DE LA RECHERCHE À L'INDUSTRIE

Use of active scintillating targets in nuclear physics experiments - Measurement of spontaneous fission

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LSC 2017 , Copenhagen 1-5 may

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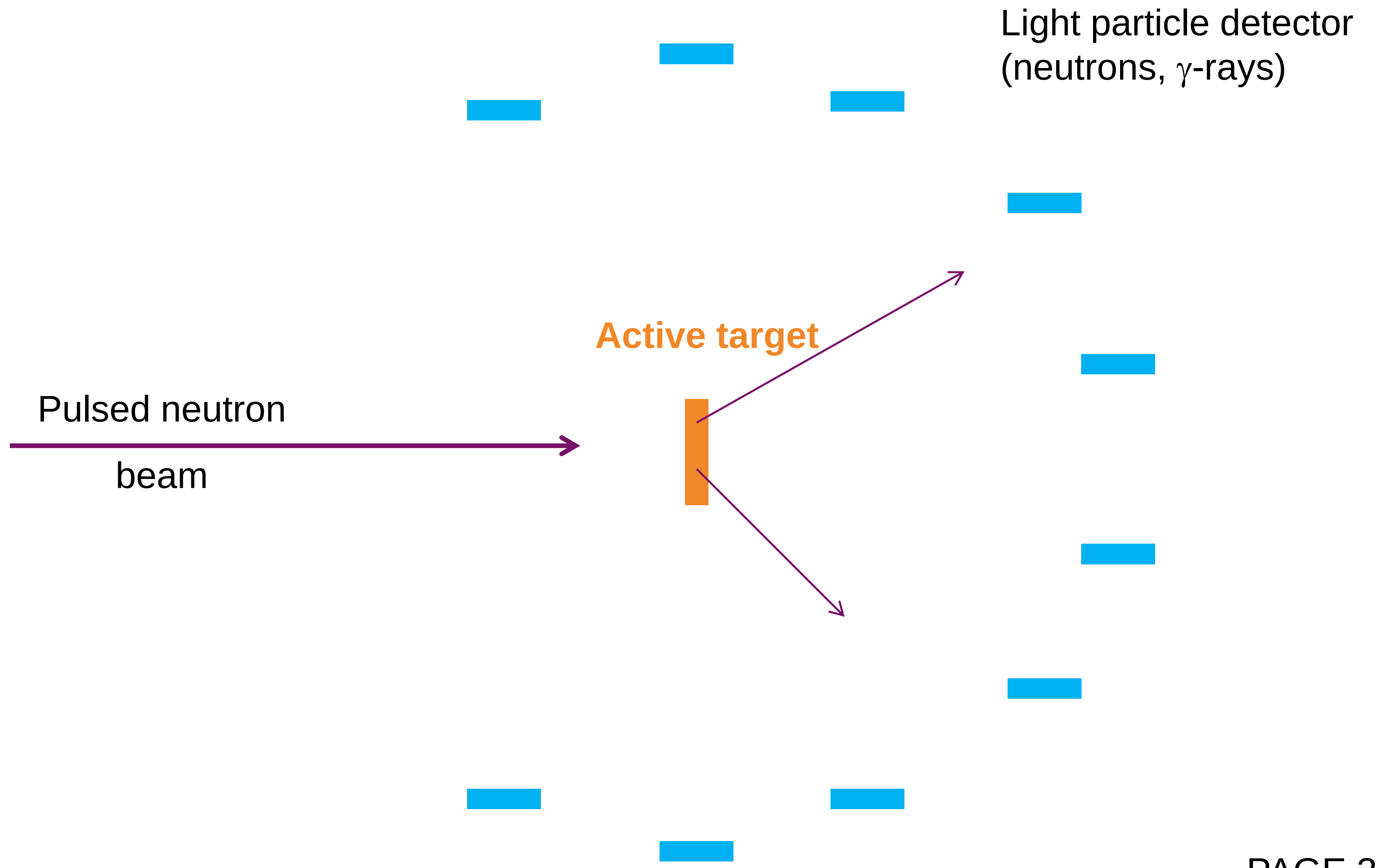
Motivations

