Frontier technologies in Picosecond Timing

Prague - *Friday, February 22. 2012*

Hervé Grabas - CEA Saclay Irfu.

How I got implied

Large-Area Picosecond Photo-Detectors Project

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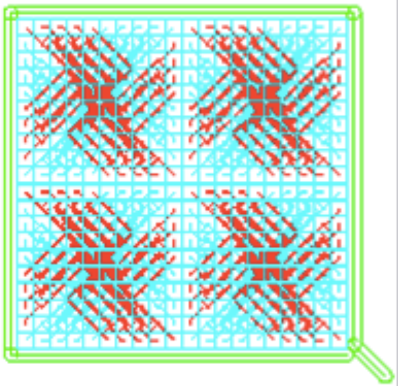


A group of us from The University of Chicago, Argonne, Fermilab and Berkeley are interested in the development of large-area systems to measure the time-of-arrival of relativistic particles with (ultimately) 1 pico-second resolution, and for signals typical of Positron-Emission Tomography (PET), a resolution 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 fast, economical, low-power 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#

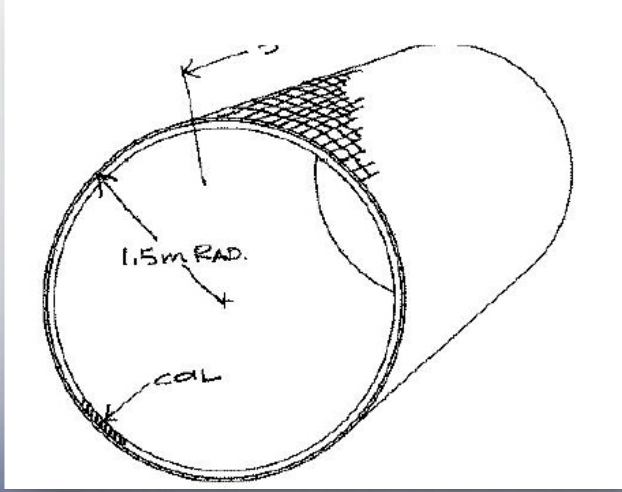
Mechanicals Meeting
Fridays at 10:00 am CST
Call to join: 866-740-1260
Meeting ID: 2529377

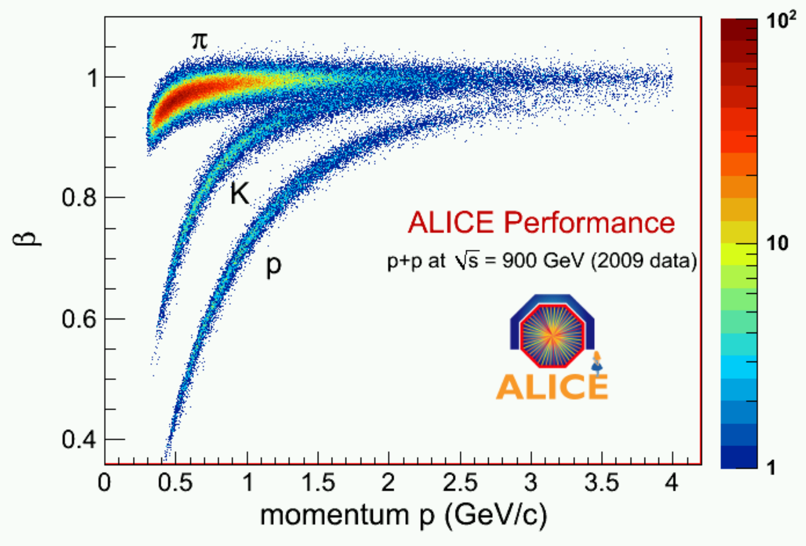
Blog Posting Instructions

What can we do with TOF

Particle identification

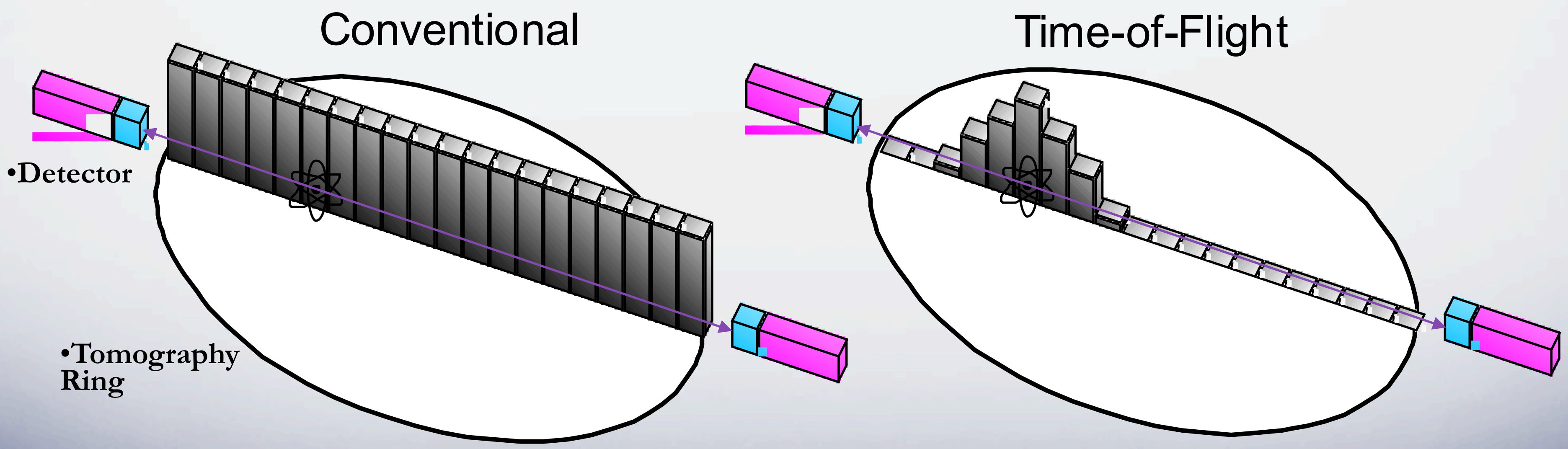
- Allows differentiation of pions, kaons and protons in particle detector.
- Thin TOF calorimeters.





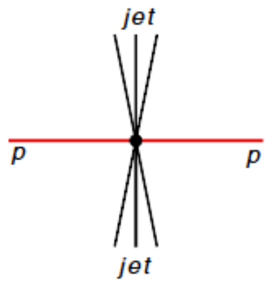
PET TOF

- For relativistic particles ($v \sim c$), a precision of $10ps$ or better on the time of arrival gives a $3mm$ precision.

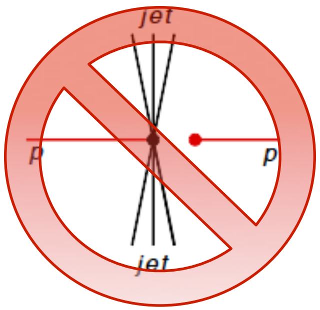


•Height represents weight assigned to each voxel by reconstruction algorithm

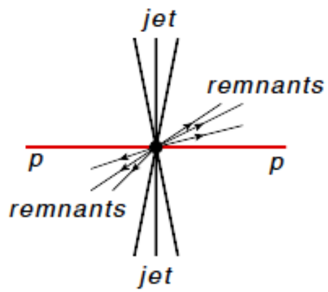
Pile-up suppression



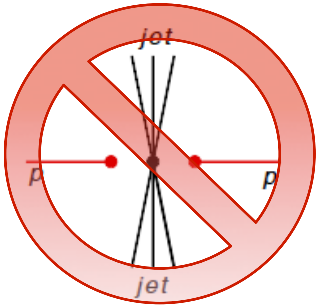
Signal: exclusive jets
CS (jet $p_T > 150$ GeV) = 0.49 pb



Background: single diffractive jets
CS (jet $p_T > 150$ GeV) = 2.26 nb



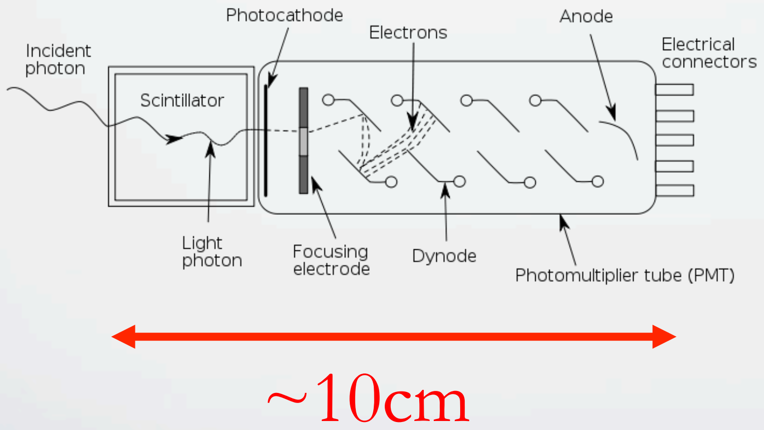
Background: DPE jets
CS (jet $p_T > 150$ GeV) = 40 pb



