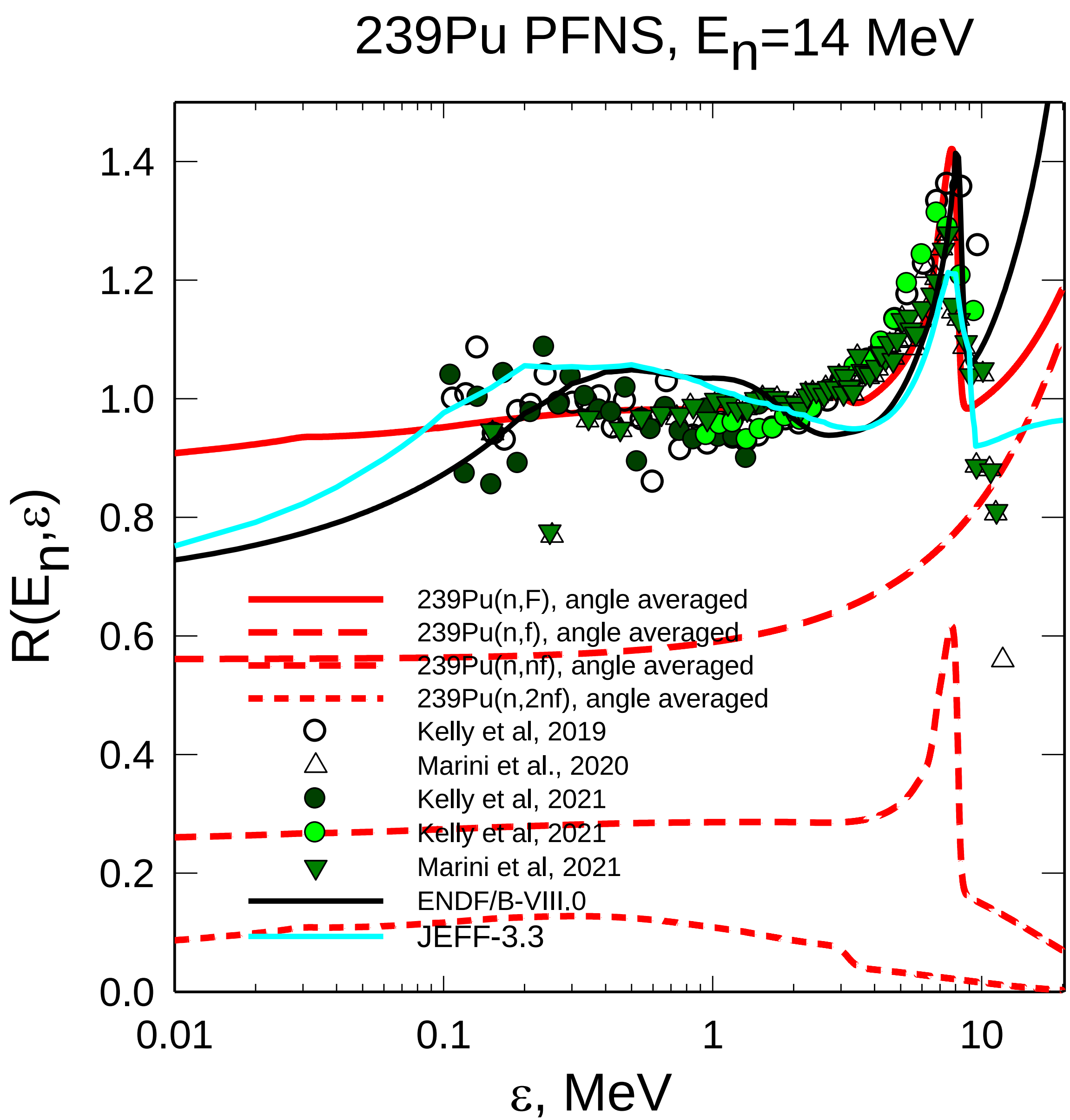
CONFIRMED IN 2019-2020

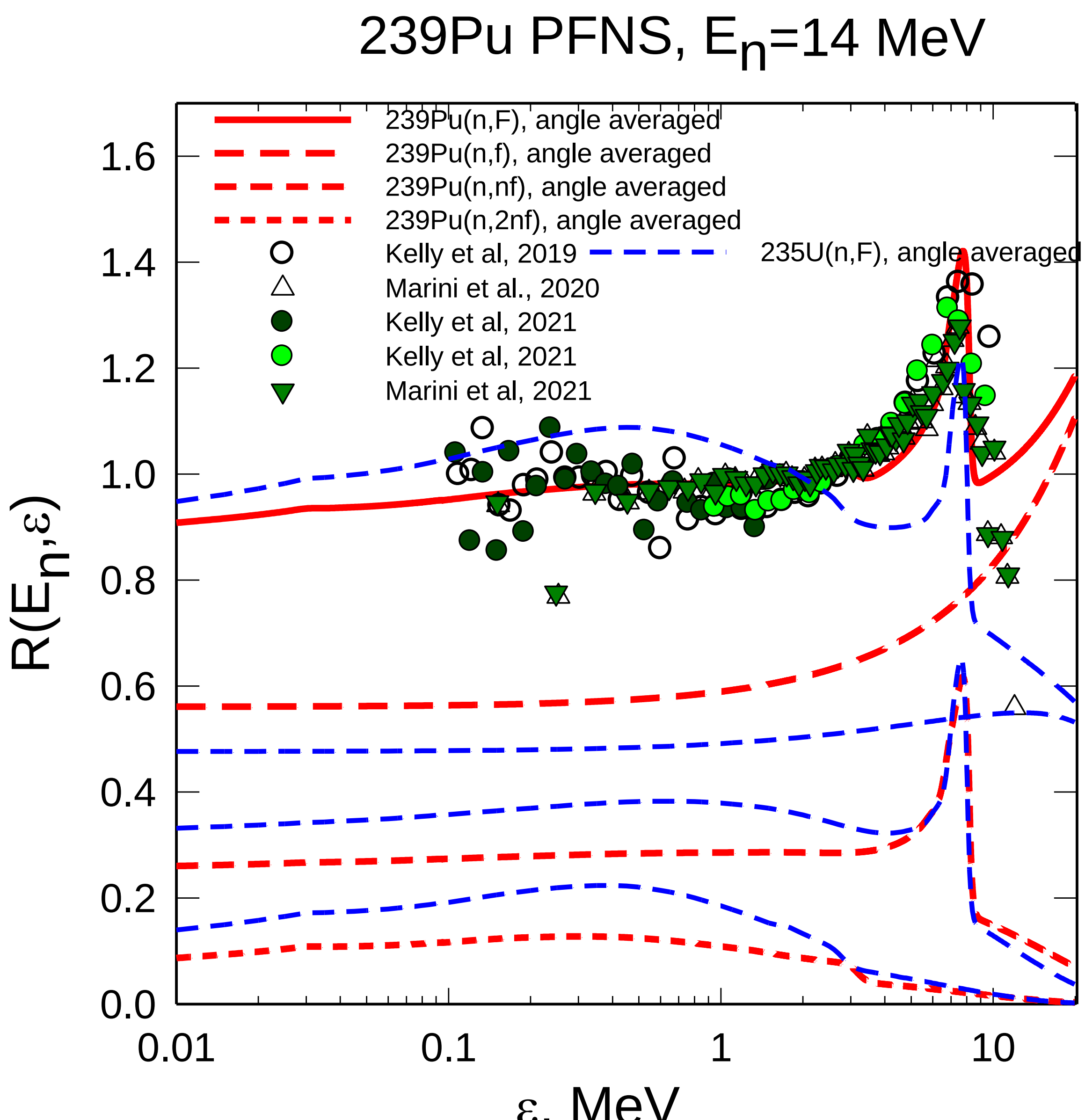
M. Devlin e.a. Eur. Phys. Journ. Web of Conferences, 2020, v. 239, 01003.

