HEPMC Standards and the Path Forward

http://hepmc.web.cern.ch/hepmc/

hepmc-dev@cern.ch

Andrii Verbytskyi[a], for the HepMC authors [1]

[a] Max-Planck-Institut für Physik (Werner-Heisenberg-Institut)

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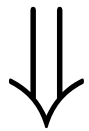
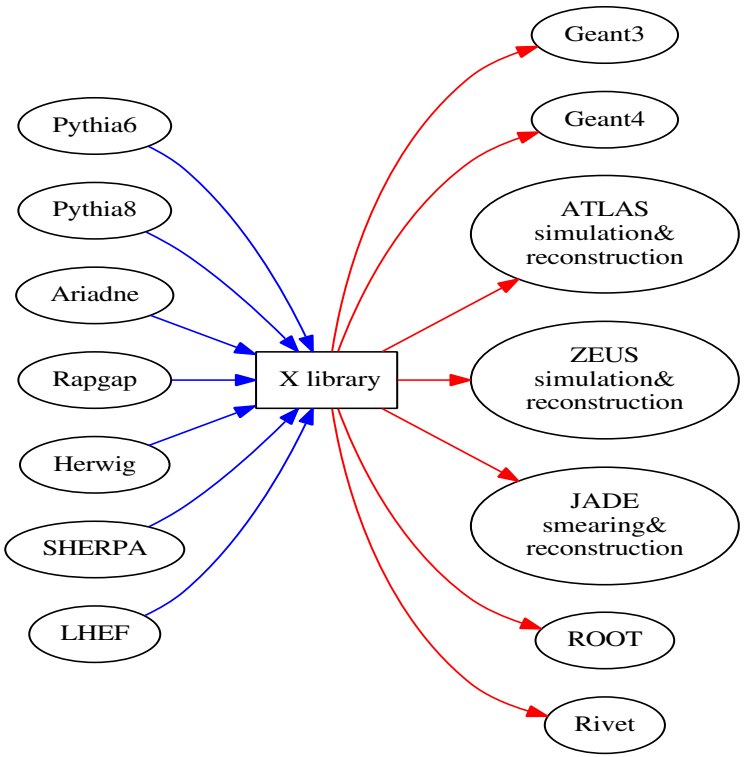
What is HepMC3: Definition and application

- HepMC3 is a library designed to operate with Monte Carlo event records in High Energy physics (HEP), see Ref. [1].
- Event record contains all physical information on the initial, intermediate and final state particles in the simulated collision: particle flavours, momenta, production coordinates, etc.



- The library should be used to store and transfer Monte Carlo event records between different HEP software and/or disk.
- HEP software in focus: Monte Carlo event generators (e.g. Pythia8[2], Herwig7 [3], SHERPA [4]), simulation software (e.g. Geant4 [5], FLUKA [6]), analysis frameworks (ROOT [7], experiment-specific), plotting tools (e.g. Rivet [8], HZTOOL [9]) etc.

What is HepMC3: Typical application example



- The typical task is to pass MC generated events between different generators, reconstruction programs and/or analysis frameworks.
- The naive expectation is that a universal connector "X library" should exist for many years, as the task is very common...
- $\rightarrow$ **No universal connector library existed before 201X!**

Before the HepMC3-3.0.0 the closest match was de-facto a standard HepMC2 [10] and a beta version of HepMC3.

Motivation

So why not HepMC2? Don't fix what is not broken, HepMC2 is working so far! Fair enough, but:

- **The communication with users was interrupted during the changes in the developers team and platform migrations in CERN**.
- Maintenance:
  - HepMC2 is not actively developed for a long time, last minor release is in **2012**, many users have to apply patches.
  - Many small changes would break compatibility but will not allow significant design improvements.
- Features:
  - Physics-related issues should be resolved to meet requirements of **modern physics**, e.g. Heavy Ion information [11], event weight treatment, etc.
  - I/O capabilities should be modernised, e.g. ROOT, LHEF [12], serialisation of custom information.

HepMC3 is a natural successor of HepMC2. With an idea to keep what is good in HepMC2 and add more.

New in HepMC3 (vs. HepMC2)

- General features and I/O:
  - Consistent I/O for all popular existing formats of event records.
  - The original LHEF routines by Leif Lönnblad.
  - ROOT interface out of the box.
  - Python2/Python3/PyPy interface out of the box.
  - Simpler event record that allows extensions via attributes.
  - Search engine to navigate in the event record.
- Programming and interfaces:
  - Multi-threading/thread safety.
  - CMake instead of autotools.
  - "const correctness" for the library.
  - Smart pointers everywhere.
- Quality assurance:
  - Code CERN GitLab with CI and tickets. **JIRA is obsolete!**
  - Test engine based on CTest ($\approx$ 60 tests) and valgrind.
  - Extensive documentation and examples.
- Distribution and deployment:
  - Close collaboration with MCEG authors, other users and maintainers of Linux distributives. **Thanks to all of them!**

Current usage

User	Type of SW	HepMC3 interface implementation
Rivet	Analysis/Plotting	3.2.0 in Rivet 3.1.0+
HIJING	MCEG	?
HIJING++	MCEG	?
EPOS	MCEG	?
PHSD	MCEG	?
SMASH	MCEG	3.1+
JetScape	MCEG	3.1+
AMPT	MCEG	?
Athena@ATLAS	Main SW of experiment	3.2.3 in a separate branch
SHERPA-MC	MCEG	3.1+ in SHERPA-MC 2.2.5+
ThePEG	MCEG	3.1 in ThePEG 2.2.0
Herwig7	MCEG	3.1 via ThePEG
Pythia8	MCEG	3.0+ in Pythia8.3 and in HepMC3
Pythia6	MCEG	3.1+ in HepMC3 examples
Tauola	MCEG	3.1+ in Taoula 3.64 and in HepMC3
Photos	MCEG	3.1+ in Photos 1.1.8 and in HepMC3
WHIZARD	MCEG	3.1+ in Whizard 2.8.2+
EvtGen	MCEG	3.1+ in EvtGen 2.0.0+
GeantV	Simulation	3.0
ACTS	Tracking	3.2+ in multiple versions
Rapgap	MCEG	3.1+, in a private RapGap version
Cascade	MCEG	3.1+, in a merge request to master
MC-TESTER	Analysis/Plotting	3.1+ in MC-TESTER 1.25.1 and in HepMC3

Note: HepMC3 3.1+ and HepMC2 can co-exist in one installation.

HepMC3 for Heavy Ion

- GenHeavyIon is a standard attribute to hold information in Heavy Ion collisions.
- Significantly expanded in comparison to HepMC2.
- Close to Lisbon Accord [11], but can be extended even more to fulfil needs of Heavy Ion experiments.

```
1   int    Ncoll_hard;                    /// the number of hard nucleon-nucleon collisions.
    int    Npart_proj;                    /// the number of participating nucleons in the projectile.
3   int    Npart_targ;                    /// the number of participating nucleons in the target.
    int    Ncoll;                         /// the number of inelastic nucleon-nucleon collisions.
5   int    N_Nwounded_collisions;         /// Collisions with a diffractively excited target nucleon.
    int    Nwounded_N_collisions;         /// Collisions with a diffractively excited projectile nucleon.
7   int    Nwounded_Nwounded_collisions;  /// Non-diffractive or doubly diffractive collisions.
    double impact_parameter;              /// The impact parameter.
9   double event_plane_angle;             /// The event plane angle.
    double sigma_inel_NN;                 /// The assumed inelastic nucleon-nucleon cross section
11  double centrality;                    /// The centrality.
    double user_cent_estimate;            /// A user defined centrality estimator.
13  int Nspec_proj_n;                     /// The number of spectator neutrons in the projectile
    int Nspec_targ_n;                     /// The number of spectator neutrons in the target
15  int Nspec_proj_p;                     /// The number of spectator protons in the projectile
    int Nspec_targ_p;                     /// The number of spectator protons in the target
17  map<int,double> participant_plane_angles; /// Participant plane angles
    map<int,double> eccentricities;       /// Eccentricities
```

Obviously that is not enough...Otherwise there would be no this meeting.

