ProMC: Input-output data format for HEP applications using varint encoding

S.V. Chekanov^{a,*}, E. May^a, K. Strand^b, P. Van Gemmeren^a

^aHEP Division, Argonne National Laboratory, 9700 S.Cass Avenue, Argonne, IL 60439 USA

^b Department of Physics, Winona State University, 175 West Mark St., Winona, MN 55987,

USA

Abstract

A new data format for Monte Carlo (MC) events, or any structural data, including experimental data, is discussed. The format is designed to store data in a compact binary form using variable-size integer encoding as implemented in the Google's Protocol Buffers package. This approach is implemented in the PROMC library which produces smaller file sizes for MC records compared to the existing input-output libraries used in high-energy physics (HEP). Other important features of the proposed format are a separation of abstract data layouts from concrete programming implementations, self-description and random access. Data stored in PROMC files can be written, read and manipulated in a number of programming languages, such C++, JAVA, FORTRAN and PYTHON.

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1. Introduction

A crucial requirement for many scientific applications is to store, retrieve and process large-scale numeric data with a small signal and large background (or "noise"). Information on background objects is not required to be stored with the same relative numeric precision as that for signal objects. An input/output library which dynamically streams data depending on the content of information becomes important for effective data storage and analysis.

A typical example is the Large Hadron Collider (LHC) experiments designed to investigate proton-proton and heavy-ion collisions in order to understand the basic structure of matter. The LHC experiments are currently involved in event processing and physics analysis of petabytes of data. A single analysis requires a processing of tens of terabytes of data located on the grid storage across the globe. The number of collisions recorded by the ATLAS experiment since 2009 exceeds

^{*}Corresponding author

Email address: chekanov@anl.gov (S.V. Chekanov)

20 billion. The number of particles in a single collision will increase by a factor 5-10 for future high-luminosity LHC runs. Currently, the LHC experiments store more than 100 petabytes of data and this number will increase by a factor 10 over the next 10 years. Most stored data has a small fraction of "signal" particles, while most of low-energetic particles from other events are less interesting and represent "pileup" background. It is important to store pileup particles to derive corrections, but to store such particles with the same numeric precision as signal particles is not justified and inefficient.

This paper discusses an input-output library which has a content-dependent compression of data for files. It stores less energetic particles with reduced relative numeric precision and smaller numbers of bytes compared to to high-energetic particles. The library is designed for Monte Carlo (MC) simulation events, but it can naturally be extended to store any information. The library was created during the Snowmass Community Studies [1] with the goal to store MC simulations in a compact form on public web pages.

2. The proposal

This paper discusses an input/output persistent framework which:

- streams data into a binary form and dynamically writes less interesting, low-energetic particles with a reduced numeric precision compared to more energetic "signal" particles. For example, it is expected that such contentdependent compression may decrease the LHC data volume by 30% or more [2]. Although we use the word "compression", it should be noted that no standard compression algorithms (gzip, zip, bunzip2) are used since the file-size reduction is achieved using a highly efficient binary format.
- is multiplatform. Data records can be manipulated in C++, JAVA and PYTHON. This opens the possibility to use a number of "opportunistic" platforms for data analysis, such as Windows or Android, which have not been used widely in HEP.
- is a self-describing data format based on a template approach to encode complex data structures. One can generate C++, JAVA and PYTHON analysis codes from the file itself.
- has random access capabilities. Events can be read starting at any index. Individual events can be accessed via the network without downloading the entire files. Metadata information can be encoded for each record, allowing for a fast access to interesting events.
- is implemented as a simple, self-containing library which can easily be deployed on a number of architectures including supercomputers, such as IBM Blue Gene/Q system.

The proposed input-output framework is expected to be used in many scientific areas. In particular, it is useful for (a) data reduction for large generalpurpose detectors at colliders and other experiments; (b) effective data preservation due to small file sizes, backward compatibility and self-descriptive property; (c) effective data analysis without CPU overhead due to the standard decompression algorithms.

3. Existing approaches

The LHC experiments store data and experiment-specific MC events in compressed ROOT format [3]. To store events generated by MC models in a more generic and exchangeable way, HEPMC [4], STDHEP [5], HepML [6] and the Les Houches event format (LHEF) [7] file formats have been developed. For example, the HEPMC library is interfaced with all major Monte Carlo models and is widely used by the HEP community due to its simplicity, platform independence, exchangeability and reusability. However, the HEPMC format stores data in uncompressed ASCII files, which are typically ten times larger than ROOT files with the default compression.

