Application of Digital Sampling Techniques to a "Single Chip Telescope" for Isotopic Particle Identification

L.Bardelli, G.Poggi, M.Bini, G.Pasquali, N.Taccetti

I.N.F.N. and University of Florence, ITALY

- Introduction
- Example of a custom digital sampling system
- Performances of On-line Digital Signal Processing:
  - – Amplitude measurements (Energy)
  - – Timing measurements (Pulse Shape Analysis – ToF)
- Pulse Shape in a **reverse mount** Silicon.
- Application to a “new” detector: the Single Chip Telescope
  - – Description of the detector
  - – Results of the very first prototype
- Conclusions.

One of the main purposes of nuclear dynamics studies with future RNB facilities is the investigation of nuclear matter far from the stability line

⇓ ⇓

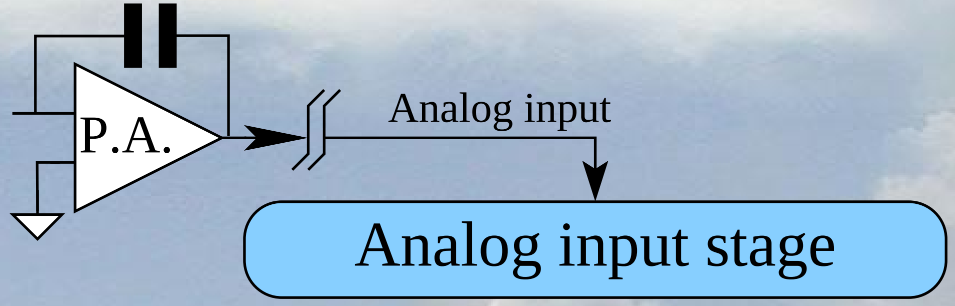
Strong requirements on experimental capability of **charge** and **mass** identification.

High detection granularity, and thus a very **high number** of electronic channels.

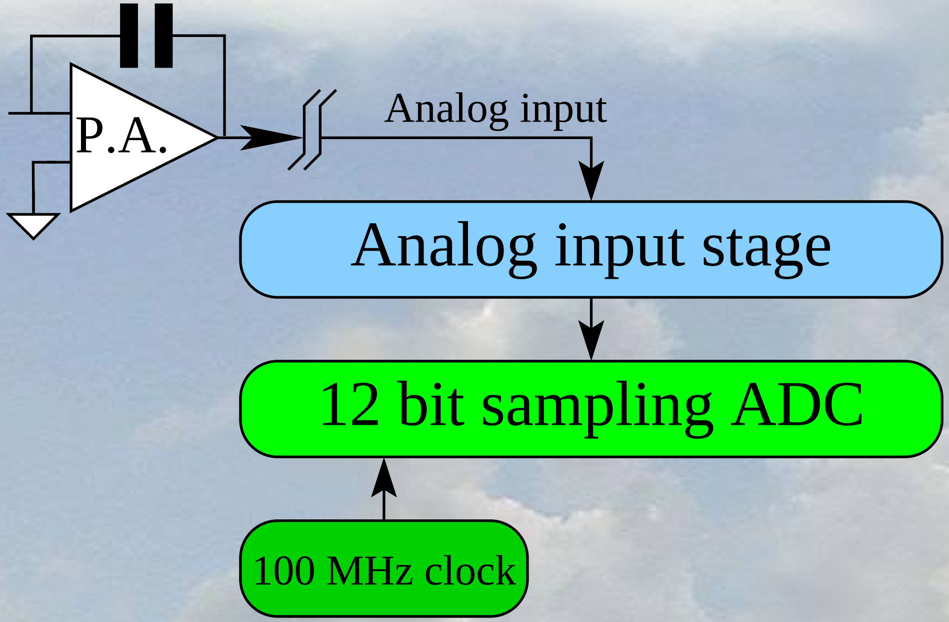
Both requirements can benefit from the use of **fast digital sampling techniques**:

- Performances as good as standard analog techniques
- Much simpler electronic setup: a single fast Analog to Digital Converter can extract all the information needed from a detector preamplifier (energy, pulse shape, timing)
  $\Rightarrow$ much lower costs.

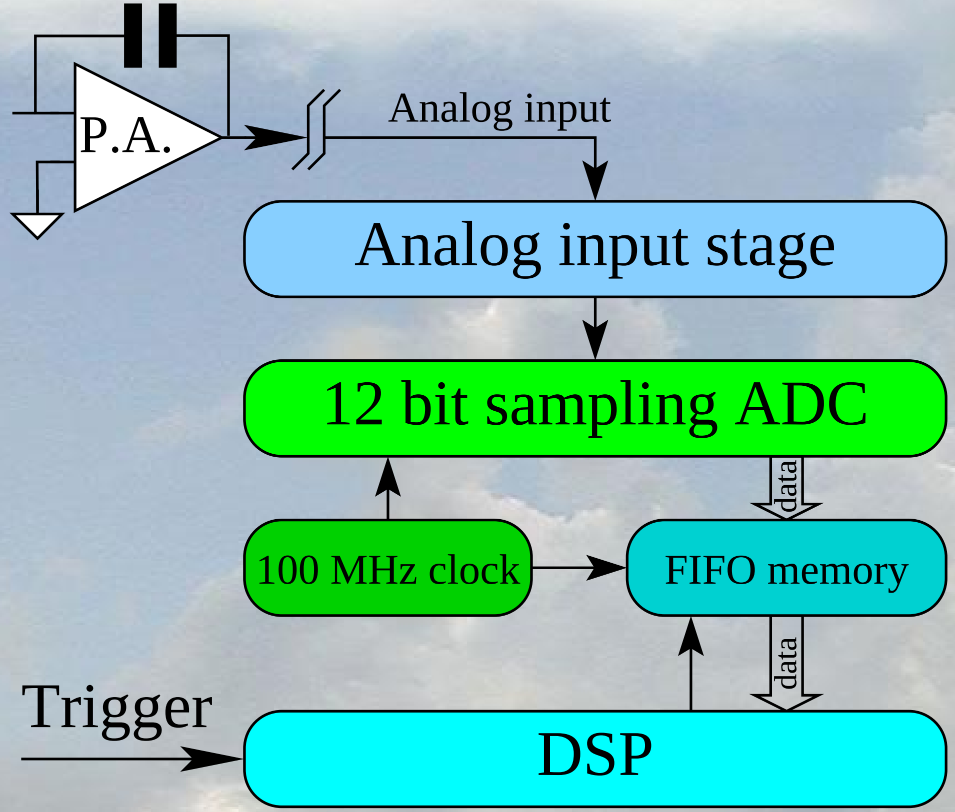
A custom sampling system



P.A.
Analog input
Analog input stage


P.A.
Analog input
Analog input stage
12 bit sampling ADC
100 MHz clock

A custom sampling system



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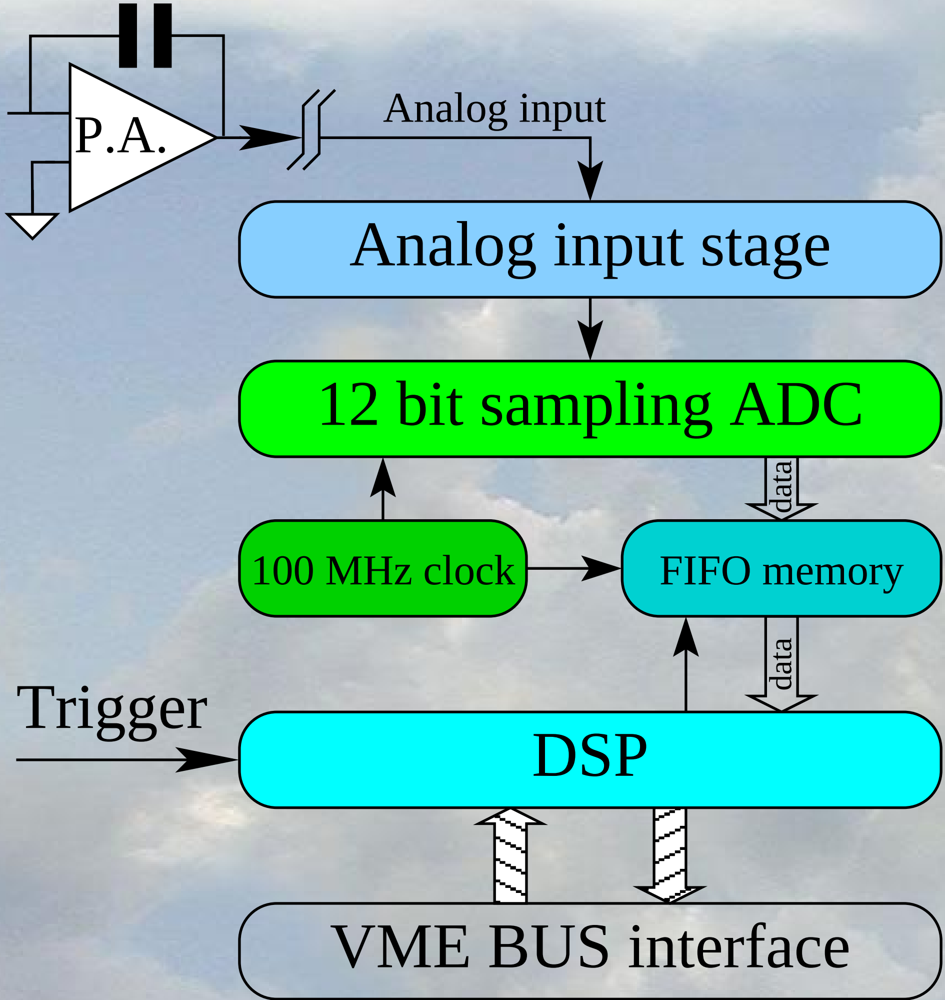


Custom system designed and built in Florence.

- Constant phase antialiasing input stage.
- **100 MSamples/s, 12 bit** fast Analog-to-Digital Converter.
- Digital Signal Processor (DSP) for **on-line** processing of detector signals: **one processor can compute many variables**
- Data readout via VME bus.

A first prototype (without DSP) is described in: L.Bardelli, M.Bini, G.Poggi, N.Taccetti, Nuclear Instruments and Methods in Physics Research **A491** (2002) 244-257

High resolution (12 bit)
fast AD converter

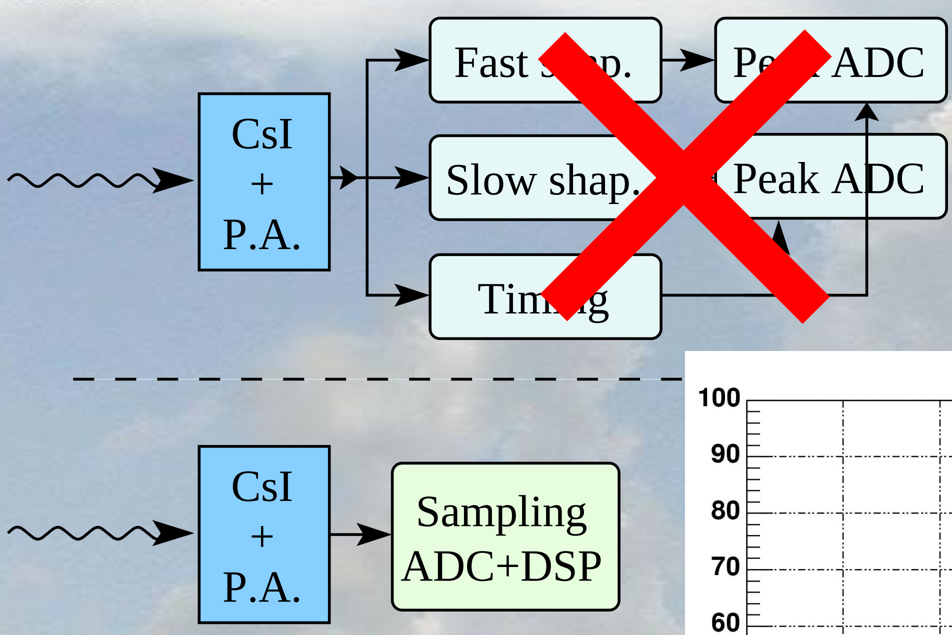
Electronic resolution that **well compares** with standard analog **high-resolution** and **high dynamic range** systems.

