Nuclear Instruments and Methods in Physics Research A 608 (2009) 48–54

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

# Development of GEM tracking detector for intermediate-energy nuclear experiments

K. Fujita [a,*], Y. Sakemi [b], M. Dozono [a], K. Hatanaka [d], M. Nomachi [c], T. Sawada [d], T. Wakasa [a]

[a] Department of Physics, Kyushu University, Hakozaki, Fukuoka 812-8581, Japan
[b] Cyclotron and Radioisotope Center, Tohoku University, Sendai, Miyagi 980-8578, Japan
[c] Department of Physics, Osaka University, Toyonaka, Osaka 560-0043, Japan
[d] Research Center for Nuclear Physics, Osaka University, Ibaraki, Osaka 567-0047, Japan

ARTICLE INFO

*Article history:*
Received 17 June 2009
Accepted 25 June 2009
Available online 1 July 2009

*Keywords:*
Gas electron multiplier
GEM
Tracking
Coherent pion production

ABSTRACT

We have developed a tracking detector with a gas electron multiplier (GEM) for nuclear experiments. The developed GEM detector was installed inside the dipole magnet used for transporting the primary beam to the beam dump and it was used to measure the momentum of charged particles. A sufficiently high spatial resolution was achieved at a high counting rate and a magnetic field for coherent pion production with a 392 MeV proton beam to study the short-range component of the residual nuclear interaction. The detector systems and development procedure are described.



## 1. Introduction

A detector system has been developed for measuring the coherent pion production (CPP) induced by an intermediate-energy proton beam with the reaction $^{12}C(p, n\pi^{+})$ $^{12}C$ (ground state) to study the short-range component of the residual nuclear interaction. In order to identify the CPP process, detectors with high energy resolutions are required for the emitted neutrons and the generated pions. Coherent pions together with other generated charged particles are momentum analyzed by a swinger magnet, which is a dipole magnet used for transporting the primary proton beam to the beam dump. They are detected by the developed tracking detector that has newly been installed inside the swinger magnet. Since the detector is located close to the reaction point, it must be able to operate in a harsh radiation environment and a high magnetic field of about 1 T. In order to satisfy these requirements, we selected gas electron multiplier (GEM) technology.

In this study, we developed new GEM detectors for tracking the charged particles produced in a nuclear reaction, together with read-out electronics and a data acquisition system. We accessed the detector performance for CPP experiments. The experimental conditions and detector design are discussed in Section 2. The procedure for fabricating the detector and the readout electronics are described in Section 3. The performance test for the newly developed detector with a proton beam is given in Section 4. To assess the feasibility of using the detection system for CPP measurements, a test experiment was conducted and the results are presented in Section 5.

## 2. GEM detector design

The CPP experiment was performed at the neutron time of flight facility (NTOF) at the Research Center for Nuclear Physics (RCNP), Osaka University (see Fig. 1). Protons were accelerated by the AVF and a ring cyclotron up to 392 MeV and were transported to a target of a thin $^{12}C$ plate (54 mg/cm$^2$). In order to identify CPP events, an exclusive measurement was carried out by detecting neutrons and pions in coincidence. The emitted neutrons passed through a 70-m-long time-of-flight tunnel and were detected by a neutron detector and polarimeter NPOL [2,3].

We selected GEM [1] technology as being the most suitable for realizing a large-area tracking detector for a pion detector operating in a harsh radiation environment. The charged particles including pions are measured by two planes of the two-dimensional position sensitive counters, which were realized by the GEM-based detector. Since the detector is installed at a distance of only 20–30 cm from the primary proton beam and the reaction point near the target, it is exposed to a high background of scattered particles and gamma-rays. The test experiment revealed that the counting rate of background events was higher than 100 kcps for a proton beam intensity of 50 nA. The detectors need to be capable of withstanding such high counting rates without suffering any reduction in their detection efficiency.

* Corresponding author. Tel./fax: +81 92 642 2542.
*E-mail address:* kfujita@phys.kyushu-u.ac.jp (K. Fujita).

0168-9002/$ - see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.nima.2009.06.051

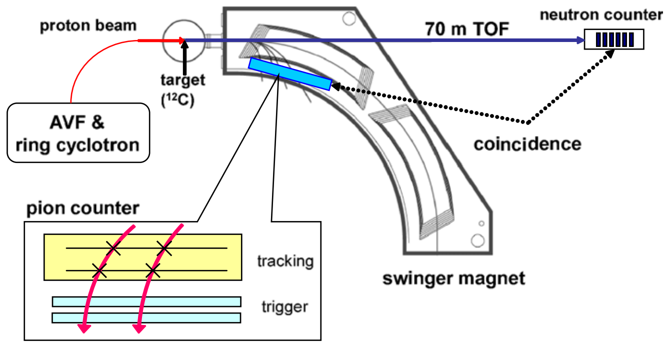


**Fig. 1.** Schematic layout for $^{12}C(p, n\pi^+)^{12}C$ experiment at RCNP.

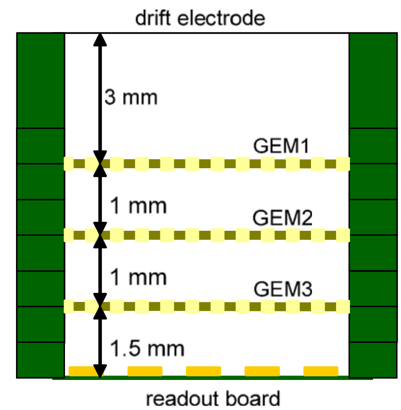


**Fig. 2.** The configuration of each component in the GEM detector.

Another requirement is that the detectors should be capable of being operated in a magnetic field of about 1 T generated by the swinger magnet.

