V.V.Varlamov, S.Yu.Komarov, N.N.Peskov, M.E.Stepanov

Skobeltsyn Institute of Nuclear Physics and Physics Faculty,
Lomonosov Moscow State University, 119992 Moscow, Russia

GDR NEUTRON DECAY CHANNEL DIRECT AND STATISTICAL PROCESSES COMPETITION NEW EVALUATIONS

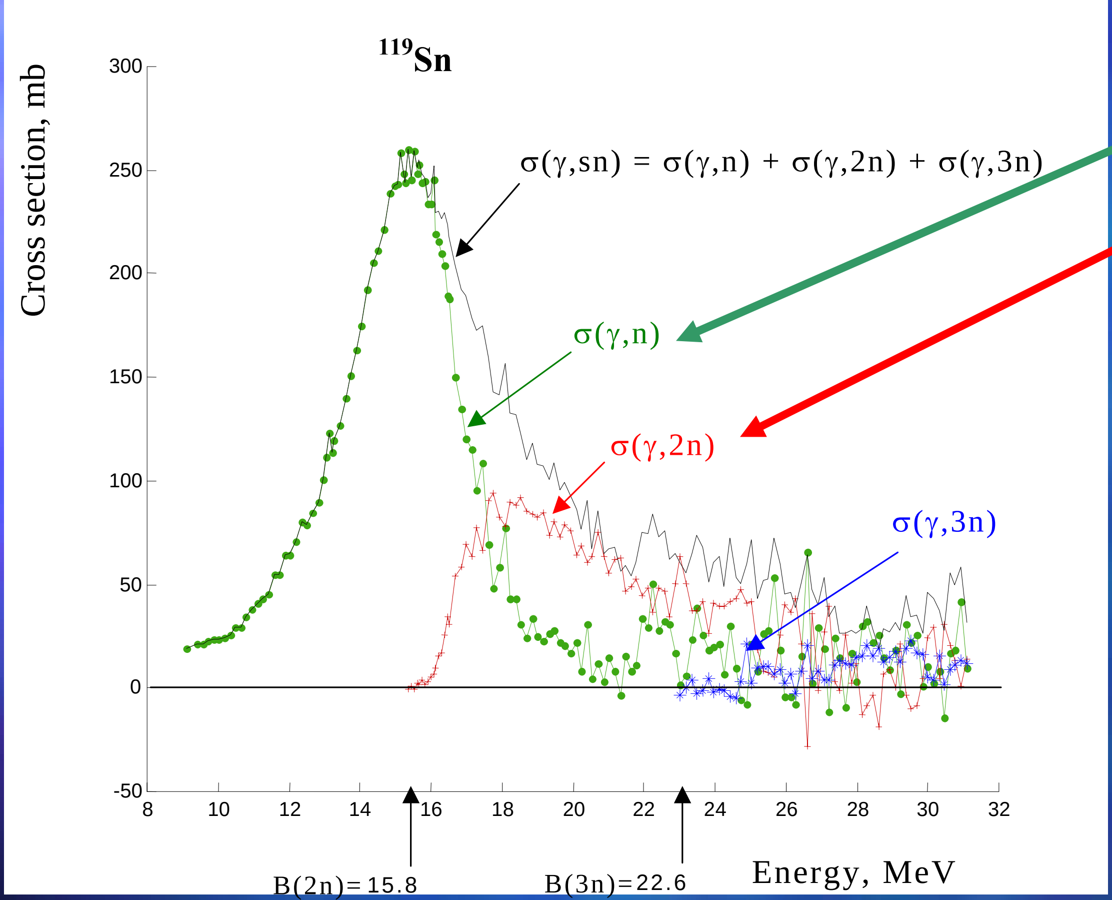
Title

Abstract

New evaluations of the direct processes contributions into the GDR neutron decay channel have been obtained on the base of results of previous detailed analysis of partial photoneutron reactons (γ,n) and $(\gamma,2n)$ cross sections obtained at Livermore (USA) and Saclay (France) using quasimonoenergetical annihilation photon beams.

Joint corrections of those both laboratories data for 17 nuclei ^{51}V, ^{75}As, ^{89}Y, ^{90}Zr, ^{115}In, ^{116,117,118,120,124}Sn, ^{127}I, ^{133}Cs, ^{159}Tb, ^{165}Ho, ^{181}Ta, ^{197}Au and ^{208}Pb lead to those evaluations under discussion as whole not larger than ~ 10% in agreement with the correspondent estimations of Livermore.

Giant Dipole Resonance (for example, ^{119}Sn)



Balance of cross sections of reactions with 1 and 2 outgoing neutrons is very important characteristic of nucleus photodisintegration process, depending on its excitation and decay mechanisms.

Deviation of (γ,n) reaction cross section energy dependence from the statistical model predictions - evidence of the presence of direct process of neutron knock-out by the γ–quantum.

$$(\gamma,abs) = \underbrace{(\gamma,n) + (\gamma,2n) + (\gamma,3n)} + \ldots + (\gamma,p) + \ldots + (\gamma,f) =$$

$$= (\gamma,sn) + (\gamma,p) + \ldots + (\gamma,f)$$

$$(\gamma,xn) = (\gamma,n) + 2(\gamma,2n) + 3(\gamma,3n) + \ldots$$

n-2n-3n

Main ideas of the method
used for evaluation of direct (non-statistical) contributions into the GDR neutron decay channel

1) Photon absorption process is a one-body effect, that is, the photon excites a single nucleon into higher shell-model orbit, but such a nucleus does not often deexcite by direct nucleon emission or even by precompaund decay.

