The half-life of ^{212}Po

N.V. Sokur, P. Belli, R. Bernabei, R.S. Boiko, F. Cappella, V. Caracciolo, R. Cerulli, F.A. Danevich, A. Incicchitti, D.V. Kasperovych, V.V. Kobychev, O.G. Polischuk, V.I. Tretyak

August 23rd – September 2nd

Content

- 1. Introduction
- 2. Experiment
- 3. Data analysis and results
- 4. Conclusions

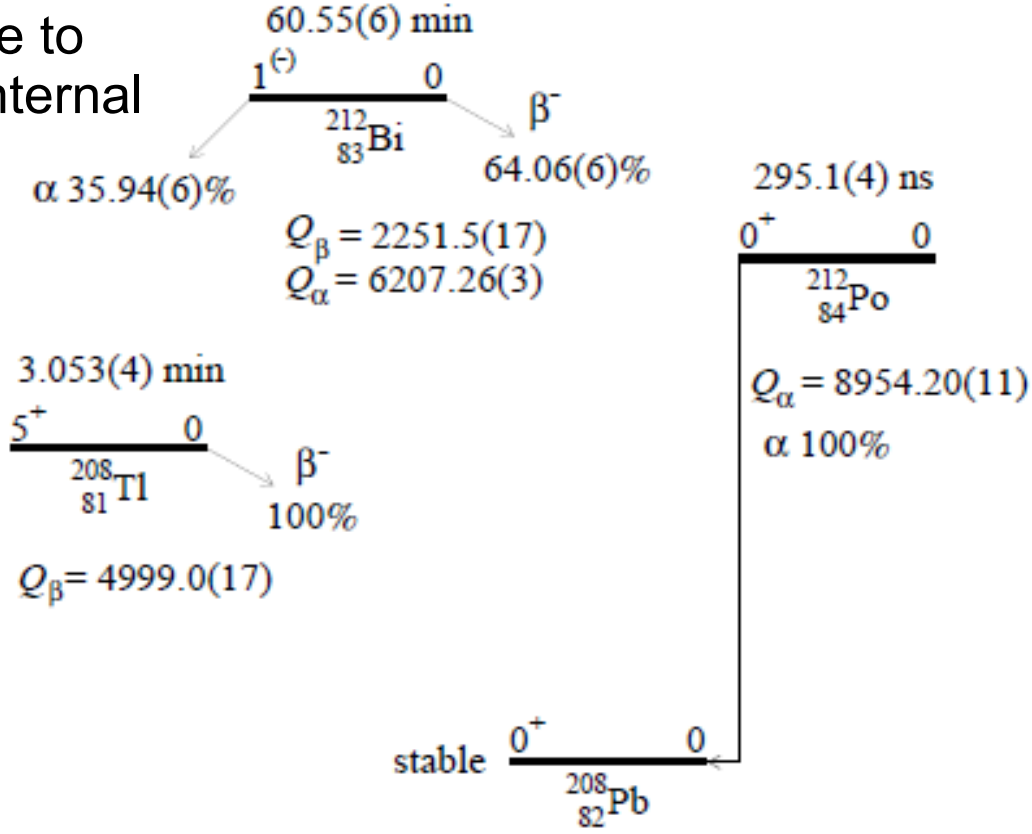
1. Introduction

The ^{212}Po is the α active daughter of ^{232}Th decay chain with the shortest decay time among the naturally occurring radioactive nuclides.

The current recommended value of the ^{212}Po half-life is $T_{1/2}$ = 294.3(8) ns [1].

Historically, the experiments for measuring the ^{212}Po half-life changed from Geiger-Müller counters with an external source to different types of scintillators with an internal source.

To improve the half-life accuracy, one should minimize the liquid scintillator volume and use a fast response PMT/electronics.



BiPo event – ^{212}Bi β-decay followed by ^{212}Po α event

[1] K. Auranen, E.A. McCutchan, Nuclear Data Sheets for A = 212, Nucl. Data Sheets 168 (2020) 117.

2.1 Thorium-loaded liquid scintillator

1) A 20% solution of trioctylphosphine oxide (TOPO) in toluene was taken as complexing organophosphorous agent to bind thorium in the organic phase.

2) The mixture was stirred with thorium nitrate pentahydrate salt (2 mg of Th/1 mL of TOPO):

$$Th^{4+} + 4\,NO_3^- + 3\,\overline{TOPO} \Leftrightarrow \overline{Th\left(NO_3\right)_4\left(TOPO\right)_3}$$

