Photon strength function of ^{196}Pt extracted from neutron radiative capture measured with DANCE detector

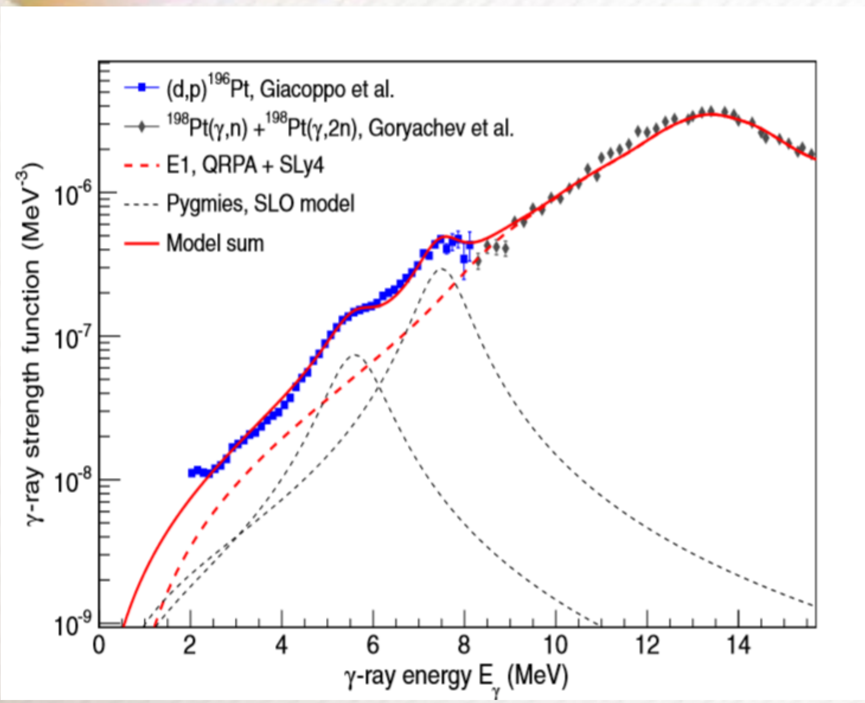
***N. Simbirtseva*[1,2], F. Bečvář[3], R. Casten[4], A. Couture[5], W. Furman[1], M. Krtička[3], S. Valenta[3]**

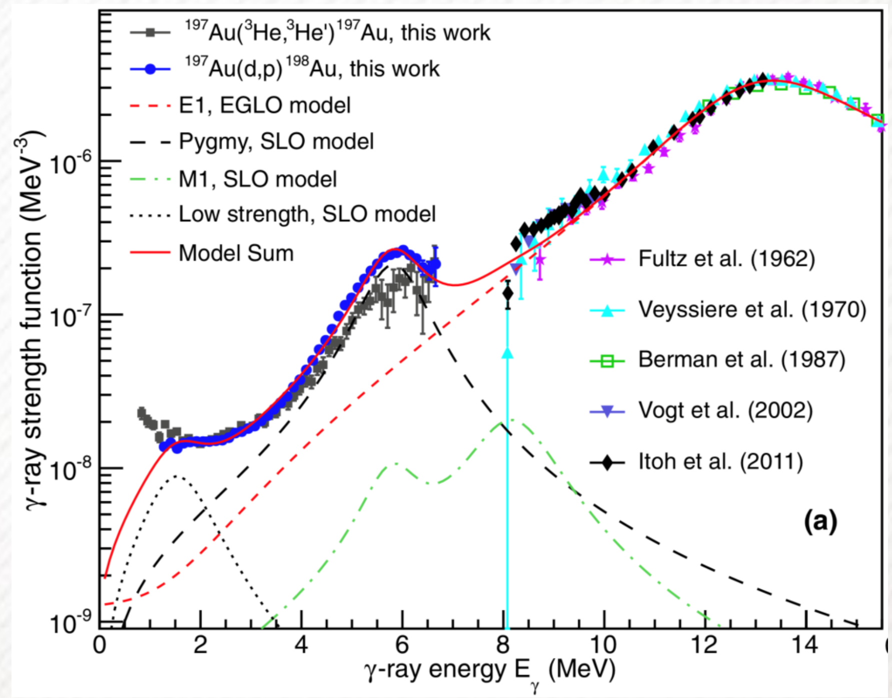
[1]Joint Institute for Nuclear Research, RU-141980, Dubna, Russia
[2]Institute of Nuclear Physics, Almaty, 050032, the Republic of Kazakhstan
[3]Charles University in Prague, CZ-180 00 Prague 8, Czech Republic
[4] Yale University, Wright Lab, New Haven, CT 06520 USA and MSU FRIB, E Lansing, MI 48823 USA
[5]Los Alamos National Laboratory, P.O. Box 1663, Los Alamos, New Mexico 87545, USA

Motivation

- The neutron radiative capture plays an important role in the process of nucleosynthesis as well as in the dynamics of nuclear reactors and ADS. The correct and reliable description of (n,γ)-reaction requires detailed understanding of the cascade γ-decay of highly excited nuclear states. This in turn needs information on the photon strength functions (PSFs) and the level density (LD).
- At excitation energy near and below the neutron binding energy B_n the main contribution into PSF comes from E1 and M1 strengths and for discrete excitations near the ground state from the E2 strength too. The E1 part of PSF is mainly given by the giant dipole resonance (GDR) but some additional structures such as the pygmy resonances and scissors modes can play an essential role.
- Data from several different experimental techniques indicate a presence of resonance-like structures in the PSF at E_γ~4-8 MeV in several A~190-200 nuclei.

Motivation



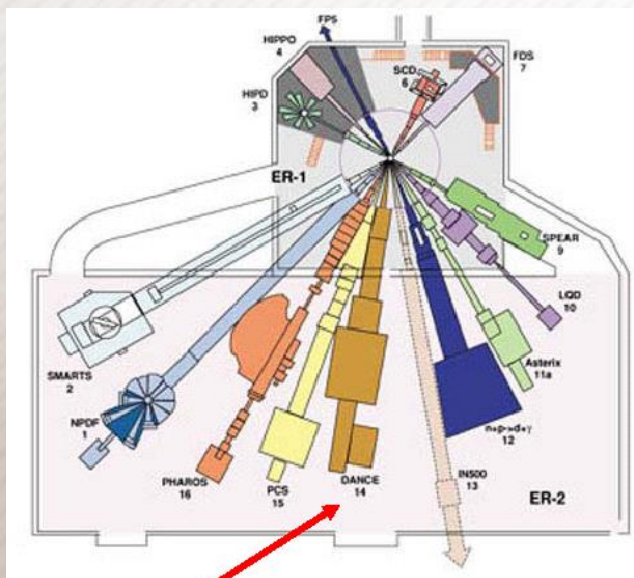


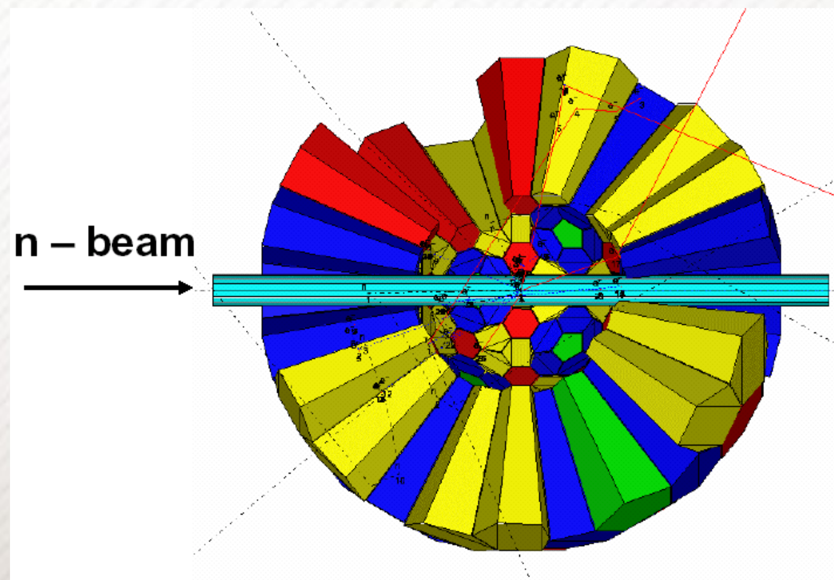
PSF presented in these picture were extracted from experiments when summation took place over many intermediate excited states with wide set of J^{π} combinations.

The experiment ^{195} Pt (n, γ) considered in the present talk performed with aid of the multidetector system DANCE directly measures (n, γ)-reaction from isolated compound-states of ^{196}Pt nucleus with known J^{π} . Moreover there is measured spectra of multy-step cascades (MSC) by γ-coincidence-method.

