

Read-Out Electronics: where data come from

Lecture 1

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Outlook

- **Why we build detectors**
- **Research in Physics:**
 - A look at yesterday
 - A look at today
- **The electronics**
 - The Read-Out Electronics
 - From the analog to the digital world
 - Characteristics/requirements of an electronics chain
- **An example: Particle IDentification (PID) using the Time of Flight (ToF)**

Outlook

Why do we build detectors?

- **As humans, we are curious: we want to know the place we live in, we want to understand what the matter is made of!!!**
- **For that, we build machines (experiments and detectors) to investigate the matter**



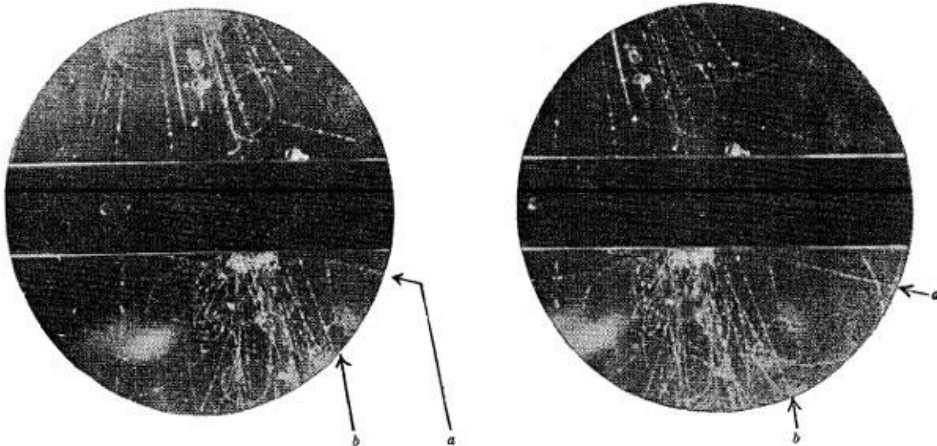
...it is important to use
correctly the tools we have!!!

Outlook

Why do we build detectors?

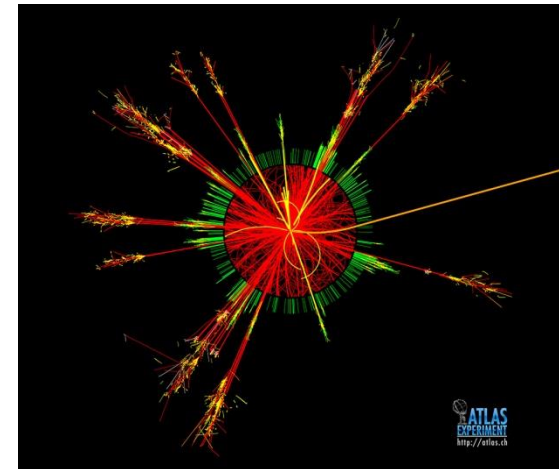
- We want to study what we can not simply see with our eyes
- For that we “ask” the detectors to record a scene
- So that we can analyze it

yesterday



20.12.1947 - G.D. Rochester & C.C. Butler, *Evidence for the existence of a new unstable elementary particles*, Nature 160, 855

today



An event in the ATLAS detector

Research in Physics

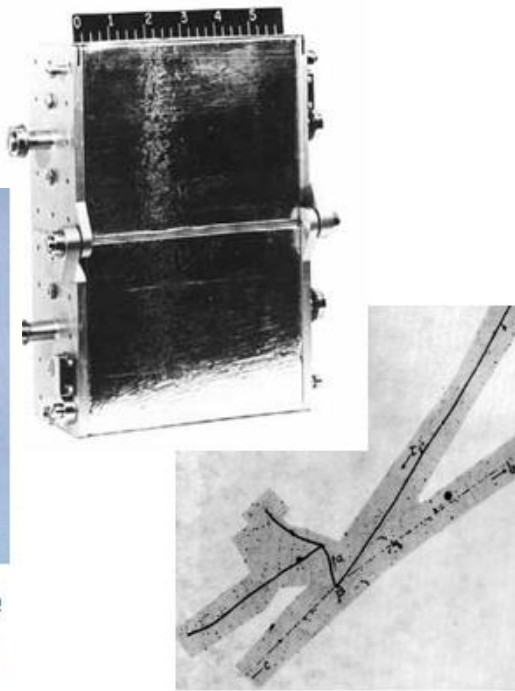
a very general overview of the evolution of the
detectors used in experimental set-ups

Research in Physics

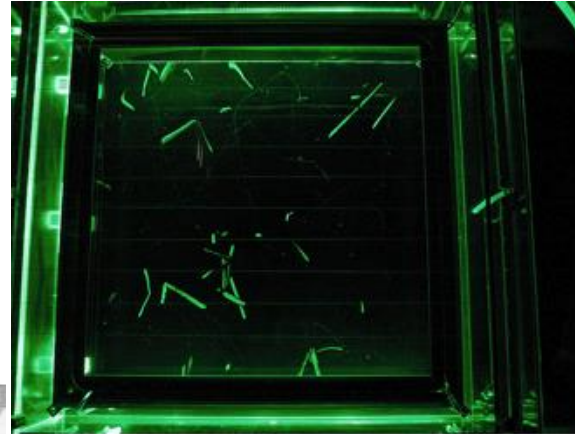
A look at yesterday...



Cathode ray tube
1897 – F. Braun



Nuclear Emulsion
1910 - S. Kinoshita



Cloud Chamber
1911 – C.T.R. Wilson



Geiger-Müller tube
1928 – H. Geiger & W. Müller

Nuclear physics research was based on observation of tracks from charged particles

Research in Physics

A look at yesterday...

Discovery of “elementary” particles...

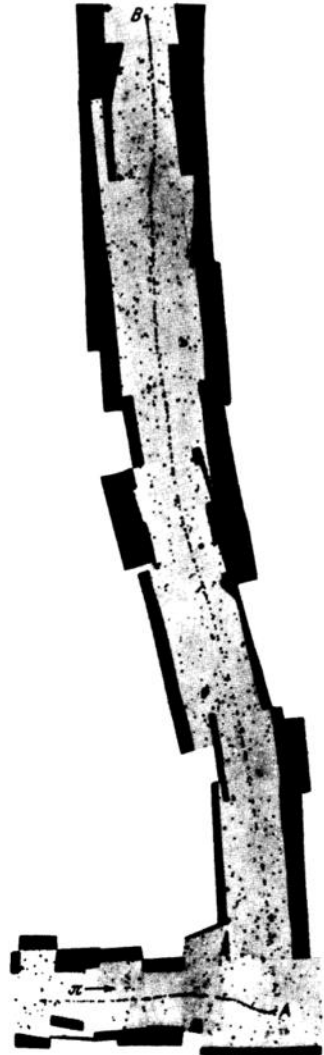


Figure 1.4 One of Powell's earliest pictures showing the track of a pion in a photographic emulsion exposed to cosmic rays at high altitude. The pion (entering from the left) decays into a muon and a neutrino (the latter is electrically neutral, and leaves no track). Reprinted by permission from C. F. Powell, P. H. Fowler, and D. H. Perkins, *The Study of Elementary Particles by the Photographic Method* (New York: Pergamon, 1959). First published in *Nature* 159, 694 (1947).

Year	Particle	Instrument
1947	π^+ and π^-	Nuclear Emulsion
	π^0	Counters and Emulsion
	Λ	Cloud Chamber
1947	K^+ and K^-	Nuclear Emulsion
	K^0	Cloud Chamber
1953	Σ^+	Nuclear Emulsion
	Σ^-	Cloud Chamber
	Σ^0	Bubble chamber
	Ξ^-	Cloud Chamber
	Ξ^0	Buble Chamber
1958	Anti Λ^0	Nuclear Emulsion

Research in Physics

A look at yesterday...

