Crab Waist Scheme Luminosity and Background Diagnostic at DAFNE

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Abstract

Test of the crab waist scheme, undergoing at the Frascati DAFNE accelerator complex, needs a fast and accurate measurement of the luminosity, as well as a full characterization of the background conditions. Three different monitors, a Bhabha calorimeter, a Bhabha GEM tracker and a gamma bremsstrahlung proportional counter have been designed, tested and installed on the accelerator at the end of January 2008. Results from beam-test measurements, comparison with the Monte Carlo simulation and preliminary data collected during the SIDDHARTA run are presented.

INTRODUCTION

The promising idea to enhance the luminosity with the introduction of a large Piwinski angle and low vertical beta function compensated by crab waist [1], will be a crucial point in the design of future factory collider [2], where the luminosity is the fundamental parameter. The DAFNE accelerator, located in the National Laboratory of Frascati (INFN), optimized for the high production of Φ mesons (√s=1020 MeV), has been modified during last year to test the crab waist sextupoles compensation scheme. Since fall of 2007 the machine has restarted operations, and at the beginning of February various luminosity detectors have been put in operation in order to guarantee an accurate measurement of the luminosity and of backgrounds, as well as to provide powerful and fast diagnostics tools for the luminosity improvement.

Three different processes are used to measure the luminosity at DAFNE:

- The Bhabha elastic scattering $e^+e^- \rightarrow e^+e^-$; it has a very clean signature (two back-to-back tracks); the available angle is limited due to the presence of the low-β quadrupoles, however, in the actual polar angle range covered by our calorimeters, 18^0-27^0, the expected rate (~440 Hz at a luminosity of 10^{32} cm^{-2} s^{-1}) is high enough and the backgrounds low enough to allow an online clean measurement.
- The very high rate $e^+e^- \rightarrow e^+e^-\gamma$ (radiative Bhabha process); it has the advantage that 95% of the signal in contained in a cone of 1.7 mrad aperture, but it suffers heavily from beam losses due to: interactions with the residual gas in the beam-pipe, Touschek effect, and particles at low angles generated close to interaction region (IR).
- The resonant decay $e^+e^- \rightarrow \Phi \rightarrow K^+K^-$; a rate of about 25 Hz at 10^{32} is expected in the SIDDHARTA experiment monitor at ~90^o [3].

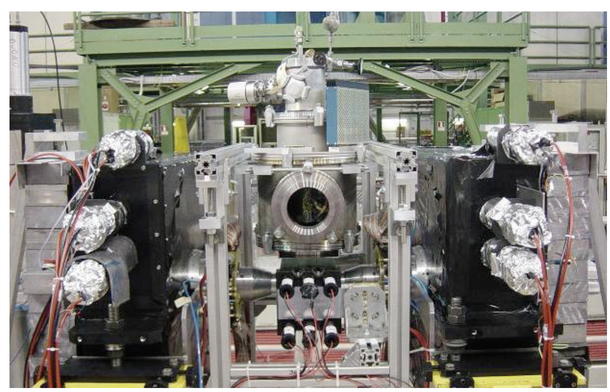

Figure 1: the SIDDHARTA preliminary setup installed at DAFNE. The Bhabhas calorimeters (black boxes) are visible on the left and right of the interaction region.

BHABHA MONITOR

The Bhabha monitors consist of two different detectors, a 4-module sandwich calorimeter, made of lead and scintillator, and two triple GEM annular trackers.

Calorimeters

Four modules of calorimeters surround the final permanent quadrupole magnets, located at a distance of 32.5 cm on both sides of the interaction region (IR), as shown in Fig. 1. They cover an acceptance of 18^o -27^o in polar angle, and are segmented in azimuthal angle in five sectors, 30^o wide. The choice of not instrumenting 1/6 of the acceptance, i.e. the ±15^o region, was dictated by the consideration that most of the machine backgrounds are expected on the machine plane. Each sector is a sandwich of 12 trapezoidal tiles of 1cm thick scintillator, wrapped with Tyvek* paper, alternated with lead plates: eight 5 mm thick plates towards the interaction point and three 1cm thick plates in the back part, lead plates for a total thickness of 19 cm. This choice was driven by the compromise between the need of having a good longitudinal containment of 510 MeV electron showers (the total depth corresponds to about 12.5 X_0), and the necessity of having a detector not exceeding the permanent quadrupole length.

