A Lane consistent optical model potential for nucleon induced reactions on ^{238}U and ^{232}Th nuclei with full coupling

José Manuel Quesada Molina

Department of Atomic, Molecular and Nuclear Physics
University of Seville, Spain

WONDER 2012

Aix-en-Provence, September 26, 2012

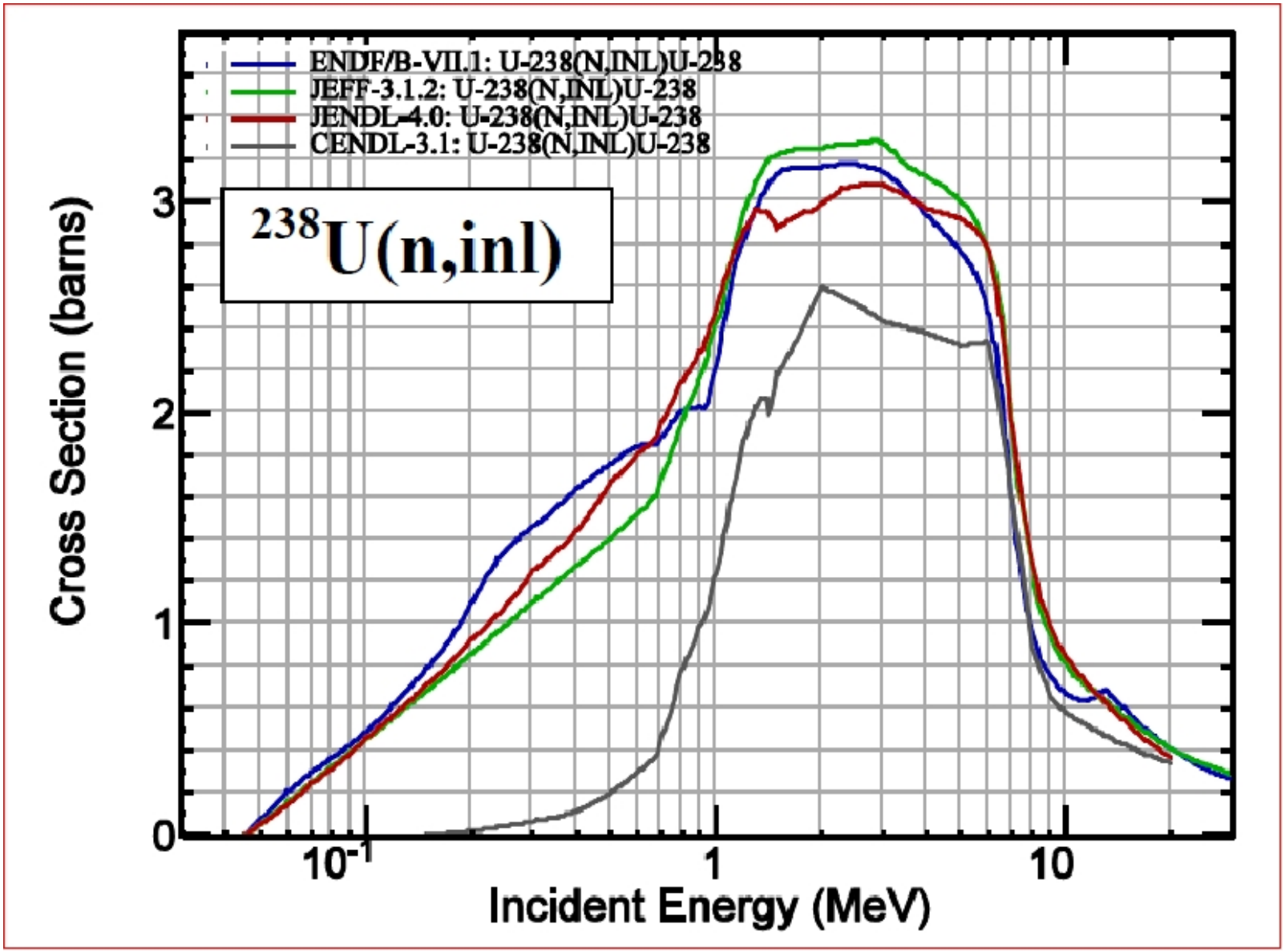
Content

OECD/NEA WPEC Subgroup 26 Final Report: "Uncertainty and Target Accuracy Assessment for Innovative Systems Using Recent Covariance Data Evaluations", M Salvatores (coordinator), R. Jacquemin (monitor), Tech. Rep. NEA No. 6410 (2008)

The request for improved cross sections and emission spectra and their accuracies for neutron induced reactions on 238U is an important issue that emerges in several of cases studied. High accuracy requirements were placed on inelastic cross-sections 238U(n,inl) in the whole energy range up to 20 MeV.

+ Benchmark sensitivity to elastic and inelastic cross sections, and corresponding angular distributions ⇒ Optical Model

IAEA/NEA studies and recommendations



IAEA/NEA studies and recommendations

IAEA
International Atomic Energy Agency

INDC(NDS)-0597
Distr. J+NM

INDC International Nuclear Data Committee

Summary Report

Technical Meeting on

Inelastic Scattering and Capture Cross-section Data of Major Actinides in the Fast Neutron Region

IAEA Headquarters
Vienna, Austria
6 – 9 September 2011

Prepared by A.Plompen, T.Kawano, and R.Capote
Available at
http://www-nds.iaea.org/publications/indc/indc-nds-0597.pdf

Content

Dispersive OMPs

- **Dispersive OMPs Spherical magic nuclei, ^{40}Ca, ^{48}Ca, ^{90}Zr, ^{208}Pb, ..**
  - R. Lipperheide. Z. Phys. 202, 58 (1967); G. Passatore, Nucl. Phys. A95 (1967) 694
  - R. Lipperheide and A.K. Schmidt, Nucl. Phys. A112 (1968) 65
  - **C. Mahaux and co-workers : 1984-**
  - W. Tornow et al (TUNL):1993-
  - A. Molina, R.Capote, J. M. Quesada and M. Lozano, PRC 65 (2002) 034616
- **Coupled channels OMPs (Deformed nuclei)**
  - A.C. Merchant, P.E. Hodgson and H.R. Schelin. Nucl. Sc. Eng. 111 (1992) 132
  - P. Romain and J.P. Delaroche. Proceedings of the Meeting on Nucleon-Nucleus Optical Model up to 200 MeV, Bruyres-le-Chtel, p.167 (OECD, Paris, 1997)
  - A.B. Smith . Ann. Nucl. Energy 28 (2001); 29 (2002); 31 (2004)

  - E. Sh. Soukhovitskii, R. Capote, J. M. Quesada and S. Chiba, Phys. Rev. C 72 (2005) 024604
  - R. Capote, E. Sh. Soukhovitskii, J. M. Quesada and S. Chiba, Phys. Rev. C 72 (2005) 064610
  - J. M. Quesada, R. Capote, E. Sh. Soukhovitskii, S. Chiba, Phys. Rev. C 76 (2007) 057602
  - R. Capote, S. Chiba, E. Sh. Soukhovitskii, J. M. Quesada and E. Bauge, Jou. Nucl. Sci. Tech. 45 (2008) 333-340;
  - R.Capote et al, "RIPL ..", Nucl. Data Sheets 110 (2009) 3107-3214;
  - W. L. Sun, L. J. Hao, E. Sh Soukhovitskii, R. Capote and J. M. Quesada, AIP Conf. Proc.1235 (2010) 43-49

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  - P. Romain and J.P. Delaroche. Proceedings of the Meeting on Nucleon-Nucleus Optical Model up to 200 MeV, Bruyres-le-Chtel, p.167 (OECD, Paris, 1997)
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- J. M. Quesada, R. Capote, E. Sh. Soukhovitskii, S. Chiba, Phys. Rev. C 76 (2007) 057602
- R. Capote, S. Chiba, E. Sh. Soukhovitskii, J. M. Quesada and E. Bauge, Jou. Nucl. Sci. Tech. 45 (2008) 333-340;
- R.Capote et al, "RIPL ..", Nucl. Data Sheets 110 (2009) 3107-3214;
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Content

Nucleon-nucleus dispersive OMP

Key ingredient: dispersion relation

$$\Delta V(\mathbf{r}, E) = \frac{\mathcal{P}}{\pi} \int_{-\infty}^{\infty} \frac{W(\mathbf{r}, E')}{E' - E} dE'$$

$$\begin{aligned}
&V(r, R(\theta', \varphi'), E^*) = \\
&-V_{HF}(E^*) f_{WS}(r, R_{HF}(\theta', \varphi')) \\
&-[\Delta V_v(E^*) + iW_v(E)]\, f_{WS}(r, R_v(\theta', \varphi')) \\
&-[\Delta V_s(E^*) + iW_s(E)]\, g_{WS}(r, R_s(\theta', \varphi')) \\
&+\left(\frac{\hbar}{m_\pi c}\right)^2 [V_{so}(E) + \Delta V_{so}(E) + iW_{so}(E)] \times \frac{1}{r}\frac{d}{dr} f_{WS}(r, R_{so}(\theta', \varphi'))(\hat{l} \cdot \hat{\sigma}) \\
&+V_{Coul}(r, R_c(\theta', \varphi'))
\end{aligned}$$

$$E^* = E - C_{Coul} \frac{Z_p Z_T}{A^{1/3}}$$

Coupled 5 levels of the ground state band within the rigid rotor model +..

Formalism

$$V_{HF}(E) = A_{HF} \exp(-\lambda_{HF}(E - E_F))$$

$$A_{HF} = V_0 \left[1 + (-1)^{Z'+1} \frac{C_{viso}}{V_0} \frac{N - Z}{A}\right]$$

$$W_s(E) = A_s \frac{(E - E_F)^2}{(E - E_F)^2 + (B_s)^2} \exp(-C_s|E - E_F|)$$

$$A_s = W_0 \left[1 + (-1)^{Z'+1} \frac{C_{wiso}}{W_0} \frac{N - Z}{A}\right]$$

$$W_v(E) = A_v \frac{(E - E_F)^2}{(E - E_F)^2 + (B_v)^2}$$

Lane consistency

Key ingredient: Isospin simmetry

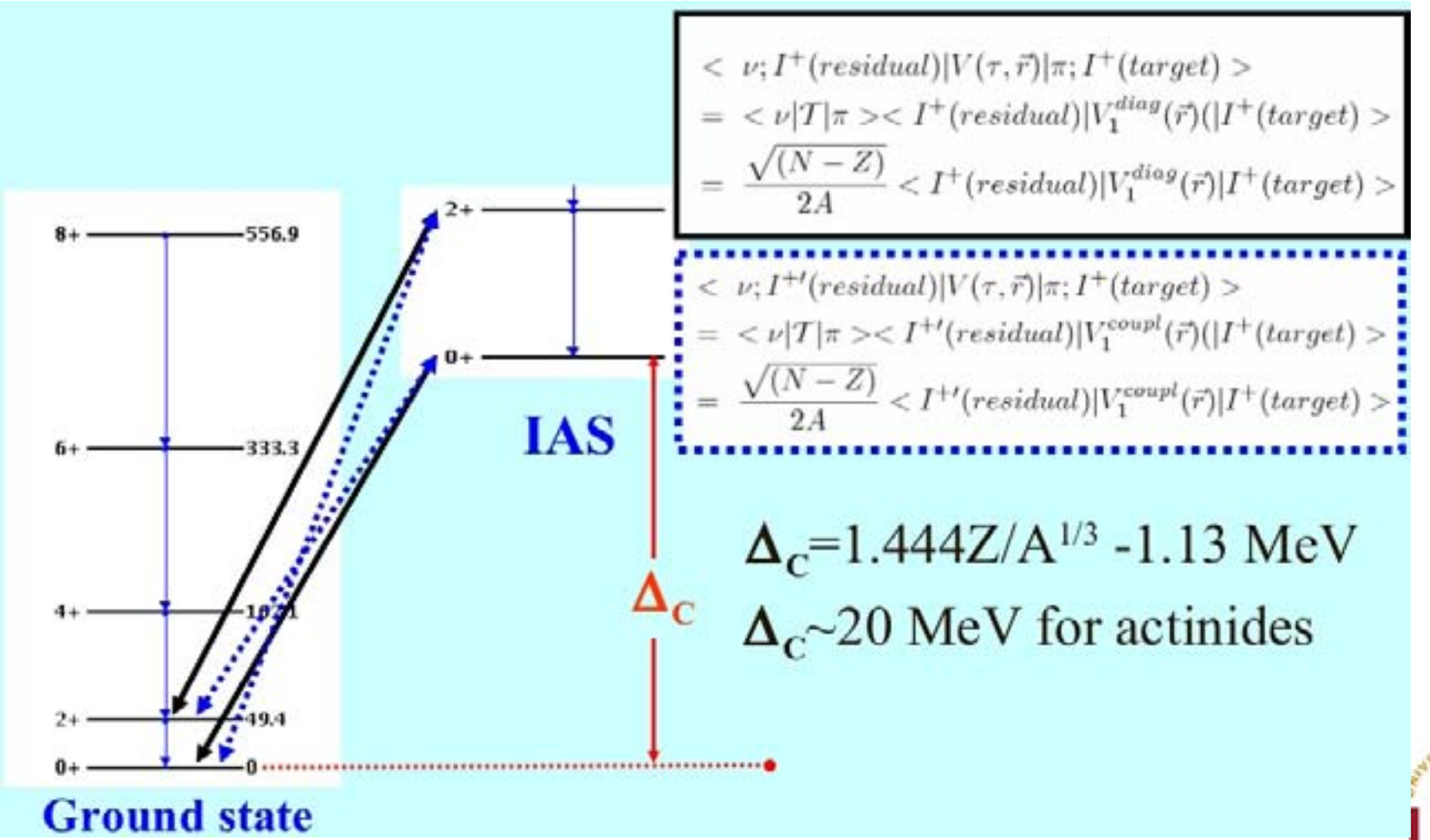
$$V_{pp} = V_0 + \frac{N-Z}{4A} V_1$$
$$V_{nn} = V_0 - \frac{N-Z}{4A} V_1$$
$$V_{pn} = \frac{\sqrt{N-Z}}{2A} V_1$$