DANCE @ LANSCE

- Spallation neutrons were produced by irradiation of a tungsten target with 800-MeV protons
- Moderated W target gives “white” neutron spectrum, ~14 n’s/proton
- DANCE is on a 20 m flight path /
  ~1 cm @ beam after collimation
- repetition rate 20 Hz
- pulse width ≈ 125 ns
- DANCE consists of 160 BaF_2 crystals



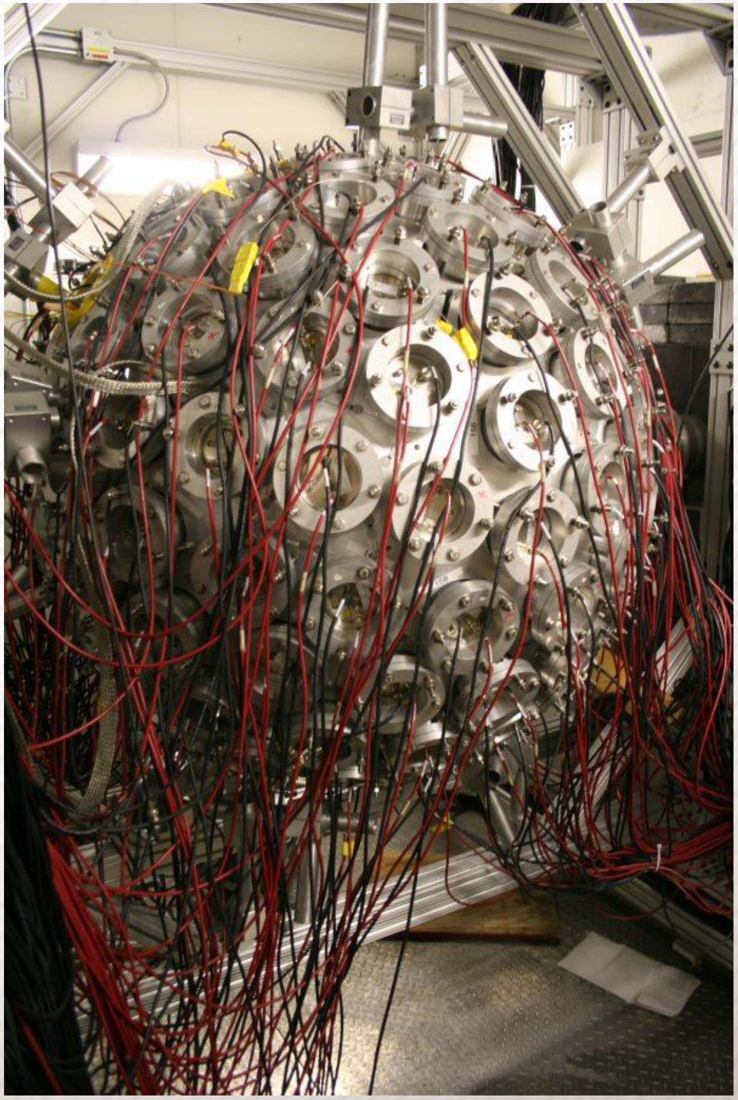


DANCE detector

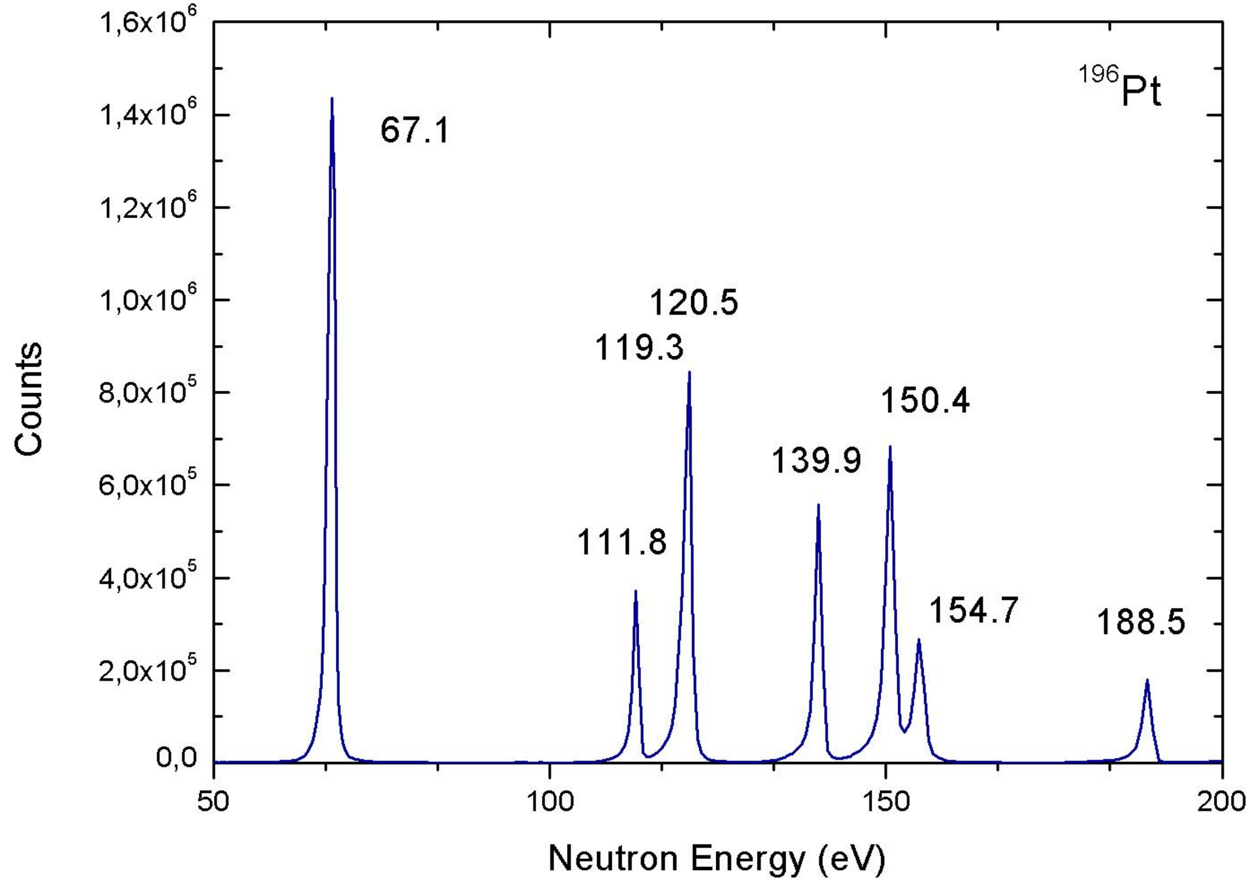
- Measurement of cross sections of small amounts of (radioactive) samples (advanced fuel cycle, astrophysics)

- Determination of properties of neutron resonances (spins and parities)

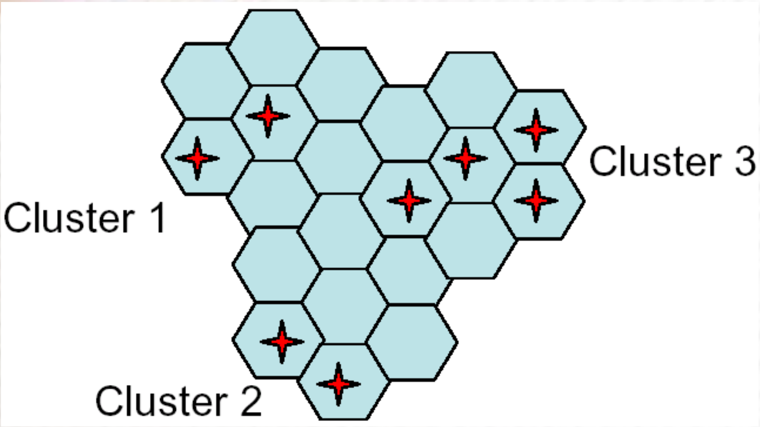
- Study of γ -decay of distinct neutron
  resonances and photon strength functions



