The FARCOS frontend electronics: status and perspectives

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Summary. — FARCOS is a 20-telescope modular detection system intended to extend the capacity of 4π detectors in the field of dynamics of heavy ion collisions and spectroscopy of light nuclei at the border of neutron and proton drip lines. The performance of the detection system is mainly set by the custom CMOS frontend electronics with selectable full-scale energy range from $100MeV$ up to $2.2GeV$ with $4-bit$ granularity and high energy resolution below $10keV$ FWHM at the pulser line ($100MeV$ full-scale energy range). Automatic test and calibration tools - based on an on-chip pulser - ease the use of telescopes in experiments. The contribution reviews the status and perspectives of the FARCOS frontend.

1. – The FARCOS detection system

FARCOS [1] is a novel Femtoscope Array for Correlation and Spectroscopy conceived to perform studies of two- and multi-particle and Intermediate Mass Fragments (IMFs) correlations in heavy-ion collisions at Fermi energies with stable and radioactive beams. It is based on a hodoscope configuration and will be composed of 20 telescopes in its final configuration. At present 10 telescopes are fully operational at Laboratori Nazionali del Sud of the Istituto Nazionale di Fisica Nucleare (INFN) in Catania (Italy).

Fig. (**1**) shows the scheme of principle of the FARCOS detection system. One telescope is exploded to highlight the main components. Each detector have an active area of $64mm \times 64mm$. Each telescope is composed by two silicon detection stages based on the double sided silicon strip technology (Double Sided Silicon Strip Detectors DSSSDs), with different thicknesses ($300\mu m$ and $1500\mu m$) and $32 + 32$ orthogonal strips and by 4 CsI(Tl) troncopyramidal scintillator crystals ($3.2cm \times 3.2cm$, $6cm$ thick) readout by a Si photodiode ($1.8cm \times 1.8cm$, $300\mu m$ thick Silicon PIN diode). Kapton flexirigid custom interconnection to the frontend electronics are not shown. The total numer of output channels is 2560 for the DSSSD and 80 for the CsI(Tl) scintillators. The paper is organized as follows. Section 2 describes the FARCOS frontend electronics and section 3 illustrates the performance measured during the first experiments.

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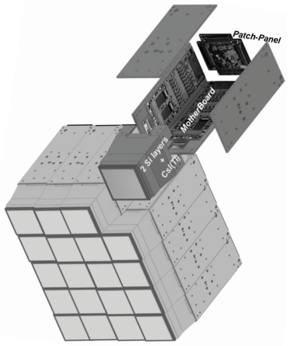

Fig. 1. – Scheme of principle of the FARCOS detection system. One telescope is exploded to highlight the main components.

2. – The FARCOS frontend electronics

The FARCOS frontend electronics is available in two releases. The first one has been used to equip the first 10 telescopes and extensively tested. The second release will equip the remaining telescopes and in the future all telescopes can be upgraded.

Fig. (**2**) shows the layout of the custom-designed second-release $10-$layer PCB (2 more layers are used wrt the first release due to the increased board complexity) that houses two FARCOS ASICs. Each chip in ams $0.35 \mu m$ $C35B4C3$ technology ($3.3V$ supply voltage, 4 metal layers, high resistivity poly, poly precision capacitors) houses $16-$channel custom charge preamplifiers with selectable full-scale energy range from $100MeV$ up to $500MeV$ (with extended gain granularity up to $2.2GeV$ with external capacitors) for the DSSSD strips [2], [3] together with the CsI(Tl) frontend [4] and few additional slow control services, like an on-chip pulser, a channel-by-channel test signal injection system and a temperature monitor. The energy resolution measured in the lab by coupling the frontend with a $300 \mu m$ DSSSD channel is well below $10keVFWHM$ (at $100MeV$ full-scale energy range). he $20\% - 80\%$ rise time of the frontend is below $2ns$ at zero added input capacitance, with a slope of $0.13ns/pF$ resulting in $6ns$ for the $1500 \mu m$ thick DSSSD, $10ns$ for the $300 \mu m$ thick DSSSD and $19ns$ for the CsI(Tl) coupled with the photodiode. The power dissipation is approximately $10mW/$channel (ASIC only) and $24mW/$channel in total. The preamplifier $-$ AC coupled with an external decoupling capacitor $-$ is based on a telescopic cascode architecture thus allowing the increase of

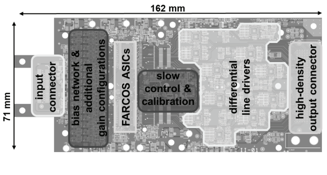

Fig. 2. – Layout of the custom-designed second-release $10-$layer upgraded motherboard that houses two $(16 + 1)$ channel ASICs and reads out $32 + 2$ detector channels.

