Probing the Standard Model with the CMS@LHC

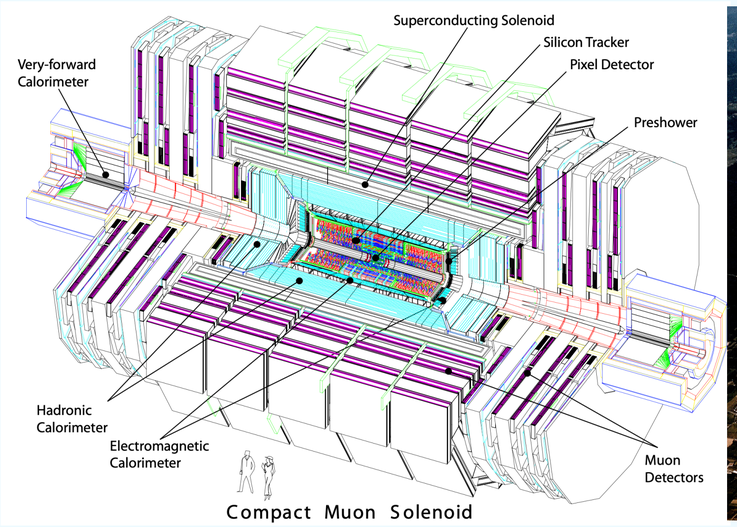
Machine Learning and More!

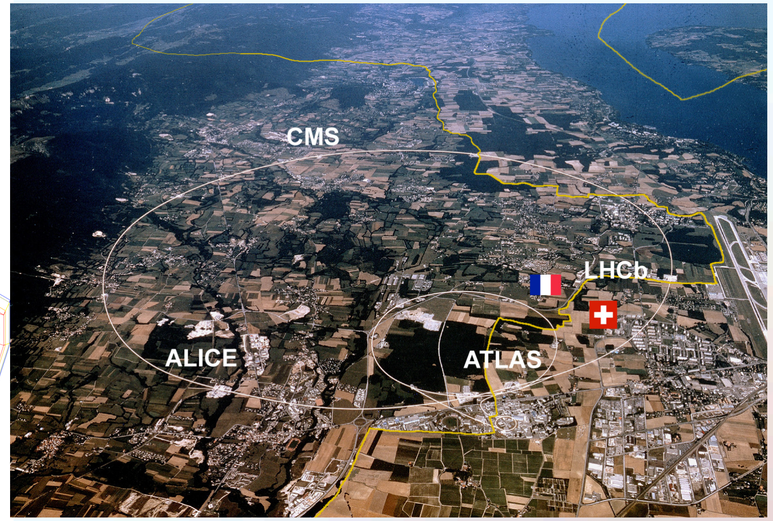
Cristóvão B. da Cruz e Silva, Matteo Pisano

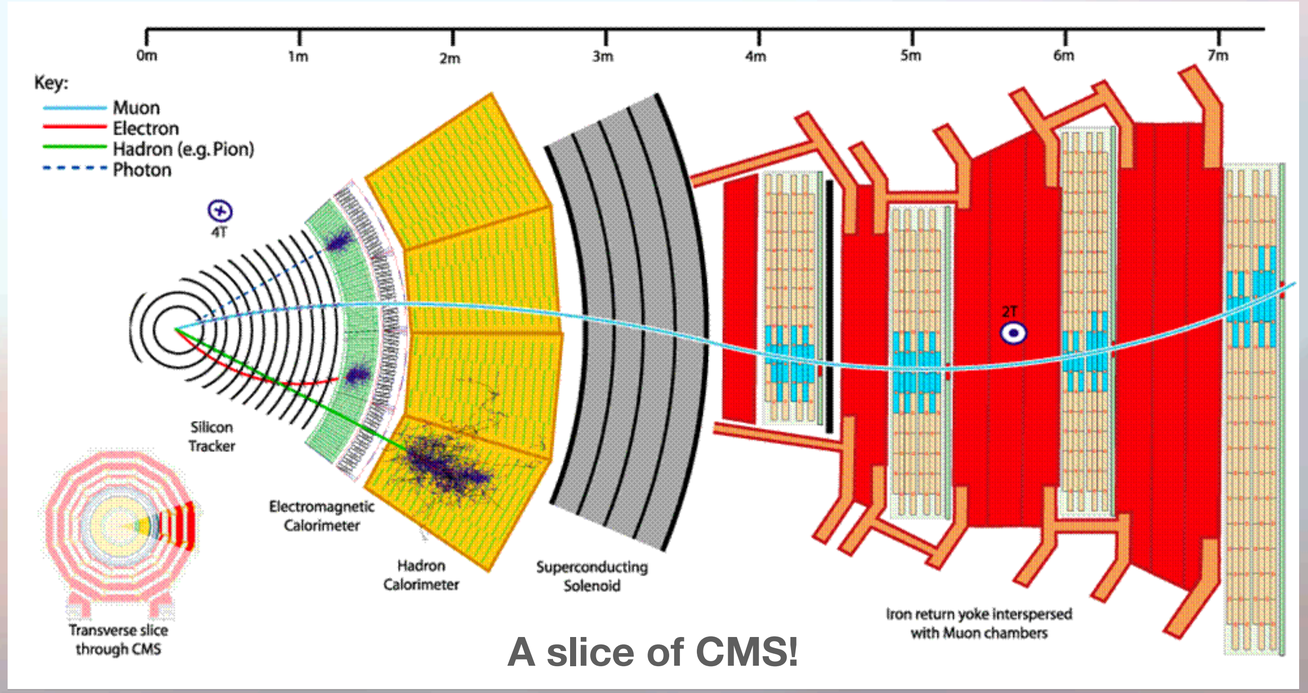
LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS

The CMS Experiment at the LHC

- CMS is located at one of the **LHC interaction points:**
  - where the LHC beams are made to collide
- CMS is a **General Purpose Experiment:**
  - Study a large spectrum of physics processes at the LHC
- **Layered design** to distinguish particles





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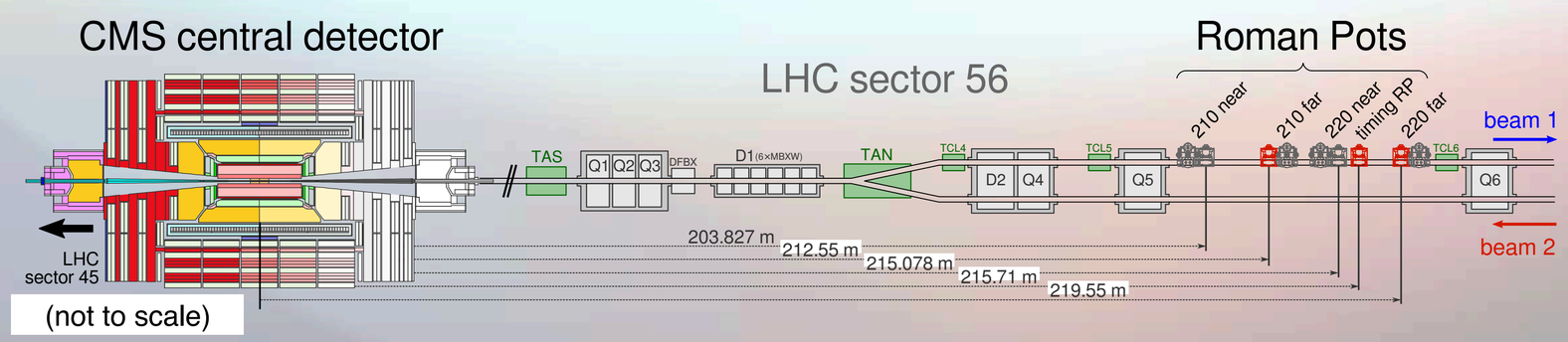
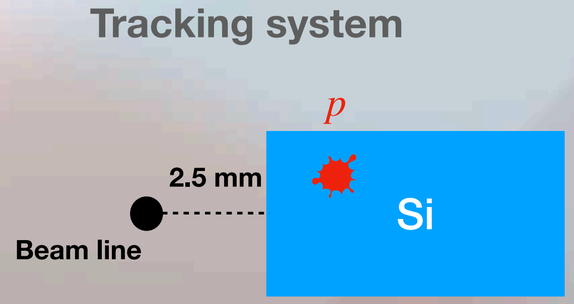
PPS: looking for intact protons!