“TOF” spectrum for ^{195}Pt

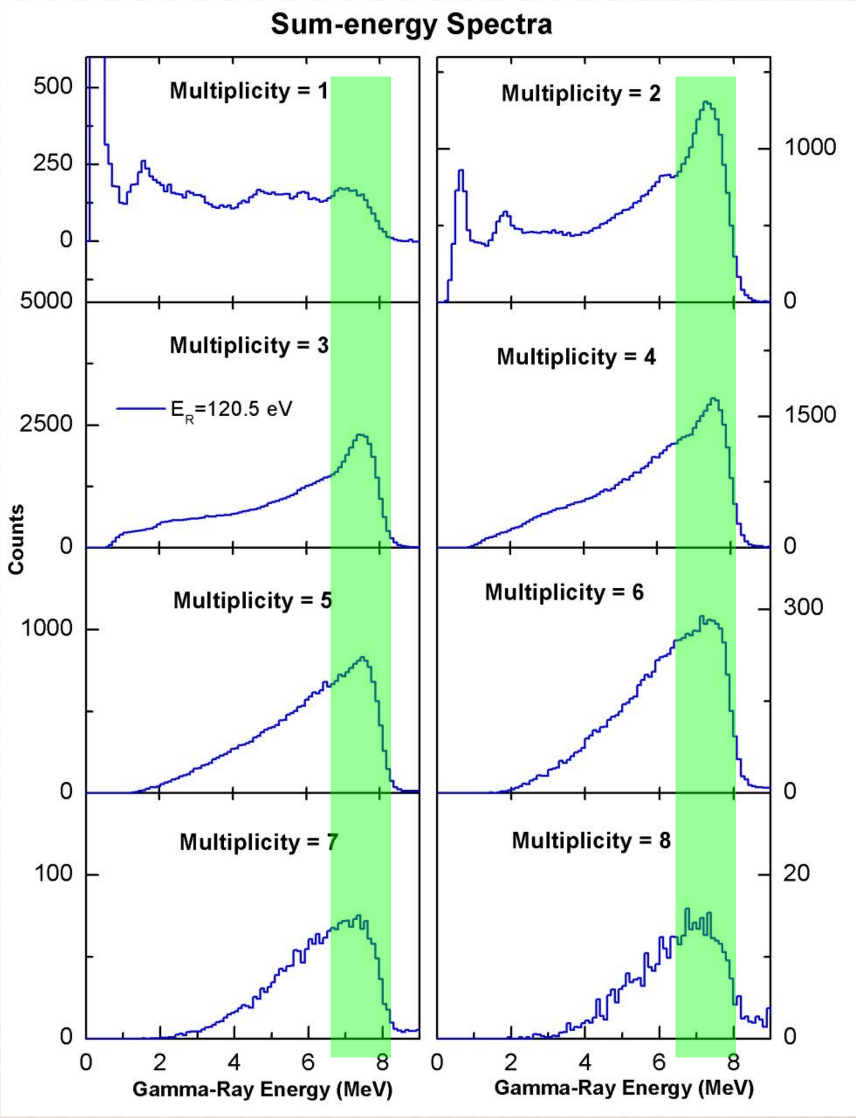


What can be compared?

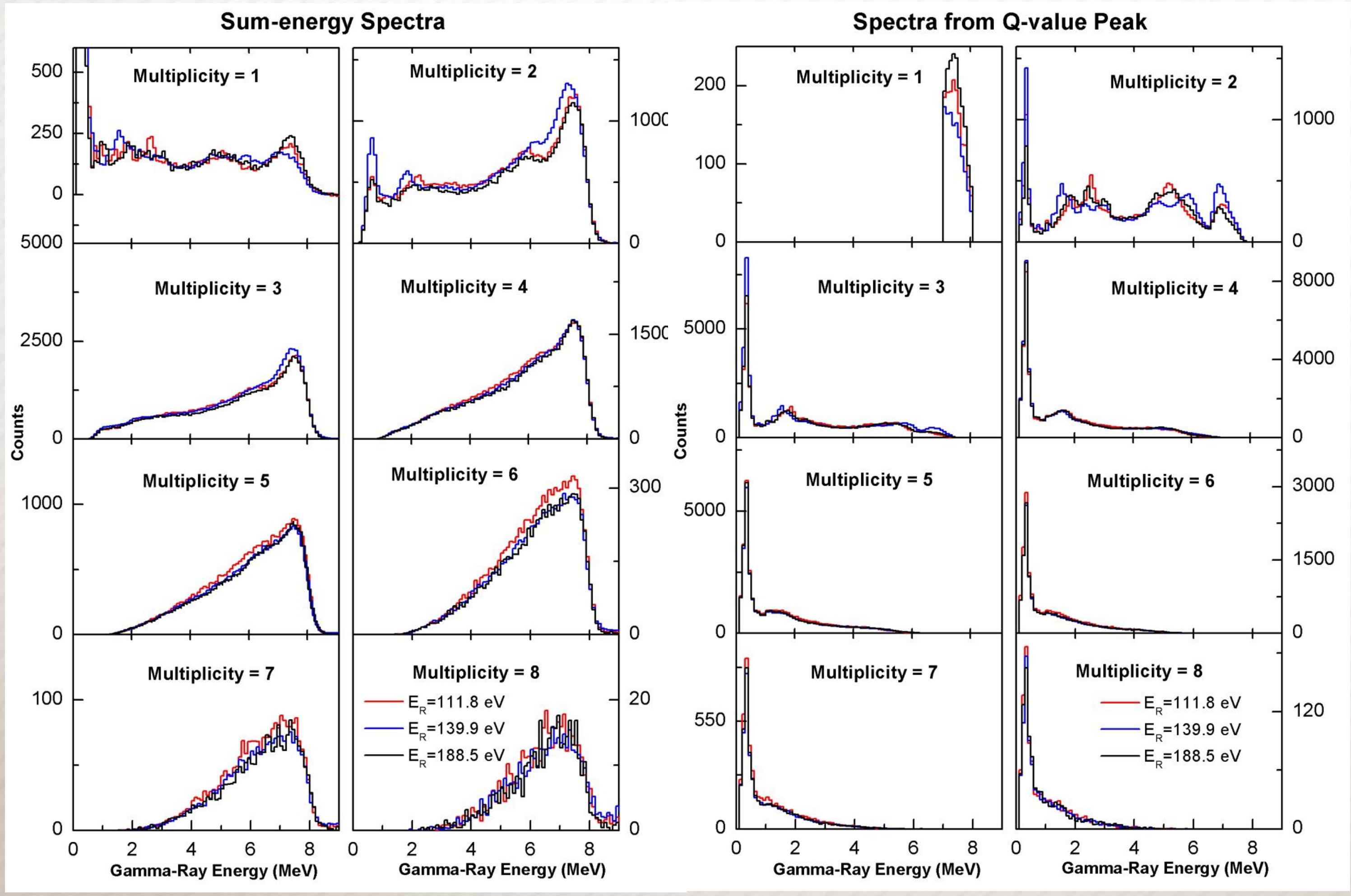


Each spectrum consists of a full-energy peak which is located near the neutron separation energy S_n and a low-energy tail that corresponds to cascades for which part of the emitted γ- energy escaped the detection.

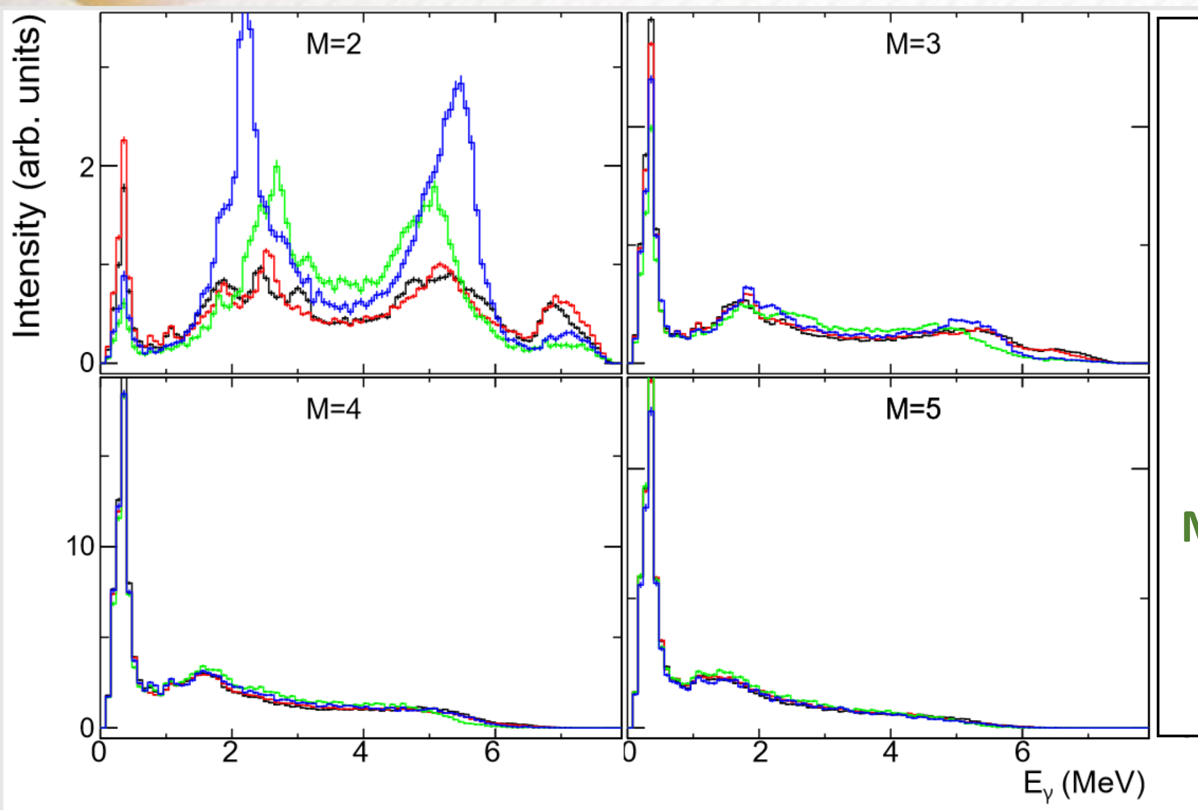
Only events for which the detected E is close to the full-energy peak were included in our analysis.