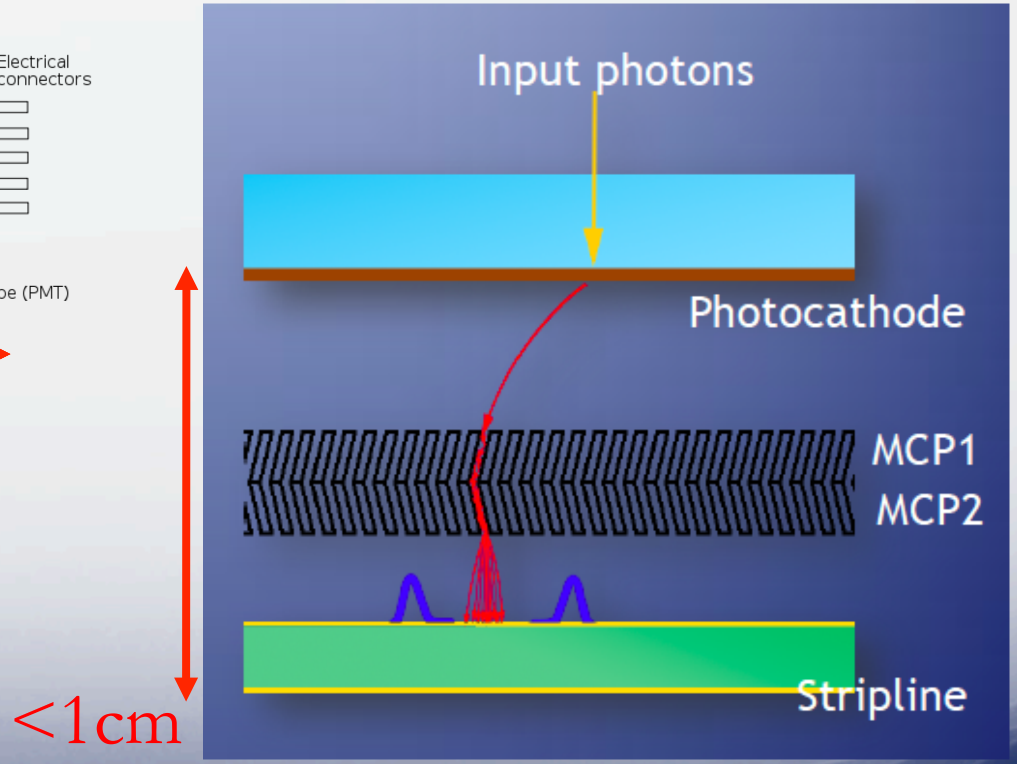
Background: non-diffractive jets
CS (jet $p_T > 150$ GeV) = 645 nb

Measuring time of arrival

Photomultiplier

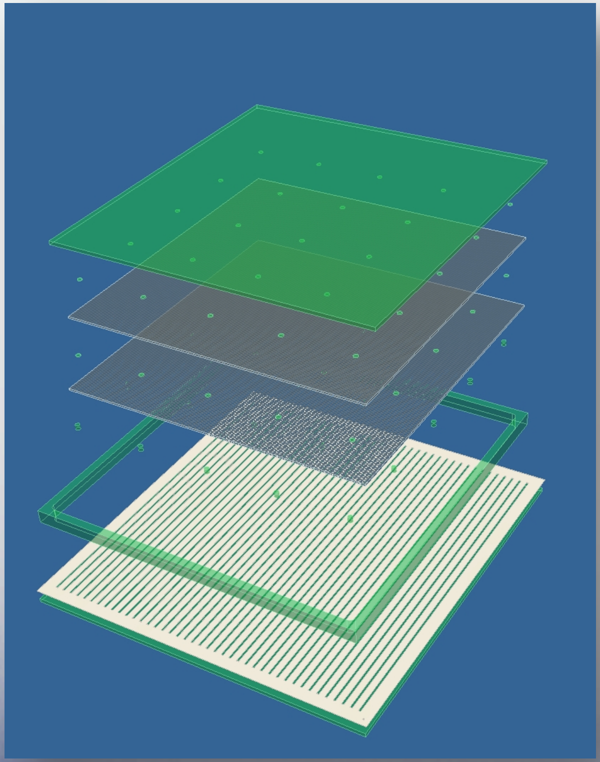


Microchannel plate

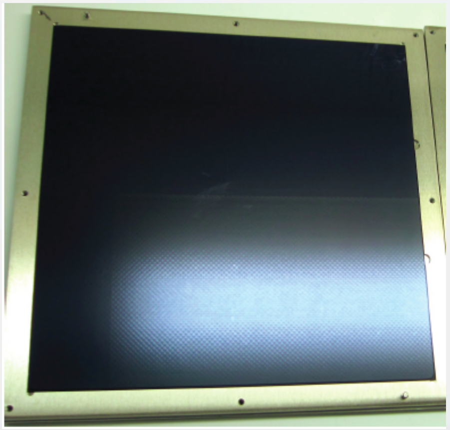


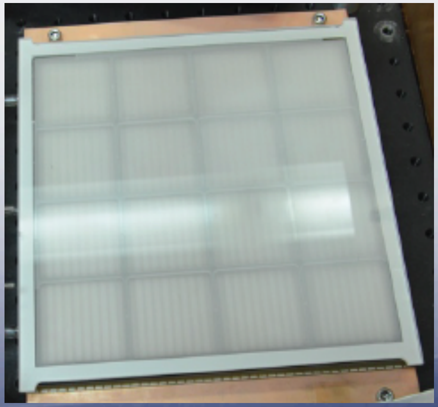
Building a new fast 8in^2 MCP detector

Specified

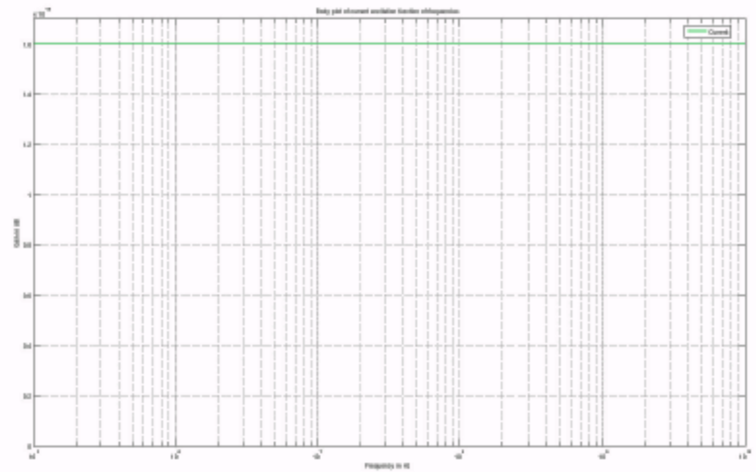


Under design at UChicago

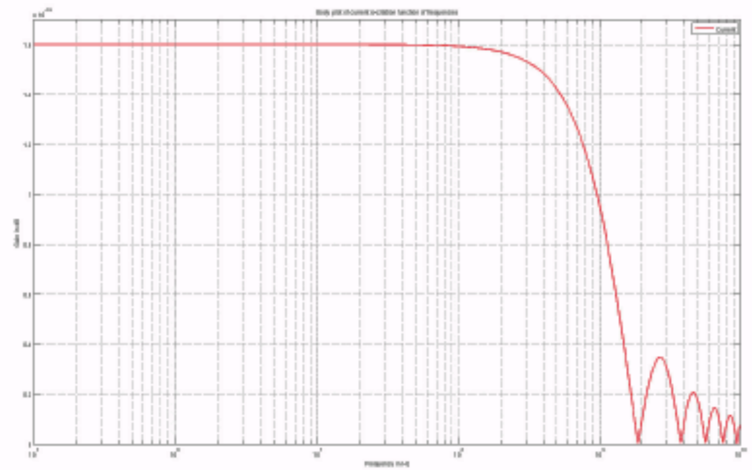




Getting precise time of flight



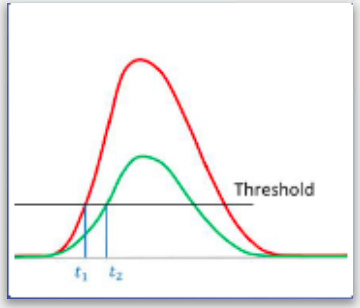
(a) In the frequency domain, the current given by a point charge Q (see Equation 3):
$\hat{i}(f) = Q \times e^{\frac{-2i\pi f d}{v_0}}$



(b) In the frequency domain, the current given by a rectangular charge distribution of width s and integrated charge Q (See Equation 4):
$\hat{i}(f) = Q \times \text{sinc}\left(\frac{\pi f s}{v_0}\right) \times e^{\frac{-2i\pi f d}{v_0}}$

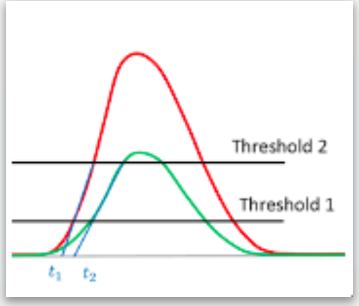
Getting precise timing

Single threshold



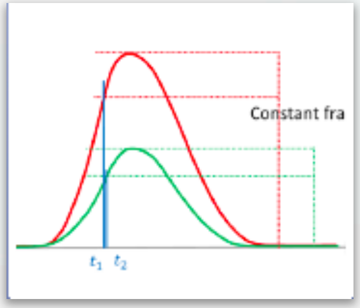
The single threshold is the least precise time extraction measurement. It has the advantage of simplicity.

Multiple threshold



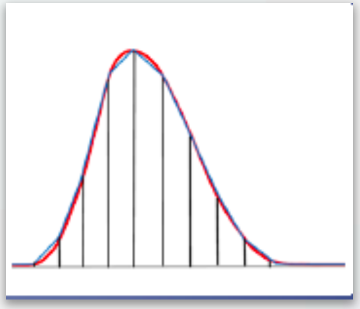
The multiple threshold method takes into account the finite slope of the signals. It is still very easy to implement.

