with front-end DAQ processors.

In the event of no further improvement in the SNR with respect to what is currently achieved in the dedicated R&D (as discussed in Sec. ??), an optimal filter would be inserted in the input stage before the discriminator in order to get a trigger signal for S1 while an unfiltered copy of the signal will need to be recorded to extract a precise timing information (see also the discussion in Sec. ??). Similarly, in the event of a doubling of the readout channels in LAr TPC, a doubling of the size and costs of the first stage of the digitization process will be implied. In addition, some additional hardware resources for the software event builder and trigger 1 1.4 will be needed to cope with the increased data flow coming from the unfiltered waveform that would be acquired for optimal photon timing reconstruction. These are conceptually simple modifications to the scheme proposed in this chapter for the DAQ electronics and software trigger and will not be discussed further.

The trigger rate during dark matter search data taking in DarkSide-20k has three major contributors: background events from detector materials, background events from $^{39}$Ar, and random triggers. To estimate the first term, the event rate measured in the UAr running of DarkSide-50 is taken, excluding the contribution from the PMTs and from the remaining $^{39}$Ar in DarkSide-50, and scaled by the ratio of surface areas of DarkSide-20k and DarkSide-50, a factor of 55, obtaining an expected rate of 27 Hz; it is noted that these events will be concentrated at the surfaces of the active volume. At an expected $^{39}$Ar depletion of $10^5$ in the DAr, there will still be a small additional rate of about 1 Hz from $^{39}$Ar, uniformly distributed throughout the active volume. Overall hits SiPM tiles with a correlated S1 and S2 signals at a rate of $\sim 30$ Hz are expected in DarkSide-20k. The average singles rate per channel is dominated on the other hand by the DCR of SiPMs. With the required 0.1 Hz/mm$^2$ specification, this will imply a single rate for detector module of about 250 Hz. It is assumed there is only a very small possibility of occasional light leakage between which is neglected in the following, thus, for the LAr TPC a total of $250\,\mathrm{Hz} \times 5210 = 1.3\,\mathrm{MHz}$ singles rate is expected.

Data acquisition could be initiated by a coincidence of hits in the TPC within a specified time window. A coincidence of 7 hits in 200 ns would result in a random trigger rate well below 0.1 Hz. For nuclear recoils a signal producing $\sim 15$ PE in 5 µs would result in the 6 PE to 8 PE collected within the first 200 ns considering the DarkSide-20k geometry and the fast response of SiPMs. Thus DarkSide-20k trigger would be fully efficient for Wimp-like signal of interest with a predicted total rate around 30 Hz, allowing to open the recording of data for the maximum drift-time (2.5 ms). Real S1 events produce signals with no more than 1 PE per tile and one correlated S2 signal. There are $3.3 \times 10^3$ noise hits during an electron drift time, but the probability of another S2 signal is very low.

For storing S1 hits 6 Bytes are enough (4 Bytes for timing and 2 for Channel id), while for storing the S2 digitized data 16 Bytes would allow storing 10 samples for pulse integration. Various rate estimations are provided in Table I.

Synchronization between the TPC and veto DAQ and between the different readout boards running the TPC digitization is fundamental for the effectiveness of the design, and should be provided and maintained during data taking. The same clock source of the TPC DAQ must be used and digital signals (like GPS time stamps or trigger IDs) should be generated to uniquely identify each event regardless of the trigger origin and the detector. Pulsed signal to all channels of DarkSide-20k should be used to check and correct the alignment of each channel among the three detectors.

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## 1.2. Expected Performances from Simulation of DarkSide-20k DAQ

Simulation studies have been performed to understand the expected performance of the readout scheme discussed above. Simulated samples of both electron recoils from $^{39}$Ar decay and $^{40}$Ar nuclear recoils have been produced using the DarkSide-20k geometry; the SiPMs planes have been segmented in tiles of 25 cm$^2$ each, separated by 2 mm wide gaps, resulting in a geometric efficiency of about 92.5%. The expected Photon Detection Efficiency of the tiles has been set to 40%. In order to obtain a more accurate simulation of the system response SiPMs noises are taken into account and injected in the data-flow: the dark count rate is set to 250 cps per tile uniformly distributed in time, while the correlated noises amount to 10% for the After-Pulse probability and 15% for the Direct Cross Talk; Delayed Cross Talk has been neglected due to the results described in the ?? section ( put the correct reference: )

. The readout simulation is performed on two parallel tracks: the first employs TDCs to produce "hits", the second one uses ADCs to sample the analogical waveforms in a temporal window, thus giving the charge. The ADC is set to have 12 bits; the Single Photo-Electron response is set to have on average an amplitude of 6 bits, leaving the other 6 free to have a dynamic range of 64 PE. Hits carry the arrival time information, performing well in the es-