Couplings GS band $\longleftrightarrow$ IAS band

$$\begin{aligned} &< \nu; I^{+\prime}(residual)|V(\tau,\vec{r})|\pi; I^{+}(target) > \\ = &< \nu|\mathcal{T}|\pi >< I^{+\prime}(residual)|V_1(\vec{r})(|I^{+}(target) > \\ = &\frac{\sqrt{(N-Z)}}{2A} < I^{+\prime}(residual)|V_1(\vec{r})|I^{+}(target) > \end{aligned}$$

..+ 2 IAS states

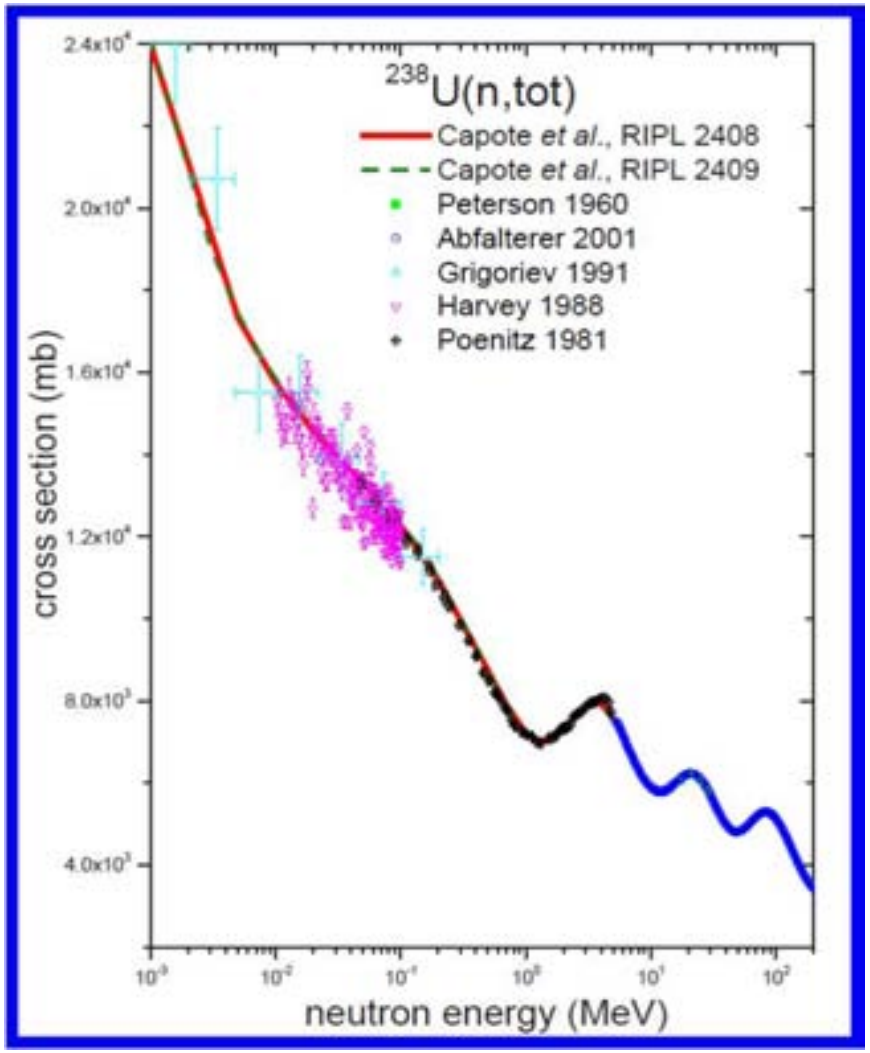
GS $\longleftrightarrow$ IAS coupling in (p,n) reactions (^{232}Th)

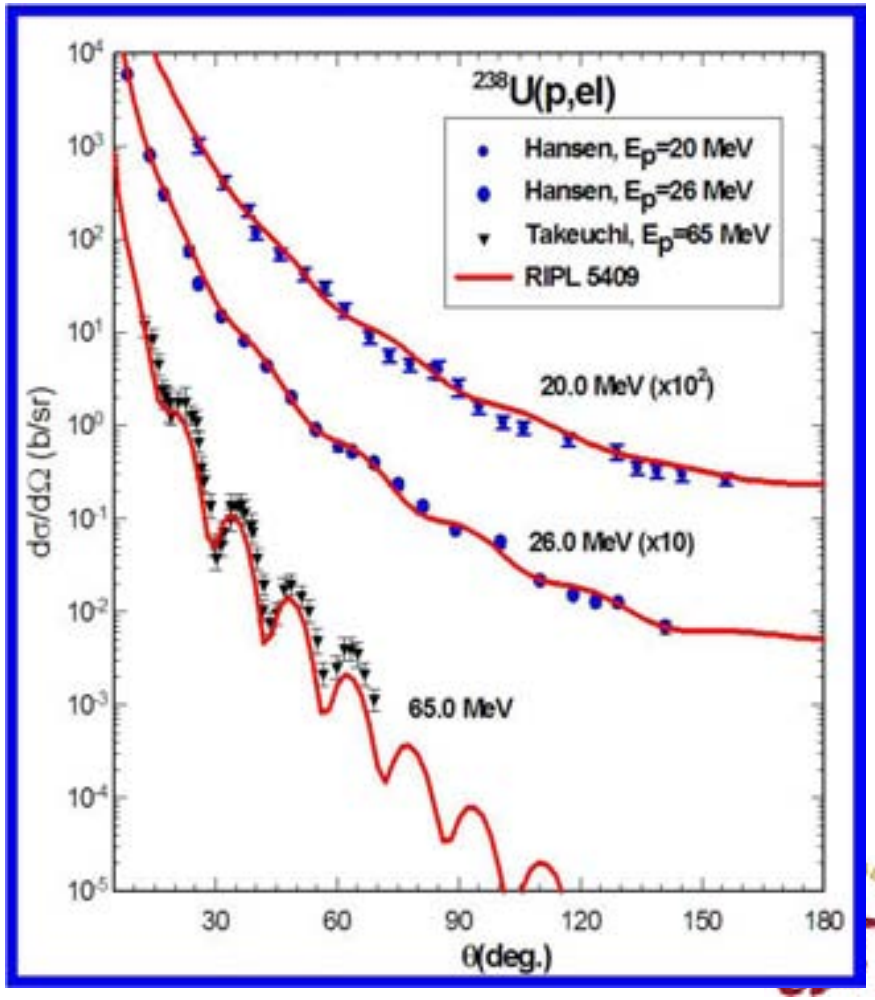


$$< \nu; I^+(residual)|V(\tau,\vec{r})|\pi; I^+(target) >$$
$$= < \nu|T|\pi >< I^+(residual)|V_1^{diag}(\vec{r})(|I^+(target) >$$
$$= \frac{\sqrt{(N-Z)}}{2A} < I^+(residual)|V_1^{diag}(\vec{r})|I^+(target) >$$

$$< \nu; I^{+\prime}(residual)|V(\tau,\vec{r})|\pi; I^+(target) >$$
$$= < \nu|T|\pi >< I^{+\prime}(residual)|V_1^{coupl}(\vec{r})(|I^+(target) >$$
$$= \frac{\sqrt{(N-Z)}}{2A} < I^{+\prime}(residual)|V_1^{coupl}(\vec{r})|I^+(target) >$$

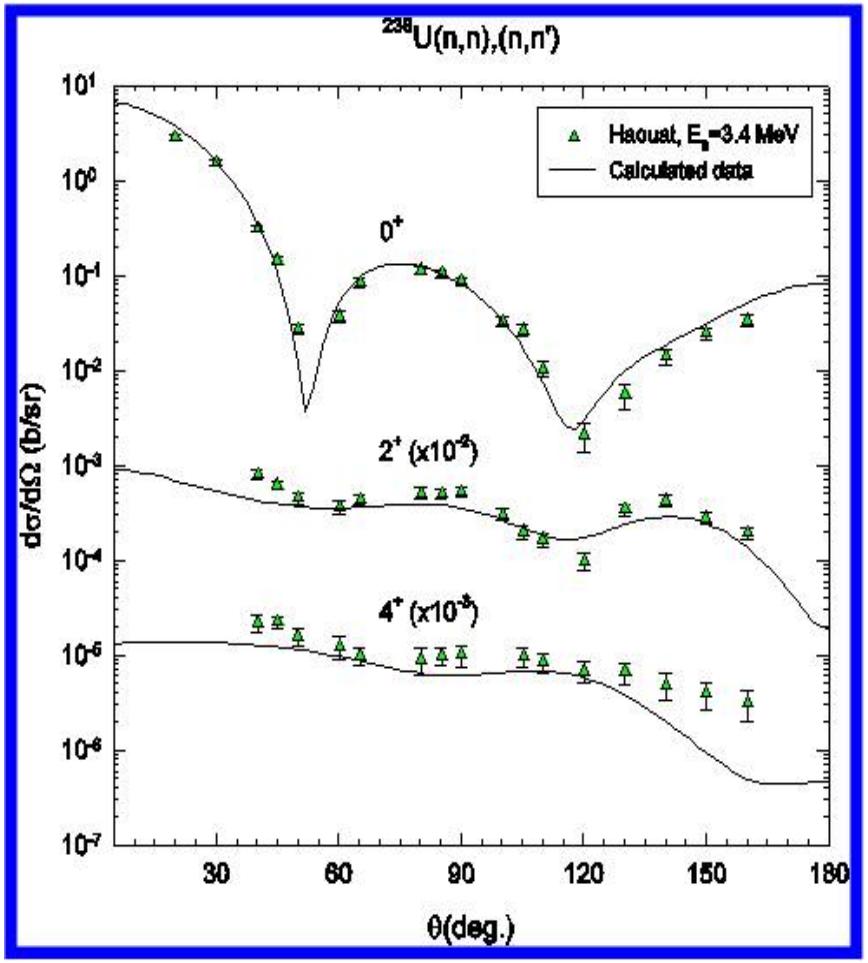
Dispersive and Lane consistent OMP (1)





Dispersive and Lane consistent OMP (2)

