DAΦNE TECHNICAL NOTE

INFN-LNF, Accelerator Division

Frascati, April 2016
Beam Measurements #18
Presented at the 101 Congresso SIF

Double arm luminometer for DAΦNE: feasibility study

ANTONIO DE SANTIS

Laboratori Nazionali di Frascati - I.N.F.N.
via E. Fermi, 50
00044 Frascati (RM).
E-mail: antonio.desantis@lnf.infn.it

Abstract The luminosity measurement is one of the most important diagnostic tools to setup and optimize the performances of a collider. The luminosity at DAΦNE, the Frascati lepton collider, is measured by a gamma bremsstrahlung proportional counter and by the KLOE-2 experiment calorimeter [1, 2, 3]. The gamma monitor is fast but highly imprecise and it is routinely used only for machine fine tuning during operations while the luminosity measurement given by KLOE-2 apparatus is used to check the machine setup variation and to log long term performances providing measurements at 1/15 Hz rate with expected accuracy of the order of $\delta_{\mathcal{L}}(L_{inst} = 10^{32}\text{cm}^{-2}\text{s}^{-1}) \simeq 4\%$.

This work is a "proof of concept" of the possibility to use the KLOE-2 small angle calorimeter to perform a fast double-arm luminometer to ensure accurate and reliable measurement of the DAΦNE luminosity [4].

1 Introduction

The luminosity of DAΦNE is measured by the KLOE-2 experiment using dedicated selection of Bhabha scattering events directly at the trigger (TRG) level using the coincidence between Electro-Magnetic Calorimeter (EMC) barrel sectors fired by charged particles while the experiment is taking data [5, 6]. This method is based on the rate measurement of the Bhabha events at Very Large polar Angle (VLABHA), using TRG multiplicity of high energy release in the EMC (e.g. above 300 MeV) . The cross section of VLABHA process is of the order of 430 nb [7] that imply an effective rate of 40-50 Hz at the instantaneous luminosity of $10^{32}\text{cm}^{-2}\text{s}^{-1}$. A dedicated DAQ monitoring process [8] provides every 15 seconds ("fast" data) a measurement based on the number of coincidence in a given time interval normalized by a scale factor evaluated by Monte-Carlo and corrected for the measured dead time of the trigger. The time interval has been fixed to 15 seconds to ensure accuracy of the order of 5% on the measurement[1] when the luminosity is ranging between 0.5 and 1.5 $10^{32}\text{cm}^{-2}\text{s}^{-1}$. The time interval of 15 seconds is too large when compared with the beam lifetime at the maximal currents (*e.g.* 950 s) and does not allow to setup the best collisions conditions. For this reason two indipendent gamma monitors, for positron and electron side respectively, are installed to measure single bremsstrahlung [9]. This process has a larger rates allowing for collisions fine tuning. The strong dependence of the acceptance from the machine setup and the large background contribution inhibit the usage of the gamma monitors as absolute luminometers.

In this context considering a process with higher cross section, like the Bhabha scattering at small angle, will allow to increase the counting rate (*e.g.* reducing the statistical uncertainty) and to reduce the sampling time from the current 0.08 to 1-2 Hz while keeping under control background contribution.

Such measurement can be compared with the indirect estimated of the luminosity based on the beam currents and cross sections [10]:

$$L = \frac{N_e N_p}{N_b \sigma_x \sigma_y} f_{rev} \frac{\sigma_x + \sigma_y}{\sigma_x \sqrt{1+\phi^2} + \sigma_y} \qquad (1)$$

where: $N_{e/p}$ are the number of electron/positron in the beams, N_b is the number of bunches for each beam, $\sigma_{x/y}$ are the size of the beams at the interaction region, f_{rev} is the the revolution frequency and ϕ is the Piwinsky angle:

$$\phi = \frac{\sigma_z}{\sigma_x} \tan\frac{\vartheta}{2}$$

From eq. 1 the luminosity is expected to increase linearly with the product of the beam currents ($I_e I_p$). A comparison between the eq. 1 and the measured value is shown in fig. 1.

In the case of intense beams, as the ones stored in the DAΦNE main rings, the eq. 1 describes the observed behavior only if collective effects determining the transverse beam size evolution are properly taken under control. In fig. 1 the transverse beam size measured at the Synchrotron Light Monitor (SLM) have been used to evaluate the theoretical luminosity (L_{calc}), together with the beam currents. The *r.m.s.* transverse beam size measured with SLM have been scaled with the ratio of the betatron functions to obtain the value at the Interaction Point (IP).

