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CMD-2 Detector Upgrade

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The project of upgrading the detector CMD-2 is presented. The upgraded detector is called CMD-2M and is going to take data with the new collider VEPP-2000 at BINP. The general structure of the detector CMD-2 will remain as is but major parameters of the detector, such as momentum and angular resolution for charged particle and energy and spatial resolution for photons, will be substantially improved.

1. INTRODUCTION

The general-purpose Cryogenic Magnetic Detector (CMD-2) (Figure 1) [1] has been running at the VEPP-2M electron-positron collider in Novosibirsk from 1992 to 2000 studying the centre-of-mass energy range from 0.36 to 1.4 GeV. The total integrated luminosity collected is about 25 pb^{-1}. It allows the study, with high precision, of many channels of e^+e^- annihilation to hadrons and rare decays of the light vector mesons [2].

At present time, a modernization of the VEPP-2M accelerator-collider complex is in progress. The main part of the modernization is the creation of the new collider VEPP-2000 [3] with centre-of-mass energy up to 2 GeV and luminosity up to 10^{32} $cm^{-2}s^{-1}$.

The change of the collider interaction point design and the increase of its energy and luminosity require the upgrade of the detector. The general structure of the detector will be the same. The most expensive components of the CMD-2 detector, such as BGO and CsI crystals, as well as a substantial part of digitizing electronics and software will be used in the CMD-2M detector. All systems of the detector will be upgraded or replaced by new ones.

2. GENERAL DESCRIPTION OF THE CMD-2M DETECTOR

The layout of the CMD-2M detector is shown on Figure 2.

The electron and positron beams collide at the center of the vacuum chamber (1) which has an internal diameter of 34 mm. The central part of the vacuum chamber is a Be tube with thickness of 0.77 mm ($2.1 \times 10^{-3} X_0$). A set of masks protects thin part of the vacuum chamber from synchrotron radiation.

*On behalf of the CMD-2M collaboration listed in appendix A.

The coordinate, angle and momentum of charged particles are measured by the cylindrical drift chamber (2) with a hexagonal cell. The chamber diameter is 600 mm, its length 440 mm. The charge division along the wires is used for measuring the Z-coordinate of tracks.

The Z-chamber (4) produces a fast pretrigger signal for charge trigger and measures the Z-coordinate of tracks with high resolution.

The drift and Z-chambers are placed inside the superconductive solenoid (5) with a magnetic field of 1.5 T. The total thickness of the solenoid is 0.18 X_0. The collider focusing solenoids (9) with a magnetic field of 13 T are almost inside the detector but their influence on the magnetic field in the volume of the drift chamber is small.

The coordinates and energy of photons are measured by the barrel calorimeter based on liquid Xe (6) and CsI crystals (7) and the endcap calorimeter based on BGO crystals (3). Both the barrel and endcap calorimeters cover a solid angle of $0.94\times4\pi$ steradians. The barrel calorimeter is located outside the magnet. To minimize the amount of passive matter in front of the calorimeter the liquid Xe calorimeter and the magnet are placed into a common cryostat.

The iron flux return yoke (8) is octagonal in shape with a length of 1660 mm and a height of 1800 mm. The range system, based on plastic scintillator, is located outside the yoke.

The main parameters of the CMD-2M detector are listed in Table I for comparison with the CMD-2 detector.

3. DRIFT CHAMBER

The drift chamber of the CMD-2 detector has a jet-like structure [4]. At energies above 1 GeV the event multiplicity increases substantially. Events with at least 4 tracks have the largest cross sections. To study those events, a drift chamber with a uniform, relatively small cell, is well suitable. The cell has a hexagonal shape with a diagonal distance of 17 mm. Also this structure allows for high reconstruction efficiency for particles, decaying inside the sensitive volume, that is important for K_S-meson reconstruction.

Table I Main parameters of CMD-2 and CMD-2M detectors.

