Large Area Picoseconde Photo-multiplier and fast timing electronics

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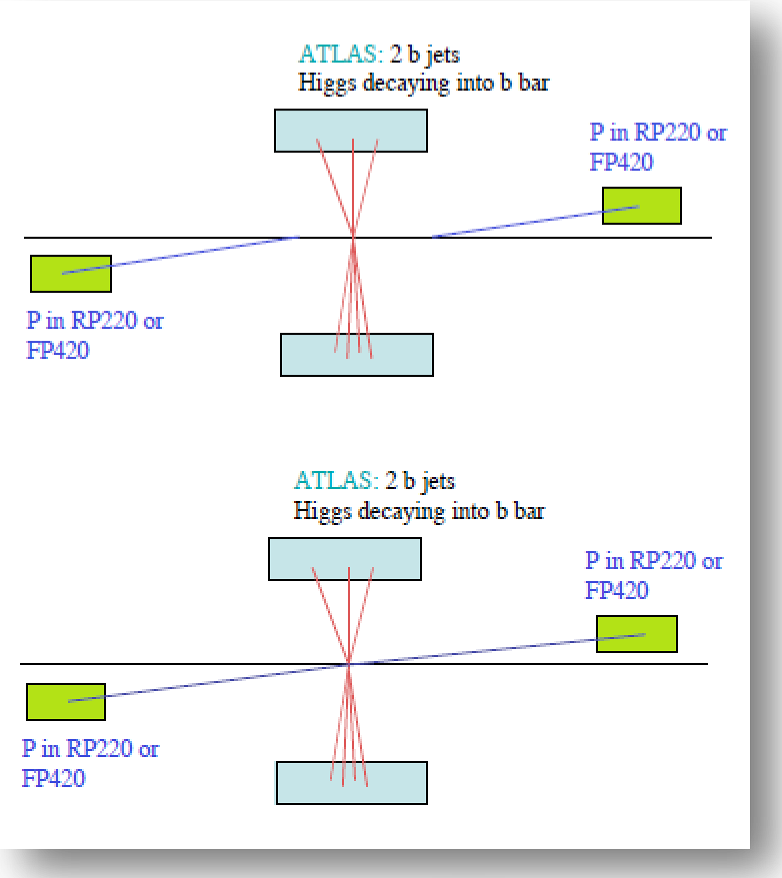
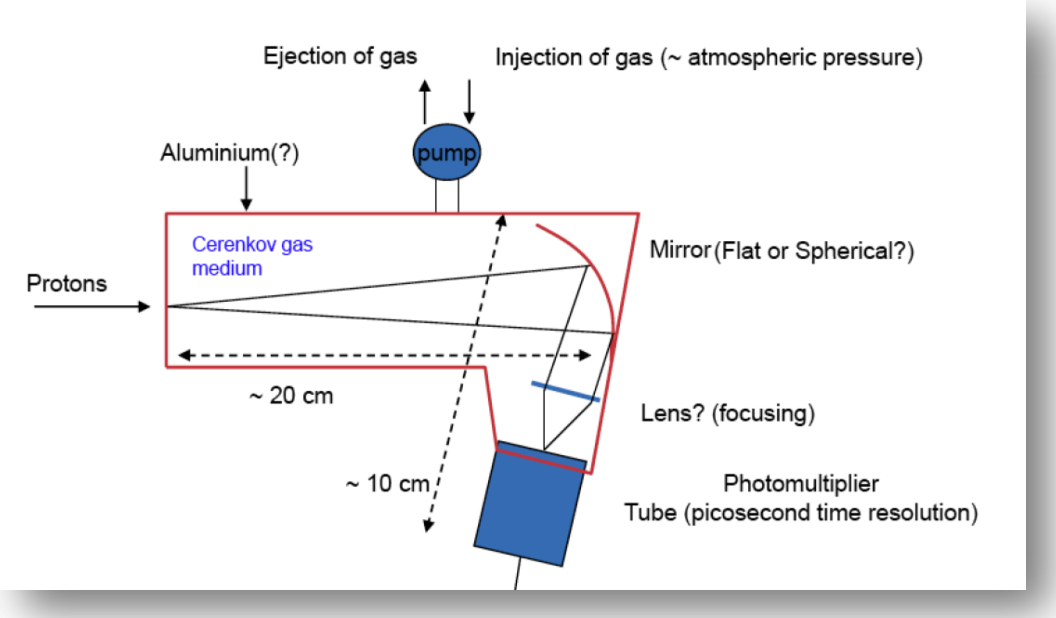
Context: TOF and vertex protons

- In the search for protons coming from the main interaction vertex, the TOF allows to exclude out-of-time protons.
- Gain of a factor 40 over background noise with 10-15ps TOF.



Proton detector

- GasTOF: Protons are converted into photon by the Cerenkov gas medium.
- The photons are then converted to photo-electrons and amplified by an MCP.
- Advantages:
  - Very fast (Cherenkov).
  - Low jitter (ngas ~ 1).
- Drawbacks:
  - Low light (~10PE).
  - Lifetime (40MHz).



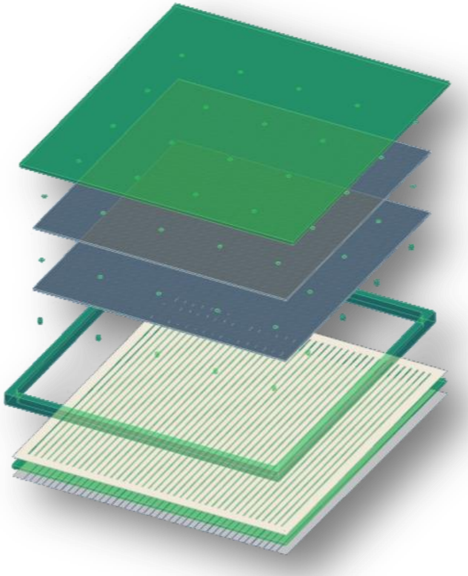
Detector characteristics and requirements

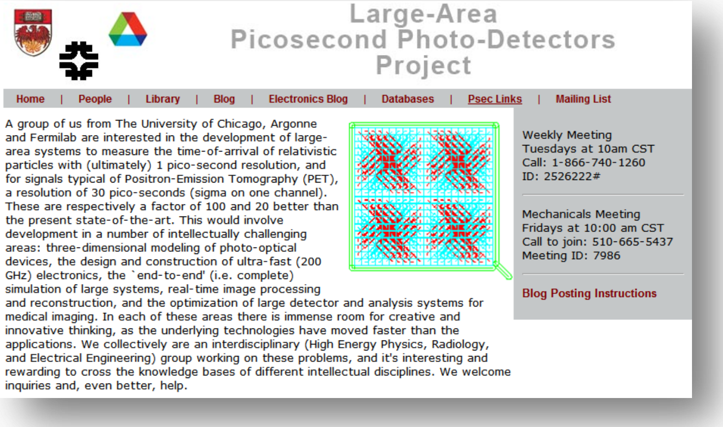
Characteristics	Value
Detector to detector distance	440m & 840m
Detector size	$2cm^2$
Distance to beam	2mm – 2.5mm

Requirements	Values
Absolute timing precision	Better than 10-15ps
Spacial resolution of the MCP	1mm
Photon sensitivity	>10PE
Lifetime	>5 years
Radiation Hard	Yes

LAPPD: Project presentation

- Objective: Built a large-area photomultiplier with a ~1mm spatial resolution and ~1ps timing resolution.
- Effort distributed in 5 groups:
  - Hermetic packaging
  - Photocathode
  - MCP
  - Electronics
  - Integration.
- Team : 3 Nat. Labs, 5 Universities, 3 US companies.
- Time scale: 3 years.
- Funding: Dept. Of Energy
- Web page and docs: http://psec.uchicago.edu
- Status: beginning of year 2.





