Processing of the Liquid Xenon Calorimeter's signals for timing measurements.

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I. CMD-3 detector.

The CMD-3 Detector is a universal detector, purposed for registration of the charged particles and photons with high accuracy. Schematic images of the cross-sections of the detector are shown in fig.1. One of the goals of the CMD-3 experiment is the study of nucleons production in electron-positron annihilation. An important example of such processes is a neutron-antineutron pair production near the threshold. A distinctive feature of this process is a large energy deposition in the barrel or endcap calorimeters due to antineutron annihilation. In the barrel calorimeter, the antineutron annihilation typically occurs 5 ns or later after beams collision. For identification of such events it is necessary to determine the time of signal appearance with the accuracy of a few nanoseconds. **The arrival time measurement and recognition of the antineutron annihilation must be accomplished On-Line in 1.2 microseconds after the beam collision** so that the trigger signal can be generated in time for the registration of this event.

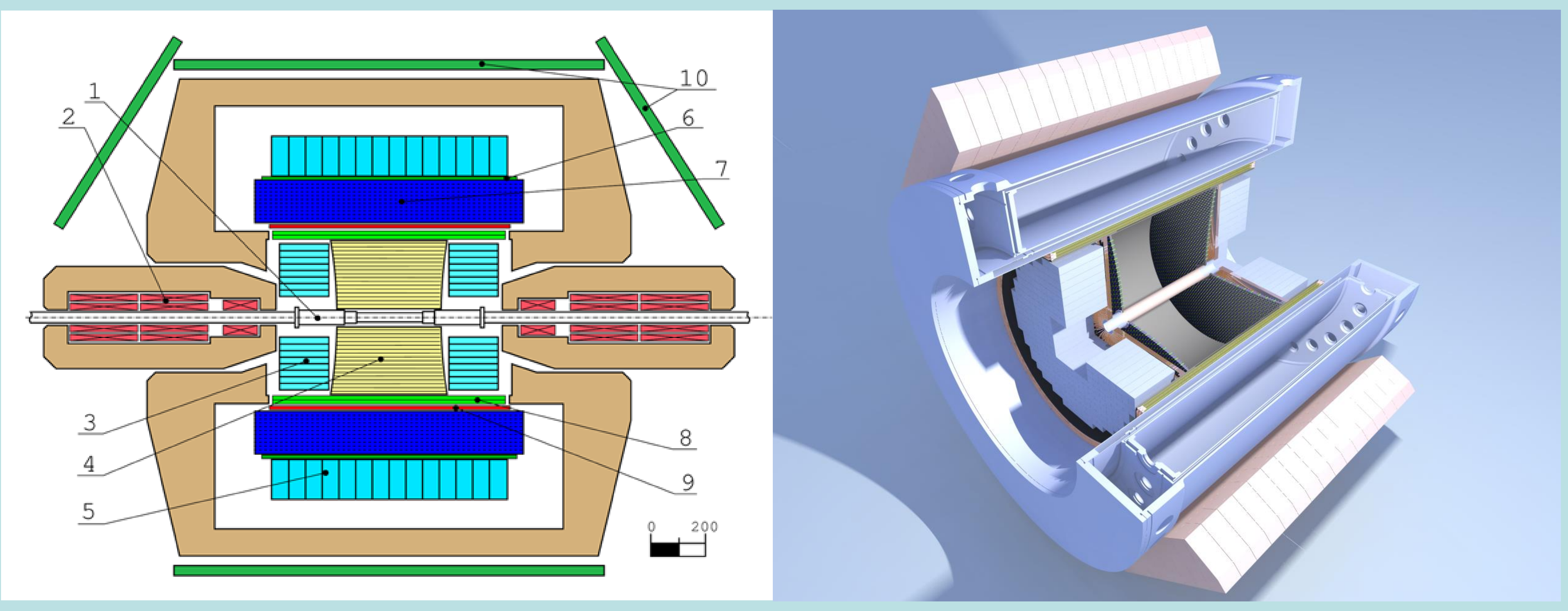


Figure. 1. CMD-3 detector: 1-Vacuum chamber, 2-VEPP-2000 Solenoids, 3-BGO Calorimeter, 4-Drift Chamber, 5-CsI Calorimeter, 6-TOF system, 7-LXe Calorimeter, 8-Z-Chamber, 9-SC Solenoid, 10-Muon system.

