Contribution aux exercices de prospective nationale 2020-2030

Accélérateurs et instrumentation associée

COMPTON POLARIMETRY AT FUTURE COLLIDERS

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1. Informations générales

Titre : Compton polarimetry at future colliders

Acronyme : *CPFC*

Résumé *(max. 600 caractères espaces compris)*
Polarized electron/positron beam are of interest for high precision physics measurements in order to increase the sensitivity to new physics measurements. One of the key tools on the accelerator side is the implementation of a Compton polarimeter that allow to cleanly measure the beam polarization at a level of few permil. We propose here to pursue developments started at the HERA time at LAL to push forward the technology to meet requirements of a Belle II upgrade and the ILC.

Préciser le domaine de recherche *(plusieurs choix possibles)*

- ✓ *Physique des accélérateurs (nouveaux concepts machines, optique et dynamique des faisceaux…)*
- o *Sources de particules (électrons, positrons, muons, protons, ions lourds stables, ions radioactifs…) et cibles associées*
- o *Développement durable de la discipline (infrastructures technologiques, efficacité énergétique, fiabilité…)*
- o *Autre R&D spécifique : (préciser)*

Préciser la motivation principale visée par la contribution :

- o *Accélérateurs pour la physique nucléaire*
- ✓ *Accélérateurs pour la physique des particules*
- o *Accélérateurs pour les sources de lumière ou de neutrons*
- o *Accélérateurs pour les applications sociétales (santé, énergie, industrie…)*
- o *Autre : (préciser)*

2. Description des objectifs scientifiques et techniques
(2 pages max incl. figures)

Electron-positron colliders such as the B-factory at KEK-B and a Z/Higgs factory are facilities for high precision physics. Beam polarization is a key tool, both at Belle II and at a future Z/Higgs factory, to increase sensitivity to new physics and accuracy of standard model processes by reducing the background and/or increasing the signal. Measuring the actual beam polarization will thus be critical for the measurement precision. For Z/Higgs factories, two distinct options are available, a linear accelerator with polarized beams upgradable in beam energy and a circular accelerator with higher luminosity which may need a Compton polarimeter for a precise measurement of the beam energy through resonant depolarization. In any case, precise polarimeters working in steady state able to cope either with the high occupancy of or high rates are necessary. Specific R&D is thus required. The LAL ILE ("Interactions Laser Electrons") group was recently involved in updating the design of the laser system for the ILC polarimeters and also is being involved in preliminary design work for the possible upgrade of SuperKEKB with polarized electrons. Both projects are at a different level of preparation, SuperKEKB is extremely prospective for now. Polarized electron beam in colliders are of major interest since they allow e.g for a clean disentangling of helicity-dependent effects as for example in heavy quark production and reduction of otherwise irreducible backgrounds that induces an increase of sensitivity at constant integrated luminosity. The knowledge of beam polarization will be one of the main sources of the systematic error of precision measurements [1-4].

The longitudinal polarization is precisely estimated from collision data using physics measurements averaging over very long time periods. It is however equally important to have a precise real-time monitoring of the beam polarization for data quality aspects and accelerator operational aspects. This can be achieved with a polarimeter based on the Compton process, since it is a theoretically well known process with an excellent control of the higher order QED corrections that could spoil the measurement (as it is the case in Moller scattering for instance). The circular polarization of the laser beam must thus be maximized and measured to a 1 per mil precision (ILC specification) over long periods of data taking in the difficult accelerator environment. Today's best demonstration of this control of photon helicity, performed by the LAL Group, must be improved by a factor three to reach the required accuracy [5]. A future SuperKEKB Compton polarimeter would also benefit from this development.

