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DAΦNE LUMINOSITY MONITOR

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Abstract

The DAΦNE collider instantaneous luminosity has been measured identifying Bhabha scattering events at low polar angle (~10°) around the beam axis by using two small crystal calorimeters shared with the KLOE-2 experiment. Independent DAQ setup based on !CHAOS, a novel Control System architecture, has been designed and realized in order to implement a fast luminosity monitor, also in view of the DAΦNE future physics runs. The realized setup allows for measurement of Bunch-by-Bunch (BBB) luminosity that 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 KLOE-2 Physics run [1] has been measured by the experiment selecting on-line a special class of Bhabha scattering events directly at the trigger level while taking data [2, 3]. KLOE-2 dedicated DAQ process was used to provide a instantaneous luminosity measurement every 15 seconds with 3-5% relative uncertainty typically.

Furthermore two independent gamma monitors were installed to measure single bremsstrahlung [4] from both electron and positron beams. This diagnostic is well suited for collisions fast fine tuning because of the high rates of the observed process. The usage of gamma monitors for absolute luminosity measurement however is not possible because the acceptance of the detectors has a strong dependence on the machine setup and a large background hitting the diagnostic is observed.

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).

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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.

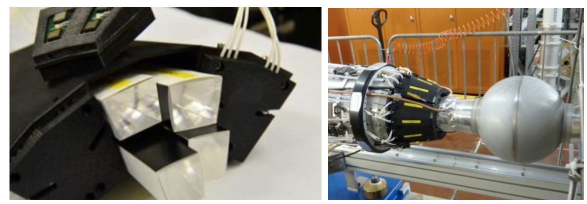

Figure 1: Left: CCALT detector macro-sector before the SiPM installation. The four crystal per sector are clearly visible. Each side of the detector is made of four macro-sectors. This segmentation is needed in order to leave space for the Beam position Monitor feed-trough.
Right: Detector fully assembled and installed in front of the QD0 magnets. The spherical beam pipe around 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[3] signals arrival time are determined.

The luminometer dedicated 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 length caused at least a detector efficiency loss of 10% (50 ms veto every 500 ms corresponding to the single shot of the injection cycle) that has to be taken into account for online measurement of the luminosity.

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

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

The *!CHAOS* environment provides also a synchronized acquisition of several other data sources: KLOE-2 luminosity, beam parameters as current, beam spot size, bunch number and bunch current structure from DAΦNE diagnostics.

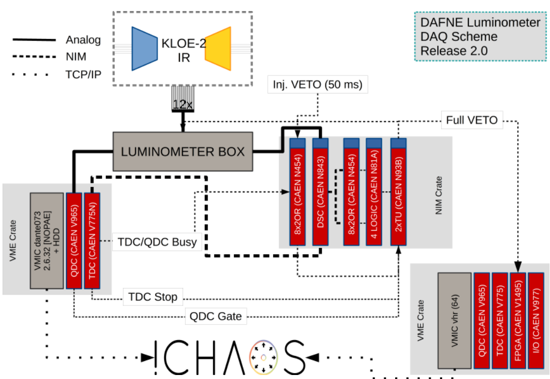

Figure 2: Schematic view of the DAQ acquisition. The signals coming from a corresponding sectors on the two sides are compared with a fixed threshold and used to measure arrival time and integrated charge when the trigger logic condition is fulfilled.

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. The trigger logic already provides events acquisition when opposite detector sides are fired. The signal selection requires the expected geometrical correlation because candidate signal events fires opposite sectors of the luminometer, while accidental coincidence almost uniformly fires the whole detector.

Background events with wrong geometrical signature are discarded and their rate is measured in order to monitor the expected behavior of accidentals as a function of the beam currents.

Events with the expected signal signatures are retained and their rate is evaluated. Accidental coincidence are still expected in the selected sample, because of unavoidable statistical contamination. To evaluate the residual background in the signal selection the events with wrong geometrical signature are used by normalizing the background counting rate with the ratio between geometrical acceptance of the two category.

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 accounts for 10% relative contribution 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 repetition rate of 0.5 Hz to each event with a trigger rate of ~400 Hz.