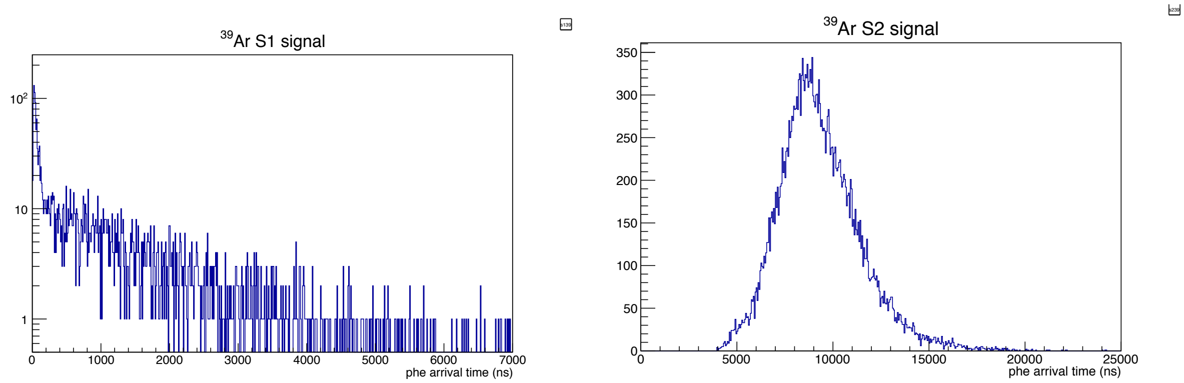


FIG. 1. S1 (left) and S2— (right) signals resulting from a Monte Carlo simulation of the DarkSide-20k photoelectronics and DAQ system.

timation of the S1 prompt fraction of light, while ADC sampled signals allow to better measure the S2 number of photons due to the high occupancy of the channels. Events in the simulation are uniformly distributed in the LAr volume, with the $^{3}$9 Ar energy spectrum for electron recoils and a power law spectrum for $^{40}$Ar nuclear recoils. The resulting S1 and S2 signals can be seen in Fig. 2. Typical hit maps are shown in Fig. 3 for both S1 and S2 signals. Using a fiducial cut of 5 cm from the top and bottom planes of the SiPMs in the TPC volume no saturation is observed for S1 and S2 signals.

In the energy region relevant for dark matter searches, the great majority of detector modules report at most 1 PE, hence energy can be reconstructed by just counting the number of detector modules above threshold in an appropriate time window, here set to 6 $\mu$s. As shown in Fig TOT the resulting distribution is quite narrow, thus resulting in a good resolution up to energies of few hundred of keV. Taking into account also the hit multiplicity per tiles results in a good linearity for S1 signal but in a slightly worse resolution. This effect is due to the SiPMs noise injected in the simulation, whose intrinsic nature spoils the hits counting keeping relatively unaffected the number of tiles above threshold. The resolution of both the S1 estimators is on average around $1.5 - 2\%$, with higher values in the very low energy region (around 4% between 0 and 60 keV).

For S2 is a different story: the signal sampling in a fixed time window may not integrate the whole charge of the pulses, whose duration can well exceed the microsecond. Moreover the baseline noise further degrades the resolution of the estimation, although this phenomenon has not been implemented yet. The S2distribution and the relative resolution are shown in Fig. 6.

### 1.3. Signal Digitization

In the following, two technical solutions implementing a time and energy measurement of the SiPMs hits are proposed. The first is our current baseline solution. It implements a TDC using a discriminator for each channel and a conveniently sized FPGA for timing and signal processing. Signals are also digitized at 12 bits and 100 MHz, and buffered. The FPGA would also serve, when triggered by a signal above threshold, to zero suppress and format data to be sent to a crate level logic and then to the event builder via fast ethernet. The FPGA can easily handle 32 channels per single board and achieve the O(10 ns) time resolution needed for DarkSide-20k. The second option may achieve similar goals using a recent ASIC developed at the Paris Omega institute (CATIROC). Detailed investigation on this solution and cost estimate are still on-going.

#### *1.3.1. FPGA based TDC+ADC boards*

In the baseline design each module accepts 32 channels with 15 modules per crate resulting in a total of 11 crates, see Fig. 7. There is 1 FPGA board in each module receiving the 32 differential signals from the tiles on 2 flats of 16channel twisted pair cable. The signals from the tilesare received in preamplifier-shapers which amplify, shape and split the signal. The preamplifier sends one signal component to a discriminator to obtain a time pickoff and the other to a 12 bit, discrete ADC. This information is buffered and entered in an FPGA.

