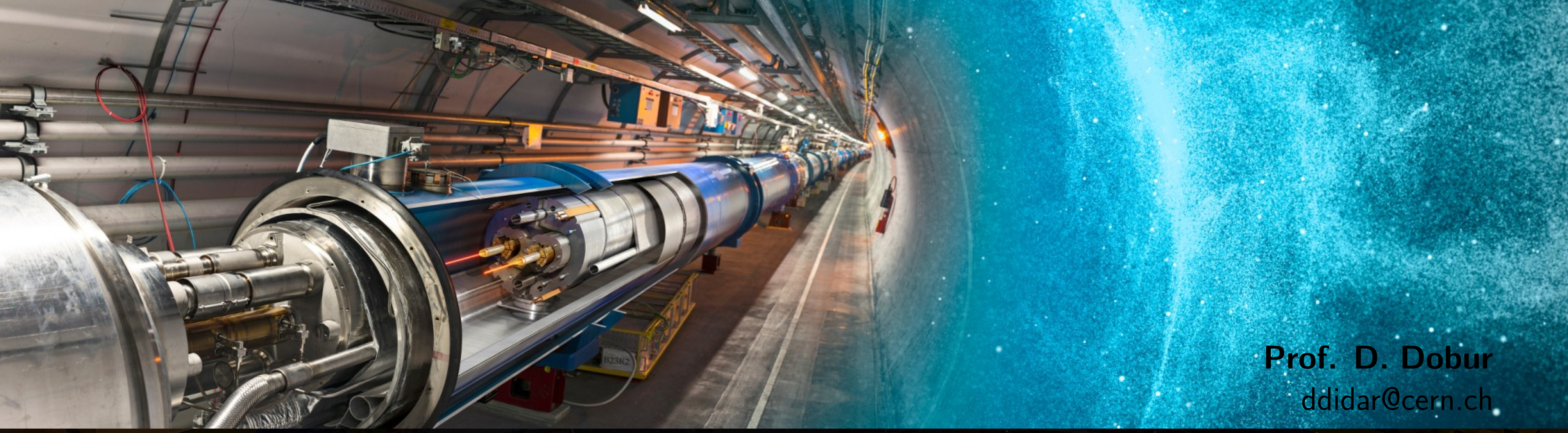

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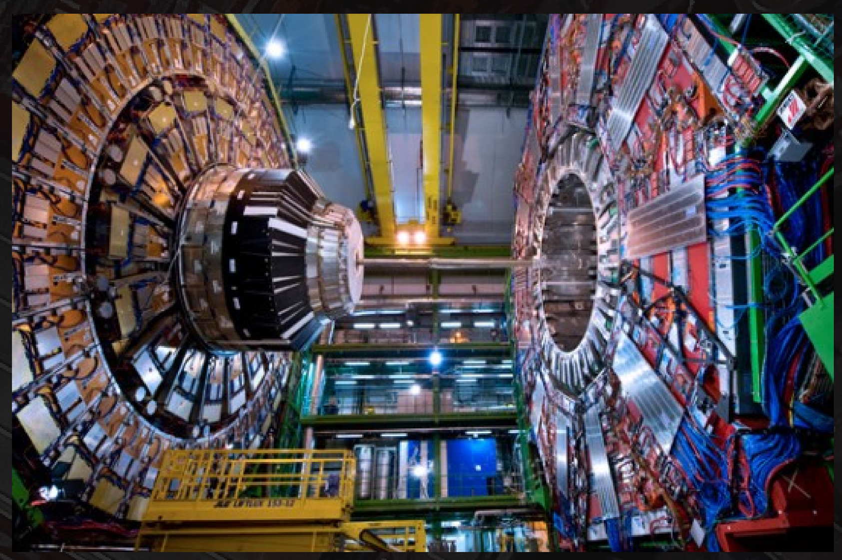
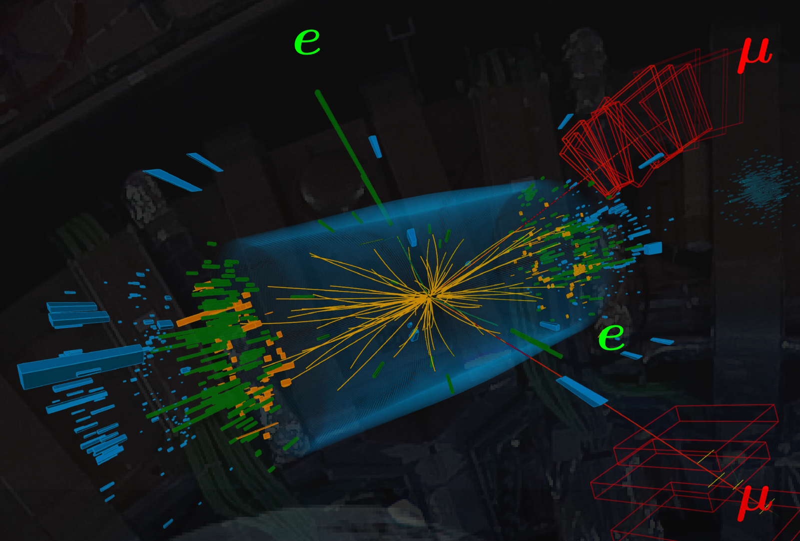
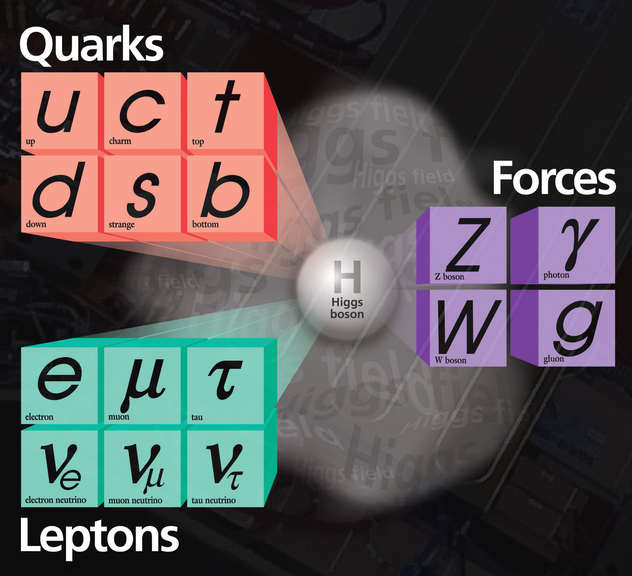
CMS: Expedition into the high-energy frontier

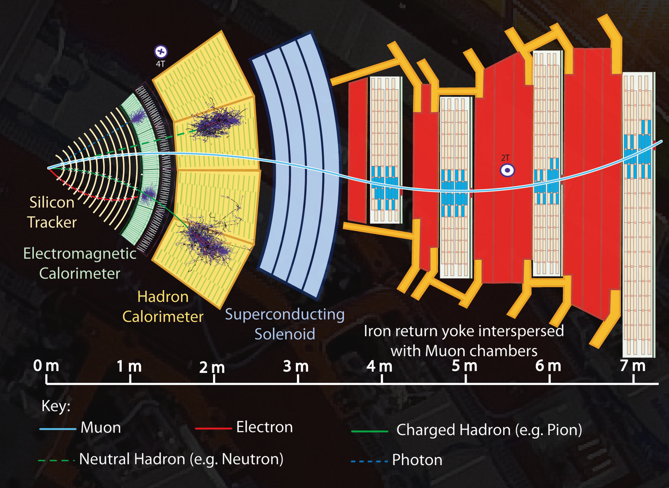
The **Compact Muon Solenoid (CMS) experiment** is a particle-physics experiment at the **Large Hadron Collider** (LHC), the world's most powerful particle accelerator located at CERN, Geneva. CMS is designed to detect a wide range of particles and phenomena produced in the LHC's high-energy proton-proton collisions. During its first years of operation, CMS achieved many new precision results on the Standard Model and limits on new physics beyond the Standard Model, as well as the long awaited discovery of the Higgs boson. In the previous years (2015-2018), CMS took data at an **unprecedented centre-of-mass energy of 13 TeV**, and at a rate of 40 million collisions per second. In your master thesis, you will use these data for precision measurements or searches for new physics, acquiring useful knowledge of data analysis techniques for your future academic or professional career!