RIPL 2409



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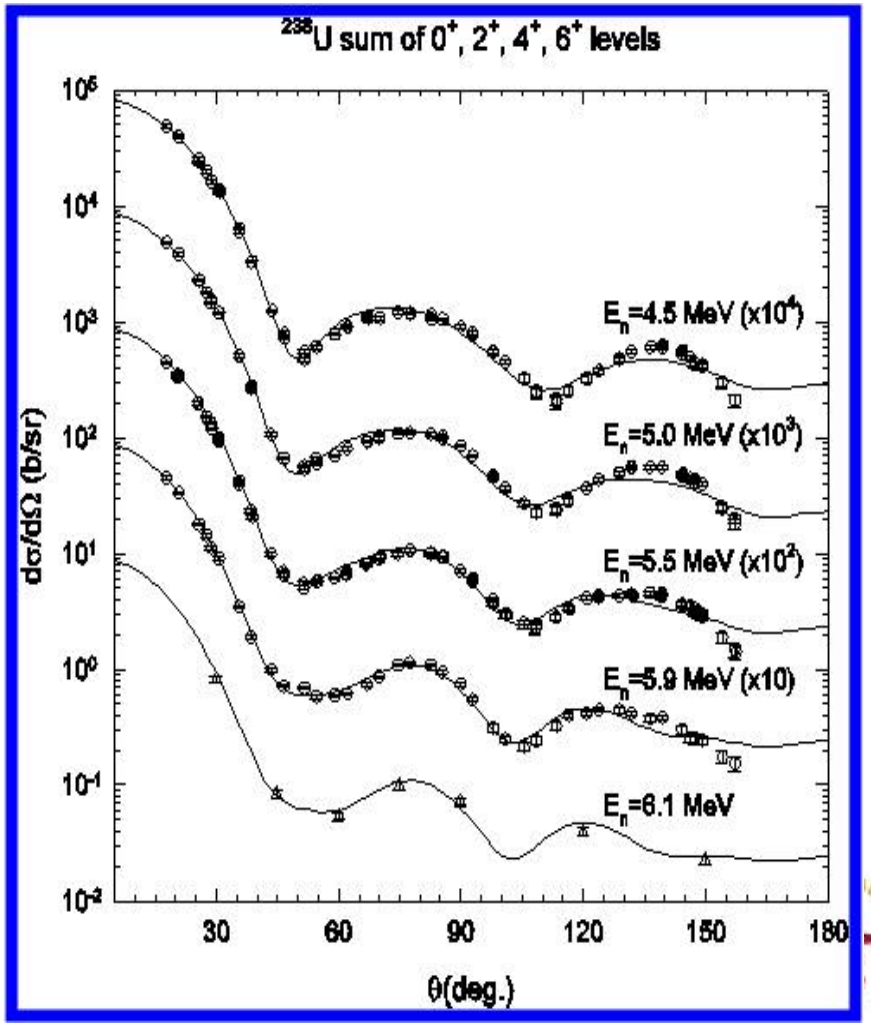
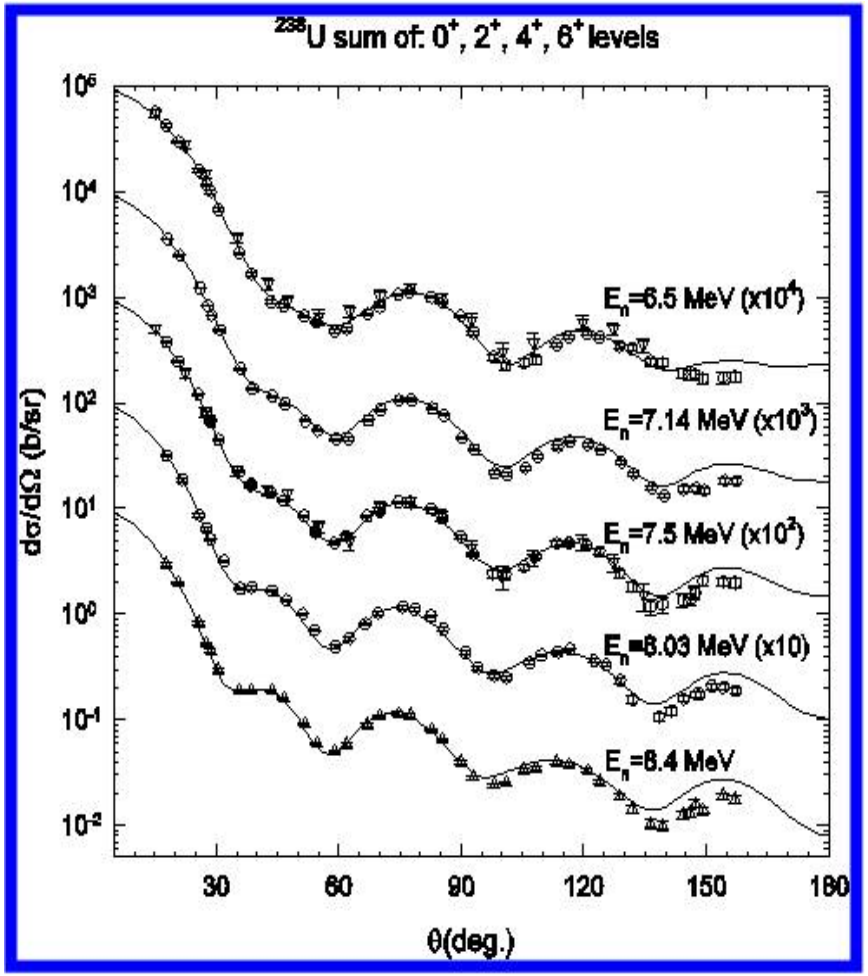
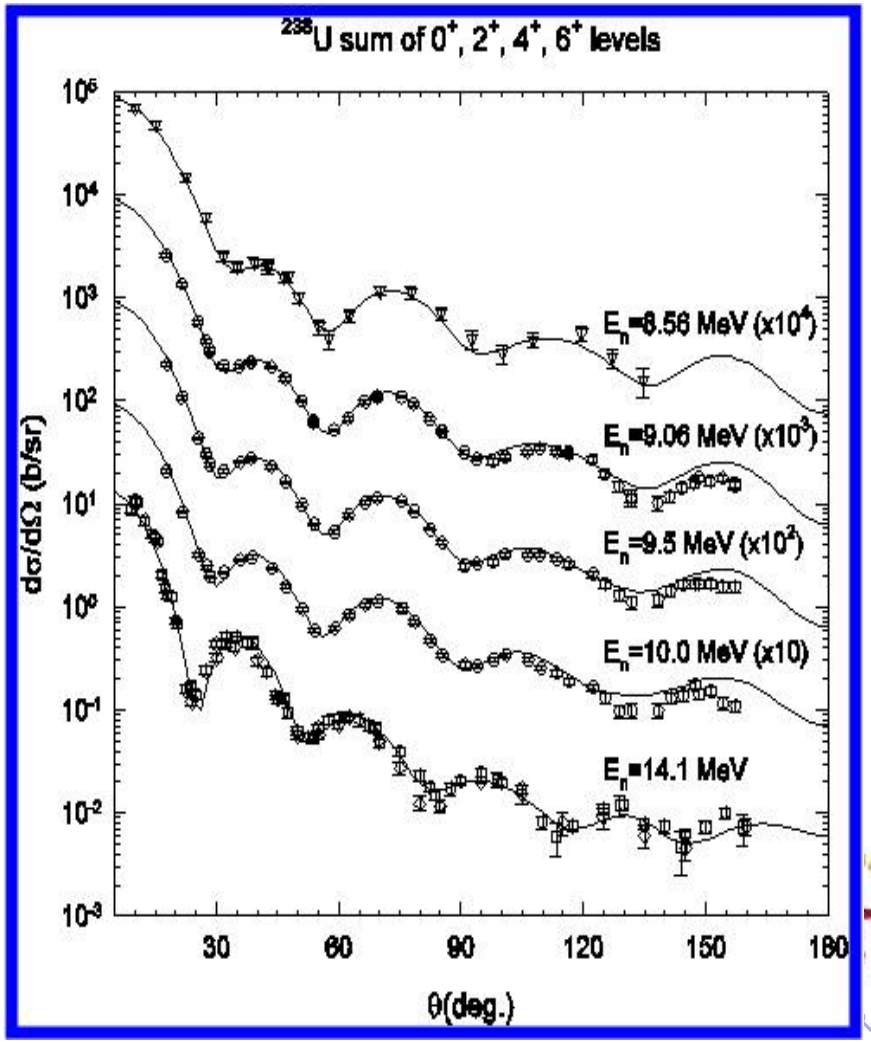


Dispersive and Lane consistent OMP (3)

RIPL 2409

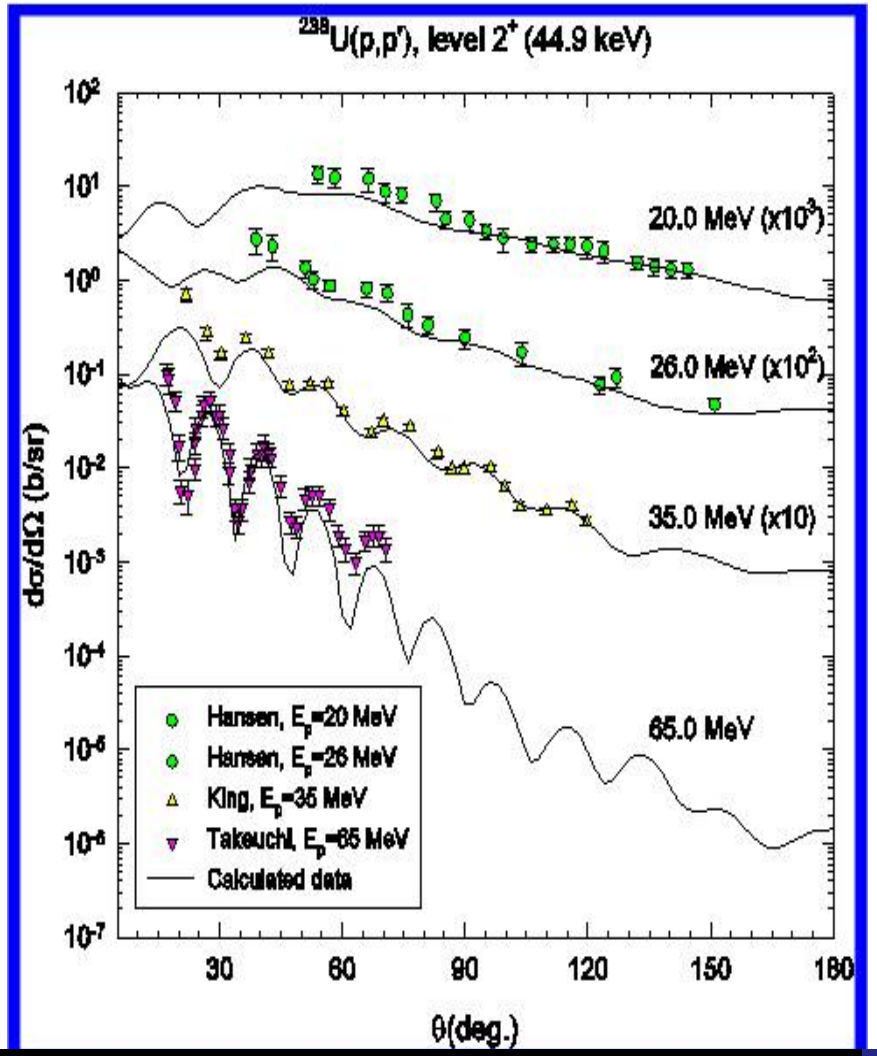


RIPL 2409

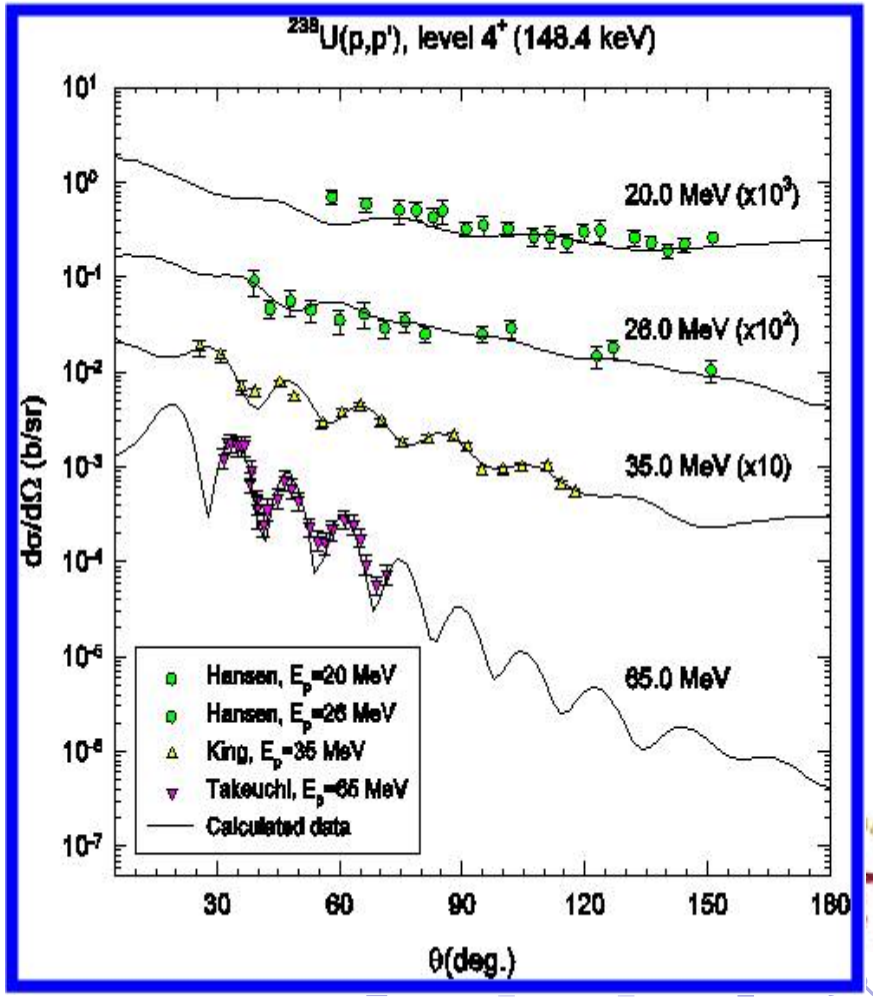


Dispersive and Lane consistent OMP (4)

