FROM RESEARCH TO INDUSTRY

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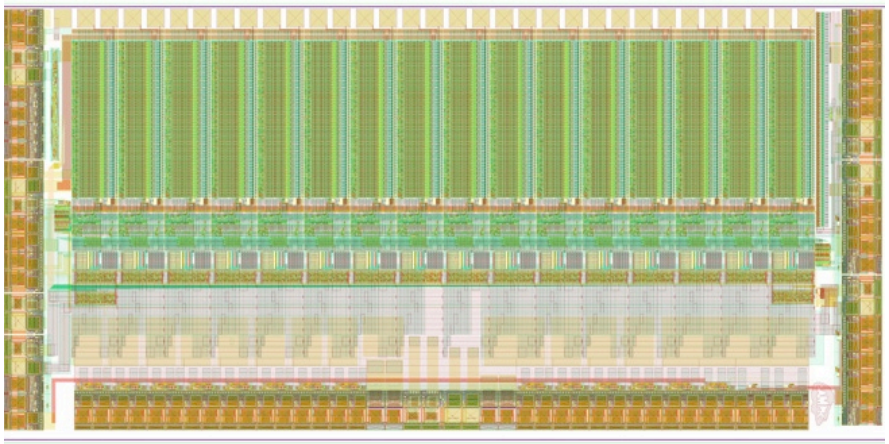
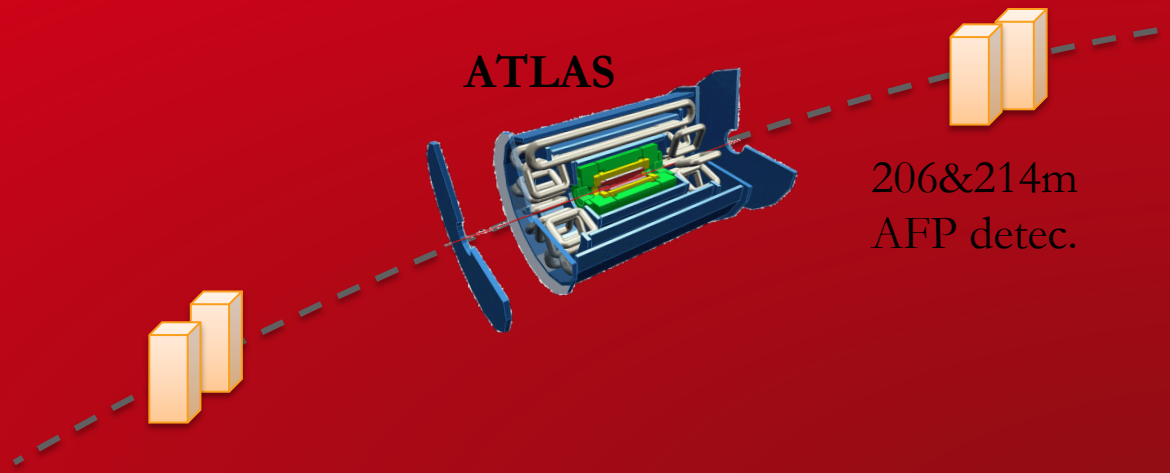
The SamPic readout chip

Phd Thesis work supervised by E. Delagnes and C.Royon

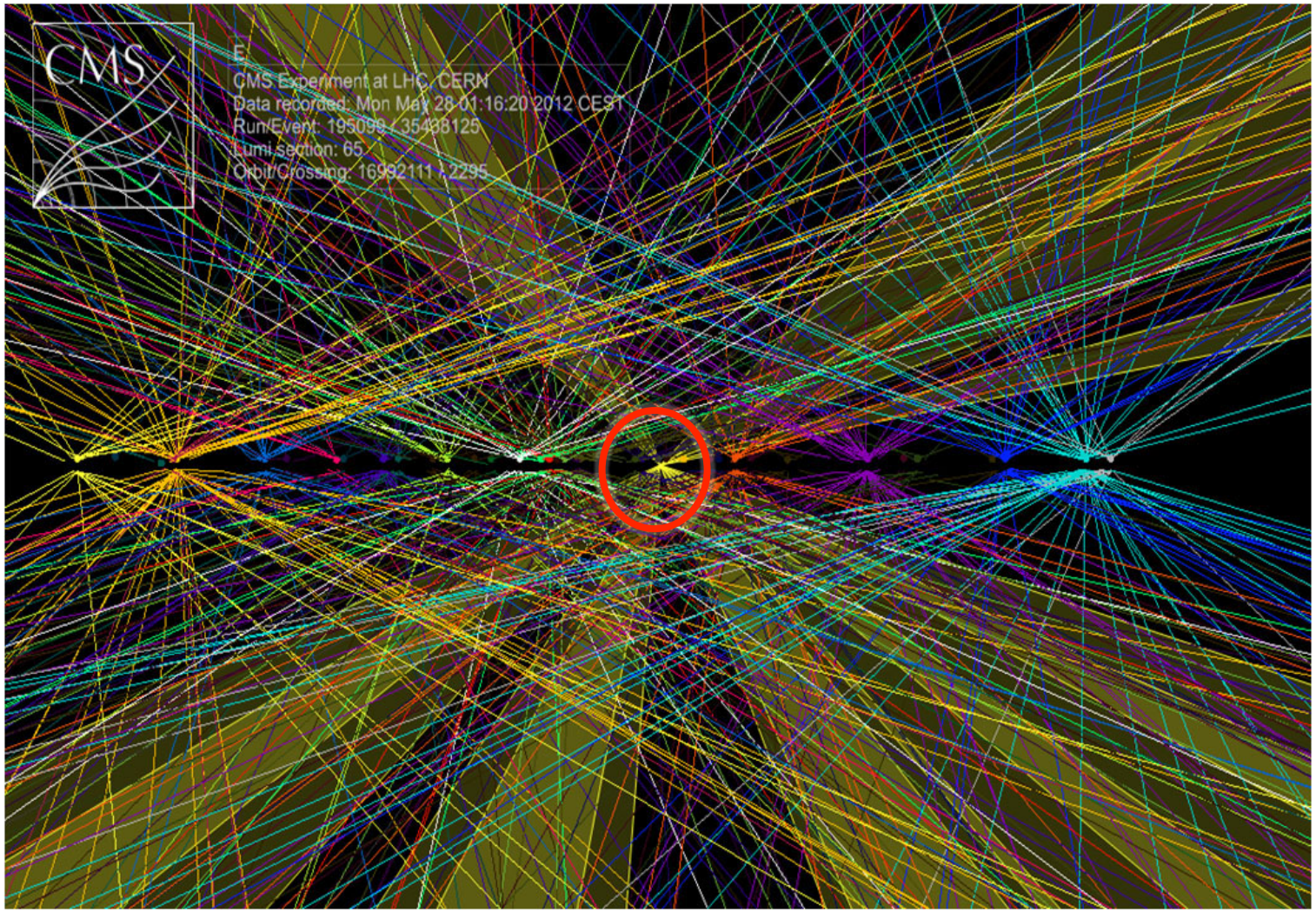


27 AUGUST 2013

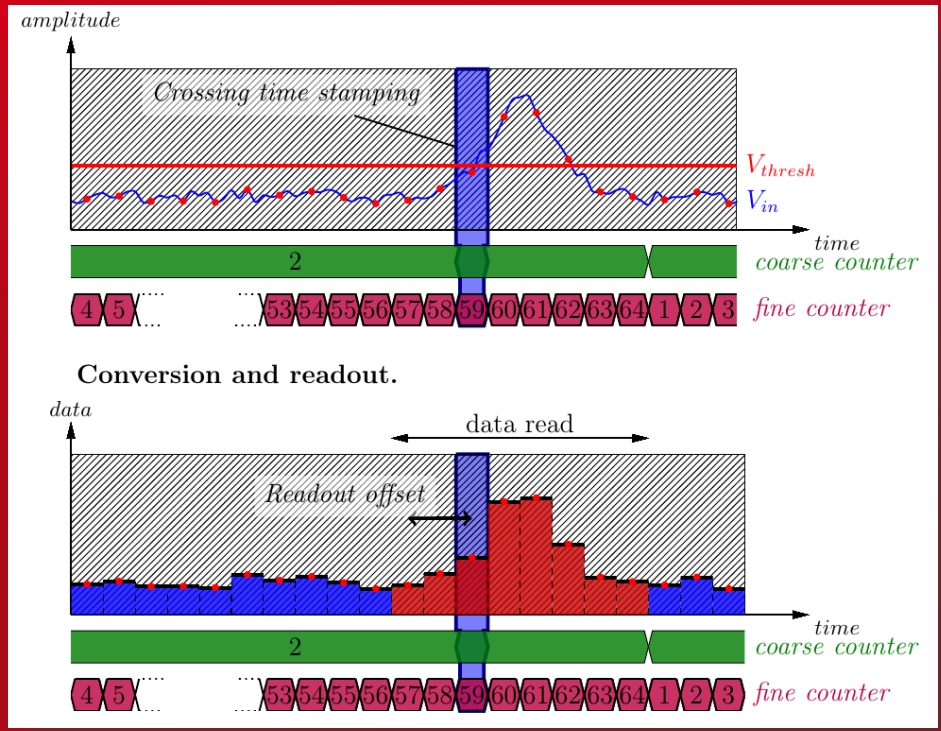
INTRO: MEASURE PICOSECOND TIME OF FLIGHT IN PARTICLE DETECTORS



PILE-UP SUPPRESSION

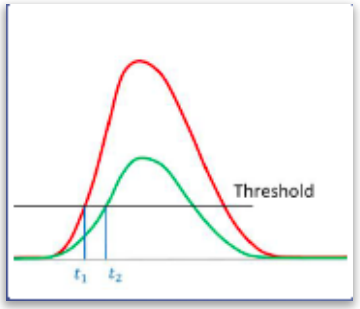


TIME MEASUREMENT



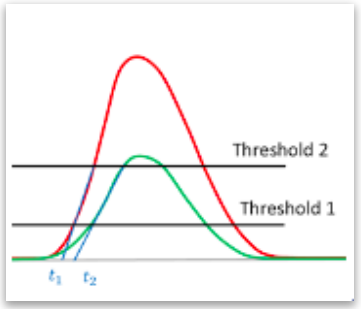
TIME EXTRACTION

Single threshold



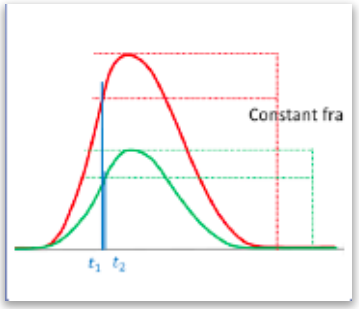
Advantage of simplicty. Poor results

Multiple threshold



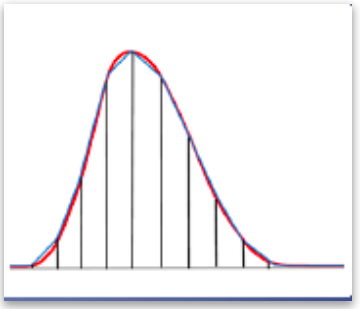
Basically interpolation on the rising edgel.

Constant fraction



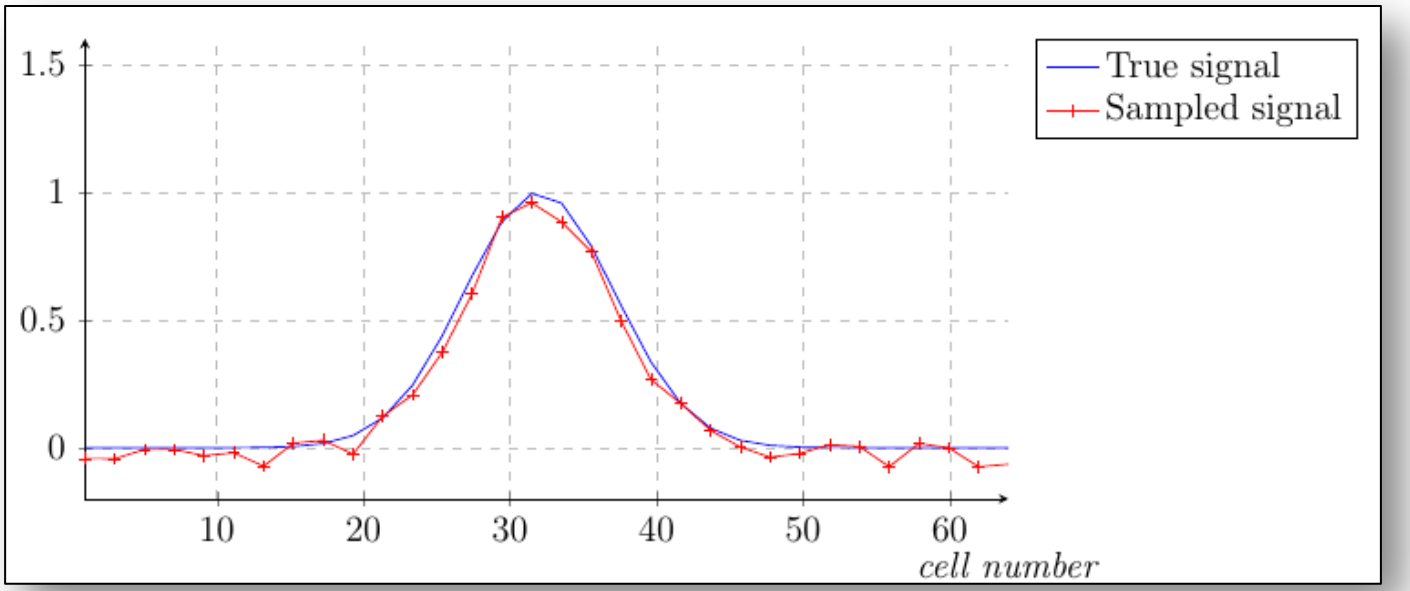
Complicated hardware. Relatively good precision.