2) The decay of GDR is dominated by statistical processes in sense of the compaund-nucleus picture of Bohr: statistical parameters of the nucleus could be extracted from an analysis of GDR decay products.

If all electric dipole E1 absorption by a nucleus lead to the formation of a compound nucleus before the evaporation of one or two neutrons can occur, the nucler temperature parameter «θ» or the nuclear level density parameter «a» for the target minus-one-neutron nucleus can be obtained from the measured partial cross sections of the target nucleus:

$$[\sigma_{\gamma,2n}(E)]/[\sigma_{\gamma,n}(E)+\sigma_{\gamma,2n}(E)] = \int_{\varepsilon=0}^{\varepsilon=E-B2n} \varepsilon\rho(U)d\varepsilon \; / \int_{\varepsilon=0}^{\varepsilon=E-Bn-\delta} \varepsilon\rho(U)d\varepsilon,$$

where $U = (E - Bn - \varepsilon - \delta)$ is the effective excitation energy of the (A – 1) nucleus,
ε is the kinetic energy of the emitted neutron,
δ is the pairing energy of the (A – 1) nucleus,
$\rho(U)$ is the (A-1) nucleus level density formula, $\rho(U) = CU^{-2}\exp(2\sqrt{aU})$ in Fermi gas model,
Bxn is the threshold value for the (γ,xn) reaction.

If level density form of the (A - 1) nucleus at the excitation energy U is of Blatt and Weisskopf type

$$[\sigma_{\gamma,2n}(E)]/[\sigma_{\gamma,n}(E)+\sigma_{\gamma,2n}(E)] = 1 - [1 + (E - B2n)/\theta]\exp[-(E - B2n)/\theta].$$

For reasonable values of «θ» and «a» both formule predict the complete dissappearance of the σ^{n} curve a few (3 - 5) MeV above the B2n.

Direct

So if for energy $E \approx B_{2n} + (3 - 5)$ MeV neutron cross section $\sigma^n(E) \neq 0$, the classic statistical evaporation of neutrons is not the only mechanism responsible for the emission of photoneutrons. The low-energy part of the neutron spectrum can be completely represented by an evaporation formulae and the residdue of high energy neutrons which cannot be fitted pertains to the so called direct interaction neutrons.

Therefore some part (x %) of all nuclear photon absorptions will be followed by the emission of direct high-energy neutron. Such a direct neutron emission toward to the low-lying energy levels of the (A - 1) nucleus makes the emission of a second neutron constituting a $(\gamma,2n)$ reaction impossible. Based on some experimental data for energies ~ 12 - 20 MeV the assumption is used that x to be about constant: «direct» $x\sigma^{tot}$ and «statistical» $(1 - x)\sigma^{tot}$ parts of total cross section $\sigma^{tot} = \sigma(\gamma,sn) = (\gamma,n) + (\gamma,2n)$ can be connected.

The neutron multiplisity is defined as follows

$$M(E) = [\sigma^n + 2\sigma^{2n}]/[\sigma^n + \sigma^{2n}] = \sigma^{xn}/\sigma^{sn}.$$

Above the threshold B2n the value of M(E) tends towards its asymptotic form

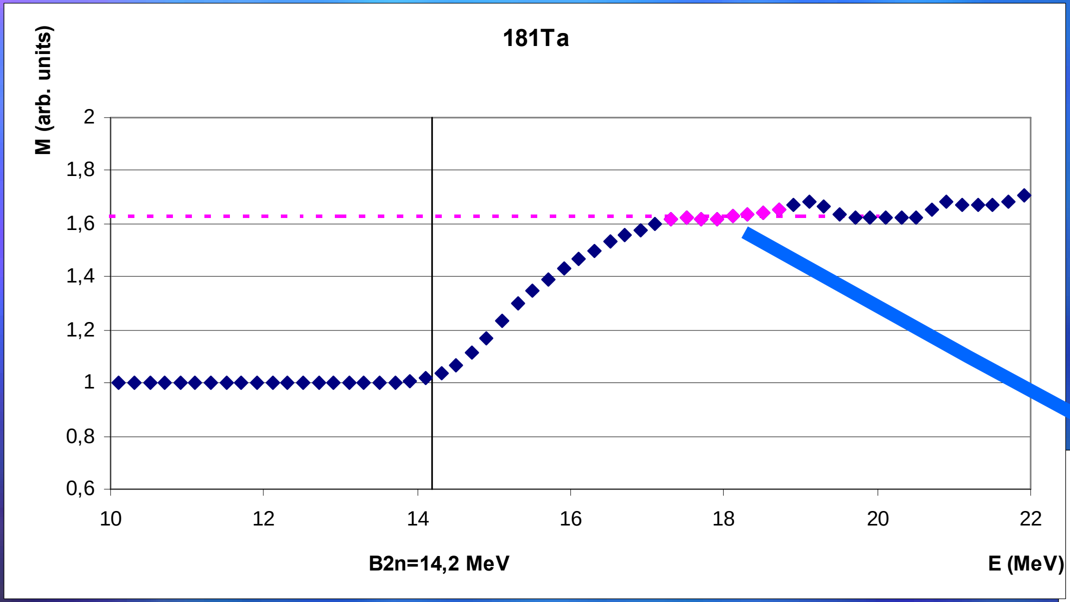
$$M_A = (2 - x_A) = [x_A\sigma^{tot} + 2\,(1 - x_A)\sigma^{tot}]/[x_A\sigma^{tot} + (1 - x_A)\sigma^{tot}].$$

Contribution of «direct» neutrons is

$$n_{direct} = x_A/(2 - x_A).$$

Multiplisity

Example (^{181}Ta) of photoneutron multiplisity M_A asymptotic using for determonation of the «direct» process contribution n_{direct}.



