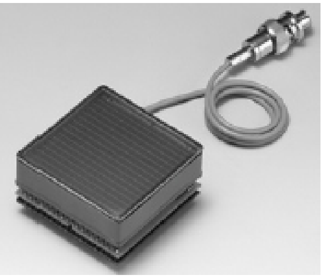
Picosecond Timing with Micro-Channel Plate Detectors

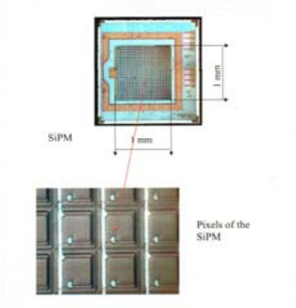
Jean-Francois Genat

Fast Timing Workshop
Lyon, Oct 15th 2008

Fast Timing Devices

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



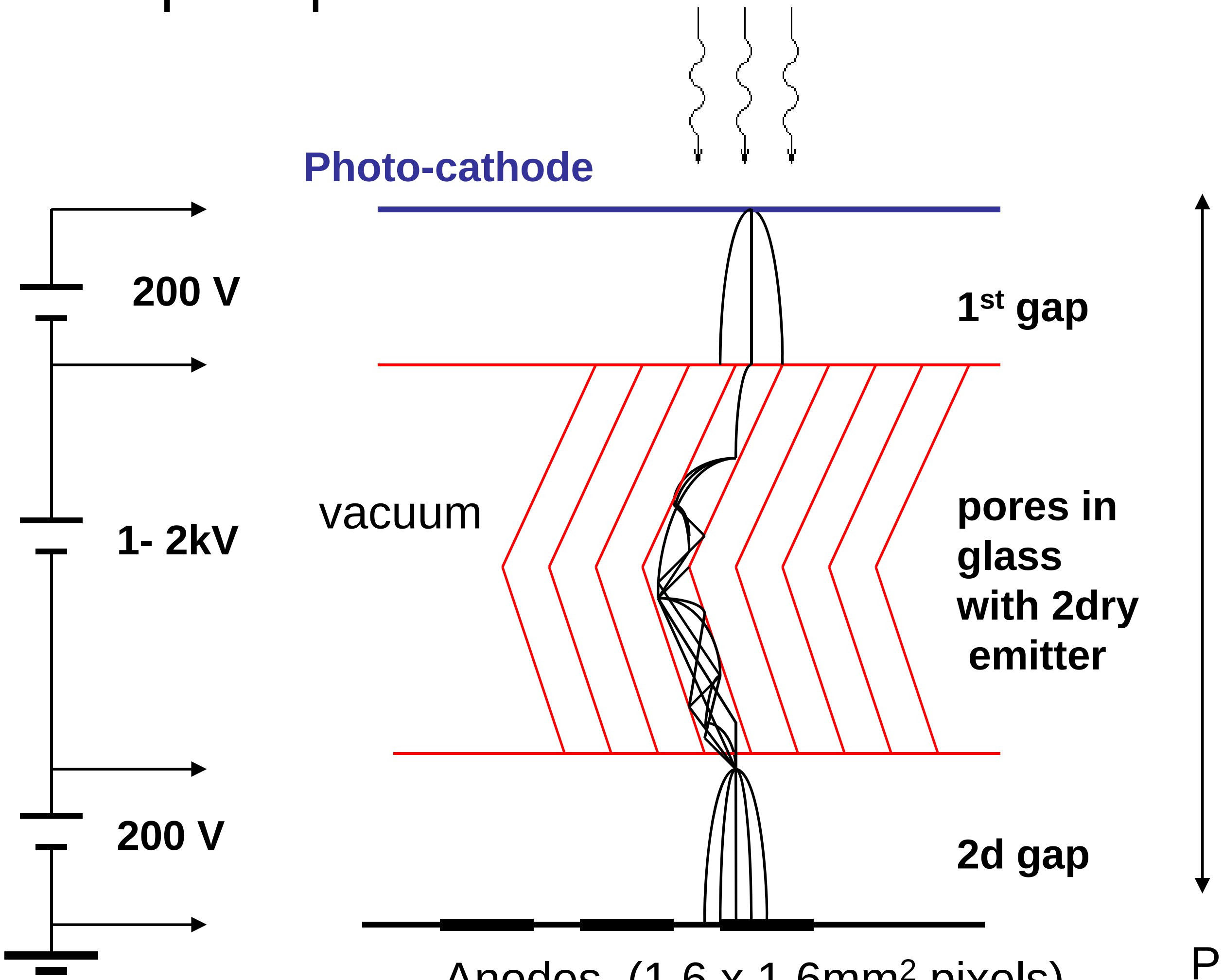


	Multi-anodes PMTs	Si-PMTs	MCPs
QE	30%	90%	30%
CE	90%		70%
Rise-time	0.5-1ns	250ps	60-200ps
TTS (1PE)	150ps	100ps	20-30ps
Pixel size	2x2mm^2	50x50μm^2	1.5x1.5mm^2
Dark counts	1-10Hz	1-10MHz/pixel	1-10 kHz/cm^2
Dead time	5ns	100-500ns	1μs
Magnetic field	no	yes	15kG
Radiation hardness		1kRad=noisex10	
Lifetime	-	?	~ Coulomb total charge

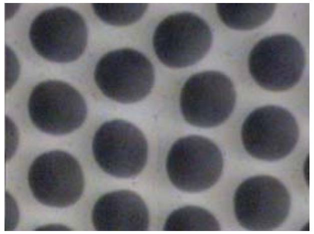
- Micro Channel Plate Detectors
- MCP Signals
- Fast Timing
- Integrated Electronics for fast Timing
- Conclusion

Micro-Channel Plate Detectors

Basic principle

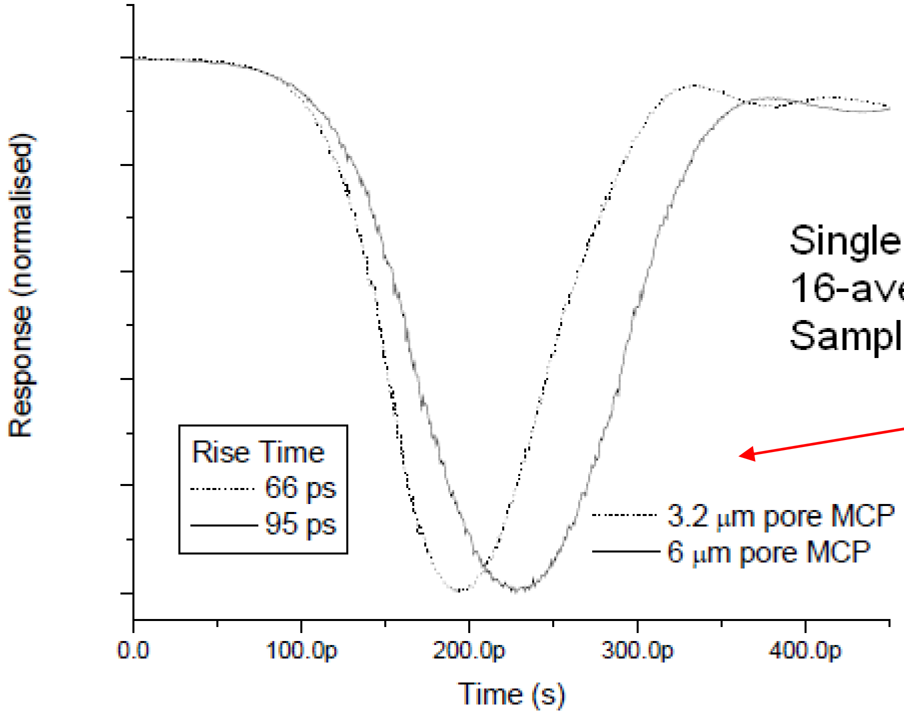


Anodes (1.6 x 1.6mm^2 pixels)



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

Micro-Channel Plate Detectors



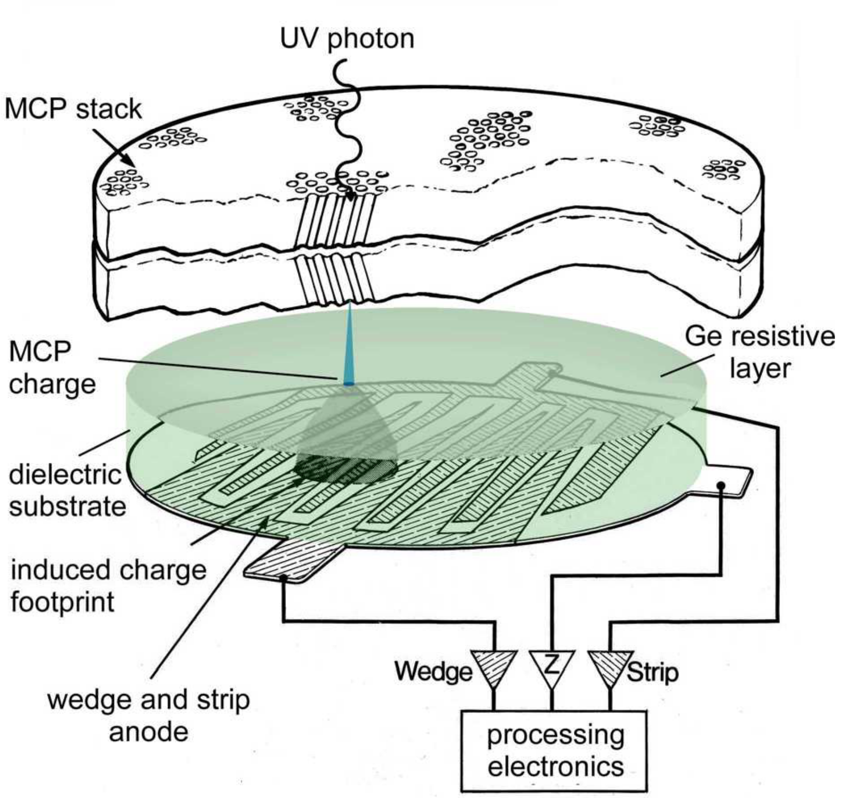
Time response curves for two models of PMT110 with different MCP pore diameters.