2 Experimental apparatus

The experimental apparatus is based on the small angle Crystal CALorimeters with Time measurement (CCALT) [11] of the KLOE-2 detector. A simplified layout is shown in fig. 2, where only the essential geometry has been drawn.

The CCALT is constituted by two identical crystal calorimeters installed in front of the permanent defocusing quadrupole QD0 of the DAΦNE low-β doublet providing the proper focusing of the beams at the IP.

[1] Assuming an effective rate of 50 Hz the number of observed events in 15 seconds will be $50 \times 15 = 750$ corresponding to an accuracy of 3.7%.

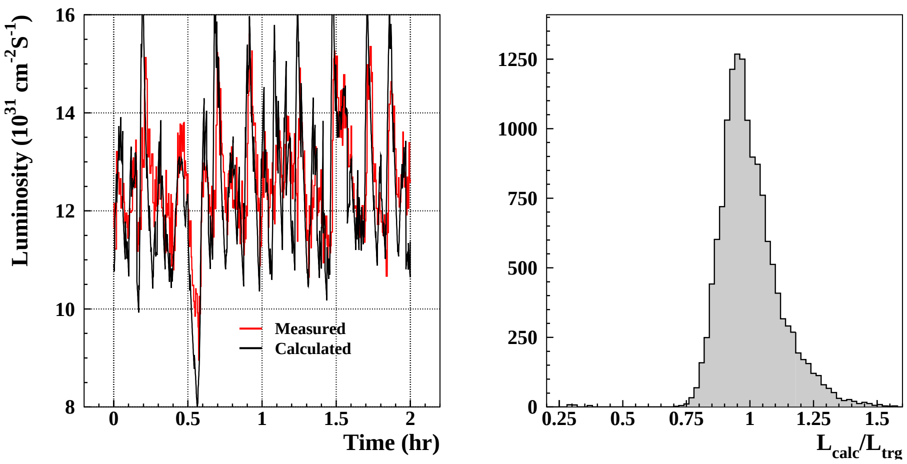

Figure 1: Instantaneous luminosity (measured by KLOE-2 L_{Trg}) compared with the one obtained by eq. 1 (L_{calc}) as a function of time (left) and their ratio (right). The asymmetry observed in the distribution of the ratio is induced by the not completely correct dependence of the beams transverse sizes with respect the beam currents. Deviation from unity is partly due to not perfect collision condition of the two beams (overlap). The calculated luminosity mean value has been normalized to the measured data in the same range.

The detector covers the polar angle between 8 and 18 degree. Each calorimeter is segmented in 48 small LYSO[2] crystal. Each segment is readout with Silicon Photo-Multiplier (SiPM). For the KLOE-2 experiment purpose the signals from SiPMs are routed to special boards named SDS, that were originally designed for the main EMC [12]. These boards sample and shape the SiPM signals for charge and arrival time measurements. Group of signals, four in the case of CCALT and five for EMC, are analogically summed in order to be used for the KLOE-2 trigger formation. The sum signal from CCALT sectors does not concur to the trigger logic, thus can be acquired separately with respect the full stream of KLOE-2 data to observe the particles coming from the primary interactions/decays at the IP.

The segmentation of the CCALT, with respect to DAΦNE IP is represented in fig. 2. The whole apparatus corresponds to a "single" effective crystal covering azimuthal sectors, 30° wide, around the IP. The bold regions correspond to the sector used in this preliminary analysis.

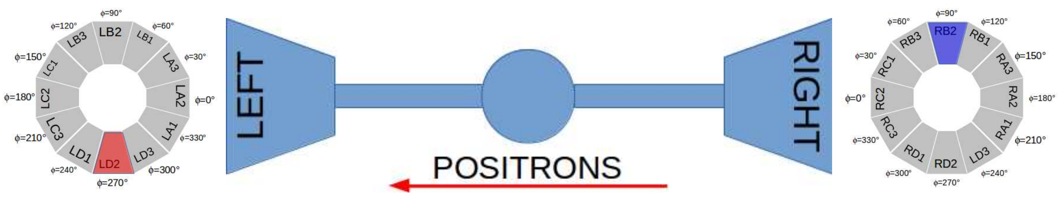

Figure 2: Layout of the DAΦNE interaction region inside the KLOE-2 detector. The two trapezoidal highlighted areas represent the two halves of the CCAL-T. Conventionally we will name the sector of the detector receiving particles from the electron and positron as Right (R) and Left (L) sides respectively.