Digital Filters

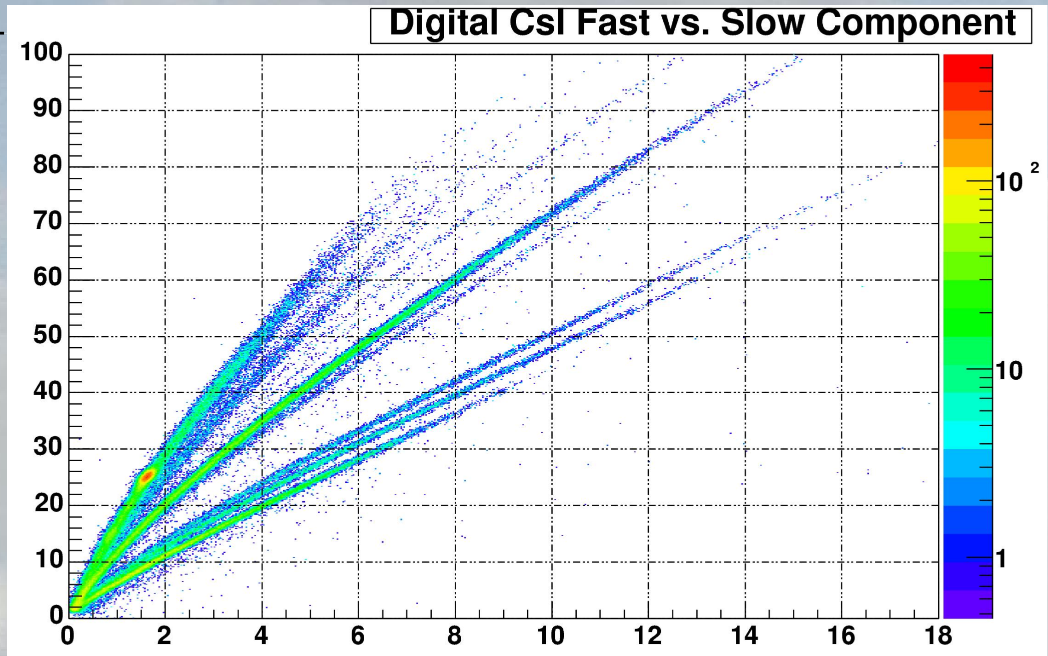
Digital versions of analog filters (i.e. spectroscopy amplifiers, . . .)

New (better) filters, for example *optimal* filtering

Some experimental examples

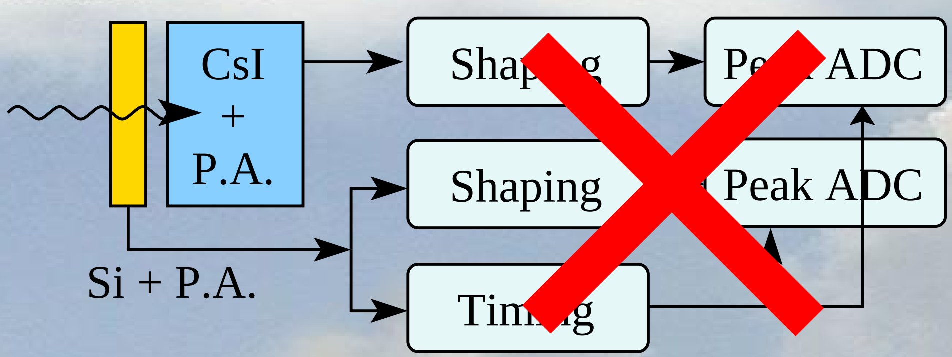


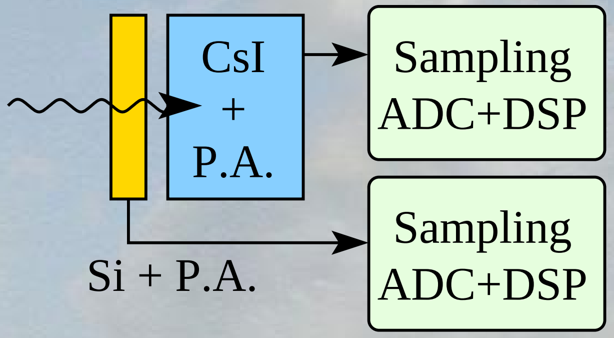
Much simpler digital electronic chain



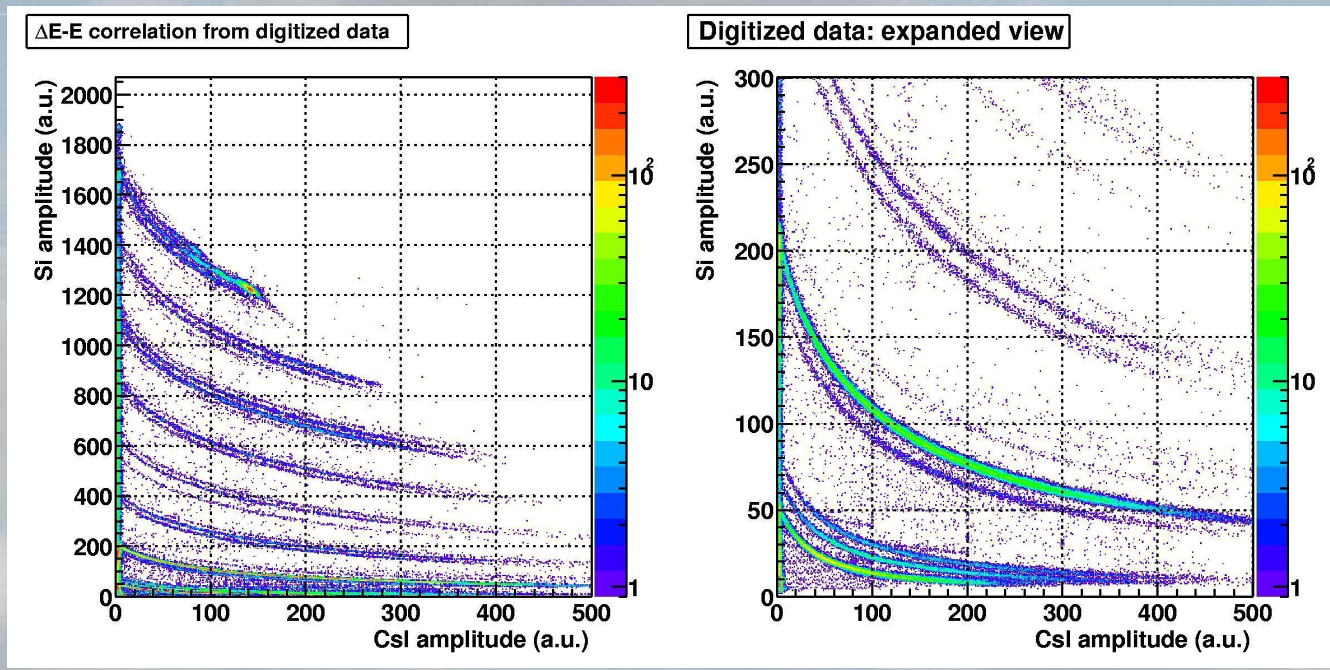
Standard Fast vs. Slow correlation for a CsI scintillator, obtained using a 12 bit fast sampling ADC and processing data with two **digital** semigaussian filters ($\tau_{fast} \simeq 700$ ns, $\tau_{slow} \simeq 2$ μs).

Si-CsI telescope: ΔE-E





Simpler digital electronic chain



Standard ΔE-E correlation using digital semigaussian filters:

Both high and low ranges with a single AD converter for ΔE

Timing measurements for Pulse Shape Analysis can be achieved using a **digital Constant Fraction Discrimination**:

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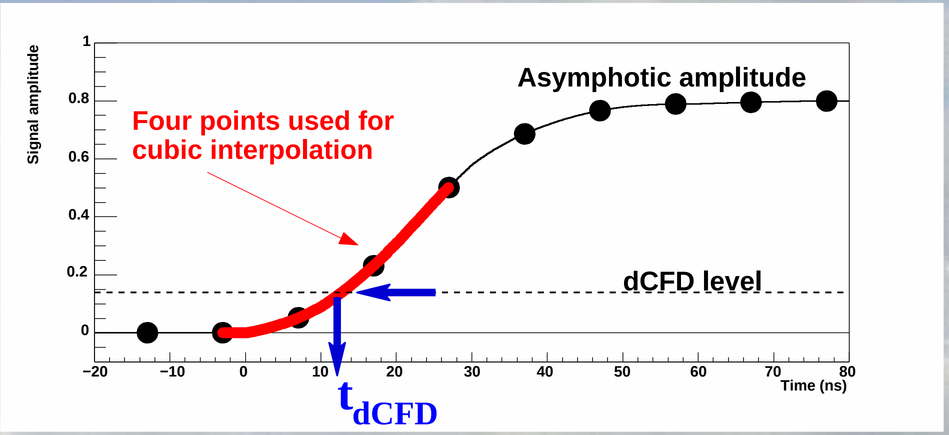

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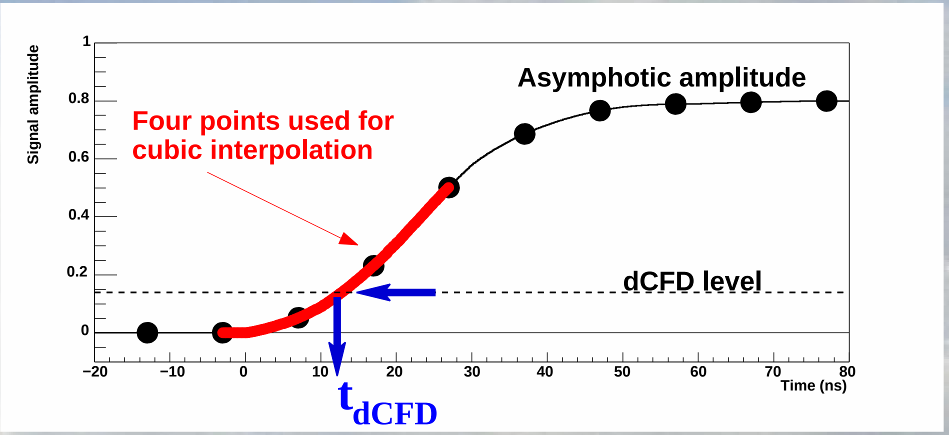
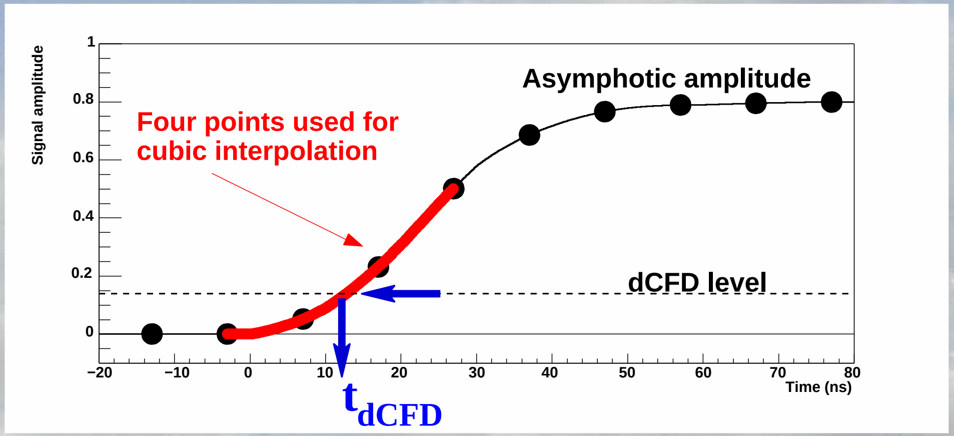


1 Find the asymphotic amplitude A of the signal

Timing measurements for Pulse Shape Analysis can be achieved using a **digital Constant Fraction Discrimination**:



1. Find the asymphotic amplitude A of the signal

2. Interpolate the time where $S(t_{\mathrm{dCFD}}) = f \cdot A$ (**cubic interpolation needed**)

This is **different from** what **analog CFDs** perform!

Which AD converter ?

Realistic simulations: (L.Bardelli *et al.*, submitted to NIM **A**)

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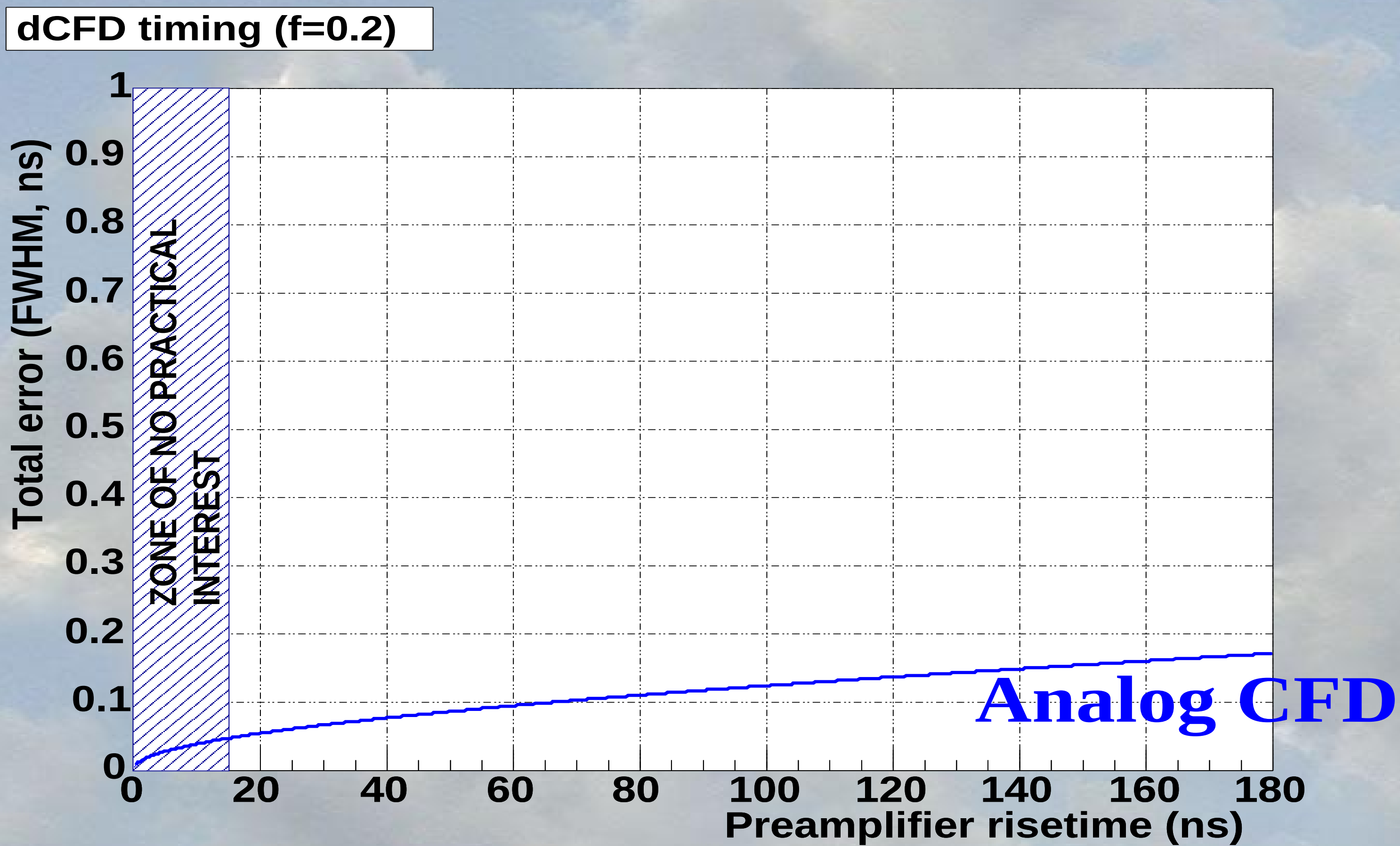