The 240 scintillator tiles have been produced with injection-molded technique in IHEP, Protvino. Each tile has three radial grooves on one face, 2 mm deep (one in the middle and two 1 cm from the edge of the tile) inside which wavelength shifting (WLS) fibers of 1 mm diameter are placed; the 36 WLS fibers (Fig. 2), are collected to an optical adapter to fit the photocathode of 20 Photonis-Philips XP 2262B photomultipliers, read by a prototype data acquisition system of the KLOE2 experiment: the analog signals are actively splitted to be digitized by a constant fraction discriminator for time measurement (using the KLOE TDC, 1.04 ns resolution), and for the pulse height measurement by the KLOE charge ADC, with a 0.25 pC resolution.

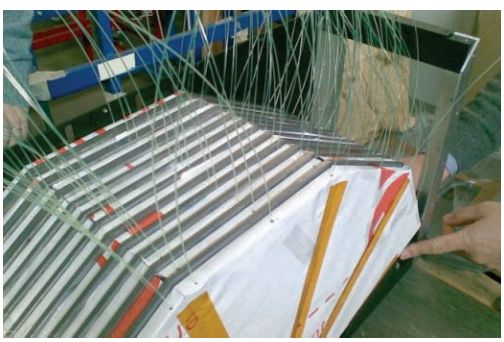

Figure 2: One of the four calorimeters modules during the assembly, wrapped tile, wavelength shifter, and lead plate are clearly visible.

The design energy resolution of 15% at 510 MeV is adequate to put a threshold for selecting Bhabha events.

The triple GEM tracker

In front of each calorimeter, at a distance of 18.5cm from the IR, a ring of triple-GEM detectors [4] is installed around the beam pipe. The two GEM trackers are divided in two units, with an half-moon shape; the top (bottom) half covers azimuthal angles between 14° and 166° (194° and 346°) respectively. Each of the four GEM units is segmented into 32 pads: eight cells in azimuth (covering 19° each) are arranged in four rings of equal radial extension. When a charged particle crosses the 3 mm drift gap, it generates electrons that will be multiplied by the three GEM foils separated by 2/1/2 mm. Each of the GEM planes is made of a thin (50μm) kapton foil sandwiched between two copper clads and perforated by a dense set of holes (70μm diameter, 140 μm pitch).

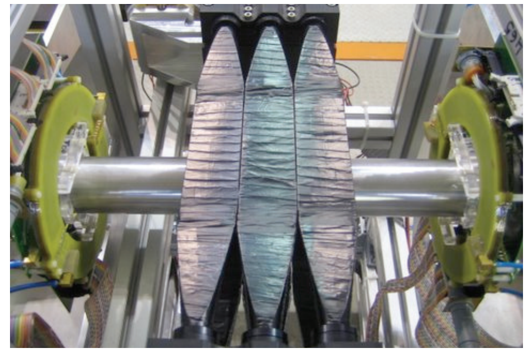

Figure 3: Gem ring (left, right) and SIDDHARTA scintillator K-Monitor (center) mounted on DAFNE IR.

As a high potential difference (about 400 kV) is applied between the copper sides, the holes act as multiplicating channels and the gain of each layer is about 20 (and hence roughly 8,000 in total).

The GEM trackers, as well as the gamma monitors, have been included into the main DAQ system.

GAMMA MONITOR

Two gamma monitor detectors are located 170 cm away from the IR, collecting the photons radiated by electron or positron beam.

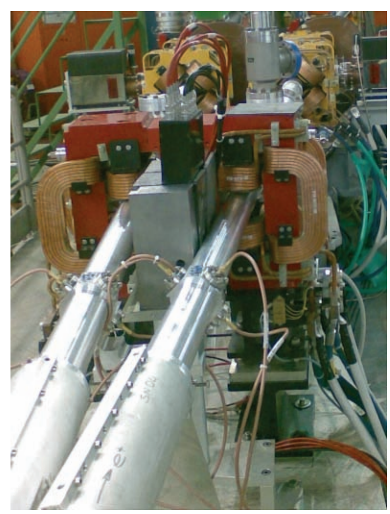

Figure 4: One of the gamma monitor installed between the two last correctors and the final permanent quadrupoles of DAFNE IR.

The detectors replace the gamma monitors previously installed in DAFNE [5] and are now made of four $PbW0_4$ crystals (squared section of 30×30mm^2 and 110mm high) assembled together along z, in order to have a 30 mm face towards the photon beam, and a total depth of 120 mm corresponding to about 13X_0. Each crystal is readout by a Hamamatsu R7600 compact photomultiplier. Each of the crystal signals is splitted: one half is sent to the charge

* Tyvek™ is a trademark of DuPont company.

ADC of the KLOE2 data acquisition system, while the other is sent to an analog mixer. The analog sum of the four crystals is then discriminated and the counts are read by the DAFNE Control system, providing a prompt estimate of the luminosity for machine optimization.

