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A cylindrical GEM detector with analog readout for the BESIII experiment

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We are developing a low mass, cylindrical GEM detector with analog readout for the inner tracker upgrade of the BESIII experiment at the BEPC-II e^+e^- collider. The GEM detector will replace the current inner drift chamber that is suffering early aging due to the increase of the machine luminosity. The new inner tracker is expected to match the momentum resolution (σ_{p_t}/p_t 0.55% at 1 GeV) and radial resolution ($\sigma_{xy} \sim 100\,\mu$m) of the drift chamber and to improve significantly the spatial resolution along the beam direction ($\sigma_z \sim 150\,\mu$m) with very small material budget (about 1 X_0). The inner tracker will be composed by three layers of triple cylindrical GEM with an angular coverage of 93% of the solid angle. Each layer is composed by five cylindrical structures: the cathode, three GEMs and the anode readout. To minimize the amount of material, no support frames are used inside the active area and the GEM foils are mechanically stretched being glued to fiberglass rings at their ends. The anode configuration is studied by means of Maxwell and Garfield simulations and with a small-scale planar prototype that is tested with cosmic rays. Preliminary R&D and simulation studies is presented together with the mechanical design of the detector. Due to the 1 T magnetic field of the experiment an analog readout is mandatory to achieve the desired spatial resolution; the charge will be measured with "time-over-threshold" technique. Our plan to develop a new ASIC chip based on UMC-110 nm technology with limited power consumption is presented also.

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1. The BESIII CGEM-IT project

The Inner Tracker (IT) is a key detector in particle physics spectroscopy: excellent spatial and momentum resolution, radiation hardness and high occupancy capability are the main requirements. The existing IT detector of the Beijing Spectrometer BESIII [1], the Multilayer Drift Chamber (MDC), is showing aging effects due to the high luminosity reached by the Beijing Electron Positron Collider II (BEPCII). We propose to design and construct a new IT, which will be installed in the available space left after the removal of the inner MDC. Such a new IT should be characterized by a significant radiation hardness, high rate capability of about 10^4 Hz/cm^2, an efficiency of 98% with a coverage close to 4π, excellent resolution both in the longitudinal ($\sigma_z \leq 2$ cm) and transverse ($\sigma_{XY} \leq 120$ μm) directions, a good time resolution, and a limited total radiation length.

The proposed solution consists in a cylindrical triple-GEM detector (CGEM) composed by five concentric electrodes: the cathode, three GEM foils, and the readout anode. The spacing between the cathode and the first GEM foil (conversion gap) is 3 mm, while all the other gaps are 2 mm. Each GEM foil is made of 50 μm thick Kapton foil, copper clad on each side, with a high surface density of holes [2]. The holes have a bi-conical structure with external (internal) diameter of 70 μm (50 μm). A voltage of 300 V to 500 V is applied between the two copper sides in order to produce a strong field in the holes, of the order of 100 kV/cm, which multiplies the number of electrons produced by a charged particle crossing the detector. The triple-GEM configuration allows to reach high gains minimizing the discharge probability [3].

In order to obtain cylindrical GEM electrodes, a special assembling technique has been developed by KLOE-2 [4]. If needed, two GEM foils are glued together on a plane to obtain a single larger foil. The foil is then rolled on an aluminum mold coated with a very precisely machined 400 μm thick Teflon film, which provides a non-sticky, low friction surface. Two Permeglass annular rings are glued on the edges of the electrode, acting as spacer for the gaps and providing the mechanical frames needed to support detector. Finally, the mold is inserted on a vacuum bag. After the end of cycle, the cylindrical electrode can be easily extracted from the mold thanks to the Teflon surface. Cathode and anode are obtained with a similar procedure, and the assembly of the five electrodes proceeds from the outermost electrode (the anode) to the innermost one (the cathode).

Due to the limited space available in the inner part of the BESIII spectrometer, the mechanical design of the detector must be very compact and optimized. We need to take into account several constraints: the mechanics of the interaction region, the fact that the front-end boards need to be placed “on” the detector in order to minimize the noise and to avoid signal degradation, and the placement of the high voltage distribution cards at the edges of the detector.

2. BESIII CGEM innovations

The experience acquired during the development of the KLOE-2 CGEM detector [4, 5] allows us to replicate what has worked best in the KLOE-2 experience and to further proceed by introducing new innovative concept in the design and construction of the BESIII CGEM-IT detector.

A new Rhoacell based technique, instead of standard Honeycomb, will be adopted to manufacture the anode and the cathode electrodes in order to minimize the material budget. The main

Rohacell characteristics are the excellent mechanical properties in a wide temperature range, even at low densities, unique compressive creep behavior, excellent dynamic strength and cell size that can be tailored for each processing method. The Rohacell can be machined very precisely. This technique has been successfully tested in laboratory of the University of Ferrara with a cathode prototype production.