Sampling



All digital algorithm possible: Mean square, Cross-correlation, …

TIME DELAY ESTIMATORS



- Normalized cross-correlation

$$c[k] = \frac{\sum_0^{N-1} s[i] \times t[i-k]}{\sqrt{\sum_0^{N-1} s[i]^2 \times \sum_0^{N-1} t[i]^2}} \; k \in [-N+1..N-1]$$

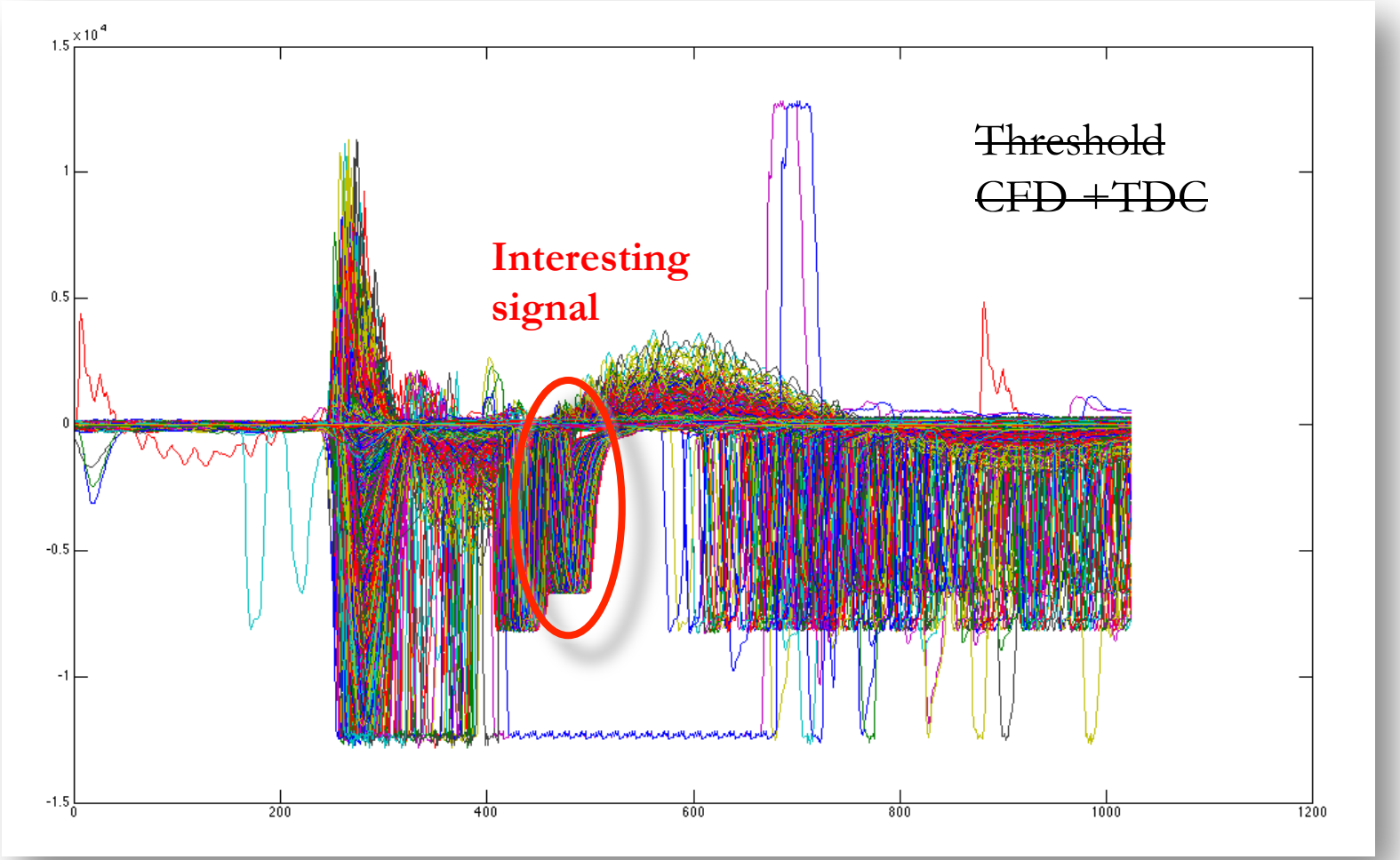
- Sum of absolute difference

$$a[k] = \sum_0^{N-1} |s[i] - t[i-k]| \; k \in [-N+1..N-1]$$

- Least mean squares

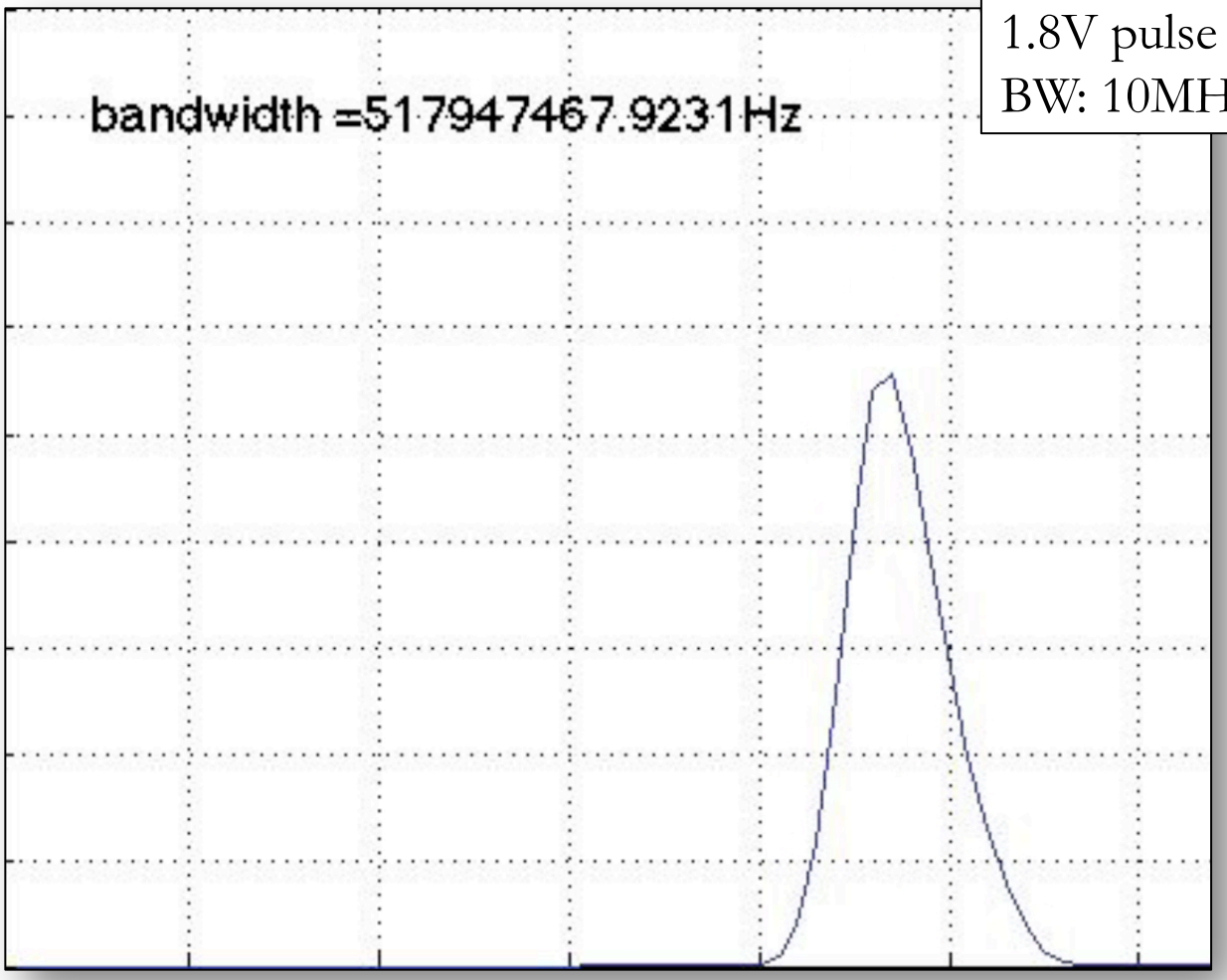
$$l[k] = \sum_0^{N-1} (s[i] - t[i-k])^2 \; k \in [-N+1..N-1]$$

WHY SAMPLING?



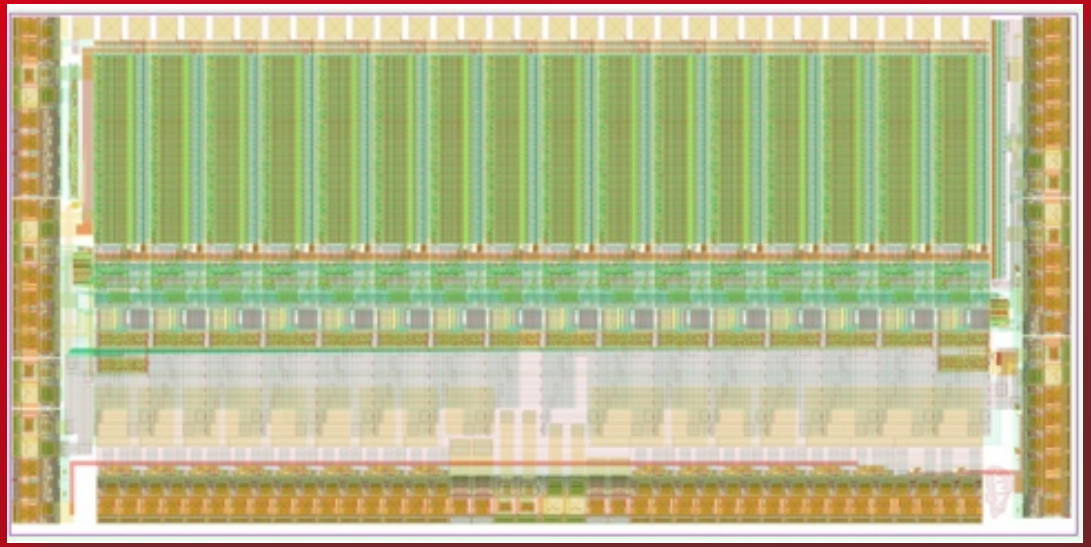
SPS CERN test beam – October 2012

WHY HIGHER BANDWIDTH?



1.8V pulse
BW: 10MHz – 10GHz

THE SAMPIC CHIP



INTRODUCTION

SamPic is a CMOS chip designed to read the forward timing detectors of ATLAS. **Sam**pler for **Pic**osecond time pick-off.

R&D financed by P2IO

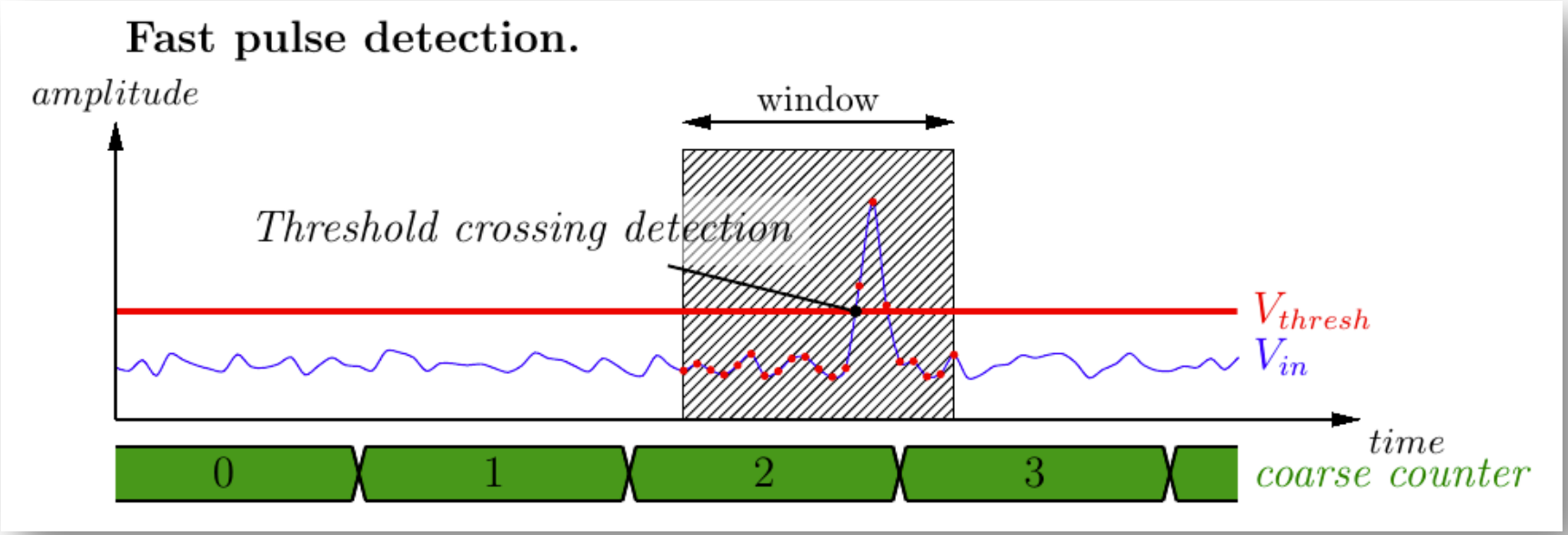
Goals:

- Technology evaluation (IBM 0.18µm)
- Tests of design choices (DLL & SCA architecture)
- Simultaneous Read&Write
- Creating a multi-channel chip easily integrable in large-scale experiments (ATLAS).

