Read-Out Electronics:

where data come from

Lecture 2

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Outlook

- **Prologue**
- **The magic key: Electronics**
- **The FPGA (Field Programmable Gate Array)**
- **An example: features extraction from a Sampling-ADC**
- **From the chip to the board**
- **High Speed Digital Signals**

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Prologue

Modern set-ups are made of several different detectors; each detector is generating electrical signals that have to be pre-processed to be stored. Electronics is a crucial key in this process…

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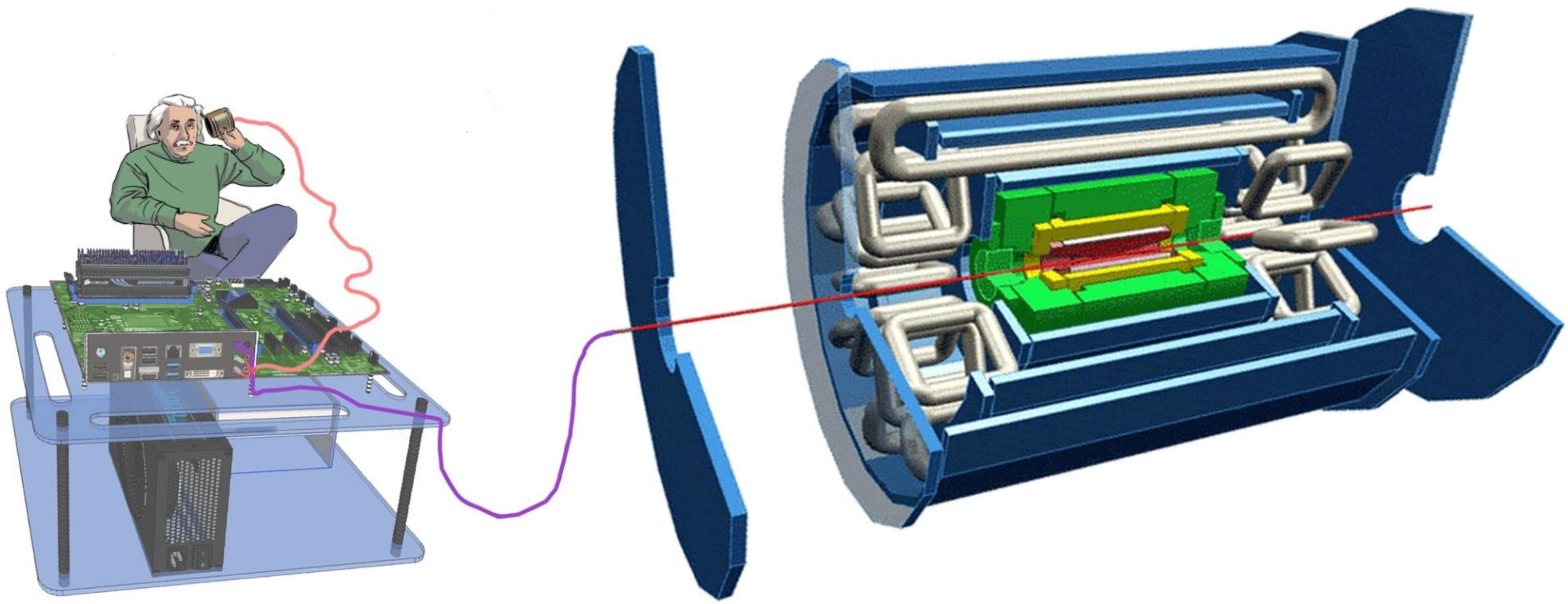
Prologue…

Modern experimental set-ups

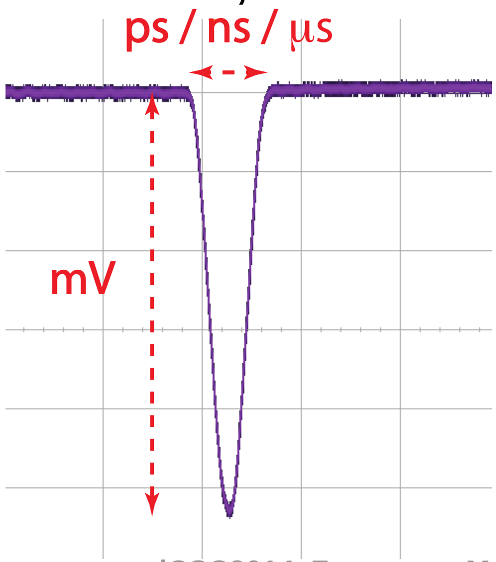
- **Modern experimental set-ups are made of a large number of different detectors, each looking at a particular aspect**
- **Modern detectors are producing analog electrical signals**
- **Detectors are “talking” through the electronics**