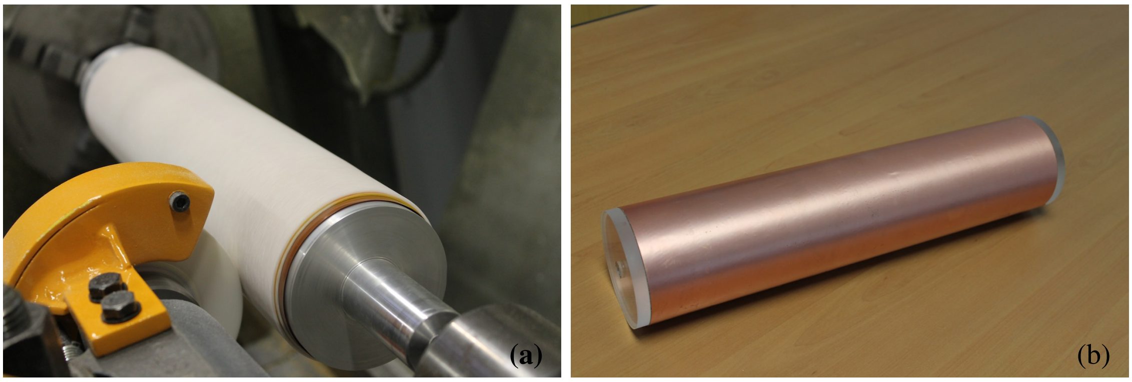

Figure 1: (a) Machining of the Rohacell during the fake cathode construction. (b) Picture of the fake cathode with the radius of the innermost layer of the CGEM-IT.

Based on simulation studies, we identified a new anode design in order to reduce parasitic capacitance. The readout anode circuit is manufactured starting from the 5 μm copper clad and 50 μm thick polyimide substrate (Kapton). Two such foils with copper segmented strips is used to have two dimensional readout: X-strips, 570 μm wide, parallel to CGEM axis, and provvide $r\phi$ coordinates, and V-strips, wide 130 μm and with a stereo angle in respect to the X-strip, give the z coordinate. The strip pitch is 650 μm for both X- and V-strips, and the space between the readout and the ground plane will be filled by a Rohacell structure. A “jagged” configuration (see Fig. 2) has been studied to minimize the inter-strip capacitance. By using of the Ansys Maxwell-3D [6] simulation we estimated a reduction of the inter-strip capacitance of about 30% with respect to the standard linear strip configuration. Additional studies of the anode design will be performed by Garfield simulation software and tested also on a small prototype.

To achieve the required spatial resolutions $\sigma_{xy} \leq 100\ \mu$m an analog readout is necessary. The digital method identified clusters more easier by detecting adjacent strips with a collected charge above a fixed threshold. The reconstructed position of the track is the geometrical center of the cluster and the resolution is equal to $cluster_{size}/\sqrt{12} \sim 300\ \mu$m, with a gas mixture of $ArCO_2$ (70/30). The analog readout method, instead, allows to set both a threshold on the single strip and a threshold on the total charge, and improve the ghost hit rejection. Moreover, the strip collected charge encoding allows the reconstruction of the charge centroid, which raises the resolution above the $cluster_{size}/\sqrt{12}$ ratio of the binary readout method. The analog readout circuit allows also to use a larger strips pitch, which leads to a more manageable number of channels and a lower number of cables.

3. Plans and conclusions

The mechanical design of the first layer of the CGEM detector has been already completed

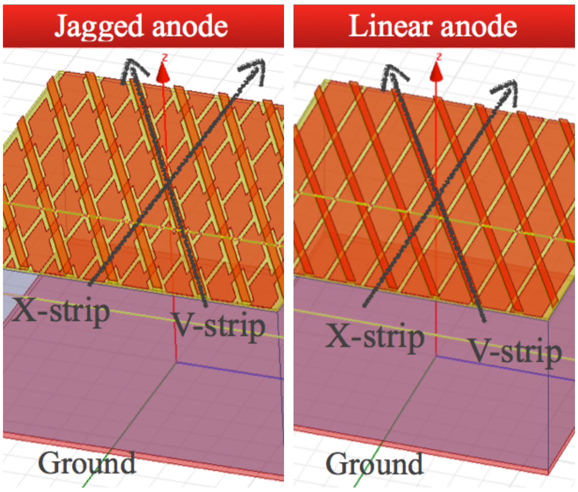

Figure 2: Left: the “jagged” configuration where the overlap region between the strips is reduced by decreasing the size of the X-strips on the intersections in order to minimize the inter-strip capacitance. Right: standard linear strip configuration.

and the corresponding material already procured in the frame of the INFN-MAE-MOST Project. A Geant4 simulation package [7] for CGEM is under development in the BESIII software system. The CGEM planar prototype has been assembled at the Laboratori Nazionali di Frascati (LNF) and will be used to test the new anode design and to optimize the gas mixtures. In order to achieve the spatial resolution of about 100 μm, an analogue readout ASIC has to be designed to measure the charge centroid by the using of the technology. In particular, the UMC 0.11 μm technology is under investigation by INFN-Turin and will be used as baseline. We plan to provide the new CGEM-IT at the end of 2017 and to perform the first BESIII data taking as well as the CGEM-IT tests in 2018.

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