# Proposal for Beam Test of Improved Trigger Counter for the J-PARC E72 Experiment

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Request summary of the proposed experiment

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| Objective | Validation for improved trigger counter |
| Beam line | K1.8BR |
| Beam particles | Negative $\pi$ and $K$ at 600 and 735 MeV/$c$ |
| Beam intensity | Up to $10^6$ charged particles per spill |
| Beam time | 6 hours |

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**Abstract**

The J-PARC E72 experiment aims to investigate a narrow $\Lambda^*$ resonance with $J = 3/2$ around 1665 MeV near the $\Lambda\eta$ threshold via the $p(K^-, \Lambda)\eta$ reaction. Key detector developments focus on the Beam Aerogel Cherenkov (BAC) and Kaon Veto Cherenkov (KVC) counters, which were tested using electron beams at KEK PF-AR in December 2023 and meson beams at J-PARC in February 2025. While the BAC demonstrated high pion rejection efficiency, the KVC exhibited insufficient efficiency, likely due to inadequate photon collection. The small Cherenkov radiation angle at 735 MeV/$c$ $K$-beam operation limits total internal reflection in quartz, and an air gap between the Teflon and quartz may have hindered light collection. To address this, we will test the 2-cm-thick quartz, expecting a threefold increase in photon yield based on previous KEK PF-AR tests. To confirm the improved KVC's efficiency of with 2-cm-thick quartz in a $K^-$-beam environment, we propose a dedicated 6-hour beam test at the K1.8BR beamline. This test will provide critical data to finalize the KVC design for the E72 experiment.

# 1 Introduction

The physics motivation for the J-PARC E72 experiment originates from differential cross-section data of the $K^-p \to \Lambda\eta$ reaction measured in the Crystal Ball experiment, which suggest the existence of an unestablished resonance not listed in the PDG. The angular distribution at $p_K \sim 734$ MeV/$c$ exhibits a concave-up shape, indicating the presence of a $J = 3/2$ or higher state, independent of specific model assumptions. Two theoretical calculations support the existence of a $J = 3/2$ resonance, but due to limited statistical precision, they yield opposite parity assignments. If confirmed, this resonance would challenge conventional quark models, as its narrow width ($\sim$10 MeV) suggests it is unlikely to be a conventional resonance and may correspond to an exotic state, such as a meson-baryon molecule or a pentaquark-like structure, similar to the meson-baryon nature of $\Lambda(1405)$. Further experimental studies are necessary to confirm its existence and clarify its properties.

The J-PARC E72 experiment aims to investigate a possible narrow $\Lambda^*$ resonance with $J = 3/2$ around 1665 MeV near the $\Lambda\eta$ threshold via the $p(K^-, \Lambda)\eta$ reaction. The experiment is conducted at the K1.8BR beamline, utilizing a 735 MeV/$c$ $K^-$ beam impinging on a liquid hydrogen target. The main detector system is the Hyperon Spectrometer, which consists of a superconducting dipole magnet and the Time Projection Chamber (HypTPC) for precise tracking of charged particles. The $\Lambda$ baryon is identified by reconstructing its decay products ($p$ and $\pi^-$), while the $\eta$ meson is inferred from the missing mass of the $p(K^-, \Lambda)X$ reaction.

To ensure clean kaon beam selection and suppress background, the beamline includes the Beam Aerogel Cherenkov counter (BAC) for pion rejection at the trigger level. Additionally, the Kaon Veto Cherenkov counter (KVC) is placed downstream of the HypTPC to veto beam kaons while allowing decay products to pass, improving event selection. The plastic scintillation counter (HTOF) surrounding HypTPC provides further trigger refinement by detecting outgoing particles. The conceptual illustration of the experimental setup is shown in Fig. 1. The data acquisition system is based on the General Electronics for TPCs (GET), which was successfully operated in the J-PARC E42 experiment. The magnetic field strength is set to 1 T to optimize acceptance and momentum resolution. By collecting statistics approximately 100 times larger than those of the Crystal Ball experiment, the J-PARC E72 experiment aims to establish the resonance's existence and determine its quantum numbers. For further details, refer to the E72 proposal and the technical design report [1, 2].