The ROOT IO is an integrated part of the C++ ROOT analysis framework [3] developed at CERN. This framework is heavily integrated in the Linux platform. It uses the "gzip" compression which is a CPU intensive and lacks flexibility for storing particles depending on their importance. As discussed before, the current and future LHC experiments will collect events with only a small fraction of signal particles that are important for analyzers, while most of low-energetic particles from other (overlayed) events represent "pileup" background. For high-luminosity LHC runs, one "signal" event (for example, event with a Higgs particle) will contain 50-140 pileup events, with up to 10,000 low-energy particles that are not important for analysis of signal signatures. Still, such particles (or a fraction of such particles) should be kept to derive corrections to signals. Therefore, to store low-energetic particles with a smaller numeric precision becomes crucial in effective data storage and analysis. The fixed-number of bytes to represent numeric data used by ROOT and by other data formats does not allow implementation of a compression that depends on particle properties (particle energy, mass, origin, etc.).

4. Varint data encoding

A possible solution for data reduction is to use "varints" [8] which can encode integer (int32, int64, etc.) values using variable number of bytes¹. Such algorithm is implemented in the Google's Protocol Buffers library [8]. This library

 $^{^{1}}$ In the case of 4-momentum, one can convert a float variable to varint using a predefined conversion factor

encodes complex data in the form of platform-neutral "messages". A message is a logical record of information containing a series of name-value pairs. Smaller integer numbers represented by varints in such messages use a smaller number of bytes compared to large numbers. For HEP applications, this implies that four-momenta of low-energetic particles encoded using the integer values can be represented with a smaller number of bytes. In addition, many particle characteristics (such as particle status, particle ID, etc.) should be represented by integer values anyway and this is well suited to the varint representation.

Historically, the approach to store HEP data using Google's Protocol Buffers was first attempted in the JHEPWORK² data-analysis framework [10] in 2008, which offered the CBOOK C++ package to keep Monte Carlo records and other structural data using varints. Later, the PROTOCOL BUFFERS library became the core of another HEP library, the so-called A4 project [11], that had the goal of providing fast I/O for structured data.

Although the varint data encoding is available in the PROTOCOL BUFFERS library publicly released by Google, this library alone is not sufficient to pursuit the goal of creating large files with multiple logically-separated records. The Protocol Buffers approach is most effective if each separate Protocol Buffers message has a size of less than 1 MB (as recommended by Google). The major problems that need to be addressed are: 1) to design Protocol Buffers message to store particles in a single event to allow for the varint representation; 2) to find a method of serialization of multiple messages ("events") into a file which can keep many events; 3) how to implement metadata model for fast access of interesting events and particles. While (1) is rather specific to HEP, (2) and (3) are very general issues that have to be solved in any research area where logically-separated event records with varint-based information is an attractive option for data storage and processing. Because of such problems, the usage of Google's Protocol Buffers to keep large numeric data is still limited in science and technology.

5. Current implementation

The following sections will discuss the current implementation of the library, called PROMC, which implements all the features discussed above. In the following, we will use small-caps typeface fonts to indicate the PROMC library implemented in C++, while files generated using this library, "ProMC" files, will be shown using the normal fonts. A similar convention is applied for other library names, such as the PROTOCOL BUFFERS library that is used to write and read Protocol Buffers messages.

The PROMC C++ library [2] is designed to store HEP collision events using the Google's PROTOCOL BUFFERS library as a backend. The data are stored in a file with the file headers and multiple logically-separated messages. Each separate

²JHEPWORK was renamed to SCAVIS [9] in 2013.

message leverages the varint encoding for representing a single MC event. Figure 1 shows a schematic representation of a ProMC file. All Protocol Buffers messages are stored as ZIP entries inside the ProMC file using the ZIPIOS++ package [12] for reading and writing ZIP files through the standard C++ iostreams. The ZIP method for archiving supports lossless data compression, as implemented in the ZLIB library [13]. However, this library is only used to organize binary Protocol Buffers's messages (which do not require compression) in the ProMC files. In this sense, ZIP is a method of archiving binary records, rather than the actual method of compressing event records. The ZIP compression, however, is used for some metafile records, such as text templates describing file layouts and logfiles which can be embedded inside the ProMC files.

