Digital Positron Lifetime @ EPOS

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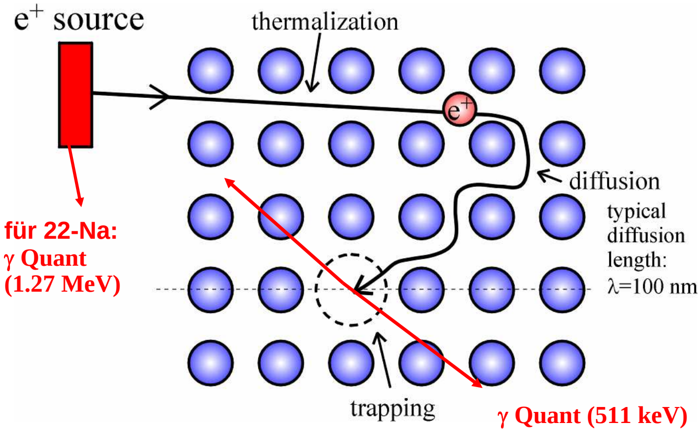
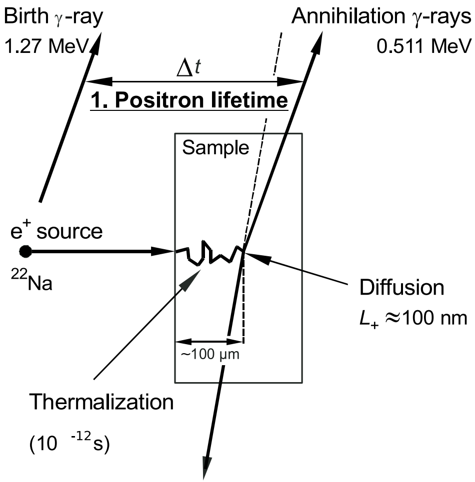
Positrons

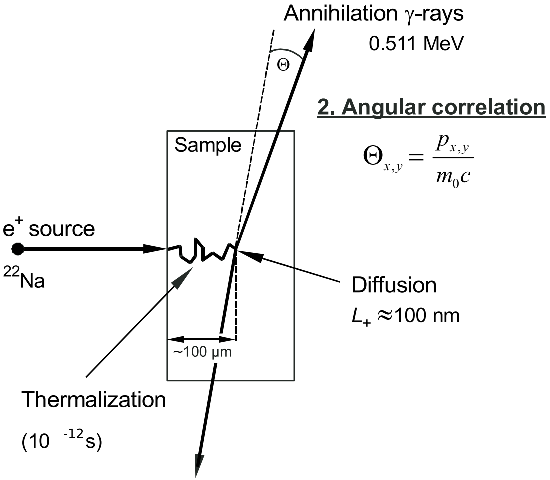


e+ source
thermalization
e+
diffusion
typical
diffusion
length:
λ=100 nm
trapping
für 22-Na:
γ Quant
(1.27 MeV)
γ Quant (511 keV)

