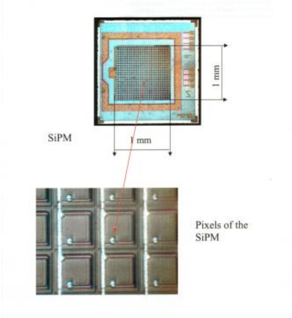
Fast Timing Workshop

June 8-10th 2015
FZU Prague

Timing Methods with Fast Integrated Technologies

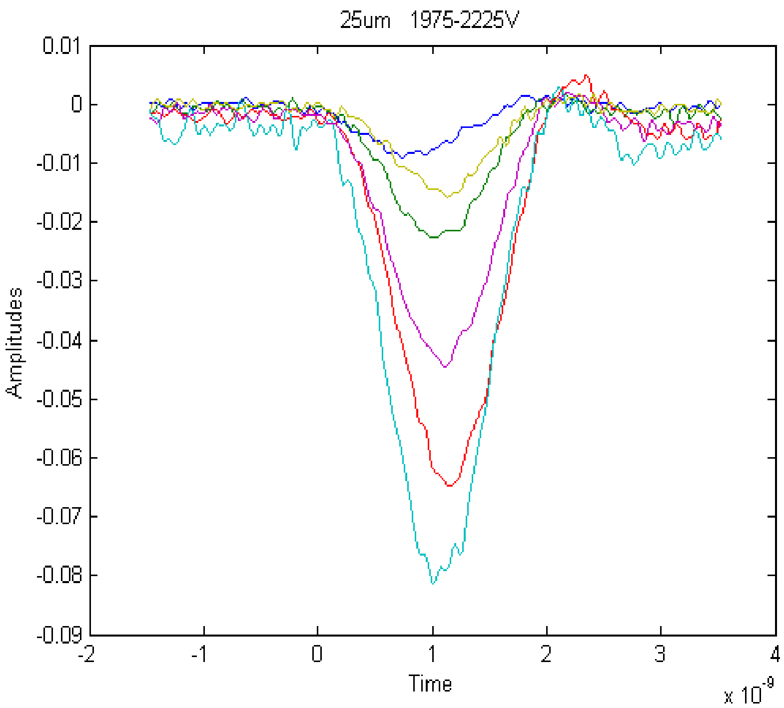
Jean-François Genat

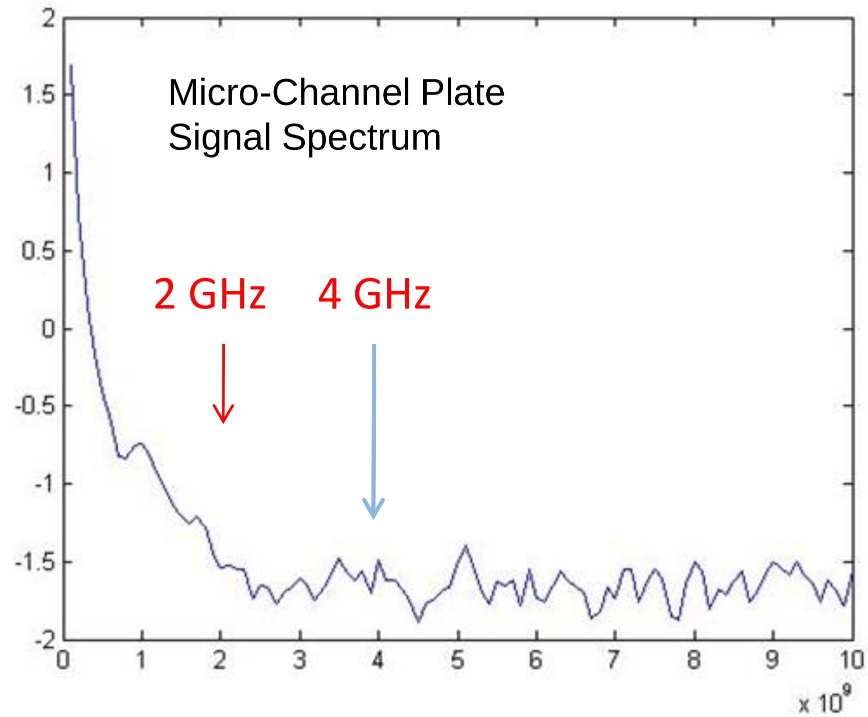
Fast Timing/Imaging Photo-detectors

	Multi-anodes PMTs Dynodes	Silicon-PMTs Quenched Geiger	Micro Channel Plates Micro-Pores
		 	
QE	30%	90%	20-30%
CE	90%	70%	60%
Rise-time	0.5-1ns	250ps	50-200ps
TTS (1PE)	150ps	100ps	30-50ps
Pixel size	$2x2mm^2$	$50x50\mu m^2$	$1.5 x1.5 mm^2$
Dark counts	1-10Hz	1-10MHz/cm2	$1\text{-}10 kHz/cm^2$
Dead time	5ns	100-500ns	$1\mu s$
Magnetic field	no	yes	15kG
Radiation hardness	1kRad (PC)	noise x 10	1kRad (PC)
Total Charge			0.5-2C/year

Example: GHz Bandwidth Micro-Channel Plate Signals

- Detector + electronics noise >> quantization noise (LSB/√12)
- Sampling frequency > 2 x Shannon-Nyquist=4GHz