Needs for highly precise nuclear data: Neutron induced reactions on actinides

→ Requires an active target to generate a fission trigger/veto

- ✓ Fission cross sections measurements – **spontaneous fission half-lives**
- ✓ Prompt fission neutron and γ-rays spectra measurements
- ✓ Fission product yields: **on-going analysis on activation experiment performed at ILL on ^{235}U** (collaboration with ILL, Grenoble France)
- ✓ Spectroscopy of fission fragments prompt γ-rays: collaboration with ILL for phase 1 FIPPS experiments
- ✓ (n,xn) and (n,γ) reactions

A typical measurement with an actinide target



Principle of the active scintillating target

Use of actinide loaded organic liquid scintillators

Advantages:

- ✓ **Very low count losses for α decays and fission events**
- ✓ **Pulse Shape Discrimination capability → particles identification**
- ✓ **Fast fluorescence**
  - **→ Time resolution about ~ 0.8 ns**
  - **→ Limited piled-up events**
- ✓ **Ease of fabrication: it's a 10 minutes work!!!**

What is known on fission fragments detection with organic scintillators?

- **D.L. Horrocks, Rev. Of Sci. Instruments 34(1963)1035 Interaction of fission fragments with organic scintillators**
  - → Response of stilbène, NE150 plastic and toluene based scintillator
  - → Fission PSD similar to electron's PSD
  - → Fission light yield is 75 times lower than for electrons

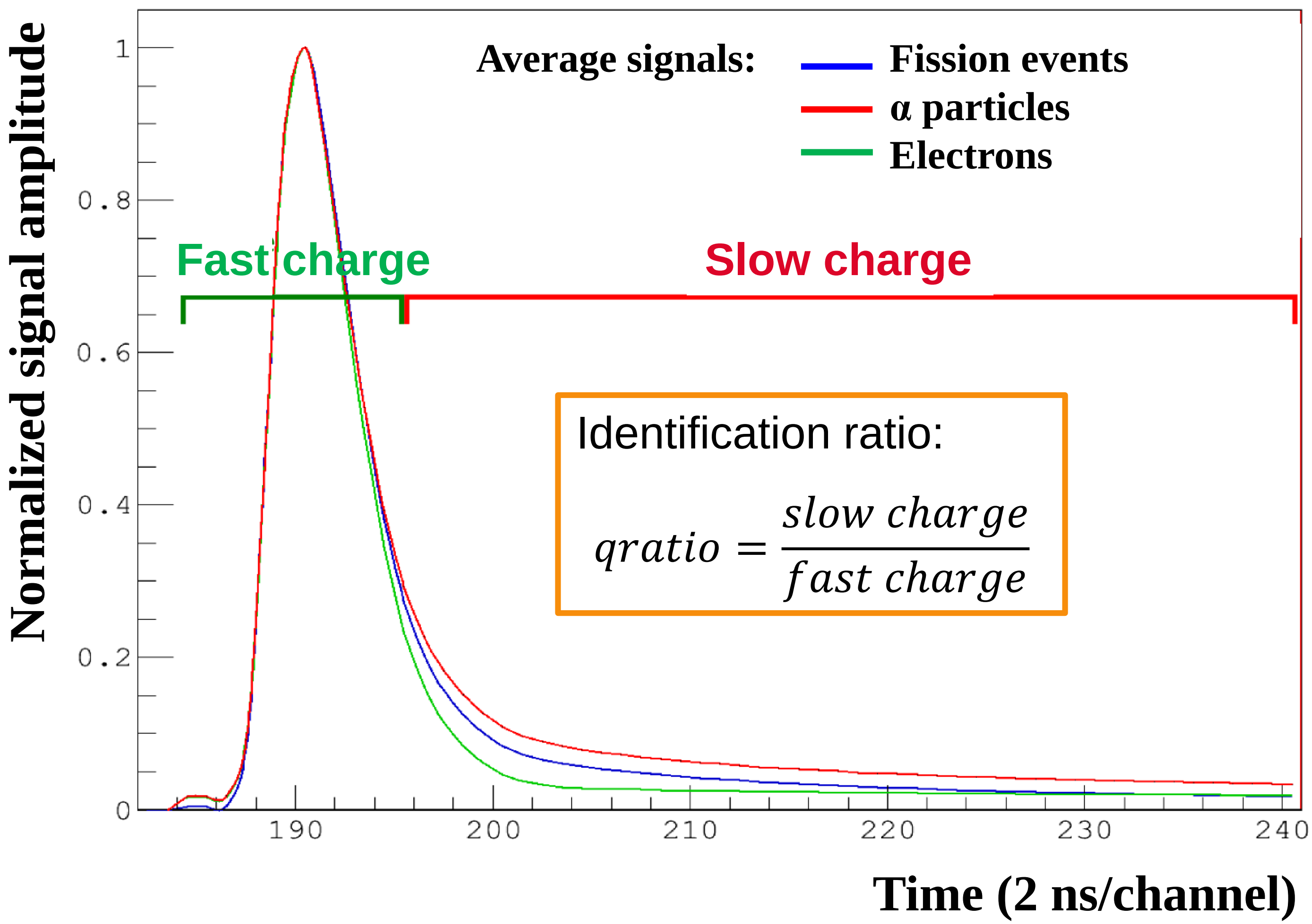
- **B. Wierczinski *et al.*, NIMA370(1996)532 Liquid-scintillation spectroscopy of α-particle emitters and detection of spontaneous fission events for on-line studies of actinide and transactinide elements**
  - → Flowing scintillator for heavy ions decay characterization
  - → Fission PSD similar to α-particles PSD
  - → Light yield for FF is 12.5 x lower compared to α-particles for toluene based scintillator

