Electronics and Signal Processing for Fast Detectors

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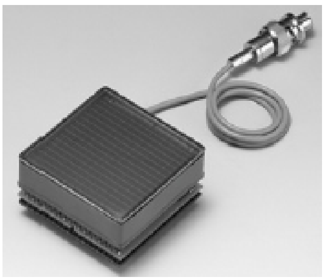
March 19th 2009

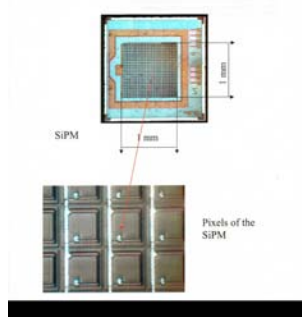
Outline

- Fast (photo) detectors
- Signals
- Timing extraction techniques, waveform sampling
- Application to time and position measurements using delay-line readout
- Developments

Fast Timing and Imaging Photo-detectors

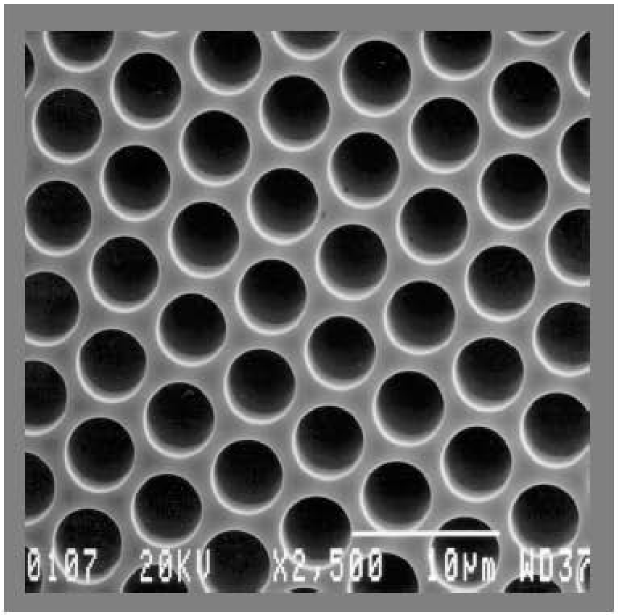
Multi-anodes PMTs	Si-PMTs	MCPs
Dynodes	Ouenched Geiger	Micro-Pores

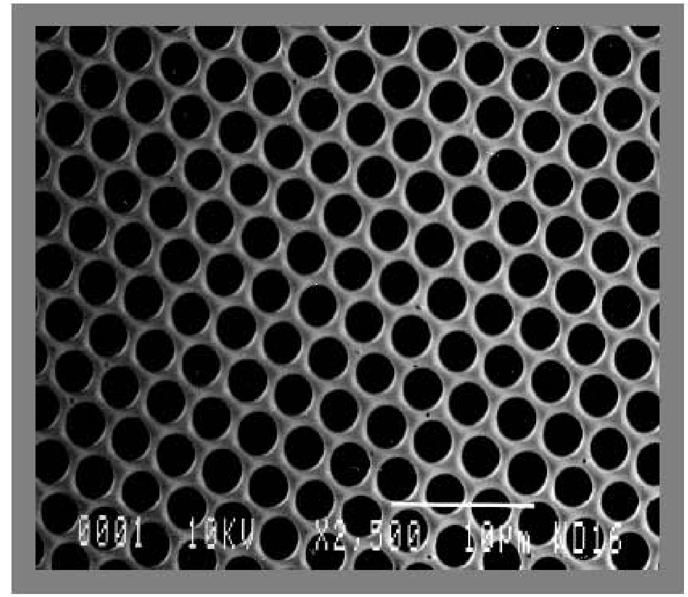




	Multi-anodes PMTs	Si-PMTs	MCPs
QE	30%	90%	30%
CE	90%		70%
Rise-time	0.5-1ns	250ps	50-200ps
TTS (1PE)	150ps	100ps	20-30ps
Pixel size	$2x2mm^2$	$50x50\mu m^2$	$1.5x1.5mm^2$
Dark counts	1-10Hz	1-10MHz/pixel	1-10 kHz/cm^2
Dead time	5ns	100-500ns	$1\mu s$
Magnetic field	no	yes	15kG
Radiation hardness		1kRad noise x 10	

Micro-channel Plates: Micro-Pores

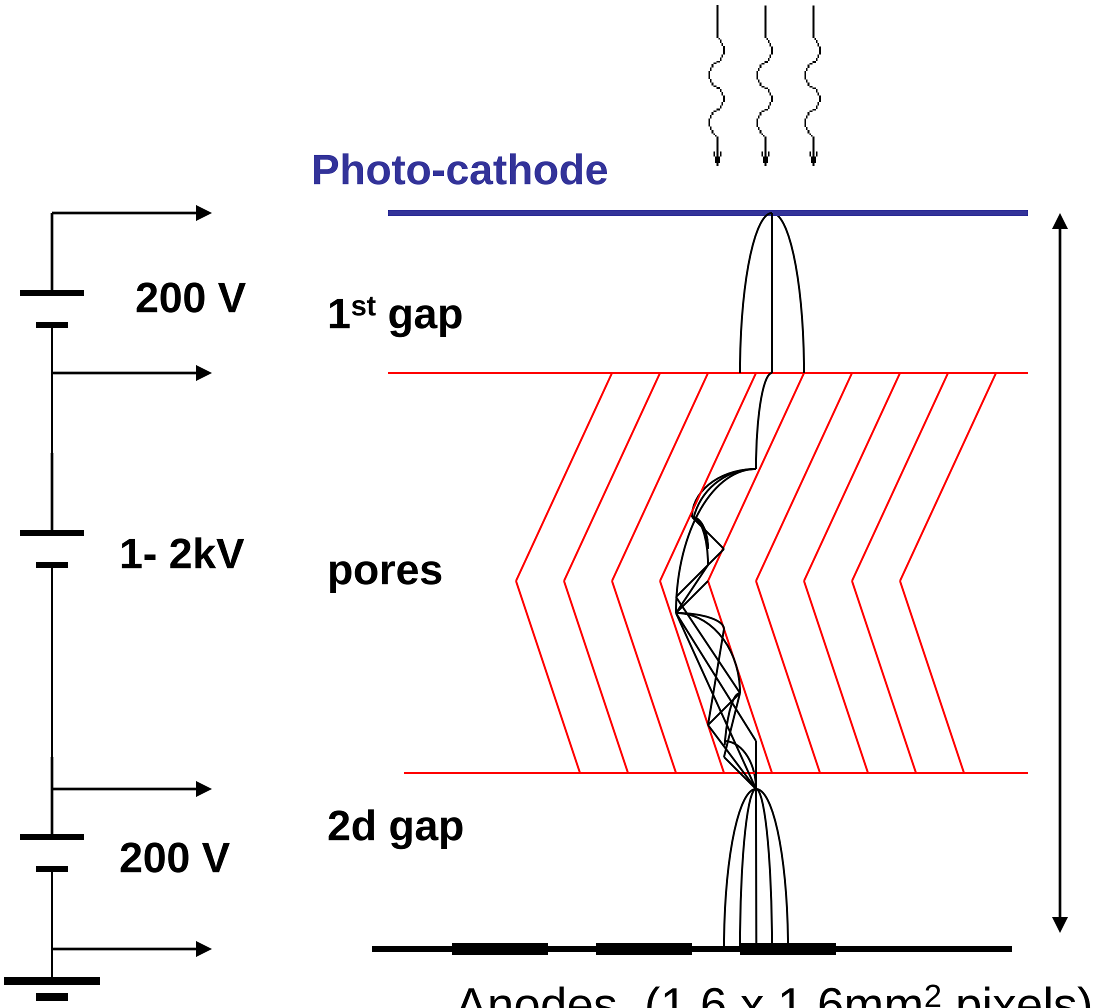




Comparison of 5micron pore and 2 micron pore MCP's (same magnification)

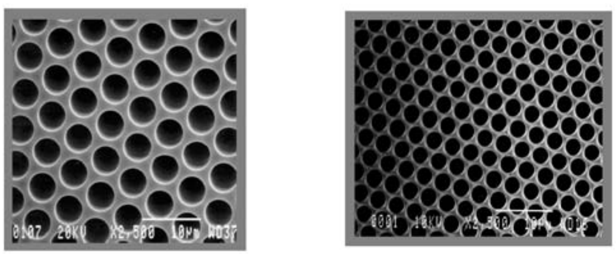
From BURLE-Photonis

Micro- Channel Plate Detectors



Anodes (1.6 x 1.6mm^2 pixels)

a few mm



Comparison of 5micron pore and 2 micron pore MCP's (same magnification)

Pore diameter 3-25 μm
Pore aspect ratio: 1:50

Micro-Channel Plates

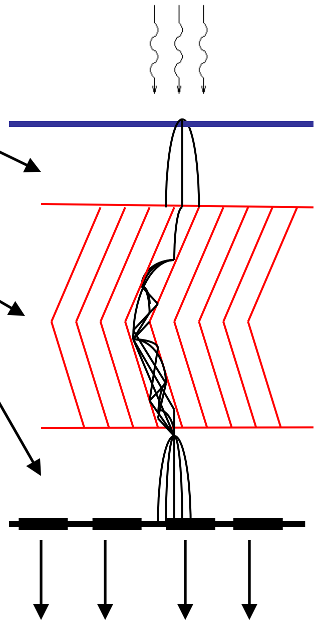
Optimization for timing

Reduce Transit time

The thinner, the best
Reduce pore size, primary and secondary gaps

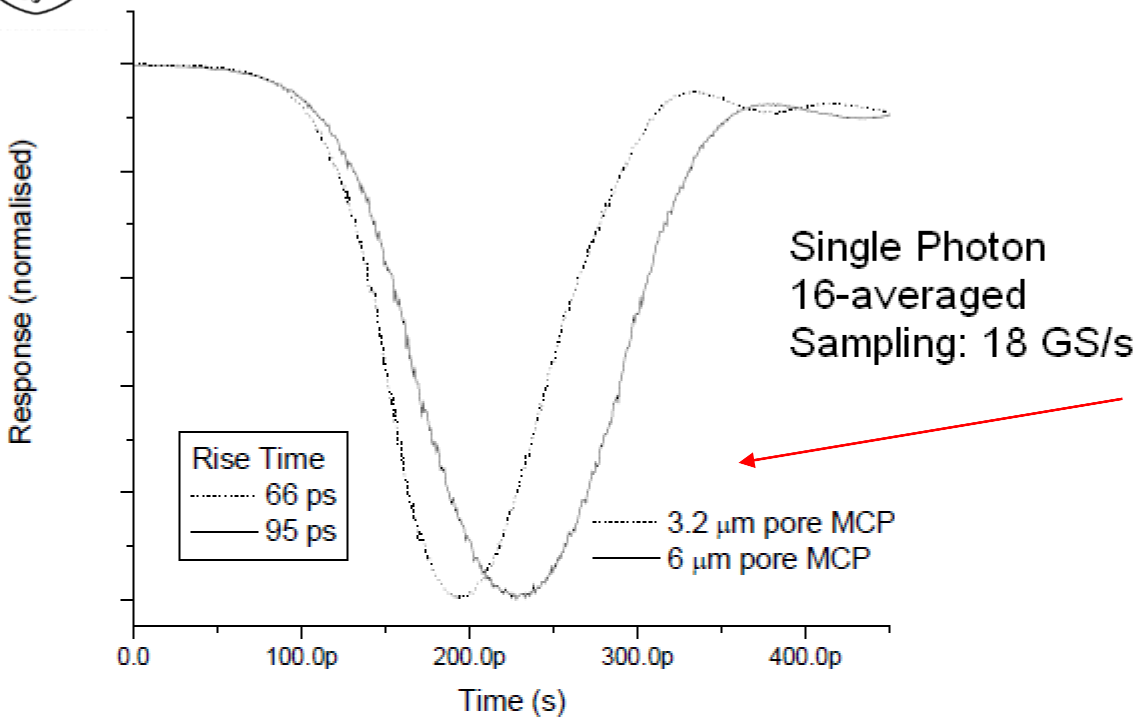
Avoid parasitic readout components

Connectors (!)
Parallel capacitances
Series inductances



Reduce rise-time, consequently improve time resolution

Micro-Channel Plate Signals



Time response curves for two models of PMT110 with different MCP pore diameters.

