Simulation of the PADME active target

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The PADME Collaboration is pursuing an innovative approach[1] to the search for “*the dark photon*”, A’, a hypothetical massive gauge boson of an extra $\mathrm{U_d}(1)$ symmetry describing the scattering of pairs of particles of a “*secluded*” or “*dark*” sector[2], that exhibits very limited interactions with the known particles. Even in case the Standard Model particles are neutral for the new interaction, a kinetic mixing between the gauge fields associated to $\mathrm{U_{em}}(1)$ and $\mathrm{U_d}(1)$ must occur leading to a certain probability of conversion of a SM photon into a dark photon or viceversa [3]. In practice, the coupling of SM fermions to A’ is described by an effective charge q_d of the SM particles under $\mathrm{U_d}(1)$ equal to ϵq_{em}, where ϵ is the mixing constant, which is expected to be small, given the elusiveness of dark matter, and q_{em} is the electromagnetic charge of the

The experiment will run in 2018 at the Beam Test Facility (BTF)[4] of the DAΦNE accelerator complex, of Laboratori Nazionali di Frascati (LNF). A small size experimental apparatus will search for invisible decays of A’ bosons generated in the process $\mathrm{e^+e^-} \rightarrow \mathrm{A'}\gamma$, using the positron beam accelerated by the LINAC and electrons from a thin diamond target.

The refinement of the design of the experiment, after the first proposal, has been based on a GEANT4-based [5] simulation, called PadmeMC, developed during the early stages of the project in 2014 and subsequently evolved to follow closely the needs of the project. The current version of PadmeMC is available from GitHub[6]. It represents the main components of the PADME detector including the dipole magnet and the vacuum vessel enclosing the target and the charged particle veto systems. In addition, PadmeMC describes the time structure of the positron beam, its expected energy spread, spatial distribution and emittance at the target.

The Lecce group is responsible for the design, construction and operation of the diamond active target of PADME and, as a consequence, it’s taking responsibility of the simulation of this detector. The target consists of a 20×20 $\mathrm{mm^2}$ polycrystalline diamond with a thickness of 100 μm. Two orthogonal sets of 19 readout strips with a pitch of 1 mm are built on the two sides of the diamond, by inducing the graphitization of the diamond surface with an excimer laser. They are used to reconstruct the X and Y coordinates of the charge weighted center of the beam profile, bunch by bunch. The target goal is to measure the position of the beam with a spatial resolution better than 1 mm and its total charge with a precision better than 10%.

Within PadmeMC the target is described as a unique homogeneous volume of diamond. The simulation of the interactions of beam particles with the active target are completely demanded to the standard GEANT4 physics libraries. The PADME physics list derives from the standard QGSP_BERT physics list of the GEANT4 package. It includes by default multiple scattering, Coulomb scattering, ionization, Bremsstrahlung emission, two photon annihilation, synchrotron radiation emission. Specific datacards allow the inclusion of photonuclear interactions and the selection of the high precision neutron transport library. A custom event generator provides the simulation of the signal process $\mathrm{e^+e^-} \rightarrow \mathrm{A'}\gamma$ when activated by data cards. The kinematics of Standard Model three gammas final state events, $e^+e^- \rightarrow \gamma\gamma\gamma$, is produced externally to GEANT4 using the CalcHEP generator[7]. The energy released in A realistic description of the reconstruction of the positron beam impinging on the target is crucial to the correct evaluation of the resolution in the measurement of the A’ mass. Therefore, the emulation of the response of the active target based on the energy released by the beam, as described by GEANT4, is very important. The DAQ system of PADME is based on the CAEN V1742 board, with 32 DRS4 digitiser channels, each sampling the input signals at 1GS/s (or 5GS/s) with 12 bit FADCs. This emulation of the active target response, implemented in the digitization stage of PadmeMC, consists in the representation of the signal as a digital waveform for all strips affected by the beam interaction with the target, taking into account the geometry of the strips, which defines the effective active area of the target, the typical current pulse induced by a charge drifting in the diamond volume, the distortion of the signal induced by the front-end electronics (noise and pulse amplification and integration), the effects of charge trapping

