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Development of a Micro Pixel Chamber for the ATLAS upgrade

Atsuhiko Ochi [1], Yasuhiro Homma, Hidetoshi Komai, Yuki Edo, and Takahiro Yamaguchi

Kobe University,
Kobe, 657-8501, Japan

Abstract

The Micro Pixel Chamber (μ-PIC) is being developed as a candidate for the muon system of the ATLAS detector for upgrading in LHC experiments. The μ-PIC is a micro-pattern gaseous detector that doesn't have floating structure such as wires, mesh, or foil. This detector can be made by printed-circuit-board (PCB) technology, which is commercially available and suited for mass production. Operation tests have been performed under high flux neutrons under similar conditions to the ATLAS cavern. Spark rates are measured using several gas mixtures under 7 MeV neutron irradiation, and good properties were observed using neon, ethane, and CF_4 mixture of gases. Using resistive materials as electrodes, we are also developing a new μ-PIC, which is not expected to damage the electrodes in the case of discharge sparks.

Keywords: MPGD, μ-PIC, HL-LHC, ATLAS, neutron, gaseous detector

1. Introduction

We proposed and developed the Micro Pixel Chamber (μ-PIC) for a muon trigger detector to upgrade ATLAS. From the year 2022, LHC operation in high luminosity (HL-LHC) is scheduled and planned up to 5×10^{34}p/cm^2/s. The current ATLAS detectors in LHC experiments are designed for 10^{34}p/cm^2/s, so replacing them is critical. One serious impact will appear in the first stage trigger (LVL1 trigger) that uses muon tracking. The current LVL1 trigger rate is designed for a maximum of 100 kHz. [1] However, the trigger rate is predicted to surpass that rate at HL-LHC in the current muon system. In addition, the cavern background (caused by hadronic reactions) will be increased to 5 kHz/cm^2 at the endcap inner muon detectors, which are set about 5 m from the interaction point. To reduce the LVL1 trigger rate and to operate the detectors in a dense background condition, the following muon detector properties are required for LHC upgrading:
(a) Fine position resolutions ($\sim$100 μm) with two-dimensional readout to realize 1 mrad of tracking resolution, which is necessary for reducing the LVL1 trigger rate.
(b) No saturation in the heavy cavern background (which is around 5 kHz/cm^2).

[1]Email: ochi@kobe-u.ac.jp

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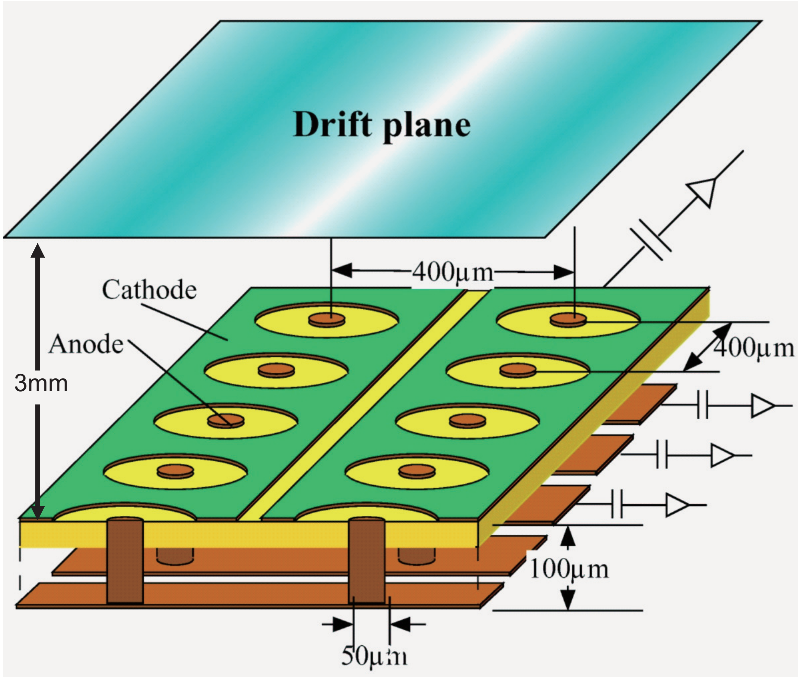

Fig. 1. Schematic view of micro pixel chamber. Primary electrons are drifted toward anode electrodes in the detection volume (between anode/cathode electrodes and drift plane). These electrons are multiplied by higher electric field between anodes and cathodes. Two-dimensional hit coordinates are obtained by reading out both the anode and cathode strips. The thickness of the detection volume was designed to be a few mm in order to allow a fast muon trigger within 25 nsec for the ATLAS upgrade.