S. Mouatassim *et al.*, NIMA359(1995)530

→ NE213 scintillator **^{1,2,3}H and ^{3,4}He** Monotonic increase of the slow fluorescence/fast fluorescence ratio with ion mass

Pulse Shape Discrimination (PSD)

Di-Isopropyl-Naphtalene (DIN) based scintillator

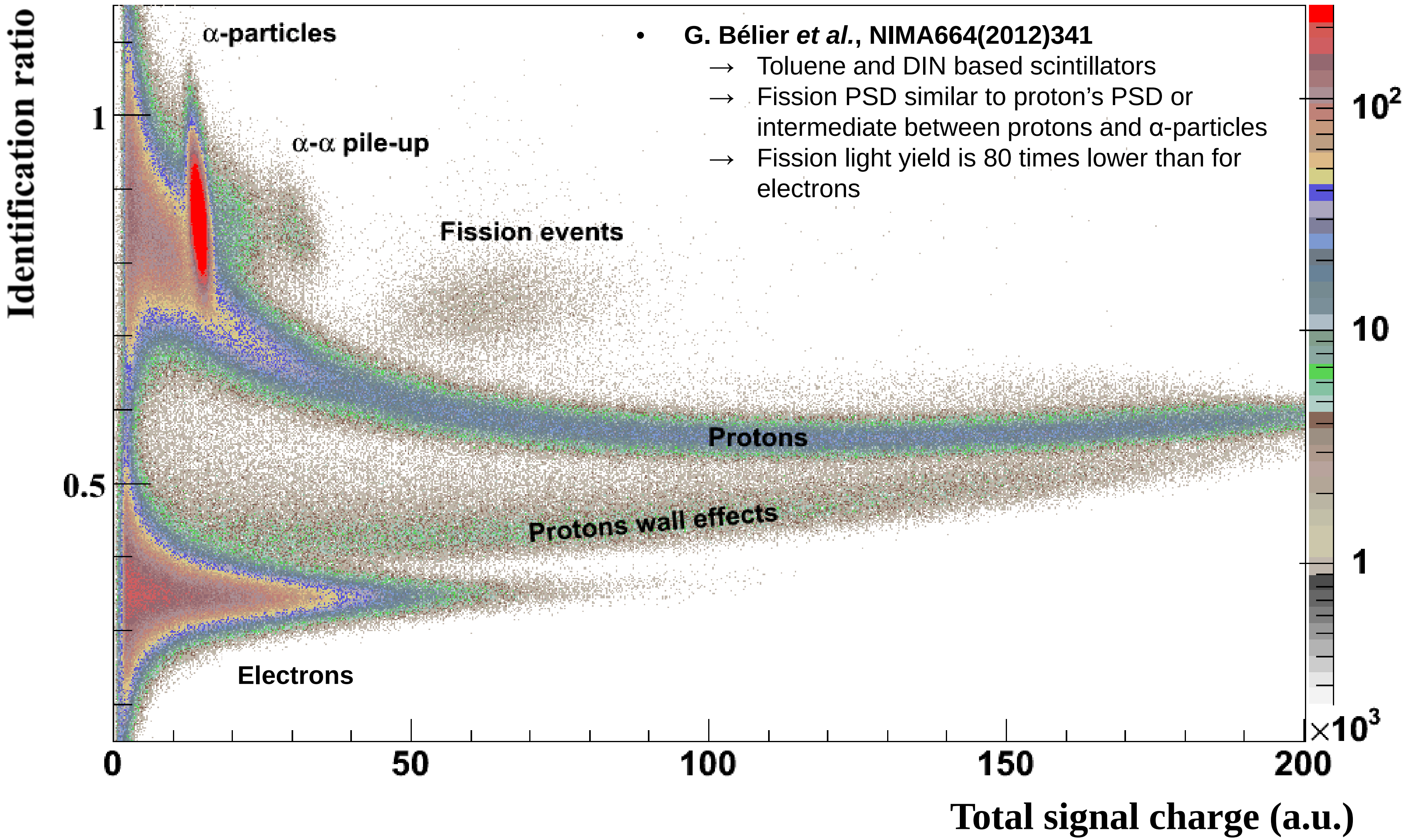


Identification ratio:

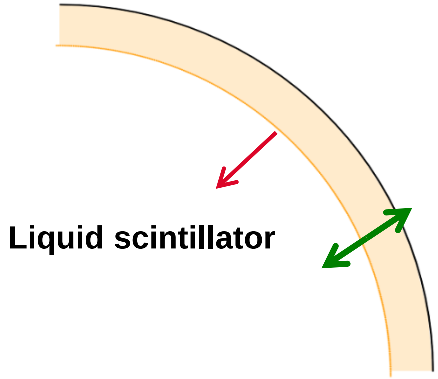
$$qratio = \frac{slow\ charge}{fast\ charge}$$

