What can we say about the dipole photon strength in ^{57}Fe from the $(n_{\rm th},\gamma)$ data?

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Introduction

In the statistical model of γ decay, the photon strength function (PSF), $f^{(XL)}$, determines the partial radiative width $\Gamma_{i\gamma f}$ from the initial level i to the final level f as

$$\Gamma_{i\gamma f} = \sum_{XL} f^{(XL)}\, \xi_{XL}\, E_\gamma^{2L+1}\, D_{J_i^\pi} = \sum_{XL} f_l^{(XL)}\, E_\gamma^{2L+1}\, D_{J_i^\pi}, \qquad (1)$$

where $D_{J_i^\pi}$ is the average spacing for given J_i^π in the vicinity of the initial level and the factors ξ_{XL} reflect the fluctuations of $\Gamma_{i\gamma f}$ or the individual PSF values, $f_l^{(XL)}$. These fluctuations are assumed to follow the Porter-Thomas distribution. The summation goes over all allowed types X and multipolarities L of transition connecting the initial and final level. In practice the decay of highly excited levels is usually dominated by dipole transitions, $E1$ or $M1$, with the only possible relevant mixed transition being $M1+E2$. For the sake of clarity we omit the XL labeling hereafter.

- the $E1$ PSF above neutron separation energy, S_n, dominated by the giant electric dipole resonance (GEDR)
- the $E1$ PSF shape below S_n still uncertain, often found inconsistent with standard Lorentzian description of GEDR
- other resonances play a role - pygmy $E1$, spin-flip and scissors $M1$
- the first observation of low-energy enhancement (LEE) in ^{56,57}Fe by the Oslo method [1]
- the exact magnitude depends on normalization of the data [2, 3], see Fig. 1
- the presence and magnitude of LEE has impact on (n,γ) cross section predictions

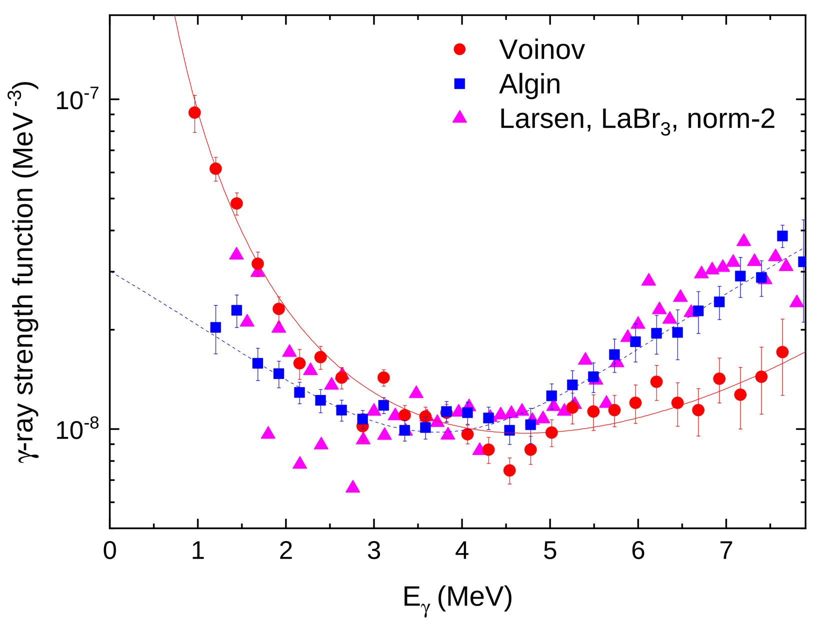

Figure 1: The dipole PSF as determined by the Oslo method. The datasets correspond to Refs. [1, 2, 3], respectively. The uncertainties of Larsen dataset are omitted for the sake of clarity.

Thermal neutron capture measurements

The ^{56}Fe$(n_{\rm th},\gamma)$ was measured at Cold neutron PGAA facility at Budapest [4] and thermal neutron two-step γ cascade (TSC) facility at Řež [5]. The singles spectrum from Budapest was used to get intensity values, while the TSC spectra were used to check the placement of some transitions.

