ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-MOPMF089

DAΦNE LUMINOSITY MONITOR

A. De Santis*, C. Bisegni, O. R. Blanco-García, O. Coiro, A. Michelotti, C. Milardi, A. Stecchi
INFN - Laboratori Nazionali di Frascati, Frascati, 00044, Roma, Italy

Abstract

This work presents a new method to measure the DAΦNE collider instantaneous luminosity. The method is based on the identification of Bhabha scattering events at low polar angle (~10°) around the beam axis by using two small crystal calorimeters shared with the KLOE-2 experiment. An indipendent data acquisition setup has been designed and realized in order to implement the fast luminosity monitor, also in view of the DAΦNE future physics runs. Besides total instantaneous luminosity the new diagnostic measures also Bunch-by-Bunch (BBB) luminosity. This peculiarity allows to investigate the beam-beam interaction for the Crab-Waist collisions at DAΦNE and luminosity dependence on the bunch train structure.

INTRODUCTION

The luminosity of DAΦNE during last year of operation [1] has been measured by the KLOE-2 experiment using dedicated selection of Bhabha scattering events directly at the trigger level while taking data [2,3]. A dedicated KLOE-2 DAQ monitoring process provides every 15 seconds a measurement with 3-5 % relative uncertainty in the instantaneous luminosity range observed during the KLOE-2 run.

Furthermore two independent gamma monitors are installed on positron and electron side respectively, to measure single bremsstrahlung [4]. This process has high rates suitable for collisions fine tuning; however the strong dependence of this diagnostic acceptance on the machine setup and the large background hitting the detectors inhibits the usage of the gamma monitors as absolute luminometer.

The realization of a further luminometer based on the observation of the Bhabha scattering events emitted at low angle aims at combining accuracy and high repetition rate in the same diagnostic

EXPERIMENTAL SETUP

The experimental apparatus is based on the small angle Crystal CALorimeters with Time measurement (CCALT) [5] of the KLOE-2 detector that measures the Bhabha scattering events, the dominant process in that angular region.

Detector Layout

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 Interaction Point (IP).

The detector covers the polar angle between 8° and 18°. Each calorimeter is segmented in 48 small LYSO[1] crystal. Each segment is readout with Silicon Photo-Multiplier (SiPM). Signals from group of four crystal are analogically summed in CCALT sectors, acquired independently with respect the KLOE-2 data, to measure the luminosity. Each sectors covers an azimuthal angle of 30°. The detector assembly and final installation are shown in Fig. 1.

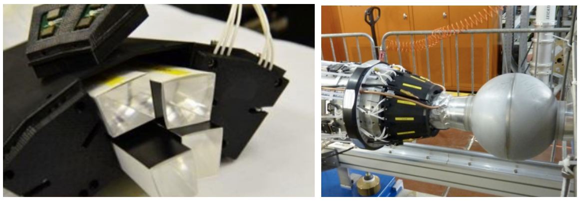

Figure 1: Left: CCALT detector macro-sector before the SiPM installation. The four crystal per sector are clearly visible. Each side of the detector is made of four macro-sectors. This segmentation is needed in order to leave space for the Beam position Monitor feed-trough.
Right: Detector fully assembled and installed in front of the QD0 magnets. The spherical beam pipe arount the IP is also shown. Only one side of the detector is visible.

DAQ and Control System

The DAQ scheme is sketched in Fig. 2. CCALT sectors signals are split and compared with a constant fraction discriminator[2] in order to measure arrival time and integrated charge.

Discriminated signals are used to feed the trigger logic: same side pulses are logically merged to reduce multiplicity, then time coincidence between the two side of the detector are used to form trigger pulses when single side signals overlap for at least 4 ns. When trigger pulse is received by the TDC and QDC boards[3] signals arrival time and the charge are determined. Trigger pulse is routed to a Time-Unit that generates a gate (390 ns wide) and an end-marker signals that starts the QDC charge integration and terminate the TDC time conversion, respectively.

The DAQ is completed with a programmable FPGA[4] that allows monitoring of DAQ rates and the acquisition dead-time. The most relevant source of dead-time is the injection trigger veto that must be used in order to reduce the trigger rate observed during the first 50 ms after the injection pulse. The veto lenght caused at least a detector efficiency loss of 10% (50 ms veto every 500 ms corresponding to the single

---

* antonio.desantis@lnf.infn.it

[1] Cerium-doped Lutetium Yttrium Orthosilicate.
[2] CAEN N843
[3] CAEN V775N and CAEN V977 respectively.
[4] CAEN V1495

shot injection cycle) that has to be taken into account for online measurement of the luminosity.

The DAQ acquisition chain and the data-flow is fully handled within the CHAOS control system frameworkt [6]. CHAOS provides also tools for online monitoring of the DAQ status and luminosity measurement.