K. J., Kelly, J. A.Gomez e. a. Eur. Phys. Journ. WOC, 2020, v. 239, 05010.

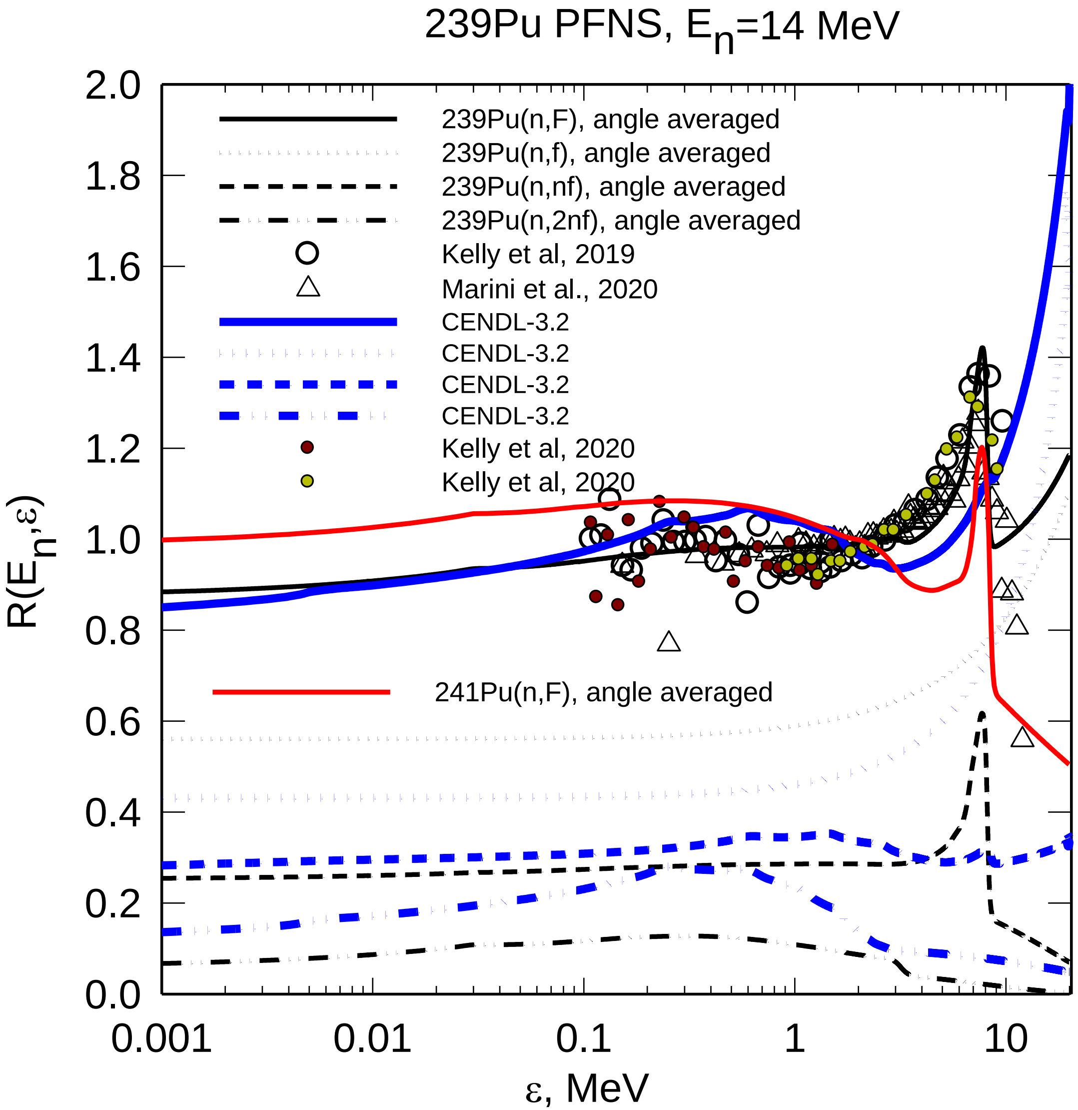
K. J. Kelly, M. Devlin, e. a. Phys. Rev., 2020, v. C 102, p. 034615

A. Chatillon et al., Phys. Rev. C89, 014611 (2014).


239Pu PFNS, En=14 MeV
R(En,ε)
ε, MeV
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
0.01
0.1
1
10
239Pu(n,F), angle averaged
239Pu(n,f), angle averaged
239Pu(n,nf), angle averaged
239Pu(n,2nf), angle averaged
Kelly et al, 2019
Marini et al., 2020
Kelly et al, 2021
Kelly et al, 2021
Marini et al, 2021
ENDF/B-VIII.0
JEFF-3.3



239Pu PFNS, En=14 MeV
239Pu(n,F), angle averaged
239Pu(n,f), angle averaged
239Pu(n,nf), angle averaged
239Pu(n,2nf), angle averaged
Kelly et al, 2019
235U(n,F), angle averaged
Marini et al., 2020
Kelly et al, 2021
Kelly et al, 2021
Marini et al, 2021
R(En,ε)
ε, MeV
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
0.01
0.1
1
10


239Pu PFNS, En=14 MeV
239Pu(n,F), angle averaged
239Pu(n,f), angle averaged
239Pu(n,nf), angle averaged
239Pu(n,2nf), angle averaged
Kelly et al, 2019
Marini et al., 2020
CENDL-3.2
CENDL-3.2
CENDL-3.2
CENDL-3.2
Kelly et al, 2020
Kelly et al, 2020
241Pu(n,F), angle averaged
R(En,ε)
ε, MeV
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.001
0.01
0.1
1
10