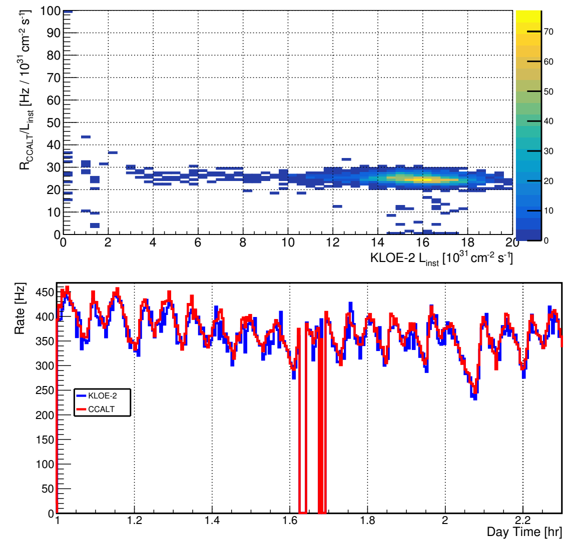

Figure 3: Top: Ratio between CCAL-T signal rate and luminosity reference measurement performed with KLOE-2 detector as a function of the luminosity. The linearity of the CCAL-T signal rate w.r.t. the luminosity is clearly seen. The increased spread in the ratio distribution at low luminosity is purely 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 relative uncertainty of 10%.

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.

A complete Monte-Carlo (MC) simulation of the detector has been developed in order to fully understand the luminosity measurement process and to completely qualify the detector behavior. The Bhabha event generator used is BABAYAGA [7] and a GEANT4 [8] description has been implemented for the detector response. The simulation has

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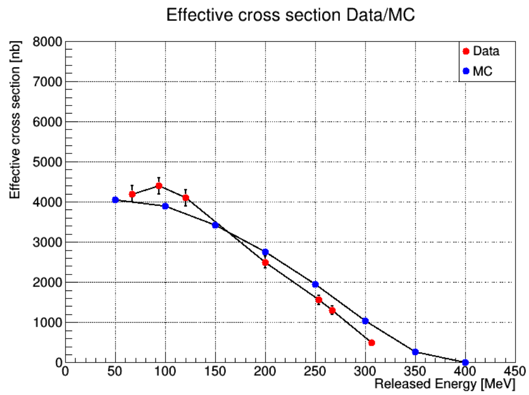

Figure 4: Preliminary comparison between real and simulated data. In the plot a comparison between the Bhabha scattering visible cross section is shown. The energy scale for the real data has been obtained rescaling the signal amplitudes used for the discrimination.

been performed only for the signal events (Bhabha scattering) while a full simulation with background insertion is still ongoing.

The MC simulation includes DAQ and Trigger behavior allowing to describe the different DAQ setup used during the data acquisition. The variation of the observed rate as a function of the discriminator threshold has been chosen for the preliminary validation of the MC simulation. In Fig. 4 the comparison between Bhabha scattering visible cross section measurement and simulation is shown. The cross section measurement has been obtained by varying the discriminator threshold in the range 25-115 mV and calculating the corresponding ratio between observed rate and KLOE-2 luminosity measurement as shown in Fig. 3 for each different threshold. The energy calibration has been obtained by comparing the simulation with the real data. The simulated cross section has been derived by applying the same analysis chain to the MC events. The agreement obtained is promising.

The validation of the MC simulation is fundamental for the usage of the same luminometer during the forthcoming SIDDHARTA-2 Physics run at DAΦNE [9].

"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.

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. 5 the time distribution of the signal event is shown. The peak structure of the counting of fiducial signal as a function of the distance w.r.t. the trigger time reveals the underlying bunch structure of the beams.

To perform synchronization and calibration of the DAQ boards several special runs were performed. The Fig. 5 shows an example of a DAQ run acquired with a special batch fill pattern: one over five filled for a total of 10 buckets for both beams. The flat distribution between peaks is due to residual accidental coincidences. The different height of the peaks is related to the bunch current dishomogeneity.

The TDC setup imply for the scale a minimum time-to-count of $T_{LSB} = 8.9$ ns/75 $\simeq$ 119 ps. The intrinsic jitter in time induced by FEE on each single channel is of the order of 200-300 ps. The observed resolution for the fiducial time measurement, being due to a coincidence between two different channel is at the expected level.

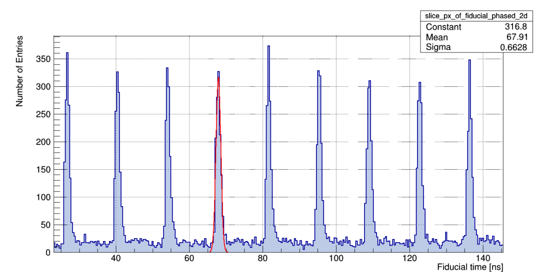

Figure 5: Distribution of the fiducial time w.r.t. the trigger for a special run acquired during KLOE-2 physics run (March 2018). The beam batch was filled with ten bunches only with a spacing between them of four buckets for both beams. The structure is clearly visible and the events due to a single bunch are well identified. The forth peak is fitted with a Gaussian showing a time resolution of 0.66 ns w.r.t. bunch spacing of 2.7 ns.