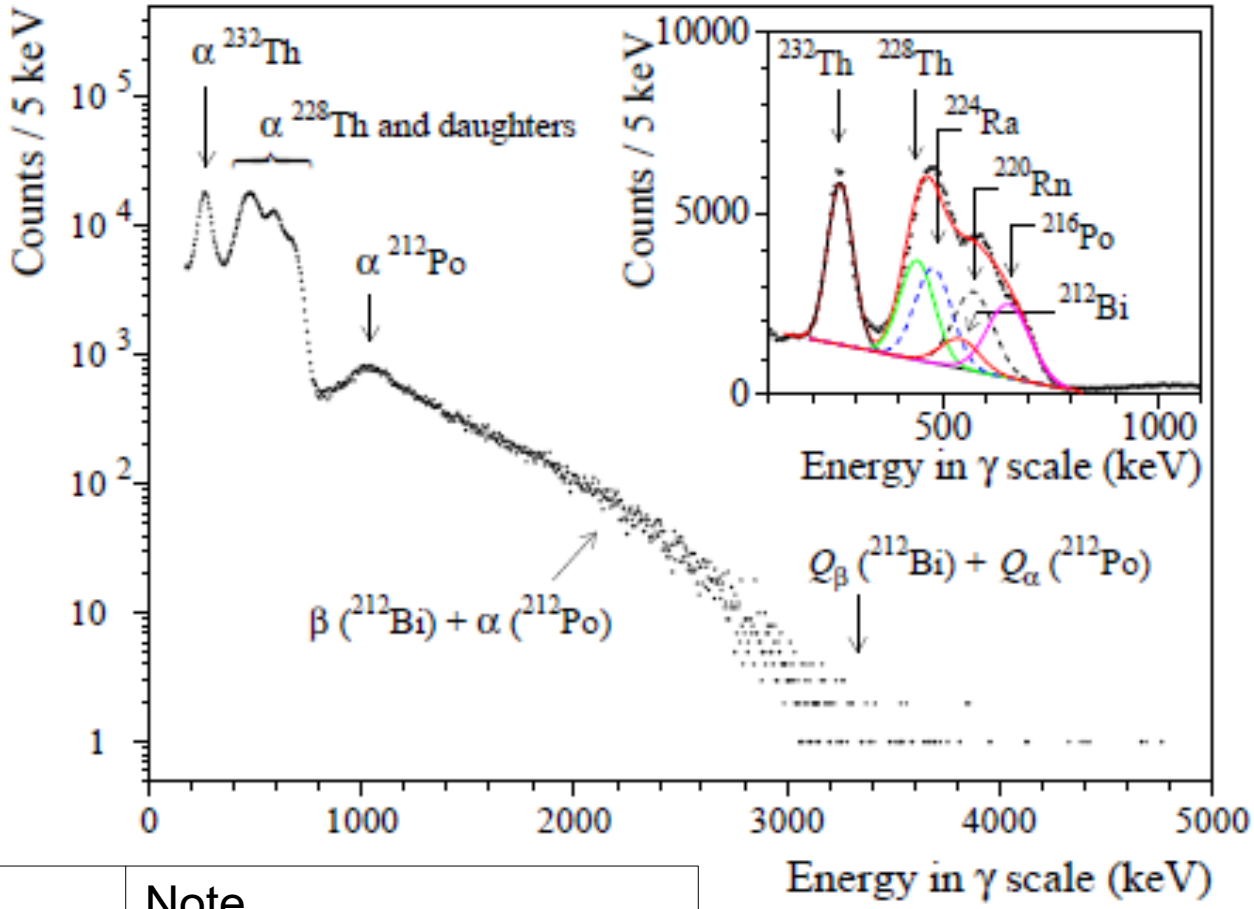
3) Th-containing organic solution was diluted 20-fold with the liquid scintillator based on toluene with additional 0.1% of PPO and 0.01% of POPOP.

4) The liquid scintillator contains $\approx$ 0.1 wt% of thorium (^{232}Th and ^{228}Th with daughters).

2.1 Thorium-loaded liquid scintillator

A 7 mL of the LS(Th) was sealed inside a quartz vial with inner size (⊘33×14) mm

Energy spectrum taken with 7 mL LS(Th) scintillator over 5910 s.



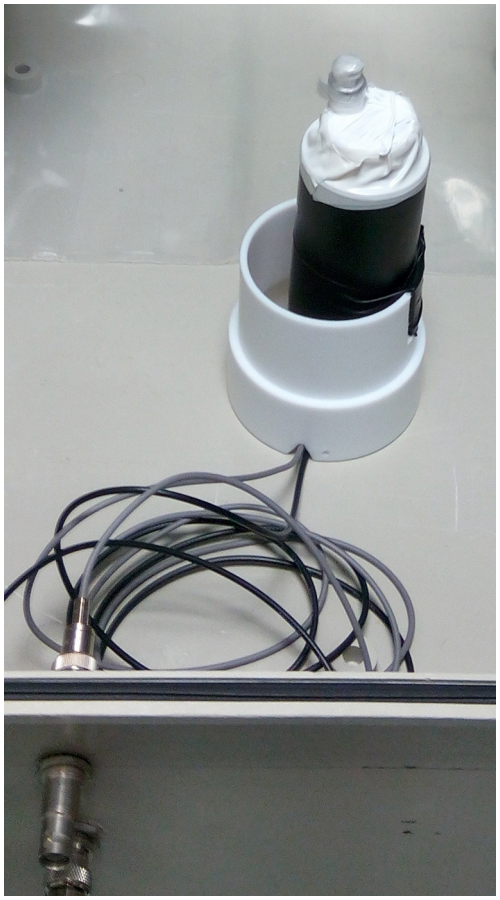
Property	Value	Note
Light yield	42(3)%	Relatively to polystyrene based plastic scintillator
Activity of ^{232}Th	4.61(2) Bq/mL	Reference date July 8th, 2016
Activity of ^{228}Th	3.82(7) Bq/mL	
Total α activity	20.7(10) Bq/mL	
Concentration of thorium	0.113(1) wt%	

2.2 Recording of BiPo waveforms

Fast-time-response photomultiplier tube Hamamatsu R13089-100-11:

- rise time: 2.0 ns,
- transit time: 20 ns,
- transit time spread: 170 ps (full width at half maximum).