PRINCIPLE AND TRESHOLD DETECTION

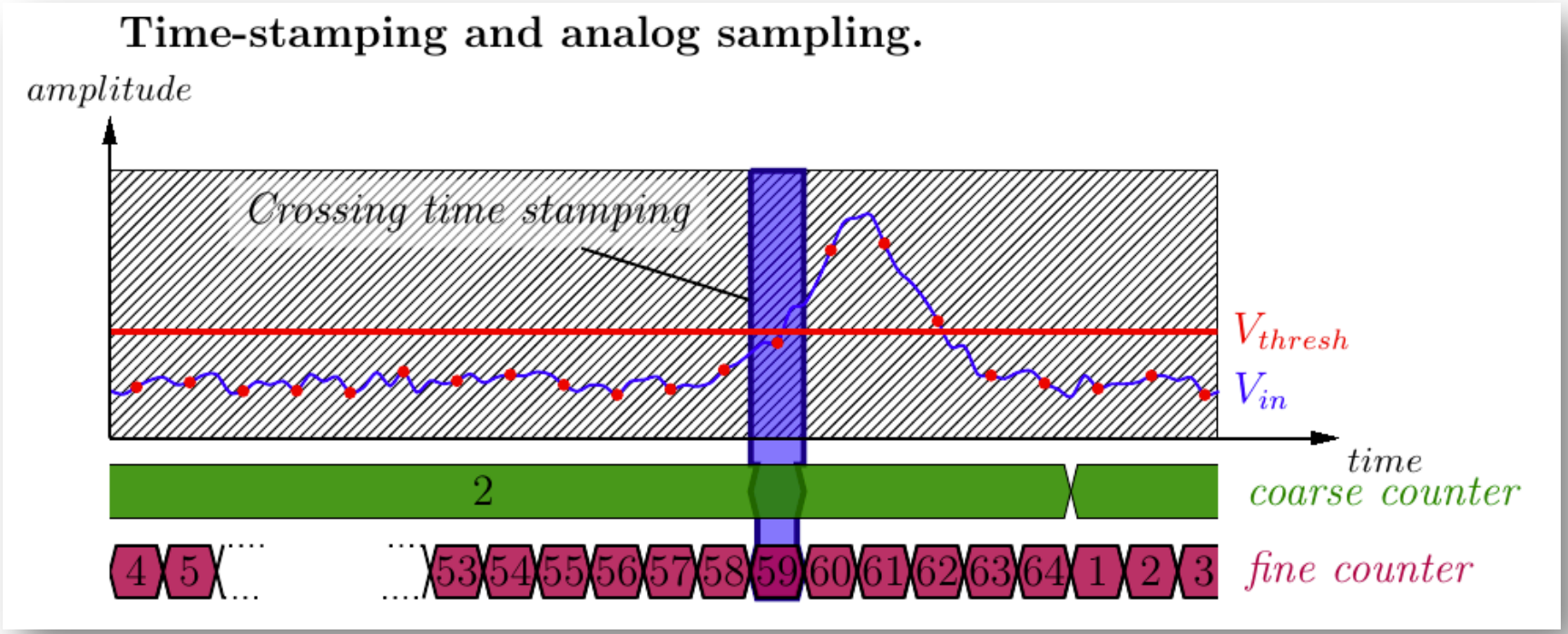
Detection of 'Event of interest' above threshold.

- Adjustable threshold (DAC).
- Pulse polarity (rising or falling edge).
- Additional post-trigger delay.



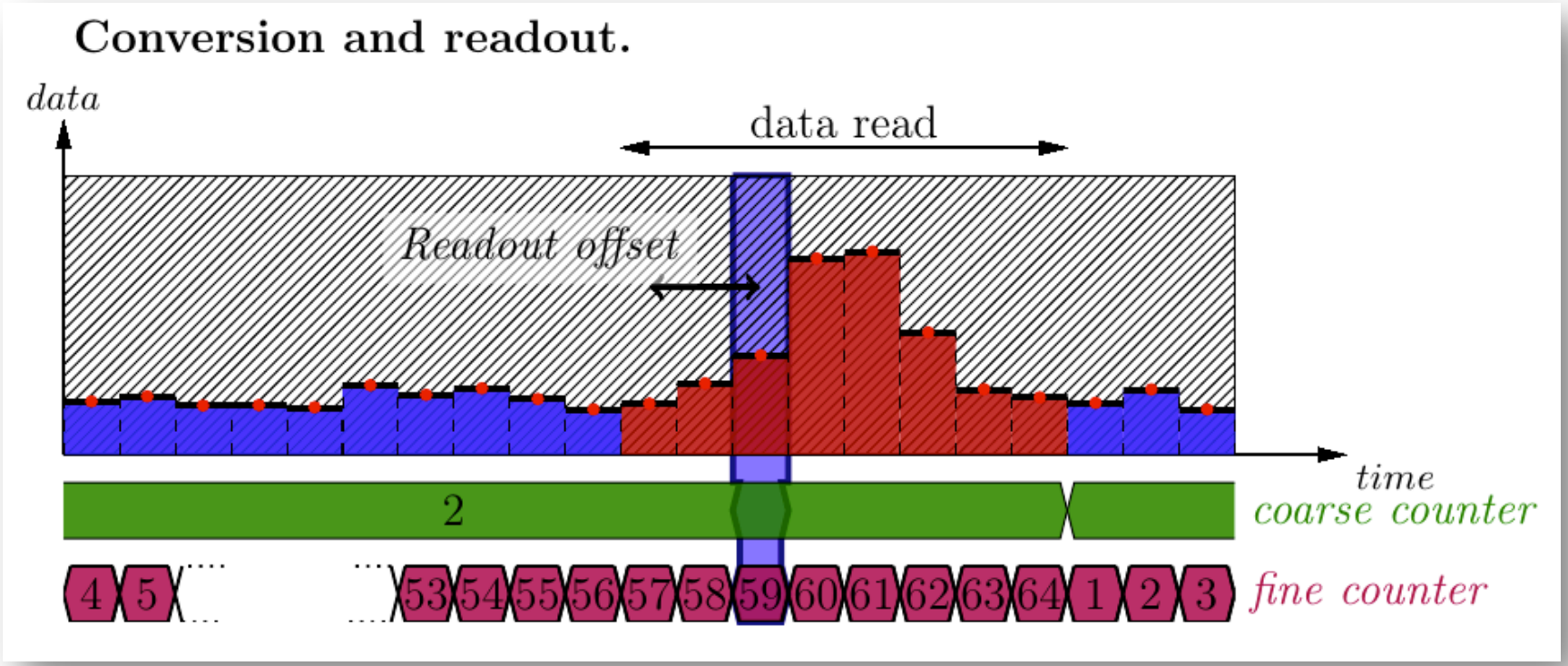
Sampling & time-stamping.

- 64 points from 1 to 10Gs/s.
- TDC 18 bits – 100ps precision.



Conversion and readout.

- Wilkinson 11 bits - 2GHz.
- Region of interest readout LVDS 400MHz.

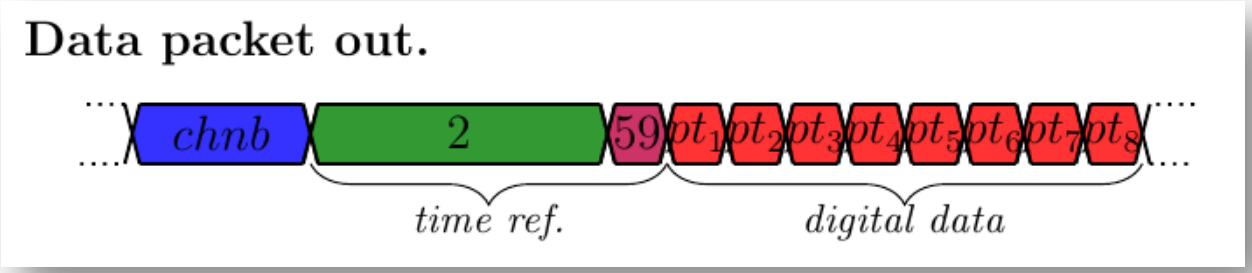


READOUT DATA STRUCTURE

Priority token readout between the 16 channels.

- If channels 2, 5 and 15 are hit they will be sequentially read, until no more available data.
- Process transparent to the user.

Structure of readout data.



SPECIFIC FEATURES OF SAMPIC

- Internal discriminators on all channels (with indiv. thresholds).
- 64 fully recorded samples (no dead zone).
- High bandwidth design.
- Reset before write (ghosts pulses removal).
- Gray code ADC conversion (limitation of metastability errors).
- Wide sampling range (Fast and Slow DLL modes).
- Fully configurable by serial link.

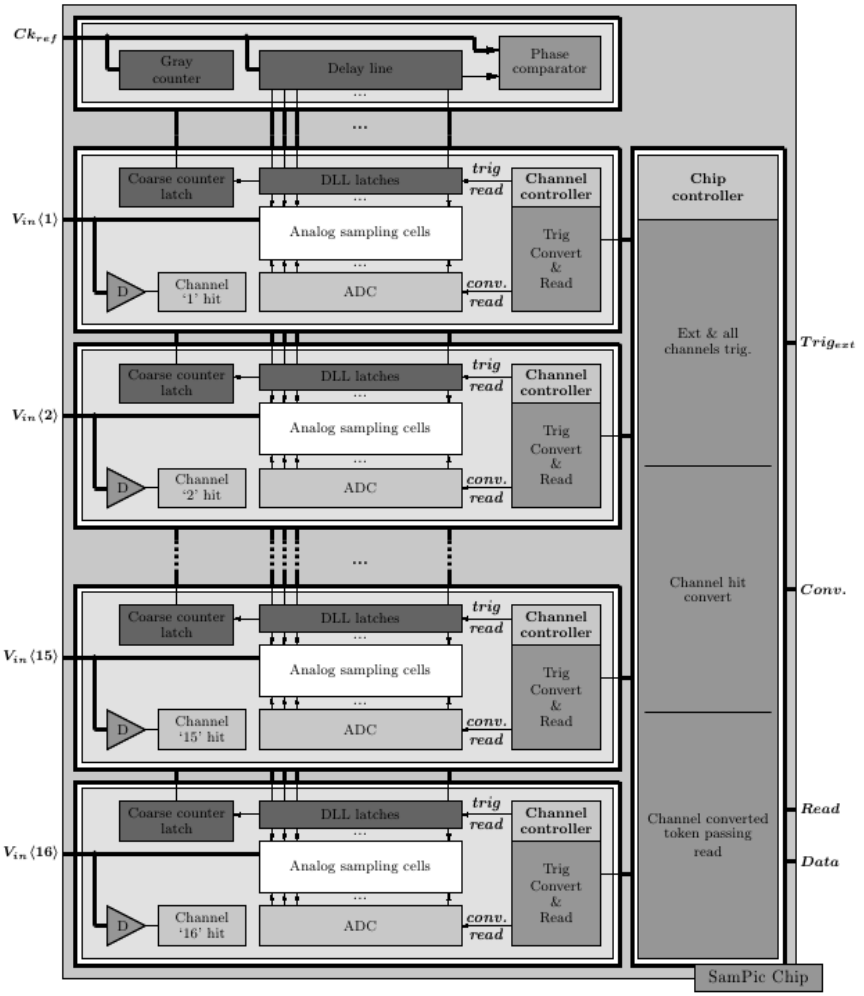
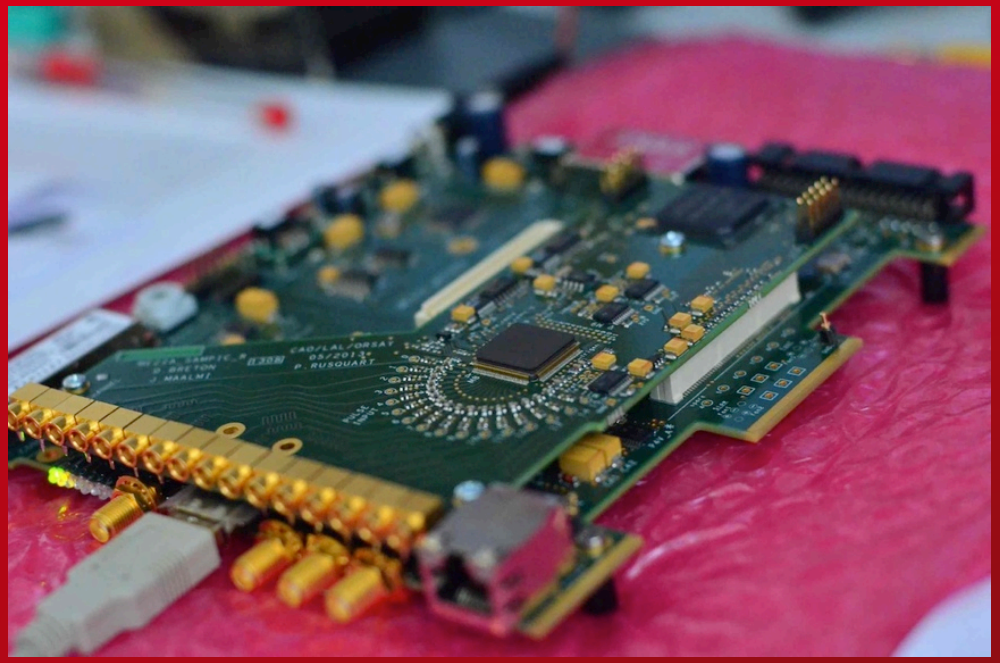


Figure 1 – Top level bloc diagram of the SamPic chip.