# Emissive neutron spectra

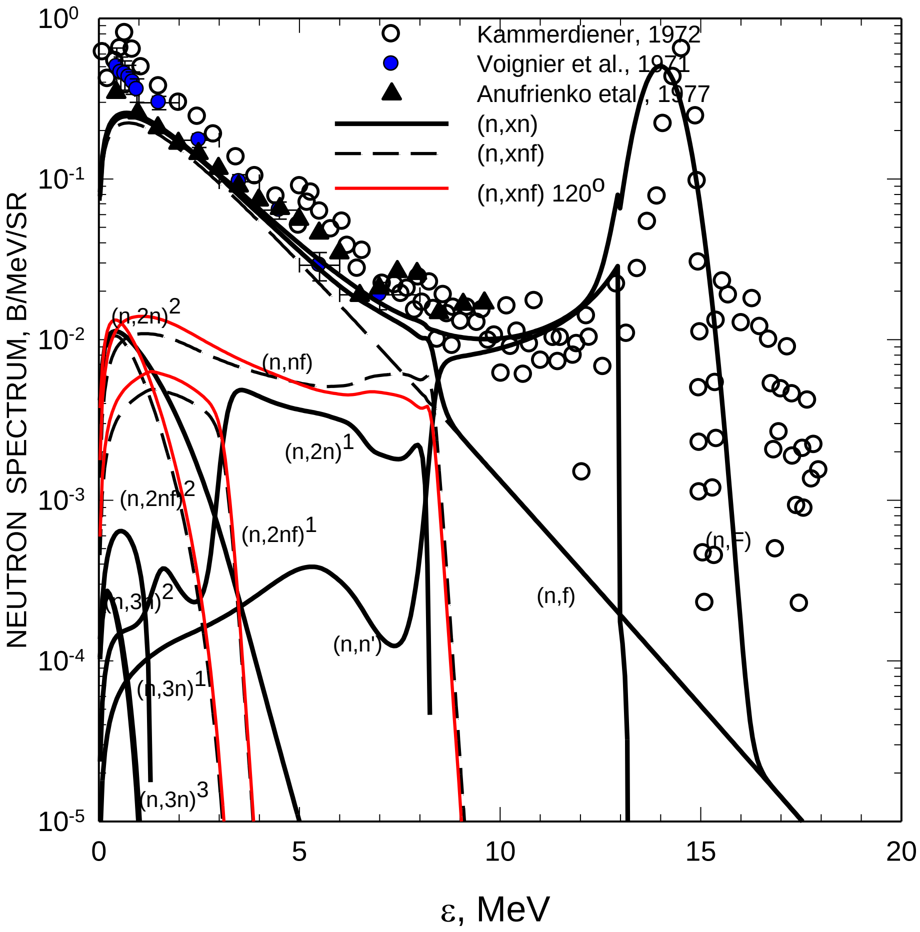
**superposition of exclusive (n,xn) spectra and fission spectra $S_F\ (\varepsilon, E_n)$**

$$\frac{d\sigma^2\left(\varepsilon, E_n, \theta\right)}{d\varepsilon d\theta} = \frac{1}{4\pi}\Big[\nu_p(E_n)\sigma_{\mathrm{nF}}\left(E_n\right)S_F(\varepsilon, E_n) + \frac{d\sigma_{\mathrm{nn'}}\left(E_n\right)}{d\varepsilon}$$

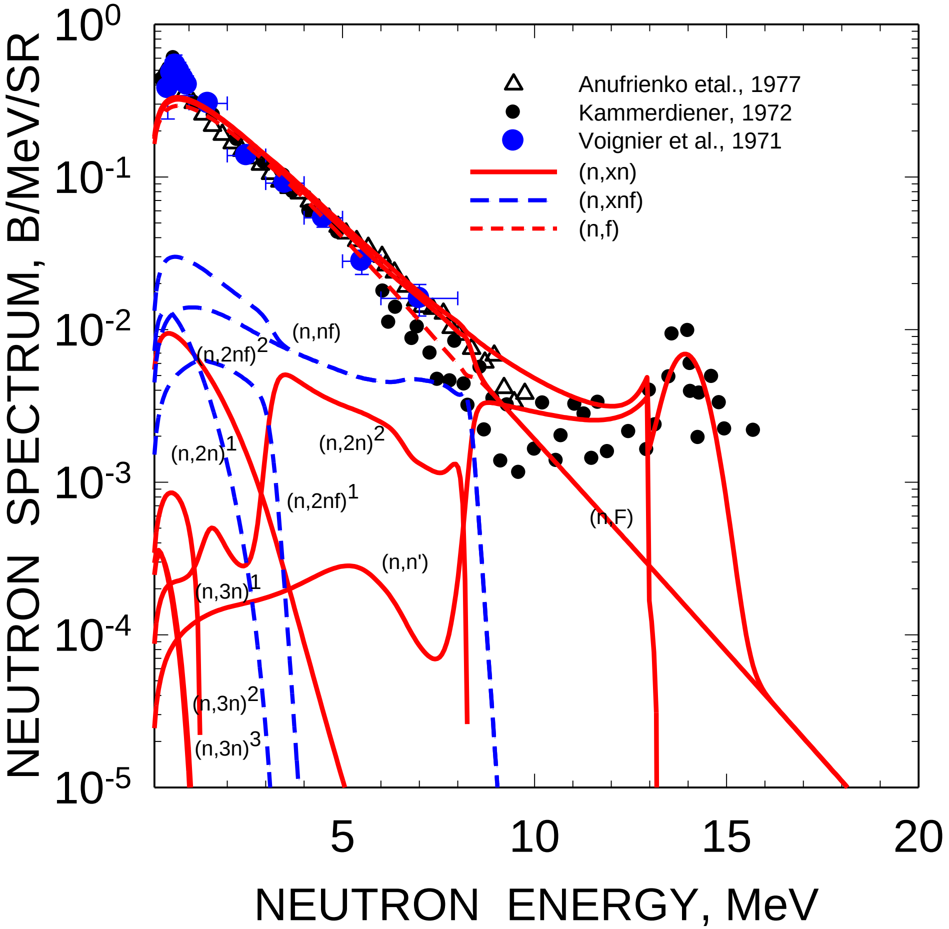
$$+\left(\frac{d\sigma^1_{\mathrm{n2n}}\left(E_n\right)}{d\varepsilon} + \frac{d\sigma^2_{\mathrm{n2n}}\left(E_n\right)}{d\varepsilon}\right) + \left(\frac{d\sigma^1_{\mathrm{n3n}}\left(E_n\right)}{d\varepsilon} + \frac{d\sigma^2_{\mathrm{n3n}}\left(E_n\right)}{d\varepsilon} + \frac{d\sigma^3_{\mathrm{n3n}}\left(E_n\right)}{d\varepsilon}\right)$$

$$+\Sigma\frac{d\sigma\left(E_q, E_n, \theta\right)}{d\theta}G\left(E_q, E_n, \theta, \Delta\right)\Big]$$

Neutron emission spectrum of $^{239}Pu$ at $E_n$=14 MeV ($30^o$)



$^{239}$Pu $E_n$=14 MeV (120$^o$)

