Final Scientific EFNUDAT Workshop
CERN, Geneva, 30 Aug - 2 Sept 2010

Key issues of pre-equilibrium emission for consistent description of nucleon-induced reactions

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http://www.nipne.ro/research/departments/dfn.php , http://tandem.nipne.ro/~vavrig/
http://cordis.europa.eu/partners-service/, RCN 49105

- **Status of fast-neutron activation analysis for ^{50,52,53,54}Cr isotopes**
  - EFNUDAT Workshop (April 2009): nuclear models calculations @ E_n<60 MeV
    - Global Approach: TALYS-1.0; EMPIRE-2.19
    - Local Approach: STAPRE-H
- Related questions of neutron OMP (April 2009)
- Related questions of proton OMP (April 2009)
- Related questions of E1 gamma-ray strengths functions (April 2009)
- Related questions of nuclear level densities (April 2009)
- **Consistent agreement of calculated activation cross sections: p+^{51}V, n+^{50,52,53,54}Cr**
  - **Shell-correction in p-h state densities @ GDH PE-model**
- **Conclusions**

Former comparison of measurements and local calculations for ^{50,52}Cr

Z. Phys. A – Atomic Nuclei 335, 299–313 (1990)

20 years ago

Zeitschrift für Physik A
Atomic Nuclei

Nuclear Level Densities Below 40 MeV Excitation Energy in the Mass Region $A \simeq 50$

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Received May 22, 1989; revised version July 25, 1989

Consistent pre-equilibrium emission and statistical model calculations of fast neutron induced reaction cross sections are used to validate nuclear level densities for excitation energies up to 40 MeV in the mass region $A \simeq 50$. A "composed" level density approach has been employed by using the back-shifted Fermi gas model for excitation energies lower than 12 MeV and a realistic analytical formula for higher excitations. In the transition region from the BSFG model range to that of full applicability of the realistic formula, an interpolation between the predictions of the two models is adopted. The interpolation rule, suggested by microscopic level density calculations, has been validated through the comparison of the calculated and experimental cross sections.

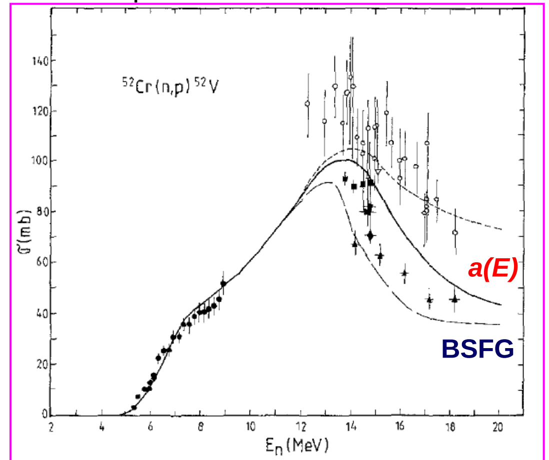

Fig. 7. Comparison of experimental and calculated cross sections of the reaction: ^{52}Cr(n, p)^{52}V. The curves shown have the same significance as in Fig. 6. Experimental data: ○ [58], ▽ [59], △ [60],

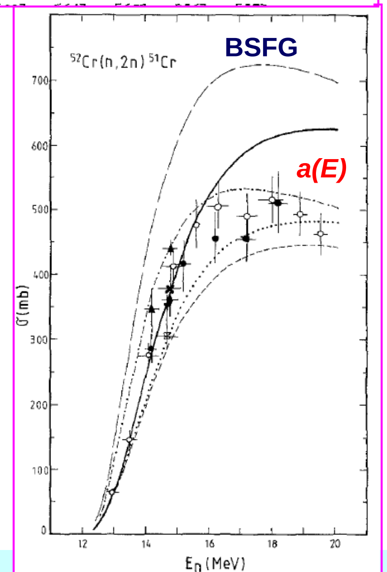

Fig. 9. Same as Fig. 6, for the reaction ^{52}Cr(n, 2n)^{51}

Systematic analysis of *n*-activation for ^{50,52}Cr isotopes (2/4)

Excitation functions of $(n,2n)$, (n,p), $(n,np+pn+d)$, and (n,α) reactions on isotopes of chromium

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[2]Commission of the European Communities, Joint Research Centre, Institute for Reference Materials and Measurements, B-2440 Geel, Belgium
[3]Argonne National Laboratory, Technology Development Division, Argonne, Illinois 60439

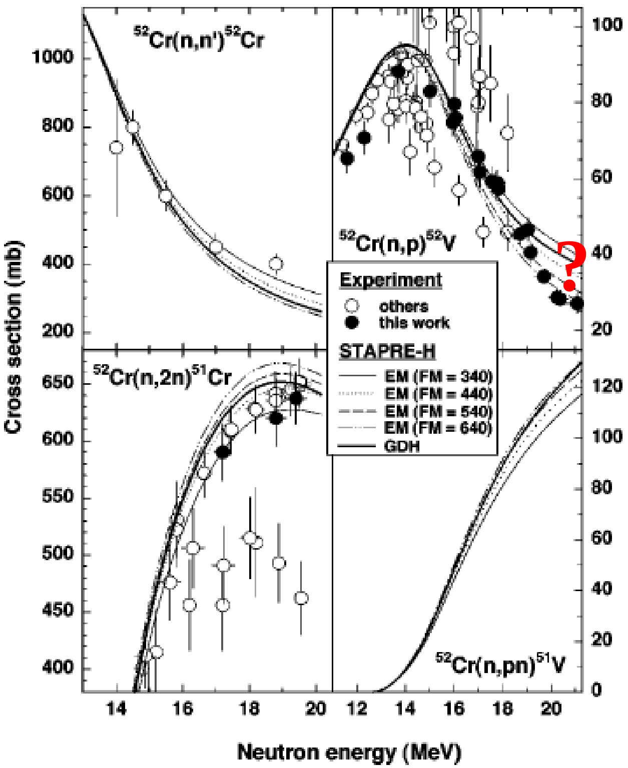

FIG. 8. Influence of the F_M parameter in the exciton mod[el on] the excitation functions of different reactions on ^{52}Cr, and com[pari]son with the results of the GDH model.

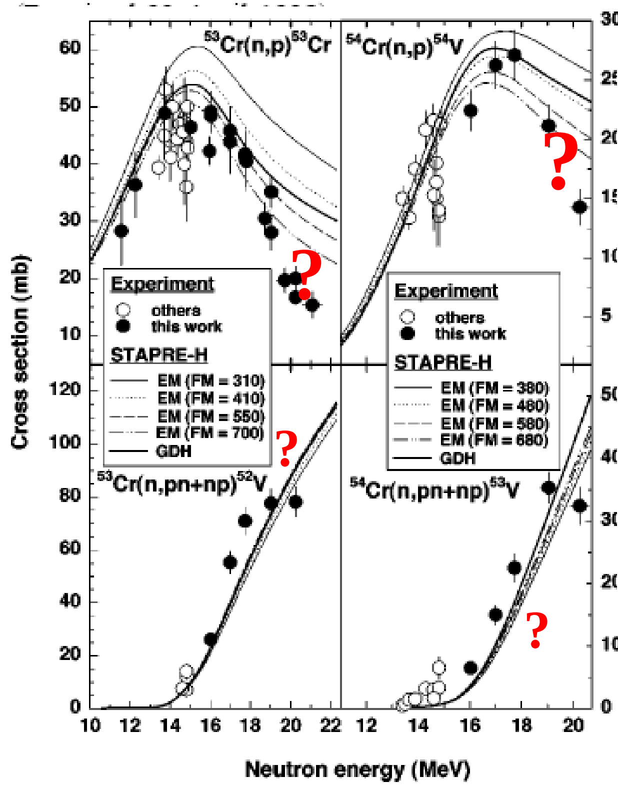

FIG. 9. Influence of the F_M parameter in the exciton mo[del on] the excitation functions of different reactions on ^{53}Cr and ^{54}C[r, and] comparison with the GDH model.

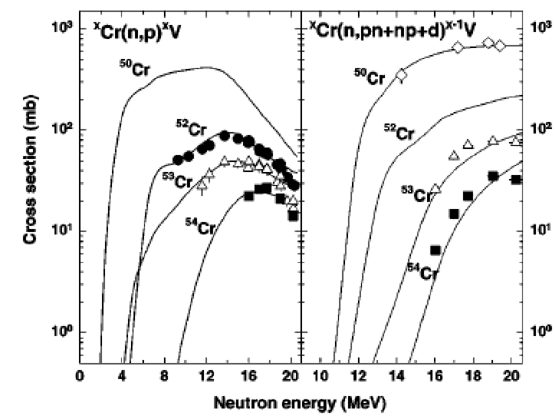

FIG. 10. Systematics of excitation functions of (n,p) and $(n,pn+np+d)$ reactions on Cr isotopes. The symbols represent the experimental data points of this work, the solid lines the STAPRE-H calculations. The data points for the ^{50}Cr$(n,pn+np+d)^{49}$V process were taken from a recent measurement [67].

[21] M. Avrigeanu and V. Avrigeanu, "Recent Improvements of the STAPRE-H Preequilibrium and Statistical Model Code," Report No. NP-86-1995, IPNE, Bucharest, Romania, 1995.
[27] V. Avrigeanu, P. E. Hodgson, and M. Avrigeanu, Phys. Rev. C 49, 2136 (1994).
[30] M. Avrigeanu, A. Harangozo, and V. Avrigeanu, "Surface effects in Feshbach-Kerman-Koonin analysis of (n,n') and (n,p) reactions at 7 to 26 MeV," Report No. NP-85-1995, IPNE, Bucharest, Romania, 1995.
[33] M. Avrigeanu and V. Avrigeanu, J. Phys. G **20**, 613 (1994).
[34] M. Avrigeanu, M. Ivascu, and V. Avrigeanu, Z. Phys. A **335**, 299 (1990).

ELSEVIER Nuclear Physics A 748 (2005) 75–111

Systematic analysis of *n*-activation for $^{50,52}Cr$ isotopes

Calculations and analysis of n + $^{50,52,53,54}Cr$ reactions in the $E_n \leqslant 250$ MeV energy range

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Available online 11 November 2004

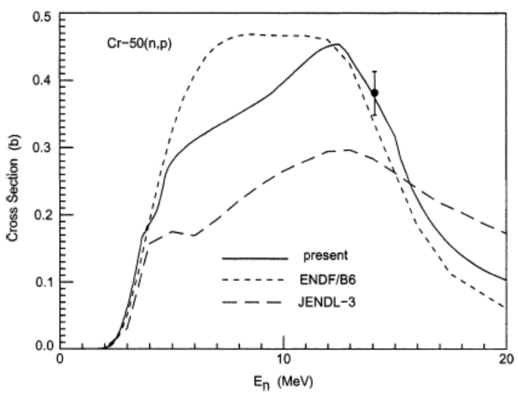


Fig. 22. Calculated (n, p) reaction cross section (solid line) compared with experimental data (syr
evaluated data (ENDF/B6 and JENDL-3 libraries) for n + ^{50}Cr reaction.