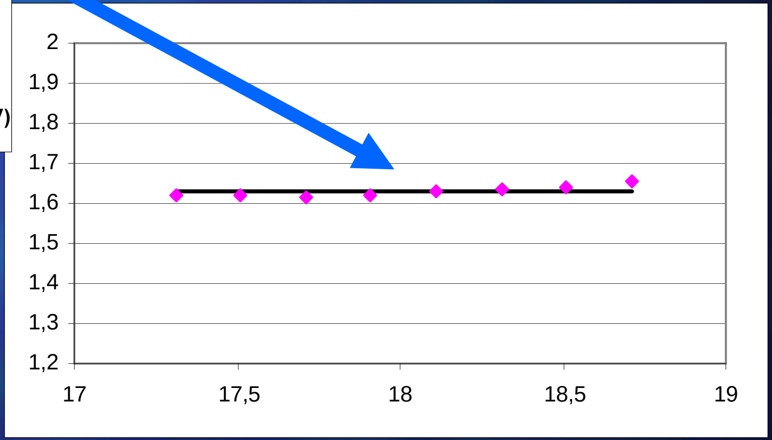
Asymptotic value for energy

$E \approx B_{2n}$ + (3 – 5) MeV ≈ 17.3 – 18.7 MeV:

$M_A = 1,63 \quad \Rightarrow \quad x_A = (2,00 - 1,63) = 0,37$

$\Downarrow$

$n_{«direct»} = 0,37/1,63 = 0,23$



Asymptotic

Using the procedure described the «direct» process contributions have been obtained at Saclay and Livermore.

Data significantly differ - as a whale those of Saclay are larger than those of Livermore.

Nucleus	n_{direct}, arb. units	
	Saclay	Livermore
^{51}V	0,34	0,20
^{75}As	0,24	0,07
^{89}Y	0,36	0,25
^{90}Zr	0,37	0,17
^{115}In	0,30	0,10
^{116}Sn	0,20	0,11
^{117}Sn	*0,19*	*0,21*
^{118}Sn	0,16	0,14
^{120}Sn	0,21	0,16
^{124}Sn	0,22	0,11
^{127}I	*0,23*	*0,18*
^{133}Cs	0,33	0,06
^{159}Tb	0,23	0,05
^{165}Ho	0,16	0,14
^{181}Ta	0,23	0,04
^{197}Au	0,25	0,06
^{208}Pb	0,19	0.21

Saclay,
Livermore

Using the procedure described the «direct» process contributions have been obtained at Saclay and Livermore. Data significantly differ - as a whale those of Saclay are larger than those of Livermore.

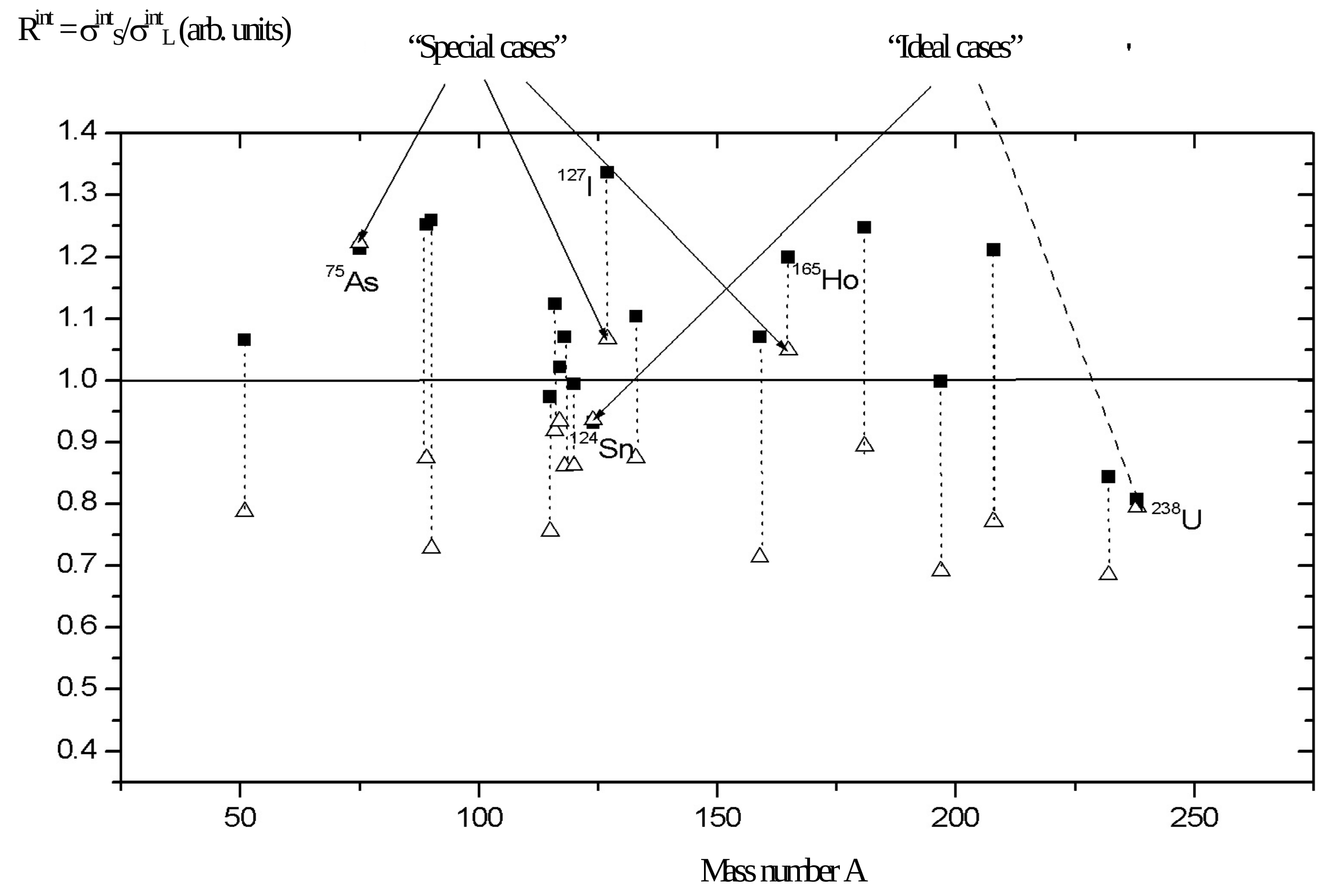
On the whole Saclay data (0.16 - 0.37, $<n_{direct}> = 0.27$) are clearly larger than Livermore (0.04 - 0.25, $<n_{direct}> = 0.12$) ones.