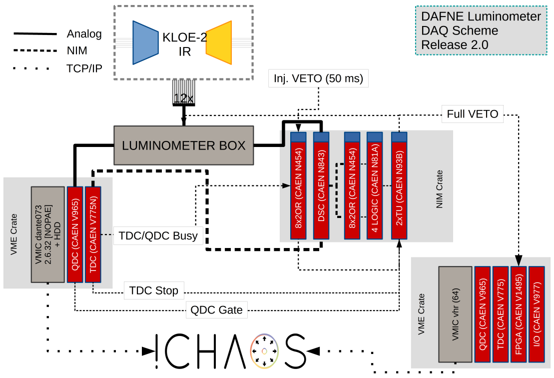

Figure 2: Schematic view of the DAQ acquisition. The signals coming from a corresponding sectors on the two sides are compared with a fixed threshold and used to measure arrival time and integrated charge when the trigger logic condition is fulfilled.

DATA ANALYSIS

The data collected by the luminometer have been analyzed in order to extract the rate of Bhabha scattering events to be normalized with the KLOE-2 reference luminosity. Data analysis is mainly based on the signal arrival time measurement. The detector segmentation allows to strongly reduce the accidental coincidence rate because the signal events are expected to fire opposite sectors of the luminometer, while accidental coincidence almost uniformly fires the whole detector. Background events are discarded and their rate is measured in order to monitor the expected behaviour of accidental rate as a function of the beam currents.

Total Instantaneous Luminosity Measurement

The total signal event rate is determined by counting the number of events satisfying the following requirements:

- at least one hit per detector side. This condition is not granted by the trigger selection because of the *common-stop* operation mode. It could happen that TDC channels acquiring the sectors that originates the trigger pulse formation are in the auto-reset state due to an earlier uncorrelated hit.
- exactly two sectors (one per side) in time coincidence within 10 ns among them and with a fixed delay w.r.t. the trigger pulse.
- angular distribution of the hits compatible with Bhabha scattering hypotesis. Because of the residual momentum in the tranverse plane of the colliding beams (~ 25MeV) the two fired sectors could have a maximum azimuthal angle difference of 50°.

The aforementioned criteria strongly suppress the accidental coincidences allowing for a very precise determination of the signal event rate. The number of residual background events has been estimated by the accidental coincidence observed out of the trigger time window. This allows for a data-driven determination of the background rate that follows the colliding conditions.

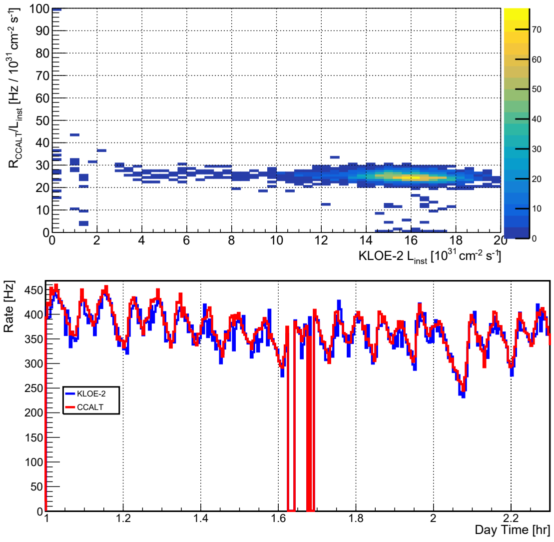

Figure 3: Top: Ratio between CCAL-T signal rate and luminosity reference measurement performed with KLOE-2 detector as a funcion of the luminosity. The linearity of the CCAL-T signal rate w.r.t. the luminosity is clearly seen. The increased spread in the ratio distribution at low luminosity is purely due to unavoidable statistical fluctuation.
Bottom: Comparison between the Luminometer signal rate (red) and the reference luminosity measured by KLOE-2 (blue). The reference histogram has been rescaled with a scale factor obtained from the upper plot by fitting the data with a constant function. A good agreement can be appreciated. The scale factor is 26.4 ± 2.1 Hz with an overall realtive uncertainty of 10%.

The observed signal rate has to be corrected taking into account the measured dead-time. The main source of the DAQ dead-time is the “injection-veto”, described previously, that accouns for 10% relative contibution during the beam injection phase. The remaining 1-2% is related to the DAQ conversion and acquisition time. This contribution could increase depending on the total trigger rate and CHAOS infrastructure load. The CHAOS infrastructure allows for a time synchronization between the different DAQ sources at the level of the ms. This aspect is fundamental when we have to assign the dead-time measured by DAQ Monitor with a repetetion rate of 0.5 Hz to each event with a trigger rate of ~400 Hz.

In Fig. 3 the result of the measurement is shown. The calibration coefficient between luminometer signal rate and instantaneous luminosity is extracted by fitting the ratio of this two as a function of the reference luminosity. A good linearity is observed along the whole operating scale. This allows to use the luminometer signal rate as absolute luminosity measurement.