Prologue…

Electronics as a “transmission line” from the detector to the data storage

- **We want:**
  - to receive the correct information → reliability
  - to receive the full information transmitted → efficiency
  - to understand the message → no distortion
- **Read-Out Electronics:**
  - From a small, fast analog signal to a bit-stream of data



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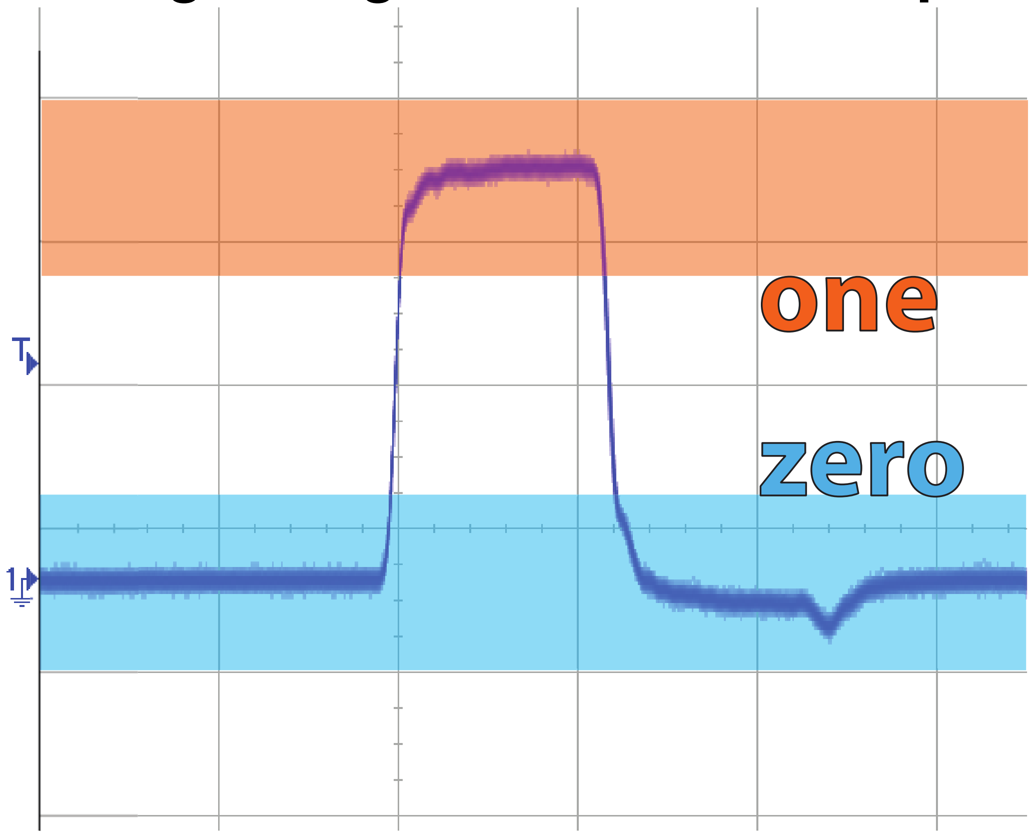
Prologue…

From the analog to the digital world

- **Digital signal → two states: present or absent, "1" or "0"**



Family		One (V)	Zero (V)
TTL		2 to 5	0 to 0.8
NIM		3 to 12	-2 to 1.5
ECL		-0.81 to -1.13	-1.48 to -1.95
LVDS	p	1.27 to 2.40	0.92 to 1.12
	n	0.92 to 1.12	1.27 to 2.4

