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Editorial: Precision detectors and electronics for fast timing: Advances and applications

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Editorial on the Research Topic
Precision Detectors and Electronics for Fast Timing: advances and applications

During the last decade, the increasing demand for particle detectors capable of accurate time resolution pushed the physics community to invest resources for the upgrade and optimization of this technology. Precision timing detectors for particles and radiation with picosecond time resolution are currently of great interest in applications over a range of disciplines including high energy physics, space, biological sciences, medical imaging, remote sensing, and environmental monitoring. The role of industry and Research and Technology Organizations (RTO) has significantly changed in their relationship with university and academia. The link with everyday's life in biological and medical applications and the need for large-scale detectors using front-line technologies in physics have strengthened the partnership between university research and industry. New solutions to improve the timing capability of detectors are being developed in close collaboration, more than in the past. In this Research Topic we address some state-of-the-art methods and applications to improve the time resolution of detectors in many fields.

Researchers working on High Energy Physics (HEP) experiments at the LHC are developing solutions which prove a timing resolution of tens of picosecond, thus significantly improving the separation of different events and rejecting background more efficiently reducing pile-up effects. In parallel with sensor technology, dedicated fast readout electronics are being developed. Recent advances in solid-state detectors for timing involves Single Photon Avalanche Detectors (SPADs) and silicon photomultipliers (SiPMs) in combination with electronics, such as multichannel time-to-digital converters or waveform digitizers. Cryogenic detectors combine fast timing with photon color sensitivity and are being used in imaging arrays for applications in physics and astronomy. Novel technologies and materials include graphene, operable in different configurations as a high bandwidth photodetector from THz to X-ray wavelengths. Micro pattern gas detectors are also candidates for fast particle timing applications, as well as vacuum tube technology. Given the expected radiation levels in HEP experiments, the radiation-tolerance of timing devices is of the utmost importance. Within this framework, Low Gain Avalanche Detectors (LGADs) and 3Ds represent the state-of-the-art for high performance in harsh operating environment.

Particle tracking for future experiments at colliders is an incredible challenge both in terms of sensor technology and readout systems. Simulation tools represent a crucial ingredient to investigate new layouts able to cope with harsh radiation conditions and, at the same time, provide valuable timing information for track finding algorithms. D. Brundu et al. present two software packages developed within the TimeSPOT collaboration, to simulate detailed and realistic energy deposits as well as sensor and front-end electronics responses in semiconductor 3D sensor devices. The induced current is assessed at the sensor electrodes due to the motion of charge carriers created by an initial energy deposit *via* the Ramo's theorem. The developed software packages allow for a significant speed-up in simulation time without losing the results accuracy. In particular, the use of heavy parallelization allows for a significant speed-up of simulation time, even in presence of complex geometries.

F. Pagano et al. present a new method to simultaneously measure the time resolution and light output of scintillators using pulsed X-ray irradiation and SiPM photodetectors. One of the issues of many existing methods of time resolution characterization at low-energy is that they are based on β^+ sources, whose positron annihilation gives the two 511 keV γ rays in coincidence. This does not allow to investigate time resolution at lower energy. Lower energy radiation sources, such as ^{55}Fe are sometimes used, but they present a single emission, which is not making any coincidence system possible. The proposed method uses the signal sent to the fast laser used to excite the X-ray tube as a trigger for the measurement.

Due to the high photodetection efficiency of SiPM, and the optimized electronics, is particularly suited for the characterization of materials with low stopping power. This technique is, therefore, proposed as a fundamental tool for characterization of nanomaterials and, more in general, of materials with low stopping power to better guide their development. Moreover, it opens the way to new applications where fast X-ray detectors are requested, such as time-of-flight X-ray imaging.

In the context of improving the detector performance of time-of-flight positron emission tomography (TOF-PET), the combination of charge induction readout and prompt Cherenkov photon production in semiconductor materials can lead to outstanding detector performance in energy, time, and spatial resolution. G. Terragni et al. advanced the understanding of high refractive index Cherenkov radiators and light propagation in TlBr and thallium chloride (TlCl) crystals through experimental measurements and simulations. They have shown that the big advantage of using the Cherenkov component for the timing determination in Tl-based crystals can be easily lost if the crystal setup is not optimized. They have also shown a significant dependence of the timing performance and the coincidence Time Resolution on the postprocessing of the crystal surface through polishing. They also studied the effect of the refractive index of materials together with their transmission cutoff on the final time resolution. The timing performance has also been simulated as a function of the parameters of the SiPM used in the readout.

A. Gonzales-Montoro et al. propose the development of a scalable detector element able to achieve excellent coincidence time resolution required for time-of-flight positron emission tomography TOF-PET using Bismuth germanate oxide BGO scintillator elements of various lengths. BGO has been the crystal of choice in PET systems for decades but had been more recently replaced by faster but more expensive scintillators. Now, with the development of near-ultraviolet high-density (NUV-HD) silicon photomultipliers able to provide the fast timing information from the Cherenkov photons emitted in the crystal, BGO is again a very interesting crystal candidate for PET-TOF. It presents a high Cherenkov yield due to its index of refraction and an high transmission coefficient for UV light, due to the position of its 300 nm absorption band. The results presented here indicate that fast, low-noise front-end electronics employed as readout for BGO-based PET detectors are suitable for building BGO-based PET detectors that provide CTR values equivalent to what is currently achievable in state-of-the-art TOF-PET systems (214–480 ps FWHM).

All these applications represent an important step forward in future precision timing detectors.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work, and approved it for publication.

Conflict of interest

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