Single Photon
16-averaged
Sampling: 18 GS/s

From Photek

The fastest photo-detector to date

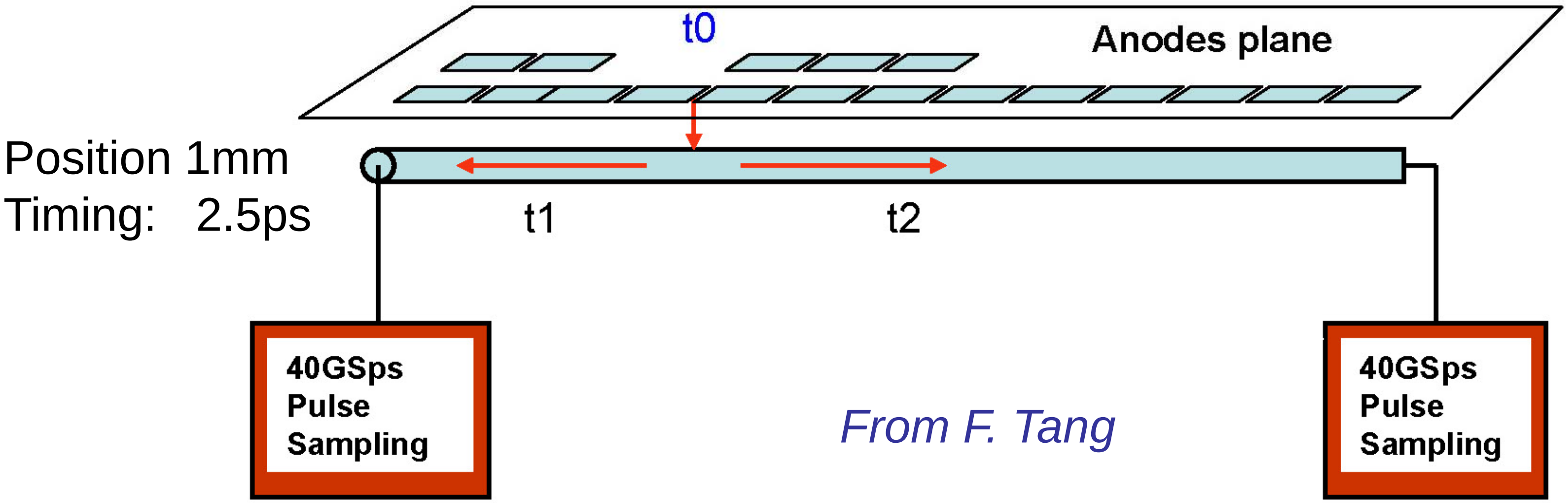
Imaging MCP: Image Charge Technique



- Stable charge footprint distribution on the readout
- No partition noise – caused by quantisation of charge
- No image degradation due to secondary electron effects
- Substrate provides electrical isolation
- Can always operate anode at ground – lower noise
- Intensifier or flange mounted detector - can use external readout
- Readouts easily interchanged

Timing ~ 1ns !

MCP for Timing and position: Transmission Line Readout



From F. Tang

Timing: $t_0 = \frac{t_1 + t_2}{2}$

Position: $x_i = \frac{t_1 - t_2}{t_1 + t_2}$

Energy: $E_i = q_1 + q_2$

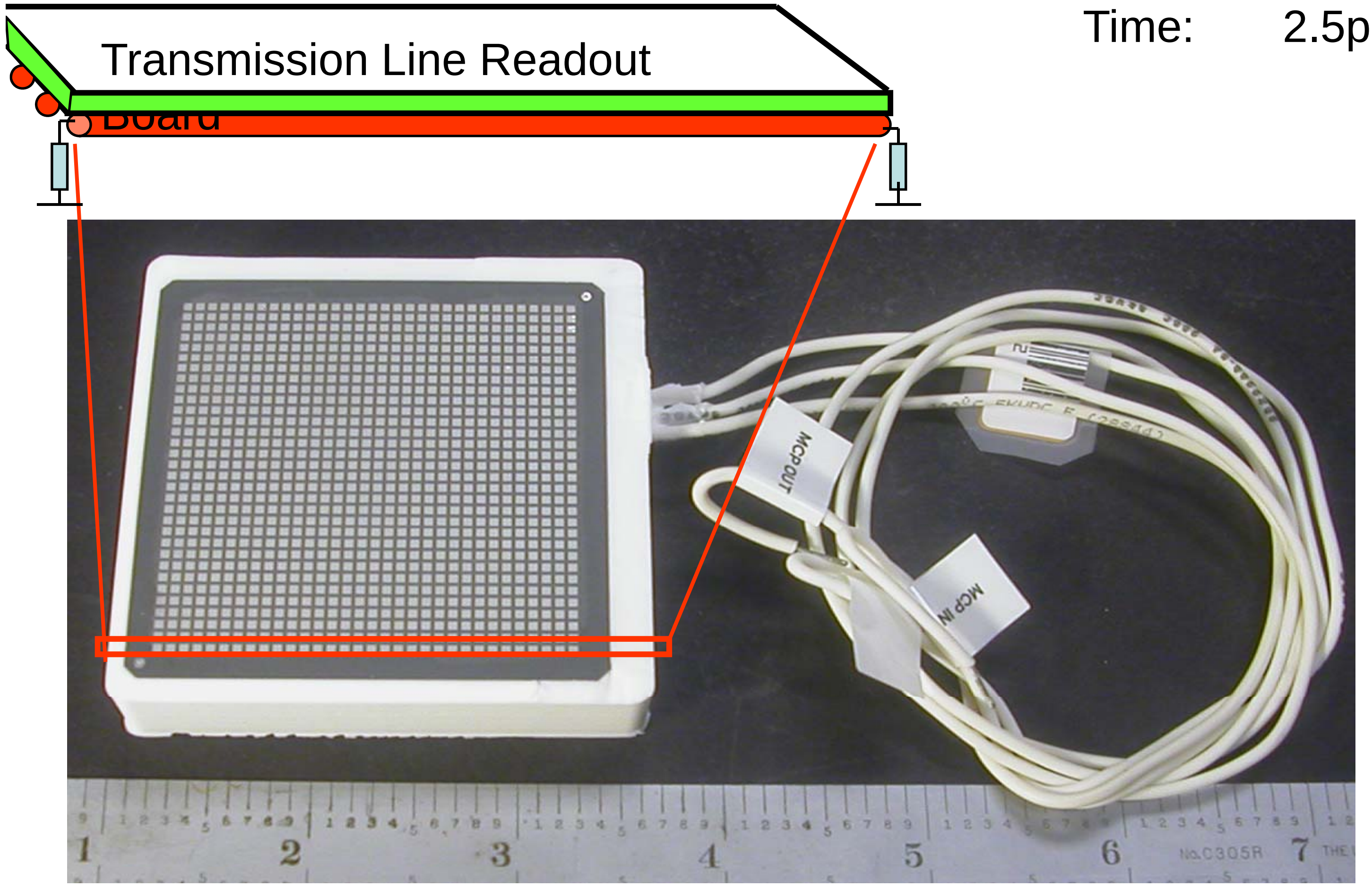
Less readout channels
1024 down to 64 channels

Timing, position and energy information
Full pulse information

Wide transmission-line bandwidth
up to 3.5GHz

Can be serialized for large area detectors

Transmission Line Readout



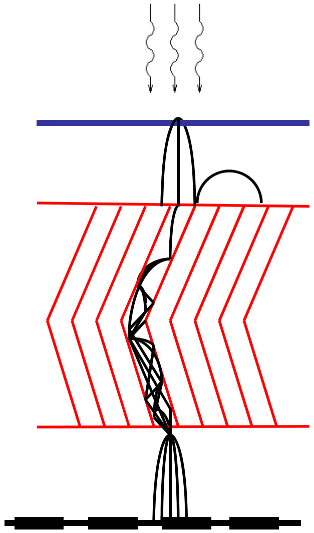
Position: 1 mm resolution
Time: 2.5ps

From F. Tang

MCP characteristics

Quantum efficiency	Photo-cathode, pores geometry, field
Charge gain	Pores properties, pores walls material, field
Dark counts	Photo-cathode, pores properties
Transit time (rise time)	All dimensions,recoil electrons
Ringing	Pores geometry, (chevron, curved)
After-pulses	“
Dead-time	“
Lifetime	Total charge (Coulombs):
	gain in electronics ?

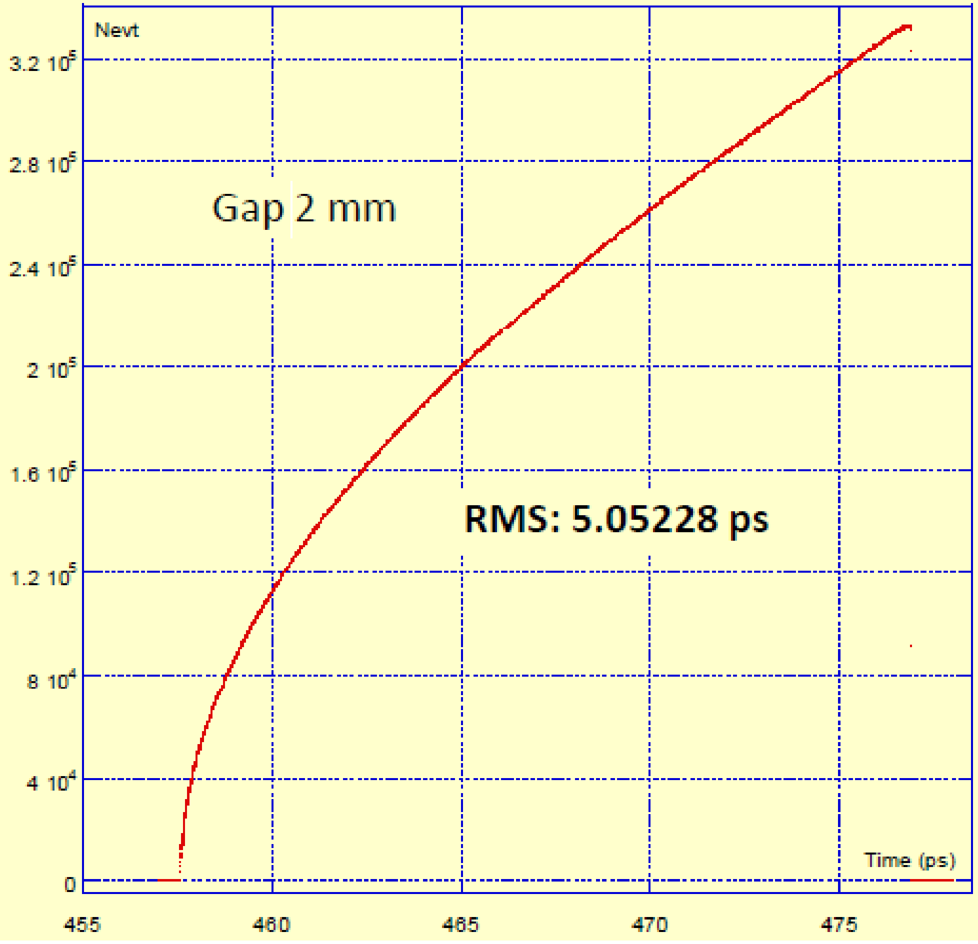
Time resolution: Transit Time Spread (TTS)



