Optimization of a digital measurement system for PALS

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Agenda

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2. Determination of γ-energy
3. Determination of positron lifetime
4. Optimization of timeresolution
5. Measurement of a polymer
6. Conclusion

Motivation

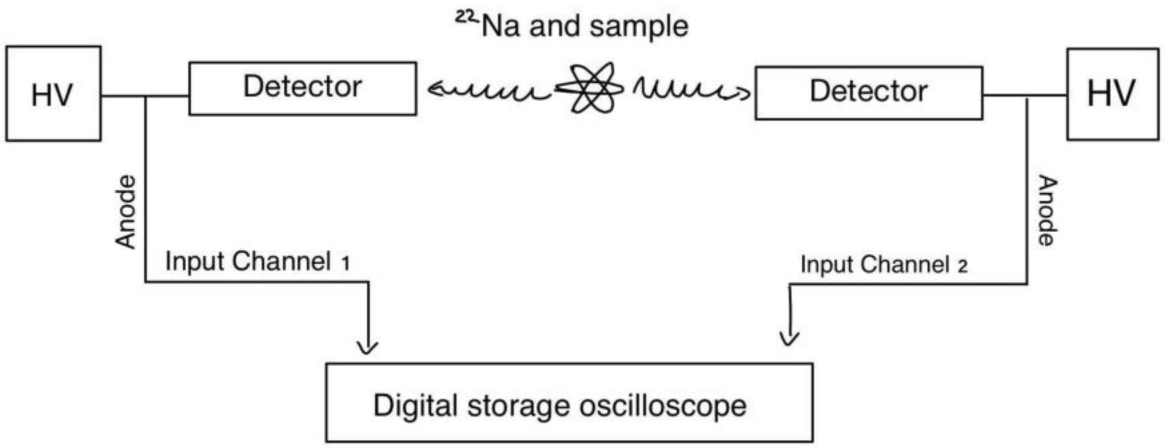
Why take a digital setup instead of an analog?

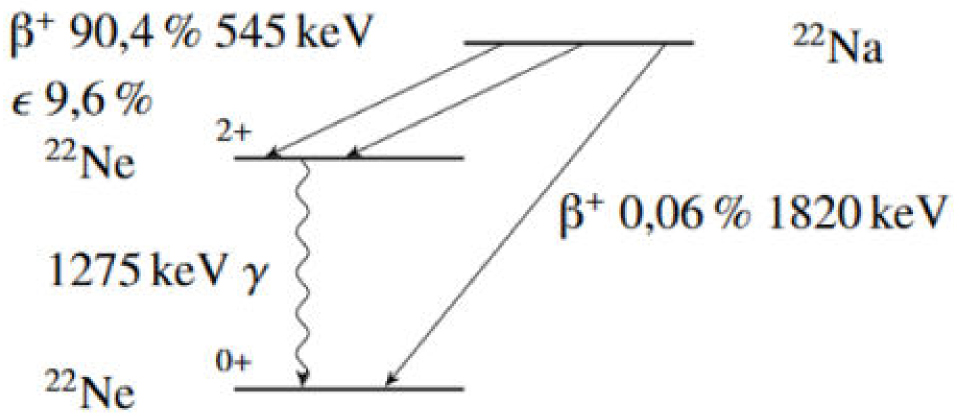
1. Easier to use and adjust
2. Numerical methods to improve time and energy resolution offline
3. Possible to reach high counting rates as every detector can be used as start and stop detector at the same time

Experimental setup 1/2

- Both $\mathrm{BaF_2}$ – scintillation detectors act as "start and stop" detector
- Na^{22} with activity of 80 kBq

- Start signal Na deexcitation 1275 keV γ-quanta
- Stop signal Annihilation 511 keV γ-quanta





Experimental setup 2/2

- $\mathrm{BaF_2}$ − scintillation detectors:
  - Ø38/20 x 30mm
  - density: 4,89 $\mathrm{gcm^{-3}}$
  - time constants 0.6ns and 620ns

- Digital oscilloscope to save the data:
  - Bandwidth: 1 GHz
  - sampling rate: 40GS/s

Determination of γ-energy 1/2

Two options [L. Hui]:

- $E_\gamma \propto$ amplitude of detector signal
- $E_\gamma \propto$ integral of signal

Influence on energy resolution:

- PMT bias voltage: higher voltage increases number of electrons
- Two time constants for BaF_2-detector (0.6ns and 620ns); digital setup can only use the fast one, while analog can use both