System	CMD-2	CMD-2M
Drift chamber	512 sensitive wires $\sigma_{R-\phi} = 250\ \mu$m, $\sigma_Z = 5$ mm, σ_θ=15·10^{-3}, $\sigma_\phi = 7 \cdot 10^{-3}$, $\sigma_{dE/dx}$=0.2·E	1218 sensitive wires $\sigma_{R-\phi} = 140\ \mu$m, $\sigma_Z = 2$ mm, σ_θ=7·10^{-3}, $\sigma_\phi = 4 \cdot 10^{-3}$, $\sigma_{dE/dx}$=0.15·E
Z-chamber	Double layers proportional chamber with cathode strips anode wires are combined to 2×32 sectors, number of cathode strips - 512 $\sigma_Z = 250 \div 1000\ \mu$m , σ_t=5 ns	
Barrel Calorimeter	892 CsI crystals in 8 octants readout PMT thickness 8.1 X_0 $\sigma_E/E = 8\%$, $\sigma_{\theta,\phi} = 0.03\div0.02$ rad at $E_\gamma = 100\div700$ MeV	1152 CsI crystals in 8 octants readout Si photodiodes 400 l LXe thickness 5(LXE)+8.1(CsI)=13.1 X_0 $\sigma_E/E = 4.7 \div 3\%$, $\sigma_{\theta,\phi}$=0.005 rad at $E_\gamma = 100\div900$ MeV
Endcap Calorimeter	680 BGO crystals in 2 endcaps readout vacuum phototriodes thickness 13.4 X_0 $\sigma_E/E = 8 \div 4\%$, $\sigma_{\theta,\phi} = 0.03\div0.02$ rad at $E_\gamma = 100\div700$ MeV	680 BGO crystals in 2 endcaps readout Si photodiodes thickness 13.4 X_0 $\sigma_E/E = 8 \div 3.5\%$, $\sigma_{\theta,\phi} = 0.03\div0.02$ rad at $E_\gamma = 100\div900$ MeV
Range system	Streamer tubes, 2 double layers, σ_Z=5 cm	Plastic scintillator counters, σ_t <1 ns
Superconductive solenoid	Magnetic field 1 T, thickness 0.38 X_0	Magnetic field 1.5 T, thickness 0.18 X_0

The number of cells for chosen geometry is 1218. The sensitive wires of 15 μm diameter are made with gold-plated W-Re alloy. The field wires of 80 μm diameter are made with gold-plated titanium. The ratio between numbers of sensitive and field wires is 1:2.

The gas mixture is Ar:iC_4H_{10} (80:20), and the gas gain coefficient is about 10^5 at 2 kV applied voltage. The electric field strength on the surface of the field wires is less than 20 kV/cm which is safe from the point of view of aging. Maximum drift time is 600 ns.

The frame of the chamber is made from carbon fibers. To minimize the amount of passive matter in front of the endcap calorimeter the flanges are spherical in shape with a radius of curvature of 1515 cm (Figure 3). The flanges thickness is 7 mm, and the outer wall thickness 2 mm. The inner wall is made from 0.2 mm kapton. The chamber thickness for 90 degrees tracks is 0.01 X_0. The thickness of passive matter in front of the endcap calorimeter is 0.04 X_0.

The average spatial resolution in the cell is about 140 μm taking into account the cluster effect and diffusion. According to this spatial resolution and multiple scattering the momentum resolution is shown on Figure 4.

The Z-coordinate of a track is determined with resolution of about 2 mm by measurements of charges from both ends of wires. Also the measurement of charges is used for dE/dx measurement. Based on CMD-2 drift chamber experience, estimated resolution will be 15%. It allows the separation of kaons from pions in a momentum range up to 450 MeV/c. The preamplifiers, designed for the KEDR detector, are used for amplification of the signals. The digitizing electronics are replaced by modern ones.

4. Z-CHAMBER

The Z-chamber of the CMD-2 detector is used in the CMD-2M detector. The Z-chamber is a double-layer proportional chamber with cathode strips [5]. The signals from the anode wires are used for triggering. Signals from cathode strips are used for measurements of the Z-coordinate of the tracks.

