^{241}Am(n,γ) cross section in the neutron energy region between 0.02 eV and 300 keV

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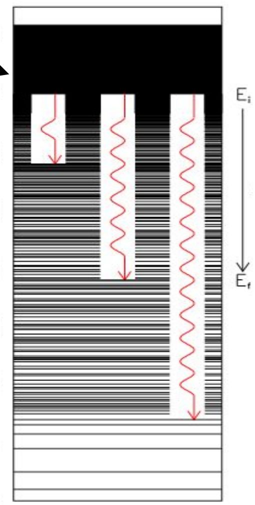
The Detector for Advanced Neutron Capture Experiments (DANCE)

^{242}Am*

$E^{*} = S_n + E_n = Q$

$Q = \sum E_\gamma$



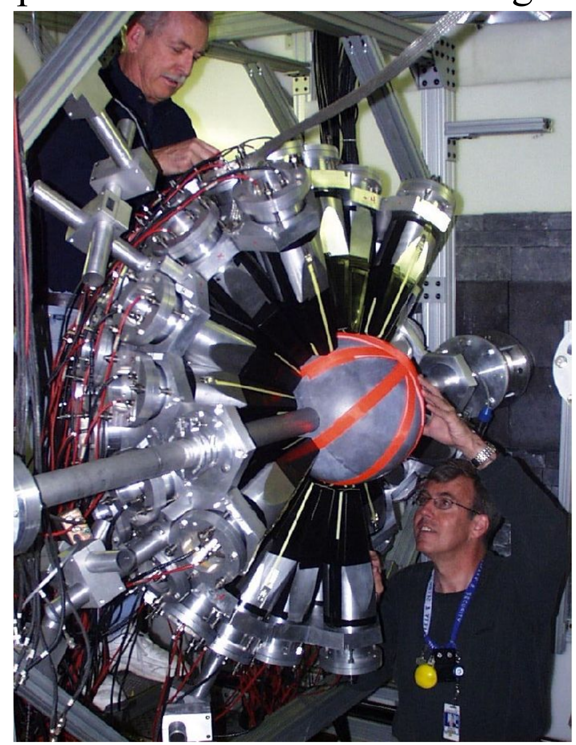
^{242}Am (g.s.)

- Neutron capture process: n+^{241}Am→^{242}Am*, cascade of γ-rays is emitted from excited compound nucleus to reach to g.s. of ^{242}Am
- Excitation energy of ^{242}Am*

  $$E^{*} = S_n + E_n = Q = \sum E_\gamma,$$
- By γ-ray detection the capture process can be identified using total absorbed energy

DANCE

- Located at the Lujan Center at the Los Alamos Neutron Science Center on flight path 14
- 160 BaF_2 crystals in 4π geometry
- ^{6}LiH ball placed around the target to attenuate scattered neutrons
- Designed to run with radioactive targets (up to 1 Curie)



Data Acquisition

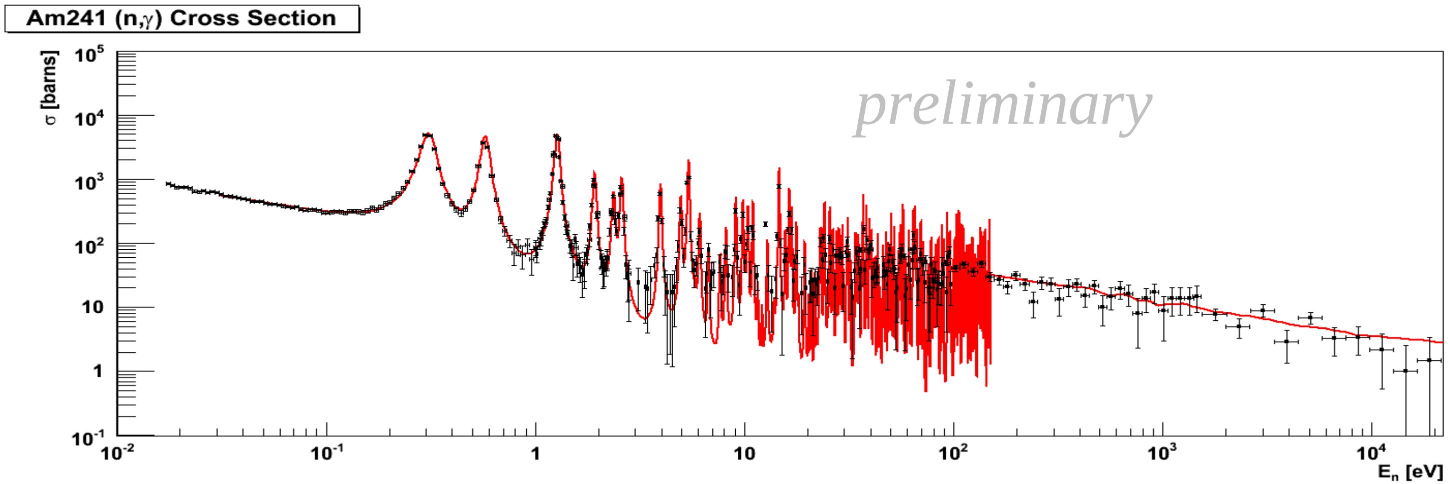
- 324 channels of Acqiris DC265 digitizers 500 Msamples/s
- 14 frontend computers
- Raw Data:
  - Typical BaF_2 signal consist from slow and fast component
  - Software CFD identifies the signal
  - The fast component: 32 points of a waveform (64 ns)
  - The slow component: 5 x 100-point sections which are integrated (5x200 ns)
  - Reduced waveform is then stored to disk with the timing information
- Off-line Analysis:
  - In the software coincidence window the events are identified
  - For each event we extract (after proper calibrations)
    - Time of the leading edge - E_n
    - Slow and fast component integral - E_γ
    - Multiplicity of crystals and clusters
- DAQ - *J.M. Wouters et al., IEEE Transactions on Nucl. Sci., Vol. 53, No 3., (2006) 880*

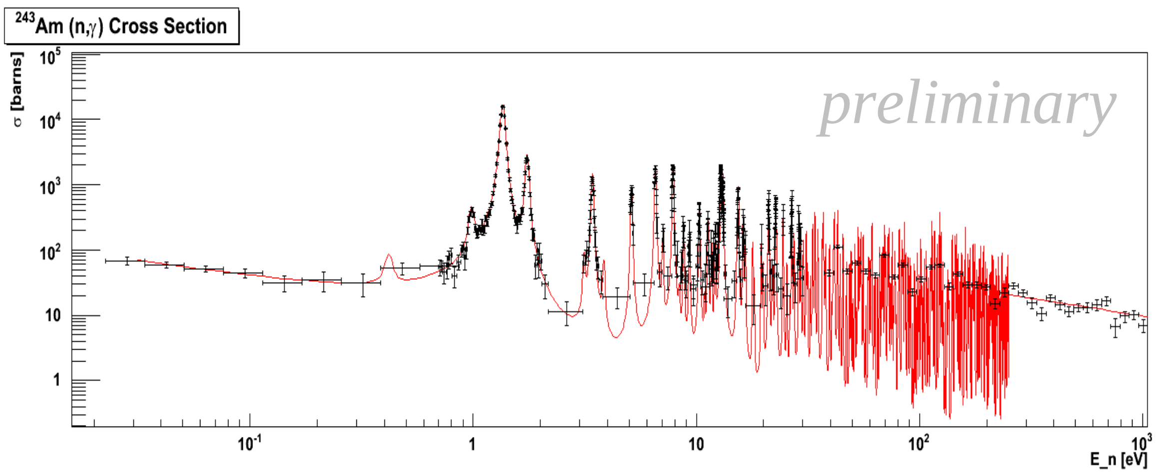
Parallel Plate Avalanche Counter (PPAC)