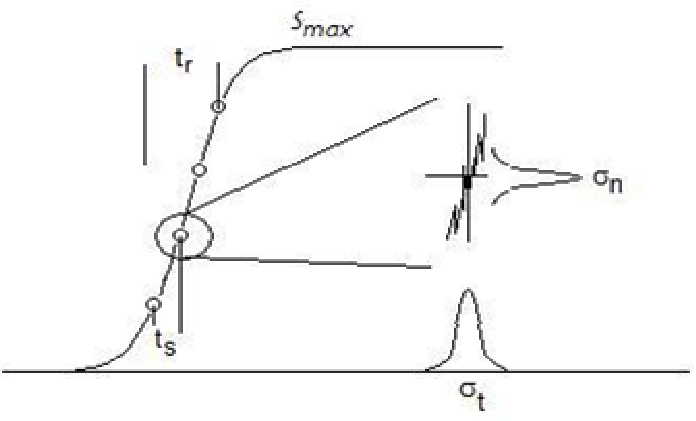


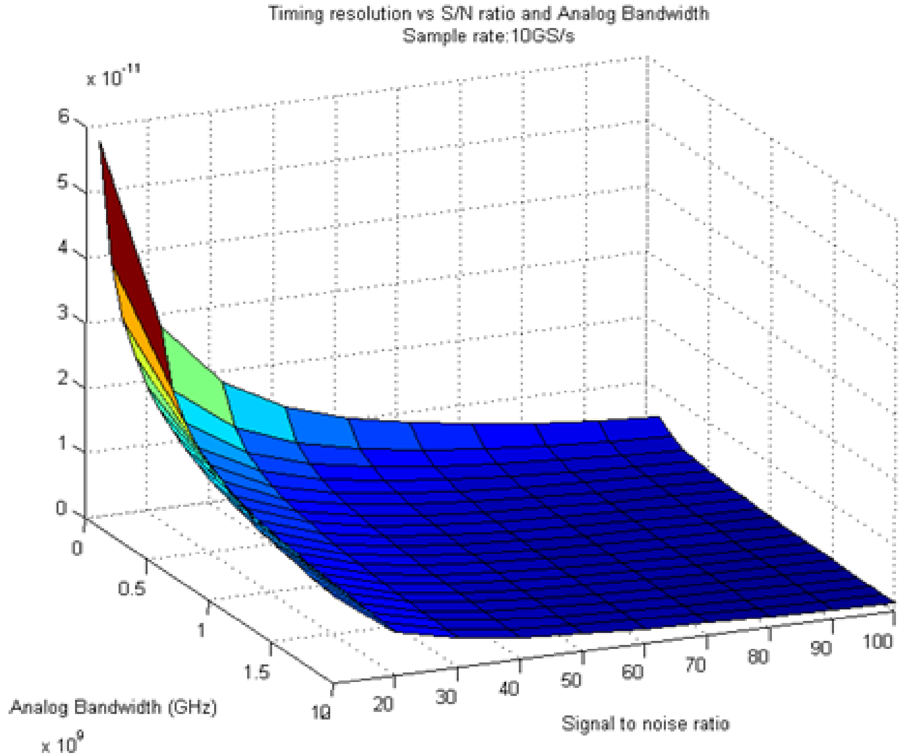
Timing spreads

Contributions to timing spreads:

Detector:

- Transit Time
- $Noise_{detector}$
- Rise time
- Gain (Signal/noise)





Electronics:

- $Noise_{elec}$
- Sample rate
- Analog bandwidth

$$SN = S_{max}/\sigma_n \qquad \sigma_{t,n} = \frac{\sigma_n}{\sqrt{n}}$$

$$\sigma_n = \sigma_{n\ det} + \sigma_{n\ elec}$$

Stefan Ritt: $$\sigma_{t,n} = \frac{\sqrt{t_r t_s}}{SN} = \frac{1}{SN}\sqrt{\frac{0.35 t_s}{abw}}$$

$$S = G\ Npe$$

Electronics: Fast Timing Techniques

• Threshold techniques

- Single Threshold
- Double Threshold
- Multiple Thresholds
- Constant Fraction

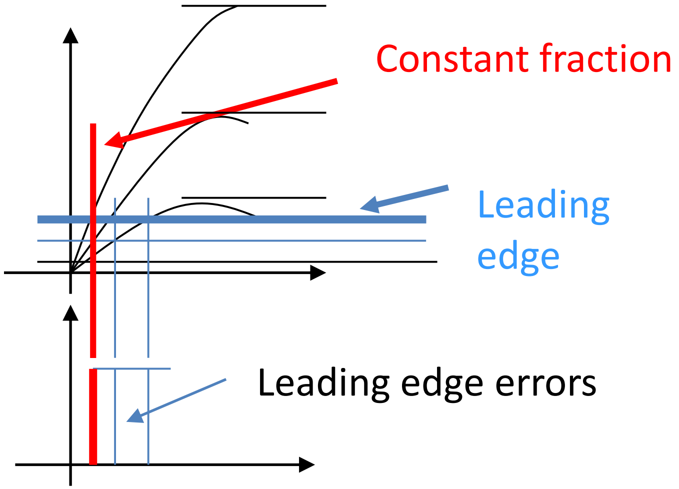
• Waveform sampling techniques

- Waveform sampling using Flash ADCs (up to 8-9 bit) or
- Analog memories fast sampling + AD conversions with slow ADCs (12-bit)