MCP Device Simulations

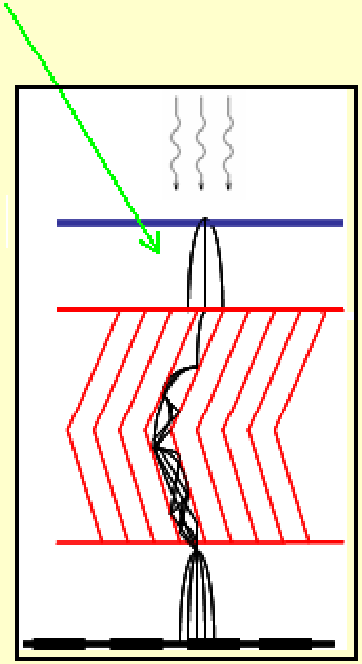
Monte-Carlo: 10^6 single photoelectrons events
Simulation of the first gap: photocathode - pores input

Angular distribution: asin { rand [-1,+1] }



Gap 2 mm

RMS: 5.05228 ps



5ps contribution to TTS

Lionel de Sa

Pores simulations: David Yu

- Micro Channel Plate Detectors
- MCP Signals
- Fast Timing
- Integrated Electronics for fast Timing
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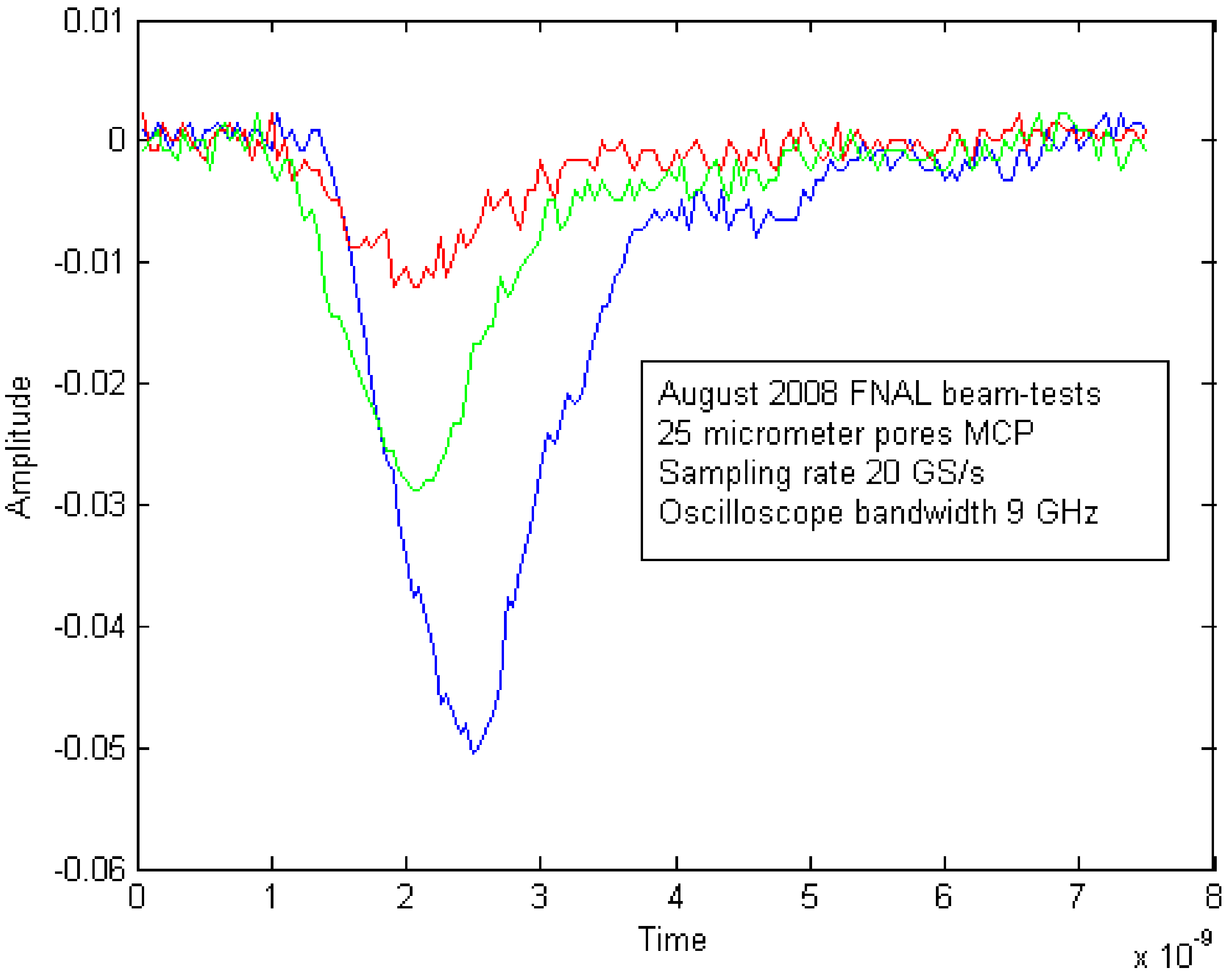
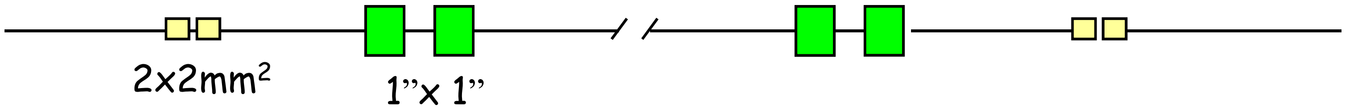
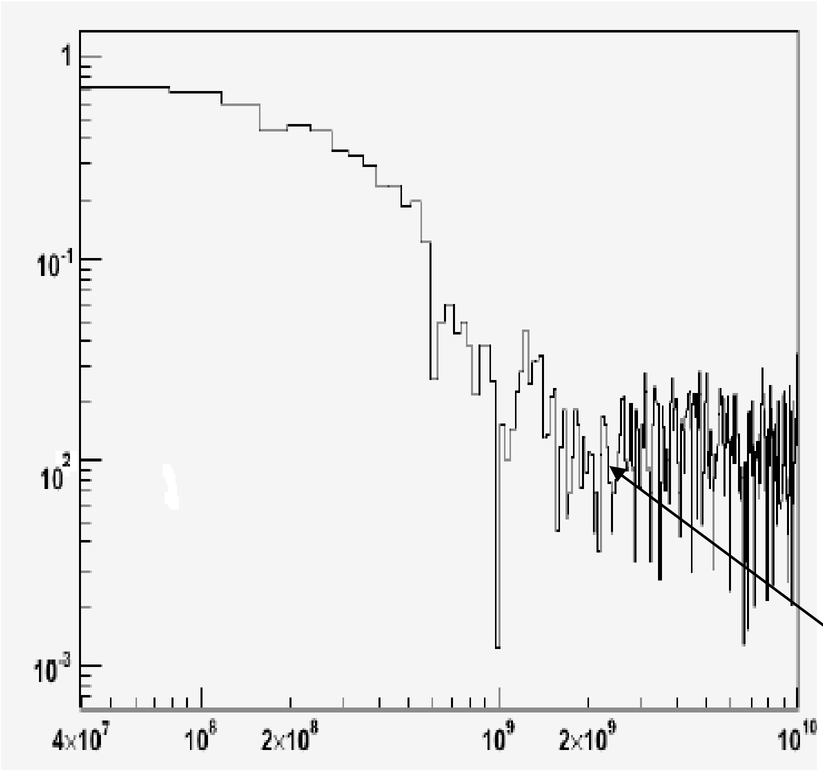
Measured MCP Signals