The PROTOCOL BUFFERS library (version 2.5) is included in the PROMC package to avoid clashes with the already installed PROTOCOL BUFFERS library (which can be version 2.42 for many Linux distributions), to provide better self-containment and to simplify the deployment of examples and conversion tools which use a predefined location of the PROTOCOL BUFFERS library. However, PROMC can also be installed using the existing PROTOCOL BUFFERS library, as described in the ProMC web page [2]. In this form, all ProMC Makefiles of the conversion tools should be redesigned.

To work with the ProMC files, the PROMC C++ library does not need to be installed. This C++ library has to be installed if events will be written or read in C++. ProMC files can also be read and created using JAVA or PYTHON, without the platform-dependent PROMC library.

The current PROMC library is built on the assumption that the new data format should be self-describing and can generate analysis source codes (in C++, JAVA, PYTHON) from a ProMC file itself without knowing how it was originally created. Additional notable features of PROMC are random access to any given event and a possibility to stream individual events through the network without reading or downloading entire files.

Several benchmarks have shown that ProMC files are rather compact, typically 40% smaller than ROOT files assuming Double32_t types for float values and the default ROOT compression. Table 1 shows the file sizes for 10,000 $t\bar{t}$ events generated with PYTHIA 8 [14] for a pp collider at 14 TeV. The ProMC files are 38% smaller than files with the same information using ROOT, and significantly smaller than LHEF [7] and HEPMC (production release: 2.03.11) [4] files, including those with the compression based on the gzip, bzip2 and lzma algorithms. In case of events with large pileup (i.e. a large fraction of soft particles), ProMC files can lead to almost a factor two smaller files compared to ROOT files with the same information stored using Double32_t data types.

The same table shows benchmark tests for the read speed. For these tests, the files were opened, and all entries with 4-momenta of particles were extracted, but no calculations are performed. The read speed of the ProMC files is 30% faster than for the ROOT files based on the default gzip compression, and is substan-

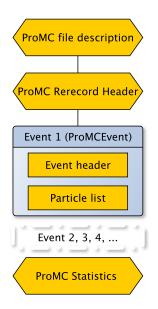


Figure 1: A schematic representation of the ProMC file format. All records are encoded using the Protocol Buffers messages. In addition, some metadata information is stored as text files inside the ZIP file for easy access on platforms without the installed PROMC library.

tially faster compared to the other formats. It can be seen that this difference in the read speed is roughly proportional to file sizes. Files in the LHEF and HEPMC formats after compression were not tested, given that such, technically challenging tests, can hardly show much improvement in the read speed since a typical time for file decompression is 1-2 min. No significant difference in the file creation speed was detected (this test was dominated by event generation).

In addition to the C++ compiled programs, benchmark tests were also performed using programs implemented in JAVA and JYTHON (the PYTHON language implemented in JAVA) using the SCAVIS [9, 10] framework. The JAVA Virtual Machine (JVM) processes the ProMC files faster than the programs implemented in C++. This indicates that JVM creates a more optimized binary code to deliver a better performance. In the case of LHEF ASCII files and JVM, the benchmark program parses all lines and tokenizes the strings, without attempting to build complete particle record, therefore, such test may not be accurate when comparing with the ROOT and ProMC approaches.

Benchmarks tests using PYTHON implemented in C have also been performed. The read speed of ROOT files (67 sec) was found to be substantially faster than for the ProMC files (980 sec). This was explained by the fact that the PYTHON benchmark program for the ProMC file tests was implemented in pure PYTHON and does not use a C++ binding (unlike PyROOT that uses C++libraries). In order to perform a fair comparison for the PYTHON benchmark programs, a C++ backend for the PROTOCOL BUFFERS should be enabled. This has not been implemented yet for the PROMC library.

The ProMC file size depends on many factors, but there are three major factors that should be mentioned: 1) energy distributions of stored particles; 2) what information is stored; 3) how the information is represented using integer values and a typical range of integer values. In the first case, events with large fraction of low-energy ("soft") particles will use smaller file size than those that contain particles with large values of 4-momenta of particles. The file size depends on a conversion factor which converts float values to integer representation.