3 DAQ

The DAQ scheme is sketched in fig. 3. Signal coming from SDS boards are compared with a fixed threshold using a NIM discriminator (CAEN Mod.N844 [13]) allowing thresholds and pulse width tunability. In fig. 4 pulses from two sectors of CCALT and their coincidence are shown, together with a detail of the pulses around the threshold value showing the expected time jitter of the

[2] Cerium-doped Lutetium Yttrium Orthosilicate.

discriminator pulses. The width of the NIM pulses from discriminator is set equal to the measured jitter in order to maximize the efficiency for time coincidence measurement.

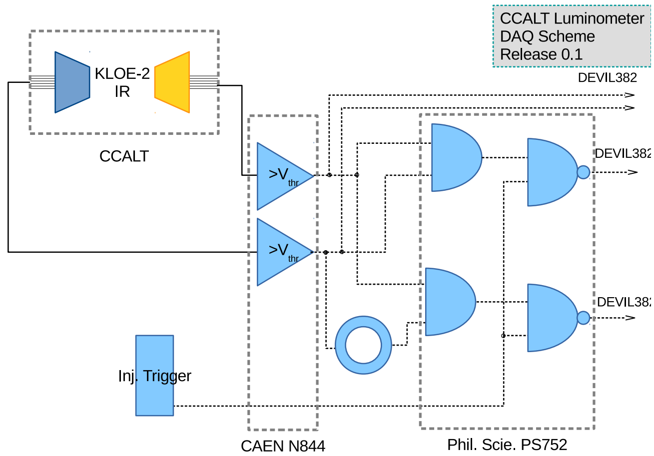

Figure 3: Schematic view of the DAQ acquisition. the signals coming from a corresponding sectors on the two sides are compared with a fixed threshold. NIM pulses are formed when signals from CCALT sectors are lower than the threshold (SiPM has negative pulses). The logic unit issues a high level when the NIM pulses from the discriminator overlap for at least 4 ns only. A veto is applied to the logic unit to forbid coincidence formation during a fixed time window after the beam injection shot (typically 50 ms). One of the side is delayed to allow direct measurement of accidental coincidence. Pulses from single channels and coincidence are brought to a scaler for rate measurement.

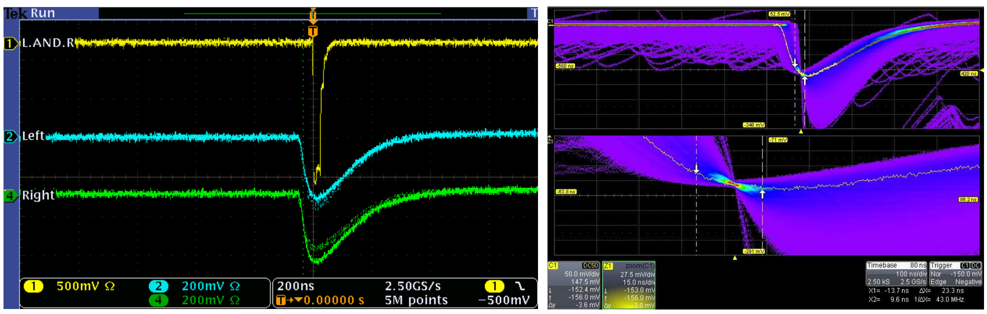

Figure 4: Pulses from CCALT sectors: coincidence from the two sides (left) and pulses from the CCALT R sector (right). The zoomed area shows the trigger jitter for a threshold of -150 mV. The width of the selected area corresponds to 23 ns.

Pulses from discriminator are used to establish time coincidence by a logic unit (Philips Scientific PS702). Signals from the positron side are delayed in time by 100 ns in order to measure directly the accidental coincidence rate.

Rates from single channels (electron and positron side) and coincidence (direct and accidentals) are measured using a VME counter (STRUCK STR7200) already used for DAΦNE single-arm luminometer [9]. The rate measurement is performed as ratio between the number of signal counts and a reference provided by a 10 MHz generator directly at the level of the Devil 385, the CPU that controls the VME bus with the counter installed.