The CMS experiment is one of the largest international scientific collaborations in history, involving 4300 particle physicists, engineers, technicians, students and support staff from 229 universities and institutes in 51 countries.





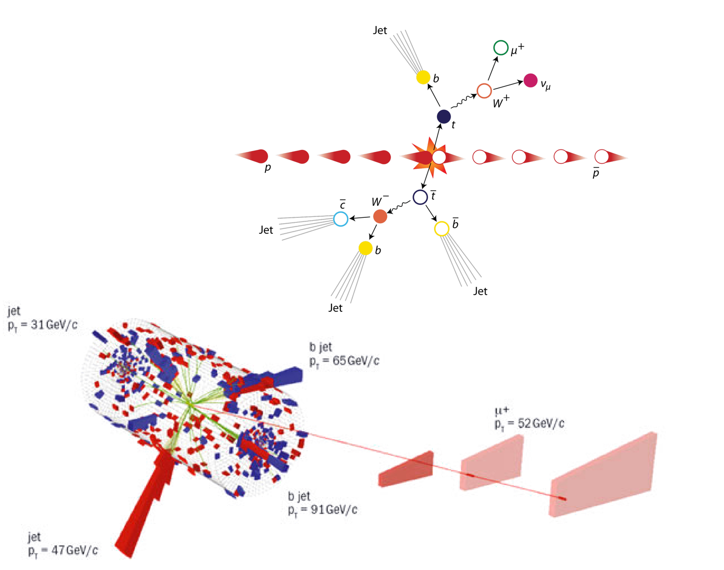
Multiple observations and the everyday experience of gravity hint at the fact that the Standard Model (SM) is not the ultimate theory of nature. Why is the Higgs boson so light? Why is matter so abundant compared to antimatter? Why is gravity so much weaker than the other forces? How can neutrinos be so light? New data, never before explored, might hold keys to unlocking these secrets about the fundamental nature of nature itself! Data collected in the recently finished Run II, at the never aforetime reached energy of 13 TeV, will provide a matchless opportunity for joining this expedition into the high energy frontier. There are several available thesis subjects focussed on analysing the many uncharted dwellings in the LHC's data, all complementary to the research being performed in the Gent CMS group.

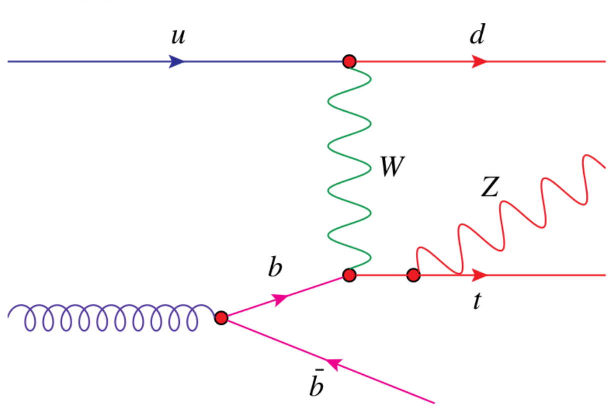
The Ghent CMS team is involved in several analyses at CMS, which include supersymmetry searches, top quark physics, and searches for heavy sterile neutrinos. Master students are welcome to join in one of our analyses groups where they get the opportunity to explore the large amounts of new data. Under the daily supervision of our CMS team, you will acquire the necessary knowledge to identify particles, select the events of interest and to use big data analysis techniques. You get the opportunity to gain experience in an international collaboration, and present/discuss results at CERN.

