The CGEM-IT of the BESIII experiment: project update and test results in magnetic field

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Abstract. The BESIII experiment is a multi-purpose detector operating on the electron-positron collider BEPCII in Beijing. Since 2008, the world's largest sample of J/ψ, ψ' were collected. Due to increasing luminosity, the inner drift chamber is showing signs of aging. In 2014, an upgrade was proposed by the Italian collaboration based on the Cylindrical Gas Electron Multipliers (CGEM) technology, developed within the KLOE-II experiment, but with several new features and innovations. In this contribution, an overview of the project will be presented. Preliminary results of a beam test will be shown, with particular focus on the detector performance in magnetic field, with different configurations of electric field. A new readout mode, the μTPC readout, will also be described. The project has been recognized as a Significant Research Project within the Executive Programme for Scientific and Technological Cooperation between Italy and P.R.C for the years 2013-2015, and more recently has been selected as one of the project funded by the European Commission within the call H2020-MSCA-RISE-2014.

1. Introduction

Since the start of its operations in 2008, the Beijing Electron Spectrometer III (BESIII) has collected the largest sample of data in the energy region between 2 and 4.6 GeV, thanks of the high luminosity of the Beijing Electron-Positron Collider (BEPC − II). The complete physics program of BESIII [1] covers charmonium physics, open charm decay studies, search of exotic XYZ states and light hadron spectroscopy. Starting from the beryllium beam pipe to the outside, a Multi-layer Drift Chamber (MDC) is operating as tracking system, Time-Of-Flight (TOF) detectors are used to extract time information of the passage of particle, that combined with the energy information collected in the CsI(Tl) eletromagnetic calorimeter (ECAL), allows the particle identification (PID). A solenoidal superconducting magnet provides a uniform 1 Tesla magnetic field, while in its return yoke, Resistive Plate Chambers (RPC) operate as muon detectors.[2]

The innermost layers of the MDC exhibit aging effects. To compensate the increment of spark rate caused by these effects, the first layers must operate at lower relative gains. Since this deterioration seems to be constant in time, and is measured to be net 4% per year, the replacement is mandatory by 2018. In 2014, Italian collaborators proposed a possible upgrade based on Cylindrical Gas Electron Multipliers (CGEM), a Micro Pattern Gas Detector (MPGD) technology already developed within the KLOE-II collaboration [3], but with several innovation

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and new features with respect to the former case. The Conceptual Design Report [4] was approved by the BESIII board.

Several requirements, based on both spatial and momentum resolution of the new chamber (therein called CGEM-IT), were proposed by the BESIII Executive and Technical Board and are listed in Table 1 for further reference.

Requirements
Inner radius = 78 mm (min)
Outer radius = 179 mm (max)
93% of 4π solid angle
$\sigma_{xy} \sim 130\,\mu$m (per layer)
$\sigma_z < 1$ mm (per layer)
$X_0 < 1.5\%$
Trigger rate $\sim 10^4$Hz/cm^2

Table 1. List of all the requirements provided by the BESIII collaboration for the new inner tracker

In the following sections, a brief report on the CGEM-IT project will be described. Also, data from a recent beam test will be discussed in order to understand if we are able to push the technology to match the requirements.

2. The CGEM-IT project

Based on the experience gained in building the KLOE-II CGEM, we started developing a three layer triple-GEM detector with analog readout. This is the most crucial difference between the KLOE-II case and the BESIII CGEM-IT. This type of readout is the best compromise between the spatial resolution and the number of instrumentable channels. The charge centroid method allows to improve the spatial resolution over the one achievable with digital information, which has a limit of $pitch/\sqrt{12}$. With our project we will match the momentum resolution requirements, while we will improve by at least by a factor 2 the resolution along the beam axis. With this improved resolution, the performance of BESIII in recostructing primary and secondary vertices will largely improve, leading to better background rejection. Moreover, decays with a more complex topology will be finally accessible, boosting the open charm decay and exotic states physics program that BESIII will run likely until 2022.

