Nuclear data evaluation challenges

Roberto Capote

IAEA Nuclear Data Section, Vienna, Austria

Thanks to:

- Organizers for the invitation

- IAEA projects' participants

- Collaborators

PFNS

OMP

  - A. Trkov (IAEA)
  - D.L. Smith (ANL, USA)
  - D. Neudecker (LANL, USA)
  - E. Soukhovitskii (JIENR, Belarus)
  - J.M. Quesada (Univ. Sevilla, Spain)
  - S. Chiba (Tokyo Inst. Technology, Japan)

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OUTLOOK

- Introduction
- $^{235}U(n_{th},f)$ PFNS non-model evaluation
- PFNS model evaluation challenges
- Reaction modelling challenges
- Evaluation methodology challenges
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- Lessons learned on EXFOR compilation
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Nuclear Data Sheets

Volume 118, April 2014, Pages 1–25

The CIELO Collaboration: Neutron Reactions on ^{1}H, ^{16}O, ^{56}Fe, ^{235,238}U, and ^{239}Pu

M.B. Chadwick[a], E. Dupont[b], E. Bauge[c], A. Blokhin[d], O. Bouland[e], D.A. Brown[f], R. Capote[g], A. Carlson[h], Y. Danon[i], C. De Saint Jean[e], M. Dunn[j], U. Fischer[k], R.A. Forrest[g], S.C. Frankle[a], T. Fukahori[l], Z. Ge[m], S.M. Grimes[n], G.M. Hale[a], M. Herman[f], A. Ignatyuk[d], M. Ishikawa[l], N. Iwamoto[l], O. Iwamoto[l], M. Jandel[a], R. Jacqmin[a], T. Kawano[a], S. Kunieda[l], A. Kahler[a], B. Kiedrowski[a], I. Kodeli[o], A.J. Koning[p], L. Leal[j], Y.O. Lee[q], J.P. Lestone[a], C. Lubitz[r], M. MacInnes[a], D. McNabb[s], R. McKnight[t], M. Moxon[u], S. Mughabghab[f], G. Noguere[e], G. Palmiotti[v], A. Plompen[w],

IAEA contributions:

- Neutron standards project
- Actinide PFNS Coordinated Research Project
- Technical work for actinide evaluations
  e.g. OMP developments, ^{238}U evaluation
- Collaboration with BNL on ^{56}Fe evaluation

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PFNS evaluation challenges

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$^{235}U(n_{th},f)$ PFNS GANDR evaluation

- Kornilov *et al.* (IRMM) data taken as reference
- All data converted to $^{252}Cf/^{235}U$ or ^{235}U/Mxw(1.32MeV) ratios
- Upper energy cut-off 10 MeV
- $^{252}Cf/^{235}U$ or ^{235}U/Mxw(1.32MeV) ratios integrated over the overlapping interval for each experiment
- Measured data normalised to match integrals over the overlapping regions **(data taken as shape data)**
- GANDR (GLSQ fit) with almost uninformative prior

Model independent evaluation (Neutron STD)

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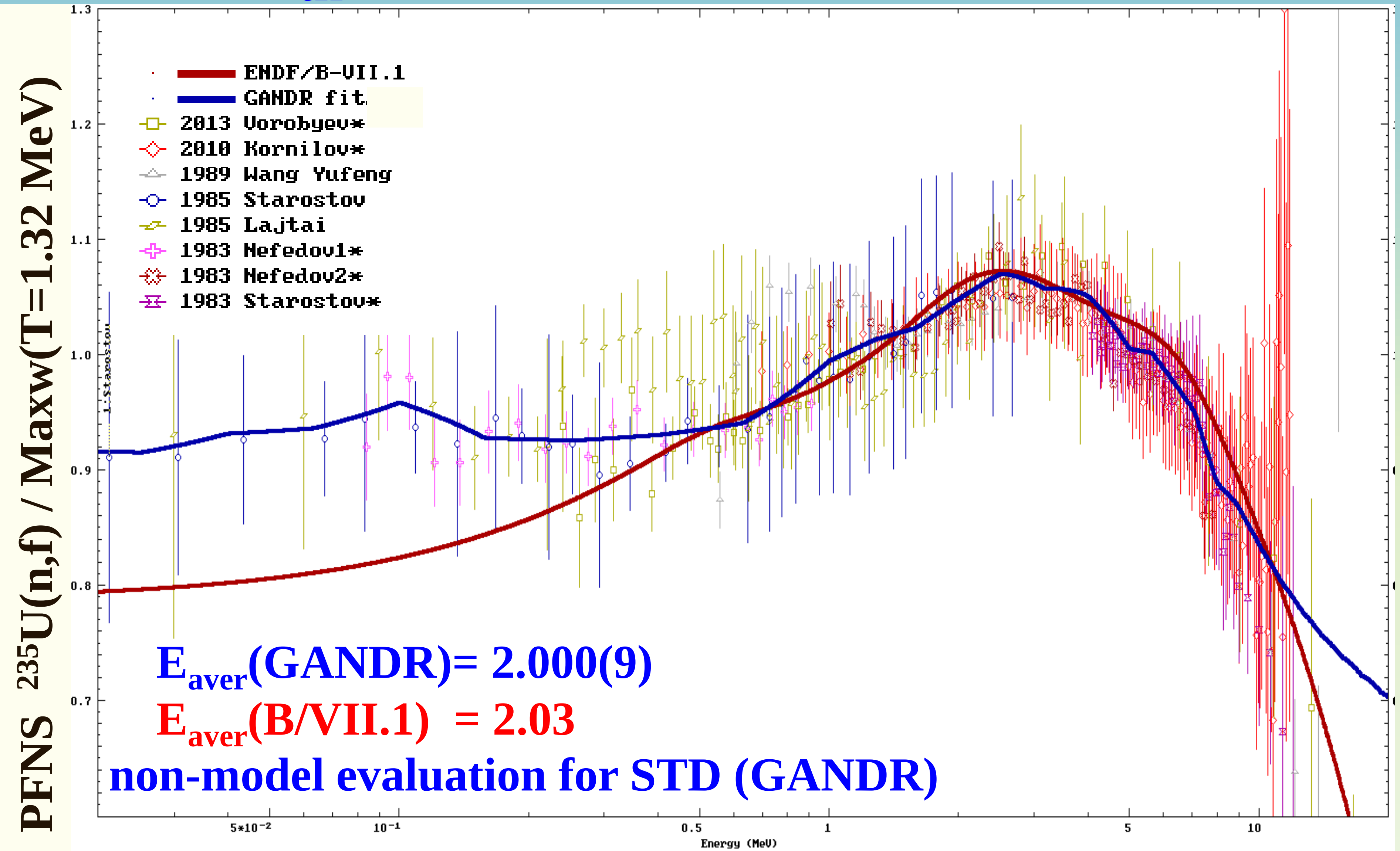
$^{235}U(n_{th},f)$ PFNS GANDR evaluation