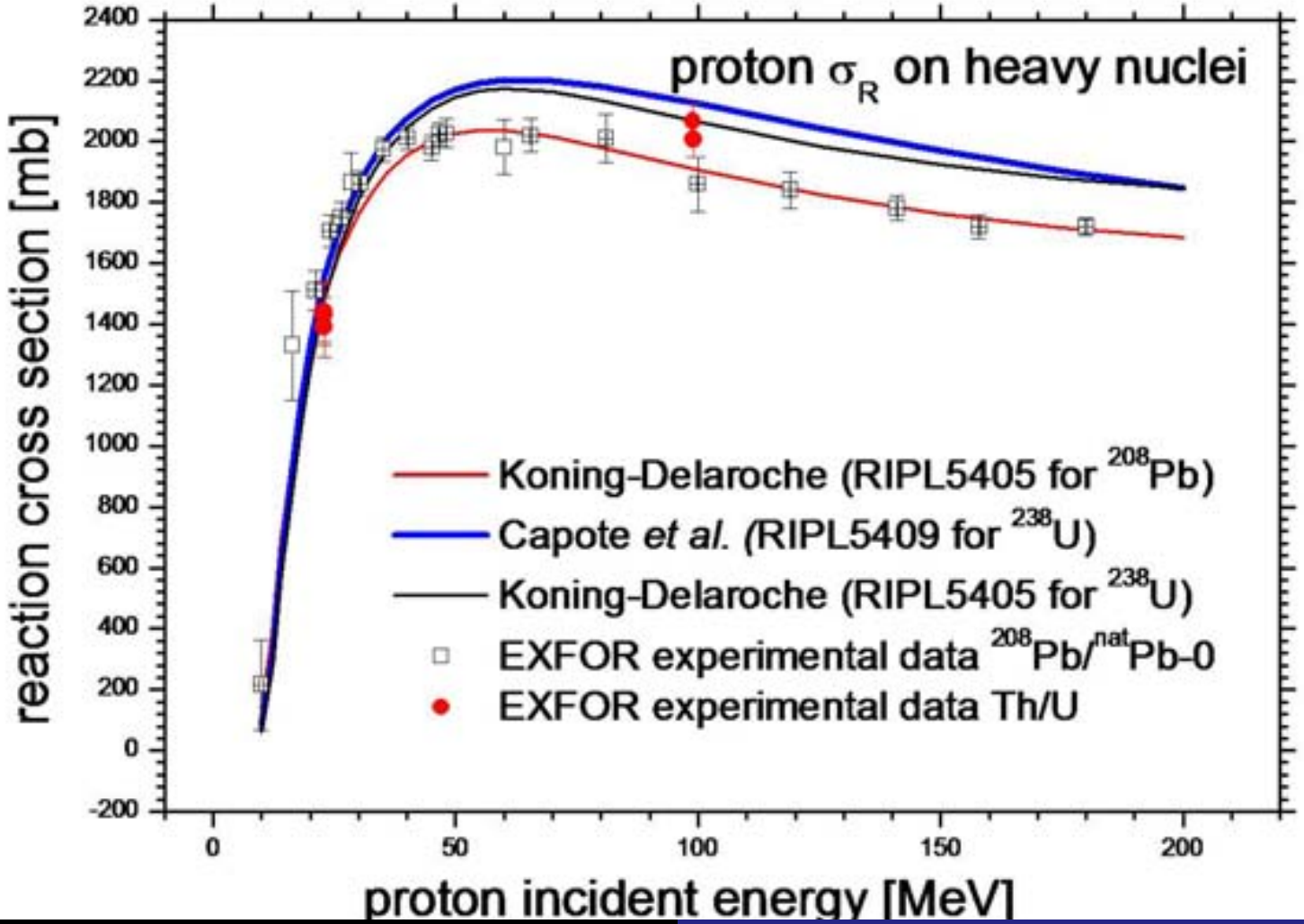
RIPL 5409



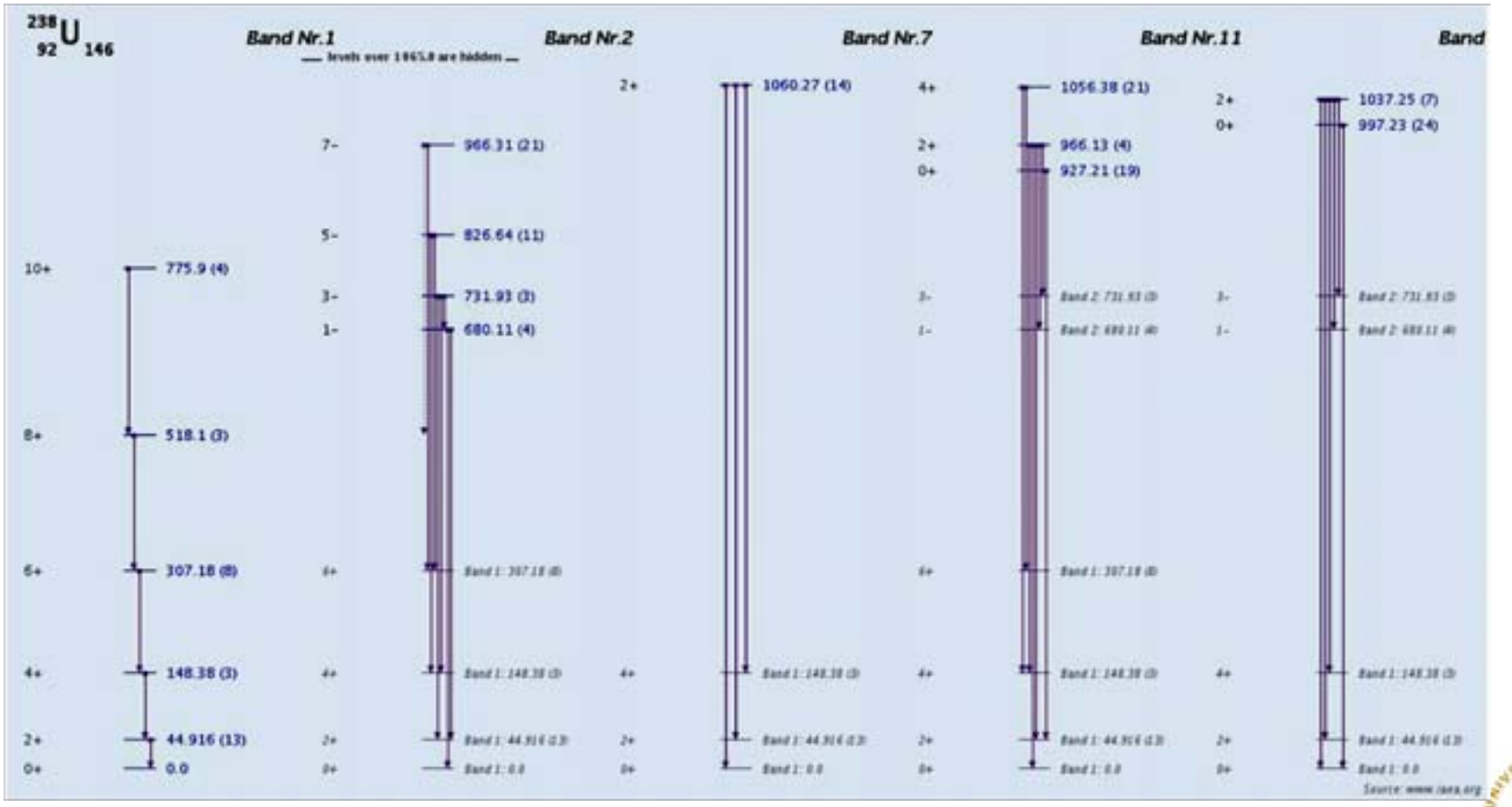
RIPL 5409



Dispersive and Lane consistent OMP (5)



^{238}U low lying nuclear levels



Expanded coupling scheme

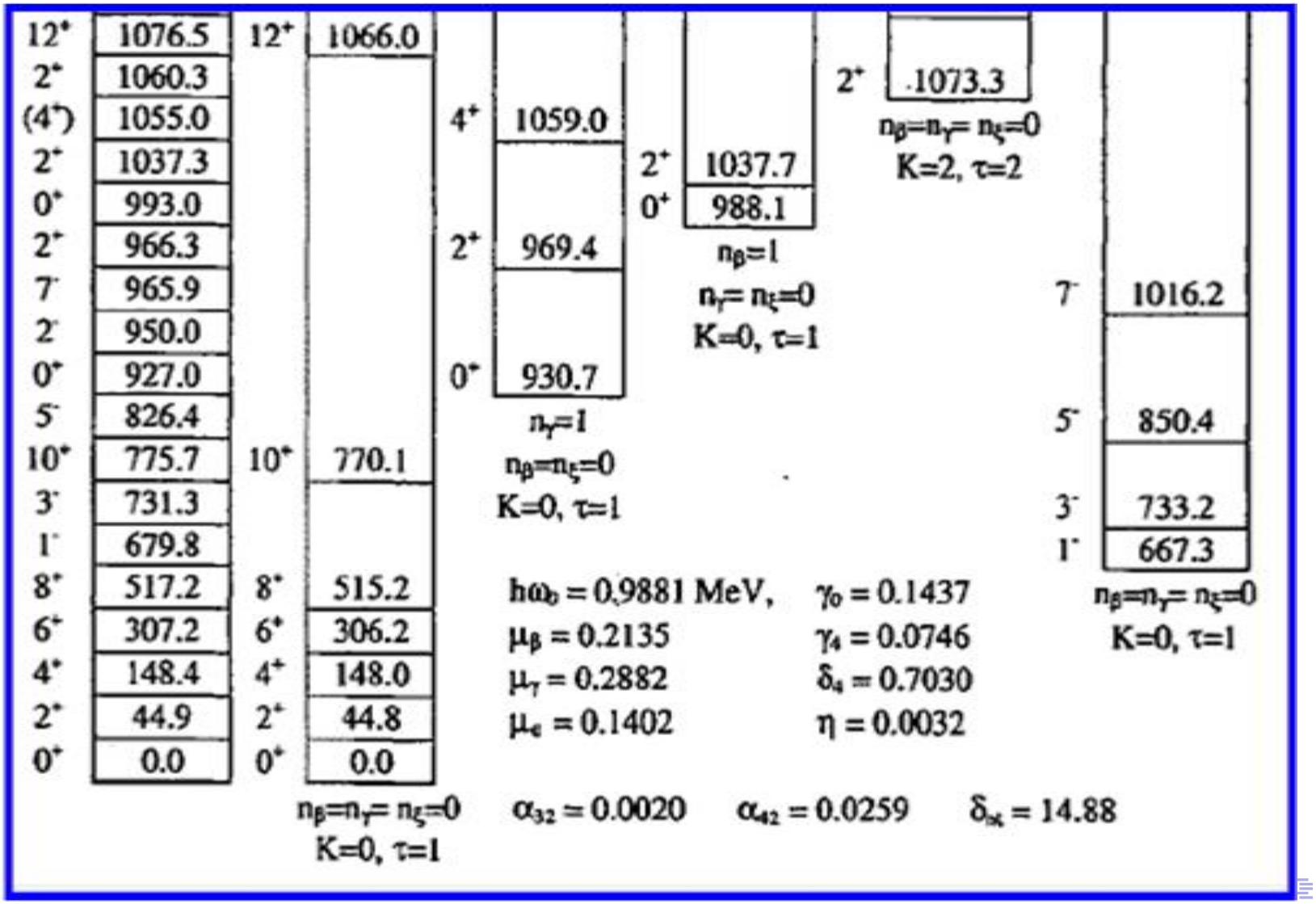
- **Vibrational-rotational model**
  - D.W.Chan et al, PRC26 (1982) 841, PRC26 (1982) 861
  - E.Sheldon. L.E.Beghian, D.W.Chan et al, J.Phys.G:Nucl. Phys. 12, 443 (1986)
  - T. Kawano, N. Fujikawa and Y. Kanda, INDC(JPN)-169 (1993) JENDL-3.2

- **Soft (non-axial) rotor**
  Yu.V.Porodzinkij and E. Soukhovitdkii, Phys. At. Nuclei 59 (1996) 228-237

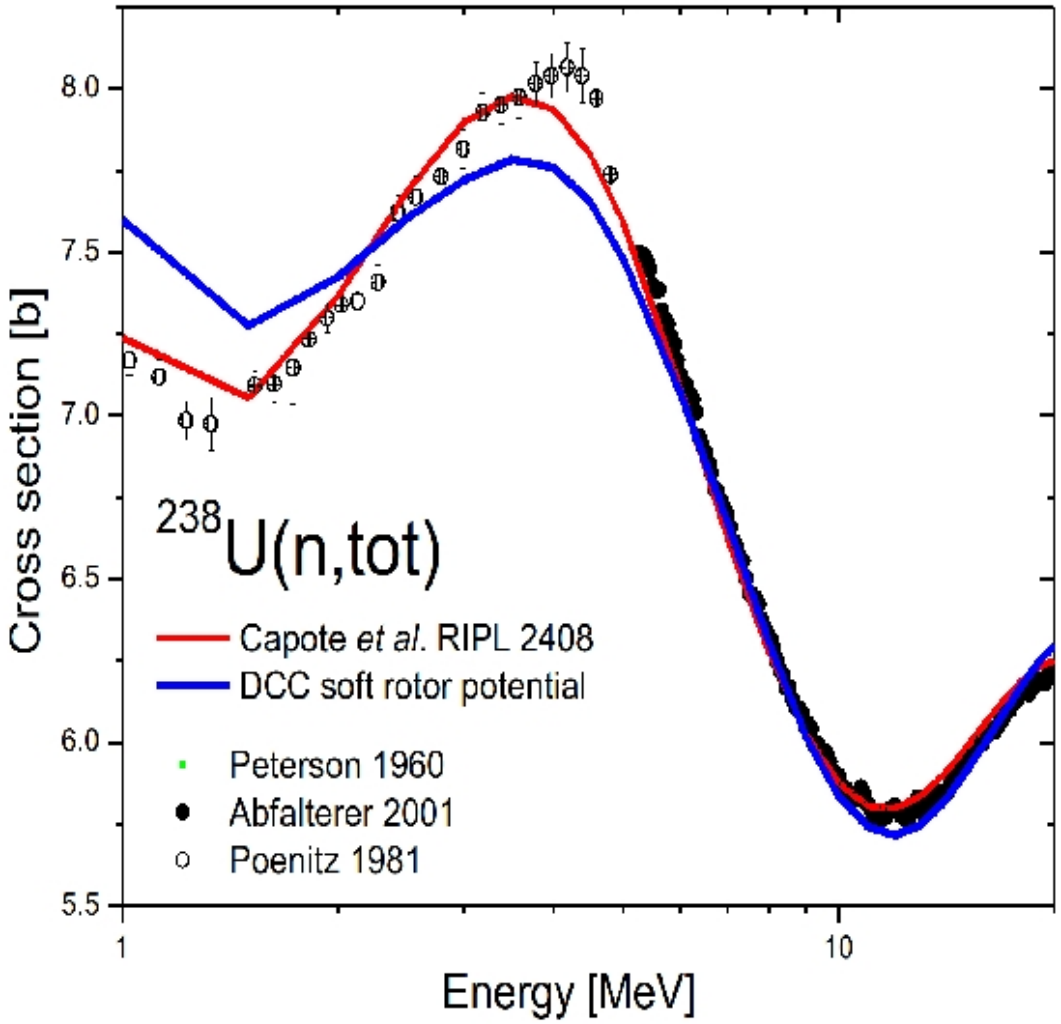
$$R(\theta',\varphi') = R_0 \left\{ 1 + \beta_2 \left[\cos\gamma\, Y_{20}(\theta') + \frac{1}{\sqrt{2}} \sin\gamma \left[Y_{22}(\theta',\varphi') + Y_{2-2}(\theta',\varphi') \right] \right] \right.$$
$$\left. + \sum_{\lambda=4,6....} \beta_{\lambda 0} Y_{\lambda 0}(\theta') + \beta_3 \left[\cos\eta\, Y_{30}(\theta') + \frac{1}{\sqrt{2}} \sin\eta \left[Y_{32}(\theta',\varphi') + Y_{3-2}(\theta',\varphi') \right] \right] \right\}$$

^{238}U as soft rotor with octupole deformations

Yu.V.Porodzinkij and E. Soukhovitdkii, Phys. At. Nuclei 59 (1996) 228



Soft rotor model in (rigid) actinides



Nuclear shape description

- **Soft (non-axial) rotor: all deformations ($\beta's, \gamma, \eta$) are considered as dynamic quantities**

$$R(\theta',\varphi') = R_0 \left\{ 1 + \beta_2 \left[\cos\gamma\, Y_{20}(\theta') + \frac{1}{\sqrt{2}} \sin\gamma \left[Y_{22}(\theta',\varphi') + Y_{2-2}(\theta',\varphi') \right] \right] \right.$$
$$\left. + \sum_{\lambda=4,6....} \beta_{\lambda 0} Y_{\lambda 0}(\theta') + \beta_3 \left[\cos\eta\, Y_{30}(\theta') + \frac{1}{\sqrt{2}} \sin\eta \left[Y_{32}(\theta',\varphi') + Y_{3-2}(\theta',\varphi') \right] \right] \right\}$$