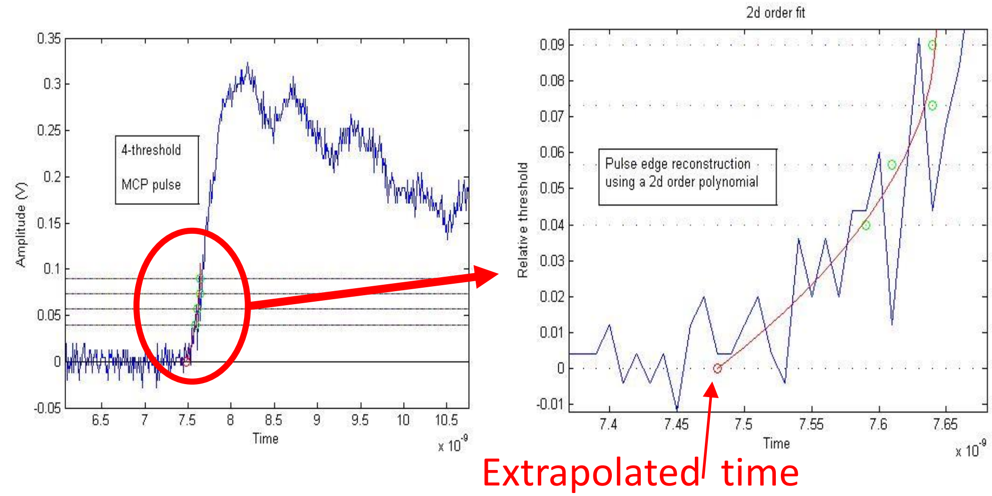
and Digital Signal Processing

Fast Timing techniques

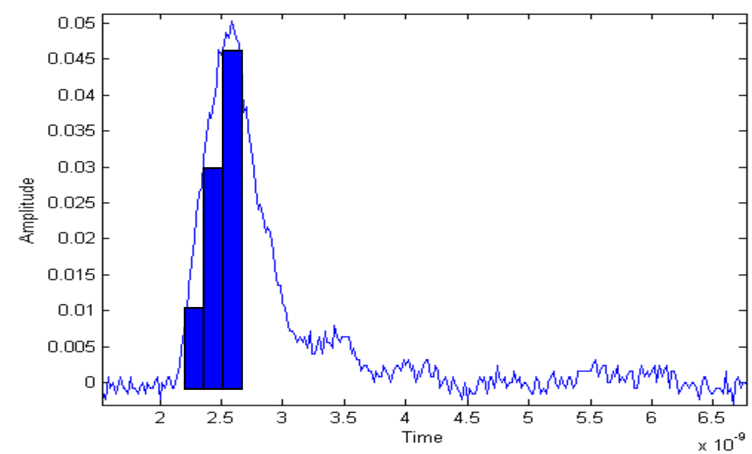
Constant-fraction



Multi-threshold

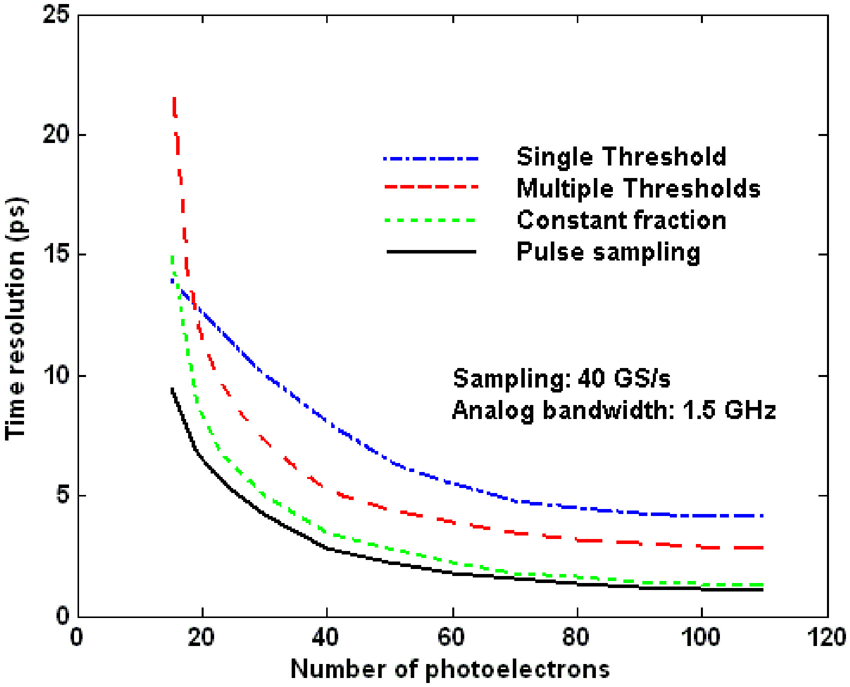


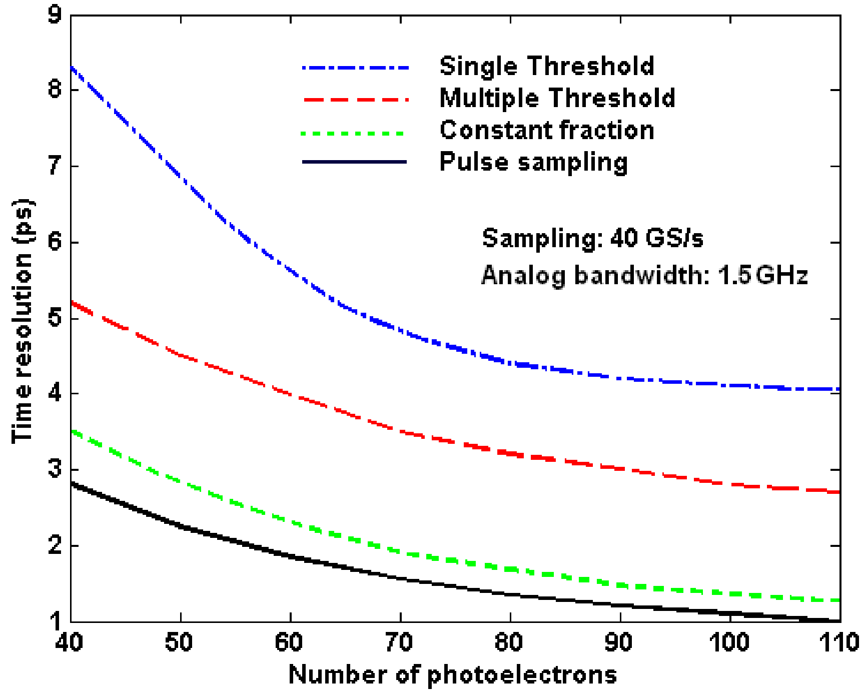
Waveform sampling



Electronics: Timing Methods

Methods: *Single threshold*
Multiple thresholds
Constant fraction
Waveform sampling





Time resolution vs Number of photo-electrons

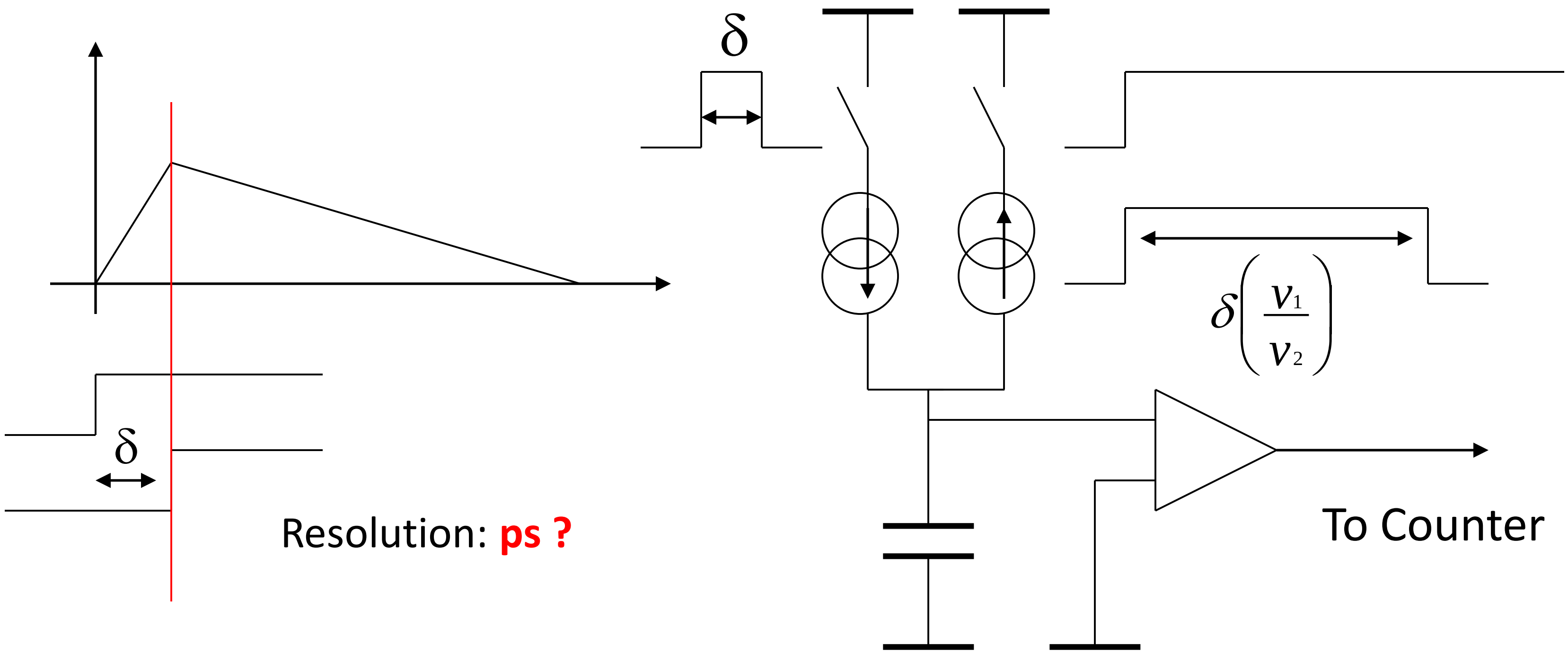
zoom

Time Stretching

Différential:

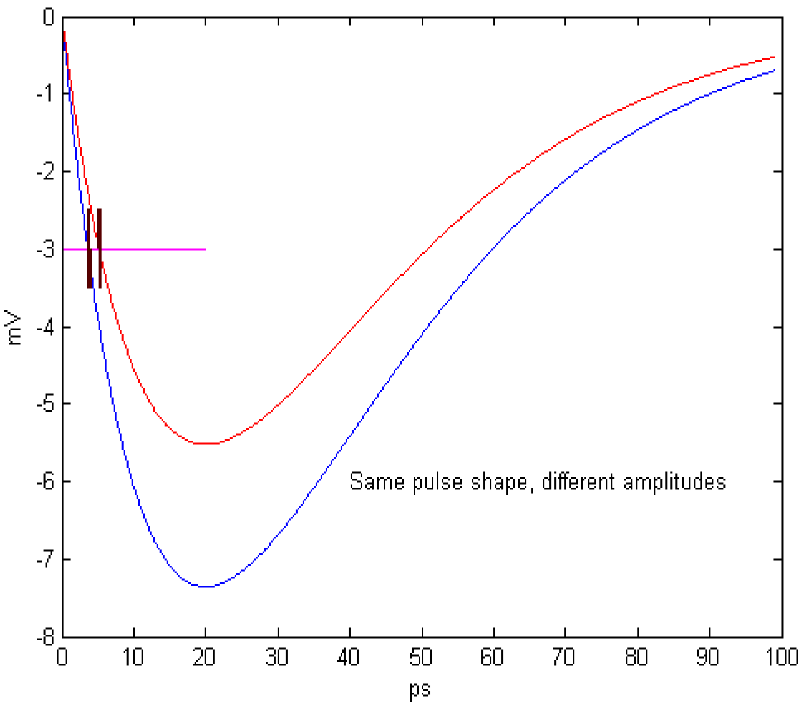
Ramp goes up at rate ν_1 , down at rate ν_2 $\qquad \nu_2 \ll \nu_1$