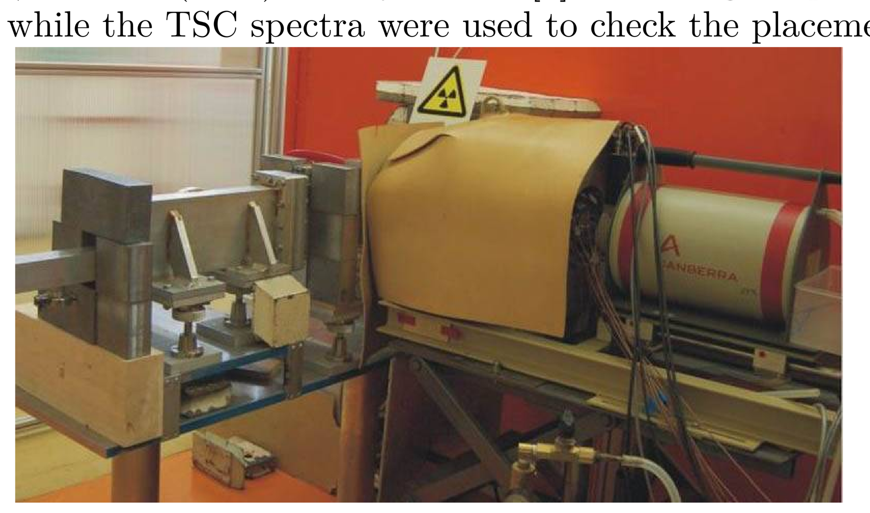

Figure 2: The PGAA apparatus at Budapest Neutron Center. The photo was taken from https://www.iperionhs.eu/tool/70/.

Figure 3: The TSC gamma coincidence facility at LWR-15 research reactor, NPI CAS Řež at the time of measurement in 2005.

Intensities of transitions

A detailed level scheme constructed by Firestone *et al.* [6], authors deduced ***transition probabilities*** P_γ per neutron capture.

- 98 levels in ^{56}Fe with 448 γ-rays between them, substantial revision w.r.t. ENSDF [7] and references therein
- total observed ***intensity*** $P_\gamma E_\gamma / S_n = 0.989(14)$
- 24 unplaced transitions account only for 0.14% of total observed intensity
- **primary transitions** - 85 observed, 32 of known XL, see Fig. 4
- 3 high-energy γ-rays observed, which can not be primaries in the present level scheme ⇒ we can assume their P_γ from the corresponding secondaries, shown as "unobserved" in Fig. 4
- improved thermal neutron capture cross section $\sigma_\gamma = 2.394(19)$ b.

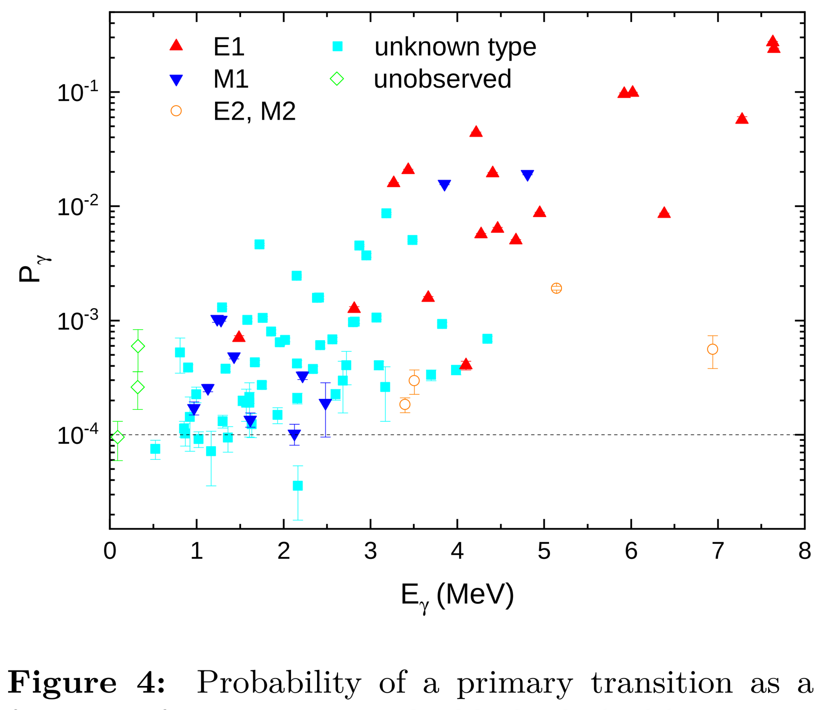

Figure 4: Probability of a primary transition as a function of γ-ray energy. The blacki dashed line corresponds to the observation threshold assumed in further analysis.