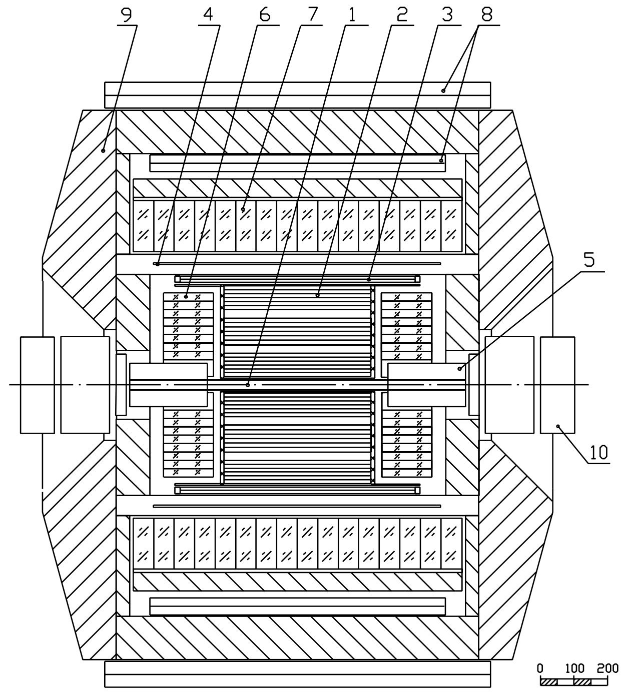

Figure 1: Layout of the CMD-2 detector. 1 – vacuum chamber, 2 – drift chamber, 3 – Z-chamber, 4 – main solenoid, 5 – compensating solenoid, 6 – endcap calorimeter, 7 – barrel calorimeter, 8 – range system, 9 – flux return yoke, 10 – storage ring lens

The anode wires with a diameter of 28 μm are made with gold-plated W-Re alloy. The step between wires is about 2.8 mm, and the total number of wires is 1408. To minimize the number of readout channels, the anode wires in both layers are combined in 32 sectors. The sectors in the outer layer are rotated relatively to the sectors in the inner layer by half of the angular size of the sectors.

Use of the fast gas mixture CF_4:iC_4H_{10} (80:20) allows to achieve time resolution of better than 5 ns. Time between collisions in VEPP-2000 collider is 80 ns. Therefore the Z-chamber time resolution is enough for unambiguous synchronization of events and beams collisions.

There are 256 cathode strips in each layer. The Z-coordinate is measured by the centre of gravity of the induced charge method. High resolution (0.25 mm for a 90 degree track and 1 mm for a 45 degree track) allow to perform absolute calibration of the Z-coordinate measurements in the drift chamber and calorimeter.

The upgrade of electronics is the only change. The anode wires readout is the same with drift chamber. The analog electronics used to readout the cathode strips are of the same design as of those used for the liquid Xe calorimeter, while the present ADC cards remain.

5. ENDCAP CALORIMETER

The endcap calorimeter covers forward-backward angles from 16^o to 49^o and from 131^o to 164^o. Its total solid angle is $0.3\times4\pi$. For the energy of incident photons from 100 to 700 MeV the energy resolution is 8–4% and the angular resolution 0.03-0.02 radians.

The endcap calorimeter of the CMD-2 detector consists of 680 rectangular BGO crystals with the size of $25 \times 25 \times 150$ mm^3, arranged in two endcaps [6]. The thickness of the crystals is 13.4 X_0 for normal incidence. The transverse dimensions of the crystals were chosen as a compromise between the spatial resolution and the number of electronic channels. All faces of the crystals are polished and light is collected by total internal reflection. The total weight of crystals is about 450 kg.

The light readout is performed by vacuum phototriodes. Signals from the phototriodes are amplified by low noise charge sensitive preamplifiers [7]. The preamplifiers are placed directly on the phototriodes inside the detector for best noise performance. After further amplification and filtration by shaping amplifiers the signals come to an ADC.

The same BGO crystals are used in the CMD-2M detector but the photosensitive devices have to be changed. The focusing solenoids of the VEPP-2000 collider cause nonuniform magnetic field in the endcap calorimeter volume and limit the available space from 204 mm to 179 mm. As a result vacuum phototriodes cannot be used. The HAMAMATSU silicon PIN photodiodes with sensitive area 1×1 cm^2 looks like the best choice. They are compact and insensitive to the magnetic field. Additional features of silicon photodiodes are high quantum efficiency, stability and reliability.

Silicon photodiodes have an order of magnitude larger capacitance compared to vacuum phototriodes. So new charge sensitive preamplifiers have to be designed for better signal-to-noise ratio. The rest of the electronics does not change.

Measurements with a prototype show a light yield of 600 e/MeV and electronic noise of 500 e. It gives an effective noise 0.8 MeV which is about the same with the CMD-2 data of 0.9 MeV. Therefore the expected resolution of the CMD-2M endcap calorimeter is close to that obtained with the CMD-2 detector.

6. BARREL CALORIMETER

The barrel calorimeter covers polar angles from 38^o to 142^o. Its total solid angle is $0.79\times4\pi$. It consists of 2 parts: liquid Xe calorimeter and CsI crystal calorimeter. The thickness of liquid Xe calorimeter is $5X_0$. The total volume of liquid Xe is about 420 l (weight is about 1.2 t). It is a new system in the CMD-2M detector. The CMD-2 detector barrel calorimeter crystals with a thickness 8.1 X_0 are used in the crystal part. The number of crystals increases from 892 to 1152 because of the extension of the internal radius by 15 cm.