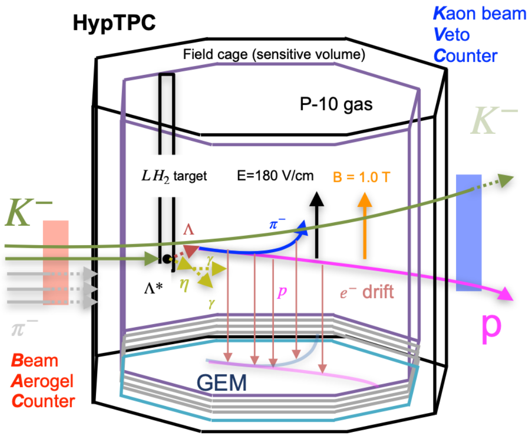


Figure 1: Schematic of the experimental setup around HypTPC for the E72 experiment

## 2 Status of Detector Development

The HypTPC has already demonstrated stable operation for one month in the E42 experiment under a high-intensity beam environment of 700 k/spill. Since the expected beam intensity in E72 is lower, no operational issues are anticipated. The development of the liquid hydrogen target system has completed. This section focuses on the development and testing status of the BAC and KVC.

The BAC is a threshold-type Cherenkov detector designed to efficiently reject pions in the kaon beam. It utilizes aerogel radiators with a refractive index of 1.115, optimized to separate kaons from pions at a beam momentum of 735 MeV/$c$. The detector employs three aerogel tiles, each with an area of 115 $\times$ 115 mm$^2$ and a thickness of 10 mm. The readout of BAC is performed using four MPPC arrays (S13361-6050AE-04), chosen for their suitability in a high-magnetic-field environment and compact design, allowing placement as close as possible to the target despite limited space. The light collection is enhanced using a mirror made of aluminized Mylar, as shown in Fig. 2. The BAC underwent extensive testing using electron beams at KEK PF-AR, achieving nearly 100% detection efficiency. In the beam test conducted at J-PARC K1.8BR in February 2025, BAC was further evaluated under realistic conditions using an actual 0.735 GeV/$c$ pion beam ($\beta = 0.98$). The results confirmed a detection efficiency more than 99%, which remained stable even at beam intensities up to 900 k/spill, demonstrating that BAC is fully operational and ready for the E72 experiment.

The KVC is also a threshold-type Cherenkov detector, positioned downstream of the HypTPC to veto kaon beam particles that did not interact in the target while avoiding vetoing protons emitted in forward direction from the decay of produced Λ hyperons. Rod-shaped quartz segments with a refractive index of 1.46 are used. The segmentation design was chosen to minimize the signal overkill ratio in the

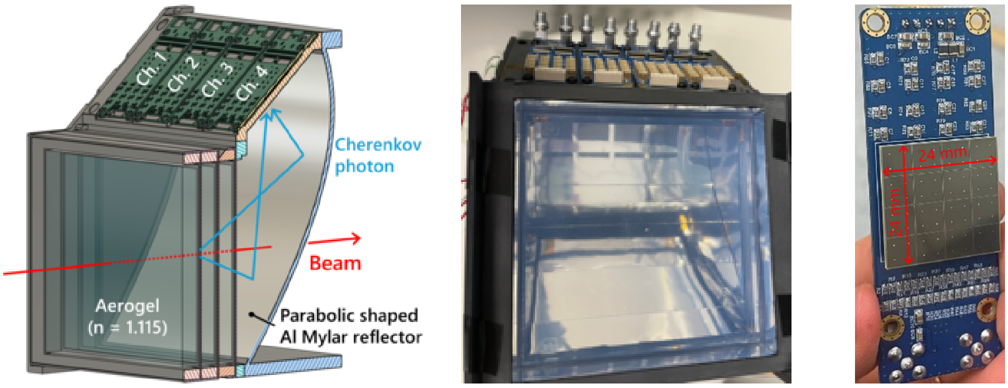


Figure 2: Schematic illustration and photographs of the Beam Aerogel Cherenkov (BAC) counter