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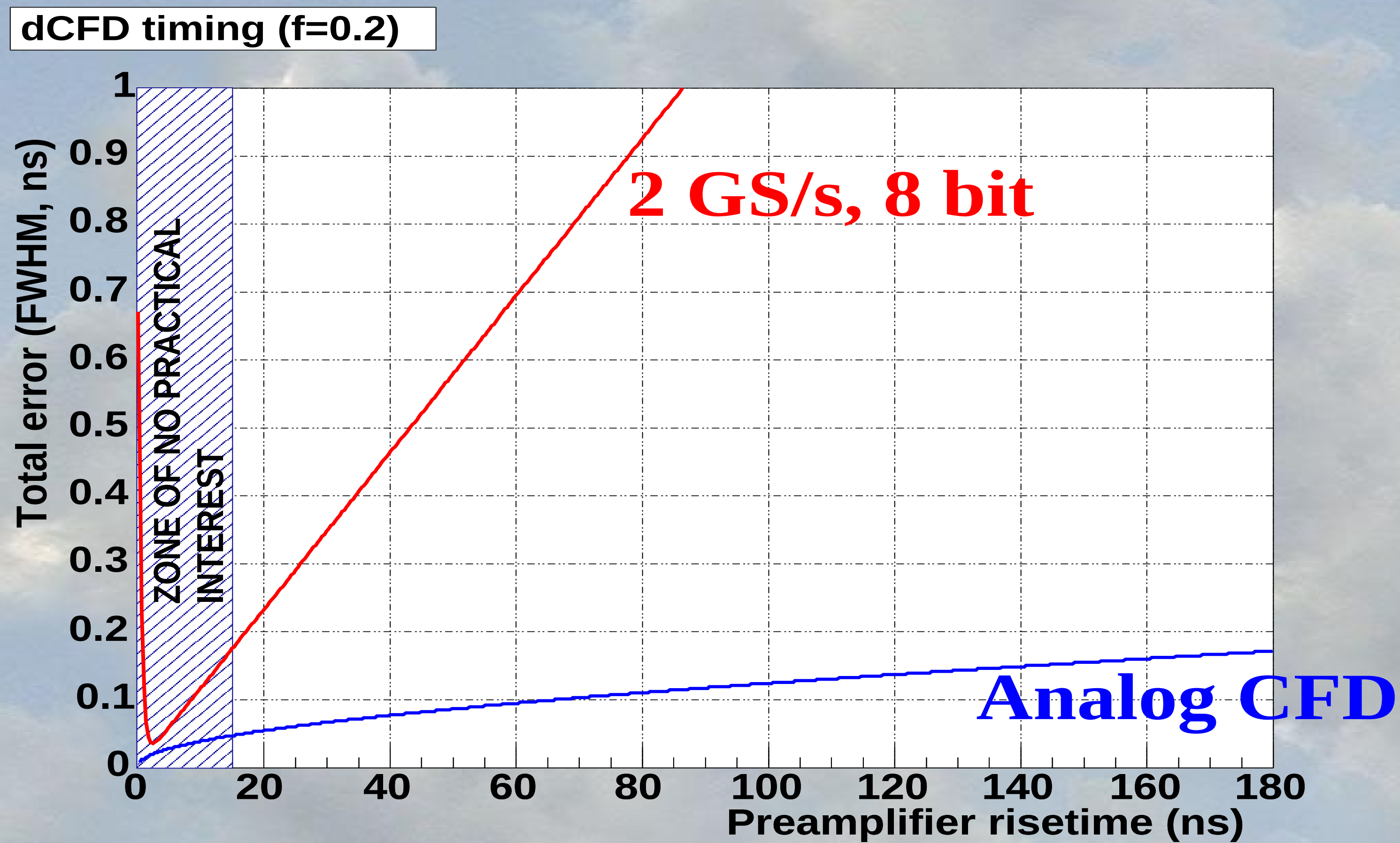

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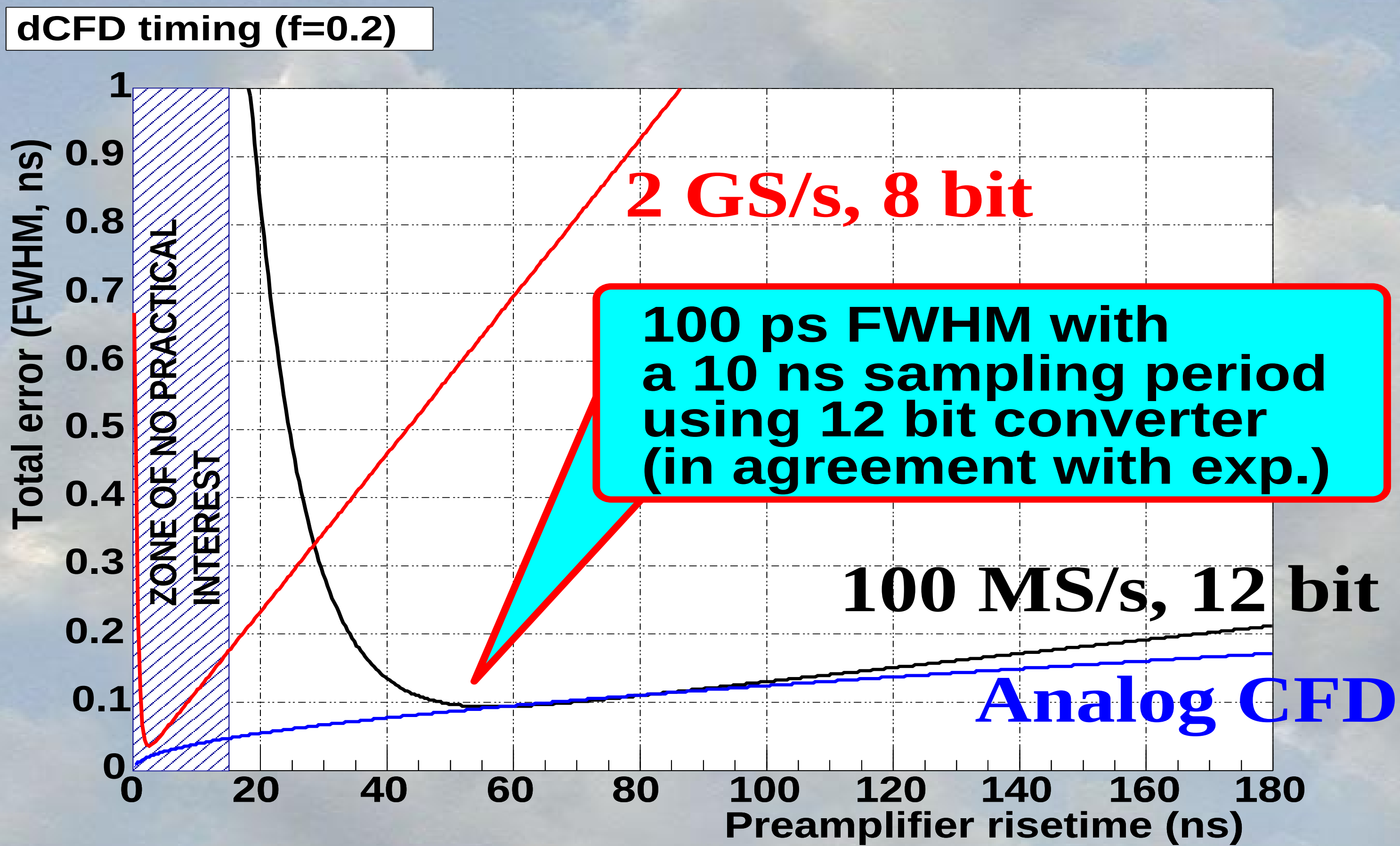

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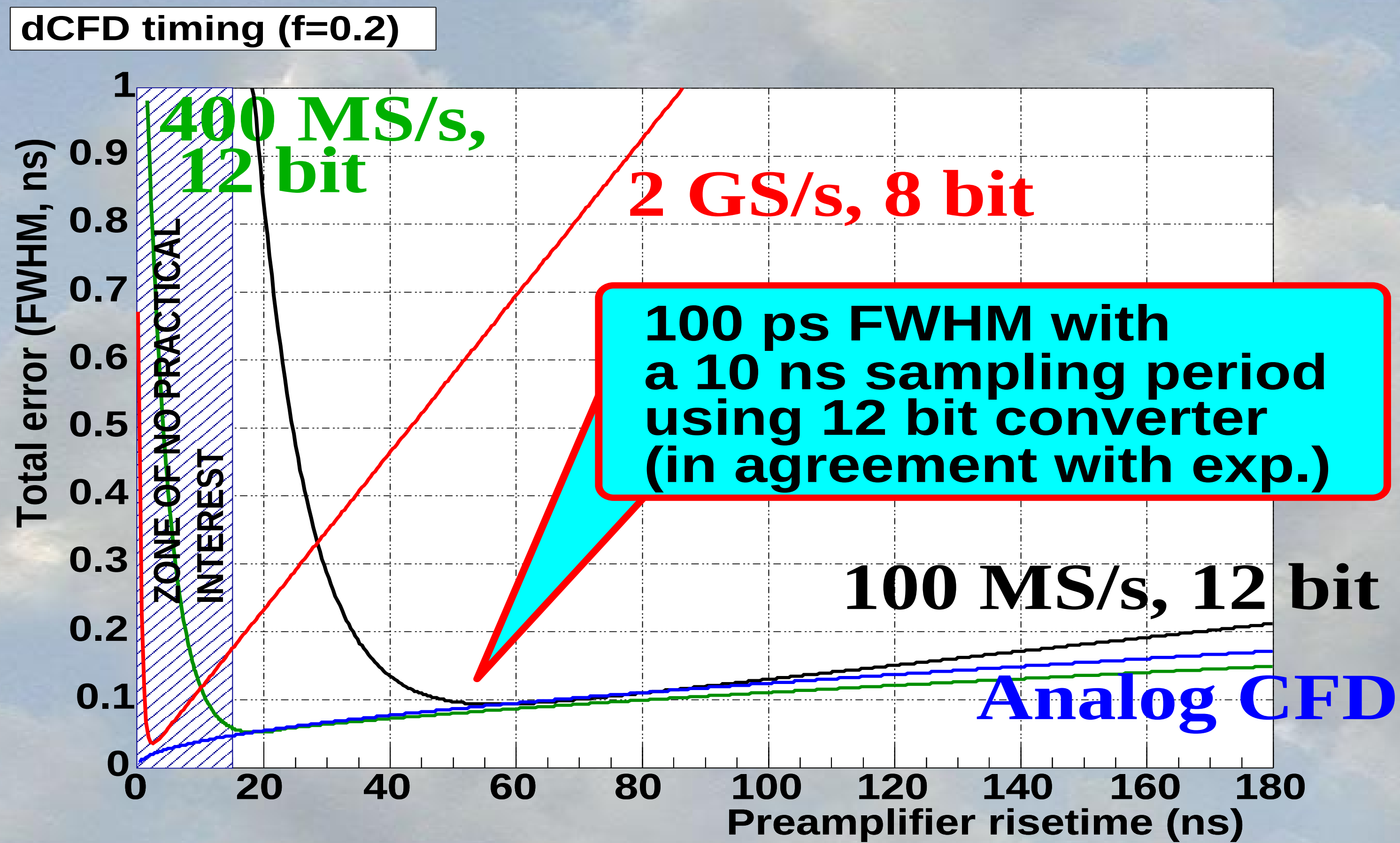
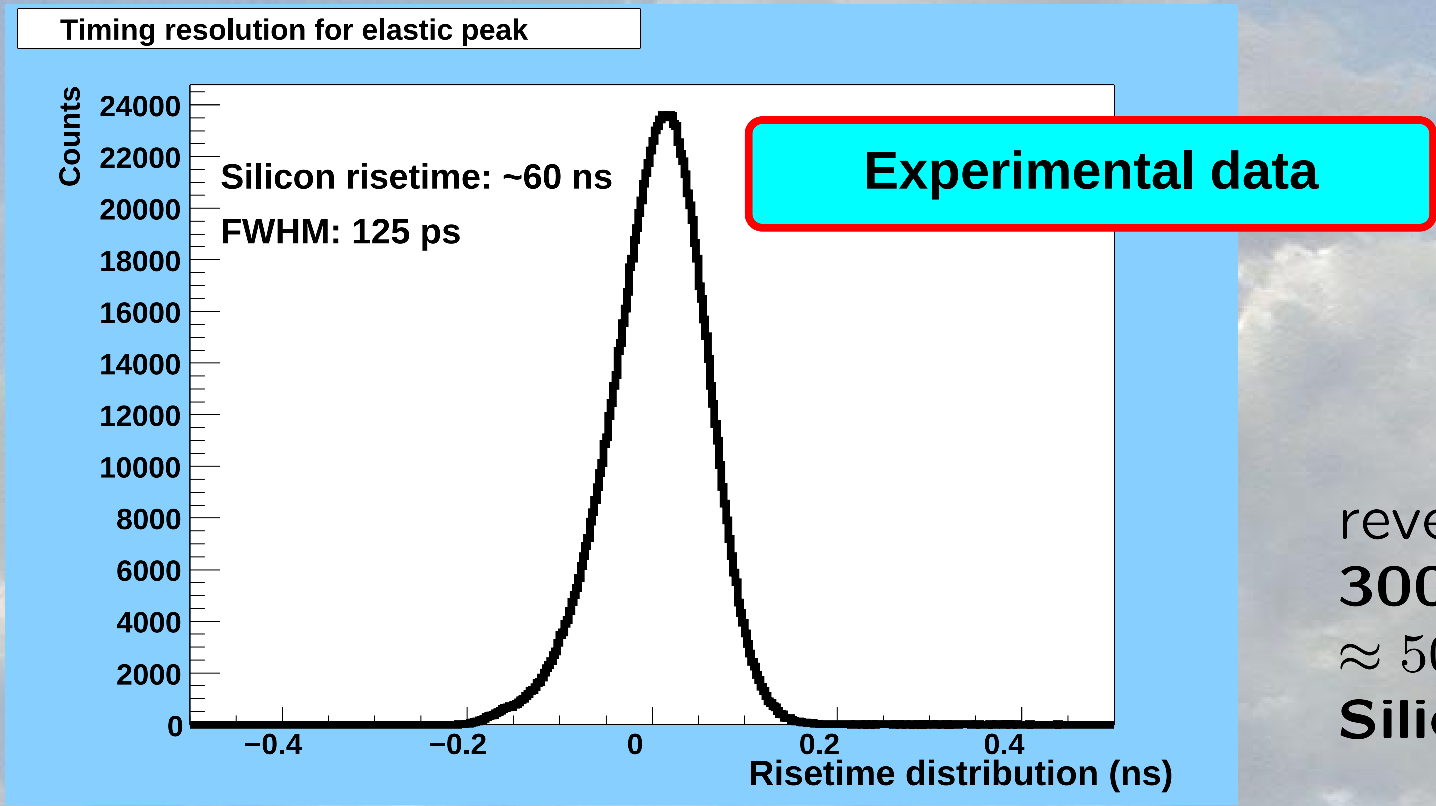