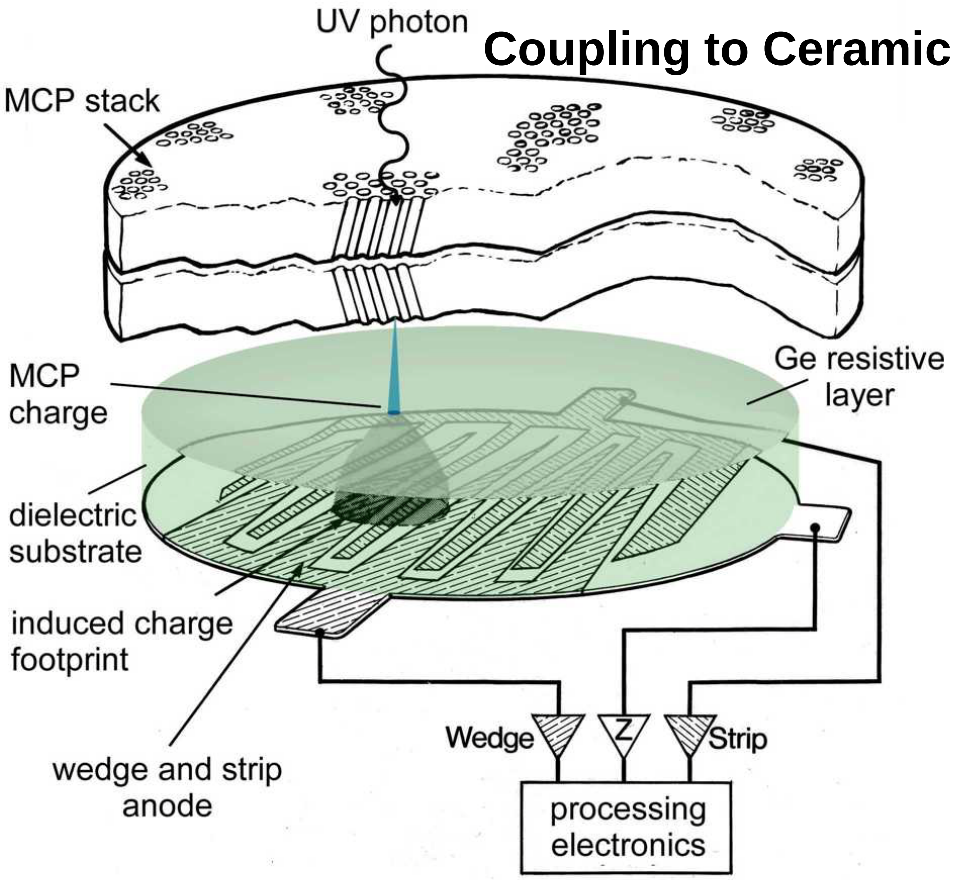
From Photek

The fastest photo-detector to date

Imaging Micro-Channel Plates Detectors

As imaging device…

Coupling to Ceramic

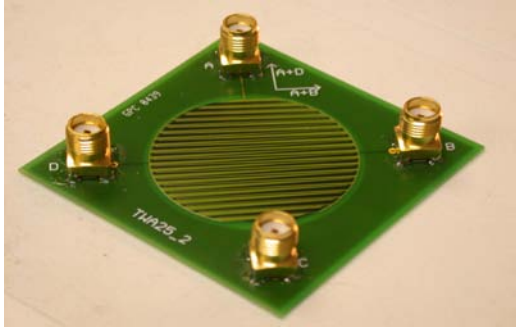


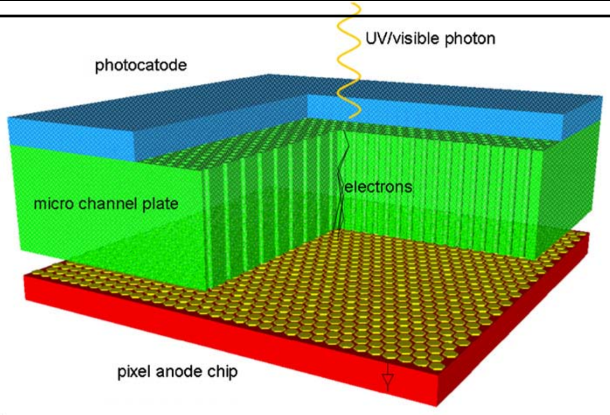
From J. Lapington, for WSO, Uni. Leicester, UK

Coupling to Board

Position: 10µm resolution

Time: 1ns





Coupling to ASIC: 3 µm

From GLAST, Siegmund et al NIM 591 2008

Two-micron space resolution using analog charge division technique

High precision analog measurements.

But integration time= 200ns !

R. Bellazzini et al. / Nuclear Instruments and Methods in Physics Research A 591 (2008) 125–128

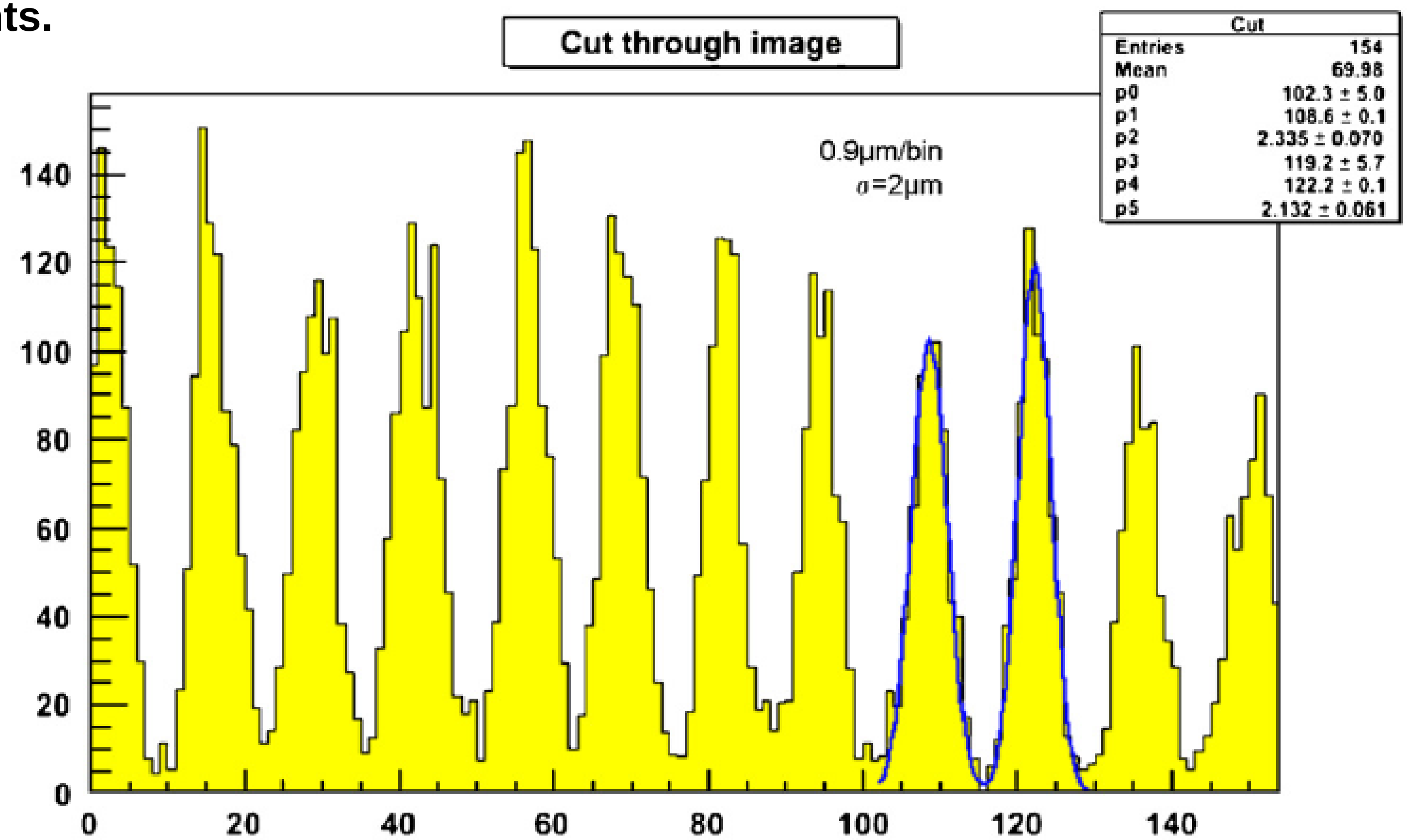


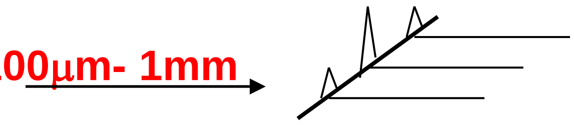
Fig. 4. A profile along a line cut across the MCP pores of Fig. 3. The spatial resolution of the readout is ~2 µm rms, capable of resolving every single MCP pore.