μ-PIC is one type of micro-pattern gaseous detector (MPGD) that has both fine (<100 μm) position resolution and tolerance for the high counting rate of incident particles (> 10^7cps/mm^2) [2, 3]. Each pixel consists of a pillar of an anode and a surrounding cathode. The primary electrons in the gas volume drift toward the anode and are multiplied by the gas avalanche mechanism due to a higher electric field between the anodes and the cathodes. The μ-PIC can be operated around 10^4 gas multiplication, which enables us to detect minimum ionizing particles. However, if large energy deposits exist, such as hadronic particles, the discharge and spark probabilities are increased because of dense electrons called the ”Raether limit.” This problem is critical for using MPGD for intense hadron experiments.

The objective of these studies is to measure the performance of μ-PIC in a background of fast neutrons. Neutrons of several MeV give rise to recoiling charged particles called High Ionizing Particles (HIPs). We also measured the discharge probabilities of the detector along with the gas gain and tested the spark rate differences for several types of gas mixtures.

2. Experimental setup

The schematic structure of μ-PIC is shown in Fig. 1. The anodes are connected to the back strips, and the cathodes are printed on the surface to surround the anode pin; there is also a field plane. Two-dimensional signals can be read from the anodes and the cathodes. Anode pins and cathode lines are printed for a 400 μm pitch. The spacing between the readout board and the drift plane was set to 3 mm to optimize both a fast muon trigger and hit efficiency. Positive voltage was supplied (+400 V∼ +700 V) to the anodes via 1 MΩ resistances. Negative potential was applied to the drift plane. The potentials of the cathodes were set around 0 V. The anode current was monitored to measure sparks. The spark rates were measured by counting large pulses in the current monitor.

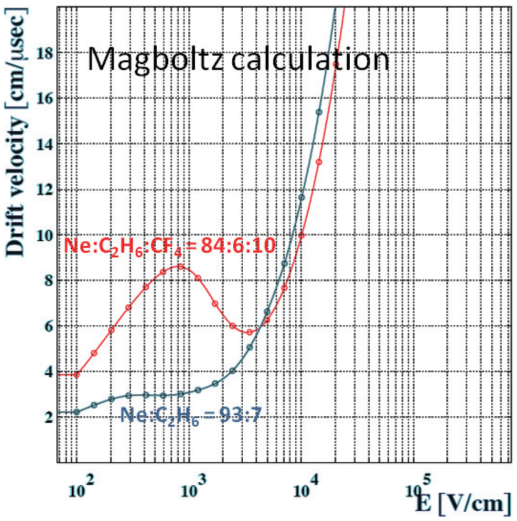

Fig. 2. Electron drift velocity versus the electric field for neon 93%+ ethane 7% gas mixture (blue line) and neon 84% + ethane 6% + CF_4 10% gas mixture (red line). These plots are calculated using Magboltz [4]. There is a local maximum in the drift velocity of approximately 9 cm/μsec near an electric field of 1kV/cm, which is very appropriate for operating the μ-PIC as a muon trigger chamber.

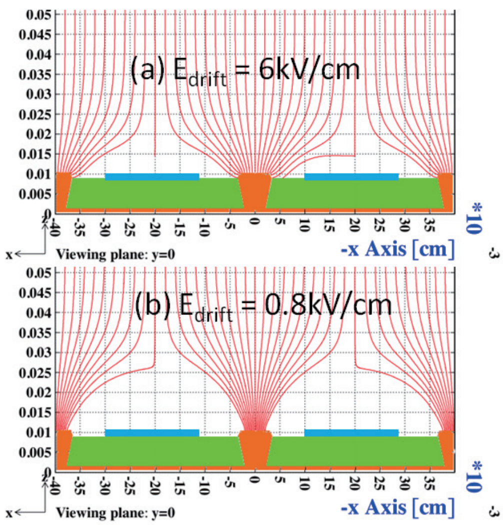

Fig. 3. Electron drift lines in the vicinity of the readout electrodes. These plots are calculated using Garfield [5] and Maxwell 3D [6]. Figure 3 (a) shows the electron drift lines for 6 kV/cm and the neon + ethan mixture, and figure 3 (b) shows the drift lines for 0.8 kV/cm and the neon + ethan + CF_4 mixture. The electron drift velocities are about the same for the two cases (a) and (b).