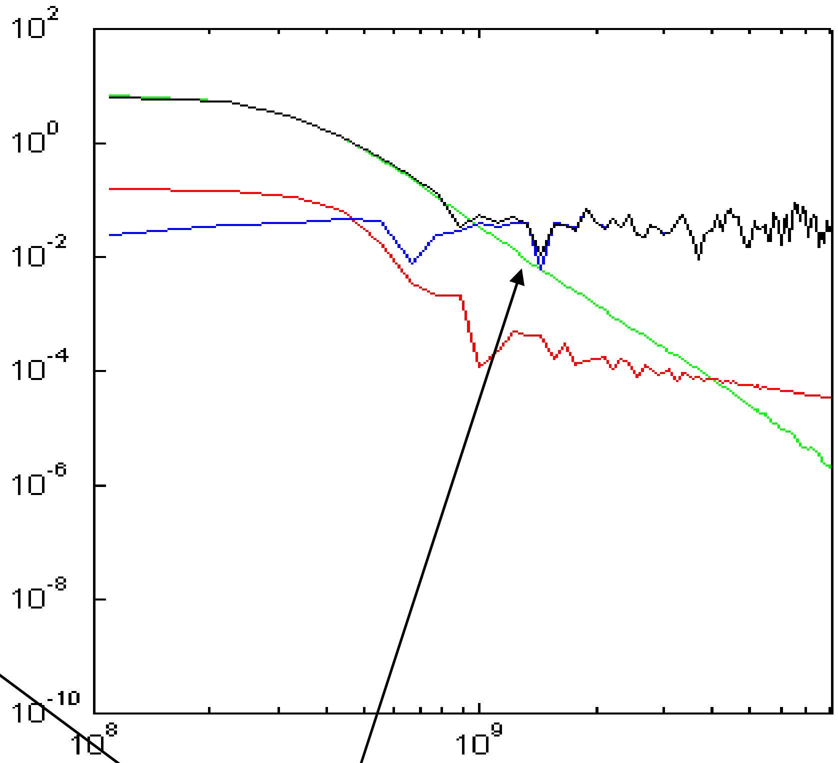


2” x 2” MCP, 64 anodes, one single pad

Beam-Tests: MCP Signals spectra







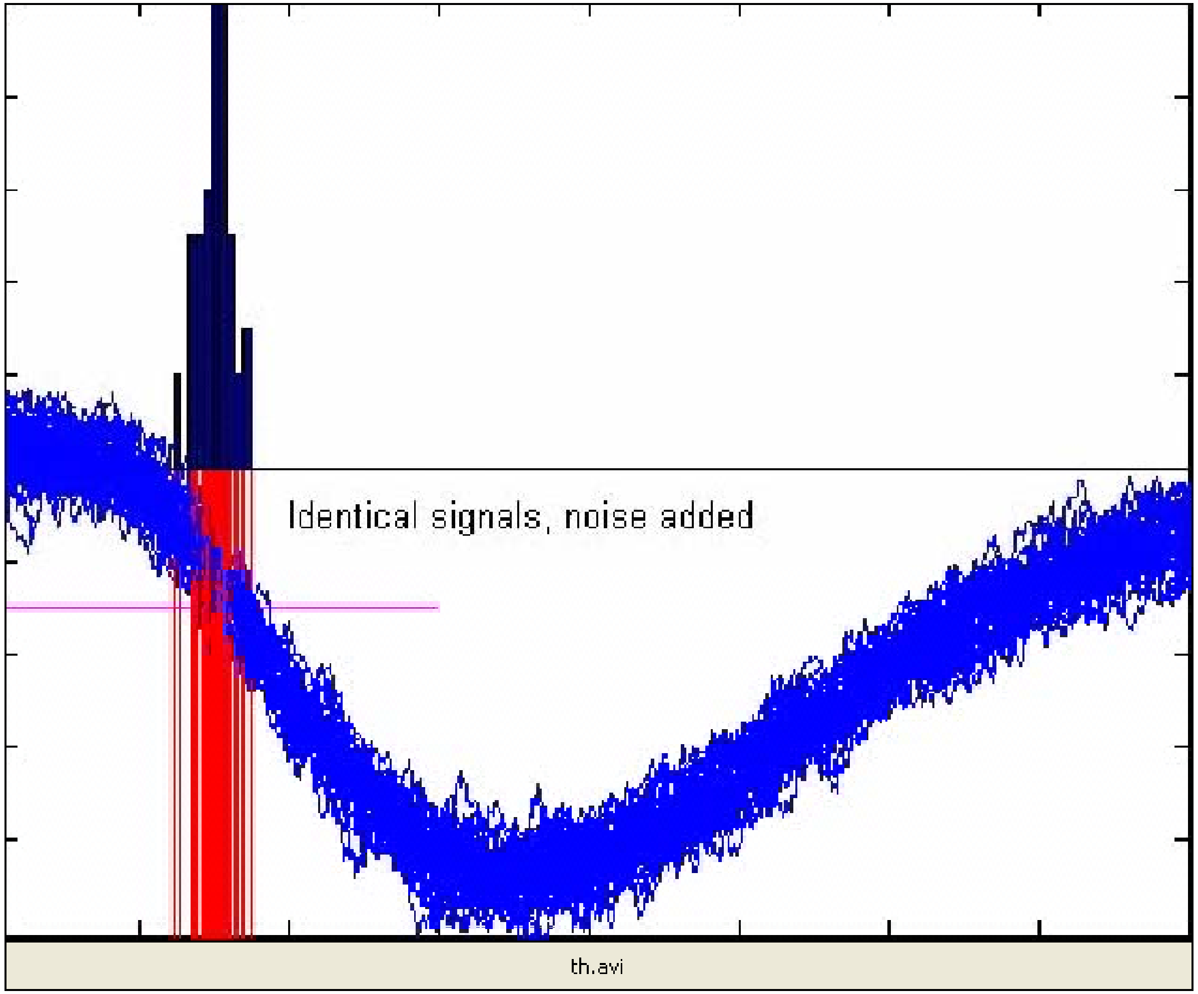
Measured (FNAL MTBF T979 Beam-Tests)

Simulated

Same noise corner at 1.2 GHz

- Micro Channel Plate Detectors
- MCP Signals
- Fast Timing with MCPs
- Integrated Electronics for fast Timing
- Conclusion