- **Our approach:** $\beta_2 = \beta_2^0 + \delta\beta_2$
  Rigid rotor axial (static $\beta_2^0 \simeq \beta_{20}$**) +**
  axial ($\delta\beta_2, \beta_3 \cos\eta$) **and non-axial** ($\delta\beta_2 \sin\gamma, \beta_3 \sin\eta$) *dynamic* **corrections**

$$R(\theta',\varphi') = R_0 \left\{ 1 + \sum_{\lambda=2,4,6....} \beta_{\lambda 0} Y_{\lambda 0}(\theta') \right\}$$
$$+ R_0 \left\{ \delta\beta_2 Y_{20}(\theta') + \beta_2^0 \frac{1}{\sqrt{2}} \sin\gamma \left[Y_{22}(\theta',\varphi') + Y_{2-2}(\theta',\varphi') \right] \right.$$
$$\left. + \beta_3 \left[\cos\eta\, Y_{30}(\theta') + \frac{1}{\sqrt{2}} \sin\eta \left[Y_{32}(\theta',\varphi') + Y_{3-2}(\theta',\varphi') \right] \right] \right\}$$

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Formalism

Expanding around the equilibrium axially simmetric shape:

$$
\begin{aligned}
V(r,\theta',\varphi') &= \left[V(r,\theta',\varphi')\right]_{\delta\beta_2=0,\beta_2^0 sin\gamma=0,\beta_3=0} + \left[\frac{\partial}{\partial R}V(r,\theta',\varphi')\right]_{\delta\beta_2=0,\beta_2^0 sin\gamma=0,\beta_3=0} \times \\
&\left\{ \delta\beta_2 Y_{20}(\theta') + \frac{1}{\sqrt{2}}\beta_2^0 \sin\gamma \left[Y_{22}(\theta',\varphi') + Y_{2-2}(\theta',\varphi')\right] \right. \\
&+ \left. \beta_3 \left[\cos\eta\, Y_{30}(\theta') + \frac{1}{\sqrt{2}}\sin\eta \left[Y_{32}(\theta',\varphi') + Y_{3-2}(\theta',\varphi')\right]\right] \right\}
\end{aligned}
$$

Which can be expanded in multipoles:

$$
\begin{aligned}
V(r,\theta',\varphi') &= \sum_\lambda v_\lambda^{(1)}(r) Y_{\lambda,0}(\theta') + \sum_\lambda v_\lambda^{(2)}(r) Y_{\lambda,0}(\theta') \times \\
&\left\{ \delta\beta_2 Y_{\lambda,0}(\theta') + \frac{1}{\sqrt{2}}\beta_2^0\gamma \left[Y_{\lambda,2}(\theta',\varphi') + Y_{\lambda,-2}(\theta',\varphi'\right] \right. \\
&+ \left. \beta_3 \left[\cos\eta\, Y_{30}(\theta') + \frac{1}{\sqrt{2}}\sin\eta \left[Y_{32}(\theta',\varphi') + Y_{3-2}(\theta',\varphi')\right]\right] \right\}
\end{aligned}
$$

Formalism

$$
\begin{aligned}
< \; & i|V(r,\theta',\varphi')|f >=< (ljI)_{JM},K| \sum_{\lambda(even)} v_\lambda^{(1)}(r)\left[D_{;0}^{\lambda}\cdot Y_\lambda\right]|(l'j'I')_{JM},K'> + \\
< \; & (ljI)_{JM},K|\delta\beta_2 \sum_{\lambda=2,4,6,..} \tilde{v}_\lambda^{(2)}(r)\left[D_{;0}^{\lambda}\cdot Y_\lambda\right]|(l'j'I')_{JM},K'> + \\
< \; & (ljI)_{JM},K|\beta_2^0\gamma \sum_{\lambda=2,4,6,..} \tilde{v}_\lambda^{(2)}(r)\frac{1}{\sqrt{2}}\left[\left(D_{;2}^{\lambda}+D_{;-2}^{\lambda}\right)\cdot Y_\lambda\right]|(l'j'I')_{JM},K'> + \\
< \; & (ljI)_{JM},K|\beta_3\cos\eta \sum_{\lambda=3,5,7,..} \tilde{v}_\lambda^{(3)}(r)\left[D_{;0}^{\lambda}\cdot Y_\lambda\right]|(l'j'I')_{JM},K'> + \\
< \; & (ljI)_{JM},K|\beta_3\sin\eta \sum_{\lambda=3,5,7,..} \tilde{v}_\lambda^{(3)}(r)\left[\left(D_{;2}^{\lambda}+D_{;-2}^{\lambda}\right)\cdot Y_\lambda\right]|(l'j'I')_{JM},K'>
\end{aligned}
$$

$$
\begin{aligned}
< \; & (ljI)_{JM},K|\beta_2\gamma \sum_{\lambda=2,4,6,..} \frac{1}{\sqrt{2}}\left[\left(D_{;2}^{\lambda}+D_{;-2}^{\lambda}\right)\cdot Y_\lambda\right]|(l'j'I')_{JM},K'>= \\
& A(lI;l'I';\lambda J)\;\beta_2^{eff}\gamma < IK||\frac{1}{\sqrt{2}}\left(D_{;2}^{\lambda}+D_{;-2}^{\lambda}\right)||I'K'>
\end{aligned}
$$

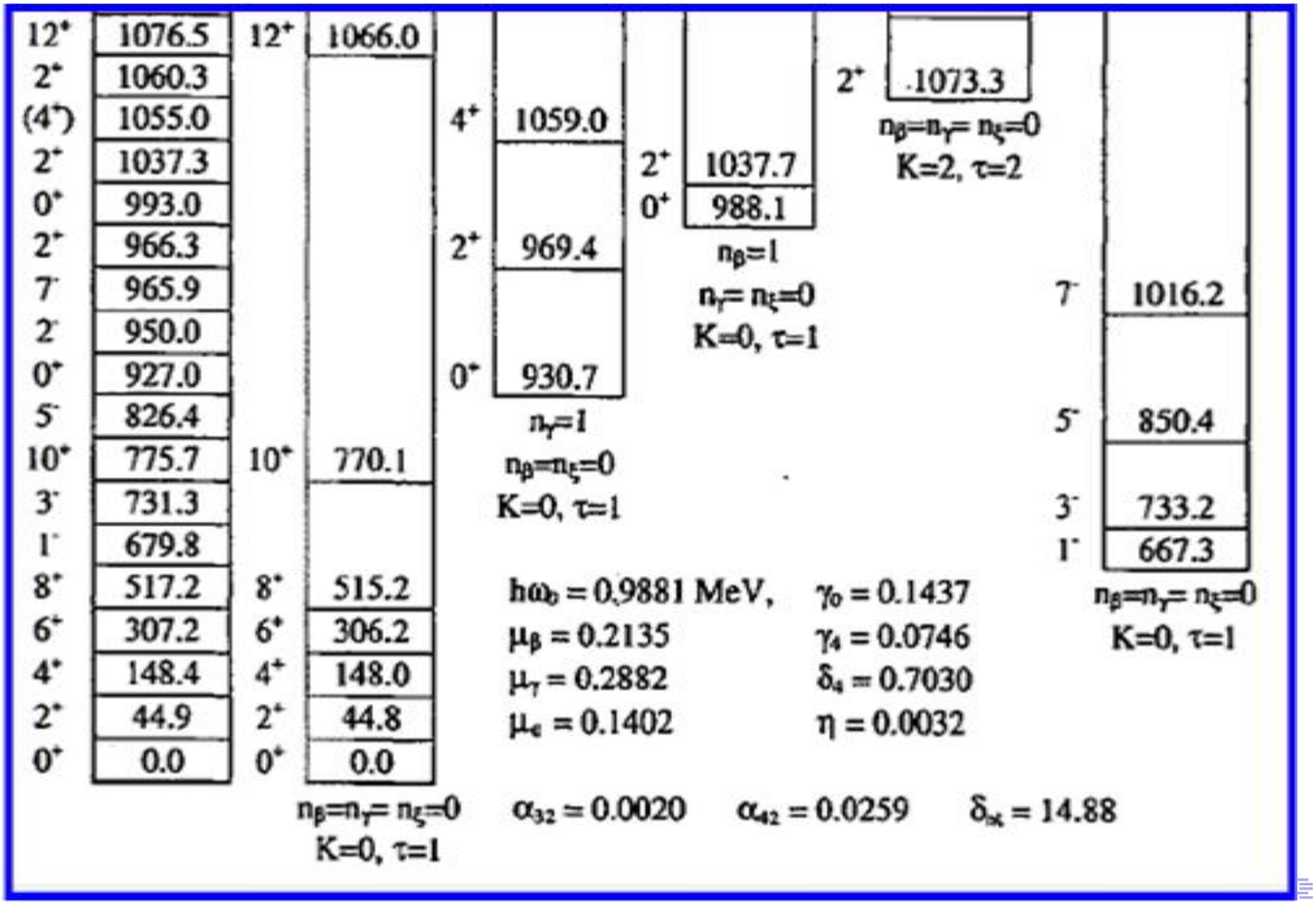
where these reduced matrix elements can be easily calculated, as for instance:

$$
< I0||\left[D_{;2}^{\lambda}+D_{;-2}^{\lambda}\right]||I'2> \;=\; \sqrt{2I'+1}\times\sqrt{2}\times\left[< I'\lambda 2-2|I0>\right.
$$

Formalism

^{238}U

First β, γ, octupole and non-axial bands are now included



Content

New OMP results:

RIPL 2408 $\chi^2(^{238}\mathrm{U}) = 2.05$

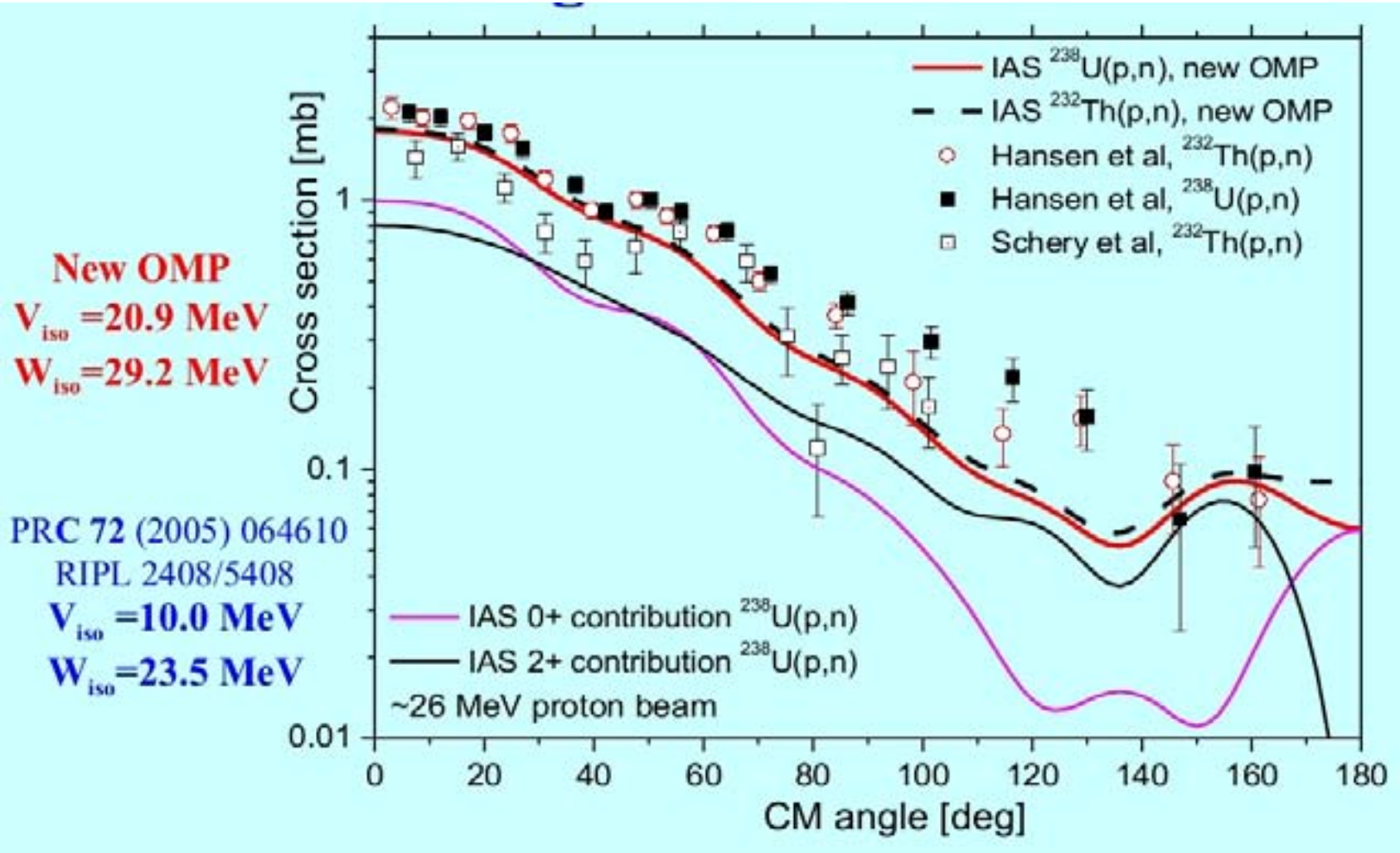
Table 2 Dispersive coupled-channel OMP parameters for actinides

	VOLUME	SURFACE	SPIN-ORBIT	COULOMB
Real depth [MeV]	$V_0 = 48.62$ $\lambda_{HF} = 0.01037$ $C_{viso} = 10.0$ + dispersive ΔV_V	dispersive ΔV_S	$V_{so} = 6.03$ $\lambda_{so} = 0.005$ + dispersive ΔV_{SO}	$C_{Coul} = 1.62$
Imaginary depth [MeV]	$A_v = 12.53$ $B_v = 80.94$ $E_a = 350$	$W_0 = 17.73$ $B_s = 11.56$ $C_s = 0.01328$ $C_{wiso} = 23.5$	$W_{so} = -3.1$ $B_{so} = 160$	
Geometry [fm]	$r_{HF} = 1.2516 + 0.001367\ (238 - A)$ $a_{HF} = 0.636 - 0.002\ (238 - A)$ $r_v = 1.253$ $a_v = 0.680 - 0.00033\ (238 - A)$	$r_s = 1.1808$ $a_s = 0.603 - 0.0005\ (238 - A)$	$r_{so} = 1.1214$ $a_{so} = 0.59$	$r_c = 1.2174$ $a_c = 0.551$