Because of the boost introduced by the beam crossing angle, the trajectories of the photons are shifted towards the inner side (along x coordinate) of the machine; the gamma monitors and GEM trackers are then placed along the beam pipe at x=−5cm and rotated by 4^o in the horizontal plane with respect to the beam axis.

Thanks to the high rate, those detectors are mainly used as a fast feedback for the optimization of machine luminosity versus background, more than providing a measurement of the luminosity, since the relative contribution of background is changing with the machine conditions. However, on the short time scale and as relative luminosity monitors, those counters have demonstrated to be extremely useful.

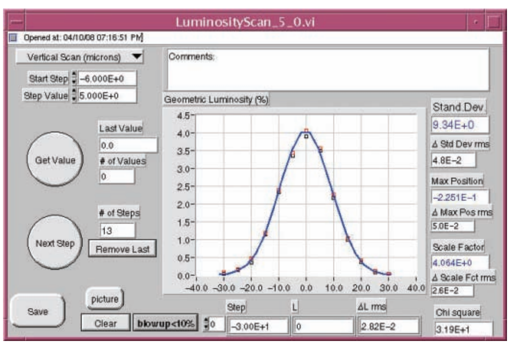

Figure 5: A vertical beam-beam scan performed by the crystal gamma monitor.

SIMULATION

In order to correct the Bhabha event rate measured using the calorimeters and the GEM trackers for the detectors' acceptance and selection efficiency, we developed a full simulation of the whole experimental set-up, based on the GEANT3 package. This includes all the materials and fields present in the interaction region as well as a simulation of the detectors response.

The BHWIDE package is used to generate Bhabha events with a full treatment of the radiation [6].

The contamination due to the Touschek background is investigated by interfacing an ad hoc generator [7] with the simulation.

Particular care was given to the implementation in the simulation of the materials and fields distribution all along the interaction region, since this impacts directly on the background level in the calorimeters as well as on the signal detection efficiency of the gamma monitors.

The simulation predicts a measured Bhabha event rate of ~440 Hz when the luminosity equals 10^{32} cm^{-2} s^{1}. The rate actually measured at the IP is compared with this number to derive the actual luminosity. The simulation is also used to evaluate the systematic uncertainties affecting this measurement. Tab. 1 lists the various contribution to this uncertainty. It's dominated by the alignment of the calorimeter and of the conical shielding in front of it ("Soyuz"), as well as by the definition of the energy threshold. Also the presence of the SIDDHARTA detector is taken into account. For a preliminary measurement involving only the calorimeters, an 11% uncertainty should be quoted. It drops to 7% when the GEMs are also in operation.

Table 1:Systematic errors according to the MC simulation

Sources	**No tracker σ_{syst}**	**GEM tracker σ_{syst}**
Calo alignment ± 2mm	4%	2%
Soyuz alignment ± 2mm	8%	6%
SIDDHARTA Exp.	2%	0%
Energy Th. ± 60MeV	5%	1%
BKG Accidentals	3%	0%
BKG $\gamma\gamma$	0.1%	0%
Total (Σquad)	**11%**	**7%**

We also used the simulation to determine the optimal location for the GEMs. They're shifted in the horizontal plane by 5 mm in the direction of the boost to compensate for the loss of back-to-back-ness caused by this boost.

Finally, we based on the simulation to design the part of the beam-tests devoted to the measurement of the attenuation length of the scintillating tiles. This constant has to be precisely known for the simulation to describe accurately the energy reconstruction, thus the signal efficiency.

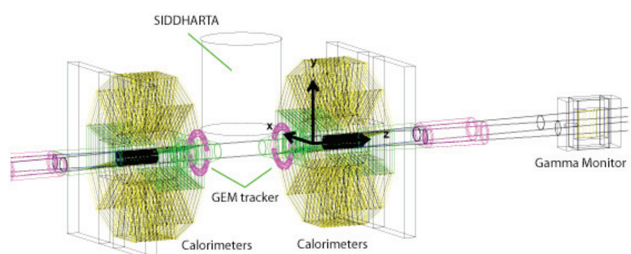

Figure 6: GEANT simulated setup

TEST BEAM

All the four modules have been tested and calibrated with 470 MeV electrons at the DAFNE Beam Test Facility [8], where linearity and energy resolution have also been measured.

Part of the test has been dedicated to comparison of data with Monte Carlo especially on edge effects, wave length fiber attenuation, dependence upon the position of the impact point on the tile due to attenuation of scintillation photons along their way to the fibers, etc.