12 bit ⇒ Resolution 100 times smaller than sampling period

PSA analysis: differences between two **dCFDs**.
Timing of 250 MeV Oxygen elastic peak using a Si detector:



reverse
300 μm,
≈ 500 **mm^2**
Silicon

Time difference between 90% and 10% dCFDs
500 mm^2 Si detector.

L.Bardelli *et al.*, submitted to NIM **A**

PSA analysis: differences between two **dCFDs**.

Time of Flight or **coincidence** measurements?

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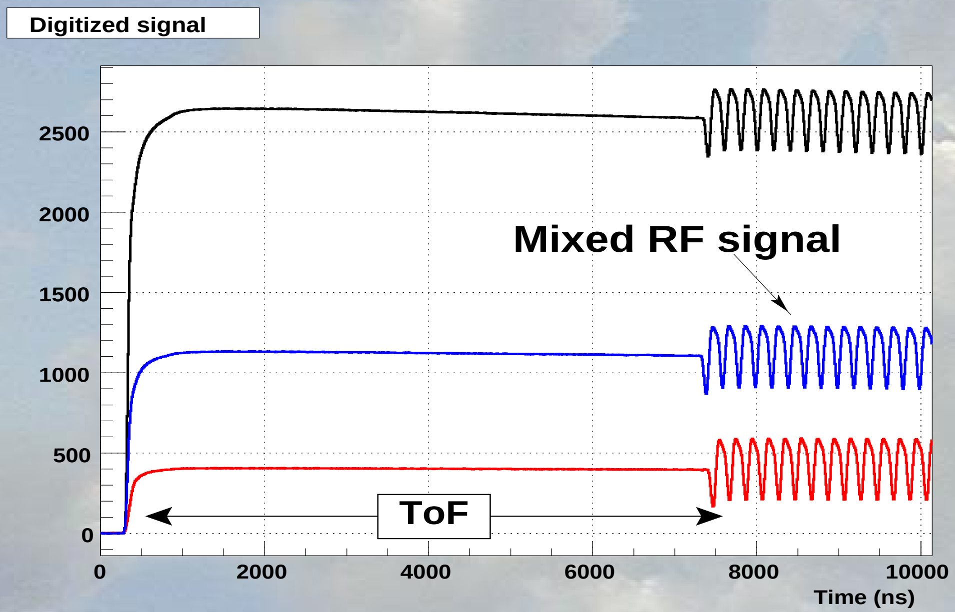
Mix a common time reference signal with the preamplifier output:



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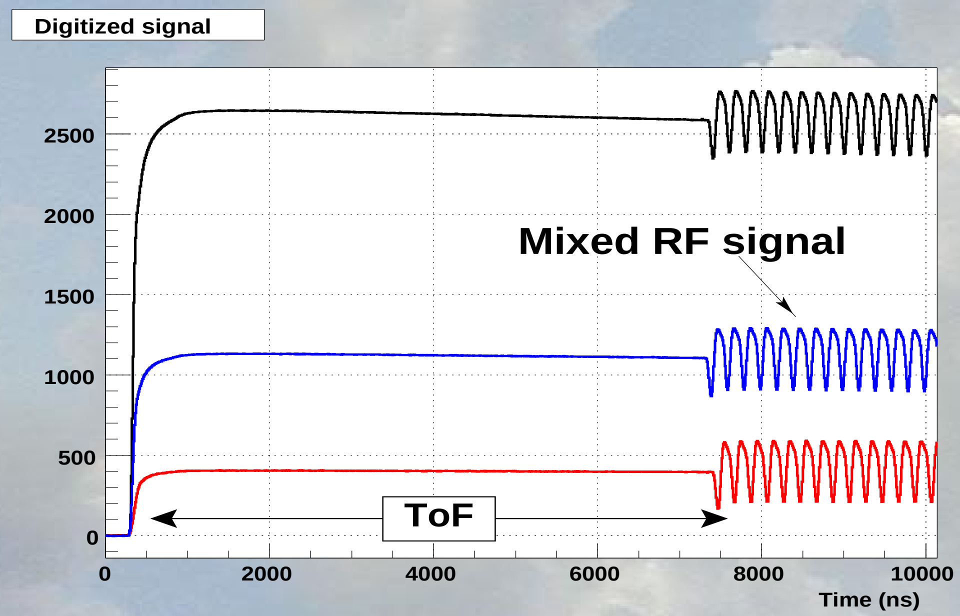


The DSP software can separate the "true" signal from the "reference" one and compute the time difference.

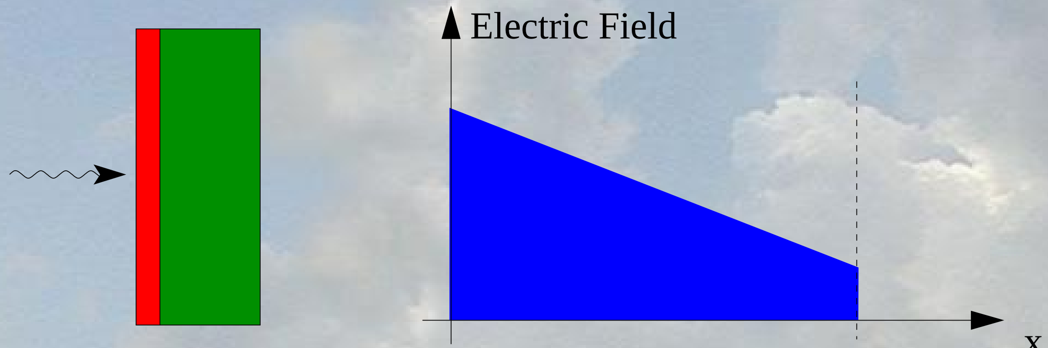
Using a train of pulses as reference the resolution can be significantly improved (i.e. 50 ps FWHM using 10 pulses)

The same solution allows for **syncronization** between many channels: **coincidence** measurements possible.

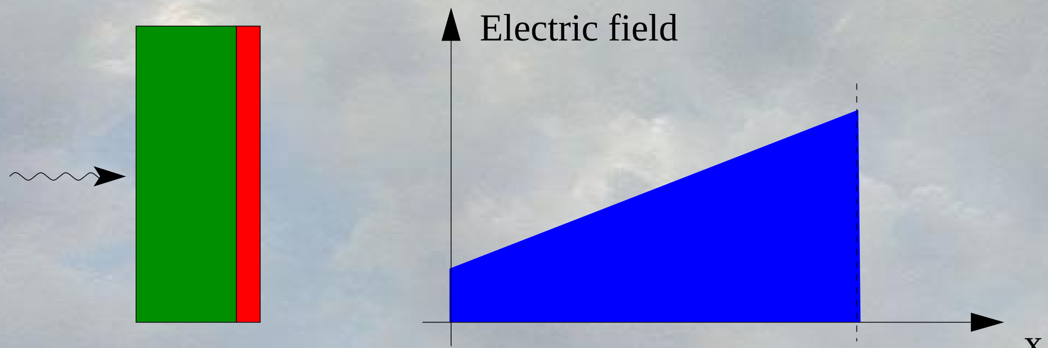
L.Bardelli *et al.*, submitted to NIM **A**

The standard ΔE-E technique does not identify particles stopped in the Silicon detector.
One possibile solution: **reverse mount Silicon detector**

Standard configuration

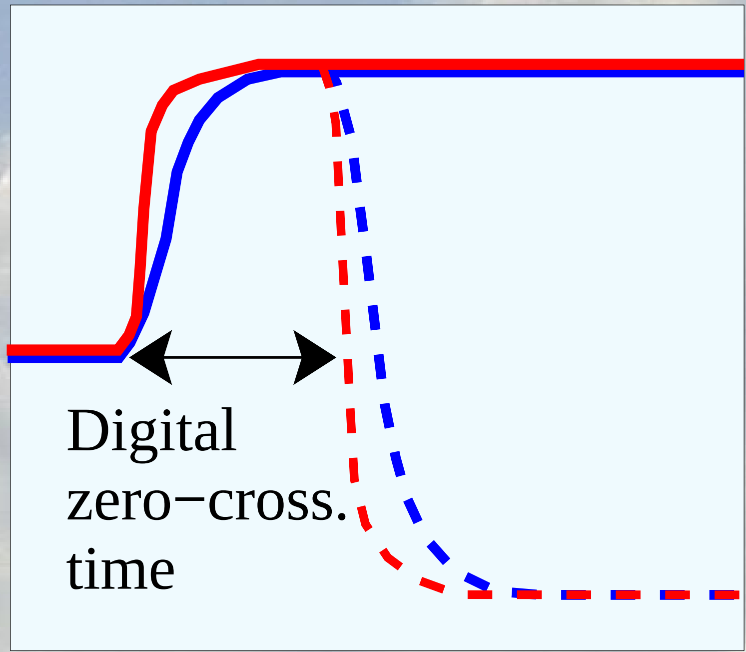


Reverse configuration



Increased **Pulse Shape** capabilities due to **charge collection** effects.

