

Kick off XLI PhD cycle

Development, integration and optimization of high-rate data analysis platforms for the HL-LHC phase

Tutor:
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Background

- **B.Sc. in Physics** 2019 — University of Perugia
 - "Analisi della divergenza della serie perturbativa in QED" | Relatore: Prof. Simone Pacetti
- **M.Sc. in Theoretical Physics** 2022 — University of Perugia
 - "Vincoli sulle interazioni efficaci a quattro fermioni di tipo NJL dal doppio decadimento beta senza neutrini" | Relatore: Dr. Orlando Panella
 - Studied contributions from heavy Majorana neutrinos via effective right-handed couplings beyond the Standard Model.
- **Borsa di Studio Post-Laurea** (1 year) in *Theoretical Physics of Fundamental Interactions and Phenomenology*
 - **Published a scientific paper** [1] based on the Master's thesis during this fellowship.
- **Assegno di Ricerca Tecnologico Senior Fascia II** (1.5 years) at INFN Perugia
 - Extension of HEP Data Management solutions to heterogeneous data (astrophysical, satellite)
 - Joined the **CMS Data Management group**
 - Worked on **R&D** activities regarding **high-rate analyses**

Analytical
Computations

Phenomenological
Studies

Distributed Data
Management

High-Rate Data
Analysis

[1] [Pacioselli, L., Panella, O., Presilla, M. et al. Constraints on NJL four-fermion effective interactions from neutrinoless double beta decay. *J. High Energ. Phys.* 2023, 54 \(2023\).](#)

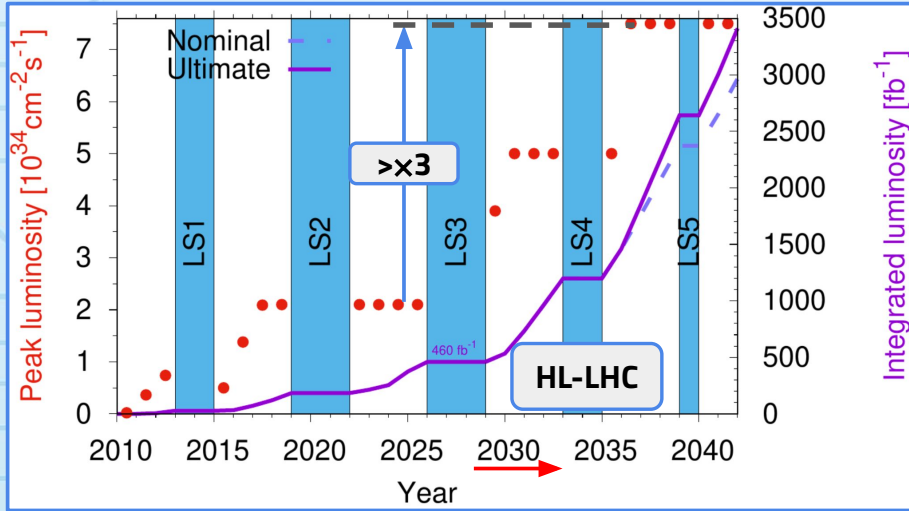
My thesis work is part of the **CMS experiment at the LHC**, and it spans multiple working groups within the collaboration:

- **Software and Computing**
- **CMS Common Analysis Tools (CAT)**
- **ROOT**
- **Data Analysis**

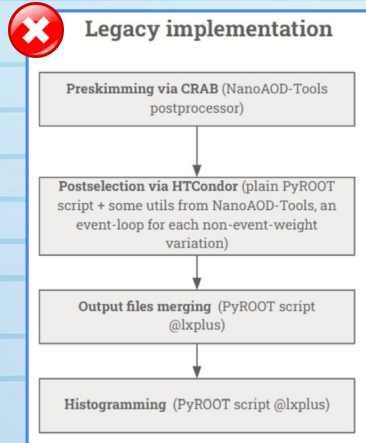
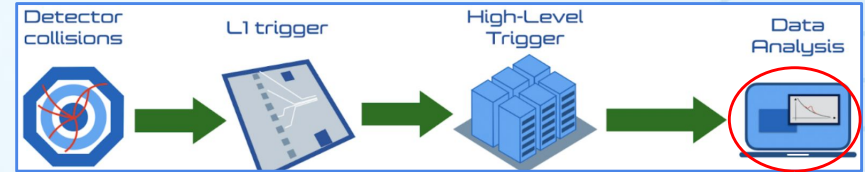
At the local level, the work is carried out within the **CMS group in Perugia**, specifically:

- **Data Analysis**, under the guidance of **Valentina Mariani**
- **Software and Computing**, coordinated by **Daniele Spiga**