Positrons: Decay Parameters



Positrons: Decay Parameters



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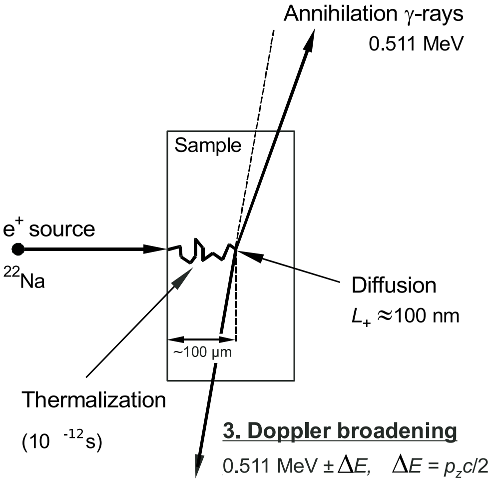
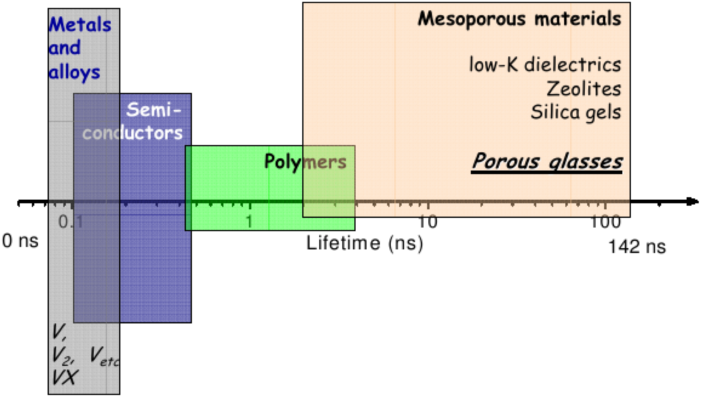
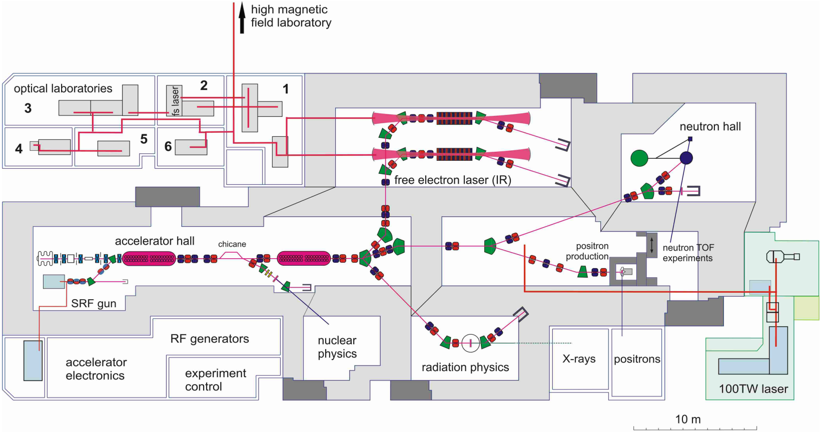


Fields of Usage



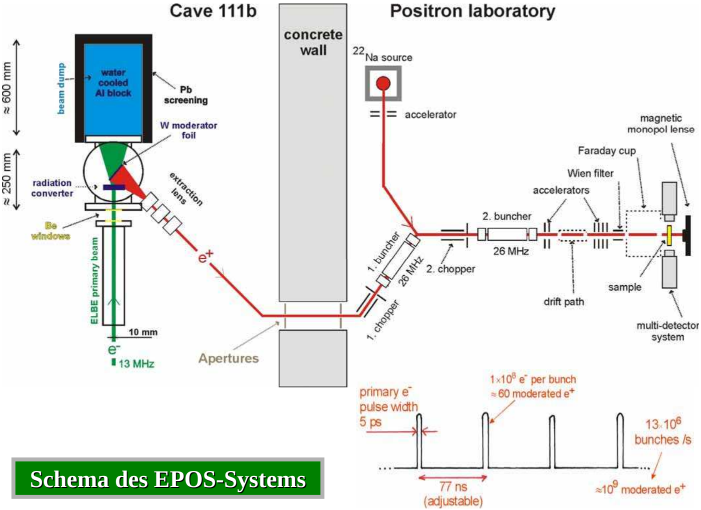
EPOS @ ELBE



1: Diagnostic station, IR-imaging and biological IR experiment
2: Femtosecond laser, THz-spectroscopy, IR pump-probe experiment
3: Time-resolved semiconductor spectroscopy, THz-spectroscopy

4: FTIR, biological IR experiment
5: Near-field and pump-probe IR experiment
6: Radiochemistry and sum frequency generation experiment, photothermal deflection spectroscopy