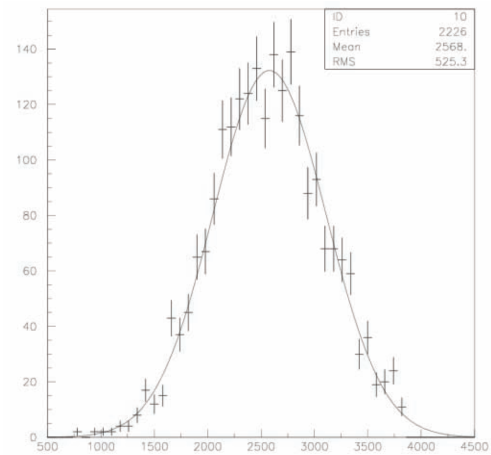

Figure 7: energy resolution of 14%/√E(GeV) obtained at the test beam with 470 MeV electron impinging the center of one of the 20 sectors.

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In the following figure Monte Carlo data are compared with test beam measured data: (read/bottom line)

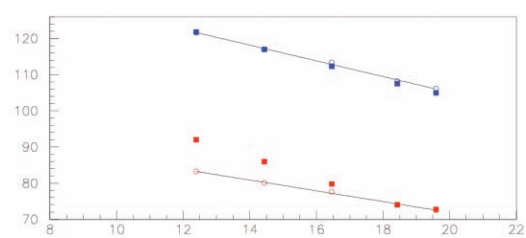

Figure 8: Photo-electron yield in data (open circles) and MC (plain squares) before the tile attenuation length was corrected in MC (red) and after this correction, based on test beam data (blue).

RESULTS

The four calorimeters, the GEM trackers and the crystal gamma detectors are acquired by KLOE2 farm data acquisition prototype. The trigger condition (T1FREE) consists of the coincidence of two opposite, upside down modules when the energy released in the modules is above 200MeV. Data can be acquired for offline analysis when particular studies have to been performed. All single and coincidence rate are acquired by the DAFNE control system, in order to provide a fast reading of luminosity and background condition very useful for machine parameters optimization.

Various analyses of trigger condition, luminosity and background have been performed in order to check the trigger efficiency and background contamination in the luminosity evaluation. For this reason an online filtering process has been implemented on the DAQ farm, providing an offline estimate of the rate (T2FARM), corrected by the percentage of background contamination in the coincidence. This correction is estimated analyzing blocks of 1000 events, and by looking at the time distribution of the time of the two triggering modules. The difference of the arrival time of a Bhabha candidate for the couple of triggering modules is shown in Fig. 9, as selected by the T1FREE hardware trigger. As expected, a Gaussian distribution peaked at $\Delta t=0$ is clearly visible. Superimposed on this narrow Gaussian ($\sigma \cong 2$ counts), a flat distribution due to background is also present. Indeed, the narrow peak completely disappears when the beams are longitudinally separated. The width of the background flat distribution is determined by the duration of the digital signals building the coincidence (≈25 ns).

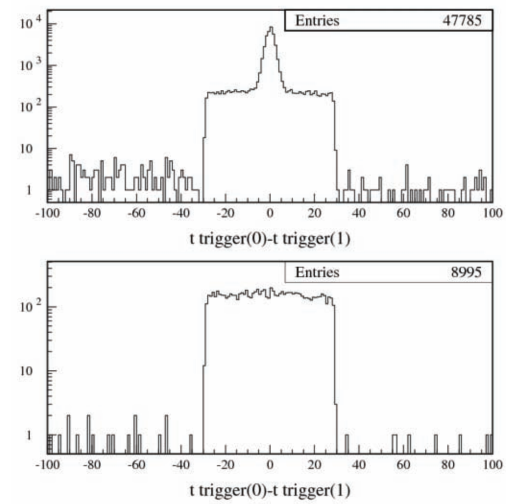

Figure 9: (top) Bhabha time of arrivals in the opposite modules as selected by the T1FREE hardware trigger. (bottom) background time of arrivals when the beams are not colliding (180 degree longitudinal separation)

In order to isolate genuine Bhabha's, the online filter selects events in a $\Delta t=\pm 3\ \sigma$ window (±6 counts). In order to estimate the amount of background beneath the peak, events in the sideband (12 counts wide) are counted and subtracted. In Figure 10 the energy distribution of events selected as good candidates are compared to the ones flagged as background.