- CMS central detector cannot tag particles produced at low angles with respect to the beam line;
- As an exemple, this is of crucial importance to study events characterized by the presence of undissociated protons:
  - $pp \rightarrow p + X + p$
- **PPS** is a **symmetrical detector** located at a **distance of ~200 m** from the interaction point;
- At present, each side of PPS is composed by:
  - **Two pixel tracking stations**: allow to tag particles (e.g. protons) slightly deflected and to measure the momentum lost in the interaction;
  - **One timing station**: can correlate the particles tagged by PPS with the CMS central detector.



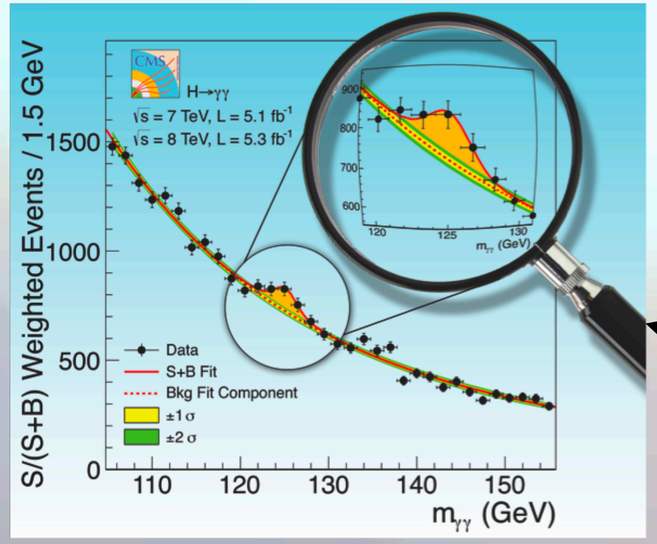


The Higgs Boson

- Discovery of the Higgs boson in 2012 - final piece of Standard Model
- Studying its properties will prove whether it is the SM Higgs Boson
  - Deviations from SM expectations would be an indication of new physics
- The LIP-CMS group is working on this front and Machine Learning tools are extensively used:

Higgs Discovery & Couplings

Discovery of the Higgs boson in the diphoton channel and Higgs properties measurements



PLB 716(2012)30, JHEP 08(2016)045

Machine Learning:

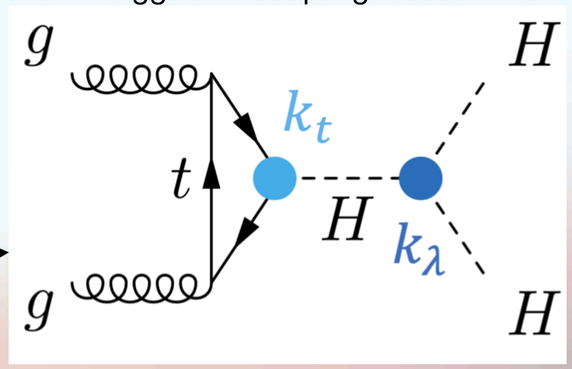
- Advanced Neural Network techniques, such as parametric NN
- NN for b-jet ID, event classification and signal extraction

Machine Learning:

- Multivariate tool is trained for photon reconstruction
- BDT used for di-photon event selection/classification

Higgs Pairs

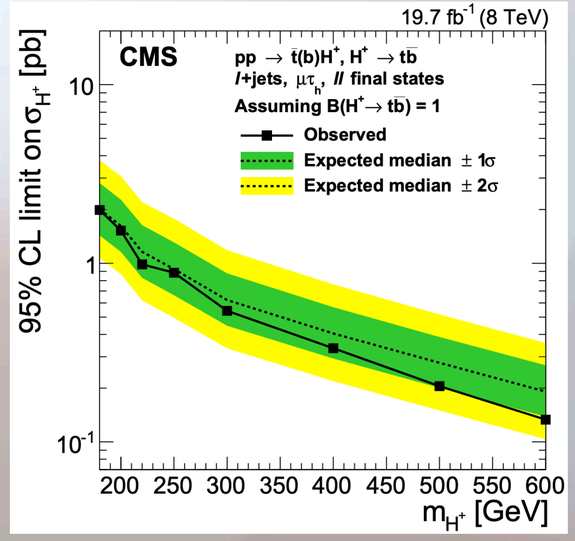
Usage of Machine Learning tools to find Higgs Pairs → Higgs self-coupling measurement