Constant fraction



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

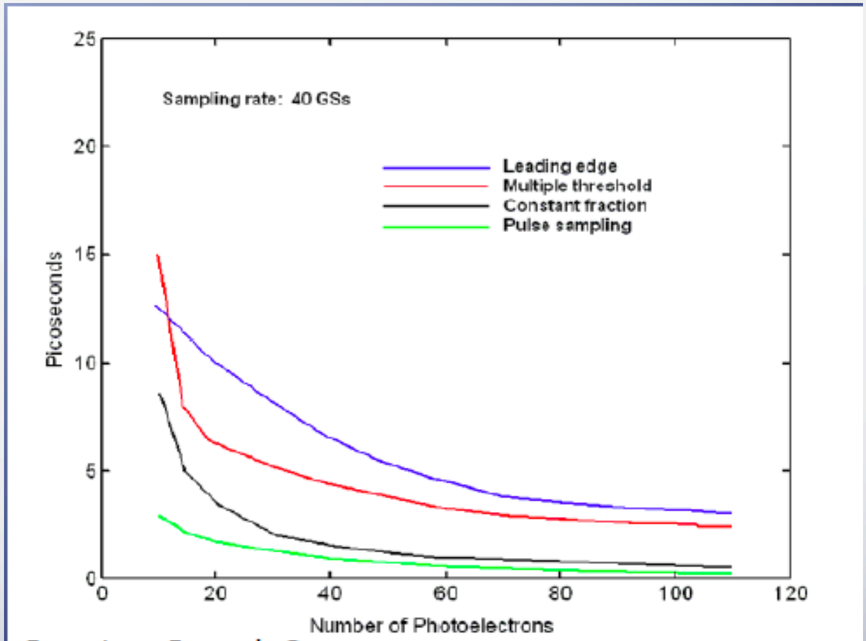
Waveform sampling



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

Why use sampling chips

- The four models have been simulated using Matlab.
- • For pulse sampling the time is extracted with template fitting using the LMS algorithm.
- • The pulse sampling algorithm give the best results, more noticeably for small number of PE.
- • The best readout chip for an MCPPMT detector is therefore a sampling chip.
- • The sampling frequency is taken to be 2times the fastest harmonic in the signal: 10Gs/s

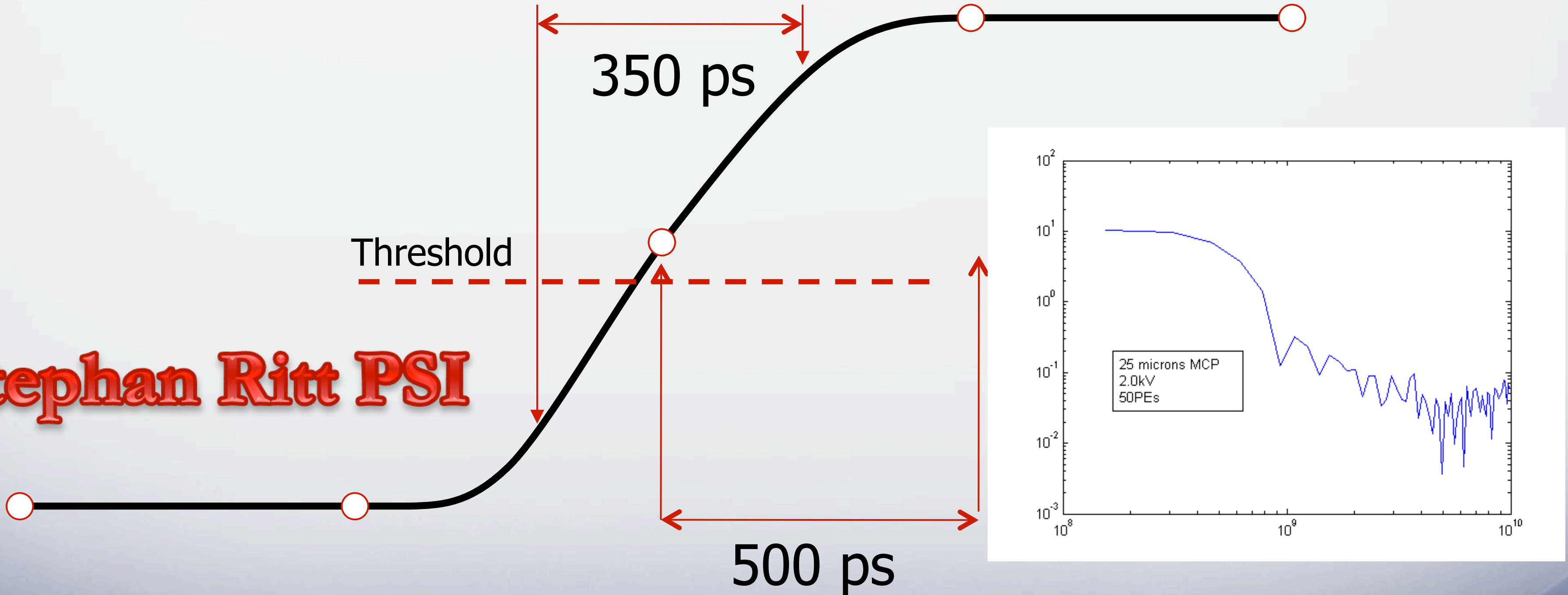


From Jean-François Genat

J-F Genat IN2P3

Sampling speed

Theory (Nyquist): 1 GHz signal: 350 ps rise-time, 2 GSPS

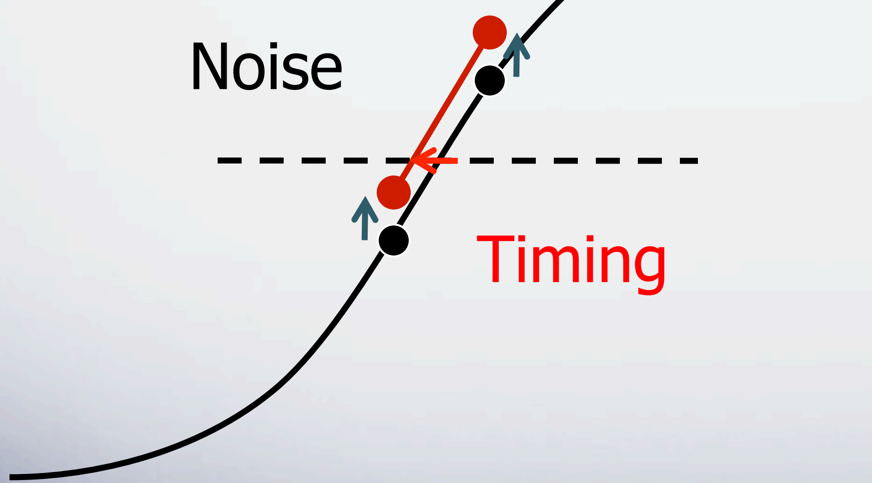


Stephan Ritt PSI

Reality: Noise! (e.g. quantization noise of ADC) and tail of input power

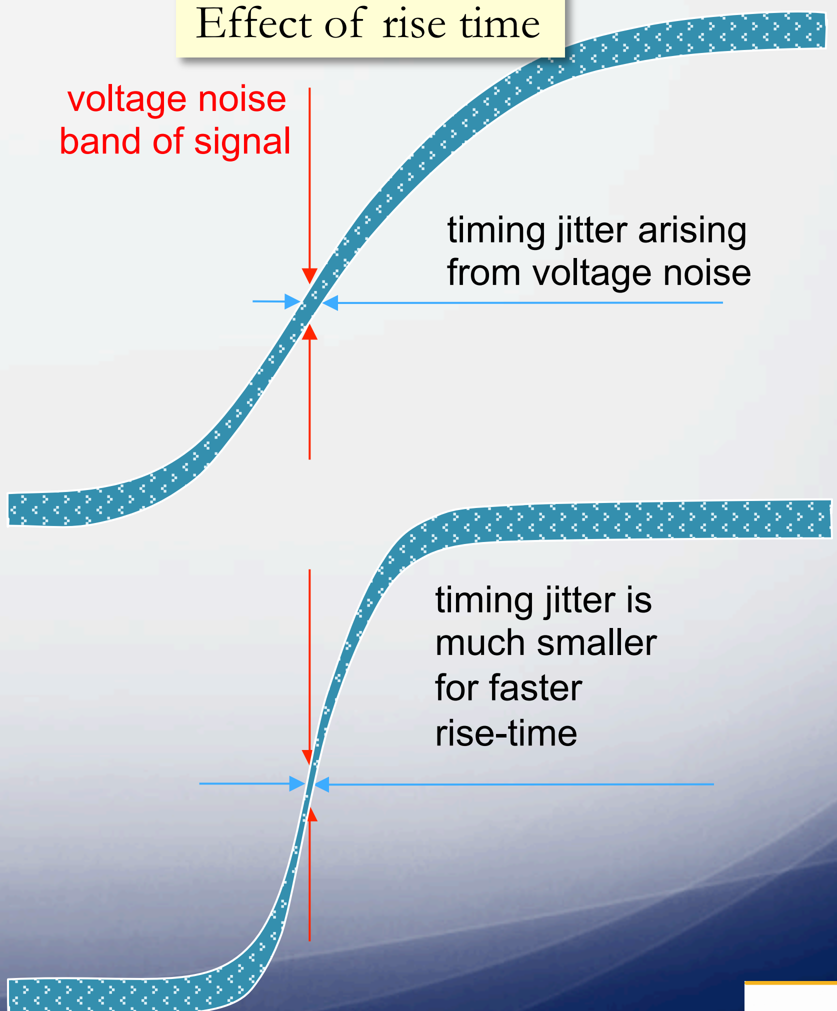
Realistic signal with noise

Noise affects timing!