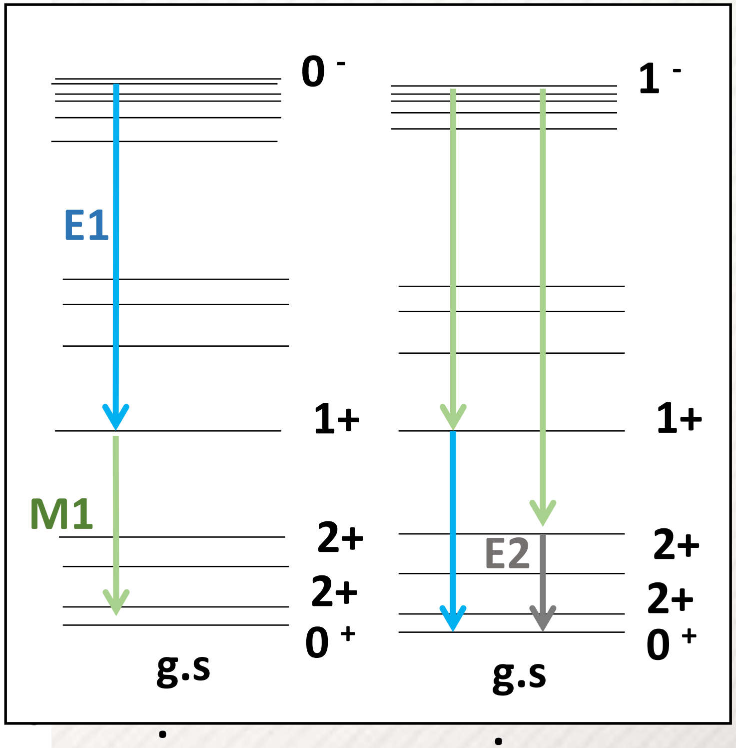


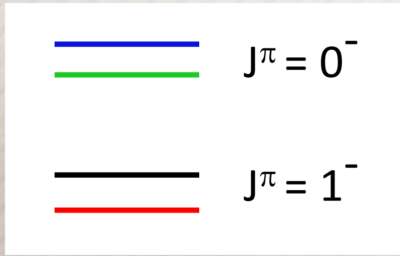
Experimental multi-step γ cascades (MSC) spectra of ^{196}Pt



Experimental spectra from different resonances

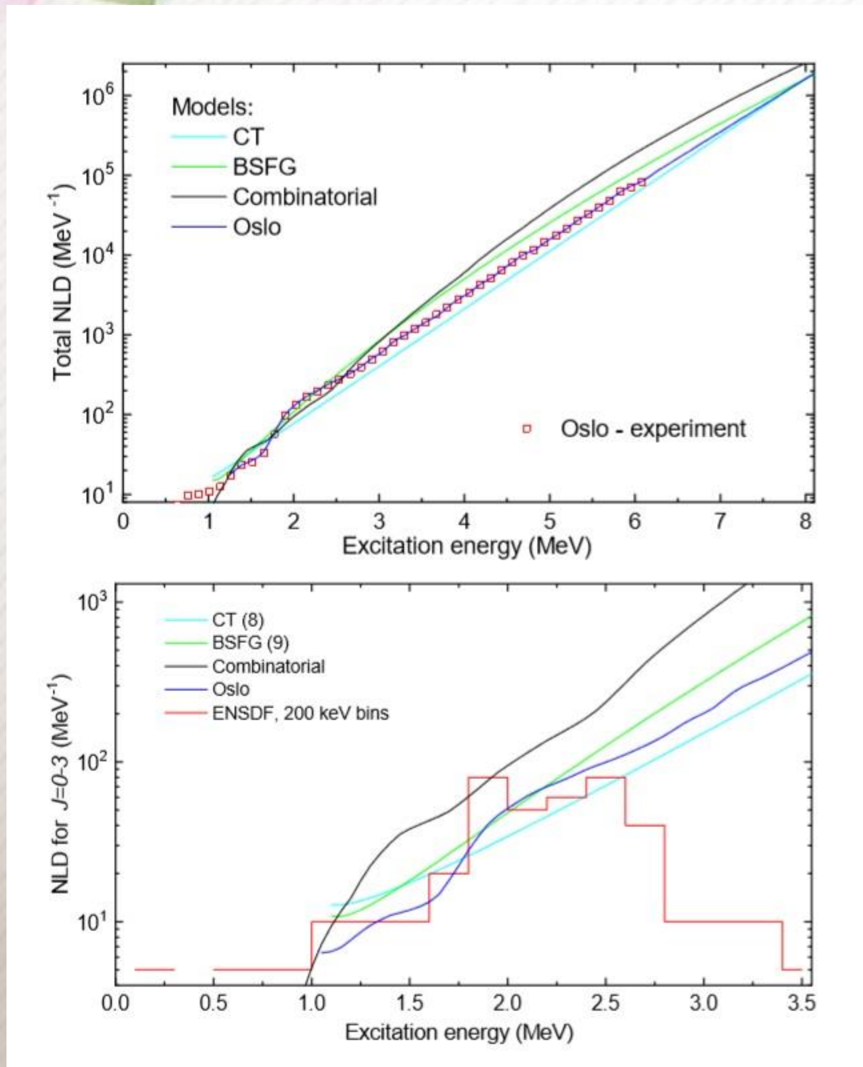






- The experimental MSC spectra are products of a complex interplay between the PSFs, NLD and a non-trivial detector response.
- Experimental spectra are compared with predictions from simulations based on statistical model for different photon strength function (PSF) and level density (LD) models – “trial and error approach”
- DICEBOX code is used for simulation of γ–decay of neutron resonances with different J^{π} ; the detector response simulated using GEANT4

