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

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Outline

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)  
  ⇒ much lower costs.
A custom sampling system

Analog input stage
A custom sampling system

- 100 MHz clock
- 12 bit sampling ADC
- Analog input stage
- Analog input
A custom sampling system

**Diagram:**
- **P.A.** to Analog input stage
- Analog input stage to 12 bit sampling ADC
- 100 MHz clock to FIFO memory
- FIFO memory to DSP
- Trigger to DSP

**Components:**
- Analog input stage
- 12 bit sampling ADC
- FIFO memory
- DSP
- 100 MHz clock
A custom sampling 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
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 ($\tau_{fast} \approx 700$ ns, $\tau_{slow} \approx 2$ $\mu$s).
Si-CsI telescope: $\Delta E$-$E$

Standard $\Delta E$-$E$ correlation using digital semigaussian filters:
Both high and low ranges with a single AD converter for $\Delta E$
Timing measurements for Pulse Shape Analysis can be achieved using a **digital Constant Fraction Discrimination**.
Timing measurements for Pulse Shape Analysis can be achieved using a **digital Constant Fraction Discrimination**:

![Graph showing Asymptotic amplitude, dCFD level, and four points used for cubic interpolation.](image)
Timing measurements for Pulse Shape Analysis can be achieved using a **digital Constant Fraction Discrimination**: 

Find the asymptotic 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 $S(t_{dCFD}) = f \cdot A$ (cubic interpolation needed).

This is different from what analog CFDs perform!
Which AD converter?

Realistic simulations: (L. Bardelli et al., submitted to NIM A)
Which AD converter?

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

- **Preamplifier risetime (ns)**
  - 0 20 40 60 80 100 120 140 160 180

- **Total error (FWHM, ns)**
  - 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

- **dCFD timing (f=0.2)**
  - **ZONE OF NO PRACTICAL INTEREST**

- **Analog CFD**
Timing measurements

Which AD converter?

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

Preamplifier risetime (ns)

Total error (FWHM, ns)

2 GS/s, 8 bit

ZONE OF NO PRACTICAL INTEREST

dCFD timing (f=0.2)

Analog CFD
Timing measurements

Which AD converter?

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

- Analog CFD
- dCFD timing (f=0.2)

![Graph showing time measurements and AD converter choices](image)

- 100 ps FWHM with a 10 ns sampling period using 12 bit converter (in agreement with exp.)
- 2 GS/s, 8 bit
- 100 MS/s, 12 bit

ZONE OF NO PRACTICAL INTEREST
Which AD converter?

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

100 ps FWHM with a 10 ns sampling period using 12 bit converter (in agreement with exp.)

12 bit ⇒ Resolution 100 times smaller than sampling period
PSA analysis: differences between two \textbf{dCFDs}. Timing of 250 MeV Oxygen elastic peak using a Si detector:

- **Silicon risetime**: \(\sim 60\ \text{ns}\)
- **FWHM**: 125 ps

**Timing resolution for elastic peak**

- **Experimental data**

**Time difference between 90\% and 10\% dCFDs**

- **500 mm\(^2\) Si detector.**

L. Bardelli \textit{et al.}, submitted to \textit{NIM A}
PSA analysis: differences between two dCFDs. Time of Flight or coincidence measurements?
PSA analysis: differences between two dCFDs.

**Time of Flight** or **coincidence** measurements?

Mix a common time reference signal with the preamplifier output:

![Graph showing Digitized signal, Mixed RF signal, and ToF (Time of Flight)]
PSA analysis: differences between two dCFDs.

**Time of Flight** or **coincidence** measurements?

Mix a common time reference signal with the preamplifier output:

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 **synchronization** between many channels: **coincidence** measurements possible.

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

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6th International Conference on Radioactive Nuclear Beams, 22-26 September 2003
The standard $\Delta E-E$ technique does not identify particles stopped in the Silicon detector.