- Designed to surround the actinide target to help separate competing (n,f) and (n,γ) processes
- The goal is to measure (n,f)/(n,γ) and make improved (n,γ) measurements
- PPAC is used for fission tagging (no info on mass and energy of the fission fragments)
- Working conditions:
  - Two anodes at +250V
  - Cathode "target" at -250V with the sample
  - Isobutane gas flowing at 8 ccm
  - Pressure 6 torr

PPAC is customized to fit in the beampipe

2005 - Results
^{241,243}Am cross section (n,γ)





- PPAC untagged events analyzed
- Larger uncertainties at small σ
- Comparison with ENDF VII (red lines)
- (n,f) contamination is less 0.1 %

2006 - ^{241}Am(n,γ) measurement

- no need for PPAC, cuts on multiplicity and E_{tot} will reduce fission contribution to tenths of a percent
- August 2006 - 17 days of continuous measurement, included data taking in segmented mode 14ms, 2ms (0.02-36eV) and continuous mode above 36 eV, with the sample and blank targets

Experimental quantities to determine

$$\sigma = \left(\frac{A}{N_A \rho_s S} \right) \frac{N_{n,\gamma}}{F \varepsilon_{cut} \varepsilon_{tot}}$$

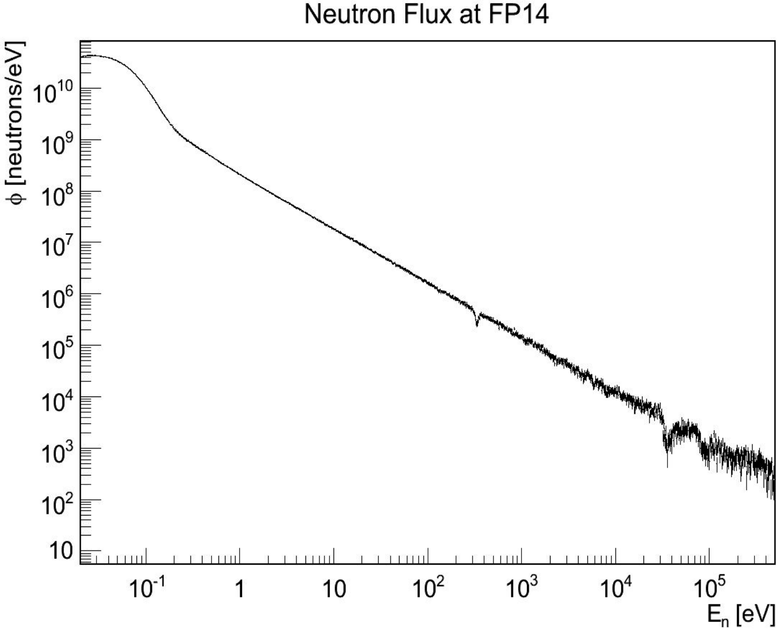
- Mass of the target material $M\ (\rho_s S)$
- Neutron flux F per cm^2, per second, per eV on target
- Total efficiency ε_{tot} of detecting at least one γ-ray from the de-excitation cascade that follows neutron capture
- Efficiency of detecting the cascade ε_{cut} after applying the cuts on experimental data, namely γ-ray multiplicity and total energy of γ–rays
- Flux of γ–rays corresponding to the neutron capture cascade $N_{n,\gamma}$, after the background subtraction

^{241}Am target

- electroplated on two Ti 2.5 um foils sandwiched back-to-back
- covered from both sides with thin aluminized mylar foils
- very pure 99.9% material
- diameter ¼ of inch (6.35 mm)
- total mass from gamma-counting 203(1) ug
- total mass from alpha-counting 219(1) ug
- discrepancy due to the loss of material after alpha counting

Neutron Flux Measurements

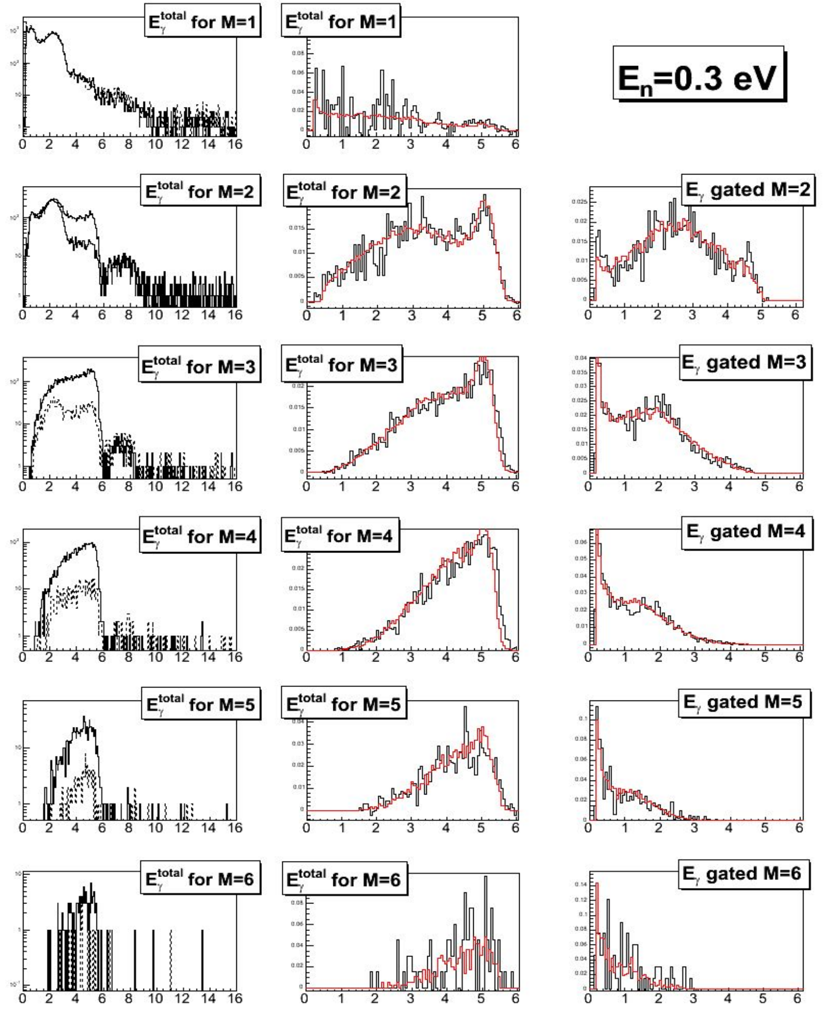
- FP14 uses three neutron beam monitors
  1) foil with enriched ^{6}Li. Products of the break-up are detected in Si detector position perpendicular to beam, 2 cm away from the foil. The foil is at 45 degrees.
  2) BF3 monitor – $^{10}B(n,\alpha)^{7}Li$
  3) U monitor – fission fragments ^{235}U
- three monitors are triggered with the common T_0 trigger as DANCE
- concurrent measurement
- monitors can cover 0-14 ms after T_0



