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A hardware implementation of Region-of-Interest selection in LAr-TPC for data reduction and triggering

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ABSTRACT: Large Liquid Argon TPC detectors in the range of multi-kton mass for neutrino and astroparticle physics require the extraction and treatment of signals from some $10^5$ wires. In order to increase the throughput of the DAQ system an on-line lossless data compression has been realized reducing by almost a factor 4 the data flow. Moreover a new efficient on-line identification algorithm of wire hits was studied, implemented on the ICARUS digital read-out boards and fully tested on the ICARINO LAr-TPC facility operated at LNL INFN Laboratory with cosmic-rays. This system permits the extraction of the event Region-of-Interest maximizing the global throughput of the DAQ and the realization of a trigger based on charge deposition on the wires. Capability to trigger isolated low energy events down to few MeV visible energy was also demonstrated.

KEYWORDS: Data processing methods; Trigger concepts and systems (hardware and software); Data reduction methods; Time projection chambers

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1 Introduction

Developments in neutrino and astroparticle physics will require the realization of gigantic detectors with mass of order of hundreds kton or of megaton to be installed in underground laboratories. Such apparatus will be addressed to study long base-line neutrino oscillations at accelerators as well as from cosmic sources including Supernovae, and to test the barion matter stability searching for proton decay. Among the proposed detection techniques, the Liquid Argon TPC detector (LAr-TPC) is expected to play a special role. Accounting for its excellent event imaging capability and its superior performance concerning event detection efficiency and identification, the LAr-TPC allows to keep the detector size in the multi-kton mass range with respect to the megaton masses required for example by the water Cherenkov technique. Thus the efforts linked to the underground site excavation and infrastructures, as well as the engineering needs, can be largely reduced.

The successful start of ICARUS-T600 operations [1] 600 ton LAr-TPC at INFN LNGS underground laboratory using the CERN CNGS neutrino beam, represents a milestone towards the realization of large LAr-TPC mass detectors for neutrino and astroparticle physics.

The extrapolation of LAr-TPC detector to multi-kton mass requires some improvements in different aspects of the technology, such as cryogenics, LAr purity and detector read-out [2]. Moreover extraction and handling of the corresponding huge amount of data will constitute a not negligible aspect to be addressed in the detector exploitation. In the present ICARUS-T600 about 54000 channels of the wire TPC are read-out. To increase the bandwidth of the DAQ system two improvements have been studied for the TPC wire signal read-out: an on-line lossless factor 4 data compression, and a new algorithm to detect the local Region of Interest (ROI) of each event avoiding the full acquisition of the detector. In particular the latter will allow triggering isolated low energy events down to few MeV visible energy using directly the wire signals, an essential feature, for example, in the search for Solar or Supernovae neutrinos interactions.
In the following the algorithm description and implementation on the TPC read-out board is described as well as the performance, tested with the ICARINO LAr-TPC facility in the framework of the ICARUS R&D activity at the INFN-LNL laboratories in Legnaro (Italy).
2 Cosmic-ray test-run with ICARINO

The ICARINO test facility is a \( \sim 30 \) liters LAr-TPC equipped with external scintillation counters to trigger on cosmic ray events. The experimental set-up [3] is shown in figure 1.

The TPC consists of two vertical electrode planes, \( 32.6 \times 32.6 \) cm\(^2\), acting as anode and cathode, laterally delimited by 4 vetronite \( 29.4 \times 29.4 \) cm\(^2\) boards supporting the field-shaping electrodes (30 strips of gold-plated copper) resulting in a 38 kg LAr active mass (figure 2). In order to facilitate the LAr re-circulation in the TPC active volume, the cathode at the front of the chamber has been realized with a thin etched stainless steel grid.

The chamber is contained in a stainless steel cylindrical vessel, whose upper face is an ultra high vacuum flange hosting the feed-throughs for vacuum, LAr filling and re-circulation, high voltage cables and read-out electronics. The whole detector vessel is contained in an open-air stainless steel dewar, which is initially filled with commercial LAr acting as cryogenic bath for the ultra-pure LAr injected in the detector vessel.