A dedicated application has been developed, under the DAΦNE Control System [14, 15], to drive data acquisition. A screen-shot of the graphical user interface is presented in fig. 5, whose central panel shows the diagnostic behavior as moving the beams out of collisions. The applications tracks several data: beam currents, beam measured dimensions, coincidence rates (direct and accidentals), single hits counting rates, KLOE-2 end-caps calorimeter counting rates and instantaneous luminosity.

Figure 5: Screen-shot of the DAΦNE control system application performing data acquisition of the CCALT luminometer test set-up. In the center bottom panel is presented the effect on the coincidence rate obtained moving the two beams out of collisions.

4 MonteCarlo expectations

The experimental setup has been simulated using a toy Monte-Carlo. The MC generator for the physics is `BABAYAGA` [16]. Events have been generated with a minimum polar angle of 5° ($\pi - 5°$) including Initial State Radiation (ISR) effect. Real luminous point widths (transverse and longitudinal) and center of mass residual momentum have been included in the simulation. The detector geometry has been simplified using only the annulus between minimum and maximum radius of the real CCALT to estimate an upper limit to the geometrical acceptance of this detector for the Bhabha events.

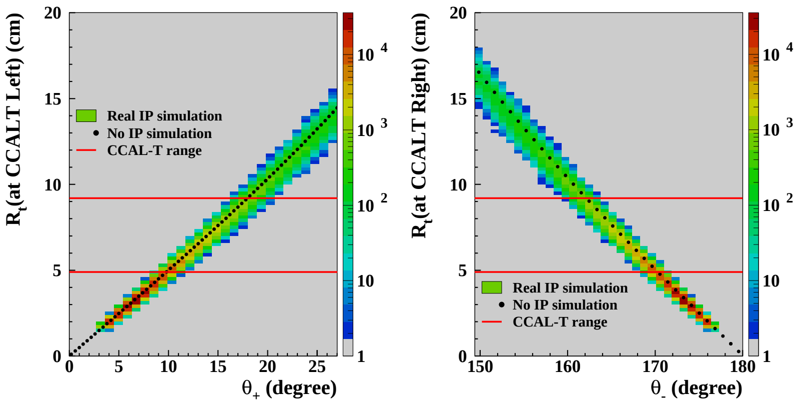

Figure 6: Transverse radius of charged particle helix as a function of electron(positron) on left(right) CCALT backplane emission polar angle.

In the propagation of electron (positron) particles the effect of the KLOE-2 solenoid has been taken into account. The transverse radius of the helix that a charged particle will follow is shown in fig. 6 where the comparison between the expected theoretical behavior (eq. 2) and the real distribution of the impact points is shown.

$$R_t(\Delta z, \vartheta)[\mathrm{m}] = \frac{\sqrt{2}p[\mathrm{GeV}]\sin\vartheta}{0.3B[\mathrm{T}]}\sqrt{1-\cos\frac{0.3B[\mathrm{T}]\Delta z[\mathrm{m}]}{p[\mathrm{GeV}]\cos\vartheta}} \tag{2}$$

The expected density of impact point, projected at the end of the CCALT crystals is shown in fig. 7, where the shape of the CCALT detector is superimposed. The reference frame is the same used in the data reconstruction by KLOE-2: z axis is longitudinal with the same orientation as the positron beam, the y axis is vertical while the x axis is horizontal with outward orientation,

From toy-MC estimate the effective cross section of the Bhabha process for the particles whiting the in the detector acceptance is 32 μb, corresponding to a ~ 3 kHz expected rate at the instantaneous luminosity of $10^{32}\text{cm}^{-2}\text{s}^{-1}$. The expected rate for the pair of sectors considered in this preliminary setup is 80 Hz with 100% efficiency.

