

Heavy Ion Jet Interaction Generator

C++ version

[arXiv:1905.11272](https://arxiv.org/abs/1905.11272)

[arXiv:1901.04220](https://arxiv.org/abs/1901.04220)

[arXiv:1811.02131](https://arxiv.org/abs/1811.02131)

[arXiv:1805.02635](https://arxiv.org/abs/1805.02635)

[arXiv:1707.09973](https://arxiv.org/abs/1707.09973)

[arXiv:1701.08496](https://arxiv.org/abs/1701.08496)

Introducing HIJING++: the Heavy Ion Monte Carlo Generator for the High-Luminosity LHC Era

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Presented by A. Krasznahorkay on
CHEP'23 Conference, Norfolk, 9 May, 2023

In collaboration with:

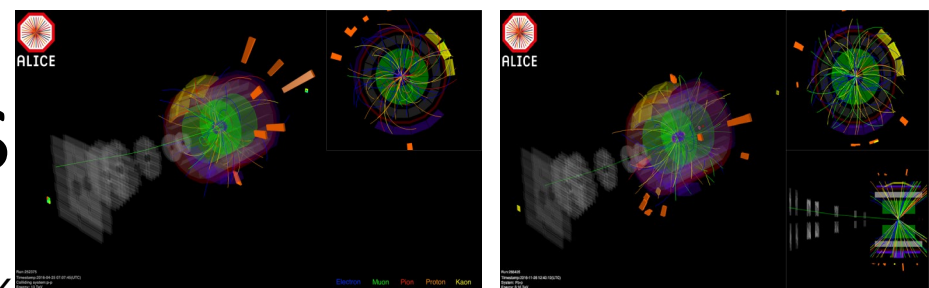
X.N. Wang, M. Gyulassy, B.W. Zhang

Former collaborators:

Sz. Harangozó, B. Csurgai, B. Majoros, G.Y. Ma



MC event generators

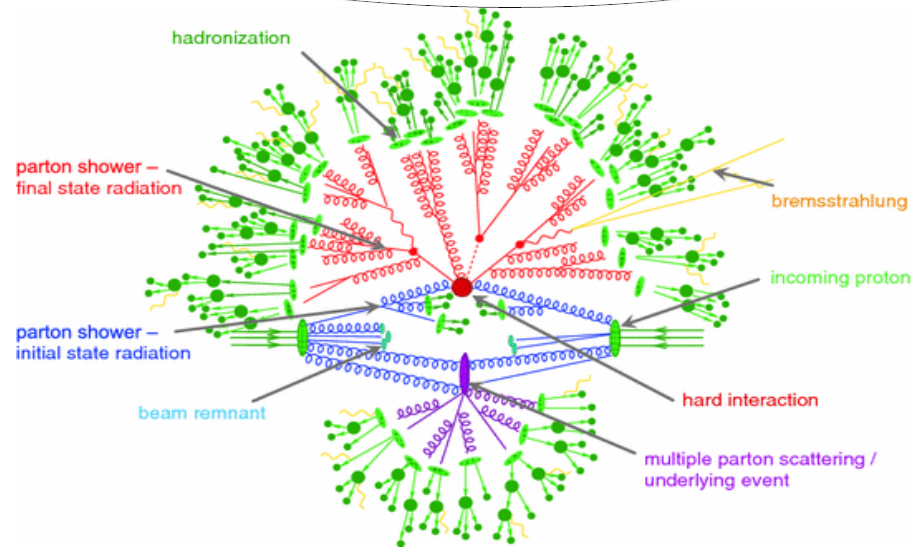
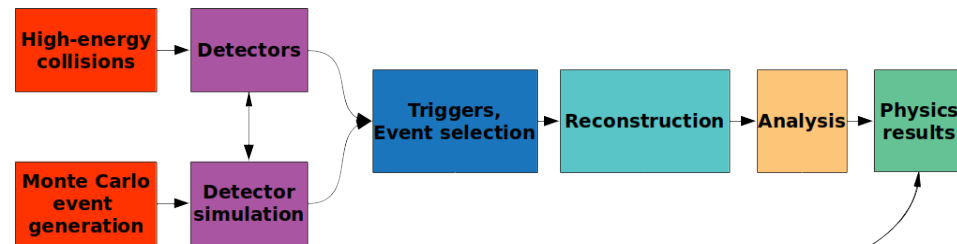


Simulation of one **proton-proton** collision event: complicated, but OK

1) Perturbative QCD calculation (extension of lepton-proton coll.)

$$\frac{d^2\sigma^{lP\rightarrow hX}}{dx dQ^2} = \sum_{i=q,\bar{q},g} \int_x^1 \frac{dz}{z} f_i(z, \mu) d\hat{\sigma}_{il\rightarrow iX} \left(\frac{x}{z}, \frac{Q}{\mu} \right) D_i^h(z)$$

- 1) Additional phenomenological processes:
MPI, color reconnection, hadronization scheme...
- 2) Compromise: computational time \leftrightarrow precision
 - Tons of random numbers
- 3) Empirical parameters: need to be tuned



MC event generators

Simulation of one **heavy-ion** collision event: **even more** complex

1) Perturbative QCD calculations (extension of lepton-proton calc.)

$$\frac{d^2\sigma^{lP\rightarrow hX}}{dx dQ^2} = \sum_{i=q,\bar{q},g} \int_x^1 \frac{dz}{z} f_i(z, \mu) d\hat{\sigma}_{il\rightarrow iX} \left(\frac{x}{z}, \frac{Q}{\mu} \right) D_i^h(z)$$

1) Additional phenomenological processes:
MPI, color reconnection, hadronization scheme...

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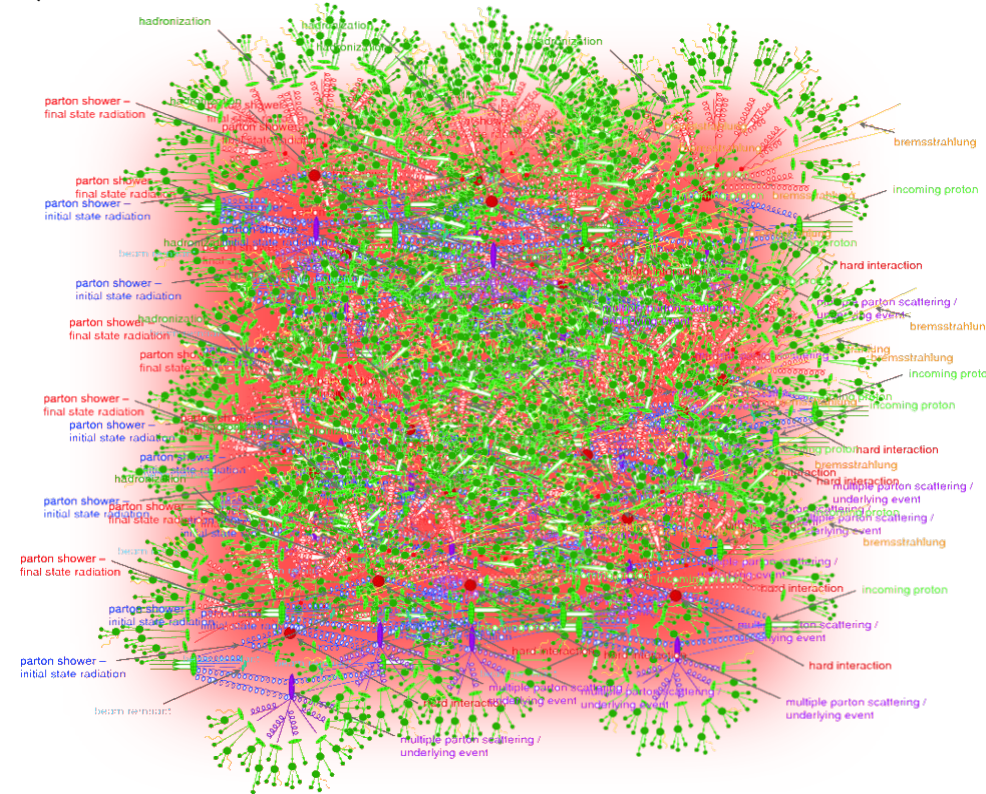
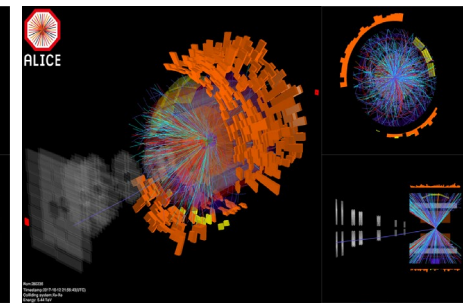
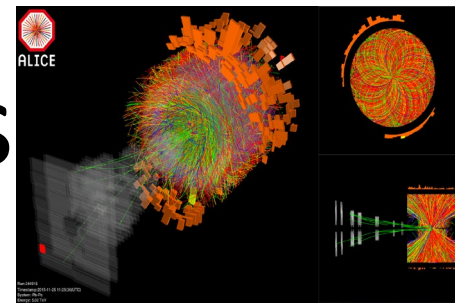
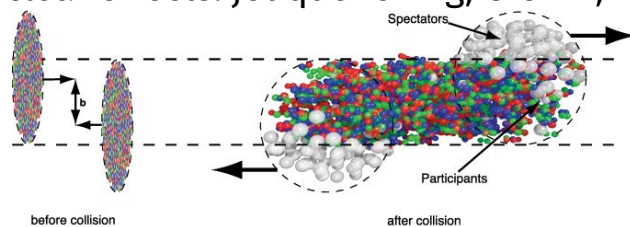
- **Tons** of random numbers

3) Empirical parameters: need to be tuned

4) Multiple nucleon-nucleon interactions

5) Additional nuclear effects: jet quenching, Cronin,

6) shadowing..