That has been shown before that discrepancies between Saclay and Livermore data for partial photoneutron reaction cross sections are produced by neutron multiplicity sorting procedure difference. Saclay procedure was not correct and therefore (γ,2n) data were underestimated (some of those were interpreted as (γ,n) events) and correspondingly that for (γ,n) reaction – vise versa overestimated.

Therefore «direct» process contributions obtained for energies ~ $E = B_{2n} + (3 – 5)$ MeV ((γ,2n) reaction) using Saclay data are not correct and must be re-evaluated.

Saclay, Livermore

Graphical presentation of (γ,n) – (γ,2n) disagreements between Saclay and Livermore data



Squares - ■ - ratios for (γ,n) reactions – are clearly systematically larger than 1.0

Triangles - △ - ratios for (γ,2n) reactions – are clearly systematically smaller than 1.0.

“(γ,n) – (γ,2n)” – Fig.

Neutron multiplicity sorting procedure test:

Twice measurement of ^{181}Ta(e,2n)^{180}Ta cross section s(e,2n) = 1/2 (s(e,xn) - s(e,n)):

1. **σ_1(e,n) – neutron multiplicity sorting measurement;**
2. **σ_2(e,n) – measurement of induced activity (decay ^{180}Ta → ^{180}Hf , 93.3 keV, Ge-Li).**

Mean-square ratio $\langle\sigma_1(e,n)/\sigma_2(e,n)\rangle = 1.057 \pm 0.023$ means high reliability of multiplicity sorting procedure.

Comparison of (e,n) and (γ,n) data show that Saclay data for (γ,2n) reaction are underestimated and correspondingly that for (γ,n) reaction – vise versa overestimated.

M-check

Total photoneutron reaction cross section in GDR energy region

$$(\gamma,xn) = (\gamma,n) + 2(\gamma,2n).$$

Ratio R (“Saclay/Livermore” normalization) for all reactions cross sections

$$R = \sigma^{xn}{}_{S}/\sigma^{xn}{}_{L} = \sigma^{n}{}_{S}/\sigma^{n}{}_{L} = \sigma^{2n}{}_{S}/\sigma^{2n}{}_{L} = (\sigma^{n}{}_{S} + 2\sigma^{2n}{}_{S})/(\sigma^{n}{}_{L} + 2\sigma^{2n}{}_{L}),$$

$$\sigma^{xn}{}_{S} = (\sigma^{n}{}_{S} + 2\sigma^{2n}{}_{S}) = R\sigma^{xn}{}_{L} = R(\sigma^{n}{}_{L} + 2\sigma^{2n}{}_{L}) .$$