PLB 778(2018)101, arXiv:1902.00134, CMS-HIG-20-010, CMS-TDR-020

Charged Higgs

Some BSM theories predict the existence of a charged Higgs boson



JHEP 07(2012)143, JHEP 11(2015)018

Probing the Standard Model

- Precise measurement of SM processes and the study of rare decays, searching for deviations from SM expectations → Indication of new physics
- The LIP-CMS group develops efforts on many fronts, some of which are:

Top Physics

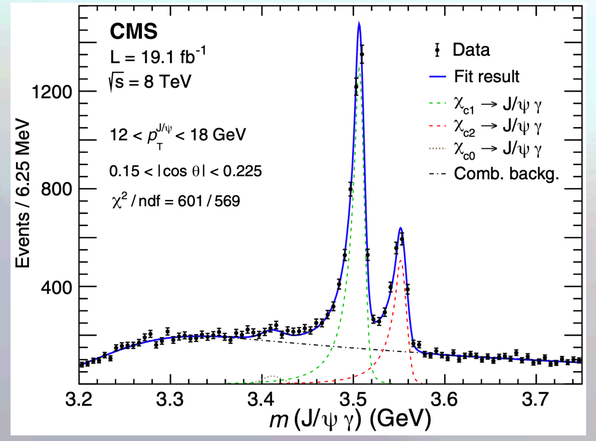
Lepton Flavour Universality - Does the top quark decay at the same rate to all lepton flavours?

JHEP 02(2020)191

Quarkonia

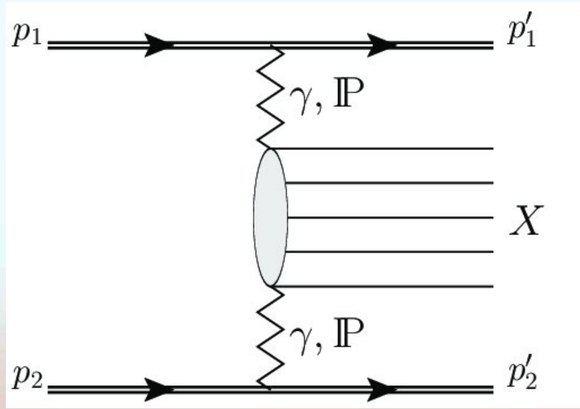
Polarization studies of quark/antiquark states produced at the LHC

PRL 124(2020)162002



Central Exclusive Production

Use PPS to tag events where protons remain intact. Provide a cleaner event and precise knowledge about the initial state kinematics



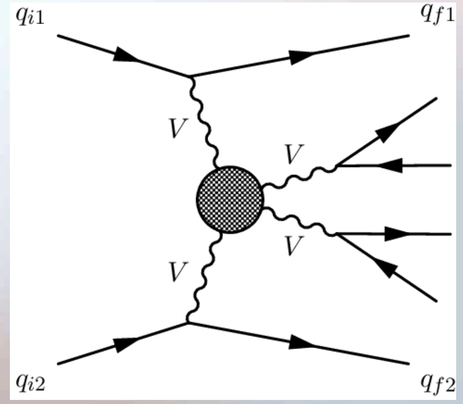
JHEP 07(2018)153, TOP-21-007, SMP-21-014, arXiv:2210.05854

A Member of the group is coordinating the PPS project

Vector Boson Scattering

Deviations from SM expectations would be evidence of New Physics. BDTs and NN will play an important role

Rev.Phys. 8 (2022) 100071



B-Physics

Precise measurements of rare decays and effects of the Heavy Ions collision environment

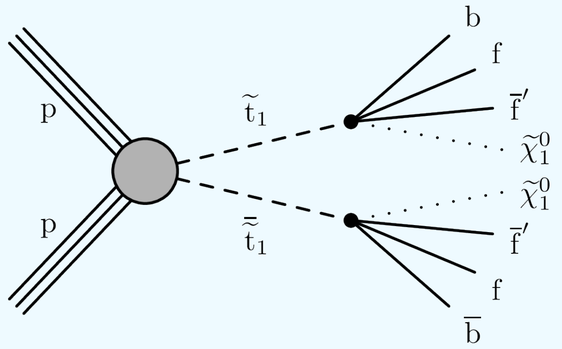
JHEP 04(2020)188, arXiv:1812.07638, PLB 829 (2022) 137062

