# Master 2 Internship

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# Building a new event classifier to unravel the QCD properties of hadronic matter with event generators

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**Advisors:**
Tulika Tripathy `tulika.tripathy@clermont.in2p3.fr`
Sarah Porteboeuf Houssais `sarah@clermont.in2p3.fr`

**Research unit:**
Laboratoire de Physique de Clermont (UMR 6533, UBP – CNRS/IN2P3)
http://clrwww.in2p3.fr/

## Summary

At extremely high temperatures and energy densities, ordinary hadronic matter undergoes a phase transition into a state where quarks and gluons move freely, the Quark–Gluon Plasma (QGP). This deconfined state of matter is believed to have filled the early universe microseconds after the Big Bang. Understanding the emergence of collective behavior, exhibited by QGP, in QCD systems remains a central challenge in modern high-energy physics [1].

An important way to study such collective effects is through the measurement of **charged-particle multiplicity**, the number of charged particles produced in each collision across different regions of pseudorapidity. By correlating the particle yields between the central and forward regions, one can build a **two-dimensional (2D) event classifier** that encodes the global activity of the event. This observable may reveal topological patterns or long-range correlations that are sensitive to the underlying QCD dynamics.

Such a classifier could help disentangle the respective roles of **initial-state geometry**, **parton-level dynamics**, and **hadronization** in the emergence of collective-like behaviour. As no direct LHC measurement currently isolates these effects, the study could contribute to defining new observables suitable for future experimental analyses. The project therefore combines computational modeling, statistical analysis, and QCD

phenomenology, providing a strong foundation for understanding the emergence of collective effects in hadronic collisions.

In the Large Hadron Collider (LHC), protons and heavy nuclei are accelerated to nearly the speed of light and collide together. Each *collision* produces a large number of new particles. This single occurrence is called an *event*. Studying millions of such events helps understanding how quarks and gluons interact at extreme energies.

An **event generator** is a computer program that simulates what happens in these collisions based on known physical laws and models. It produces synthetic "events", where each event contains information about all generated particles, such as their momentum, direction, and type. This allows testing of theories and analysis methods before comparing them with real experimental data.

Two of the most commonly used event generators are:

- **PYTHIA8** [2]: simulates proton–proton (pp) and proton–nucleus collisions based on perturbative Quantum Chromodynamics (QCD) and models of hadronization.
- **EPOS-LHC** [3] and **EPOS-4** [4]: include additional modeling of collective effects and hydrodynamic-like features.

The simulated events will be compared to the acceptance of LHC experiments such as **ALICE**, which studies strongly interacting matter under extreme conditions [5].

## Work Plan

The initial part of the project will focus on events simulated with **PYTHIA8**, one of the most widely used Monte Carlo generators for proton–proton collisions. The student will generate large datasets of simulated pp events and study the charged-particle multiplicity in both the central and forward pseudorapidity regions. These data will be used to construct the 2D event classifier described above.

Once the PYTHIA-based analysis pipeline is fully established, it may be **extended to other models**, such as **EPOS-LHC** and **EPOS 4**, if time permits. Comparing these different generators will help assess the model dependence of the observed correlations.

The goal will be to:

1. Download and install PYTHIA 8 code from the web platform [6].
2. Generate samples of pp collision events using PYTHIA.
3. Analyze the events to count how many charged particles are produced in two different regions of pseudorapidity: one in the **central region** (around midrapidity) and one in the **forward region**.
4. Build a **2D event classifier**, a map showing how particle production in these two regions correlates.

5. Study the evolution of this correlation with respect to different parameters of the PYTHIA model.
6. Discuss the physics interpretation of the correlations with different model parameters.
7. Perform a similar study with other event generators.

By the end of the project, the student will understand how particle-level simulations are used in high-energy physics, how to handle simulated data, and how collective behavior may appear even in small collision systems.

### Profile and Skills

- The interested candidate should hold a Bachelor's degree and be preparing a Master's degree (preferably in physics, computer science, or a related field).
- Knowledge of programming languages like `C++` and `PYTHON` will be useful. Knowledge of ROOT [7] is a plus.
- General communication skills and ability for teamwork.
- The eligible candidate should be able to communicate with a good scientific level in English (spoken and written).

## References


[1] **ALICE Collaboration**, "The ALICE experiment: a journey through QCD," *Eur. Phys. J. C* **84**, 813 (2024).
https://arxiv.org/abs/2211.04384

[2] **T. Sjöstrand et al.**, "An Introduction to PYTHIA 8.2," *Comput. Phys. Commun.* **191** (2015) 159–177.
https://pythia.org

[3] **T. Pierog et al.**, "EPOS LHC: Test of Collective Hadronization with LHC Data," *Phys. Rev. C* **92** (2015) 034906.
https://arxiv.org/abs/1306.0121

[4] **EPOS Collaboration**, "EPOS4: A Monte Carlo tool for simulating high-energy scatterings."
https://klaus.pages.in2p3.fr/epos4/code/install.html

[5] **ALICE Collaboration**, "ALICE Experiment at the CERN LHC," *JINST* **3** (2008) S08002.
http://iopscience.iop.org/article/10.1088/1748-0221/3/08/S08002/pdf

[6] **PYTHIA Collaboration**, "PYTHIA8 Website."
https://pythia.org/

[7] ROOT Data Analysis Framework.
https://root.cern/install/