RESULTS & PERFORMANCES

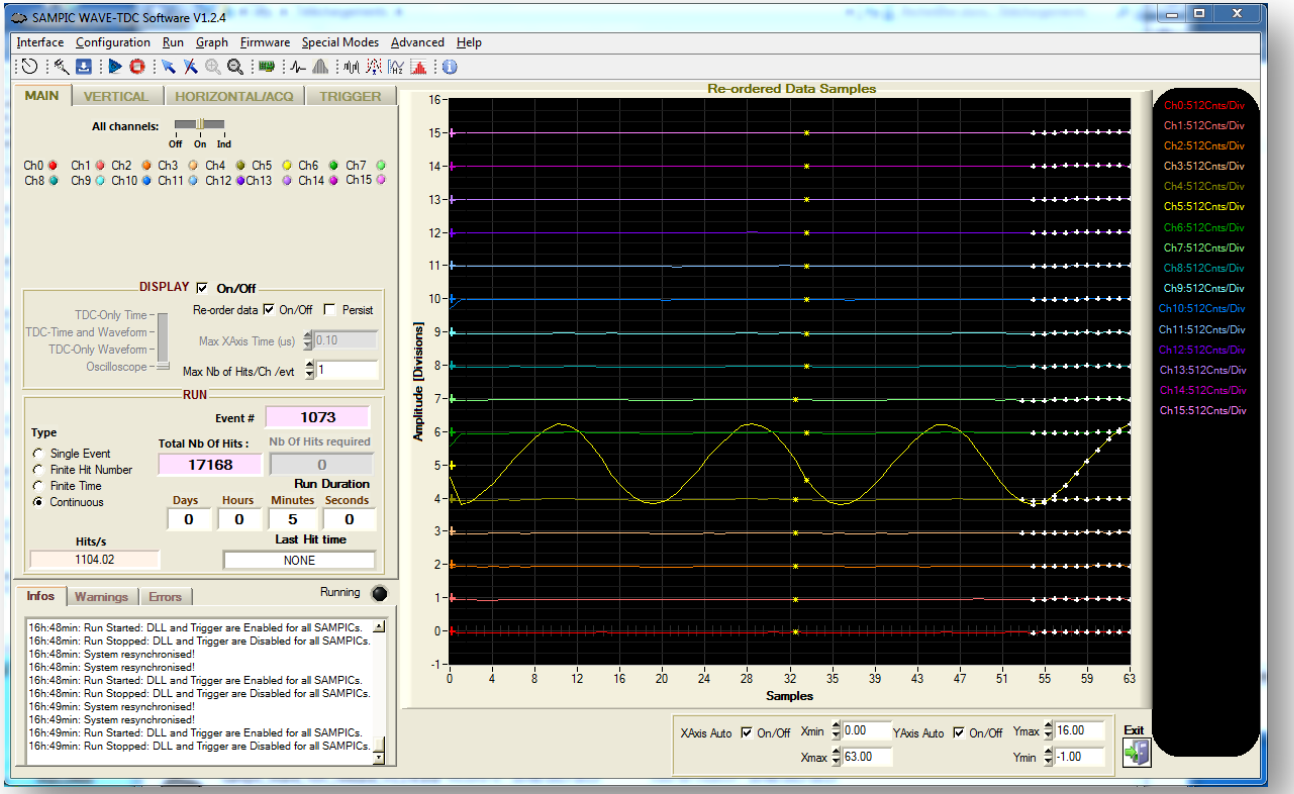


THE ACQUISITION BOARD (LAL)

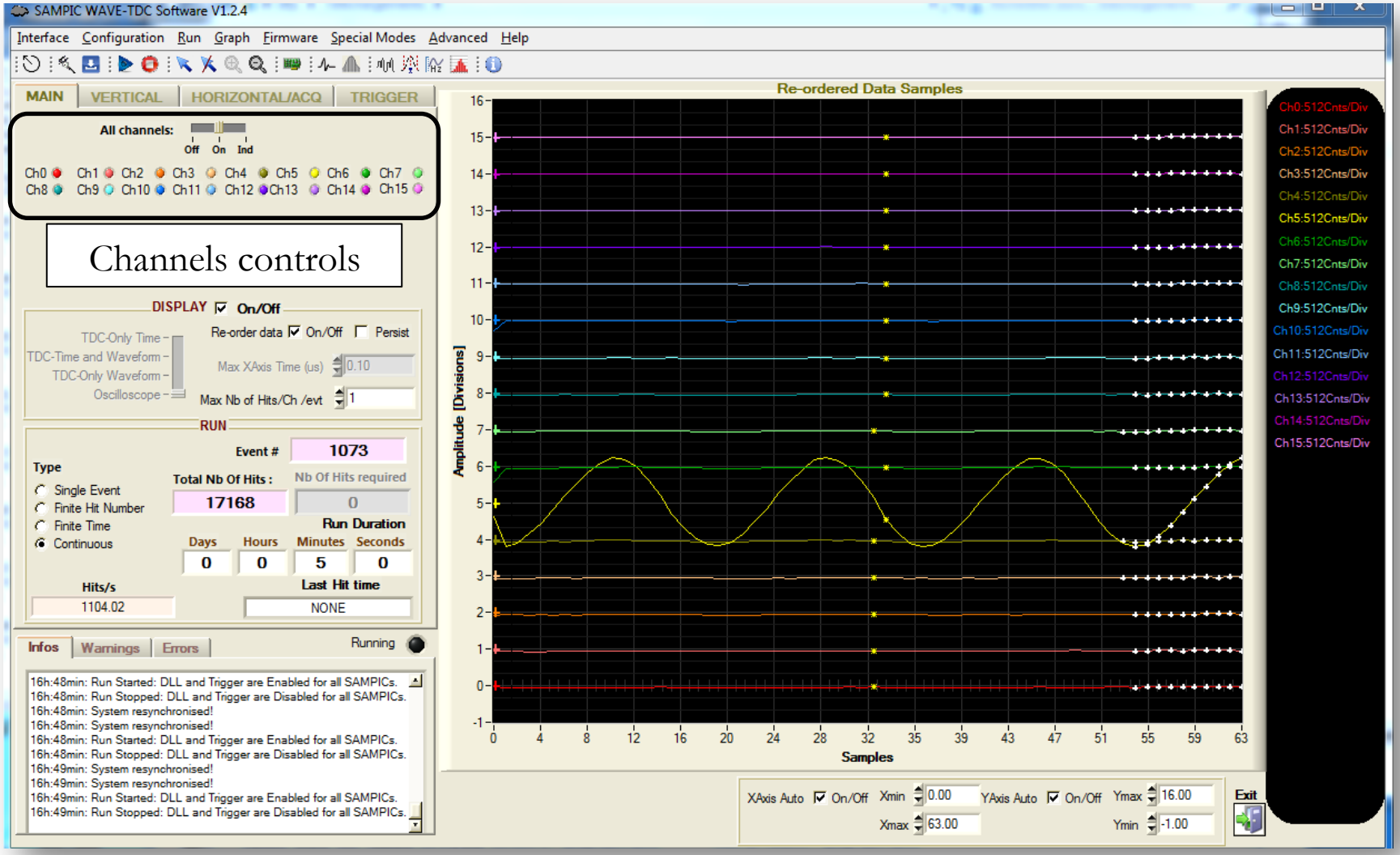
Jihane Maalmi
Dominique Breton
Pascal Rusquart

THE ACQUISITION SOFTWARE (LAL)

- 5V voltage supply – 1Amp.
- USB – Ethernet – Fiber Optic readout.
- Windows PC with LAL USB DLLs (easy: .exe 5min install).

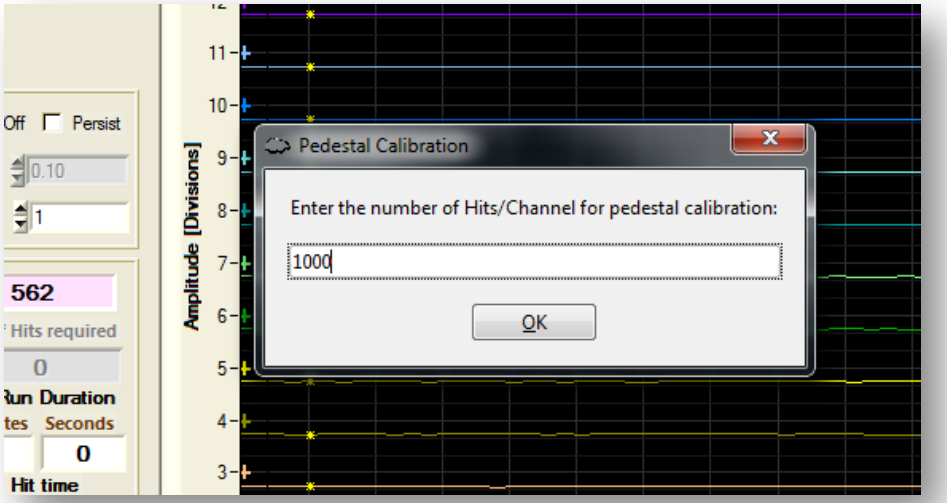


GUI – EASY CONFIGURATION AND MONITORING



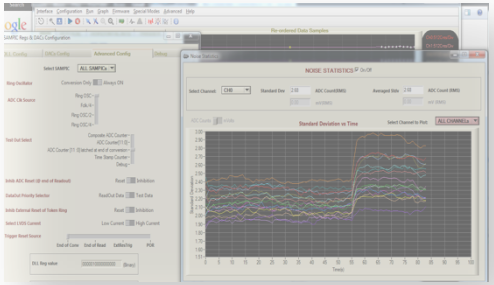
EXAMPLE OF FEATURE : PEDESTAL CALIBRATION

- Simple graphic interface for all calibrations.
- Calibration parameters loaded automatically at start-up.
- Pedestal & Fix pattern sampling time jitter correction.



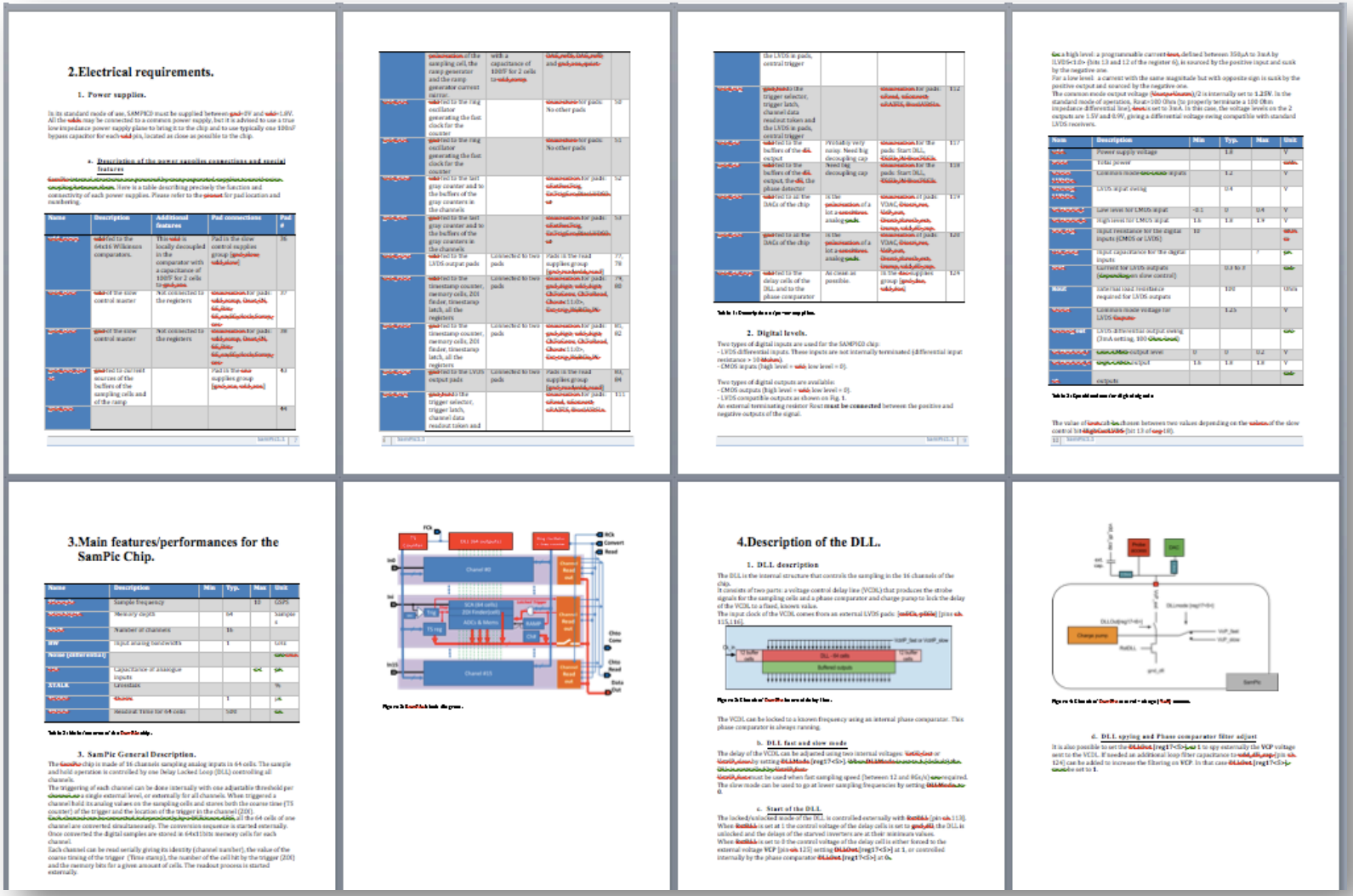
OTHER SOFTWARE CAPABILITIES

- Save data to file.
- Noise measurements.
- Sampling time jitter measurements.
- Sampling frequency modification.