Heavy
Ion
Jet

Interaction
Generator
(C++ version)

核易经

[Hé -yì -jīng]

COMPLETE MONTE-CARLO CODE for HEAVY-ION COLLISION (First version was made 33 years ago !)

"Nuclear change theory" \leftrightarrow Book of Changes, "Originally a divination manual in the Western Zhou period (1000–750 BC)"

First (FORTRAN) version: 1991, X.N. Wang, M. Gyulassy, **Phys. Rev. D 44, (1991) 3501.**

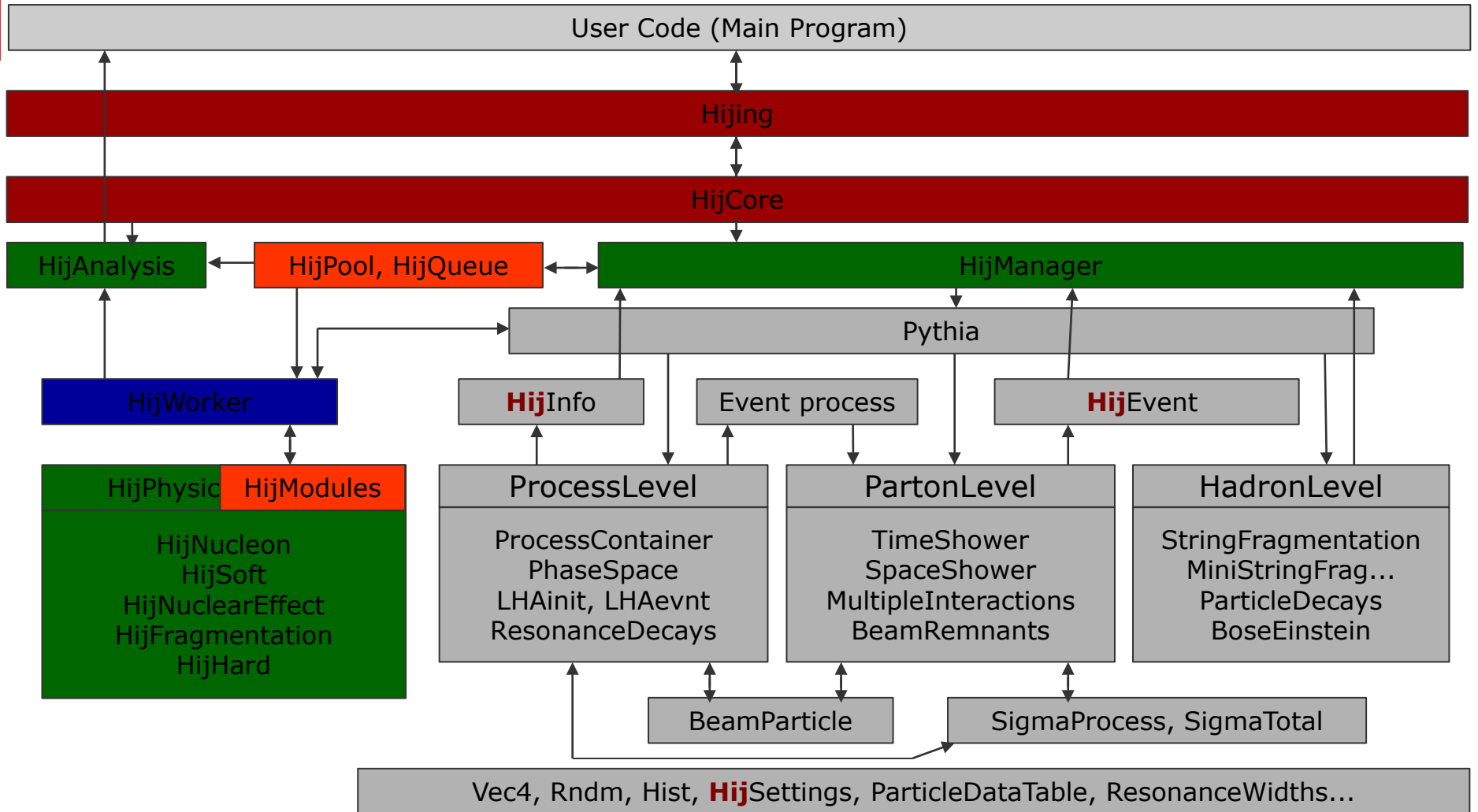
Computational challenge at LHC energies: more than 600 million collision in each second
 \rightarrow HiLumiLHC: even more collisions \rightarrow FCC: final frontier

Requirements for a new version: multithreaded mode, maintainability, intuitive usage

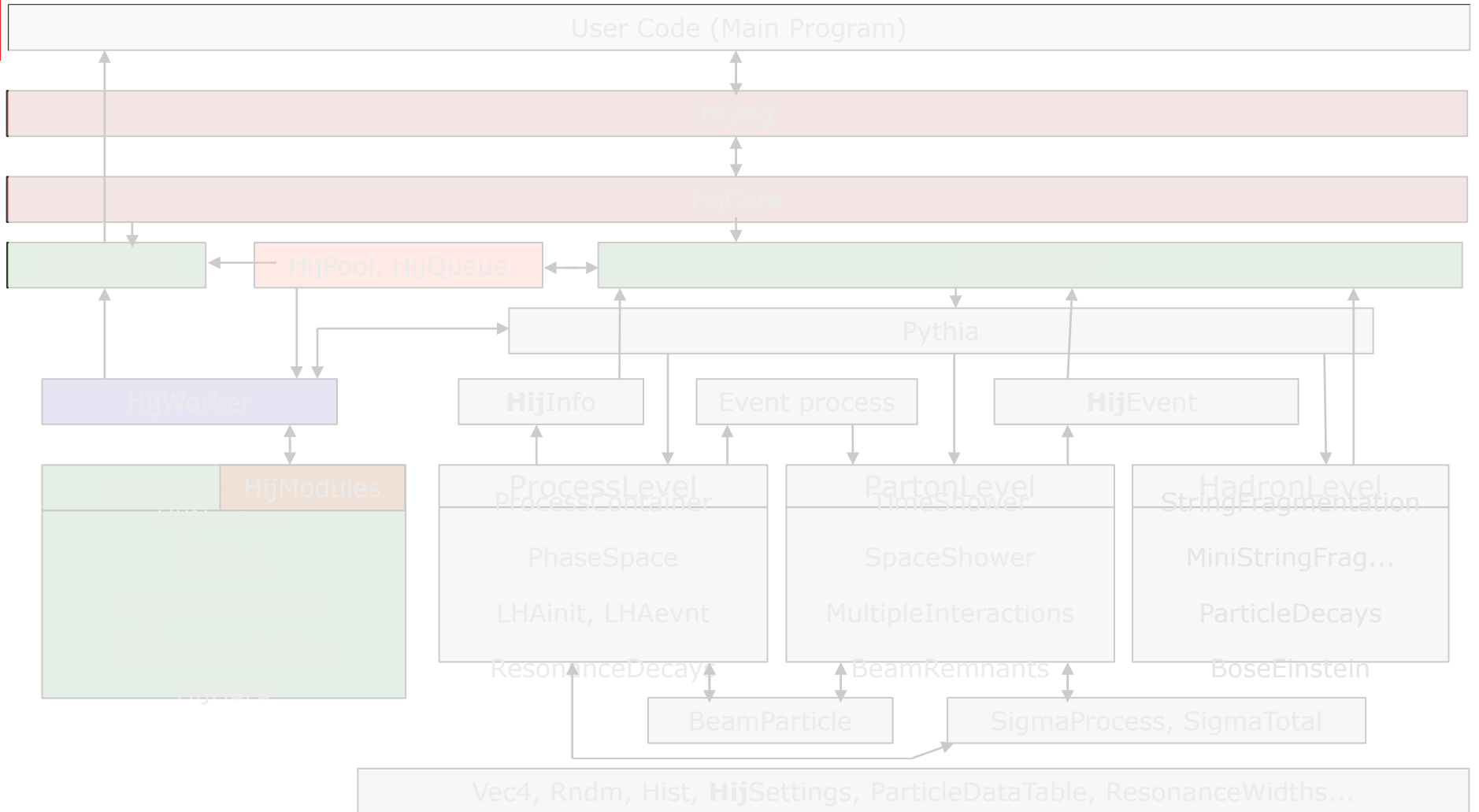
	FORTRAN HIJING	HIJING++ v3.0	HIJING++ v3.1
Precision	simple	double	double
Pythia version	5.3	8.2	8.2+
(n)PDF	GRV98lo	LHAPDF6.2	LHAPDF6.2+
Jet quenching	(✓)	(✓)	(✓)
Multithreading	x	x	✓
Analysis interface	x	x	✓
Module management	x	x	✓
Dependencies, build system	Makefile	Makefile	CMake