Large-Area Picosecond Photo-Detectors Project

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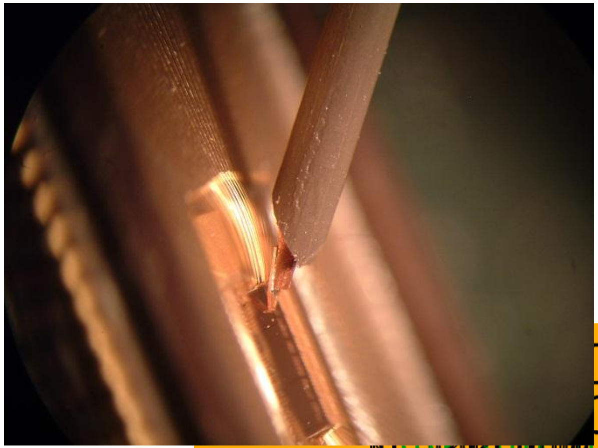
A group of us from The University of Chicago, Argonne and Fermilab are interested in the development of large-area systems to measure the time-of-arrival of relativistic particles with (ultimately) 1 pico-second resolution, and for signals typical of Positron-Emission Tomography (PET), a resolution of 30 pico-seconds (sigma on one channel). These are respectively a factor of 100 and 20 better than the present state-of-the-art. This would involve development in a number of intellectually challenging areas: three-dimensional modeling of photo-optical devices, the design and construction of ultra-fast (200 GHz) electronics, the `end-to-end' (i.e. complete) simulation of large systems, real-time image processing and reconstruction, and the optimization of large detector and analysis systems for medical imaging. In each of these areas there is immense room for creative and innovative thinking, as the underlying technologies have moved faster than the applications. We collectively are an interdisciplinary (High Energy Physics, Radiology, and Electrical Engineering) group working on these problems, and it's interesting and rewarding to cross the knowledge bases of different intellectual disciplines. We welcome inquiries and, even better, help.

Weekly Meeting
Tuesdays at 10am CST
Call: 1-866-740-1260
ID: 2526222#

Mechanicals Meeting
Fridays at 10:00 am CST
Call to join: 510-665-5437
Meeting ID: 7986

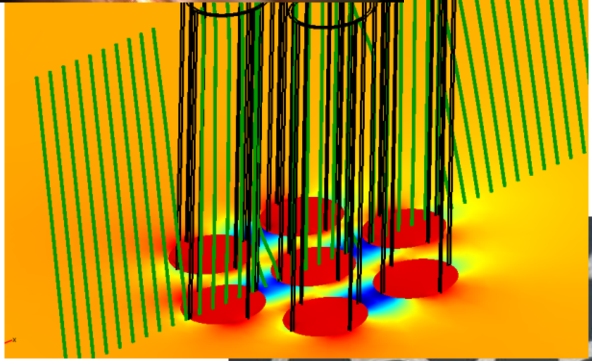
Blog Posting Instructions

LAPPD: 3 parts → 3 efforts.



- **Readout**: use of transmission lines and high speed readout.

Anodes is a 50Ω stripline, scalable up to many feet in length. Readout at both end with fast custom CMOS SCA chips.



- **Integration and Simulation**: use computational model to make design choices.

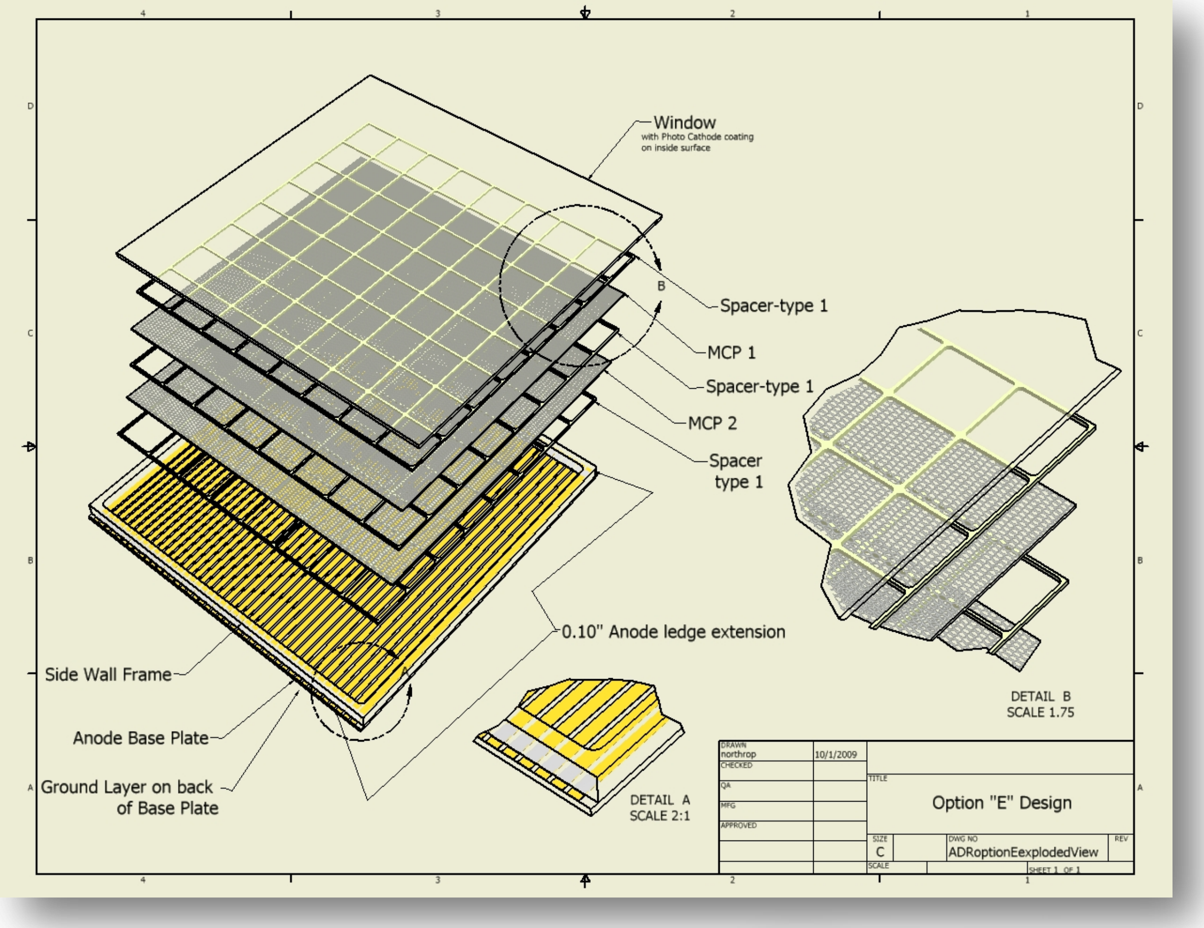
Models of the detector with modern computing tools allows simulation and validation of data.

- **MCP, Photocathode and Sealing**: use modern fabrication processes to control emissivities, resistivities, out-gassing.

Use ALD for improvement on cheap inert substrates (glass capillary arrays). Scalable to large, economical, stable panels. Lifetime and QE improvements.

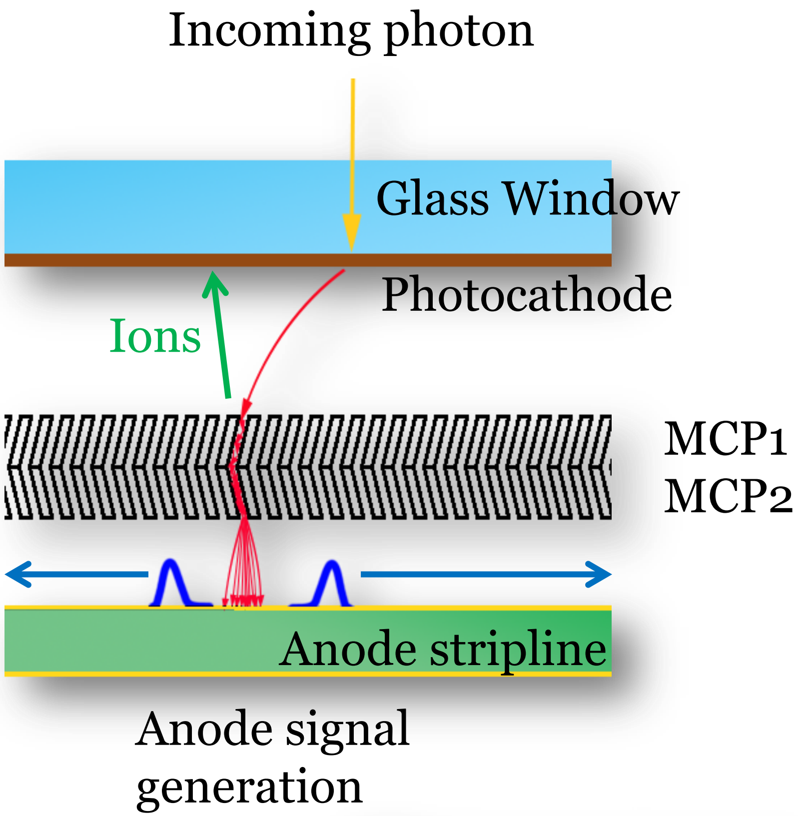
LAPPD: MCP-PMT description

- Large area detector: 8in×8in×.8in (possibility smaller size).
- Material: glass (Borofloat 33).
- Photocathode QE: unknown.
- MCP gain: 10^6.
- Rise time: 100ps - 1ns.
- Lifetime: similar commercial.
- Spatial resolution: ~1mm.
- Rad hardness: not tested.
- Output lines: 80.