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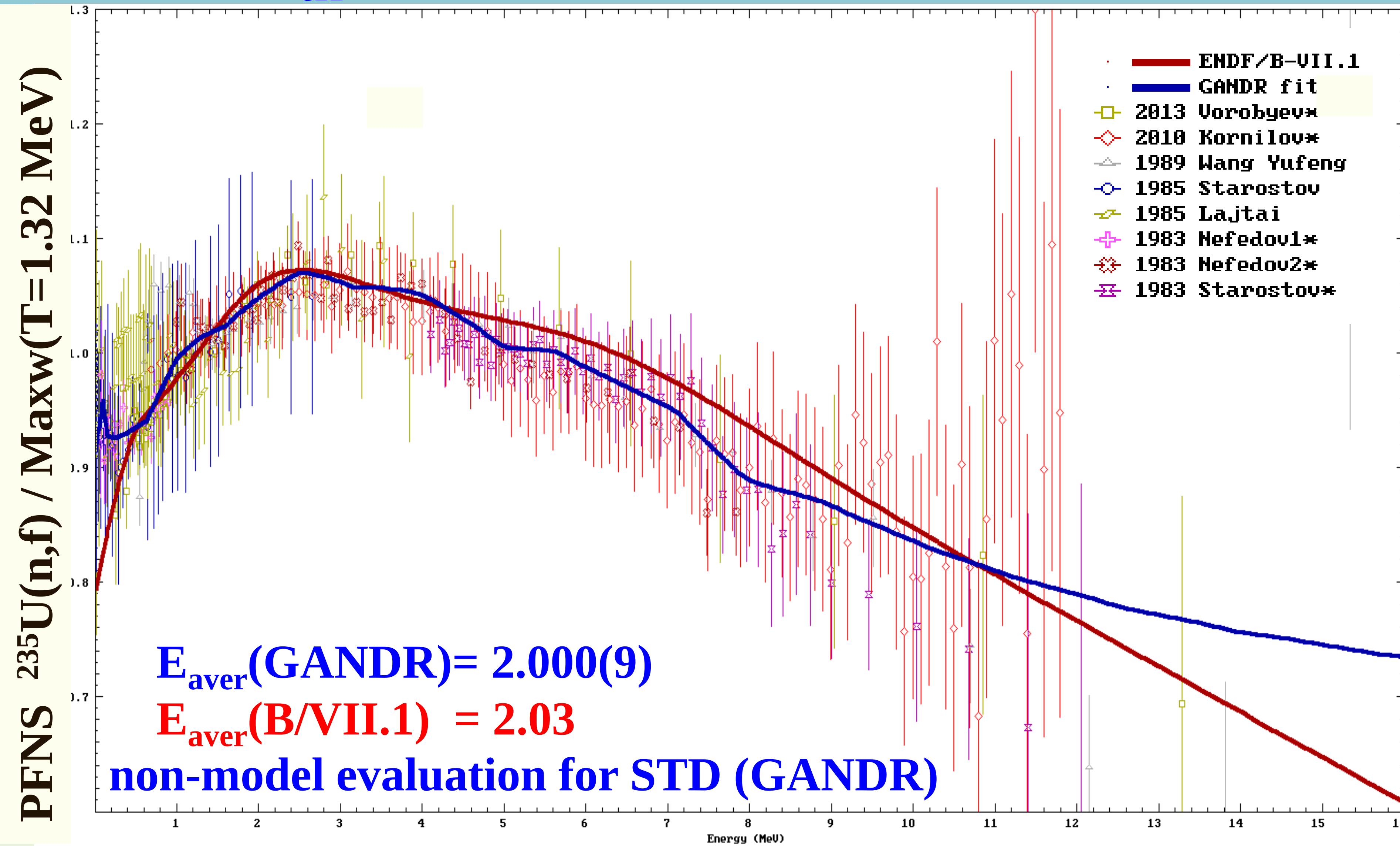

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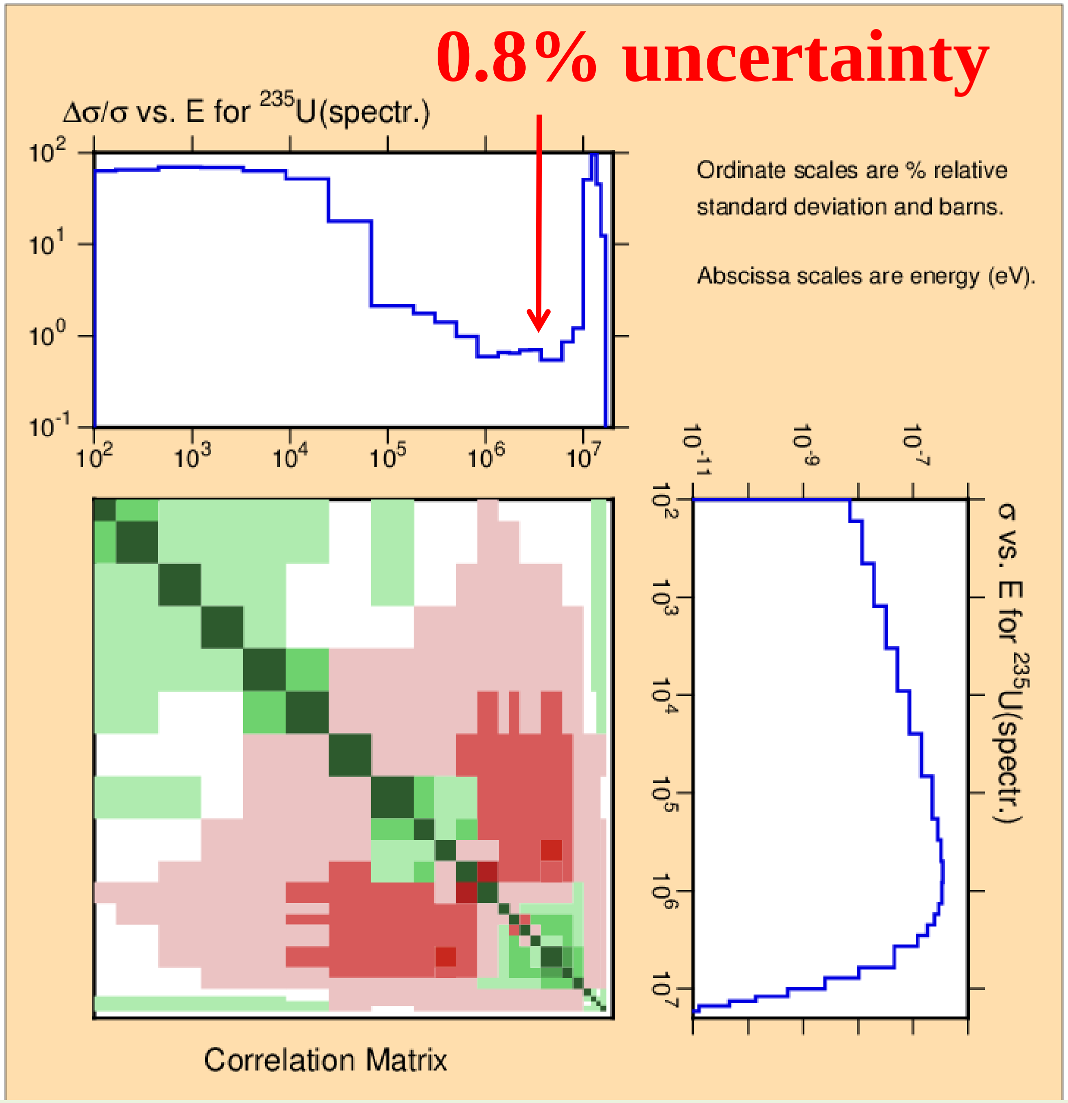
GANDR evaluation: uncertainty analysis