Digital Amplitude vs. Digital Zero Crossing time:



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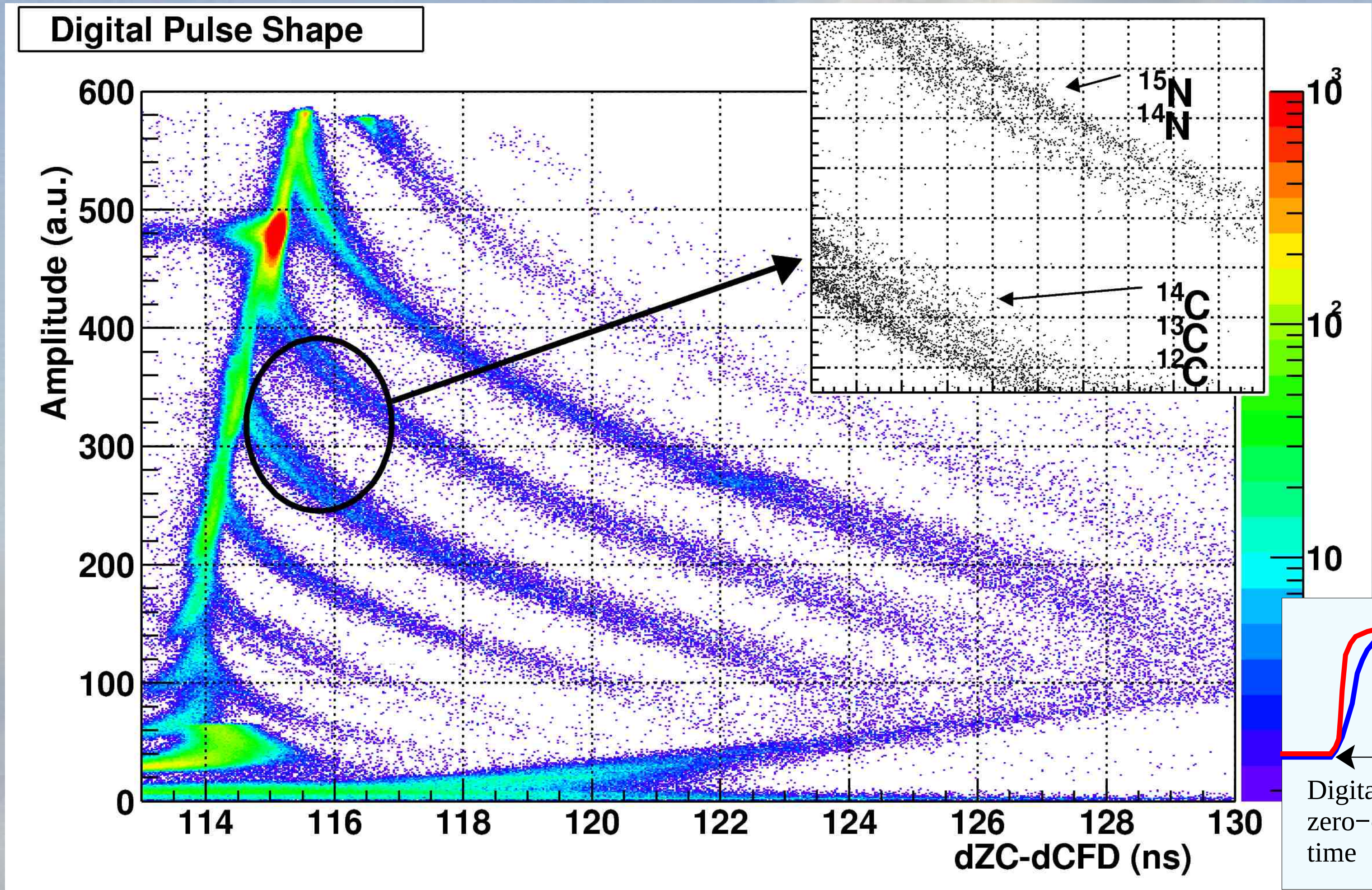
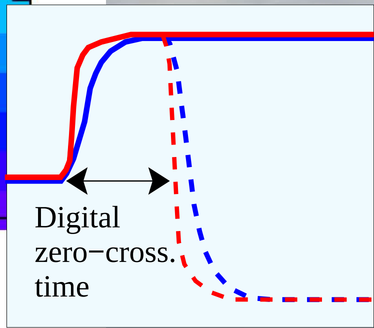
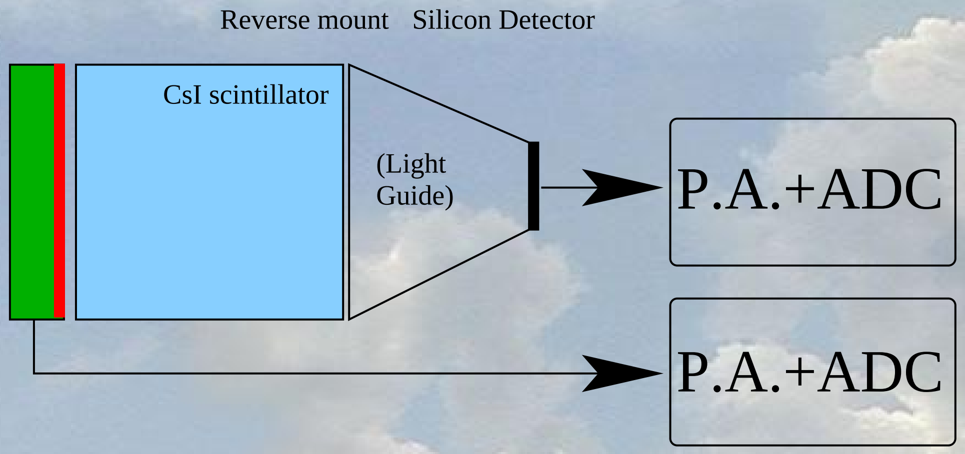




reverse
300 μm,
≈ 500 **mm^2**
Silicon

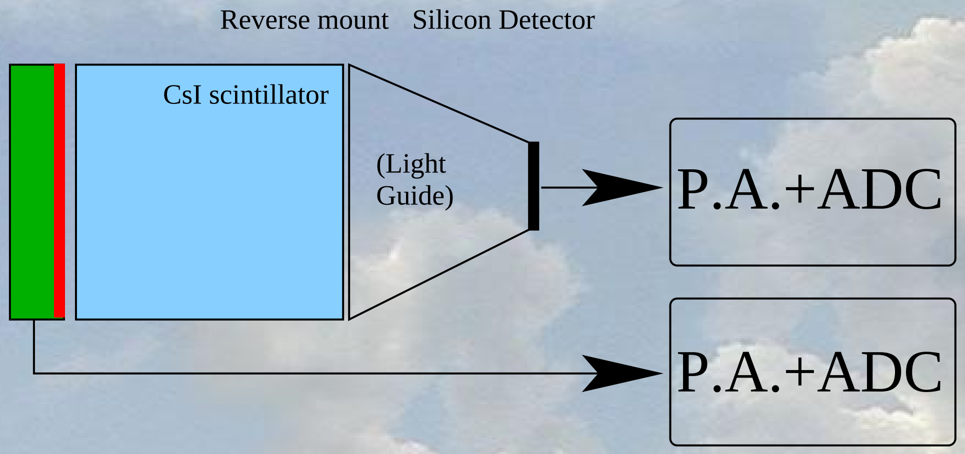
Evident **sub-nanosecond** resolution even with 10ns sampling

Standard reverse mount Si-CsI:



Single Chip Telescope:

Standard reverse mount Si-CsI:



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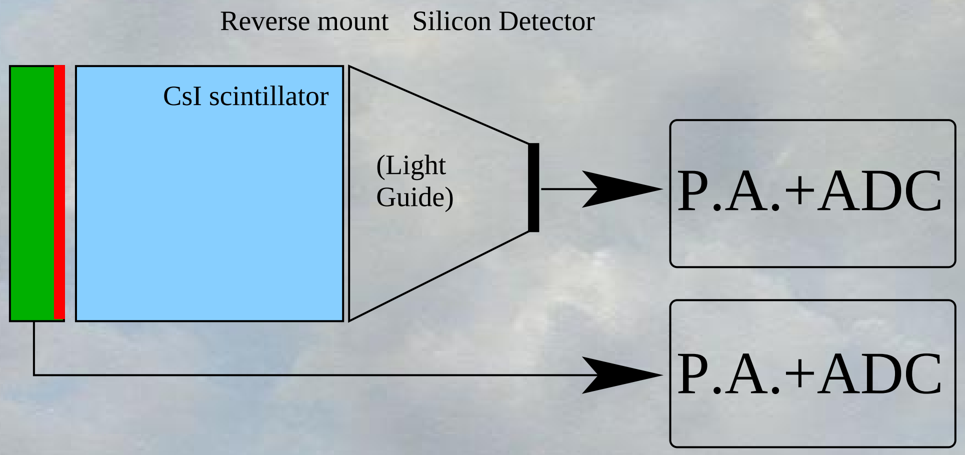

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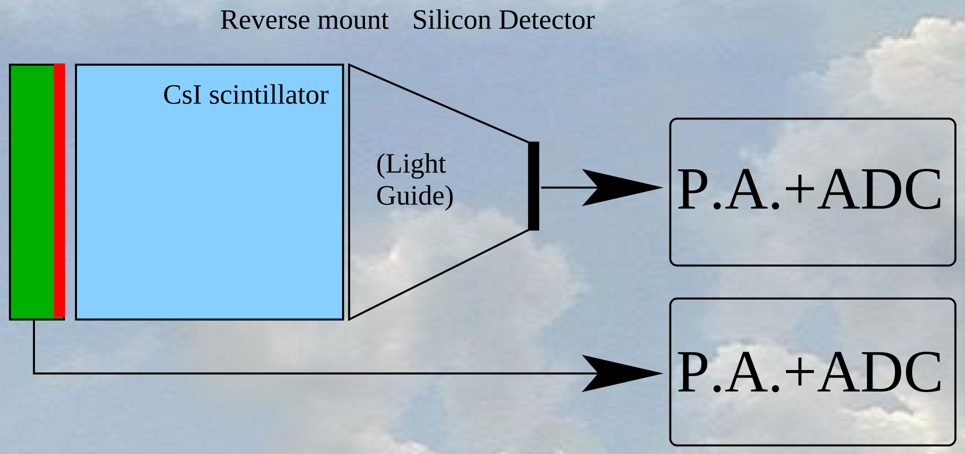

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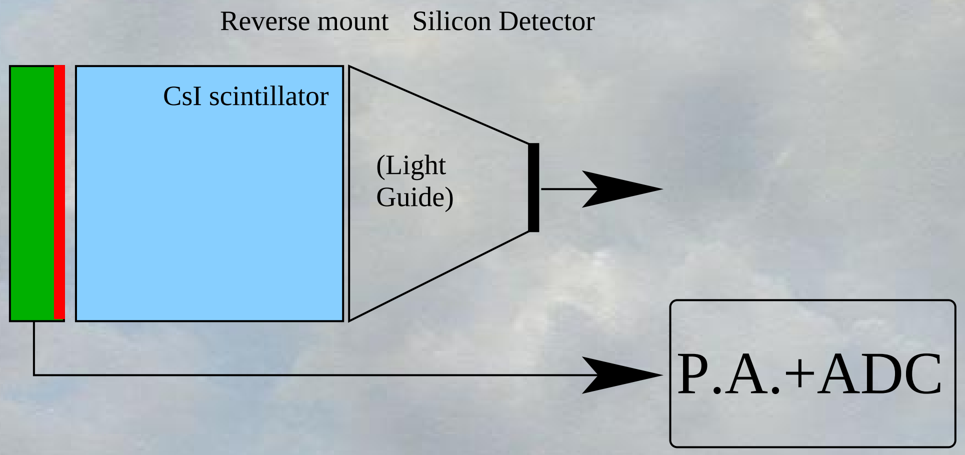

The Single Chip Telescope

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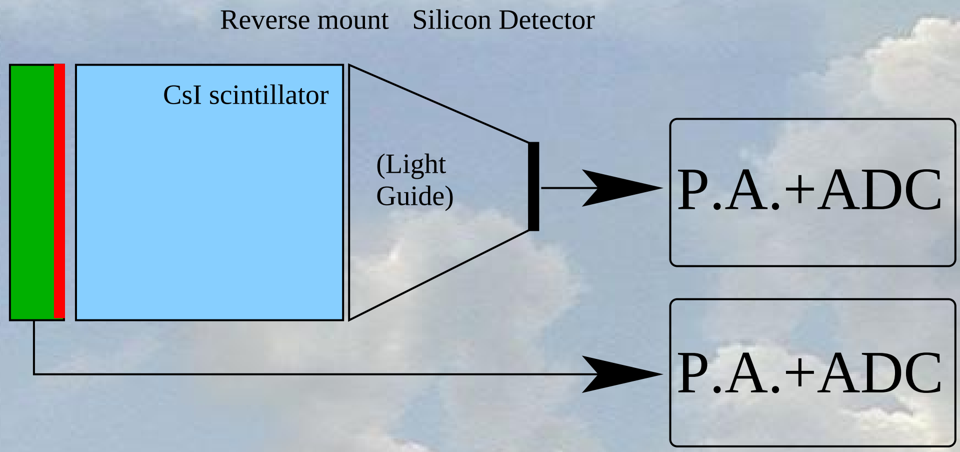

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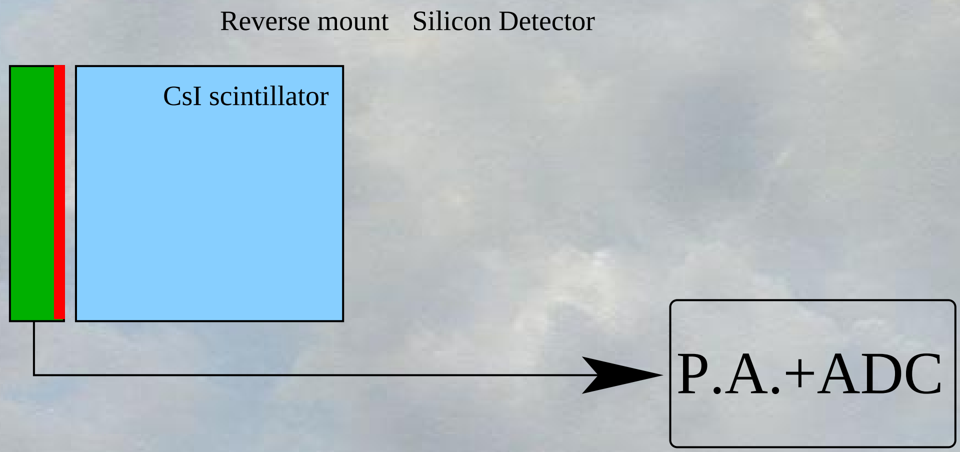

