Proceedings of CONF-CIAP 2026 Symposium: International Conference on Atomic Magnetometer and Applications
DOI: 10.54254/2753-8818/2026.HZ28780

# *Comparative Analysis of the Performance between Scintillation Detectors and Cherenkov Detectors*

**Yixin Zhang**

*Hangzhou No.4 High School, Hangzhou, Zhejiang, China*
*zhangyixin12391@outlook.com*

***Abstract.*** To date, no systematic research has been conducted on the performance comparison and analysis of scintillation detectors and Cherenkov detectors. Meanwhile, considering that the requirements for detectors in terms of energy resolution, timing response, environmental robustness, and other parameters vary across different scenarios, there is a need to address the issue of accurate detector matching for diverse scenarios. This paper systematically presents and compares the performances of scintillation detectors and Cherenkov detectors, including energy threshold, time resolution, and environmental robustness. Additionally, it summarizes the limitations of the two types of detectors and discusses their prospects. The research results show that scintillation detectors are more suitable for multiple fields, such as medical applications and nuclear physics experiments, while Cherenkov detectors are more applicable to fields like high-energy physics and astrophysics. The contributions of this paper are twofold. First, it provides a comprehensive and systematic comparison between scintillation detectors and Cherenkov detectors across multiple performance dimensions. Second, it offers practical guidance for selecting appropriate detectors in different application scenarios, thereby supporting both scientific research and engineering practice.

***Keywords:*** Scintillators, Detectors, Cherenkov Detectors, Time Resolution, Environmental Robustness

## 1. Introduction

Particle detection technology plays a crucial role in various fields such as nuclear physics, astrophysics, and medical imaging. As a result, the performance of particle detectors directly affects the accuracy and reliability of experimental data. As two essential tools in the field of particle detection, scintillation detectors and Cherenkov detectors operate based on distinct physical mechanisms and principles, each playing an irreplaceable role in different scenarios. Scintillation detectors offer a wide range of applicability and high detection efficiency, while Cherenkov detectors exhibit efficient detection capabilities for high-energy particles [1]. However, their differences in principles, applicability, and limitations still require systematic collation and comparison.

Scintillation detectors, with broad-spectrum response to α, β, γ radiation and flexible performance tuning, are core for cross-scenario detection. In medicine, NaI (Tl) detectors are long used in

© 2025 The Authors. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

DOI: 10.54254/2753-8818/2026.HZ28780

radionuclide imaging; new scintillators like GAGG: Ce and $LaBr_3$(Ce) boost PET spatial accuracy and radiotherapy dose monitoring. In nuclear physics, they fit neutron capture and nucleon decay search (e.g., GAGG: Ce for γ-spectroscopy under high radiation). For environmental monitoring, NaI (Tl) detects γ-dose rates, while plastic scintillators serve β-counting and fast coincidence experiments. Cherenkov detectors, with strong environmental robustness and excellent time resolution, excel in high-energy and high-precision scenarios. In high-energy/astrophysics, MEMPHYS-like water-Cherenkov detectors capture supernova neutrinos, study nucleon decay, and support leptonic sector CP-phase measurement. In medicine, $PbF_2$-based ones enhance TOF-PET SNR and reduce reconstruction artifacts via ultra-short coincidence time resolution. They also monitor nuclear reactors, maintaining stability in high humidity/strong radiation for safe operation.

Given their distinct performance characteristics, this paper will investigate and compare the core performance metrics (such as detection efficiency and energy resolution) of scintillation detectors and Cherenkov detectors. It will sort out the differences in their applicable particle types, energy ranges, and environmental requirements. Specific case studies will be used to analyze the different application scenarios and advantages of the two detectors. Finally, the respective limitations of each detector will be summarized, providing reference suggestions for future detector selection and development directions.

## 2. Detector principles and types

### 2.1. Scintillation detectors

Scintillation detectors utilize scintillation crystals along with photodetectors and light guides to detect types of radiation such as α particles and γ rays, among others [2]. These detectors work by converting the energy from the radiation into signals through interactions with scintillators to produce fluorescence signals, for detection purposes. The fluorescence is then transformed into signals which are used to detect high-energy particles and nuclear radiation by recording these signals electrically; scintillators, within scintillation detectors, absorb high-energy particles and transform it into visible or ultraviolet photons. Scintillators typically consist of types such as inorganic ones like NaI (Thalium), Cs1 (Thalium), organic versions including plastic and liquid scintillators, as well as gas-based ones that are grouped based on their composition and form characteristics. Photodetectors play a role in converting the faint optical signals generated by scintillation detectors into detectable initial electrical signals and can be broadly classified into two main categories. Photomultiplier tubes (PMTs) and silicon-based photodetectors, like SiPs and APDs. PMTs are commonly used as the photodetectors in scintillation detectors when high detection sensitivity is needed and there is no strong magnetic field present. They are effective in addressing challenges related to direct photon transmission that include issues like photon escape and absorption by the housing, which can lead to a loss of photons that the photodetector fails to capture due to the light guide, in a scintillation detector." The light guide allows collected photons (emitted from angles) to be transmitted over long distances, with minimal loss through total internal reflection.

