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DAΦNE MONITORED BY FINUDA

The FINUDA Collaboration[1]

Abstract

The FINUDA spectrometer, devoted to hypernuclear physics and installed on the DAΦNE two rings collider at the Laboratori Nationali di Frascati, is able to monitor the relevant machine parameters, as luminosity, collision vertexes, c.m. energy and transversal momentum boost, during the process of data taking to study hypernuclear physics without affecting it. The collider parameters relevant to optimize the machine performances to the needs of the experiment are measured both on-line and off-line in a run-to-to run basis, in an efficient, redundant way, allowing the continuous extraction of reliable and cross-checked information on the machine working conditions.

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1 Introduction

The aim of the FINUDA experiment is the systematic study of hypernuclear formation and decay using low energy stopped K^-. The FINUDA apparatus is a high acceptance, high resolution spectrometer whose unique feature is that of employing a low energy K^- beam produced by the decay of ϕ mesons generated in the interaction of the e^+ and e^- beams circulating in a two ring collider, DAΦNE, at the Frascati National Laboratories of INFN.

Indeed, the DAΦNE collider [1] is optimized in performance and energy to collide e^+ and e^- beams of 510 MeV energy, in order to produce ϕ(1020) mesons almost at rest. The ϕ(1020) decays with B.R. = 0.49 into a pair of back-to-back K^-K^+ mesons with momenta of 127 MeV/c. Thanks to these peculiar features, very thin targets (0.21-0.38 g/cm^2) can be used to stop the K^-. Therefore, the deterioration of the momentum resolution of the emitted particles, due to the target crossing, is minimized, contrarily to all the other experiments employing extracted kaon and also pion beams. Moreover, the hadronic background, already intrinsically low in an electromagnetic machine, can be further reduced by triggering on the specific topology and momentum of the K^-K^+ pairs coming from the ϕ(1020) decay.

The FINUDA spectrometer consists of a non-focusing, superconducting solenoid (B = 1.0 T, ∅ = 240 cm) located around the thin (500 μm, ∅ = 10 cm) beam pipe of DAΦNE and instrumented with several arrays of tracking detectors and two scintillator

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barrels, arranged with axial symmetry around the axis of the apparatus. The innermost scintillator barrel (TOFINO) is placed just around the beam pipe and is composed by 12 thin (2.3 mm thickness, 20 cm length) scintillator slabs, whereas the outer barrel (TOFONE) is composed by 72 thick large scintillator slabs (10 cm thickness, 255 cm length) and is placed in outermost position, just close to the magnet cryostat. The two scintillator barrels are used for triggering and time of flight (t.o.f.) measurements, while TOFONE detects also neutral particles.

The momentum resolution of the spectrometer is optimized for the prompt π^- coming from Λ-hypernucleus formation (260-270 MeV/c) and is presently 0.6% FWHM. The apparatus is also able to detect the hypernucleus decay products and, quite in general, the charged particles produced in the K^- (and K^+) interactions on the target nuclei. In the FINUDA interaction region up to eight different thin (about 200 mg/cm^2) targets can be installed, between two co-axial arrays of bi-dimensional Si micro-strip, detectors, 400 μm thick and 20 cm long. The internal array (ISIM) allows to measure the crossing point of the K^- (K^+) coming from the ϕ(1020) decay close to the targets, while the external array (OSIM) measures the crossing points of the outgoing charged particles resulting from kaon interactions in the targets. The Si micro-strip arrays provide also particle identification by dE/dX measurement.

The tracking of the charged particles in the spectrometer volume, between the vertex region and the outer scintillator barrel, is performed by means of two co-axial octagonal layers of low mass drift chambers (LMDC) followed by six circular layers of thin-walled straw tubes (STRAW), two layers of which are arranged along the apparatus axis, the other two couples of layers are tilted by $\pm$ 15^o relative to the axis of the apparatus, for stereo reconstruction of the crossing track trajectory. The whole FINUDA tracking volume is filled with Helium gas, in order to minimize the effect of the multiple scattering on the particle trajectories. A more detailed description of the FINUDA set-up, shown in Fig. 1, is given in [2].

The first level trigger of the FINUDA apparatus is based on the fast signals coming from the two scintillator barrels and is produced by a selectable combination of defined hit topologies and energy deposition in the slabs. In particular, the latter condition allows for the recognition of highly ionizing particles, like low energy kaons, at trigger level, against the minimum ionizing ones. Proper scalers record the counts of the different detected trigger conditions, during the data taking.

The unconventional way in which the K^- beam is produced in DAΦNE imposes severe constraints to the machine performances, in order to fit at best the specific needs of FINUDA. The critical parameters to be optimized are: the machine luminosity at the c.m. energy of 1020 MeV, the K^- and K^+ fluxes, the positions of the e^+e^- collision

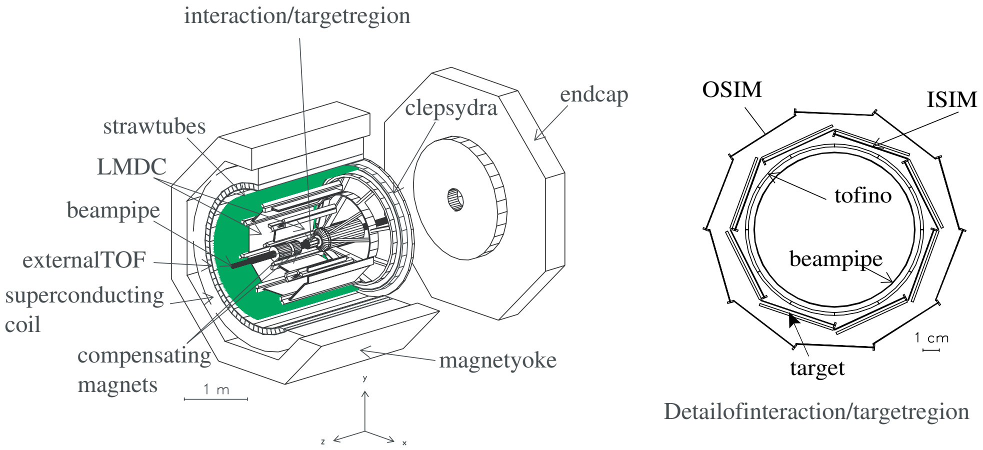

Figure 1: The FINUDA setup. Left: overall 3D view; right: 2D view of the vertex-target region.

vertexes, which must be aligned at the center of the spectrometer to provide the maximum apparatus acceptance. Moreover, the usual machine parameters, as stability and a low level of background, need also to be achieved and continuously monitored.