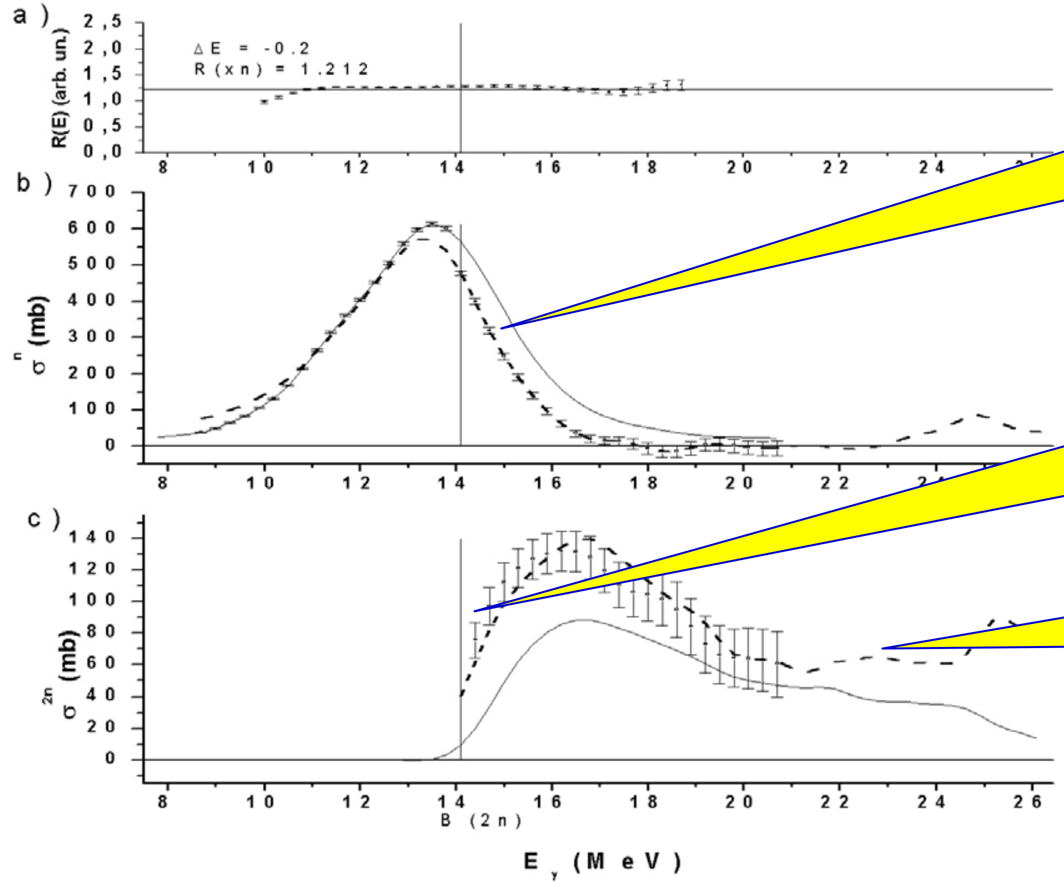
Saclay corrected $\sigma^{2n}{}_{S}{}^{*}$ must be equal to Livermore corrected: $\sigma^{2n}{}_{L}{}^{*} = R\sigma^{2n}{}_{L}$,

therefore: $\sigma^{2n}{}_{L}{}^{*} = \sigma^{2n}{}_{S}{}^{*} = R\sigma^{2n}{}_{L} = \sigma^{2n}{}_{S} + 1/2\ (\sigma^{n}{}_{S} - R\sigma^{n}{}_{L})$.

Saclay (γ,n) reaction cross section part $1/2\ (\sigma^{n}{}_{S} - R\sigma^{n}{}_{L})$ is “transmitted back” to Saclay (γ,2n) reaction cross section $\sigma^{2n}{}_{S}$.

“n-2n”
correction

Joint correction of both (γ,n) and (γ,2n) reaction cross sections of Saclay and Livermore for ^{208}Pb



Part of Saclay (γ,n) reaction cross section transported back into (γ,2n) cross section

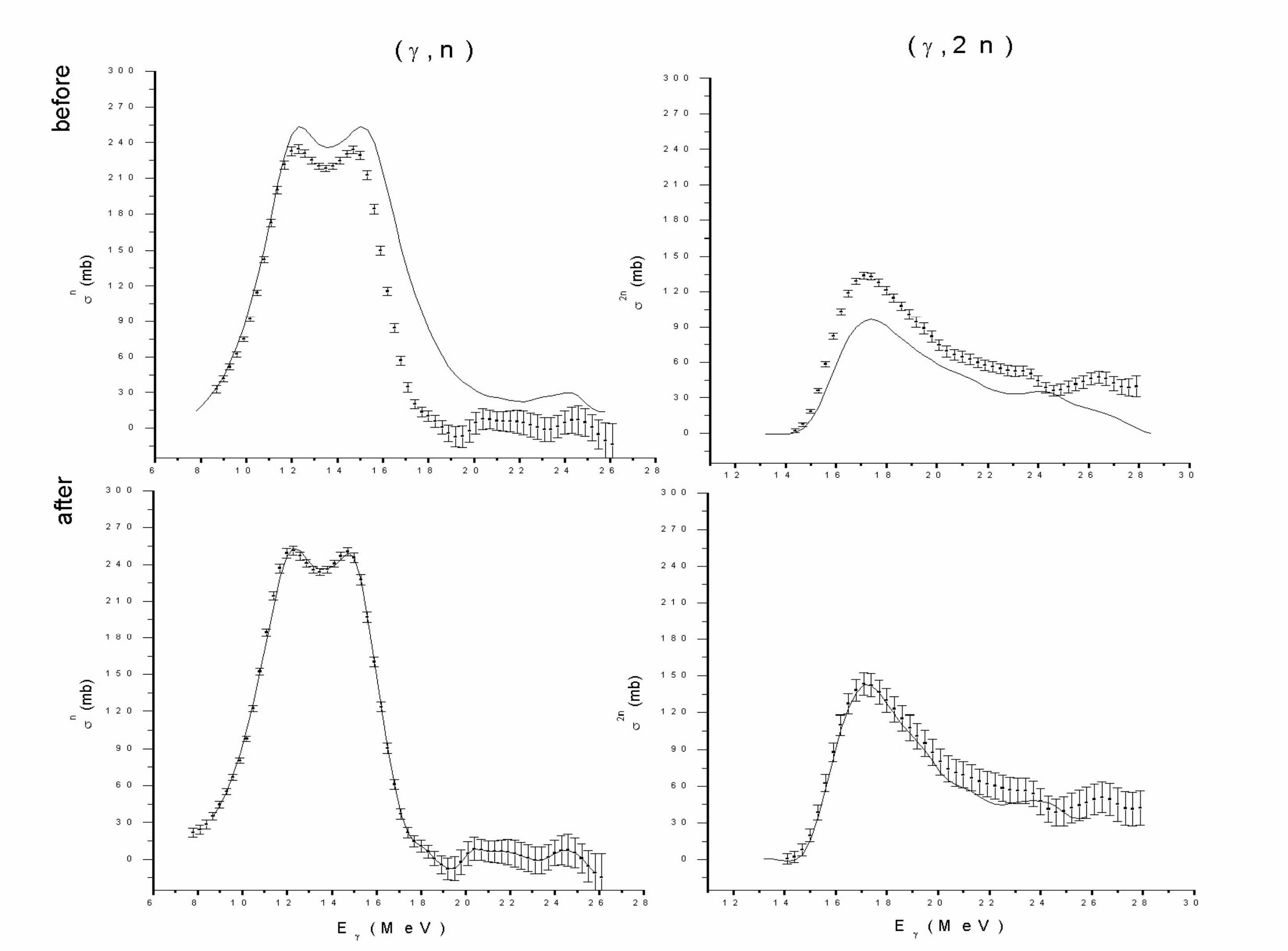
Corrected Saclay (γ,n) reaction cross section – error bars (line – uncorrected data).