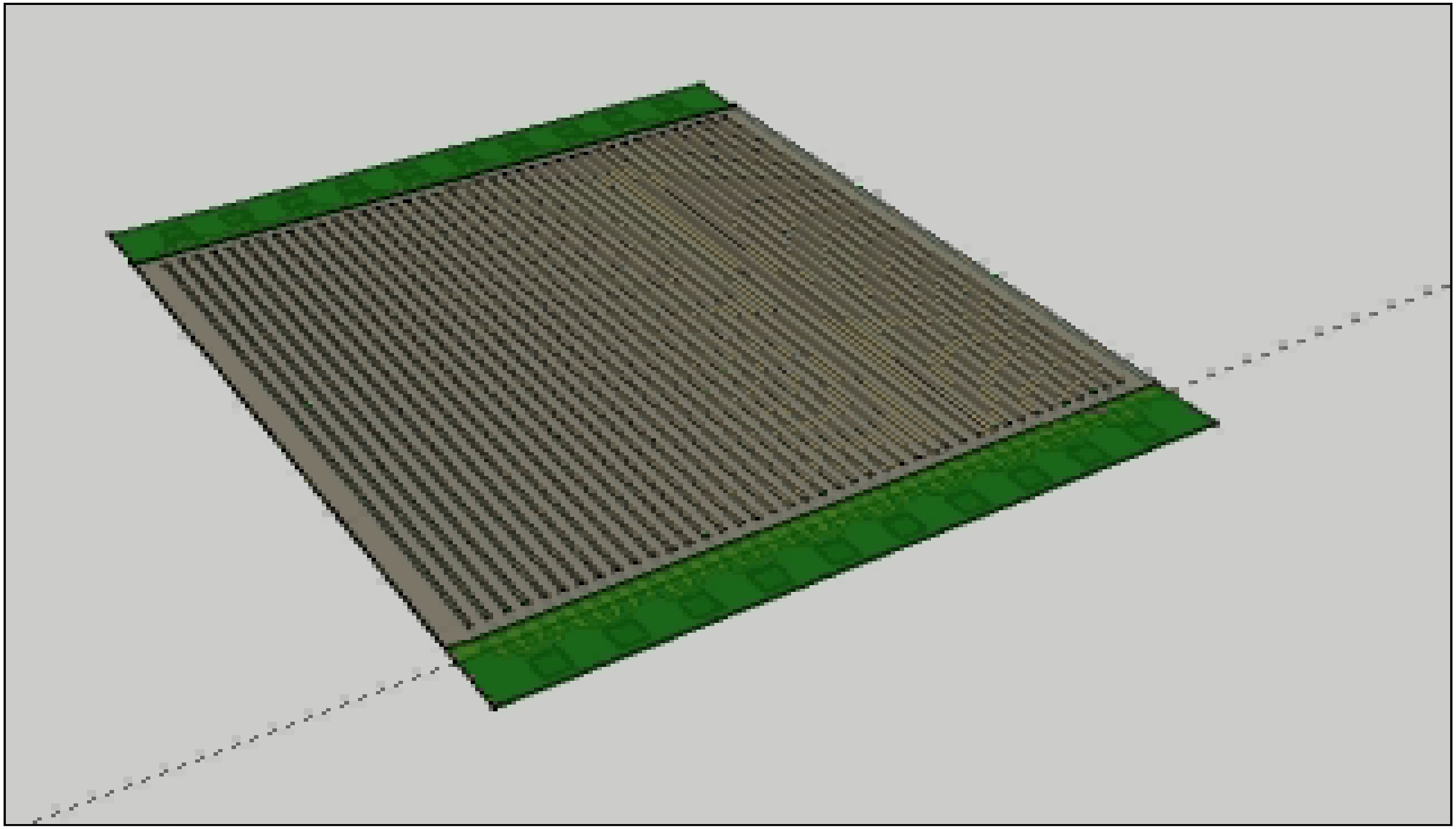


LAPPD: MCP-PMT signal development and transmission line readout.

- Incoming photons are converted in electron with 30 to 40% efficiency (λ dependent).
- They are accelerated by the high voltage across the MCPs to the anode striplines.
- The electron shower produce two EM pulse propagating to each end of the stripline where they are readout.
- Ions bombarding the photocathode provoke aging: solution depositing the photocathode on top of the MCP.
- MCP-PMT noise: thermal electrons from the photocathode.