The read-out anode’s electrodes facing the drift volume are two parallel 96 stainless steel wire planes spaced by 3 mm and with 3 mm pitch: the first one works in Induction mode and is made of vertical wires while the second one collects the drifting electrons and is made of horizontal wires. A third wire plane electrically biased, called grid, is inserted 3.5 mm in front of the Induction wires. It acts as an electromagnetic shield improving the Induction signal sharpness and reducing the noise due to the HV biasing. Finally, another thin stainless steel grid has been inserted behind the Collection wire plane and put to ground to confine the electric field around the wires.

A -14.8 kV voltage is applied on the cathode corresponding to a uniform electric field of 474 V/cm in the drift volume. In order to ensure a full transparency of the Grid and of the Induction plane to drifting electrons, the potential is fixed at 350 V for the Collection wires, -100 V for the Induction wires and -350 V for the Grid. This set of values was chosen after a careful study on the reconstructed muon tracks collected in several preliminary test runs, optimizing the electric field uniformity in the whole drift region.

The TPC vessel is filled with ultra pure LAr, following the procedure described in [3]. First the chamber is evacuated to at least \( 10^{-3} \) Pa with turbo-molecular pumping system for several days, to maximize degassing of the detector materials. Then the chamber is cooled down in the LAr bath as fast as possible and is filled with commercial LAr purified by an Oxysorb/Hydrosorb\(^\text{TM}\) filter. An additional small evacuated tank immersed into a LAr bath, acting as a cryogenic trap, is connected to the TPC vessel during the first phase of the filling to remove the gaseous Argon, produced by the evaporation on the warm inner detector surfaces and possibly contaminated by degassing. This additional vessel is disconnected soon after the completion of the filling procedure.

The level of the LAr cryogenic bath, in which the detector vessel is immersed, is lowered with respect to that in the inner detector, to increase the heat losses and allow the recirculation system to start. The gaseous Argon (GAr), evaporating from the liquid in the detector vessel, is purified by an Oxysorb/Hydrosorb\(^\text{TM}\) filter, condensed in a passive heat exchanger (LAr bath) and finally re-injected at the bottom of the detector. The total LAr volume is completely recirculated every 2.5 days.

The read-out electronics is a subset of the one implemented in the ICARUS-T600 detector [1]. It is designed to provide continuous digitization and waveform recording of the signals from each
Figure 3. Block diagram of the LAr-TPC electronic read-out.

TPC wire; the chain is composed of three basic units, each one serving 32 channels (figure 3): the Decoupling Board, the Analog Board, and the Digital Board.

The Decoupling Board receives 32 analogue signals from the chamber and passes them to the analogue board via decoupling capacitors; it also provides wire biasing voltage and the distribution of the test signals.

The Analogue Board hosts the front-end amplifiers and performs 16:1 channel multiplexing and 10-bit digitization at 40 MHz rate (i.e. 400 ns sampling period per channel, corresponding to \( \sim 0.6 \) mm drift distance). The overall gain is about 1000 electrons per count, thus setting the signal of minimum ionizing particles to \( \sim 15 \) ADC counts (\( \sim 5000 \) electrons / mm accounting for electron-ion recombination and 3 mm wire pitch), with a dynamic range of about 100 mip’s. To match the different signal’s shapes two versions of this board have been used, differing for the integration time constant. The Collection version has a time constant of 3 \( \mu \)s, much shorter than the signal duration, and is used for the unipolar signals coming from Collection wires; the area of the shaped signal is proportional to the charge. The Induction version has a time constant of 100 \( \mu \)s, much longer than the signal duration, and is used for the bipolar current signals coming from the Induction wires. In the ICARUS detector the Collection version is also used to instrument the Induction plane facing the drift volume, not instrumented in the present test-facility.