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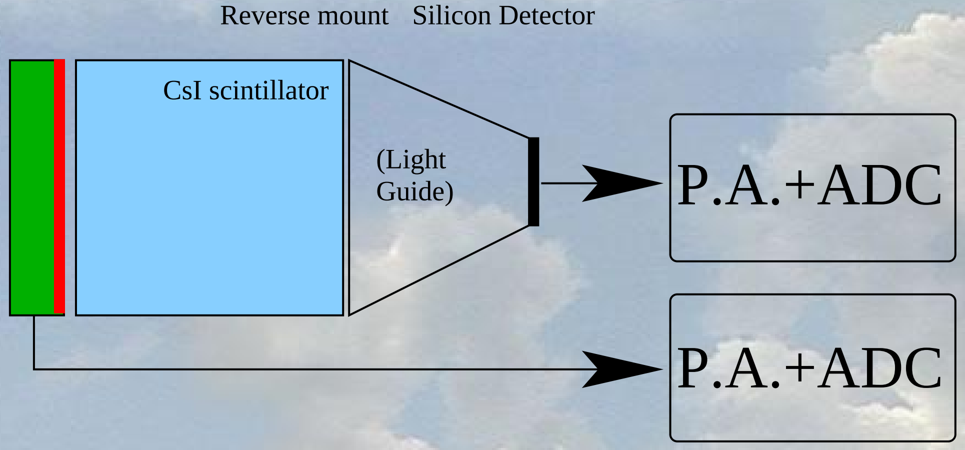

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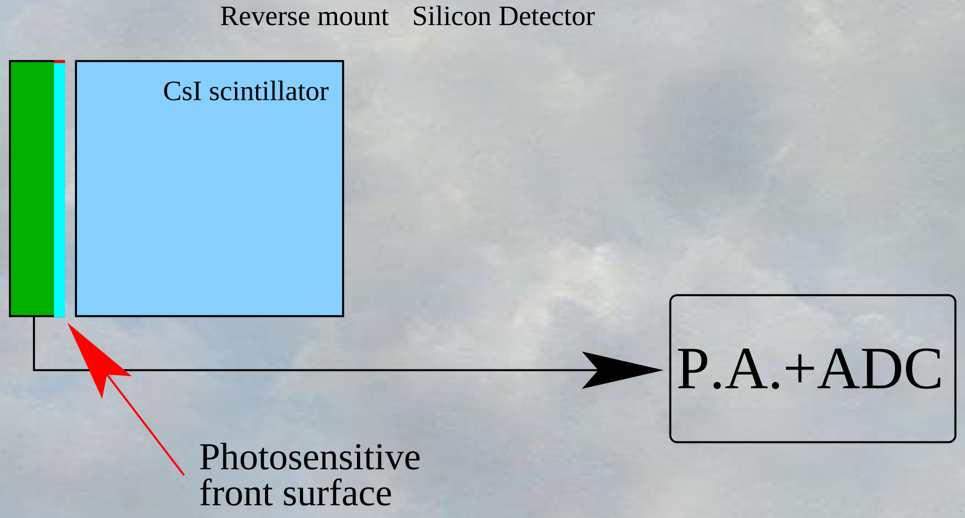

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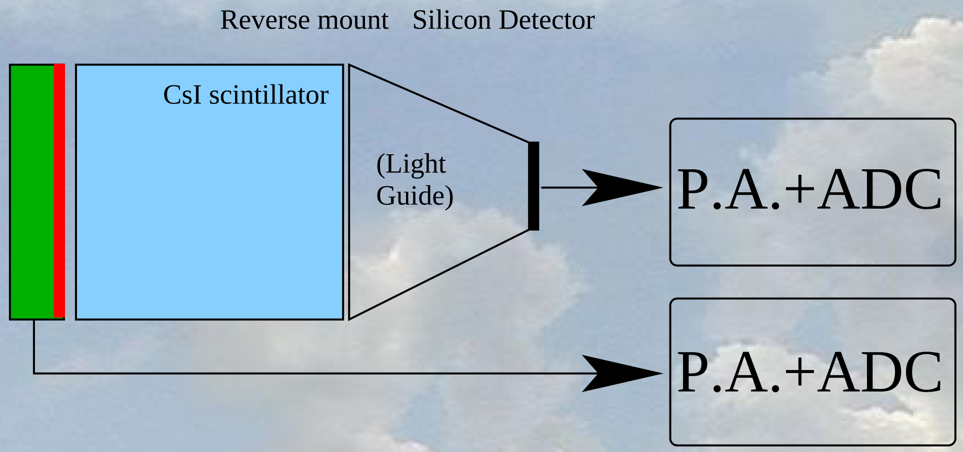

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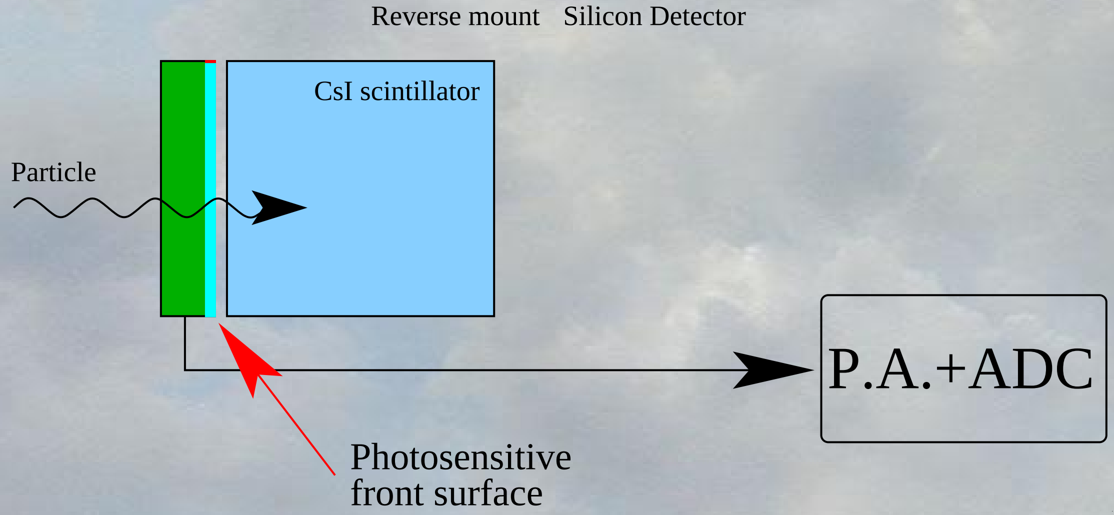

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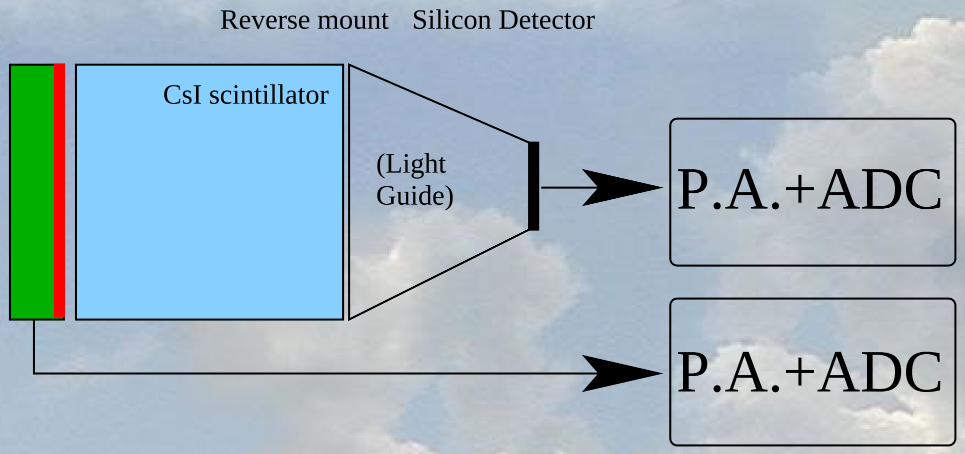

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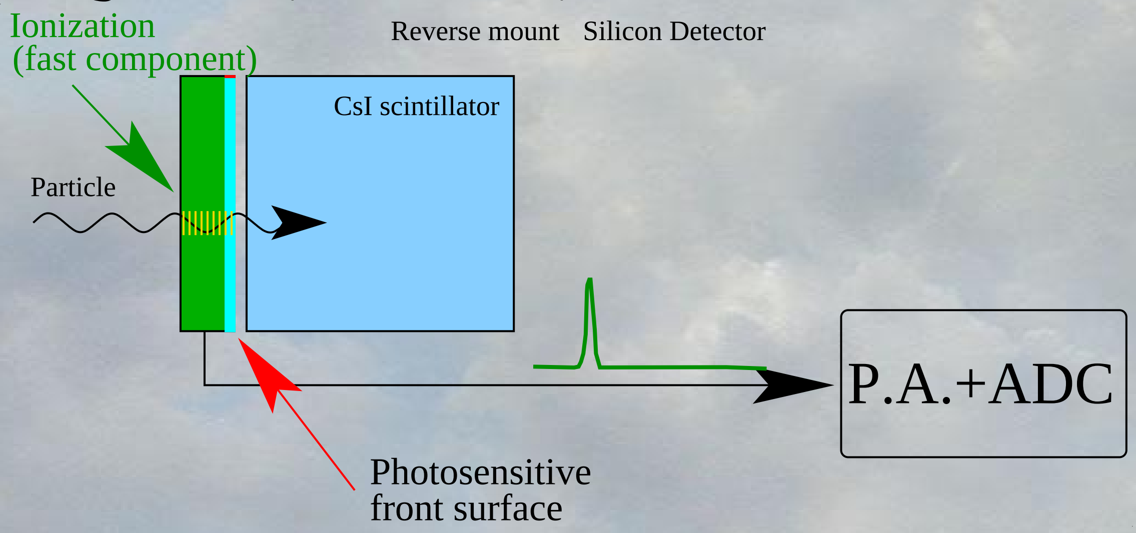

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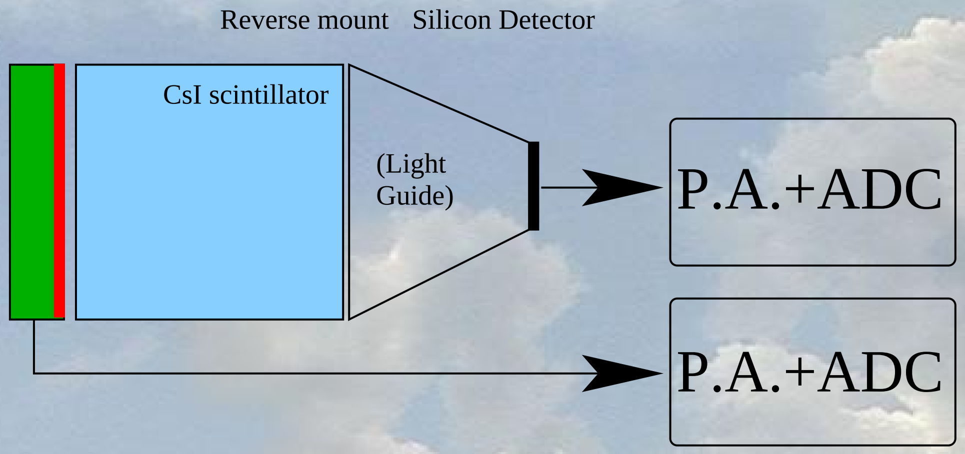

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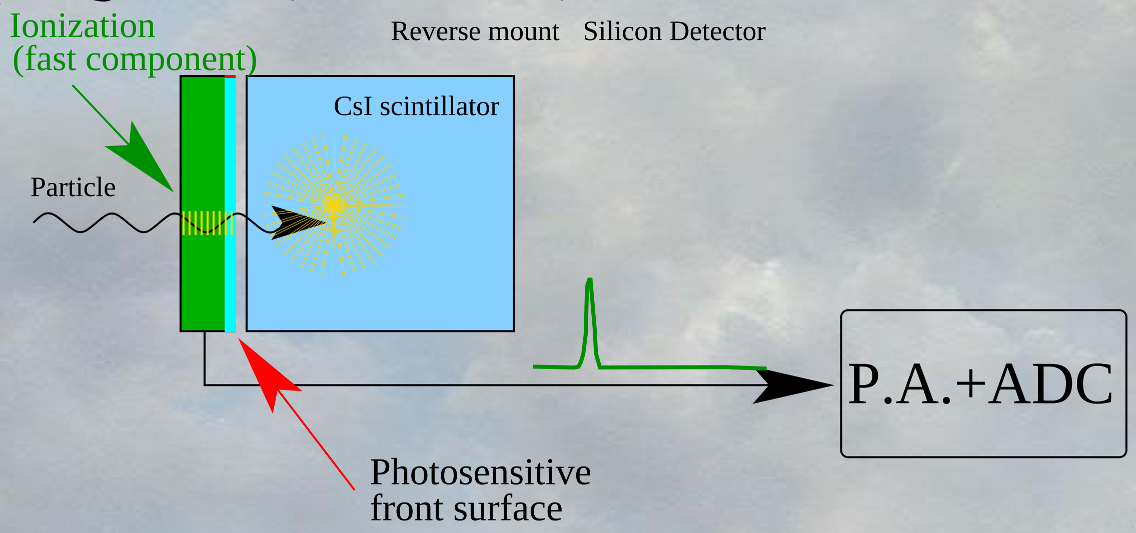