Waveforms were recorded by a LeCroy WavePro 735Zi-A oscilloscope with a sampling frequency of 20 GSa/s and a 3.5 GHz bandwidth.



First stage (June 2017):
A 4.4 g (5 mL) sample of LS,
$\approx 70 \times 10^3$ BiPo events [2];

Second stage (April-May 2018):
A 10.6 g (12 mL) sample of LS,
216.67 hours of measurement,
$\approx 2.7 \times 10^6$ BiPo events [3].

[2] P. Belli et al., Half-life measurements of ^{212}Po with thorium loaded liquid scintillator, Nucl. Phys. At. Energy 19 (2018) 307 (in Ukrainian)

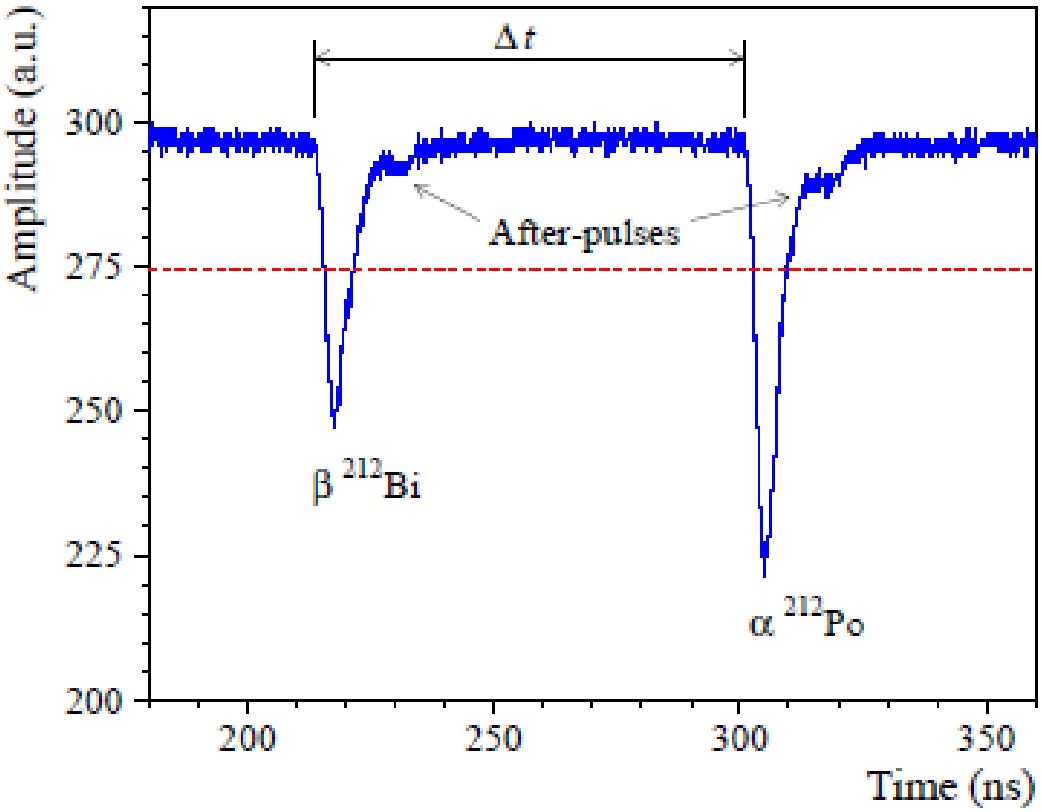
[3] P. Belli et al., The half-life of ^{212}Po, Eur. Phys. J. A 57 (2021) 215.

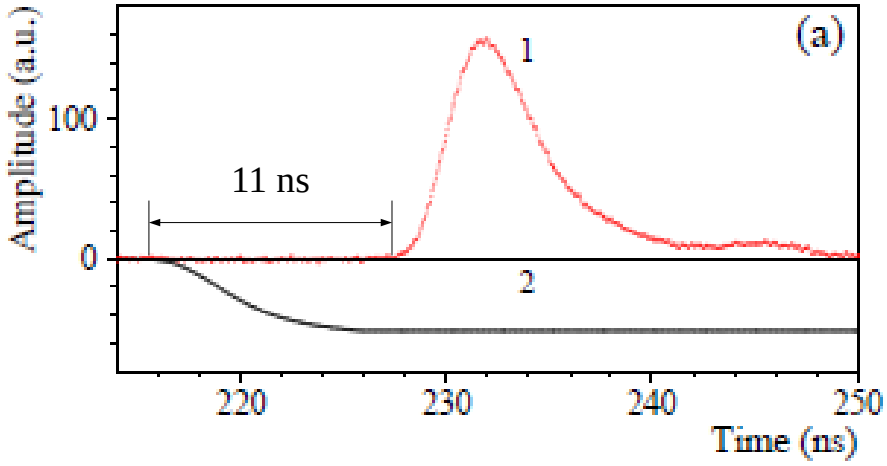
3.1 Time intervals between β and α pulses in BiPo events