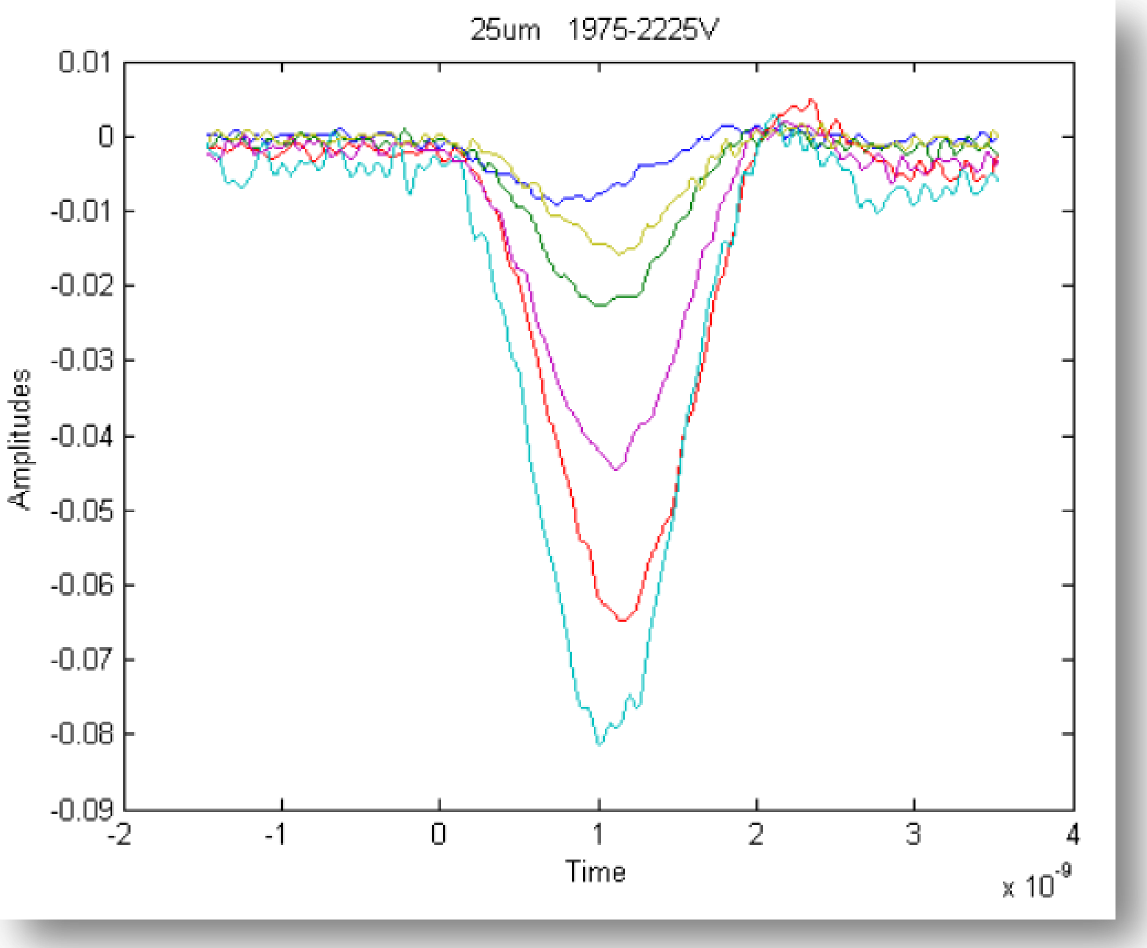


LAPPD : MCP-PMT readout



Output pulses shapes from the MCPs

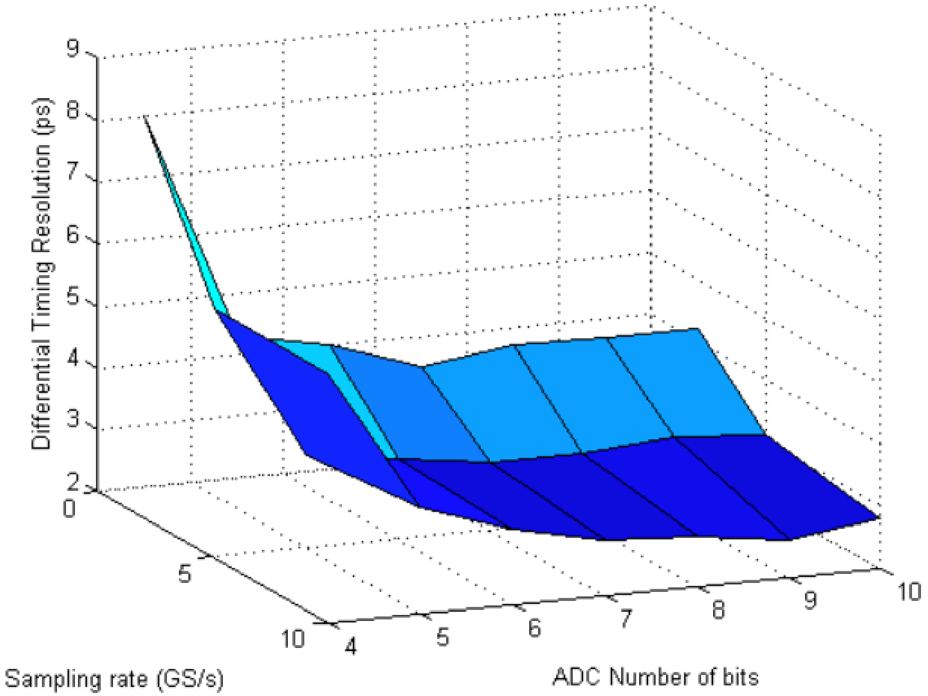
- Pulses for different high voltage across the MCP.
- Mesured with a fast 20 Gs/s scope across a 50Ω terminaison resistance.
- Here the noise on the signal is principally the noise of the scope.
- The pulse have been recorded for MCP still in test phase. Several coating and high voltage are being currently tested .
- Timing precision mostly given by the slope of the rising edge (the faster the better).



Timing precision from MCP-PMTs

At 1GHz analog bandwidth:

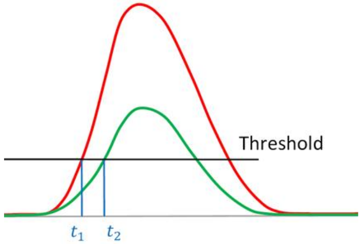
bits	2GS/s	5GS/s	10GS/s
10	*4.2ps*	*3.1ps*	*2.8ps*
9	*4.2ps*	*3.2ps*	*2.6ps*
8	4.2ps	3.1ps	2.8ps
7	4.0ps	3.1ps	2.9ps
6	4.5ps	3.3ps	3.2ps
5	4.8ps	3.5ps	3.7ps
4	8.5ps	6.1ps	5.9ps



Data taken at Argonne with 10um MCP, 2.5kV, 158PEs, 8-bit oscilloscope

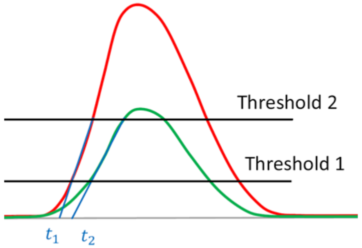
Timing extraction algorithm.

Single threshold



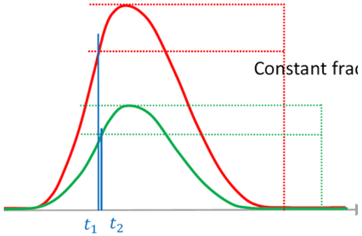
The single threshold is the least precise time extraction measurement. It has the advantage of simplicity.

Multiple threshold



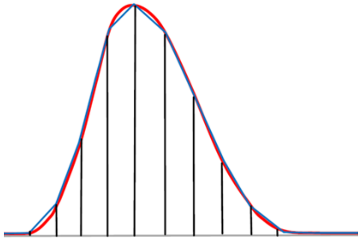
The multiple threshold method takes into account the finite slope of the signals. It is still very easy to implement.

Constant fraction



The constant fraction algorithm is very oftently used due to its relatively good results for and relative simplicity.

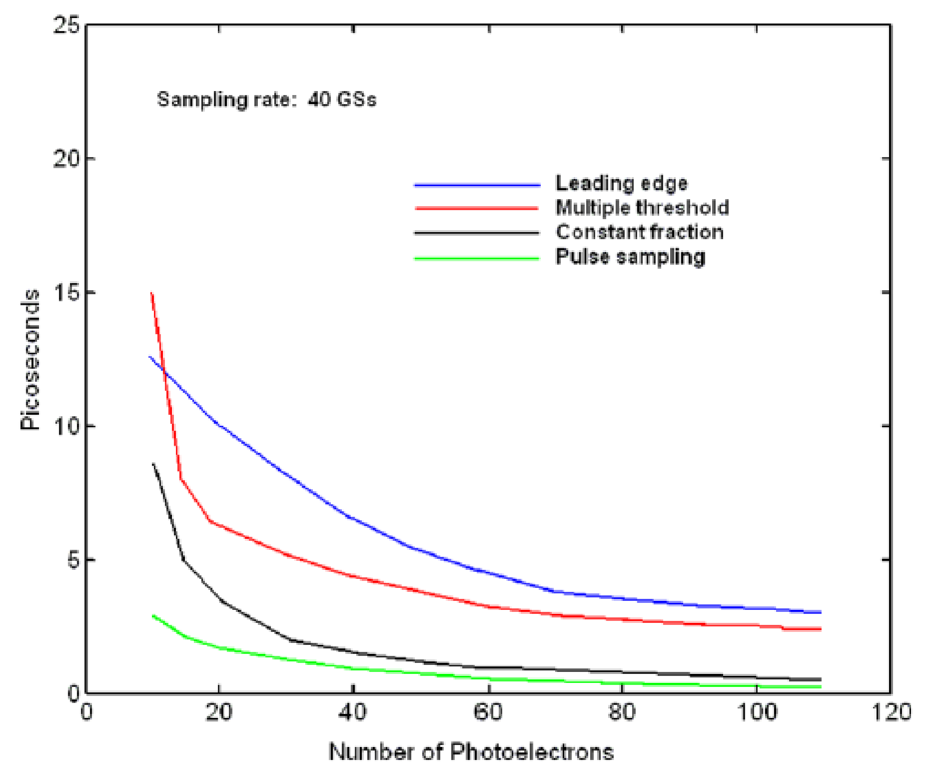
Waveform sampling



The waveform sampling above the Shannon frequency is the best algorithm since it is preserving the signal integrity.