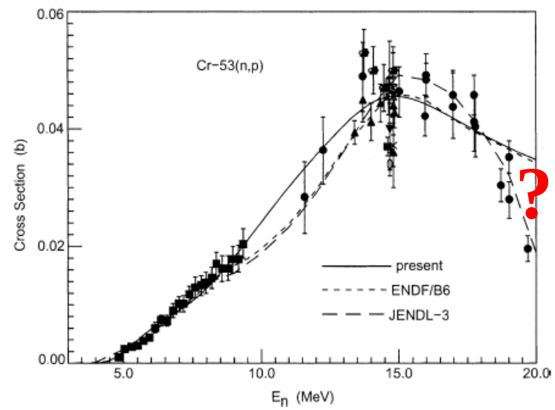


Fig. 24. Calculated (n, p) reaction cross section (solid line) compared with experimental data (
evaluated data (ENDF/B6 and JENDL-3 libraries) for n + ^{53}Cr reaction.

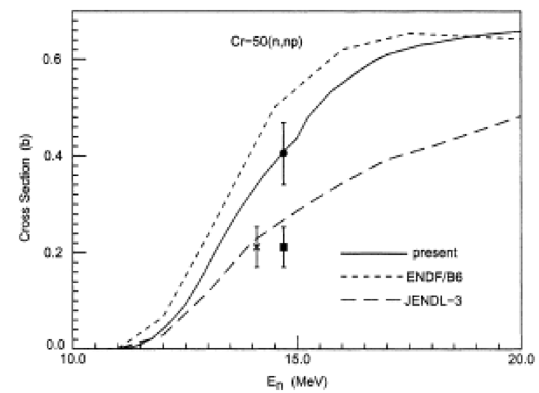


Fig. 28. Calculated (n, np) reaction cross section (solid line) compared with experimental data (
evaluated data (ENDF/B6 and JENDL-3 libraries) for n + ^{50}Cr reaction.

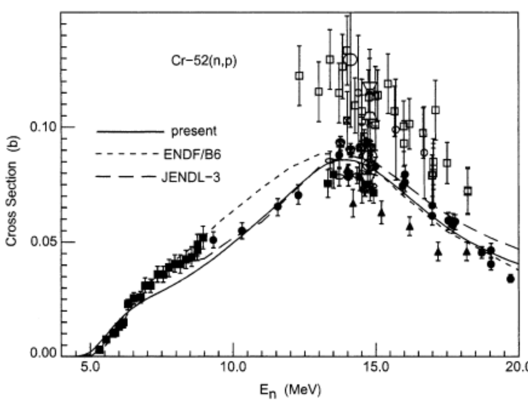


Fig. 23. Calculated (n, p) reaction cross section (solid line) compared with experimental data
evaluated data (ENDF/B6 and JENDL-3 libraries) for n + ^{52}Cr reaction.

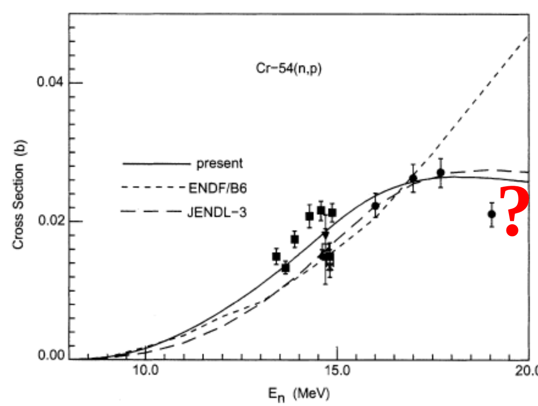


Fig. 25. Calculated (n, p) reaction cross section (solid line) compared with experimental data (
evaluated data (ENDF/B6 and JENDL-3 libraries) for n + ^{54}Cr reaction.

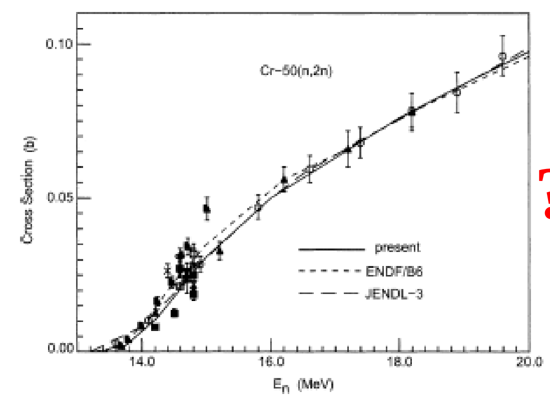


Fig. 29. Calculated (n, 2n) cross sections (solid line) compared with experimental data (symbols) a
data (ENDF/B6 and JENDL-3 libraries) for n + ^{50}Cr reaction.

Original comparison of measurements and EMPIRE v. 2.18 results for ^{52}Cr

[M. Hermann et al., EMPIRE-II v.2.18, p. 171-172; http://www-nds.iaea.org/empire/]

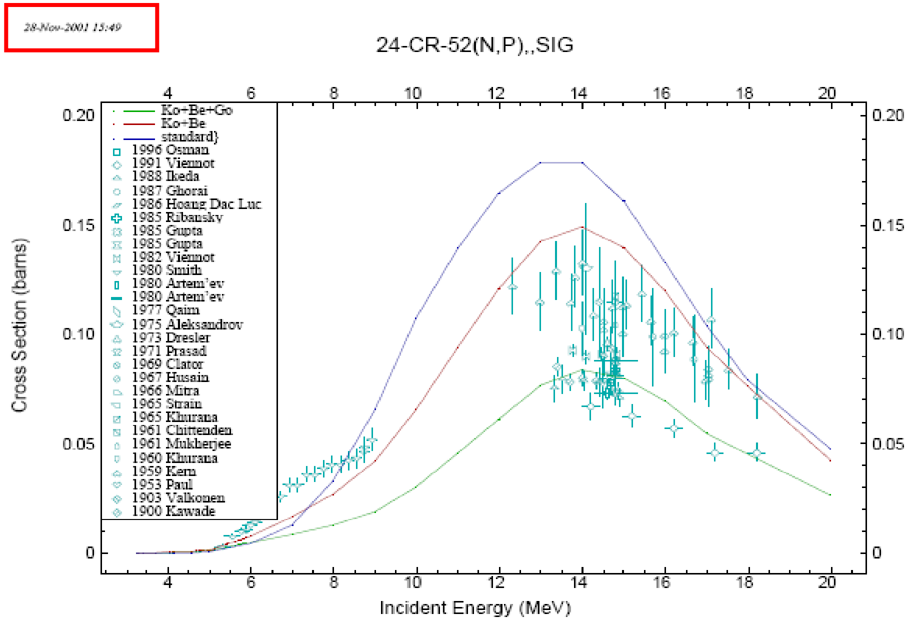


Figure 4.4: Comparison of experimental data with results calculated using three sets of parameters for the ^{52}Cr(n,p) reaction (see text).

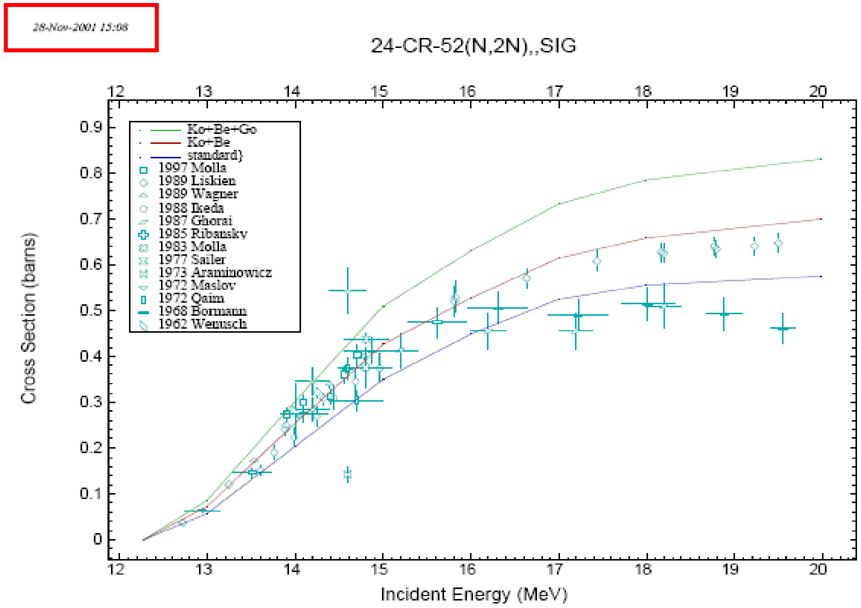
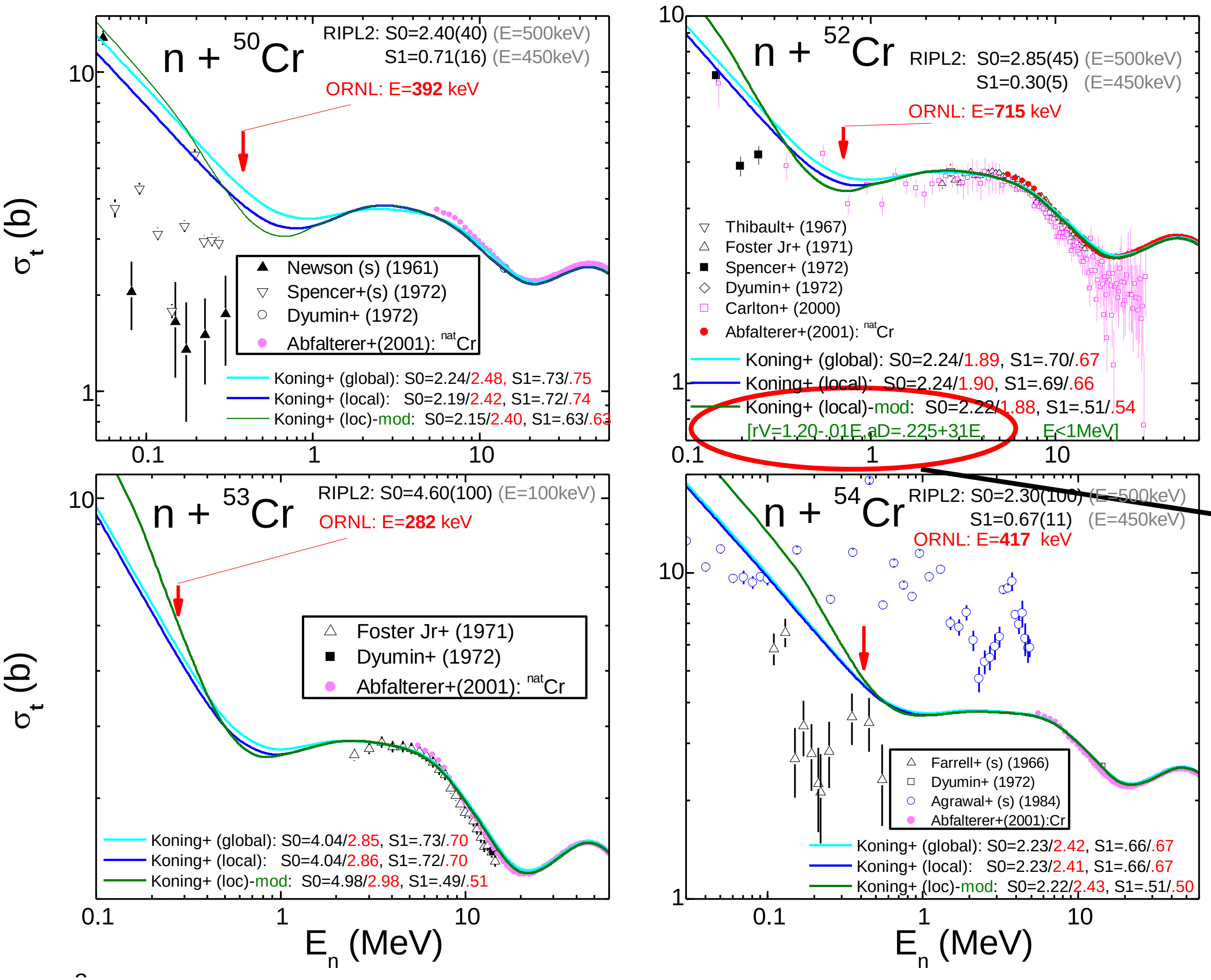