Typical cumulative flux measured with BF3 monitor

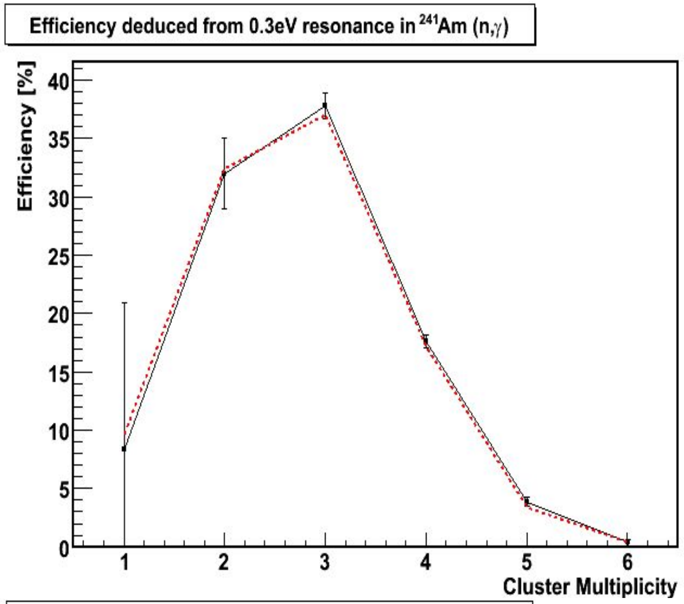
^{241}Am γ-cascade detection efficiency

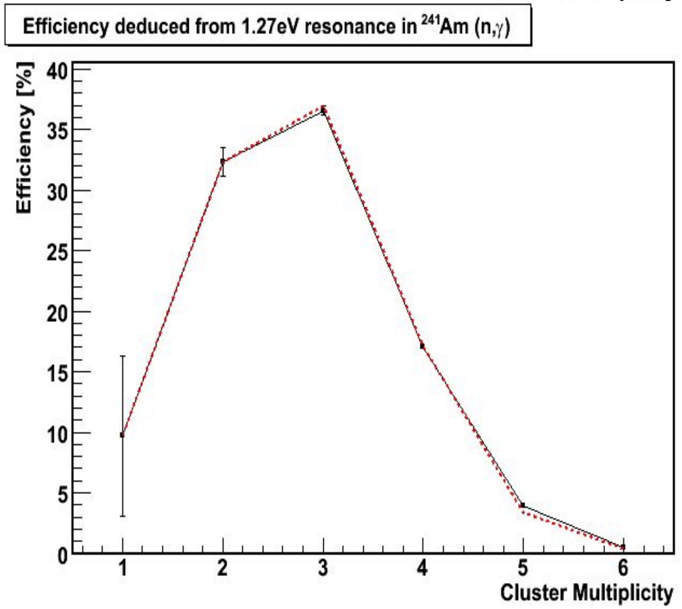
- at resonances the multiplicity distribution can be analyzed
- easy background subtraction
- red lines is DICEBOX-Geant4 calculation assuming average 2.5 spin state
- very good agreement in gamma-ray spectra between experiment and calculation
- withing experimental uncertainties one cannot distinguish spectra from two different resonances !



Cascade efficiency

- multiplicity distribution identical for both resonances
- red lines is DICEBOX-Geant4 calculation assuming average 2.5 spin state
- very good agreement in gamma-ray spectra between experiment and calculation
- withing experimental uncertainties one cannot distinguish spectra from two different resonances !
- the consequence is very important for cross sections analysis, we can apply E_{tot} and M cuts for any neutron energy without the need to make correction for different cascade efficiencies due to different spin state
- Signal-to-noise was found to be best for following cuts: **M=4 and E_{tot}=3.675-6 MeV**, with the total efficiency **0.125(1)**.



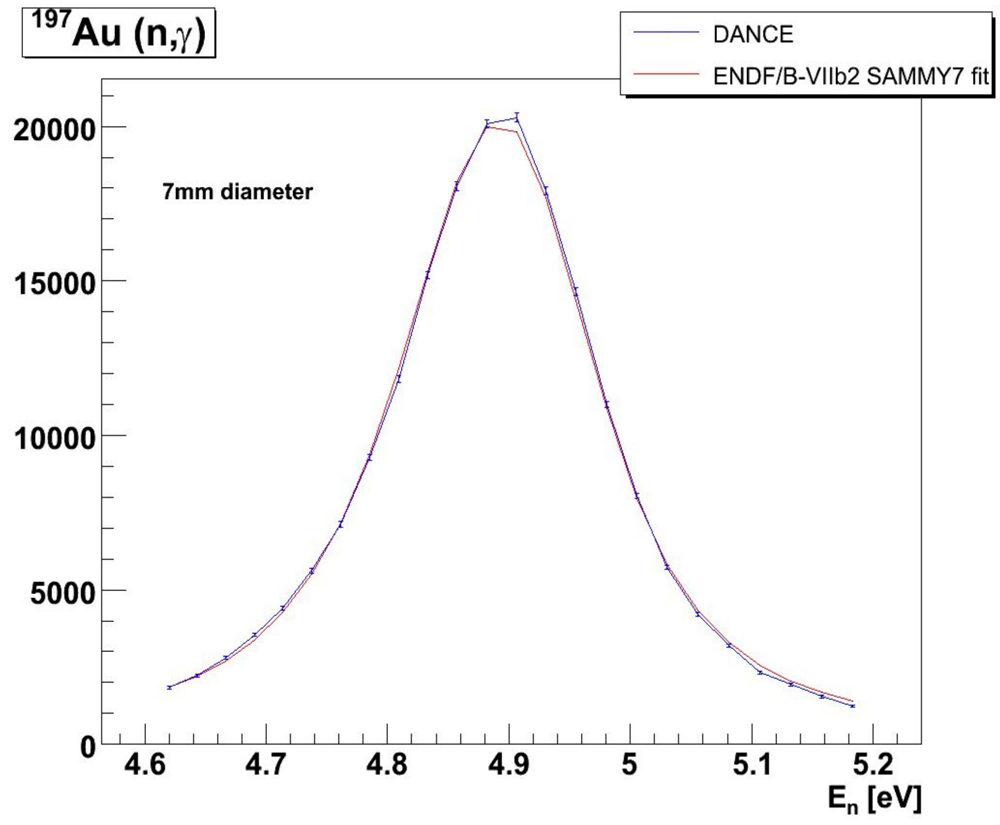


Monitor Flux Normalization

- The idea is to determine the flux at target position using ^{197}Au target with known thickness and the same diameter
- Assuming the shape of flux spectrum doesn't change from experiment to experiment (well confirmed)
- we had 7mm diameter target available of 487.5 nm thickness
- flux measured at the monitor position $F_{target} = a\ f_{monitor}$
- using $$\sigma = \left(N_A \frac{\rho_s}{A} \right)^{-1} \frac{N}{FS} = \left(N_A \frac{\rho_s}{A} \right)^{-1} \frac{N}{afS}$$
- the fit was performed with SAMMY on 4.9 eV resonance with EDNF7 parameters

