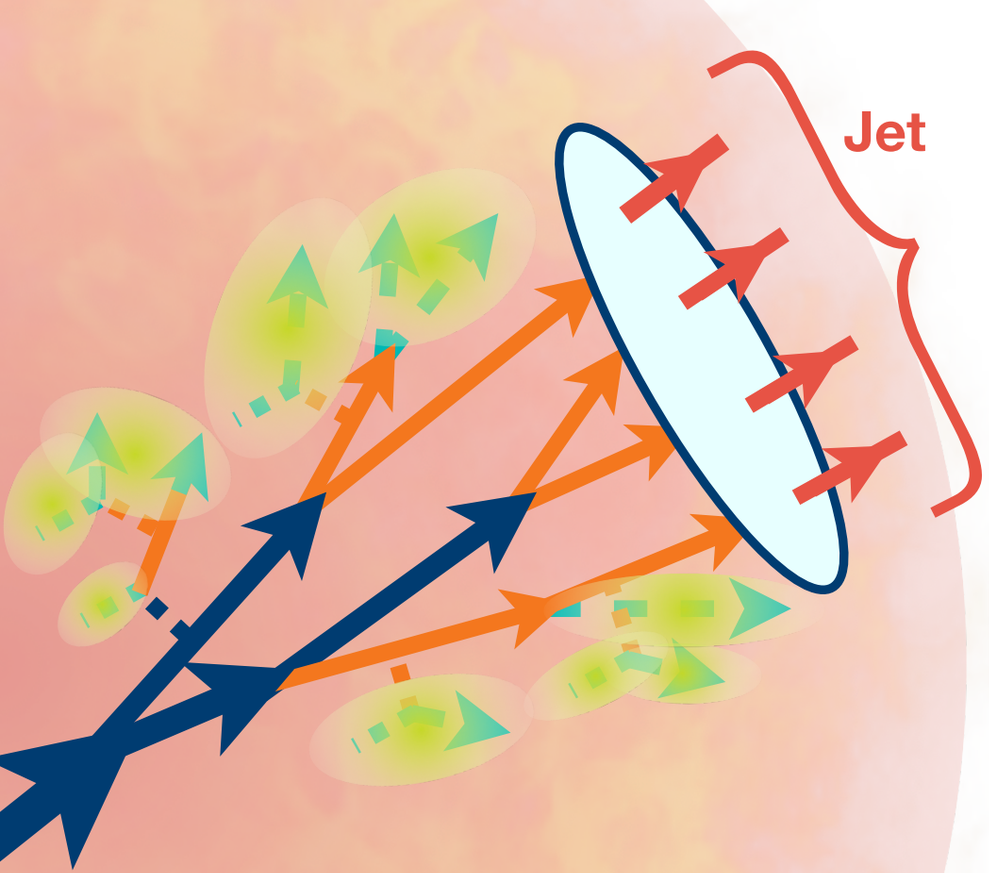
# The JETSCAPE Framework

## Lecture

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**(UC Berkeley / LBNL)**

***JETSCAPE Online School***
**July 13 2020**

Ask questions in slack channel: **#software-mulligan**

# JETSCAPE

## Event generator

- A ***framework*** for general-purpose MC event generators in heavy-ion collisions

**https://github.com/JETSCAPE/JETSCAPE**

## Statistical toolkit

- Extract model parameters via Bayesian analysis with Gaussian Process Emulators

**https://github.com/JETSCAPE/STAT**

**Topic for today**

# A general-purpose MC framework

**JETSCAPE is not just for jets!**
**It is a framework for *general-purpose* event generators**

1 **The JETSCAPE framework is modular**

The core framework decides how physics modules can interact with each other — but the modules themselves can be user-contributed

2 **Physics modules are open-source**

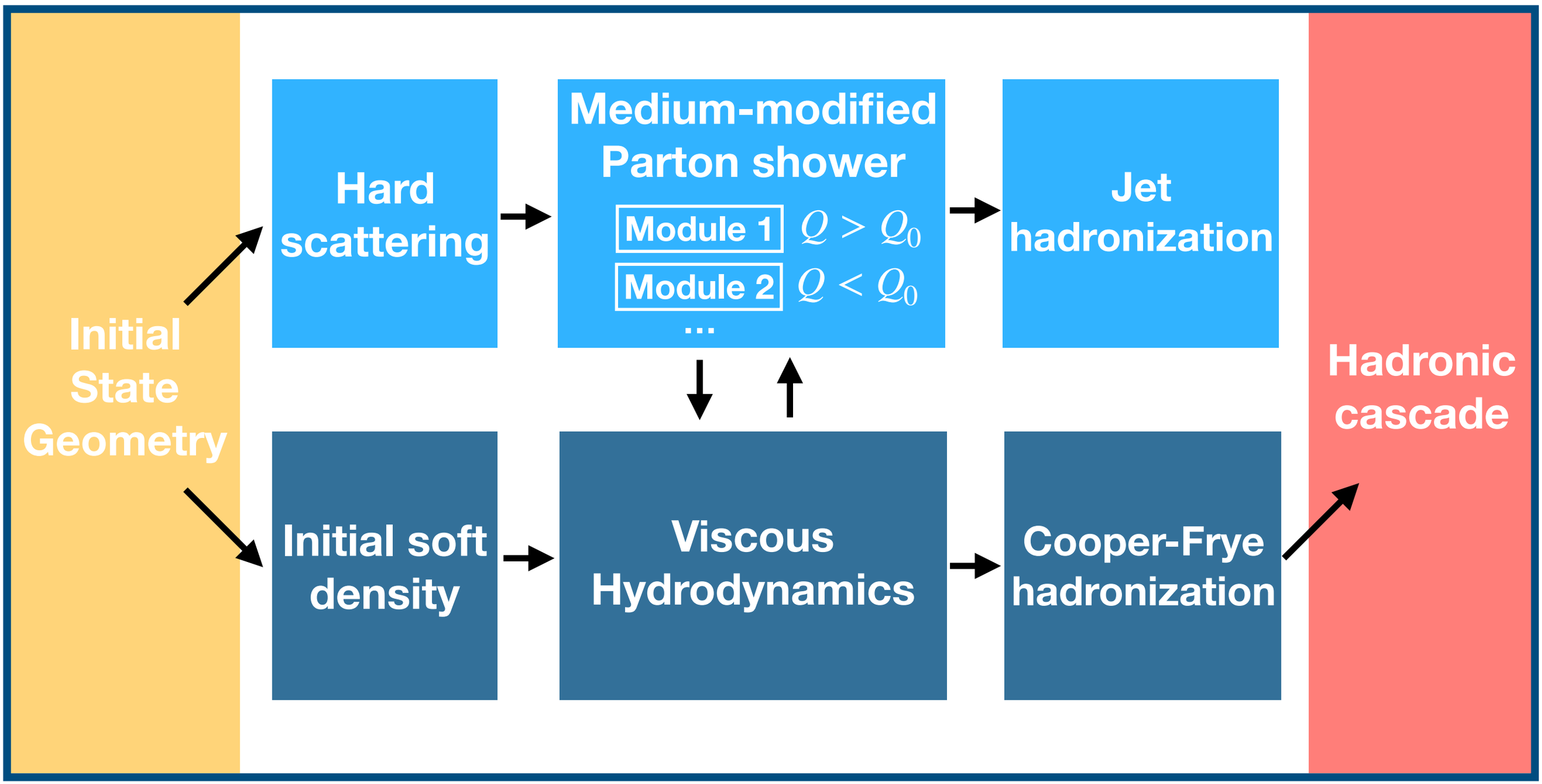
Key improvement in heavy-ion physics — predictions can be checked against many observables simultaneously