II. Liquid Xenon Calorimeter

The liquid xenon based calorimeter (LXe-calorimeter) consists of 14 cylindrical ionization chambers with the anode and cathode readout, which are located co-axially at increasing radii. Each anode surface is divided in the rectangular cells (33 cells in azimuth and 8 cells along the beam axis, as shown in fig.2). The cells at all anode surfaces are located so that the overlapping cells constitute stacks, or "towers" (264 towers in total), directed approximately to the interaction point. All anode cells of each tower are electrically connected, so the signals from those ionization chambers in which ionization was induced are added up. The sum signal of each tower is fed to a channel of electronics.

The charge collection to the anode cells takes about 4.5 microseconds. Thus, the typical signal of a tower is a current pulse with sharp rise and approximately linear fall; the total duration of the pulse is equal to the charge collection time. However, the amplitude and shape of tower signal in a particular event depends on the pattern energy deposition and ionization clusters in the volume of the tower.

So, the total uncertainty of signal arrival time determination must be less than $^1/_{1000}$ of charge collection time, including the uncertainty introduced by the difference of input signals' shapes.

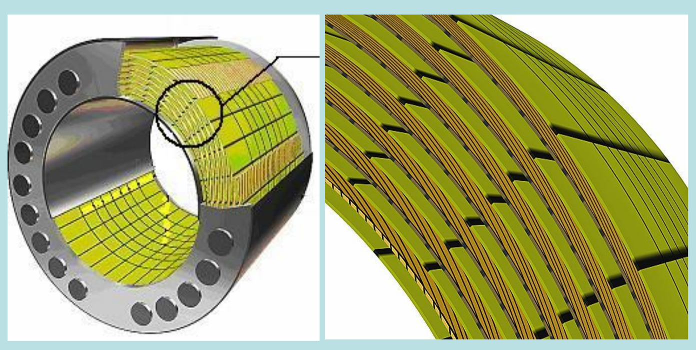


Figure 2. Anode cells of Liquid Xenon Calorimeter.

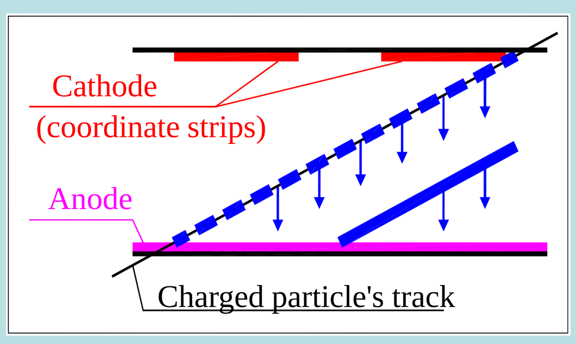


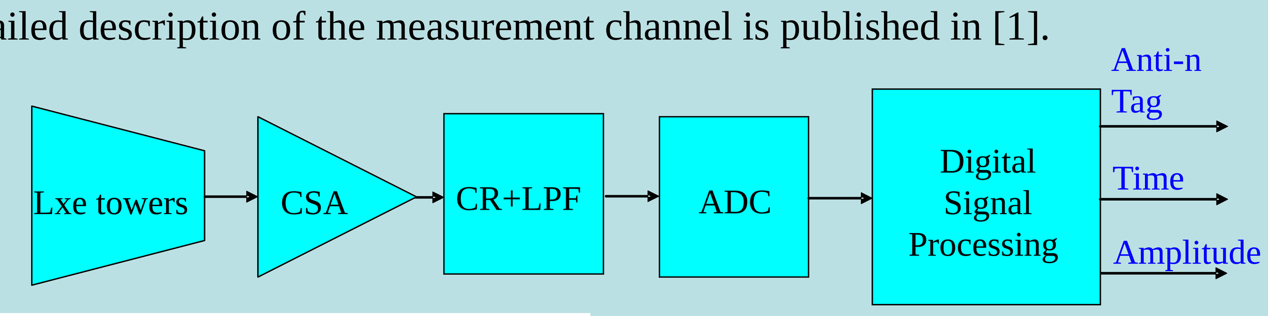
Figure 3. Charge collection inside the ionization chamber.