### 2.2. Cherenkov detectors

In contrast to that, Cherenkov detectors work based on a concept. They identify high-energy charged particles by using Cherenkov radiation. This type of radiation is the radiation produced by a small number of photons released in a conical pattern when a fast-moving charged particle moves evenly

DOI: 10.54254/2753-8818/2026.HZ28780

through a see-through medium at a speed greater than the light phase velocity, in that medium. The charged particle interacts with the field of atoms in the medium to disrupt its electromagnetic field and prompt electrons to move from the ground state to the excited state effectively when these excited electrons return to the ground state; they emit energy in the form of Cherenkov radiation light which is picked up by a photodetection system, in the detector and converted into detectable electrical signals. Following amplification of these signals in the process by an electronic system is aimed at extracting vital information regarding the particle in question. Concurrently measuring the Cherenkov angle facilitates the calculation of particle speed, making this detector particularly beneficial for identifying high-energy charged particles and gauging their velocity.

## 3. Detector principles and types

### 3.1. Comparison of energy thresholds

The detection of radiation involves two main types of detectors; scintillation detectors and Cherenkov detectors exhibit performance traits due to their different physical principles guiding their operation methods and detection abilities across scientific and industrial contexts vary significantly between the two types; while scintillation detectors can detect a wide spectrum of radiation such, as α particles β particles γ rays X rays and neutrons proficiently [3]. One significant benefit of this type of detector is its adaptability. It can easily accommodate types of radiation by simply replacing the scintillator material. The crucial element that transforms radiation energy into light. No alterations are required to the core structure of the detector itself, for instance, the photoelectric conversion module or signal amplification circuit. The modular design greatly reduces the expenses related to adjusting detection equipment by removing the necessity for an overhaul or replacement of the entire detection system when transitioning between different radiation targets. Scintillation detectors do not have an energy threshold, which enables them to detect a wide range of energy levels from low-energy radiation like keVs used in medical X rays to high-energy radiation, in the MeVs range emitted during nuclear processes. The extensive range of applications these devices offer makes them valuable across industries like medical imaging and environmental radiation assessment.

Besides nuclear safety monitoring purposesly different from Cherenkov detectors which have a precise function limited to detecting high energy charged particles like fast electrons or protons due to the unique way they operate based on Cherenkov radiation where charged particles need to move faster than the speed of light in a medium to produce light signals accurately as, per their design specifications and physical principles involved not seen in other detectors available. This condition implies that a threshold amount of energy is required for the detection of particles. Once the kinetic energy of a charged particle exceeds this threshold, it attains the necessary velocity to generate Cherenkov radiation. If the energy of the particle is less than this requirement, the sensor won't show any detectable response, making it inadequate for identifying low-energy charged particles or neutral radiation, like neutrons and gamma rays. The strict energy threshold of Cherenkov detectors restricts their use to scenarios with high-energy particles, like those in high-energy physics experiments or relativistic particle detection.

### 3.2. Energy resolution

One key difference between the two detectors is their energy resolution. A measure of how a detector can differentiate between radiations with slightly varying energies, Scintillation detectors