**A unified framework has clear benefits when we want to compare models of one particular part of a multi-stage event evolution**

# JETSCAPE Event Generator

**JETSCAPE Manual: 1903.07706**

https://github.com/JETSCAPE/JETSCAPE



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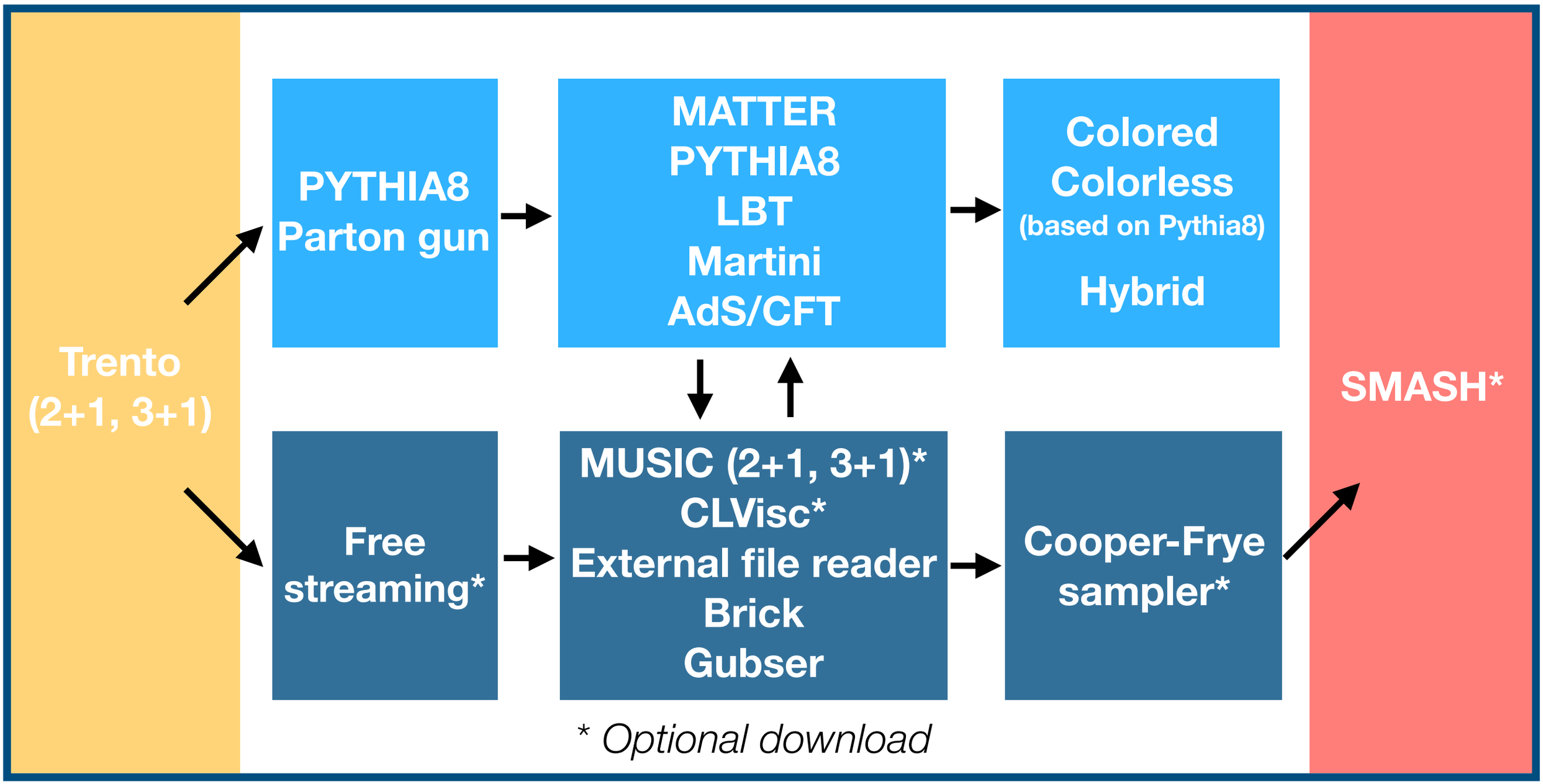

# The current status

**The framework is available and ready for public use**

**Many recent improvements to user experience**

**Ideal time to contribute additional physics modules**

## JETSCAPE 3.1

The JETSCAPE simulation framework is an overarching computational envelope for developing complete event generators for heavy-ion collisions. It allows for modular incorporation of a wide variety of existing and future software that simulates different aspects of a heavy-ion collision. For a full introduction to JETSCAPE, please see The JETSCAPE framework.