2D+ time with T-lines and Pico-second Timing

- Transmission lines (T-lines) readout and pulse sampling provides

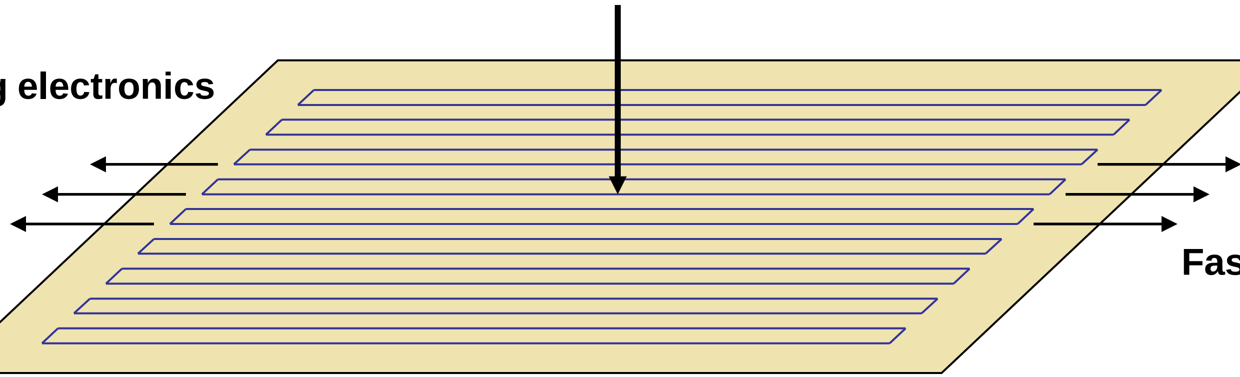
  - **Fast timing (2-10ps)**
  - **One dimension with T-lines readout 100µm- 1mm**
    Transverse dimension from centroids

    Less electronics channels for large area sensors



Fast sampling electronics

t_1, a_1



t_2, a_2

Fast sampling electronics

$\frac{1}{2}(t_1 + t_2)$ = **time**

$v(t_1 - t_2)$ = **longitudinal position**

$\Sigma\, \alpha_i\, a_i \,/\, \Sigma\, \alpha_i$ = **transverse position**

Outline

- Fast (photo) detectors
- Signals
- Timing extraction techniques, waveform sampling
- Application to time and position measurements using delay-line readout
- Future developments

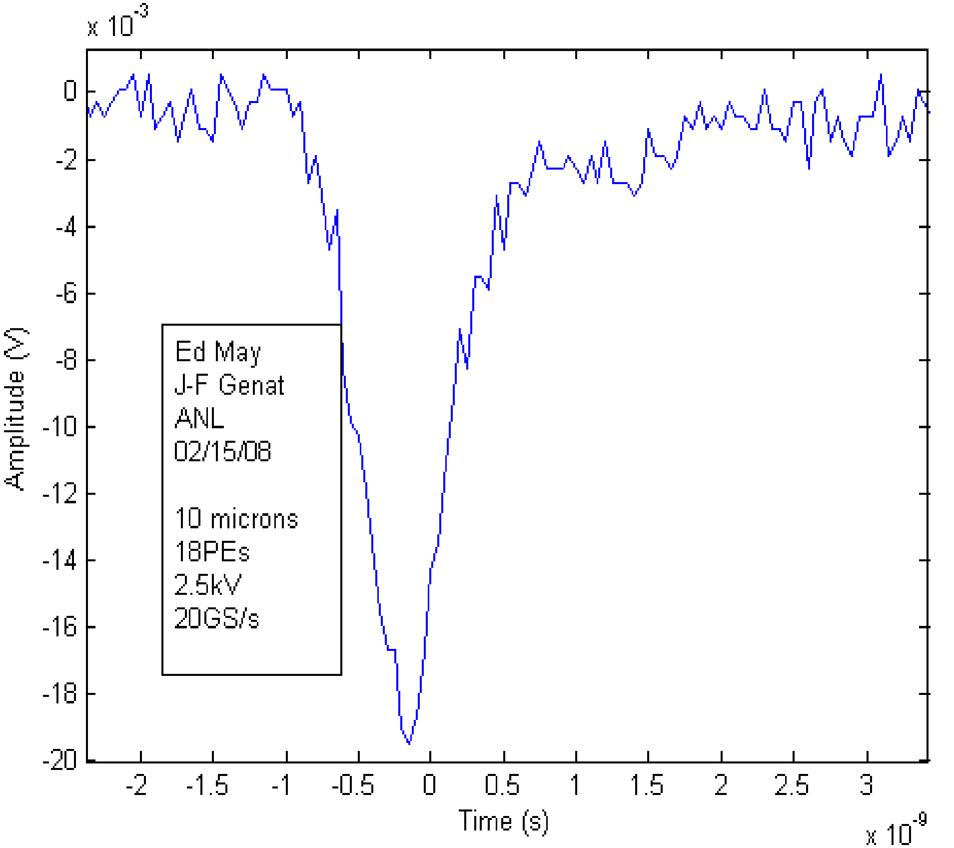
Micro-channel Plates Sampled Waveforms

- **Amplitudes (10µm, 2.5 kV)**

18 Photo-Electrons	**20**	**mV**
50 Photo-Electrons	**35**	**mV**
158 Photo-Electrons	**78**	**mV**

- **Rise times**

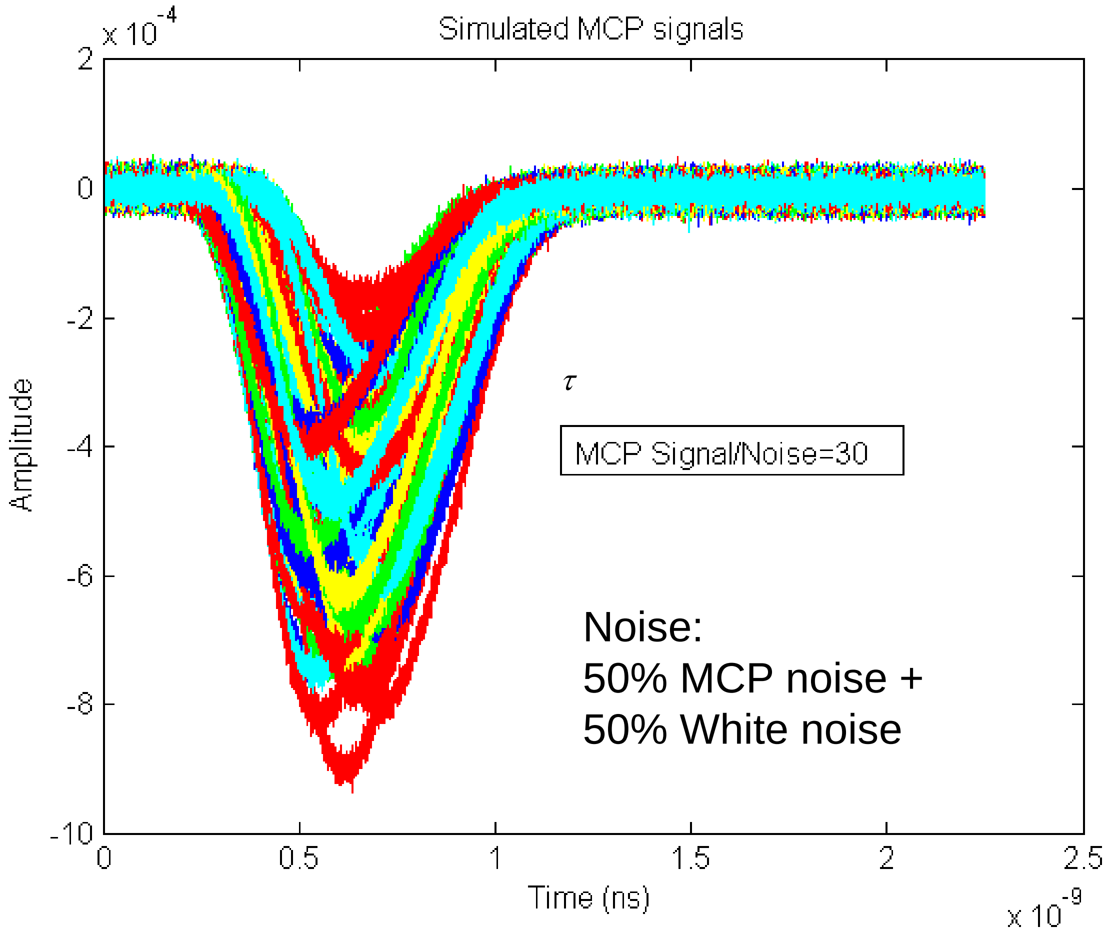
25µm	**600ps**
10µm	**550ps**



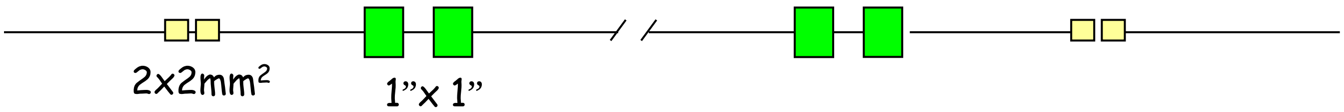
Synthesized signals for simulations

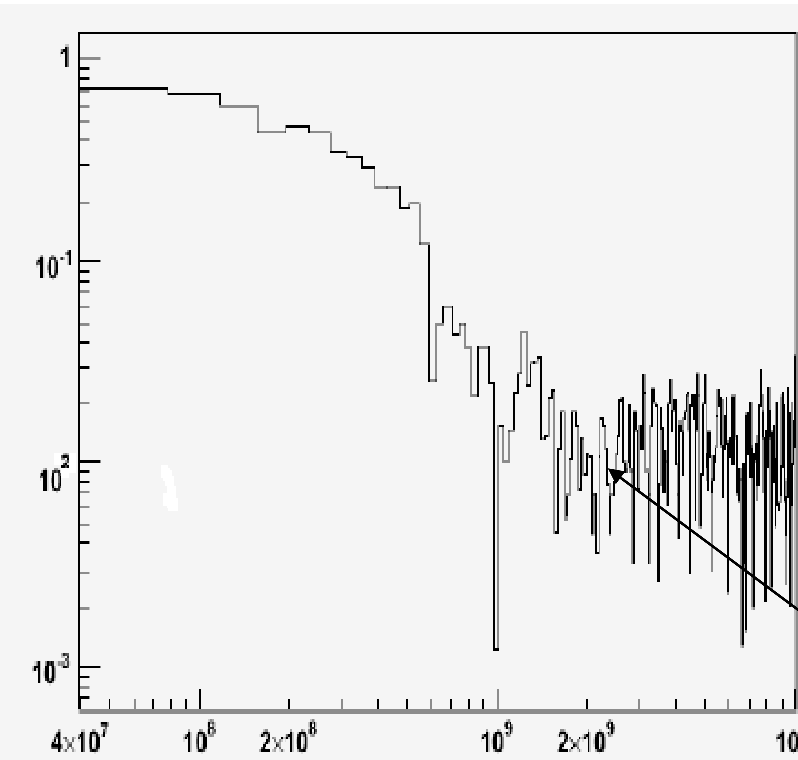
MCP signals: $(t/\tau)\exp(-t/\tau)\otimes(t/\tau)\exp(-t/\tau)$