^{252}Cf loaded DIN scintillator

16 MeV neutron irradiation

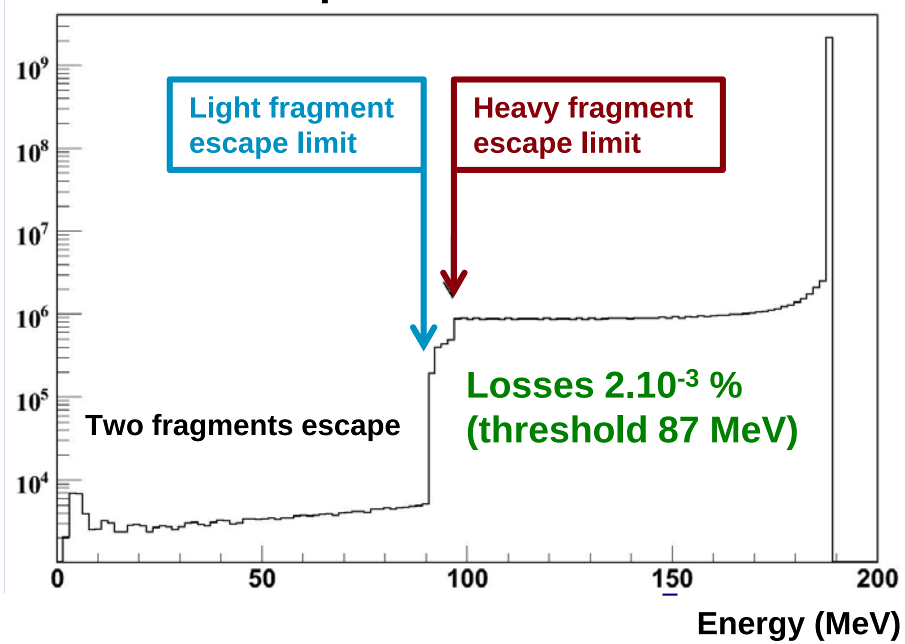


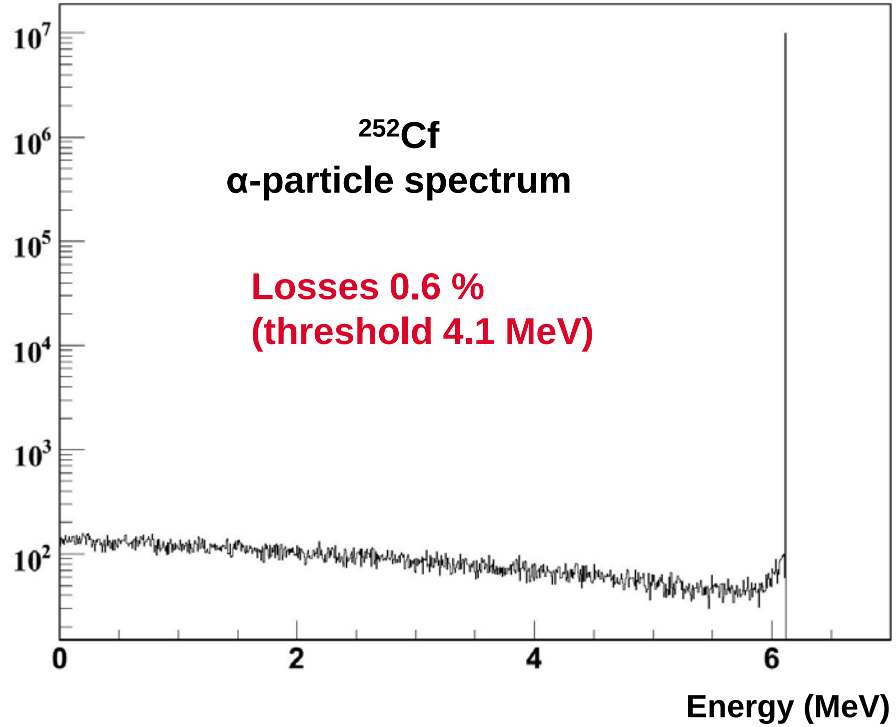
Detection efficiencies for PERALS tube geometry



- Count losses due to wall effects
- Skin thickness given by particle ranges:
  - α-particles 50 µm
  - Fission fragments 20-30 µm (HF-LF)
- Typical volume: 1 cm^3

Simulations performed with MCNPX 2.6





SPONTANEOUS FISSION MEASUREMENTS