The operation gases tested in the detector system were mixtures of argon + ethan, neon + ethan, and neon + ethan + CF_4. Neon-based gas provides a lower spark rate for fast neutron irradiation (results are shown below). However, the electron drift velocity is slow (~ 3cm/μsec) with a neon + ethan mixture. The CF_4 gas was mixed to improve the electron drift velocity. Fig. 2 shows the simulated results of the drift velocity of neon:ethan=93:7 gas (blue line) and neon:ethan:CF_4=84:6:10 gas (red line). These simulations, which were done with Magboltz [4], suggest that more than 8 cm/μsec drift velocity can be attained with an appropriate electric field. The electron drift time of 2-mm thick detector is less than 25 nsec., which is short enough to distinguish the bunch crossing of the LHC machine. In addition, the lower electric field in the drift region (fiducial volume) was applied for the gas mixture with CF_4 to attain the fast electron drift velocity. Those conditions cause the ideal electron line to drift toward the anode pixel. Fig. 3 shows the simulated electron drift line in the μ-PIC at 6 kV/cm (a) and 0.8 kV/cm (b) electric fields in the drift volume. Condition (a) using the neon + ethane mixture corresponds to the same electron drift velocity as condition (b) using the mixture with CF_4. In these simulations, we used Garfield [5] and Maxwell 3D [6]. For the drift line in (b), almost all electrons are collected at the anodes, but for (a) about 50% are lost between the anodes and the cathodes. Addressing this problem is our highest motivation to test a CF_4 gas mixture.

A neutron source was provided by the tandem electrostatic accelerator at the Kobe University Faculty of Maritime Science (Fig. 4). The 3-MeV deuteron beam generated by this accelerator was guided to a beryllium target placed at the end of the beam line. The neutron was produced by a $^{9}Be(d,n)^{10}B$ exoergic (4 MeV) reaction. The neutron kinematic energy is 7 MeV at the beam direction. In this beam-line, about 10^8 neutrons can be produced in a second. The neutron intensity at the detector position was measured by indium activation. Fig. 5 shows the μ-PIC setup on the beam-line. The distance between the beryllium target and the μ-PIC was varied from 7 to 72 cm, depending on the required neutron flux. Neutron emission was controlled by the deuteron beam current. The current at the beryllium target was monitored by the current monitor and controlled from 10 nA to 1 μA.

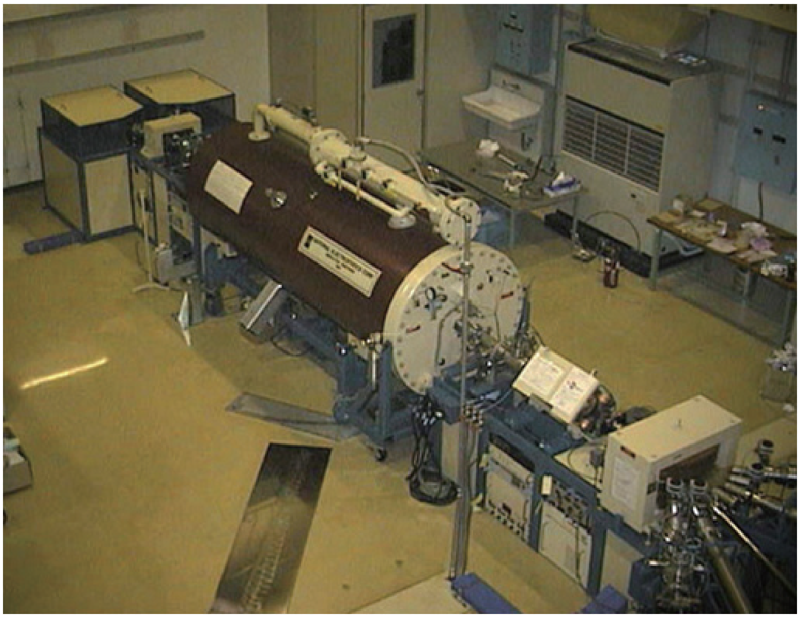

Fig. 4. Picture of a tandem electrostatic Accelerator at the Maritime Science Faculty, Kobe University. Ions are generated at the top of the system (left - up part of the picture), and accelerated in the tandem accelerator. The maximum achievable energy (for proton or deuteron) is about 3.5 MeV.