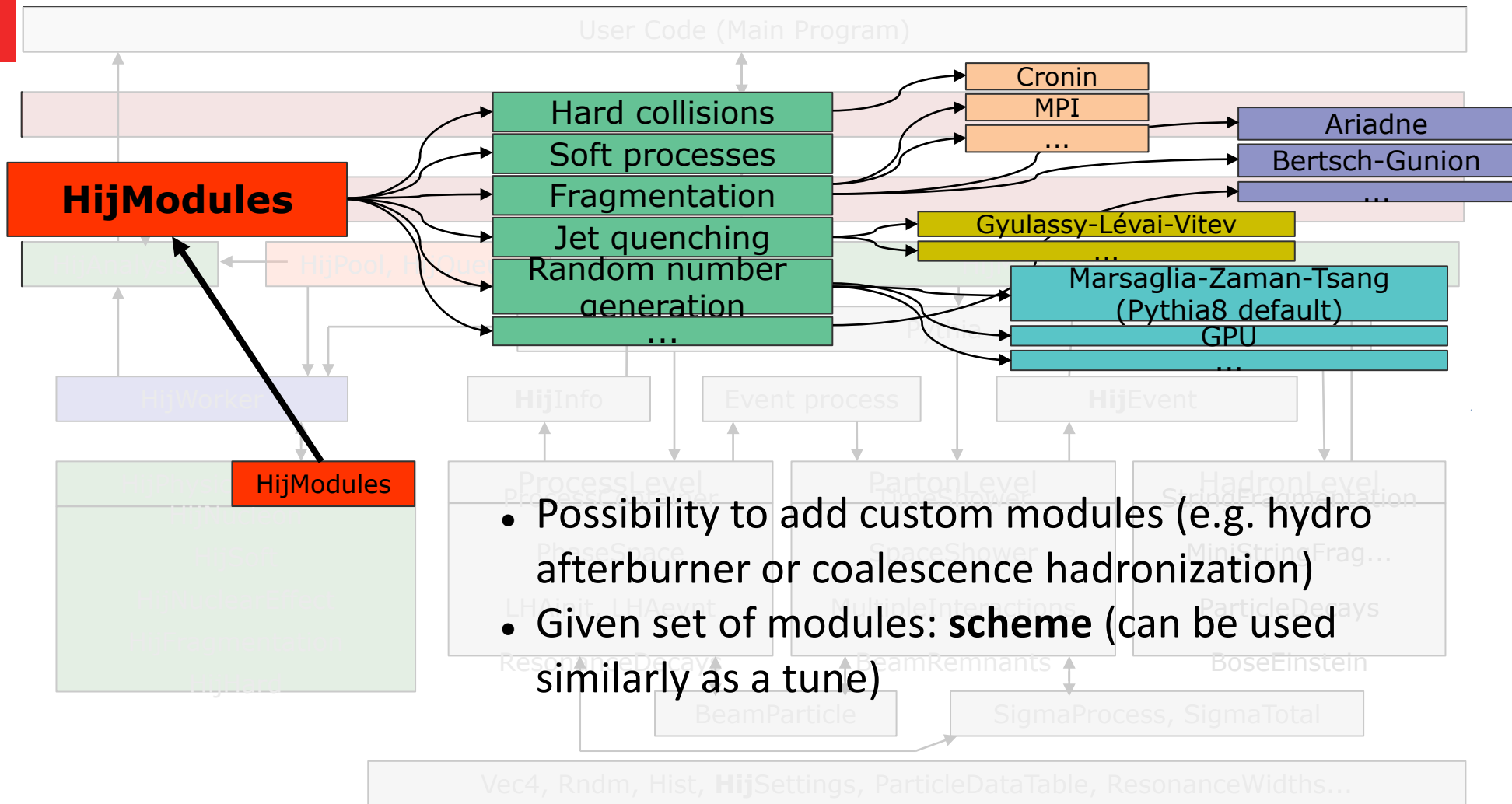
HIJING++ structure



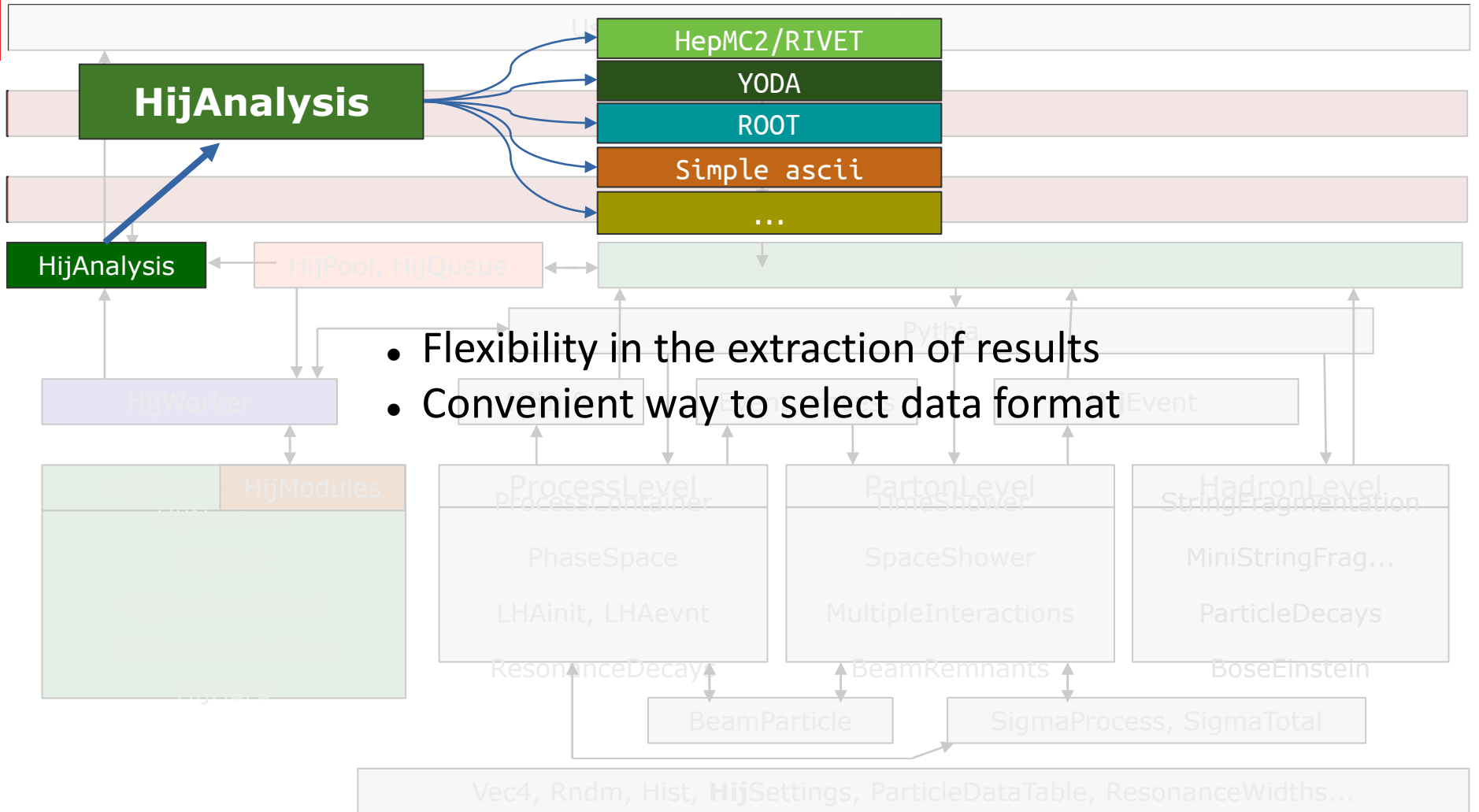
HIJING++ structure



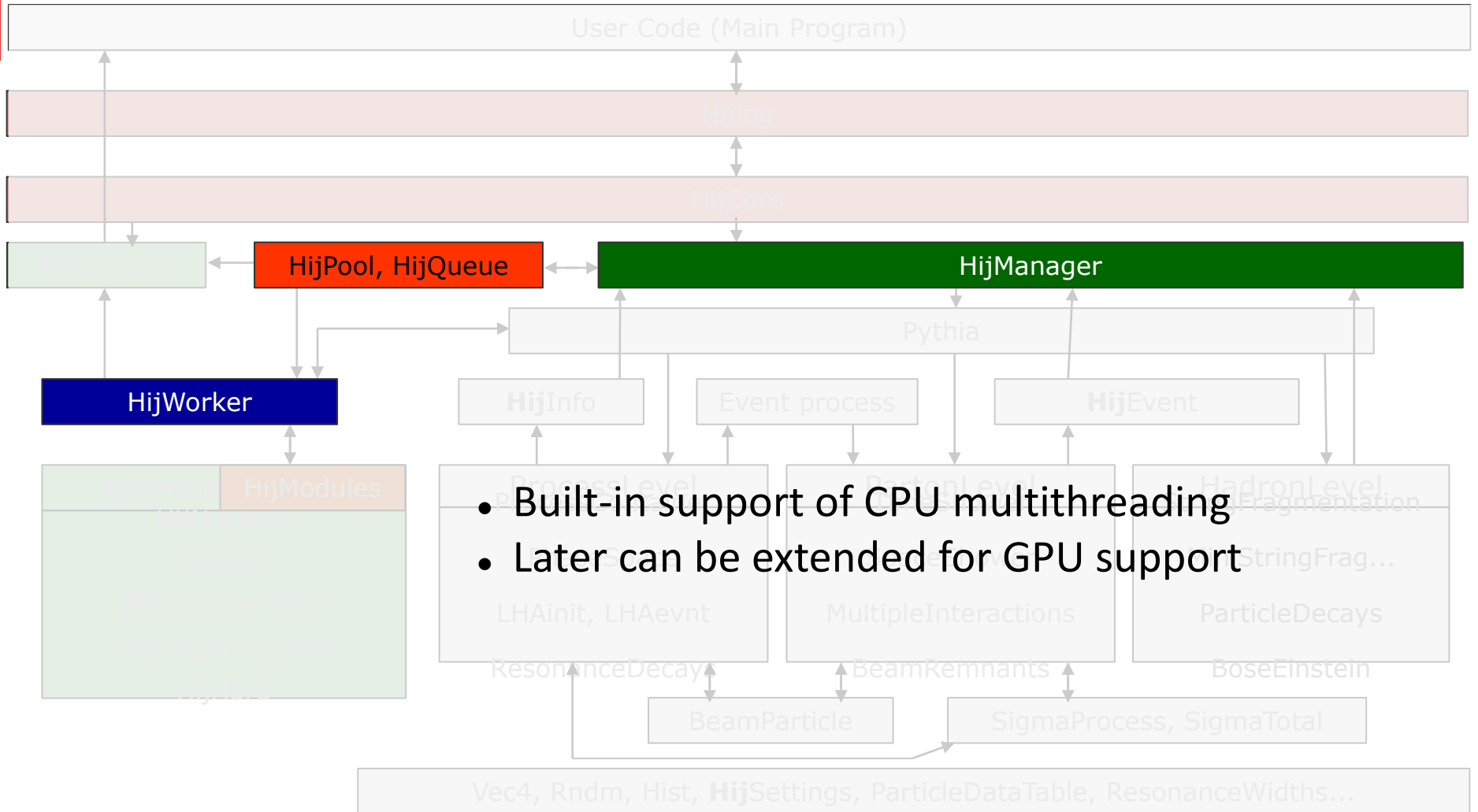
HIJING++ structure



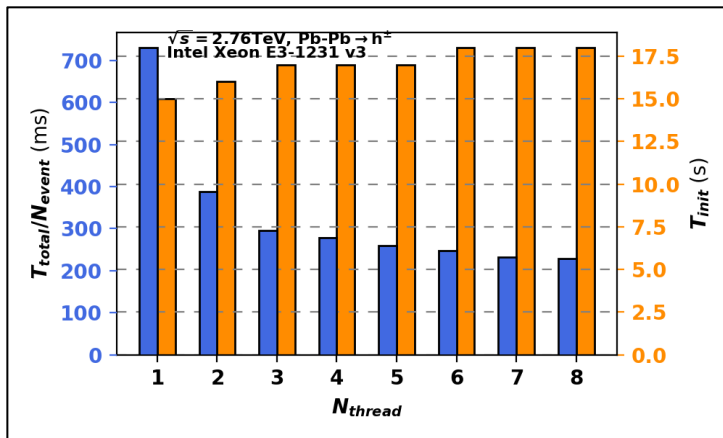