The default ProMC mapping between the energy units used in HEP and integer values is given in Table 2 for a typical pp collision experiment at centreof-mass (CM) energies up to 20 TeV. This mapping between integer type in C++/JAVA and the varint type was obtained by multiplying energies, masses and 4-momentum components expressed in GeV by the factor 10⁵, and rounding the resulting value to nearest integer. For a collider at $\sqrt{s} = 100$ TeV, this mapping can fail for storing particles (jets) with energies above 21 TeV, therefore, a multiplication factor should be reduced to 10⁴ in order to be store possible particles or jets close to this CM energy range. On the other hand, the conversion factor can be increased for low-energy experiments. To avoid overflows for large energies, the primary rule to remember when using the multiplicative conversion factor is that \sqrt{s} times the multiplicative factor should not be larger than $2^{31} - 1$ assuming integer data type is in the 32-bit representation. Another consideration is the required relative numeric precision, since large numbers may lead to less effective storage for varints.

Table 3 shows the default mapping between energy (or masses,4-momentum etc.) values and the 32-bit integer representation using the variat encoding. The last column shows the rounding errors which should be noted when restoring the data. This table corresponds to the default conversion factor 10^5 as discussed above and which is suitable for the current LHC experiments. Table 4 shows a suggested conversion and relative rounding errors using the conversion factor 10^4 for post-LHC era colliders.

The varint conversion factor for float values is included in the metadata section of the ProMC file format. It should be restored while processing ProMC files. This approach provides a certain flexibility: For example, instead of using a single constant conversion factor that leads to relative numerical precision that changes with the stored energy, one can use an energy-dependent conversion factor that leads to roughly constant, energy-independent, relative rounding error. It should also be pointed out that the PROMC library can store particle's 4-momenta using float or double precision types, while keeping varints only for information that requires integer values. In this case, the ProMC data-size reduction will be less effective.

Another factor that determines data reduction depends on the fraction of information which can be represented using integer types, such as int32 and int64. For a typical MC truth event record, several particle characteristics can be

written using varints without loosing numeric precision. Such examples include particle ID, status code, 1st and 2th daughter and mother particles. In many cases, their values are small and thus can be represented by only a few bytes using int32.

The current approach to the data reduction by particle experiments is often based on removing particles (or tracks, calorimeter cells, etc.) below some transverse-momentum cut, which is typically 0.2-0.5 GeV for the LHC experiments. Such rejection of the information on final-state particle collisions may not be required for the ProMC files that use a smaller number of bytes to store low-energetic particles.

5.1. Working with ProMC files

The PROMC package can be downloaded from the HepForge web page [2]. The only required external library is ZLIB [13] which is used to organize individual binary messages with separate MC events as discussed in Sect. 5.

After installation as discussed in the online manual, an environmental variable "PROMC" pointing to the installation directory should be defined. The installed package contains the directory "\$PROMC/examples" with a number of examples, converters from other formats, as well as with several tools to work with the ProMC files.

Table 5 lists the tools included in the PROMC package to work with ProMC files. These programs are implemented in PYTHON and stored in the directory "\$PROMC/bin".

As discussed before, the ProMC files are simple ZIP archives, thus they can be unzipped to view the file structure. This can be observed without unpacking individual records as "unzip -1 <ProMC file>". A proper unpacking the ProMC file can be done with the same command but without the option "-l". Each file represents an event record written as the binary file that can be read using the PROTOCOL BUFFERS library.

The ZIP program can also be used to extract any given event. For example, extracting an event 100 and saving it to a file "100.event" will require to run:

```
unzip -p <ProMC file> 100 > 100.event
unzip -p <ProMC file> ProMC.proto > ProMC.proto
```

The last example creates a text file that describes the Protocol Buffers platformneutral layout of the event. Similarly, one can look at the attached logfile and print the number of stored events as:

```
unzip -p <ProMC file> logfile.txt
unzip -p <ProMC file> promc_nevent
```

In these examples, we send the contents of the files "logfile.txt" and "promc_nevent" via pipe into a Linux shell console.

Table 6 lists the converters from/to ProMC format included with the PROMC package. These programs are located in the directory "\$PROMC/examples" and should be compiled for final deployment.