Timing



Time spread proportional to rise-time and noise

Fast timing with MCPs

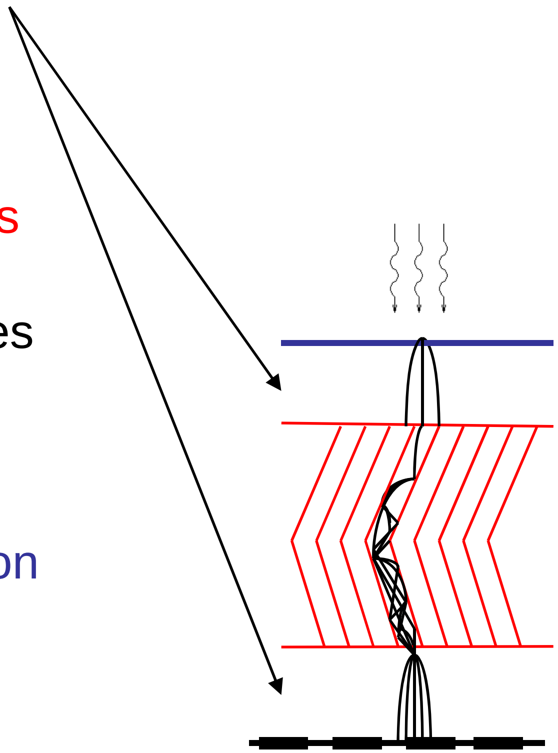
MCP level: Dimensions critical

Reduce primary and secondary gaps

- Transit time reduced

Electronics level: Avoid parasitic readout components

- Parallel capacitances
- Series inductances

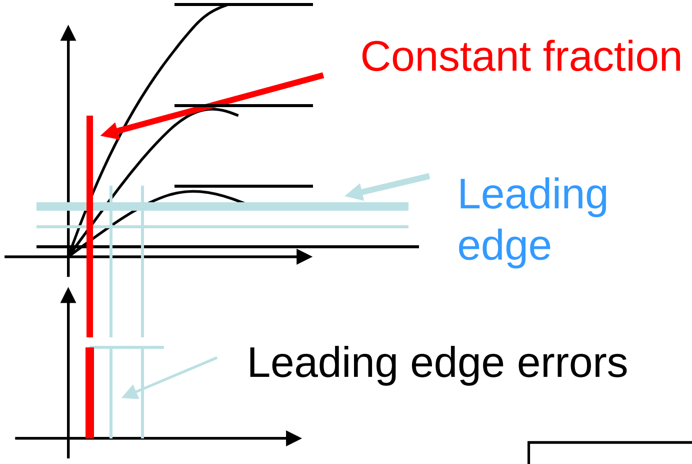


Reduce Rise-time, consequently improve Time resolution

Jean-Francois Genat, Fast Timing Workshop, Lyon, Oct 15th 2008

Advanced Timing techniques

Constant-fraction

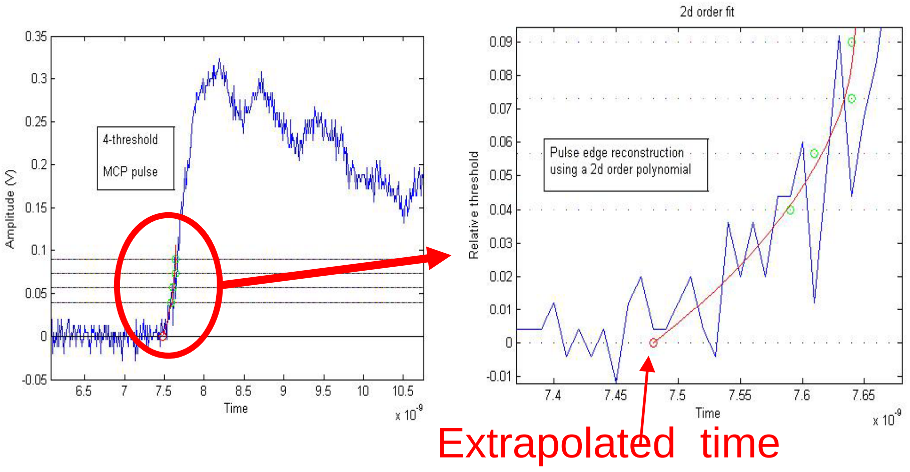


Constant fraction

Leading edge

Leading edge errors

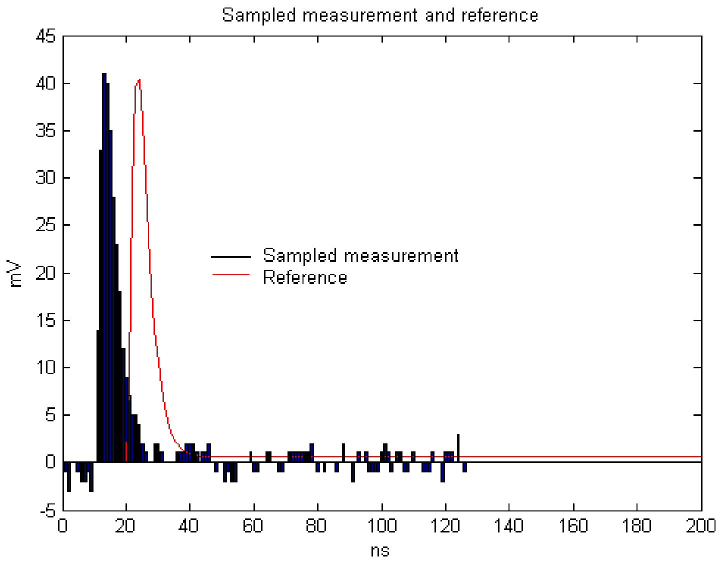
Multi-threshold



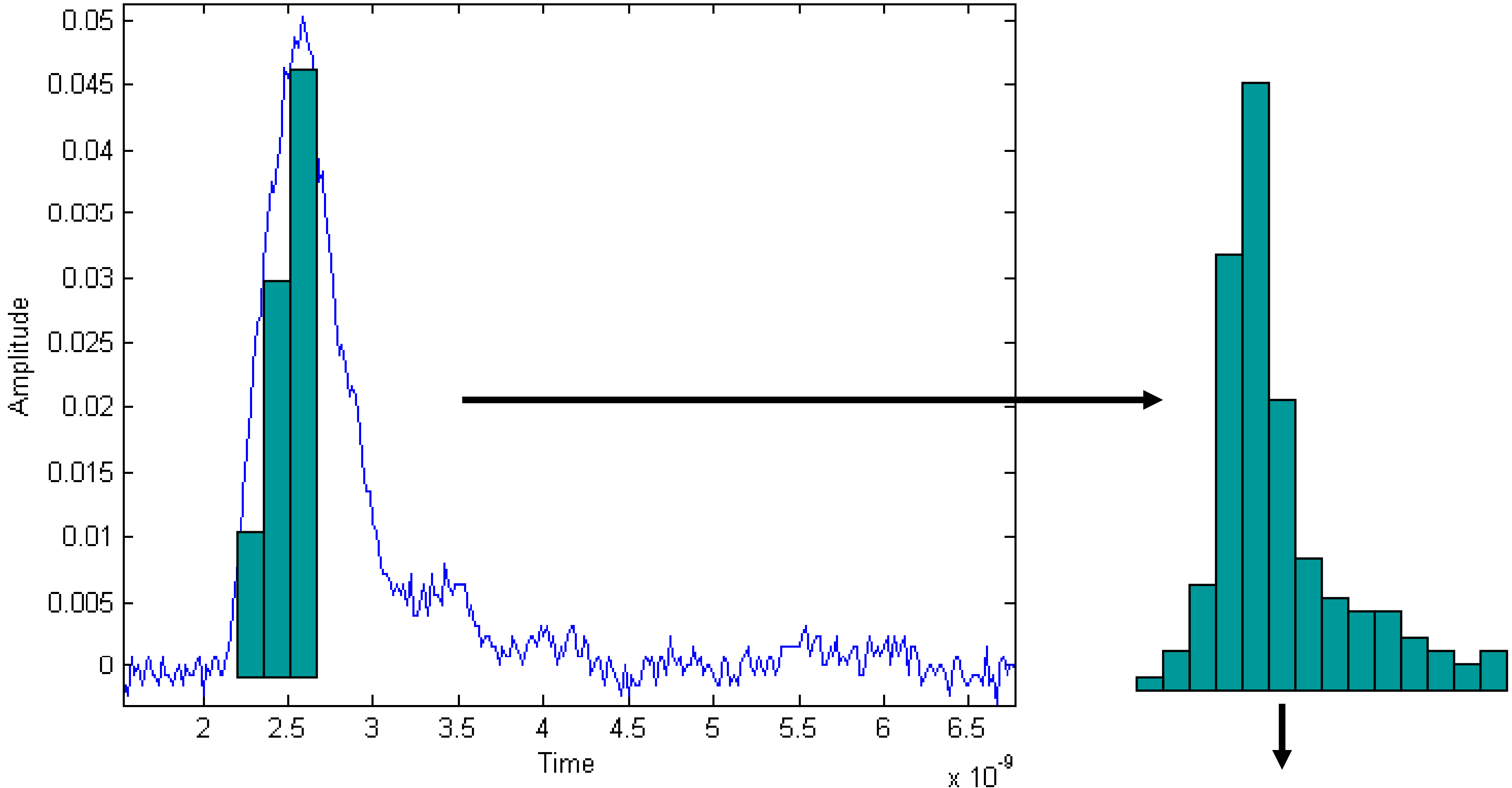
Extrapolated time

Pulse sampling and Waveform analysis

Sample, digitize,
Fit to the known waveform



Pulse Sampling

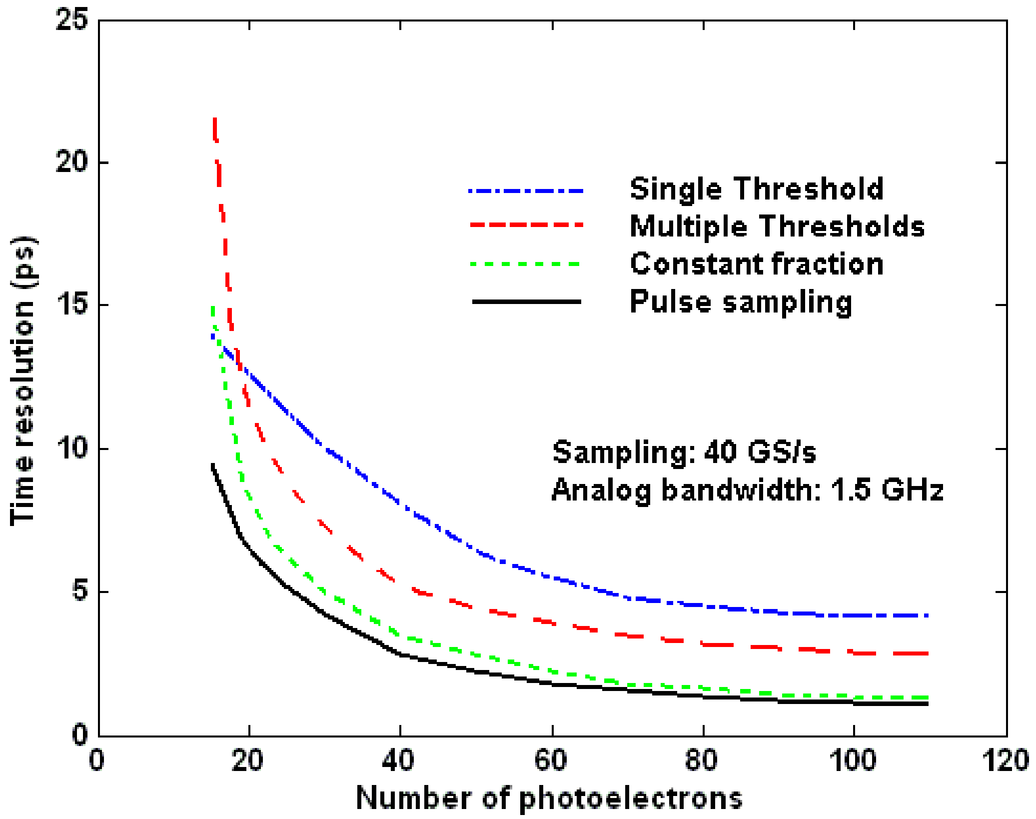


Sampling period = 200 ps

2 12 25 80 128 50 32 …

Timing

Methods compared
Matlab simulations (cpp by David Salek)



Monte-Carlo:
300 synthesized events

Time resolution vs Number of photo-electrons

Beam Tests Check

Run the same algorithm using actual MCP beam-tests data taken at the FNAL T979 Meson Beam-Tests Facility

Beam tests conditions:

- 350 MHz analog bandwidth
- 20 GS/s sampling
- 8-bit
- ~ 10 photo-electrons (?)
- 25 µm pores Photonis MCPs 2”x 2”

Simulation with synthesized data: 34ps

With measurement data: 40ps

Fast Timing Electronics for MCPs

				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	6.4ps
	Orsay/Saclay	- SAM line	3.2GS/s		25ps
	PSI	- DRS line	5GS/s		3ps ?

Under development:

- 40 GS/s, multi-GHz range analog bandwidth sampling chip

Chicago + Hawaii + Orsay/Saclay
Reviews by PSI

Timing with Sampling

Critical parameters:

Detector

- Signal dynamics (NPE, Rise-time, TTS)
- Signal/noise ratio

Sampling device

- Analog bandwidth
- Sampling rate
- Clock jitter
- ADC resolution
- Trigger modes

- Micro Channel Plate Detectors
- MCP Signals
- Fast Timing
- Integrated Electronics for fast Timing
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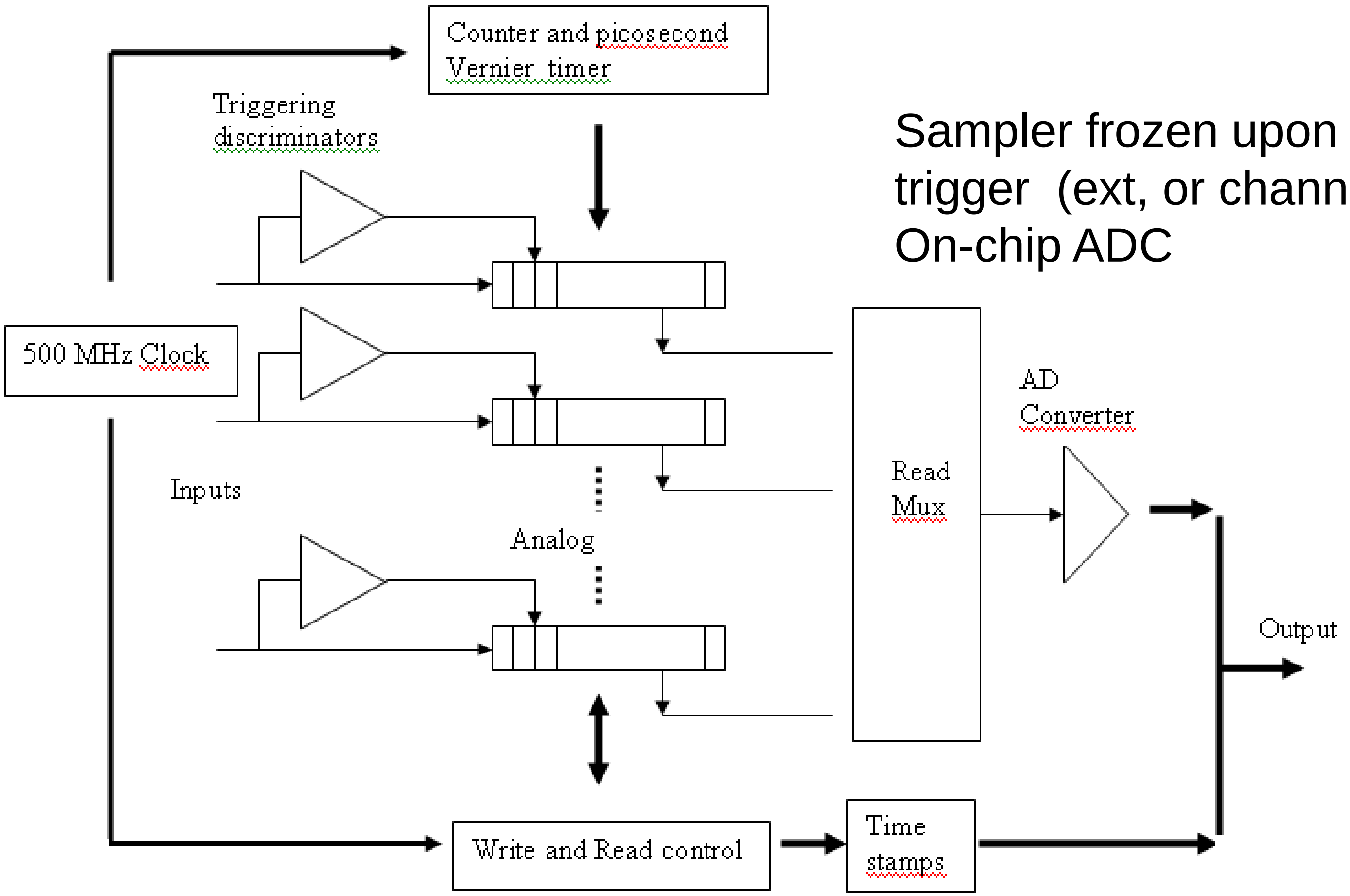
Fast sampling ASIC architecture



