CMS at IPHC : context and research project

The CMS group of IPHC contributes to the CMS collaborations since its origin. Through the years, we gained internationally-recognize expertise in several fields: on the construction and operation of the tracker, on identification of b-quark jets and tau leptons, on precision measurements and on (direct and indirect) searches for new physics with signatures containing top quarks, Higgs bosons or new particles predicted by supersymmetry or exotic models. Our research projects for the coming years is based upon our current activities to prepare for the LHC Run 3 (2022-2024) and to expand further for the HL-LHC (starting in 2027). The activities related to the construction of the future tracker are ramping up and will be, *de facto*, central in the coming years. It will be also important to prepare at best the nice scientific opportunities which will be opening at the HL-LHC.

1. Physics at the LHC

We can mention two main research topics:

- **Measurement of the Higgs CP properties:**

The measurement of the charge-parity (CP) state of the Higgs boson is particularly important and thus has drawn the attention of the scientific community. Indeed, the observation of a non-pure scalar state would be a clear sign of new physics, and would have strong implications on cosmology and on our understanding of the origin of the matter-antimatter imbalance in the universe. We are focusing on Higgs decays into tau leptons pair, as the tau decay products retain a large fraction of the spin information, and thus constitute excellent fermionic channels for probing CP violations. The CMS collaboration has recently released a first preliminary analysis that has been presented at the ICHEP conference. This work, that will be submitted for publication in fall 2020, will include results from the "polarimetric vector" method developed at IPHC. This method exhibits the best sensitivity in the a_1+a_1 channel. As a complementary study, we use our expertise to measure the tau polarization in Z boson decays, thus allowing a determination of the effective electroweak mixing angle at the LHC.
Ref: CMS PAS HIG-20-006 (http://cds.cern.ch/record/2725571?ln=en)
Ref: http://arxiv.org/abs/arXiv:1805.10552

- **Search for long lived exotic particles:**

Since several years, the CMS group at IPHC is involved in the search for physics Beyond the Standard Model (BSM) by looking for supersymmetric partner of top quark (top squark) with large missing transverse energy, either in stop-quark pair signatures or signatures comprising a singly produced top quark (monotop). Searches for deviations of top quark precision measurements, compared to SM predictions, have also been performed.
Currently, the CMS team at IPHC works on the search for long lived particles. The idea is to expand the coverage of BSM searches while benefiting at best from the group expertise on the tracker and on track reconstruction.
Ref: https://iopscience.iop.org/article/10.1088/1361-6471/ab4574

HSCP Analysis: (« Heavy Stable Charged Particles »)
Top squark with long lifetime would form heavy bound states, R-hadrons, which could then go through the tracker or even through the entire detector before decaying. The experimental signature would consist in a single track with large transverse momentum, characterized by a low relativist β factor ($\sim$ 0.3-0.9), leading to a large energy deposition in the tracker and a large time-of-flight in the external layers of the detectors, i.e. the muon chambers.

The CMS group at IPHC is currently performing the search for HSCP with the data collected at Run 2 and is preparing its extension for the Run 3 data. At the HL-LHC however, the information related to the charge deposit in the silicon sensors, on which the analysis strategy is based upon, will not be available with the new tracker modules. An original analysis strategy would have then to be investigated.
Ref: CMS EXO-15-010 (http://arxiv.org/abs/1609.08382)

Searches for displaced top quarks:
Several searches for long lived particles are based on the reconstruction of displaced vertices and associated tracks (displaced leptons or jets). The CMS group at IPHC is involved in the improvement of the track reconstruction algorithm for displaced tracks. Currently, we are adapting and optimizing the CMS track reconstruction for displaced tracks. It is foreseen with the Run 2 and 3 data to benefit from our expertise in tracking and top-quark physics to perform innovative searches: the pair production of displaced top quarks, arising from new long lived particles. These searches are relevant in case where the new physics couples preferentially to the 3^{rd} generation of quarks, as it could be possible given the peculiarities of the top quark within the SM, because of its high mass, its strong coupling with the Higgs boson, and the resulting naturalness aspects.
Ref: CMS EXO-18-007 (http://arxiv.org/abs/1811.07991)