$$Y(\varepsilon) = \nu\chi(\varepsilon)$$

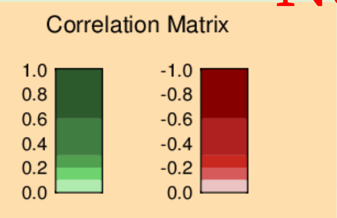
$$\left(\frac{\delta Y}{Y}\right)^2 = \left(\frac{\delta \nu}{\nu}\right)^2 + \left(\frac{\delta \chi}{\chi}\right)^2$$

$$\frac{\delta \nu}{\nu} = 0.3\%$$

$$\frac{\delta \chi}{\chi}(\varepsilon = 2) = 0.8\%$$

$$\left(\frac{\delta Y}{Y}(\varepsilon = 2)\right) = 0.85\ \%$$

Non-model fit



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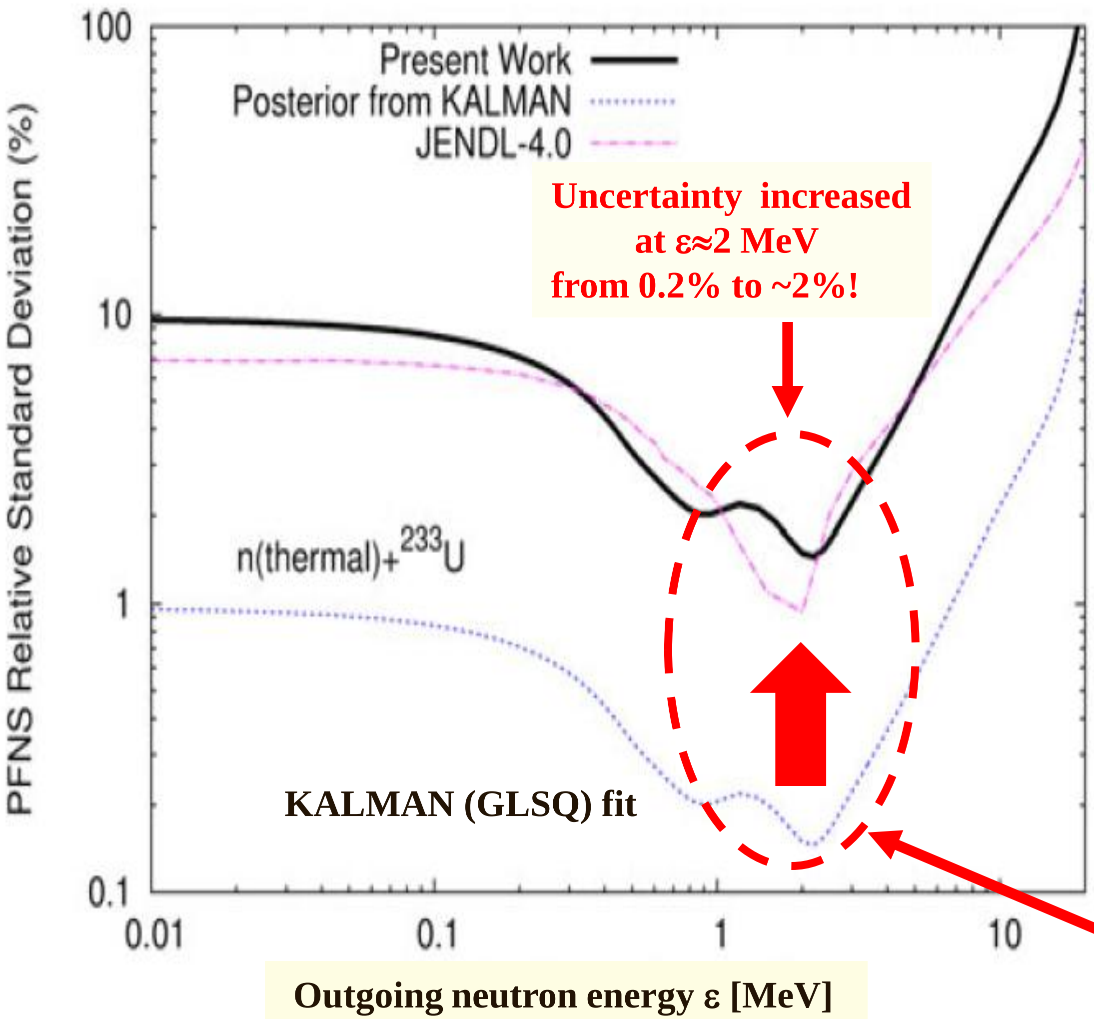
Challenges of PFNS model evaluation (I)



M. Rising, P. Talou, T. Kawano, A.K. Prinja *et al.*, NSE 175 (2013) 81

$$Y(\varepsilon) = \nu\chi(\varepsilon)$$

$$\left(\frac{\delta Y}{Y}\right)^2 = \left(\frac{\delta\nu}{\nu}\right)^2 + \left(\frac{\delta\chi}{\chi}\right)^2$$

