

Present status of the FARCOS detection system

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Abstract– Few years ago we proposed a novel detection system – named FARCOS (Femtoscopia ARray for CORrelations and Spectroscopy) – to target different open cases in nuclear physics. The basic cluster unit of the FARCOS array is a telescope structure with an active area of $6.4 \times 6.4 \text{ cm}^2$ composed of three detection stages. The first two detection layers are DC-coupled Double-Sided Silicon Strip Detectors (DSSSDs), $300 \mu\text{m}$ thick and $1500 \mu\text{m}$ thick, featuring 32×32 orthogonal strips. The third stage, acting as calorimeter, is composed of four truncated pyramids of CsI(Tl) crystals with an active area of $3.2 \times 3.2 \text{ cm}^2$ and an absorption length of 6 cm arranged in window configuration. The final system will be a modular assembly of 20 telescopes.

A key feature of FARCOS is the identification of the particles stopping even in the first detection layer, relying on pulse shape analysis techniques. The FARCOS frontend electronics features a full scale energy range up to 2 GeV with 5 different selectable ranges and an energy resolution down to 10 keV FWHM with a power budget of about 10 mW/channel in the case of the lower full scale energy range. Its core is a custom multichannel charge preamplifier VLSI chip.

The system performance has been extensively qualified on few workhorses in view of the assembly of the final telescopes foreseen for 2018.

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I. INTRODUCTION

FEW years ago we proposed a novel detection system – named FARCOS (Femtoscopia ARray for CORrelations and Spectroscopy) [1] – to target different open cases in nuclear physics: i) Correlation measurement and imaging at intermediate energies and symmetry energy: the study of the dependence on density of the symmetry energy would benefit of determining the space-time properties of the particle emitting sources produced in nuclear reactions that allows spotting out emission processes occurring in different instants of the dynamical evolution of the system (chronology). ii) Two-particle correlations at low energies, in order to study the density and emission times of emission sources of different particles coming out a compound nucleus. In particular it will be possible to analyze the variation of the space-time properties of the decay of compound nuclei with large N/Z asymmetries. iii) Correlation and spectroscopy among different particles: the collision of heavy ions produces a large variety of fragments, among which we find also exotic nuclei in non-excited bound states. By measuring all the decay products and their momentum, it is possible to give an insight in the parent nucleus and its spectroscopic features. iv) Bose condensates in nuclei: these states should feature 0 spin and positive parity and could be identified by the coherent emission of alpha particles. v) Direct reactions with stable and radioactive beams to probe the exotic nuclei decay in inverse kinematics.

From the instrumental standpoint FARCOS is a modular array of independent clusters (20 in the final system) each of which is a telescope assembly of three detection layers: two silicon layers made of Double Sided Silicon Strip Detectors (DSSSDs) and one calorimeter stage constituted by 4 CsI (Tl) scintillator crystals readout by a photodiode.

The paper describes the present status of the FARCOS detection system by analyzing its main building blocks together with their experimentally assessed performance.

II. THE FARCOS SYSTEM: MAIN BLOCKS AND THEIR PERFORMANCE

A. Basic brick: the FARCOS cluster

Fig. 1 shows a 3D sketch of one FARCOS cluster seen from the front. Each telescope features a detector active area of $6.4 \text{ cm} \times 6.4 \text{ cm}$. A custom designed flexi-rigid frame houses each DSSSD and connects to a custom PCB (motherboard)

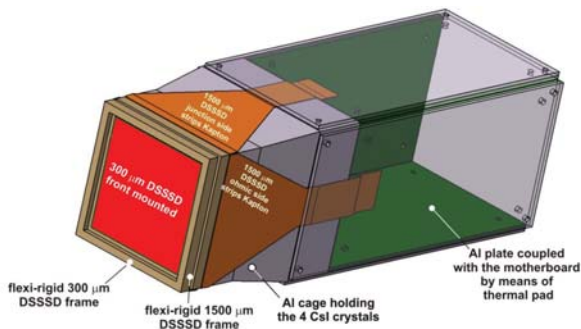


Fig. 1. 3D sketch of one FARCOS cluster seen from the front (two of the four motherboards (in green) housing the frontend ASICs and acting as walls of the telescope itself are set transparent).

housing the frontend ASICs ($2 \times (16 + 1)$ channel per PCB), the line-drivers and the local slow control. Four custom motherboards for each cluster – coupled with G-Alu 25 plates by means of thermal pad – form the mechanical walls of the cluster. A patch panel acting as the rear-side of the telescope hosts the output connectors for the signal cables and the cluster housekeeping. Thanks to their modularity, the FARCOS clusters can be arranged in different configurations, depending on the physics case one wants to address.