Monitor Flux Normalization using Au targets

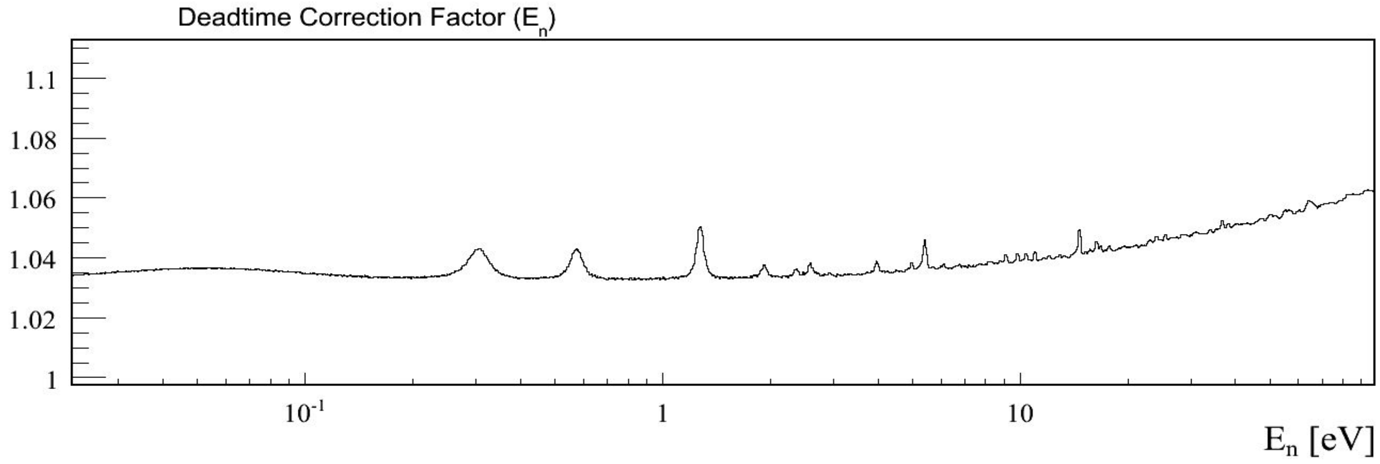
- Flux measured with BF_3 monitor during Au(n,γ) measurement
- self shielding correction applied on the data
- 7mm diameter - 478.5 nm thickness
  - a = 0.866
- 4mm diameter - 492.5 nm thickness
  - a = 0.887
- to reduce uncertainties we will remeasure flux profile at target position



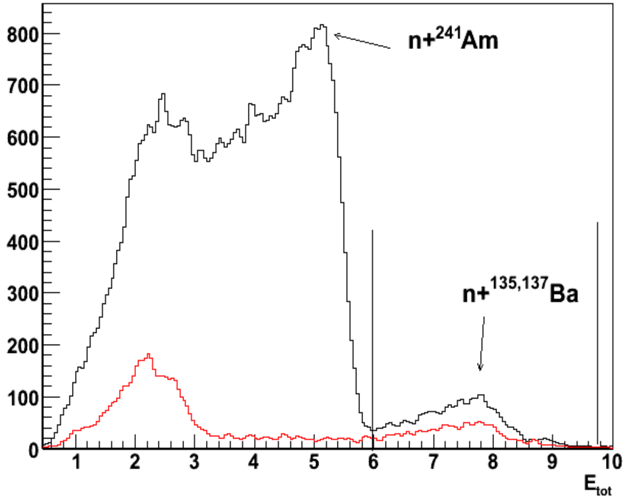
Summary of important variables

- Mass of ^{241}Am: 219(1) μg
- Best signal-to-noise ratio: M=4, E_{tot}=3.675-6 MeV
- Total cascade efficiency: $\varepsilon_{tot}\varepsilon_{cut}$= 0.125(1)
- Flux normalization factor: a = 0.870(1)