$$\frac{\delta\nu}{\nu} = \mathbf{0.3\%}$$

$$\frac{\delta\chi}{\chi}(\varepsilon = 2) = \mathbf{0.2\%}$$

$$\left(\frac{\delta Y}{Y}(\varepsilon = 2)\right) = \mathbf{0.36\ \%}$$

model fit

Model too rigid !!
Too few parameters

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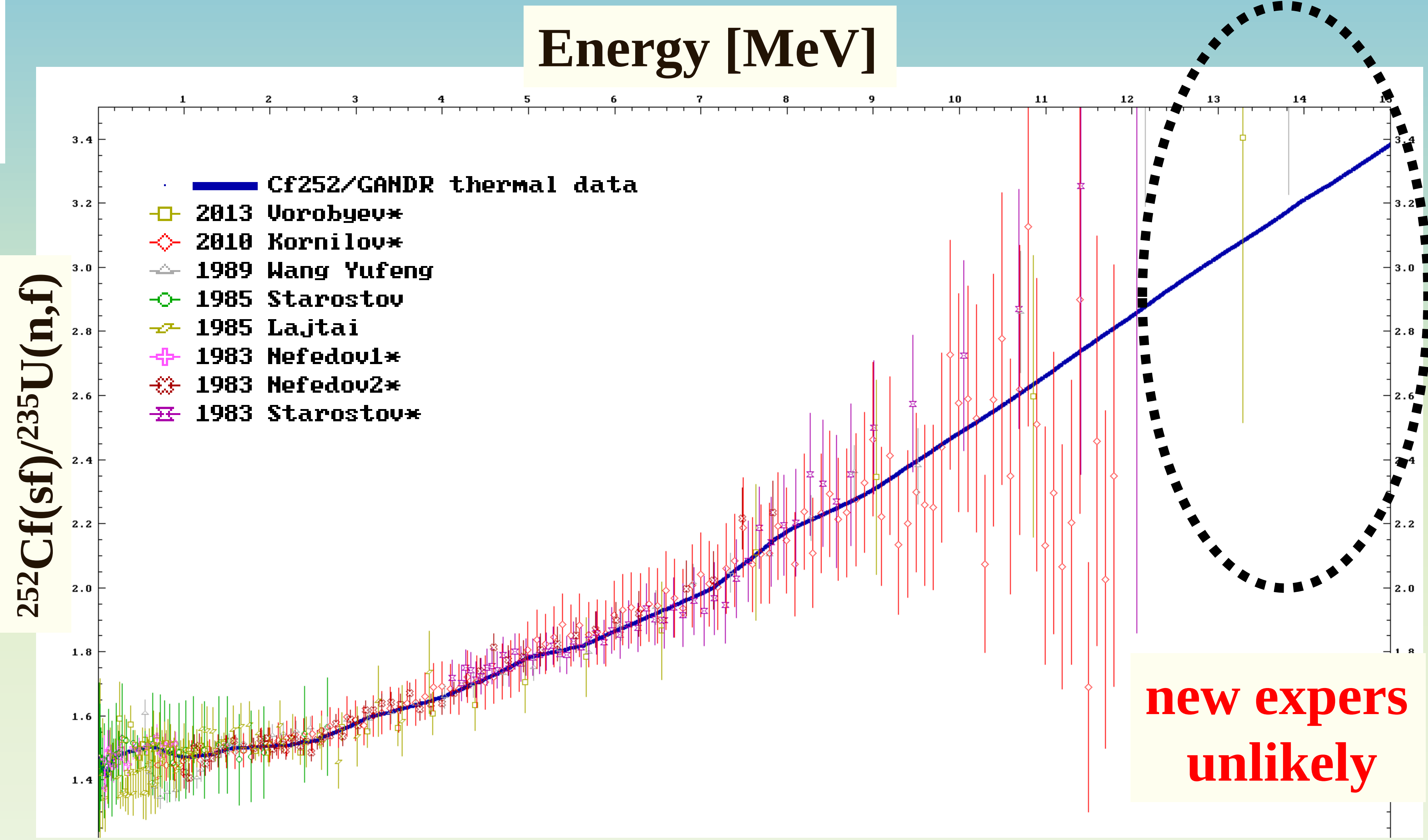
$^{235}U(n_{th},f)$ PFNS GANDR evaluation



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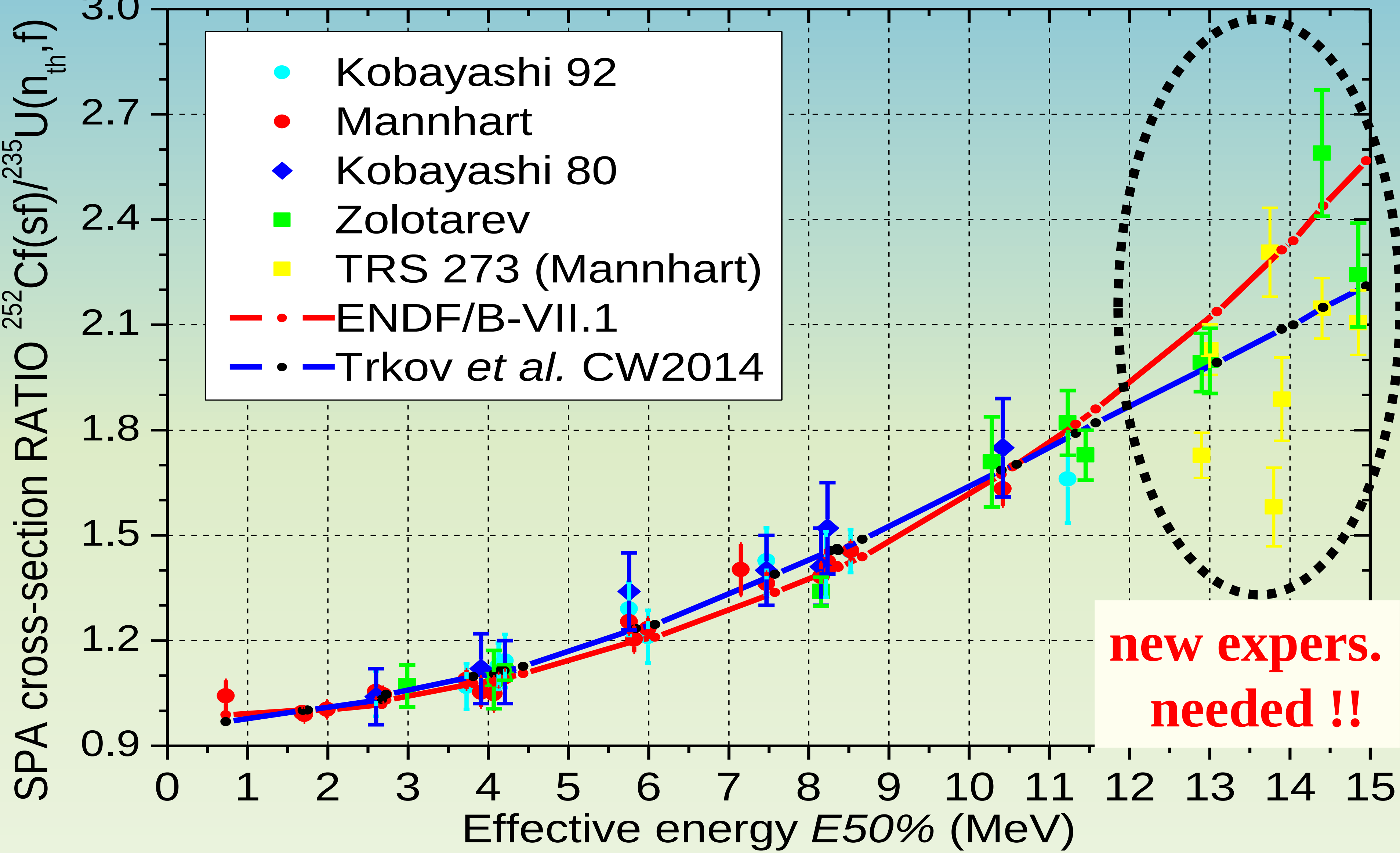
PFNS validation using dosimetry data