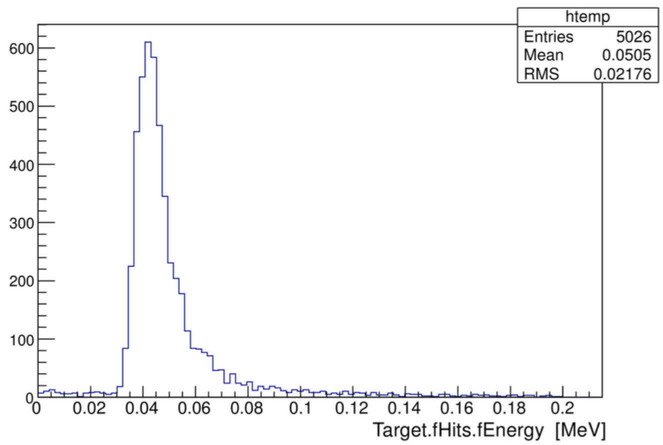

Figure 1. Energy released by the charged track fragments in the diamond target in a single bunch. The positron multiplicity in the beam is 5000 per bunch.

in the polycristalline material. The default setting of PadmeMC assumes a multiplicity of positrons in the beam of 5000 per bunch, a bunch duration and 40 ns with an almost flat time profile, and a gaussian beam spot profile with 1 mm RMS both in the x and y direction. In a typical event, corresponding to a bunch of the beam impinging on the target, the distribution of energy deposits in the sensitive volume of the diamond target is shown in Fig. 1. Each of these energy releases gives rise to the production of a pulse of induced current on the x and y strips which provide the electric field for the drift of the free electrons and holes produced in the medium. A typical current pulse produced by a single m.i.p. traversing the entire film of diamond, 100 μm thick, is shown in Fig.2(Left) and the overlap in time of signals induced by many positrons traversing the target each arriving at a different time in the 40 ns time window of a beam bunch is shown in Fig.2(Right). In the experiment, for each strip, the pulse trail is processed

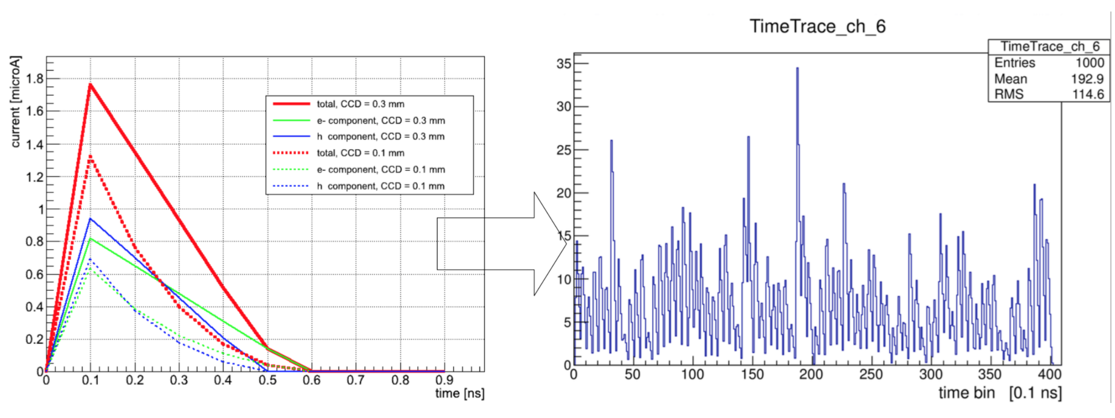

Figure 2. (Left) Current pulse induced by a m.i.p. traversing a 300 μm thick diamond film. The effect of signal suppression produced by a non-ideal charge collection distance (CCD=0.1 mm) is shown along with the ideal pulse corresponding to fully efficient charge collection (CCD=0.3 mm). (Right) Cumulative effects of current pulses occurring at various times within the 40 ns interval of the bunch of the BTF beam on a single strip.