Selected new features: Attributes in HepMC3

- An attribute is class that holds information on event, particle or vertex and can be represented as a string.
- Every attribute class should inherit from HepMC3::Attribute. The attribute is handled all the time as a string (in memory and in I/O operations) till an explicit request to convert it to an object of some type.

Example of attributes are given below

```
GenCrossSection 2.64422551e+03 2.64422551e+03 -1 -1
```

```
GenPdfInfo 11 -11 9.97420767e-01 9.99999975e-01 9.18812775e+01 1.56824725e+01 2.82148362e+06 0 0
```

```
alphaQCD 0.129844
```

These attributes represent information of classes

```
HepMC3::GenCrossSection
HepMC3::GenPdfInfo
double
```

One can add arbitrary complex information to event record.

Selected new features: custom readers/writers for different formats

HepMC3 I/O is easily extendable for different purposes

- E.g. **30 LOCs** to write events for ZEUS detector simulation.
- Simple example to write into dot format and use with GraphViz.

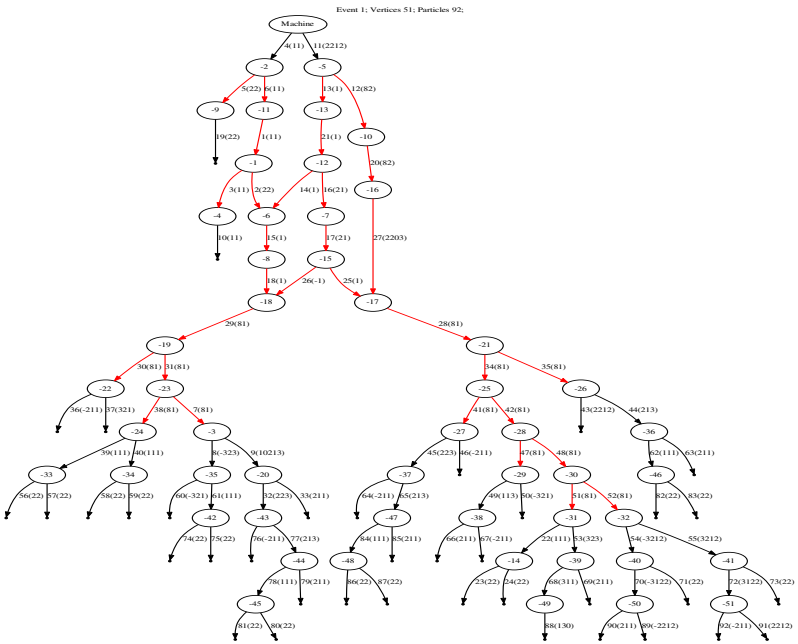


Figure: $e^- p$ collision in Herwig 7.1.4

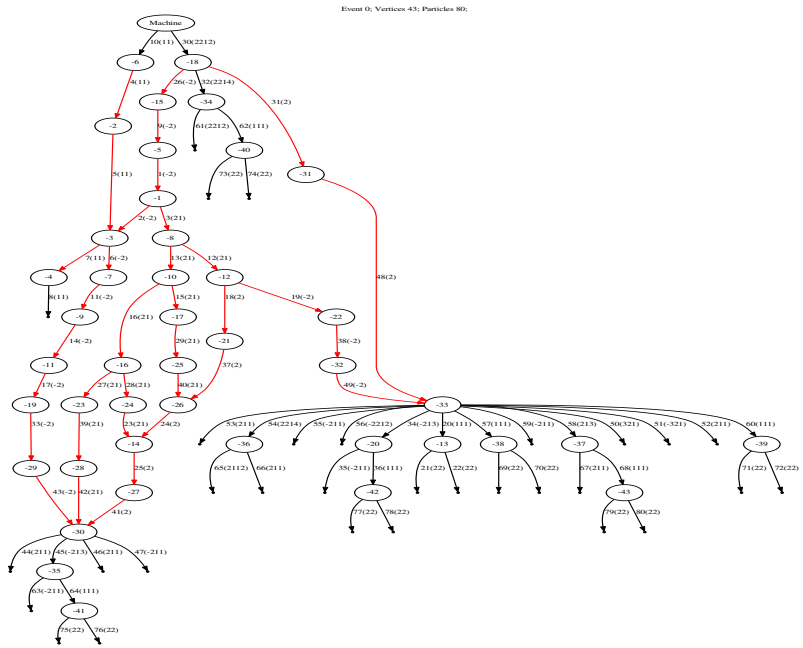


Figure: $e^- p$ collision in Pythia 8.2.40

What could be done in HepMC3 for the HI community

- Add/update the content of standard HI attribute.
- Add a module with extra attributes, e.g. to hold information on TMDs, Heavy Ion observables, DVCS observables, polarisation of beams, etc.
- At least add some "HepMC3::Reader"s for event formats common in HI physics. Practically, it should be straightforward to implement readers that would read only the final state, e.g. for OSCAR format. However, it would be **very desirable** to have the writters as well.
- Speedup the I/O in the default readers. There are already opened issues in the gitlab and some ideas will be implemented in 3.2.4. However, the ultimate speedup of I/O will **always** require a usage of binary format, e.g. ROOT or a multi threaded parsing. The later can be trivially implemented with the current library.

Disk-resident formats and HepMC3::GenEvent

- The 'HepMC3::GenEvent' objects in memory are constructed from the information on disk, but **"Events on disk"** $\neq$ **"Events in memory"**.
- The same input file processed with different 'HepMC3::Reader' can produce different events. **If you want e.g. only the stable particles in the final state – no need to invent new formats! Just use a custom reader with standard files and read only stable particles!**

What Rivet can do with HepMC3

If compiled with HepMC3>3.2.0, Rivet uses standard HepMC3 functions

```
1  std::shared_ptr<HepMC3::Reader> deduce_reader(const std::string &filename);
   std::shared_ptr<HepMC3::Reader> deduce_reader(std::istream &stream);
```

to deal with input, i.e. it is **disk format-agnostic** and the format of input will be deduced automatically. So, if HepMC3 can read some format, Rivet will be able to do it as well. **No need for separate "converters" that use disk. And yes, Rivet can read ROOT.**

Performance, file size, optimisations, etc., part I

From **my personal experience** the performance was never an issue. The typical workflow I've used for QCD studies is

- Run MCEG with HepMC3/ROOT support and produce HepMC3/ROOTTree events. Typically that is 10^{7-8} events for $e^+e^-/e^\pm p$ or 10^{6-7} for pp. The ROOTTree output is quite small and is stored locally. But if not – it is OK to store ROOT files in dCache etc.
- Run ROOT analysis on the produced files (HepMC3 is NOT needed at this point) using PROOF. The input can be local or remote. With a 64 core machine, the typical QCD analysis runs at 10^5 events per second. I/O speed is not a problem. All the samples can be processed in $\mathcal{O}(1)$ hours.
- Use the filled histograms and don't bother to do any I/O optimisation that probably will not bring any benefits.

Performance, file size, optimisations, etc., part II

But if one would like to optimise something in the end?