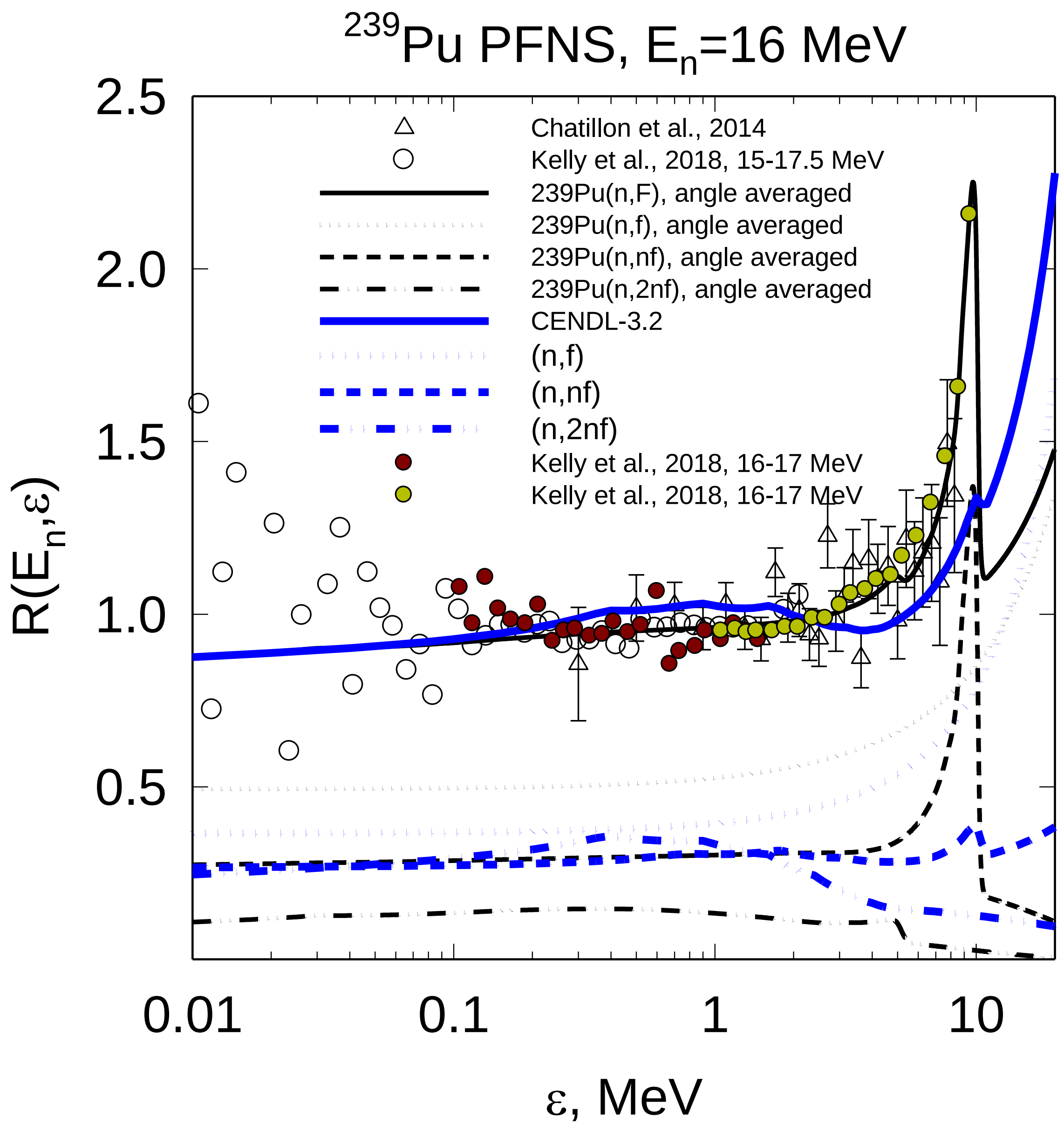


$$d\sigma^1_{nnx}/d\varepsilon \approx d\tilde{\sigma}^1_{nnx}/d\varepsilon + \sqrt{\frac{\varepsilon}{E_n}}\,\frac{\omega(\theta)}{E_n-\varepsilon}$$

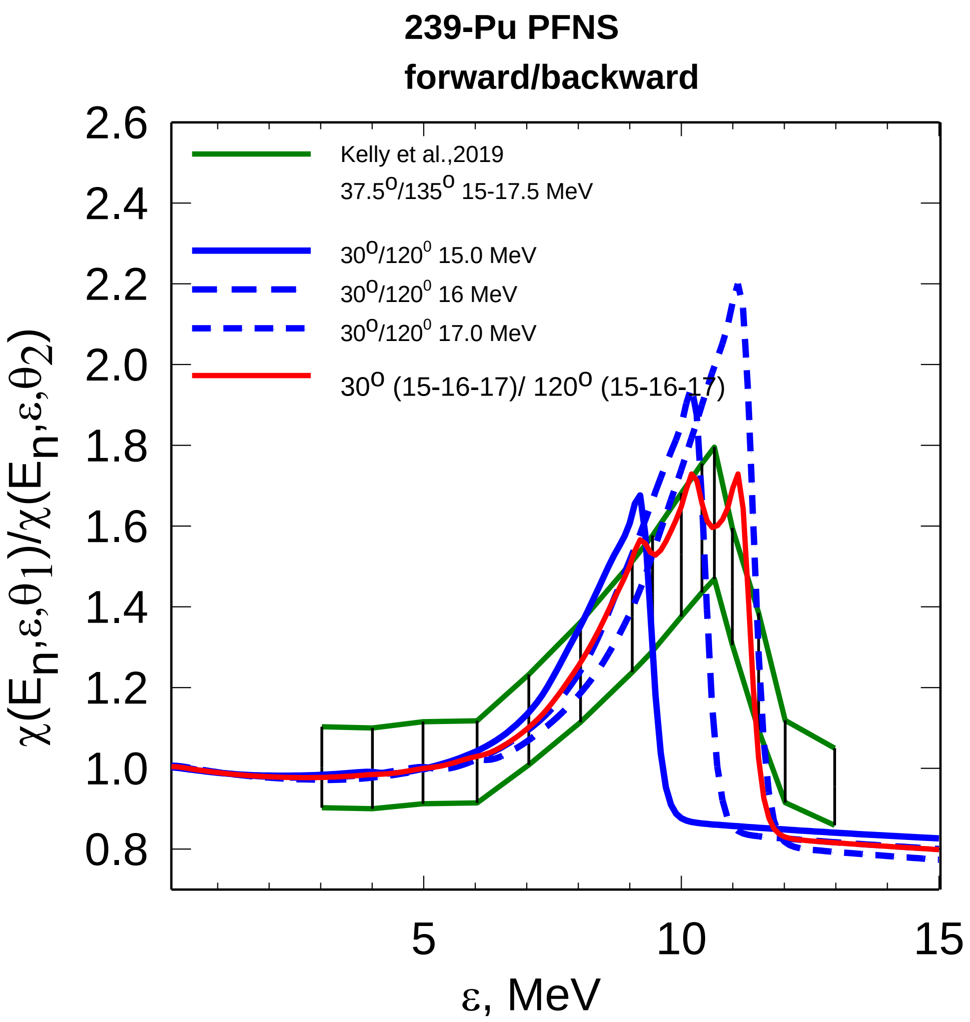
$$\frac{d\sigma^1_{n2nx}}{d\varepsilon} = \frac{d\sigma^1_{nnx}(\varepsilon)}{d\varepsilon}\,\frac{\Gamma^A_n(E_n-\varepsilon)}{\Gamma^A(E_n-\varepsilon)}$$