In this paper, we describe how the FINUDA apparatus is able to measure the relevant machine parameters, allowing the performances of DAΦNE to be continuously monitored and optimized, during the data taking and without disturbing it. The experimental data here referred to, have been taken during the first FINUDA run on DAΦNE, started on December 1st 2003, after a period of machine tuning and detector debugging, and lasted till March 22, 2004, cumulating an overall integrated luminosity of $\mathcal{L}_{\rangle\backslash\sqcup}$ = 250 pb^{-1} (debugging and data taking).

2 Monitoring DAΦNE parameters

2.1 Machine luminosity and energy

The most important machine parameter to be monitored is the luminosity of the collider. The luminosity $\mathcal{L}$ is defined, as usual, as the quantity to be multiplied by the cross section σ of a given process to obtain the number of events expected from that process. It is related, in the case of a collider, to several machine parameters as the beam currents, the number of bunches, the transversal sizes of the circulating beams, the R.F. frequency, and so on.

We can speak of instantaneous luminosity, $\mathcal{L}_{\rangle\backslash\int\sqcup}$, in which case the product $\mathcal{L}_{\rangle\backslash\int\sqcup}\sigma$ gives the counting rate expected for the process whose cross section is σ; the units of

$\mathcal{L}_{\rangle\backslash\int\sqcup}$ are, therefore, cm^{-2}s^{-1}. We can also speak of the integrated luminosity in a given time interval ΔT, $\mathcal{L}_{\rangle\backslash\sqcup}$, in which case the product of $\mathcal{L}_{\rangle\backslash\sqcup}\sigma$ gives the total number of events collected during ΔT for the process whose cross section is σ. The units for $\mathcal{L}_{\rangle\backslash\sqcup}$, in this case, are simply the units of the inverse of a cross section, cm^{-2} or a multiple like nb^{-1} or pb^{-1}.

FINUDA is able to measure and monitor the machine luminosity, both $\mathcal{L}_{\rangle\backslash\int\sqcup}$ and $\mathcal{L}_{\rangle\backslash\sqcup}$, exploiting different and independent physical processes occurring after e^+e^- collisions:

1. counting e^+e^- scattering events (Bhabha events) provided by a dedicated trigger and reconstructed by the apparatus; the cross section of the Bhabha process is well known [3] and rather flat with energy around the nominal energy value of DAΦNE; the counting of the Bhabha events detected by the apparatus allows the number of e^+e^- collisions and hence the beam luminosity to be directly evaluated;

2. counting the K^0_S events, produced by the ϕ(1020) decay into $K^0_S K^0_L$ (B.R. = 0.34), filtering inside the Bhabha trigger and reconstructed by the apparatus; the cross section of this process is well known [4], but strongly dependent on the machine energy, let's say on the position on the ϕ resonance, which is only 4.43 MeV wide. Therefore, the counting of reconstructed K^0_S events allows not only the luminosity to be evaluated and compared with the value obtained from the Bhabha events, but also the machine energy to be measured and monitored;

3. during the data taking the luminosity and machine energy can also be monitored by counting the number of K^+K^- pairs from the decay of the ϕ(1020), as recorded by the hypernuclear trigger and reconstructed by the apparatus.

The Bhabha scattering [3] is a collision of the DAΦNE e^+e^- beams proceeding through the following channels:

$$e^+e^- \to e^+e^-(n\gamma) \tag{1}$$

The Bhabha scattering is called elastic if the number n of γ-rays is zero, and inelastic if there is at least one ($n = 1$) γ-ray. In case of elastic or highly elastic (i.e. with a $soft$ energy emitted γ-ray) Bhabha scattering, the e^+e^- pair in the final state will be emitted back-to-back and have the same or very similar momenta, close to the 510 MeV/c of the circulating beams. Fig. 2 shows, as an example, a typical highly elastic Bhabha event recorded by the FINUDA spectrometer and reconstructed and fitted by the FINUDA reconstruction procedures.

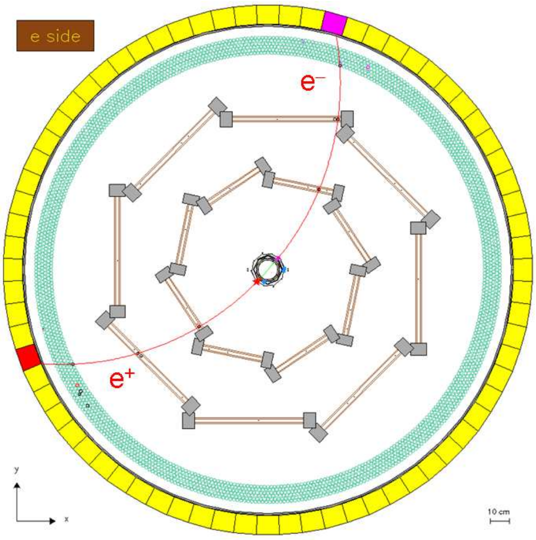

Figure 2: Highly elastic Bhabha event $e^+e^- \rightarrow e^+e^-$ recorded by the FINUDA spectrometer. The reconstructed momenta of the e^+ and e^- track are 512 MeV/c and 492 MeV/c, respectively.

Such events are selected using a dedicated trigger, called Bhabha trigger, requiring the fulfillment of the following criteria: a) two opposite (back-to-back) coincident hits, with minimum ionizing energy deposition, in the slabs of TOFINO scintillator barrel; b) coincidence with at least two hits in the slabs of the TOFONE scintillator barrel; c) time coincidence window between TOFINO and TOFONE hits: 4 $\div$ 18 ns. The geometrical acceptance of the FINUDA apparatus (from 45^o to 135^o polar angle) and these trigger conditions allow to collect a number of Bhabha pairs corresponding to about 700 nb of integrated Bhabha cross section. It's worth reminding that the Bhabha cross section strongly depends on the polar angle and has not a finite total value, but diverges at zero polar angle. With a nominal luminosity of $\mathcal{L}_{\rangle\backslash\int\sqcup}$ =5$\cdot$10^{31} cm^{-2}s^{-1}, about 35 Hz Bhabha events are accepted by the trigger and recorded by the apparatus.