Please cite The JETSCAPE framework if you use this package for scientific work.

### Installation

Please see the Installation Instructions.

### Running JETSCAPE

The main executable to generate JETSCAPE events is `runJetscape`, located in the `build/` directory. To generate JETSCAPE events, you should pass an XML file specifying the settings with which you would like to run:

```
./runJetscape ../config/jetscape_user.xml
```

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**What this means for physics comparisons**

First physics results of “out-of-the-box” models from the JETSCAPE Collaboration

Use responsibly — it is a framework — you get out the physics you put in

There is a lot of theoretical work inside — but currently only slices of the theory landscape

→ **We are at the start of the exciting phase — well-controlled theory comparisons**

# Steps to run JETSCAPE

1. **Install and build JETSCAPE**
2. **Create a configuration file: *config/jetscape_user.xml***
   - **List of which modules to run, and which model parameters to use**
   - See examples in: *config/*
3. **Execute *runJetscape***

***That's it!***

# Installing JETSCAPE

https://github.com/JETSCAPE/JETSCAPE/wiki/JETSCAPE-Installation

## JETSCAPE Installation

James Mulligan edited this page on Mar 17 · 1 revision

To run JETSCAPE, you will need to install several software pre-requisites, and then build JETSCAPE.

### Recommended Installation

We recommend to install JETSCAPE and its pre-requisities using Docker.

### Manual Installation (not recommended)

Please see the instructions here.

### External packages

To run certain external software (MUSIC, CLVisc, SMASH), you will need to explicitly download them, and you may need to re-run `cmake` with specific command-line options. Scripts to download and install the external packages are provided in `external_packages/`. Please see external packages for full details.

The available cmake options are:

```
cmake .. -DUSE_MUSIC=ON -DUSE_ISS=ON -DUSE_FREESTREAM=ON -DUSE_SMASH=ON -DUSE_CLVISC=ON
```

# Installing JETSCAPE

## Docker support

One line of code to create environment with all software pre-reqs

README.md

### Using JETSCAPE via Docker

Docker is a software tool that allows one to deploy an application in a portable environment. A docker "image" can be created for the application, allowing any user to run a docker "container" from this image. We have prepared a docker image for the JETSCAPE environment, which allows you to use JETSCAPE on macOS or linux without installing a long list of pre-reqs or worrying about interference with software you already have installed. Step-by-step instructions are provided below.

Create and start a docker container that contains all of the JETSCAPE pre-reqs:

**macOS:**

```
docker run -it -v ~/jetscape-docker:/home/jetscape-user --name myJetscape jetscape/base:v1
```

**linux:**

```
docker run -it -v ~/jetscape-docker:/home/jetscape-user --name myJetscape --user $(id -u):$(id -g)
```

https://github.com/JETSCAPE/JETSCAPE/tree/master/docker

**For this school, we require you to run JETSCAPE via docker**

This allows everyone in the school to have a uniform software environment

# Configuring JETSCAPE

**JETSCAPE is configured via two XML files**

- **Master XML file — *you don't modify this***
  - Contains default values for every possible module and parameter
- **User XML file — *you provide this***
  - List of which modules to run, and which default parameter values to override

# Configuring JETSCAPE

**Master XML file**

*you don't modify this*

**A "database" of all possible modules and parameters**

*All possible initial state module parameters*

...

config/jetscape_master.xml

```
<jetscape>

 <!-- General settings -->
 <nEvents> 100 </nEvents>
 <setReuseHydro> true </setReuseHydro>
 <nReuseHydro> 10 </nReuseHydro>

 <!-- Technical settings -->
 <debug> on </debug>
 <remark> off </remark>
 <vlevel> 0 </vlevel>
 <enableAutomaticTaskListDetermination> true </enableAutomaticTaskListDetermination>

 <!--  JetScape Writer Settings -->
 <outputFilename>test_out</outputFilename>
 <JetScapeWriterAscii> off </JetScapeWriterAscii>
 <JetScapeWriterAsciiGZ> off </JetScapeWriterAsciiGZ>
 <JetScapeWriterHepMC> off </JetScapeWriterHepMC>

 <!--  Random Settings. For now, just a global  seed. -->
 <Random>
   <seed>1</seed>
 </Random>

 <!-- Inital State Module  -->
 <IS>
   <!-- x range [-grid_max_x, grid_max_x] -->
   <!-- y range [-grid_max_y, grid_max_y]-->
   <!-- longitudinal range [-grid_max_z, grid_max_z]-->
   <!-- in units of [fm] -->
   <grid_max_x> 10 </grid_max_x>
   <grid_max_y> 10 </grid_max_y>
   <grid_max_z> 0 </grid_max_z>
   <grid_step_x> 0.2 </grid_step_x>
   <grid_step_y> 0.2 </grid_step_y>
   <grid_step_z> 0.2 </grid_step_z>

   <Trento use_module="pre_defined">
     <!-- pre-defined system: default collisions have auau200, pbpb2760, pbpb5020, more in
          the future -->
     <pre_defined collision_system="auau200" centrality_min="30" centrality_max="40" />
     <!-- user-defined system: to get one event in 0-100% centrality range -->
     <user_defined projectile="Au" target="Au" sqrts="200" cross_section="4.2" />
   </Trento>

   <!-- Options to read initial conditions from saved file  -->
   <initial_profile_path>../examples/test_hydro_files</initial_profile_path>
 </IS>
```

*All possible basic settings*

...