Comparison of the 4 algorithms

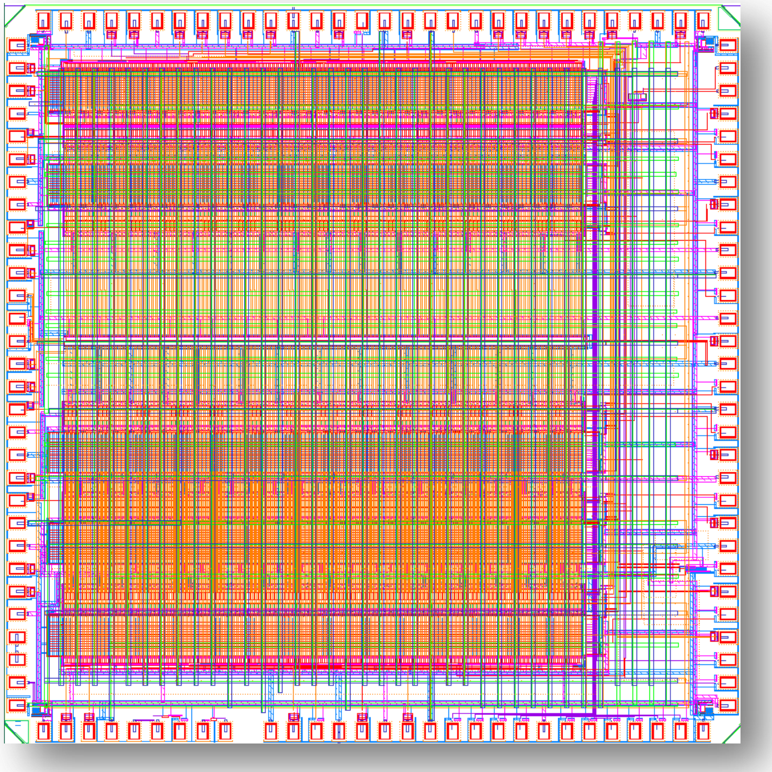
- The four models have been simulated with Matlab.
- The pulse sampling algorithm give the best results, more noticeably for small number of PE.
- The best readout chip for an MCP-PMT detector is therefore a sampling chip.
- The sampling frequency is given by 2× the fastest harmonic in the signal: 10Gs/s



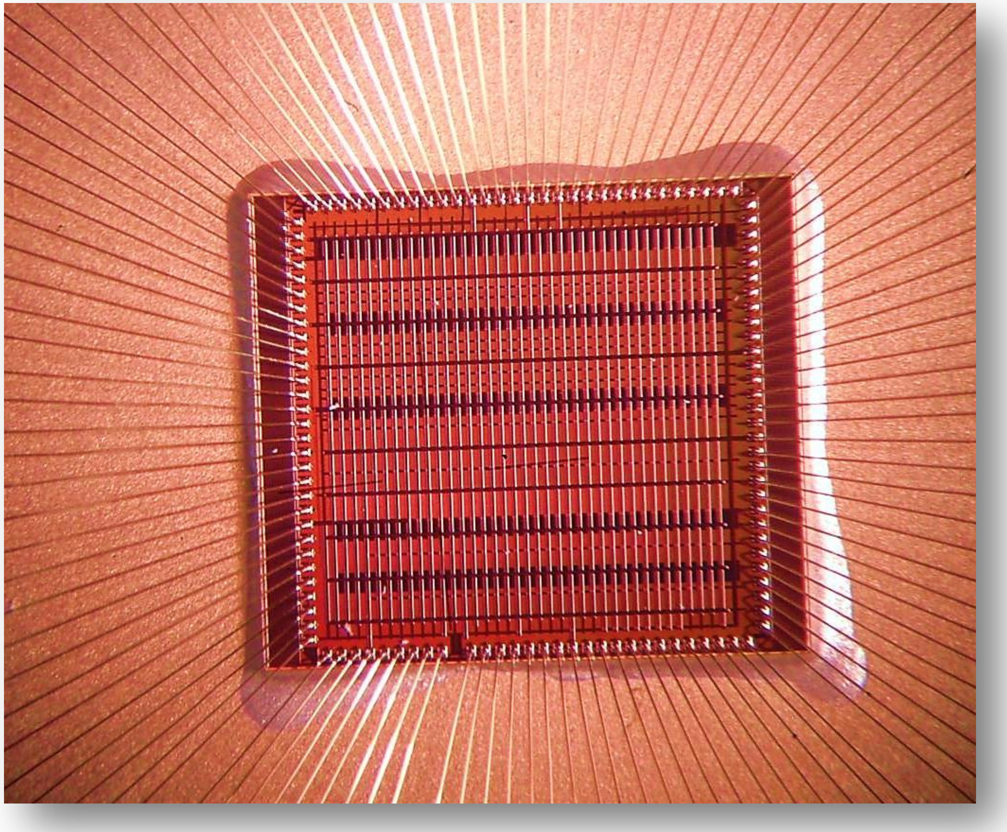
LAPPD: Development of a 10Gs/s sampling chip.

Chip characteristics	Value	Can be changed
Technology	IBM CMOS 0.13µm	No
Sampling frequency	>10Gs/s	Yes
Number of channel	4	Yes
Number of sampling cells	256	Yes
Input bandwidth	>2GHz	No
Dead time	2µs	No
Number of bits	8	Yes
Power consumption	5mW	Yes
Rad. Hard	Yes	-

Psec sampling chip

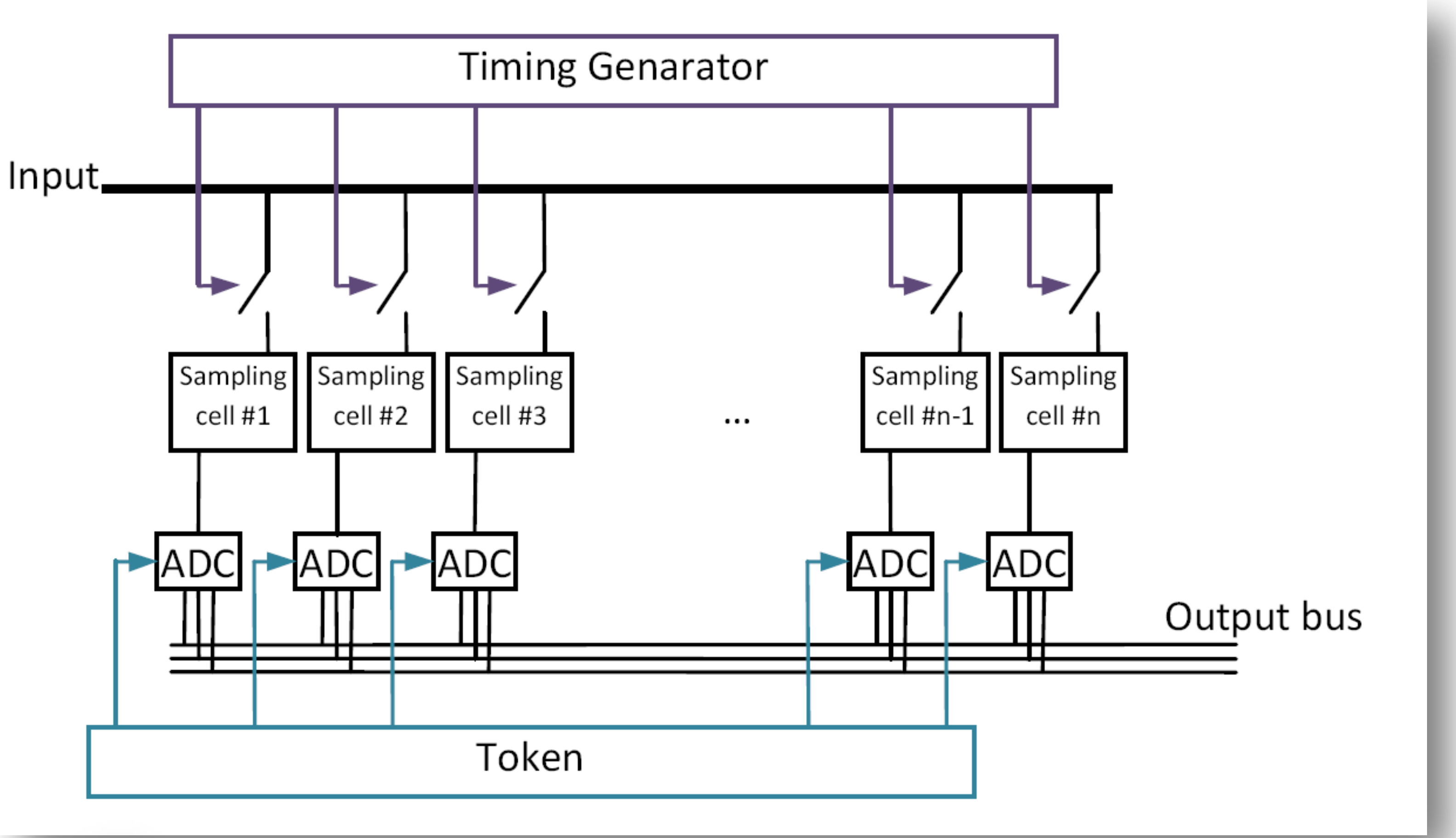


Layout.