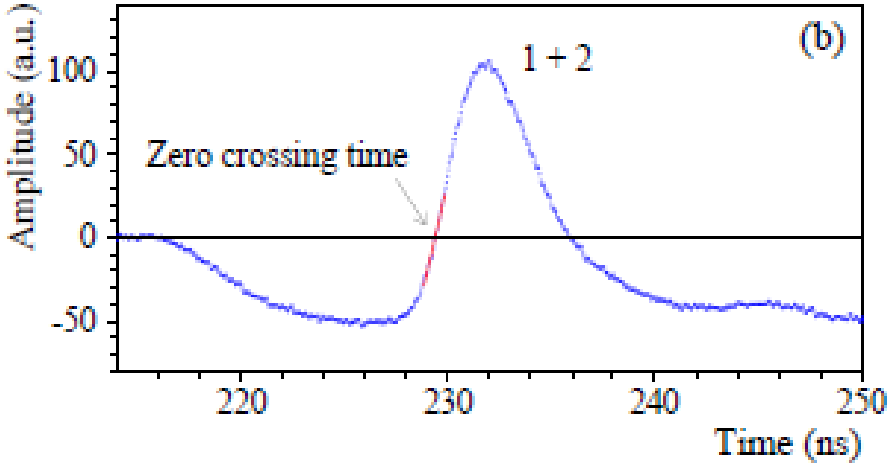
Determination of Δt:

1) A simple low-level-discriminator algorithm with a high threshold to find pairs of events in the data.
2) The recognized pairs of events were then analyzed by using the method of digital constant-fraction discrimination.
3) Δt = zero crossing time(2nd) – zero crossing time (1st)

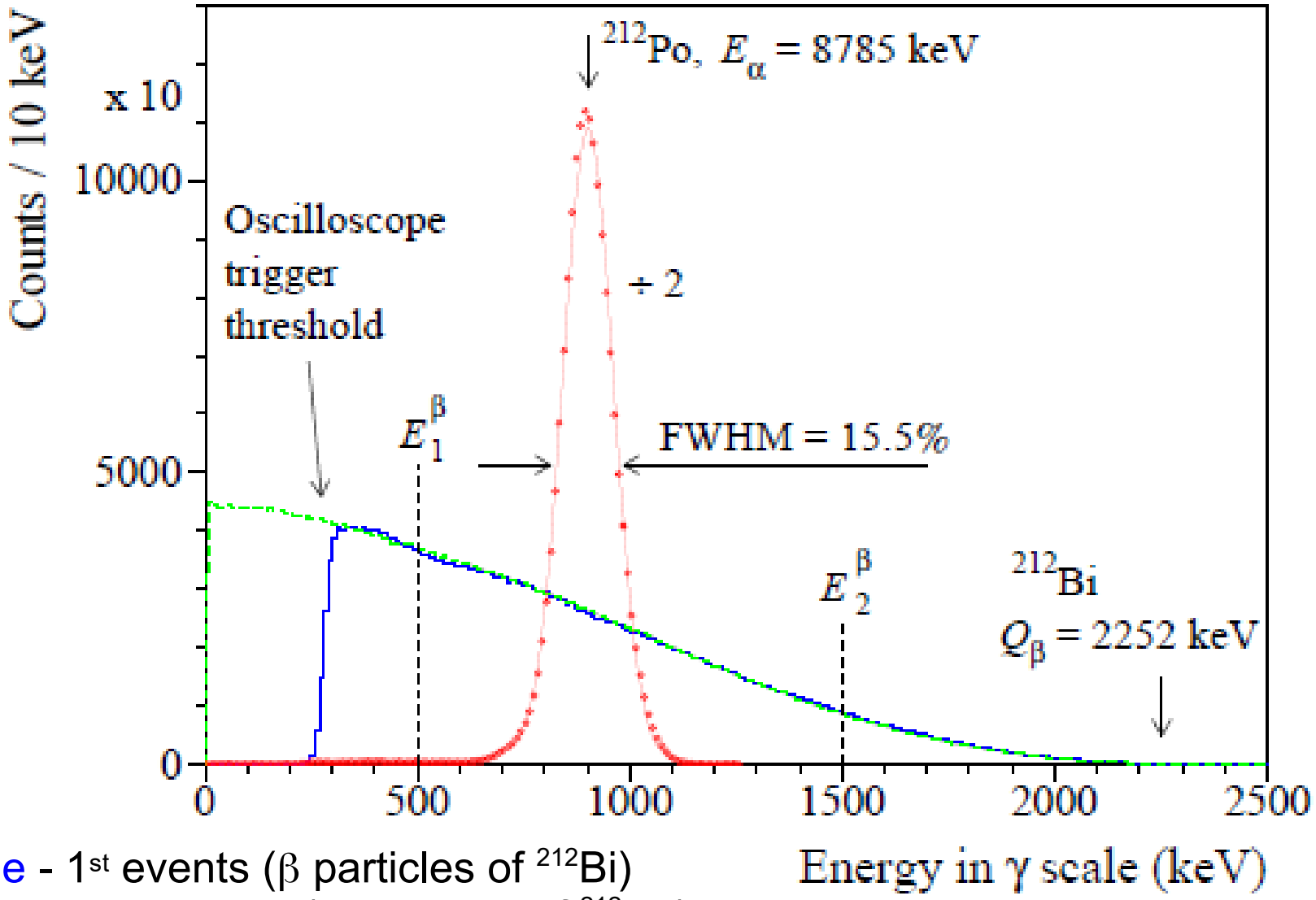
Possible reason for after-pulses is an elastic scattering of the accelerated photoelectrons on the 1st dynode.