The Digital Board (figure 4) acts as a 32 channels, 10 bit wide, waveform recorder. It continuously reads the data out of the Analogue Board, stores them in multi-event circular buffers (MEBs) and analyzes them according to a complex, programmable logic. MEBs length can be chosen among 7 different values, ranging from 64 to 4096 t-samples (1 t-sample = 400 ns), corresponding
to a drift distance from 38 mm to 2.5 m at nominal electric field; this feature permits a segmentation of data along the drift direction, defining Regions of Interest (ROI’s). As soon as a trigger signal is received, the active buffer is frozen, writing operations are moved to the next free buffer, and the stored data are read out by the DAQ.

Once the read out is completed, the frozen buffer is released and it is available to be overwritten by new incoming data. This configuration guarantees no dead time, at least until the maximum DAQ throughput (up to 1 Hz, i.e. 1 full-drift event per wire per second in the ICARUS-T600 configuration) is reached.

The buffer data are formatted in four different modes. The first records the actual raw data while the three additional ones introduce several degrees of lossless compression as an additional feature of the upgraded firmware. The four data formats work as follows:

- **RAW-DATA**: no compression is performed, and the wire signal waveform is written to the MEB as it is (figure 5 top);
- **FULL-DIFFERENCE**: for each wire the difference between two consecutive t-samples is written using 10 bit. This mode is intended for debugging purposes only (figure 5 middle top);
- **COMPRESSION 2**: for each wire the difference is always written using 8 bit. For “physical” signals overflows are highly improbable (figure 5 middle bottom);

**Figure 4.** Picture of the Digital Board equipped with SuperDaedalus chip. In the developing phase a very powerful Xilinx Virtex5 has been used. In production a Spartan6, as already tested, will be enough to implement the VHDL code that performs the double rebinning algorithm.
Figure 5. Data formats as implemented in the ICARUS Digital boards: from top to bottom RAW-DATA, FULL-DIFFERENCE, COMPRESSION 2 and COMPRESSION 4.

- COMPRESSION 4: for each set of 4 consecutive wires, the signal amplitude value for a t-sample is compared to the previous one. If the difference is less than or equal to ±7 ADC counts the four 4 bit differences are stored in a 16 bit word (figure 5 bottom). If one or more differences are above that value (OVERFLOW) all the four differences are stored each one in a 16 bit word, flagged setting to “1000” the 4 more significant bits (“1000 = 8”, out of the compression 4 difference range) i.e. in FULL-DIFFERENCE format;

All the data compression modes have been extensively tested in dedicated run of ICARINO test-facility with cosmic rays at LNL. In particular thousands of test pulse and cosmic muon events, both in raw data and compression 4 modes, were collected triggering on the external scintillation counters and analyzed to test the functionality of the compression algorithm. Examples of cosmic muon track events with a large local energy deposition exceeding 7 ADC counts as recorded in COMPRESSION 4 mode are shown in figure 6. About 30% of the events with single muon tracks resulted to be affected by overflows. The detailed study of event reconstruction and signal shape in compression 4 mode next to the overflows shows no anomaly, no signal truncation or distortion. No difference was found between the two modes by comparing the pulse-height and the difference between contiguous t-samples (figure 7). The distributions of hit number and amplitude per track confirm that no difference is present between compression 4 mode and raw data (figure 8), allowing to validate the new firmware of the digital boards. Therefore an effective reduction factor 3.9, with a consequent reduction in the read out time of the same factor, was established for single tracks.

In addition in the ICARINO test-facility set-up both Induction and Collection boards are equipped with a new chip (SuperDaedalus) which implements a new hit-finding algorithm able to define the Region of Interest (ROI) of the LAr-TPC. The study of the performance of the new digital boards with trough-going cosmic ray muons in terms of signal identification and ROI def-
Figure 6. Example of a cosmic muon track event as detected with Compression Mode 4 in Collection view (left window) together with zoomed details (right window). Wire numbering is quoted on the vertical axis, drift time is on the horizontal one in 400 ns t-sample units. The gray level is proportional to the pulse height of the waveform, also shown as an histogram for a specific wire. The overflows signals, exceeding 7 ADC counts difference are correctly reconstructed.