- File size: ROOT/HepMC3 with a high compression is the best option. Works out of the box. For Ascii formats, Asciiv3 is slightly better than HepMC2 IO_GenEvent and in 3.2.4 it will be possible to write the Asciiv3 in a more compact form using "g" specifier for the floating point number instead of default "e". This can reduce the size by ≈30% in the extreme cases.
- Faster Ascii input: one can use a multi-threaded reader with a default "HepMC3::RederAscii" or "HepMC3::RederAsciiHepMC2". This is almost a trivial task.
- Implement a custom reader that would skip the unstable particles.

HepMC3 installation

There is a peception that the MCEG-related software stack is too complex and hard to install. Not the case for HepMC3:

OS	Repository	HepMC3 versions	Recommended for installation?	Credits
Fedora	Standard	last	Yes	Mattias Ellert
CentOS	EPEL	last	Yes	Mattias Ellert
MacOS	homebrew-hep	last	Yes	Enrico Bothmann/AV
ArchLinux	AUR	last	Yes	Frank Siegert
openSUSE	science	last	Yes	Atri Bhattacharya
Windows10	PyPi	last	Yes	AV
Debian, Ubuntu	Standard	3.1.1	Outdated, install from source	Mo Zhou
Others		last	Install from source	

One should be able to do

```
[username@fedora ~]$ dnf install HepMC3
or
[username@centos ~]$ yum install HepMC3
or
username—macbook% brew install HepMC3
```

without knowing the requirements.

Installation of MC stack, e.g. including Rivet

As any problem, the installation of software has standard solutions of "enterprise" level. Rivet and many MC tools can be installed within minutes.

- Install Fedora/CentOS/RHEL/openSUSE
- Do as root in, e.g. Fedora

```
[root@fedora ~]$ dnf -y install dnf-plugins-core
[root@fedora ~]$ dnf -y copr enable averbyts/HEPrpms
[root@fedora ~]$ dnf -y install Rivet
```

- Docs at https://github.com/andriish/HEPrpms

Adoption of mainstream Linux tools solves the complexity almost immediately.

What could be done by the MCEG (HI) community

- If you have a good idea, feature request or bug report, please, create an issue in https://gitlab.cern.ch/hepmc/HepMC3 or send a mail to hepmc-devATcern.ch mailing list. **We do answer mails!** .
- If your idea was implemented, the issue was resolved, a bug was fixed – please give some **feedback**, close the resolved issues etc. **Even one-word answers as "Good", "OK" or "Bad" are better than nothing.**
- Availability and visibility of HI-MCEG sources and documentation for colleagues from other fields is important. A web-page with a contact information and the code is always a good thing. A public repository is even better. Adding links to the web-pages in the talks is also very helpful.
- Extending Heavy Ion event record standard.

Summary

- HepMC3 3.2+: Moving towards full replacement of HepMC2, e.g. in ATLAS and MCEG community.
- Collecting feedback from LHC experiments, MCEG authors and interested individuals. **Discussions during this workshop will provide a crucial information.**

Visit http://hepmc.web.cern.ch/hepmc/
Write an e-mail to hepmc-dev@cern.ch or to any of authors.

- **HI community opinions and suggestions are important!**
- **Even if not everything can be implemented now, it is important to do the first steps and establish a connection between HI MCEGs and non-HI MCEGs.**

Backup slides

Obsolete and removed features (vs. HepMC2)

- General features and I/O:
  - Some duplicated functions.
  - Operators '«' and '»' for event input/output that violated class hierarchy.
  - Custom iterator-based access. Finally usage of STL is possible!
  - Flow and Polarisation classes are removed and the information should be represented by generic attributes. Event record is simplified!

Particle in standard HepMC2 representation (IO_GenEvent)

```
1 P 10001 11 0.0e+00 0.0e+00 4.59999e+01 4.60000e+01 5.10999e-04 4 0 0 -1 0
```

Particle in standard HepMC3 representation (Asciiv3)

```
1   P 1 0 11 0.0e+00 0.0e+00 4.59999e+01 4.60000e+01 5.10999e-04 4
```

The difference stands for polarisation and event flow information
$\rightarrow$ rarely filled and meaningful.

```
                                                          0 0 -1 0
```

Requirements for HepMC3 3.2.3+

Minimal:

- Modern Linux, OSX, BSD, Solaris or Windows system
- C++11 compatible compiler (gcc/clang/Intel/Oracle SunPro/PGI/IBM XL)
- CMake 3.7+

Recommended=Minimal+

- ROOT6

Full=Recommended+

- doxygen, latex, graphviz for documentation
- valgrind, Pythia8, HepMC2, Photos [13], Tauola [14], MC-TESTER [15] for tests
- Fortran77 compiler for examples
- Python2/Python3/PyPy modules

Contact developers in case something is not working.
Hopefully, there will be no need to know the requirements.

Performance

A test suite from Leif Lönnblad was used to estimate the HepMC3 performance.

- The suite contained $\mathcal{O}(100)$ MC generated event samples with different processes at different colliders: B-factories, LEP, HERA, LHC.
- Test parameters: size of file with events, reading time for the first event, reading time for the sample.

No big surprises.

- Asciiv3 and HepMC2 GenEvent have similar performance.
- ROOT-based format is much faster and requires less storage.
- ROOT-based format is more storage-efficient than the Gzipped ASCII formats as well.

See details in backups.

Tests: reading time (after first event)

