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Current Status of Luminosity Measurement with the CMD-3 Detector at the VEPP-2000 e^+e^- collider

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Abstract
The CMD-3 detector has taken data at the electron-positron collider VEPP-2000 since december 2010. The collected data sample corresponds to an integrated luminosity of 60 pb^{-1} in the c.m. energy range from 0.32 up to 2 GeV. Preliminary results of the luminosity measurement are presented for various energy ranges and its accuracy is estimated to be 1%.

Keywords
Luminosity; VEPP-2000; CMD-3 detector.

1 Introduction

The electron-positron collider VEPP-2000 [1] has been operating at Budker Institute of Nuclear Physics since 2010. The collider is designed to provide a luminosity of up to $10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ at a maximum center-of-mass energy of $\sqrt{s} = 2$ GeV. There are two detectors, CMD-3 [2] and SND [3], installed in the two interaction regions of the collider. Both detectors have high detection efficiency and good energy and angular resolutions for charged particles and for photons.

Precise luminosity measurement is a key requirement for many experiments studying hadronic cross sections at e^+e^- colliders. As a rule, the systematic error of the luminosity determination is one of the largest sources of uncertainty, which can cause significant reduction in the hadronic cross section accuracy. Therefore it is very important to have several well-known QED processes such as $e^+e^- \to e^+e^-$, $\mu^+\mu^-$, $\gamma\gamma$ to determine the luminosity. The combined usage of them will help to better understand and estimate the systematic accuracy of the luminosity measurement. The CLEO collaboration was the first to show in practice how a combined usage of the processes $e^+e^- \to e^+e^-$, $\mu^+\mu^-$ and $\gamma\gamma$ helped to achieve a 1% accuracy for luminosity [4].

The process $e^+e^- \to \gamma\gamma$ has essential advantages in luminosity determination [5, 6] over the first two ones. This process is free of effects due to radiation of the final state particles and Coulomb interaction. It is also of importance that the corresponding Feynman graphs do not contain photon propagators affected by vacuum polarization effects. Events of this process have two collinear photons with similar energy depositions in calorimeters, providing a clean signature for their selection among other events. These reasons are the main motivation to explore this process as an independent tool for luminosity determination. Preliminary results of the luminosity determination are presented in a wide energy range.

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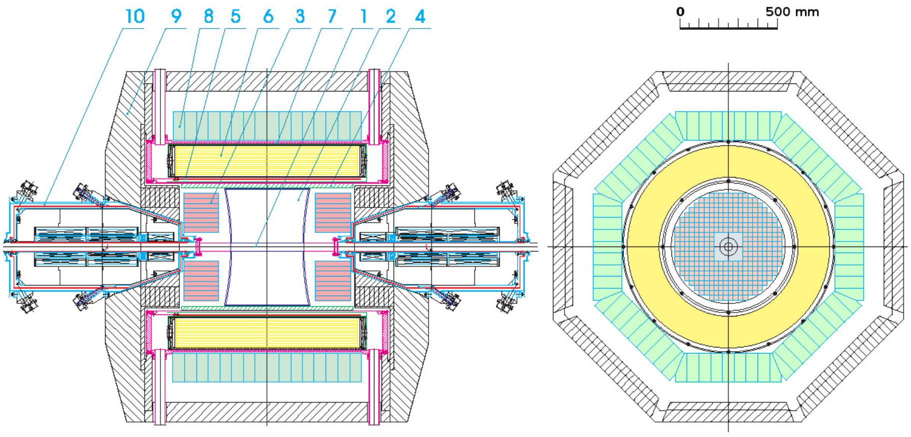

Fig. 1: The CMD-3 detector: 1 – beam pipe, 2 – drift chamber, 3 – BGO, calorimeter, 4 – Z-chamber, 5 – SC solenoid ($0.13X_0$, $1.3T$), 6 – LXe calorimeter, 7 – TOF system, 8 – CsI electromagnetic calorimeter, 9 – yoke, 10 – VEPP-2000 SC solenoids ($13T$). The outer muon range system is not shown.