Figure 7. Distribution of the wire signal pulse-height (left) and of the corresponding differences between two consecutive t-samples (right) for both compression 4 (black) and raw (red) data modes (empty events).
Figure 8. Distribution of the hit number per track (left) and of their corresponding amplitude in ADC counts (right) in Compression Mode 4 and Raw data (muon events).

Figure 9. Typical signal shape of a Collection wire. Both the high and low frequency components of the electronic noise can be clearly seen.

...inition capability has been addressed in a dedicated run, and is the subject of next section. The system was run with a global stop signal provided by the trigger system based on the external scintillation counters or on the internal TPC wires signal processed by the new SuperDaedalus chip that produces a Global Trigger Output (GTO) from each digital board.

3 The new hit finding algorithm

As observed during the 2001 test-run with a half of ICARUS T600 detector the hit signals on the Collection wires produced by through-going muons are characterized by a pulse-height in the range 10÷30 ADC counts depending on the track inclination and extending over ~ 25 t-samples. The data exhibits also the presence of a ~ 4 ADC counts peak to peak high frequency noise with period less than 10 t-samples overlapped to a 10 ADC counts low frequency oscillation of the baseline with a ~ 1500 t-samples period (figure 9). The high frequency noise is essentially due to the serial noise of the front-end amplifier, linear function of the input capacitance that in our case is around 400-500 pF, while the low frequency component is essentially due to microphonic pick-up by the many meters long detector wires.
Figure 10. Example of the DR-slw algorithm applied to the wire signal in previous figure: $Q_{\text{short}}(t_j)$ (top), $Q_{\text{long}}(t_j)$ (middle) and $S(t_j)$ (bottom).

In order to extract the hit signal from the wire chambers, a dedicated algorithm had been developed with the aim of on-line filtering the genuine hit signals from both the low and high frequency components of the noise by means of a double rebinning technique applied to each wire signal. Since quick response time would be essential for trigger purposes, the algorithm was conceived as simple as possible to be easily implemented in a hardware-wise frame. It consists in calculating the average of the signal amplitude $Q$ at the $t$-sample $t_j$ over a short ($N_S \simeq 10$ t-samples) and a long ($N_L \simeq 200$ t-samples) time intervals, well suited also for hardware implementation, to treat the high and the low frequency components respectively:

\[
Q_{\text{short}}(t_j) = \frac{\sum_{i=j+1-N_S}^j Q(t_i)}{N_S} \\
Q_{\text{long}}(t_j) = \frac{\sum_{i=j+1-N_L}^j Q(t_i)}{N_L}
\]  

(3.1)

where the binning interval sizes have to be chosen according to hit signal features compared to the noise. The presence of the physical hit is then recognized requiring the difference $S(t_j)$ to exceed a
Figure 11. Hit identification efficiency for three different track inclination (top) and fake frequency per wire and ms drift time (bottom) of the DR-slw algorithm (software) as a function of the discrimination threshold in data collected in Pavia with a semi-module of T600.
Figure 12. Block diagram of the DR-slw hit finding procedure and generation of a local trigger signal.

The performance of this algorithm as well as the parameter choice was studied through an offline analysis of the cosmic muon data collected during the 2001 test run. As a starting point, the algorithm turned out full efficient (\(\sim 100\%\)) in the physical hit recognition with a negligible fake rate (\(\leq 3\%\)) for threshold values \(Q_{\text{thr}} = 4\) ADC counts over a wide range of the long rebinning interval (100 ÷ 300 t-sample).

This kind of algorithm is perfectly adequate to be applied in pipeline with data taking because the intervals into which the signal averages (long and short) are calculated is a “sliding window” over the full data recording (DR-slw). At each clock cycle the average over \(N_S = 8\) and \(N_L = 128\) t-sample is recalculated adding the value of the sample \(t_0\) and subtracting that of sample \(t_0 - N_S\)

fixed threshold \(Q_{\text{thr}}\):

\[
S(t_j) = Q_{\text{short}}(t_j) - Q_{\text{long}}(t_j) \geq Q_{\text{thr}}.
\]  

(3.2)
Figure 13. Example of off-line data reduction on a real event using ROI recognition based on hit identification on a drift-time (1024 t-samples) vs. wire coordinate (128 wires). Left: raw data as recorded in Collection (top) and Induction (bottom) views; right: corresponding reduced data.

and $t_0 - N_L$ respectively. When the difference of short and long rebinned signals is above a given threshold for at least 3 t-sample, a PEAK signal is output (figure 10).