B. Detection layers

Each FARCOS telescope features three detection layers, two Double Sided Silicon Strip Detectors (DSSSDs) and a calorimeter stage, made with CsI(Tl) scintillator crystals. The DSSSDs are made by Micron Semiconductor Ltd on a standard design (BB7) but mounted on a custom flexi-rigid carrier in order to minimize dead area and to improve signal integrity, thanks to the careful design of the Kapton cables directly attached to the flexi-rigid carrier. The DSSSDs are 300 μm and 1500 μm thick and feature 2 mm pitch strips – 32 strips on the front side and 32 strips on the back side. Fig. 2a shows the photograph of one DSSSD (300 μm thick) prototype.

The calorimeter stage features 4 highly homogeneous 60 mm thick CsI(Tl) crystals, made by SCIONIX, with Tl concentration of the order of 1200 to 1500 ppm and a tronco-pyramidal shape (32.1 mm \times 32.1 mm at the entrance window and 39.5 mm \times 39.5 mm at the optical interface) and arranged in a 2×2 window configuration. The output light is read out by a Hamamatsu 18 mm \times 18 mm PIN diode S3204-08, attached to the rear face (optical interface) of each crystal. Fig.

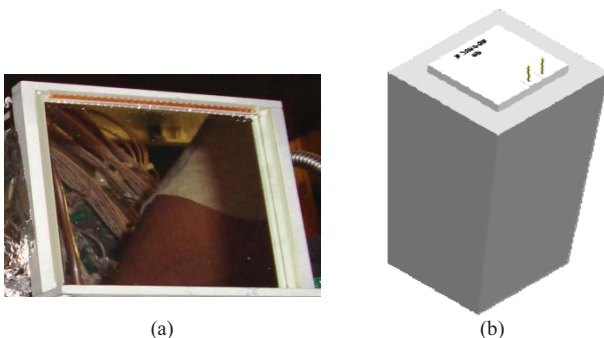


Fig. 2. (a) Photograph of one DSSSD (300 μm thick) prototype and (b) 3D rendering of a CsI(Tl) scintillator crystal.

2b shows the 3D rendering of a CsI(Tl) scintillator crystal.

C. Frontend electronics – custom designed ASICs

The core of the frontend electronics is the charge sensing amplifier stage [2], [3]. It is AC coupled, by means of an external capacitor and a biasing resistor and features a telescopic cascode architecture. The independent biasing of the first branch allows using a single chip to readout both signal polarities. Fig. 3 shows the simplified schematics of one channel of the charge sensing amplifier. An external resistor or an on-chip MOS transistor can be chosen as feedback network. The selectable feedback capacitance and the adjustable compensation network allows selecting the full scale energy range from 90 MeV up to 2 GeV Silicon equivalent.

The VLSI chip in ams [4] 0.35 μm C35B4C3 technology houses a 16-channel charge sensing amplifier for the DSSSD readout and two channels of charge sensing amplifiers for the CsI(Tl) coupled with the photodiode readout. In addition some ancillary circuits are available for additional functionalities and housekeeping (on-chip pulser, channel-by-channel test signal injection, temperature monitor, ...).

A frontend motherboard – dedicated to the readout of one DSSSD side and one CsI(Tl) coupled with the photodiode – houses two ASICs and the differential line drivers to drive the signals coming from the ASIC towards the output of the vacuum chamber.

The designed frontend has been fully qualified [5] and features a pulse rise time below 20 ns up to 500 MeV full scale energy range and no slew rate limitation. At 2 GeV full scale energy range [6] the output pulse rise time on the falling edge keeps below 30 ns. It is a versatile frontend for input capacitances in the range 10 pF – 200 pF, with a slope dependent on the level of compensation capacitance needed of 0.13 ns/pF. The integral-non-linearity assessed both via electrical injection and verified up to more than 500 MeV with a pulsed 3 MeV proton beam with variable bunch multiplicity (from 1 proton up to more than 200 protons) is below 0.5% over all the designed energy ranges for both signal polarities and all detectors [7]. The energy resolution measured in the lab with the frontend coupled with a 300 μm thick DSSSD (junction side strips, ext. resistor feedback, 90 MeV full scale

