FRENCH-ITALIAN INITIATIVE of a NOVEL $4\pi$ DETECTOR ARRAY for NUCLEAR REACTION DYNAMICS and THERMODYNAMICS STUDIES

FAZIA (Four $\pi$ A and Z Identification array)

aka

AZ4$\pi$-France + IIF (Iniziativa Italo Francese)
Characteristics of the detector array

- Large solid angle coverage (asymptotically $4\pi$, for high energy operation at Eurisol)
- High granularity for reverse kinematics experiments at lower energies, for higher energy studies and nuclear interferometry measurements
- Extension, with respect to existing apparatuses, of the Z and A identification performances
- Low energy detection-identification thresholds
- Possibility of coupling the array with present generation apparatuses to cover the full solid angle during the first phase at low energy or to improve a particular detection capability (i.e. gas detectors for QT detection with ToF) over a limited solid angle
- QP, QT and fission fragment detection capability (coupling with the spectrometer very attractive)
- Good timing → good time structure of the beam (ToF needed for QP and QT detection)
- Compactness of the device, to allow for addition of outer detection shells for neutral detection
- Easy implementation of future upgrading for higher energy studies, mainly in terms of detector thickness (energetic LCP)
- Ease of calibration:
  - cocktail beam + properly designed mechanics to allows all-detector-illumination
  - Possible implementation of "automatic" calibration procedures to improve analysis efficiency
- Transportability

Design a detector array for isospin-oriented reaction dynamics studies, performed in a somewhat large bombarding energy range.

The final goal is the construction of a unique detector array able to fulfill the needs for low energy (SPIRAL2 / LNL / SPES) and higher energy (GANIL / LNS / FAIR / EURISOL) studies with exotic and stable beams.

Underlined items are the most demanding in terms of R&D
Presently envisaged solutions for the prototypes, meant to solve --at least part of-- the technical challenges underlined before:

**Detector:**

1. Pulse Shape Analysis of the particles stopped in the first Silicon detector to extract Z and A, also exploiting ToF (better understanding of the physics of the process, R&D on Silicon and CsI materials)
2. Three stage \(\Delta E-\Delta E-E\) (Si-Si-CsI telescope), with a possible novel solution for the second \(\Delta E-E\) stage

**Fully Digital Electronics is presently envisaged because of:**

1. Compactness
2. Flexibility in terms of signal treatment
3. Feasibility of digital energy, digital pulse shape and digital timing, with at most two digital channel per sensitive element (current and charge)
4. High dynamic ranges
5. Improved transportability
6. Possible implementation of on-line DSP-based calibration procedures
7. Expected much lower cost
Pulse Shape Analysis of particles stopped in Silicon: a very promising approach to significantly lower the energy for Z (and A?) identification capability

Progresses on the understanding of the physical process at the basis of the current signal formation have been done in the framework of the AZ4π Initiative. A first principles approach has been followed to describe the current signals in the Silicon detector: no free parameters, strong electrostatic interactions of electrons and holes in the ionization wake of the particle are considered. Necessity of studying the Pulse Shape in Silicon both for rear-side and front-side injection. Experimental tests were also done.

Very important to also push the identification capabilities in CsI(Tl)
Silicon Rear injection
Digital Pulse Shape experiment and simulation
Simulation $\rightarrow$ L. Bardelli et al in preparation

Silicon Front injection
Digital Pulse Shape experiment and simulation
Experiment: Chimera Coll.
LNS Report 2004, 129
Simulation: $\rightarrow$ L. Bardelli et al in preparation
Basic detection module (a $\Delta E-\Delta E-E$ telescope, SI-Si-CsI) with innovative solutions on:

- Preamplifier electronics
- Digital electronics for energy, pulse shape ($Z$ and $A$ identification) and timing
- Telescope signal read-out
The prototype: basic principles

Charge & Current preamp

125 MSample/s 12 bit Digitizer + DSP/FPGA

Energy ΔE2
FAST CsI(Tl)
SLOW CsI(Tl)
DTof ΔE2 (?)

Trigger out
Energy ΔE1
DTof ΔE1
Q Pulse Shape ΔE1(?)

I Pulse Shape ΔE1
I DTof ΔE1

RF in

Charge & Current preamp

Si Si
ΔE1 ΔE2
H.I.

CSI(Tl)

Charge preamp

125 MSample/s 12 bit Digitizer + DSP/FPGA

RF in

Synchronization by RF mixing
The prototype: basic principles

A novel, efficient read-out scheme is provided for the second Silicon detector and the CsI(Tl), fully exploiting the features offered by signal digitalization and processing. More on this later.

Particles stopped in CsI: Z and A identification by digitally implemented ΔE-ΔE-E technique and by digital pulse shape in CsI(Tl).

Particles stopped in the first Silicon: Z and A identification by means of Digital Pulse Shape. Low energy thresholds for identification are obtained.

A novel, efficient read-out scheme is provided for the second Silicon detector and the CsI(Tl), fully exploiting the features offered by signal digitalization and processing. More on this later.
What a fast ADC + *(well programmed)* DSP/FPGA can replace

The preamplifier gives, beside the charge signal, the shape of the current pulse. Few ns rise-time.

The preamplifier characteristics are well matched with our needs. \textit{In order to exploit the high dynamic range attainable with digital processing}, the next preamplifier version will probably feature differential outputs, to reduce at most the interference and pick-up along the connection to the sampling ADC’s (provided with differential inputs)
2a. Digital electronics for pulse shape analysis on current signals: a ASIC digitizer based on an analogue pipeline (2GSample/s, 12 bits) to sample the current signal, developed in Orsay.