trigger and to flexibly control the effective width according to the actual beam profile. These segments are wrapped in Teflon to diffuse the light, which is then detected by MPPCs placed on both ends. Each segment measures 120 × 26 × 10 $\mathrm{mm}^2$, and a total of eight segments are used, covering an effective area of 120 × 208 $\mathrm{mm}^2$. For light readout, four 6 mm × 6 mm MPPCs (S13360-6050VE) are aligned on each end of a segment, and the signals from both the top and bottom MPPCs are summed to form the segment signal. The detector design is shown in Fig. 3. In beam tests at KEK PF-AR using electron beams, KVC prototypes with 1 cm and 2 cm thicknesses were evaluated, both achieving nearly 100% detection efficiency, similar to BAC. Considering the placement of readout boards and the need to reduce the number of channels, the 1 cm thick design was deemed sufficient and adopted for the final implementation. However, when tested with kaon beams at 735 MeV/$c$ ($\beta = 0.83$), the 1 cm thick KVC exhibited only about 50% detection efficiency, which was unexpectedly low. Based on the Frank-Tamm equation, the expected average number of detected photons was approximately 28, assuming ideal light collection. However, the measured value was significantly lower, around 10, indicating substantial light loss. Since the loss is likely more pronounced for $K^-$ mesons, this suggests that the presence of an air gap may contribute to a reduction in detected photon yield for $K^-$ mesons due to photon transmission through the quartz-air boundary.

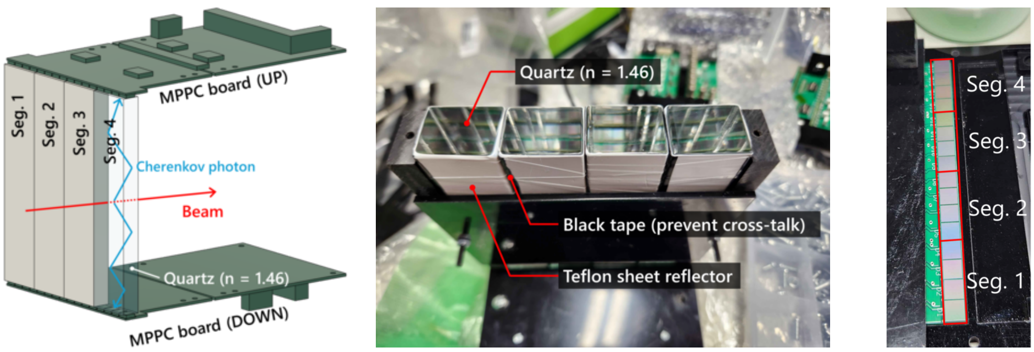


Figure 3: Schematic illustration and photographs of the Kaon Veto Cherenkov (KVC) counter

# 3 Detector Improvement

The unexpectedly low detection efficiency of the KVC is likely influenced by a combination of factors, including the presence of an air gap, light leakage, and variations in quartz surface properties. The observed discrepancy between the expected and measured number of detected photons suggests that the air gap allows photon transmission for $K^-$ mesons, leading to light loss. To address this issue, we propose increasing the thickness of the quartz to 2 cm. Tests conducted at KEK PF-AR have shown that increasing the quartz thickness to 2 cm results in a threefold increase in photon yield, ensuring a significant improvement in detection efficiency. This modification is straightforward, as we already possess the necessary 2 cm thick quartz and the corresponding readout system. In parallel, we are considering an alternative option using a plastic scintillator in case the expected improvements do not sufficiently enhance the light yield. Even if a plastic scintillator is adopted, the decay protons have an opposite charge to the $K^-$ beam and are deflected in the opposite direction by the magnet. By optimizing the detector placement, the signal overkill can be minimized to just a few percent or less. Furthermore, implementing a matrix-coincidence trigger with HTOF is expected to further reduce the overkill rate. Simulations are currently underway to validate these considerations regarding the KVC and to evaluate the overkill rate introduced by the trigger when using a plastic scintillator. These efforts will help determine the most effective approach for improving detection efficiency prior to the E72 main experiment.