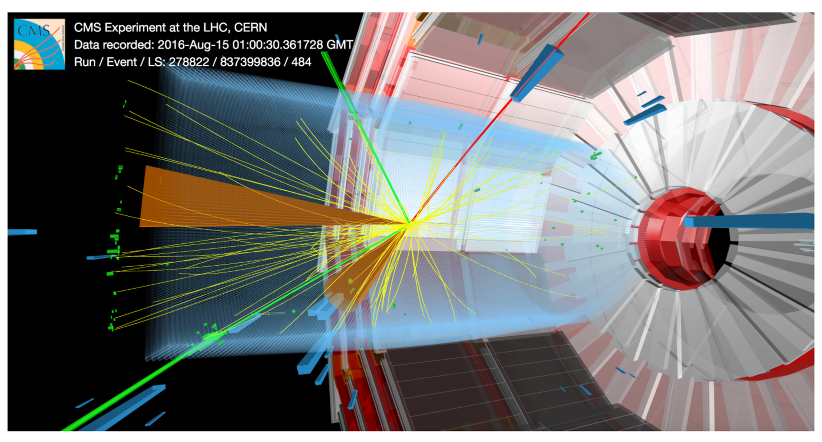
Precise measurements in top quark sector

The heaviest particle in the Standard Model is the top quark. As such, its properties are very sensitive to the existence of new physics beyond the SM. If we study top-quark production in processes where they appear together with electroweak bosons, we get an excellent handle on the SM electroweak sector, as well as on top quark properties. These properties can be measured using a number of production modes and decay channels. We propose theses on measuring the rates of single top quark or top-quark pair production in association with W and Z bosons. The production of a single top quark in combination with a Z boson was discovered for the very first time last year by the Ghent CMS group, based on a partial Run II dataset. We propose a thesis project to help improve the existing analysis techniques in the context of a new analysis that will use the full Run 2 dataset for this high-profile measurement.

- Precision measurement of top quark pair production in association with W and Z bosons
- Precision measurement of a single top-quark in association with a Z boson

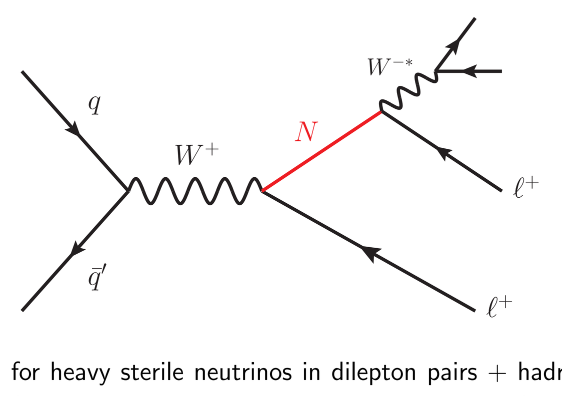






Searches for heavy sterile neutrinos

Only a few years ago, the Nobel prize was awarded for the discovery of neutrino oscillations, a phenomenon strongly suggesting that neutrinos are in fact massive particles. Several experiments have however constrained this mass to be extremely small, below the eV scale. It might be conceived as unnatural that the Higgs mechanism would be responsible for their masses as the Yukawa couplings would have to be many orders of magnitude smaller than those of the other SM particles. By introducing heavy sterile neutrinos, in the SM, the mass of the left-handed neutrino can be pushed down below the eV scale while retaining a Yukawa coupling constant similar to those of other SM particles. This is known as the see-saw mechanism. If they exist in nature, sterile neutrinos might also be searched for in the LHC's proton-proton collisions. W bosons, which are copiously produced at the LHC, may decay to a heavy sterile neutrino, due to it's coupling to the neutrino, and a charged lepton. This leads to characteristic signatures, which can be efficiently distinguished from known Standard Model processes. No discovery was made during the LHC Run I, nor with the first data from Run II, collected in 2016 at a center-of-mass energy of 13 TeV. But the increase in integrated luminosity from the 2017 and 2018 data taking, along with refined analysis techniques and the addition of new decay channels of the heavy neutrino, will allow us to expand the horizon of these searches.