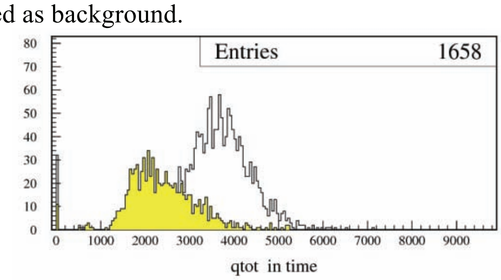

Figure 10: Bhabha total energy deposited: shaded histogram, out of time events, empty histogram, in time Bhabha candidates.

All online and filtered data are stored by DAFNE slow control system with a sampling time of 15 seconds and are available for offline analysis and on the word wide web for online performance presentation.

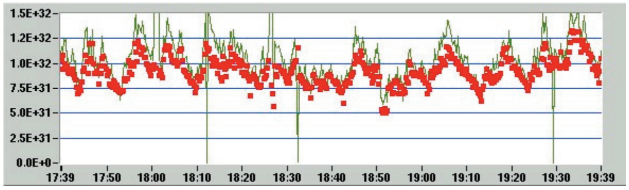

Figure 11: red dots T2FARM luminosity estimate; green line T1FREE uncorrected luminosity.

The GEM tracker is able to measure the Bhabha impact point with good precision and allows a better evaluation of the systematics on rate measurements. Fig. 12 shows the correlation between the impact point polar and azimuth angle of electron and positron tracks.

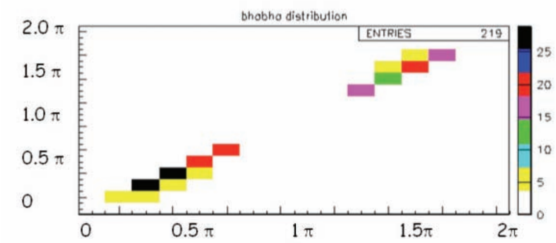

Figure 12: Azimuthally vs polar Bhabha angular correlation detected by GEM tracker.

CONCLUSIONS

The diagnostics installed on the new DAFNE IR in order to measure luminosity for the test of the new crab waist scheme, started to operate at the beginning of February 2008 and is collecting the first encouraging results from the machine (see Fig.13 and 14).

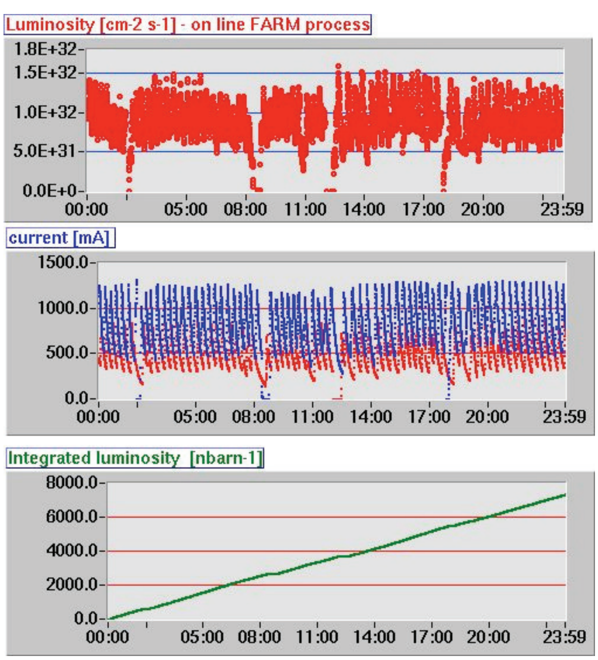

Figure 13: DAFNE WWW online data presentation.

All systems showed very good performance and fully achieved the design parameters. A total systematic uncertainty on the luminosity measurement of 11% can be estimated.

Detectors have been fully implemented in the machine controls, and data are available for the community on the world wide web DAFNE accelerator page.

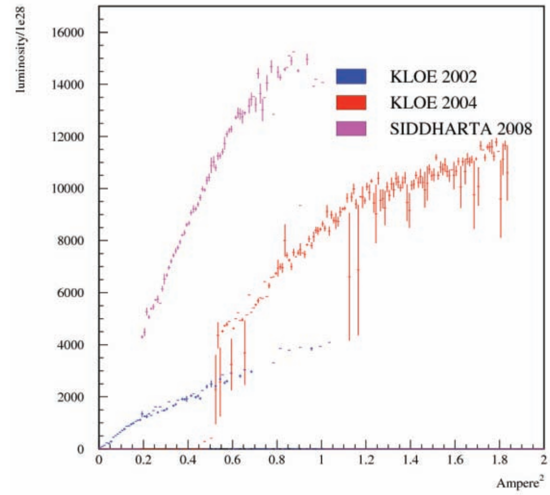

Figure 14: DAFNE performance (luminosity vs current product) during the tree major optics steps.

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