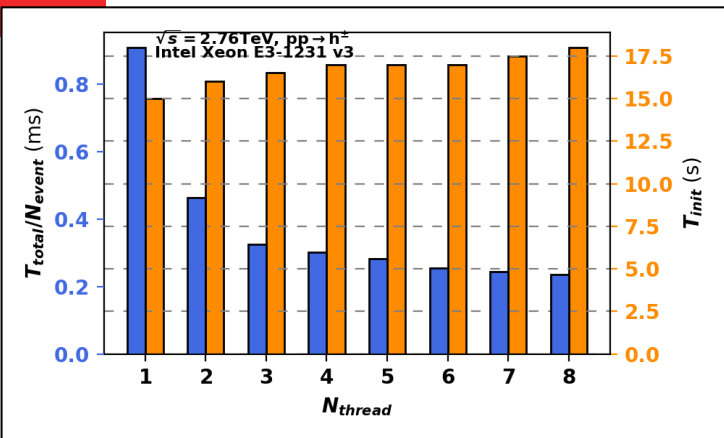
HIJING++ structure



HIJING++ structure



HIJING++ multithreading

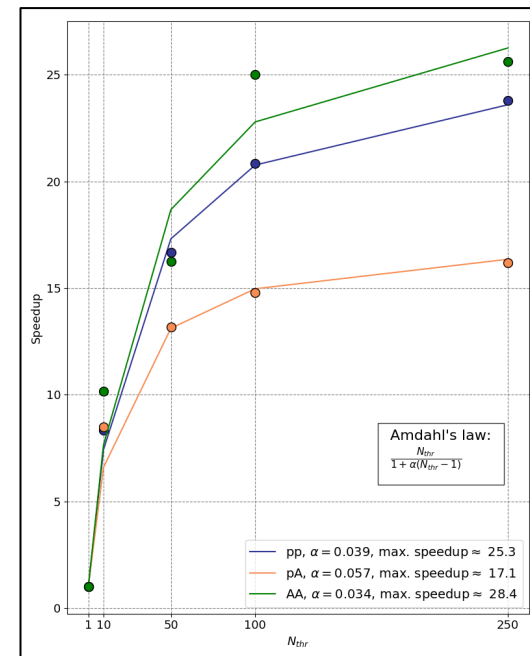
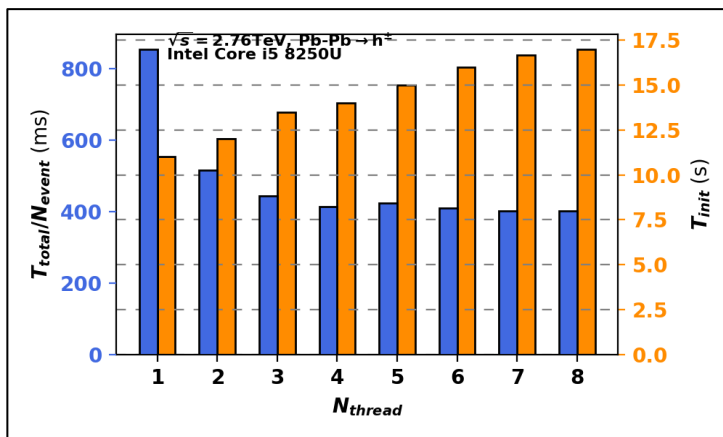
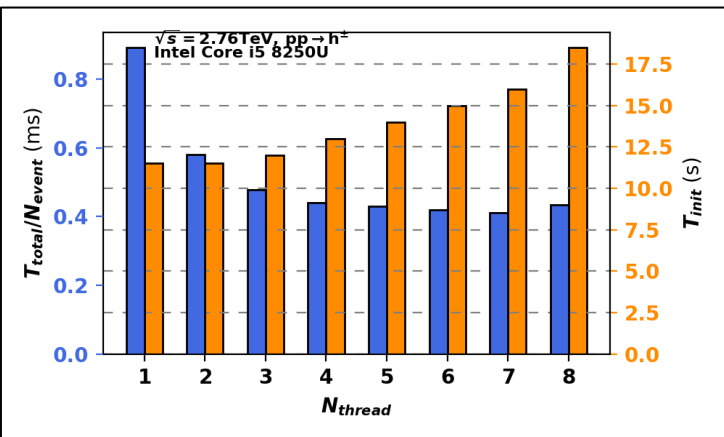