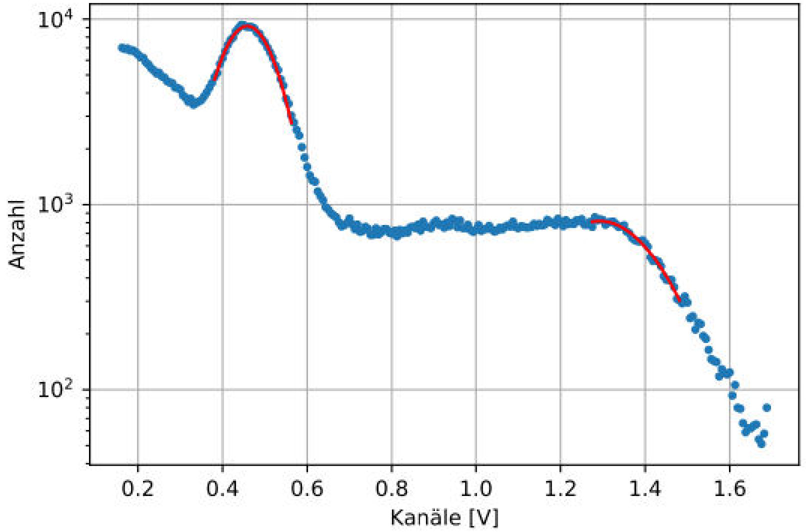
Determination of γ-energy 2/2

Chosen method for best energy resolution:

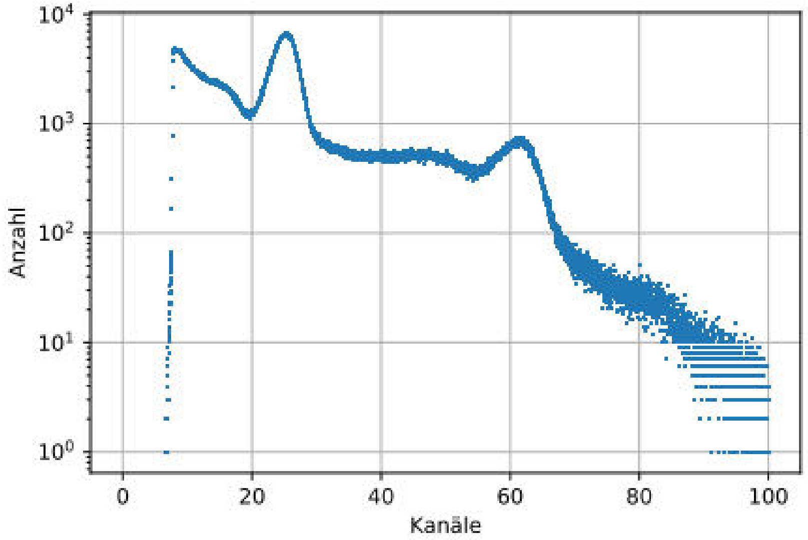
- Fitting polynominal second order for amplitude
- Background substraction with linear fit

Measured energy resolution:
- digital system: about 30%
- analog system: about 11%

digital:



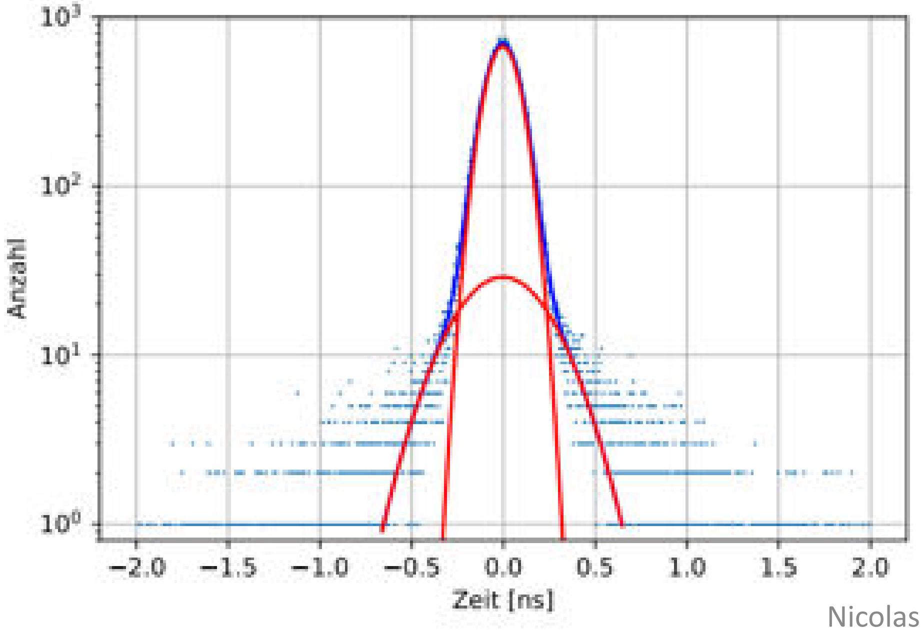
analogue:

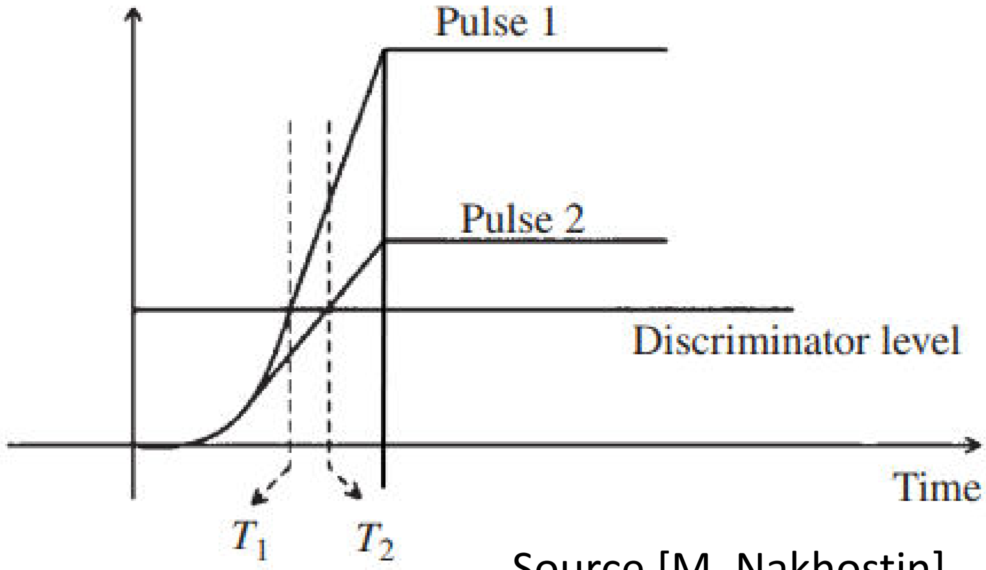


Determination positron lifetime 1/2

- Constant rising time for every signal
  -> Constant fraction value needed (cf)
  -> „Leaning edge discriminator“

- Defining time resolution: 511/ 511 prompt measurement -> taking fwhm





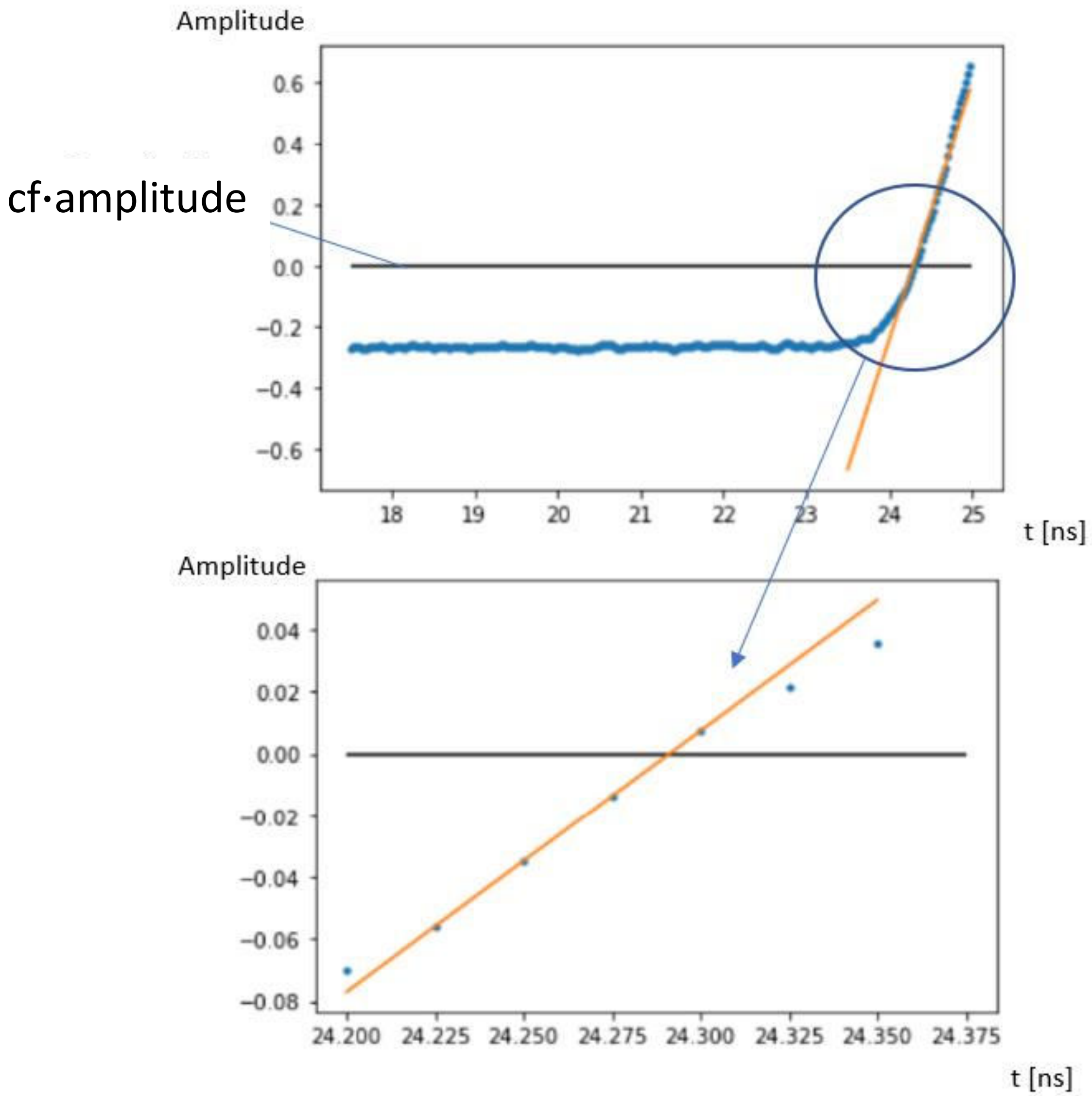
Source [M. Nakhostin]