τ is tuned to a 280ps rise-time

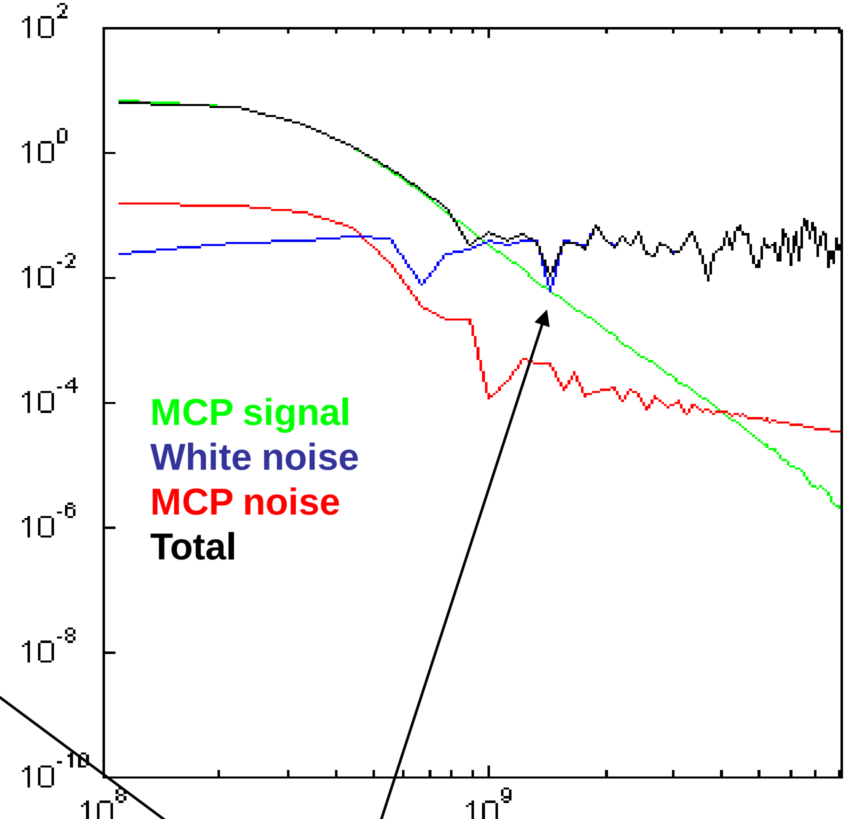


MCP Signals spectra





Measured (FNAL T979 Beam-Tests)



Simulated

Same noise corner at 1.2 GHz

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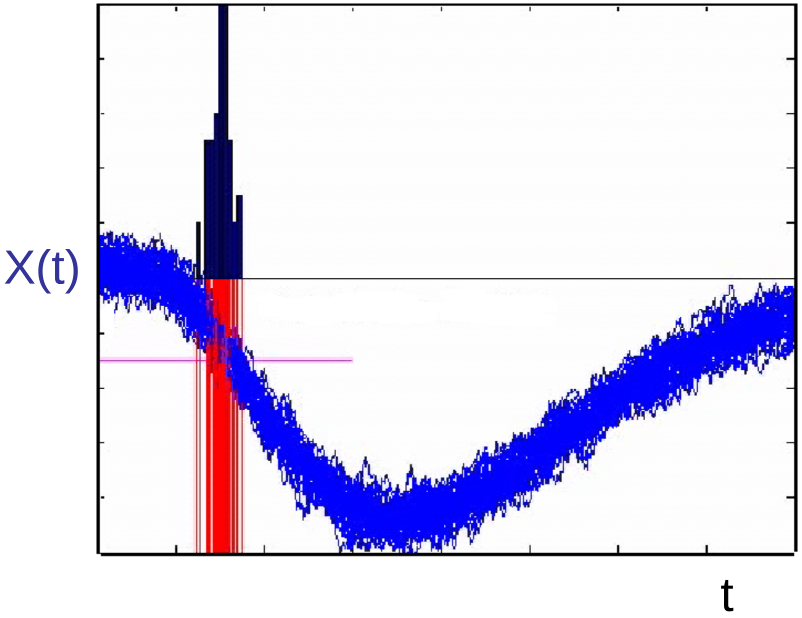
Single Threshold: Noise and Slope

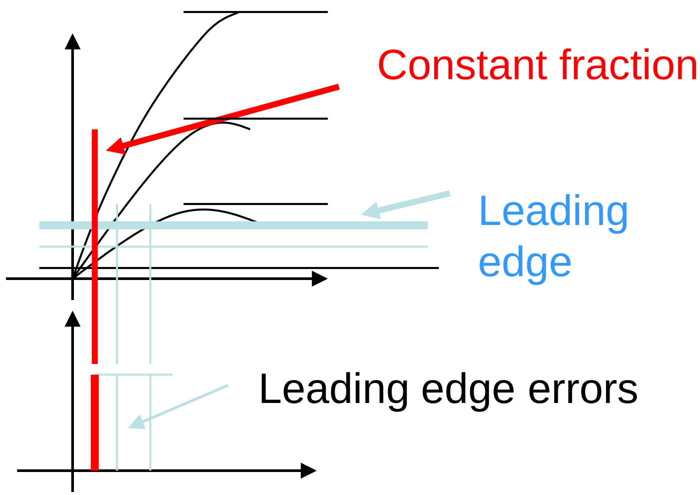


- $rms_{noise} = \sigma_x$
- $\sigma_t = \sigma_x / \frac{dx(t)}{dt}$

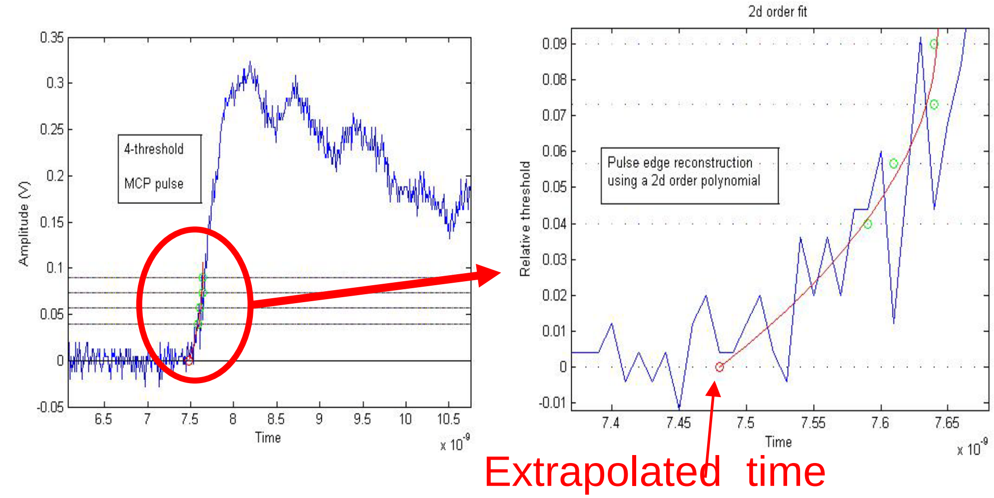
Single threshold: Time spread proportional to amplitude noise and inverse to slope