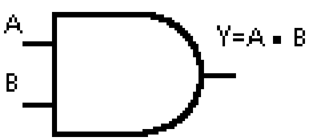
…and many more…

Prologue…

Binary logic: functions

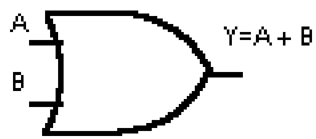
AND

A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1



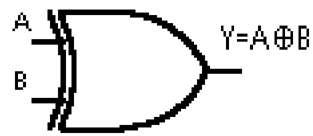
OR

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1



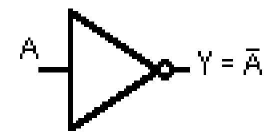
XOR

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	0



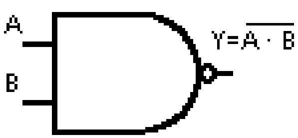
NOT

A	Y
0	1
1	0



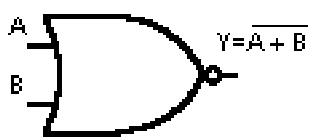
NAND

A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0



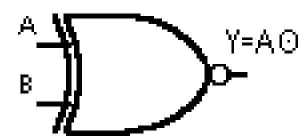
NOR

A	B	Y
0	0	1
0	1	0
1	0	0
1	1	0



NXOR

A	B	Y
0	0	1
0	1	0
1	0	0
1	1	1



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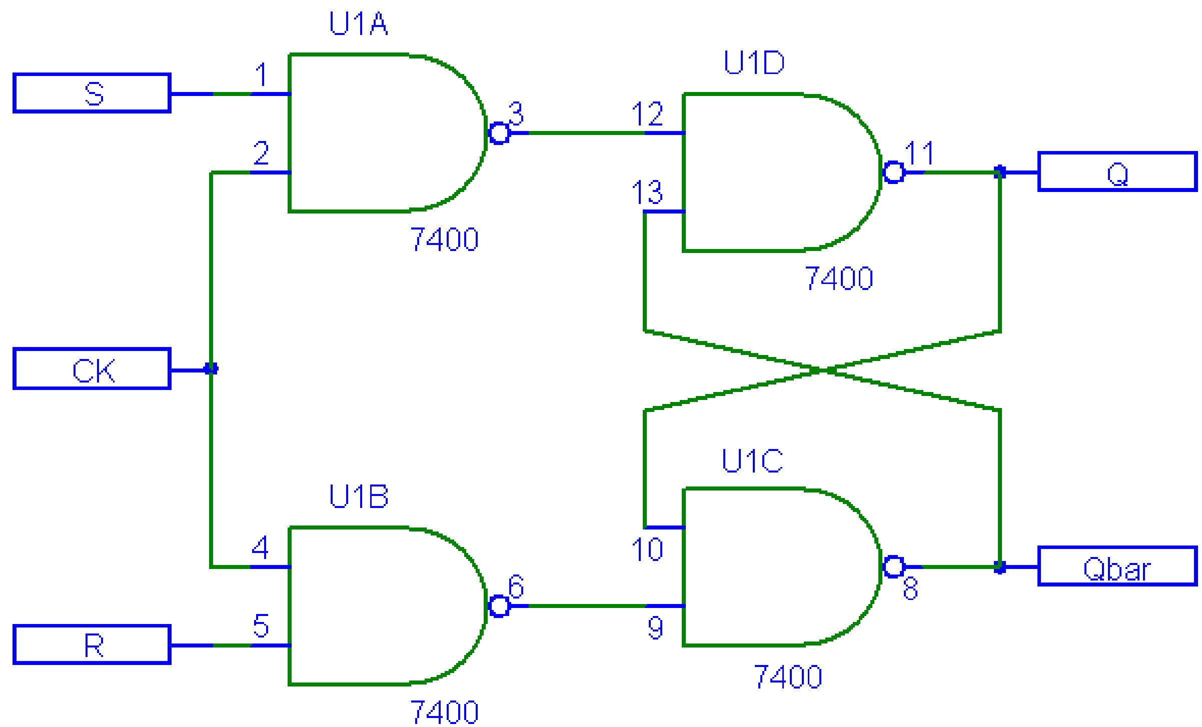
Prologue…

Binary logic: FlipFlop

CK	S	R	Qn	Qn+1
0	X	X	0	0
0	X	X	1	1
1	0	0	0	0
1	0	0	1	1
1	0	1	0	0
1	0	1	1	0
1	1	0	0	1
1	1	0	1	1
1	1	1	?	?



The magic key: electronics

what do we gain by the usage of electronics and what do we have to worry about?

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The magic key: electronics

What do we gain from the usage of electronics?

- **1) It is much faster than human in taking decisions**
  - E.g. evolution of photo cameras
    - automatic setting of focus, timing, opening…

yesterday

today

Fast response
Fast set-up
Much easier to duplicate data
Storage/management of lots of data more simple…

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The magic key: electronics

What do we gain from the usage of electronics?