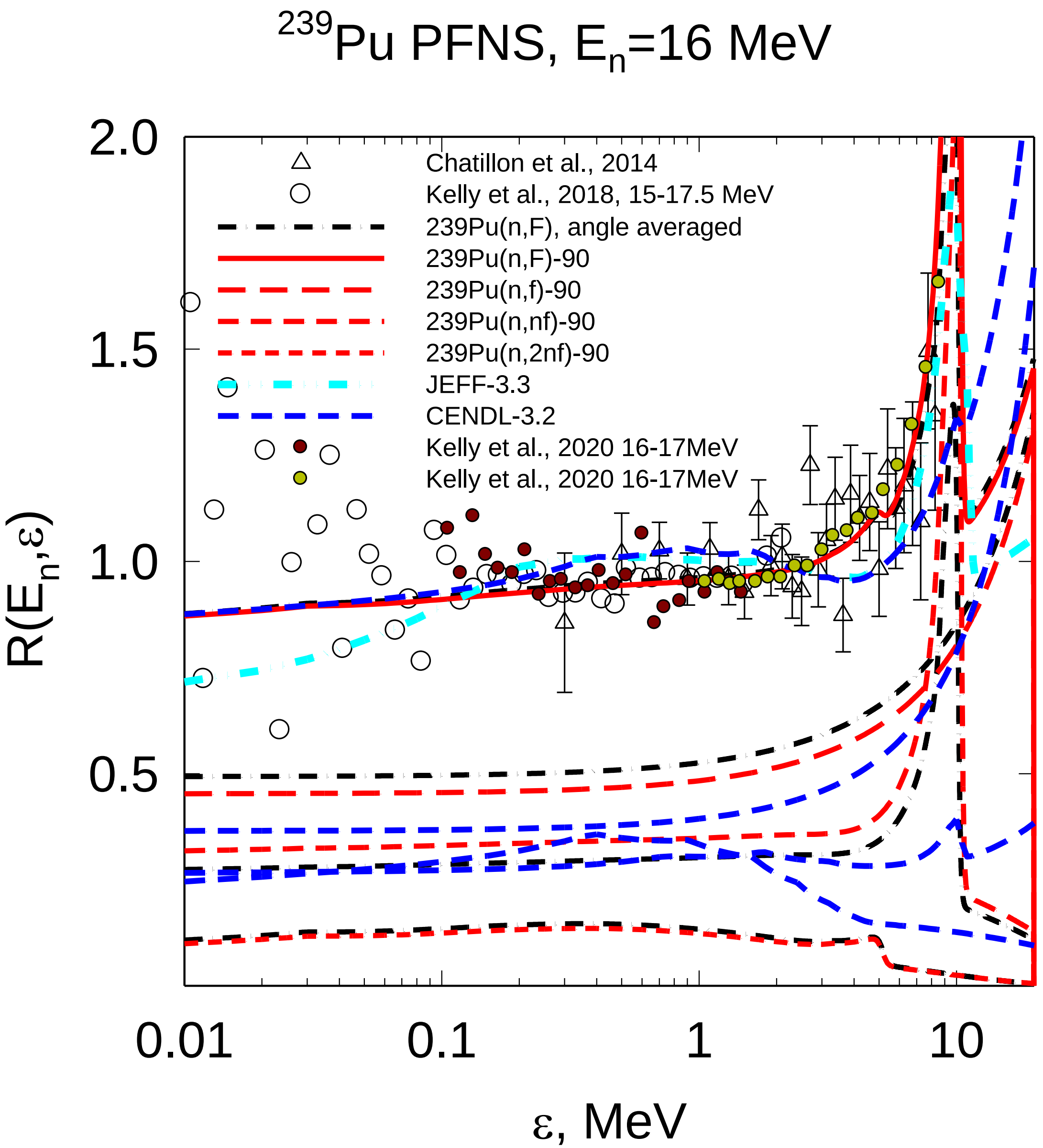
$$\frac{d\sigma^1_{n2nx}}{d\varepsilon} = \frac{d\sigma^1_{nnx}(\varepsilon)}{d\varepsilon}\,\frac{\Gamma^A_n(E_n-\varepsilon)}{\Gamma^A(E_n-\varepsilon)}$$

$$\frac{d\sigma^1_{n2nf}}{d\varepsilon} = \int_0^{E\ -B_n-\varepsilon} \frac{d\sigma^1_{n2nx}(\varepsilon)}{d\varepsilon}\,\frac{\Gamma^{A-1}_f(E_n-B^A_n-\varepsilon-\varepsilon_1)}{\Gamma^{A-1}(E_n-B^A_n-\varepsilon-\varepsilon_1)}d\varepsilon_1$$

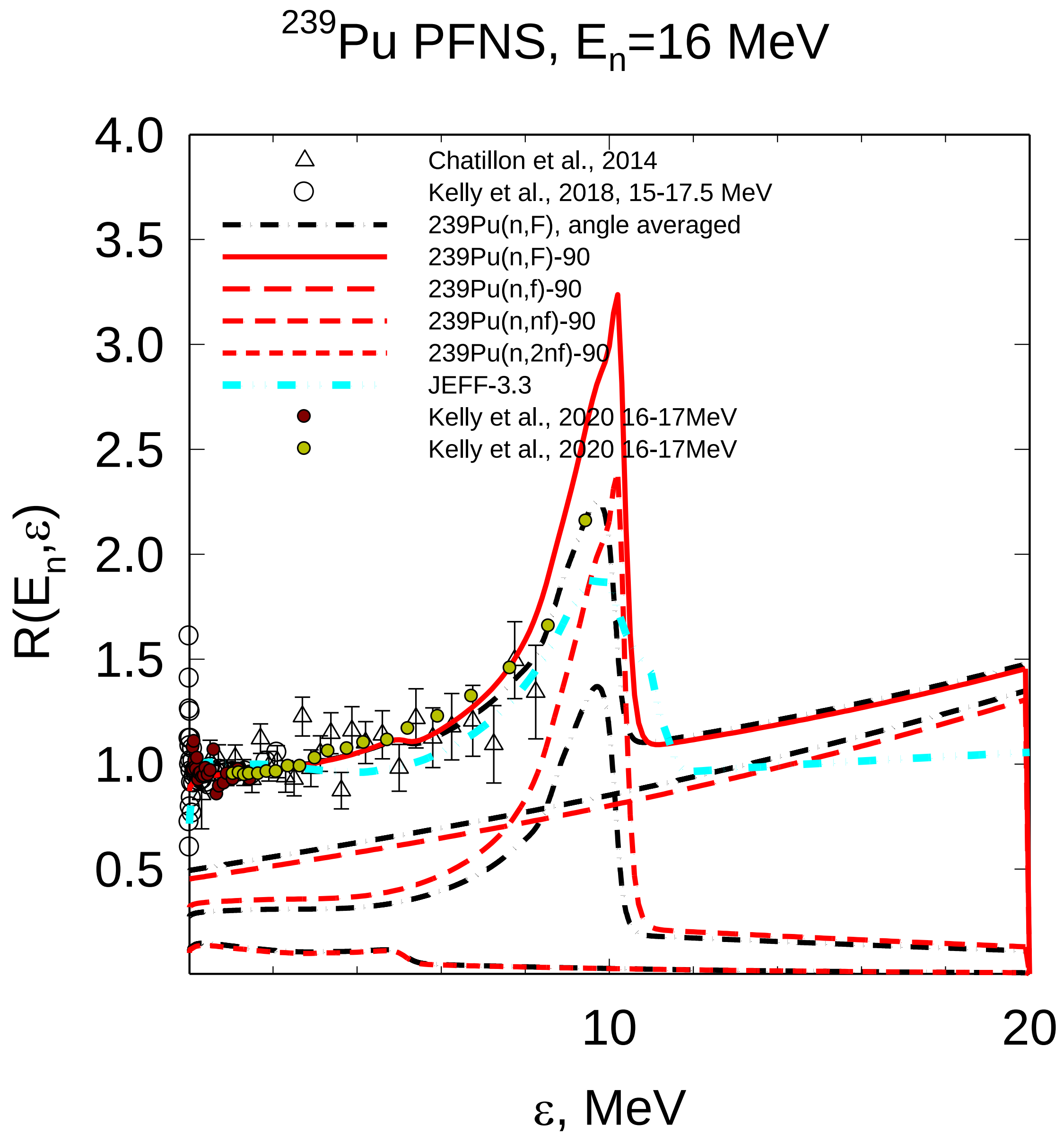


$^{239}$Pu PFNS, $E_n$=16 MeV
Chatillon et al., 2014
Kelly et al., 2018, 15-17.5 MeV
239Pu(n,F), angle averaged
239Pu(n,f), angle averaged
239Pu(n,nf), angle averaged
239Pu(n,2nf), angle averaged
CENDL-3.2
(n,f)
(n,nf)
(n,2nf)
Kelly et al., 2018, 16-17 MeV
Kelly et al., 2018, 16-17 MeV
R($E_n$,ε)
ε, MeV
0.01
0.1
1
10
0.5
1.0
1.5
2.0
2.5