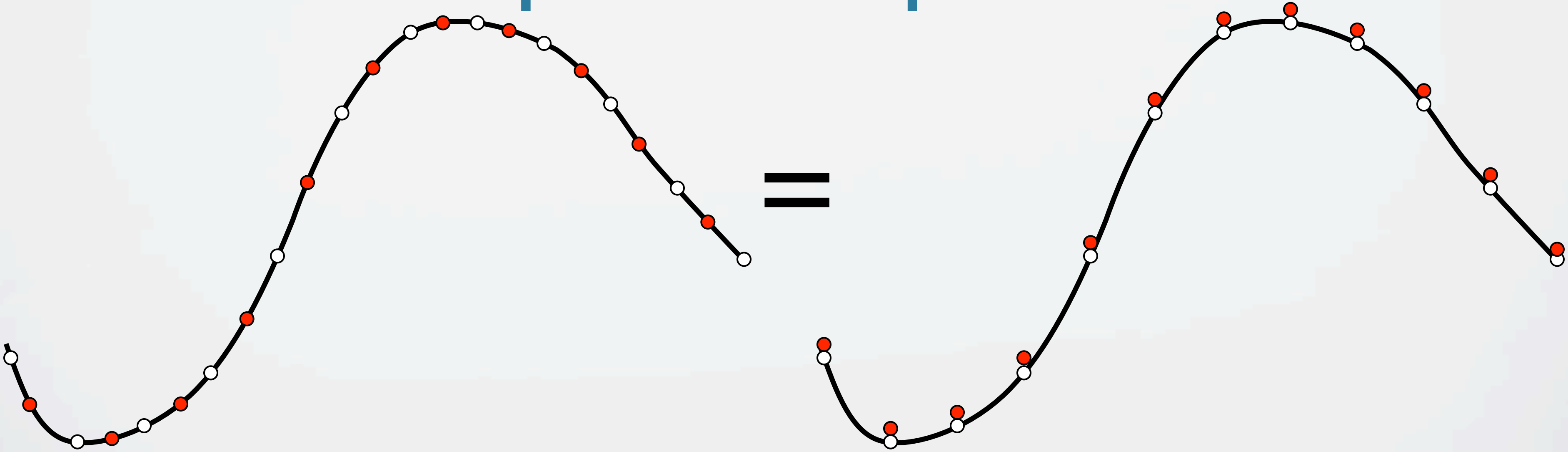


Stephan Ritt PSI

Effect of rise time



Does higher sampling speed help?



Stephan Ritt PSI

- Higher sampling speed adds only *redundant* points if Nyquist is fulfilled
- If noise comes from chip → reduce noise √2
- Equivalent to double sampling of points

How is timing resolution affected?

- **Assumes zero aperture jitter**

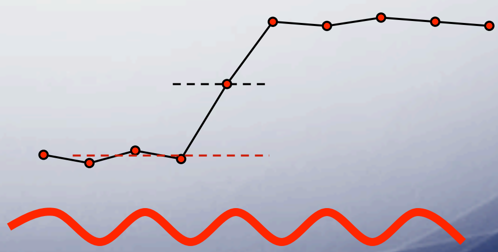
$$\Delta t = \frac{\Delta u}{U} \cdot \frac{1}{\sqrt{3 f_s \cdot f_{3dB}}}$$

	U	Du	f_s	f_{3db}	Dt
•today:	100 mV	1 mV	2 GSPS	300 MHz	~10 ps
•optimized SNR:	1 V	1 mV	2 GSPS	300 MHz	1 ps
•next generation:	100 mV	1 mV	20 GSPS	3 GHz	0.7 ps
•next generation •optimized SNR:	1V	1 mV	10 GSPS	3 GHz	0.1 ps

- **How to achieve this?**

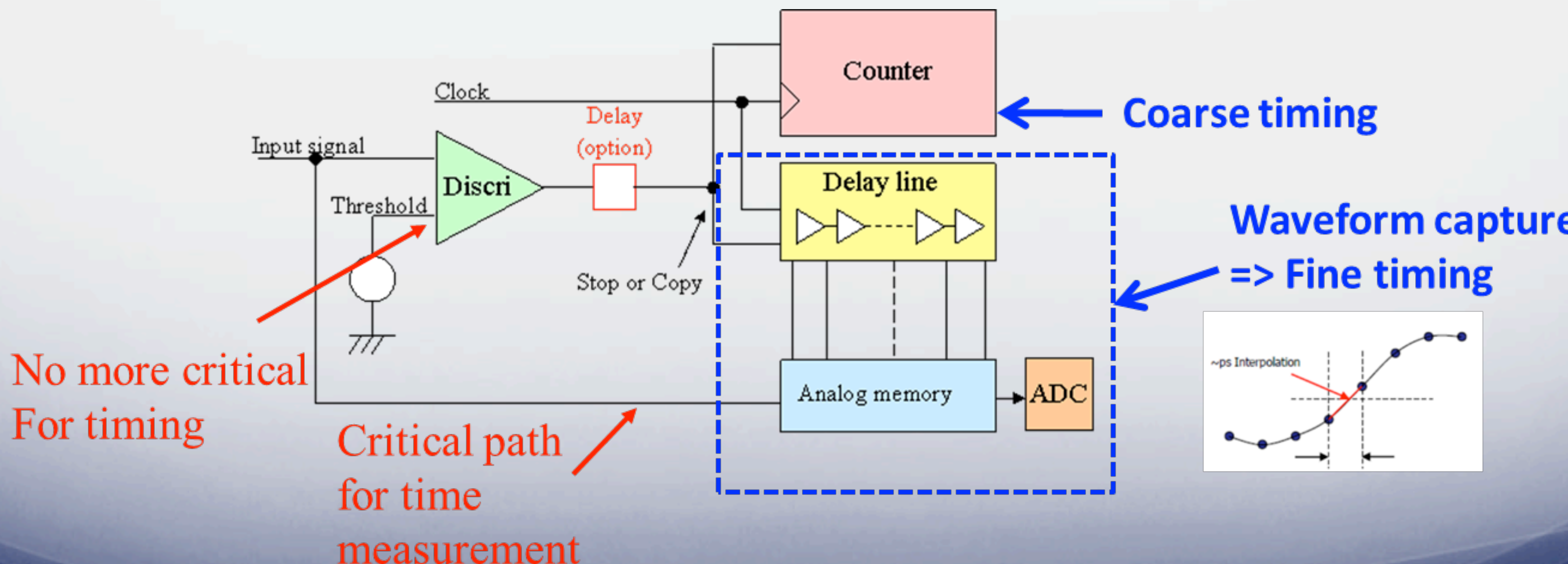
Stephan Ritt PSI

- **includes detector noise in the frequency region of the rise time**
- **and aperture jitter**



Why use Analog Memories

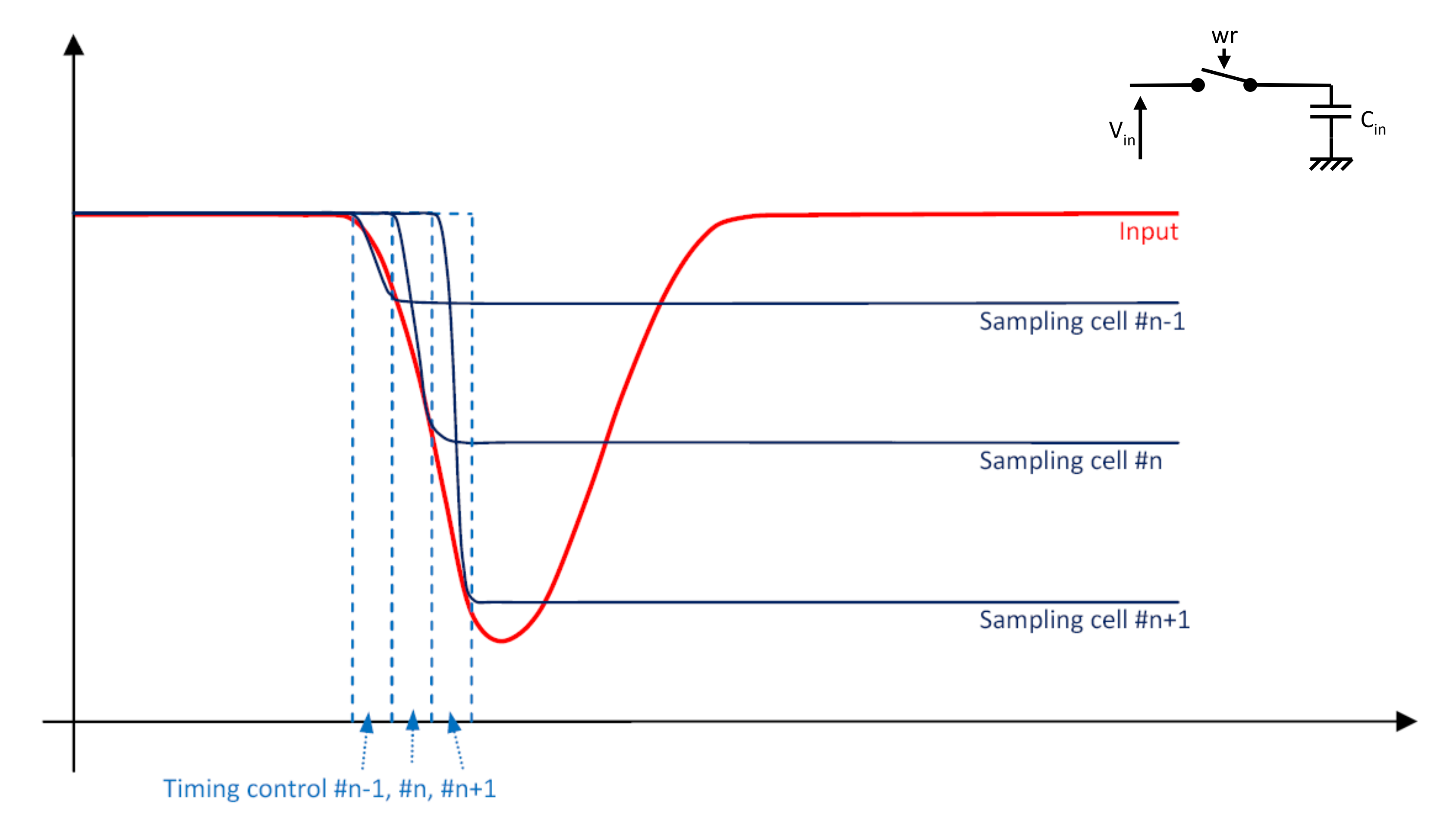
- Saclay patented architecture (2009). Coarse timing is given by a counter whereas fine timing can be determined by the waveform sampled in the analog memory.
- The comparator is only used as a trigger and is not in the critical time path anymore.