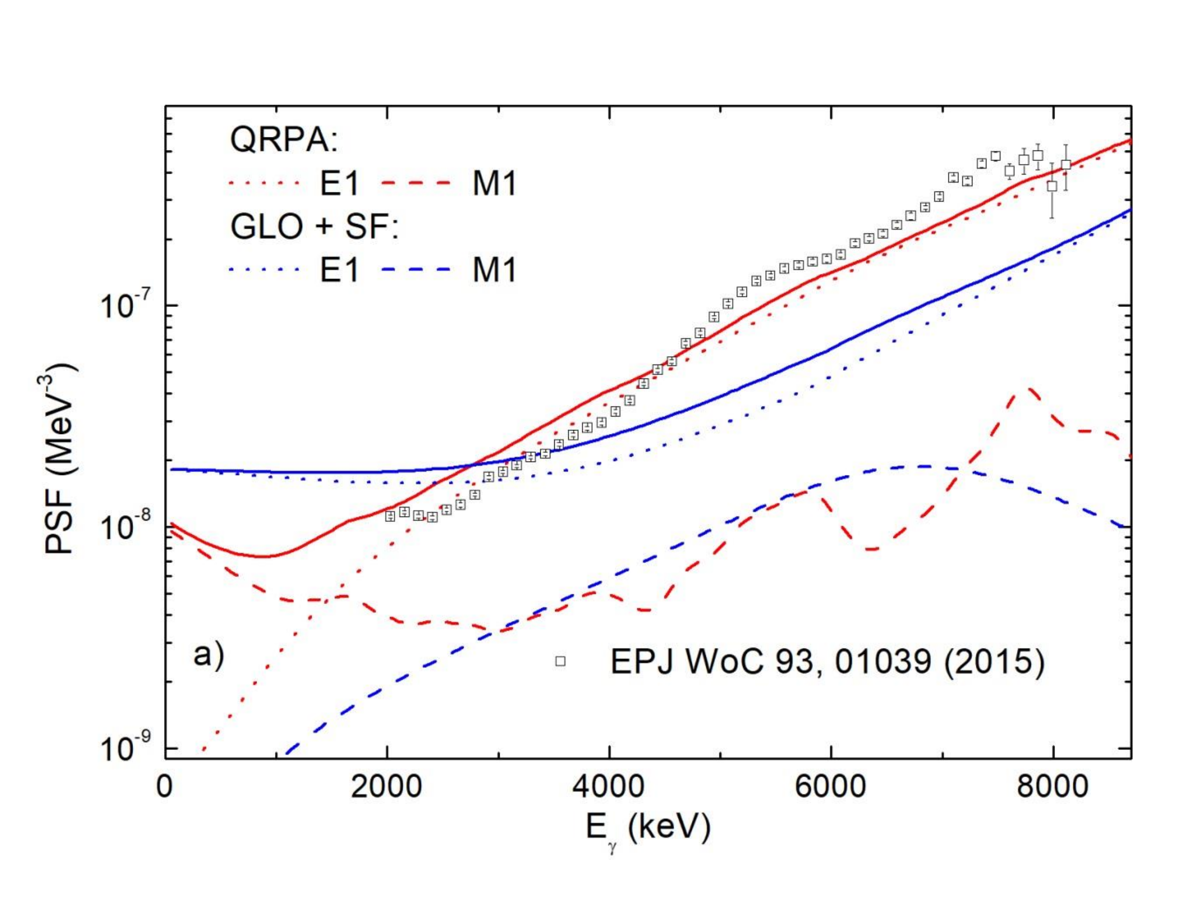
Level density



- For low lying excited states of ^{196}Pt below E_{cr} =1.9 MeV we used known level scheme with respective gamma-transition probabilities.
- Above E_{cr} different models of NLD were tested .
- For ^{196}Pt there is only one negative parity level below E_{cr}. So in NLD models we took it into account respective parity dependence up to about 4 MeV. (PhysRevC.67.015803)

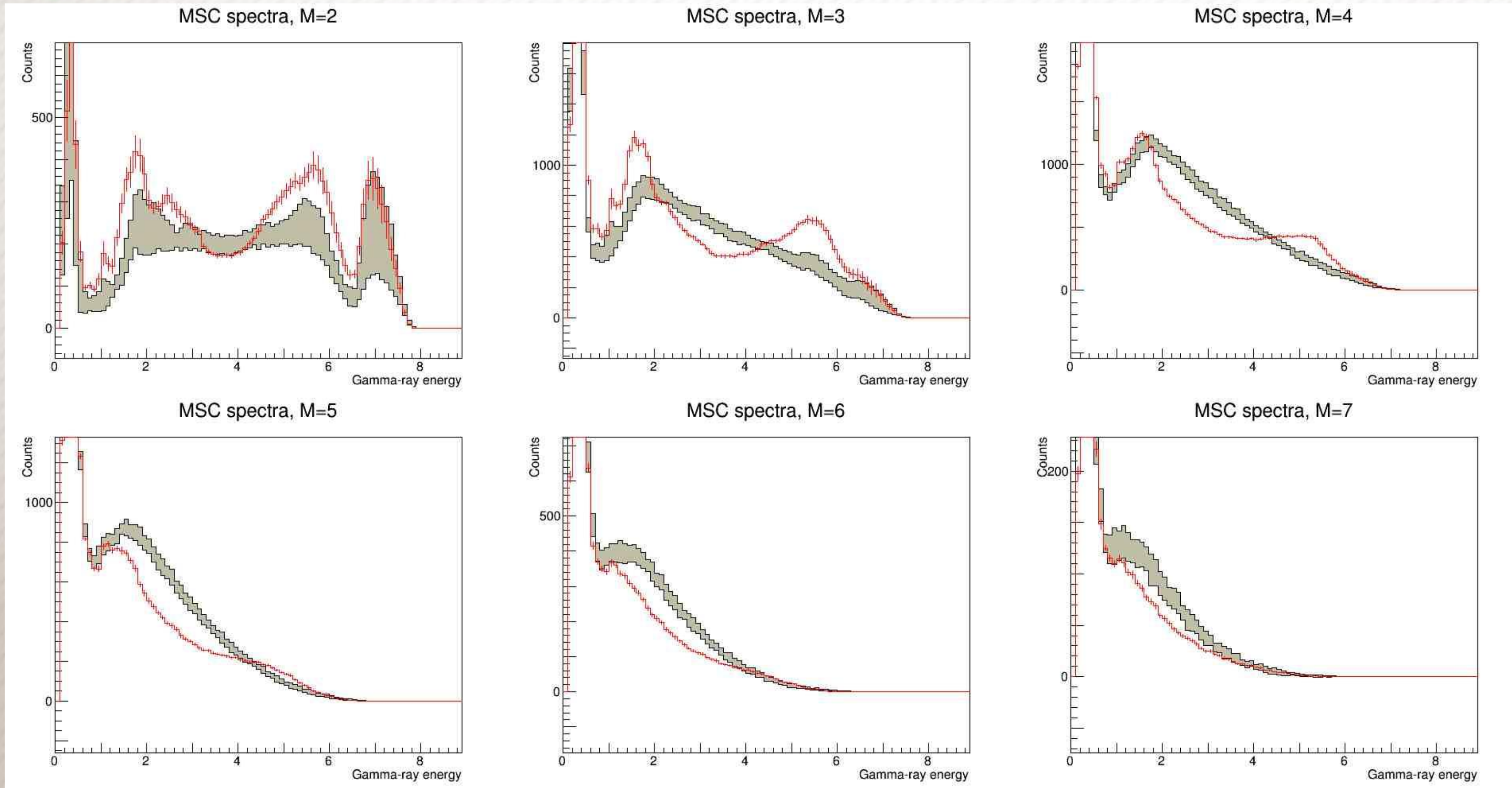
Standard models of PSF

- Let’s start with PSF models that are recommended in the literature. One of them consists of widely used Generalized Lorentzian (GLO) model for E1 and the M1 spin-flip Standard Lorentzian model.



Comparison of MSC data with simulations

For NLD were used Oslo LD model.

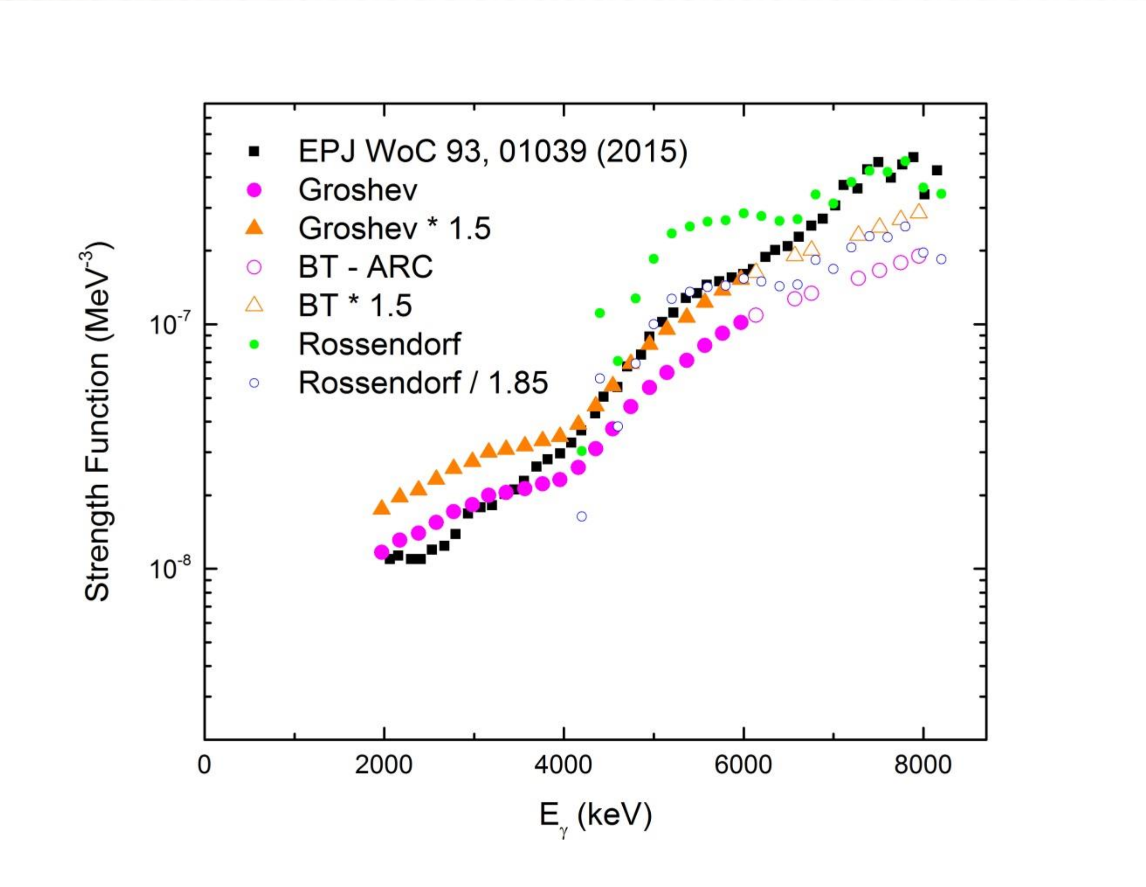


The MSC spectra averaged over 1^- resonances.