Timing techniques

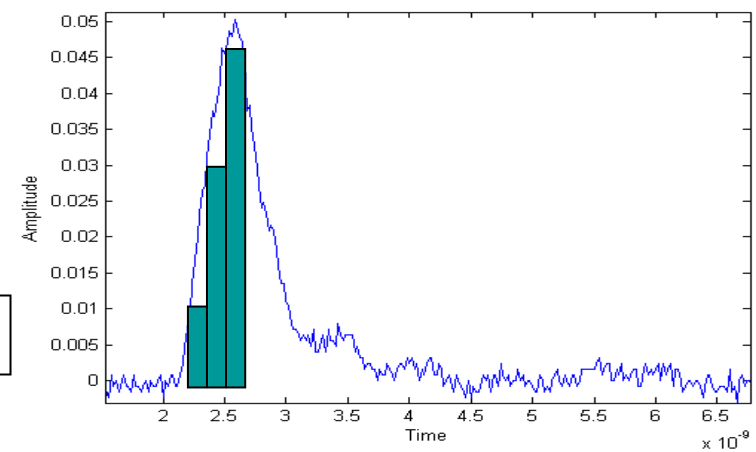
Constant-fraction



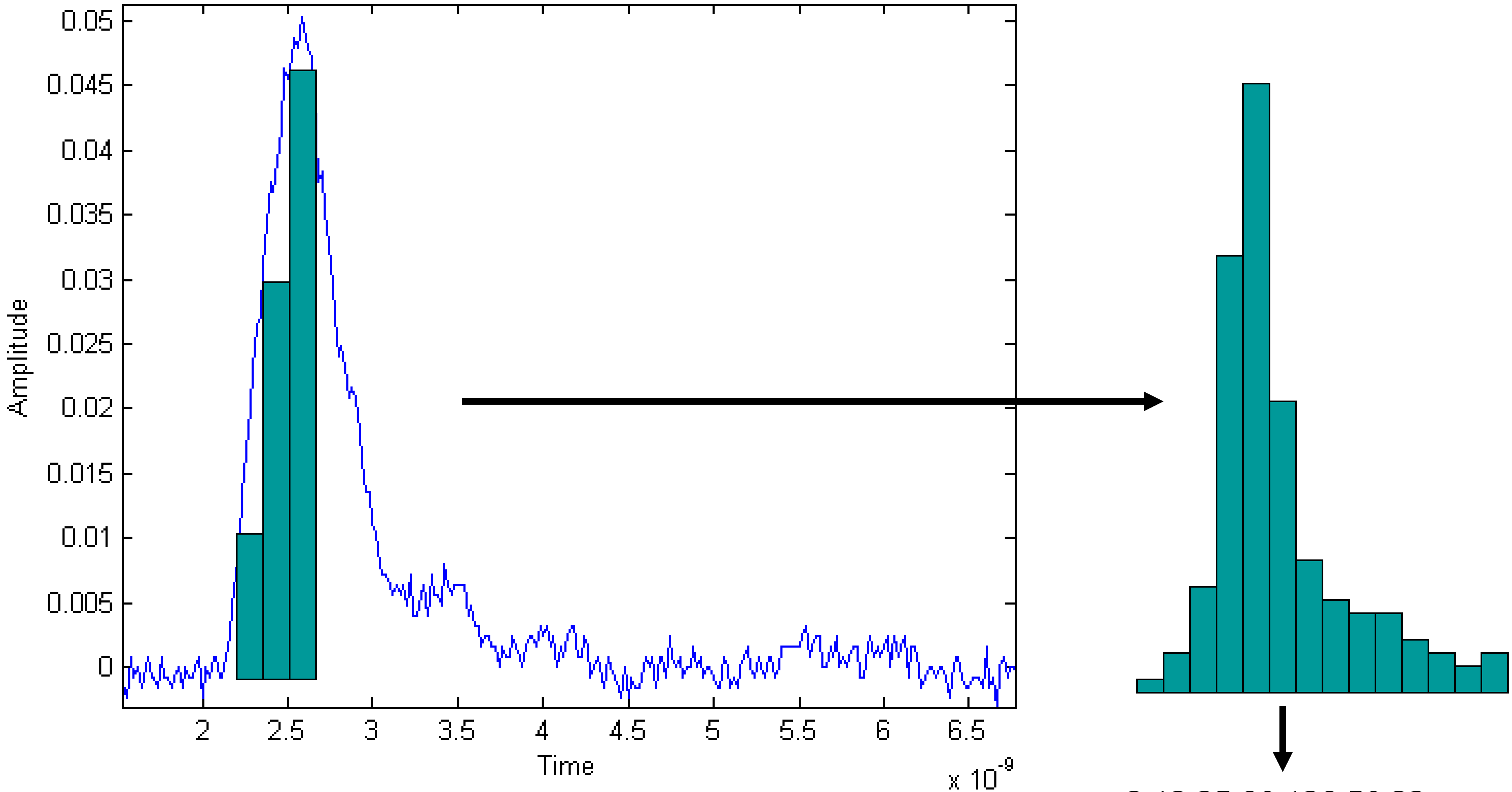
Multi-threshold



Pulse sampling



Pulse Sampling



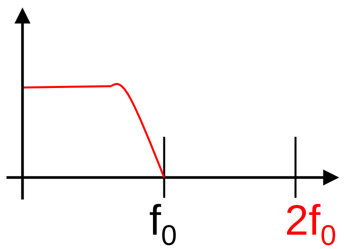
2 12 25 80 128 50 32 …

Waveform analysis

Sampling period, digitization (number of bits)

Pulse sampling and Waveform analysis

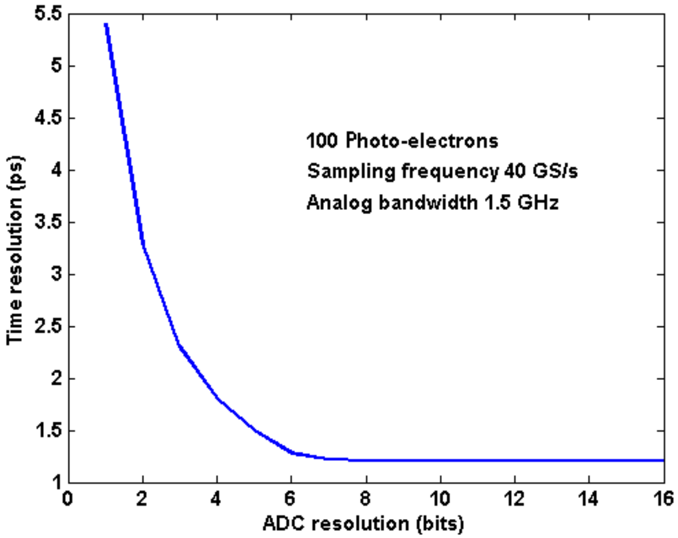
- Sampling frequency: Set at twice the largest frequency in the signal spectrum



- Digitization: Evaluate what is needed from signals properties:

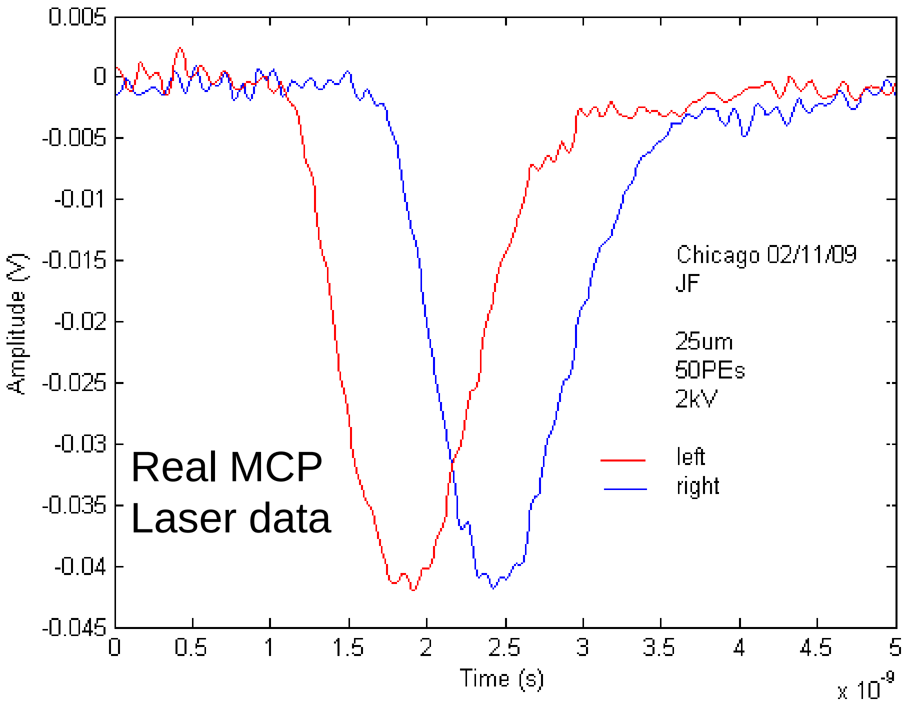
Example:

MCP signals



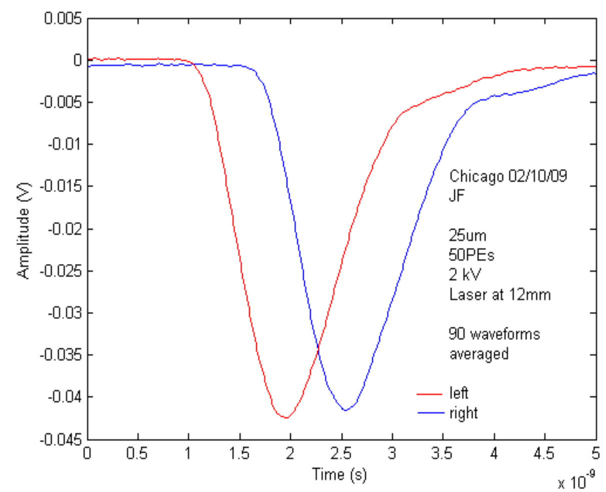
Sampled pulses analysis

Many techniques



B. Cleland and E. Stern, BNL

Signal Template

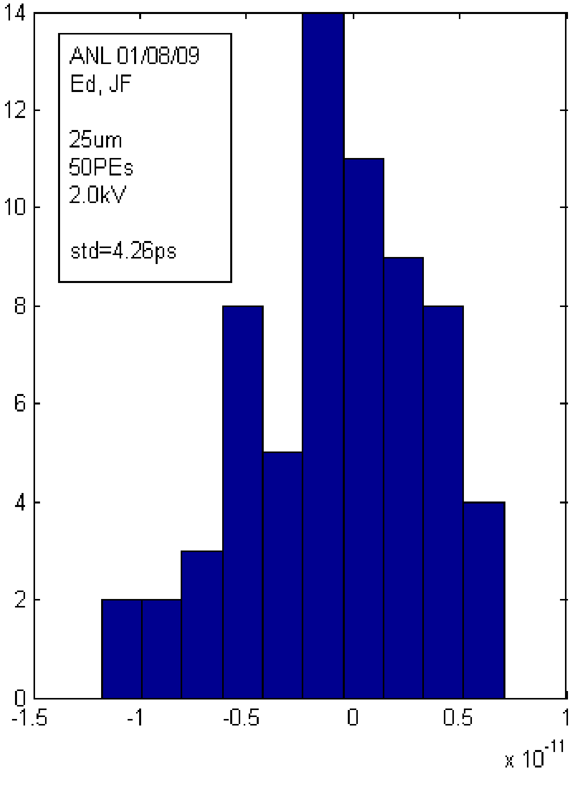


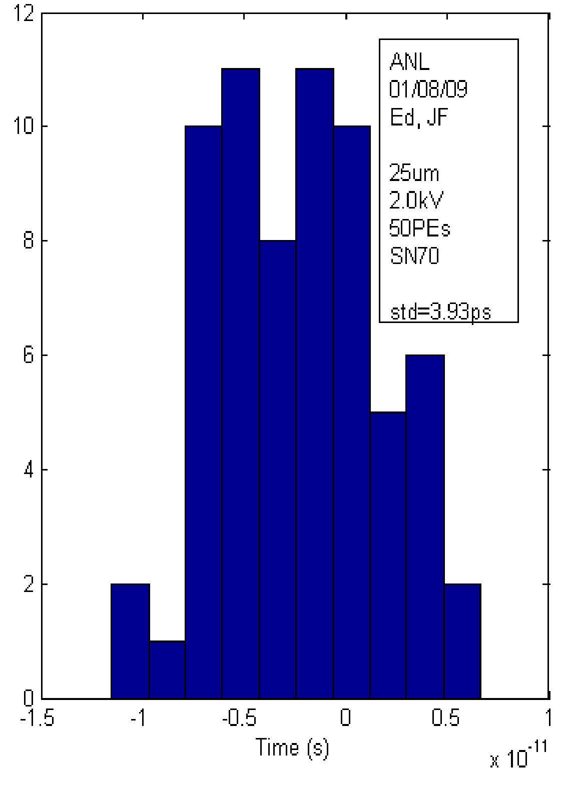
- Extract precise time and amplitude from minimization of χ^2 evaluated wrt a template deduced iteratively from the measurements, at the two ends of the T-line.

- With T-lines, the two ends are highly correlated, so, MCP noise is removed.