by the front-end electronics that provides an amplified signal where the fine temporal structure, which is not carrying a relevant information, is lost and only the arrival time of the bunch can be extracted from the digitised waveform along with the overall pulse height. A random fluctuation around a baseline value, superimposed to the signal waveform as produced in output of the electronics simulation, allows to describe the noise introduced by the front-end electronics and by the signal readout chain. The realistic wavefoms obtained at this stage can be treated as real data; a calibration procedure allows to correlate the integral, or the pulse height, of the output signal to the ionization charge produced in the region of the strip; therefore the x and y distributions of the overall energy release, provide a measurement of the beam profile and of the total intensity. Event by event, the beam profile, i.e. the distribution of ionization charge as seen by the strips, is finally used to measure the most the x and y coordinate of the center of the beam, which is clearly related to the reconstruction of the kinematics of the final state. Fig.3 shows the distribution of the beam center, as reconstructed by integrating the digitised simulated signals on the strips, in 100 events.

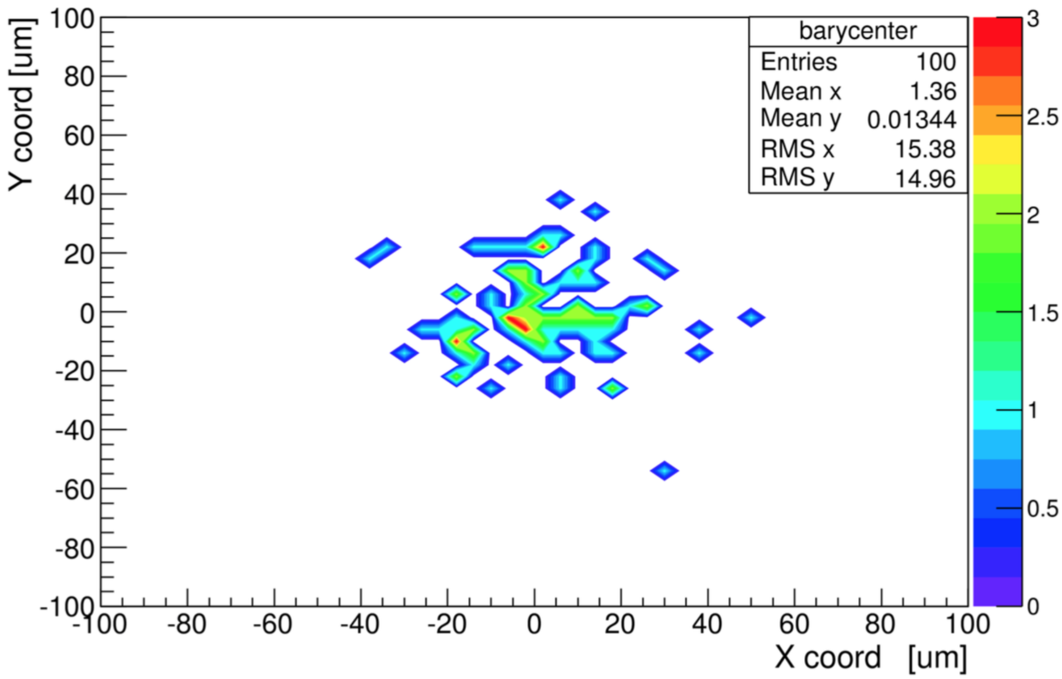

Figure 3. Beam center reconstructed from the calibration of the simulated signals observed on the X and Y strips of the diamond active target. The RMS of this distribution in the two views provides a measurement of the resolution on the reconstruction of the centre of the beam profile for a beam intensity of 5000 e^+. In the simulation the beam is centered at (0,0) and has a gaussian profile with RMS of 1 mm both in X and Y at the entrance surface of the diamond target and its divergence is 1 mrad.

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