Possible impact of this parameters choice on the algorithm performance has been investigated on a sample of real muon events collected in Pavia. The results confirm the possibility to obtain full single hit detection efficiency (~ 99%) together with a negligible fake signal rate (~ 1% per ms and wire) applying a threshold value $Q_{thr} = 6$ ADC counts (figure 11).

The hit identification procedure can be used for the recognition of a ROI (figure 13) and the generation of an internal trigger. The block diagram of the on-line algorithm implementation is shown in figure 12. Serial data (10 bit for each channel) are de-multiplexed before applying the rebinning algorithm. To maintain backward compatibility with the digital boards the data-flow has been divided in two identical parts, serving each 16 channels.

A majority stage has been included from a set of 16 PEAK signals from adjacent wires, in order to reduce the rate of fake triggers, while keeping the system sensitive to short tracks (16 wires correspond to 5 cm).

Taking the logical OR of the two majority of the same board, a "Global Trigger Output" (GTO) signal is generated, which can be used to build more complex trigger patterns including adjacent boards.

A possible drawback of this solution could arise for tracks inclined with respect to the wire plane: as the PEAK signals may not overlap, the efficiency of the majority would decrease with the angle (figure 11). To avoid this situation, the final stage of the SuperDaedalus performs a stretching of the PEAK signals among four values, 25, 50, 75, and 125 µs. Analysis made on data of the 2001 test-run showed that the efficiency never falls below 99% for traces of all angles if a stretching of 50 or 75 µs is applied.

In order to determine the optimal parameters for the new Collection boards, cosmic muon tracks have been collected with the ICARINO test-facility with the external scintillation counter trigger. Then the new GTO internal signal from Collection boards has been used to trigger cosmic muons and to study the algorithm performance also in Induction view.

While the minimum size of the ROI along the wires is 10 cm (32 wires), along the drift direction the modularity is given by the size of the MEB that ranges from 64 to 4096 samples. In compression 4 mode this turns into a range from 100 µs to 6.5 ms, i.e. from 15 cm up to 10 m.
Figure 14. Visualization of an inclined muon track in the wire/t-sample plane (top). The hit signals (ADC counts) in the Collection (left) and Induction (right) view are drawn for several wires as a function of the drift coordinate (t-samples); the red line represents the peak signal for the threshold value $Q_{th} = 6$ ADC counts.

A further parameter “polarity” has been implemented to set the trigger on the rising or on the falling edge. In particular the falling edge is used for the Induction wires.

Finally a dedicated configuration of internal TPC trigger, aiming at the detection of isolated low energy events (solar neutrino like) has been set-up. This last measurement represents a crucial test in view of the future development of huge LAr-TPC detectors, since the localization of low energy events represents a challenging item for large volume detectors.
Figure 15. Mean hit identification efficiency on the single wire in Collection view as a function of the threshold value $Q_{thr}$ measured for vertical and 45° inclined muon tracks. As a reference the values obtained with the software simulation of the DR-slw algorithm are also represented.

Figure 16. Average fake trigger rate on the single wire in Collection and Induction view, measured on the whole 1024 t-samples interval.

3.1 Single hit detection in Collection view

The hit finding efficiency on the single wire in Collection view has been measured as a function of the threshold value $Q_{thr}$ ranging in the interval 4 ÷ 10 ADC counts and looking for the PEAK signal within 10 $\mu$s from the hit identified in the off-line analysis. Among all the vertical and 45° inclined
Muon tracks, collected by means of the external trigger, only the through going muons without energetic $\delta$ rays were selected (figure 14) resulting in about $\sim 1000$ and $500$ events statistics for vertical and inclined tracks respectively. Referring to the single hit detection efficiency, values above $95\%$ were measured for $Q_{\text{thr}} \leq 7$ ADC counts (figure 15). For higher threshold values the efficiency degrades especially in the case of vertical tracks.