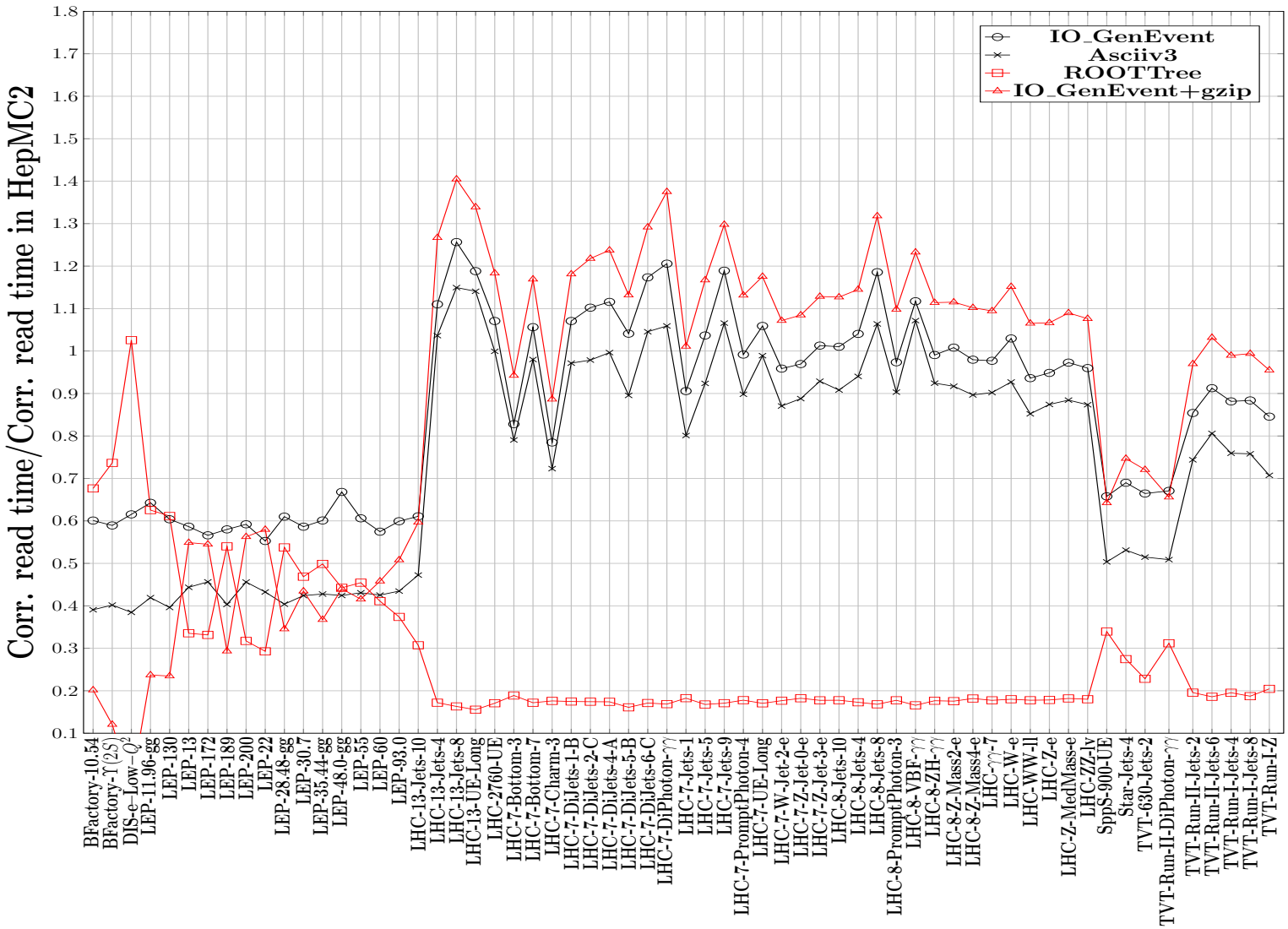
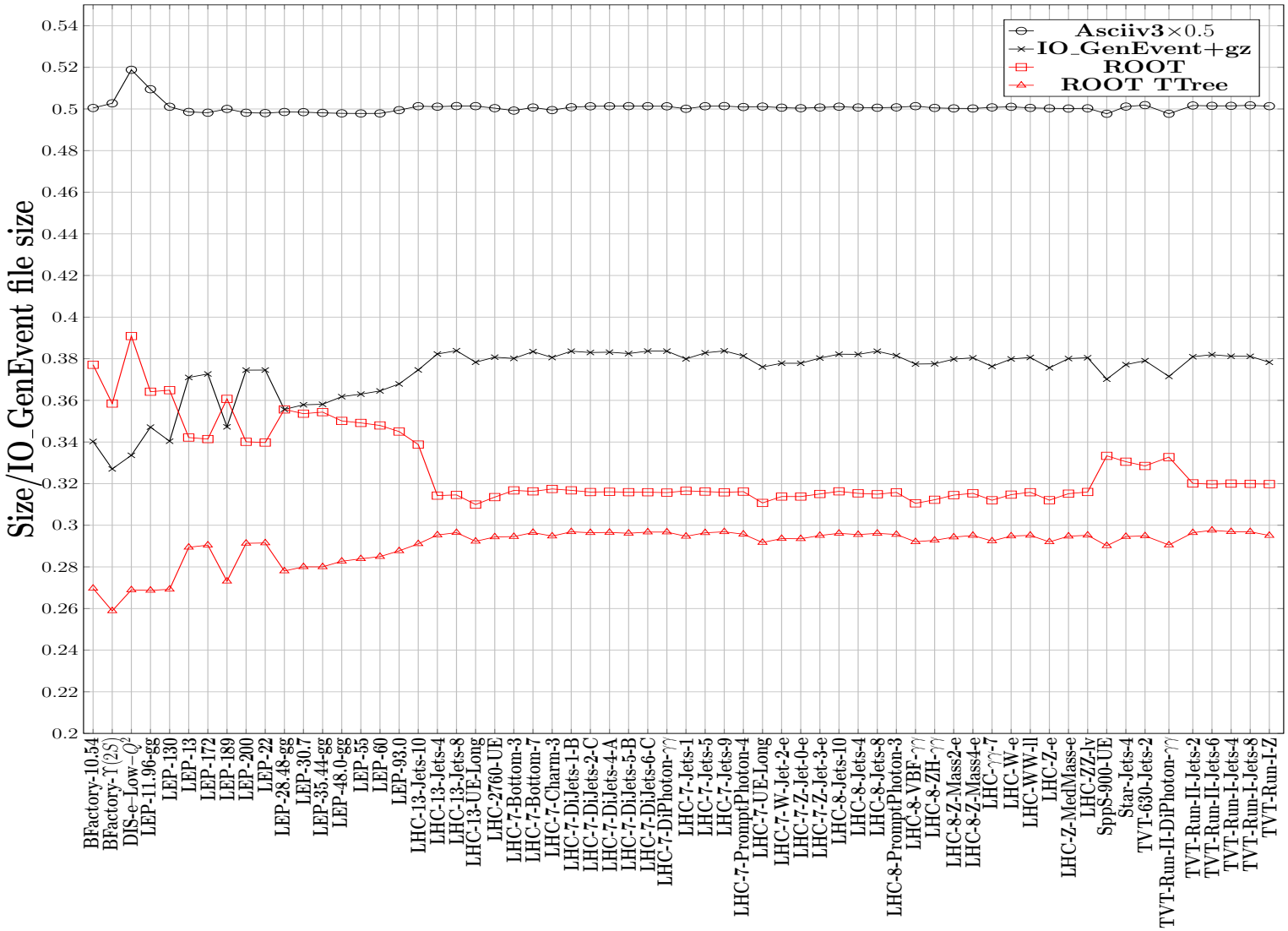
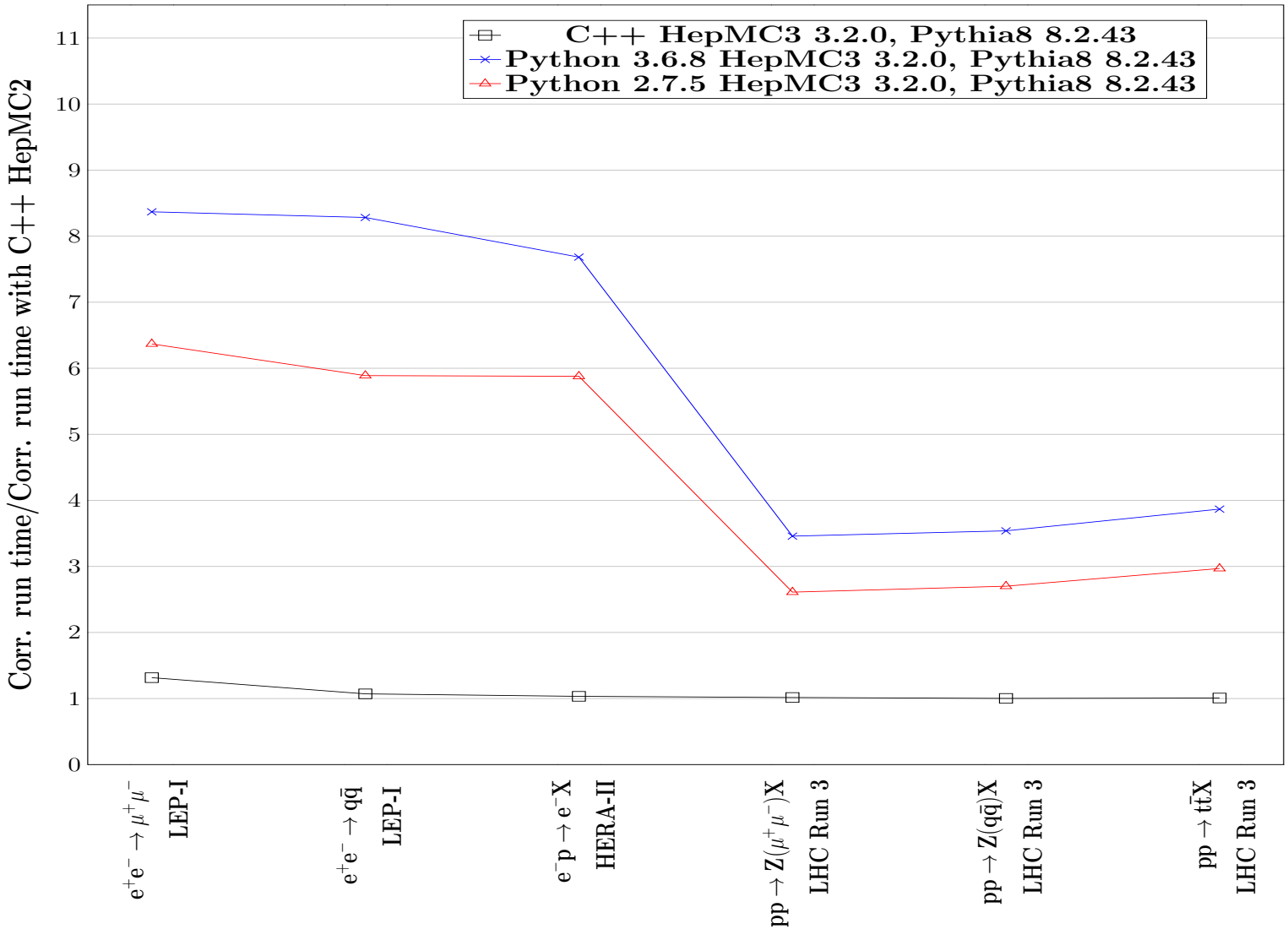