Figure 4.3: Comparison of experimental data with results calculated using three sets of parameters for the ^{52}Cr(n,2n) reaction (see text).

where:

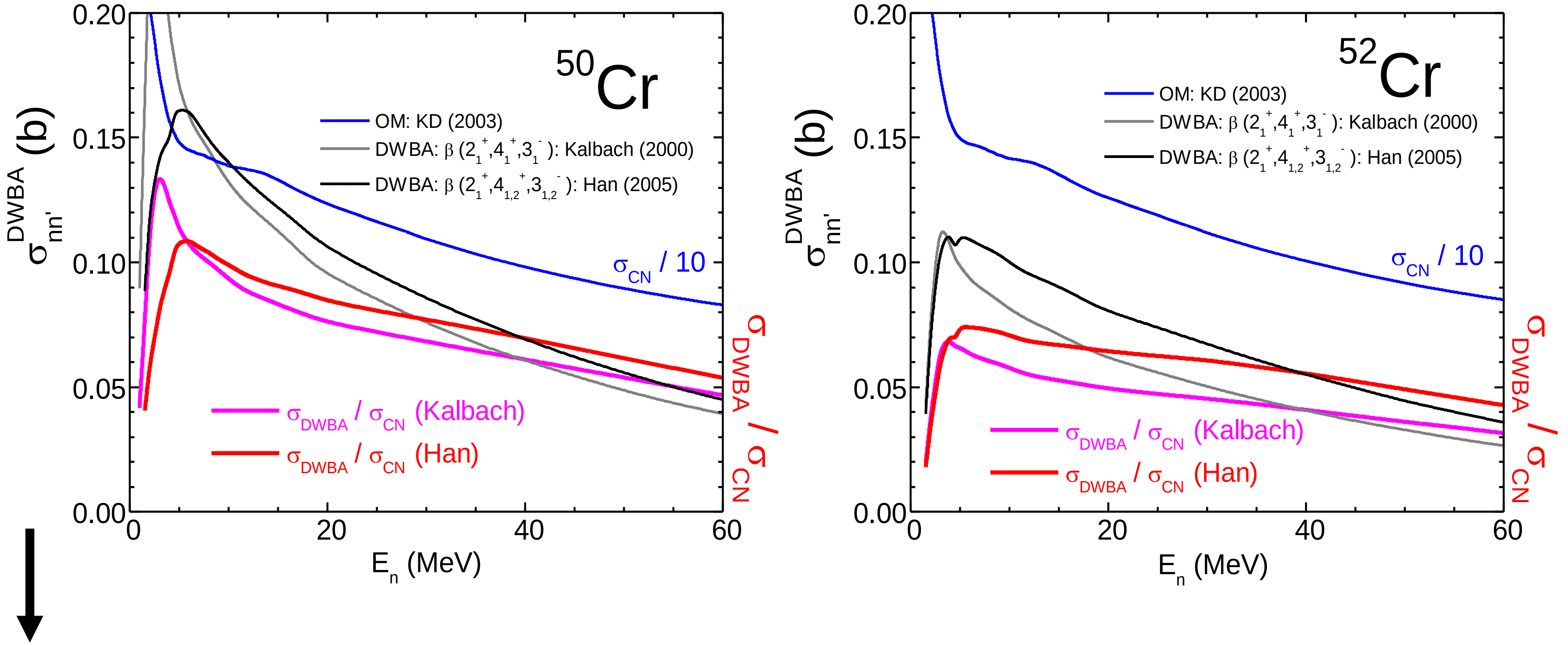
standard	Wilmore-Hodgson S-OMP for neutrons and Becchetti-Greenlees for protons, EMPIRE-specific level densities with internal systematics, and discrete levels up to $N_{max} = 10$ (note that in EMPIRE-2.19 Koning-DeLaroche potential is a standard),
Ko-Be	Koning-DeLaroche S-OMP for neutrons and protons, discrete levels up to the N_{max} recommended by RIPL-2 (limited to 40 by the ENDF-6 format), and EMPIRE-specific level densities,
Ko-Be-Go	as above but using HF-BCS microscopic level densities[53] instead of the EMPIRE-specific ones.

Comparison of calculated and experimental neutron total cross sections for $^{50,52,53,54}Cr$



σ_t decrease of ~7% at $E_n \le 1$ MeV

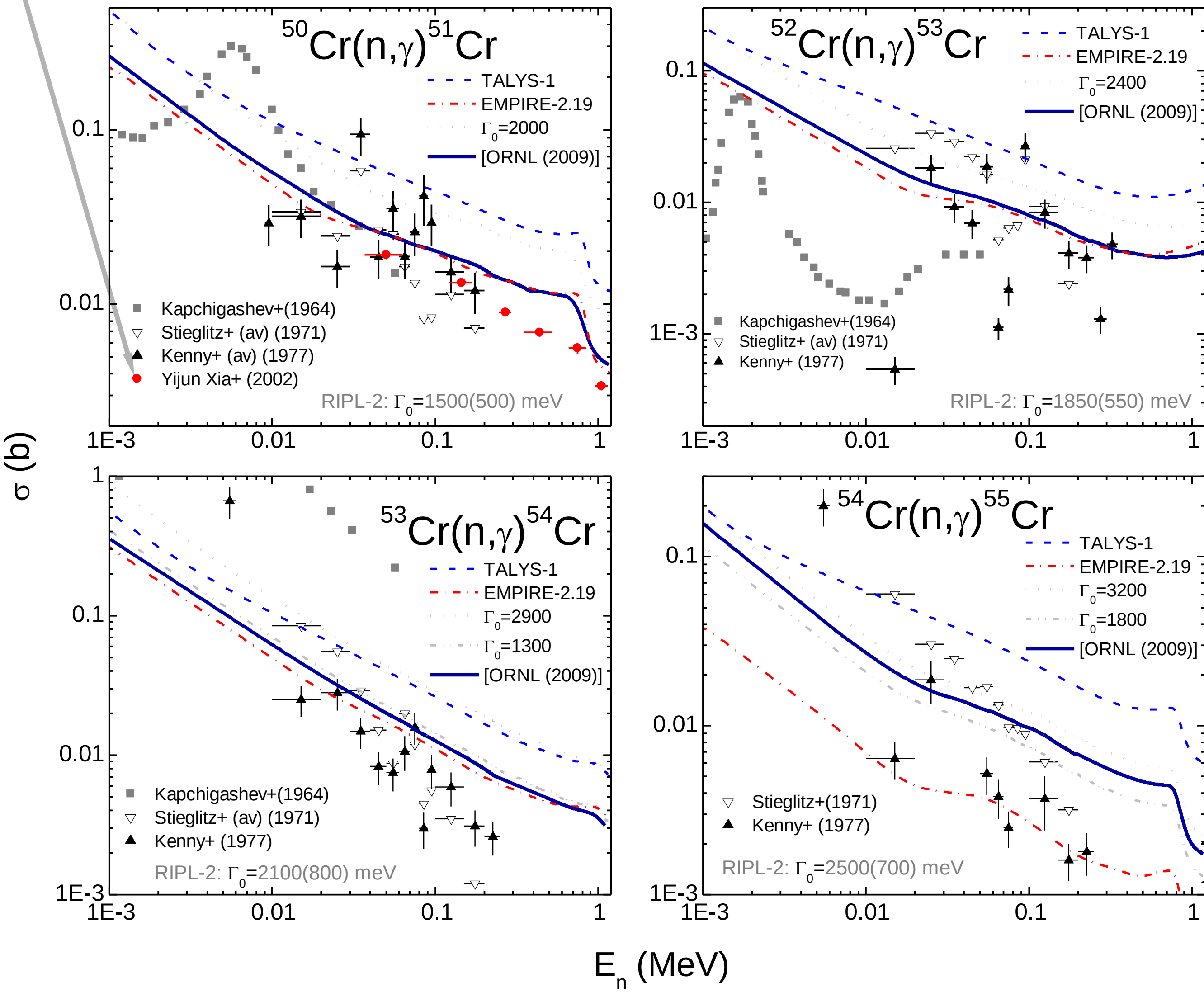
Direct inelastic scattering cross sections by using the same OMP within the DWBA method, for $^{50,52}Cr$



