# Simulations and physics analysis for a vertex detector optimization of a future Higgs factory (FCCee/ILC): from heavy flavor tagging to long lived particles searches.

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The internship will be welcomed by the PICSEL group (Physics with Integrated Cmos Sensors and ELectron machines) which works closely with the microelectronic platform of IPHC. Together, they've been proposing, designing and testing CMOS pixel sensors since 1999. In the last 20 years, they played a pioneer role in using this technology in subatomic physics. The PICSEL group has been engaged in a long term effort to equip vertex detectors in e+e- machines with CMOS pixels sensors, and in particular in the future Higgs factory, considered as the highest priority next collider beyond LHC. There are 4 Higgs factory project (ILC, FCCee, CEPC, CLIC) that could start in the 2030s. All of them contains a very rich Higgs physics program by producing (e+e- -> Z H) with a center of mass energy around sqrt(s) = 250 GeV. Historically, the PICSEL group has been involved in the ILC project but our R&D is generic enough to allow to work also in the context of FCCee.

The physics program of the Higgs factories will cover a wide spectrum, including studying the Higgs boson and measuring its properties very precisely but also top physics, electroweak physics and searches beyond the Standard Model. The expected precision of the measurements in the Higgs sector will be typically at the per mil level, improving significantly the HL-LHC measurements. This will allow constraining or excluding unambiguously the different theories beyond the Standard Model.

To accomplish this ambitious program, the foreseen detectors will have to reach unprecedented performances. The vertex detector, probably equipped with CMOS pixels sensors, will have to allow an impact parameter measurement resolution on the vertex of the order of 5 microns with a material budget below ~ 0.15% X0 per layer while being able to cope with the data flow governed by the beam background. The vertex detector will play a crucial role to tag heavy flavors (b and c quarks, tau leptons), to allow jet charge measurements and to reconstruct low momentum tracks.

The vertex detector requirements are well established. However a fine optimization remains to be done and can only be performed thanks to a complete physics analysis where the vertex detector plays a prominent role, like in analysis where the final states contains heavy flavour-quarks or displaced vertex. For instance, the Higgs to c-cbar coupling, the e+e- -> c cbar production or any final states containing a W boson decaying into c-s could allow to study extensively the expected performances of the vertex detector. Another very promising benchmark consists in studying the long lived particles production in the e+e- -> h + Z production.

**Internship**:

**The goal of the internship will be to characterize and optimize the performances of the vertex detector in terms of b/c tagging performances in the full simulation software of ILC and/or FCCee for different vertex design options.**

The working plan is the following:

- Generation and production of Monte-Carlo samples of events containing b/c-quarks in the final states (e.g. e+e- -> b bar ; e+ e- -> c cbar ; e+ e- -> Z Z, etc.) as well as production of background events (e+ e- -> u ubar, d dbar, s sbar) in the software framework of ILC/FCCee which shares common tools.
- Reconstruction of simulated events using the flavor tagging existing tools which provides the (LCFI+).
- Production of tagging efficiency vs background rejection curves.
- Development of a simple and standalone heavy flavor tagger as much as possible independent of other reconstruction algorithms (vertex finder, tracking, etc.).
- Comparison of the performances between different detector geometries and design options.

The added value of this study will allow improving significantly our fine understanding of the vertex detector requirements and hence guides us in the CMOS sensor R&D in the future.

## PhD program

The main goal of the PhD will be to perform a complete physics analysis using full simulation tools which will allow optimizing the vertex detector and the tracking system. The proposed physics benchmark which will be the core of the thesis consists in studying the long lived particles (LLP) production in the golden channel (e+e- -> h + Z). Many Beyond Standard Model theories predict the existence of a long lived particle which can have different signatures. One will focus on models where the LLP is relatively light and has relatively short flying distance before its decay (typically less than 1 meter). The Higgs boson may then decay into a pair of LLPs (such as Higgs boson coupled to BSM scalars) which will therefore decay somewhere inside the tracking detector. These very peculiar signatures will allow testing the inner tracking capabilities to reconstruct displaced vertex far from the interaction point.

Short visits in foreign labs to work with our international collaborators may be planned (DESY in Germany, Japan, etc.). The student will have to present his work regularly in international conferences and workshops of the Higgs factories projects. In addition, the student will be able to participate to the R&D effort on CMOS pixels sensors through beam test campaigns and beam test data analysis complementing perfectly his/her thesis with a hardware component.

Working plan:

- **Heavy flavour tagging performances with full simulation tools in the continuity of the internship.** The student will continue to develop the heavy flavor tagger in order to optimize in the context of a vertex detector designed with CMOS pixel sensors.
- **Development of a displaced vertex finder.** This work will be necessary to optimize the signal selection in the physics analysis.
- **Simulation and physics analysis in the context of Long lived particle searches.** The core of the thesis will consist in producing the signal and background Monte-Carlo samples and then to achieve an analysis which will allow to estimate the discovery potential of light LSPS in the Higgs factories. **Interesting Comparisons between FCCee and ILC might be realized.**
- **Involvement in the CMOS R&D, participation to test beam analysis.** Understanding deeply the CMOS pixel sensors technology will allow the student to explore the parameter space of the performances (spatial resolution, time resolution, material budget, etc.) and to study how it affects the global detector performances and its design.