# Configuring JETSCAPE

**User XML file**

*you provide this*

**Specify which modules to run**

**Specify parameter values (otherwise taken from master)**

See examples in: config/

*Set nEvents*

*Set Writer*

*Activate modules (in order)*

*Override values*

```
<jetscape>

  <nEvents> 200 </nEvents>

  <!-- Jetscape Writer -->
  <JetScapeWriterAscii> on </JetScapeWriterAscii>

  <!-- Inital State Module  -->
  <IS>
    <Trento use_module="user_defined"> </Trento>
  </IS>

  <!-- Hard Process -->
  <Hard>
    <PGun> </PGun>
  </Hard>

  <!-- Hydro  Module  -->
  <Hydro>
    <MUSIC> </MUSIC>
  </Hydro>

  <!--Eloss Modules -->
  <Eloss>
    <Matter>
      <Q0> 2.0 </Q0>
      <qhat0> 5.0 </qhat0>
    </Matter>
    <AdSCFT> </AdSCFT>
  </Eloss>

  <!-- Jet Hadronization Module -->
  <JetHadronization>
    <name>colored</name>
  </JetHadronization>

</jetscape>
```

# Running JETSCAPE

**There is one central executable: runJetscape.cc**

- Modules are automatically added according to User XML
- You don’t ever need to re-compile this executable

**Pass your user configuration file as a command line argument:**

```
./runJetscape /path/to/my/user_config.xml
```

# JETSCAPE Output

**JETSCAPE output contains:**

Final state hadrons
Final state partons
Full parton-shower history

**You can produce JETSCAPE output in two formats:**

**Ascii**

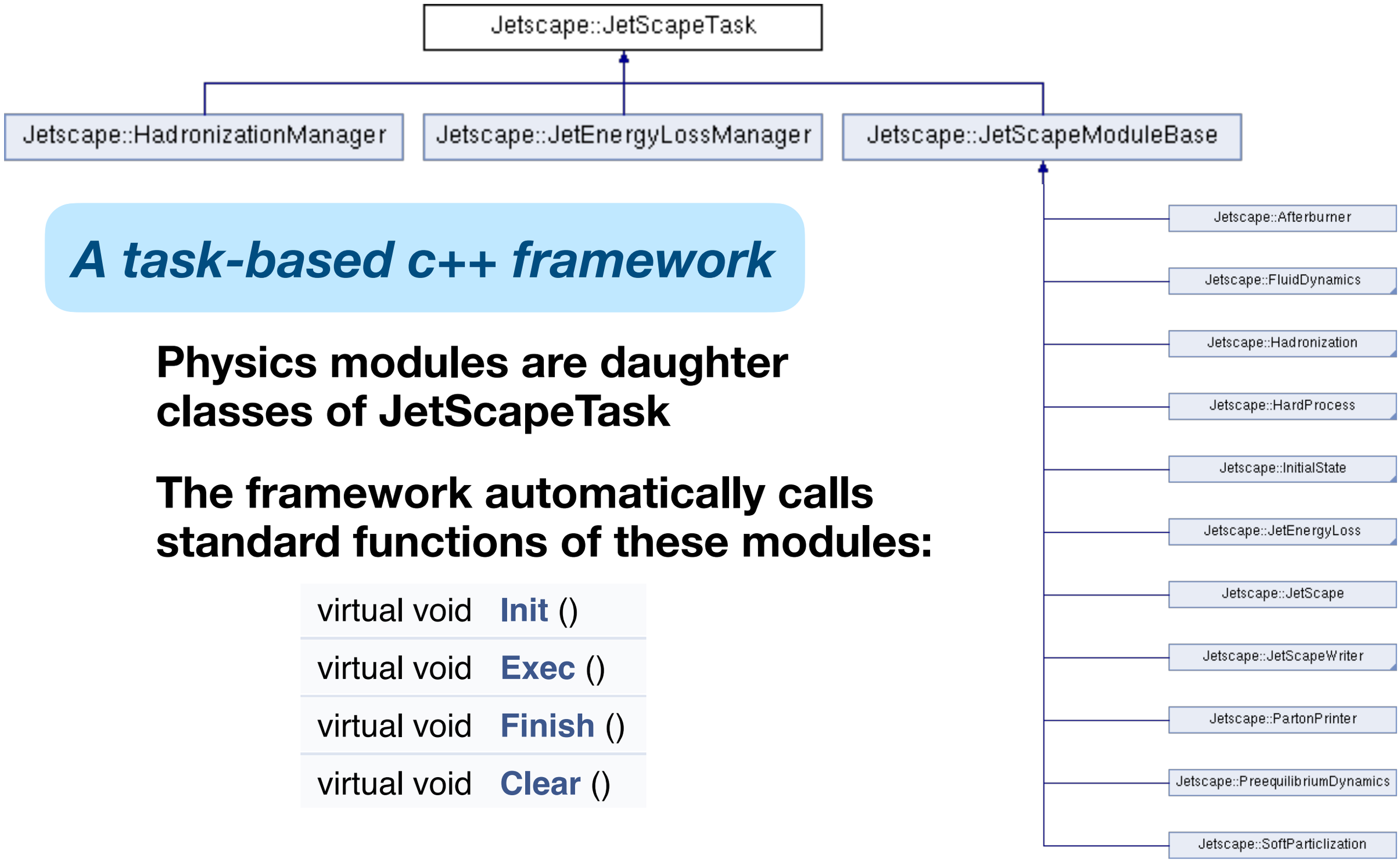
Custom JETSCAPE format
Executables are provided to extract final-state hadrons/partons
Can also directly write gzipped ascii

**HepMC3**

Standard event format (larger size)
Compatible with Rivet

# Framework design: Inner workings

*arXiv 1903.07706*




***A task-based c++ framework***

**Physics modules are daughter classes of JetScapeTask**

**The framework automatically calls standard functions of these modules:**

| | |
|---|---|
| virtual void | **Init** () |
| virtual void | **Exec** () |
| virtual void | **Finish** () |
| virtual void | **Clear** () |