From the technological point of view, we will deploy two innovations with respect to the state-of-art in GEM detectors. Given the strict requirement on the material budget, we will use a PMI-based foam called Rohacell [5] to give mechanical rigidity to the anode and the cathode. The jagged anode (in Figure 2) will allow us to reduce up to 30% the interstrip capacitance. This is essential because our strip pitch is quite large ($pitch = 650\,\mu m$) and long ($length = 82\,cm$): these leads to parasitic capacitance effect by design. If it is not kept under control, the noise will raise until the signal will be undetectable.

The first cylindrical prototype was assembled in INFN Laboratori Nazionali of Frascati at the end of February and the beginnning of March 2016. Currently, the gas is fluxing inside the detector that will be ready to be tested before of the end of the year with a custom readout electronics.

3. Beam test results in magnetic field

To prove the features of the final detector design, in-beam test of two prototypes was performed in June 2015 at H4 line in Prevessin, North Area, CERN. The only differences between the two

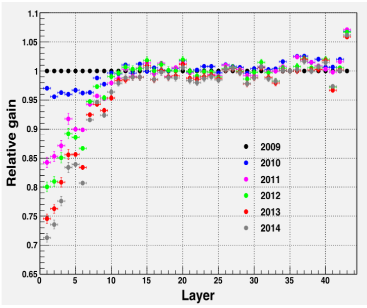

Figure 1. Relative gain as a function of the layer ID. The different colored lines show different years. To compensate the aging effect, first layers operate with reduced relative gain year by year.

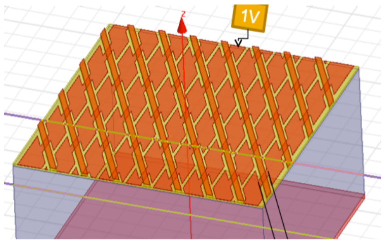

Figure 2. Pictorical example of a jagged anode that it is intended to be deployed in CGEM-IT project.

chambers were the anode and the drift gaps. In the so called prototype 1, the anode was linear and the gap was 5 mm, while in the prototype 2 we installed a jagged anode with a 3 mm gap. A dipole magnet GOLIATH can provide magnetic field up to 1.5 T with both field polarisations. During three weeks of data taking within RD51 Collaboration [6] several configurations were tested. In the following, two of the most interesting results in magnetic field will be discussed. All the results discussed are obtained by means of the charge centroid method.

The confidential resolution is extracted as the width of the residual distribution. In Figure 3 the confidential resolution as a function of the magnetic field strength and polarisation is presented. As expected, the extracted width increases with the field strength. This effect is mainly caused by the presence of the distorsion of the diffusion electron cloud by the Lorentz angle, that is due to the presence of a magnetic field. This Lorentz angle represents the difference of the mean position of the cloud direction with and without magnetic field, as shown in Figure 4 in a Garfield [7] simulation. This distortion enlarges the average cluster and reduces the mean charge per strip. The charge centroid method is not anymore optimal. A possible solution to improve the resolution will be discussed in the next section.

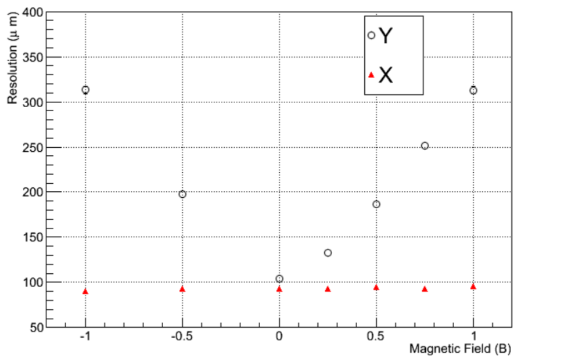

Figure 3. Residual distribution of the bending (white circle, Y) and non-bending (red triangle, X) view of one prototype with respect of the magnetic field in $ArCO_2$ (70/30) gas mixture. (color online)

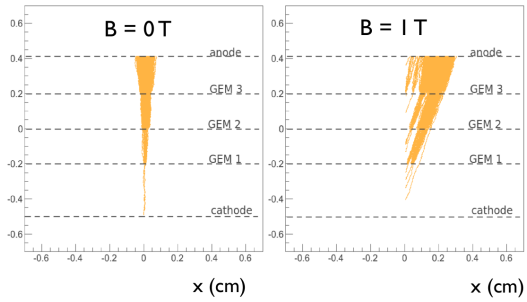

Figure 4. Garfield simulation of the effect of the magnetic field on to the diffusion cloud. The angle between the mean position without (left) and with (right) magnetic field is called Lorentz angle.