- **Nuclear emulsion:**

- Photographic emulsion were send to the high atmosphere
- Interaction with the cosmic rays would leave a track
- Studying the tracks it is possible to identify different particles and decays:
 - The grain density is proportional to the energy loss by ionization (Bethe-Bloch) \rightarrow direction and (\sim)energy
 - A big deviation from a trajectory \rightarrow interaction and new particles
 - A neutral particle does not leave a signature

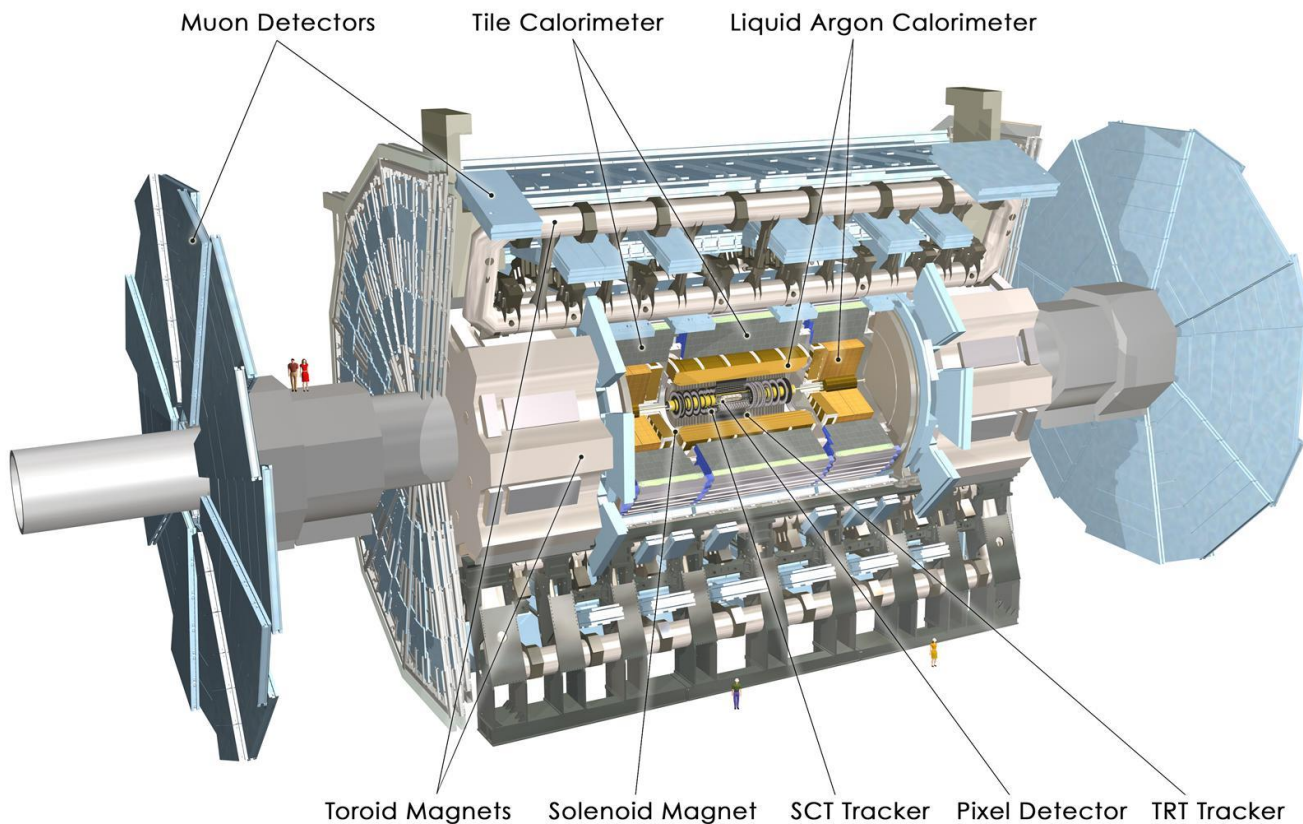
e.g. used today in the OPERA experiment
(Oscillation Project with Emulsion-tRacking Apparatus)



Research in Physics

A look at today...

- **Experimental set-up made of a large number of detectors**



Investigation of the
“constituents of matter”

Looking for the “Fundamental
particles” → e.g. Higgs Boson

Exploration of “rare channels”

Research in Physics

A look at today...

- **Experimental set-up made of a large number of detectors:**
 - Tracker: detecting the passage of a charge particle ideally without perturbation of its trajectory
 - (e.g. silicon strips or pixels)
 - Calorimeter: measuring the energy released by a particle in the interaction with the detectors
 - (e.g. inorganic scintillators)
 - Time of Flight: suited to measure the time of flight of the particle
 - Always at least in couple: one start and one stop time needed
 - etc...
- **Each detector can acquire data with a rate of MHz or more...**
- **Usage of fast electronics is needed to read the data.**

Research in Physics

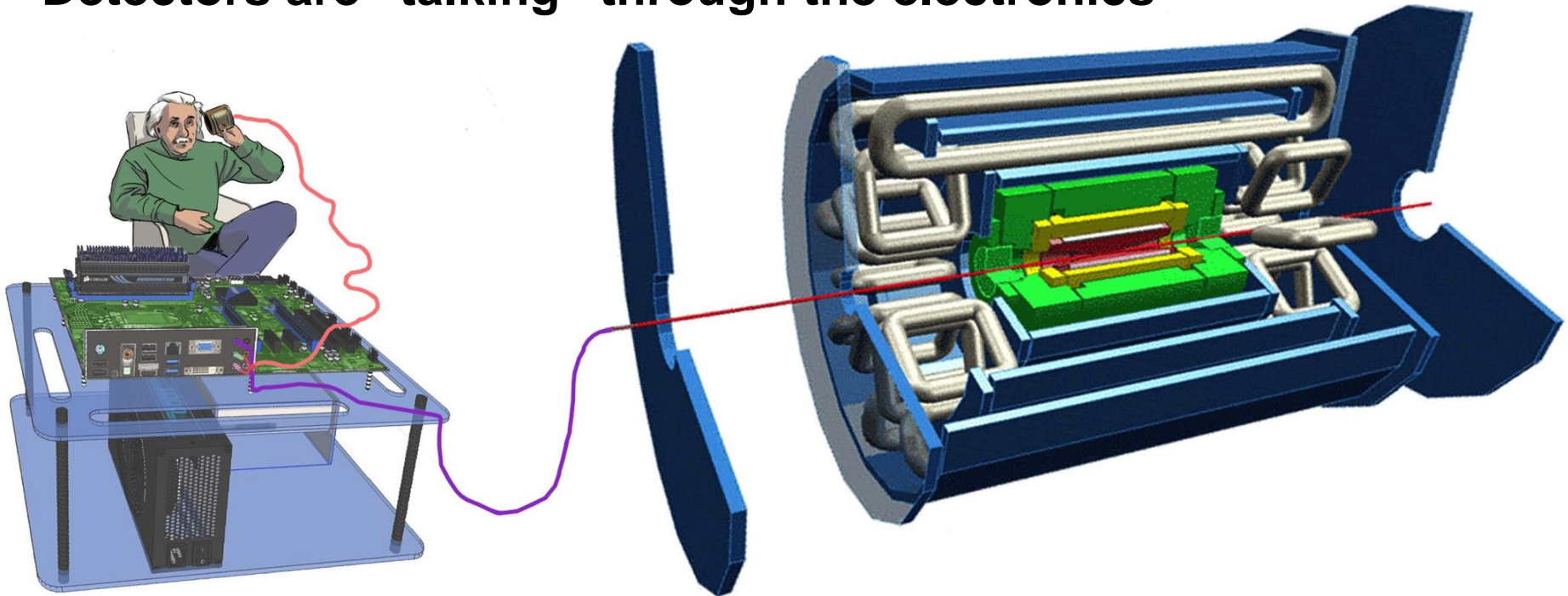
A brief summary...