Basic Concept



Schema des EPOS-Systems

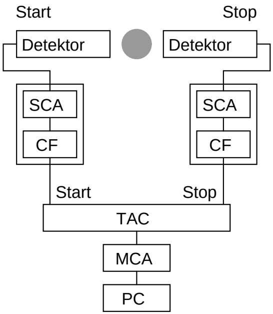
Key features of EPOS

- Positrons by pair production
- Unique time structure
  - High repetition rate (77ns)
  - Sharp pulses (∼5ps)
  - Machine pulse for start of lifetime measurements
- Good timing resolution
- Full digitial measurement and control
- Project started 2001
- First positrons planned for end 2008
- User dedicated facility
- User access should start 2009/2010

Basic Setup

Analog Setup:

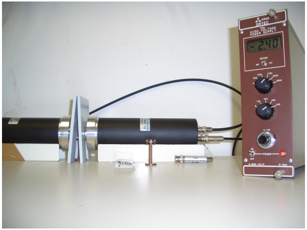
- γ-quants detected by scintillator and photomultiplier
- Energy-discrimination with SCA
- Event extraction with CF
- Time measurement with TAC
- Spectrum with MCA



Analog vs. Digital

The task

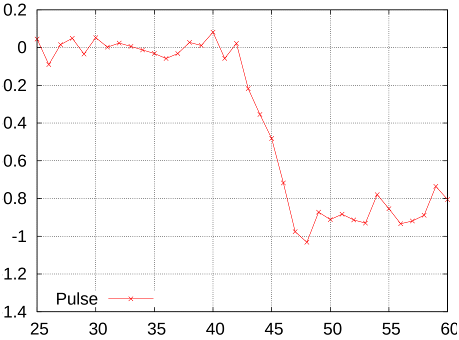
Replace all the (50+ years old) analog electronics with PC, digitizer and mathematics.



Benefits of digital processing:

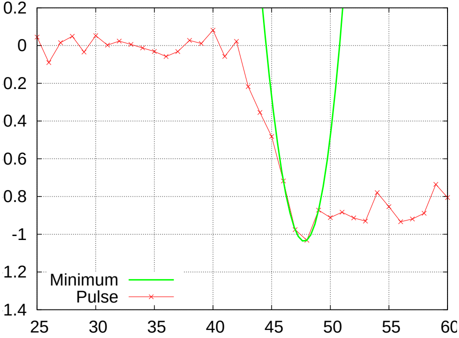
+ Cheaper
+ Simplier
+ Better time base
+ Easy to extent/change
- Less knowledge available
? Better timing resolution

The Algorithms to Extract the Timing Information



How to extract the timing information?

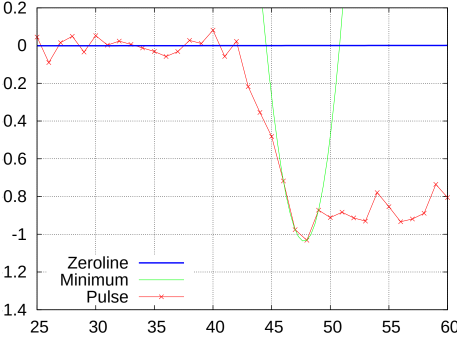
Algorithms: PolyCF



1. Find and interpolate the extremum[1]
2. Determine the zeroline (and its deviation) before the extremum
3. Interpolate the constant fraction point on the rising slope between zeroline and extremum[1]
4. Lifetime = $t_{Channel\ 1} - t_{Channel\ 2}$

[1] By simple polynom interpolation of 3rd order.

