Master 2 & PhD

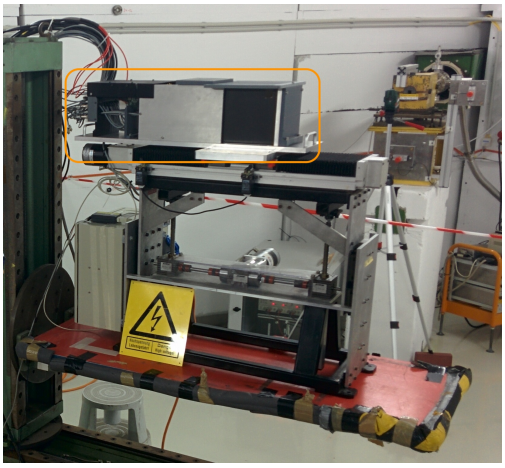
Imaging Calorimetry for Lepton Colliders

La calorimétrie ultra-granulaire pour des accélérateurs leptoniques.

After the discovery of the Higgs Boson, its properties must be precisely determined. This will be started with the High-Luminosity phase of the LHC, to be started in 2023, and with very high precision Lepton Colliders like the ILC, CEPC or FCC-ee; all these projects are planning the use of a new generation of detectors, combining advanced instrumental and algorithmic techniques: *Imaging Calorimetry* and *Particle Flow* reconstruction. In this new paradigm the measurement of every individual particle in jets, allows to fully benefit from the performance of the trackers for all charged particles and use the calorimeters "merely" for neutral ones, providing a doubling of performances in term of jet energy resolution w.r.t. standard measurements.

This is only possible thanks to the recent development of *imaging* or *ultra-granular calorimeter,* typically a factor of 1000 in the density of channel w.r.t. present experiments. The images of showers of can be 3D (purely spatial for digital calorimeter), 4D (standard ones, with energy), or 5D (adding the timing).

A first generation of high-granularity electromagnetic calorimeter (ECAL) has been build by the CALICE / ILC group of LLR at École polytechnique (Palaiseau). It was extensively tested in particle beams over the last few years. A second generation prototype with 4 times the density of channel (~10 000 in 8 dm^3) and including several important improvements in design is being built; it was already tested with a reduced number of layers in 2017 and should be completed in 2018.



Detector (in the orange box) in an electron beam, on top a movable table

In combination with Semi-Digital HCAL built at IPNL (Lyon), the beam-test data will be used to improve the understanding of hadronic shower development and the knowledge building by the reconstruction algorithms, possibly by machine learning to treat the complexity. While the algorithm are more or less universal, the optimal design depends on physics performances, and selected channels for each machine.

Our studies concern mainly the most probable next particle accelerator in the Tera-Scale range: the ILC, a linear collider running at centre-of-mass energies from 250 GeV and later up-to 500 GeV, which has a high probably to be decided in 2018 and built in Japan before 2030. Such a machine will bring unprecedented precision to the measurement of particle physics at the Electro-Weak scale and beyond, for example the properties of the Higgs boson, the top quark sector or (yet to be found) dark sector or supersymmetric particles. Recently the activities were extended to the CEPC, a circular collider promoted by China at about the same time scale.

Since 2015, imaging calorimetry has been chosen for the CMS-HGCAL and the ATLAS-HGTD end-cap upgrades. We work in close collaboration with the implied CMS and ATLAS groups.

Subject of internship (2–6 months)

It is proposed to work on data analysis of 2015 and 2017 beam test data of the first final design of sensors, and depending on dates to take part to the next campaign at DESY (Hambourg) or CERN (Geneva) and on the prototypes in development (electronics & instrumentation).

Alternatively student versed in complex algorithms and statistics could work on the improvement of Particle Flow algorithms development, and applications to the physics optimisation of the detector models on tau's and multiple jets events.

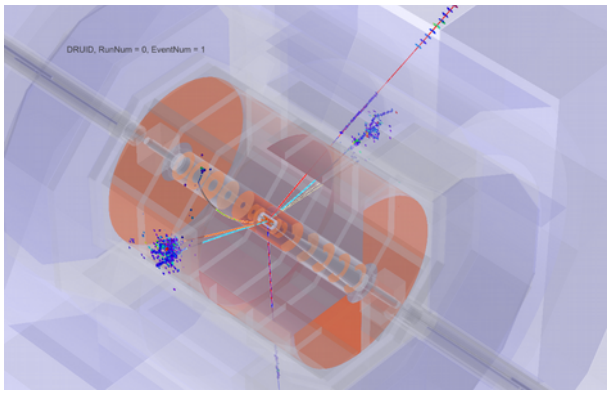
Subject of PhD thesis:

- Participation in and data analysis of test beam campaigns of 2nd generation ECAL prototype. First tests took place in 2012 and 2013; large-scale tests took place in 2015 and 2017 at CERN and DESY, to be completed in 2018; in 2019 and 2020 campaigns a Fermilab (Chicago) or SLAC (Stanford) are envisaged. Raw and advanced performances of the prototype will be key ingredients to the Technical Design of the ILC/CEPC detector models, will help improving simulation code (GEANT4) and fine description of showers.
- Optimisation of physics measurements at a future Lepton Collider at 250 GeV. Most of the channels are directly affected by the performances of the ECAL, as jets include in average 25% of photons and 2/3 of hadrons start an interaction inside it; so events jets and tau's will be the touchstones of physics performances, such as sensibility to Higgs CP states and BR($H \to \tau\tau$) (and new physics). The good reconstruction of the direction of high energy photons is also importance to identify hypothetic channels ("mono-photon events", $H \to Z\gamma$).
  These studies will be done using detailed simulation of the detectors at ILC and CEPC in close collaboration with colleagues from IHEP(Beijing), and KEK (Tsukuba) and Kyushu University.

Regular travel both inside and outside France will be required: CERN (Geneva) and/or DESY (Hamburg) for beam tests, as well as for regular meetings of the CALICE and ILC communities (typically in Japan, US, and Europe). Short stay in Japan (Kyushu) or in China (Beijing) could be organised. A cotutelle between LLR and IHEP (Beijing) is possible.

About the team

The Lepton Colliders group of LLR is a key player in the development of this novel type of calorimeters. Its scope of expertise ranges from broad detector design and optimisation, using parametric geometry for detailed simulation, data analysis and advance reconstruction algorithms, to detector prototype realisation implying all the technological challenging aspects of a strongly integrated calorimetry (silicon sensor design, mechanics, thermic, electronics and readout).



$ee \to Z \to ZH$; $Z \to \mu\mu$, $H \to \tau\tau$ in one of the ILD models.

For further information

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