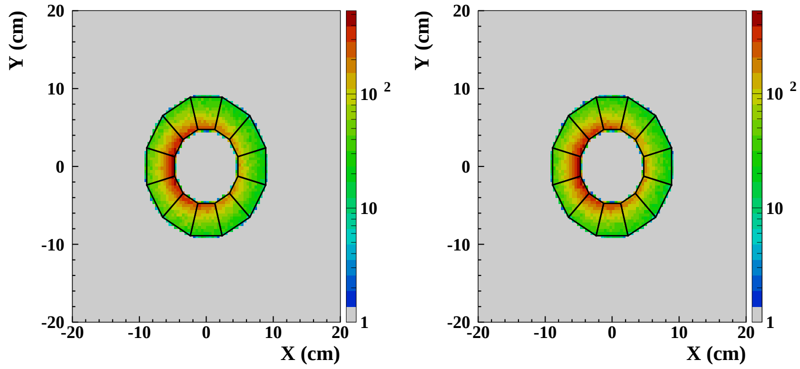

Figure 7: Distribution of the impact points of the generated particles projected on the surface of the CCALT. The negative horizontal direction is toward the center of DAΦNE. The observed asymmetry along the X direction is due to the *CoM* momentum of 30 MeV due to beam crossing angle.

5 Data analysis

This analysis is a “proof of concept” aimed at studying the effective design of a luminometer based on the CCALT detector. In this context few well grounded properties of the apparatus have been proved:

- coincidence rate higher than the one observed in the EMC calorimeter (50 Hz@$10^{32}\text{cm}^{-2}\text{s}^{-1}$);
- accidental coincidence lower than the signal;
- good linearity with respect to the absolute luminosity measured by KLOE-2
- good stability of the absolute scale calibration between coincidence rate and luminosity.

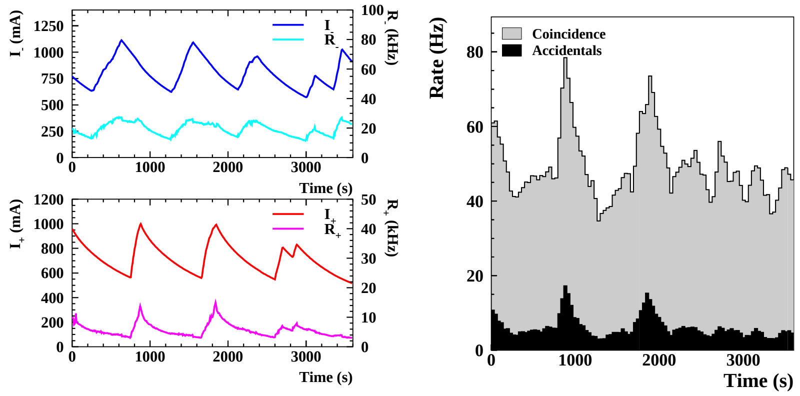

Figure 8: Measured rate as a function of time. Left: single hit rate measurement for electron (top/cyan) and positron (bottom/pink) compared with the corresponding beam currents (blue for electron and red for positron). Right: direct coincidence rate (gray) and accidental rate (black). For coincidence (direct and accidentals) a veto of 30 ms following the beam injection has been applied. This veto increases the dead time of the system and it is not applied to the DAQ, resulting in a systematic depression of the counting rate during the injections. The integration window was 15 seconds and the applied threshold was -100 mV. Data are from 28/02/2015

Collision data, acquired in the period between February and May 2015, have been analyzed in order to measure the effective rate of coincidence as a function of luminosity. In fig. 8 a sample of raw data collected at the end February is shown. The signal over background ratio is 6 : 1, that gives a contribution to the relative signal count uncertainty of the order of 20% (*e.g.* from 10% to 12%)[3].

The linearity of the signal counting rate is shown in fig. 9. The signal rate has been obtained by subtracting the accidental rate from the raw direct coincidence measurement in the same time window. During the acquisition a tunable width veto is applied when beams are injected in the main rings at the level of the logic unit. This veto affects only the acquisition of the direct and accidental coincidence, while single hits and normalization clock are left unaltered. This implies that during the injection a correction factor for the dead time of the logic unit have to be considered. This factor, evaluated as the ratio between the duration of the veto and the time between two consecutive injection (*e.g.* typically 50 out of 500 ms because the 2 Hz injection rate), is applied online during the acquisition for graphical purpose only; data are stored without this correction. The distribution of the signal rate as a function of the measured luminosity has been obtained discarding data acquired during the beam injections. For each interval of instantaneous luminosity the distribution of the observed coincidence, minus by the accidental rate, has been fitted with a Gaussian to measure mean values (S_μ) and widths (σ_S). In fig. 9 the result of these fits is shown. The linearity of S_μ versus $\mathrm{L}_{\mathrm{Trg}}$ has been verified by fitting the distribution shown in fig. 9 with a straight line: $S_\mu = \alpha^V \mathrm{L}_{\mathrm{Trg}} + \beta$ where α^V is the calibration factor for a given value of the discriminator threshold (V_{thr}). A good linearity is observed getting an effective rate of $\sim$ 44Hz@$10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ similar to the rate observed for the EMC calorimeter with a single pair of CCALT sectors. The relative uncertainty of normalization factor is 4%.