The proven effectiveness of the CCALT based luminometer in measuring the absolute instantaneous luminosity, with reasonable accuracy (5-10% depending on repetition rate and treshold settings), leads naturally to propose the diagnostics as machine luminometer for the forthcoming DAΦNE run dedicated to SIDDHARTA-2 experiment [7].

"Bunch-by-Bunch" Luminosity Measurement

The BBB luminosity measurement is one of the most intriguing features of this luminometer that allows to verify any dependence of the luminosity on collective effects (*e.g.* electron cloud) that can cause a non-negligible variation of bunch parameters, such as transverse bunch sizes and betatron tunes, along the batch.

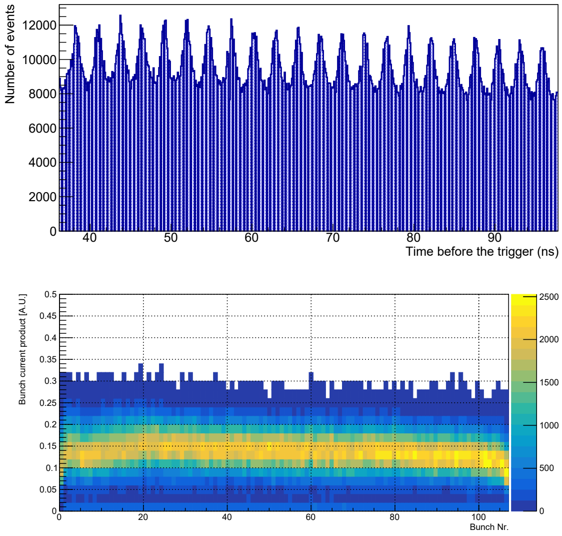

Figure 4: Top: distibution of the event w.r.t. the revolution period. The peak structure follows from the bunch structure of the beam. The time separation of 2.7 ns between highlights the luminometer effectiveness in resolving bunch structure. The time resolution forces to define a "No Man Land" between two peaks in order to minimize the misidentification of the correspondig bunch event by event. Bottom: beam charge product as a function of the bunch number. This information is needed to properly normalize the BBB signal event rate in order to compare the diffent bunches on the same beam current scale.

The BBB measurement is performed measuring the arrival time of the revolution clock (fiducial) with respect to the single event trigger. In order to maintain a high efficiency, while operating in TDC common-stop mode, it is required to phase-lock the fiducial signal w.r.t. the trigger. The arrival time of the first fiducial pulse after the trigger formation is measured. In the Fig. 4-top the time distribution of the signal event is shown. The peak structure of the rate of fiducial signal as a function of the distance w.r.t. the trigger time reveals the underlying bunch structure of the beams.

The resolution of the time measurement is compatible with the expected one according to the TDC specifications. To increase the time resolution a larger buffer would be required (18 bit TDC vs the present 12 bit TDC). With the used setting for the luminometer the whole bunch train time structure (2.7 ns × 108 bunches = 291 ns) could be observed. The resolution forced us to define a "NO MAN LAND" between consecutives bunch in order to minimize the misidentification of event bunch number as shown in Fig. 4-top.

The BBB luminosity requires the knowledge of the bunch charge in order to correct for spurious effects on bunch luminosity purely induced by different intensities during the normal evolution of the beam current, as shown in Fig. 4-bottom.

CONCLUSION

The CCALT based luminometer developed for DAΦNE has proven to be a suitable diagnostics in order to implement high rate absolute luminosity measurement. The work on the CCALT based luminometer for DAΦNE showed the possibility to perform accurate measurements of the absolute luminosity with this kind of device. The excellent time resolution of the detector allowed to resolve the single bunch structure. BBB study of the luminosity will improve the understanding of the collisions at DAΦNE. The experience gained and the data collected during the KLOE-2 run will be extremely useful for the forthcoming DAΦNE run for the SIDDHARTA-2 experiment [7].

REFERENCES

[1] C. Milardi et al. A Review of the DAΦNE Performances During the KLOE-2 Run . paper TUYGBD2, 2018, this conference.

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

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

[4] G. Mazzitelli et al. Single bremsstrahlung luminosity measurements at DAPHNE. *Nucl. Instrum. Meth.*, A486(2002)568.

[5] F. Happacher et al. Tile and crystal calorimeter for KLOE-2 experiment. *Nucl. Phys. Proc. Suppl.*, 197(2009)215.

[6] L. Catani et al. Introducing a new paradigm for accelerators and large experimental apparatus control systems. *Phys. Rev. ST Accel. Beams*, 15(2012)112804.

[7] C. Milardi et al. Preparation Activity for the Siddharta-2 Run at DAΦNE. paper MOPMF088, 2018, this conference.