Simulation

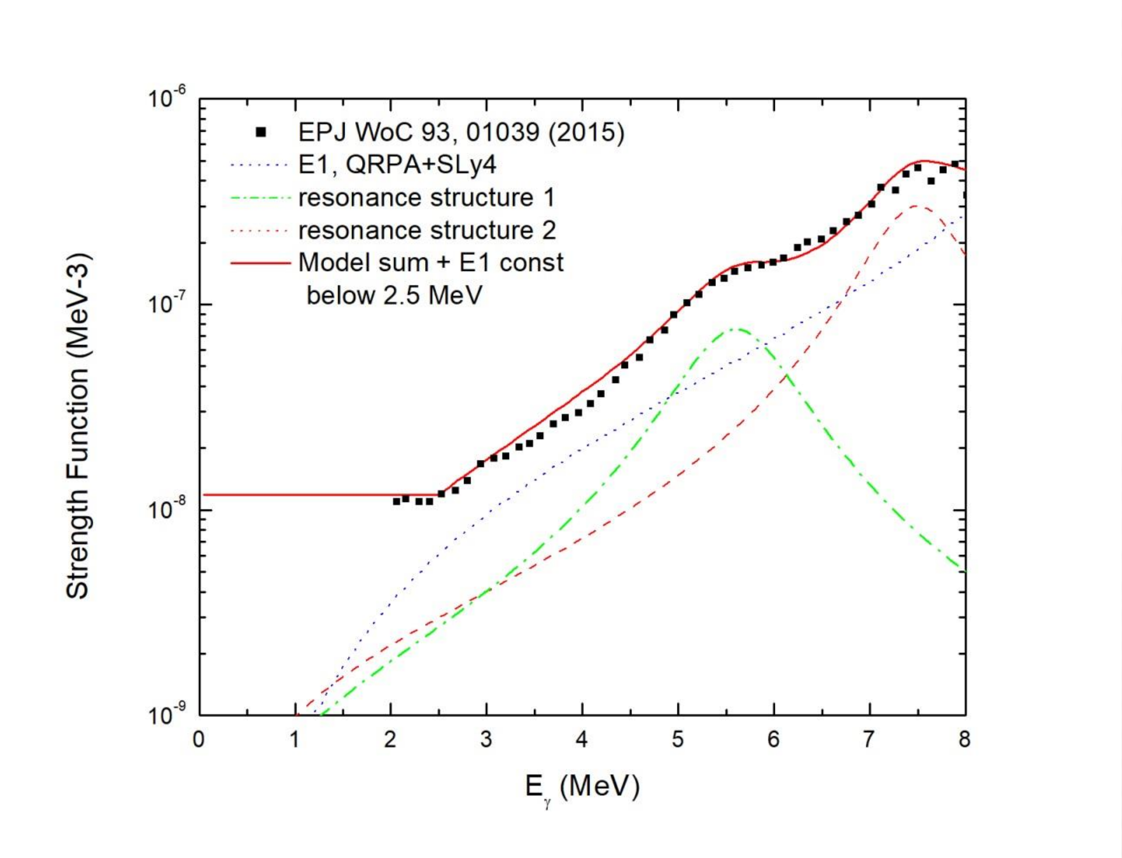
Phenomenological PSF models

- Several phenomenological models from several experiments were tested.



Models based on all tested data seem to indicate a presence of the bump-like structures. In all cases, the PSFs data are absent for low gamma-energies and an extrapolation is thus needed.

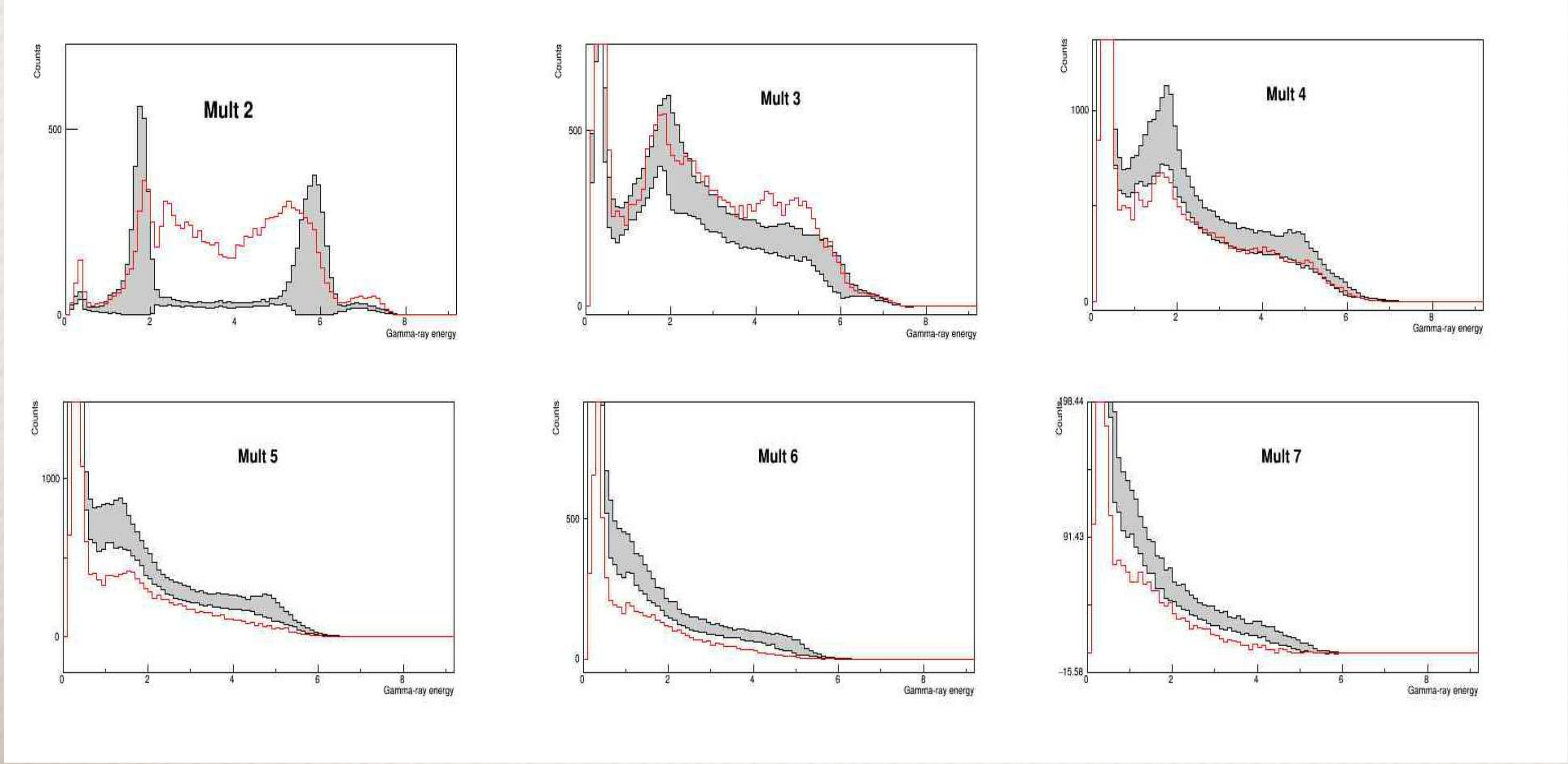
Modified Oslo Model of PSF



The basic model which we used are shown in the picture. It consists of QRPA with constant below 2.5 MeV for E1 and two resonance structures near 5.6 and 7.5 MeV. We tested the E1 or M1 character of this resonances.

Comparison with simulations

- To clarify a role of M1 PSF we tried the model where the both resonance structures have E1 character.