Proton-proton

Data center: Intel Xeon E3 312 (4 core, 8 thread)

Laptop: Intel Core i5 8250U (4 core, 8 thread)

Pb-Pb



CPU	Speedup		
	pp	p-Pb	Pb-Pb
Intel Core i5-8250U	2.6x	2.7x	2.6x
Intel Xeon E3-1231 v3	6.4x	6.6x	4.5x

Installation

Introduction

These are the setup instructions.

Prerequisites

- git
- cmake (min. v3.2)
- LHAPDF6 (v6.2.0 or newer)
- Pythia8 (v8219 or newer)
- c++ compiler with c++14 support (gcc 5 or later)

LHAPDF6

```
wget http://www.hepforge.org/archive/lhapdf/LHAPDF-6.X.Y.tar.gz
tar -xvf LHAPDF-6.X.Y.tar.gz
cd LHAPDF-6.X.Y
./configure --prefix=/where/to/install
make -jN
sudo make install
```

Install (nuclear) pdf sets

The pdf set *GRV98lo* is included in the downloaded package. It is mainly used during the development, since it is an unvalidated, "unofficial" set. However, if you wish

1. copy the *GRV98lo* folder (you can find it in *misc*) into `/path/to/install/LHAPDF6/share/LHAPDF`
2. insert into the file `pdfsets.index` at the correct line number (i.e. between 80000 and 80111) the following: *80060 GRV98lo 1*:

```
sed -i '80000\ META\10LHC\ 2/a 80060 GRV98lo 1' /path/to/install/LHAPDF6/share/LHAPDF/pdfsets.index
```

If you wish to use other npdf sets, visit <http://lhapdf.hepforge.org/pdfsets.html> and repeat the first step.

Pythia8

Download and install the latest version from the official webpage:

HIJING++ analysis interface

```
#include "Hijing.hpp"

using namespace Hijing3;

int main(int argc, char* argv[])
{
    Hijing hijing;

    // collision energy, beams, #threads, event number...
    hijing.readFile("testSettings.cmd");

    hijing.init();
    hijing.newAnalysis("root", "EventEnd", "histo_id1", 50, 0.0, 20.0);
    hijing.newAnalysis("ascii", "EventEnd", "eta_charged_ascii", 20, -5.0, 5.0);
    // ...
    hijing.newAnalysis("yoda", "EventEnd", "ALICE_2010_I880049/d01-x01-y01", binnum_cent, edges_cent);
    hijing.newAnalysis("hepmc2", "ascii", "EventEnd", "output_file");

    hijing.analysisCustomCode(90001, [&](HijEvent &hijevent, pair<double, double> &val) {
        int cent = getMultClass(hijevent.b(), hijevent.Nbin(), hijevent.Npart());
        val.first = edges_cent[cent] + 0.1;
        double mult = 0;
        Event &event = hijevent(EventType::mainEvent);
        for (int iE = 0; iE < event.size(); iE++) {
            if (event[iE].isFinal() && abs(event[iE].y()) < 0.5 && event[iE].isCharged())
                mult++;
            else
                continue;
        }
        val.second = mult;});

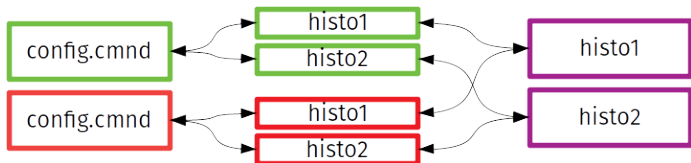
    hijing.analysisProperties("histo_id1", "final", "pT", "yw-0.5to0.5", "ID211", "ID-211");
    hijing.analysisProperties("ALICE_2010_I880049/d01-x01-y01", "CC#90001", "nonorm");
    // ...
    hijing.run();
}
```

HIJING++ tuning (WIP)

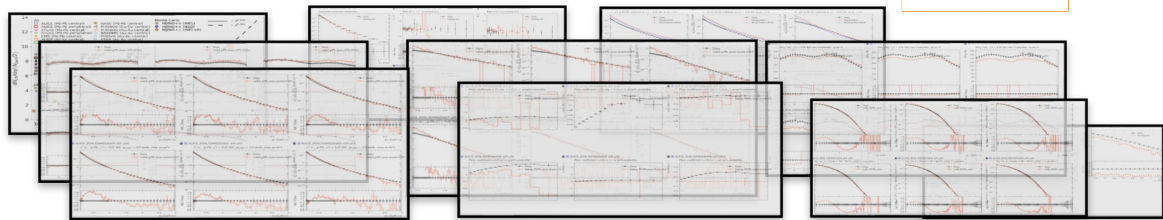
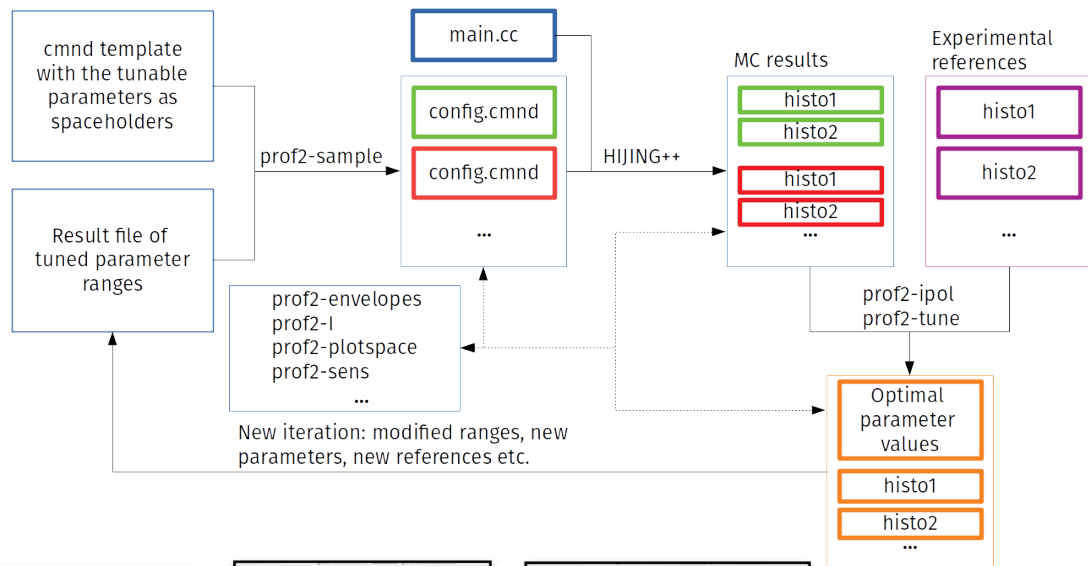
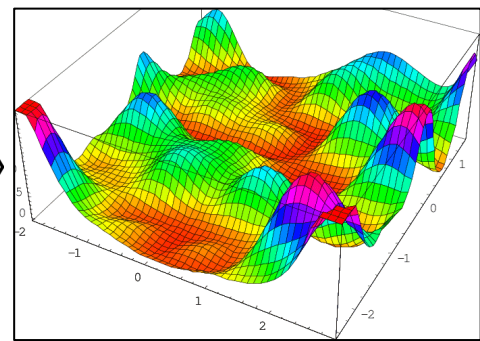
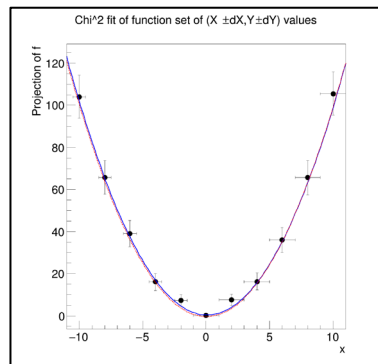
Tuning: set the empirical parameters to fit the experimental data → basically „just“ an iterative χ^2 minimization → **very serious business**

$$\chi^2 = \sum_i \left[\frac{y_i - f(x_i)}{\sigma_i} \right]^2$$

sample → **calculate** → **minimize** → **repeat**



- YODA (Yet more Objects for Data Analysis)
- Rivet (Robust Independent Validation of Experiment and Theory)
- Professor (Tuning tool for Monte Carlo event generators)
- MCNNUTNES (A machine learning based optimization tool)