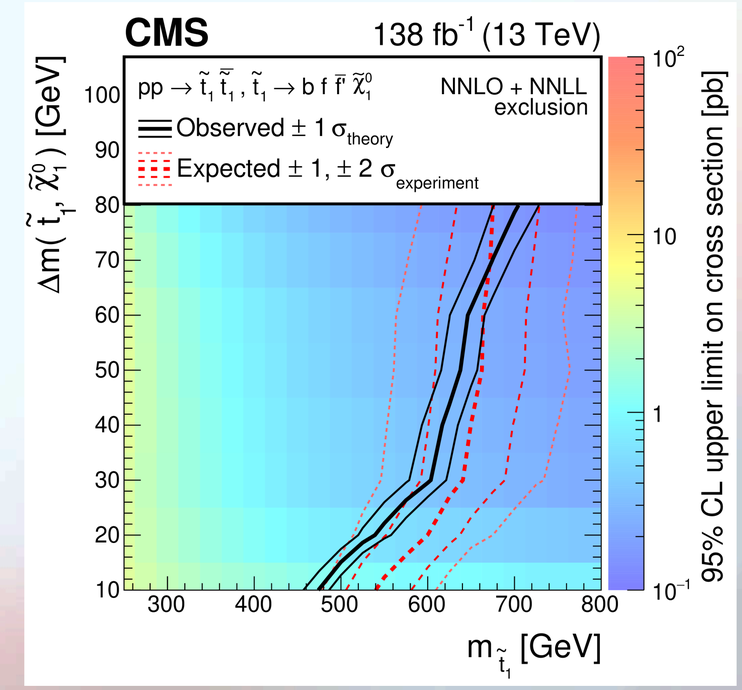
Beyond the Standard Model

- The SM is not a complete theory:
  - What is dark matter?
  - Hierarchy problem
  - Gravity is not included
  - …
- The LIP-CMS group has a leading role in:

Supersymmetry

Search for supersymmetric top quark partner in the compressed mass region, where the difference in mass between the stop and the LSP is smaller than the W mass



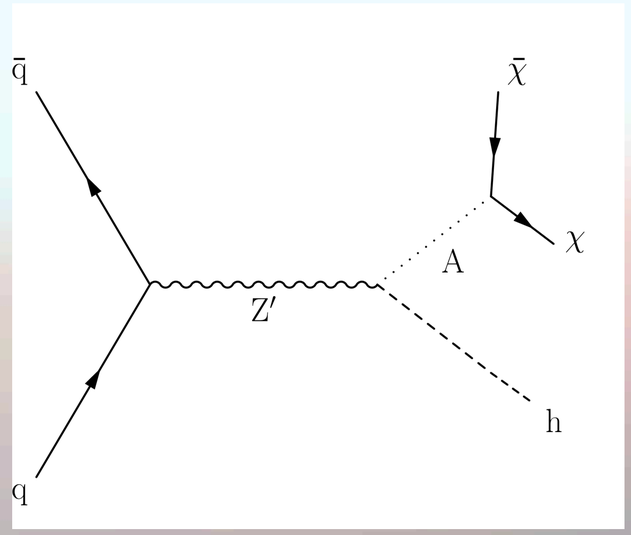


Dark Matter

Direct search for dark matter produced in association with a Higgs boson. Few events with large MET

JHEP 03 (2020) 025

- Machine Learning tools were trained for classifying different signal hypothesis and for signal extraction



- Machine Learning was critical for achieving these results
- Coupled with domain specific knowledge, the ML tools resulted in improved limits