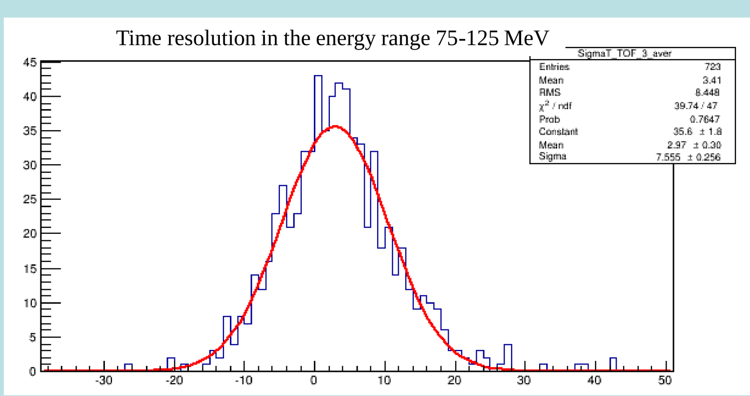
III. Measuring channel prototype of the towers' electronics.

Output signals from each tower are amplified by a Charge Sensitive Amplifiers (CSA), which provides the best signal-to-noise ratio. The CSA integrates the input current, so in response to the current pulses arriving from the tower the CSA produces output signals which have a roughly parabolic-shaped rising edge with duration of about 4.5 us whilst the exact shape of their rising edge differs from event to event. The amplitudes of the signals are defined mainly by the energy deposition and in antineutron annihilation events can differ by a factor of more than 6. The difference of the signals' shapes introduces a substantial error when deriving a time-tag signal by means of a discriminator of any type.

In order to check what accuracy of signal arrival time measurement can be achieved with the current version of electronics, a prototype of the measurement channel was made which included the existing CSA and a existing waveform digitizing module. There were just 62 words of sampling data available for OFF-LINE processing.

The detailed description of the measurement channel is published in [1].