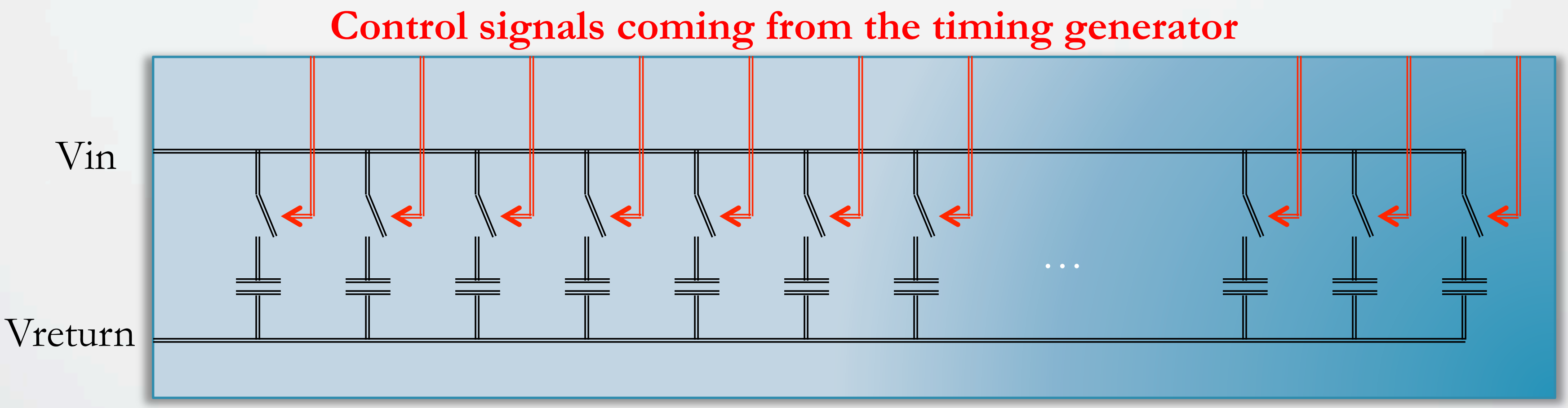
Saclay R&D project SAMPIC

- SAMPIC (SAMpler for PICosecond time pick-off).
- Build a prototype demonstrating sub-10ps timing measurement capabilities.
- With limited deadtime (ideally deadtime-less) with an architecture easily scalable to several thousands of channels.
- Project funded by the CSTS of CEA/IRFU and by P2IO. 100k€.

How to sample the signal

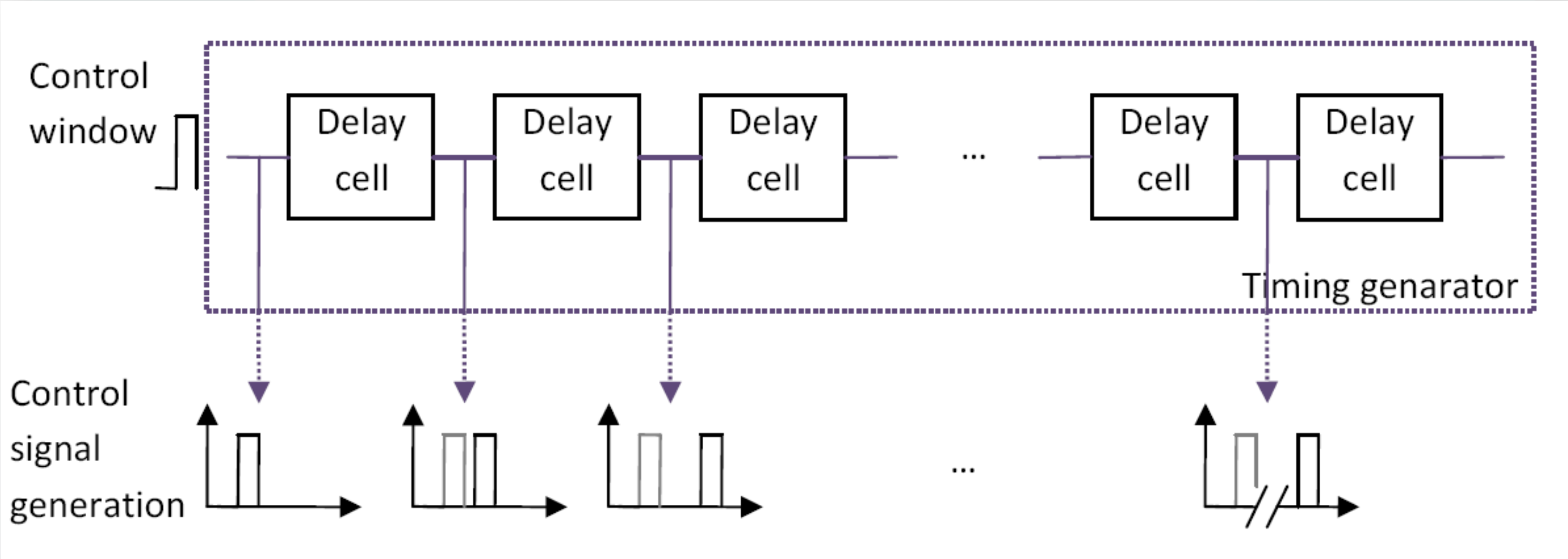


How to sample fast enough



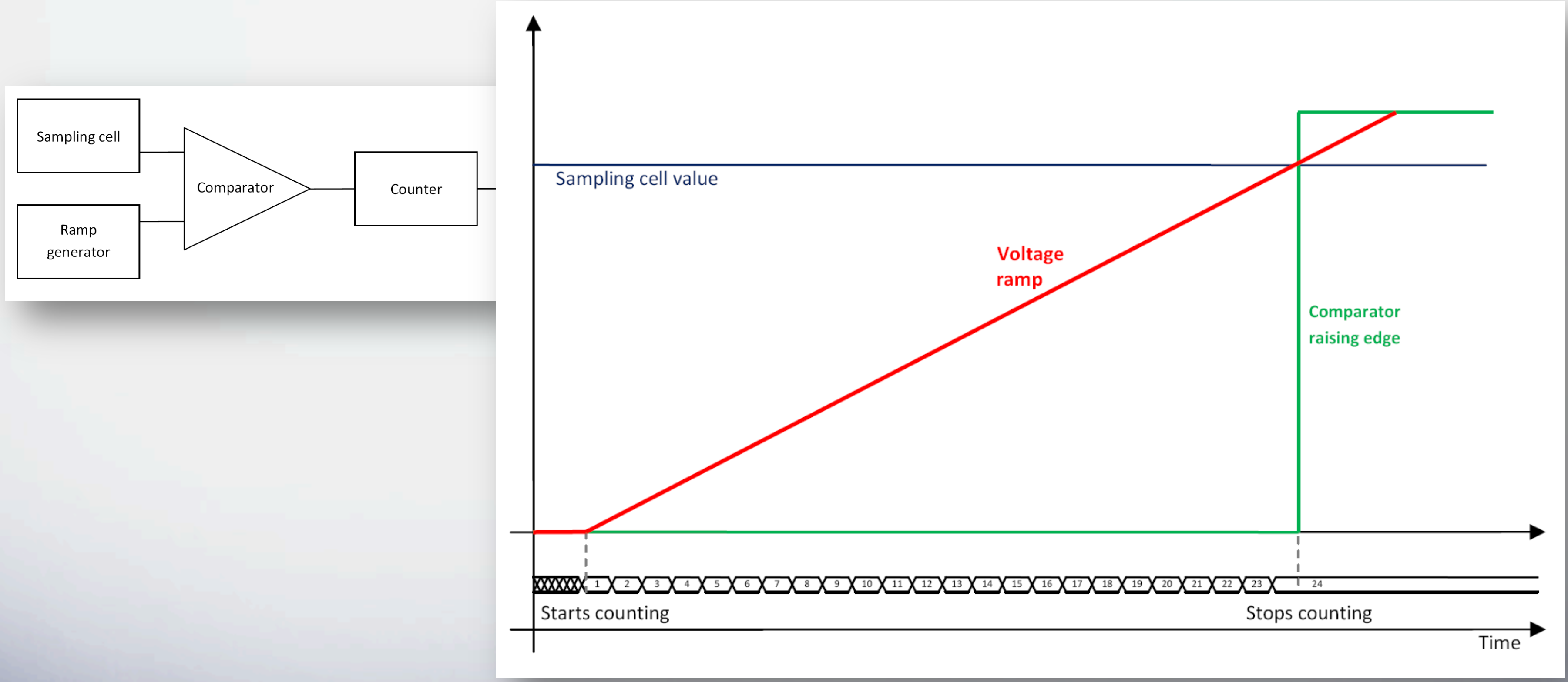
- Store the signal in a bank of capacitance controlled by very fast switching controlled signal.
- One bank used over and over (loop on the bank): can only store fast, short signals.

How to generate fast signals



- The controlled signals are created by a loop of chained delay cells. Basically two logic inverters.
- The small the technology, the faster the logic, the faster we sample.