With the optimization of gas mixture and drift field it is possible to achieve a resolution below $\sigma = 200\,\mu m$, as shown in Figure 5. In Ar/Iso (90/10), the Lorentz angle decreases as the drift field become stronger. The distorsion due to the magnetic field are thereby reduced, and so the resolution improves. Despite being one of the best results obtained by triple-GEM detectors in magnetic field, it is still not enough to match the requirements. To overcome this limit, a new readout mode, the μTPC, has been proposed.

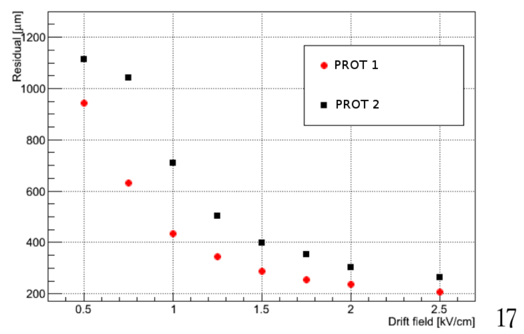

Figure 5. Residual distribution of the bending view with respect to the drift field in argon/isobutane (90/10) gas mixture. The only differences between the two prototypes are the different anodes and the gaps.

4. A new readout mode for GEM detector: the μTPC mode

In the case of a very broad distribution, *i.e.* with a very large incident angle or with magnetic field, the charge centroid method does not provide sufficient position resolution. The ATLAS collaboration has recently developed for their Small Wheel upgrade [8] a new type of readout mode, based on the time information that in this case is more precise than the charge one. Since the approach is similar to what is done in the large Time Projection Chambers (TPCs), the readout mode is called μTPC, as the drift gap is only few millimeters wide.

Based on ATLAS approach on MicroMegas [9], a similar procedure is developed for GEM detectors. The idea is to extract the differential time of arrival of the maximum value of the inducted charge in each strip. In this way it is possible to extract, being the drift velocity well-known, the position of a particular primary ionization cluster inside the drift gap.

From the ATLAS results with different angles [9], as depicted in Figure 6, we are very confident that, once the algorithm will be ready, it will allow to match the requirements. Preliminary studies indicate the improvement od the resolution and first will be available soon.

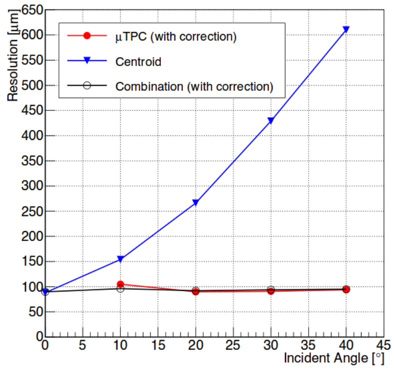

Figure 6. Comparison between the μTPC readout (red) and the charge centroid method (blue) with respect to the incident angle [9] in ATLAS MicroMegas studies. The black line represents the results obtained combining the two readouts. (color online)

5. Conclusion and outlook

To overcome the aging effect of the inner part of the BESIII MDC, we proposed an upgrade based on CGEM technology. The future chamber will deploy innovative features with respect to the present GEM detector, allowing for reach $\sigma_{xy} \sim 130\,\mu m$ position resolution in transverse plane and better than $\sigma_z < 200\,\mu m$ along the beam direction. The first cylindrical prototype has been built and it will be tested in-beam test before the end of the year.

Results in magnetic field show that is possible to optimize the combination of gas mixture and drift field to reach a position resolution around $200\,\mu m$ in magnetic field. This is one the world's best results for GEM detectors in magnetic field with charge centroid method. However, it is still not sufficient to match the required performance. This is due to the spread of the drift cloud. To pass the limits of the charge centroid method, a new readout, named μTPC, is being tested. Based on ATLAS results with MicroMegas at large angles, itr is expected to reach the required resolution in 1 T magnetic field. Preliminary studies on this new method show that it is feasible to be apply it in BESIII CGEM-IT and it will improve the spatial resolution. Soon the very first result will be available.

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