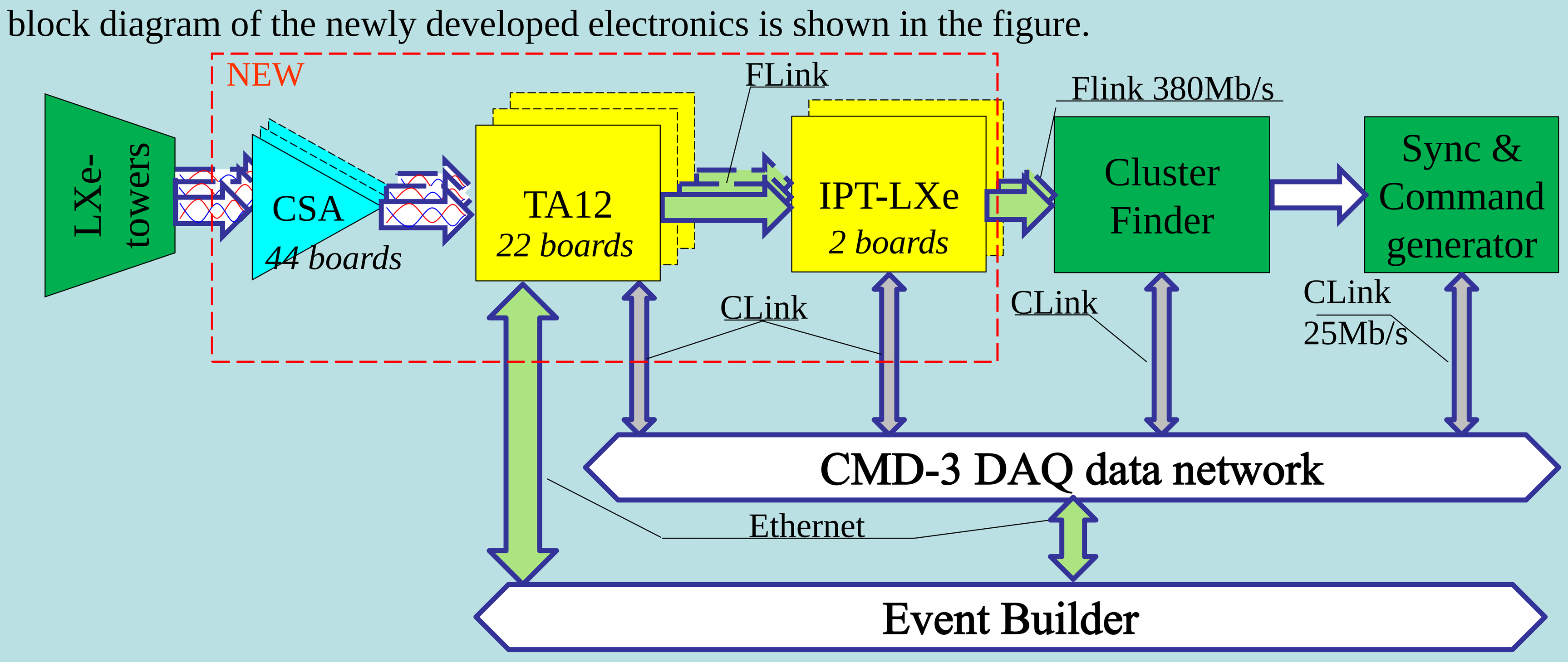


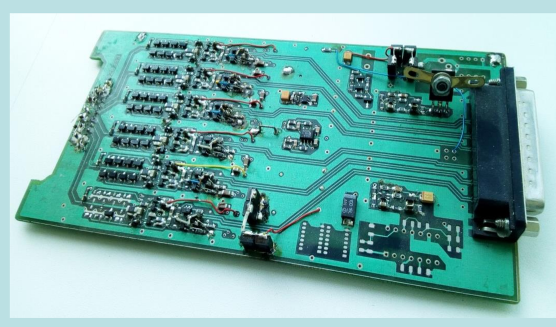
The overall time resolution (including the contributions of the noise and of the difference of signals' shapes) was measured to be **7.6 ns at 75-125 MeV energy range.**

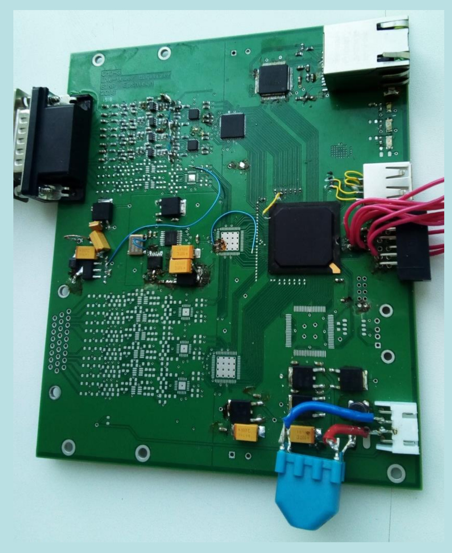
The test revealed that with the current version of electronics the required accuracy could not be achieved.

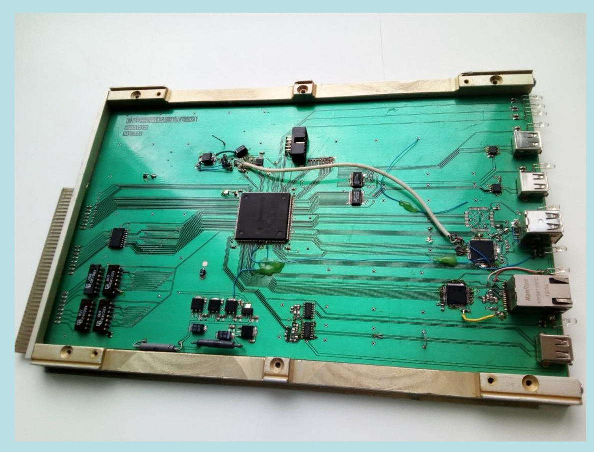
IV. Development of a new electronics for LXe towers

In order to achieved the required accuracy of the signal arrival time measurements, a new electronics has been developed for LXe towers. Within this new approach, the noise level of CSA has been reduced by 2 times. Accordingly, ADCs with higher resolution (12 bits) than that of existing electronics are used. To obtain the best time resolution using the improved quality of the sampling data, it was also necessary to develop a more complex time extraction algorithm based on fitting procedure. The block diagram of the newly developed electronics is shown in the figure.









