Calorimeters for absolute luminosity at upgraded DAΦNE

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Abstract. This paper describes the LUMI project which aims at providing fast, reliable and absolute luminosity measurements at the modified DAΦNE interaction point in Frascati for testing the new “crabbed waist” scheme. We present a description of the experimental setup (two luminometers, LUMI1 and LUMI2), the simulation framework developed for this project and summarize the results and performances.

1. Introduction
The LNF Accelerator Division (LNF-DA) is currently modifying the DAΦNE interaction region. The new layout is based on the crabbed waist scheme [1] which is expected to increase the collider luminosity by up to an order of magnitude. The study of the machine performances in this configuration is of utmost importance, both for the DAΦNE experiment and for a future SuperB-factory whose luminosity should exceed $10^{36}$ cm$^{-2}$s$^{-1}$ [2]. The upgraded machine has started operations in January 2008, it is going to deliver beam to the SIDDHARTA experiment for about six months.

SIDDHARTA $^1$ will estimate the machine luminosity from the kaon pairs rate seen by the detector. However, given the importance of the experiment, additional measurements of the

$^1$ The SIDDHARTA (Silicon Drift Detector for Hadronic Atom Research by Timing Application) experiment will be devoted to precision measurements on kaonic hydrogen and kaonic deuterium
luminosity based on more standard calorimetric techniques are needed. Therefore, we have built and installed two luminometers around the interaction point (IP). The first one, LUMI1, is a double-arm lead-scintillator calorimeter operated in coincidence with a thin GEM tracker to measure Bhabha scattering events. The second one, LUMI2, is a crystal forward calorimeter, aiming at measuring the rate of single bremsstrahlung events.

2. Description of the experimental setup

In this section, we describe the experimental setup designed and built for the LUMI project: the two luminometers LUMI1 and LUMI2, its electronics and the associated readouts. A careful characterisation of the detector performances has been obtained with dedicated calibrations with test-beam data at the BTF.

2.1. Conventions

The (horizontal) beam axis is labelled $z$, with the positrons (electrons) traveling towards $+z$ ($-z$) respectively. $y$ is the vertical axis (orientated upwards) and $x$ is chosen so that $(x, y, z)$ is a direct orthonormal frame. In the DAΦNE IP, the beams cross each other with a 25 mrad horizontal angle whose effect is to boost the tracks to the $-x$ direction.

2.2. LUMI1

This luminometer is symmetrical with respect to the plane containing the IP and perpendicular to the beam axis ($z$); its main components are a lead-scintillator calorimeter and a GEM tracker.

The lead-scintillator calorimeters surround the QD0 final quadrupole magnets and are located at 32.5 cm from the IP.

Their inner and outer radius (respectively 104mm and 341mm) have been chosen to cover the polar angle range between $18-27^\circ$ which corresponds to the GEM angular acceptance. In the plane transverse to the beam axis they are segmented in twelve 30 degrees-wide sectors. Two of them intersecting the horizontal ($x-z$) plane (on each side of the beampipe) are not instrumented, both for engineering/mechanical reasons and because the background is expected to be very high in these areas (horizontal plane).

Each instrumented trapezoidal sector is built by sandwiching eleven lead slabs between trapezoidal plastic scintillator tiles. The first eight (last three) slabs are 5 mm (10 mm) thick while the scintillator tiles are 1 cm thick. The total thickness of the calorimeter, 17.5 cm, corresponds to $\sim 12.5 \times X_0$. The expected energy resolution at 510 MeV (nominal beam energy for the $\Phi$-factory) is about 25%.

Lead and scintillator elements are inserted inside a properly machined aluminum frame providing mechanical support. The tiles are connected to three wave-length shifting fibers (WLS), Bicron BCF-92, collecting the light and conveying it a Photonis-Philips XP 2262B photomultiplier (PMT). Each PMT integrates the light coming from all the tiles of a given sector: therefore, the luminometer is not sensitive to the longitudinal development of the shower. In front of each calorimeter, at a distance of 18.5 cm from the IP, a ring of triple-GEM detectors is installed around the beampipe. Each unit of the GEM tracker has an half-moon shape; the top (bottom) half covers azimuthal angles between 14 and 166° (194 and 346°) respectively. A detailed description of the GEM detector can be found in [3]. In principle, Bhabha events are tagged by the coincidence of two back to back high energy ($\sim 500$ MeV) deposits in the calorimeters, properly combined with the signals from the GEM detectors. We keep however open the possibility of determining the rate of Bhabha events with the two systems independently. At a luminosity of $5 \times 10^{32}$ cm$^{-2}$s$^{-1}$, this rate is $\sim 150$ Hz in the angular region of interest.
Table 1. Expected rate of events at $10^{33}$cm$^{-2}$sec$^{-1}$

| Process | Rate (Hz) | Angular Range | Energy Distribution |
|---------|-----------|---------------|---------------------|
| $e^+e^-\rightarrow e^+e^-$ | 312.5 | $18 < \theta < 27^\circ$ | 95% below 1.7mrad |
| $e^+e^-\rightarrow e^+e^-\gamma$ | | | 15% below 1.7mrad |

2.3. LUMI2

A second luminometer, LUMI2, is located 170 cm away from the IP on the 'electron' (-z) side of the detector just after the beam lines are split. It is made of four PbW0$_4$ crystals (squared section of 30×30mm$^2$ and 110mm height) are put in series along z corresponding to about ~13 $X_0$). The detector are equipped with Hamamatsu R7600 PMT; in this configuration the electronic stays at about 110mm from the horizontal plane. The aim of these detectors is to measure the rate of the photons emitted by $e^+e^-\rightarrow e^+e^-\gamma$ processes. They occur with a cross section of 85 mb for photon energies above 100 MeV, and 95% of the radiated photons can be found inside a cone of 1.7 mrad aperture.