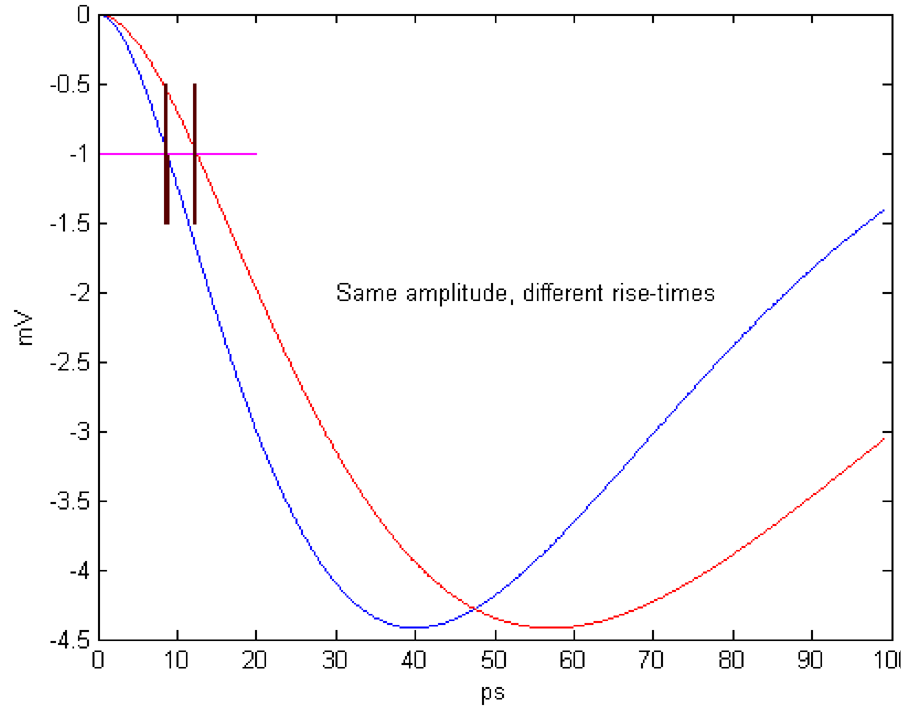
Time is stretched by $\dfrac{\nu_1}{\nu_2}$, measured using a “slow” TDC



Resolution: **ps ?**

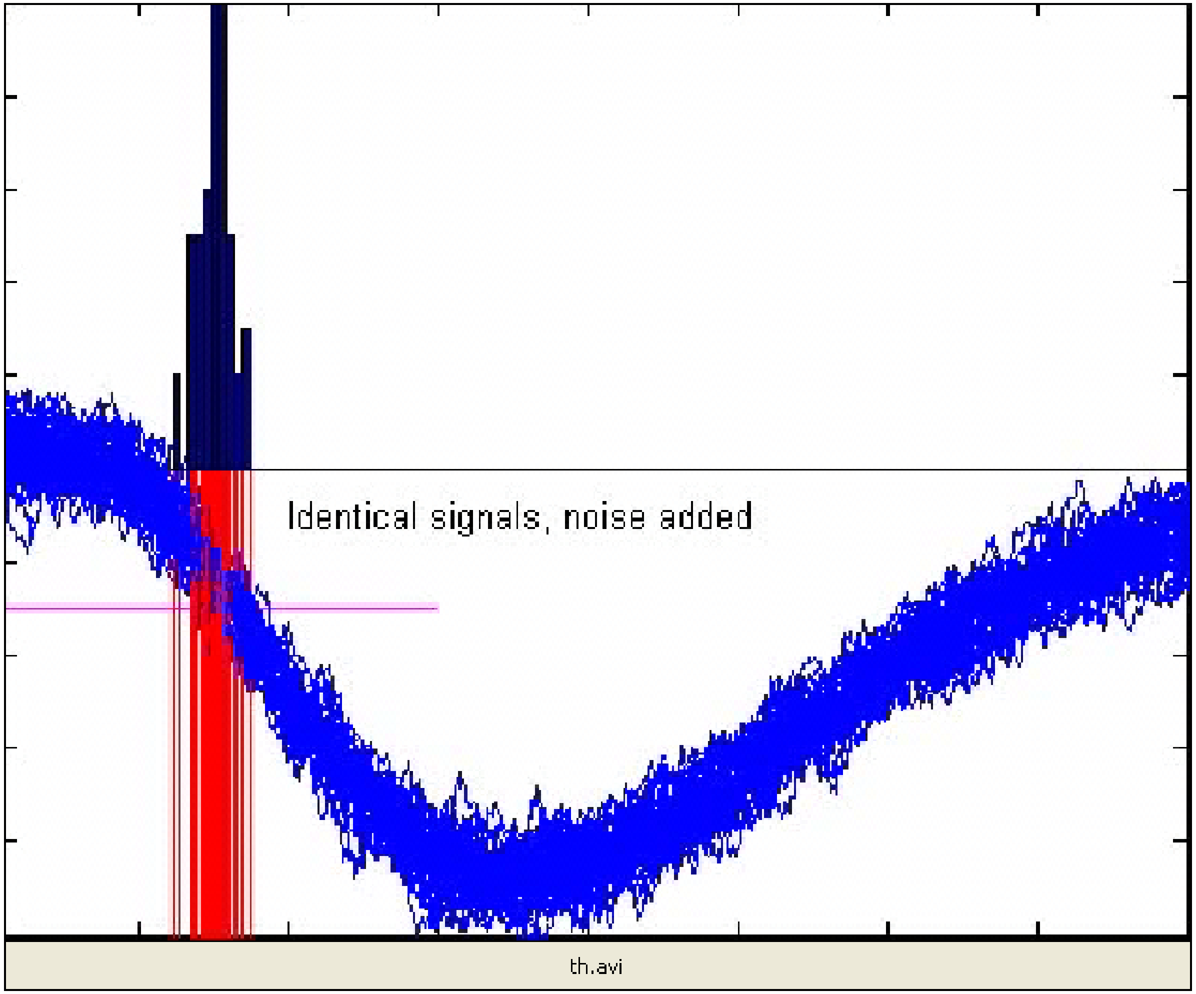
Single Threshold
Effects of Amplitude and Rise-time spreads