# Framework design: Inner workings

*arXiv 1903.07706*

**The framework defines how different types of modules can interact with each other**

For example: Jet energy loss module needs access to hydro info

**This is implemented in a "signal-slot" paradigm:**

| Module 1 | Module 2 | Signal | Slot |
|---|---|---|---|
| `JetEnergyLossManager` | `HardProcess` | `GetHardPartonList()` | `GetHardPartonList()` |
| `JetEnergyLoss` | `FluidDynamics` | `jetSignal()` | `UpdateEnergyDeposit()` |
| `JetEnergyLoss` | `FluidDynamics` | `edensitySignal()` | `GetEnergyDensity()` |
| `JetEnergyLoss` | `FluidDynamics` | `GetHydroCellSignal()` | `GetHydroCell()` |
| `JetEnergyLoss` | `JetEnergyLoss` | `SentInPartons()` | `DoEnergyLoss()` |
| `Hadronization` | `Hadronization` | `TransformPartons()` | `DoHadronization()` |
| `HadronizationManager` | `HardProcess` | `GetHadronList()` | `GetHadronList()` |
| `HadronizationManager` | `JetEnergyLoss` | `GetFinalPartonList()` | `SendFinalStatePartons()` |

Table 3: The list of all connection methods between JETSCAPE modules provide by the `JetScapeSignalManager`.