Digitalization of current signal is expected to permit the Z (and A) identification of particles stopped in the first ΔE1 detector.

Item to specifically address during the prototype R&D:

• thickness optimization of the first Si detector (200/300 μm)
• test Silicon strips to improve granularity
• Check A and Z discrimination for rear- or front-side injection of particles (presently preferred rear-side)
• check current-based against charge-based discrimination capabilities of Digital Pulse Shape
• Careful determination of identification thresholds (presently estimated around 50 μm)

E = 80 MeV
Digital Pulse Shape analysis of charge signal. Particle identification of particles stopped in a “reverse mounted” Silicon detector.
2b. Digital electronics for energy measurement: charge signal digitalization using *ad hoc* designed ADC/DSP/FPGA boards, exploiting the experience gained in the Nucl-ex Collaboration and the AZ4π french-italian collaboration.

Charge signal digitalization and processing permit a very effective replacement of standard analog chains. We demonstrated recently the capabilities of such systems to replacing standard analog methods, with much higher dynamic ranges.

L. Bardelli *et al*:

More recently similar results have been obtained by a subgroup of CHIMERA:
M. Alderighi *et al*:

The technique is now quite sound.

Another example of digital energy/pulse shape: Fast/slow nel CsI (Tl)
Very good particle identification, over a large dynamic range.

Sampling system @ 12 bit (10.7 effective), 100 MsSample/s.
Digital sampling and processing techniques give dynamic ranges far better than analog standard approach. A 12 bit sampling ADC running at 100 MSample/s coupled to a properly designed digital filter can provide the same dynamic range of conventional a 16 bit Peak Sensing ADC (typically obtained by doubling the shaping chain). See (L.Bardelli and G.P.)x2, accepted on NIMA

One demonstrates that, because of the large information available, for a digital signal processing and shaping using a Sampling ADC with:

1. \(f_s\) sampling frequency (100 MSample/s)
2. ENOB Effective Number of Bits (typically 10-11 for an ADC with 12 physical bits)

and a semiconductor detector and associated filter having:

1. noise corner time constant \(\tau_c\) depending of the noise characteristics of detector+preamp (typically between 2 and 7\(\mu\)s)
2. a detector-well-matched digital filter with a parameter \(k_{G^*}^2\) (closely related to the \(\delta\)-noise index, typically ~1)
3. baseline subtraction time at least as long as \(2 \cdot \tau_c\)

one gets the equivalent resolution of a standard peak sensing ADC with as many bits as:

\[
PSENOB = ENOB + \frac{1}{2} \cdot \log_2(f_s \cdot \tau_c / k_{G^*}^2) - \frac{1}{2}
\]

In the considered case: about 16 bits!
2c. Digital timing: Digital Constant Fraction Timing and synchronization on charge signal, developed in Florence in the framework of Nucl-ex and the AZ4π initiative.

DCFT with cubic interpolation permits sub-nanosecond timing on Silicon.

Sub-nanosecond synchronization of various channels makes it possible ToF.

To carefully check:

- verifying time resolution and reliability on a larger scale basis (only few detectors tested); study resolutions as a function of deposited energy to determine the timing thresholds
- timing comparison between rear and front injection
- verifying on a larger scale the synchronization with RF mixing
- Check baseline stability with RF “switching” versus “mixing”
- Check timing and synchronization on the current signals


Timing resolution for elastic peak

![Timing Resolution Graph](image)
RF (~5 MHz)

To the digitizer

Electronic switch, DSP-controlled and delayed by a few μs with respect to the event trigger. **Mixing, instead of switching, also possible.**
The RF reference signal common to all the used ADC’s \( \rightarrow \) synchronization/timing between all detectors possible with a “detector limited” resolution (in the difference between any two \( \Delta T \)'s the common RF disappears; no significant additional uncertainty in the difference with the DCFT mark).

ToF either with a beam-reference on one input or using as RF the RF itself from the accelerator, if available. No common sampling Clock is needed \( \text{(hard to implement)} \). More easily manageable common RF signal, because sinusoidal with a frequency in the MHz region.
The first prototype: a possible solution

ΔE1
Si

ΔE2
Si

H.I.

200-300 μm Strip?

500-700 μm

30-50 mm

CSI(Tl)

The Silicon detector provides both the ionization signal produced by the impinging charged particles and the fluorescence in the CsI(Tl) induced by the same particles if energetic enough to punch-thru the Silicon.

Digital techniques permits an easy and fast discrimination of the two components

To carefully check:

- verifying the actual discrimination capabilities (A and Z)
- optimization of the Silicon thickness: 500-700 μm (cost/benefit analysis)
- Stabilization of the optical coupling between Si and CsI(Tl) with the lowest as possible dead layer
The Single Chip Telescope (SCT)

Standard Si-CsI(Tl) telescope configuration

The Si-CsI(Tl) SCT telescope

Ionization (fast component) Reverse mount Silicon Detector

Particle CsI scintillator

Collected Light (slow component) Current signal (fast + slow)

Photosensitive front surface P.A.+ADC

Standard Si-CsI(Tl) telescope with photodiode read-out

Si

CsI scintillator

(Light Guide)

P.A.+ADC

P.A.+ADC