3.2 Energy spectra



Blue line - 1st events (β particles of ^{212}Bi)
Red dotes - 2nd events (α particles of ^{212}Po)

Green dashed line – Monte Carlo simulated detector response function of the ^{212}Bi β decay

3.3 Half-life of ^{212}Po

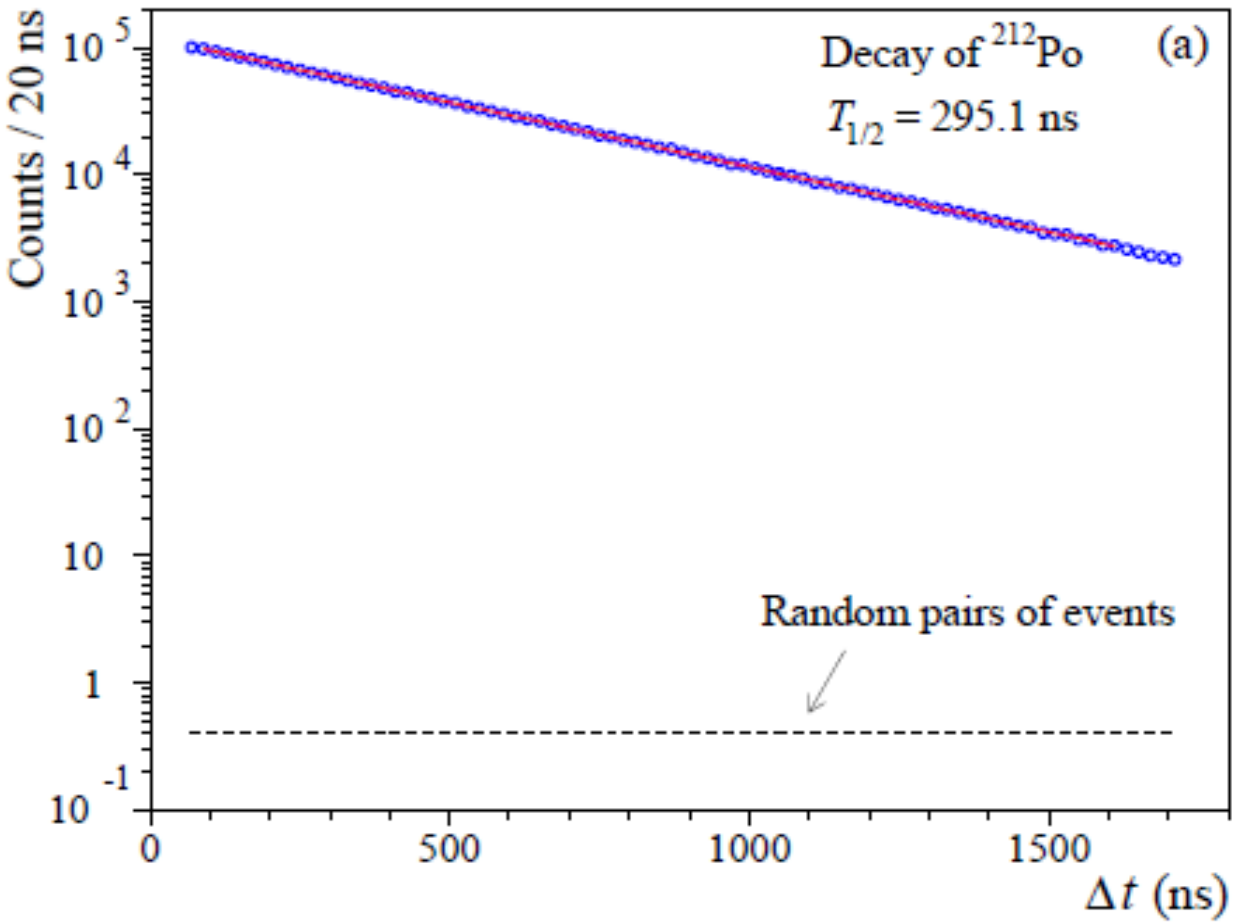
Fitted function:

$$N(t) = N_1 e^{-t \ln 2/T_{1/2}} + N_2 e^{-t\, b}$$

N_1 – proportional to the number of ^{212}Po nuclei

N_2 – proportional to the number of random pairs of events.