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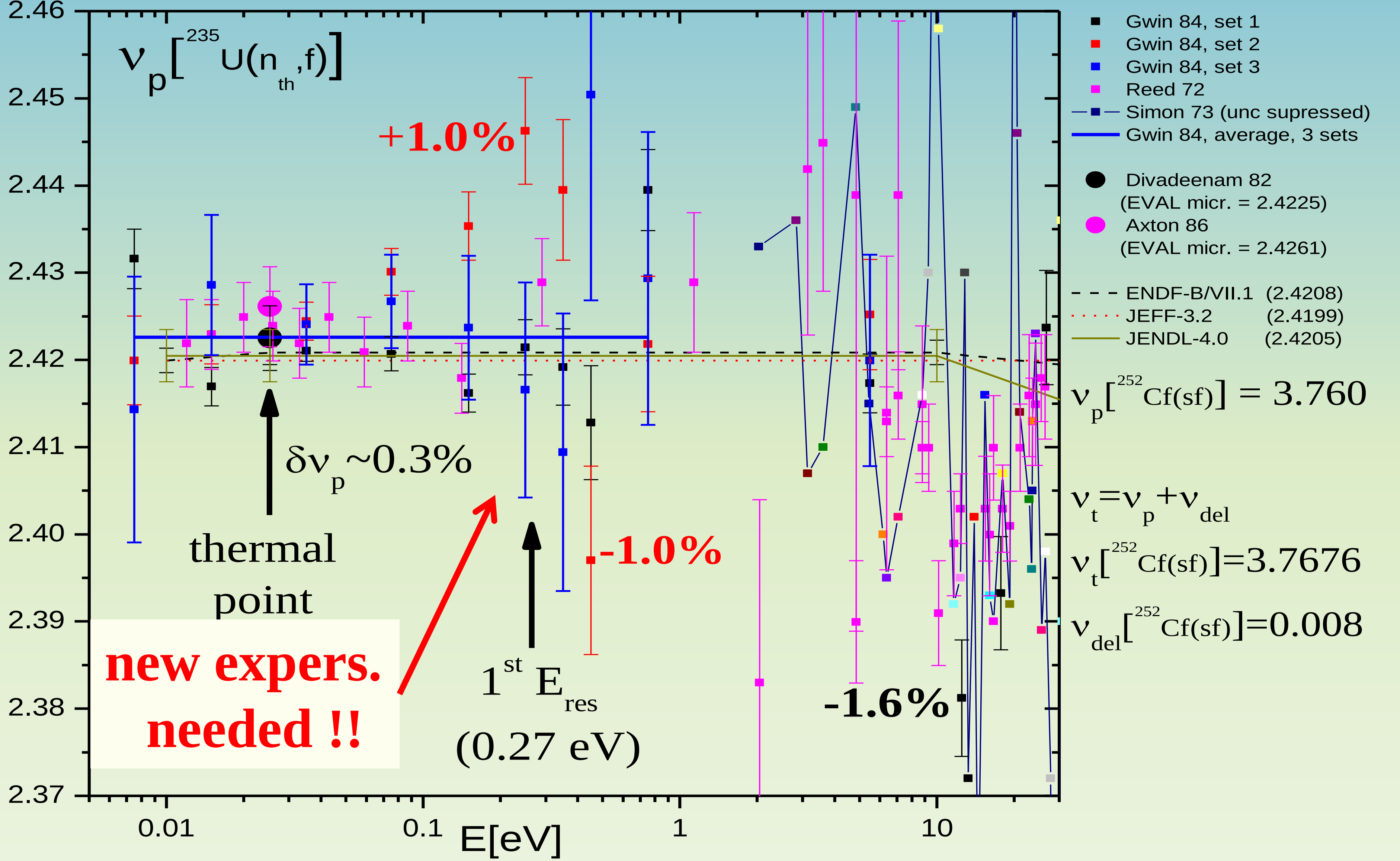
^{235}U nubar fluctuations



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Reaction modelling challenges

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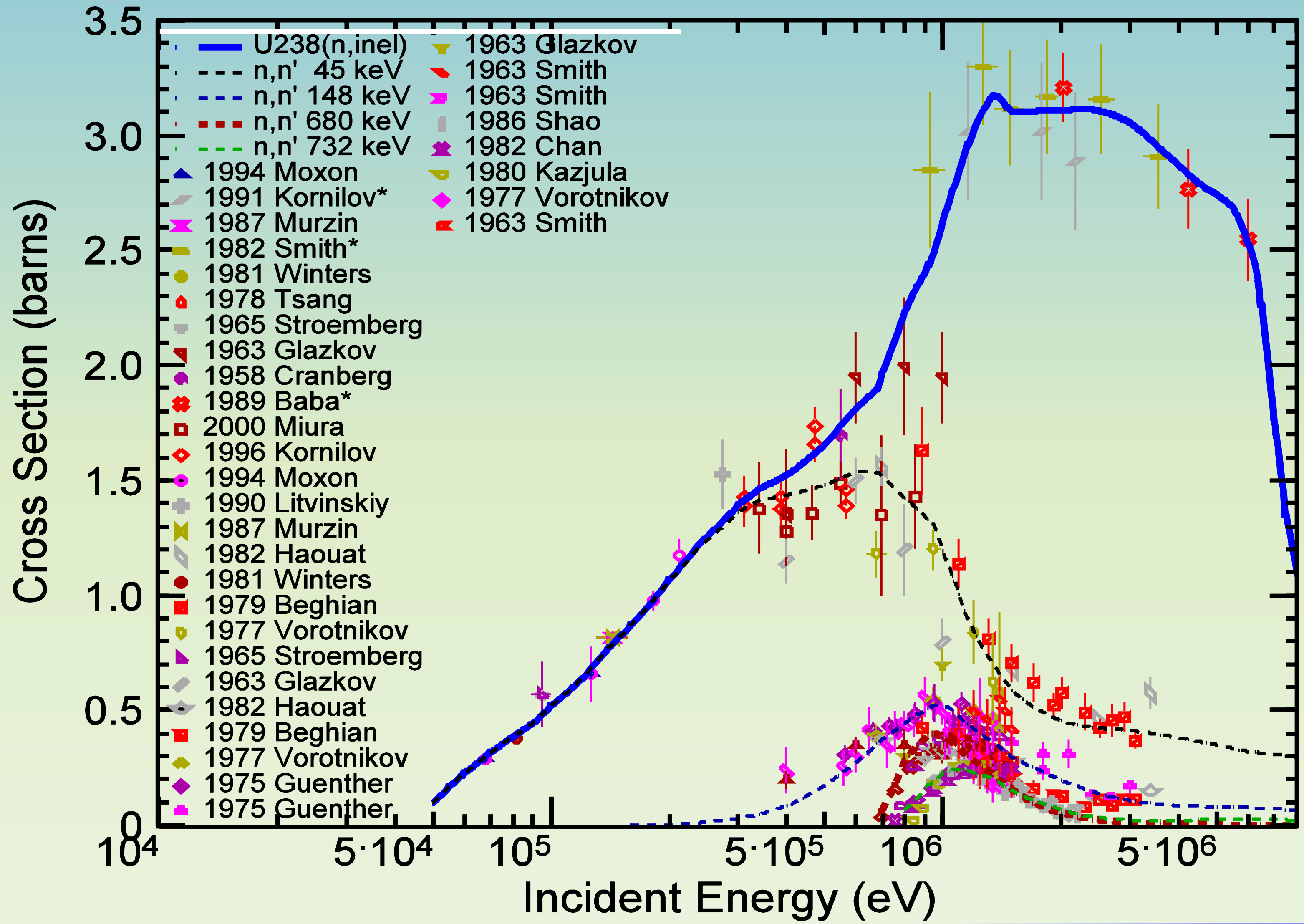
Reaction modelling challenges: (n,inl)

R. C., M. Sin, A. Trkov, M. W. Herman, D. Bernard, G. Noguere, A. Daskalakis, and Y. Danon.
NEMEA-7 proceedings, NEA SG-40 (2014) "Evaluation of neutron induced reactions on ^{238}U nucleus"