Algorithms: PolyCF



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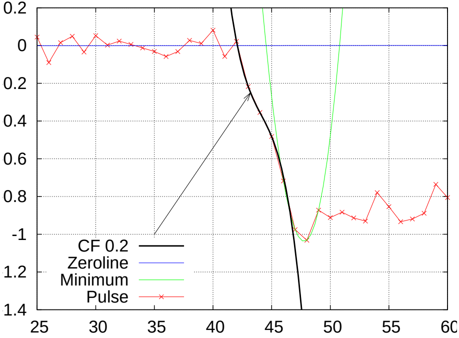

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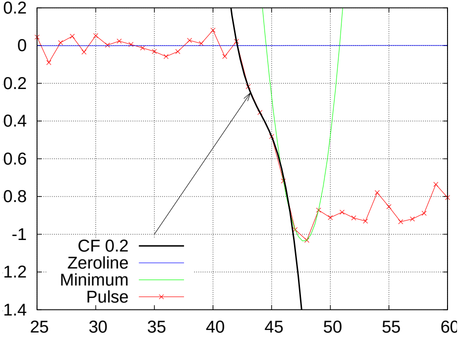

1. Find and interpolate the extremum[1]
2. Determine the zeroline (and its deviation) before the extremum
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Similar to analog constant fraction, called *true constant fraction* by [Bečvář, 2007].

Algorithms: integral Constant Fraction (iCF)

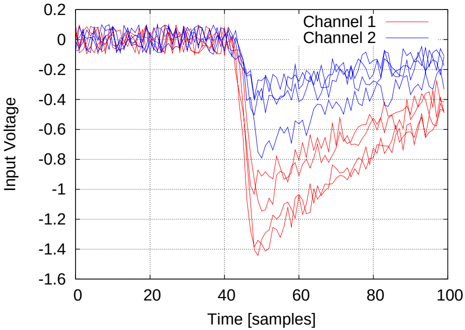
1. Integrate the pulse
2. Filter on risetime of integrated signal
   rightarrow Pulse-shape of original signal
3. Do *true constant fraction* like before on integrated signal

Seems to give better timing resolution of 144ps [Bečvář, 2007].

Timing Resolutions

Method	**Lit. / Setup**	**Resolution** (FWHM)
Analog measurements		our lab: >200ps
Polynom-Int.	[Bečvář et al., 2005] 4GS/s 1GHz 8bit:	150ps
	4GS/s 1GHz 8bit	$\sim$170ps ^{60}Co, 230ps Si
Gauss-Int.	[Aavikko et al., 2005] 4GS/s 1GHz 8bit:	200ps
(Smoothing) Spline	[Saito et al., 2002] 4GS/s 1GHz 8bit:	118ps - 144ps
	[Bardelli et al., 2004] 100MS/s 50MHz 12bit:	100ps - 125ps
		$\sim$170ps ^{60}Co
Integral CF	[Bečvář, 2007]	$\sim$144ps

The Influence of Noise: Generated Pulses

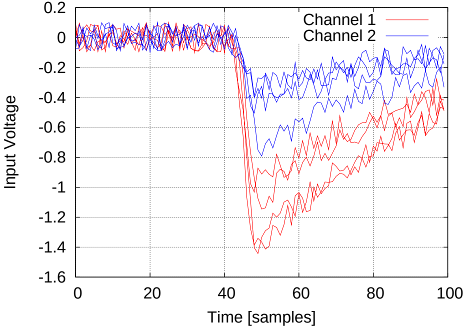


Four pulse pairs generated by EPOS Software

Side Note

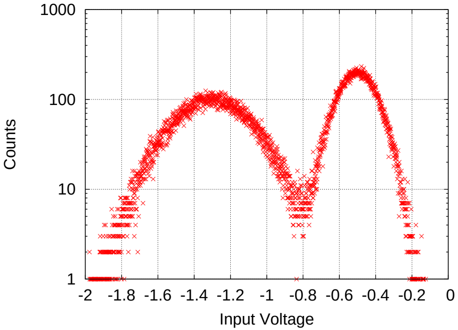
The EPOS Software is gone open-source and looking for users!
See `http://positron.physik.uni-halle.de/EPOS/Software`.