The ProMC files can also be written from FORTRAN programs using an external package called FortranProMC. This package should be downloaded and compiled separately, as long as the original PROMC package is installed. The FortranProMC includes an example that shows how to fill ProMC files using the PYTHIA6 [15] generator. This example can be used to create ProMC files using any FORTRAN-based generator.

5.2. Reading ProMC files

Since ProMC files are self-describing, one can generate analysis codes in C++, JAVA, PYTHON from the available file, even without knowing how data are organized inside the file. For this example, the C++ PROMC library should be installed.

promc_info	<name>.promc</name>	#	check information
promc_proto	<name>.promc</name>	#	extracts Protocol Buffers files
promc_code		#	create analysis code in C++, JAVA, PYTHON
make		#	compiles the C++ code

This example shows how to access the information about the existing file using the command promc_info. Next, the command promc_proto extracts the platform neutral description of data layout in the Protocol Buffers format. Such description files will be located in the directory "proto" and can be used to generate analysis code for reading or writing ProMC files. Finally, the command promc_code generates the analysis codes in C++, PYTHON and JAVA. Such files will be located in the corresponding directories where this command is executed. The execution of the "make" compiles the C++ analysis code.

5.3. ProMC browser

ProMC files can be accessed without any external C++ library using a browser implemented in JAVA. The browser, together with the complete source code, is included in the directory "examples/browser" of the PROMC package which can be downloaded separately from the ProMC web page [2].

Figure 2 shows the browser window with particle records for a specific event. The browser also displays general information about the ProMC file as well as the metadata file included in the ProMC header. The browser can be accessed by either of the following commands:

```
java -jar browser_promc.jar <name>.promc (or)
promc_browser <name>.promc
```

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5	Eventinfo	18		p^+	2212	4	0	0	59	0	0	0	.,		0.938	0	0	0	0
6	Particles			p^+	2212	4	0	0	60	0	0		-7,000			0	0	0	0
1	Tarcicies	1	3	-	3	21	6	6 0	5	0	0		60.348			0	0	0	0
8		1.5		s~ Z^0	-3 23	21	3	4	5	0	0		-36 23.369			0	0	0	0
9		100	6		23	42	59	59	3	3	0		60.348			0	0	0	0
10		100	7		21	41	60	60	9	4	0	0		95.457	0	0	0	0	0
11		100		Z^0	23	44	5	5	61	61	1.63	-3.12		97.357	-	0	0	0	0
12		100	9		3	43	7	0	62	62	-1.63		-58.34		0.5	0	0	0	0
13			10	-	21	31	14	14	12	13	0	0		5.456		0	0	0	0
14		10	11	q	21	31	15	0	12	13	0	0	-4.186	4.186	0	0	0	0	0
15			12	g	21	33	10	11	16	16	-2.846	-1.939	-2.708	4.381	0	0	0	0	0
16		10	13	g	21	33	10	11	17	17	2.846	1.939	3.978	5.261	0	0	0	0	0
17			14		21	42	22	0	10	10	0		5.456		0	0	0	0	0
18			15	d~	-1	41	23	23	18	11	0	0	-9.663	9.663	0	0	0	0	0
19		100	16		21	44	12	12	21						-	0	0	0	0
20		100	17	9	21	44	13	13	25	25	2.725		3.79	5.122	0	0	0	0	0
21		100	18		-1	43	15	0	19	20			-5.227		0.33	0	0	0	0
22		100	19		-1	51	18	0	26				-4.597		0.33	0	0	0	0
23	-		20	g	21	51	18	0	27	27	0.489	0.678	-1.485	1.704	0	0	0	0	0 💌
ProM	C version=2	Tot	tal event	s=1000	Event	=5													7/57Mb

Figure 2: A JAVA browser for ProMC files with events from a MC generator. The upper field is a search for a given particle name.

where <name>.promc is a ProMC file with the extension .promc.

A ProMC file can also be accessed via URL links without the need to download the file on the hard drive. This can be done by revising the above commands to the following:

java -jar browser_promc.jar <file URL> (or) promc_browser <file_URL>

The above example can be used to view event records from leading-order parton-shower MC simulations. Next-to-leading order event generators typically have a few particles from hard interactions, but the event records contain additional information on event weights. In this case, one should use the following syntax:

```
java -cp browser_promc.jar probrowser.NLO <file URL> (or)
promc_browser_nlo <name>.promc
```

Unlike leading-order parton-shower Monte Carlo models, this brings up a window which can be used to view an array of weights representing uncertainties on predictions. More information about how to store events in the ProMC files from NLO event generators is given in Ref. [16].