Because of the boost which pushes towards the -x direction the trajectory of the photon, LUMI2 is placed along the beampipe at $x=-5$ cm and rotated by 4 degrees in the horizontal plane with respect to the beam axis. The two modules of the calorimeter were tested at the beam test facility (btf) in Frascati. The energy distribution for a 500 MeV impinging electron are shown in figure 1 and 2 for the two different modules. The different peaks of the energy distribution correspond to the average number of electrons present in the beam. The resolution we get is about 15%.

3. LUMI1 performances

Before installation each module of the LUMI1 calorimeter has been tested and extensively calibrated using the btf in Frascati. Equalization was performed setting the beam energy at 510 MeV and varying the photomultiplier (PM) high voltage (HV). The ADCs peak values for a typical PMT are shown in figure 3 as a function of the HV. The performances of the calorimeter were studied in terms of linearity and resolution using the same setup we have later.
GEANT3 has been used to simulate the shower initiated by the electrons and positrons in the calorimeter, and to estimate the energy lost by all the corresponding particles while they cross the scintillating tiles. The parameters used as inputs to the simulation were: the photon yield produced by the scintillator per unit energy, the photon attenuation in this material and in the WLS optical fibers and finally the gain of the PMTs to which these fibers drive the photons. Fig. 5 shows the number of reconstructed photons found in the calorimeter central sector and in its two closest neighbours. The average number of photons correspond to the nominal energy of 510 MeV. We expect therefore an energy resolution close to 25% for a 510 MeV electron. Fig. 6 shows the number of collected photons as a function of the azimuthal track angle. The \( \phi \)-dependence is clearly due to the calorimeter segmentation and to the correlation between this angle and the distance between the hit location in the tile and the fibers collecting the light. The same phenomenon is responsible for the \( \theta \) dependence shown in 7.

To correct for this effect, a correction matrix

\[
C_{i,j} = N_{i,j} / N_{\text{ideal}}
\]  

is constructed where \( N_{i,j} \) is the number of photons collected in a given \( (\theta_i, \phi_j) \) cell and \( N_{\text{ideal}} \) the number of photons in the best \( (\theta, \phi) \) cell (in principle located at the bottom and in the middle of the tile). The \( \theta \) information is based on the GEM radial segmentation. The azimuthal angle \( \phi \) is estimated via an weighted average of the \( \phi \) values of the calorimeter sectors. The weights used to compute this barycenter are the number of photons in each of the calorimeter sector. Figure 8 shows the energy distribution obtained for selected Bhabha on data after correction (red cross) together with Monte Carlo prediction (black line). The correction used improves the calorimeter resolution from 25% to 20%.
3.1. Trigger

The trigger system is based on local energy deposits in the calorimeter. Analog signals delivered by the phi sector of a single module are added. NIM equipment has been used to set a threshold for the single module and perform the coincidence with the module on the opposite side. A Bhabha was defined as two energy deposits of more than 200 MeV each occurring in two opposite modules within a time window of 50 ns. A two level scheme has been adopted in order to produce a first trigger signal (T1) to start the calorimeter FEE digitisation while the second level trigger signal (T2), delayed by 4 μs with respect to the T1 starts the front-end electronics (FEE) read-out. The time between bunch crossing in DAΦNE is 2.7 ns, therefore the trigger operates in continuous mode. To avoid the intrinsic jitter of the trigger signal formation the first
level trigger is synchronized within 50 ps with the machine radiofrequency before being delivered to the FEE.

3.2. Electronics and Readout
Most of the FEE and data acquisition (DAQ) components, as well as the HV supplies are borrowed from KLOE [4]. The signals coming from the LUMI photomultipliers are amplified, inverted and delivered to a 3-stage splitter. One stage consists of a constant fraction discriminator which delivers a current signal to the FEE KLOE TDCs [5]. Another stage consists of a 3-pole Bessel filter followed by a KLOE ADC. The third stage sums the signal over up to five pmts (the top or bottom half of one calorimeter side) and this signal is used to trigger the experiment.

The KLOE FEE modules are build around a custom bus, the AUX-bus [4], which only uses the VME standard for initialization purposes. The AUX interface allows crate event building and data synchronization checks. A trigger-driven read out controller starts the data taking process from the FE boards and delivers data frames to the control manager through C-bus. The control manager board is acquired using the KLOE procedures via VME by a MVME6100 processor. This CPU is in charge of the data framing and delivers data frames to a PC computer via a gigabit ethernet link. The data are finally written to disk by the PC. A simple graphical user interface (GUI) developed in JAVA performs the run control functions. The entire acquisition chain has been installed in the DAΦNE IP pit.

4. Conclusions
The detector has been installed in February 2008. It has been running continuously since then giving feed-back to the DAΦNE team.

5. References
[1] D. Alesini et al., LNF-06/33 (IR), (2006).
[2] SuperB Collaboration, SuperB CDR arXiv:0709.0451.
[3] F. Sauli, Nucl. Instrum. Meth. A386, (1997) 531-534.
[4] A. Aloisio et al., Nucl. Instrum. Meth. A516 (2004) 288-314.
[5] M. Passaseo, E. Petrolo, S. Veneziano, Nucl. Instrum. Meth. A367 (1995) 418-421.