FCPPL-CSC PhD proposal - 2015

Thesis title: Beam halo and Compton process investigation using single crystal chemical vapour deposition diamond sensors at the ATF2 and PHIL electron beam lines

Type of proposed PhD diploma: French X   Chinese □   French & Chinese □   (tick correct answer)

French host laboratory: Laboratoire de l'Accelerateur Lineaire (LAL), CNRS-IN2P3

Chinese laboratory (if applicable):

Thesis advisor(s) and email(s): Philip Bambade, bambade@lal.in2p3.fr

Planned date of start of stay in French lab: September or October, 2015

Planned duration of stay in French lab (months): 36

Expected date of thesis defense: September 2018

Detailed description of the thesis subject:

ATF2 is a 1.3 GeV electron accelerator facility operated at KEK (Japan), where an ultra low emittance beam can be focused to a transverse size of ~ 40 nanometers. The main goal is validating the novel beam handling techniques needed for future high energy linear electron positron colliders. PHIL is a low energy photo-injector test accelerator operated at LAL for beam physics and instrumentation research. The thesis work at LAL will focus on developing the methodology for characterising and controling the beam halo distribution in both these beam lines, using a set of custom made radiation hard single crystal chemical vapour deposition diamond sensors prepared by the LAL group. In addition, at ATF2, the Compton recoil spectrum of the beam electrons interacting with the photons of the laser used to measure its size will be measured. The thesis project will involve modeling of the beam halo generation and propagation, usage and simulation of collimators needed for beam halo control, as well as preparation and testing of new diamond sensors. The selected student will have the opportunity to contribute to the operation of the accelerator facilities during the experimentation at LAL and KEK and to acquire hands-on beam physics skills.

Candidates' requested qualifications:

Applicants need to have a master's degree or equivalent in physics, have strong experimental and analytical skills, and be able to communicate at a scientific level in English. Prior experience in subatomic experimental physics and computing skills would be an advantage.

Tentative timeline of the PhD preparation

The ILC (International Linear Collider) and CLIC (Compact Linear Collider) are two high energy electron positron colliders planned in the next decade [1,2] to complement the Large Hadron Collider (LHC) presently operating at CERN. Achieving the very high specified luminosities will require maintaining stably focused beams with nanometer transverse sizes at the collision point. For this purpose, ultra-low emittance beams must first be provided, through radiation damping of the particle phase space, in special storage rings similar to 3rd generation synchrotron light facilities. After acceleration, the beam sizes must be reduced by another factor of about 50 at the collision point. This is achieved via a new « final focus » concept, providing the needed optical demagnification through a sophisticated scheme with local control of the chromatic and geometric aberrations up to 3rd order [3].

The Accelerator Test Facility (ATF) is an international accelerator R&D complex based at KEK, operating an electron damping ring with transverse emittances reaching unprecedently low values of less than 2 nm and 10 pm in the horizontal and vertical planes, respectively [4]. In the past few years, ATF2, a low energy prototype of the final focus system for future linear colliders, has been added, using the extracted ultra-low emittance beam from ATF as input [5]. The main goals of both ATF and ATF2 are developing and validating the state of the art instrumentation and experimental beam handling techniques needed for future linear colliders. The specific goals of the ATF2 project are to (1) produce and maintain over time a stable beam with transverse size smaller than 40 nanometers and (2)

demonstrate 1-2 nanometer beam position stability at the collision point using bunch to bunch feedback. Two teams from IN2P3 laboratories participate in ATF2 within a community of American, Asian and European specialists.

A major issue in ATF2 and in linear colliders, as well as in many other accelerator facilities for high energy physics, is controling the beam halo before the collision point. Beam halo consists of tails extending far beyond the Gaussian core of the beam. Halo can be generated during the acceleration process, through wakefields and so-called « dark current » emission, as well as in the damping ring, via non-linearities, or through multiple Coulomb scattering of particles within bunches, scattering off the residual gas molecules in the vacuum chamber, and even scattering off photons from the black body thermal radiation present in the environment. From the experience at the Stanford Linear Collider (SLC) in the nineties and from more recent measurements at ATF, typically $\sim 10^{-3}$ of the total bunch charge can populate the halo. When tail particles reach the vacuum chamber and start showering in the material, large numbers of secondary particles are produced. The place where tail particles are the most likely to be intercepted are in the last focusing quadrupole magnets, just before the collision point. In a linear collider, such particle losses will be unacceptable near the collision point, as the produced secondary particles would have devastating effects on the experiments. For this reason, special collimation sections are planned far upstream in the system to clean up the beam halo. The design of these sections uses assumptions and experience from the SLC concerning the population and propagation of halo particles.

At ATF2, there are at present no collimators for the beam halo, although physical apertures of the vacuum chamber at various locations along the beam line will intercept some of it. Dedicated collimators are however now being prepared within the collaboration. The main tool to measure the beam size at the focal point of ATF2 is based on setting up an interference pattern between two laser beams and detecting the Compton scattered γ photon rate while the beam is scanned accross the interference fringes. From the modulation in the γ photon rate, the beam size could be extracted with a resolution as small as 20 nm [6]. This tool is however very sensitive to bremstrahlung photons emitted when halo particles are intercepted in the last quadrupole magnets and in the vacuum chamber after the collision point. Although specific collimation has been installed to shield the solid angle of the γ photon detector against such bremstrahlung photons, this background prevents the use of the largest horizontal and vertical demagnifications factors available in the optics. Recently, vertical beam sizes of ~ 45 nm are routinely produced at low charge [7].