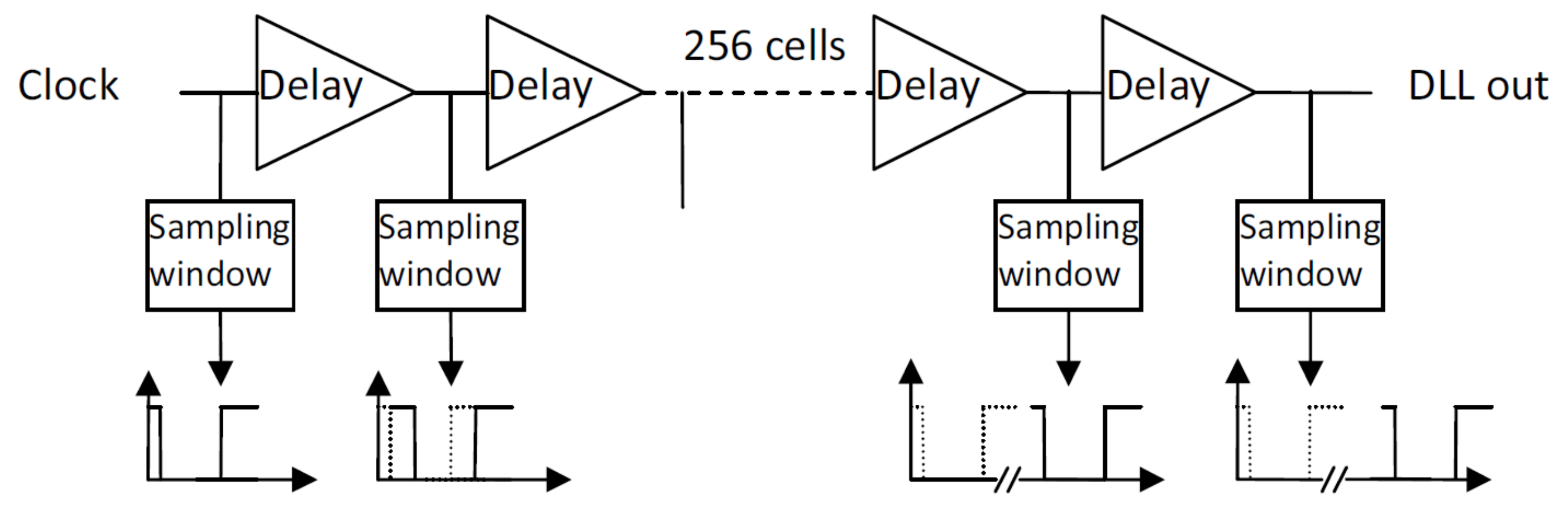


Produced chip.