# Framework design: Inner workings

arXiv 1903.07706

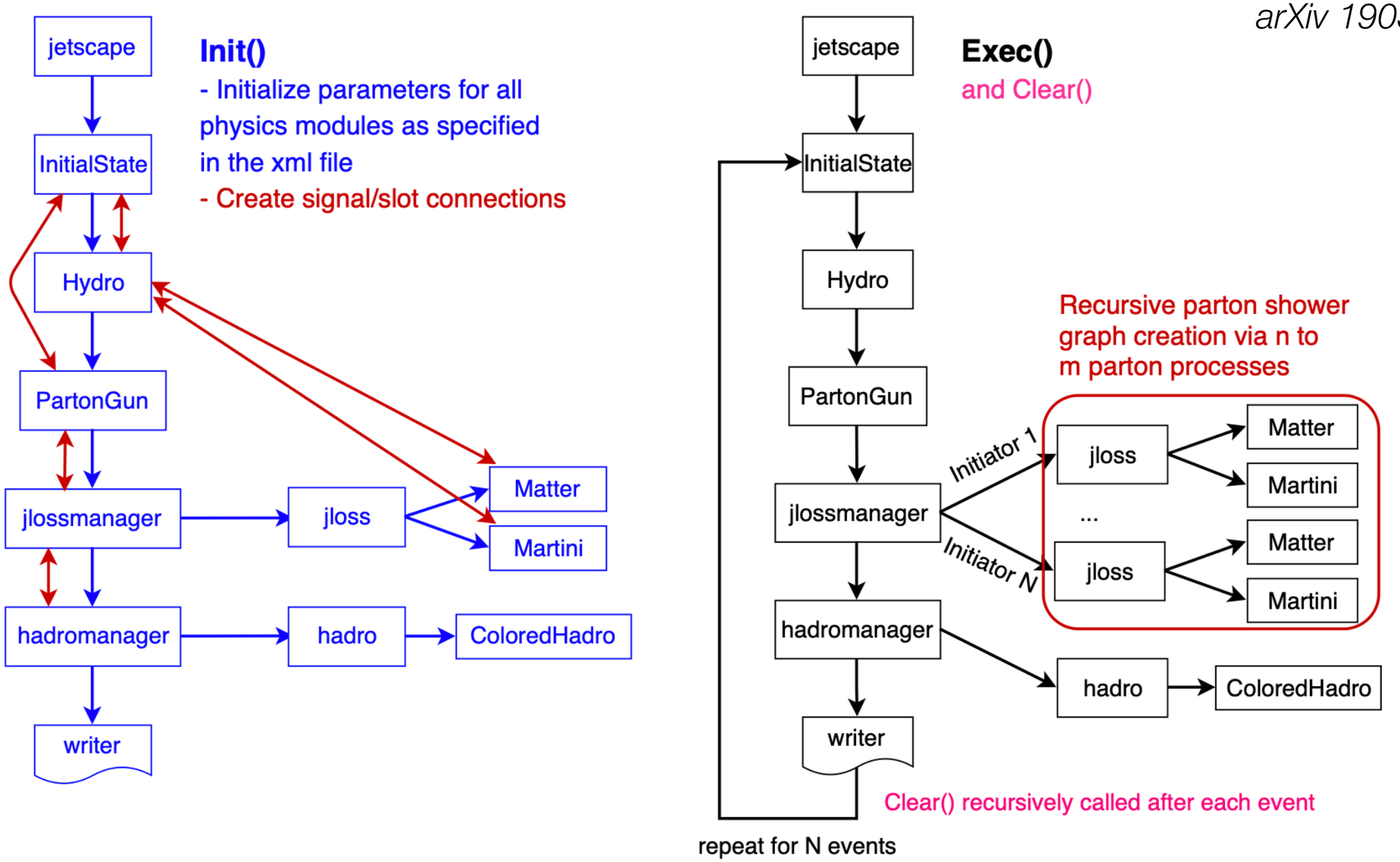


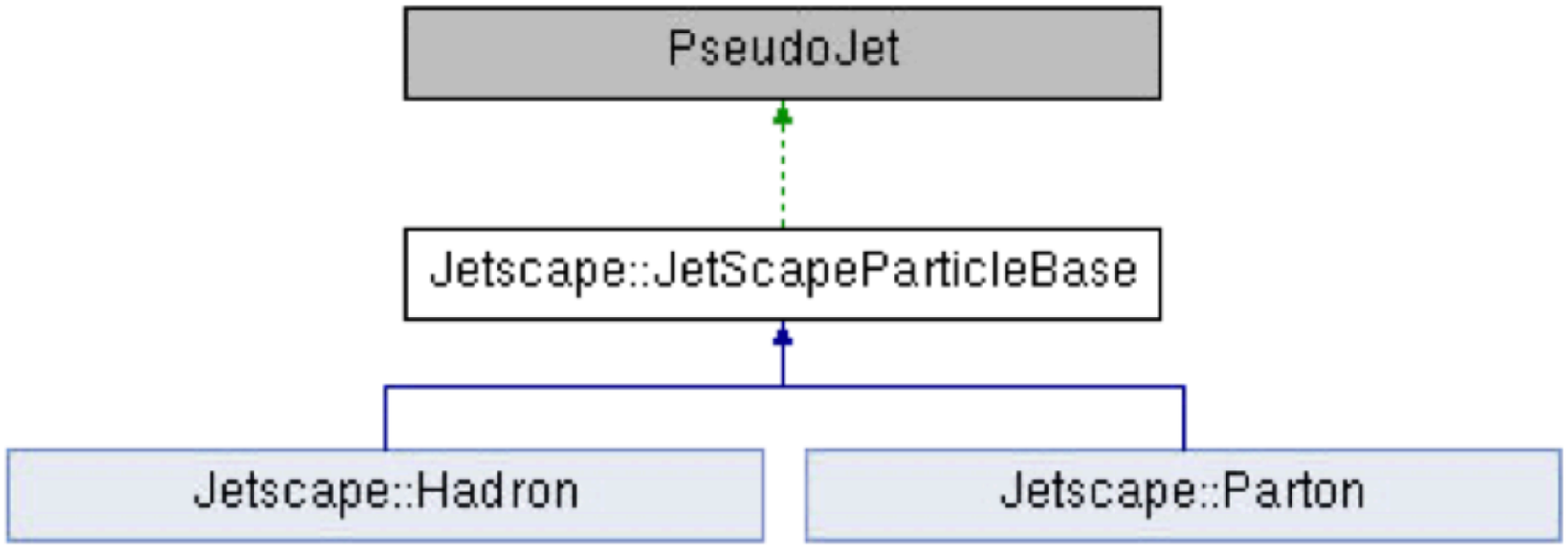

Figure 4: Example workflow of the `Init()` (left side) and `Exec()` (and `Clear()`) (right side) phase of the task based JETSCAPE framework (the not extensively used Finish() phase is omitted). One should be aware that the created signal/slot connections in the `Init()` phase are of course present and utilized in the `Exec()` phase, but are not show in the figure for simplicity.

# Data structures

*arXiv 1903.07706*

Class **JetScapeParticleBase**

- The base class for all the JETSCAPE particles
- Privately inherits from FastJet PseudoJet and has
  - PID and rest mass
  - A location (4-vector)
  - Label and status
- Derived classes so far:
  - Parton and Hadron



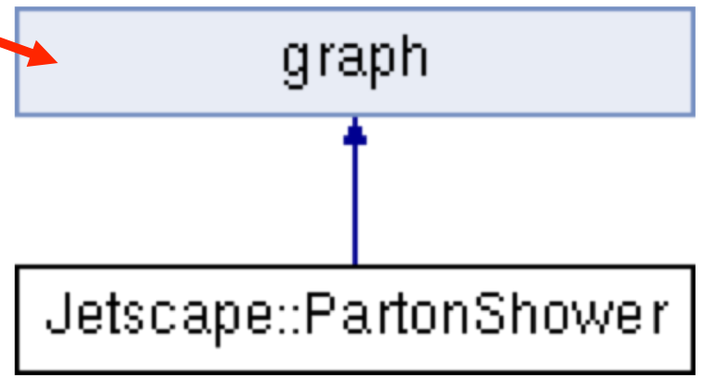

```
Parton (int label, int id, int stat, const FourVector& p, const FourVector& x);
Parton (int label, int id, int stat, double pt, double eta, double phi, double e, double* x=0);
 ...
```

*Slide from: J. Putschke and E. Khalaj*

# Data structures

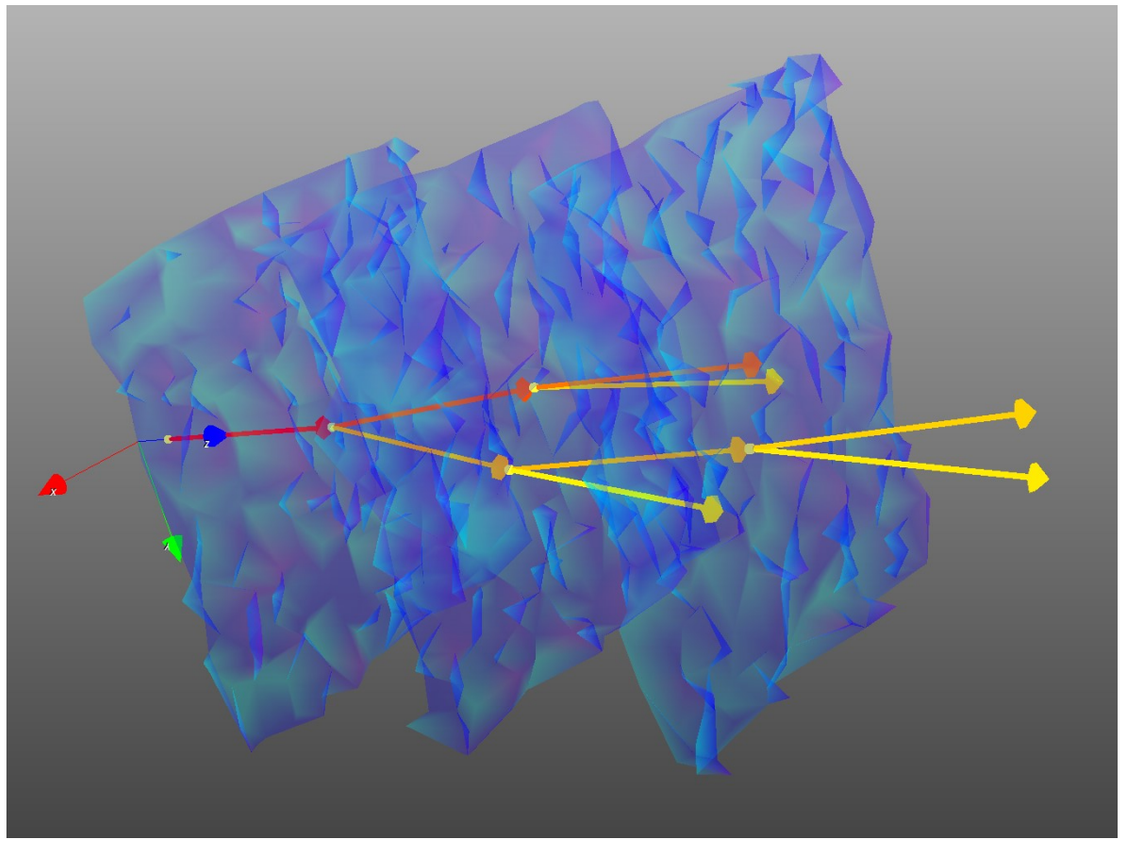
- Class **PartonShower**
- Models parton showering as a **Graph**
  - Partons are the **edges**
  - Partons split at **vertices**