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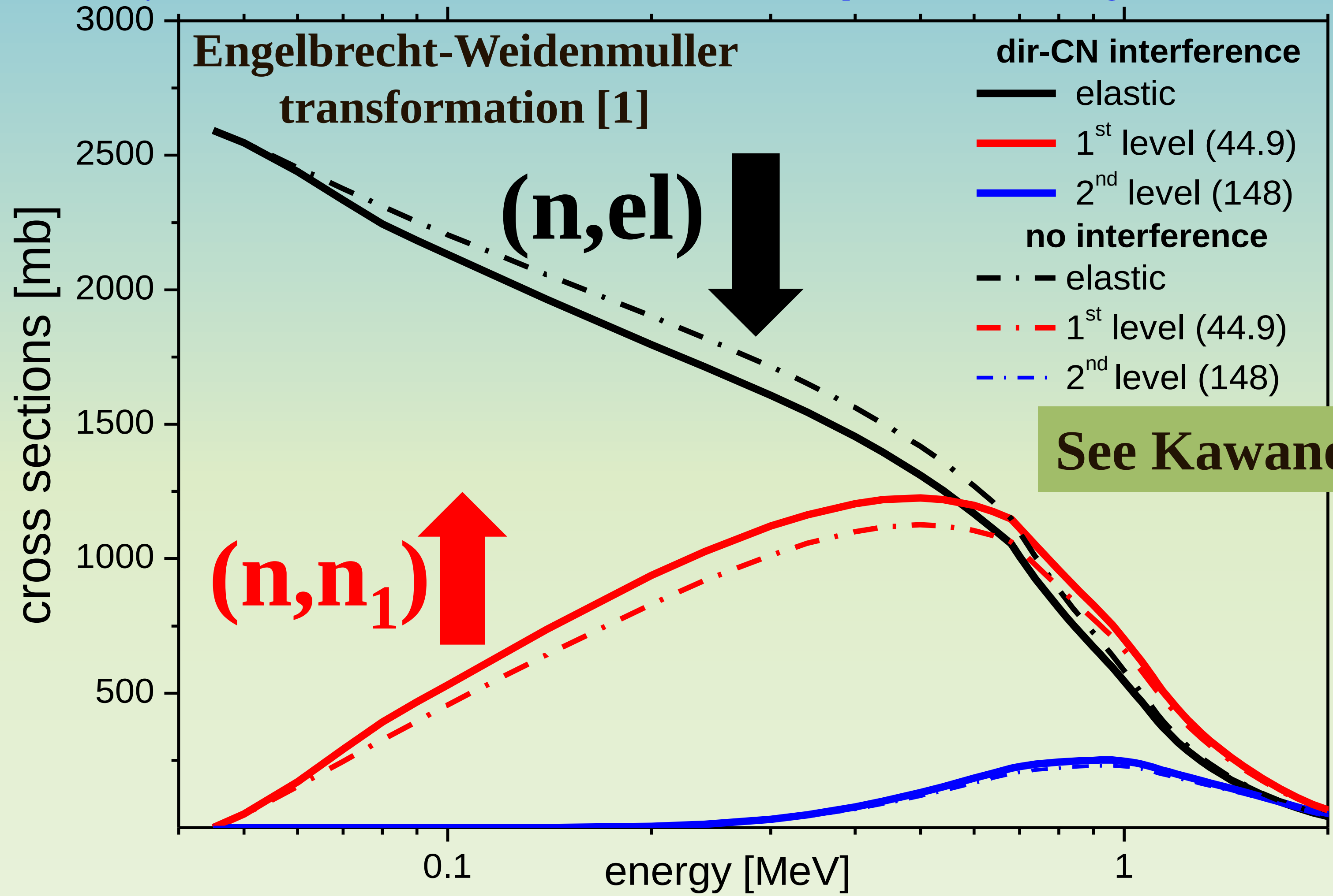
new physics: DIR-CN interference

R. C., A. Trkov, M. Sin, M. Herman, A. Daskalakis, Y. Danon, *Nucl. Data Sheets* ***118*** *(2014) 26-31*
"Physics of Neutron Interactions with ^{238}U: New Developments and Challenges"



See Kawano talk

[1] C.A. Engelbrecht, H.A. Weidenmuller, "Hauser--Feshbach theory and Ericson fluctuations in the presence of direct reactions", Phys.Rev. **C8** (1974) 859-862

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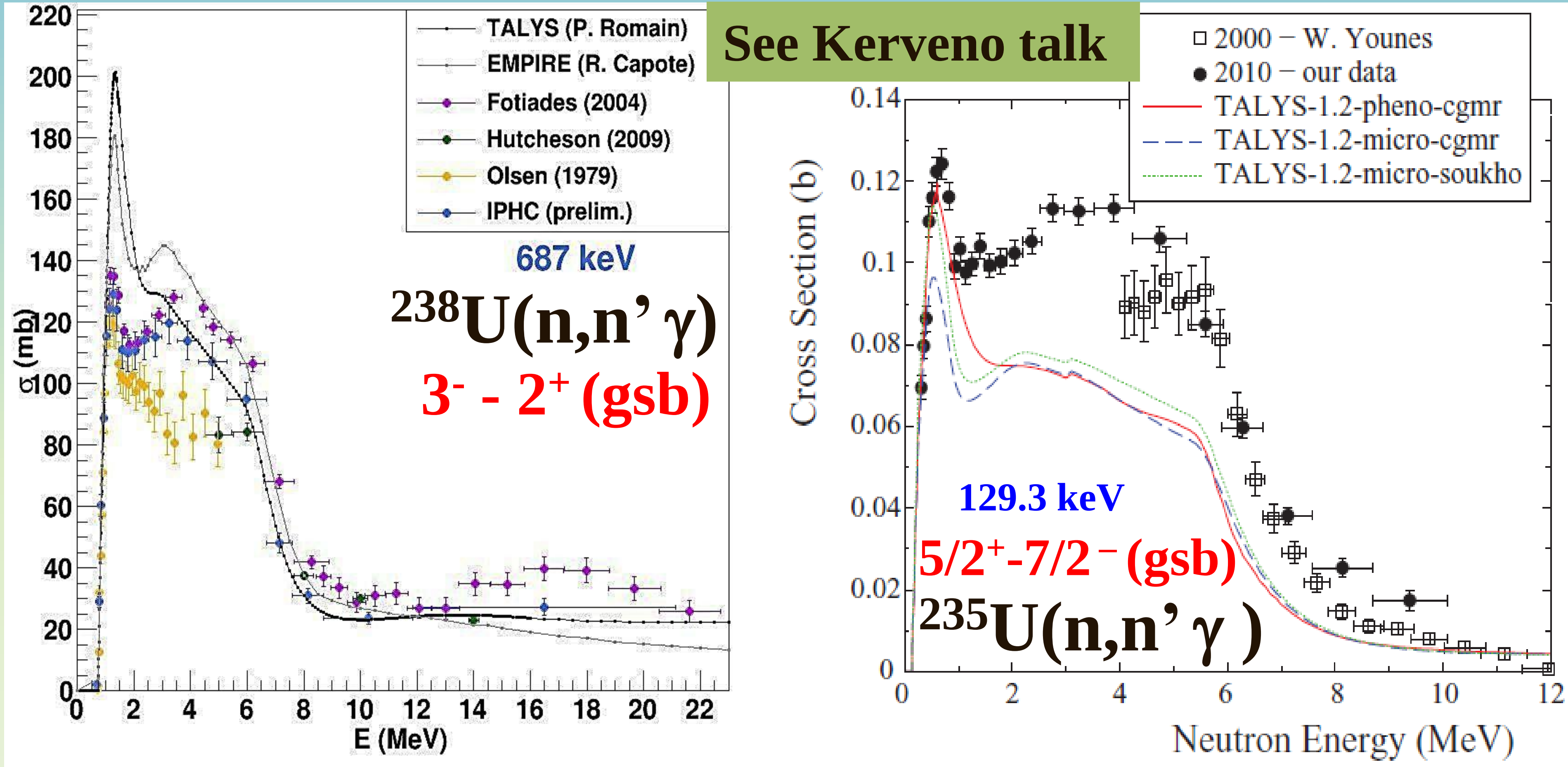
Reaction modelling challenges: (n,n'γ)