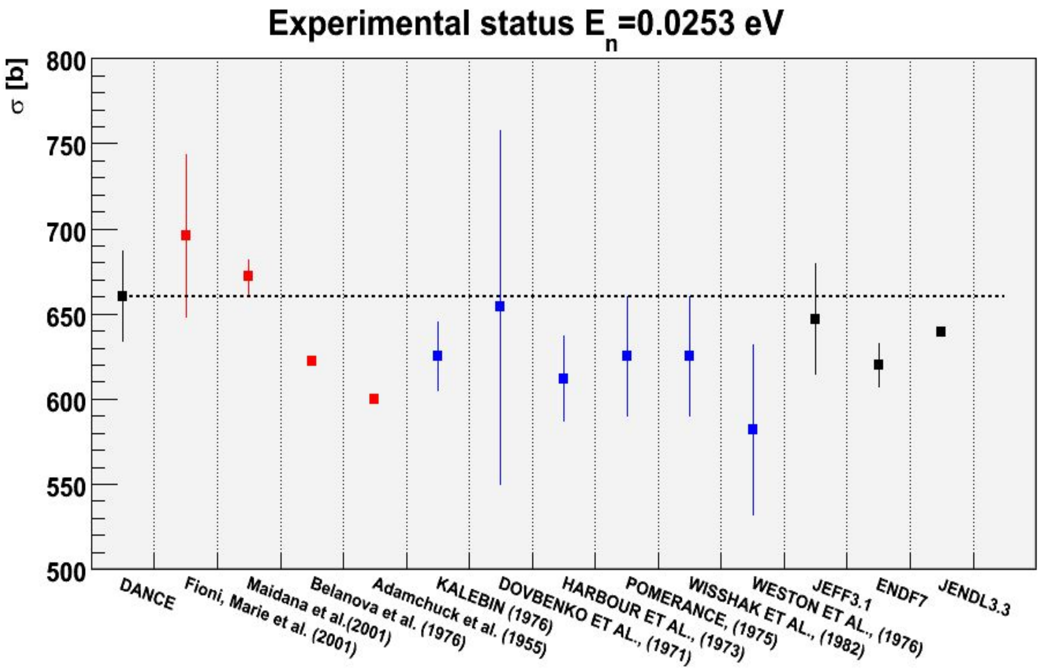
N(n,γ) spectrum

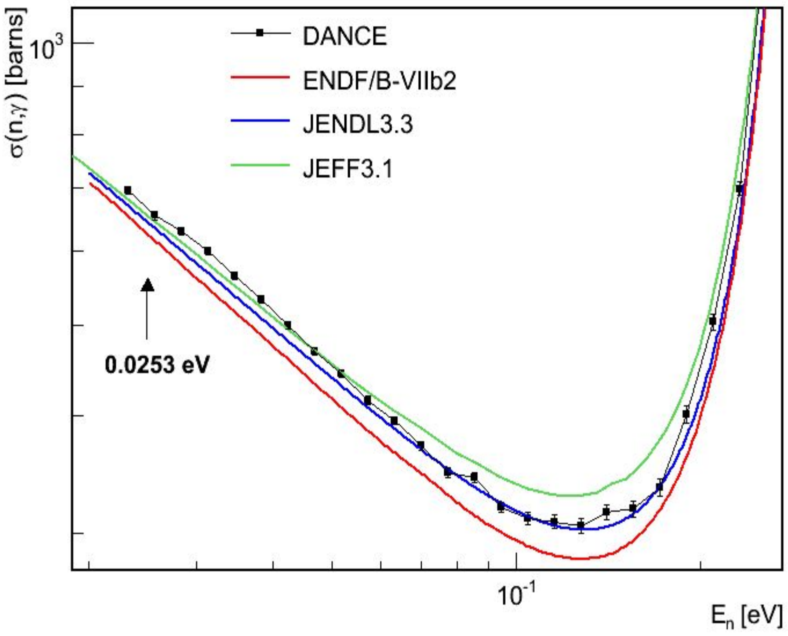


- In segmented mode we apply dead time correction
- Best signal-to-noise ratio: M=4, E_{tot}=3.675-6 MeV
- Background is subtracted using the blank runs and normalizing on Ba capture peaks in every bin

