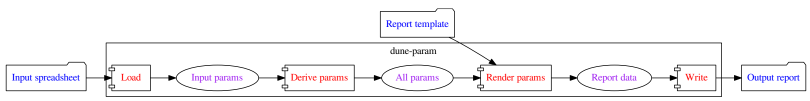
Annex 4B: Expected Data Rates for the DUNE Detectors

Annex to the LBNF/DUNE Conceptual Design Report



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1

Contents

1

List of Figures

1

List of Tables

1

Todo list

Chapter 1

Far Detector

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1.1 Overview

A number of parameters from DUNE/LBNF requirements, design documents, and studies are used as input for estimations of the data rates in DUNE. In cases when derived parameters need to be generated based on these inputs this is accomplished using the software package *dune-params*[1] developed specifically for this purpose. As the inputs and estimations are refined the results presented in this annex can be regenerated at will.

Because the triggering and readout strategy and algorithms of the DAQ and analyses are under development and far from their final state of readiness, the data rate estimations involve some broad assumptions and leave open some choices. This is described in more detail in the following subsections.

1.2 Thresholds for the LArTPC Data

There are three threshold levels considered for the purposes of characterizing the LArTPC data rates. These thresholds are assumed to be applied "per-wire" and on the basis of ADC values (which can be translated to units like MeV with proper calibration). Note that they are meant to reflect different energy scales of the physics phenomena being measured in the TPC and must be considered separately from thresholds and other parameters used in the DAQ for its internal real-time processing of the data (for example in the anticipated internal "trigger stream").

[1] `https://github.com/DUNE/dune-params`

In other words, each such threshold will translate into a corresponding rate of data coming out of DAQ. These are:

full-stream The full-stream (FS) threshold means there is no threshold at all. FS data is data where every time bin (as defined by the ADC clock) on every channel is read out.

zero-suppressed The zero-suppressed (ZS) threshold is applied at $\approx 3\sigma$ above the mean noise level of the front-end electronics. Given the existing requirement on signal/noise ratio and the wire spacing, this effectively places an energy threshold of 0.5 MeV.

high-energy The high-energy (HE) threshold is one that is placed high enough to largely suppress signals from radioactive decays but still low enough to not impact activity from beam neutrino interactions or proton decay (if it exists). Further studies are needed to determine this threshold but currently it is taken to be 10.0 MeV.

The design of the DAQ is expected to allow reading of the TPC data into the system memory at FS rates. It is also expected to be flexible enough to allow for different thresholds to be applied to the data while it is still resident in its buffers, based on real-time calculations.

1.3 Sources of Data in the TPC

Data is expected to be produced by a number of specific sources (cf. cosmic ray muons vs beam neutrinos). Each source will have a different rate depending on the threshold applied. In the following the corresponding data rates are estimated individually for each source and threshold. This provides a means to compare different assumptions, designs and strategies.

The sources of data being considered are:

in-spill Activity in the detector which is coincident with the passage of beam neutrinos through the detector.

cosmic-μ Activity due to the passing of cosmic-ray muons through the detector.

radioactivity Activity due to the decay of radioactive isotopes such as ^{39}Ar, U/Th and others.

atm-ν Activity which is not in-spill and which is consistent with interactions from atmospheric neutrinos.

1.4 Fundamental Parameters of the LArTPC

This section provides the fundamental parameters taken as input to the data rate estimations. The parameters are summarized in table 1.1

Table 1.1: The fundamental parameters serving as input to data rate estimations.

Full height	12.0 m
Full width	14.5 m
Full length	58.0 m
Detectors	4
channel/APA	2560
APA/detector	150
Active height (APA)	6.0 m
Active width (APA)	2.3 m
Drift distance	3.60 m
Drift velocity	1.6 mm μs^{-1}
Drift time	2.25 ms
bytes/sample	1.5 B
sample rate	2.0 MHz
# drifts/readout	2.4
readout time	5.4 ms
samples/readout	10,800

These aren't all.

1.5 Full-stream Data

Full-stream (FS) data corresponds to reading all data in every ADC channel without application of any threshold. Estimating its rate is an exact calculation based on known parameters as it does not depend on the activity in the detector or the noise level of the electronics. As its name implies, it is the most voluminous type of data that can be generated by the TPC. The parameters which apply to this data are given in table 1.2.

The expected data rates for two scenarios of FS data are given in table 1.3. The first row gives the data size of one DAQ readout (5.4 ms). The second is appropriate for any strategy that intends to record FS data for each beam spill. The third contains two numbers that characterize data volume relevant to a strategy which

Table 1.2: Parameters pertaining to full-stream data rates.