- **2) Allows to trigger**
  - Choice of record when a specific scenario happens
  - Why? We can not record all the information
  - We need to choose which one is interesting…

  - E.g.: bubble chamber experiments: cannot trigger =
    - One picture each spill
    - millions of pictures of the chamber
    - maybe few hundreds with an event…

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The magic key: electronics

Triggering…

- **Think about the LHC experiments:**
  - even with selecting the event to be stored (= triggering), the data-stream to the storage system is of the order 100 Mbytes/s

- **Different from monitoring the temperature in a room:**
  - not sampling at a fixed frequency,
  - but analyzing the event in real time and taking a decision…

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The magic key: electronics

Triggering…

- **E.g. a movie and a picture:**
  - The video camera is recording everything:
    - you will not lose events, but…
    - big amount of data to be stored
    - once you look out for the event, you need to watch all the movie
  - The photo camera is registering only scenes that are “triggered” by the operator:
    - less data to be stored
    - much simpler to look at them, but…
    - you lose all what happened in between one trigger and another

→Be careful: acquired raw data are a selected subsection of what the experimental set-up could detect!!!

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The magic key: electronics

A brief summary:

- **With the usage of electronics we gain two major aspects:**
  - 1) velocity in taking decisions
  - 2) trigger capability

- **but be careful: acquired data are a selected subsection !!!**

The FPGA

FPGAs are widely used in modern set-ups.
A general overview of what an FPGA is and how it works will be presented, focusing on the usage in physics research…

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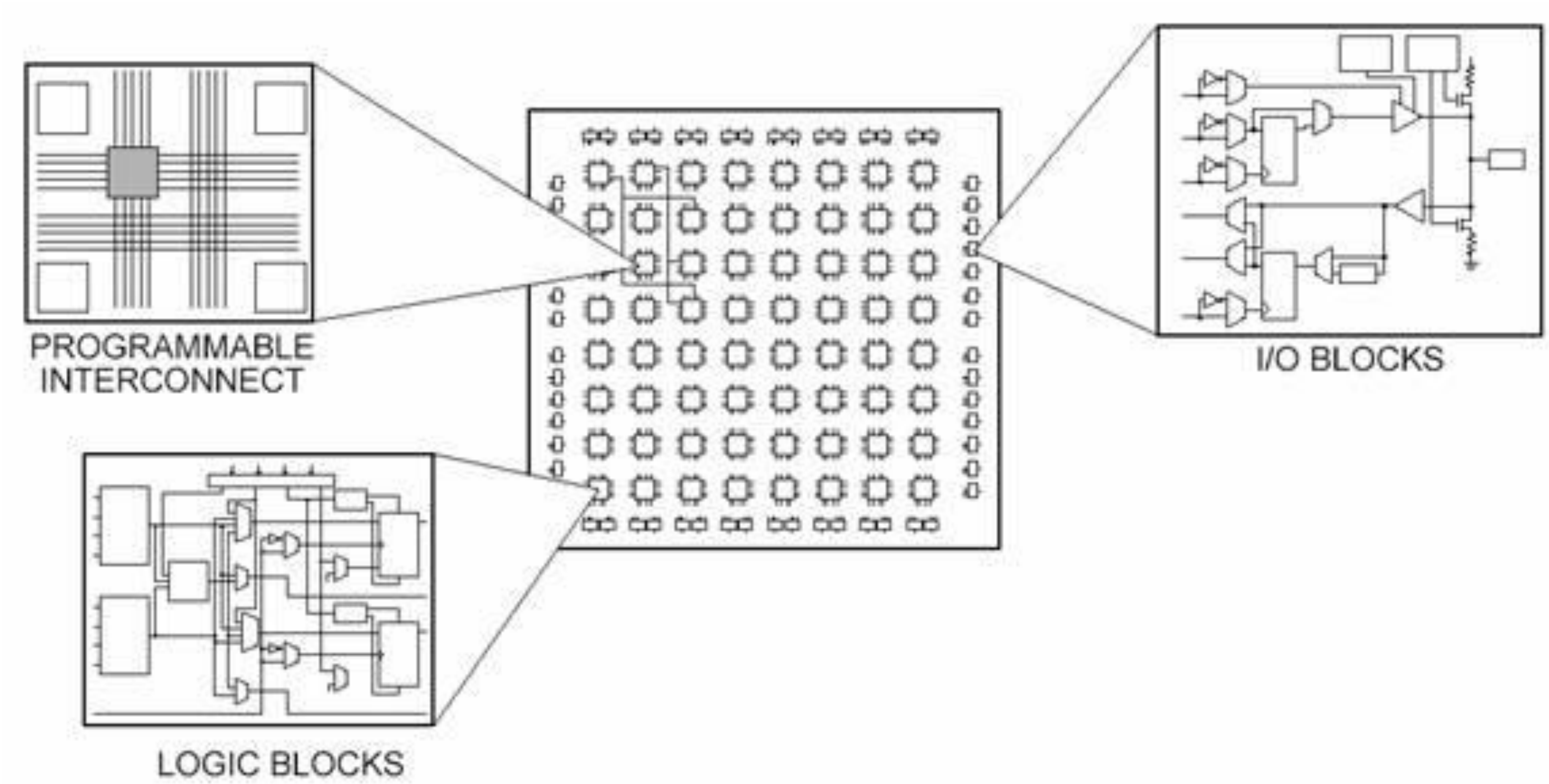
Signal processing: the FPGA