the current in the input branch with a positive impact both on the noise performance and on stability. Two different feedback networks are available: an external feedback resistor, for top linearity performance and an on-chip MOS transistor, for sake of compactness. Independent biasing of the first branch allows coping with the requirement of a single chip to readout both signal polarities. The full-scale energy range is digitally selectable. The first release of the frontend electronics features the following ranges $100MeV$, $200MeV$, $350MeV$, $500MeV$ and $2.2GeV$, thus giving a wide dynamic range up to more than 15 bits. The granularity is increased in the second release in order to better cope with the different experimental needs, adding 8 additional charge to voltage conversion factors in the range $600MeV - 1.70GeV$. As far as the temperature dependence of the voltage-to-energy conversion factor, we simulated a variation of $7 \times 10^{-3}\%/°C$ in the case of $100MeV$ full-scale energy range and $3 \times 10^{-3}\%/°C$ in the case of $500MeV$ full-scale energy range [5]. A dedicated calibration circuitry is placed on the front-end board in order to ease the debug and the calibration of the full system during mounting and data taking. The full calibration routine as well as the telescope slow control is handled by a microcontroller placed on the slow-control board. In order to increase the granularity of the input calibration signal, extremely relevant for the low full-scale energy range of $100MeV$, in the second release we substituted the $8-$bit DAC with the $12-$bit version. Differential line drivers drive the signals coming from the ASIC towards the output of the vacuum chamber through 11 meter-long twinax cables. Hi-Density right-angle open-pin-field connectors interconnect each motherboard with the slow control/interface board (patch-panel) controlling 4 motherboards and acting also as telescope endcup. The FARCOS DAQ is based on GET [6], featuring $12 - bit$ resolution of the analog-to-digital conversion. In order to mitigate the limited number of bits that spoil the achievable resolution at low energies a dual gain amplifier feeds the signals from the frontend motherboard to the GET system.

3. – FARCOS frontend electronics performance in experiments

During the first experiment employing the FARCOS telescopes, named CHIFAR, in November 2019 at INFN-LNS, Catania Italy, the system performed very well [7]. However only single gain amplifiers [8] were available thus limiting the achievable energy resolution. The FARCOS system was, then, optimized to perform other new experiments that were unluckily cancelled due to the SARS-Cov-2 pandemic. However, on June 22-23, 2020, we had a short commissioning beam time at INFN LNS in Catania (Italy) with a $24MeV$ proton Tandem beam. In this way, we were able to perform the full commissioning of the first 10 telescopes of the FARCOS system in their final configuration. 8 telescopes were assembled within ring 9 of the CHIMERA [9] detector in a circular geometry. The energy resolution was probed with a mixed nuclei alpha source. Fig. (**3**) shows the measured spectrum with the resolution limited by the spectral purity of the source.

Fig. (**3**) shows the $\Delta E - E$ identification plot acquired at one channel of the $300\mu m$ thick DSSSD and at the corresponding one of the $1500\mu m$ thick DSSSD during a test beam at INFN LNS in Catania (Italy) with 4 telescopes installed as in the final configuration with a CS α beam at $64MeV$ on a ^{12}C target.

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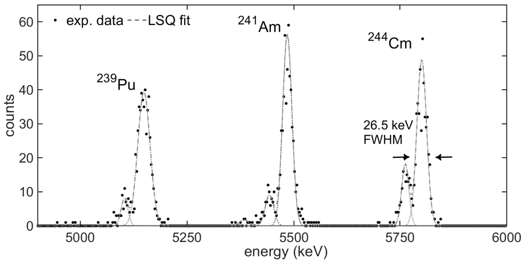

Fig. 3. – Mixed nuclei alpha source energy spectrum at one $300\mu m$ DSSSD channel during the commissioning beam time at INFN LNS in Catania (Italy) with a $24MeV$ proton Tandem beam.

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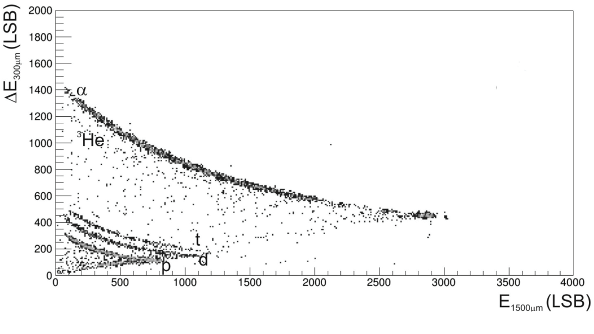

Fig. 4. – $\Delta E - E$ identification plot acquired at one channel of the $300\mu m$ thick DSSSD and at the corresponding one of the $1500\mu m$ thick DSSSD during a test beam at INFN LNS in Catania (Italy) with 4 telescopes installed as in the final configuration with a CS α beam at $64MeV$ on a ^{12}C target.