2 CMD-3 detector and dataset

The Cryogenic Magnetic Detector, CMD-3, is a general purpose detector, shown in Fig. 1. The cylindrical drift chamber (DC) measures the coordinates, angles and momenta of charged particles. The position resolution in the r-ϕ plane is $\sim$120 μm. The resolution along the beam axis is $\sim$2 mm as measured from charge division along the wires. The proportional Z-chamber mounted outside the DC provides a more accurate z-coordinate measurement of the tracks. The resulting z-coordinate resolution is $\sim$400 μm. The signals coming from the anode wires are used for the first level trigger and have a time jitter of $\sim$5 ns.

The calorimeter consists of three subsystems. The endcap BGO calorimeter with a depth of $13.4X_0$ is placed on both sides of the DC flanges. The barrel part, which is placed outside the superconducting solenoid with a 1.3 T magnetic field ($0.13X_0$), consists of two systems: an inner Liquid Xenon calorimeter ($5.4X_0$) and a calorimeter based on CsI crystals with a depth of $8.1X_0$. The latter comprises 1152 crystals, which are spread over 8 octants. The LXe calorimeter has a tower structure (264 channels) and seven cylindrical double layers with strip readout (2112 channels). The strip information allows one to measure coordinates of the photon conversion point with a precision of about 1-2 mm.

The outer muon range system, located outside the iron yoke, consists of 36 scintillation counters in the barrel part and 8 counters in the endcap. This system is used as a cosmic veto and has a time resolution of $\sim$1 ns.

In 2011 the energy range from 1 to 2 GeV was scanned up and down with a step size of 50 MeV. At each energy point an integrated luminosity of $\sim$500 nb^{-1} was collected. During the scan down the energy points were shifted by 25 MeV with respect to the previous scan. The data were collected at an average luminosity of $\sim 4{\cdot}10^{30}$s^{-1}cm^{-2}. At the highest energies the peak luminosity reached approximately $2{\cdot}10^{31}$s^{-1}cm^{-2} and was limited by the positron storage rate in the booster. The design luminosity of $\sim 10^{32}$s^{-1}cm^{-2} will be reached only with the new positron injection facility, starting in 2016. In 2012 the luminosity was measured at 16 energy points from 1.32 GeV to 1.98 GeV and the collected luminosity was about $\sim$14 pb^{-1}.

In 2013 the energy range from 0.32 GeV to 1 GeV was scanned with 10 MeV steps. Integrated luminosities of about 8.3 and 8.4 pb^{-1} were collected around the ω and ϕ mesons, respectively. In 2013 an integrated luminosity of $\sim$25 pb^{-1} was collected.

The average trigger counting rate was about 200 - 400 Hz and strongly depended on the fine tuning of the beam optics.

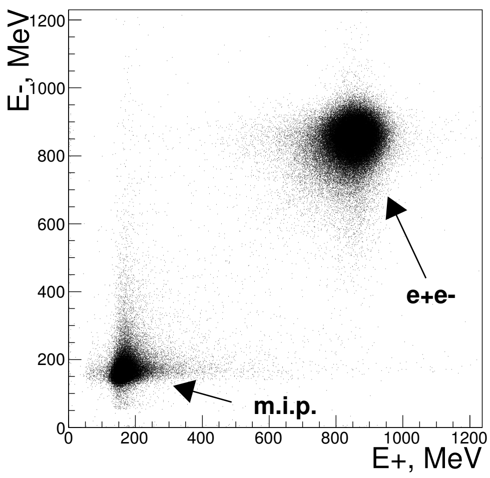

Fig. 2: Correlation between energy depositions in calorimeters for two collinear tracks.

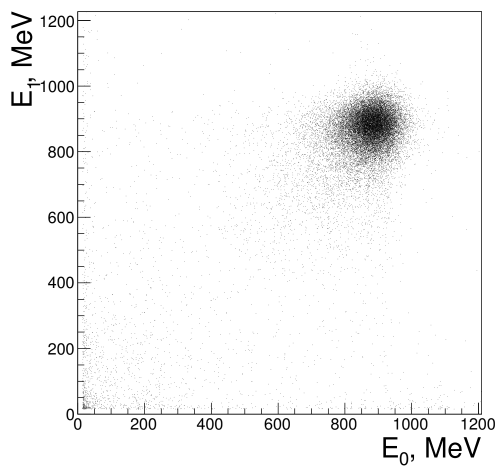

Fig. 3: Correlation between energy depositions in calorimeters for two collinear photons.