- Single event – Continuous – Finite Hit number – Finite time acquisition mode.
- Time measurement – Charge measurement mode.
- DLL jitter monitoring.
- Hit rate monitoring.
- On-board internal pulsers for calibrations.
- Any other requirements, …

SAMPIC DOCUMENTATION



2.Electrical requirements.

1. Power supplies.

3.Main features/performances for the SamPic Chip.

3. SamPic General Description.

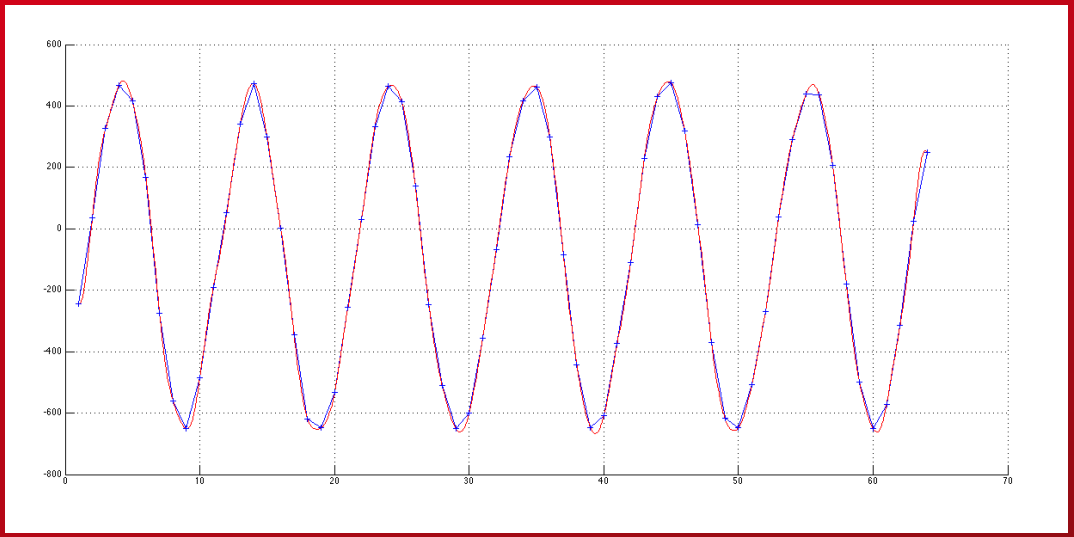
4.Description of the DLL.

1. DLL description

2. Digital levels.

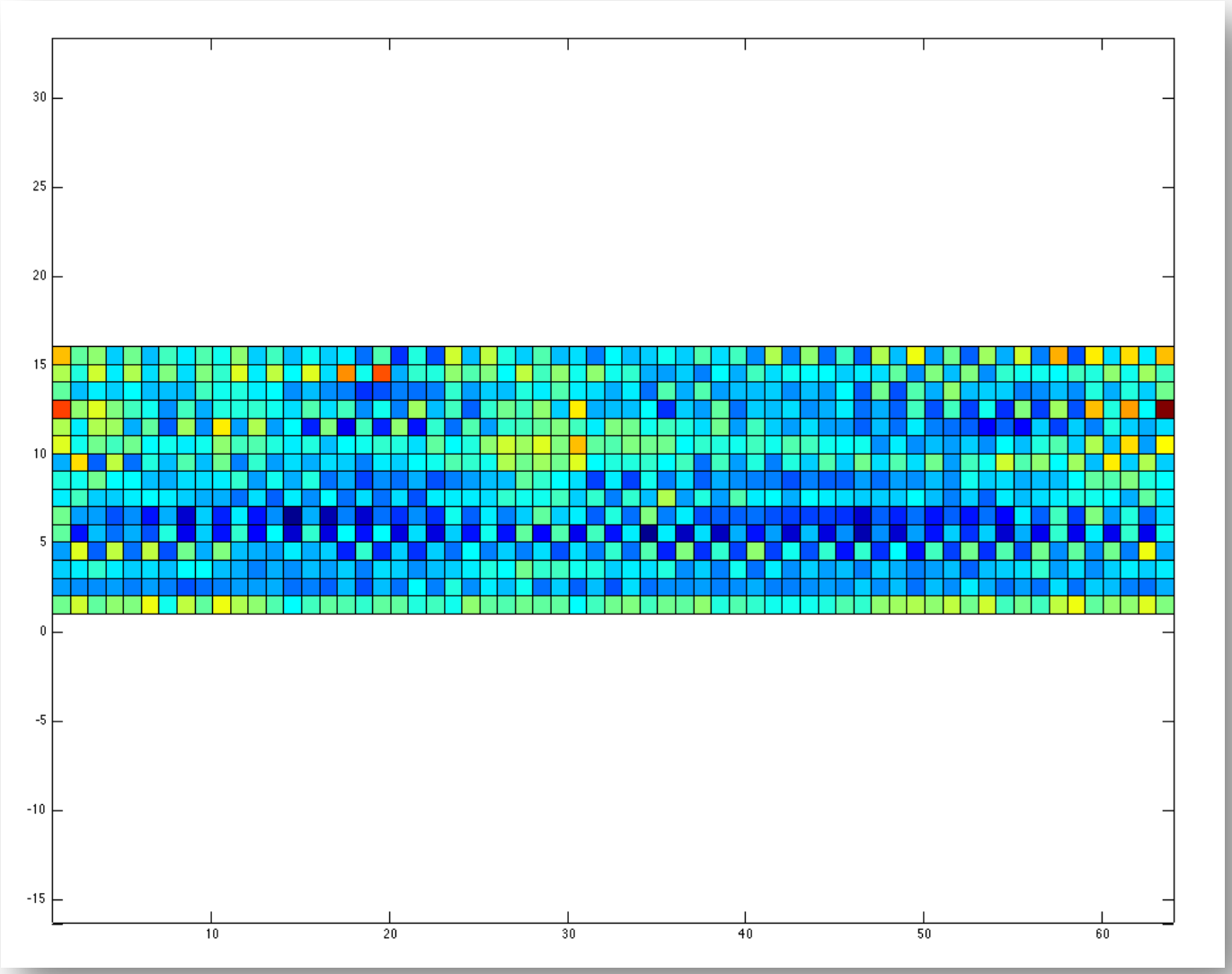
Extensive documentation – Proof-read – User tested

SAMPIC PERFORMANCES



SAMPIC NOISE MAP

- Noise floor at 1mV for input dynamic of 1V.
- Noisiest cell are at 1.3mV
- Result with no shielding nor filtering applied.
- RF shielding and better insulation will improve things.



BANDWIDTH AND TRIGGER

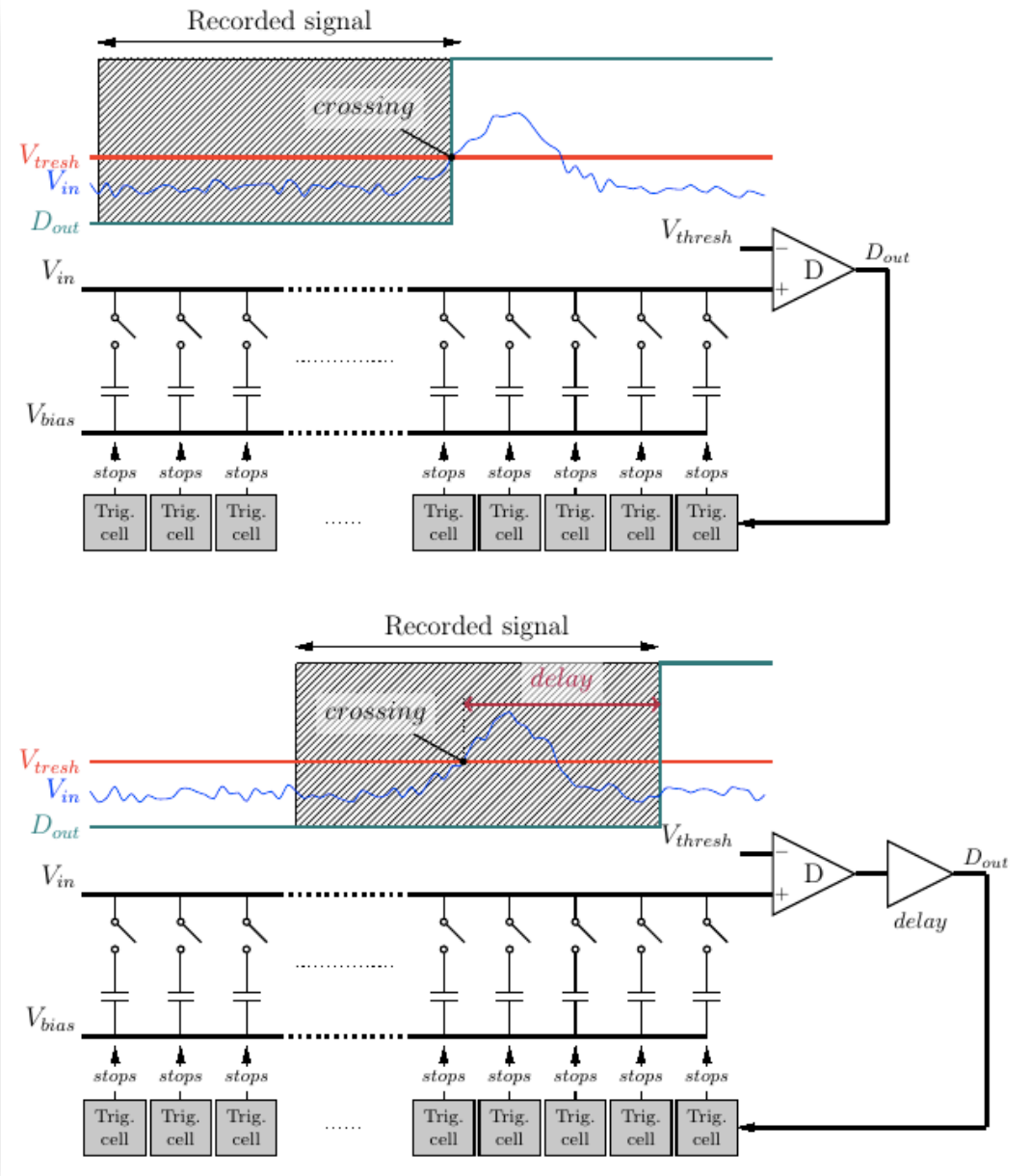
Bandwidth

- Measurements show 1.5GHz 3db-bandwidth in all channels.
- Bandwidth is uniform over all 64x16 cells.
- No resonance peak.

Trigger

- All internal triggers functional.
- Adjustable threshold per channel.
- Adjustable delay per channel.
- External trigger for selected channels possible.