A dedicated run with random external trigger was performed to measure the corresponding fake hit detection rate on the single wire recognizing the presence of the PEAK signals on the whole $1024$ t-samples interval in empty events (i.e. with no hits identified by the off-line software analysis). The rate of fakes is rapidly decreasing down to $10^{-3}$ per wire per $1024$ t-samples with threshold for both Collection and Induction views for $Q_{\text{thr}} \geq 6$ ADC counts (figure 16) ($1000$ events overall collected statistics). The obtained results demonstrated the robustness and reliability of single hit finding, allowing to work satisfactorily, with high efficiency and low associated fake hit signals.
3.2 Study of the Global Trigger Out signal in Collection view

Tests were addressed to understand the use of the majority circuit to select clusters of hits in adjacent wires and then generate an internal trigger (GTO signal).

At first, the GTO signal generation in Collection view was studied on a sample of clean through-going muon tracks, selected among vertical and 45° cosmic muon events collected with the external scintillator trigger system (figure 17). GTO signals from two out of the three Collection boards were recorded together with the event for a fixed threshold value $Q_{th} = 6$ ADC counts (according to the analysis described in the previous section), for different values of the majority ($M = 8, 12, 15$) and stretching parameters.

Time delay of the GTO signal with respect to the track first hit, depends mainly on the track dip angle, due to time displacement of the PEAK signals on consecutive wires, and on the required majority level. Therefore the GTO signal presence was investigated into a suitable time window of 50 and 300 t-samples depending of the track inclination. In almost 100% of the cases, the GTO was observed for majority values up to $M = 15$ for inclined and vertical tracks for both boards (figure 18) even with the shortest stretching parameter. Actually small inefficiencies in the first board for the inclined track sample are caused by not completely contained events, i.e. muons entering the TPC volume after the 24th wire and then occupying less than 8 hits on the first board.

3.3 Internal trigger based on the Collection GTO signal to search for tracks in Induction view

As a second step, an internal trigger system based on the coincidence of the GTO signals from the first and the third boards in Collection view was set-up. A sample of events of through going $\mu$
Figure 19. Visualization of a through-going muon track parallel to the TPC wire planes and with $\sim 36^\circ$ inclination with respect to the Induction and Collection wires orientation. The values of the threshold and majority parameters are $Q_{\text{thr}} = 6$ ADC counts and $M = 8$ respectively.

almost parallel to the TPC wire planes were collected and used to study the generation of the peak signal in Induction view. In particular, only tracks with $35^\circ \div 55^\circ$ inclination with respect to the Induction and Collection wire orientation were selected (figure 19).

As a result, the hit finding efficiency on the single wire was exceeding 97% up to threshold values $Q_{\text{thr}} = 6$ ADC counts, like in Collection view, but decreased more quickly with $Q_{\text{thr}}$.

Therefore, in order to avoid geometrical bias, the efficiency of the GTO signal from the central board in Induction view was measured with an upgraded internal trigger requiring in addition the coincidence of the GTO signals from the first and the third (i.e. external) Induction boards. This insured that the muon track was occupying all the wires of the central Induction board.

The obtained result, 98.0 $\pm$ 0.3% efficiency ($Q_{\text{thr}} = 5$ ADC counts, $M = 6$ and stretching $50 \div 75 \mu$s), is really satisfactory also because almost half of the small residual inefficiency was due to vanishing tracks with few hits above threshold (figure 20), as recognized by a visual scan of the events.
Figure 20. Example of GTO signal inefficiency of the central Induction board for a vanishing muon track recorded with internal trigger. On the right it can be noticed that the number of hits identified by the DR-slw algorithm (red contour), even if larger than that one identified via software (blue stars), isn’t enough to generate a GTO signal, which is instead incorrectly generated by correlated noise (blue contour).