One possible solution: **reverse mount Silicon detector**

Increased **Pulse Shape** capabilities due to **charge collection** effects.
Digital Amplitude vs. Digital Zero Crossing time:

Digital zero-cross. time
Evident **sub-nanosecond** resolution even with 10ns sampling
Standard reverse mount Si-CsI:

Reverse mount Silicon Detector

CsI scintillator (Light Guide)

P.A.+ADC

P.A.+ADC

Single Chip Telescope:
The Single Chip Telescope

Standard reverse mount Si-CsI:
Reverse mount Silicon Detector

Single Chip Telescope:
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Single Chip Telescope:
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Single Chip Telescope:

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Standard reverse mount Si-CsI:
Reverse mount Silicon Detector

- CsI scintillator
- (Light Guide)
- P.A.+ADC
- P.A.+ADC

Single Chip Telescope:
Reverse mount Silicon Detector

- CsI scintillator
- Photosensitive front surface
- P.A.+ADC
The Single Chip Telescope

Standard reverse mount Si-CsI:

- Reverse mount Silicon Detector
- CsI scintillator (Light Guide)
- P.A.+ADC
- P.A.+ADC

Single Chip Telescope:

- Reverse mount Silicon Detector
- CsI scintillator
- Particle
- Photosensitive front surface
- P.A.+ADC

Luigi Bardelli
Standard reverse mount Si-CsI:

![Diagram of Standard reverse mount Si-CsI](image)

Single Chip Telescope:

![Diagram of Single Chip Telescope](image)
The Single Chip Telescope

Standard reverse mount Si-CsI:

- CsI scintillator
- Reverse mount Silicon Detector
- P.A.+ADC
- Light Guide
- P.A.+ADC

Single Chip Telescope:

- Ionization (fast component)
- Reverse mount Silicon Detector
- Particle
- Photosensitive front surface
- Csl scintillator
- P.A.+ADC
The Single Chip Telescope

Standard reverse mount Si-CsI:
- CsI scintillator
- Reverse mount Silicon Detector
- P.A.+ADC
- P.A.+ADC

Single Chip Telescope:
- Ionization (fast component)
- Reverse mount Silicon Detector
- P.A.+ADC
- Particle
- Collected Light (slow component)
- Photosensitive front surface
Standard reverse mount Si-CsI:

- CsI scintillator
- Reverse mount Silicon Detector
- (Light Guide)
- P.A.+ADC
- P.A.+ADC

Single Chip Telescope:

- Ionization (fast component)
- Reverse mount Silicon Detector
- Csl scintillator
- Current signal (fast + slow)
- P.A.+ADC
- Particle
- Collected Light (slow component)
- Photosensitive front surface
The Single Chip Telescope

Standard reverse mount Si-CsI:

Reverse mount Silicon Detector

CsI scintillator

(Light Guide)

P.A.+ADC

P.A.+ADC

Single Chip Telescope:

Ionization (fast component)

Reverse mount Silicon Detector

Particle

Csl scintillator

Current signal (fast + slow)

P.A.+ADC

Only one digital acquisition channel

Collected Light (slow component)

Photosensitive front surface

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:

[Diagram showing the signal output with fast and slow components]
Processing the signal coming from the preamplifier with two digital semigaussian filters ($\tau_{\text{fast}} \simeq 200$ ns, $\tau_{\text{slow}} \simeq 1$ $\mu$s):

300 $\mu$m, $
\approx 500$ mm$^2$
Silicon
$^{16}\text{O} + ^{116}\text{Sn}$ at 250 MeV

Very first prototype
In our experimental test we had a beam resolution of $\sim 1.5\text{ns}$ 😞 (expected digital res. is $\sim 100\text{ ps FWHM}$)

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

In our experimental test we had a beam resolution of $\sim 1.5\text{ns}$ 😞 (expected digital res. is $\sim 100\text{ ps FWHM}$)

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

**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

- L.Bardelli et al., Nucl. Instr. and Meth. A491 (2002) 244.
- L.Bardelli et al., submitted to NIM A.
Digital “ToF” for $^{16}\text{O} + ^{116}\text{Sn}$ at 250 MeV reaction:

**Distorsion** of lines due to charge collection effects:

**charge identification** dominant over **mass**!

*Same results using analog methods.*
Standard $\Delta E$-$E$ correlation for a Si-CsI telescope, obtained from digital samples using two digital semigaussian filters:

Both high and low range performed with a single AD converter for $\Delta E$. 