HIJING++ tuning (WIP)

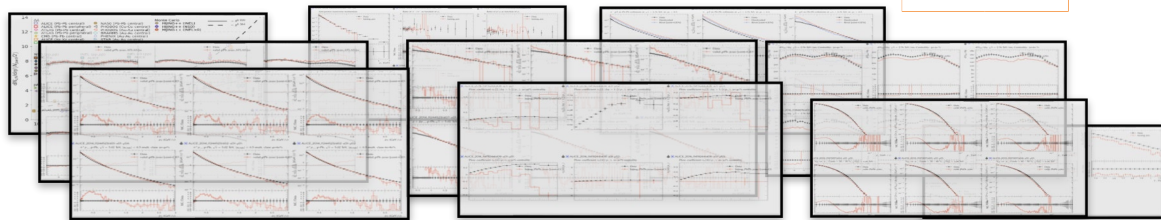
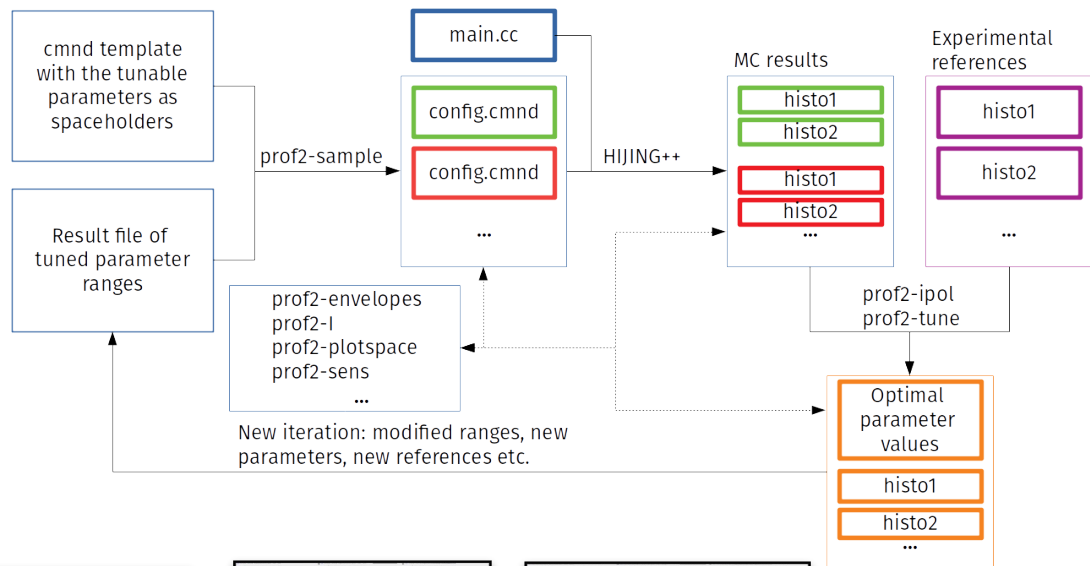
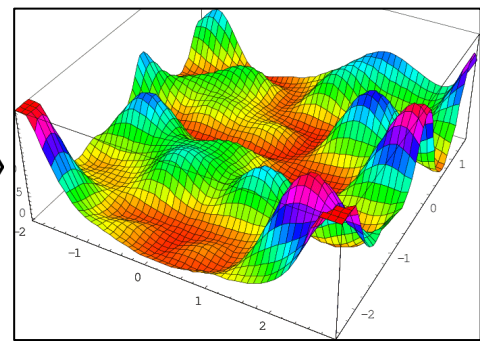
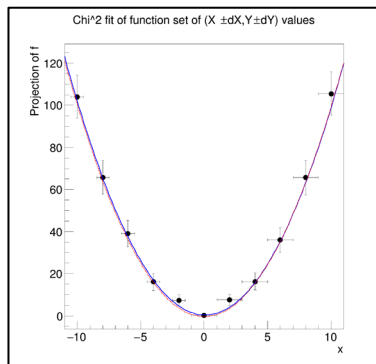
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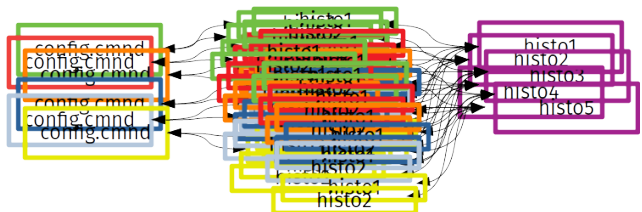


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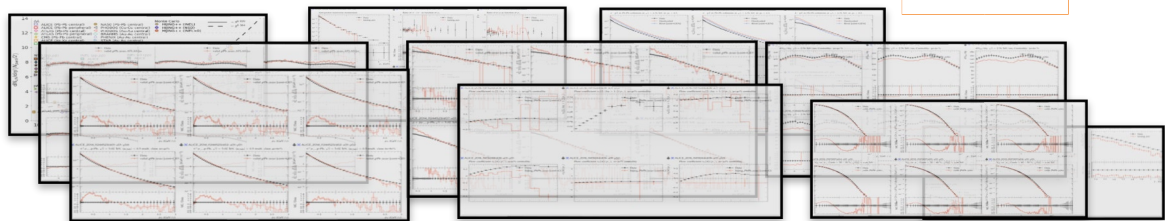
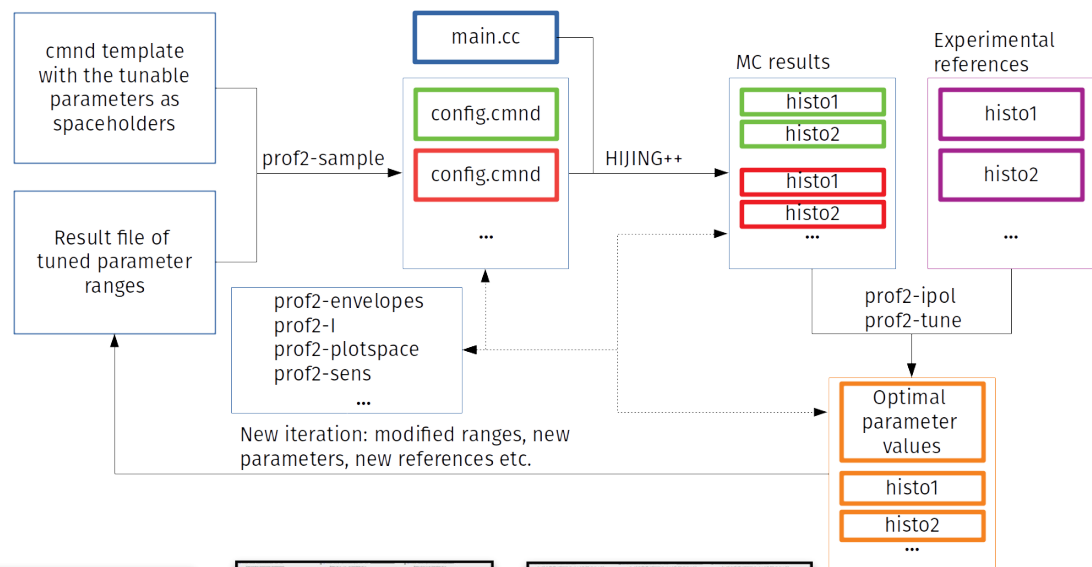
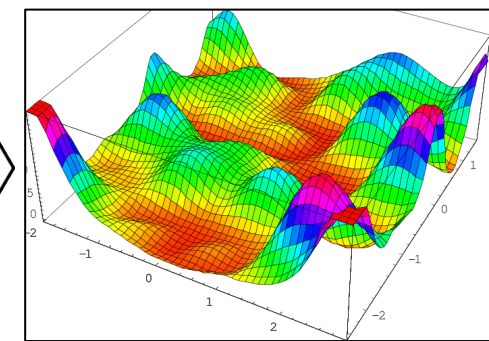
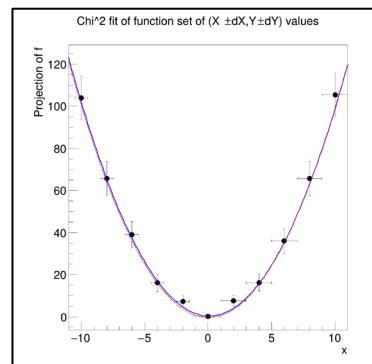
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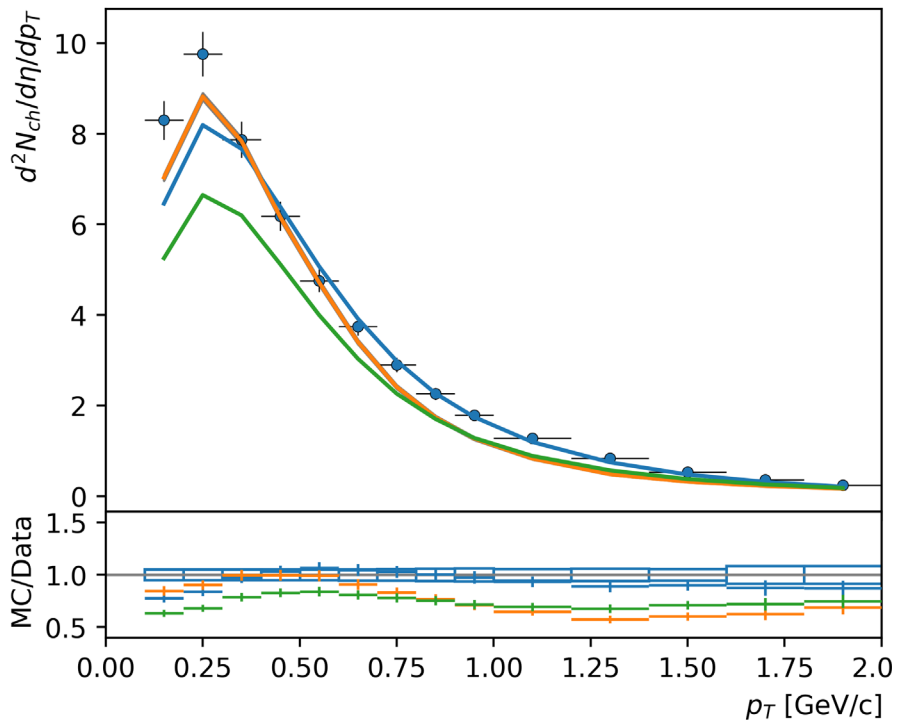