Due to the increase of the calorimeter thickness the energy resolution will be substantially improved (Figure 5). The

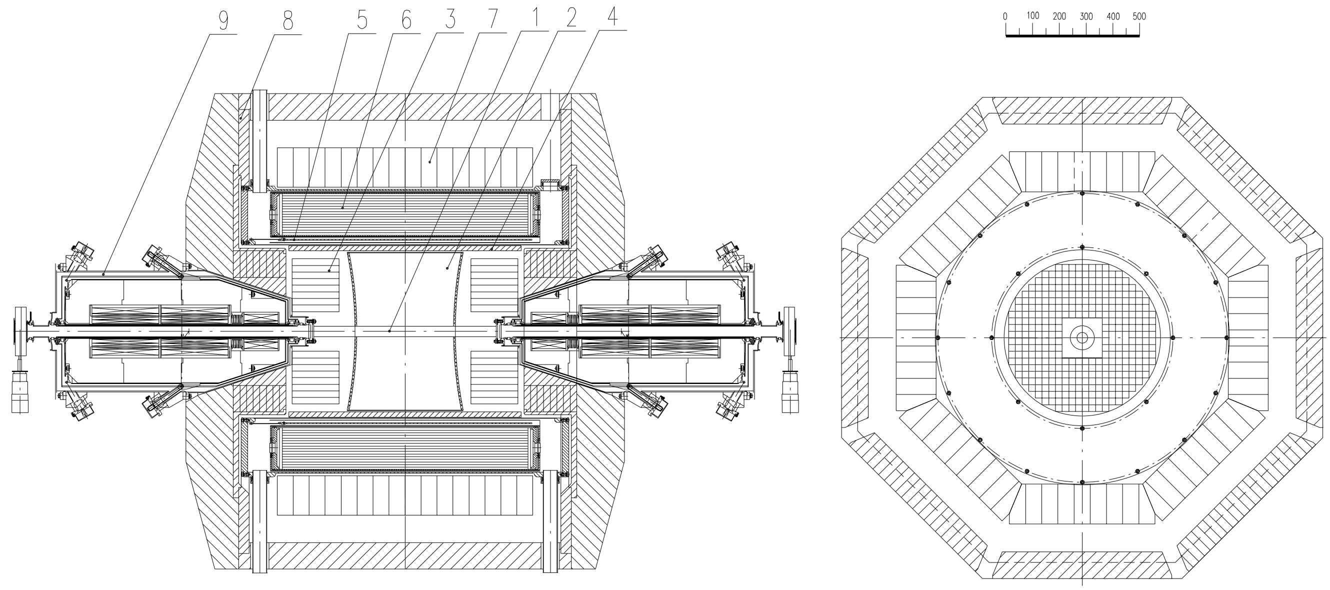

Figure 2: Layout of the CMD-2M detector. 1 – vacuum chamber, 2 – drift chamber, 3 – BGO endcap calorimeter, 4 – Z-chamber, 5 – main solenoid, 6 – liquid Xe barrel calorimeter, 7 – CsI barrel calorimeter, 8 – flux return yoke, 9 – collider focusing solenoids.

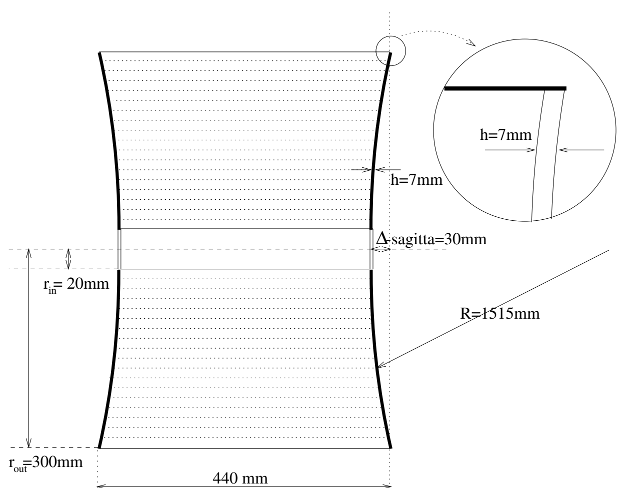

Figure 3: Layout of the drift chamber.