The Influence of Noise: Shape



- Shaped like LSO on Hamamatsu H3378-50
- Risetime like 4 GS/s

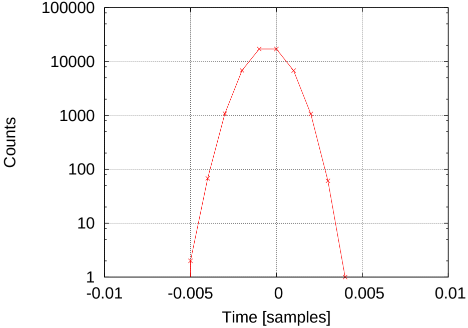
The Influence of Noise: Energy Spectrum



- Shaped like LSO on Hamamatsu H3378-50
- Risetime like 4 GS/s
- Energy distribution like ^{22}Na

- Energy spectrum closely to ^{22}Na but idealistic.

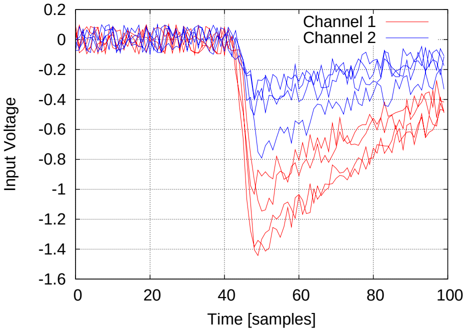
The Influence of Noise: Timing Distribution



- Shaped like LSO on Hamamatsu H3378-50
- Risetime like 4 GS/s
- Energy distribution like ^{22}Na
- Gaussian distributed timing

- Shift between pulses is Gaussian distributed.
- Shift of pulses to sampling clock is box distributed.

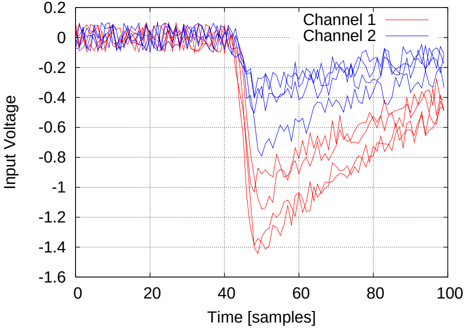
The Influence of Noise: Bit-depth



- Shaped like LSO on Hamamatsu H3378-50
- Risetime like 4 GS/s
- Energy distribution like ^{22}Na
- Gaussian distributed timing
- Variable bit-depth

- Possible bit-depths: 1-32 bits
- Native double resolution also possible

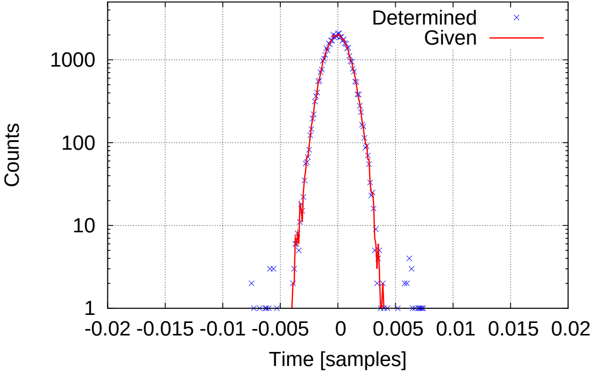
The Influence of Noise: Adding Noise



- Shaped like LSO on Hamamatsu H3378-50
- Risetime like 4 GS/s
- Energy distribution like ^{22}Na
- Gaussian distributed timing
- Variable bit-depth
- White noise added as wanted

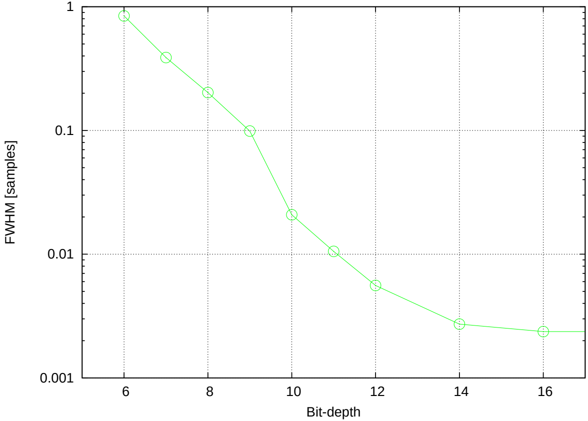
- White noise to simulate the uncertainties of the analog electronics.
- Level can be adjusted as wanted.