- In the last century there was a big evolution of detectors
- Nuclear physics research was mainly based on the observation of tracks from charged particles
- Detectors were “purely analog” devices
- Each detector was built to perform the full experiment
- The search for the constituent of the matter requires:
 - high energies,
 - very short times,
 - “rare channels”

Research in Physics

A brief summary...

- 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

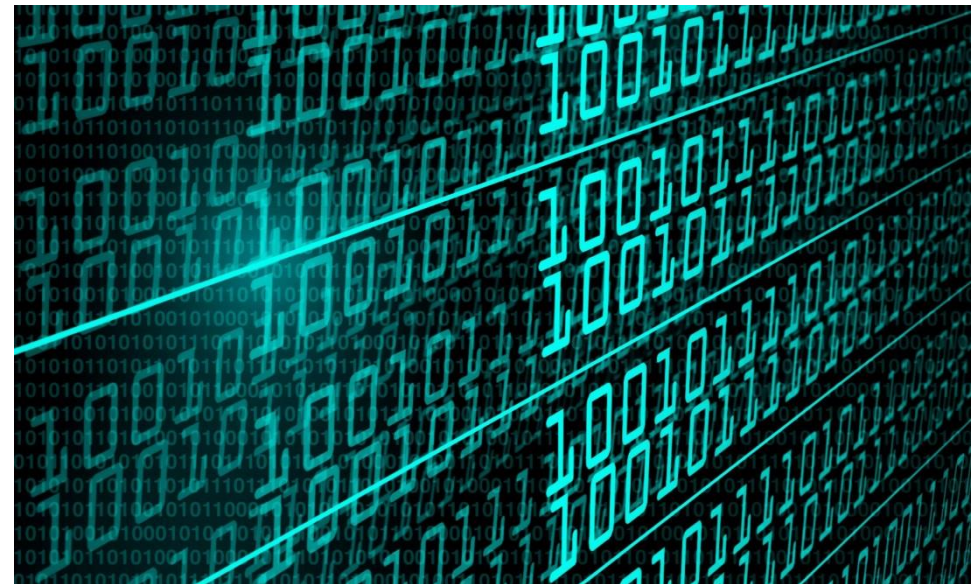
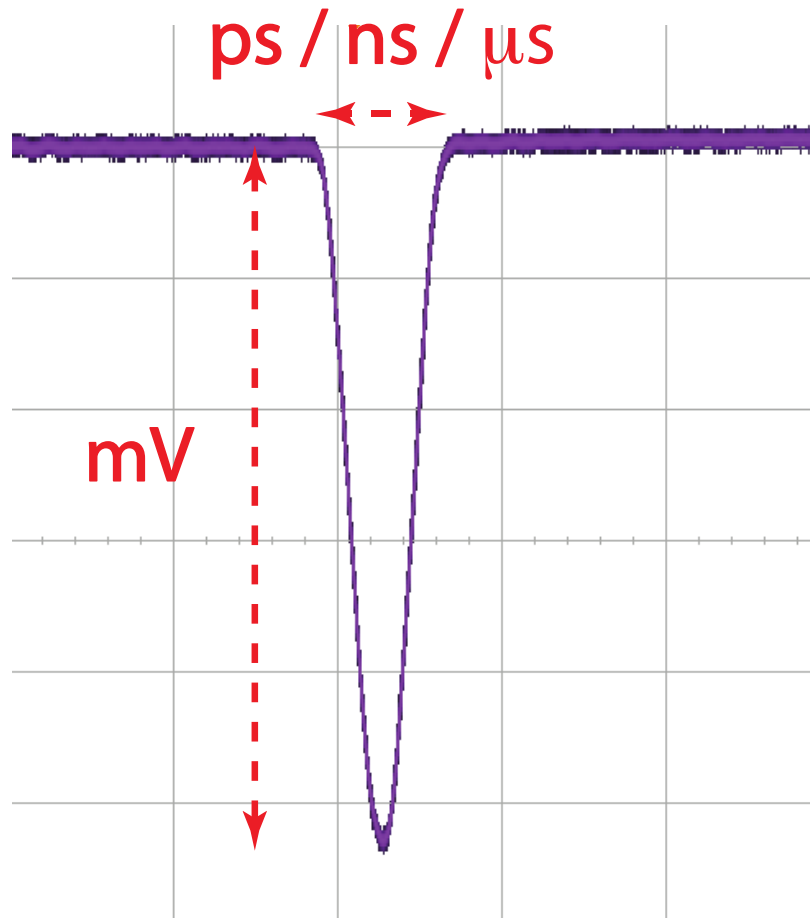


The electronics

The Read-Out Electronics, used to communicate with the detectors, is the tool used to transport information from the analog world (spoken by detectors) to the digital world (spoken by the Data Storage System)

The Read-Out Electronics

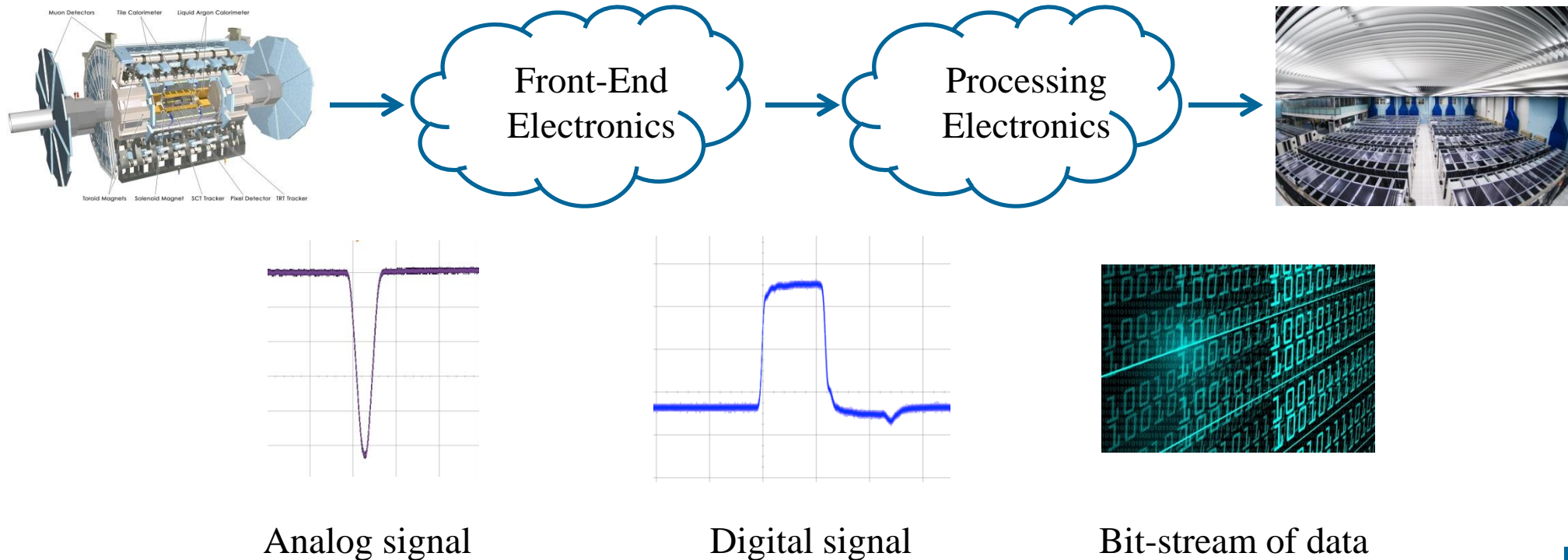
From a small, fast electrical signal to a bit-stream of data



Binary world
High transmission rate

The Read-Out Electronics

From a little, fast electrical signal to a bit-stream of data



The Read-Out Electronics

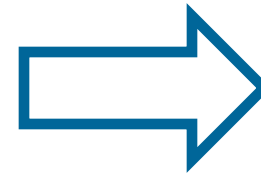
In two major steps:

① Front-End Electronics: from the analog to the digital world

- Comparators
- Analog to Digital Converters (ADC)
- Time to Digital Converters (TDC)

② Signal processing: the FPGA

- Where they are used...
- For what...
- Why...