Other types of events, coming mainly from the ϕ(1020) decays, can filter through the Bhabha trigger as defined above, since their topologies basically fulfill, with lower efficiencies, the same criteria:

- $e^+e^- \rightarrow \phi \rightarrow K^0_S K^0_L$ followed by K^0_S decay $K^0_S \rightarrow \pi^+\pi^-$
- $e^+e^- \rightarrow \phi \rightarrow \rho\pi$ followed by $\rho^{\pm 0}$ decay into two pions
- $e^+e^- \rightarrow \phi \rightarrow \pi^+\pi^-\pi^0$

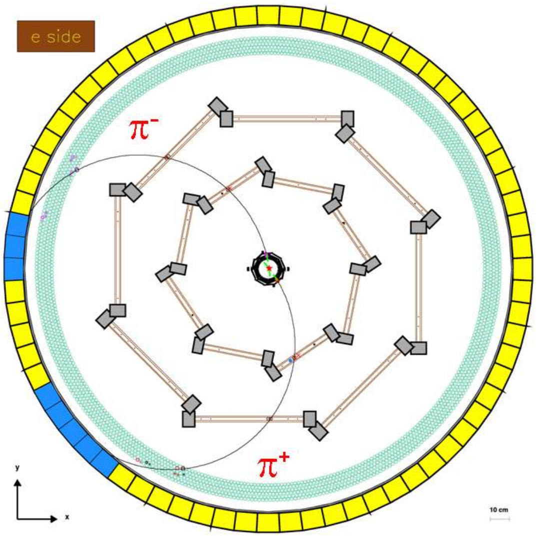

Figure 3: Event $e^+e^- \to \phi$, $\phi \to K^0_L K^0_S$, $K^0_S \to \pi^+\pi^-$ recorded by the FINUDA spectrometer.

- $e^+e^- \to \phi \to K^+K^-$ followed by $K^+ \to \mu^+\nu$, $K^+ \to \pi^+\pi^0$

Among the mentioned processes, the $K^0_S \to \pi^+\pi^-$ decay gives the main contribution to the background of the Bhabha trigger. The other processes are efficiently rejected by the trigger or have lower branching ratios; their contributions to the total counts have anyway to be considered for an accurate evaluation of the luminosity. Finally, thanks to the selectivity of the trigger, the machine e.m. background hardly fulfills the trigger conditions and can be completely neglected.

In Fig. 3, an event $\phi \to K^0_S K^0_L$ followed by $K^0_S \to \pi^+\pi^-$, recorded with the Bhabha trigger and reconstructed by the FINUDA reconstruction procedure is shown.

The topologies of the two types of events (Bhabha and K^0_S decay) are very similar. The charged π's from a low momentum K^0_S ($\approx$110 MeV/c) are also nearly back-to-back and mimic the trigger feature of the Bhabha events. The different average momenta of the produced π's, 206 MeV/c, instead of 510 MeV/c for the Bhabha events, do not prevent events from K^0_S decay to satisfy the trigger conditions. Simply, the K^0_S decay events will be collected with less efficiency respect to the Bhabha events, due to the higher curvature of the π's in the high magnetic field of FINUDA, hampering them to reach the external TOFONE scintillator barrel.

The instantaneous machine luminosity was continuously monitored by counting the reconstructed Bhabha events, in time intervals ΔT, and evaluating the following formula:

$$\mathcal{L}^{\mathcal{B}\langle\dashv\lfloor\langle\dashv}_{\rangle\backslash\int\sqcup} = \frac{\mathcal{N}^{\nabla\rceil\rfloor}_{\mathcal{B}\langle\dashv\lfloor\langle\dashv}/\cdot\mathcal{T}}{[\sigma_{\mathcal{B}\langle\dashv\lfloor\langle\dashv}\cdot\epsilon_{\sqcup\nabla\rangle\}}\cdot\epsilon_{\nabla\rceil\rfloor}]_{\theta>\theta_\prime}\cdot\epsilon_{\lceil\rceil\sqcup\rceil\rfloor}} \tag{2}$$

where N^{rec}_{Bhabha} is the number of the Bhabha events reconstructed by the apparatus, σ_{Bhabha} is the Bhabha cross section for emission polar angles larger than $\theta_0 = 30^o$ (relative to the beam direction), ϵ_{detec} is the global apparatus efficiency estimated with cosmic ray calibrations, and ϵ_{trig} and ϵ_{rec} are the trigger and reconstruction efficiencies for Bhabha events. These efficiencies are calculated by the FINUDA Monte Carlo program using the Bhabha event generator from [5] and accounting for the beam characteristics. The values of ϵ_{trig} and ϵ_{rec} for Bhabha events turn out to be 0.31 and 0.81, respectively.

The instantaneous machine luminosity was also calculated using the K^0_S decay events filtered inside the Bhabha trigger, by means of a formula similar to the relation (2):

$$\mathcal{L}^{\mathcal{K}'_{\mathcal{S}}}_{\rangle\backslash\int\sqcup} = \frac{\mathcal{N}^{\nabla\rceil\rfloor}_{\mathcal{K}'_{\mathcal{S}}}/\cdot\mathcal{T}}{[\sigma_\phi\cdot\mathrm{BR}_{(\mathrm{K^0_S K^0_L})}\cdot\epsilon_{\mathrm{trig}}\cdot\epsilon_{\mathrm{rec}}]\cdot\epsilon_{\mathrm{detec}}} \tag{3}$$

where $N^{rec}_{K^0_S}$ is the number of the K^0_S events reconstructed by the apparatus, σ_ϕ is the effective cross section for the formation of the ϕ ($\sigma_\phi = 3.26\ \mu$b), BR$_{(K^0_S K^0_L)}$ is the branching ratio for the decay of the ϕ into $K^0_S K^0_L$, ϵ_{detec} is the global apparatus efficiency, estimated with cosmic ray calibrations, and ϵ_{trig} (= 0.29) and ϵ_{rec} (= 0.78) are the trigger and reconstruction efficiencies, respectively, for K^0_S events calculated using the FINUDA Monte Carlo code.

The reconstruction of the events fulfilling the Bhabha trigger conditions was performed using two different procedures. A simple and robust one, called *single arm* procedure, was used mainly in the phase of the machine and apparatus commissioning. With this procedure, all hits generated by the two charged prongs of the triggered events in the FINUDA detectors were fitted by only a single curved trajectory. The advantages of such a method are: (i) a high reconstruction efficiency for Bhabha events (larger than 90%); (ii) the use of several spatial points (up to 10) to reconstruct the *single arm* trajectory; (iii) the insensitivity to detector inefficiencies and possible single detector failures; (iv) the high rate of reconstructed events. At the nominal luminosity of $\mathcal{L}_{\rangle\backslash\int\sqcup}$ =5·10^{31} cm^{-2}s^{-1}, a rate of about 30 Hz of reconstructed Bhabha events are expected.