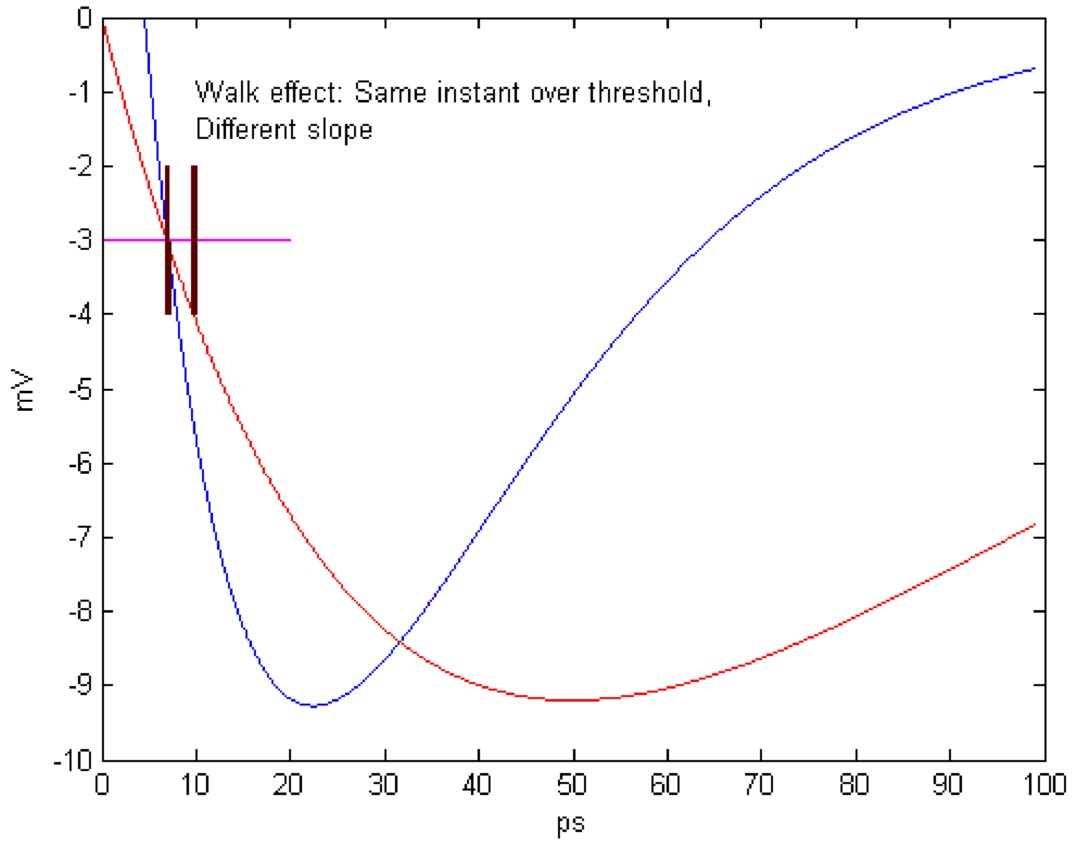
Amplitude and/or Rise-time spectra translate into
time spreads in case of single threshold

Effect of Noise using Single Threshold Methods



Time spread proportional to rise-time

Discriminator walk effects



Walk: Discriminator delay depends on the pulse slope across threshold

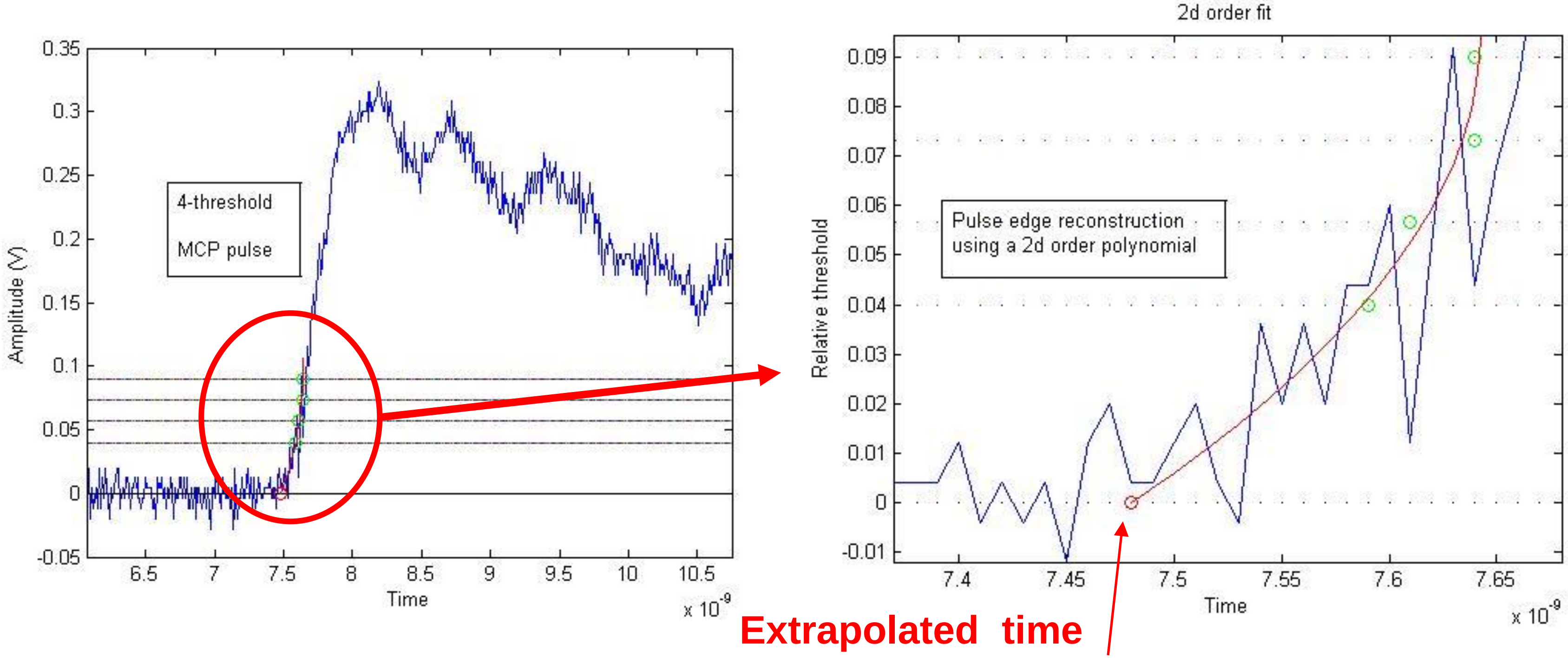
Pulse slope: detector rise-time + amplifier