Direct Interaction: - as large as ~11% for ^{50}Cr and ~7% for ^{52}Cr, from σ_{CN}
- decreasing with the energy by ~50% up to 60 MeV

Gamma-ray Strength Functions $f_{E1}(E_\gamma)$ based on comparison of measured/calculated (n,γ) cross sections: $^{50,52,53,54}Cr$

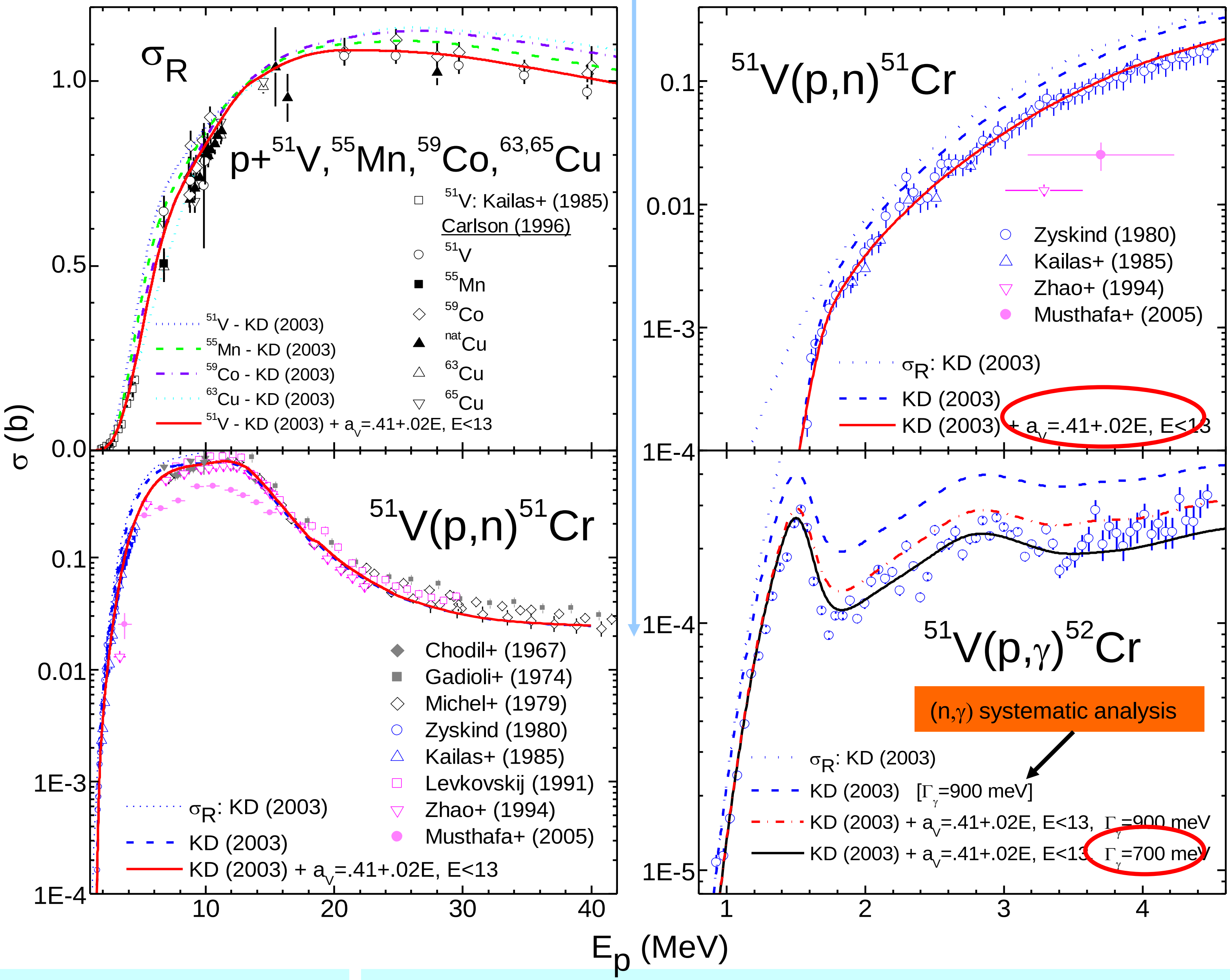
more recent data (2002)



+ EDBW Model (D.G. Gardner, 1982)

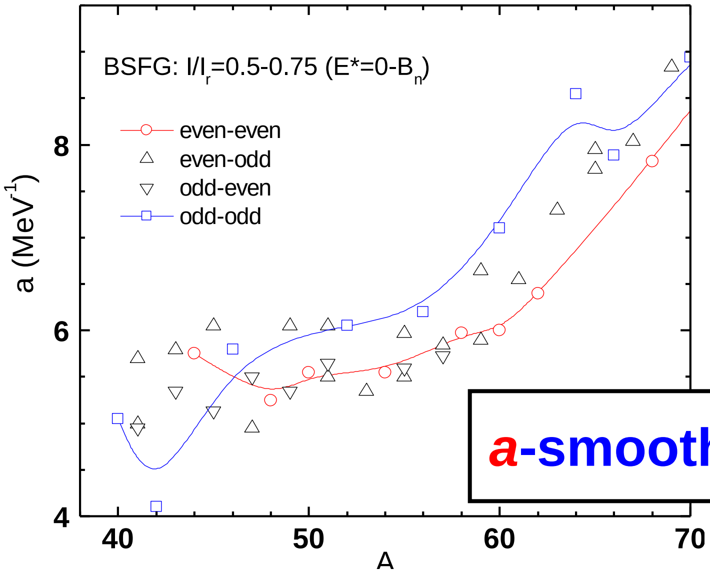
RIPL-2 upper/lower limits

Consistent proton-OMP (PE) validation: σ_R, (p,γ) & (p,n) reactions analysis



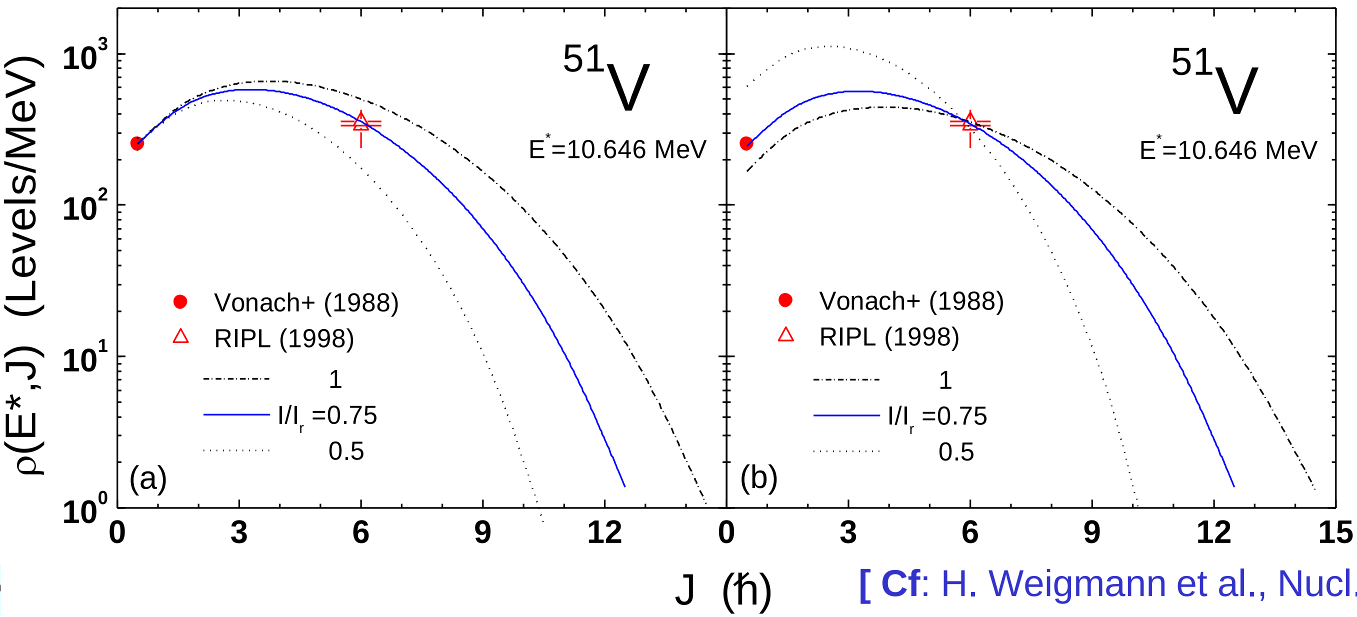
Level density parameter systematics (E*<15 MeV)

[*J. Nucl. Sci. Tech. S2, 746 (2002)*
Nucl. Phys. A730, 255 (2004)
http://tandem.nipne.ro/~vavrig/]



a-smooth curve method → **Δ-values for nuclei without resonance data**

I/Ir=0.75: describe both **neutron (RIPL-2)** and **proton** *s*-wave resonance spacings:



[**Cf**: H. Weigmann et al., Nucl. Phys. **A368**,117(1981)]

Level density parameters @ E*>15 MeV:

***a(E*)*:** A.V. Ignatyuk *et al.*, Yad.Fiz. **2**, 485(1975)
A.R. Junghans *et al.,* Nucl. Phys. **A629**, 635 (1998)
A.J. Koning and M.B. Chadwick, Phys. Rev. C **56**, 970 (1998)

Transition range from BSFG: 12 – 25-50 MeV [M. Avrigeanu *et al.,* Z. Phys. **A335**, 299 (1990)]
F. Puhlhofer, Nucl. Phys. **A280**, 267 (1977): CASCADE
M.J. Canty et al., Nucl. Phys. **A317**, 495 (1979): Shell Model