Bytes per sample	1.5 B
DAQ sample rate	2.0 MHz
Channels per APA	2560
Number of APA per detector	150
Number of detectors	4
Total channels in DUNE	1,536,000
Drifts per readout	2.4
Drift time	2.25 ms
Beam spill repetition rate	0.83 Hz
Annual run time fraction	0.667

eam-parameters

aims to record FS data for Supernova Burst candidates. The final row shows the total annual data volume that the DUNE DAQ is capable of producing (in theory).

Table 1.3: Data volumes and rates for full-stream data acquisition.

Full-stream readout size	24.9 GB
Full-stream in-spill data rate	436 PB year^{-1}
Full-stream 1 second data volume	4.6 TB
Full-stream 1 minute data volume	276.5 TB
Full-stream 1 year data volume	145.4 EB

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1.6 Zero-suppressed Data

There are options in choosing the exact zero-suppression (ZS) procedure, and the final choice has not been made. For these data rate estimates a very simple procedure is assumed: in each channel all digitized time bins in which the ADC values are below the given threshold are removed. Timing information for the above-threshold bins can be included without adding much to the data volume.

The ZS threshold is taken as the ADC equivalent to a 0.5 MeV energy deposition near the CPA and localized in such a way that it passes near one induction wire and is collected on one collection wire. Given the requirement that the minimum signal to noise ratio is 15 this ZS threshold represents at least 3σ noise exclusion. For the purpose of this estimate it is assumed that all noise is removed. The threshold is low enough that most pertinent activity in the detector volume still be observed in ZS data.

Table 1.4: Parameters pertaining to zero-suppressed data.

Zero-suppression threshold	0.5 MeV
Minimum signal/noise	15
Maximum signal/noise	74

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By construction, the ZS is assumed to remove electronics noise, hence the ZS data rate depends simply on the size of the class of the particular event and the rate at which it is expected to occur. This information is summarized in table 1.5. tab:zs-volume

Table 1.5: Data rate estimations for ZS data from various sources. An additional FS data estimation is given for supernova burst (SNB).

source	event rate	event size	data rate	annual data volume
^{39}Ar	37.8 MHz	36 B	1.4 GB s^{-1}	43 PB
cosmic-μ	0.259 Hz	50.0 kB	12.9 kB s^{-1}	409 GB
beam-ν	8770 year^{-1}	10.0 MB	2.78 kB s^{-1}	88 GB
SNB cand. (ZS)	12 year^{-1}	13.6 GB	5175 B s^{-1}	163 GB
SNB cand. (FS)	12 year^{-1}	46.1 TB	17.5 MB s^{-1}	553 TB

tab:zs-volume

The beam rate is averaged over one full year assuming run fraction of 0.667, a rep rate of 0.83 Hz and a beam spill occupancy of 0.0005.

The Supernova Burst (SNB) data is estimated assuming a false-positive SNB rate of 12 year^{-1} and a readout time of 10.0 s. It should be emphasized that both these parameters are subject to modification and are used simply to provide benchmark examples. It is assumed that the bulk of the data in such candidate events will be due to signals produced by ^{39}Ar decays. This is due to the following factors. Actual SNB events will have neutrino energies in tens of MeV and up to 100 MeV. Roughly speaking, 1000 events across DUNE are expected from a real SNB with the neutrino front lasting some 10 s. This corresponds to less than a single neatrino interaction per APA readout on average, with the rest of the readout time filled with signals from radiological background.

In terms of comparison with the beam neutrino data, due to difference in energy scale each SNB neutrino is expected to contribute only about 10% of the data of the GeV-scale beam events or about 1 MB. For the entire SNB this would then add about 1 GB to the event and thus does not greatly impact the estimate.

The SNB event size is what must be acquired promptly through that readout time and the data rate is averaged over the year. The annual data volume is what would be saved to disk if all false positive events are kept. The table also includes the an estimation assuming full-stream data is kept for the SNB candidates.

1.7 High-energy Threshold

For the purpose of these estimates the high-energy (HE) threshold is chosen at the level above the energy scale of the radiological backgrounds relevant for the LArTPC, and set at 10.0 MeV. A more careful study is needed to determine a potentially more optimal value for this threshold. The data rates with the HE threshold applied are summarized in table 1.6.

Table 1.6: Data rate estimations for data from activity above the high-energy (HE) threshold from various sources.

source	event rate	event size	data rate	annual data volume
^{39}Ar	-	-	-	-
cosmic-μ	0.259 Hz	50.0 kB	12.9 kB s^{-1}	409 GB
beam-ν	8770 year^{-1}	10.0 MB	2.78 kB s^{-1}	88 GB
SNB cand.	-	-	-	-

With the HE threshold in place, activity from the ^{39}Ar events and any SNB candidates will not be visible (i.e. will be rejected in DAQ). Although actual SNB events may result in neutrino with energies as high as 100 MeV applying such a high threshold to SNB candidates won't be optimal and is not being considered at this point. For this reason, contribution from SNB to these data is not calculated for this threshold setting.