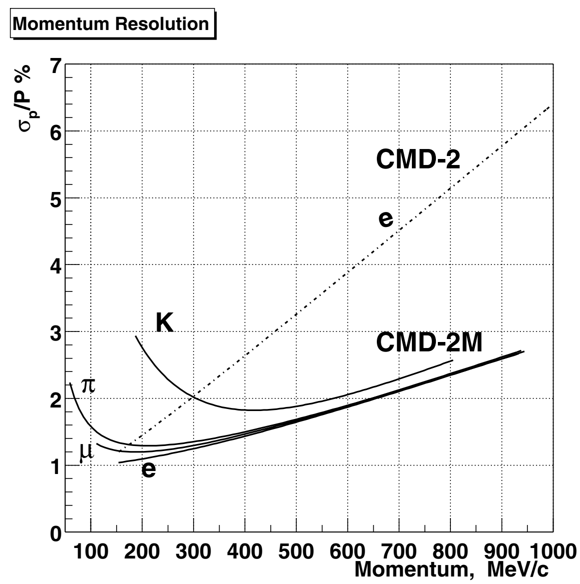

Figure 4: Momentum resolution of the drift chamber.

measurement of the coordinates of the conversion points will achieve an angular resolution of about 0.005 radians.

6.1. Liquid Xe (LXe) Calorimeter

The LXe calorimeter project is based on successful R&D in BINP during the last years [8]. It consists of a set of ionization chambers with readout from both electrodes (see Figure 6). The cathode electrodes are divided on strips for measurement of conversion point coordinates. The anode electrodes have rectangular pads for measurements of an energy deposition. There are 7 cathode and 8 anode cylindrical electrodes. The longitudinal segmentation uses dE/dx measurements for K_L/γ, $\pi^{\pm}/K^{\pm}$ and π/e separation. The electrodes are made with copper foil G10 plates with a thickness of 0.5 mm (anode) and 0.8 mm (cathode). A gap size is 10.2 mm. Drift time is 4.5 μs.

The conversion point coordinates are measured by the centre of gravity of induced charge method. Both surfaces of cathode electrodes are divided on 2 mm width strips spaced by 2 mm.

The angle between strips on different surfaces of one electrode is 90^o. This structure is semitransparent: the induced charges on both surfaces of the electrodes is almost the same. It measures both coordinates of a conversion point in one gap. This feature is important to measure the angles of soft photons with short range e^+e^- conversion pairs. To minimize the number of readout channels, the strips are grouped in 4. The total number of cathode channels is 2124.

The anode pads form towers with projections to the interaction point. The LXe calorimeter is divided onto 8 rings along the Z-axis and onto 33 sectors in the R-φ-plane. So it consists of 264 towers with an angular size of about $11^o \times 11^o$.

The capacitance of the cathodes strips and anode tower are close to 500 pF. They are readout independently by similar chains. Analog electronics consist of specially designed charge sensitive preamplifiers and shaping amplifiers and are located inside the detector. The shaping time of the cathode channels is 4.5 μs in accordance with the drift time. The shaping time of the anode channels 0.4 μs is chosen as a compromise between the electronic noise and the geometry factor contributions to the energy resolution. The electronic noise of the cathode and anode channels is 350 e + 1.6 e/pF and 900 e + 2.1 e/pF respectively. The ADC cards are the same as for the crystal calorimeters.

6.2. CsI Calorimeter

The CsI calorimeter of the CMD-2M detector design is based on experience with the CMD-2 detector barrel calorimeter [9]. It consists of 8 identical octants. Each octant contains 9 linear modules (rows) by 16 crystals. The rows are oriented along the beam axis. Seven central rows consist of rectangular crystals with a size of 60 × 60 × 150 mm^3. Two side rows are built from special shape crystals to avoid gaps between octants.

The crystals are covered by diffuse reflector for light collection. In the CMD-2M detector the light readout from CsI

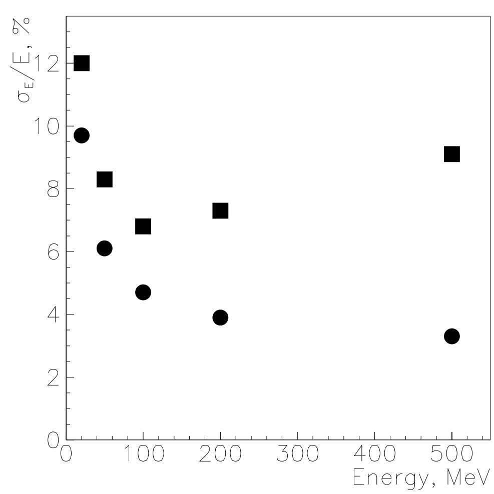

Figure 5: Energy resolution of the barrel calorimeter (MC). Boxes – CMD-2, circles – CMD-2M.