2.C: 2.N

Nuclear Physics A317 (1979) 495–510; © *North-Holland Publishing Co., Amsterdam*

SHELL MODEL LEVEL DENSITIES IN EVAPORATION CALCULATIONS

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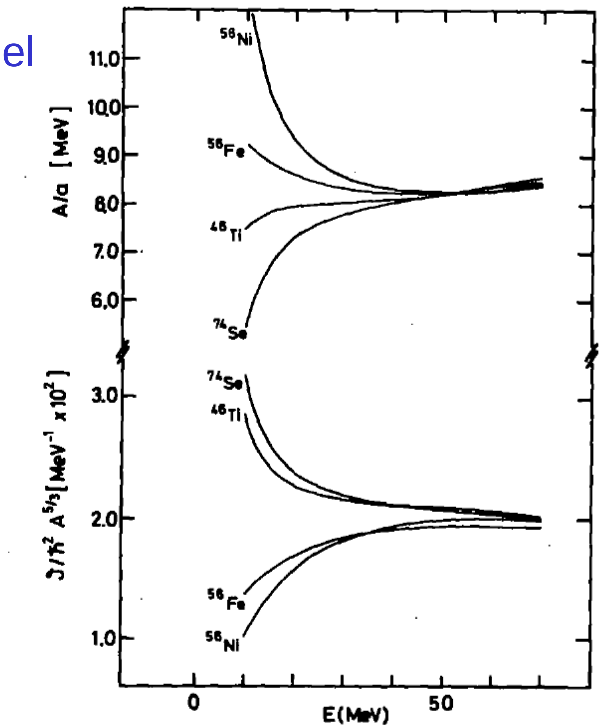
Received 20 October 1978

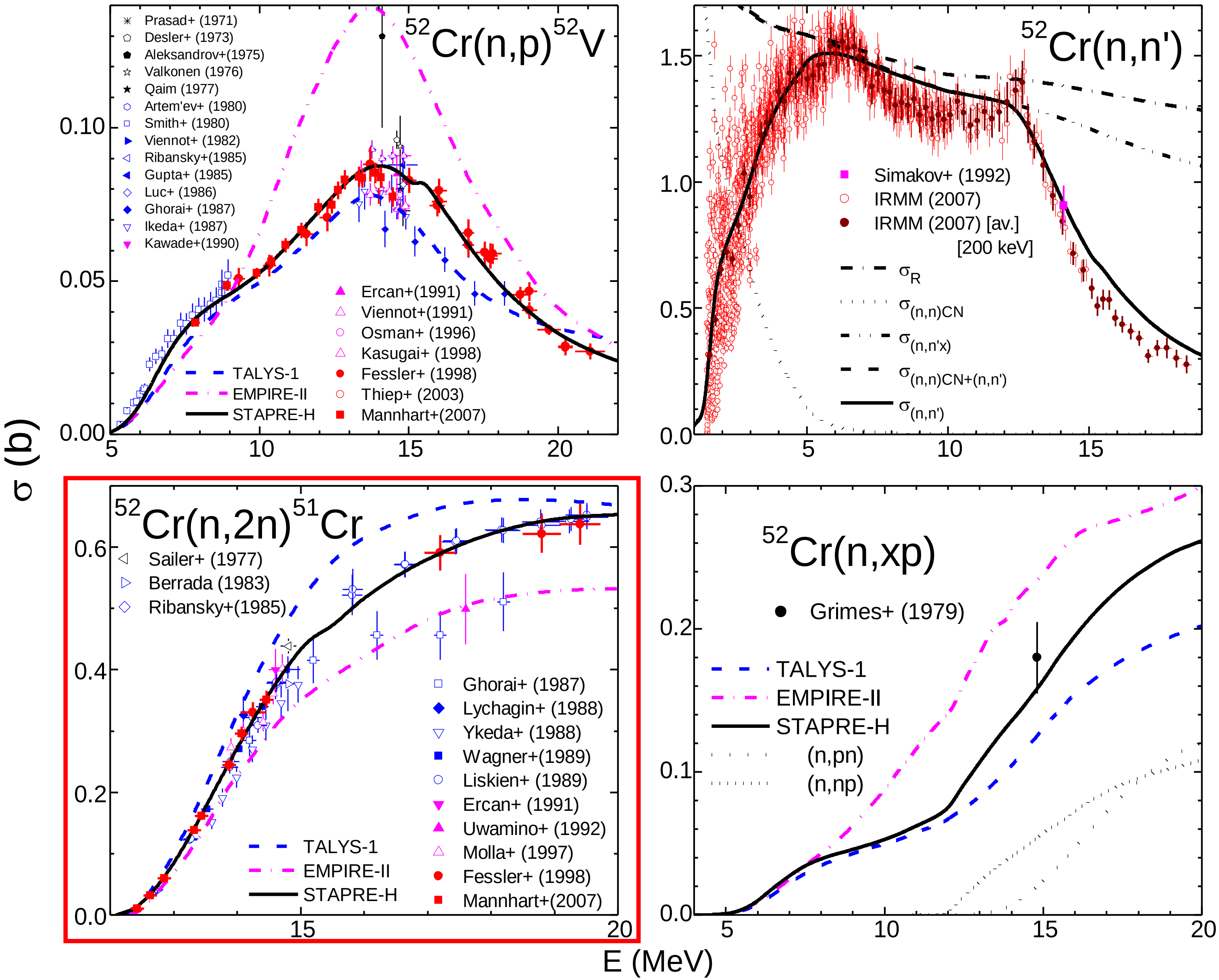
Abstract: The energy and spin dependence of nuclear level densities are calculated from realistic shell model potentials in the saddle point approximation. Effective Fermi gas level density parameters are extracted and their behaviour as a function of nucleon number, excitation energy and angular momentum is examined. Evaporation residue distributions following heavy ion induced fusion reactions leading to compound nuclei near doubly magic ^{56}Ni are predicted from Hauser-Feshbach theory with the shell model level densities. Good agreement with experimental residue cross sections is obtained, provided nuclear deformation is included.



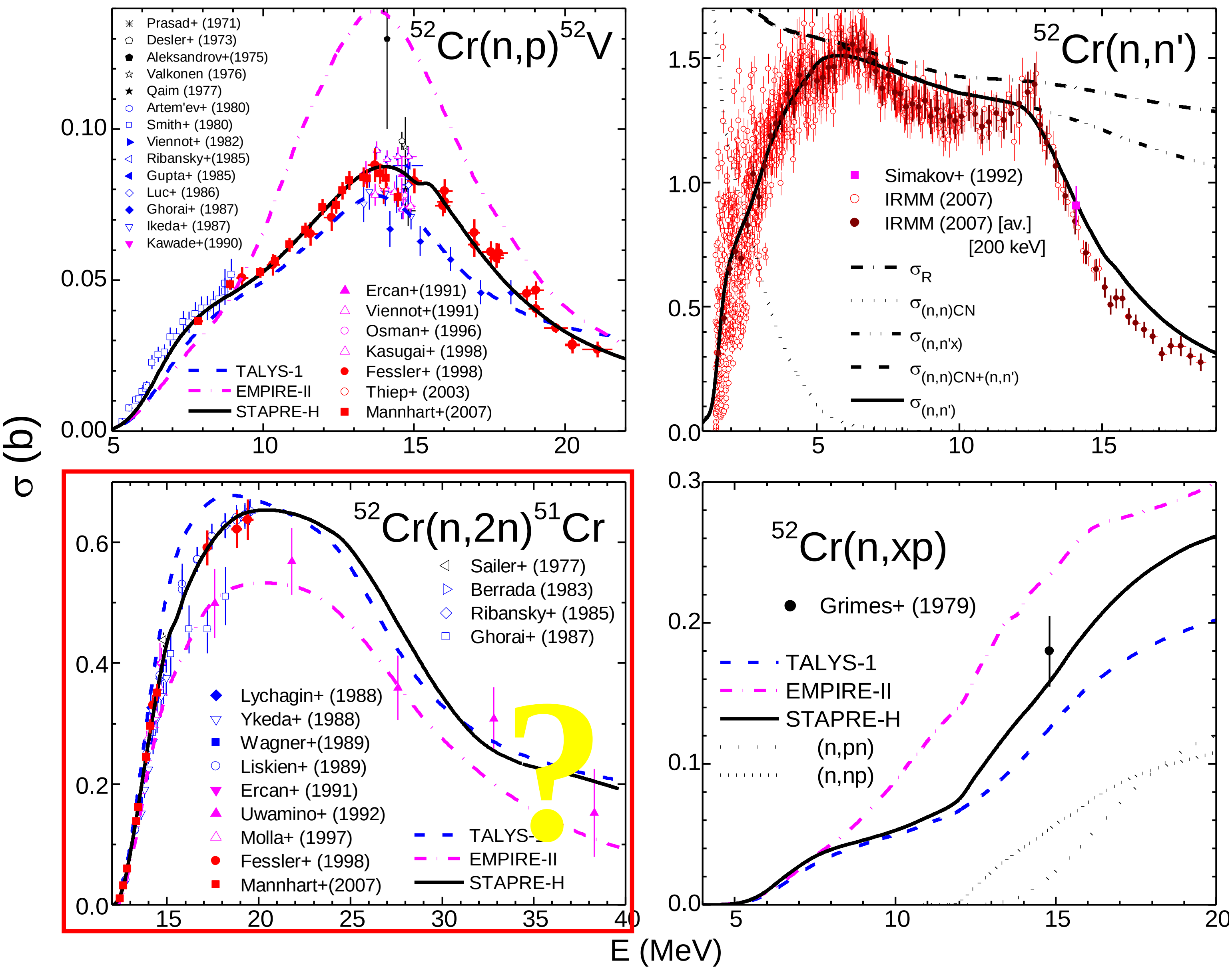
Energy dependence of the level density and moment of inertia parameters systems. The same single particle levels were used as in fig. 1

Comment: A. Fessler, PhD Thesis, Jul-3503,1998,p.106:
"*transition … appears to be unjustified… since there are no experimental data available between 20 and 50 MeV*"