Use appropriate gain x bandwidth technology to match the detector speed

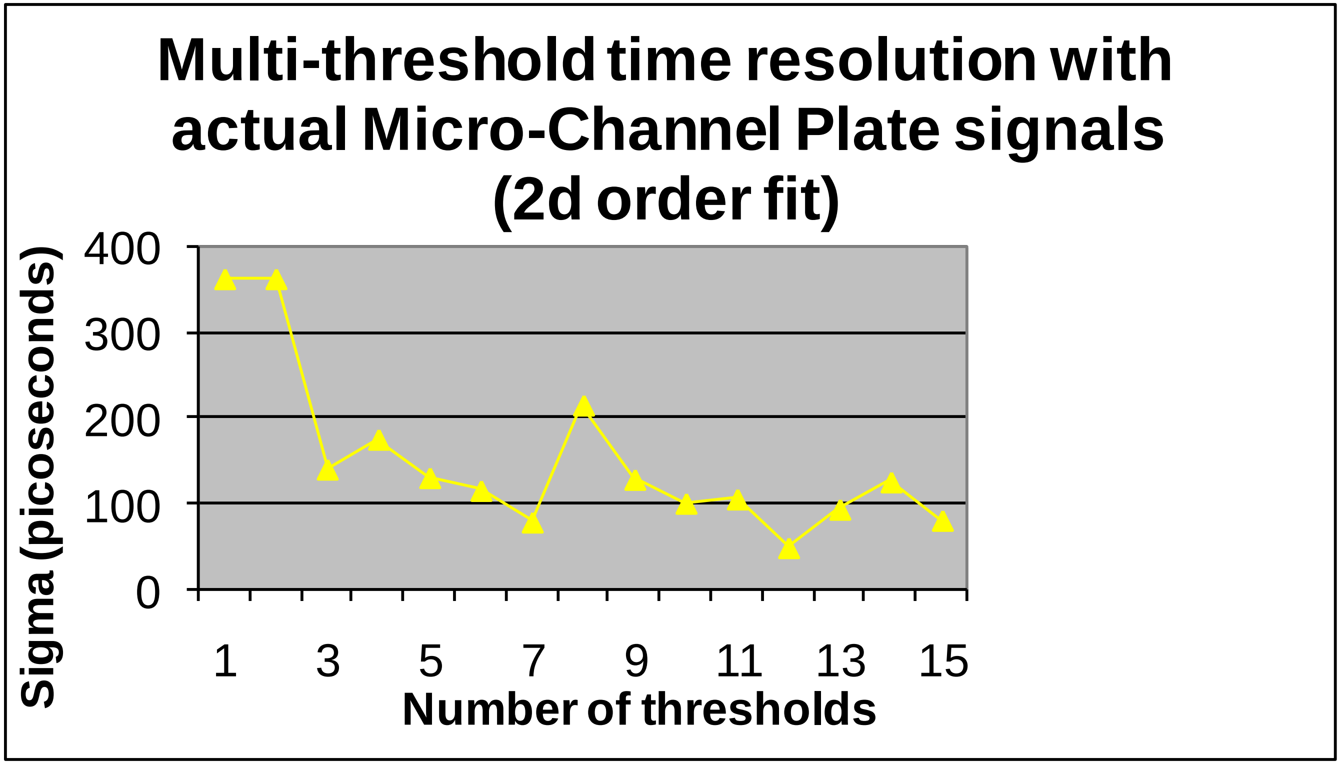
Multi-threshold
(simulation)

Multi-threshold: sampling times instead of amplitudes :

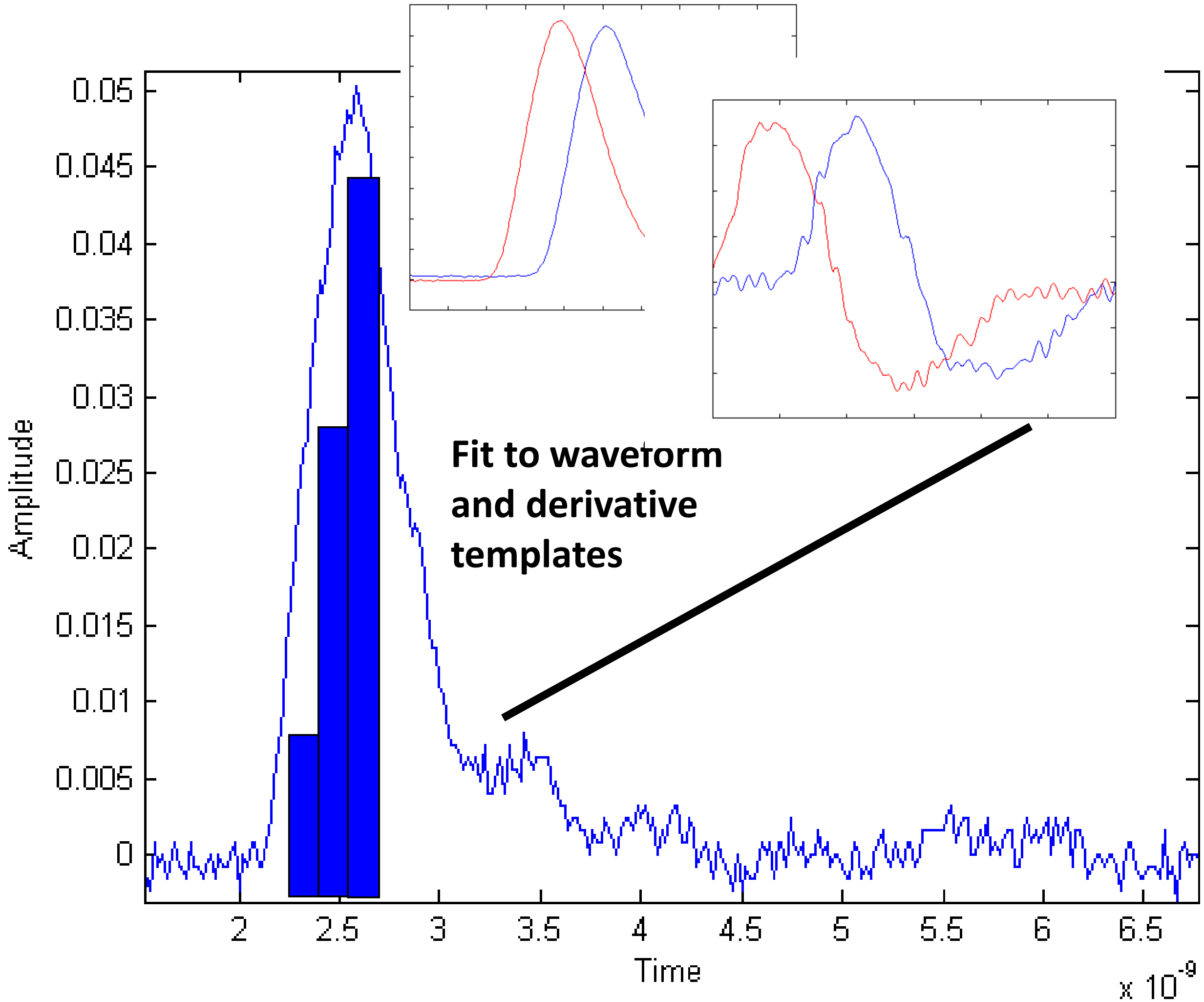
- Number of thresholds 4-8
- Thresholds values equally spaced
- Order of the fit: 2d order optimum