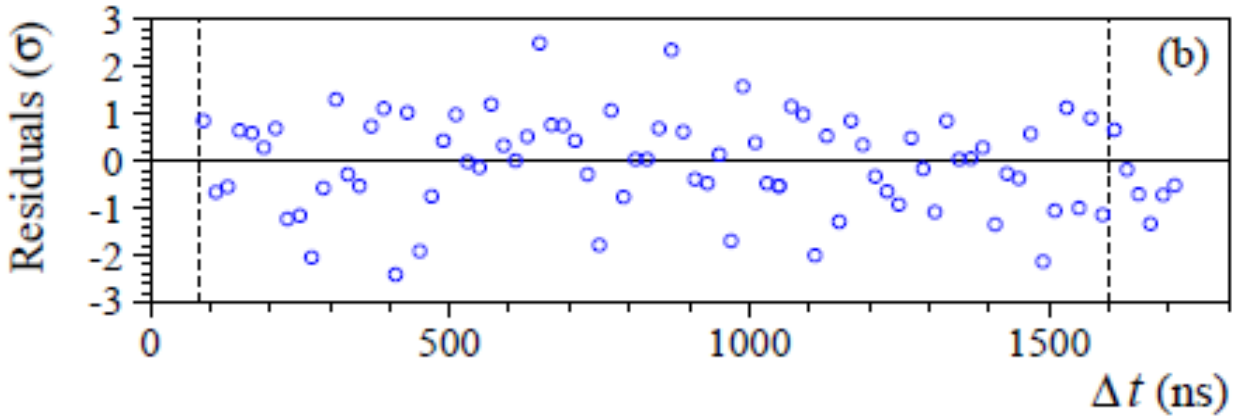
$T_{1/2}$ = 295.10(26) ns with χ^2 = 77.4/73



N_2 and b was estimated theoretically:

$N_2 \approx 3.3\times10^{-6}\ N_1$

$b \approx 2.4\ s^{-1}$

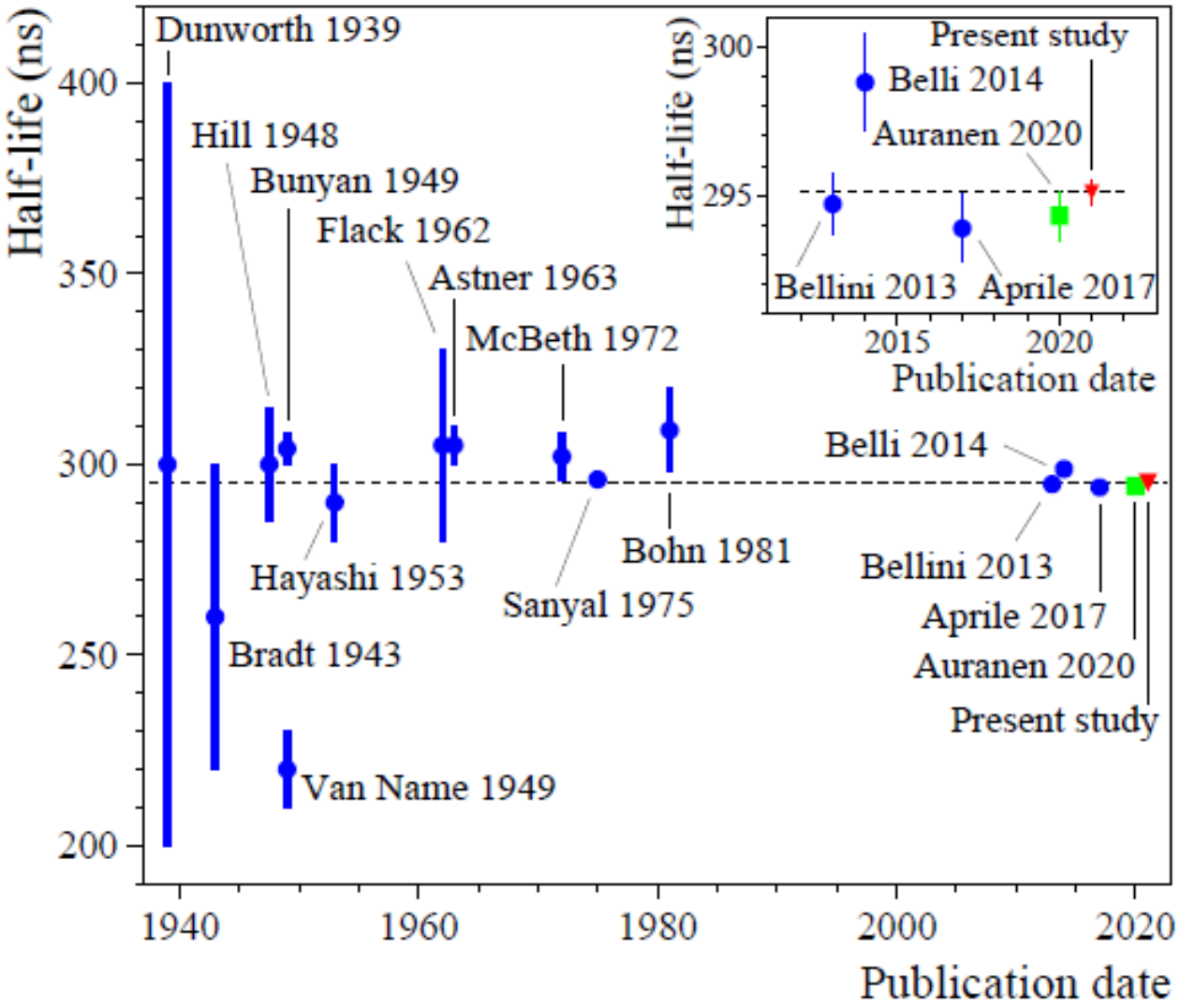


3.4 Combined standard uncertainty and results

Uncertainty evaluation of the half-life of ^{212}Po (ns)

Standard deviation by statistical methods	± 0.26
Lower bound of the fit	+ 0.09 – 0.22
Upper bound of the fit	+ 0.07 – 0.06
Amplitude of β events	+ 0.13 – 0.16
Amplitude of α events	+ 0.16 – 0.15
Time bin	± 0.02
Variations of temperature	± 0.12
Uncertainty of the oscilloscope	± 0.0017
Combined standard uncertainty	+ 0.37 – 0.43

$T_{1/2}$ = 295.1(4) ns



4. Conclusions

1) The half-life of ^{212}Po relative to α decay to the ground state of ^{208}Pb (the only known channel of ^{212}Po decay) was measured with thorium-loaded liquid scintillator as $T_{1/2}$ = 295.1(4) ns, which is the most accurate up-to-date value (relative uncertainty: 0.14%).

2) Further improvement of $T_{1/2}$ accuracy can be achieved by using a photodetector with much lower dependence of the transit time on the pulse amplitude.

Back-up slides

Digital constant fraction discrimination

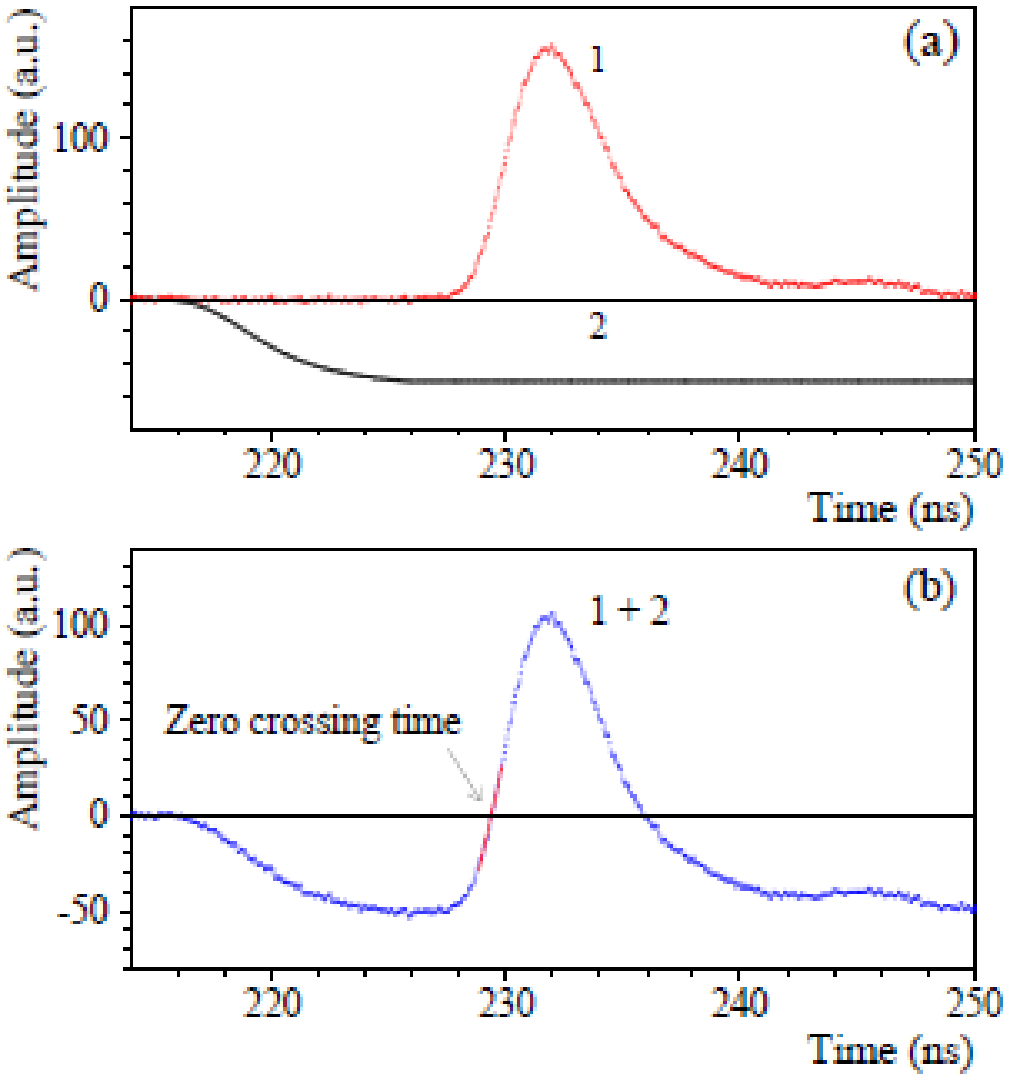
a) A scintillation pulse inverted and shifted by 11 ns (1); the pulse integrated and multiplied by a factor 0.003 (2).

b) Sum of pulses 1 and 2.