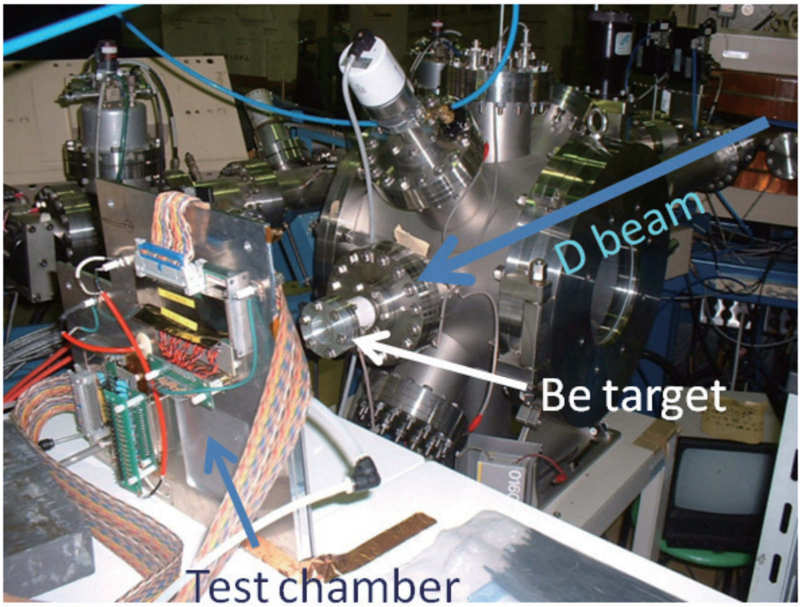

Fig. 5. Picture of experimental setup for the neutron irradiation test. The deuteron beam line is terminated by a beryllium target. Fast neutrons are generated by deuteron + beryllium reaction, and those neutrons irradiate the test chamber.

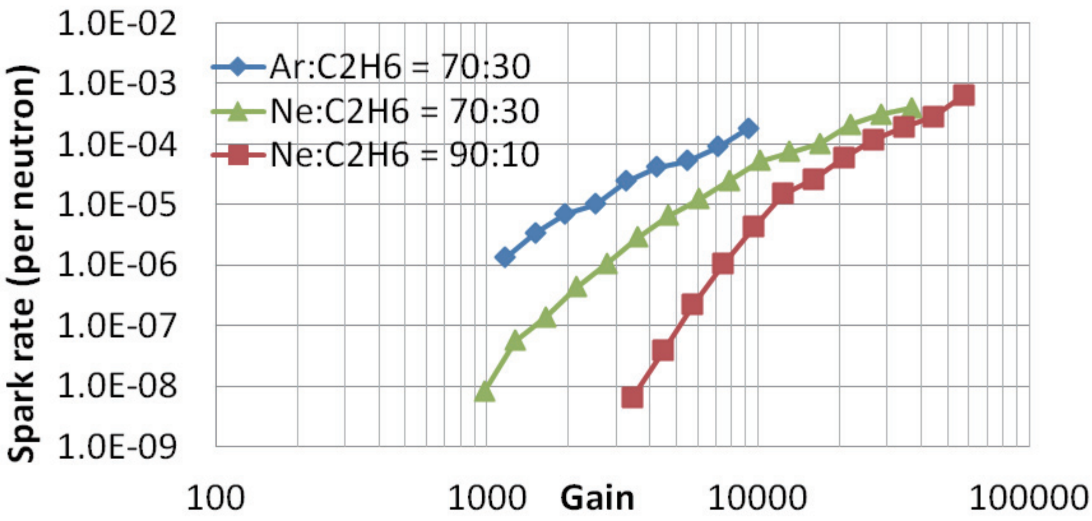

Fig. 6. Spark rate versus gas gain for the following gases: 70% argone + 30% ethane (blue), 70% neon + 30% ethane (green), and 90% neon + 10% ethane (red).