New OMP 19 CC $\chi^2(^{238}\mathrm{U}) = 1.80$

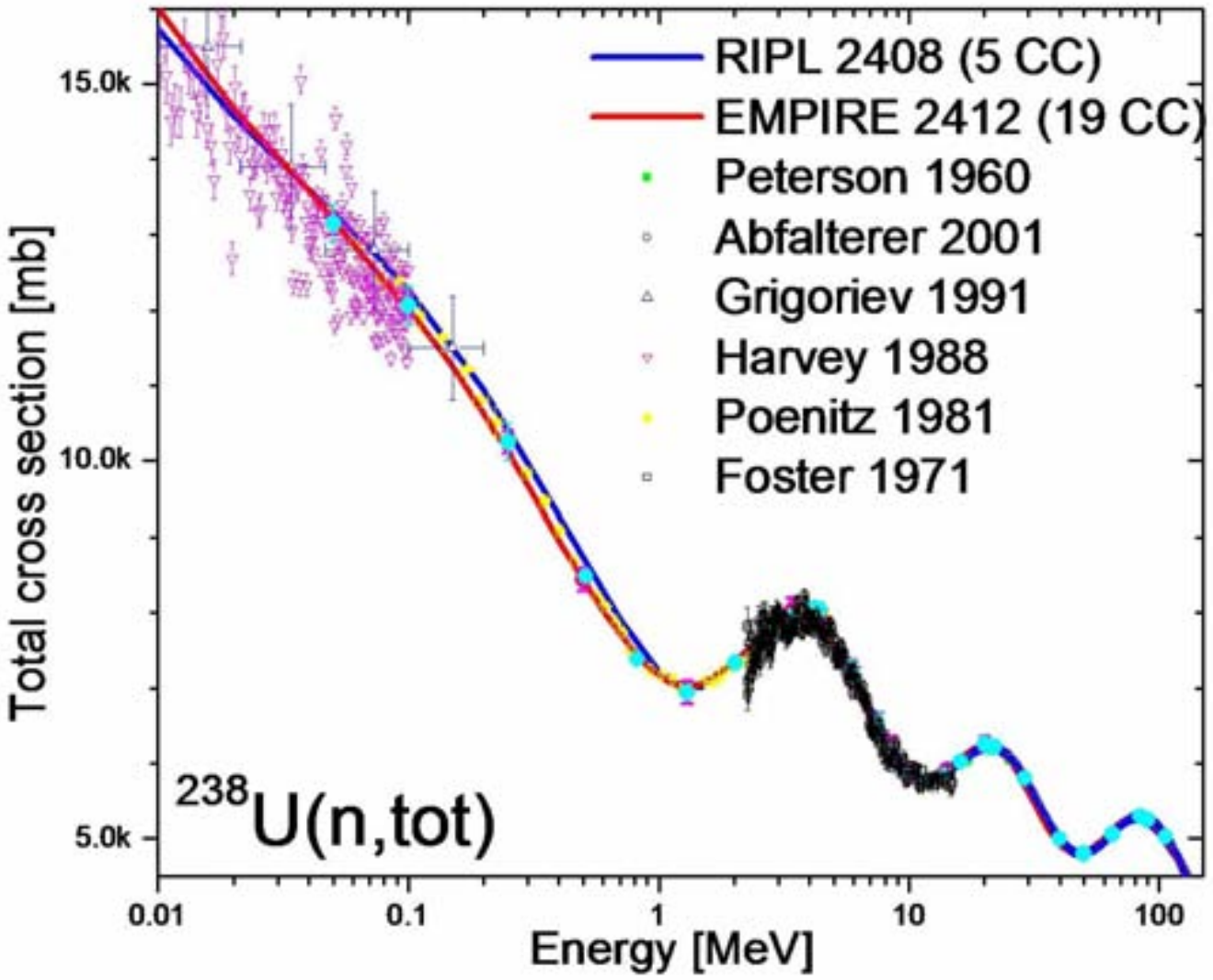
New OMP results:

IAS angular distributions



New OMP results:

n+238U total cross section



DCC OMP low energy observables

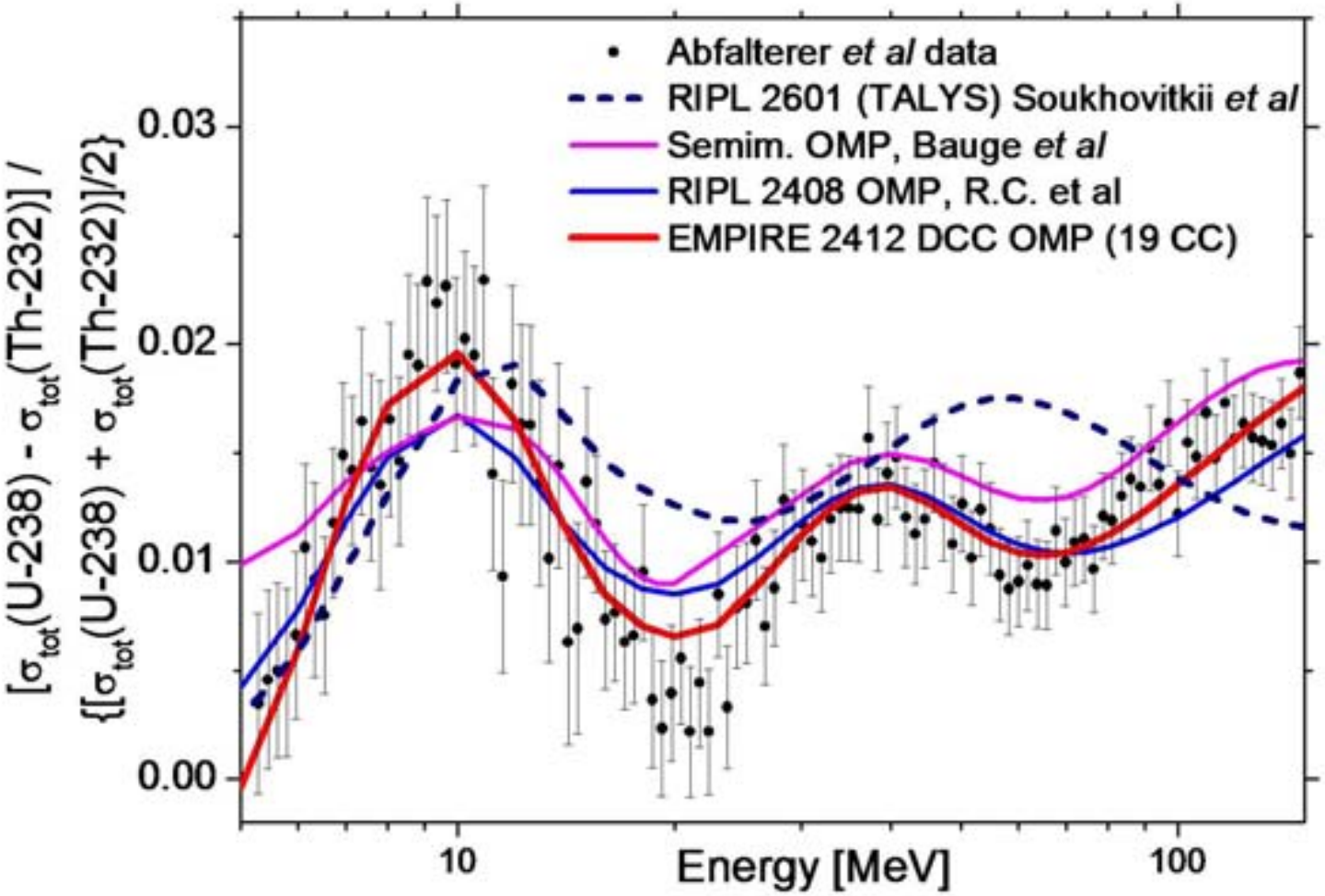
	^{238}U nucleus		^{232}Th nucleus	
	RIPL 2408	new OMP 19 CC	RIPL 2408	new OMP 19 CC
S_0	0.92	1.04	0.85	0.85
RIPL-3 [1]	1.03 (.08)		0.84 (.07)	
Porodzinskij [2]	1.03 (.13)		0.84 (.08)	
S_1	1.72	1.63	1.72	1.84
RIPL-3 [1]	1.6 (.2)		1.5 (.3)	
R` (fm)	9.64	9.51	9.68	9.68
CSEWG 1991	9.6 (.1)		9.65 (.3)	

(1) R. Capote et al, Nucl. Data Sheets 110 (2009) 3107-3214, online at http://www-nds.iaea.org/RIPL-3
(2) Yu.V. Porodzinskij, E.Sh. Sukhovitskij and V.M. Maslov, INDC(BLR)-012, IAEA, 1998

New OMP results:

^{238}U: OMP observables intercomparison

Figure of merit

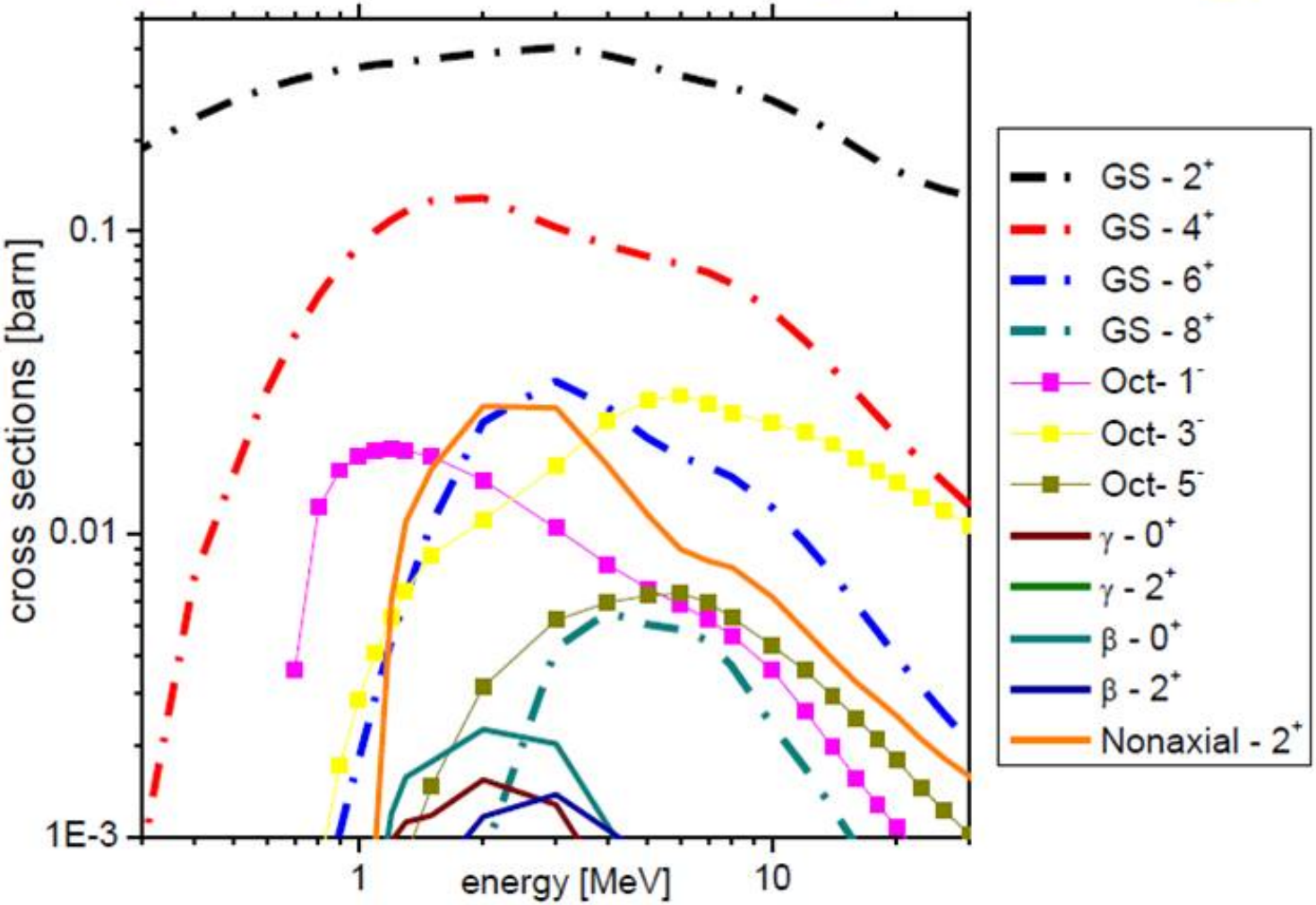


New OMP results:

^{238}U: OMP observables intercomparison

^{238}U: inelastic cross sections for level excitations

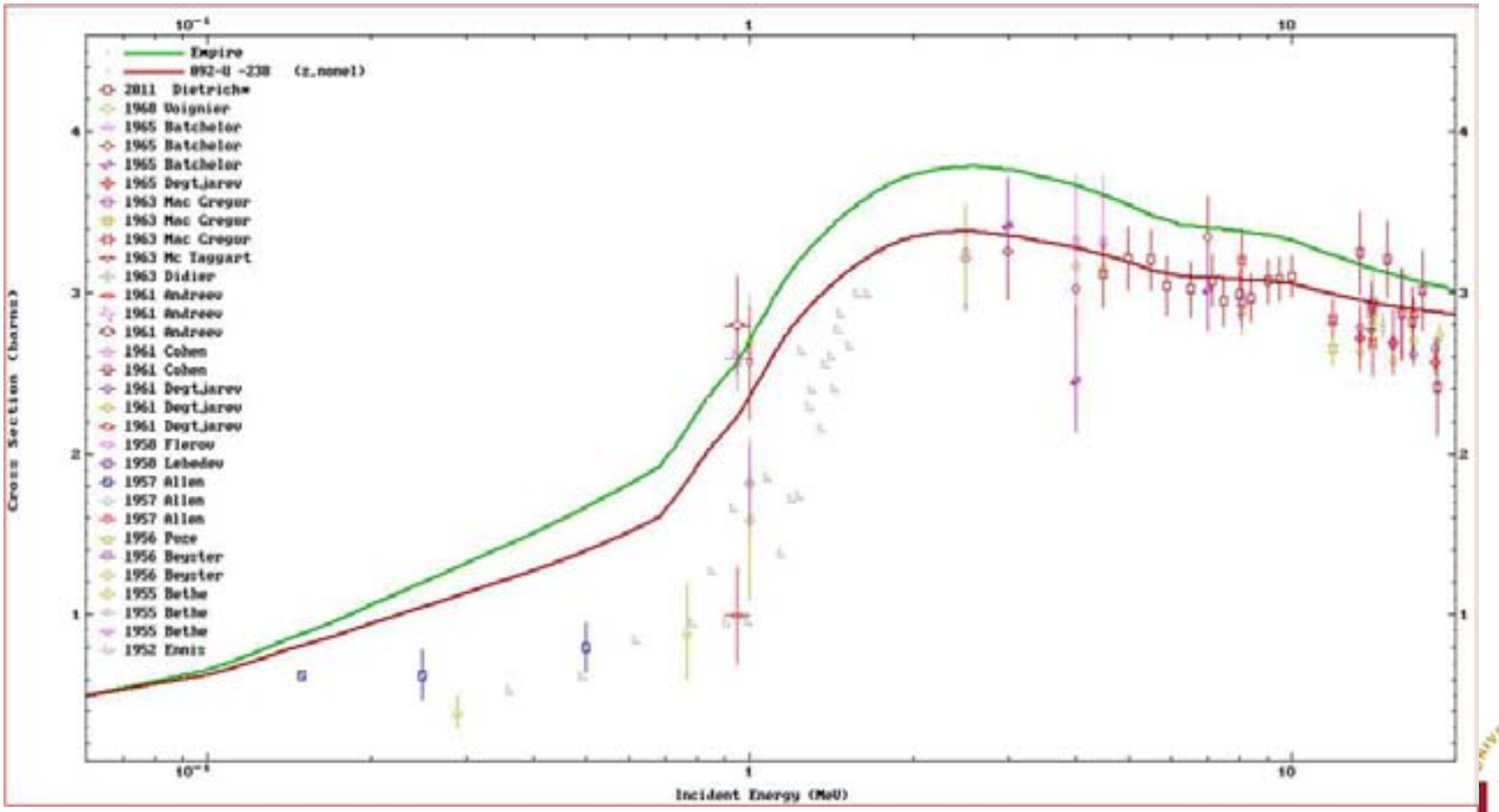
Coupled-levels cross sections using EMPIRE 2412 [4]



New OMP results:

^{238}U: OMP observables intercomparison

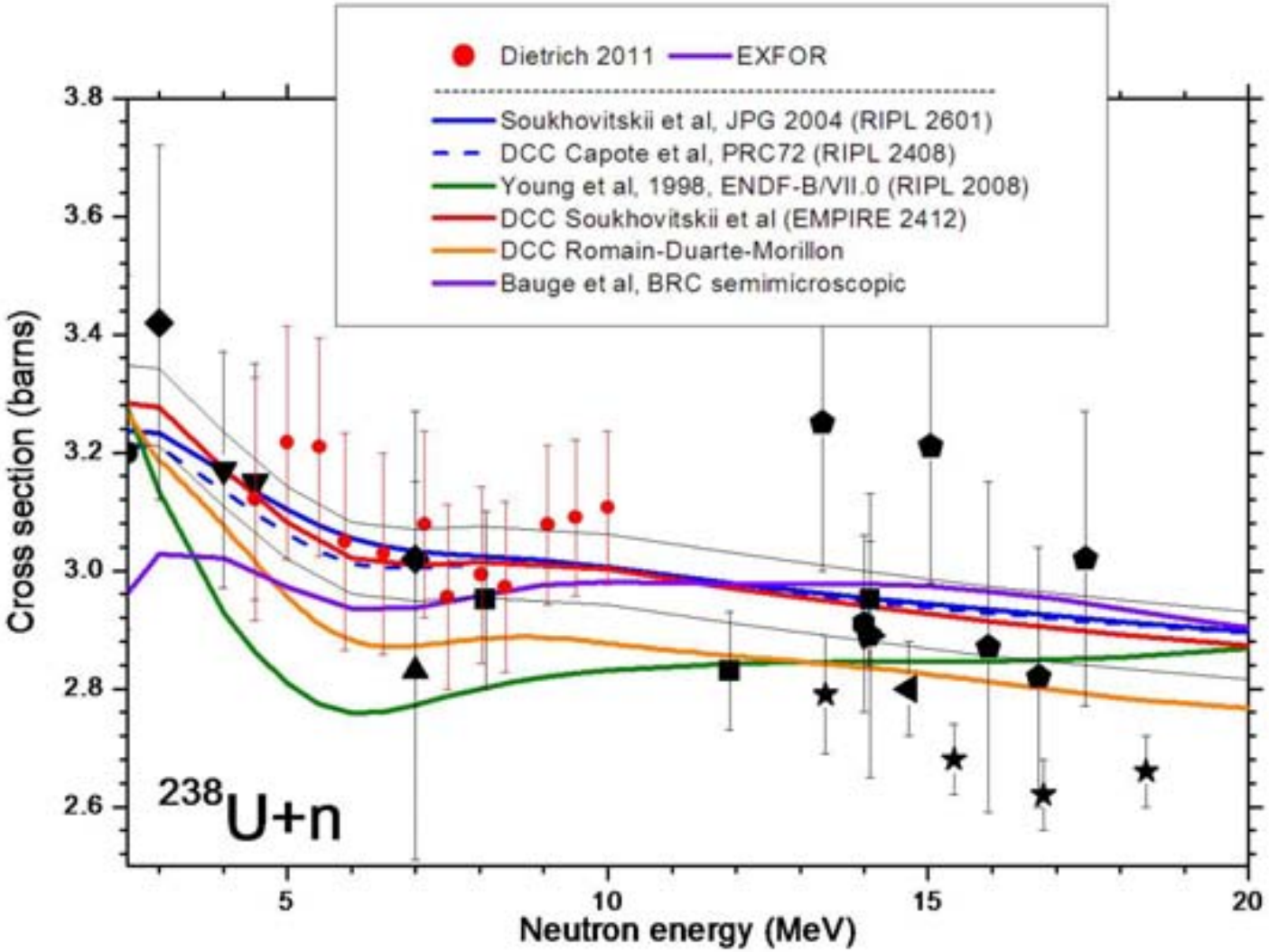
n+^{238}U nonelastic cross section: EMPIRE 2412 OMP



New OMP results:

^{238}U: OMP observables intercomparison

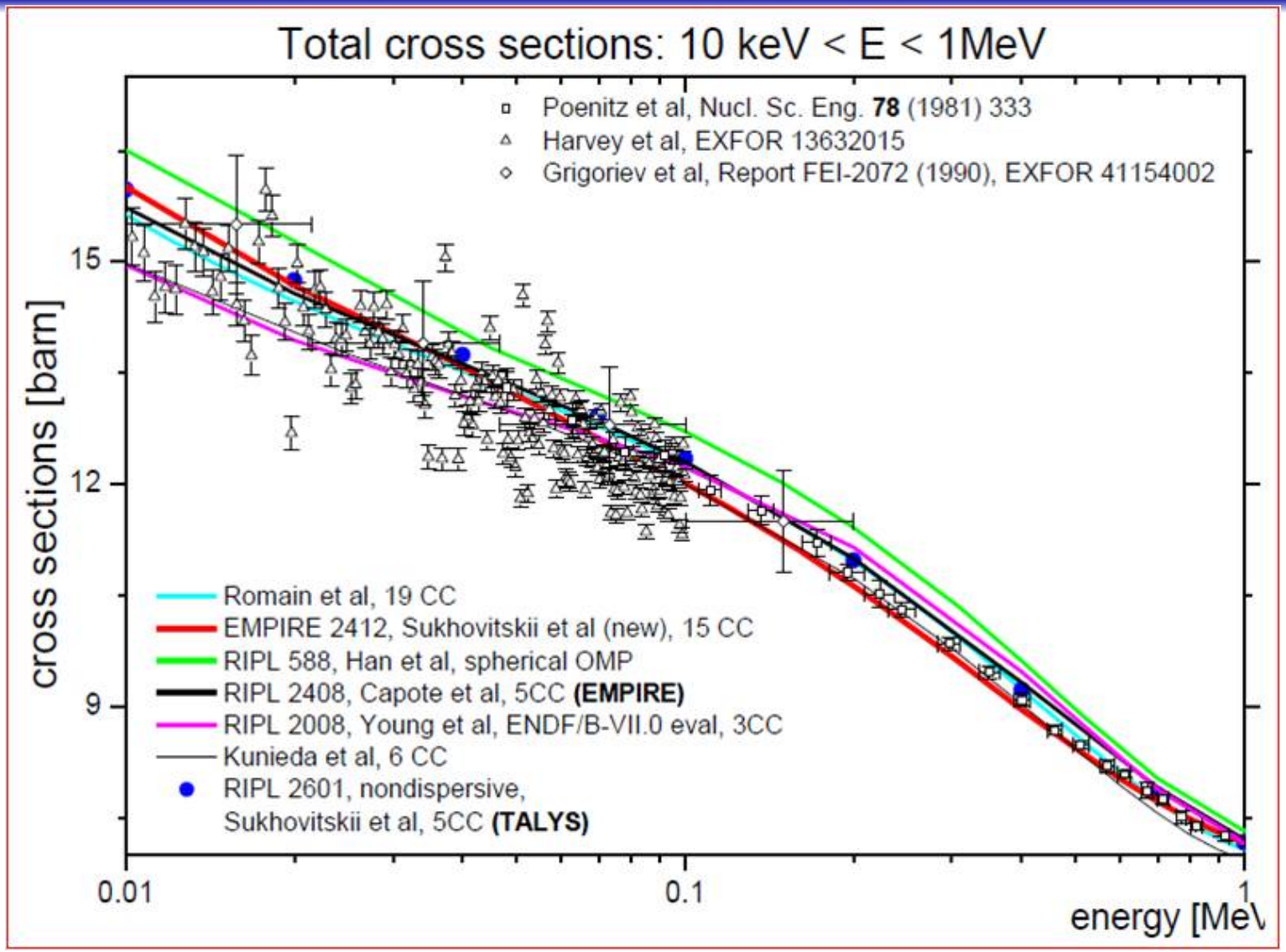
n+^{238}U nonelastic cross section: EMPIRE 2412 OMP



New OMP results:

^{238}U: OMP observables intercomparison

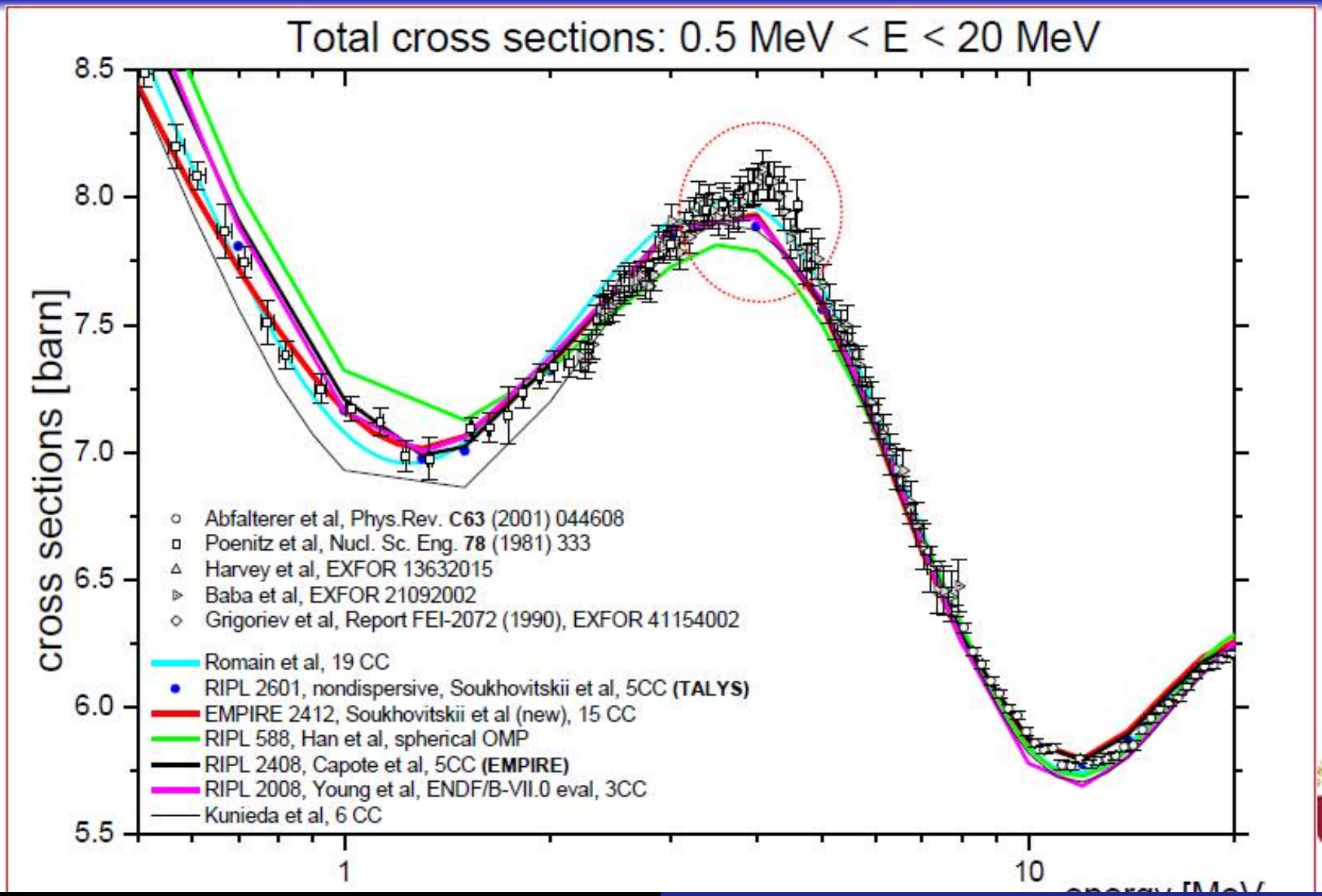
n+^{238}U total cross section 10 keV < E < 1 MeV