The ProMC browser can also display information on separate events, platformindependent data layout files and logfiles (if such files are embedded into the ProMC file structure).

6. ProMC usage and documentation

The PROMC library was used for the Snowmass 2013 community studies in order to store truth and DELPHES [17, 18] MC events in a compact binary form on the web servers for HEP community The DELPHES version 3.10 fast simulation [18] can read the ProMC files with the truth records and convert such files to reconstructed events. Due to its compactness and fast read speed, PROMC is used for the HEPSIM repository [16] with data from theoretical computations. This file repository includes MC events from leading-order parton-shower generators as well as weighted events from next-to-leading order QCD calculations.

Since PROMC is implemented as a simple, self-containing library, it was deployed on a number of platforms including high-performance computers, such as IBM BlueGene/Q, located at the Argonne Leadership Computing Facility, the description of which is beyond the scope of this paper. The PROMC library is installed on CERN AFS and, at this moment, under tests within the ATLAS collaboration.

A number of examples illustrating how to read and write the ProMC files is given on the PROMC web page [2]. The web page includes several examples of how to read, write and manipulate with ProMC files using several programming languages: C++, JAVA and PYTHON. Some basic information on stored data can also be extracted using PHP and other languages that can use the PROTOCOL BUFFERS library.

For C++ and PYTHON examples of reading and writing data, ROOT/PyROOT can be used for graphical visualization. There are also examples which illustrate how to read data using JYTHON, the PYTHON language implemented in JAVA. In this case, no platform specific libraries are used to read and display the data. In case of JAVA or JYTHON, SCAVIS [9, 10] and JAS [19] JAVA-based analysis environments can be used for visual representation of data (histograms, scatter plots etc.). There is also an example which shows the random access capability of the ProMC format and how to access certain events from a network without reading the entire ProMC file. In addition, a few examples are given which illustrate how to fill ProMC files directly from the PYTHIA 8 [14] MC generator or from HEPMC files.

6.1. Current limitations

The current prototype version of the PROMC library is 1.3. The file-size limitation of this version for both the ProMC 1.3 files and Protocol Buffers messages is given by the ZLIB archive library, which is $2^{32} - 1$ bytes (or 4 GB minus 1 byte). In order to handle larger files, other libraries supporting ZIP archives should be implemented. It should be pointed out that the 4 GB restriction does not limit the usage of the current PROMC prototype library for production: The information stored in a 4 GB ProMC file is equivalent to that stored in a 32 GB of uncompressed LHEF, and such large LHEF files are unpractical for real usage.

Generally, there is no limit on the number of files stored in the ProMC files. The ProMC files can hold any number of events that can be read by PYTHON or JAVA. However, it was observed that the ZIPIOS++ [12] package used for the standard C++ iostreams has a limit of 65520 entries. This limitation is a consequence of the chosen ZIPIOS++ library to read ProMC entries in C++ programs, rather than a principle limitation of the PROMC format. This problem will be corrected in future.

7. Conclusion

The PROMC C++ library [2] is available for download and testing. The current version of this library is 1.31. Although it is an early-stage prototype, the PROMC library has already been used in a number of projects as discussed in this paper. ProMC has a potential to be an important file format for current and future experiments since it leads to small file sizes which are suitable for effective data storage, has fast data access, and supports multiple programming languages.

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Tables

File format	File size (in MB)	Re	seconds)	
		C++	JAVA VM	JYTHON
ProMC	307	15.8	11.7,12.1*	$33.3, 34.6^*$
ROOT	423	20.4	—	—
LHEF	2472	84.7	$9.0, 9.6^*$	—
HEPMC	2740	175.1	_	_
LHEF $(gzip)$	712	_	_	_
HEPMC(gzip)	1021	_	_	_
LHEF $(bzip2)$	552	_	_	_
HEPMC(bzip2)	837	_	—	—
LHEF (lzma)	513	_	_	_
$\operatorname{HEPMC}(\operatorname{lzma})$	802	—	—	—