Livermore (γ,n) reaction cross section multiplied by (γ,xn) cross section ratio (1.212 at this case)

(γ,n) – (γ,2n) correction

^{159}Tb

(γ,n) and (γ,2n) reaction data



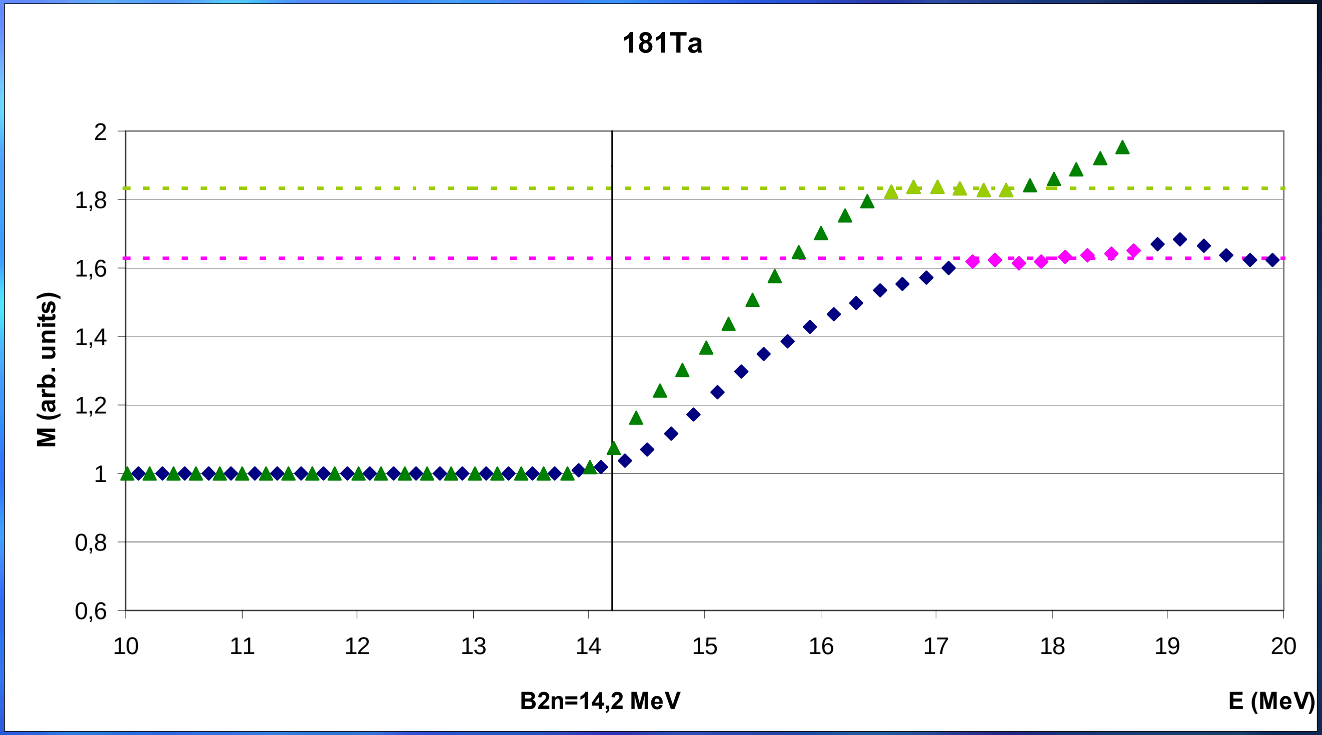
← before

and

← after

joint correction procedure.