Results

pp Charged Hadron p_T for
 $|\eta| = 0.1$ $\sqrt{s} = 7$ TeV

- CMS
- HIJING++
- F-HIJING
- Pythia8

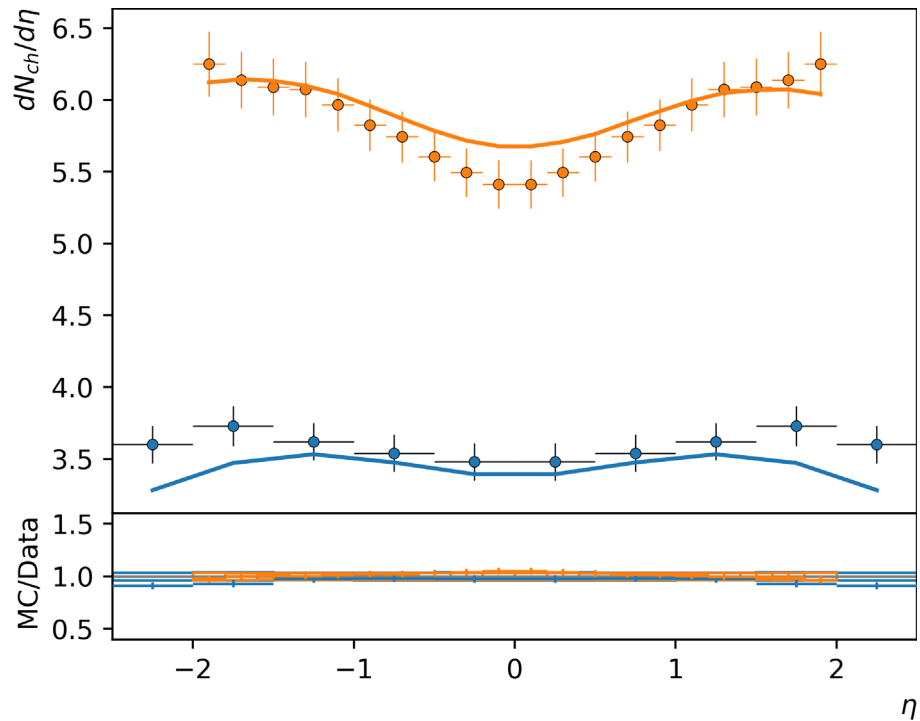
PRELIMINARY



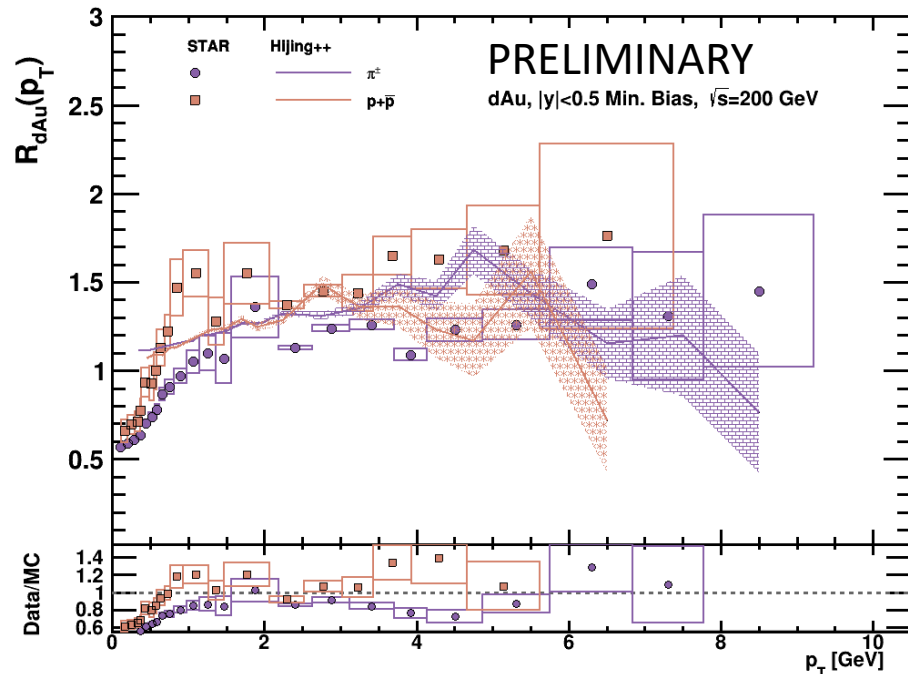
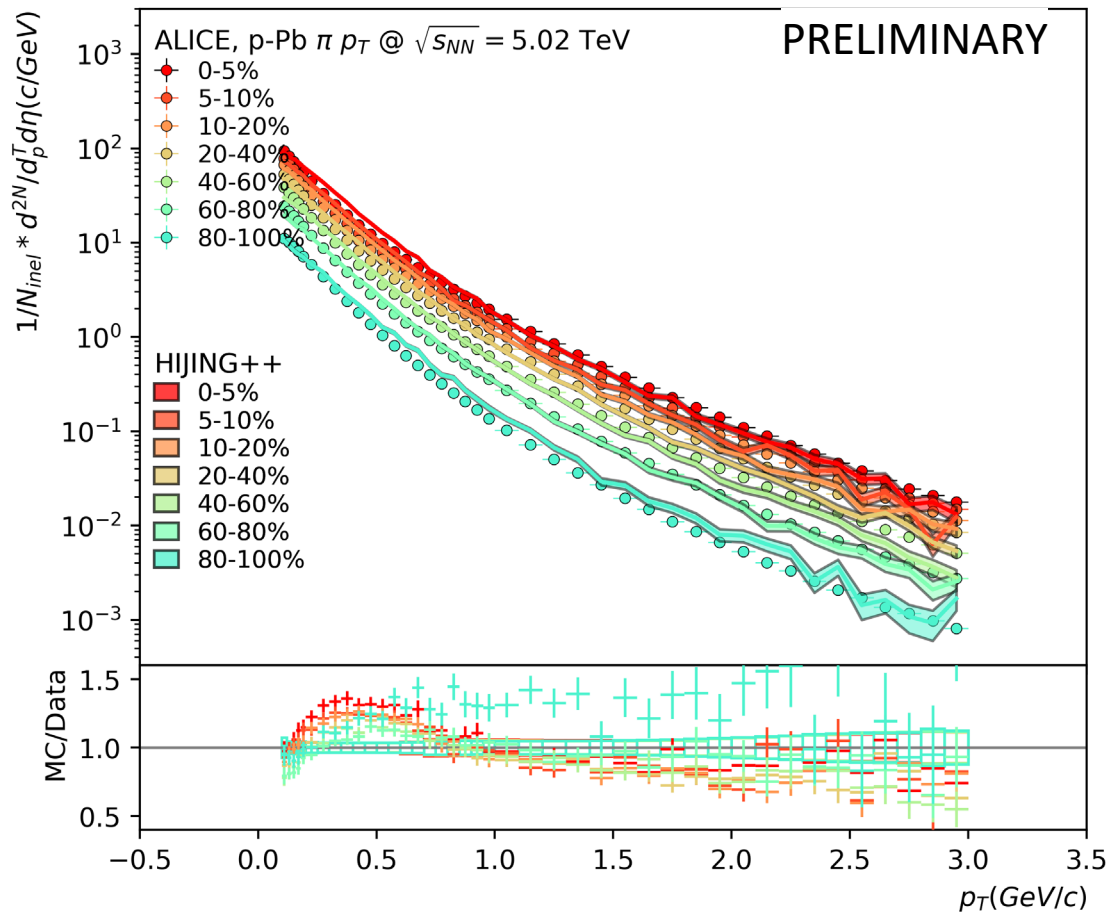
p-p Charged hadron η integrated
over p_T at $\sqrt{s} = 0.9, 13$ TeV