Chip internal architecture

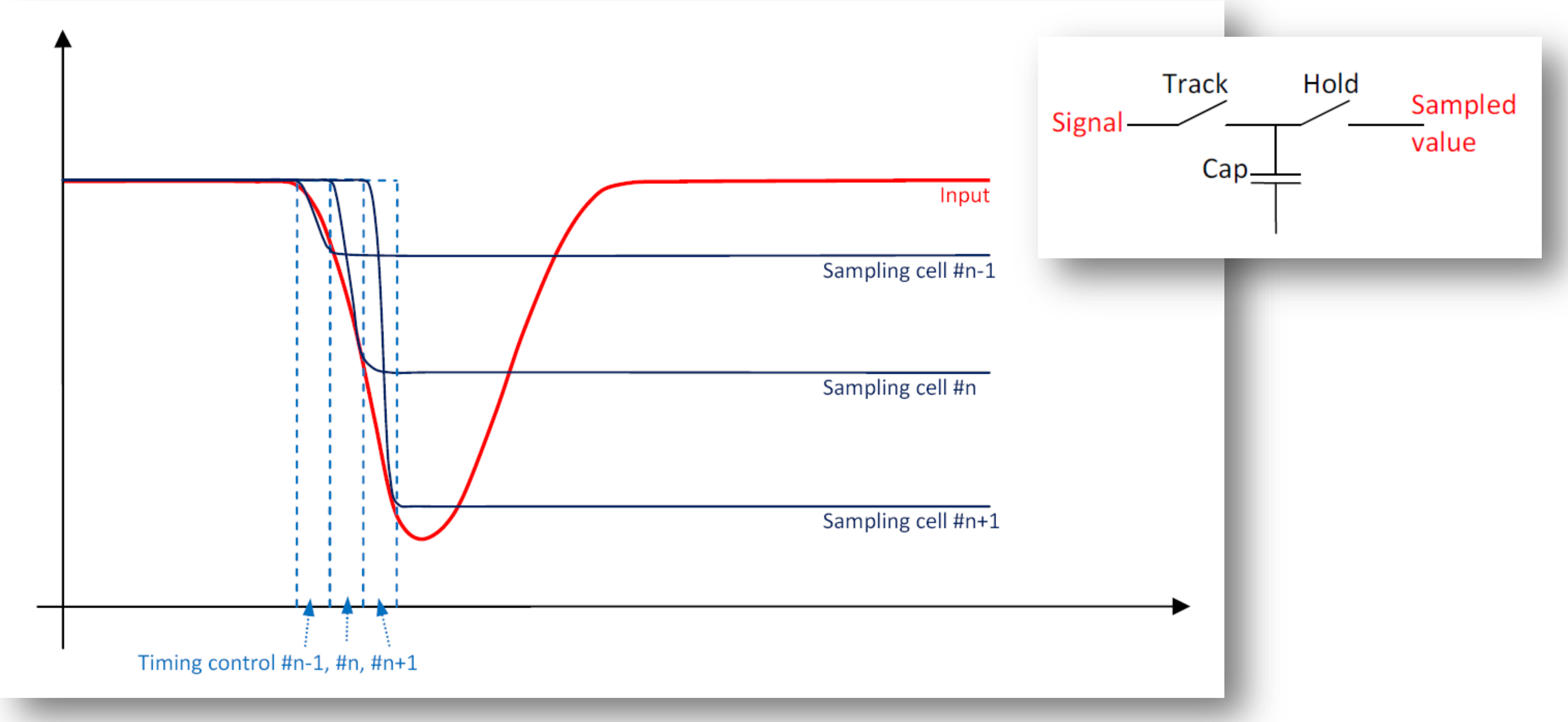


Timing generator



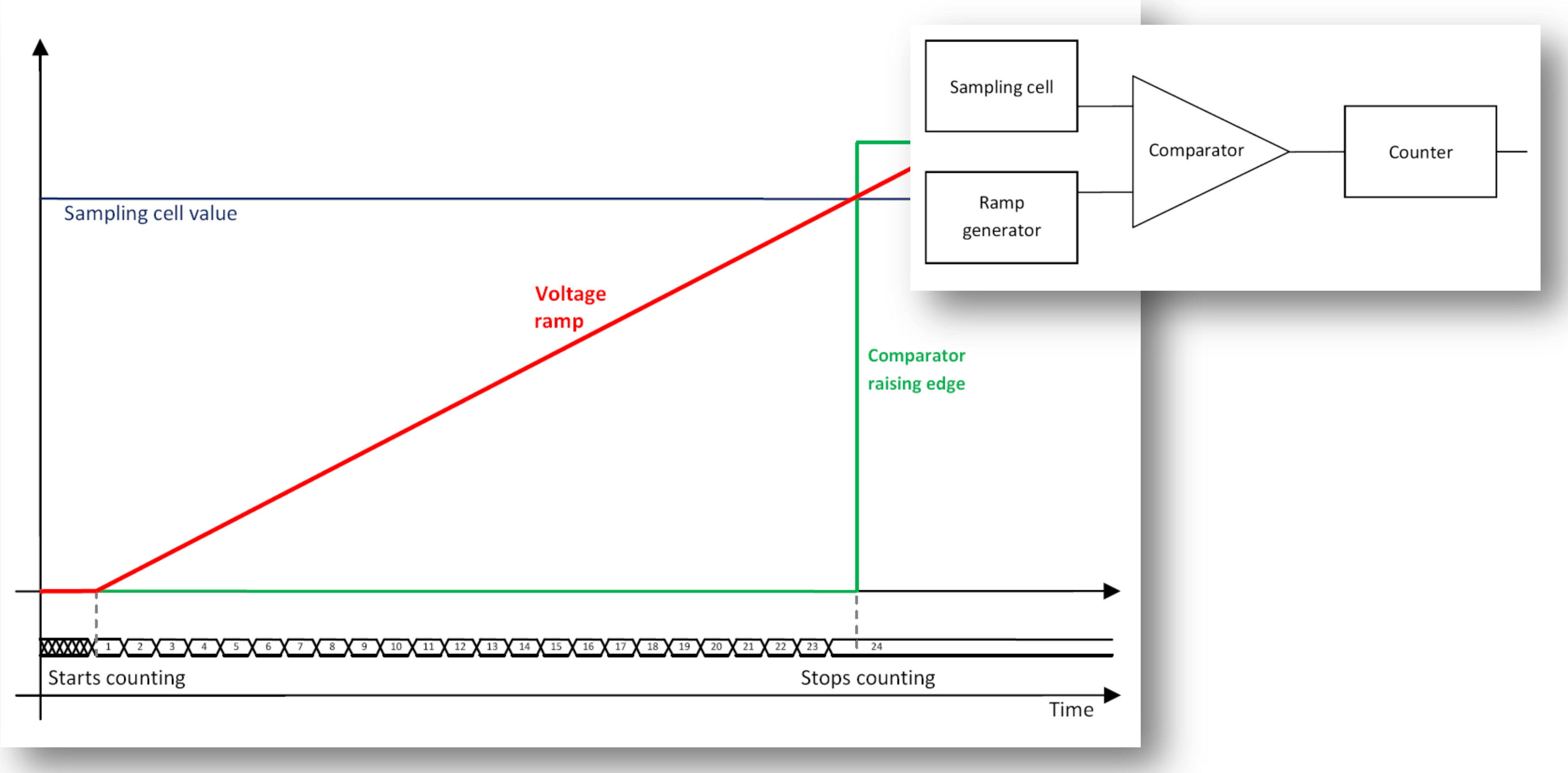
$$\text{Génère une fréquence d'échantillonnage} = \frac{1}{\text{Delay}}$$

Signal sampling



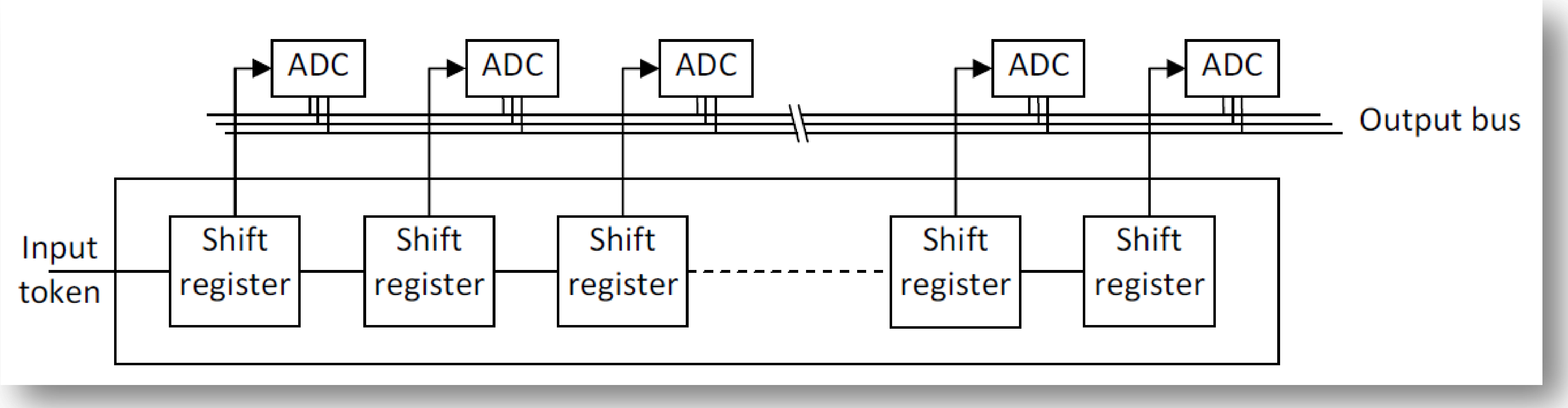
For each window of the timing generator the signal is tracked and held in the corresponding sampling cell.

The digitization



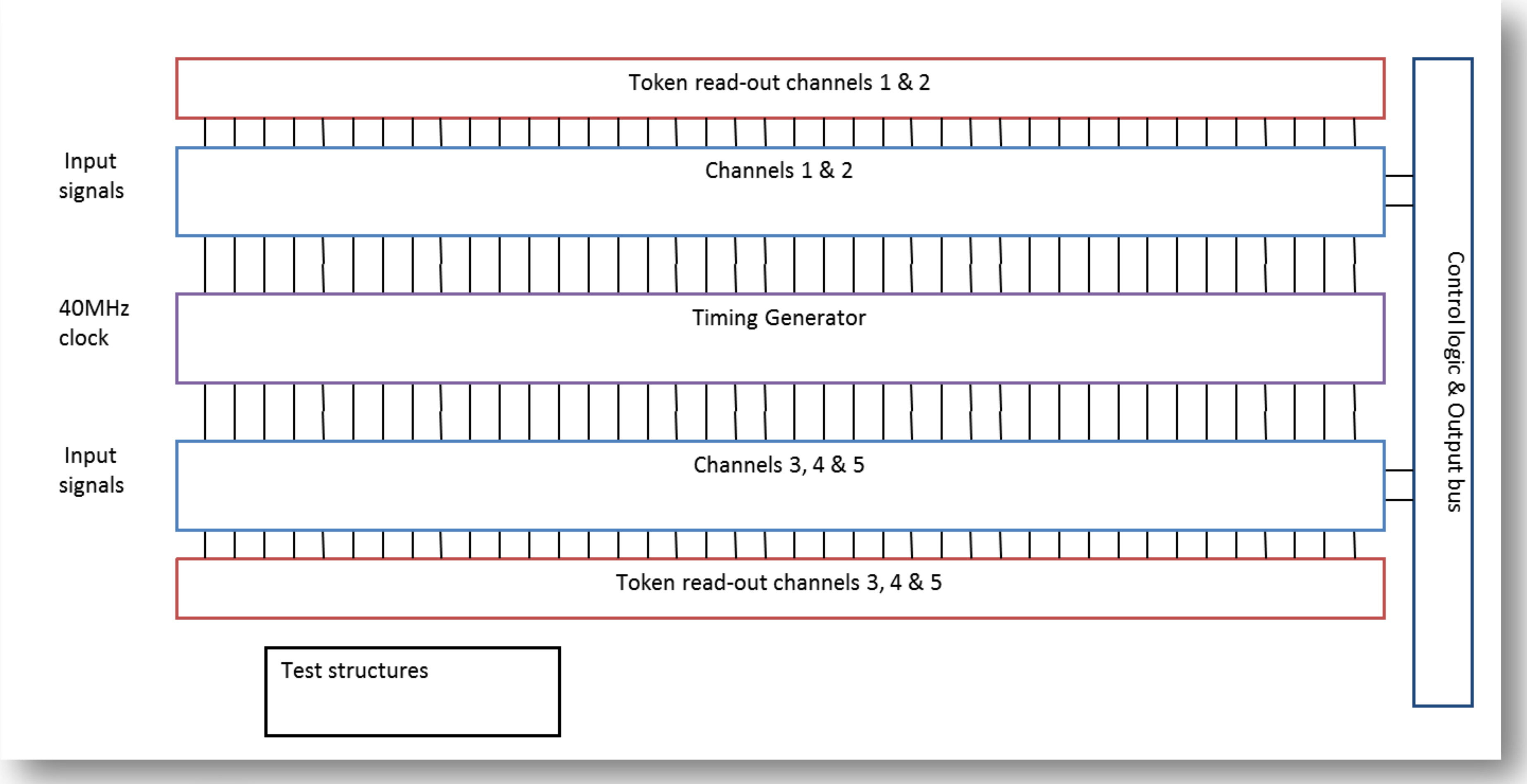
Wilkinson ADC : The ramp and counters are started. When the ramp reaches the sampled value it stops the counter.