3.4 A low energy event trigger based on GTO signals

A challenging item for future huge mass detectors is the selection of localized low energy events, such as for example those involved in the search for solar or Supernovae neutrinos interactions [4]. Thus an interesting application of the internal trigger based on TPC wire signals was realized in ICARINO requiring, in Collection view, the GTO signal from the central board vetoed by the coincidence of the GTO signals from the two lateral boards. This scheme allows to select events with signals only in the central slice of the detector due to isolated low energy deposition or crossing muons running almost parallel to the Collection view wires and with any dip angle.

As an example, three isolated low energy events, collected with $Q_{\text{thr}} = 6$ ADC counts, $M = 4$ and $Q_{\text{thr}} = 5$ ADC counts, $M = 3$ are shown in figures 21), (22 and 23. For $Q_{\text{thr}} = 6$ ADC counts and $M = 4$, the average hit multiplicity per event was 9.1 and 14.6 in Collection and Induction.
Figure 21. Isolated low energy event recorded in ICARINO with the solar neutrino like internal trigger, for $Q_{\text{thr}} = 6$ ADC counts and $M = 4$, visualized in the Collection (top) and Induction (bottom) views. On the right a zoomed view of the region interested by the event is shown.
Figure 22. Isolated low energy event recorded in ICARINO with the solar neutrino like internal trigger, for $Q_{\text{thr}} = 6$ ADC counts and $M = 4$, visualized in the Collection (top) and Induction (bottom) views. On the right a zoomed view of the region interested by the event is shown.
Figure 23. Isolated low energy event recorded in ICARINO with the solar neutrino like internal trigger, for $Q_{\text{thr}} = 5$ ADC counts and $M = 3$, visualized in the Collection (top) and Induction (bottom) views. On the right a zoomed view of the region interested by the event is shown.
Figure 24. Example of deposited energy spectrum in Collection view $E_{dep}$ distribution of events recorded with the internal trigger described in section 3.4. for $Q_{thr} = 6$ ADC counts and Majority $M = 4$ (top).

respectively. No fake events, attributed to electronic noise only, were recorded over a sample of about $10^4$ events. The deposited ionization energy $E_{dep}$ was measured event by event from the integral of the wire signal recorded in Collection view $A_i$, according to $E_{dep} = \sum_i A_i C \cdot E_{ion}$, where $e = 1.6 \cdot 10^{-4}$ fC is the electron charge and $E_{ion} = 23.6$ eV is the ionization energy in LAr, $C = (1.39 \pm 1\%)\cdot 10^{-2}$ fC/(ADC counts $\cdot$ t-sample) is the electronic chain calibration constant, extracted in a dedicated test-pulse run [3]. Corrections to $E_{dep}$ from electron recombination ($R \sim 0.55$) was included (the attenuation due to Argon impurities is negligible because of the short drift path).

The resulting energy spectrum of the collected events extended up to 100 MeV, with an average value of 15.6 MeV, the most energetic events referred to inclined muon tracks with large $\delta$-rays traversing only the central region of the TPC (figure 24). The effective trigger cut-off at about 4 MeV is due to the 4 wire hit multiplicity threshold which defines the minimum projected track length. As a result the trigger efficiency is largely dominated by the track inclination with respect to the wire plane and not by the single hit detection (see section 3.1).
4 Conclusions

The realization of a multi-kton mass LAr-TPC detector requires the extraction and the treatment of the corresponding huge quantity of data from some $10^5$ channels. To increase the throughput of the DAQ system an on-line lossless factor $\sim 3.9$ data compression based on the recording of the difference between the wire signal at two consecutive time sample was implemented in the front end electronics and tested with cosmic rays at the INFN LNL ICARINO test-facility.

A new algorithm based on a double rebinning - sliding window technique was studied and implemented on the read-out board for a full efficiency detection of a single hit signal on a TPC wire. In such a way a local trigger system was successfully implemented and tested with cosmic rays allowing triggering isolated low energy events down to 1 MeV visible energy using directly the wire signals. This implementation allows to define at the front end level the event ROIs, permitting to restrict the read out to the regions with physical signals, which means a huge reduction of the amount of data to be handled by the DAQ and to be stored for successive analysis.

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