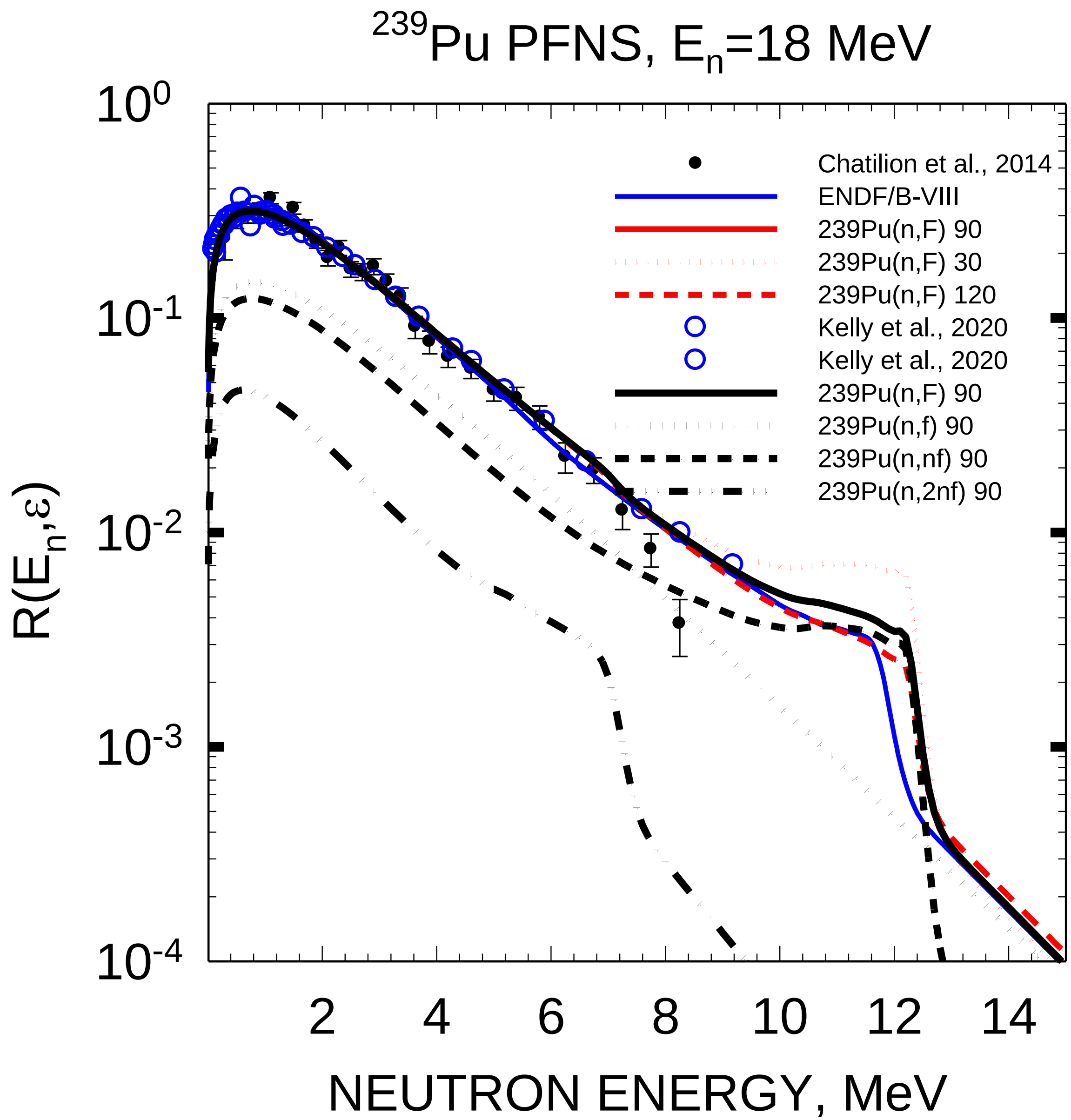

239-Pu PFNS
forward/backward
Kelly et al.,2019
37.5°/135° 15-17.5 MeV
30°/120° 15.0 MeV
30°/120° 16 MeV
30°/120° 17.0 MeV
30° (15-16-17)/ 120° (15-16-17)
χ(Eη,ε,θ1)/χ(Eη,ε,θ2)
ε, MeV
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
5
10
15



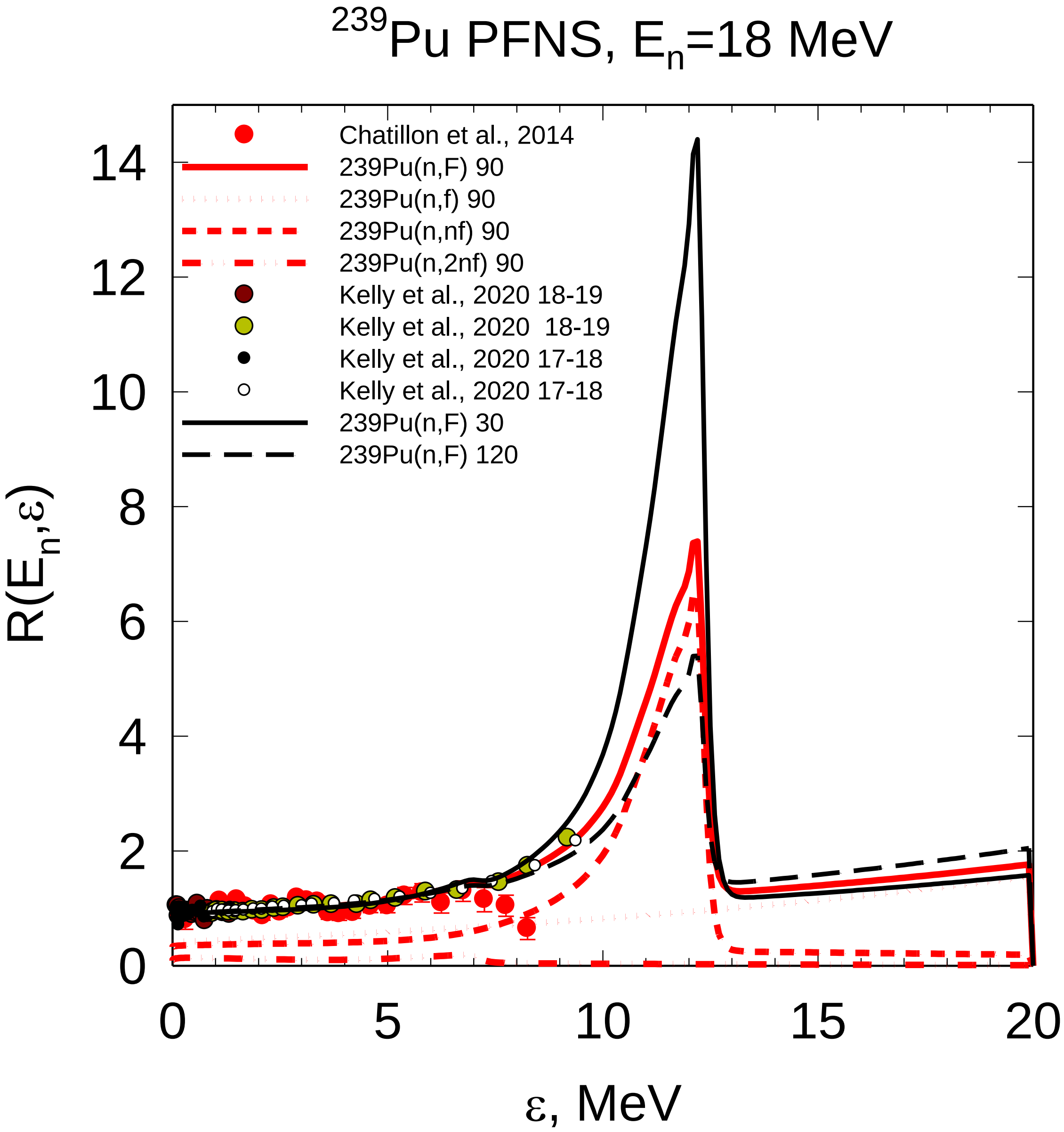
239Pu PFNS, En=16 MeV
2.0
1.5
1.0
0.5
R(En,ε)
0.01
0.1
1
10
ε, MeV
Chatillon et al., 2014
Kelly et al., 2018, 15-17.5 MeV
239Pu(n,F), angle averaged
239Pu(n,F)-90
239Pu(n,f)-90
239Pu(n,nf)-90
239Pu(n,2nf)-90
JEFF-3.3
CENDL-3.2
Kelly et al., 2020 16-17MeV
Kelly et al., 2020 16-17MeV