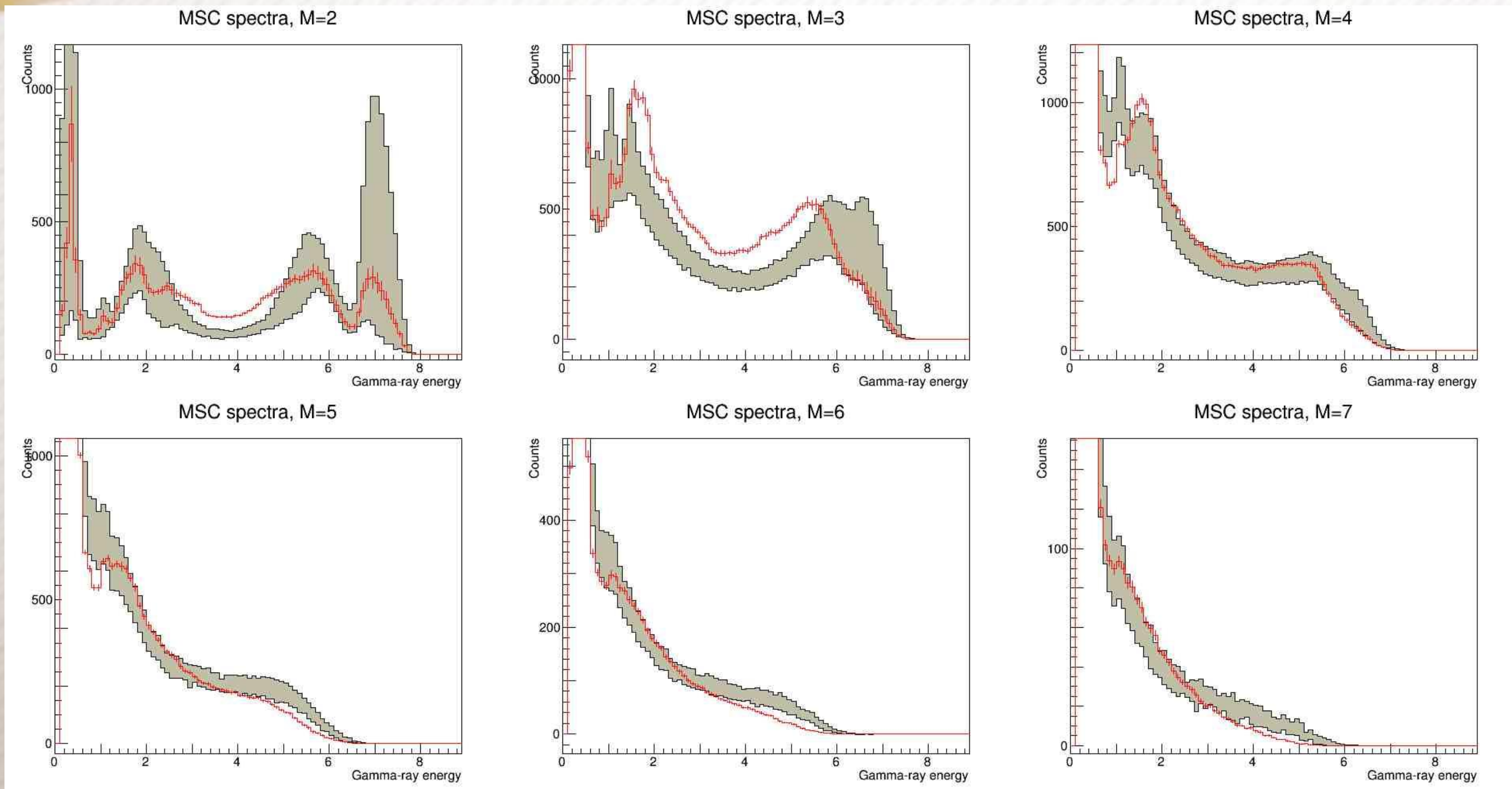


The MSC spectrum for 0^- resonance with E= 309.6 eV .
Simulation

The comparison proves that the M1 strength is not negligible.

Comparison with simulations

- To clear out a role of M1 PSF we tried the model where the both resonance structures have E1 character.

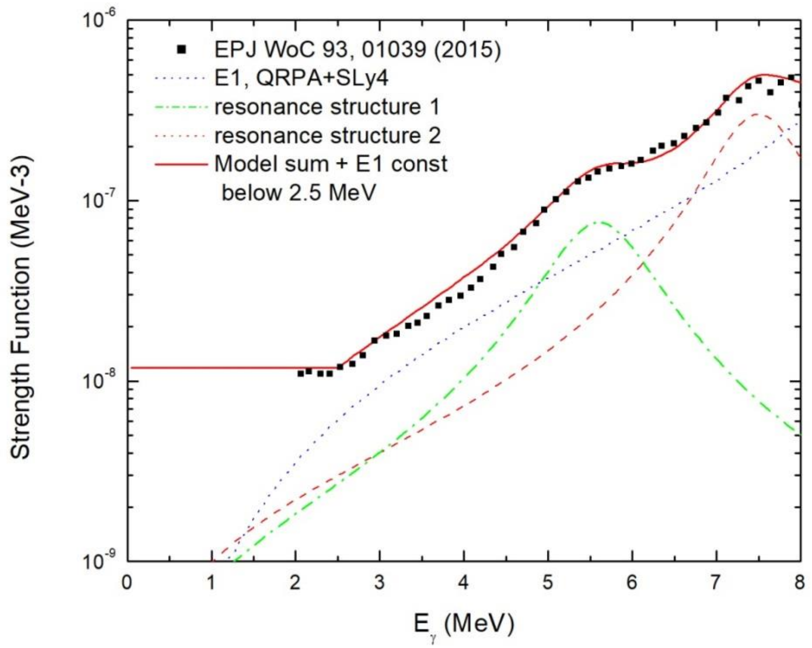


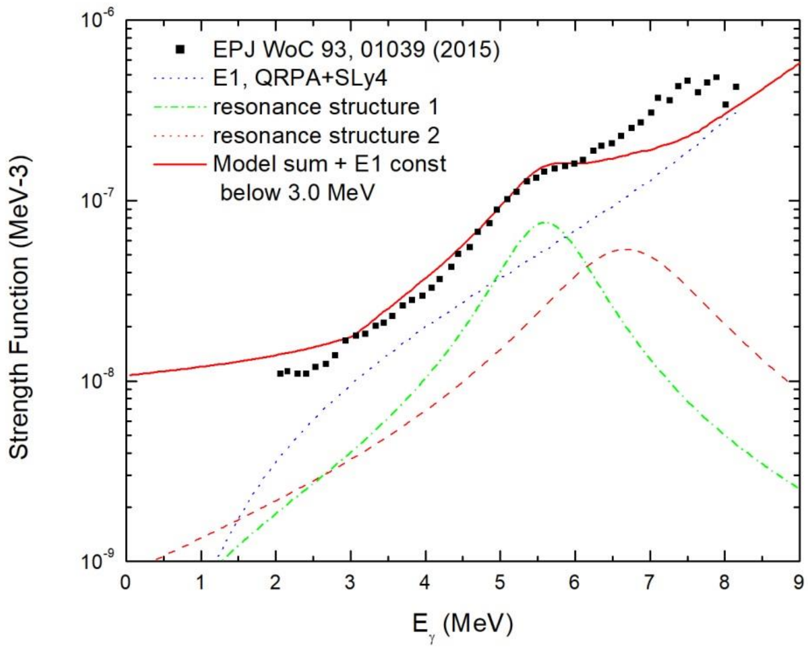
The MSC spectra averaged over 1^- resonances.

Simulation

The comparison proves that the M1 strength is not negligible.