3 Event selection

At first, collinear events with back-to-back tracks in the DC were selected according to the following criteria: two tracks with opposite charge were reconstructed in the DC; the distance from both tracks to the beam axis in the r-ϕ plane was less than 0.5 cm; the distance from both tracks along beam axis to the interaction point did not exceed 10 cm; the acollinearity angle between the two tracks in the scattering plane (containing the beam axis) $|\Delta\Theta| = |\Theta_1 - (\pi - \Theta_2)| \leq$0.25 rad; the acollinearity angle between the two tracks in the azimuthal plane (perpendicular to the beam axis) $|\Delta\Phi| = |\pi - |\Phi_1 - \Phi_2|| \leq$0.15 rad; the average polar angle of the two tracks $[\Theta_1 + (\pi - \Theta_2)]/2$ should be between 1 and $(\pi - 1)$ rad.

Samples of collinear events e^+e^-, $\mu^+\mu^-$, $\pi^+\pi^-$, K^+K^- and cosmic background were selected for the luminosity determination. Correlation between energy depositions in calorimeters for these events is presented in Fig. 2 for a beam energy of 950 MeV. It is clearly seen that Bhabha events are located predominantly in the upper right corner, whereas other particles are concentrated in the bottom left corner. Collinear events are accepted as Bhabha events if the energy deposition of each particle is within the interval from 0.5E$_{beam}$ to 1.5E$_{beam}$. Thus, the integrated luminosity can be determined from selected Bhabha events:

$$\int L \cdot \mathrm{d}t = \frac{N_{ee}}{\sigma_{ee} \cdot \epsilon_{\mathrm{rad}} \cdot \epsilon}, \tag{1}$$

where N_{ee} is the number of selected Bhabha events, σ_{ee} is the Bhabha cross section integrated within the detector acceptance, ϵ_{rad} $\sim$$0.947 \pm 0.002$ is the radiative correction calculated according to [7] and ϵ is the event detection efficiency.

Events of the process $e^+e^- \to \gamma\gamma$ were also used to determine the integrated luminosity. It is worth noting that this method has completely different systematic uncertainties. It is important that this method has absolutely different systematic errors as compared to the method based on the Bhabha events. The $\gamma\gamma$ neutral collinear events were selected according to the following criteria: back-to-back clusters in the barrel calorimeters; the energy of each cluster is required to be within the interval from 0.5E$_{beam}$ to 1.5E$_{beam}$; no tracks in the DC coming from the interaction region and no hits in the Z-chamber sectors associated with the clusters. The last condition helps to eliminate Bhabha events which slip through the previous cuts. The polar angle of the cluster is calculated by the center-of-gravity method using the information from strips in the LXe calorimeter [8]. A two dimensional plot of the energy deposition E_o vs E_1 is presented in Fig. 3.

The detection efficiency of the $e^+e^- \to e^+e^-$ events is determined as $\epsilon = \epsilon_{2\mathrm{tr}} \cdot \epsilon_{\mathrm{trg}} \cdot \epsilon_{cal} \cdot \epsilon_{en}^2$, where ϵ_{2tr} is the track reconstruction efficiency in the DC, ϵ_{trg} is the trigger efficiency, ϵ_{cal} is the cluster reconstruction efficiency, ϵ_{en} is the cluster selection efficiency for the energy depositions in the calorimeters.

The detection efficiency of the $e^+e^- \to \gamma\gamma$ events is determined as $\epsilon = \epsilon_{cal} \cdot \epsilon_{en}^2 \cdot \epsilon_{ntr}$, where ϵ_{cal} is the cluster reconstruction efficiency, ϵ_{en} is the cluster selection efficiency for the energy deposition in the calorimeters, ϵ_{ntr} is the neutral trigger efficiency. The radiation length of the LXe calorimeter for photons is about $5X_0$ only, resulting in a $\sim$99% interaction probability of one photon in this calorimeter.

Since the Bhabha and $\gamma\gamma$ cross sections are complex functions of the polar angle θ, systematic corrections have to be applied bacause of the finite angular resolution σ_θ. For example, for σ_θ $\sim$0.03 rad and polar angle θ = 60° the correction is about 0.5% for Bhabha events. Bhabha events were used to determine the calorimeter angular resolution. To this end the tracks from the DC were extended to the intersection with the LXe calorimeter. The width of the distribution of the difference in the coordinates determined by the strips and by the track serves as the angular resolution. It is better than $\sim$0.05 rad.