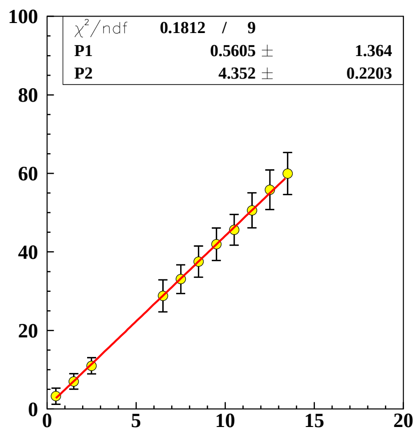

Figure 9: Signal counting rate as a function of the instantaneous luminosity. The fit has been performed with a straight line of the form $S_\mu = P_2 \mathrm{L}_{\mathrm{Trg}} + P_1$. A good $\chi^2/ndof$ is obtained. The constant term P_1 is compatible with zero, implying the absence of any offset related to accidental rate subtraction. The integration window for the rate measurement was 15 seconds and the applied threshold was -100 mV. Data were taken on 28/02/2015.

In the fig. 10-left the dependence of measured rate corresponding to the reference luminosity of $10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ as a function of the applied threshold is shown, while fig. 10-right shows the behavior of the scale factor between signal rate and luminosity.

[3]With S:B=6:1 $\Rightarrow N(= S + B) = 7B$.

$$\hat{\delta}_S = \frac{\sigma_S}{S} = \frac{\sigma_N \oplus \sigma_B}{N - B} = \frac{\sqrt{2}}{3\sqrt{B}}$$

Assuming signal poissonian distributed:

$$\delta_S = \frac{1}{\sqrt{S}} = \frac{1}{\sqrt{6B}} \Rightarrow \frac{\hat{\delta}_S}{\delta_S} = \frac{2\sqrt{3}}{3} \simeq 1.2$$

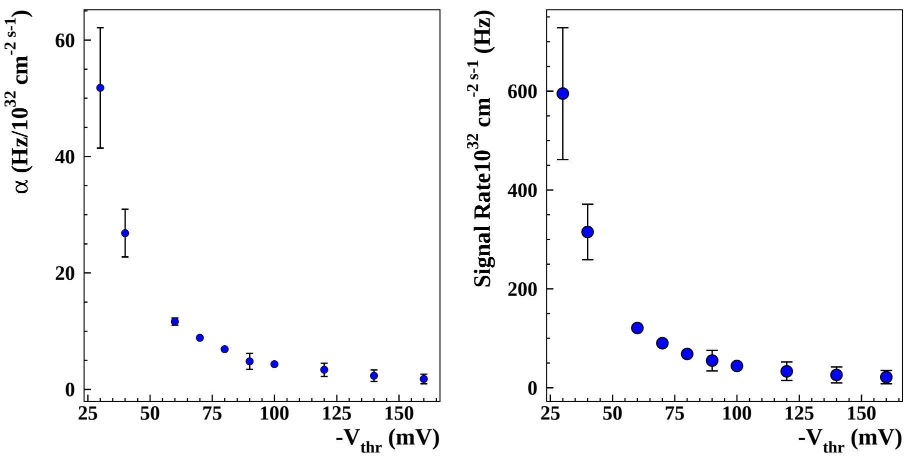

Figure 10: Left: dependence of the calibration constant with respect to the discriminator threshold. The errors have been determined by fitting the distribution of S_μ with respect to L_{Trg}. Right: dependence of the .

6 Conclusions and perspectives

As shown from a single sector pairs it is possible to observe a coincidence signal rate comparable to the one observed with the KLOE-2 EMC at large angle, this implies that integrating more sectors it will be possible to have a counting rate of the order of kHz that allows a statistical accuracy of the order of 5% with sampling rates of 1 or 2 Hz. From MC simulation it is expected that the number of useful pairs is around 20, giving an extra factor of two.

The acquisition from the horizontal sectors will be probably too much polluted by background, nevertheless the absolute rate of signal should be enough even excluding those sectors from the measurement.