In Fig. 4 the momentum distribution of the *single arm* tracks reconstructed in the FINUDA apparatus, after a 10 minute typical run with Bhabha trigger, is shown. The larger momentum peak around 500 MeV/c corresponds to elastic and highly elastic Bhabha events, whereas the smaller peak around 200 MeV/c corresponds to K^0_S events filtered

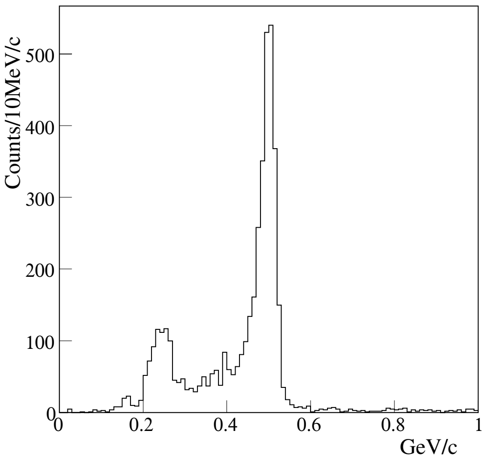

Figure 4: The momentum distribution of *single arm tracks* reconstructed by FINUDA in a 10 minute run with Bhabha trigger. The peak around 500 MeV/c corresponds to elastic and highly elastic Bhabha events. The other one, around 200 MeV/c, corresponds to K^0_S events filtered through the Bhabha trigger.

inside the Bhabha trigger. Events in between the two peaks are mainly due to other processes, in particular to the $\rho^0\pi^0$ one. This process gives indeed a not negligible trigger rate, since it has a large branching ratio and produces energetic and almost back-to-back charged pions, the ρ^0 being produced almost at rest.

By counting the number of events in the Bhabha and K^0_S peaks and applying the relations (2) and (3), respectively, the value of the machine luminosity $\mathcal{L}_{\rangle\backslash\int\sqcup}$ can be evaluated on-line from two different and independent physical processes. The results obtained were always in good relative agreement and nicely compatible with the luminosity evaluated by the machine staff. Moreover, since the K^0_S process depends not only on the instantaneous luminosity, but also on the centering of the machine energy on the ϕ resonance, the ratio between the contents of the two peaks allowed also the machine energy to be roughly monitored on-line during the machine commissioning phase.

The described *single arm* procedure is very efficient, robust and fast. However, it is not very accurate and has been complemented by a second reconstruction procedure, called *double arm* procedure, in which the two opposite charged arms of the triggered event are both reconstructed and accurately fitted. Results of the procedure have already be shown in Fig. 2 and Fig. 3 for a Bhabha and a K^0_S event, respectively. This procedure is slower, since it requests both tracks to be accurately measured, but allows the complete kinematics of the event to be reconstructed: the momentum of each prong with resolution

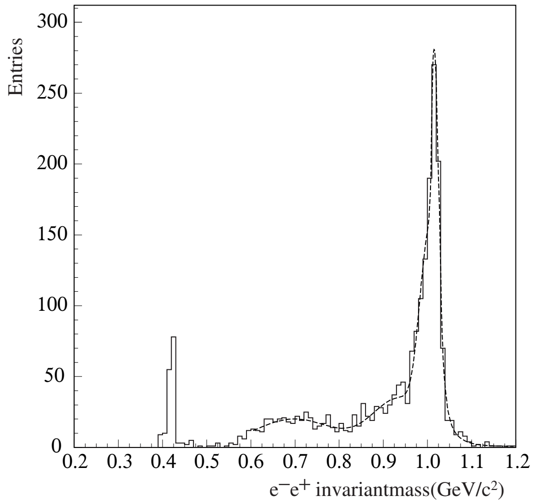

Figure 5: Invariant mass of the (e^+e^-) system. The main peak at M_{inv} = 1.019 ± 0.015 GeV/c^2 measures the e^+e^- collision energy. This figure is obtained summing two Bhabha trigger runs to increase the statistics.

of the order of few per mil, the vertex of the event (if any), the invariant mass of the two system of two tracks, according to a given mass hypothesis.

In Fig. 5 the invariant mass distribution for events with two opposite charged particles, collected during two runs with Bhabha trigger, is shown, in the hypothesis that the two tracks are e^+e^- pairs. The peak at the highest mass corresponds to highly elastic Bhabha processes. The machine collision energy during these runs as measured by the position of this peak results $M_{inv} = 1.019 \pm 0.015$ GeV/c^2. The narrow peak at the lowest mass corresponds to the events from $K^0_S \to \pi^+\pi^-$: the peak is displaced from the nominal K^0_S mass simply due to the use of the electron mass instead of the pion one in the invariant mass formula. The broad structure in between the two main peaks corresponds to the decay of the $\rho^0(770) \to \pi^+\pi^-$ coming from the $\phi \to \rho\pi$ decay.

The analysis is performed off-line, after the end of the run, analyzing the collected data and performing the complete reconstruction of the events. The Bhabha trigger runs have normally a statistics of 20 000 events which, at the typical (average) instantaneous luminosity $\mathcal{L}_{\rangle\setminus\int\sqcup} = \triangle \cdot \infty\prime^{\ni\infty}$cm^{-2}s^{-1}, are collected in a time ΔT of ≈ 10 minutes.