4 Systematic uncertainties

The fiducial volume of the CMD-3 detector can be determined independently with the LXe calorimeter and Z-chamber. It allows one to monitor the detector operation stability during data collection. The possibility of cross-checking a z-scale measurement with two subsystems will allow one to keep the systematic uncertainty from this source at a level of $\sim$0.1%. Measurement of the beam energy by the Compton back scattering of laser light with a precision σ_E below 50 keV [9] will keep the systematic uncertainty from this source below 0.1%.

Another important source of systematic uncertainty is the theoretical precision of radiative corrections [10]. Additional studies are required in this field and a comparison with experimental data is necessary. We expect that this uncertainty can be reduced to 0.1%.

The axis of the CMD-3 detector has a slight slope with respect to the beam axis and this parameter is unstable in time. Therefore the measured luminosity can change by up to 0.4% and thus a careful monitoring is required. Event selection criteria for collinear tracks also contribute to the systematic error of the integrated luminosity, as well as energy and momentum resolutions, angular resolution, the stability of the z-scale in the DC and similar factors.

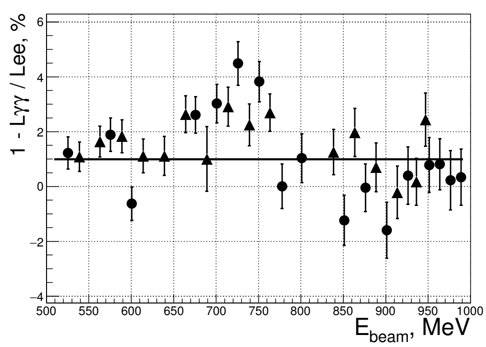

Fig. 4: The ratio of the luminosities for the processes e^+e^- and $\gamma\gamma$ as a function of energy. Scan 2011, circles - scan up $(0.9 \pm 0.4)\%$, triangles - scan down $(1.5 \pm 0.3)\%$. Only statistical errors are shown.

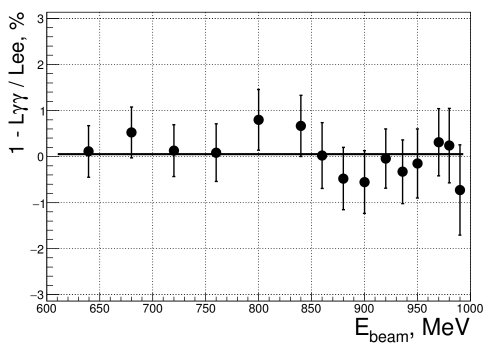

Fig. 5: The ratio of the luminosities for the e^+e^- and $\gamma\gamma$ processes as a function of energy. Scan 2012. The horizontal line represents the average result.

5 Results, Conclusion, Summary

The VEPP-2000 collider successfully operates with a goal to collect $\sim$1 fb^{-1} in 5-10 years and provide new precise results on hadron physics. Two types of the first level triggers, "CHARGED" and "NEUTRAL", delivered independent information, thereby enabling the determination of trigger efficiencies and estimation of their uncertainties. The collected integrated luminosity is $\sim$60 pb^{-1} with about 34.5 pb^{-1} above the ϕ resonance energy, 8.3 and 8.4 pb^{-1} at the ω and ϕ resonances respectively, and 9.4 pb^{-1} from a scan below the ϕ. A peak luminosity of $\sim$2$\cdot$10^{31}s^{-1}cm^{-2} was reached. It is currently limited by the deficit of positrons and the maximum beam energy of the booster (825 MeV now). Data analysis is in progress. The already collected data sample has the same or better statistical precision for the hadronic cross sections than achieved in previous experiments. An upgrade of the injection facility will increase the luminosity ten-fold at least. The current integrated luminosity of the collider was measured using two well known QED processes $e^+e^- \to e^+e^-$ and $\gamma\gamma$. The luminosity ratio determined using the two processes as a function of energy is shown in Fig. 4 and Fig. 5, where only statistial errors are shown. It is worth noting that the systematic uncertainties of the luminosity measurement are totally different for the e^+e^- and $\gamma\gamma$ processes and cannot be compensated in their ratio. The current luminosity accuracy is estimated to be 1%. The study of the different systematics is still in progress. In the forthcoming future we hope to reduce it to a $\sim$0.5% level.

Acknowledgements

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