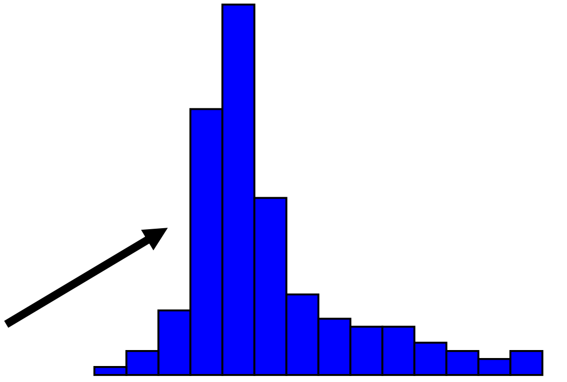
Multi-threshold performance

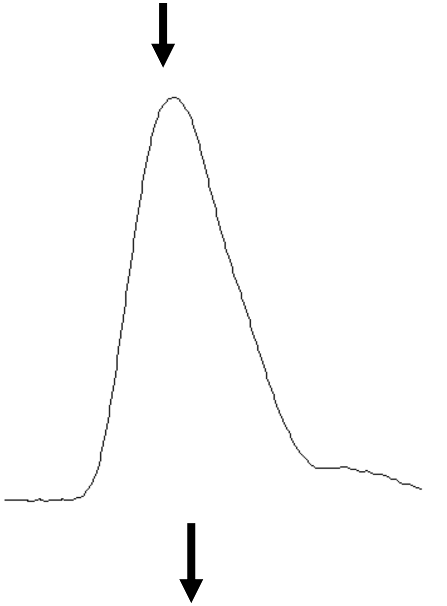


Waveform Sampling and Analysis



B. Cleland and E. Stern





Fast Timing

Timing Resolution using Waveform Sampling

abw= analog bandwidth

t_r = rise time (10-90%)

t_s = sampling period

S = signal amplitude

Since $\sigma_t = \frac{\sigma_n}{dS/dt}$ with $dS/dt = \frac{S}{t_r}$ $SN = \frac{S}{\sigma_n}$

and $\sigma_{t,n} = \sigma_t \sqrt{t_s / t_r}$

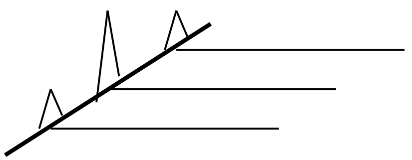
$$\sigma_t = \frac{\sqrt{t_r t_s}}{SN} = \frac{1}{SN}\sqrt{\frac{0.35 t_s}{abw}}$$

(Stefan Ritt, PSI)

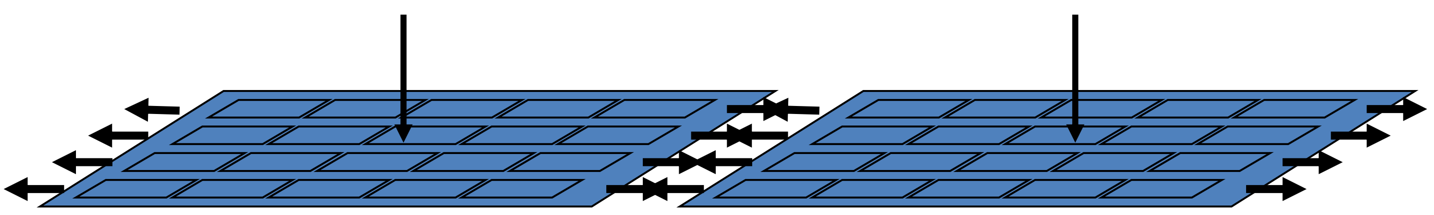
An Application of Waveform Sampling
Two-dimension readout using delay lines

Waveform sampling and analysis:

- Picosecond timing with fast detectors
- Charge: centroids for 2D readout
- Resolve double pulse

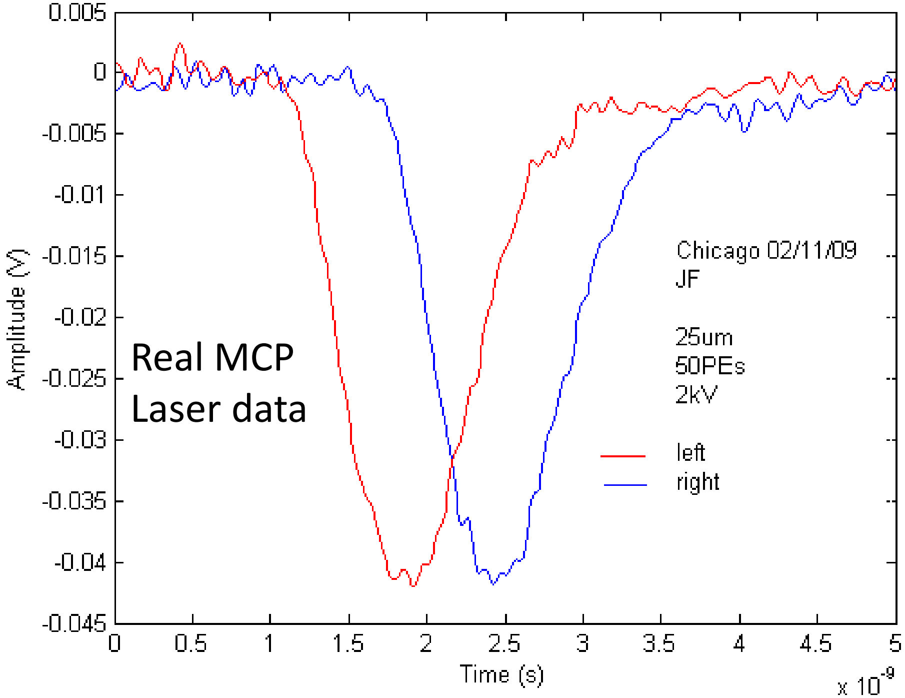


Large area detectors read with delay lines in series

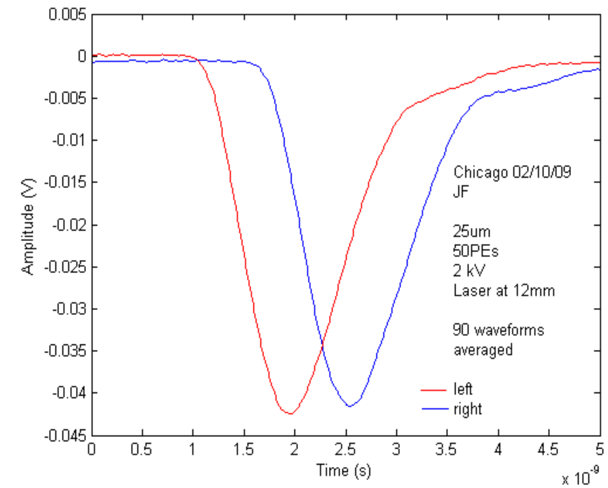


Waveform Sampling and Analysis
Two-dimension readout using delay lines

B. Cleland and E. Stern, BNL



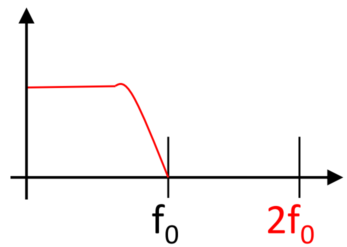
Signal Template



Extract precise time and amplitude from minimization of χ^2 evaluated wrt a waveform template deduced from the measurements.