According to DICEBOX simulations, missing transition probability is $\sum P_\gamma \approx 0.3\%$ for primary transitions, and $\sum P_\gamma \approx 0.47\%$ for feeding of GS + 14 keV levels *assuming* the constant threshold of 10^{-4} shown in Fig. 4. **Unique dataset** going down to **very low** γ**-ray energy**.
Despite the significant progress, many levels do not have a definite J^π assignment, hence many transitions remain of unknown type. In further analysis we assume these are dominated by dipole transitions.

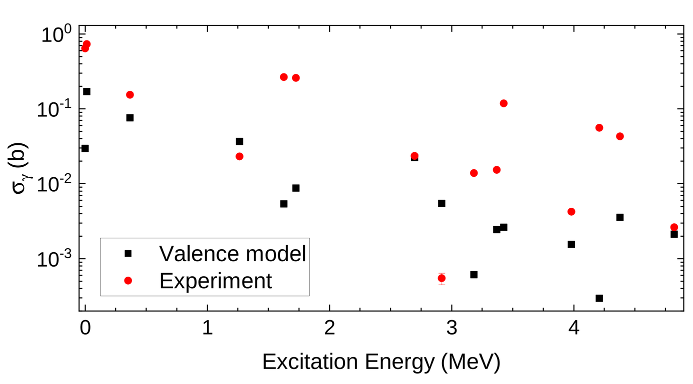

Figure 5: The possible influence of non-statistical effects. Plotted is the partial thermal neutron capture cross section as a function of excitation energy. The experimental points are deduced from probability of corresponding primary transition, the predictions of valence model are calculated according to Ref. [8].

Photon strength function

The individual PSF values f_l are obtained from probabilities of transitions as

$$f_l = \frac{\Gamma_{i\gamma f}}{E_\gamma^{2L+1} D_{J^\pi}} = \frac{\Gamma_{i\gamma}\left(P_{i\gamma f} / \sum_f P_{i\gamma f}\right)}{E_\gamma^{2L+1} D_{J^\pi}}, \qquad (2)$$

we omit the i and f indices for the sake of clarity.

- individual values are expected to fluctuate according to Porter-Thomas distribution, see Eq. (1)

⇒ to obtain the mean PSF value we need to average

× only handful of transitions in relatively wide, high-energy γ-ray interval

- need to assume a PSF shape within each interval, e.g. constant

! influence of threshold in low-energy intervals – the result slightly depends on nuclear level density model