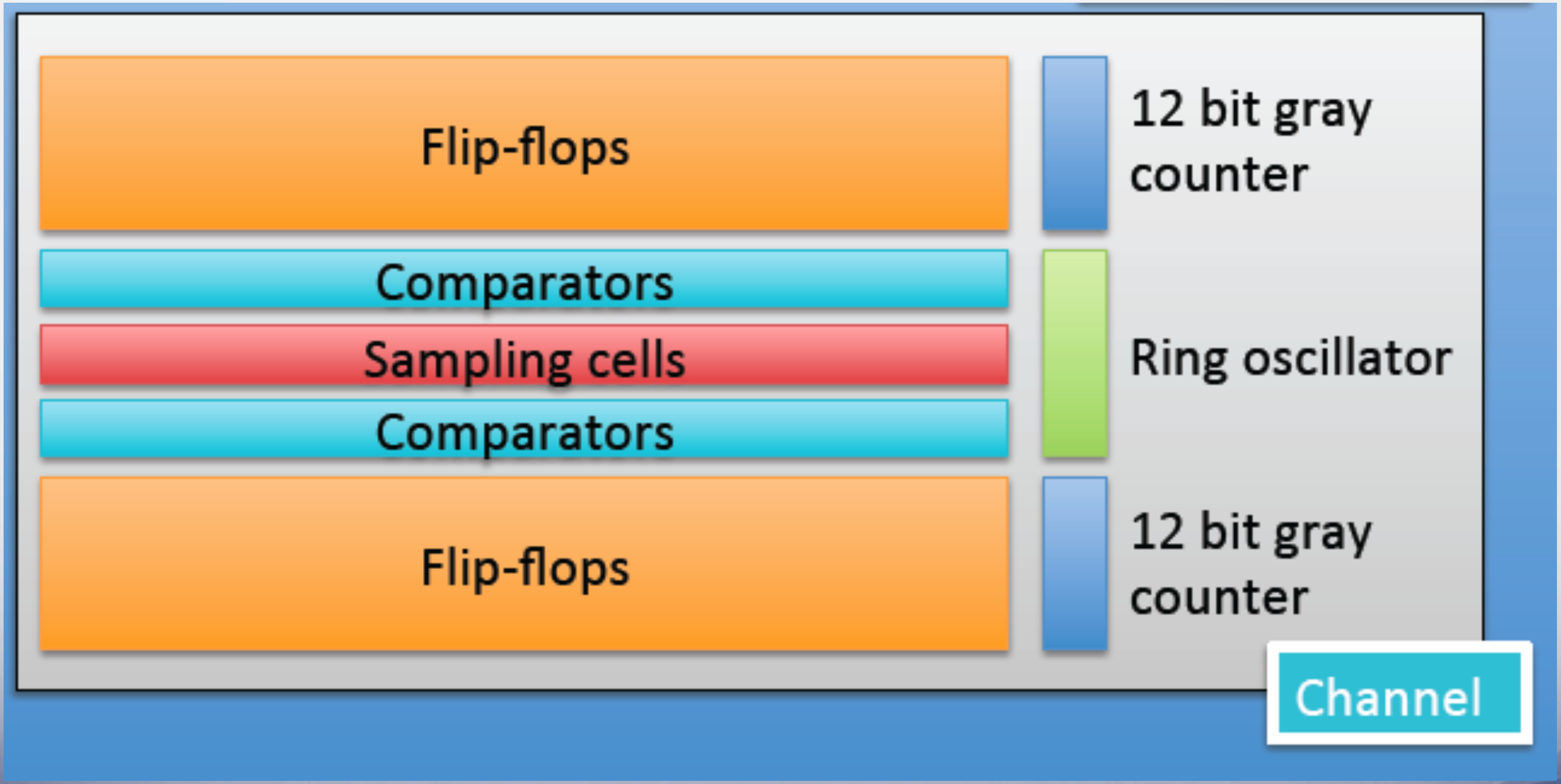
How to digitize the signals



- At the beginning of the digitization process a counter and a ramp are started. When the ramp reaches the value stored in the sampling capacitance the comparator fires and stops the counter.

Chip architecture

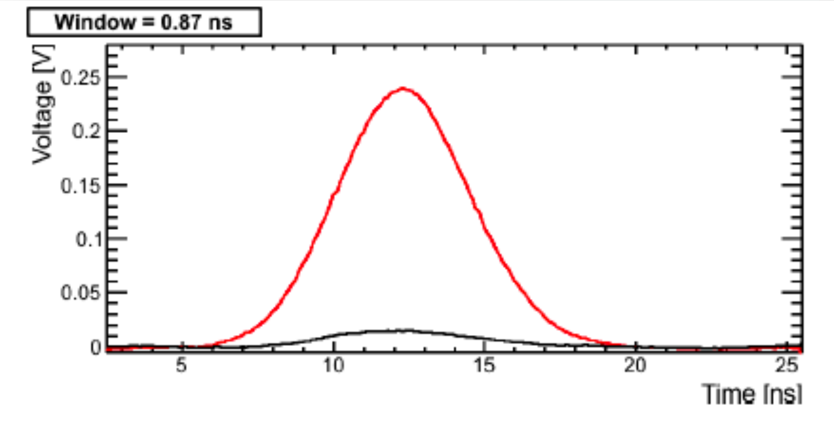
Channel architecture

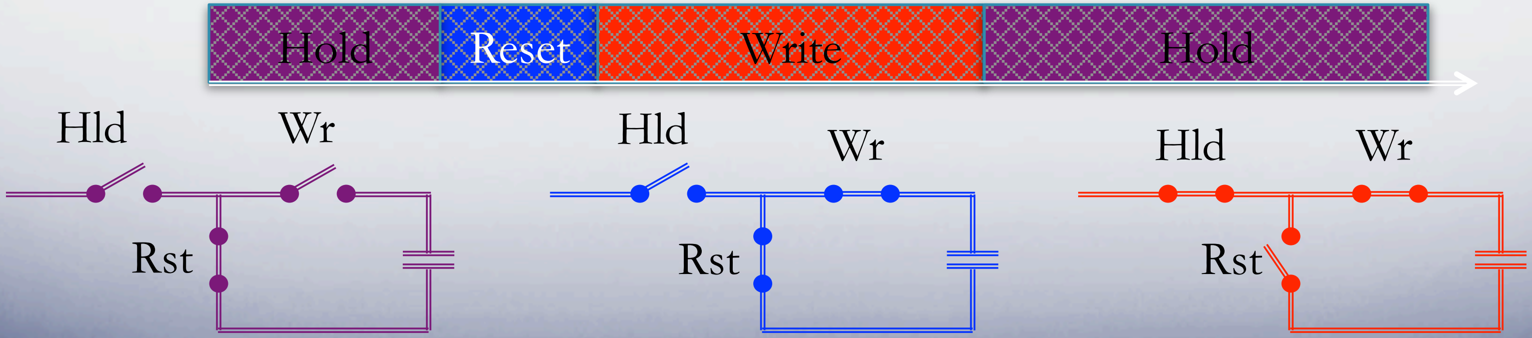


Towards a better sampling cell

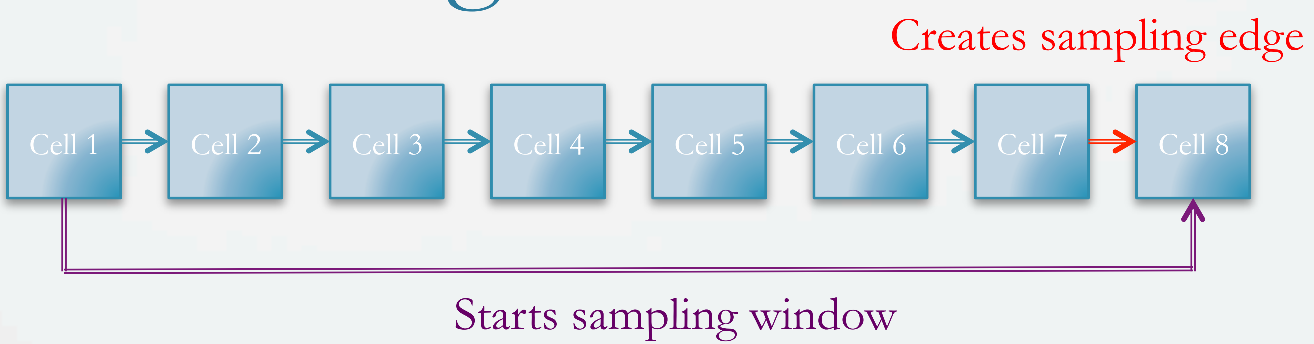
- Reset before write sampling cell: removes the ghost pulses.