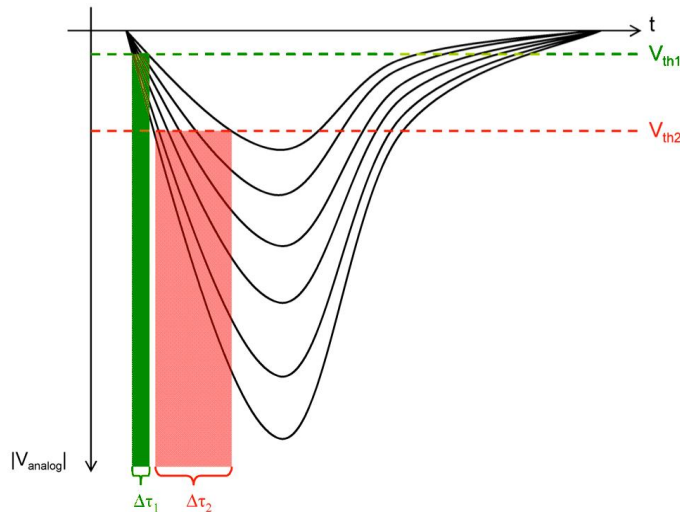


In lecture 2

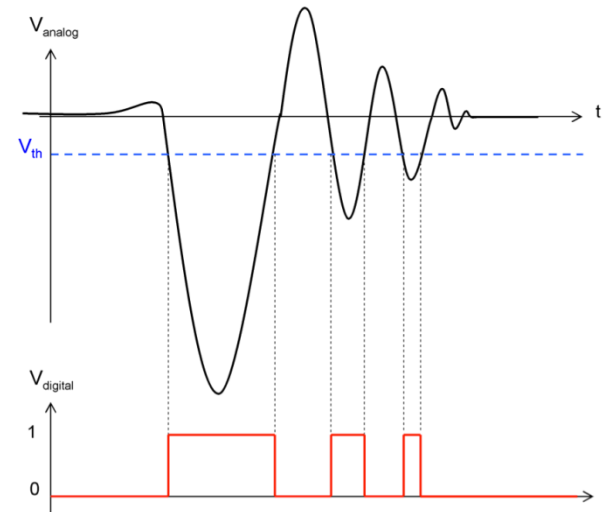
From the analog to the digital world...

1) Comparator

- Digital “ONE” if the signal is above a fixed threshold



Amplitude can vary to any value
Shape can vary



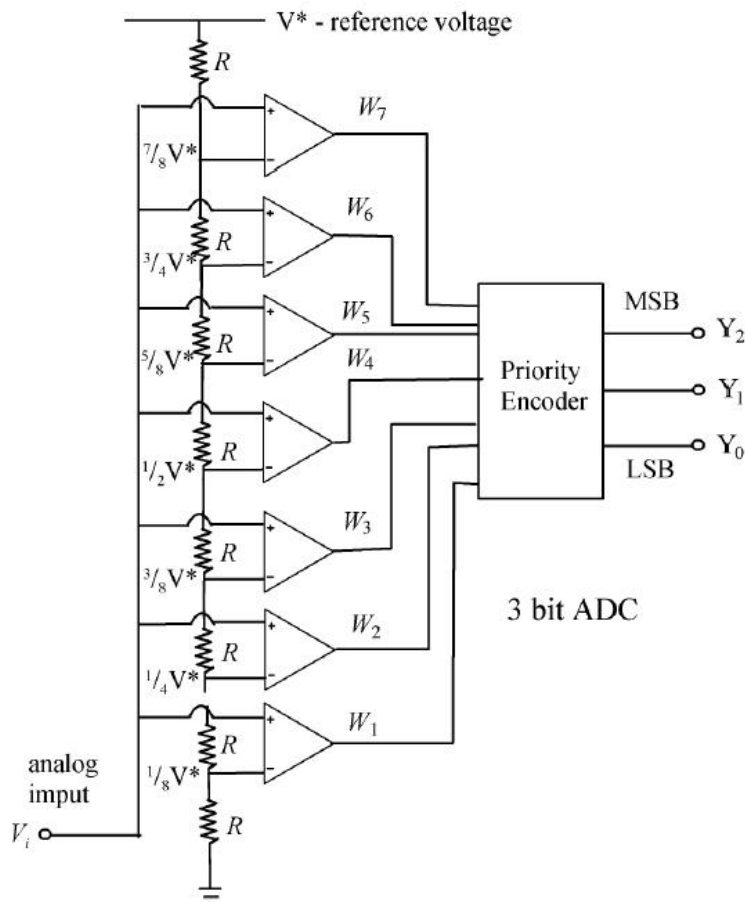
Binary logic: “1” or “0”
Square signal

- Applying a threshold we decide (discriminate) what is noise and what is a good signal

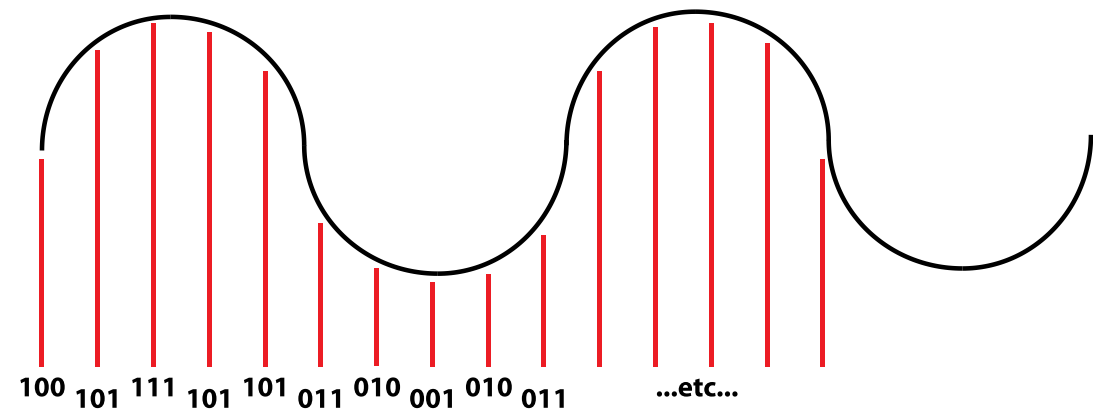
From the analog to the digital world...