JHEP 09 (2018) 065, CMS-SUS-21-003

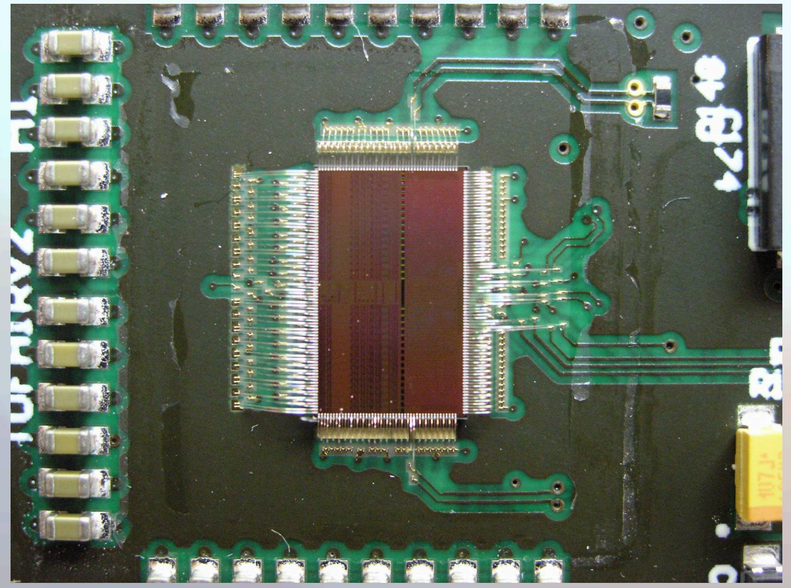
Detector Upgrades

- During the HL-LHC (the LHC upgrade), the data taking conditions will be more challenging
  - Collision pileup is expected to increase up to 200

- Must exploit additional time dimension to handle the PU, the LIP-CMS group is working on:

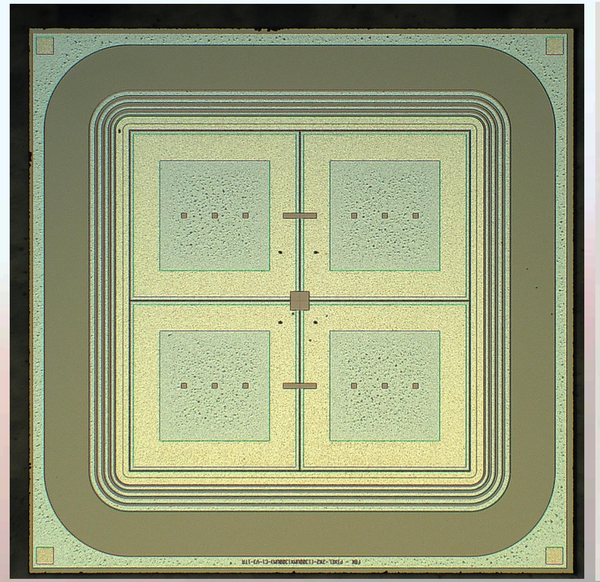
MIP Timing Detector

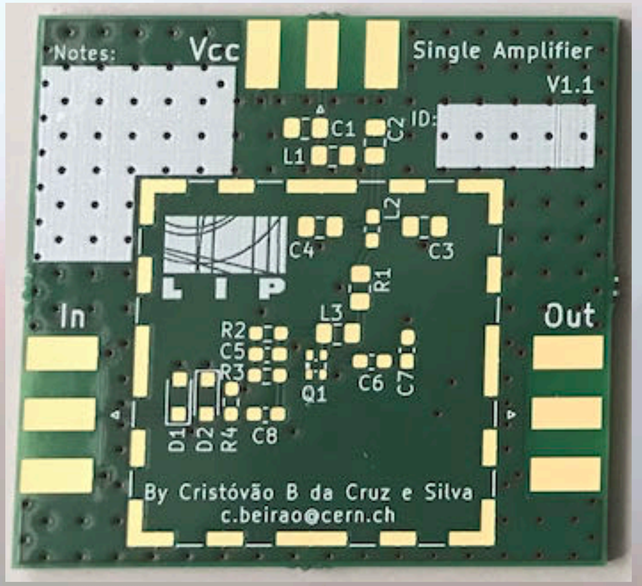
Group is responsible for developing the BTL readout electronics for precise time measurement of charged particles



Precision Proton Spectrometer

Group is developing new timing detectors to deliver improved timing resolution and withstand HL-LHC conditions





Conclusion

- LIP-CMS group activities on several fronts:
  - **Data analysis**: experience with exploiting new analysis techniques such as ML
  - **Detector Upgrades**: strong emphasis on taking advantage of the new time dimension for HL-LHC
  - **Detector Operations**: Understanding and running the different detectors of the experiment
    - Responsibility as experimental physicists

- There is a lot to **learn and contribute** to
  - **Master and PhD thesis** projects in all fields of activity
  - Your contribution will have an impact

- If you want more background information: Course on Physics at the LHC (yearly March-May)

- You are still in time to enroll in the **LIP Summer Internships**, where the CMS group provided several activities!