Figure: Reading the whole sample

Tests: file size



Tests: python performance



Example of event analysis in ROOT (Headers omitted).

```
class SomeAnalysis{
public :
    TChain          *fChain;   //!pointer to the analyzed TTree or TChain
    Int_t           event_number;
    Int_t           momentum_unit;
    TBranch         *b_hepmc3_event_event_number;   //!
    TBranch         *b_hepmc3_event_momentum_unit;   //!
    TBranch         *b_hepmc3_event_length_unit;   //!
    TBranch         *b_hepmc3_event_particles_;   //!
    void Init(TChain *tree) {
        if (!tree) return;
        fChain = tree;
        fChain->SetMakeClass(1);
        fChain->SetBranchAddress("event_number", &event_number, &b_hepmc3_event_event_number);
    SomeAnalysis(const std::string& file) {
        TChain* TempChain= new TChain("hepmc3_tree");
        TempChain->Add(file.c_str());
        Init(TempChain);
    }
};
int main(){
    TH1D H1("H1","Pt of pions or electrons;Events/100MeV;P_{T},GeV",1000,0,100);
    SomeAnalysis* A= new SomeAnalysis("inputIO4.root");
    if (!A->fChain->GetEntries()) return 1;
    for (int entry=0; entry<A->fChain->GetEntries(); entry++){
            A->fChain->GetEntry(entry);
            for (int i=0; i<A->particles_; i++)
                if (A->particles_status[i]==1&&(std::abs(A->particles_pid[i])==211||std::abs(A->particles_pid[i])==11))
                    H1.Fill(std::sqrt(A->particles_momentum_m_v1[i]*A->particles_momentum_m_v1[i]+A->particles_momentum_m_v2[i]*
        A->particles_momentum_m_v2[i]) );
    }
    delete A;
    H1.Print("All");
    return 0;
}
```

- Reading file in ROOT format without HepMC3.

Event analysis listing of ROOT HepMC3 tree, with HepMC3

```
#include "HepMC3/GenEvent.h"
#include "HepMC3/GenParticle.h"
#include "HepMC3/ReaderRootTree.h"
#include <TH1D.h>
int main()
{

    TH1D H2("H2","Pt of pions or electrons;Events/100MeV;P_{T},GeV",1000,0,100);
    HepMC3::ReaderRootTree inputA("inputIO4.root");
    if(inputA.failed()) return 10002;
    while( !inputA.failed() )
        {
            HepMC3::GenEvent evt(HepMC3::Units::GEV,HepMC3::Units::MM);
            inputA.read_event(evt);
            if( inputA.failed() )  {printf("End of file reached. Exit.\n"); break;}
            for(auto p: evt.particles() )
            if ( std::abs(p->status()) == 1 && (std::abs(p->pdg_id()) == 211||std::abs(p->pdg_id()) == 11) )
                H2.Fill( p->momentum().perp());
            evt.clear();
        }
    inputA.close();
    H2.Print("All");
    return 0;
}
```

Listing 11: Reading file in ROOT format with HepMC3

MC events for ZEUS simulation

One of options for MC simulations in ZEUS was to use ASCII input very similar to HEPEVT format. The implementation of format in HepMC3 is listed below.

```
#include "HepMC3/WriterHEPEVT.h"
namespace HepMC3 {
class WriterHEPEVTZEUS : public  WriterHEPEVT {
public:
    WriterHEPEVTZEUS(const std::string &filename);
    void write_hepevt_event_header();
    void write_hepevt_particle( int index, bool iflong );
};
}
```

Listing 12: Header

```
#include "WriterHEPEVTZEUS.h"
#include "HepMC3/HEPEVT_Wrapper.h"
namespace HepMC3{
WriterHEPEVTZEUS::WriterHEPEVTZEUS(const std::string &filename):WriterHEPEVT(filename) {}
void WriterHEPEVTZEUS::write_hepevt_event_header()
{    fprintf(m_file," E % 12i% 12i% 12i\n",HEPEVT_Wrapper::event_number(),0,HEPEVT_Wrapper::number_entries());}
  void WriterHEPEVTZEUS::write_hepevt_particle( int index, bool /*iflong*/ ){
    fprintf(m_file,"% 12i% 8i",HEPEVT_Wrapper::status(index), HEPEVT_Wrapper::id(index));
    fprintf(m_file,"% 8i% 8i",HEPEVT_Wrapper::first_parent(index),HEPEVT_Wrapper::last_parent(index));
    fprintf(m_file,"% 8i% 8i",HEPEVT_Wrapper::first_child(index),HEPEVT_Wrapper::last_child(index));
    fprintf(m_file,      "% 19.11E% 19.11E% 19.11E% 19.11E% 19.11E\n",HEPEVT_Wrapper::px(index),HEPEVT_Wrapper::py(index),
        HEPEVT_Wrapper::pz(index),HEPEVT_Wrapper::e(index),HEPEVT_Wrapper::m(index));
    fprintf(m_file, "%-52s% 19.11E% 19.11E% 19.11E% 19.11E% 19.11E\n"," ",HEPEVT_Wrapper::x(index),HEPEVT_Wrapper::y(index),
        HEPEVT_Wrapper::z(index),HEPEVT_Wrapper::t(index),0.0);
}
}// namespace HepMC3
```