DOI: 10.54254/2753-8818/2026.HZ28780

have better energy resolution than Cherenkov detectors do [4]. One of the reasons for this advantage is the high amount of light produced by scintillators when they absorb radiation energy. The atoms or molecules in the scintillator get excited to higher energy levels and then release a large number of visible light photons during the de-excitation process. Typical scintillators like NaI(TL) or a type of NE213 liquid scintillators have a much higher photon yield compared to Cherenkov radiation, which usually results in only a few tens to hundreds of photons per particle interaction. The heightened photon output lessens the variability in the quantity of photons detected and enhances the accuracy of energy measurement in Cherenkov detectors. Poor energy resolution in Cherenkov detectors stems from two causes: 1) The naturally low photon output of Cherenkov radiation exacerbates statistical errors in photon tally. 2) The nonlinear correlation between the count of Cherenkov photons and the kinetic energy of particles contributes to this issue. In contrast to scintillators that show a near-linear relationship between light output and absorbed energy within a specific range, the amount of Cherenkov photons varies with the particle's velocity (corresponding to its energy in a non-linear fashion) and the refractive index of the medium. This non-linear relationship complicates the estimation of a particle's energy based on the detected Cherenkov photons, resulting in a reduction in the accuracy of the detector regarding energy resolution. Both scintillation detectors and Cherenkov detectors are known for their timing accuracy in measuring when a radiation event occurs efficiently and effectively; however, the timing capabilities of scintillation detectors are naturally restricted by the luminescence decay duration of the scintillator material. The time taken for excited atoms or molecules to revert to their base state and emit light particles. Among the range of scintillators available, organic scintillators such as plastic or liquid organic types provide the swiftest response times. The reason for this is that their glow comes from how molecules change energy levels rather than atoms changing levels; organic molecules are simpler, and when excited, molecules calm down (which is about the relaxation of $\pi$ electrons in connected systems), which happens very quickly within 1 to 10 nanoseconds typically [5]. In contrast, to that Cherenkov detectors don't go through any calming down process after being excited. Cherenkov light is produced immediately when a charged particle moves through a substance at a speed faster than light within that medium and causing the molecules around it to polarize and coherently emit radiation to create Cherenkov light. The quick production of light in Cherenkov detectors naturally provides them with timing accuracy that usually ranges from tens to hundreds of picoseconds (ps) [6]. This characteristic makes them well-suited for tasks that demand fast event timing, like measuring particle time of flight (TOF) in high-energy physics colliders efficiently.

### 3.3. Environmental robustness

Additionally, these detectors can withstand environmental conditions giving them a crucial edge in demanding operational settings. Cherenkov detectors usually use crystalline or inorganic materials like water or quartz glass for their detection medium due to their consistent physical and chemical properties over time and environments with high interference levels, like nuclear reactors or high-energy physics experiments, where radiation and particle fluxes are intense, as well as industrial settings, with extreme temperatures or chemical hazards. The production of Cherenkov radiation is influenced mainly by the index of the material—a property that stays quite consistent for inorganic substances like water and quartz glass due to their stable atomic structures, even when exposed to high levels of radiation exceeding $10^6$ gray (Gy). This stability in arrangement leads to minimal changes in their refractive indices and ensures that Cherenkov detectors maintain their detection efficiency even under intense radiation exposure, without significant degradation. The inorganic materials mentioned can withstand temperatures well; for example, quartz glass stays transparent

DOI: 10.54254/2753-8818/2026.HZ28780

and maintains its refractive index stability even at temperatures below 1000 ° C, while water can stay liquid at temperatures over 300 ° C under pressure, such as in pressurized water nuclear reactors with minimal changes to its refractive index. Moreover, these materials are chemically inactive as they do not interact with water (thereby preventing deliquescence). They can withstand corrosion from the majority of acids, bases, and organic solvents, making them ideal for deployment in chemically harsh settings such as nuclear chemical waste processing facilities [6].' On the other hand, scintillation detectors face challenges in adapting to environmental conditions, especially in terms of resistance to radiation and moisture [7]. High doses of radiation can severely harm the structures of organic scintillators when exposed to levels exceeding $10^4$ Gy. Ionizing radiation is responsible for breaking the carbon-hydrogen (C H) bonds within the molecular chains, which can either cause chain scission or cross-linkage. This type of damage results in a decrease in the amount of fluorophores present in the scintillator – these are responsible for emitting light–consequently reducing its luminescence efficiency. In instances of radiation exposure, effects may occur where impurities formed by the breaking of molecular chains absorb light emitted by the detector, leading to signal attenuation and eventually causing it to malfunction. Conversely, most inorganic scintillators are susceptible to absorbing moisture from the environment. Inorganic scintillators commonly used, like NaITL and CsITL, are crystals with lattice structures that include cations such as sodium and cesium, with high water solubility properties. In conditions, the water molecules in the air enter the crystal structure, creating hydrates with certain cations like $NaI{\cdot}2H_2O$. This process leads to cracking and breaking of the lattice. The damage to the structure hinders the absorption of radiation and emission of photons, resulting in efficiency in both photon generation and output as the crystal loses its ability to absorb radiation effectively, and cracks scatter or absorb emitted photons. Moreover, the melted crystal surface could create a layer that eats away at the connection point of solar-powered conversion tools (such as the light-sensitive cathode of a photomultiplier tube), causing system malfunctions or lasting harm [8].