Double Resolution without Noise



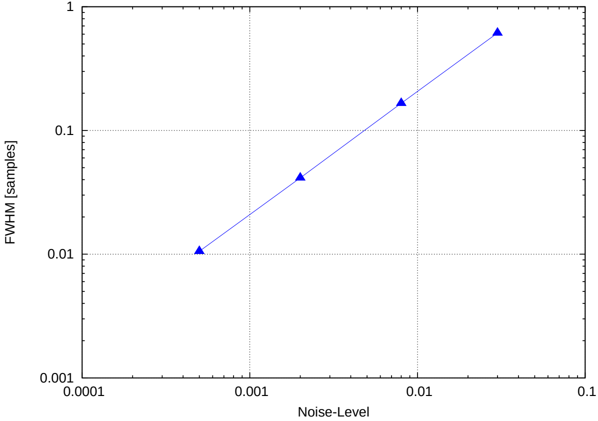
- No noise, native double resolution
- Given timing distribution: FWHM $= 0.0023582$ samples $\equiv 0.589$ ps
- Given distribution ($-$) $\equiv$ determined resolution ($\times$)
  $\Rightarrow$ Method works

Reducing the Bit-depth



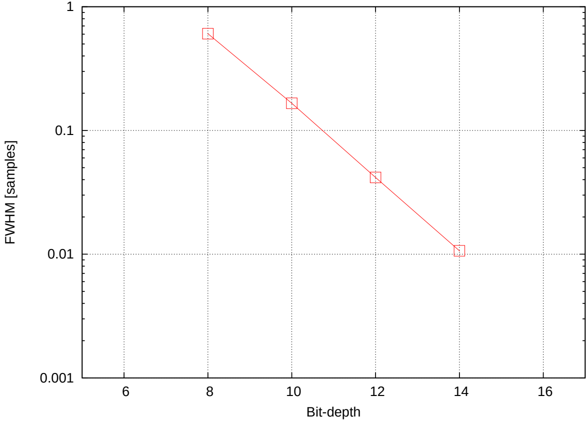
- Reduced bit-depth, no noise
- Timing resolution at 8-bit: 0.202 samples ≡ 50 ps

Noise of Effective Bits



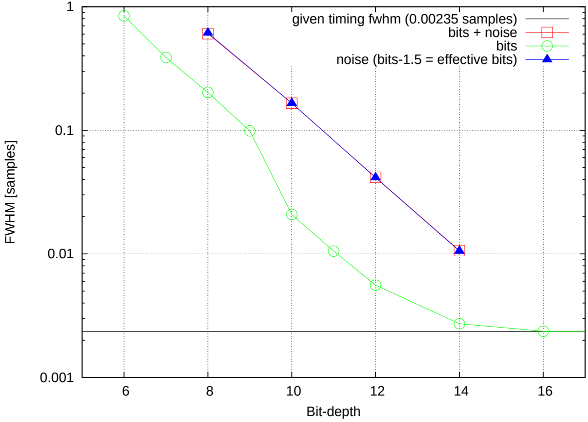
- Native double resolution, noise according to effective bits added
- Strong log-log dependency of timing resolution and noise level.