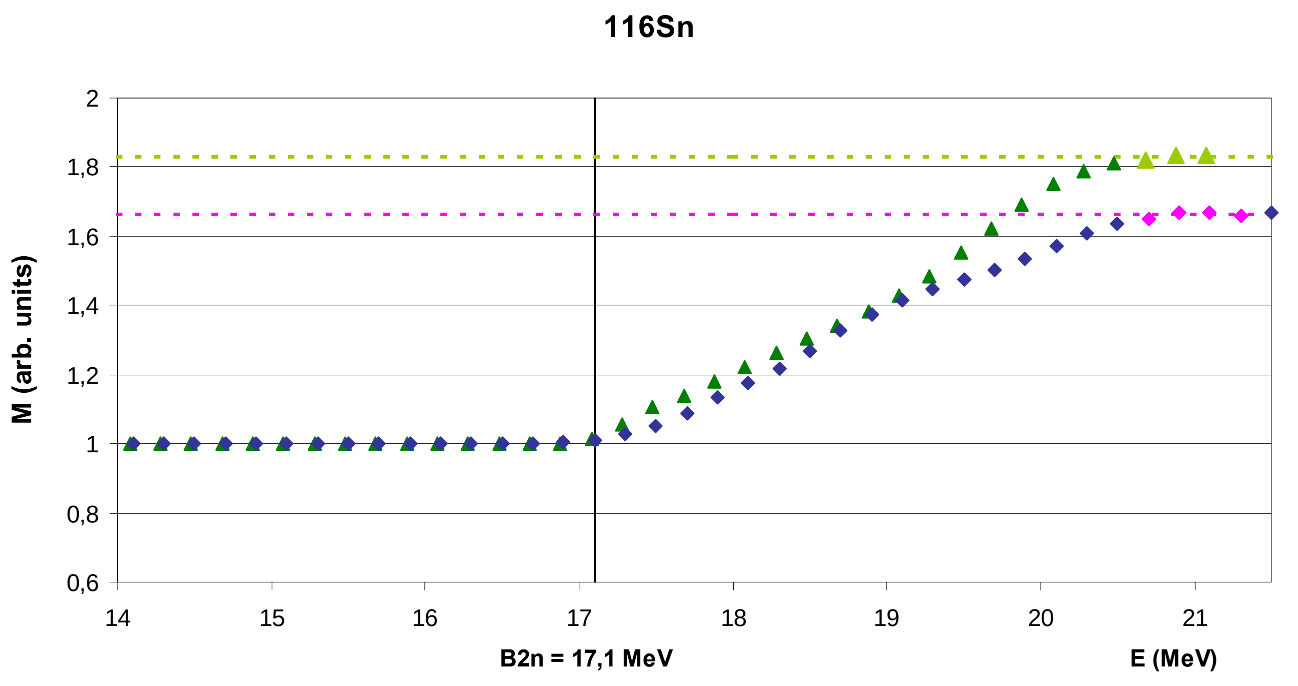
“Before” and “after”



Comparison of old (diamonds) and new (triangles) energy photoneutron multiplisity dependencies M(E) for ^{181}Ta photodisintegration, obtained using Saclay data:

M_A(old) = 1,63, n_{direct} = 0,23;

M_A(new) = 1,83, n_{direct} = 0,09.



Comparison of old (diamonds) and new (triangles) energy photoneutron multiplisity dependecies M(E) for ^{116}Sn photodisintegration, obtained using Saclay data:

M_A(old) = 1,66, n_{direct} = 0,20;

M_A(new) = 1,84, n_{direct} = 0,09.

^{116}Sn

Comparison of new and old evaluations of «direct» process contributions

	Saclay data		Livermore data
Nucl	**Old**	**New**	
^{51}V	0.34	0.22	0.20
^{75}As	0.24	0.06	0.07
^{89}Y	*0.36*	*0.30*	*0.25*
^{90}Zr	0.37	0.01	0.17
^{115}In	0.30	0.14	0.10
^{116}Sn	0.20	0.09	0.11
^{117}Sn	0.19	0.22	0.21
^{118}Sn	0.16	0.18	0.14
^{120}Sn	0.21	0.22	0.16
^{124}Sn	0.22	0.16	0.11
^{127}I	0.23	0.22	0.18
^{133}Cs	0.33	0.09	0.06
^{159}Tb	0.23	0.03	0.05
^{165}Ho	0.16	0.22	0.14
^{181}Ta	0.23	0.09	0.04
^{197}Au	0.25	0.09	0.06
^{208}Pb	0.19	0.09	0.21

On the whole:

new Saclay «direct» process contribitions ($\langle n_{direct}\rangle = 0,14$) are clearly smaller than old ones ($\langle n_{direct}\rangle = 0,27$) and much more close to Livermore data ($\langle n_{direct}\rangle = 0,12$).

Table

Important physical consequence:

E1 GDR decays dominantly statistically

Saclay partial photoneutron reactions (γ,n) and (γ,2n) cross sections are not correct and consistent each other because of incorrect neutron multiplicity sorting procedure used and must be recalculated.