Technical specifications of CSA:
- 12-channels amplifier
- 12 ouput diff.signal
- Noise: **1932e⁻** @ Cd=750pF, @ CR-RC^4 = 200ns
- +12V@ 0.31A, -5V@0.1A

Technical specifications of TA12:
- 12 input diff.signal
- 12-channels digitizing
- ADC chip: 4ch, 105MSPS, 12bits
- Digital signal processing in FPGA (waveform analysis)
- External flash-memory (1Mb)
- Ethernet (Raw/UDP-100Mb/s)
- C-Link (LVDS) 25Mb/s
- F-Link (LVDS) 360Mb/s
- +5V@1.2A, -5V@0.2A

Technical specifications of IFLT_LXe:
- 11 input LVDS lines
- C-Link (LVDS) 25Mb/s
- 3 F-Link (LVDS) 360Mb/s
- Ethernet (Raw/UDP-100Mb/s)
- CAMAC standard

V. Preliminary signals processing algorithm for timing measurements.

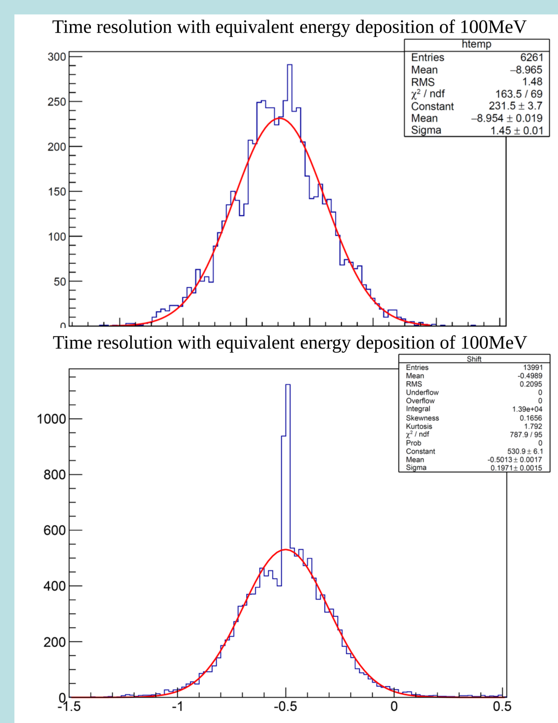
To provide the required accuracy of the On-Line measurements of the signal arrival time **a special signal processing algorithm has been developed.** It allows one to extract the value of the signal arrival time before trigger firing and to process the event data Off-Line. The signal arrival time is measured in two stages. The detailed description of the measurement channel is published in [2].

VI. Results and conclusion.

At the moment, a prototype of the entire measuring channel (including new CSA and new signal processing module) for LXe towers has been manufactured and successfully tested at test-bench and at the detector. Test signals from a generator (the input current pulses with linear fall of 4.5 us similar to the typical tower's signals, with amplitude being equivalent to the energy deposition of 100 MeV in the tower) and cosmic events were used for tests.

- At the test-bench a **time resolution of 1.45 ns was obtained** (including the contribution of the noise only);
- On the detector a **time resolution of 1.97 ns was obtained** (including the contribution of the noise only);
- Analysis of the cosmic and physical events (contribution of the noise and the difference of the signals' shapes) is now ongoing.

This result allows us to expect that **with the new electronics the required accuracy of time measurements will be achieved**.



References:

[1] "CMD-3 Liquid Xenon Calorimeter's signals processing for timing measurements", 2014 JINST 9 C09019

[1] "Processing of the signals from the Liquid Xenon Calorimeter for timing measurements ", 2017 JINST 12 C02035

[2] "The CMD-3 TOMA DAQ infrastructure", 2014 JINST 9 C10016

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