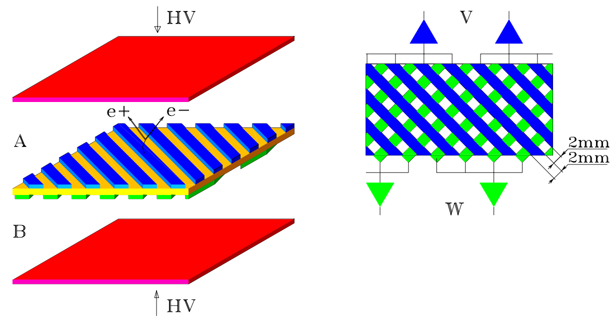

Figure 6: Design of electrodes of the LXe calorimeter.

crystals is performed by HAMAMATSU silicon PIN photodiodes with sensitive area 1 × 2 cm^2 instead of PMTs as used in the CMD-2 detector. The main reason of changing the readout is high sensitivity of the PMTs to the scattered magnetic field magnitude which is hard to keep under the control.

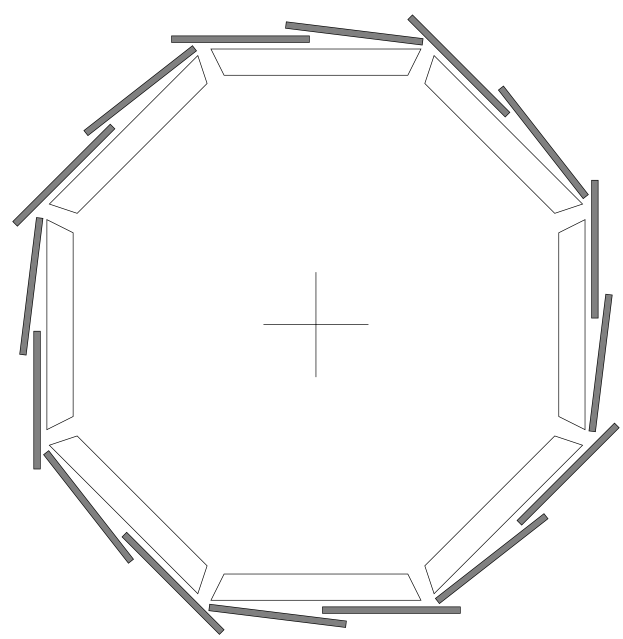

Figure 7: Layout of the range system.

Usage of photodiodes requires more sophisticated electronics compared to the PMT readout. The analog electronics consist of low noise charge sensitive preamplifiers designed for endcap calorimeter and upgraded version of designed for the KEDR detector shaping amplifiers. The ADC cards remain. Measurements with a prototype show a light yield of 2500 e/MeV and electronic noise of 800 e. It gives an effective noise of 0.3 MeV which does not affect the resolution.

7. RANGE SYSTEM

The range system of the CMD-2M detector (Figure 7) consists of 16 counters which are located outside the flux return yoke. Beam muons with energy above 550 MeV will reach it at all angles.

The counters are made from plastic scintillator sheets with a thickness og 2 cm. The width and length of the counters is 40 cm and 150 cm respectively. The scintillator are viewed from both ends by PMTs. The expected time resolution is better than 1 ns. It is enough to separate cosmic muons from beam produced ones.

8. CONCLUSION

The project of the upgraded detector CMD-2M for the new collider VEPP-2000 built at BINP is presented.

Compared to the VEPP-2M collider, the new collider VEPP-2000 will have a wider centre-of-mass energy range up to 2 GeV and higher luminosity up to 10^{32} cm^{-2}s^{-1}.

The general structure of the detector CMD-2 and its most expensive components, such as BGO and CsI crystals, as well as a substantial part of electronics and software will remain as they are. At the same time, all systems of the detector will either be upgraded or replaced by new ones. After upgrade, major parameters of the detector, such as momentum and angular resolutions for charged particles and energy and spatial resolutions for photons, will be improved substantially. Improvement of the detector parameters and upgrade of the accelerator-collider complex will carry research to a new level of precision.

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A. CMD-2M COLLABORATION

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