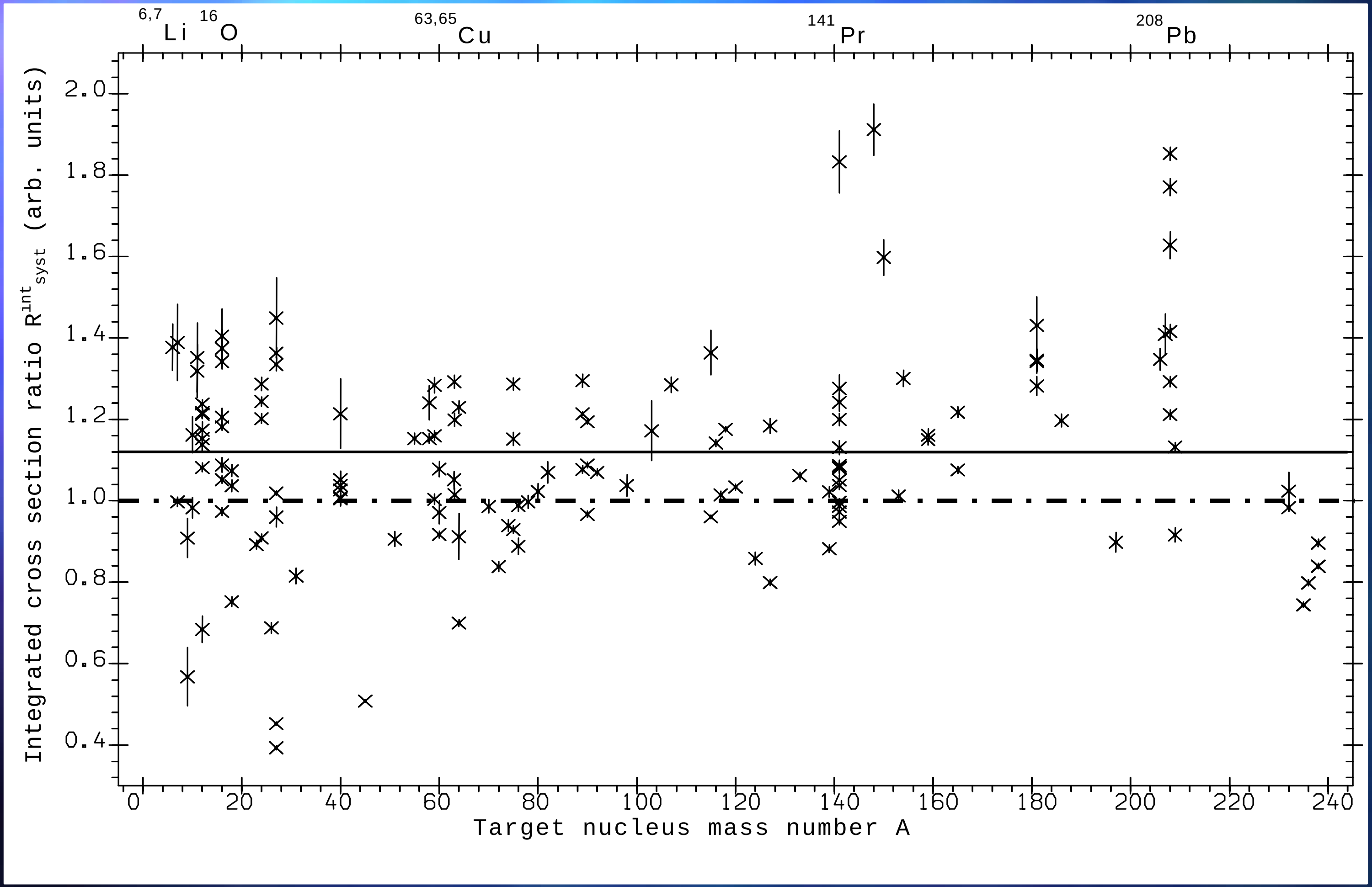
Saclay interpretation of high-energy tails of (γ,n) reaction cross sections as contributions of high-energy neutrons from GDR non-statistical direct decay (those contributions evaluated to be about (averaged) 27 %) because of small decreasing of (γ,n) reaction cross sections for energies higher than (γ,2n) reaction threshold B(2n) looks like as not correct;

Saclay (γ,n) data corrections described decrease those and put them into accordance with Livermore data: direct decay contributions are about (averaged) 12 - 14 % .

Consequence

THANKS A LOT FOR ATTENTION !

Systematic of integrated cross section ratios “All other/Livermore” for about 500 total photoneutron reaction (γ,xn) cross sections.



$R^{int}_{syst} = 1.12$.

Int. cross. sect. ratios

Important results:

- clear data discrepancies force one to use data existed strongly individually;
- Livermore total photoneutron reaction (γ,xn) cross sections have in general absolute values smaller then that obtained at various other laboratories; the reason: "… an Livermore experiments error either in the photon flux determination or in the neutron detection efficiency or in both"; therefore Livermore (γ,xn) cross sections data of for 19 nuclei studied specially must be multiplied by appropriate coefficients $R^{int}(\gamma,xn)$ and for others – by $<R^{int}_{syst}> = 1.12$ at least;
- Saclay partial photoneutron reactions (γ,n) and (γ,2n) cross sections are not correct and consistent each other because of incorrect neutron multiplicity sorting procedure used and must be recalculated;
- Livermore neutron multiplicity sorting procedure at the same time is correct and therefore Livermore (γ,n) and (γ,2n) cross sections are in consistence with each other and with (γ,xn) cross sections and both can be used but again only multiplied by coefficients $R^{int}(\gamma,xn)$ or $<R^{int}_{syst}>$.