2) Analog to Digital Converter: ADC

- Digital word proportional to the charge of the analog signal**



For a dynamic signal: Sampling-ADC

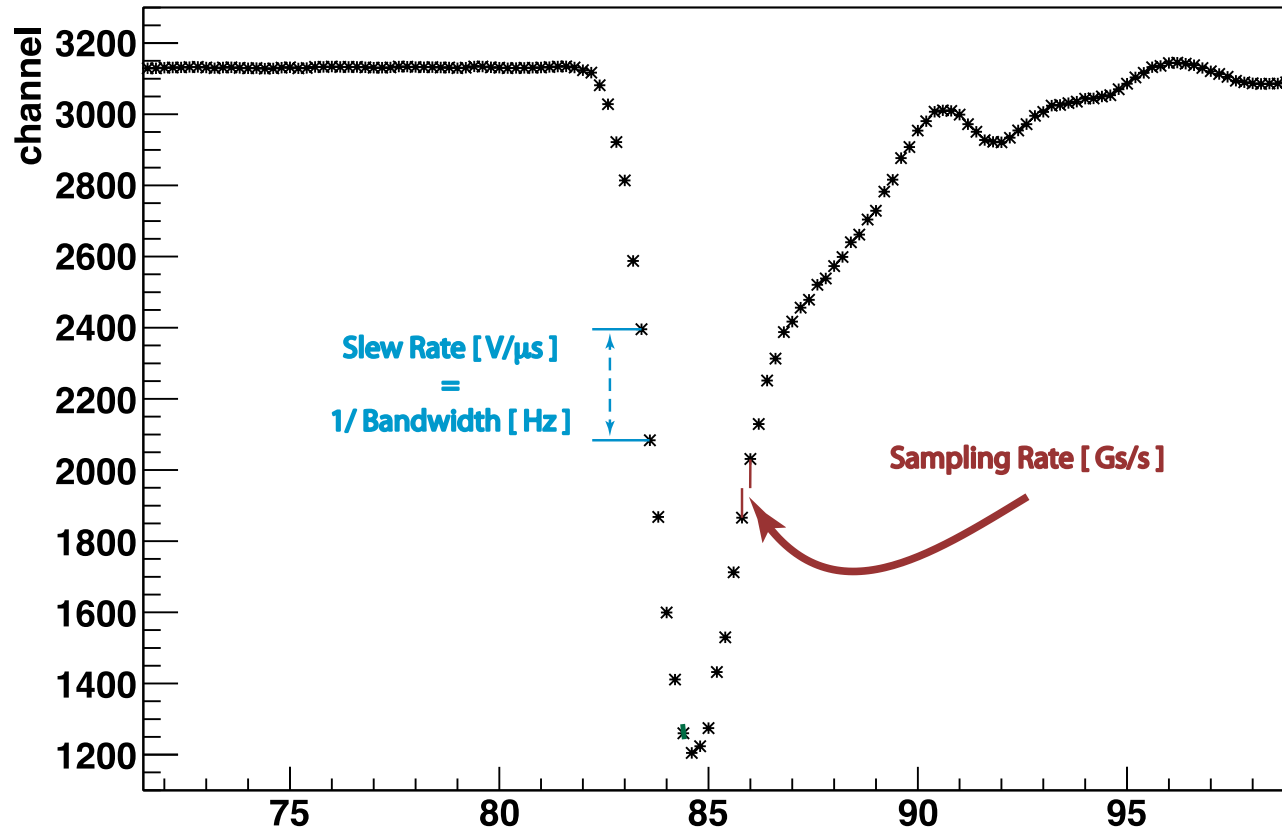


...talking about sampling...

* Picture from: <http://dev.emcelettronica.com/>

From the analog to the digital world...

2) Analog to Digital Converter: ADC

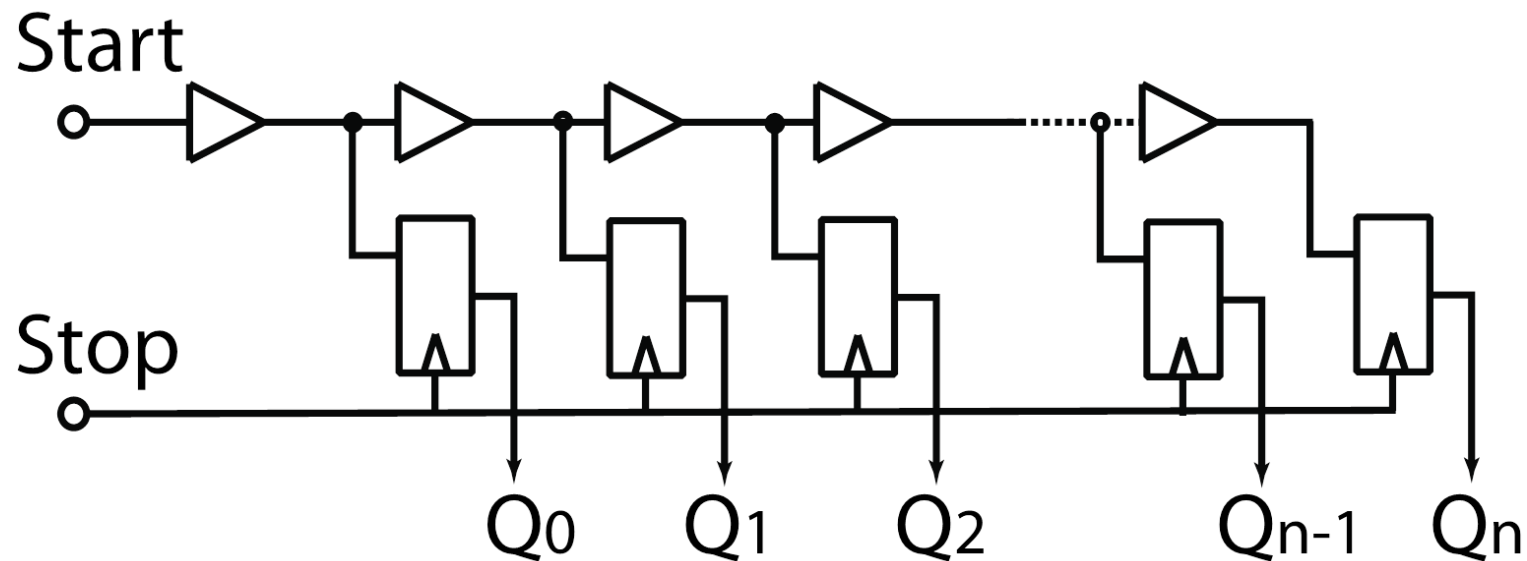


- Bandwidth gives information about how fast is the device
- Sampling Rate gives information about how accurate is the digitalization of the signal seen by the device

From the analog to the digital world...

3) Time to Digital Converter: TDC

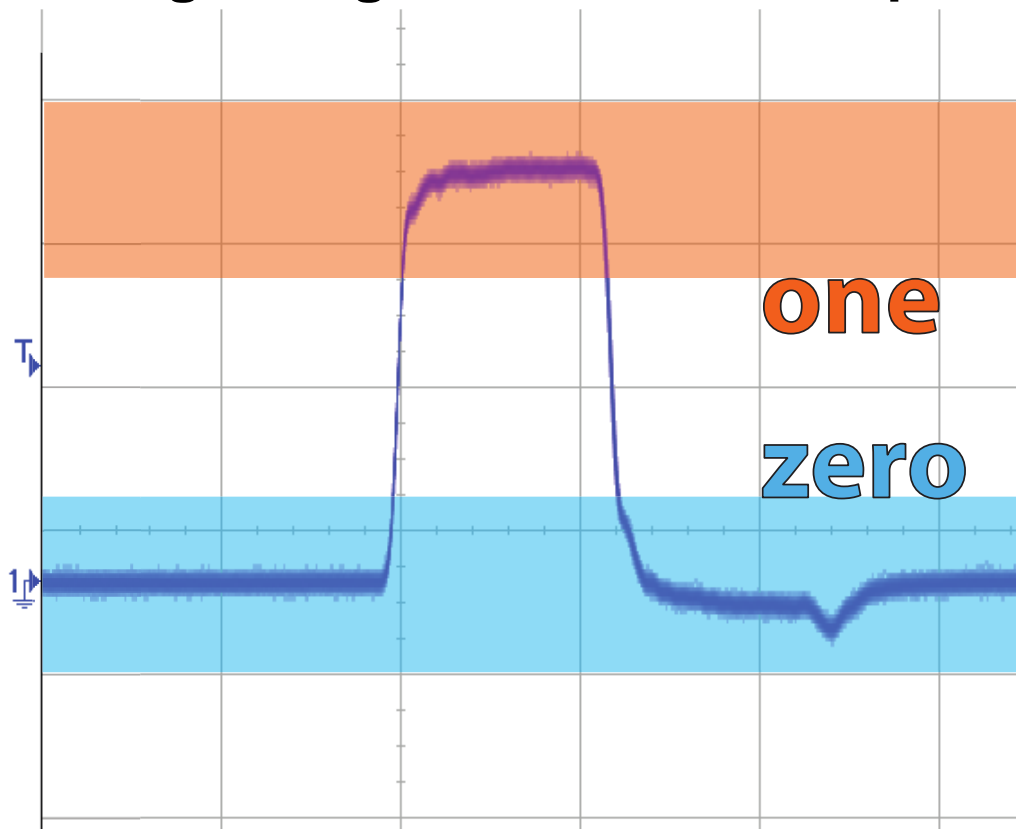
- **Digital word proportional to the time of the signal**



From the analog to the digital world...