Iterative template

At T-lines ends

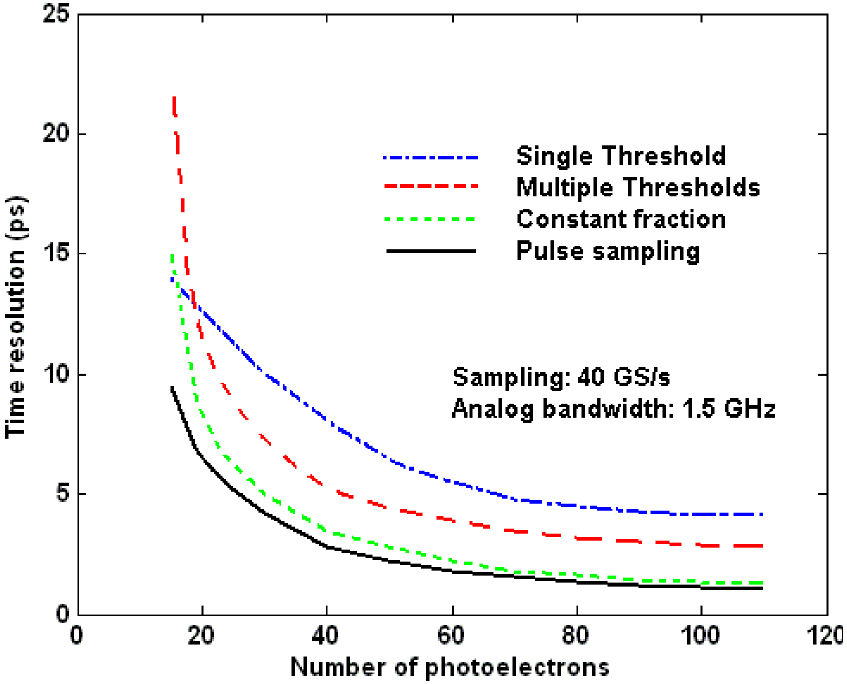


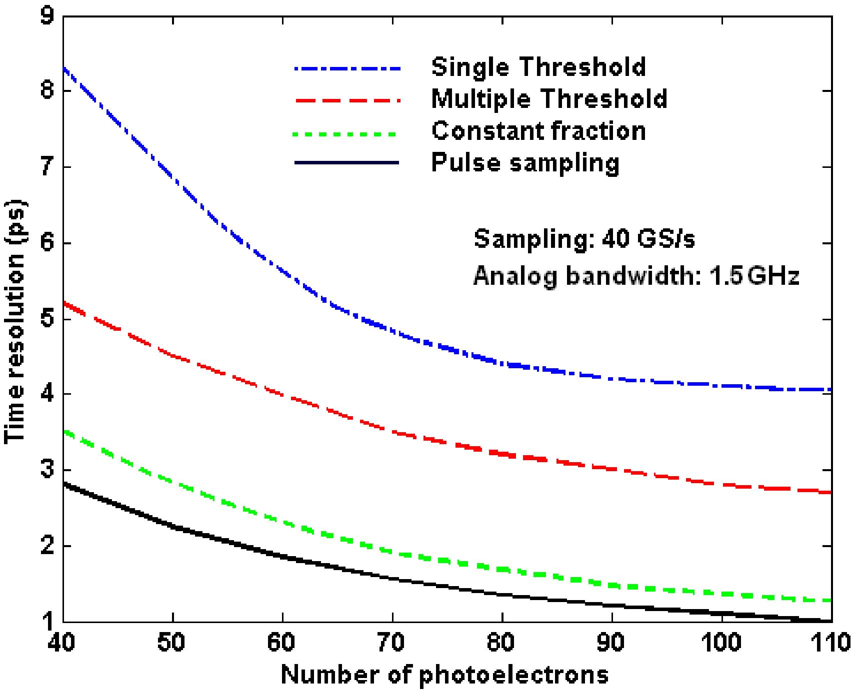


Template from average
std= 4.26ps

Template iterative
std=3.93

Methods compared (simulation)

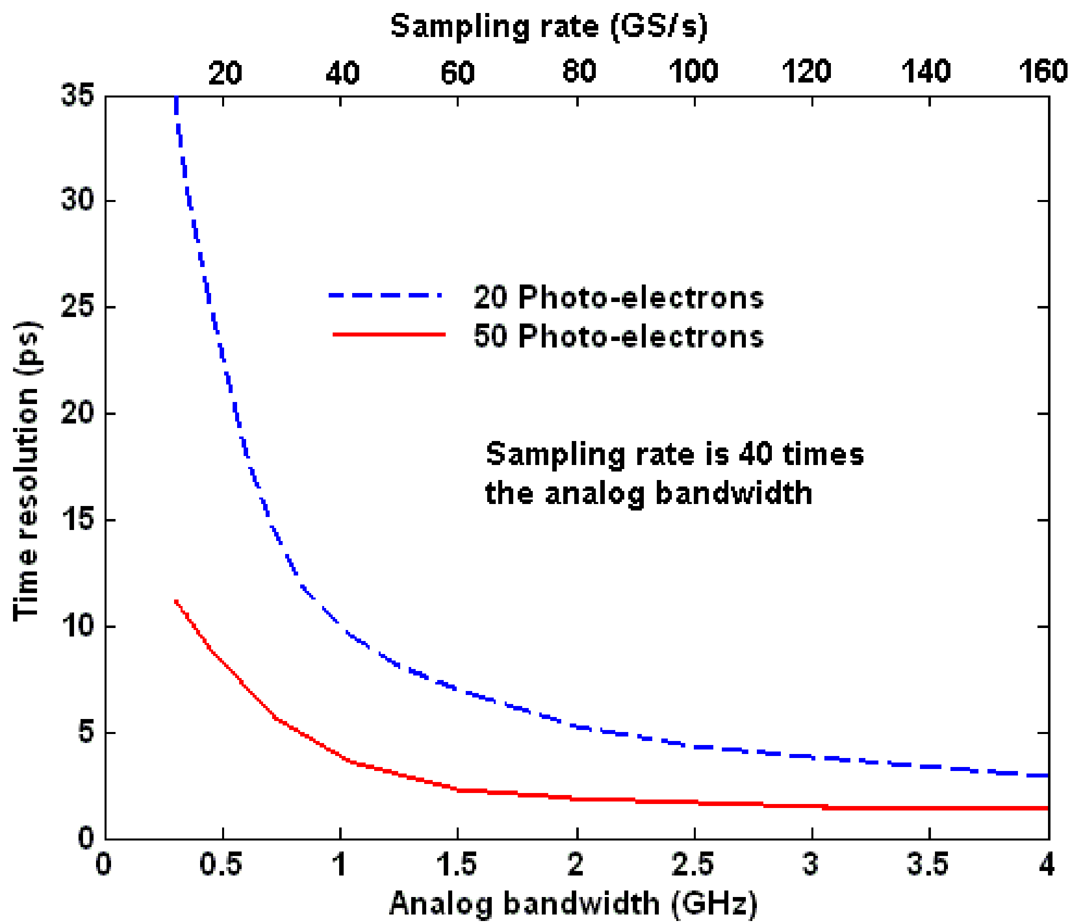




zoom

Time resolution vs Number of photo-electrons

Pulse sampling
Timing resolution vs Sampling rate (simulation)

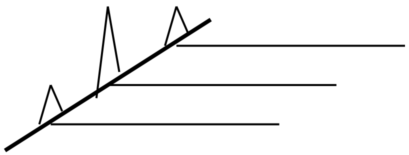


Timing resolution vs   Sampling rate / Analog bandwidth

Pulse sampling benefits

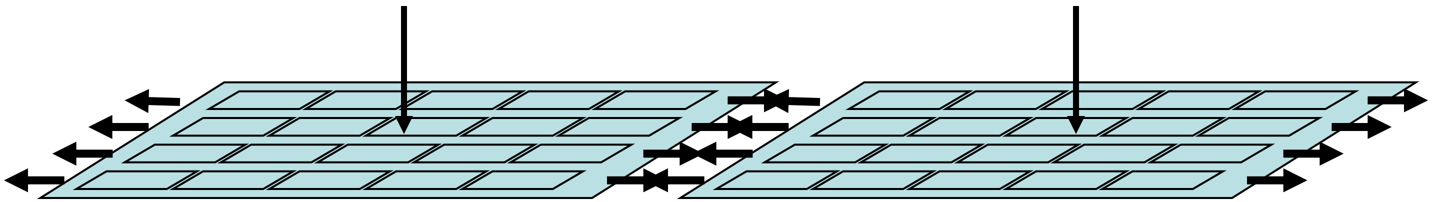
Pulse sampling and waveform analysis:

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



- Resolve double pulse

For large area detectors read with delay lines in series



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- Timing extraction techniques, waveform sampling
- Application to time and position measurements using delay-line readout
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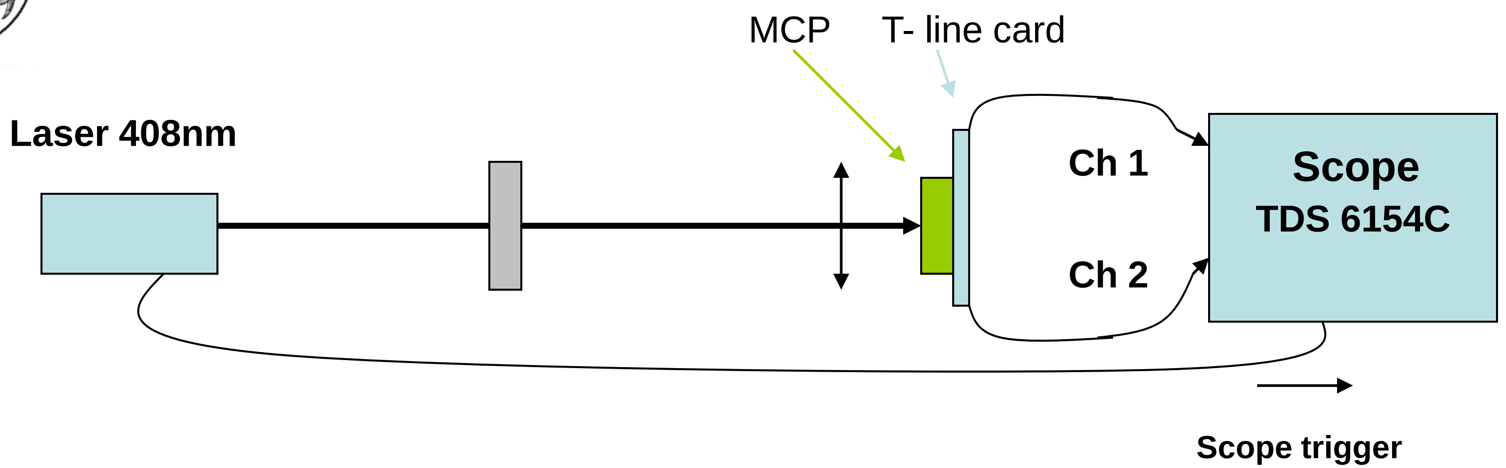
Position sensing using fast timing