In Fig. 6 the invariant mass is shown for the $\pi^+\pi^-$ mass hypothesis on events belonging to the same runs. The narrow peak at $M_{inv} = (0.496 \pm 0.002)$ GeV/c^2 corresponds to the decay of the K^0_S, in good agreement with the PDG mass of the K^0_S, $M_{K^0_S} = 0.4977$ GeV/c^2. The position and the width of the peak provide information on the absolute calibration and on the global mass resolution of the spectrometer. The

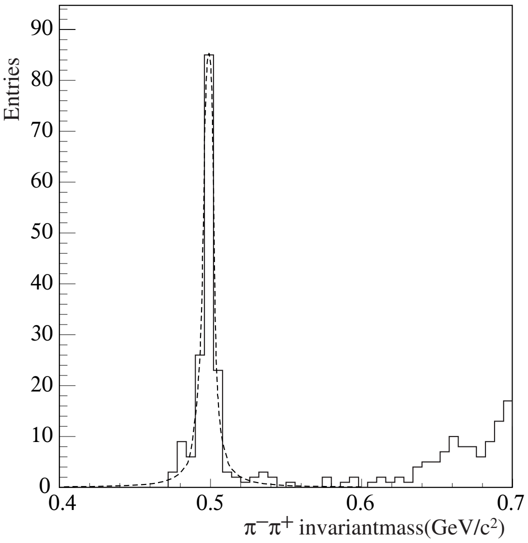

Figure 6: Invariant mass of the $(\pi^+\pi^-)$ system. The narrow peak at M_{inv} = 0.496 ± 0.002 GeV/c^2 corresponds to the $K_S^0 \to \pi^+\pi^-$ decay. This figure is obtained summing two Bhabha trigger runs to increase the statistics.

wide bump on the right of the K_S^0 peak corresponds, as already mentioned, to the decay of the $\rho^0(770) \to \pi^+\pi^-$.

The two above described methods (*single* and *double arm* procedures) provide a cross check of the measured values of the average luminosities, after a time interval ΔT of at least several minutes. This information is very useful but the delivering rate is not always fast enough to serve all the needs of the experiment. Due the specific features of DAΦNE, the life times of the beams are of the order of few tens of minutes, and the life time of the luminosity of their collision even shorter. Due to this fact, in order to properly tuning the machine and continuously checking its working conditions, the luminosity values must be known on an on-line basis. In other terms, instantaneous luminosities values or, at least, luminosities averaged in time intervals of the order of few seconds, must also be provided in order to be useful for the optimization of DAΦNE performance to the FINUDA needs.

One possibility to obtain these instantaneous values is to calculate them using accelerator physics relations and standard machine parameters, continuously measured by instruments positioned along the rings. This procedure is accurate, but it is not a direct measurement of the luminosity in the FINUDA interaction region. A direct measurement can however be provided by the same FINUDA detectors.

To provide the on-line luminosity values in time intervals of the order of few seconds, FINUDA can exploit the counts of the scalers measuring the Bhabha trigger rate. Such counts are transformed in $\mathcal{L}_{\rangle\backslash\int\sqcup}$ values using a conversion factor obtained from the Bhabha runs where events have been fully reconstructed. There is indeed a fixed relationship between the total counted Bhabha triggers and the total number of Bhabha events reconstructed with the above described procedure. This relationship has been determined using the FINUDA Monte Carlo code and tuned experimentally at the beginning of FINUDA runs, in order to find and optimize the conversion factor; then it has been used to provide the on-line values of the machine luminosity based on the Bhabha trigger rate.

The luminosity measured with this method, in spite of its larger error respect to those provided by the reconstruction procedures, is however precise enough for the aim of on-line monitoring the $\mathcal{L}_{\rangle\backslash\int\sqcup}$ values of DAΦNE luminosity. Moreover, with this method, the values of $\mathcal{L}_{\rangle\backslash\int\sqcup}$ can be obtained also when the trigger used in the data taking is not the Bhabha one since, in regime conditions, no reconstruction of Bhabha events is needed, but only the reading of a dedicated scaler permanently counting the Bhabha trigger conditions occurring during any run. The conversion factor (evaluated as 0.17) was periodically checked during the run period to verify its stability.

In Fig. 7 a typical plot of the $\mathcal{L}_{\rangle\backslash\int\sqcup}$ luminosity measurement provided with the method described above, is given. The figure shows the circulating e^- and e^+ currents, and the instantaneous and integrated luminosity values as measured by FINUDA during a two hours period of data taking. For the sake of comparison, the instantaneous luminosity values calculated using accelerator physics relations by means of the data provided by DAΦNE monitoring devices are shown as well.

The luminosity measured using Bhabha events, both with the on-line and the off-line methods, is however not very sensitive to the actual machine energy setting. Indeed, the behavior of the Bhabha cross section is rather flat with c.m. energy and the determination of the true mass of the Bhabha system invariant mass is affected by radiative corrections. It is however pivotal for FINUDA to work exactly at the c.m. energy corresponding to the mass of the ϕ meson, to get the maximum flux of (K^-, K^+) pairs from its decay. In fact, with a width of the ϕ meson of only 4.43 MeV (FWHM), there is a loss of charged kaon beam intensity of a factor 2 if the energy of both beams is displaced, for instance, of ± 1 MeV only from the nominal 510 MeV value. For such a small energy displacement, the variation of the Bhabha counts or the displacement of the invariant mass Bhabha peak are practically not detectable.

Hence, a different method of performing an accurate monitoring of both the luminosity and the c.m. energy had to be employed by FINUDA: the method is based on the complete reconstruction and counting of events coming from the $\phi(1020)$ decay mode into $K^0_S K^0_L$ collected during Bhabha runs. After the K^0_S mass peak has been identified

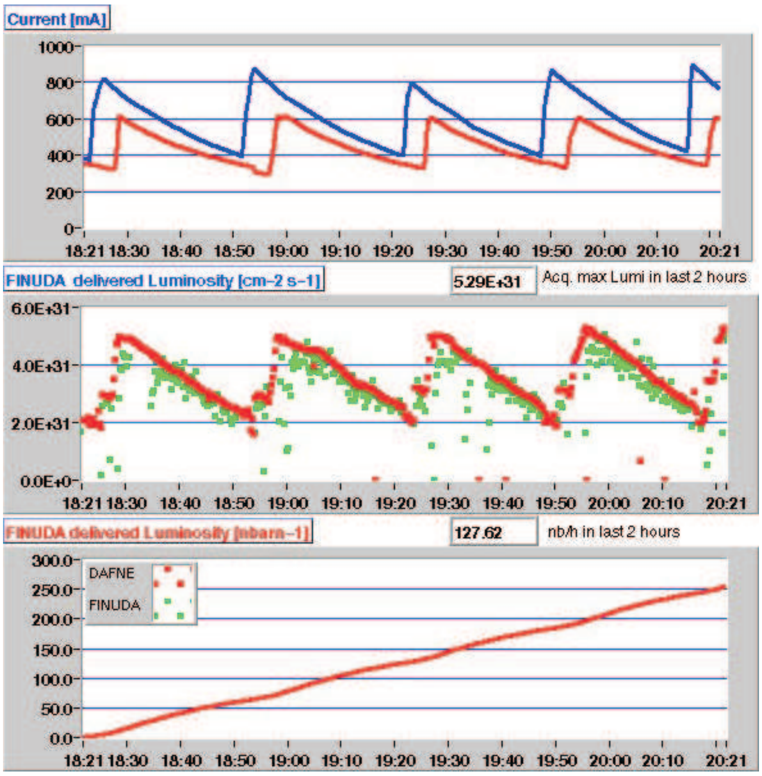

Figure 7: The DAΦNE currents (top plot) for e^+ (red) and e^- (blue); the corresponding instantaneous luminosities (mid plot) as measured by FINUDA (green points) and provided by DAΦNE (red points), and the DAΦNE integrated luminosity (bottom plot), during a two hour interval of data taking.