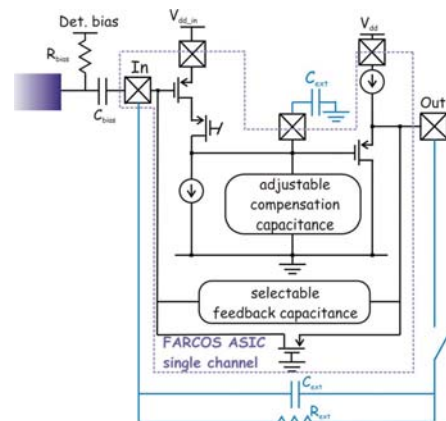


Fig. 3. Simplified schematics of one channel of the charge sensing amplifier.

energy range) is 7.7 keV FWHM at the pulser line. 179 keV FWHM have been measured in the lab at the ^{241}Am a line with the readout dedicated to the photodiode coupled with the CsI(Tl) scintillator (external feedback resistor, 90 MeV full scale energy range).

D. Backend electronics – the GET system

The data acquisition of the final FARCOS system is the Generic Electronics for TPCs (GET) [8]. It was originally developed to readout signals from various types of TPCs. GET samples the signals from the sensors to give – after digital filtering and signal processing – the position, energy loss and time. GET is designed to be reconfigurable and user-friendly in regard to the choice of components, the front end and DAQ.

In particular since GET features only 12 bits and readouts single – ended signals, dedicated dual-gain differential to single-ended antialiasing amplifier have been developed [9].

E. Interconnections

The total number of readout channels for the final FARCOS system constituted by 20 clusters is:

- DSSSDs:

$$(20 \text{ telescopes} \times 2 \text{ layers} \times 32 \text{ channels/side} \times 2 \text{ sides}) = 2560 \text{ channels}$$

- CsI(Tl): $(20 \text{ telescopes} \times 4 \text{ CsI(Tl)}) = 80 \text{ channels}$.

Three interfaces require dedicated interconnection strategies: i) detector – motherboard; ii) motherboard – patchpanel; iii) patchpanel – backend (with vacuum feedthroughs). The main issue is to guarantee signal integrity and minimize parasitics for the signal lines and to provide, low resistance, low inductance interconnections for the power lines.

The motherboard – patchpanel interconnection is based on High-Speed High-Density Open-Pin-Field Array Connectors provided by Samtec Inc.

A custom-designed vacuum flange (DN160 - ISO K) features all the interconnections needed for two clusters (264 differential lines + 8 differential control signals for calibration purposes, 20 bias lines and 4 lines for the I²C slow control) and is shown in Fig. 4.

III. PRELIMINARY ON-BEAM TESTS ON A FARCOS TELESCOPE WORKHORSE

The performance of the individual components has been extensively qualified together with the performance of few workhorses of the FARCOS clusters in view of the assembly of the final telescopes foreseen for 2018. The most demanding test has been the qualification of the performance during the first on-beam test of the designed VLSI frontend electronics [10]. The test took place in February 2017 at the Laboratori Nazionali del Sud (LNS) of INFN in Catania. A ^{16}O beam at 88 MeV – at different intensities – accelerated by the Tandem accelerator bombarded different targets (LiF, Au, C, Ni). The setup was mounted in Camera2000 at LNS. Two DSSSDs (300 μm and 1500 μm thick) were assembled in telescope configuration and readout by four FARCOS motherboard, while two CsI(Tl) crystals coupled with the silicon photodiode

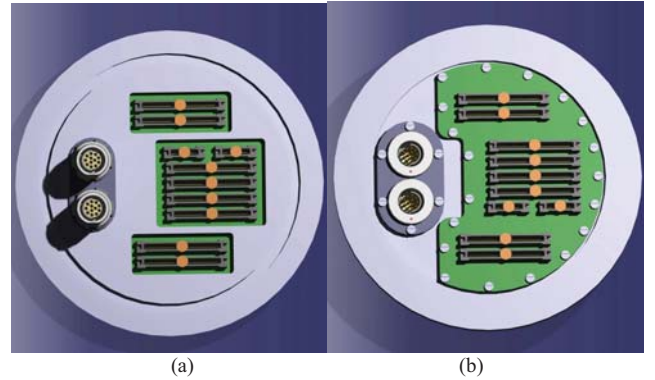


Fig. 4. Custom-designed vacuum flange with interconnections for two clusters (a) vacuum side, (b) air side.

were located at the same angle on the opposite side due to the limited beam energy that does not allow punching through 1800 μm of silicon and readout by a dedicate board housing the same FARCOS ASIC. For test purposes we used two different backend systems. All channels were readout by a dedicated high resolution DAQ based on the SIS3301 VME Fast Digitizers [11] (14 bits, 100 MSps), while 4 channels have been acquired with the GET electronics [6].