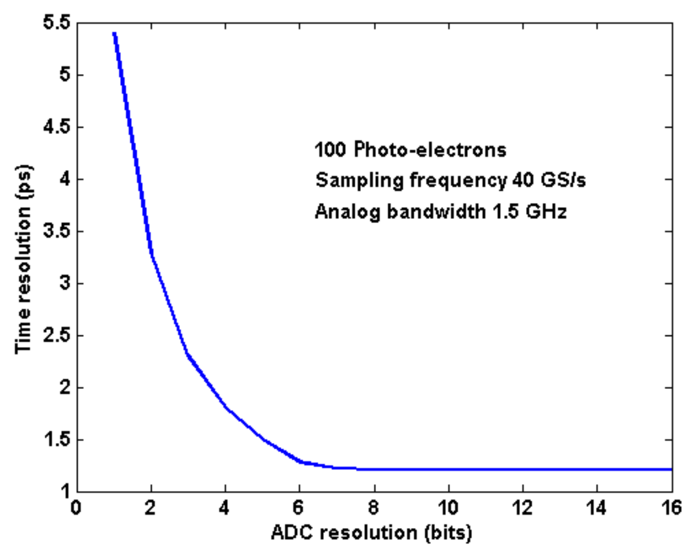
Waveform Sampling Parameters

- **Sampling frequency:** Set at twice the largest frequency in the signal spectrum



- **Digitization accuracy**: Evaluate what is needed from signals properties:

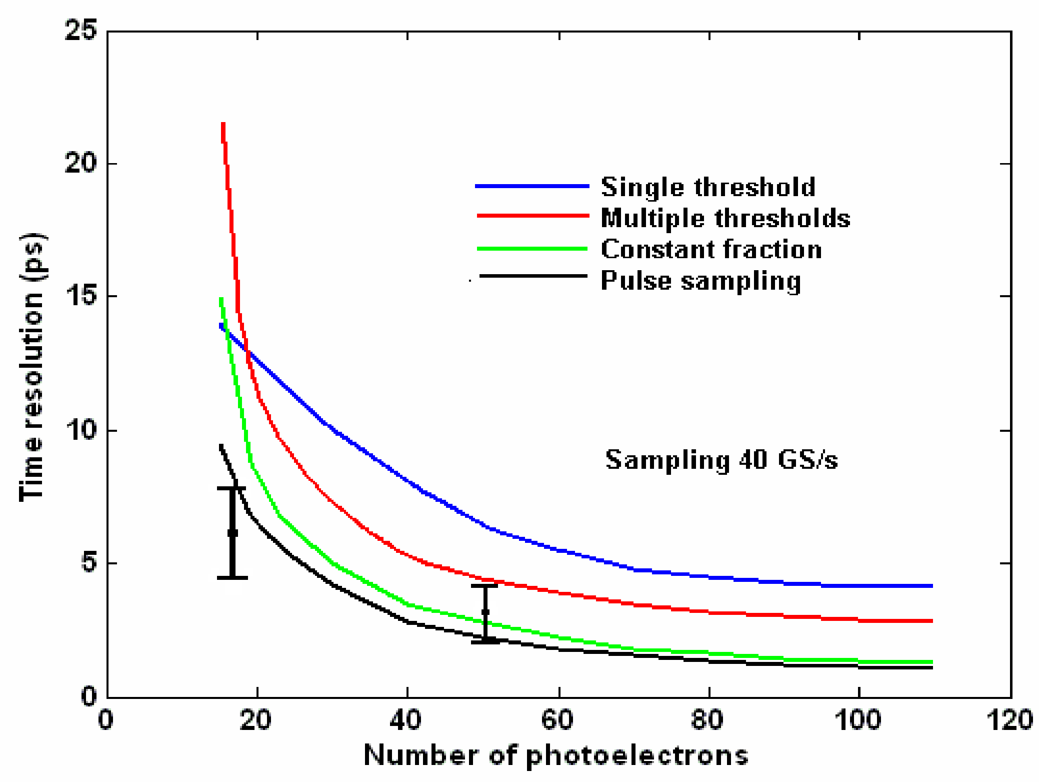
Example (simulation)
Micro-Channel Plate signals



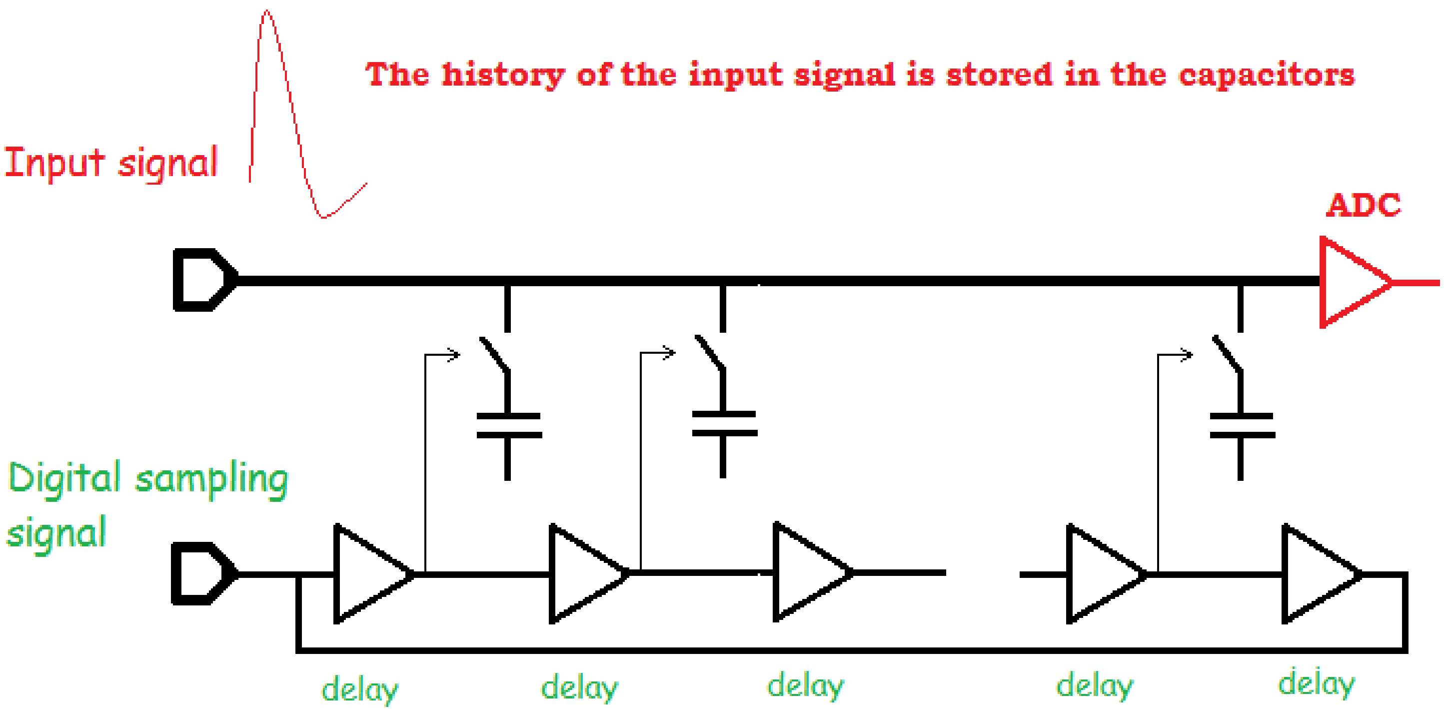
Waveform sampling: Measurements vs Simulation

50 Photo-electrons rms=3.82ps vs 2.5ps (simulation)

18 Photoelectrons rms = 6.05ps vs 7ps (simulation)



Waveform sampling:
Switched Capacitors Arrays



Sampling

The input signal is sampled at the elementary delay period (ns-ps)

Readout

ADC can be very accurate (10-14 bit), at the expense of the conversion time, external device

Today, 10 ps timing is available integrated

1 ps under work, looks promising
from the 10-100 GHz range VLSI technologies

Hear during the Workshop …?

The End