Field Programmable Gate Array



*picture from: http://www.ni.com/white-paper/6983/en/

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Signal processing: the FPGA

Some numbers…

	Spartan-6	Virtex-7	Virtex UltraScale
Logic Cells	147,443	1,954,560	4,407,480
BlockRAM	4.8Mb	68Mb	115Mb
DSP Slices	180	3,600	2,880
DSP Performance (symmetric FIR)	140 GMACs	5,335 GMACs	4,268 GMACs
Transceiver Count	8	96	104
Transceiver Speed	3.2 Gb/s	28.05 Gb/s	32.75 Gb/s
Total Transceiver Bandwidth (full duplex)	50 Gb/s	2,784 Gb/s	5,101 Gb/s
Memory Interface (DDR3)	800	1,866	2,400
I/O Pins	576	1,200	1,456
I/O Voltage	1.2V - 3.3V	1.2V - 3.3V	1.0 – 3.3V

*table from: http://www.xilinx.com/products/silicon-devices/fpga/

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Signal processing: the FPGA

Why should an FPGA be used?

- **Programmable = re-usage of the same hardware for multiple tasks**
- **Parallelism = in principle any n-to-one logic**
  - Massive performances on same algorithms
- **Exact determination of the execution order of the different tasks**
  - Hardware chain of binary functions

An example…

Each detector used in experimental set-ups consists of numerous channels, detecting signals with rate of the order of MHz or even GHz; a large amount of data are produced. To select which data are interesting to be recorded, it is important to process the data as soon as possible near the detector…

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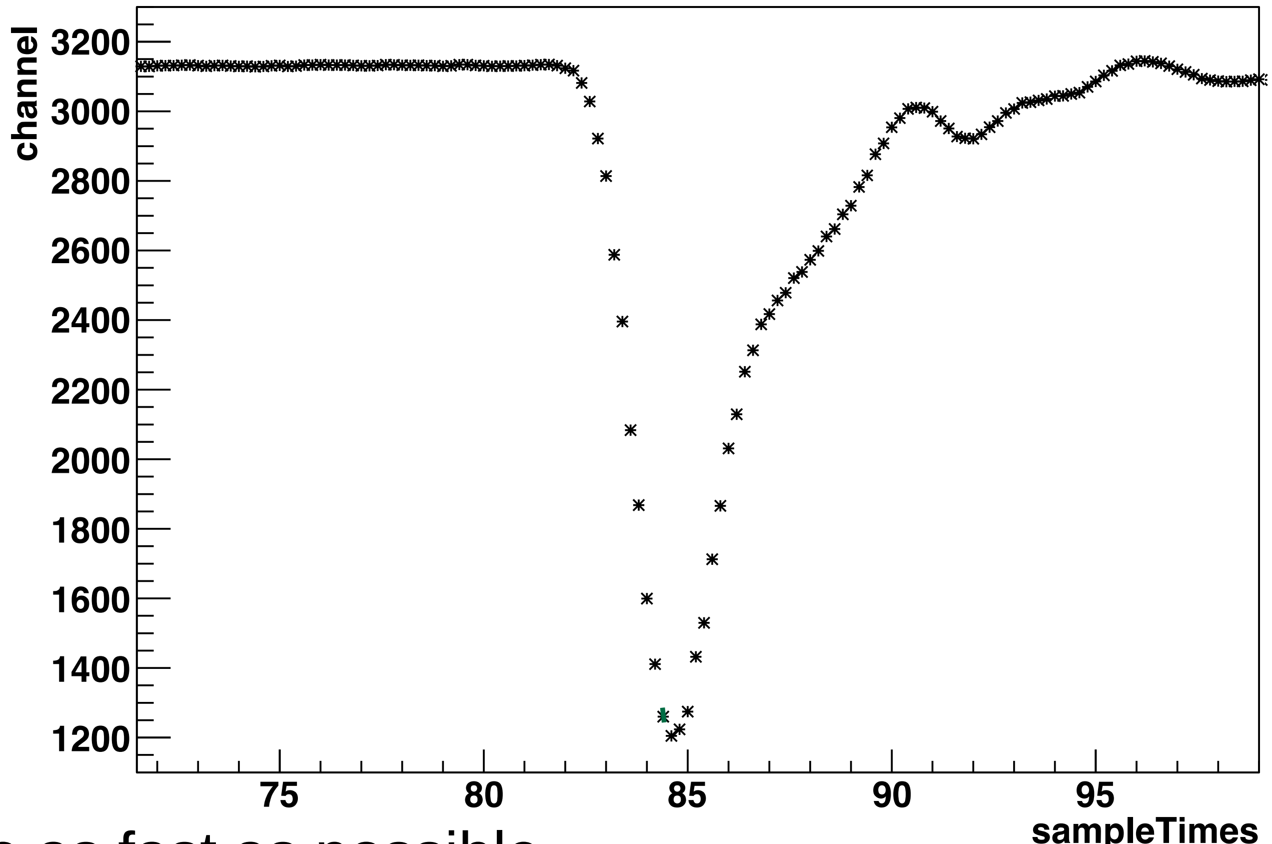
An example