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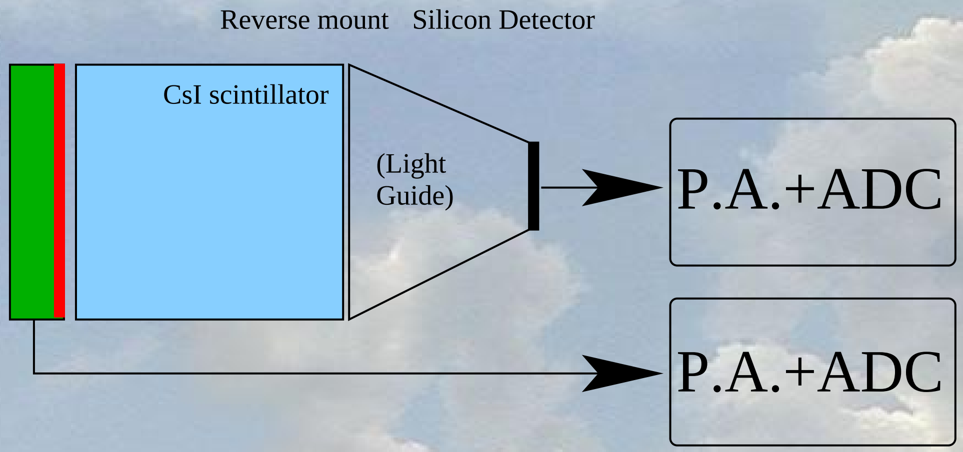

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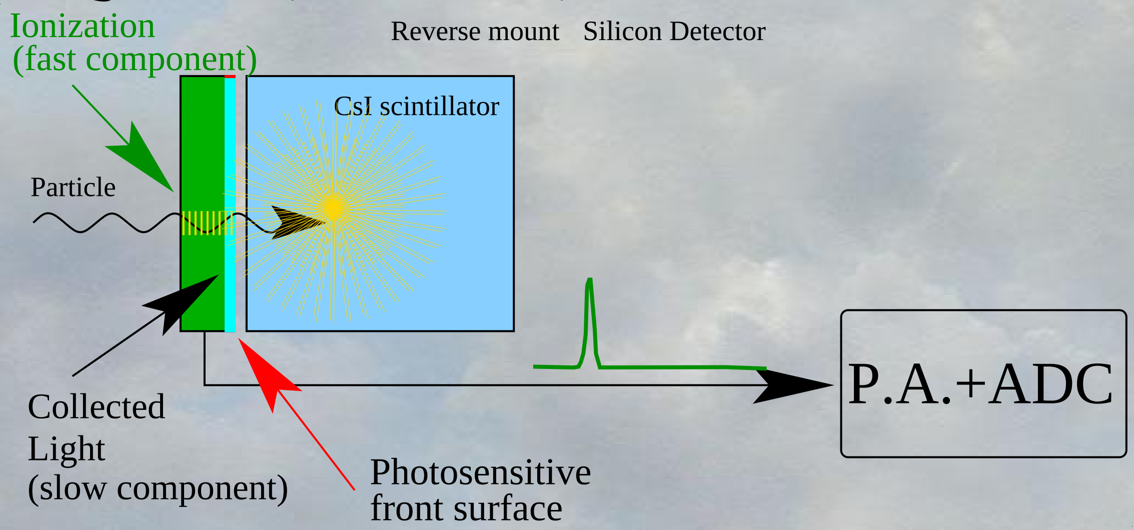

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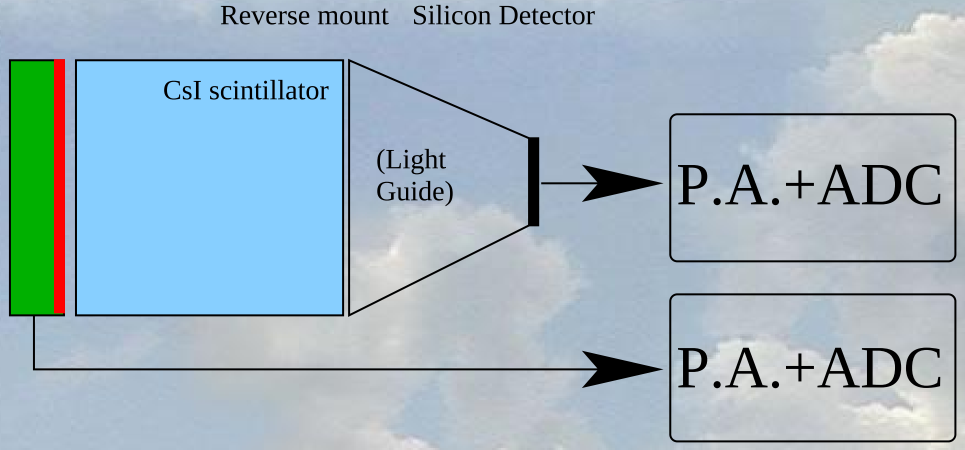

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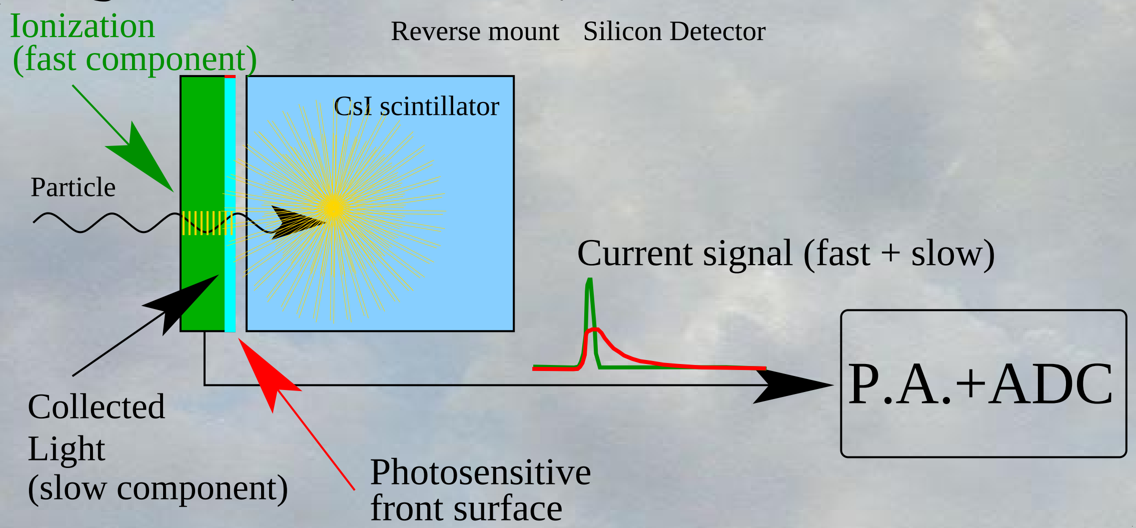

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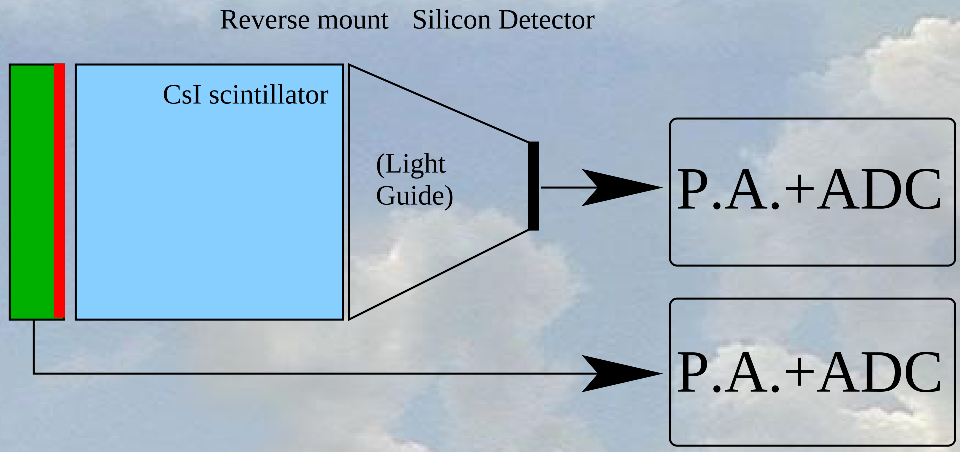

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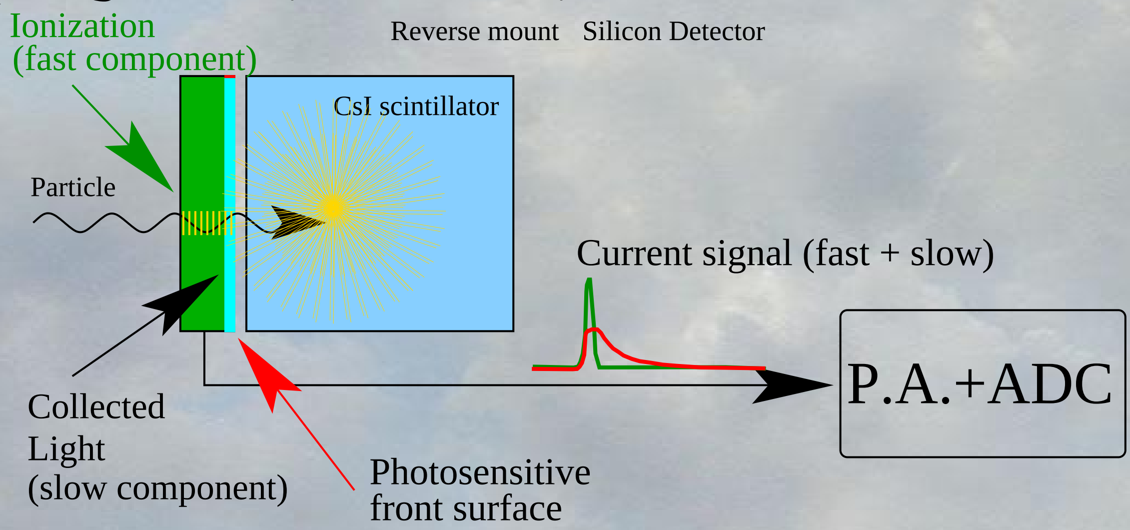
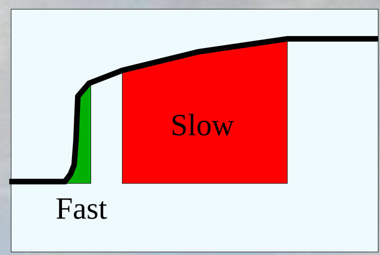


This detector was first proposed in G.Pasquali *et al.*, Nucl. Instr. and Meth. **A301** (1991)