As the trigger is based on integrating the S1 and S2 events over a 200 ns time window, the FPGA easily stores the number of digitized events in 10 ns bins using a 100 MHz clock as a coincidence timer. Hit data, including time correlated event number and

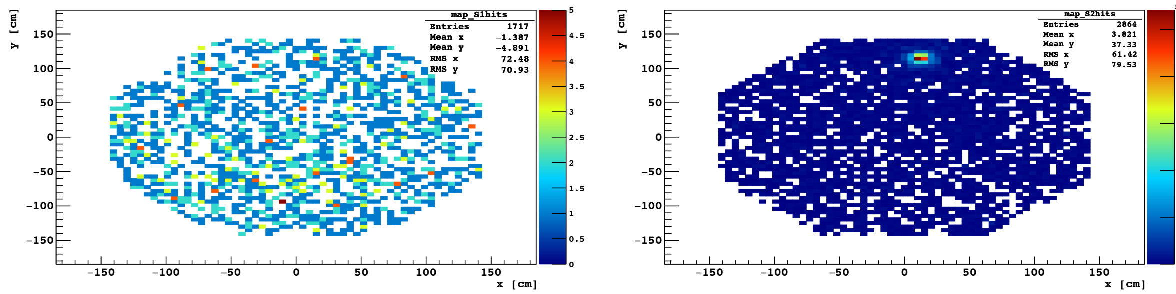


FIG. 2. Hit Maps for top and bottom plan for typical S1 (left) and S2 events (right)

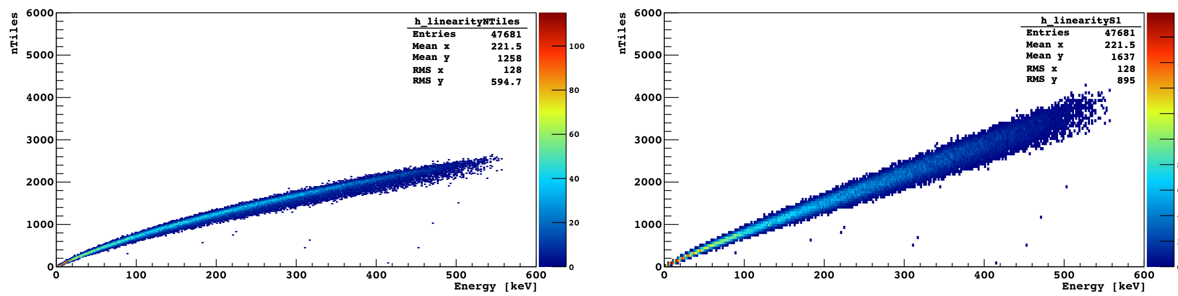


FIG. 3. S1 distribution of number of tiles above threshold (left panel) and number of hits (right panel) as a function of event energy.

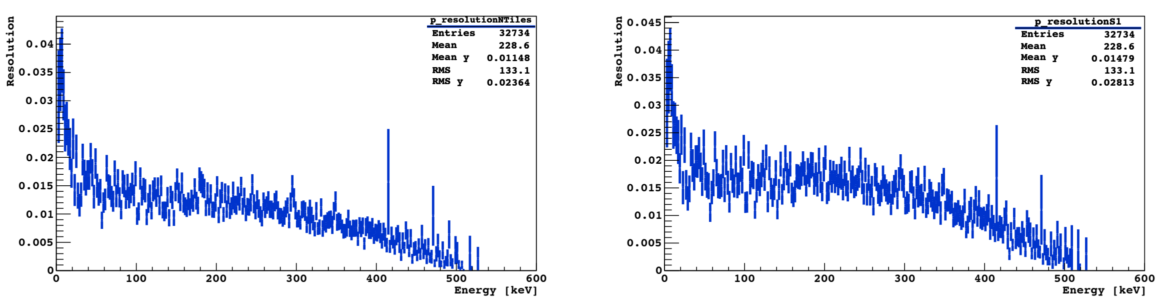


FIG. 4. S1 resolution obtained with tiles above threshold (left panel) and with number of hits (right panel) as a function of event energy.

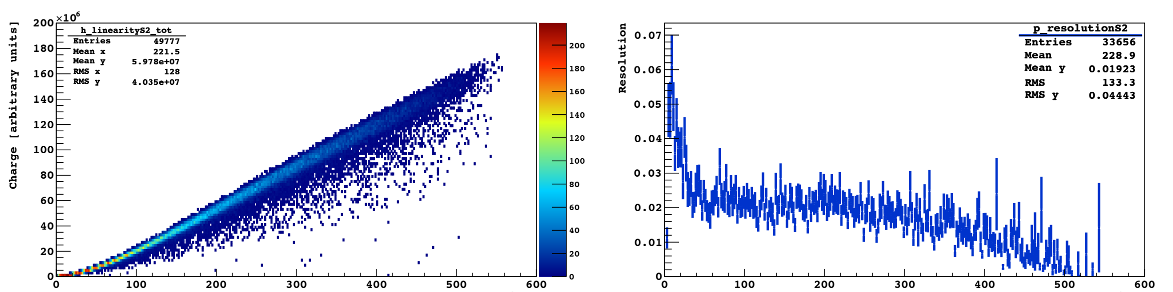


FIG. 5. Linearity of S2 (left panel) and resolution (right panel) as a function of event energy.

amplitude, is transmitted to the FPGA/microprocessor in the crate controller where it is stored in