Why is it needed?

Precises fission cross section measurements require precise knowledge of fission fragment detection efficiency:

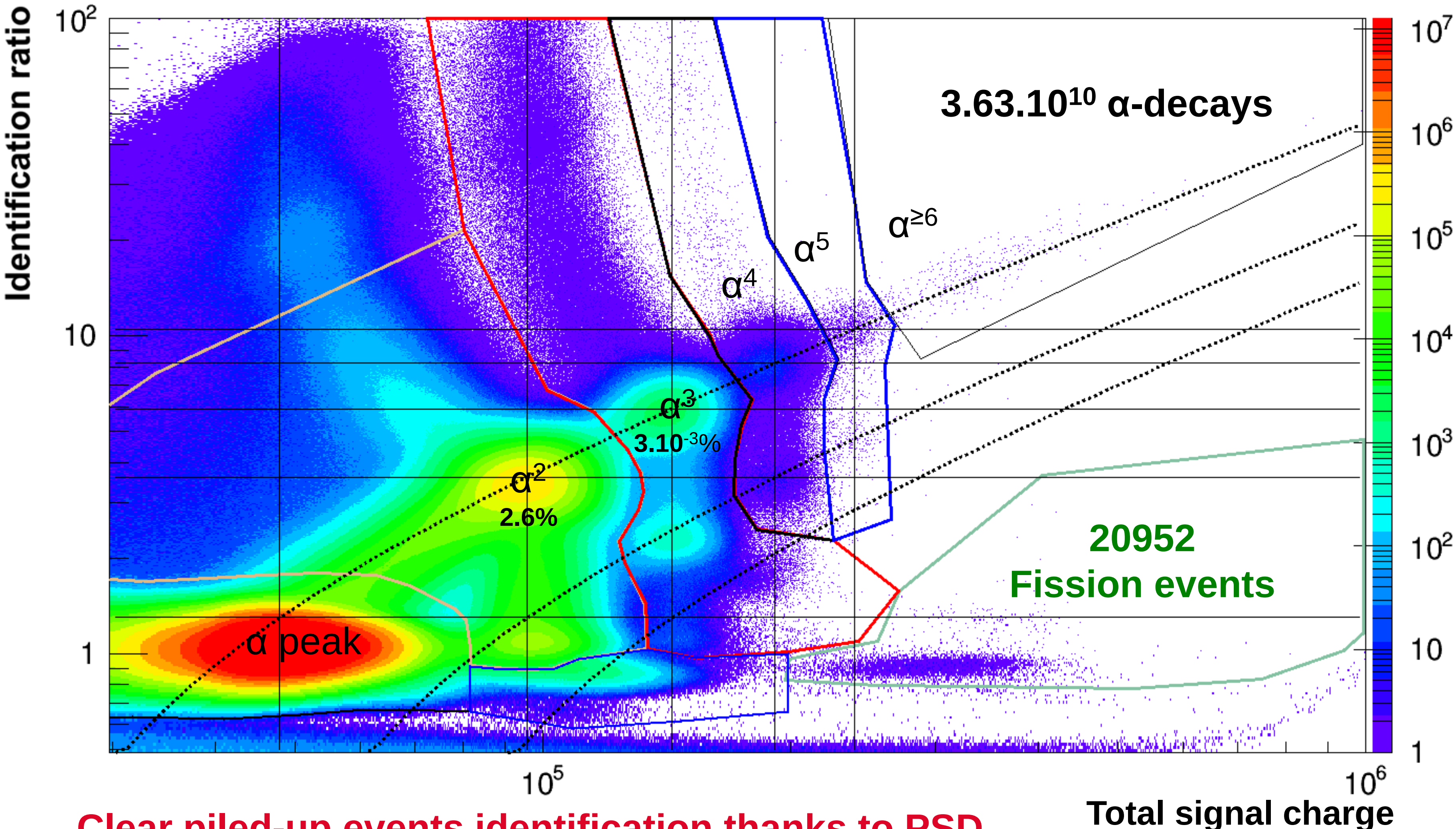
- Coincidence method: need high count rates
- Simulations: help for designing the detector (alpha-fission separation) but is not quantitative
- Spontaneous fission: can be used when branching ratio is sufficiently high, and precisely known