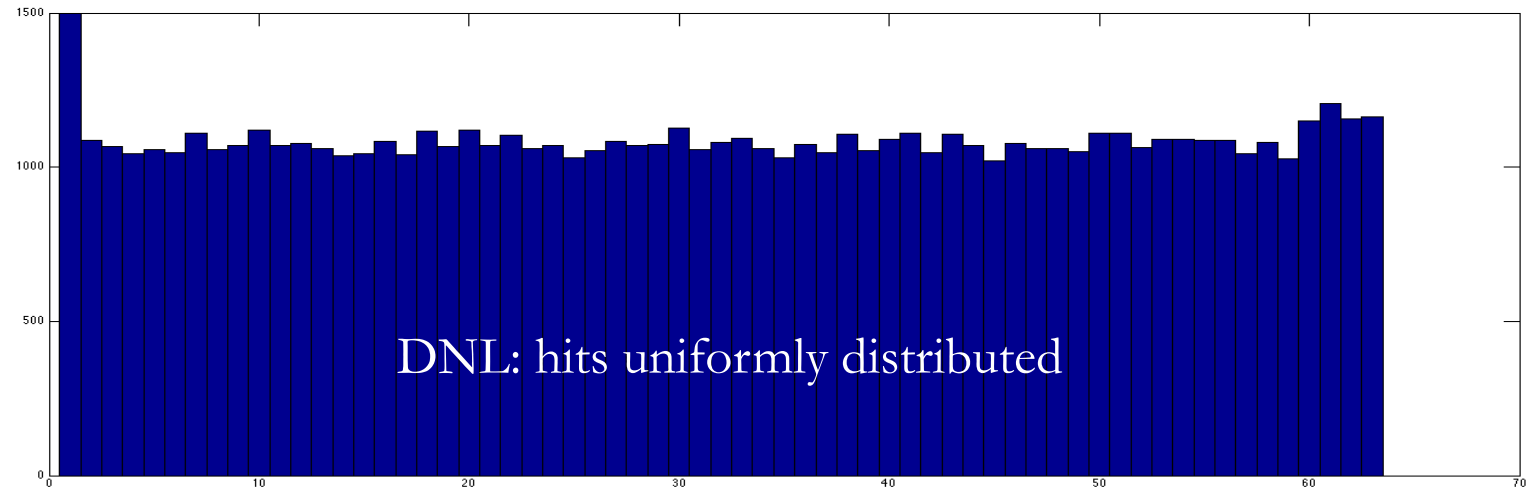
POST TRIGGER

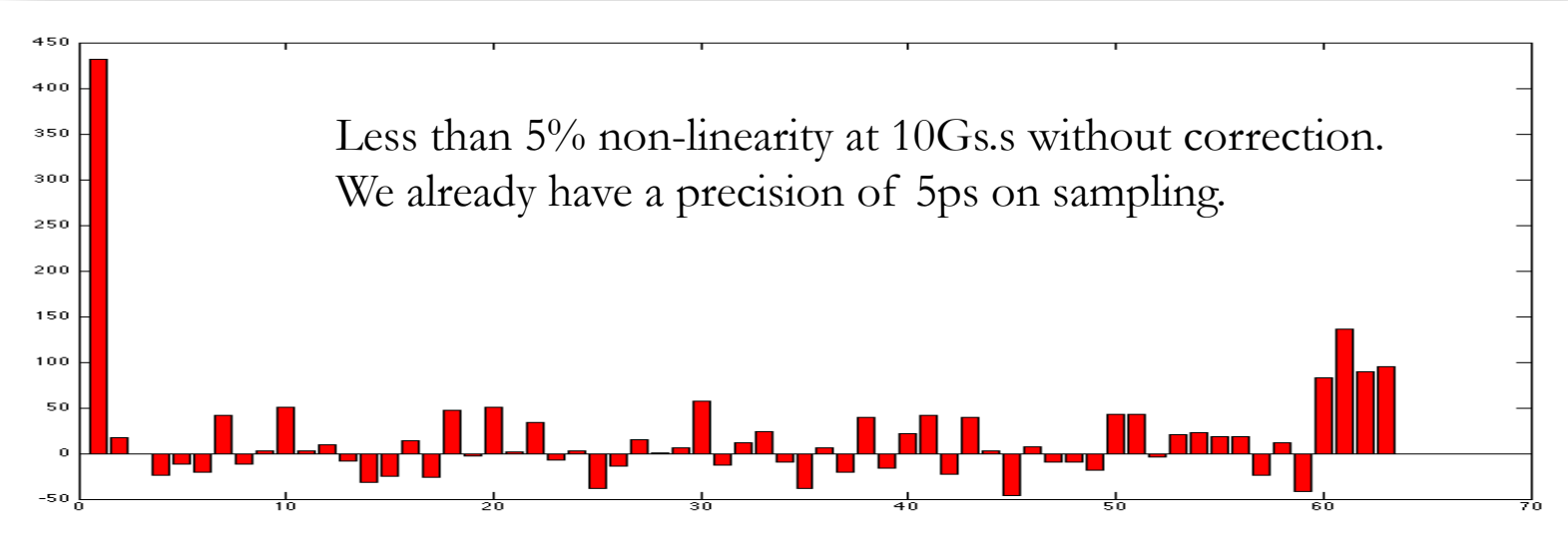


3 post-trig modes

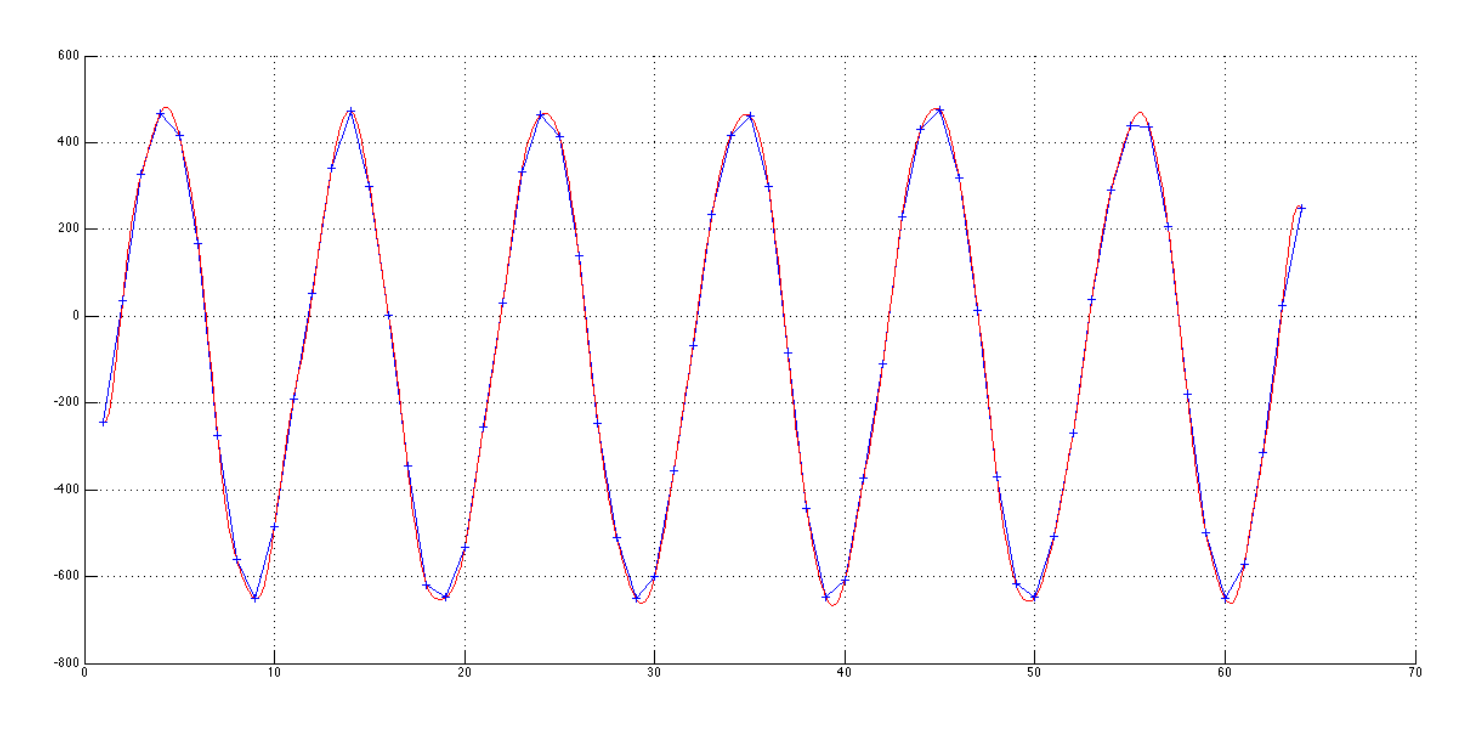
- No delay
- 800ps delay
- 1.6ns delay

DLL STABILITY AND NON-LINEARITY CORRECTIONS





QUALITY OF SAMPLING



1GHz sinewave 64 samples 'out of the box' (pedestal cal. only) @ 10Gs/s.
64 usable data points.
Will improve with DNL calibration.
Will improve with linearity corrections.

HITS – CONVERSION & READOUT RULES

The SamPic rules for Hits – Conversion & Readout

Rule 1. All SamPic channels that are not triggered are tacking data.

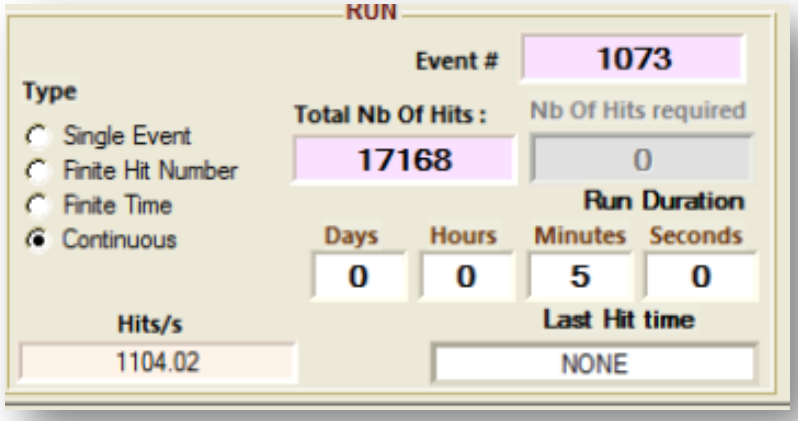
Rule 2. All triggered channels that are not holding data to read are converted **simultaneously**. User activated.

Rule 3. All converted channels are readout **sequentially**. User activated.

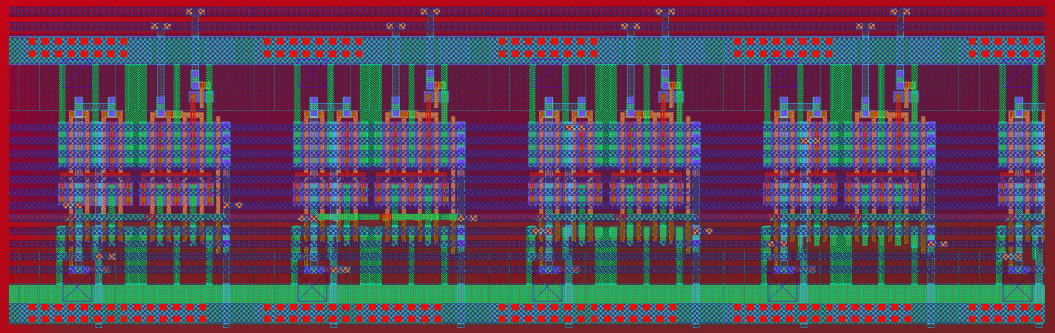
HIT RATE

Maximum SamPic Hit rate:

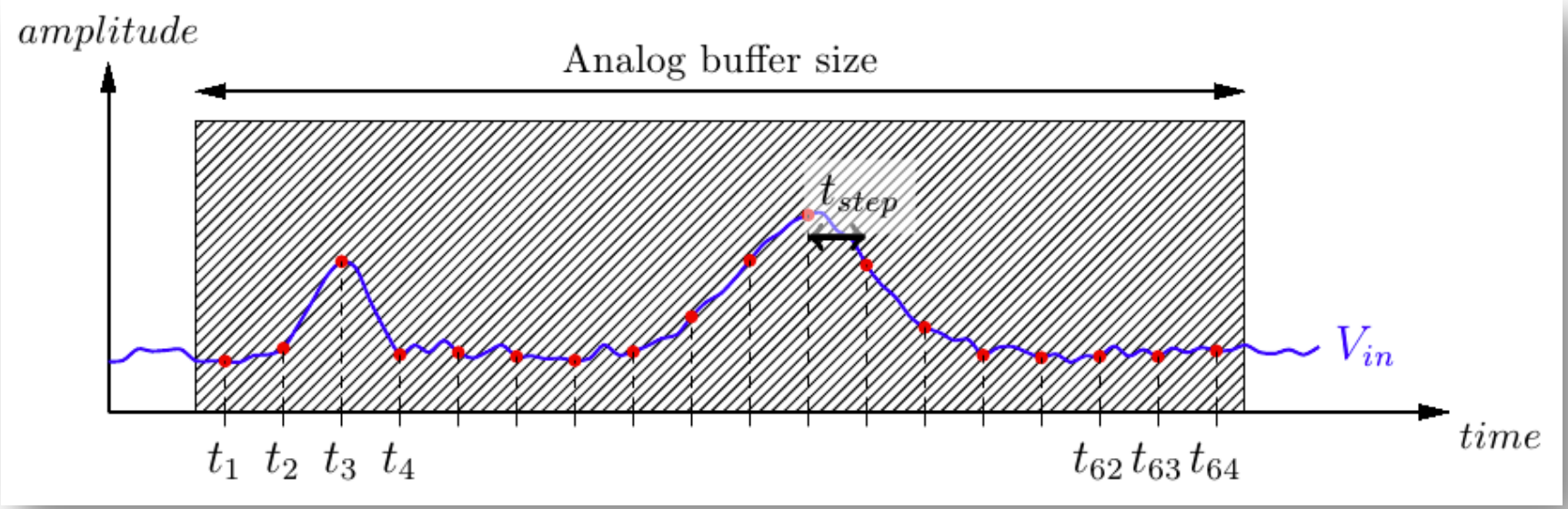
- 1µs for conversion
- 2.5ns/word read (min 20ns – max 170ns x 16).
- SamPic can take data during read sequence.
- Hit rate does not vary if int. or ext trigger used.
- Currently software limited!
- Acquisition board is Optic fiber ready and Ethernet ready