! the resulting mean PSF value can be below threshold

- many primaries are of unknown type ⇒ assumptions about $E1$-to-$M1$ PSF ratio

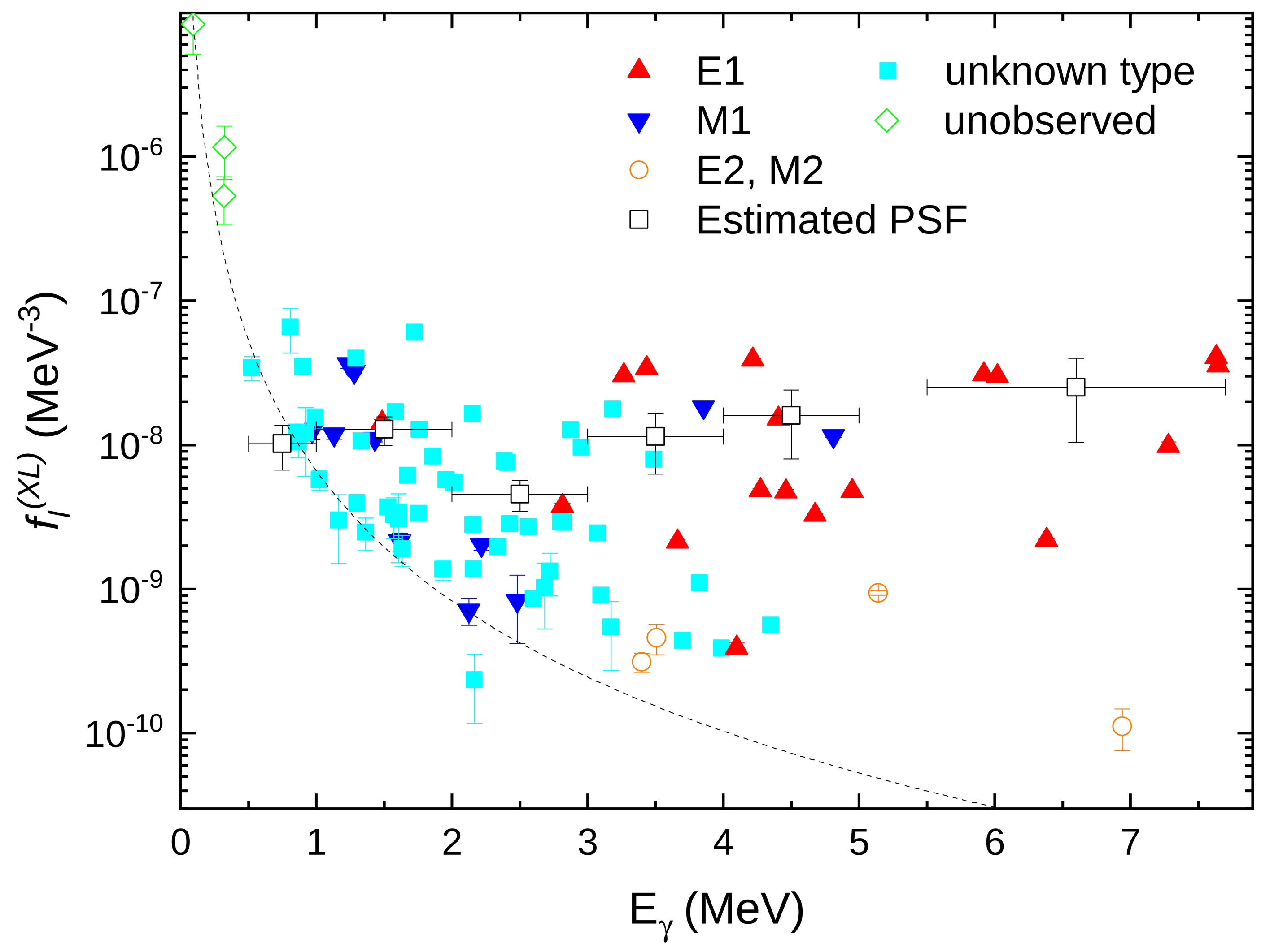

Figure 6: PSF deduced from intensities of primary transitions as a function of γ-ray energy. The black dashed line corresponds to the threshold in Fig. 4.

To convert probabilities of primary transitions to PSF values, we have used $D_{J^\pi} = D_0 = 22.0(17)$ keV and $\Gamma_{i\gamma} = 1474$ meV from Mughabghab's atlas [8]. The resonance that dominantly contributes to the thermal capture is the bound state according to Mughabghab, hence the choice of $\Gamma_{i\gamma}$.
The average total radiative width is quoted as 900(470) meV therein. The uncertainty probably reflects the expected significant fluctuations of $\Gamma_{i\gamma}$ in such a light nucleus, see Fig. 7.
In any case, the value of $\Gamma_{i\gamma}$ does not influence the *shape* of deduced PSF.
The integrated TSC data can be used for comparison with DICEBOX simulations under different assumptions. The sensitivity is limited because of sizable P-T fluctuations when intensities of primaries are not taken from experiment, see Fig. 8.

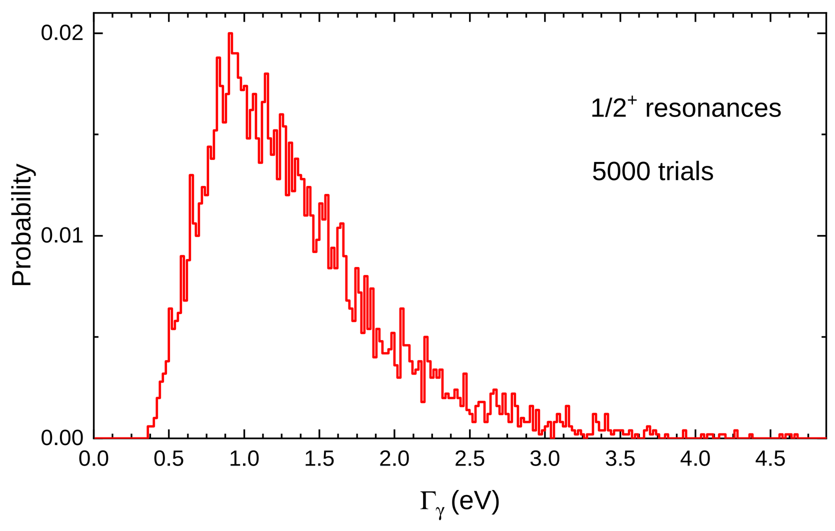

Figure 7: Distribution of total radiative widths as simulated by DICEBOX for $1/2^+$ level at S_n in ^{57}Fe. Only P_γ of primary transitions were varied in the simulations.