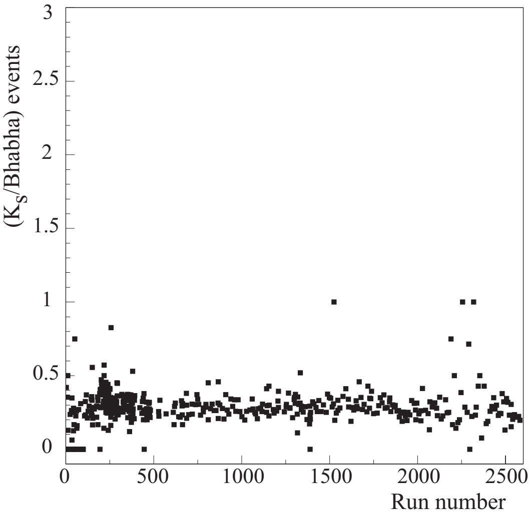

Figure 8: Ratio of the counts of the reconstructed events in the K^0_S peak over the corresponding counts of the reconstructed events in the Bhabha peak, as a function of the run number, during the whole period of the FINUDA data taking, including also debugging, test and short runs.

(see Fig. 5), the number of corresponding events $N_{K^0_S}$ is divided by the number N_{Bhabha} of Bhabha events collected and reconstructed in the same run. This procedure is repeated changing slightly the energy of the two DAΦNE beams at each step. The tuning of the machine at the $\phi(1020)$ energy corresponds to the maximization of the ratio $\frac{N_{K^0_S}}{N_{Bhabha}}$. After the collider has been properly tuned in energy, this ratio is checked at regular time intervals to monitor its stability during the whole period of data taking. In Fig. 8 the ratio $\frac{N_{K^0_S}}{N_{Bhabha}}$ is shown during the whole data taking period of FINUDA. As it can be seen, after an initial period of beam tuning, the ratio remains roughly constant, demonstrating the stability of DAΦNE c.m. energy at the mass of the ϕ meson.

2.2 Measurement of the DAΦNE beam boost

FINUDA is able to monitor another important parameter of the DAΦNE machine: the transversal boost of the generated $\phi(1020)$ mesons. DAΦNE is a two rings collider and, due to this particular feature, in the FINUDA interaction region the e^+ and e^- beams do not collide exactly head on, but form a crossing angle different from zero and amounting to about 25 mrad. Due to this crossing angle, the $\phi(1020)$ mesons are not produced at rest, but have a small transversal momentum (boost) of 12.3 MeV/c. In the case of the FINUDA interaction point, the vector momentum is directed outward with respect to the center of the rings.

This small total momentum of the ϕ affects, of course, also the momenta of the (K^-, K^+) produced in the ϕ decay. Indeed, if the ϕ decay occurred at rest, the kaon momenta would be 127 MeV/c, independently from their direction, and their angular distribution would be symmetric around the e^+, e^- beam axis. The presence of a transversal beam boost changes the values of the kaon momenta making them dependent on the azimuthal angle of emission: the momenta are slightly increased in the boost direction and decreased in the opposite one. Moreover the kaon emission distribution is modified and is no longer axially symmetric.

These features of the DAΦNE kaon beam are of big relevance for FINUDA, which is optimized to study interactions of stopped kaons in thin targets of different materials. Due to the low momentum of the generated charged kaons, their energy loss in crossing the beam pipe, the TOFINO scintillator, the silicon microstrips of the vertex detector and the target materials is huge and increasing highly non linearly during the slowing down. Therefore, a variation of the beam crossing angle, and consequently of the momenta of the charged kaons, could change their range, and modify their stopping distribution inside the targets.

In fact, the thicknesses of the different targets have been determined in order to have the K^- stopping point distribution as close as possible to their outward surface, in order to minimize the amount of residual target material crossed by the outgoing particles and, consequently, the perturbation of their momentum to be measured in the spectrometer. In extreme cases, the charged kaons may not even stop in the thin targets, either stopping before or passing through them.

For this reason, it is of paramount importance for FINUDA to check, during the data taking, that the beam boost remains constant and stable at the nominal value. The monitor of the stability of the beam boost is performed, by FINUDA, on a run-to-run basis, by means of a set of events periodically collected using the Bhabha trigger prescaled to the main hypernuclear trigger. To this aim, a sample of Bhabha events, fully reconstructed and recognized as highly elastic by the values of the momenta of both positive and negative prongs close to 510 MeV/c, is selected. For each event, the reconstructed momenta of the e^+ and of the e^- are then vectorial added and the magnitude of the resulting total momentum is calculated.

The magnitude of the total momentum of the event may differ from zero due to several reasons, a part from the presence of the total beam boost: radiative losses of the electron or positron, deviations of the trajectories due to multiple scattering or errors in the reconstruction. The distribution, however, of the values of the magnitude of the total e^+ and e^- momentum should show a minimum value, that corresponds to the magnitude

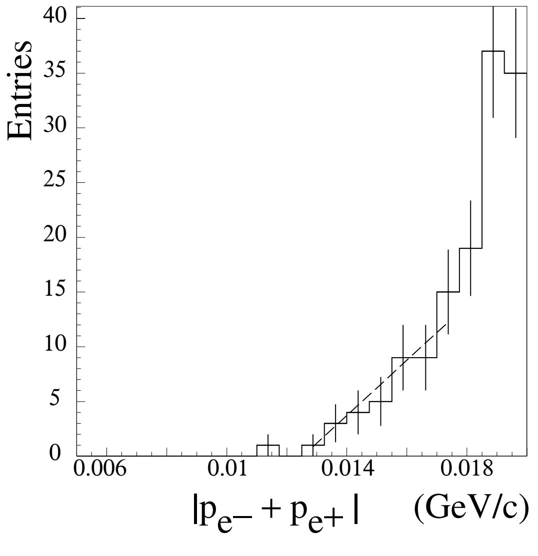

Figure 9: Distribution of the magnitude of the vectorial sum of the e^+ and e^- momenta in Bhabha trigger runs. The intersection of the dashed line with the abscissa axis gives the value of the DAΦNE boost momentum In order to increase the statistics in the shoulder region, five consecutive Bhabha runs have been summed up.

of the boost of the not perfectly head-on (e^+e^-) collision. This minimum value should be zero in case the Bhabha reaction was due to e^+ and e^- with momenta of equal magnitude and colliding exactly head on, and should correspond to the boost of the DAΦNE e^+e^- beams, in the FINUDA interaction region, when different from zero.