2. Upgrade of the CMS tracker for the HL-LHC

The future CMS tracker for the HL-LHC will consist of the Inner Tracker (IT), innermost layers of pixel detectors, and the Outer Tracker (OT) composed of double micro-strip (2S) and macro-pixel-micro-strip pT-modules. These modules allow a fast measurement of the transverse momentum of incoming tracks, thus offering new opportunities for the new triggering system. The OT barrel is itself composed of two sub-detectors: the TBPS and the TB2S. The IPHC contributions to the construction of the CMS tracker is mainly focused on the TB2S, with one of our IPHC members being in charge of the coordination of the construction activities for CMS. The TB2S is the most external mechanical structure, and support ladder shape sub-structures which are holding twelve 2S modules. The related IPHC activities are:

Ladder integration
After receiving and testing the various elements of the ladders (including metrology), the 2S modules are placed and fixed on the ladders, then the cabling (electric cables and optical fibers) takes place. Detailed tests will also be performed in a cold environment, provided by a CO2 cooling system, in order to reproduce temperature conditions close to those of the final detector. After being certified, the equipped ladders will be shipped to CERN for final installation into the wheel.

TB2S mechanic
We participate to the design and the construction of the global mechanical structure of the TB2S, called the wheel. In particular, we contribute to the design of the supporting structure of the wheel (feet), on the simulations and deformation tests, and we follow-up the construction of the parts built by the industry. The IPHC is also in charge of the final assembly of the TB2S wheel, and of the design and the construction of the corresponding tooling (assembly table, wheel manipulation). Once the wheel is assembled, metrology measurements will be performed, as well as load tests.

TB2S wheel integration at CERN
This activity is related to the reception of the TB2S wheel, and of the equipped ladders, at CERN. There, the ladders will have to be inserted inside the wheel, cabled and connected to the cooling system. The simultaneous operation of multiple ladders will then be tested.

Contributions to the Data Acquisition System (DAQ)
We are participating to the development of the DAQ system of the tracker. In particular, we contribute to the firmware development of the backend of the IT. Furthermore, the use of System On Chip (SoC) in DAQ systems is also investigated. In parallel, contributions to the DAQ software development will be performed. Finally, we are participating to the tests of the DAQ system with test beams, in particular thanks to the availability of the CYRCé cyclotron at IPHC.

Test beam and irradiation with CYRCé
Thanks to the support of IN2P3, the IPHC has designed and constructed a beam line attached to the CYRCé cyclotron. This line allows first to test the CMS Phase 2 tracker modules under a high rate of particles. Indeed, the large range of beam intensities available at CYRCé is well adapted to this kind of tests. Furthermore, thanks to the bunch structure of the beam line and its frequency (42.5 MHz), it is possible to perform these tests in conditions close to those of the LHC. In addition to the tests at high particle rates, it is foreseen to perform soft irradiation studies, thus possibly measuring the evolution of irradiated sensors while the irradiation is happening.

Ref: Tracker TDR CERN-LHCC-2017-009 (https://cds.cern.ch/record/2272264)
Ref: https://iopscience.iop.org/article/10.1088/1748-0221/15/03/P03014

3. Development of identification algorithms for the HL-LHC

The future CMS detector will be innovating regarding several aspects: the L1 trigger system will benefit from the tracker informations; the tracker will have reduced material budget and enlarged acceptance for charged particles (up to 4 in pseudo-rapidity, to be compared to 2.5 with the current tracker); the high granularity calorimeter (HGCAL) will cover the forward region ($1.5<|\eta|<3$); the muon system will have a larger angular coverage (up to $|\eta|=3$); the Mip timing layer detector (MTD) will provide time measurement for charged particles with resolution ~40 ps.
These new features will allow us to maintain, or even improve, the performances of the present detector, despite the high pileup amount at HL-LHC. Significant studies have been performed at IPHC to achieve this goal, in particular for the identification of tau leptons and of b-quark jets. These studies will be pursued in the coming years, to make sure that physics analyses will benefit at best from the new detector capabilities.
Ref: MTD TDR CERN-LHCC-2019-003 (https://cds.cern.ch/record/2667167)
Ref: CMS-NOTE-2018-006 (http://cds.cern.ch/record/2650976)