3. Measurements and results

The spark rate is defined as the ratio of huge signals to the flux of neutrons. Figure 6 shows the spark rate versus gas gain for various gases: 70% argone + 30% ethane, 70% neon + 30% ethane, and 90% neon + 10% ethane. The spark rate for the neon mixture was more that ten times smaller than that for the argon mixture (with the same % of ethane) in the gain region of a few thousand. The μ-PIC can be operated with higher gain (several tens of thousand) in the mixture 90% neon + 10% ethane with a very strong spark suppression that is more than 100 times smaller than the arone + ethane mixture in the 10^4 gain region.

Even though these properties of the spark reduction with a neon + ethane mixture are very promising, a higher electric field of fiducial volume is needed to have a high electron drift velocity. As mentioned in the previous section, adding CF_4 gas is one solution for achieving a fast drift velocity with a low electric fields. The timing properties must also be measured for the different conditions; we are preparing such measurements. Figure 7 shows the ^{55}Fe pulse height distributions for (a) neon + ethane gas and (b) neon + ethane + CF_4 gas. The field of the drift volume chosen for the fastest electron drift velocity was calculated by Magboltz. The energy resolution of the photo-electron peak is better in (b) than in (a), suggesting that the electron drift lines in the mixture with CF_4 are well concentrated at the anodes (Fig. 2). Figure 8 shows the spark rate as a function of the gas gain for the mixtures: 84% neon + 6% ethane + 10% CF_4, and 84% neon + 10% ethane + 6% CF_4. The plots of the argon + ethane gas and the neon + ethan gas are also superimposed on the same graph. The results show a high spark rate with the CF_4 mixture, which is close to the spark rate of the argon + ethane gas at the higher gain region (> 5000). Good reduction of the spark rate was observed at a lower gain.

4. Conclusion and future work

We developed a μ-PIC detector for high luminosity LHC experiments (e.g., the ATLAS upgrade) and tested its operation in fast-neutrons. Spark probabilities under neutron irradiation were measured in several gas mixtures at gas gains up to 10^4 or higher. Assuming the conditions of an ATLAS endcap inner muon detector, we expect that spark probabilities less than 10^{-5} or 10^{-6} will be required. Neon-based gas might be a good solution in our measurements, and CF_4 gas also has good properties that satisfy both a low spark

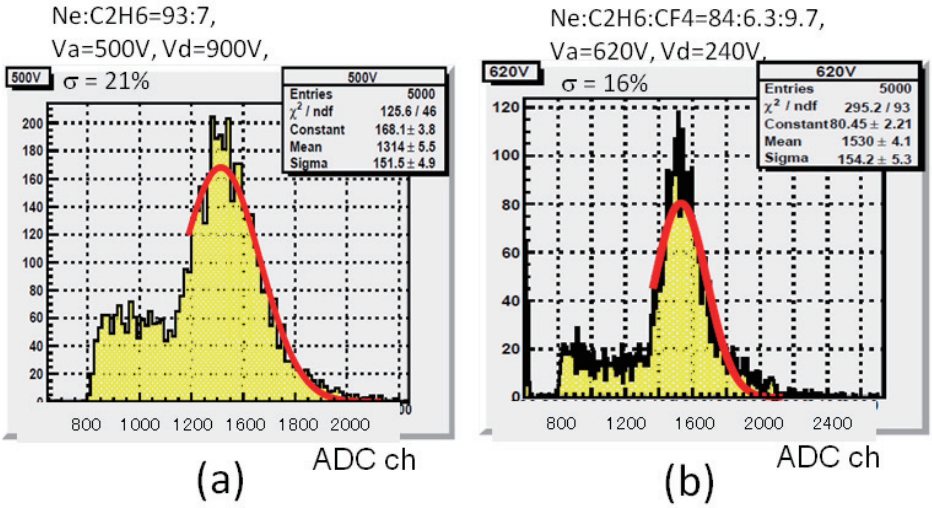

Fig. 7. Pulse height spectra obtained with an ^{55}Fe source using gas mixtures of (a) neon + ethane and (b) neon + ethane + CF_4.