New OMP results:

^{238}U: OMP observables intercomparison

n+^{238}U total cross section 0.5 MeV $<$ E $<$ 20 MeV



New OMP results:

^{238}U: OMP observables intercomparison

σ_{CN} 40 keV $<$ E $<$ 20 MeV

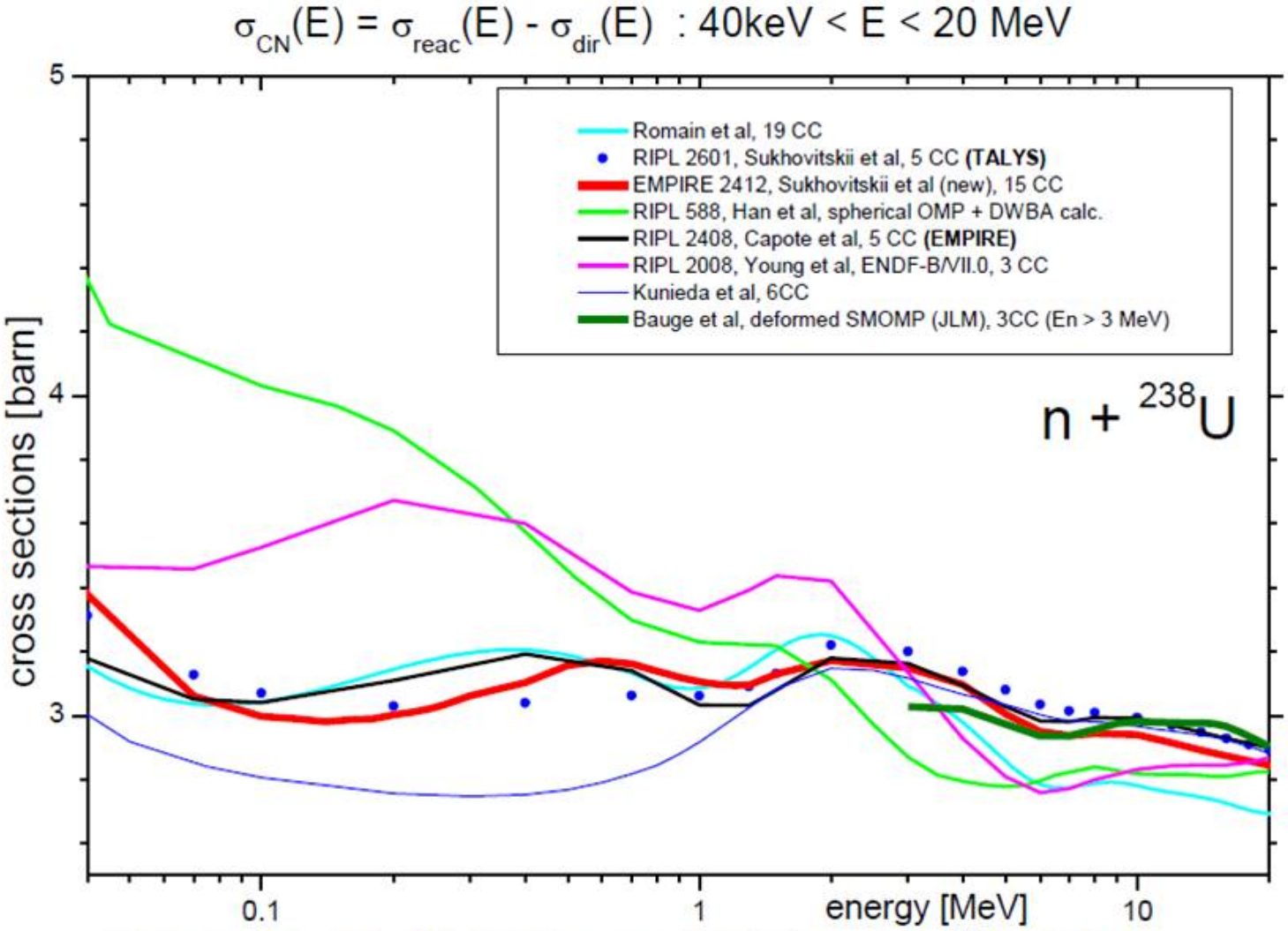


Figure A-3: Compound nucleus formation cross sections for the reaction n+ ^{238}U up to 20 MeV

New OMP results:

Dispersive OMP with improved structure model based on soft rotor description

- New OMP derived for nucleon scattering on ^{238}U and ^{232}Th nuclei
- The use of proton and neutron scattering data (including quasielastic (p,n)) simultaneously made it possible to reduce the uncertainty of estimated optical potential parameters.
- OMP highlights:
  - Based on dispersive relations and Lane consistent
  - Least-squares fit of OMP parameters from (n,n),(p,p) & (p,n)IAS
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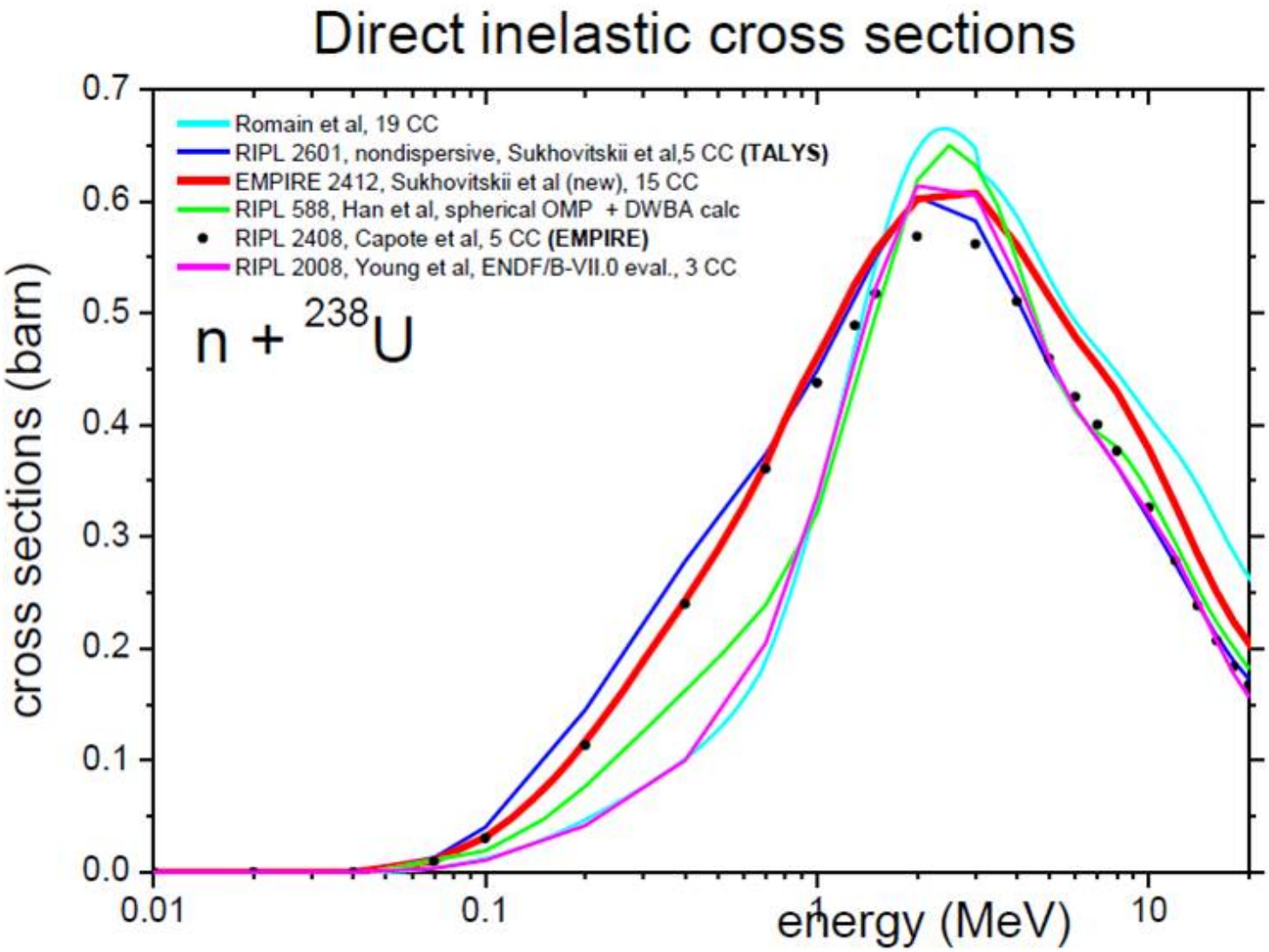
Thanks for your attention

Bibliography

- A. Molina R. Capote, **J. M. Quesada** and M. Lozano, **" Dispersive spherical optical model of neutron scattering from ^{27}Al up to 250 MeV "** *Physical Review C* **65** 034616 (2002)
- **J. M. Quesada**, R. Capote, A. Molina and M. Lozano, **"Dispersion relations in the nuclear optical model"** *Computer Physics Communications* **153** (2003) 97-105
- **J.M. Quesada**, A. Molina, M. Lozano, R. Capote and J.Raynal,**" Analytical expressions for the dispersive contributions to the nucleon-nucleus optical potential "** *Physical Review C* **67** 067601 (2003)
- **E. Sh. Soukhovitskii, R. Capote, J. M. Quesada and S. Chiba**, **"Dispersive coupled-channel analisis of nucleon scattering from ^{232}Th up to 200 MeV"** *Physical Review C* **72** 024604 (2005)
- E. Sh. Soukhovitskii, R. Capote, J. M. Quesada and S. Chiba, **"Dispersive coupled-channel analisis of nucleon scattering from ^{232}Th up to 200 MeV"** , Physical Review C72, 024604 (2005)
- R. Capote, E. Sh. Soukhovitskii, J. M. Quesada and S. Chiba, **"Is a global coupled-channel dispersive optical model potential for actinides feasible?"**, Physical Review C72, 064610 (2005)
- N. T. Okumusoglu, F. Korkmaz Gorur, J. Birchall, E. Sh. Souhovitskii, R. Capote, J. M. Quesada and S. Chiba, **"Angular distributions of protons scattered by ^{40}Ar nuclei with excitation of the 2+(1.46 MeV) and 3- (3.68 MeV) collective levels for incident energies of 25.1, 32.5 and 40.7 MeV"**, Physical Review C75, 034616 (2007)
- J. M. Quesada, R. Capote, E. Sh. Soukhovitskii and S. Chiba, **"Approximate Lane consistency of the dispersive coupled.channels potential for actinides"**, Physical Review C76 057602 (2007)
- Capote, R; Chiba, S; Soukhovitskii, ES; Quesada, JM and Bauge, E, **"A Global Dispersive Coupled-Chanel Optical Model Potential for Actinides"**, Journal of Nuclear Science and Technology 45,(4) 333-340 (2008)
- W. L. Sun, L. J. Hao, E. Sh Soukhovitskii, R. Capote, and J. M. Quesada, **"Description of analyzing power and (p,n) reaction by a global dispersive coupled-channel optical model potential"**, 7th Japan-China Joint Nuclear Physics Symposium, AIP Conference Proceedings 2010; 1235(1):43 - 4, University of Tsukuba, Ibaraki (Japan) November, 9-13 2009

^{238}U: OMP observables intercomparison

Direct inelastic cross sections



Very last results for ^{238}U

Table: DCC OMP parameters for ^{238}U, EMPIRE 2412, full coupling.

	VOLUME		SURFACE	SPIN-ORBIT	- COULOMB
Real depth [MeV]	$V_0 = 51.13$ $\lambda_{HF} = 0.00976$ $C_{viso} = 20.9$ + dispersive ΔV_V		dispersive ΔV_S	$V_{so} = 5.94$ $\lambda_{so} = 0.005$ + dispersive ΔV_{SO}	$C_{Coul} = 1.10$
Imaginary depth [MeV]	$A_v = 11.91$ $B_v = 81.69$ $E_a = 52$	$\alpha = 0.375$	$W_0 = 17.85$ $B_s = 10.95$ $C_s = 0.01334$ $C_{wiso} = 29.2$	$W_{so} = -3.1$ $B_{so} = 160$	
Geometry [fm]	$r_{HF} = 1.2500$ $a_{HF} = 0.638$ $r_v = 1.2619$ $a_v = 0.693$		$r_s = 1.1701$ $a_s = 0.612$	$r_{so} = 1.1214$ $a_{so} = 0.59$	$r_c = 1.1974$ $a_c = 0.400$

^{238}U: STATIC: $\beta_2 = 0.23$; $\beta_4 = 0.06$; $\beta_6 = -0.0064$ DYNAMIC: $\beta_\beta^{eff} = 0.008$; $\beta_{oct}^{eff} = 0.055$; $\beta_\gamma^{eff} == 0.010$; $\beta_{non-axial}^{eff} = 0.02$

Couplings GS band $\longleftrightarrow$ IAS band

$$
\begin{aligned}
&< \nu; I^{+}(residual)|V(\tau,\vec{r})|\pi; I^{+}(target) > \\
&= < \nu|\mathcal{T}|\pi >< I^{+}(residual)|V_1^{diag}(\vec{r})(|I^{+}(target) > \\
&= \frac{\sqrt{(N-Z)}}{2A} < I^{+}(residual)|V_1^{diag}(\vec{r})|I^{+}(target) >
\end{aligned}
$$

$$
\begin{aligned}
&< \nu; I^{+\prime}(residual)|V(\tau,\vec{r})|\pi; I^{+}(target) > \\
&= < \nu|\mathcal{T}|\pi >< I^{+\prime}(residual)|V_1^{coupl}(\vec{r})(|I^{+}(target) > \\
&= \frac{\sqrt{(N-Z)}}{2A} < I^{+\prime}(residual)|V_1^{coupl}(\vec{r})|I^{+}(target) >
\end{aligned}
$$