DE LA RECHERCHE À L'INDUSTRIE

Measurement of prompt fission γ-ray spectra in fast neutron-induced fission

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Motivations

- Fission mechanism
  - ✓ Fission fragments decay.
  - ✓ Fission fragments angular momentum.

- Application: Prompt γ in fission represents 40 % of the γ production in typical fast reactor

  → NEA Nuclear Data HPRL:
  - ✓ Spectrum shape from 0 to 10 MeV
  - ✓ Mean total energy and multiplicity (maximum uncertainty 7.5%)
  - ✓ Thermal and fast neutron-induced fission of ^{235}U et ^{239}Pu (^{241}Pu)

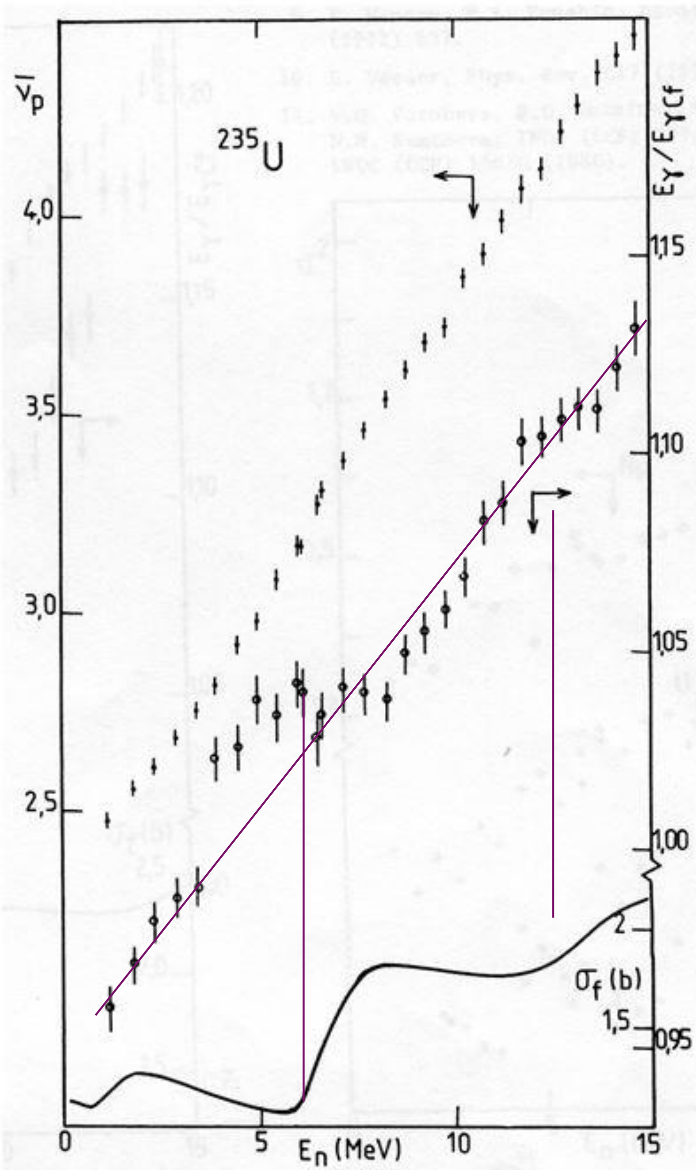
- Very few experimental measurement with fast neutrons

Existing data – thermal neutron induced and spontaneous fission

https://www.oecd-nea.org/dbdata/hprl/ HPRLgammafission.pdf

Isotope	Total energy MeV	Total Multiplicity MeV	Average Energy MeV	Energy Range MeV	Reference
U233	6.69 ± 0.3	6.31 ± 0.3	1.06 ± 0.07	*0.09-10.0*	*[Ple72]*
U235	6.43 ± 0.3	6.51 ± 0.3	0.99 ± 0.09	*0.09-10.0*	*[Ple72]*
	6.51 ± 0.4	6.70 ± 0.3	0.97 ± 0.05	*0.14-10.0*	*[Ver72]*
	7.18 ± 0.3	7.45 ± 0.3	0.96 ± 0.05	*0.14-10.0*	*[Pee71]*
	7.25 ± 0.3	8.13 ± 0.3	0.89 ± 0.05	*0.01-10.5*	*[Pee71]*
PU239	6.73 ± 0.35	6.88 ± 0.4	0.98 ± 0.07	*0.09-10.0*	*[Ple72]*
	6.81 ± 0.3	7.23 ± 0.3	0.94 ± 0.05	*0.14-10.0*	*[Ver72]*
Cf252	7.06 ± 0.3	8.32 ± 0.4	0.85 ± 0.06	*0.09-10.0*	*[Ple72]*
	6.84 ± 0.3	7.80 ± 0.3	0.88 ± 0.04	*0.14-10.0*	*[Ver72]*
	8.6	*10*	*0.90* ± 0.06		*[Bow58]*
	6.7 ± 0.4				*[Nar73]*

Existing data: Fast neutron-induced fission



Ref.: J. Fréhaut, A. Bertin, R. Bois, Proceedings of the Conference on Nuclear Data for Science and Technology, 1983, 78-81.

Gd loaded ball:

→ Neutron multiplicity

→ Total γ-ray energy

→ ^{235}U, ^{237}Np and ^{232}Th fission for 2-15 MeV neutron

But:

- Measurement relative to ^{252}Cf
- Underestimation of the prompt neutron contribution in H.Nifenecker & al. NPA189,285
- PhD work S.Vayre 03/27/2015 Univ. Paris-Sud

→ 30 % < ν contribution < 50 %

Recent results for fast neutron induced fission

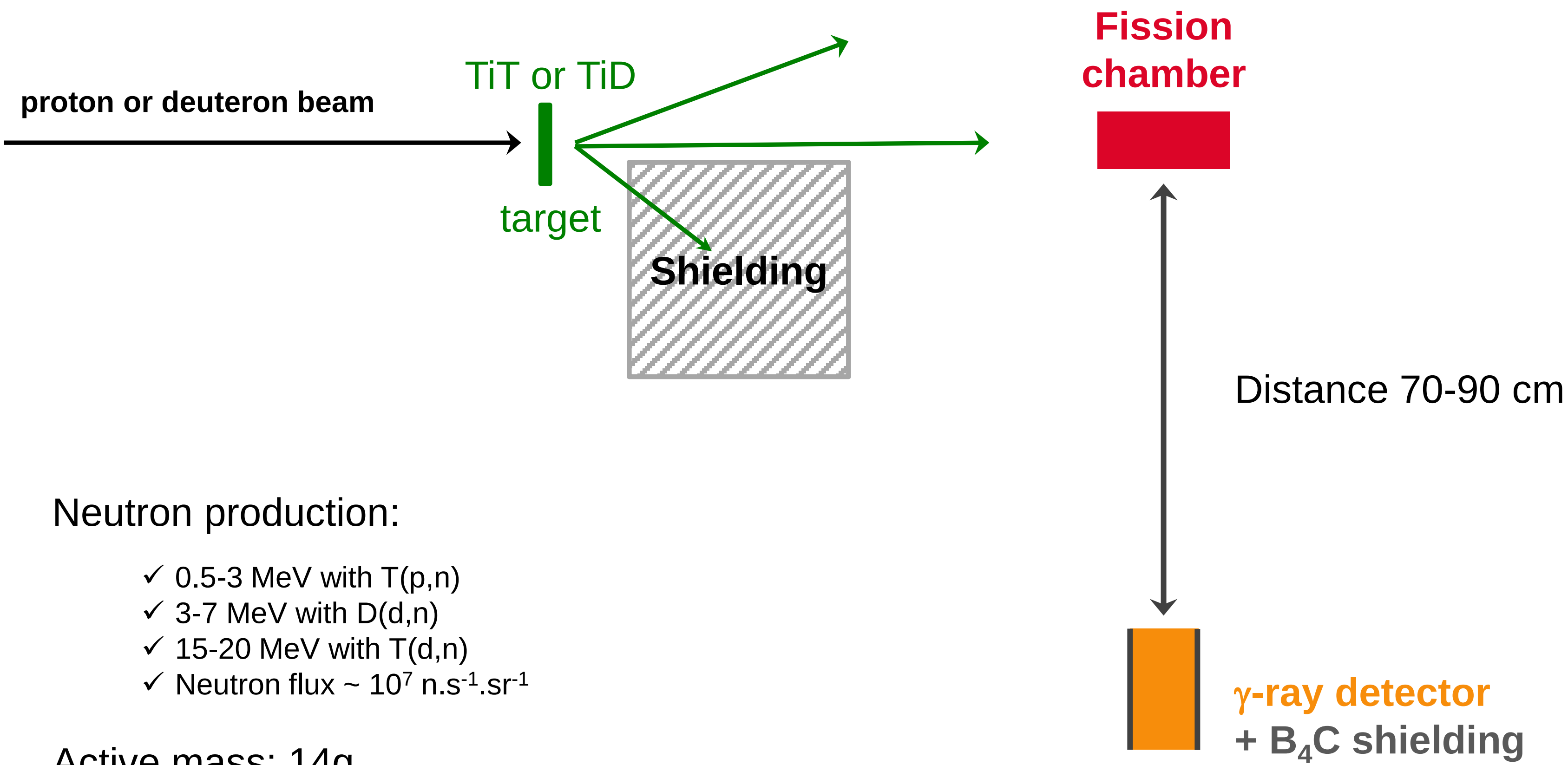
- E. Kwan & al. NIM **A688**(2012)55

  - ✓ ^{252}Cf (SF) & ^{235}U
  - ✓ EJ309 organic scintillator
  - ✓ Spectrum characterized from 1 to 4 MeV

- M.Lebois & al. Phys.Rev. **C92**, 034618 (2015)

  - ✓ ^{235}U & ^{238}U
  - ✓ BaF_2 scintillator
  - ✓ Spectrum characterized up to ~6 MeV

Experimental setup at CEA,DAM,DIF's 4 MV accelerator



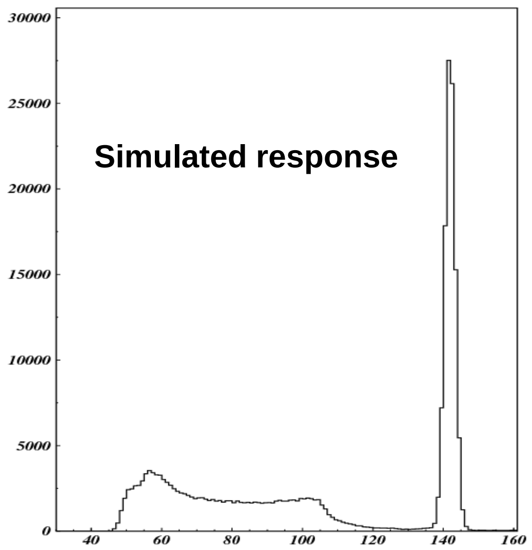
Neutron production:

- ✓ 0.5-3 MeV with T(p,n)
- ✓ 3-7 MeV with D(d,n)
- ✓ 15-20 MeV with T(d,n)
- ✓ Neutron flux ~ 10^7 $n.s^{-1}.sr^{-1}$

Active mass: 14g
Typical fission rate: 100 $f.s^{-1}$

Neutron - γ-ray discrimination: TOF technique

Which γ-ray detector?



P/T = $\frac{\text{Peak area}}{\text{Total spectrum area}}$

Response to mono-energetic γ-rays:

- Full energy peak
- Compton diffusion: **in the detector & in the setup**
- pair production above 1022 keV

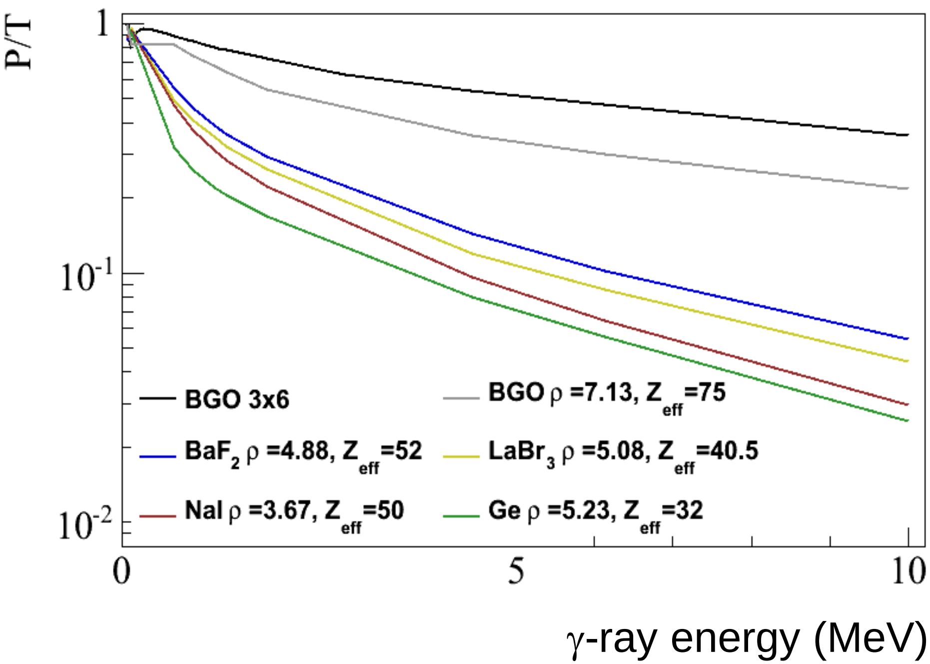
→ **Need to be characterized over the whole energy range**

Ideal detector:

- Good energy resolution (of course)
- Good time resolution → γ-ν discrimination
- High P/T ratio → minimize uncertainties

Which γ-ray detector?

Simulations for 2”x2” detectors



Our choice BGO detector 3’’x6’’:

- Much higher detection efficiency
- Much higher P/T

Despite:

- Poor energy resolution
- Poor time resolution (~2 ns FWHM)

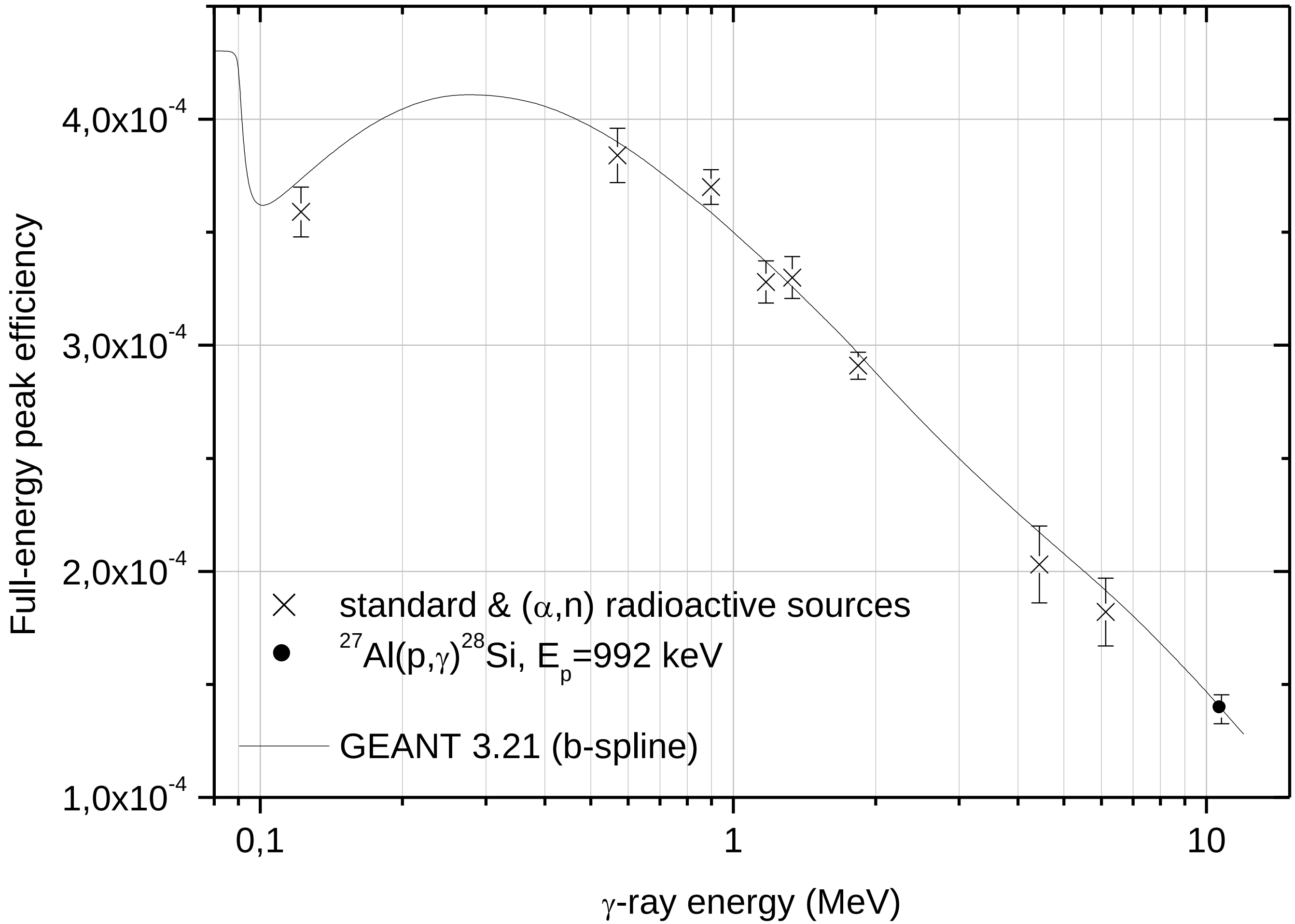
→ More statistic at high energies

→ Lower uncertainties on the whole spectrum

Detector details (Scionix Holland BV-PMT Photonis XP3330):

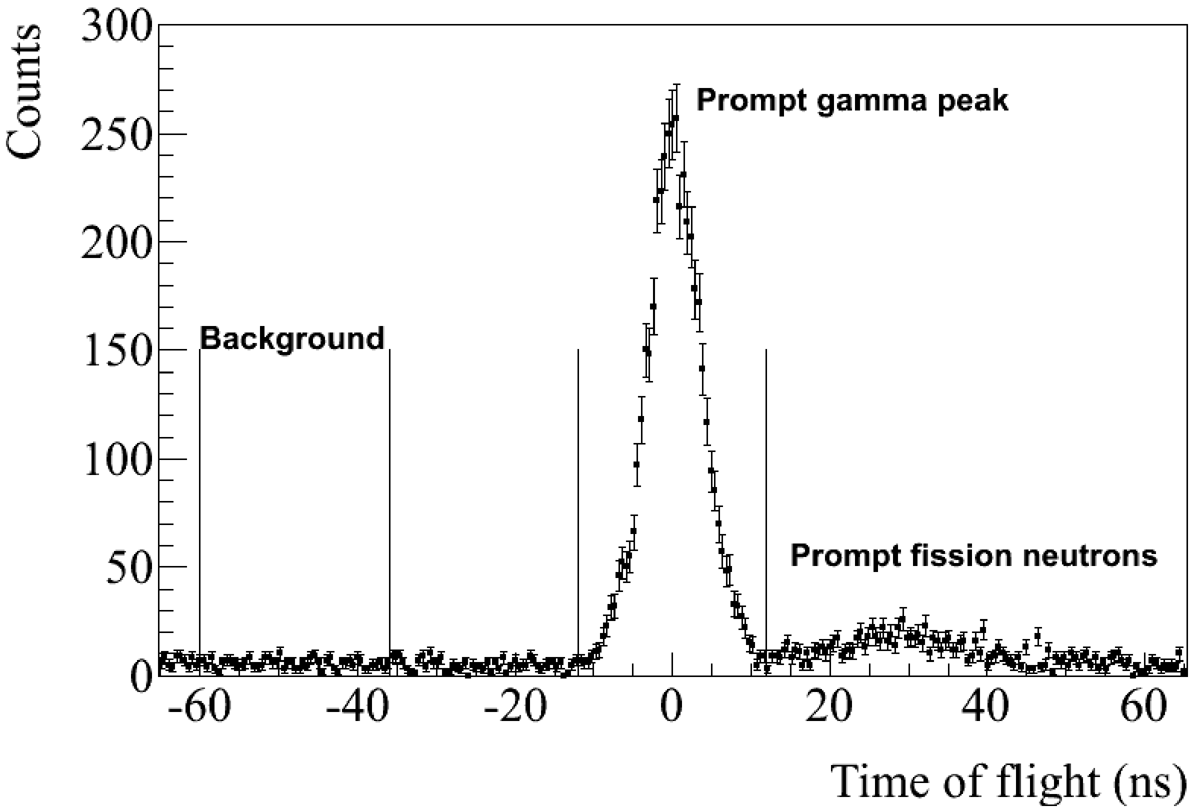
- Φ = 7.6 cm (3’’) – L=15.2 cm (6’’) – m= 5 kg
- P/T = 83% @1 MeV & 36% @10 MeV – $\varepsilon_{intrinsic}$ = 73%@1MeV & 31%@10MeV

Full-energy peak efficiency curve



→ Good agreement between experimental values and Geant 3.21 up to 11 MeV.

Neutron and background suppression

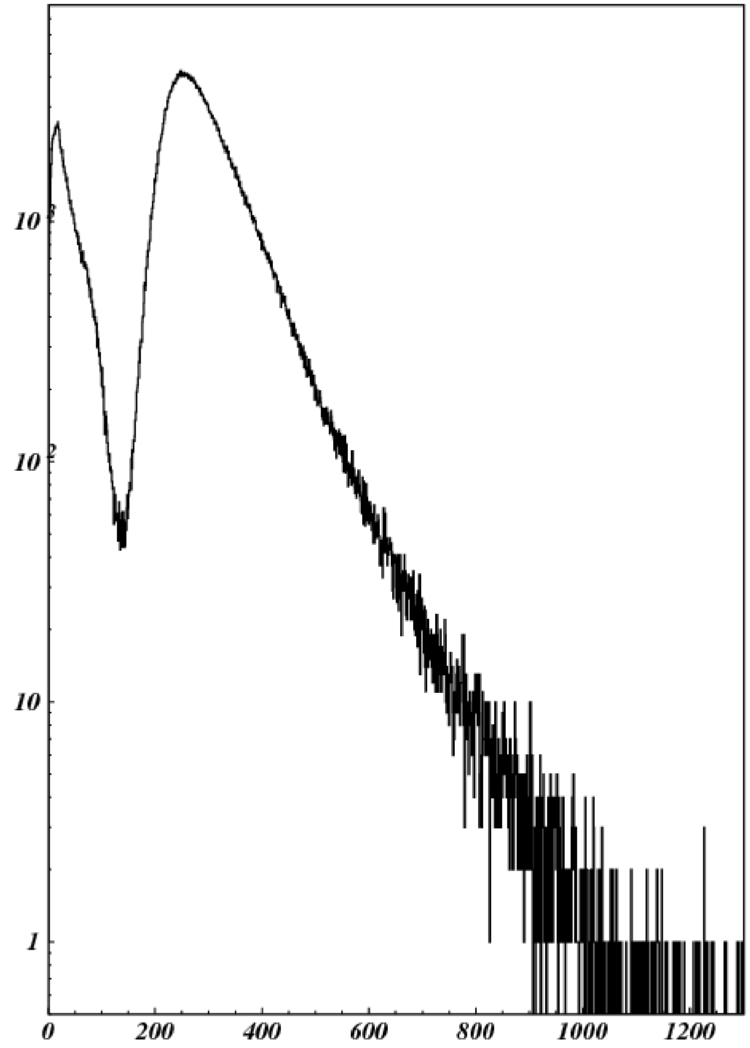


- Proportion of delayed γ-rays estimated to be less than 1 %
- Assuming a Watt spectrum for fast neutron 99.5 % were rejected

Fission chamber

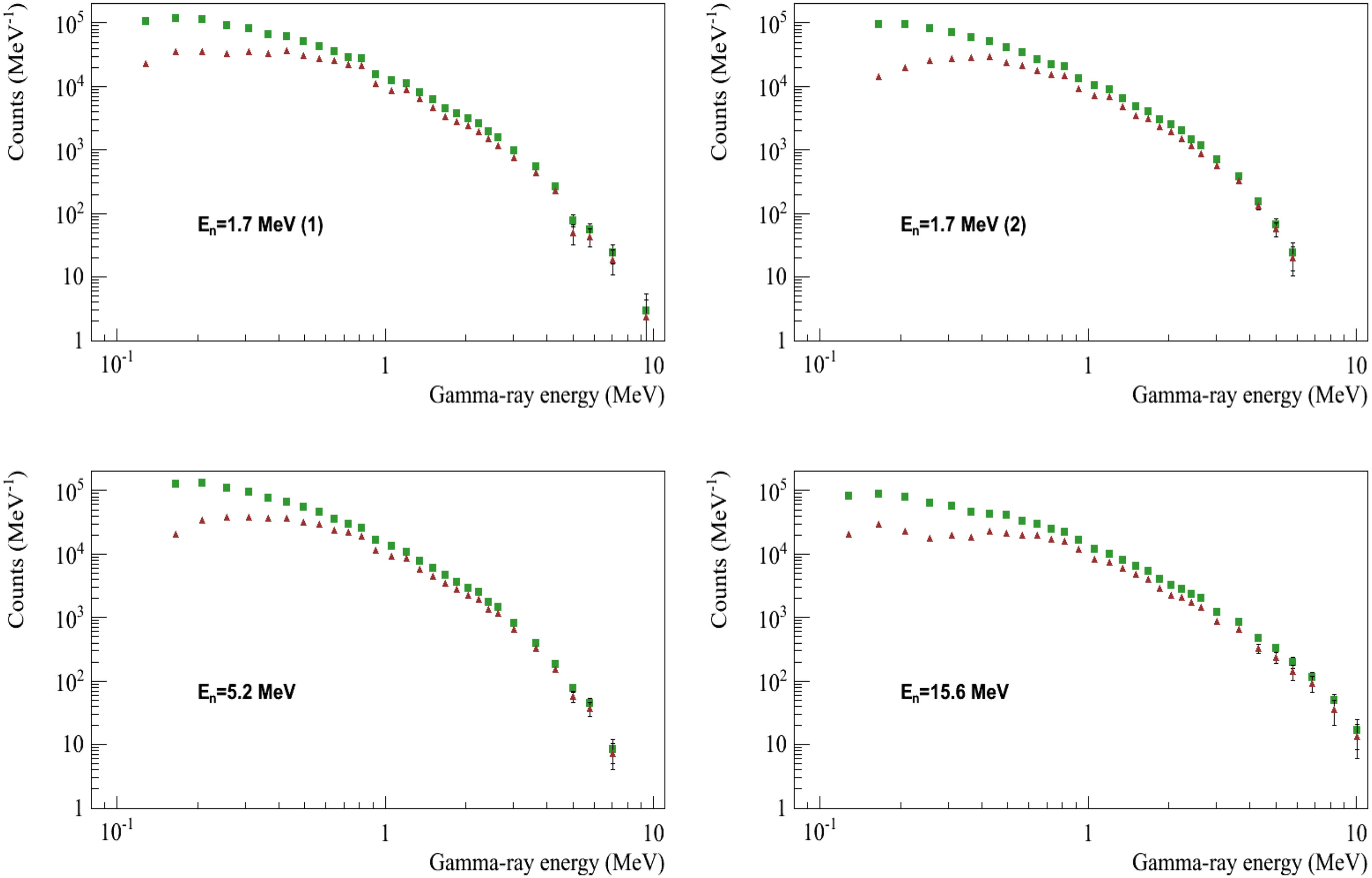
Fission chamber with 14 g ^{238}U

- 100 plates with 1.7 mg/cm^2
- P20 gas at 5 bars

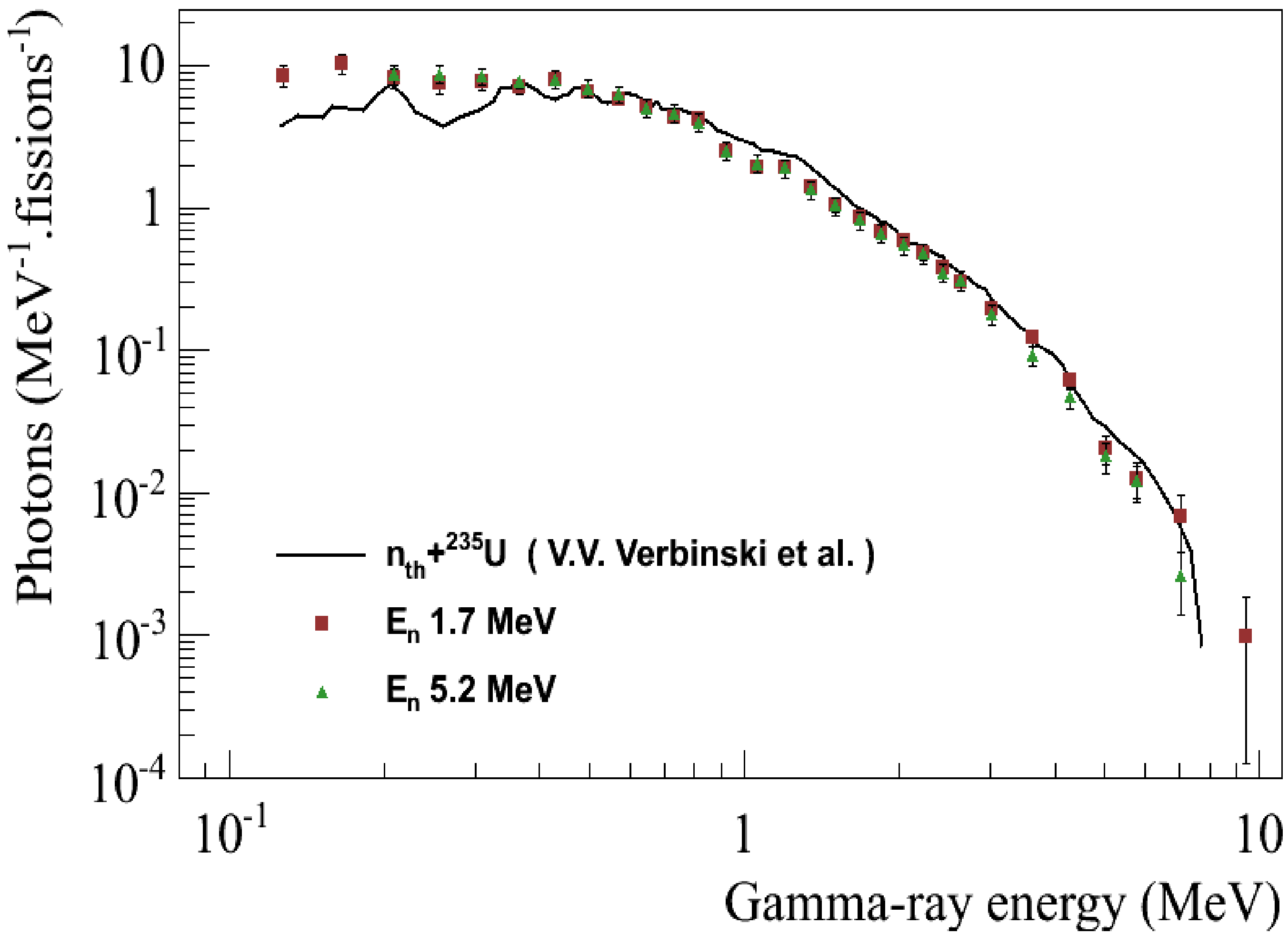


Spectrum unfolding method

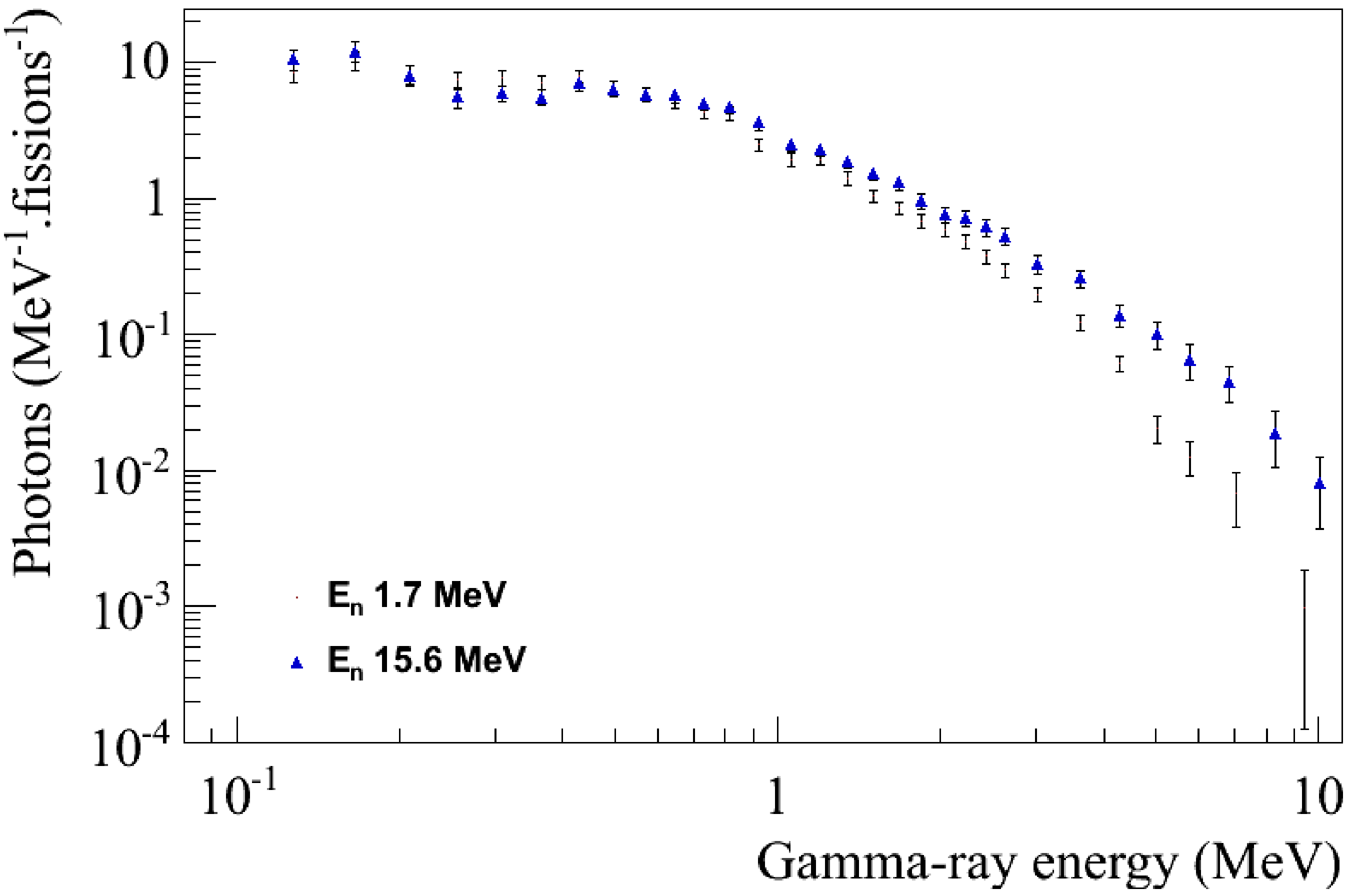
- **Detector response simulated with the PENELOPE code.**
- **Unfolding starting from the highest measured energy down to lowest.**



Influence of incoming neutron energy - 1



Influence of incoming neutron energy - 2



Conclusion

Prompt γ-ray spectrum measured in fast neutron-induced fission of ^{238}U (1.7 - 15.6 MeV)

- Strong effect in the spectrum shape while increasing incident neutron energy
- Predictions from models ?

Outlooks

- New ^{238}U fission chambers (B. Laurent's talks) developed for PFNS measurement
  - → Material budget minimized → less Compton scattering
  - → Reverse kinematics neutron production (J.Wilson's talk)
  - → Measurements on ^{235}U and ^{239}Pu