# 4 Beam Request

To evaluate the efficiency of the improved KVC, we request a 6-hour beam test at K1.8BR. This test will focus on measuring the detection efficiency of the improved KVC and assessing the increase in photon yield and collection efficiency. Since increasing the photon yield may reduce the high-intensity tolerance, we will also conduct a beam test with increased intensity. The experimental setup is shown in Fig. 4. KVC testing will be conducted at the K1.8BR beamline using $\pi$ and $K$ meson beams with momenta of 735 and 600 MeV/$c$. The intensity of the low-momentum kaon beam is limited, and at 80 kW MR operation, it was 40 k/spill with a $K/\pi$ ratio of 0.14. Therefore, a high accelerator power condition is desirable for this test as well. The electrostatic separator (ESS1) will be operated at 100 kV, and the expected beam intensity is at most $10^6$ charged particles per spill. The trigger will be generated using existing beamline counters, and a prescale factor will be applied to achieve a trigger request rate of approximately $10^4$ per spill. The DAQ efficiency is expected to exceed 95%.

# 5 Summary

The February 2025 beam test revealed that the KVC exhibited insufficient detection efficiency, prompting a reassessment of its optical design. Based on our investigation, several possible causes have been considered, including light leakage due to the presence of an air gap, inefficient internal reflection, and surface properties of the quartz radiator. To address these issues, we have revised the optical design and developed a new KVC with a 2 cm thick quartz radiator. The previous test at

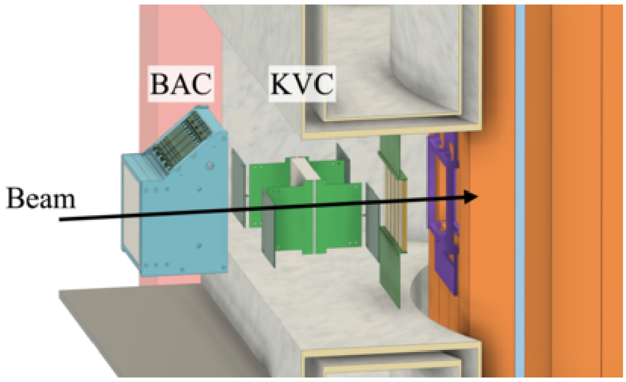


Figure 4: Proposed detector test setup at J-PARC K1.8BR.

KEK PF-AR have shown that increasing the quartz thickness to 2 cm results in a threefold increase in photon yield, To validate the improvement, we propose a 6-hour beam test at K1.8BR, where the modified KVC will be evaluated using $K^-$ and $\pi$ beams at 735 and 600 MeV/$c$. Furthermore, we are investigating an alternative approach using a plastic scintillator, which could serve as a backup solution should the optical modifications not yield the expected improvements. Simulation studies are also underway to evaluate the impact of trigger conditions on overkill rates and overall detection performance. This beam test will provide critical data to finalize the KVC design for the E72 experiment. The results will guide the selection of the optimal configuration to ensure efficient particle identification and reliable data acquisition in the main experiment.

# References

[1] K. Tanida *et al.*, J-PARC Proposal E72, "Search for a Narrow $\Lambda^*$ Resonance using the $p(K^-, \Lambda)\eta$ Reaction with the HypTPC Detector" (2017).

[2] K. Tanida *et al.*, J-PARC Technical Design Report on the E72 experiment (2018).