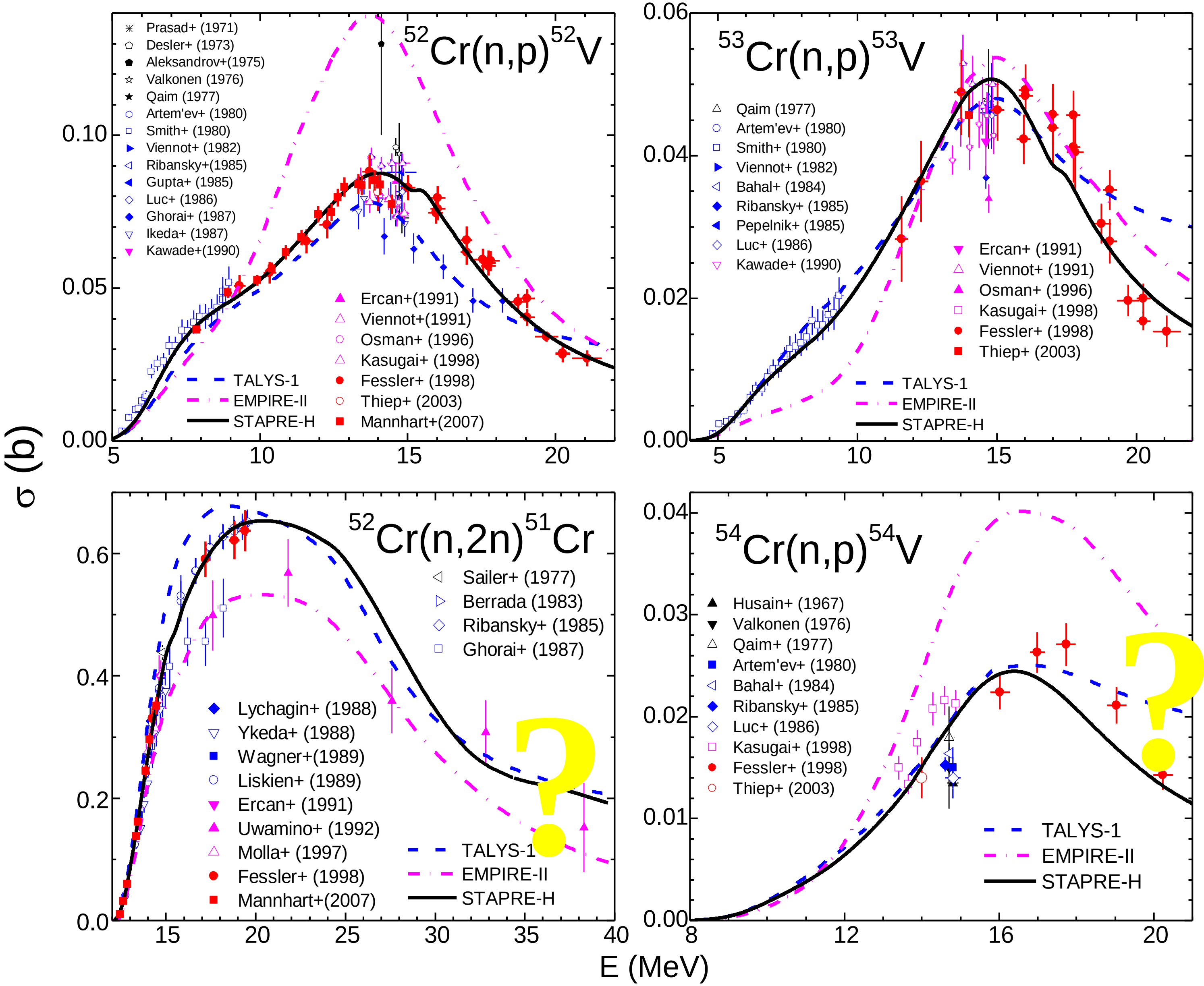
Comparison of measurements and global/local calculations for ^{52}Cr (1/4)



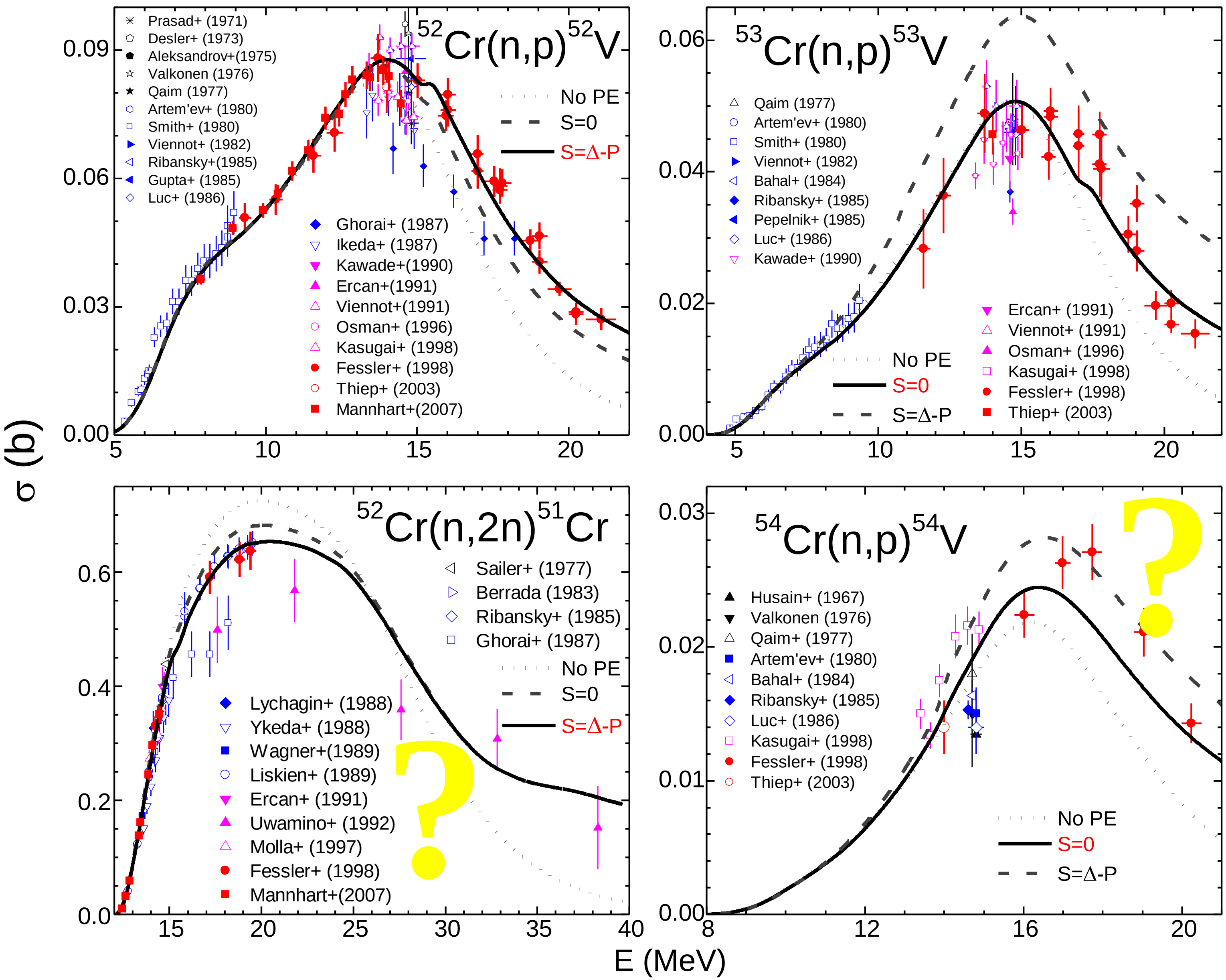
Comparison of measurements and global/local calculations for ^{52}Cr (2/4)



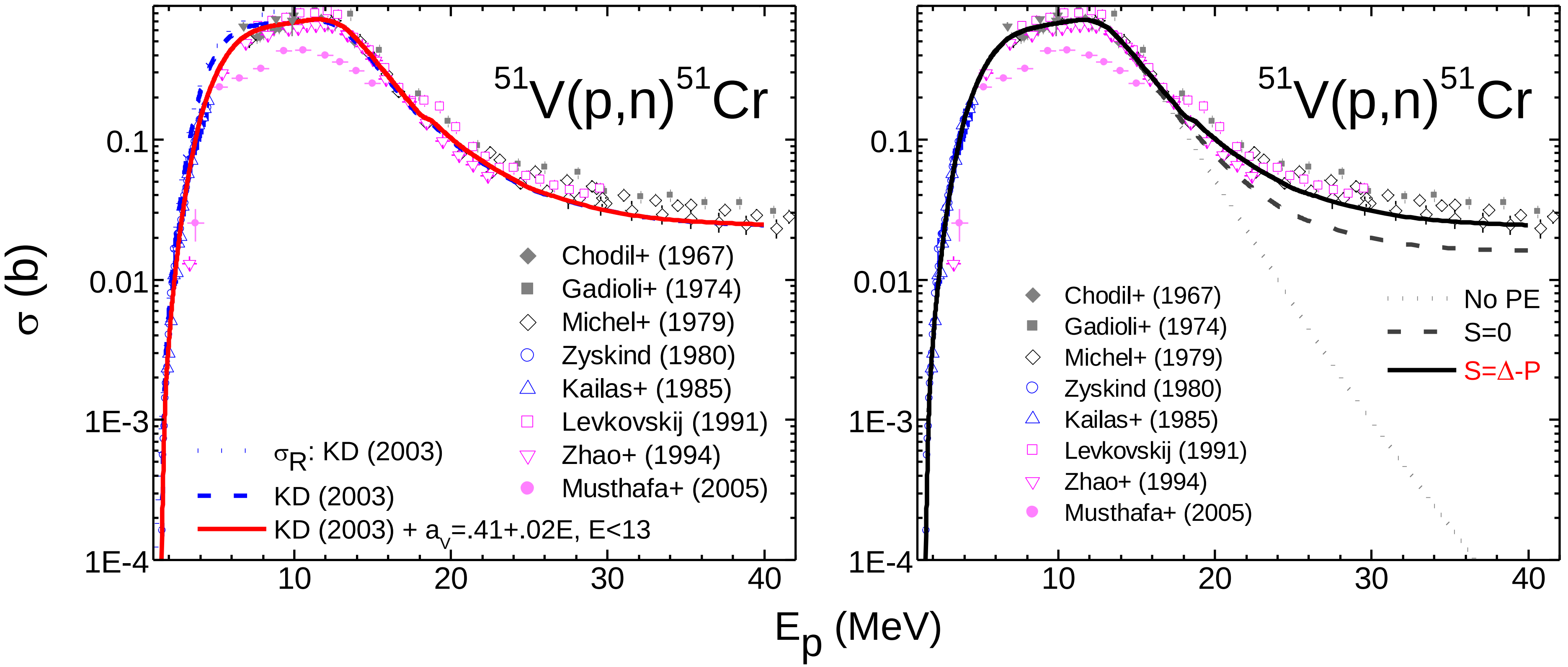
Comparison of measurements and global/local calculations for $^{52,53,54}Cr$