In Fig. 9 the distribution is shown of the magnitude of the total momentum of the positive and negative reconstructed tracks of Bhabha highly elastic events. The straight line fit to the shoulder of the distribution allows to determine, by its intersection with the momentum axis, the boost of DAΦNE. In this example, it amounts to about 12.5 MeV/c, as expected from e^+ and e^- beam interaction with the nominal crossing angle of 25 mrad. This procedure has been performed systematically during the whole data taking, to check the value of the DAΦNE boost.

The result of this monitoring is plotted in Fig. 10 for the whole data taking period and shows how FINUDA is able to measure the boost value of DAΦNE during the data taking. This information can be used during the data analysis to improve the event reconstruction.

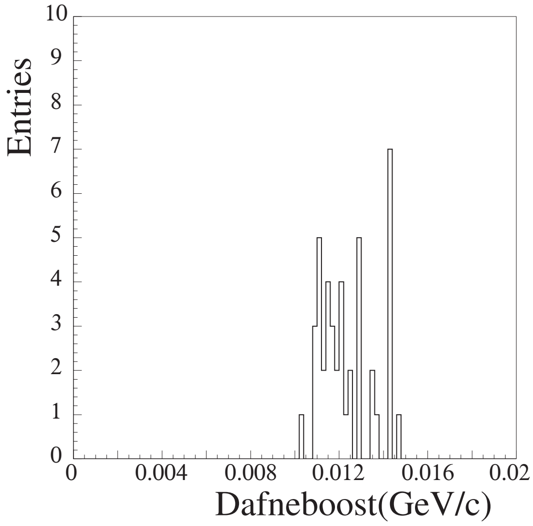

Figure 10: The distribution of the DAΦNE boost momentum measured by FINUDA during the whole period of data taking (consecutive Bhabha trigger runs have been summed up five by five increasing the statistics to better determine the boost value).

2.3 Distribution of the e^+e^- collision points

FINUDA is also able, on a run-to-run basis, to monitor both the distribution of the e^+e^- collision points and the distribution of the $\phi(1020)$ decay vertexes, using two different types of events. This information is relevant, since the limited extension along the beam axis of the FINUDA vertex region and the geometry of its tracking volume, symmetrical around the e^+e^- axis and covering a polar angle of acceptance from about 45° to 135°, require to center the spot of the e^+e^- collisions in the middle of the spectrometer, in order to maximize its geometrical acceptance.

The distribution of the e^+e^- collision points can be measured, especially during the commissioning phase, using the reconstruction of the Bhabha events with the *single arm* procedure. In fact, each *single arm* trajectory, which averages the trajectories of the two single e^+e^- prongs, crosses the horizontal plane in which the e^+e^- beams are contained. This crossing point is a good estimation of the e^+e^- collision point, where the two prongs are generated. It's worth reminding, in fact, that the DAΦNE collision spot is essentially distributed along the beam axis z and in the transverse direction x, since in the vertical direction y its spread is just 20 μm.

In Fig. 11 the distributions of the x and z coordinates of the e^+e^- collision spot, obtained with the fast *single arm* procedure in only one run of ΔT=10 min, are shown,

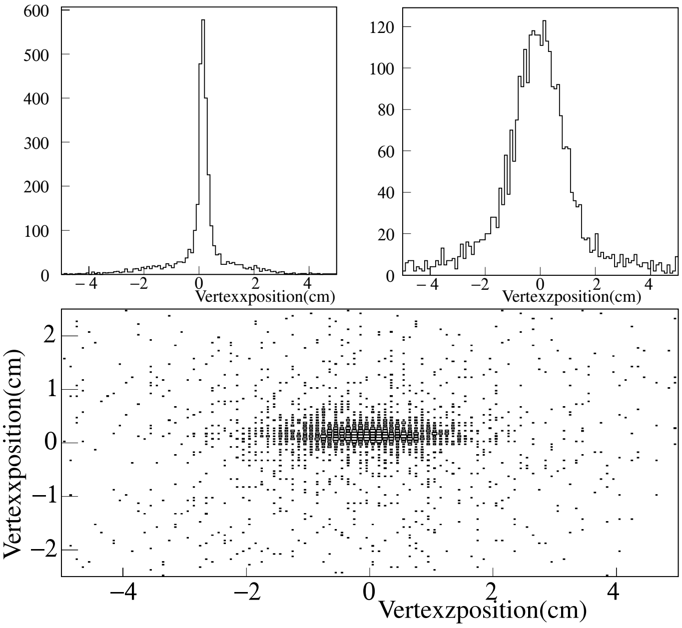

Figure 11: Distributions of the x (top left) and z (top right) e^+e^- collision points as reconstructed by FINUDA with the *single arm* procedure in one Bhabha trigger run. Bottom: the corresponding x vs. z scatter plot.

together with the corresponding scatter plot. It should be worth noticing that the x distribution obtained with this method is not corrected for the boost effect; this can be seen from the mean value of the x distribution, which is displaced in the +x (i.e. boost) direction.

The distribution of the ϕ(1020) decay vertexes may be obtained, during the data taking, by the accurate reconstruction of the origin vertexes of the K^+K^- pairs. The reconstruction procedure of the K^+K^- trajectories is based on a two helix algorithm that accounts for the average value of the mass of the ϕ(1020) and for the e^+e^- beam crossing angle (25 mrad). The algorithm determines, event by event, the ϕ formation point and the two kaon directions and momenta, solving possible ambiguities. Input information to the procedure are the interaction points of the two kaons on the ISIM microstrips facing the two TOFINO fired slabs. The hits of the kaons on ISIM are recognized, against the hits of the other particles, thanks to the high specific ionization of the very slow kaons.