Sampler frozen upon input
trigger (ext, or channel)
On-chip ADC

Foreseen technology: CMOS IBM 130nm

Jean-Francois Genat, Fast Timing Workshop, Lyon, Oct 15th 2008

Fast Sampling ASIC

Technology

IBM 8RF DM 130nm CMOS
Design kit from CERN

Key numbers

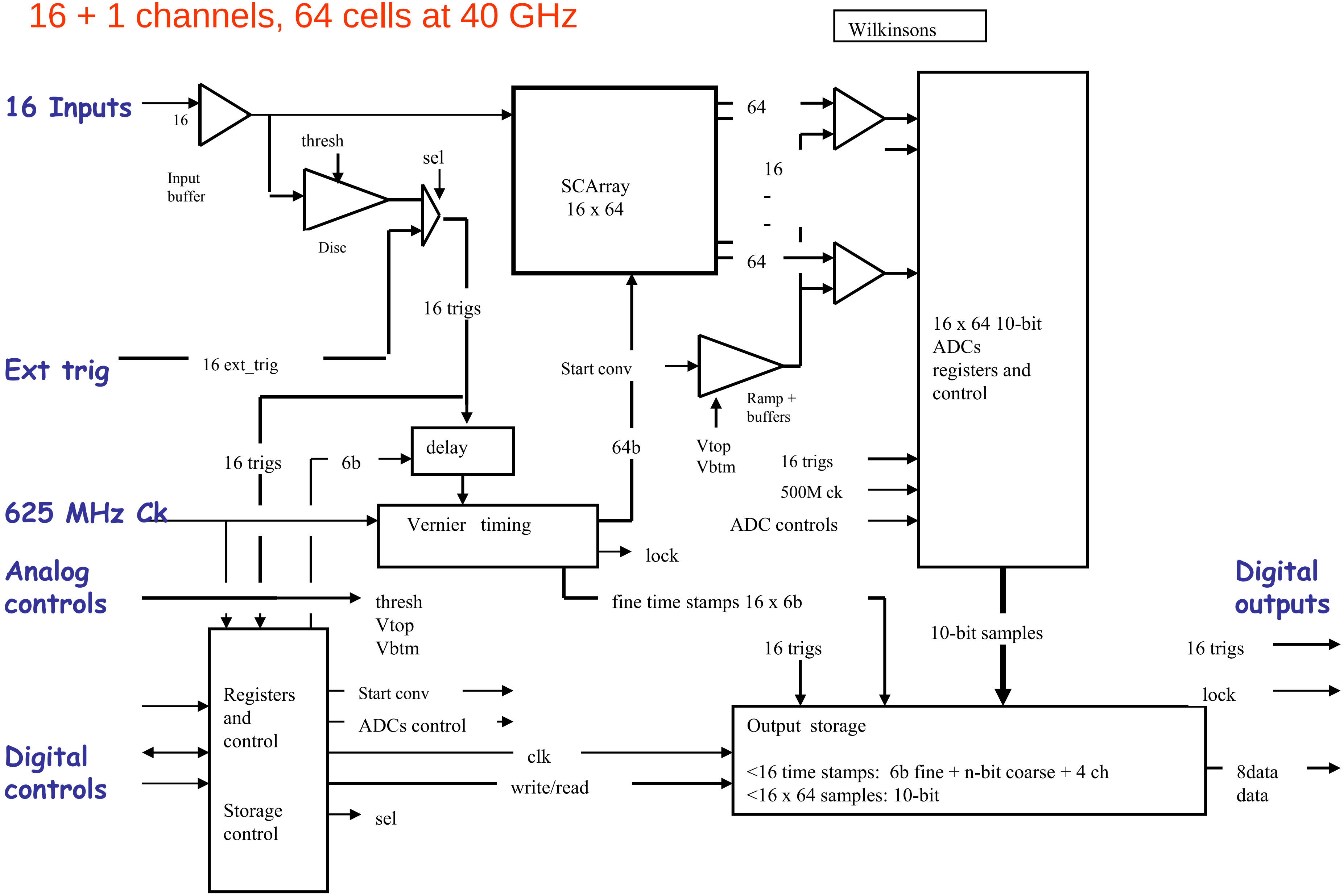
40 GS/s sampling
1.5 GHz analog bandwidth
Gain
Depth 64-128
8 -10 bit ADCs
Self/Global trigger
Time stamp

Blocks:

Input buffer
Discriminator
Delay generator (optional PLL)
Clock buffer
Switched capacitors array
ADC
Control

Fast Sampling ASIC Details

16 + 1 channels, 64 cells at 40 GHz



Wilkinsons

16 Inputs

16

Input
buffer

thresh

Disc

sel

SCArray
16 x 64

64

16
-
-

64

16 x 64 10-bit
ADCs
registers and
control

16 trigs

Ext trig

16 ext_trig

Start conv

Ramp +
buffers

Vtop
Vbtm

16 trigs

6b

delay

64b

16 trigs

500M ck

625 MHz Ck

Vernier timing

ADC controls

lock

Analog
controls

thresh
Vtop
Vbtm

fine time stamps 16 x 6b

10-bit samples

Digital
outputs

16 trigs

16 trigs

lock

Registers
and
control

Start conv

ADCs control

Digital
controls

clk

write/read

Output storage

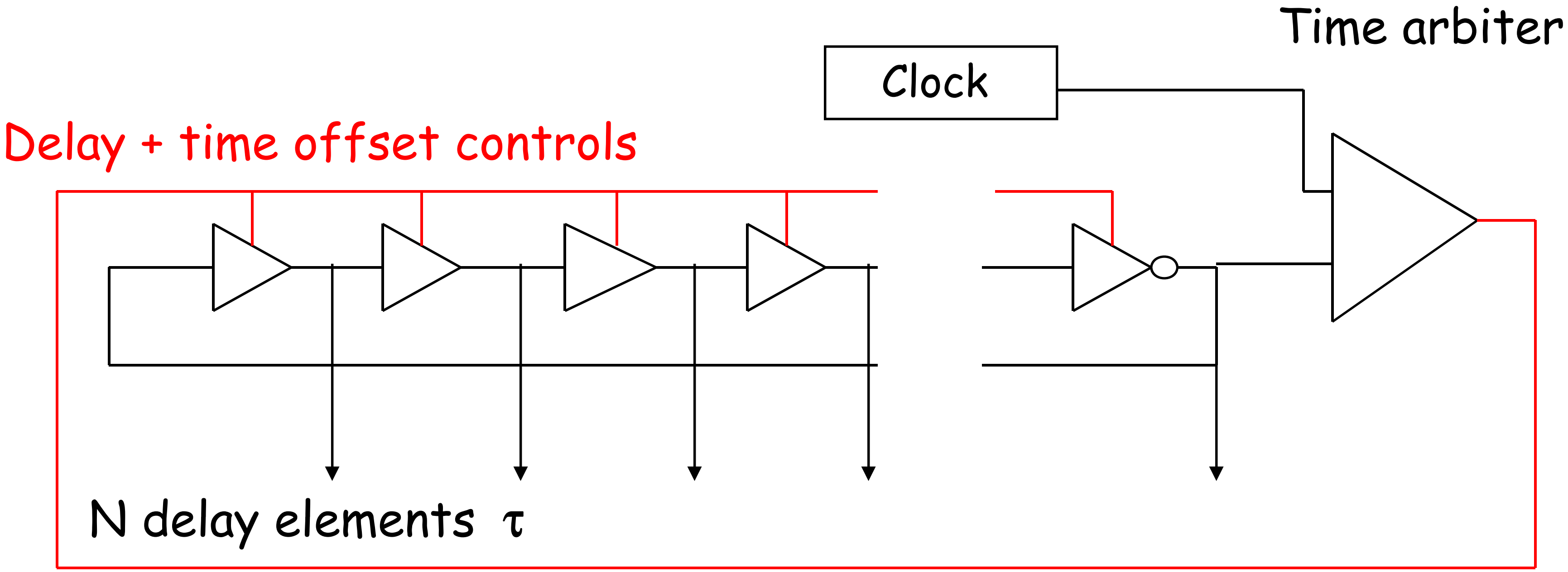
<16 time stamps: 6b fine + n-bit coarse + 4 ch
<16 x 64 samples: 10-bit

8data
data

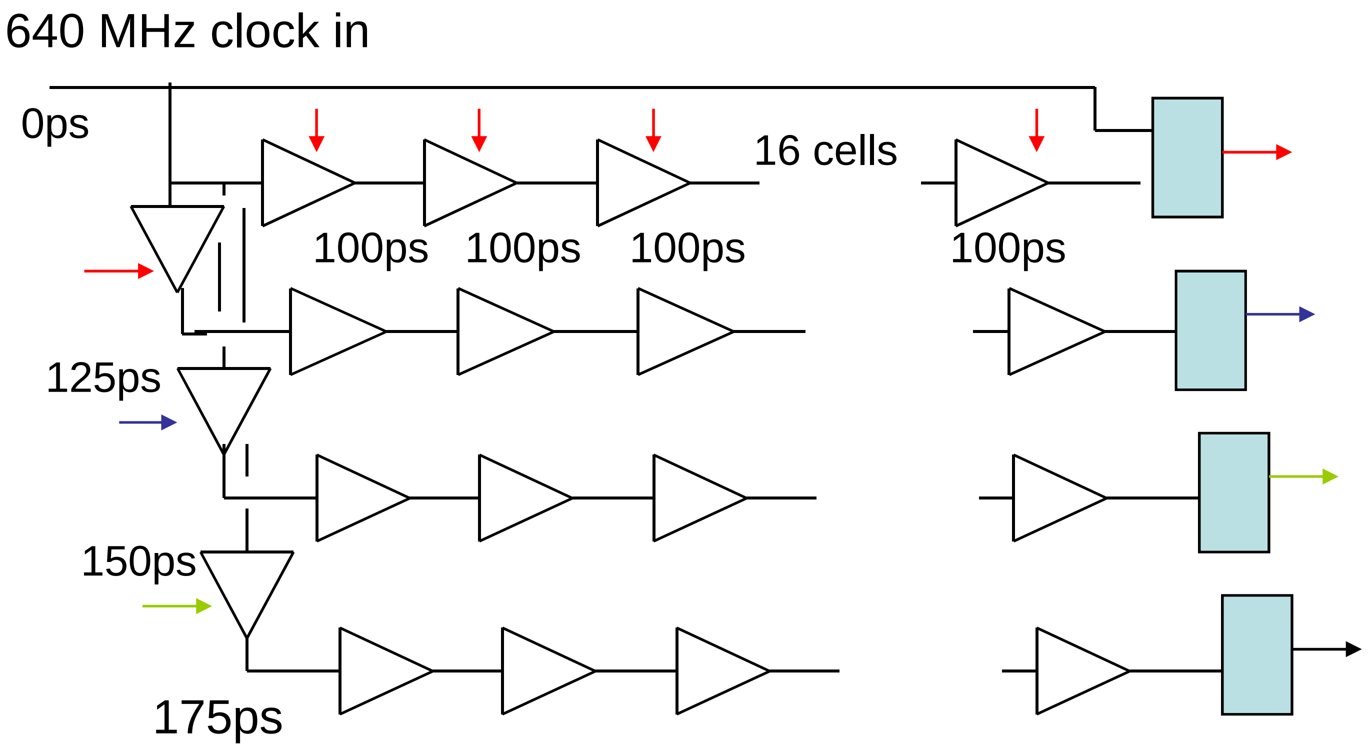
Storage
control

sel

Delay Locked Loop



40 GS/s Timing generator



16 x 4 = 64 cells,   25ps step delays

Physical Layout critical

MCPs electronics plans at EDG Chicago

Fast sampling chip plans:

- Year 1

    2-channel chip @ 40 GHz
    Check with one delay-line channel

- Year 2

    Implement 16-channels to read a full 1024-anode MCP

- IBM 130nm CMOS design kit running on Sun workstations

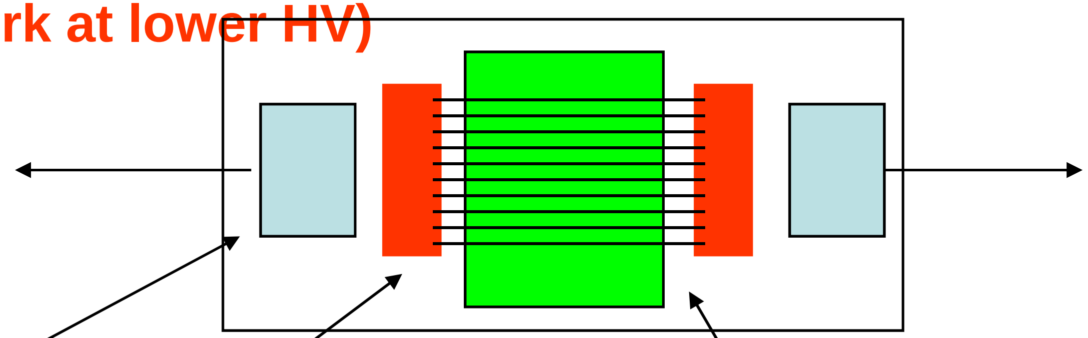
- Hawaii, Orsay and Saclay are joining

- Micro Channel Plate Detectors
- MCP Signals
- Fast Timing
- Integrated Electronics for fast Timing
- Conclusion

MCPs Readout for 220m AFP

- **Use self-trigger mode and time stamp**
- **Digitize/process on L1 data in time with L1**
- **4 protons/BCO: 4 x 2.5µs / 25ns = 400evts to buffer / L1 latency**

Caveat:
- **radiation hardness**
- **lifetime (work at lower HV)**



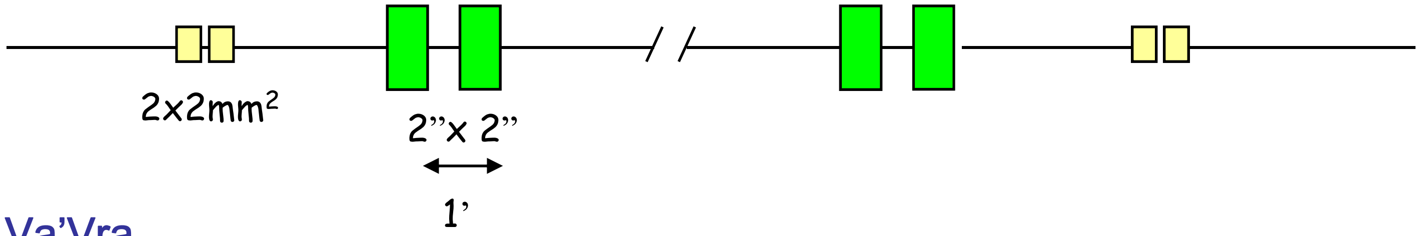
TTC device (or GBT)

MCP

- **40 GHz Sampling**
- **32-channel x 512-evts x 256-samples analog buffer**
- **Wilkinson ADCs**
- **DSP**

Transmission lines PCB

MCP MTest T979 (FNAL) Beam-Tests Results



Jerry Va’Vra
Erik Ramberg
Tyler Natoli
Henry Frisch
Ed May + …

25 μm Burle/Photonis	**2” x 2”**	1.3-13.9 ps	23 PE (?)
10 μm Burle/Photonis	2” x 2”	14.2-12.4 ps	35 PE (?)
5-6 μm Photek	1cm^2	7.4-8.8 ps	16 PE (?)

- 5.6-10mm quartz radiator
- Electronics **noise** (CFD + TAC + ADC) : 6.5 ps (subtracted)

Anatoly Ronzhin

Silicon PMs: 47 ps

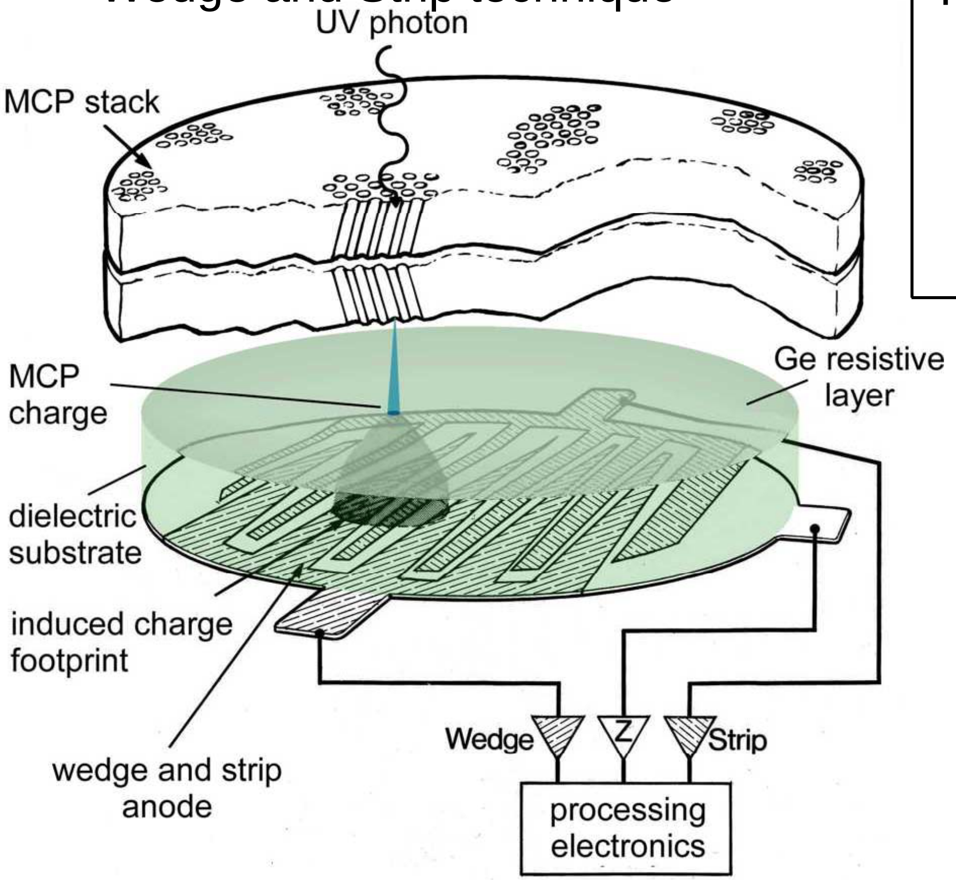
the end…

Extra slides

Imaging Micro-Channel Plates Detectors

As an
Imaging device…

Wedge and Strip technique

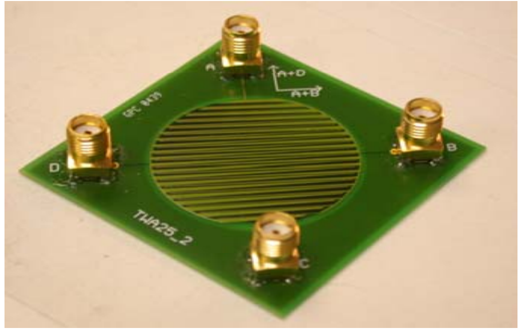


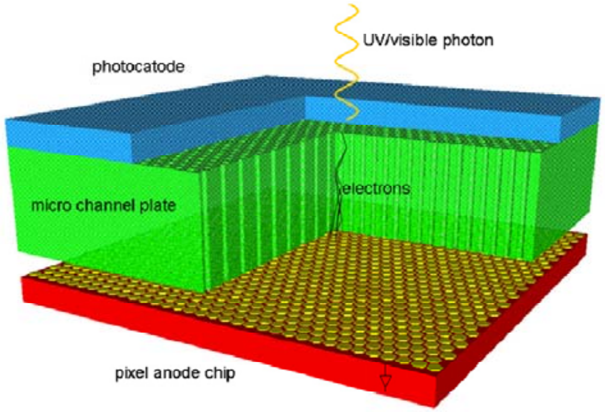
From J. Lapington, for WSO, Uni. Leicester, UK