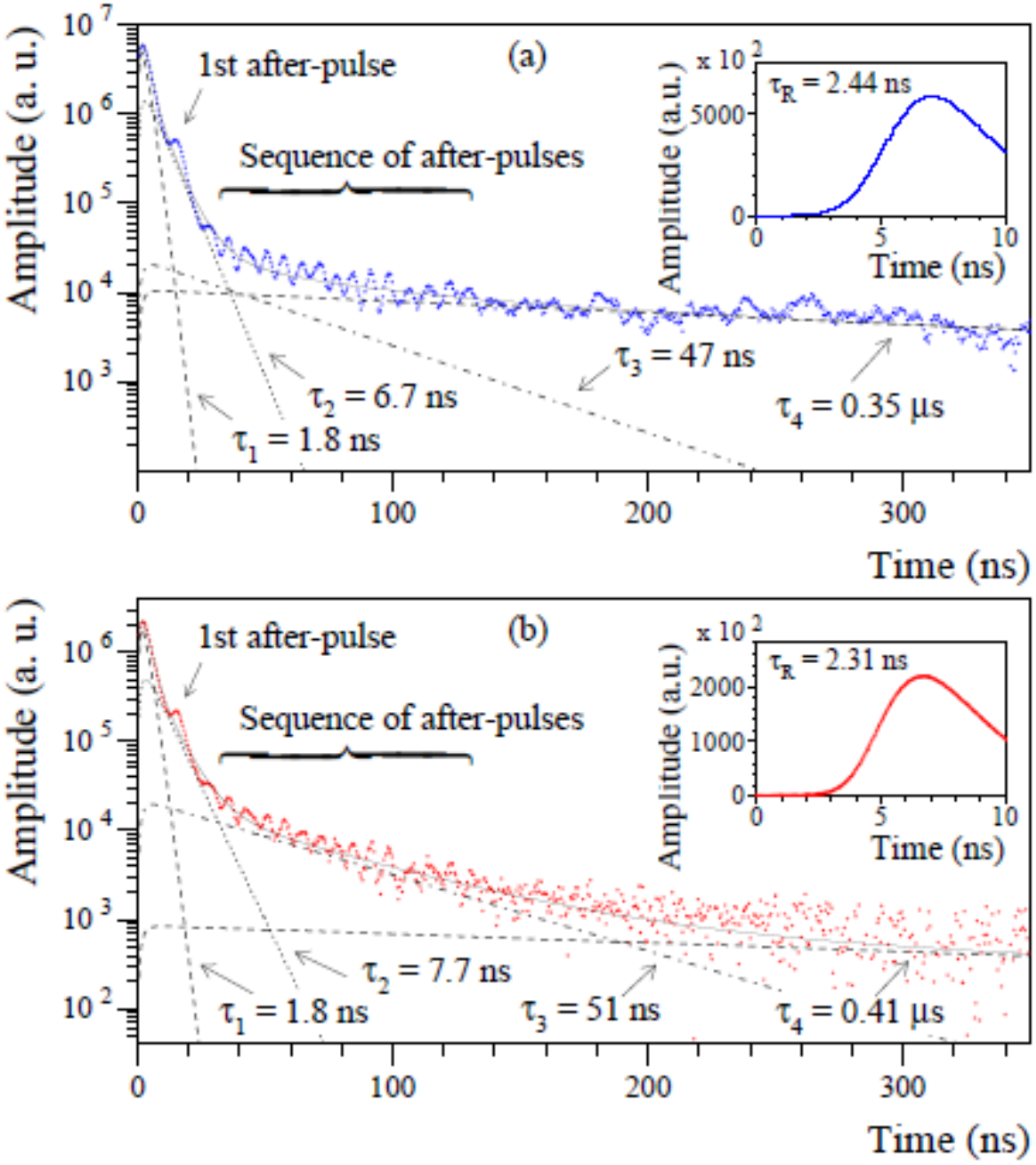
The solid line shows the fit of the data by an exponential function.

A zero crossing time takes as the signal starting time.

The difference 0.26 ns was added to the Δt values for each BiPo event due to the difference in the rising edge of β pulse and α pulse.



Shape of scintillation pulses



BiPo selection

The $\pm 3\sigma$ intervals for the mean-time and rise-time values for β events selection are depicted by dashed lines and by solid green ellipses for α particles.

The rise time – a time interval of the (10-90)% rising edge.

The mean time was defined using the following parameterization,

$$\zeta = \sum f(t_k) \times t_k \,/\, \sum f(t_k)$$

starting from the origin of the signal up to 60 ns; $f(t_k)$ is the digitized amplitude (at the t_k time) of a given signal.