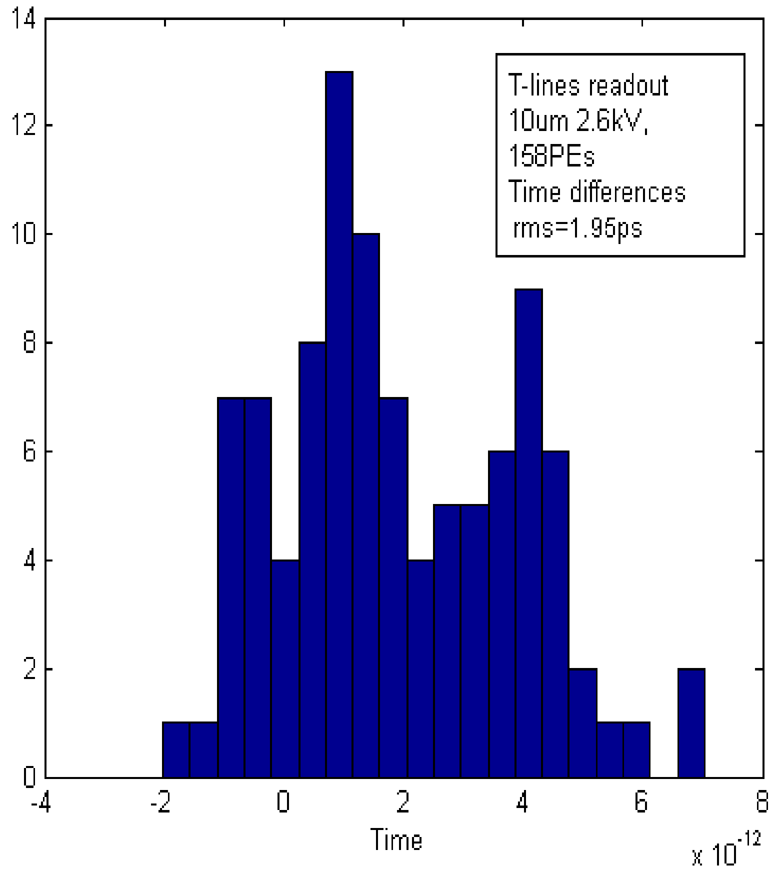


- Edward May, Argonne:

Laser test bench calibrated with the single PE response of a Quantacon (single photon sensitive) PMT.

- 25/10um pores MCP on transmission lines card
- Scope triggered by the (somewhat jittery) laser signal
- Record two delay lines ends from the same trigger
- Tek 6154C scope at 20 Gs/s

Results



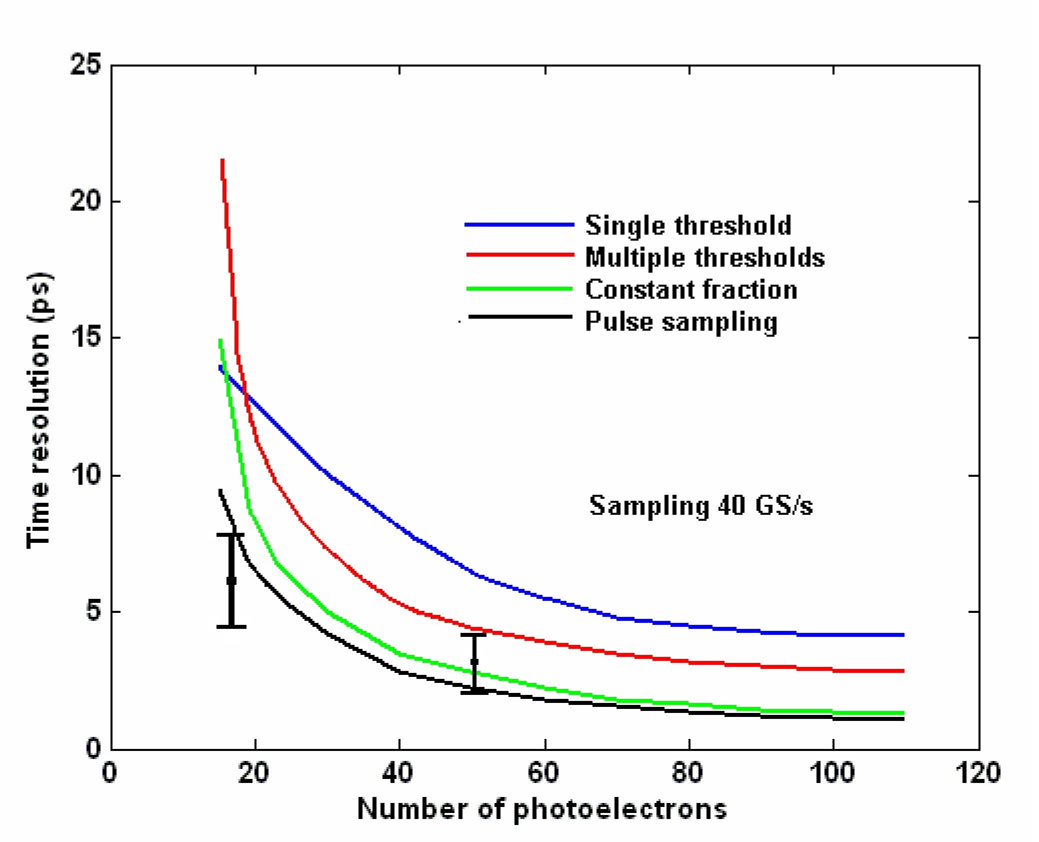
Position resolution (velocity=8.25ps/mm) :	50PEs	4.26ps	213µm
	158PEs	1.95ps	97µm

Measurements vs simulation

50PEs rms=3.82ps vs 2.5ps (simulation)

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

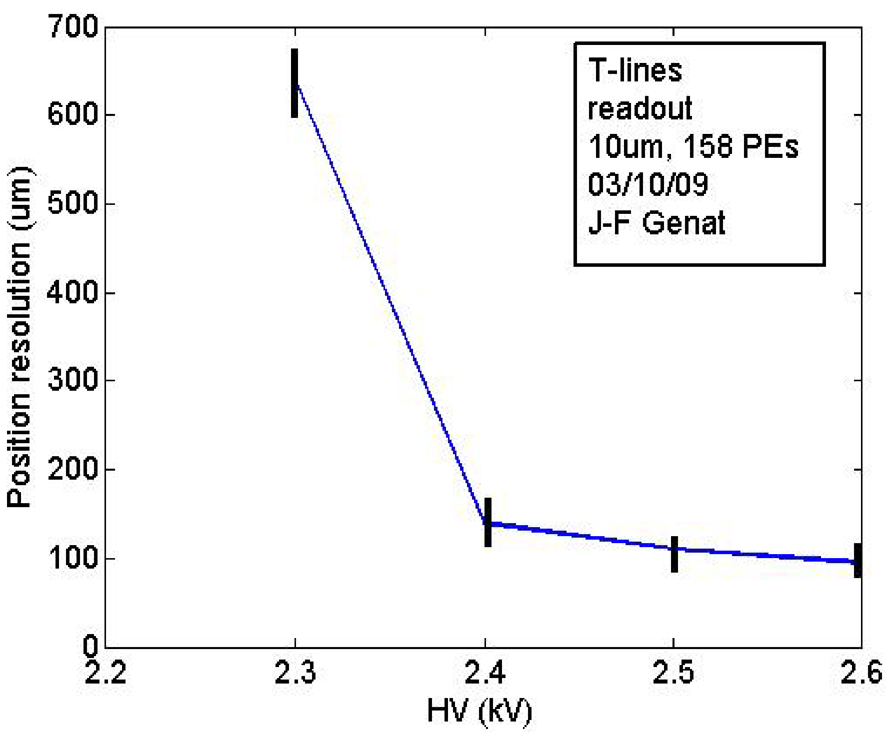
Measurements
do not match exactly
since MCP noise
is partly removed
(T-lines ends correlated)

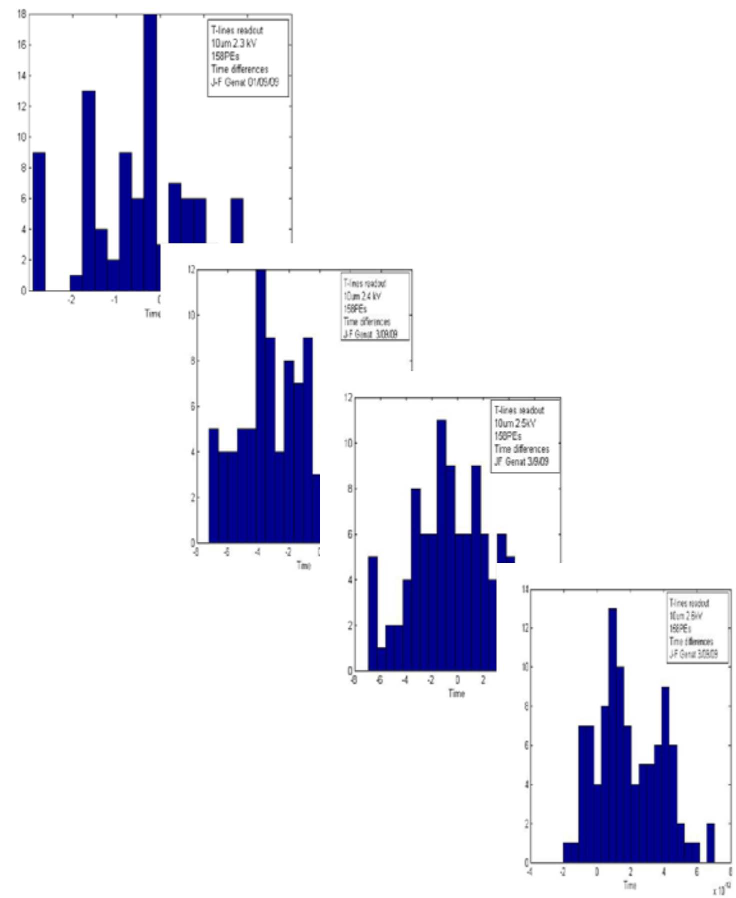


Position Resolution at 158PEs

158 PEs

	HV = 2.3 kV	HV = 2.4 kV	2.5 kV	2.6 kV
Std	12.8ps	2.8ps	2.2 ps	1.95 ps
	640µm	140µm	110µm	97µm





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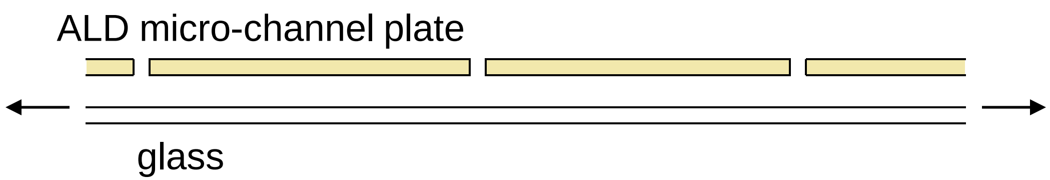
Transmission lines as anodes

- Present Photonis MCPs:
  Pixellated anodes, pitch of 1.6 x 1.6 mm

  - Atomic Layer Deposition (ALD) detectors
  - Waveform sampling with fast sampling chips