Coupling to Board

Position: 10μm resolution

Time: 1ns



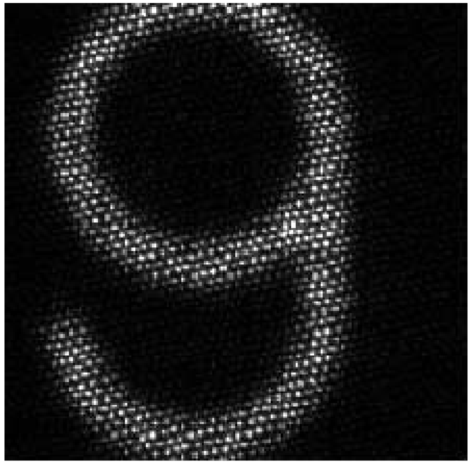


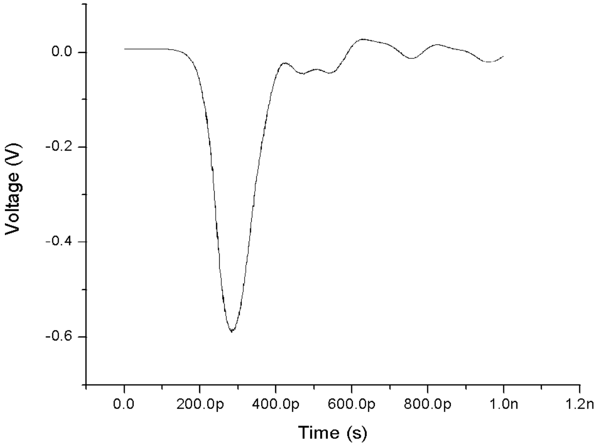
Coupling to ASIC: 3 μm

From GLAST, Bellazini et al…
NIM 591 2008

MCP characteristics

- Spatial resolution
  - Fundamentally limited by MCP pore geometry
  - Pore diameters as low as 2 µm
  - 2 µm resolution requires centroiding!
- Temporal resolution
  - Small pores
    - Smaller geometry
    - Faster pulses
    - $\tau = 66$ ps, FWHM = 110 ps
    - Multiple MCPs, pulse saturation slows risetime
- Noise
  - Background
    - Typically <1.0 cm-2 s-1
  - Low noise glass
    - Reduced Potassium-40 decay
    - Low noise glass <0.1 cm-2 s-1
- Lifetime
  - Dependent on extracted charge
  - Gain plateau from 0.1C/cm^2 to 1C/cm^2
    - Equivalent to ~10^{13} events/cm^2

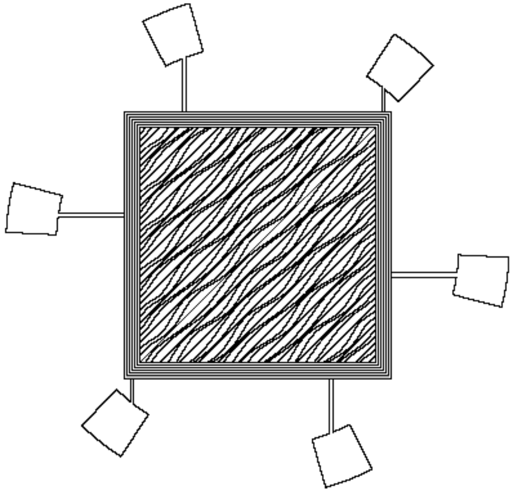


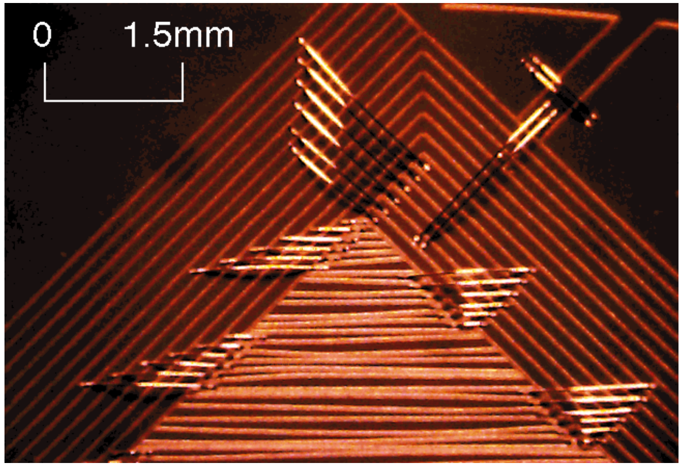


Readout comparison

	Vernier Anode	**Intensified CCD**	**Intensified APS**	**Delay line**	**Parallel strips – interpolated position**	**Discrete pixel array**	**Medipix2**
Image Format	30×20 mm (flexible)	25 mm Ø	25 mm Ø	Up to 100×100 mm	Currently 45×45 mm (Cross-Strip)	32×32	256×256
Pixel Format (resolution elements)	3000×2000	2048×2048	>2k×2k	3000×3000	Currently 5k×5k (up to 10k×10k - Cross-Strip)	32×32	256×256
Number of channels	9	256×256 (CCD pixels)	256×256 (APS pixels)	4	128/axis (2D parallel strip) 2/mm/axis (Cross-strip)	1024	64k
Readout Resolution (FWHM)	10 µm	<10 µm	MCP limited	30 µm	MCP limited	0.5 mm	55 µm
Dynamic range							
Global	1×10^5	2×10^5	400 kHz >1MHz (goal)	> 1MHz	>10MHz (2D parallel strip)	MCP limited	266 µs / frame
Local	MCP limited	CCD frame rate	MCP limited	kHZ/pixel	MCP limited	>10 MHz/channel	200 kHz / pixel
Deadtime	10 µs	CCD frame rate	2 µs	400 ns (10 ns inter-event) (Hexanode 0 ns inter-event)	10 ns (2D parallel strip – NINO ASIC)	10 ns	500 ns
Time resolution	~ ns	CCD frame rate limited	2 µs	<100 ps	~10-20 ps (using NINO ASIC)	< 10 ps	266 µs
Digital resolution	12 bit	-	-	13 bit	12 bit (Cross-Strip)	n/a	13 bit counter
MCP gain	1.5×10^7	5×10^5	5×10^5	10^7	~5×10^5 – 2D parallel strip 5×10^6 - Cross-strip	5×10^5	~10^4
Comments	High MCP gain 4 µm electronic noise limited. Flexible format	Can suffer from cyclic nonlinearity due to centroiding errors	Can suffer from cyclic nonlinearity due to centroiding errors	Low channel count but requires high gain, limited parallel capability	High channel count for realistic formats, multiple simultaneous event capability	Event rate MCP limited, crosstalk →double counting, overcome with intelligent readout	Single MCP, low unsaturated gain, thresholding inaccuracies

Vernier Anode – enhanced performance geometric charge division

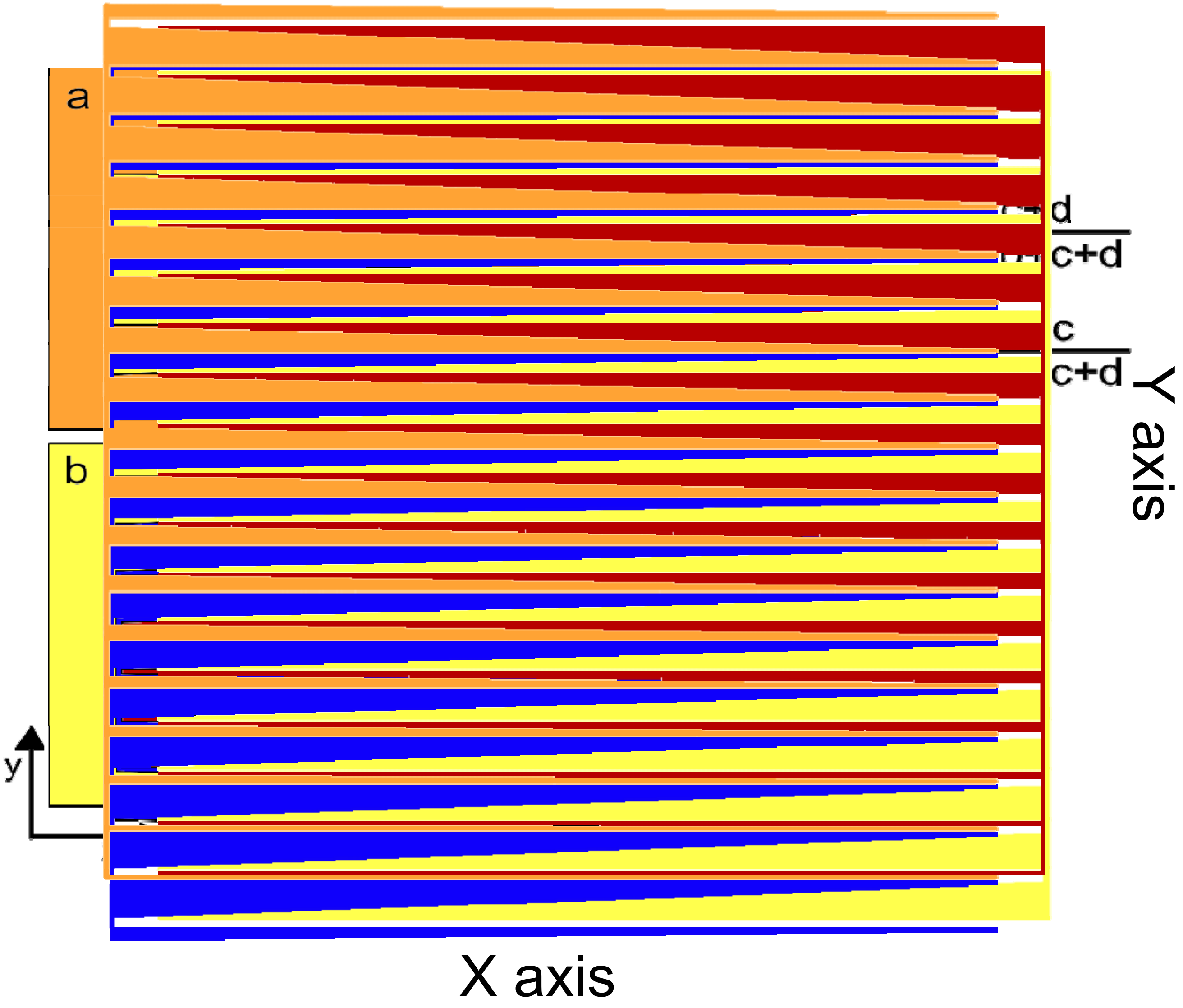




- Geometric charge division using 9 electrodes
- 3 groups of 3 sinusoidal electrodes
- 3 cyclic phase coordinates
- Cyclically varying electrodes allow
  - Determination of a coarse position using a Vernier type technique
  - Spatial resolution greater than charge measurement accuracy
  - The full unique range of the pattern can be utilized
- Typically 3000 x 3000 FWHM pixel format
- Easy to reformat – e.g. 6000 x 1500, etc.
- Up to 200 kHz max. global count rate

Tetra Wedge Anode

PCB Layer 1



Sensitivity to transistor size

- Sampling frequency

- Storage capacitance value	No	(kT/C limited)
- Timing jitter	Yes	

- Input analog bandwidth

- Transistors performance	Yes	
- IO pads ESD protections	Yes	(RF diodes)
- Effective input signal load (R, L, C)	Yes	

- Analogue dynamic range

- Maximum range	Voltage supply	
- Noise	No	(if no 1/f)
- Leakages	Subthreshold	
- Overall precision	Parasitics	