Information in binary logic...

- 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...

Characteristics of an electronics chain

What do we want from our electronics chain?

- **to receive the correct information → Reliability**
- **to receive the full information transmitted → Efficiency**
- **to understand the message → No distortion**
- **→ we want large bandwidth**

The electronics

A brief summary...

- **Electronics is needed to read out the information from detectors**
- **Several stages of different electronics are needed**
- **Final goal is to convert information from a small, fast analog signal in a bit-stream of data**
- **The electronics chain must:**
 - Preprocess the signals w/o distortion
 - Be reliable
 - Be efficient
 - Be fast
 - Be calibrated to the experiment!!!

An example...

Particle identification can be made in many ways and with different set-ups; in this example protons and positive pions are identified by the measure of the Time of Flight in correlation with their momentum.

The electronics used for the measurement of the time can be crucial for the kind of physics one wants to investigate...

An example: PID using ToF

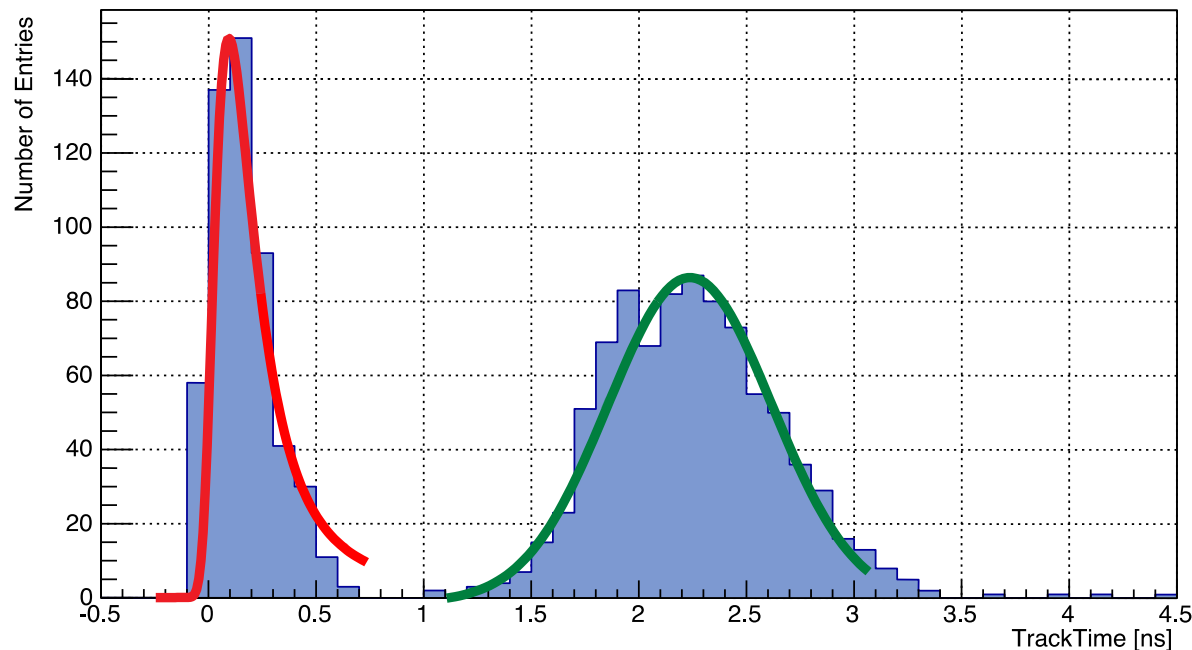
Particle Identification

- Imagine you need to identify Protons from Pions (π^+)
- We know from particle physics that, for a fixed momentum, the velocity of the two particles are different
- → we can identify the particles measuring the Time of Flight

An example: PID using ToF

Particle IDentification

- We measure the ToF of the particles
- We plot them on histograms
- We must be able to distinguish the two time distributions



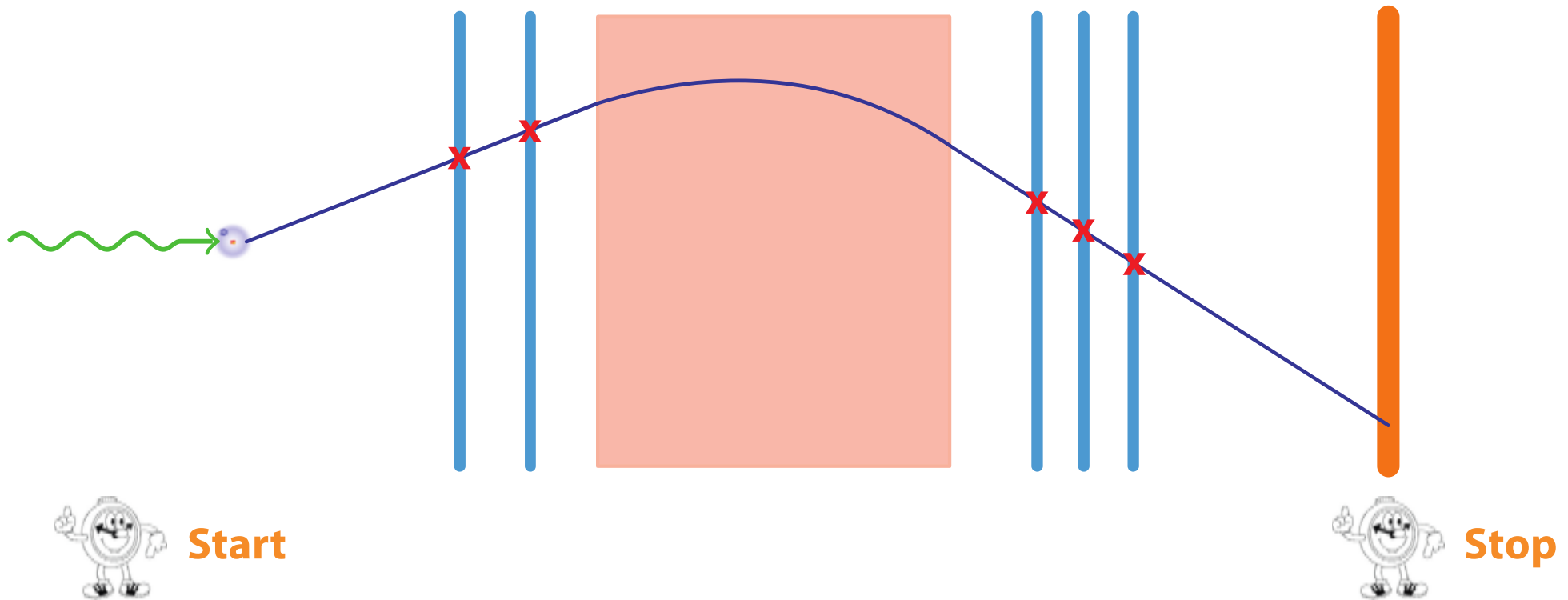
Separation Power

$$SP = \frac{|\langle x \rangle_1 - \langle x \rangle_2|}{\sigma_1/2 + \sigma_2/2}$$

An example: PID using ToF

Set-up principle

Tracker detectors + **fix magnet** = momentum spectrometer



Time_Stop - Time_Start = Time of Flight (ToF)