Feature extraction from a Sampling-ADC

- **Baseline**
- **Slope**
- **Start time**
- **Charge integral**
- **Etc..**



- Needs to be done as fast as possible
- With a fixed delay time
- In parallel for many channels

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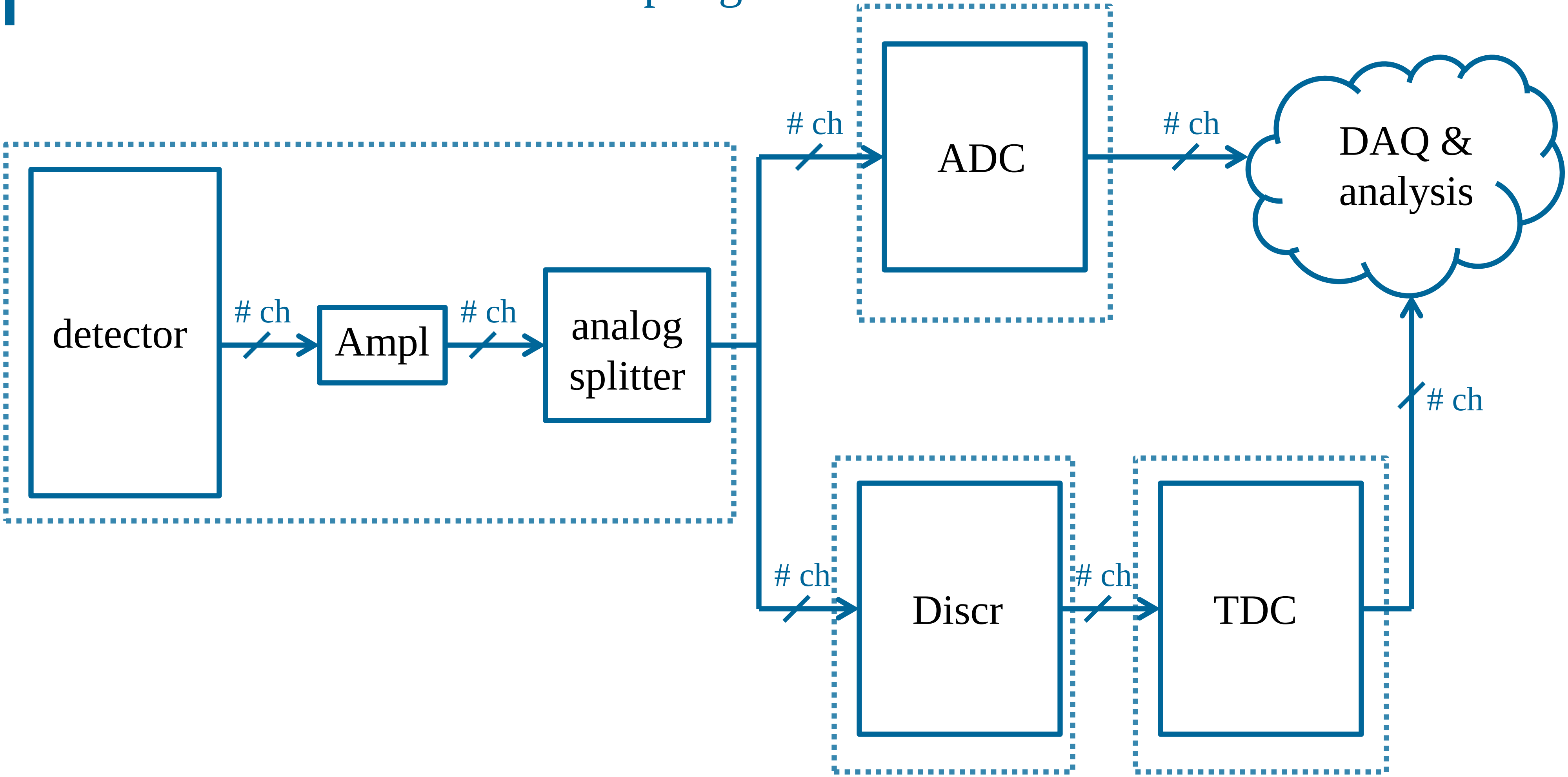
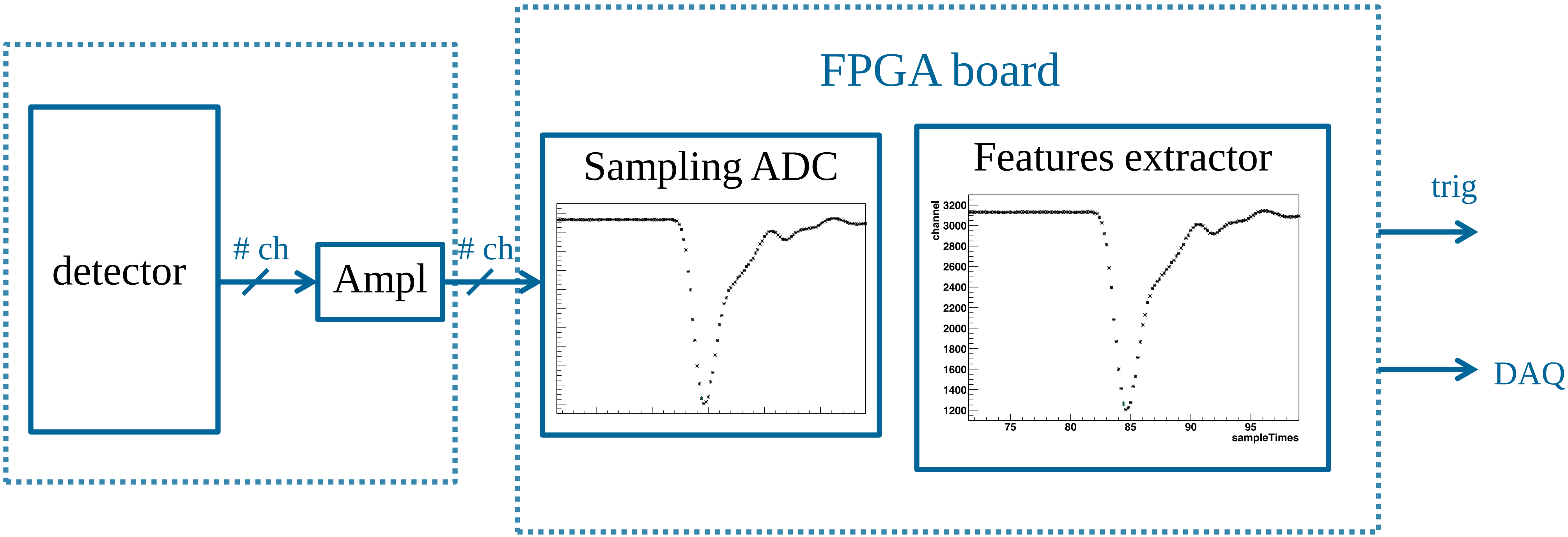
An example

Feature extraction from a Sampling-ADC



An example

Feature extraction from a Sampling-ADC



An example

Feature extraction from a Sampling-ADC

- **Less cabling**
- **Less electronics modules**
- **Trigger capability**
- **But…**
  - Sampling of the analog signal

From the chip to the board

Each electronic chip is generally mounted on boards, to provide the necessary power and buffering of the signals; even if the performance of the chip itself (FPGA or ASIC) is very high, one of the other components can limit the characteristic of the board…

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From the chip to the board

- **FPGA: very powerful**

…ok but what about the electronics around it???