We evaluated the performance of the different identification techniques: i) ΔE - E for the two silicon layers, ii) *Energy-RiseTime* for the 300 μm DSSSD both in front and in back injection, iii) *Fast-Slow* for the CsI(Tl) scintillator crystals. The full data analysis is on-going but the preliminary results demonstrate that the developed frontend is fully adequate for the FARCOS instrument.

IV. CONCLUSIONS AND OUTLOOK

The final FARCOS system will be composed of 20 clusters and the first prototypes will be ready to take data starting from spring 2018. A single custom ASIC design fits all detectors for a total of 2560 channels of DSSSDs and 80 channels of CsI(Tl). The performance of the individual components has been qualified in detail. The first on-beam qualification of a FARCOS cluster workhorse equipped with the custom VLSI electronics was a success.

For the first 10 telescopes we are in the process of i) producing, populating, coupling with supporting G-Alu25 plates, and testing 60 motherboards and 15 patch panels; ii) gluing 120 ASICs onto the motherboards and bonding (about 100 bonding per ASIC); iii) producing and mounting the custom interconnection flanges; iv) qualifying the assembled components; v) last but not least, assembling the first 10 telescopes.

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REFERENCES

- [1] FARCOS TDR, available at <https://drive.google.com/file/d/0B5CgGWz8LpOOc3pGTWdOcDBoWF E/view>
- [2] A. Castoldi, C. Guazzoni, T. Parsani, "A Selectable-Gain CMOS Frontend for Pulse Shape Analysis in Double Sided Silicon Microstrip Detectors", *2014 IEEE Nuclear Science Symposium and Medical Imaging Conference Records*, 2014 IEEE, Seattle, Washington (USA), Nov. 8-15, 2014, pp. 1– 5.
- [3] A. Castoldi, C. Guazzoni, T. Parsani, "A CMOS Frontend for Scintillators Readout by Photodiodes for Nuclear Physics Experiments", *IEEE Trans. Nucl. Sci.*, Vol. 64, pp. 2678-2682.
- [4] ams AG, Tobelbader Strasse 30, A-8141 Premstaetten, Austria.
- [5] A. Castoldi, C. Guazzoni, T. Parsani, "Experimental qualification of an 8-channel selectable-gain CMOS frontend for Double-Sided Silicon Strip Detectors", *2015 IEEE Nuclear Science Symposium and Medical Imaging Conference Records*, 2015 IEEE, San Diego, California (USA), Oct. 31-Nov. 7, 2015, pp. 1– 3.
- [6] A. Castoldi, C. Guazzoni, T. Parsani, G. Cardella, N. Martorana, "2 GeV full scale energy range CMOS charge preamplifier for Pigmy Dipole Resonance study in ^{68}Ni nuclei", *2017 IEEE Nuclear Science Symposium and Medical Imaging Conference Records*, 2017 IEEE, Atlanta, Georgia (USA), Oct. 21-Oct. 28, 2017, pp. 1– 3.
- [7] A. Castoldi, C. Guazzoni, S. Maffessanti, T. Parsani, L. Carraresi, C. Czelusniak, "Experimental evaluation of the dynamic range of the FARCOS microstrip frontend with a pulsed proton beam", *2016 IEEE Nuclear Science Symposium and Medical Imaging Conference Records*, 2016 IEEE, Strasbourg, France, Oct. 29-Nov. 5, 2016, pp. 1– 3.
- [8] E. Pollacco et al., "GET: A Generic Electronic System for TPCs for Nuclear Physics Experiments", *Physics Procedia*, Vol. 37, 2012, pp. 1799-1804.
- [9] A. Castoldi, P. Chang, C. Guazzoni, T. Parsani, G. Cardella, G. Sacca', "256-channel differential to single ended antialiasing filter for pulse shape analysis in nuclear physics experiments", *2017 IEEE Nuclear Science Symposium and Medical Imaging Conference Records*, 2017 IEEE, Atlanta, Georgia (USA), Oct. 21-Oct. 28, 2017, pp. 1– 6.
- [10] L. Acosta et al., "First on-beam tests of the FARCOS frontend electronics", *2017 IEEE Nuclear Science Symposium and Medical Imaging Conference Records*, 2017 IEEE, Atlanta, Georgia (USA), Oct. 21-Oct. 28, 2017, pp. 1– 3.
- [11] Online: <http://www.struck.de/digitizers.htm>