The exact K^+K^- trajectories and stopping points are then calculated by a tracking procedure based on the GEANE tracking package [6] and starting from the ϕ formation point and the K^- and K^+ directions and momenta. The procedure accounts for the geometrical structure and the material composition of the vertex region, accurately described

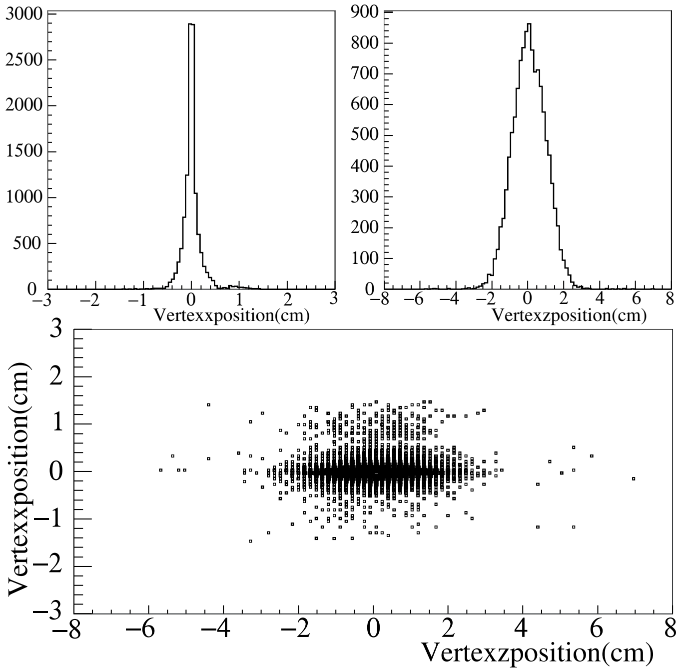

Figure 12: Distributions of the x (top left) and z (top right) ϕ vertexes as reconstructed by FINUDA with the *double arm* procedure in runs using the trigger optimized for hypernucleus event selection. Bottom: the corresponding x v.z scatter plot.

in the FINUDA Monte Carlo program. As an example of the result obtained, the distributions of the K^-K^+ origin vertexes, in a typical run, are shown in Fig. 12. In the picture, the horizontal transverse x and longitudinal z distributions of the $\phi(1020)$ vertexes are shown, as well as the x versus z scatter plot. It should be noted that, with the *double arm* procedure, the boost effect is properly taken into account and, correspondingly, the x distribution is centered at the origin.

By means of this last procedure, the stability in position and width of the $\phi(1020)$ decay vertex distribution was monitored during the whole data taking. In Fig. 13 (Fig. 14), the center and the sigma of the transversal-x (longitudinal-z) coordinates of the vertexes during the whole period of FINUDA data taking are plotted, showing the pretty good stability of the $e^+e^- \to \phi(1020)$ generation positions in DAΦNE.

3 Conclusions

The FINUDA spectrometer, devoted to hypernuclear physics, employs, for the first time, an e^+e^- collider to provide the primary K^- beam. The apparatus is able, during the nor-

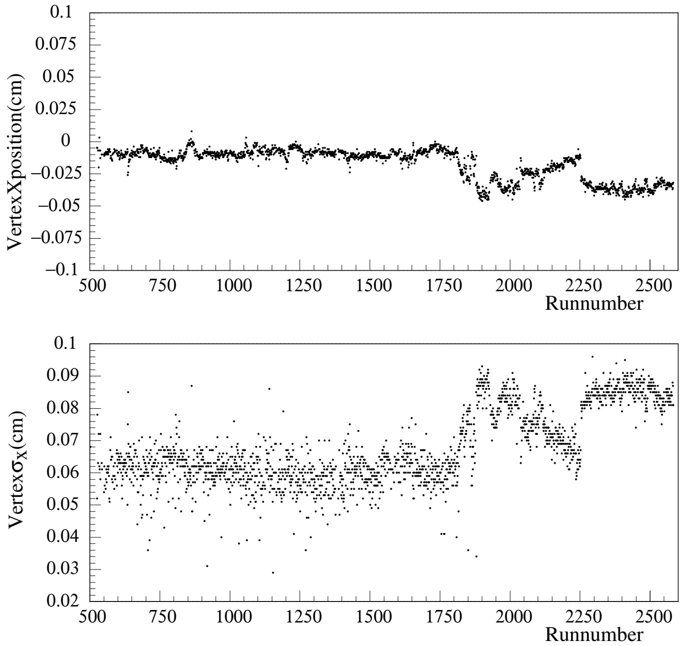

Figure 13: The centroid (top) and the σ (bottom) of the x distribution of the ϕ vertexes as a function of the run number during the FINUDA data taking period.

mal data taking, to provide also information on the machine performances: instantaneous luminosity, total beam boost, distribution of e^+e^- collision points. This information, provided to the machine staff on-line and off-line, in a run-to-run basis and in a continuous way, allows for the optimization, the stability control and background reduction of the DAΦNE accelerator. Moreover, the information on the DAΦNE performance is provided without perturbing the ordinary collection of data for the primary physical aims of the experiment.

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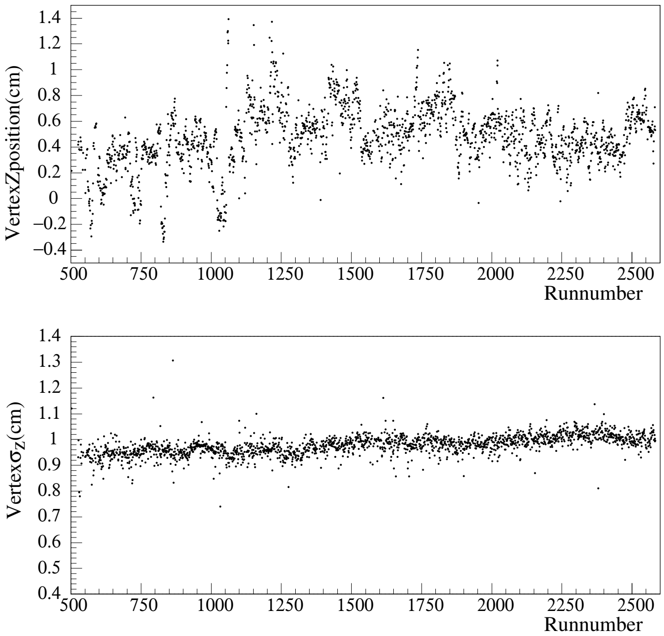

Figure 14: The centroid (top) and the σ (bottom) of the z distribution of the ϕ vertexes as a function of the run number during the FINUDA data taking period.

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