Table 1: Typical file sizes for 10,000 $t\bar{t}$ events generated for a pp colliders at $\sqrt{s} = 14$ TeV. The table also shows the read speed using a C++, JAVA and JYTHON (the Python language implemented in JAVA and running inside the JVM). The ROOT uses Double32_t for float values and the default compression. For all tests, the memory cache on Linux was cleared to avoid the data caching. The programs were tested on Intel(R) Xeon(R) CPU X5660 @ 2.80GHz. In case of C++, the benchmark program reads complete particle records using the appropriate ROOT or PROMC file libraries. The numbers indicated with asterisks give the read speed for tests that take into accoung the intialization of the JVM before file processing. In the case of LHEF file format and JAVA benchmark, the program parses all lines and tokenizes the strings, without attempting to build MC particle records, therefore, this test may not be accurate. The read speed for the test programs implemented in PYTHON (written in C) is discussed in the text.

Energy	integer representation	Nr of bytes
$0.01 { m MeV}$	1	1
$0.1 {\rm ~MeV}$	10	1
$1 { m MeV}$	100	2
$1 { m GeV}$	100 000	4
$1 { m TeV}$	$100 \ 000 \ 000$	8
$20 { m TeV}$	2000 000 000	8

Table 2: The default ProMC mapping between energy units and C++/JAVA integer representation when using the int64 variet type of the PROTOCOL BUFFERS library, together with the number of bytes used for the encoding.

Energy (Gev)	int representation	Rounding error (in $\%$)
0.0001	10	10
0.001	100	1
0.01	1,000	0.1
0.1	10,000	0.01
1	100,000	0.001
10	1,000,000	0.0001
100	10,000,000	0.00001
1,000	100,000,000	0.000001
10,000	1,000,000,000	0.0000001
21,474	$2,\!147,\!483,\!647$	0.00000005

Table 3: The mapping between energy values (in GeV) and C++/JAVA integer representation using the int64 varint type of the PROTOCOL BUFFERS library and the multiplicative factor 10^5 in the default ProMC varint conversion. The last column shows the relative rounding errors for the varint conversion.

Energy (Gev)	int representation	Rounding error (in $\%$)
0.001	10	10
0.01	100	1
0.1	1,000	0.1
1	10,000	0.01
10	100,000	0.001
100	1,000,000	0.0001
1,000	10,000,000	0.00001
10,000	100,000,000	0.000001
100,000	1,000,000,000	0.0000001
214,744	$2,\!147,\!483,\!647$	0.00000005

Table 4: Suggested mapping between energy values (in GeV) and C++/JAVA integer representation using the int64 varint type of the PROTOCOL BUFFERS library and the multiplicative factor 10^4 for colliders with the center-of-mass energies above $\sqrt{s} = 20$ but below $\sqrt{s} = 200-400$ TeV. The last column lists the relative rounding errors for the varint conversion.

Pro	MC Tools
promc_browser <file></file>	a JAVA browser to open ProMC files in order to study data layout of data, as well as the stored data. Currently, the latter feature supports only truth MC records. Files can be streamed using the network.
promc_browser_nlo <file></file>	a similar browser to open ProMC files with NLO predictions.
promc_code	Generates analysis code in C++ JAVA, and PYTHON.
promc_dump <file></file>	Prints event numbers, file description statistics, and meta data to screen.
<pre>promc_extract <file> <out> N</out></file></pre>	Extracts a desired number (N) of sequential events and saves them to an other file.
promc_info <file></file>	Displays the information of the ProMC file.
<pre>promc_log <file></file></pre>	Extracts a log file (if attached).
promc_proto <file></file>	Extracts the file layouts in the form of Protocol Buffers data templates.
promc_split <file> N</file>	Splits a ProMC file into desired number (N) of smaller files ^{<i>a</i>}

Table 5: A list of tools and commands available in the PROMC package. The tools are can be called from any file path upon set up of PROMC.

^{*a*}To be compiled separately since depends on the actual data structure.

	ProMC conversion tools
hepmc2promc	Converts a HEPMC 2.03.11 file [4] to the PROMC file
	format.
promc2hepmc	Converts a PROMC file to a HEPMC 2.03.11 file [4].
promc2root	Converts stores a PROMC file in a ROOT tree [3].
stdhep2promc	converts a STDHEP file [5] to the PROMC file.

Table 6: A list of converters from/to different file formats supported by the PROMC library. The tools should are located in the directory "examples" of the PROMC packages and should be compiled.