An example: PID using ToF

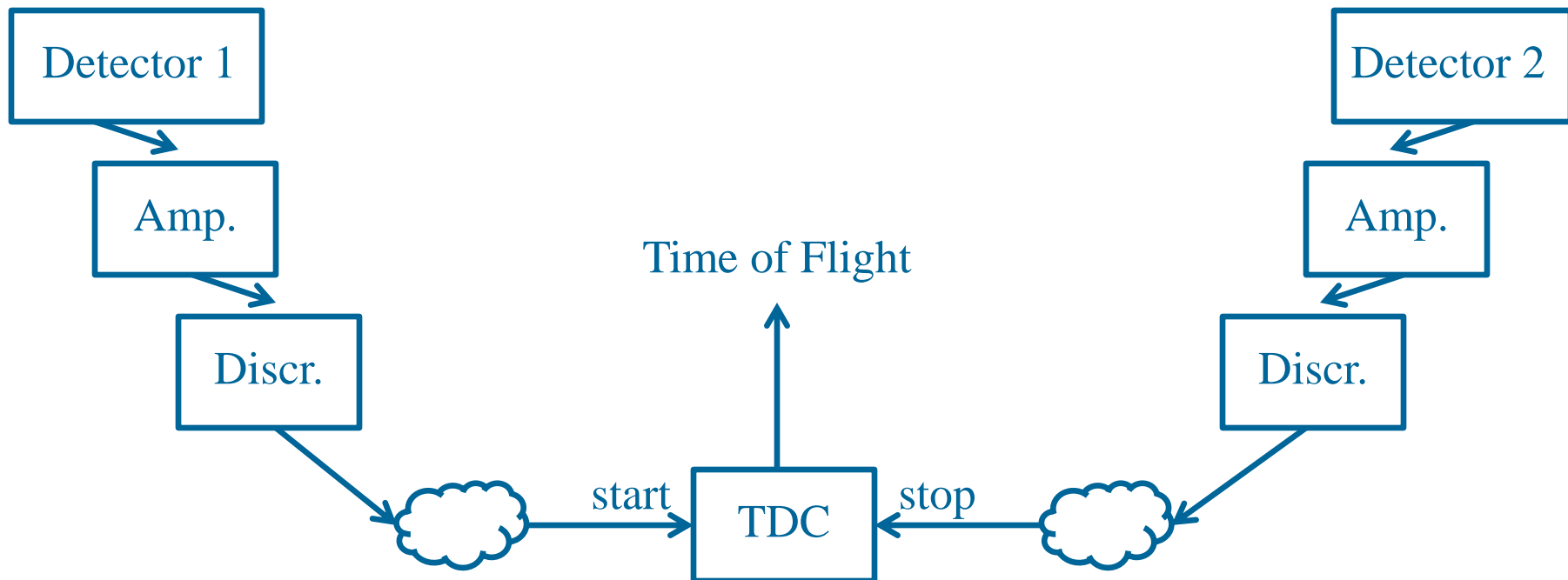
Set-up principle

- **Let's focus only on the Time of Flight:**
- **We need a start detector**
 - E.g. a tagger for the incoming photons
- **We need a stop detector**
 - E.g. a ToF wall
- **Time of Flight = stop_time – start_time**

An example: PID using ToF

Set-up principle

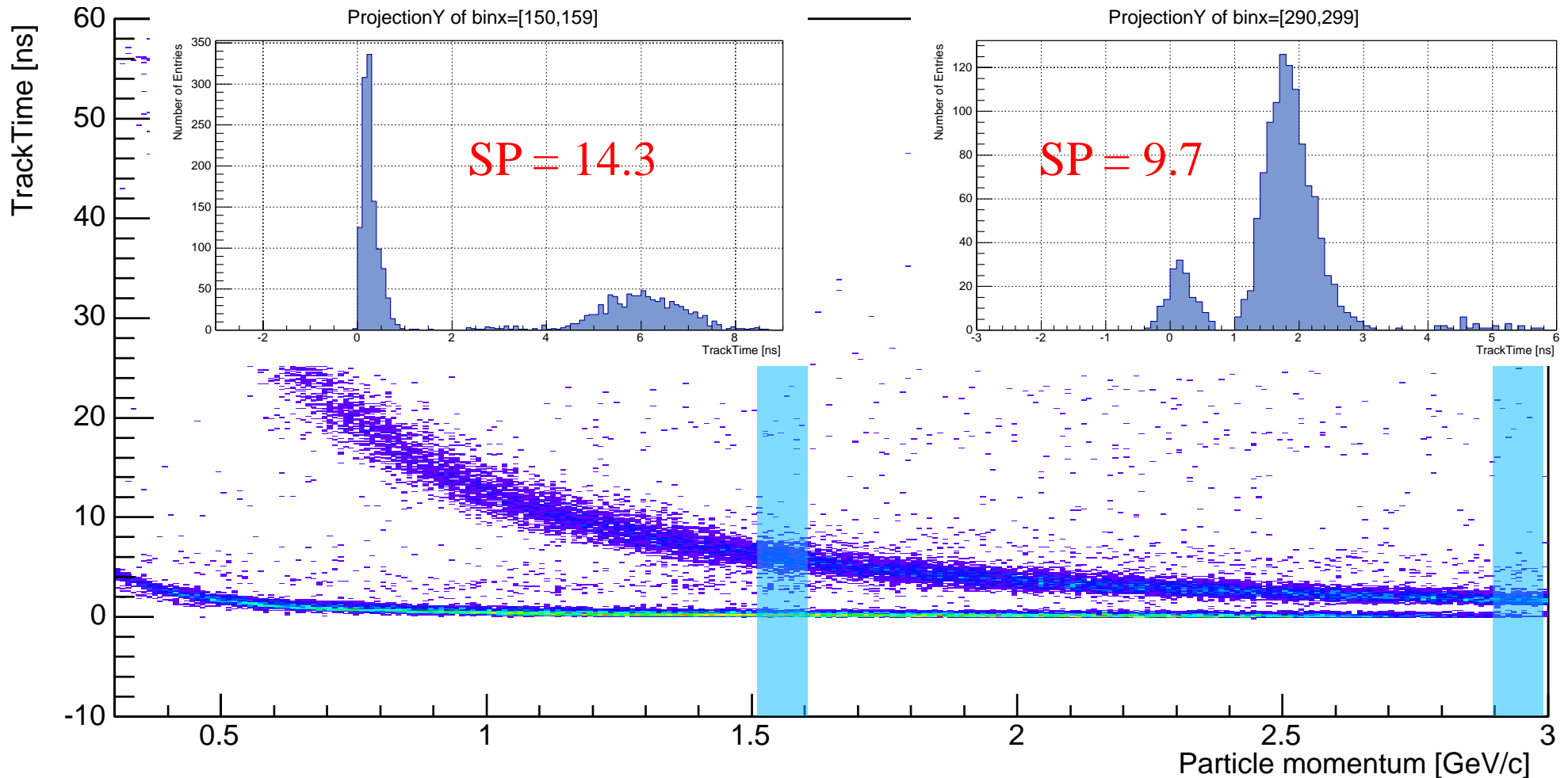
- It is a simple measurement, but involves a lot of electronics



- How much does the time resolution of the stop detector influence the measure? → let's simulate different resolutions...