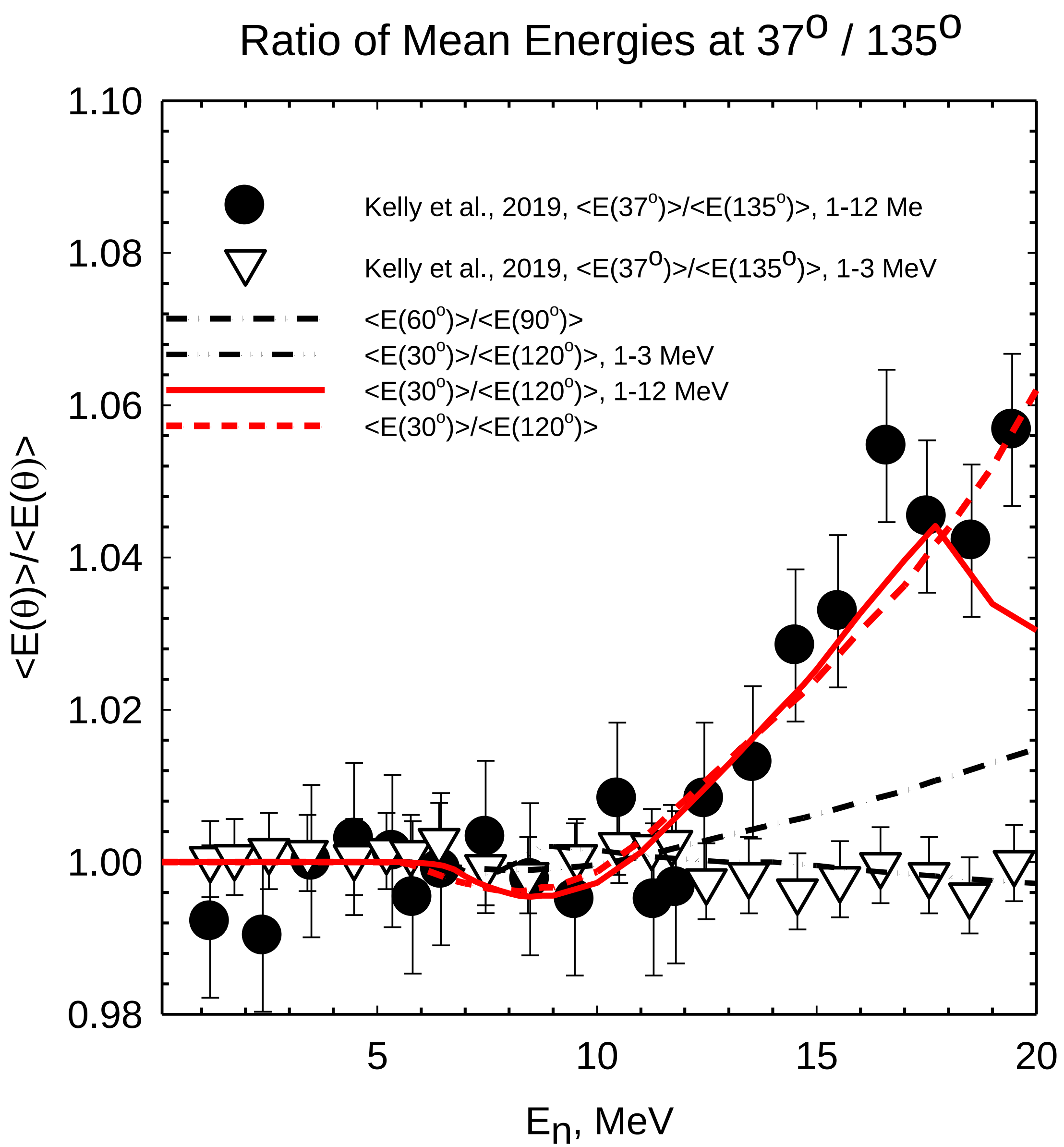
$^{239}$Pu PFNS, $E_n$=16 MeV
Chatillon et al., 2014
Kelly et al., 2018, 15-17.5 MeV
239Pu(n,F), angle averaged
239Pu(n,F)-90
239Pu(n,f)-90
239Pu(n,nf)-90
239Pu(n,2nf)-90
JEFF-3.3
Kelly et al., 2020 16-17MeV
Kelly et al., 2020 16-17MeV
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
$R(E_n,\varepsilon)$
10
20
$\varepsilon$, MeV