Listing 13: Source

Installation on CentOS7

```
[root@hostname1 username]# yum install HepMC3 HepMC3-devel  HepMC3-search HepMC3-search-devel  HepMC3-rootIO HepMC3-rootIO-devel HepMC3-interfaces-devel HepMC3-doc
Resolving Dependencies
Skipping filters plugin, no data
--> Running transaction check
---> Package HepMC3.x86_64 0:3.1.0-3.el7 will be installed
---> Package HepMC3-devel.x86_64 0:3.1.0-3.el7 will be installed
---> Package HepMC3-doc.noarch 0:3.1.0-3.el7 will be installed
---> Package HepMC3-interfaces-devel.noarch 0:3.1.0-3.el7 will be installed
---> Package HepMC3-rootIO.x86_64 0:3.1.0-3.el7 will be installed
---> Package HepMC3-rootIO-devel.x86_64 0:3.1.0-3.el7 will be installed
---> Package HepMC3-search.x86_64 0:3.1.0-3.el7 will be installed
---> Package HepMC3-search-devel.x86_64 0:3.1.0-3.el7 will be installed
--> Finished Dependency Resolution

Dependencies Resolved

================================================================================================================================================================
 Package                                                          Arch                                            Version                                                Repository                                                 S
================================================================================================================================================================
Installing:
 HepMC3                                                           x86_64                                          3.1.0-3.el7                                            epel-testing                                              21
 HepMC3-devel                                                     x86_64                                          3.1.0-3.el7                                            epel-testing                                               5
 HepMC3-doc                                                       noarch                                          3.1.0-3.el7                                            epel-testing                                               4
 HepMC3-interfaces-devel                                          noarch                                          3.1.0-3.el7                                            epel-testing                                               2
 HepMC3-rootIO                                                    x86_64                                          3.1.0-3.el7                                            epel-testing                                               4
 HepMC3-rootIO-devel                                              x86_64                                          3.1.0-3.el7                                            epel-testing                                              5.
 HepMC3-search                                                    x86_64                                          3.1.0-3.el7                                            epel-testing                                               2
 HepMC3-search-devel                                              x86_64                                          3.1.0-3.el7                                            epel-testing                                               1

Transaction Summary
================================================================================================================================================================
Install  8 Packages

Total download size: 44 M
Installed size: 85 M
Is this ok [y/d/N]: y
Downloading packages:
HepMC3-doc-3.1.0-3.el7.noarch.rpm                                                                                                                                                                                   |  43 MB  00:00:01
(1/7): HepMC3-3.1.0-3.el7.x86_64.rpm                                                                                                                                                                                | 218 kB  00:00:00
(2/7): HepMC3-devel-3.1.0-3.el7.x86_64.rpm                                                                                                                                                                          |  52 kB  00:00:00
(3/7): HepMC3-interfaces-devel-3.1.0-3.el7.noarch.rpm                                                                                                                                                               |  21 kB  00:00:00
(4/7): HepMC3-rootIO-3.1.0-3.el7.x86_64.rpm                                                                                                                                                                         |  43 kB  00:00:00
(5/7): HepMC3-rootIO-devel-3.1.0-3.el7.x86_64.rpm                                                                                                                                                                   | 5.5 kB  00:00:00
(6/7): HepMC3-search-3.1.0-3.el7.x86_64.rpm                                                                                                                                                                         |  29 kB  00:00:00
(7/7): HepMC3-search-devel-3.1.0-3.el7.x86_64.rpm                                                                                                                                                                   |  10 kB  00:00:00
----------------------------------------------------------------------------------------------------------------------------------------------------------------
Total                                                                                                                                                                                                   874 kB/s | 378 kB  00:00:00
Running transaction check
Running transaction test
Transaction test succeeded
Running transaction
  Installing : HepMC3-3.1.0-3.el7.x86_64
  Installing : HepMC3-devel-3.1.0-3.el7.x86_64
  Installing : HepMC3-search-3.1.0-3.el7.x86_64
  Installing : HepMC3-rootIO-3.1.0-3.el7.x86_64
  Installing : HepMC3-rootIO-devel-3.1.0-3.el7.x86_64
  Installing : HepMC3-search-devel-3.1.0-3.el7.x86_64
  Installing : HepMC3-interfaces-devel-3.1.0-3.el7.noarch
  Installing : HepMC3-doc-3.1.0-3.el7.noarch
  Verifying  : HepMC3-devel-3.1.0-3.el7.x86_64
  Verifying  : HepMC3-3.1.0-3.el7.x86_64
  Verifying  : HepMC3-search-devel-3.1.0-3.el7.x86_64
  Verifying  : HepMC3-search-3.1.0-3.el7.x86_64
  Verifying  : HepMC3-doc-3.1.0-3.el7.noarch
  Verifying  : HepMC3-rootIO-devel-3.1.0-3.el7.x86_64
  Verifying  : HepMC3-rootIO-3.1.0-3.el7.x86_64
  Verifying  : HepMC3-interfaces-devel-3.1.0-3.el7.noarch

Installed:
  HepMC3.x86_64 0:3.1.0-3.el7         HepMC3-devel.x86_64 0:3.1.0-3.el7         HepMC3-doc.noarch 0:3.1.0-3.el7  HepMC3-interfaces-devel.noarch 0:3.1.0-3.el7  HepMC3-rootIO.x86_64 0:3.1.0-3.el7  HepMC3-rootIO-devel.x86_64 0:3.1.0-3.e
  HepMC3-search.x86_64 0:3.1.0-3.el7  HepMC3-search-devel.x86_64 0:3.1.0-3.el7

Complete!
New leaves:
  HepMC3-doc.noarch
  HepMC3-interfaces-devel.noarch
  HepMC3-rootIO-devel.x86_64
  HepMC3-search-devel.x86_64
```

I/O: ASCII formats

```
HepMC::Version 3.0.0
HepMC::Asciiv3-START_EVENT_LISTING
W 0
E 0 7 12
U GEV MM
W 1.0000000000000000000000e+00
A 0 GenCrossSection 2.64422551e+03 2.64422551e+03 -1 -1
A 0 GenPdfInfo 11 -11 9.97420767e-01 9.99999975e-01 9.18812775e+01 1.56824725e+01 2.82148362e+06 0 0
A 0 alphaQCD 0.129844
A 0 alphaQED 0.007818181
A 0 event_scale 91.88128
A 0 mpi 0
A 0 signal_process_id 221
A 0 signal_process_vertex 0
P 1 0 11 0.0000000000000000e+00 0.0000000000000000e+00 4.5999999997161737e+01 4.6000000000000007e+01 5.1099999999999995e-04 4
P 2 1 11 0.0000000000000000e+00 0.0000000000000000e+00 4.5881355265109356e+01 4.5881355265109356e+01 0.0000000000000000e+00 61
P 3 1 22 0.0000000000000000e+00 0.0000000000000000e+00 1.1864473489064407e-01 1.1864473489064407e-01 0.0000000000000000e+00 1
P 4 0 -11 0.0000000000000000e+00 0.0000000000000000e+00 -4.5999999997161737e+01 4.6000000000000007e+01 5.1099999999999995e-04 4
P 5 4 -11 0.0000000000000000e+00 0.0000000000000000e+00 -4.5999998855671230e+01 4.5999998855671230e+01 0.0000000000000000e+00 61
P 6 4 22 0.0000000000000000e+00 0.0000000000000000e+00 -1.1443287704082650e-06 1.1443287704082650e-06 0.0000000000000000e+00 1
P 7 2 11 0.0000000000000000e+00 0.0000000000000000e+00 4.5881355265109356e+01 4.5881355265109356e+01 0.0000000000000000e+00 21
```