Determination positron lifetime 2/2

To improve time resolution: interpolation

- linear interplation sufficient, if timedifference between two discrete timevalues (25ps with 40GS/s) way smaller than rising time (1.2ns) [M. Nakhostin]

- empirically confirmed

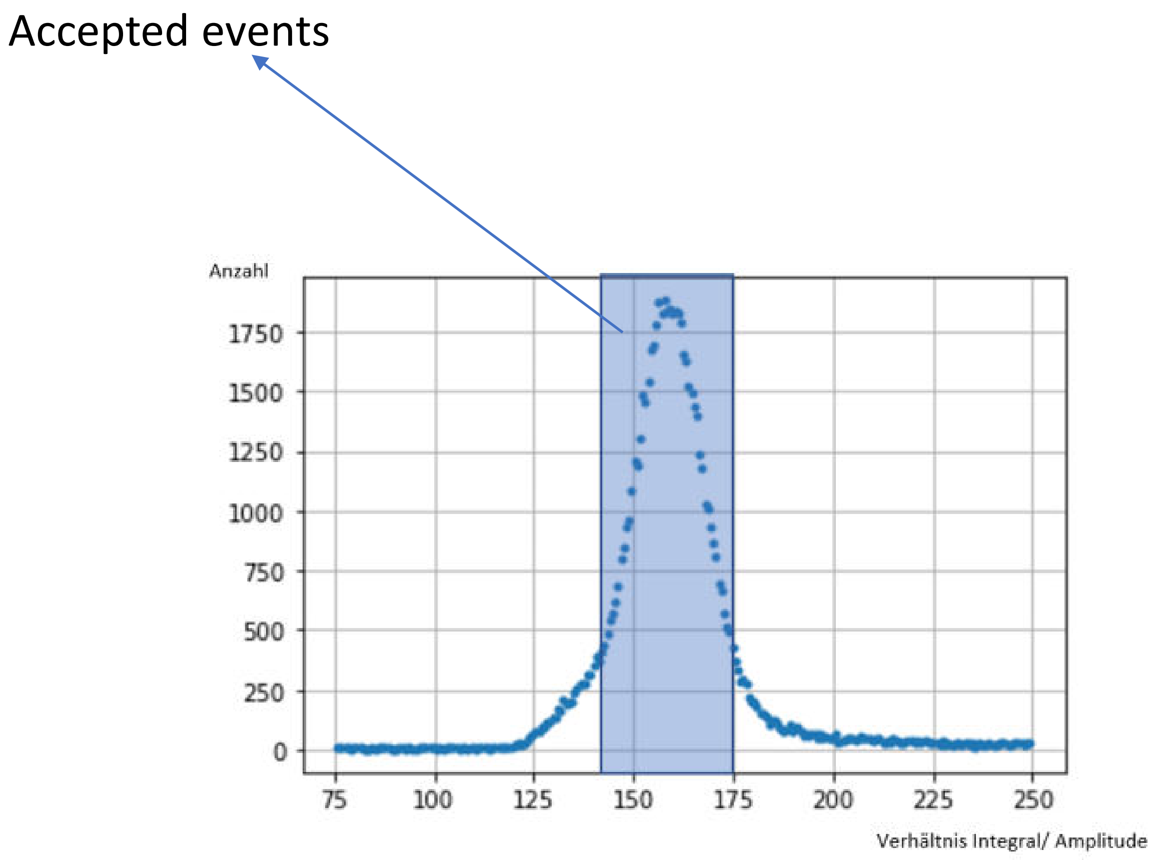


Optimization of time resolution 1/2

Possible „Quality Check“ of signal [H. Saito]:

- Constant ratio of amplitude and integral of signal
- Constant rising time for every signal

Deviation indicates an increased probability for false coincidence (like pile up event)