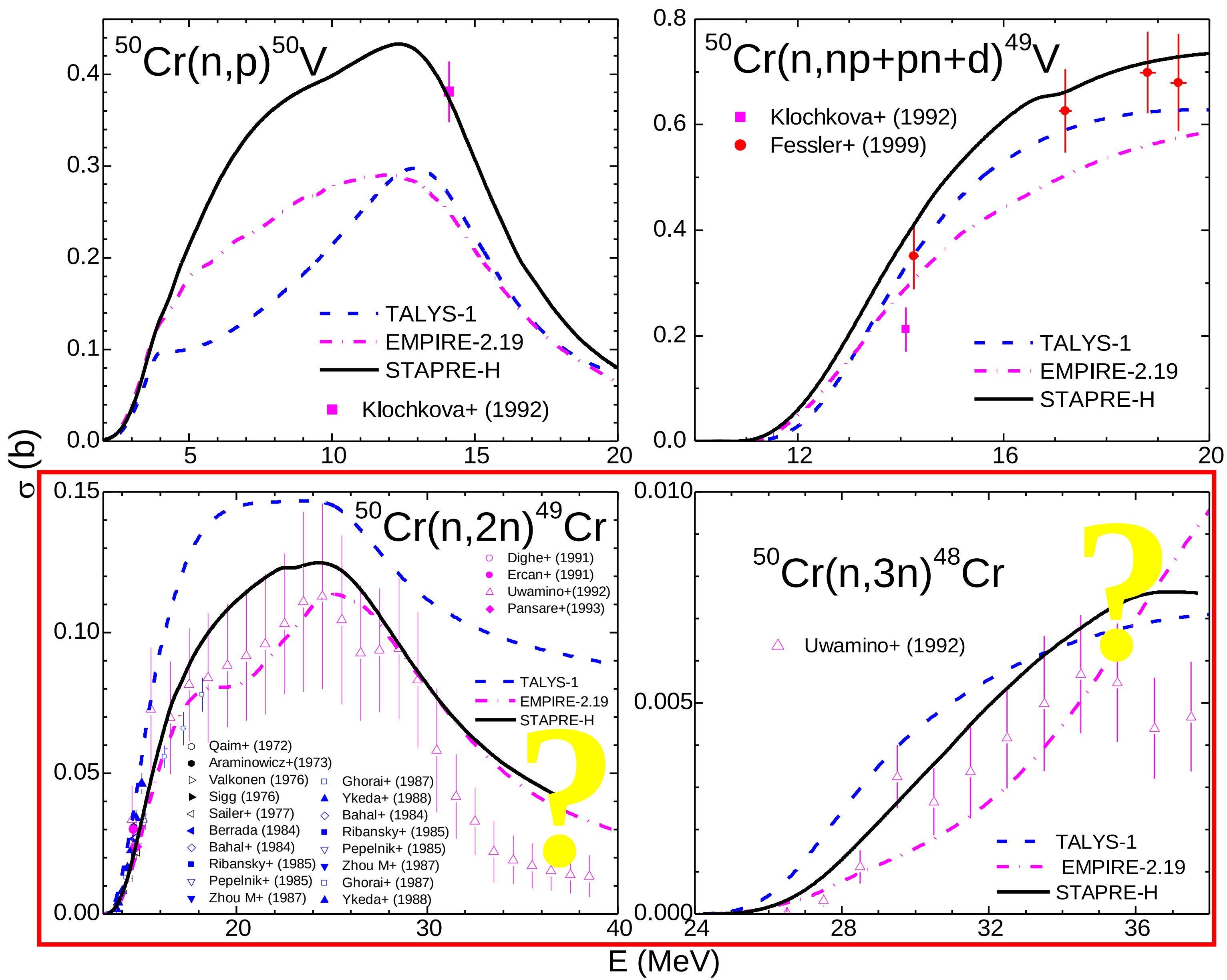
Shell-correction effect (p-h state densities - GDH PE-model) for $^{52,53,54}Cr$



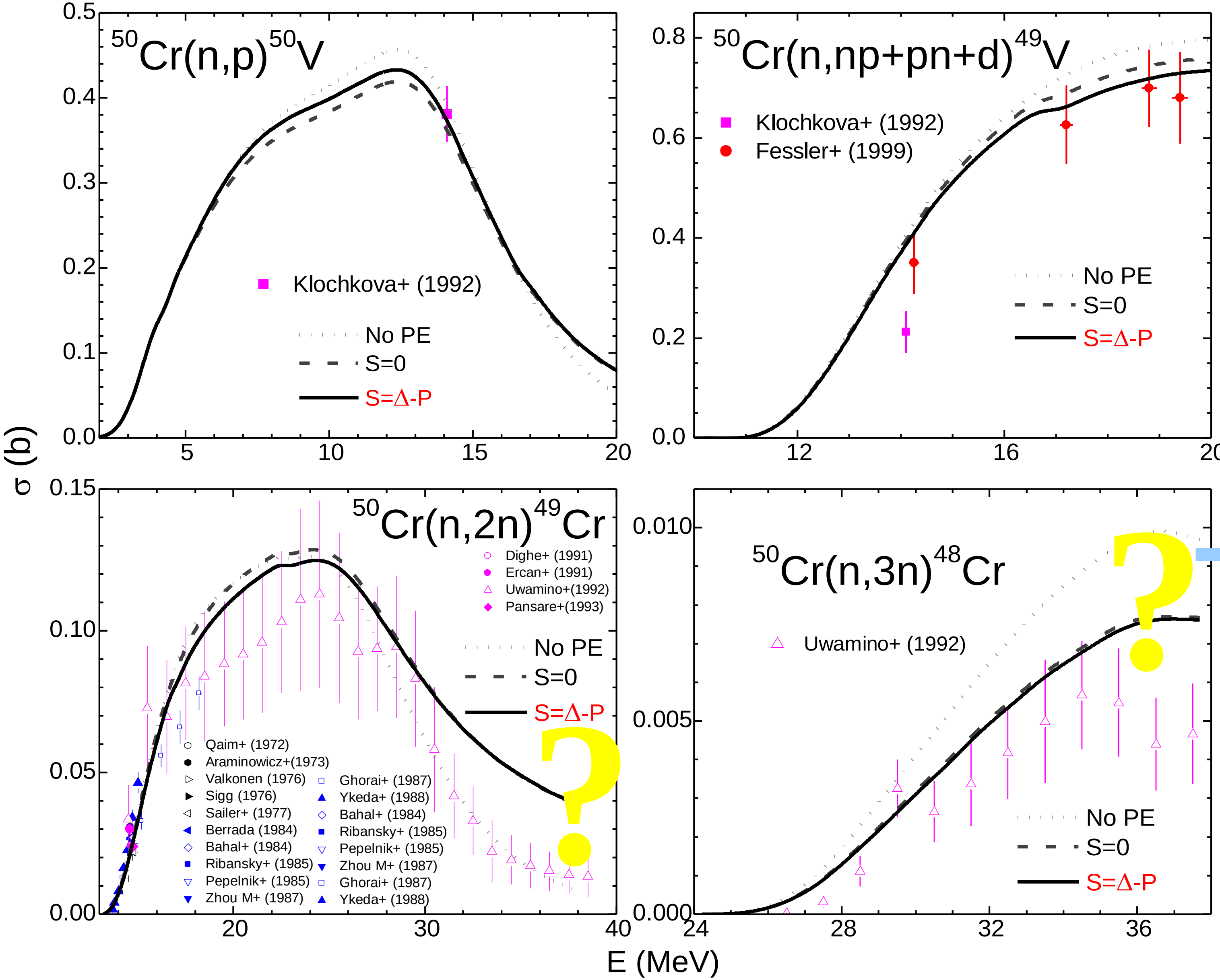
Shell-correction effect (p-h state densities - GDH PE-model) for $^{51}V(p,n)^{51}C$



Comparison of measurements and global/local calculations for ^{50}Cr



Shell-correction effect (p-h state densities - GDH PE-model) for ^{50}Cr



NFS@SPIRAL2 ?

Conclusions

- **Achievements (?)**
  - **Unitary description of all neutron activation experimental data by using a local parameter set in STAPRE-H code: accuracy ~5 %**
  - **Good results of blind calculations and global parameters within TALYS and EMPIRE-II codes : accuracy ~20 %**

- **<u>Final aim</u>: rising global-prediction accuracy to the level proved by the local approach <u>based on their differences understanding</u>**

- **Experimental-data critical role:**
  - **@ E ≤ 20 MeV (including particle-emission spectra): parameter validation**
  - **@ E>20 MeV: model validation (PE, basic assumptions)**

- **Experimental data needs: especially for E_n=15-40 MeV (NFS@SPIRAL2)**

?

THANK YOU FOR YOUR ATTENTION

Nuclear data (ND) ***consistent*** model calculations

[E.D. Arthur – P.G. Young, LANL, '80]

[IAEA/NDS RCs (12), Bucharest, 1982-2005]

YES

i. **unitary use of *common model parameters* for different mechanisms**

ii. **use of *consistent sets* of input parameters - determined by *analyses of various independent* experimental data**

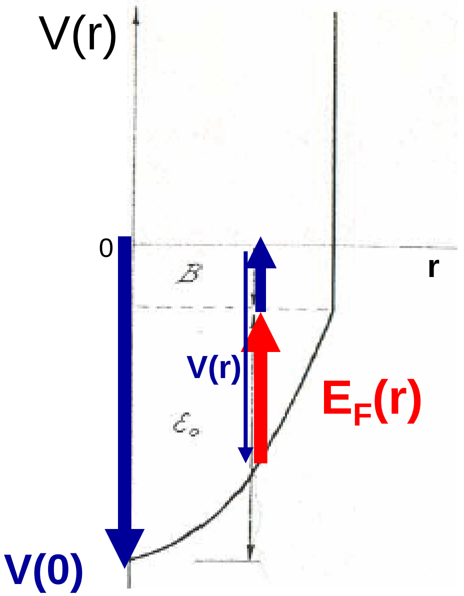
iii. **unitary account of *whole body* of related experimental data for *isotope chains* and *neighboring elements***

[activation & particle-emission spectra]

[enlarged incident-energy range]

NO **re-normalization or free parameters (widely-used within ND libraries)**

Surface localization of PE at low energies



- **Local energy approximation**

M. Kawai, Prog. Theor. Phys. **27**, 155 (1962): **SCDW model**
Y.L. Luo and M. Kawai, Phys. Rev. C **43**, 2367 (1991)
M. Kawai and H.A. Weidenmüller, Phys. Rev. C **45**, 1856 (1992)
Y. Watanabe and M. Kawai, Nucl. Phys. A **560**, 43 (1993)