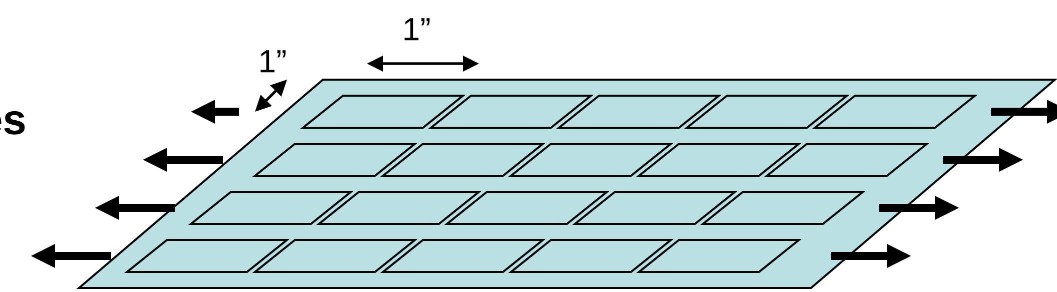
- **Integration of lines as anodes in vacuum for large area sensors**
- **Plates of 1" x 1" in ALD process**
- **Modules of 8 " x 8 " ?**
- **One vacuum vessel (glass)**

Henry Frisch, (U-Chicago)
W. Hau, M. Pellin (ANL)



Check in vacuum
T-lines coupled to Micro-Channel Plates (impedance, velocity)

B. Adams, K Attenkoffer, ANL



Fast Sampling Electronics

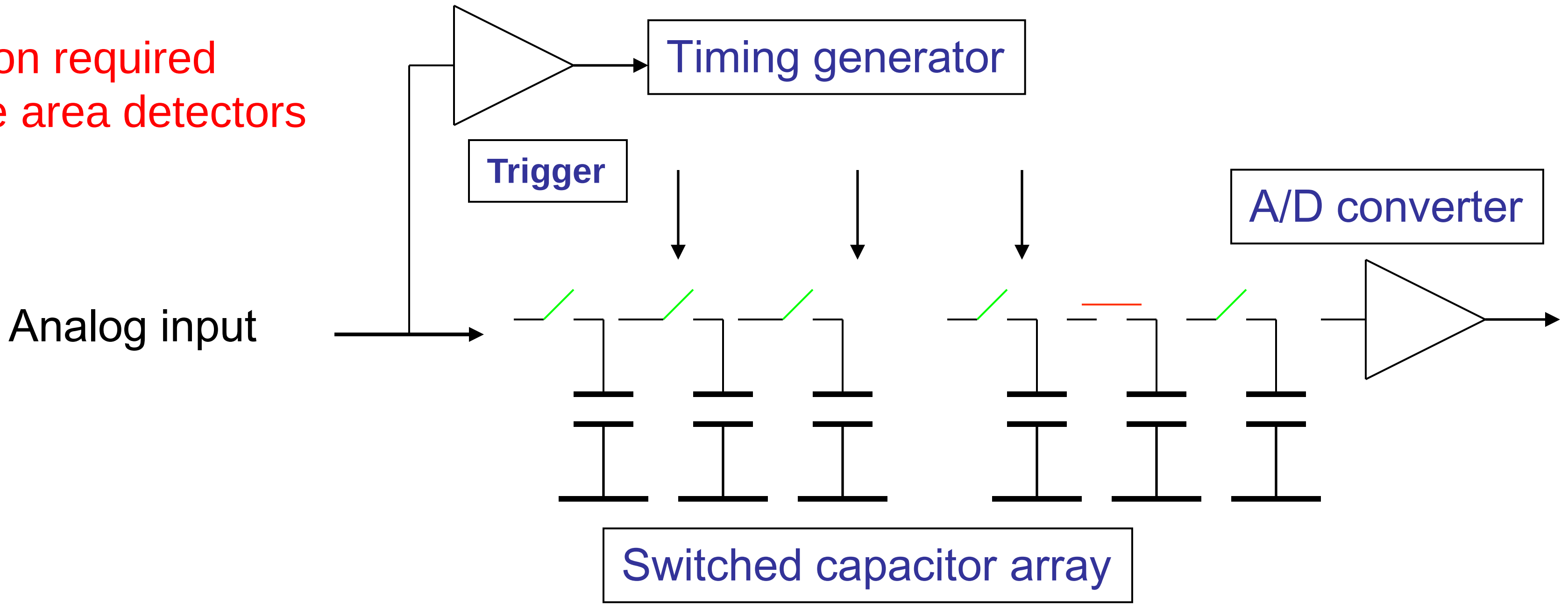
				MCP	Electronics
Constant fraction	SLAC	- NIM		6ps	3.4ps
	LBNL/Hawaii	- Discrete			
Multi threshold	Chicago	- Discrete + CERN TDC chip			
Waveform analysis	Hawaii	- BLAB line chips	6GS/s	20ps	10ps
	Orsay/Saclay	- SAM line	2GS/s		
	PSI	- DRS line	5GS/s		

Under development:

10-40 GS/s sampling chip Chicago + Hawaii + Orsay/Saclay

Fast Sampling Integrated Circuit

Integration required
For large area detectors



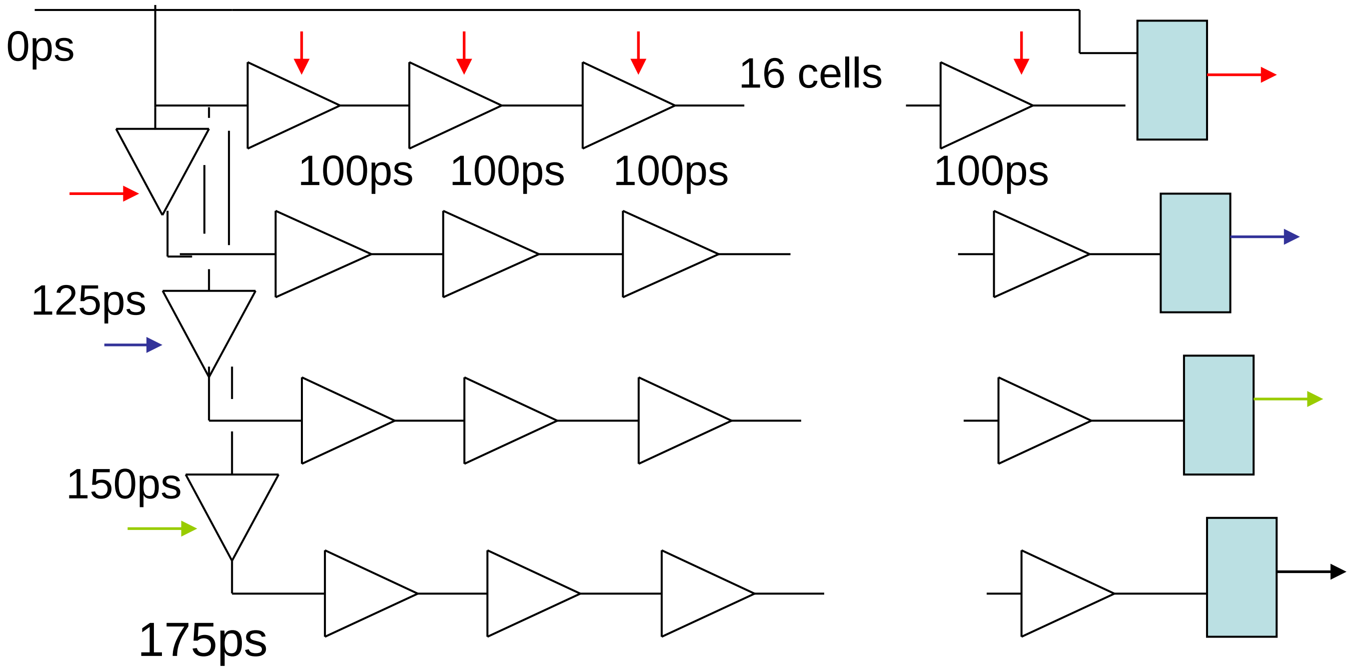
- Sampling frequency
- Analog bandwidth
- Analog dynamic range
- Depth
- Readout frequency
- Read/Write

- Existing ASICS have limited bandwidth

130nm CMOS technology would allow
>1.5GHz bandwidth, 10-50 GS/s sampling rate
Timing resolutions of 2-3ps

40 GS/s Timing generator

640 MHz clock in



16 x 4 = 64 cells, 25ps step delays

Design by Fukun Tang (U-Chicago)

Conclusion

Sampling electronics and waveform analysis for large-area fast detectors such as Micro-channel Plate should achieve :

- 2-10ps timing (electronics)
- 2 dimension position sensing with 100μm-1mm precision

Extra slides

Best position

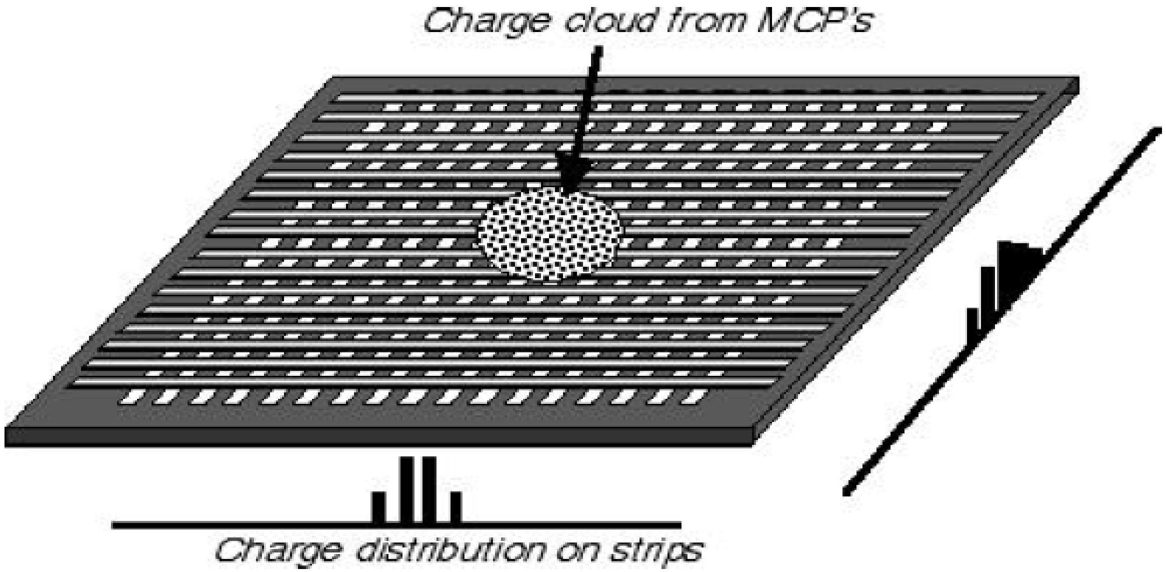


Figure 1. Schematic of the cross strip anode showing the MCP charge cloud, and charge distribution on the cross strips.

A few microns position resolution

From O. Siegmund, A. Tremsin (LBL)