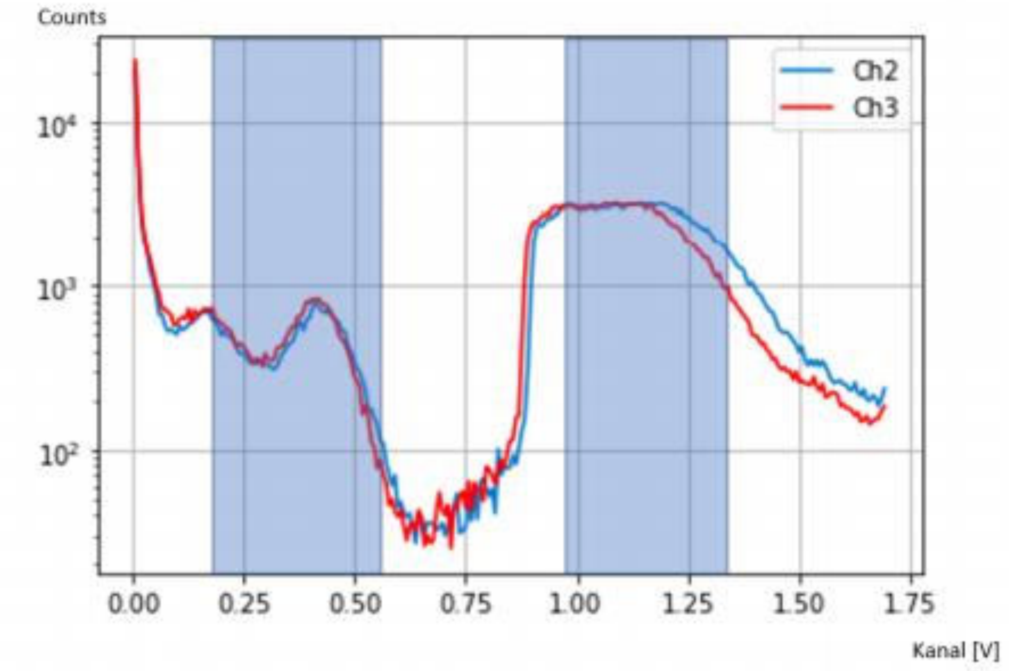


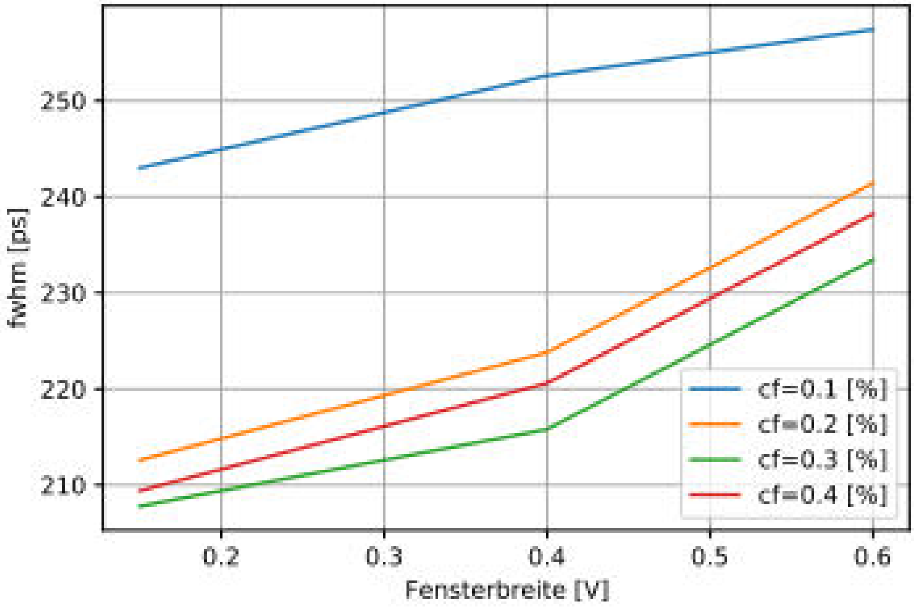
Optimization of time resolution 2/2

Influence on time resolution:

- Window width
- cf-value

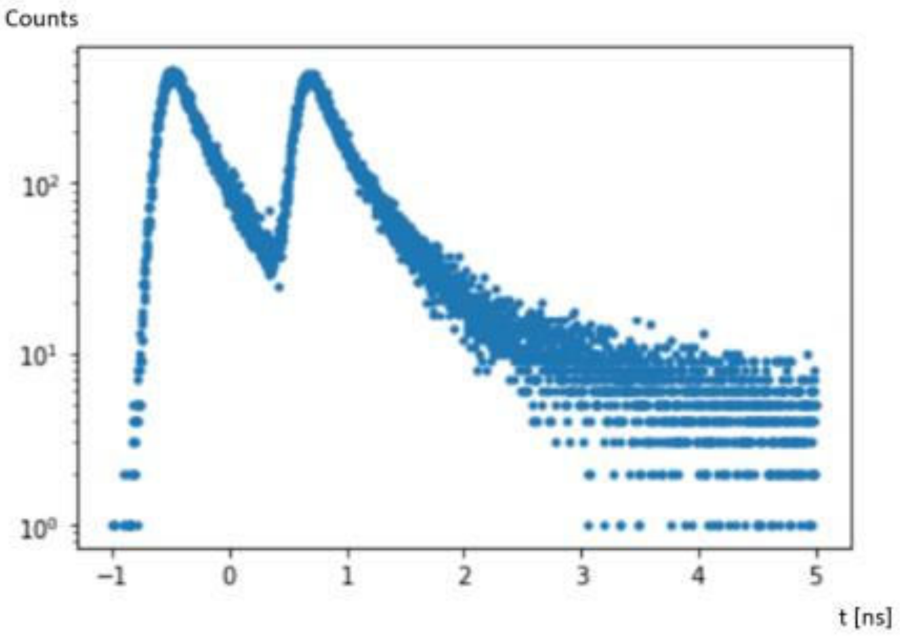
-> time resolution of about 208ps to 230ps
-> analog system about 300ps