Bacquias/Kerveno *et al (prelim., unpublished)* Kerveno *et al*, PRC87(2013) 024609

Better structure models => CC OMP

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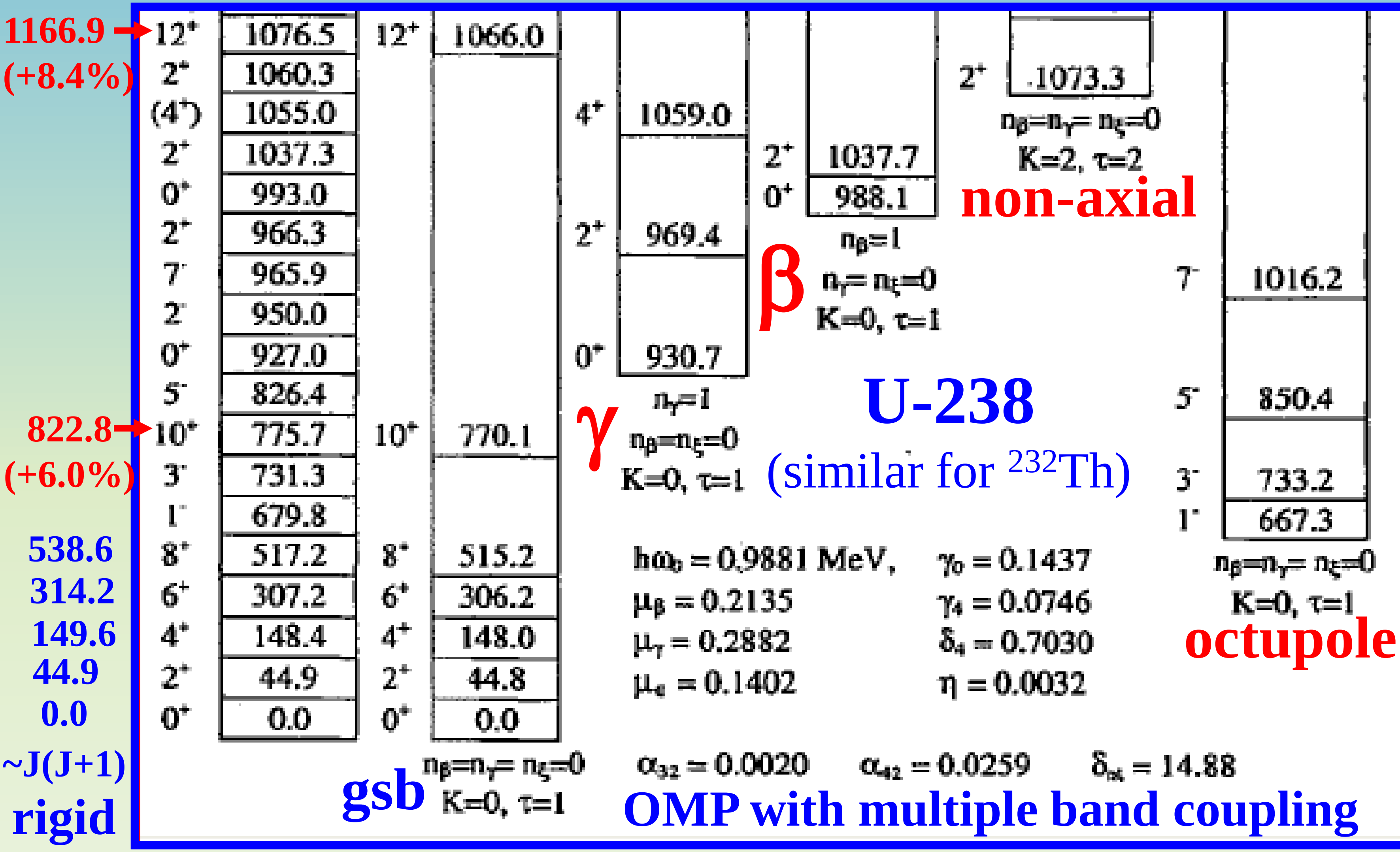
Rigid rotor with soft-rotor (vibr.) corrections



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

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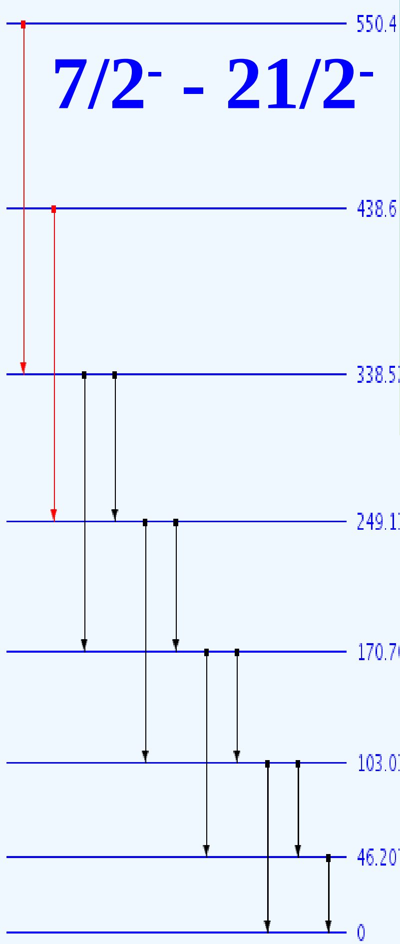
Rigid rotor with soft-rotor corrections
Odd nuclei: multiple-band coupling

^{235}U; 4 coupled bands, 21 coupled levels
DOMP = ^{238}U, different coupling scheme

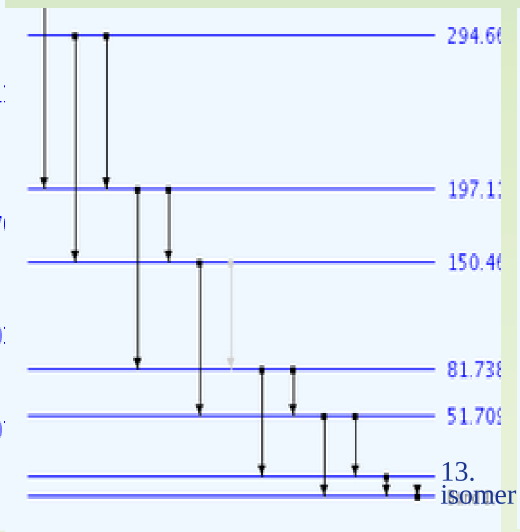
(similar for ^{239}Pu, ^{233}U)