Listing 15: HepMC3 Asciiv3 (HepMC3 standard)

```
HepMC::Version 3.0.0
HepMC::IO_GenEvent-START_EVENT_LISTING
E 0 0 9.188128e+01 1.298440e-01 7.818181e-03 221 0 7 10001 10004 0 1 1.0000000000000000e+00
N 1 "0"
U GEV MM
C 2.6442255100000002e+03 2.6442255100000002e+03
F 11 -11 9.97420767e-01 9.99999975e-01 9.18812775e+01 1.56824725e+01 2.82148362e+06 0 0
V -1 0 0 0 0 0 1 2 0
P 10001 11 0.0000000000000000e+00 0.0000000000000000e+00 4.5999999997161737e+01 4.6000000000000007e+01 5.1099999999999995e-04 4 0 0 -1 0
P 10002 11 0.0000000000000000e+00 0.0000000000000000e+00 4.5881355265109356e+01 4.5881355265109356e+01 0.0000000000000000e+00 61 0 0 -3 0
P 10003 22 0.0000000000000000e+00 0.0000000000000000e+00 1.1864473489064407e-01 1.1864473489064407e-01 0.0000000000000000e+00 1 0 0 0 0
V -2 0 0 0 0 0 1 2 0
P 10004 -11 0.0000000000000000e+00 0.0000000000000000e+00 -4.5999999997161737e+01 4.6000000000000007e+01 5.1099999999999995e-04 4 0 0 -2 0
P 10005 -11 0.0000000000000000e+00 0.0000000000000000e+00 -4.5999998855671230e+01 4.5999998855671230e+01 0.0000000000000000e+00 61 0 0 -4 0
P 10006 22 0.0000000000000000e+00 0.0000000000000000e+00 -1.1443287704082650e-06 1.1443287704082650e-06 0.0000000000000000e+00 1 0 0 0 0
V -3 0 0 0 0 0 0 1 0
```

Listing 16: IO_GenEvent (HepMC2 standard) as implemented in HepMC3

```
E 0 12
 4 -11 0 0 3 11 0.00000000E+00 0.00000000E+00 -4.60000000E+01 4.60000000E+01 5.11000000E-04
       0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 4 11 0 0 4 12 0.00000000E+00 0.00000000E+00 4.60000000E+01 4.60000000E+01 5.11000000E-04
       0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
61 -11 1 1 5 5 0.00000000E+00 0.00000000E+00 -4.59999989E+01 4.59999989E+01 0.00000000E+00
       0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
61 11 2 2 6 6 0.00000000E+00 0.00000000E+00 4.58813553E+01 4.58813553E+01 0.00000000E+00
       0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
21 -11 3 3 7 7 0.00000000E+00 0.00000000E+00 -4.59999989E+01 4.59999989E+01 0.00000000E+00
```

We keep compatibility! Note

Listing 17: HepEVT (Fortran era generators) as implemented in HepMC3

absence of unused color flow information in Asciiv3.

I/O: LHEF

- The original Les Houches accord event format (LHEF) is designed for communicating between Matrix element generators and MCEG.
- It agreed upon in 2001 [16](see updates in Refs. [12][17][18]).
- **The routines to handle LHEF is a precious part of HepMC3.**

```
<LesHouchesEvents version="3.0">
  <header>
  <MG5ProcCard>
#*************************************************************
#*                        MadGraph 5                         *
#*                                                           *
#*               *                       *                   *
#*                 *        * *        *                     *
#*                   * * * * 5 * * * *                       *
#*                 *        * *        *                     *
#*               *                       *                   *
#*                                                           *
#*         VERSION 2.0.0.beta4           2013-06-22          *
#*                                                           *
#*    The MadGraph Development Team - Please visit us at     *
#*    https://server06.fynu.ucl.ac.be/projects/madgraph      *
#*                                                           *
#*************************************************************
#*                                                           *
```

Listing 18: First lines of LHEF header

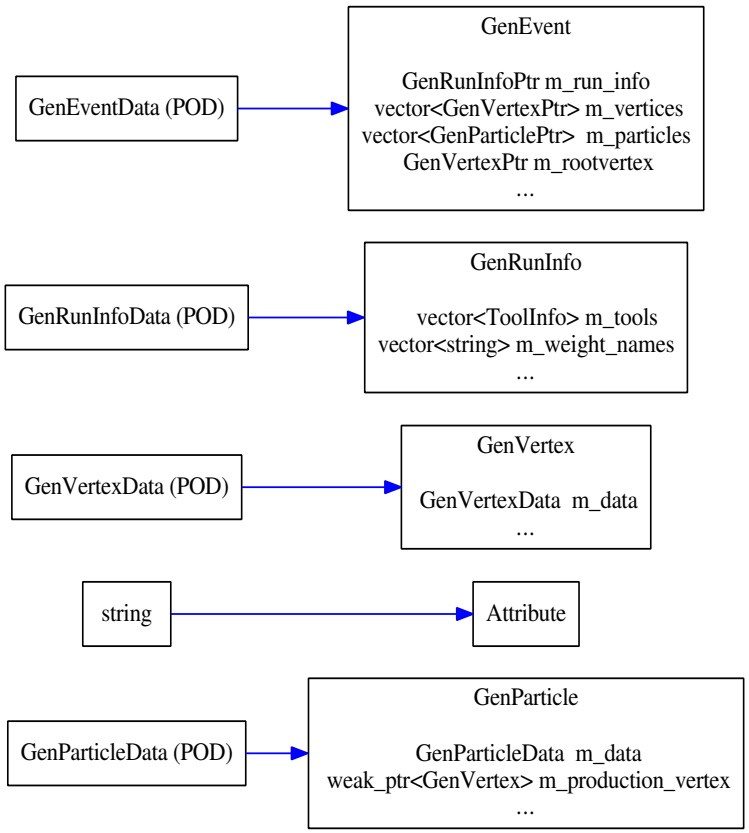
```
  <event>
  6     66 0.50109093E+02 0.88344569E+02 0.75563862E-02 0.12114027E+00
        2 -1    0    0  502    0 0.00000000E+00 0.00000000E+00 0.62728157E+03 0.62728166E+03 0.33000000E+00 0.0000E+00 0.0000E+00
        5 -1    0    0  501    0 0.00000000E+00 0.00000000E+00 -.44481443E+02 0.44739678E+02 0.48000000E+01 0.0000E+00 0.0000E+00
        6  2    1    2  501    0 -.59350665E+02 0.72244533E+02 0.21037840E+03 0.28804239E+03 0.17311146E+03 0.0000E+00 0.0000E+00
       24  1    3    3    0    0 0.28747403E+02 0.66692858E+02 0.11544955E+03 0.15832494E+03 0.80398000E+02 0.0000E+00 0.0000E+00
        5  1    3    3  501    0 -.88098069E+02 0.55516749E+01 0.94928843E+02 0.12971745E+03 0.48000000E+01 0.0000E+00 0.0000E+00
        1  1    1    2  502    0 0.59350665E+02 -.72244533E+02 0.37242173E+03 0.38397894E+03 0.33000000E+00 0.0000E+00 0.0000E+00
#aMCatNLO 1  6  2  0  0 0.00000000E+00 0.00000000E+00 9  0  0 0.10000000E+01 0.86321681E+00 0.11022720E+01 0.00000000E+00 0.00000000E+00
#aMCatNLO 1  6  2  0  0 0.00000000E+00 0.00000000E+00 9  0  0 0.10000000E+01 0.91292678E+00 0.10493312E+01 0.00000000E+00 0.00000000E+00
#aMCatNLO 1  6  2  0  0 0.00000000E+00 0.00000000E+00 9  0  0 0.10000000E+01 0.91292678E+00 0.10493312E+01 0.00000000E+00 0.00000000E+00
#aMCatNLO 1  6  2  0  0 0.00000000E+00 0.00000000E+00 9  0  0 0.10000000E+01 0.91292678E+00 0.10493312E+01 0.00000000E+00 0.00000000E+00
  <rwgt>
   <wgt id="1001"> 0.50109E+02 </wgt>
   <wgt id="1002"> 0.43255E+02 </wgt>
   <wgt id="1003"> 0.55234E+02 </wgt>
```

Listing 19: First lines of some LHEF event

LHEF is basically XML with extra rules.