- **Local Fermi energy** **[E.Gadioli et al.,** NPA **217**,589(1973)**]:**

$$E_F(r)=-[V(r)+B]$$

- **Local density approximation**

[J.-P. Jeukenne, A. Lejeune, C. Mahaux, PRC **16**, 80 (1977)**]:**

$$V_E(r)+iW_E(r)=V(\rho(r),E)+iW(\rho(r),E)$$

(LDA) ascribes to the OMP at the density $\rho(r)$ the same value as in a uniform medium with the same value of the density, with the same neutron excess

$$E_F(r)=\frac{\hbar^2 k_F^2(\mathbf{r})}{2m}=\frac{\hbar^2}{2m}\left[\frac{3\pi^2}{2}\rho(\mathbf{r})\right]^{2/3}$$

$$\overline{E_F}=\frac{\int d\mathbf{r}\rho(\mathbf{r})P(r)E_F(r)}{\int d\mathbf{r}\rho(\mathbf{r})P(r)}$$

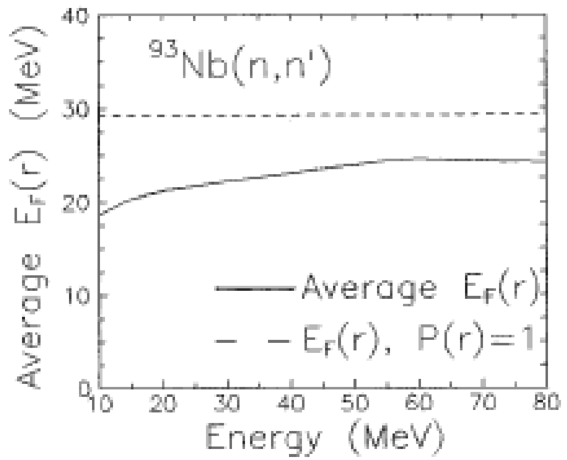


FIG. 2. Average local Fermi energy calculated for the first two-body collision in the case of ^{93}Nb(n,n') reaction (solid curve). The dashed curve corresponds to the assumption of an equiprobable site of interaction, i.e., to the use of the constant unity value for the first NN-collision probability $P(r)$.

J.Phys. G **20**, 613 (1994)

ESM+*g(u)*: $g_h(p,h)=g(F-\overline{u}_h)$ $\overline{u}_h=\dfrac{E-p\overline{u}_p}{h}$ $\overline{u}_p=\dfrac{E}{n}\dfrac{f_K^+(p,h,E,F)}{f_K(p,h,E,F)}$

GDH: $u_F(R_l)$ → **PE ⟷ $\overline{u}_h \le u_F(R_l)$**

PHYSICAL REVIEW C 71, 044617 (2005)

Reaction mechanisms of fast neutrons on stable Mo isotopes below 21 MeV

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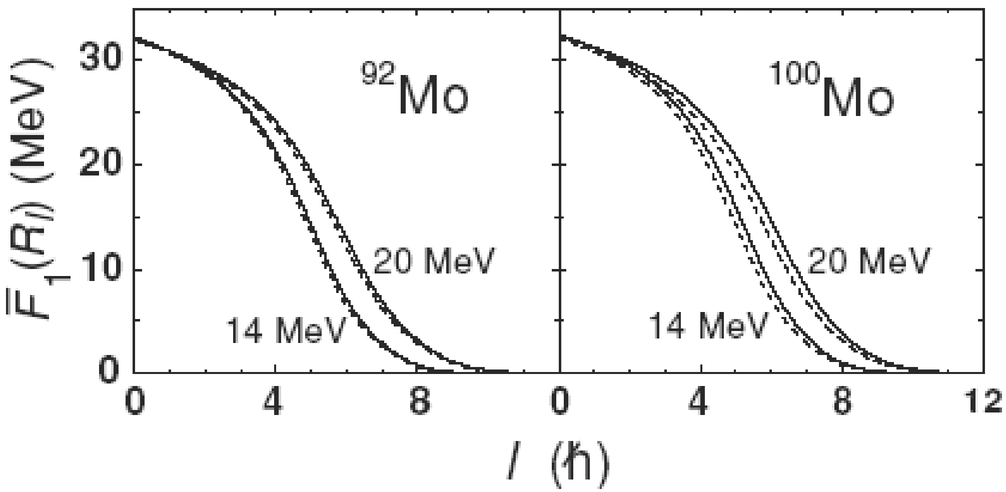

FIG. 4. Local-density Fermi energies for neutrons (solid curves) and protons (dashed curves) versus incident partial wave for incident neutrons on the target nuclei ^{92,100}Mo at 14 (lower curves) and 20 MeV (upper curves). The central well Fermi energy is $F_0 = 40$ MeV.

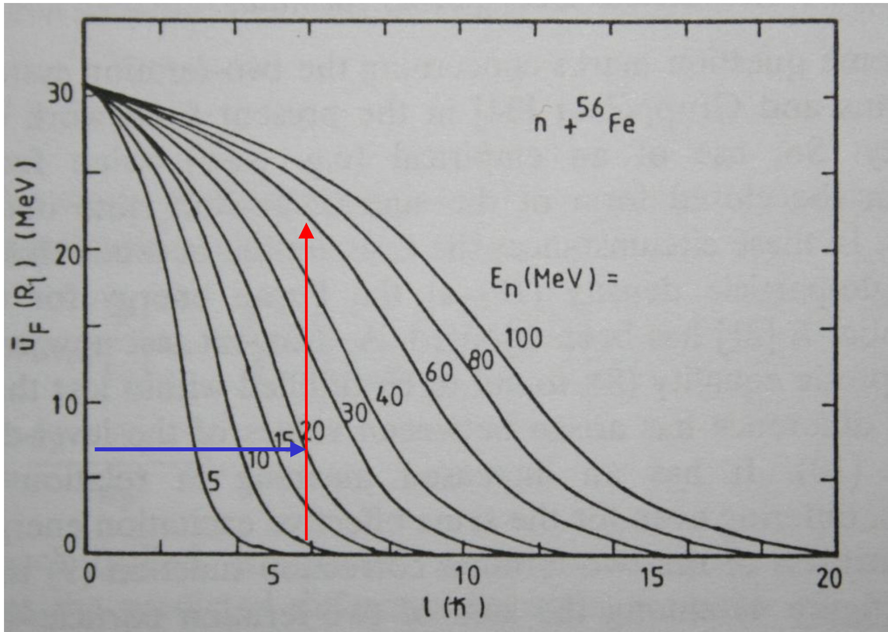

Figure 5. Local-density Fermi energies versus impact parameter on the target nucleus ^{56}Fe for noted incident energies.

PRC **65,** 014604 (2001)

Surface effects within GDH model (2)

PHYSICAL REVIEW C, VOLUME 65, 014604

Reaction mechanisms of fast neutrons on ^{51}V below 21 MeV

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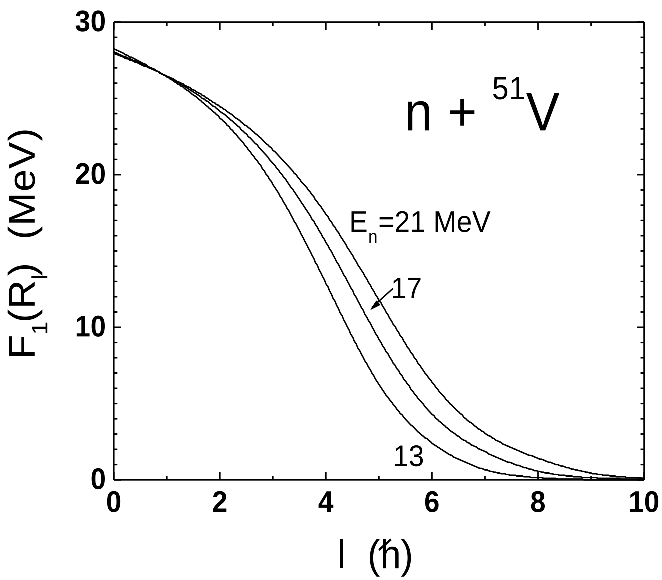
[3]*"Horia Hulubei" National Institute for Physics and Nuclear Engineering, P.O. Box MG-6, 76900 Bucharest, Romania*
(Received 5 June 2001; published 3 December 2001)



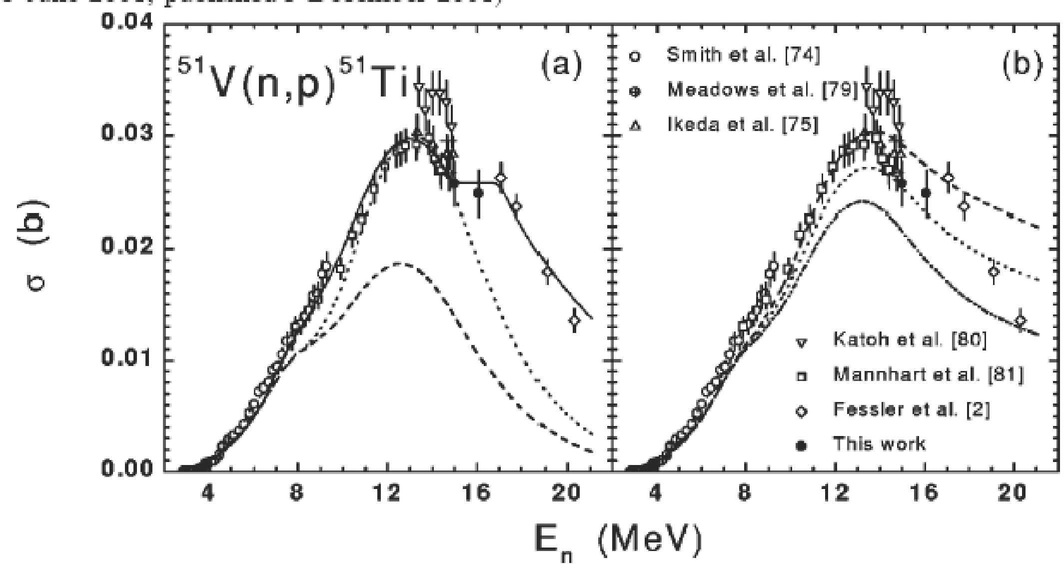


FIG. 6. (a) Comparison of experimental and calculated cross sections for the reaction ^{51}V$(n,p)^{51}$Ti by using the present model (solid curve), the pure Hauser-Feshbach statistical model (dashed curve), and the pure HF statistical model with level density parameters corresponding to a smaller average neutron-resonance spacing $D_0^n = 59$ keV (dotted curve). (b) Also shown are calculations with the exciton model with three choices for the average effective matrix element, $FM = 500$ (dashed curve), 700 (dotted curve), and 1100 MeV^3 (dash-double-dotted curve).

M. Avrigeanu *et al.,* J.Phys.Sci.Technol.Suppl. **2**, 803 (2002)