Eric Oberla
UChicago

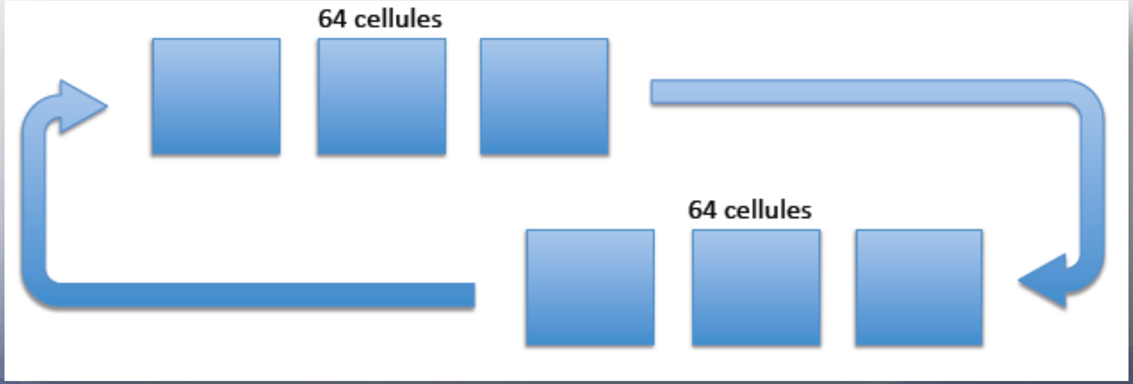




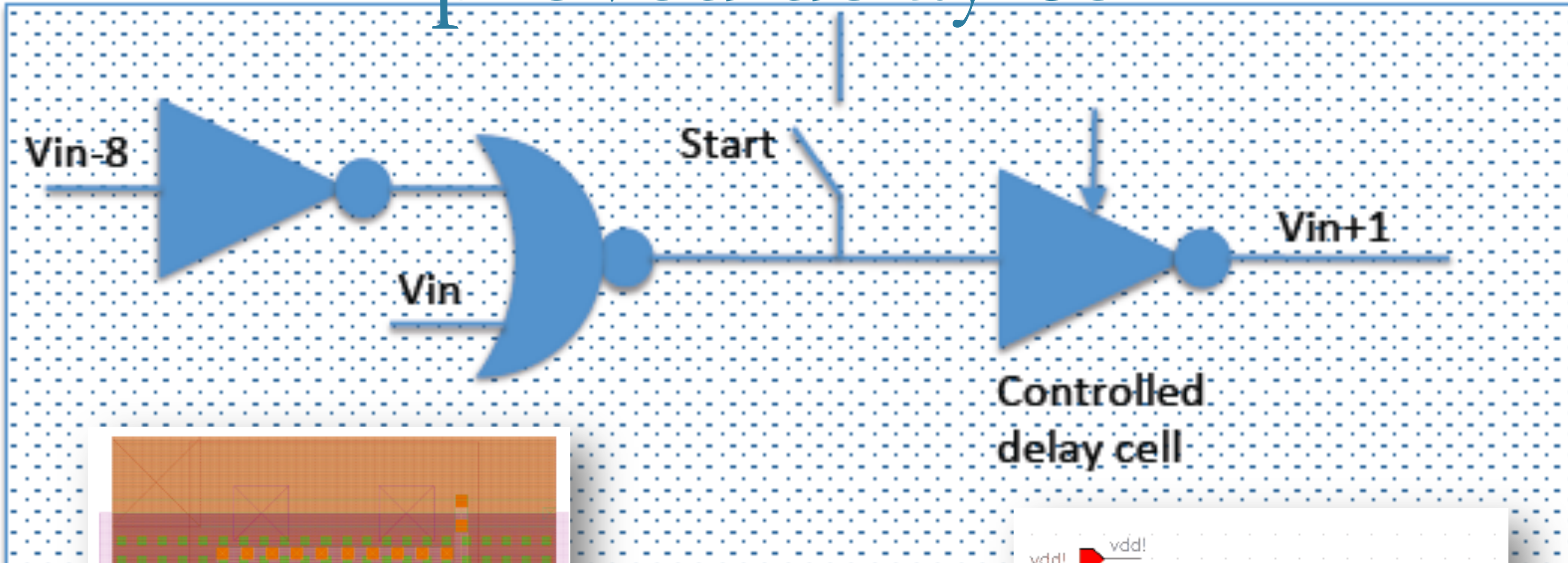
Toward a better timing generator

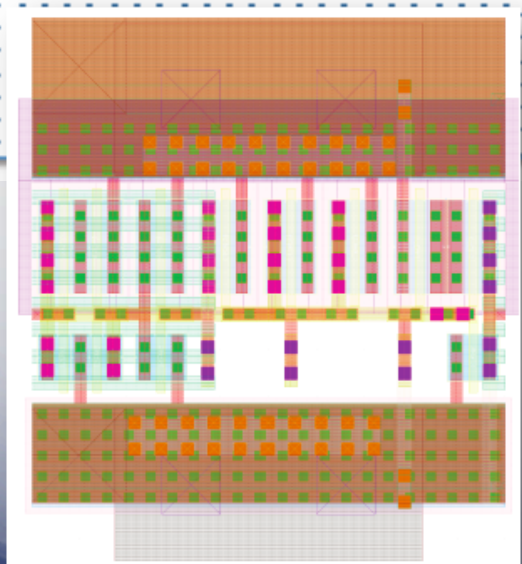


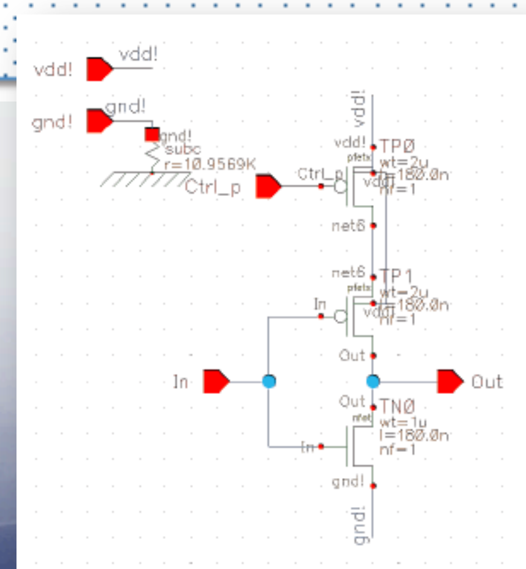
- Cell n-8 starts the sampling window.
- The sampling edge is propagating in the chain.
- Looped timing generator. Get rid of dead zones.