An alternative technique to measure the rate of Compton scatters during the interaction of the beam with the interference fringes is to detect the recoil electrons. Since these electrons have up to 2.23% lower energy compared to other beam particles, detection behind a large 20° bending magnet used after the collision point can be considered. The visibility in the presence of the beam halo was checked in simulation. While the halo is clearly dominating, by installing an extra focusing quadrupole between the collision point and the bending magnet, the halo can be focused enough to enable the edge and about half the Compton spectrum to be clearly measured. A new diamond sensors with four strips has been installed for this purpose in the vacuum chamber, near the beam, using a movable stage to scan the horizontal dimention [8]. A second one is planned in 2015 for scans in the vertical dimensions. The radiation that would have to be tolerated from backscattered neutrons and from the intercepted halo itself was estimated using a preliminary GEANT4 simulation, showing that the maximum yearly dose would be less than 25 kGy. This would be acceptable for scCVC diamonds. The electronics and signal processing chain are relatively simple given the large signal and low bunch frequency (1.5 to 6 Hz). However, the very large dynamic range implies special care to enable collecting the largest charges without biases at the higher end of the dynamic range. Shielding against high frequency electromagnetic pickup induced by the passage of the beam is also an issue in the lower end of the dynamic range.

In parallel, an identical device has been prepared to characterize the beam distribution at the exit of the PHIL facility at LAL, where the main aim is to provide a diagnostic capable of probing very low intensity beams suitable for detector R&D activities. PHIL is a facility at LAL for photo-cathode R&D with very short pulses [9]. Electron beams with 3-5 MeV, 10-500 pC, 7 ps FWHM bunches are produced daily, including for users doing other R&D. Recently, the high power sub-picosecond laser of the LASERIX team has been installed at LAL and it is planned to send a small fraction of its power onto the PHIL photo-cathode. A novel multi-photonic beam production mechanism is also being investigated at PHIL, to drastically reduce the beam charge, by reducing the photon energy on the photo-cathode below the threshold for extracting electrons, requiring hence coincident photons. The diamond sensor will be essential for tuning and operating in this multi-photon production mode.

Summarising, the main goals of the project to which the student will contribute are:

- Measure and characterise the beam halo for different optical magnifications and parameters at ATF2 and PHIL beam lines, respectively at KEK and LAL
- Simulate beam halo generation, propagation and experimental setups
- Detect the recoil electron spectrum for linear (first order) Compton scattering
- Participate in R&D towards new diamond sensors with improved performances
- Contribute to the operation of the ATF2 and PHIL accelerators

The expected timeline is indicated below :

- <u>Autumn 2015</u> : Basic accelerator concepts ; Participation in operation and experimentation with presently installed diamond sensor scanner at PHIL ; Study bibliography and do ^{241}Sr β / ^{90}Am α source testing of first sensor fabricated at LAL.
- <u>Winter – Summer 2016</u> : Simulation of the experimental setup at ATF2 with tracking and GEANT4 ; First experimentation period at ATF2 for beam halo studies. Beam testing after exit window of PHIL of LAL produced diamond sensor. General post-graduate course in accelerator physics and instrumentation (to be defined)
- <u>Autumn 2016 – Summer 2017</u> : Add quadrupole focusing to experimental setup behind ATF2 collision point ; Halo and Compton spectrum measurements with collimation ; Contribute to ATF2 operation ; Further testing of LAL produced diamond sensors at PHIL ; Topical post-graduate training school during Summer (to be defined)
- <u>Autumn 2017 – Summer 2018</u> : Analysis and interpretation of experimental data ; Detailed simulation and characterisation ; Extrapolation for future usage of diamond sensors for other facilities ; Documentation and public presentation (refereed publications, seminars) ; PhD writing and defense at Orsay.

Publications related to the PhD subject:

1. R. Tomàs, Phys. Rev. STAccel. Beams 13, 014801 (2010), http://clic-study.org/
2. ILC-REPORT-2007-001, http://www.linearcollider.org/cms/
3. P. Raimondi and A. Seryi, Phys. Rev. Lett. 86, 3779
4. K. Kubo et al., Phys. Rev. Lett. 88, 194801 (2002), http://atf.kek.jp/collab/ap/
5. P. Bambade et al., Phys. Rev. STAccel. Beams 13, 0142801 (2010)
6. T. Suehara et al., Nucl.Instrum.Meth.A616:1-8 (2010)
7. G. White et al, Physical Review Letters 112, 034802 (2014)
8. S. Liu et al., http://accelconf.web.cern.ch/AccelConf/IPAC2014/papers/thpme091.pdf
   See also: http://agenda.linearcollider.org/event/6389/session/14/contribution/51/material/slides/0.pdf
9. R. Roux et al., https://accelconf.web.cern.ch/AccelConf/LINAC2012

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