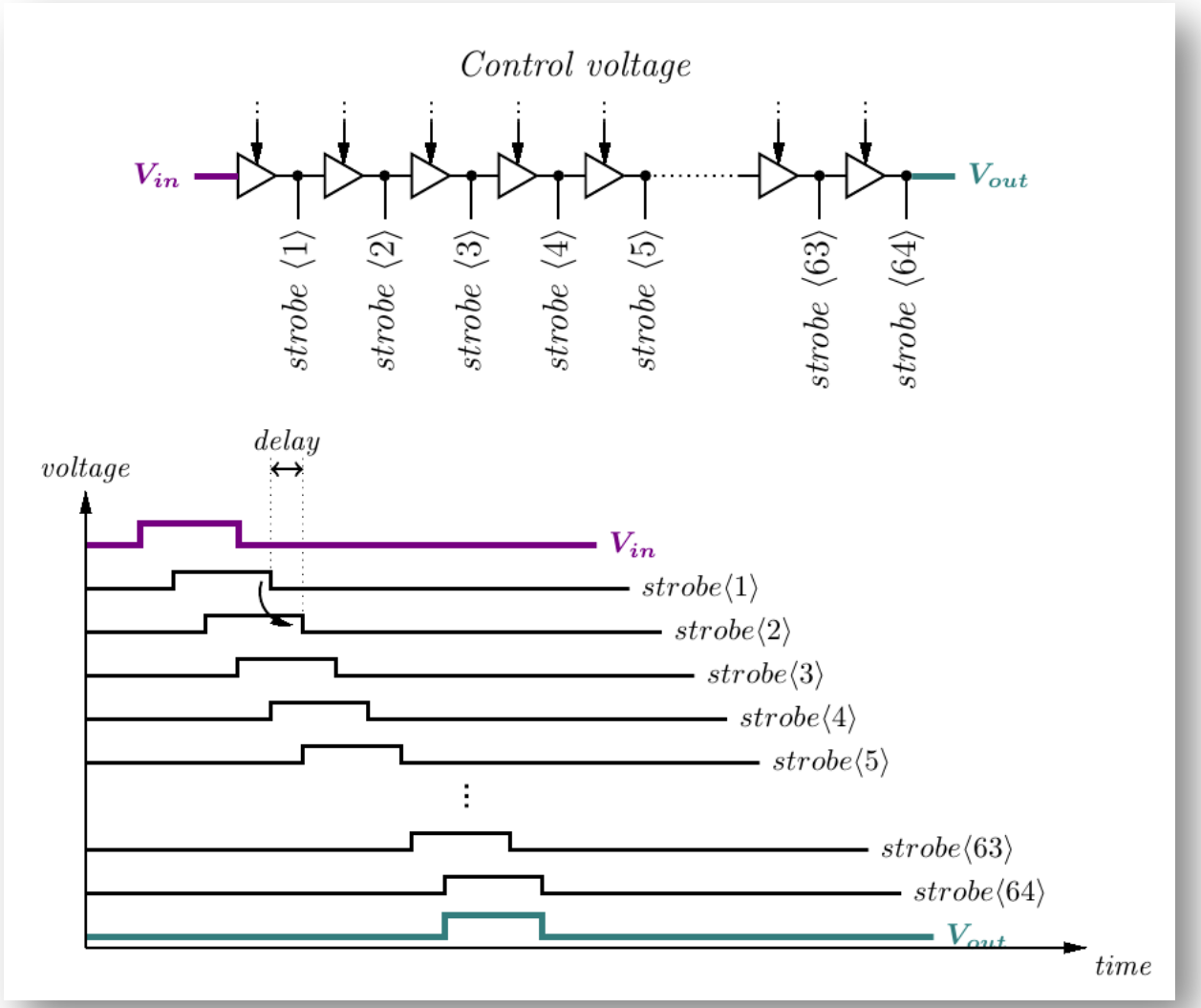


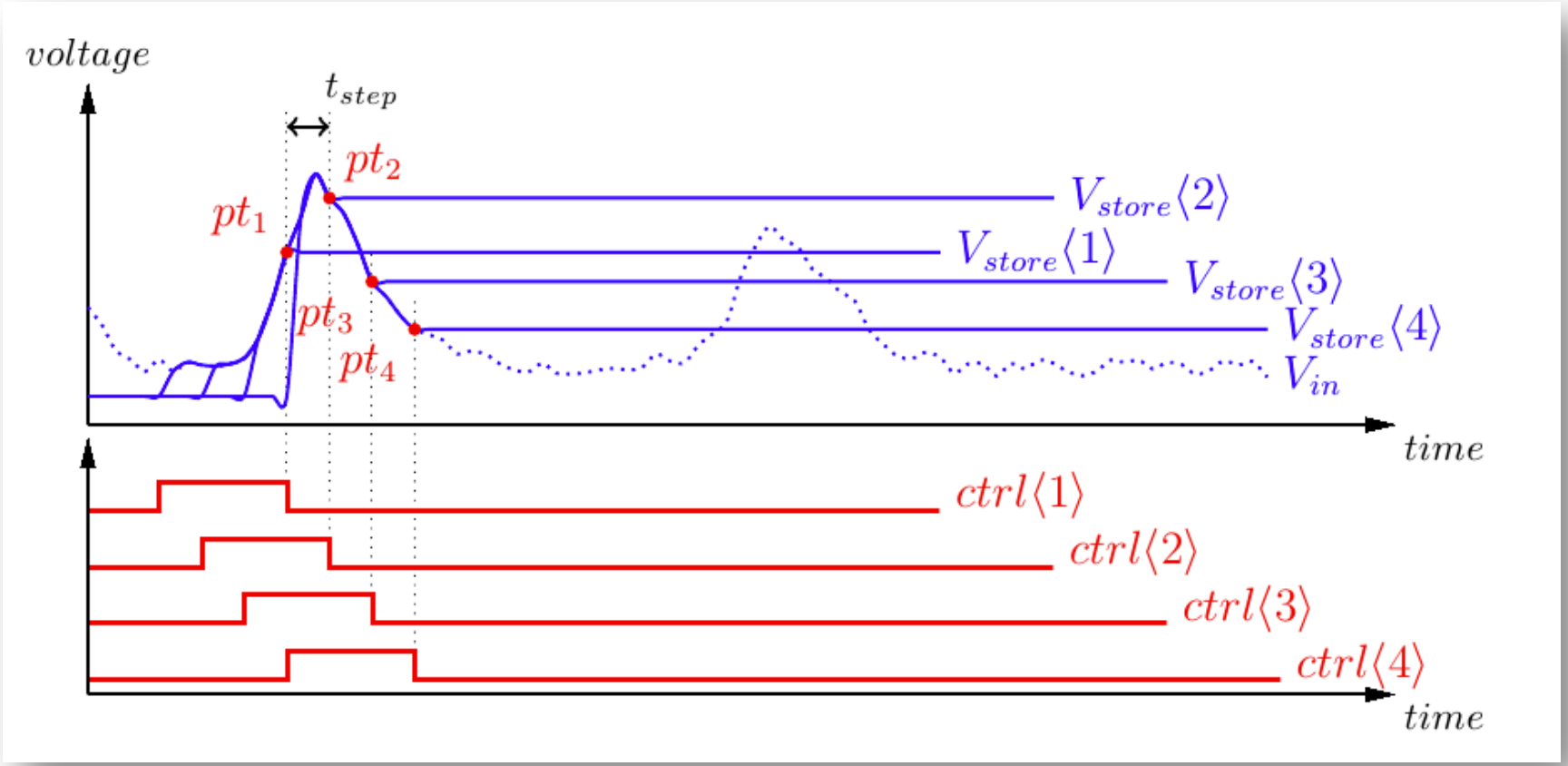
DÉTAIL D'UNE STRUCTURE: LA DLL

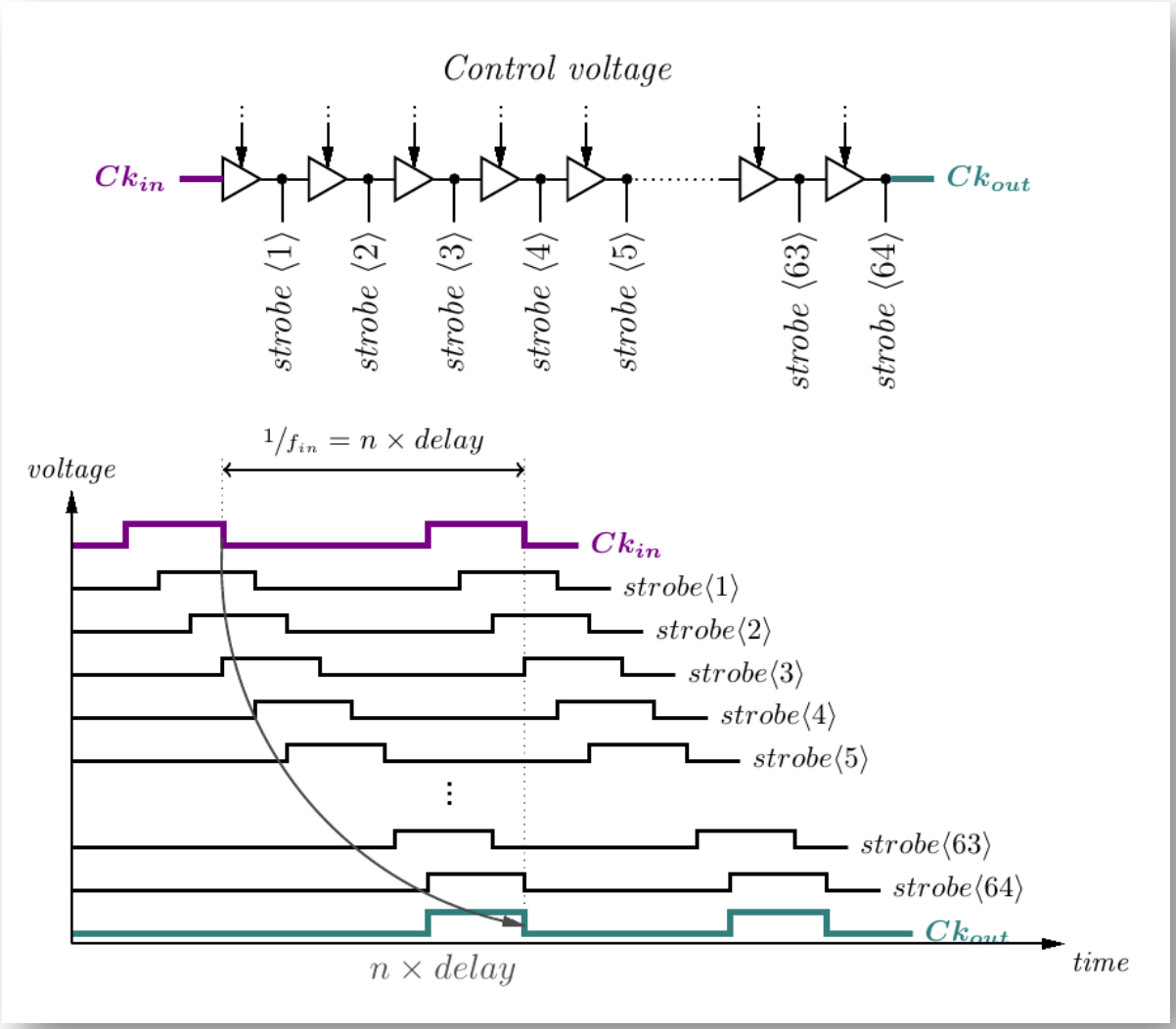


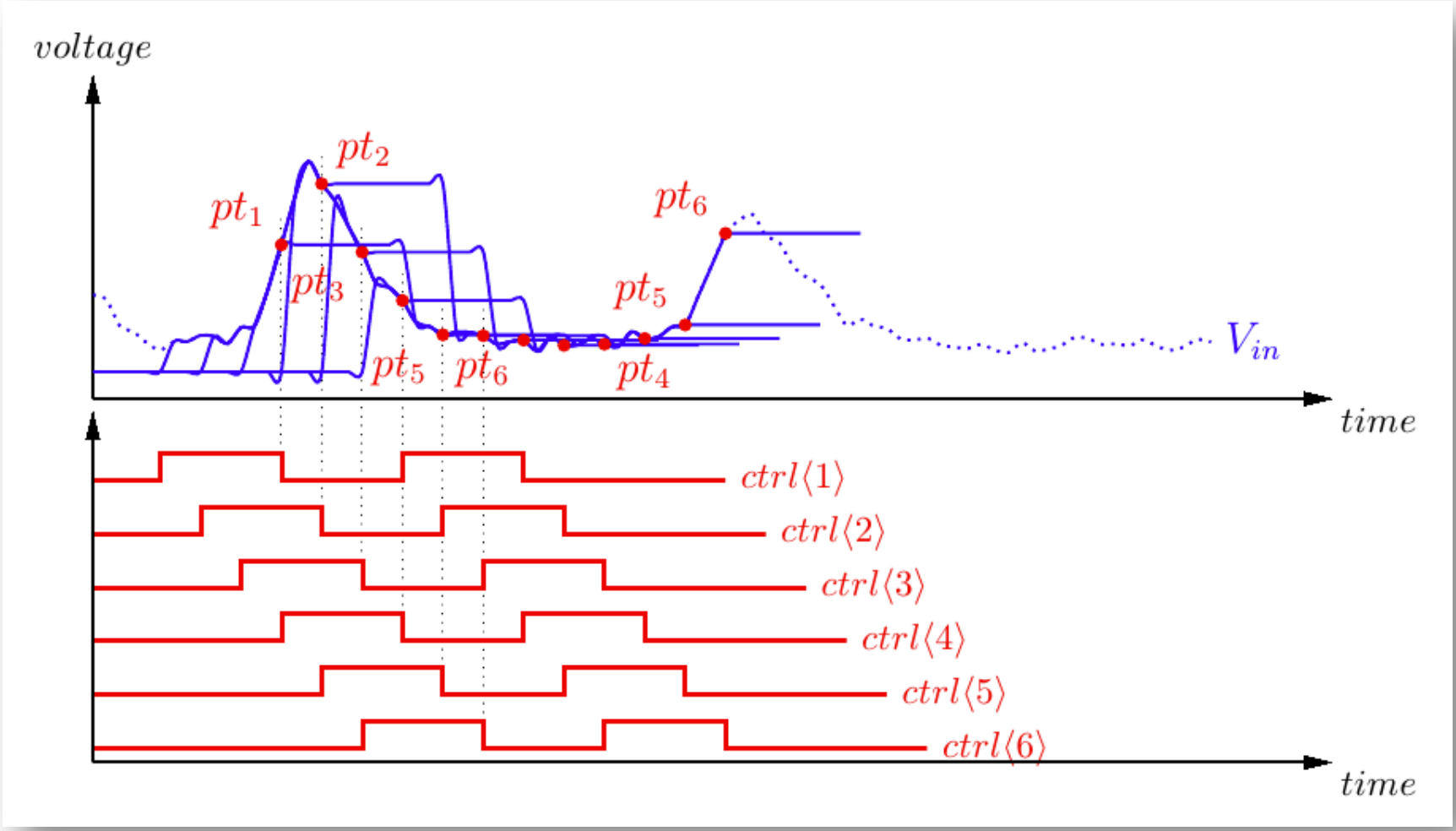
Le rôle de la DLL est de définir les instants d'échantillonages t_1, t_2, …, t_{64} dans SamPic.