- Not possible to connect the signals from the detector directly to the FPGA!
  - Your transmission line could “speak a different language”
  - Power and filtering are needed
  - Space constrains
  - BUFFERING:
    - never trust the transmission lines: unknown signals can arrive and we don’t want to damage our FPGA chips!!!

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From the chip to the board

- **Not always the most performing board is the correct choice:**
  - more performance = more power
  - more power = more cooling
  - more cooling = more material budget in the detector…
  - Is it fine with “my physics”???

- **It is important to look at the full system, more than at the single module…**

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From the chip to the board

A brief summary…

- **Signal processing**
  - FPGAs used for fast, parallel, on-line operations
  - Not possible to connect analog signals directly to the FPGA!
  - Bandwidth (in/out-put buffers, etc…)
- **System optimization more than component optimization**
  - Logistic constrains (space, cooling, power, etc…)

High-Speed Digital Signal

High-Speed digital signals need to be handled as analog signals…

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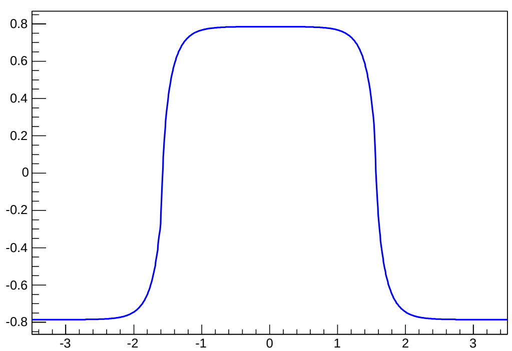
High Speed digital signals

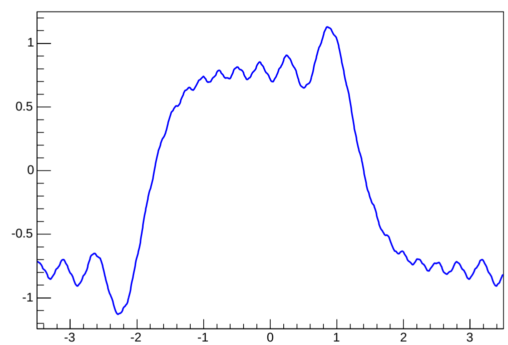
need to be handled as analogue ones…

- **A digital signal is in binary logic**
  - I have to take care only of two states: “1” and “0”
  - It is less affected by noise than an analog signal
  - Than it is much simpler to handle…

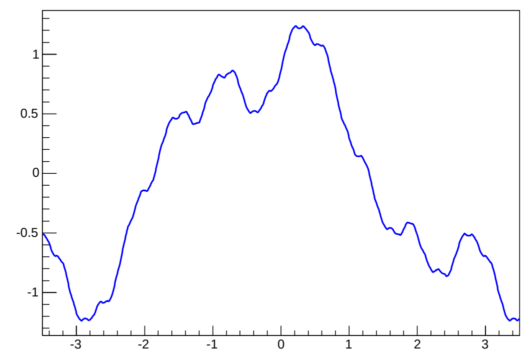
- **→ true in principle, but…**



Far below the bandwidth limit



Close to the bandwidth limit



Far outside the bandwidth limit

Read-Out Electronics:
where data come from

lecture 2
summary and conclusions

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Summary and conclusions

Lecture 1

- **To investigate the matter, we build detectors**
- **Modern detectors are providing analog electrical signals**
- **Electronics is needed to "read the information" from the detectors**
- **The electronics chain has to:**
  - Preprocess the signals w/o distortion
  - Be reliable
  - Be efficient
  - Be fast
  - Be calibrated to the experiment!!!

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Summary and conclusions

Lecture 2

- **Modern electronics is very powerful**
  - High bandwidth
  - High programmability
  - But…
- **One element is enough to decrease the performance of the full chain**
  - →System optimization more than component optimization
- **High speed digital signals need to be handled as analog ones**