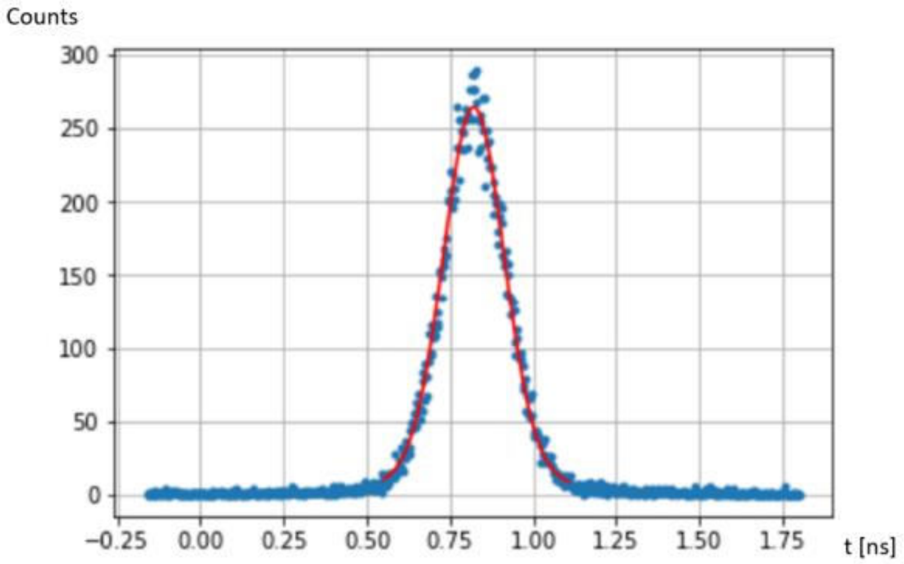


Lifetime Measurements 1/3

Both detectors are either start/ stop-detector: different times for processing the signal depending on the detector



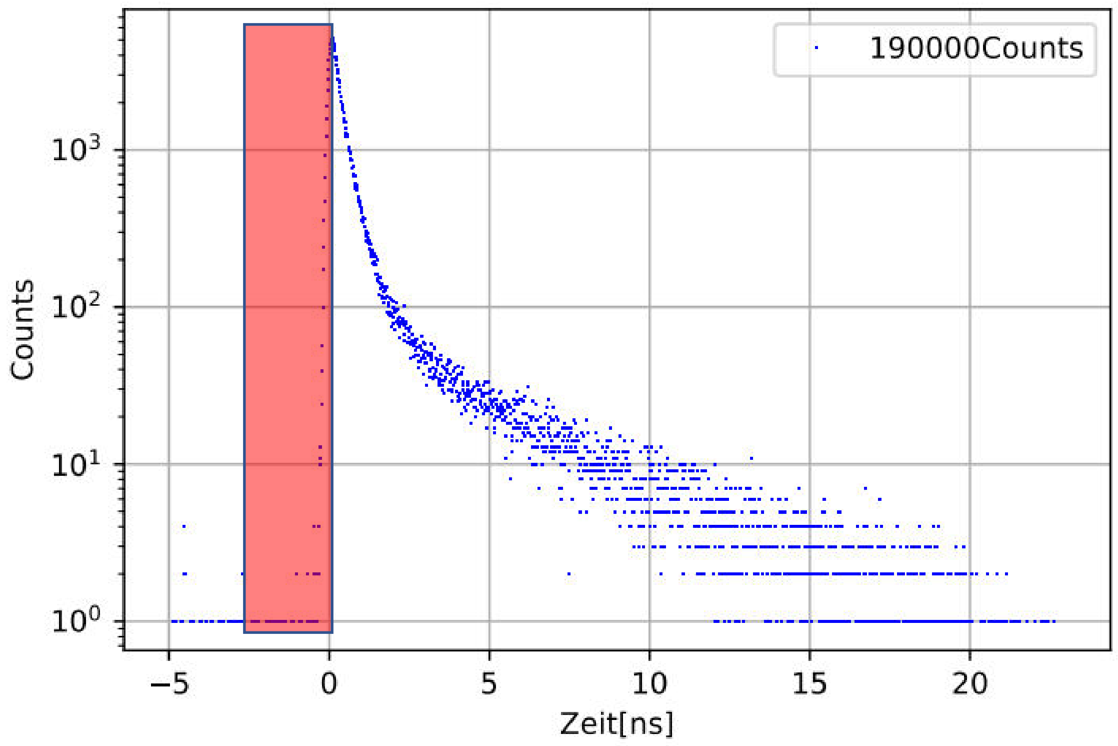
taking one as start detector, taking prompt measurement to determine the relative time difference:

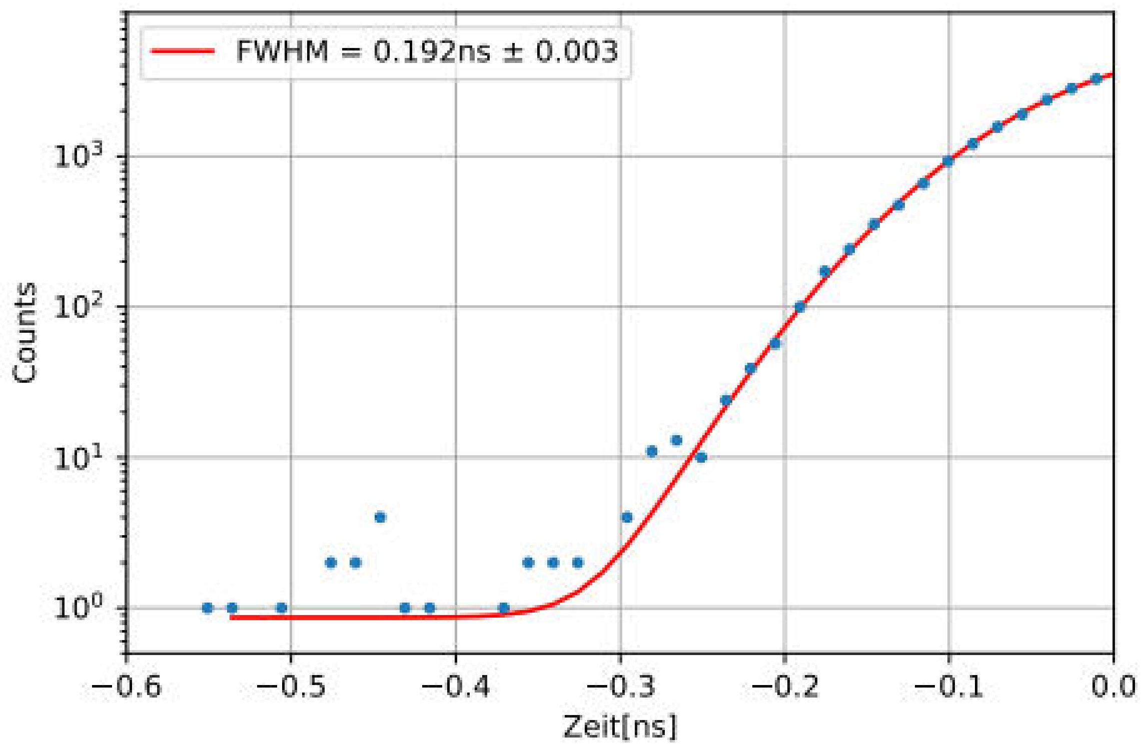


Lifetime Measurements 2/3

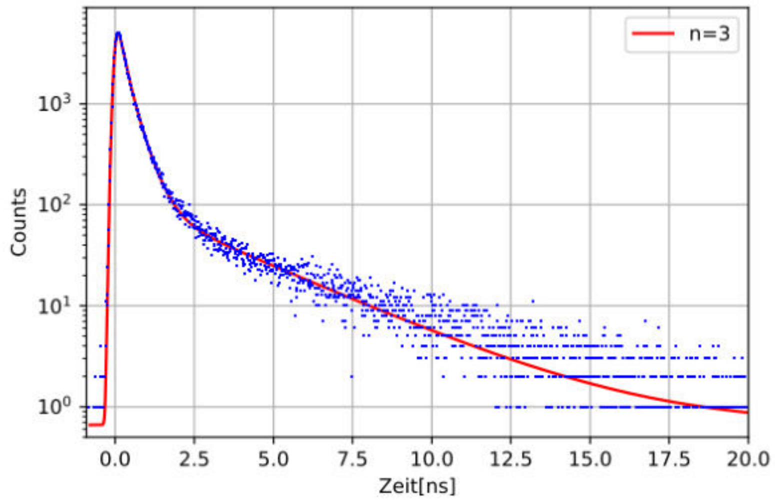
Fitting an single gaussian for time resolution function:
Instead of a sum of gaussians in analogue LT-spectra