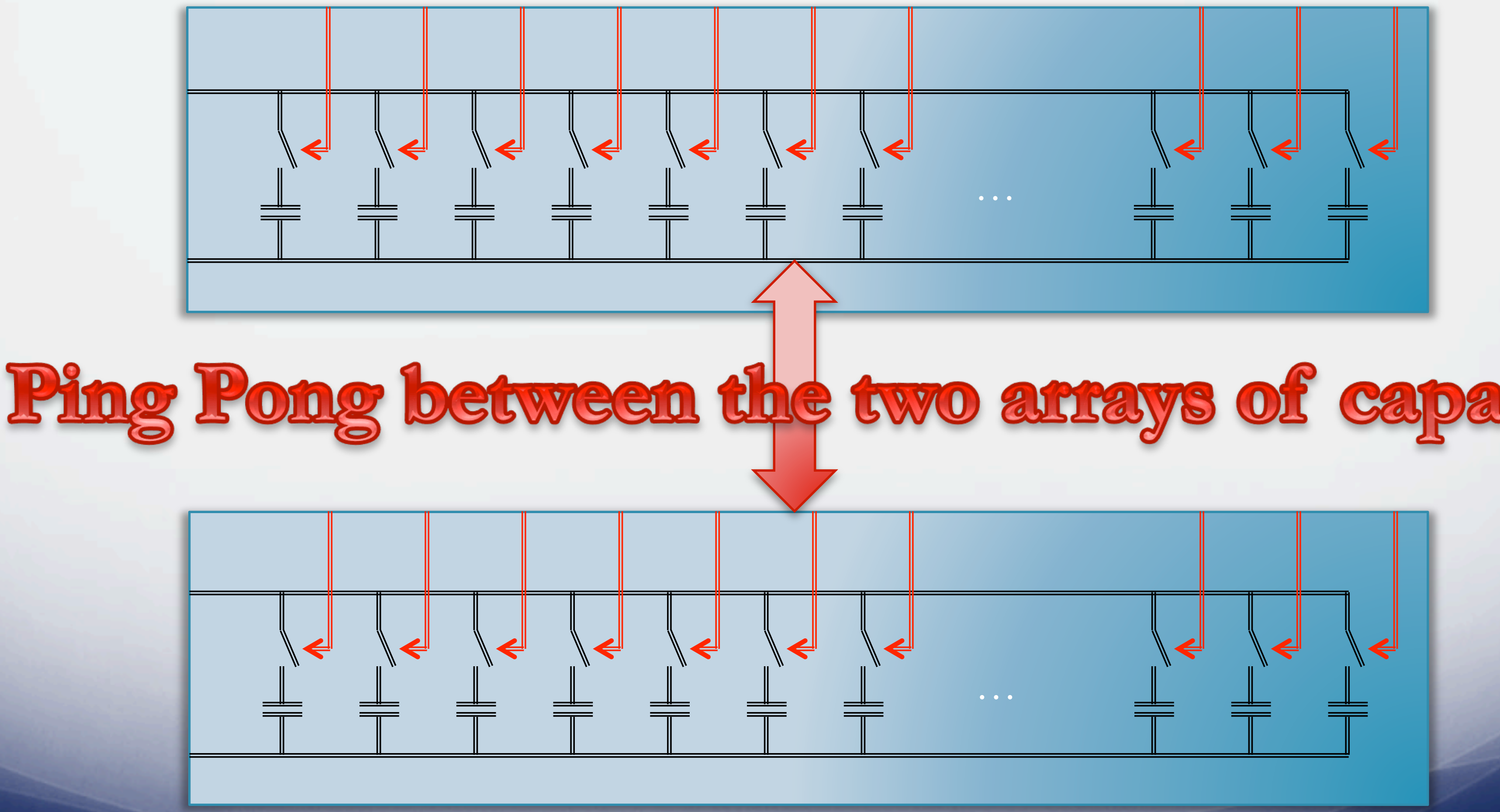
Improved delay cell



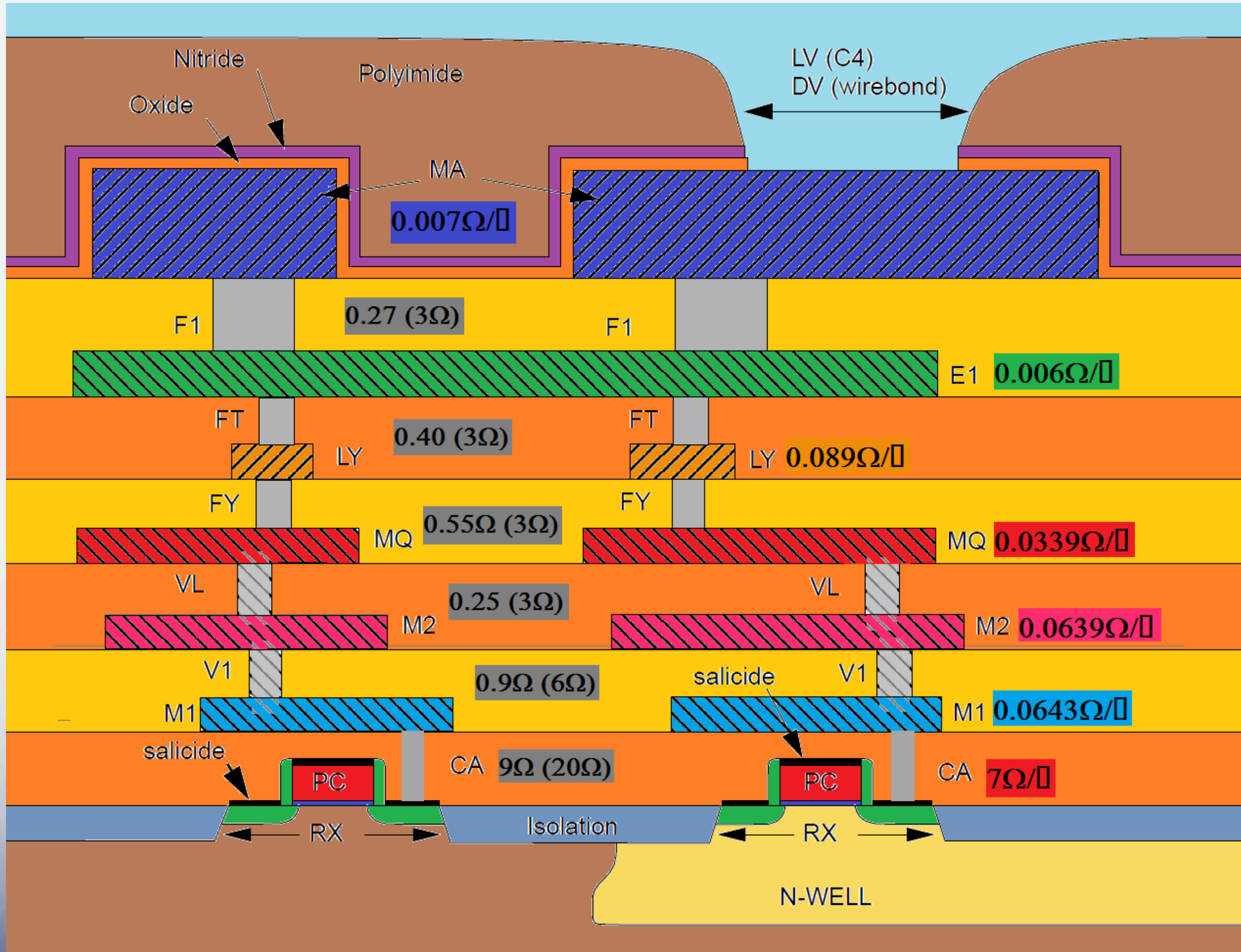




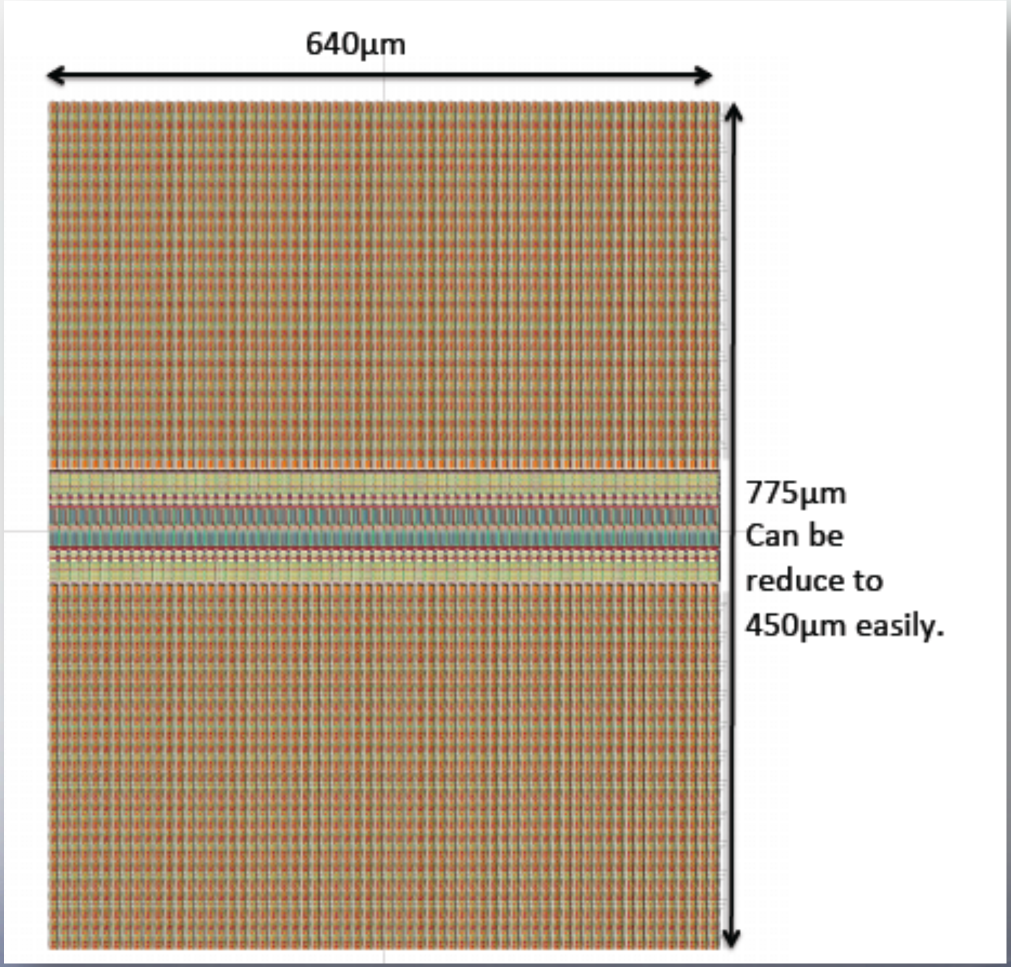
Towards no dead time



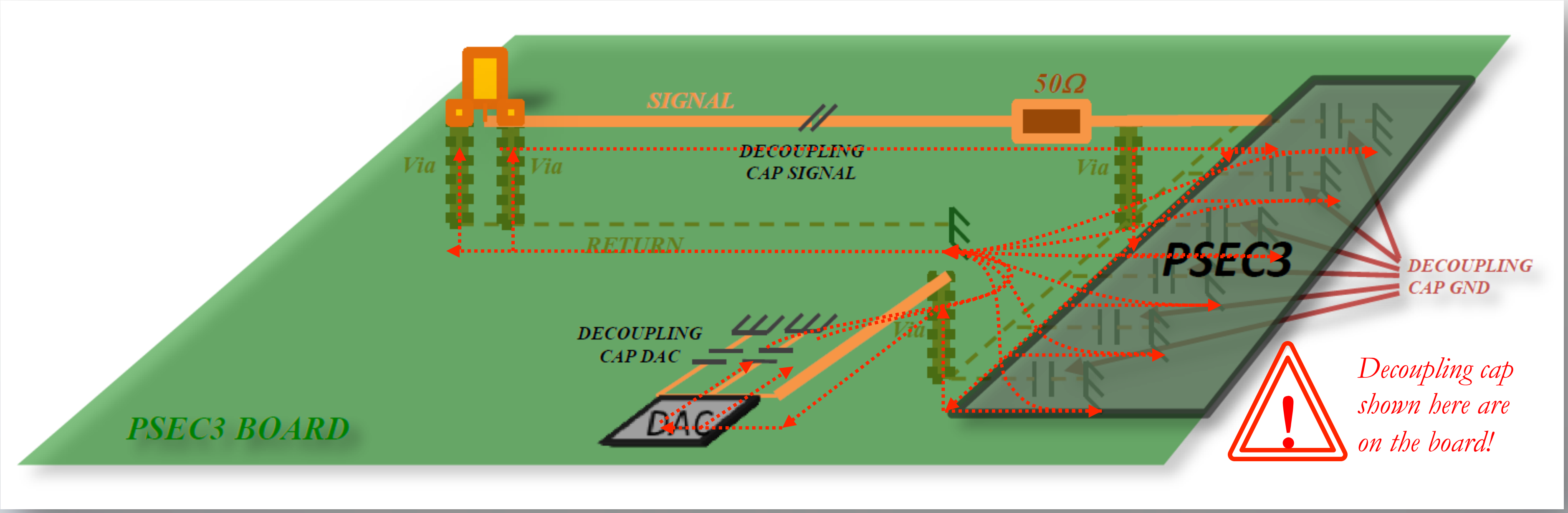
Chip design


Nitride
Oxide
Polyimide
LV (C4)
DV (wirebond)
MA
0.007Ω/□
F1
0.27 (3Ω)
F1
E1
0.006Ω/□
FT
LY
0.40 (3Ω)
FT
LY
0.089Ω/□
FY
MQ
0.55Ω (3Ω)
FY
MQ
0.0339Ω/□
VL
M2
0.25 (3Ω)
VL
M2
0.0639Ω/□
V1
0.9Ω (6Ω)
salicide
V1
M1
M1
0.0643Ω/□
salicide
PC
CA
9Ω (20Ω)
PC
CA
7Ω/□
RX
Isolation
RX
N-WELL

Complete (almost) sampling channel



Board bandwidth limitation



Within the actual Psec3 tester board:

1. The signal goes through the 50Ohms to the chip
2. The signal returns via gnd on the board through all decoupling cap of all channels and the DAC.
3. The signal returns through the line to the connector

Conclusion

- Fast timing can help AFP but also many other fields in physics.
- SAMPIC target: up to 80Mhz working frequency. Which can cover pretty much any physics experiment.
- Very versatile and easily scalable to large physics experiment.
- Controlled by FPGA which can do time, amplitude, charge, … extraction.

Thank you