$\rightarrow$ Measurement of ^{240}Pu and ^{242}Pu

$\rightarrow$ ^{252}Cf

Exemple ^{240}Pu sample, activity 78 kBq

Acquisition duration 60 days - Experiment duration 109.3 days



Clear piled-up events identification thanks to PSD

Measurements summary

^{240}Pu

- **This work *** — $T_f=1.132(8).10^{11}$ y
- **Holden evaluation [1]** — $T_f=1.140(10).10^{11}$ y
- **Salvador-Castiñeira [2]** — $T_f=1.165(13).10^{11}$ y

^{242}Pu

liquid-liquid extraction → highly effective ^{241}Am separation!

- **This work*** — $T_f=6.77(5).10^{10}$ y
- **Holden evaluation [1]** — $T_f=6.77(6).10^{10}$ y
- **Salvador-Castiñeira [2]** — $T_f=6.74(9).10^{10}$ y

^{252}Cf

- **This work*** — $T_f=85.245(75)$ y (statistical uncertainty)
- **Holden [1]** — $T_f=86.000(1000)$ y
- **Nuclear Data Sheet 32 (1981) 87*** — $T_f=85.540(220)$ y

*** NB: Ground state half-lives uncertainties not included!**

[1] Pure Appl. Chem. 72(2000)1525 **[2] Phys. Rev C88**(2013)064611

Uncertainties

^{240}Pu sample Isotopic content May, 12th 2011			
Isotope	**Abundance (%)**	**Activity (% Bq)**	**SF rate (%)**
^{238}Pu	0,0733(29)	0.050(2)	0.001(1)
^{239}Pu	0,0144(18)	0.0037(5)	-
^{240}Pu	99,8915(18)	0.9486(10)	0.9980(1)
^{241}Pu	0,00041(31)	0.0014(11)	-
^{242}Pu	0,02027(41)	0.0003	0.00001
^{244}Pu	0,000046(88)	-	-

k=2 uncertainties

α-decay detection efficiency	0.01 %
α-α pile-up	0.04 %
α count	0.04 %
Isotopic content	**0.12 %**
Fission statistic	0.67 %
Total	**0.68 %**

→ **Absolute limit due to sample knowledge**

Conclusion

- **Active scintillating targets are very precise for spontaneous half-lives measurements.**
- **On going analysis on FP activation measurement on $^{235}U(n_{th},f)$ very promising (collaboration with ILL)**
- **Detector R&D effort in order to extend the use of active targets to high neutron energies (current limit at 6 MeV)**
- **Development of a fission trigger for FIPPS phase 1**
- **Long term: active scintillating targets are very promising for highly precise nuclear data measurements on actinides**