- CMS 900 GeV
- CMS 13000 GeV
- HIJING++ 900 GeV
- HIJING++ 13000 GeV

PRELIMINARY

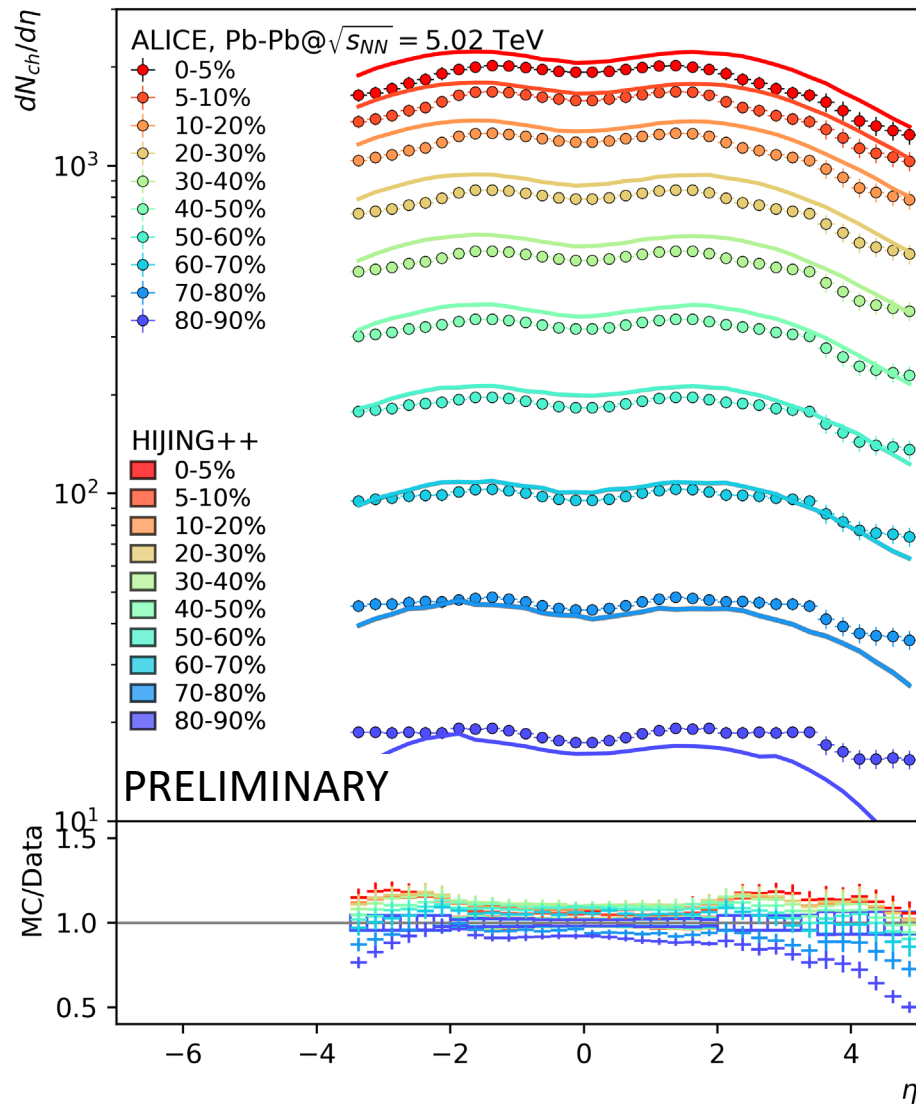
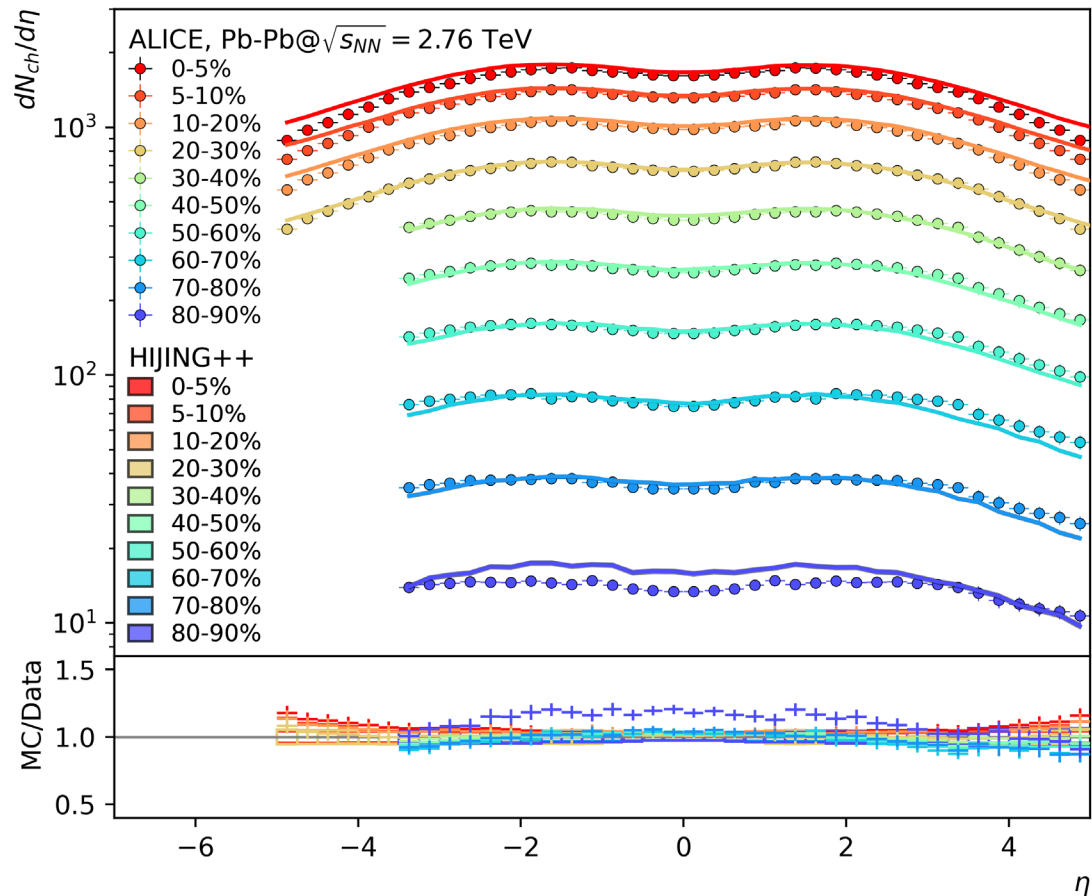


Results



Results

PRELIMINARY



Summary



Monte Carlo event generators **were/are/will be** crucial in high-energy physics

- Computationally very demanding (both to operate and to develop)
- **HIJING++**: the next generation of high-energy heavy-ion simulations
- Multithreaded, modular, intuitive
- Needs to be tuned → time consuming
- Room for future improvements → compatible with other popular frameworks, e.g. **JetScape**
- **Future**: support of Machine Learning-based modules

See related works: **Wigner Scientific Computing Laboratory (The former Wigner GPU Laboratory):**

<https://wigner.hu/en/wsclab>

Cutting-edge technologies and infrastructure

Several partners both from academy and industry

Open opportunities for collaborations!