These two projects however imply different challenges in terms of implementation. On the one hand the design of the ILC polarimeters is already relatively well known since several years. In particular, efforts have concentrated to improve on the SLC design of the detector for the scattered electrons. In order to further control the systematic uncertainties, it could be complemented by a calorimeter of the scattered photon. This option has not much been considered for ILC, and could be of interest. Not much work has been done on the design of a robust laser system, though. This system must be functioning in burst mode with a relatively large average power. Recent laser technology developments opens the path to the use of commercial laser systems. In this context LAL ILE group proposed a new laser system that could routinely be operated remotely for the ILC [6]. One key critical aspect in the laser system will be the optimization of the laser design and specific design of the laser helicity control at several tens of Watts of average power. Which open metrological challenges in controlling the laser beam polarization at the per mil level. On the other hand, the SuperKEKB electron-positron collider is currently taking data. A recent idea emerged to operate the collider with polarized electron beam [1] by using ideas developed for SuperB. For this application, industrial laser system with the relatively low average power needed can be easily found. Again a critical aspect will be the stability of the laser polarization over long period of times, its continuous tuning and regular flip. The R&D on the laser-beam polarimetry will thus present a first low-average power before developing it at high power for ILC, thus presenting synergies. Another key point that has not been investigated much at this stage is the detection system that will need to be operated at the bunch repetition rate of 250MHz which induces specific challenges on the choice of the photon and electron detectors and careful design of the related electronics. The signal-related radiation dose in the photon detector will be most probably in a range of 100 to 1000 Mrad which induces additional constraints on the detection system. Given LAL ILE group experience in a regime where about 1 photon is scattered in average per beam crossing at HERA, LAL ILE group could be involved in the polarimeter design and photon detection system for instance. Though a formal collaboration and splitting of activities still need to be done with partners from University of Victoria (where the upgrade was initiated) and University of Manitoba (where some complementary expertise on Compton polarimetry in the GeV range do exist), mainly. This is expected to be done over the year 2020. Once done, and if there is an interest expressed by the Belle II collaboration, an actual implication of the LAL ILE group can be envisaged, on the design of the laser system and polarization control and also on the global design of the polarimeter in collaboration with the other Belle II groups. The LAL group is also interested in evaluating the performance of the absolute calibration of the Compton polarimeter with $e^+e^- \rightarrow \tau^+\tau^-$ events in Belle II detector by analyzing existing datasets of Belle and Belle II and extracting measurements of the tau vertex form factors, that are related to the tau EDM and anomalous magnetic moment. These measurements have barely been done at present at B-factories and present already an interesting part of a thesis subject.

3. Développements associés, calendrier et budget indicatifs *(1 page max. incl. figures)*

To achieve this goal a careful benchmarking of the choice of birefringent crystals used for the preparation of the laser-beam polarization by properly assessing the effect of manufacturing defects, environmental influences (mostly temperature) on the birefringence of the crystals, and the influence of laser-beam transport optics. A metrology of the laser beam polarization must be performed at sub per mil level. A first solution is to use thermally controlled balanced photodiodes along with the use of several kHz polarization modulation coupled to lock-in amplifiers to remove DC and low frequency fluctuations related to environmental changes in the measurement chain rather than of the laser-beam polarization at the interaction point. A technical solution must be first designed in a controlled environment at low average laser power to be further tested in a less thermally controlled environment, typical of accelerator bays. In order to reach the statistical precision required for instance at the ILC, the average power of the laser must be increased to several tens of Watts. This induces thermal gradients in the crystals traversed by the optical beam, modifying their optical properties. No precise polarimetric measurement have been reported in this regime. These effects have to be handled compatible with operation in an accelerator environment. Reaching the performance at metrology level on laser-beam ellipsometry in an accelerator environment requires extensive R&D for use at KEK-B (ILC or circular colliders). The final goal of the envisioned R&D program is the development of tools for laser-beam polarization control and determination with unprecedented precision for high power lasers. Hardware needs are optical birefringent crystals with high quality manufacturing and electronics. LAL provides a well-equipped infrastructure including powerful laser system and clean rooms.

We intend to propose to engage a PhD thesis starting in 2021 (so that the situation of the polarization upgrade is clarified) with both physics analysis and R&D on the laser polarimetry [7]. An amount of 50k€ of hardware would be needed to perform this R&D by re-using most of the components already available at LAL. It is planned that the daily operation (after a period of commissioning at KEK) of the system would be supported by KEK collaborators. If the upgrade is actually approved, it is envisaged that a post-doctoral fellowship could be hired to contribute to the operations of the polarimeter and to the key data analysis of the $e^+e^- \rightarrow \tau^+\tau^-$ with Belle II data. This implies a substantial support for travels to KEK if the project is approved and regular yearly meetings before for the setup of the collaboration on the polarization upgrade. If the ILC project is finally approved in the coming months, the first R&D steps will be common to that of Belle II and the contribution will essentially begin with a consolidated design of utilities and the laser system to be integrated. It implies concrete discussions with laser providers. R&D initiated for Belle II would be pushed further for high average power laser by a PhD student that could also contribute to a specific analysis subject in the LAL ILC group. A budget of about 50k€ for this complementary R&D can be envisaged to complement the hardware needed for high-power operations.

Impact
(0.5 page max.)

The interest in Compton polarimetry is real for all future e+e- colliders, namely ILC, a possible SuperKEKB upgrade, but also FCC-ee since it is an option for the precise beam energy measurement through resonant depolarization. Also the demonstration, at a low energy, that a lepton collider with polarized leptons and with top-up operation can be achieved with SuperKEKB may have interesting implications for FCC-ee. In any case, a real time control of the laser polarization is a critical aspect that is required to avoid a blow up of the systematic uncertainties related to environmental fluctuations at the several tens of seconds timescale. Commercial industrial laser systems, as those for instance developed by Amplitude Laser Group, will be in use in these systems with some specific developments that may be needed for the ILC case. That company could naturally become a good candidate for an industrial partner that would be involved in the optimization of the laser system.

Références

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