7/2^{-} - 21/2^{-}



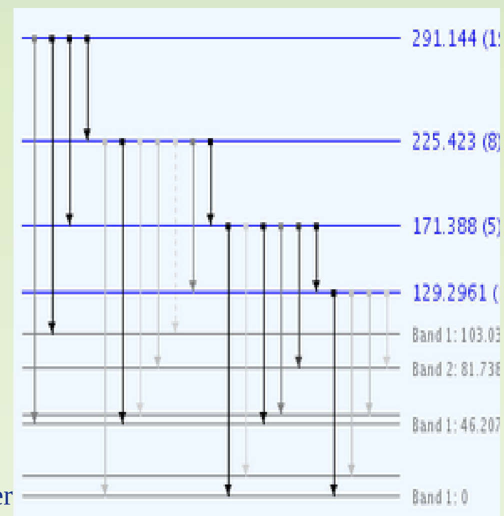
7/2-, gsb

1/2^{+} - 13/2^{+}



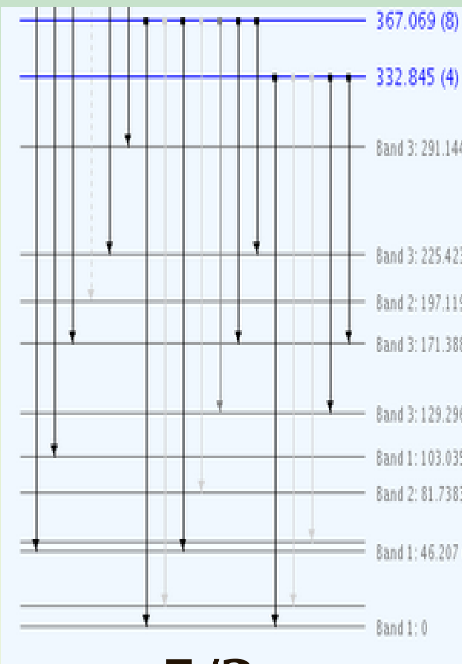
1/2+

5/2^{+} - 11/2^{+}



5/2+

5/2^{+} - 7/2^{+}



5/2+

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Evaluation methodology challenges

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Evaluation Methodology Challenges

1) MC modeling (EMPIRE, TALYS, CCONE, CoH,…) $\{\boldsymbol{\sigma}_\mathbf{i}\}$

2) For each random set $\{\boldsymbol{\sigma}_\mathbf{i}\}$ we calculate $w^{\exp}(\vec{\sigma}_i) = \mathsf{L}(\mathbf{y_E}, \mathbf{V_E} \mid \boldsymbol{\sigma}_\mathbf{i})$

$$\mathsf{L}(\mathbf{y_E}, V_E \mid \boldsymbol{\sigma}_\mathbf{i}) = \exp\{-(½)[(f(\boldsymbol{\sigma}_\mathbf{i}) - \mathbf{y_E})^T \bullet (V_E)^{-1} \bullet (f(\boldsymbol{\sigma}_\mathbf{i}) - \mathbf{y_E})]\}$$

$$\langle \vec{\sigma} \rangle = \frac{\sum_{i=1}^{N} w^{\exp}(\vec{\sigma}_i) \quad \vec{\sigma}_i}{\sum_{i=1}^{N} w^{\exp}(\vec{\sigma}_i)}, \qquad \operatorname{cov}(\vec{\sigma}_i, \vec{\sigma}_j) = \langle \vec{\sigma}_i \vec{\sigma}_j \rangle$$

UMC-B

Unified Monte Carlo

OUTPUT: 1) $\langle \vec{\sigma} \rangle, \quad \operatorname{cov}(\vec{\sigma}_i, \vec{\sigma}_j) = \langle \vec{\sigma}_i \vec{\sigma}_j \rangle$

2) Stochastic set $\{\boldsymbol{\sigma}_\mathbf{i}\}$ (e.g. to be used in TMC)

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Evaluation Methodology Challenges

Alternatives to GLSQ evaluation: **See e.g. Koning talk**

- **MC methods: No covariance generation needed**

- **UMC-B : Solution is obtained as a linear combination of model results**

However:
The solution may not be reproducible by model calculations (additional information is derived from experimental data allowing to overcome potential model defects)

➡ **Go beyond model calculations !**

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Challenges in using integral data

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Challenges in use of integral data

Cross-correlations among “reactions”:

Elastic vs Inelastic (CS&DA) vs PFNS ***in fast assemblies***

ν-bar vs PFNS ***in thermal solutions***

Cross-correlations among isotopes:

- **Big Ten, Flattop-25, Jemima fast critical assemblies**

^{235}U (ν, PFNS, fission, capture) vs

^{238}U (capture, elastic and inelastic)

- **Thermal solutions**

^{235}U, ^{233}U, ^{239}Pu (ν, PFNS, fission, capture) vs

^{16}O & H (elastic)

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Lessons learned on EXFOR compilation

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PFNS @ E_n=500 keV, ANL experiment

Measured: PFNS ratios ^{252}Cf/^{233,235}U; ^{252}Cf/^{239,240}Pu from 0.6-7 MeV

Fully determines the PFNS average energy <E>

Authors never provided the data, only the <E> shift (model dep.) !!

NSE 76, 357 (Dec. 1980)

TECHNI

Note on the Prompt-Fission-Neutron Spectra of Uranium-233 and -235 and Plutonium-239 and -240 Relative to That of Californium-252

A. Smith, P. Guenther, G. Winkler,* and R. McKnight

Argonne National Laboratory, Applied Physics Division
9700 South Cass Avenue, Argonne, Illinois 60439

Received February 4, 1980
Accepted July 1, 1980

ABSTRACT

The prompt-neutron-induced fission spectra of ^{233}U, ^{235}U, ^{239}Pu, and ^{240}Pu were measured relative to the prompt-spontaneous-fission-neutron spectrum of ^{252}Cf. Analysis of the measured values indicates that the incremental average-fission-neutron energies relative to a ^{252}Cf fission-neutron spectrum of Maxwellian form with an average energy of 2.13 MeV are −123 ± 30 (^{233}U), −157 ± 24 (^{235}U), −76 ± 29 (^{239}Pu), and −46 ± 29 (^{240}Pu) keV.

Check EXFOR

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SUMMARY

- ❑ PFNS evaluation challenges:

  New methodology and PFNS models, uncertainty analysis

- ❑ Reaction modelling challenges:

  Use better structure in reaction calculations (e.g. CC OMPs)

- ❑ Evaluation methodology challenges

  Going beyond model calculations (e.g. UMC-B+TMC)

- ❑ Challenges in use of integral data

  Cross-isotope and cross-"reaction" correlations

- ❑ EXFOR compilation challenges

  Authors should provide measured ***(model indep.)*** *quantities (e.g.* ***capture yields*** *not RP,* ***PFNS ratio*** *not the <E> shift)*

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