The BBB luminosity measurement requires, together with the determination of the instantaneous luminosity and the bunch association, also 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. The Fig. 6-bottom, shows the bunch current product between electron and positron beam when in DAΦNE there was 108 bunches circulating for a corresponding maximal current of 1.5 and 0.95 A for electron and positron, respectively.

The bunch luminosity is expected to be proportional to the bunches current product. To observe the luminosity along the batch a long time exposure is needed, then all the concurring effect (dead-time, bunches current variation, background contribution), have to be measured synchronously and corrected for along the time of the measurement in order to observe a genuine effect.

The BBB luminosity measurement capabilities are under investigation and the data analysis is still ongoing. In order

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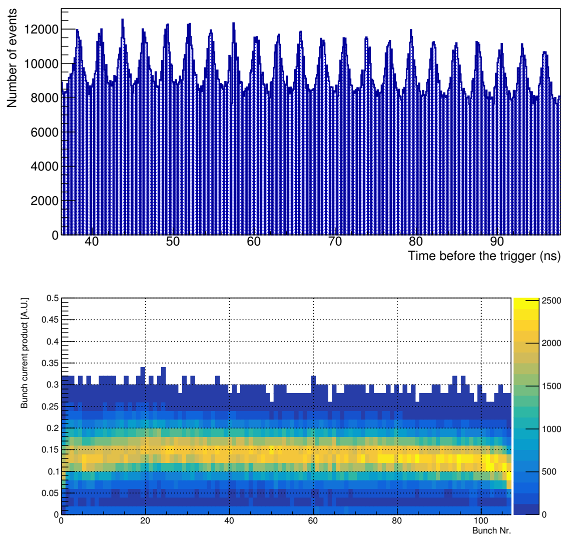

Figure 6: Top: distribution of the event w.r.t. the revolution period. The peak structure follows from the bunch structure of the beam. The time separation of 2.7 ns between highlights the luminometer effectiveness in resolving bunch structure. The time resolution forces to define a "No Man Land" between two peaks in order to minimize the misidentification of the corresponding 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 different bunches on the same beam current scale. Here the cumulative distribution in time is shown. The correction for the luminosity have to use the instantaneous value of the bunch current product to deconvolute variation along the time induced by bunch current dishomogeneity.

to verify the sensitivity a genuine bunch dependence has been induced in a special test run, shown in Fig. 7, where the positron beam fill was kept unbalanced with two different levels between the first fifty bunches and the following sixty.

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 [9].

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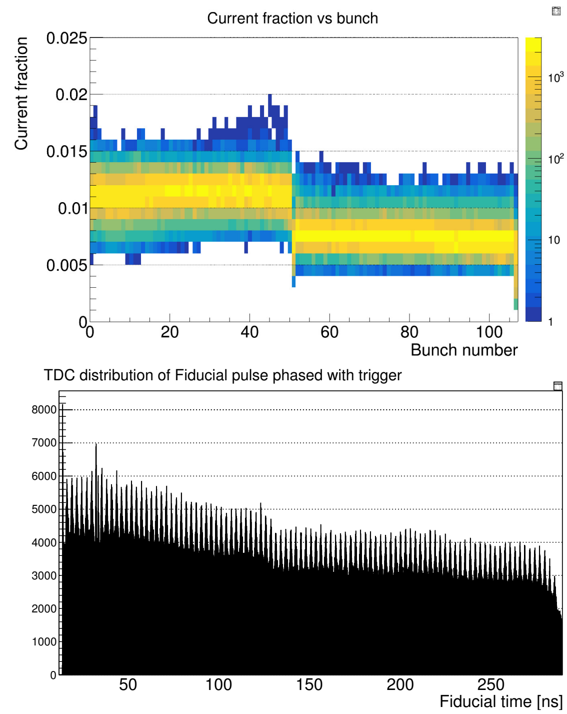

Figure 7: Top: positron beam fill. The vertical axis is the bunch current and the horizontal is the bunch position along the batch. The unbalance between the first fifty and the last sixty is clearly visible.
Bottom: BBB luminosity for the corresponding test run. The difference between the two sections is clearly visible.

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