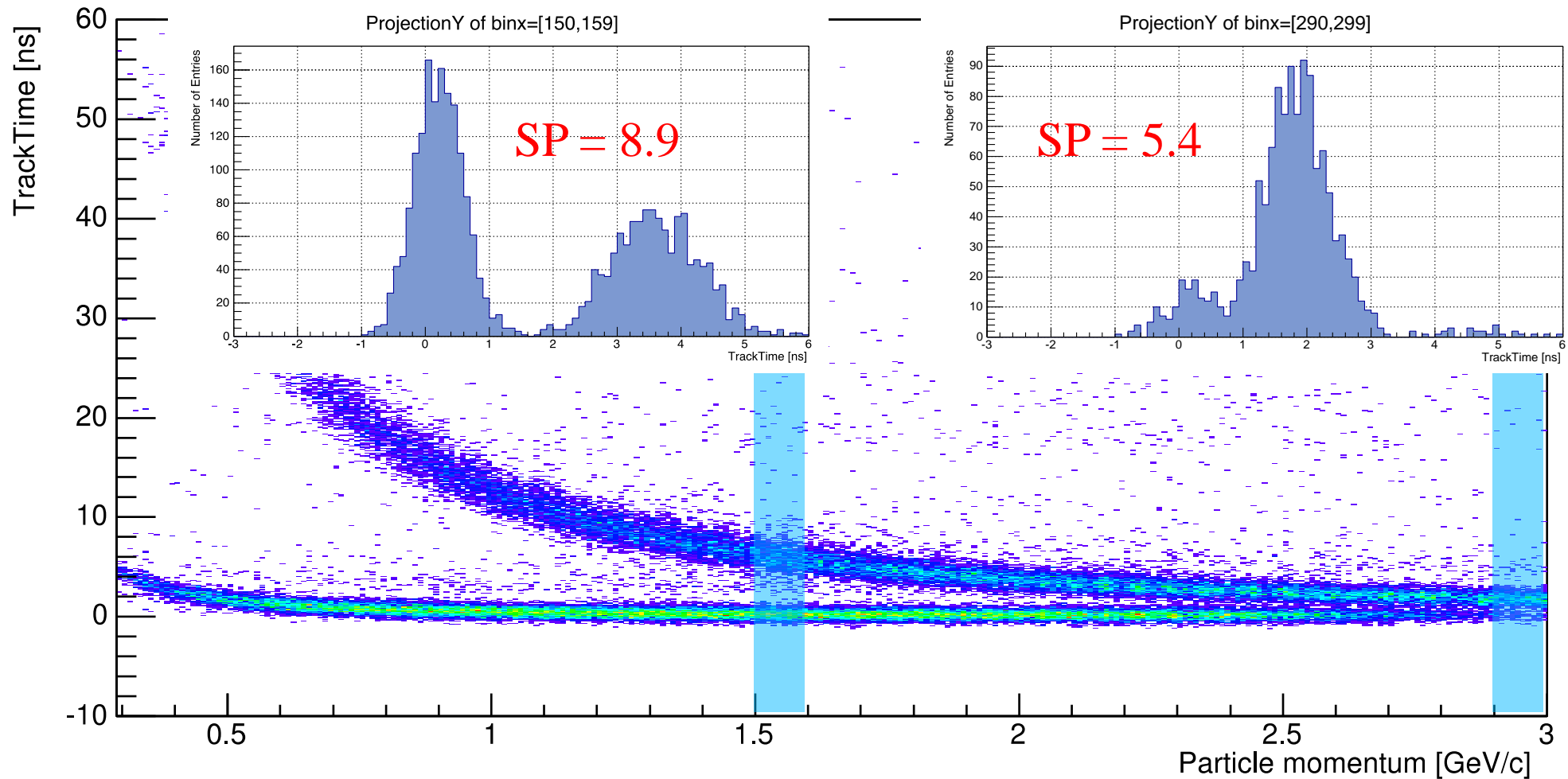
An example: PID using ToF

1) Ideal electronics: no spread of time due of the TDC



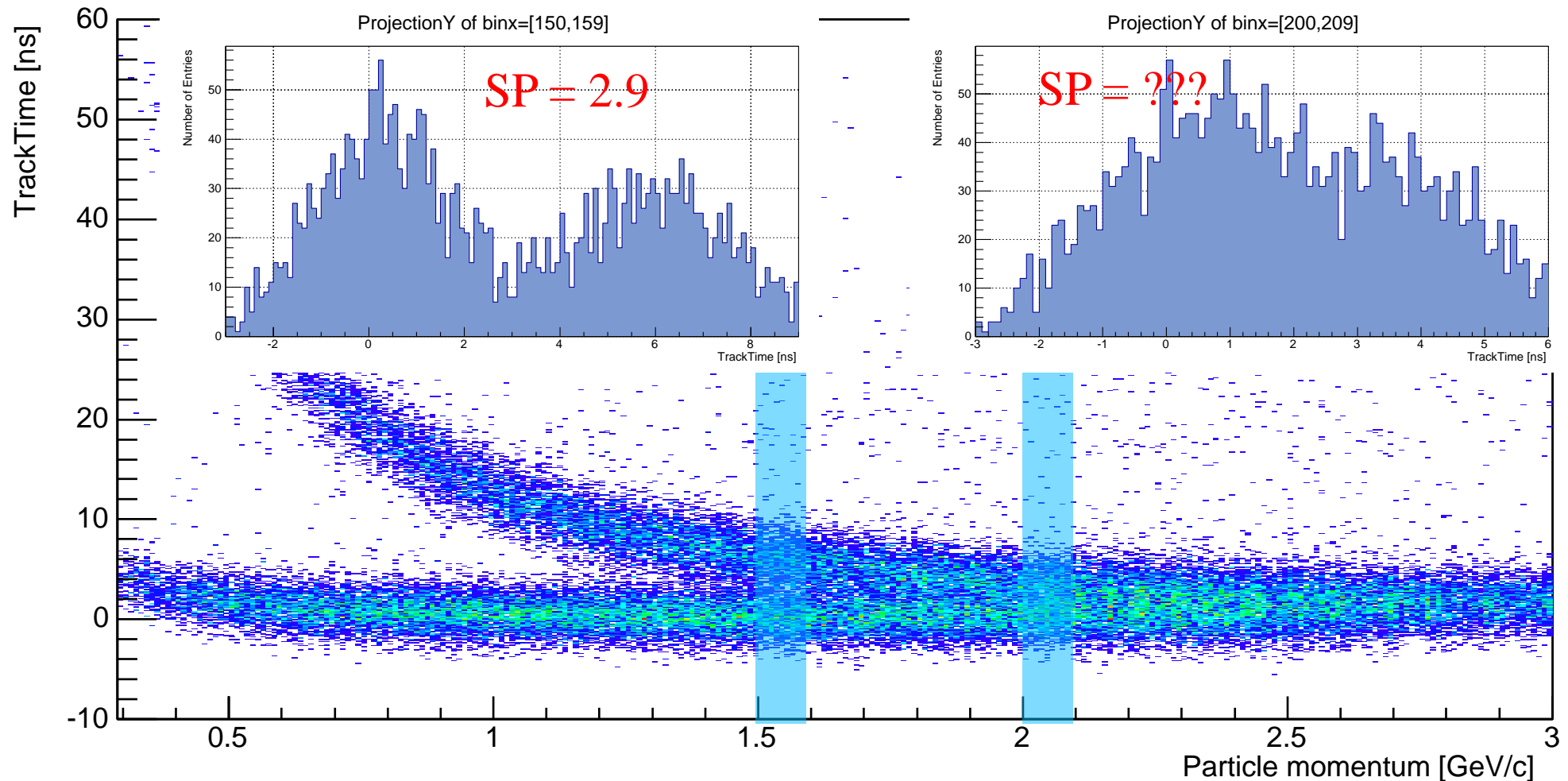
An example: PID using ToF

2) A “good” electronics: ~ 480 ps time resolution



An example: PID using ToF

3) A “bad” electronics: ~ 1.9 ns time resolution



An example: PID using ToF

Conclusions...

- **We want to identify Protons and π^+ using a Time of Flight**
- **From the plot “ToF vs Momentum” we can distinguish the two particles only if we can separate the two time distributions**
- **The time resolution of the electronics chain affects which kind of physics you can investigate**
 - Different technologies allow for different time resolutions...
 - ...but budgets are limited
- **You must choose your electronics taking into account your specific physics program!!!**

Read-Out Electronics: where data come from

lecture 1
summary and conclusions

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!!!