Tested models of PSF

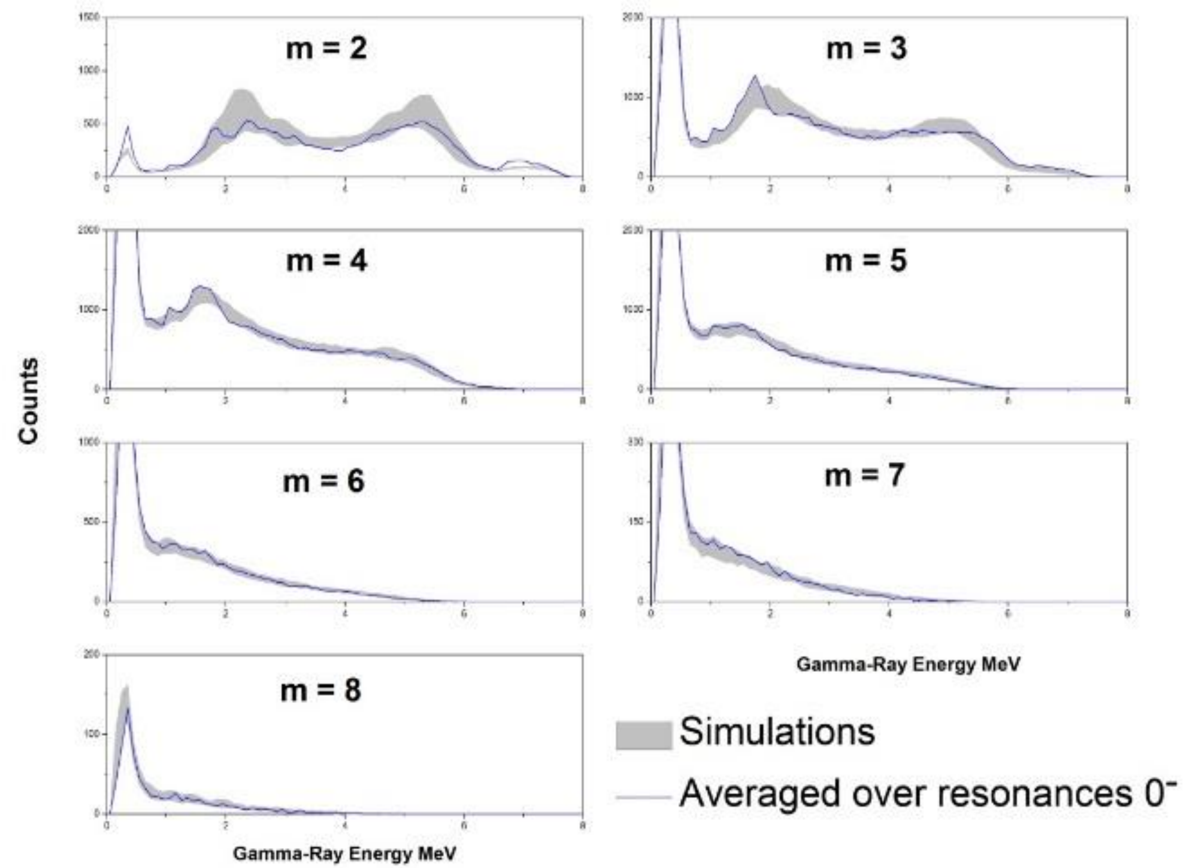




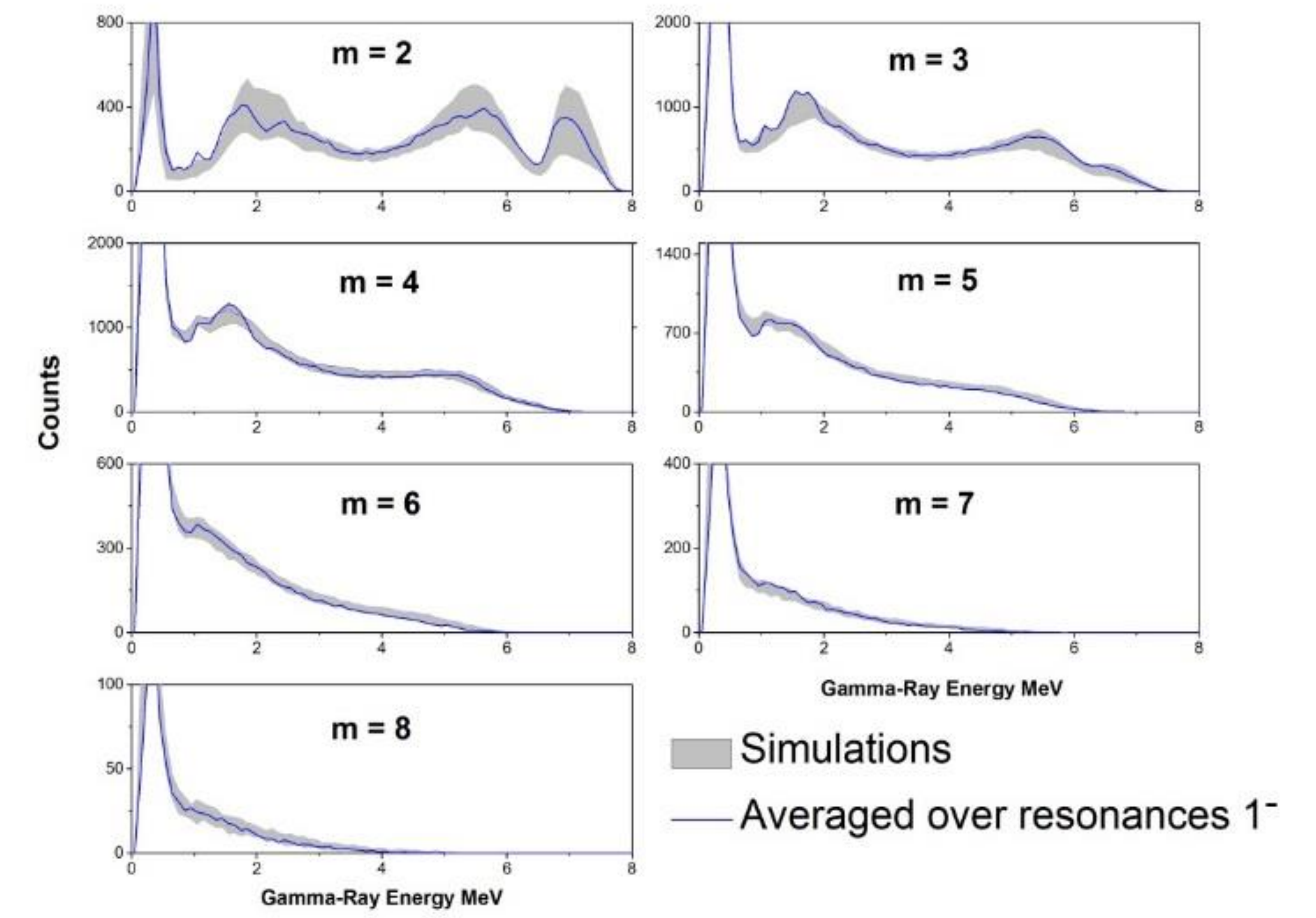
We tested of many variants of M1 strength in this PSF. More or less satisfactory agreement was obtain if we introduce M1 resonance structure at about 5.6 MeV together with E1 pigmy resonance at 7.5 MeV.

However much better agreement with experimental MSC spectra was obtained with PSF shown on the right panel. It consists of E1 QRPA plus constant below 3.0 MeV and E1 pigmy resonance at 5.6 MeV as well as M1 spin-flip resonance at 6.0 MeV. The M1 resonance has relatively small magnitude and allows E1 strength to dominate in the PSF over M1 one in all gamma energy range.

“Best” agreement



“Best” agreement



Conclusions

- Simulations with PSFs that do not contain any resonance structure near E_γ ~ 5.6 MeV were found to be unable to reproduce the shape of the MSC spectra. So our results confirm a presence of a resonance-like structure at this energy. It is most probable this resonance is E1 type. The conclusion is in agreement with experimental data of thermal neutron radiative capture.
- A reasonable reproduction of MSC spectra requires PSF which is not very far from a constant value for $E_\gamma < 2\text{-}3$ MeV. Predictions with PSFs models having either a zero limit or a limit higher than about 2×10^{-8} MeV^{-3} for $E_\gamma = 0$ are unable to correctly reproduce the MSC spectra.
- Simulations with PSF without E1 resonance near 7.5 MeV reproduce experimental data better for E_γ ~ 6.5 MeV than with inclusion of this resonance.
- Our analysis also indicates that the M1 strength is not negligible.
- We have also found that the simulated MSC spectra are sensitive to parity dependence of the LD for excitation energies below about 4 MeV. A parity dependence can be expected as there are only a few negative parity levels below about 2 MeV known in ^{196}Pt.

Thanks for your attention !

Simulation of γ cascades - DICEBOX algorithm

Main assumptions:

- For nuclear levels below certain "critical energy" spin, parity and decay properties are known from experiments
- Energies, spins and parities of the remaining levels are assumed to be a random discretization of an *a priori* known level-density formula
- A partial radiation width $\Gamma_{i\gamma f}^{(XL)}$, characterizing a decay of a level *i* to a level *f*, is a random realization of a chi-square-distributed quantity the expectation value of which is equal to

  $$f^{(XL)}(E_\gamma)\, E_\gamma^{2L+1}/\rho(E_i),$$

  where $f^{(XL)}$ and ρ are also *a priori* known
- Selection rules governing the γ decay are fully observed
- Any pair of partial radiation widths $\Gamma_{i\gamma f}^{(XL)}$ is statistically uncorrelated