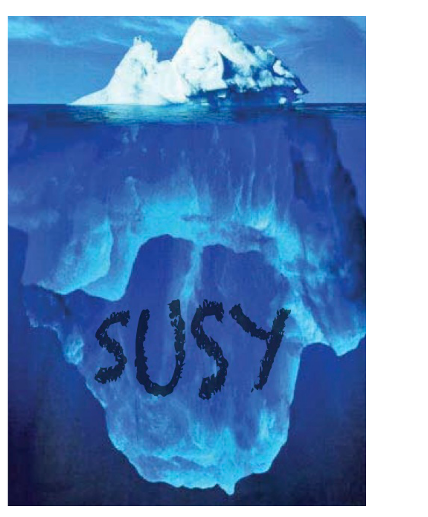
- Search for heavy sterile neutrinos in dilepton pairs + hadrons, with and without displaced vertices
- Search for heavy sterile neutrinos in 3 prompt lepton final states
- Search for heavy sterile neutrinos in final states with hadronically decayed taus
- Search for heavy sterile neutrinos in B hadron decays

Searches for supersymmetry

Among many theories going beyond the standard model is Supersymmetry (SUSY). It can be used to address the problem of dark matter, and cure the hierarchy problem that afflicts the SM. SUSY is a spacetime symmetry relating fermions and bosons. In a supersymmetric theory there are an equal number of bosonic and fermionic degrees of freedom which naturally leads to cancellations between the divergent mass corrections to the Higgs boson's mass. Every fermion would therefore have a bosonic partner in SUSY models and vice versa. To achieve a cancellation of the chiral anomaly arising from the fermionic partner of the Higgs, atleast one other scalar doublet is required, leading to the presence of 5 or more scalar Higgs bosons. In order to protect the proton from decaying, R-parity conservation is introduced, leading to the stability of the lightest supersymmetric particle. So the requirement of a stable proton can lead to an excellent dark matter candidate in SUSY.

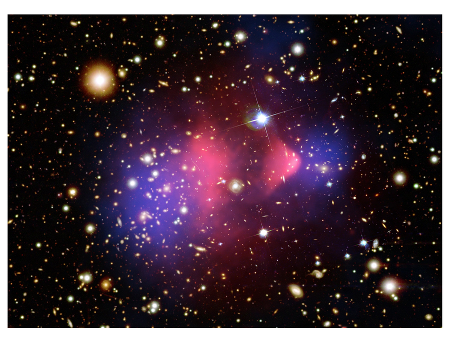
The discovery of supersymmetric particles would mark a revolutionary leap in the field of particle physics and our understanding of nature. Several searches, approaching the problem from different angles, are proposed.

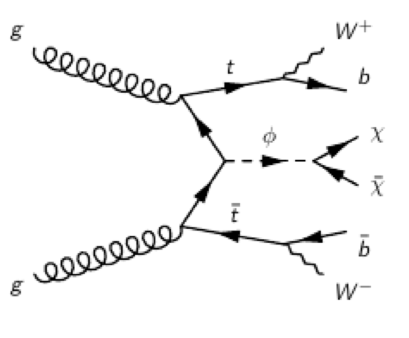
- Search for supersymmetry in three leptons and missing energy final states
- Search for supersymmetry using same-sign dileptons and missing energy
- Search for the stop, the supersymmetric partner of the top quark

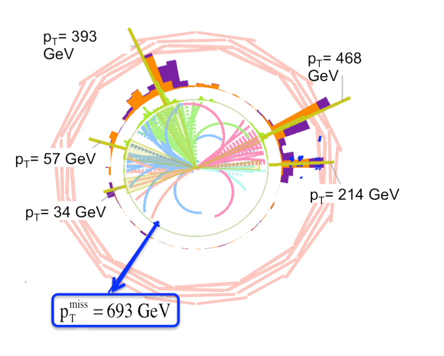


Search for dark matter

While searches for SUSY might be considered as dark matter searches, one can also look for direct production of other possible dark matter candidates, without involving a cascade decay of SUSY particles.







- Search for direct dark matter production in top quark pair events

Ghent CMS Group, Campus Proeftuin, N3, https://epp.ugent.be/index.php/masterthesesubjects/