More:

I/O: ROOT Tree format



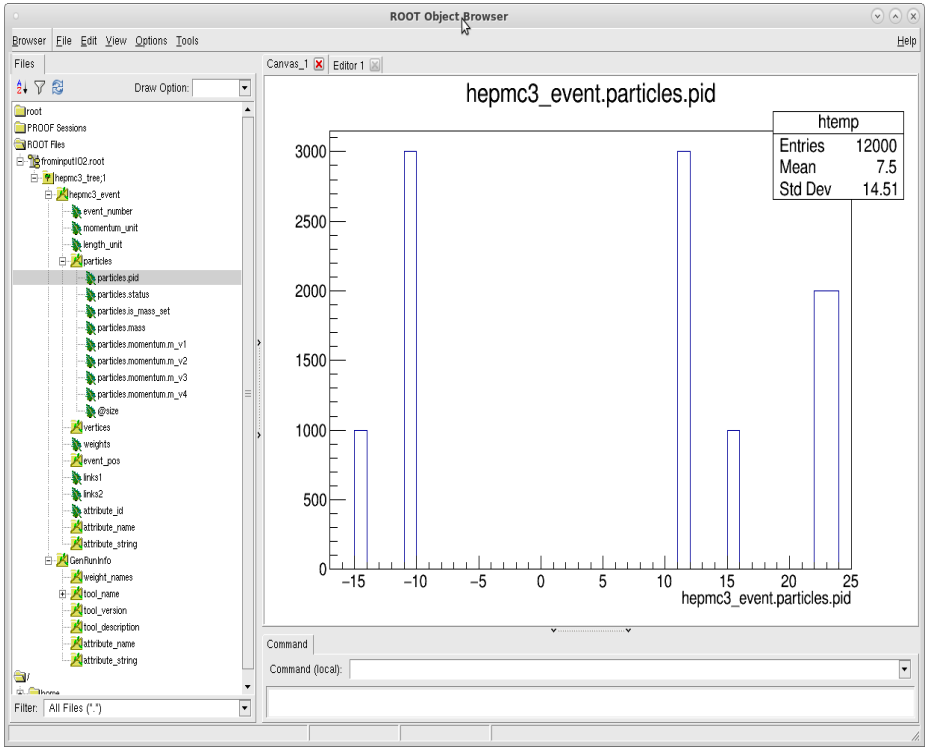


Figure: HepMC3 ROOT file in TBrowser.

HepMC3 uses custom streamers + POD types for ROOT I/O. **HepMC3 ROOT files are readable with standard ROOT, NO externals needed.**

I/O: code example

```
#include "HepMC3/GenEvent.h"
#include "HepMC3/WriterAscii.h"
#include "HepMC3/ReaderAsciiHepMC2.h"
int main()
{
    HepMC3::ReaderAsciiHepMC2 inputA("inputIO1.hepmc");
    if(inputA.failed()) return 1;
    HepMC3::WriterAscii       outputA("frominputIO1.hepmc");
    if(outputA.failed()) return 2;
    while( !inputA.failed() )
        {
            HepMC3::GenEvent evt(HepMC3::Units::GEV,HepMC3::Units::MM);
            inputA.read_event(evt);
            if( inputA.failed() )  {printf("End of file reached. Exit.\n"); break;}
            outputA.write_event(evt);
            evt.clear();
        }
    inputA.close();
    outputA.close();
    return 0;
}
```

Listing 20: Reading file in HepMC2 format (IO_GenEvent) and writing in HepMC3 (Asciiv3)

- **Note: Works in the same way for all formats in different combinations.**

The examples in HepMC3 provide a simple event browser

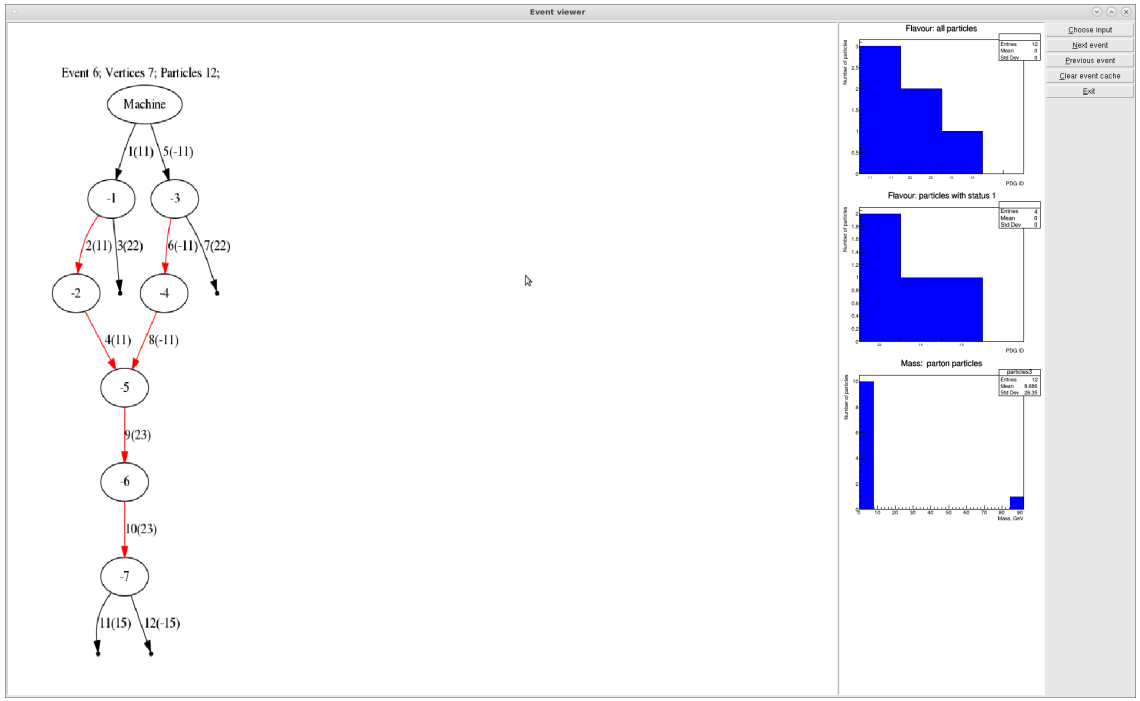


Figure: Pythia 8.2.40 simulated process $e^+e^- \to \tau^+\tau^-$ with ISR and w/o hadronisation and decays. The display shows event information (e.g. run and event number, ...), depicts vertices as ellipses and the particles as arrows. The information on vertices and particles (ids and flavor) are given as well. The right panel shows selected distributions of physical quantities in the event, e.g. transverse momentum.

Search engine

The main class to perform selection is HepMC3::Selector.

```
ConstSelectorPtr status = std::make_shared<SelectorWrapper<int> >([](ConstParticlePtr p)->int{return p->status();});
ConstSelectorPtr pt = std::make_shared<SelectorWrapper<double> >([](ConstParticlePtr p)->double{return p->momentum().pt();});
```

One can then use the Selector to construct Filter functions that evaluate on particles, e.g.

```
Filter is_stable = (*status) == 1;
bool stable = is_stable(p);
bool beam = (*status == 4)(p);
```

Selector contains a few standard Selectors already defined, e.g.

```
ConstGenParticlePtr p;
(Selector::STATUS == 1)(p);
(Selector::PT > 15.)(p);
(abs(Selector::RAPIDITY) < 2.5)(p);
```

One can also combined them e.g.

```
Filter myCuts = (Selector::PT > 15.) && (*abs(Selector::RAPIDITY) < 2.5) || (Selector::PT > 100.);
bool passCuts = myCuts(p);
```

Advantages of C++11 in action.

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