Simultaneous acquisition of several sectors of the detector will require the assembly of a dedicated DAQ capable to measure with reasonable accuracy arrival time and total charge of the CCALT pulses. This will allow to lower as much as possible the threshold at the level of the discriminator that will be used to generate the trigger for the acquisition and to apply an effective threshold based on the charge of the signals and their "topology". Maybe a kind of "clustering" based on contiguous in time sectors could be considered.

Measuring the time with a resolution of few hundreds of picoseconds will allow, extending the acquisition also to the "Fiducial" signal to measure bunch-by-bunch luminosity. This features could be very important to study the impact of the collective effects on the machine luminosity.

Aknoledgments

This work has been strongly encouraged and followed by C. Milardi and A. Drago to whom goes my acknowledgment for all the support, discussion and trust given. I would like to acknowledge technicians from SELCED (O. Coiro, D. Pellegrini, E. Gaspari and C. Mencarelli) who fight against cables to bring signals from CCALT in the "Sala strumentazione", O. Giacinti for the support given with the VME crate setup, F. Galletti for the support given in understanding and "cracking" the Devil 385 to acquire rates from CCALT in the DAΦNE control system, G. Mazzitelli and L. Foggetta for their support and advice to collect the needed HW to perform the measurement, A. Gallo as "scope provider" and A. Ghigo for the support given.

Last but not least, i would like to thank S. Miscetti, S. Giovannella and F. Happacher for all the discussion and help in the understanding the CCALT from the KLOE-2 side.

References

[1] C. Milardi et al. **DAΦNE operation with the upgraded KLOE-2 detector**. In *Proceedings, 5th International Particle Accelerator Conference (IPAC 2014)*, page WEOCA03, 2014.

[2] Antonio De Santis. **DAΦNE and KLOE-2**. *Phys. Scripta*, T166:014015, 2015.

[3] Catia Milardi et al. **DAΦNE Consolidation Program and Operation with the KLOE-2 Detector**. *ICFA Beam Dyn. Newslett.*, 67:9–27, 2015.

[4] De Santis, A. **Double arm luminometer for DAΦNE**. *SIF Conference*, 1, 2015.

[5] A. Aloisio et al. **The KLOE trigger system. (Addendum to the KLOE technical report).** *LNF Preprints*, 96/043, 1996.

[6] M. Adinolfi et al. **The trigger system of the KLOE experiment**. *Nucl.Instrum.Meth.*, A492:134–146, 2002.

[7] Denig, A., Ngyen, F. **The KLOE Luminosity Measurement**. *KLOE NOTE*, 202, 2005.

[8] Branchini, P., Palutan, M., Patera, V., Sciascia, B. **The KLOE online trigger monitor system**. *KLOE MEMO*, 275, 2002.

[9] G. Mazzitelli, F. Sannibale, M. Serio, G. Vignola, F. Cervelli, and T. Lomtadze. **Single bremsstrahlung luminosity measurements at DAPHNE**. *Nucl. Instrum. Meth.*, A486:568–589, 2002.

[10] Raimondi, P., Zobov, M. **Tune Shift in Beam-Beam Collisions with a Crossing Angle**. *Note Tecniche DA*, General:58, 2003.

[11] F. Happacher, M. Martini, S. Miscetti, and I. Sarra. Tile and crystal calorimeter for KLOE-2 experiment. *Nucl. Phys. Proc. Suppl.*, 197:215–218, 2009.

[12] M. Adinolfi et al. **The KLOE electromagnetic calorimeter**. *Nucl. Instrum. Meth.*, A482:364–386, 2002.

[13] CAEN. **MOD. N844/N844P/N845 8-16 CHANNEL LOW THRESHOLD DISCRIMINATOR**. *Technical Information Manual*, 00103/00:844-5.MUTx/07, 2011.

[14] Di Pirro, G., Milardi, C., Stecchi, A., Trasatti, L. **The DANTE control system**. *Note Tecniche DA*, Control System:6, 1992.

[15] Verola, M. **DANTE control system data flow**. *Note Tecniche DA*, Control System:9, 1994.

[16] Giovanni Balossini, Carlo M. Carloni Calame, Guido Montagna, Oreste Nicrosini, and Fulvio Piccinini. **Matching perturbative and parton shower corrections to Bhabha process at flavour factories**. *Nucl. Phys.*, B758:227–253, 2006.