**GTL Graph Template Library**
[https://github.com/rdmpage/graph-template-library]




```
                    int   GetNumberOfParents (int n)
                    int   GetNumberOfChilds (int n)
ared_ptr< Parton > >  GetFinalPartons ()
< fjcore::PseudoJet >  GetFinalPartonsForFastJet ()
                    int   GetNumberOfPartons () const
                    int   GetNumberOfVertices () const
```

**Provides functionalities to query shower**



*Slide from: J. Putschke and E. Khalaj*

# Contributing modules

*arXiv 1903.07706*

**JETSCAPE is designed for users to contribute new physics modules**

Framework connects those modules together

**To contribute modules, just need to interface to JETSCAPE:**

Implement appropriate standard functions:

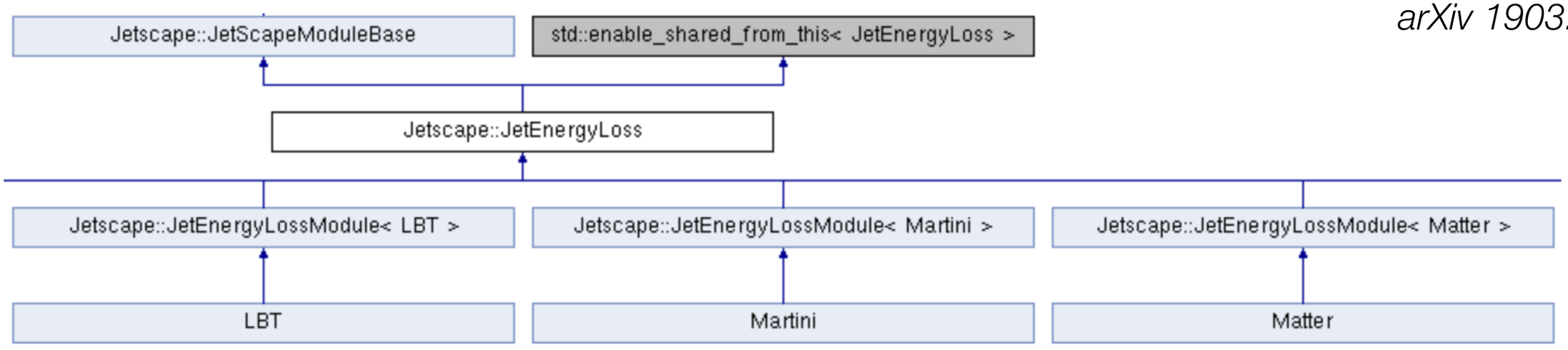
| | |
|---|---|
| virtual void | **Init** () |
| virtual void | **Exec** () |
| virtual void | **Finish** () |
| virtual void | **Clear** () |

Use appropriate signal/slot info to interact with other modules

See existing modules for examples

# Example: Jet energy loss

*arXiv 1903.07706*




- User's code must be a subclass of **JetEnergyLossModule**
- User's code must override **init()** method for initializations
- User's code must override **DoEnergyLoss()** method
  - The actual energy loss calculations happen in this method

**Note:** Jet energy loss modules are "special" in that DoEnergyLoss() is called by the framework **per-parton**. Most modules are called **per-event** with Exec()

*Slide from: J. Putschke and E. Khalaj*

# XML Reader

*arXiv 1903.07706*

**An XML singleton class is provided to allow easy initialization of your module parameters from the XML files**

- **JetScapeXML** provides functionality to first examine the User file for a given parameter, and if it is not found, it takes the value from the Master file.

- To init a parameter, call ***GetElementDouble*({"Eloss", "Martini", "x"})**
  - No need to keep track of XML elements in modules! Just call the function!
  - Similar functions ***GetElementText*, *GetElementInt*, *GetElement***

- An optional second argument in these functions allows the parameter to be optional in the XML file (by default, a parameter is required to be present or else the program will crash when it is not found).

# Summary

**JETSCAPE is a framework for general-purpose heavy-ion event generators**

Modular, extensible — please contribute modules!