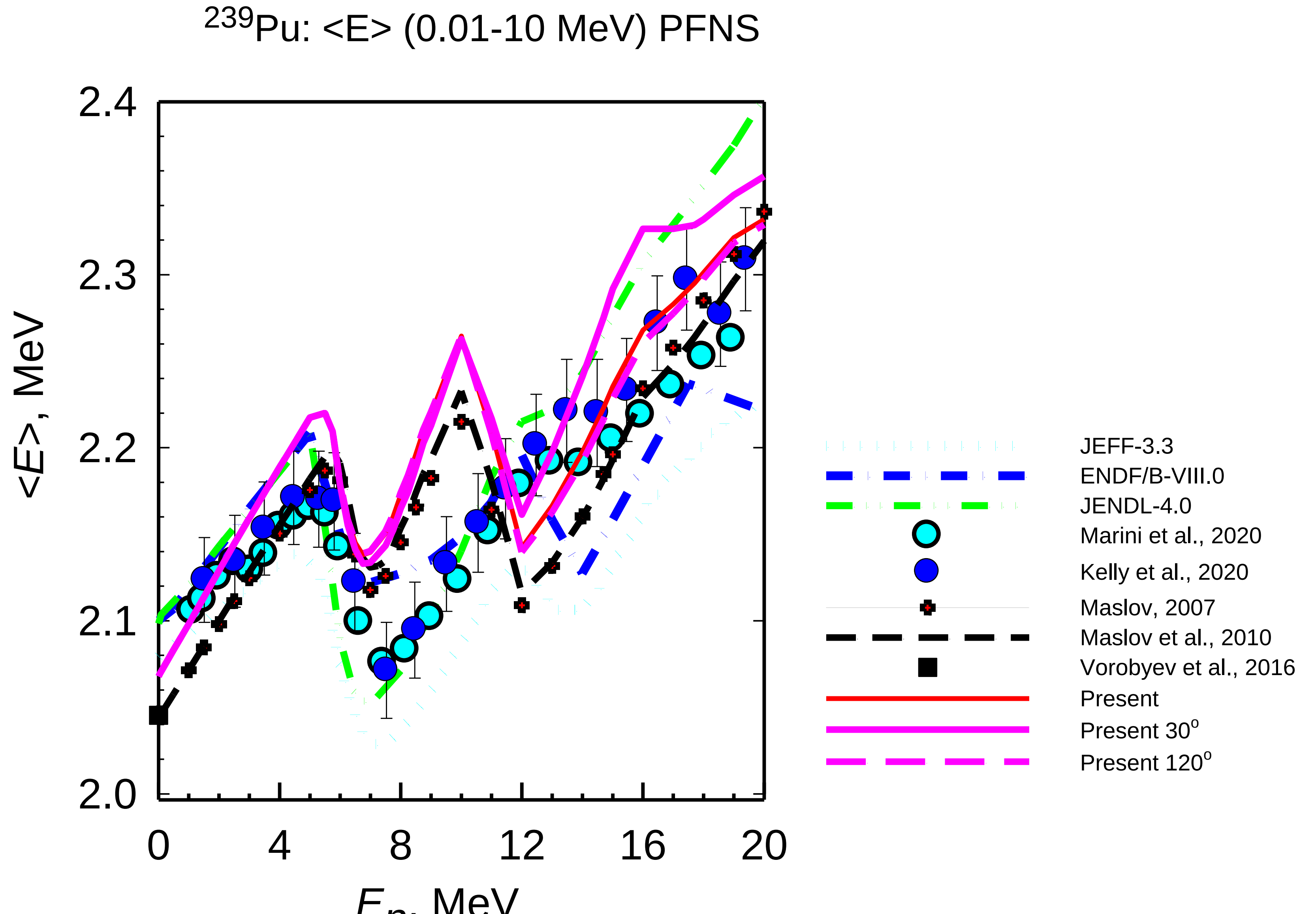
$^{239}$Pu PFNS, $E_n$=18 MeV
$10^0$
$10^{-1}$
$10^{-2}$
$10^{-3}$
$10^{-4}$
$R(E_n,\varepsilon)$
2
4
6
8
10
12
14
NEUTRON ENERGY, MeV
Chatilion et al., 2014
ENDF/B-VIII
239Pu(n,F) 90
239Pu(n,F) 30
239Pu(n,F) 120
Kelly et al., 2020
Kelly et al., 2020
239Pu(n,F) 90
239Pu(n,f) 90
239Pu(n,nf) 90
239Pu(n,2nf) 90



$^{239}$Pu PFNS, $E_n$=18 MeV
Chatillon et al., 2014
239Pu(n,F) 90
239Pu(n,f) 90
239Pu(n,nf) 90
239Pu(n,2nf) 90
Kelly et al., 2020 18-19
Kelly et al., 2020 18-19
Kelly et al., 2020 17-18
Kelly et al., 2020 17-18
239Pu(n,F) 30
239Pu(n,F) 120
R(E$_n$,ε)
ε, MeV
0
2
4
6
8
10
12
14
0
5
10
15
20



Ratio of Mean Energies at 37o / 135o
1.10
1.08
1.06
1.04
1.02
1.00
0.98
Kelly et al., 2019, <E(37o)>/<E(135o)>, 1-12 Me
Kelly et al., 2019, <E(37o)>/<E(135o)>, 1-3 MeV
<E(60o)>/<E(90o)>
<E(30o)>/<E(120o)>, 1-3 MeV
<E(30o)>/<E(120o)>, 1-12 MeV
<E(30o)>/<E(120o)>
<E(θ)>/<E(θ)>
5
10
15
20
En, MeV


239Pu: <E> (0.01-10 MeV) PFNS
<E>, MeV
2.4
2.3
2.2
2.1
2.0
0
4
8
12
16
20
En, MeV
JEFF-3.3
ENDF/B-VIII.0
JENDL-4.0
Marini et al., 2020
Kelly et al., 2020
Maslov, 2007
Maslov et al., 2010
Vorobyev et al., 2016
Present
Present 30o
Present 120o

1. **Multiple-chance fission – pre-saddle (pre-fission) plus post-scission (post-fission) neutrons (emitted from accelerating fragments)**
2. **Consistent analysis of (n,f) and competing (n,xn) reactions .**
3. **Exclusive pre-fission (pre-saddle) (n,xnf) reaction neutron spectra+ multiple-chance fission cross section structure**
4. **Prompt fission neutron spectra (PFNS) of $^{235}U(n,f)$, $^{239}Pu(n,f)$**

**at $E_{th}<E_n < 20$ MeV**

5. **Neutron emission spectra (PFNS) of $^{235}U(n,f)$ $^{239}Pu(n,f)$ at $E_n = 14$ MeV**

# Conclusions

1. **GMA +phenomenological fit, at thermal**

2. **The energy balance model is validated for $E_{th}<E_n<20$ MeV, describing fission cross sections, nu_bar, TKE & PFNS.**

3. **Pre-fission neutrons are interpreted at $5<E_n<20$ MeV**

4. **Pre-fission neutron angular asymmetry with respect to the beam axis at $E_n>12$ MeV is interpreted for 239Pu(n,F).**

5. **Pre-fission neutron forward/backward asymmetry with respect to the beam axis at $E_n>12$ MeV is interpreted.**

# Prompt fission neutron spectra

## *S(ε,E<sub>n</sub>)* - sum of two Watt distributions:

-

$$S(\varepsilon, E_n) = 0.5 \sum_{i=1}^{2} W_i(\varepsilon, E_n, T_{ij}(E_n), \alpha)$$

# Kornilov, Kagalenko, Hambsch, YaF, 62, 209, 1999
# **pre-acceleration NE + NE from accelerated fragments**

$$W_i(\varepsilon, E_n, T_{ij}(E_n), \alpha) = \frac{2}{\sqrt{\pi} T_{ij}^{3/2}} \sqrt{\varepsilon} \exp(-\frac{E^*_{vij}}{T_{ij}}) \frac{sh(\sqrt{b_{ij}\varepsilon})}{\sqrt{b_{ij}\varepsilon}}$$

-

$$b_{ij} = \frac{4E^*_{vij}}{T_{ij}}, T_{ij} = k_{ij}\sqrt{E_r - TKE_i - U_i}$$

$T_{ij}$ **-temperature for light and heavy fragments, α =TKE/TKE$_\propto$**

**In Watt' equation CMS energy per nucleon -**

$$E^*_{vij} = \alpha E_{vij}$$