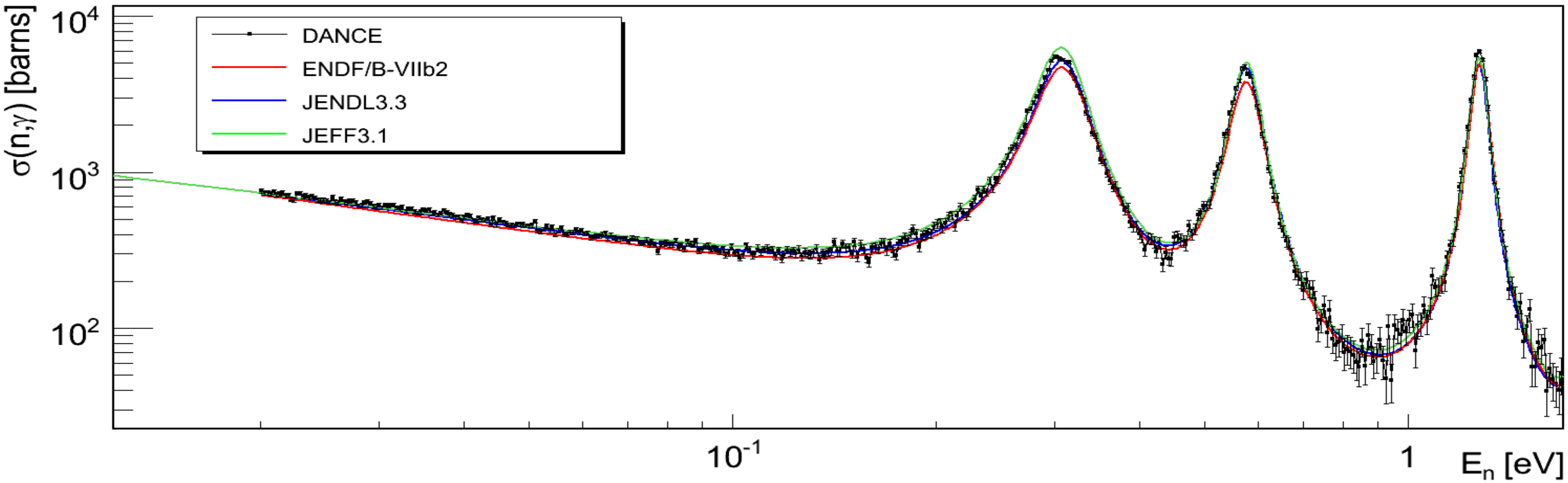


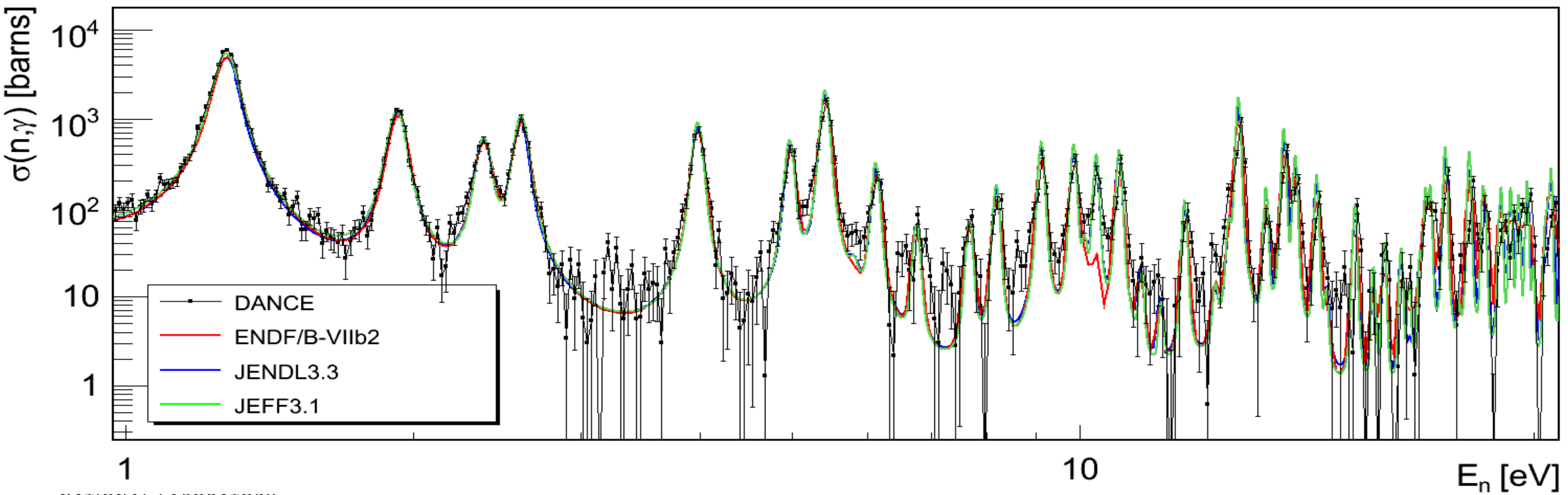
Cross section at thermal





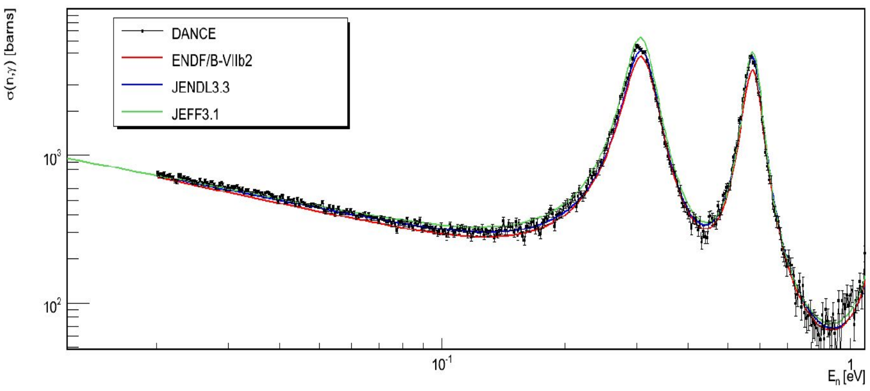
Cross section 0.02-36 eV   (bins 1%)

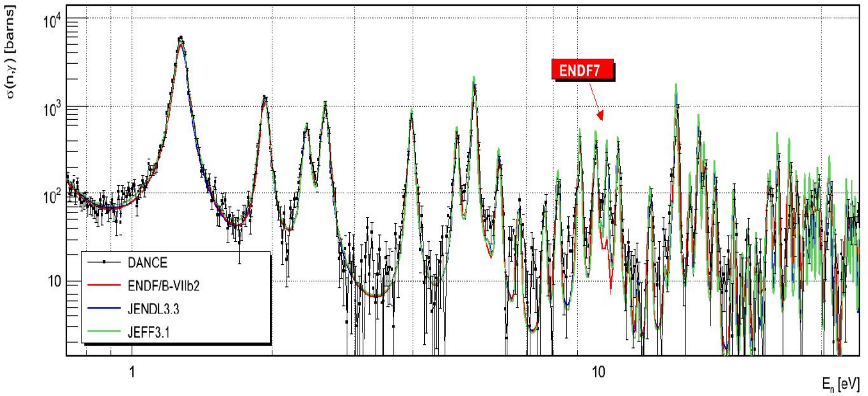


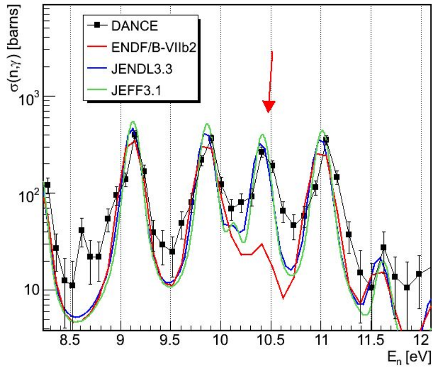


Cross section 0.02-36 eV

- At first two resonances our data are closer to JEFF and JENDL evaluations than ENDF
- self shielding correction was not applied yet on the data, and is planned at the last stage when precise SAMMY fit will be performed
- resonance at 10.4 eV is underestimated in ENDF evaluation (our analysis excludes fission contribution to a high degree)
- statistical uncertainties are decided manly with dE/E choice
- at thermal (0.02-0.1eV) 4% systematic uncertainty should be considered, stemming from the inconsistency between our beam monitors

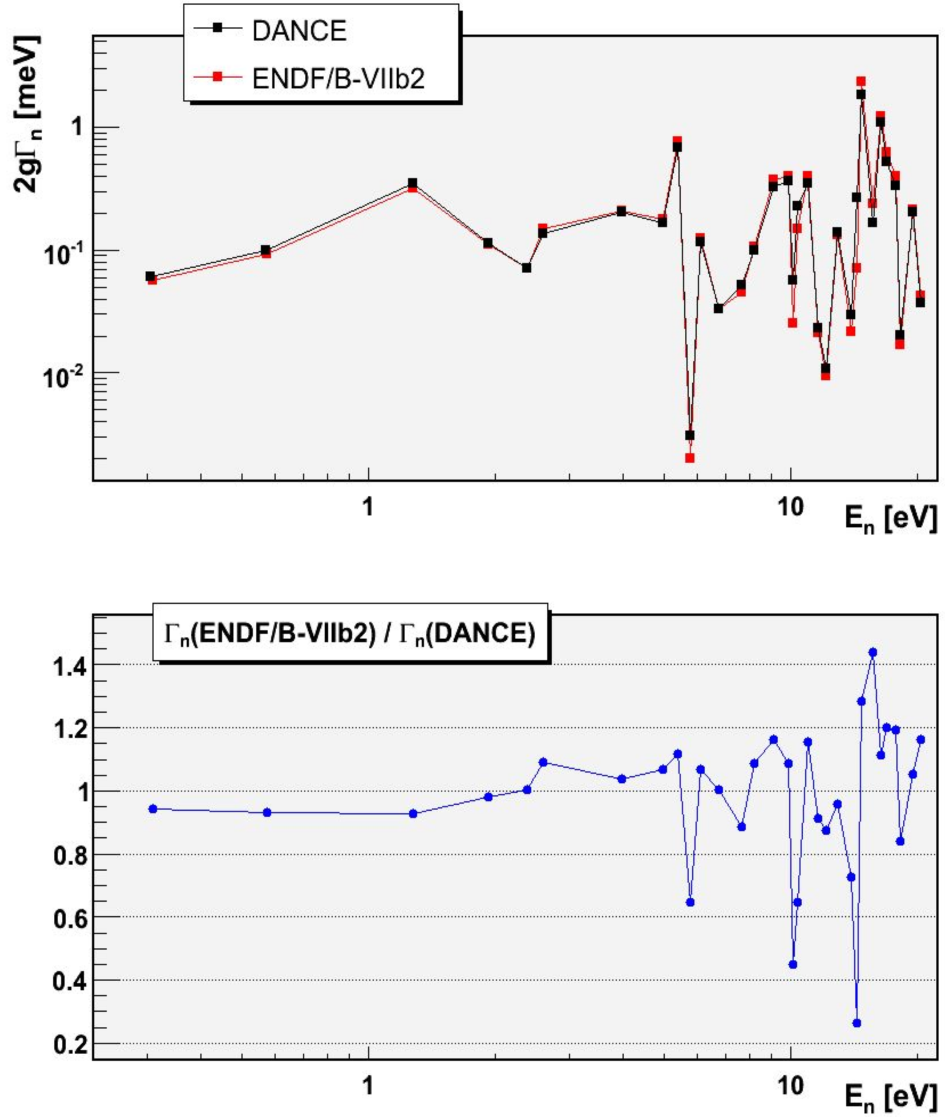




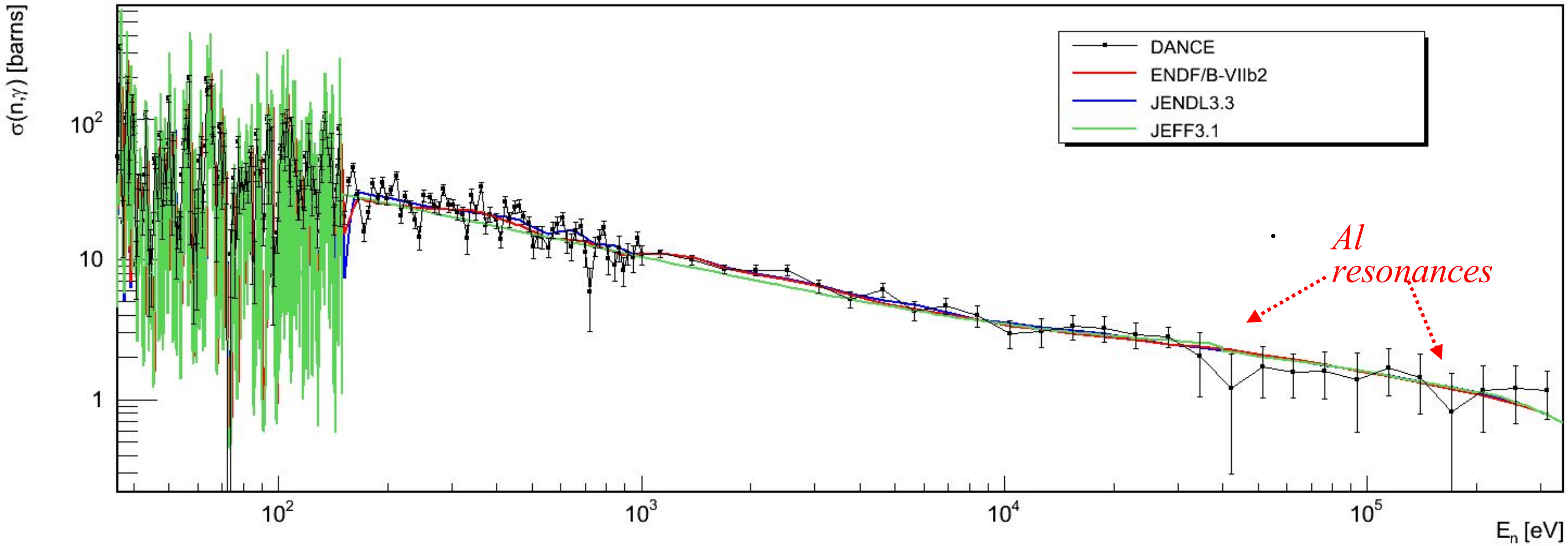


Resonance Parameters

- comparison to ENDF/B-VIIb2
- SAMMY7 was used to fit resonances below 20 eV
- self shielding + multiple scattering effects included in the fitting procedure
- neutron widths as a fitting parameter
- gamma width kept from ENDF
- $2g\Gamma_n$ are compared in the upper panel
- lower panel shows the ratio of Γ_n ENDF/DANCE

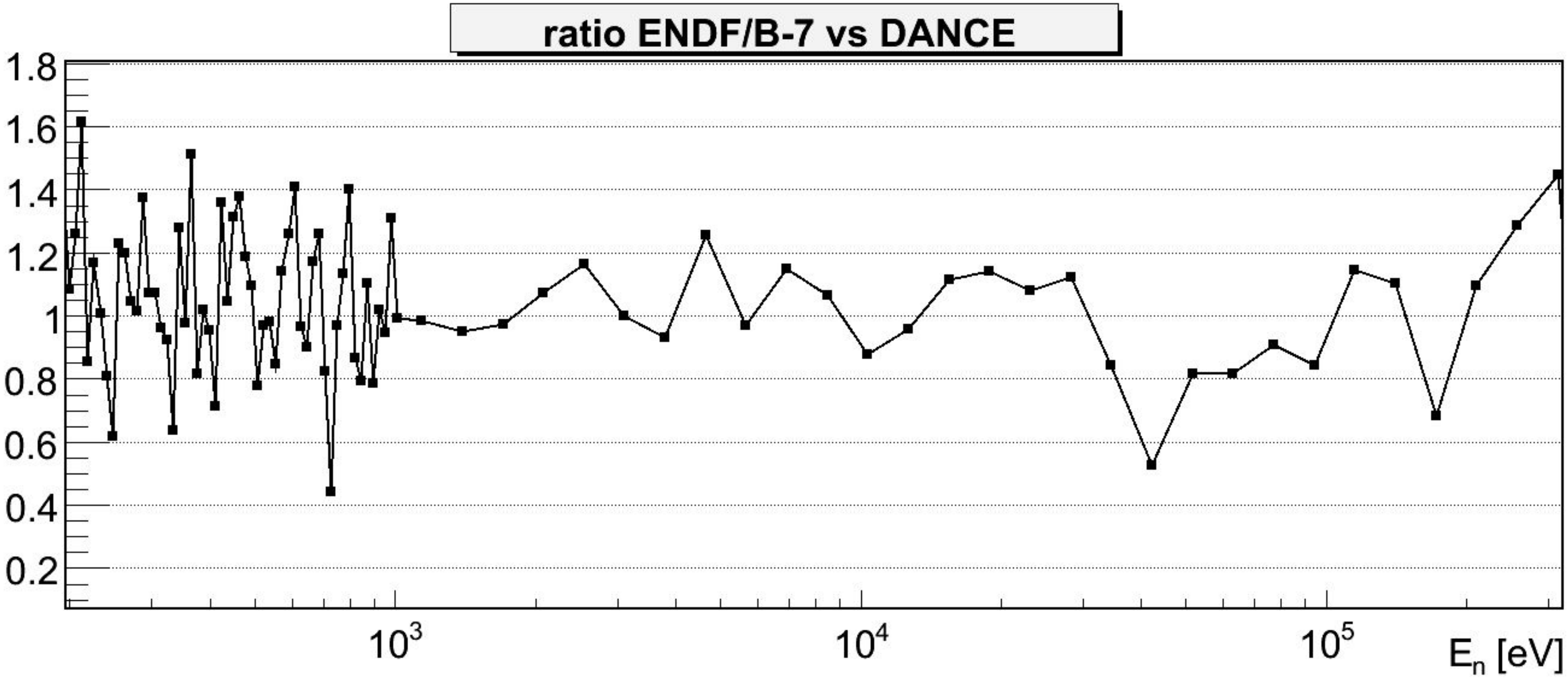


Cross section 36 eV – 300 keV



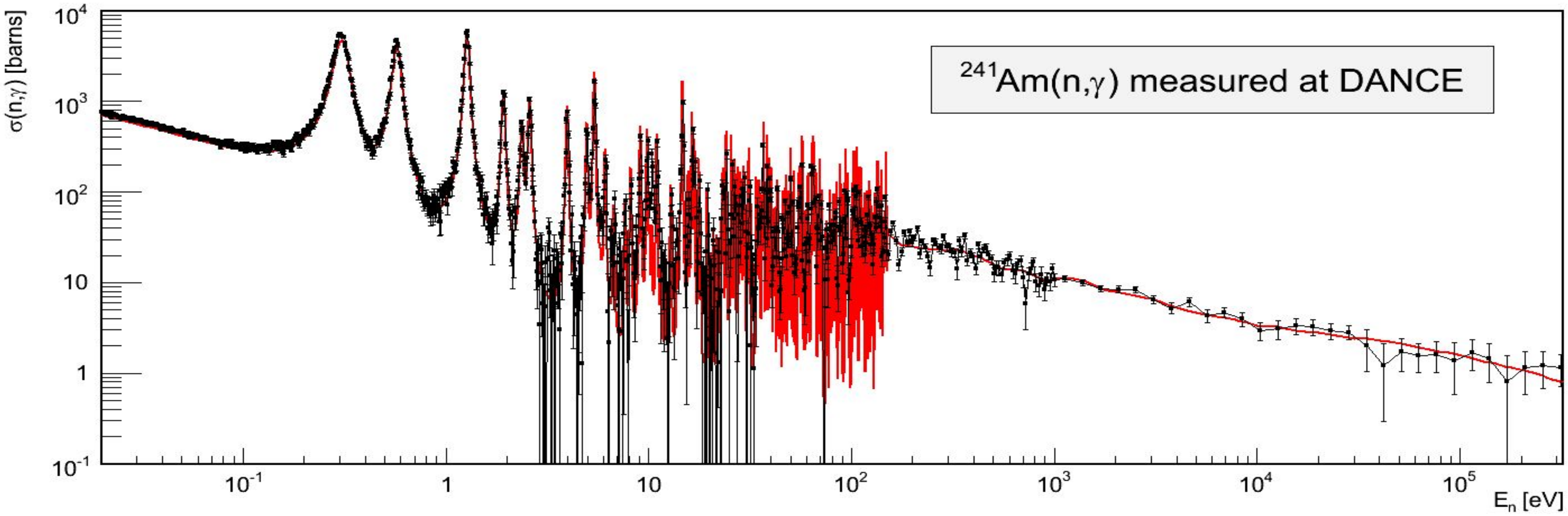
- Our data agree well with ENDF and JENDL evaluations. In 1 keV region the trend follows these two
- The data points at 30 keV and 180 keV are effected by the aluminum in the flight path and should not be considered

Cross section 36 eV – 300 keV



- Our data agree well with ENDF and JENDL evaluations. In 1 keV region the trend follows these two
- The data points at 30 keV and 180 keV are effected by the aluminum in the flight path and should not be considered

Cross section 0.02 eV – 320 keV



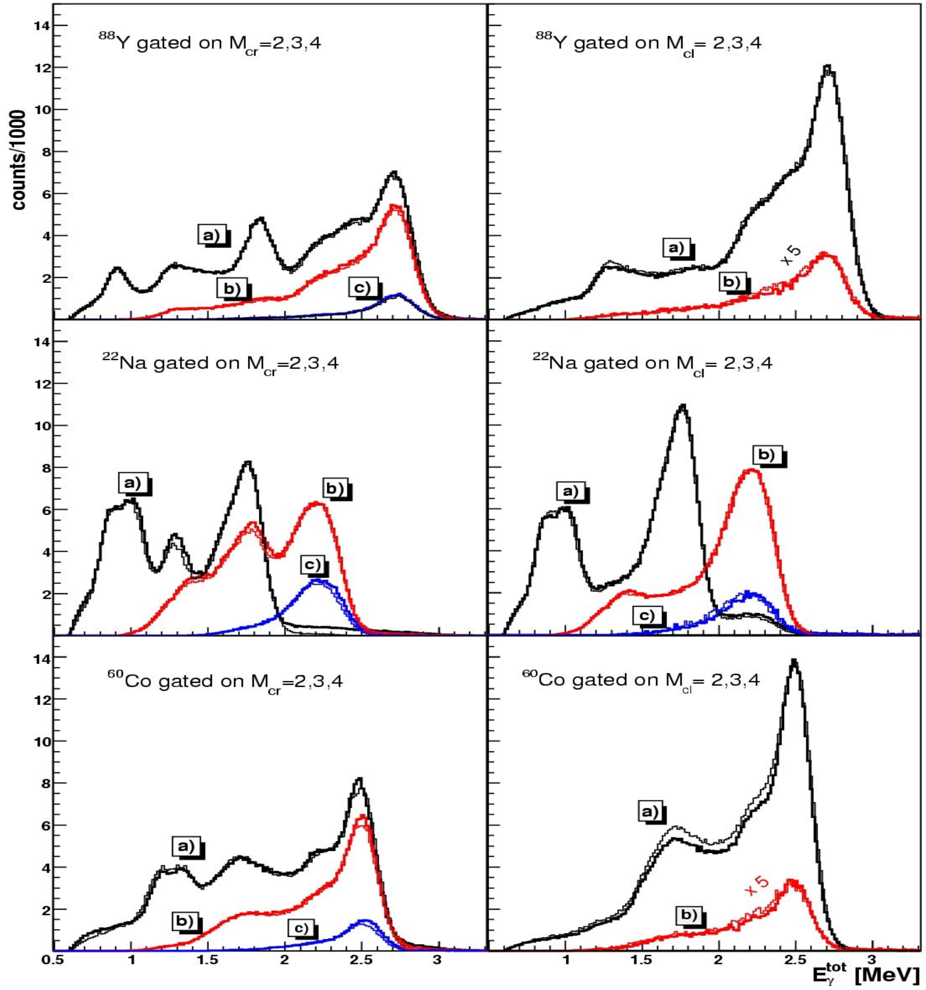
- DANCE measurement results compared to ENDF7b (red line) in the full range of neutron energies
- no weighing is assumed – results represent average cross sections in E_n bins, the points are in the center of bins
- binning convention ΔE/E 1% (0.02-150 eV), 3% (150 eV -1 keV) and 20% above 1 keV
- uncertainties: 4% thermal, 6% 1KeV, 18 % 10 keV

Major Achievements

- It is possible to perform absolute cross section measurements at DANCE in the span of 7 orders of magnitude of neutron energy
- We found reliable way how to normalize the flux at target position using Au targets
- Method to determine the cascade detection total efficiency was developed
- Computer simulations (Geant4, DICEBOX) were performed with good agreements
- Software treatment of the data, both in on-line data collection and off-line analysis has been improved

DANCE-GEANT4 code – Calibration sources

- ^{88}Y, ^{22}Na, ^{60}Co
- Total γ-ray energy spectra gated on cluster and crystal multiplicity
  - Experiment (thick lines)
  - GEANT4 (thin lines)
  - M=2 (black)
  - M=3 (red)
  - M=4 (blue)
- Overall good agreement between the simulation and experiment (3%)



Cascade efficiency

- relative efficiency for different cuts on E_{tot} compared to DICEBOX-Geant4 calculations