We need to separate events of recoil $^{12}$C target kept in the ground state from the excited states ($E_x > 4.4$ MeV) to obtain an accurate signature of the CPP. Ideally, the resolution of the missing mass should be better than 3 MeV. A high energy resolution of the detector system is important for achieving a high missing mass resolution in CPP experiments. A Monte Carlo simulation was performed [4] using GEANT4 [5] with an accurate magnetic field map obtained from the simulation by OPERA3D-TOSCA [6]. The Monte Carlo study reveals that a spatial resolution of within 2 mm is required to realize a sufficiently high missing mass resolution to identify CPP.

The data acquisition (DAQ) system needs to be able to combine and reconstruct the two different kinds of data obtained from the neutron counter and the tracking detector whose DAQ system is located 70 m from the NPOL. The trigger information for the tracking counter is sent to the NPOL DAQ system where the charged particles are examined to determine whether they are coincident with a neutron or not. Although the digitized data of the neutrons and the charged particles are temporarily stored in different memory modules, the data should be recorded on the same storage disk of a computer when a coincidence event is generated. Counting rates of ~2 kHz for the NPOL, ~3 kHz for the tracking detector and ~10 Hz for the coincidence events are expected from the test experiment with an incident proton beam intensity of 8 nA.

## 3. Construction of GEM detector

The tracking detector consisted of two position-sensitive detector planes, each having the capability to determine the two-dimensional coordinates of the charged particles. The sensitive area was $307.2\,W \times 48\,H\,\mathrm{mm}^2$, which is the maximum size that can be installed in the limited space of the narrow gap in the swinger magnet. It covers the energy range of positive pions emitted at an angle of 0° from 80 to 200 MeV, which is sufficient for measuring CPP events. The three GEM foils were stacked to obtain a high gain of more than $10^4$ with stable operation. The drift electrode, three-layer GEM foils (GEM1, 2, 3) and the readout board (ROB) are fixed with a glass epoxy frame forming a detector plane (see Fig. 2). The total thickness of a detector plane was $0.182\,\mathrm{g/cm^2}$. This is sufficiently thin to ensure that multiple scattering had no influence on the position resolution within the required resolution. Two identical detector planes, which were separated by 67.8 mm, were placed in a detector box (see Fig. 3) into which a flow of the counter gas was introduced. Since the detectors should be capable of operating in a high magnetic field,

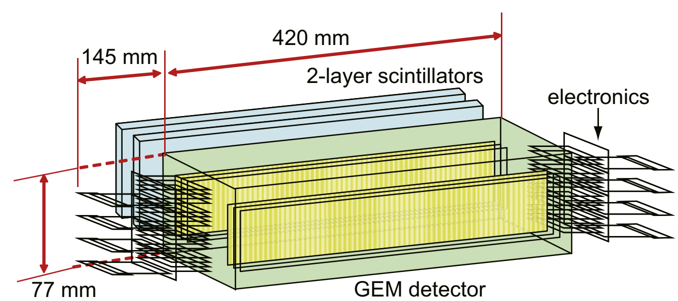


**Fig. 3.** The structure of the GEM detector including the backup scintillators.

**Table 1**
Specifications of the GEM detector in the tracking counter.

| | |
|---|---|
| Active area | $307.2\,W \times 48\,H\,\mathrm{mm}^2$ |
| Number of strips | $768(x) \times 120(y)$ |
| Strip pitch | 400 μm |
| Drift electrode–ROB gap | 6.5 mm |
| Cathode voltage | −2670 V |
| Gas mixture | argon/$CO_2$ (7:3) |
| Gas pressure | 1 atm |
| Drift electrode material | 6 μm carbon–aramid film |
| GEM foil | 50 μm Kapton film, $2 \times 5\,\mu\mathrm{m}^2$ copper |
| ROB | 100 μm fiberglass (G10), 25 μm Kapton, $2 \times 4\,\mu\mathrm{m}^2$ copper strips |
| Entrance and exit windows | 4 μm aramid film |
| Distance between two ROBs | 67.8 mm |
| Dimensions of detector box | $420\,W \times 77\,H \times 105\,t\,\mathrm{mm}^3$ |

all of the components were made of non-magnetic materials. The specifications of the GEM detector are summarized in Table 1.

### 3.1. GEM foil

The GEM foil was a 50 μm thick polyimide (Kapton) foil coated with 5 μm thick copper layers on both sides. It has been reported that the larger the hole size is, the higher the gas gain becomes and that the smaller pitch of the holes is, the better the position resolution becomes [7]. By considering these results together with the practical limitations of wet etching, we used holes that were 70 μm in diameter arranged at intervals of 140 μm (see the microscope image in Fig. 4). This is the so-called standard geometry of the GEM electrode developed at CERN. The GEM