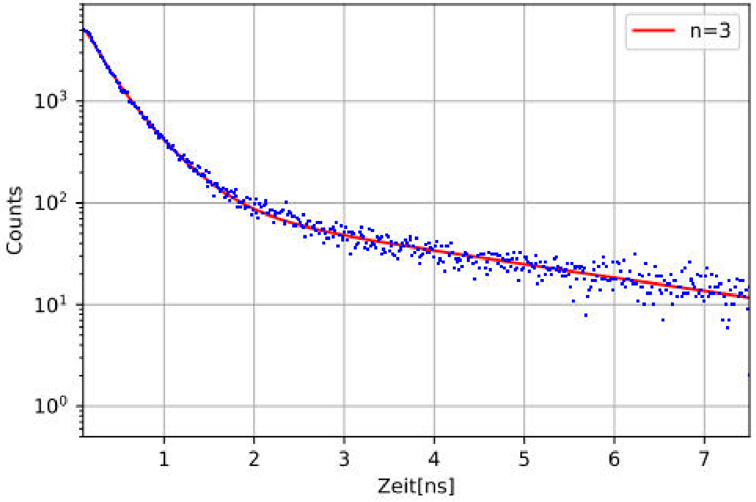
Test with PTFE:





Lifetime Measurements 3/3





Lifetime [ns]	Intensity [%]
0.385 ± 0.0098	61.0
0.159 ± 0.013	25.4
3.175 ± 0.054	13.6

Kapton Lifetime (source component) + Annihilation of free Positrons in PTFE

Annihilation of p-Ps

Annihilation of o-Ps

Conclusion

- Optimized time resolution of 208ps possible
- Better time resolution than analogue system (300ps)
- Lifetime spectrum with minimal background

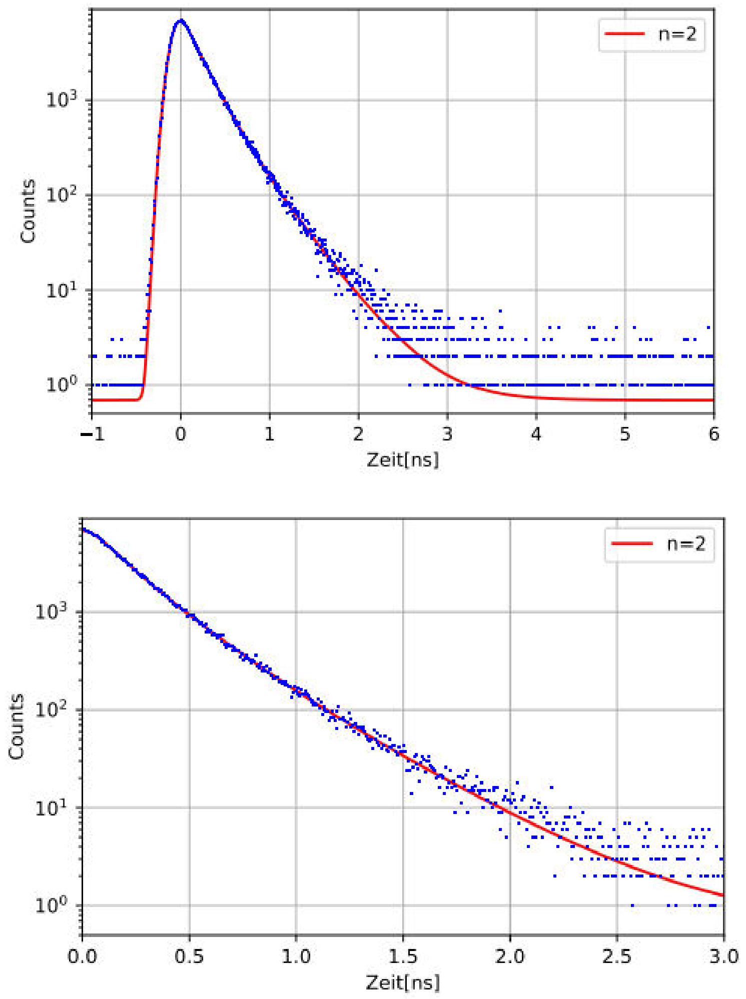
Sources

[L. Hui] L. Hui, S. Yundong, Z. Kai, P. Jingbiao und W. Zhu, „A simplified digital positron lifetime spectrometer based on a fast digital oscilloscope," Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Jg. 625, Nr. 1, S. 29–34, 2011. doi: 10.1016/j.nima.2010.10.005

[M. Nakhostin] M. Nakhostin, Signal Processing for Radiation Detectors, 1st. Boston, MA: John Wiley und Sons, Inc, 2018

[H. Saito] H. Saito, Y. Nagashima, T. Kurihara und T. Hyodo, „A new positron lifetime spectrometer using a fast digital oscilloscope and BaF2 scintillators," Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Jg. 487, Nr. 3, S. 612–617, 2002. doi: 10.1016/S0168-9002(01)02172-6

Lifetime Measurements: Si



Lifetime [ns]	Intensity [%]
0.385 ± 0.0014	20.3
0.215 ± 0.004	79.7

Annihilation in Kapton

Annihilation of Positrons in Si-Bulk