Noise and Reduced Bit-depth



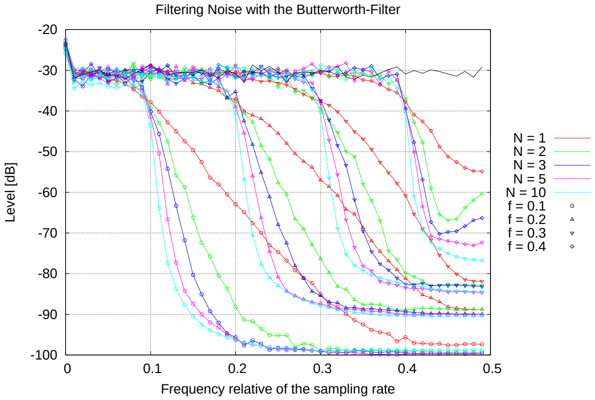
- Reduced bit-depth and noise from effective bits
- Timing resolution at 8-bit: 0.612 samples ≡ 153 ps

Finally Comparing the results



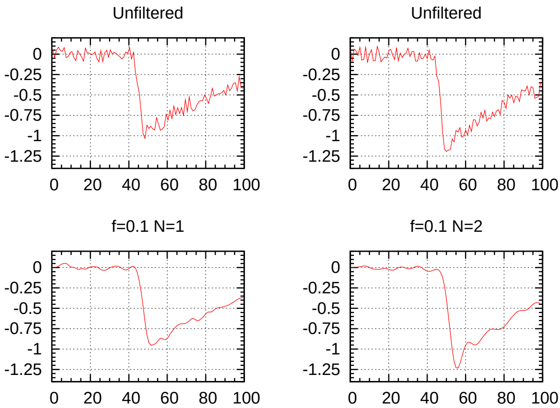
- Noise from effective bits has most influence
- Resulting timing resolutions: 8-bit: 153 ps, 10-bit: 41 ps

The Influence of Noise



- Butterworth lowpass (implementation taken from literature [Stearns, 1975])
- Order and cutoff frequency can be set

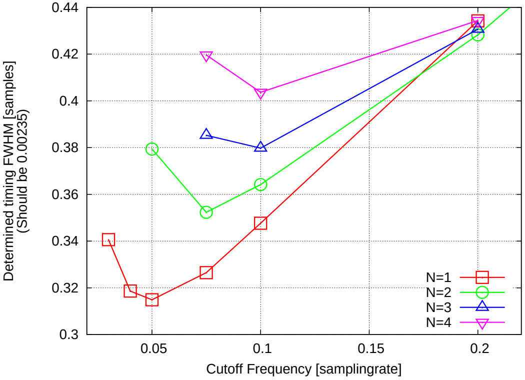
The Influence of Noise



Upper row Original signals as generated

Lower row Filtered by lowpass

The Influence of Noise: Results



Best Timing Resolution

$N = 1$ and $f = 0.05$ has FWHM of 0.31 samples $\equiv$ 75 ps.

Comparison of the Results

Method	**Relative Timing FWHM** [samples]	**4-GS/s "real" FWHM** [ps]
Vertical quantization (8-bit)	0.202 samples	50 ps
Noise of effective 6.5 bit	0.612 samples	153 ps
Butterworth-Lowpass f=0.05 N=1	0.314 samples	75 ps

Comparing the results.

Lowpass filtering can almost remove the effect of the noise added from the analog electronics.

$\Rightarrow$ All with simple polynom interpolation for energy and constant fraction.

Next Task: Comparing Photomultipliers

Comparing Photomultipliers

- Hamamatsu H3378-50
- Photonis XP20Z8

Measurement Program:

- ☑ Energy resolution (same scintillators!)
- ☑ Timing resolution (same scintillators and source/sample)
  – *currently running*
- ☐ Risetime, Pile-up, Pulse-Shape (DFT, etc...)

Next Task: Comparing Scintillators

Compare Scintillators

- BaF_2
- LSO
- ZnO
- LaBr3(Ce)

Measurement Program:

- ☐ Energy Spectrum/Resolution
- ☐ Risetime / Pulse-shape
- ☐ Relative Effectivity (through $\frac{1}{r^2}$)
- ☐ Optical Spectrum

Thanks for your attention!

Get the slides from http://positron.physik.uni-halle.de.

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