Control voltage
V_{in}
V_{out}
strobe ⟨1⟩
strobe ⟨2⟩
strobe ⟨3⟩
strobe ⟨4⟩
strobe ⟨5⟩
strobe ⟨63⟩
strobe ⟨64⟩
delay
voltage
V_{in}
strobe⟨1⟩
strobe⟨2⟩
strobe⟨3⟩
strobe⟨4⟩
strobe⟨5⟩
strobe⟨63⟩
strobe⟨64⟩
V_{out}
time


voltage
t_{step}
pt_1
pt_2
pt_3
pt_4
$V_{store}\langle 2\rangle$
$V_{store}\langle 1\rangle$
$V_{store}\langle 3\rangle$
$V_{store}\langle 4\rangle$
V_{in}
time
$ctrl\langle 1\rangle$
$ctrl\langle 2\rangle$
$ctrl\langle 3\rangle$
$ctrl\langle 4\rangle$
time


Control voltage
Ck_{in}
Ck_{out}
strobe ⟨1⟩
strobe ⟨2⟩
strobe ⟨3⟩
strobe ⟨4⟩
strobe ⟨5⟩
strobe ⟨63⟩
strobe ⟨64⟩
$^1/_{f_{in}} = n \times delay$
voltage
Ck_{in}
strobe⟨1⟩
strobe⟨2⟩
strobe⟨3⟩
strobe⟨4⟩
strobe⟨5⟩
strobe⟨63⟩
strobe⟨64⟩
Ck_{out}
time
$n \times delay$

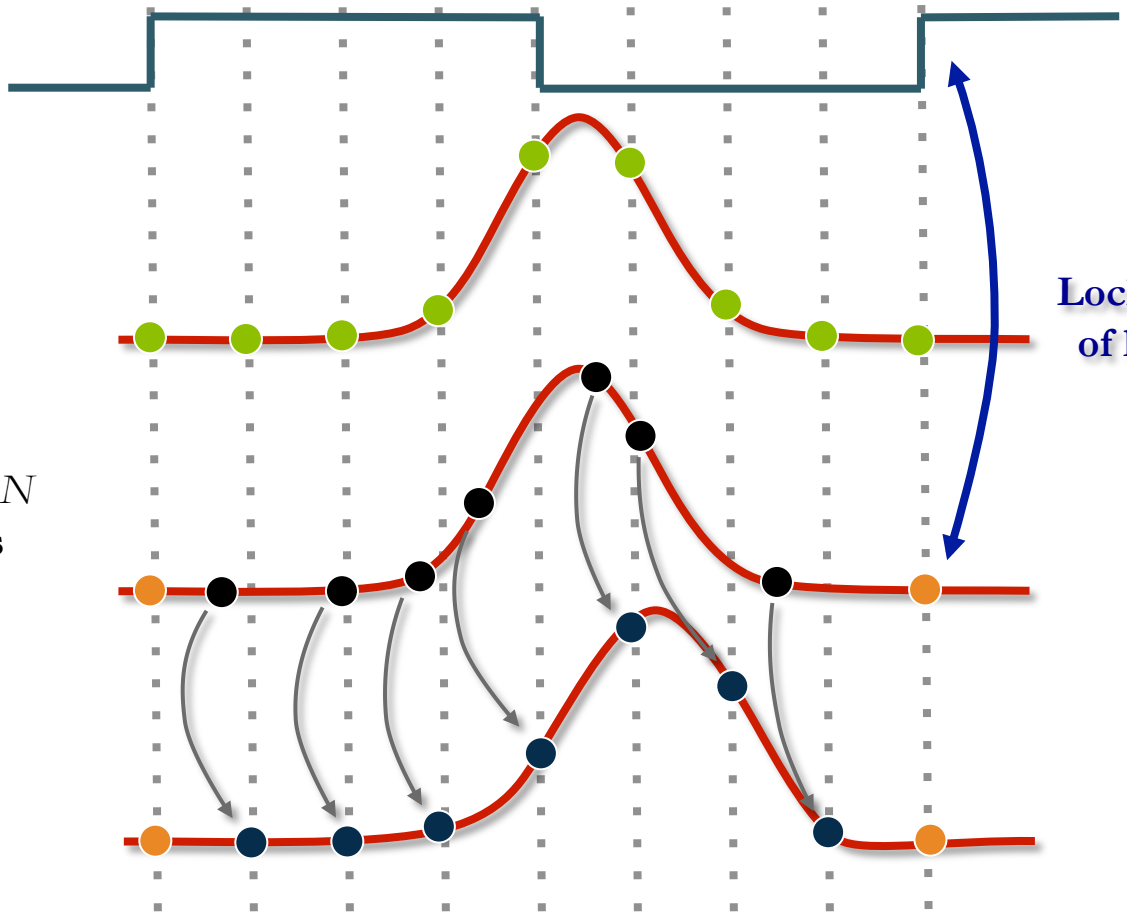

voltage
pt_1
pt_2
pt_3
pt_4
pt_5
pt_6
pt_5
pt_6
V_{in}
time
$ctrl\langle 1\rangle$
$ctrl\langle 2\rangle$
$ctrl\langle 3\rangle$
$ctrl\langle 4\rangle$
$ctrl\langle 5\rangle$
$ctrl\langle 6\rangle$
time

Coarse clock

Real input signal with N perfectly time-spaced samples

Reality: non-perfectly N time spaced samples

Waveform obtained assuming perfectly spaced samples.



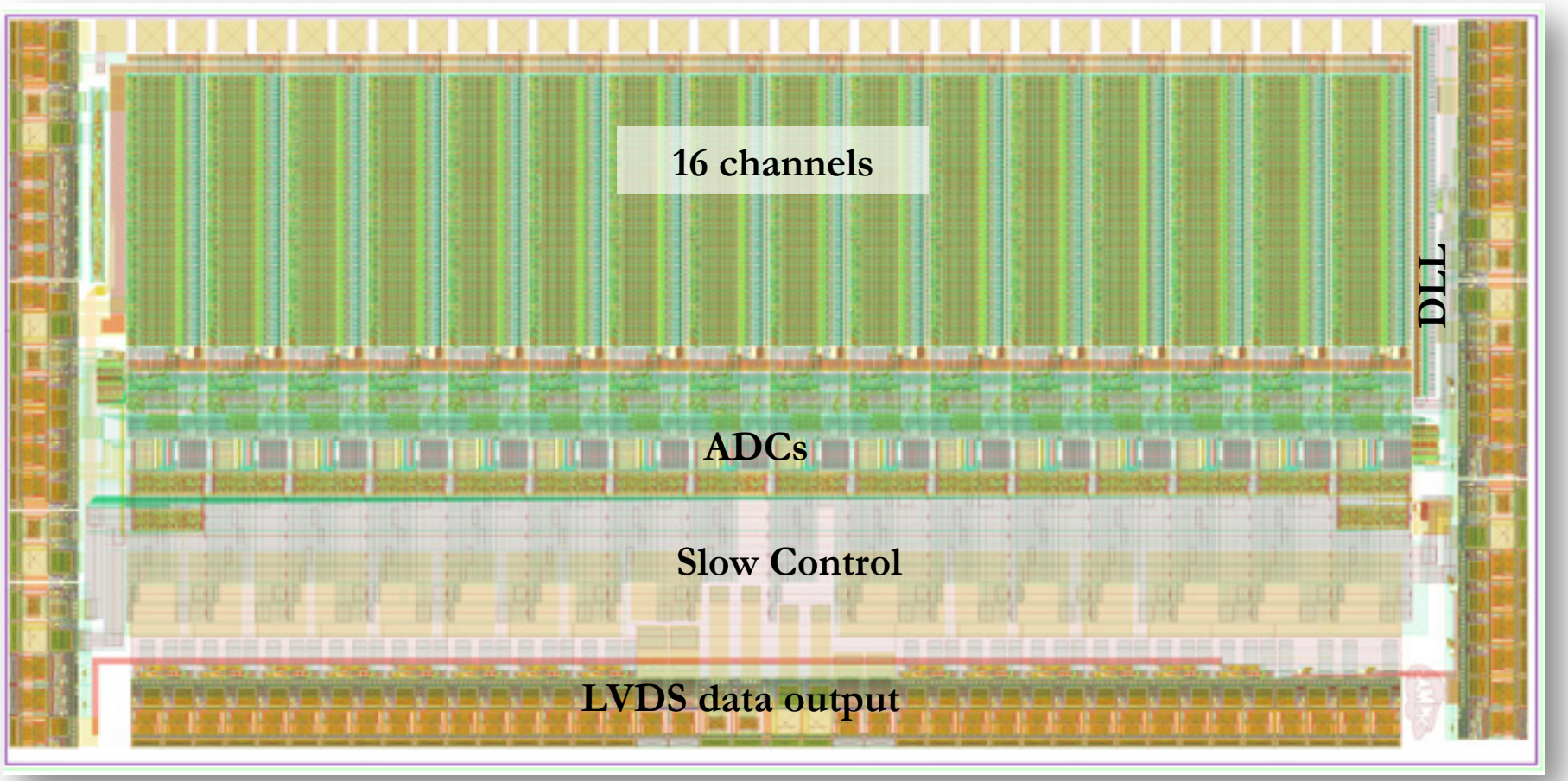
Lock time of sample of last point to the coarse clock

CONCLUSION

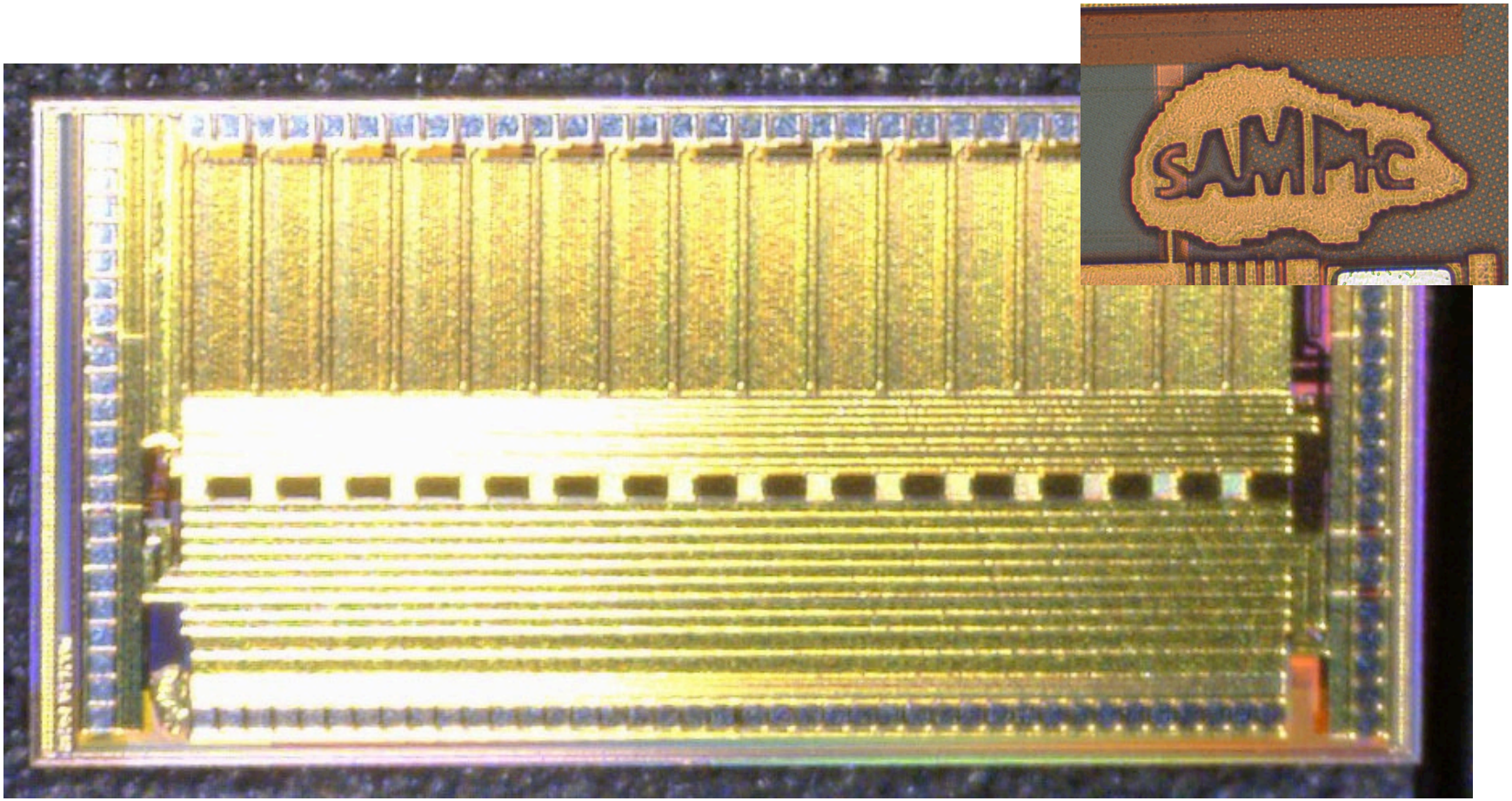
SAMPIC CHARACTERISTICS

	Measure
Channel number	16
Input bandwidth	1.5 GHz
Sampling frequency	1 - 10GHz
ADC precision	11bit
Noise	1mV
Range	1V
Conversion time	1µs
Readout clock	400MHz max. (* not verified)
Readout time	2.5ns/word+ header x nb of channels

LAYOUT



THE SAMPIC CHIP



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