## 4. Technical challenges and future development directions

Scintillation detectors and Cherenkov detectors are crucial in fields like medical imaging and high-energy physics, as they have unique physical mechanisms distinguishing them from each other. However, due to the growing need for precision in scientific studies and improved equipment versatility, in civilian applications, the drawbacks of these detectors have started to become more apparent over time. To overcome this obstacle and drive progress in technology and innovation in the present time frame is a focus area for both types of detectors mentioned earlier; technological integration and expanding scenarios are essential research themes for their advancement. Within scintillation detectors lies a need to address the performance limitations associated with scintillation materials; to illustrate, inorganic scintillator materials are susceptible to deliquescence issues, while organic counterparts demonstrate resistance to radiation exposure. The creation of scintillation materials holds considerable importance in scientific endeavors. Various techniques that show promise in theory but have not been put into practice yet could address the problem of scintillators' deliquescence. One proposed solution is to shield the scintillators with metals or robust glass to inhibit moisture ingress successfully [9]. However, the intricate nature of the encapsulation process makes it challenging to maintain quality across all products in mass production endeavors. Thus, this approach still needs exploration and refinement.

The organic-inorganic hybrid scintillator mentioned combines the rapid response of organic scintillators with the superior luminescence efficiency of inorganic ones. This specific hybrid material has found use in producing "flexible detector arrays" for medical PET scans, enabling high-

DOI: 10.54254/2753-8818/2026.HZ28780

resolution imaging on the curved surfaces of the body while also enduring radiation exposure during radiotherapy to prolong its operational lifespan. Advancements are anticipated to expand towards the early identification of various ailments and customized therapies that enhance tumor treatment effectiveness [10]. They also enable the creation of more productive radiotherapy procedures. Artificial intelligence (AI) can play a role in improving detection efficiency and data analysis capabilities during the data processing phase of scintillation detectors. Cherenkov detectors have strengths such as exceptional environmental resilience and precise timing resolution; however, they are still used within restricted application domains. In the future, researchers should aim to broaden their usage in fields extending into industries like healthcare and beyond to have a greater impact on civilian sectors as well.

## 5. Conclusion

This paper conducts a study on the performance of scintillation detectors and Cherenkov detectors. By comparing their performance characteristics, it is found that scintillation detectors possess superior energy resolution and the capability to detect multiple types of radiation. Cherenkov detectors, because the medium they use is mostly crystalline or inorganic amorphous materials, exhibit extremely strong environmental robustness. In contrast, different types of scintillators in scintillation detectors are more prone to deliquescence, molecular chain breakage, and other issues under different scenarios, which significantly reduces their luminescence efficiency. Meanwhile, both types of detectors have relatively strong time resolution. Finally, this paper also presents some existing ideas proposed by researchers for the technological innovation and application scenario expansion of the two types of detectors, which require further research and practice.

## References

[1] Wang J, Chen B X, Zhuang R L. A review of inorganic scintillation detectors. Nuclear Electronics & Detection Technology, 2006, (6): 1039-1045.
[2] Xu J C, Le Y K, Yu X. Research on water-based Cherenkov muon detectors. College Physics, 2011, 30(6): 5-9.
[3] Gu Z W, Yan W Q, Liu W B, Zhang G L. Comparison of performances of lanthanum bromide, sodium iodide and plastic scintillator detectors. Research and Exploration in Laboratory, 2015, 34(4): 4-8.
[4] Martinazzoli L, Kratochwil N, Gundacker S, Auffray E. Scintillation properties and timing performance of state-of-the-art Gd3Al2Ga3O12 single crystals. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 2021, 1000: 165231.
[5] Balibrea-Correa J, Lerendegui-Marco J, Babiano-Suarez V, Domingo-Pardo C, Ladarescu I, Tarifeño-Saldivia A, Žugec P. Pushing the high count rate limits of scintillation detectors for challenging neutron-capture experiments. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 2024, 1064: 169385.
[6] Ota R, Nakajima K, Hasegawa T, Ogawa I, Tamagawa Y. Timing-performance evaluation of Cherenkov-based radiation detectors. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 2019, 923: 1-4.
[7] Lin C Y, He L, Chen Y, Nie L X, Xia Y, Xu W F. Research on the performance of SiPM applied in scintillation detectors. Nuclear Electronics & Detection Technology, 2016, 36(5): 3-7.
[8] Morishita Y, Yamamoto S, Izaki K, Kaneko J H, Toui K, Tsubota Y, Higuchi M. Performance comparison of scintillators for alpha particle detectors. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 2014, 764: 383-386.
[9] Ouyang X P, Liu B, Zhang Y, Li C, Zhou H. Research progress on photonic crystal scintillators. Modern Applied Physics, 2017, 8(4): 040101-1–040101-9.
[10] Qian R X, Lu J, Cui M, Wang S H, Wang P K, Li B Y, Guo G C. High-resolution X-ray imaging with 0D organic–metal halide scintillator featuring reversed exciton trapping. Laser & Photonics Reviews, 2025, 19(4): 2401342.