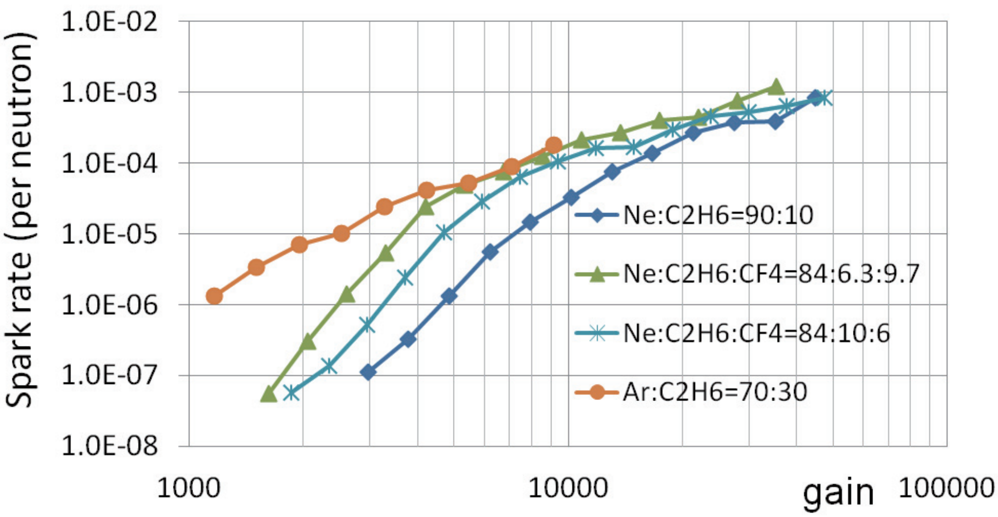

Fig. 8. Spark rate versus gas gain for the following gas mixtures: 84% neon + 6% ethane + 10% CF_4 (green) and 84% neon + 10% ethane + 6% CF_4 (sky blue). The plots for argon + ethane (orange) and neon + ethan (dark blue) are also shown for comparison.

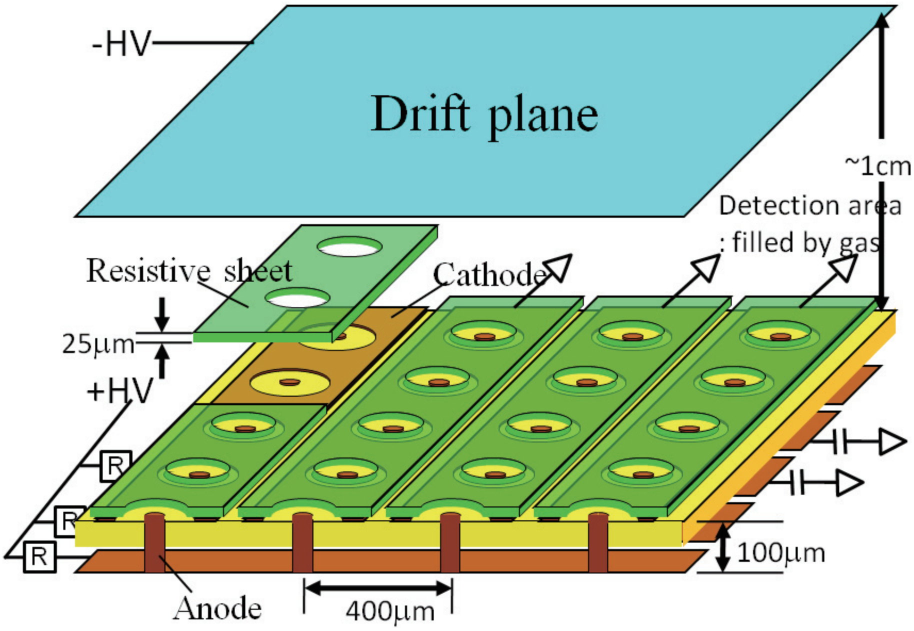

Fig. 9. Schematic structure of μ-PIC with resistive cathodes. It has been developed in order to reduce damage to the readout electrodes caused by sparking, and is currently under tests.

rate and good signal electron collection. Although further research is required, our result show the promise of good operating conditions in high hadronic backgrounds.

We have developed a new μ-PIC using resistive materials bonded to the cathodes to reduce damage to the detector by sparking. (See Fig. 9).

5. Acknowledgment

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