Token readout



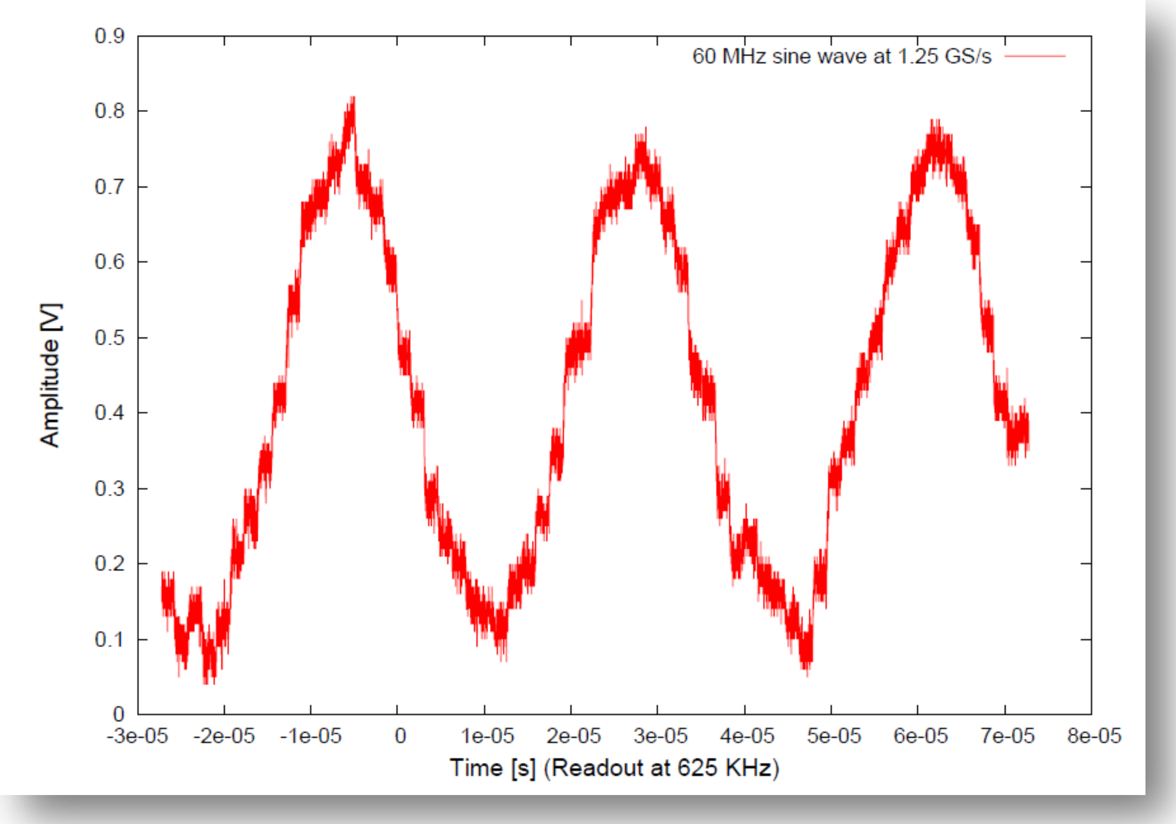
- 256 token passing D-Flip-Flop
- Each Q output of the register controls a switch from the ADC to the output bus.
- 40 MHz clock common to all flip-flops.

Chip general architecture.



Chip measurements

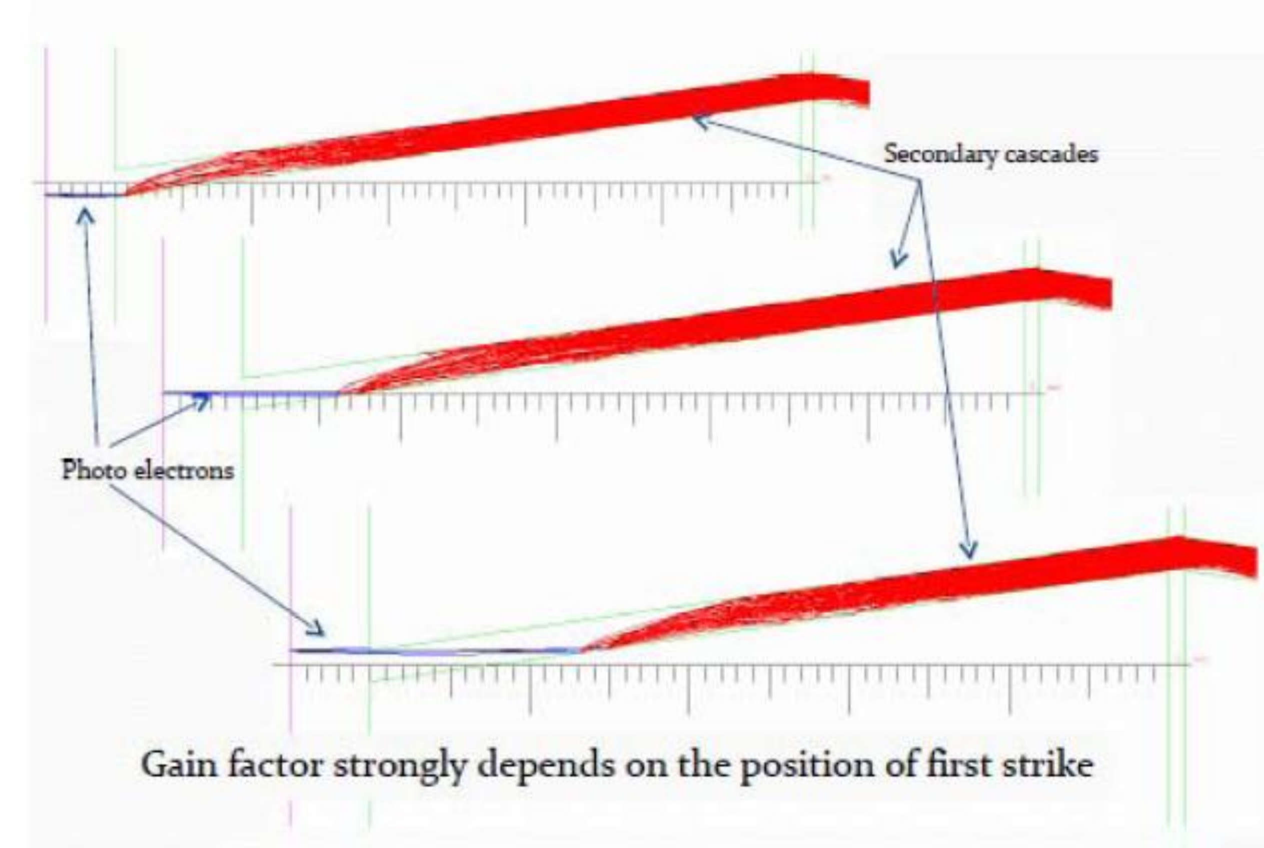
- 3 issues on current chip
  - Bad connection for trigger → no trigger.
  - Leackage in Dflip-Flop.
  - Counters not starting. ??
- An analog readout is possible but very slow and noisy. A custom board for this functioning mode is being developed.
- A new chip has been submitted with corrections.



MCP-PMT known difficulties and solutions

Difficulties	Proposed solution
Photocathode low QE	ALD work
Ions back-scattering	Reflexion-mode photocathode
First strike	Funnel
MCP gain	Custom resistive layer
Anode signal development understanding	Simulation/Measurement
50Ω stripline matching	HFSS modeling/ Network analyzer measurements.

MCP-PMT known issue: first strike



Gain factor strongly depends on the position of first strike

Chip know difficulties and solutions

Difficulties	Solutions
Working, error free design	Internal and external reviews, simulations.
Input impedance matching	50Ω termination.
>10GHz sampling	Fast, small features design.
>2GHz bandwith	Low R and low C design.
Leakage	Simulation and innovative design.
Jitter	Internal DLL
Cell to cell mismatch	Calibration

Summary

- Large area MCP-PMT developed here, although very fast may not be interesting for AFP (size).
- A new fast sampling chip (Psec) is being developed and will be tested in three months. Real timing capabilities will be measured then.
- The timing is nPE dependent. We hope to achieve a below 10ps precision in timing measurement (100PE) with our chip. In principle it could be use for AFP.
- For now the timing resolution is limited by the electronics. However we wait until the measurement and tests to know each contribution for sure.
- Maintaining a 10ps overall precision for detector at 800m might reveal itself challenging too.

Thank you!

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