**JETSCAPE is a tool for the community**

To enable well-controlled event generator comparisons

As a testbed for theoretical and experimental development

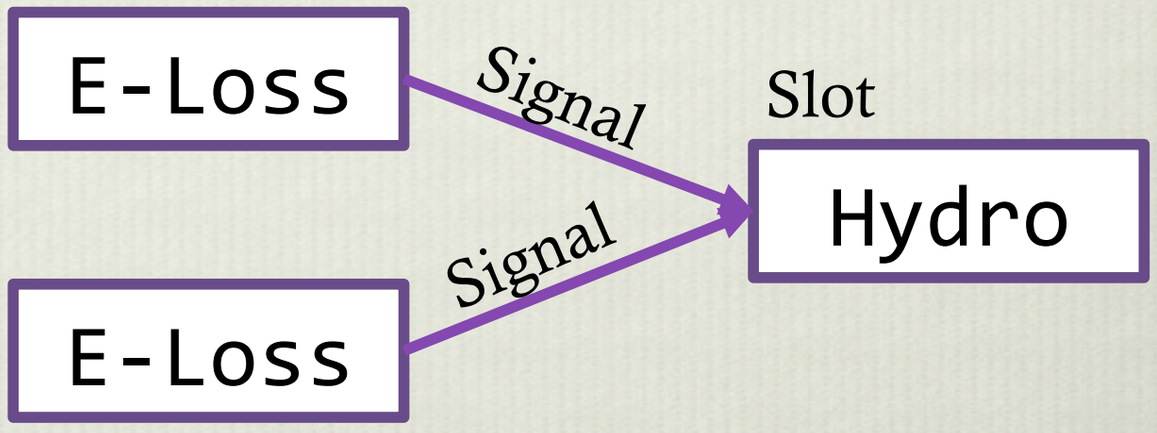
# Thank you!

# Backup

# Advanced: Code design

- C++11
  - Smart pointers
    → no memory leaks!
  - Encapsulation
- Infrastructure:
  - XML reader
  - thread-safe logger
  - Unified random numbers across modules
    → reproducibility!
  - Signal Managers

- Communication via **Signals & Slots**

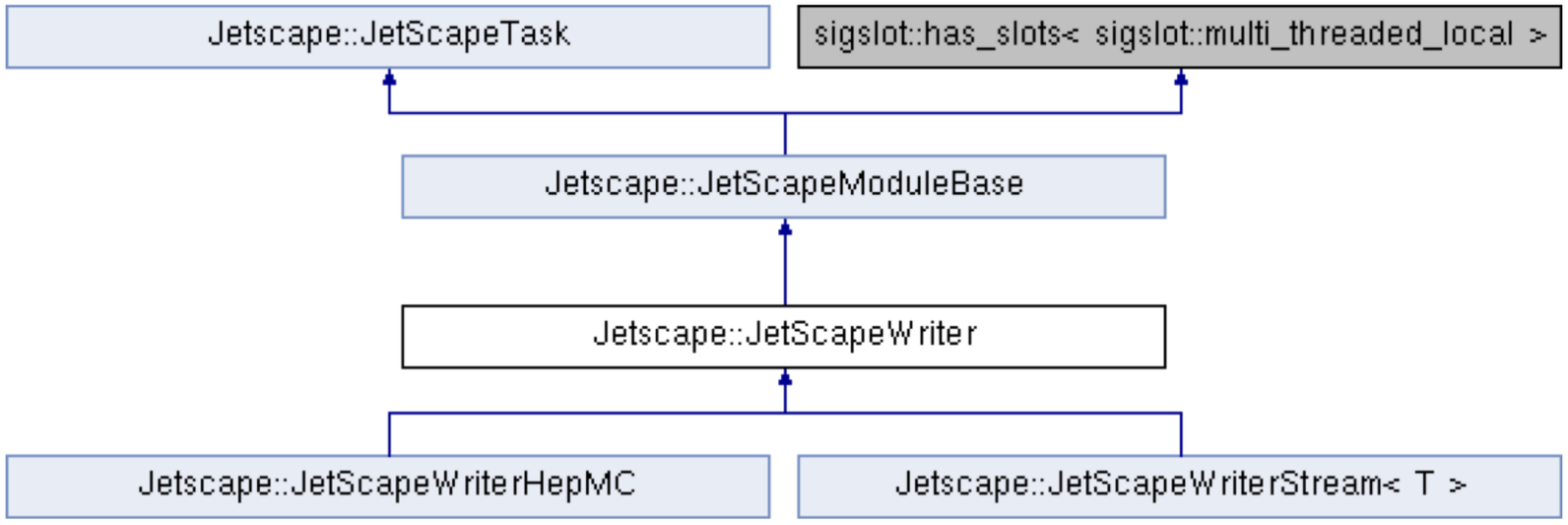



  - Developed by the Qt project,
  - Using light `sigslot`
    by Sarah Thompson
  - Manage module switching

All under the hood!

# Output

## Class **JetScapeWriter**




Subclass of JetScapeModuleBase

- Can be attached as a task

Derived classes so far:

- HepMC writer
- ASCII writer

**Each task overrides its own write method**

| | |
|---|---|
| virtual void | **FinishTask** () |
| virtual void | **FinishTasks** () |
| virtual void | **WriteTasks** (weak_ptr< **JetScapeWriter** > w) |
| virtual void | **WriteTask** (weak_ptr< **JetScapeWriter** > w) |
| virtual void | **CollectHeader** (weak_ptr< **JetScapeWriter** > w) |
| virtual void | **CollectHeaders** (weak_ptr< **JetScapeWriter** > w) |

*Slide from: J. Putschke and E. Khalaj*

# Output

Class **JetScapeReader**

- Base class for reading JETSCAPE output files

Not a JETSCAPE task

- To be used after producing output

Derived classes so far:

- JetScapeReaderAscii

```
void   Next ()
bool   Finished ()
int    GetCurrentEvent ()
int    GetCurrentNumberOfPartonShowers ()
ptr< PartonShower > >   GetPartonShowers ()
hared_ptr< Hadron > >   GetHadrons ()
or< fjcore::PseudoJet >   GetHadronsForFastJet ()
```

**Provides access to PartonShower for final state Partons, and Hadrons**

*Slide from: J. Putschke and E. Khalaj*