Context Overview

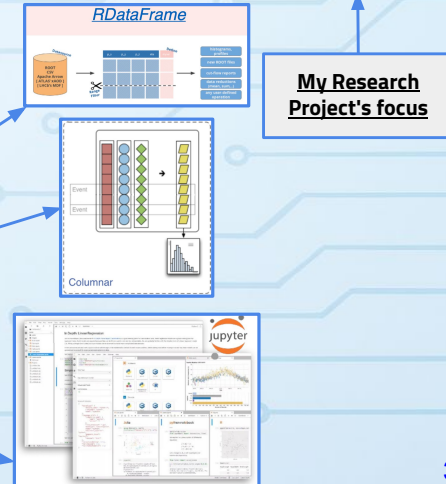


- Projections show that computational resources will be **insufficient** for HL-LHC with the **current LHC computing model**
- A few emerging challenges:
 - **Rising costs** of resources
 - **Environmental sustainability concerns**



"High-rate" analysis paradigm based on three pillars is emerging:

- **Declarative** approach: specify *what* to calculate, framework handles *how*
- **Flat data** formats and **columnar analysis** tools: access only needed data
- **(Quasi-)interactive analysis**: fast iteration without long batch jobs



Project Strategy


Software & Metrics:

- Local computational resources
- Identify key metrics of CMS analyses
- Test and compare open-source software and data formats
- **Build benchmark** analyses to stress those metrics

- Rate
- CPU efficiency
- I/O operations
- Network usage
- ...

TTree vs RNTuple

Hardware Integration and Optimization:

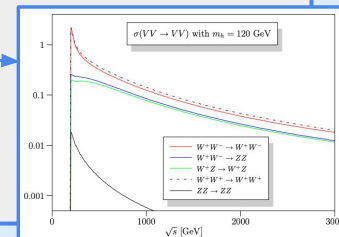
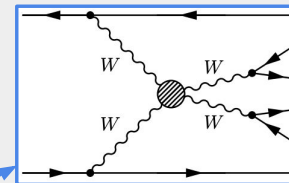
- Dedicated hardware based on the CMS INFN AF
- Integrate it with heterogeneous resources (HPC, FPGA, )
- Explore modern technologies (NVMe SSD, caching, ML/DL algorithms)
- Execute benchmarks on various hardware configurations
- **Find the optimal solution** wrt the analysis rate

Grants:



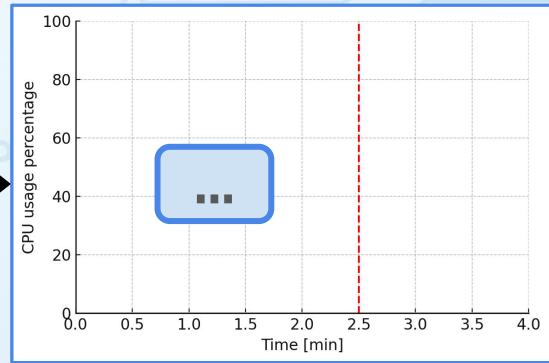
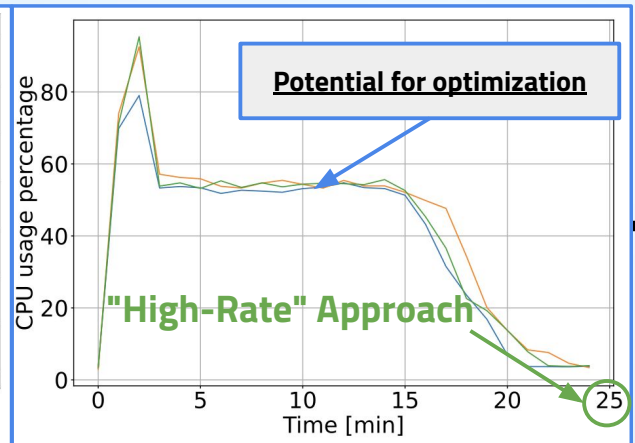
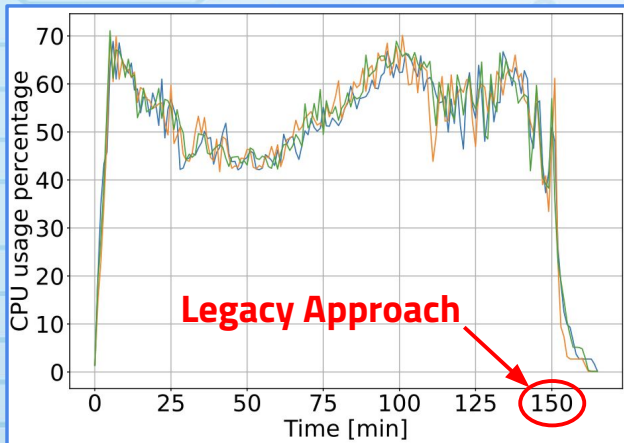
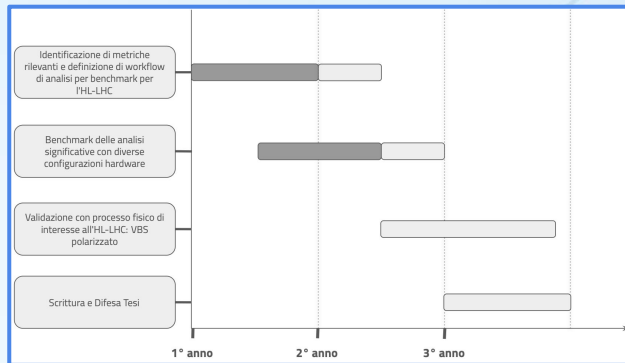
Physics Validation:

- Validate the proposed solution to a real physics analysis: Vector Boson Scattering
- Of interest at HL-LHC: should measure individual polarization states → **EW SSB direct test**
- Fully hadronic final state: challenging yet **ideal testbed** for the optimal hardware configuration, on Run 3 data and extrapolated at the HL-LHC scale



Conclusions

- Phases 1 and 2: dark grey sections represent development stage, light grey sections correspond to consolidation and fine-tuning
- Phases overlap to allow feedback and improve optimization



Target: demonstrate feasibility of an order of magnitude increase in analysis rate, with respect to the current state of the art, while preserving other performance metrics (e.g. energy consumption)

Training Plan

I plan to **attend**:

- **Physics PhD courses** at UniPG (18.5 ECTS):
 - including all the common courses and most of those from the *Fundamental Physics of Interactions* curriculum
- **Interdisciplinary courses** from the Dipartimento di Ingegneria (6 ECTS), such as “*How to Write a PhD Thesis*” and similar
- The **SOSC26** school (5 ECTS)
- The **FPGA School** at UniMIB (1 ECTS)
- **PerAPS 2026 seminars** and **CERN colloquia**

In addition, I am:

- Actively looking for **GPU-oriented schools**, workshops, and training events
- Exploring further opportunities for specialized courses and seminars

Thanks for your attention!

The background features a light blue color with a subtle pattern of white circuit traces and glowing light trails on the left side. A white rounded rectangular button with a blue border is positioned on the right.

Backup

Training Plan

| EDUCATION ACTIVITIES @ PhD Physics course (minimum 12 ECTS) | YEAR (I, II, or III) | N. Hours | N. ECTS |
|---|-----------------------------|----------------------|----------------|
| List of courses, seminars, etc. specifically activated for the PhD course | | | |
| Physics at Collider | I | 9 | 1.5 |
| Flavour Physics | I | 9 | 1.5 |
| Future Experiments | I | 6 | 1 |
| Introduction to Quantum Computing | I | 18 | 3 |
| Teaching and Learning Physics | I | 21 | 3.5 |
| Machine Learning and Deep Learning for Physics | I | 12 | 2 |
| Introduction to the History of Physics | I | 12 | 2 |
| Advanced programming for scientists | I | 24 | 4 |
| EDUCATION ACTIVITIES @ other PhD Courses | YEAR (I, II, or III) | N. Hours | N. ECTS |
| List of courses, seminars, etc. specifically activated for the PhD course | | | |
| Corso in Programmazione FPGA (UniMIB) | I | | 1 |
| Seminari PerAPS - Ciclo 2026 | I | | |
| CERN Colloquia | I | | |
| Frontal and cross-disciplinary teaching at the University and/or another Doctoral Program, possibly from another University, with a multi/inter/trans-disciplinary approach (Minimum 6 ETCS) | YEAR (I, II, or III) | N. Hours | N. ECTS |
| Etica della Ricerca (Dipartimento di Ingegneria) | I | 12 | 2 |
| How to write a PhD thesis (Dipartimento di Ingegneria) | I | 3 | 0.5 |
| Writing EU research projects (Dipartimento di Ingegneria) | I | 6 | 1 |
| How to make presentations at conferences (Dipartimento di Ingegneria) | I | 9 | 2.5 |
| Other education activities (E.g. conference, doctoral schools, seminars etc) | YEAR (I, II, or III) | N. Hours/days | N. ECTS |
| N. of conferences | | | |
| N. of seminars | | | |
| N. doctoral schools | | | |
| ... | | | |
| SOSC - International School on Open Science Cloud | I | 5 days | 5 |