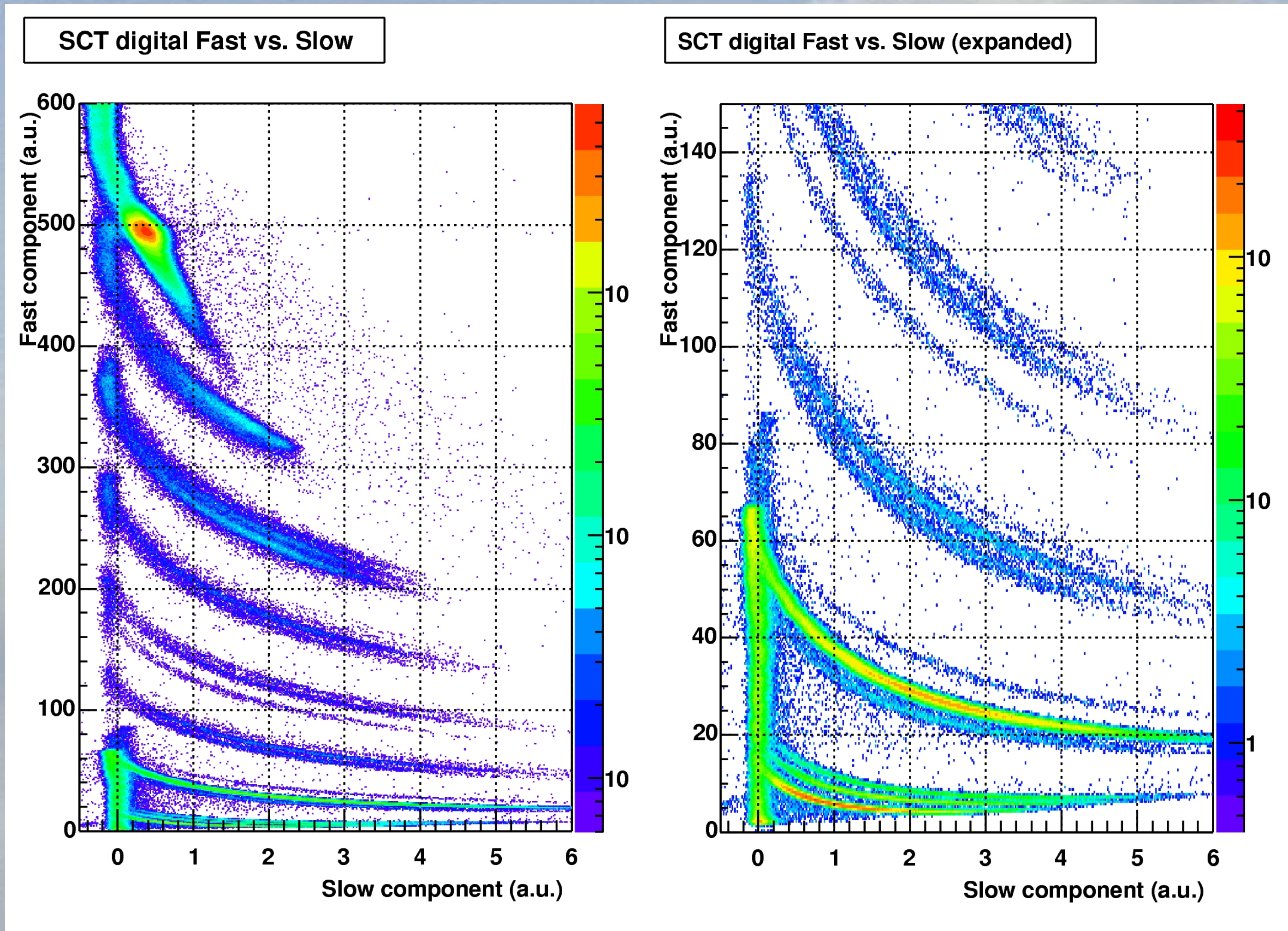
- **Fast** component from Ionization in Si, **Slow** from scintillation of CsI.
- **Stopped in Silicon**: **identical** to the previous case
- **Stopped in CsI**: **fast-slow discrimination**.

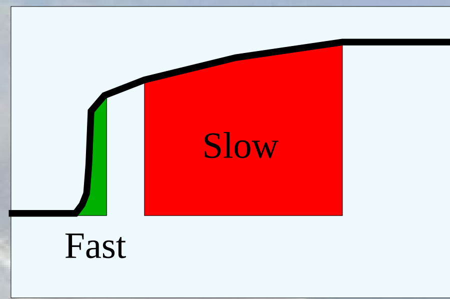
Example of preamplifier output:



Only one digital acquisition channel

Processing the signal coming from the preamplifier with two digital semigaussian filters ($\tau_{fast} \simeq 200\ ns$, $\tau_{slow} \simeq 1\ \mu s$):





300 μm, ≈ 500 mm^2 Silicon

^{16}O+^{116}Sn at 250 MeV

Very first prototype

In our experimental test we had a beam resolution of ~ 1.5ns (expected digital res. is ~100 ps FWHM)

No identification from Time of Flight (more tests needed).

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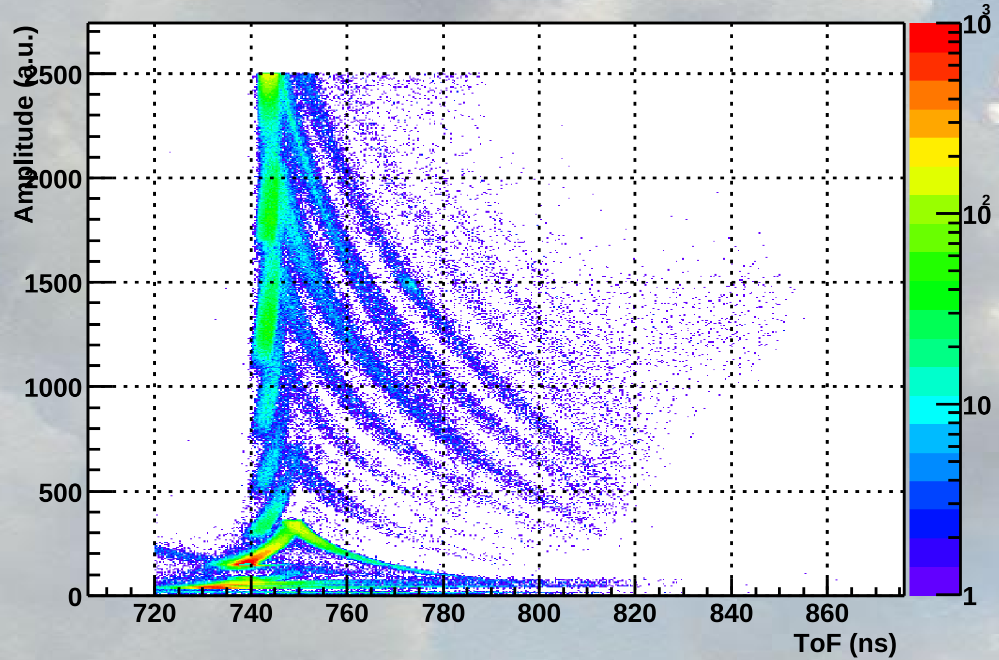
Distorsion of lines due to charge collection effects: **charge identification** dominant over **mass**!

Same results using analog methods.



- The main features of high resolution, fast sampling AD converters have been presented.
- Experimental examples of good resolution energy and timing measurements using digital sampling techniques have been discussed and applied to standard Si-CsI telescopes.
- A "new" detector has been proposed and the performances of the **very first prototype** discussed (experimental data collected with fast sampling ADC). More tests needed.

? Effect of Silicon inhomogeneities on particle identification resolution

Some references: - G.Pasquali *et al.*, Nucl. Instr. and Meth. **A301** (1991) 101.

- L.Bardelli *et al.*, Nucl. Instr. and Meth. **A491** (2002) 244.
- L.Bardelli *et al.*, Laboratori Nazionali di Legnaro Annual Report 2002.
- L.Bardelli *et al.*, submitted to NIM **A**.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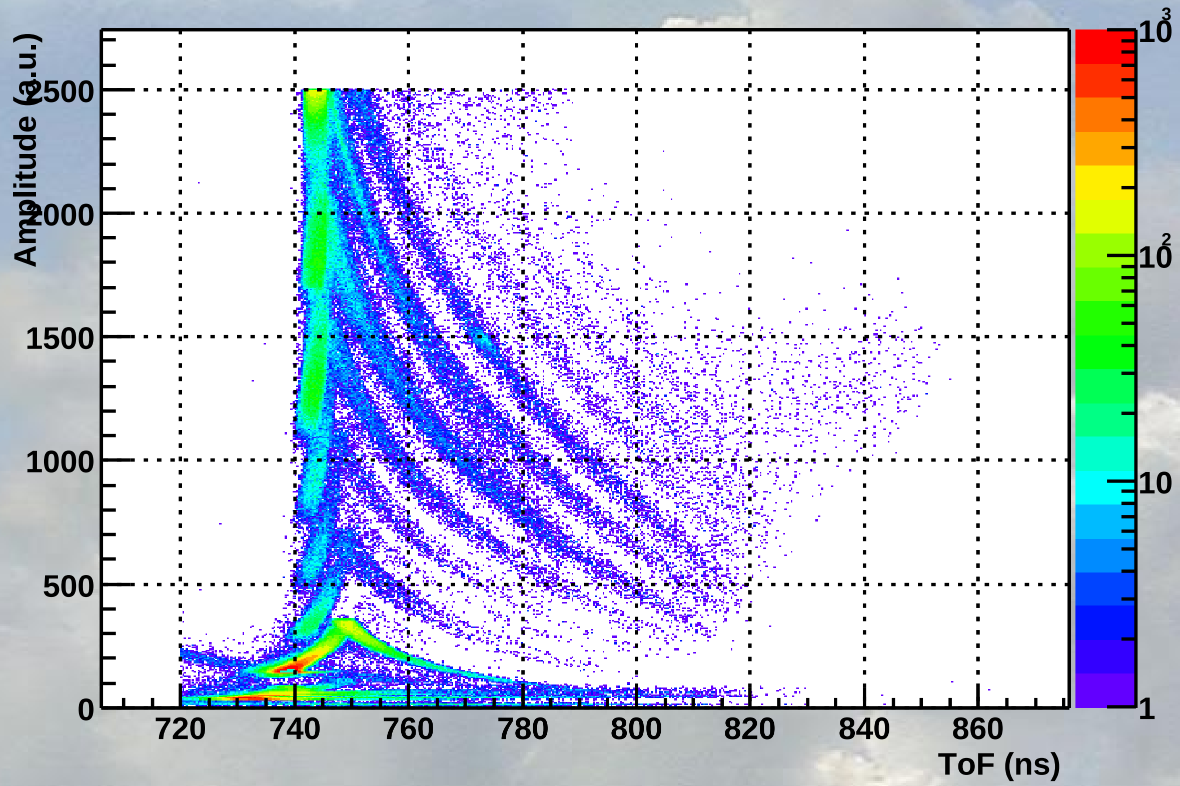

Digital "ToF" for ^{16}O+^{116}Sn at 250 MeV reaction:

Distorsion of lines due to charge collection effects:

charge identification dominant over **mass**!

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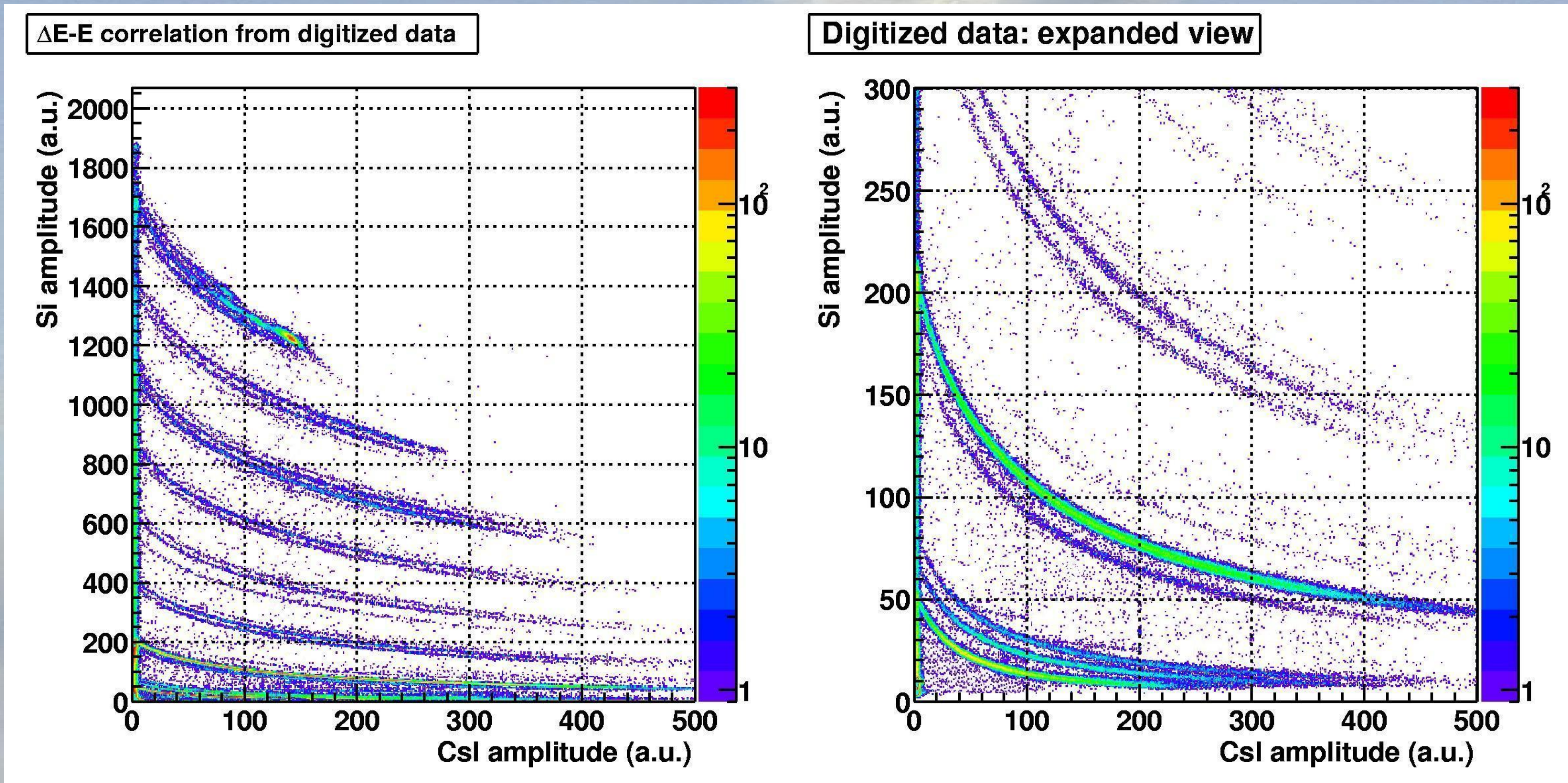
Standard ΔE-E correlation for a Si-CsI telescope, obtained from digital samples using two digital semigaussian filters:



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