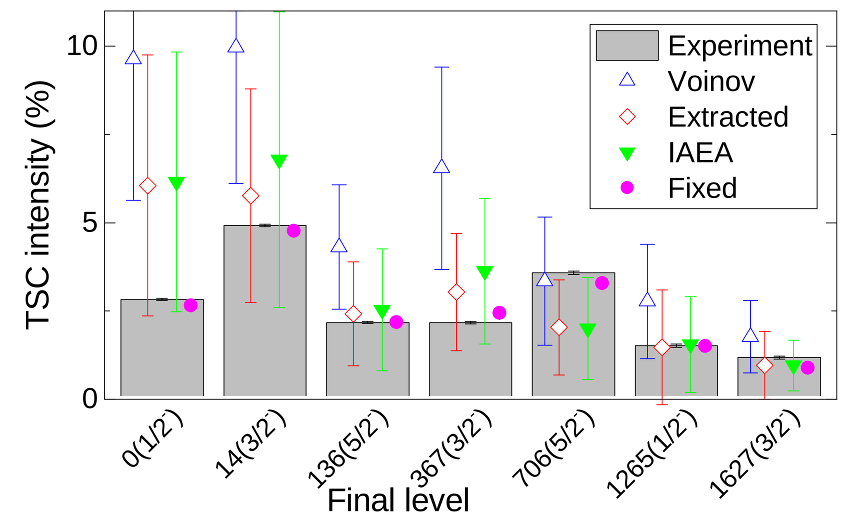

Figure 8: Comparison of experimental and simulated TSC intensity integrated over 4 MeV central interval. The "IAEA" PSFs were taken from S. Goriely *et al.*, Eur. Phys. J. A 55 (2019) 172.

Results

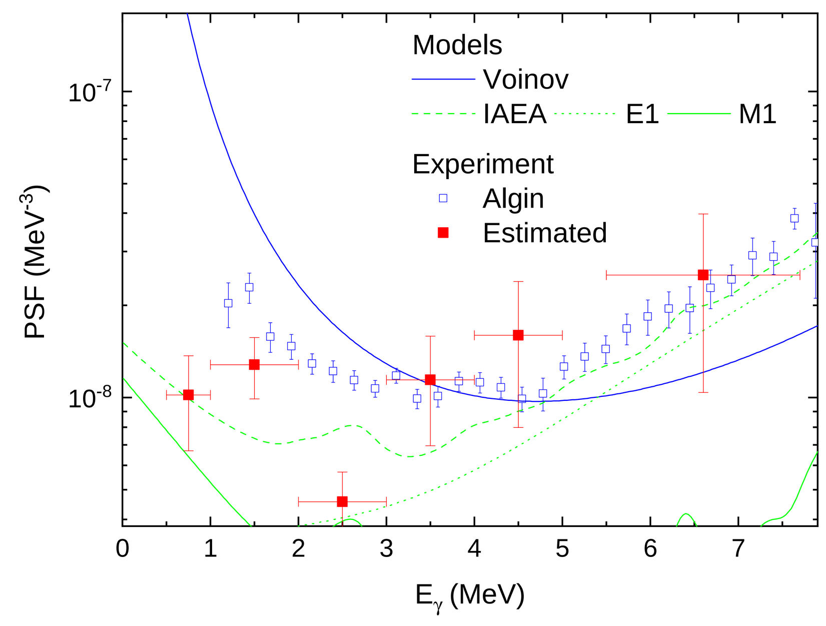

Figure 9: Selected PSF data and models.

- PSF was extracted from probabilities of primary transitions
- sizable uncertainties of at best 20%, dominated by P-T fluctuations
- a dip at 2-3 MeV observed
- no clear sign of strong LEE down to 0.5 MeV

⇒ data in disagreement with PSF by Voinov *et al.* [1]

- other models can not be ruled out due to uncertainties

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DICEBOX

Poster on web: