# The $^{240,242}$Pu(n,f) measurement at the CERN n_TOF facility

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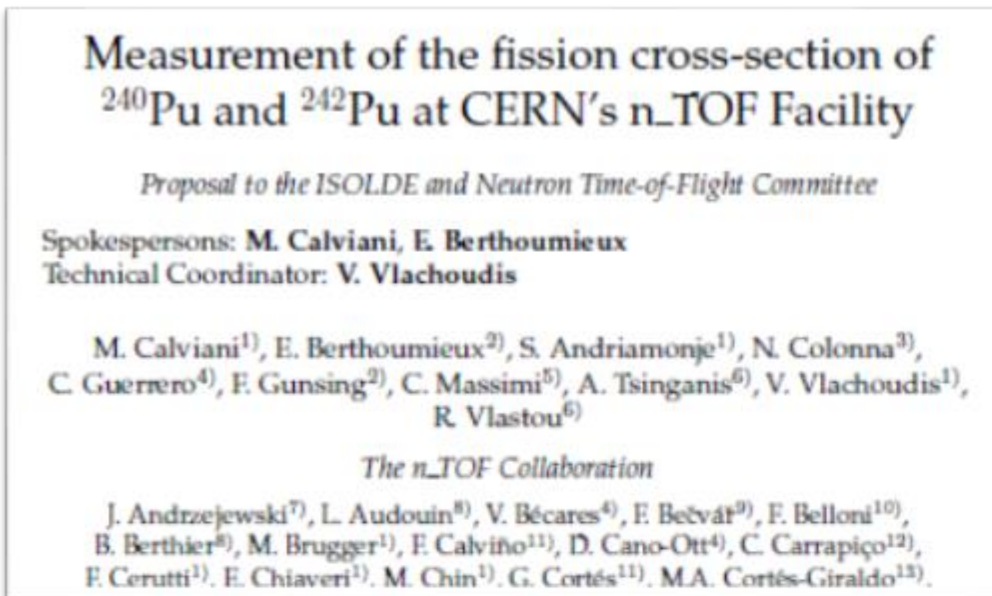
# Outline

- Experimental
  - Samples
  - Detectors
  - Main experimental issues
- Data analysis
- Preliminary results
  - Resonances
  - Fission threshold
  - Pu / U ratio
- Simulations

# The measurement

- An (n,f) measurement on $^{240,242}Pu$
  - Requested in the **NEA Nuclear Data High Priority Request List**
- Proposal CERN-INTC-2010-042 / INTC-P-280 (21/05/2010)
  - [http://cdsweb.cern.ch/record/1266869/files/INTC-P-280.pdf](http://cdsweb.cern.ch/record/1266869/files/INTC-P-280.pdf)
- The measurement was accepted by the INTC


Measurement of the fission cross-section of $^{240}Pu$ and $^{242}Pu$ at CERN's n_TOF Facility

*Proposal to the ISOLDE and Neutron Time-of-Flight Committee*

Spokespersons: **M. Calviani, E. Berthoumieux**
Technical Coordinator: **V. Vlachoudis**

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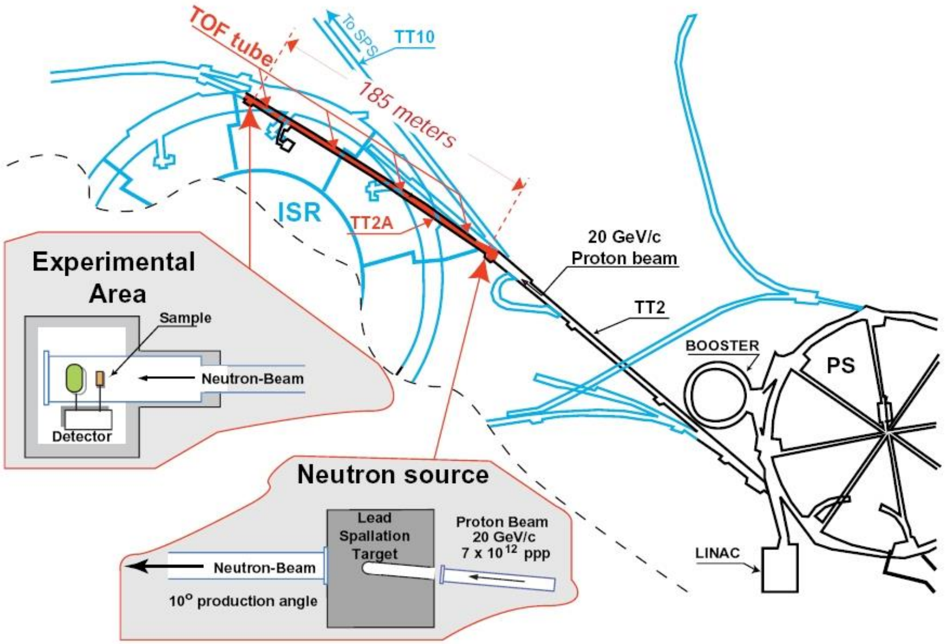
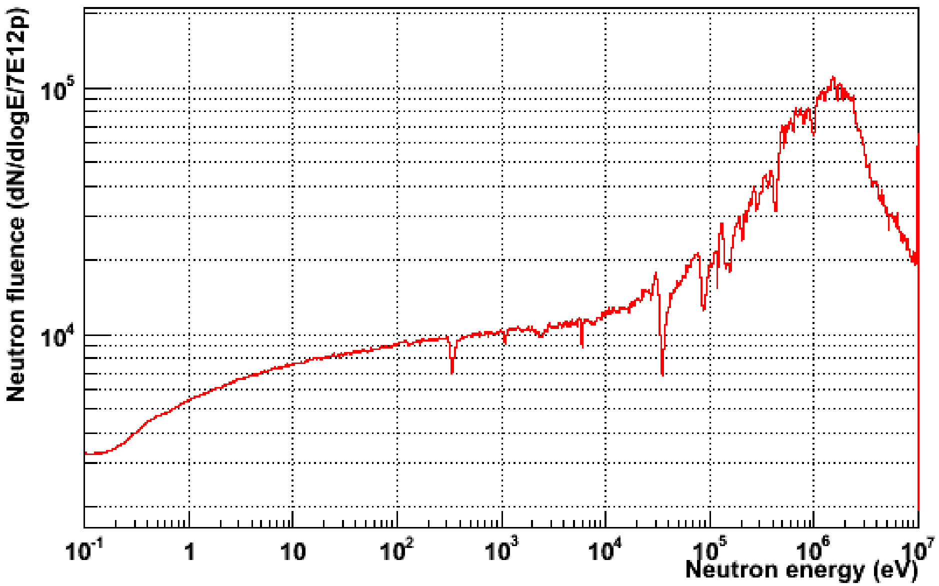
# The n_TOF facility

- n_TOF @ CERN
  - Neutrons produced by spallation of 20GeV/c protons provided by the CERN PS on Pb target
  - Pulses of $7 \times 10^{12}$ protons, 7ns width, low repetition rate
  - 185m neutron flight path
  - Very high instantaneous flux ($10^6$ n/cm$^2$/pulse)
  - Good energy resolution
  - Wide neutron spectrum (thermal to GeV)

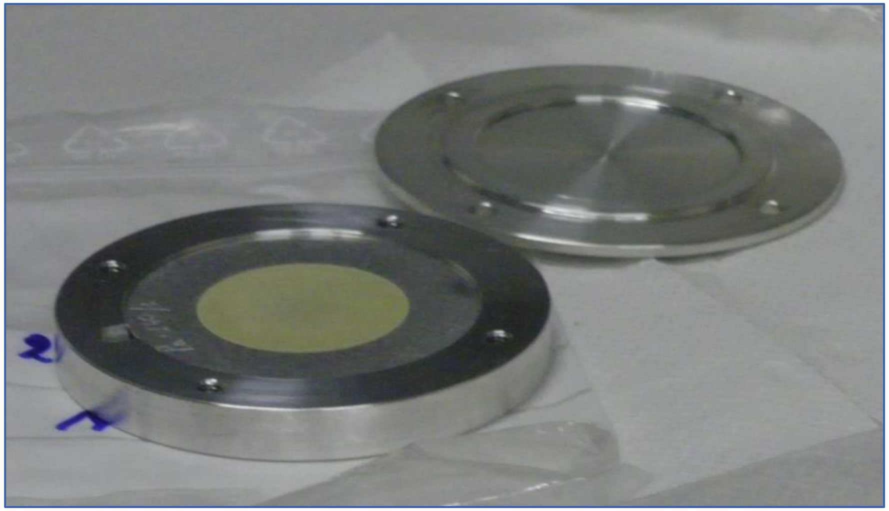


# Samples

- Eight (8) samples (4 x $^{240}Pu$, 4 x $^{242}Pu$) received from IRMM (Geel) (*)
  - 3 cm diameter $PuO_2$ deposit
  - 0.25 mm aluminium backing (5cm diameter)

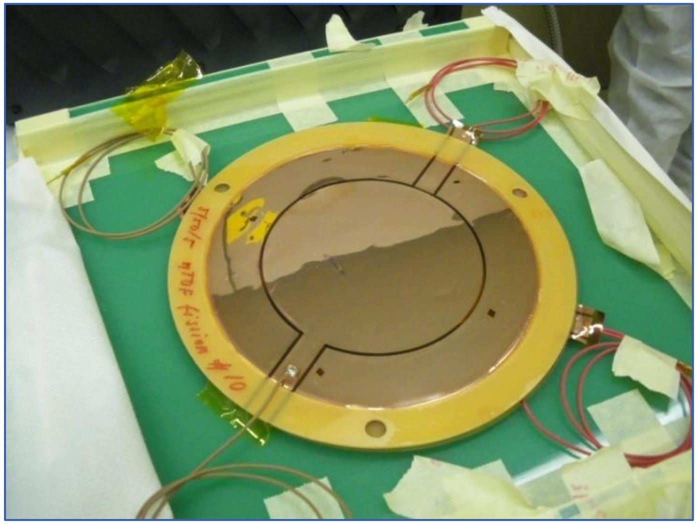
| $^{240}Pu$ | | $^{242}Pu$ | |
|---|---|---|---|
| $^{238}Pu$ | 0.0733% | $^{238}Pu$ | 0.002719% |
| $^{239}Pu$ | 0.0144% | $^{239}Pu$ | 0.00435% |
| **$^{240}Pu$** | **99.8915%** | $^{240}Pu$ | 0.01924% |
| $^{241}Pu$ | 0.00041% | $^{241}Pu$ | 0.00814% |
| $^{242}Pu$ | 0.02027% | **$^{242}Pu$** | **99.96518%** |
| $^{244}Pu$ | 0.000046% | $^{244}Pu$ | 0.00036% |
| | | | |
| **Mass** | 3.1mg | **Mass** | 3.6mg |
| **Activity** | 25.7MBq | **Activity** | 0.53MBq |
| | | | |
| **Surface density** | | **0.10 – 0.13 mg/cm²** | |

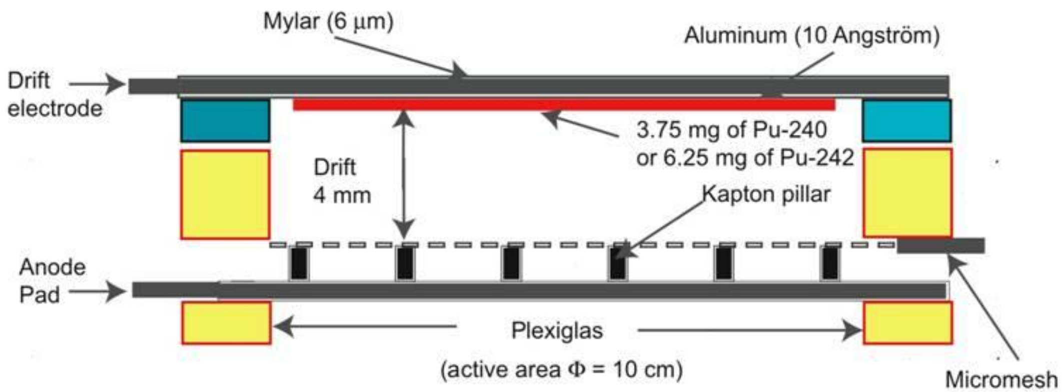


(*) **G. Sibbens et al.**, *Preparation of $^{240}Pu$ and $^{242}Pu$ targets to improve cross-section measurements for advanced reactors and fuel cycles*, Journal of Radioanalytical and Nuclear Chemistry (2013), http://dx.doi.org/10.1007/s10967-013-2668-7

# The Micromegas detector

- **MICRO-MEsh GAseous Structure**
- Wireless gaseous detector
  - Drift electrode
  - Drift space (mm)
    - Primary ionisation and charge drift
  - Micromesh
  - Amplification region (25-50μm)
    - Charge multiplication
    - Readout
- Already used for beam monitoring at n_TOF
  - $^{10}B(n,\alpha)$ and $^{235}U(n,f)$





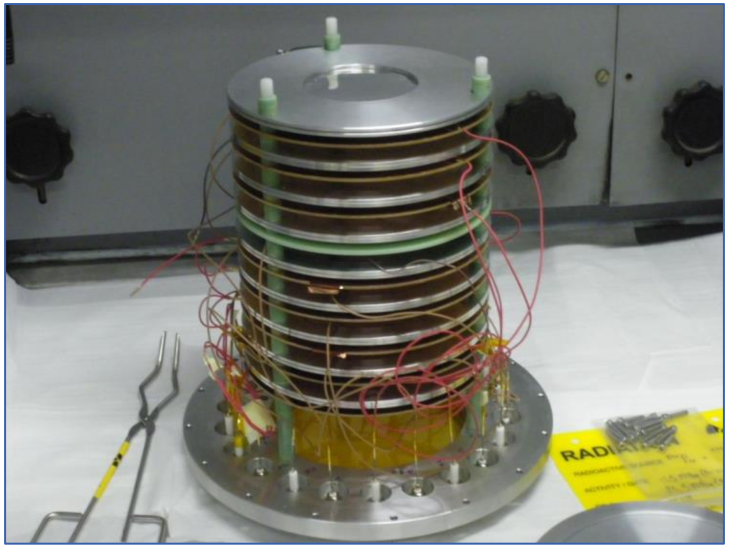

- Advantages
  - Low background (transparent detector)
  - Fast signal

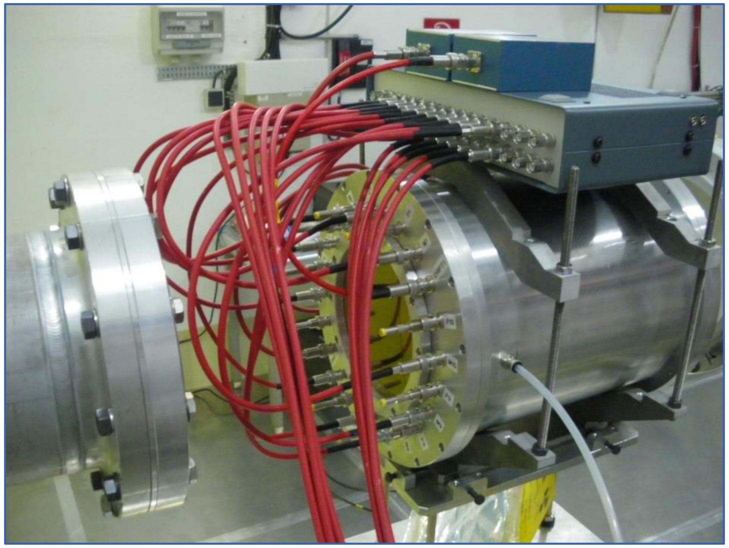
# The detector chamber & preamplifier module

- Designed to hold up to 10 samples and microbulk Micromegas detectors
  - BNC connections for signals and HV
  - Aluminium chamber
  - Kapton windows

- Gas mixture
  - 88% Ar : 10% $CF_4$ : 2% iso-$C_4H_{10}$
    p = 1 bar

- Preamplifier module
  - Electronic protection in place to prevent channel breakage
  - Shielding improved to reduce baseline oscillations



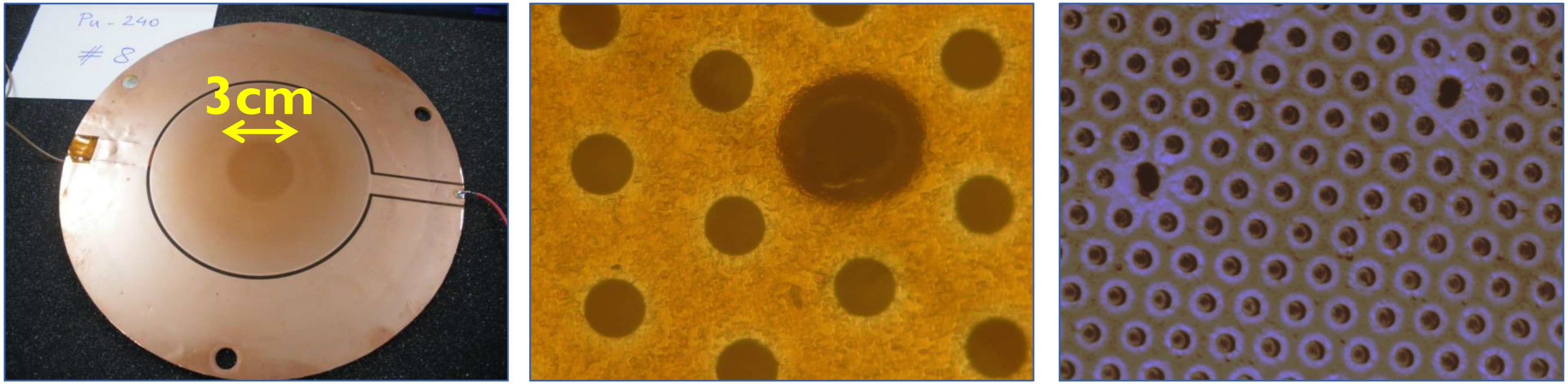
neutrons

# 4 challenging experimental aspects

- Baseline oscillation after the γ-flash
  - …affects the high-energy region (> 1-2 MeV)
- High α-activity of the $^{240}Pu$ samples (>6MBq/sample)
  - Long pile-up tail (>30% pile-up probability) worsens the α-FF separation
- Spontaneous fission background in $^{242}Pu$
- Gradual deterioration of detector performance due to high current / high α-activity
  - …critical for $^{240}Pu$
  - …but also relevant for $^{242}Pu$ **NEW**

# Detector deterioration: the case of $^{240}$Pu

- An unexpected alteration of some detectors was observed after removal from the chamber
  - A distinct discoloration of the micromesh is visible in the 4 detectors used with the $^{240}$Pu samples
  - Physical damage to the micromesh is visible under inspection with a microscope
  - This leads to a deterioration of the electrical field and a severe reduction of the gain
  - (Of interest to the MPGD community, a unique – if inadvertent – ageing test)

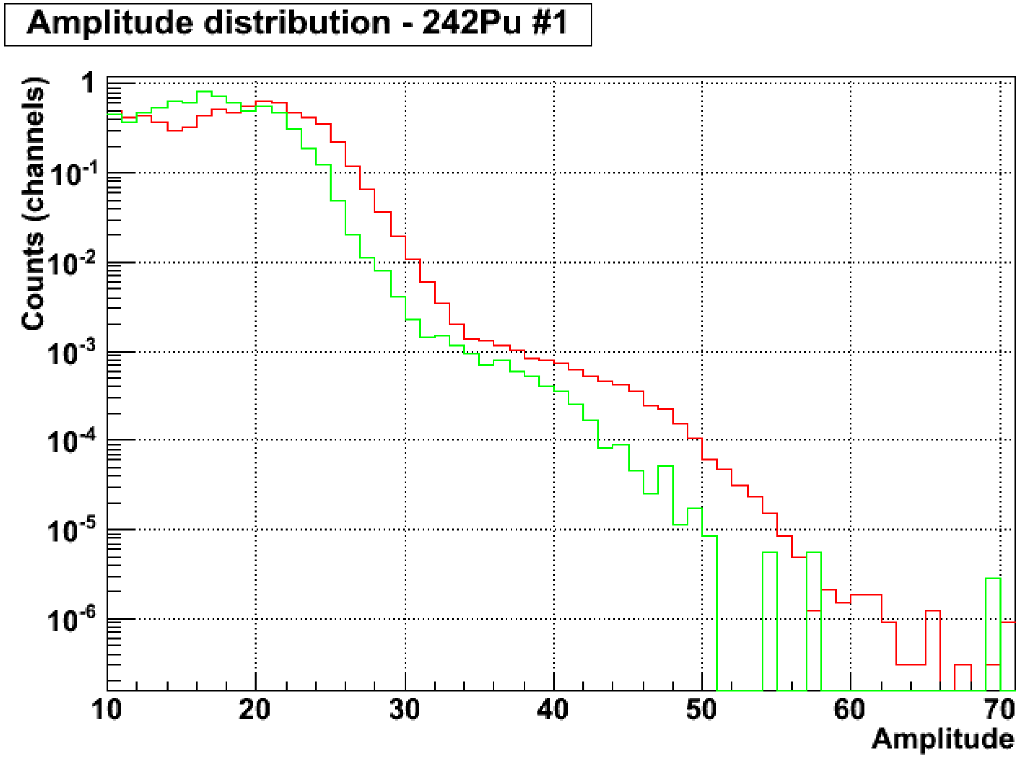



*Courtesy A. Teixeira (CERN)*

- A significant part of the data will have to be discarded
  - Only results for $^{242}$Pu in this talk

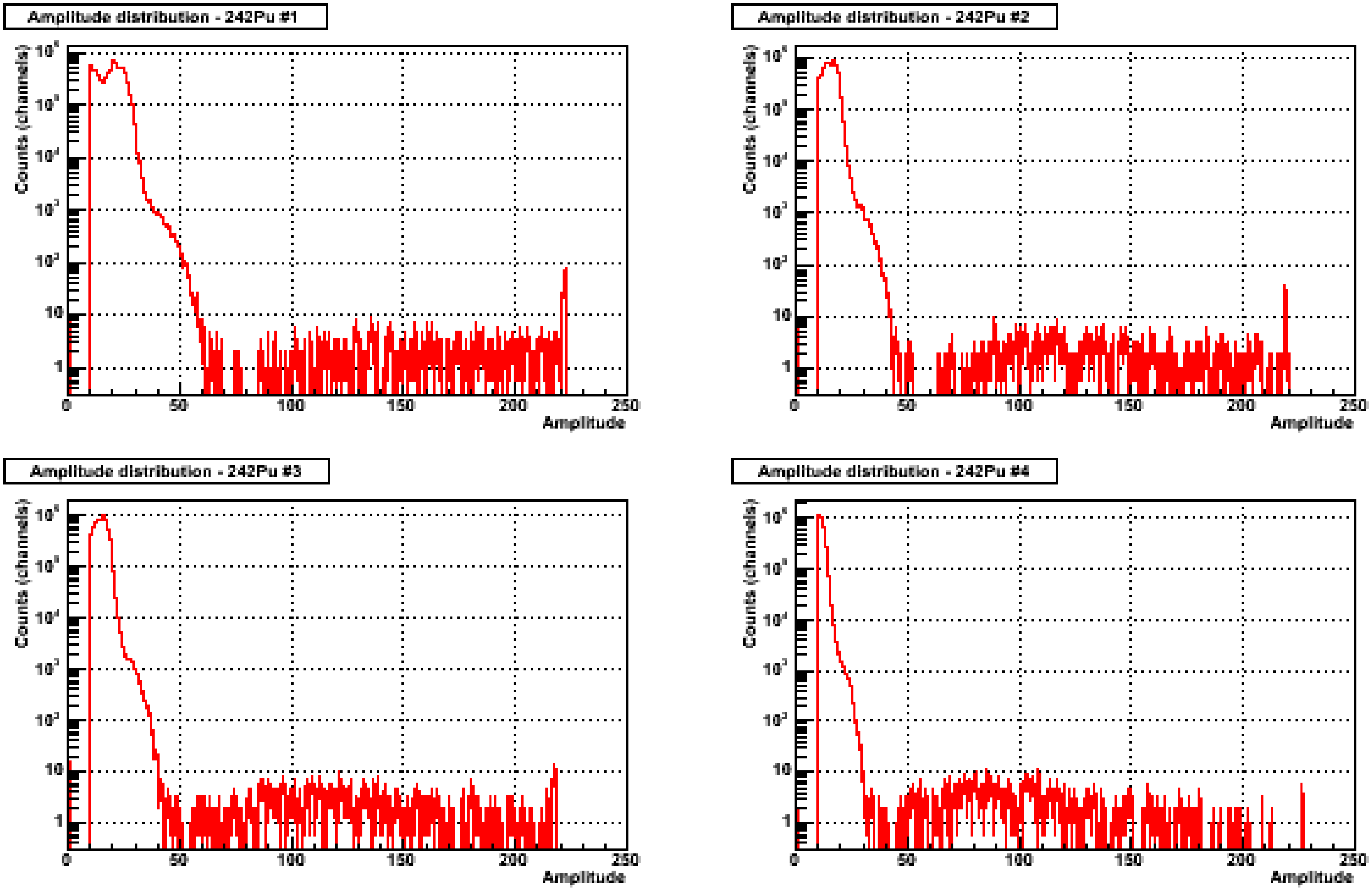
# Detector deterioration: the case of $^{242}$Pu

- The α-activity of the $^{242}$Pu samples is considerably lower (~0.13MBq/sample)
- A similar visible discoloration was NOT observed
  - …but the detectors have not been studied under a microscope
- A slow but non-negligible deterioration of the gain is observed!



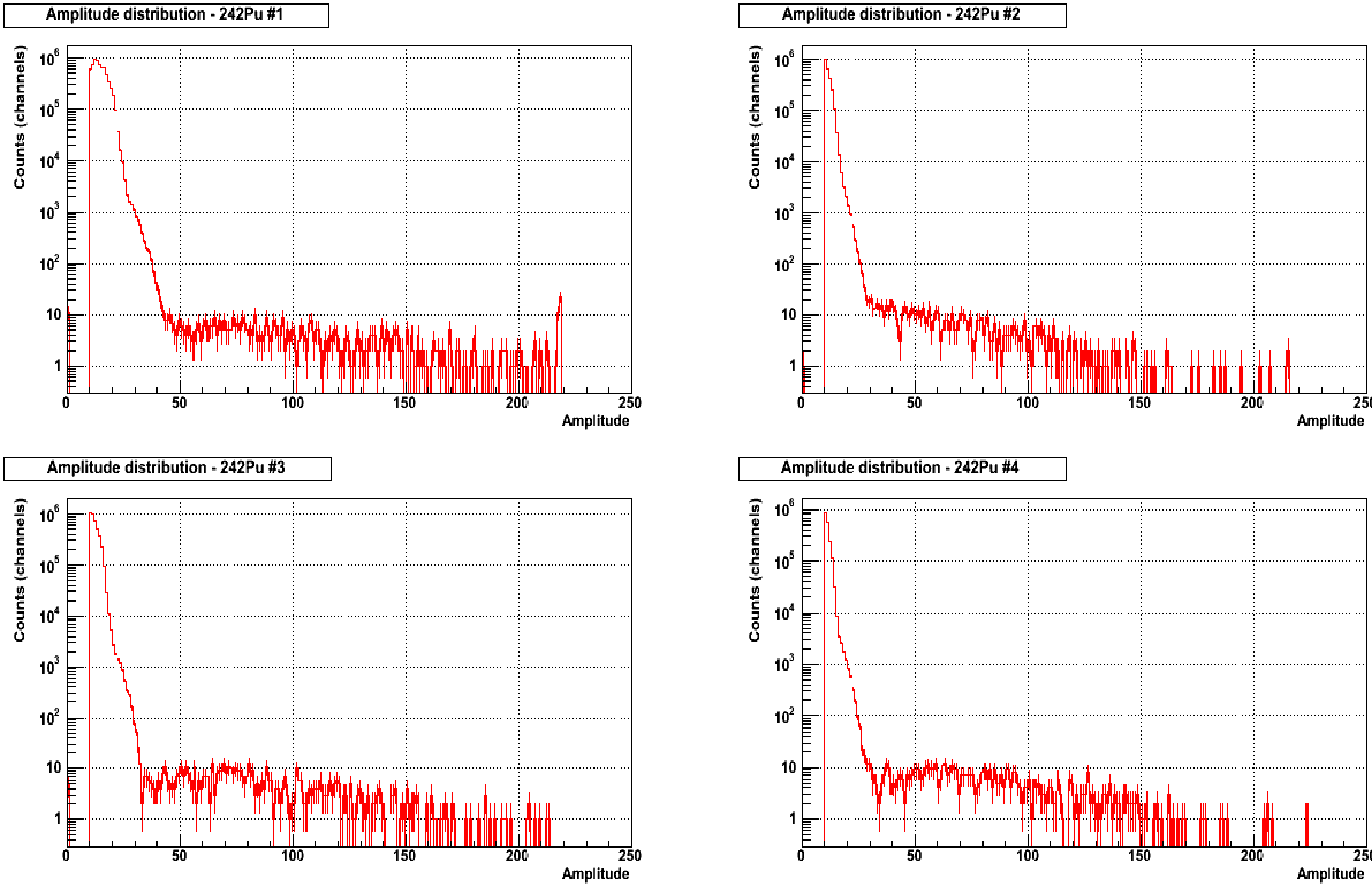

- Beam-off runs in det. #1 ($^{242}$Pu)
  - Evolution during 2012 run

# Detector deterioration: the case of $^{242}Pu$




***Start of 2012 run***

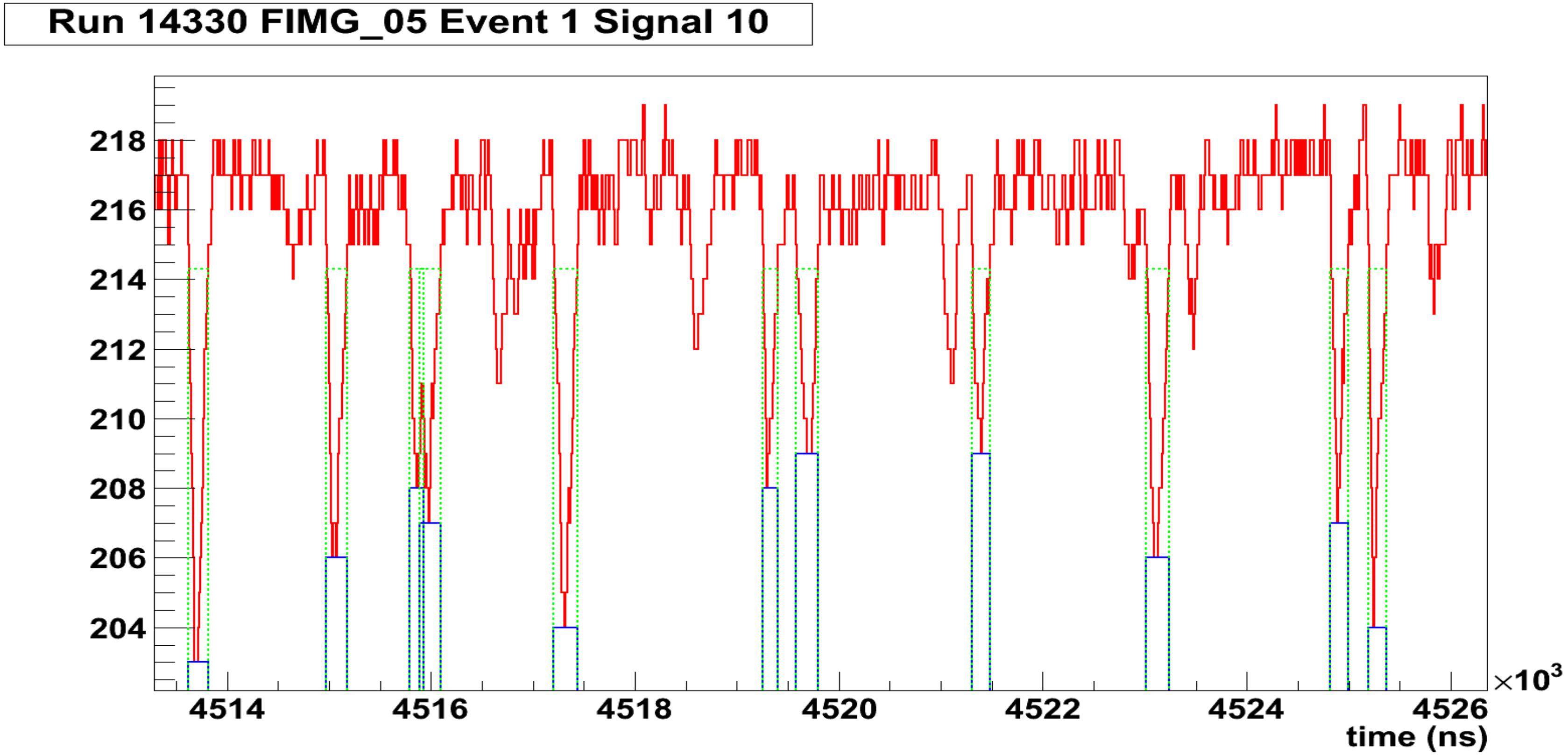
# Detector deterioration: the case of $^{242}$Pu



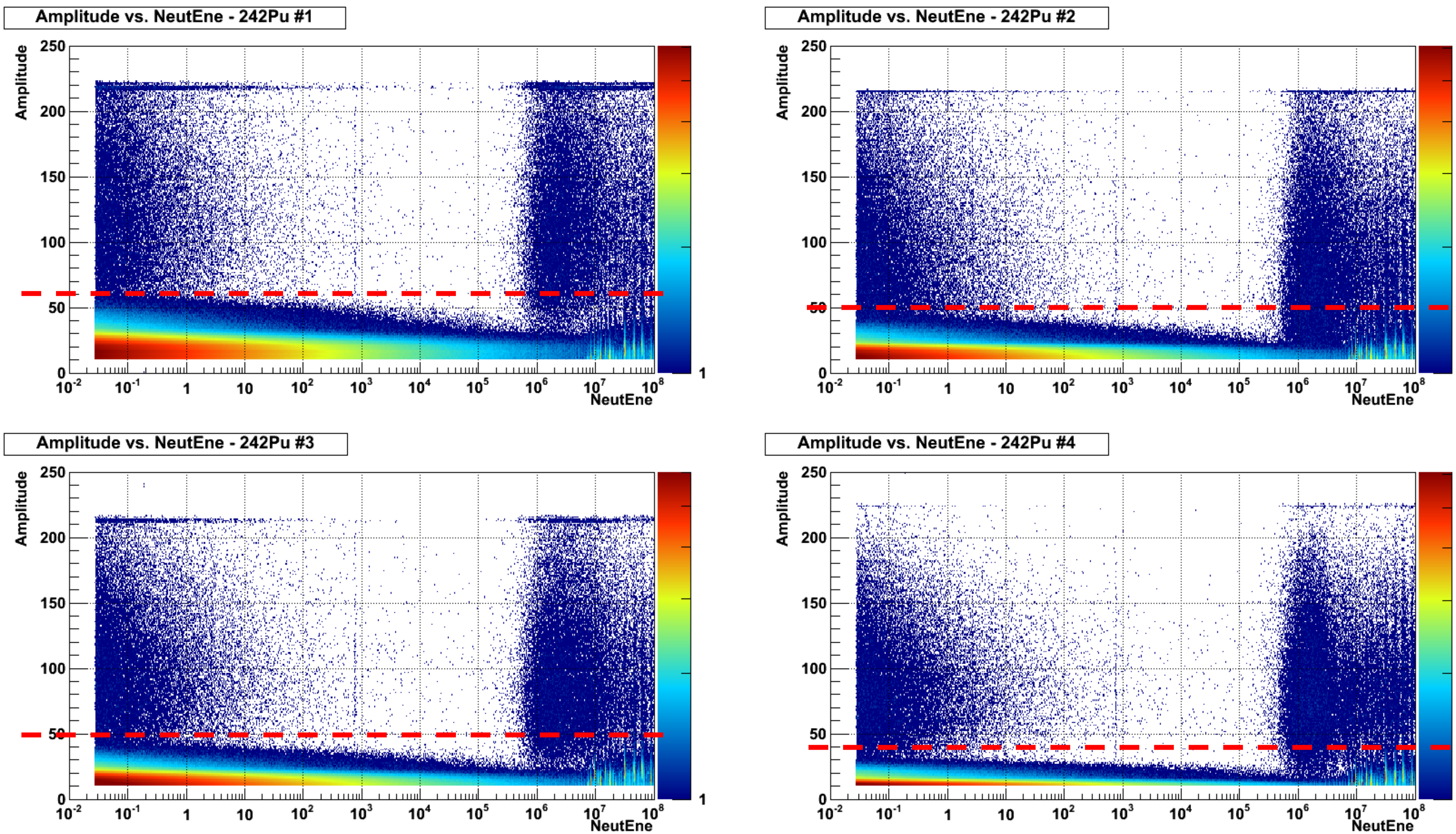

***End of 2012 run***

# Raw data analysis

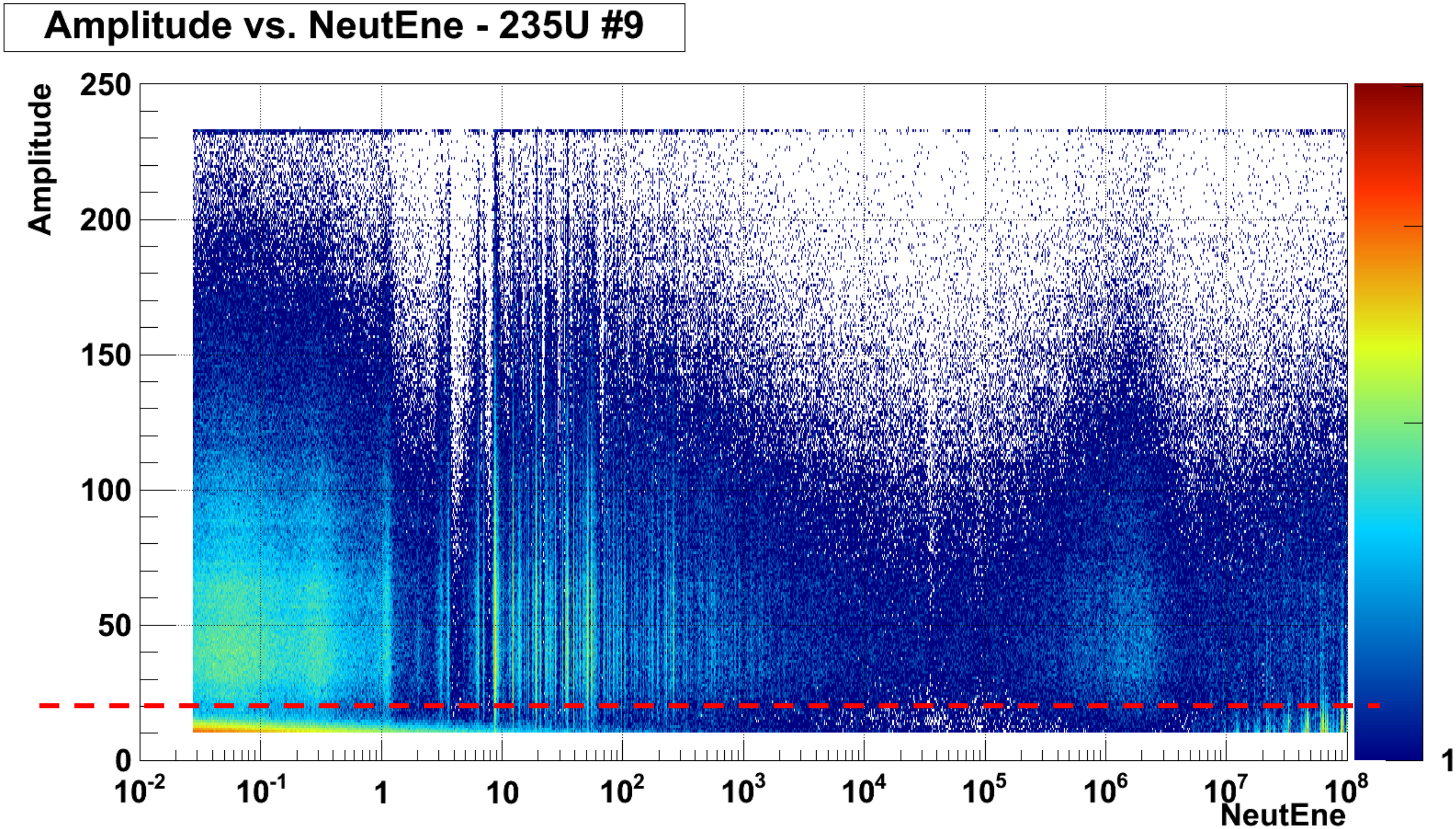
- Raw data is processed with a peak-search algorithm
- Several quantities are stored
  - Time and amplitude
  - FWHM, area, total width



# Amplitude vs. $E_n$ – $^{242}$Pu

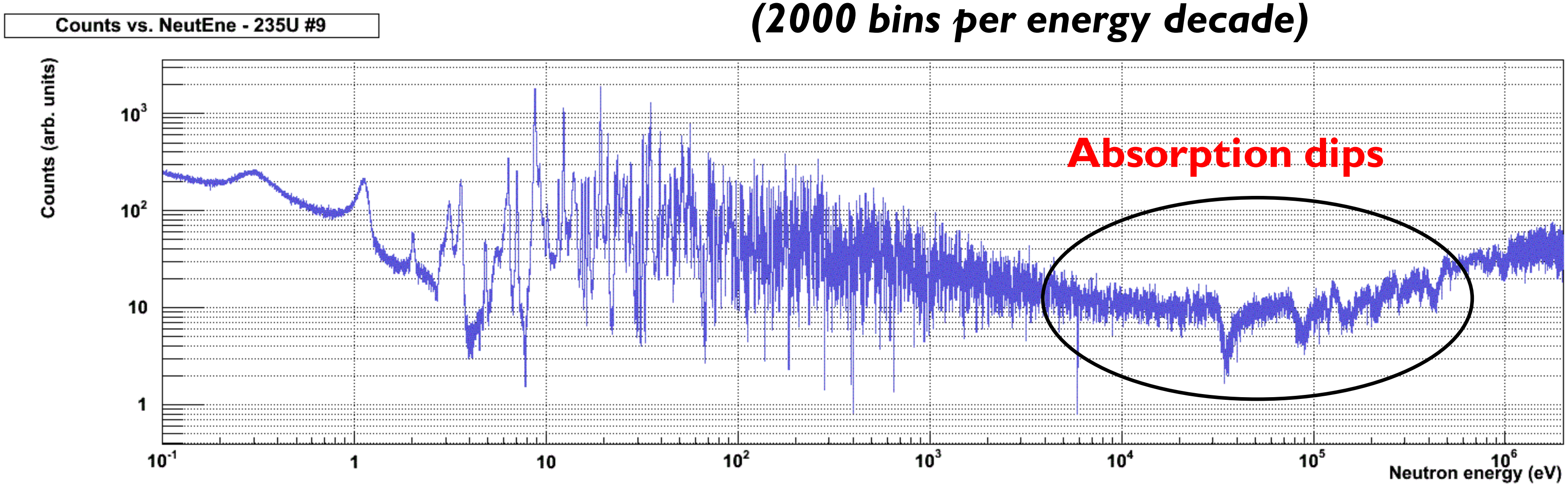


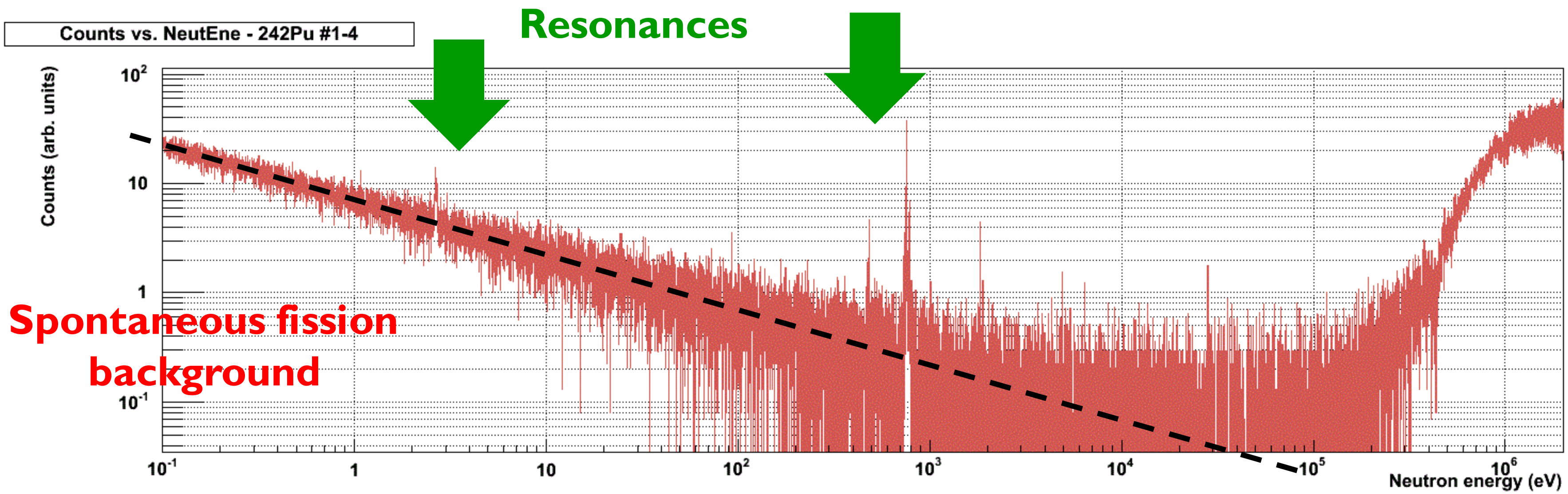
# Amplitude vs. $E_n$ – $^{235}U$



# $^{235}U$ & $^{242}Pu$

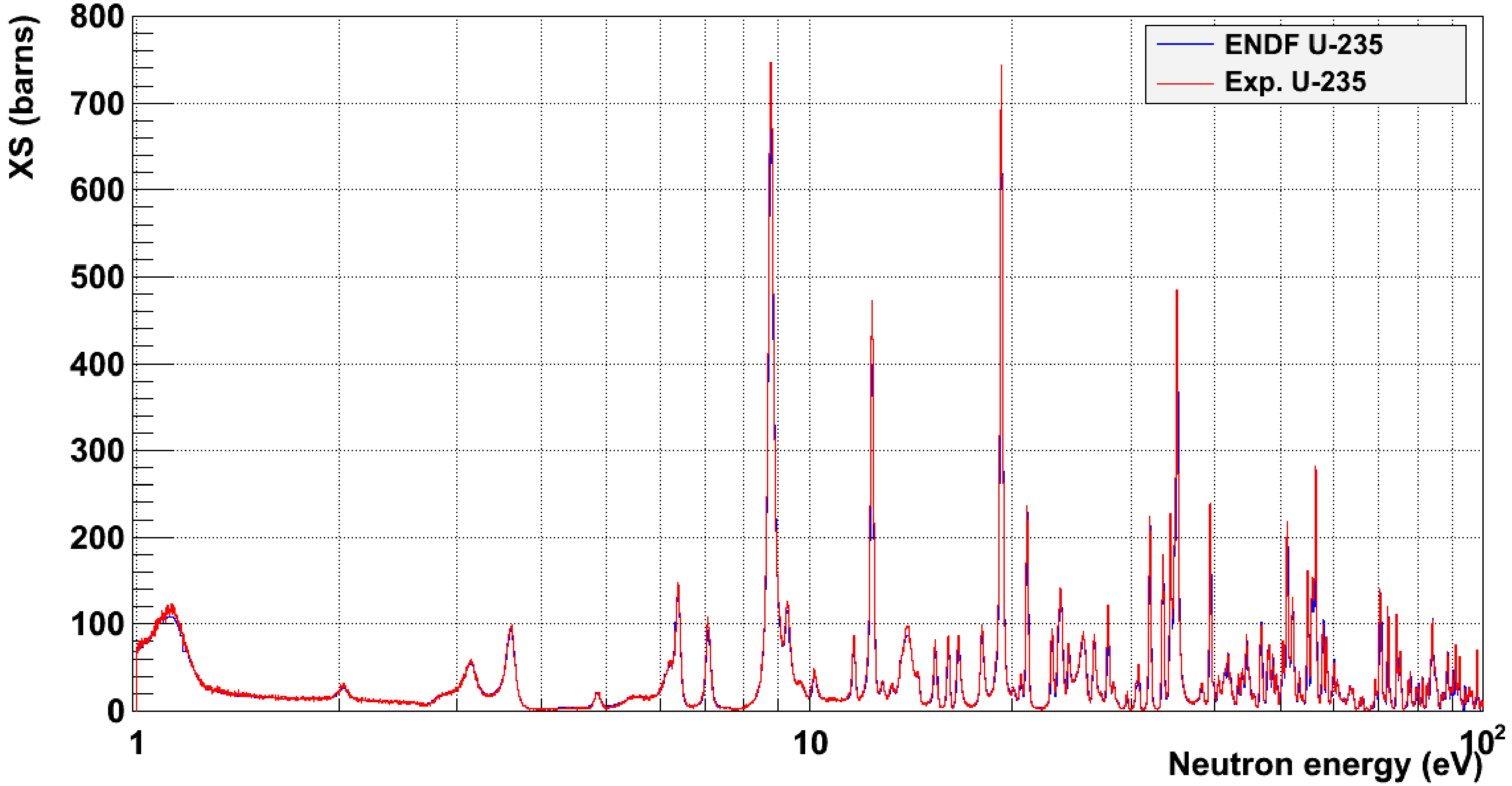
*(2000 bins per energy decade)*



# $^{235}U(n,f)$

- Comparing with ENDF…

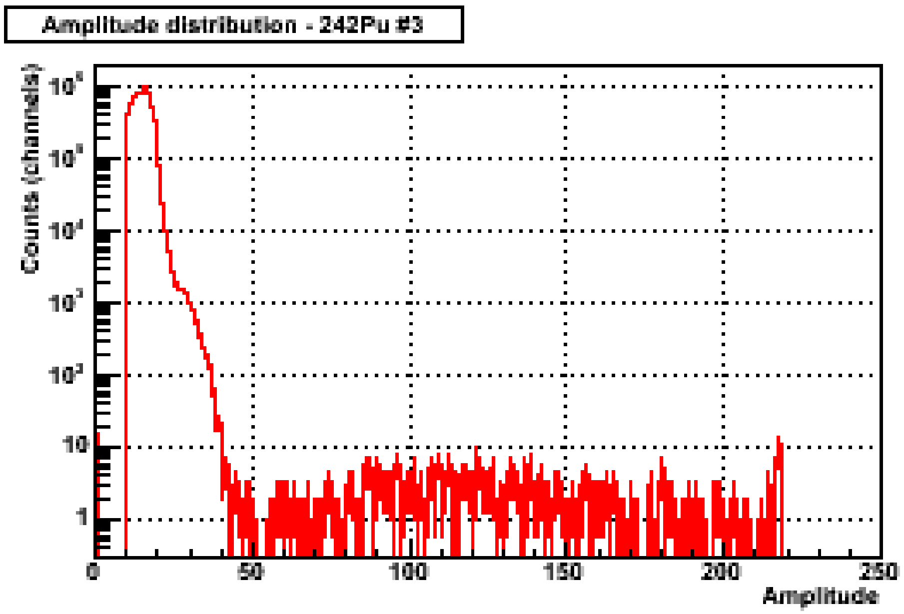


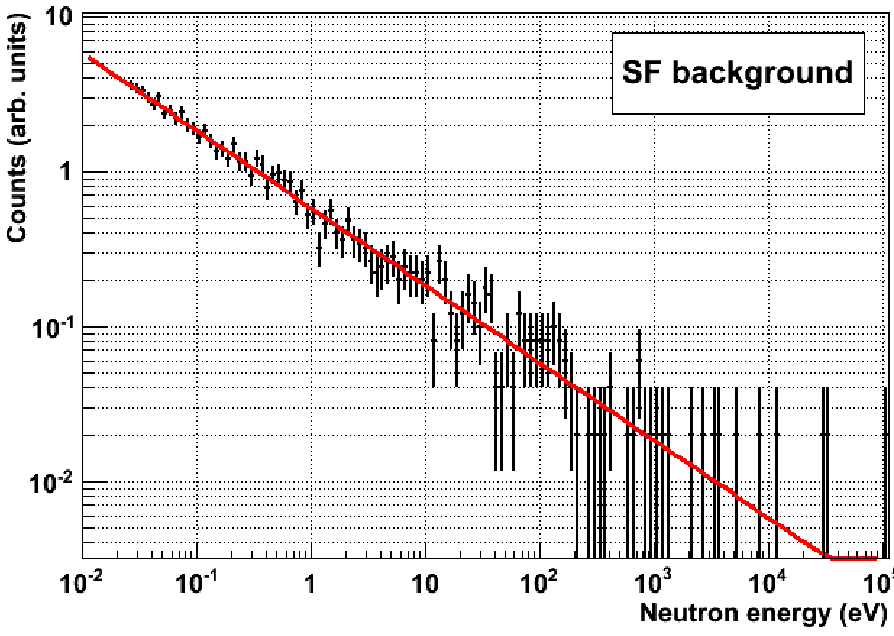
# $^{242}$Pu spontaneous fission background

- The spontaneous fission background dominates the low energy region and remains visible up to ~10 keV.
  - Still, several resonances can be observed above this background.
- Spontaneous fission branching ratio: 5.5 x $10^{-4}$ %
  - Fitted with an appropriate function

$$BGR = A \cdot e^{B \cdot logE_n} \quad ,$$

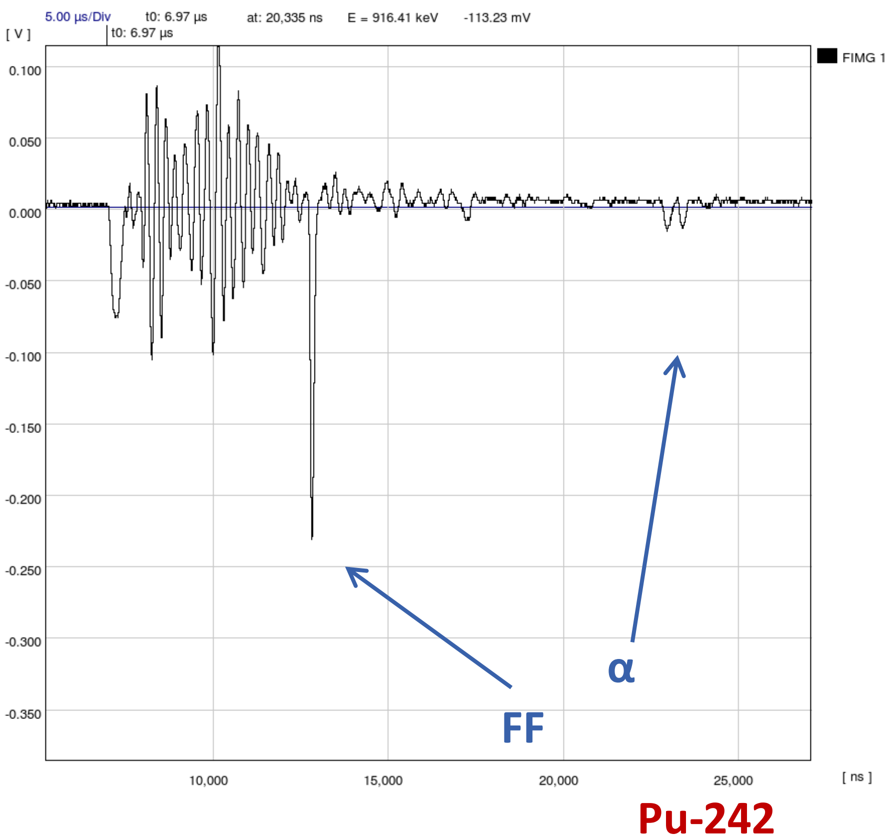
$$B = 1.15129$$

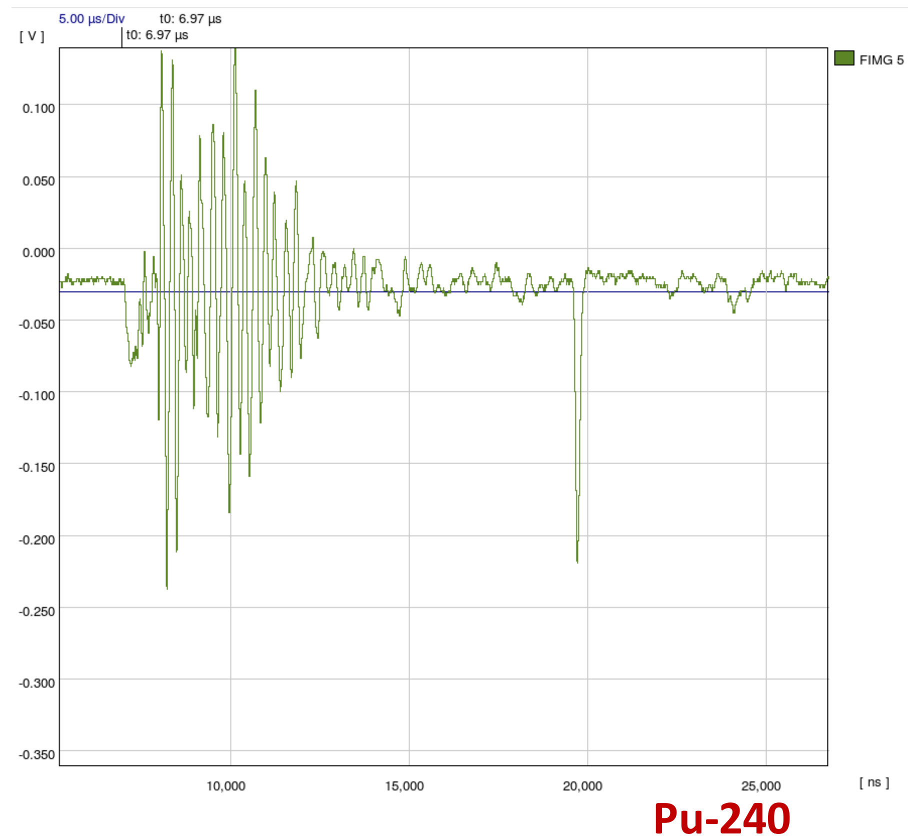


# Detector response to the γ-flash

- Baseline oscillations are dealt with off-line (next slide)

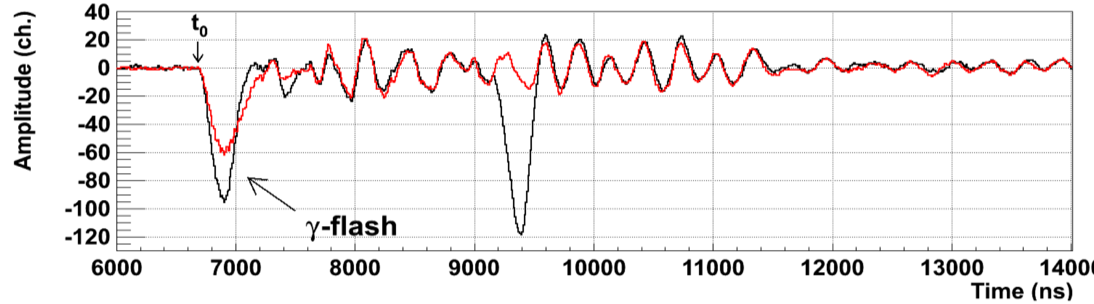


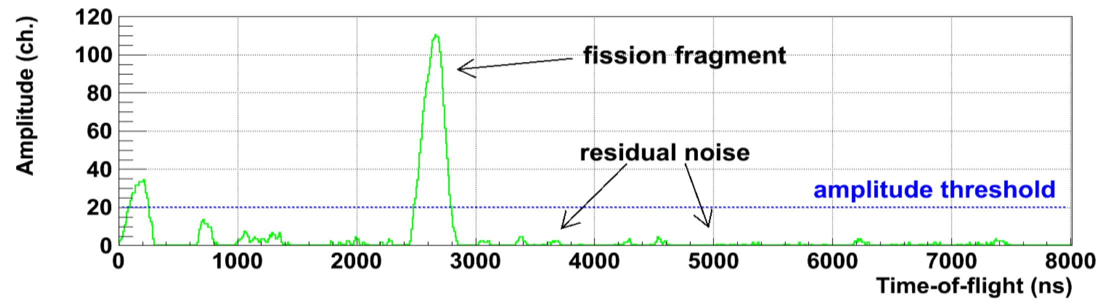



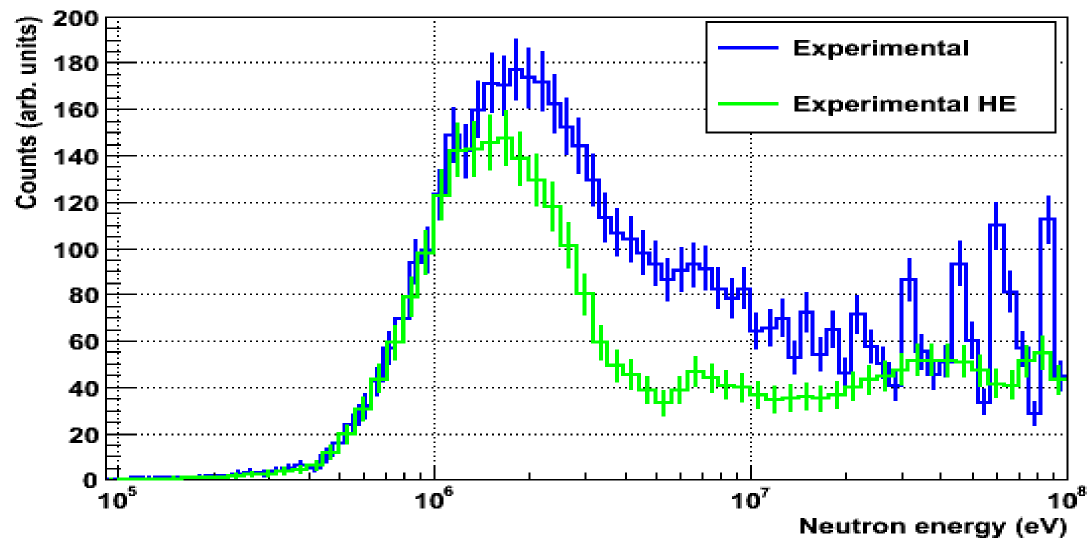

- Shielding of preamplifier mitigates problem

# The high-energy region

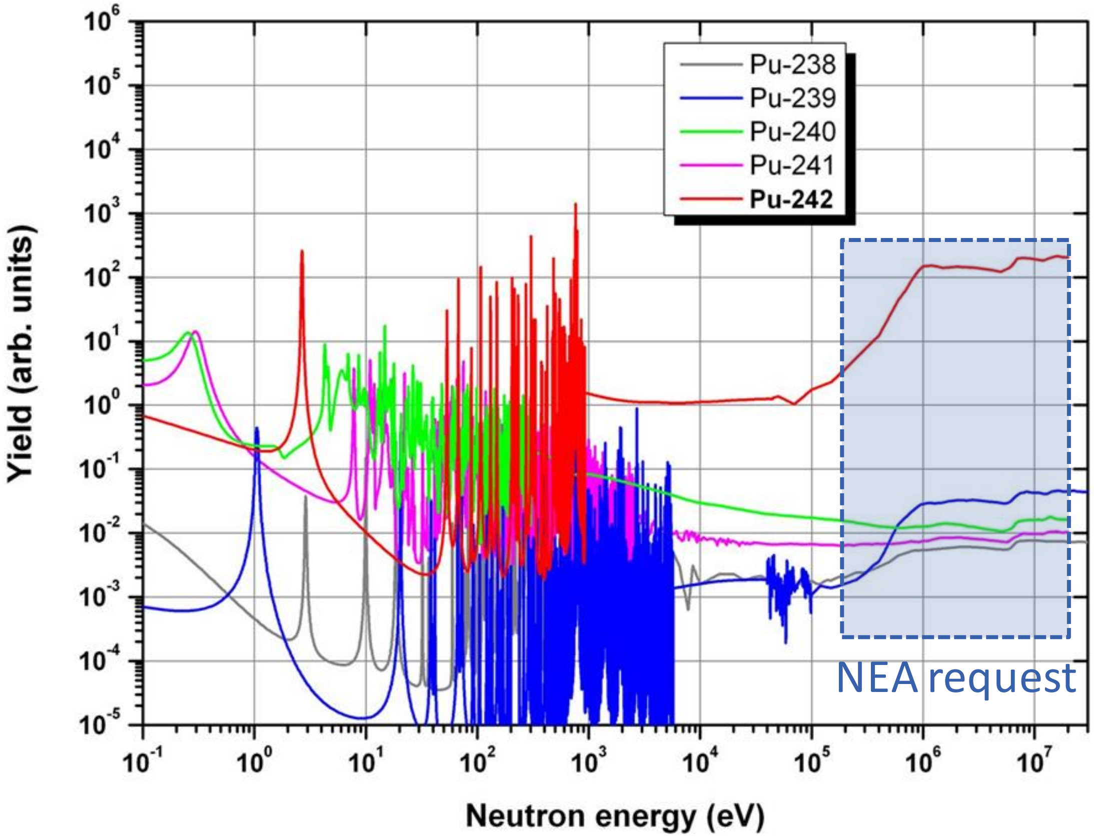
- Spallation process leads to significant production of prompt γ-rays and other relativistic particles
  - Initial γ-flash signal (hundreds of ns)
  - Baseline oscillation after the γ-flash lasts several μs and affects the high-energy data
- "Compensation method"
  - Oscillations recorded in adjacent detectors for the same proton bunch are almost identical
  - Baseline oscillation can be subtracted from adjacent detector
- One step added in the data-processing flow
  - Raw data are cleaned, the same peak-search routine is used to process the clean data



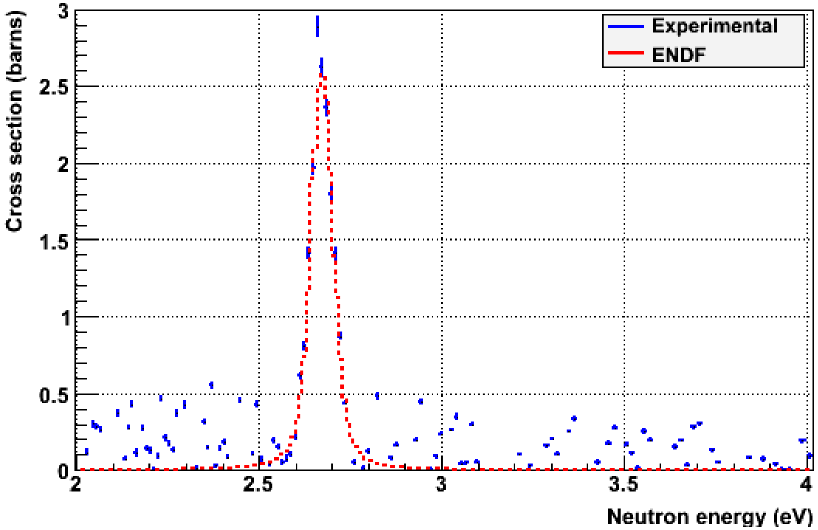



# The case of $^{242}$Pu




- Contribution of contaminants is very significant below few hundred eV
  - …up to 2 orders of magnitude greater than $^{242}$Pu yield
- However the contribution is negligible above a few keV

# Resolved resonances

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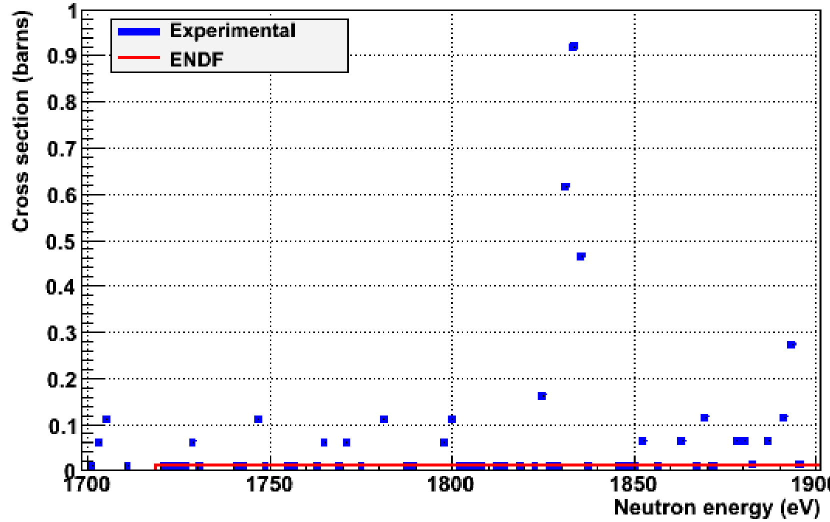


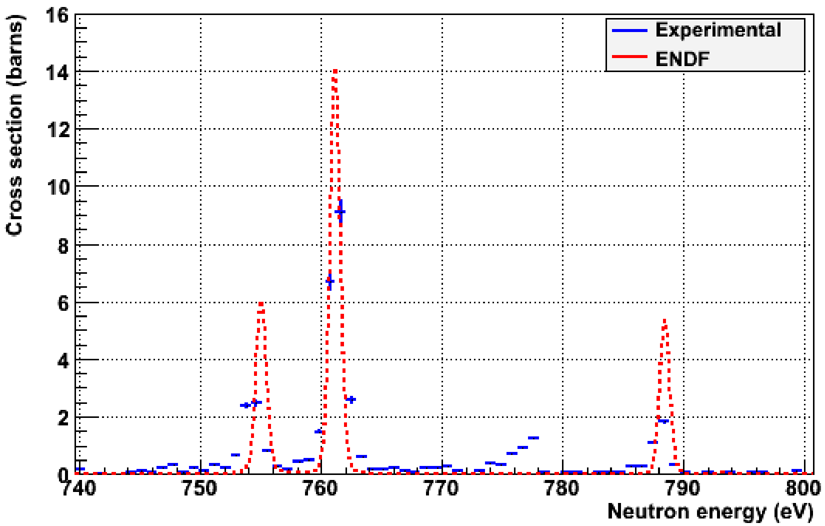


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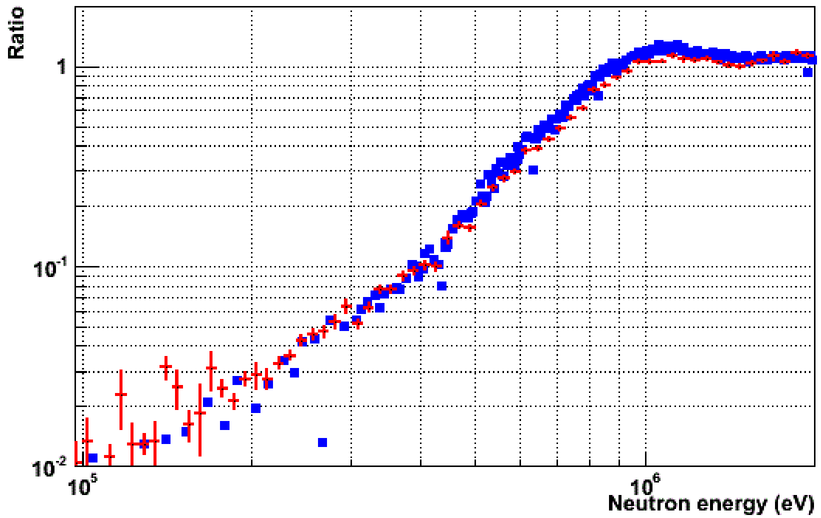
- 1) First resonance at ~2.7eV
  - Visible over spontaneous fission background
- 2) Resolved resonances around 700-800 eV
  - At ~780eV, a resonance not attributable to any of the stated sample impurities (at a preliminary analysis)
- 3) Resonance at 1833 eV, again not immediately attributable
- A few possible candidates at higher energy

# Above the fission threshold and the $^{242}Pu(n,f)$ / $^{235}U(n,f)$ ratio

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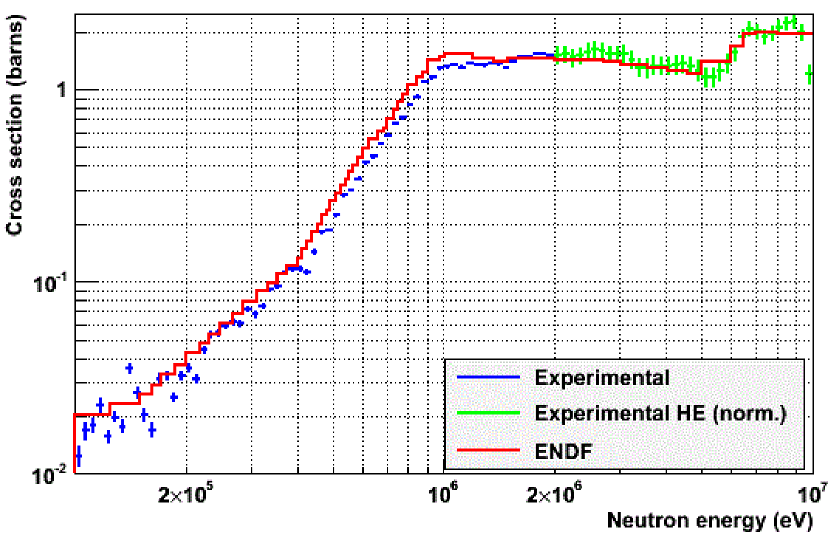
- 1) The $^{242}Pu(n,f)$ / $^{235}U(n,f)$ ratio
  - Compared to EXFOR data

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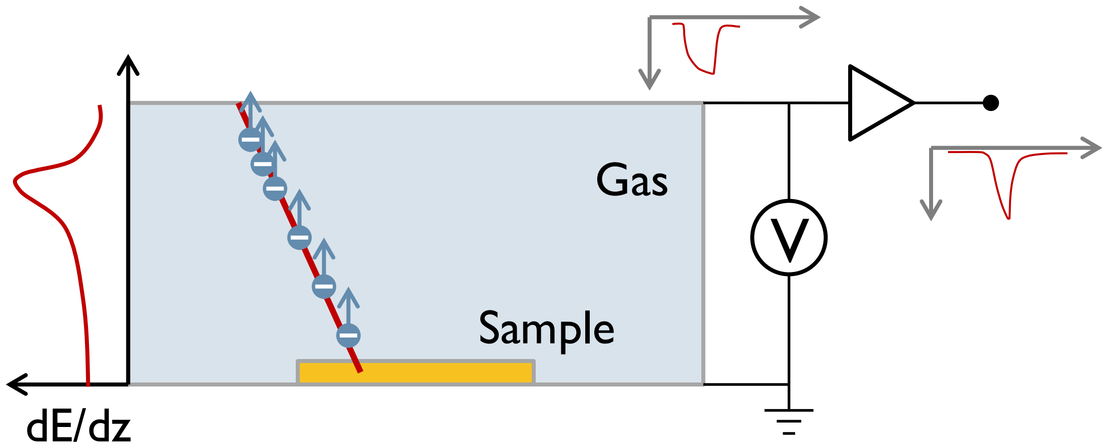
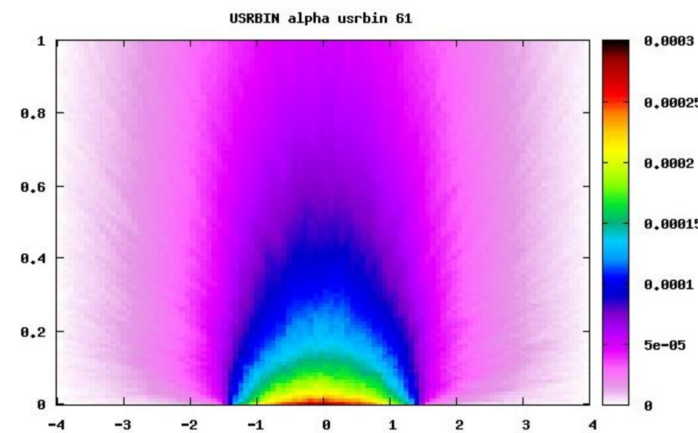
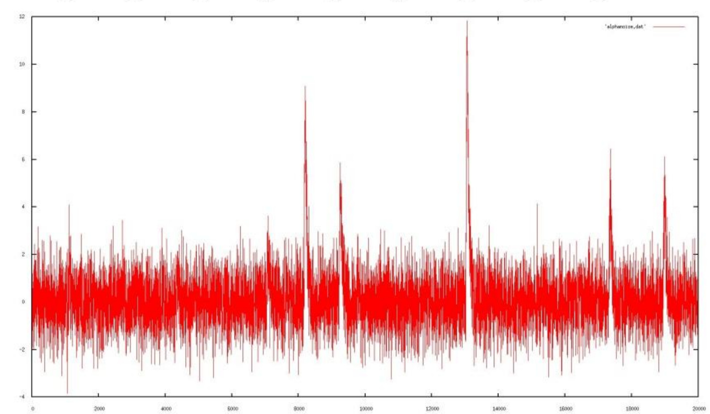
- 2) Above the fission threshold
  - Max. energy limit will be pushed as high as possible

# Simulations

- Reproducing signals from α-particles and fission fragments
- Simplified geometry of samples and active detector volume created in FLUKA
- Energy deposition is scored event-by-event and transformed to charge
- Electron drift velocity calculated for given gas mixture and drift voltage (GARFIELD)
- We can thus calculate the current reaching the readout electrode and “pass” it through an appropriate circuit to reconstruct the signal



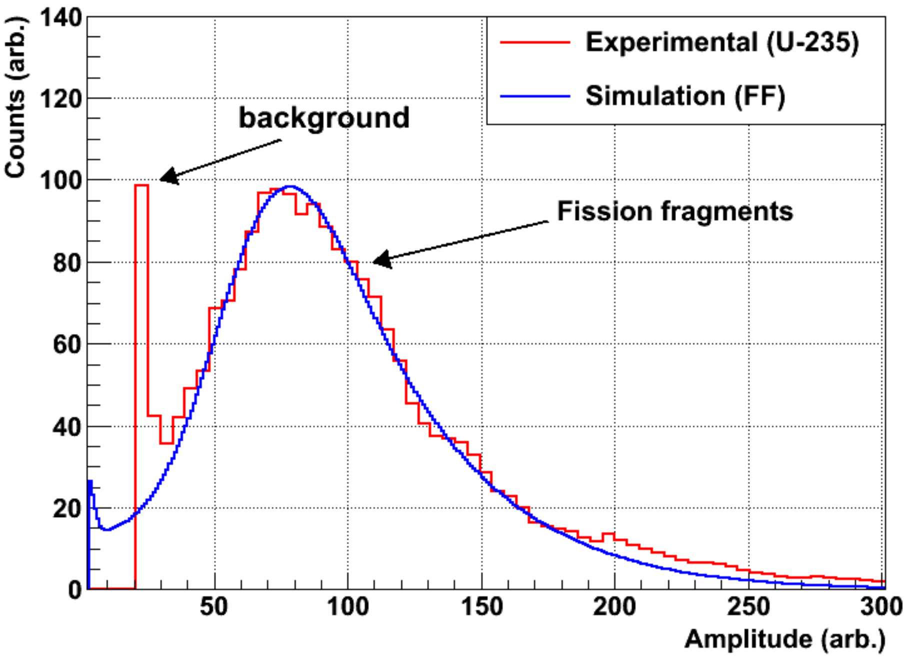



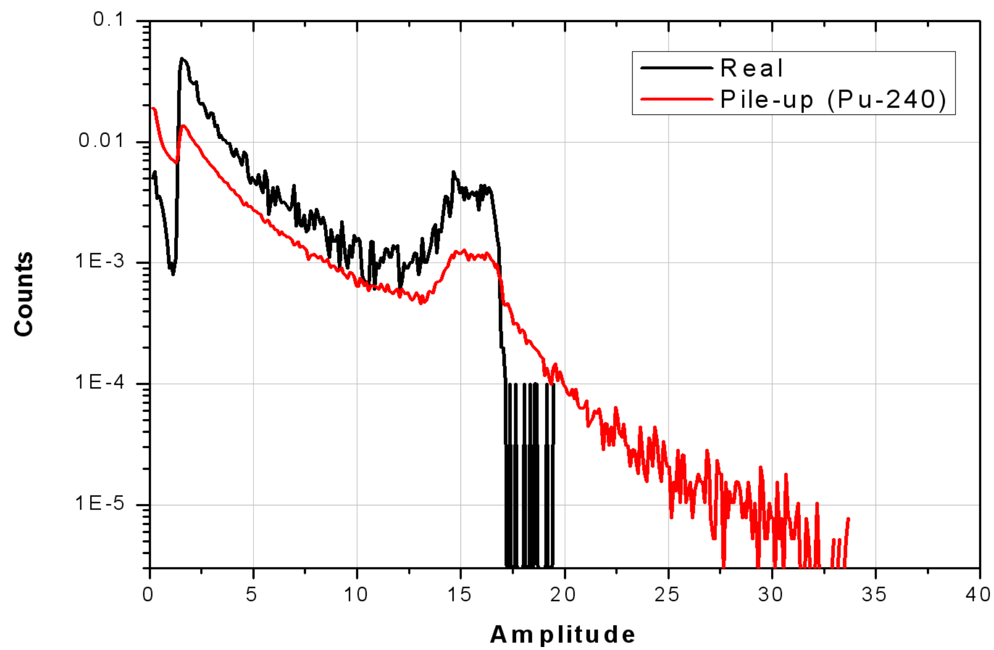



- A large time window is selected in which we randomly add:
  - white noise
  - α-particle and fission fragment pulses (at appropriate rates)

# Simulations

- Left: fission fragment pulse-height spectrum
  - Comparison of the real amplitude distribution of simulated fission fragments with the distribution extracted by the pulse analysis routine
- Right: how does α-pile-up (especially in $^{240}$Pu) affect the α-particle amplitude spectrum?
  - A long tail at higher amplitudes appears (just like in experimental data)



# The end

- *Support from ERINDA (travel expenses to n_TOF for 2 scientists) ☺*